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### Title

MAJOR DETECTORS IN ELEMENTARY PARTICLE PHYSICS Suppl. Mar. 1983

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MAJOR DETECTORS IN ELEMENTARY PARTICLE PHYSICS

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Abstract

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

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LBL-91 suppl.  
c-2

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## Introduction

With the 1983 issue of LBL-91 we introduce a supplement -- a folio of descriptions of the world's major elementary particle physics detectors. Modern high energy physics usually involves the use of massive, costly, carefully engineered, large solid angle detectors. These detectors require a long lead time for construction, are often integrated with an accelerator, accumulate data over many years, and are in reality a combination of numerous subsystems. As was the case with bubble chambers, many experiments are performed with the same data, or with data taken after relatively minor changes or additions to the detector configuration. These experiments are often reported in journals whose space limitations make repeated full descriptions of the detector impossible. The detailed properties and performance of the detector are usually described in a fragmented series of papers in more specialized, technologically oriented journals. New additions are often not well documented.

Several detectors often make similar measurements and physicists want to make quick comparisons of their respective capabilities. Designers of new large detectors and even of smaller experiments need to know what already exists and what performance has been achieved.

To aid the physics community, the Particle Data Group has produced this brief folio of the world's major large detectors. It is in looseleaf form to allow periodic updates and additions. This first edition has some notable omissions: in particular, the bubble chambers and any associated spectrometers, and the still somewhat tentative LEP, SLC, and TRISTAN detectors. We apologize to those whose detectors have been left out of this edition. Suggestions for inclusion in future editions are welcome.

None of this would have been possible without the help of the physicists working with each detector who took the time to summarize its properties and to supply us with the appropriate drawings. We thank them again and ask all experimenters to help us make this an accurate, up-to-date, and useful compendium.

## 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  $\text{GeV}/c^2$  and  $p$  in  $\text{GeV}/c$ .
- For further information, please contact the experimental group itself. Current spokesmen for particular experiments can be found in the Spokesman Index of LBL-91.
- In the Table of Contents, the experiments column refers to the summaries in the March 1983 edition of LBL-91. Experiments completed before 1979 are not included.

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TPC	SLAC-PEP-004
UA1	CERN-UA-01
UA2	CERN-UA-02



## ARGUS

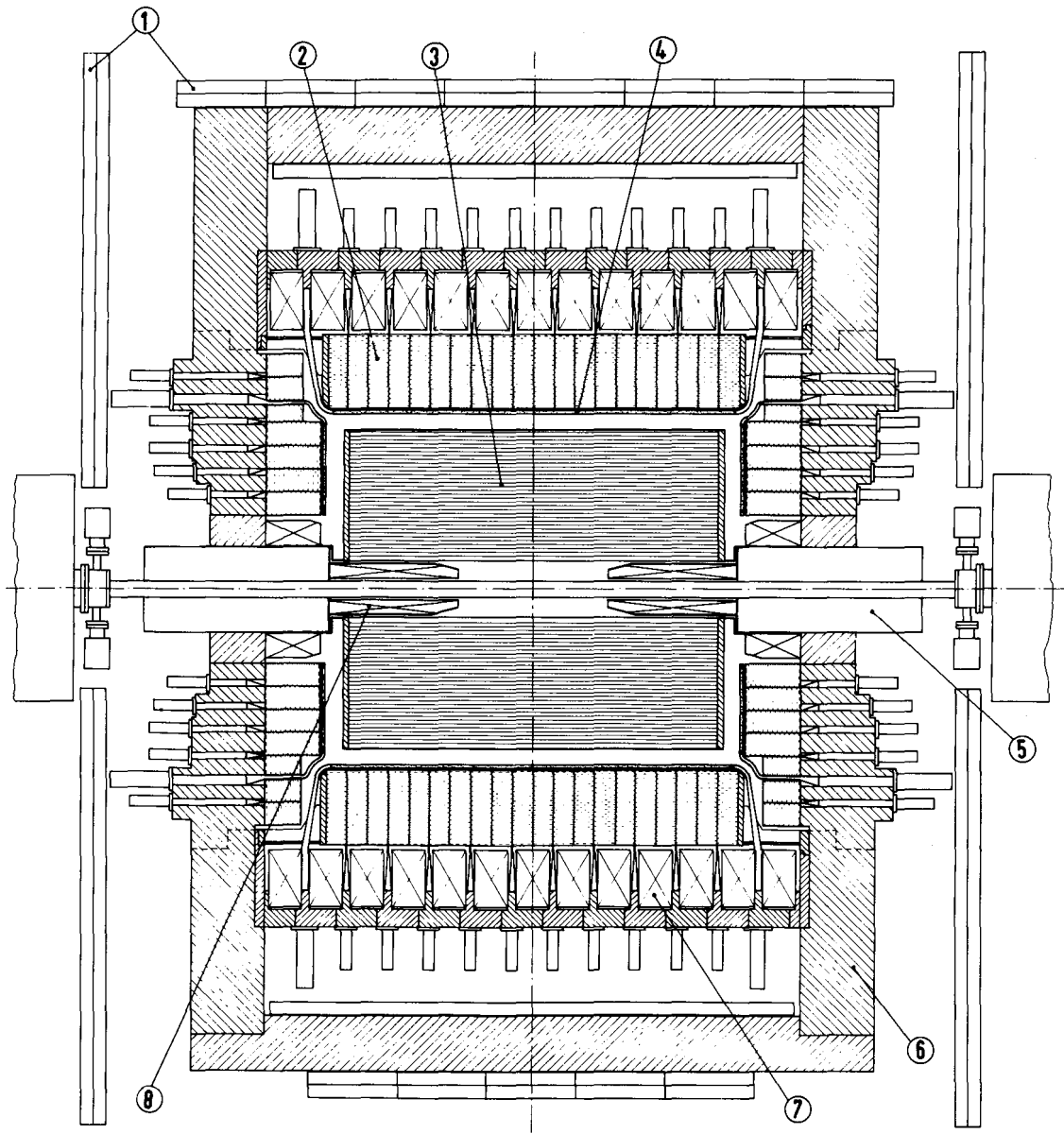
LOCATION	DORIS II $e^+e^-$ ring DESY, Hamburg, W. Germany
COLLABORATION	DESY, Univ. Dortmund, Univ. Heidelberg, IPP Canada, Univ. Kansas, Univ. Lund, ITEP Moscow, Univ. South Carolina
MAGNET	0.8 Tesla solenoid, 13 copper coils Diameter 2.8 m, length 2.9 m
MINIBETA	Quads integrated and compensated inside magnet
TRACKING	Cylindrical drift chamber Radius 15 to 85 cm, length 200 cm 5940 drift cells with $18 \times 18.8 \text{ mm}^2$ 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 $\sigma_p/p = 1.2\% p$ $\sigma_\theta = 3.4 \text{ mrad}$
SHOWER COUNTERS	Barrel arranged as 20 rings, 64 counters in each ring 40 cm deep, $12.5 X_0$ sandwich of 1 mm lead and 5 mm scintillator, BBQ readout, lightguides between coils $\sigma_E/E = 8\%/\sqrt{E}$ , $\sigma_\theta = 11 \text{ mrad}$ Endcaps $2 \times 240$ counters Solid angle 96% in total
TIME OF FLIGHT	Barrel of 64 counters, radius 96 cm Endcaps $2 \times 48$ counters TOF resolution 270 ps Solid angle 92%
MUON DETECTION	1744 proportional tubes with $6 \times 6 \text{ cm}^2$ cross section Layer behind shower counters and coil Layer behind the return yoke Solid angle 85%
VERTEX CHAMBER	Radius 5 to 14 cm Length 1 m (in preparation)

### REFERENCES

1. ARGUS, a new detector for DORIS, DESY F15/Pro 148, October 1978.



# ARGUS



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

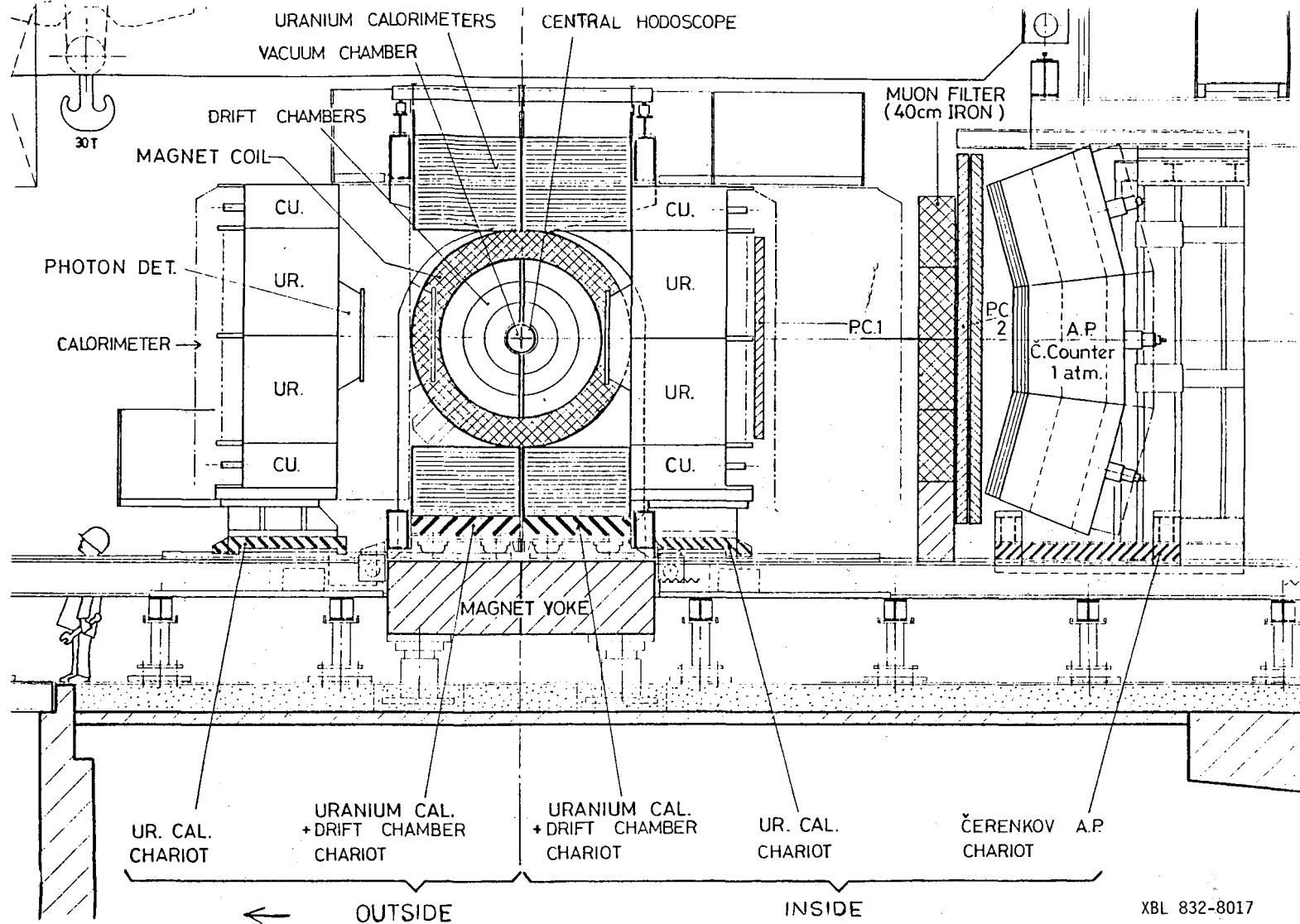
XBL 831-7896

## Axial Field Spectrometer (AFS)

LOCATION	ISR (pp, p $\bar{p}$ , $\alpha$ p, $\alpha\alpha$ -beams, $\sqrt{s}$ from 22 to 63 GeV) CERN, Geneva, Switzerland
MAGNET	Open axial field magnet, 0.5 Tesla Unobstructed aperture: azimuthal $0 < \phi < 2\pi$ , polar $0^\circ \leq \theta \leq 15^\circ$ and $40^\circ \leq \theta \leq 140^\circ$
TRACKING	Cylindrical drift chamber 1.4 m long, extending radially from 20 cm to 80 cm 4° sectors with 42 sense wires each Argon/ethane (50/50 vol%) at 1 atm. $\sigma = 220 \mu\text{m}$ (averaged), $\sigma_z = 1.4 \text{ cm}$ (averaged) $\sigma(dE/dx) = 11\%$ , $\pi/K/p$ separation in the region of 300 < p < 800 MeV/c, electron/ $\pi$ separation for p < 100 MeV/c and p > 300 MeV/c $\sigma_p/p = 0.02 p$
SHOWER COUNTERS	Two walls of 600 NaI crystals each 5.25 X <sub>0</sub> , vacuum photo diode readout, noise $\simeq 1 \text{ MeV}$ , coverage 1.3 sterad $\sigma_E/E = 9\%$ for 1 GeV electrons (incl. U-calorimeter) Hadron calorimeter, coverage $\sim 8$ sterad Uranium/copper-scintillator with wavelength shifter readout, 20 $\times$ 20 cm <sup>2</sup> 'towers', twofold longitudinal segmentation Electrons: $\sigma_E/E = 16\%/\sqrt{E}$ , $\sigma_x = \sigma_y = 1 \text{ cm}$ Hadrons: $\sigma_E/E = 37\%/\sqrt{E}$ , $\sigma_x = \sigma_y = 3\text{--}10 \text{ cm}$ (dep. on angle) e/ $\pi$ energy response = 1.15 e/ $\pi$ separation 1:50 at 2 GeV for 75% electron acc.
MUON IDENTIFICATION	Filter consisting of uranium calorimeter and 40 cm of iron Two planes of MWPC and Cerenkov counters covering 1 sterad, $P_{\text{threshold}} = 2 \text{ GeV}/c$
TRIGGER	Parallel triggers based on analog computation of event topology and particle composition (e.g., hadrons vs. electrons, jets vs. single particles) Both calorimeter information and drift chamber tracking information used Typical trigger selectivity: 1:10 <sup>6</sup>

### REFERENCES

1. H. Gordon et al., Nucl. Instr. & Meth. **196** (1982) 303.
2. O. Botner et al., Nucl. Instr. & Meth. **196** (1982) 315, Nucl. Instr. & Meth. **179** (1981) 45, and IEEE NS **28** (1981) 510.



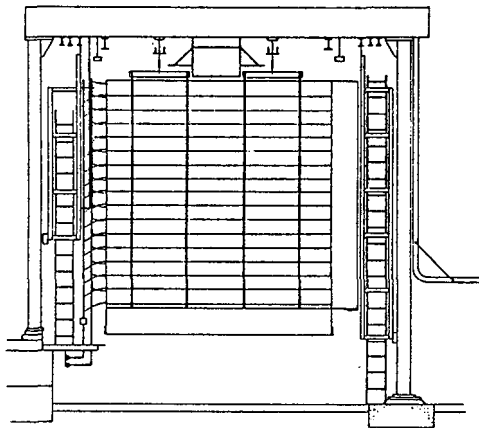
Axial Field Spectrometer (AFS)

## Brookhaven Neutrino Detector

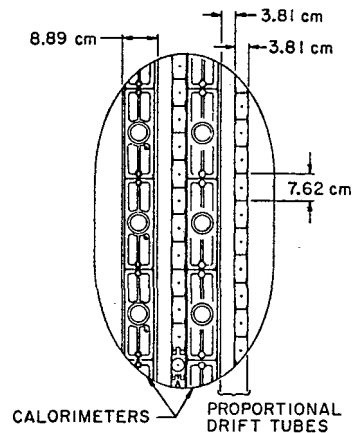
LOCATION	Brookhaven National Laboratory Upton, NY, USA
INCIDENT BEAM	Neutrino, horn focussed from 28 GeV Protons 110 m from proton target
ASSEMBLY	Modular construction, each module consisting of a plane of calorimeter and two planes (x,y) of tracking proportional drift tubes 112 Modules + $\gamma$ -catcher + spectrometer Weight: 172 + 30 metric tons
CALORIMETER (LIQUID SCINTILLATOR)	Active area $4.22 \times 4.09 \text{ m}^2$ ; 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 $4.2 \times 4.2 \text{ m}^2$ 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 $\langle \int B dl \rangle = 70 \text{ MeV/c}$ $(\Delta p/p)^2 = [0.10^2 + (0.067p)^2] p$

# BNL NEUTRINO DETECTOR

FRONT VIEW



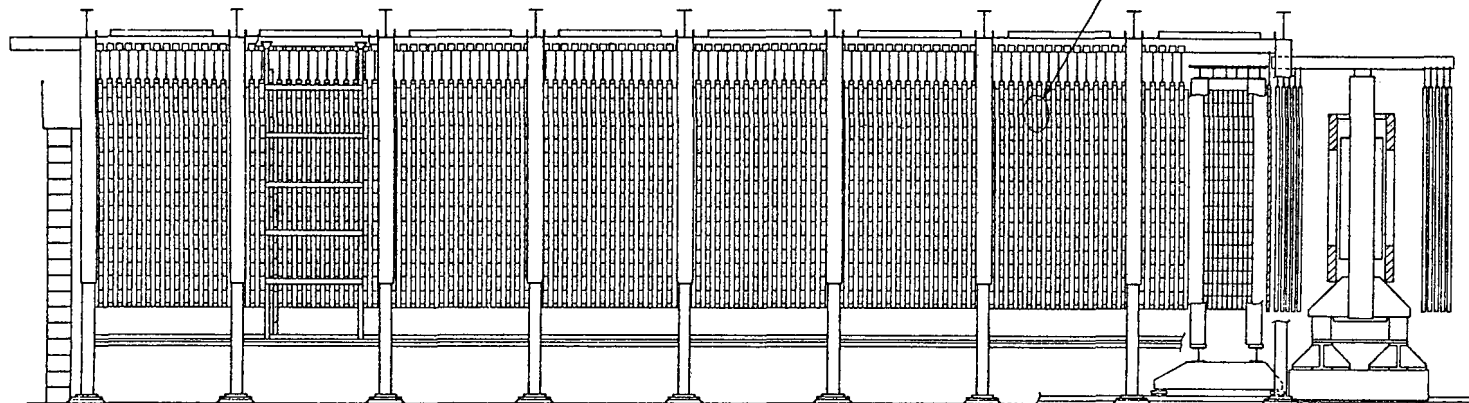
DETAIL A



## INSTITUTIONS

- BNL
- BROWN
- KEK
- OSAKA
- TOKYO (INS)
- PENNSYLVANIA
- SUNY STONYBROOK

→ NEUTRINO BEAM DIRECTION



MAIN DETECTOR, ELEVATION

GAMMA  
CATCHER

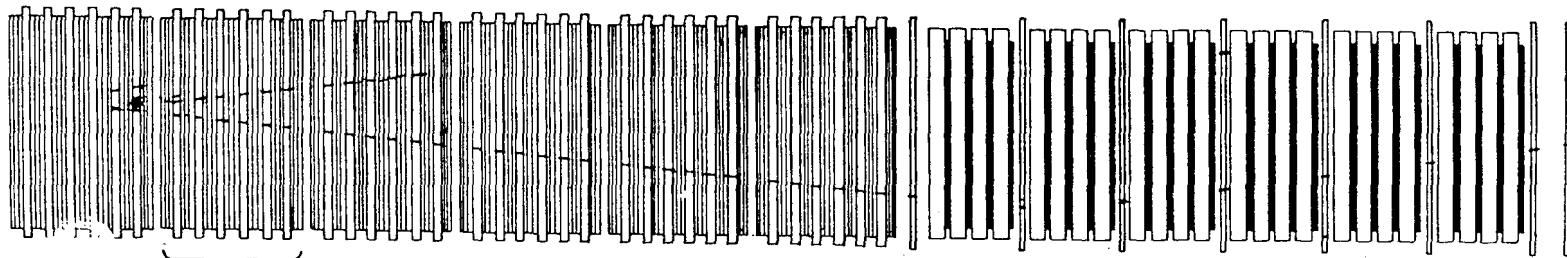
MUON  
SPECTROMETER

XBL 831-7890

Brookhaven Neutrino Detector

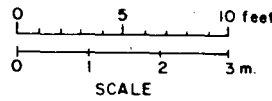
**CCFR Neutrino Detector**  
(Columbia-Chicago-Fermilab-Rochester)

<b>LOCATION</b>	Fermilab Neutrino Area, Lab E Batavia, IL, USA
<b>TARGET</b>	8 m × 3 m × 3 m Fe tracking calorimeter
<b>MAGNETS</b>	35 m diameter iron toroids, instrumented with acrylic scintillator every 20 cm steel Three toroids, each with 1.6 m steel along beam direction
<b>TARGET CALORIMETRY</b>	10 cm steel separation between 2.5 cm liquid scintillator planes with BBQ wavelength shifting bars on side Four 2-in. phototubes per counter $\sigma/E = 0.84/\sqrt{E}$
<b>TARGET TRACKING</b>	20 cm steel separation between 3 m × 3 m drift chambers, each with x and y planes Chambers have 24 cells in each plane: 12 cm transverse for each cell, with two- wire readout (no left-right ambiguity) $\sigma = 200 \mu$ positional accuracy Multi-hit readout with measurement of leading and trailing edges Linear output available for charge vs. time readout
<b>TOROID TRACKING</b>	Same drift chambers located as shown in figure $\Delta p/p \approx 0.11$ , dominated by multiple scattering
<b>BEAM</b>	Dichromatic neutrino beam (Tevatron) $p_{\text{sec}} \lesssim 700 \text{ GeV}$
<b>INTENSITY MONITORS</b>	Neutrino lab facility providing calibrated ion chamber monitoring of momentum-selected hadron beam Additionally, rf cavity monitors, Cerenkov counter, and muon monitors for redundant measures of flux



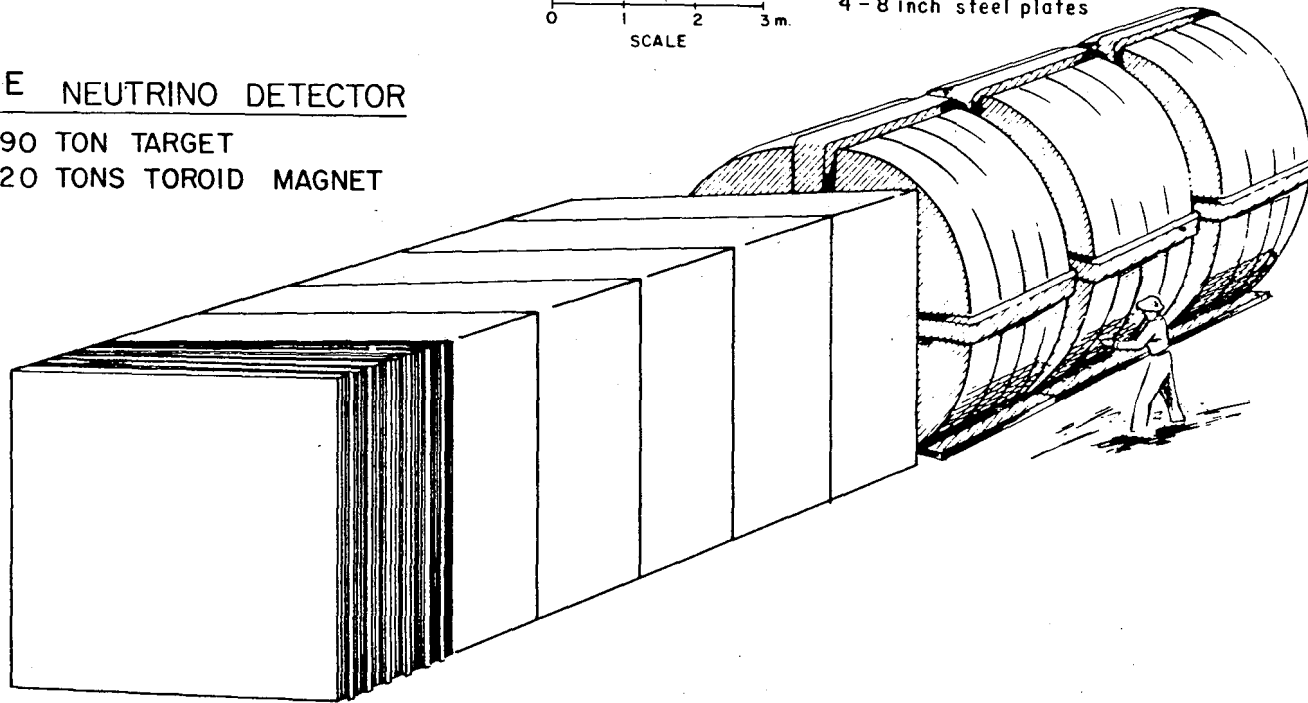
TARGET CART:  
 7 Drift chambers  
 14 Scintillators  
 28-12 inch steel plates } 115 tons each,  
 Total of 6

TOROID MAGNET UNIT:  
 4 Drift chambers  
 4 Scintillators  
 4-8 inch steel plates } 70 tons each,  
 Total of 6



LAB E NEUTRINO DETECTOR

690 TON TARGET  
 420 TONS TOROID MAGNET



CCFR Neutrino Detector

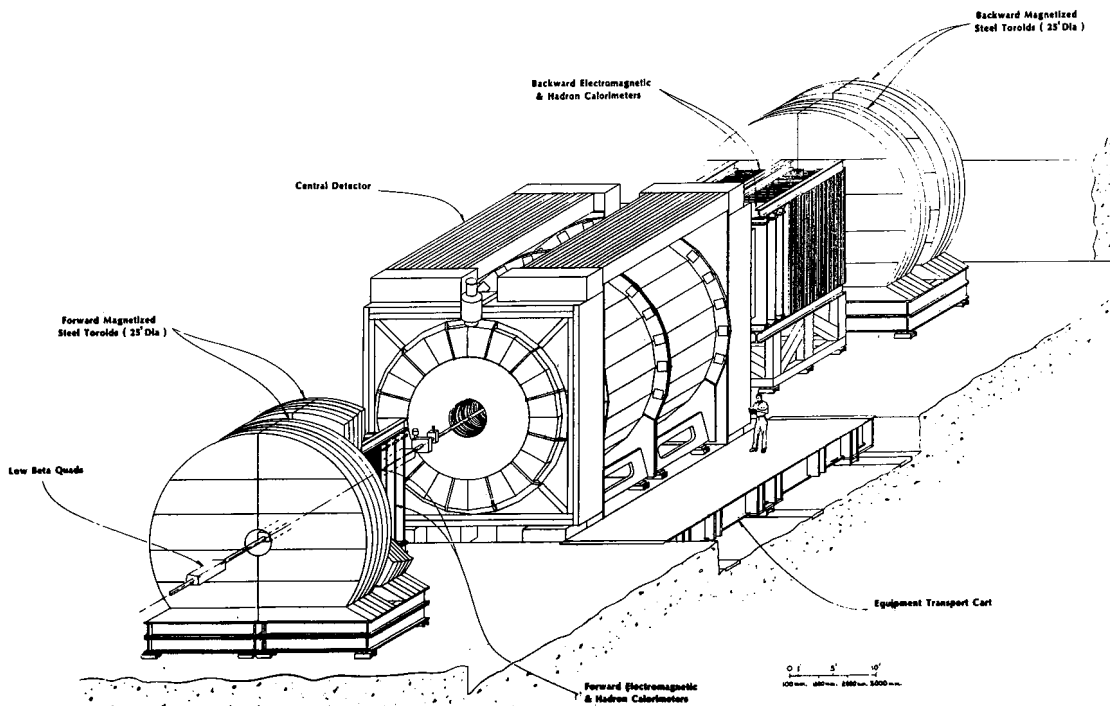
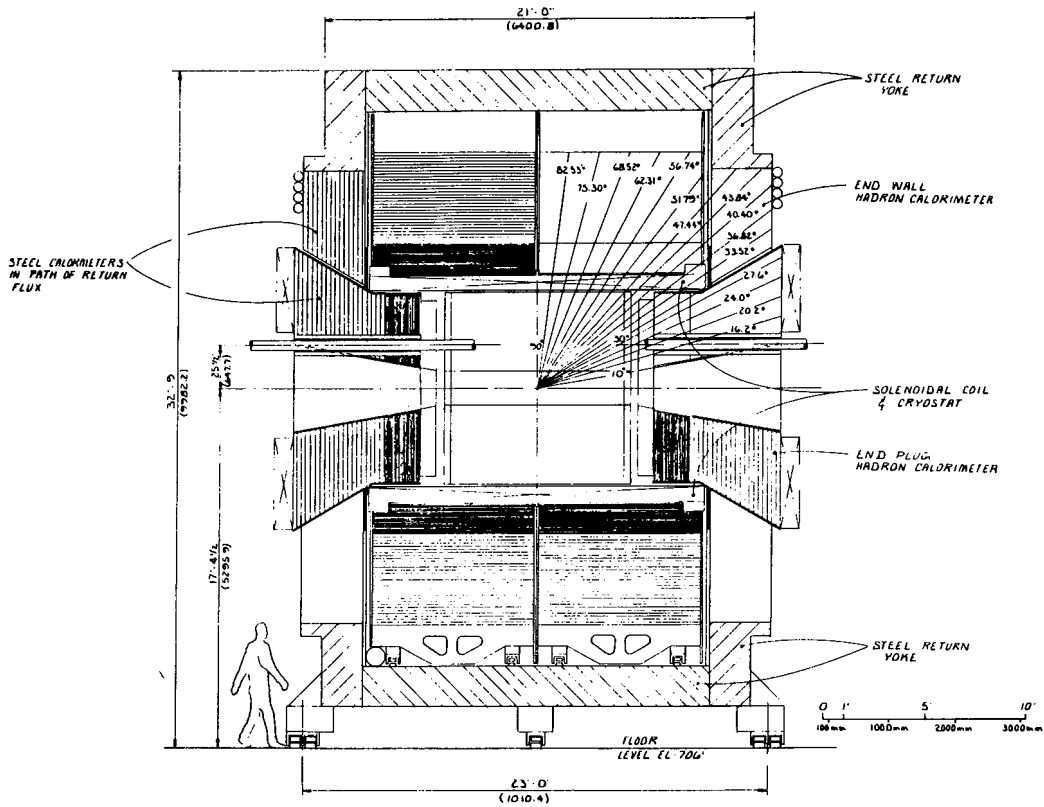
XBL 832-8441

## Collider Detector at Fermilab (CDF)

LOCATION	BO $\bar{p}p$ collision area Fermilab, Batavia, IL, USA
MAGNET	1.5 Tesla superconducting solenoid 5 m long $\times$ 3 m diameter
TRACKING	Cylindrical drift chamber 11 double planes of axial wires, half-cell staggered 8 planes of $3.4^\circ$ small angle stereo wires 15.7 mm cell size 10,080 total sense wires
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 $\sigma_E/E \approx 29\%/\sqrt{E}$ Spatial resolution $\approx 3$ mm at 40 GeV
SMALL ANGLE	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) $\sigma/E \approx 5.5\% + 62\%/\sqrt{E}$
END WALL	5 cm steel, 1 cm scintillator Construction similar to central modules $\sigma/E \approx 6\% + 77\%/\sqrt{E}$
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 $\sigma/E \approx 11\%$ at 100 GeV
SMALL ANGLE	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



# Collider Detector at Fermilab (CDF)



XBL 832-8022

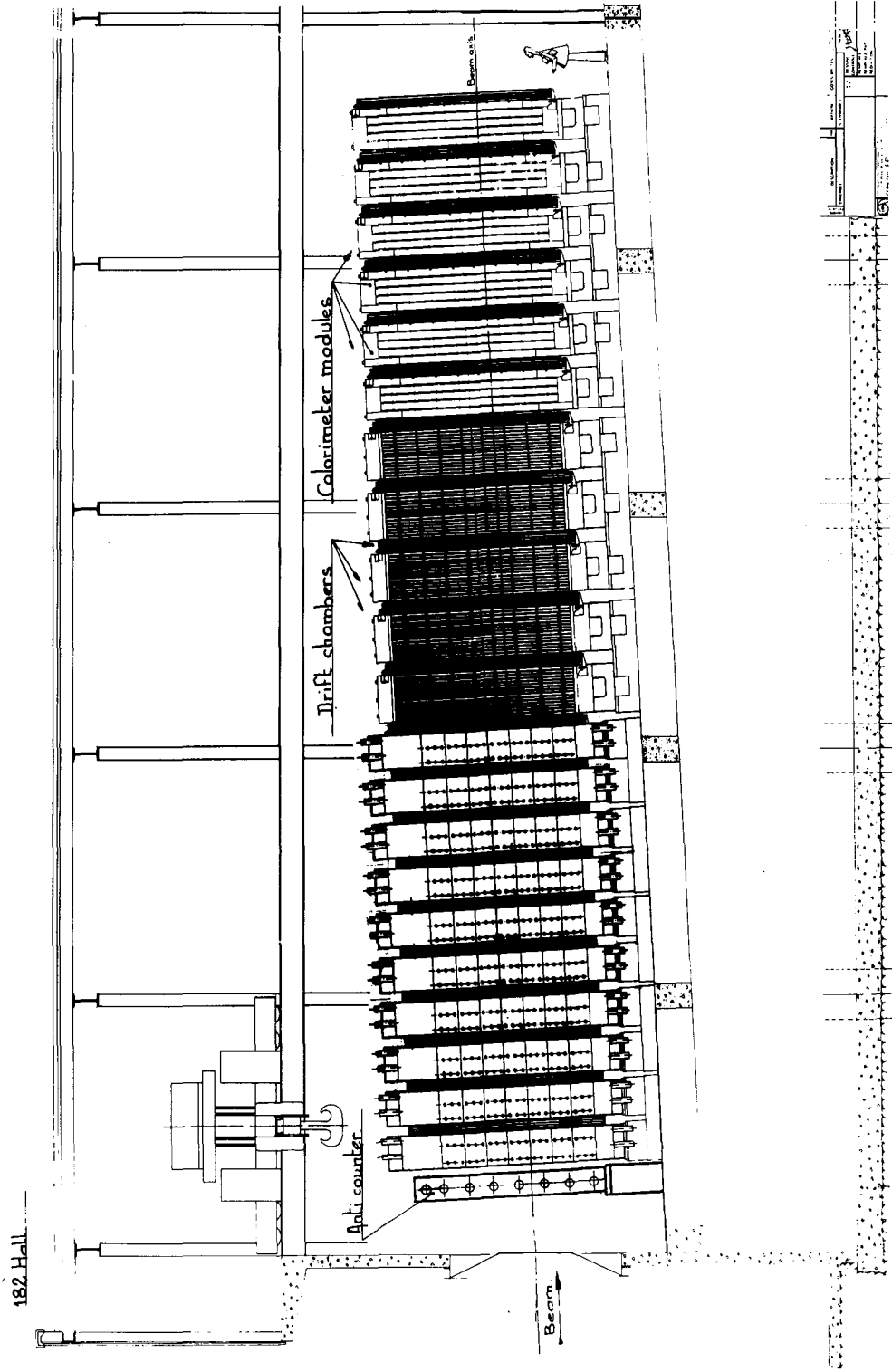
## CDHS Neutrino Detector

LOCATION	CERN SPS CERN, Geneva, Switzerland
MAGNET	21 Fe-toroids, diameter 3.85 m <math>\langle B \rangle = 16.5 \text{ kG}</math> First 10 toroids have 50 cm, the rest 75 cm of iron in beam direction
TRACKING	21 planar drift chambers with 3 planes (y, u, v) each, after each toroid $\Delta p_\mu/p_\mu \approx 9\%$ on average, for $p_\mu > 5 \text{ GeV}$ , dominated by multiple scattering in toroids
CALORIMETER	Toroidal magnets are iron-scintillator sandwiches First 10 toroids have 20 plates of 2.5 cm iron thickness, 5 toroids with 15 plates of 5 cm, and 6 toroids with 5 plates of 15 cm iron each In the first 10 toroids scintillators are in x and y direction In the last 11 toroids scintillators are only in x direction $\Delta E/E = 0.5/\sqrt{E}, 0.7/\sqrt{E}, 1.3/\sqrt{E}$ corresponding to sample thickness

### REFERENCES

1. M. Holder et al., Nucl. Instr. & Meth. **148** (1978) 235.
2. H. Abramowicz et al., Nucl. Instr. & Meth. **180** (1981) 429.

# CDHS Neutrino Detector



XBL 831-7900

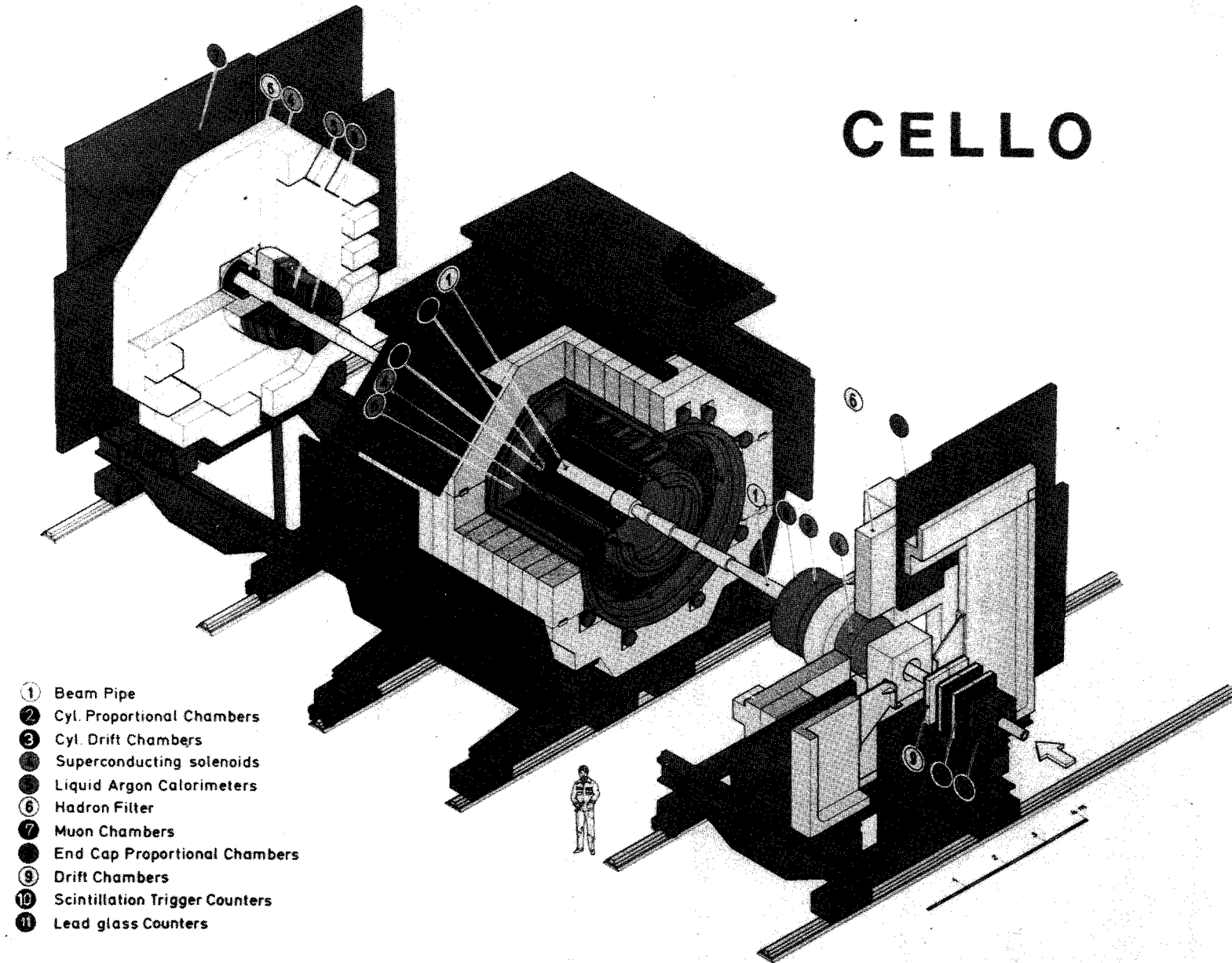
## CELLO

LOCATION	PETRA $e^+e^-$ rings DESY, Hamburg, W. Germany
COLLABORATION	DESY, Hamburg KfK und Universität, Karlsruhe MPI, München LAL, Université de Paris XI, Orsay Université de Paris VI CEN, Saclay
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 8 planar end-cap chambers 2 cylindrical layers of drift tubes (vertex detector installed end 1982) Tracking down to $\theta = 150$ mrad $\sigma_p/p = 2\% p \sin \theta$ ( $p > 2$ GeV, $\theta > 30^\circ$ ) $\sigma_z = 0.4$ mm centroid measurement on cathode strips
EM CALORIMETRY	20 lead-liquid argon modules ( $20X_0$ ) down to $\theta = 130$ mrad 5 layers in depth for shower sampling $\sigma_E/E = 13\%/\sqrt{E}$ $\sigma_\theta = 4$ mrad
MUON DETECTION	32 planar proportional chambers (covering 92% of $4\pi$ ) $\sigma_{\text{position}} = 6$ mm $p_{\text{cut-off}} = 1.4$ GeV
FORWARD DETECTORS	Pb-glass blocks + scintillators $50 \theta < 100$ mrad
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



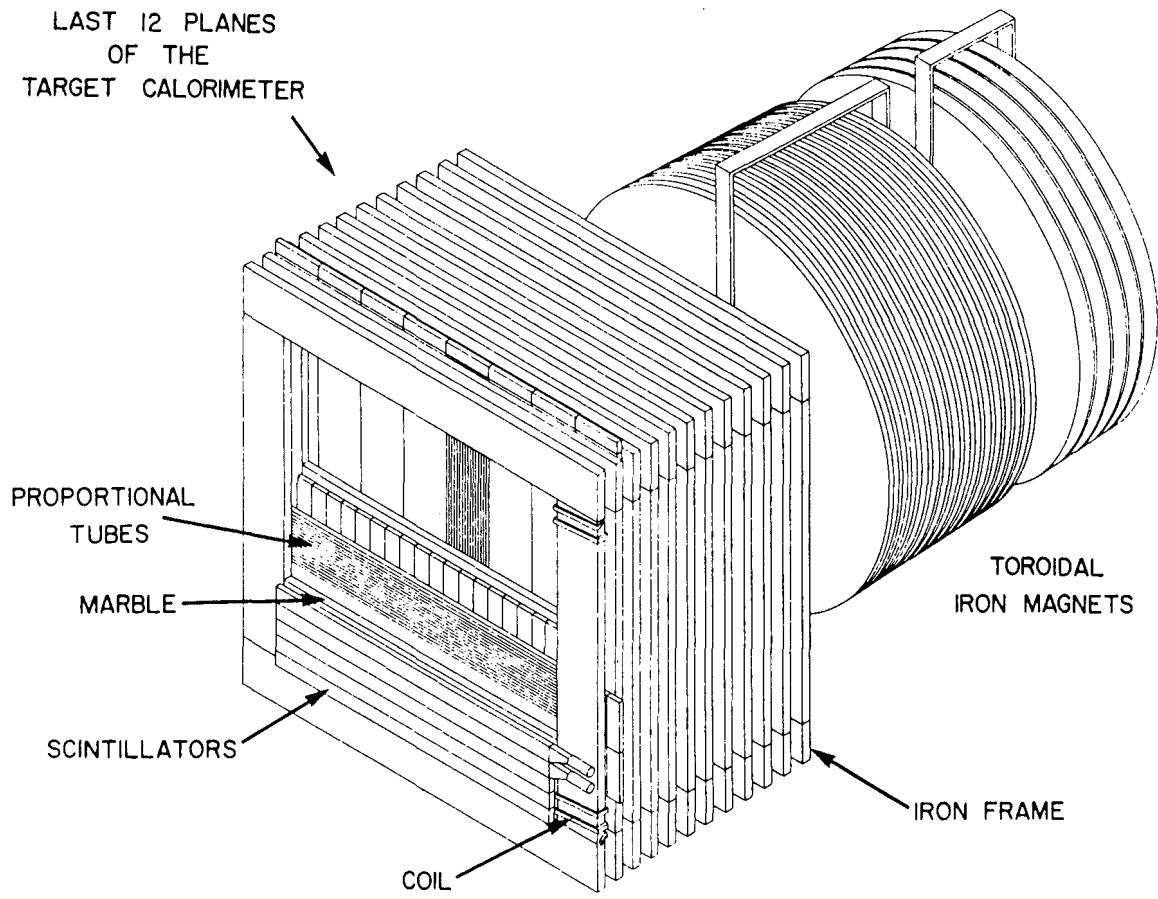
- ① Beam Pipe
- ② Cyl. Proportional Chambers
- ③ Cyl. Drift Chambers
- ④ Superconducting solenoids
- ⑤ Liquid Argon Calorimeters
- ⑥ Hadron Filter
- ⑦ Muon Chambers
- ⑧ End Cap Proportional Chambers
- ⑨ Drift Chambers
- ⑩ Scintillation Trigger Counters
- ⑪ Lead glass Counters

CELLO

## CHARM Neutrino Detector

- LOCATION** 400 GeV Proton Synchrotron  
Neutrino Beam Facility  
CERN, Geneva, Switzerland
- FINE GRAIN TARGET CALORIMETER**  
78 modules ( $1X_0$  and  $0.28\Lambda_{\text{abs}}$  each), each consisting of a target plate (marble)  
 $3 \times 3 \text{ m}^2$  and 8 cm thick, 128 proportional drift tubes, 4 m long and  $3 \times 3 \text{ cm}^2$   
cross section, 256 streamer tubes (digital readout) and 20 scintillators  $3\text{m} \times 0.15\text{m}$   
at  $90^\circ$  with respect to the proportional tubes  
100 tons fiducial volume
- TRIGGER** At least one hit in any four planes of scintillator  
Trigger efficiency of 100% at  $E_h = 2 \text{ GeV}$
- MUON TRACKING** A minimum track length of 18 target modules is required, corresponding to muon range  
of 1 GeV and filtering through  $5.2 \Lambda_{\text{abs}}$   
For magnetic charge and momentum analysis, a  $p_\mu > 2 \text{ GeV}/c$  is required
- PERFORMANCE**  
 $\sigma(E_h)/E_h \sim 0.45/\sqrt{E_h}$   
 $\sigma(E_{\text{elm}})/E_{\text{elm}} \sim 0.20/\sqrt{E_{\text{elm}}}$   
 $\sigma(\theta_\mu) \sim 2-5 \text{ mrad}$  ( $E_\mu \sim 150-50 \text{ GeV}$ )  
 $\sigma(\theta_h) \sim 18 \text{ mrad}$  at  $E_h \sim 100 \text{ GeV}$   
 $\sigma(\theta_e) \sim 10 \text{ mrad}$  at  $E_{\text{elm}} \sim 15 \text{ GeV}$
- MUON SPECTROMETER** 45 cm wide, 8 cm thick magnetized Fe frames surrounding each calorimeter module  
Acts as coarse calorimeter for leakage  
Following the calorimeter is a forward muon spectrometer consisting of iron disks with  
toroidal magnetic field  
Tracking and calorimetry in frame and end magnets by proportional drift tubes  
 $\sigma(p_\mu)/p_\mu \sim 15-20\%$
- REFERENCES**
1. A.N. Diddens et al., Nucl. Instr. & Meth. **178**, (1980) 27.
  2. C. Bosio et al., Nucl. Instr. & Meth. **176**, (1980) 189.
  3. M. Jonker et al., Nucl. Instr. & Meth. **200**, (1982) 183.

# CHARM Neutrino Detector



XBL 831-7886

## CLEO

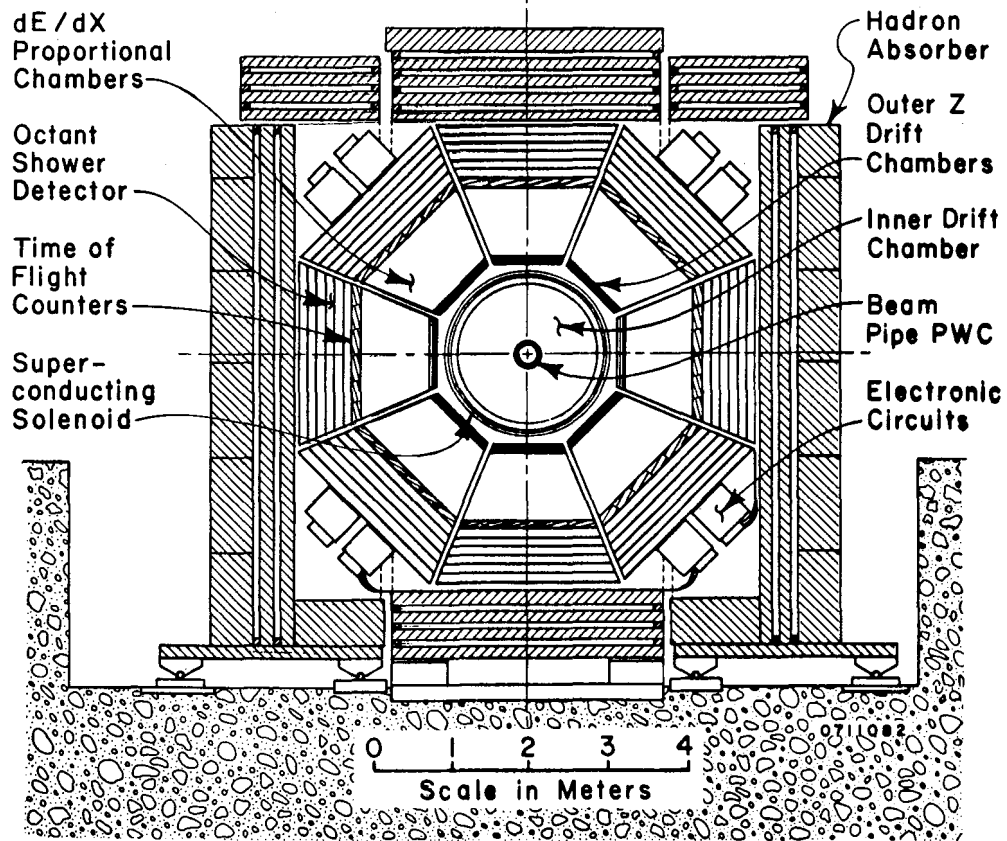
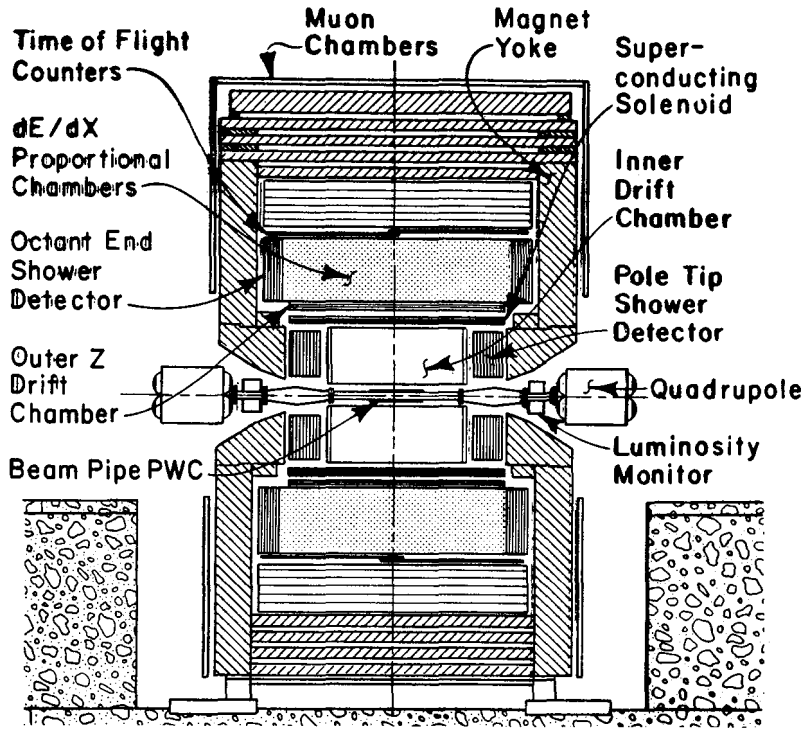
LOCATION	CESR $e^+e^-$ ring Wilson Laboratory, Cornell University, Ithaca, NY, USA
MAGNET	1.0 Tesla (superconducting)
TRACKING	Proportional chamber + drift chamber $(\Delta p/p)^2 = (0.012p)^2 + (0.006/\beta)^2$
SHOWER COUNTERS	12 $X_0$ of Pb-proportional tube sandwich $\Delta E/E = 0.17/\sqrt{E}$ $\Delta\theta = 6$ mrad
END CAP SHOWER COUNTERS	10 $X_0$ of Pb-proportional tube sandwich $\Delta E/E = 0.39/\sqrt{E}$ $\Delta\theta = 6$ mrad
PARTICLE IDENTIFICATION	Time-of-flight counters $\sigma = 400$ ps ( $\pi$ , K, p separation) dE/dx chambers $\sigma = 5.8\%$ (e, $\pi$ , K, p separation)
MUON DETECTION	4-10 interaction lengths of iron $p_{\text{cutoff}} \approx 1.5$ 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



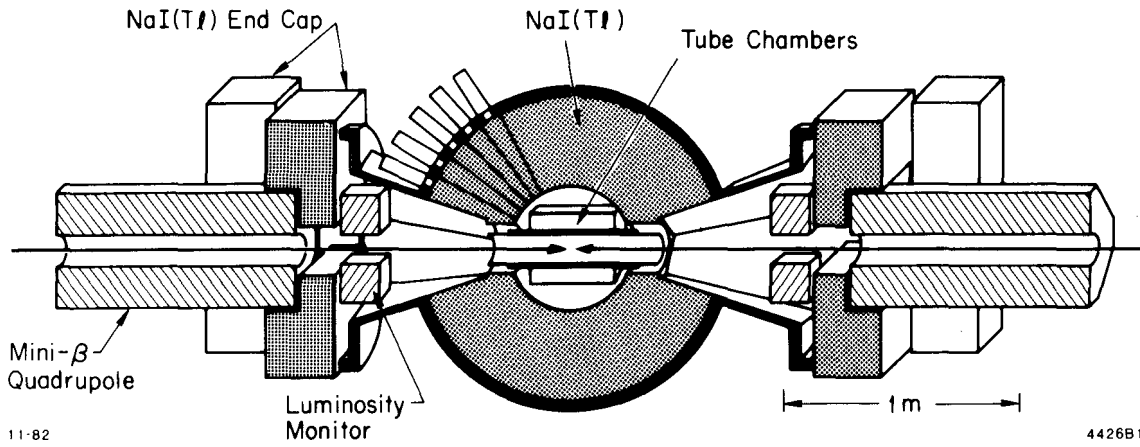
## Crystal Ball

LOCATION	DORIS $e^+e^-$ ring DESY, Hamburg, W. Germany
SCINTILLATOR	16 $X_0$ of NaI(Tl)
(MAIN ARRAYS)	(1 nuclear absorption length) Segmentation: 672 truncated triangular pyramidal crystals Solid angle covered = 93% of $4\pi$ Resolution on $\gamma$ or $e^-$ : $\sigma_E/E = 0.026/E^{1/4}$ $\sigma_\theta = 1$ to $2^\circ$ , depending on energy $\sigma_\phi = \sigma_\theta/\sin\theta$
(ENDCAP ARRAYS)	NaI(Tl) - 40 hexagonal crystals, extending solid angle coverage to 98% of $4\pi$
TRACKING	3 double layers of drift tubes with charge division readout (640 tubes total) $\sigma_\phi = 1^\circ$ - $2^\circ$ $\sigma_z = 1$ -2% of length (66 cm inner layer, 33 cm outer layer) Solid angle covered = 98% of $4\pi$ (inner layer), 75% of $4\pi$ (outer layer)
LUMINOSITY MONITOR	4 scintillator + shower counter telescopes

### REFERENCES

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



11-82

4426B1

XBL 831-7893

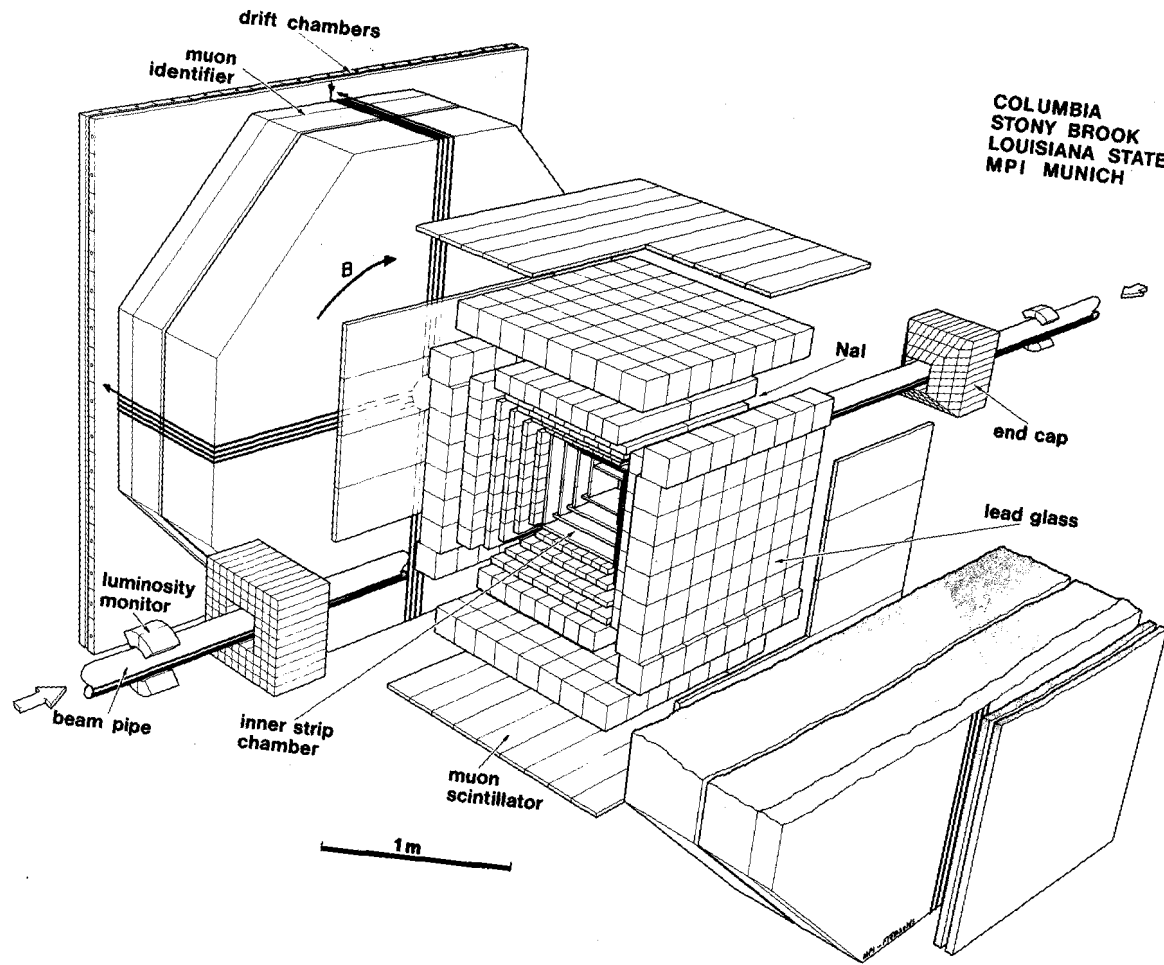
## CUSB

LOCATION	CESR $e^+e^-$ ring Wilson Laboratory, Cornell University, Ithaca, NY, USA
COLLABORATING INSTITUTES	Columbia University, SUNY at Stony Brook, Max Planck Institute at Munich, Louisiana State University, Cornell University
TRACKING	Proportional chambers with cathode strip (9 mm) readout (inner strip chambers) 16 chambers in 4 planes, $47^\circ < \Delta\theta < 132^\circ$ $\Delta\phi = 2\pi$ , 2 track efficiency $> 95\%$ , $\sigma_{\text{along wire}} = 0.8 \text{ mm}$ , $\sigma_{\text{perp wire}} = 1.2 \text{ mm}$ , $\Delta\Omega = 62\%$
CENTRAL CALORIMETER	Segmented NaI(Tl) array with interspersed strip chambers (not shown) surrounded by lead-glass array, PM readout 332 NaI(Tl) crystals (580 liters), $9X_0$ , in 5 radial layers, 32 $\phi$ sectors, 2 $\theta$ sectors 16 proportional chambers with cathode strip (1 cm) readout located in 4 planes between NaI(Tl) layers, $\Delta\Omega = 64\%$ , $\sigma_{\text{shower}} = 0.6 \text{ cm}$ 256 lead-glass blocks in four 8x8 arrays surrounding the NaI(Tl) array, $7X_0$ $\Delta\Omega = 60\%$ , $\sigma_E/E = 4\%/E^{1/4}$
END CAPS	Segmented NaI(Tl) array with interspersed scintillator hodoscope 16 $\times$ 16 $\theta$ - $\phi$ scintillator hodoscopes in each endcap 168 NaI(Tl) crystals (70 liters), $8X_0$ , in 3 radial layers, $\langle\sigma_E/E\rangle = 12\%$ , $\Delta\Omega = 28\%$ , $\sigma_\theta = 80 \text{ mrad}$ , $\sigma_\phi = 35 \text{ mrad}/\sqrt{E}$
MUON IDENTIFICATION	Dimuon identification with 35 scintillation counters surrounding lead-glass arrays, $\Delta\Omega = 42\%$ Single muon identifier: 2 magnetized (15 kG) iron toroids (60 and 90 cm thick) with scintillator trigger after 60 cm of iron, 2 planes of drift chambers in front and 4 planes in back of each toroid (400 wires), $\Delta\Omega = 25\%$ , $p_{\text{cutoff}} = 1 \text{ GeV}$ , $\sigma_p/p = 25\%$
LUMINOSITY MONITOR	2 scintillators and lead-scintillator shower counters 45 mrad $< \Delta\theta < 90 \text{ mrad}$ , $\Delta\phi = 61\%$ of $2\pi$

### REFERENCES

1. P. Franzini and J. Lee-Franzini, Phys. Rep. **81** (1982) 241.
2. The CUSB Detector, A15 at the XXI<sup>st</sup> International Conference on High Energy Physics, Paris (1982).

CUSB



COLUMBIA  
STONY BROOK  
LOUISIANA STATE  
MPI MUNICH

XBL 831-7894

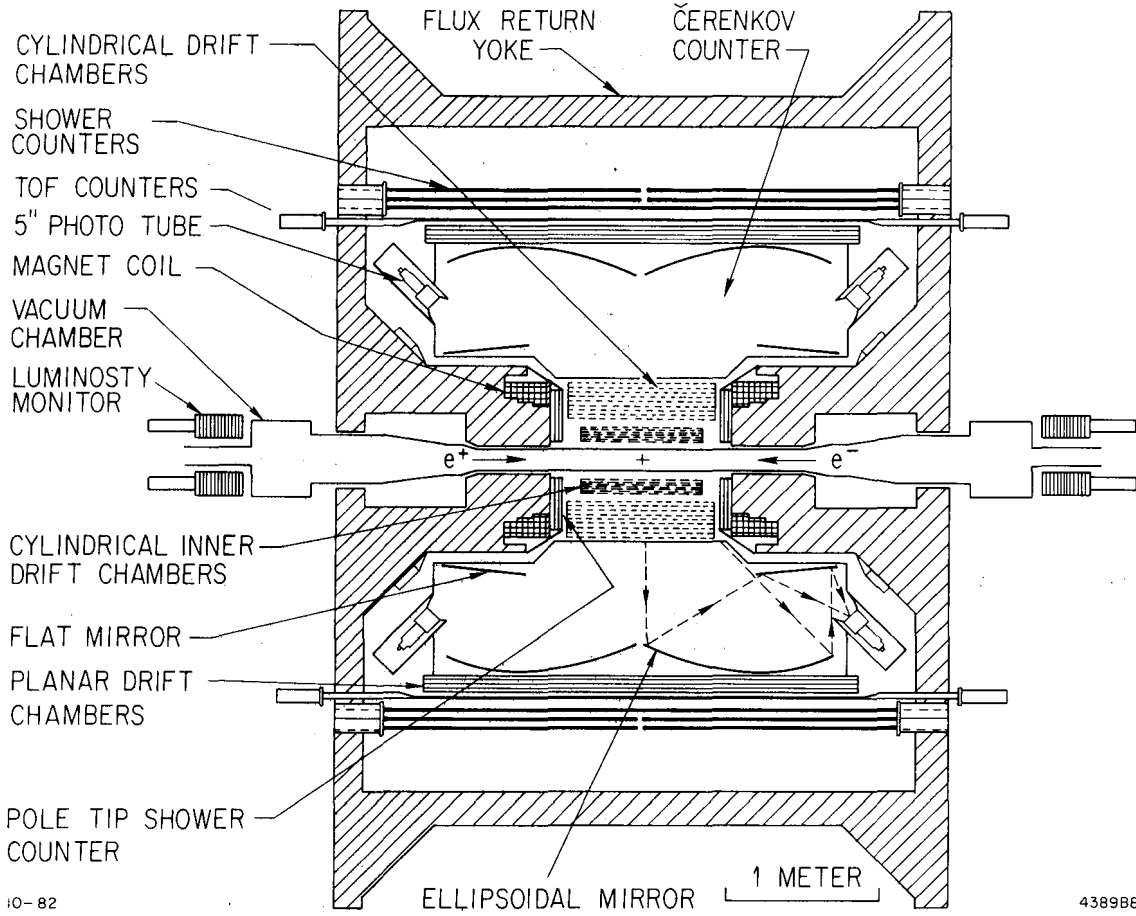
## DELCO

LOCATION	PEP $e^+e^-$ ring SLAC, Stanford, CA, USA
MAGNET	Open-geometry (aperture $ \cos\theta  < 0.78$ ) Pole-tip diameter 101 cm, separation 125 cm $B_0 = 3.3$ kG, $\int Bdl = 1.8$ kG-m
TRACKING	Central (cylindrical) drift chambers: 94 cm maximum wire length, 12-49 cm radius Low mass (2.3% $X_0$ ) Depth (z) measurement by narrow angle stereo 16 points on tracks with $ \cos\theta  < 0.69$  Outer (planar) drift chambers: 285 cm wire length, 160 cm <radius> Depth measurement by wide angle stereo 6 points on tracks with $ \cos\theta  < 0.65$  Multiple hit digital electronics (4 ns bin width) $\sigma_p/p = \sqrt{(2\% p)^2 + (6\%)^2}$
CERENKOV COUNTER	1 atm. isobutane threshold counter ( $\gamma_t = 19.1$ ) 36 cells each with (pTP-coated) 5'' RCA 8854 quantacon Radiator length 55-110 cm, <p.e.>=18, < $N_0$ >=80 $\text{cm}^{-1}$ $\sigma_t = 300$ ps Acceptance $ \cos\theta  < 0.62$
SHOWER COUNTERS	Barrel ( $ \cos\theta  < 0.62$ ) : 48 Pb-scintillator counters, $6X_0$  Pole-tip ( $0.79 <  \cos\theta  < 0.98$ ) : 36 Pb-scintillator BBQ counters, $5X_0$
TIME OF FLIGHT	52 counters 324 cm length, 180 cm <radius> $\sigma_t = 350$ ps Acceptance $ \cos\theta  < 0.67$
LUMINOSITY MONITOR	12 Pb-scintillator BBQ counters, $16X_0$ Acceptance 25-68 mrad relative to beam axis

## REFERENCES

1. W. Bacino et al., Phys. Rev. Lett. **40** (1978) 671.
2. W.E. Slater et al., Nucl. Instr. & Meth. **154** (1978) 223.
3. D. Ouimette et al., IEEE Trans. NS **29**, No. 1 (1982) 290.

DELCO



10-82

438988

XBL 831-7897

## EHS (European Hybrid Spectrometer)

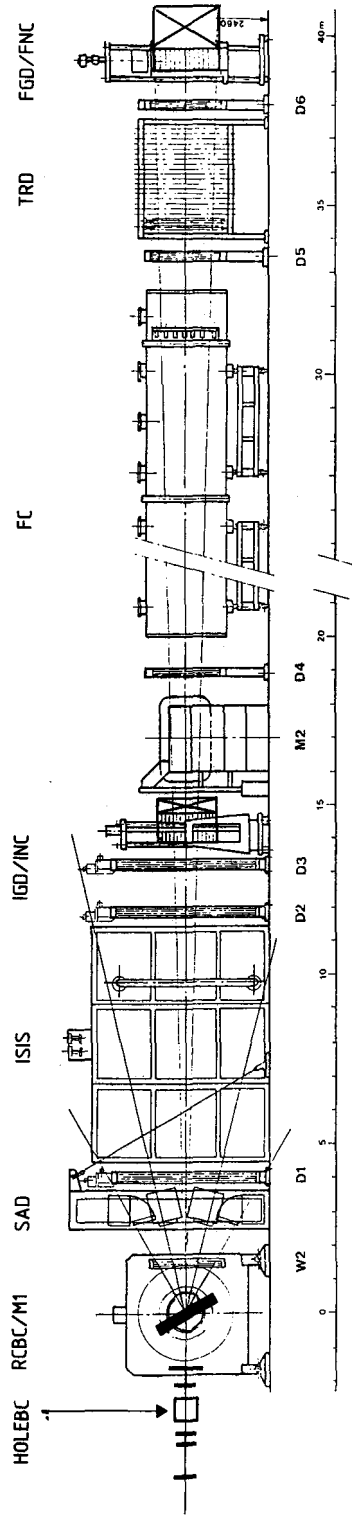
LOCATION	CERN-EHN1-SPS Geneva, Switzerland
BEAM	SPS H2 beam line $\pi^\pm, K^\pm, p^\pm$ up to 400 GeV/c — $\Delta p/p = \pm 0.02$ $\pi^\pm$ intensities: $10^7$ (for $10^{12}$ ppp) Tagged photon beam ( $2 \times 10^7$ electrons at 100 GeV/c)
TARGETS	(1) 30 Hz hydrogen bubble chamber (RCBC) Length: 80 cm; depth: 40 cm Precision: $50 \mu\text{m}$ ; resolution: $250 \mu\text{m}$ Magnetic field: 3 Tesla  (2) 50 Hz high-resolution hydrogen bubble chamber (HOLEBC) Length: 12 cm; depth: 5 cm Resolution: $20 \mu\text{m}$ No magnetic field
SPECTROMETER	2 lever arms Acceptance: $\pm 30^\circ$ in bending plane $\pm 13^\circ$ in dip plane $\Delta p/p = 1\%$
PARTICLE IDENTIFICATION	Silica aerogel Cerenkov (SAD) Ionization sampling (ISIS) High-temperature gas Cerenkov (FC) Transition radiation detectors (TRD) $\pi/K/p$ identification 3-200 GeV/c
PHOTON DETECTION	Lead-glass detectors (IGD + FGD) $\pi^0$ reconstruction: $\Delta p/p = 2\%$
CALORIMETRY	Iron-scintillator calorimeters (INC + FNC) INC matches IGD, FNC matches FGD

### REFERENCES

1. M. Aguilar-Benitez et al., Nucl. Instr. & Meth. **205** (1983) 79.
2. W.W.M. Allison and J.H. Cobb, Ann. Rev. Nucl. Part. Sci. **30** (1980) 253.
3. B. Powell et al., Nucl. Instr. & Meth. **198** (1982) 217.



# EHS (European Hybrid Spectrometer)



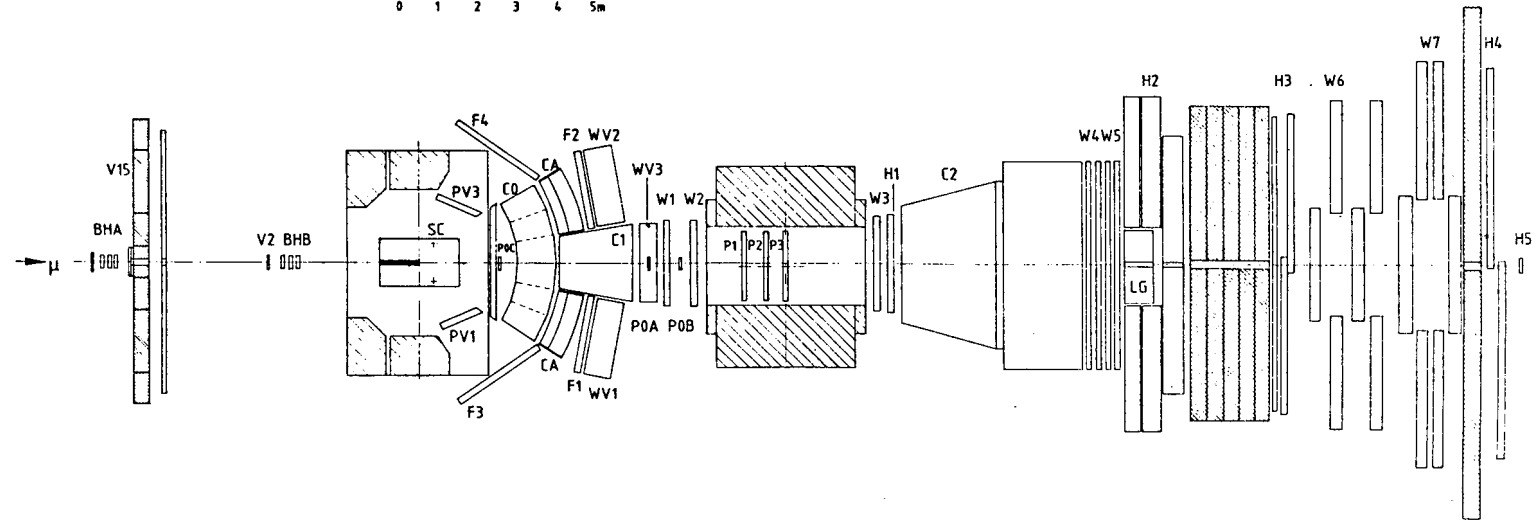
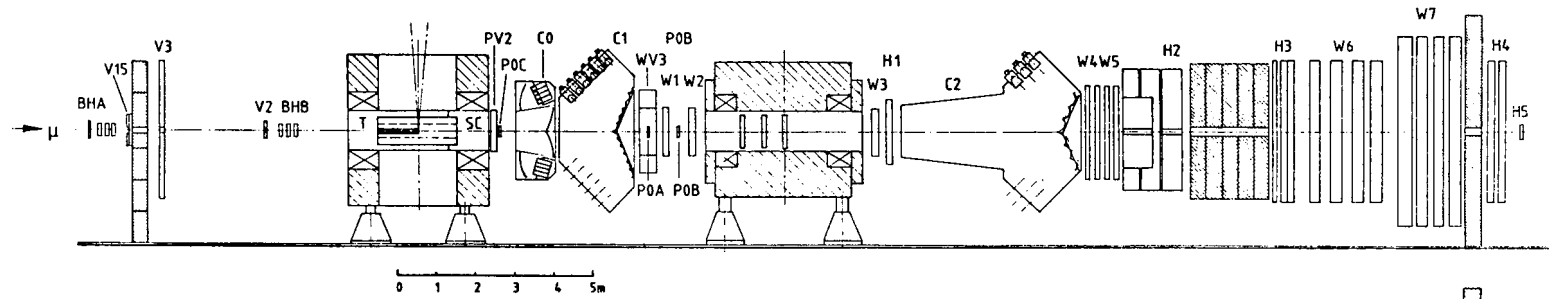
XBL 845-2032

## EMC

LOCATION	CERN-SPS Geneva, Switzerland
BEAM	SPS muon beam line M2 $E_\mu = 120\text{--}280$ GeV (400 GeV protons) Intensity $1\text{--}5 \times 10^7$ $\mu$ /pulse 1.6 sec pulse, rep. rate 11 sec Beam momentum $\Delta p = 4.5\%$ Halo 6% Intensity monitor hodoscope Beam hodoscope
TARGET	NA2: 6 m $\text{H}_2/\text{D}_2$ , 4.75 (2.75) m iron-scintillator NA9: 1 m $\text{H}_2/\text{D}_2$ , heavy targets NA28: heavy targets
MAGNET	Forward Spectrometer (FS) 15 kG, Bdl = 5.18 T-m Vertex Spectrometer (VS) 16 kG, Bdl = 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 $\mu$ 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) $\sigma_E/E = 120\%/\sqrt{E}$

### REFERENCES

1. O.C. Allkofer et al., Nucl. Instr. & Meth. **179** (1981) 445.
2. J.P. Albanese et al., to be published in Nucl. Instr. & Meth.



EMC

XBL 832-8140

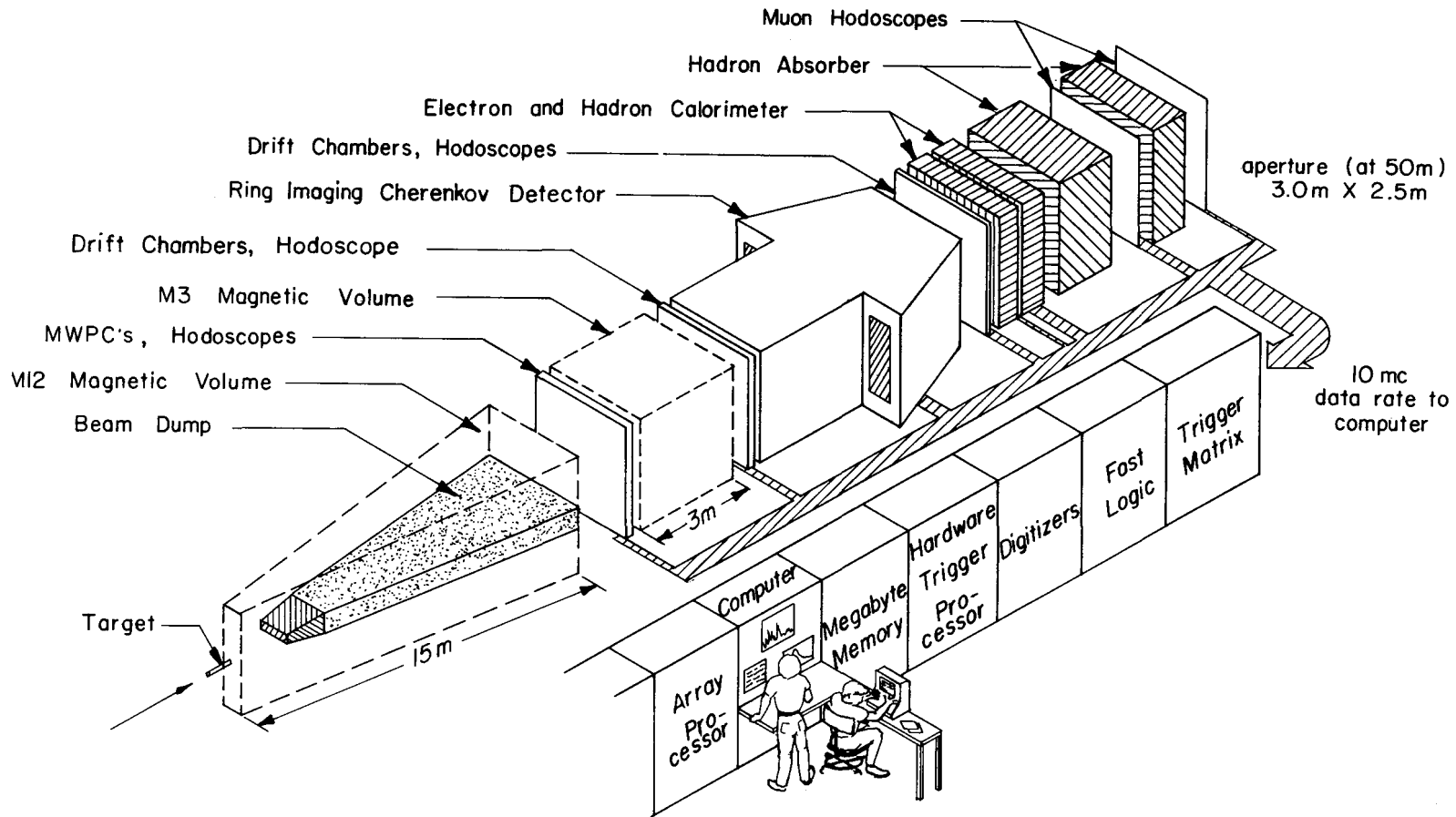
## FNAL-605

LOCATION	ME External Proton Beam, FNAL Batavia, IL, USA
INCIDENT BEAMS	External Proton Beam, Pions (Future)
MAGNETS <sup>1</sup>	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 <sup>2</sup>	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 <sup>3</sup>	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

### REFERENCES

1. R.W. Fast et al., submitted to the 7<sup>th</sup> 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.



FNAL-605

XBL 831-7892

## FNAL Multiparticle Spectrometer

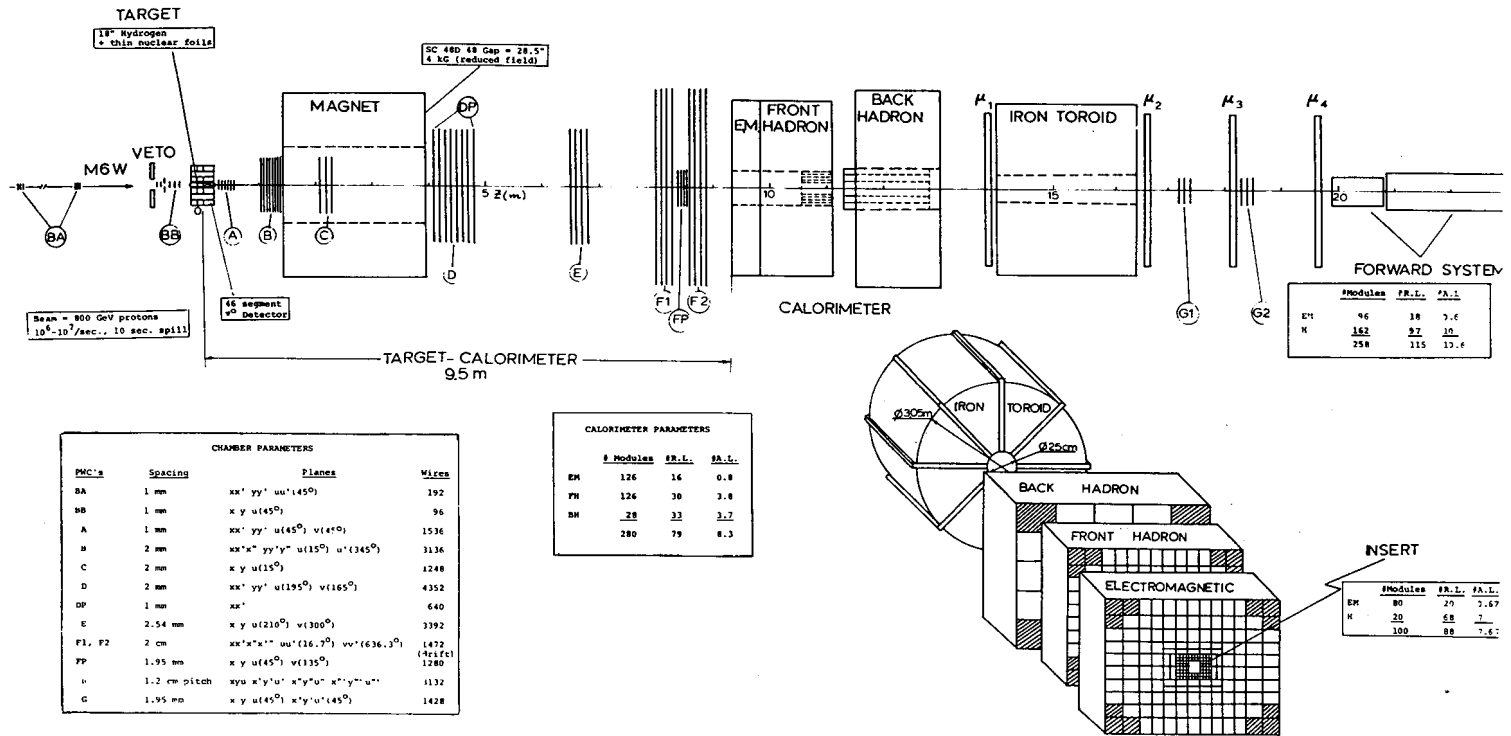
LOCATION	Fermilab, meson area, MT beam line (old N6W) Batavia, IL, USA
MAGNET	16.9 kG (superconducting) $p_{\perp}$ kick $\sim 0.7$ GeV/c
TRACKING	PWC + drift chambers $\sigma_p/p = (0.003 \sqrt{1+(p_0/p)^2})p$
RECOIL DETECTOR	46 segments Pb glass $\Delta\phi = 2\pi$
CENTRAL CALORIMETER	EM Pb-scintillator, $16X_0$ , $\sigma_E/E = 20\%/\sqrt{E}$ , 206 elements Hadron Fe-scintillator, $3.8X_0$ , $\sigma_E/E = 70\%/\sqrt{E}$
MUON DETECTION	Fe toroid, 2.5 m thick 18 kG
FORWARD CALORIMETER	EM Pb-scintillator, $16X_0$ , 96 elements Hadron Fe-scintillator, $10X_0$ , 162 elements

### REFERENCES

1. P. Rapp et al., Nucl. Instr. & Meth. **188** (1981) 285.

# MPS LAYOUT FOR E557/E672 1983-1984

Arizona - Cal Tech - Fermilab - IHEP (Serpukhov) - Illinois (Chicago) - Indiana - Maryland - George Mason - Rutgers



FNAL Multiparticle Spectrometer

XBL 831-7887

## FNAL Neutrino Detector

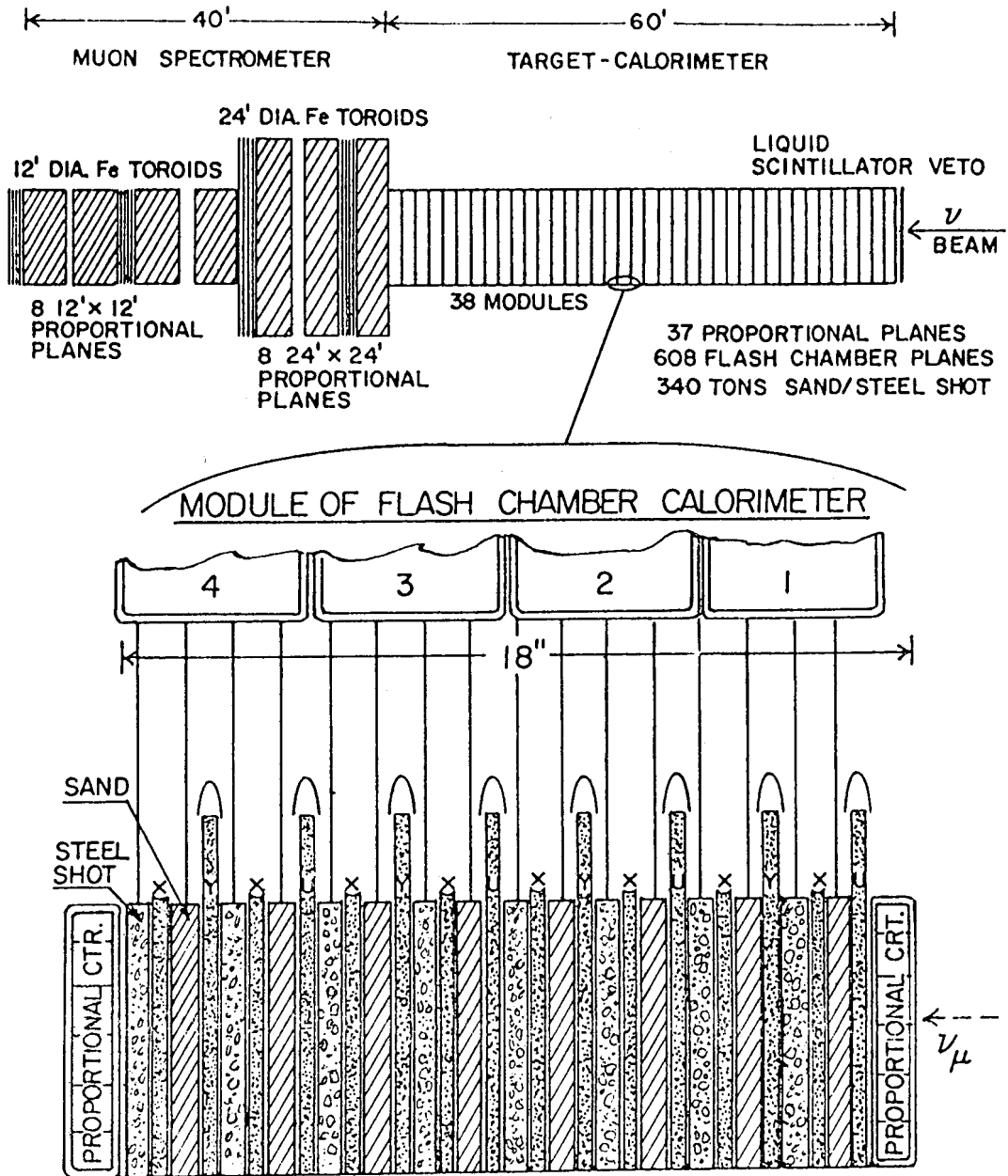
- LOCATION** FNAL neutrino beam line, Lab C  
Batavia, IL, USA
- CALORIMETER** 608 flash chambers,  $3.66 \times 3.66 \text{ m}^2$  sensitive area, and 37 proportional tube chambers  
Half are with horizontal cells and the other half at  $\pm 10$  degrees from the vertical  
Between each flash chamber 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  $\lambda_{\text{abs}}$   
The angular resolution for electrons and hadrons is:  
 $\sigma_e = 3.5 + 53/E_e \text{ mrad}$   
 $\sigma_h = 6 + 640/E_h \text{ mrad}$   
The energy resolution is:  
 $\sigma_E/E = 10\%$  for  $5 \leq E \leq 100 \text{ GeV}$   
for both electrons and hadrons
- TRIGGER COUNTERS** Proportional chambers,  $3.66 \times 3.66 \text{ m}^2$  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  $p < 300 \text{ GeV}/c$

### REFERENCES

1. D. Bogert et al., IEEE Trans. Nucl. Sci. NS 29 (1982) 363.
2. J. Bofill et al., IEEE Trans. Nucl. Sci. NS 29 (1982) 400.



# FNAL Neutrino Detector



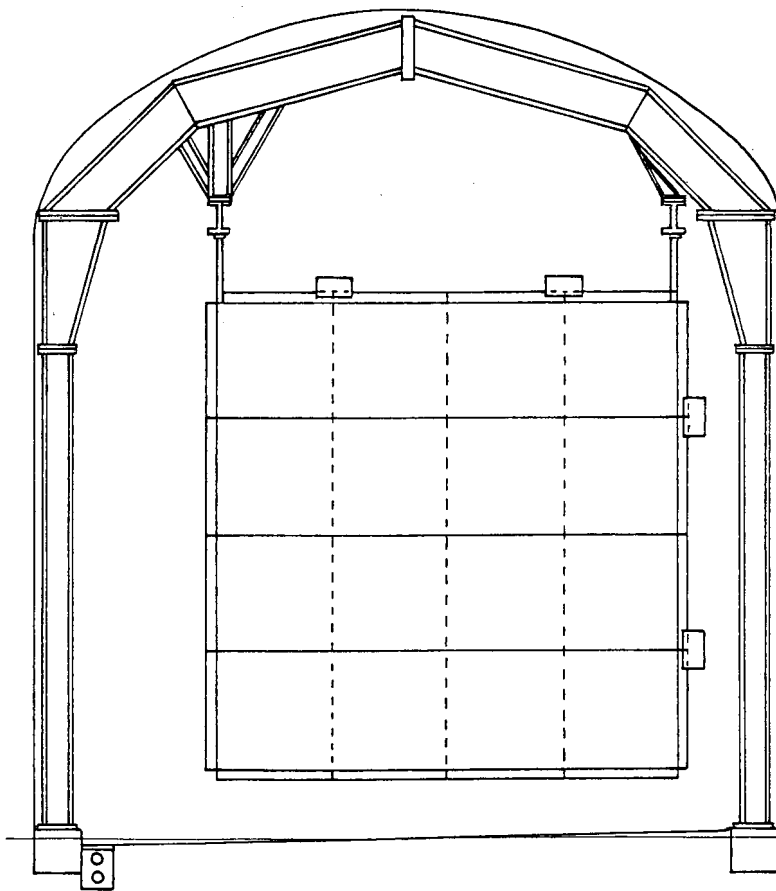
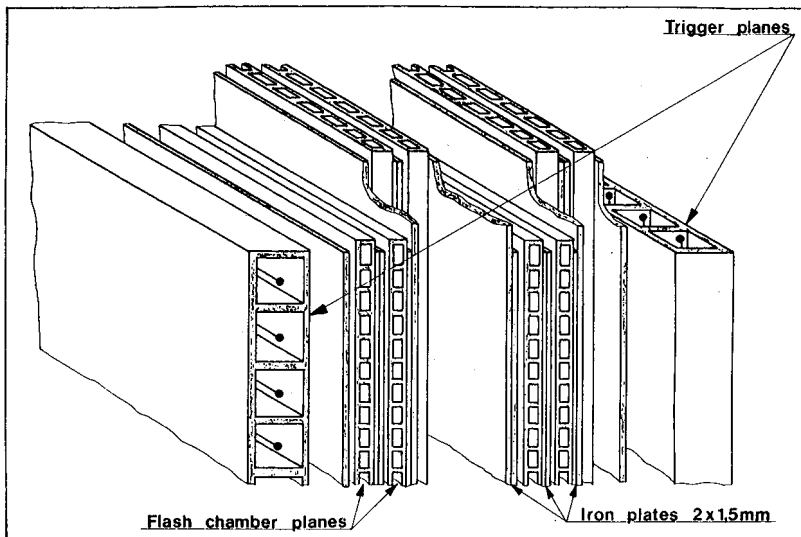
## FREJUS Detector for Nucleon Decay

LOCATION	FREJUS Tunnel, 4500 m water-equiv.-depth Modane, France
TRACKING-PLASTIC	Flash chambers $0.5 \times 0.5$ cm <sup>2</sup> section Neogal (70% neon, 30% helium) 1 atm. Crossed planes (1024 tubes) of $6 \times 6$ m <sup>2</sup> Iron sampling 3 mm between F.C. planes Capacitive strips readout Energy resolution $15\%/\sqrt{E}$ for electrons 12-20% for muons-pions around 0.3 GeV/c
TRIGGER	Geiger tubes $1.5 \times 1.5$ cm <sup>2</sup> section Argon-ethylal-freon 1 atm. Crossed planes (344 tubes) of $6 \times 6$ m <sup>2</sup>
MASS	8 tons per module (8 F.C. planes, 1 Geiger plane) Detector modular, mass up to 1.5 kt Average density $\sim 2$ Fiducial mass up to 1 kt
SENSITIVITY	10 events fully identified/year for nucleon lifetime of $10^{31}$ years

### REFERENCES

1. P. Bareyre et al., (Orsay, Palaiseau, Saclay), Proposal to Study the Instability of the Nucleon Lifetime with a Modular Flash Chamber Detector (1980).
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

## 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  $\times$  2.4 m, deployed over one square kilometer  
Liquid scintillator modules - PVC housings 30 cm  $\times$  30 cm  $\times$  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  $\times$  8 m  $\times$  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  
Operational: August 1983

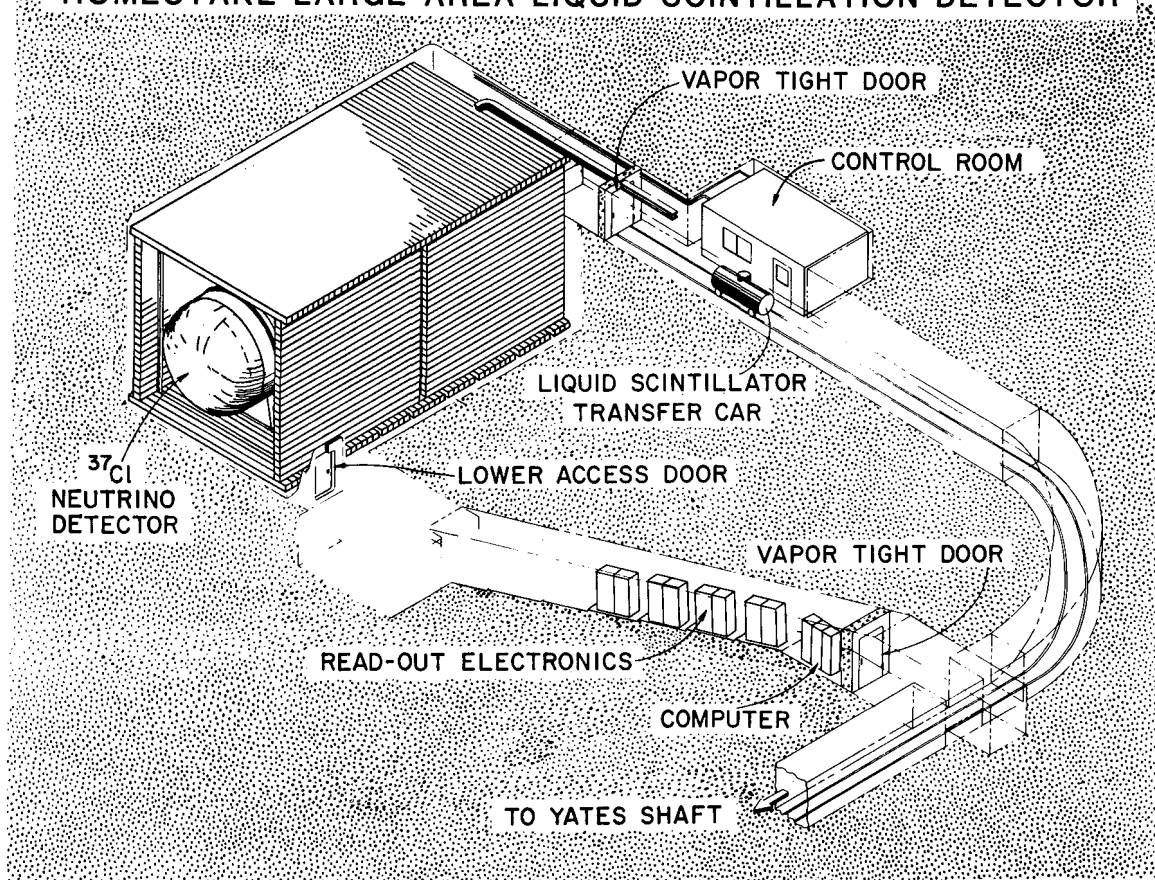
**PHASE 2:** 1878 detector modules (same as those in phase 1) arranged in 3 stacks, each 8 m  $\times$  8 m  $\times$  8 m  
The detector elements are arranged with alternate layers in crossed directions  
Tracking chambers are interspersed between the scintillator elements  
Parameters are as in phase 1 except for the following:

Spatial resolution: 1 cm  
Nucleon decay modes: All modes except those with more than one neutrino

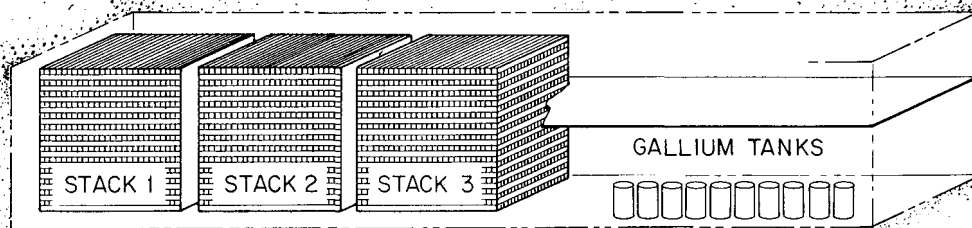
Muon  $\rightarrow$  electron decay detection efficiency: 90%  
Detector mass: 1400 tons  
Nucleon lifetime sensitivity:  $5 \times 10^{32}$  yr

# Homestake Detector

## HOMESTAKE LARGE AREA LIQUID SCINTILLATION DETECTOR



## NEW HOMESTAKE UNDERGROUND LABORATORY



1400 TON  
PROTON DECAY  
DETECTOR

GALLIUM SOLAR  
NEUTRINO  
EXPERIMENT

XBL 832-8406

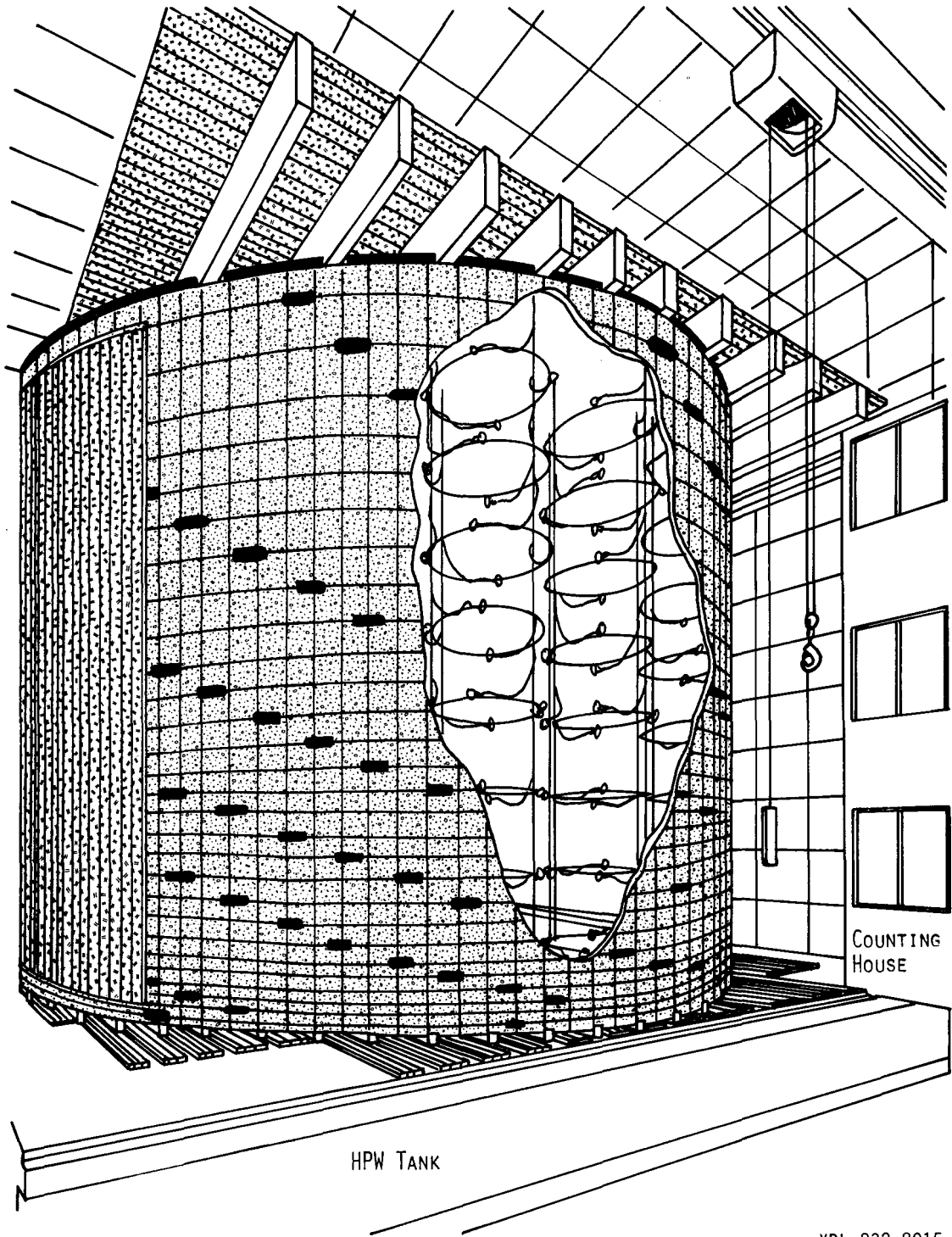
## HPW Detector for Nucleon Decay

LOCATION	Silver King Mine, Park City, UT, USA Elevation 2135 meters; overburden 1500 MWE; adit 4,500 meters; temperature 8.3°C
VOLUME	800 metric tons in a Hypalon-lined cylindrical wooden tank 12 m diameter, 7.3 m height All inside surfaces covered with teflon-coated aluminum mirrors
DETECTORS	704 EMI 5" photomultipliers with nearly $4\pi$ acceptance distributed throughout the volume on a 1 m grid Electronic cabling and cool dry air are available to each base via polyethelene tubes
SHIELD	Proportional wire chambers cover top, sides, and 70% of bottom
ELECTRONICS	ADC and multi-TDC on each PMT Data flow controlled by LSI 11/23 near detector Communication to trailer via M-baud fast link, slow links 4,500 m away to outside LSI 11/23, PDP 11/45

### REFERENCES

1. J.A. Gaidos et al., Proceedings of the 1982 Summer Workshop on Proton Decay Experiments, Argonne National Laboratory (1982).
2. J.A. Gaidos et al., Neutrino '81 Conference, University of Hawaii (1981).
3. R. Morse et al., Third Workshop on Grand Unification, University of North Carolina (1982).

# HPW Detector for Nucleon Decay



XBL 832-8015

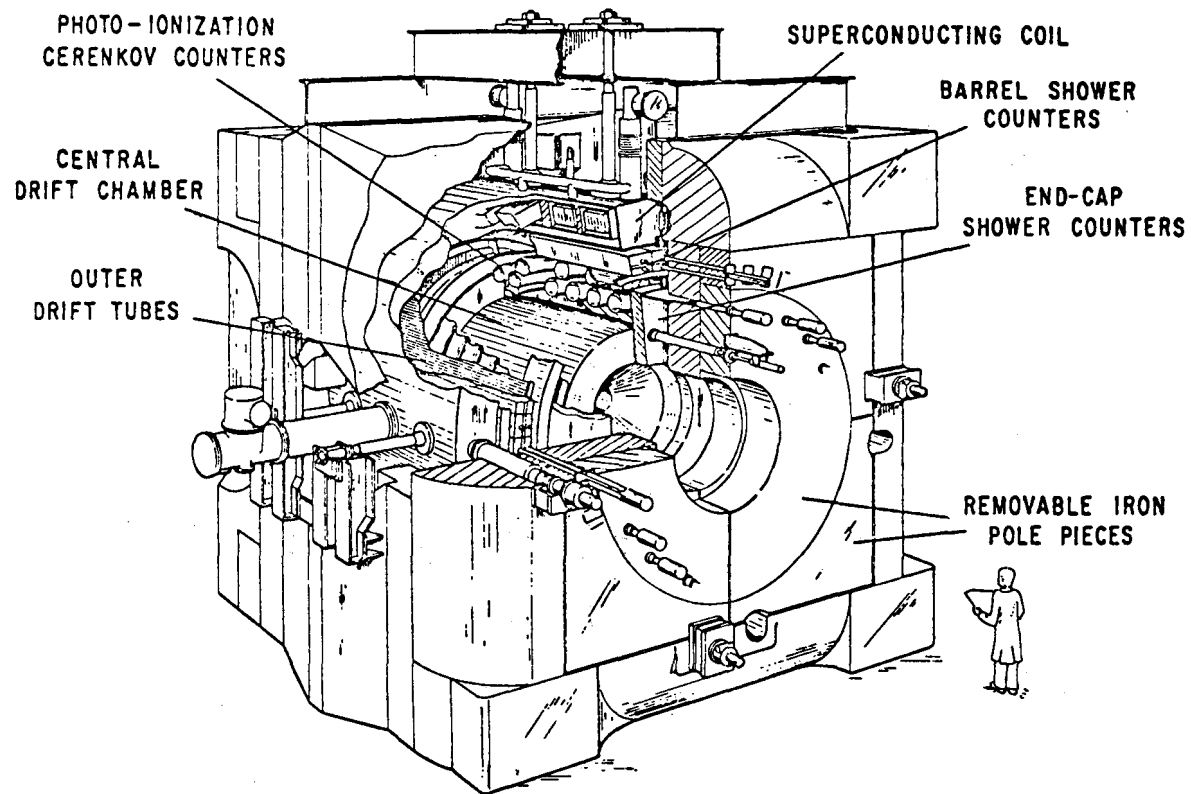
## High Resolution Spectrometer (HRS)

LOCATION	PEP $e^+e^-$ ring SLAC, Stanford, CA, USA
MAGNET	16 kG (superconducting) Diameter = 4 m, length = 3.8 m
TRACKING	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 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
END CAPS	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 $\sigma_\tau = 170$ ps for Bhabhas $\sigma_\tau = 350$ ps for hadrons
PHOTO-IONIZATION CERENKOV	704 segments in 11 toroids 15 atmospheres give (K, p) $\pi$ separation between 1 and 4 GeV/c
LUMINOSITY MONITOR	Telescope with Pb-glass at 32–60 mradians

### REFERENCES

1. D. Rubin et al., Nucl. Instr. & Meth. **203** (1983) 90.
2. J. Chapman et al., Nucl. Instr. & Meth. **158** (1979) 387.
3. J. Chapman et al., IEEE Trans. on Nuc. Sci. **NS 29** (1982) 332.
4. N. Harnew and D. Meyer, Nucl. Instr. & Meth. **186** (1981) 513.





High Resolution Spectrometer

HIGH RESOLUTION SPECTROMETER  
ARGONNE - INDIANA - LBL - MICHIGAN - PURDUE - SLAC

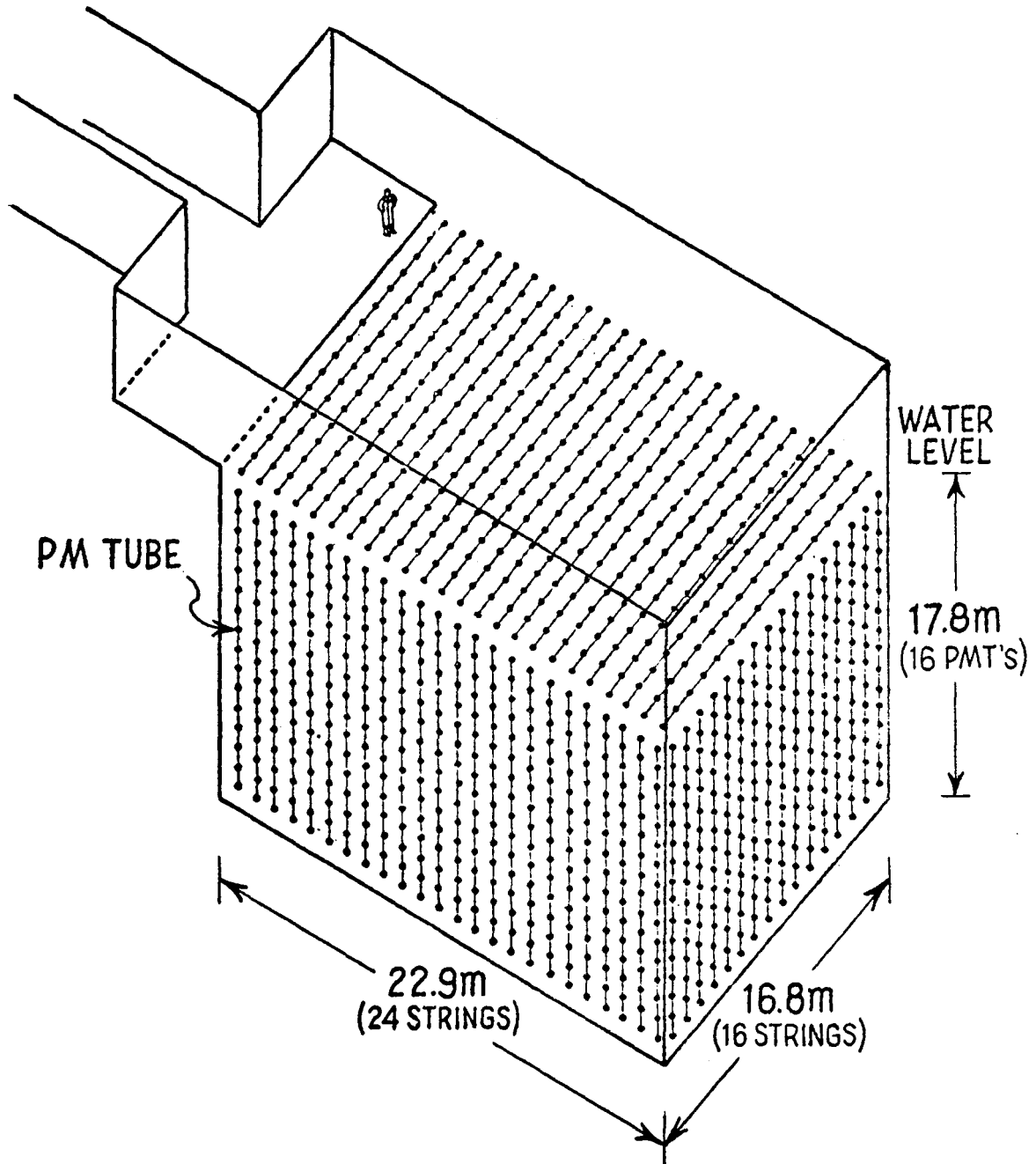
XBL 831-7884

## 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 $\sim 1/\text{day}$ (2:1 = $\nu_\mu:\nu_e$ ) Stopping muon rate $\sim 3\%$ Dimuon rate $\sim 3\%$
ACTIVE MEDIUM	Pure water Transmission length $> 40$ m at 440 nm $\geq 20$ m at 330 nm and 550 nm Cerenkov angle = 41° (at $\beta = 1$ )
DETECTORS	2048 5''-diameter, hemispherical PM tubes PM threshold $\sim 1/4$ photoelectron PM noise rate = 1.5 kHz median Dynamic range recorded per PM: fast time = 512 ns (1 ns least count) slow time = 7 $\mu\text{s}$ (15 ns least count) pulse height $\sim 200$ photoelectrons ( $\sim 1/4$ pe least count)
THRESHOLD	$>25$ MeV dE/dx at $\beta = 1$
SENSITIVITY	$\sim 4$ MeV dE/dx at $\beta = 1$ produces 1 photoelectron Efficiency for $\mu \rightarrow e$ detection = 60%
DETECTOR LAYOUT	Regular, rectangular array at $\sim 1$ m spacing on 6 faces; $16 \times 24$ PM's on 4 faces, $16 \times 16$ PM's on 2 faces Totally absorptive face behind PM's $\sim 0.5$ m water behind PM's
MASS	Total = 8000 tons (17.8 m $\times$ 18.7 m $\times$ 23.9 m) Fiducial for $p \rightarrow e^+ \pi^0$ = 3300 tons = $2 \times 10^{33}$ nucleons (13 m $\times$ 14 m $\times$ 19 m)
RESOLUTION	For $p \rightarrow e^+ \pi^0$ depositing $\sim 225$ photoelectrons: vertex $\Delta r = 0.6$ m energy $\Delta E/E = \pm 10\%$ opening angle $\Delta\sigma = 15^\circ$ Similar vertex and energy resolutions for $\mu^+ K^0$ with $K^0 \rightarrow \pi^0 \pi^0$
OPERATIONAL	August 1, 1982 Duty cycle $\sim 70\%$

# IMB Detector for Nucleon Decay



XBL 832-8407

## IRVINE - MICHIGAN - BROOKHAVEN DETECTOR

## JADE

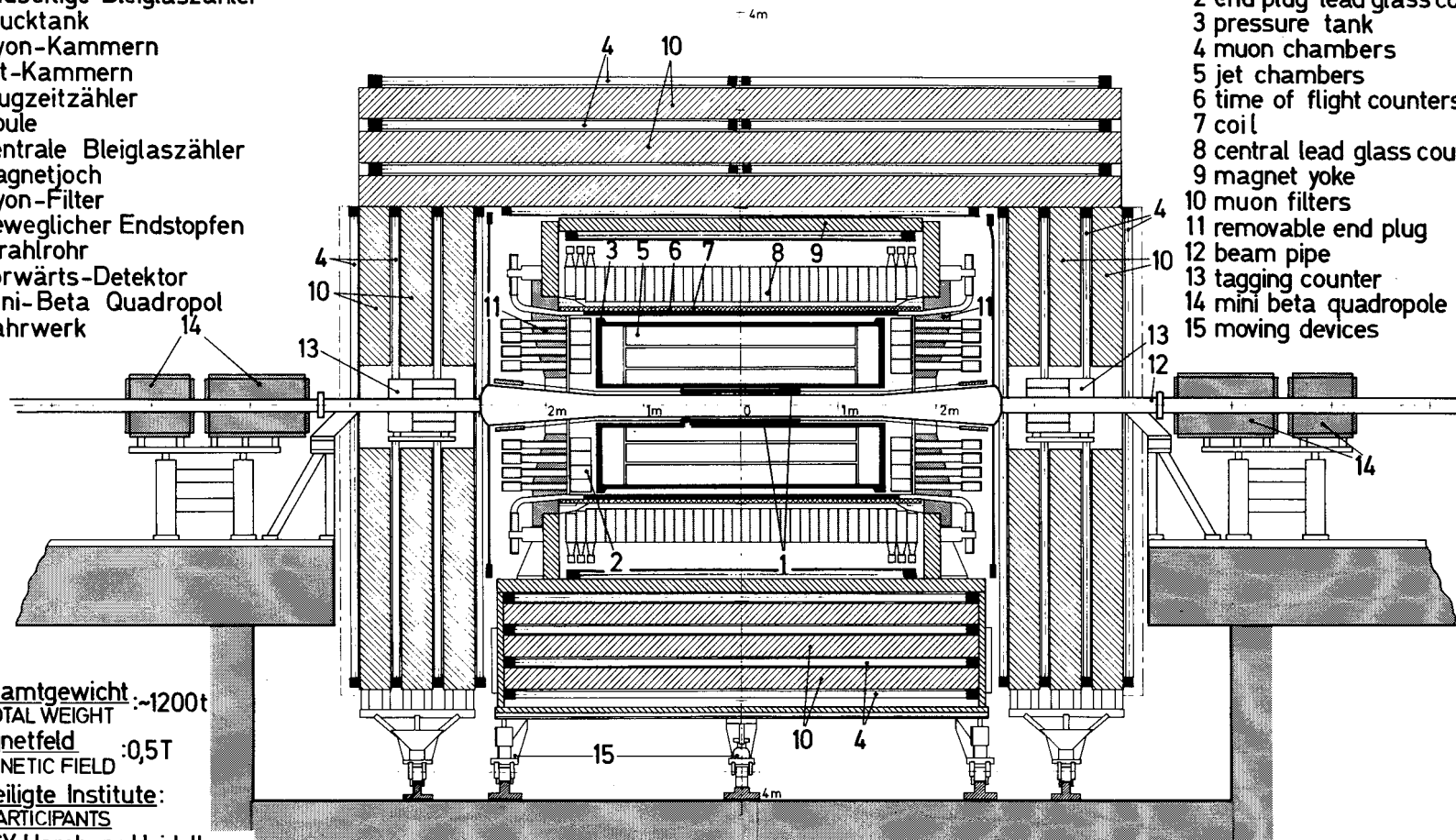
LOCATION	PETRA $e^+e^-$ rings DESY, Hamburg, W. Germany
MAGNET	4.8 kG solenoid; normally conducting, water-cooled, Al coil; thickness $0.5X_0$ Diameter = 2 m, length = 3.5 m
TRACKING	Cylindrical drift chamber (JET chamber) 2.36 m long at 21–79 cm radius Argon-methane-isobutane at 4 atm. 48 points on tracks with $ \cos\theta  < 0.83$ $\geq 8$ points over 97% of $\Omega$ 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
SHOWER COUNTERS	
BARREL	2604 tapered modules of Pb-glass 30 cm deep, arranged in 31 rings, 84 wedges per ring (central 6 rings Schott SF6, 17.3 $X_0$ , remainder SF5, 12.5 $X_0$ ) $\Delta E/E = 6\%/\sqrt{E}$ $\sigma_\theta = 0.6^\circ$ , $\sigma_\phi = 0.6^\circ$
END CAPS	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 <sup>2</sup> ) Covers 93% of $\Omega$
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 (20 $X_0$ ), 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	24-counter scintillator hodoscope surrounding beam pipe ( $r = 15$ cm) for background monitoring 20-counter forward scintillator hodoscope, between end caps and muon detector, for forward muon triggering

# MAGNETDETEKTOR **JADE**

MAGNET DETECTOR

- 1 Strahlrohrzähler
- 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

- 1 beampipe counters
- 2 end plug lead glass counters
- 3 pressure tank
- 4 muon chambers
- 5 jet chambers
- 6 time of flight counters
- 7 coil
- 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



Gesamtgewicht :~1200t  
TOTAL WEIGHT

Magnetfeld :0,5T  
MAGNETIC FIELD

Beteiligte Institute:  
PARTICIPANTS  
DESY, Hamburg, Heidelberg,  
Lancaster, Manchester,  
Rutherford Lab, Tokio

JADE

35152

XBL 832-8308

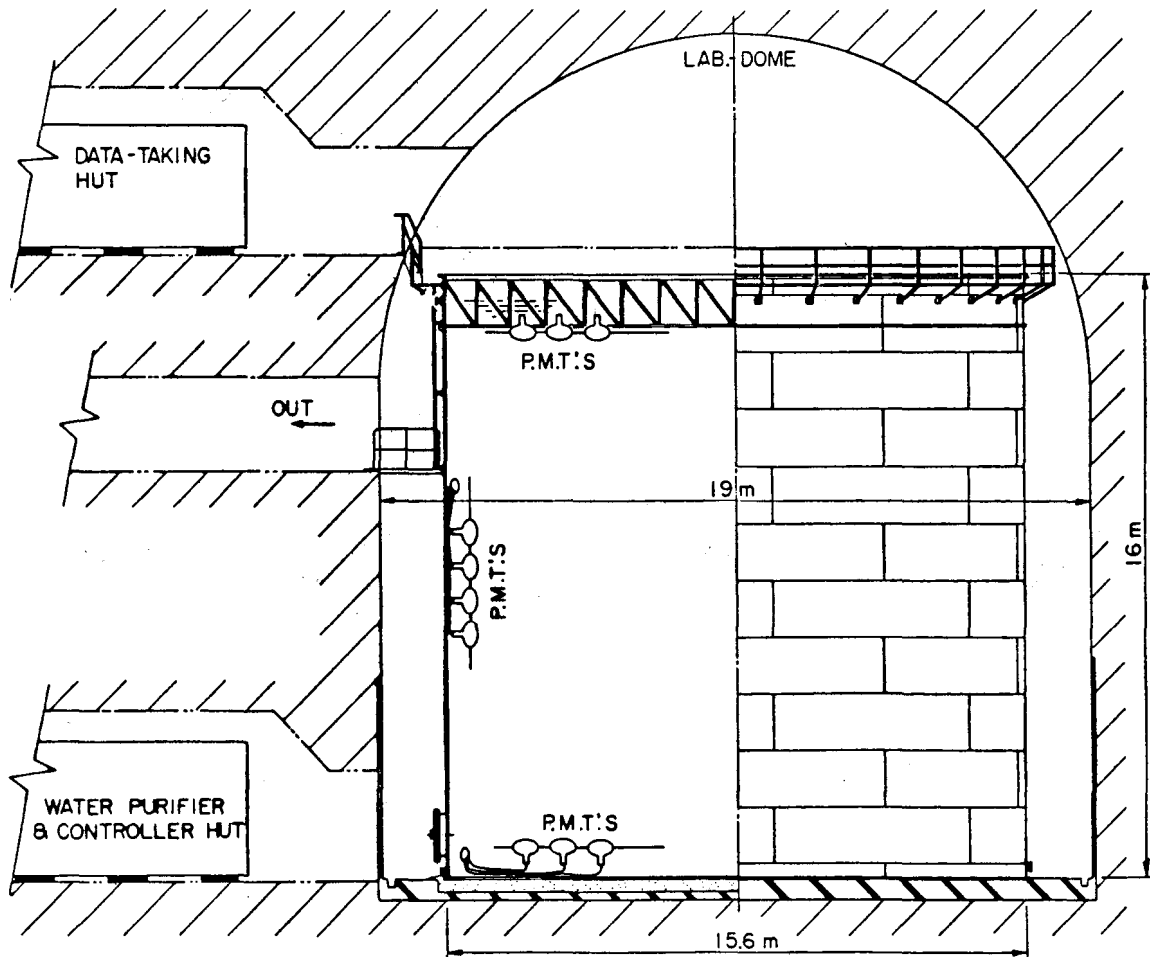
## Kamiokande Detector for Nucleon Decay

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 $\times$ 16 m high, containing 2900 m <sup>3</sup> of pure water
WATER PURIFIER	50 $\mu$ filter-20 $\mu$ filter-ion exchange purifier-0.45 $\mu$ filter-UV sterilizer-0.22 $\mu$ filter
CERENKOV LIGHT DETECTOR	1050 $\times$ 20" diameter photomultipliers, R1449X, distributed over the inner surfaces of the water tank at 1 PM/m <sup>2</sup> Photocathode covers 20% of the entire surface Expected energy resolution of $p \rightarrow e\pi^0$ event is 4% Equipped with transient digitizers to record $\mu$ -e decays and/or successive nucleon decays, if such existed
DATA TAKING	PDP 11/60

### REFERENCES

1. T. Suda et al., Neutrino '81 Conf., Hawaii (July 1981).
2. K. Takahashi et al., Third Workshop on Grand Unification, Univ. of North Carolina (April, 1982).
3. M. Koshihara et al., 21<sup>st</sup> Int. Conf. on High Energy Physics, Paris (July 1982).

# Kamiokande Detector for Nucleon Decay



XBL 831-7885

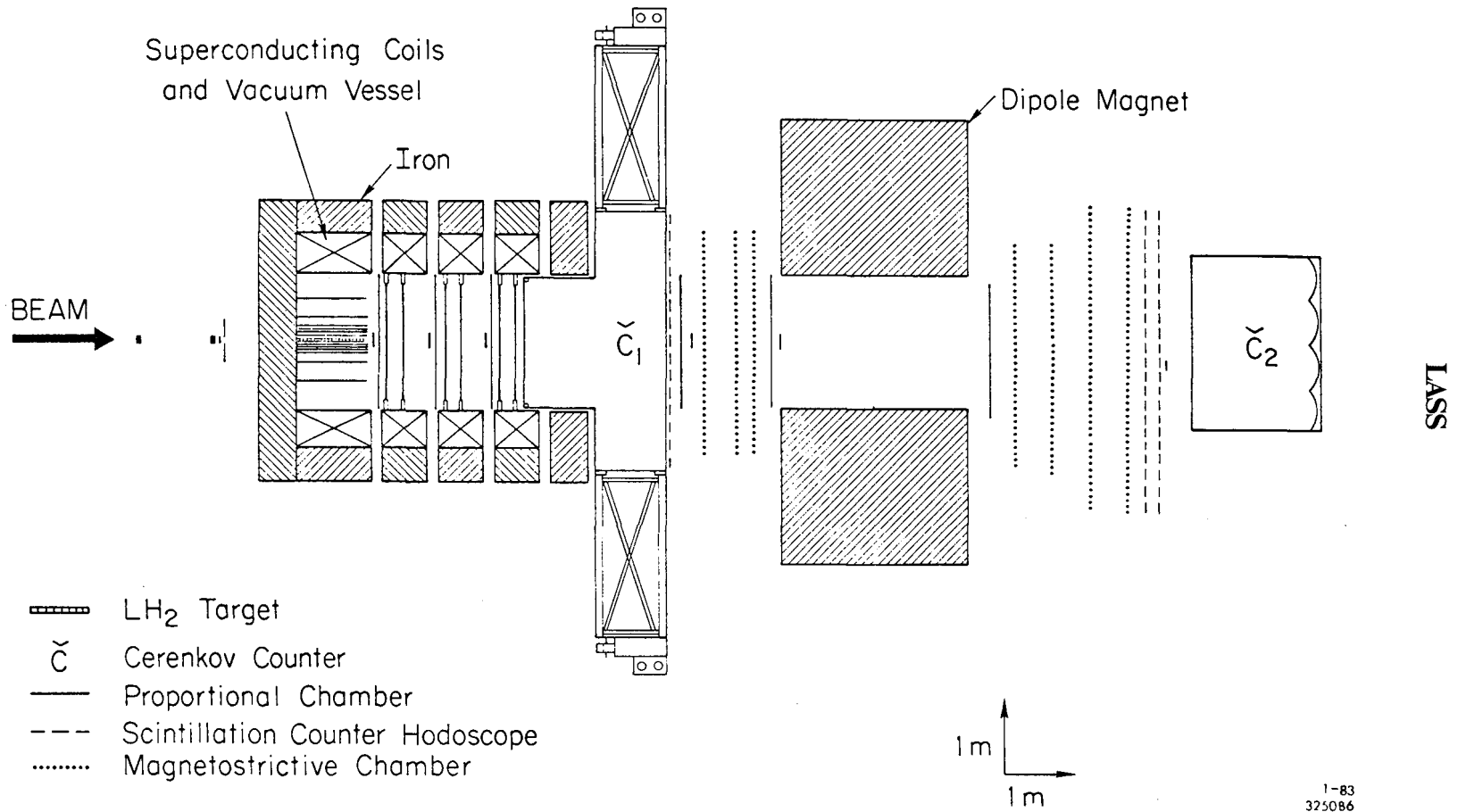
## LASS

LOCATION	SLAC, Stanford, CA, USA
BEAM	An R.F. separated hadron beam Beam momentum up to 16 GeV/c Typical K/ $\pi$ ratio of 60:1 at 11 GeV/c
BEAM LINE INSTRUMENTATION	Two high-pressure Cerenkov counters 10 planes of 1 mm anode spacing proportional chambers Momentum and position measuring scintillation hodoscopes
MAGNETS	Solenoid magnet with a 1.85 m diameter open bore and a 22.4 kG central field parallel to the beam axis Dipole magnet having an aperture 2 m wide $\times$ 1 m high, and a field integral of 30 kG-m
TRACKING	Essentially $4\pi$ coverage consisting of:
Solenoid:	Low $P_L$ /high $P_T$ : 6 cylindrical MWPC's, each having 2 mm anode wire spacing and cathode readout having strips at $\pm 10^\circ$ High $P_L$ /low $P_T$ : 9 planes of 1 mm anode wire spacing MWPC 12 planes of 2 mm anode wire spacing MWPC 6 planes of cathode strip readout 3 planes of pattern readout Resolution: anode: $\sigma \simeq \frac{\text{wire spacing}}{2} \times \frac{1}{\sqrt{12}}$ cathode: $\sigma \simeq 200 \mu$
Dipole:	Conventional dipole spectrometer having 21 coordinate measurements and a scintillation counter hodoscope at the dipole entrance, and 17 coordinate measurements at its exit Momentum resolution $\Delta p/p = 6.5 \times 10^{-4} p + 1.15 \times 10^{-3}$
PARTICLE IDENTIFICATION	C <sub>1</sub> : a 38 sector, air pressure Freon 114 filled Cerenkov counter having a pion threshold of $\sim 3$ GeV/c C <sub>2</sub> : an 8 cell, high pressure Freon 12 filled Cerenkov counter having a settable pion threshold of $\sim 2$ GeV/c TOF: a 24 element scintillation counter hodoscope having $\pi$ K separation up to 1 GeV/c, and a ( $\pi$ ,K)/p separation up to 2.5 GeV/c

## REFERENCES

1. D.L. Blockus, PhD. Thesis, The Johns Hopkins Univ., 1980.
2. L.S. Durkin, PhD. Thesis, SLAC, Report-238, 1980.
3. A.K. Honma, PhD. Thesis, SLAC, Report-235, 1980.
4. G. Aiken et al., Design and Performance of the New Cathode Readout Proportional System -- LASS; SLAC PUB-2642, 1980.
5. S.L. Shapiro et al., IEEE Nucl. Sci. NS **23** (1976) 264, and *ibid* p. 269.
6. F.C. Winkelmann et al., Design and Operation of SLAC Beam Line 20-21-22, SLAC, Report-160, 1973.





1-83  
325086

XBL 832-8063

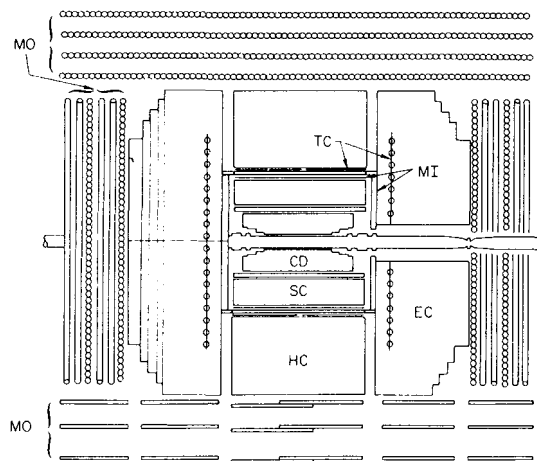
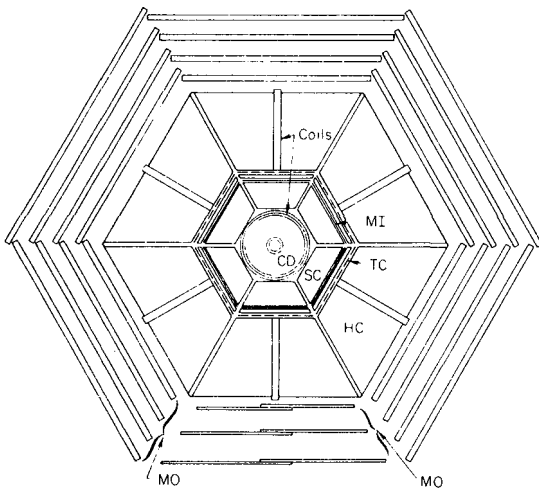
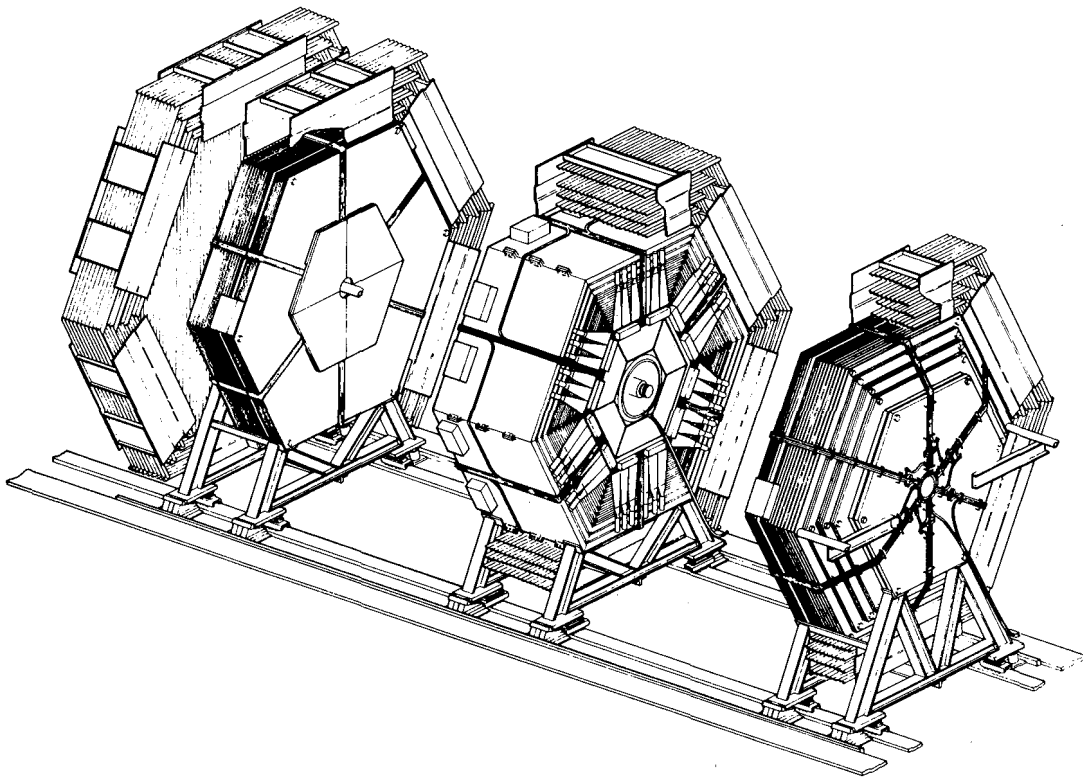
## MAC (MAGnetic Calorimeter)

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	Cylindrical drift chamber 2.2 m long, 12-45 cm tracking radius Argon - 10% methane at 1 atm. 10 layers, double sense wires $\geq 5$ points on tracks over $\Delta\Omega = 95\%$ of $4\pi$ $3^\circ$ stereo gives $\Delta z = 4$ mm $dE/dx$ to $\pm 15\%$ $\sigma_p/p = 6.5\%$ p
MUON DETECTION	Muon tracking chambers 4 planes of 10 cm diameter drift tubes surrounding magnetized iron toroids $\sigma_p/p = 30\%$ $\Delta\Omega = 97\%$ of $4\pi$
SHOWER DETECTORS	Barrel: 14 $X_0$ of Pb - proportional chamber sandwich $\sigma_E/E = 20\%/ \sqrt{E}$ z-coordinate from charge division $\sigma_\phi = 0.8^\circ$ , $\sigma_\theta = 1.3^\circ$ Endcaps: 14 $X_0$ of Fe - proportional chamber sandwich $\sigma_E/E = 45\%/ \sqrt{E}$ $\phi$ -coordinate from cathode strips $\sigma_\phi = 2^\circ$ , $\sigma_\theta = 1.5^\circ$ Total: $\Delta\Omega = 97\%$ of $4\pi$
HADRON CALORIMETER	$5.5 \lambda_{\text{abs}}$ of Fe - proportional chamber sandwich $\sigma_E/E = 75\%/ \sqrt{E}$ $\sigma_\theta = 2^\circ$ ; $\sigma_\phi = 1^\circ$ (barrel), $4^\circ$ (endcaps) $\Delta\Omega = 97\%$ of $4\pi$
TIME OF FLIGHT	144 scintillation counters (72 barrel, 72 endcaps) $r = 1.3$ m $\Delta t = 1$ ns $\Delta\Omega = 97\%$ of $4\pi$
LUMINOSITY MONITOR	4 scintillator/shower counter telescopes at 32 mrad horizontally

### REFERENCES

1. R.L. Anderson et al., IEEE Trans. NS 25, (1978) 340.
2. W.T. Ford, SLAC-PUB-2894, March 1982 (Proceedings SLAC International Conference on Instrumentation for Colliding Beams).

# MAC (MAGnetic Calorimeter)



### MAC Detector Components:

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

XBL 831-7898

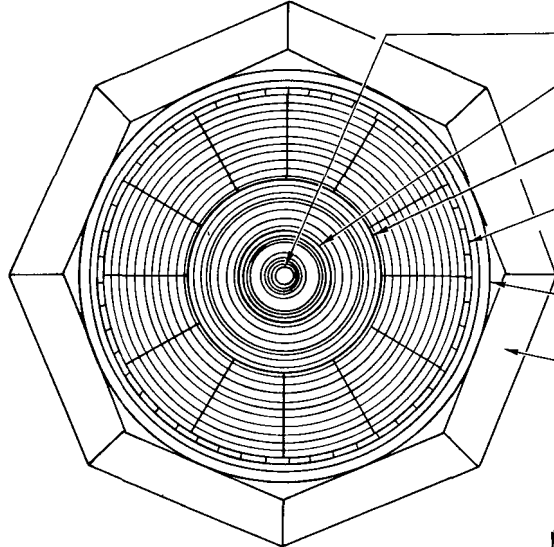
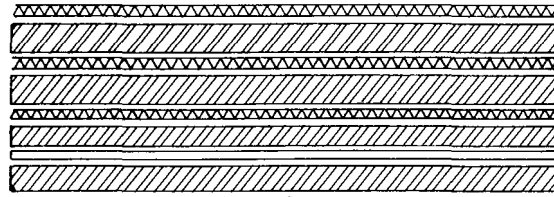
## MARK II

LOCATION	PEP $e^+e^-$ storage ring SLAC, Stanford, CA, USA
MAGNET	4.6 kG Al coil solenoid, 1.5 m radius (currently running at 2.3 kG)
TRACKING	Central drift chamber: Active length = 2.64 m, inner radius = 0.41 m, outer radius = 1.45 m 6 axial layers, 10 stereo layers ( $\pm 3^\circ$ ) 50% ethane, 50% argon $\sigma \simeq 200 \mu$ Vertex drift chamber: Cylindrical drift chamber, 1.2 m long, inner radius = 10 cm, outer radius = 35 cm Only axial wire layers (4 near $r = 12$ cm, 3 near $r = 30$ cm) $\sigma \simeq 100 \mu$ Be beam pipe ( $0.006X_0$ ) Combined $(\Delta p/p)^2 = (0.015)^2 + (0.01p)^2$ Tracks extrapolated to interaction point within $100 \mu$
SHOWER COUNTERS	8 modules of Pb-liquid argon ( $15X_0$ each), arranged in octagon outside coil Covers 64% of $4\pi$ 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 $\phi$ , $\theta$ , u directions $\Delta E/E \simeq 13\%/\sqrt{E}$
TIME OF FLIGHT	48 scintillation counters read out at both ends Cover 75% of $4\pi$ 1.50 m flight path at $\theta = 90^\circ$ ; $\sigma = 340$ ps $K, \pi$ separation up to 1.35 GeV/c at $1\sigma$ level
END CAPS	2 layers Pb-proportional chamber ( $5X_0$ ) with 4 successive cathode strip readouts ( $\theta$ , $\phi$ , R-spiral, L-spiral) 50% argon, 50% ethane
MUON DETECTION	Proportional tubes interleaved with steel absorber (4 layers each for total thickness of 1 m) covering 55% of $4\pi$
SMALL ANGLE TAGGING LUMINOSITY MONITOR	6 planar drift chambers followed by shower counters Octagonal shower counters cover $22 \text{ mrad} < \theta < 80 \text{ mrad}$ contain 18 layers $1/4''$ Pb and $1/2''$ scintillator, read out with BBQ wave shifter, front 5 layers separately from back 13 $\Delta E/E = 15.5\%/\sqrt{E}$ 3 sets of scintillation counters

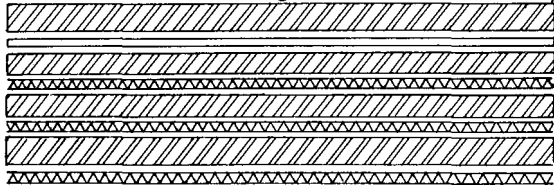
### REFERENCES

1. G.S. Abrams et al., Phys Rev. Lett. **43** (1979) 477, and *ibid* 481.
2. W. Davies White et al., Nucl. Instr. & Meth. **160** (1979) 227.
3. G.S. Abrams et al., IEEE Trans. Nucl. Sci. **NS 25** (1978) 1, *ibid* 309, and **NS 27** (1980) 59.
4. J.A. Jaros, Proc. Int. Conf. on Instrumentation for Colliding Beam Physics, SLAC-250 (1982).

# MARK II

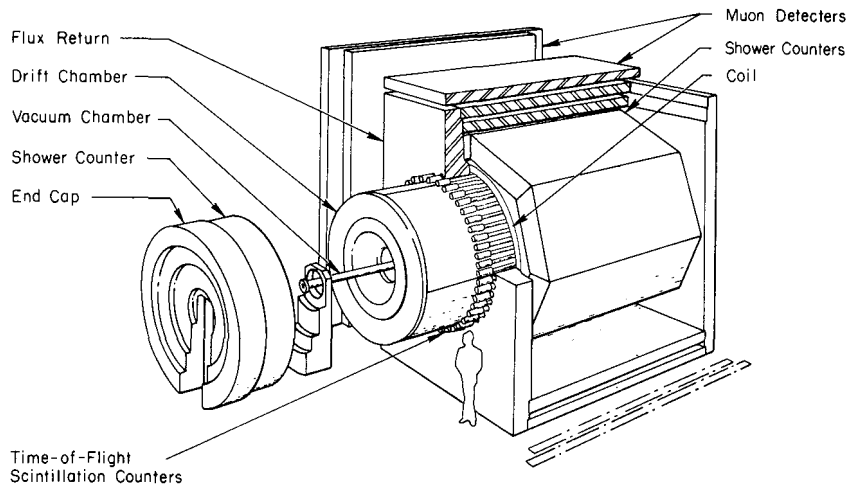


- Vacuum Chamber
- Vertex Detector
- Drift Chamber
- Time of Flight Counters
- Solenoid Coil
- Liquid Argon Shower Counter
- Iron Flux Return and Hadron Absorber



- Muon Proportional Tubes

1 m

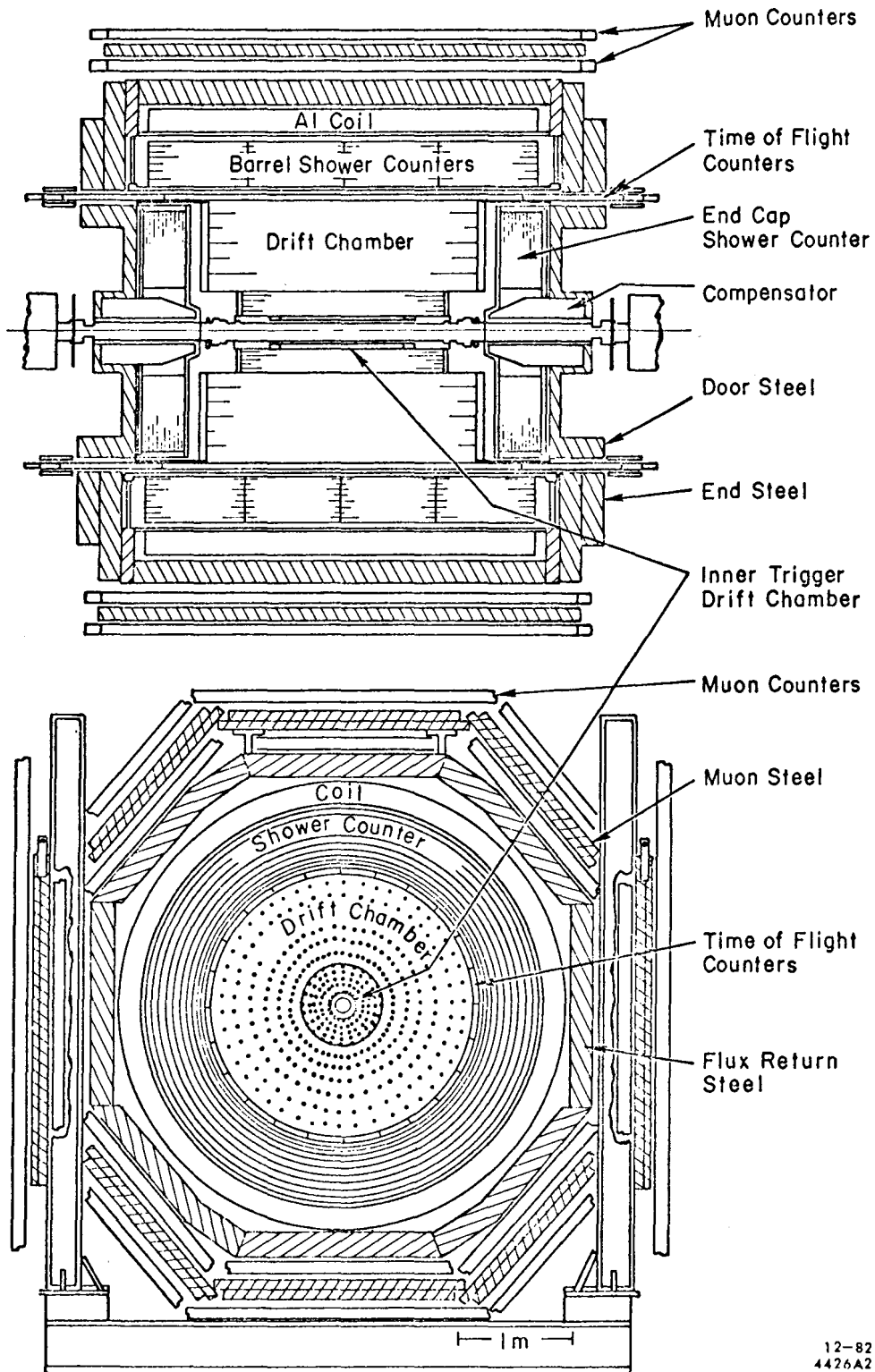


- Flux Return
- Drift Chamber
- Vacuum Chamber
- Shower Counter
- End Cap
- Time-of-Flight Scintillation Counters
- Muon Detectors
- Shower Counters
- Coil

## 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 <sub>2</sub> , 1% methane $(\Delta p/p)^2 = (1.5\%)^2 + (1.5\% p)^2$
SHOWER COUNTER	24 layers of Pb-gas proportional chamber sandwich (12X <sub>0</sub> total) A cylindrical array of 1.3 cm × 2.9 cm × 3.5 m cells, 320 per layer readout 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 $\sigma_\phi = 6$ mrad; $\sigma_\theta = 14$ mrad at 45°; $\sigma_E/E = 18\%/\sqrt{E}$
END CAPS	24 layers of Pb-gas proportional chamber sandwich (12X <sub>0</sub> total) An array of rectangular 1.2 cm × 2.6 cm wide aluminum proportional tubes are glued between 1/2 X <sub>0</sub> layers of Pb 80% argon, 20% methane $\sigma_x = 0.8$ cm; $\sigma_y \sim 2-4$ 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 $\sigma_t \simeq 150-170$ 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 $\sigma_\phi = 7$ mrad; $\sigma_\theta = 30$ mrad
TRIGGER	Uses timing information from 2 layers of the inner trigger chamber and a chronotron circuit to restrict the trigger to a ±45 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



12-82  
4426A2

XBL 831-7891

## MARK-J

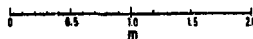
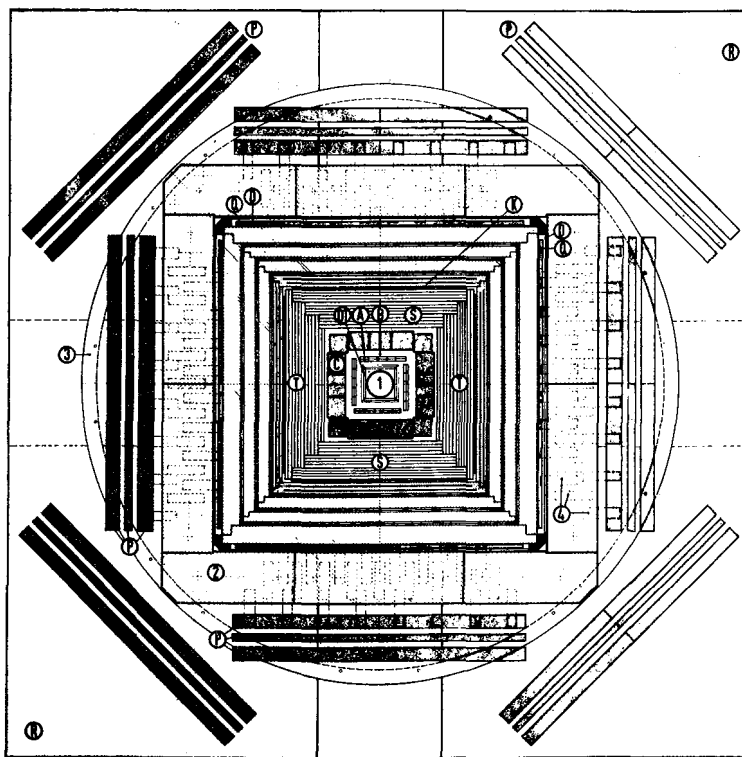
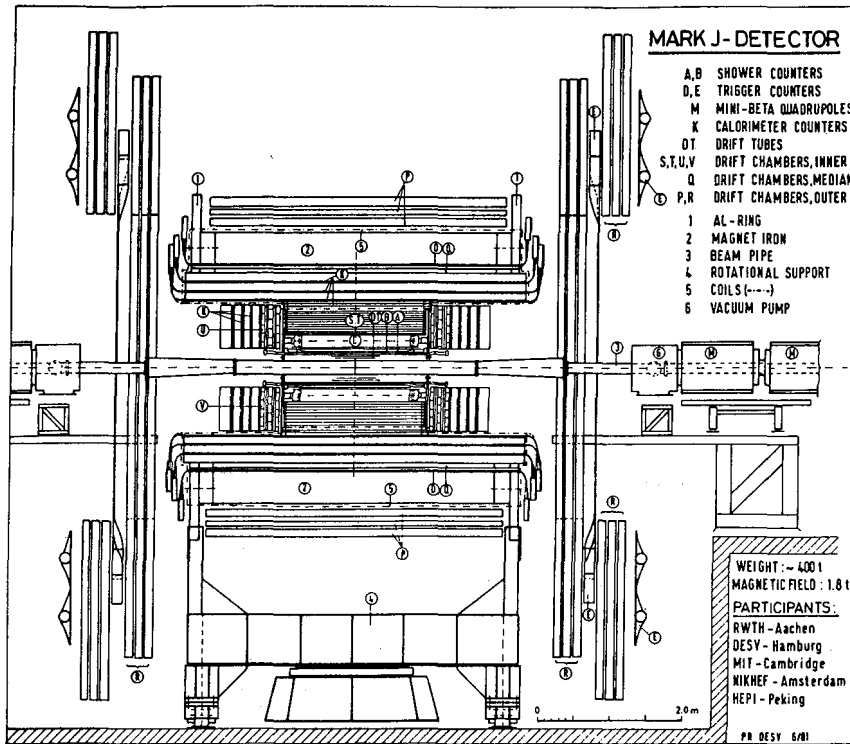
LOCATION	PETRA $e^+e^-$ rings DESY, Hamburg, W. Germany
DETECTOR	Calorimetric, specialized for $\mu$ -detection and asymmetry measurements Can rotate around the beam $\phi \pm \pi$ and $\theta \pm \pi/2$ Decay path $\sim 20$ cm
MAGNET	Toroid, 500 To, iron magnetized to 17 kG 5 concentric squares of 87 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 $\phi$ ; $12 < \theta < 168^\circ$ coverage $\Delta E/E \simeq 12\%/\sqrt{E}$
CALORIMETER	192 scintillators in 7 layers of magnetized iron Resolution $\leq 20\%$ 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.



# MARK-J



XBL 832-8019

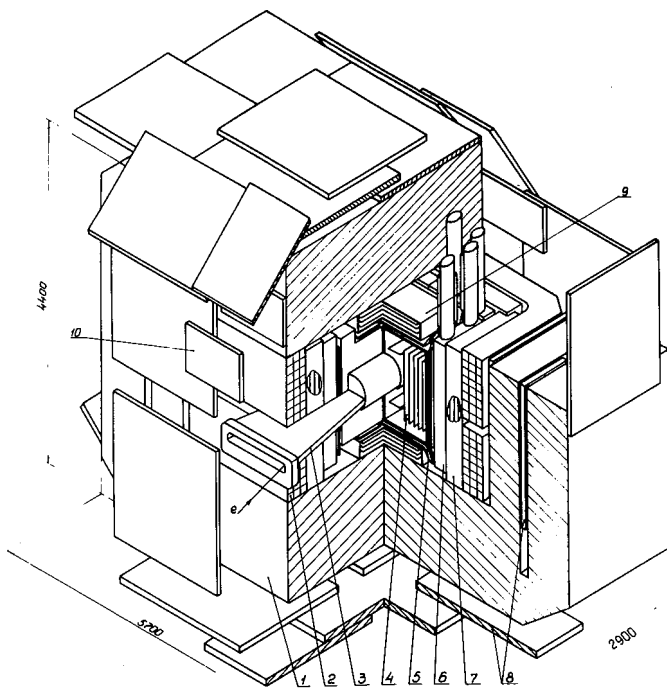
## MD-1

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 $\sigma_p/p = (5+10)\%$ p
SCINTILLATION COUNTERS	24 counters, $40 \times 40 \times 1$ cm <sup>3</sup> $\sigma_A/A = 20\%$ ( $\beta = 1$ ), $\sigma_{\text{TOF}} = 0.4$ ns
CHERENKOV	8 counters, $160 \times 70 \times 20$ cm <sup>3</sup> , 60% of $\Omega$ Gas: ethylene, $P = 25$ atm. $(p_\pi)_{\text{thresh}} = 0.7$ GeV/c, $(p_k)_{\text{thresh}} = 2.5$ GeV/c $\epsilon(\beta=1) = 98\% \rightarrow \epsilon(\beta < \beta_{\text{th}}) < 0.1$ $\epsilon(\beta=1) = 60\% \rightarrow \epsilon(\beta < \beta_{\text{th}}) < 5 \times 10^{-3}$
SHOWER-RANGE CHAMBERS	14 chambers, $10 \times (13$ mm Fe + 10 mm MWPC) Gas: Ar + 20% CO <sub>2</sub> , $P = 1$ atm. $\sigma_E/E = (40+15)\%$ at $E_\gamma = 0.15 + 5$ GeV $\epsilon_\gamma = 50\%$ at 150 MeV, $\epsilon_\gamma \geq 90\%$ at $E_\gamma \geq 250$ MeV $\sigma_\theta \approx \sigma_\phi \sim 1+2^\circ$
MUON DETECTION	MWPC, $(p_\mu)_{\text{thresh}} = 0.75+2.1$ GeV/c
SCATTERED ELECTRON	MWPC with $s = 4$ mm and with delay
TAGGING SYSTEM	Line readout with $\sigma = 0.1$ mm For $E = E_b$ , $\theta = 12+100$ mrad For $\theta = 0$ , $(E_b - E)/E_b = 0.1+0.5$ $\sigma_E/E = 1+1.5\%$
LUMINOSITY MONITOR	1. $ee \rightarrow ee\gamma$ , NaI(Tl) counters 2. $ee \rightarrow ee$ at small angles, scintillation counters

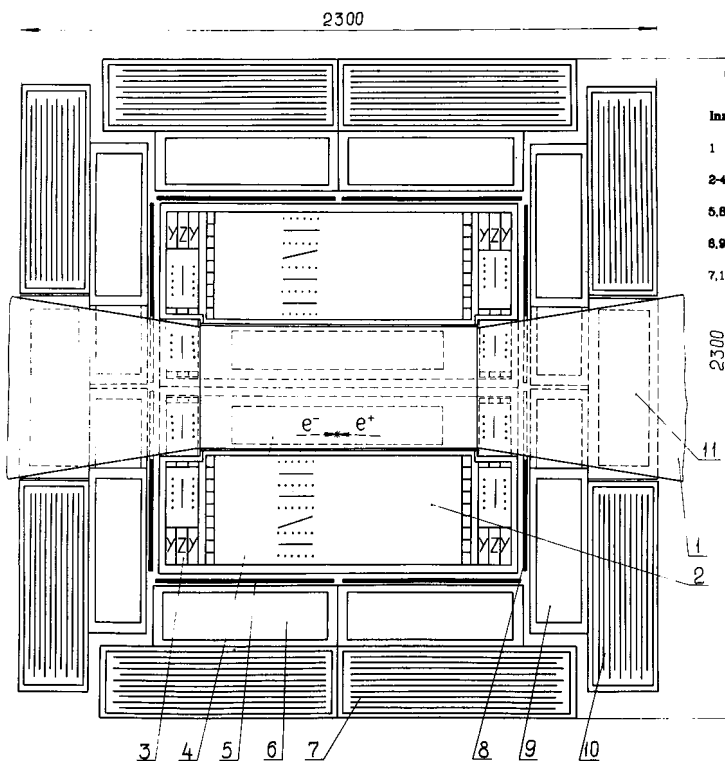
### REFERENCES

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

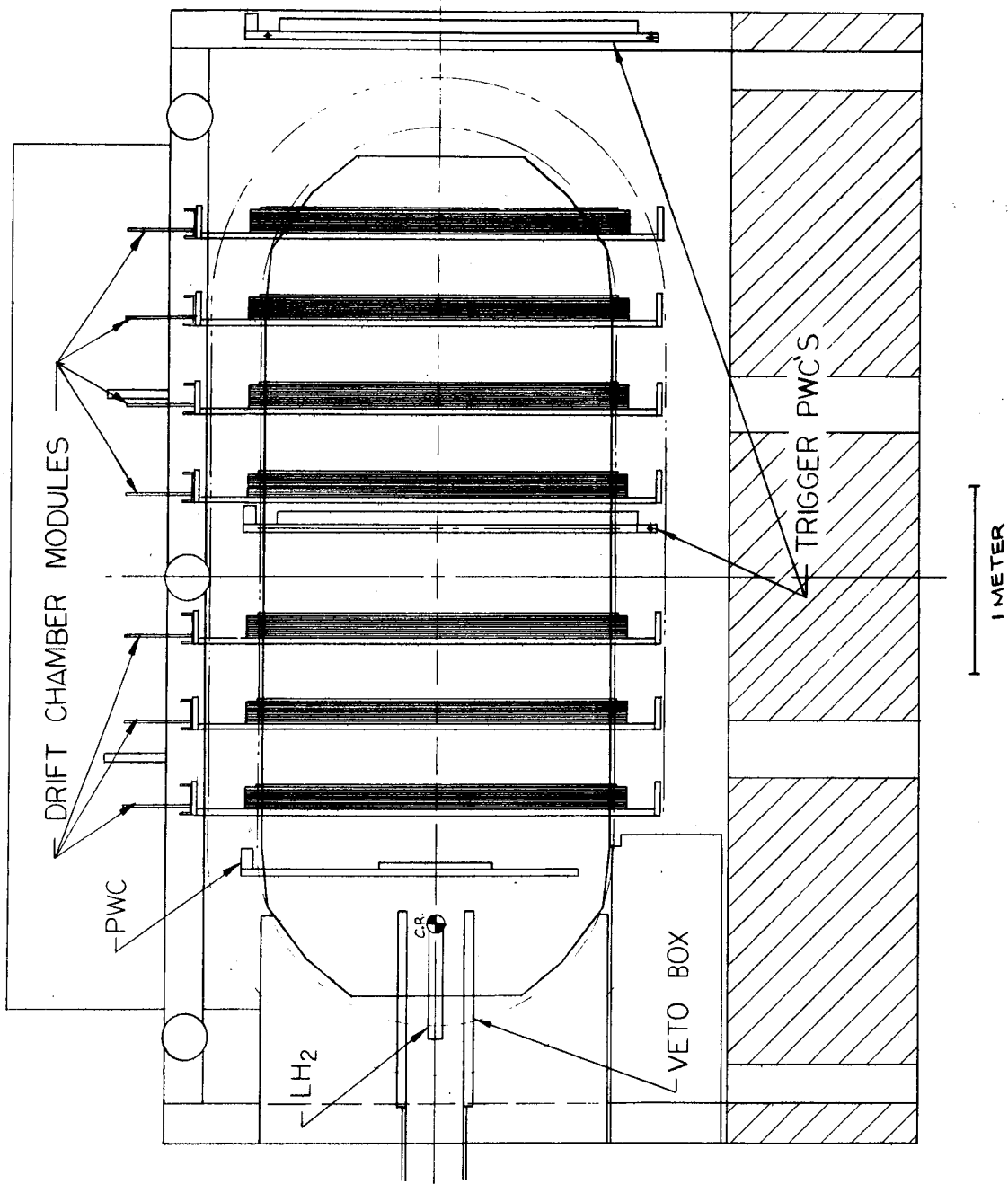
## MPS II

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, $\bar{p}$ 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 $\approx 250 \mu\text{m}$ 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 $\gamma_r$ (Freon 114) $\approx 20$  High pressure Cerenkov counter hodoscope (60 psi max) 350 cm W $\times$ 120 cm H Typical $\gamma_r \approx 10$  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

## Multimuon Spectrometer

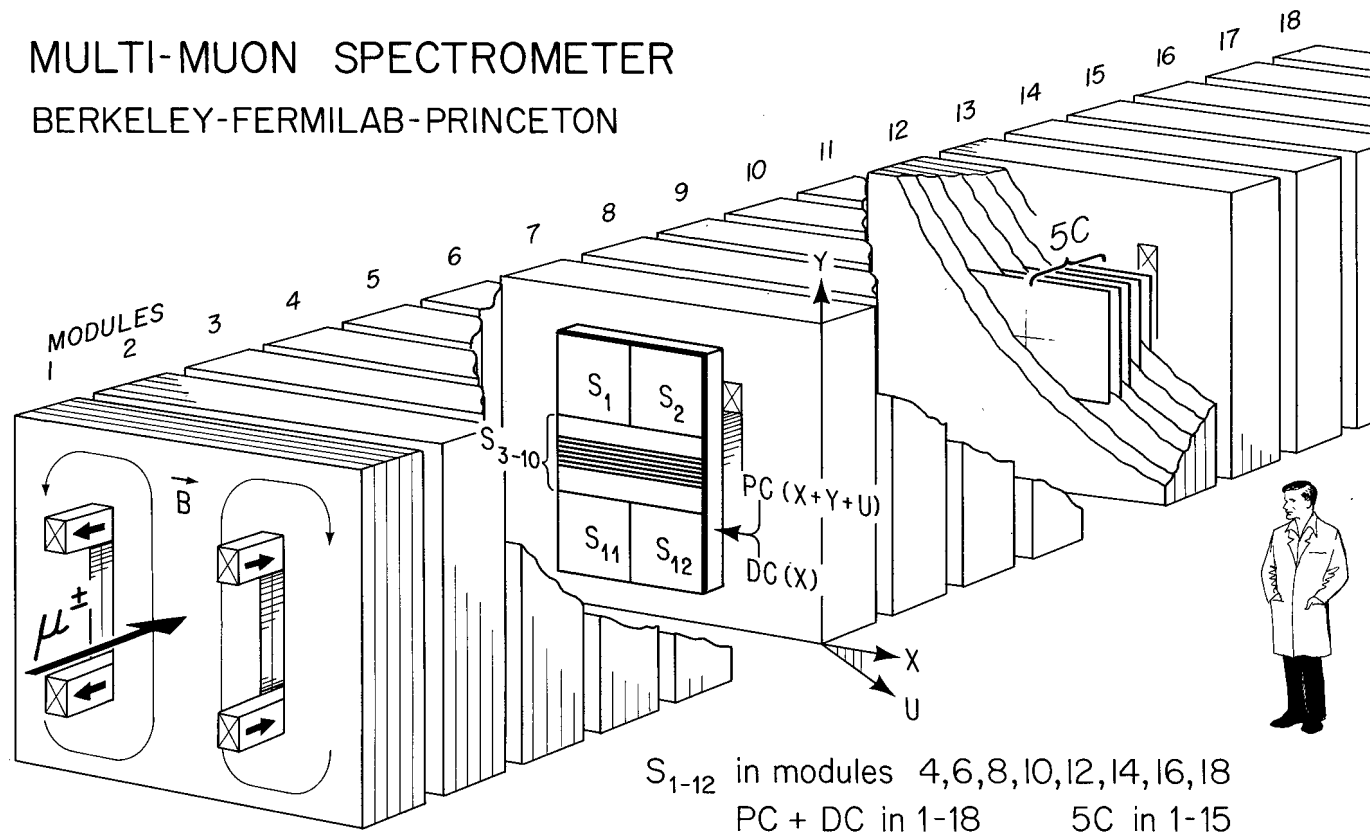
LOCATION	Muon Laboratory, FNAL Batavia, IL, USA
COLLABORATION	Lawrence Berkeley Laboratory, Fermilab, Princeton University
MAGNET	Solid iron spectrometer serves as analyzing magnet, target, hadron absorber, and hadron calorimeter Magnet size $2.5 \text{ m} \times 2.5 \text{ m} \times 16 \text{ m}$ Fiducial volume $1.8 \times 1 \times 12 \text{ m}^3$ Field is 2 Tesla, uniform to 3% and mapped to 0.2% Magnet constructed of 10-cm thick plates with gaps between for instrumentation
TRACKING	19 multiwire proportional chambers, $1.8 \text{ m} \times 1.0 \text{ m}$ active area, 3 coordinate (x,y,u) readout, $\sigma_x = 900 \mu\text{m}$ , $\sigma_y = \sigma_u = 1500 \mu\text{m}$ 19 drift chambers, $1.8 \text{ m} \times 1.0 \text{ m}$ , $\sigma_x = 250 \mu\text{m}$ Momentum resolution $\sigma_p/p \sim 8\%$
HADRON CALORIMETER	75 counters of plastic scintillator, each $1 \text{ m} \times 0.8 \text{ m}$ , downstream of each 10-cm thick iron plate $\sigma_\nu/\nu = 1.4/\sqrt{\nu}$ where $\nu$ is the hadron shower energy in GeV
TRIGGER	Parallel triggers using 8 banks of scintillator hodoscopes separated by 1 m of iron, and energy deposition in hadron calorimeter Apparatus is triggered by single muon scattered at large angle ( $\theta \gtrsim 20 \text{ mrad}$ ) Multimuon triggering is fully sensitive in the forward direction Two-muon trigger requires energy deposition in the calorimeter; three-muon triggers have no calorimeter requirement

### REFERENCES

1. G. Gollin et al., IEEE Trans. Nucl. Sci. **NS 26** (1979) 59.
2. G. Gollin et al., Phys. Rev. **D24** (1981) 559.
3. W.H. Smith et al., Phys. Rev. **D25** (1982) 2762.

# MULTI-MUON SPECTROMETER

## BERKELEY-FERMILAB-PRINCETON



Multimuon Spectrometer

XBL 795-9605

## NUSEX Detector for Nucleon Decay

LOCATION	Mont Blanc Laboratory Italian-French border
SHIELDING DEPTH	~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 <sup>3</sup> )
VOLUME	(3.5m) <sup>3</sup>
SENSITIVE ELEMENTS	48,880 plastic streamer tubes with resistive cathode Cell 9 × 9 mm <sup>2</sup> , 100 μm wire, gas mixture Ar+CO <sub>2</sub> +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 (~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
$\mu \rightarrow e$ DETECTION EFFICIENCY	40%
MINIMUM TRIGGER	4 contiguous planes

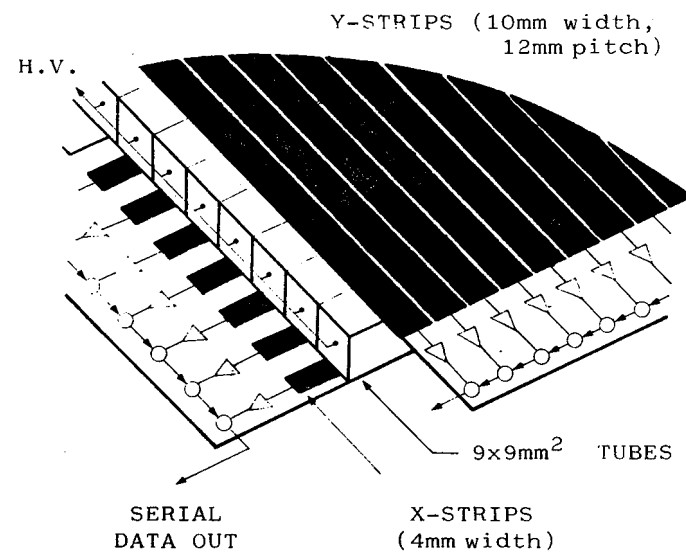
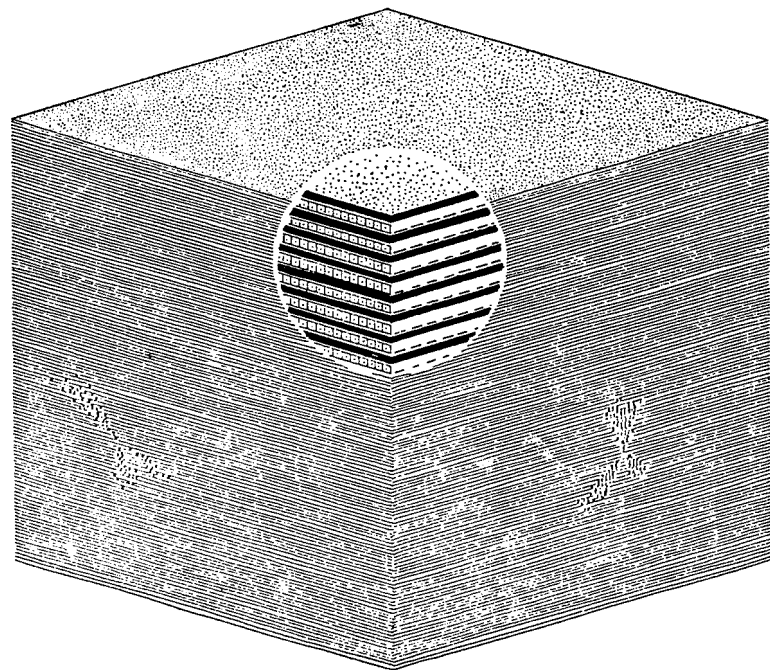
### REFERENCES

1. G. Battistoni et al., Phys. Lett. **118B** (1982) 461.
2. G. Battistoni et al., Nucl. Instr. & Meth. **176** (1980) 297.



# NUCLEON STABILITY EXPERIMENT

FRASCATI-MILANO-TORINO-CERN



NUSEX Detector for Nucleon Decay

XBL 832-8141

## OMEGA

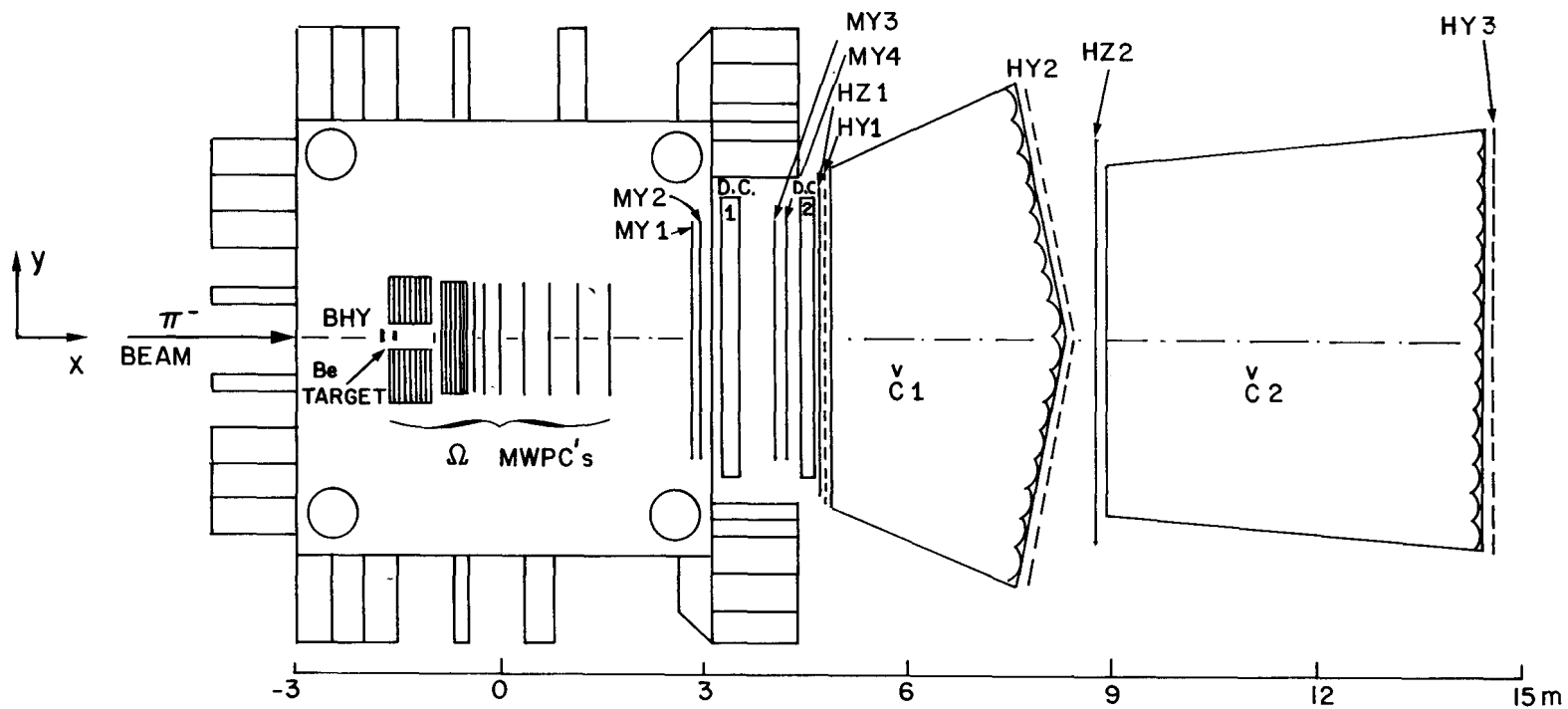
LOCATION	West area, 450 GeV secondary beam CERN, Geneva, Switzerland
MAGNET	18 kG (superconducting) Field volume: height, 150 cm; diameter ( $\frac{1}{2}$ field), 400 cm
TRACKING	Proportional chambers inside field $\sigma_p/p = 10^{-3} p$ + level arm drift chambers $\sigma_p/p = 2 \times 10^{-4} p$
PARTICLE IDENTIFICATION	Two threshold Cerenkov counters 30 cells each
FUTURE DETECTORS	50 $\mu$ m pitch microstrips for measurement of beam and decay vertices Ring image Cerenkov (5 m gas radiator) Photon calorimeter $4 \times 4 \text{ m}^2$ , $27X_0$ , 1 cm bins $\sigma_E/E = 15\%/\sqrt{E}$

### REFERENCES

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

### FIGURE CAPTION

OMEGA spectrometer layout shown (1983) is for experiment WA77 (H... = hodoscopes, M... = multiwire proportional chambers, DC = drift chambers, Č... = gas Čerenkov counters. Target: here Be, usually H<sub>2</sub>, also emulsions for photoproduction of unstable particles).

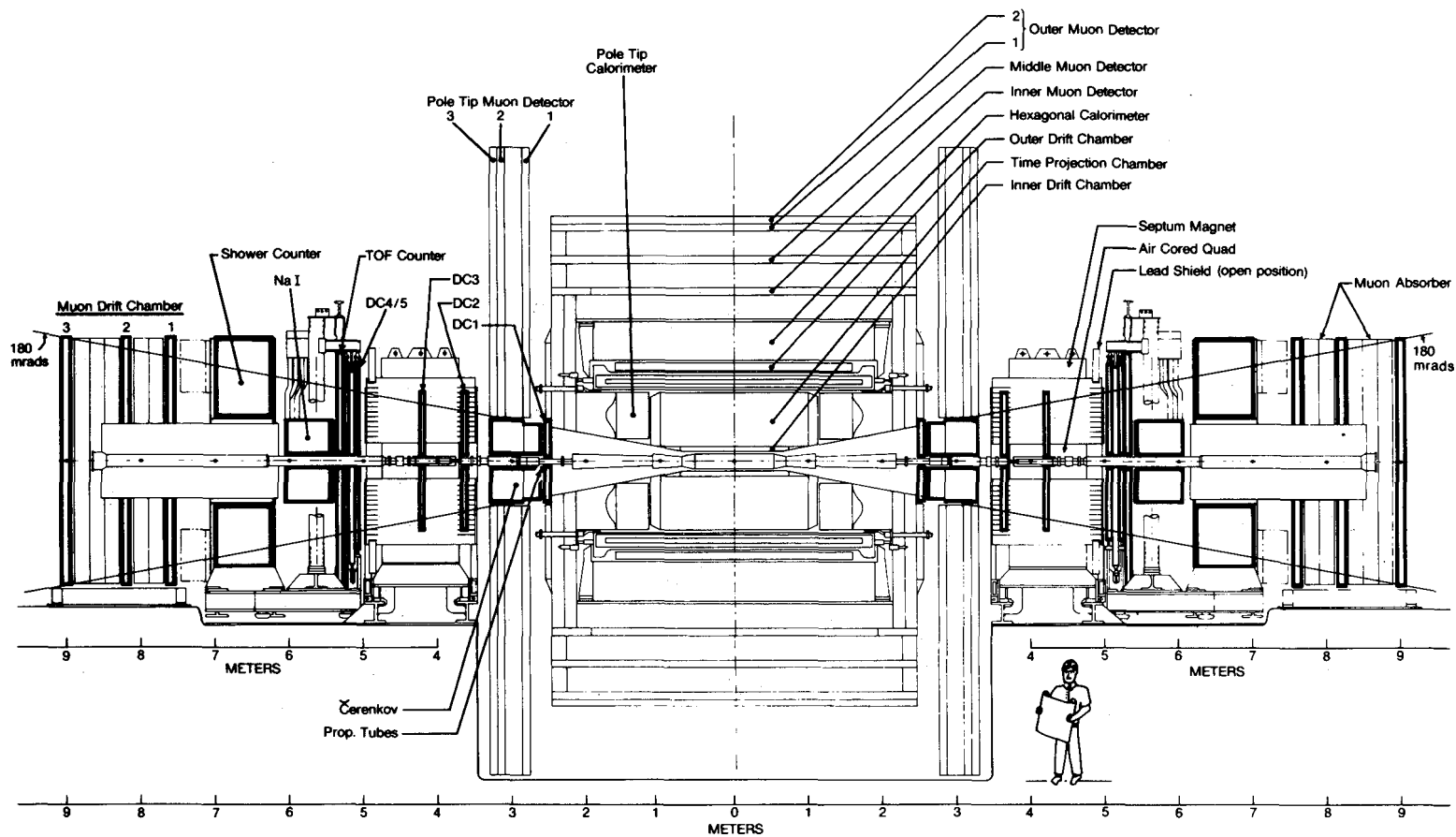


OMEGA

XBL 832-8065

## PEP-9 $2\gamma$ 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; $\int Bd\ell \cong 2.6$ 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 ( $\pm 10^\circ$ ), Ar-Eth (50%-50%) DC-3: 2 vertical ( $\pm 10^\circ$ ), Ar-CO <sub>2</sub> (83%-17%) DC-2,4,5: 3 planes, 1 horizontal, 2 vertical ( $\pm 10^\circ$ ), Ar-CO <sub>2</sub> (83%-17%) $\sigma$ position $\cong 300 \mu\text{m}$ $\sigma_p/p \cong \pm \sqrt{(0.008p)^2 + (0.025)^2}$ Angular acceptance of system — 22 mr to 180 mr
NaI SHOWER DETECTOR	Angular acceptance — 22 mr to 100 mr at either end Each detector contains 60 individual NaI crystals each 22" long and hexagonal cross-section 6" apex to apex $\sigma_E/E = 0.9\%$ @ 14.5 GeV (best performance without radiation damage) Spatial resolution: $\sigma \cong 0.4$ cm
Pb-SCINTILLATOR SHOWER	Angular acceptance — 100 mr to 180 mr 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 <sub>0</sub> $\sigma_E/E = \pm 15\%/\sqrt{E}$ 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: $\sigma_T = 0.3$ ns
MUON DETECTOR	1 meter of iron (787 g/cm <sup>2</sup> ) 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: $\sigma = 220 \mu\text{m}$
CERENKOV	1 atm., CO <sub>2</sub> radiator, 70 cm long, divided into 12 azimuthal segments at each end Efficiency for electrons $> 90\%$ overall, $> 95\%$ over 80% of angular coverage (22 mr to 180 mr)
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

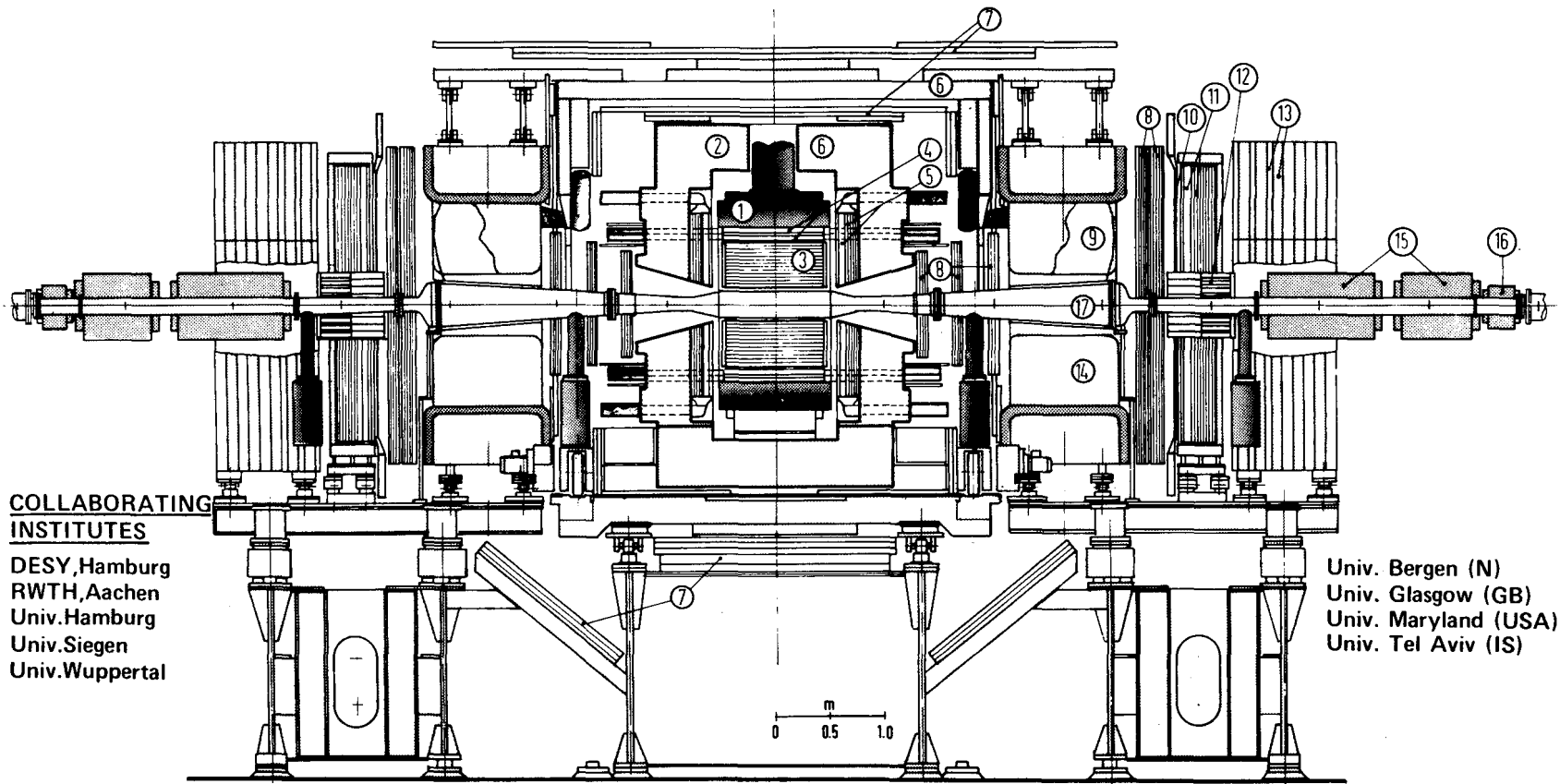
# PLUTO

LOCATION	DORIS $e^+e^-$ ring (1974-1978) PETRA $e^+e^-$ ring (1978-1982) DESY, Hamburg, W. Germany
MAGNET*	16.5 kG (superconducting)
TRACKING	13 proportional chambers + cathode readout $\sigma_p/p = 3\%$ for $p > 3 \text{ GeV}/c$
SHOWER COUNTERS	8.6 $X_0$ of Pb-scint. sandwich $\sigma_E/E = 35\%/\sqrt{E}$ Double layer helix tubes $\sigma_\phi = 1.3^\circ$ , $\sigma_\theta = 1.4^\circ$
END CAPS	10.3 $X_0$ Pb-scint. sandwich, 12° segments ( $\phi$ ) $\sigma_E/E = 19\%/\sqrt{E}$ One layer MWPC $\sigma_\theta = 1^\circ$
MUON DETECTION	100 cm iron including coil and flux return yoke $p_{\text{cutoff}} = 1.4 \text{ GeV}/c$
FORWARD SPECTROMETERS	SAT (29-57 mrad) 19.5 $X_0$ Pb-scint. sandwich, 30° segments ( $\phi$ ) $\sigma_E/E = 18\%/\sqrt{E}$ , $\sigma_\theta = 2 \text{ mrad}$ , $\sigma_\phi = 20 \text{ mrad}$ 4 planes PWC in front  LAT (70-260 mrad) 18 Pb-scint. sandwiches, 14.5 $X_0$ $\sigma_E/E = 11\%/\sqrt{E}$ 4 layers proportional tubes  Analyzing septum magnets with drift chamber telescopes before and after $\sigma_p/p = 2.5\%$  Time-of-flight counters
*FOOTNOTE	All data concern the 1981/82 version of the detector

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3. C. Berger et al., Phys. Lett. **81B** (1979) 410 and Phys. Lett. **89B** (1979) 120.
4. L. Criegee and G. Knies, Phys. Rept. **83** (1982) 151.

# PLUTO Detector (1981)



**COLLABORATING  
INSTITUTES**

DESY, Hamburg  
RWTH, Aachen  
Univ. Hamburg  
Univ. Siegen  
Univ. Wuppertal

Univ. Bergen (N)  
Univ. Glasgow (GB)  
Univ. Maryland (USA)  
Univ. Tel Aviv (IS)

- |  |   |   |                           |
|--|---|---|---------------------------|
| 1. Superconductive coil                      | 5. Endcap shower counters<br>with proportional chambers | 10. TOF counters  | 14. Septum magnet         |
| 2. Magnet yoke                               | 6. Hadron absorber                                      | 11. Large angle tagger (LAT)<br>with proportional tubes | 15. Mini beta quadrupoles |
| 3. Cylindrical driftchambers                 | 7. Muon chambers  | 12. Small angle tagger (SAT)                            | 16. Correction quadrupole |
| 4. Barrel shower counter<br>with helix-tubes | 8. Forward drift chambers                               | 13. Forward muon detector                               | 17. Vacuum pipe           |
|  | 9. Cerenkov counter                                     |   |                           |

33528

F 33/PR- kn (1980)

XBL 832-8307

## SFM

LOCATION	ISR pp storage ring CERN, Geneva, Switzerland
MAGNET	10 kG split field magnet Gap 1.1 m, length 10 m
TRACKING	MWPC system, 70,000 wires Argon-isobutane-methylal
PARTICLE IDENTIFIER	Time-of-flight system, 74 scintillators Atmospheric and high pressure Cerenkov counters dE/dx chambers (momentum below minimum ionizing)

### REFERENCES

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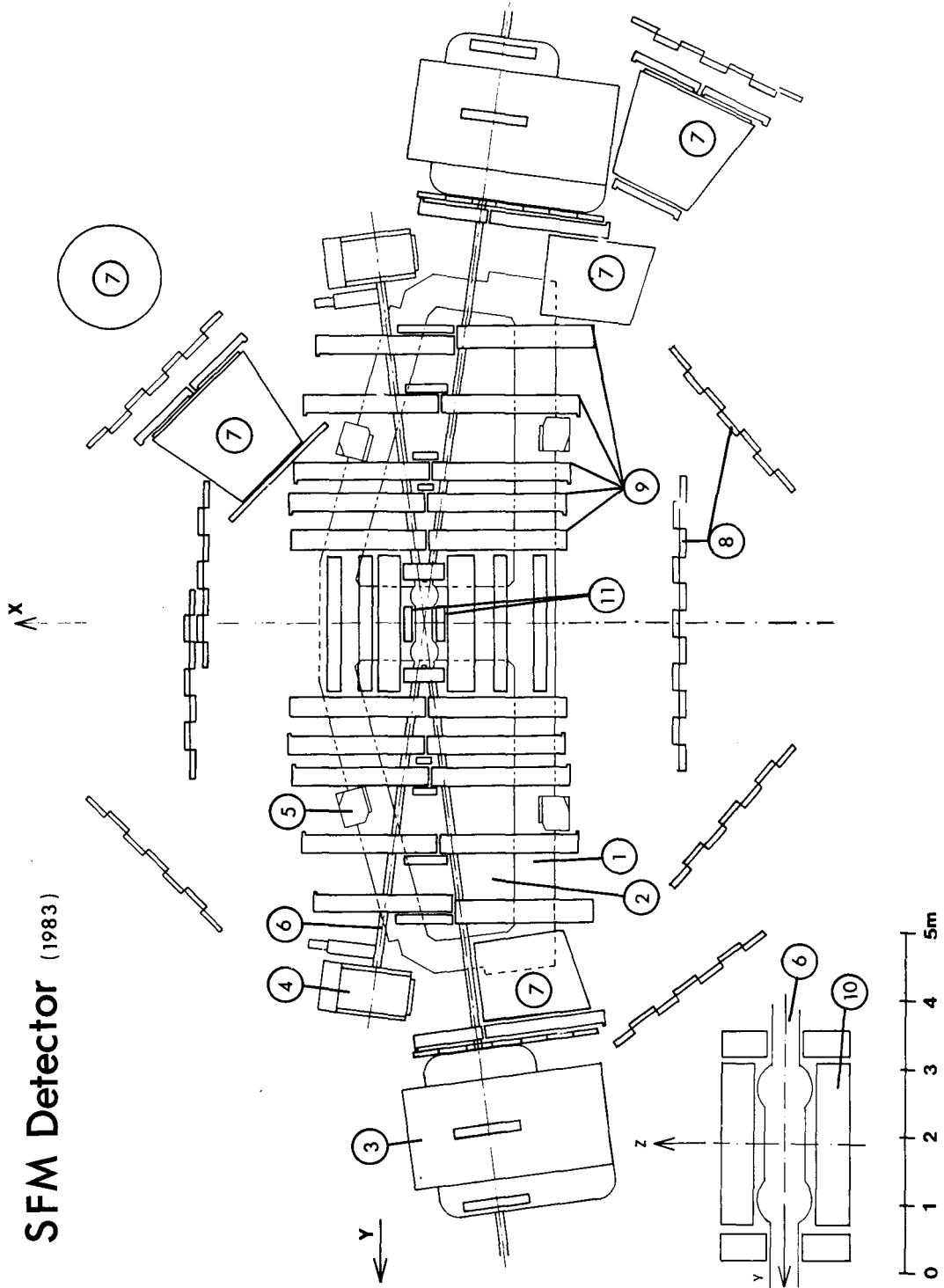
### FIGURE CAPTION

1. MAIN MAGNET COIL
2. MAIN MAGNET YOKE
3. LARGE COMPENSATOR MAGNET
4. SMALL COMPENSATOR MAGNET
5. NON-MAGNETIC PILLAR
6. VACUUM CHAMBER
7. CERENKOV COUNTER
8. TIME-OF-FLIGHT COUNTER
9. MWPC FORWARD DETECTION SYSTEM
10. MWPC CENTRAL VERTEX DETECTOR
11. MWPC ENERGY LOSS DETECTOR



# SFM

## SFM Detector (1983)



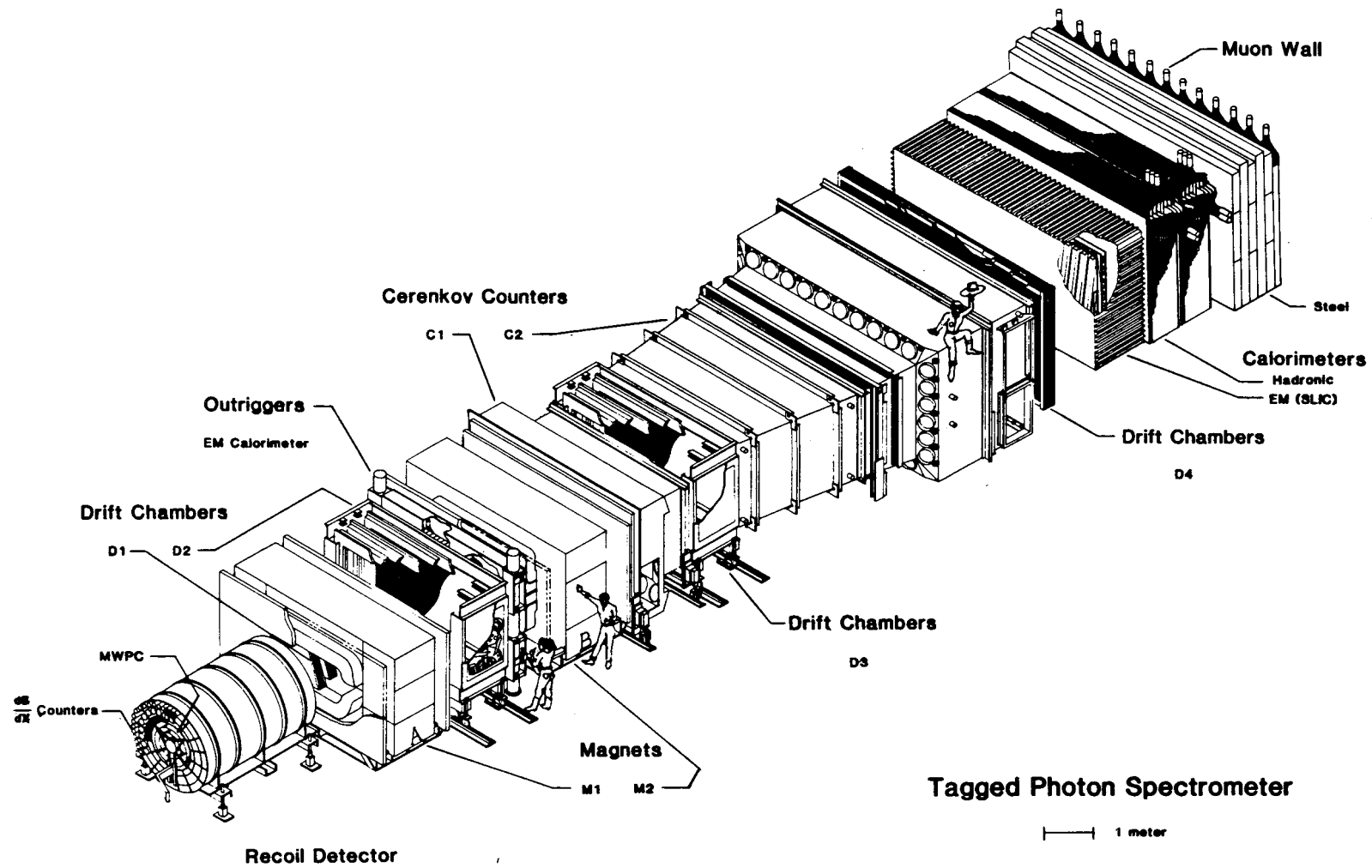
831-7889

# 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
RECOIL DETECTOR	$\Delta\phi = 5.9$ rad, $\Delta z(\text{scintillator}) = 210$ cm at radius 54 cm Cyl. proportional chamber with cathode readout: $\sigma_\theta = 5$ mr, $\sigma_\phi = 15$ mr 2 layers plastic + 2 layers liquid dE/dx scintillators in 15 azim. sectors $0.06 < t < 1.2$ GeV <sup>2</sup> , $\sigma_t/t = 5-10\%$ End to end timing - $\sigma_z = 10$ cm
FORWARD SPECTROMETER	Tracking: 29 drift chamber planes 2 magnets: $ \theta_x  < 170$ mr and $ \theta_y  < 72$ mr $\sigma_\theta = 1.0$ mr, $\sigma_p/p^2 = 5.0 \times 10^{-4}$ GeV <sup>-1</sup> 1 magnet: $ \theta_x  < 350$ mr and $ \theta_y  < 36$ mr $\sigma_\theta = 2.7$ mr, $\sigma_p/p^2 = 60 \times 10^{-4}$ GeV <sup>-1</sup> Charged particle identification: 2 atm. press. Cerenkov detectors N <sub>2</sub> and 20% N <sub>2</sub> - 80% He mixture, 20 segments each Separation: $\pi$ vs K or p $6 < p < 36$ GeV $\pi$ vs K vs p $20 < p < 33$ GeV Neutral Detection: Electromagnetic - Pb-liq. scint. (SLIC): u,v,y readout, 60 $\times$ 0.16 cm Pb samples $\sigma_\theta = 0.3$ mr, $\sigma_E/\sqrt{E} = 12\%$ ( $ \theta_x  < 134$ mr and $ \theta_y  < 67$ mr) Pb-plastic scint. (Outrigger): x,y readout, 16 $\times$ 0.64 cm Pb samples $\sigma_\theta = 2.0$ mr, $\sigma_E/\sqrt{E} = 20\%$ ( $ \theta_x  < 157$ mr and $ \theta_y  = 58-160$ mr) Hadronic - Fe-plastic scint. (Hadrometer): x,y readout, 36 total samples (2.5 cm Fe each) $\sigma_\theta = 2$ mr, $\sigma_E/\sqrt{E} = 70\%$ Muon detector hodoscope: 30 counters following $\sim 200$ cm Fe
BEAM	300 GeV e <sup>-</sup> with $\gamma$ tagging system ( $0.45 < E_\gamma/E_e < 0.95$ ) $\sigma_\gamma \approx 3-6$ GeV
BUILDERS	Tagged Photon collaboration: Fermilab, Carleton Univ., Toronto Univ., Univ. of California at Santa Barbara, Univ. of Colorado

## REFERENCES

1. J. Appel et al., Tagged Photon Magnetic Spectrometer Facility Report, Fermilab, 1977.
2. V.K. Bharadwaj et al., Nucl. Instr. & Meth. **155** (1978) 411.
3. T. Nash, Proceedings Top. Conference Applic. of Microprocessors to HEP Experiments, Geneva, May 1981, p. 132.
4. J. Martin et al., *ibid.*, p. 164.
5. E. Barsotti et al., IEEE Trans. Nucl. Sci. **NS 26** (1979) 686.
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Tagged Photon Spectrometer

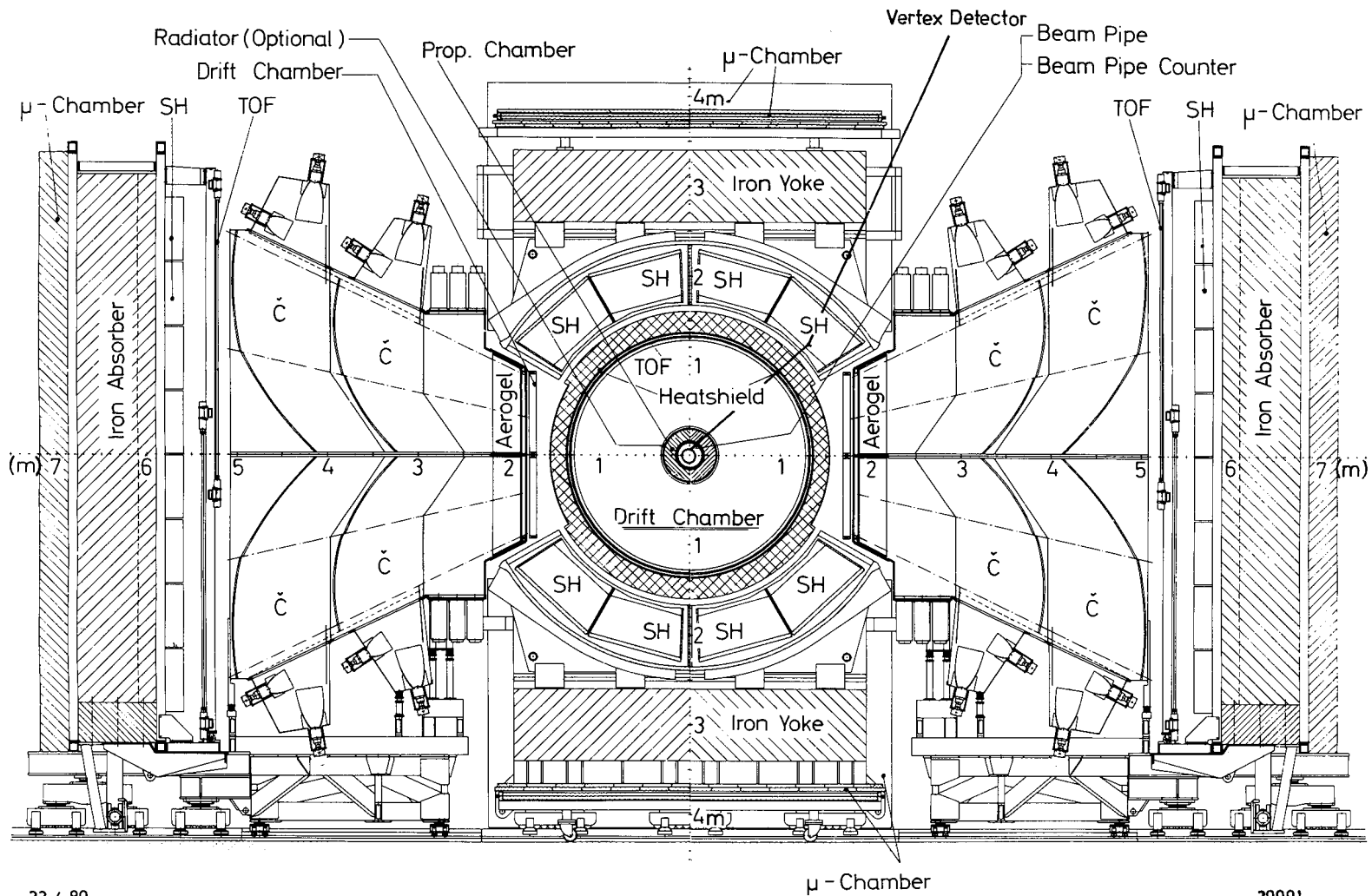
XBL 831-7899

# 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 $\sim 3$ mm, 1920 signal wires, 8 cathode layers, 960 channels, $R_i = 17$ cm, $R_o = 29$ cm, $L = 140$ cm Cyl. drift chamber, 15 layers, 9 with $0^\circ$ , 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, $390 \times 17 \times 2$ cm <sup>3</sup> , $\sigma_{TOF} = 270$ –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 $42^\circ < \theta < 138^\circ$ ; $\phi$ : $30^\circ$ – $150^\circ$ , $210^\circ$ – $330^\circ$ ; 0.2 cm Pb, 0.5 cm argon, $14X_0$ , 5088 front towers, 1248 back towers, 4592 strips for $z$ , $\phi$ , $dE/dx$ $\sigma_E/E = (0.11 + \frac{0.02}{E-0.5})/\sqrt{E}$ , $E > 1$ GeV; $\sigma_\theta = \sigma_\phi = 2$ mrad Endcap $12^\circ < \theta < 30^\circ$ , $150^\circ < \theta < 168^\circ$ , $\phi$ : $0$ – $360^\circ$ , 0.2 cm Pb, 0.3 cm argon, $12.6X_0$ , 1444 front towers, 872 back towers, 840 strips for $R$ and $\phi$																
HADRON ARMS	For particle identification up to high momenta; $50^\circ < \theta < 130^\circ$ , $-26^\circ < \phi < 26^\circ$ , $154^\circ < \phi < 206^\circ$ ; 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 <sub>2</sub> , $n = 1.00043$ , 1 atm., 64 cells <table border="0" style="margin-left: 40px;"> <tr> <td style="padding-right: 20px;">threshold momenta (GeV/c)</td> <td style="padding-right: 20px;"><math>\pi</math></td> <td style="padding-right: 20px;">K</td> <td>p</td> </tr> <tr> <td style="padding-right: 20px;">Aerogel</td> <td style="padding-right: 20px;">0.6</td> <td style="padding-right: 20px;">2.2</td> <td>4.2</td> </tr> <tr> <td style="padding-right: 20px;">Freon 114</td> <td style="padding-right: 20px;">2.6</td> <td style="padding-right: 20px;">9.3</td> <td>17.8</td> </tr> <tr> <td style="padding-right: 20px;">CO<sub>2</sub></td> <td style="padding-right: 20px;">4.8</td> <td style="padding-right: 20px;">16.8</td> <td>32.0</td> </tr> </table> Time-of-flight, 96 counters, $\sigma = 450$ ps Shower counters: lead-scintillator with wavelength shifter readout, $7.4X_0$ , 128 counters, $\sigma/E = 17\%$	threshold momenta (GeV/c)	$\pi$	K	p	Aerogel	0.6	2.2	4.2	Freon 114	2.6	9.3	17.8	CO <sub>2</sub>	4.8	16.8	32.0
threshold momenta (GeV/c)	$\pi$	K	p														
Aerogel	0.6	2.2	4.2														
Freon 114	2.6	9.3	17.8														
CO <sub>2</sub>	4.8	16.8	32.0														
MUON DETECTION	Behind magnet yoke (50–80 cm Fe) and behind hadron wall (87 cm Fe), 4 layers of proportional tube chambers, $4 \times 4$ cm <sup>2</sup>																
FORWARD DETECTOR	25–115 mrad, scintillation hodoscope, proportional tube chambers, lead-scintillator shower counter																

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TASSO

22.4.80

29991

TASSO

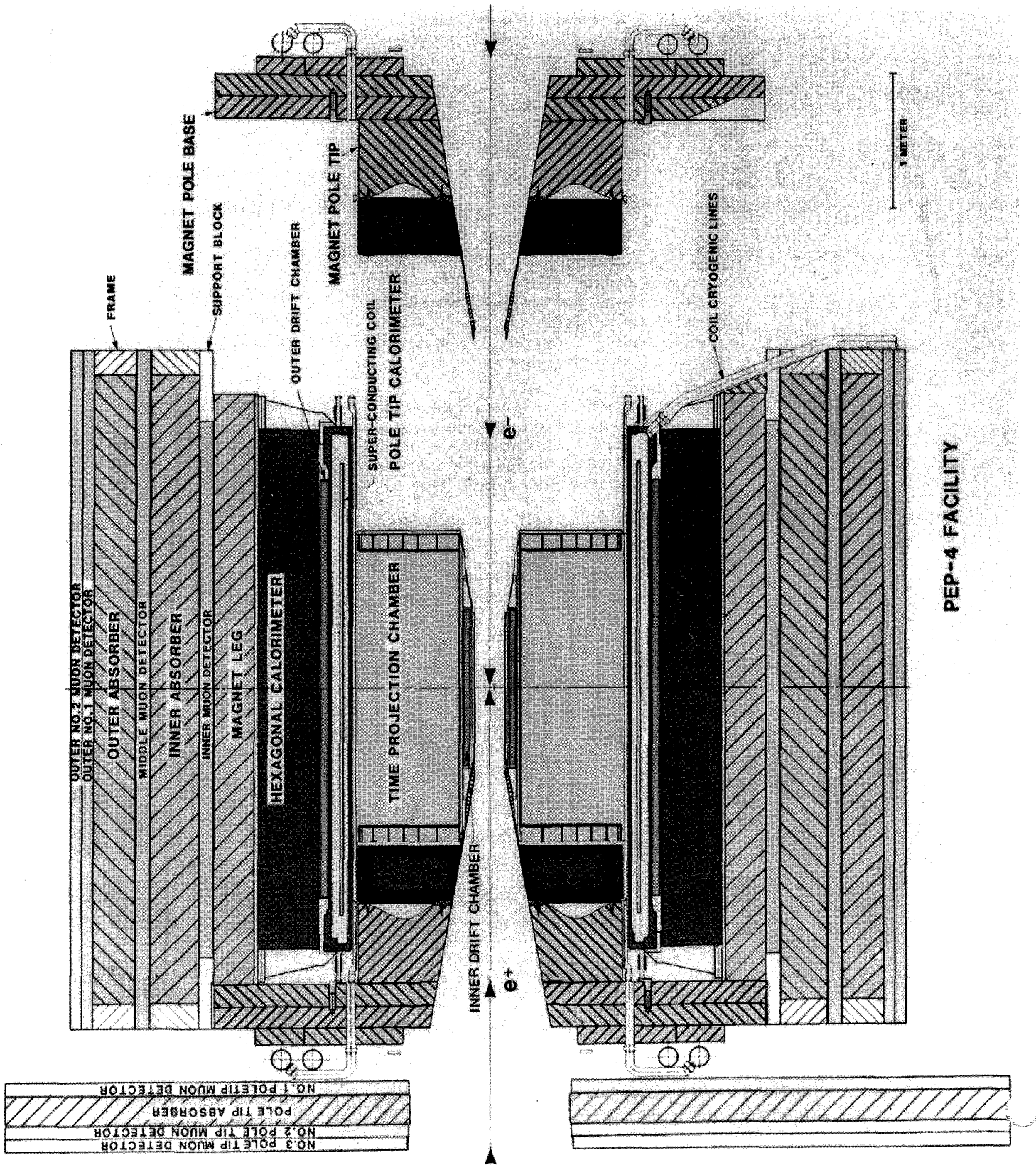
XBL 831-7895

## TPC

LOCATION	PEP $e^+e^-$ ring, Interaction Region (IR) 2 SLAC, Stanford, CA, USA
MAGNET	1982-83: 4 kG Al coil solenoid (1.32 $X_0$ coil package) 1984: 14.5 kG superconducting coil (0.86 $X_0$ 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 20 $\mu$ sec, 75 kV/m drift electric field 183 proportional wire hits on tracks with $ \cos \theta  < 0.71$ , each wire gives r,z and amplitude for six 60° sectors at each end and provides dE/dx meas. by multiple ionization sampling 15 3-dim. space points from induced cathode signals on several of 13,824 channels to give r, $\phi$ , and z (from the drift time), for $ \cos \theta  < 0.71$ $\geq 3$ -d points and $\geq 15$ wire hits over 97% of $4\pi$ sterad Track pair resolution of 1-2 cm dE/dx $\pm 3.5\%$ for Bhabhas $\pm 4.0\%$ for tracks in jet events with $\geq 120$ samples $\sigma_p/p^2 = \pm 3.6\%$ for $p \geq 2$ GeV/c position resolution in bending plane is 190 microns and in axial (z) direction 340 microns; presently low magnet field and drift distortions increase $\sigma_p/p^2$ Inner drift chamber at 13 to 19 cm radius 8.5 atm Ar-CH <sub>4</sub> (80%-20%), 150 microns in bend plane 1.2 m long covering 95% of $4\pi$ , with 4 axial layers Outer drift chamber at 1.19 to 1.24 m radius 1 atm Ar-CH <sub>4</sub> (80%-20%), 200 microns in bend plane 3 m long covering 77% of $4\pi$ , with 3 axial layers
POLE-TIP CALORIMETER	Gas, proportional mode, sampling Pb-laminate calorimeter 2 modules, 13.5 $X_0$ deep, at z = 1.1 m, covering 18% of $4\pi$ 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
HEXAGONAL CALORIMETER	Gas, limited Geiger mode, sampling Pb-laminate calorimeter 6 modules, 10 $X_0$ deep, 4.2 m long at 1.2 m radius Argon-ethyl bromide (96%-4%) at 1 atm. Solid angle coverage of 75% (90% including PTC) 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 $\sigma_E/E = \pm 14\%/\sqrt{E}$ , below 1 GeV $\pm 12\%$ for Bhabhas at 14.5 GeV
MUON DETECTOR	Magnet flux return + 2 layers iron, total 810 g/cm Triangular, double layer, extruded Al proportional tubes Argon-methane (80%-20%) at 1 atm. 3 layers with axial wires and 4th layer at 90 deg. Endcap with 3 layers provides 98% of $4\pi$ sterad coverage Resolution = 1 cm, expect 3 mm when operated as drift tube
TRIGGER	$\geq 2$ charged over 85% of $4\pi$ sterad; neutral energy of $\geq 4$ GeV, or energy in two or more calorimeter modules of $\geq 1.5$ GeV; $\geq 1$ charged and neutral energy of $\geq 750$ MeV or energy in two or more calorimeter modules of $\geq 1.5$ GeV

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# UA1

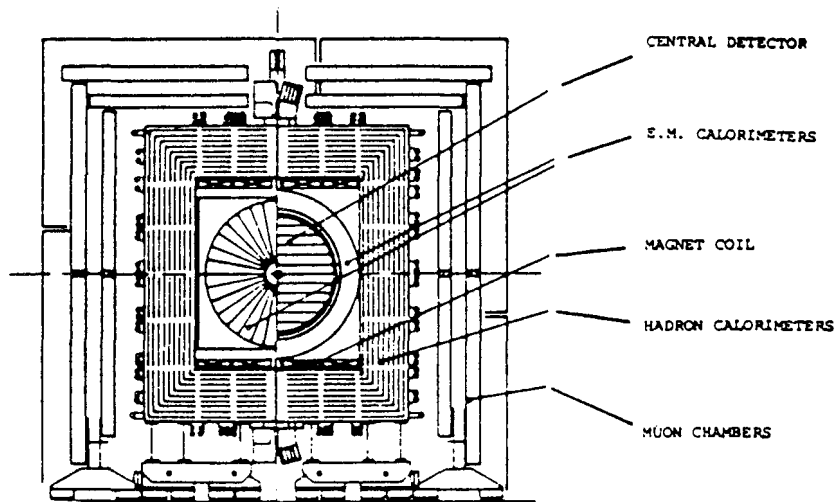
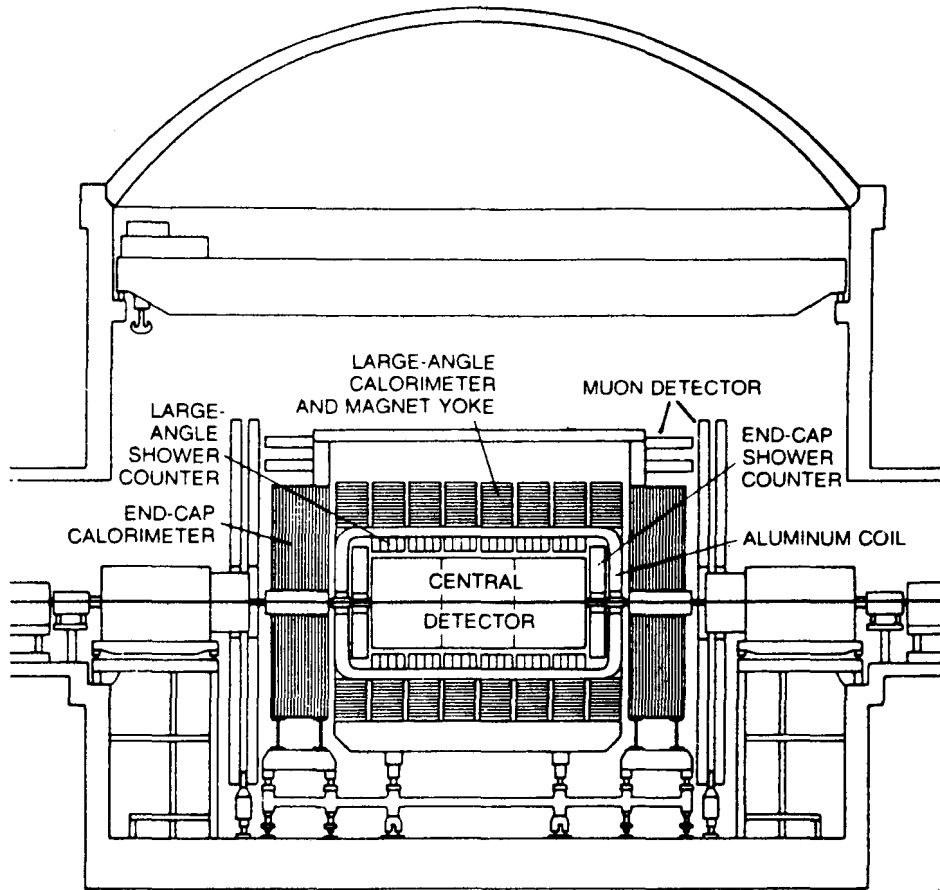
LOCATION	CERN SPS $\bar{p}p$ Collider CERN, Geneva, Switzerland
MAGNET	Dipole field up to 0.7 Tesla, Al coils Magnetic volume = $7.0 \times 3.5 \times 3.5 \text{ m}^3$
CENTRAL DETECTOR	Cylinder (6 m long, 2.2 m diameter) made of 6 independent modules containing drift chambers with 18 cm drift space Covers $5^\circ < \theta < 175^\circ$ 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 $\sigma \simeq 250 \mu\text{m}$ 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 ( $25^\circ < \theta < 155^\circ$ ) and Bouchons ( $5^\circ < \theta < 25^\circ$ , $155^\circ < \theta < 175^\circ$ ) $(\sigma_E/E)^2 = (0.15/\sqrt{E})^2 + (0.016)^2$ $\sigma_x = 4 \text{ cm}/\sqrt{E}$ ( $\theta$ direction) $\sigma_y = 16 \text{ cm}/\sqrt{E}$ ( $\phi$ 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 $\sigma = 1 \text{ mrad}$
FORWARD DETECTORS	$0.2^\circ < \theta < 5^\circ$ 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, $1.7 \lambda_{\text{abs}}$ 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 $\pm 22 \text{ m}$ from collision point, which enter the SPS vacuum pipe vertically

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UA1



XBL 832-8020

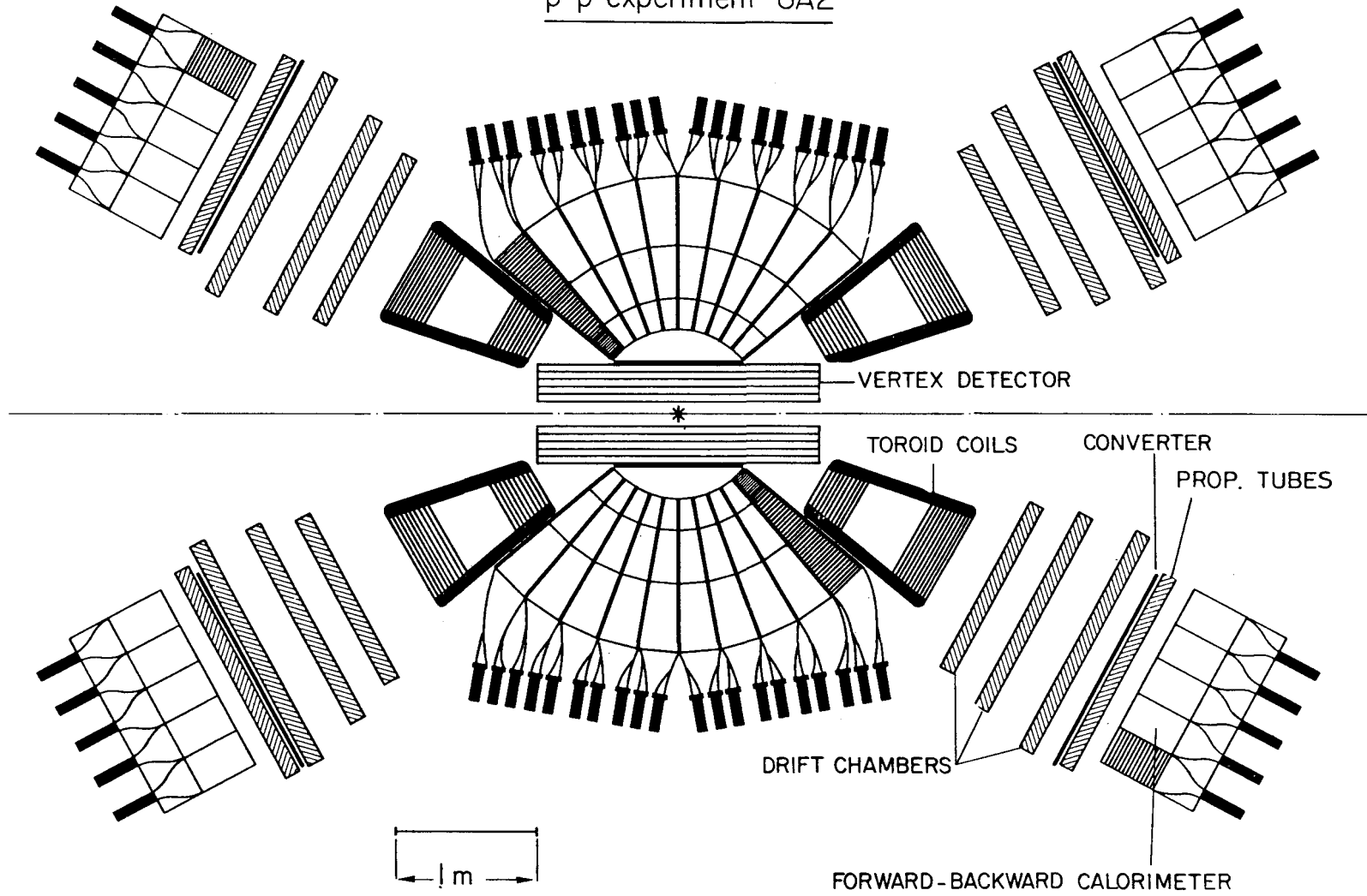
## UA2

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	$20^\circ < \theta < 160^\circ$ , $2\pi$ in $\phi$ 4 cylindrical multiwire proportional chambers (MWPC) with helicoidal cathode strips at $\pm 45^\circ$ 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	$40^\circ < \theta < 140^\circ$ , $2\pi$ in $\phi$ 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 $\Delta\phi \times \Delta\theta = 15^\circ \times 10^\circ$ 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 $20^\circ < \theta < 37.5^\circ$ and $142.5^\circ < \theta < 160^\circ$ , 80% of $2\pi$ in $\phi$ 12 spectrometer sectors on each side
TRACKING	9 drift chamber planes ( $\pm 7^\circ$ , $0^\circ$ ) 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 $\Delta\phi \times \Delta\theta = 15^\circ \times 3.5^\circ$ , two longitudinal segments $\sigma_E/E = 15\%/\sqrt{E}$

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p-p̄ experiment UA2



UA2

XBL 831-7888

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