# MINOS Progress and Status

R. Bernstein
Neutrino Telescopes
Venice 1999

- Review of Experiment Goals
- Progress in Construction
- Progress in Simulations
- Plans

***Me***

***ICARUS, OPERA, NOE,...***

Wings for Venice

# *Funding and Review Committees*

*The True Danger for MINOS and NGS*

# Beams

## *Three Beams: Low, Medium, High Energy*

- Physics:

| Beam | Physics | CC/kt*yr | Problems |
|---|---|---|---|
| Low | $\Delta m^2 \sim< 3 \times 10^{-3}$ | 400 | Efficiency? |
| Medium | $10^{-3} \sim \Delta m^2 \sim 5 \times 10^{-3}$, some $\tau$ | 2000 | Lower $\Delta m^2$ Reach |
| High | $\Delta m^2 \sim 3 \times 10^{-3}$, NC Tests | 5000 | My Favorite |

- Technical Status:
  - Horns Designed for All Three
  - Water Cooling Measured and More than Enough
  - Design of Target for Low Energy Horn in Progress
- Upcoming Work:
  - Target Tests
  - Power Supply Tests

From MC;
Variations in Beam
$\lesssim 2\%$ in any
2GeV bin

Events/kt/yr/GeV

for different NuMI Beams

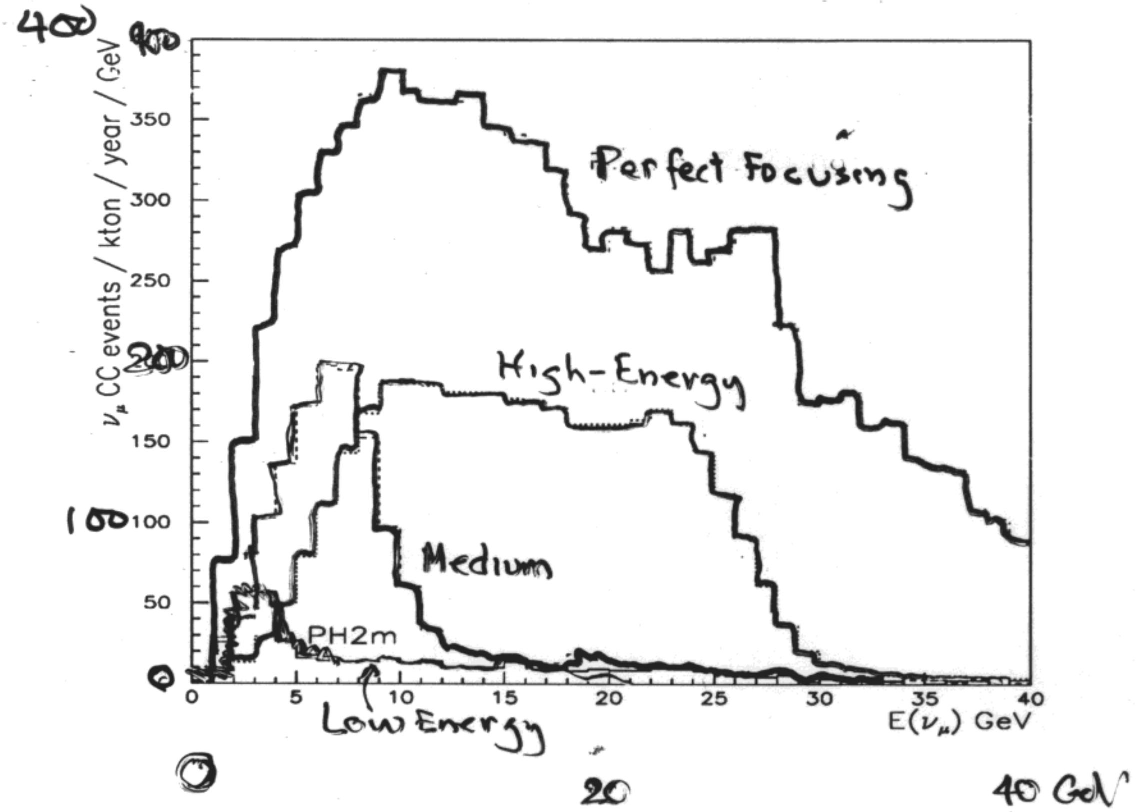


Figure 9: The energy spectrum of $\nu_\mu$ charged current events for different focusing systems according to the GEANT/Fluka Monte Carlo. 'Perfect Focusing' refers to an ideal case, where all pions emerging from the target are somehow focused exactly parallel to the beam line. 'H66' refers to the NUMI baseline focusing design described in the conceptual design report[20]. The spectra labeled 'PH2' and 'PH2m' result from new designs for lower energy beams. (Note: the spectra are artificially cut off below 1 GeV to save computer time.)

somewhat larger radius and shorter length to increase rates.

Figure 11 shows the 'wrong' flavor backgrounds calculated for the three beams described above. The Monte Carlo calculation used GNUMI, a program based on GEANT/Fluka, which adds to GEANT such effects as polarization in the muon decay and the V-A nature of 3-body decays.

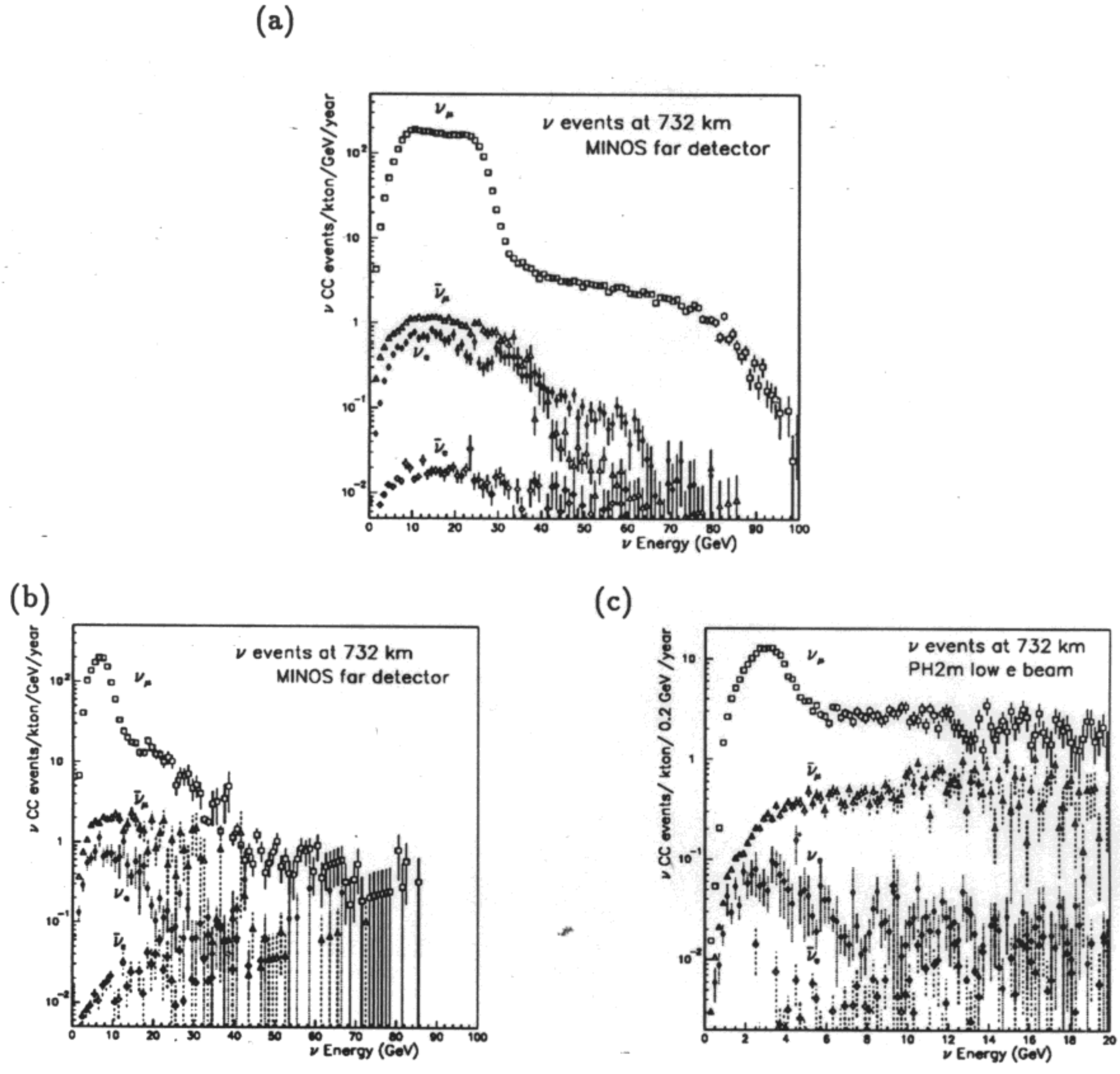


Figure 11: The neutrino flavor components of (a) the baseline H66 design, (b) the PH2 design, and (c) the PH2m design. Note the different horizontal scale for the PH2m plot.

The low energy beam spectra shown in Figure 9 both show substantial high energy tails. If such tails turn out to produce backgrounds in some oscillation tests, they can be suppressed by a 'beam plug' which absorbs very forward pions. This technique has been used successfully on some previous neutrino experiments, but has not yet been studied for NuMI low energy beam designs.

JIM HYLEN

# NuMI Beam Update

- Specifications for Civil Construction Title II signed off:
  Size/location of tunnels, target hall, labrynths, ..., fixed

- Prototype Target Test
  Setup nearly complete at AP0
  Beam schedule unknown: anytime over next year
  Requested $10^{19}$ protons on target – may not get all

- Horn Cooling Test Stand Results: Encouraging
  Needed at least 1700 W/m$^2$C heat transfer coefficient
  for water spray, appears easy to achieve

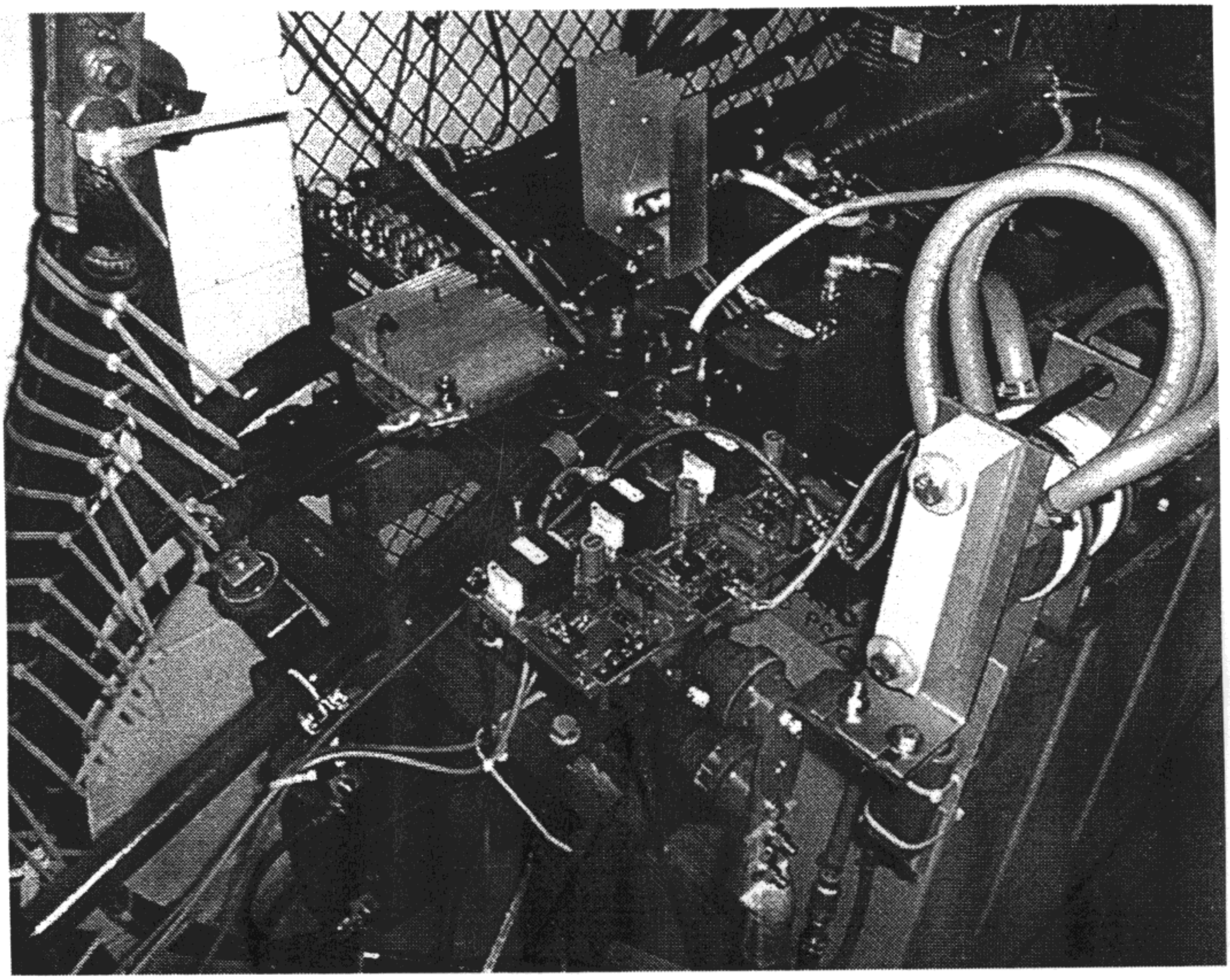
- Prototype Horn
  Drawing package going out for bids now
  Expect to assemble prototype horn next Fall

- Horn Baseline Design
  Minor modification made to horn shape in December,
  to provide more room for low energy target
  Stress calculations show modified horn OK

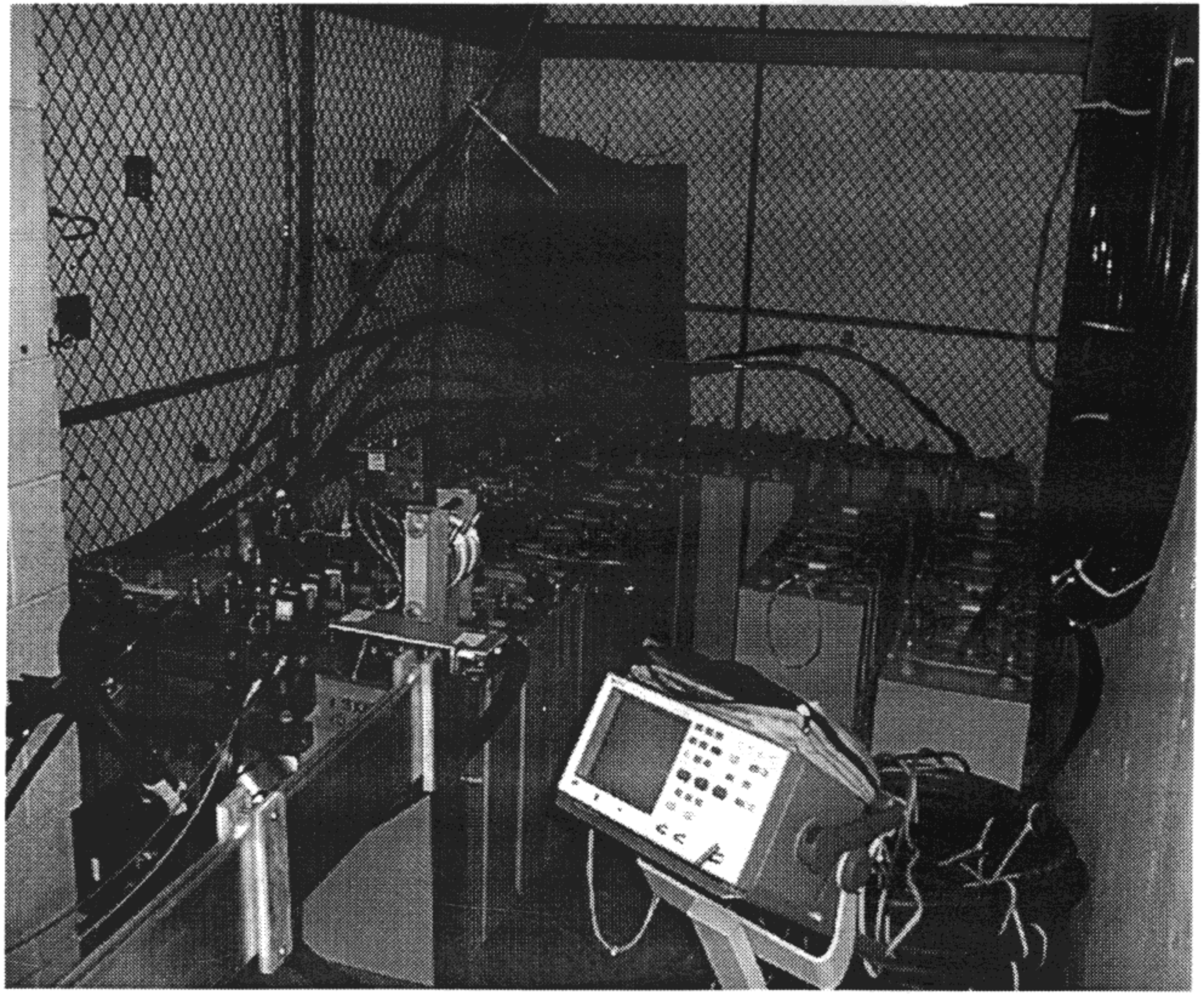
- Horn Power Supply Test – 1/8 of system
  SCRs performing well, accumulated $10^5$ pulses
  Found stripline connections need silver plating

- Radiation Safety calculations
  Continues to be a large effort
  Nancy Grossman appointed to coordinate

- IHEP will continue PH2(le) target conceptual design



# NuMI Horn Power Supply SCR Test Fixture



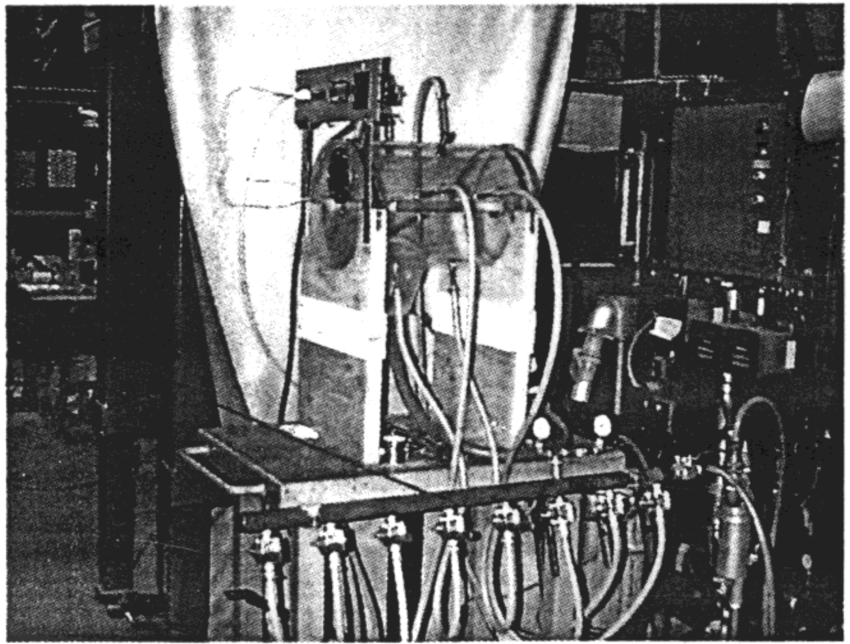
# Horn Water Spray Cooling Test

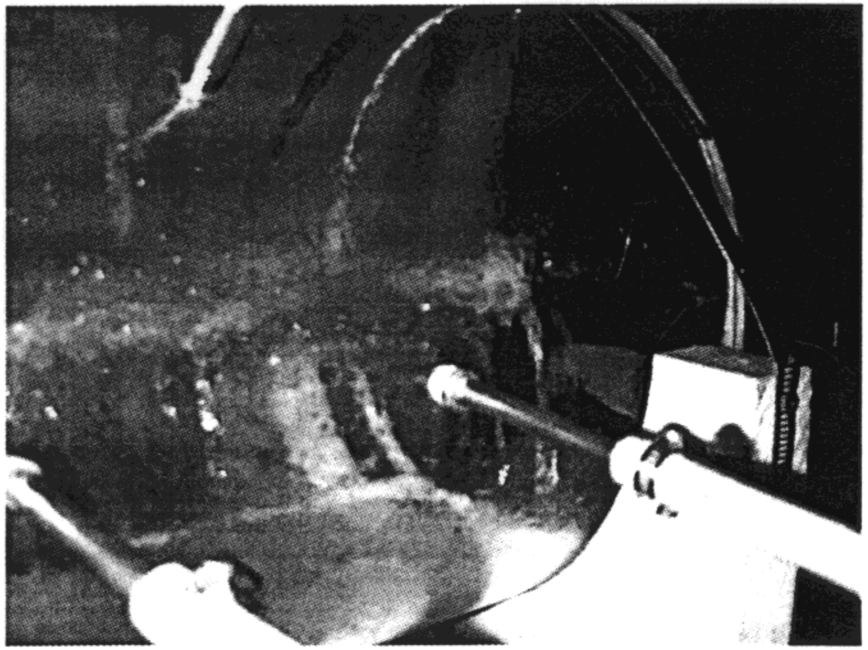
Measure Heat Transfer Coefficient

- Have achieved more than necessary 1700 $W/m^2C$

Examine spray pattern, water buildup

- Water film is thin enough that beam absorption should not be significant



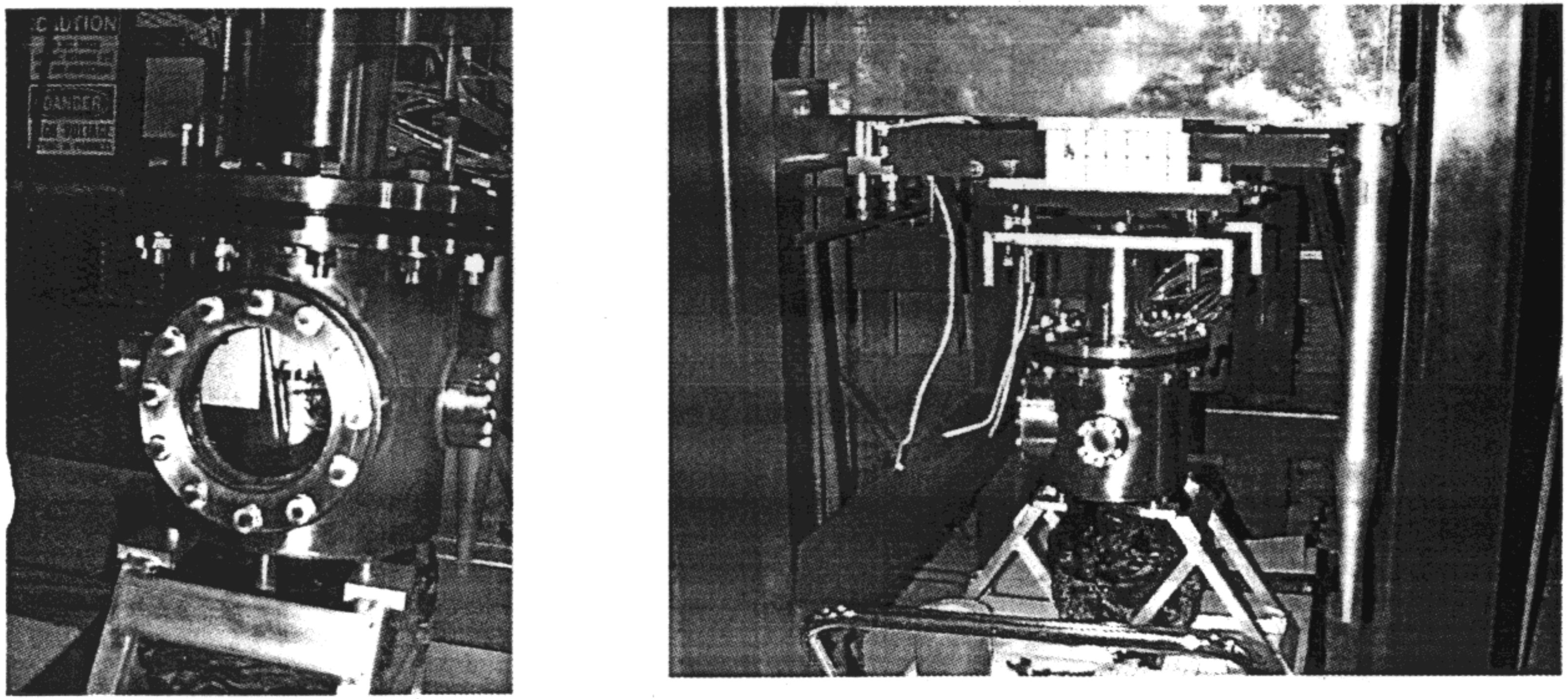


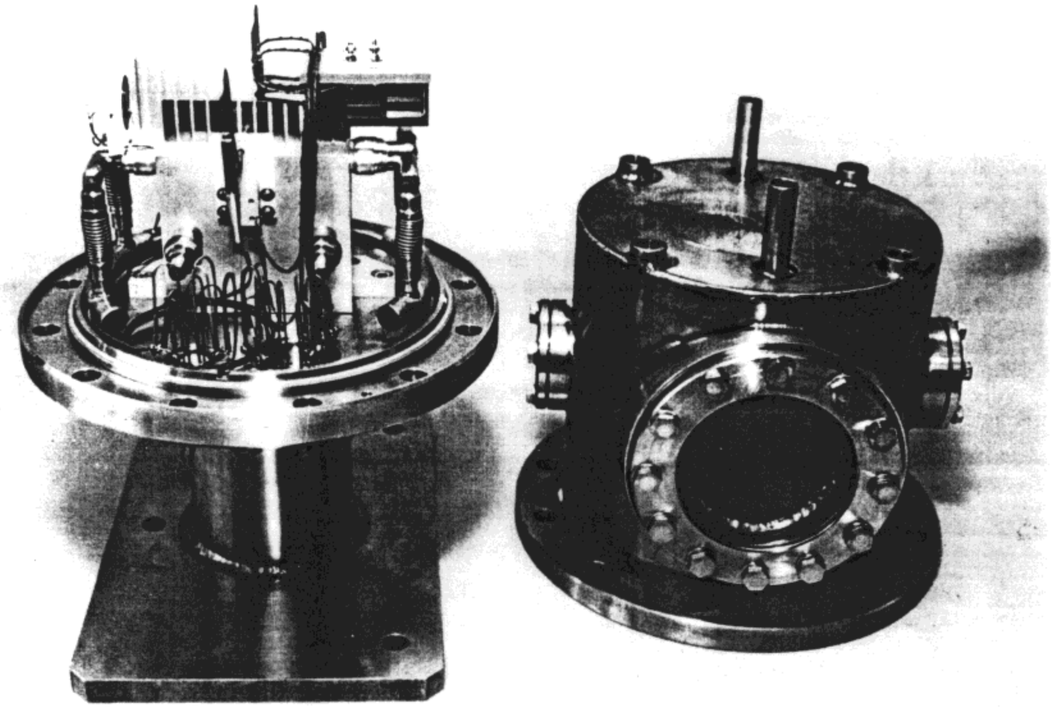
NUMI

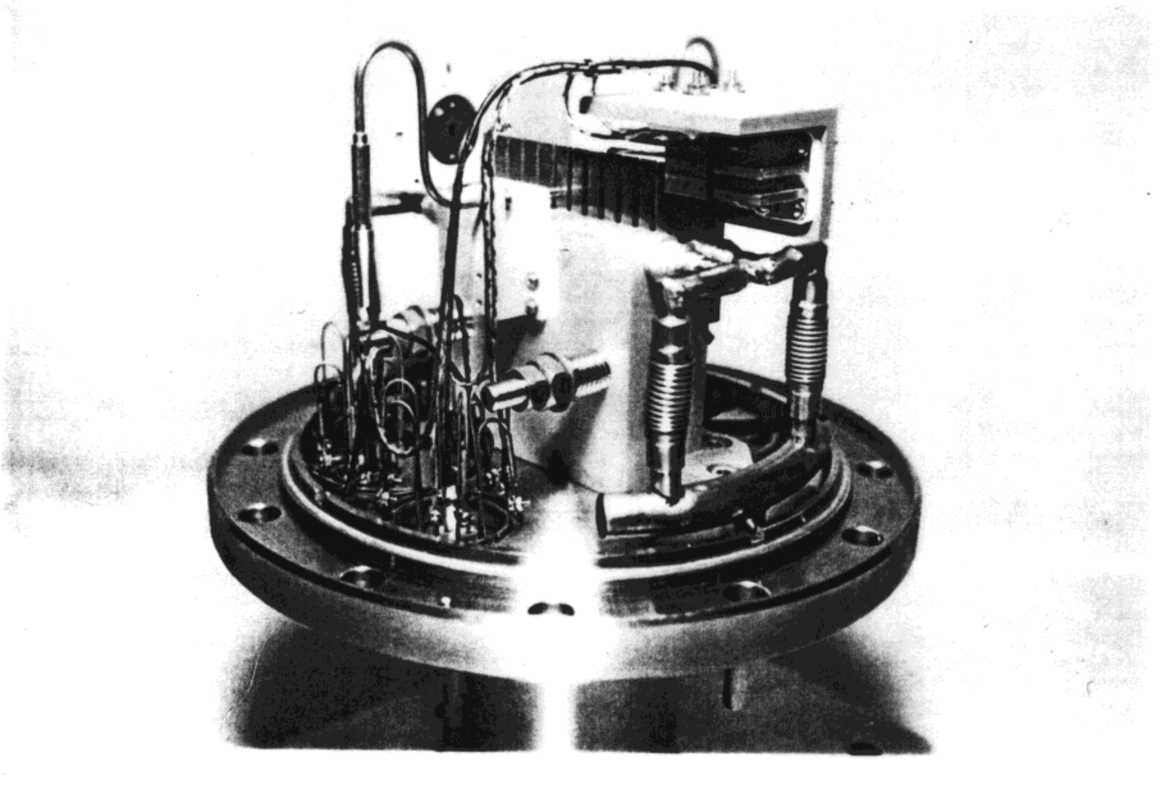
MINOS

# NuMI Target Prototype

## Mounted on AP0 Shielding/Alignment Module







# Near Detector Status

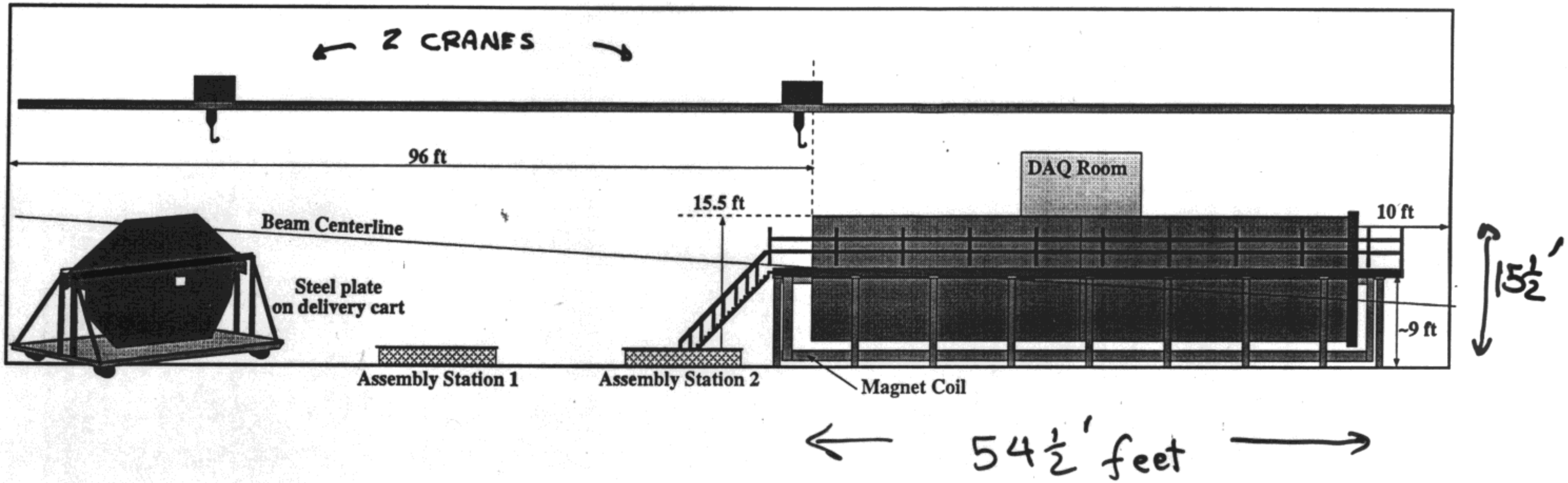
Catharine James,
Rob Plunkett

- *Not* A Copy of Far Detector
  - Smaller
  - Field Different
  - Instrumentation Different
  - Spectrum Different
- Examples:

  (1) Scintillator
  - Smaller Scintillator (length)
  - One PMT per Strip
    (Two At Far Detector)
  - Not Multiplexed

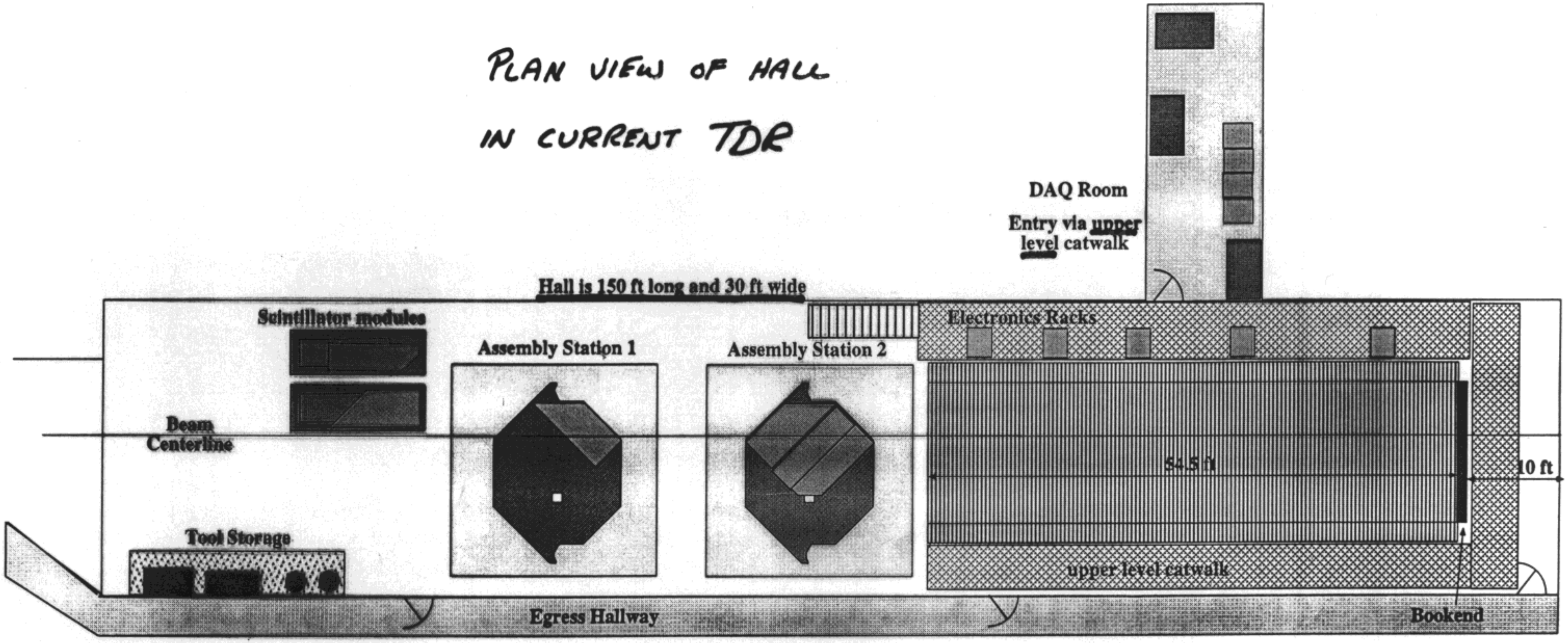
  (2) Field
  - Field Shape and Magnitude Different
  - Acceptance Different
  - Fortunately, practically 100% acceptance
    in Fiducial Volume

# ELEVATION VIEW



PLAN VIEW OF HALL

IN CURRENT TDR



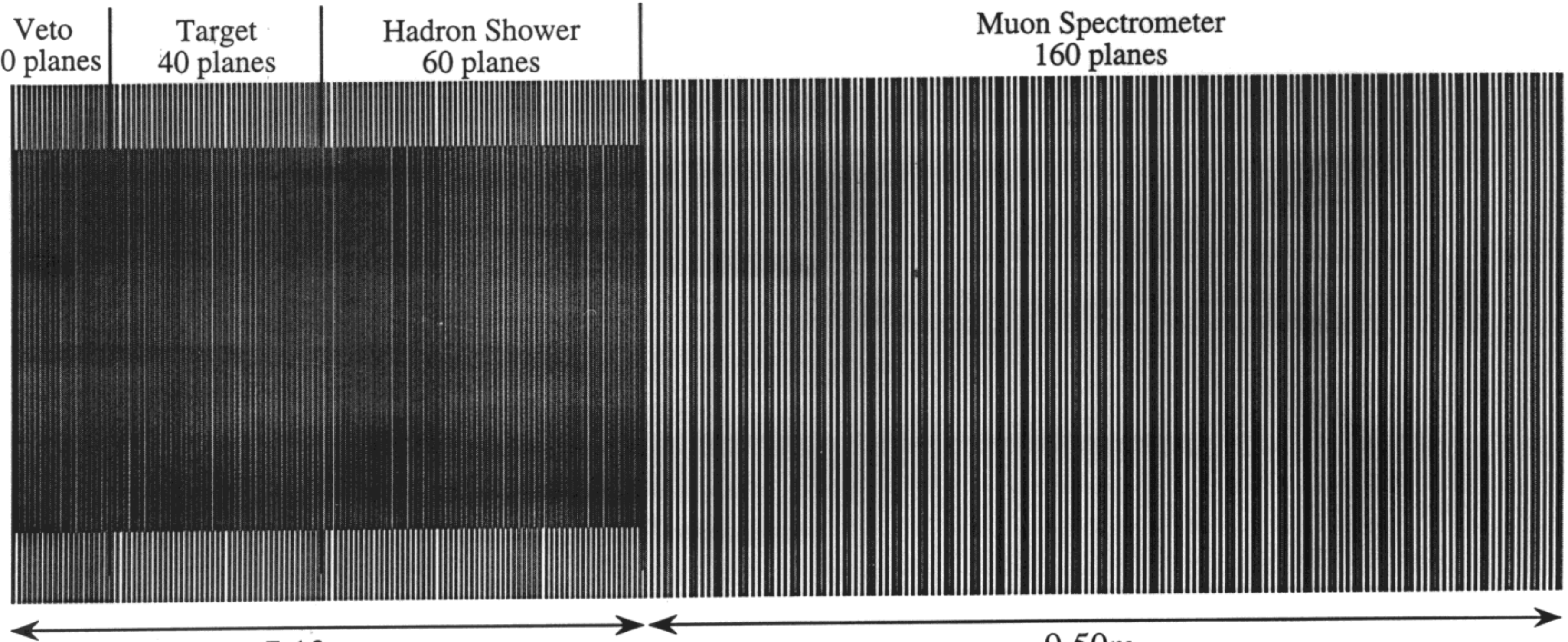
MINOS Director's Review 4/27/98
WBS 2.5 Near Detector Installation
C. James & R. Plunkett

MINOS

# *Longitudinal Schematic of Detector*

**Forward Section**
**1/4 coverage on every plane** ↪ EXCEPT FULL COVERAGE ON EVERY 5TH

**Spectrometer Section**
**Full coverage on every 4th plane**



7.13m
3.05m Steel 1.20m Scintillator 2.88m gap

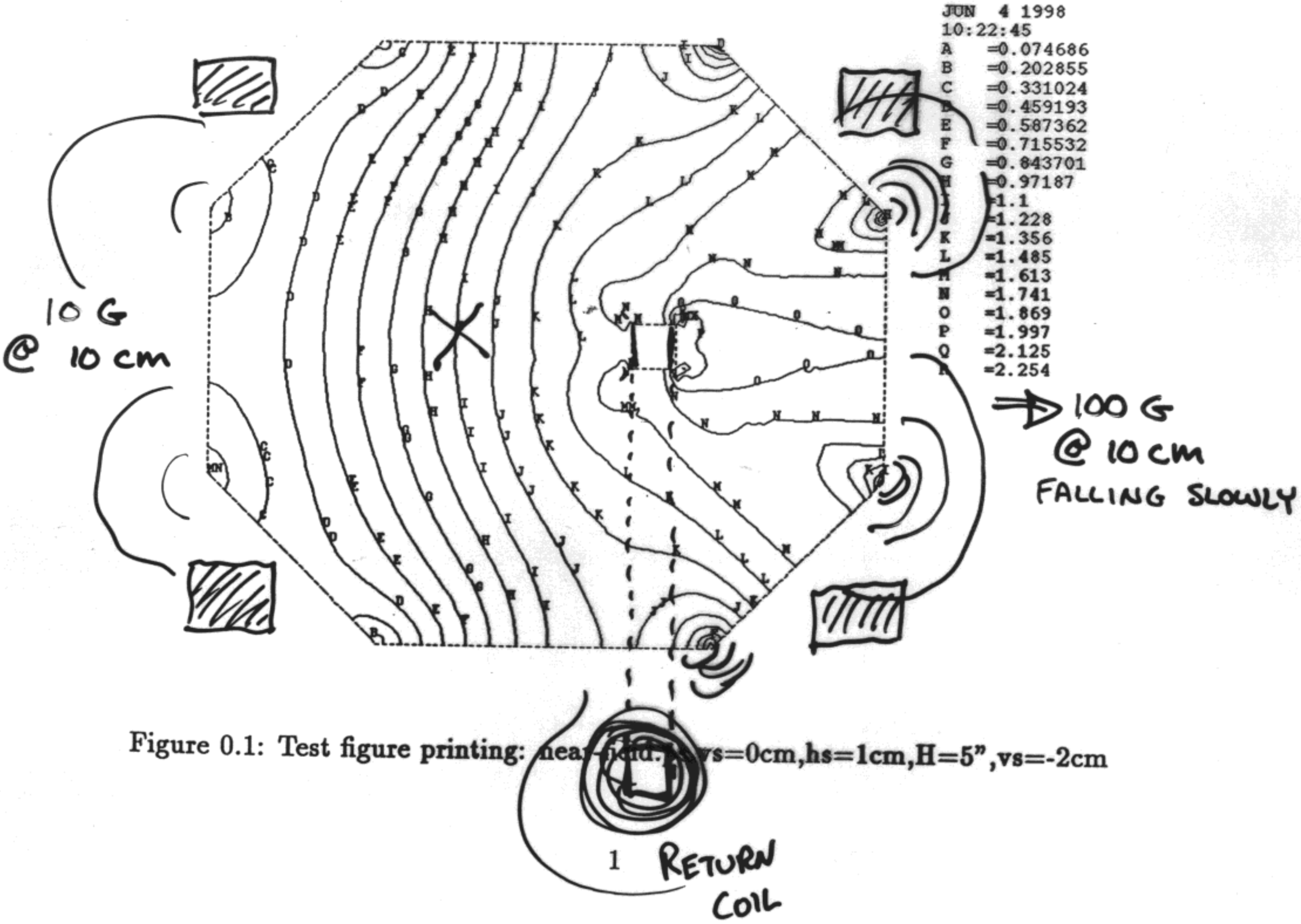
7.13 meters

9.50m
4.06m Steel 0.4m Scintillator 5.04m gap

9.5 meters

NEAR DETECTOR FIELD

OFFSET COIL ⇒ FRINGE FIELDS ON COIL SIDE
SOME PLANES, IN CURRENT SCHEME, WILL
HAVE PHOTODETECTORS ON THAT SIDE
⇒ CAN THEY COPE?
⇒ PERFORMANCE CRITERIA?



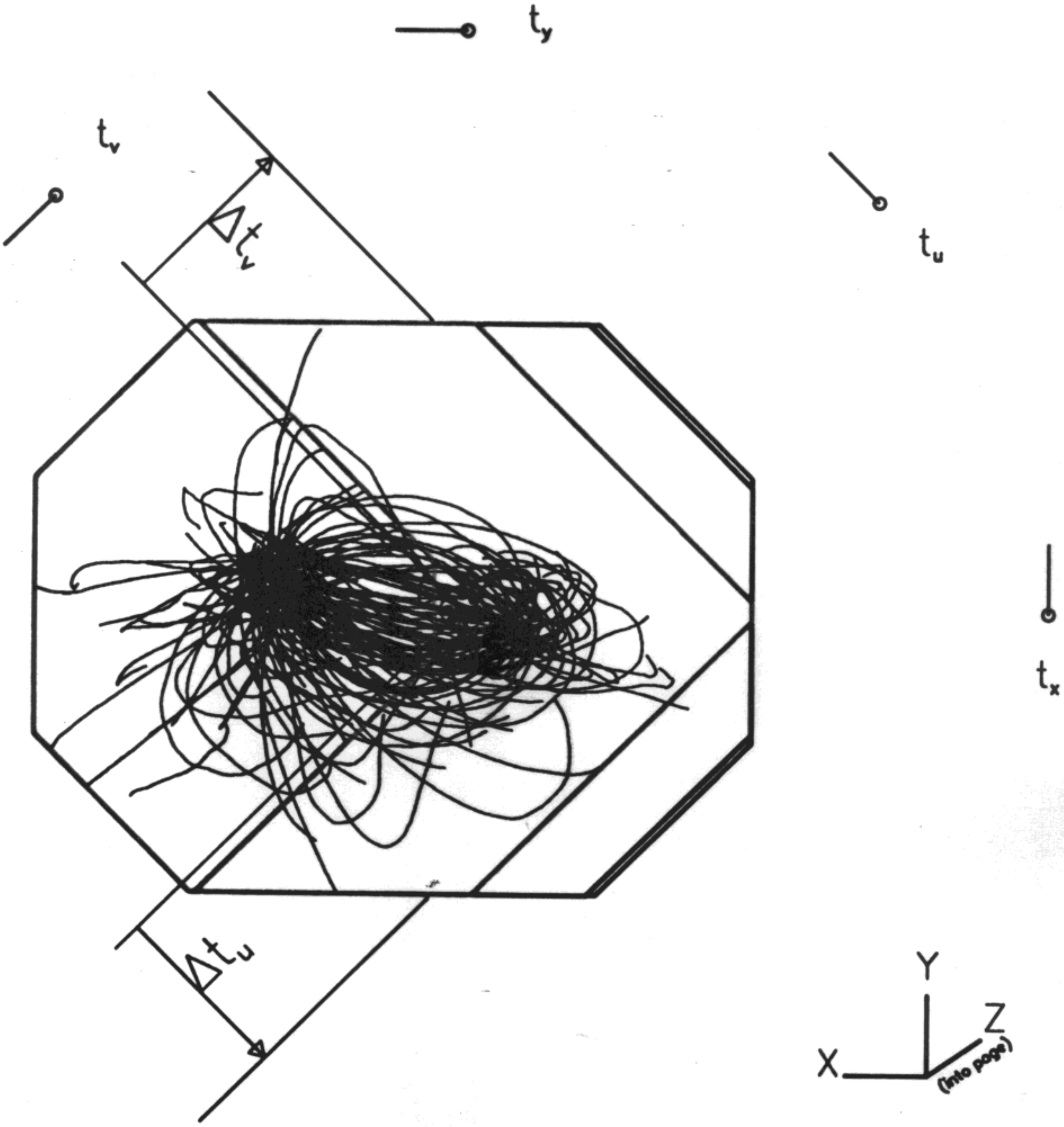
10 G
@ 10 cm

⇒ 100 G
@ 10 cm
FALLING SLOWLY

RETURN
COIL

Figure 0.1: Test figure printing: near-field.ps vs=0cm,hs=1cm,H=5",vs=-2cm

Robert Hatcher



Run 956110 Evt 1

- energy spectrum and $\vec{B}$ similar in fiducial volume (central 25 cm)

# Detector

~6 kTon

*Decided on PMTs Rather than HPDs*

- Extremely Close Decision
- Technical Risk *vs.* Light *vs.* Cost
- Working on Multiplexing Schemes

*Current Light Yield* $\sim$ *5 p.e. at Center*

- Effect on Muon Reconstruction?
- Effect on Neutral Current Efficiency?

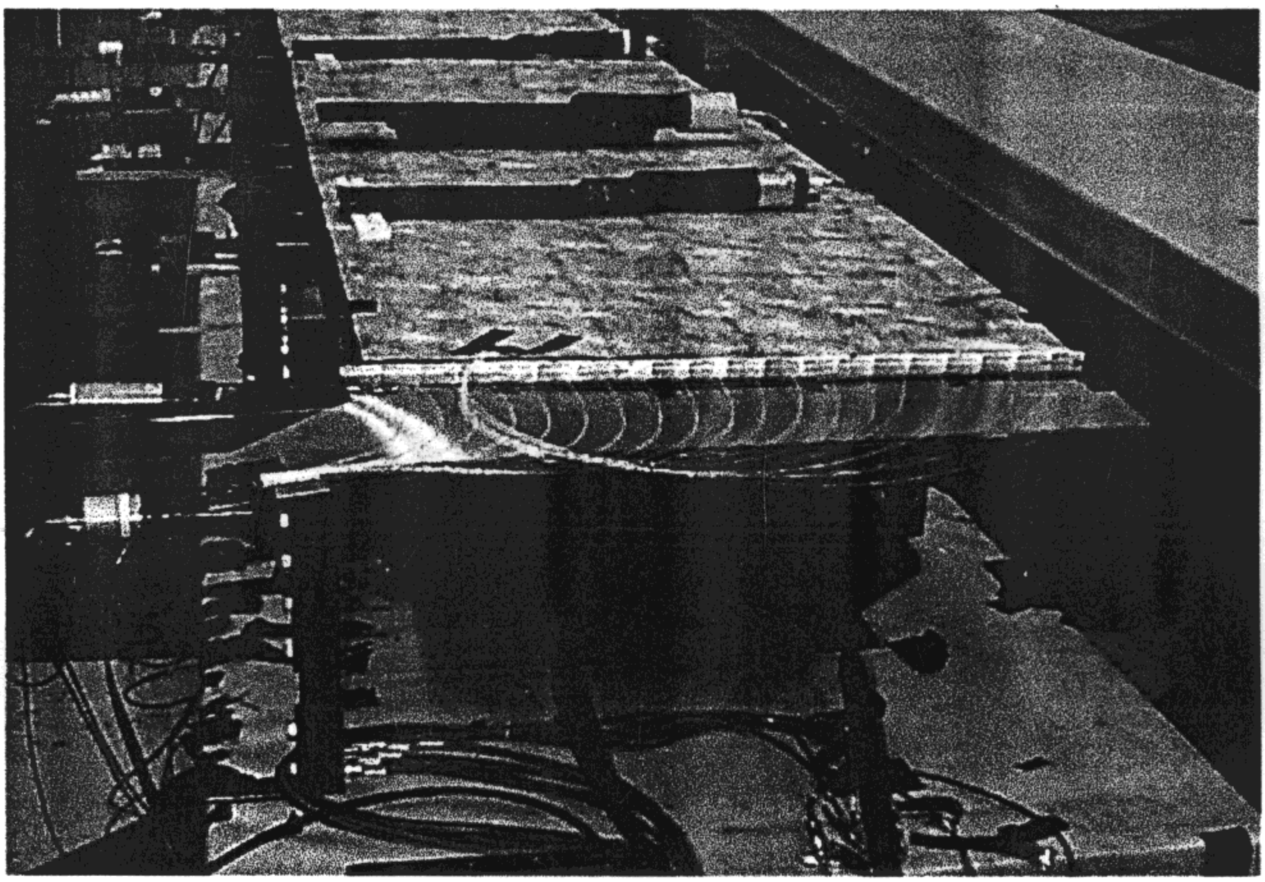
*Both Under Study*

- Prototype Plane Constructed
- Field Studies Underway
- Prototype Modules Being Tested
- Four-Plane Prototype Held up
  by FNAL Funding
  *the usual...*

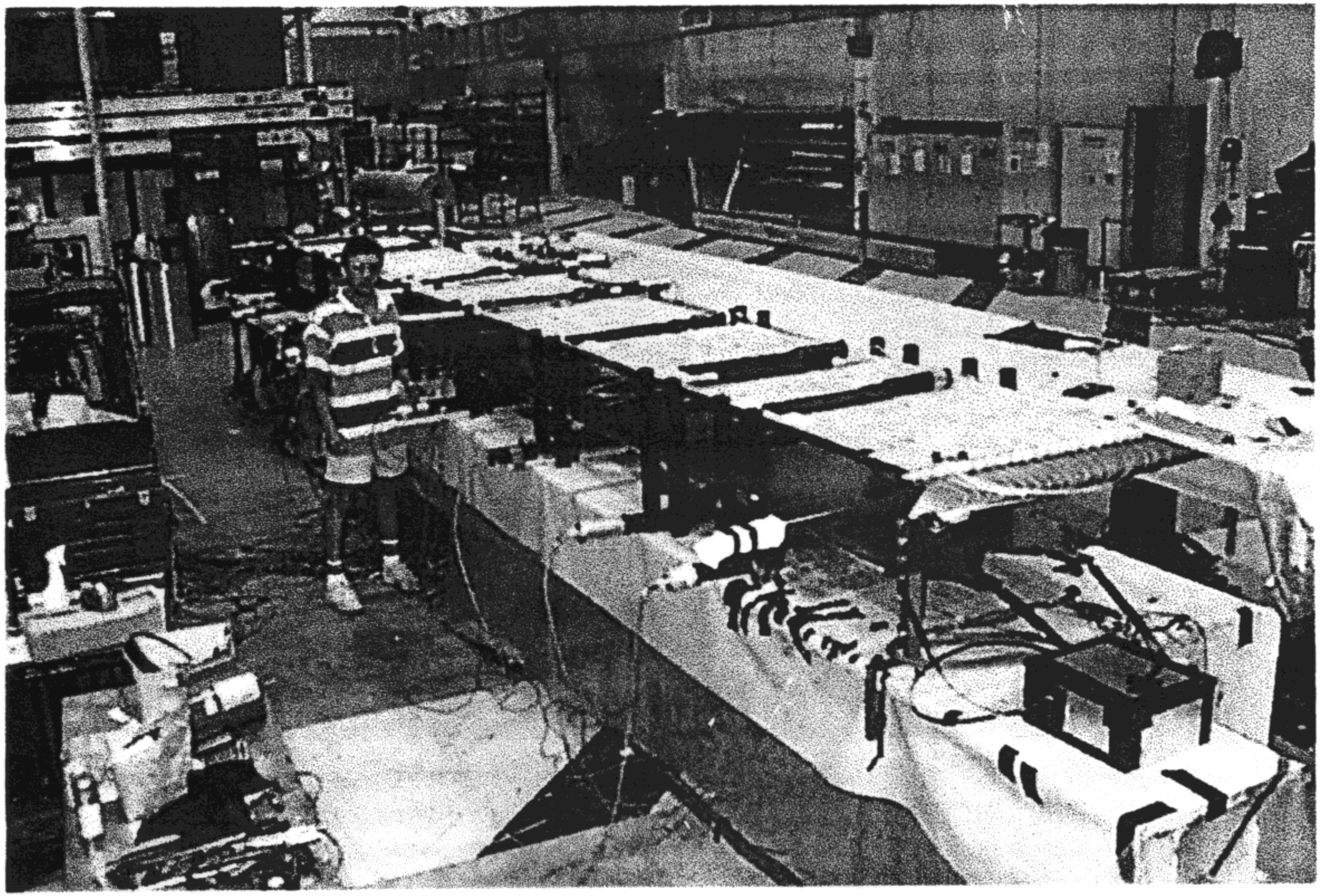
Typical
MINOS
Collaborator

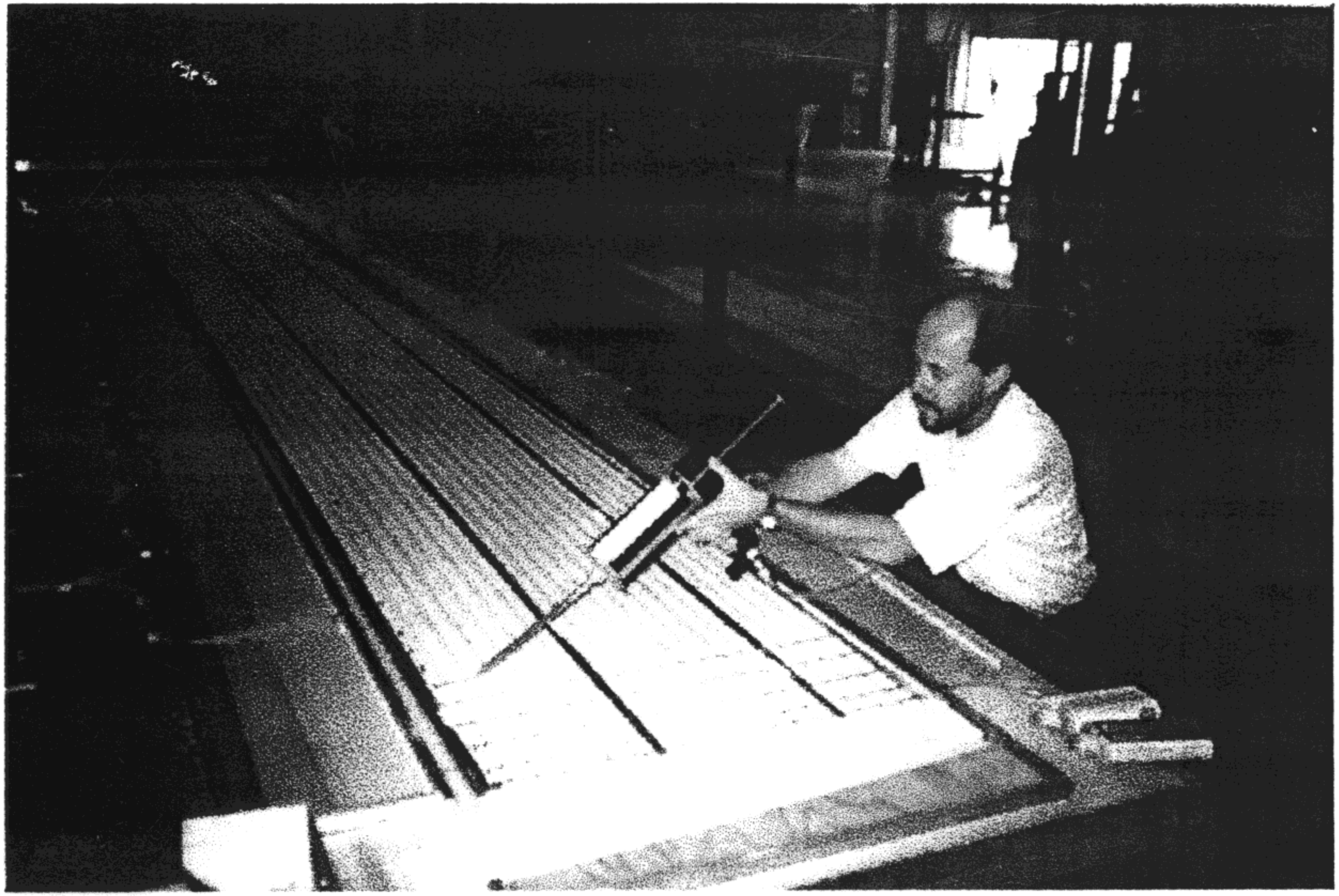
*(really
Doug
Michael)*

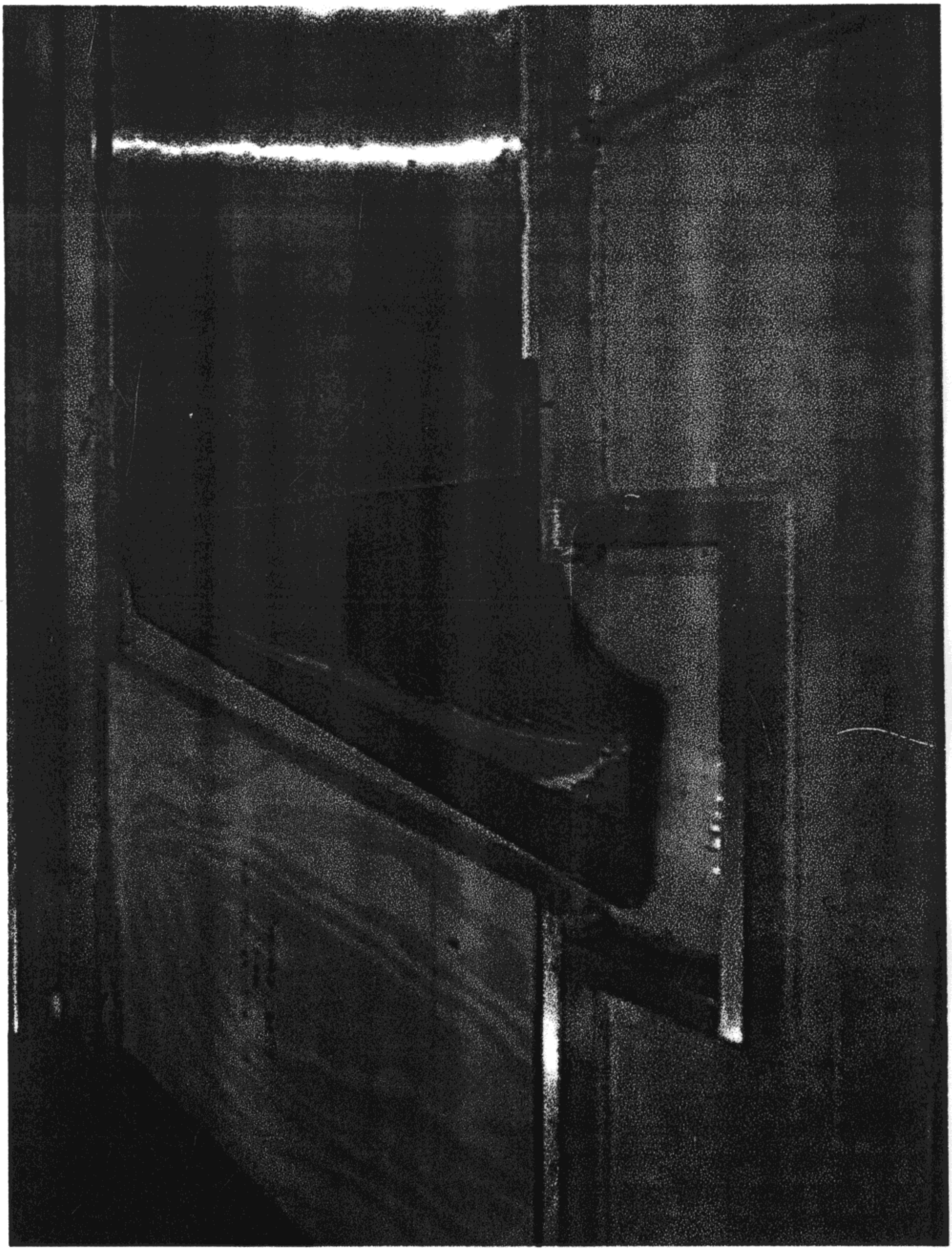
# *MINOS Scintillator Module*

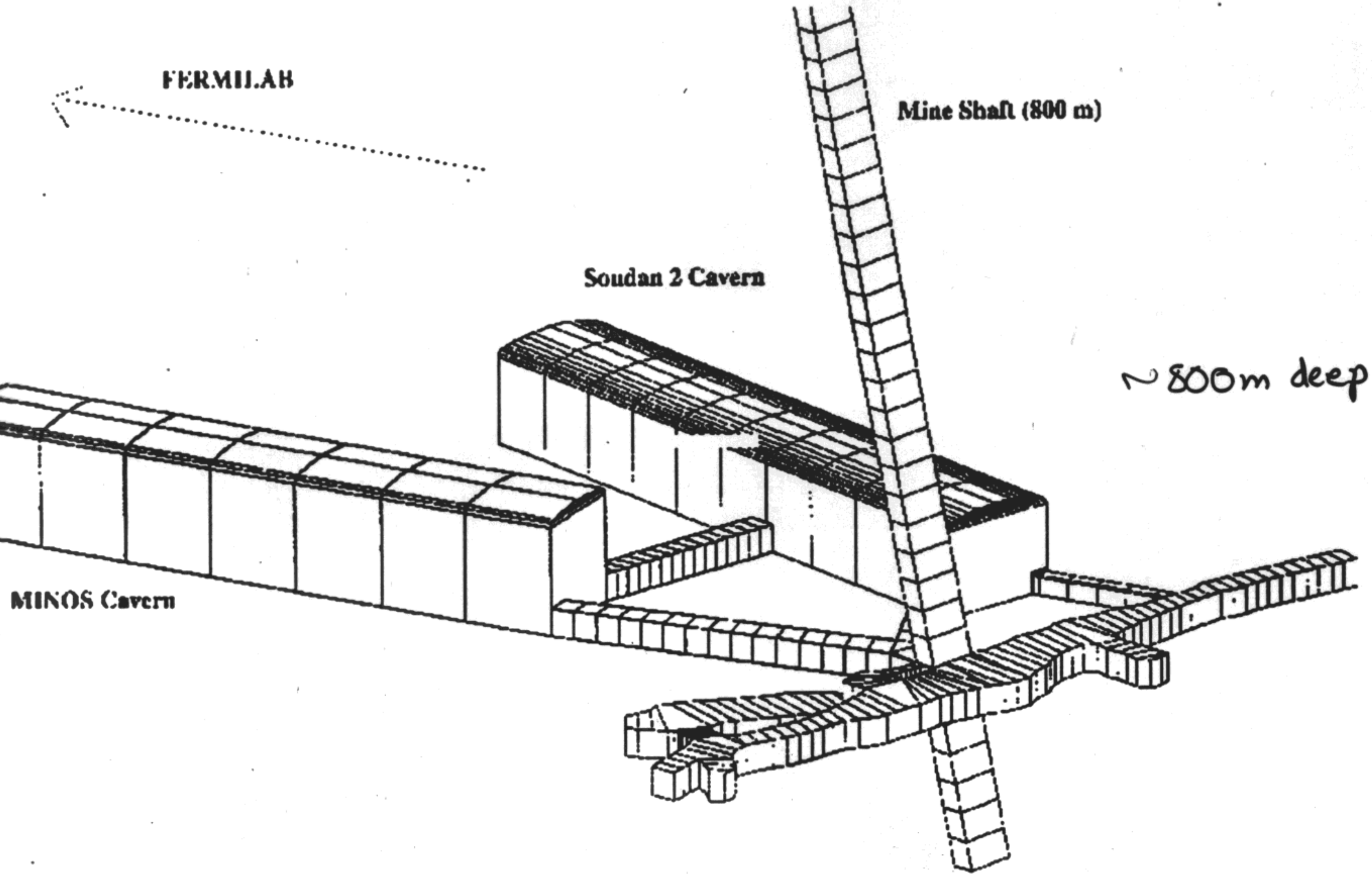


# *FNAL Test Stand*



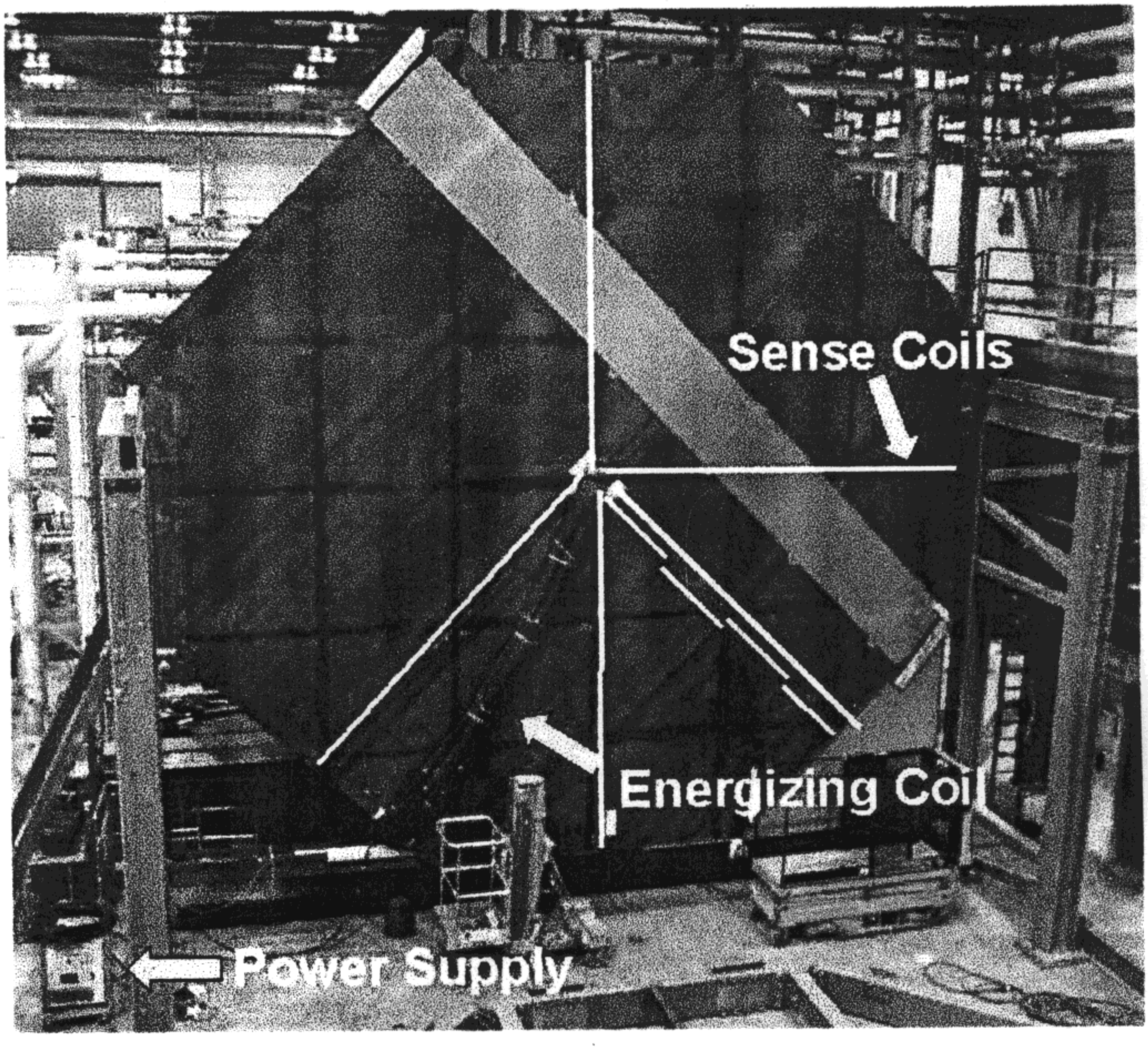


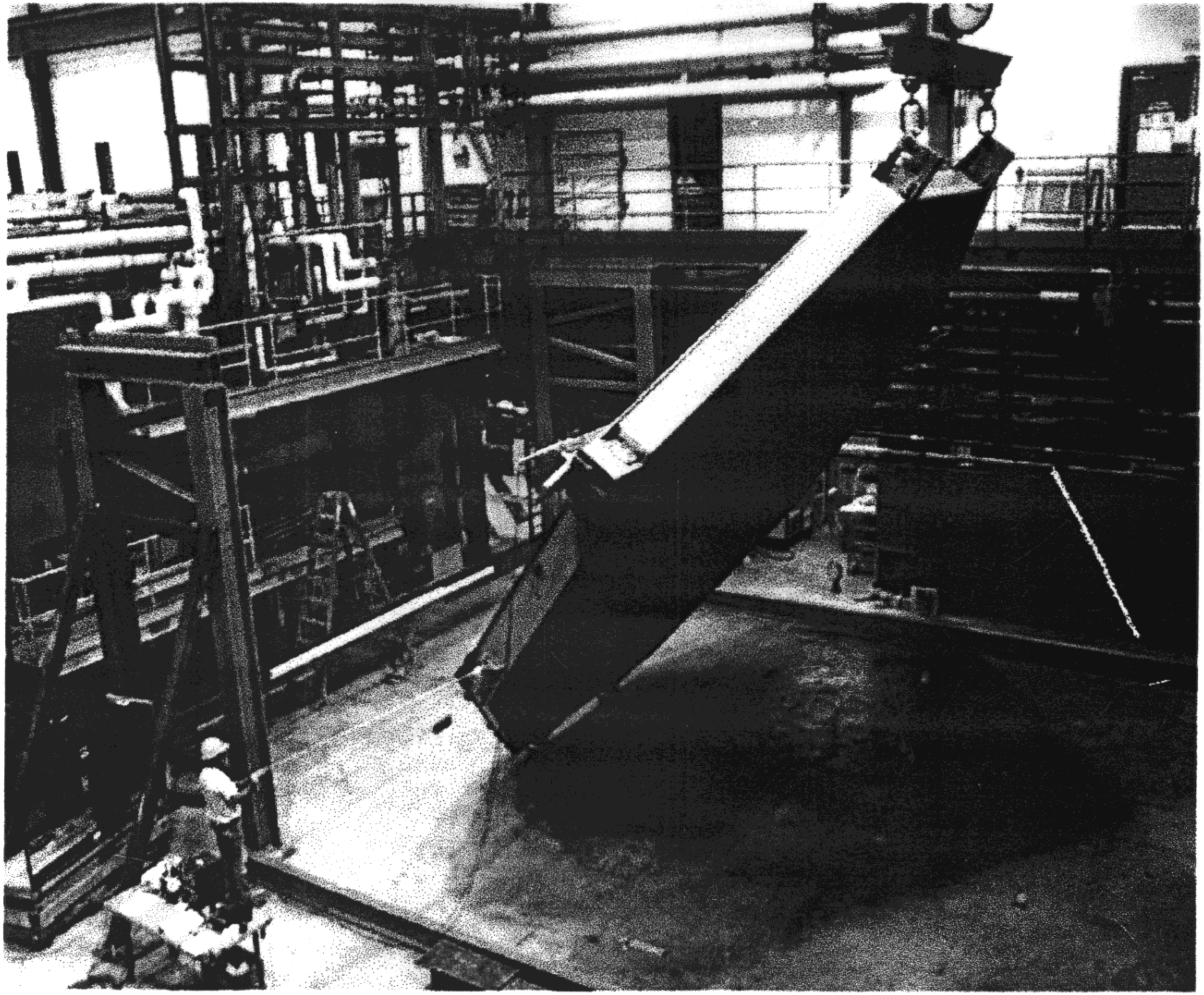


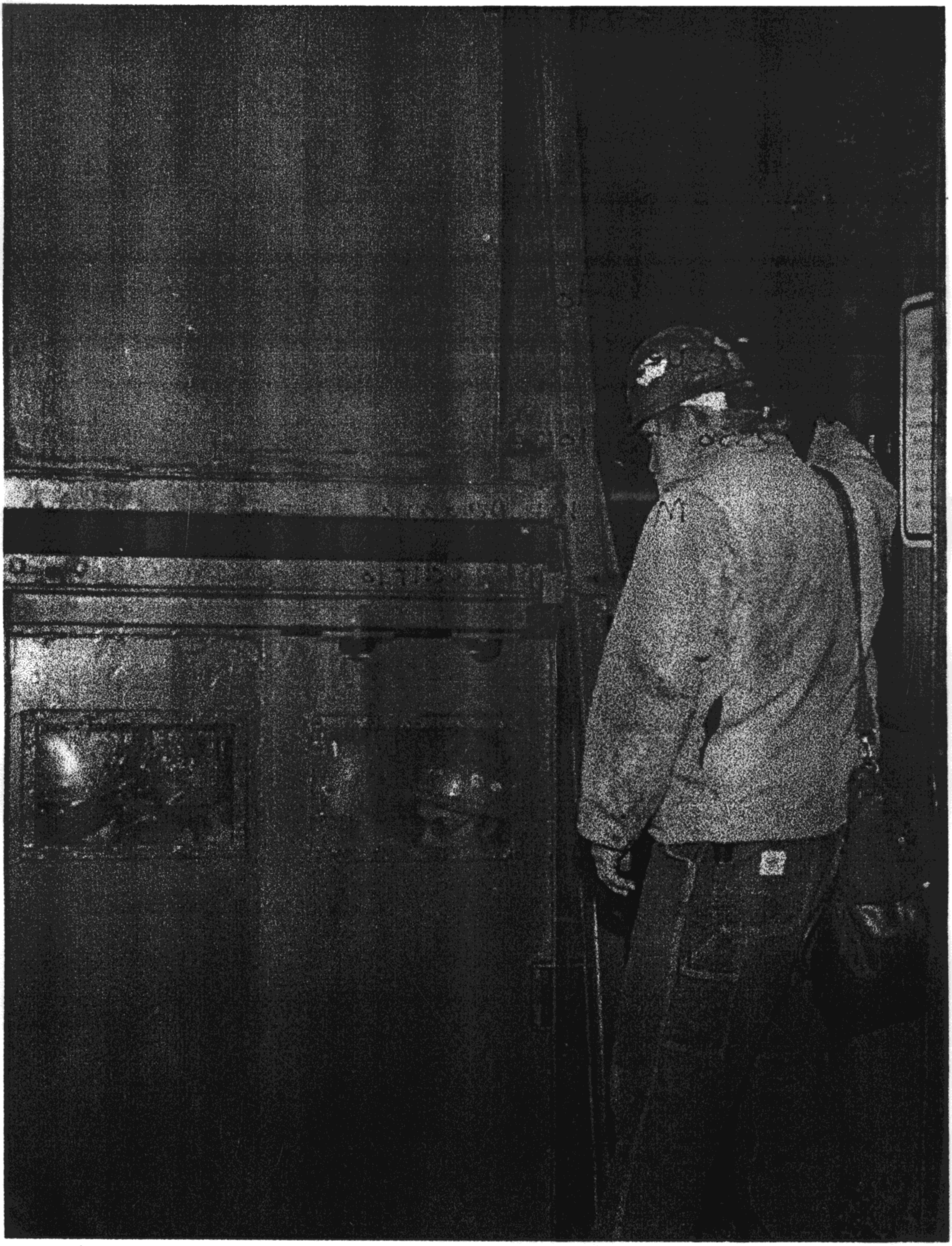


~800m deep

# Soudan 2 Hall


Sense Coils
Energizing Coil
Power Supply





## Analysis

↙ Neyman / Pearson
(Cowan, Statistical Methods...
Oxford U. Pres

- Feldman/Cousins Fitter Written for CC Tests
  ***first results today...***
- Signal Finding Ability Under Study
- Not Just a Disappearance Experiment!!!

$$\Delta\left(\frac{\mathrm{CC}}{\mathrm{CC}+\mathrm{NC}}\right) \Leftrightarrow \text{Appearance of } \nu_\tau$$

No More a Disappearance Experiment than SNO:
First "Signal Finding" Tests Today

## Simulations

↙ R. Heinz

- Detailed Simulation of Light Yield Underway
- Working on Unifying MC Work:
  GEANT, ***etc.***
- Deciding on OO/FORTRAN ↙ P. Litchfield

# Effect of Oscillations on Muon Momentum, Low Energy

David Petyt

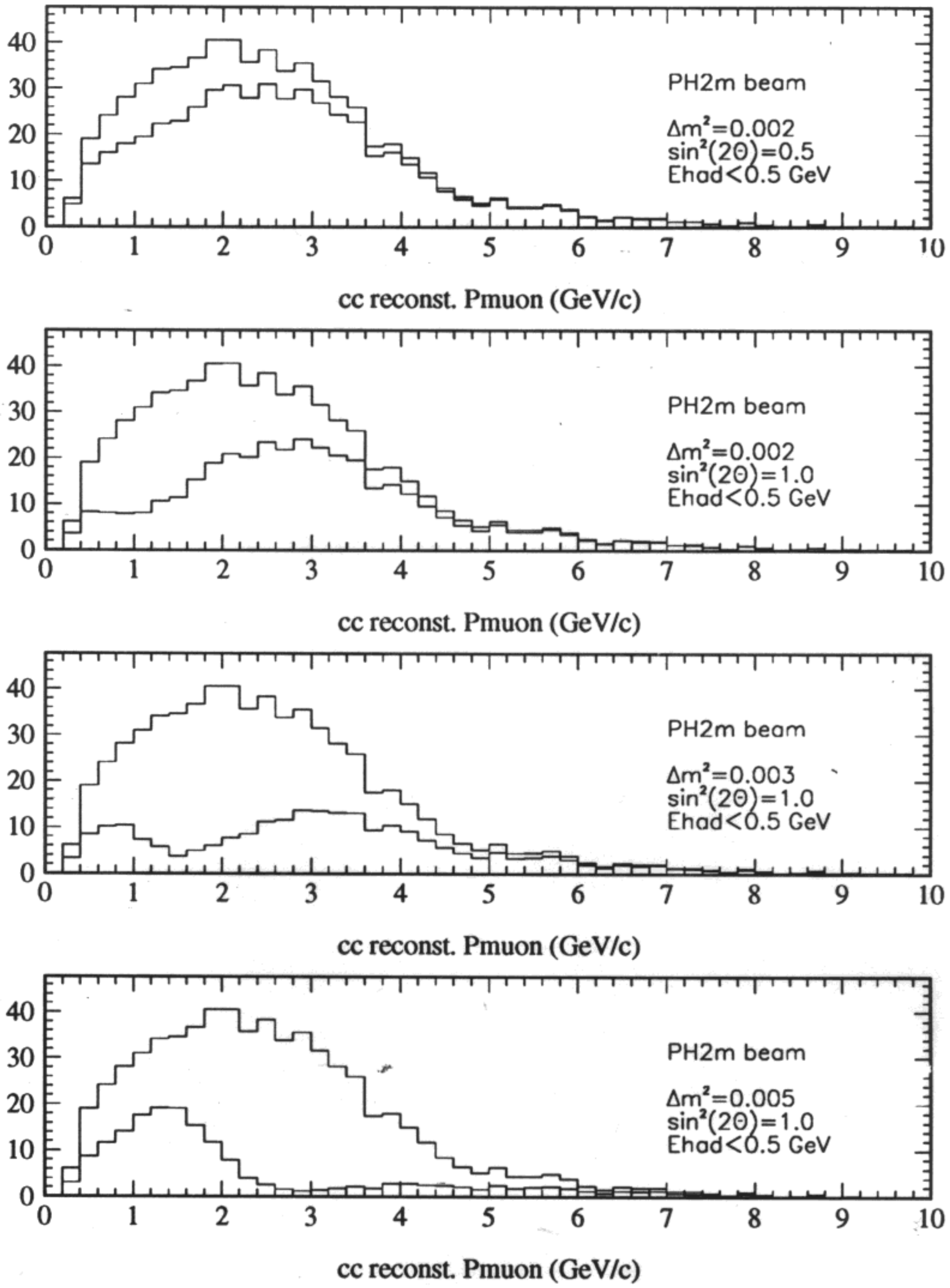


**Figure 18:** Muon momentum spectra for different oscillation parameters obtained with the lowest energy beam design (PH2m in Section 6.2). The upper histograms are the no-oscillation spectra and the lower ones show the effects of oscillations.

10 kt·yr, $E_{had} < 0.5$ GeV

Effect of Oscillations on Muon Momentum, Medium Energy

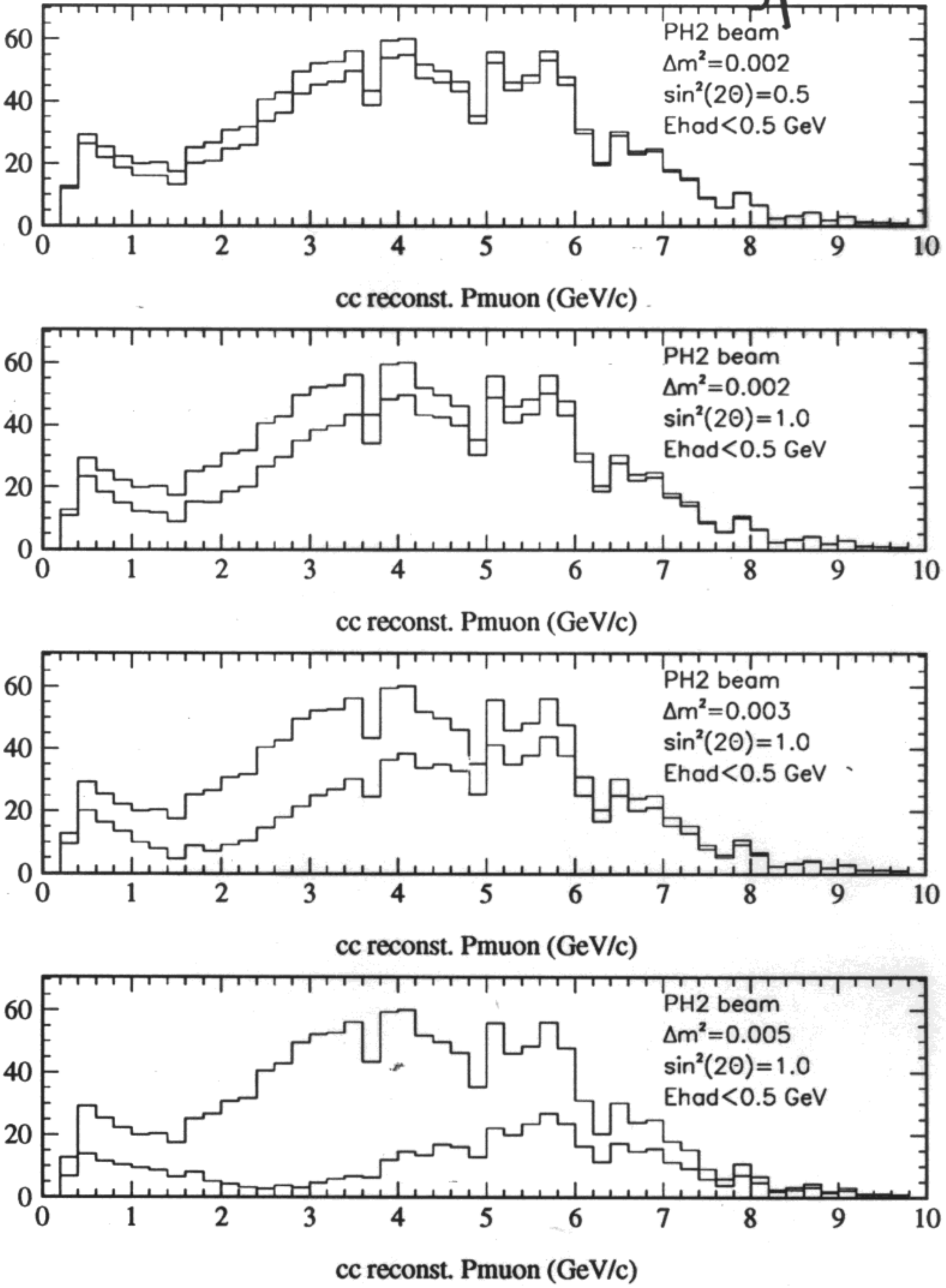


Figure 17: Muon momentum spectra for four sets of oscillation parameters obtained with the medium energy beam design (PH2 in Section 6.2). The upper histograms are the no-oscillation spectra and the lower ones show the effects of oscillations.

# Effect of Oscillations on Visible Energy

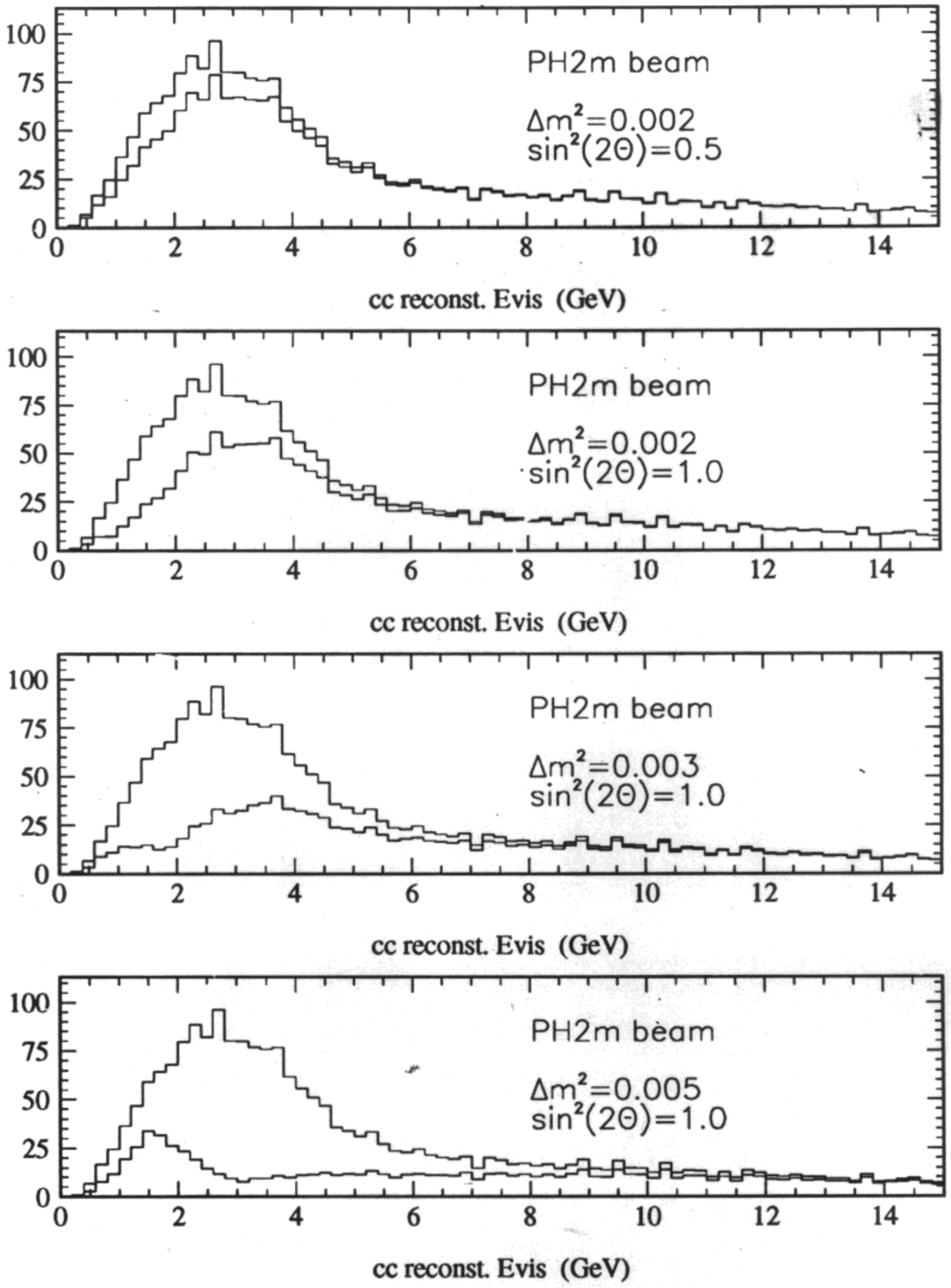
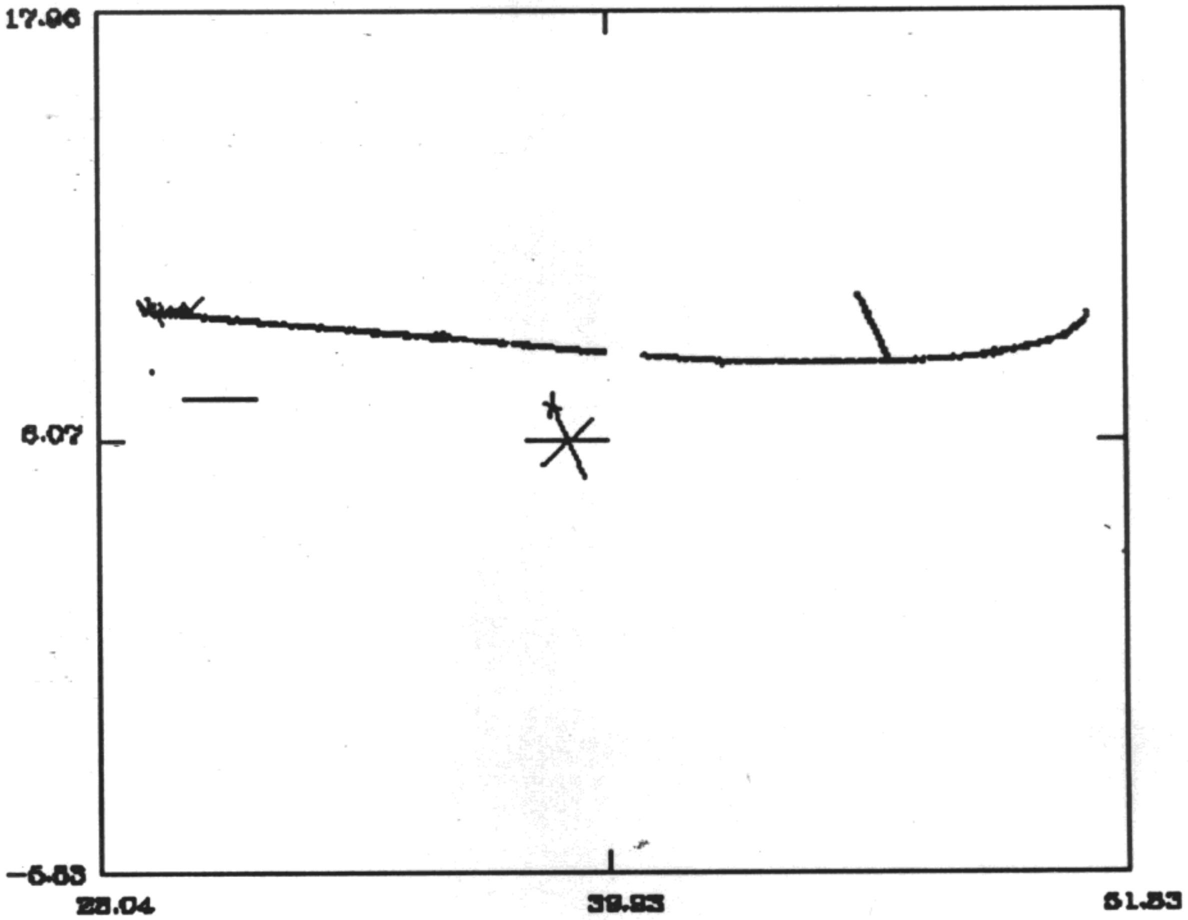


**Figure 16:** Visible energy spectra for four sets of oscillation parameters obtained with the lowest energy beam design (PH2m in Section 6.2). The upper histograms are the no-oscillation spectra and the lower ones show the effects of oscillations.

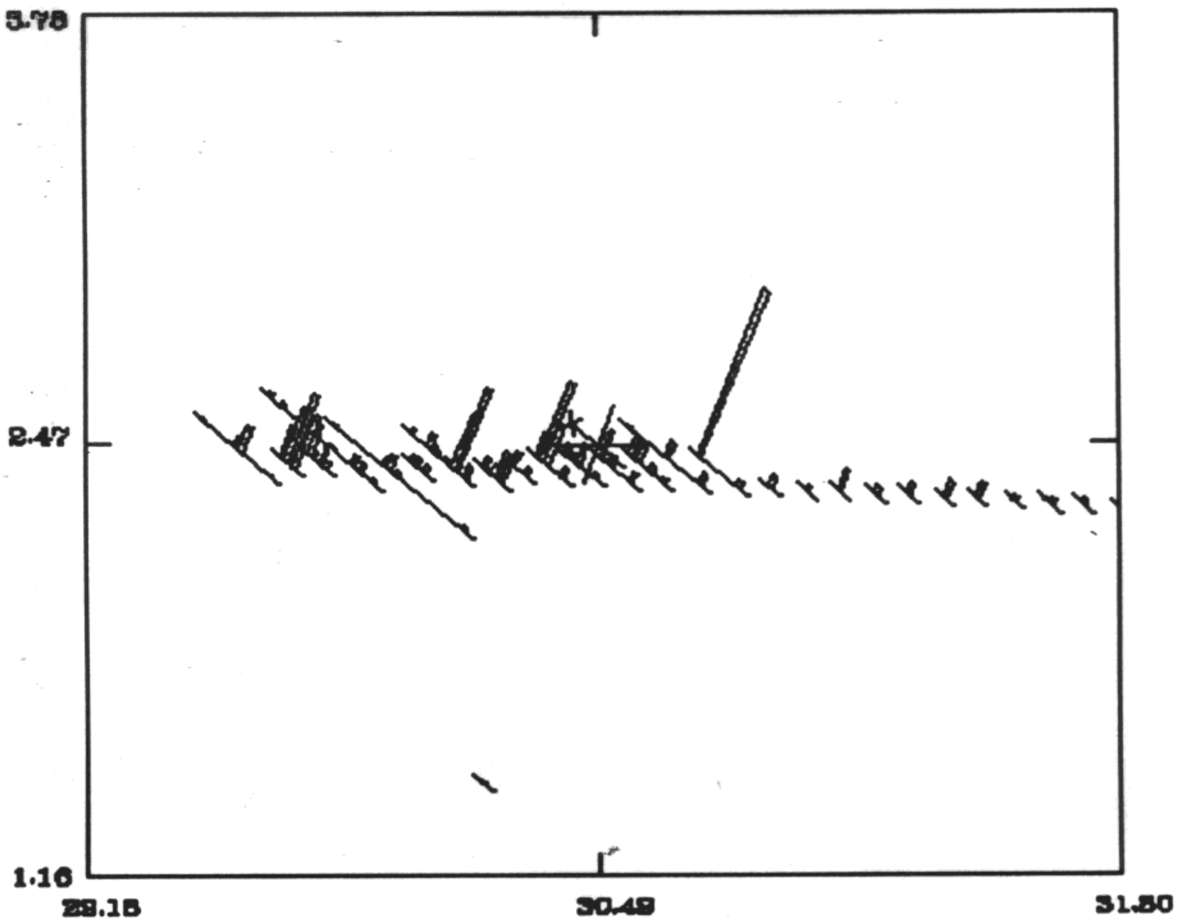
Robert Hatcher
(GEANT simulation)

$\nu_\mu$ Charged Current



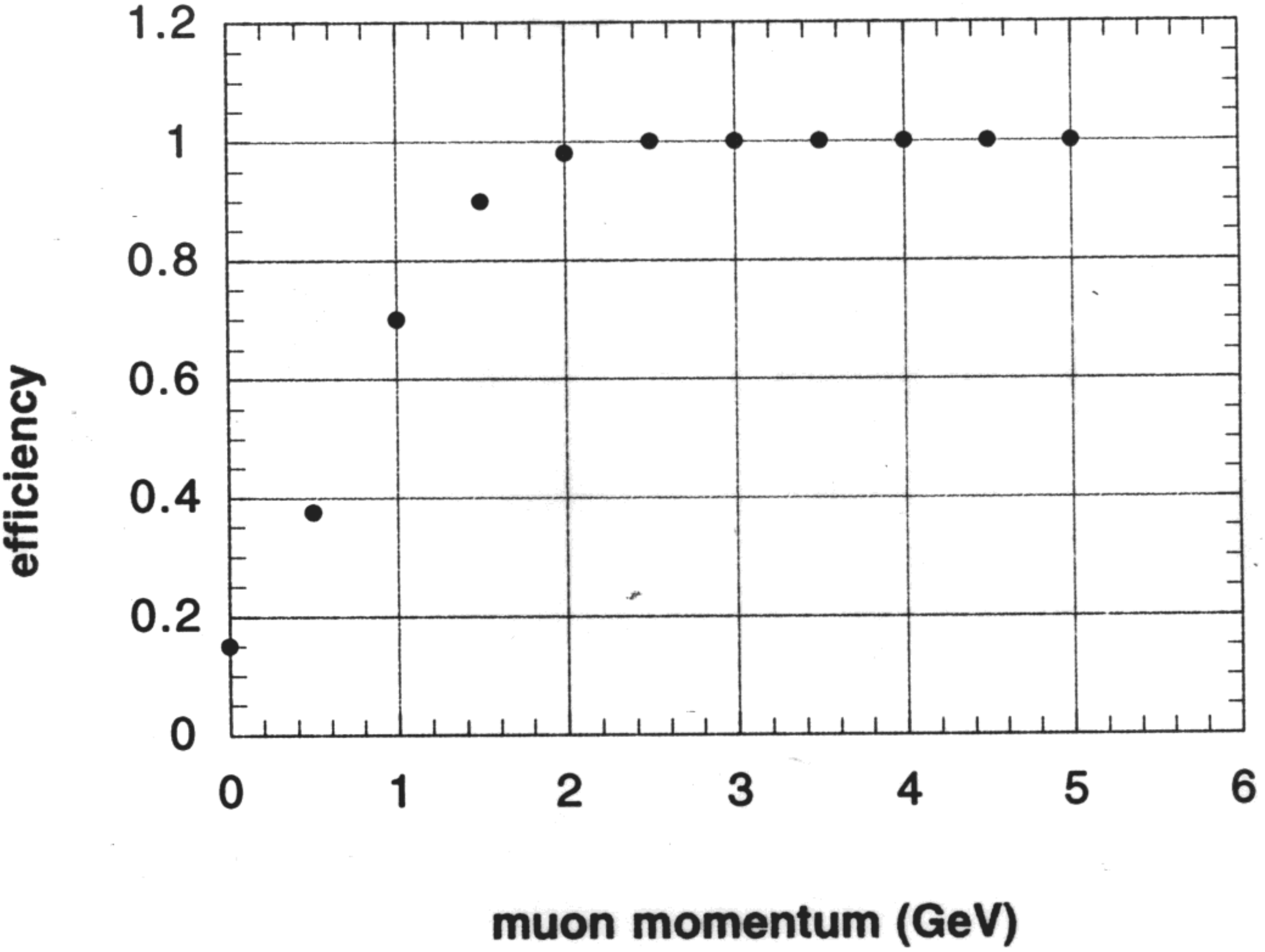
$P_\mu \sim 20$ GeV

# $\nu_e$ Charged Current



# Charged Current Reconstruction Efficiency

—David Petyt, PhD thesis



- studying variation of efficiency with light yield, not too strong
- errors? measure in near, but if detectors not identical, ...

"Standard Method"

$\chi^2_{min} + \Delta$, $1.28/N$, etc.

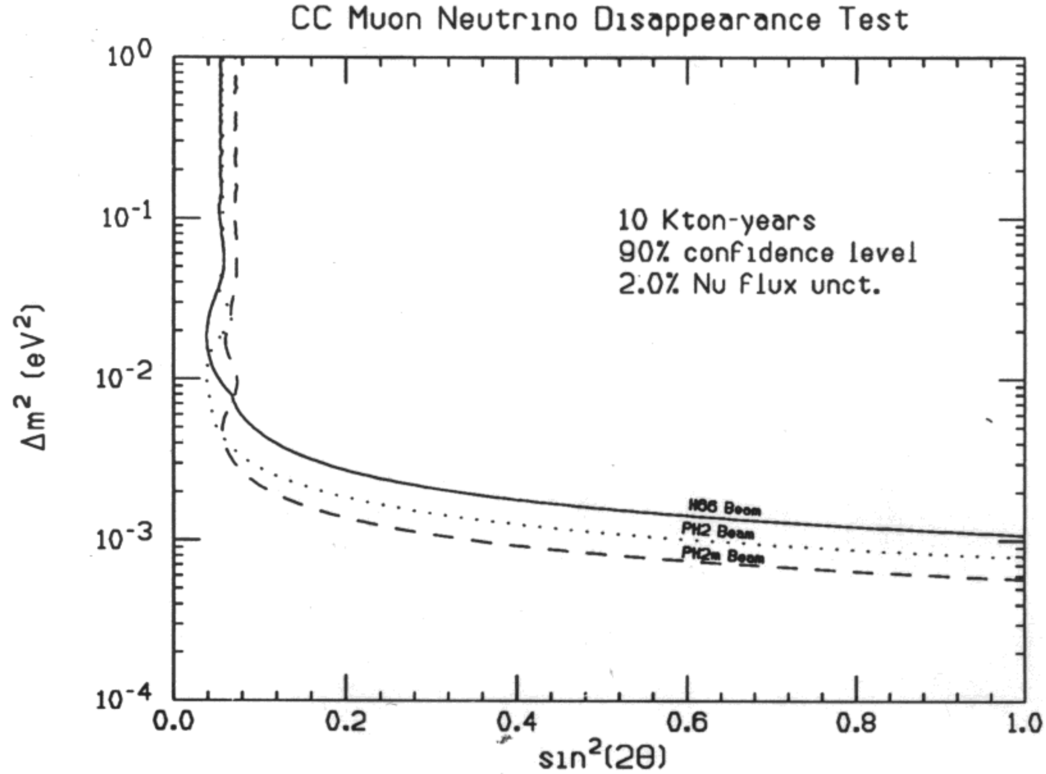
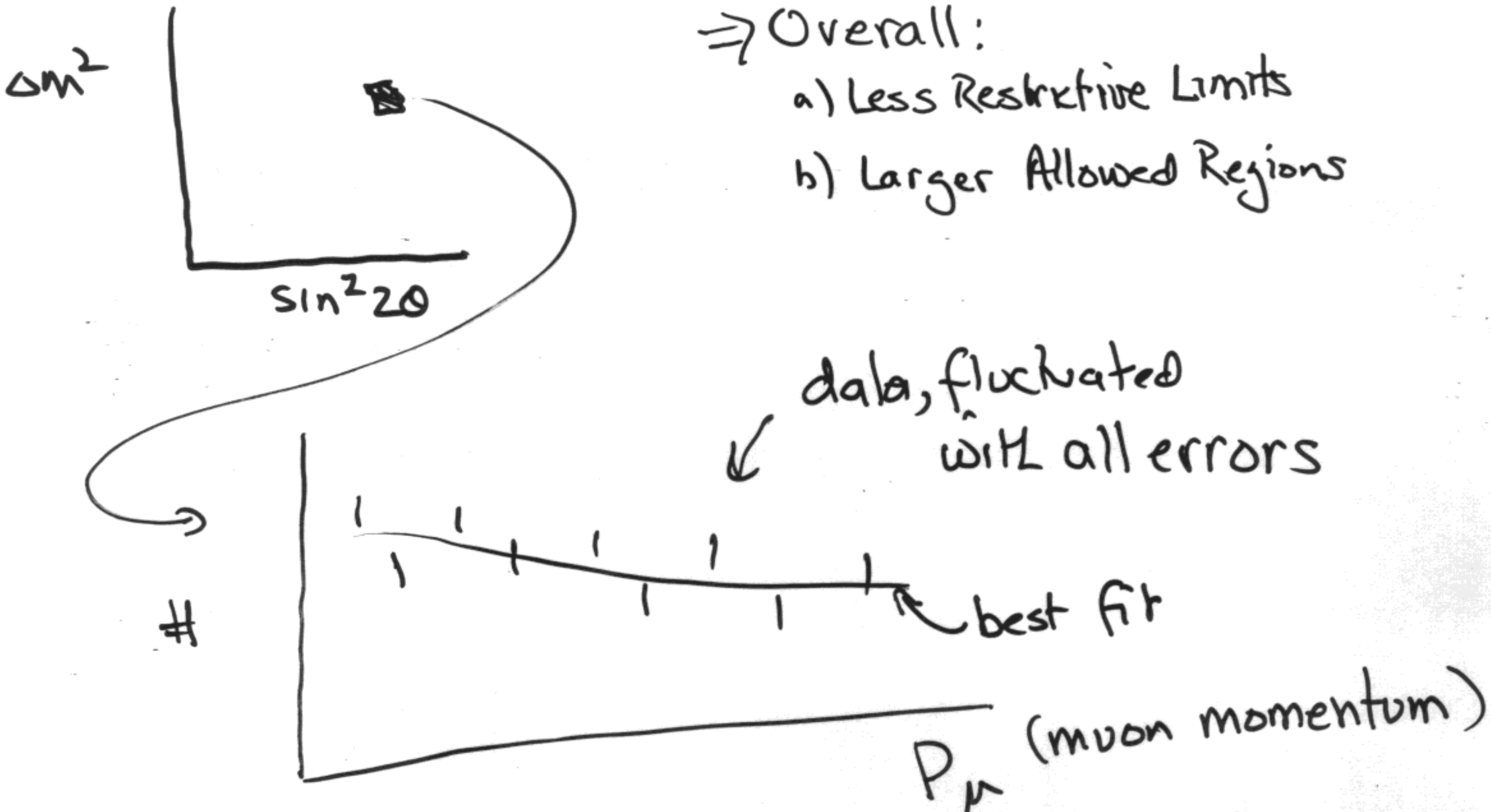


Figure 15: Oscillation sensitivity of the three beam designs using optimized CC-event selection algorithms and 2% systematic uncertainties.

Limit → 1.28σ method

- Why isn't this good enough?

# Method (obvious after much thought)



⇒ Overall:

a) Less Restrictive Limits

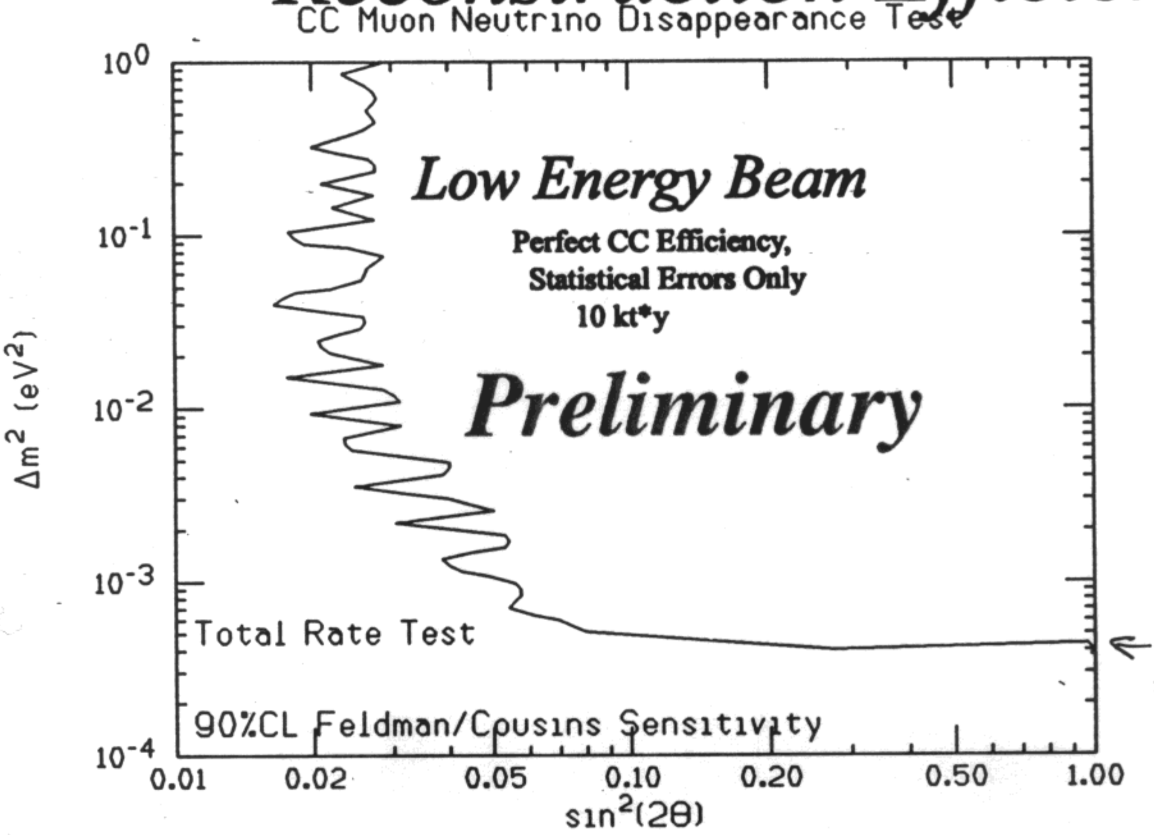
b) Larger Allowed Regions

- Generate Ensemble of Experiments

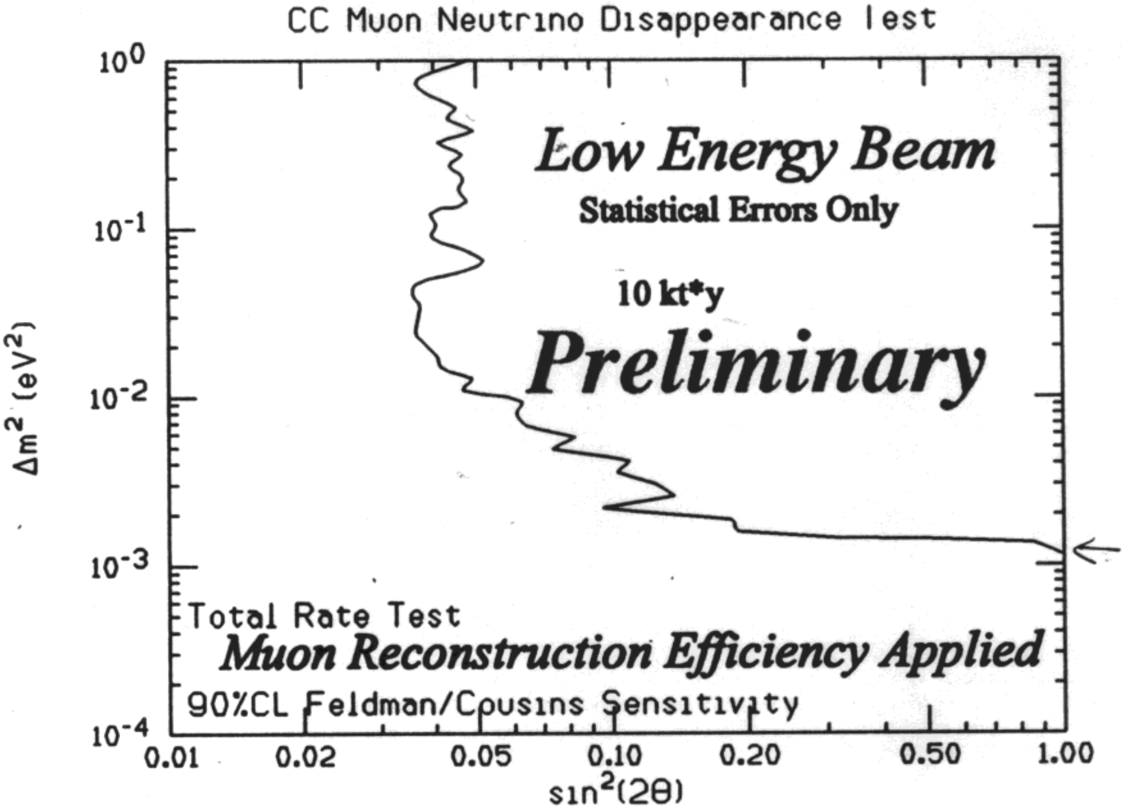
$\chi^2 = \chi^2$(DATA to "true") $- \chi^2$(DATA to "best-fit")

- most powerful accept/reject (Neyman-Pearson)
- same for data, signal
- lose "goodness-of-fit"

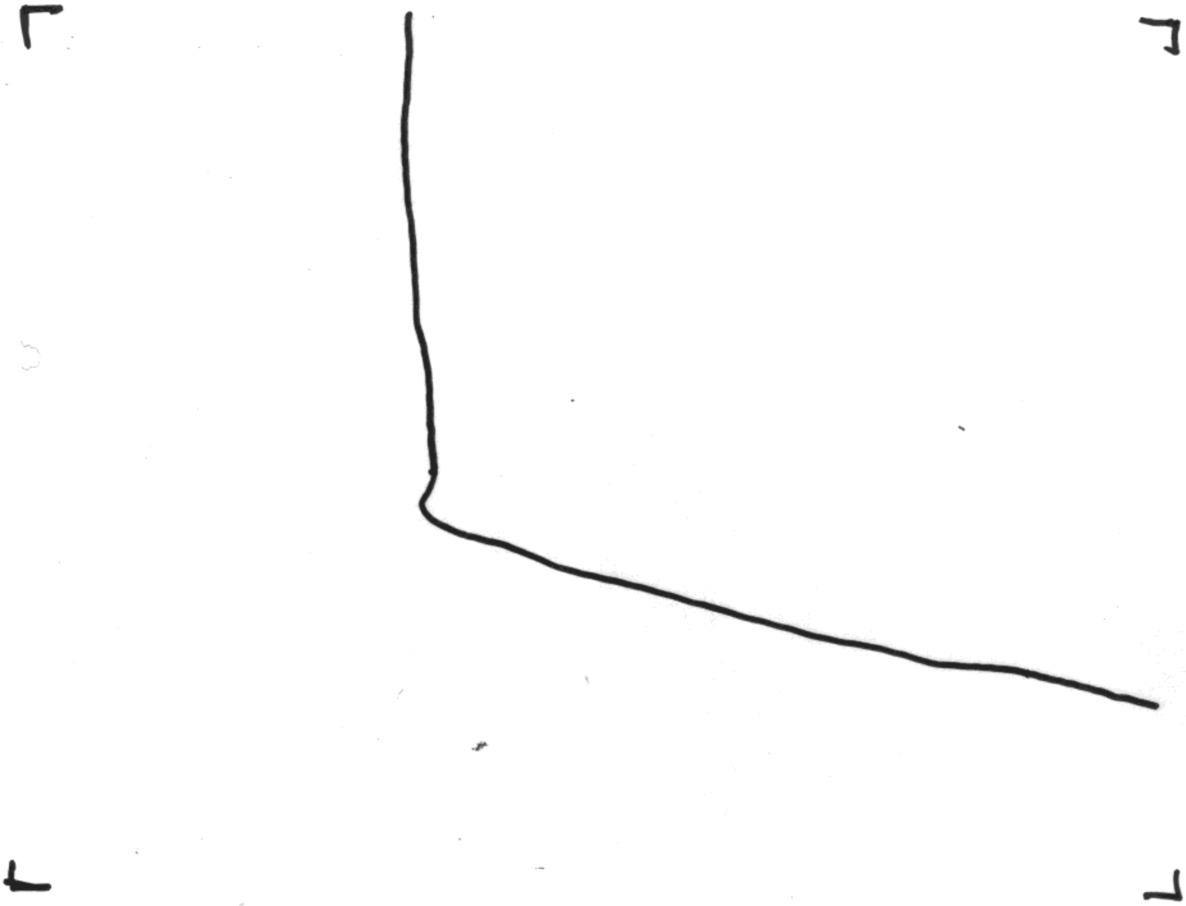
# *Effect of Charged Current Reconstruction Efficiency*



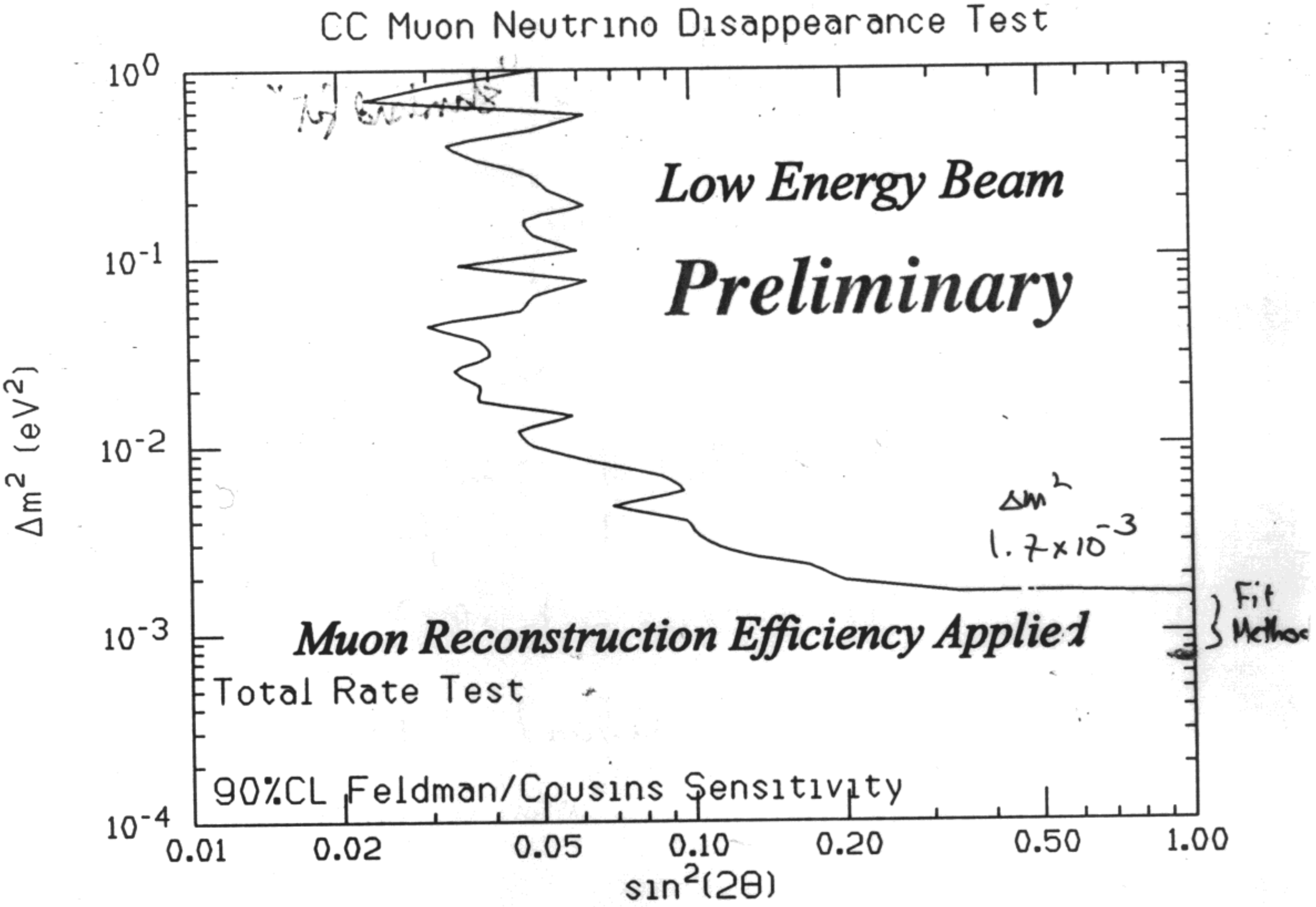
← $\Delta m^2 = 5\times10^{-4}$



← $\Delta m^2 = 1.2\times10^{-3}$



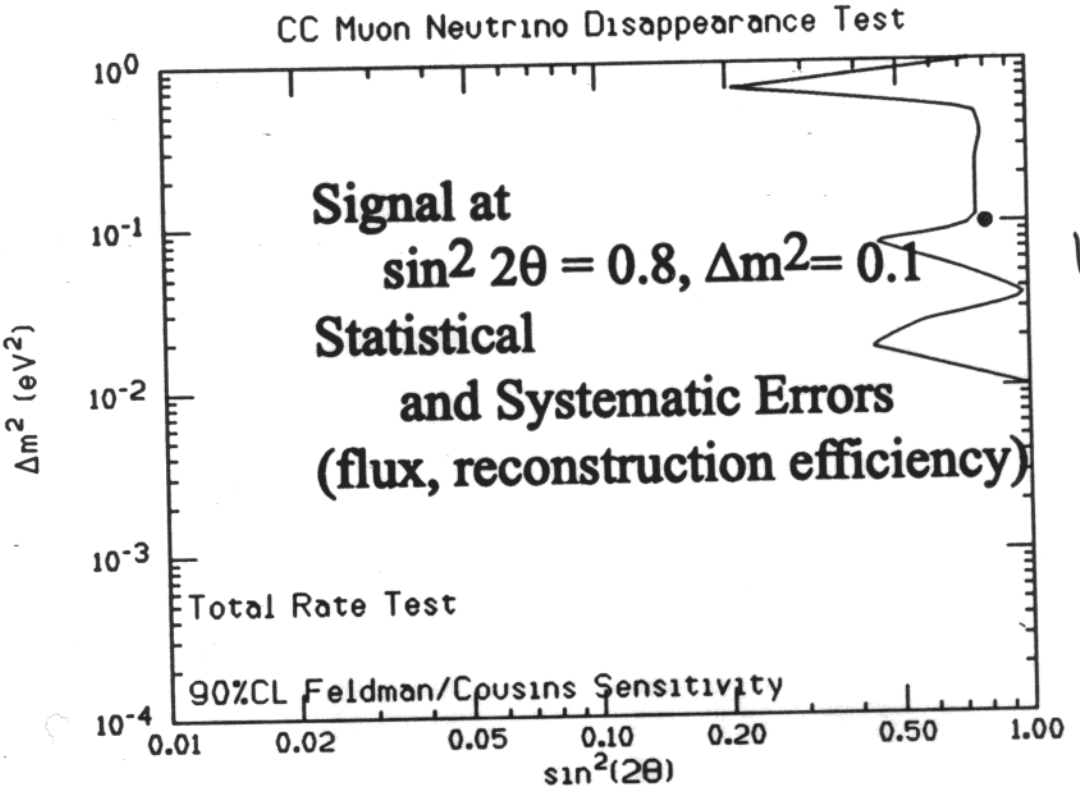
# *Preliminary "Worst-Case" Sensitivity*



***Statistical and Systematic Flux Errors:***
***10 kt*y, 2% Correlated,***
***2% Uncorrelated***

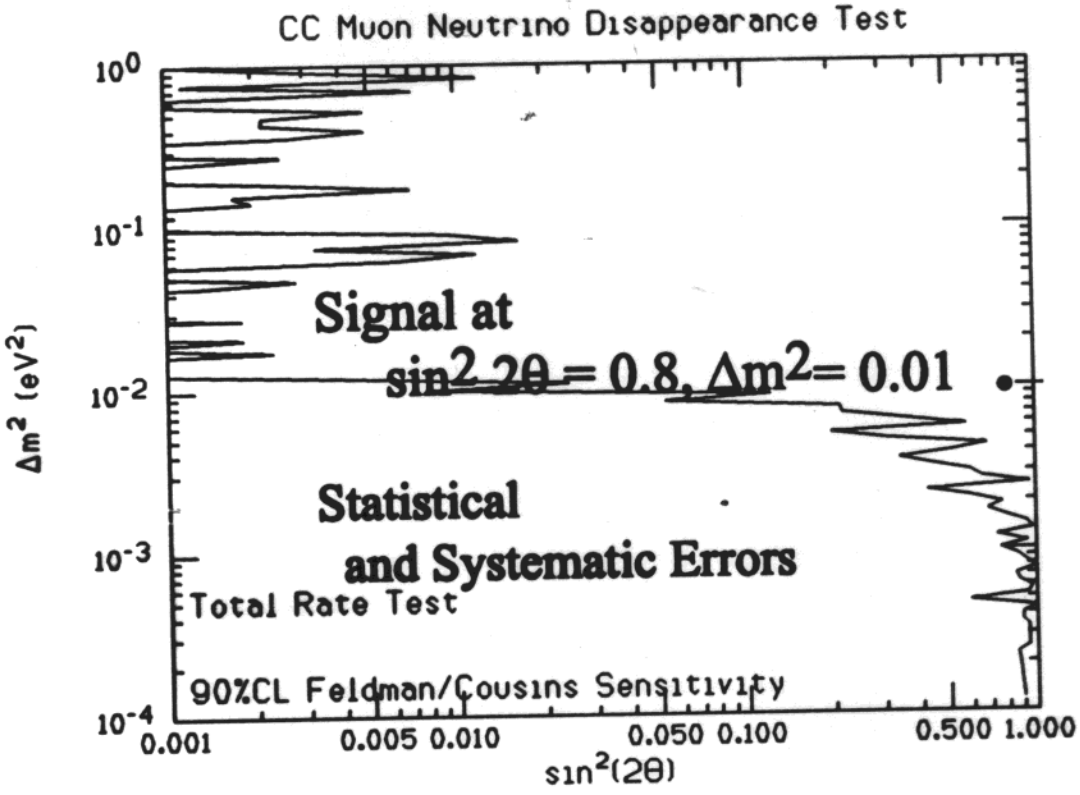
# *Signal Finding Ability : Rate Test Only*

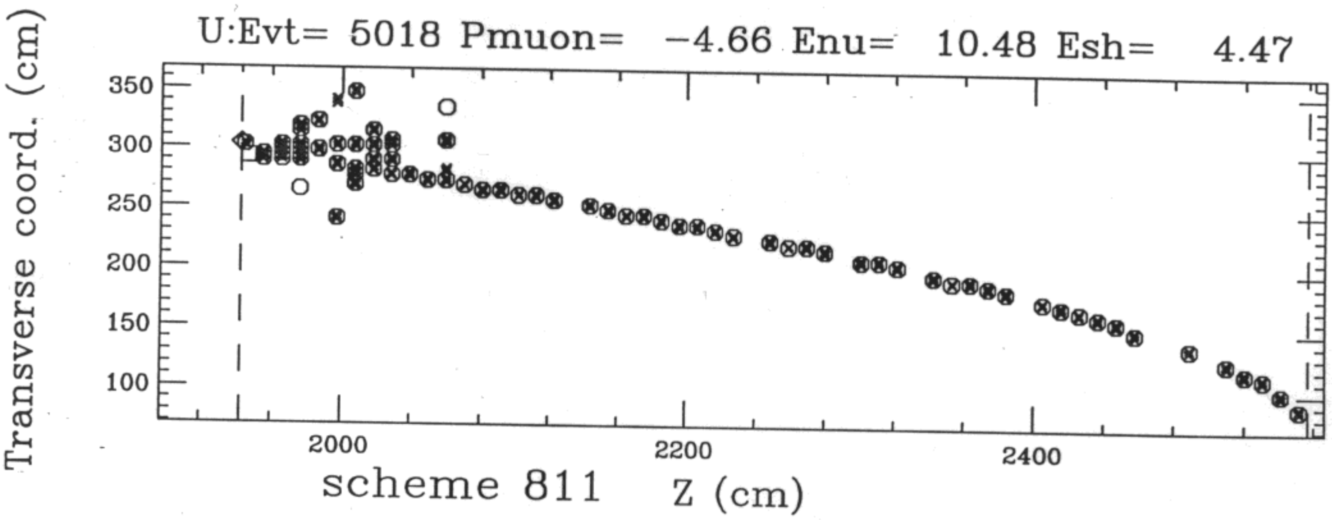
- fiducial cuts applied

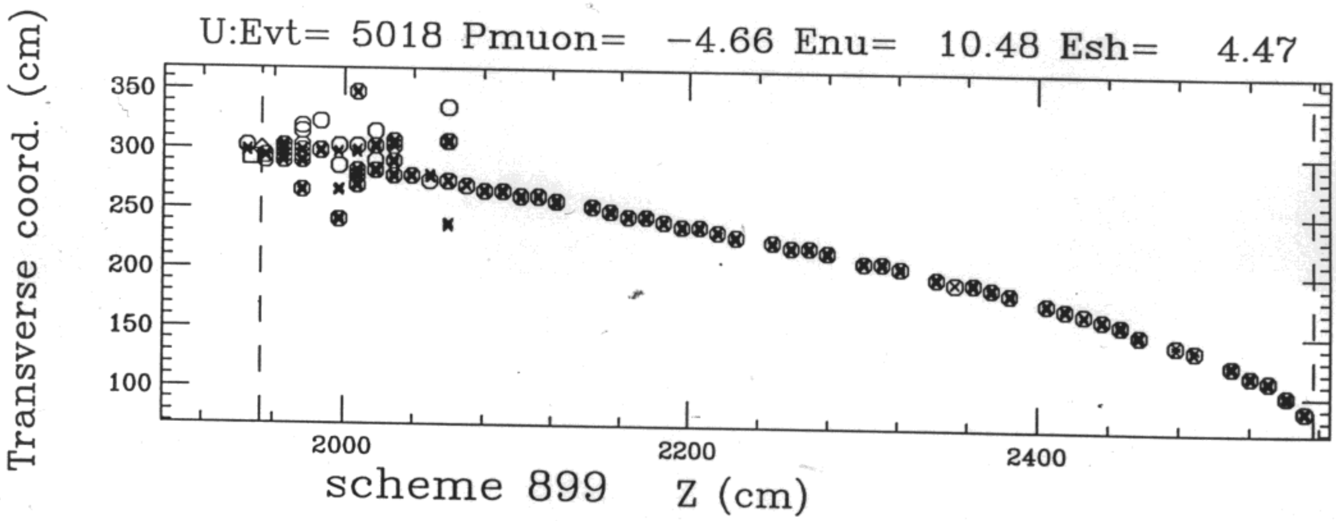


10kt·years

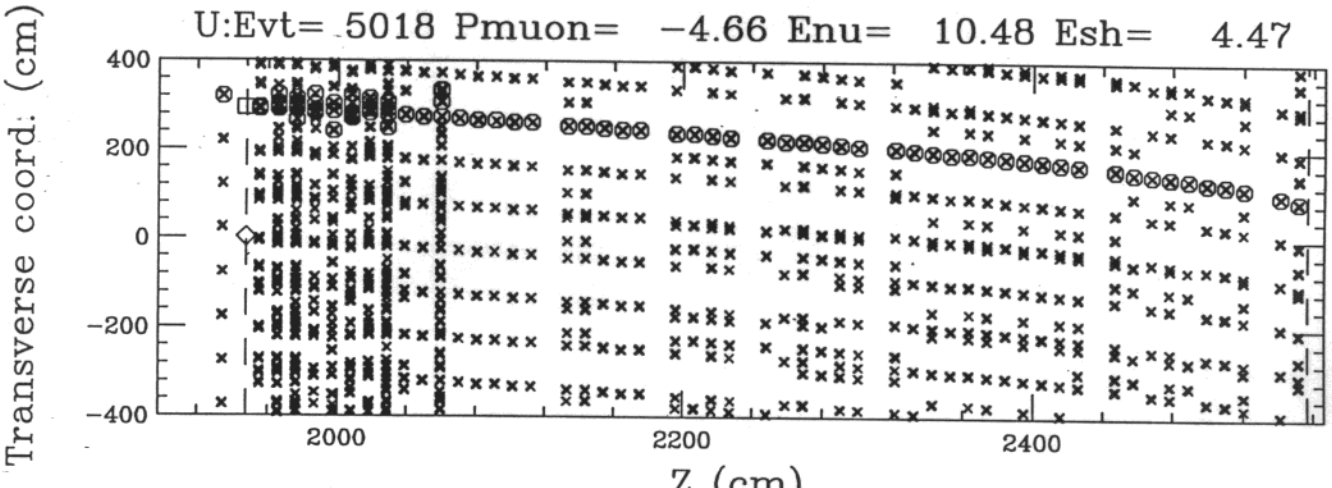
Low Energy Beam



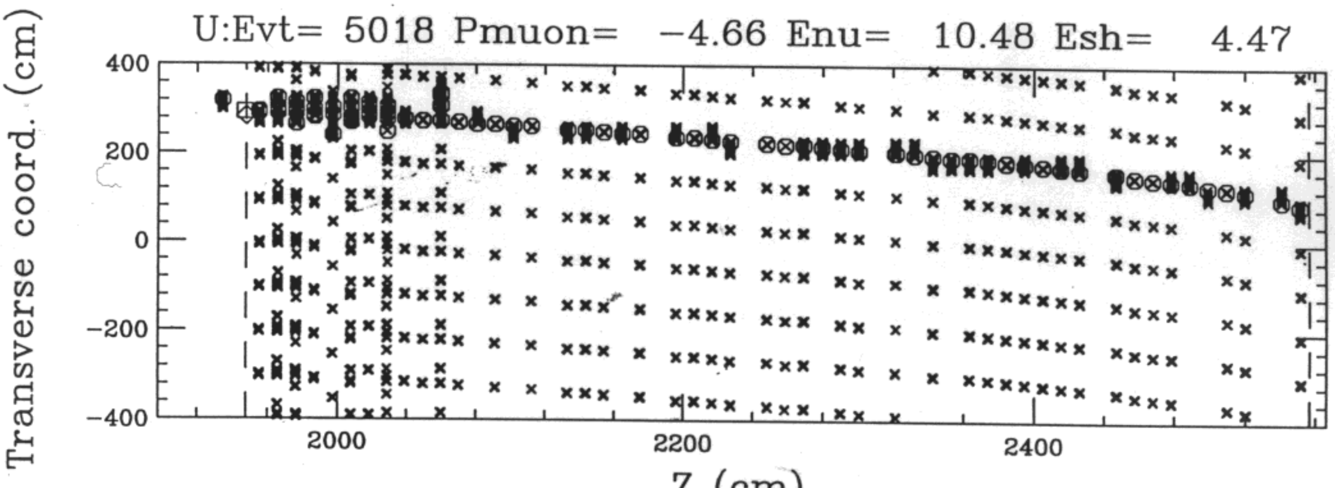

U:Evt= 5018 Pmuon= −4.66 Enu= 10.48 Esh= 4.47
Transverse coord. (cm)
350
300
250
200
150
100
2000
2200
2400
scheme 811
Z (cm)


U:Evt= 5018 Pmuon= −4.66 Enu= 10.48 Esh= 4.47
Transverse coord. (cm)
350
300
250
200
150
100
2000
2200
2400
scheme 899
Z (cm)

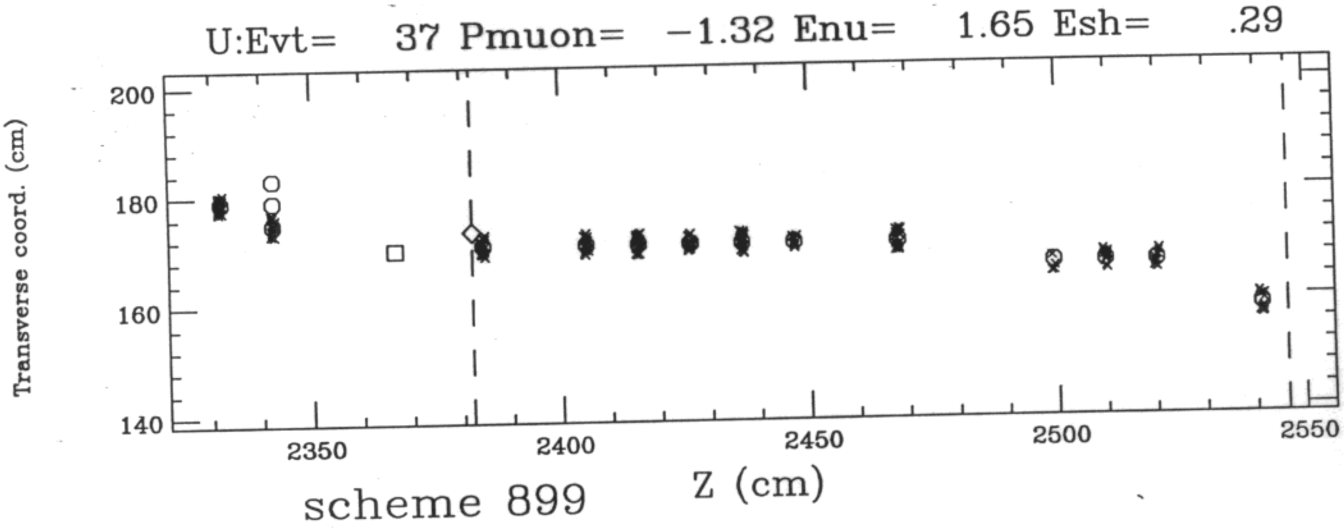
Carlos Arroyo

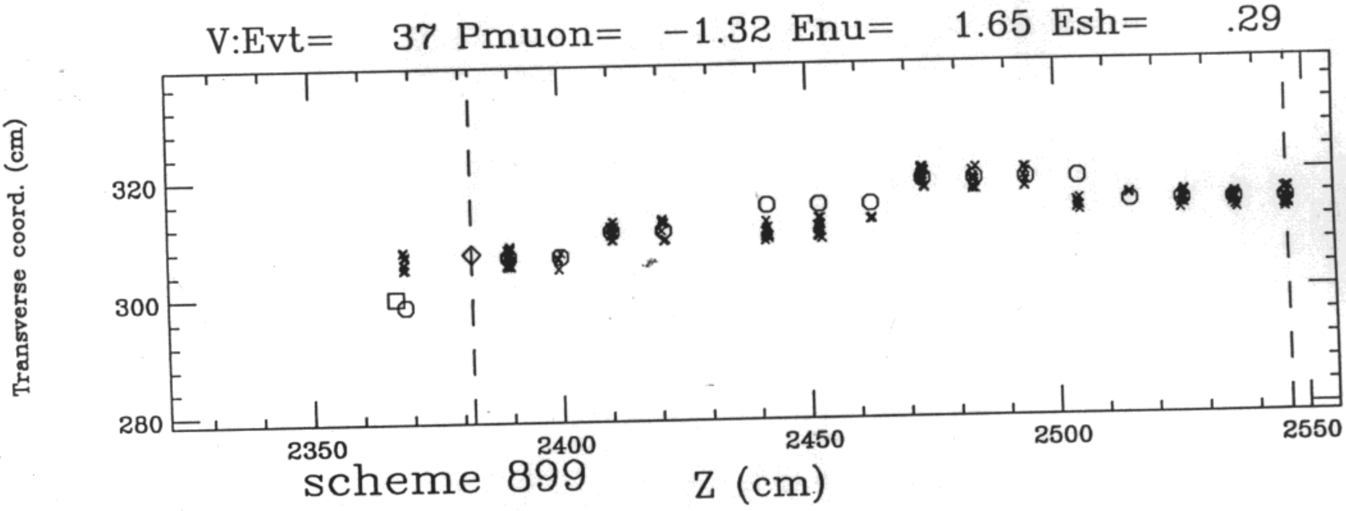


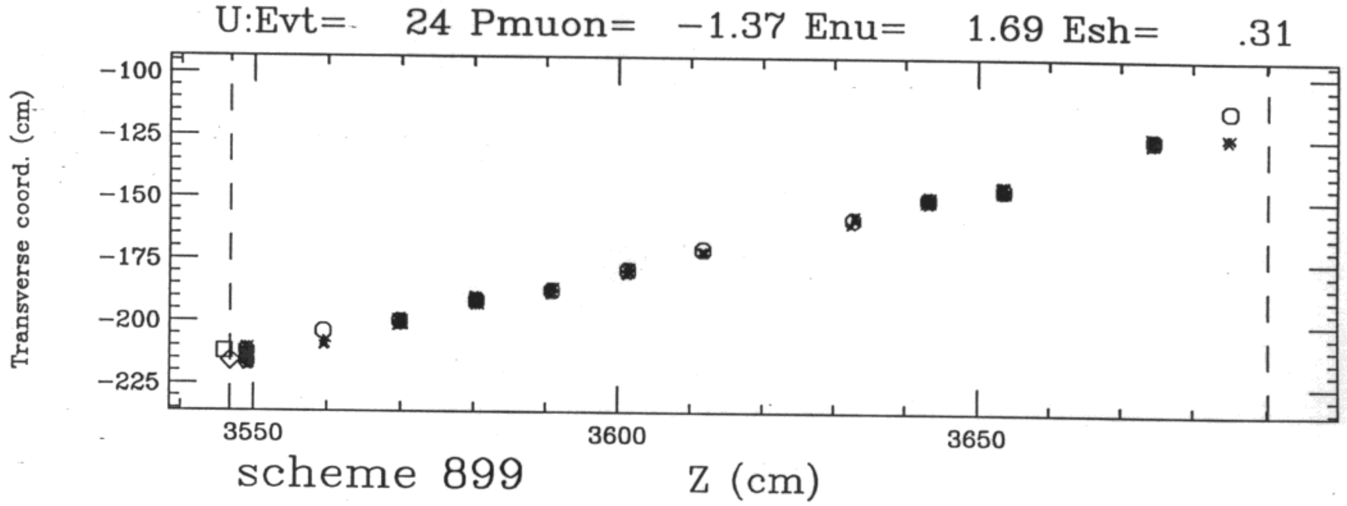
scheme 811

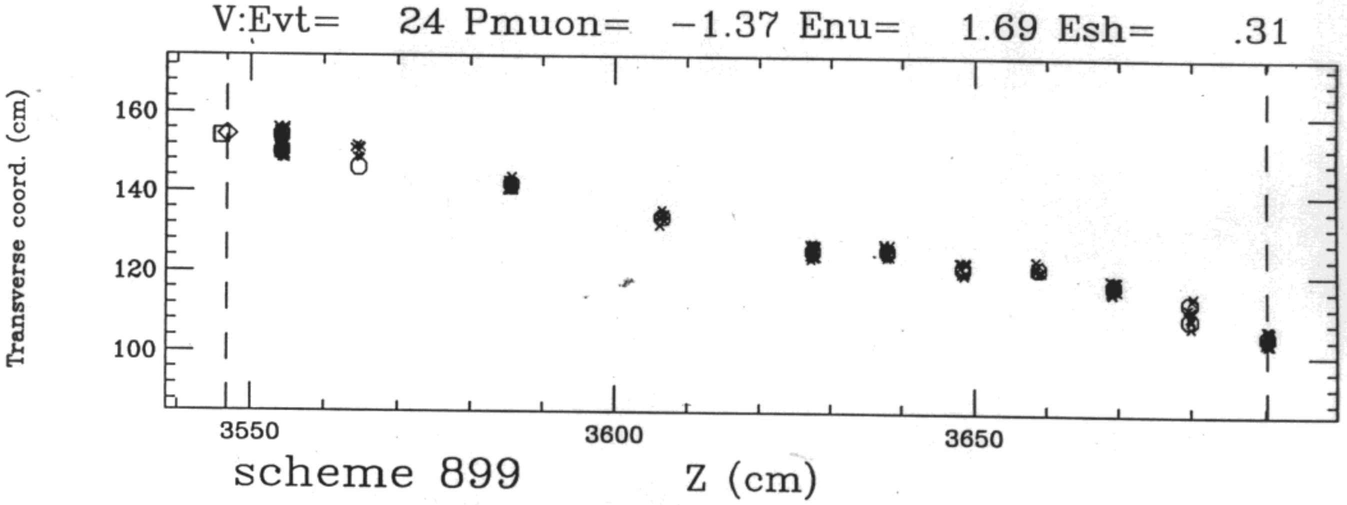


scheme 899


U:Evt= 37 Pmuon= −1.32 Enu= 1.65 Esh= .29
Transverse coord. (cm)
200
180
160
140
2350
2400
2450
2500
2550
Z (cm)
scheme 899


V:Evt= 37 Pmuon= −1.32 Enu= 1.65 Esh= .29
Transverse coord. (cm)
320
300
280
2350
2400
2450
2500
2550
scheme 899
Z (cm)


U:Evt= 24 Pmuon= −1.37 Enu= 1.69 Esh= .31
Transverse coord. (cm)
−100
−125
−150
−175
−200
−225
3550
3600
3650
scheme 899
Z (cm)


V:Evt= 24 Pmuon= −1.37 Enu= 1.69 Esh= .31
Transverse coord. (cm)
160
140
120
100
3550
3600
3650
scheme 899
Z (cm)

Events
kT·yr·GeV

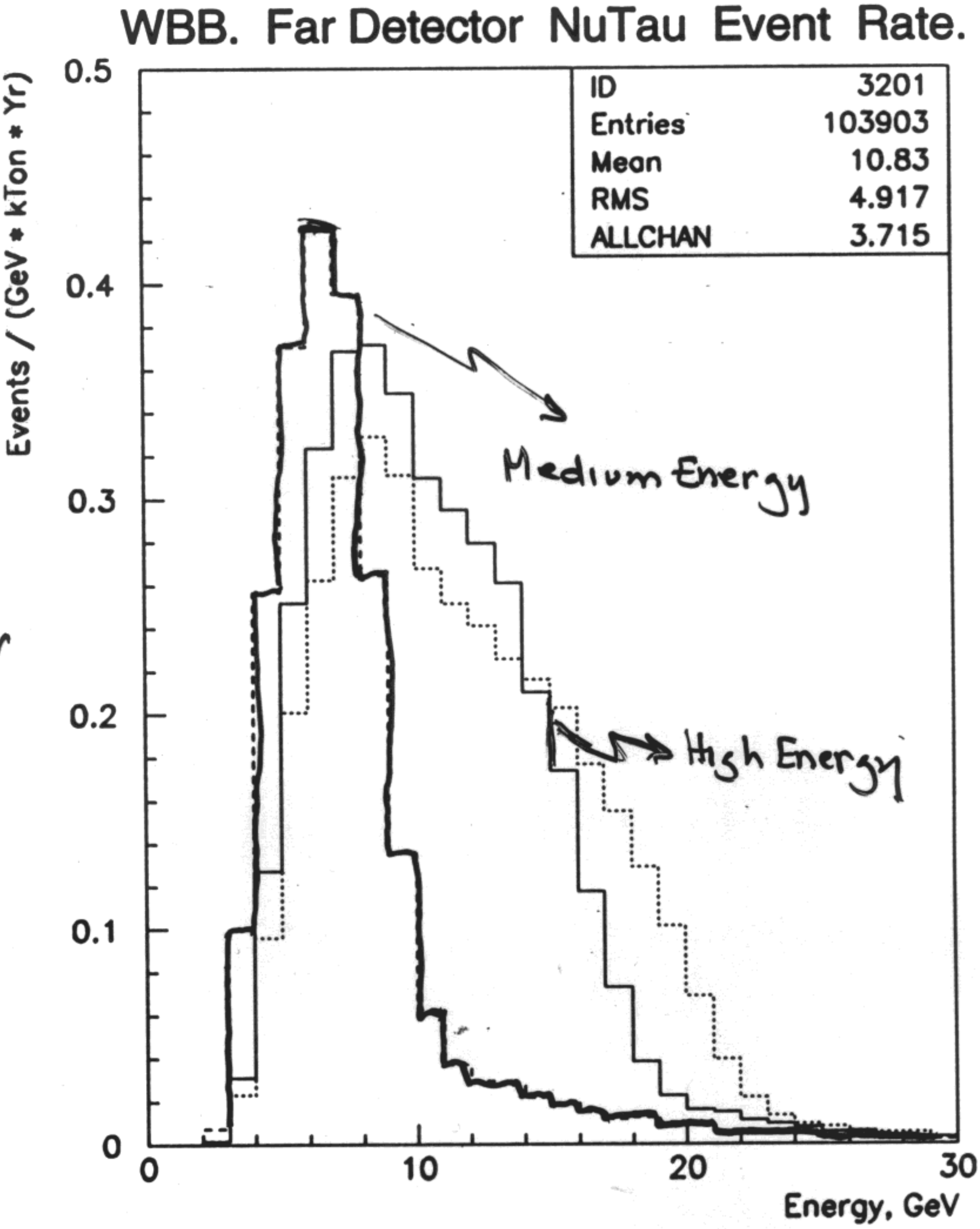
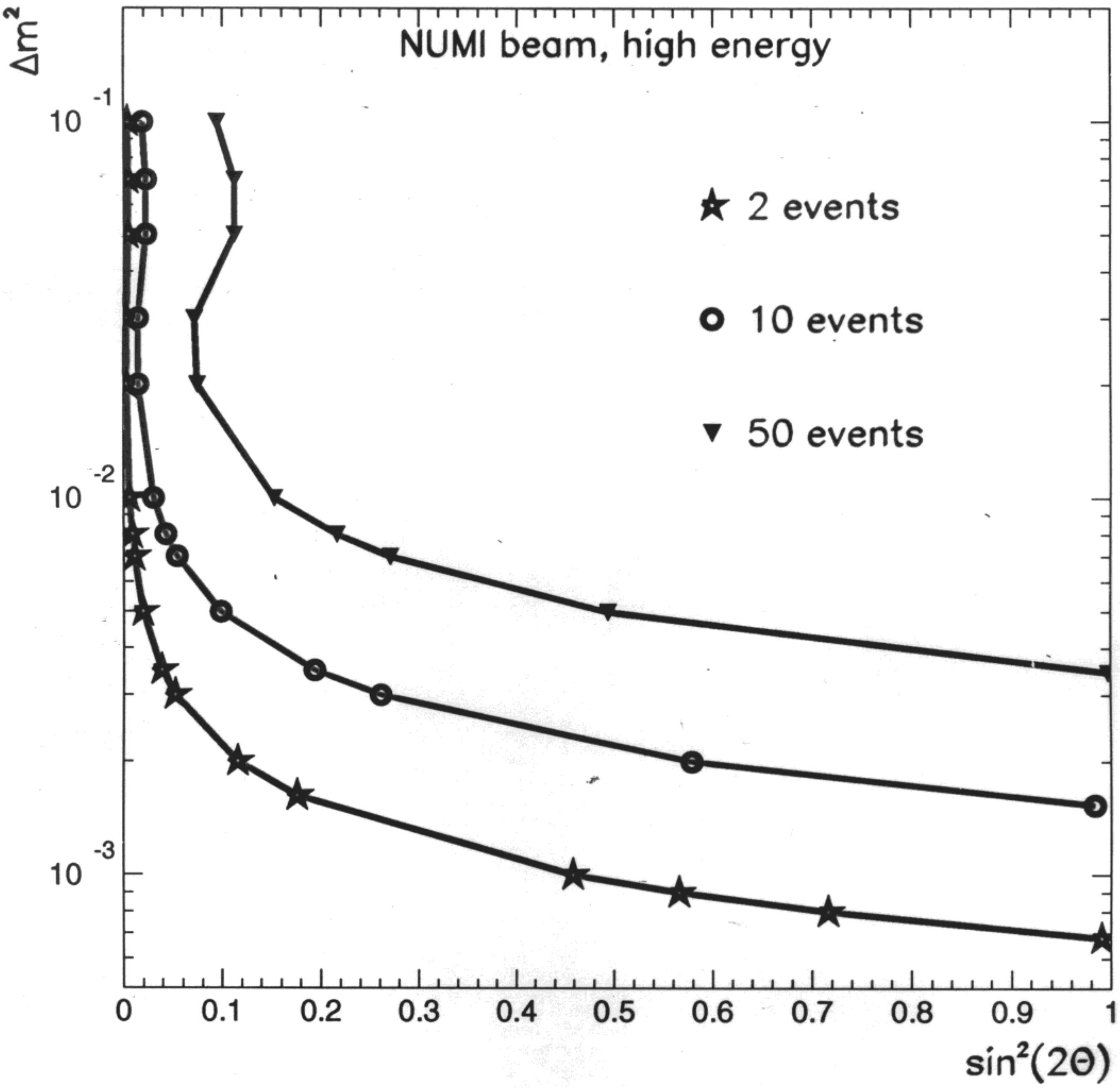


**Figure 5: $\nu_\tau$ CC event rates for different WBB designs. Dashed line corresponds to the PH2(me) beam, solid and dotted lines correspond to the PH2(he) beams with the target located 1.5 m and 2.4 m upstream the first horn (see also Table 1).**

Adam Para

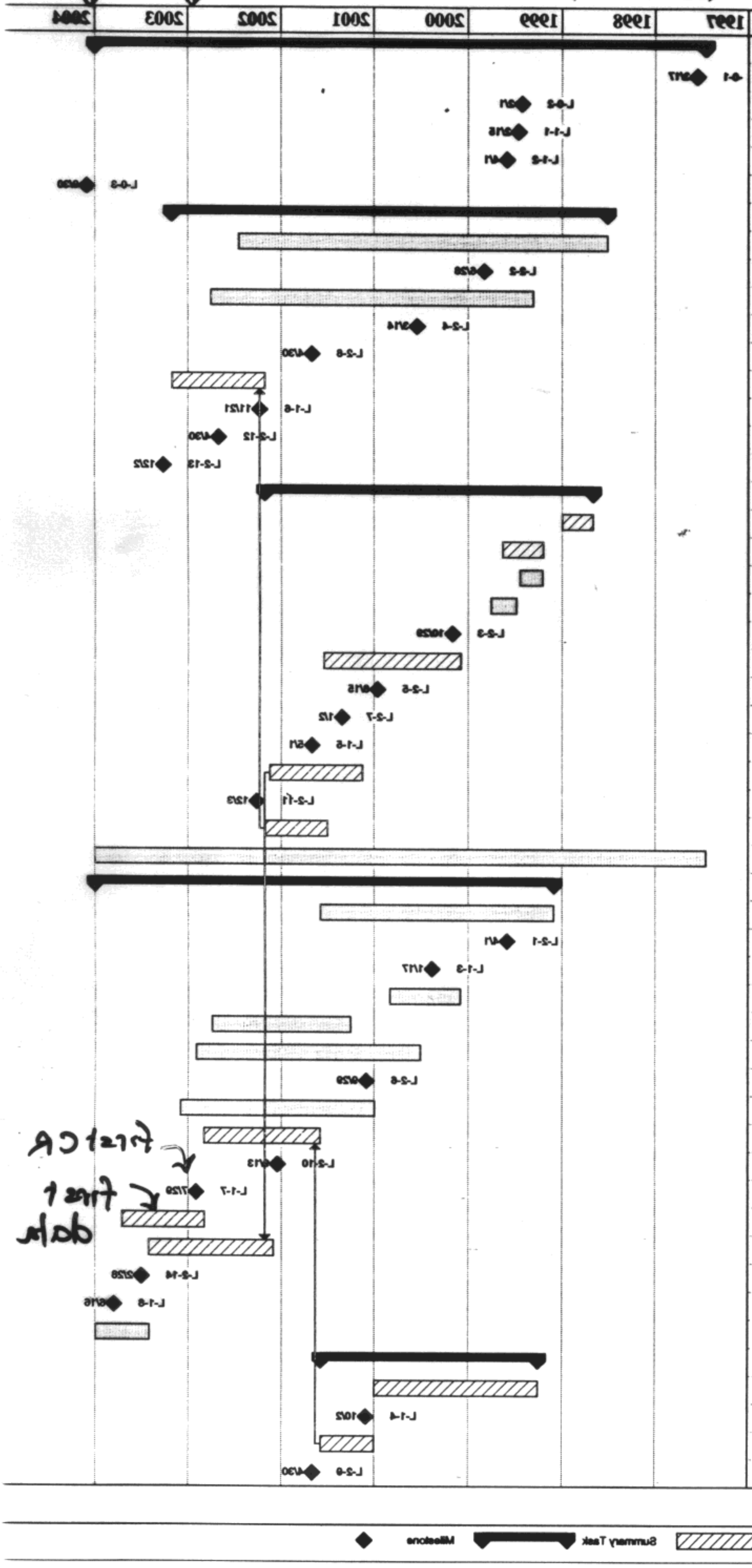
Number of produced $\tau$ per kton*year



# NuMI Project
# DOE Project Master Schedule
## (Fiscal Years)

2003 2004

| WBS | Description |
|---|---|
| | **Critical Decisions** |
| | CD-1 Approve Mission Need |
| | CD-2 Approve Baselines |
| | CD-3a Start Limited Construction |
| | CD-3b Continue Construction |
| | CD-4 Start Operations |
| 1.1 | **Technical Components** |
| | Tech Components Design |
| | Top of Soudan #8 Mineshaft Located with GPS |
| | Tech Components Construction |
| | High Current Pulse into Prototype Horn |
| | Magnets for MI Stub Refurbished |
| | Tech Components Installation |
| | Inner & Outer Conductors for First Production Horn Assembl |
| | Lambertson & C-Magnets Assembled & Tested |
| | First Horn Installed |
| 1.2 | **Conventional Construction** |
| | Facility Construction Title I Design Phase |
| | Facility UG Construction Title II Design Phase |
| | Site Prep & Util Title II Design |
| | Execute Site Prep & Util (Site Work) Sub-Cont |
| | NTP Issued for Fermilab Underground Subcontract |
| | Execute Fermi Underground Sub-Cont |
| | Fermilab Underground Construction 50% Complete |
| | Near Detector Excavation Complete |
| | Target Hall Excavation Complete |
| | Execute MINOS Service Building Sub-Cont |
| | Beneficial Occupancy of Service Buildings at Fermilab |
| | Execute Target Service Building Sub-Cont |
| 1.3 | **Project Management** |
| 2.0 | **MINOS Detector Construction** |
| | 4 Plane Prototype |
| | MINOS Steel Purchase Subcontract Awarded |
| | Far Detector Prototype Erected |
| | Final Detector Design |
| | Near Steel Procurement |
| | Far Steel Procurement |
| | CalTech Factory Commissioned |
| | Scintillator Module Production |
| | 1st Super-Module Installation |
| | Cosmic Rays Observed in Far Detector |
| | First Far Detector Super Module Complete & Tested |
| | 2nd Super-Module Installation |
| | Near Detector Installation |
| | Near Detector Complete & Tested |
| | Far Detector Complete & Tested |
| | System Commissioning |
| 3.3 | **Soudan Cavern** |
| | Soudan Cavern Excavation |
| | Far Detector Excavation Complete |
| | Soudan Cavern Outfitting |
| | Outfitting of Far Detector Enclosure Complete |



first CR

first data

Project: NuMI_Master_Sched
Date: 2/17/99