

UC Irvine

UC Irvine Previously Published Works

Title

Combination of searches for invisible decays of the Higgs boson using 139 fb⁻¹ of proton-proton collision data at s = 13 TeV collected with the ATLAS experiment

Permalink

<https://escholarship.org/uc/item/21013871>

Authors

Aad, G

Abbott, B

Abeling, K

et al.

Publication Date

2023-07-01

DOI

10.1016/j.physletb.2023.137963

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed



Combination of searches for invisible decays of the Higgs boson using 139 fb^{-1} of proton-proton collision data at $\sqrt{s} = 13 \text{ TeV}$ collected with the ATLAS experiment

The ATLAS Collaboration

Many extensions of the Standard Model predict the production of dark matter particles at the LHC. Sufficiently light dark matter particles may be produced in decays of the Higgs boson that would appear invisible to the detector. This Letter presents a statistical combination of searches for $H \rightarrow$ invisible decays where multiple production modes of the Standard Model Higgs boson are considered. These searches are performed with the ATLAS detector using 139 fb^{-1} of proton–proton collisions at a centre–of–mass energy of $\sqrt{s} = 13 \text{ TeV}$ at the LHC. In combination with the results at $\sqrt{s} = 7 \text{ TeV}$ and 8 TeV , an upper limit on the $H \rightarrow$ invisible branching ratio of 0.107 (0.077) at the 95% confidence level is observed (expected). These results are also interpreted in the context of models where the 125 GeV Higgs boson acts as a portal to dark matter, and limits are set on the scattering cross-section of weakly interacting massive particles and nucleons.

Contents

1	Introduction	2
2	Combination inputs	4
2.1	VBF + E_T^{miss} search	4
2.2	$Z(\rightarrow \ell\ell) + E_T^{\text{miss}}$ search	5
2.3	$t\bar{t} + E_T^{\text{miss}}$ search	5
2.4	VBF + $E_T^{\text{miss}} + \gamma$ search	5
2.5	Jet + E_T^{miss} search	6
2.6	Run 1 combination	6
3	Statistical Model	6
3.1	Uncertainty correlation in Run 2 combination	7
3.2	Uncertainty correlation in Run 1 and Run 2 combination	7
4	Results	8
5	Comparison to direct dark matter detection experiments	9
6	Conclusion	11

1 Introduction

Compelling astrophysical evidence suggests that dark matter (DM) comprises most of the matter in the universe [1–4]. However, its nature is still unknown and poses one of the central questions in modern physics. A possible candidate for DM is a massive, stable and electrically neutral particle χ , interacting weakly with the known particles of the Standard Model (SM).

Several theoretical frameworks predict the production of DM particles in proton–proton collisions at the Large Hadron Collider (LHC) [5–7]. In a wide class of those models, the 125 GeV Higgs boson [8, 9] acts as a portal between a dark sector and the SM sector, either through Yukawa-type couplings to fermionic DM, or other mechanisms [10–23]. If kinematically allowed, pairs of DM particles can then be produced via the decay of the Higgs boson. The DM particles would traverse the detector without interacting and are inferred indirectly through the presence of missing transverse momentum (E_T^{miss})¹ in the interaction. This decay channel is therefore called “invisible.” In the SM, the branching fraction to invisible final states is about 0.1% [24] arising from the decay of the Higgs boson via $ZZ^* \rightarrow 4\nu$.

Direct searches for invisible decays of the Higgs boson were carried out with the ATLAS detector [25, 26] during Run 1 of the LHC, using up to 4.7 fb^{-1} of pp collision data at a centre-of-mass energy of $\sqrt{s} = 7 \text{ TeV}$ and up to 20.3 fb^{-1} at 8 TeV. Various event topologies were considered: vector boson fusion (VBF) [27], production in association with a Z boson (ZH) that decays into a pair of electrons or muons [28], and with a

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points to the centre of the LHC ring, and the y -axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z -axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. The distance between two objects in η – ϕ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_T = p \sin \theta$.

W or Z boson that decays into hadrons [29]. A statistical combination of these ATLAS searches resulted in an observed (expected) upper limit at the 95% confidence level (CL) on the invisible Higgs boson branching ratio of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.25$ ($0.27^{+0.10}_{-0.08}$) [30]. These searches were expanded with up to 36 fb^{-1} of Run 2 data and their combination, including Run 1 results, yielding an upper limit of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.26$ ($0.17^{+0.07}_{-0.05}$) at the 95% CL [31]. A combination from the CMS experiment using a similar dataset reported an observed (expected) upper limit of 0.19 (0.15) [32].

More recently, new direct searches for invisible decays of the Higgs boson using the full Run 2 data of up to 139 fb^{-1} were performed, covering most of the Higgs boson production modes, by ATLAS [33–37] and CMS [38–40]. In both experiments the VBF final state is the most sensitive channel resulting in an upper limit of 0.145 (0.103) for ATLAS and 0.18 (0.12) for CMS.

A partial combination of the ATLAS VBF and ZH searches together with the analyses targeting visible decays of the Higgs boson was carried out [41] and its results reduce the observed (expected) upper limit on $\mathcal{B}_{H \rightarrow \text{inv}}$ to 0.13 (0.08). Such a combination considers the impact of $\mathcal{B}_{H \rightarrow \text{inv}}$ on the Higgs boson total decay width and simultaneously determines $\mathcal{B}_{H \rightarrow \text{inv}}$, together with the coupling of the Higgs boson to all the SM particles as well as a potential contribution to undetected Higgs boson decays not generating missing transverse energy. The approach relies on a different set of assumptions to what is used in this letter.

This letter presents the statistical combination of all ATLAS direct searches for invisible decays of the Higgs boson using the full Run2 dataset. This includes the gluon–gluon fusion, VBF, ZH and ttH production modes, represented in Figure 1 and assumes the production cross-sections of the Higgs boson does not deviate from the SM predictions [24, 42–47]. In addition, a statistical combination with the combined Run 1 result [30] from ATLAS is included, yielding the most sensitive direct constraint to invisible Higgs boson decays in ATLAS.

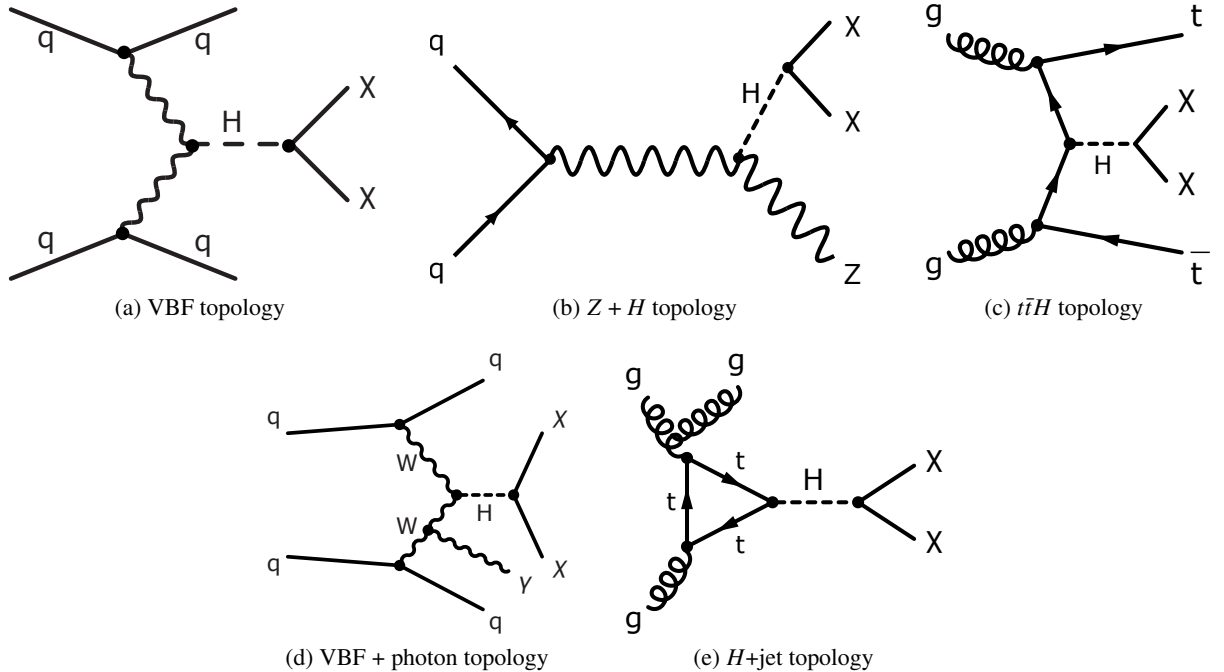


Figure 1: Diagrams illustrating the Higgs boson production mode targeted for the Run 2 searches.

2 Combination inputs

The inputs to the combination for the Run 2 result consist of searches for invisible decays of the Higgs boson, with the following production modes:

- VBF topology (VBF + E_T^{miss}) [33]
- associated production with a Z boson decaying into electrons or muons ($Z(\rightarrow \ell\ell) + E_T^{\text{miss}}$) [36]
- associated production with a $t\bar{t}$ pair, using all top-quark decay modes except those with hadronically decaying τ -leptons ($t\bar{t} + E_T^{\text{miss}}$) [48]
- VBF topology in association with an emitted photon (VBF + $E_T^{\text{miss}} + \gamma$) [34]
- gluon-gluon fusion, in association with a high p_T jet (Jet + E_T^{miss}) [37]

all of which use the full data sample, corresponding to an integrated luminosity of 139 fb^{-1} .

These analyses target different production modes of the Higgs boson and so their event selection criteria are made to be largely orthogonal by using different requirements on lepton, photon, jet and b-tagged jet multiplicity. The level of residual non-orthogonality was evaluated by considering both the data events and signal samples for all the Higgs boson production modes. The largest set of shared events is between the Jet + E_T^{miss} and VBF + E_T^{miss} searches, which select events with large missing transverse energy, no reconstructed leptons, and multiple jets in the final state. The number of overlapping events corresponds to 0.2% (1.5%) of the total data (expected signal Monte Carlo (MC) samples) events selected by the Jet + E_T^{miss} analysis. The impact of the overlap on the final combined result is negligible, altering the upper limit on $\mathcal{B}_{H\rightarrow\text{inv}}$ by less than 0.001. A brief overview of the Run 2 analyses and the inputs to the Run 1 combined result [30] is given below.

2.1 VBF + E_T^{miss} search

In the VBF production mode, the $H \rightarrow$ invisible signal is characterised by two jets with a large separation in pseudorapidity and missing transverse momentum arising from the invisible decays of the Higgs boson. The analysis targetting this signature selects events collected with a trigger selection based on the presence of E_T^{miss} . Events are further selected if their two jets with the highest p_T fulfill the VBF topology requirements: lying in opposite longitudinal hemispheres, being well separated in η , and not back-to-back in the transverse plane. In order to reduce the contribution from W , Z +jets and $t\bar{t}$ production, and to ensure orthogonality with the other analyses, events containing leptons or photon candidates, or two or more jets identified as b-tagged jets [49] are vetoed.

In this signature, the dominant background sources are $Z(\rightarrow \nu\nu) +$ jets and $W(\rightarrow \ell\nu) +$ jets production, where in the latter process the charged lepton ℓ is not detected or mis-identified. These backgrounds are evaluated simultaneously using high-statistics control regions in the 1-lepton and 2-leptons channels. A dedicated theoretical calculation at next-to-leading order in the phase space relevant for this analysis [50] allows the estimation of the total irreducible background with a precision of few-percent. The multijet background is directly estimated from data.

The final discrimination is obtained by splitting signal and control region events into 16 bins based on E_T^{miss} , the invariant mass of selected dijet pair, their separation in ϕ , and jet multiplicity to maximise the

signal/background separation. Assuming the SM cross-section for the VBF production mode, an observed (expected) upper limit of 0.145 (0.103) at the 95% CL is placed on $\mathcal{B}_{H \rightarrow \text{inv}}$.

2.2 $Z(\rightarrow \ell\ell) + E_{\text{T}}^{\text{miss}}$ search

The search targeting the Higgs boson production in association with a Z boson selects events containing a pair of electrons or muons and significant missing transverse momentum. The two charged leptons are required to have an invariant mass within a narrow window around the Z boson mass for the events to satisfy the signal selection requirements.

The dominant backgrounds for this signature are ZZ , where one of the Z bosons decays into a neutrino–antineutrino pair, and WZ production. Contributions from $t\bar{t}$ and WW production are estimated from data, using events with two identified different-flavour charged leptons (electrons and muons).

Beyond the signature selections, sensitivity for the $H \rightarrow \text{invisible}$ model is enhanced using a boosted decision tree (BDT) discriminator to improve the separation between signal and background. A profile likelihood fit to the BDT output distribution results in an observed (expected) upper limit on $\mathcal{B}_{H \rightarrow \text{inv}}$ of 0.185 (0.185) at the 95% CL, assuming the SM production cross-section for this process.

2.3 $t\bar{t} + E_{\text{T}}^{\text{miss}}$ search

The production mode of the Higgs boson in association with a top-quark pair is targeted by reinterpreting the combination of several searches for new phenomena in association with heavy flavour quarks [51–53]. The final states arising from this production mode are characterised by the presence of b -tagged jets and different charged lepton multiplicities, depending on the decay mode of the two W bosons from the $t\bar{t}$ decays. In addition, a relevant amount of $E_{\text{T}}^{\text{miss}}$ is present, coming from the invisible decay products of the Higgs boson and from neutrinos.

A targeted event selection is developed for each lepton multiplicity, resulting in different dominant background contributions from SM processes: $t\bar{t}$ and $Z(\rightarrow \nu\nu) + \text{jets}$ in the 0-lepton channel, $t\bar{t}$ in the 1-lepton channel and $t\bar{t}Z$ in the 2-lepton channel. For all the combined analyses, background-enriched selections are defined in order to allow the data to aid in estimating the dominant backgrounds, and validation regions are used to verify the robustness of these estimates.

The combination of the three analyses of each lepton multiplicity, considered in this document as a single combined analysis, places an observed (expected) upper limit on $\mathcal{B}_{H \rightarrow \text{inv}}$ of 0.376 (0.295) at the 95% CL, assuming the SM production cross-section for this process.

2.4 VBF + $E_{\text{T}}^{\text{miss}} + \gamma$ search

The VBF topology is further investigated by a dedicated analysis targeting the final states with an emitted photon. The event signature is characterised by significant missing transverse momentum and one photon in the final state, in addition to a pair of forward jets. In the SM this topology can arise from $V\gamma + \text{jets}$ production, where V is either a Z boson decaying into a neutrino pair or a W boson decaying leptonically, where the charged lepton is missed.

A dense neural network was designed and trained to separate such backgrounds from the $H \rightarrow \text{invisible}$

signal by using kinematic properties of the events. The residual SM contribution to the signal regions is estimated with the aid of specific control regions requiring the presence of electron or muon candidates, to set the normalisation of the MC simulation for $V\gamma$ +jets processes. Assuming the SM production cross-section on the signal model, an observed (expected) upper limit on $\mathcal{B}_{H\rightarrow\text{inv}}$ of 0.375 (0.346) at the 95% CL is evaluated.

2.5 Jet + $E_{\text{T}}^{\text{miss}}$ search

The gluon–gluon fusion production mode of the Higgs boson is targetted by a search for new phenomena in events with at least one jet and large missing transverse momentum. Data are collected with a trigger selection based on the presence of $E_{\text{T}}^{\text{miss}}$ and events are vetoed if any charged lepton or photon is reconstructed.

The dominant SM background for this search arises from the irreducible process $Z \rightarrow \nu\nu$ or $W \rightarrow \ell\nu$ in association with jets, where the W boson decays into either hadronically decaying τ -leptons or undetected electrons or muons. Additional contributions include $t\bar{t}$ pair or single-top production, diboson production, and non-collision and multijet backgrounds. The estimate of the major SM processes in the analysis selection is based on a profile likelihood fit to the distribution of the p_{T} of the system recoiling against the jets reconstructed in the event, performed simultaneously in the signal region and in orthogonal control regions enriched with the targetted backgrounds. Assuming the SM cross-section for Higgs boson gluon–gluon fusion production, an observed (expected) upper limit on $\mathcal{B}_{H\rightarrow\text{inv}}$ of 0.329 (0.383) at the 95% CL is achieved.

2.6 Run 1 combination

The Run 1 ATLAS $H \rightarrow$ invisible combination utilises 4.7 fb^{-1} of pp collision data at $\sqrt{s} = 7 \text{ TeV}$ and 20.3 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$ [30]. This combination considers inputs from direct detection of $H \rightarrow$ invisible through Higgs bosons produced via VBF or in association with a vector boson V , where the vector boson decays either leptonically ($Z \rightarrow \ell\ell$) or hadronically ($W/Z \rightarrow jj$). All of the signal and control regions are utilized in a maximum-likelihood fit resulting in an observed (expected) upper limit of $\mathcal{B}_{H\rightarrow\text{inv}} < 0.252$ (0.265) at the 95% CL. The sensitivity is driven by the VBF channel.

3 Statistical Model

The statistical combination of the analyses is performed by constructing the product of their respective likelihoods and maximising the resulting profile likelihood ratio [54]:

$$\Lambda(\beta; \theta) = \frac{L(\beta, \hat{\theta}(\beta))}{L(\hat{\beta}, \hat{\theta})}$$

where β and θ are the parameter of interest and the nuisance parameters respectively. In the numerator, the nuisance parameters are set to their fitted values $\hat{\theta}(\beta)$, which maximise the likelihood function for fixed values of the parameter of interest, β . In the denominator, both the parameter of interest and the nuisance parameters are set to the values $\hat{\beta}$ and $\hat{\theta}$ which jointly maximise the likelihood. This is done following

the implementation described in Ref. [55, 56], with $\mathcal{B}_{H \rightarrow \text{inv}}$ as the parameter of interest, β . Systematic uncertainties are modelled in the likelihood function as nuisance parameters, θ , constrained by Gaussian or log-normal probability density functions. Upper limits on $\mathcal{B}_{H \rightarrow \text{inv}}$ are determined following the CL_s formalism [57] using the profile likelihood ratio as a test statistic.

3.1 Uncertainty correlation in Run 2 combination

In the combination of Run 2 results, most experimental systematic uncertainties, as well as the uncertainty on the integrated luminosity and the modelling of additional pp collisions in the same and neighbouring bunch crossings (pile-up), are correlated across all search channels. The assessment of some of the uncertainties associated with the calibration of the jet energy scale (JES) and the jet energy resolution varies between the different analyses in terms of jet reconstruction algorithms and parameterisation choices. For this reason, the uncertainty components stemming from identical methodologies are presumed to be correlated, while the rest of the uncertainties are treated as uncorrelated. Finally, a few experimental systematic uncertainties that are tightly constrained in a given analysis are not correlated in order not to introduce any potential phase space specific biases. The impact of these assumptions on the combined result is estimated by using alternative correlation models and found to have an absolute effect on the $\mathcal{B}_{H \rightarrow \text{inv}}$ limit of the order of 0.003.

The uncertainties related to background predictions are considered to be uncorrelated among analyses due to the different nature of the leading backgrounds, the variety of kinematic phase space covered by the various analyses, and the usage of data-driven techniques. The systematic uncertainties in the prediction of Higgs boson production follow the recommendations in Ref. [24]. Variations connected to the choice of parton distribution functions (PDF) are considered as correlated among channels while effects of missing higher-order contributions (estimates through variations of factorisation and renormalisation scales) and parton shower/hadronisation models are considered independently for each Higgs boson production mode and therefore uncorrelated across the analyses.

3.2 Uncertainty correlation in Run 1 and Run 2 combination

The Run 2 result described above is combined with the Run 1 searches for $H \rightarrow$ invisible decays. The adopted correlation scheme follows closely the statistical combination of the partial Run 2 results with the Run 1 combination [31].

The correlation schemes of the individual Run 1 and Run 2 combinations are preserved when combined together. Due to the differences between the detector layouts and data-taking conditions, reconstruction algorithms, which are calibrated using data, and treatment of systematic uncertainties, the correlations between the two LHC runs are not clearly identifiable. Hence, no correlations between Run 1 and 2 are assumed for most instrumental uncertainties. Exceptions are made for uncertainties related to the modelling of the calorimeter response dependence on jet flavour and pile-up, the calibration of the JES across different η regions, and the uncertainties related to the JES of b -quark jets. Such components are treated as correlated given that the same methodology was applied to compute them in both of the datasets.

Background modelling uncertainties are considered to be uncorrelated in order to reflect improvements in the MC simulation tools and general theory predictions that have evolved significantly since Run 1, both on the side of the hard process simulation and on the side of the parton shower and hadronisation models. For

similar reasons, the signal modelling uncertainties are considered uncorrelated between the Run 1 and Run 2 combinations.

The result of the combination shows little sensitivity to the exact correlation scheme between the Run 1 and Run 2 results due to the dominant weight of the latter.

4 Results

The value of twice the negative logarithmic profile likelihood ratio $-2 \ln(\Lambda)(\mathcal{B}_{H \rightarrow \text{inv}}; \theta)$ as a function of $\mathcal{B}_{H \rightarrow \text{inv}}$ of the individual analyses and of the combined Run 2 result are shown in Figure 2 (left). The combined best-fit value for $\mathcal{B}_{H \rightarrow \text{inv}}$ is 0.04 ± 0.04 . Good agreement among the best fit values of the individual analyses, reported in Table 1, is observed.

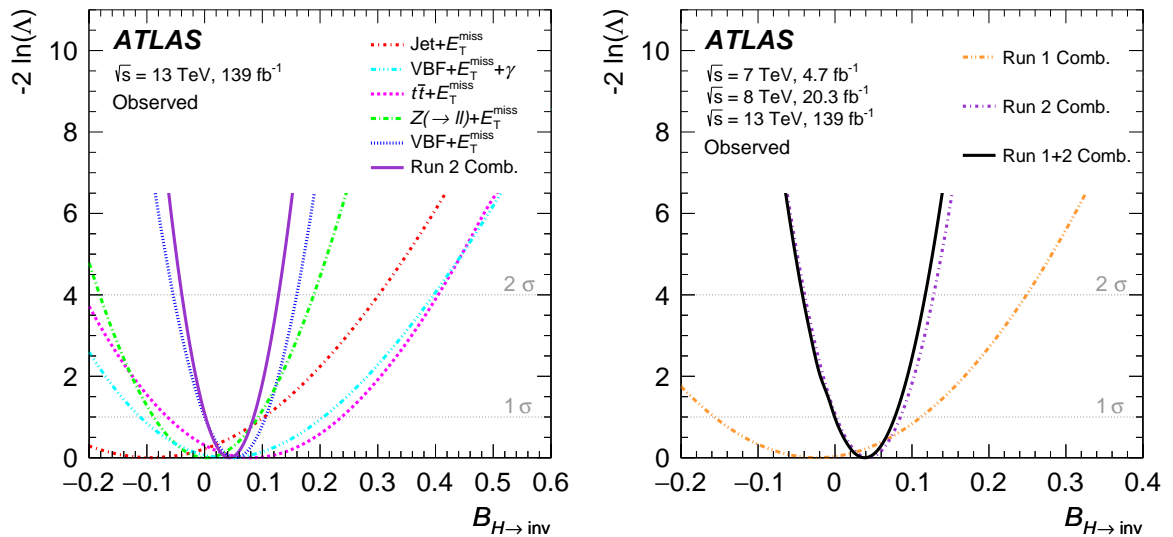


Figure 2: The observed value of $-2 \ln(\Lambda)$ as a function of $\mathcal{B}_{H \rightarrow \text{inv}}$ for the individual Run 2 analyses and their combination (left) and the Run 2 combination together with the Run 1 combination and the total Run 1+2 combination (right).

The best-fit values for $\mathcal{B}_{H \rightarrow \text{inv}}$ together with the 95% CL expected and observed upper limits for each individual Run 2 analysis and their combination are also shown in Table 1. An upper limit of 0.113 is observed for the combined Run 2 data, while an upper limit of 0.080 was expected in the case of no observed excess in data. Relative to the most sensitive single analysis, the VBF final state, the Run 2 combination brings a relative sensitivity improvement of 22%.

Overall, the leading systematic uncertainty of the result is due to the modelling uncertainties of the W/Z +jets prediction in the VBF + E_T^{miss} search [33]. Subdominant uncertainties with similar contribution are related to the statistical precision of the data sample; the number of simulated MC events, in particular for the W/Z +jets process; the reconstruction and identification of jets and leptons; and the modelling of background processes other than from W/Z +jets production.

Table 1: Best fit value, observed and expected 95% upper limit on $\mathcal{B}_{H \rightarrow \text{inv}}$ for each individual Run 2 analysis, their combination, the Run 1 combination and the full Run 1+2 combination.

Analysis	Best fit $\mathcal{B}_{H \rightarrow \text{inv}}$	Observed 95% U.L.	Expected 95% U.L.
Jet + $E_{\text{T}}^{\text{miss}}$	$-0.09^{+0.19}_{-0.20}$	0.329	$0.383^{+0.157}_{-0.107}$
VBF + $E_{\text{T}}^{\text{miss}} + \gamma$	$0.04^{+0.17}_{-0.15}$	0.375	$0.346^{+0.151}_{-0.097}$
$t\bar{t} + E_{\text{T}}^{\text{miss}}$	0.08 ± 0.15	0.376	$0.295^{+0.125}_{-0.083}$
$Z(\rightarrow \ell\ell) + E_{\text{T}}^{\text{miss}}$	0.00 ± 0.09	0.185	$0.185^{+0.078}_{-0.052}$
VBF + $E_{\text{T}}^{\text{miss}}$	0.05 ± 0.05	0.145	$0.103^{+0.041}_{-0.028}$
Run 2 Comb.	0.04 ± 0.04	0.113	$0.080^{+0.031}_{-0.022}$
Run 1 Comb.	$-0.02^{+0.14}_{-0.13}$	0.252	$0.265^{+0.105}_{-0.074}$
Run 1+2 Comb.	0.04 ± 0.04	0.107	$0.077^{+0.030}_{-0.022}$

The observed $-2 \ln(\Lambda)(\mathcal{B}_{H \rightarrow \text{inv}}; \theta)$ scan of the combined Run 1+2 result is represented in Figure 2 (right), alongside the individual Run 1 and Run 2 combinations. A best-fit value of $\mathcal{B}_{H \rightarrow \text{inv}} = 0.04 \pm 0.04$ is obtained for the Run 1+2 combination, corresponding to an observed (expected) upper limit of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.107$ (0.077) at the 95% CL. The result is dominated by the Run 2 analysis with the addition of Run 1 combination improving the expected relative sensitivity by 4%.

The overall picture of the most relevant sources of uncertainty in the Run 1+Run 2 combination is very similar to that of the Run 2 combination. The upper limit would improve by 50% if all sources of systematic uncertainties were ignored.

The upper limits for each individual Run 2 analysis, their combination, the Run 1 combination and the overall Run 1+2 combined result are summarised in Figure 3. The current combination improves the constraints on $\mathcal{B}_{H \rightarrow \text{inv}}$ by more than a factor of two as compared to the previous ATLAS combination from Run 1 and partial Run 2 results [31].

5 Comparison to direct dark matter detection experiments

The combined observed Run 1+2 upper limit on $\mathcal{B}_{H \rightarrow \text{inv}}$ can be converted into a limit on the spin-independent scattering cross-section of a weakly interacting massive particle (WIMP) and a nucleon [13, 18, 58, 59] ($\sigma_{\text{WIMP-Nucleon}}$), to allow the comparison of the results with the ones from experiments based on different detector technologies. The translation is performed in the context of Higgs portal models [15, 60] using an effective field theory framework, where the mediator of new interactions is assumed to be above the TeV-level and therefore well above the scale probed at the Higgs boson mass. The approach assumes that Higgs boson decays into a pair of WIMP particles are kinematically possible ($m_{\text{WIMP}} < m_H/2$) and that the WIMP particle is either a scalar, a Majorana fermion, or a vector-like state². In addition, in the case of vectorial DM states, various ultraviolet-complete (UV) models were proposed [62–64]. In such scenarios, the vector DM candidate is introduced as a gauge field of a $U(1)'$ group which extends the

² The value of $f_N = 0.308 \pm 0.018$ [61] is used as nuclear form factor.

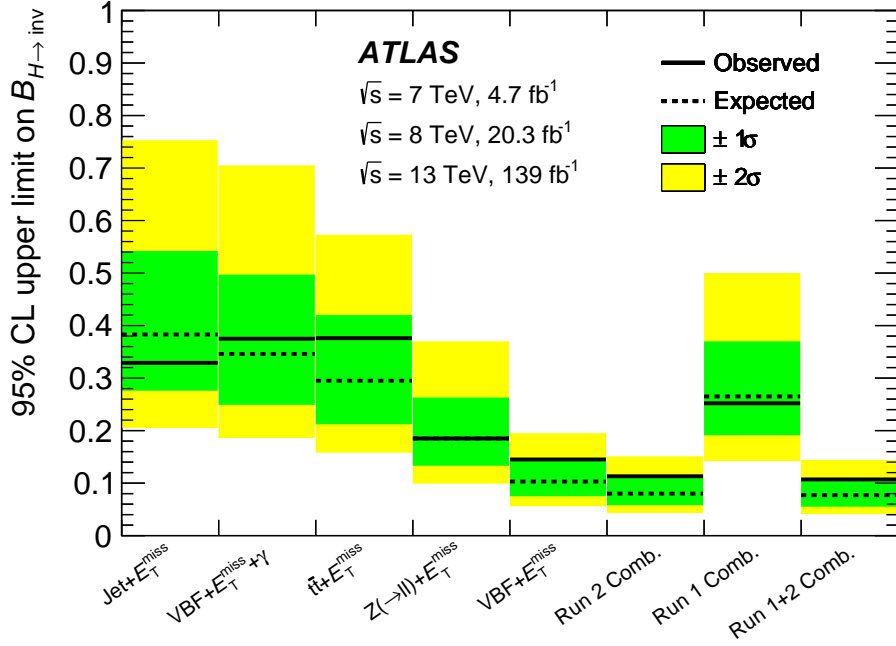


Figure 3: The observed and expected upper limits on $\mathcal{B}_{H \rightarrow \text{inv}}$ at 95% CL for the Run 2 analyses targeting the $\text{Jet} + E_T^{\text{miss}}$, $\text{VBF} + E_T^{\text{miss}} + \gamma$, $t\bar{t} + E_T^{\text{miss}}$, $Z(\rightarrow \ell\ell) + E_T^{\text{miss}}$, $\text{VBF} + E_T^{\text{miss}}$ final states and their combination, the Run 1 combination and the full Run 1+2 result; the 1σ and 2σ contours of the expected limit distribution are also shown.

SM symmetry group and a dark Higgs sector is added to generate the vector boson mass via the Higgs spontaneous symmetry breaking mechanism. This adds at least two free parameters to the model: the mass m_2 of the additional dark Higgs boson and its mixing angle α with the SM Higgs boson.

The constraint from the combined observed Run 1+2 exclusion limit of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.093$ at 90% CL is compared to the results from representative direct DM detection experiments [65–68] in Figure 4. The excluded $\sigma_{\text{WIMP-Nucleon}}$ values range from 10^{-45} cm^2 to 10^{-42} cm^2 in the scalar WIMP scenario. In the Majorana fermion WIMP case, the effective coupling is reduced by a factor m_H^2 [27], excluding cross-section values down to $2 \times 10^{-47} \text{ cm}^2$ for low WIMP masses; $\sigma_{\text{WIMP-Nucleon}}$ values down to 10^{-54} cm^2 can be excluded for the vector WIMP hypothesis. For UV-complete models, Figure 4 also shows the upper limit cross-section behaviour for a mixing angle $\alpha = 0.2$ and for masses of the dark Higgs particle equal to 65 GeV and 100 GeV corresponding to the worst and best limit for a scan of m_2 in the range [65, 1000] GeV [64]. This comparison illustrates the complementarity in coverage by the direct-detection experiments and the searches at colliders, such as the presented analysis.

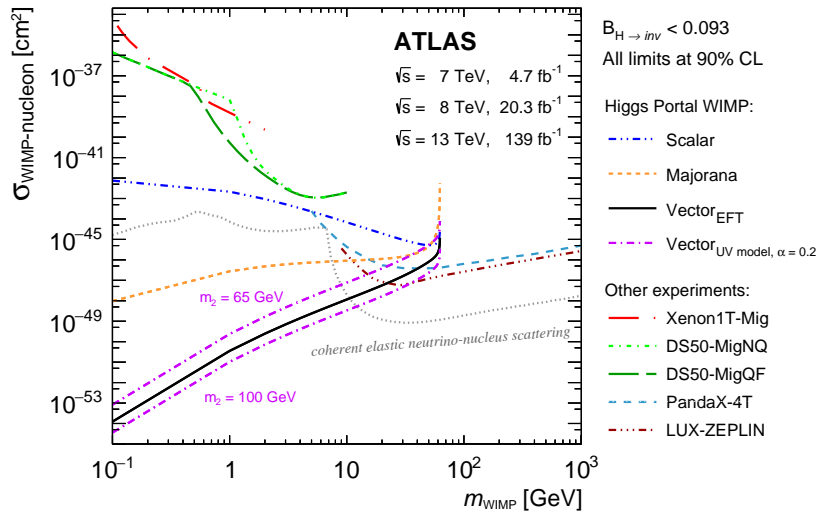


Figure 4: Upper limit at the 90% CL on the spin-independent WIMP-nucleon scattering cross-section as a function of the WIMP mass for direct detection experiments and the interpretation of the $H \rightarrow \text{invisible}$ combination result in the context of Higgs portal models considering scalar, Majorana and vector WIMP hypotheses. For the vector case, results from UV-complete models are shown (pink curves) for two representative values for the mass of the predicted Dark Higgs particle (m_2) and a mixing angle $\alpha=0.2$. The uncertainties from the nuclear form factor are smaller than the line thickness. Direct detection results are taken from Refs. [65–68]. The neutrino floor for coherent elastic neutrino-nucleus scattering (dotted gray line) is taken from Refs. [69, 70], which assume that germanium is the target over the whole WIMP mass range. The regions above the limit contours are excluded in the range shown in the plot.

6 Conclusion

In summary, searches for invisible decays of the Higgs boson using 139 fb^{-1} of pp collision data at $\sqrt{s} = 13 \text{ TeV}$ recorded in Run 2 of the LHC in several Higgs boson production topologies were statistically combined assuming SM Higgs boson production. An upper limit on the invisible Higgs boson branching ratio of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.113$ ($0.080^{+0.031}_{-0.022}$) is observed (expected) at the 95% CL. A statistical combination of this result with the combination of $H \rightarrow \text{invisible}$ searches using up to 4.7 fb^{-1} of pp collision data at $\sqrt{s} = 7 \text{ TeV}$ and up to 20.3 fb^{-1} at 8 TeV collected in Run 1 of the LHC yields an observed (expected) upper limit of $\mathcal{B}_{H \rightarrow \text{inv}} < 0.107$ ($0.077^{+0.030}_{-0.022}$) at the 95% CL. The combined Run 1+2 result is translated into upper limits on the WIMP-nucleon scattering cross-section for Higgs portal models. The derived limits on $\sigma_{\text{WIMP-Nucleon}}$ range down to 10^{-45} cm^2 (scalar), $2 \times 10^{-47} \text{ cm}^2$ (Majorana) and 10^{-54} cm^2 (vector), highlighting the complementarity of DM searches at the LHC and direct detection experiments.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMFWF and FWF, Austria; ANAS, Azerbaijan; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRf

and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TENMAK, Türkiye; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; PRIMUS 21/SCI/017 and UNCE SCI/013, Czech Republic; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d’Avenir Labex, Investissements d’Avenir IDEX and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and MINERVA, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [71].

References

- [1] F. Zwicky, *Die Rotverschiebung von extragalaktischen Nebeln*, *Helv. Phys. Acta* **6** (1933) 110.
- [2] G. Bertone, D. Hooper and J. Silk, *Particle dark matter: Evidence, candidates and constraints*, *Phys. Rept.* **405** (2005) 279, arXiv: [hep-ph/0404175](https://arxiv.org/abs/hep-ph/0404175).
- [3] E. Komatsu et al., *SEVEN-YEAR WILKINSON MICROWAVE ANISOTROPY PROBE (WMAP) OBSERVATIONS: COSMOLOGICAL INTERPRETATION*, *Astrophys. J. Suppl.* **192** (2011) 18, arXiv: [1001.4538](https://arxiv.org/abs/1001.4538) [[astro-ph.CO](https://arxiv.org/abs/hep-ph)].
- [4] Planck Collaboration, *Planck 2015 results. XIII. Cosmological parameters*, *Astron. Astrophys.* **594** (2016) A13, arXiv: [1502.01589](https://arxiv.org/abs/1502.01589) [[astro-ph.CO](https://arxiv.org/abs/hep-ph)].
- [5] D. Abercrombie et al., *Dark Matter benchmark models for early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum*, *Phys. Dark Univ.* **27** (2020) 100371, arXiv: [1507.00966](https://arxiv.org/abs/1507.00966) [[hep-ex](https://arxiv.org/abs/hep-ex)].
- [6] J. L. Feng, *Dark Matter Candidates from Particle Physics and Methods of Detection*, *Annual Review of Astronomy and Astrophysics* **48** (2010) 495, arXiv: [1003.0904](https://arxiv.org/abs/1003.0904) [[astro-ph.CO](https://arxiv.org/abs/hep-ph)].
- [7] A. Boveia and C. Doglioni, *Dark Matter Searches at Colliders*, *Annual Review of Nuclear and Particle Science* **68** (2018) 429, arXiv: [1810.12238](https://arxiv.org/abs/1810.12238) [[hep-ex](https://arxiv.org/abs/hep-ex)].
- [8] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, *Phys. Lett. B* **716** (2012) 1, arXiv: [1207.7214](https://arxiv.org/abs/1207.7214) [[hep-ex](https://arxiv.org/abs/hep-ex)].

- [9] CMS Collaboration,
Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,
Phys. Lett. B **716** (2012) 30, arXiv: [1207.7235 \[hep-ex\]](#).
- [10] I. Antoniadis, M. Tuckmantel and F. Zwirner,
Phenomenology of a leptonic goldstino and invisible Higgs boson decays,
Nucl. Phys. **707** (2005) 215, arXiv: [hep-ph/0410165 \[hep-ph\]](#).
- [11] N. Arkani-Hamed, S. Dimopoulos, G. R. Dvali and J. March-Russell,
Neutrino masses from large extra dimensions, *Phys. Rev. D* **65** (2001) 024032,
arXiv: [hep-ph/9811448 \[hep-ph\]](#).
- [12] A. Datta, K. Huitu, J. Laamanen and B. Mukhopadhyaya,
Linear collider signals of an invisible Higgs boson in theories of large extra dimensions,
Phys. Rev. D **70** (2004) 075003, arXiv: [hep-ph/0404056 \[hep-ph\]](#).
- [13] S. Kanemura, S. Matsumoto, T. Nabeshima and N. Okada,
Can WIMP dark matter overcome the nightmare scenario?, *Phys. Rev. D* **82** (2010) 055026,
arXiv: [1005.5651 \[hep-ph\]](#).
- [14] A. Djouadi, O. Lebedev, Y. Mambrini and J. Quevillon,
Implications of LHC searches for Higgs–portal dark matter, *Phys. Lett. B* **709** (2012) 65,
arXiv: [1112.3299 \[hep-ph\]](#).
- [15] A. Djouadi, A. Falkowski, Y. Mambrini and J. Quevillon,
Direct detection of Higgs–portal dark matter at the LHC, *Eur. Phys. J. C* **73** (2013) 2455,
arXiv: [1205.3169 \[hep-ph\]](#).
- [16] R. E. Shrock and M. Suzuki, *Invisible Decays of Higgs Bosons*, *Phys. Lett. B* **110** (1982) 250.
- [17] D. Choudhury and D. P. Roy, *Signatures of an invisibly decaying Higgs particle at LHC*,
Phys. Lett. B **322** (1994) 368, arXiv: [hep-ph/9312347 \[hep-ph\]](#).
- [18] O. J. P. Eboli and D. Zeppenfeld, *Observing an invisible Higgs boson*, *Phys. Lett. B* **495** (2000) 147,
arXiv: [hep-ph/0009158 \[hep-ph\]](#).
- [19] H. Davoudiasl, T. Han and H. E. Logan,
Discovering an invisibly decaying Higgs boson at hadron colliders, *Phys. Rev. D* **71** (2005) 115007,
arXiv: [hep-ph/0412269 \[hep-ph\]](#).
- [20] R. M. Godbole, M. Guchait, K. Mazumdar, S. Moretti and D. P. Roy,
Search for ‘invisible’ Higgs signals at LHC via associated production with gauge bosons,
Phys. Lett. B **571** (2003) 184, arXiv: [hep-ph/0304137 \[hep-ph\]](#).
- [21] D. Ghosh, R. Godbole, M. Guchait, K. Mohan and D. Sengupta,
Looking for an Invisible Higgs Signal at the LHC, *Phys. Lett. B* **725** (2013) 344,
arXiv: [1211.7015 \[hep-ph\]](#).
- [22] G. Belanger, B. Dumont, U. Ellwanger, J. F. Gunion and S. Kraml, *Status of invisible Higgs decays*,
Phys. Lett. B **723** (2013) 340, arXiv: [1302.5694 \[hep-ph\]](#).
- [23] D. Curtin et al., *Exotic decays of the 125 GeV Higgs boson*, *Phys. Rev. D* **90** (2014) 075004,
arXiv: [1312.4992 \[hep-ph\]](#).
- [24] D. de Florian et al.,
Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector, (2016),
arXiv: [1610.07922 \[hep-ph\]](#).

- [25] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.
- [26] ATLAS Collaboration, *ATLAS Insertable B-Layer Technical Design Report*, ATLAS-TDR-19; CERN-LHCC-2010-013, 2010, URL: <https://cds.cern.ch/record/1291633>, Addendum: ATLAS-TDR-19-ADD-1; CERN-LHCC-2012-009, 2012, URL: <https://cds.cern.ch/record/1451888>.
- [27] ATLAS Collaboration, *Search for invisible decays of a Higgs boson using vector-boson fusion in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *JHEP* **01** (2016) 172, arXiv: 1508.07869 [hep-ex].
- [28] ATLAS Collaboration, *Search for Invisible Decays of a Higgs Boson Produced in Association with a Z Boson in ATLAS*, *Phys. Rev. Lett.* **112** (2014) 201802, arXiv: 1402.3244 [hep-ex].
- [29] ATLAS Collaboration, *Search for invisible decays of the Higgs boson produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **75** (2015) 337, arXiv: 1504.04324 [hep-ex].
- [30] ATLAS Collaboration, *Constraints on new phenomena via Higgs boson couplings and invisible decays with the ATLAS detector*, *JHEP* **11** (2015) 206, arXiv: 1509.00672 [hep-ex].
- [31] ATLAS Collaboration, *Combination of Searches for Invisible Higgs Boson Decays with the ATLAS Experiment*, *Phys. Rev. Lett.* **122** (2019) 231801, arXiv: 1904.05105 [hep-ex].
- [32] CMS Collaboration, *Search for invisible decays of a Higgs boson produced through vector boson fusion in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *Phys. Lett. B* **793** (2019) 520, arXiv: 1809.05937 [hep-ex].
- [33] ATLAS Collaboration, *Search for invisible Higgs-boson decays in events with vector-boson fusion signatures using 139 fb^{-1} of proton–proton data recorded by the ATLAS experiment*, *JHEP* **08** (2022) 104, arXiv: 2202.07953 [hep-ex].
- [34] ATLAS Collaboration, *Observation of electroweak production of two jets in association with an isolated photon and missing transverse momentum, and search for a Higgs boson decaying into invisible particles at 13 TeV with the ATLAS detector*, *Eur. Phys. J. C* **82** (2021) 105, arXiv: 2109.00925 [hep-ex].
- [35] ATLAS Collaboration, *Constraints on spin-0 dark matter mediators and invisible Higgs decays using ATLAS 13 TeV pp collision data with two top quarks and missing energy in the final state*, ATLAS-CONF-2022-007, 2022, URL: <https://cds.cern.ch/record/2805211>.
- [36] ATLAS Collaboration, *Search for associated production of a Z boson with an invisibly decaying Higgs boson or dark matter candidates at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Phys. Lett. B* **829** (2021) 137066, arXiv: 2111.08372 [hep-ex].
- [37] ATLAS Collaboration, *Search for new phenomena in events with an energetic jet and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Phys. Rev. D* **103** (2021) 112006, arXiv: 2102.10874 [hep-ex].
- [38] CMS Collaboration, *Search for dark matter produced in association with a leptonically decaying Z boson in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J. C* **81** (2021) 13, arXiv: 2008.04735 [hep-ex].

- [39] CMS Collaboration, *Search for invisible decays of the Higgs boson produced via vector boson fusion in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *Phys. Rev. D* **105** (2022) 092007, arXiv: [2201.11585 \[hep-ex\]](#).
- [40] CMS Collaboration, *Search for new particles in events with energetic jets and large missing transverse momentum in proton–proton collisions at $\sqrt{s} = 13$ TeV*, *JHEP* **11** (2021) 153, arXiv: [2107.13021 \[hep-ex\]](#).
- [41] ATLAS Collaboration, *A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery*, *Nature* **607** (2022) 52, arXiv: [2207.00092 \[hep-ex\]](#).
- [42] K. Kudashkin, J. M. Lindert, K. Melnikov and C. Wever, *Higgs bosons with large transverse momentum at the LHC*, *Phys. Lett. B* **782** (2018) 210, arXiv: [1801.08226 \[hep-ph\]](#).
- [43] A. Djouadi, J. Kalinowski, M. Mühlleitner and M. Spira, *HDECAY: Twenty++ years after*, *Comput. Phys. Commun.* **238** (2019) 214, arXiv: [1801.09506 \[hep-ph\]](#).
- [44] M. Bonetti, K. Melnikov and L. Tancredi, *Higher order corrections to mixed QCD-EW contributions to Higgs boson production in gluon fusion*, *Phys. Rev. D* **97** (2018) 056017, arXiv: [1801.10403 \[hep-ph\]](#), Erratum: *Phys. Rev. D* **97** (2018) 099906.
- [45] F. Dulat, A. Lazopoulos and B. Mistlberger, *iHixs 2 – Inclusive Higgs cross sections*, *Comput. Phys. Commun.* **233** (2018) 243, arXiv: [1802.00827 \[hep-ph\]](#).
- [46] R. V. Harlander, J. Klappert, S. Liebler and L. Simon, *vh@nnlo-v2: new physics in Higgs Strahlung*, *JHEP* **05** (2018) 089, arXiv: [1802.04817 \[hep-ph\]](#).
- [47] M. Cacciari, F. A. Dreyer, A. Karlberg, G. P. Salam and G. Zanderighi, *Fully Differential Vector-Boson-Fusion Higgs Production at Next-to-Next-to-Leading Order*, *Phys. Rev. Lett.* **115** (2015) 082002, arXiv: [1506.02660 \[hep-ph\]](#), Erratum: *Phys. Rev. Lett.* **120** (2018) 139901.
- [48] ATLAS Collaboration, *Constraints on spin-0 dark matter mediators and invisible Higgs decays using ATLAS 13 TeV pp collision data with two top quarks and missing transverse momentum in the final state*, 2022, arXiv: [2211.05426 \[hep-ex\]](#).
- [49] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J. C* **79** (2019) 970, arXiv: [1907.05120 \[hep-ex\]](#).
- [50] J. M. Lindert, S. Pozzorini and M. Schönherr, *Precise predictions for V+2 jet backgrounds in searches for invisible Higgs decays*, 2022, arXiv: [2204.07652 \[hep-ph\]](#).
- [51] ATLAS Collaboration, *Search for a scalar partner of the top quark in the all-hadronic $t\bar{t}$ plus missing transverse momentum final state at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **80** (2020) 737, arXiv: [2004.14060 \[hep-ex\]](#).
- [52] ATLAS Collaboration, *Search for new phenomena with top quark pairs in final states with one lepton, jets, and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *JHEP* **04** (2020) 174, arXiv: [2012.03799 \[hep-ex\]](#).

- [53] ATLAS Collaboration, *Search for new phenomena in events with two opposite-charge leptons, jets and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, [JHEP **04** \(2021\) 165](#), arXiv: [2102.01444 \[hep-ex\]](#).
- [54] G. Cowan, K. Cranmer, E. Gross and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, [Eur. Phys. J. C **71** \(2011\) 1554](#), arXiv: [1007.1727 \[physics.data-an\]](#), Erratum: [Eur. Phys. J. C **73** \(2013\) 2501](#).
- [55] W. Verkerke and D. Kirkby, *The RooFit toolkit for data modeling*, 2003, arXiv: [physics/0306116 \[physics.data-an\]](#).
- [56] L. Moneta et al., *The RooStats project*, [PoS ACAT2010 \(2010\) 057](#), arXiv: [1009.1003 \[physics.data-an\]](#).
- [57] A. L. Read, *Presentation of search results: the CL_S technique*, [J. Phys. G **28** \(2002\) 2693](#).
- [58] P. J. Fox, R. Harnik, J. Kopp and Y. Tsai, *Missing energy signatures of dark matter at the LHC*, [Physical Review D **85** \(2012\)](#), ISSN: 1550-2368, arXiv: [1109.4398](#).
- [59] A. De Simone, G. F. Giudice and A. Strumia, *Benchmarks for dark matter searches at the LHC*, [JHEP **06** \(2014\) 081](#), arXiv: [1402.6287](#).
- [60] B. Patt and F. Wilczek, *Higgs-field portal into hidden sectors*, 2006, arXiv: [hep-ph/0605188 \[hep-ph\]](#).
- [61] M. Hoferichter, P. Klos, J. Menéndez and A. Schwenk, *Improved Limits for Higgs-Portal Dark Matter from LHC Searches*, [Phys. Rev. Lett. **119** \(2017\) 181803](#), arXiv: [1708.02245 \[hep-ph\]](#).
- [62] S. Baek, P. Ko and W.-I. Park, *Invisible Higgs decay width versus dark matter direct detection cross section in Higgs portal dark matter models*, [Phys. Rev. D **90** \(2014\) 055014](#), arXiv: [1405.3530 \[hep-ph\]](#).
- [63] G. Arcadi, A. Djouadi and M. Kado, *The Higgs-portal for vector Dark Matter and the Effective Field Theory approach: a reappraisal*, [Phys. Lett. B **805** \(2020\) 135427](#), arXiv: [2001.10750 \[hep-ph\]](#).
- [64] M. Zaazoua, L. Truong, K. A. Assamagan and F. Fassi, *Higgs Portal Vector Dark Matter Interpretation: Review of Effective Field Theory Approach and Ultraviolet Complete Models*, [Letters in High Energy Physics \(2022\) 270](#), arXiv: [2107.01252 \[hep-ph\]](#).
- [65] P. Agnes et al., *Search for Dark-Matter–Nucleon Interactions via Migdal Effect with DarkSide-50*, [Phys. Rev. Lett. **130** \(10 2023\) 101001](#), arXiv: [1802.06994](#).
- [66] Y. Meng et al., *Dark Matter Search Results from the PandaX-4T Commissioning Run*, [Physical Review Letters **127** \(2021\)](#), arXiv: [2107.13438](#).
- [67] J. Aalbers et al., *First Dark Matter Search Results from the LUX-ZEPLIN (LZ) Experiment*, (2022), arXiv: [2207.03764 \[hep-ex\]](#).
- [68] E. Aprile et al., *Search for Light Dark Matter Interactions Enhanced by the Migdal Effect or Bremsstrahlung in XENONIT*, [Phys. Rev. Lett. **123** \(2019\) 241803](#), arXiv: [1907.12771 \[hep-ex\]](#).
- [69] J. Billard, E. Figueroa-Feliciano and L. Strigari, *Implication of neutrino backgrounds on the reach of next generation dark matter direct detection experiments*, [Physical Review D **89** \(2014\)](#), arXiv: [1307.5458 \[hep-ph\]](#).

- [70] F. Ruppin, J. Billard, E. Figueroa-Feliciano and L. Strigari,
Complementarity of dark matter detectors in light of the neutrino background,
Physical Review D **90** (2014), arXiv: 1408.3581.
- [71] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2021-003, 2021,
URL: <https://cds.cern.ch/record/2776662>.

The ATLAS Collaboration

G. Aad ¹⁰², B. Abbott ¹²⁰, K. Abeling ⁵⁵, S.H. Abidi ²⁹, A. Abouhorma ^{35e},
H. Abramowicz ¹⁵¹, H. Abreu ¹⁵⁰, Y. Abulaiti ¹¹⁷, A.C. Abusleme Hoffman ^{137a},
B.S. Acharya ^{69a,69b,n}, C. Adam Bourdarios ⁴, L. Adamczyk ^{85a}, L. Adamek ¹⁵⁵,
S.V. Addepalli ²⁶, J. Adelman ¹¹⁵, A. Adiguzel ^{21c}, S. Adorni ⁵⁶, T. Adye ¹³⁴, A.A. Affolder ¹³⁶,
Y. Afik ³⁶, M.N. Agaras ¹³, J. Agarwala ^{73a,73b}, A. Aggarwal ¹⁰⁰, C. Agheorghiesei ^{27c},
J.A. Aguilar-Saavedra ^{130f}, A. Ahmad ³⁶, F. Ahmadov ^{38,x}, W.S. Ahmed ¹⁰⁴, S. Ahuja ⁹⁵,
X. Ai ⁴⁸, G. Aielli ^{76a,76b}, M. Ait Tamlihat ^{35e}, B. Aitbenkikh ^{35a}, I. Aizenberg ¹⁶⁸,
M. Akbiyik ¹⁰⁰, T.P.A. Åkesson ⁹⁸, A.V. Akimov ³⁷, N.N. Akolkar ²⁴, K. Al Houry ⁴¹,
G.L. Alberghi ^{23b}, J. Albert ¹⁶⁴, P. Albicocco ⁵³, S. Alderweireldt ⁵², M. Aleksa ³⁶,
I.N. Aleksandrov ³⁸, C. Alexa ^{27b}, T. Alexopoulos ¹⁰, A. Alfonsi ¹¹⁴, F. Alfonsi ^{23b},
M. Alhroob ¹²⁰, B. Ali ¹³², S. Ali ¹⁴⁸, M. Aliev ³⁷, G. Alimonti ^{71a}, W. Alkakhri ⁵⁵,
C. Allaire ⁶⁶, B.M.M. Allbrooke ¹⁴⁶, C.A. Allendes Flores ^{137f}, P.P. Allport ²⁰, A. Aloisio ^{72a,72b},
F. Alonso ⁹⁰, C. Alpigiani ¹³⁸, M. Alvarez Estevez ⁹⁹, A. Alvarez Fernandez ¹⁰⁰,
M.G. Alvigi ^{72a,72b}, M. Aly ¹⁰¹, Y. Amaral Coutinho ^{82b}, A. Ambler ¹⁰⁴, C. Amelung ³⁶,
M. Amerl ¹⁰¹, C.G. Ames ¹⁰⁹, D. Amidei ¹⁰⁶, S.P. Amor Dos Santos ^{130a}, K.R. Amos ¹⁶²,
V. Ananiev ¹²⁵, C. Anastopoulos ¹³⁹, T. Andeen ¹¹, J.K. Anders ³⁶, S.Y. Andrean ^{47a,47b},
A. Andreazza ^{71a,71b}, S. Angelidakis ⁹, A. Angerami ^{41,z}, A.V. Anisenkov ³⁷, A. Annovi ^{74a},
C. Antel ⁵⁶, M.T. Anthony ¹³⁹, E. Antipov ¹⁴⁵, M. Antonelli ⁵³, D.J.A. Antrim ^{17a}, F. Anulli ^{75a},
M. Aoki ⁸³, T. Aoki ¹⁵³, J.A. Aparisi Pozo ¹⁶², M.A. Aparo ¹⁴⁶, L. Aperio Bella ⁴⁸,
C. Appelt ¹⁸, N. Aranzabal ³⁶, V. Araujo Ferraz ^{82a}, C. Arcangeletti ⁵³, A.T.H. Arce ⁵¹,
E. Arena ⁹², J-F. Arguin ¹⁰⁸, S. Argyropoulos ⁵⁴, J.-H. Arling ⁴⁸, A.J. Armbruster ³⁶,
O. Arnaez ⁴, H. Arnold ¹¹⁴, Z.P. Arrubarrena Tame ¹⁰⁹, G. Artoni ^{75a,75b}, H. Asada ¹¹¹,
K. Asai ¹¹⁸, S. Asai ¹⁵³, N.A. Asbah ⁶¹, J. Assahsah ^{35d}, K. Assamagan ²⁹, R. Astalos ^{28a},
R.J. Atkin ^{33a}, M. Atkinson ¹⁶¹, N.B. Atlay ¹⁸, H. Atmani ^{62b}, P.A. Atmasiddha ¹⁰⁶, K. Augsten ¹³²,
S. Auricchio ^{72a,72b}, A.D. Auriol ²⁰, V.A. Austrup ¹⁷⁰, G. Avner ¹⁵⁰, G. Avolio ³⁶, K. Axiotis ⁵⁶,
G. Azuelos ^{108,ab}, D. Babal ^{28b}, H. Bachacou ¹³⁵, K. Bachas ^{152,p}, A. Bachiu ³⁴,
F. Backman ^{47a,47b}, A. Badea ⁶¹, P. Bagnaia ^{75a,75b}, M. Bahmani ¹⁸, A.J. Bailey ¹⁶²,
V.R. Bailey ¹⁶¹, J.T. Baines ¹³⁴, C. Bakalis ¹⁰, O.K. Baker ¹⁷¹, E. Bakos ¹⁵, D. Bakshi Gupta ⁸,
R. Balasubramanian ¹¹⁴, E.M. Baldin ³⁷, P. Balek ¹³³, E. Ballabene ^{71a,71b}, F. Balli ¹³⁵,
L.M. Baltes ^{63a}, W.K. Balunas ³², J. Balz ¹⁰⁰, E. Banas ⁸⁶, M. Bandieramonte ¹²⁹,
A. Bandyopadhyay ²⁴, S. Bansal ²⁴, L. Barak ¹⁵¹, E.L. Barberio ¹⁰⁵, D. Barberis ^{57b,57a},
M. Barbero ¹⁰², G. Barbour ⁹⁶, K.N. Barends ^{33a}, T. Barillari ¹¹⁰, M-S. Barisits ³⁶, T. Barklow ¹⁴³,
P. Baron ¹²², D.A. Baron Moreno ¹⁰¹, A. Baroncelli ^{62a}, G. Barone ²⁹, A.J. Barr ¹²⁶,
L. Barranco Navarro ^{47a,47b}, F. Barreiro ⁹⁹, J. Barreiro Guimarães da Costa ^{14a}, U. Barron ¹⁵¹,
M.G. Barros Teixeira ^{130a}, S. Barsov ³⁷, F. Bartels ^{63a}, R. Bartoldus ¹⁴³, A.E. Barton ⁹¹,
P. Bartos ^{28a}, A. Basan ¹⁰⁰, M. Baselga ⁴⁹, I. Bashta ^{77a,77b}, A. Bassalat ⁶⁶, M.J. Basso ¹⁵⁵,
C.R. Basson ¹⁰¹, R.L. Bates ⁵⁹, S. Batlamous ^{35e}, J.R. Batley ³², B. Batool ¹⁴¹, M. Battaglia ¹³⁶,
D. Battulga ¹⁸, M. Bauce ^{75a,75b}, M. Bauer ³⁶, P. Bauer ²⁴, J.B. Beacham ⁵¹, T. Beau ¹²⁷,
P.H. Beauchemin ¹⁵⁸, F. Becherer ⁵⁴, P. Bechtle ²⁴, H.P. Beck ^{19,o}, K. Becker ¹⁶⁶,
A.J. Beddall ^{21d}, V.A. Bednyakov ³⁸, C.P. Bee ¹⁴⁵, L.J. Beemster ¹⁵, T.A. Beermann ³⁶,
M. Begalli ^{82d,82d}, M. Begel ²⁹, A. Behera ¹⁴⁵, J.K. Behr ⁴⁸, C. Beirao Da Cruz E Silva ³⁶,
J.F. Beirer ^{55,36}, F. Beisiegel ²⁴, M. Belfkir ^{116b}, G. Bella ¹⁵¹, L. Bellagamba ^{23b},
A. Bellerive ³⁴, P. Bellos ²⁰, K. Beloborodov ³⁷, N.L. Belyaev ³⁷, D. Bencheikroun ^{35a},
F. Bendebba ^{35a}, Y. Benhammou ¹⁵¹, M. Benoit ²⁹, J.R. Bensinger ²⁶, S. Bentvelsen ¹¹⁴,

L. Beresford ⁴⁸, M. Beretta ⁵³, E. Bergeaas Kuutmann ¹⁶⁰, N. Berger ⁴, B. Bergmann ¹³²,
 J. Beringer ^{17a}, S. Berlendis ⁷, G. Bernardi ⁵, C. Bernius ¹⁴³, F.U. Bernlochner ²⁴, T. Berry ⁹⁵,
 P. Berta ¹³³, A. Berthold ⁵⁰, I.A. Bertram ⁹¹, S. Bethke ¹¹⁰, A. Betti ^{75a,75b}, A.J. Bevan ⁹⁴,
 M. Bhamjee ^{33c}, S. Bhatta ¹⁴⁵, D.S. Bhattacharya ¹⁶⁵, P. Bhattacharai ²⁶, V.S. Bhopatkar ¹²¹,
 R. Bi ^{29,ad}, R.M. Bianchi ¹²⁹, O. Biebel ¹⁰⁹, R. Bielski ¹²³, M. Biglietti ^{77a}, T.R.V. Billoud ¹³²,
 M. Bindi ⁵⁵, A. Bingul ^{21b}, C. Bini ^{75a,75b}, A. Biondini ⁹², C.J. Birch-sykes ¹⁰¹, G.A. Bird ^{20,134},
 M. Birman ¹⁶⁸, M. Biroš ¹³³, T. Bisanz ³⁶, E. Bisceglie ^{43b,43a}, D. Biswas ¹⁶⁹, A. Bitadze ¹⁰¹,
 K. Bjørke ¹²⁵, I. Bloch ⁴⁸, C. Blocker ²⁶, A. Blue ⁵⁹, U. Blumenschein ⁹⁴, J. Blumenthal ¹⁰⁰,
 G.J. Bobbink ¹¹⁴, V.S. Bobrovnikov ³⁷, M. Boehler ⁵⁴, D. Bogavac ³⁶, A.G. Bogdanchikov ³⁷,
 C. Bohm ^{47a}, V. Boisvert ⁹⁵, P. Bokan ⁴⁸, T. Bold ^{85a}, M. Bomben ⁵, M. Bona ⁹⁴,
 M. Boonekamp ¹³⁵, C.D. Booth ⁹⁵, A.G. Borbély ⁵⁹, H.M. Borecka-Bielska ¹⁰⁸, L.S. Borgna ⁹⁶,
 G. Borissov ⁹¹, D. Bortoletto ¹²⁶, D. Boscherini ^{23b}, M. Bosman ¹³, J.D. Bossio Sola ³⁶,
 K. Bouaouda ^{35a}, N. Bouchhar ¹⁶², J. Boudreau ¹²⁹, E.V. Bouhova-Thacker ⁹¹, D. Boumediene ⁴⁰,
 R. Bouquet ⁵, A. Boveia ¹¹⁹, J. Boyd ³⁶, D. Boye ²⁹, I.R. Boyko ³⁸, J. Bracinik ²⁰,
 N. Brahimí ^{62d}, G. Brandt ¹⁷⁰, O. Brandt ³², F. Braren ⁴⁸, B. Brau ¹⁰³, J.E. Brau ¹²³,
 K. Brendlinger ⁴⁸, R. Brenner ¹⁶⁸, L. Brenner ¹¹⁴, R. Brenner ¹⁶⁰, S. Bressler ¹⁶⁸, D. Britton ⁵⁹,
 D. Britzger ¹¹⁰, I. Brock ²⁴, G. Brooijmans ⁴¹, W.K. Brooks ^{137f}, E. Brost ²⁹, L.M. Brown ¹⁶⁴,
 T.L. Bruckler ¹²⁶, P.A. Bruckman de Renstrom ⁸⁶, B. Brüers ⁴⁸, D. Bruncko ^{28b,*}, A. Bruni ^{23b},
 G. Bruni ^{23b}, M. Bruschi ^{23b}, N. Bruscino ^{75a,75b}, T. Buanes ¹⁶, Q. Buat ¹³⁸, A.G. Buckley ⁵⁹,
 I.A. Budagov ^{38,*}, M.K. Bugge ¹²⁵, O. Bulekov ³⁷, B.A. Bullard ¹⁴³, S. Burdin ⁹²,
 C.D. Burgard ⁴⁹, A.M. Burger ⁴⁰, B. Burghgrave ⁸, O. Burlayenko ⁵⁴, J.T.P. Burr ³²,
 C.D. Burton ¹¹, J.C. Burzynski ¹⁴², E.L. Busch ⁴¹, V. Büscher ¹⁰⁰, P.J. Bussey ⁵⁹,
 J.M. Butler ²⁵, C.M. Buttar ⁵⁹, J.M. Butterworth ⁹⁶, W. Buttinger ¹³⁴, C.J. Buxo Vazquez ¹⁰⁷,
 A.R. Buzykaev ³⁷, G. Cabras ^{23b}, S. Cabrera Urbán ¹⁶², D. Caforio ⁵⁸, H. Cai ¹²⁹, Y. Cai ^{14a,14e},
 V.M.M. Cairo ³⁶, O. Cakir ^{3a}, N. Calace ³⁶, P. Calafiura ^{17a}, G. Calderini ¹²⁷, P. Calfayan ⁶⁸,
 G. Callea ⁵⁹, L.P. Caloba ^{82b}, D. Calvet ⁴⁰, S. Calvet ⁴⁰, T.P. Calvet ¹⁰², M. Calvetti ^{74a,74b},
 R. Camacho Toro ¹²⁷, S. Camarda ³⁶, D. Camarero Munoz ²⁶, P. Camarri ^{76a,76b},
 M.T. Camerlingo ^{72a,72b}, D. Cameron ¹²⁵, C. Camincher ¹⁶⁴, M. Campanelli ⁹⁶, A. Camplani ⁴²,
 V. Canale ^{72a,72b}, A. Canesse ¹⁰⁴, M. Cano Bret ⁸⁰, J. Cantero ¹⁶², Y. Cao ¹⁶¹, F. Capocasa ²⁶,
 M. Capua ^{43b,43a}, A. Carbone ^{71a,71b}, R. Cardarelli ^{76a}, J.C.J. Cardenas ⁸, F. Cardillo ¹⁶²,
 T. Carli ³⁶, G. Carlino ^{72a}, J.I. Carlotto ¹³, B.T. Carlson ^{129,q}, E.M. Carlson ^{164,156a},
 L. Carminati ^{71a,71b}, M. Carnesale ^{75a,75b}, S. Caron ¹¹³, E. Carquin ^{137f}, S. Carrá ^{71a,71b},
 G. Carratta ^{23b,23a}, F. Carrio Argos ^{33g}, J.W.S. Carter ¹⁵⁵, T.M. Carter ⁵², M.P. Casado ^{13,i},
 A.F. Casha ¹⁵⁵, M. Caspar ⁴⁸, E.G. Castiglia ¹⁷¹, F.L. Castillo ^{63a}, L. Castillo Garcia ¹³,
 V. Castillo Gimenez ¹⁶², N.F. Castro ^{130a,130e}, A. Catinaccio ³⁶, J.R. Catmore ¹²⁵, V. Cavaliere ²⁹,
 N. Cavalli ^{23b,23a}, V. Cavalinini ^{74a,74b}, E. Celebi ^{21a}, F. Celli ¹²⁶, M.S. Centonze ^{70a,70b},
 K. Cerny ¹²², A.S. Cerqueira ^{82a}, A. Cerri ¹⁴⁶, L. Cerrito ^{76a,76b}, F. Cerutti ^{17a}, A. Cervelli ^{23b},
 G. Cesarini ⁵³, S.A. Cetin ^{21d}, Z. Chadi ^{35a}, D. Chakraborty ¹¹⁵, M. Chala ^{130f}, J. Chan ¹⁶⁹,
 W.Y. Chan ¹⁵³, J.D. Chapman ³², B. Chargeishvili ^{149b}, D.G. Charlton ²⁰, T.P. Charman ⁹⁴,
 M. Chatterjee ¹⁹, C. Chauhan ¹³³, S. Chekanov ⁶, S.V. Chekulaev ^{156a}, G.A. Chelkov ^{38,a},
 A. Chen ¹⁰⁶, B. Chen ¹⁵¹, B. Chen ¹⁶⁴, H. Chen ^{14c}, H. Chen ²⁹, J. Chen ^{62c}, J. Chen ¹⁴²,
 S. Chen ¹⁵³, S.J. Chen ^{14c}, X. Chen ^{62c}, X. Chen ^{14b,aa}, Y. Chen ^{62a}, C.L. Cheng ¹⁶⁹,
 H.C. Cheng ^{64a}, S. Cheong ¹⁴³, A. Cheplakov ³⁸, E. Cheremushkina ⁴⁸, E. Cherepanova ¹¹⁴,
 R. Cherkaoui El Moursli ^{35e}, E. Cheu ⁷, K. Cheung ⁶⁵, L. Chevalier ¹³⁵, V. Chiarella ⁵³,
 G. Chiarelli ^{74a}, N. Chiedde ¹⁰², G. Chiodini ^{70a}, A.S. Chisholm ²⁰, A. Chitan ^{27b},
 M. Chitishvili ¹⁶², M.V. Chizhov ³⁸, K. Choi ¹¹, A.R. Chomont ^{75a,75b}, Y. Chou ¹⁰³,
 E.Y.S. Chow ¹¹⁴, T. Chowdhury ^{33g}, L.D. Christopher ^{33g}, K.L. Chu ^{64a}, M.C. Chu ^{64a},

X. Chu ^{14a,14e}, J. Chudoba ¹³¹, J.J. Chwastowski ⁸⁶, D. Cieri ¹¹⁰, K.M. Ciesla ^{85a}, V. Cindro ⁹³,
 A. Ciocio ^{17a}, F. Cirotto ^{72a,72b}, Z.H. Citron ¹⁶⁸, M. Citterio ^{71a}, D.A. Ciubotaru ^{27b},
 B.M. Ciungu ¹⁵⁵, A. Clark ⁵⁶, P.J. Clark ⁵², J.M. Clavijo Columbie ⁴⁸, S.E. Clawson ¹⁰¹,
 C. Clement ^{47a,47b}, J. Clercx ⁴⁸, L. Clissa ^{23b,23a}, Y. Coadou ¹⁰², M. Cobal ^{69a,69c},
 A. Cocco ^{57b}, R.F. Coelho Barrue ^{130a}, R. Coelho Lopes De Sa ¹⁰³, S. Coelli ^{71a}, H. Cohen ¹⁵¹,
 A.E.C. Coimbra ^{71a,71b}, B. Cole ⁴¹, J. Collot ⁶⁰, P. Conde Muiño ^{130a,130g}, M.P. Connell ^{33c},
 S.H. Connell ^{33c}, I.A. Connelly ⁵⁹, E.I. Conroy ¹²⁶, F. Conventi ^{72a,ac}, H.G. Cooke ²⁰,
 A.M. Cooper-Sarkar ¹²⁶, F. Cormier ¹⁶³, L.D. Corpe ³⁶, M. Corradi ^{75a,75b}, F. Corriveau ^{104,v},
 A. Cortes-Gonzalez ¹⁸, M.J. Costa ¹⁶², F. Costanza ⁴, D. Costanzo ¹³⁹, B.M. Cote ¹¹⁹,
 G. Cowan ⁹⁵, K. Cranmer ¹¹⁷, S. Crépe-Renaudin ⁶⁰, F. Crescioli ¹²⁷, M. Cristinziani ¹⁴¹,
 M. Cristoforetti ^{78a,78b,c}, V. Croft ¹¹⁴, G. Crosetti ^{43b,43a}, A. Cueto ³⁶,
 T. Cuhadar Donszelmann ¹⁵⁹, H. Cui ^{14a,14e}, Z. Cui ⁷, W.R. Cunningham ⁵⁹, F. Curcio ^{43b,43a},
 P. Czodrowski ³⁶, M.M. Czurylo ^{63b}, M.J. Da Cunha Sargedas De Sousa ^{62a},
 J.V. Da Fonseca Pinto ^{82b}, C. Da Via ¹⁰¹, W. Dabrowski ^{85a}, T. Dado ⁴⁹, S. Dahbi ^{33g},
 T. Dai ¹⁰⁶, C. Dallapiccola ¹⁰³, M. Dam ⁴², G. D'amen ²⁹, V. D'Amico ¹⁰⁹, J. Damp ¹⁰⁰,
 J.R. Dandoy ¹²⁸, M.F. Daneri ³⁰, M. Danninger ¹⁴², V. Dao ³⁶, G. Darbo ^{57b}, S. Darmora ⁶,
 S.J. Das ²⁹, S. D'Auria ^{71a,71b}, C. David ^{156b}, T. Davidek ¹³³, B. Davis-Purcell ³⁴, I. Dawson ⁹⁴,
 K. De ⁸, R. De Asmundis ^{72a}, N. De Biase ⁴⁸, S. De Castro ^{23b,23a}, N. De Groot ¹¹³,
 P. de Jong ¹¹⁴, H. De la Torre ¹⁰⁷, A. De Maria ^{14c}, A. De Salvo ^{75a}, U. De Sanctis ^{76a,76b},
 A. De Santo ¹⁴⁶, J.B. De Vivie De Regie ⁶⁰, D.V. Dedovich ³⁸, J. Degens ¹¹⁴, A.M. Deiana ⁴⁴,
 F. Del Corso ^{23b,23a}, J. Del Peso ⁹⁹, F. Del Rio ^{63a}, F. Deliot ¹³⁵, C.M. Delitzsch ⁴⁹,
 M. Della Pietra ^{72a,72b}, D. Della Volpe ⁵⁶, A. Dell'Acqua ³⁶, L. Dell'Asta ^{71a,71b}, M. Delmastro ⁴,
 P.A. Delsart ⁶⁰, S. Demers ¹⁷¹, M. Demichev ³⁸, S.P. Denisov ³⁷, L. D'Eramo ¹¹⁵,
 D. Derendarz ⁸⁶, F. Derue ¹²⁷, P. Dervan ⁹², K. Desch ²⁴, K. Dette ¹⁵⁵, C. Deutsch ²⁴,
 F.A. Di Bello ^{57b,57a}, A. Di Ciaccio ^{76a,76b}, L. Di Ciaccio ⁴, A. Di Domenico ^{75a,75b},
 C. Di Donato ^{72a,72b}, A. Di Girolamo ³⁶, G. Di Gregorio ⁵, A. Di Luca ^{78a,78b},
 B. Di Micco ^{77a,77b}, R. Di Nardo ^{77a,77b}, C. Diaconu ¹⁰², F.A. Dias ¹¹⁴, T. Dias Do Vale ¹⁴²,
 M.A. Diaz ^{137a,137b}, F.G. Diaz Capriles ²⁴, M. Didenko ¹⁶², E.B. Diehl ¹⁰⁶, L. Diehl ⁵⁴,
 S. Díez Cornell ⁴⁸, C. Diez Pardos ¹⁴¹, C. Dimitriadi ^{24,160}, A. Dimitrievska ^{17a}, J. Dingfelder ²⁴,
 I-M. Dinu ^{27b}, S.J. Dittmeier ^{63b}, F. Dittus ³⁶, F. Djama ¹⁰², T. Djobava ^{149b}, J.I. Djuvsland ¹⁶,
 C. Doglioni ^{101,98}, J. Dolejsi ¹³³, Z. Dolezal ¹³³, M. Donadelli ^{82c}, B. Dong ¹⁰⁷, J. Donini ⁴⁰,
 A. D'Onofrio ^{77a,77b}, M. D'Onofrio ⁹², J. Dopke ¹³⁴, A. Doria ^{72a}, M.T. Dova ⁹⁰, A.T. Doyle ⁵⁹,
 M.A. Draguet ¹²⁶, E. Drechsler ¹⁴², E. Dreyer ¹⁶⁸, I. Drivas-koulouris ¹⁰, A.S. Drobac ¹⁵⁸,
 M. Drozdova ⁵⁶, D. Du ^{62a}, T.A. du Pree ¹¹⁴, F. Dubinin ³⁷, M. Dubovsky ^{28a}, E. Duchovni ¹⁶⁸,
 G. Duckeck ¹⁰⁹, O.A. Ducu ^{27b}, D. Duda ¹¹⁰, A. Dudarev ³⁶, E.R. Duden ²⁶, M. D'uffizi ¹⁰¹,
 L. Duflot ⁶⁶, M. Dührssen ³⁶, C. Dülsen ¹⁷⁰, A.E. Dumitriu ^{27b}, M. Dunford ^{63a}, S. Dungs ⁴⁹,
 K. Dunne ^{47a,47b}, A. Duperrin ¹⁰², H. Duran Yildiz ^{3a}, M. Düren ⁵⁸, A. Durglishvili ^{149b},
 B.L. Dwyer ¹¹⁵, G.I. Dyckes ^{17a}, M. Dyndal ^{85a}, S. Dysch ¹⁰¹, B.S. Dziedzic ⁸⁶,
 Z.O. Earnshaw ¹⁴⁶, B. Eckerova ^{28a}, S. Eggebrecht ⁵⁵, M.G. Eggleston ⁵¹,
 E. Egidio Purcino De Souza ¹²⁷, L.F. Ehrke ⁵⁶, G. Eigen ¹⁶, K. Einsweiler ^{17a}, T. Ekelof ¹⁶⁰,
 P.A. Ekman ⁹⁸, Y. El Ghazali ^{35b}, H. El Jarrari ^{35e,148}, A. El Moussaouy ^{35a}, V. Ellajosyula ¹⁶⁰,
 M. Ellert ¹⁶⁰, F. Ellinghaus ¹⁷⁰, A.A. Elliot ⁹⁴, N. Ellis ³⁶, J. Elmsheuser ²⁹, M. Elsing ³⁶,
 D. Emelianov ¹³⁴, Y. Enari ¹⁵³, I. Ene ^{17a}, S. Epari ¹³, J. Erdmann ⁴⁹, P.A. Erland ⁸⁶,
 M. Errenst ¹⁷⁰, M. Escalier ⁶⁶, C. Escobar ¹⁶², E. Etzion ¹⁵¹, G. Evans ^{130a}, H. Evans ⁶⁸,
 M.O. Evans ¹⁴⁶, A. Ezhilov ³⁷, S. Ezzarqtouni ^{35a}, F. Fabbri ⁵⁹, L. Fabbri ^{23b,23a}, G. Facini ⁹⁶,
 V. Fadeyev ¹³⁶, R.M. Fakhruddinov ³⁷, S. Falciano ^{75a}, L.F. Falda Ulhoa Coelho ³⁶, P.J. Falke ²⁴,
 S. Falke ³⁶, J. Faltova ¹³³, C. Fan ¹⁶¹, Y. Fan ^{14a}, Y. Fang ^{14a,14e}, M. Fanti ^{71a,71b},

M. Faraj [id](#)^{69a,69b}, Z. Farazpay⁹⁷, A. Farbin [id](#)⁸, A. Farilla [id](#)^{77a}, T. Farooque [id](#)¹⁰⁷, S.M. Farrington [id](#)⁵²,
F. Fassi [id](#)^{35e}, D. Fassouliotis [id](#)⁹, M. Faucci Giannelli [id](#)^{76a,76b}, W.J. Fawcett [id](#)³², L. Fayard [id](#)⁶⁶,
P. Federic [id](#)¹³³, P. Federicova [id](#)¹³¹, O.L. Fedin [id](#)^{37,a}, G. Fedotov [id](#)³⁷, M. Feickert [id](#)¹⁶⁹,
L. Feligioni [id](#)¹⁰², A. Fell [id](#)¹³⁹, D.E. Fellers [id](#)¹²³, C. Feng [id](#)^{62b}, M. Feng [id](#)^{14b}, Z. Feng [id](#)¹¹⁴,
M.J. Fenton [id](#)¹⁵⁹, A.B. Fenyuk³⁷, L. Ferencz [id](#)⁴⁸, R.A.M. Ferguson [id](#)⁹¹, S.I. Fernandez Luengo [id](#)^{137f},
J.A. Fernandez Pretel [id](#)⁵⁴, M.J.V. Fernoux [id](#)¹⁰², J. Ferrando [id](#)⁴⁸, A. Ferrari [id](#)¹⁶⁰, P. Ferrari [id](#)^{114,113},
R. Ferrari [id](#)^{73a}, D. Ferrere [id](#)⁵⁶, C. Ferretti [id](#)¹⁰⁶, F. Fiedler [id](#)¹⁰⁰, A. Filipčič [id](#)⁹³, E.K. Filmer [id](#)¹,
F. Filthaut [id](#)¹¹³, M.C.N. Fiolhais [id](#)^{130a,130c,b}, L. Fiorini [id](#)¹⁶², W.C. Fisher [id](#)¹⁰⁷, T. Fitschen [id](#)¹⁰¹,
I. Fleck [id](#)¹⁴¹, P. Fleischmann [id](#)¹⁰⁶, T. Flick [id](#)¹⁷⁰, L. Flores [id](#)¹²⁸, M. Flores [id](#)^{33d},
L.R. Flores Castillo [id](#)^{64a}, F.M. Follega [id](#)^{78a,78b}, N. Fomin [id](#)¹⁶, J.H. Foo [id](#)¹⁵⁵, B.C. Forland⁶⁸,
A. Formica [id](#)¹³⁵, A.C. Forti [id](#)¹⁰¹, E. Fortin [id](#)³⁶, A.W. Fortman [id](#)⁶¹, M.G. Foti [id](#)^{17a}, L. Fountas [id](#)⁹,
D. Fournier [id](#)⁶⁶, H. Fox [id](#)⁹¹, P. Francavilla [id](#)^{74a,74b}, S. Francescato [id](#)⁶¹, S. Franchellucci [id](#)⁵⁶,
M. Franchini [id](#)^{23b,23a}, S. Franchino [id](#)^{63a}, D. Francis³⁶, L. Franco [id](#)¹¹³, L. Franconi [id](#)⁴⁸, M. Franklin [id](#)⁶¹,
G. Frattari [id](#)²⁶, A.C. Freegard [id](#)⁹⁴, W.S. Freund [id](#)^{82b}, Y.Y. Frid [id](#)¹⁵¹, N. Fritzsche [id](#)⁵⁰, A. Froch [id](#)⁵⁴,
D. Froidevaux [id](#)³⁶, J.A. Frost [id](#)¹²⁶, Y. Fu [id](#)^{62a}, M. Fujimoto [id](#)¹¹⁸, E. Fullana Torregrosa [id](#)^{162,*},
E. Furtado De Simas Filho [id](#)^{82b}, J. Fuster [id](#)¹⁶², A. Gabrielli [id](#)^{23b,23a}, A. Gabrielli [id](#)¹⁵⁵, P. Gadow [id](#)⁴⁸,
G. Gagliardi [id](#)^{57b,57a}, L.G. Gagnon [id](#)^{17a}, E.J. Gallas [id](#)¹²⁶, B.J. Gallop [id](#)¹³⁴, K.K. Gan [id](#)¹¹⁹,
S. Ganguly [id](#)¹⁵³, J. Gao [id](#)^{62a}, Y. Gao [id](#)⁵², F.M. Garay Walls [id](#)^{137a,137b}, B. Garcia^{29,ad}, C. García [id](#)¹⁶²,
J.E. García Navarro [id](#)¹⁶², M. Garcia-Sciveres [id](#)^{17a}, R.W. Gardner [id](#)³⁹, D. Garg [id](#)⁸⁰, R.B. Garg [id](#)¹⁴³,
C.A. Garner¹⁵⁵, S.J. Gasiowski [id](#)¹³⁸, P. Gaspar [id](#)^{82b}, G. Gaudio [id](#)^{73a}, V. Gautam¹³, P. Gauzzi [id](#)^{75a,75b},
I.L. Gavrilenko [id](#)³⁷, A. Gavriyuk [id](#)³⁷, C. Gay [id](#)¹⁶³, G. Gaycken [id](#)⁴⁸, E.N. Gazis [id](#)¹⁰,
A.A. Geanta [id](#)^{27b,27e}, C.M. Gee [id](#)¹³⁶, C. Gemme [id](#)^{57b}, M.H. Genest [id](#)⁶⁰, S. Gentile [id](#)^{75a,75b},
S. George [id](#)⁹⁵, W.F. George [id](#)²⁰, T. Gerialis [id](#)⁴⁶, L.O. Gerlach⁵⁵, P. Gessinger-Befurt [id](#)³⁶,
M.E. Geyik [id](#)¹⁷⁰, M. Ghneimat [id](#)¹⁴¹, K. Ghorbanian [id](#)⁹⁴, A. Ghosal [id](#)¹⁴¹, A. Ghosh [id](#)¹⁵⁹, A. Ghosh [id](#)⁷,
B. Giacobbe [id](#)^{23b}, S. Giagu [id](#)^{75a,75b}, P. Giannetti [id](#)^{74a}, A. Giannini [id](#)^{62a}, S.M. Gibson [id](#)⁹⁵,
M. Gignac [id](#)¹³⁶, D.T. Gil [id](#)^{85b}, A.K. Gilbert [id](#)^{85a}, B.J. Gilbert [id](#)⁴¹, D. Gillberg [id](#)³⁴, G. Gilles [id](#)¹¹⁴,
N.E.K. Gillwald [id](#)⁴⁸, L. Ginabat [id](#)¹²⁷, D.M. Gingrich [id](#)^{2,ab}, M.P. Giordani [id](#)^{69a,69c}, P.F. Giraud [id](#)¹³⁵,
G. Giugliarelli [id](#)^{69a,69c}, D. Giugni [id](#)^{71a}, F. Giuli [id](#)³⁶, I. Gkialas [id](#)^{9j}, L.K. Gladilin [id](#)³⁷, C. Glasman [id](#)⁹⁹,
G.R. Gledhill [id](#)¹²³, M. Glisic¹²³, I. Gnesi [id](#)^{43b,f}, Y. Go [id](#)^{29,ad}, M. Goblirsch-Kolb [id](#)³⁶, B. Gocke [id](#)⁴⁹,
D. Godin¹⁰⁸, B. Gokturk^{21a}, S. Goldfarb [id](#)¹⁰⁵, T. Golling [id](#)⁵⁶, M.G.D. Gololo^{33g}, D. Golubkov [id](#)³⁷,
J.P. Gombas [id](#)¹⁰⁷, A. Gomes [id](#)^{130a,130b}, G. Gomes Da Silva [id](#)¹⁴¹, A.J. Gomez Delegido [id](#)¹⁶²,
R. Gonçalves [id](#)^{130a,130c}, G. Gonella [id](#)¹²³, L. Gonella [id](#)²⁰, A. Gongadze [id](#)³⁸, F. Gonnella [id](#)²⁰,
J.L. Gonski [id](#)⁴¹, S. González de la Hoz [id](#)¹⁶², S. Gonzalez Fernandez [id](#)¹³, R. Gonzalez Lopez [id](#)⁹²,
C. Gonzalez Renteria [id](#)^{17a}, R. Gonzalez Suarez [id](#)¹⁶⁰, S. Gonzalez-Sevilla [id](#)⁵⁶,
G.R. Gonzalvo Rodriguez [id](#)¹⁶², R.Y. González Andana [id](#)⁵², L. Goossens [id](#)³⁶, P.A. Gorbounov [id](#)³⁷,
B. Gorini [id](#)³⁶, E. Gorini [id](#)^{70a,70b}, A. Gorišek [id](#)⁹³, T.C. Gosart [id](#)¹²⁸, A.T. Goshaw [id](#)⁵¹, M.I. Gostkin [id](#)³⁸,
S. Goswami [id](#)¹²¹, C.A. Gottardo [id](#)³⁶, M. Gouighri [id](#)^{35b}, V. Goumarre [id](#)⁴⁸, A.G. Goussiou [id](#)¹³⁸,
N. Govender [id](#)^{33c}, I. Grabowska-Bold [id](#)^{85a}, K. Graham [id](#)³⁴, E. Gramstad [id](#)¹²⁵, S. Grancagnolo [id](#)^{70a,70b},
M. Grandi [id](#)¹⁴⁶, V. Gratchev^{37,*}, P.M. Gravila [id](#)^{27f}, F.G. Gravili [id](#)^{70a,70b}, H.M. Gray [id](#)^{17a},
M. Greco [id](#)^{70a,70b}, C. Grefe [id](#)²⁴, I.M. Gregor [id](#)⁴⁸, P. Grenier [id](#)¹⁴³, C. Grieco [id](#)¹³, A.A. Grillo [id](#)¹³⁶,
K. Grimm [id](#)^{31,1}, S. Grinstein [id](#)^{13,s}, J.-F. Grivaz [id](#)⁶⁶, E. Gross [id](#)¹⁶⁸, J. Grosse-Knetter [id](#)⁵⁵, C. Grud¹⁰⁶,
J.C. Grundy [id](#)¹²⁶, L. Guan [id](#)¹⁰⁶, W. Guan [id](#)¹⁶⁹, C. Gubbels [id](#)¹⁶³, J.G.R. Guerrero Rojas [id](#)¹⁶²,
G. Guerrieri [id](#)^{69a,69b}, F. Guescini [id](#)¹¹⁰, R. Gugel [id](#)¹⁰⁰, J.A.M. Guhit [id](#)¹⁰⁶, A. Guida [id](#)⁴⁸,
T. Guillemain [id](#)⁴, E. Guilloton [id](#)^{166,134}, S. Guindon [id](#)³⁶, F. Guo [id](#)^{14a,14e}, J. Guo [id](#)^{62c}, L. Guo [id](#)⁶⁶,
Y. Guo [id](#)¹⁰⁶, R. Gupta [id](#)⁴⁸, S. Gurbuz [id](#)²⁴, S.S. Gurdasani [id](#)⁵⁴, G. Gustavino [id](#)³⁶, M. Guth [id](#)⁵⁶,
P. Gutierrez [id](#)¹²⁰, L.F. Gutierrez Zagazeta [id](#)¹²⁸, C. Gutschow [id](#)⁹⁶, C. Gwenlan [id](#)¹²⁶, C.B. Gwilliam [id](#)⁹²,
E.S. Haaland [id](#)¹²⁵, A. Haas [id](#)¹¹⁷, M. Habedank [id](#)⁴⁸, C. Haber [id](#)^{17a}, H.K. Hadavand [id](#)⁸, A. Hadeef [id](#)¹⁰⁰,

S. Hadzic ¹¹⁰, E.H. Haines ⁹⁶, M. Haleem ¹⁶⁵, J. Haley ¹²¹, J.J. Hall ¹³⁹, G.D. Hallewell ¹⁰²,
 L. Halser ¹⁹, K. Hamano ¹⁶⁴, H. Hamdaoui ^{35e}, M. Hamer ²⁴, G.N. Hamity ⁵²,
 E.J. Hampshire ⁹⁵, J. Han ^{62b}, K. Han ^{62a}, L. Han ^{14c}, L. Han ^{62a}, S. Han ^{17a}, Y.F. Han ¹⁵⁵,
 K. Hanagaki ⁸³, M. Hance ¹³⁶, D.A. Hangal ^{41,z}, H. Hanif ¹⁴², M.D. Hank ¹²⁸, R. Hankache ¹⁰¹,
 J.B. Hansen ⁴², J.D. Hansen ⁴², P.H. Hansen ⁴², K. Hara ¹⁵⁷, D. Harada ⁵⁶, T. Harenberg ¹⁷⁰,
 S. Harkusha ³⁷, Y.T. Harris ¹²⁶, N.M. Harrison ¹¹⁹, P.F. Harrison ¹⁶⁶, N.M. Hartman ¹⁴³,
 N.M. Hartmann ¹⁰⁹, Y. Hasegawa ¹⁴⁰, A. Hasib ⁵², S. Haug ¹⁹, R. Hauser ¹⁰⁷, M. Havranek ¹³²,
 C.M. Hawkes ²⁰, R.J. Hawkins ³⁶, S. Hayashida ¹¹¹, D. Hayden ¹⁰⁷, C. Hayes ¹⁰⁶,
 R.L. Hayes ¹¹⁴, C.P. Hays ¹²⁶, J.M. Hays ⁹⁴, H.S. Hayward ⁹², F. He ^{62a}, Y. He ¹⁵⁴, Y. He ¹²⁷,
 N.B. Heatley ⁹⁴, V. Hedberg ⁹⁸, A.L. Heggelund ¹²⁵, N.D. Hehir ⁹⁴, C. Heidegger ⁵⁴,
 K.K. Heidegger ⁵⁴, W.D. Heidorn ⁸¹, J. Heilman ³⁴, S. Heim ⁴⁸, T. Heim ^{17a}, J.G. Heinlein ¹²⁸,
 J.J. Heinrich ¹²³, L. Heinrich ¹¹⁰, J. Hejbal ¹³¹, L. Helary ⁴⁸, A. Held ¹⁶⁹, S. Hellesund ¹⁶,
 C.M. Helling ¹⁶³, S. Hellman ^{47a,47b}, C. Helsen ³⁶, R.C.W. Henderson ⁹¹, L. Henkelmann ³²,
 A.M. Henriques Correia ³⁶, H. Herde ⁹⁸, Y. Hernández Jiménez ¹⁴⁵, L.M. Herrmann ²⁴,
 T. Herrmann ⁵⁰, G. Herten ⁵⁴, R. Hertenberger ¹⁰⁹, L. Hervas ³⁶, N.P. Hessey ^{156a}, H. Hibi ⁸⁴,
 S.J. Hillier ²⁰, F. Hinterkeuser ²⁴, M. Hirose ¹²⁴, S. Hirose ¹⁵⁷, D. Hirschbuehl ¹⁷⁰,
 T.G. Hitchings ¹⁰¹, B. Hiti ⁹³, J. Hobbs ¹⁴⁵, R. Hobincu ^{27e}, N. Hod ¹⁶⁸, M.C. Hodgkinson ¹³⁹,
 B.H. Hodgkinson ³², A. Hoecker ³⁶, J. Hofer ⁴⁸, T. Holm ²⁴, M. Holzbock ¹¹⁰,
 L.B.A.H. Hommels ³², B.P. Honan ¹⁰¹, J. Hong ^{62c}, T.M. Hong ¹²⁹, J.C. Honig ⁵⁴,
 B.H. Hooberman ¹⁶¹, W.H. Hopkins ⁶, Y. Horii ¹¹¹, S. Hou ¹⁴⁸, A.S. Howard ⁹³, J. Howarth ⁵⁹,
 J. Hoya ⁶, M. Hrabovsky ¹²², A. Hrynevich ⁴⁸, T. Hryn'ova ⁴, P.J. Hsu ⁶⁵, S.-C. Hsu ¹³⁸,
 Q. Hu ⁴¹, Y.F. Hu ^{14a,14e}, D.P. Huang ⁹⁶, S. Huang ^{64b}, X. Huang ^{14c}, Y. Huang ^{62a},
 Y. Huang ^{14a}, Z. Huang ¹⁰¹, Z. Hubacek ¹³², M. Huebner ²⁴, F. Huegging ²⁴, T.B. Huffman ¹²⁶,
 M. Huhtinen ³⁶, S.K. Huiberts ¹⁶, R. Hulsken ¹⁰⁴, N. Huseynov ^{12,a}, J. Huston ¹⁰⁷, J. Huth ⁶¹,
 R. Hyneman ¹⁴³, G. Iacobucci ⁵⁶, G. Iakovidis ²⁹, I. Ibragimov ¹⁴¹, L. Iconomidou-Fayard ⁶⁶,
 P. Iengo ^{72a,72b}, R. Iguchi ¹⁵³, T. Iizawa ⁵⁶, Y. Ikegami ⁸³, A. Ilg ¹⁹, N. Ilic ¹⁵⁵, H. Imam ^{35a},
 T. Ingebretsen Carlson ^{47a,47b}, G. Introzzi ^{73a,73b}, M. Iodice ^{77a}, V. Ippolito ^{75a,75b}, M. Ishino ¹⁵³,
 W. Islam ¹⁶⁹, C. Issever ^{18,48}, S. Istin ^{21a}, H. Ito ¹⁶⁷, J.M. Iturbe Ponce ^{64a}, R. Iuppa ^{78a,78b},
 A. Ivina ¹⁶⁸, J.M. Izen ⁴⁵, V. Izzo ^{72a}, P. Jacka ^{131,132}, P. Jackson ¹, R.M. Jacobs ⁴⁸,
 B.P. Jaeger ¹⁴², C.S. Jagfeld ¹⁰⁹, P. Jain ⁵⁴, G. Jäkel ¹⁷⁰, K. Jakobs ⁵⁴, T. Jakoubek ¹⁶⁸,
 J. Jamieson ⁵⁹, K.W. Janas ^{85a}, A.E. Jaspan ⁹², M. Javurkova ¹⁰³, F. Jeanneau ¹³⁵, L. Jeanty ¹²³,
 J. Jejelava ^{149a,y}, P. Jenni ^{54,g}, C.E. Jessiman ³⁴, S. Jézéquel ⁴, C. Jia ^{62b}, J. Jia ¹⁴⁵, X. Jia ⁶¹,
 X. Jia ^{14a,14e}, Z. Jia ^{14c}, Y. Jiang ^{62a}, S. Jiggins ⁴⁸, J. Jimenez Pena ¹¹⁰, S. Jin ^{14c}, A. Jinaru ^{27b},
 O. Jinnouchi ¹⁵⁴, P. Johansson ¹³⁹, K.A. Johns ⁷, J.W. Johnson ¹³⁶, D.M. Jones ³², E. Jones ¹⁶⁶,
 P. Jones ³², R.W.L. Jones ⁹¹, T.J. Jones ⁹², R. Joshi ¹¹⁹, J. Jovicevic ¹⁵, X. Ju ^{17a},
 J.J. Junggeburth ³⁶, T. Junkermann ^{63a}, A. Juste Rozas ^{13,s}, S. Kabana ^{137e}, A. Kaczmarek ⁸⁶,
 M. Kado ¹¹⁰, H. Kagan ¹¹⁹, M. Kagan ¹⁴³, A. Kahn ⁴¹, A. Kahn ¹²⁸, C. Kahra ¹⁰⁰, T. Kaji ¹⁶⁷,
 E. Kajomovitz ¹⁵⁰, N. Kakati ¹⁶⁸, C.W. Kalderon ²⁹, A. Kamenshchikov ¹⁵⁵, S. Kanayama ¹⁵⁴,
 N.J. Kang ¹³⁶, D. Kar ^{33g}, K. Karava ¹²⁶, M.J. Kareem ^{156b}, E. Karentzos ⁵⁴, I. Karkanias ^{152,e},
 S.N. Karpov ³⁸, Z.M. Karpova ³⁸, V. Kartvelishvili ⁹¹, A.N. Karyukhin ³⁷, E. Kasimi ^{152,e},
 J. Katzy ⁴⁸, S. Kaur ³⁴, K. Kawade ¹⁴⁰, T. Kawamoto ¹³⁵, G. Kawamura ⁵⁵, E.F. Kay ¹⁶⁴,
 F.I. Kaya ¹⁵⁸, S. Kazakos ¹³, V.F. Kazanin ³⁷, Y. Ke ¹⁴⁵, J.M. Keaveney ^{33a}, R. Keeler ¹⁶⁴,
 G.V. Kehris ⁶¹, J.S. Keller ³⁴, A.S. Kelly ⁹⁶, D. Kelsey ¹⁴⁶, J.J. Kempster ¹⁴⁶, K.E. Kennedy ⁴¹,
 P.D. Kennedy ¹⁰⁰, O. Kepka ¹³¹, B.P. Kerridge ¹⁶⁶, S. Kersten ¹⁷⁰, B.P. Kerševan ⁹³,
 S. Keshri ⁶⁶, L. Keszezhova ^{28a}, S. Ketabchi Haghghat ¹⁵⁵, M. Khandoga ¹²⁷, A. Khanov ¹²¹,
 A.G. Kharlamov ³⁷, T. Kharlamova ³⁷, E.E. Khoda ¹³⁸, T.J. Khoo ¹⁸, G. Khorauli ¹⁶⁵,
 J. Khubua ^{149b}, Y.A.R. Khwaira ⁶⁶, M. Kiehn ³⁶, A. Kilgallon ¹²³, D.W. Kim ^{47a,47b},

Y.K. Kim ³⁹, N. Kimura ⁹⁶, A. Kirchhoff ⁵⁵, C. Kirfel ²⁴, J. Kirk ¹³⁴, A.E. Kiryunin ¹¹⁰,
 T. Kishimoto ¹⁵³, D.P. Kisliuk ¹⁵⁵, C. Kitsaki ¹⁰, O. Kivernyk ²⁴, M. Klassen ^{63a}, C. Klein ³⁴,
 L. Klein ¹⁶⁵, M.H. Klein ¹⁰⁶, M. Klein ⁹², S.B. Klein ⁵⁶, U. Klein ⁹², P. Klimek ³⁶,
 A. Klimentov ²⁹, T. Klioutchnikova ³⁶, P. Kluit ¹¹⁴, S. Kluth ¹¹⁰, E. Kneringer ⁷⁹,
 T.M. Knight ¹⁵⁵, A. Knue ⁵⁴, R. Kobayashi ⁸⁷, M. Kocian ¹⁴³, P. Kodyš ¹³³, D.M. Koeck ¹²³,
 P.T. Koenig ²⁴, T. Koffas ³⁴, M. Kolb ¹³⁵, I. Koletsou ⁴, T. Komarek ¹²², K. Köneke ⁵⁴,
 A.X.Y. Kong ¹, T. Kono ¹¹⁸, N. Konstantinidis ⁹⁶, B. Konya ⁹⁸, R. Kopeliansky ⁶⁸,
 S. Koperny ^{85a}, K. Korcyl ⁸⁶, K. Kordas ^{152,e}, G. Koren ¹⁵¹, A. Korn ⁹⁶, S. Korn ⁵⁵,
 I. Korolkov ¹³, N. Korotkova ³⁷, B. Kortman ¹¹⁴, O. Kortner ¹¹⁰, S. Kortner ¹¹⁰,
 W.H. Kostecka ¹¹⁵, V.V. Kostyukhin ¹⁴¹, A. Kotsokechagia ¹³⁵, A. Kotwal ⁵¹, A. Koulouris ³⁶,
 A. Kourkoumeli-Charalampidi ^{73a,73b}, C. Kourkoumelis ⁹, E. Kourlitis ⁶, O. Kovanda ¹⁴⁶,
 R. Kowalewski ¹⁶⁴, W. Kozanecki ¹³⁵, A.S. Kozhin ³⁷, V.A. Kramarenko ³⁷, G. Kramberger ⁹³,
 P. Kramer ¹⁰⁰, M.W. Krasny ¹²⁷, A. Krasznahorkay ³⁶, J.A. Kremer ¹⁰⁰, T. Kresse ⁵⁰,
 J. Kretschmar ⁹², K. Kreul ¹⁸, P. Krieger ¹⁵⁵, S. Krishnamurthy ¹⁰³, M. Krivos ¹³³,
 K. Krizka ²⁰, K. Kroeninger ⁴⁹, H. Kroha ¹¹⁰, J. Kroll ¹³¹, J. Kroll ¹²⁸, K.S. Krowpman ¹⁰⁷,
 U. Kruchonak ³⁸, H. Krüger ²⁴, N. Krumnack ⁸¹, M.C. Kruse ⁵¹, J.A. Krzysiak ⁸⁶,
 O. Kuchinskaia ³⁷, S. Kuday ^{3a}, S. Kuehn ³⁶, R. Kuesters ⁵⁴, T. Kuhl ⁴⁸, V. Kukhtin ³⁸,
 Y. Kulchitsky ^{37,a}, S. Kuleshov ^{137d,137b}, M. Kumar ^{33g}, N. Kumari ¹⁰², A. Kupco ¹³¹,
 T. Kupfer ⁴⁹, A. Kupich ³⁷, O. Kuprash ⁵⁴, H. Kurashige ⁸⁴, L.L. Kurchaninov ^{156a}, O. Kurdysh ⁶⁶,
 Y.A. Kurochkin ³⁷, A. Kurova ³⁷, M. Kuze ¹⁵⁴, A.K. Kvam ¹⁰³, J. Kvita ¹²², T. Kwan ¹⁰⁴,
 N.G. Kyriacou ¹⁰⁶, L.A.O. Laatu ¹⁰², C. Lacasta ¹⁶², F. Lacava ^{75a,75b}, H. Lacker ¹⁸,
 D. Lacour ¹²⁷, N.N. Lad ⁹⁶, E. Ladygin ³⁸, B. Laforge ¹²⁷, T. Lagouri ^{137e}, S. Lai ⁵⁵,
 I.K. Lakomic ^{85a}, N. Lalloue ⁶⁰, J.E. Lambert ¹²⁰, S. Lammers ⁶⁸, W. Lampl ⁷,
 C. Lampoudis ^{152,e}, A.N. Lancaster ¹¹⁵, E. Lançon ²⁹, U. Landgraf ⁵⁴, M.P.J. Landon ⁹⁴,
 V.S. Lang ⁵⁴, R.J. Langenberg ¹⁰³, A.J. Lankford ¹⁵⁹, F. Lanni ³⁶, K. Lantzsch ²⁴, A. Lanza ^{73a},
 A. Lapertosa ^{57b,57a}, J.F. Laporte ¹³⁵, T. Lari ^{71a}, F. Lasagni Manghi ^{23b}, M. Lassnig ³⁶,
 V. Latonova ¹³¹, A. Laudrain ¹⁰⁰, A. Laurier ¹⁵⁰, S.D. Lawlor ⁹⁵, Z. Lawrence ¹⁰¹,
 M. Lazzaroni ^{71a,71b}, B. Le ¹⁰¹, E.M. Le Boulicaut ⁵¹, B. Leban ⁹³, A. Lebedev ⁸¹, M. LeBlanc ³⁶,
 F. Ledroit-Guillon ⁶⁰, A.C.A. Lee ⁹⁶, G.R. Lee ¹⁶, S.C. Lee ¹⁴⁸, S. Lee ^{47a,47b}, T.F. Lee ⁹²,
 L.L. Leeuw ^{33c}, H.P. Lefebvre ⁹⁵, M. Lefebvre ¹⁶⁴, C. Leggett ^{17a}, K. Lehmann ¹⁴²,
 G. Lehmann Miotto ³⁶, M. Leigh ⁵⁶, W.A. Leight ¹⁰³, A. Leisos ^{152,r}, M.A.L. Leite ^{82c},
 C.E. Leitgeb ⁴⁸, R. Leitner ¹³³, K.J.C. Leney ⁴⁴, T. Lenz ²⁴, S. Leone ^{74a}, C. Leonidopoulos ⁵²,
 A. Leopold ¹⁴⁴, C. Leroy ¹⁰⁸, R. Les ¹⁰⁷, C.G. Lester ³², M. Levchenko ³⁷, J. Levêque ⁴,
 D. Levin ¹⁰⁶, L.J. Levinson ¹⁶⁸, M.P. Lewicki ⁸⁶, D.J. Lewis ⁴, A. Li ⁵, B. Li ^{62b}, C. Li ^{62a},
 C-Q. Li ^{62c}, H. Li ^{62a}, H. Li ^{62b}, H. Li ^{14c}, H. Li ^{62b}, J. Li ^{62c}, K. Li ¹³⁸, L. Li ^{62c},
 M. Li ^{14a,14e}, Q.Y. Li ^{62a}, S. Li ^{14a,14e}, S. Li ^{62d,62c,d}, T. Li ^{62b}, X. Li ¹⁰⁴, Z. Li ^{62b}, Z. Li ¹²⁶,
 Z. Li ¹⁰⁴, Z. Li ⁹², Z. Li ^{14a,14e}, Z. Liang ^{14a}, M. Liberatore ⁴⁸, B. Liberti ^{76a}, K. Lie ^{64c},
 J. Lieber Marin ^{82b}, H. Lien ⁶⁸, K. Lin ¹⁰⁷, R.A. Linck ⁶⁸, R.E. Lindley ⁷, J.H. Lindon ²,
 A. Linss ⁴⁸, E. Lipeles ¹²⁸, A. Lipniacka ¹⁶, A. Lister ¹⁶³, J.D. Little ⁴, B. Liu ^{14a},
 B.X. Liu ¹⁴², D. Liu ^{62d,62c}, J.B. Liu ^{62a}, J.K.K. Liu ³², K. Liu ^{62d,62c}, M. Liu ^{62a},
 M.Y. Liu ^{62a}, P. Liu ^{14a}, Q. Liu ^{62d,138,62c}, X. Liu ^{62a}, Y. Liu ^{14c,14e}, Y.L. Liu ¹⁰⁶, Y.W. Liu ^{62a},
 J. Llorente Merino ¹⁴², S.L. Lloyd ⁹⁴, E.M. Lobodzinska ⁴⁸, P. Loch ⁷, S. Loffredo ^{76a,76b},
 T. Lohse ¹⁸, K. Lohwasser ¹³⁹, E. Loiacono ⁴⁸, M. Lokajicek ¹³¹, J.D. Lomas ²⁰, J.D. Long ¹⁶¹,
 I. Longarini ¹⁵⁹, L. Longo ^{70a,70b}, R. Longo ¹⁶¹, I. Lopez Paz ⁶⁷, A. Lopez Solis ⁴⁸,
 J. Lorenz ¹⁰⁹, N. Lorenzo Martinez ⁴, A.M. Lory ¹⁰⁹, X. Lou ^{47a,47b}, X. Lou ^{14a,14e},
 A. Lounis ⁶⁶, J. Love ⁶, P.A. Love ⁹¹, G. Lu ^{14a,14e}, M. Lu ⁸⁰, S. Lu ¹²⁸, Y.J. Lu ⁶⁵,
 H.J. Lubatti ¹³⁸, C. Luci ^{75a,75b}, F.L. Lucio Alves ^{14c}, A. Lucotte ⁶⁰, F. Luehring ⁶⁸, I. Luise ¹⁴⁵,


O. Lukianchuk ⁶⁶, O. Lundberg ¹⁴⁴, B. Lund-Jensen ¹⁴⁴, N.A. Luongo ¹²³, M.S. Lutz ¹⁵¹, D. Lynn ²⁹, H. Lyons⁹², R. Lysak ¹³¹, E. Lytken ⁹⁸, V. Lyubushkin ³⁸, T. Lyubushkina ³⁸, M.M. Lyukova ¹⁴⁵, H. Ma ²⁹, L.L. Ma ^{62b}, Y. Ma ⁹⁶, D.M. Mac Donell ¹⁶⁴, G. Maccarrone ⁵³, J.C. MacDonald ¹³⁹, R. Madar ⁴⁰, W.F. Mader ⁵⁰, J. Maeda ⁸⁴, T. Maeno ²⁹, M. Maerker ⁵⁰, H. Maguire ¹³⁹, A. Maio ^{130a,130b,130d}, K. Maj ^{85a}, O. Majersky ⁴⁸, S. Majewski ¹²³, N. Makovec ⁶⁶, V. Maksimovic ¹⁵, B. Malaescu ¹²⁷, Pa. Malecki ⁸⁶, V.P. Maleev ³⁷, F. Malek ⁶⁰, D. Malito ^{43b,43a}, U. Mallik ⁸⁰, C. Malone ³², S. Maltezos¹⁰, S. Malyukov³⁸, J. Mamuzic ¹³, G. Mancini ⁵³, G. Manco ^{73a,73b}, J.P. Mandalia ⁹⁴, I. Mandić ⁹³, L. Manhaes de Andrade Filho ^{82a}, I.M. Maniatis ¹⁶⁸, J. Manjarres Ramos ¹⁰², D.C. Mankad ¹⁶⁸, A. Mann ¹⁰⁹, B. Mansoulie ¹³⁵, S. Manzoni ³⁶, A. Marantis ¹⁵², G. Marchiori ⁵, M. Marcisovsky ¹³¹, C. Marcon ^{71a,71b}, M. Marinescu ²⁰, M. Marjanovic ¹²⁰, E.J. Marshall ⁹¹, Z. Marshall ^{17a}, S. Marti-Garcia ¹⁶², T.A. Martin ¹⁶⁶, V.J. Martin ⁵², B. Martin dit Latour ¹⁶, L. Martinelli ^{75a,75b}, M. Martinez ^{13,s}, P. Martinez Agullo ¹⁶², V.I. Martinez Outschoorn ¹⁰³, P. Martinez Suarez ¹³, S. Martin-Haugh ¹³⁴, V.S. Martoiu ^{27b}, A.C. Martyniuk ⁹⁶, A. Marzin ³⁶, S.R. Maschek ¹¹⁰, D. Mascione ^{78a,78b}, L. Masetti ¹⁰⁰, T. Mashimo ¹⁵³, J. Masik ¹⁰¹, A.L. Maslennikov ³⁷, L. Massa ^{23b}, P. Massarotti ^{72a,72b}, P. Mastrandrea ^{74a,74b}, A. Mastroberardino ^{43b,43a}, T. Masubuchi ¹⁵³, T. Mathisen ¹⁶⁰, N. Matsuzawa¹⁵³, J. Maurer ^{27b}, B. Maček ⁹³, D.A. Maximov ³⁷, R. Mazini ¹⁴⁸, I. Maznas ^{152,e}, M. Mazza ¹⁰⁷, S.M. Mazza ¹³⁶, C. Mc Ginn ²⁹, J.P. Mc Gowan ¹⁰⁴, S.P. Mc Kee ¹⁰⁶, E.F. McDonald ¹⁰⁵, A.E. McDougall ¹¹⁴, J.A. Mcfayden ¹⁴⁶, R.P. McGovern ¹²⁸, G. Mchedlidze ^{149b}, R.P. Mckenzie ^{33g}, T.C. Mclachlan ⁴⁸, D.J. Mclaughlin ⁹⁶, K.D. McLean ¹⁶⁴, S.J. McMahon ¹³⁴, P.C. McNamara ¹⁰⁵, C.M. Mccpartland ⁹², R.A. McPherson ^{164,v}, T. Megy ⁴⁰, S. Mehlhase ¹⁰⁹, A. Mehta ⁹², D. Melini ¹⁵⁰, B.R. Mellado Garcia ^{33g}, A.H. Melo ⁵⁵, F. Meloni ⁴⁸, A.M. Mendes Jacques Da Costa ¹⁰¹, H.Y. Meng ¹⁵⁵, L. Meng ⁹¹, S. Menke ¹¹⁰, M. Mentink ³⁶, E. Meoni ^{43b,43a}, C. Merlassino ¹²⁶, L. Merola ^{72a,72b}, C. Meroni ^{71a}, G. Merz¹⁰⁶, O. Meshkov ³⁷, J. Metcalfe ⁶, A.S. Mete ⁶, C. Meyer ⁶⁸, J-P. Meyer ¹³⁵, R.P. Middleton ¹³⁴, L. Mijović ⁵², G. Mikenberg ¹⁶⁸, M. Mikesikova ¹³¹, M. Mikuž ⁹³, H. Mildner ¹³⁹, A. Milic ³⁶, C.D. Milke ⁴⁴, D.W. Miller ³⁹, L.S. Miller ³⁴, A. Milov ¹⁶⁸, D.A. Milstead^{47a,47b}, T. Min^{14c}, A.A. Minaenko ³⁷, I.A. Minashvili ^{149b}, L. Mince ⁵⁹, A.I. Mincer ¹¹⁷, B. Mindur ^{85a}, M. Mineev ³⁸, Y. Mino ⁸⁷, L.M. Mir ¹³, M. Miralles Lopez ¹⁶², M. Mironova ^{17a}, M.C. Missio ¹¹³, T. Mitani ¹⁶⁷, A. Mitra ¹⁶⁶, V.A. Mitsou ¹⁶², O. Miu ¹⁵⁵, P.S. Miyagawa ⁹⁴, Y. Miyazaki⁸⁹, A. Mizukami ⁸³, T. Mkrtychyan ^{63a}, M. Mlinarevic ⁹⁶, T. Mlinarevic ⁹⁶, M. Mlynarikova ³⁶, S. Mobius ⁵⁵, K. Mochizuki ¹⁰⁸, P. Moder ⁴⁸, P. Mogg ¹⁰⁹, A.F. Mohammed ^{14a,14e}, S. Mohapatra ⁴¹, G. Mokgatitwane ^{33g}, B. Mondal ¹⁴¹, S. Mondal ¹³², G. Monig ¹⁴⁶, K. Mönig ⁴⁸, E. Monnier ¹⁰², L. Monsonis Romero¹⁶², J. Montejo Berlingen ⁸³, M. Montella ¹¹⁹, F. Monticelli ⁹⁰, N. Morange ⁶⁶, A.L. Moreira De Carvalho ^{130a}, M. Moreno Llácer ¹⁶², C. Moreno Martinez ⁵⁶, P. Moretini ^{57b}, S. Morgenstern ³⁶, M. Morii ⁶¹, M. Morinaga ¹⁵³, A.K. Morley ³⁶, F. Morodei ^{75a,75b}, L. Morvaj ³⁶, P. Moschovakos ³⁶, B. Moser ³⁶, M. Mosidze^{149b}, T. Moskalets ⁵⁴, P. Moskvitina ¹¹³, J. Moss ^{31,m}, E.J.W. Moyses ¹⁰³, O. Mtintsilana ^{33g}, S. Muanza ¹⁰², J. Mueller ¹²⁹, D. Muenstermann ⁹¹, R. Müller ¹⁹, G.A. Mullier ¹⁶⁰, J.J. Mullin¹²⁸, D.P. Mungo ¹⁵⁵, J.L. Munoz Martinez ¹³, D. Munoz Perez ¹⁶², F.J. Munoz Sanchez ¹⁰¹, M. Murin ¹⁰¹, W.J. Murray ^{166,134}, A. Murrone ^{71a,71b}, J.M. Muse ¹²⁰, M. Muškinja ^{17a}, C. Mwewa ²⁹, A.G. Myagkov ^{37,a}, A.J. Myers ⁸, A.A. Myers¹²⁹, G. Myers ⁶⁸, M. Myska ¹³², B.P. Nachman ^{17a}, O. Nackenhorst ⁴⁹, A.Nag Nag ⁵⁰, K. Nagai ¹²⁶, K. Nagano ⁸³, J.L. Nagle ^{29,ad}, E. Nagy ¹⁰², A.M. Nairz ³⁶, Y. Nakahama ⁸³, K. Nakamura ⁸³, H. Nanjo ¹²⁴, R. Narayan ⁴⁴, E.A. Narayanan ¹¹², I. Naryshkin ³⁷, M. Naseri ³⁴, C. Nass ²⁴, G. Navarro ^{22a}, J. Navarro-Gonzalez ¹⁶², R. Nayak ¹⁵¹, A. Nayaz ¹⁸, P.Y. Nechaeva ³⁷, F. Nechansky ⁴⁸, L. Nedic ¹²⁶, T.J. Neep ²⁰, A. Negri ^{73a,73b}, M. Negrini ^{23b}, C. Nellist ¹¹⁴,

C. Nelson ¹⁰⁴, K. Nelson ¹⁰⁶, S. Nemecek ¹³¹, M. Nessi ^{36,h}, M.S. Neubauer ¹⁶¹,
 F. Neuhaus ¹⁰⁰, J. Neundorf ⁴⁸, R. Newhouse ¹⁶³, P.R. Newman ²⁰, C.W. Ng ¹²⁹, Y.W.Y. Ng ⁴⁸,
 B. Ngair ^{35e}, H.D.N. Nguyen ¹⁰⁸, R.B. Nickerson ¹²⁶, R. Nicolaidou ¹³⁵, J. Nielsen ¹³⁶,
 M. Niemeyer ⁵⁵, N. Nikiforou ³⁶, V. Nikolaenko ^{37,a}, I. Nikolic-Audit ¹²⁷, K. Nikolopoulos ²⁰,
 P. Nilsson ²⁹, I. Ninca ⁴⁸, H.R. Nindhito ⁵⁶, G. Ninio ¹⁵¹, A. Nisati ^{75a}, N. Nishu ²,
 R. Nisius ¹¹⁰, J-E. Nitschke ⁵⁰, E.K. Nkadimeng ^{33g}, S.J. Noacco Rosende ⁹⁰, T. Nobe ¹⁵³,
 D.L. Noel ³², T. Nommensen ¹⁴⁷, M.A. Nomura ²⁹, M.B. Norfolk ¹³⁹, R.R.B. Norisam ⁹⁶,
 B.J. Norman ³⁴, J. Novak ⁹³, T. Novak ⁴⁸, L. Novotny ¹³², R. Novotny ¹¹², L. Nozka ¹²²,
 K. Ntekas ¹⁵⁹, N.M.J. Nunes De Moura Junior ^{82b}, E. Nurse ⁹⁶, J. Ocariz ¹²⁷, A. Ochi ⁸⁴,
 I. Ochoa ^{130a}, S. Oerdek ¹⁶⁰, J.T. Offermann ³⁹, A. Ogrodnik ^{85a}, A. Oh ¹⁰¹, C.C. Ohm ¹⁴⁴,
 H. Oide ⁸³, R. Oishi ¹⁵³, M.L. Ojeda ⁴⁸, Y. Okazaki ⁸⁷, M.W. O'Keefe ⁹², Y. Okumura ¹⁵³,
 L.F. Oleiro Seabra ^{130a}, S.A. Olivares Pino ^{137d}, D. Oliveira Damazio ²⁹, D. Oliveira Goncalves ^{82a},
 J.L. Oliver ¹⁵⁹, M.J.R. Olsson ¹⁵⁹, A. Olszewski ⁸⁶, J. Olszowska ^{86,*}, Ö.O. Öncel ⁵⁴,
 D.C. O'Neil ¹⁴², A.P. O'Neill ¹⁹, A. Onofre ^{130a,130e}, P.U.E. Onyisi ¹¹, M.J. Oreglia ³⁹,
 G.E. Orellana ⁹⁰, D. Orestano ^{77a,77b}, N. Orlando ¹³, R.S. Orr ¹⁵⁵, V. O'Shea ⁵⁹, R. Ospanov ^{62a},
 G. Otero y Garzon ³⁰, H. Otono ⁸⁹, P.S. Ott ^{63a}, G.J. Ottino ^{17a}, M. Ouchrif ^{35d}, J. Ouellette ²⁹,
 F. Ould-Saada ¹²⁵, M. Owen ⁵⁹, R.E. Owen ¹³⁴, K.Y. Oyulmaz ^{21a}, V.E. Ozcan ^{21a}, N. Ozturk ⁸,
 S. Ozturk ^{21d}, H.A. Pacey ³², A. Pacheco Pages ¹³, C. Padilla Aranda ¹³, G. Padovano ^{75a,75b},
 S. Pagan Griso ^{17a}, G. Palacino ⁶⁸, A. Palazzo ^{70a,70b}, S. Palestini ³⁶, J. Pan ¹⁷¹, T. Pan ^{64a},
 D.K. Panchal ¹¹, C.E. Pandini ¹¹⁴, J.G. Panduro Vazquez ⁹⁵, H. Pang ^{14b}, P. Pani ⁴⁸,
 G. Panizzo ^{69a,69c}, L. Paolozzi ⁵⁶, C. Papadatos ¹⁰⁸, S. Parajuli ⁴⁴, A. Paramonov ⁶,
 C. Paraskevopoulos ¹⁰, D. Paredes Hernandez ^{64b}, T.H. Park ¹⁵⁵, M.A. Parker ³², F. Parodi ^{57b,57a},
 E.W. Parrish ¹¹⁵, V.A. Parrish ⁵², J.A. Parsons ⁴¹, U. Parzefall ⁵⁴, B. Pascual Dias ¹⁰⁸,
 L. Pascual Dominguez ¹⁵¹, F. Pasquali ¹¹⁴, E. Pasqualucci ^{75a}, S. Passaggio ^{57b}, F. Pastore ⁹⁵,
 P. Pasuwan ^{47a,47b}, P. Patel ⁸⁶, U.M. Patel ⁵¹, J.R. Pater ¹⁰¹, T. Pauly ³⁶, J. Pearkes ¹⁴³,
 M. Pedersen ¹²⁵, R. Pedro ^{130a}, S.V. Peleganchuk ³⁷, O. Penc ³⁶, E.A. Pender ⁵², H. Peng ^{62a},
 K.E. Pensi ¹⁰⁹, M. Penzin ³⁷, B.S. Peralva ^{82d,82d}, A.P. Pereira Peixoto ⁶⁰,
 L. Pereira Sanchez ^{47a,47b}, D.V. Perepelitsa ^{29,ad}, E. Perez Codina ^{156a}, M. Perganti ¹⁰,
 L. Perini ^{71a,71b,*}, H. Pernegger ³⁶, S. Perrella ³⁶, A. Perrevoort ¹¹³, O. Perrin ⁴⁰, K. Peters ⁴⁸,
 R.F.Y. Peters ¹⁰¹, B.A. Petersen ³⁶, T.C. Petersen ⁴², E. Petit ¹⁰², V. Petousis ¹³²,
 C. Petridou ^{152,e}, A. Petrukhin ¹⁴¹, M. Pettee ^{17a}, N.E. Pettersson ³⁶, A. Petukhov ³⁷,
 K. Petukhova ¹³³, A. Peyaud ¹³⁵, R. Pezoa ^{137f}, L. Pezzotti ³⁶, G. Pezzullo ¹⁷¹, T.M. Pham ¹⁶⁹,
 T. Pham ¹⁰⁵, P.W. Phillips ¹³⁴, M.W. Phipps ¹⁶¹, G. Piacquadio ¹⁴⁵, E. Pianori ^{17a},
 F. Piazza ^{71a,71b}, R. Piegai ³⁰, D. Pietreanu ^{27b}, A.D. Pilkington ¹⁰¹, M. Pinamonti ^{69a,69c},
 J.L. Pinfeld ², B.C. Pinheiro Pereira ^{130a}, C. Pitman Donaldson ⁹⁶, D.A. Pizzi ³⁴,
 L. Pizzimento ^{76a,76b}, A. Pizzini ¹¹⁴, M.-A. Pleier ²⁹, V. Plesanovs ⁵⁴, V. Pleskot ¹³³,
 E. Plotnikova ³⁸, G. Poddar ⁴, R. Poettgen ⁹⁸, L. Poggioli ¹²⁷, D. Pohl ²⁴, I. Pokharel ⁵⁵,
 S. Polacek ¹³³, G. Polesello ^{73a}, A. Poley ^{142,156a}, R. Polifka ¹³², A. Polini ^{23b}, C.S. Pollard ¹⁶⁶,
 Z.B. Pollock ¹¹⁹, V. Polychronakos ²⁹, E. Pompa Pacchi ^{75a,75b}, D. Ponomarenko ¹¹³,
 L. Pontecorvo ³⁶, S. Popa ^{27a}, G.A. Popeneciu ^{27d}, D.M. Portillo Quintero ^{156a}, S. Pospisil ¹³²,
 P. Postolache ^{27c}, K. Potamianos ¹²⁶, P.P. Potepa ^{85a}, I.N. Potrap ³⁸, C.J. Potter ³², H. Potti ¹,
 T. Poulsen ⁴⁸, J. Poveda ¹⁶², M.E. Pozo Astigarraga ³⁶, A. Prades Ibanez ¹⁶², M.M. Prapa ⁴⁶,
 D. Price ¹⁰¹, M. Primavera ^{70a}, M.A. Principe Martin ⁹⁹, R. Privara ¹²², M.L. Proffitt ¹³⁸,
 N. Proklova ¹²⁸, K. Prokofiev ^{64c}, G. Proto ^{76a,76b}, S. Protopopescu ²⁹, J. Proudfoot ⁶,
 M. Przybycien ^{85a}, W.W. Przygoda ^{85b}, J.E. Puddefoot ¹³⁹, D. Pudzha ³⁷, D. Pyatiizbyantseva ³⁷,
 J. Qian ¹⁰⁶, D. Qichen ¹⁰¹, Y. Qin ¹⁰¹, T. Qiu ⁵², A. Quadt ⁵⁵, M. Queitsch-Maitland ¹⁰¹,
 G. Quetant ⁵⁶, G. Rabanal Bolanos ⁶¹, D. Rafanoharana ⁵⁴, F. Ragusa ^{71a,71b}, J.L. Rainbolt ³⁹,

J.A. Raine [ID⁵⁶](#), S. Rajagopalan [ID²⁹](#), E. Ramakoti [ID³⁷](#), K. Ran [ID^{48,14e}](#), N.P. Rapheeha [ID^{33g}](#),
 V. Raskina [ID¹²⁷](#), D.F. Rassloff [ID^{63a}](#), S. Rave [ID¹⁰⁰](#), B. Ravina [ID⁵⁵](#), I. Ravinovich [ID¹⁶⁸](#), M. Raymond [ID³⁶](#),
 A.L. Read [ID¹²⁵](#), N.P. Readioff [ID¹³⁹](#), D.M. Rebuzzi [ID^{73a,73b}](#), G. Redlinger [ID²⁹](#), K. Reeves [ID²⁶](#),
 J.A. Reidelsturz [ID¹⁷⁰](#), D. Reikher [ID¹⁵¹](#), A. Rej [ID¹⁴¹](#), C. Rembser [ID³⁶](#), A. Renardi [ID⁴⁸](#), M. Renda [ID^{27b}](#),
 M.B. Rendel [ID¹¹⁰](#), F. Renner [ID⁴⁸](#), A.G. Rennie [ID⁵⁹](#), S. Resconi [ID^{71a}](#), M. Ressegotti [ID^{57b,57a}](#),
 E.D. Resseguie [ID^{17a}](#), S. Rettie [ID³⁶](#), J.G. Reyes Rivera [ID¹⁰⁷](#), B. Reynolds [ID¹¹⁹](#), E. Reynolds [ID^{17a}](#),
 M. Rezaei Estabragh [ID¹⁷⁰](#), O.L. Rezanova [ID³⁷](#), P. Reznicek [ID¹³³](#), N. Ribaric [ID⁹¹](#), E. Ricci [ID^{78a,78b}](#),
 R. Richter [ID¹¹⁰](#), S. Richter [ID^{47a,47b}](#), E. Richter-Was [ID^{85b}](#), M. Ridel [ID¹²⁷](#), S. Ridouani [ID^{35d}](#), P. Rieck [ID¹¹⁷](#),
 P. Riedler [ID³⁶](#), M. Rijssenbeek [ID¹⁴⁵](#), A. Rimoldi [ID^{73a,73b}](#), M. Rimoldi [ID⁴⁸](#), L. Rinaldi [ID^{23b,23a}](#),
 T.T. Rinn [ID²⁹](#), M.P. Rinnagel [ID¹⁰⁹](#), G. Ripellino [ID¹⁶⁰](#), I. Riu [ID¹³](#), P. Rivadeneira [ID⁴⁸](#),
 J.C. Rivera Vergara [ID¹⁶⁴](#), F. Rizatdinova [ID¹²¹](#), E. Rizvi [ID⁹⁴](#), C. Rizzi [ID⁵⁶](#), B.A. Roberts [ID¹⁶⁶](#),
 B.R. Roberts [ID^{17a}](#), S.H. Robertson [ID^{104,v}](#), M. Robin [ID⁴⁸](#), D. Robinson [ID³²](#), C.M. Robles Gajardo [ID^{137f}](#),
 M. Robles Manzano [ID¹⁰⁰](#), A. Robson [ID⁵⁹](#), A. Rocchi [ID^{76a,76b}](#), C. Roda [ID^{74a,74b}](#), S. Rodriguez Bosca [ID^{63a}](#),
 Y. Rodriguez Garcia [ID^{22a}](#), A. Rodriguez Rodriguez [ID⁵⁴](#), A.M. Rodríguez Vera [ID^{156b}](#), S. Roe [ID³⁶](#),
 J.T. Roemer [ID¹⁵⁹](#), A.R. Roepe-Gier [ID¹³⁶](#), J. Roggel [ID¹⁷⁰](#), O. Røhne [ID¹²⁵](#), R.A. Rojas [ID¹⁰³](#),
 C.P.A. Roland [ID⁶⁸](#), J. Roloff [ID²⁹](#), A. Romaniouk [ID³⁷](#), E. Romano [ID^{73a,73b}](#), M. Romano [ID^{23b}](#),
 A.C. Romero Hernandez [ID¹⁶¹](#), N. Rompotis [ID⁹²](#), L. Roos [ID¹²⁷](#), S. Rosati [ID^{75a}](#), B.J. Rosser [ID³⁹](#),
 E. Rossi [ID⁴](#), E. Rossi [ID^{72a,72b}](#), L.P. Rossi [ID^{57b}](#), L. Rossini [ID⁴⁸](#), R. Rosten [ID¹¹⁹](#), M. Rotaru [ID^{27b}](#),
 B. Rottler [ID⁵⁴](#), C. Rougier [ID¹⁰²](#), D. Rousseau [ID⁶⁶](#), D. Rousso [ID³²](#), A. Roy [ID¹⁶¹](#), S. Roy-Garand [ID¹⁵⁵](#),
 A. Rozanov [ID¹⁰²](#), Y. Rozen [ID¹⁵⁰](#), X. Ruan [ID^{33g}](#), A. Rubio Jimenez [ID¹⁶²](#), A.J. Ruby [ID⁹²](#),
 V.H. Ruelas Rivera [ID¹⁸](#), T.A. Ruggeri [ID¹](#), A. Ruiz-Martinez [ID¹⁶²](#), A. Rummeler [ID³⁶](#), Z. Rurikova [ID⁵⁴](#),
 N.A. Rusakovich [ID³⁸](#), H.L. Russell [ID¹⁶⁴](#), J.P. Rutherford [ID⁷](#), K. Rybacki [ID⁹¹](#), M. Rybar [ID¹³³](#),
 E.B. Rye [ID¹²⁵](#), A. Ryzhov [ID³⁷](#), J.A. Sabater Iglesias [ID⁵⁶](#), P. Sabatini [ID¹⁶²](#), L. Sabetta [ID^{75a,75b}](#),
 H.F.W. Sadrozinski [ID¹³⁶](#), F. Safai Tehrani [ID^{75a}](#), B. Safarzadeh Samani [ID¹⁴⁶](#), M. Safdari [ID¹⁴³](#),
 S. Saha [ID¹⁰⁴](#), M. Sahinsoy [ID¹¹⁰](#), M. Saimpert [ID¹³⁵](#), M. Saito [ID¹⁵³](#), T. Saito [ID¹⁵³](#), D. Salamani [ID³⁶](#),
 A. Salnikov [ID¹⁴³](#), J. Salt [ID¹⁶²](#), A. Salvador Salas [ID¹³](#), D. Salvatore [ID^{43b,43a}](#), F. Salvatore [ID¹⁴⁶](#),
 A. Salzburger [ID³⁶](#), D. Sammel [ID⁵⁴](#), D. Sampsonidis [ID^{152,e}](#), D. Sampsonidou [ID^{123,62c}](#), J. Sánchez [ID¹⁶²](#),
 A. Sanchez Pineda [ID⁴](#), V. Sanchez Sebastian [ID¹⁶²](#), H. Sandaker [ID¹²⁵](#), C.O. Sander [ID⁴⁸](#),
 J.A. Sandesara [ID¹⁰³](#), M. Sandhoff [ID¹⁷⁰](#), C. Sandoval [ID^{22b}](#), D.P.C. Sankey [ID¹³⁴](#), T. Sano [ID⁸⁷](#),
 A. Sansoni [ID⁵³](#), L. Santi [ID^{75a,75b}](#), C. Santoni [ID⁴⁰](#), H. Santos [ID^{130a,130b}](#), S.N. Santpur [ID^{17a}](#), A. Santra [ID¹⁶⁸](#),
 K.A. Saoucha [ID¹³⁹](#), J.G. Saraiva [ID^{130a,130d}](#), J. Sardain [ID⁷](#), O. Sasaki [ID⁸³](#), K. Sato [ID¹⁵⁷](#), C. Sauer [ID^{63b}](#),
 F. Sauerburger [ID⁵⁴](#), E. Sauvan [ID⁴](#), P. Savard [ID^{155,ab}](#), R. Sawada [ID¹⁵³](#), C. Sawyer [ID¹³⁴](#), L. Sawyer [ID⁹⁷](#),
 I. Sayago Galvan [ID¹⁶²](#), C. Sbarra [ID^{23b}](#), A. Sbrizzi [ID^{23b,23a}](#), T. Scanlon [ID⁹⁶](#), J. Schaarschmidt [ID¹³⁸](#),
 P. Schacht [ID¹¹⁰](#), D. Schaefer [ID³⁹](#), U. Schäfer [ID¹⁰⁰](#), A.C. Schaffer [ID^{66,44}](#), D. Schaile [ID¹⁰⁹](#),
 R.D. Schamberger [ID¹⁴⁵](#), E. Schanet [ID¹⁰⁹](#), C. Scharf [ID¹⁸](#), M.M. Schefer [ID¹⁹](#), V.A. Schegelsky [ID³⁷](#),
 D. Scheirich [ID¹³³](#), F. Schenck [ID¹⁸](#), M. Schernau [ID¹⁵⁹](#), C. Scheulen [ID⁵⁵](#), C. Schiavi [ID^{57b,57a}](#),
 E.J. Schioppa [ID^{70a,70b}](#), M. Schioppa [ID^{43b,43a}](#), B. Schlag [ID¹⁴³](#), K.E. Schleicher [ID⁵⁴](#), S. Schlenker [ID³⁶](#),
 J. Schmeing [ID¹⁷⁰](#), M.A. Schmidt [ID¹⁷⁰](#), K. Schmieden [ID¹⁰⁰](#), C. Schmitt [ID¹⁰⁰](#), S. Schmitt [ID⁴⁸](#),
 L. Schoeffel [ID¹³⁵](#), A. Schoening [ID^{63b}](#), P.G. Scholer [ID⁵⁴](#), E. Schopf [ID¹²⁶](#), M. Schott [ID¹⁰⁰](#),
 J. Schovancova [ID³⁶](#), S. Schramm [ID⁵⁶](#), F. Schroeder [ID¹⁷⁰](#), H-C. Schultz-Coulon [ID^{63a}](#), M. Schumacher [ID⁵⁴](#),
 B.A. Schumm [ID¹³⁶](#), Ph. Schune [ID¹³⁵](#), H.R. Schwartz [ID¹³⁶](#), A. Schwartzman [ID¹⁴³](#), T.A. Schwarz [ID¹⁰⁶](#),
 Ph. Schwemling [ID¹³⁵](#), R. Schwienhorst [ID¹⁰⁷](#), A. Sciandra [ID¹³⁶](#), G. Sciolla [ID²⁶](#), F. Scuri [ID^{74a}](#), F. Scutti [ID¹⁰⁵](#),
 C.D. Sebastiani [ID⁹²](#), K. Sedlaczek [ID⁴⁹](#), P. Seema [ID¹⁸](#), S.C. Seidel [ID¹¹²](#), A. Seiden [ID¹³⁶](#),
 B.D. Seidlitz [ID⁴¹](#), C. Seitz [ID⁴⁸](#), J.M. Seixas [ID^{82b}](#), G. Sekhniaidze [ID^{72a}](#), S.J. Sekula [ID⁴⁴](#), L. Selem [ID⁴](#),
 N. Semprini-Cesari [ID^{23b,23a}](#), S. Sen [ID⁵¹](#), D. Sengupta [ID⁵⁶](#), V. Senthilkumar [ID¹⁶²](#), L. Serin [ID⁶⁶](#),
 L. Serkin [ID^{69a,69b}](#), M. Sessa [ID^{77a,77b}](#), H. Severini [ID¹²⁰](#), F. Sforza [ID^{57b,57a}](#), A. Sfyrla [ID⁵⁶](#),
 E. Shabalina [ID⁵⁵](#), R. Shaheen [ID¹⁴⁴](#), J.D. Shahinian [ID¹²⁸](#), D. Shaked Renous [ID¹⁶⁸](#), L.Y. Shan [ID^{14a}](#),

M. Shapiro ^{17a}, A. Sharma ³⁶, A.S. Sharma ¹⁶³, P. Sharma ⁸⁰, S. Sharma ⁴⁸, P.B. Shatalov ³⁷,
K. Shaw ¹⁴⁶, S.M. Shaw ¹⁰¹, Q. Shen ^{62c,5}, P. Sherwood ⁹⁶, L. Shi ⁹⁶, C.O. Shimmin ¹⁷¹,
Y. Shimogama ¹⁶⁷, J.D. Shinner ⁹⁵, I.P.J. Shipsey ¹²⁶, S. Shirabe ⁶⁰, M. Shiyakova ³⁸,
J. Shlomi ¹⁶⁸, M.J. Shochet ³⁹, J. Shojaii ¹⁰⁵, D.R. Shope ¹²⁵, S. Shrestha ^{119,ae}, E.M. Shrif ^{33g},
M.J. Shroff ¹⁶⁴, P. Sicho ¹³¹, A.M. Sickles ¹⁶¹, E. Sideras Haddad ^{33g}, A. Sidoti ^{23b},
F. Siegert ⁵⁰, Dj. Sijacki ¹⁵, R. Sikora ^{85a}, F. Sili ⁹⁰, J.M. Silva ²⁰, M.V. Silva Oliveira ³⁶,
S.B. Silverstein ^{47a}, S. Simion ⁶⁶, R. Simoniello ³⁶, E.L. Simpson ⁵⁹, H. Simpson ¹⁴⁶,
L.R. Simpson ¹⁰⁶, N.D. Simpson ⁹⁸, S. Simsek ^{21d}, S. Sindhu ⁵⁵, P. Sinervo ¹⁵⁵, S. Singh ¹⁴²,
S. Singh ¹⁵⁵, S. Sinha ⁴⁸, S. Sinha ^{33g}, M. Sioli ^{23b,23a}, I. Siral ³⁶, S.Yu. Sivoklov ^{37,*},
J. Sjölin ^{47a,47b}, A. Skaf ⁵⁵, E. Skorda ⁹⁸, P. Skubic ¹²⁰, M. Slawinska ⁸⁶, V. Smakhtin ¹⁶⁸,
B.H. Smart ¹³⁴, J. Smiesko ³⁶, S.Yu. Smirnov ³⁷, Y. Smirnov ³⁷, L.N. Smirnova ^{37,a},
O. Smirnova ⁹⁸, A.C. Smith ⁴¹, E.A. Smith ³⁹, H.A. Smith ¹²⁶, J.L. Smith ⁹², R. Smith ¹⁴³,
M. Smizanska ⁹¹, K. Smolek ¹³², A.A. Snesarev ³⁷, H.L. Snoek ¹¹⁴, S. Snyder ²⁹,
R. Sobie ^{164,v}, A. Soffer ¹⁵¹, C.A. Solans Sanchez ³⁶, E.Yu. Soldatov ³⁷, U. Soldevila ¹⁶²,
A.A. Solodkov ³⁷, S. Solomon ⁵⁴, A. Soloshenko ³⁸, K. Solovieva ⁵⁴, O.V. Solovyanov ⁴⁰,
V. Solovyev ³⁷, P. Sommer ³⁶, A. Sonay ¹³, W.Y. Song ^{156b}, J.M. Sonneveld ¹¹⁴,
A. Sopczak ¹³², A.L. Sopio ⁹⁶, F. Sopkova ^{28b}, V. Sothilingam ^{63a}, S. Sottocornola ⁶⁸,
R. Soualah ^{116c}, Z. Soumami ^{35e}, D. South ⁴⁸, S. Spagnolo ^{70a,70b}, M. Spalla ¹¹⁰,
D. Sperlich ⁵⁴, G. Spigo ³⁶, M. Spina ¹⁴⁶, S. Spinali ⁹¹, D.P. Spiteri ⁵⁹, M. Spousta ¹³³,
E.J. Staats ³⁴, A. Stabile ^{71a,71b}, R. Stamen ^{63a}, M. Stamenkovic ¹¹⁴, A. Stampekis ²⁰,
M. Standke ²⁴, E. Stanecka ⁸⁶, M.V. Stange ⁵⁰, B. Stanislaus ^{17a}, M.M. Stanitzki ⁴⁸,
M. Stankaityte ¹²⁶, B. Stapf ⁴⁸, E.A. Starchenko ³⁷, G.H. Stark ¹³⁶, J. Stark ¹⁰², D.M. Starko ^{156b},
P. Staroba ¹³¹, P. Starovoitov ^{63a}, S. Stärz ¹⁰⁴, R. Staszewski ⁸⁶, G. Stavropoulos ⁴⁶,
J. Steentoft ¹⁶⁰, P. Steinberg ²⁹, B. Stelzer ^{142,156a}, H.J. Stelzer ¹²⁹, O. Stelzer-Chilton ^{156a},
H. Stenzel ⁵⁸, T.J. Stevenson ¹⁴⁶, G.A. Stewart ³⁶, J.R. Stewart ¹²¹, M.C. Stockton ³⁶,
G. Stoicea ^{27b}, M. Stolarski ^{130a}, S. Stonjek ¹¹⁰, A. Straessner ⁵⁰, J. Strandberg ¹⁴⁴,
S. Strandberg ^{47a,47b}, M. Strauss ¹²⁰, T. Strebler ¹⁰², P. Strizenec ^{28b}, R. Ströhmer ¹⁶⁵,
D.M. Strom ¹²³, L.R. Strom ⁴⁸, R. Stroynowski ⁴⁴, A. Strubig ^{47a,47b}, S.A. Stucci ²⁹,
B. Stugu ¹⁶, J. Stupak ¹²⁰, N.A. Styles ⁴⁸, D. Su ¹⁴³, S. Su ^{62a}, W. Su ^{62d,138,62c}, X. Su ^{62a,66},
K. Sugizaki ¹⁵³, V.V. Sulin ³⁷, M.J. Sullivan ⁹², D.M.S. Sultan ^{78a,78b}, L. Sultanaliev ³⁷,
S. Sultansoy ^{3b}, T. Sumida ⁸⁷, S. Sun ¹⁰⁶, S. Sun ¹⁶⁹, O. Sunneborn Gudnadottir ¹⁶⁰,
M.R. Sutton ¹⁴⁶, M. Svatos ¹³¹, M. Swiatlowski ^{156a}, T. Swirski ¹⁶⁵, I. Sykora ^{28a},
M. Sykora ¹³³, T. Sykora ¹³³, D. Ta ¹⁰⁰, K. Tackmann ^{48,t}, A. Taffard ¹⁵⁹, R. Tafirout ^{156a},
J.S. Tafoya Vargas ⁶⁶, R.H.M. Taibah ¹²⁷, R. Takashima ⁸⁸, E.P. Takeva ⁵², Y. Takubo ⁸³,
M. Talby ¹⁰², A.A. Talyshev ³⁷, K.C. Tam ^{64b}, N.M. Tamir ¹⁵¹, A. Tanaka ¹⁵³, J. Tanaka ¹⁵³,
R. Tanaka ⁶⁶, M. Tanasini ^{57b,57a}, J. Tang ^{62c}, Z. Tao ¹⁶³, S. Tapia Araya ^{137f}, S. Tapprogge ¹⁰⁰,
A. Tarek Abouelfadl Mohamed ¹⁰⁷, S. Tarem ¹⁵⁰, K. Tariq ^{62b}, G. Tarna ^{102,27b},
G.F. Tartarelli ^{71a}, P. Tas ¹³³, M. Tasevsky ¹³¹, E. Tassi ^{43b,43a}, A.C. Tate ¹⁶¹, G. Tateno ¹⁵³,
Y. Tayalati ^{35e,u}, G.N. Taylor ¹⁰⁵, W. Taylor ^{156b}, H. Teagle ⁹², A.S. Tee ¹⁶⁹,
R. Teixeira De Lima ¹⁴³, P. Teixeira-Dias ⁹⁵, J.J. Teoh ¹⁵⁵, K. Terashi ¹⁵³, J. Terron ⁹⁹,
S. Terzo ¹³, M. Testa ⁵³, R.J. Teuscher ^{155,v}, A. Thaler ⁷⁹, O. Theiner ⁵⁶, N. Themistokleous ⁵²,
T. Thevenaux-Pelzer ¹⁰², O. Thielmann ¹⁷⁰, D.W. Thomas ⁹⁵, J.P. Thomas ²⁰, E.A. Thompson ^{17a},
P.D. Thompson ²⁰, E. Thomson ¹²⁸, Y. Tian ⁵⁵, V. Tikhomirov ^{37,a}, Yu.A. Tikhonov ³⁷,
S. Timoshenko ³⁷, E.X.L. Ting ¹, P. Tipton ¹⁷¹, S.H. Tlou ^{33g}, A. Tnourji ⁴⁰, K. Todome ^{23b,23a},
S. Todorova-Nova ¹³³, S. Todt ⁵⁰, M. Togawa ⁸³, J. Tojo ⁸⁹, S. Tokár ^{28a}, K. Tokushuku ⁸³,
O. Toldaiev ⁶⁸, R. Tombs ³², M. Tomoto ^{83,111}, L. Tompkins ¹⁴³, K.W. Topolnicki ^{85b},
E. Torrence ¹²³, H. Torres ¹⁰², E. Torró Pastor ¹⁶², M. Toscani ³⁰, C. Toscirci ³⁹, M. Tost ¹¹,

D.R. Tovey ¹³⁹, A. Traeet ¹⁶, I.S. Trandafir ^{27b}, T. Trefzger ¹⁶⁵, A. Tricoli ²⁹, I.M. Trigger ^{156a},
 S. Trincaz-Duvoid ¹²⁷, D.A. Trischuk ²⁶, B. Trocmé ⁶⁰, C. Troncon ^{71a}, L. Truong ^{33c},
 M. Trzebinski ⁸⁶, A. Trzupiek ⁸⁶, F. Tsai ¹⁴⁵, M. Tsai ¹⁰⁶, A. Tsiamis ^{152,e}, P.V. Tsiareshka ³⁷,
 S. Tsigaridas ^{156a}, A. Tsirigotis ^{152,r}, V. Tsiskaridze ¹⁴⁵, E.G. Tskhadadze ^{149a}, M. Tsopoulou ^{152,e},
 Y. Tsujikawa ⁸⁷, I.I. Tsukerman ³⁷, V. Tsulaia ^{17a}, S. Tsuno ⁸³, O. Tsur ¹⁵⁰, D. Tsybychev ¹⁴⁵,
 Y. Tu ^{64b}, A. Tudorache ^{27b}, V. Tudorache ^{27b}, A.N. Tuna ³⁶, S. Turchikhin ³⁸, I. Turk Cakir ^{3a},
 R. Turra ^{71a}, T. Turtuvshin ^{38,w}, P.M. Tuts ⁴¹, S. Tzamarias ^{152,e}, P. Tzani ¹⁰, E. Tzovara ¹⁰⁰,
 K. Uchida ¹⁵³, F. Ukegawa ¹⁵⁷, P.A. Ulloa Poblete ^{137c}, E.N. Umaka ²⁹, G. Unal ³⁶, M. Unal ¹¹,
 A. Undrus ²⁹, G. Unel ¹⁵⁹, J. Urban ^{28b}, P. Urquijo ¹⁰⁵, G. Usai ⁸, R. Ushioda ¹⁵⁴,
 M. Usman ¹⁰⁸, Z. Uysal ^{21b}, L. Vacavant ¹⁰², V. Vacek ¹³², B. Vachon ¹⁰⁴, K.O.H. Vadla ¹²⁵,
 T. Vafeiadis ³⁶, A. Vaitkus ⁹⁶, C. Valderanis ¹⁰⁹, E. Valdes Santurio ^{47a,47b}, M. Valente ^{156a},
 S. Valentinetti ^{23b,23a}, A. Valero ¹⁶², E. Valiente Moreno ¹⁶², A. Vallier ¹⁰², J.A. Valls Ferrer ¹⁶²,
 D.R. Van Arneeman ¹¹⁴, T.R. Van Daalen ¹³⁸, P. Van Gemmeren ⁶, M. Van Rijnbach ^{125,36},
 S. Van Stroud ⁹⁶, I. Van Vulpen ¹¹⁴, M. Vanadia ^{76a,76b}, W. Vandelli ³⁶, M. Vandenbroucke ¹³⁵,
 E.R. Vandewall ¹²¹, D. Vannicola ¹⁵¹, L. Vannoli ^{57b,57a}, R. Vari ^{75a}, E.W. Varnes ⁷,
 C. Varni ^{17a}, T. Varol ¹⁴⁸, D. Varouchas ⁶⁶, L. Varriale ¹⁶², K.E. Varvell ¹⁴⁷, M.E. Vasile ^{27b},
 L. Vaslin ⁴⁰, G.A. Vasquez ¹⁶⁴, F. Vazeille ⁴⁰, T. Vazquez Schroeder ³⁶, J. Veatch ³¹,
 V. Vecchio ¹⁰¹, M.J. Veen ¹⁰³, I. Veliscek ¹²⁶, L.M. Veloce ¹⁵⁵, F. Veloso ^{130a,130c},
 S. Veneziano ^{75a}, A. Ventura ^{70a,70b}, A. Verbytskyi ¹¹⁰, M. Verducci ^{74a,74b}, C. Vergis ²⁴,
 M. Verissimo De Araujo ^{82b}, W. Verkerke ¹¹⁴, J.C. Vermeulen ¹¹⁴, C. Vernieri ¹⁴³,
 P.J. Verschuuren ⁹⁵, M. Vessella ¹⁰³, M.C. Vetterli ^{142,ab}, A. Vgenopoulos ^{152,e},
 N. Viaux Maira ^{137f}, T. Vickey ¹³⁹, O.E. Vickey Boeriu ¹³⁹, G.H.A. Viehhauser ¹²⁶, L. Vignani ^{63b},
 M. Villa ^{23b,23a}, M. Villaplana Perez ¹⁶², E.M. Villhauer ⁵², E. Vilucchi ⁵³, M.G. Vincter ³⁴,
 G.S. Virdee ²⁰, A. Vishwakarma ⁵², C. Vittori ³⁶, I. Vivarelli ¹⁴⁶, V. Vladimirov ¹⁶⁶,
 E. Voevodina ¹¹⁰, F. Vogel ¹⁰⁹, P. Vokac ¹³², J. Von Ahnen ⁴⁸, E. Von Toerne ²⁴,
 B. Vormwald ³⁶, V. Vorobel ¹³³, K. Vorobev ³⁷, M. Vos ¹⁶², K. Voss ¹⁴¹, J.H. Vossebeld ⁹²,
 M. Vozak ¹¹⁴, L. Vozdecky ⁹⁴, N. Vranjes ¹⁵, M. Vranjes Milosavljevic ¹⁵, M. Vreeswijk ¹¹⁴,
 R. Vuillermet ³⁶, O. Vujinovic ¹⁰⁰, I. Vukotic ³⁹, S. Wada ¹⁵⁷, C. Wagner ¹⁰³, J.M. Wagner ^{17a},
 W. Wagner ¹⁷⁰, S. Wahdan ¹⁷⁰, H. Wahlberg ⁹⁰, R. Wakasa ¹⁵⁷, M. Wakida ¹¹¹, J. Walder ¹³⁴,
 R. Walker ¹⁰⁹, W. Walkowiak ¹⁴¹, A. Wall ¹²⁸, A.Z. Wang ¹⁶⁹, C. Wang ¹⁰⁰, C. Wang ^{62c},
 H. Wang ^{17a}, J. Wang ^{64a}, R.-J. Wang ¹⁰⁰, R. Wang ⁶¹, R. Wang ⁶, S.M. Wang ¹⁴⁸,
 S. Wang ^{62b}, T. Wang ^{62a}, W.T. Wang ⁸⁰, X. Wang ^{14c}, X. Wang ¹⁶¹, X. Wang ^{62c},
 Y. Wang ^{62d}, Y. Wang ^{14c}, Z. Wang ¹⁰⁶, Z. Wang ^{62d,51,62c}, Z. Wang ¹⁰⁶, A. Warburton ¹⁰⁴,
 R.J. Ward ²⁰, N. Warrack ⁵⁹, A.T. Watson ²⁰, H. Watson ⁵⁹, M.F. Watson ²⁰, G. Watts ¹³⁸,
 B.M. Waugh ⁹⁶, C. Weber ²⁹, H.A. Weber ¹⁸, M.S. Weber ¹⁹, S.M. Weber ^{63a}, C. Wei ^{62a},
 Y. Wei ¹²⁶, A.R. Weidberg ¹²⁶, E.J. Weik ¹¹⁷, J. Weingarten ⁴⁹, M. Weirich ¹⁰⁰, C. Weiser ⁵⁴,
 C.J. Wells ⁴⁸, T. Wenaus ²⁹, B. Wendland ⁴⁹, T. Wengler ³⁶, N.S. Wenke ¹¹⁰, N. Wermes ²⁴,
 M. Wessels ^{63a}, K. Whalen ¹²³, A.M. Wharton ⁹¹, A.S. White ⁶¹, A. White ⁸, M.J. White ¹,
 D. Whiteson ¹⁵⁹, L. Wickremasinghe ¹²⁴, W. Wiedenmann ¹⁶⁹, C. Wiel ⁵⁰, M. Wielers ¹³⁴,
 C. Wiglesworth ⁴², L.A.M. Wiik-Fuchs ⁵⁴, D.J. Wilbern ¹²⁰, H.G. Wilkens ³⁶, D.M. Williams ⁴¹,
 H.H. Williams ¹²⁸, S. Williams ³², S. Willocq ¹⁰³, B.J. Wilson ¹⁰¹, P.J. Windischhofer ³⁹,
 F. Winklmeier ¹²³, B.T. Winter ⁵⁴, J.K. Winter ¹⁰¹, M. Wittgen ¹⁴³, M. Wobisch ⁹⁷, R. Wölker ¹²⁶,
 J. Wollrath ¹⁵⁹, M.W. Wolter ⁸⁶, H. Wolters ^{130a,130c}, V.W.S. Wong ¹⁶³, A.F. Wongel ⁴⁸,
 S.D. Worm ⁴⁸, B.K. Wosiek ⁸⁶, K.W. Woźniak ⁸⁶, K. Wraight ⁵⁹, J. Wu ^{14a,14e}, M. Wu ^{64a},
 M. Wu ¹¹³, S.L. Wu ¹⁶⁹, X. Wu ⁵⁶, Y. Wu ^{62a}, Z. Wu ^{135,62a}, J. Wuerzinger ¹¹⁰,
 T.R. Wyatt ¹⁰¹, B.M. Wynne ⁵², S. Xella ⁴², L. Xia ^{14c}, M. Xia ^{14b}, J. Xiang ^{64c}, X. Xiao ¹⁰⁶,
 M. Xie ^{62a}, X. Xie ^{62a}, S. Xin ^{14a,14e}, J. Xiong ^{17a}, I. Xiotidis ¹⁴⁶, D. Xu ^{14a}, H. Xu ^{62a}, H. Xu ^{62a},

L. Xu ^{62a}, R. Xu ¹²⁸, T. Xu ¹⁰⁶, Y. Xu ^{14b}, Z. Xu ^{62b}, Z. Xu ^{14a}, B. Yabsley ¹⁴⁷, S. Yacoob ^{33a}, N. Yamaguchi ⁸⁹, Y. Yamaguchi ¹⁵⁴, H. Yamauchi ¹⁵⁷, T. Yamazaki ^{17a}, Y. Yamazaki ⁸⁴, J. Yan ^{62c}, S. Yan ¹²⁶, Z. Yan ²⁵, H.J. Yang ^{62c,62d}, H.T. Yang ^{62a}, S. Yang ^{62a}, T. Yang ^{64c}, X. Yang ^{62a}, X. Yang ^{14a}, Y. Yang ⁴⁴, Z. Yang ^{62a,106}, W-M. Yao ^{17a}, Y.C. Yap ⁴⁸, H. Ye ^{14c}, H. Ye ⁵⁵, J. Ye ⁴⁴, S. Ye ²⁹, X. Ye ^{62a}, Y. Yeh ⁹⁶, I. Yeletsikh ³⁸, B.K. Yeo ^{17a}, M.R. Yexley ⁹¹, P. Yin ⁴¹, K. Yorita ¹⁶⁷, S. Younas ^{27b}, C.J.S. Young ⁵⁴, C. Young ¹⁴³, Y. Yu ^{62a}, M. Yuan ¹⁰⁶, R. Yuan ^{62b,k}, L. Yue ⁹⁶, M. Zaazoua ^{35e}, B. Zabinski ⁸⁶, E. Zaid ⁵², T. Zakareishvili ^{149b}, N. Zakharchuk ³⁴, S. Zambito ⁵⁶, J.A. Zamora Saa ^{137d,137b}, J. Zang ¹⁵³, D. Zanzi ⁵⁴, O. Zaplatilek ¹³², C. Zeitnitz ¹⁷⁰, H. Zeng ^{14a}, J.C. Zeng ¹⁶¹, D.T. Zenger Jr ²⁶, O. Zenin ³⁷, T. Ženiš ^{28a}, S. Zenz ⁹⁴, S. Zerradi ^{35a}, D. Zerwas ⁶⁶, M. Zhai ^{14a,14e}, B. Zhang ^{14c}, D.F. Zhang ¹³⁹, J. Zhang ^{62b}, J. Zhang ⁶, K. Zhang ^{14a,14e}, L. Zhang ^{14c}, P. Zhang ^{14a,14e}, R. Zhang ¹⁶⁹, S. Zhang ¹⁰⁶, T. Zhang ¹⁵³, X. Zhang ^{62c}, X. Zhang ^{62b}, Y. Zhang ^{62c,5}, Z. Zhang ^{17a}, Z. Zhang ⁶⁶, H. Zhao ¹³⁸, P. Zhao ⁵¹, T. Zhao ^{62b}, Y. Zhao ¹³⁶, Z. Zhao ^{62a}, A. Zhemchugov ³⁸, X. Zheng ^{62a}, Z. Zheng ¹⁴³, D. Zhong ¹⁶¹, B. Zhou ¹⁰⁶, C. Zhou ¹⁶⁹, H. Zhou ⁷, N. Zhou ^{62c}, Y. Zhou ⁷, C.G. Zhu ^{62b}, J. Zhu ¹⁰⁶, Y. Zhu ^{62c}, Y. Zhu ^{62a}, X. Zhuang ^{14a}, K. Zhukov ³⁷, V. Zhulanov ³⁷, N.I. Zimine ³⁸, J. Zinsser ^{63b}, M. Ziolkowski ¹⁴¹, L. Živković ¹⁵, A. Zoccoli ^{23b,23a}, K. Zoch ⁵⁶, T.G. Zorbas ¹³⁹, O. Zormpa ⁴⁶, W. Zou ⁴¹, L. Zwalinski ³⁶.

¹Department of Physics, University of Adelaide, Adelaide; Australia.

²Department of Physics, University of Alberta, Edmonton AB; Canada.

³(^a)Department of Physics, Ankara University, Ankara; (^b)Division of Physics, TOBB University of Economics and Technology, Ankara; Türkiye.

⁴LAPP, Univ. Savoie Mont Blanc, CNRS/IN2P3, Annecy; France.

⁵APC, Université Paris Cité, CNRS/IN2P3, Paris; France.

⁶High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America.

⁷Department of Physics, University of Arizona, Tucson AZ; United States of America.

⁸Department of Physics, University of Texas at Arlington, Arlington TX; United States of America.

⁹Physics Department, National and Kapodistrian University of Athens, Athens; Greece.

¹⁰Physics Department, National Technical University of Athens, Zografou; Greece.

¹¹Department of Physics, University of Texas at Austin, Austin TX; United States of America.

¹²Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.

¹³Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain.

¹⁴(^a)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (^b)Physics Department, Tsinghua University, Beijing; (^c)Department of Physics, Nanjing University, Nanjing; (^d)School of Science, Shenzhen Campus of Sun Yat-sen University; (^e)University of Chinese Academy of Science (UCAS), Beijing; China.

¹⁵Institute of Physics, University of Belgrade, Belgrade; Serbia.

¹⁶Department for Physics and Technology, University of Bergen, Bergen; Norway.

¹⁷(^a)Physics Division, Lawrence Berkeley National Laboratory, Berkeley CA; (^b)University of California, Berkeley CA; United States of America.

¹⁸Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany.

¹⁹Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland.

²⁰School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom.

²¹(^a)Department of Physics, Bogazici University, Istanbul; (^b)Department of Physics Engineering,

Gaziantep University, Gaziantep;^(c)Department of Physics, Istanbul University, Istanbul;^(d)Istinye University, Sariyer, Istanbul; Türkiye.

^{22(a)}Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño,

Bogotá;^(b)Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia.

^{23(a)}Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna;^(b)INFN Sezione di Bologna; Italy.

²⁴Physikalisches Institut, Universität Bonn, Bonn; Germany.

²⁵Department of Physics, Boston University, Boston MA; United States of America.

²⁶Department of Physics, Brandeis University, Waltham MA; United States of America.

^{27(a)}Transilvania University of Brasov, Brasov;^(b)Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest;^(c)Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi;^(d)National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca;^(e)University Politehnica Bucharest, Bucharest;^(f)West University in Timisoara, Timisoara;^(g)Faculty of Physics, University of Bucharest, Bucharest; Romania.

^{28(a)}Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava;^(b)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic.

²⁹Physics Department, Brookhaven National Laboratory, Upton NY; United States of America.

³⁰Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires; Argentina.

³¹California State University, CA; United States of America.

³²Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom.

^{33(a)}Department of Physics, University of Cape Town, Cape Town;^(b)iThemba Labs, Western Cape;^(c)Department of Mechanical Engineering Science, University of Johannesburg,

Johannesburg;^(d)National Institute of Physics, University of the Philippines Diliman (Philippines);^(e)University of South Africa, Department of Physics, Pretoria;^(f)University of Zululand, KwaDlangezwa;^(g)School of Physics, University of the Witwatersrand, Johannesburg; South Africa.

³⁴Department of Physics, Carleton University, Ottawa ON; Canada.

^{35(a)}Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca;^(b)Faculté des Sciences, Université Ibn-Tofail, Kénitra;^(c)Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech;^(d)LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda;^(e)Faculté des sciences, Université Mohammed V, Rabat;^(f)Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.

³⁶CERN, Geneva; Switzerland.

³⁷Affiliated with an institute covered by a cooperation agreement with CERN.

³⁸Affiliated with an international laboratory covered by a cooperation agreement with CERN.

³⁹Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America.

⁴⁰LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France.

⁴¹Nevis Laboratory, Columbia University, Irvington NY; United States of America.

⁴²Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark.

^{43(a)}Dipartimento di Fisica, Università della Calabria, Rende;^(b)INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy.

⁴⁴Physics Department, Southern Methodist University, Dallas TX; United States of America.

⁴⁵Physics Department, University of Texas at Dallas, Richardson TX; United States of America.

⁴⁶National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece.

^{47(a)}Department of Physics, Stockholm University;^(b)Oskar Klein Centre, Stockholm; Sweden.

⁴⁸Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany.

- ⁴⁹Fakultät Physik , Technische Universität Dortmund, Dortmund; Germany.
- ⁵⁰Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany.
- ⁵¹Department of Physics, Duke University, Durham NC; United States of America.
- ⁵²SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom.
- ⁵³INFN e Laboratori Nazionali di Frascati, Frascati; Italy.
- ⁵⁴Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
- ⁵⁵II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany.
- ⁵⁶Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.
- ⁵⁷(^a)Dipartimento di Fisica, Università di Genova, Genova;(^b) INFN Sezione di Genova; Italy.
- ⁵⁸II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany.
- ⁵⁹SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom.
- ⁶⁰LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France.
- ⁶¹Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America.
- ⁶²(^a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei;(^b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao;(^c) School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai;(^d) Tsung-Dao Lee Institute, Shanghai; China.
- ⁶³(^a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg;(^b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany.
- ⁶⁴(^a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong;(^b) Department of Physics, University of Hong Kong, Hong Kong;(^c) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China.
- ⁶⁵Department of Physics, National Tsing Hua University, Hsinchu; Taiwan.
- ⁶⁶IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
- ⁶⁷Centro Nacional de Microelectrónica (IMB-CNM-CSIC), Barcelona; Spain.
- ⁶⁸Department of Physics, Indiana University, Bloomington IN; United States of America.
- ⁶⁹(^a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine;(^b) ICTP, Trieste;(^c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy.
- ⁷⁰(^a) INFN Sezione di Lecce;(^b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy.
- ⁷¹(^a) INFN Sezione di Milano;(^b) Dipartimento di Fisica, Università di Milano, Milano; Italy.
- ⁷²(^a) INFN Sezione di Napoli;(^b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy.
- ⁷³(^a) INFN Sezione di Pavia;(^b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy.
- ⁷⁴(^a) INFN Sezione di Pisa;(^b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy.
- ⁷⁵(^a) INFN Sezione di Roma;(^b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy.
- ⁷⁶(^a) INFN Sezione di Roma Tor Vergata;(^b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy.
- ⁷⁷(^a) INFN Sezione di Roma Tre;(^b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy.
- ⁷⁸(^a) INFN-TIFPA;(^b) Università degli Studi di Trento, Trento; Italy.
- ⁷⁹Universität Innsbruck, Department of Astro and Particle Physics, Innsbruck; Austria.
- ⁸⁰University of Iowa, Iowa City IA; United States of America.
- ⁸¹Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America.
- ⁸²(^a) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora;(^b) Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro;(^c) Instituto de Física, Universidade de São Paulo, São Paulo;(^d) Rio de Janeiro State University, Rio de Janeiro; Brazil.

- ⁸³KEK, High Energy Accelerator Research Organization, Tsukuba; Japan.
- ⁸⁴Graduate School of Science, Kobe University, Kobe; Japan.
- ⁸⁵(^a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; (^b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland.
- ⁸⁶Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland.
- ⁸⁷Faculty of Science, Kyoto University, Kyoto; Japan.
- ⁸⁸Kyoto University of Education, Kyoto; Japan.
- ⁸⁹Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka ; Japan.
- ⁹⁰Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina.
- ⁹¹Physics Department, Lancaster University, Lancaster; United Kingdom.
- ⁹²Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom.
- ⁹³Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia.
- ⁹⁴School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom.
- ⁹⁵Department of Physics, Royal Holloway University of London, Egham; United Kingdom.
- ⁹⁶Department of Physics and Astronomy, University College London, London; United Kingdom.
- ⁹⁷Louisiana Tech University, Ruston LA; United States of America.
- ⁹⁸Fysiska institutionen, Lunds universitet, Lund; Sweden.
- ⁹⁹Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain.
- ¹⁰⁰Institut für Physik, Universität Mainz, Mainz; Germany.
- ¹⁰¹School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom.
- ¹⁰²CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.
- ¹⁰³Department of Physics, University of Massachusetts, Amherst MA; United States of America.
- ¹⁰⁴Department of Physics, McGill University, Montreal QC; Canada.
- ¹⁰⁵School of Physics, University of Melbourne, Victoria; Australia.
- ¹⁰⁶Department of Physics, University of Michigan, Ann Arbor MI; United States of America.
- ¹⁰⁷Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.
- ¹⁰⁸Group of Particle Physics, University of Montreal, Montreal QC; Canada.
- ¹⁰⁹Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany.
- ¹¹⁰Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany.
- ¹¹¹Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan.
- ¹¹²Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America.
- ¹¹³Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen; Netherlands.
- ¹¹⁴Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands.
- ¹¹⁵Department of Physics, Northern Illinois University, DeKalb IL; United States of America.
- ¹¹⁶(^a) New York University Abu Dhabi, Abu Dhabi; (^b) United Arab Emirates University, Al Ain; (^c) University of Sharjah, Sharjah; United Arab Emirates.
- ¹¹⁷Department of Physics, New York University, New York NY; United States of America.
- ¹¹⁸Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan.
- ¹¹⁹Ohio State University, Columbus OH; United States of America.
- ¹²⁰Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America.

- ¹²¹Department of Physics, Oklahoma State University, Stillwater OK; United States of America.
- ¹²²Palacký University, Joint Laboratory of Optics, Olomouc; Czech Republic.
- ¹²³Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America.
- ¹²⁴Graduate School of Science, Osaka University, Osaka; Japan.
- ¹²⁵Department of Physics, University of Oslo, Oslo; Norway.
- ¹²⁶Department of Physics, Oxford University, Oxford; United Kingdom.
- ¹²⁷LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris; France.
- ¹²⁸Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America.
- ¹²⁹Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America.
- ¹³⁰^(a)Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa;^(b)Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa;^(c)Departamento de Física, Universidade de Coimbra, Coimbra;^(d)Centro de Física Nuclear da Universidade de Lisboa, Lisboa;^(e)Departamento de Física, Universidade do Minho, Braga;^(f)Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain);^(g)Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal.
- ¹³¹Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic.
- ¹³²Czech Technical University in Prague, Prague; Czech Republic.
- ¹³³Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic.
- ¹³⁴Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom.
- ¹³⁵IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France.
- ¹³⁶Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America.
- ¹³⁷^(a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago;^(b)Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago;^(c)Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena;^(d)Universidad Andres Bello, Department of Physics, Santiago;^(e)Instituto de Alta Investigación, Universidad de Tarapacá, Arica;^(f)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile.
- ¹³⁸Department of Physics, University of Washington, Seattle WA; United States of America.
- ¹³⁹Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom.
- ¹⁴⁰Department of Physics, Shinshu University, Nagano; Japan.
- ¹⁴¹Department Physik, Universität Siegen, Siegen; Germany.
- ¹⁴²Department of Physics, Simon Fraser University, Burnaby BC; Canada.
- ¹⁴³SLAC National Accelerator Laboratory, Stanford CA; United States of America.
- ¹⁴⁴Department of Physics, Royal Institute of Technology, Stockholm; Sweden.
- ¹⁴⁵Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America.
- ¹⁴⁶Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom.
- ¹⁴⁷School of Physics, University of Sydney, Sydney; Australia.
- ¹⁴⁸Institute of Physics, Academia Sinica, Taipei; Taiwan.
- ¹⁴⁹^(a)E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi;^(b)High Energy Physics Institute, Tbilisi State University, Tbilisi;^(c)University of Georgia, Tbilisi; Georgia.
- ¹⁵⁰Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel.
- ¹⁵¹Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel.
- ¹⁵²Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece.
- ¹⁵³International Center for Elementary Particle Physics and Department of Physics, University of Tokyo,

Tokyo; Japan.

¹⁵⁴Department of Physics, Tokyo Institute of Technology, Tokyo; Japan.

¹⁵⁵Department of Physics, University of Toronto, Toronto ON; Canada.

¹⁵⁶(^a)TRIUMF, Vancouver BC; (^b)Department of Physics and Astronomy, York University, Toronto ON; Canada.

¹⁵⁷Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan.

¹⁵⁸Department of Physics and Astronomy, Tufts University, Medford MA; United States of America.

¹⁵⁹Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America.

¹⁶⁰Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden.

¹⁶¹Department of Physics, University of Illinois, Urbana IL; United States of America.

¹⁶²Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia - CSIC, Valencia; Spain.

¹⁶³Department of Physics, University of British Columbia, Vancouver BC; Canada.

¹⁶⁴Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada.

¹⁶⁵Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany.

¹⁶⁶Department of Physics, University of Warwick, Coventry; United Kingdom.

¹⁶⁷Waseda University, Tokyo; Japan.

¹⁶⁸Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot; Israel.

¹⁶⁹Department of Physics, University of Wisconsin, Madison WI; United States of America.

¹⁷⁰Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany.

¹⁷¹Department of Physics, Yale University, New Haven CT; United States of America.

^a Also Affiliated with an institute covered by a cooperation agreement with CERN.

^b Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.

^c Also at Bruno Kessler Foundation, Trento; Italy.

^d Also at Center for High Energy Physics, Peking University; China.

^e Also at Center for Interdisciplinary Research and Innovation (CIRI-AUTH), Thessaloniki ; Greece.

^f Also at Centro Studi e Ricerche Enrico Fermi; Italy.

^g Also at CERN, Geneva; Switzerland.

^h Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.

ⁱ Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.

^j Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.

^k Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.

^l Also at Department of Physics, California State University, East Bay; United States of America.

^m Also at Department of Physics, California State University, Sacramento; United States of America.

ⁿ Also at Department of Physics, King's College London, London; United Kingdom.

^o Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.

^p Also at Department of Physics, University of Thessaly; Greece.

^q Also at Department of Physics, Westmont College, Santa Barbara; United States of America.

^r Also at Hellenic Open University, Patras; Greece.

^s Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.

^t Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.

^u Also at Institute of Applied Physics, Mohammed VI Polytechnic University, Ben Guerir; Morocco.

^v Also at Institute of Particle Physics (IPP); Canada.

^w Also at Institute of Physics and Technology, Ulaanbaatar; Mongolia.

^x Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.

^y Also at Institute of Theoretical Physics, Ilia State University, Tbilisi; Georgia.

^z Also at Lawrence Livermore National Laboratory, Livermore; United States of America.

^{aa} Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing; China.

^{ab} Also at TRIUMF, Vancouver BC; Canada.

^{ac} Also at Università di Napoli Parthenope, Napoli; Italy.

^{ad} Also at University of Colorado Boulder, Department of Physics, Colorado; United States of America.

^{ae} Also at Washington College, Maryland; United States of America.

* Deceased