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MAJOR DETECTORS IN ELEMENTARY PARTICLE PHYSICS

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Abstract

This report is the second edition of a loose-leaf compendium of the properties and performance characteristics of the major detectors of elementary particle physics.

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DISCLAIMER

INTRODUCTION

This introduces the second edition of the LBL-91 Supplement "Major Detectors in Elementary Particle Physics." For some detectors the update merely documents minor modifications or provides additional references. Others have undergone major rebuilding or have been augmented with new subsystems. The new LEP, SLC, TRISTAN, BEPC, and FNAL detectors have had their designs fixed and are now under construction. Some detectors have completed their programs since the last edition and so are omitted. The use of colored loose-leaf paper should allow users to maintain a historical record of each detector.

We again thank those physicists working with each detector who took the time to summarize its properties and supply us with the appropriate drawings.

Notes

- Depending on the state of completion of the detector, the performance characteristics may be actual or projected. No attempt is made to distinguish them.
- Expressions of energy and momentum resolution are correct only if E is in GeV and p is in GeV/c.
- For further information, please contact the experimental group itself. Current spokesmen for particular experiments may be found in the Spokesman Index of LBL-91, "Current Experiments in Elementary Particle Physics."
- In the Table of Contents, the experiments column refers to the summaries in the January 1985 edition of LBL-91. Experiments completed before 1980 are not included.

TABLE OF CONTENTS

ALEPH

LOCATION
LEP e^+e^- ring
CERN, Geneva, Switzerland

MAGNET
1.5 Tesla superconducting solenoid
6.4 m long at 2.65 m radius (123 m^3)

TRACKING
Time projection chamber (TPC):
- Central HV plane separates two 2.2 m long drift spaces
- Inner radius = 0.35 m, outer radius = 1.8 m
- 90% argon − 10% methane gas at 1 atm.
- 20 kV/m drift field with gating grid
- Each end plate divided into 18 sectors containing total of 20,500 pads (30 × 6.5 mm) and 3240 peripheral wires giving 21 space points and 320 ionization samples per track
- σ/p_T^2 = 0.1%, dE/dx resolution = 12%
- Nd-YAG laser calibration

Inner track chamber:
- 2.1 m long drift chamber covering 97% of 4π
- Inner radius = 12.8 cm, outer radius = 28.0 cm
- 8 sensitive cells in 4 isolated concentric tubes
- $r\phi$ tracking with $\sigma \simeq 100\ \mu m$
- z readout with cathode hoops, $\sigma_z < 40$ mm
- $1.2\% X_0$

ELECTROMAGNETIC CALORIMETERS
2 mm Pb-wire chamber sandwich with cathode pad readout, connected in 3 cm × 3 cm projective towers and summed in 3 depths corresponding to first $4X_0$, central $9X_0$, last $9X_0$
Barrel contains 4096 towers in each of 12 modules (50,000 towers)
Segmentation $\Delta\phi = 0.94°$, $\Delta\theta = 0.93° \sin\theta$
Endcaps consist of twelve 30° modules each, larger $\Delta\phi$ segmentation (25,000 towers total)
$\Delta E/E = 18\%/\sqrt{E}$

HADRON CALORIMETER
Main support and magnet return yoke instrumented every 5 cm with 23 layers of 1 cm × 1 cm plastic streamer tubes
Pad readout on one side (projective towers with $\Delta\phi = 3.75°$ and $\Delta\theta = 5°$)
Parallel strip readout on other side
3456 towers in barrel, 1320 towers in endcaps
14% argon − 56% CO_2 − 30% η-pentane gas
$\Delta E/E = 0.85/\sqrt{E}$

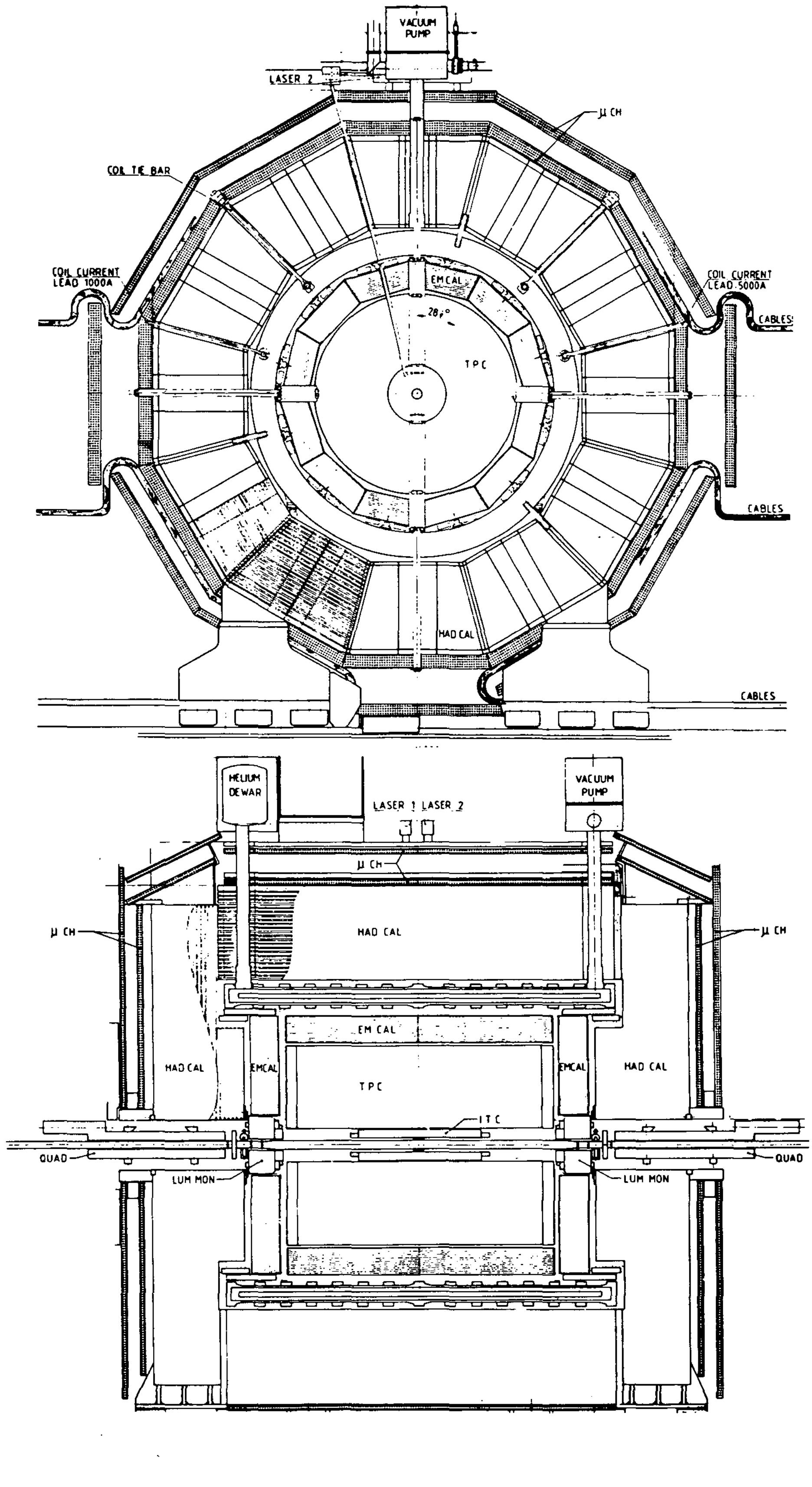
MUON TRACKING
In addition to strip readouts of hadron calorimeters
Have 2 external double layers of tubes

LUMINOSITY MONITOR
Tracking with 9 layers of tube chambers
Covers 42–89 mrad
Shower counters have 41 layers of Pb-wire tubes ($22X_0$)
Operated in saturated proportional mode cathode pad readout
Covers 39–131 mrad
$\Delta E/E = 19\%/\sqrt{E}$

REFERENCES

1. ALEPH Technical Report, CERN/LEPC 83-2, LEPC/P1 (1983).
2. ALEPH Status Report, CERN/LEPC 84-15, LEPC/M50 (1984).

ALEPH


VACUUM PUMP
LASER 2
μ CH
COIL TIE BAR
COIL CURRENT LEAD 1000A
COIL CURRENT LEAD 5000A
CABLES
EM CAL
TPC
HAD CAL
CABLES
CABLES
HELIUM DEWAR
LASER 1 LASER 2
VACUUM PUMP
μ CH
μ CH
HAD CAL
μ CH
EM CAL
HAD CAL
EMCAL
TPC
EMCAL
HAD CAL
ITC
QUAD
QUAD
LUM MON
LUM MON

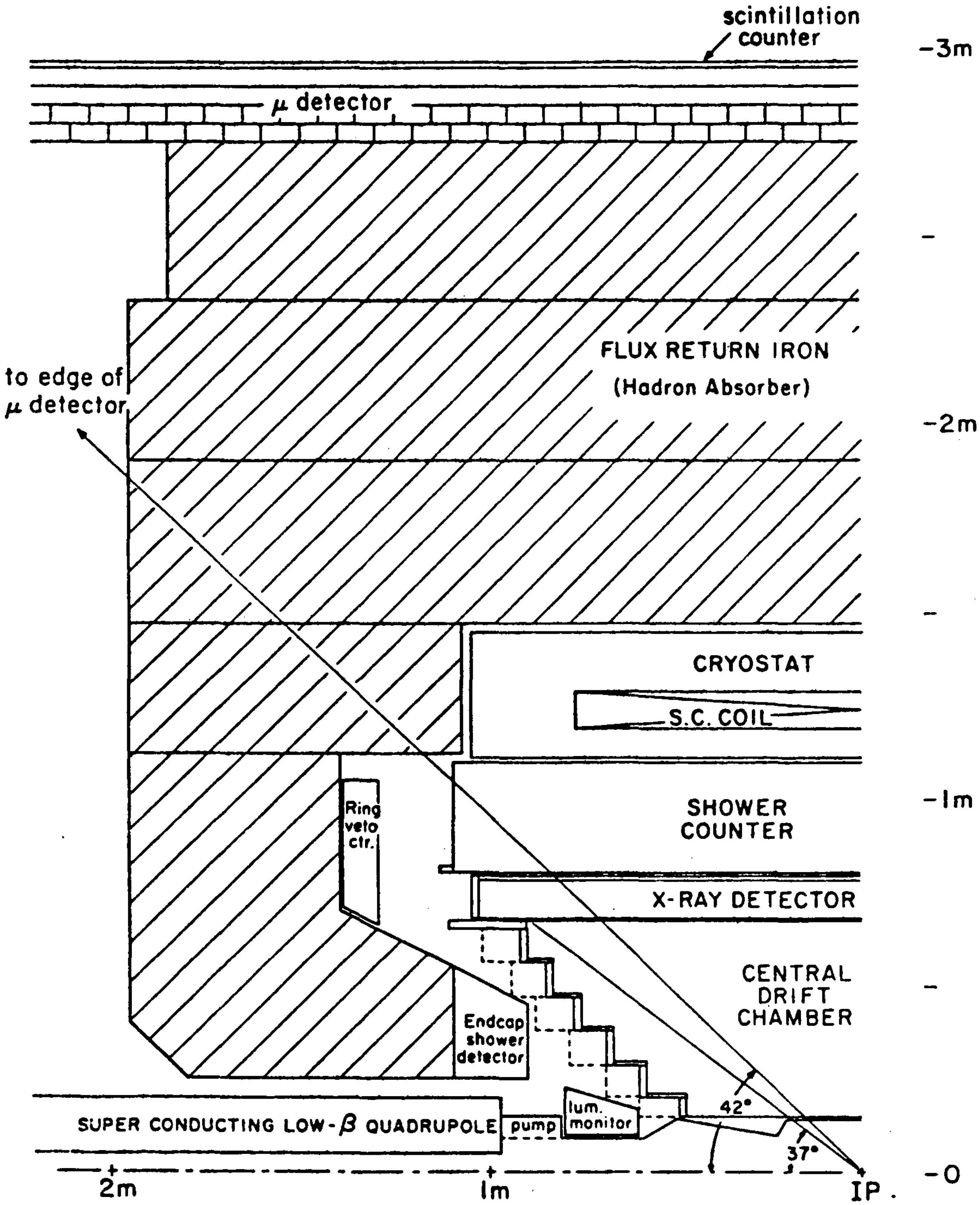
AMY

LOCATION	TRISTAN e^+e^- storage ring, the OHO experimental hall National Laboratory for High Energy Physics, KEK Tsukuba, Japan
MAGNET	30 kG superconducting solenoid 8 cm thick coil ($\sim 6.5X_0$ package) Cryogenically stable; pool boiling cooling system Cryostat inner diameter = 2.22 m, length = 2.10 m
TRACKING SYSTEM	Central drift chamber: $R_i = 0.15$ m, $R_o = 0.67$ m 40 cylinders of close packed hexagonal drift cells 25 axial and 15 small angle (4.1° – 4.9°) stereo layers Full coverage for $\|\cos\theta\| \leqslant 0.8$ (26 cylinders for $\|\cos\theta\| \leqslant 0.85$) 9072 cells; 32,158 total wires Average cell radius = 0.66 cm Inner entrance: 1.5 mm Kevlar tube Outer exit: 6 foam reinforced Kapton windows
ELECTRON TAGGING	Xe (98)% + Propane (2%) synchrotron X-ray detector 10 cm deep jet chamber, 36 cells in azimuth $R_i = 0.67$ m, $R_o = 0.77$ m, length = 2.0 m Expect $\geqslant 3$ detected X-rays for $4 \leqslant p_e \leqslant 10$ GeV $e^{\pm}$'s
BARREL SHOWER COUNTER	Pb + resistive plastic PWC's, 20 layers ($15X_0$ total) $R_i = 0.78$ m, $R_o = 1.10$ m, length = 2.20 m inside the coil Full coverage for $\|\cos\theta\| \leqslant 0.71$ Cathode strip readout: 13.5 mrad × 0.52 rad θ-strips 16.3 mrad × 0.38 rad ϕ-strips (projective geometry) 5 depth segments: $2.5X_0$, $2.5X_0$, $2.5X_0$, $2.5X_0$, $5X_0$
MUON DETECTION	$\geqslant 9$ absorption lengths (λ_a) of material for $\|\cos\theta\| \leqslant 0.71$ 4 layers of 5 cm × 10 cm drift tubes behind the return iron Transverse flight path to 1 λ_a = 1.25 m Decays in flight $\approx$ 2.5%/p, hadron punch-thru $\leqslant$ 0.1%
FORWARD-BACKWARD DETECTION	Pb-scintillator counters covering 100 mrads $\leqslant \theta \leqslant 40°$ serve as luminosity monitors of Bhabha scattering and veto counters for missing transverse energy measurements
SPECIAL FEATURES	Open space near the beam line allows μ-beta quads to extend in to $z = \pm 1.2$ m from the interaction point
STARTUP	November 1986

REFERENCE

1. AMY-Chan, C. Back et al., KEK preprint TRISTAN-EXP-003.

AMY



scintillation counter
-3m
μ detector
FLUX RETURN IRON
(Hadron Absorber)
to edge of μ detector
-2m
CRYOSTAT
S.C. COIL
SHOWER COUNTER
-1m
Ring veto ctr.
X-RAY DETECTOR
CENTRAL DRIFT CHAMBER
Endcap shower detector
lum. monitor
42°
SUPER CONDUCTING LOW-β QUADRUPOLE
pump
37°
-0
2m
1m
IP

ARGUS

LOCATION
DORIS II e^+e^- ring
DESY, Hamburg, W. Germany

COLLABORATION
DESY, Univ. Dortmund, Univ. Heidelberg, IPP Canada, Univ. Kansas, Univ. Lund, Univ. Ljubljana, ITEP Moscow, Univ. South Carolina

MAGNET
0.8 Tesla solenoid, 13 copper coils
Diameter = 2.8 m, length = 2.9 m

MINIBETA
Quads integrated and compensated inside magnet

TRACKING
Cylindrical drift chamber
Radius 15 to 85 cm, length 200 cm
5940 drift cells with 18×18.8 mm^2 cross section
36 cylindrical layers, 18 of which at stereo angles varying from 40 to 80 mrad
Propane-methylal at 1 atm.
dE/dx : 10% FWHM

$\sigma_p/p = (1.0^2 + p^2)^{1/2}$ %
$\sigma_\theta = 3.4$ mrad

VERTEX CHAMBER
Radius = 5 to 14 cm, length = 104 cm
594 hexagonal cells, 4.5 mm inscribed radius
$\sigma_x = 50\ \mu$m

SHOWER COUNTERS
Barrel arranged as 20 rings, 64 counters in each ring
40 cm deep, $12.5X_0$ sandwich of 1 mm lead and 5 mm scintillator, BBQ readout, lightguides between coils

$\sigma_E/E = (7.0^2 + 8.0^2/E)^{1/2}$ %
Solid angle 96% in total

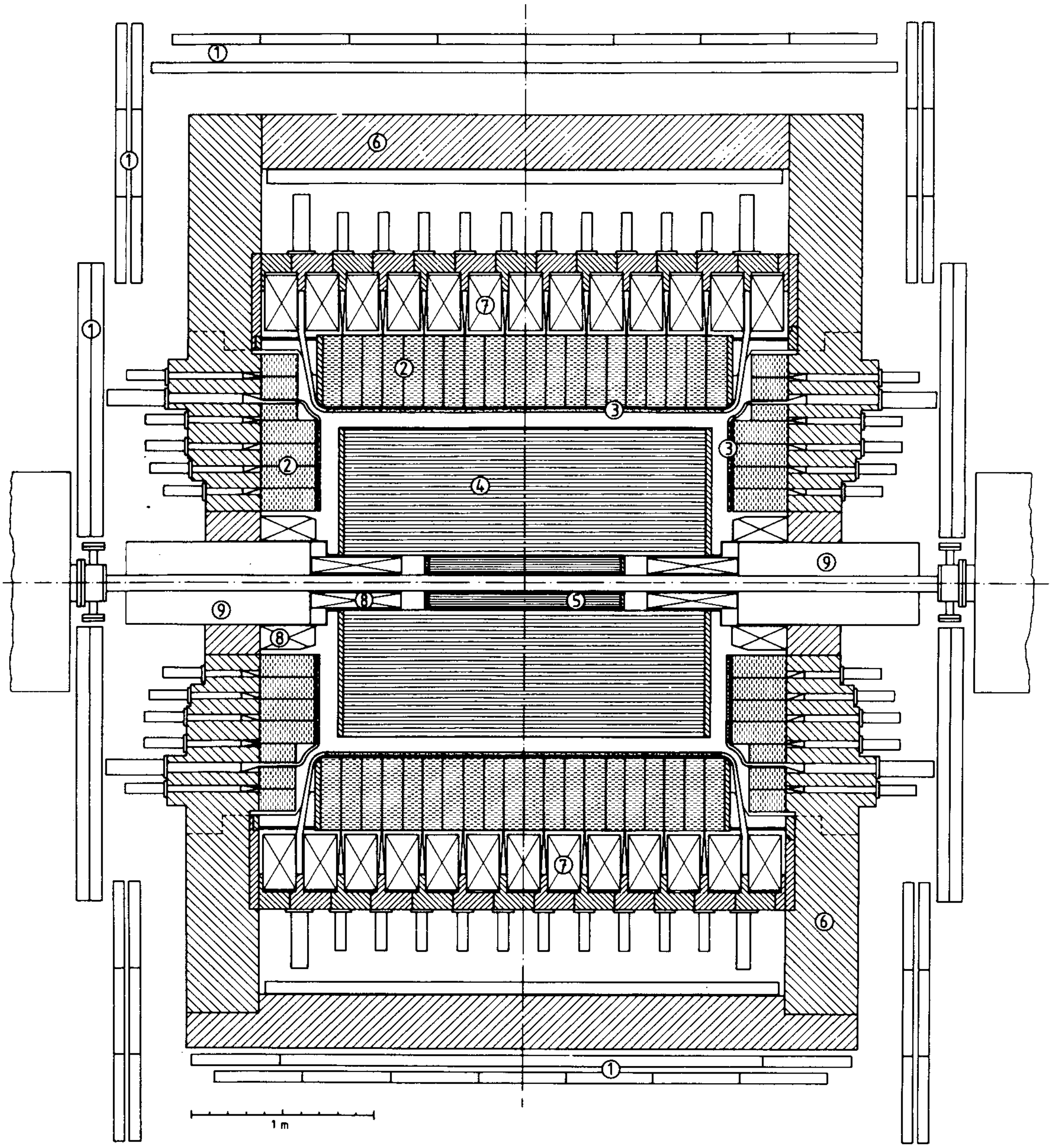
TIME-OF-FLIGHT
Barrel of 64 counters, radius 96 cm
Endcaps 2×48 counters
TOF resolution $\sigma_T = 220$ ps
Solid angle 92%

MUON DETECTION
1744 proportional tubes with 6×6 cm^2 cross section
Layer behind shower counters and coil
Layer behind the return yoke
Solid angle 85%

REFERENCES

1. ARGUS, a New Detector for DORIS, DESY F15/Pro 148, October 1978.

ARGUS



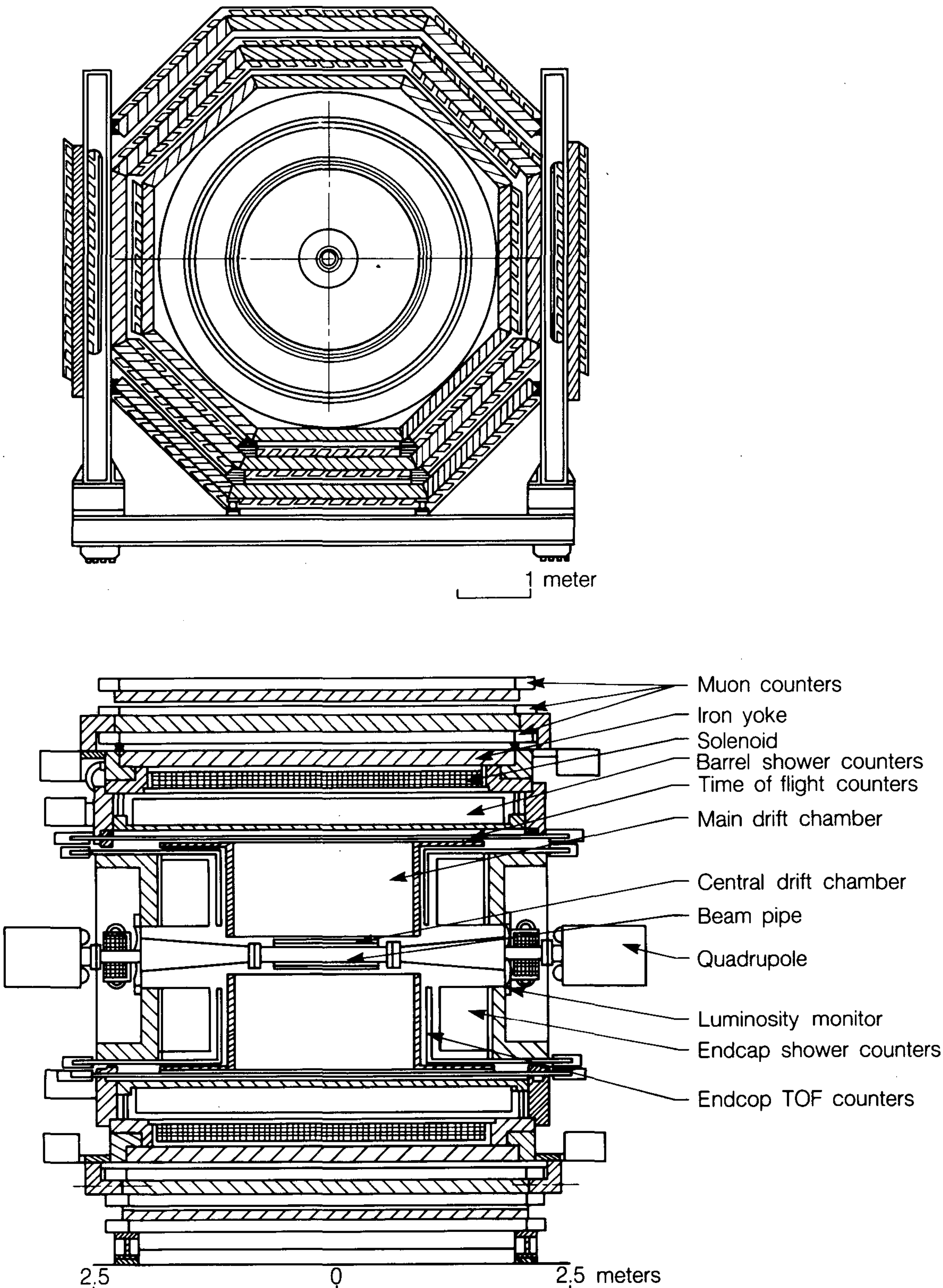
1. Muon cambers
2. Shower counters
3. Time of flight counters
4. Drift chamber
5. Vertex chamber
6. Iron yoke
7. Solenoid coils
8. Compensation coils
9. Mini beta quadrupole

38269

BES (Beijing Spectrometer)

LOCATION	BEPC e^+e^- storage ring IHEP, Beijing, People's Republic of China
MAGNET	4.5–5.0 kG conventional Al coil solenoid, 3.60 m long, inner radius 1.74 m I = 3700 A, R = 75 mΩ, W ~ 1MW
TRACKING	
CENTRAL DRIFT CHAMBER	Cylindrical, radius 8.9 to 15.0 cm, length 1.10 m 4 axial layers of cells, 48 one-sense wire cells in each layer $\sigma \sim 150\ \mu m$
MAIN DRIFT CHAMBER	Cylindrical, radius 15.5 to 115.0 cm, length 2.2 m 10 layers of cells, 5 stereo and 5 axial 702 four-sense wire cells in total and with dE/dx readout Gas 89% Argon, 10% CO_2, and 1% methane at 1 atm. $\sigma_x \sim 150–200\ \mu m$ $(\Delta p/p)^2 \sim (1.5\%)^2 + (0.8\%p)^2$ $\sigma(dE/dx) \sim 9\%$ with 40 samples each track
TIME-OF-FLIGHT	NE110 scintillation counters
BARREL	48 pieces of 15 cm × 5 cm × 2.80 m mounted in a cylindrical array around MDC Read out by XP2020 photomultipliers on each end of the scintillators Solid angle 80% of 4π, 1.17 m flight path at $\theta = 90°$ $\sigma_t \sim 170–200$ ps; π/K separation up to 1.07 GeV/c at 2 σ_t level, K/p separation up to 1.78 GeV/c at $2\sigma_t$ level
ENDCAPS	2 × 24 sector pieces form two disks with inner radius 25 cm and outer radius 108 cm 1.22 m flight path at $\theta = 0°$ $\sigma_t \sim 200$ ps, π/K separation up to 1 GeV/c at 2 σ_t level Solid angle 14% of 4π
SHOWER COUNTER	24 layers of Pb-gas tubes sandwich ($12X_0$ total)
BARREL	3.85 m long cylindrical annulus, 560 drift cells per layer, 13 cm × (1.5–1.8) cm in cross section, read out at both ends with charge division
ENDCAPS	Two circulars with inner radius 20 cm and outer radius 105 cm, 164–180 tubes per layer, 1.3 cm × 1.3 cm in cross section, with charge division readout
MUON IDENTIFIER	3 double layers of 4.4 m long proportional tubes interspersed with 3 layers of absorber (12 cm, 14 cm magnet flux return yoke and additional 14 cm Fe as the third absorber)
LUMINOSITY MONITOR	ee → ee at small angles, 4 scintillator + shower counter telescopes cover 31 mrad $< \theta <$ 66 mrad
TRIGGER	Charged track trigger uses timing information from TOF and tracking information from four layers of MDC Neutral trigger requires energy deposition in the shower counters and μ-tube cosmic veto

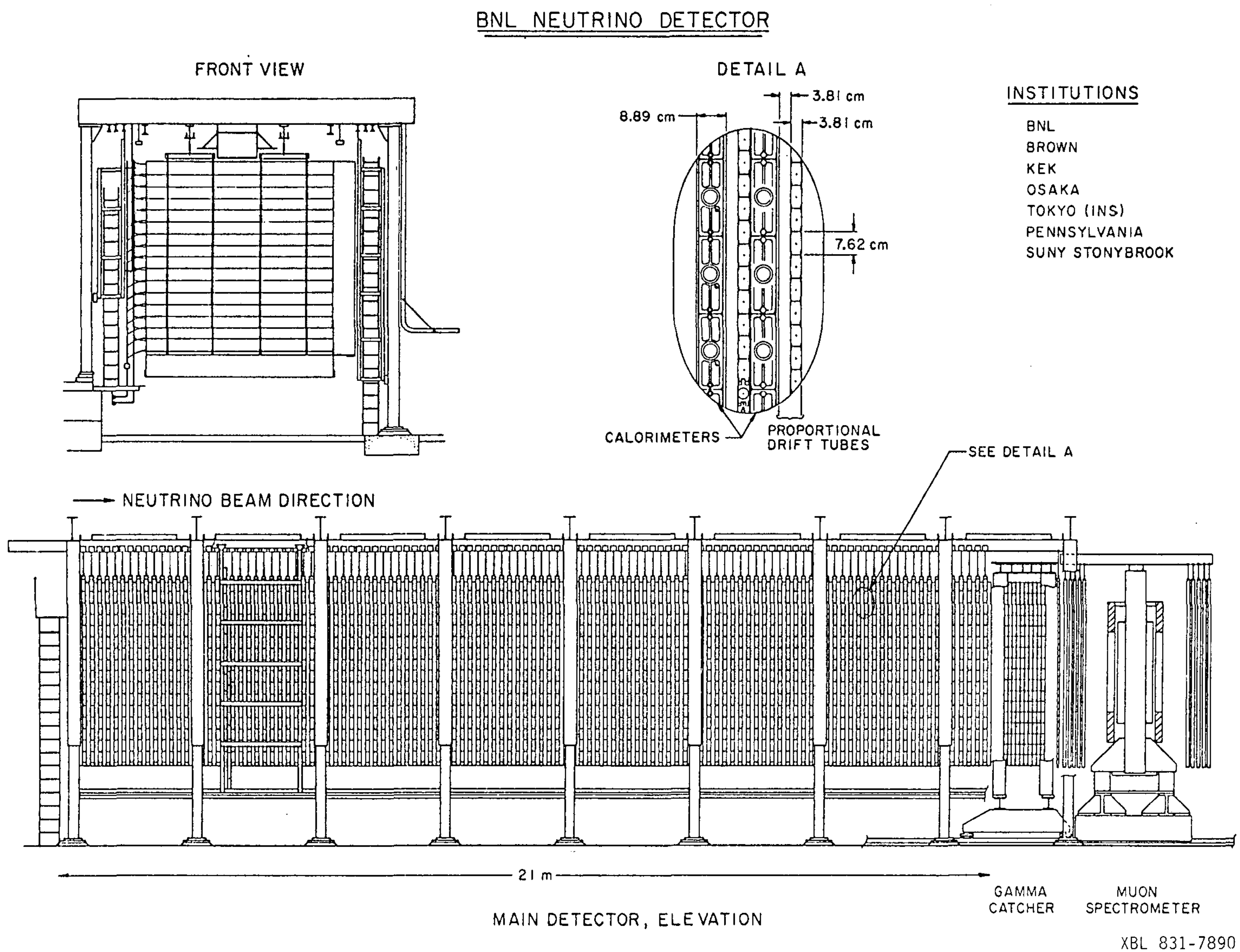
BES (Beijing Spectrometer)



XBL 852-10254

Brookhaven Neutrino Detector

LOCATION	Brookhaven National Laboratory Upton, NY, USA
INCIDENT BEAM	Neutrino, horn focussed from 28 GeV Protons 110 m from proton target
ASSEMBLY	Modular construction, each module consisting of a plane of calorimeter and two planes (x,y) of tracking proportional drift tubes 112 Modules + γ-catcher + spectrometer Weight: 172 + 30 metric tons
CALORIMETER (LIQUID SCINTILLATOR)	Active area 4.22 $\times$ 4.09 m^2; thickness 7.9 cm Weight (liquid & acrylic) 1.35 metric tons 16 cells/module, 2 Amperex 2212A phototubes/cell 1 pulse height measurement/2 time measurements per tube readout
PROPORTIONAL DRIFT TUBES (PDT)	Active area 4.2 $\times$ 4.2 m^2 Thickness (x and y) 7.6 cm, 54 x wires, 54 y wires 1 pulse height measurement/2 time measurements per wire readout
GAMMA CATCHER	10 standard calorimeter modules with 1 radiation length of lead between each module 30 metric tons target mass
MUON SPECTROMETER	2m $\times$ 2m aperture muon spectrometer $\langle \int Bdl \rangle = 70$ MeV/c $(\Delta p/p)^2 = [0.10^2 + (0.067p)^2]\, p$

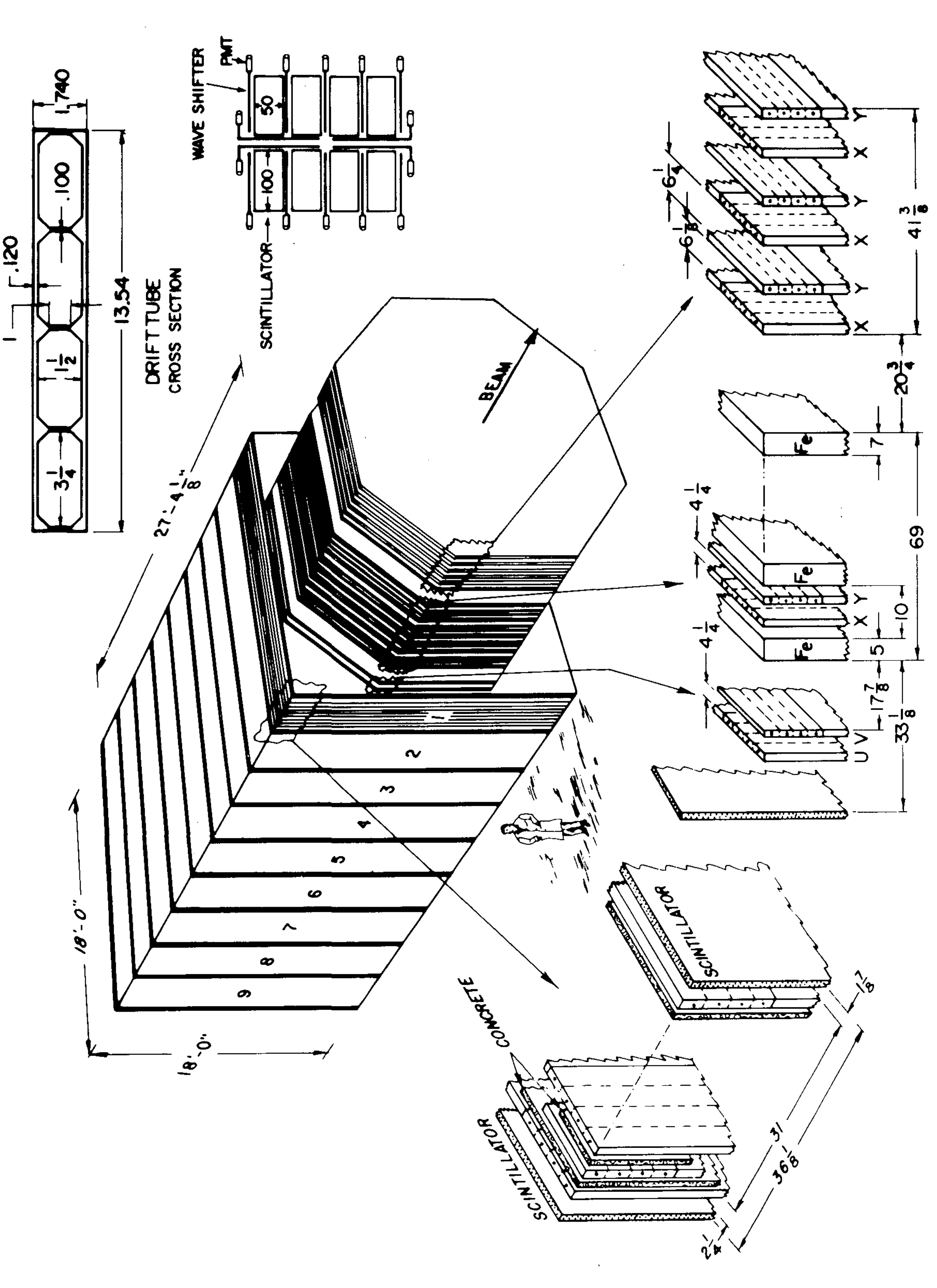


Brookhaven Neutrino Detector

Brookhaven Neutrino Oscillation Detector

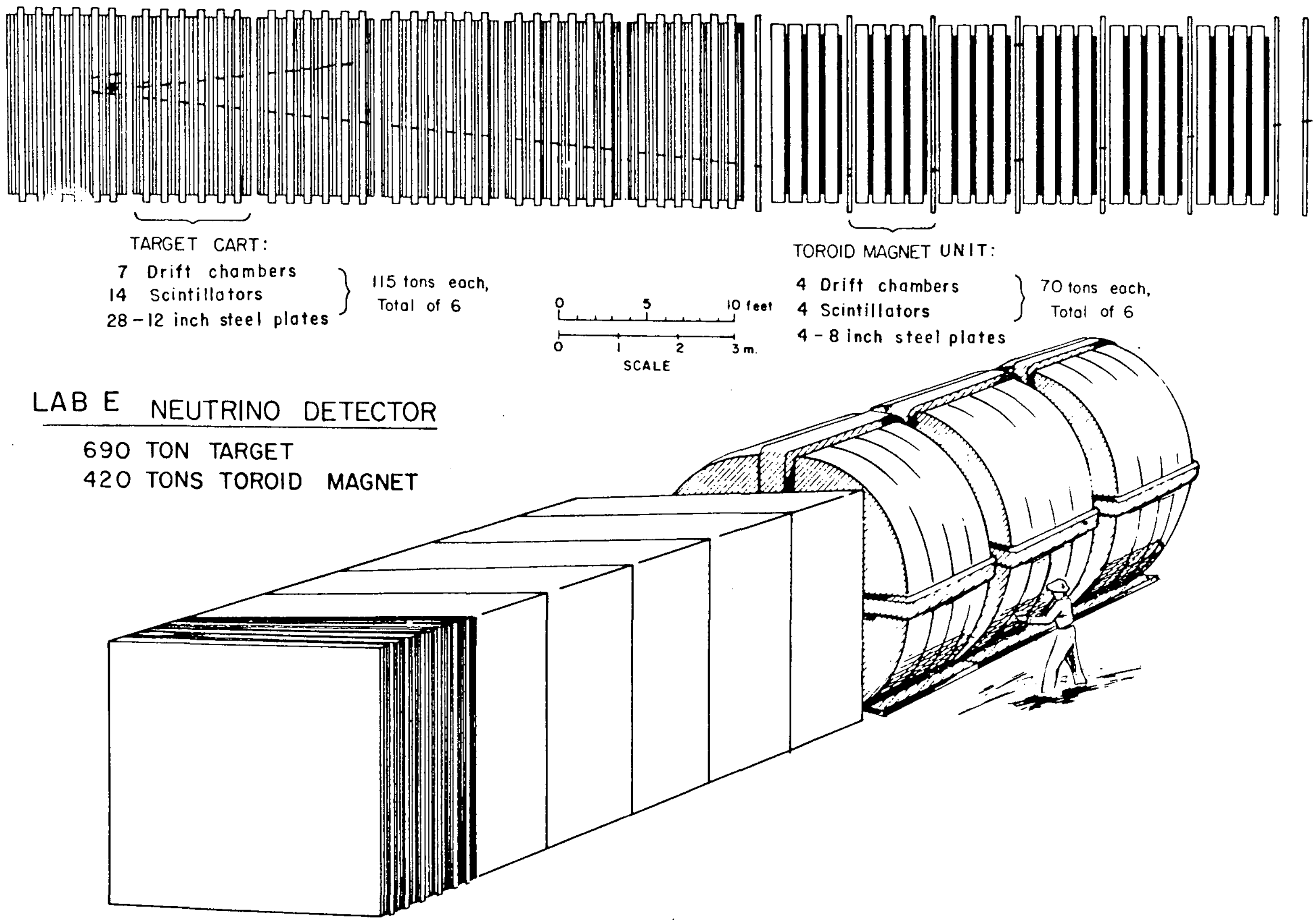
LOCATION	Brookhaven National Laboratory Upton, NY, USA
BEAM	Neutrino, horn focussed from 28 GeV protons 1 km from proton target
ELECTRON DETECTOR	Finely segmented EM calorimeter Size: 18 ft × 18 ft × 27 ft Weight: 240 metric tons (fiducial: 200 tons) Absorber: concrete (density $\simeq$ 2.3 g /cm^3), segmented every 1 in. along beam direction, 81 planes, Detector: 90 planes (45 x, 45 y) of drift tubes, 64 wires/plane; organized in 9 sections; section structure is 5 x, 5 y, 9 Abs, 1 Sci, as follows: 4(x–Abs–y–Abs) + (x–Abs–y–Sci)
DRIFT TUBES	Extruded Al, 4 tubes per extrusion, 18 ft × 3¼ in. × 1½ in. per tube Signal readout: 25 ns, 6-bit flash ADC, one per wire Memory depth: 256 bits
SCINTILLATOR	1 in. thick acrylic 200 in. × 200 in./plane 8 segments/plane, read out with 14 BBQ doped acrylic wave shifter bars, 1 in.^{2} RCA 8575 phototubes Signal readout: flash ADC's for cosmic ray trigger, and timing mainly
MUON SPECTROMETER	Five 18 ft octagonal steel toroids, 5–5–5–7–7 inches with 2 (1 x, 1 y) proportional drift tube planes per gap, 1 (u,v) pair upstream and 3 (x,y) pairs downstream Signal readout: 25 ns multihit TDC Magnetic field: 1.5–1.8 Tesla $\langle \int G d\ell \rangle \simeq$ 400 MeV/c

Brookhaven Neutrino Oscillation Detector



CCFR Neutrino Detector

LOCATION	Fermilab neutrino area, Lab E Batavia, IL, USA
TARGET	8 m × 3 m × 3 m Fe tracking calorimeter
MAGNETS	3.5 m diameter iron toroids, instrumented with acrylic scintillator every 20 cm steel Three toroids, each with 1.6 m steel along beam direction
TARGET CALORIMETRY	10 cm steel separation between 2.5 cm liquid scintillator planes with BBQ wavelength-shifting bars on side Four 2-in. phototubes per counter $\sigma_E/E = 0.84/\sqrt{E}$
TARGET TRACKING	20 cm steel separation between 3 m × 3 m drift chambers, each with x and y planes A chamber has 24 cells in each of two planes: 12 cm transverse for each cell, with two-wire readout (no left-right ambiguity) $\sigma = 250\ \mu m$ positional accuracy Multihit readout with measurement of leading and trailing edges Linear output available for charge vs. time readout
TOROID TRACKING	Drift chambers, located as shown in figure, are similar to those in target, except for one wire/cell $\Delta p/p \approx 0.11$, dominated by multiple scattering in iron toroids
BEAM	Dichromatic and quad triplet neutrino beams (Tevatron) $p_{sec} \lesssim 700$ GeV
INTENSITY MONITORS	Neutrino lab facility providing calibrated ion chamber monitoring of momentum-selected hadron beam for dichromatic running Additionally, rf cavity monitors, Cerenkov counter, and muon monitors for redundant measures of flux



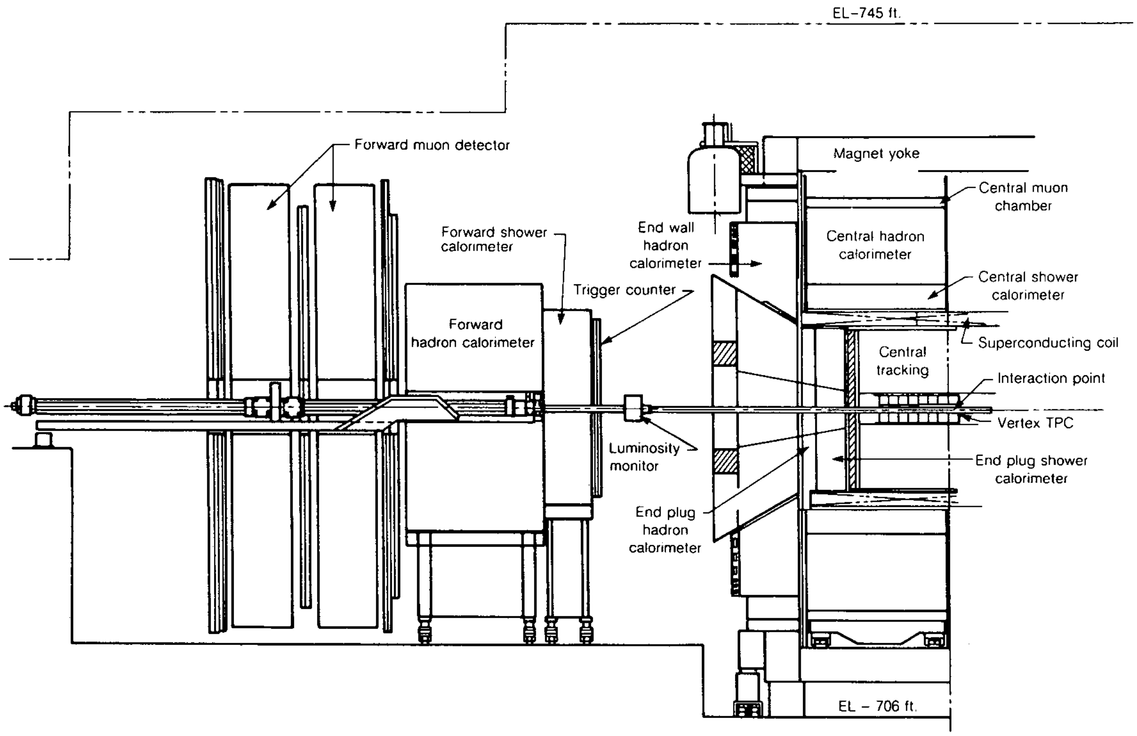
XBL 832-8441

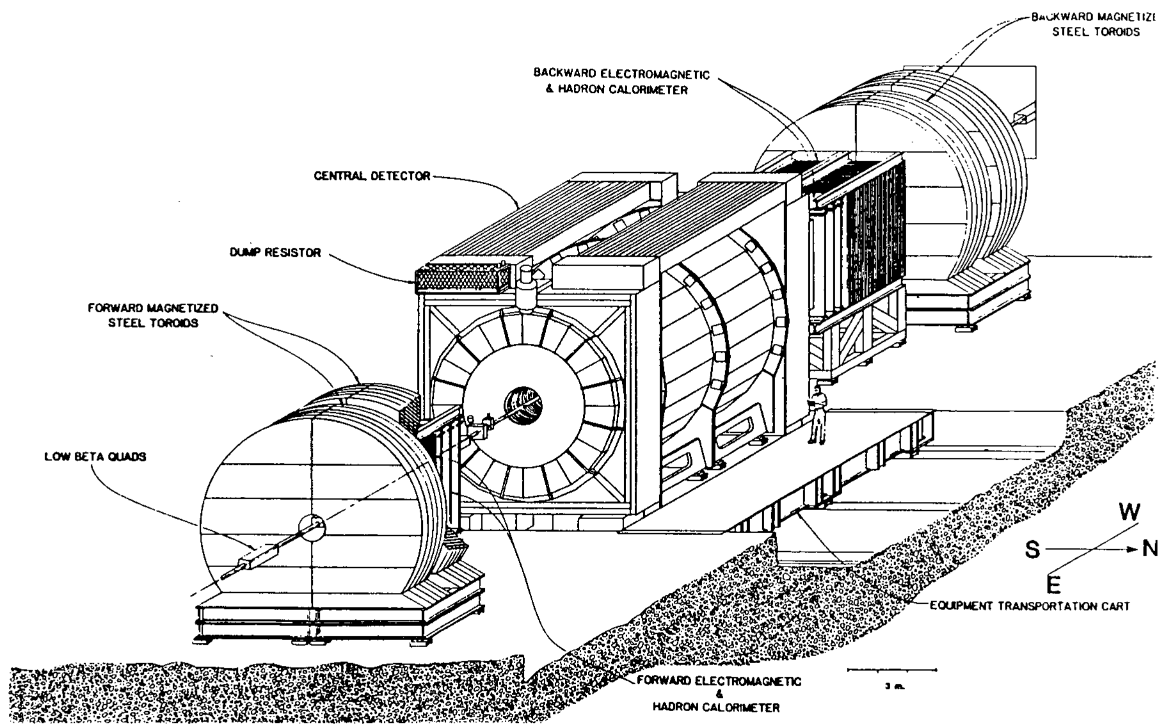
CCFR Neutrino Detector

CDF (Collider Detector at Fermilab)

LOCATION	BO $\bar{p}p$ collision area Fermilab, Batavia, IL, USA
MAGNET	1.5 Tesla superconducting solenoid 5 m long × 3 m diameter
TRACKING	
CENTRAL REGION	Cylindrical drift chamber 84 layers arranged into 9 layers of supercells 5 axial superlayers (12 wires/layer) 4 small-angle stereo superlayers 6144 total sense wires
VERTEX REGION	TPC, 150 mm drift distance 2176 sense wires 2448 pads
SHOWER COUNTERS	
CENTRAL REGION	$0.6X_0$ Pb, 0.6 cm scintillator with wave shifter readout arranged in towers of constant rapidity intervals 33 layers 1 layer of wire chamber for shower localization $\sigma_E/E = 14\%/\sqrt{E}$ 48 modules total
END PLUG	$0.7X_0$ Pb, resistive plastic proportional tubes with cathode pad readout arranged in towers of constant rapidity intervals 30 layers ($21X_0$ total thickness) 1 layer of strip readout for localization $\sigma_E/E \simeq 24\%/\sqrt{E}$ Spatial resolution $\simeq$ 3 mm at 40 GeV
FORWARD	40 layers of $0.57X_0$ Pb, proportional tubes Construction similar to end plug
HADRON CALORIMETRY	
CENTRAL	2.5 cm steel, 1 cm scintillator with wave shifter readout, arranged in towers of constant rapidity intervals and matched to shower counters 34 layers (5 absorption lengths) $\sigma/E \simeq 5.5\% + 62\%/\sqrt{E}$
END WALL	5 cm steel, 1 cm scintillator Construction similar to central modules $\sigma/E \simeq 6\% + 77\%/\sqrt{E}$
END PLUG	5 cm steel, resistive plastic proportional tubes with cathode pad readout Pads are arranged in towers of constant rapidity intervals and matched to shower counter 20 layers $\sigma/E \simeq 11\%$ at 100 GeV
FORWARD	5 cm steel, resistive plastic proportional tube readout similar in construction to end plug
MUON DETECTION	4 layers of drift tubes outside hadron calorimeter in central region Toroids and drift chambers in small angle region
TRIGGER	3 level trigger Analog energy cluster finder for level 1 (fast) trigger Fastbus-based trigger processor for higher levels

CDF (Collider Detector at Fermilab)





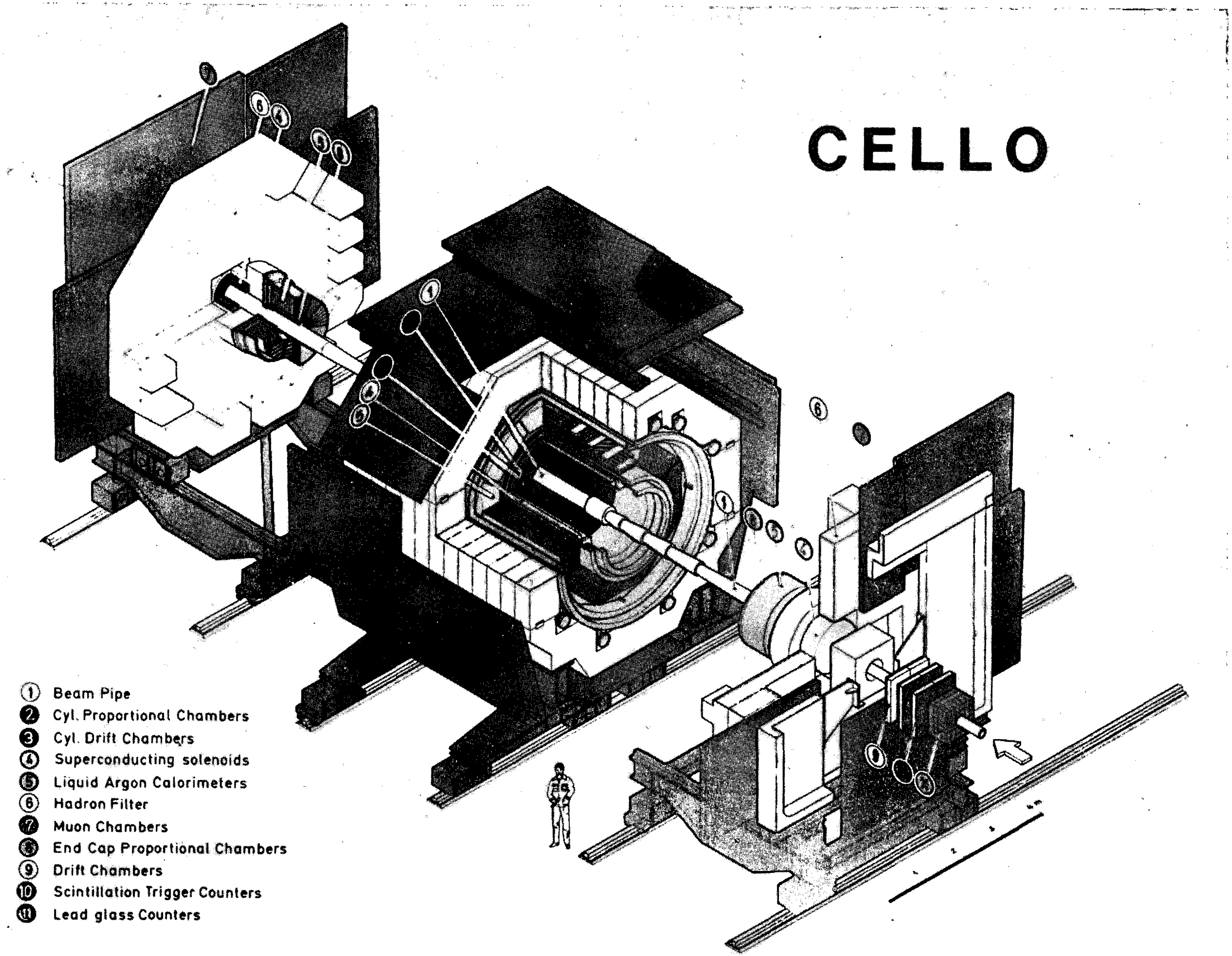
XBL 853-10349

CELLO

LOCATION	PETRA e^+e^- ring DESY, Hamburg, W. Germany
COLLABORATION	DESY, Hamburg University of Glasgow Universität Hamburg KfK und Universität, Karlsruhe MPI, München LAL, Université de Paris XI, Orsay LPNHE, Université de Paris University of Rome and INFN CEN, Saclay Tel Aviv University
MAGNET	1.3 Tesla superconducting thin ($0.49X_0$) solenoid 0.75 m inner bore radius 3.8 m length
TRACKING	5 cylindrical proportional chambers with cathode strips 7 cylindrical drift chambers 2 cylindrical layers of drift tubes (vertex detector installed end 1982) 8 planar endcap chambers Tracking down to $\theta = 150$ mrad $\sigma_p/p = 2\%\ p \sin\theta$ ($p > 2$ GeV, $\theta > 30°$) $\sigma_z = 0.4$ mm centroid measurement on cathode strips
EM CALORIMETRY	20 lead-liquid argon modules ($20X_0$) covering $30° < \theta < 150°$ and $130 < \theta < 400$ mrad 7 layers in depth for shower sampling Resolution: $\sigma_E/E = 13\%/\sqrt{E}$, $\sigma_\theta = 4$ mrad Lead-scintillator sandwich (2 layers), $23° < \theta < 30°$ Two forward detectors made of Pb-glass blocks + scintillators, $50 < \theta < 100$ mrad
MUON DETECTION	30 planar proportional chambers (covering 92% of 4π) $\sigma_{position} = 6$ mm $p_{cut\text{-}off} = 1.4$ GeV
TRIGGERS	Charged-track trigger in $r\phi$ ($p_T > 200$ MeV) and rz projections Calorimetric triggers

REFERENCES

1. H.J. Behrend et al., CELLO Collaboration, Phys. Scripta **23** (1981) 610.


CELLO
1 Beam Pipe
2 Cyl. Proportional Chambers
3 Cyl. Drift Chambers
4 Superconducting solenoids
5 Liquid Argon Calorimeters
6 Hadron Filter
7 Muon Chambers
8 End Cap Proportional Chambers
9 Drift Chambers
10 Scintillation Trigger Counters
11 Lead glass Counters

CHARM II Neutrino Detector

LOCATION
450 GeV proton synchrotron
Neutrino Beam Facility
CERN, Geneva, Switzerland

FINE GRAIN TARGET CALORIMETER
420 modules (½X_0 and $0.12\Lambda_{abs}$ each), each consisting of a target plate (glass) 3.7×3.7 m^2 and 4.8 cm thick, and 352 streamer tubes 3.7 m long and 1 cm wire spacing (digital wire readout, analog cathode strip orthogonal to wires with 2 cm spacing)
The wire orientation alternates between horizontal and vertical in successive modules
A plane of 20 scintillators 3 m $\times$ 0.15 m is inserted every fifth module, and a plane of streamer tubes with inclined vertical wires ($\pm 7°$) every twentieth module
692 tons of glass

TRIGGER
At least one hit in seven planes and shower width criteria discriminating electron and hadron showers

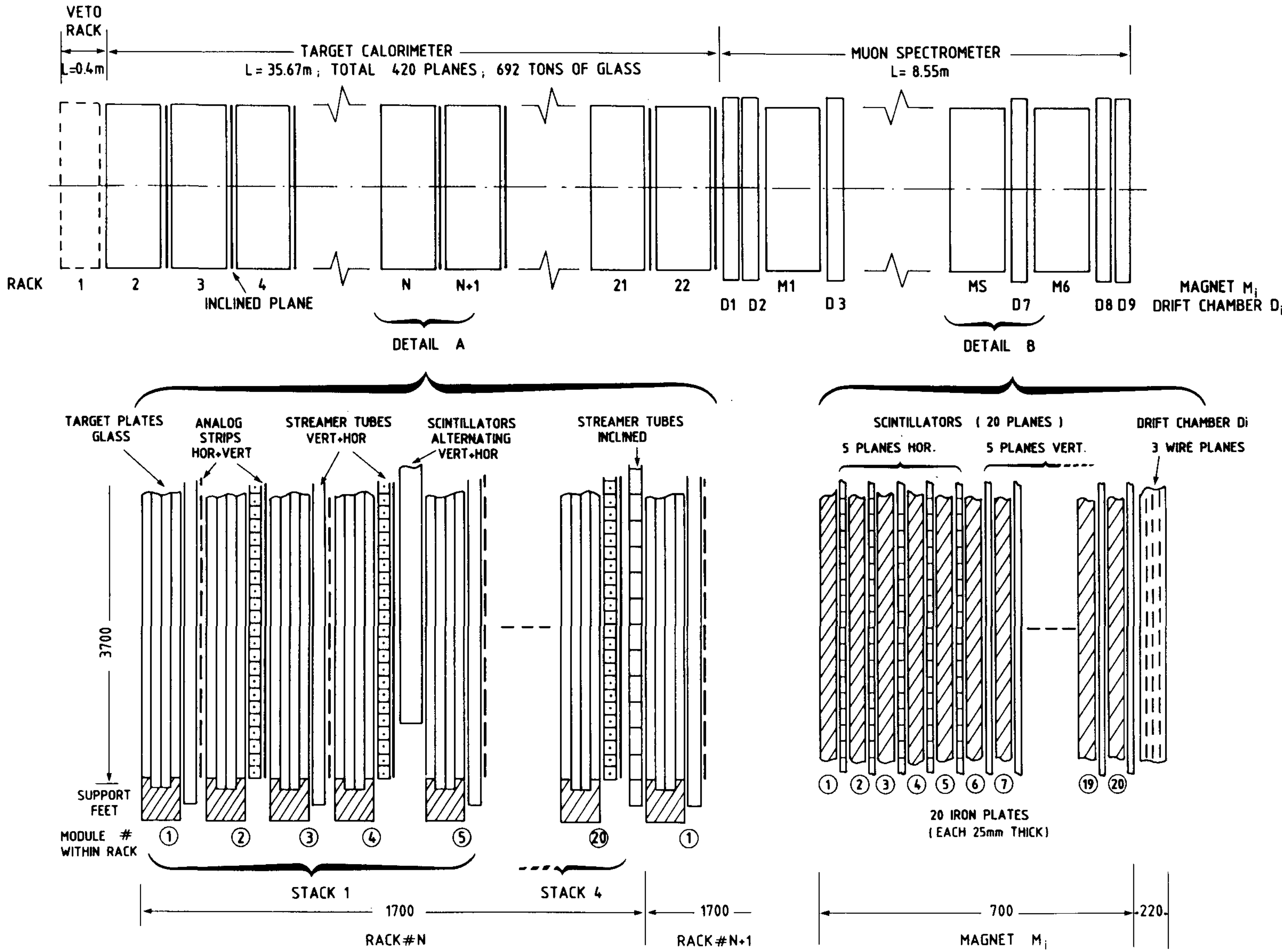
PERFORMANCE (EXPECTED)
$\sigma(E_e)/E_e \sim 0.25/\sqrt{E_e}$
$\sigma(\theta_e) \sim 16$ mrad$/\sqrt{E_e}$

MUON SPECTROMETER
Six modules of 20 magnetized iron disks of 2.5 cm thickness each
Tracking with drift chambers, two in front and two at the end, and one in each gap between modules
$\sigma(p_\mu)/p_\mu \sim 20\%$

TIMETABLE
Installation February 1985 – December 1985
Test run summer 1985
Data-taking 1986/87

REFERENCE

1. CHARM II Collaboration, Proposal for measuring the ratio of $\sigma(\nu_\mu e)$ and $\sigma(\bar{\nu}_\mu e)$, CERN/SPSC/83-24, SPSC/P186 (April 1983).



CHARM II Neutrino Detector

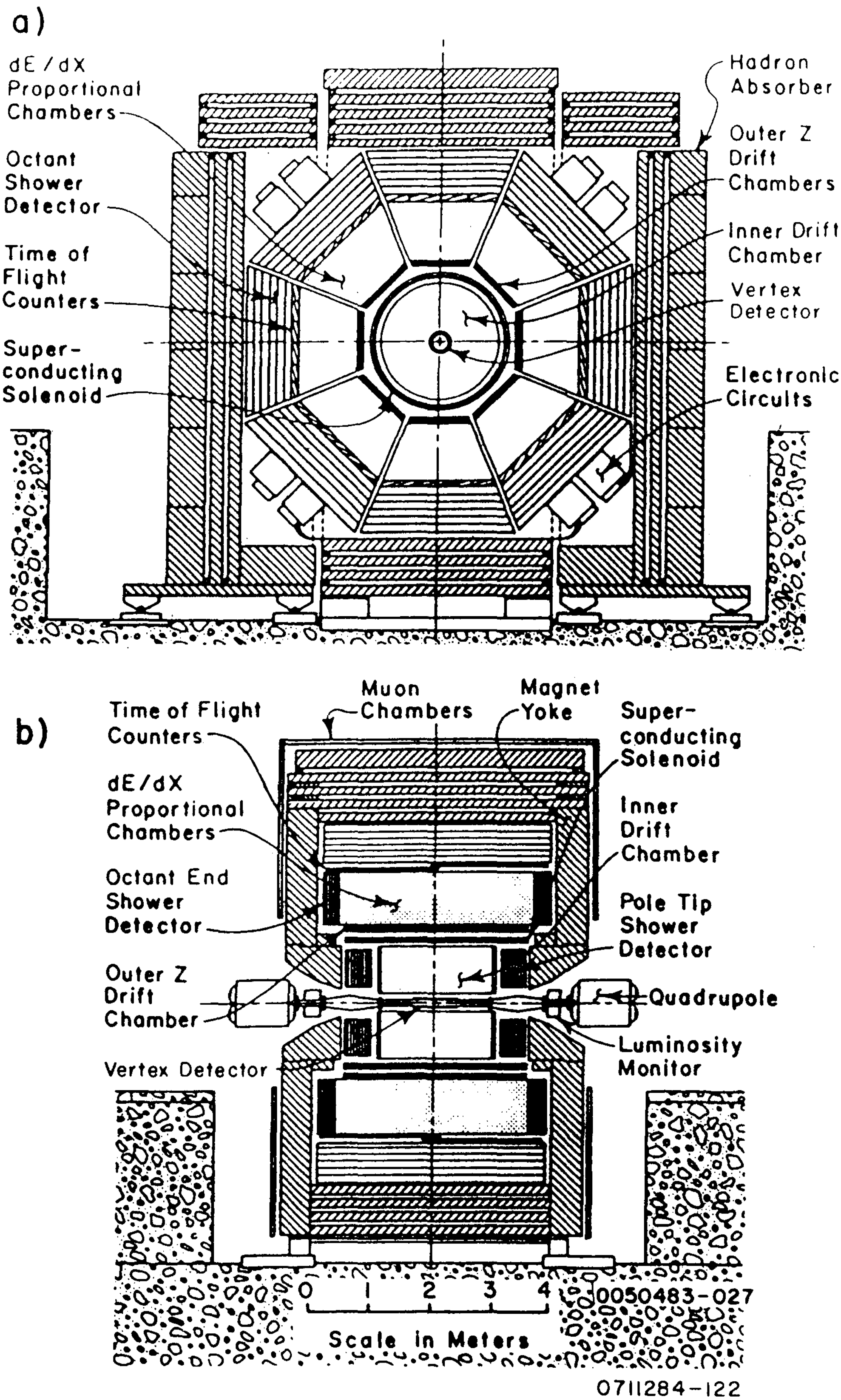
CLEO

LOCATION	CESR e^+e^- ring Wilson Laboratory, Cornell University, Ithaca, NY, USA
MAGNET	1.0 Tesla (superconducting)
TRACKING	New vertex detector + drift chamber 10 cylinders of sense wires, 2 cylinders of cathode strips Resolution: $\sigma_{r\phi} = 90\ \mu m$, $\sigma_z = 10$ mm (current division), $\sigma_z = 500\ \mu m$ (cathode strips) Momentum resolution of vertex detector + drift chamber $(\Delta p/p)^2 = (0.0065p)^2 + (0.006/\beta)^2$
SHOWER COUNTERS	12 X_0 of Pb-proportional tube sandwich $\Delta E/E = 0.17/\sqrt{E}$ $\Delta\theta = 6$ mrad
ENDCAP SHOWER COUNTERS	10 X_0 of Pb-proportional tube sandwich $\Delta E/E = 0.26/\sqrt{E}$ $\Delta\theta = 6$ mrad
PARTICLE IDENTIFICATION	Time-of-flight counters $\sigma = 320$ ps (π, K, p separation) dE/dx chambers $\sigma = 5.8\%$ (e, π, K, p separation) dE/dx in 17 cylinders of drift chamber, $\sigma_{dE/dx} = 10\%$
MUON DETECTION	4–10 interaction lengths of iron $p_{cutoff} \approx 1.5$ GeV/c
LUMINOSITY MONITOR	8 scintillator + shower counter telescopes at 39–70 mrad from the beam line

REFERENCES

1. The CLEO Collaboration, CLNS 82/538 (1982).
2. E. Nordberg and A. Silverman, The CLEO Detector, CLNS, CBX 79–6 (1979), unpublished.

CLEO


a)
dE / dX Proportional Chambers
Octant Shower Detector
Time of Flight Counters
Super-conducting Solenoid
Hadron Absorber
Outer Z Drift Chambers
Inner Drift Chamber
Vertex Detector
Electronic Circuits
b)
Time of Flight Counters
Muon Chambers
Magnet Yoke
Super-conducting Solenoid
dE/dX Proportional Chambers
Inner Drift Chamber
Octant End Shower Detector
Pole Tip Shower Detector
Outer Z Drift Chamber
Quadrupole
Luminosity Monitor
Vertex Detector
0 1 2 3 4
Scale in Meters
0050483-027
0711284-122

Crystal Ball

LOCATION	DORIS e^+e^- ring DESY, Hamburg, W. Germany
SCINTILLATOR	16 X_0 of NaI(T1)
(MAIN ARRAYS)	(1 nuclear absorption length) Segmentation: 672 truncated triangular pyramidal crystals Solid angle covered = 93% of 4π Resolution on γ or e: $\sigma_E/E = 0.026/E^{1/4}$ σ_θ = 1 to 2°, depending on energy $\sigma_\phi = \sigma_\theta/\sin\theta$
(ENDCAP ARRAYS)	NaI(T1) - 40 hexagonal crystals, extending solid angle coverage to 98% of 4π
TRACKING	4 double layers of drift tubes with charge division readout (800 tubes total) $\sigma_\phi = 1°$ σ_z = 1–2% of length (60 cm inner layer, 33 cm outer layer) Solid angle covered = 98% of 4π (inner layer), 74% of 4π (outer layer)
LUMINOSITY MONITOR	4 scintillator + shower counter telescopes

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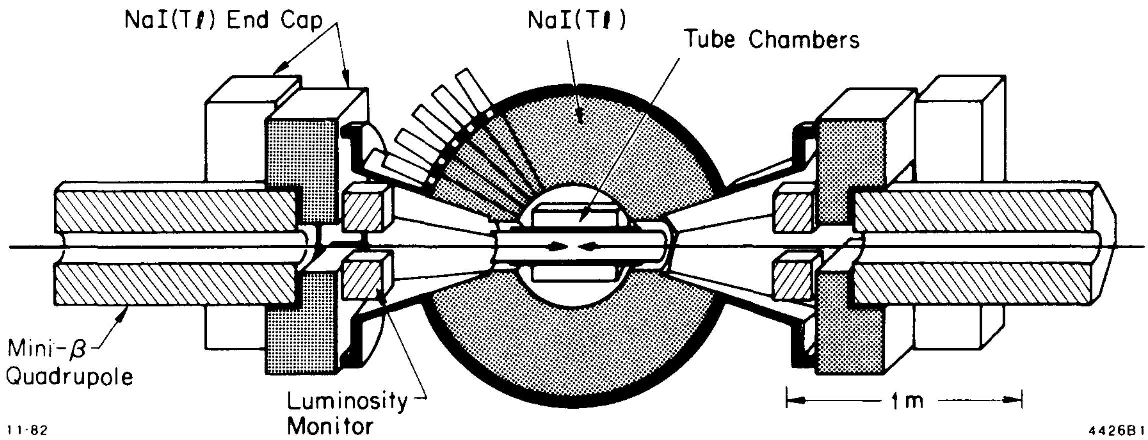
1. M. Oreglia et al., Phys. Rev. **D25** (1982) 2259.
2. R. Chestnut et al., IEEE Trans. Nucl. Sci. **NS 26** (1978) 4395.
3. G.I. Kirkbride et al., IEEE Trans. Nucl. Sci. **NS 26** (1979) 1535.
4. Proposal of the Crystal Ball collaboration to the DESY Physics Research Committee, PRC 81/09, June 30, 1981.

Crystal Ball



XBL 831-7893

CUSB-II

LOCATION	CESR e^+e^- ring Wilson Laboratory, Cornell University, Ithaca, NY, USA
COLLABORATION	Columbia University, SUNY at Stony Brook
TRACKING	Mini jet chambers, between beam pipe and first BGO plane
CENTRAL CALORIMETER	Segmented cylindrical BGO array and NaI(Tl) array with interspersed strip chambers (not shown) surrounded by lead-glass array; PM readout on all calorimeter elements 360 bismuth germanate (BGO) crystals (36 liters), $12X_0$, in 5 radial sectors, 36 ϕ sectors (10°), 2 θ sectors Scintillator strips or mini strip chambers between first and third BGO layers 332 NaI(Tl) crystals (580 liters), $9X_0$, in 5 radial layers, 32 ϕ sectors, 2 θ sectors 16 proportional chambers with cathode strip (1 cm) readout located in 4 planes between NaI(Tl) layers; $\Delta\Omega = 64\%$, $\sigma_{shower} = 0.6$ cm 256 lead-glass blocks in four 8x8 arrays surrounding the NaI(Tl) array, $7X_0$ $\Delta\Omega = 66\%$, $\sigma_E/E = 1\%/\sqrt{E} + 1\%$ (in quadrature)
MUON IDENTIFICATION	Dimuon identification with 35 scintillation counters surrounding lead-glass arrays; $\Delta\Omega = 42\%$
LUMINOSITY MONITOR	2 scintillators and lead-scintillator shower counters 45 mrad $< \Delta\theta <$ 90 mrad, $\Delta\phi = 61\%$ of 2π

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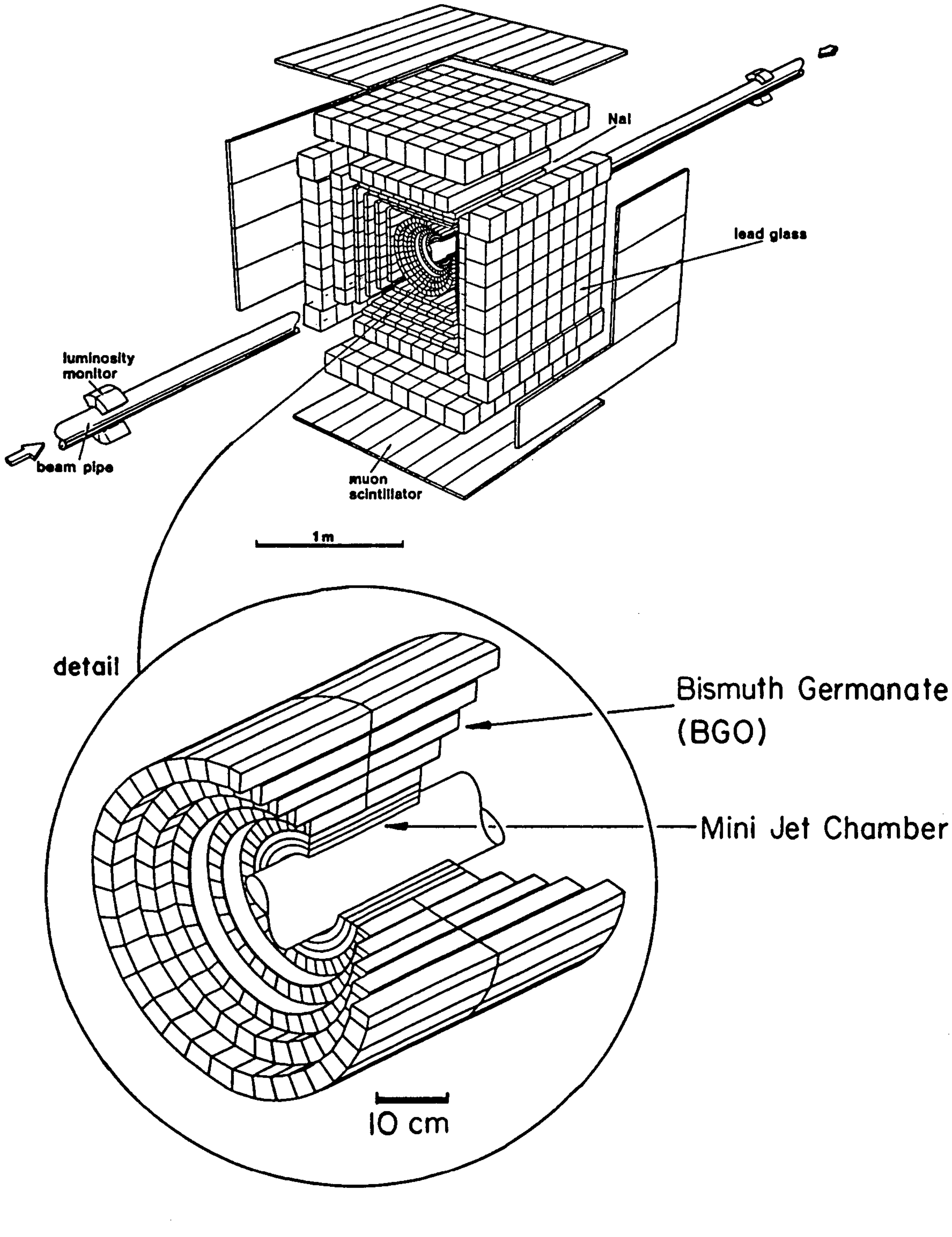
1. P. Franzini and J. Lee-Franzini, Phys. Rep. **81** (1982) 241.
2. The CUSB-II Detector, C02 at the XXIIth International Conference on High Energy Physics, Leipzig (1984).

CUSB-II



NaI
lead glass
luminosity
monitor
beam pipe
muon
scintillator
1m
detail
Bismuth Germanate
(BGO)
Mini Jet Chamber
10 cm

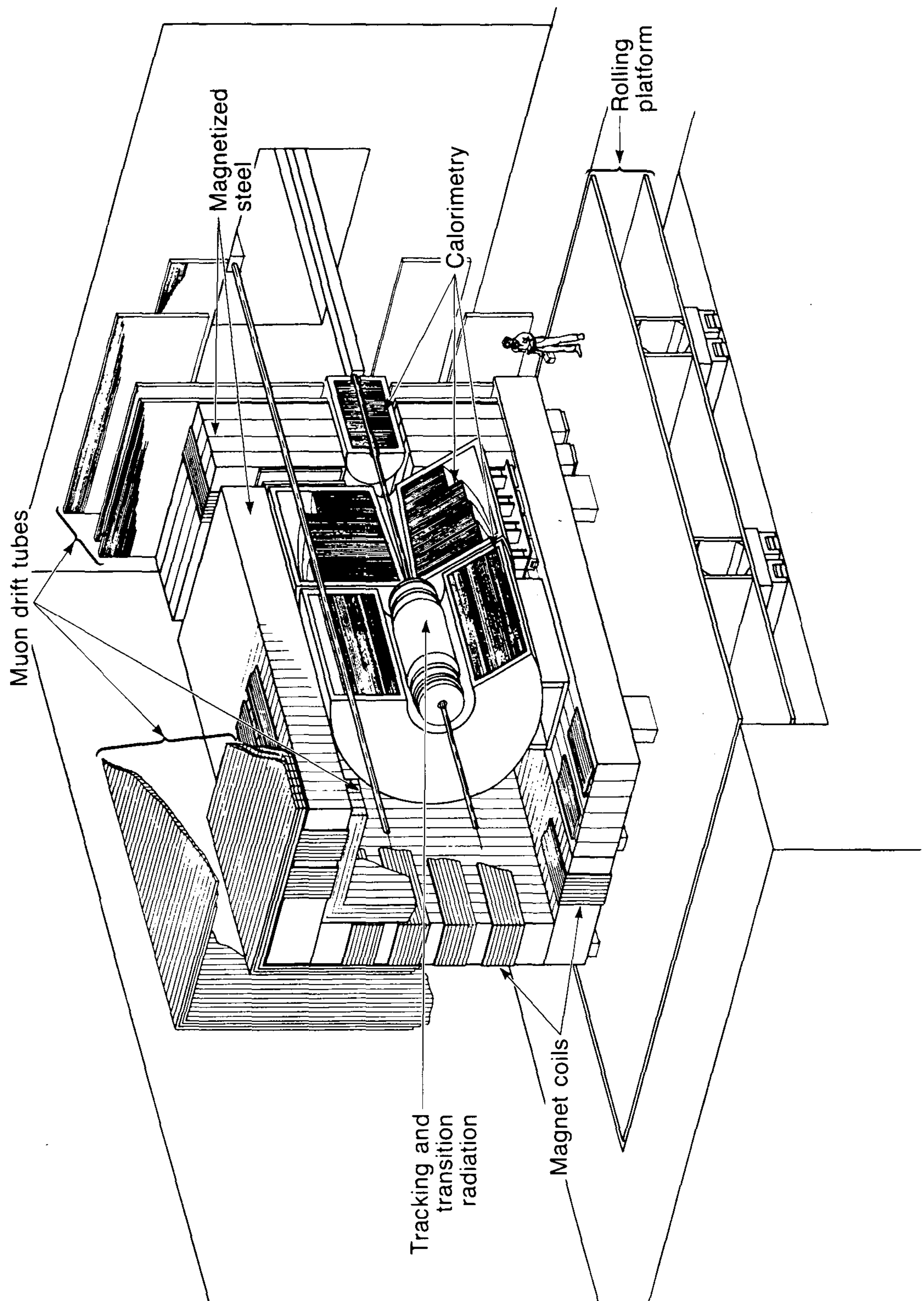
DØ

LOCATION	Fermilab $\bar{p}p$ collider Batavia, IL, USA
TRACKING	Vertex detector: $3 < r < 10$ cm, $\lvert z \rvert < 40$ cm, pseudorapidity $\lvert \eta \rvert < 2$, $r\Delta\phi$ resolution 100 μm, z resolution 5 mm, two-track resolution in $r\Delta\phi \sim 1$ mm Central drift chambers: 4 supercells of 6 sense wires and 2 delay lines for a total of 24 sense wire measurements of $r\phi$ and 8 delay line measurements of z per track, 32 azimuthal sectors, 768 sense wires, 256 delay lines, $40 < r < 70$ cm, $\lvert z \rvert < 74$ cm, $\sigma_{r\phi} = 200$ μm, $\sigma_z = 5$ mm, 2-track resolution 2.5 mm in $r\Delta\phi$, 10 cm in Δz, 2 overlapped track rejection by dE/dx 50:1 Endcap drift chambers: supercells of 7 sense wires and 2 delay lines, 14 supercells per plane, orthogonal pairs of planes before and after TRD's, total of 8 planes, 784 sense wires, 224 delay lines, $80 < \lvert z \rvert < 137$ cm, $10 < r < 65$ cm, $\sigma_x = \sigma_y = 200$ μm, $\sigma_z = 5$ mm, etc., same as central drift chamber, $\lvert \eta \rvert < 3.5$
TRANSITION RADIATION DETECTORS	Two radiator sections deep, each having 640 lithium foils of 30 μm thickness separated by 150 μm, followed by a xenon-filled proportional chamber 1 cm thick with 8 mm wire spacing, e/π discrimination 50:1, 1080 channels total for all sections Central TRD's: $10 < r < 40$cm, $\lvert z \rvert < 70$ cm Endcap TRD's: $92 < \lvert z \rvert < 122$ cm, $r < 65$ cm, $\lvert \eta \rvert < 3.1$
CALORIMETRY	Uranium/copper liquid argon stacks, projective geometry with transverse segmentation $0.1(\Delta\phi) \times 0.1(\Delta\eta)$, longitudinal segmentation 4 in EM and 4 in hadronic, 5312 towers, 42560 channels, $(\sigma_E/E)_{EM} = 12\%/\sqrt{E}$, position resolution for EM shower 8 mm$/\sqrt{E}$, $\lvert \eta \rvert < 4.7$, five parts Central calorimeter: radiation lengths $21X_0$ in EM section, absorption lengths $6.9\lambda_0$, $75 < r < 222$ cm, $\lvert z \rvert < 113$ cm, $\lvert \eta \rvert < 0.9$, 1536 towers, 13952 channels Endcap calorimeter (each): $20X_0$ in EM section, $8.9\lambda_0$, $142 < \lvert z \rvert < 340$ cm, $r < 207$ cm, $0.9 < \lvert \eta \rvert < 3.1$, 1536 towers, 12192 channels Plug calorimeter (each): $9\lambda_0$, $500 < \lvert z \rvert < 650$ cm, $9 < r < 65$ cm, $3 < \lvert \eta \rvert < 5$, 352 towers, 2112 channels
MUON SYSTEM	Proportional drift tube layers: extruded Al tubes 10 cm $\times$ 2.5 cm $\times$ ($\leq$600 cm long), 12,720 PDT's total, coordinate along wire measured to ± 1 mm by vernier cathode strips, resolution perpendicular to wire ± 0.5 mm, magnetic field inside toroids 20 kG, $\Delta p_T/p_T = 20\%$ (multiple coulomb scattering limit), sign determination at 3σ for $p_T = 300$ GeV/c, $\lvert \eta \rvert < 2.34$, $11° < \theta < 169°$ Central toroidal magnet: $\lvert z \rvert < 425$ cm, $308 < r_\perp < 410$ cm, absorption lengths including calorimeter $13.3\lambda_0$ at 90° End toroidal magnet: $447 < \lvert z \rvert < 559$ cm, $86 < r_\perp < 410$ cm, absorption lengths including calorimeter $18\lambda_0$ at 11°

REFERENCE

1. DØ Design Report (November 1984).

DØ



XBL 8501-7002

DELPHI

LOCATION	LEP e^+e^- rings CERN, Geneva, Switzerland
MAGNET	Superconducting solenoid: 12 kG, R_i = 2.6 m, L = 7.4 m
TRACKING	Vertex detector: Si strips, 25 μm pitch, 1–3 layers, R_i = 8.5 cm, $\sigma_{r\phi}$ = 5 μm, L = 42 cm Inner drift chamber: Jet chamber section: R_i = 11.8 cm, R_o = 22.3 cm, L = 80 cm, 24 rϕ signals, $\sigma_{r\phi}$ = 100 μm Outer section: 5 cylindrical layers with z readout (strips), R_o = 28 cm, L = 100 cm, σ_z = 500 μm Time projection chamber (TPC): R_i = 28 cm, R_o = 122 cm, L = 2 × 1.36 m (max. drift), 192 sense wire hits for 39° < θ < 141° to provide dE/dx and rz, 16 3-dim. space points from circular pad rows (r,ϕ,z), $\sigma_{r\phi}$ = 250 μm, σ_z < 1 mm, 2-track separation = 1–2 cm, dE/dx = 5.5%, $\sigma_p/p = [(0.6\ p)^2 + 0.5^2]^{1/2}$ Outer drift chamber: 5 layers of Al tubes (1.75 × 1.75 cm^2), R_i = 192 cm, R_o = 208 cm, L = 470 cm, $\sigma_{r\phi}$ = 300 μm; z-information from timing, 3 layers with fast response, σ_z = 15 cm Forward drift chambers: chamber A at z = 156 cm, 6 (x,u,v) projections, σ = 150 μm; chamber B at z = 266.5 cm, 12 (x,u,v) projections, σ = 150 μm
TIME-OF-FLIGHT	Scintillators, 200 counters, 3.5 × 20 × 2 cm^3, R = 314 cm, 2PM's each, σ_t = 0.5 ns
SHOWER COUNTERS	Barrel: high density projection chamber (HPC), 40 sampling slots of 8 mm Ar/CH_4, max. drift = 90 cm, 8 charge samples in R, R_i = 208 cm, R_o = 260 cm, $20X_0$; 24 × 6 modules, 41.5° < θ < 138.5°, trigger gap with proportional tubes after $5X_0$; $\sigma_E/E = 18.5\%/\sqrt{E}$ Endcap: lead-glass blocks, 5 × 5 cm^2 (1° × 1°), pointing geometry (−3°), >$22X_0$, triode readout, 10° < θ < 35.5°; $\sigma_E/E = [(0.4 + 5.9/\sqrt{E})^2 + (6/E)^2]^{1/2}$ Small angle tagger (SAT): 36–150 mrad, proportional tubes or Si strips, shower counter with scintillating fibers (1 mm) embedded in lead, $25X_0$
HADRON CALORIMETER	20 layers of streamer tubes inside return yoke, pointing geometry (2.8° × 3.6°), 4 samples in depth, $\sigma_E/E = 100\%/\sqrt{E}$ (behind coil)
HADRON IDENTIFICATION	Ring imaging Cerenkov counters (RICH), both gas (C_5F_{12}) and liquid (C_6F_{14}) Barrel: 41.5° < θ < 138.5°, R_i = 123 cm, Ro = 197 cm, 1.3 atm., 40°C; 4.2 σ separation limits: π/K = 18 GeV/c, K/p = 35 GeV/c Endcap: 15.5° < θ < 35.5°, 1 atm., 40°C; 4.2 σ separation limits: π/K = 30 GeV/c, K/p = 50 GeV/c
MUON DETECTION	2 drift chamber layers behind ⩾ 90 cm and 110 cm Fe of return yoke Barrel: 2 layers of 3 points: $\sigma_{r\phi}$ = 1 mm, σ_z = 1 cm Endcap: 2 layers of 2 points: $\sigma_x = \sigma_y$ = 1 mm
FORWARD DETECTORS	Scintillator hodoscopes, tracking chambers, and EM shower detector

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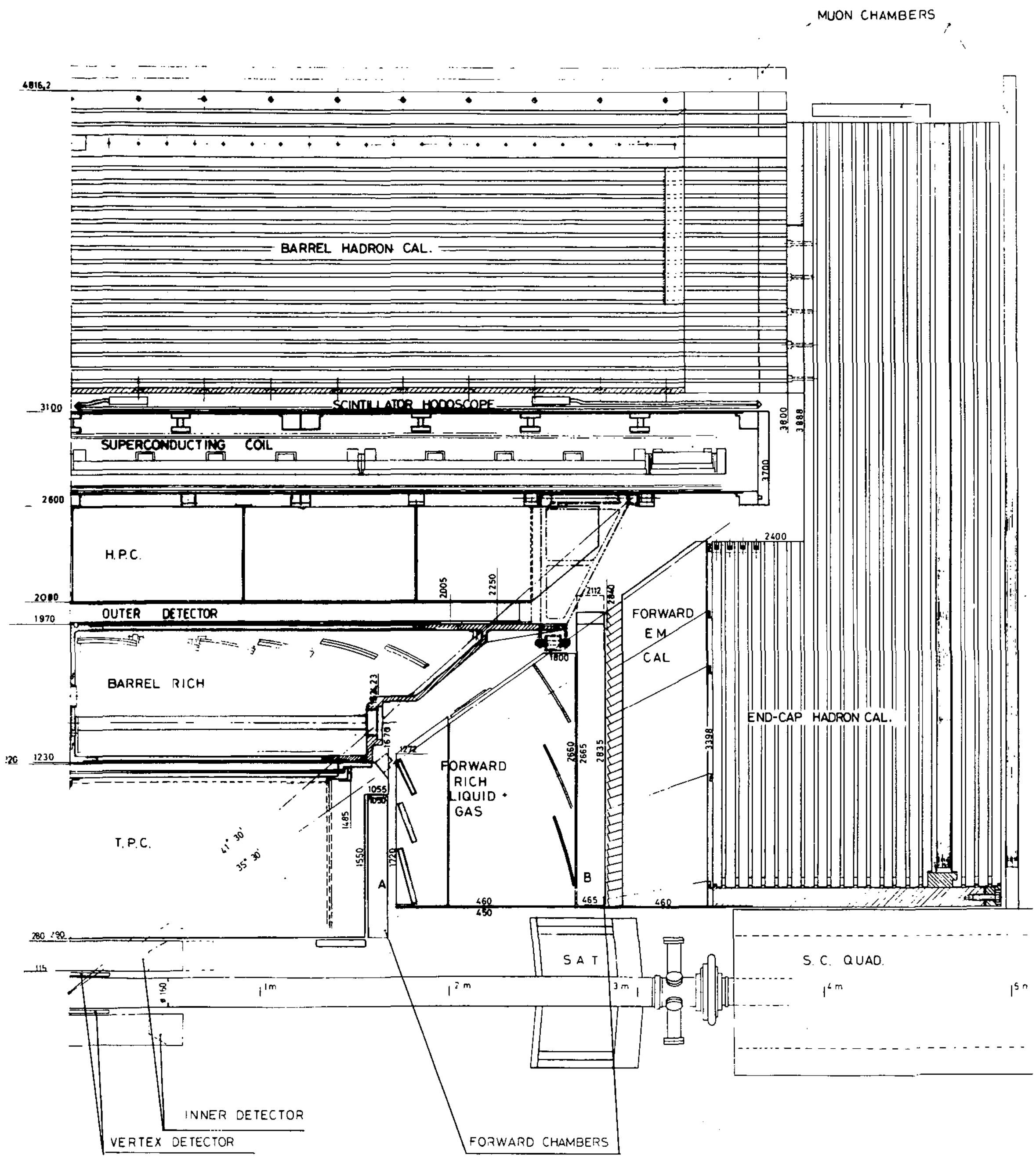
2. DELPHI Collaboration, Progress Report, CERN/LEPC 84-16, DELPHI 84-60 GEN-11.

DELPHI


MUON CHAMBERS
BARREL HADRON CAL.
SCINTILLATOR HODOSCOPE
SUPERCONDUCTING COIL
H.P.C.
OUTER DETECTOR
BARREL RICH
T.P.C.
FORWARD
EM
CAL
END-CAP HADRON CAL.
FORWARD
RICH
LIQUID +
GAS
SAT
S. C. QUAD.
INNER DETECTOR
VERTEX DETECTOR
FORWARD CHAMBERS

EMC

LOCATION	CERN-SPS Geneva, Switzerland
BEAM	SPS muon beam line M2 E_μ = 120–280 GeV (400 GeV protons) Intensity 1–5 $\times 10^7$ μ/pulse 1.8 sec pulse, rep. rate 14 sec Beam momentum $\Delta p = 4.5\%$ Halo 6% Intensity monitor hodoscope Beam hodoscope
TARGET	NA2: 6 m H_2/D_2, 4.75 (2.75) m iron-scintillator, polarized target NA9: 1 m H_2/D_2, heavy targets NA28: heavy targets
MAGNET	Forward Spectrometer (FS) 15 kG, Bdl = 5.18 T-m Vertex Spectrometer (VS) 16 kG, Bdl $\simeq$ 4 T-m, superconducting
TRACKING	FS: Drift chambers, proportional chambers VS: Streamer chamber, proportional chambers, drift tubes $\sigma_p/p \sim (20 + 1.1p) \times 10^{-4}$ (FS) $\sigma_p/p \sim 1/5\,(10 + 9p) \times 10^{-3}$ (VS)
TRIGGER	Scintillator hodoscopes + veto hodoscopes on scattered μ crossing 2.5 m iron absorber
PARTICLE IDENTIFICATION	Gas Cerenkov counter (FS + VS) (neon, nitrogen, neopentane) Aerogel Cerenkov counter (VS) TOF Hodoscopes (VS) Lead-glass array (FS) $\sigma_E/E = 20\%/\sqrt{E}$ Hadron calorimeter (FS) $\sigma_E/E = 120\%/\sqrt{E}$

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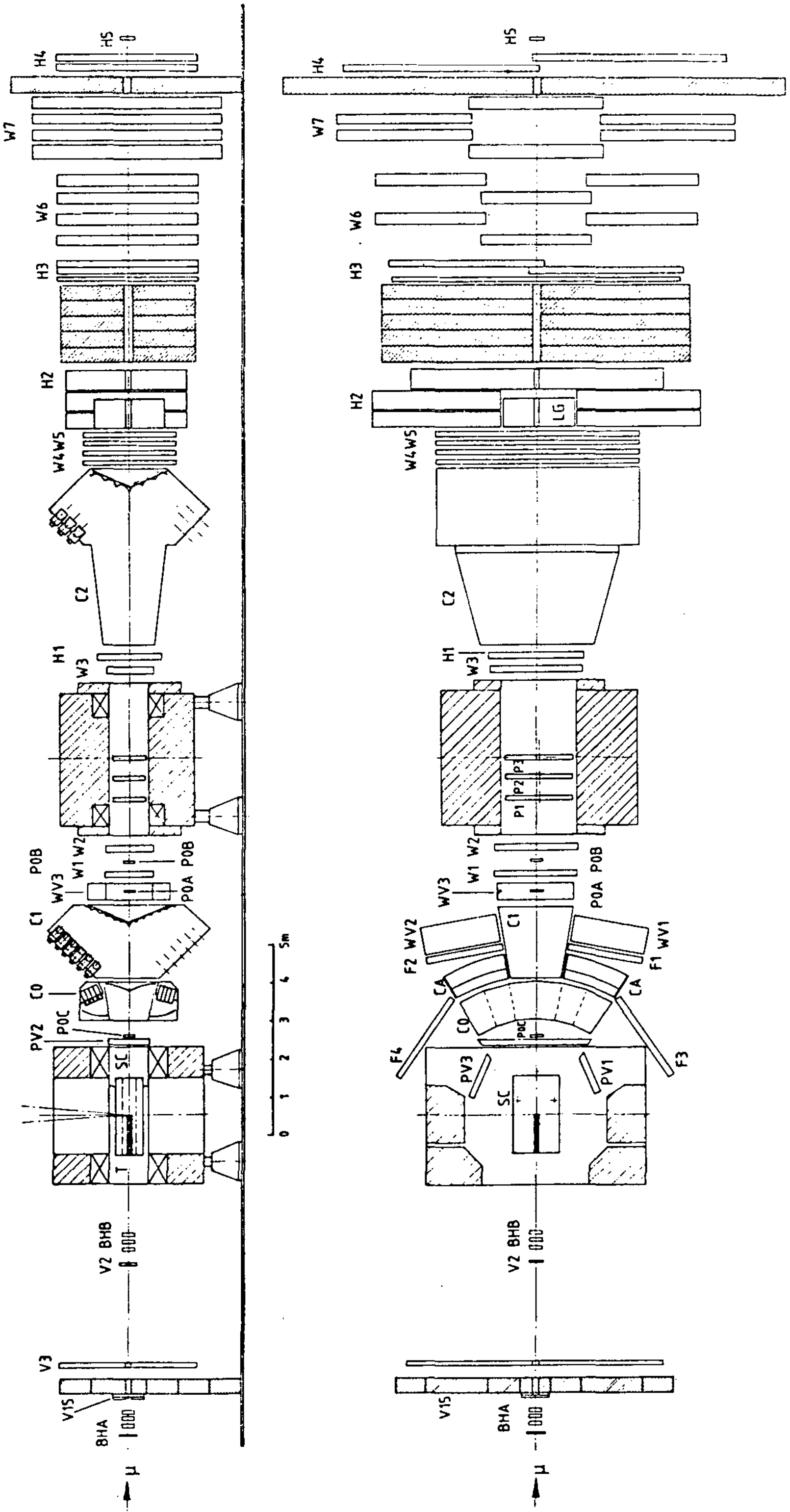
2. J.P. Albanese et al., to be published in Nucl. Instr. & Meth.

EMC



XBL 832-8140

FNAL-605

LOCATION	ME External Proton Beam, FNAL Batavia, IL, USA
INCIDENT BEAMS	External Proton Beam, Pions (Future)
MAGNETS[1]	SM12 Dipole: 15 m long by 1.2 m high by 0.9 m gap SM3 Dipole: 3 m long by 1.6 m high by 1.5 m gap
TRACKING	STATION 1: 6 planes MWPC 2 mm wire spacing STATION 2: 6 planes DC 1 cm cell size STATION 3: 6 planes DC 2 cm cell size
CERENKOV COUNTER[2]	Ring-imaging Cerenkov: intended to identify hadrons up to 200 GeV/c 15 m of helium gas at atmospheric pressure 8 m focal length mirrors Multistep PWC ultraviolet photon detector utilizing triethylamine and calcium fluoride windows
CALORIMETRY[3]	Electron calorimeter: 18 radiation length lead-scintillator sandwich array longitudinally segmented at 2, 4, 8, and 13 rad. lengths to optimize pion rejection Resolution of $15\%/\sqrt{E}$ Hadron calorimeter: iron-scintillator sandwich 12 2.5-cm plates followed by 20 5-cm plates, each section read out with wavelength shifter bars Resolution of $70\%/\sqrt{E}$
MUON DETECTION	Absorber wall of zinc and concrete followed by crossed proportional tube hodoscopes

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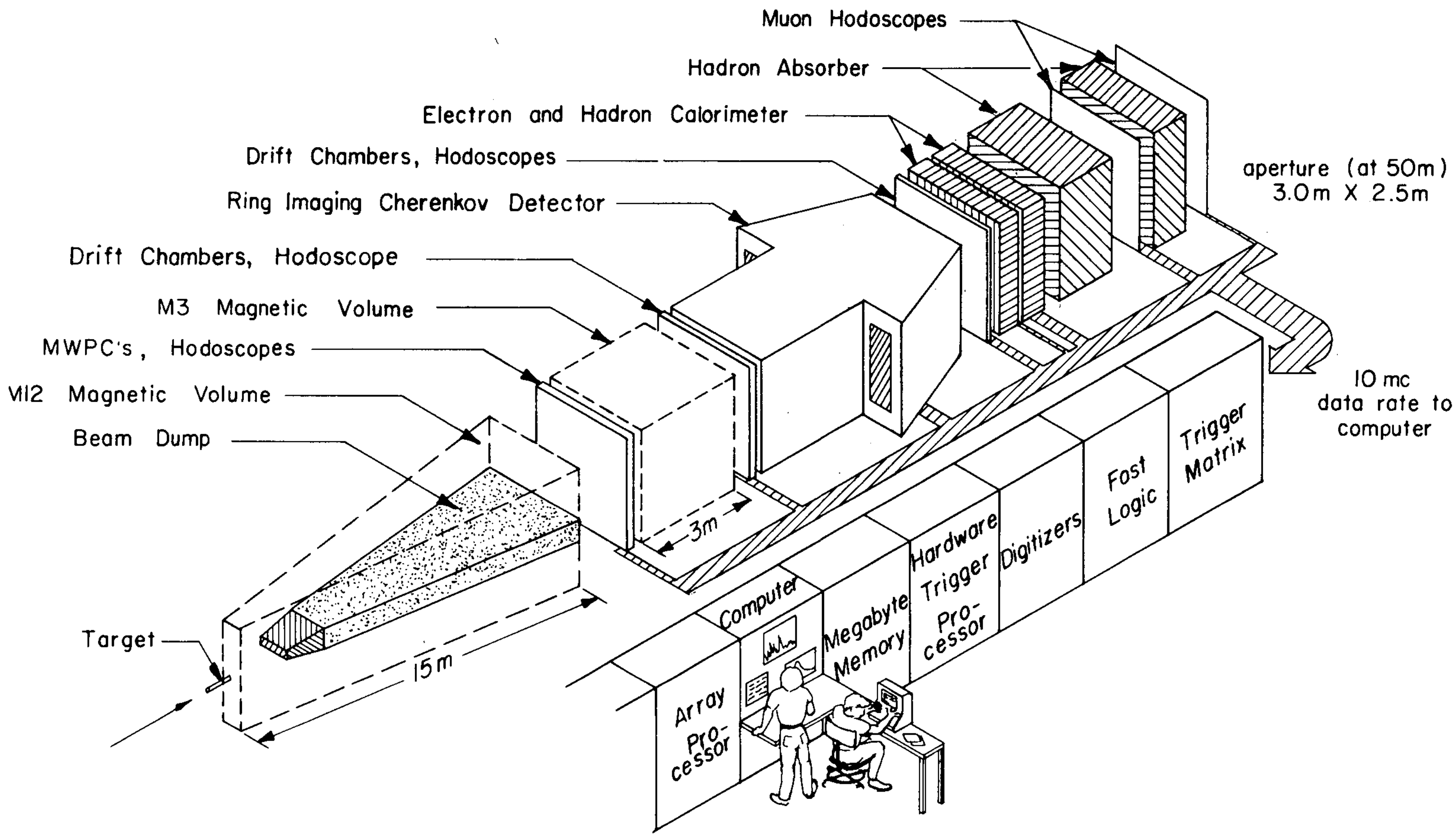
1. R.W. Fast et al., submitted to the 7th International Magnet Conference, 1981, Karlsruhe, Germany.
2. H. Glass et al., submitted to IEEE Transactions, 1982 Nuclear Science Symposium.
3. Y. Sakai et al., and J. Hanson et al., submitted to IEEE Transactions, 1980 Nuclear Science Symposium.

Fermilab 605: Precision Spectrometer for High P_T Particles.
Fermilab, StonyBrook, University of Washington,
Columbia, Saclay, CERN, Kyoto, KEK.



XBL 831-7892

FNAL-605

FNAL High Intensity Lab Spectrometer

LOCATION	Fermilab, High Intensity Lab — Proton West Beam Line Batavia, IL, USA Experiments 537, 705, 721
TARGETS	0.5 and 1.0 m H_2/D_2 targets; Be, Cu, W nuclear targets
BEAMS	$\overline{p}$, p, π^+, π^-, $e^\pm$ (30–300 GeV/c); unique antiproton tertiary beam derived from Λ decays; secondary $\pi^\pm$ beam yields up to $10^{10}/10^{13}$ 800 GeV protons with $\Delta p/p = \pm 10\%$ Beam momentum and trajectory tagged with beam Cerenkovs (90 ft long – helium filled) and beam PWC system
ANALYSIS MAGNET	Conventional analysis magnet, 1018 kG-inches, aperature $3' \times 6'$
TRACKING	Proportional wire chambers (upstream of analysis magnet) 6000 wires; wire spacings – 0.75 mm, 1.5 mm; 6 stations with x, u, v planes, 16.7° stereo Drift chambers (upstream of analysis magnet) 830 wires; drift distance 0.6 cm and 1.2 cm; 3 stations with x, u, v planes, 16.7° stereo Drift chambers (downstream of analysis magnet) 2000 wires; drift distance 2 cm; 3 stations with x, u, v, x′ planes, 16.7° stereo Drift chambers resolution – $\sigma \sim 280\ \mu m$
ELECTRO-MAGNETIC DETECTOR	600 element scintillation and lead-glass counter array; $24X_0$, $2\lambda_a$ Transverse segmentation 7.5 cm^2 and 15.0 cm^2 at 10 meters from targets Resolution of scintillation glass counters $\approx 1\% + 1.5\%/\sqrt{E}$ Resolution of lead-glass section elements $\approx 1\% + 4.5\%/\sqrt{E}$ High resolution scintillation glass section covers 5° cone in the forward direction Position measurement done by means of planes of 5 mm gas tubes (x,y,u) positioned after the first $3.5X_0$ of the glass detector Electron position resolution = 3 mm + 4.6 mm/$\sqrt{E}$ Tube hodoscope operated in the saturated avalanche mode Calibration of the electromagnetic detector performed in situ by changing beam to electron mode and automatically moving the 30 ton detector element-by-element into the beam Detector couples to analog cluster-finding trigger electronics which finds and reconstructs photon showers
MUON DETECTOR	400 element scintillation counter hodoscope used for dimuon trigger; 4 planes (y,x,x,x) First two planes situated behind $22\lambda_a$ of steel Triple coincidences between the three x planes form fast muon trigger Triple coincidences are used to define roads in the drift chambers DC4,5,6 in which a fast-muon trigger processor reconstructs track trajectories and momenta and calculates the mass of each pair-wise combination in less than 10 μs

REFERENCES

1. Fermilab-Pub. 85/35-E, submitted to Nucl. Instr. & Meth.
2. D.E. Wagoner et al., Fermilab-Conf. 84/21-E, submitted to Nucl. Instr. & Meth.
3. R. Rameika et al., Fermilab-Conf. 84/22-E, submitted to Nucl. Instr. & Meth.
4. B. Cox et al., Fermilab-Conf. 84/23-E, submitted to Nucl. Instr. & Meth.
5. B. Cox et al., Nucl. Instr. & Meth. **219** (1984) 491.
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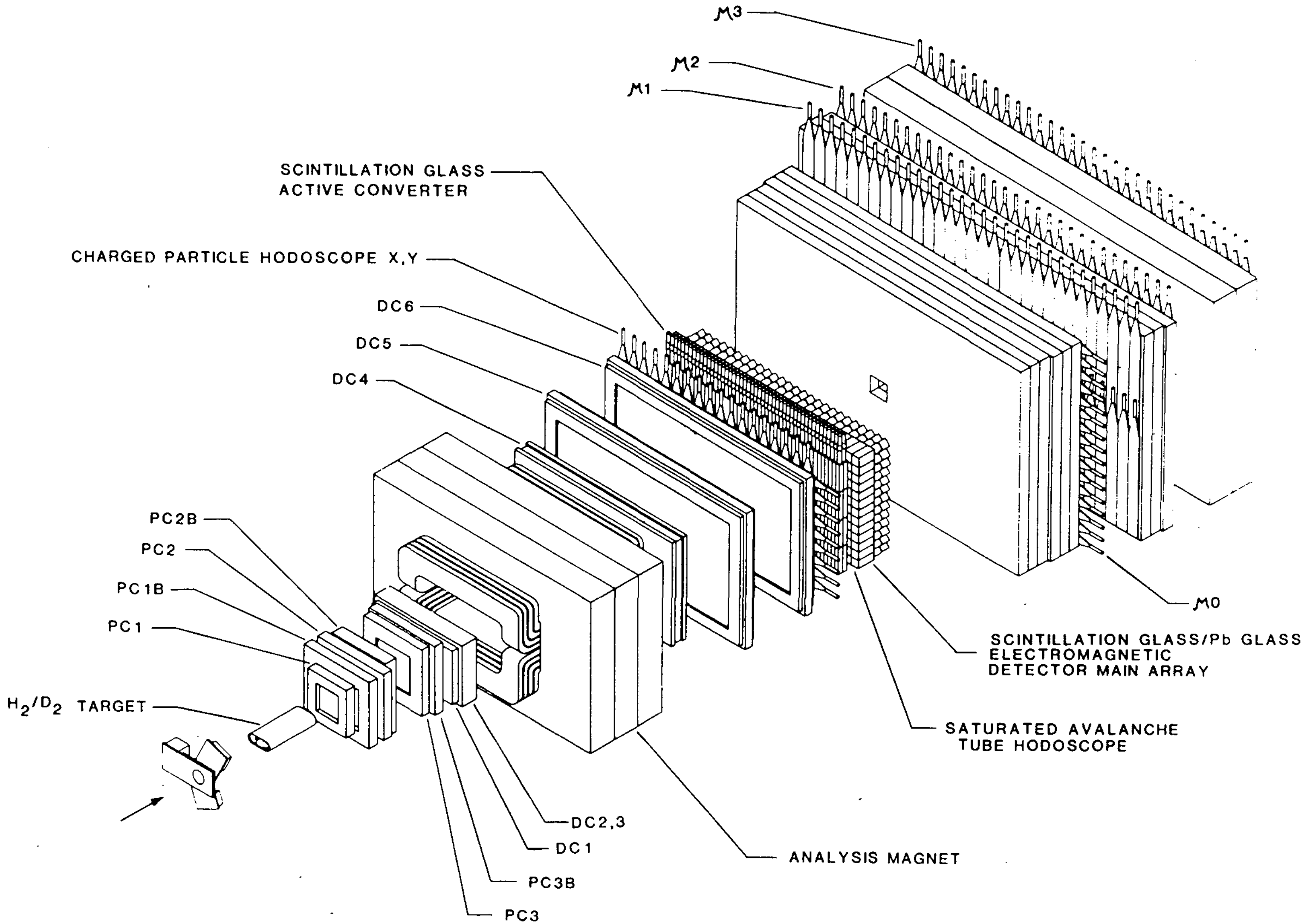


FNAL High Intensity Lab Spectrometer

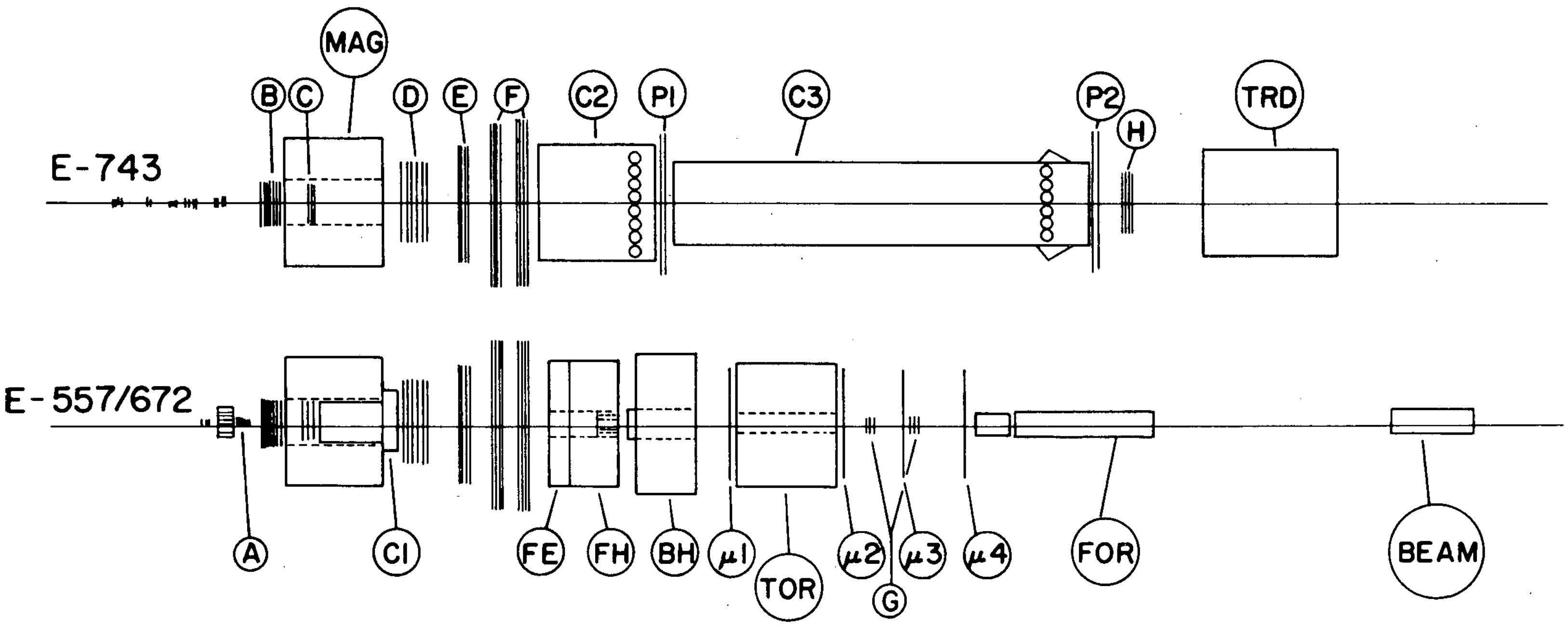
FNAL Multiparticle Spectrometer

LOCATION	Fermilab, meson area, MT beam line Batavia, IL, USA
MAGNET	16.9 kG (superconducting) p_t kick $\sim$ 0.7 GeV/c
TRACKING	PWC + drift chambers, 35 planes A through F $\sigma_p/p = \{0.003\ [1+(p_0/p)^2]^{1/2}\}p$
E-672 LAYOUT	
RECOIL DETECTOR	46 segments Pb-glass $\Delta\phi = 2\pi$
PARTICLE IDENTIFICATION	C1 44 cell atmospheric (C counter)
CENTRAL CALORIMETER	EM Pb-scintillator, $16X_0$, $\sigma_E/E = 20\%/\sqrt{E}$, 206 elements Hadron Fe-scintillator, $3.8X_0$, $\sigma_E/E = 70\%/\sqrt{E}$
MUON DETECTION	Fe toroid, 2.5 m thick, 18 kG $\mu_{1,2,3,4}$PWC
FORWARD LEVER ARM	G PWC
FORWARD CALORIMETER	EM Pb-scintillator, $16X_0$, 96 elements Hadron Fe-scintillator, $10X_0$, 162 elements
BEAM CALORIMETER	Fe-scintillator, 1 element
E-743 LAYOUT	
TARGET AREA	15μm hydrogen bubble chamber 50μm mini drift and PWC
PARTICLE IDENTIFICATION	C2 68 cell atmospheric (C counter) C3 34 cell atmospheric (C counter) P1,P2 current division proportional tubes TRD carbon fiber Xe transition radiation detector, 20 planes xenon PWC
FORWARD LEVER ARM	H PWC

REFERENCES

1. P. Rapp et al., Nucl. Instr. & Meth. **188** (1981) 285.
2. J.L. Benichou et al., Nucl. Instr. & Meth. **190** (1981) 48.
3. M. Deutschmann et al., unpublished.

MPS LAYOUT FOR E-743 AND E-672 1984-1985



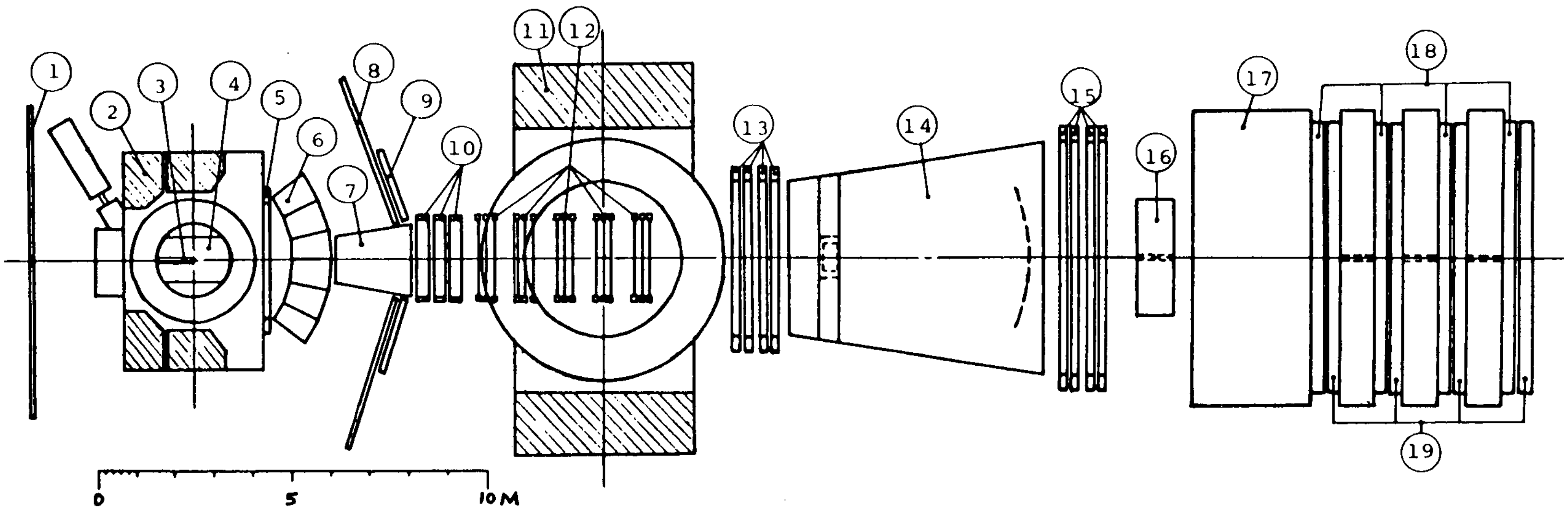
TARGET REGION	
743	Si STRIP BEAM TAG LEBC TARGET MINI DRIFT PWC
672	BEAM PWC TAG RECOIL π° DETECTOR

FNAL Multiparticle Spectrometer

FNAL Muon Spectrometer

LOCATION	Fermilab Tevatron (E665) Batavia, IL, USA
BEAM	Tevatron NM beamline E_μ = 100–700 GeV (900 GeV protons) Intensity $> 10^8$ μ/pulse 20 sec pulse; rep. rate = 1 minute Beam momentum $\Delta p \sim \pm 15\%$ Halo $\leqslant 10\%$ Beam tagging: Momentum $\sigma_p/p \sim 0.3\%$ Angle vert. $\sigma(\theta) \sim 3\mu rad$ Angle horiz. $\sigma(\theta) \sim 7\mu rad$
TARGET	1 m H_2/D_2 1 m xenon (15 atm.) Assorted heavy targets
MAGNETS	CVM - dipole, 16 kG; BL $\approx$ 4 T-m, superconducting CCM - dipole, 14 kG; BL $\approx$ 7 T-m, superconducting
TRACKING	Vertex spectrometer (CVM): Streamer chamber, proportional chambers, proportional drift tubes $\sigma_p/p \sim \frac{1}{5}(10 + 9p) \times 10^{-3}$ Forward spectrometer (CCM): Proportional chambers, drift chambers $\sigma_p/p \sim 3 \times 10^{-5}\ p$
MUON DETECTOR	Iron absorber, concrete absorbers (interleaved with scintillators and proportional tube planes)
TRIGGER	Muon track in muon detector system (fast processor) Beam tagging scintillator Halo veto hodoscopes
PARTICLE IDENTIFICATION	Vertex spectrometer: TOF hodoscopes Threshold Cerenkov counters a) Freon at STP; b) Nitrogen at STP Forward spectrometer: Ring imaging Cerenkov counter, radiator 6 m Argon/helium at STP Electromagnetic calorimeter Lead/proportional tube sandwich $\sigma(E)/E \sim 30\%/\sqrt{E}$ (for electrons) $\sigma(pos) \sim 2$ mm

FNAL Muon Spectrometer



1. 7Mx3M Veto Counter Wall
2. CERN Vertex Magnet
3. 1M LH_2/LD_2 Target
4. 1Mx2Mx0.7M Streamer Chamber
5. 3Mx1M MWPC, 6 Planes
6. 144Cell Threshold Cerenkov Cntr
7. 58 Cell Threshold Cerenkov Cntr
8. 4Mx1.6M Scintillation TOF Arrays
9. 2Mx2M Prop. Drift Tube Arrays 4 Planes
10. 2Mx2M MWPC, 12 Planes
11. Chicago Cyclotron Magnet
12. 2Mx1M MWPC, 15 Planes
13. 4Mx2M Drift Chambers, 8 Planes
14. Ring Imaging Cerenkov Counter
15. 6Mx2M Drift Chambers, 8 Planes
16. 3Mx3M EM Shower Calorimeter
17. 7Mx3Mx3M Iron Absorber
18. 7Mx3M Prop. Tube Arrays, 8 Planes
19. 7Mx3M Scintillation Trigger Arrays

FNAL Neutrino Detector

LOCATION

FNAL neutrino beam line, Lab C
Batavia, IL, USA

CALORIMETER

608 flash chambers, $3.66 \times 3.66\ m^2$ sensitive area, and 37 proportional tube chambers
Half are with horizontal cells and the other half at ± 10 degrees from the vertical
Between each flash chamber there are 1.6-cm thick alternating planes of iron shot and sand, giving a total tonnage of 340 tons
Showers are sampled every 22% of X_0 and every 3% of λ_{abs}
The angular resolution for electrons and hadrons is:

$\sigma_e = 3.5 + 53/E_e$ mrad

$\sigma_h = 6 + 640/E_h$ mrad

The energy resolution is:

$\sigma_E/E = 10\%$ for $5 \leqslant E \leqslant 100$ GeV
for both electrons and hadrons

TRIGGER COUNTERS

Proportional chambers, $3.66 \times 3.66\ m^2$ throughout the calorimeter every 16 flash chambers

MUON DETECTION

Magnetized iron toroids 7.32 m diameter and 3.66 m diameter interspersed with drift chambers
$\sigma_p/p = 10\%$ for $p < 300$ GeV/c

REFERENCES

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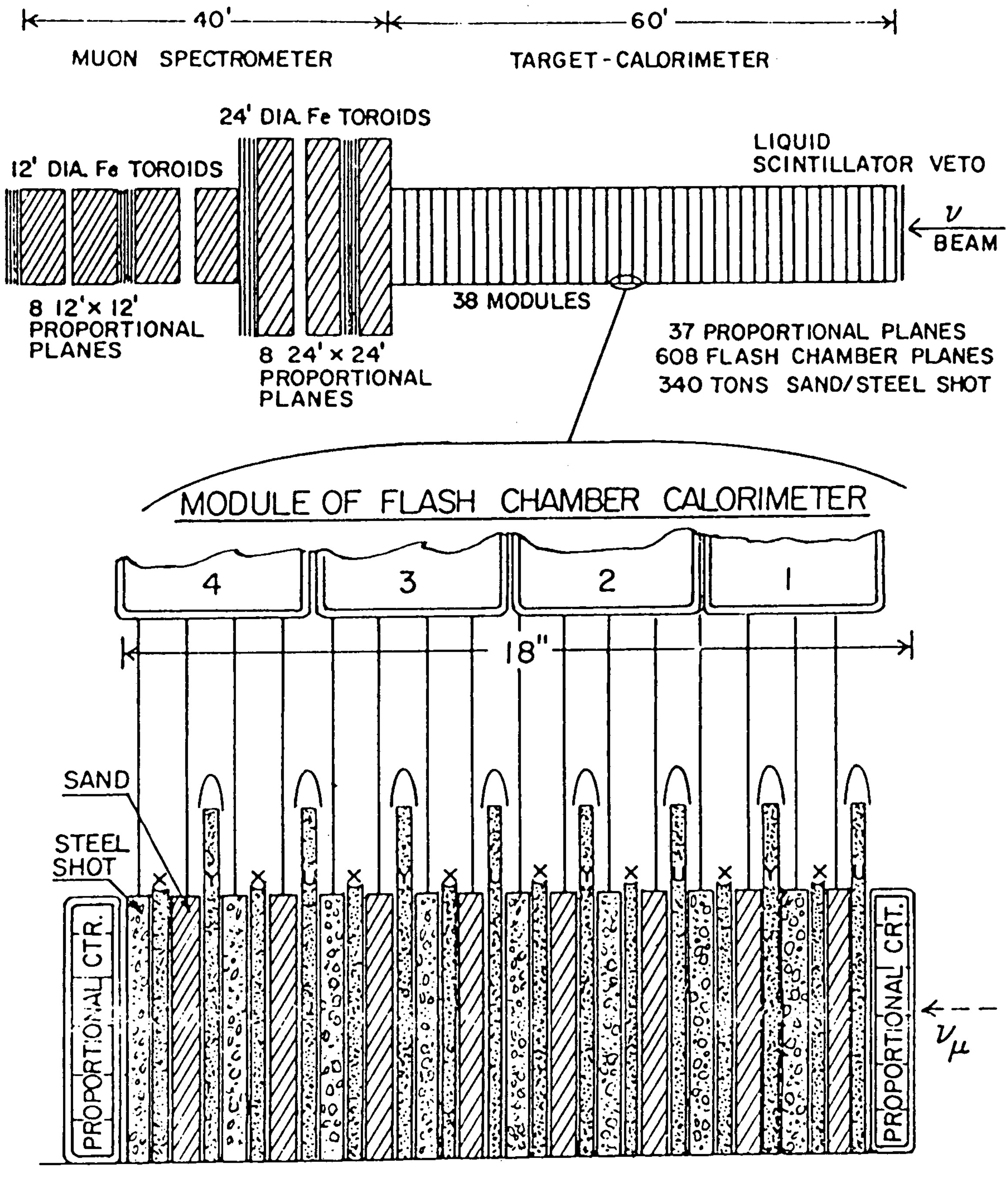
2. J. Bofill et al., IEEE Trans. Nucl. Sci. **NS 29** (1982) 400.

FNAL Neutrino Detector



FREJUS Detector for Nucleon Decay

LOCATION	FREJUS Tunnel, 4500 m water-equiv.-depth Modane, France
COLLABORATION	Aachen, Orsay, Palaiseau, Saclay, Wuppertal
TRACKING-PLASTIC	Flash chambers 0.5×0.5 cm^2 section Neogal (70% neon, 30% helium) 1 atm. Crossed planes (1024 tubes) of 6×6 m^2 Iron sampling 3 mm between F.C. planes Capacitive strips readout Energy resolution $15\%/\sqrt{E}$ for electrons $\sim$20% for pions around 0.3 GeV/c $\sim$3% for muons around 0.3 GeV/c
TRIGGER	Geiger tubes 1.5×1.5 cm^2 section Argon-ethylal-freon 1 atm. Crossed planes (344 tubes) of 6×6 m^2
MASS	8 tons per module (8 F.C. planes, 1 Geiger plane) Detector modular, mass 900 t Average density $\sim$2 Fiducial mass 600 t
SENSITIVITY	$\sim$10 events/year for well-identified decay mode of 10^{31} years partial lifetime

REFERENCES

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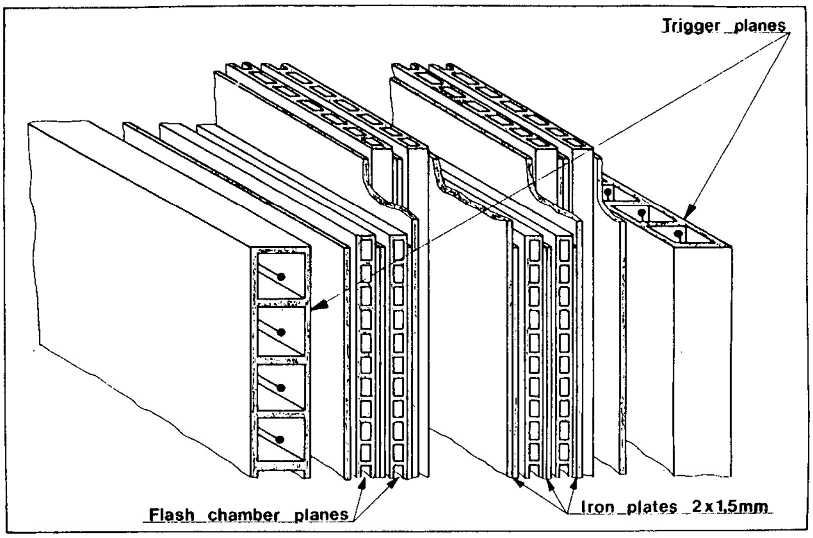
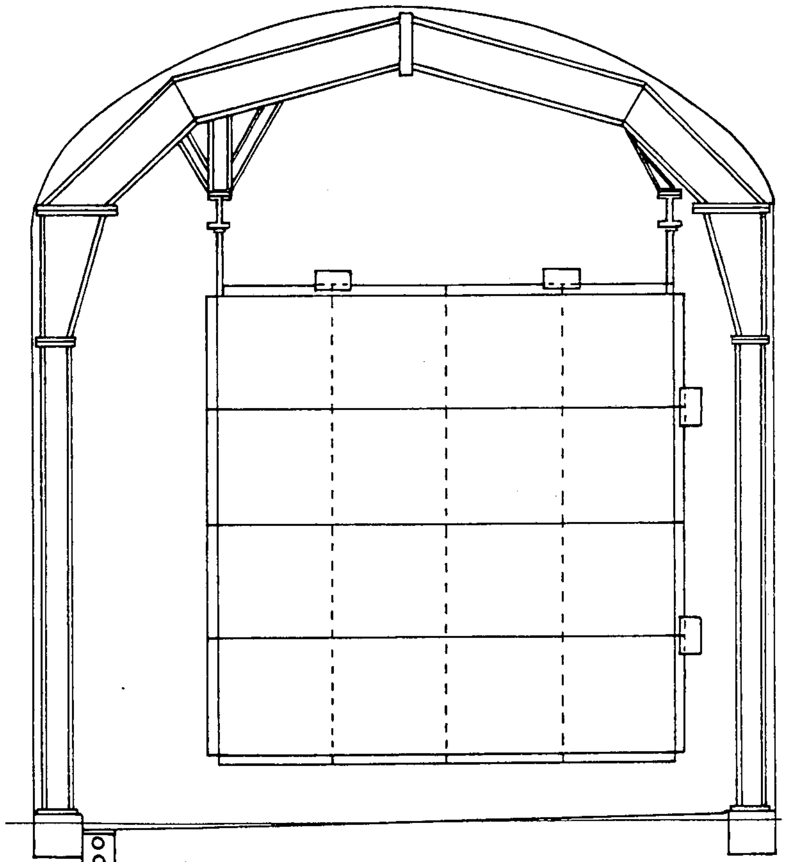
2. R. Barloutaud, Nucleon Decay Experiment with a Modular Flash Chamber Detector (Proceedings of the ICOBAN Conference, Bombay (1982).

FREJUS Detector for Nucleon Decay





XBL 832-8016

HELIOS

LOCATION	CERN-SPS (NA34) Geneva, Switzerland
BEAM/TARGET	(a) 450 GeV/c protons, 10^6/sec, <50 μm diameter spot on 50 μm Be wire target followed by 4 planes of Si detectors at z = 60, 90, 120, 150 mm (b) 200 GeV/c oxygen nuclei, 10^6/sec on 200 wire targets, each 100 μm diameter, separated by 0.5 mm along beam direction; the wires form part of a drift chamber (active target)
TRACKING	3 sets of drift chambers using CO_2 at 1 atm. in 0.35 Tesla-m dipole field $\sigma/p = 0.001\ p + 0.015$
CALORIMETERS	Dipole calorimeter: Fe yoke interleaved with 5 mm thick scintillator sheets in 24 azimuthal wedges Hadronic $\sigma/E \simeq 0.55/\sqrt{E}$ Wide-angle calorimeters: Wall of U-Cu/scintillator and Cu/scintillator modules Hadrons: $\sigma/E \simeq 0.37/\sqrt{E}$ and $0.50/\sqrt{E}$ Electrons: $\sigma/E \simeq 0.16/\sqrt{E}$ (previously used in AFS) Target and drift chamber region: Surrounded on four sides by U-Cu/scintillator calorimeters Uranium-liquid argon calorimeter: 6.0 absorption lengths thick, covering forward cone 1% methane added to reduce readout time of LA 264 cells, each 1.7 mm U, 1.5 mm LA 1.9 mm readout plane, 1.5 mm LA First 35 cells ($20X_0$) have highly segmented pad readout Read out longitudinally in 2 sections ($8X_0$, $12X_0$) Hadronic part has x-y strips Electrons: $\sigma/E = 0.11/\sqrt{E}$ Hadrons: $\sigma/E = 0.28/\sqrt{E}$ Backing calorimeter: U-Cu/scintillator modules (6 absorption lengths) as in wide-angle calorimeter
PARTICLE IDENTIFICATION	8-layer transition radiation detector Polypropylene radiator foils and Xe/CO_2 drift chamber to detect TR photons π/e rejection ~ 1000 Total hadron rejection of spectrometer $\simeq 10^5$
MUON SPECTROMETER	Proportional chamber Spectrometer used in NA3 experiment 3 mm wire spacing 4.1 Tesla-m superconducting magnet $\sigma_p/p \lesssim 10^{-3}p$
EXTERNAL SPECTROMETER	Covers rapidity region 0.9–2.0 3 drift chambers, 0.2 Tesla-m magnet $\sigma_p/p = 0.01p$ Aerogel Cerenkov counter (n = 1.031) TOF hodoscopes $\pi/k/p$ separation up to 2 GeV/c p identification up to 3.8 GeV/c AFS U-Cu/scintillator calorimeter modules

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3. H. Gordon et al., Nucl. Instr. & Meth. **196** (1982) 303, and O. Botner et al., CERN/EF 80-7 (1980).
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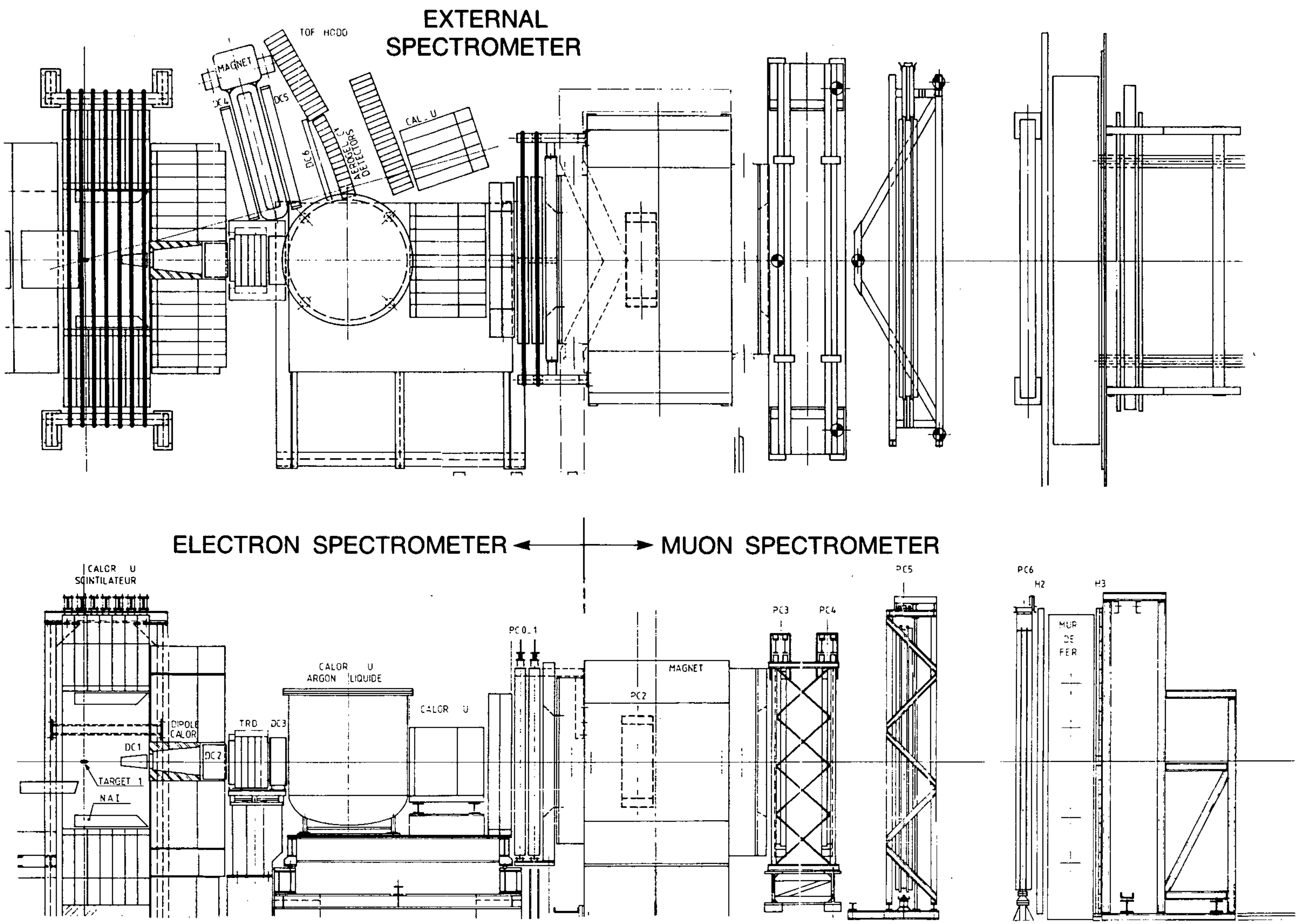


XBL 855-8864

HELIOS

Homestake Detector

LOCATION	Homestake Gold Mine Lead, SD, USA
COLLABORATION	University of Pennsylvania, Brookhaven National Laboratory
DETECTOR	Deep underground liquid scintillation detector together with a surface air shower array of 100 counters, each 1.2 m × 2.4 m, deployed over one square kilometer Liquid scintillator modules - PVC housings 30 cm × 30 cm × 8 m viewed by two hemispherical 13 cm photomultipliers Depth: 4200 m.w.e. (1480 m rock)
PHASE 1:	250 detector modules arranged into a hollow box of dimensions 8 m × 8 m × 16 m Each of the four long faces consists of 50 detector modules, while the two end faces contain 25 modules each

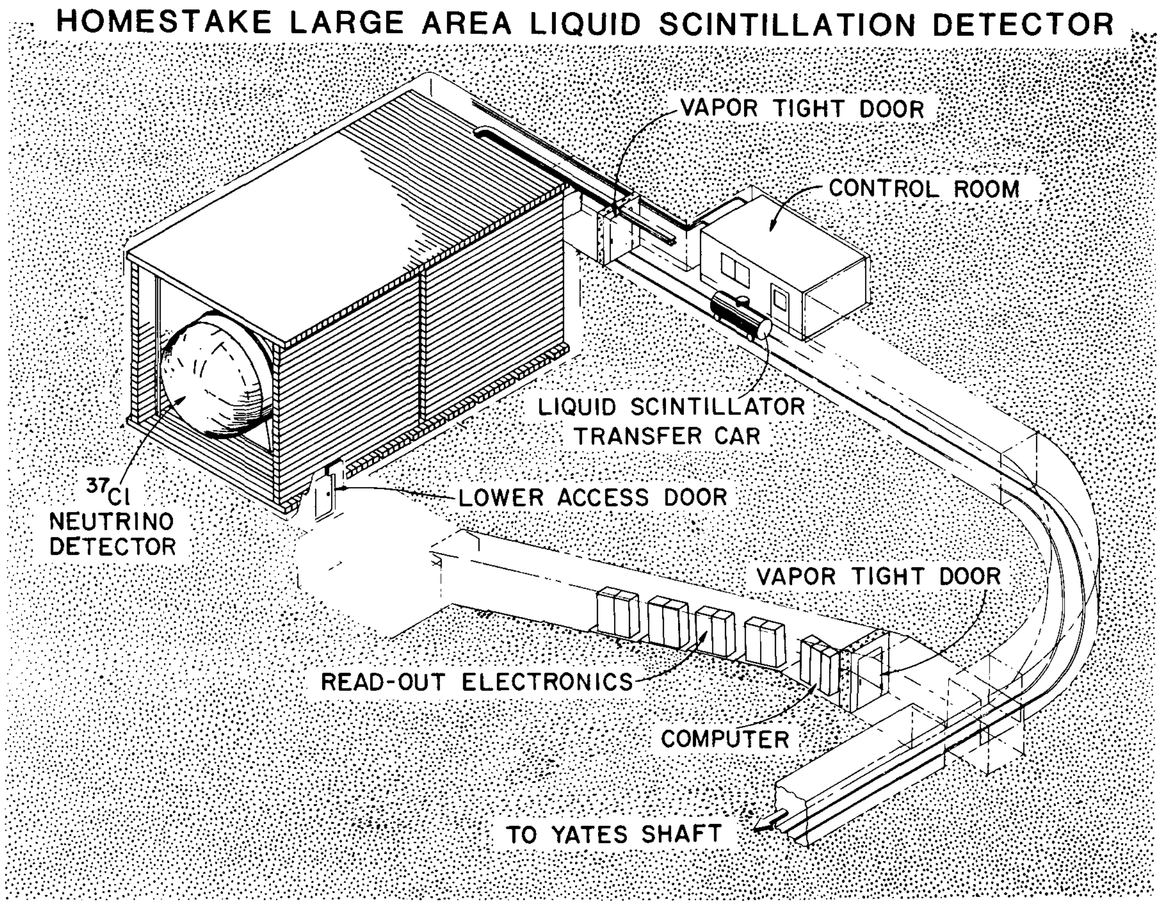
Spatial resolution:	15 cm
Energy resolution:	7.8% per module for minimum ionizing track
Energy threshold:	1/25 minimum ionizing (2 MeV)
Time resolution:	1.3 ns
Detector mass:	170 tons

PHASE 2:

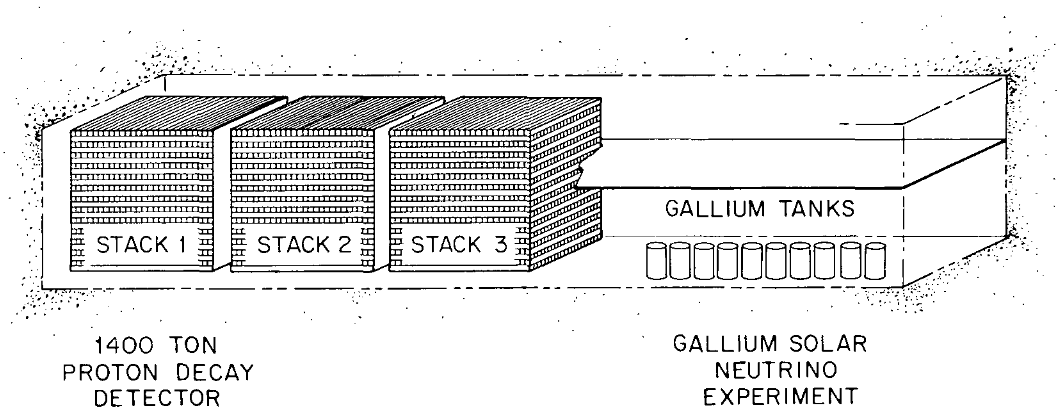
1878 detector modules (same as those in phase 1) arranged in 3 stacks, each 8 m × 8 m × 8 m
The detector elements are arranged with alternate layers in crossed directions
Tracking chambers are interspersed between the scintillator elements
Parameters are as in phase 1 except for the following:

Spatial resolution:	1 cm
Nucleon decay modes:	All modes except those with more than one neutrino
Muon → electron decay detection efficiency:	90%
Detector mass:	1400 tons
Nucleon lifetime sensitivity:	5×10^{32} yr

Homestake Detector



NEW HOMESTAKE UNDERGROUND LABORATORY



XBL 832-8406

HRS (High Resolution Spectrometer)

LOCATION	PEP e^+e^- ring SLAC, Stanford, CA, USA
MAGNET	16 kG (superconducting) Diameter = 4 m, length = 3.8 m
TRACKING	4-layer vertex chamber: 330 cells, 100 μm spatial resolution Inner cylindrical drift chamber (15 layers): 2.53 m long at 0.21–1.02 m radius Outer drift tubes (2 layers): 3.66 m long at 1.90 m radius Momentum resolution $\sigma_p/p < 0.1\%$ p for p = 14.5 GeV/c
SHOWER COUNTERS	40 Modules $11X_0$ Pb-scint. sandwich inside the coil; 1 layer PWC $\sigma_E/E = 16\% / \sqrt{E}$ 2 samples in depth
ENDCAPS	40 Modules $8X_0$ Pb-scint. sandwich Wave shifter readout; 1 layer PWC $\sigma_E/E = 20\% / \sqrt{E}$
TIME-OF-FLIGHT	From front $3X_0$ of shower counter at r = 1.95 m σ_τ = 170 ps for Bhabhas σ_τ = 350 ps for hadrons
PHOTO-IONIZATION CERENKOVS	704 segments in 11 toroids 10 atmospheres give (K, p)π separation between 1.6 and 6 GeV/c
LUMINOSITY MONITOR	Telescope with Pb-glass at 32–60 mrad

REFERENCES

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2. N. Harnew and D. Meyer, Nucl. Instr. & Meth. **186** (1981) 513.
3. D. Bender et al., Phys. Rev. **D30** (1984) 515.
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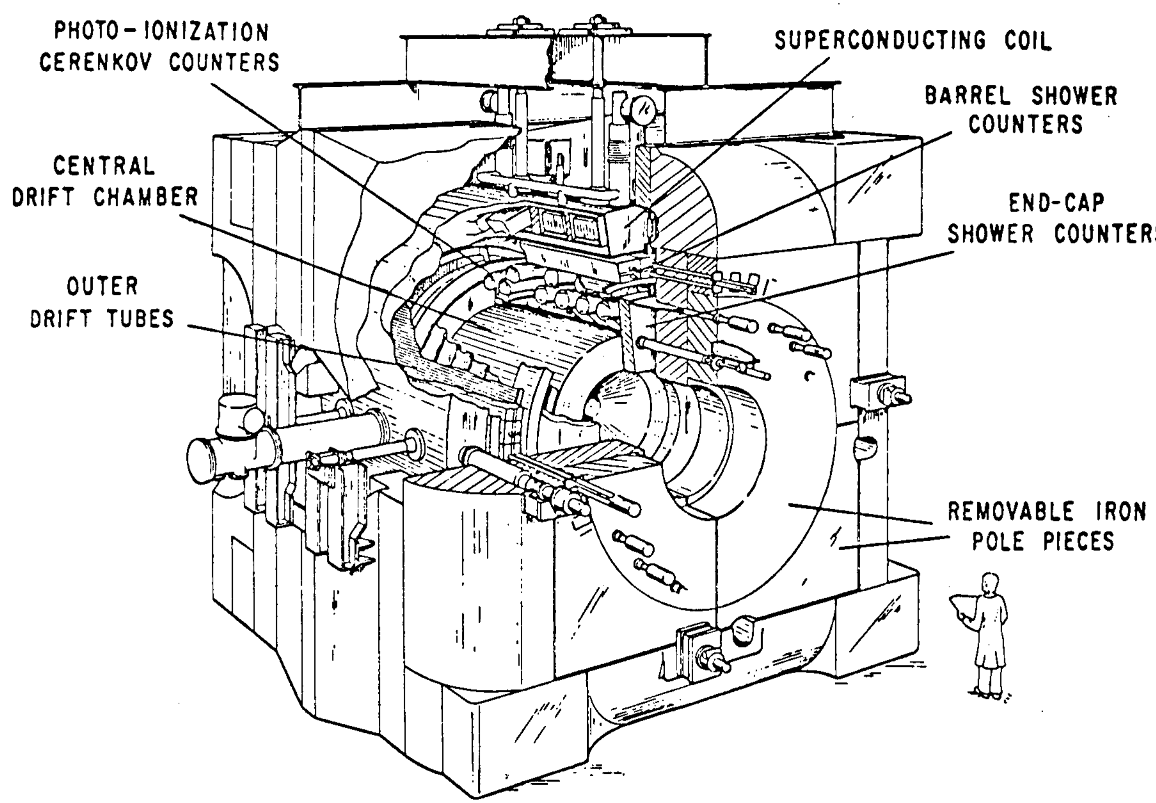


HIGH RESOLUTION SPECTROMETER

ARGONNE-INDIANA-LBL-MICHIGAN-PURDUE-SLAC

XBL 831-7884

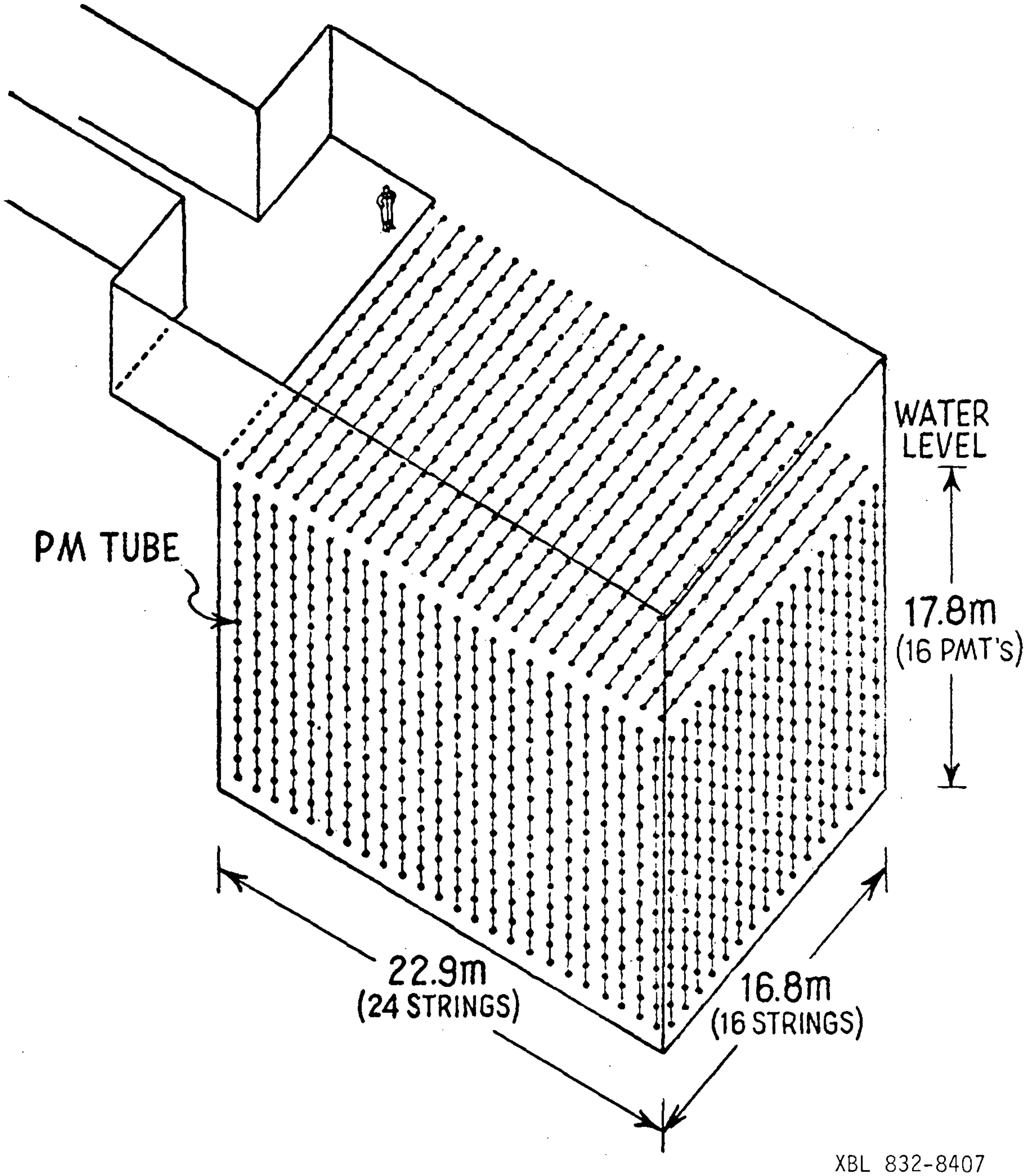
HRS (High Resolution Spectrometer)

IMB Detector for Nucleon Decay

(Irvine-Michigan-Brookhaven Water Cerenkov Detector)

LOCATION	Fairport Harbor Salt Mine, Morton-Thiokol Corporation Painesville, OH, USA Latitude = 41.72°, longitude = 81.27°
SHIELDING	1940 feet overburden 1570 m water equivalent Cosmic ray muon rate = 2.7 Hz Cosmic ray neutrino rate ~ 1/day (2:1 = $\nu_\mu:\nu_e$) Stopping muon rate ~ 3% Dimuon rate ~ 3 %
ACTIVE MEDIUM	Pure water Transmission length > 40 m at 440 nm $\geqslant$ 20 m at 330 nm and 550 nm Cerenkov angle = 41° (at β = 1)
DETECTORS	2048 5″-diameter, hemispherical PM tubes PM threshold ~ 1/4 photoelectron PM noise rate = 1.5 kHz median Dynamic range recorded per PM: fast time = 512 ns (1 ns least count) slow time = 7 μs (15 ns least count) pulse height ~ 200 photoelectrons (~ 1/4 pe least count)
THRESHOLD	>25 MeV dE/dx at β = 1
SENSITIVITY	~4 MeV dE/dx at β = 1 produces 1 photoelectron Efficiency for $\mu \to e$ detection = 60%
DETECTOR LAYOUT	Regular, rectangular array at ~1 m spacing on 6 faces; 16 × 24 PM's on 4 faces, 16 × 16 PM's on 2 faces Totally absorptive face behind PM's ~0.5 m water behind PM's
MASS	Total = 8000 tons (17.8 m × 18.7 m × 23.9 m) Fiducial for $p \to e^+\pi^0$ = 3300 tons = 2 × 10^{33} nucleons (13 m × 14 m × 19 m)
RESOLUTION	For $p \to e^+\pi^0$ depositing ~225 photoelectrons: vertex Δr = 0.6 m energy $\Delta E/E = \pm 10\%$ opening angle $\Delta\sigma$ = 15° Similar vertex and energy resolutions for μ^+K^0 with $K^0 \to \pi^0\pi^0$
OPERATIONAL	August 1, 1982 Duty cycle ~ 70%

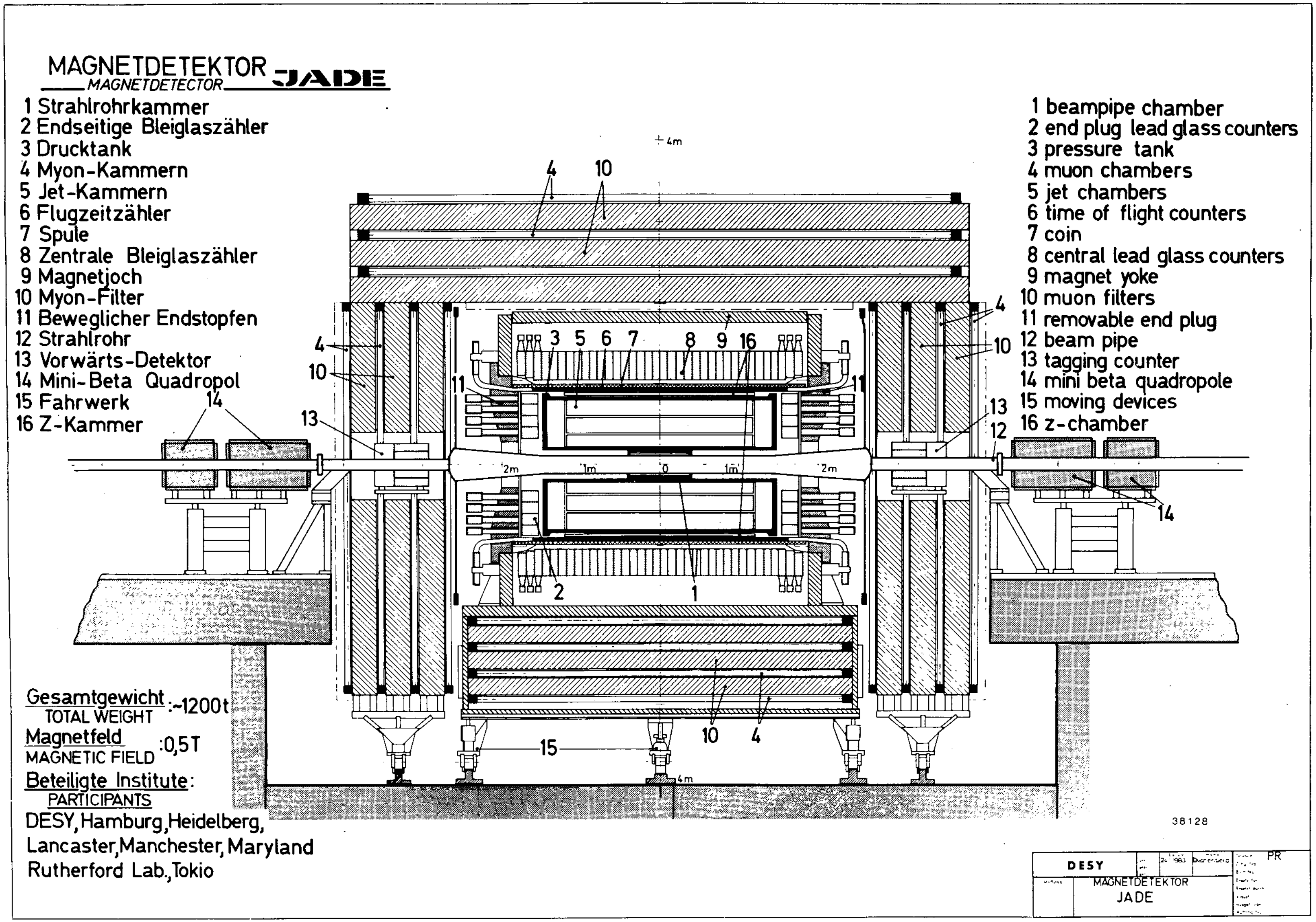
IMB Detector for Nucleon Decay



IRVINE - MICHIGAN - BROOKHAVEN DETECTOR

JADE

LOCATION	PETRA e^+e^- ring DESY, Hamburg, W. Germany
MAGNET	4.8 kG solenoid; normally conducting, water-cooled, Al coil; thickness $0.5X_0$ Diameter = 2 m, length = 3.5 m
TRACKING	Cylindrical drift chamber (JET chamber) 2.36 m long at 21–79 cm radius Argon-methane-isobutane at 4 atm. 48 points on tracks with $\|\cos\theta\| < 0.83$ $\geqslant 8$ points over 97% of Ω Charge division gives $\Delta z = 1.6$ cm dE/dx to $\pm 6\%$ for Bhabhas $\sigma_p/p = 4\%$ for $p < 2$ GeV/c $= 1.8\%$ for high p $= 1.3\%$ for high p with event vertex used in track fit Vertex chamber (beampipe chamber) 76 cm long at 9–16 cm radius 7 points on track with $\|\cos\theta\| < 0.93$ Z chamber (cylindrical drift chamber with wires strung polygonally, yielding drift fields parallel to the beam direction to allow accurate measurement of the z-coordinate) 2.4 m long at 86–88 cm radius
SHOWER COUNTERS BARREL	 2604 tapered modules of Pb-glass 30 cm deep, arranged in 31 rings, 84 wedges per ring (central 6 rings SF6, $17.3X_0$, remainder SF5, $12.5X_0$) $\Delta E/E = 6\%/\sqrt{E}$ $\sigma_\theta = 0.6°$, $\sigma_\phi = 0.6°$
ENDCAPS	192 elements of Pb-glass (SF5) as in barrel
MUON DETECTION	618 single-wire drift chambers, arranged in 4 or 5 planes, interspersed with absorber (magnet flux return + 3 layers of iron-loaded concrete; total thickness 785 g/cm^2) Covers 93% of Ω
TIME-OF-FLIGHT	42-counter scintillator hodoscope (r = 95 cm) between JET chamber and magnet coil In conjunction with beam crossing signal, gives TOF resolution = 400 ps
LUMINOSITY MONITOR	35–75 mrad Pb-scintillator sandwich, 50 cm deep ($20X_0$), arranged in 8 sectors, each divided into 3 concentric rings giving equal Bhabha rates BBQ light guides on both sides of each ring element (40 scintillator slices, 1 cm deep)
OTHER COUNTERS	20-counter forward scintillator hodoscope, between endcaps and muon detector, for forward muon triggering


MAGNETDETEKTOR JADE
MAGNETDETECTOR
1 Strahlrohrkammer
2 Endseitige Bleiglaszähler
3 Drucktank
4 Myon-Kammern
5 Jet-Kammern
6 Flugzeitzähler
7 Spule
8 Zentrale Bleiglaszähler
9 Magnetjoch
10 Myon-Filter
11 Beweglicher Endstopfen
12 Strahlrohr
13 Vorwärts-Detektor
14 Mini-Beta Quadropol
15 Fahrwerk
16 Z-Kammer
1 beampipe chamber
2 end plug lead glass counters
3 pressure tank
4 muon chambers
5 jet chambers
6 time of flight counters
7 coin
8 central lead glass counters
9 magnet yoke
10 muon filters
11 removable end plug
12 beam pipe
13 tagging counter
14 mini beta quadropole
15 moving devices
16 z-chamber
Gesamtgewicht :~1200t
TOTAL WEIGHT
Magnetfeld :0,5T
MAGNETIC FIELD
Beteiligte Institute:
PARTICIPANTS
DESY, Hamburg, Heidelberg,
Lancaster, Manchester, Maryland
Rutherford Lab., Tokio
4m
2m
1m
0
1m
2m
4m
38128
DESY
MAGNETDETEKTOR
JADE
PR

JADE

Kamioka Nucleon Decay Detector

LOCATION	1000 m underground in Kamioka mine Gifu prefecture (~300 km west of Tokyo), Japan
WATER CONTAINER	Steel tank of cylindrical shape, 15.6 m diameter × 16 m high, containing 2900 m^3 of pure water
WATER PURIFIER	50 μ filter / 20 μ filter-ion exchange purifier / 0.45 μ filter-UV sterilizer / 0.22 μ filter
CERENKOV LIGHT DETECTOR	1050 × 20″ diameter photomultipliers, R1449X, distributed over the inner surfaces of the water tank at 1 PM/m^2 Photocathode covers 20% of the entire surface Expected energy resolution of $p \rightarrow e\pi^0$ event is 4% Equipped with FADC's to record μ-e decays and/or successive nucleon decays, if such existed
ANTICOUNTER LAYERS	Water layers at least 1.2 m thick, viewed by 123×R1449X, covering the whole sensitive volume
DATA-TAKING	PDP 11/60

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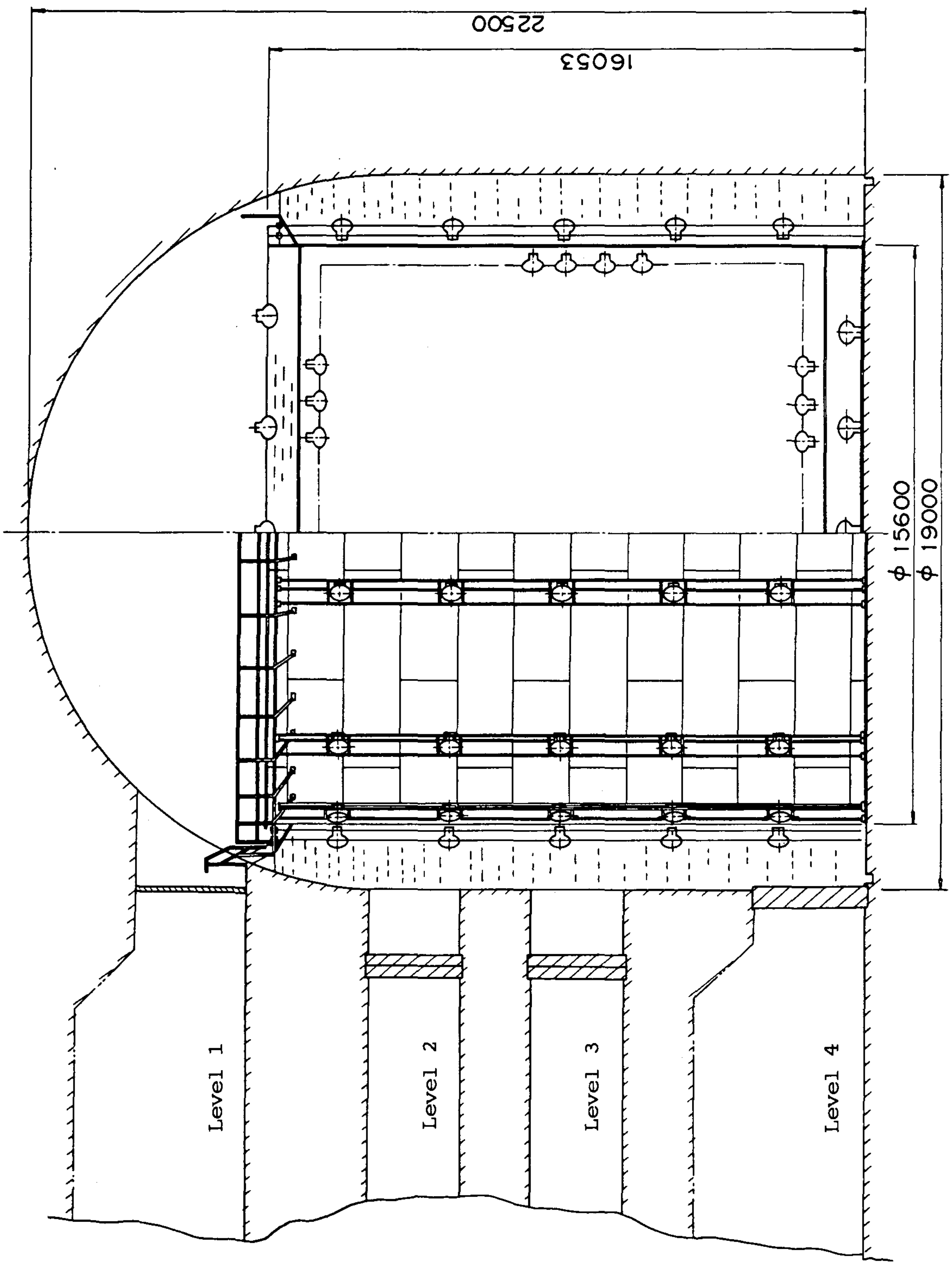
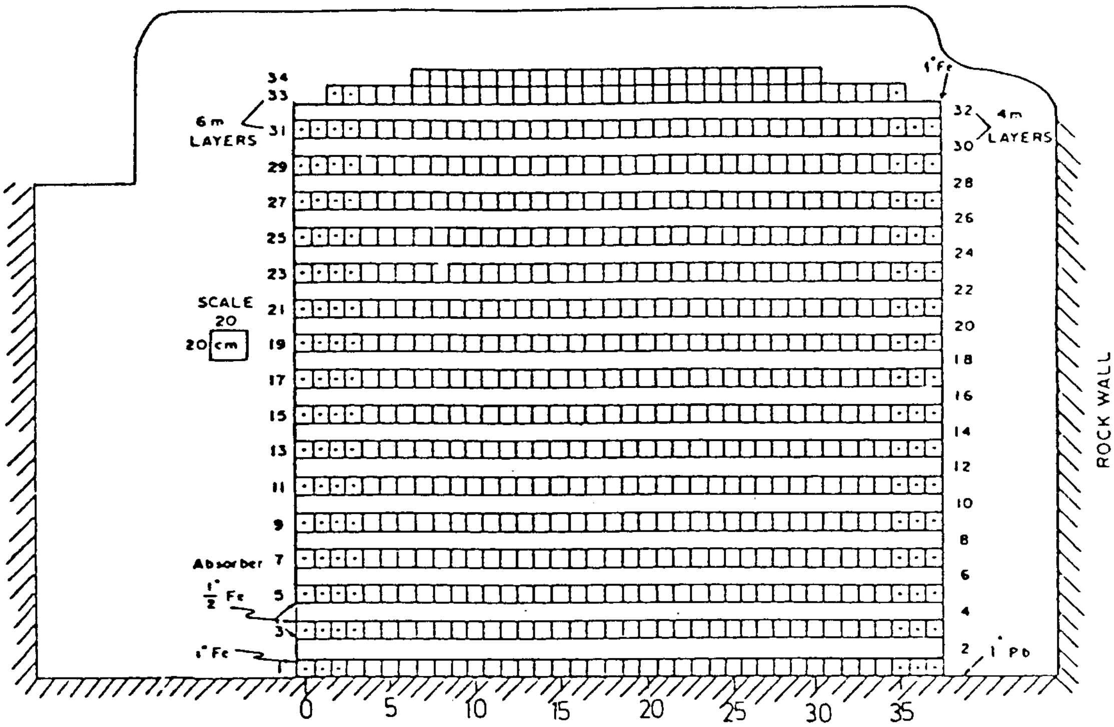
Kamioka Nucleon Decay Detector

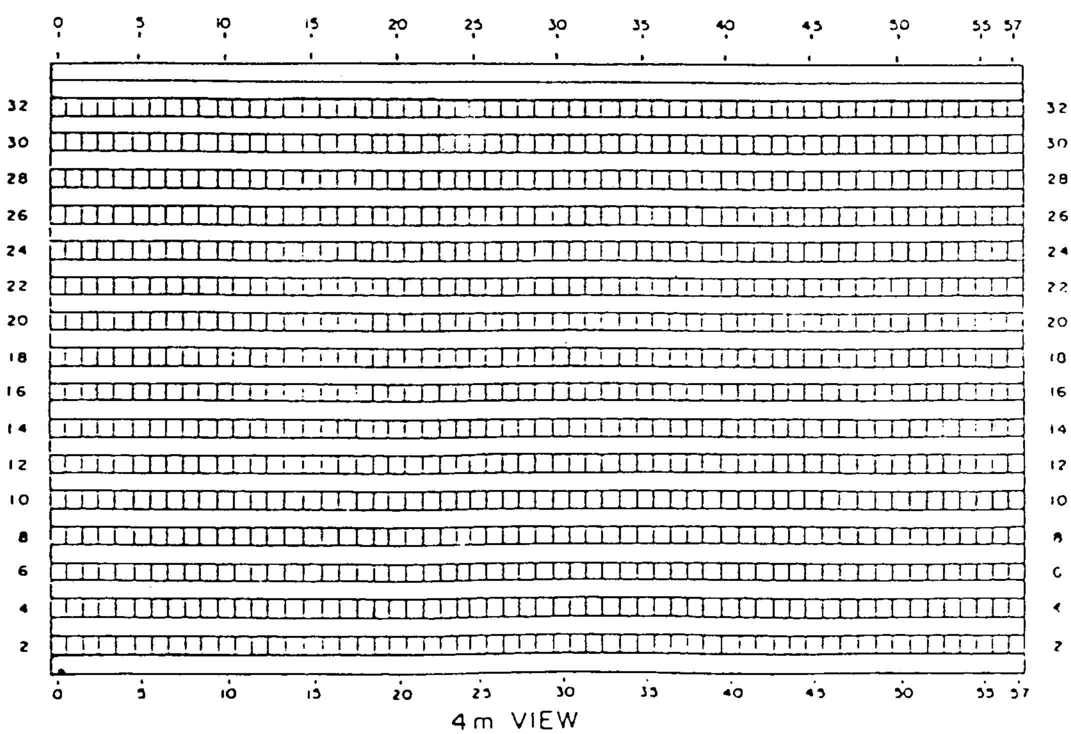


KGF Detector for Nucleon Decay

LOCATION	Kolar Gold Fields, South India, Latitude 12°N 7000 kg/cm^2 deep in Kolar rock (= 7600 m.w.e. of standard rock)
COSMIC RAYS	Rate of atmospheric muons is 1.9/day
DETECTOR	Comprised of 1594 proportional counters of sealed type filled with 90% Ar and 10% methane up to 1.1 atm. 4 m long and 6 m long counters are set in alternative layers, crossed geometry Each counter has a cross section 10$\times$10cm^2 with 2.3 mm thick iron wall Iron plates between layers are 1.2 cm thick Total weight is 140 tons
TRIGGER	5 hold coincidence in any consecutive 11 layers, or 2 hold coincidence of 2 fired counters in any 3 consecutive layers
RECORD	Position, pulse height, and time of fired counters
ANALYSIS OF TRACKS	Direction of motion: from increase of dE/dx Identification of particles: from relation of dE/dx and residual range Energy estimation: total ionization loss and also range-energy relation
OPERATIONAL	21 October 1980

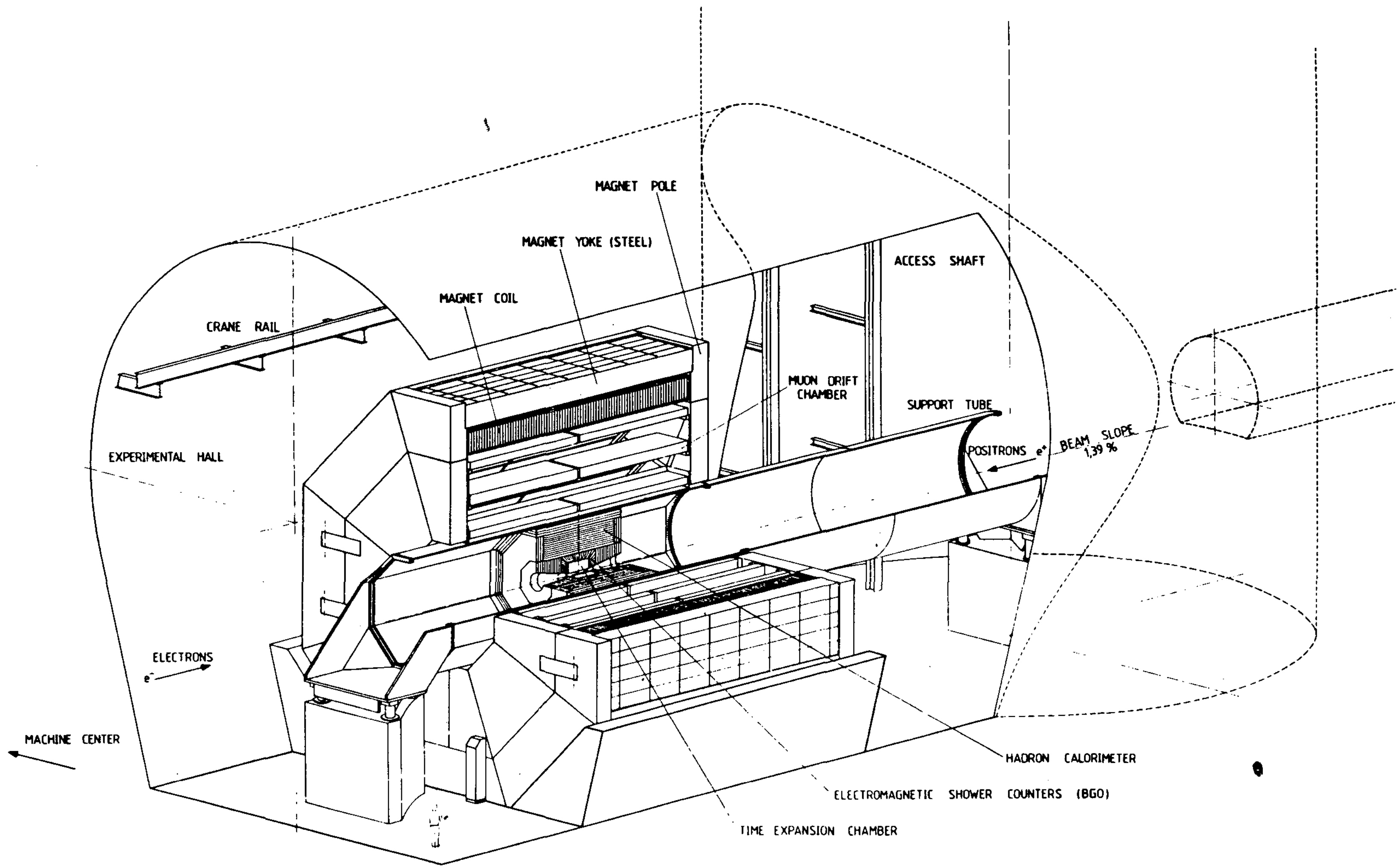
KGF Detector for Nucleon Decay





LEP3

LOCATION	LEP e^+e^- rings CERN, Geneva, Switzerland
MAGNET	Large volume, 0.5 Tesla solenoid 15.6 m high, 13.6 m long
MUON CHAMBERS	Inside magnet coil, BL^2 = 5.9 Tesla-m^2 Central drift chambers 3 layers with multiple sampling $40° < \theta < 135°$ 2 layers for 30° – 45° Forward chambers for $0° < \theta < 30°$ Δ_p/p = 0.04% p (2% at 50 GeV)
HADRON CALORIMETER	7 interaction lengths Octagonal barrel and endcaps Barrel IR = 87 cm, OR = 213 cm Cu-U absorber interspersed with proportional tubes Projective tower readout Muons below 1.6 GeV/c range out 97% 4π coverage (13.5° – 166.5° in polar angle)
ELECTROMAGNETIC CALORIMETER	12,000 BGO ($Bi_4Ge_3O_{12}$) crystals, $22X_0$ thick All point to IR with nearly equal cross sections $\sigma_E/E = 0.5\%/\sqrt{E}$ at low energies $= 1\%$ for 1 GeV $< E <$ 50 GeV $\sigma_{xy} < 3$ mm
VERTEX CHAMBER	TEC (time expansion chamber) 2 sections: inner has 12 segments, outer has 24 segments IR = 8 cm, OR = 50 cm, length = 90 cm 100 MHz flash ADC's readout 80% CO_2 – 20% isobutane $\sigma \simeq 40\ \mu m$
LUMINOSITY MONITOR	BGO crystals and proportional chambers covering 25 – 58 mrad


MAGNET POLE
MAGNET YOKE (STEEL)
MAGNET COIL
CRANE RAIL
ACCESS SHAFT
MUON DRIFT CHAMBER
SUPPORT TUBE
POSITRONS e+
BEAM SLOPE 1,39 %
EXPERIMENTAL HALL
ELECTRONS
e-
MACHINE CENTER
HADRON CALORIMETER
ELECTROMAGNETIC SHOWER COUNTERS (BGO)
TIME EXPANSION CHAMBER

LEP3

MAC (MAgnetic Calorimeter)

LOCATION	PEP e^+e^- storage ring SLAC, Stanford, CA, USA
MAGNETS	5.7 kG solenoid, 7.5 cm thick Al coil Diameter = 1 m, length = 2.3 m 17 kG iron toroids, 1 m thick
TRACKING	Vertex chamber 60 cm long, 4.5–8.5 cm tracking radius 6 layers, 7 mm diameter drift tubes 49% Ar, 50% CO_2, 1% Methane at 4 atm Cylindrical drift chamber 2.2 m long, 12–45 cm tracking radius Argon - 10% methane at 1 atm. 10 layers, double sense wires, 3° stereo $\geqslant$5 points on tracks over $\Delta\Omega$ = 95% of 4π σ_p/p = 6.5% p; dE/dx to ±15% Muon tracking chambers 4 planes of 10 cm diam. drift tubes surrounding magnetized iron toroids σ_p/p = 30%; $\Delta\Omega$ = 97% of 4π
SHOWER DETECTORS	Barrel: $14X_0$ of Pb - proportional chamber sandwich $\sigma_E/E = 20\%/\sqrt{E}$; $\sigma_\phi = 0.8°$, $\sigma_\theta = 1.3°$ z-coordinate from charge division Endcaps: $14X_0$ of Fe - proportional chamber sandwich $\sigma_E/E = 45\%/\sqrt{E}$; $\sigma_\phi = 2°$, $\sigma_\theta = 1.5°$ ϕ-coordinate from cathode strips Total: $\Delta\Omega$ = 97% of 4π
HADRON CALORIMETER	5.5 λ_{abs} of Fe - proportional chamber sandwich $\sigma_E/E = 75\%/\sqrt{E}$; $\Delta\Omega$ = 97% of 4π $\sigma_\theta = 1.5°$; $\sigma_\phi = 1°$ (barrel), 5° (endcaps)
TIME-OF-FLIGHT	144 scintillation counters (72 barrel, 72 endcaps) r = 1.3 m; Δt = 1 ns; $\Delta\Omega$ = 97% of 4π
SMALL-ANGLE VETO	$8.5X_0$ of Pb - proportional chamber sandwich Covers 5°–17° from beam
LUMINOSITY MONITOR	4 scintillator/shower counter telescopes at 32 mrad horizontally

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2. W.T. Ford, SLAC-PUB-2894, March 1982 (Proceedings SLAC International Conference on Instrumentation for Colliding Beams).
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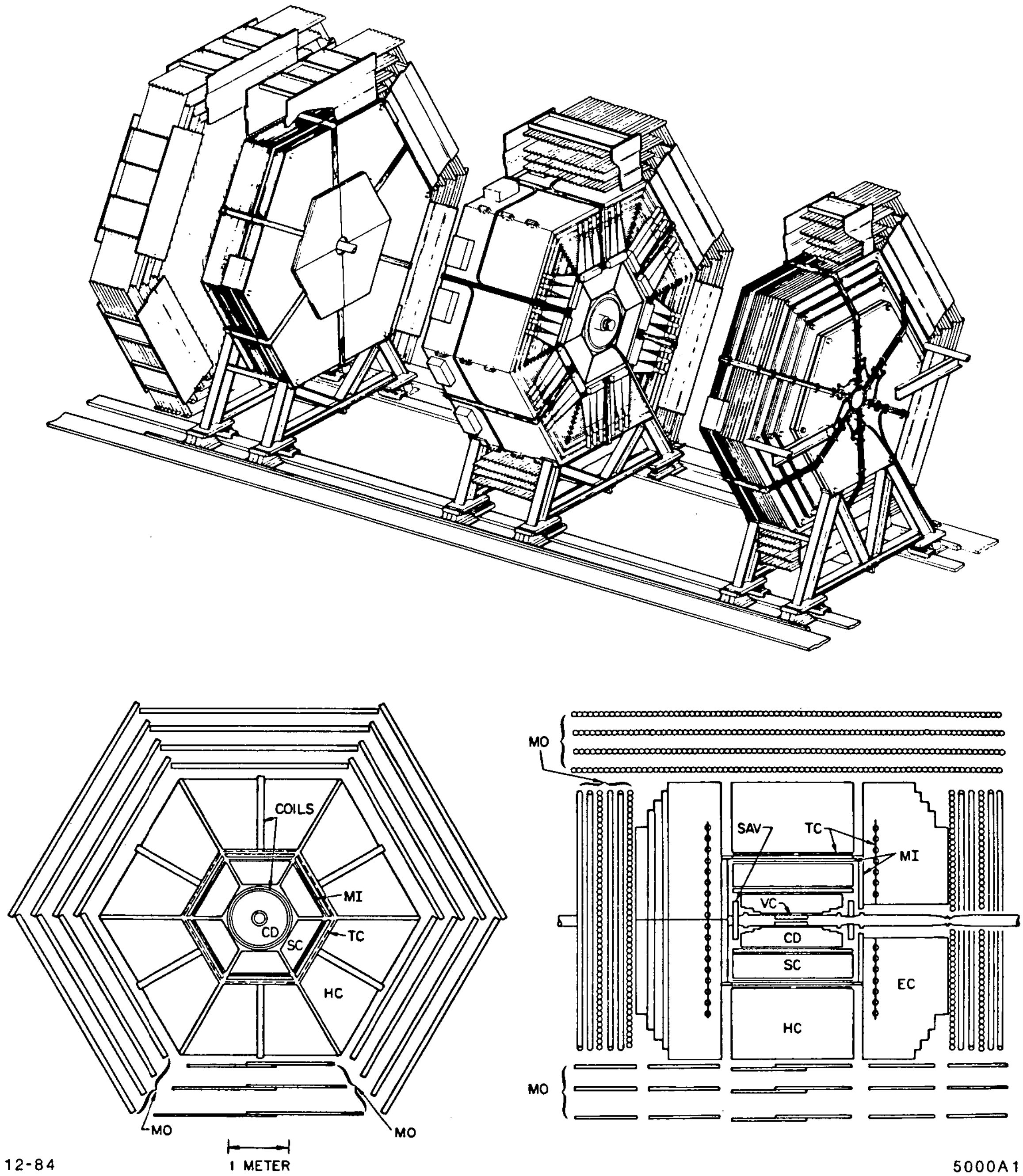
MAC (MAgnetic Calorimeter)



MAC Detector Components:

VC	- Vertex Chamber	SAV -	Small Angle Veto
CD	- Central Drift Chamber	EC -	End-cap Shower and Hadron Calorimeters
SC	- Shower Chamber (Central)		
TC	- Trigger/TOF Scintillators	MO, MI -	Muon Drift Chambers
HC	- Hadron Calorimeter (Central)	Coils -	Solenoid and Toroid

MARK II

LOCATION
PEP and SLC
SLAC, Stanford, CA, USA

MAGNET
5 kG Al coil solenoid, 1.6 m radius

TRACKING CHAMBERS

Central drift chamber:
Inner radius = 19.2 cm, outer radius = 152 cm, active length = 2.3 m
12 radial layers of cells with 6 sense wires each, ± 3.8° stereo angle on alternate layers
Each cell contains six 30 μm gold-plated tungsten wires at 8.33 mm spacing staggered at ± 380 μm from cell axis, $\sigma < 200$ μm
σ_p/p^2 with vertex constraint is
$0.15\%\ \mathrm{GeV}^{-1}$ for $|\cos\theta| < 0.7$
$0.30\%\ \mathrm{GeV}^{-1}$ for $0.7 < |\cos\theta| < 0.85$
$0.85\%\ \mathrm{GeV}^{-1}$ for $0.85 < |\cos\theta| < 0.89$
Full tracking efficiency for $|\cos\theta| < 0.89$
de/dx with 72 samples gives 6.9% resolution
Probable gas is 89% argon, 10% CO_2, 1% methane

Vertex drift chamber (SLC only):
Developing prototypes of precision drift chamber, silicon strip detector, and CCD detector

Inner trigger chamber (PEP only):
6 layers of aluminized mylar proportional tubes
Inner radius = 9.5 cm, outer radius = 14.8 cm, length = 74.6 cm
Covers polar angles between 23 and 157 degrees

TIME-OF-FLIGHT
48 counters, 5 cm thick, read out at both ends
Covers 68% of 4π
1.52 m flight path
3σ particle separation of $\begin{cases} e/\pi \text{ for } p < 7\ \mathrm{GeV/c} \\ \pi/K \text{ for } p < 1.1\ \mathrm{GeV/c} \end{cases}$

MUON DETECTION
Proportional tubes interleaved with steel absorber covering 55% of 4π (4 layers each for total thickness of 1 m)

ELECTROMAGNETIC CALORIMETERS

Barrel:
8 modules of Pb-liquid argon ($15X_0$ each), arranged in octagon outside coil
Covers 64% of 4π
2 mm Pb sheets separated by 3 mm liquid argon gaps
37 layers ($0.4X_0$ sampling) are ganged to provide 6 samples in depth
Readout in 3.8 cm wide strips in ϕ, θ, u directions
$\Delta E/E \simeq 13\%/\sqrt{E}$

Endcaps:
36 layers of alternating X, Y, U, V Pb-proportional tubes ($18X_0$)
50 micron stablohm wire in 1.5 cm × 0.9 cm tubes projectively ganged
$0.7 < |\cos\theta| \leq 0.95$
$\Delta E/E \simeq 17\%/\sqrt{E}$

Small angle monitor (SLC only):
9 drift chamber planes followed by 6 Pb drift chamber planes with $\sigma \sim 200$ μm
Covers 50–200 mrad
$\Delta E/E \simeq 30\%/\sqrt{E}$ at lower momenta and 15% at 50 GeV

LUMINOSITY MONITOR

PEP:
Defining scintillation counters + shower counter
18 layers 1/4″ Pb and 1/2″ scintillator, read out with BBQ wave shifter

SLC:
Tungsten-scintillator mini SAM
Covers 15–25 mrad

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2. G.S. Abrams et al., IEEE Trans. Nucl. Sci. **NS 25** (1978) 1, *ibid* 309, and **NS 27** (1980) 59.
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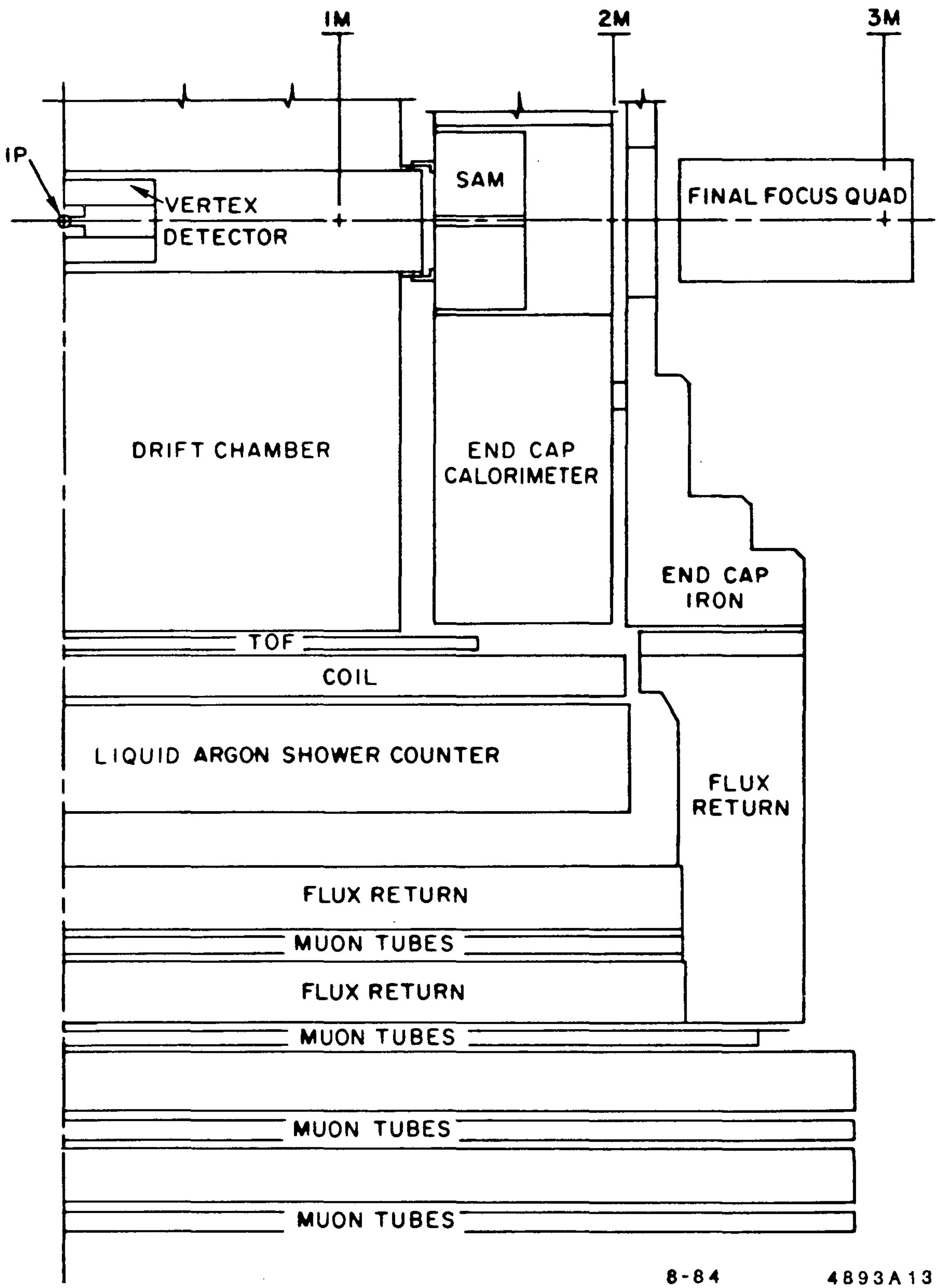
MARK II

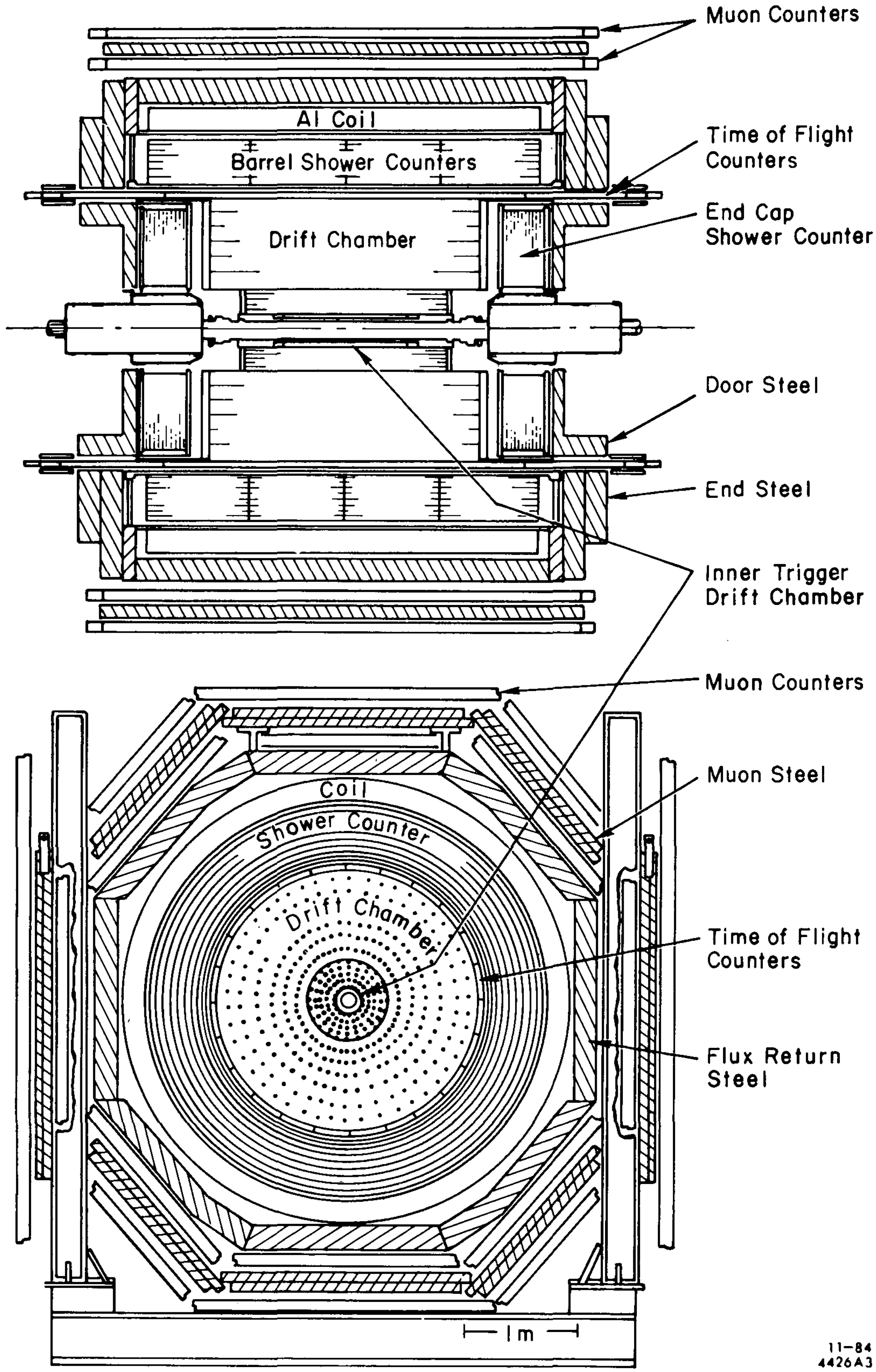


1M
2M
3M
IP
VERTEX
DETECTOR
SAM
FINAL FOCUS QUAD
DRIFT CHAMBER
END CAP
CALORIMETER
END CAP
IRON
TOF
COIL
LIQUID ARGON SHOWER COUNTER
FLUX
RETURN
FLUX RETURN
MUON TUBES
FLUX RETURN
MUON TUBES
MUON TUBES
MUON TUBES
8-84
4893A13

MARK III

LOCATION	SPEAR e^+e^- storage ring SLAC, Stanford, CA, USA
MAGNET	4.0 kG conventional aluminum coil
TRACKING	Drift chamber, O.D. 229 cm, length 234 cm 8 layers of cells, 2 stereo, 4 charge division 4 × 32 1-wire cells in trigger layer 12 × 32 sense-wire cells in inner dE/dx layer 16 × layer number, 3 sense-wire cells in outer layers 89% argon, 10% CO_2, 1% methane $(\Delta p/p)^2 = (1.5\%)^2 + (1.5\%\ p)^2$
SHOWER COUNTER	24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total) A cylindrical array of 1.3 cm × 2.9 cm × 3.5 m cells, 320 per layer, read out at both ends with charge division; the inner 6 layers are read individually, and the outer 18 in groups of 3 80% argon, 20% methane $\sigma_\phi = 7$ mrad; $\sigma_\theta \sim 15$ mrad at 45°; $\sigma_E/E = 17\%/\sqrt{E}$
ENDCAPS	24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total) An array of rectangular 1.2 cm × 2.7 cm wide aluminum proportional tubes are glued between $\frac{1}{2}X_0$ layers of Pb 80% argon, 20% methane $\sigma_x = 0.7$ cm; $\sigma_y \sim 0.9$ cm
TIME-OF-FLIGHT	48 × 15 cm × 5 cm × 3.2 m Pilot F scintillation counters mounted in a cylindrical array around the drift chamber, read out by Amperex XP2020 photo-multipliers on each end of the scintillators $\sigma_t \simeq 170$–190 ps
MUON DETECTION	2 double layers of 5 cm diameter, 4.2 m long proportional tubes mounted outside a 20 cm Fe flux return and separated by an additional 13 cm of Fe absorber The array covers 2/3 of the solid angle $\sigma_\phi = 4$ mrad; $\sigma_\theta = 24$ mrad
TRIGGER	Uses timing information from 2 layers of the inner trigger chamber and a chronotron circuit to restrict the trigger to a ±100 ns interval Three layers of unfitted tracking information from the drift chambers are used to define tracks Triggering is on one track plus time-of-flight information or 2 tracks; solid angle $\simeq 80\%$
LUMINOSITY MONITOR	4 scintillator + shower counter telescopes at 25 mrad

MARK III



Muon Counters
Al Coil
Barrel Shower Counters
Time of Flight Counters
End Cap Shower Counter
Drift Chamber
Door Steel
End Steel
Inner Trigger Drift Chamber
Muon Counters
Muon Steel
Coil
Shower Counter
Drift Chamber
Time of Flight Counters
Flux Return Steel
1m
11-84
4426A3

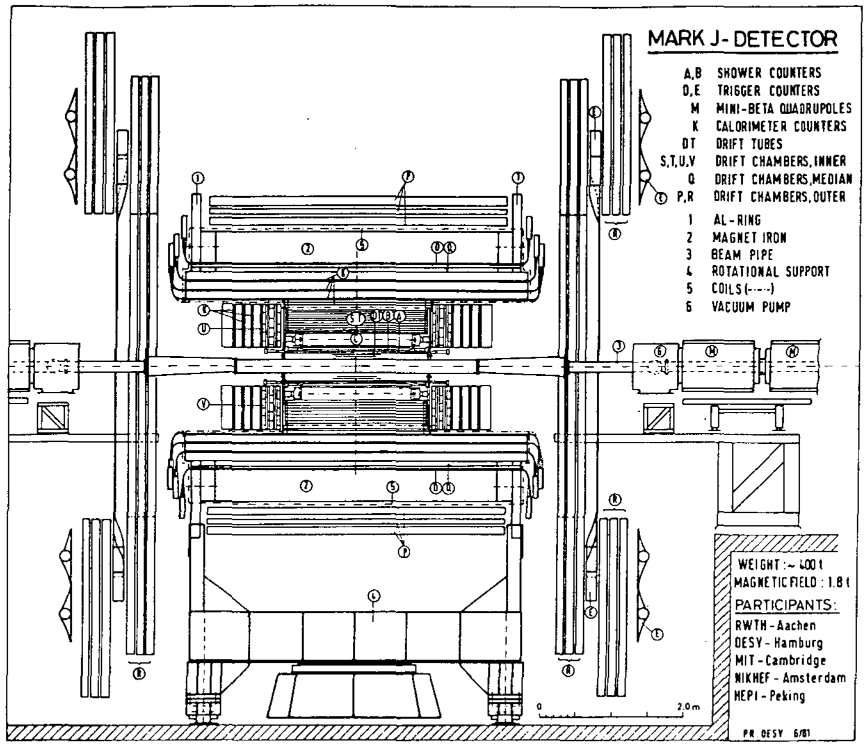
MARK-J

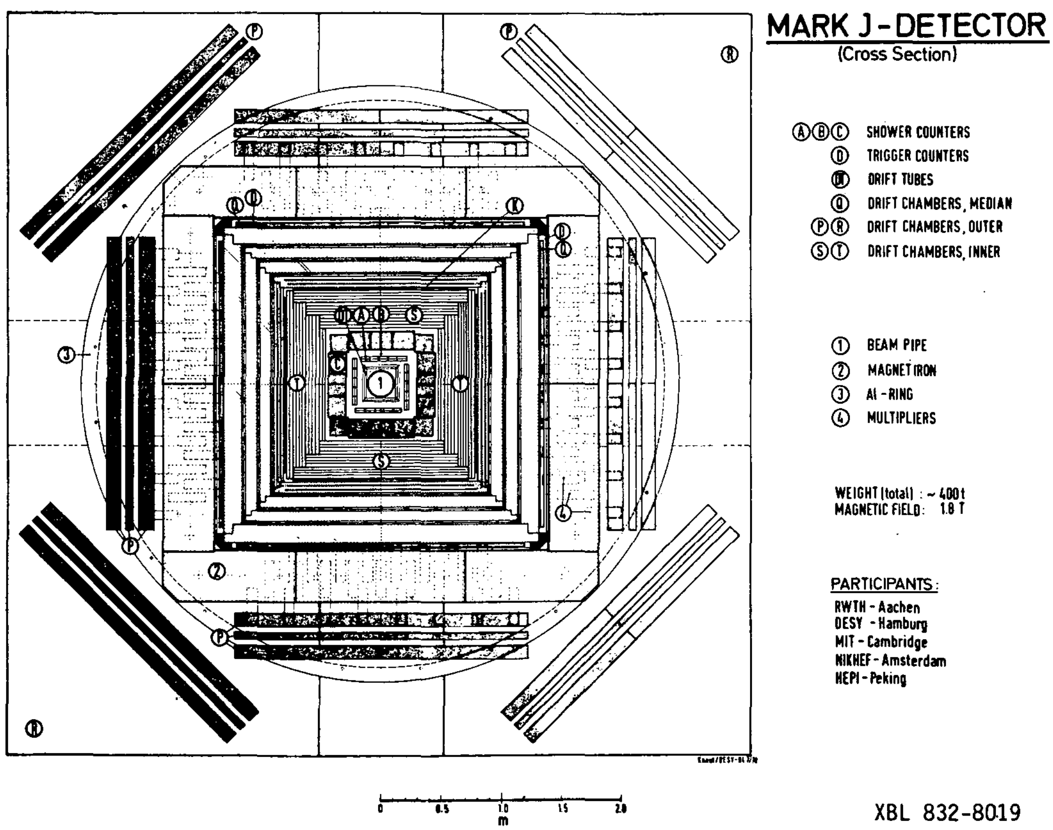
LOCATION	PETRA e^+e^- rings DESY, Hamburg, W. Germany
DETECTOR	Calorimetric, specialized for μ-detection and asymmetry measurements Can rotate around the beam $\phi \pm \pi$ and $\theta \pm \pi/2$ Decay path $\sim$ 20 cm
MAGNET	Toroid, 500 To, iron magnetized to 17 kG 5 concentric squares of 87 cm thickness No field at beam; polarity can be changed
CENTRAL TRACKING	4000 drift tubes in 4 layers orthogonal to beam from 11–17 cm radius Vertex reconstruction to 3 mm
SHOWER COUNTERS	60 modules Pb-scintillator parallel to beam with double-sided readout 3 concentric layers of 3–3–12 X_0 completely overlapping in ϕ; $12 < \theta < 168°$ coverage $\Delta E/E \simeq 12\%/\sqrt{E}$
CALORIMETER	192 scintillators in 7 layers of magnetized iron Resolution $\leqslant$ 20% at 30 GeV, detecting charged and neutral energy flow 12 layers of drift chamber in front No magnetic analysis
MUON DETECTOR	Trigger by 24(48) counters with 400 ps resolution Tracking: 12 layers of drift chamber before magnet, 2 within and 10 behind magnet Minimal pulse height followed through in 3 layers of shower + 7 layers of calorimeter counters Low cutoff: 1.3 GeV

REFERENCES

1. The MARK-J Collaboration (Aachen, DESY, MIT, NIKHEF, Peking), Phys. Rep. **63** (1980) 1.
2. The MARK-J Collaboration (Aachen, Pasadena, DESY, MIT, Madrid, NIKHEF, Peking), Phys. Rep. **109** (1984) 131.

MARK-J





XBL 832-8019

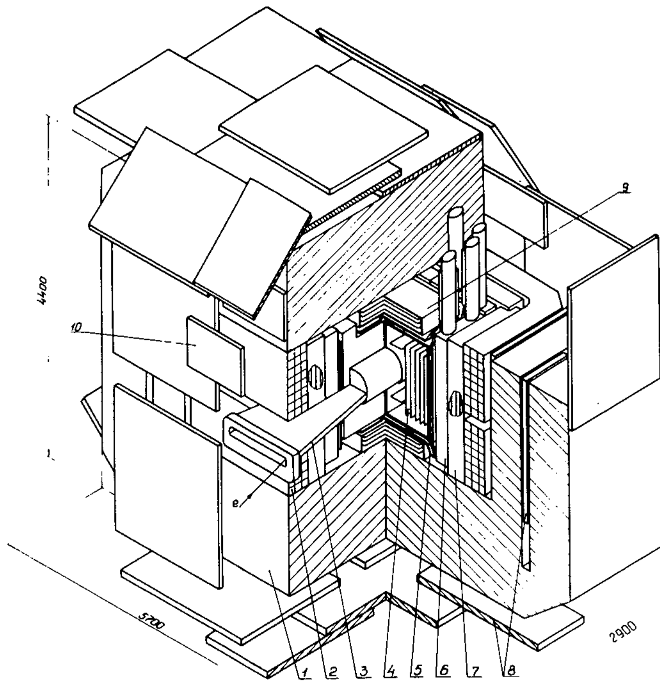
MD-1

LOCATION	VEPP-4 e^+e^- rings Novosibirsk, USSR
MAGNET	$\vec{B}$ transverse to orbit plane $B \propto E_b$, B_{max} = 16 kG B = 12 kG at E_b = 5 GeV
TRACKING	MWPC, s = 2+4 mm σ_p/p = (5+10)% p
SCINTILLATION COUNTERS	24 counters, 40 × 40 × 1 cm^3 σ_A/A = 20% (β = 1), σ_{TOF} = 0.4 ns
CHERENKOV	8 counters, 160 × 70 × 20 cm^3, 60% of Ω Gas: ethylene, P = 25 atm. $(p_\pi)_{thresh}$ = 0.7 GeV/c, $(p_k)_{thresh}$ = 2.5 GeV/c $\epsilon(\beta=1) = 98\% \rightarrow \epsilon(\beta<\beta_{th}) < 0.1$ $\epsilon(\beta=1) = 60\% \rightarrow \epsilon(\beta<\beta_{th}) < 5 \times 10^{-3}$
SHOWER-RANGE CHAMBERS	14 chambers, 10×(13 mm Fe + 10 mm MWPC) Gas: Ar + 20% CO_2, P = 1 atm. σ_E/E = (40+15)% at E_γ = 0.15+ 5 GeV ϵ_γ = 50% at 150 MeV, $\epsilon_\gamma \geqslant$ 90% at $E_\gamma \geqslant$ 250 MeV $\sigma_\theta \approx \sigma_\phi \sim$ 1plus2°
MUON DETECTION	MWPC, $(p_\mu)_{thresh}$ = 0.75+2.1 GeV/c
SCATTERED ELECTRON	MWPC with s = 4 mm and with delay
TAGGING SYSTEM	Line readout with σ = 0.1 mm For E = E_b, θ = 12+100 mrad For θ = 0, $(E_b-E)/E_b$ = 0.1+0.5 σ_E/E = 1+1.5%
LUMINOSITY MONITOR	1. ee → eeγ, NaI(T1) counters 2. ee → ee at small angles, scintillation counters

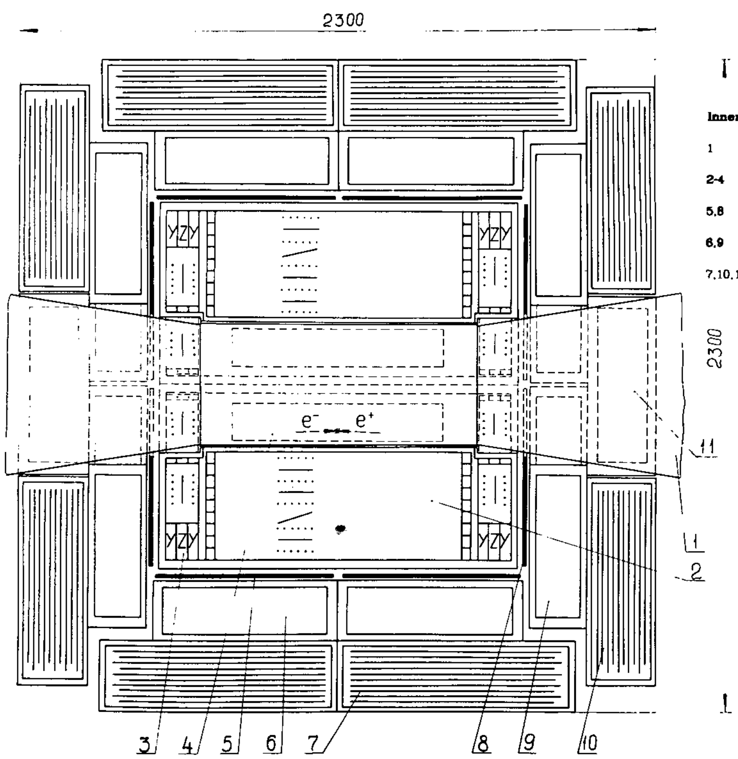
REFERENCES

1. S.E. Baru et al., Preprint INF 77–75, Novosibirsk, 1977.
2. S.E. Baru et al., Inter. Conf. on Instrumentation for Colliding Beam Physics, SLAC, 1982.

MD-1



1 yoke
2 copper winding
3 vacuum chamber
4 coordinate chambers
5 scintillation counters
6 gas Čerenkov counters
7,9 shower-range
8 muon chambers



Inner part, top view

1 vacuum chamber
2-4 coordinate chambers
5,8 scintillation counters
6,9 gas Čerenkov counters
7,10,11 shower-range chambers

XBL 832-8021

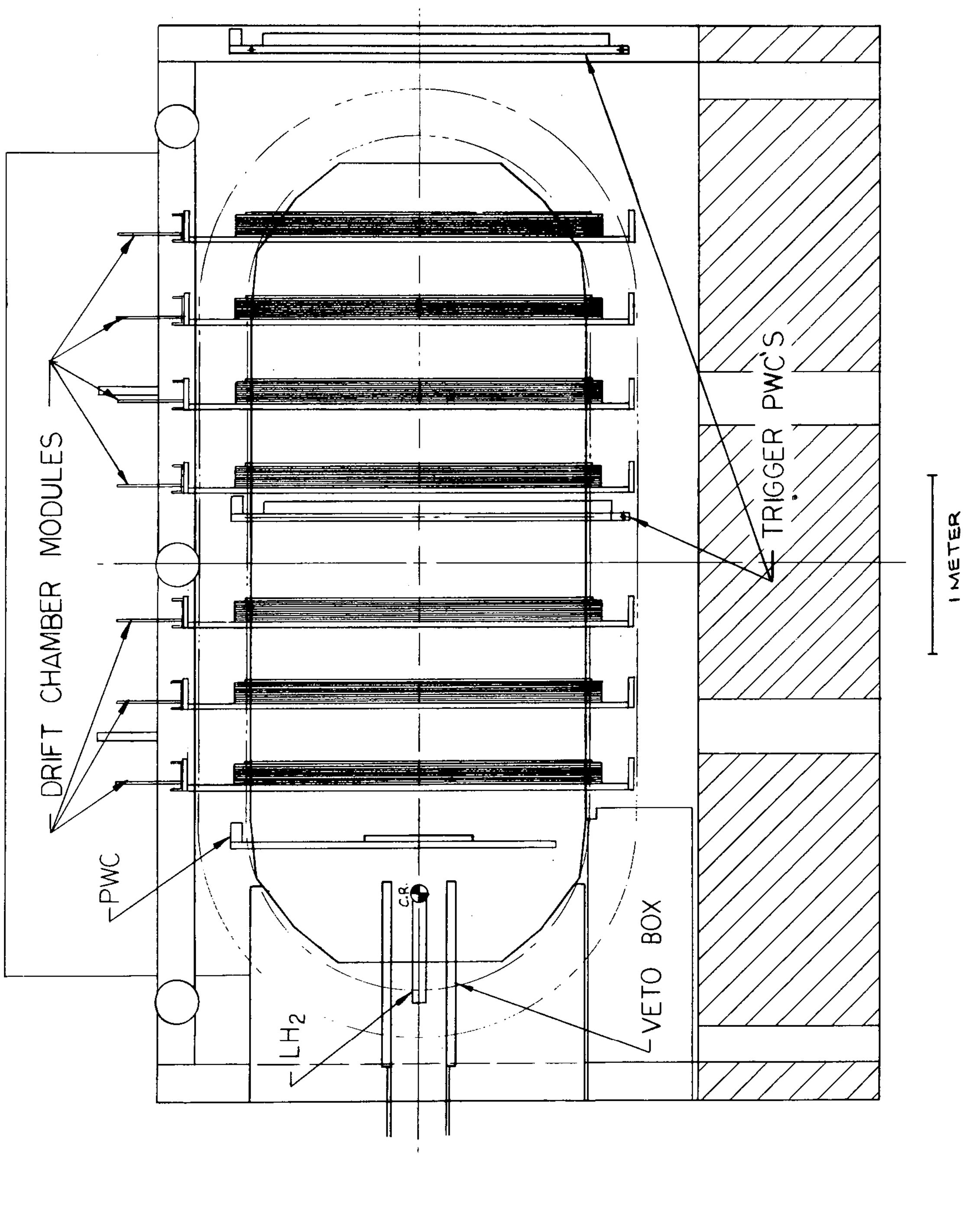
MPS II

LOCATION	AGS, Brookhaven National Laboratory Upton, NY, USA
BEAMS	High energy unseparated beam, 10–25 GeV/c Medium energy unseparated beam, K to 6 GeV/c, $\overline{p}$ to 9 GeV/c Beam Flux $\approx 2 \times 10^6$/pulse
MAGNET	"C" magnet, max field 10 kG Pole area 460 cm $\times$ 180 cm; height 120 cm
MAIN DETECTORS	Narrow cell drift chamber modules Drift distance 0.3 cm Active area 173 cm W $\times$ 100 cm H Resolution $\approx 250\ \mu m$ 7 anode planes (XXX′YY′UV) per module 7 modules available – actual location determined by experiment
EXTERNAL EQUIPMENT	Atmospheric pressure Cerenkov counter hodoscope 540 cm W $\times$ 200 cm H γ_T(Freon 114) $\approx$ 20 High pressure Cerenkov counter hodoscope (60 psi max) 350 cm W $\times$ 120 cm H Typical $\gamma_T \approx 10$ Scintillation counter hodoscope 112 counters, each 6.4 cm W $\times$ 200 cm H 3-gap drift chamber (XXX′) 400 cm W $\times$ 120 cm H 2.5 cm drift distance
TRIGGER ELEMENTS	3 PWC's, 0.25 cm between anode wires Can be used to count clusters "RAM-TRIGGER": a 2 million bit, three-dimensional look-up memory to select angle and momentum

REFERENCES

1. S. Eiseman et al., "The MPS II Drift Chamber System", paper presented at the IEEE 1982 Nuclear Science Symposium, Washington D.C. (Sept. 20-22, 1982). Proceedings to be published in IEEE Transactions on Nuclear Science. BNL-32011.
2. E.D. Platner et al., Nucl. Instr. & Meth. **140** (1977) 549.

MPS II



XBL 832-8064

NUSEX Detector for Nucleon Decay

LOCATION	Mont Blanc Laboratory Italian-French border
SHIELDING DEPTH	$\sim$5000 m.w.e.
DETECTOR	Digital tracking calorimeters; 1 cm iron interleaved with plastic streamer tubes: 134 layers
MASS	150 tons (average density: 3.5 g/cm^3)
VOLUME	$(3.5\text{m})^3$
SENSITIVE ELEMENTS	48,880 plastic streamer tubes with resistive cathode Cell 9×9 mm^2, 100 μm wire, gas mixture Ar+CO_2+n-pentane (1+2+1), HV = 3900 V External pick-up strips for x and y streamer localization on each tube layer
READOUT	81,472 readout channels Discriminator ($\sim$3 mV/50Ω threshold); shift register memory
SPATIAL RESOLUTION	$\sigma_x \sim \sigma_y \sim 3$ mm
ENERGY RESOLUTION	$\sigma_E/E \sim 20\%/\sqrt{E}$ for e.m. showers
TIME RESOLUTION	100 ns for the single streamer
$\mu \to e$ DETECTION EFFICIENCY	40%
MINIMUM TRIGGER FOR RELATIVISTIC PARTICLES	4 contiguous planes
TRIGGER FOR SLOW PARTICLES	$\left\{ \begin{array}{l} \beta > 10^{-4} \\ \dfrac{dE/dx}{(dE/dx)_{\text{min.ion.part.}}} > 6\times 10^{-2} \end{array} \right.$

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1. G. Battistoni et al., Phys. Lett. **118B** (1982) 461.
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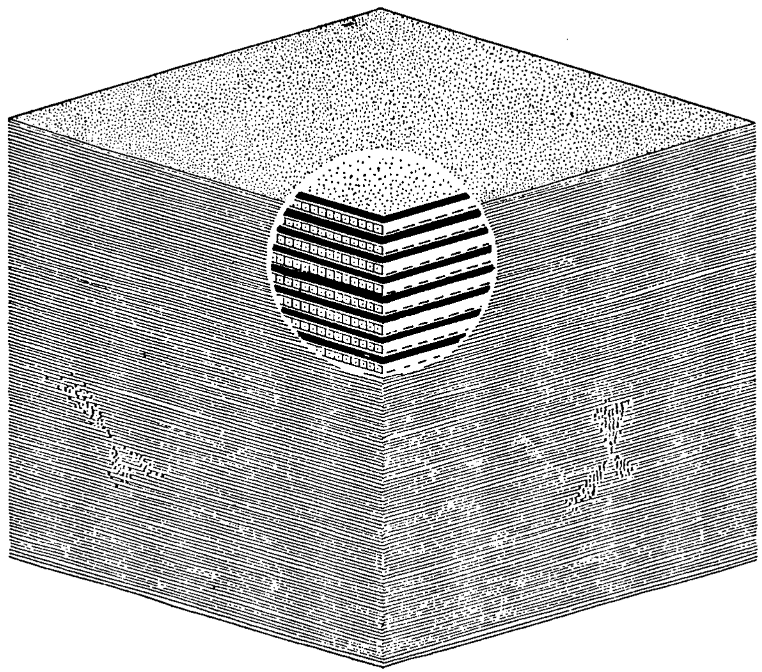
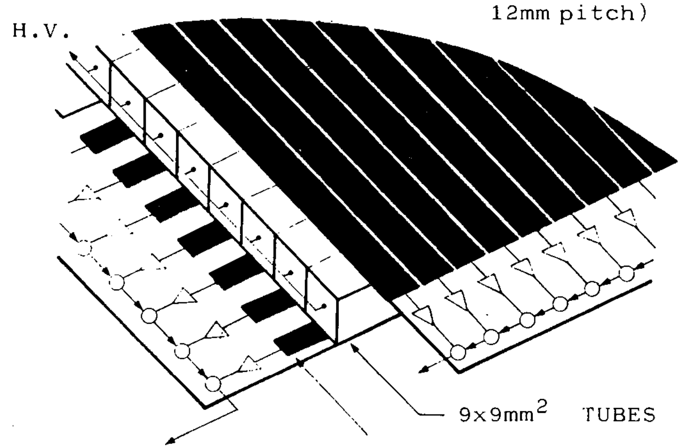
NUcleon Stability EXperiment

FRASCATI-MILANO-TORINO-CERN





XBL 832-8141

NUSEX Detector for Nucleon Decay

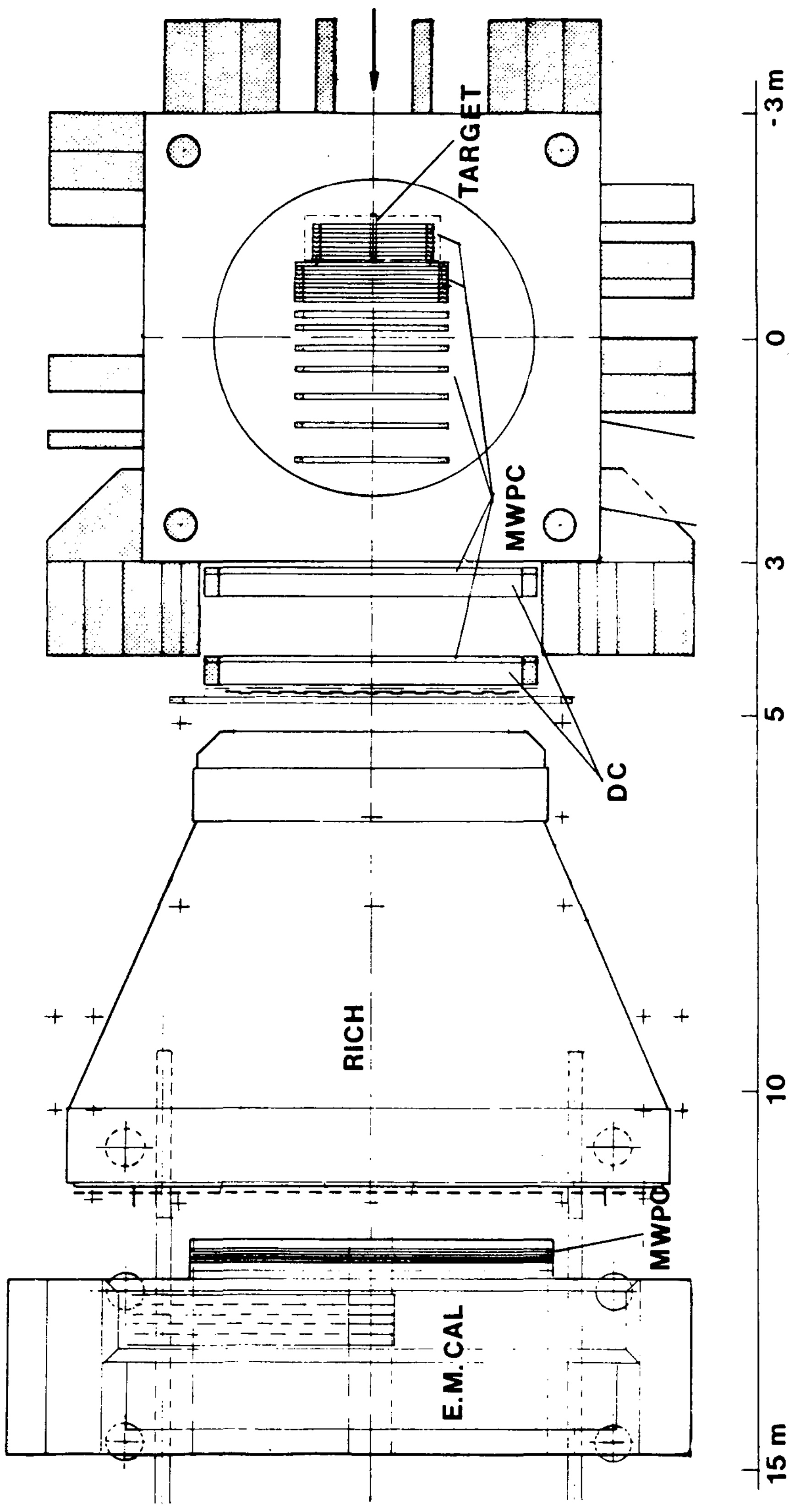
OMEGA

LOCATION	West area, 450 GeV secondary beam CERN, Geneva, Switzerland
MAGNET	18 kG (superconducting) Field volume: height = 150 cm; diameter (½ field) = 400 cm
TRACKING	Proportional chambers inside field $\sigma_p/p = 10^{-3}\ p$ with lever arm drift chambers $\sigma_p/p = 2 \times 10^{-4}\ p$
PARTICLE IDENTIFICATION	Ring image Cerenkov, 5 m gas radiator, spherical mirror 6.4 m wide, 3.2 m high; or, alternatively, two threshold Cerenkov counters with 30 and 32 cells
PHOTON DETECTORS	$4 \times 4\ m^2$ electromagnetic calorimeter, $42 \times 42\ cm^2$ central hole, $24X_0$, 1 cm liquid scintillator bins horizontal/vertical in three separate layers, $\sigma_E/E = 15\%/\sqrt{E}$ Lead and scintillating fiber calorimeter filling the central hole, $28X_0$, $3.2{\times}3.2\ cm^2$ cells
HIGH RESOLUTION DETECTORS	50μm pitch microstrips for measurement of beam and decay vertices (5000 channels)

REFERENCE

1. W. Beusch et al., CERN/SPSC/77-70 and CERN/SPSC/T-17.

OMEGA



OPAL

LOCATION	CERN-LEP CERN, Geneva, Switzerland
MAGNET	Solenoid, 0.4 Tesla, R = 2 m, L = 6.5 m
TRACKING VERTEX CHAMBER	R_i = 85 mm, R_o = 235 mm, L = 1000 mm
JET CHAMBER	R_i = 245 mm, R_o = 1850 mm, L = 4000 mm, 24 sectors, 160 anodes per sector
Z CHAMBER	Layer of axial drift chamber between R = 1880 and 1960 mm
GAS PRESSURE	$\leqslant$ 4 bar
ELECTRONICS	100 MHz flash ADC, about 11,000 channels
TIME-OF-FLIGHT	160 7m long scintillators on the outside of the coil
E.M. CALORIMETER	Lead-glass barrel and endcap about 12,300 blocks, projective geometry Presampler around the coil behind $1.4X_0$ aluminium Forward lead scintillator sandwich Coverage: 99.9% of 4π
HADRON CALORIMETER	Calorimeterized iron yoke, 10 cm Fe plates interleaved with streamer tubes Coverage: 97% of 4π Pointing geometry tower readout, about 2000 towers
MUON DETECTOR	Barrel part: 4 layers of large-area drift chambers with space point readout of ~1 mm in both coordinates Endcap: streamer tubes, X-Y readout on layers separated by 0.6 m
FORWARD DETECTORS	Scintillator hodoscopes, tracking chambers, and EM shower detector

REFERENCES

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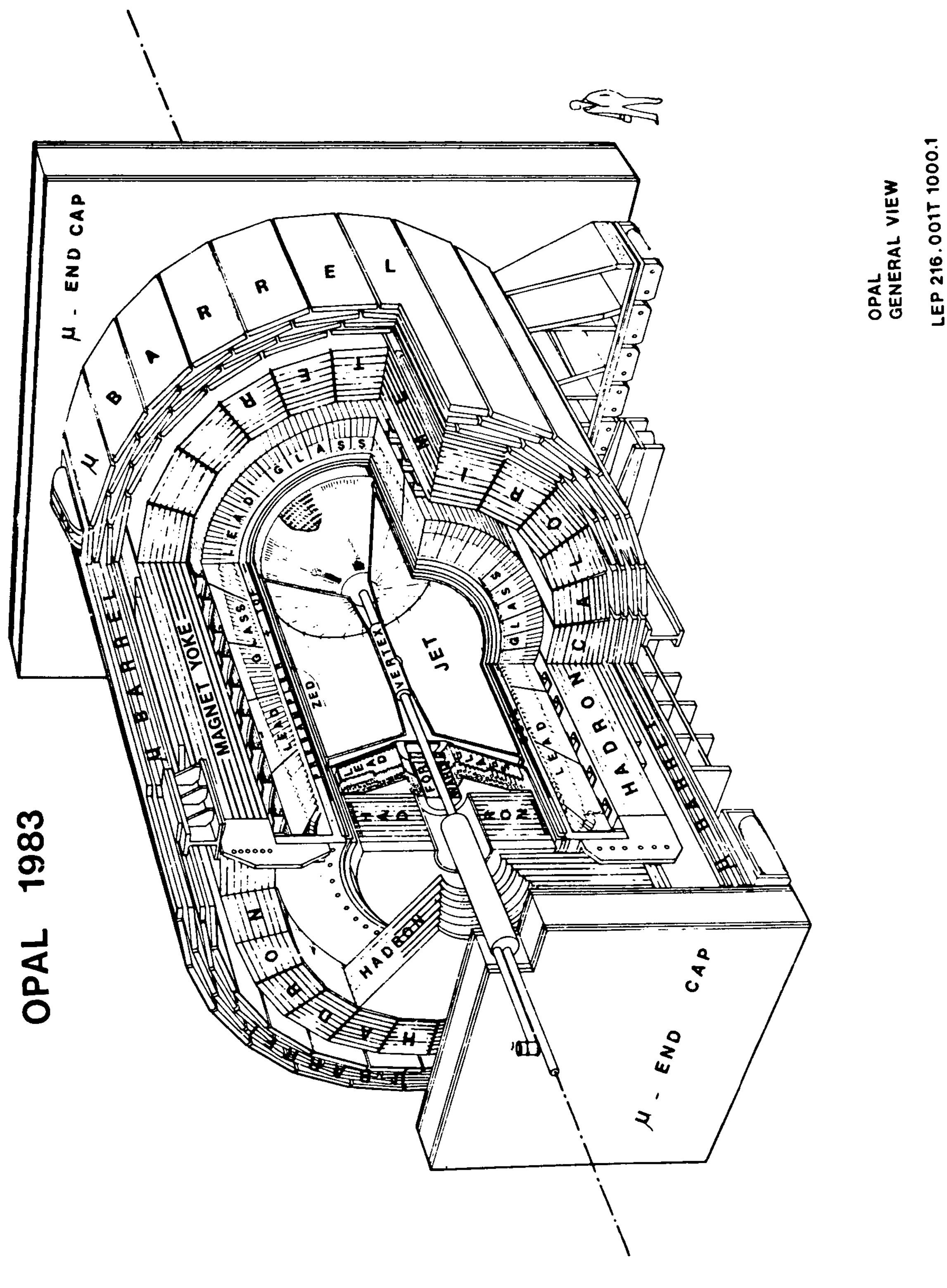
2. OPAL Status Report, CERN LEPC/84-17 (September 1984).
3. OPAL Status Report, CERN LEPC/M-51 (18 September 1984).

OPAL


OPAL 1983
μ - END CAP
μ BARREL
MAGNET YOKE
LEAD GLASS
ZED
VERTEX
JET
HADRON CAL
HADRON
μ - END CAP
OPAL
GENERAL VIEW
LEP 216.001T 1000.1

PEP-9 2γ Detector

LOCATION

PEP e^+e^- ring
Interaction Region 2 (with TPC)
SLAC, Stanford, CA, USA

MAGNETS

2 septum magnets: 1 m long, aperture 2.24 m horizontal by 2.1 m vertical
B_{max} = 1.7 kG; $\int B d\ell \cong$ 2.6 kGm; B = 0 on beam axis
Each magnet compensated by air core, skew quads immediately around the beam pipe

TRACKING

5 drift chamber (DC) modules at each end
- DC-1: 4 planes, 2 horizontal, 2 vertical (±10°), Ar-Eth (50%-50%)
- DC-3: 2 vertical (±10°), Ar-CO_2 (83%-17%)
- DC-2,4,5: 3 planes, 1 horizontal, 2 vertical (±10°), Ar-CO_2 (83%-17%)

σ position $\simeq$ 300 μm
$\sigma_p/p \cong \pm\sqrt{(0.008p)^2 + (0.025)^2}$
Angular acceptance of system — 22 mrad to 180 mrad

NaI SHOWER DETECTOR

Angular acceptance — 22 mrad to 100 mrad at either end
Each detector contains 60 individual NaI crystals each 22″ long and hexagonal cross-section 6″ apex to apex
σ_E/E = 0.9% @ 14.5 GeV (best performance without radiation damage)
Spatial resolution: $\sigma \simeq$ 0.4 cm

Pb-SCINTILLATOR SHOWER

Angular acceptance — 100 mrad to 180 mrad at either end
Alternate layers of Pb sheets and plastic scintillator strips set in three 60° stereo views; wave bar readout; 54 total layers, $18X_0$
$\sigma_E/E = \pm 15\%/\sqrt{E}$
Spatial resolution: $\sigma \cong$ 1 cm

TIME-OF-FLIGHT

Two planes of scintillation hodoscope at each end; one plane has 50 horizontal scintillator strips, the other 62 vertical strips.
Time resolution: σ_T = 0.3 ns

MUON DETECTOR

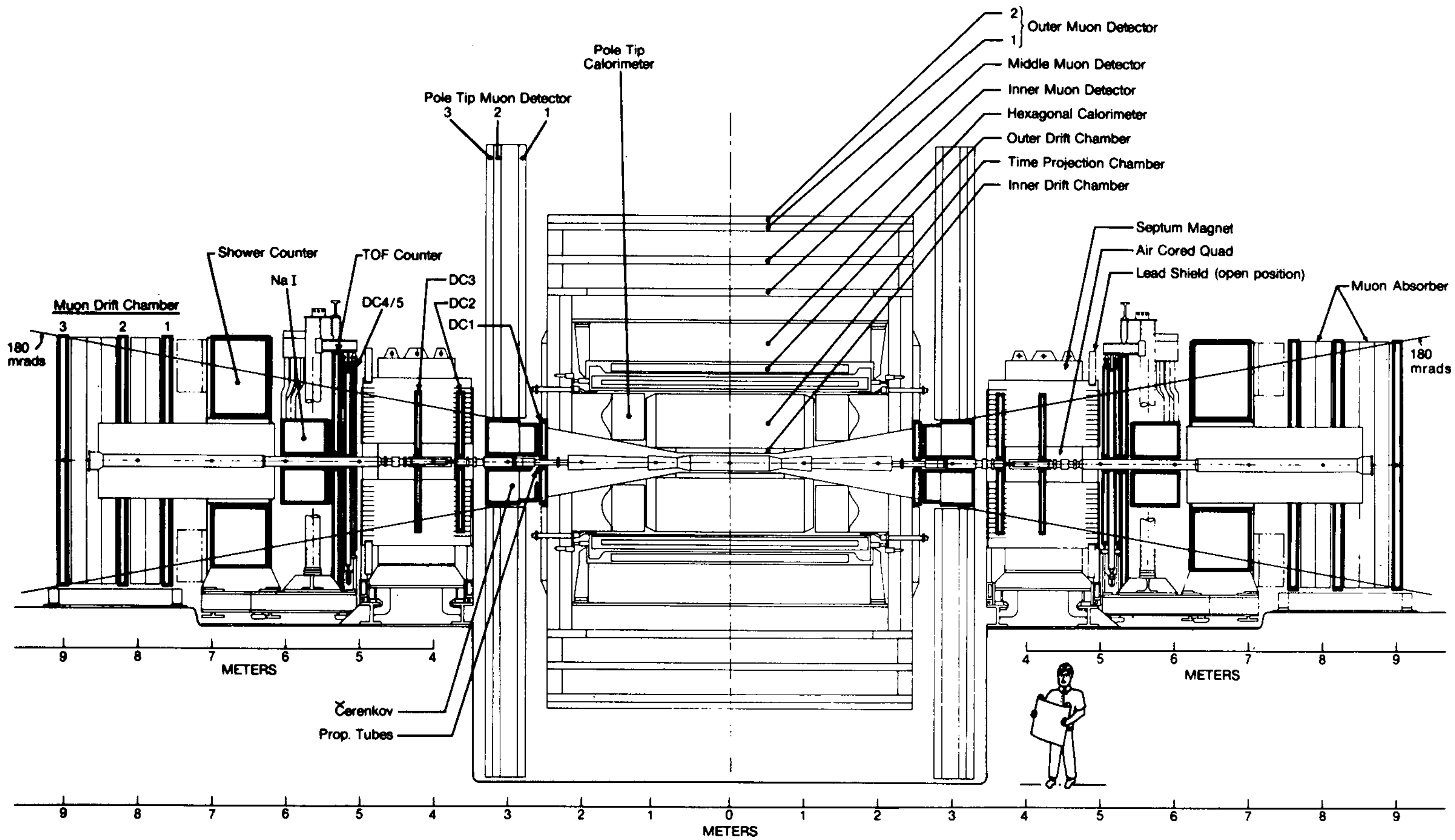
1 meter of iron (787 g/cm^2) at each end
3 drift chamber modules at each end, each module having 2 offset, vertical sense wire planes, Ar-Eth (50%-50%)
Spatial resolution: σ = 220 μm

CERENKOV

1 atm., CO_2 radiator, 70 cm long, divided into 12 azimuthal segments at each end
Efficiency for electrons >90% overall, >95% over 80% of angular coverage (22 mrad to 180 mrad)

TRIGGER

Double tag., E > 2 GeV in NaI
Single tag., E > 4 GeV in NaI, in coincidence with extra particle (charged or neutral)



PEP-9 2γ Detector

XBL 845-2033

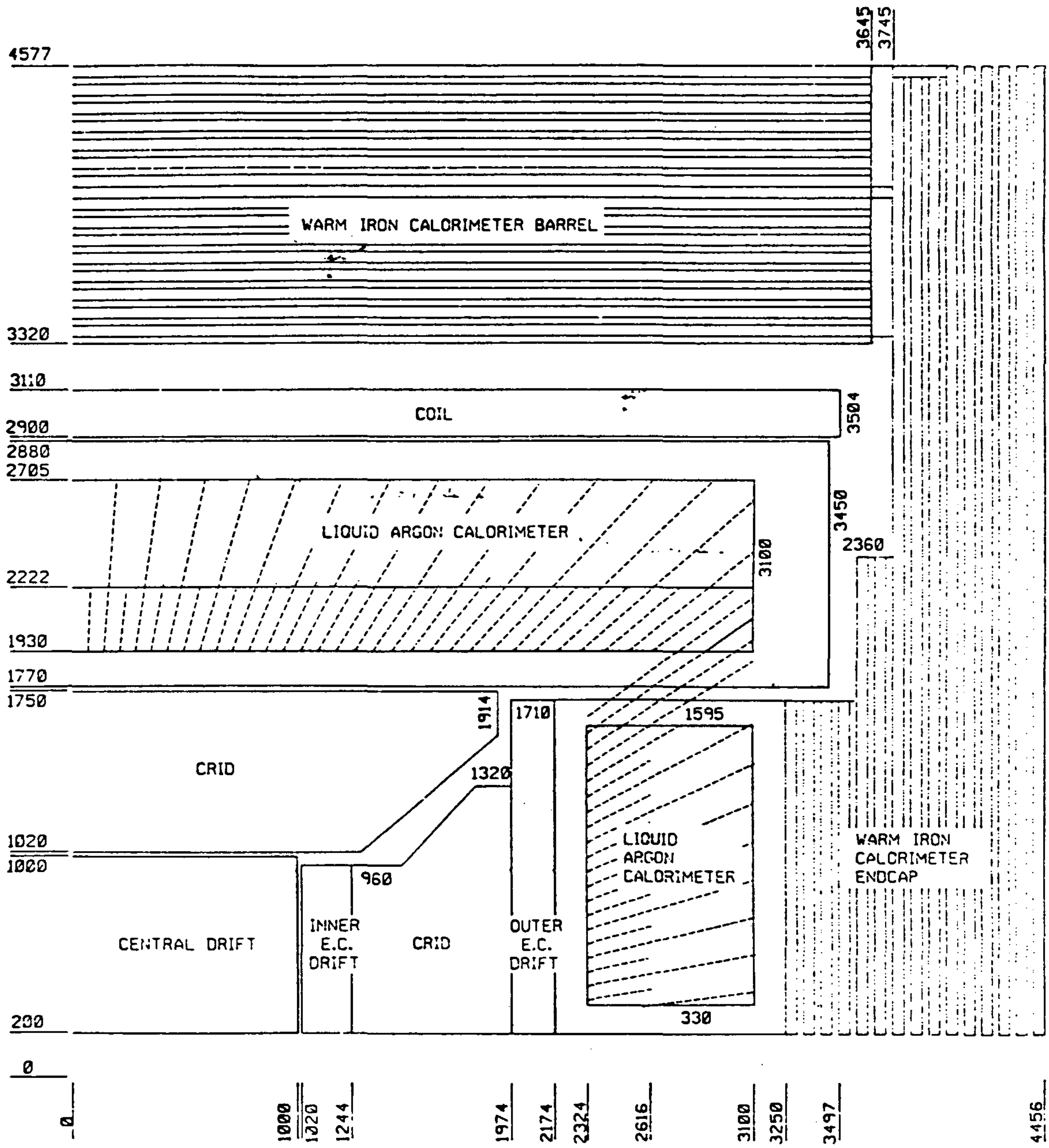
SLD

LOCATION	SLC e^+e^- collider SLAC, Stanford, CA, USA
MAGNET	6 kG aluminum solenoid Diameter = 5.8 m, length = 6.8 m 5 cm laminated iron flux return integrated with warm iron calorimeter
VERTEX DETECTOR	CCD cylinders and endplates Cylinder radii: 1,2 cm Segmentation: 22 μm × 22 μm Precision transverse to line of flight: 4–20 μm Two-track resolution: 40 μm
DRIFT CHAMBERS	Barrel drift chamber: I.R. = 20 cm, O.R. = 100 cm Length: ±1 m 10 superlayers of vector cells, each cell having 8 sense wires; 50 mrad stereo with current division for pattern recognition; CO_2-isobutane gas Endcaps at z's of ±100 and ±200 cm Spatial resolution: ~100 μm Momentum resolution: $\sigma(1/p)$ measurement limit 0.001 $(GeV/c)^{-1}$ $\sigma(p)/p$ Coulomb scattering limit 0.01–0.02 Two-track: separation 2 mm
CALORIMETRY	Uranium liquid argon inside coil (2.7 interaction lengths); calorimetry completed by WIC (warm iron calorimeter) consisting of 5 interaction lengths of 2.5 cm iron laminated with limited streamer mode readout chambers Electromagnetic: Energy resolution: $\Delta E/E \sim 8\%/\sqrt{E}$ Segmentation: ~33 mrad × 33 mrad Angular resolution: ~5 mrad Hadronic: Energy resolution: $\Delta E/E \sim 45\%/\sqrt{E}$ Segmentation: ~66 mrad × 66 mrad Angular resolution: ~10 mrad
PARTICLE IDENTIFICATION	Cerenkov ring imaging detectors, barrel, and endcaps Proximity focussed 1 cm liquid freon (FC-72) radiator Mirror focussed 45 cm isobutane radiator TMAE photodetector; number of photoelectrons (β=1) is 23 for liquid, 14 for gas Particle separation range at 90°, 3σ, both radiators e/π 0.2 to 7 GeV/c μ/π 0.2 to 1.1 GeV/c and 2.1 to 4 GeV/c π/K 0.23 to 32 GeV/c K/p 0.80 to 55 GeV/c
SOLID ANGLE COVERAGE	Tracking 97% Particle id 97% EM cal >99% Had cal 97%

REFERENCE

1. SLD Design Report SLAC-REPORT-273 (May 1984).

SLD



3645
3745
4577
WARM IRON CALORIMETER BARREL
3320
3110
COIL
3504
2900
2880
2705
LIQUID ARGON CALORIMETER
3450
3100
2360
2222
1930
1770
1750
1914
1710
1595
CRID
1320
1020
1000
960
LIQUID ARGON CALORIMETER
WARM IRON CALORIMETER ENDCAP
CENTRAL DRIFT
INNER E.C. DRIFT
CRID
OUTER E.C. DRIFT
330
200
0
0
1000
1020
1244
1974
2174
2324
2616
3100
3250
3497
4456

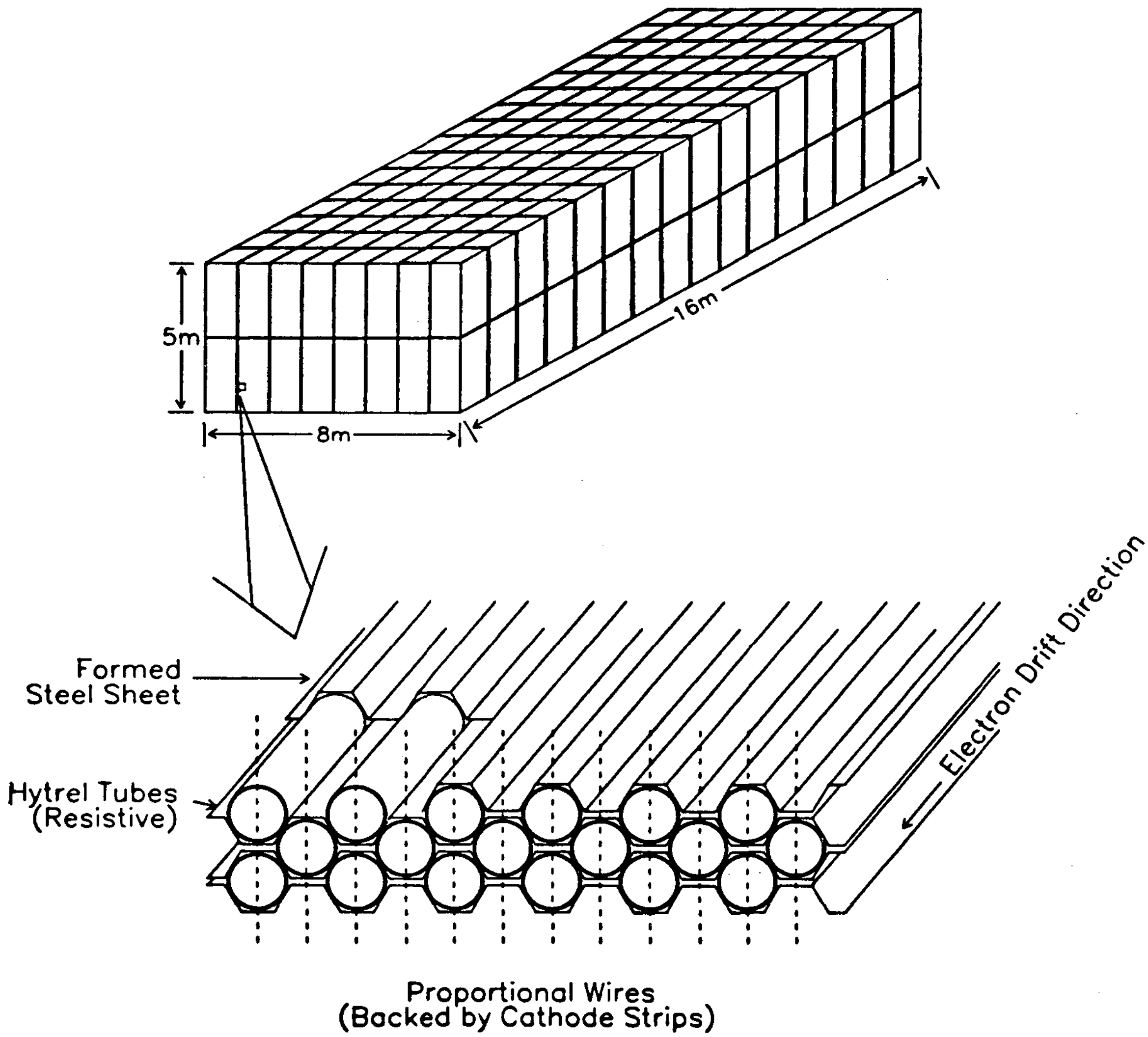
SOUDAN-2 Detector for Nucleon Decay

LOCATION	Soudan Mine, Tower-Soudan State Park Soudan, MN, USA Latitude 48°N, longitude 92°W
EARTH SHIELDING	700 m rock overburden 2200 m water-equivalent Cosmic ray muon rate = 0.5 Hz
MASS AND LAYOUT	First stage: 1100 metric tons active mass 256 modules, each 1 m × 1 m × 2.5 m (high) Modules arranged 2 high × 8 wide × 16 long Average density = 2 g/cm^2
CAVITY DIMENSIONS	14 m × 72 m × 11 m (h) Accommodates 3300 metric tons of detector
MAIN DETECTOR	Formed steel sheets 1.6 mm thick, stacked vertically to give hexagonal close-packed array of holes filled by resistive plastic tubes (OD = 16 mm, ID = 15 mm, length = 1 m), enclosed in mylar sheets Electric potential applied to tube gives up to 50 cm drift of ionization electrons, which are detected by vertical proportional wires backed by horizontal cathode strips
READOUT	6-bit flash ADC's, controlled by 24 microprocessors
TRACKING RESOLUTION	Anode wire spacing = 15 mm Cathode strip spacing = 10 mm Drift distance binning = 2 mm
ACTIVE SHIELD	Main detector is entirely surrounded by a 2-layer array of extruded aluminum proportional tubes
THRESHOLD	100 MeV kinetic energy pion, muon, or electron
SENSITIVITY	3 events/year for $\tau/B = 10^{32}$ years 150 points (x, y, z, dE/dx) for typical decay event
SCHEDULE	200 tons operational: February 1986 1100 tons operational: December 1987
INSTITUTIONS	Argonne National Laboratory University of Minnesota University of Oxford Rutherford Appleton Laboratory Tufts University

REFERENCE

1. D.S. Ayres et al., "The Soudan 2 Nucleon Decay Experiment: Description and Status Report," ANL-HEP-PR-84-30 (September 1984, unpublished).

SOUDAN-2 Detector for Nucleon Decay



Tagged Photon Spectrometer

LOCATION	Tagged Photon Lab, Proton East Fermilab, Batavia, IL, USA
MAGNETS	1. 80.9 cm gap, 183 cm wide, 100 cm long; 7.1 kG-m (can be increased to 14.2 kG-m) 2. 85.7 cm gap, 183 cm wide, 100 cm long; 14.2 kG-m
VERTEX DETECTOR	9 planes of silicon microstrip detectors 50 μm pitch, covers $\lvert\theta_x\rvert$, $\lvert\theta_y\rvert < 100$ mrad MWPC-type readout on each of 7500 strips Operates with beryllium target
RECOIL DETECTOR	$\Delta\phi = 5.9$ rad, Δz(scintillator) = 210 cm at radius 54 cm Cyl. proportional chamber with cathode readout: $\sigma_\theta = 5$ mrad, $\sigma_\phi = 15$ mrad 2 layers plastic + 2 layers liquid dE/dx scintillators in 15 azimuthal sectors $0.06 < t < 1.2$ (GeV/c)^2, $\sigma_t/t = 5$–10% End-to-end timing: $\sigma_z = 10$ cm

FORWARD SPECTROMETER

Tracking: 35 drift chamber planes
- 2 magnets: $\lvert\theta_x\rvert < 170$ mrad and $\lvert\theta_y\rvert < 72$ mrad
  - $\sigma_\theta = 1.0$ mrad, $\sigma_p/p^2 = 2.5 \times 10^{-4}$ GeV^{-1}
- 1 magnet: $\lvert\theta_x\rvert < 350$ mrad and $\lvert\theta_y\rvert < 145$ mrad
  - $\sigma_\theta = 2.7$ mrad, $\sigma_p/p^2 = 30 \times 10^{-4}$ GeV^{-1}

Charged particle identification: 2 Cerenkov detectors operating at 1 atm. pressure
N_2 and 20% N_2 – 80% He mixture, 32 segments each

Separation:		
	π vs K or p	$6 < p < 36$ GeV
	π vs K vs p	$20 < p < 33$ GeV

Neutral Detection:
Electromagnetic -
- Pb-liq. scint. (SLIC): u,v,y readout, 60 × 0.16 cm Pb samples
  - $\sigma_\theta = 0.3$ mrad, $\sigma_E/\sqrt{E} = 12\%$ ($\lvert\theta_x\rvert < 134$ mrad and $\lvert\theta_y\rvert < 67$ mrad)
- Pb-plastic scint. (Outrigger): x,y readout, 16 × 0.64 cm Pb samples
  - $\sigma_\theta = 2.0$ mrad, $\sigma_E/\sqrt{E} = 20\%$ ($\lvert\theta_x\rvert < 157$ mrad and $\lvert\theta_y\rvert = 58$–160 mrad)

Hadronic -
- Fe-plastic scint. (Hadrometer): x,y readout, 36 total samples (2.5 cm Fe each)
  - $\sigma_\theta = 2$ mrad, $\sigma_E/\sqrt{E} = 70\%$

Muon detector hodoscope: 30 counters following ~200 cm Fe

BEAM	300 GeV e^- with γ tagging system ($0.45 < E_\gamma/E_e < 0.95$); $\sigma_\gamma \simeq 3$–6 GeV
BUILDERS	Tagged Photon Collaboration: Fermilab, Carleton Univ., Toronto Univ., Univ. of California at Santa Barbara, Univ. of Colorado

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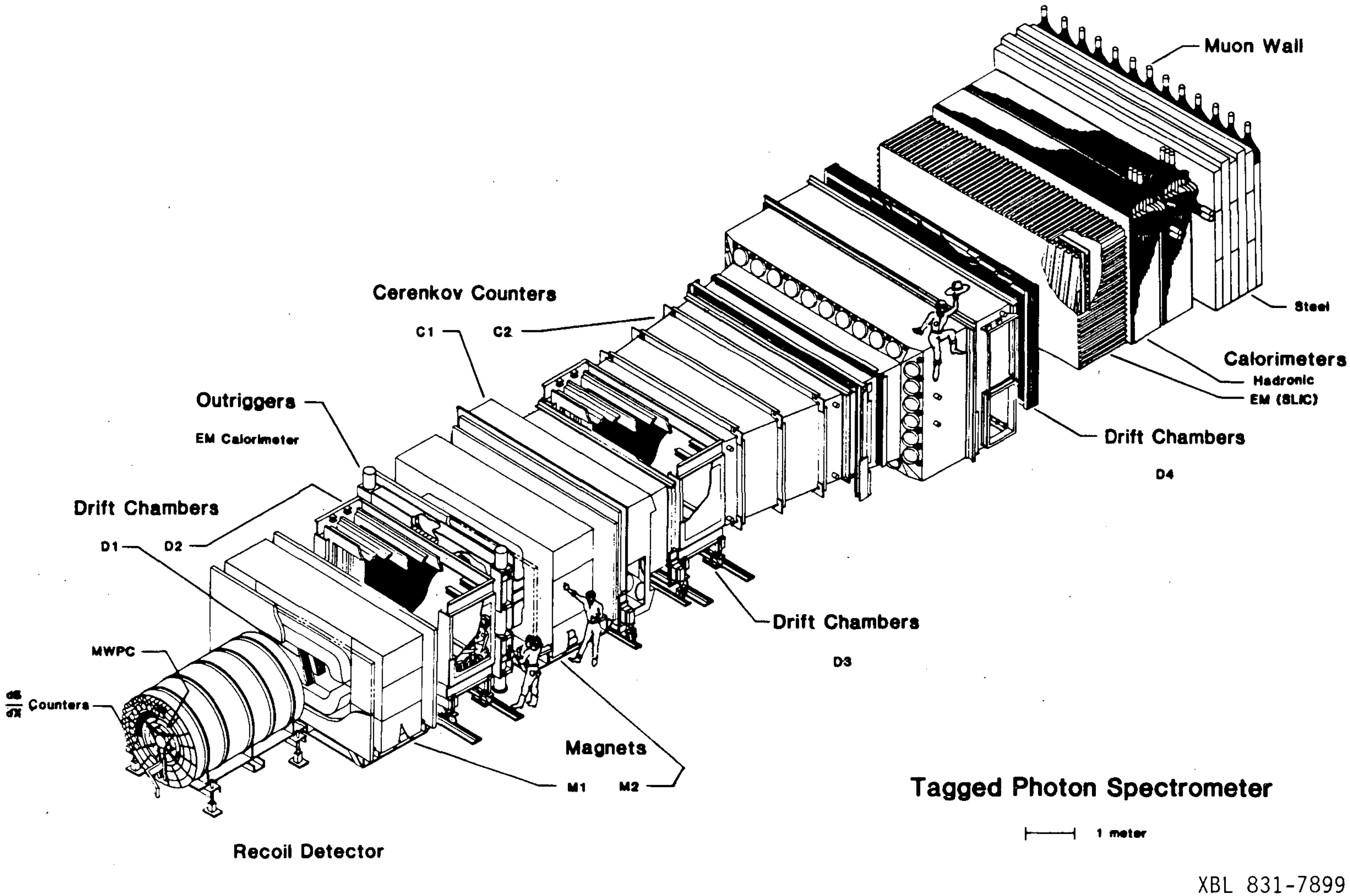

Tagged Photon Spectrometer

TASSO

LOCATION	PETRA e^+e^- rings DESY, Hamburg, W. Germany
MAGNET	Solenoid, 5 kG, R_i = 135 cm, L = 440 cm, d = 10 cm Al
TRACKING	Vertex detector, drift chamber, 8 layers, cell size 0.71–0.87 cm, 720 signal wires, R_i = 6.5 cm, R_o = 16.1 cm, L = 60 cm Cyl. proportional chamber, 4 anode layers, wire spacing ~3 mm, 1920 signal wires, 8 cathode layers, 960 channels, R_i = 17cm, R_o = 29cm, L = 140 cm Cyl. drift chamber, 15 layers, 9 with 0°, 6 stereo, cell size 3.2 cm, 2340 signal wires, R_i = 30 cm, R_o = 130 cm, L =323 cm, using all chambers $\sigma_p/p < 1\%$ p for p > 2 GeV/c
TIME-OF-FLIGHT	Between drift chamber and coil, 48 counters, 390 × 17 × 2 cm^3, σ_{TOF} = 270–450 ps depending on z
SHOWER COUNTERS NEAR CENTRAL DETECTOR	Liquid argon-lead with towers pointing to I.P.; towers for energy measurement, strips for position measurement Barrel 42° < θ < 138°; ϕ: 30°–150°, 210°–330°; 0.2 cm Pb, 0.5 cm argon, $14X_0$, 5088 front towers, 1248 back towers, 4592 strips for z, ϕ, dE/dx $\sigma_E/E = (0.11 + \frac{0.02}{E-0.5})/\sqrt{E}$, E > 1 GeV; $\sigma_\theta = \sigma_\phi$ = 2 mrad Endcap 12° < θ < 30°, 150° < θ < 168°, ϕ: 0–360°, 0.2 cm Pb, 0.3 cm argon, $12.6X_0$, 1444 front towers, 872 back towers, 840 strips for R and ϕ

HADRON ARMS

For particle identification up to high momenta; 50° < θ < 130°, −26° < ϕ < 26°, 154° < ϕ < 206°; following coils are:
Plane drift chamber, 8 layers
Aerogel Cerenkov counter, n = 1.024, d = 13.5 cm, 32 cells
Freon 114, n = 1.0014, 1 atm., 64 cells
CO_2, n = 1.00043, 1 atm., 64 cells

threshold momenta (GeV/c)	π	K	p
Aerogel	0.6	2.2	4.2
Freon 114	2.6	9.3	17.8
CO_2	4.8	16.8	32.0

Time-of-flight, 96 counters, σ = 450 ps

Shower counters: lead-scintillator with wavelength shifter readout, $7.4X_0$, 128 counters, σ/E = 17%

MUON DETECTION	Behind magnet yoke (50–80 cm Fe) and behind hadron wall (87 cm Fe), 4 layers of proportional tube chambers, 4 × 4 cm^2
FORWARD DETECTOR	25–115 mrad, scintillation hodoscope, proportional tube chambers, lead-scintillator shower counter

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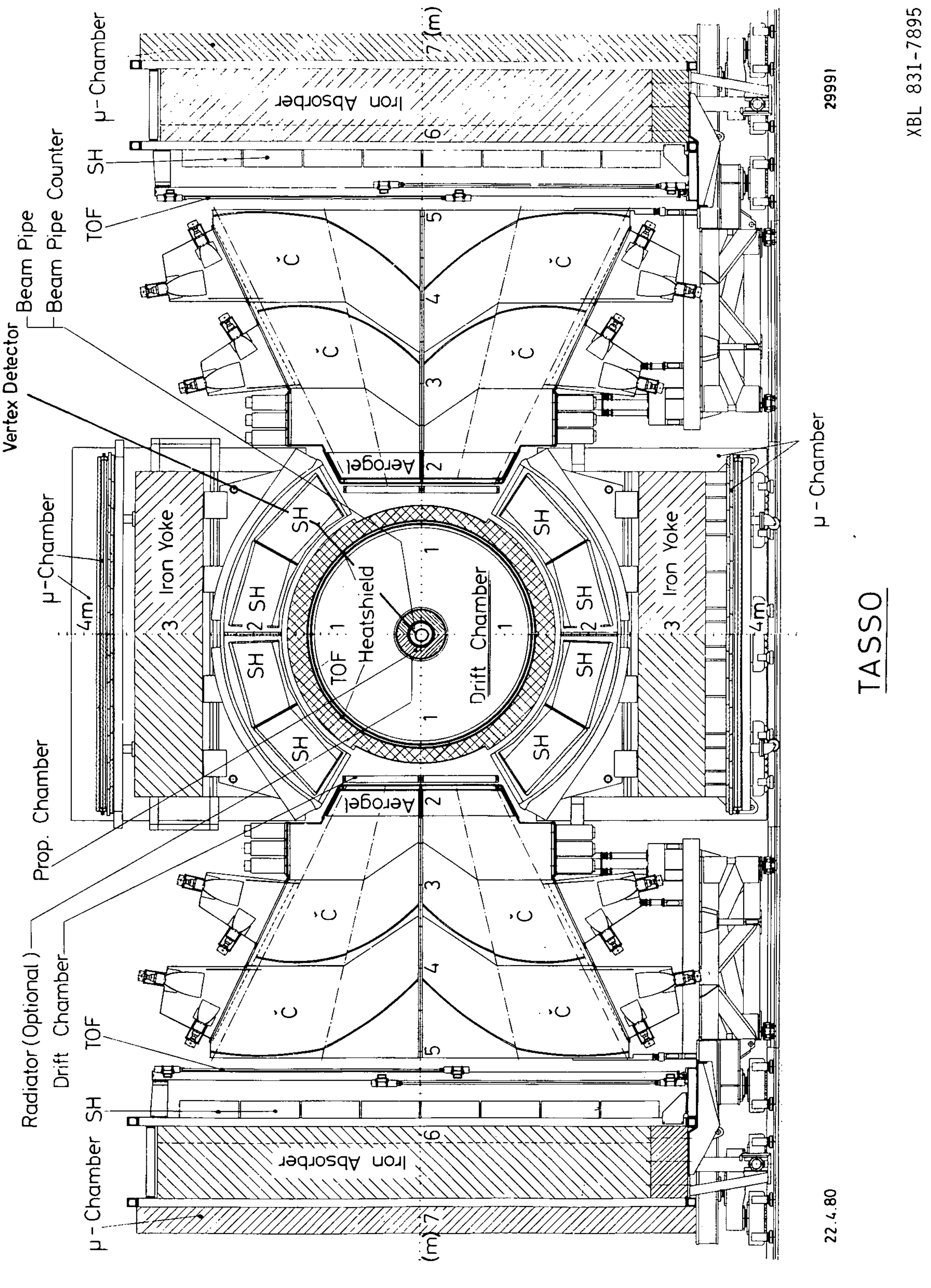
TASSO



TASSO
Vertex Detector
Beam Pipe
Beam Pipe Counter
TOF
SH
μ-Chamber
Iron Absorber
Aerogel
Iron Yoke
Heatshield
Drift Chamber
Prop. Chamber
Radiator (Optional)
Drift Chamber
22.4.80
29991
XBL 831-7895

TOPAZ

LOCATION	TRISTAN e^+e^- ring National Laboratory for High Energy Physics, KEK Tsukuba, Japan
MAGNET	1.2 Tesla superconducting thin ($0.7X_0$) solenoid Al-stablized Nb-Ti-Cu coil ID = 2.88 m, L = 5.1 m
TRACKING	Inner drift chamber (IDC): Radius 10 to 24.5 cm, L = 150 cm 10 cylindrical layers, 1024 drift cells, $\sigma_{r\phi} = 110\ \mu m$ 8 layers of printed delay line cathodes, 256 delay lines, $\sigma_z = 3$ mm Time projection chamber (TPC): Radius 30 to 130 cm, L = 260 cm (130 cm max. drift) Ar/CH_4 (90/10) at 4 atm., 385 V/cm drift field 178 sense wires ($\cos\theta < 0.8$) and 10 cathode pad rows (512 pads) per 45° sector at each end $\sigma_p/p < 1\%p$ (p > 2 GeV, 1 Tesla), $\sigma(dE/dx) = 4\%$ Outer drift chambers: 4 layers, limited streamer plastic tubes, 110 μm resolution Barrel: 1280 wires and 2000 strips, 5 m length Endcap: 560 wires and 560 strips per end, $0.97 > \cos\theta > 0.83$
TIME-OF-FLIGHT	Barrel: 64 plastic scintillators, $400 \times 13 \times 4$ cm^3, $\sigma_{TOF} = 200$ ps Endcap: 2 layer planar spark counters, 0.5 mm gap, 3 atm., 208 strips per end, $\sigma_{TOF} = 150$ ps
CALORIMETER	Barrel: $\cos\theta < 0.85$, 2π in ϕ, $R_i = 1.75$ m 4320 lead-glass counters, 12×11 cm^2 $\times$ 34 cm ($20X_0$) $\sigma_E/E = 0.08/E$ with light guide and mag. coil $\sigma_\theta = \sigma_\phi = 6$ mrad Endcap: $0.97 > \cos\theta > 0.83$, 2π in ϕ Pb-proportional counter sandwich, $18X_0$ (3 modules) 1024 projective tower signals and 320 strips per end $\sigma_E/E = 0.2/E$, $\sigma_\theta = \sigma_\phi = 3$ mrad
MUON DETECTOR	8 layers, Al proportional drift tubes, 5×10 cm^2 $\times$ 6 m Interleaved with Fe absorbers (30.5, 34.8 cm) behind magnet yoke (40 cm), >5.9 total abs. length 4230 signal wires, 0.7 - 1 mm resolution, Ar/Ch_4 (90/10)
LUMINOSITY MONITOR	2 pairs wrt I.P., 2 scintillators and a Pb-scintillator sandwich

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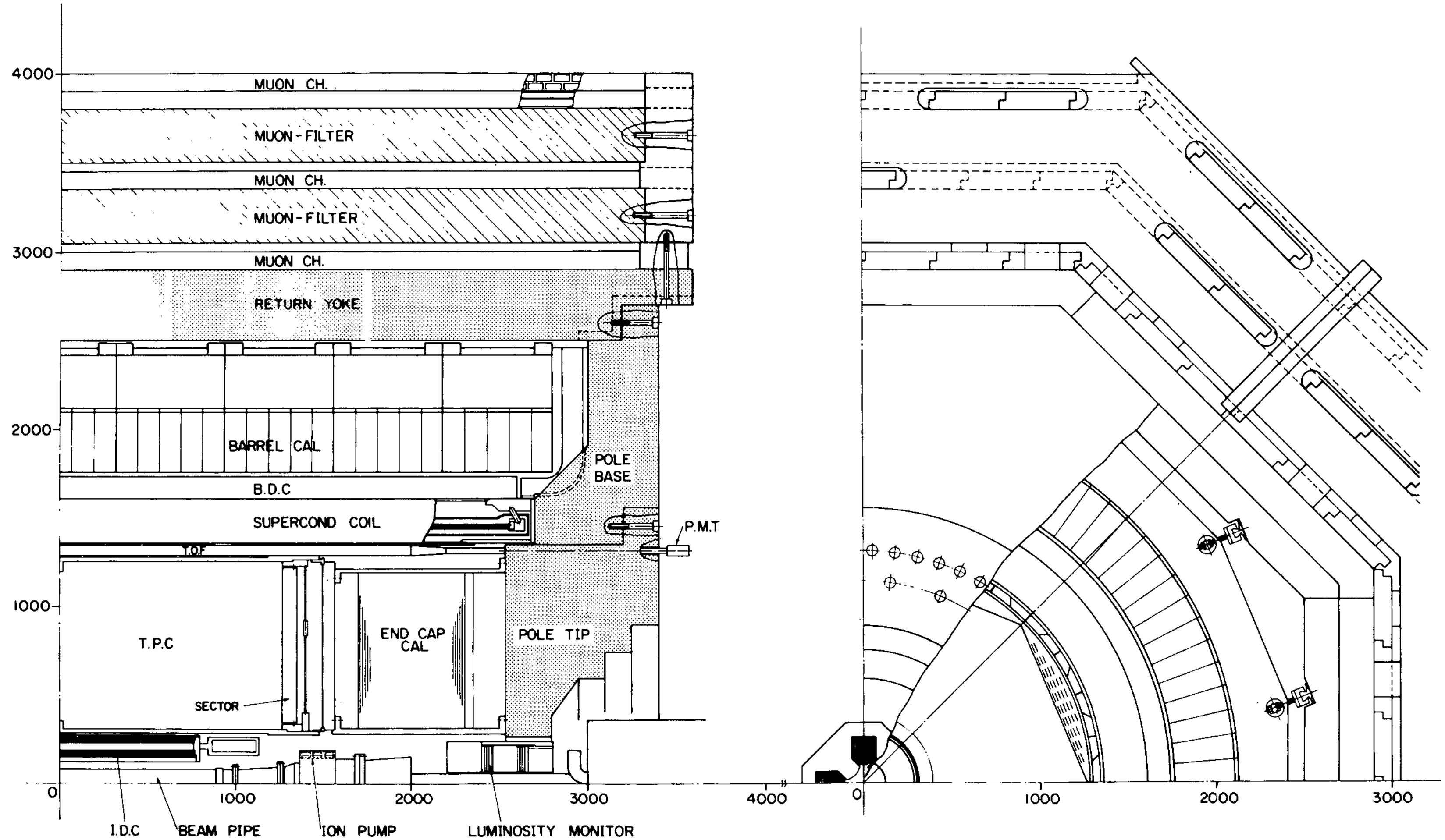
MUON CH.
MUON - FILTER
MUON CH.
MUON - FILTER
MUON CH.
RETURN YOKE
BARREL CAL
B.D.C
POLE BASE
SUPERCOND COIL
P.M.T
T.O.F
T.P.C
END CAP CAL
POLE TIP
SECTOR
4000
3000
2000
1000
0
1000
2000
3000
4000
0
1000
2000
3000
I.D.C
BEAM PIPE
ION PUMP
LUMINOSITY MONITOR

TOPAZ

TPC

LOCATION	PEP e^+e^- ring, Interaction Region (IR) 2 SLAC, Stanford, CA, USA Note: see also PEP-9 2γ detector description
MAGNET	13.2 kG superconducting coil ($0.86X_0$ package) Diameter = 2.15 m, length = 3.0 m
TRACKING	Time projection chamber (TPC) 2.0 m long (in z) at 20 to 100 cm radius (r) Argon-methane (80%-20%) at 8.5 atm. Max. drift 1.0 m in 30 μs, 50 kV/m drift electric field 183 proportional wire hits on tracks with $\|\cos\theta\| < 0.71$; each wire gives r, z, and amplitude and provides dE/dx meas. by multiple ionization sampling; the azimuth is divided into six 60° sectors 15 3-dim. space points from induced cathode signals on several of 13,824 channels to give r, ϕ, and z (from the drift time), for $\|\cos\theta\| < 0.71$ $\geqslant$2 3-dim. points and $\geqslant$15 wire hits over 97% of 4π A gating grid (+/- 100V) was installed in 1984 to eliminate positive ion feedback into the drift region Track pair resolution of 1–2 cm dE/dx = $\pm$3.0% for Bhabhas = $\pm$3.5% for tracks with $\geqslant$ 120 samples in jet events $\sigma_p/p < \pm$ 0.5% at high momentum Position resolution in bending plane is 150 μm and in axial (z) direction 300 μm Inner drift chamber at 13 to 19 cm radius 8.5 atm. Ar-CH_4 (80%-20%), 1.2 m long covering 95% of 4π, with 4 axial layers Only used for triggering at present Outer drift chamber at 1.19 to 1.24 m radius 1 atm. Ar-CH_4 (80%-20%), 3 m long covering 77% of 4π, with 3 axial layers
HEXAGONAL CALORIMETER	Gas, limited Geiger mode, sampling Pb-laminate calorimeter 6 modules, $10X_0$ deep, 4.2 m long at 1.2 m radius Argon-methylal(5.5%)-N_2O(2.2%) at 1 atm. Solid angle coverage of 75% (90% including pole tip calorimeter) 3 correlated 60° stereo views using wire and cathode signals in 40 samples (27 and 13 samples in depth) Projective strip geometry with 9 mrad angular segment. $\sigma_E/E = \pm 16\% / \sqrt{E}$, below 1 GeV = $\pm$14% for Bhabhas at 14.5 GeV
POLE-TIP CALORIMETER	Gas, proportional mode, sampling Pb-laminate calorimeter 2 modules, $13.5X_0$ deep, at z= 1.1 m covering 18% of 4π Argon-methane (80%-20%) at 8.5 atm.; total of 51 samples Three 60° stereo views, each with 13 and 4 samples in depth Projective strip geometry with 8 mrad angular segment. $\sigma_E/E = \pm 11\% / \sqrt{E}$, below 10 GeV = $\pm$6.0% for Bhabhas at 14.5 GeV
MUON DETECTOR	Magnet flux return + 2 layers iron, total 810 g/cm^2 Triangular,double layer,extruded Al proportional tubes Argon-methane (80%-20%) at 1 atm. 3 layers with axial wires and 4th layer at 90° Endcap with 3 layers provides 98% of 4π coverage Resolution = 1 cm, except 3 mm when operated as drift tube
TRIGGER	$\geqslant$2 charged tracks in the TPC covering over 85% of 4π Neutral energy of $\geqslant$2 GeV (hex calorimeter) or $\geqslant$1 GeV (pole tip calorimeter with 2 clusters required), or energy in two or more calorimeter modules of $\geqslant$0.7 GeV (each) $\geqslant$1 charged in the TPC and neutral energy of $\geqslant$750 MeV

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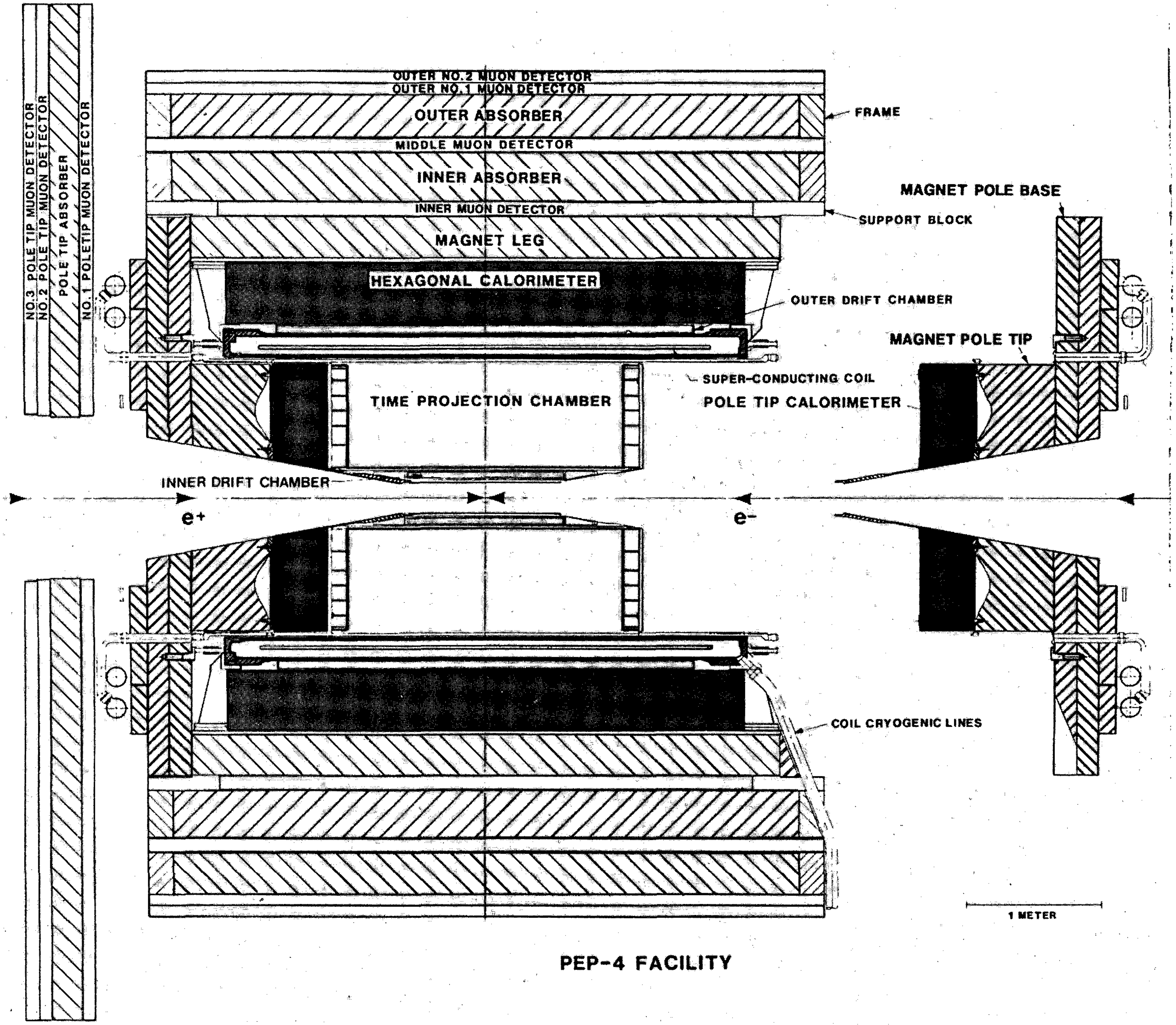

PEP-4 FACILITY

TPC

UA1

LOCATION
CERN SPS $\bar{p}p$ Collider
CERN, Geneva, Switzerland

MAGNET
Dipole field up to 0.7 Tesla, Al coils
Magnetic volume = $7.0 \times 3.5 \times 3.5\ m^3$

CENTRAL DETECTOR
Cylinder (6 m long, 2.2 m diameter) made of 6 independent modules containing drift chambers with 18 cm drift space
Covers $5° < \theta < 175°$
60% ethane - 40% argon
3-dimensional readout by continuous digitization in drift direction and charge division along wires
Average of 110 space points per track
$\sigma \simeq 250\ \mu m$ in drift plane
$\sigma \simeq 2$ % of wire length along wire
$\sigma \simeq 6\%$ for dE/dx

ELECTROMAGNETIC CALORIMETERS
Pb-scintillator sandwich ($26X_0$) with BBQ readout
Gondolas ($25° < \theta < 155°$) and Bouchons ($5° < \theta < 25°$, $155°\ \theta < 175°$)
$(\sigma_E/E)^2 = (0.15/\sqrt{E})^2 + (0.016)^2$
$\sigma_x = 4\ cm/\sqrt{E}$ (θ direction)
$\sigma_y = 16\ cm/\sqrt{E}$ (ϕ direction)
$\sigma_{E_t}/E_t = 0.12/\sqrt{E_t}$

HADRON CALORIMETERS
Fe-scintillator sandwich with BBQ readout based on the laminated return yoke of the magnet
16 samplings (5 cm Fe, 1 cm scint. each) in barrel, 23 samplings in endcaps
$\Delta E/E \simeq 0.8/\sqrt{E}$

MUON DETECTION
Large-area drift tube chambers (8 layers)
Angular resolution $\sigma = 1$ mrad

FORWARD DETECTORS
$0.2° < \theta < 5°$ and $0 < \phi < 2\pi$
Rapidity acceptance $3.4 < |y| < 7.4$
Endcap chambers
Trigger counters (4 cm thick scint.)
Electromagnetic calorimeter (4 modules Pb-scint., $7.2X_0$ each)
EM shower chambers between first and second EM modules (proportional chambers delay line readout)
Hadron calorimeter (6 modules, 1.7 λ_{abs} each), based on compensating magnet steel
Hadron shower chamber between first and second hadron calorimeter modules

ROMAN POTS
8 small drift chambers, 4 on each arm at ± 22 m from collision point, which enter the SPS vacuum pipe vertically

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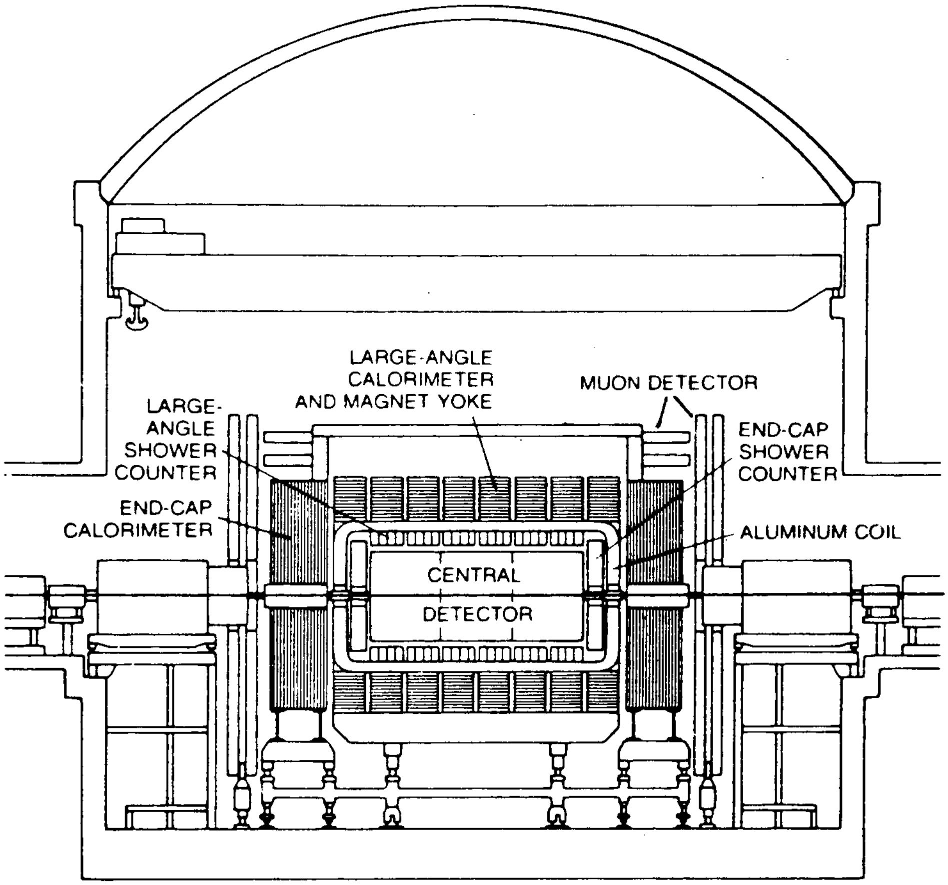
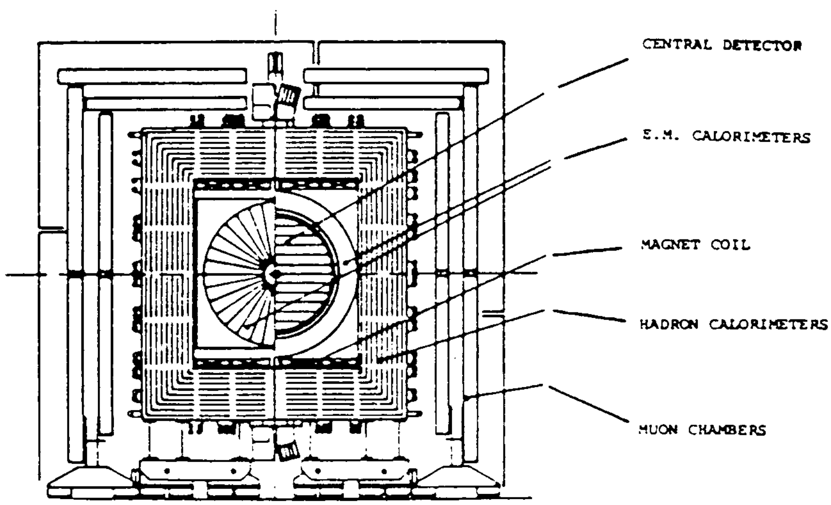
UA1





XBL 832-8020

UA2

LOCATION — CERN SPS $\bar{p}p$ Collider
CERN, Geneva, Switzerland

COLLABORATION — Univ. Bern, CERN, NBI Copenhagen, LAL Orsay, Univ. and INFN Pavia, CEN Saclay

CENTRAL DETECTOR

TRACKING — $20° < \theta < 160°$, 2π in ϕ
4 cylindrical multiwire proportional chambers (MWPC) with helicoidal cathode strips at ±45° readout
2 cylindrical JADE type drift chambers at atmospheric pressure with charge division and multihit readout
Vertex resolution $\sigma = 1$ mm in all coordinates
1 cylindrical scintillator hodoscope, 24 strips

SHOWER COUNTERS — $40° < \theta < 140°$, 2π in ϕ
Preshower counter is a cylindrical MWPC with pulse height readout on wires and helicoidal cathode strips behind a 1.5 X_0 W cylinder
17 X_0 Pb-scint. sandwich em calorimeters
4 abs. length Fe-scint. sandwich hadronic calorimeters, BBQ readout
Tower structure with cell $\Delta\phi \times \Delta\theta = 15° \times 10°$ and 3 longitudinal segments
$\sigma_E/E = 14\%/\sqrt{E}$ em and $\sigma_E/E \sim 60\%/\sqrt{E}$ hadronic showers

FORWARD-BACKWARD SPECTROMETERS

MAGNET — Toroidal magnet, 0.38 T-m
$20° < \theta < 37.5°$ and $142.5° < \theta < 160°$, 80% of 2π in ϕ
12 spectrometer sectors on each side

TRACKING — 9 drift chamber planes (±7°, 0°) per sector
5 cm drift space $\sigma_p/p \sim 0.006$ p

SHOWER COUNTERS — Preshower counter with 4 layers of multitube proportional chambers behind 1.4 X_0 lead-steel converter, $\sigma_x = \sigma_y = 5$ mm
24 + 6 X_0 lead-scint. sandwich electromagnetic calorimeters, BBQ readout, cell size
$\Delta\phi \times \Delta\theta = 15° \times 3.5°$, two longitudinal segments
$\sigma_E/E = 15\%/\sqrt{E}$

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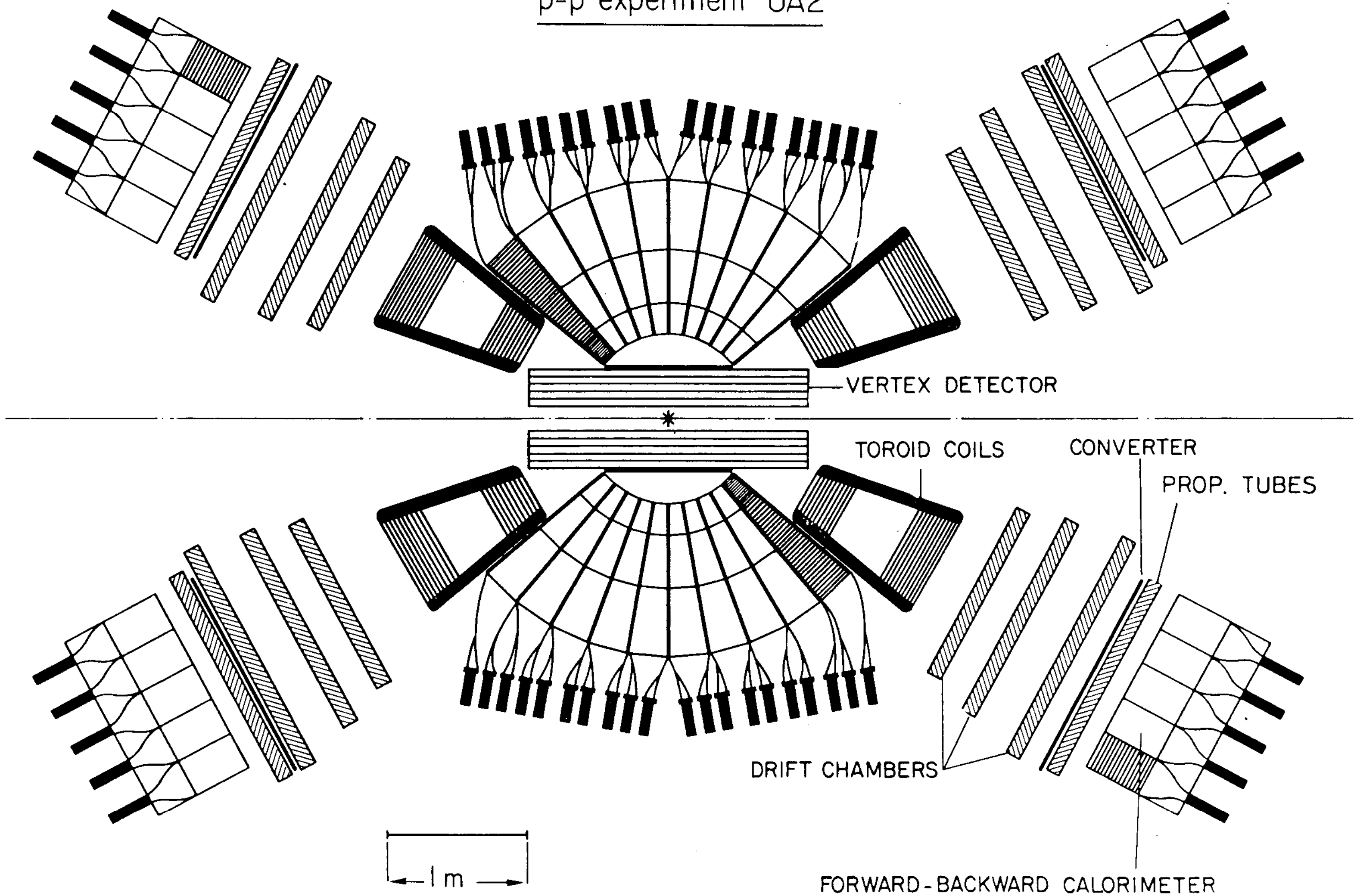
p-p̄ experiment UA2



XBL 831-7888

UA2

VENUS

LOCATION	TRISTAN 30 GeV e^+e^- ring, Fuji experiment hall National Laboratory for High Energy Physics, KEK Tsukuba, Japan
TIME SCHEDULE	Initial operation expected in November 1986
MAGNET	5–7 kG superconducting solenoid, $0.52X_0$ package, coil diameter 354cm, 564 cm long, r = 170–190.8 cm, bobbinless, 4.2°K forced He flow cooling, CFRP cryostat cylinder
TRACKING	Inner chamber (IC): r = 10–25 cm, 160 cm long, 6 layers, 640 axial wires, 1536 cathode pads for z trigger Central drift chamber (CDC): r = 25–125 cm, 300 cm long, 20 axial, 9 stereo layers, 7104 sense wires, 2 cm drift cells, σ_p/p^2 = 0.9% for p>2 GeV/c at 5 kG expected Outer drift tubes (ODT): r = 157–162 cm, 280 cm long, 3 layers, 1528 tubes, tube diameter 1.95 cm, σ_p/p^2 = 0.2% with CDC Streamer tubes (ST): r = 191–194 cm, 444 cm long, 1200 resistive tubes with 1.9×1.3 cm^2, 2 layers, 4800 cathode strips
TIME-OF-FLIGHT	96 scintillation counters at r = 166 cm, $466 \times 10.7 \times 4.2$ cm^3, 2″ phototubes on both ends, $\sigma_{TOF} \cong 200$ ps expected
BARREL CALORIMETERS	Lead glass, r = 200–230 cm, 5160 towers covering 37°–143° pointing to I.P., DF6 glass, $18X_0$, 30 cm long, cross section 11×12 cm^2 typical, 3″ phototubes with plastic light guides, monitored by 2 independent Xe-lamp and optical-fiber systems, $\sigma_E/E = 6\%/\sqrt{E}$ expected
ENDCAP CALORIMETER	Liquid argon, 480 towers/endcap, covering 150 mrad-37° spherically arranged pointing to I.P., cross section 10×10 cm^2, 71 Pb plates 1.5 mm thick, 3 mm argon gap, $20.5X_0$, 4 longitudinal segmentations, $\sigma_E/E \cong 10\%/\sqrt{E}$ expected
MUON DETECTOR	Flux return yoke + 2 layers of iron, 900 g/cm^2 at 90°, 5263 rectangular double staggered layers, extruded Al drift tubes of $7 \times 5 \times 780$ cm^3, 6 axial layers and last 2 layers at 90°, 0.8 mm position resolution expected
PARTICLE ID DEVICE	Expect transition radiation detectors (TRD) in future r = 126–156 cm, 18 μm polypropylene fibers for radiator, 3 layers of photon detectors with Xe(90%)–CH_4(10%)
LUMINOSITY MONITOR	48 Pb-scintillator shower counters with PWC's, $15X_0$, covering 60–150 mrad
TRIGGER	Combinations of r-ϕ track finder, z track finder, calorimeter energy triggers, and TOF timings

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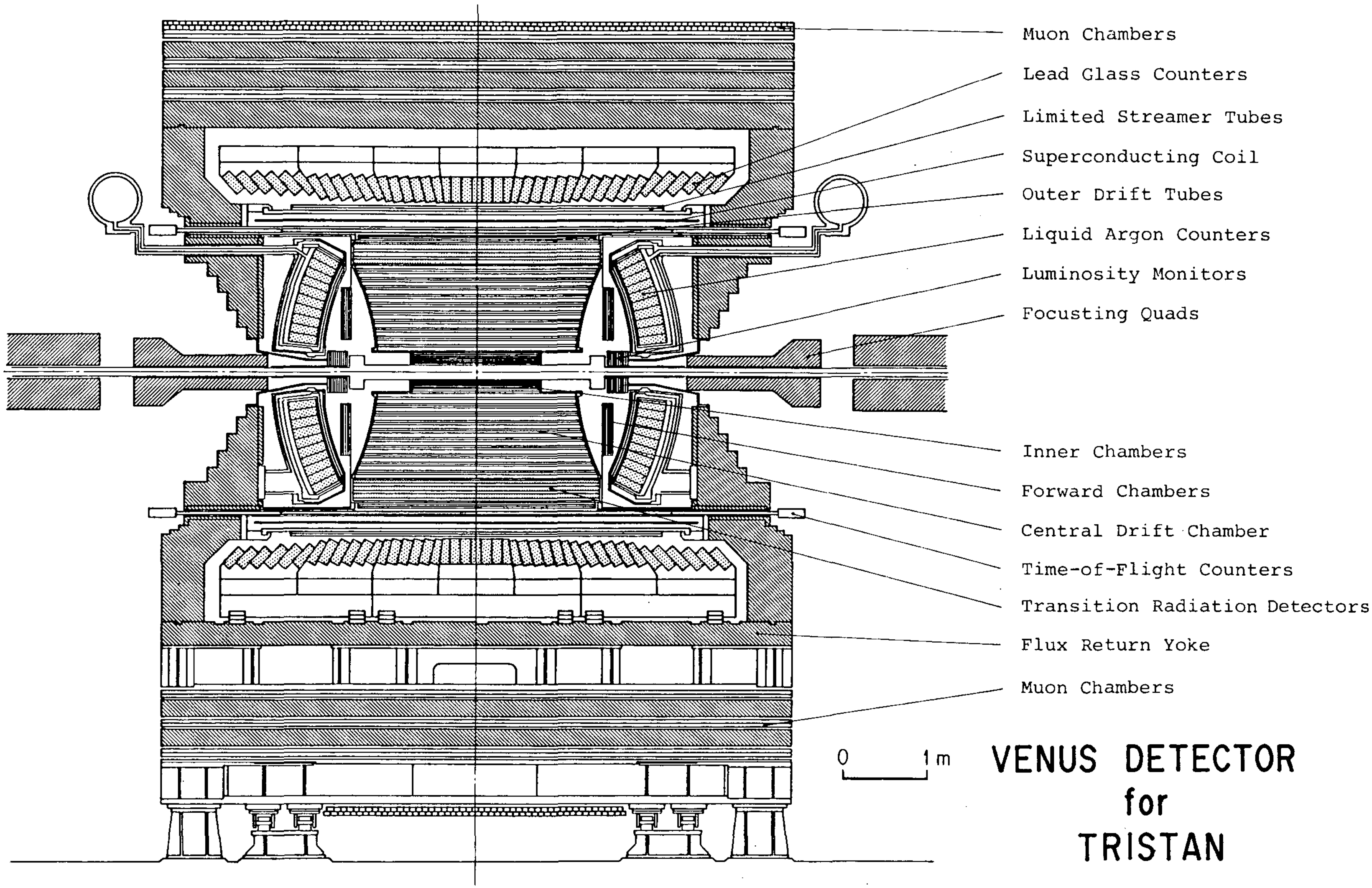

VENUS DETECTOR for TRISTAN

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