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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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MASTER

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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 $GeV/c^2$ and p in 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.

| Detector | Experiment |
|---|---|
| ARGUS | DESY-ARGUS |
| Axial Field Spectrometer (AFS) | CERN-R-807 |
| Brookhaven Neutrino Detector | BNL-734, -775 |
| CCFR Neutrino Detector | FNAL-616, -652 |
| Collider Detector at Fermilab (CDF) | FNAL-CDF |
| CDHS Neutrino Detector | CERN-PS-169, CERN-WA-001, -054, -068 |
| CELLO | DESY-PETRA-CELLO |
| CHARM Neutrino Detector | CERN-PS-181, CERN-WA-018, -065 |
| CLEO | CESR-CLEO |
| Crystal Ball | SLAC-SP-024, -030, DESY-CRYSTAL-BALL |
| CUSB | CESR-CUSB |
| DELCO | SLAC-PEP-020 |
| EMC | CERN-NA-002, -009, -028 |
| FNAL-605 | FNAL-605 |
| FNAL Multiparticle Spectrometer | FNAL-557, -580, -623, -672 |
| FNAL Neutrino Detector | FNAL-594, -649 |
| FREJUS Detector for Nucleon Decay | P-DECAY-FREJUS |
| Homestake Detector | P-DECAY-HOMESTAKE |
| HPW Detector for Nucleon Decay | P-DECAY-HPW |
| High Resolution Spectrometer (HRS) | SLAC-PEP-012 |
| IMB | P-DECAY-IMB |
| JADE | DESY-PETRA-JADE |
| Kamiokande Detector for Nucleon Decay | P-DECAY-KAMIOKA |
| LASS | SLAC-E-135 |
| MAC (MAgnetic Calorimeter) | SLAC-PEP-006 |
| MARK II | SLAC-SP-029, SLAC-PEP-005 |
| MARK III | SLAC-SP-031, -032 |
| MARK-J | DESY-PETRA-MARK-J |
| MD-1 | VEPP (not in LBL-91) |
| MPS II | BNL-747, -751, -769, -771 |
| Multimuon Spectrometer | FNAL-640 |
| NUSEX Detector for Nucleon Decay | P-DECAY-NUSEX |
| OMEGA | CERN-WA-049, -055, -056, -057, -058, -060, -063, -067, -069, -070, -071, -072, -074, -076 |
| PLUTO | DESY-PETRA-PLUTO, -PLUTO-2 |
| SFM | CERN-R-400 series |
| Tagged Photon Spectrometer | FNAL-516 |
| TASSO | DESY-PETRA-TASSO |
| TPC | SLAC-PEP-004 |
| UA1 | CERN-UA-01 |
| UA2 | CERN-UA-02 |

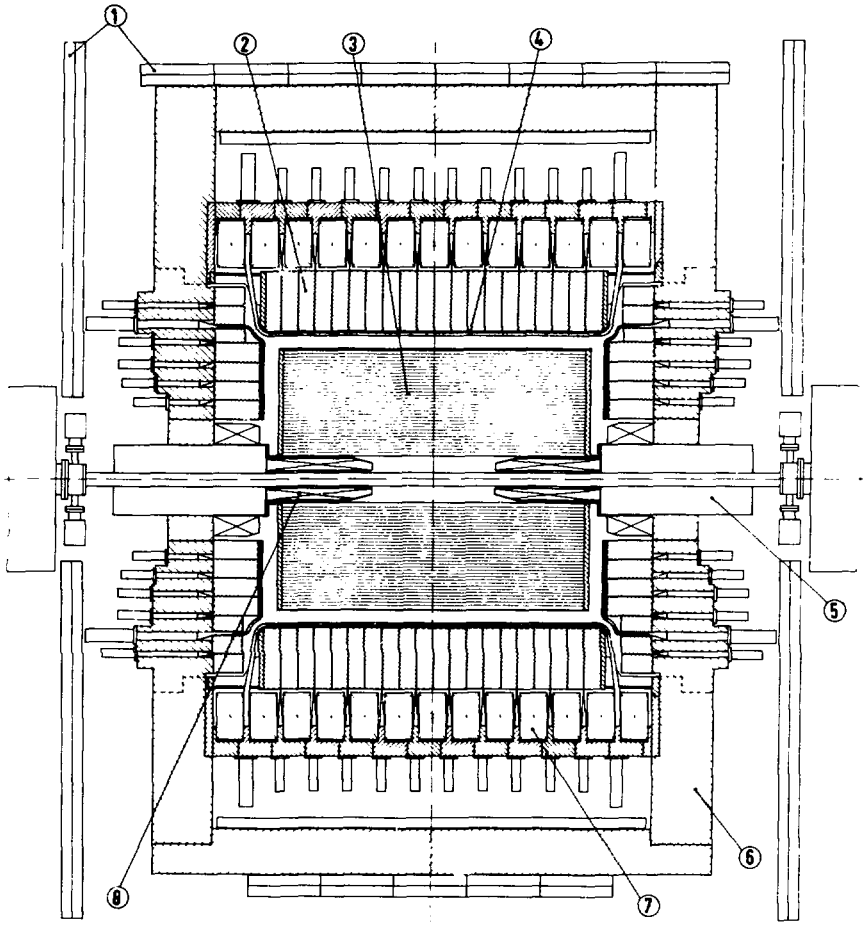
# ARGUS

| | |
|---|---|
| LOCATION | DORIS II $e^+e^-$ ring<br>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<br>Diameter 2.8 m, length 2.9 m |
| MINIBETA | Quads integrated and compensated inside magnet |
| TRACKING | Cylindrical drift chamber<br>Radius 15 to 85 cm, length 200 cm<br>5940 drift cells with 18 × 18.8 $mm^2$ cross section<br>36 cylindrical layers, 18 of which at stereo angles varying from 40 to 80 mrad<br>Propane-methylal at 1 atm.<br>dE/dx : 10% FWHM<br>$\sigma_p/p = 1.2\%\ p$<br>$\sigma_\theta = 3.4$ mrad |
| SHOWER COUNTERS | Barrel arranged as 20 rings, 64 counters in each ring<br>40 cm deep, 12.5 $X_0$ sandwich of 1 mm lead and 5 mm scintillator, BBQ readout lightguides between coils<br>$\sigma_E/E = 8\%/\sqrt{E}$, $\sigma_\theta = 11$ mrad<br>Endcaps 2 × 240 counters<br>Solid angle 96% in total |
| TIME OF FLIGHT | Barrel of 64 counters, radius 96 cm<br>Endcaps 2 × 48 counters<br>TOF resolution 270 ps<br>Solid angle 92% |
| MUON DETECTION | 1744 proportional tubes with 6 × 6 $cm^2$ cross section<br>Layer behind shower counters and coil<br>Layer behind the return yoke<br>Solid angle 85% |
| VERTEX CHAMBER | Radius 5 to 14 cm<br>Length 1 m<br>(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

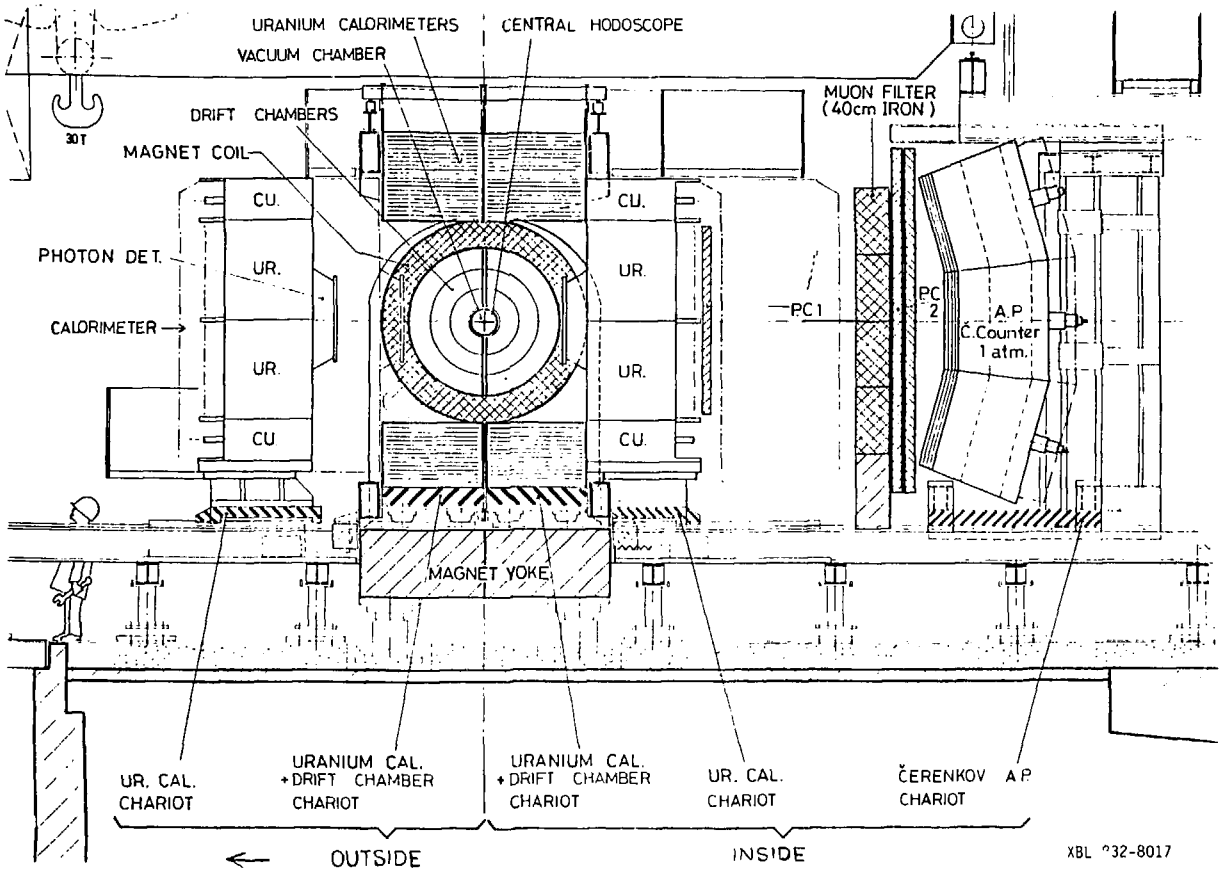
XBL 831-7896

# Axial Field Spectrometer (AFS)

| | |
|---|---|
| LOCATION | ISR (pp, $p\bar{p}$, $\alpha p$, $\alpha\alpha$-beams, $\sqrt{s}$ from 22 to 63 GeV)<br>CERN, Geneva, Switzerland |
| MAGNET | Open axial field magnet, 0.5 Tesla<br>Unobstructed aperture: azimuthal $0 < \phi < 2\pi$, polar $0° \leq \ell < 15°$ and $40° \leq \theta \leq 140°$ |
| TRACKING | Cylindrical drift chamber<br>1.4 m long, extending radially from 20 cm to 80 cm<br>4° sectors with 42 sense wires each<br>Argon/ethane (50/50 vol%) at 1 atm.<br>$\sigma$ = 220 $\mu$m (averaged), $\sigma_z$ = 1.4 cm (averaged)<br>$\sigma$ (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<br>$\sigma_p/p = 0.02\ p$ |
| SHOWER COUNTERS | Two walls of 600 NaI crystals each<br>5.25 $X_0$, vacuum photo diode readout, noise $\simeq$ 1 MeV, coverage 1.3 sterad<br>$\sigma_E/E$ = 9% for 1 GeV electrons (incl. U-calorimeter)<br><br>Hadron calorimeter, coverage ~8 sterad<br>Uranium/copper-scintillator with wavelength shifter readout, 20 × 20 cm$^2$ 'towers', twofold longitudinal segmentation<br>Electrons: $\sigma_E/E = 16\%/\sqrt{E}$, $\sigma_x = \sigma_y$ = 1 cm<br>Hadrons: $\sigma_E/E = 37\%/\sqrt{E}$, $\sigma_x = \sigma_y$ = 3–10 cm (dep. on angle)<br>e/$\pi$ energy response = 1.15<br>e/$\pi$ separation 1:50 at 2 GeV for 75% electron acc. |
| MUON IDENTIFICATION | Filter consisting of uranium calorimeter and 40 cm of iron<br>Two planes of MWPC and Cerenkov counters covering 1 sterad, $p_{threshold}$ = 2 GeV/c |
| TRIGGER | Parallel triggers based on analog computation of event topology and particle composition (e.g., hadrons vs. electrons, jets vs. single particles)<br>Both calorimeter information and drift chamber tracking information used<br>Typical trigger selectivity: 1:$10^6$ |

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.


URANIUM CALORIMETERS
CENTRAL HODOSCOPE
VACUUM CHAMBER
DRIFT CHAMBERS
MUON FILTER
(40cm IRON)
30T
MAGNET COIL
CU.
UR.
UR.
CU.
PHOTON DET.
CALORIMETER
CU.
UR.
UR.
CU.
PC1
PC
2
A.P
C.Counter
1 atm.
MAGNET YOKE
UR. CAL.
CHARIOT
URANIUM CAL.
+DRIFT CHAMBER
CHARIOT
URANIUM CAL.
+DRIFT CHAMBER
CHARIOT
UR. CAL.
CHARIOT
ČERENKOV A.P
CHARIOT
OUTSIDE
INSIDE
XBL 732-8017

## Brookhaven Neutrino Detector

| | |
|---|---|
| LOCATION | Brookhaven National Laboratory<br>Upton, NY, USA |
| INCIDENT BEAM | Neutrino, horn focussed from 28 GeV Protons<br>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<br>112 Modules + $\gamma$-catcher + spectrometer<br>Weight: 172 + 30 metric tons |

CALORIMETER (LIQUID SCINTILLATOR)

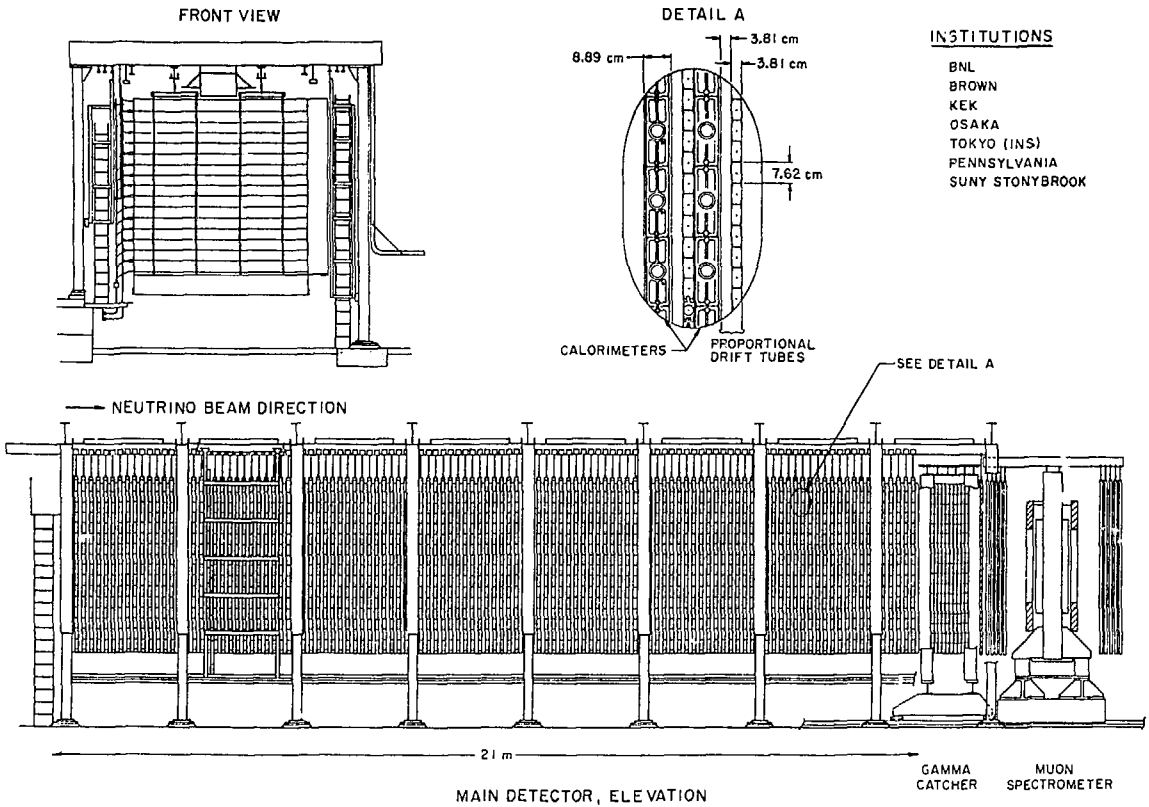
Active area $4.22 \times 4.09$ m$^2$; thickness 7.9 cm
Weight (liquid & acrylic) 1.35 metric tons
16 cells/module, 2 Amperex 2212A phototubes/cell
1 pulse height measurement/2 time measurements per tube readout

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<br>30 metric tons target mass |
| MUON SPECTROMETER | 2m $\times$ 2m aperture muon spectrometer<br>$\langle \int \mathrm{Bdl} \rangle = 70$ MeV/c<br>$(\Delta p/p)^2 = [0.10^2 + (0.067p)^2]\ p$ |

# BNL NEUTRINO DETECTOR

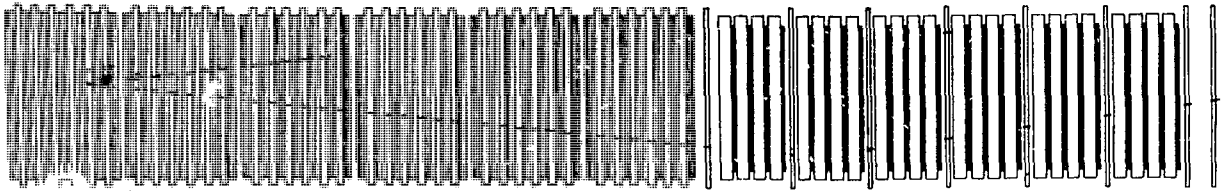



XBL 831-7890

## CCFR Neutrino Detector

(Columbia-Chicago-Fermilab-Rochester)

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



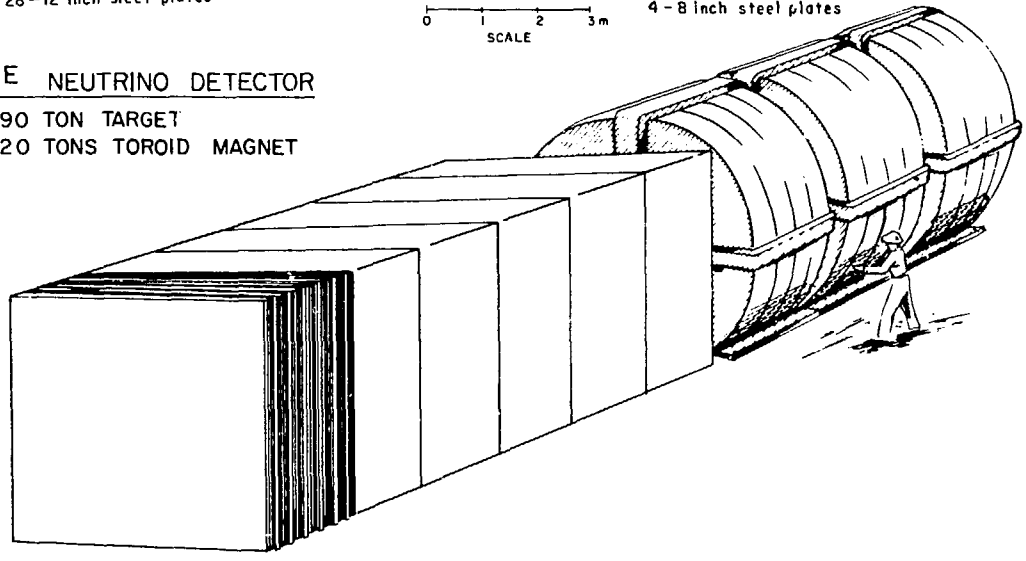
TARGET CART:
7 Drift chambers
14 Scintillators
28 – 12 inch steel plates
} 115 tons each, Total of 6

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

0 5 10 feet
0 1 2 3 m
SCALE

LAB E NEUTRINO DETECTOR

690 TON TARGET
420 TONS TOROID MAGNET



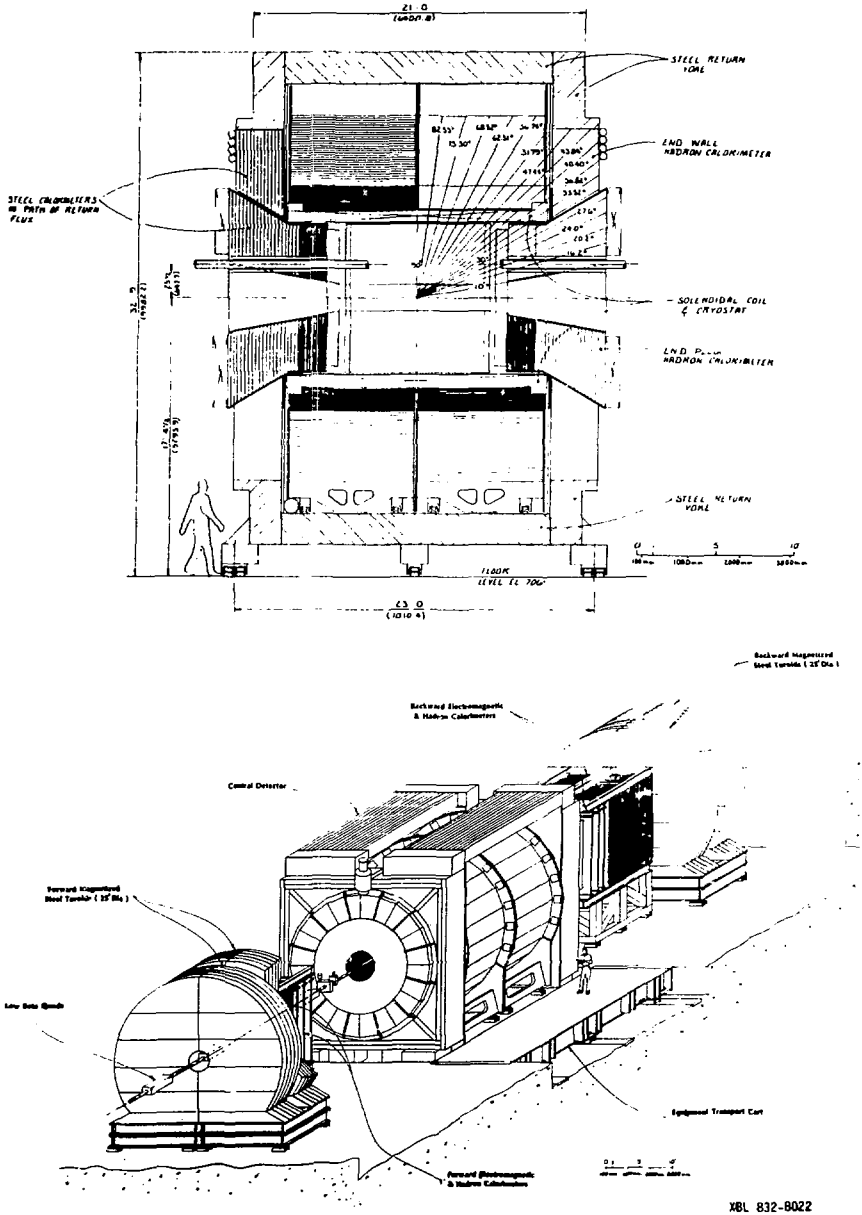
XBL 832-8441

CCFR Neutrino Detector

# Collider Detector at Fermilab (CDF)

| | |
|---|---|
| LOCATION | BO $\bar{p}p$ collision area<br>Fermilab, Batavia, IL, USA |
| MAGNET | 1.5 Tesla superconducting solenoid<br>5 m long × 3 m diameter |
| TRACKING | Cylindrical drift chamber<br>11 double planes of axial wires, half-cell staggered<br>8 planes of 3.4° small angle stereo wires<br>15.7 mm cell size<br>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<br>33 layers<br>1 layer of wire chamber for shower localization<br>$\sigma_E/E = 14\%/\sqrt{E}$<br>48 modules total |
| END PLUG | $0.7X_0$ Pb, resistive plastic proportional tubes with cathode pad readout arranged in towers of constant rapidity intervals<br>30 layers ($21X_0$ total thickness)<br>1 layer of strip readout for localization<br>$\sigma_E/E \simeq 29\%/\sqrt{E}$<br>Spatial resolution $\simeq$ 3 mm at 40 GeV |
| SMALL ANGLE | 40 layers of $0.57X_0$ Pb, proportional tubes<br>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<br>34 layers (5 absorption lengths)<br>$\sigma/E \simeq 5.5\% + 62\%/\sqrt{E}$ |
| END WALL | 5 cm steel, 1 cm scintillator<br>Construction similar to central modules<br>$\sigma/E \simeq 6\% + 77\%/\sqrt{E}$ |
| END PLUG | 5 cm steel, resistive plastic proportional tubes with cathode pad readout<br>Pads are arranged in towers of constant rapidity intervals and matched to shower counter<br>20 layers<br>$\sigma/E \simeq 11\%$ 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<br>Toroids and drift chambers in small angle region |
| TRIGGER | 3 level trigger<br>Analog energy cluster finder for level 1 (fast) trigger<br>Fastbus-based trigger processor for higher levels |

# Collider Detector at Fermilab (CDF)



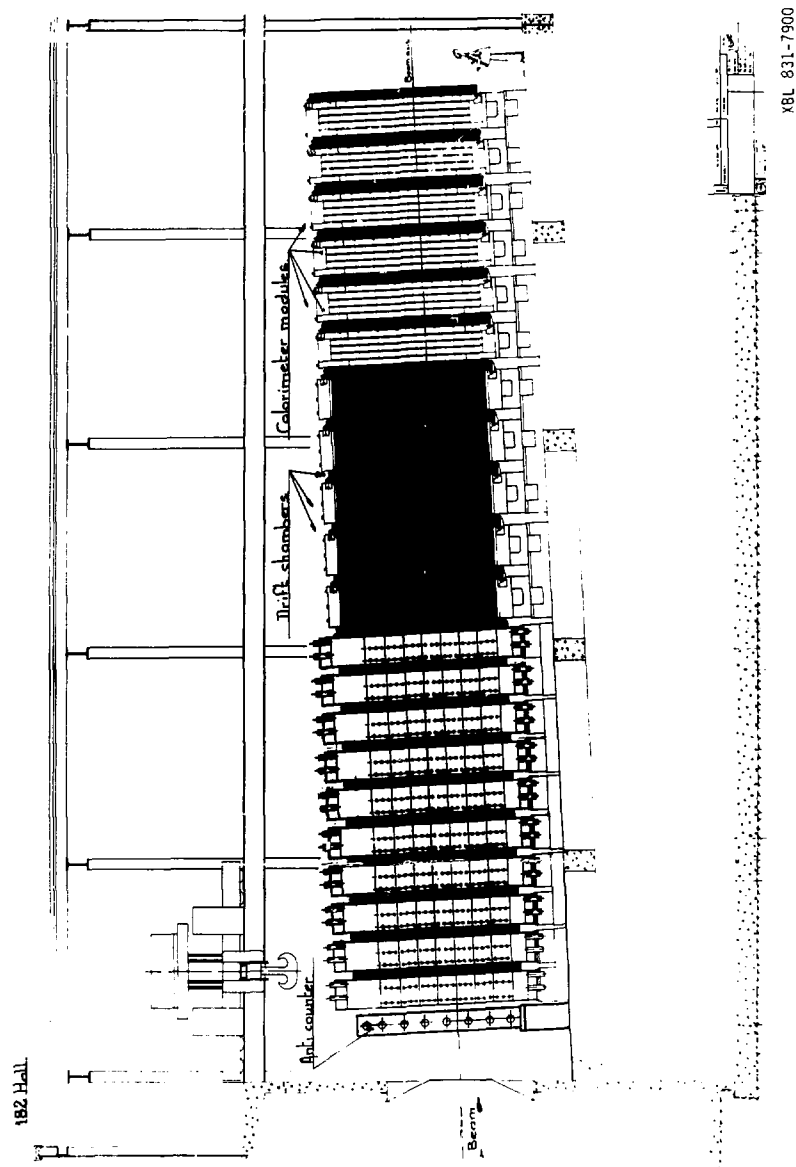
# CDHS Neutrino Detector

| | |
|---|---|
| LOCATION | CERN SPS<br>CERN, Geneva, Switzerland |
| MAGNET | 21 Fe-toroids, diameter 3.85 m<br><B> = 16.5 kG<br>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<br>$\Delta p_\mu/p_\mu \approx 9\%$ on average, for $p_\mu > 5$ GeV, dominated by multiple scattering in toroids |
| CALORIMETER | Toroidal magnets are iron-scintillator sandwiches<br>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<br>In the first 10 toroids scintillators are in x and y direction<br>In the last 11 toroids scintillators are only in x direction<br>$\Delta E/E = 0.5/\sqrt{E}$, $0.7/\sqrt{E}$, $1.3/\sqrt{E}$ 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



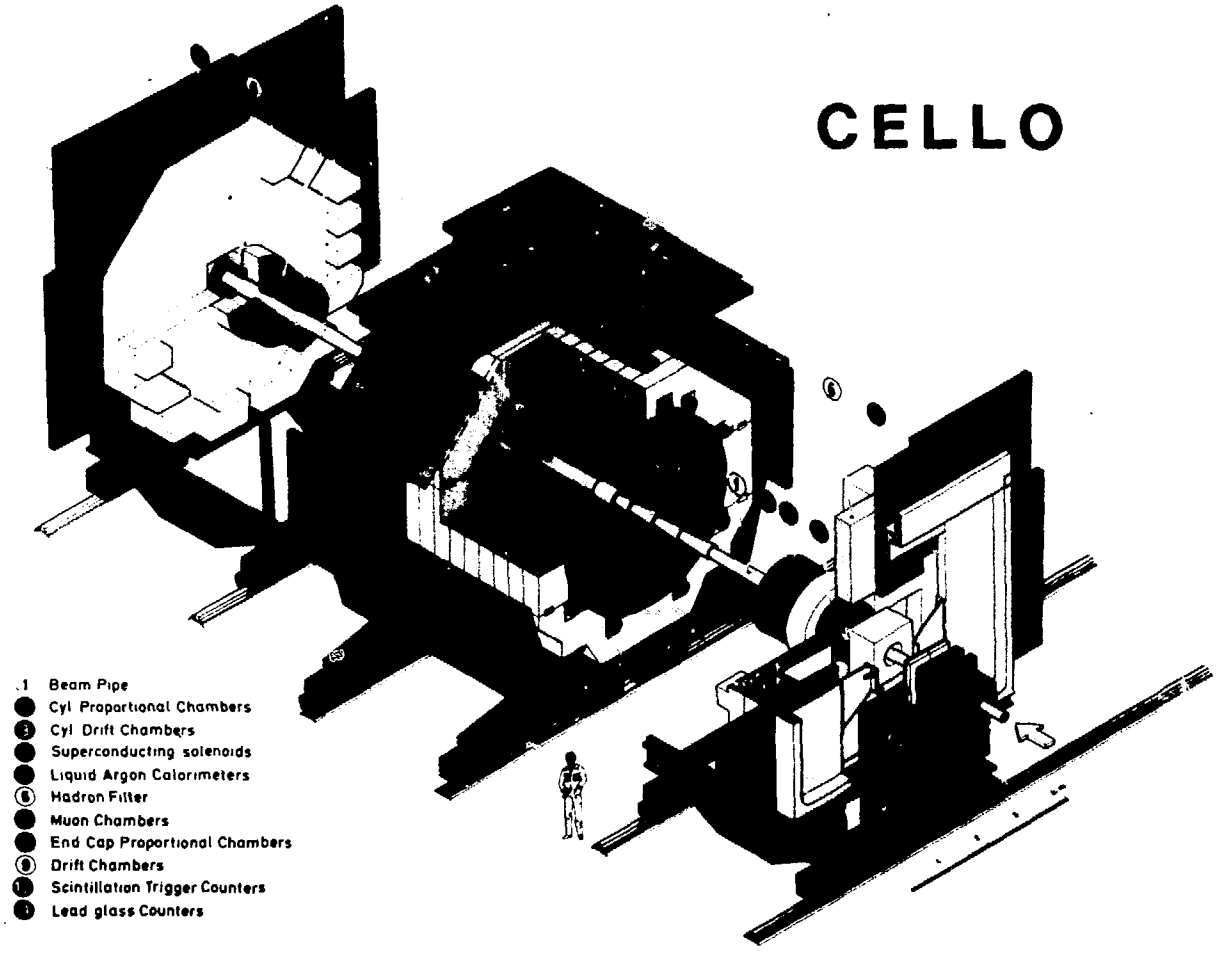
# CELLO

| | |
|---|---|
| LOCATION | PETRA $e^+e^-$ rings<br>DESY, Hamburg, W. Germany |
| COLLABORATION | DESY, Hamburg<br>KfK und Universität, Karlsruhe<br>MPI, München<br>LAL, Université de Paris XI, Orsay<br>Université de Paris VI<br>CEN, Saclay |
| MAGNET | 1.3 Tesla superconducting thin ($0.49X_0$) solenoid<br>0.75 m inner bore radius<br>3.8 m length |
| TRACKING | 5 cylindrical proportional chambers with cathode strips<br>7 cylindrical drift chambers<br>8 planar end-cap chambers<br>2 cylindrical layers of drift tubes (vertex detector installed end 1982)<br>Tracking down to $\theta = 150$ mrad<br>$\sigma_p/p = 2\%\ p \sin\theta$ ($p > 2$ GeV, $\theta > 30°$)<br>$\sigma_z = 0.4$ mm centroid measurement on cathode strips |
| EM CALORIMETRY | 20 lead-liquid argon modules ($20X_0$) down to $\theta = 130$ mrad<br>5 layers in depth for shower sampling<br>$\sigma_E/E = 13\%/\sqrt{E}$<br>$\sigma_\theta = 4$ mrad |
| MUON DETECTION | 32 planar proportional chambers (covering 92% of $4\pi$)<br>$\sigma_{position} = 6$ mm<br>$p_{cut\text{-}off} = 1.4$ 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<br>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 $0.28\Lambda_{abs}$ each), each consisting of a target plate (marble) $3 \times 3$ m$^2$ and 8 cm thick, 128 proportional drift tubes, 4 m long and $3 \times 3$ cm$^2$ cross section, 256 streamer tubes (digital readout) and 20 scintillators 3m $\times$ 0.15m at 90° 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 $E_h = 2$ GeV

**MUON TRACKING**

A minimum track length of 18 target modules is required, corresponding to muon rang of 1 GeV and filtering through 5.2 $\Lambda_{abs}$
For magnetic charge and momentum analysis, a $p_\mu > 2$ GeV/c is required

**PERFORMANCE**

$\sigma(E_h)/E_h \sim 0.45/\sqrt{E_h}$
$\sigma(E_{elm})/E_{elm} \sim 0.20/\sqrt{E_{elm}}$
$\sigma(\theta_\mu) \sim 2$–$5$ mrad ($E_\mu \sim 150$ –$50$ GeV)
$\sigma(\theta_h) \sim 18$ mrad at $E_h \sim 100$ GeV
$\sigma(\theta_e) \sim 10$ mrad at $E_{elm} \sim 15$ GeV

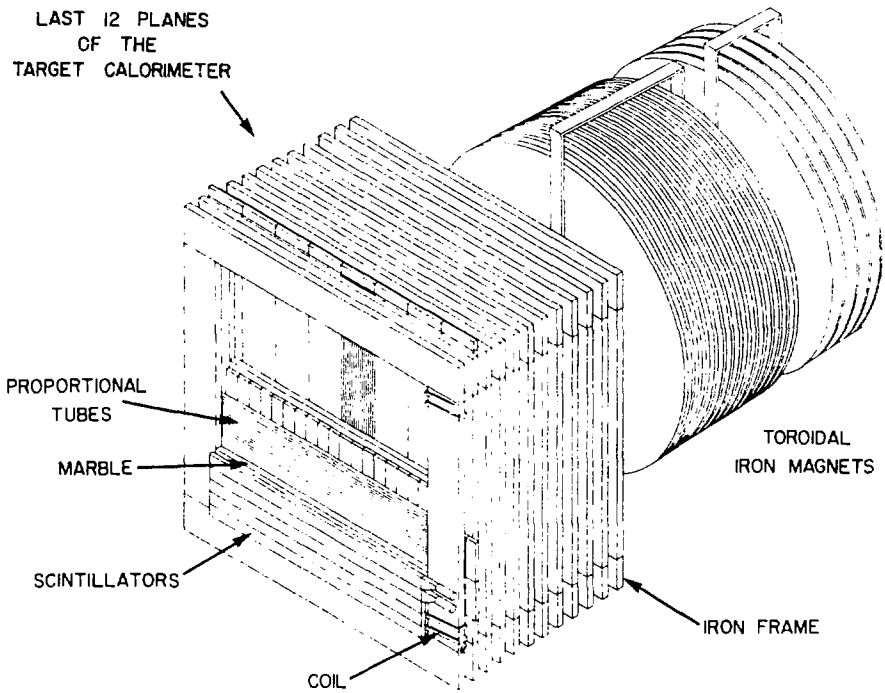
**MUON SPECTROMETER**

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

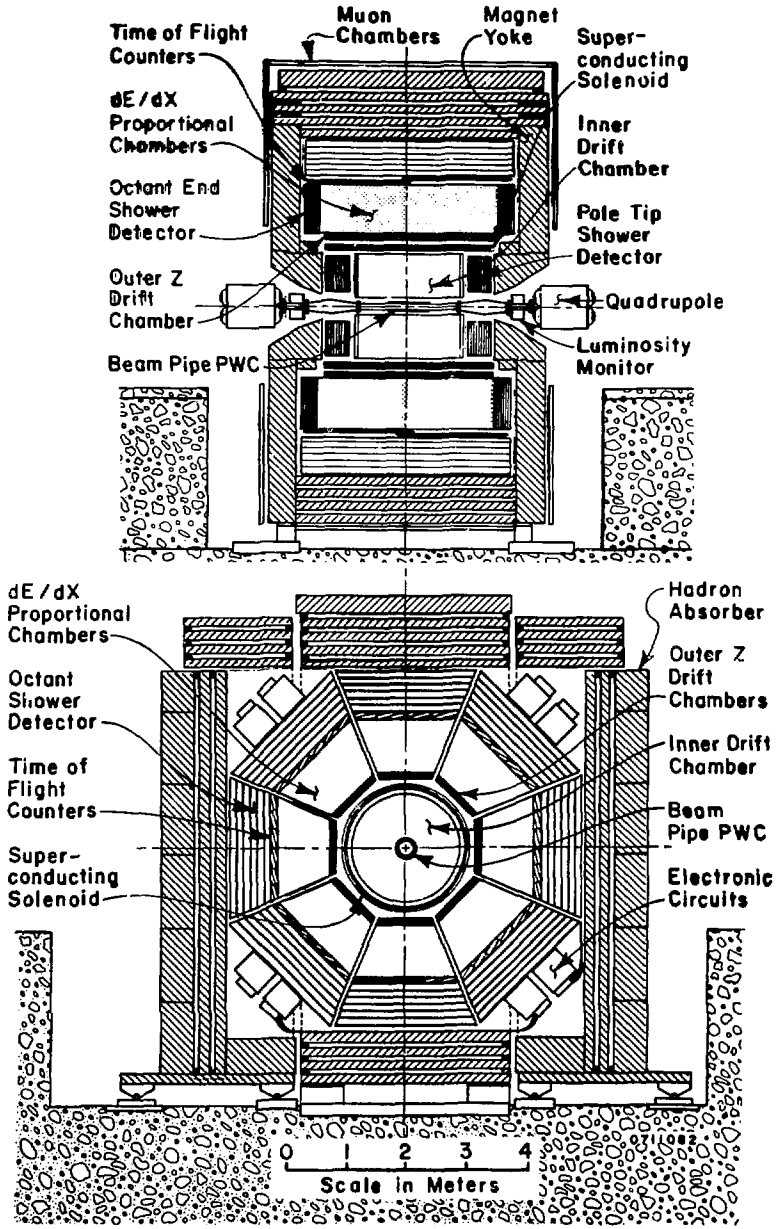
# CLEO

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




XBL 832-8018

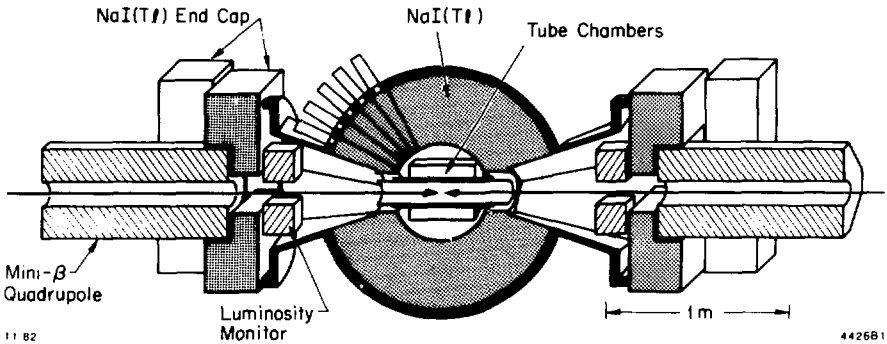
## Crystal Ball

| | |
|---|---|
| LOCATION | DORIS $e^+e^-$ ring<br>DESY, Hamburg, W. Germany |
| SCINTILLATOR | 16 $X_0$ of NaI(Tl) |
| (MAIN ARRAYS) | (1 nuclear absorption length)<br>Segmentation: 672 truncated triangular pyramidal crystals<br>Solid angle covered = 93% of $4\pi$<br>Resolution on $\gamma$ or e:<br>$\sigma_E/E = 0.026/E^{1/4}$<br>$\sigma_\theta$ = 1 to 2°, depending on energy<br>$\sigma_\phi = \sigma_\theta/\sin\theta$ |
| (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)<br>$\sigma_\phi$ = 1°–2°<br>$\sigma_z$ = 1–2% of length (66 cm inner layer, 33 cm outer layer)<br>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




XBL 831-7893

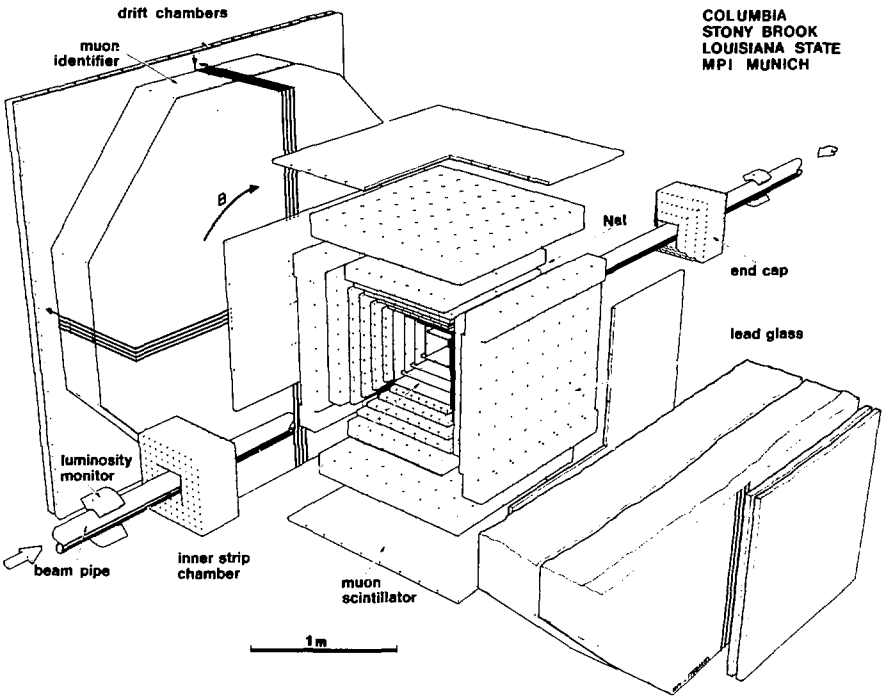
# CUSB

| | |
|---|---|
| LOCATION | CESR $e^+e^-$ ring<br>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)<br>16 chambers in 4 planes, $47° < \Delta\theta < 132°$ $\Delta\phi = 2\pi$, 2 track efficiency > 95%, $\sigma_{\text{along wire}} = 0.8$ mm, $\sigma_{\text{perp wire}} = 1.2$ mm, $\Delta\Omega = 62\%$ |
| CENTRAL CALORIMETER | Segmented NaI(Tl) array with interspersed strip chambers (not shown) surrounded by lead-glass array, PM readout<br>332 NaI(Tl) crystals (580 liters), $9X_0$, in 5 radial layers, 32 $\phi$ sectors, 2 $\theta$ sectors<br>16 proportional chambers with cathode strip (1 cm) readout located in 4 planes between NaI(Tl) layers, $\Delta\Omega = 64\%$, $\sigma_{\text{shower}} = 0.6$ cm<br>256 lead-glass blocks in four 8x8 arrays surrounding the NaI(Tl) array, $7X_0$<br>$\Delta\Omega = 60\%$, $\sigma_E/E = 4\%/E^{1/4}$ |
| END CAPS | Segmented NaI(Tl) array with interspersed scintillator hodoscope<br>$16 \times 16$ $\theta-\phi$ scintillator hodoscopes in each endcap<br>168 NaI(Tl) crystals (70 liters), $8X_0$, in 3 radial layers, $\langle\sigma_E/E\rangle = 12\%$, $\Delta\Omega = 28\%$, $\sigma_\theta = 80$ mrad, $\sigma_\phi = 35$ mrad$/\sqrt{E}$ |
| MUON IDENTIFICATION | Dimuon identification with 35 scintillation counters surrounding lead-glass arrays, $\Delta\Omega = 42\%$<br>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), $\Delta\Omega = 25\%$, $p_{\text{cutoff}} = 1$ GeV, $\sigma_p/p = 25\%$ |
| LUMINOSITY MONITOR | 2 scintillators and lead-scintillator shower counters<br>45 mrad $< \Delta\theta <$ 90 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[st] International Conference on High Energy Physics, Paris (1982).

# CUSB

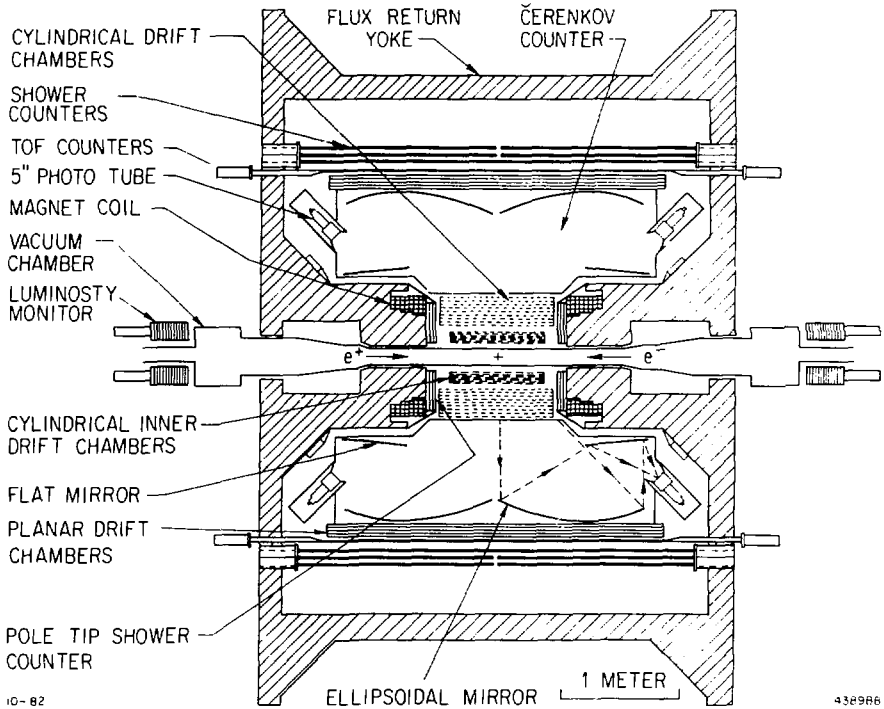

drift chambers
muon identifier
COLUMBIA
STONY BROOK
LOUISIANA STATE
MPI MUNICH
θ
NaI
end cap
lead glass
luminosity monitor
beam pipe
inner strip chamber
muon scintillator
1 m
XBL 831-7894

# DELCO

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


CYLINDRICAL DRIFT CHAMBERS
SHOWER COUNTERS
TOF COUNTERS
5" PHOTO TUBE
MAGNET COIL
VACUUM CHAMBER
LUMINOSTY MONITOR
CYLINDRICAL INNER DRIFT CHAMBERS
FLAT MIRROR
PLANAR DRIFT CHAMBERS
POLE TIP SHOWER COUNTER
FLUX RETURN YOKE
ČERENKOV COUNTER
ELLIPSOIDAL MIRROR
1 METER
e+
e−
10-82
438986

XBL 831-7697

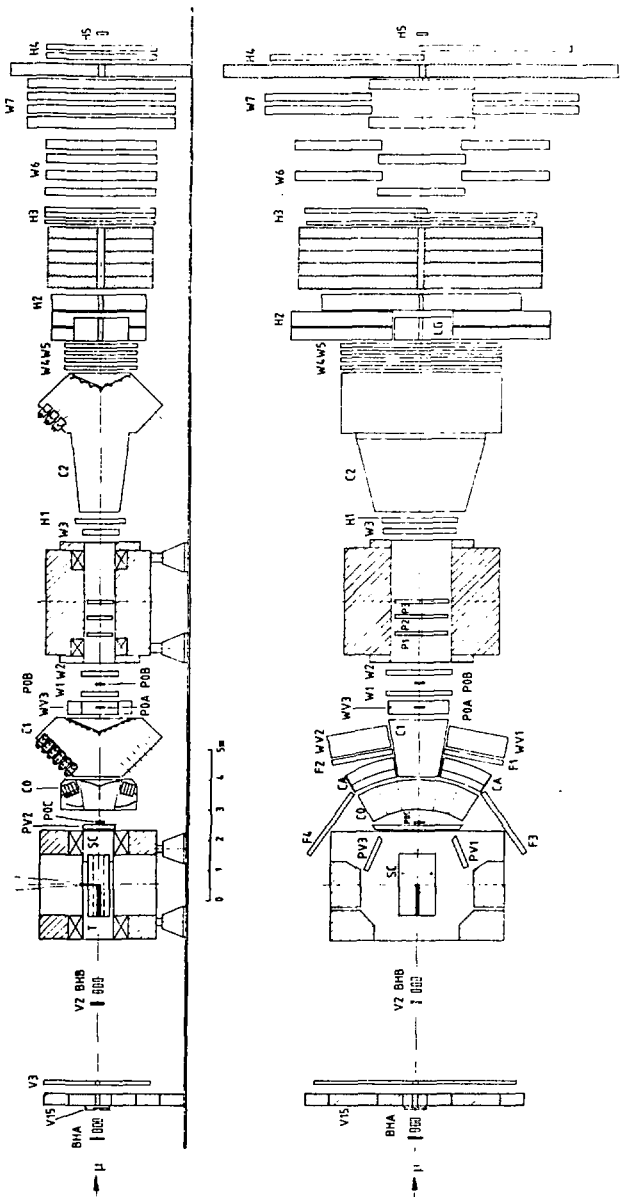
# EMC

| | |
|---|---|
| LOCATION | CERN-SPS<br>Geneva, Switzerland |
| BEAM | SPS muon beam line M2<br>$E_\mu$ = 120–280 GeV (400 GeV protons)<br>Intensity 1–5 × $10^7$ $\mu$/pulse<br>1.6 sec pulse, rep. rate 11 sec<br>Beam momentum $\Delta p = 4.5\%$<br>Halo 6%<br>Intensity monitor hodoscope<br>Beam hodoscope |
| TARGET | NA2: 6 m $H_2/D_2$, 4.75 (2.75) m iron-scintillator<br>NA9: 1 m $H_2/D_2$, heavy targets<br>NA28: heavy targets |
| MAGNET | Forward Spectrometer (FS)<br>15 kG, Bdl = 5.18 T-m<br>Vertex Spectrometer (VS)<br>16 kG, Bdl = 4 T-m, superconducting |
| TRACKING | FS: Drift chambers, proportional chambers<br>VS: Streamer chamber, proportional chambers, drift tubes<br>$\sigma_p/p \sim (20 + 1.1p) \times 10^{-4}$ (FS)<br>$\sigma_p/p \sim 1/5\,(10 + 9p) \times 10^{-3}$ (VS) |
| TRIGGER | Scintillator hodoscopes + veto hodoscopes on scattered $\mu$ crossing<br>2.5 m iron absorber |
| PARTICLE IDENTIFICATION | Gas Cerenkov counter (FS + VS) (neon, nitrogen, neopentane)<br>Aerogel Cerenkov counter (VS)<br>TOF Hodoscopes (VS)<br>Lead-glass array (FS) $\sigma_E/E = 20\%/\sqrt{E}$<br>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

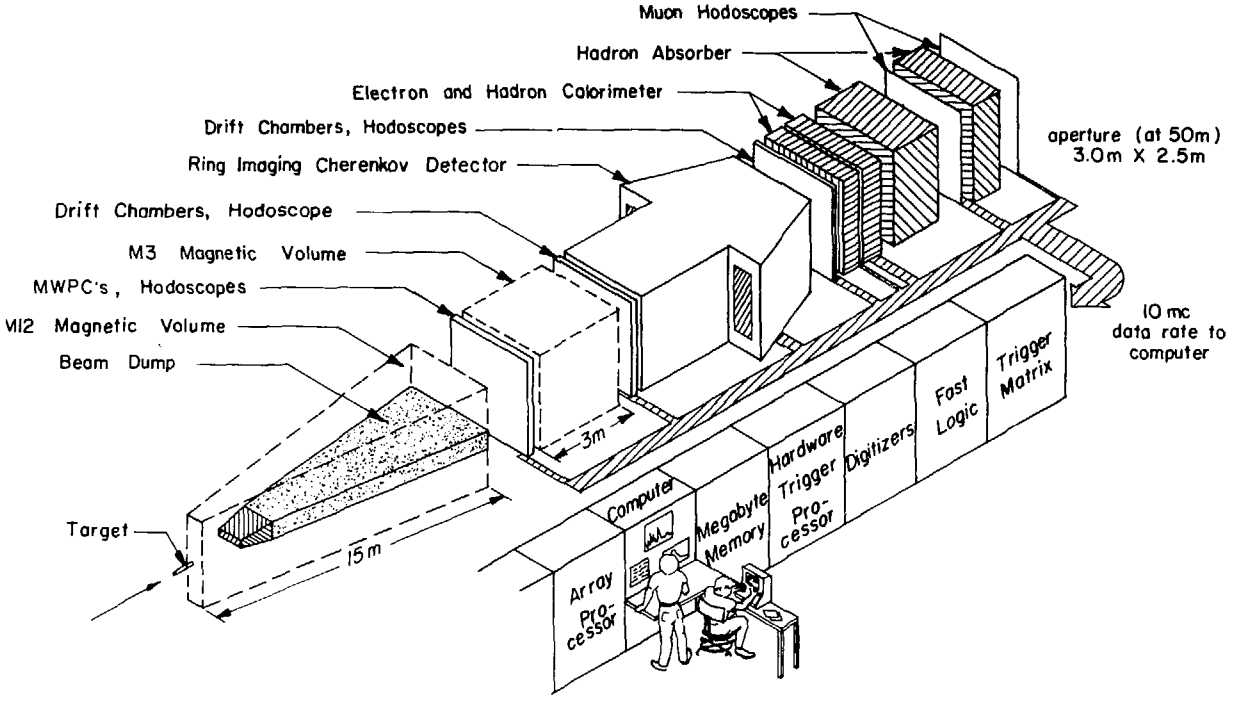
# FNAL-605

| | |
|---|---|
| LOCATION | ME External Proton Beam, FNAL<br>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<br>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<br>STATION 2: 6 planes DC 1 cm cell size<br>STATION 3: 6 planes DC 2 cm cell size |
| CERENKOV COUNTER[2] | Ring-imaging Cerenkov: intended to identify hadrons up to 200 GeV/c<br>15 m of helium gas at atmospheric pressure<br>8 m focal length mirrors<br>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<br>Resolution of $15\%/\sqrt{E}$<br>Hadron calorimeter: iron-scintillator sandwich<br>12 2.5-cm plates followed by 20 5-cm plates, each section read out with wavelength shifter bars<br>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 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 Multiparticle Spectrometer

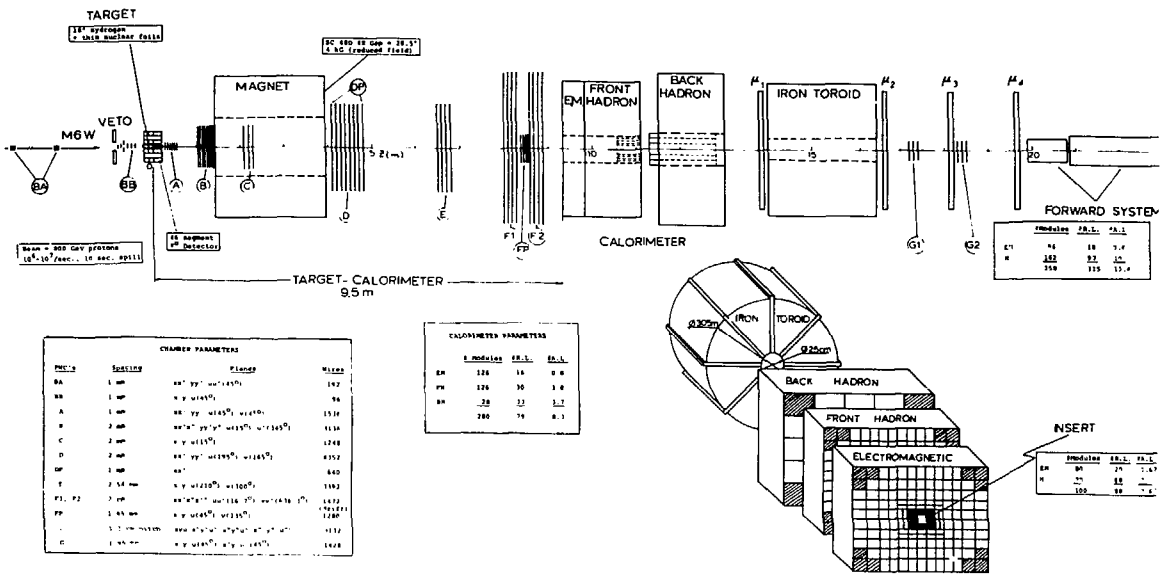
| | |
|---|---|
| LOCATION | Fermilab, meson area, MT beam line (old N6W)<br>Batavia, IL, USA |
| MAGNET | 16.9 kG (superconducting)<br>$p_\perp$ kick $\sim$ 0.7 GeV/c |
| TRACKING | PWC + drift chambers<br>$\sigma_p/p = (0.003\ \sqrt{1+(p_0/p)^2}\ )p$ |
| RECOIL DETECTOR | 46 segments Pb glass<br>$\Delta\phi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




XBL 831-7887

FNAL Multiparticle Spectrometer

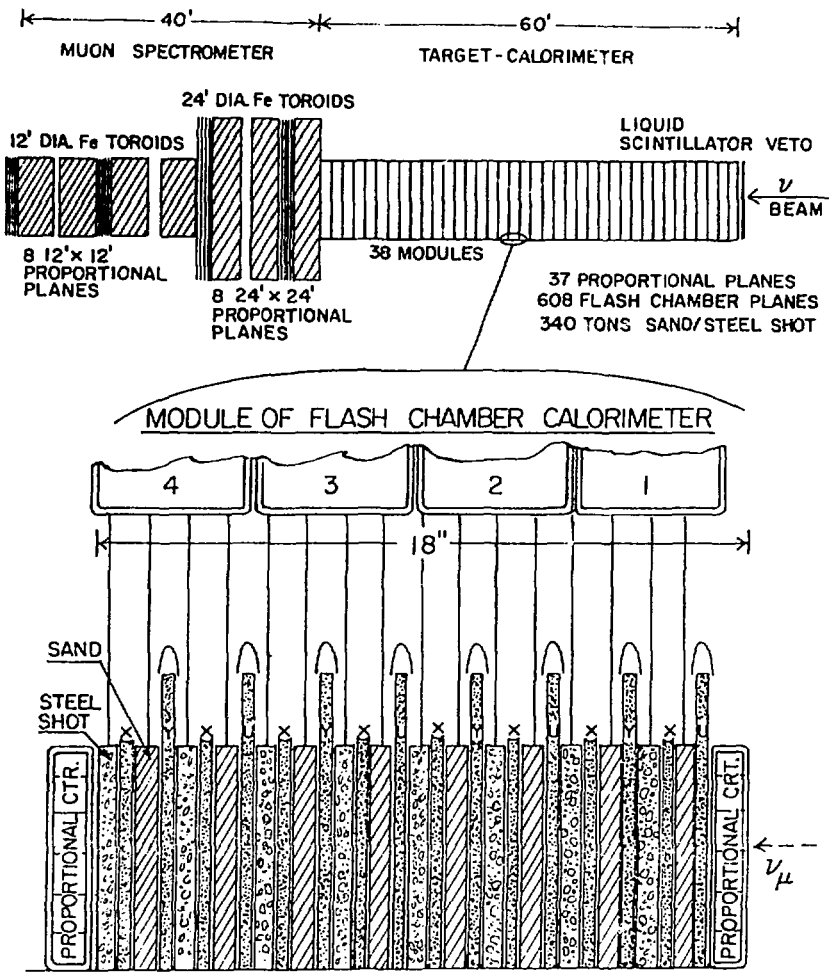
# FNAL Neutrino Detector

| | |
|---|---|
| LOCATION | FNAL neutrino beam line, Lab C<br>Batavia, IL, USA |
| CALORIMETER | 608 flash chambers, 3.66 × 3.66 $m^2$ sensitive area, and 37 proportional tube chambers<br>Half are with horizontal cells and the other half at ±10 degrees from the vertical<br>Between each flash chamber there are 1.6-cm thick alternating planes of iron shot and sand, giving a total tonnage of 340 tons<br>Showers are sampled every 22% of $X_0$ and every 3% of $\lambda_{abs}$<br>The angular resolution for electrons and hadrons is:<br>$\sigma_e = 3.5+53/E_e$ mrad<br>$\sigma_h = 6+640/E_h$ mrad<br>The energy resolution is:<br>$\sigma_E/E = 10\%$ for $5 \leq E \leq 100$ GeV<br>for both electrons and hadrons |
| TRIGGER COUNTERS | Proportional chambers, 3.66 × 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<br>$\sigma_p/p = 10\%$ for $p < 300$ 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



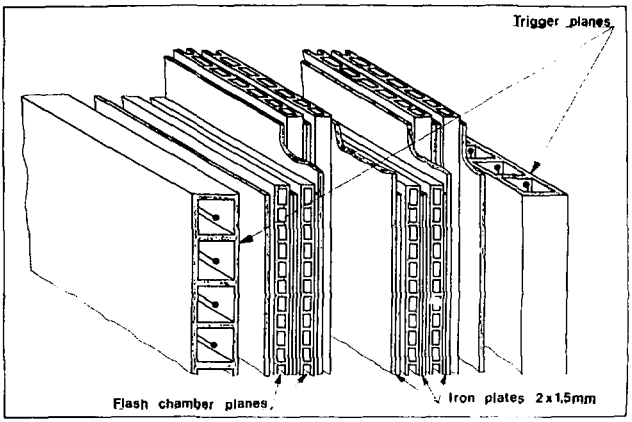
## FREJUS Detector for Nucleon Decay

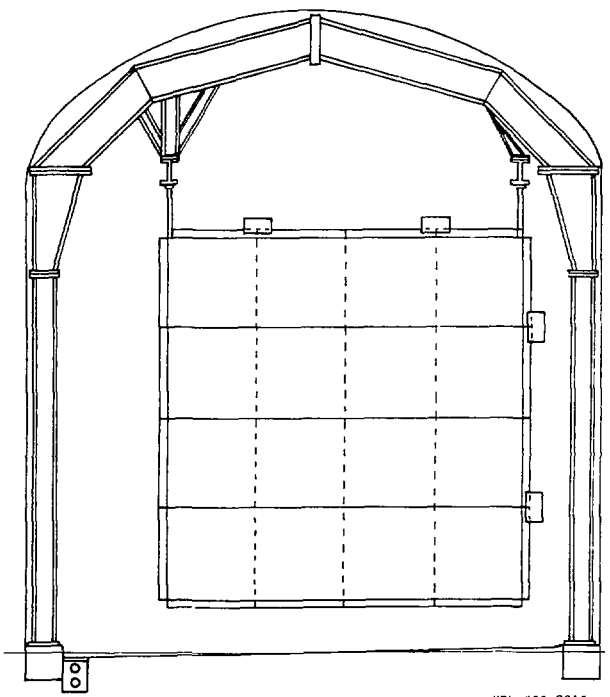
| | |
|---|---|
| LOCATION | FREJUS Tunnel, 4500 m water-equiv.-depth<br>Modane, France |
| TRACKING-PLASTIC | Flash chambers 0.5 × 0.5 $cm^2$ section<br>Neogal (70% neon, 30% helium) 1 atm.<br>Crossed planes (1024 tubes) of 6 × 6 $m^2$<br>Iron sampling 3 mm between F.C. planes<br>Capacitive strips readout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

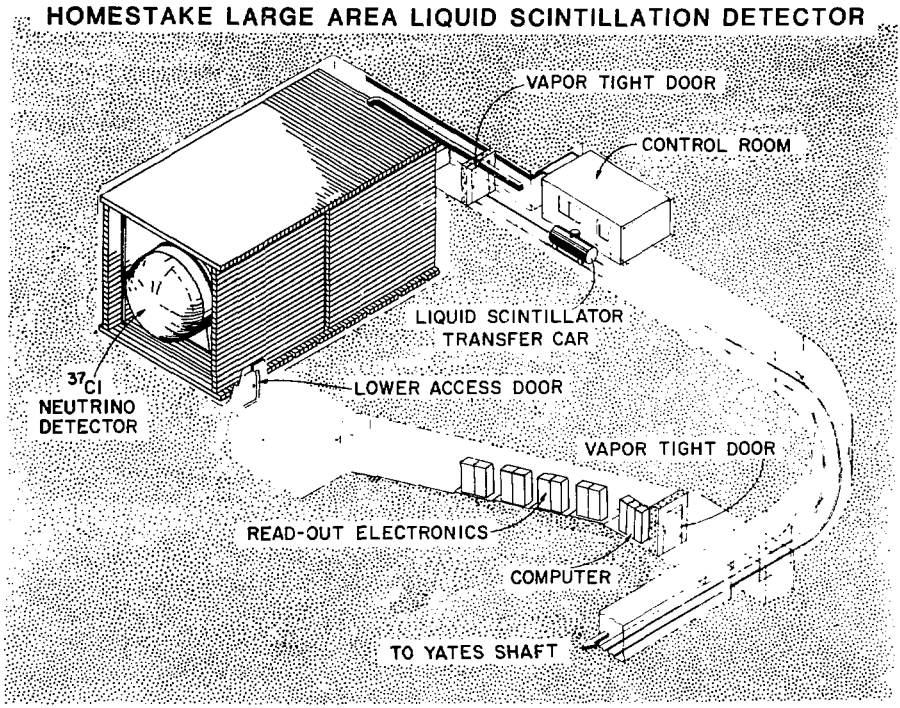
| | |
|---|---|
| Spatial resolution: | 15 cm |
| Energy resolution: | 7.8% per module for minimum ionizing track |
| Energy threshold: | 1/25 minimum ionizing (2 MeV) |
| Time resolution: | 1.3 ns |
| Detector mass: | 170 tons |
| Operational: | August 1983 |

**PHASE 2:**

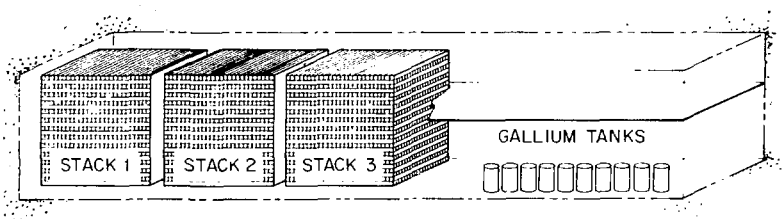
1878 detector modules (same as those in phase 1) arranged in 3 stacks, each 8 m × 8 m × 8 m
The detector elements are arranged with alternate layers in crossed directions
Tracking chambers are interspersed between the scintillator elements
Parameters are as in phase 1 except for the following:

| | |
|---|---|
| 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: | $5 \times 10^{32}$ yr |

**Homestake Detector**




NEW HOMESTAKE UNDERGROUND LABORATORY




1400 TON PROTON DECAY DETECTOR

GALLIUM SOLAR NEUTRINO EXPERIMENT

XBL 832-8406

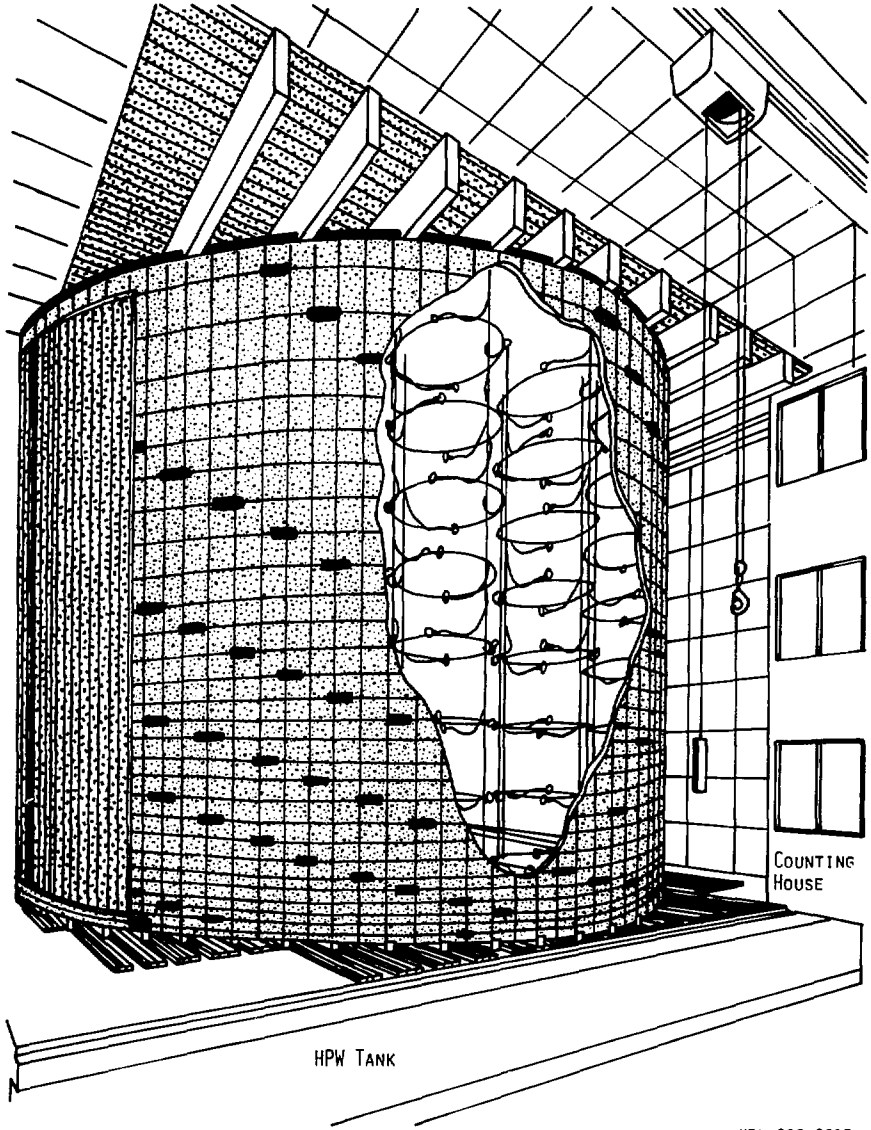
## HPW Detector for Nucleon Decay

| | |
|---|---|
| LOCATION | Silver King Mine, Park City, UT, USA<br>Elevation 2135 meters; overburden 1500 MWE;<br>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<br>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<br>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<br>Data flow controlled by LSI 11/23 near detector<br>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**



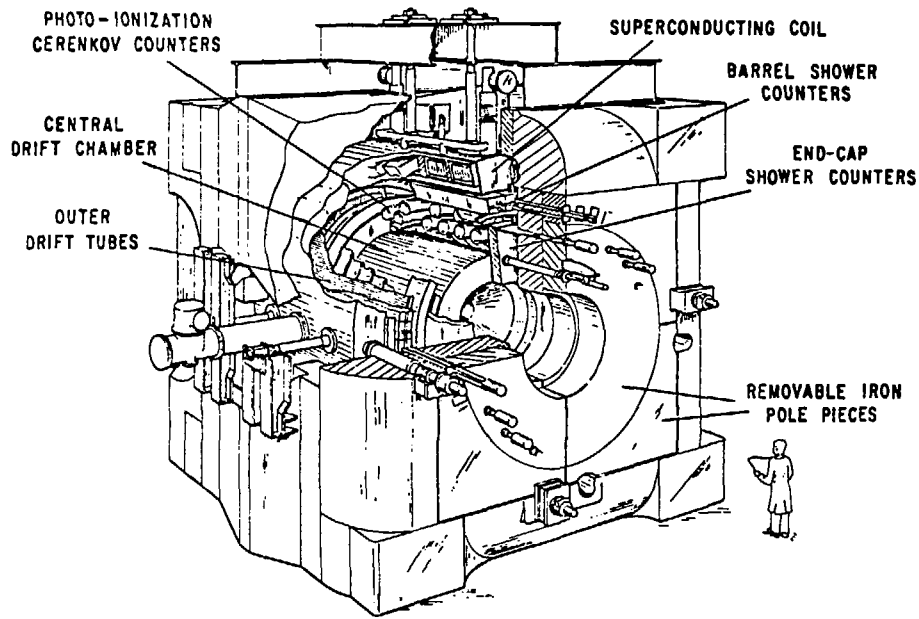

XBL 832-8015

## High Resolution Spectrometer (HRS)

| | |
|---|---|
| LOCATION | PEP $e^+e^-$ ring<br>SLAC, Stanford, CA, USA |
| MAGNET | 16 kG (superconducting)<br>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<br>Outer drift tubes (2 layers): 3.66 m long at 1.90 m radius<br>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<br>$\sigma_E/E = 16\%/\sqrt{E}$<br>2 samples in depth |
| END CAPS | 40 Modules $8X_0$ Pb-scint. sandwich<br>Wave shifter readout; 1 layer PWC<br>$\sigma_E/E = 20\%/\sqrt{E}$ |
| TIME OF FLIGHT | From front $3X_0$ of shower counter at r = 1.95 m<br>$\sigma_\tau$ = 170 ps for Bhabhas<br>$\sigma_\tau$ = 350 ps for hadrons |
| PHOTO-IONIZATION CERENKOVS | 704 segments in 11 toroids<br>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

ARGONNE - INDIANA - LBL - MICHIGAN - PURDUE - SLAC

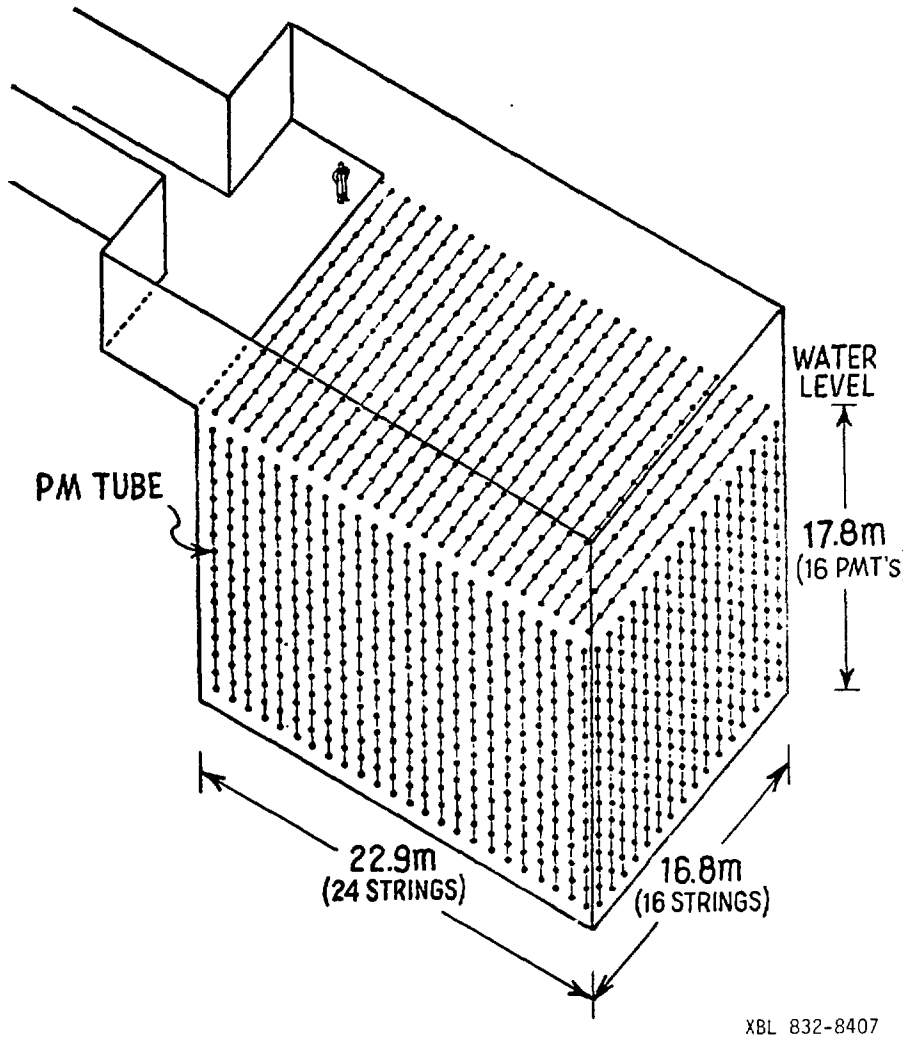
XBL 831-7884

## IMB Detector for Nucleon Decay

(Irvine-Michigan-Brookhaven Water Cerenkov Detector)

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

IMB Detector for Nucleon Decay




XBL 832-8407

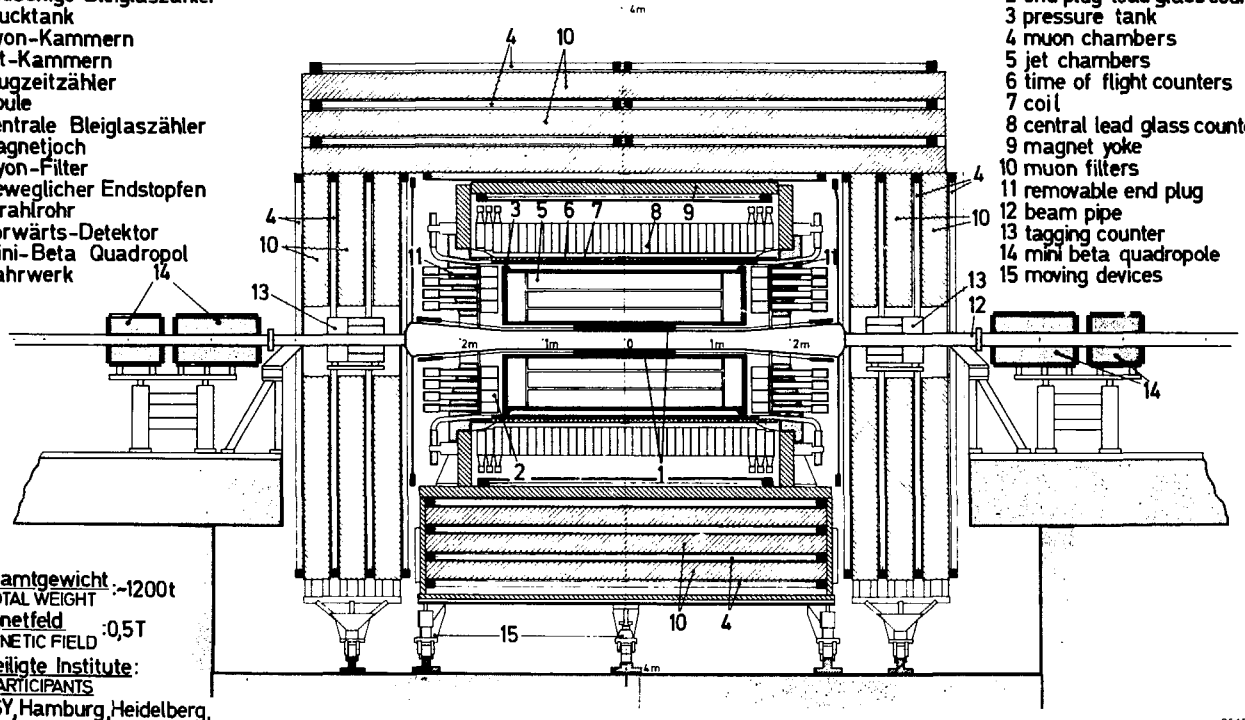
IRVINE - MICHIGAN - BROOKHAVEN DETECTOR

# JADE

| | |
|---|---|
| LOCATION | PETRA $e^+e^-$ rings<br>DESY, Hamburg, W. Germany |
| MAGNET | 4.8 kG solenoid; normally conducting, water-cooled, Al coil; thickness $0.5X_0$<br>Diameter = 2 m, length = 3.5 m |
| TRACKING | Cylindrical drift chamber (JET chamber)<br>2.36 m long at 21–79 cm radius<br>Argon-methane-isobutane at 4 atm.<br>48 points on tracks with $\|\cos\theta\| < 0.83$<br>$\geq$8 points over 97% of $\Omega$<br>charge division gives $\Delta z = 1.6$ cm<br>dE/dx to $\pm$6% for Bhabhas<br>$\sigma_p/p = 4\%$ for $p < 2$ GeV/c<br>$= 1.8\%$ for high p<br>$= 1.3\%$ for high p with event vertex used in track fit |
| SHOWER COUNTERS | |
| BARREL | 2604 tapered modules of Pb-glass<br>30 cm deep, arranged in 31 rings, 84 wedges per ring (central 6 rings Schott SF6, $17.3X_0$, remainder SF5, $12.5X_0$)<br>$\Delta E/E = 6\%/\sqrt{E}$<br>$\sigma_\theta = 0.6°$, $\sigma_\phi = 0.6°$ |
| 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$^2$)<br>Covers 93% of $\Omega$ |
| TIME OF FLIGHT | 42-counter scintillator hodoscope (r = 95 cm) between JET chamber and magnet coil<br>In conjunction with beam crossing signal, gives TOF resolution = 400 ps |
| LUMINOSITY MONITOR | 35–75 mrad<br>Pb-scintillator sandwich, 50 cm deep ($20X_0$), arranged in 8 sectors, each divided into 3 concentric rings giving equal Bhabha rates<br>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<br>20-counter forward scintillator hodoscope, between end caps and muon detector, for forward muon triggering |

## MAGNETDETEKTOR JADE
*MAGNETDETECTOR*

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

JADE

Gesamtgewicht / TOTAL WEIGHT : ~1200t
Magnetfeld / MAGNETIC FIELD : 0,5T
Beteiligte Institute: / PARTICIPANTS
DESY, Hamburg, Heidelberg,
Lancaster, Manchester,
Rutherford Lab., Tokio

XBL 832-8308

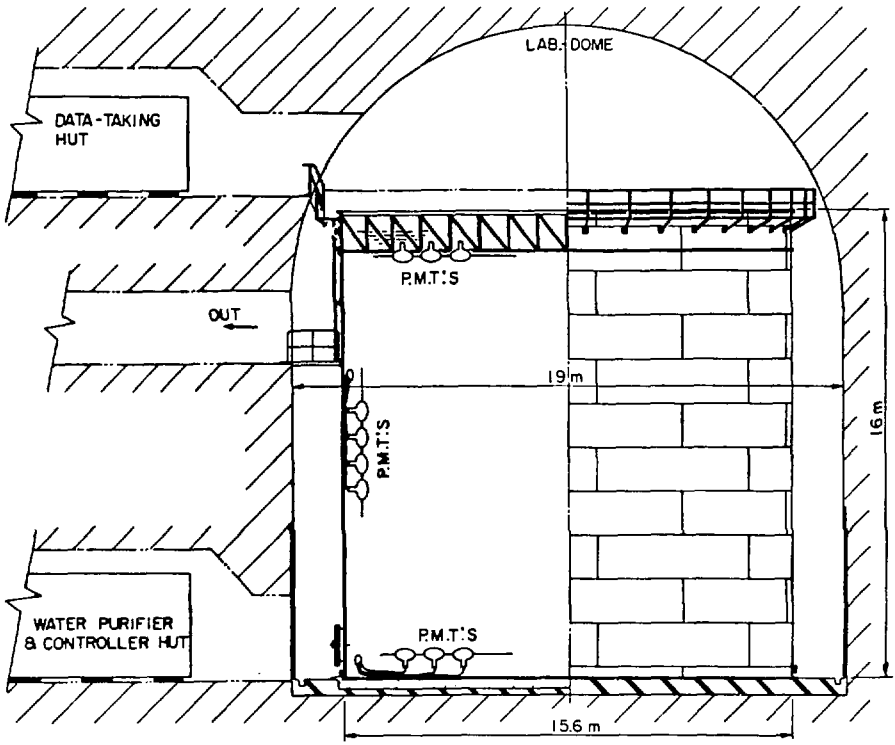
## Kamiokande Detector for Nucleon Decay

| | |
|---|---|
| LOCATION | 1000 m underground in Kamioka mine<br>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 $\mu$ filter-20 $\mu$ filter-ion exchange purifier-0.45 $\mu$ filter-UV sterilizer-0.22 $\mu$ filter |
| CERENKOV LIGHT DETECTOR | 1050 × 20″ diameter photomultipliers, R1449X,<br>distributed over the inner surfaces of the water tank at 1 PM/$m^2$<br>Photocathode covers 20% of the entire surface<br>Expected energy resolution of $p \rightarrow e\pi^0$ event is 4%<br>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. Koshiba et al., 21st Int. Conf. on High Energy Physics, Paris (July 1982).

**Kamiokande Detector for Nucleon Decay**



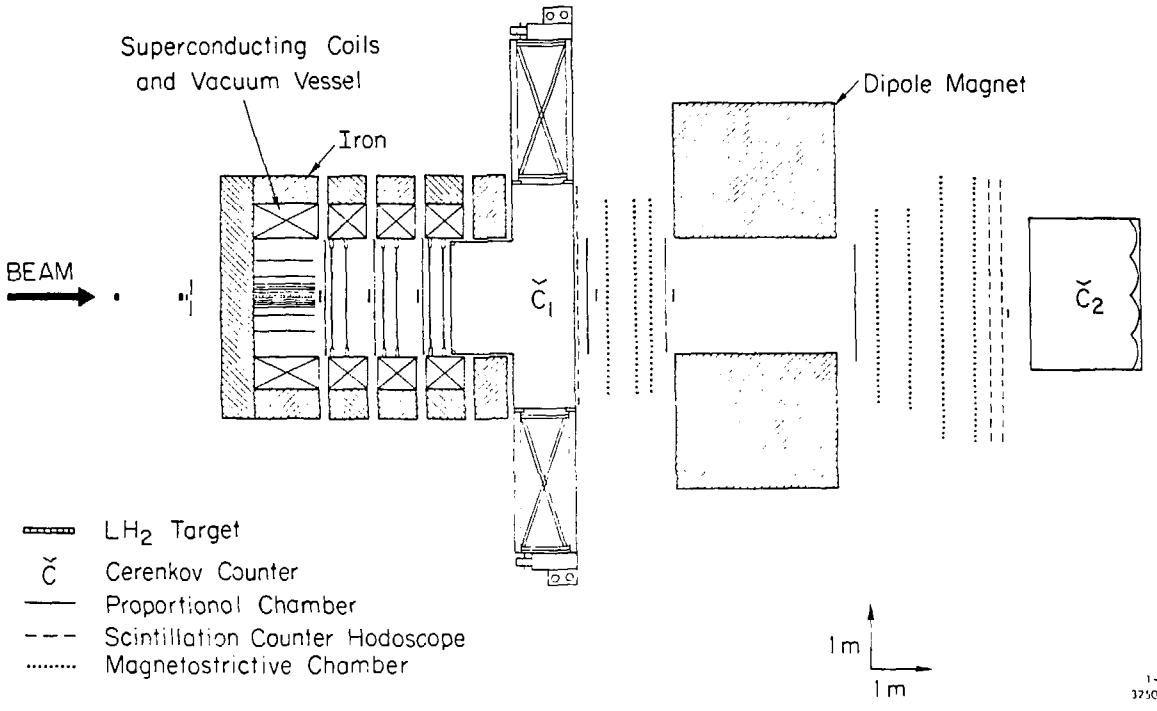

XBL 831-7885

# LASS

| | |
|---|---|
| LOCATION | SLAC, Stanford, CA, USA |
| BEAM | An R.F. separated hadron beam<br>Beam momentum up to 16 GeV/c<br>Typical K/$\pi$ ratio of 60:1 at 11 GeV/c |
| BEAM LINE INSTRUMENTATION | Two high-pressure Cerenkov counters<br>10 planes of 1 mm anode spacing proportional chambers<br>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<br>Dipole magnet having an aperture 2 m wide × 1 m high, and a field integral of 30 kG-m |
| TRACKING | Essentially $4\pi$ coverage consisting of: |
| Solenoid: | Low $P_L$/high $P_T$:<br>6 cylindrical MWPC's, each having 2 mm anode wire spacing and cathode readout having strips at $\pm 10°$<br>High $P_L$/low $P_T$:<br>9 planes of 1 mm anode wire spacing MWPC<br>12 planes of 2 mm anode wire spacing MWPC<br>6 planes of cathode strip readout<br>3 planes of pattern readout<br>Resolution:<br>anode: $\sigma \simeq \frac{\text{wire spacing}}{2} \times \frac{1}{\sqrt{12}}$<br>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<br>Momentum resolution $\Delta p/p = 6.5 \times 10^{-4} p + 1.15 \times 10^{-3}$ |
| PARTICLE IDENTIFICATION | $C_1$: a 38 sector, air pressure Freon 114 filled Cerenkov counter having a pion threshold of ~3 GeV/c<br>$C_2$: an 8 cell, high pressure Freon 12 filled Cerenkov counter having a setable pion threshold of ~2 GeV/c<br>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.




XBL 832-8063

LASS

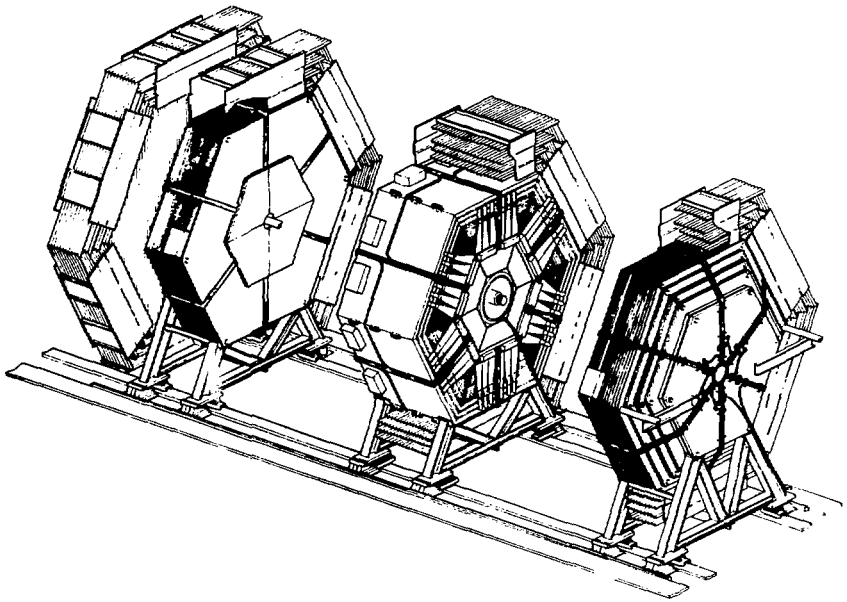
## MAC (MAgnetic Calorimeter)

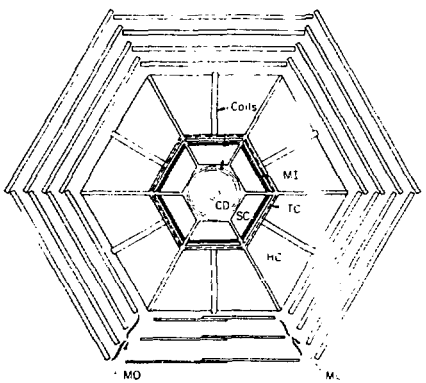
| | |
|---|---|
| LOCATION | PEP $e^+e^-$ storage ring<br>SLAC, Stanford, CA, USA |
| MAGNETS | 5.7 kG solenoid, 7.5 cm thick Al coil<br>Diameter = ' m, length = 2.3 m<br>17 kG iron toroids, 1 m thick |
| TRACKING | Cylindrical drift chamber<br>2.2 m long, 12–45 cm tracking radius<br>Argon - 10% methane at 1 atm.<br>10 layers, double sense wires<br>$\geq$5 points on tracks over $\Delta\Omega$ = 95% of $4\pi$<br>3° stereo gives $\Delta z$ = 4 mm<br>dE/dx to ±15%<br>$\sigma_p/p$ = 6.5% p |
| MUON DETECTION | Muon tracking chambers<br>4 planes of 10 cm diameter drift tubes surrounding magnetized iron toroids<br>$\sigma_p/p$ = 30%<br>$\Delta\Omega$ = 97% of $4\pi$ |
| SHOWER DETECTORS | Barrel: 14 $X_0$ of Pb - proportional chamber sandwich<br>$\sigma_E/E = 20\%/\sqrt{E}$<br>z-coordinate from charge division<br>$\sigma_\phi = 0.8°$, $\sigma_\theta = 1.3°$<br>Endcaps: 14 $X_0$ of Fe - proportional chamber sandwich<br>$\sigma_E/E = 45\%/\sqrt{E}$<br>$\phi$-coordinate from cathode strips<br>$\sigma_\phi = 2°$, $\sigma_\theta = 1.5°$<br>Total: $\Delta\Omega$ = 97% of $4\pi$ |
| HADRON CALORIMETER | 5.5 $\lambda_{abs}$ of Fe - proportional chamber sandwich<br>$\sigma_E/E = 75\%/\sqrt{E}$<br>$\sigma_\theta = 2°$; $\sigma_\phi = 1°$ (barrel), 4° (endcaps)<br>$\Delta\Omega$ = 97% of $4\pi$ |
| TIME OF FLIGHT | 144 scintillation counters (72 barrel, 72 endcaps)<br>r = 1.3 m<br>$\Delta t$ = 1 ns<br>$\Delta\Omega$ = 97% of $4\pi$ |
| LUMINOSITY MONITOR | 4 scintillator/shower counter telescopes at 32 mrad horizontally |

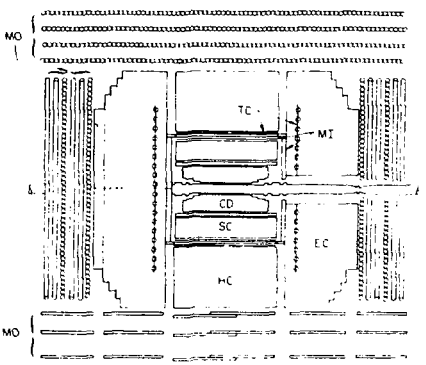
REFERENCES


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

XBL 831-7898

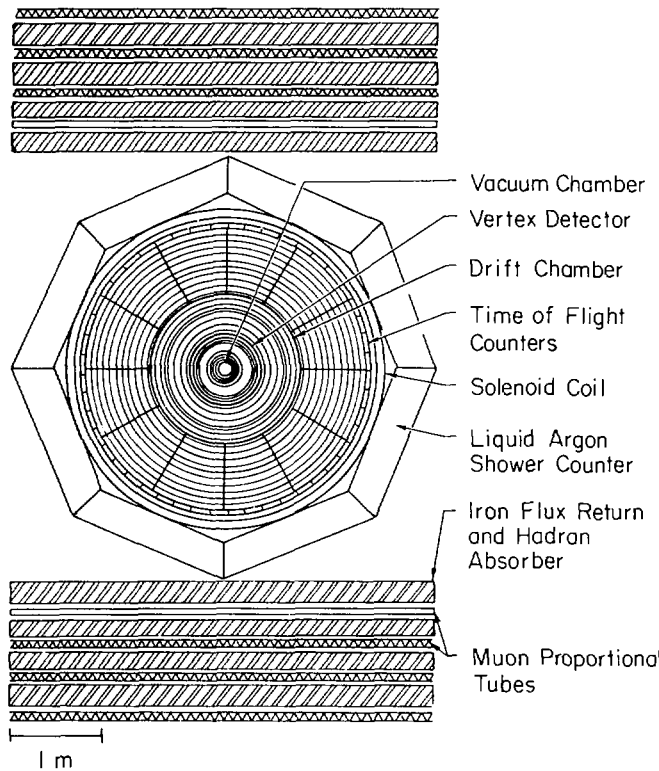
# MARK II

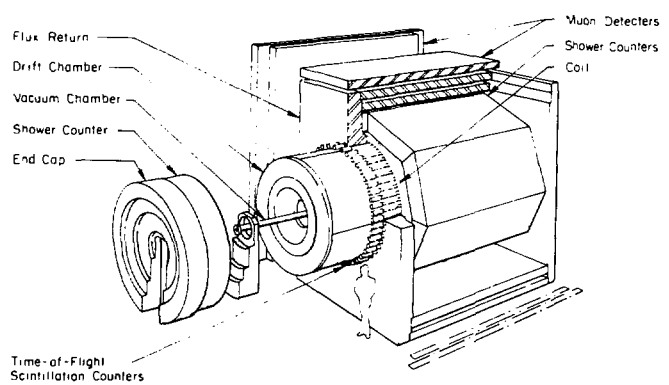
| | |
|---|---|
| LOCATION | PEP $e^+e^-$ storage ring<br>SLAC, Stanford, CA, USA |
| MAGNET | 4.6 kG Al coil solenoid, 1.5 m radius (currently running at 4.3 kG) |
| TRACKING | Central drift chamber:<br>Active length = 2.64 m, inner radius = 0.41 m, outer radius = 1.45 m<br>6 axial layers, 10 stereo layers ($\pm 3°$)<br>50% ethane, 50% argon<br>$\sigma \simeq 200\ \mu$<br>Vertex drift chamber:<br>Cylindrical drift chamber, 1.2 m long, inner radius = 10 cm, outer radius = 35 cm<br>Only axial wire layers (4 near r = 12 cm, 3 near r = 30 cm)<br>$\sigma \simeq 100\ \mu$<br>Be beam pipe ($0.006X_0$)<br>Combined $(\Delta p/p)^2 = (0.015)^2 + (0.01p)^2$<br>Tracks extrapolated to interaction point within 100 $\mu$ |
| SHOWER COUNTERS | 8 modules of Pb-liquid argon ($15X_0$ each), arranged in octagon outside coil<br>Covers 64% of $4\pi$<br>2 mm Pb sheets separated by 3 mm liquid argon gaps<br>37 layers ($0.4X_0$ sampling) are ganged to provide 6 samples in depth<br>Readout in 3.8 cm wide strips in $\phi$, $\theta$, u directions<br>$\Delta E/E \simeq 13\%/\sqrt{E}$ |
| TIME OF FLIGHT | 48 scintillation counters read out at both ends<br>Cover 75% of $4\pi$<br>1.50 m flight path at $\theta = 90°$; $\sigma = 340$ ps<br>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<br>($\theta$, $\phi$, R-spiral, L-spiral)<br>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 | 6 planar drift chambers followed by shower counters |
| LUMINOSITY MONITOR | Octagonal shower counters cover 22 mrad $< \theta <$ 80 mrad contain<br>18 layers 1/4" Pb and 1/2" scintillator, read out with BBQ wave shifter, front 5 layers separately from back 13<br>$\Delta E/E = 15.5\%/\sqrt{E}$<br>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

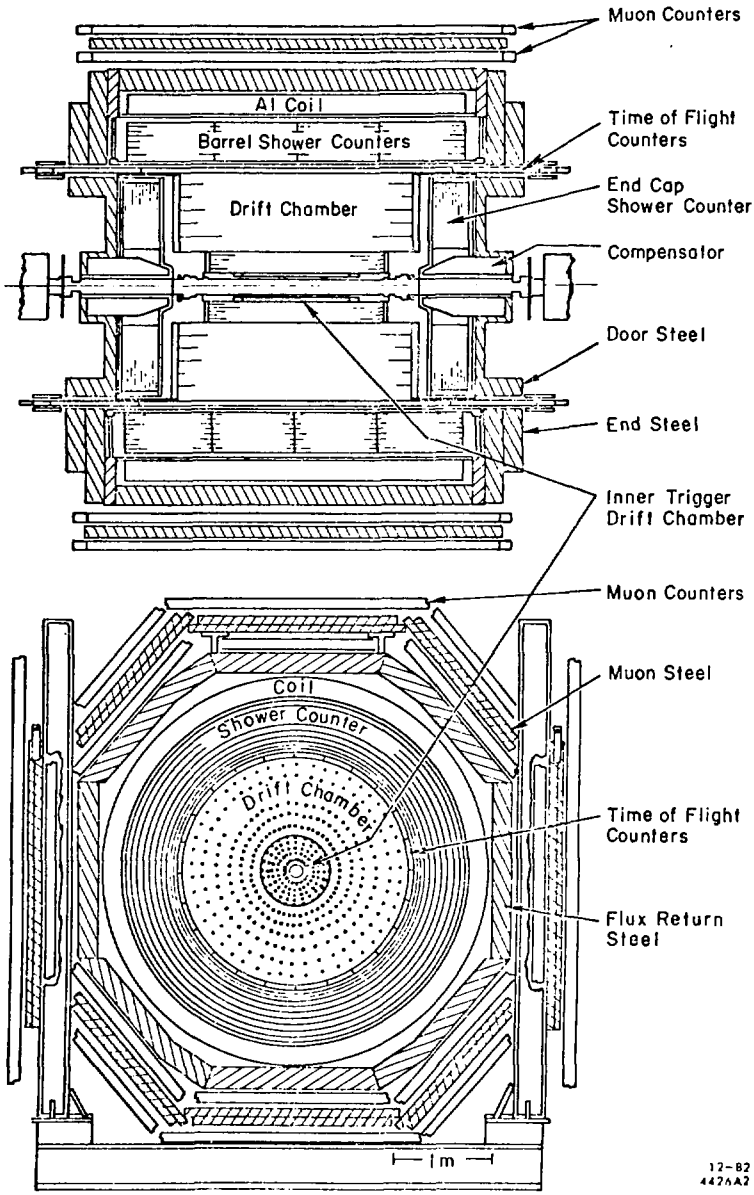

Vacuum Chamber
Vertex Detector
Drift Chamber
Time of Flight Counters
Solenoid Coil
Liquid Argon Shower Counter
Iron Flux Return and Hadron Absorber
Muon Proportional Tubes
1 m


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

# MARK III

| | |
|---|---|
| LOCATION | SPEAR $e^+e^-$ storage ring<br>SLAC, Stanford, CA, USA |
| MAGNET | 4.0 kG conventional aluminum coil |
| TRACKING | Drift chamber, O.D. 229 cm, length 234 cm<br>8 layers of cells, 2 stereo, 4 charge division<br>4 × 32 1-wire cells in trigger layer<br>12 × 32 sense-wire cells in inner dE/dx layer<br>16 × layer number, 3 sense-wire cells in outer layers<br>89% argon, 10% $CO_2$, 1% methane<br>$(\Delta p/p)^2 = (1.5\%)^2 + (1.5\%\ p)^2$ |
| SHOWER COUNTER | 24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total)<br>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<br>80% argon, 20% methane<br>$\sigma_\phi = 6$ mrad; $\sigma_\theta = 14$ mrad at 45°; $\sigma_E/E = 18\%/\sqrt{E}$ |
| END CAPS | 24 layers of Pb-gas proportional chamber sandwich ($12X_0$ total)<br>An array of rectangular 1.2 cm × 2.6 cm wide aluminum proportional tubes are glued between $1/2\ X_0$ layers of Pb<br>80% argon, 20% methane<br>$\sigma_x = 0.8$ cm; $\sigma_y \sim 2$–4 cm |
| TIME-OF-FLIGHT | 48 × 15 cm × 5 cm × 3.2 m<br>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<br>$\sigma_t \simeq 150$–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<br>The array covers 2/3 of the solid angle<br>$\sigma_\phi = 7$ 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<br>Three layers of unfitted tracking information from the drift chambers are used to define tracks<br>Triggering is on one track plus time-of-flight information or 2 tracks, solid angle ≃ 80% |
| LUMINOSITY MONITOR | 4 scintillator + shower counter telescopes at 25 mrad |

# MARK III




XBL 831-7891

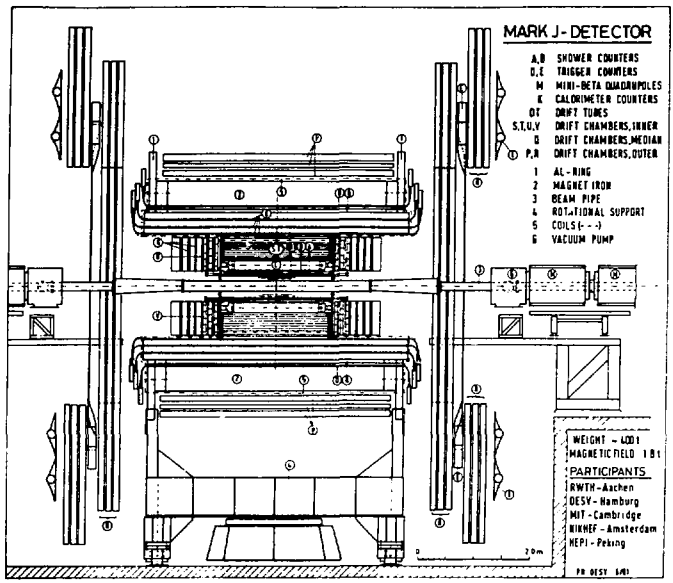
# MARK-J

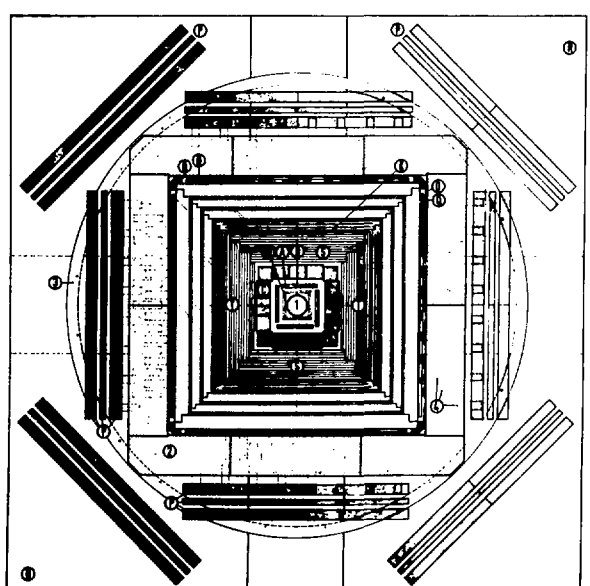
| | |
|---|---|
| LOCATION | PETRA $e^+e^-$ rings<br>DESY, Hamburg, W. Germany |
| DETECTOR | Calorimetric, specialized for $\mu$-detection and asymmetry measurements<br>Can rotate around the beam $\phi \pm \pi$ and $\theta \pm \pi/2$<br>Decay path $\sim$ 20 cm |
| MAGNET | Toroid, 500 To, iron magnetized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

REFERENCES

1. The MARK-J Collaboration (Aachen, DESY, MIT, NIKHEF, Peking), Phys. Rep. **63** (1980) 1.

# MARK-J



## MARK J - DETECTOR
(Cross Section)

- (A)(B)(C) SHOWER COUNTERS
- (D) TRIGGER COUNTERS
- (DT) DRIFT TUBES
- (Q) DRIFT CHAMBERS, MEDIAN
- (P)(R) DRIFT CHAMBERS, OUTER
- (S)(T) DRIFT CHAMBERS, INNER

- (1) BEAM PIPE
- (2) MAGNET IRON
- (3) AL-RING
- (4) MULTIPLIERS

WEIGHT (total) ~ 400 t
MAGNETIC FIELD 1 B T

PARTICIPANTS
RWTH - Aachen
DESY - Hamburg
MIT - Cambridge
NIKHEF - Amsterdam
HEPI - Peking

0 5 10 15 20 m

XBL 832-8019

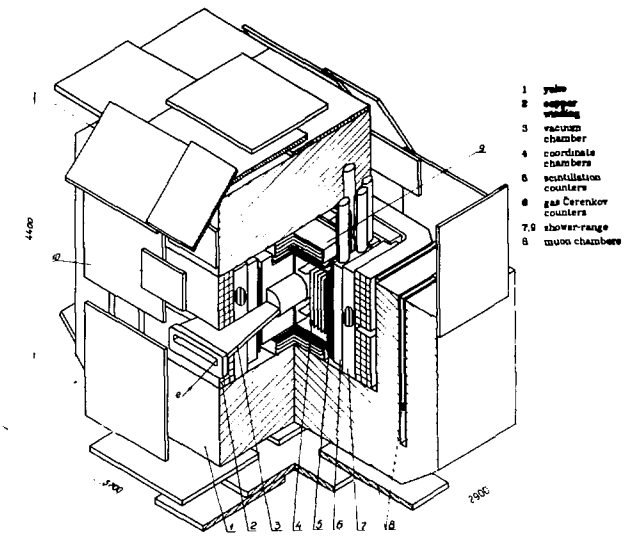
# MD-1

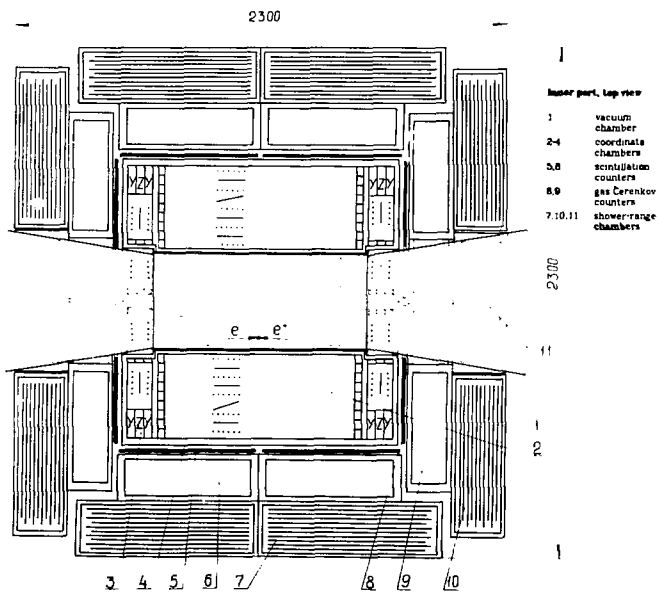
| | |
|---|---|
| LOCATION | VEPP-4 $e^+e^-$ rings<br>Novosibirsk, USSR |
| MAGNET | $\vec{B}$ transverse to orbit plane<br>$B \propto E_b$, $B_{max} = 16$ kG<br>$B = 12$ kG at $E_b = 5$ GeV |
| TRACKING | MWPC, s = 2+4 mm<br>$\sigma_p/p = (5+10)\%$ p |
| SCINTILLATION COUNTERS | 24 counters, $40 \times 40 \times 1$ cm$^3$<br>$\sigma_A/A = 20\%$ ($\beta = 1$), $\sigma_{TOF} = 0.4$ ns |
| CHERENKOV | 8 counters, $160 \times 70 \times 20$ cm$^3$, 60% of $\Omega$<br>Gas: ethylene, P = 25 atm.<br>$(p_\pi)_{thresh} = 0.7$ GeV/c, $(p_k)_{thresh} = 2.5$ GeV/c<br>$\epsilon(\beta=1) = 98\% \rightarrow \epsilon(\beta<\beta_{th}) < 0.1$<br>$\epsilon(\beta=1) = 60\% \rightarrow \epsilon(\beta<\beta_{th}) < 5 \times 10^{-3}$ |
| SHOWER-RANGE CHAMBERS | 14 chambers, 10×(13 mm Fe + 10 mm MWPC)<br>Gas: Ar + 20% $CO_2$, P = 1 atm.<br>$\sigma_E/E = (40+15)\%$ at $E_\gamma = 0.15+5$ GeV<br>$\epsilon_\gamma = 50\%$ at 150 MeV, $\epsilon_\gamma \geq 90\%$ at $E_\gamma \geq 250$ MeV<br>$\sigma_\theta \approx \sigma_\phi \sim 1+2°$ |
| 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 $\sigma = 0.1$ mm<br>For $E = E_b$, $\theta = 12+100$ mrad<br>For $\theta = 0$, $(E_b-E)/E_b = 0.1+0.5$<br>$\sigma_E/E = 1+1.5\%$ |
| LUMINOSITY MONITOR | 1. $ee \rightarrow ee\gamma$, NaI(Tl) counters<br>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



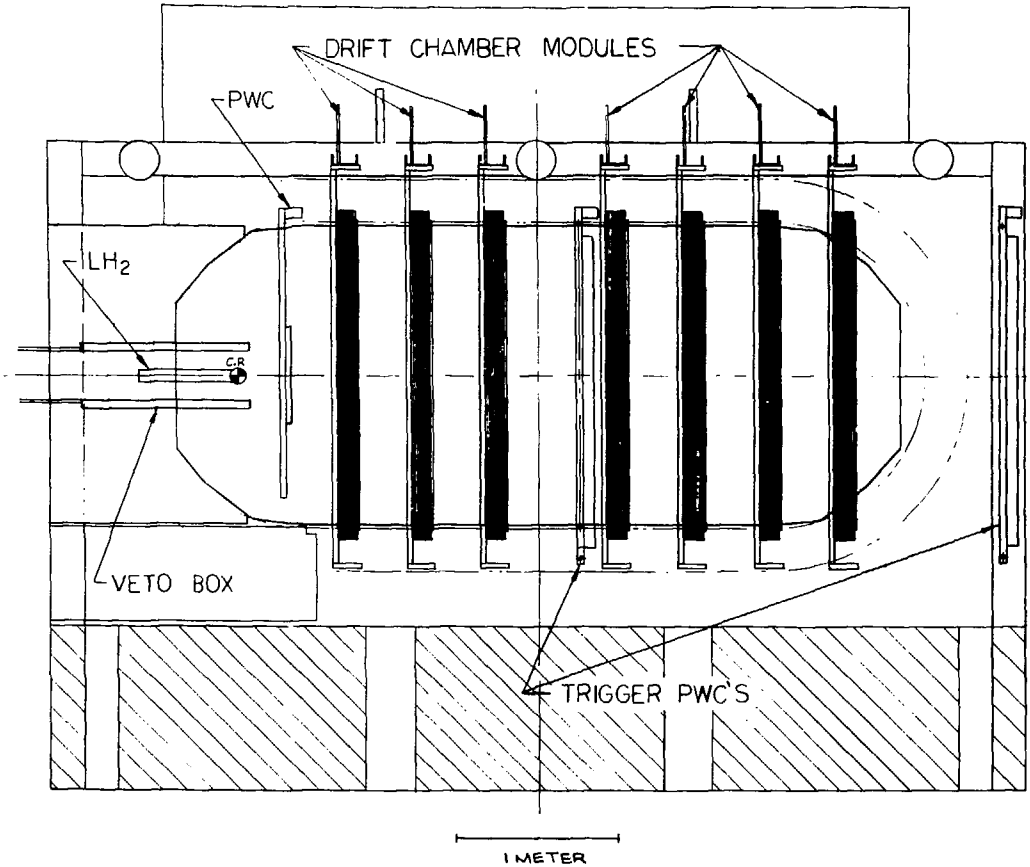

XBL 832-8021

# MPS II

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




XBL 832-8064

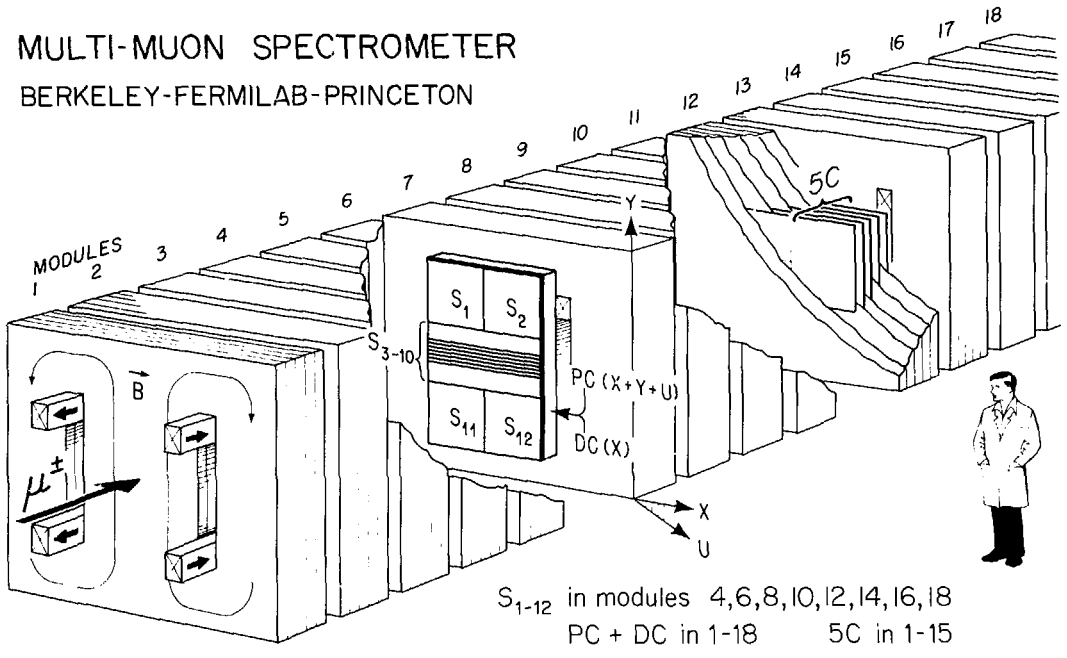
MPS 11

## Multimuon Spectrometer

| | |
|---|---|
| LOCATION | Muon Laboratory, FNAL<br>Batavia, IL, USA |
| COLLABORATION | Lawrence Berkeley Laboratory, Fermilab, Princeton University |
| MAGNET | Solid iron spectrometer serves as analyzing magnet, target, hadron absorber, and hadron calorimeter<br>Magnet size 2.5 m × 2.5 m × 16 m<br>Fiducial volume 1.8 × 1 × 12 $m^3$<br>Field is 2 Tesla, uniform to 3% and mapped to 0.2%<br>Magnet constructed of 10-cm thick plates with gaps between for instrumentation |
| TRACKING | 19 multiwire proportional chambers, 1.8 m × 1.0 m active area, 3 coordinate (x,y,u) readout, $\sigma_x = 900\ \mu m$, $\sigma_y = \sigma_u = 1500\ \mu m$<br>19 drift chambers, 1.8 m × 1.0 m, $\sigma_x = 250\ \mu m$<br>Momentum resolution $\sigma_p/p \sim 8\%$ |
| HADRON CALORIMETER | 75 counters of plastic scintillator, each 1 m × 0.8 m, downstream of each 10-cm thick iron plate<br>$\sigma_\nu/\nu = 1.4/\sqrt{\nu}$ 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<br>Apparatus is triggered by single muon scattered at large angle ($\theta \gtrsim 20$ mrad)<br>Multimuon triggering is fully sensitive in the forward direction<br>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
MODULES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
5C
Y
$S_1$
$S_2$
$S_{3-10}$
$S_{11}$
$S_{12}$
PC (X+Y+U)
DC (X)
$\vec{B}$
$\mu^{\pm}$
X
U
$S_{1-12}$ in modules 4,6,8,10,12,14,16,18
PC + DC in 1-18 5C in 1-15
XBL 795-9605

## NUSEX Detector for Nucleon Decay

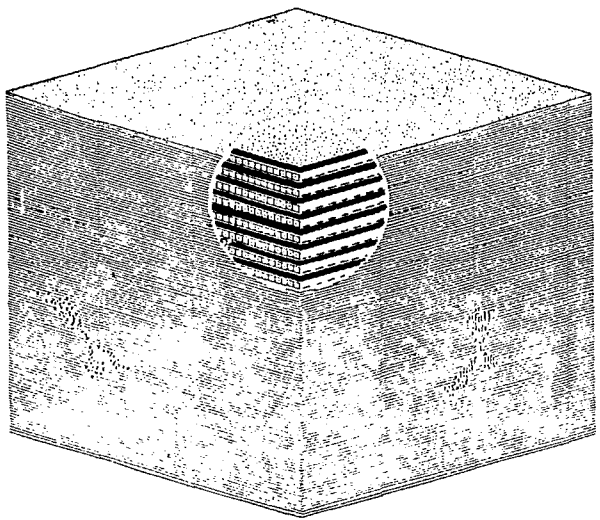
| | |
|---|---|
| LOCATION | Mont Blanc Laboratory<br>Italian-French border |
| SHIELDING DEPTH | ~5000 m.w.e. |
| DETECTOR | Digital tracking calorimeters; 1 cm iron interleaved with plastic streamer tubes: 134 layers |
| MASS | 150 tons (average density: 3.5 g/cm$^3$) |
| VOLUME | $(3.5\text{m})^3$ |
| SENSITIVE ELEMENTS | 48,880 plastic streamer tubes with resistive cathode<br>Cell 9 × 9 mm$^2$, 100 μm wire, gas mixture Ar+$CO_2$+n-pentane (1+2+1), HV = 3900 V<br>External pick-up strips for x and y streamer localization on each tube layer |
| READOUT | 81,472 readout channels<br>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 |

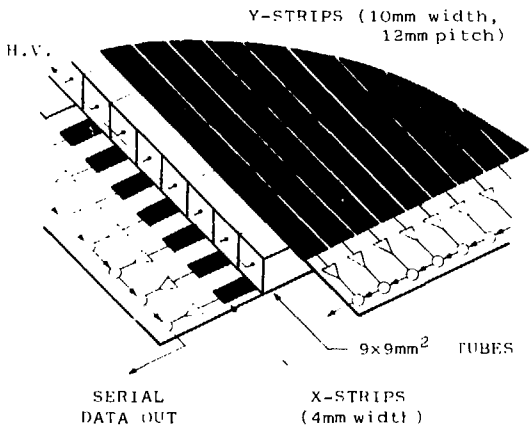
REFERENCES


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






XBL 832-8141

NUSEX Detector for Nucleon Decay

# OMEGA

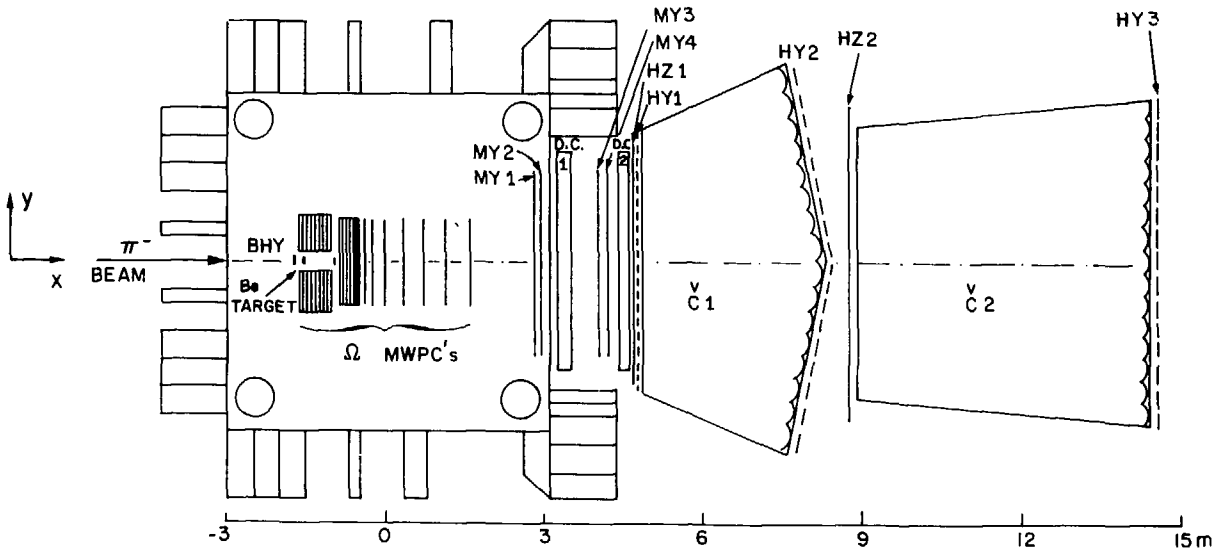
| | |
|---|---|
| LOCATION | West area, 450 GeV secondary beam<br>CERN, Geneva, Switzerland |
| MAGNET | 18 kG (superconducting)<br>Field volume: height, 150 cm; diameter ($\frac{1}{2}$ field), 400 cm |
| TRACKING | Proportional chambers inside field<br>$\sigma_p/p = 10^{-3}$ p<br>+ level arm drift chambers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

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 $H_2$, also emulsions for photoproduction of unstable particles).




XBL 832-8065

OMEGA

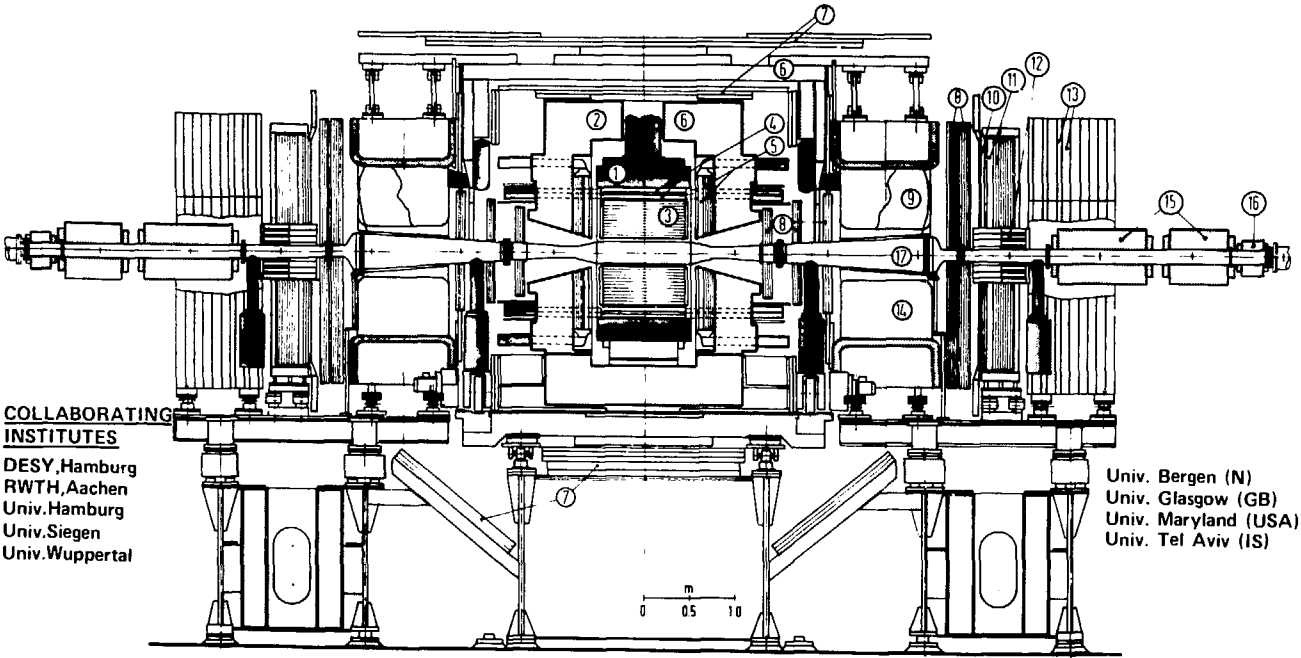
# PLUTO

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

REFERENCES


1. J. Burmester et al., Phys. Lett. **64B**, (1976) 369.
2. O. Achterberg et al., Nucl. Instr. & Meth. **156**, (1978) 287.
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
2. Magnet yoke
3. Cylindrical driftchambers
4. Barrel shower counter with helix-tubes
5. Endcap shower counters with proportional chambers
6. Hadron absorber
7. Muon chambers
8. Forward drift chambers
9. Cerenkov counter
10. TOF counters
11. Large angle tagger (LAT) with proportioal tubes
12. Small angle tagger (SAT)
13. Forward muon detector
14 Septum magnet
15 Mini beta quadrupoles
16 Correction quadrupole
17. Vacuum pipe

33528
F 33/PR· kn (1980)

XBL 832-8307

PLUTO

## SFM

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

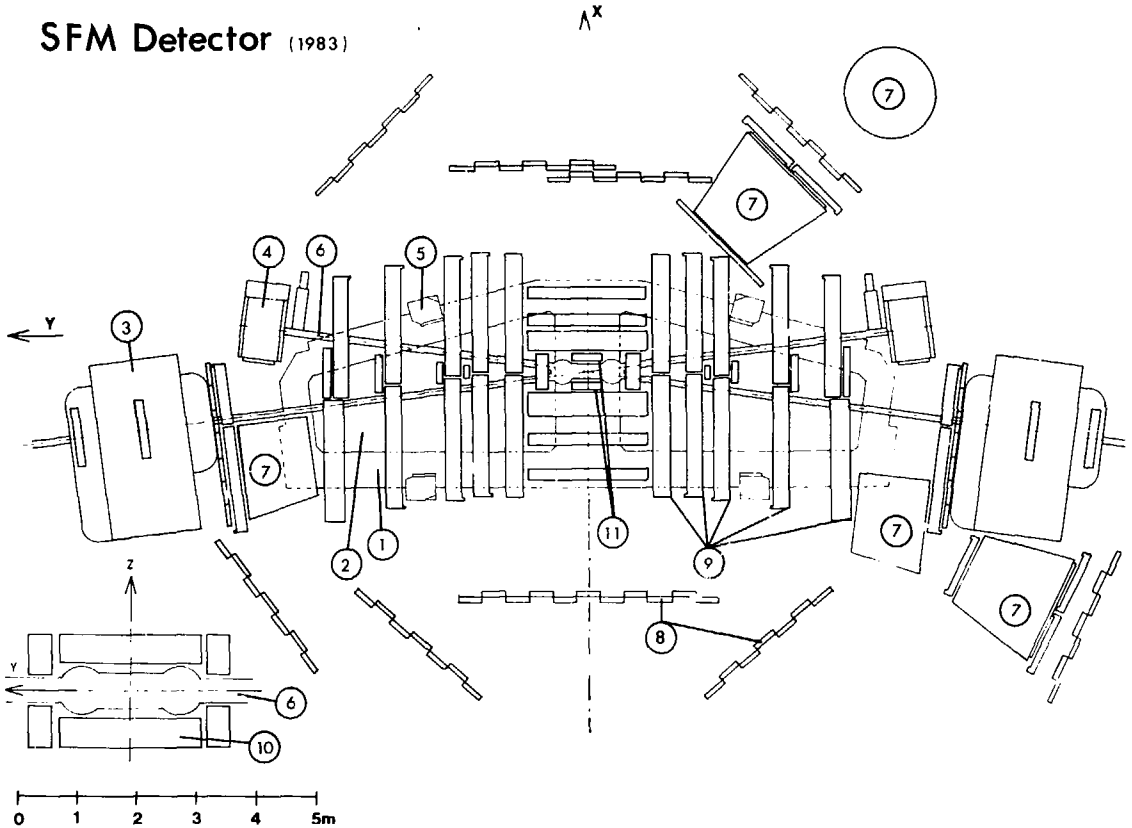
REFERENCES


1. R. Bouclier et al., Nucl. Instr. & Meth. **115** (1974) 235.
2. R. Bouclier et al., Nucl. Instr. & Meth. **125** (1975) 19.
3. W. Bell et al., Nucl. Instr. & Meth. **125** (1975) 437.


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 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, $\Delta z$(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$^2$, $\sigma_t/t$ = 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$^{-1}$
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$^{-1}$

Charged particle identification: 2 atm. press. Cerenkov detectors
$N_2$ and 20% $N_2$ – 80% He mixture, 20 segments each

Separation: $\pi$ vs K or p $\quad 6 < p < 36$ GeV
$\pi$ vs K vs p $\quad 20 < p < 33$ GeV

Neutral Detection:
Electromagnetic -
Pb-liq. scint. (SLIC): u,v,y readout, 60 × 0.16 cm Pb samples
$\sigma_\theta$ = 0.3 mr, $\sigma_E/\sqrt{E}$ = 12% ($|\theta_x| < 134$ mr and $|\theta_y| < 67$ mr)
Pb-plastic scint. (Outrigger): x,y readout, 16 × 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 ~200 cm Fe

**BEAM**

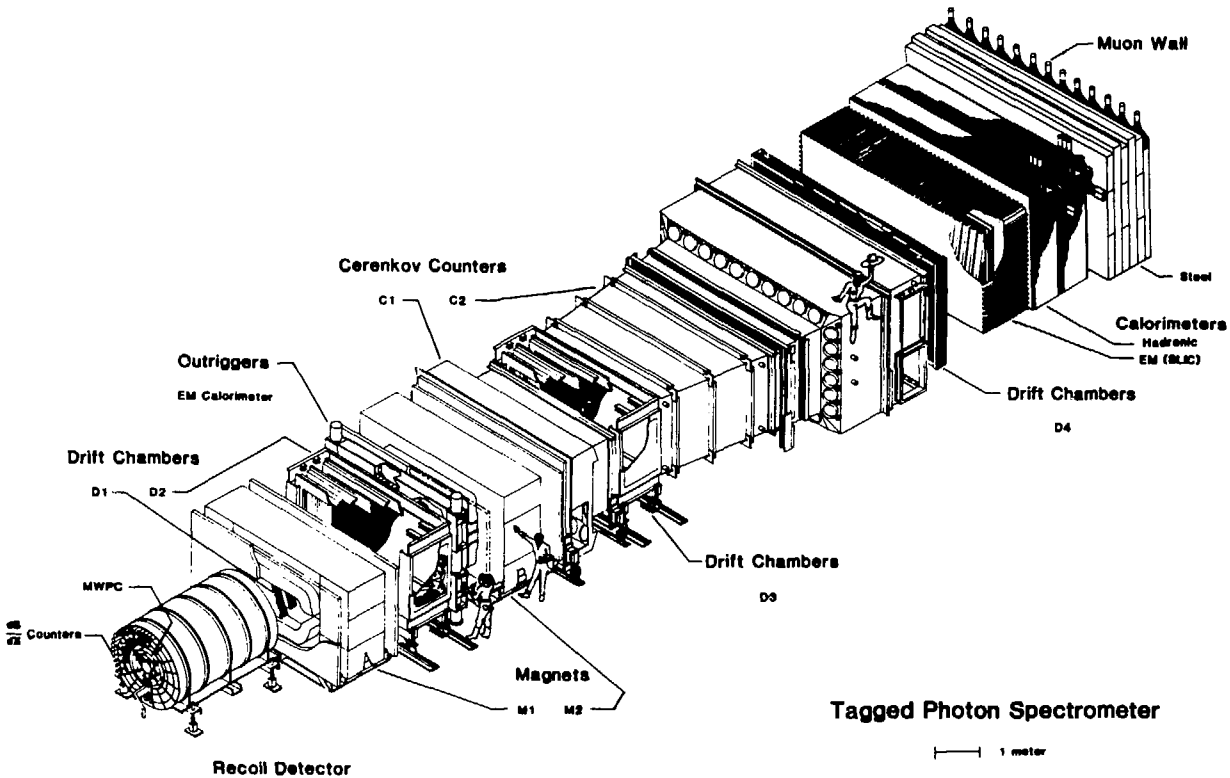
300 GeV $e^-$ with $\gamma$ tagging system ($0.45 < E_\gamma/E_e < 0.95$
$\sigma_\gamma \simeq$ 3–6 GeV

**BUILDERS**

Tagged Photon collaboration: Fermilab, Carleton Univ., Toronto Univ., Univ. of California at Santa Barbara, Univ. of Colorado

**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.
6. A.L. Duncan, Ph.D. Thesis, Univ. Colorado, 1982 (COLO-HEP-57).




XBL 831-7899

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$^3$, $\sigma_{TOF}$ = 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 $42° < \theta < 138°$; $\phi$: 30°–150°, 210°–330°: 0.2 cm Pb, 0.5 cm argon, $14X_0$, 5088 front towers, 1248 back towers, 4592 strips for z, $\phi$, dE/dx

$$\sigma_E/E = (0.11 + \frac{0.02}{E-0.5})/\sqrt{E},\ E > 1\ \text{GeV};\ \sigma_\theta = \sigma_\phi = 2\ \text{mrad}$$

Endcap $12° < \theta < 30°$, $150° < \theta < 168°$, $\phi$: 0–360°, 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: $50° < \theta < 130°$, $-26° < \phi < 26°$, $154° < \phi < 206°$; 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)

| | $\pi$ | 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, $\sigma$ = 450 ps

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

**MUON DETECTION**

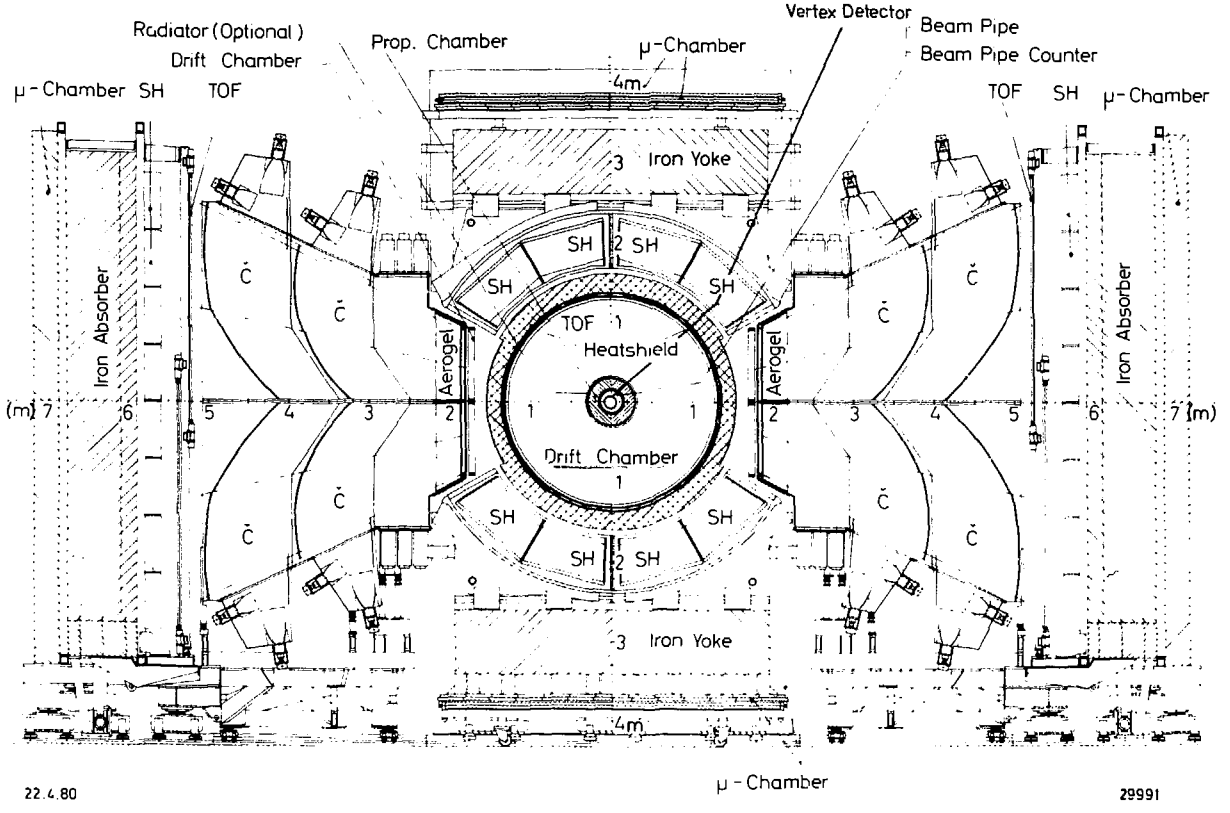
Behind magnet yoke (50–80 cm Fe) and behind hadron wall (87 cm Fe), 4 layers of proportional tube chambers, 4 × 4 cm$^2$

**FORWARD DETECTOR**

25–115 mrad, scintillation hodoscope, proportional tube chambers, lead-scintillator shower counter

**REFERENCES**


1. TASSO Collaboration, R. Brandelik et al., Phys. Lett. **83B** (1979) 261, **108B** (1982) 71, and **113B** (1982) 98.
2. H. Boerner et al., Nucl. Instr. & Meth. **176** (1980) 151.
3. K. Bell et al., Nucl. Instr. & Meth. **179** (1981) 27.
4. H. Burkhardt et al., Nucl. Instr. & Meth. **184** (1981) 319.




TASSO

XBL 831-7895

TASSO

# TPC

| | |
|---|---|
| LOCATION | PEP $e^+e^-$ ring, Interaction Region (IR) 2<br>SLAC, Stanford, CA, USA |
| MAGNET | 1982–83: 4 kG Al coil solenoid ($1.32X_0$ coil package)<br>1984: 14.5 kG superconducting coil ($0.86X_0$ package)<br>Diameter = 2.15 m, length = 3.0 m |
| TRACKING | Time Projection Chamber (TPC)<br>2.0 m long (in z) at 20 to 100 cm radius (r)<br>Argon-methane (80%–20%) at 8.5 atm.<br>Max. drift 1.0 m in 20 $\mu$sec, 75 kV/m drift electric field<br>183 proportional wire hits on tracks with $\lvert\cos\theta\rvert < 0.71$, each wire gives r,z and amplitude for six 60° sectors at each end and provides dE/dx meas. by multiple ionization sampling<br>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 $\lvert\cos\theta\rvert < 0.71$<br>$\geq$2 3-d points and $\geq$15 wire hits over 97% of $4\pi$ sterad<br>Track pair resolution of 1–2 cm<br>dE/dx ±3.5% for Bhabhas<br>±4.0% for tracks in jet events with $\geq$120 samples<br>$\sigma_p/p^2 = \pm 3.6\%$ for $p \geq 2$ GeV/c<br>position resolution in bending plane is 190 microns and in axial (z) direction 340 microns; presently low magnet field and drift distortions increase $\sigma_p/p^2$<br>Inner drift chamber at 13 to 19 cm radius<br>8.5 atm Ar-$CH_4$ (80%–20%), 150 microns in bend plane<br>1.2 m long covering 95% of $4\pi$, with 4 axial layers<br>Outer drift chamber at 1.19 to 1.24 m radius<br>1 atm Ar-$CH_4$ (80%–20%), 200 microns in bend plane<br>3 m long covering 77% of $4\pi$, with 3 axial layers |
| POLE-TIP CALORIMETER | Gas, proportional mode, sampling Pb-laminate calorimeter<br>2 modules, $13.5X_0$ deep, at z = 1.1 m, covering 18% of $4\pi$<br>Argon-methane (80%–20%) at 8.5 atm; total of 51 samples<br>Three 60° stereo views, each with 13 and 4 samples in depth<br>Projective strip geometry with 8 mrad angular segment<br>$\sigma_E/E = \pm 11\%/\sqrt{E}$, below 10 GeV<br>±6.0% for Bhabhas at 14.5 GeV |
| HEXAGONAL CALORIMETER | Gas, limited Geiger mode, sampling Pb-laminate calorimeter<br>6 modules, $10X_0$ deep, 4.2 m long at 1.2 m radius<br>Argon-ethyl bromide (96%–4%) at 1 atm.<br>Solid angle coverage of 75% (90% including PTC)<br>3 correlated 60° stereo views using wire and cathode signals in 40 samples (27 and 13 samples in depth)<br>Projective strip geometry with 9 mrad angular segment<br>$\sigma_E/E = \pm 14\%/\sqrt{E}$, below 1 GeV<br>±12% for Bhabhas at 14.5 GeV |
| MUON DETECTOR | Magnet flux return + 2 layers iron, total 810 g/cm<br>Triangular, double layer, extruded Al proportional tubes<br>Argon-methane (80%–20%) at 1 atm.<br>3 layers with axial wires and 4th layer at 90 deg.<br>Endcap with 3 layers provides 98% of $4\pi$ sterad coverage<br>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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3. HEX: H. Aihara et al., IEEE Trans. **NS 30** (1983).
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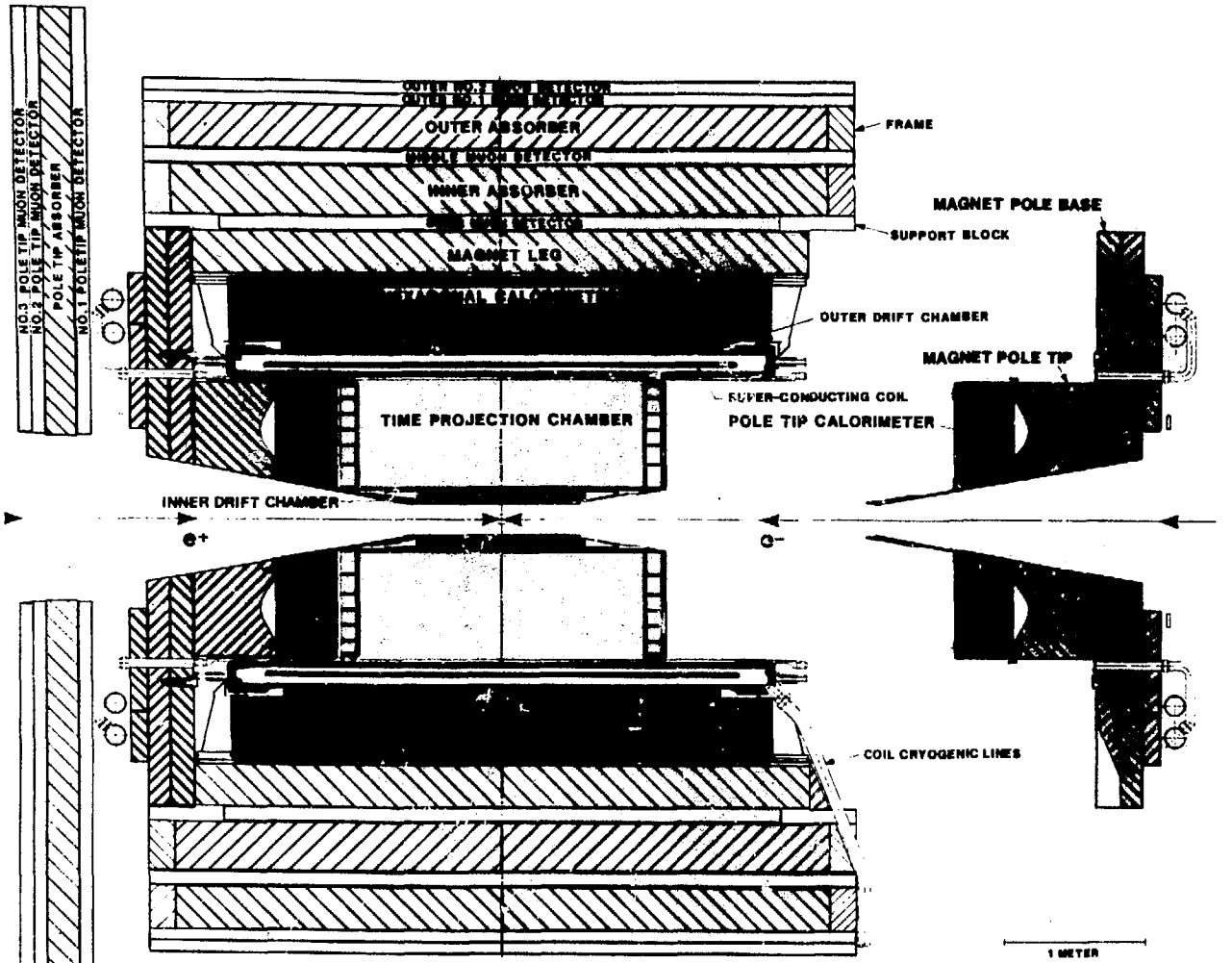


PEP-4 FACILITY

TPC

# UA1

| | |
|---|---|
| LOCATION | CERN SPS $\bar{p}p$ Collider<br>CERN, Geneva, Switzerland |
| MAGNET | Dipole field up to 0.7 Tesla, Al coils<br>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<br>Covers $5° < \theta < 175°$<br>60% ethane - 40% argon<br>3-dimensional readout by continuous digitization in drift direction and charge division along wires<br>Average of 110 space points per track<br>$\sigma \simeq 250$ $\mu$m in drift plane<br>$\sigma \simeq 2$ % of wire length along wire<br>$\sigma \simeq 6\%$ for dE/dx |
| ELECTROMAGNETIC CALORIMETERS | Pb-scintillator sandwich ($26X_0$) with BBQ readout<br>Gondolas ($25° < \theta < 155°$) and Bouchons ($5° < \theta < 25°$, $155° < \theta < 175°$)<br>$(\sigma_E/E)^2 = (0.15/\sqrt{E})^2 + (0.016)^2$<br>$\sigma_x = 4$ cm/$\sqrt{E}$ ($\theta$ direction)<br>$\sigma_y = 16$ cm/$\sqrt{E}$ ($\phi$ direction)<br>$\sigma_{E_t}/E_t = 0.12/\sqrt{E_t}$ |
| HADRON CALORIMETERS | Fe-scintillator sandwich with BBQ readout based on the laminated return yoke of the magnet<br>16 samplings (5 cm Fe, 1 cm scint. each) in barrel, 23 samplings in endcaps<br>$\Delta E/E \simeq 0.8/\sqrt{E}$ |
| MUON DETECTION | Large-area drift tube chambers (8 layers)<br>Angular resolution $\sigma = 1$ mrad |
| FORWARD DETECTORS | $0.2° < \theta < 5°$ and $0 < \phi < 2\pi$<br>Rapidity acceptance $3.4 < \|y\| < 7.4$<br>Endcap chambers<br>Trigger counters (4 cm thick scint.)<br>Electromagnetic calorimeter (4 modules Pb-scint., $7.2X_0$ each)<br>EM shower chambers between first and second EM modules (proportional chambers delay line readout)<br>Hadron calorimeter (6 modules, 1.7 $\lambda_{abs}$ each), based on compensating magnet steel<br>Hadron shower chamber between first and second hadron calorimeter modules |
| ROMAN POTS | 8 small drift chambers, 4 on each arm at $\pm 22$ m from collision point, which enter the SPS vacuum pipe vertically |

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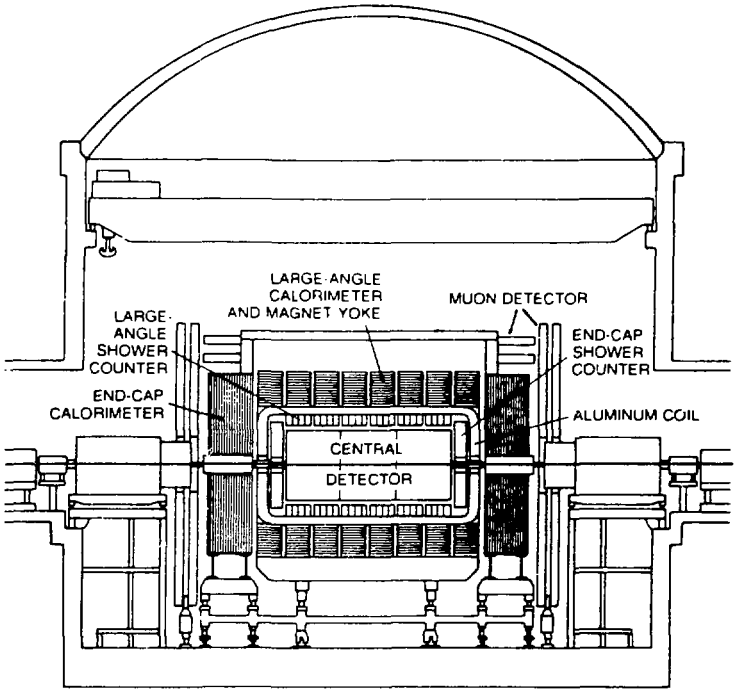
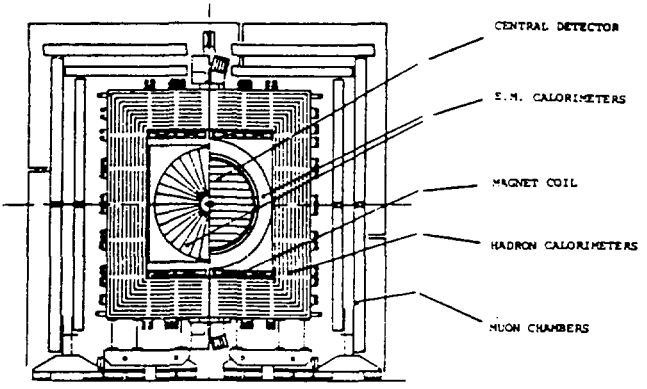

LARGE-ANGLE
CALORIMETER
AND MAGNET YOKE
MUON DETECTOR
LARGE-
ANGLE
SHOWER
COUNTER
END-CAP
SHOWER
COUNTER
END-CAP
CALORIMETER
ALUMINUM COIL
CENTRAL
DETECTOR


CENTRAL DETECTOR
E.M. CALORIMETERS
MAGNET COIL
HADRON CALORIMETERS
MUON CHAMBERS

XBL 832-8020

# UA2

| | |
|---|---|
| LOCATION | CERN SPS $\bar{p}p$ Collider<br>CERN, Geneva, Switzerland |
| COLLABORATION | Univ. Bern, CERN, NBI Copenhagen, LAL Orsay, Univ. and INFN Pavia, CEN Saclay |

## CENTRAL DETECTOR

| | |
|---|---|
| TRACKING | $20° < \theta < 160°$, $2\pi$ in $\phi$<br>4 cylindrical multiwire proportional chambers (MWPC) with helicoidal cathode strips at $\pm 45°$ readout<br>2 cylindrical JADE type drift chambers at atmospheric pressure with charge division and multihit readout<br>Vertex resolution $\sigma = 1$ mm in all coordinates<br>1 cylindrical scintillator hodoscope, 24 strips |
| SHOWER COUNTERS | $40° < \theta < 140°$, $2\pi$ in $\phi$<br>Preshower counter is a cylindrical MWPC with pulse height readout on wires and helicoidal cathode stips behind a 1.5 $X_0$ W cylinder<br>17 $X_0$ Pb-scint. sandwich em calorimeters<br>4 abs. length Fe-scint. sandwich hadronic calorimeters, BBQ readout<br>Tower structure with cell $\Delta\phi \times \Delta\theta = 15° \times 10°$ and 3 longitudinal segments<br>$\sigma_E/E = 14\%/\sqrt{E}$ em and $\sigma_E/E \sim 60\%/\sqrt{E}$ hadronic showers |

## FORWARD-BACKWARD SPECTROMETERS

| | |
|---|---|
| MAGNET | Toroidal magnet, 0.38 T-m<br>$20° < \theta < 37.5°$ and $142.5° < \theta < 160°$, 80% of $2\pi$ in $\phi$<br>12 spectrometer sectors on each side |
| TRACKING | 9 drift chamber planes ($\pm 7°$, 0°) per sector<br>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<br>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<br>$\sigma_E/E = 15\%/\sqrt{E}$ |

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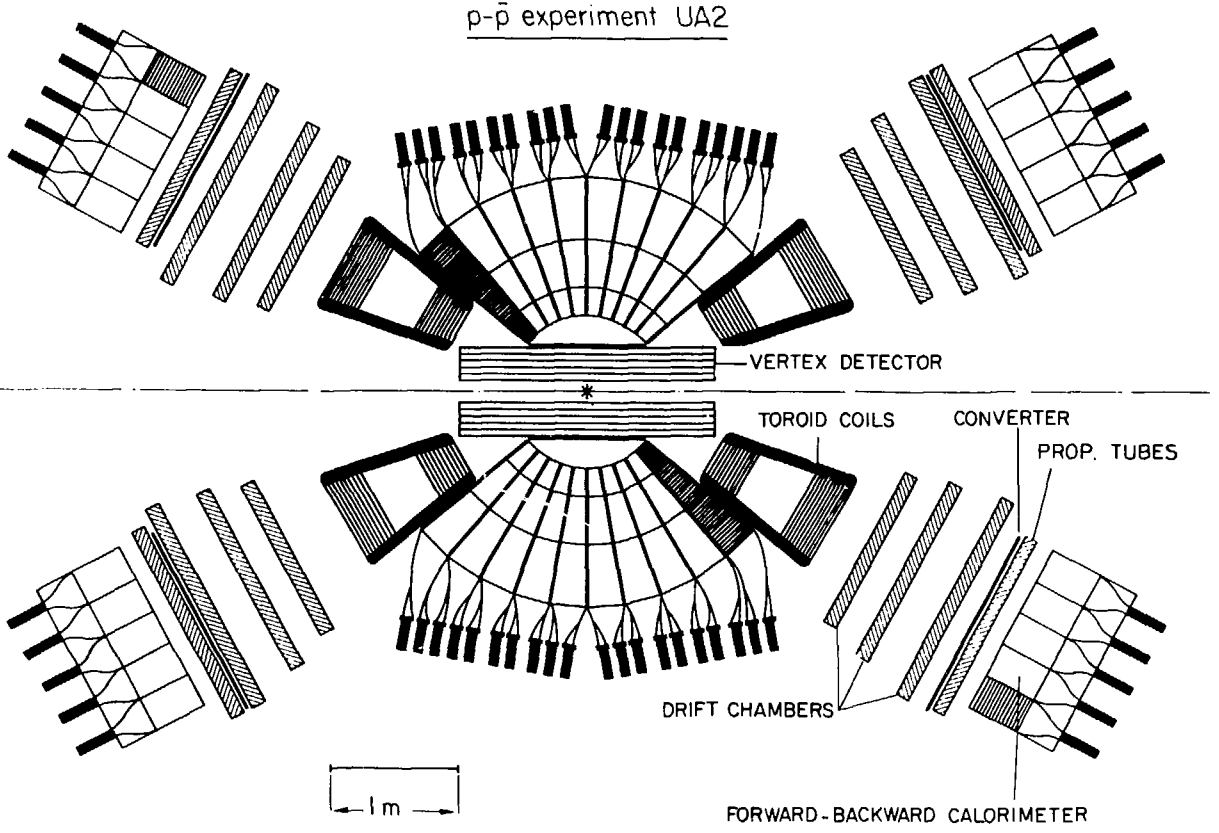


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UA2