Kaon Monitoring in MiniBooNE: The LMC Detector

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NBI 2003
KEK, Tsukuba
November 10, 2003

Kaon Monitoring at MiniBooNE

1) K-decay ν_e background at BooNE
   - K production estimates
2) Decay kinematics
3) The "Little Muon Counter" (LMC)
   - Concept/Placement
   - Civil construction/infrastructure
   - Collimator
   - Fiber Tracker
   - Temporary detector
   - Status

K-decay ν_e background

- MiniBooNE will see ~200-400 ν_e from K^+ and K^0_L decays each year -- comparable to the yield from oscillation physics if LSND is correct.
- Goal is a systematic error of <10% on K-decay ν_e.
- Information on these decays will come from:
  - Monte Carlo (GEANT4, MARS, GFLUKA) ← 50% disagreements!
  - Production measurements (BNL E910, HARP, plus other, older data)
  - In-situ measurement: LMC

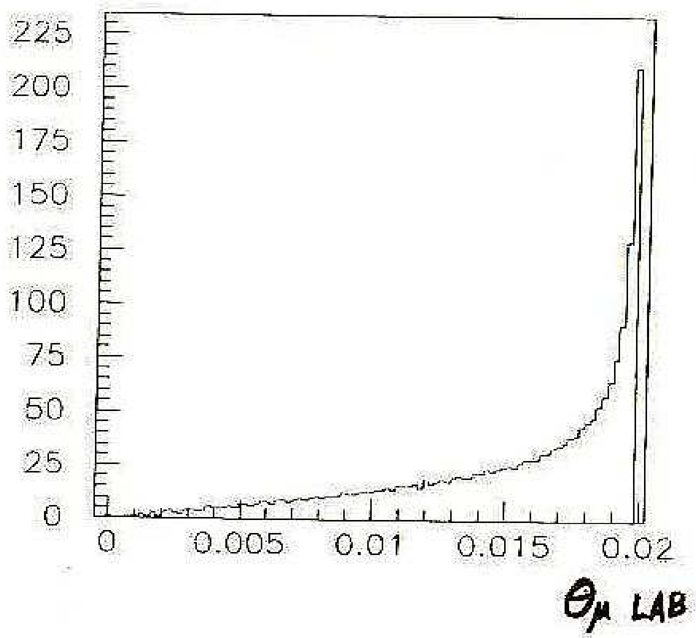
Decay Kinematics

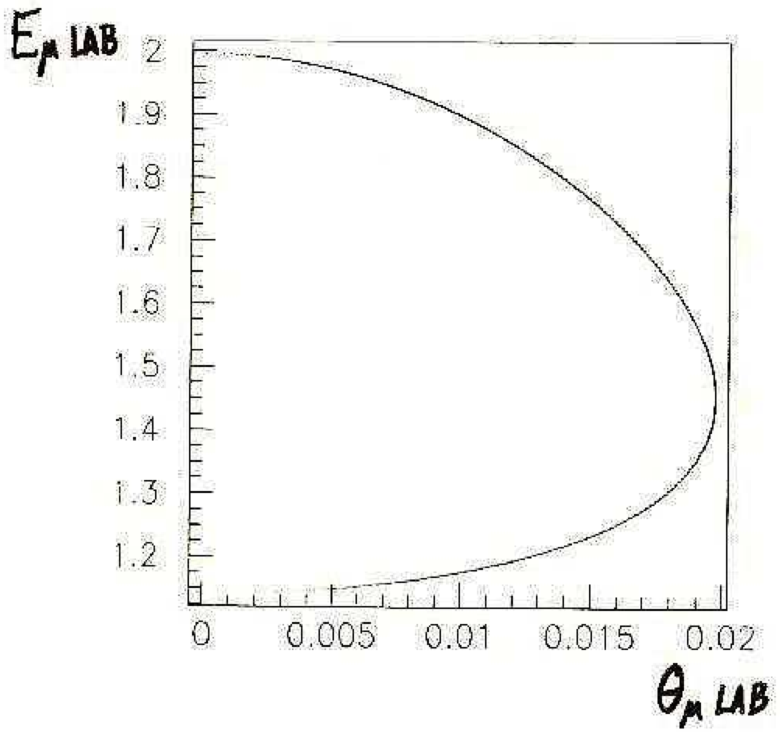
- In the downstream part of the secondary beam, high-p_T mesons have generally been removed by collimation.
  - High-p_T particles come primarily from decays. For muons:

	$p_{T(MAX)}$
$\pi^{\pm} \to \mu^{\pm} \nu$	$= 30$ MeV/c
$K^{\pm} \to \mu^{\pm} \nu$	236 MeV/c
$K_L^0 \to \pi^{\pm} \mu^{\mp} \nu$	216 MeV/c

High-p_T muons come almost exclusively from K decays.

- p_T separation becomes $|p|$ separation when specific decay angle selected.
- Exploit by measuring μ momentum distribution at a particular angle; infer parent particles.

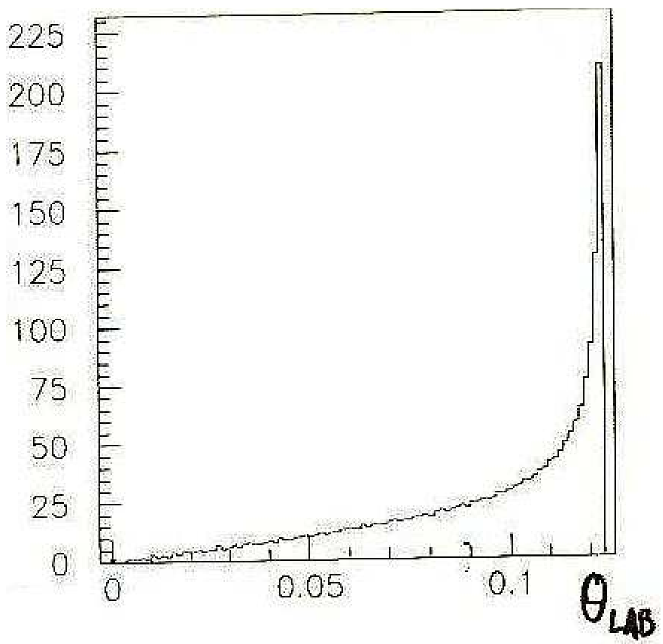


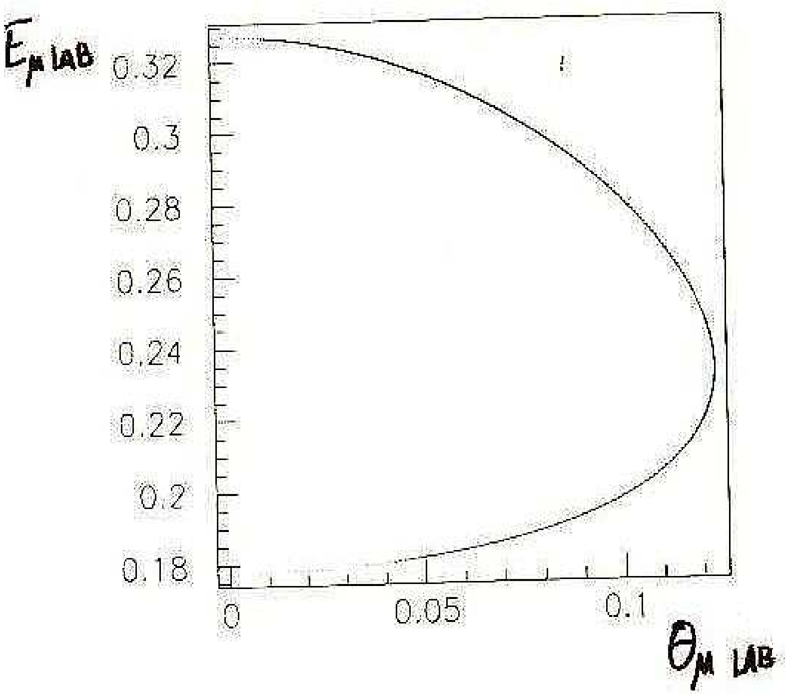


2 GeV $\pi \to \mu\nu_\mu$ decay

Muons kinematically limited to $\theta < 1.1^\circ$ (20 mrad)

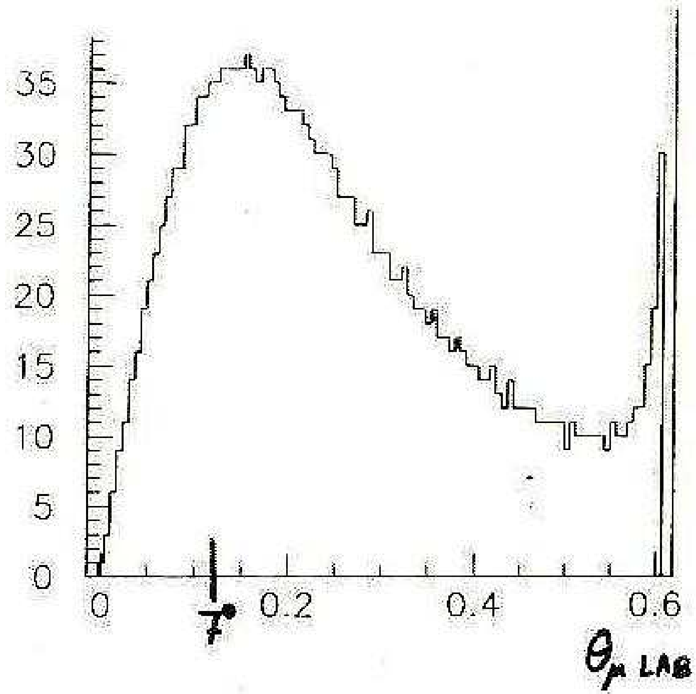
350 MeV $\pi \to \mu \nu_\mu$ decay

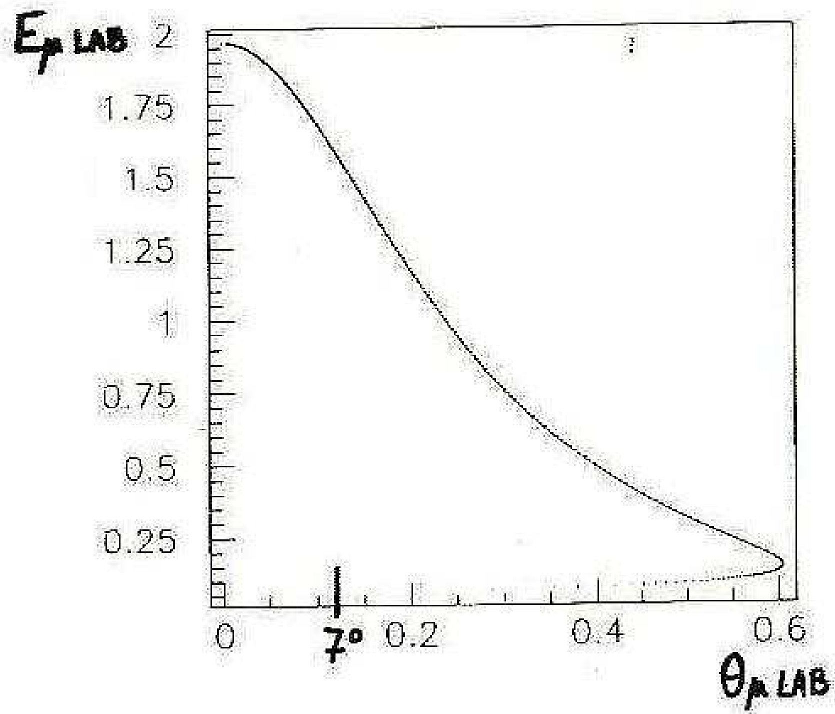




Threshold for 7° μ emission is $p_\pi \cong$ 350 MeV/*c*.

Decay muon momentum is only 230 MeV/*c*.

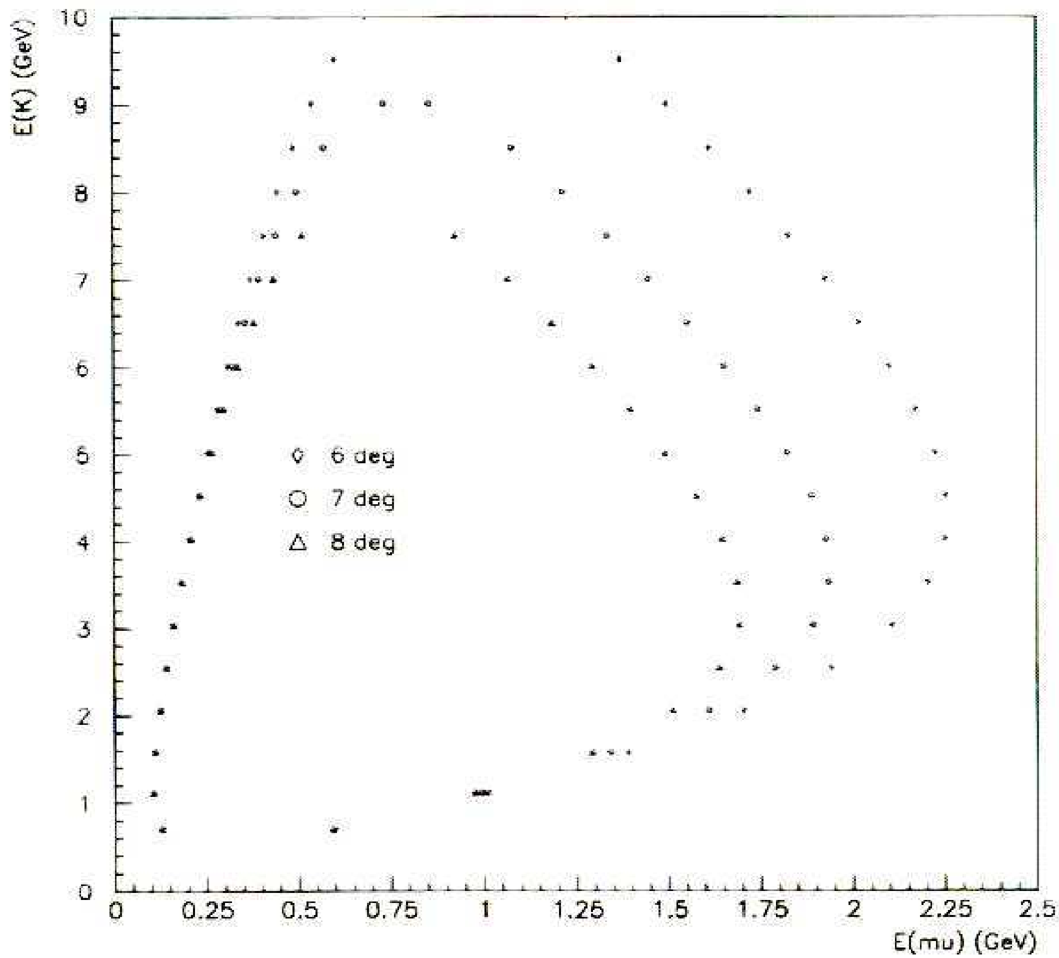




2 GeV $K^+ \rightarrow \mu\nu$ decay

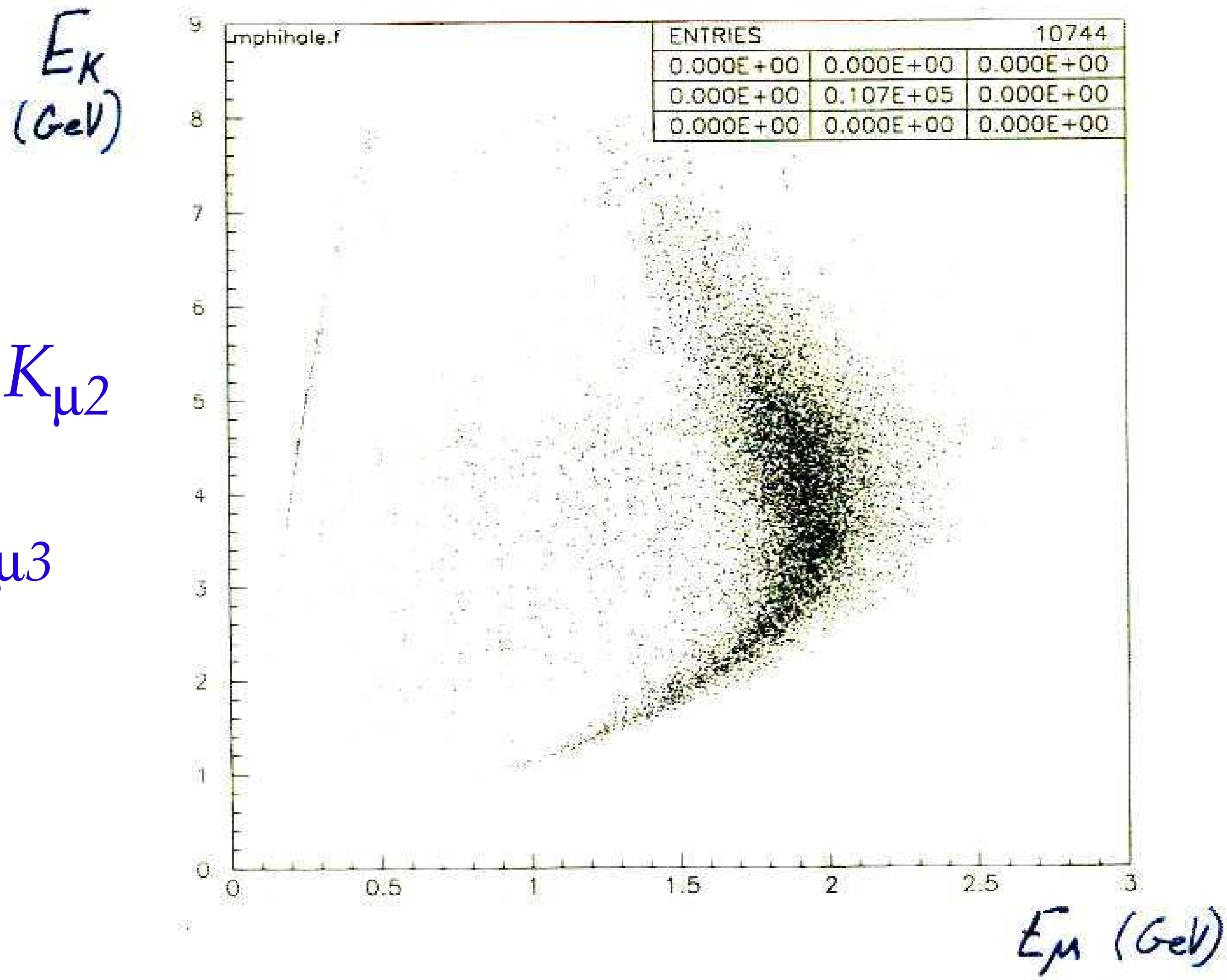
- Muons can be emitted at angles up to 0.6 rad (~34°)
- Muons at 7° have E=1.6 GeV

Decay muon energies versus parent kaon energy for different decay angles:

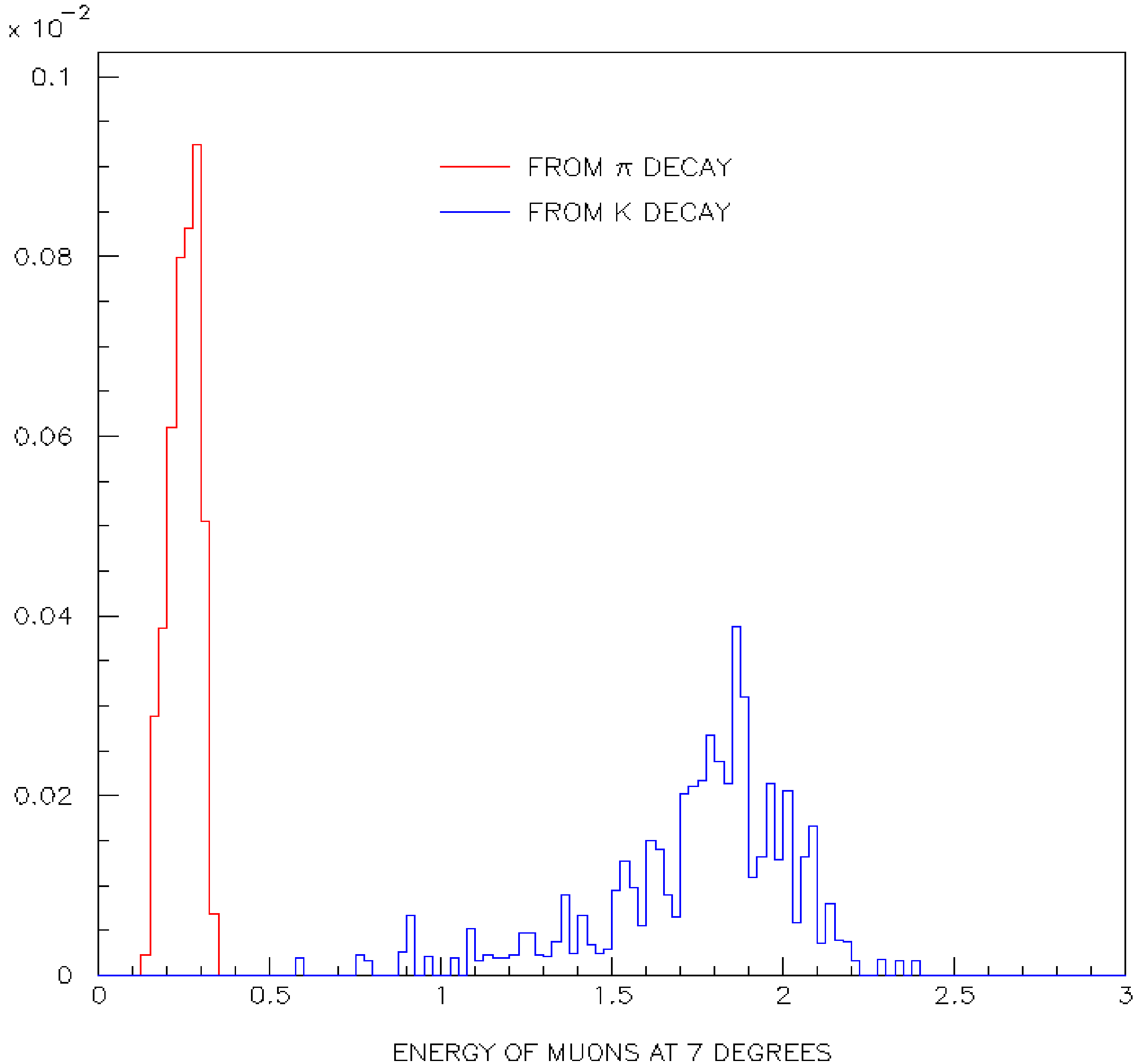


Muons from K decay in BooNE GEANT MC

- Arc pattern: $K_{\mu 2}$
- Infill from $K_{\mu 3}$



Muons at 7° from pion, kaon decay:

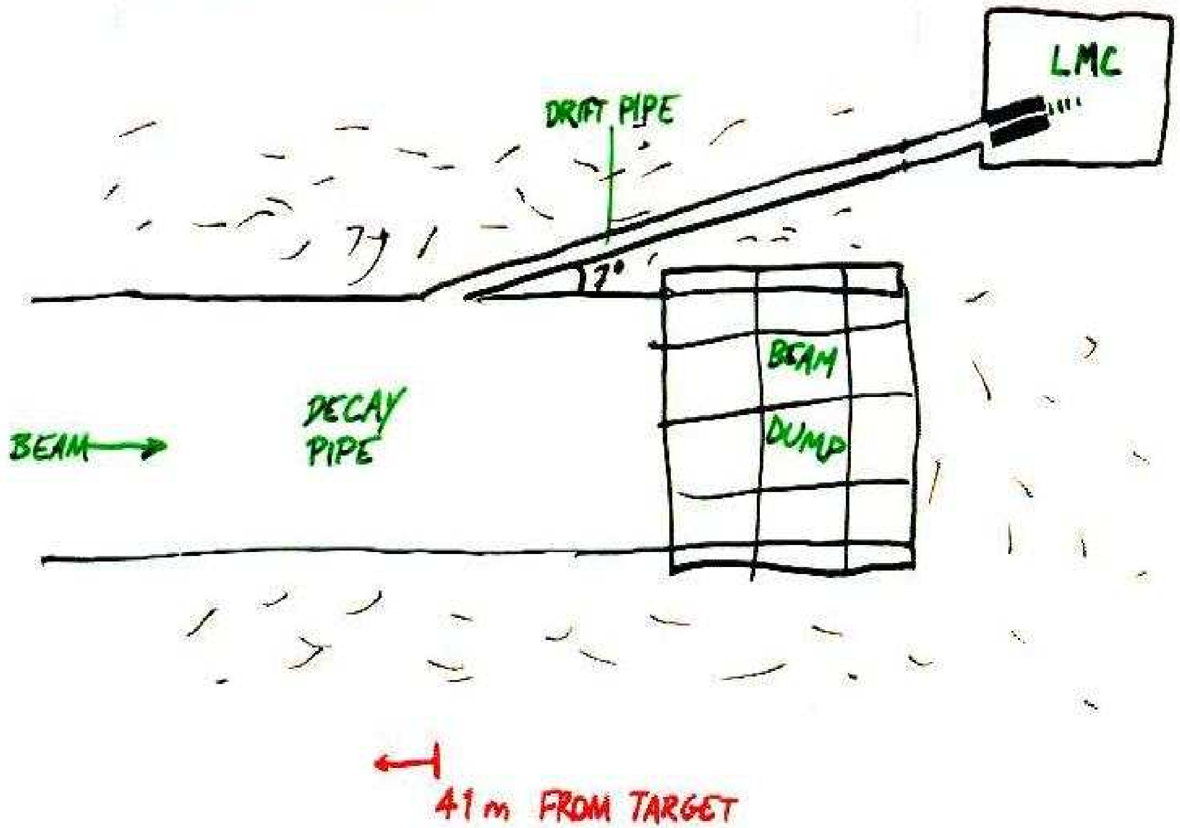


- Clear separation between π and *K* decays.
- High apparent *K*/π parentage ratio:
  - most π in beam too high energy to produce 7° muon
  - Low-energy π more likely to have decayed upstream

The LMC
"Little Muon Counter"

Concept: allow decay muons to enter an evacuated drift pipe 7° off the beam axis.

A magnetic spectrometer measures the muon momentum spectrum at the end of the drift pipe.



LMC Group

A subset of the BooNE collaboration

University of Colorado:

T. L. Hart, H. A. Koepke, R. H. Nelson, E. D. Zimmerman

Columbia University:

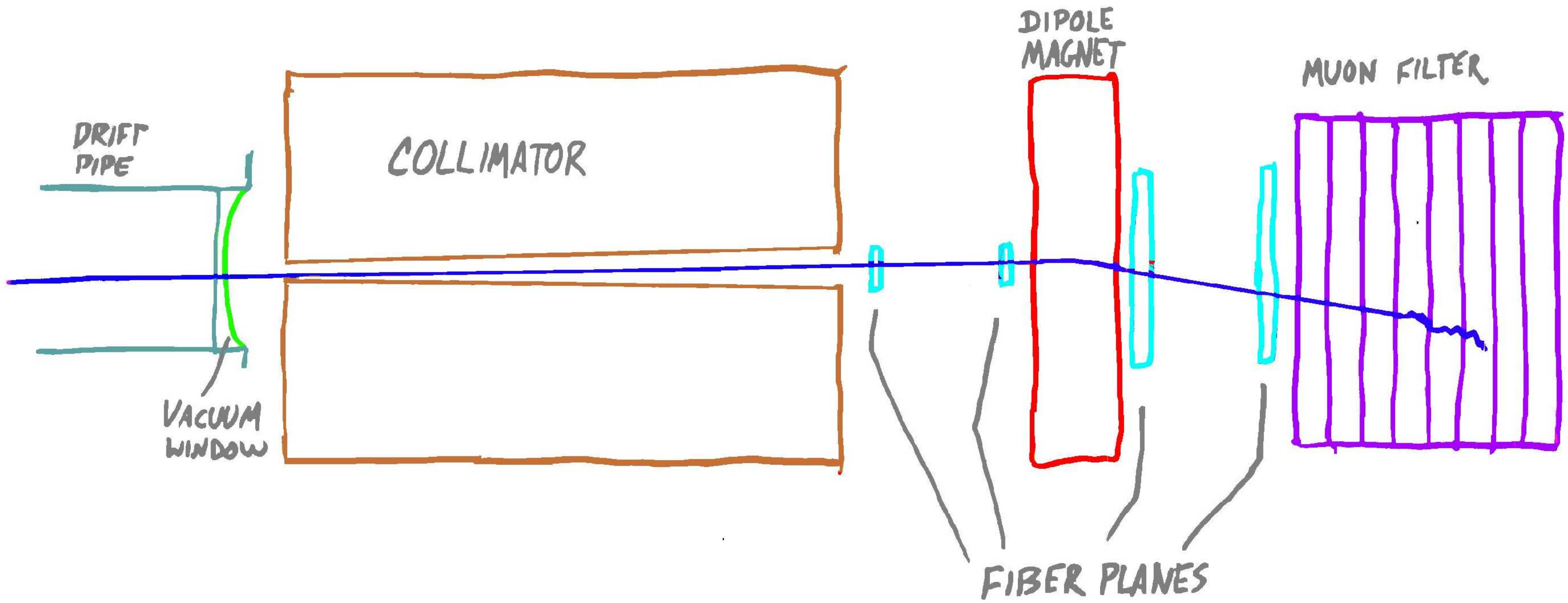
J. Formaggio (now at Univ. of Washington)

Princeton University:

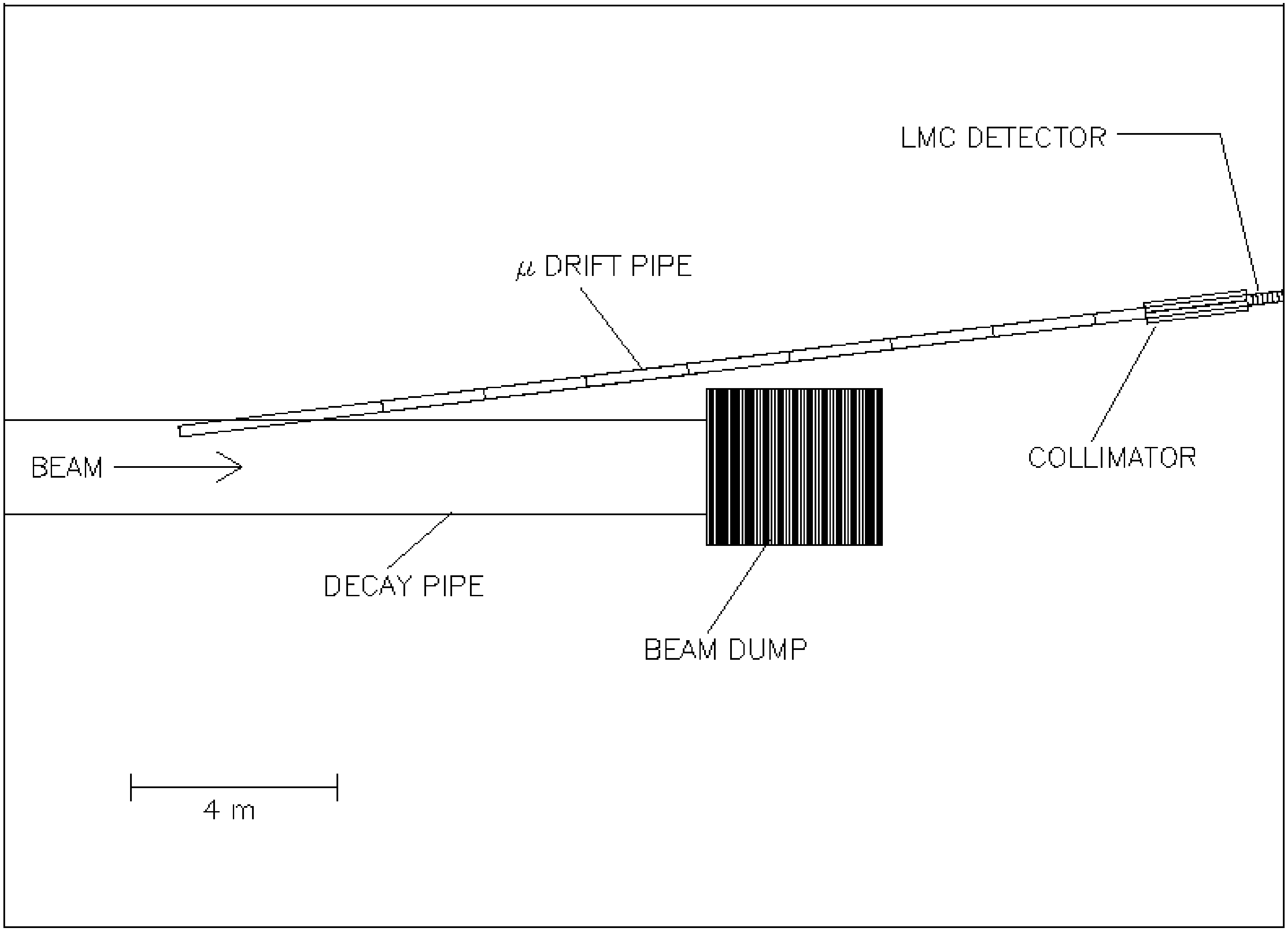
A. O. Bazarko, J. Hunt, P. D. Meyers

LMC Components

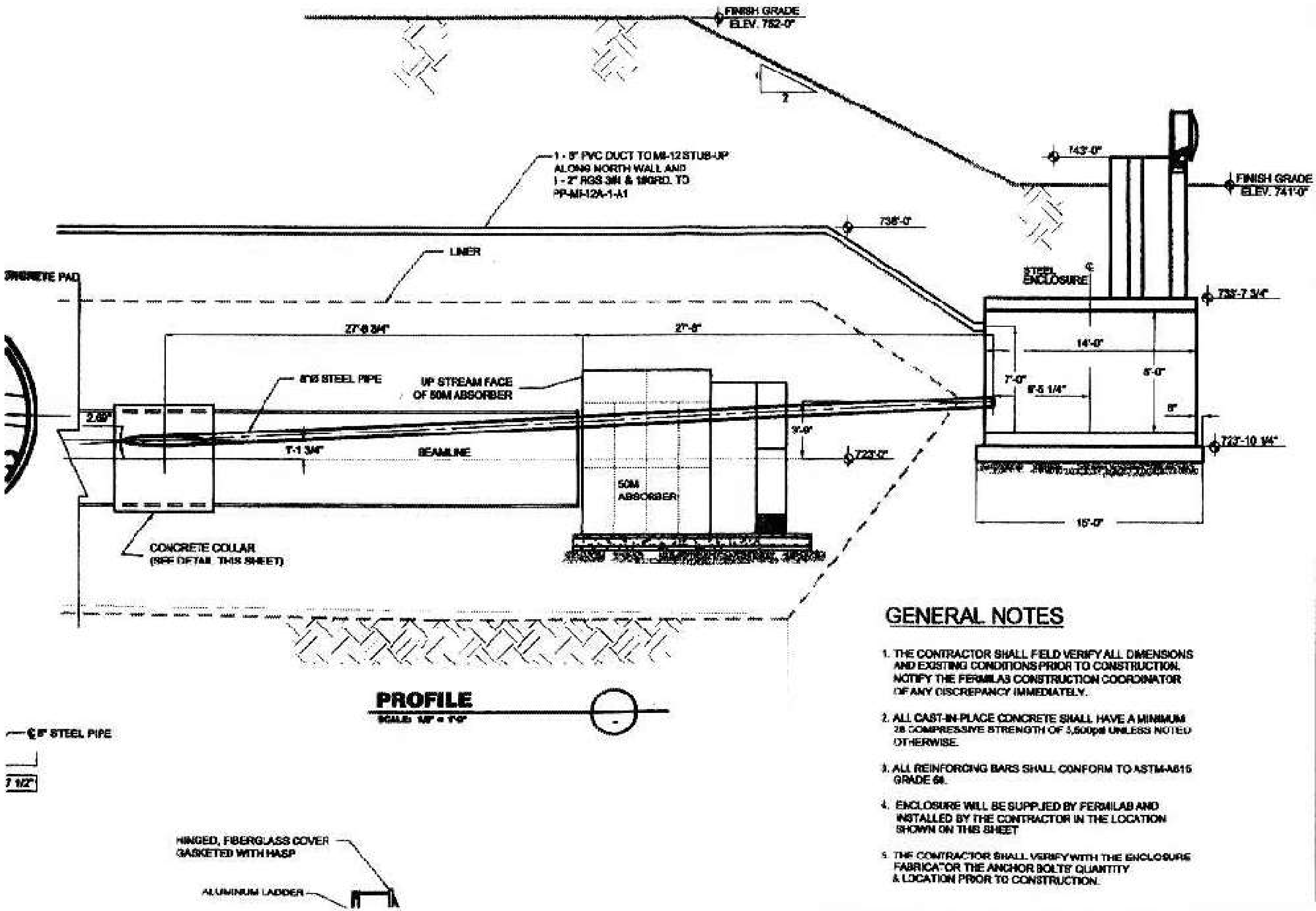
- Drift pipe
- Collimator
- Veto
- Fiber Tracler
- Dipole Magnet
- Muon Filter



GEANT model of LMC region



Civil Construction for LMC

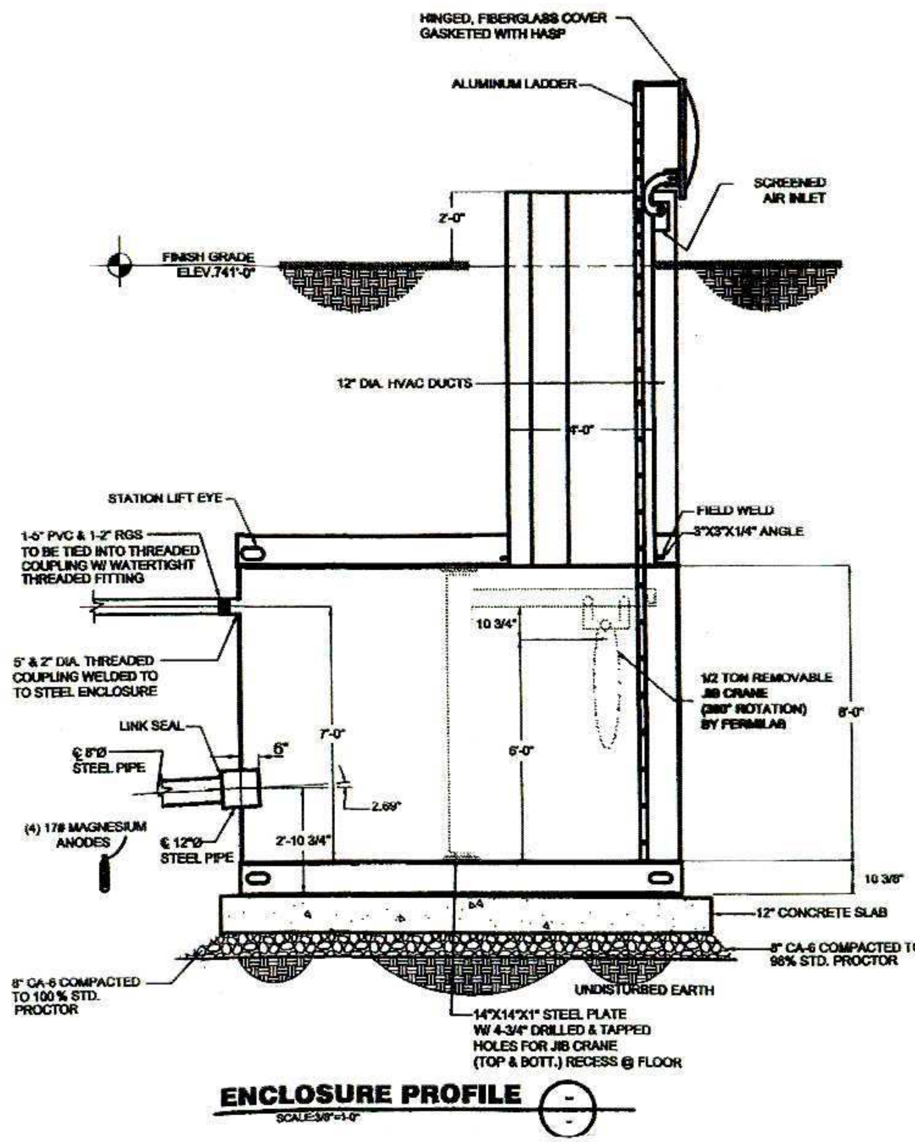


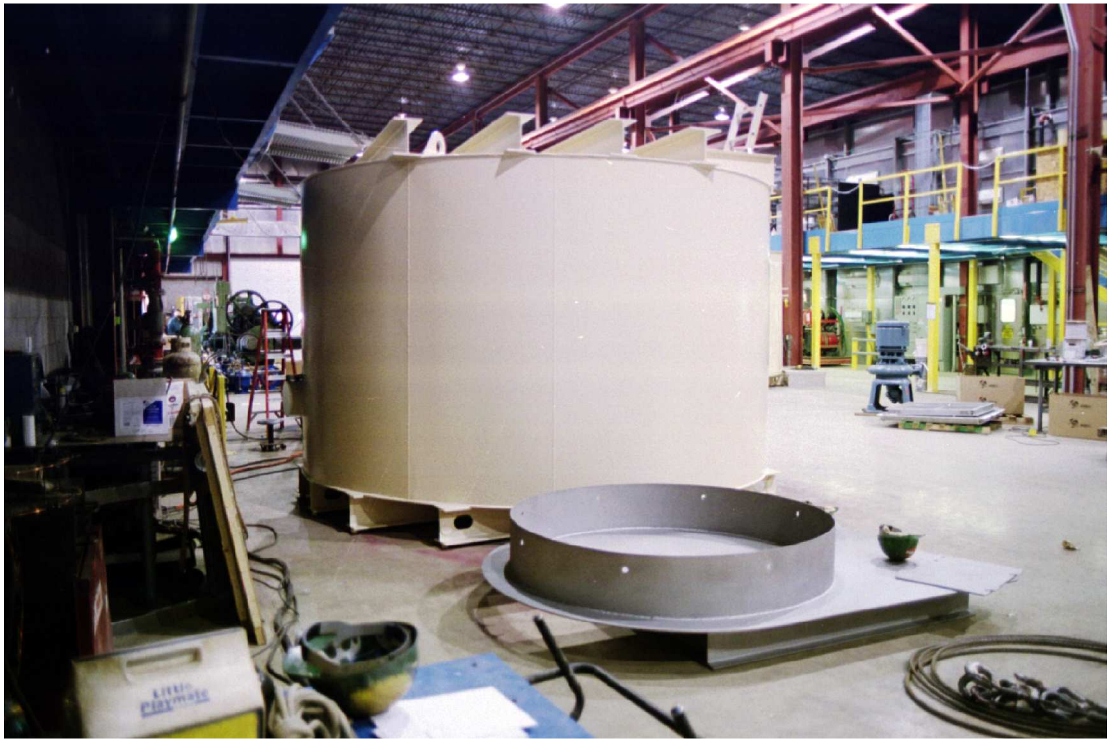
GENERAL NOTES

1. THE CONTRACTOR SHALL FIELD VERIFY ALL DIMENSIONS AND EXISTING CONDITIONS PRIOR TO CONSTRUCTION. NOTIFY THE FERMILAB CONSTRUCTION COORDINATOR OF ANY DISCREPANCY IMMEDIATELY.
2. ALL CAST-IN-PLACE CONCRETE SHALL HAVE A MINIMUM 28 COMPRESSIVE STRENGTH OF 3,500psi UNLESS NOTED OTHERWISE.
3. ALL REINFORCING BARS SHALL CONFORM TO ASTM-A615 GRADE 60.
4. ENCLOSURE WILL BE SUPPLIED BY FERMILAB AND INSTALLED BY THE CONTRACTOR IN THE LOCATION SHOWN ON THIS SHEET
5. THE CONTRACTOR SHALL VERIFY WITH THE ENCLOSURE FABRICATOR THE ANCHOR BOLTS' QUANTITY & LOCATION PRIOR TO CONSTRUCTION.

Prefabricated cylindrical steel enclosure for LMC detector equipment. Diameter 14 feet (4.2 meters); floor level 20 feet (6 meters) below grade.

Enclosure built by USEMCO, Inc. in Tomah, Wisconsin and delivered directly to site at FNAL.





Exterior and interior of LMC enclosure vault at USEMCO (February 2001)

BooNE decay pipe and LMC drift pipe, November 2000

LMC enclosure being positioned

Drift pipe connection

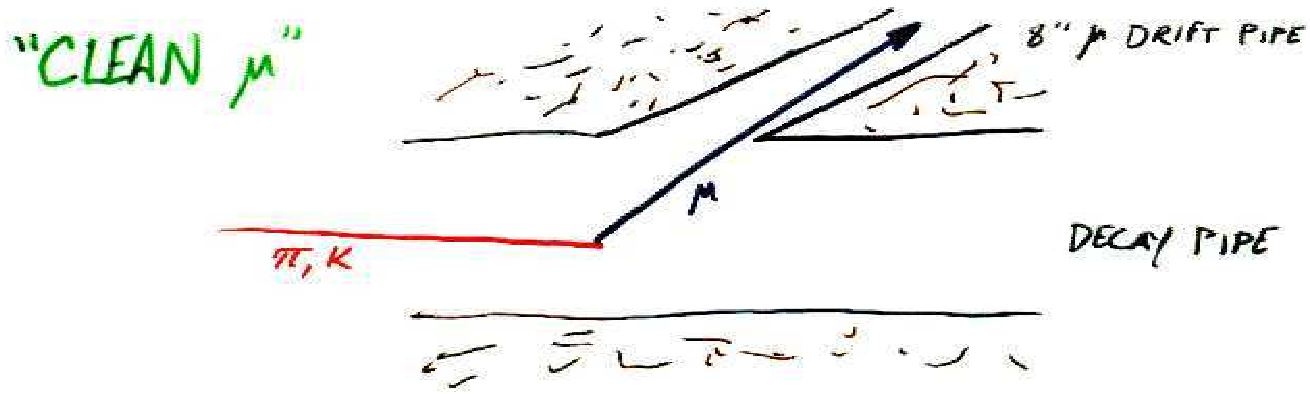
November-
December 2001

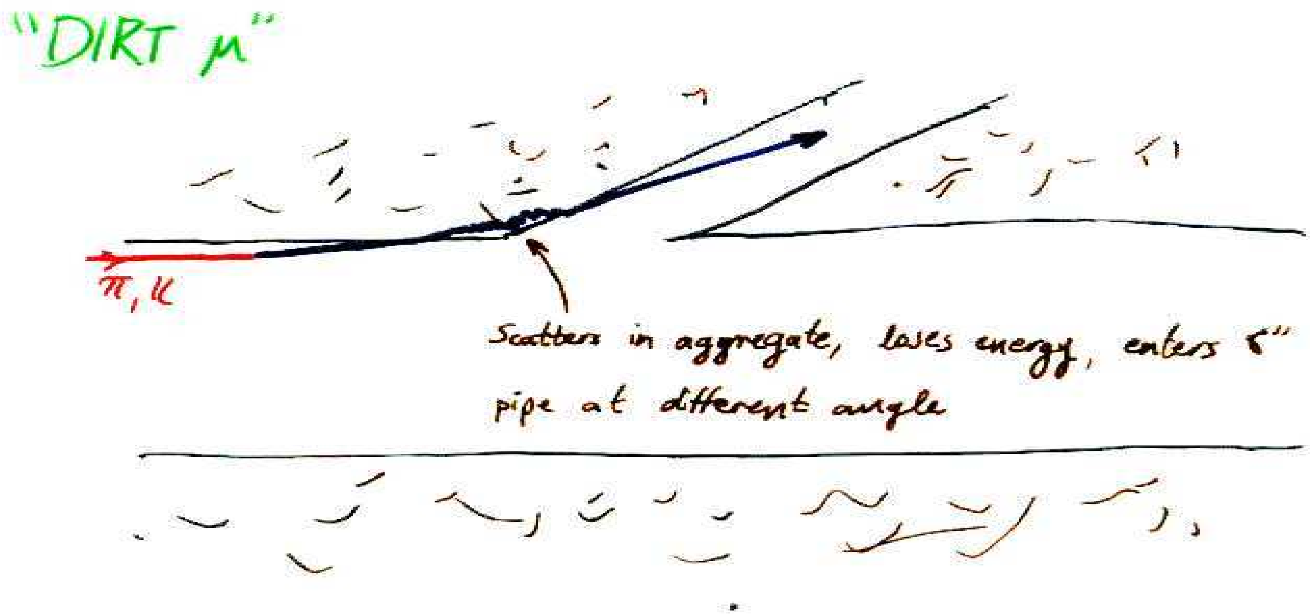
Backfilling -- only access shaft visible

MI-13A service building

Later addition to project; houses front-end readout electronics, DAQ

Collimator motivation: background from “dirt muons”



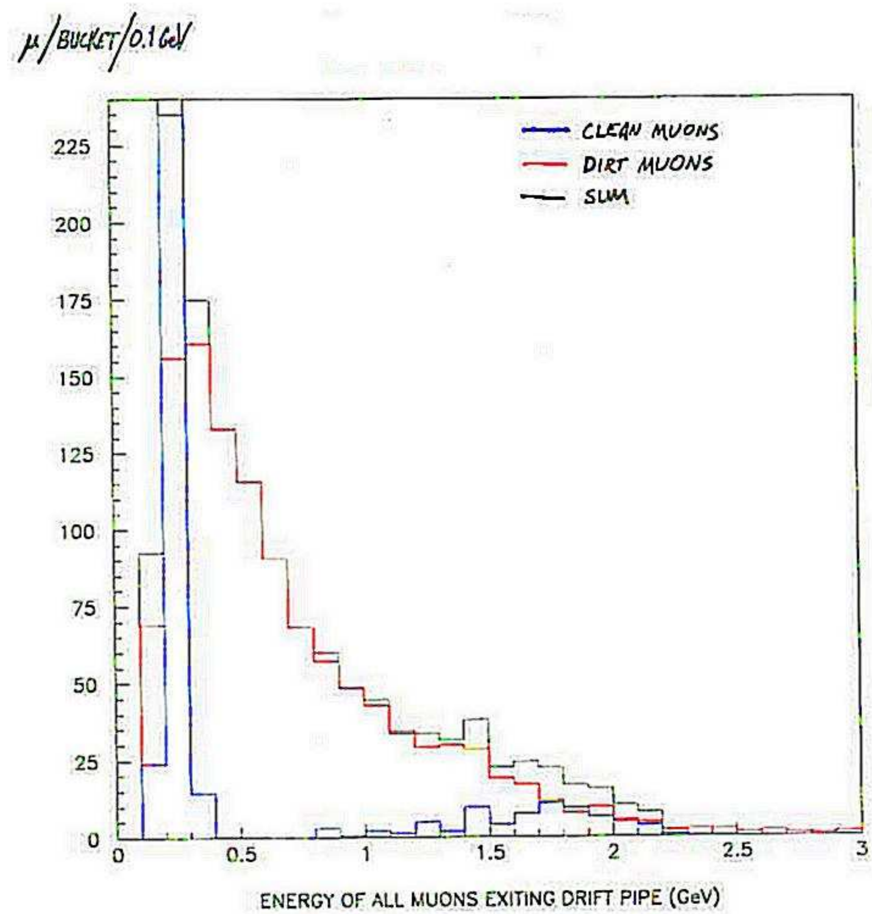


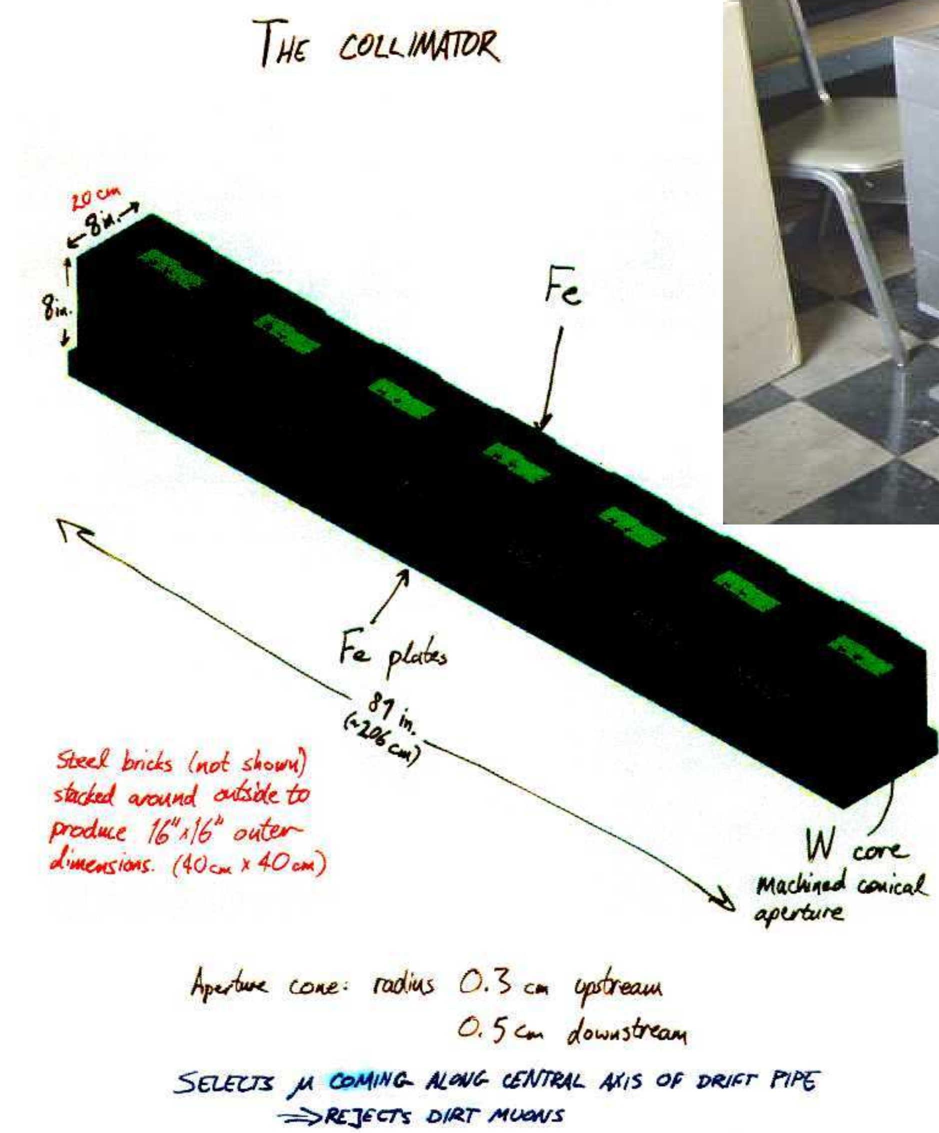
Spectrum of muons out of drift pipe

- Unmanageable rate: thousands of muons per RF bucket (19 ns)

- Dirt muons dominate

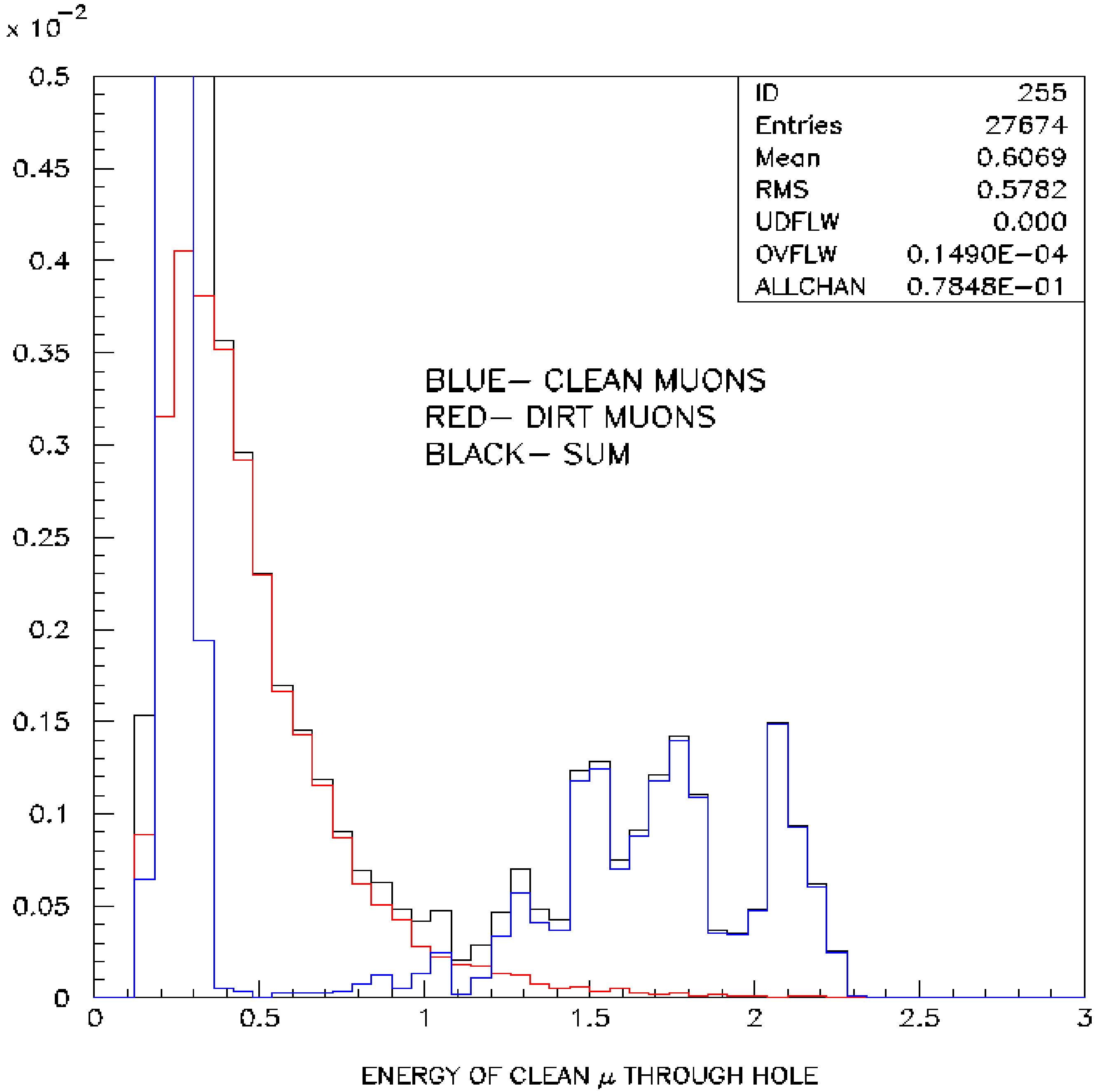
Solution to both issues: narrow collimator



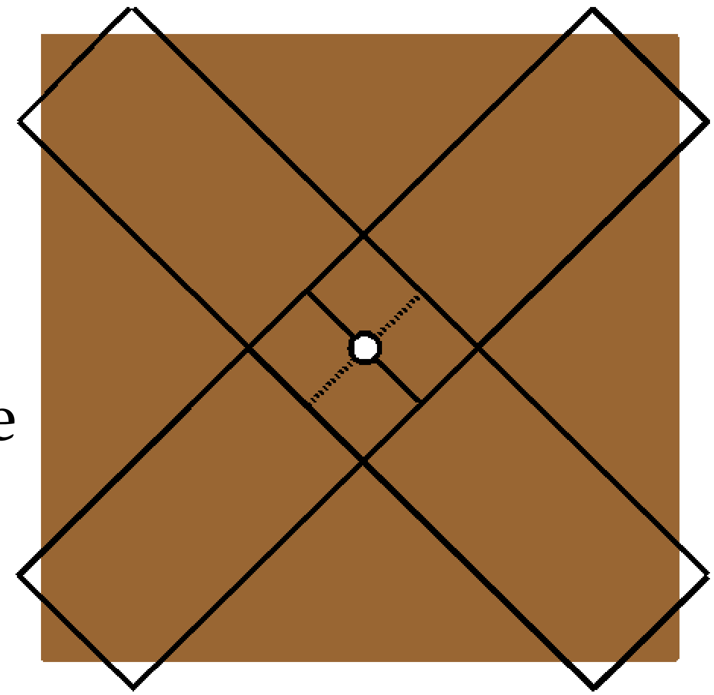


Collimator designed and machined at Princeton in 2001

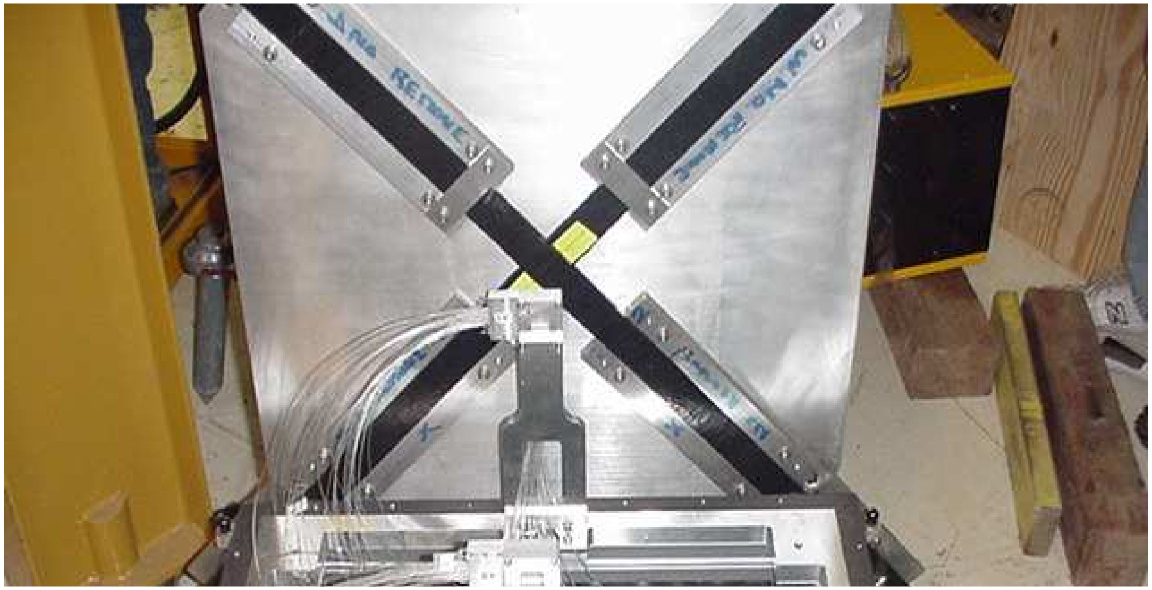
Clean muons dominate above 1.2 GeV after collimator.



Veto



Veto consists of four scintillator panels between the collimator and the fiber tracker, with a circular central aperture, radius 0.5 cm. Veto hole is aligned to the collimator hole and will be used in reconstruction to define the limiting aperture.



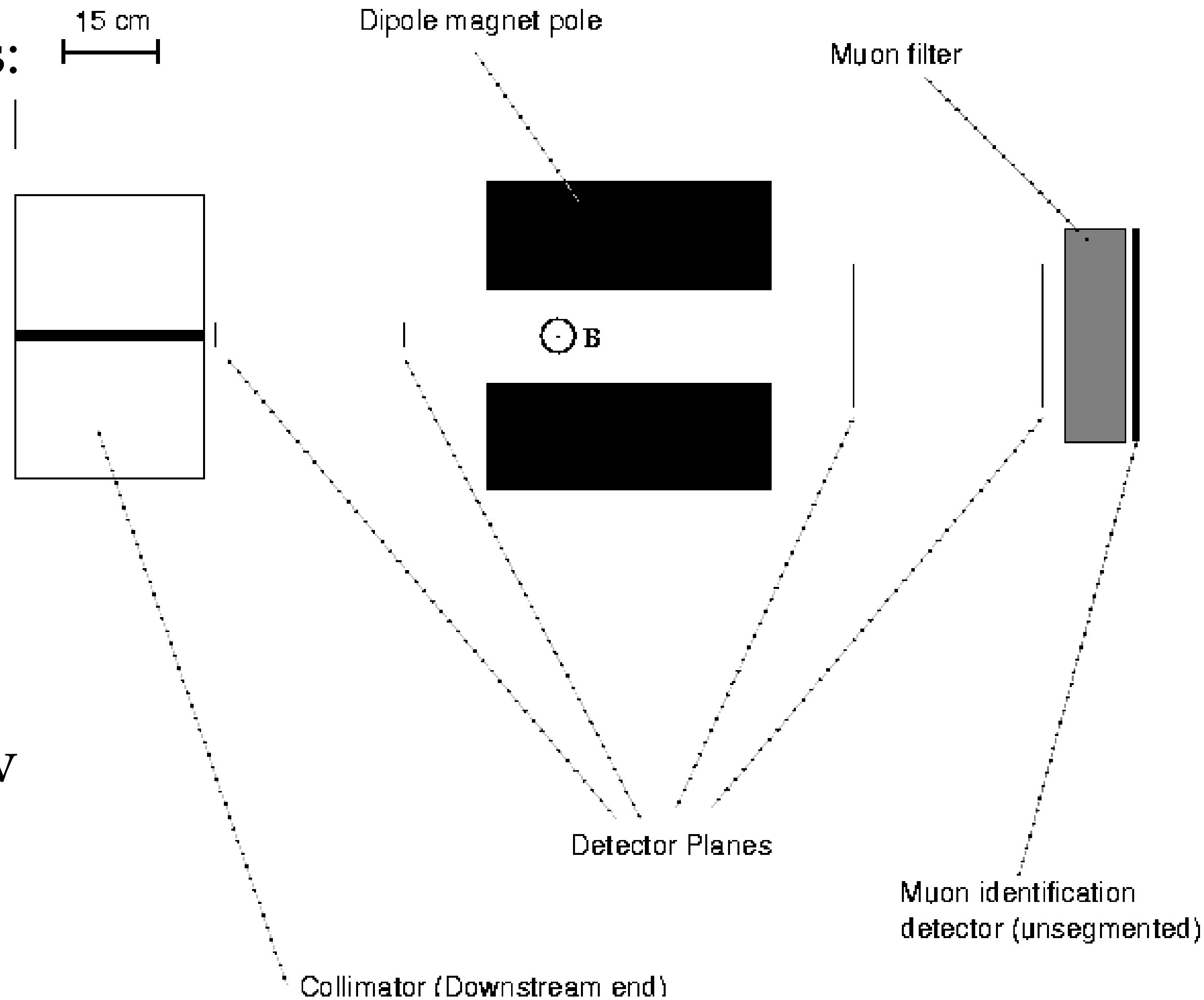
Fiber Tracker

Bicron 1mm scint. fibers; dry interface to light-guide fibers; 6-stage Hamamatsu R1666 PMTs with custom active bases

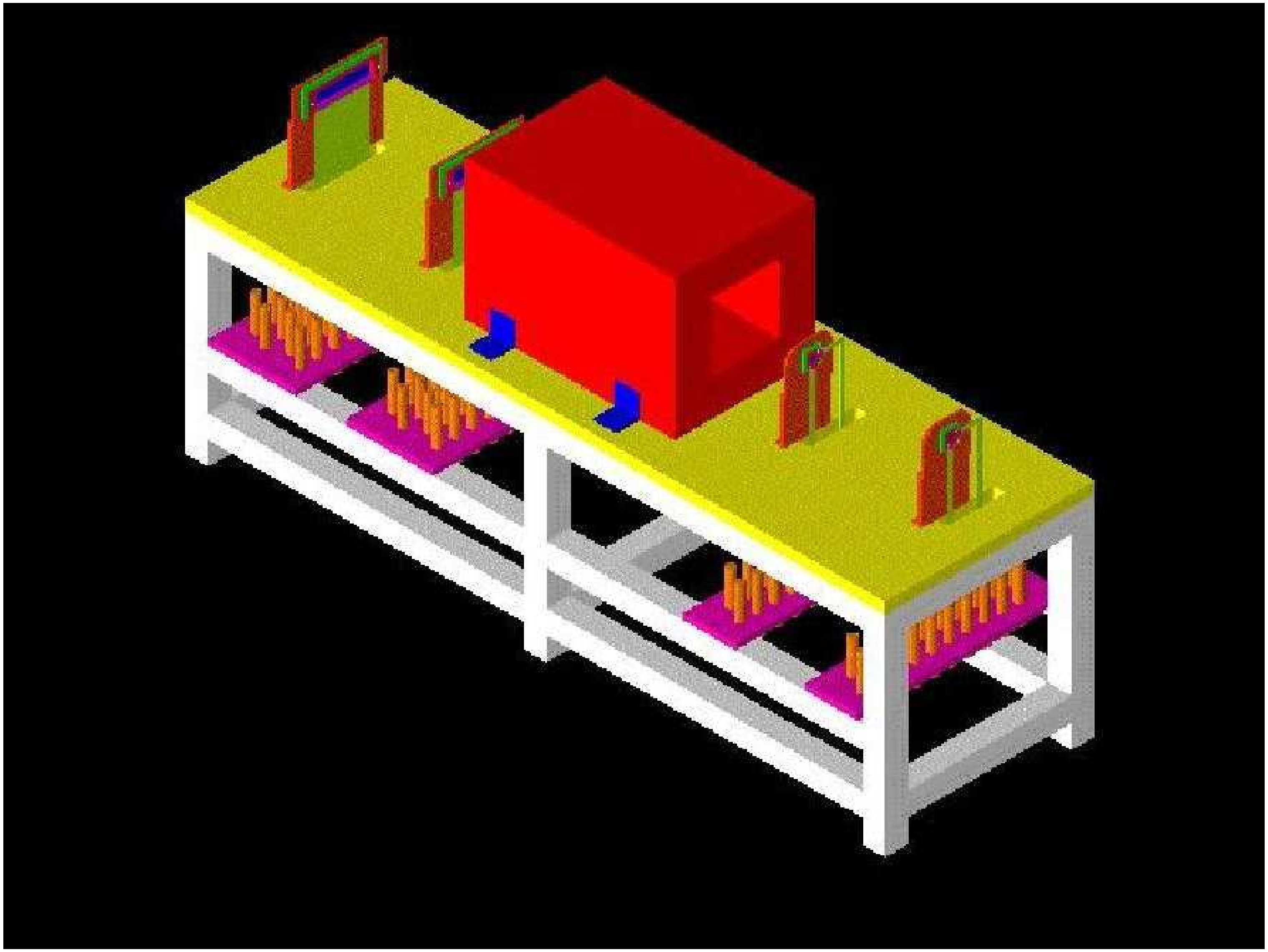
Upstream 2 detectors: 1.5x1.5 cm^2, x and y views

Magnet: permanent (ferrite), 2.7 kG, field length 22.5 cm.

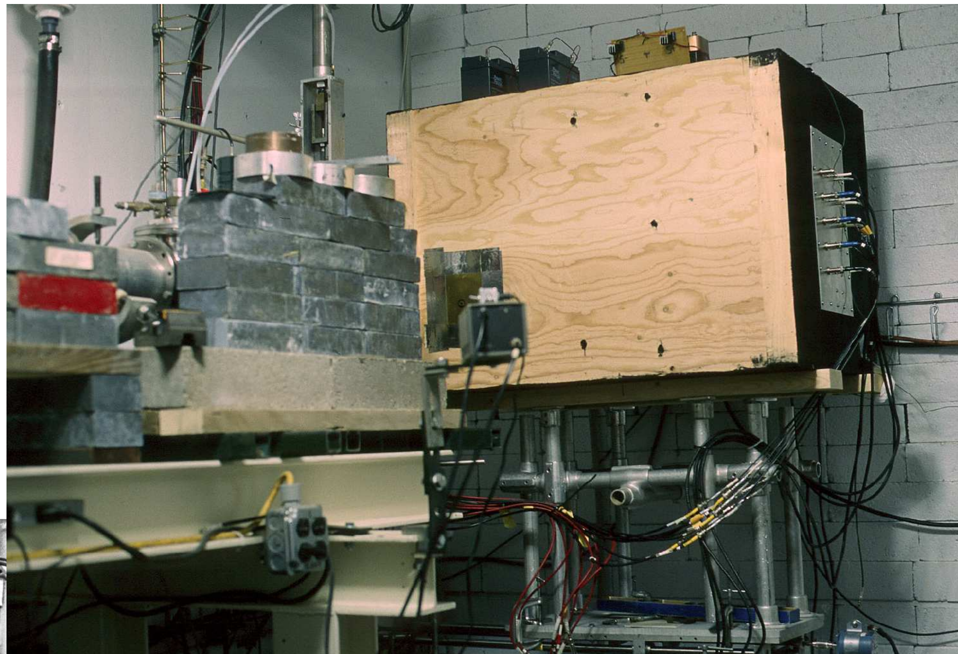
Downstream: 2x12 cm^2, only x view (for post-bend slope)

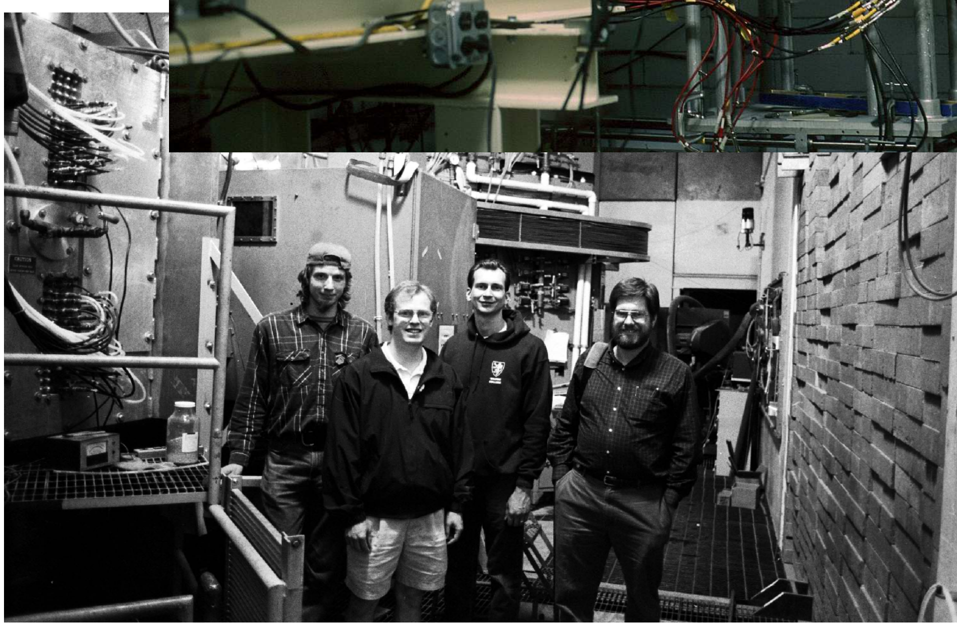


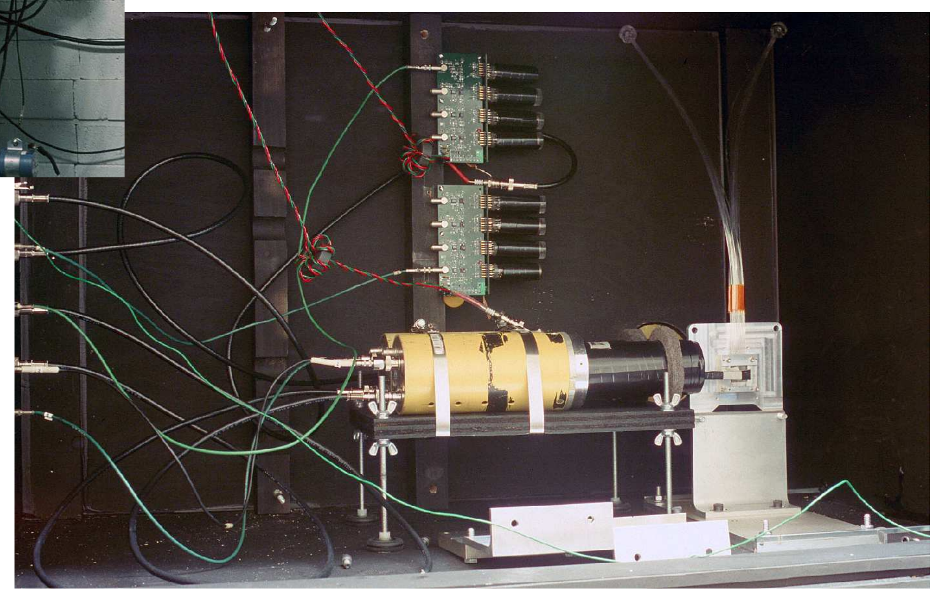
Design rendering of fiber tracker frame



June 2002 beam test of fiber plane and PMT base prototypes at Indiana University Cyclotron Facility: Charged particle inefficiency measured to be $\sim 10^{-4}$.

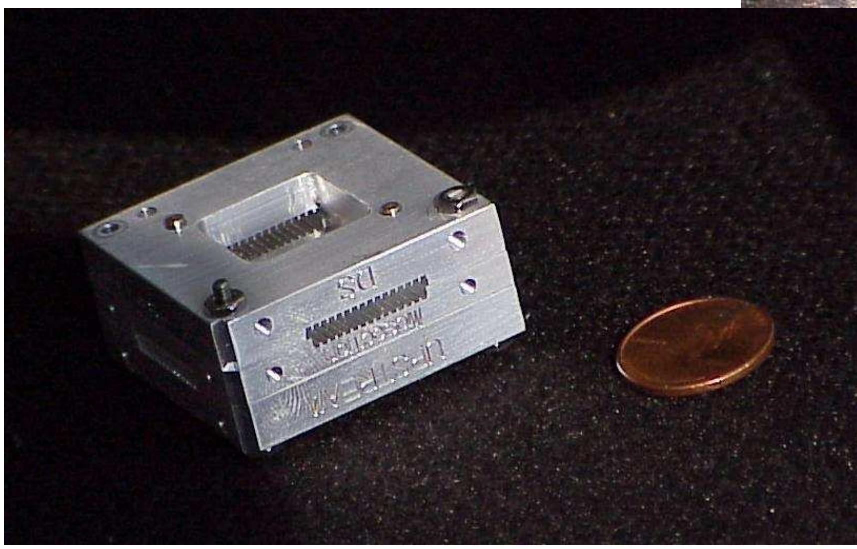




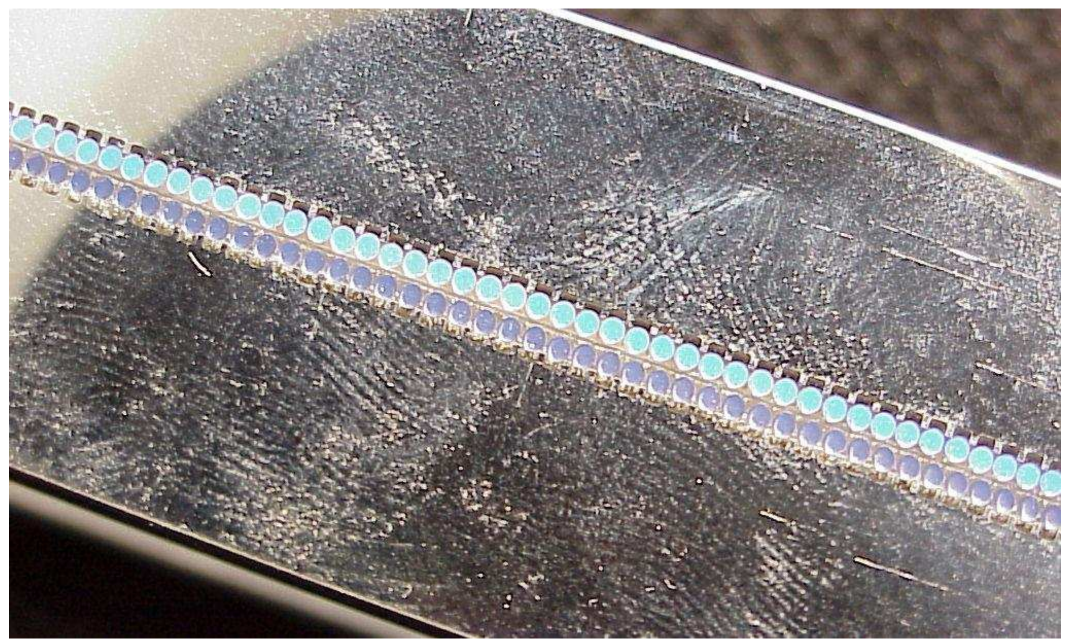


Fiber planes

Downstream plane
(X view only, 12 cm wide)



Upstream plane (without fibers)
(X and Y views, 1.5 cm square)

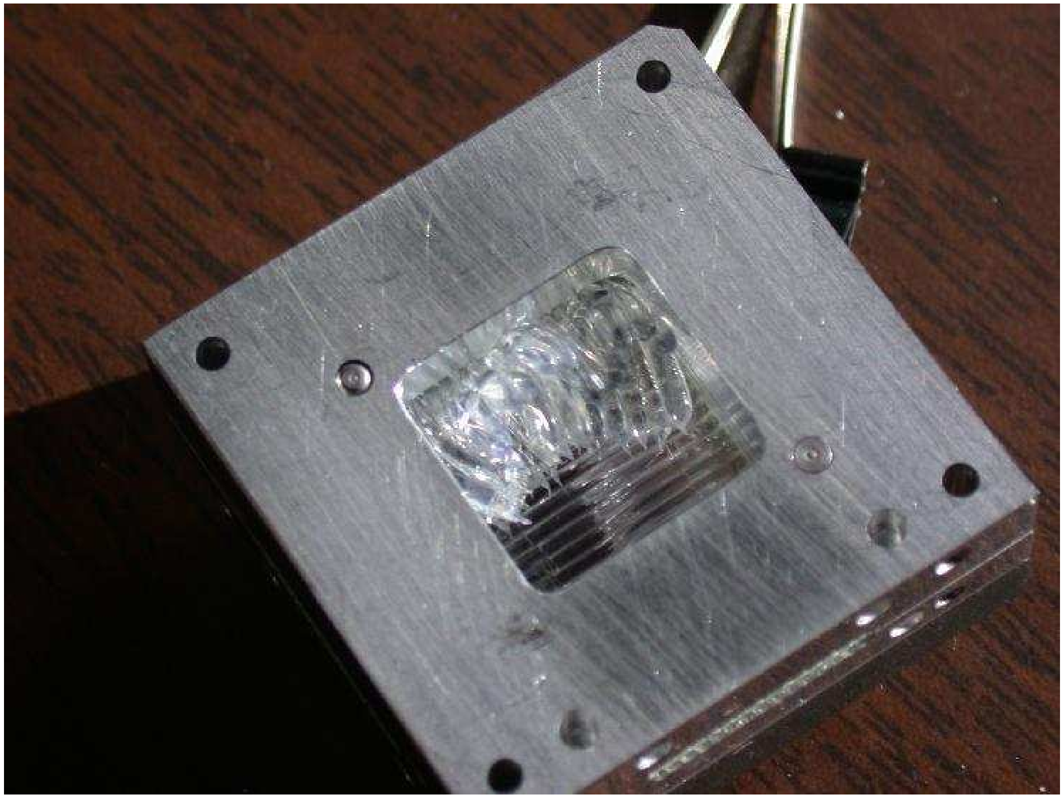


Staggered double fiber layer
removes inefficiency from cracks

Fiber placement and aluminization

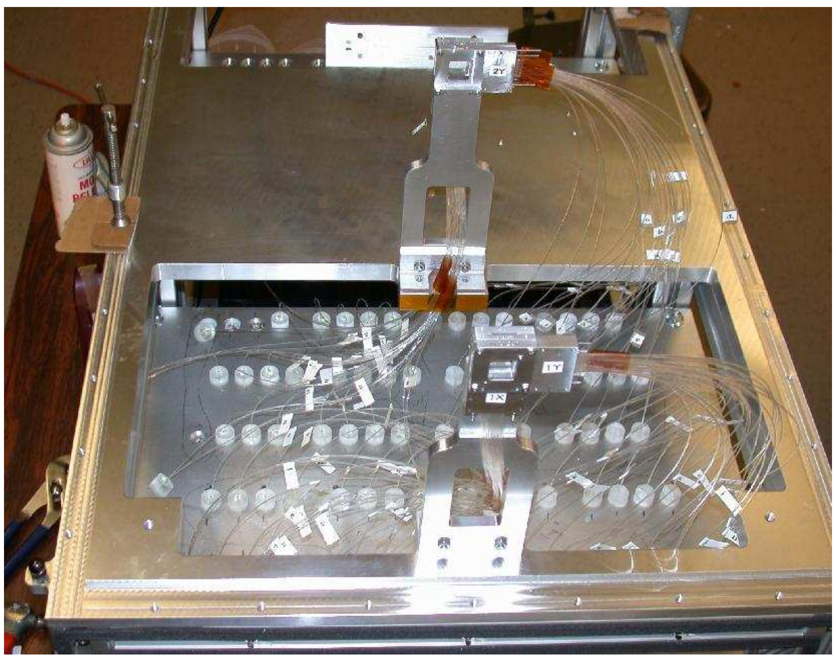
Scintillating fibers were laid in the detector frames and mounted with epoxy, then the ends were polished in the frames. The non-interface ends of the fibers were aluminized.

Aluminization was performed by a company which failed to provide enough cooling. All fibers were destroyed! Detector completion delayed several weeks.



Light guide fibers and interfaces

Fibers were mounted in frames, epoxied in place, and the interface ends polished.



Interfaces were mounted on the detector frame in nominal position, and routed through acrylic cookies which were placed on "cookie sheets" with holes at the future positions of PMT faces. Fibers were then clipped in place to exact length and epoxied into cookies; cookies were then polished with fibers in them.

PMTs and bases

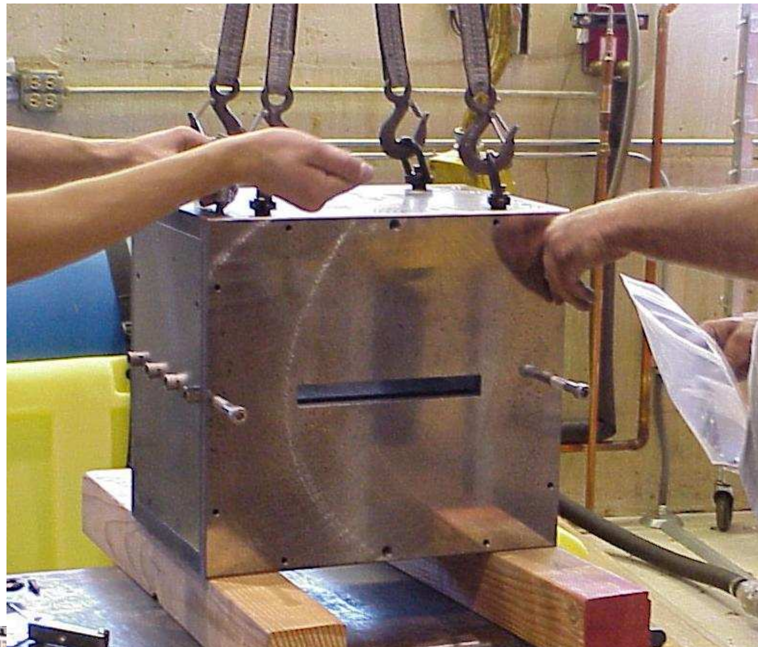
Tracker uses 160 Hamamatsu R1666 3/4 inch PMTs, previously used in FNAL E872.

New active "quad bases" with 4 PMTs and onboard preamp, postamp (total gain 400). Each HV channel serves 4 PMTs.

Road Trip!

EDZ drove the detector across the country to FNAL in a rented van in March 2003.

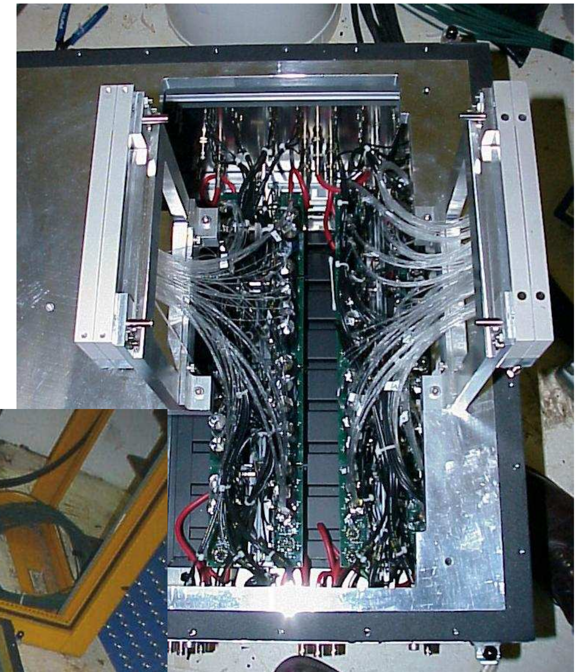
Spectrometer dipole magnet



- 2.7 kG permanent dipole
- 1 in. x 9 in. gap
- Magnet based on Recycler ring designs

Final assembly of fiber tracker at FNAL

Placing cookies on tubes



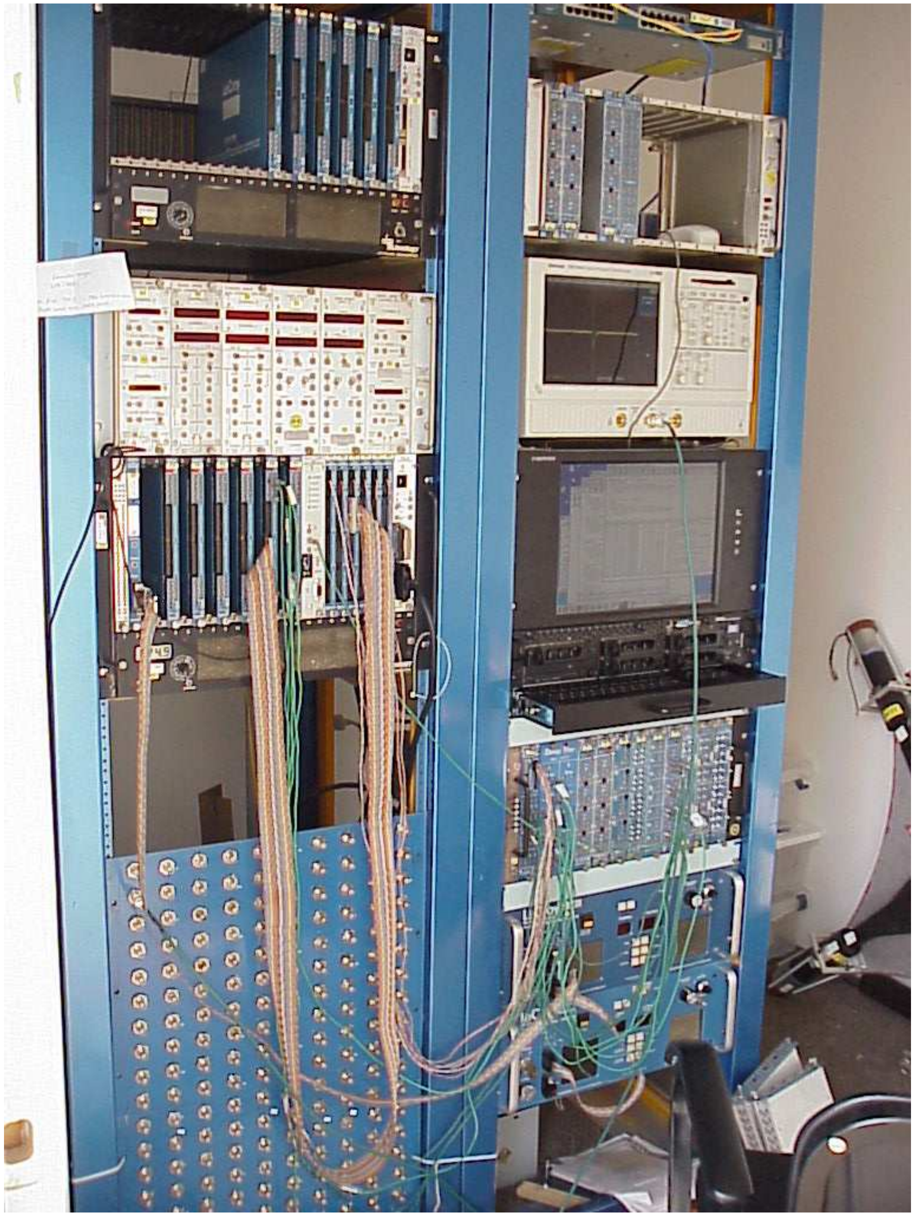
Magnet installation and final alignment

October 2003

Muon filter

- 20 inch long, 8 inch square tungsten/scintillator range stack behind fiber tracker will identify muons.
- Expect μ/π ratio of order 2-4; most π are from K_{l3} decay.

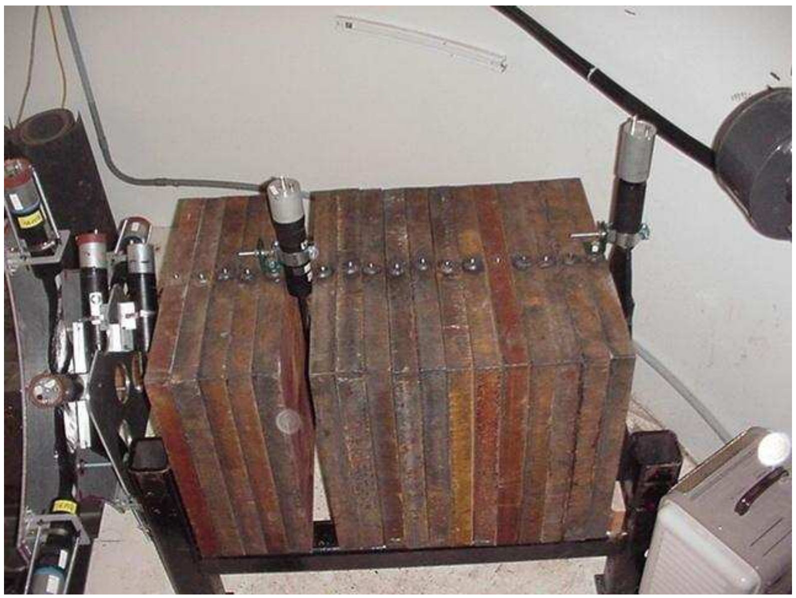
Data acquisition

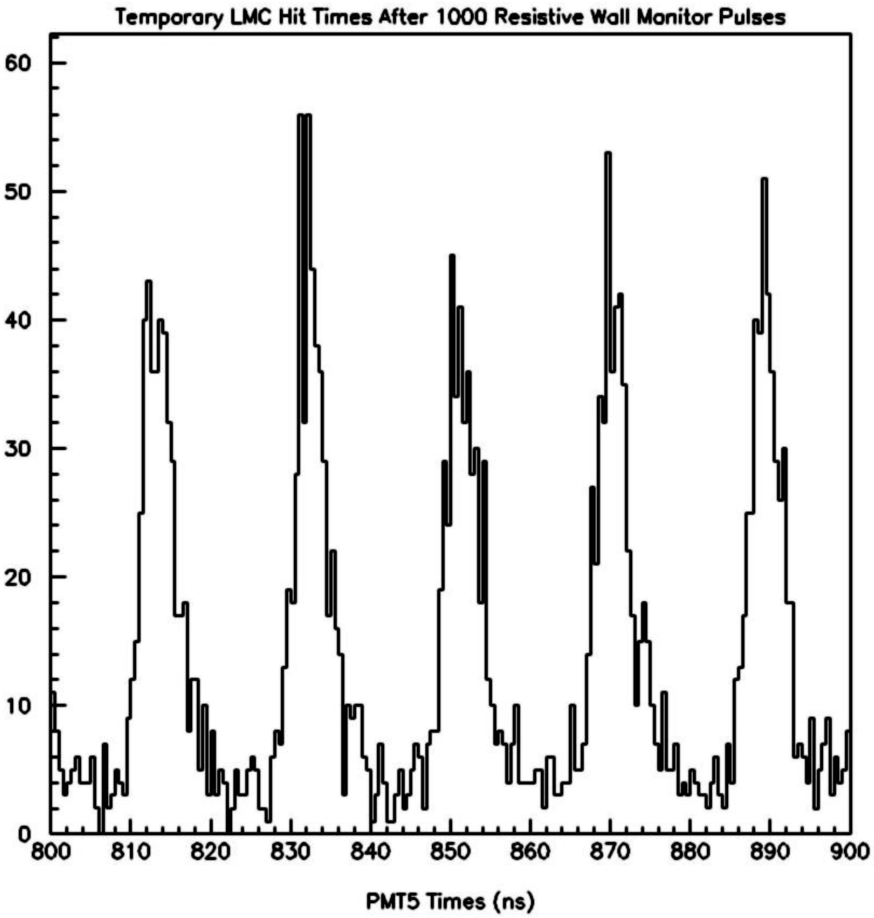


- CAMAC-based data acquisition (DAQ) read through SCSI interface into rack-mounted Linux PC.
- LeCroy 3377 500 ps multihit ECL TDCs are triggered by beam arrival signal and read each fiber tracker, veto, and muon filter channel.
- GPS module time-stamps each each event.
- Data stream is read into main MiniBooNE DAQ and events are merged with beamline and neutrino detector data based on GPS time stamp.
- High voltage supplied by LeCroy 3402 HV mainframes.

Temporary detector

After the aluminization accident we decided to place a temporary steel/scintillator range stack behind the collimator, to make a rough check of rates.





- Result: 19 ns RF beam structure easily visible.
- Low E rates difficult to measure with unsegmented detector (high occupancy) but rate of muons with E>1.3 GeV is within MC expectations of 1-3 per spill.

Status of the LMC

- Major installation work during current accelerator shutdown

- Fiber tracker is operating -- expect first beam signals any day!

- Working on analysis code infrastructure

- Expect first LMC analysis in a few months.