NuMI Secondary Beam Monitors

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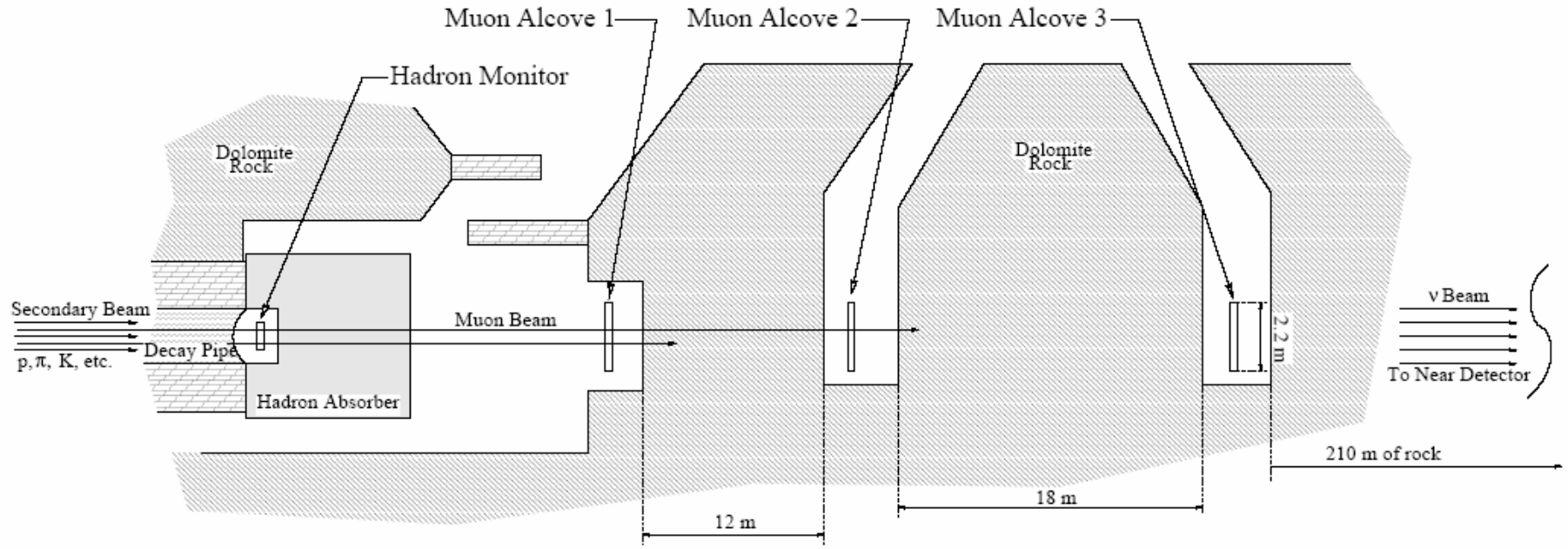
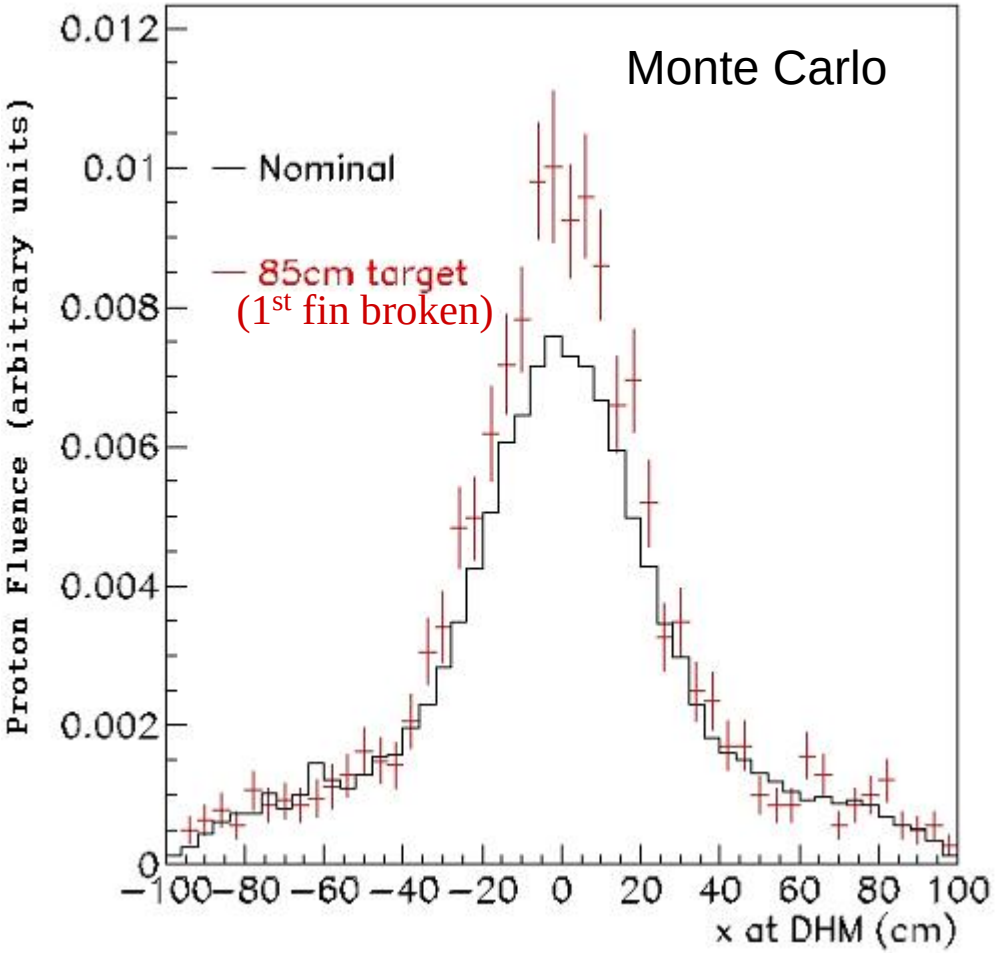
I. Detector Description
II. Chamber Performance
III. In-beam Observations
IV. My rant: is it a flux *monitoring* or *measuring* tool?



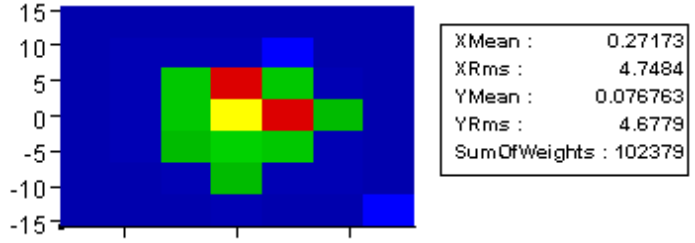
Function of the Hadron Monitor

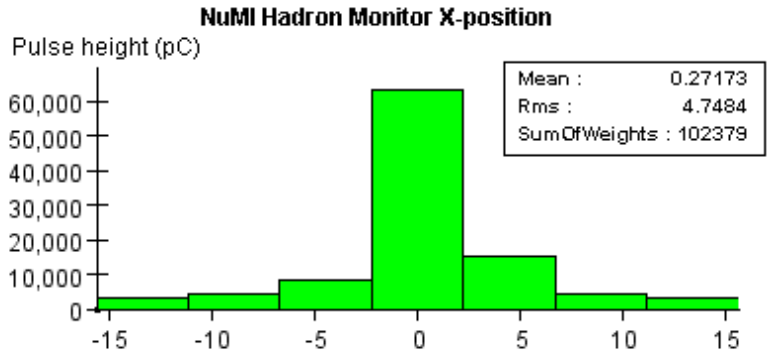
- As target monitor

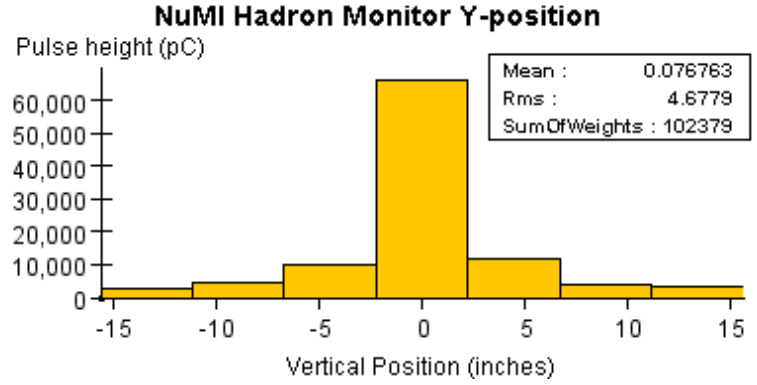


- As alignment tool:

Data!



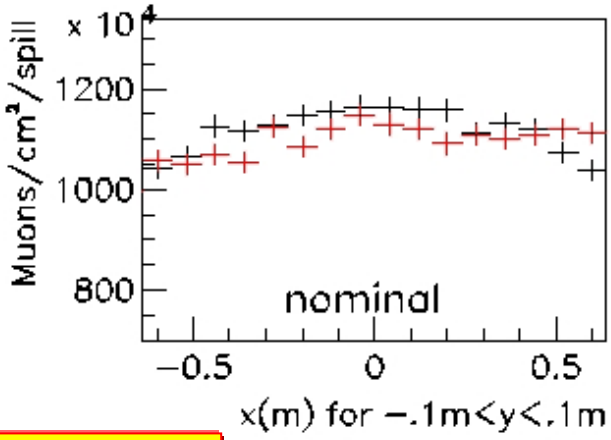




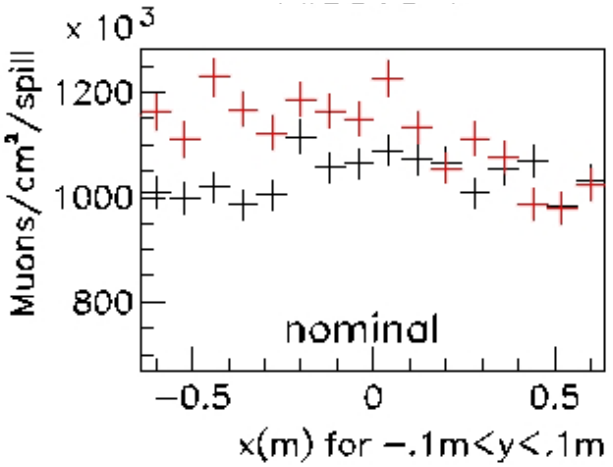
Function of the Muon Monitors

LE Beam

Alcove 1



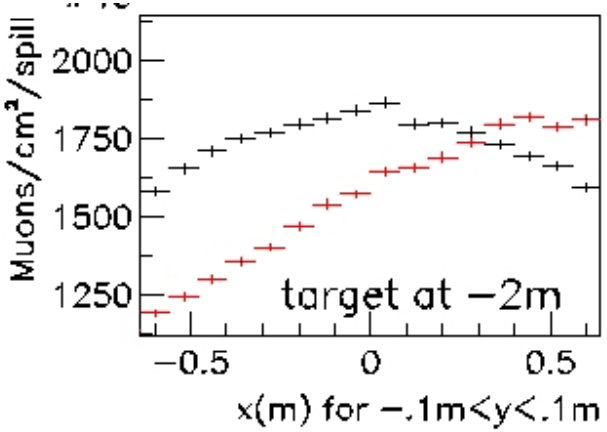
Alcove 2



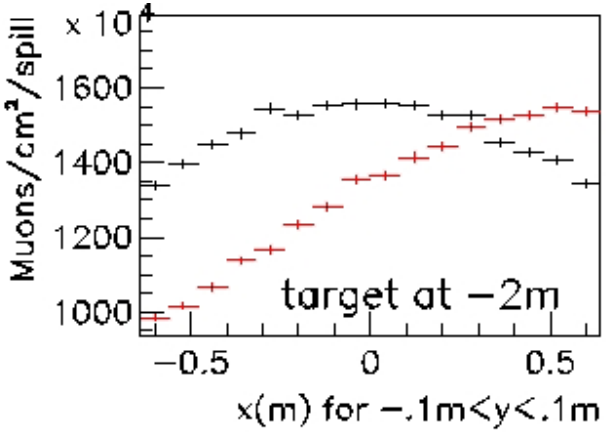
Monte Carlo!

HE Beam

Alcove 1



Alcove 2



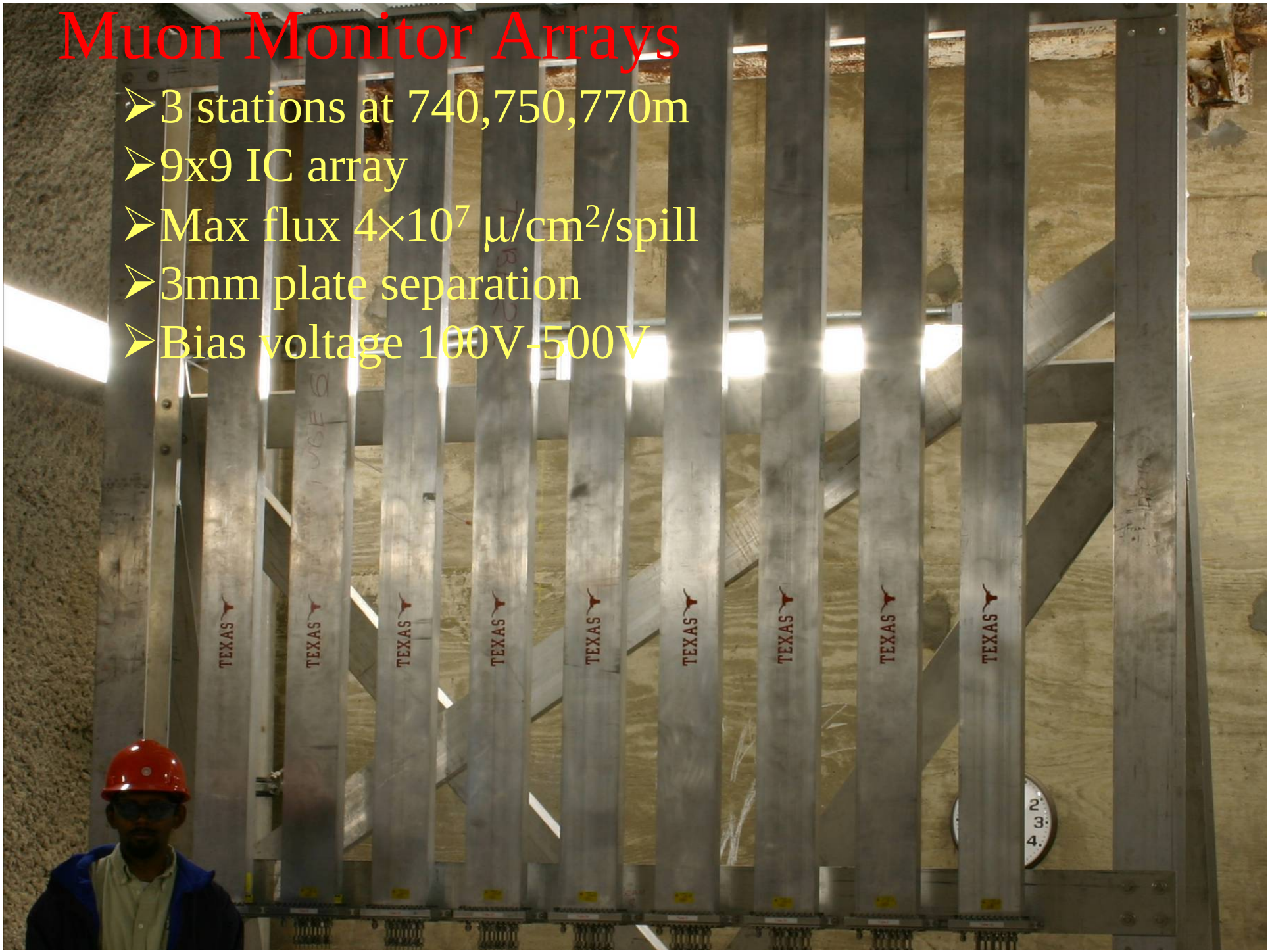
Monte Carlo!

Nominal Horn 1 position

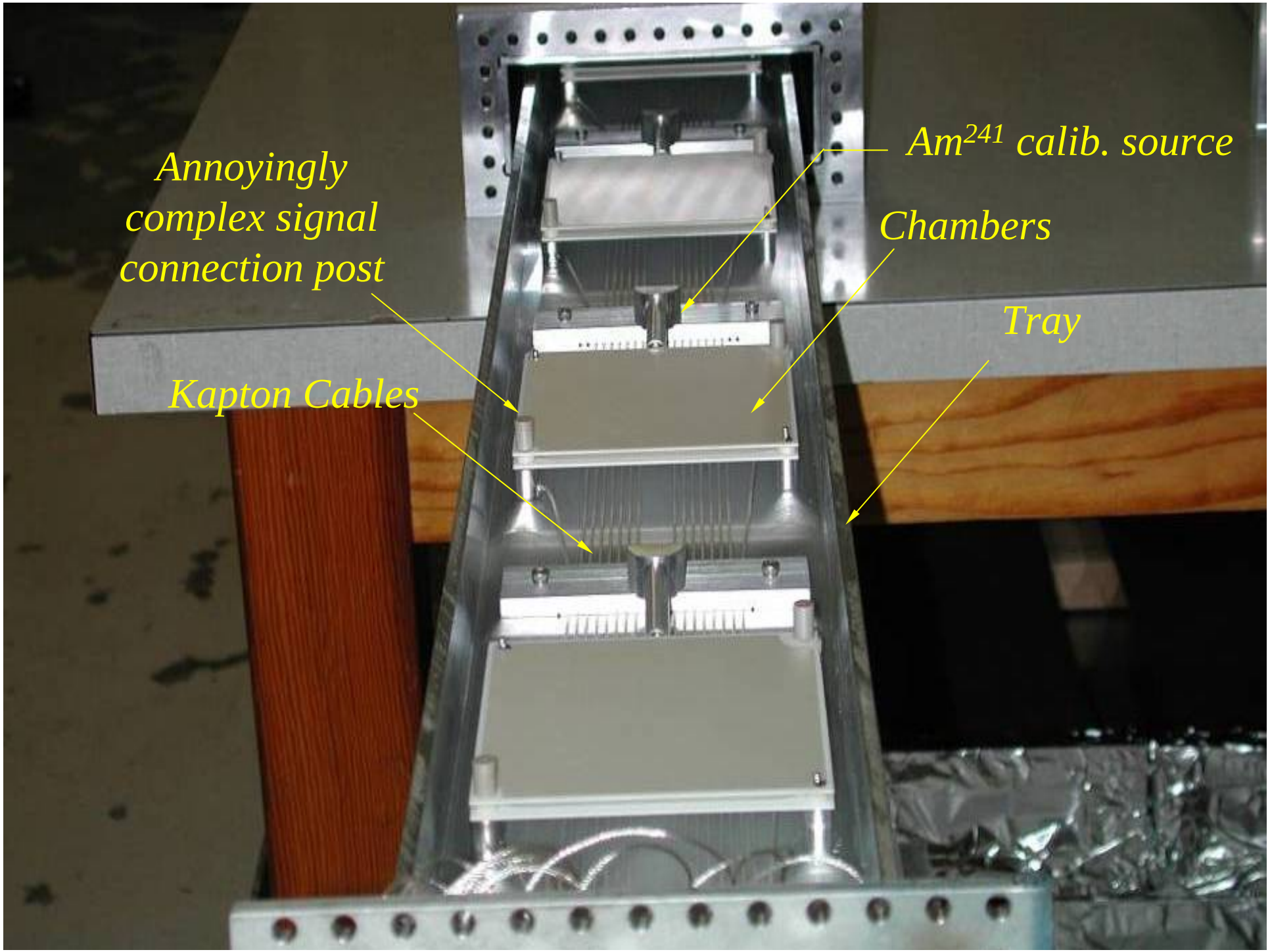
Horn 1 3mm shift

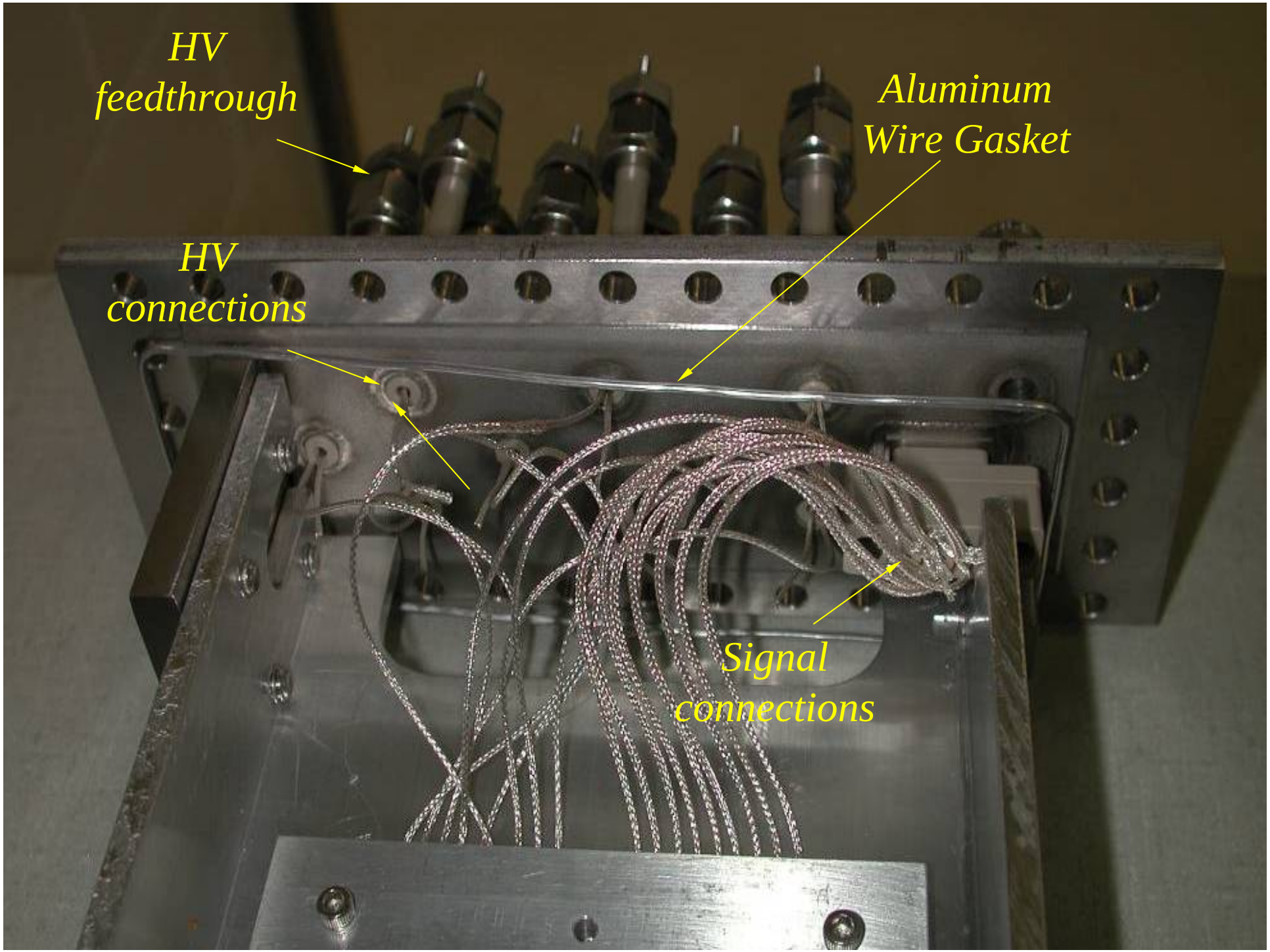
Detector Construction Details

Muon Monitor Arrays

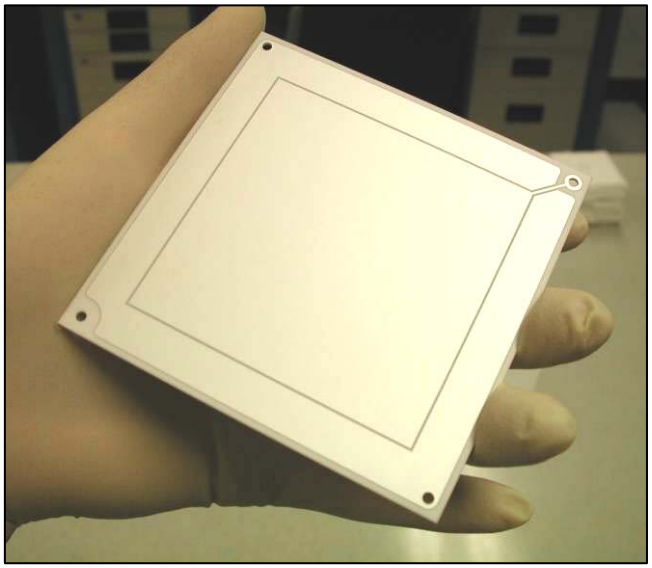


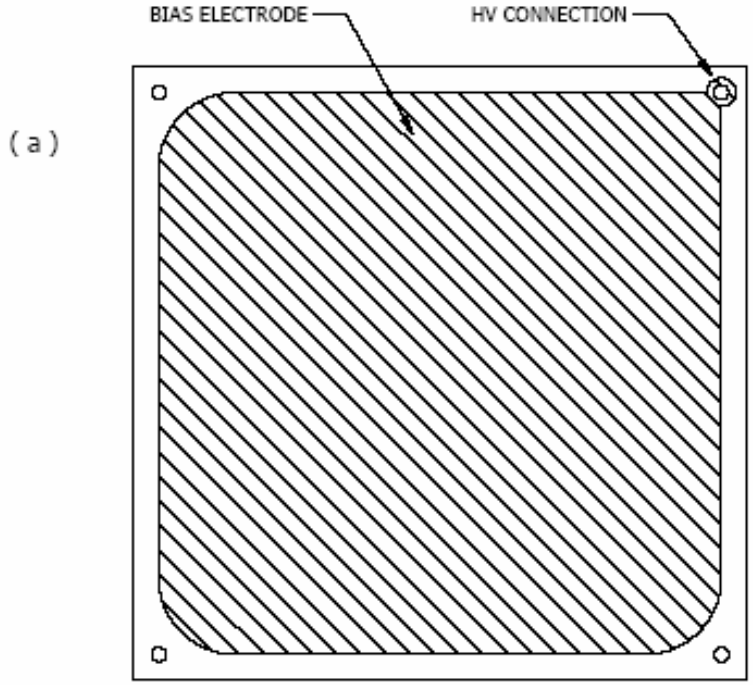
- 3 stations at 740,750,770m
- 9x9 IC array
- Max flux 4×10^{7} μ/cm^{2}/spill
- 3mm plate separation
- Bias voltage 100V-500V

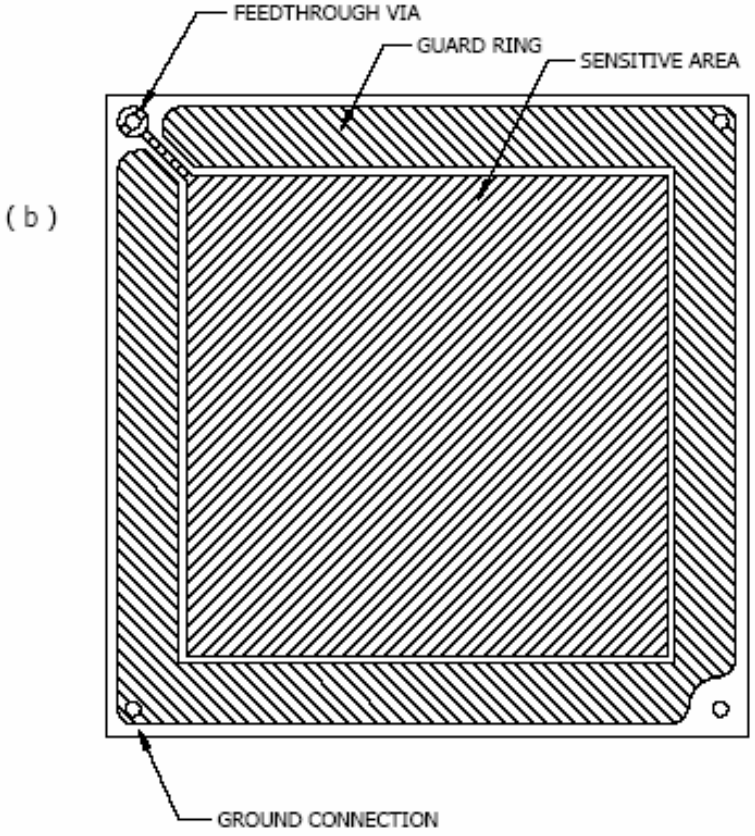

Annoyingly complex signal connection post
Kapton Cables
Am241 calib. source
Chambers
Tray


HV
feedthrough
Aluminum
Wire Gasket
HV
connections
Signal
connections

Ceramic Parallel Plate Ion Chambers

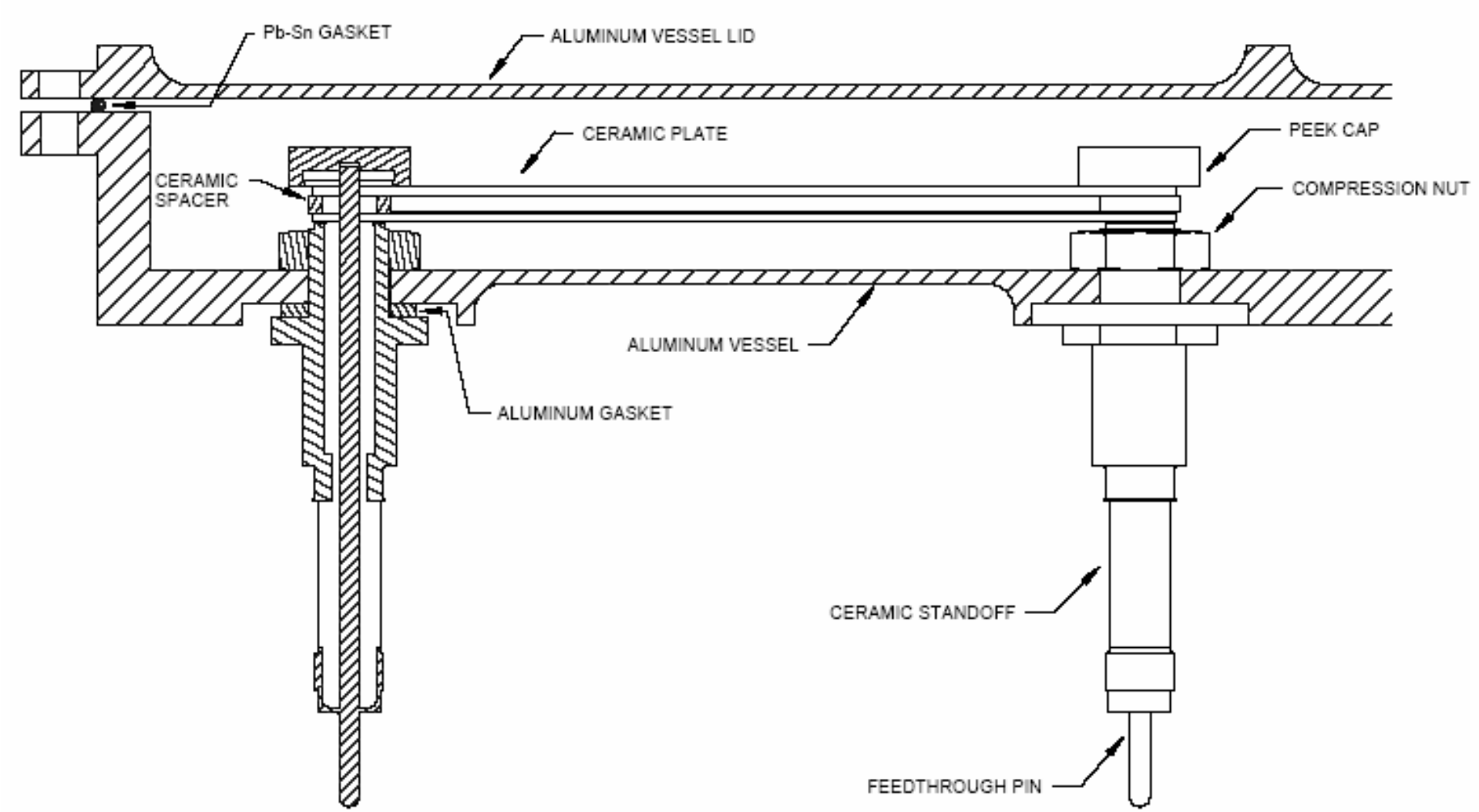


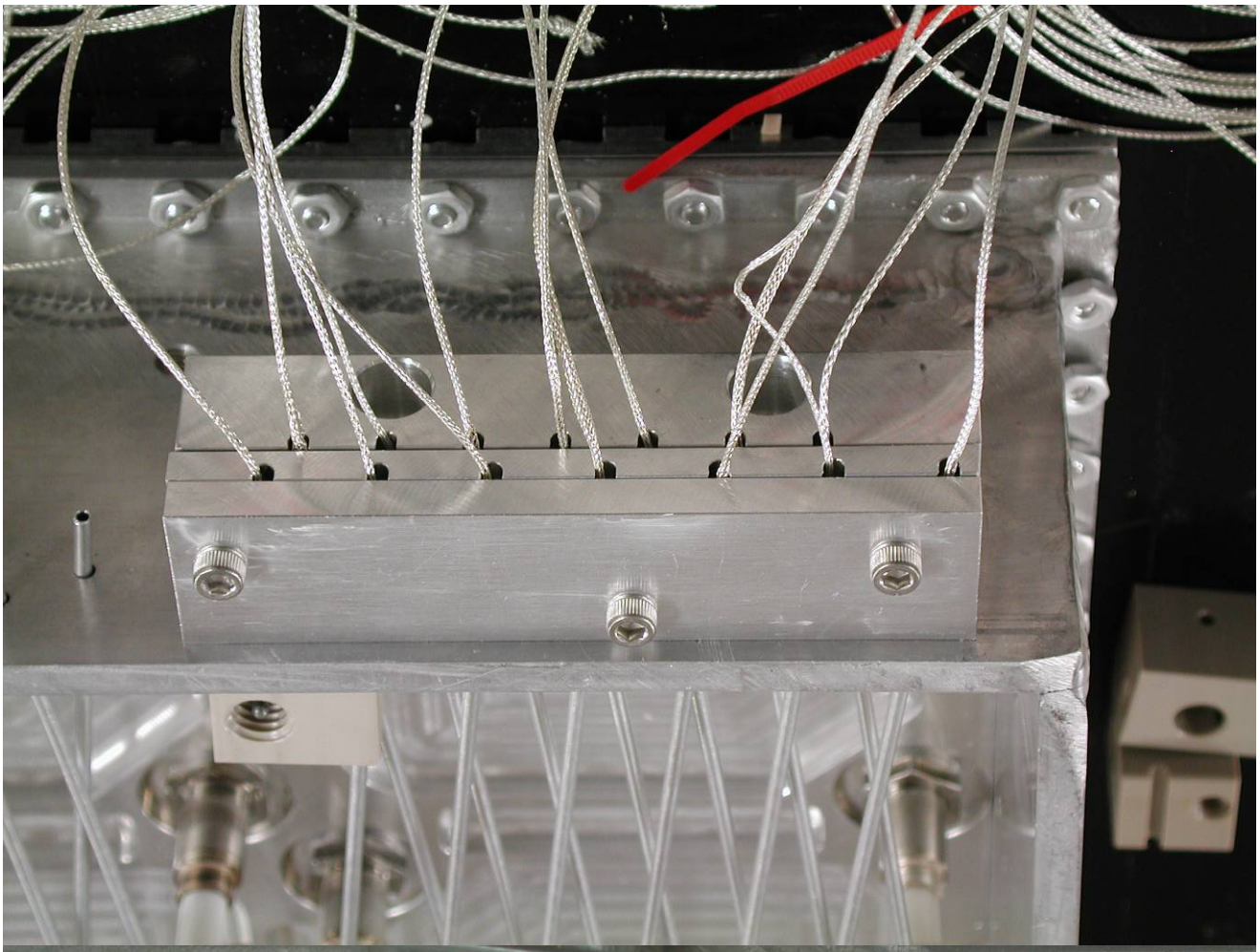


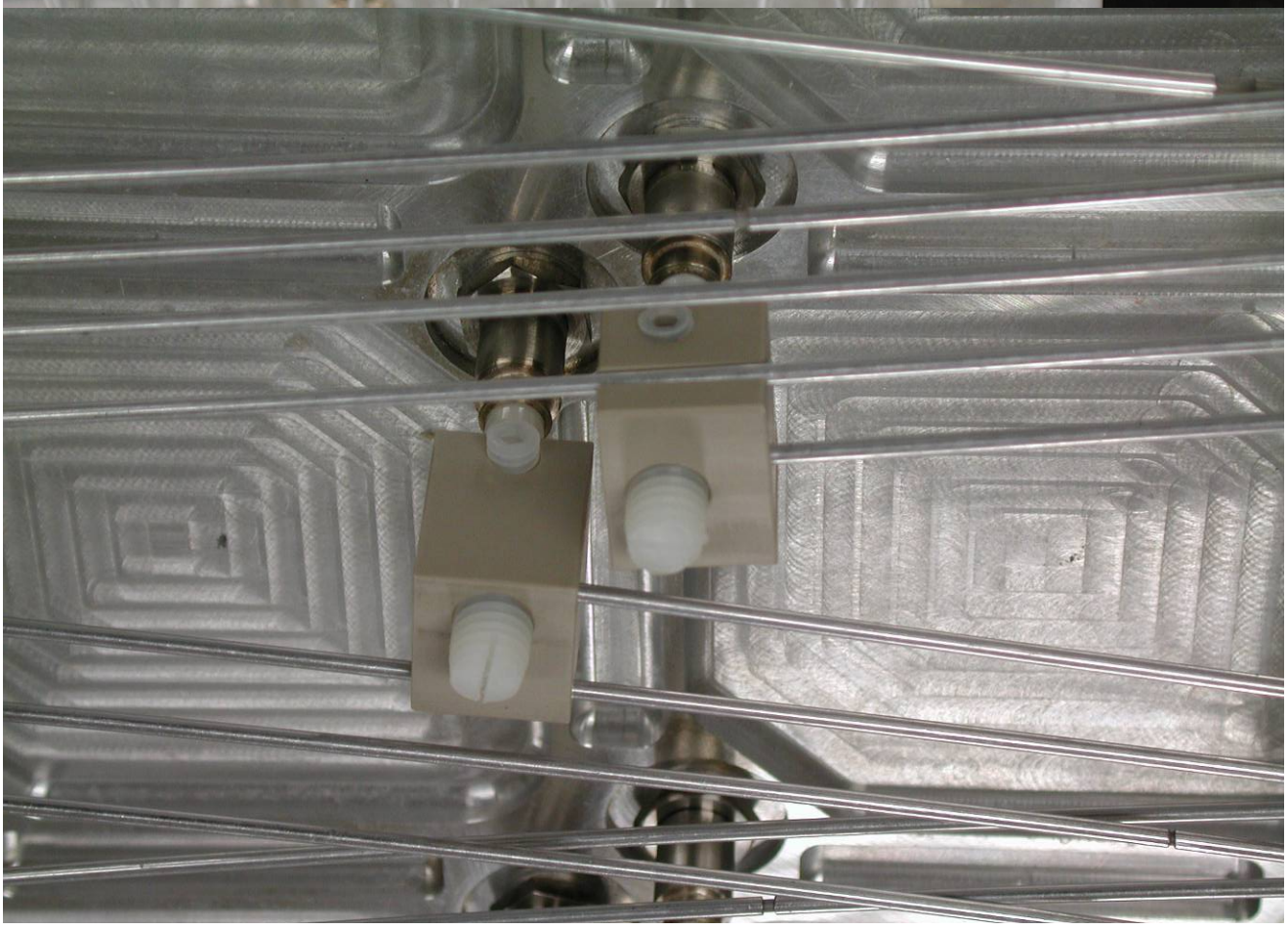


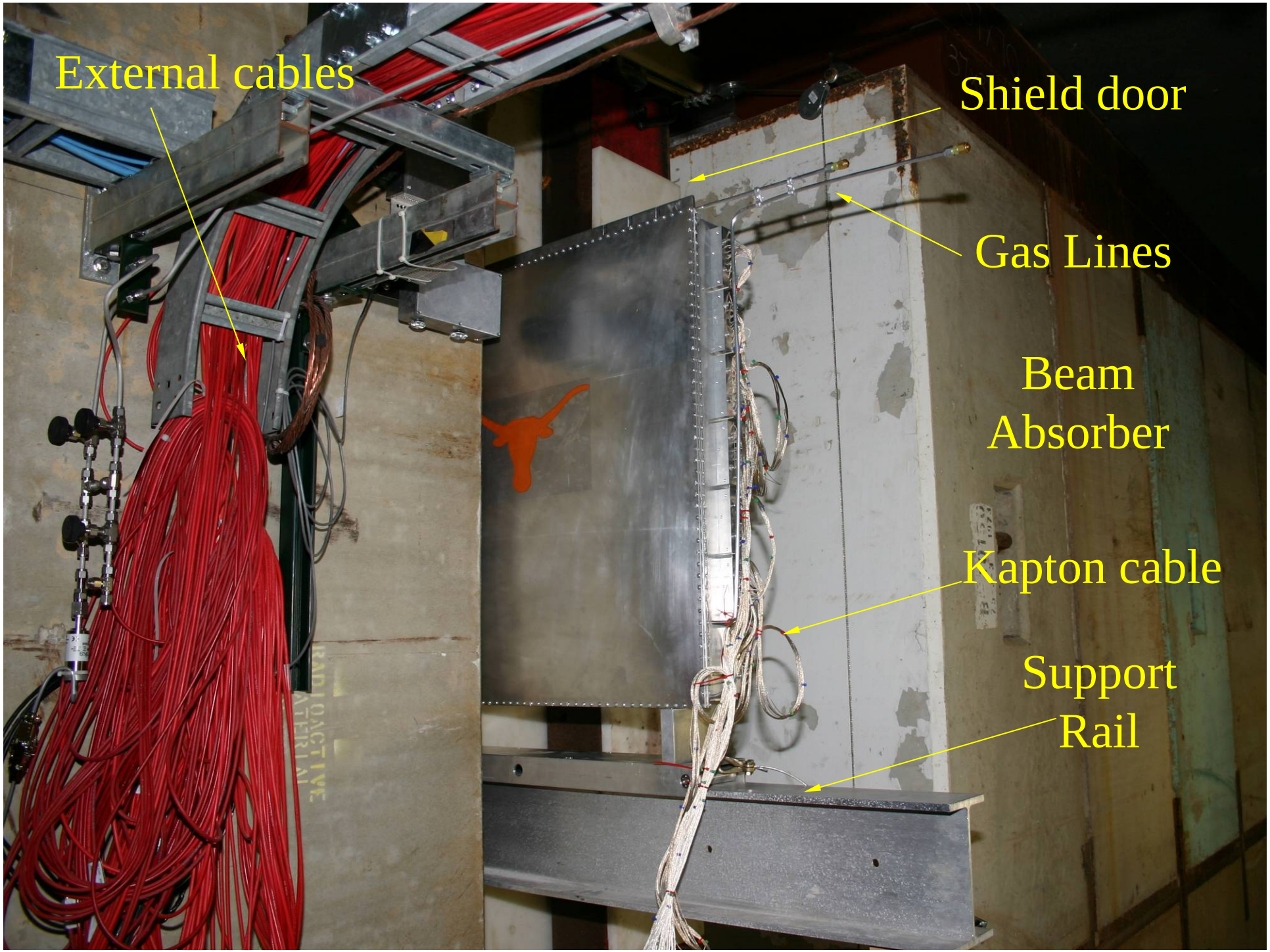
Hadron Monitor

- Max flux ~10^9/cm^2/spill
- Rad levels ~2 x 10^9 Rad/yr
- 7x7 array of Ion Chambers
  - -1 mm gap
- Residual activation 58R/hr
  - -Construction 54lbs Al, 4lbs stainless
- Components Rad Tested up to 12GRad (6 NuMI years)


Pb-Sn GASKET
ALUMINUM VESSEL LID
CERAMIC PLATE
PEEK CAP
CERAMIC SPACER
COMPRESSION NUT
ALUMINUM VESSEL
ALUMINUM GASKET
CERAMIC STANDOFF
FEEDTHROUGH PIN

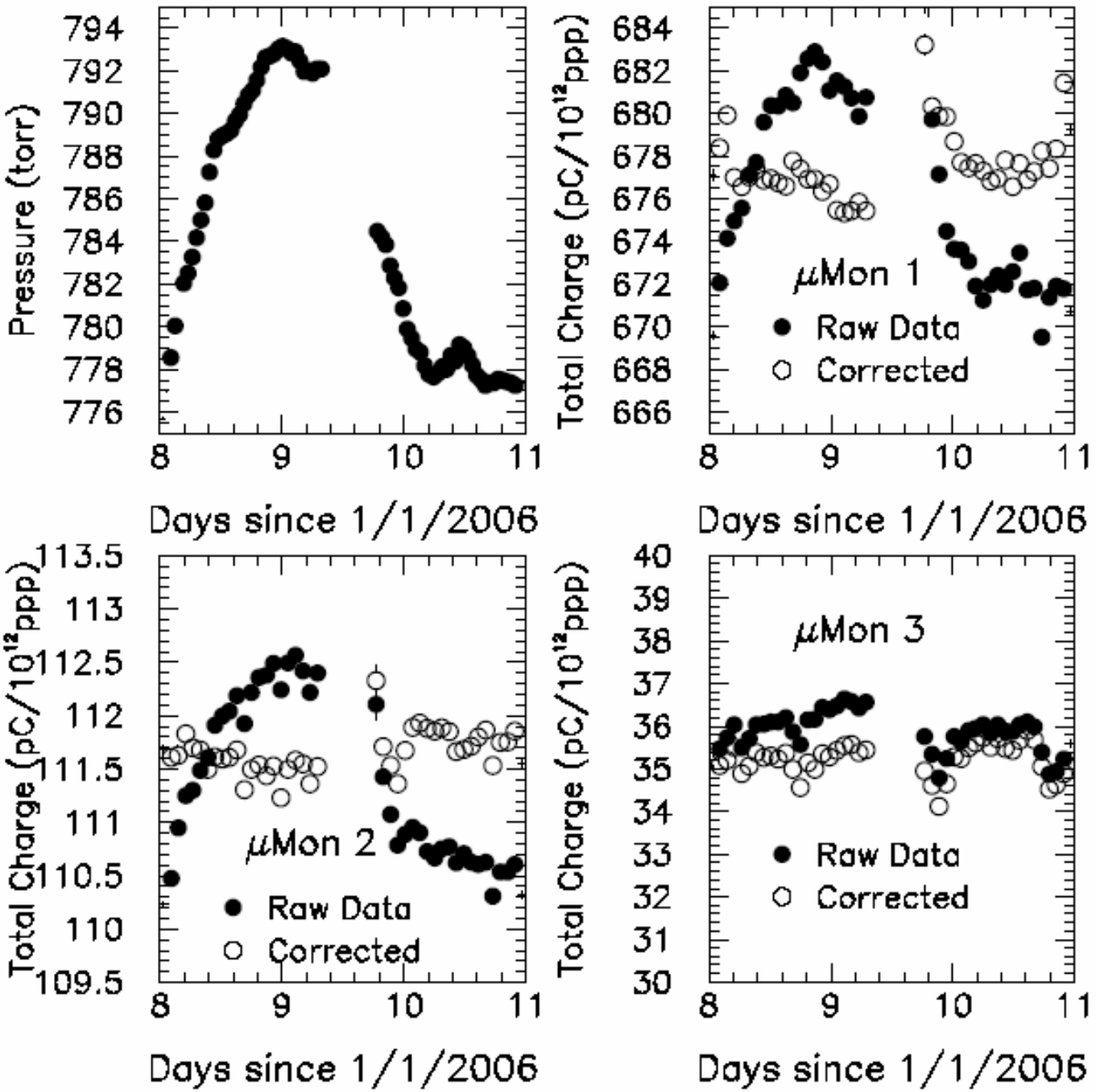




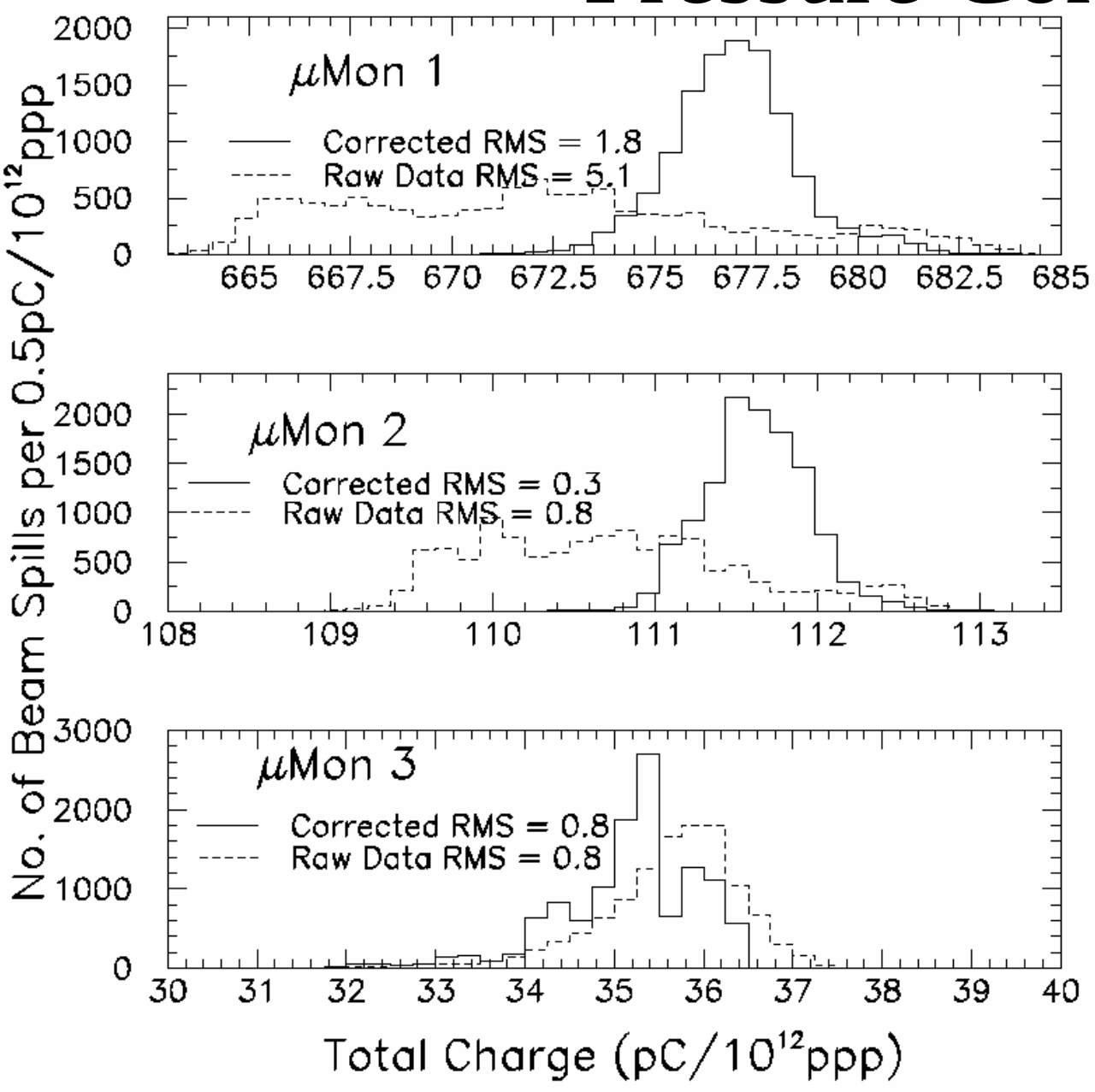

External cables
Shield door
Gas Lines
Beam
Absorber
Kapton cable
Support
Rail

Observations on Chamber Performance

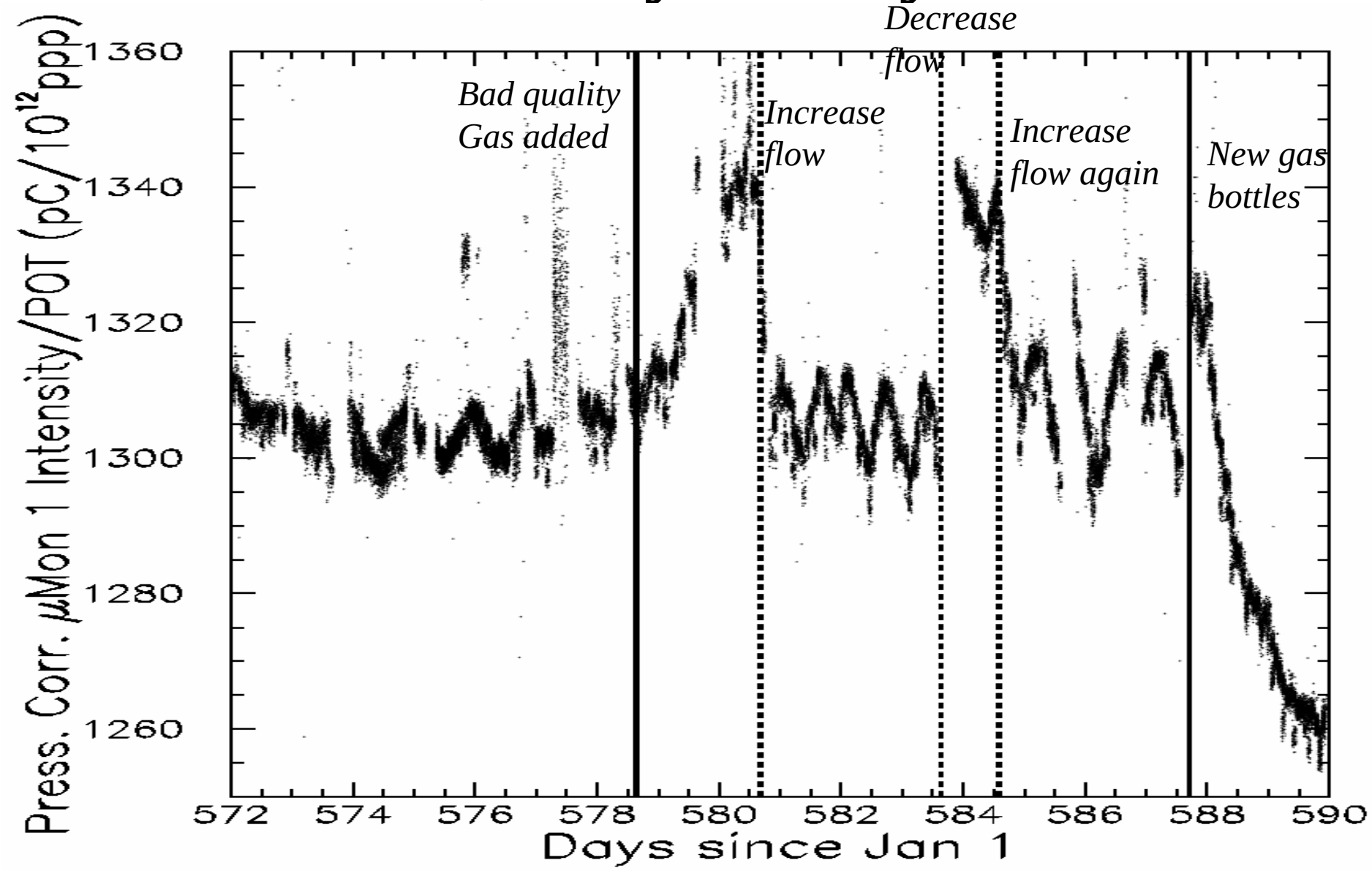
Correct for Pressure Variations



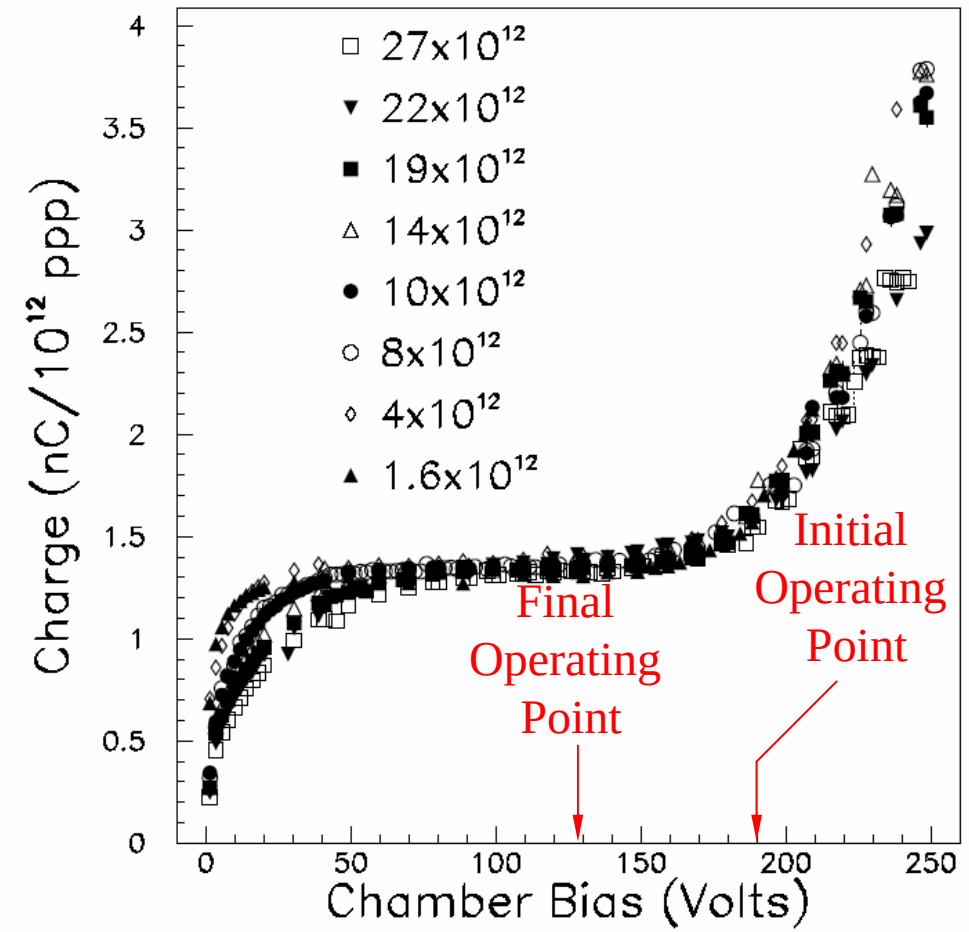
Pressure Corrections (*cont'd*)

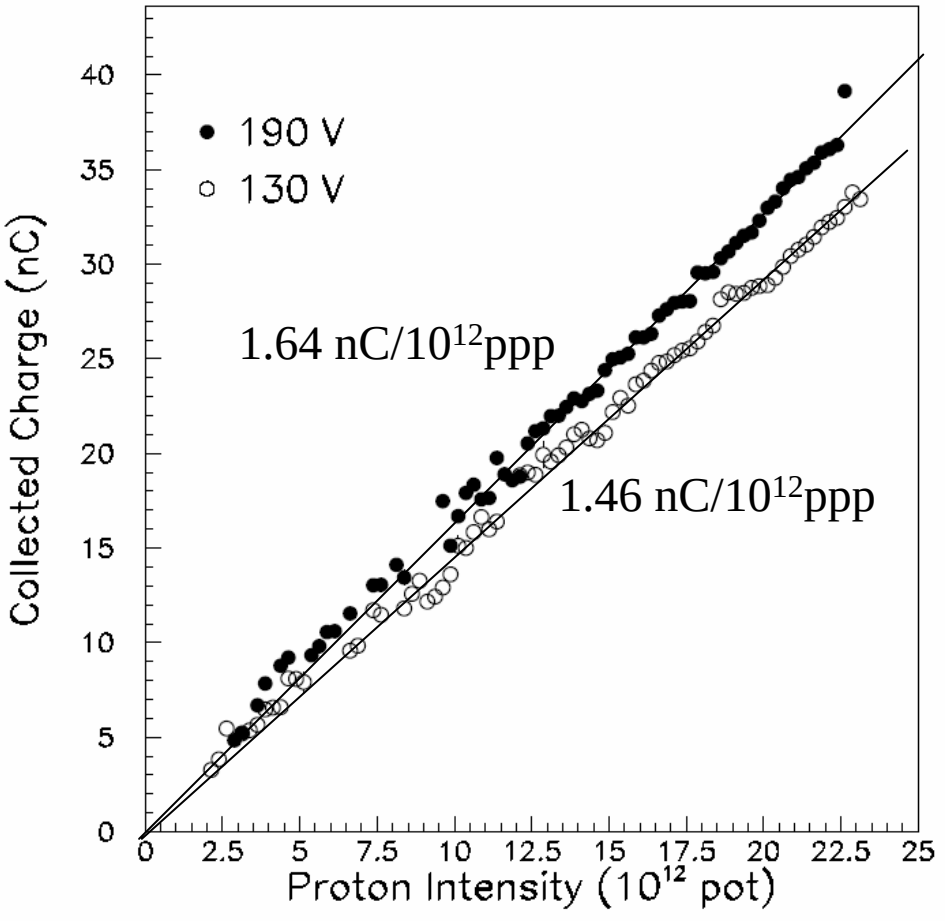


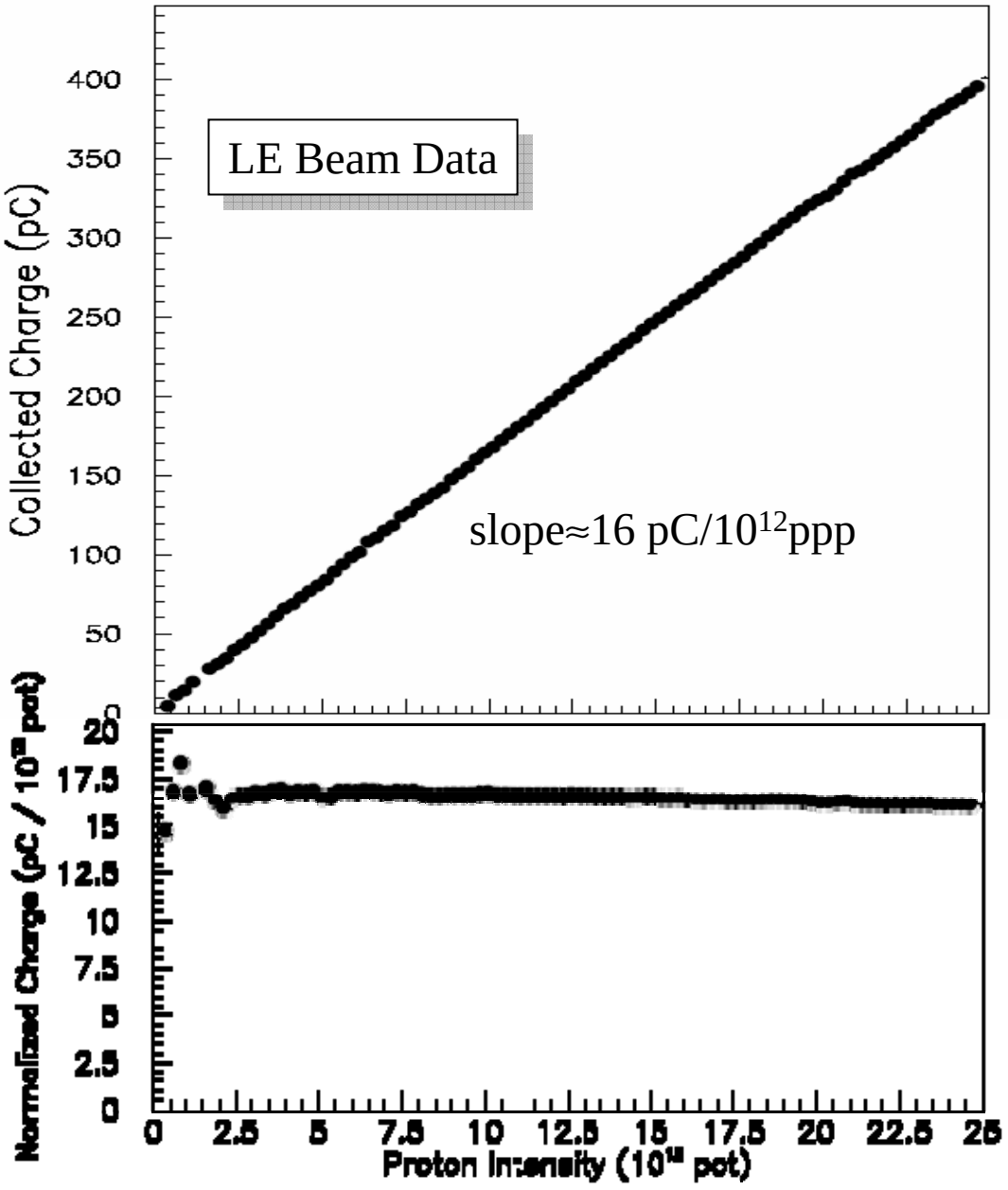
Gas Quality Annoyances



Hadron Mon. Linearity







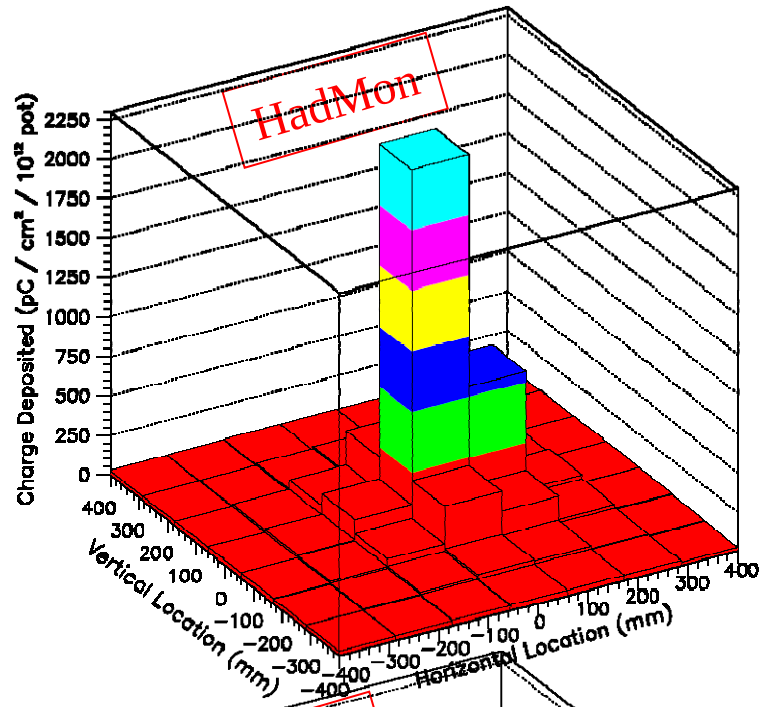
Muon Chamber Linearity

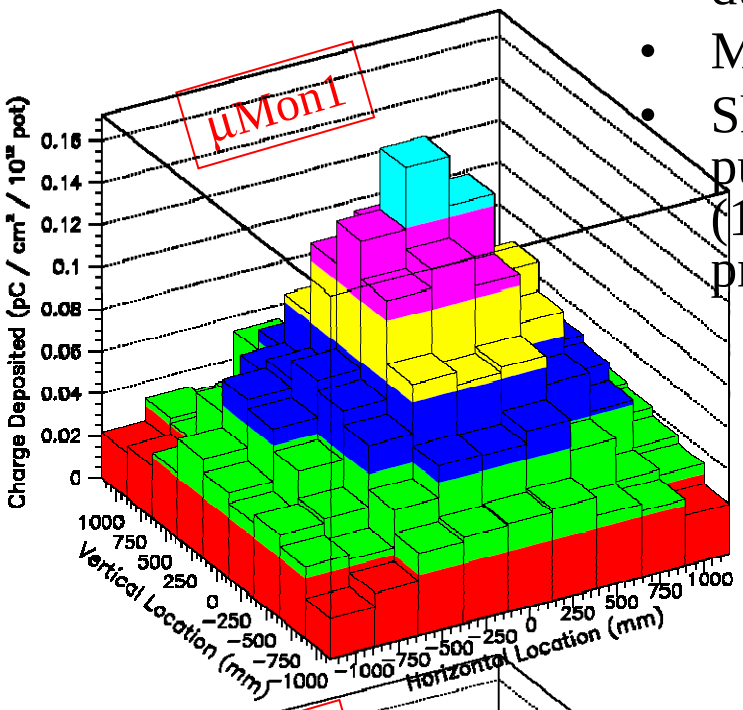
- Linearity with particle fluence pretty good
- Nonlinearity of 3% per 400pC seen – space charge??

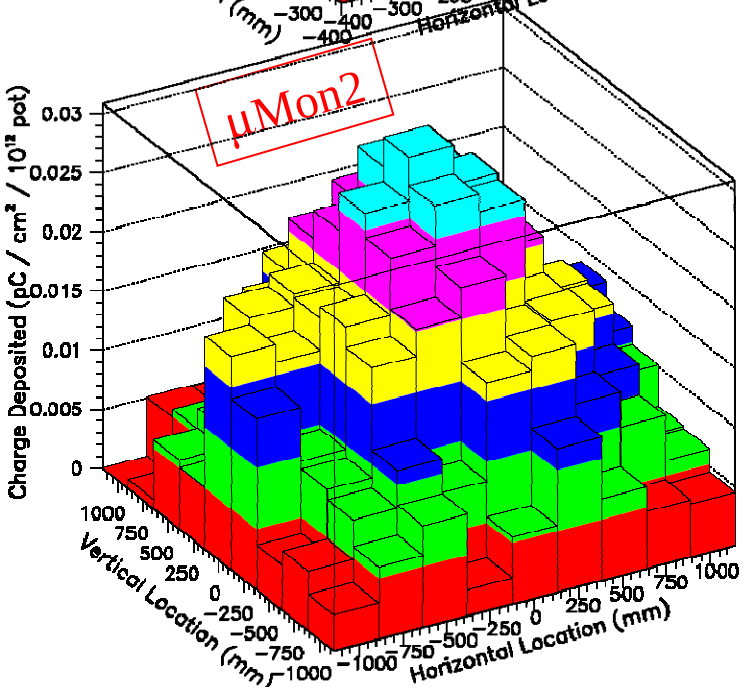

Observations In Beam

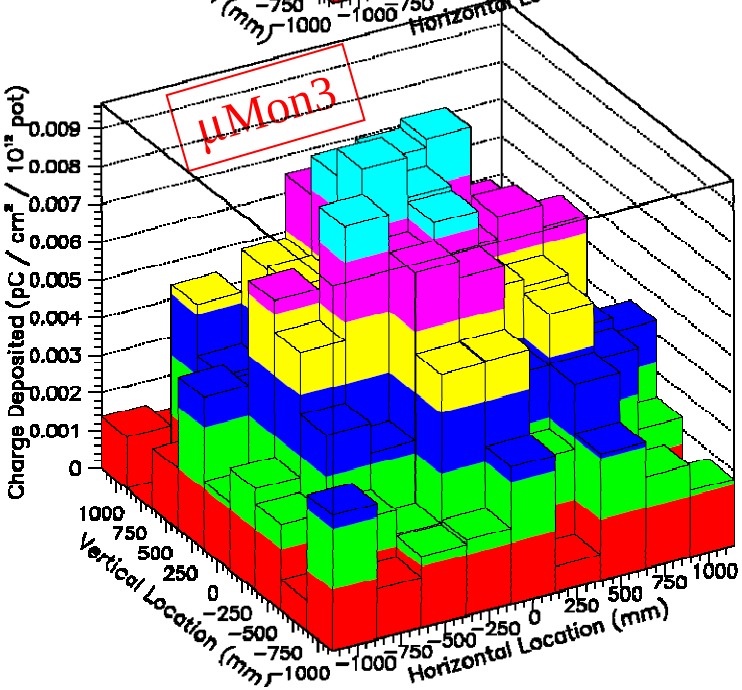
- Neutrons from dump
- Muons from dump
- Shower punchthrough (120GeV/*c* protons!)

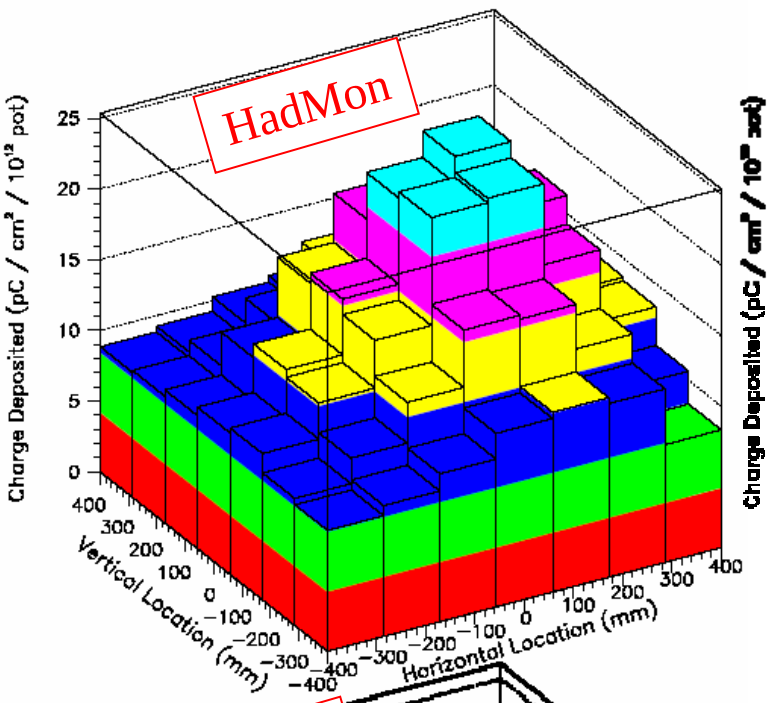
Beam to the Dump (no target)

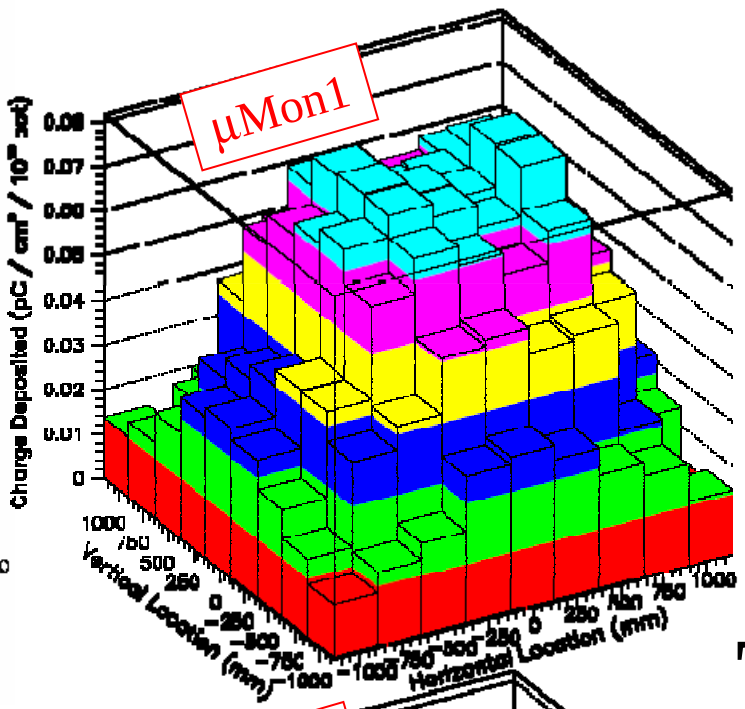


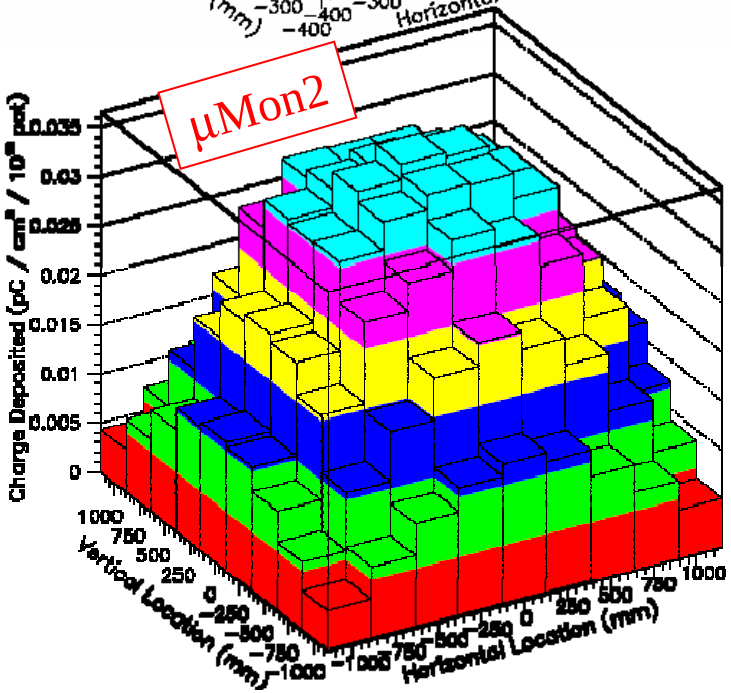


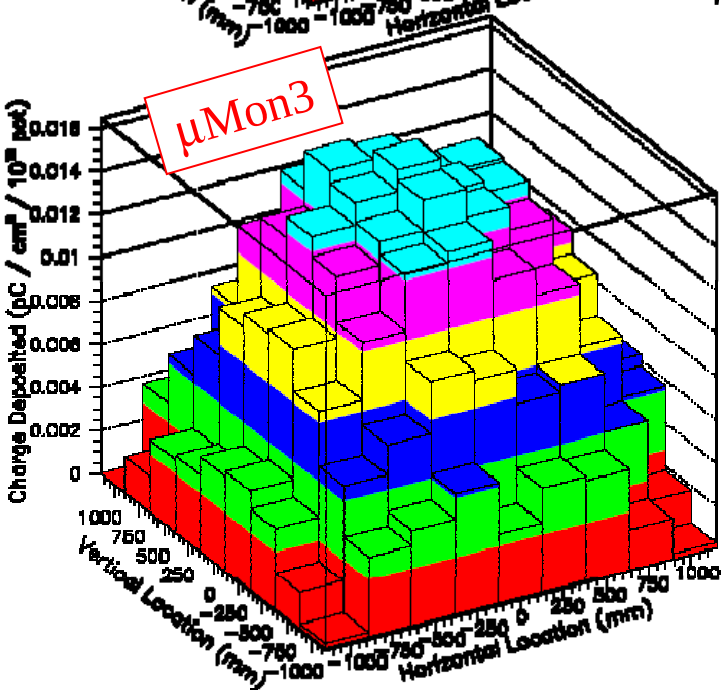




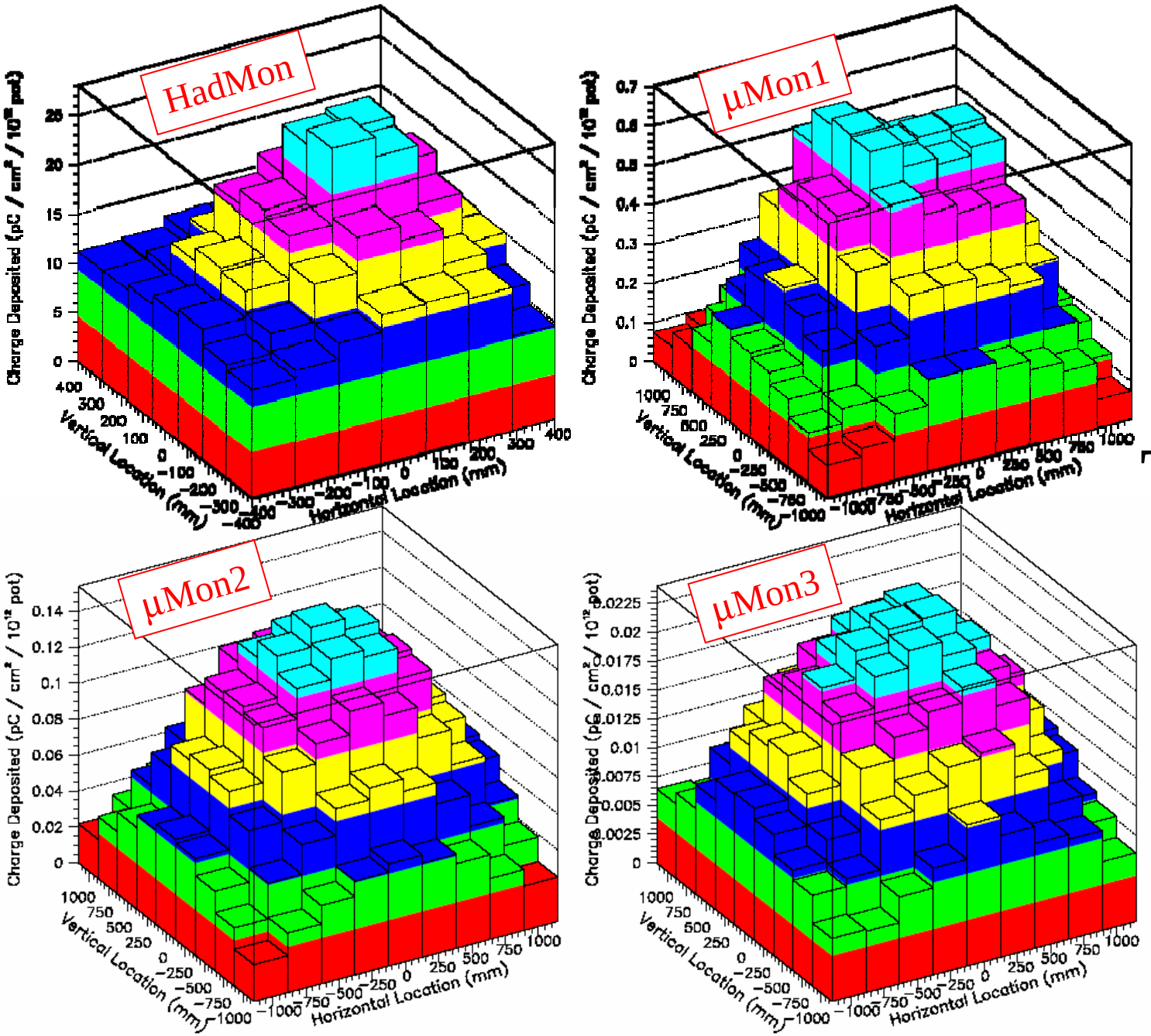




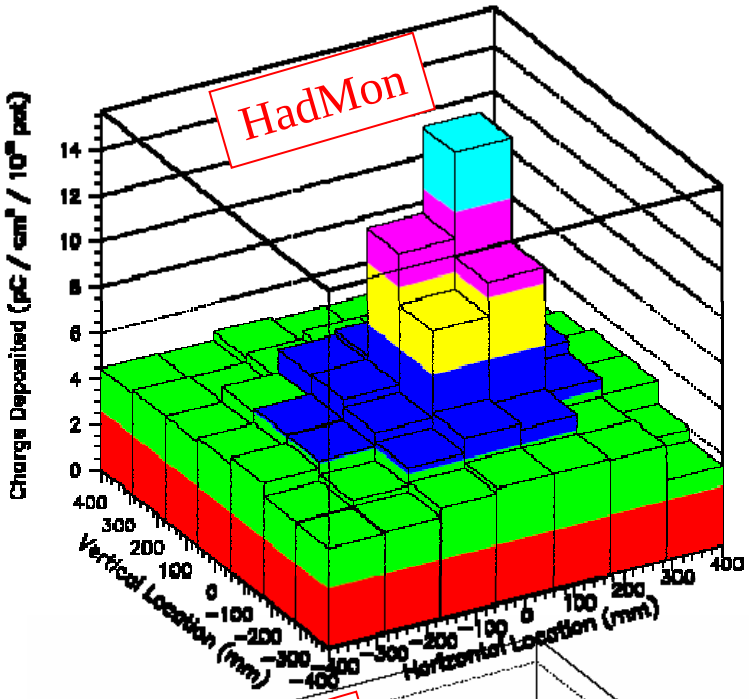


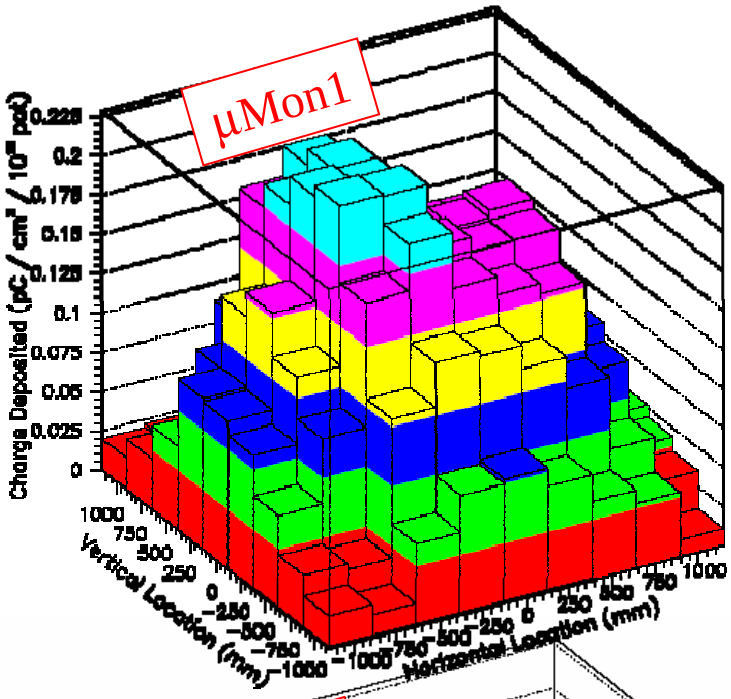


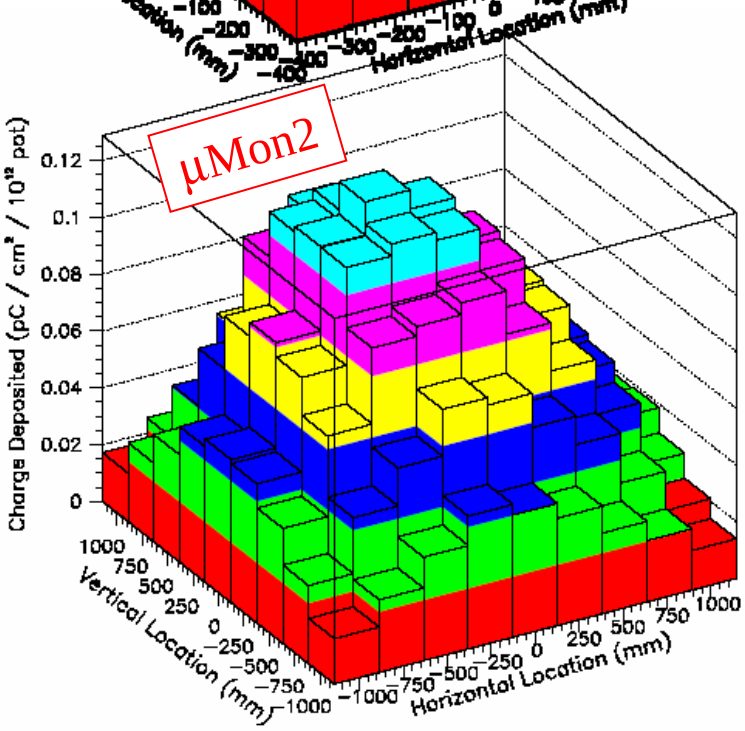
Beam on Target, Horns Off

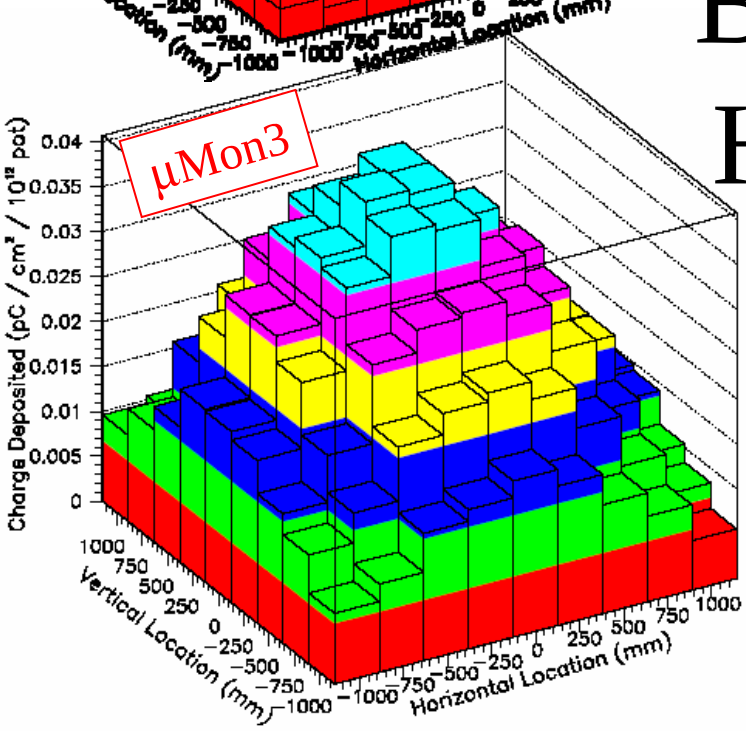


Beam on Target, Horns On (ME)



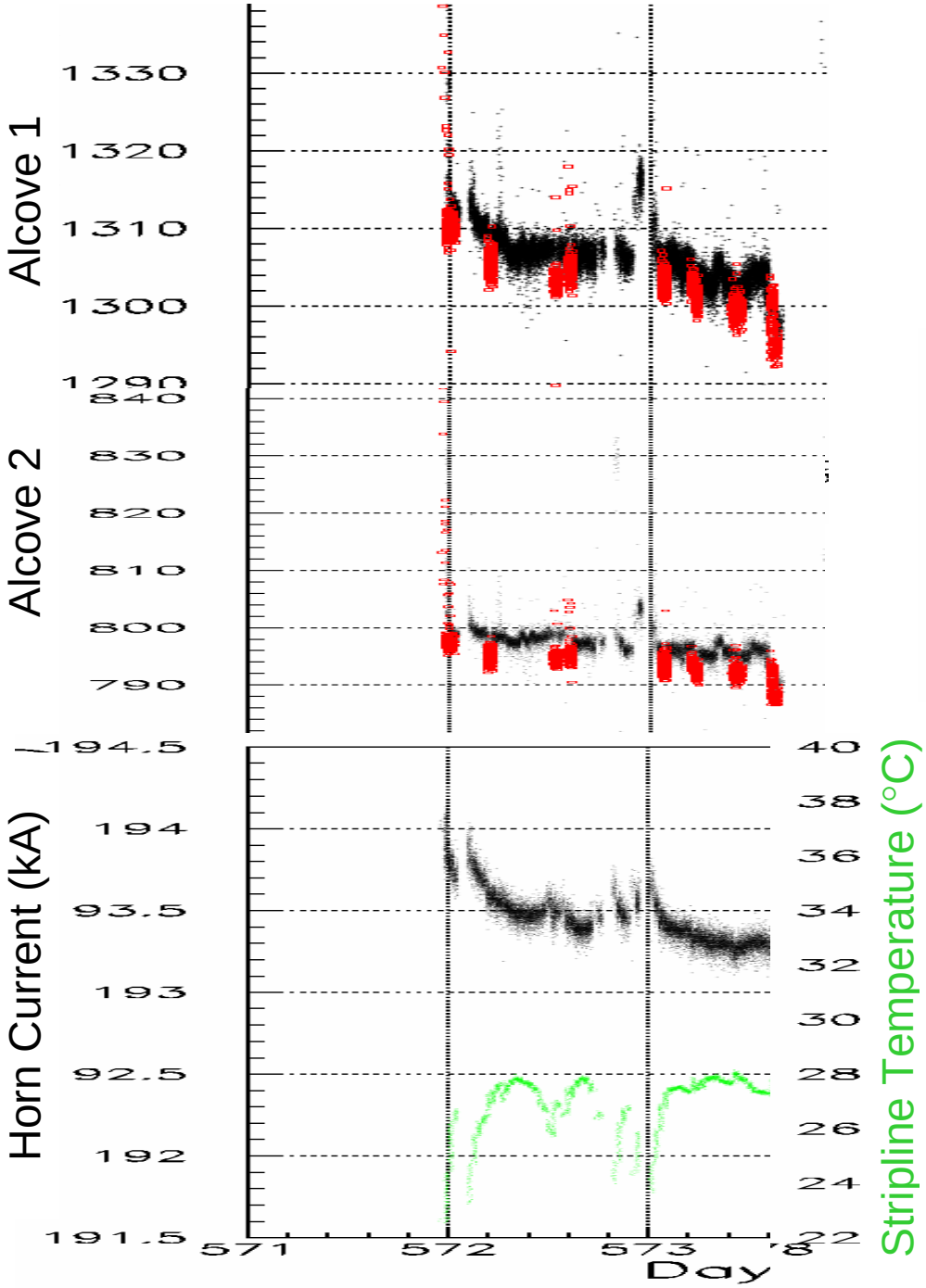


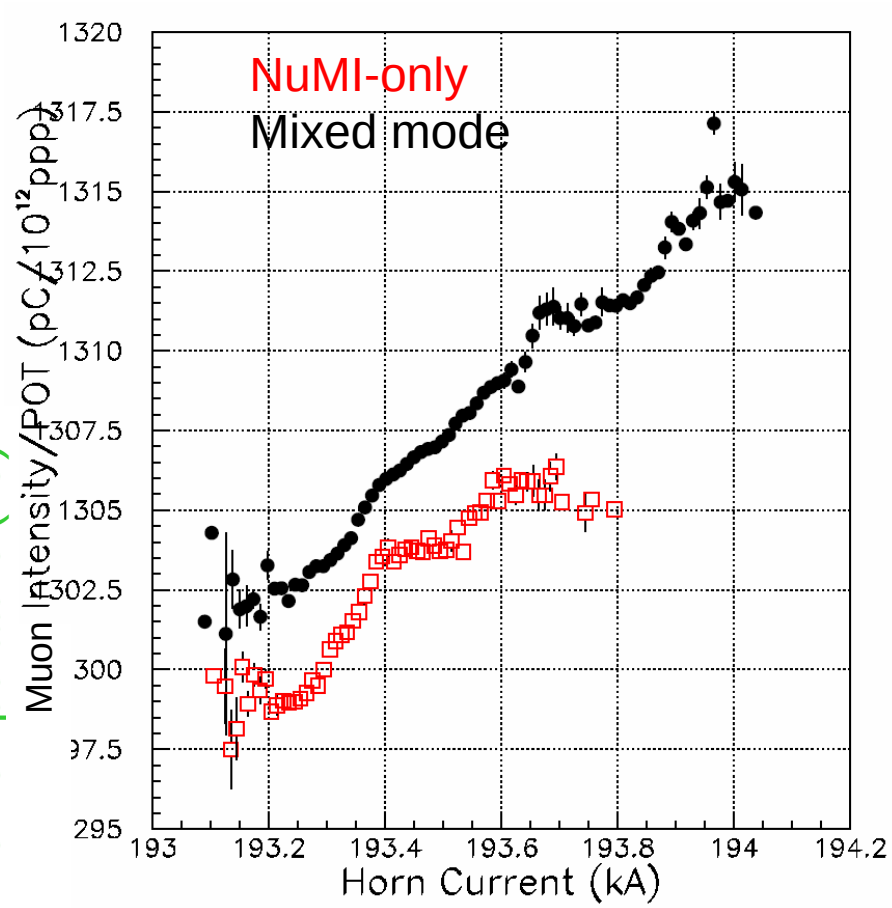


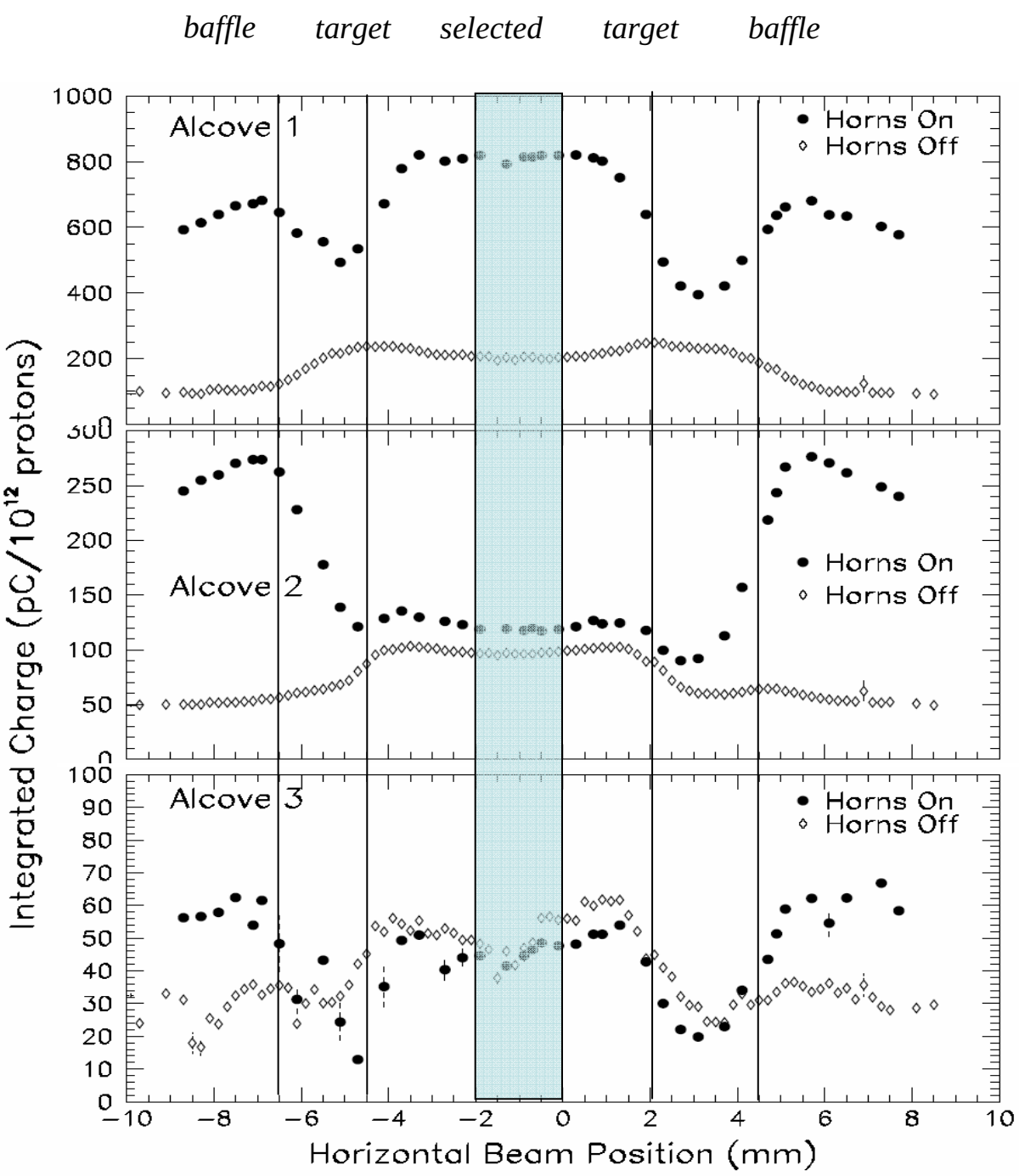


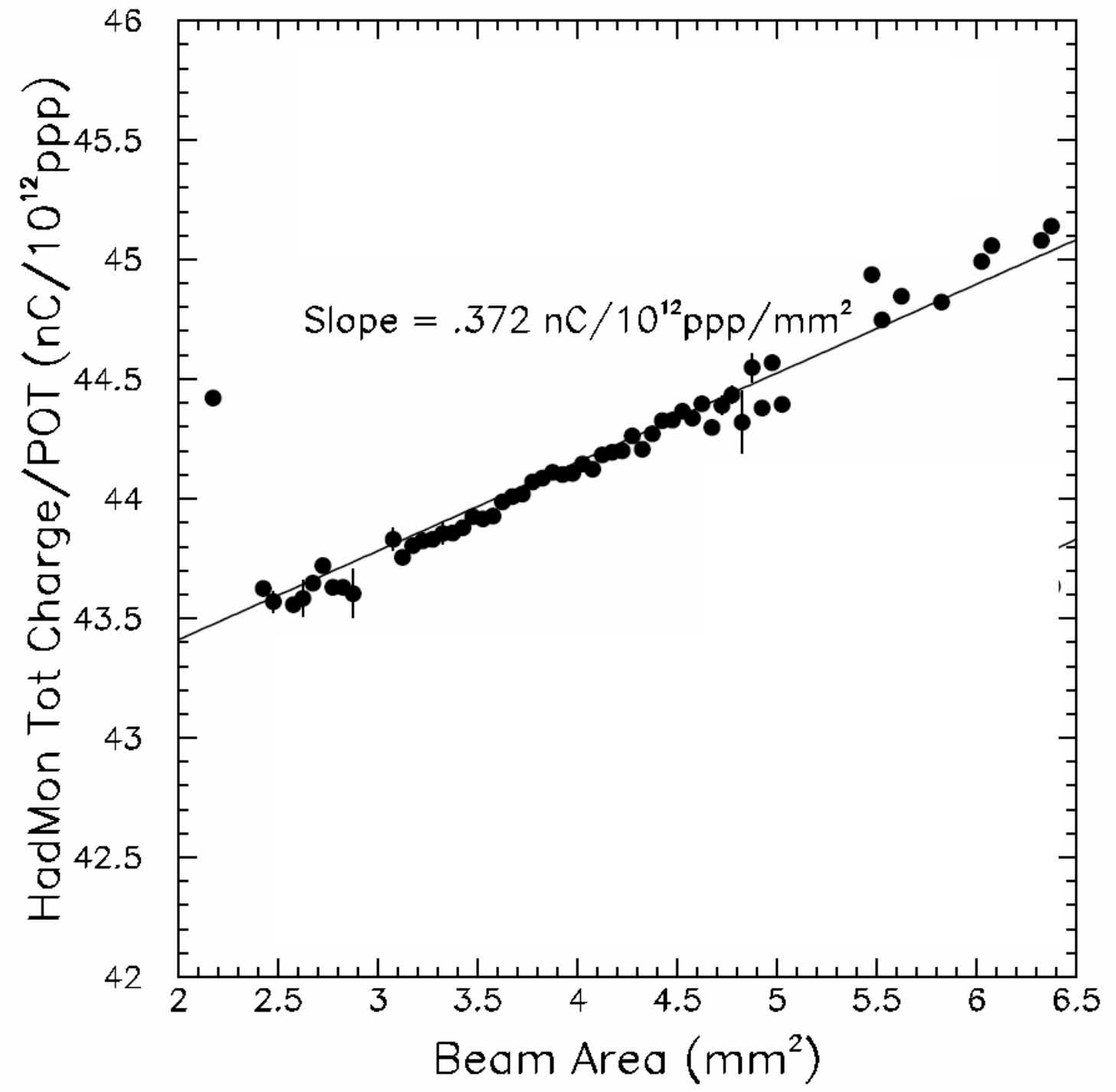
Beam on Baffle, Horns On

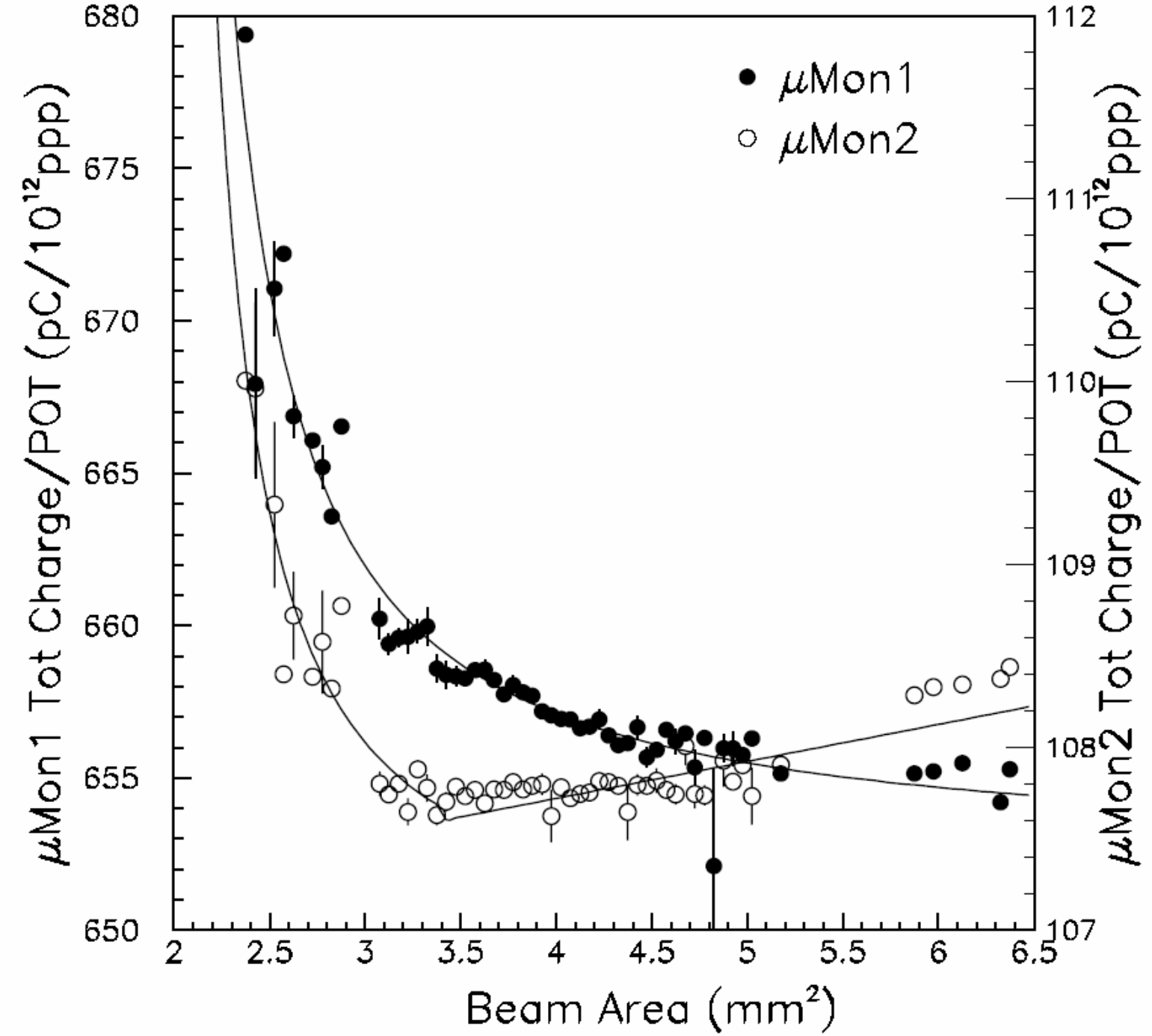
Horn Current Stability

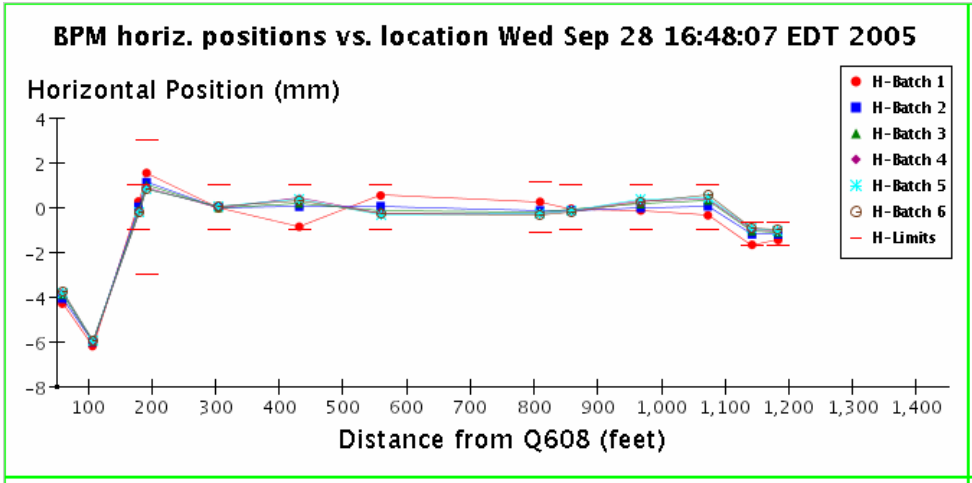


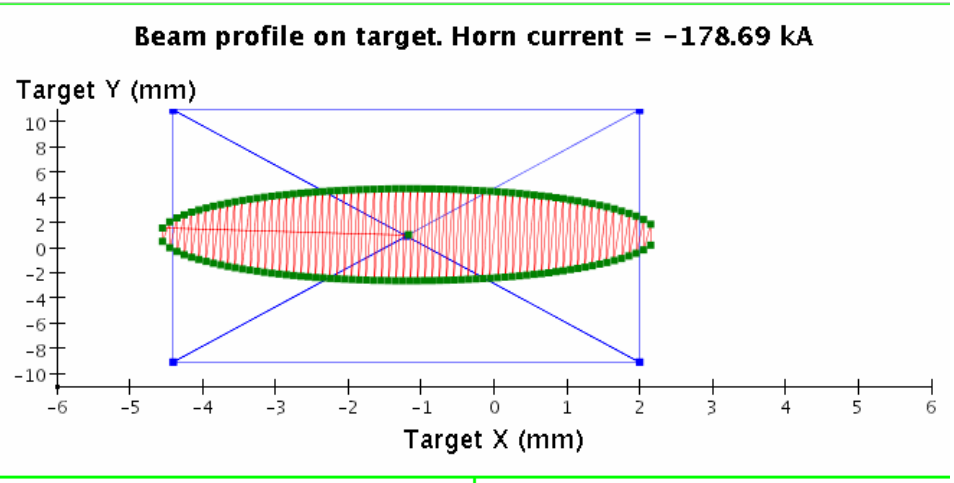


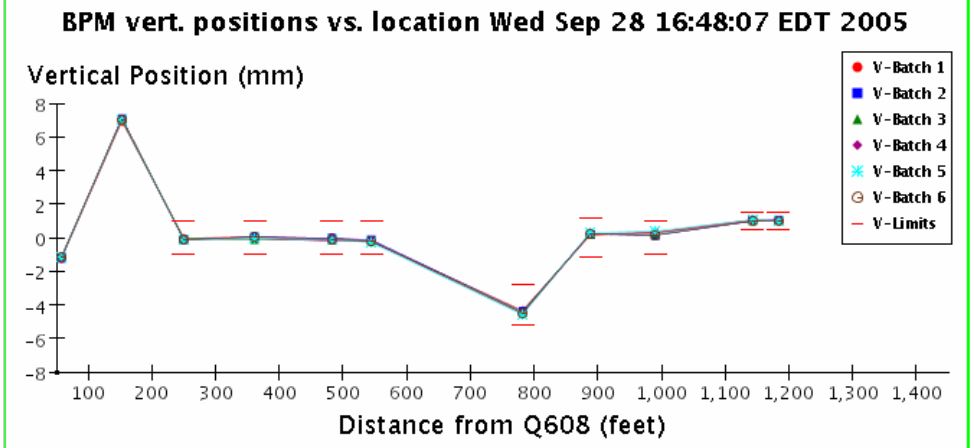

baffle
target
selected
target
baffle
Alcove 1
Alcove 2
Alcove 3
Horns On
Horns Off
Integrated Charge (pC/10¹² protons)
Horizontal Beam Position (mm)

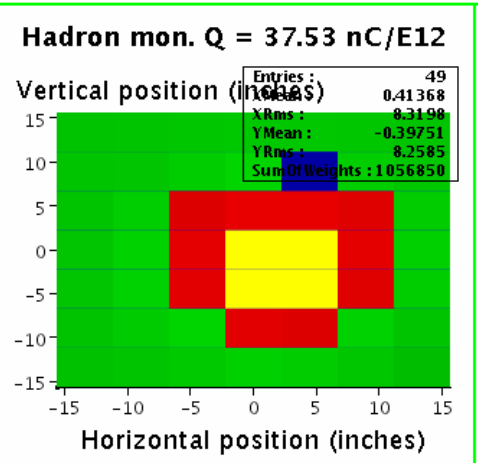

HadMon Tot Charge/POT (nC/10^12ppp)
Beam Area (mm^2)
Slope = .372 nC/10^12ppp/mm^2
46
45.5
45
44.5
44
43.5
43
42.5
42
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5

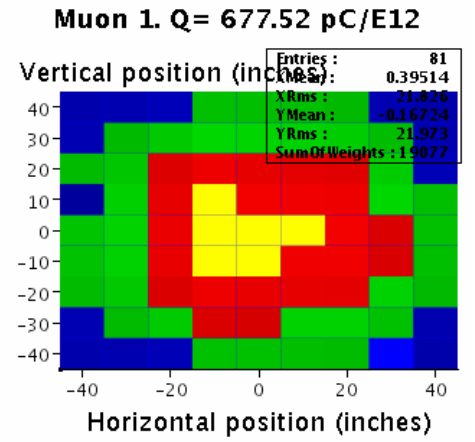

μMon1
μMon2
μMon1 Tot Charge/POT (pC/10^12ppp)
μMon2 Tot Charge/POT (pC/10^12ppp)
Beam Area (mm²)
680
675
670
665
660
655
650
112
111
110
109
108
107
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5

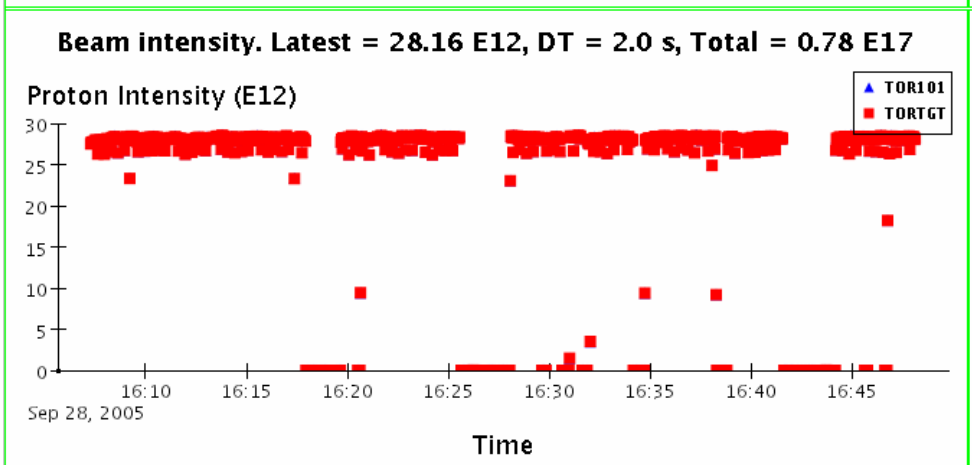

BPM horiz. positions vs. location Wed Sep 28 16:48:07 EDT 2005
Horizontal Position (mm)
H-Batch 1
H-Batch 2
H-Batch 3
H-Batch 4
H-Batch 5
H-Batch 6
H-Limits
Distance from Q608 (feet)

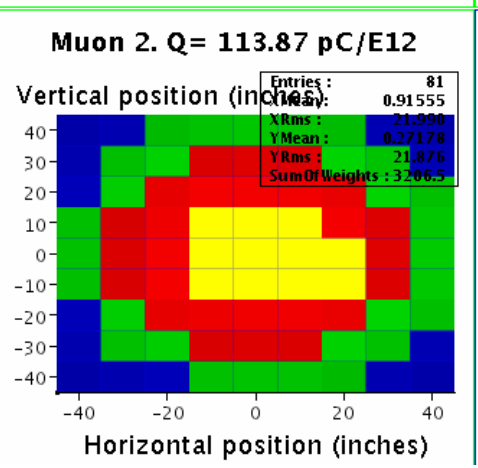

Beam profile on target. Horn current = -178.69 kA
Target Y (mm)
Target X (mm)

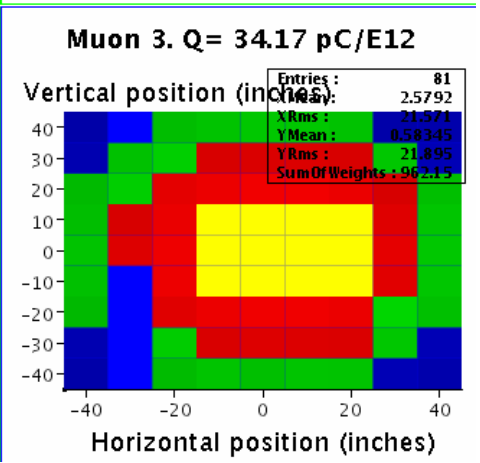

BPM vert. positions vs. location Wed Sep 28 16:48:07 EDT 2005
Vertical Position (mm)
V-Batch 1
V-Batch 2
V-Batch 3
V-Batch 4
V-Batch 5
V-Batch 6
V-Limits
Distance from Q608 (feet)


Hadron mon. Q = 37.53 nC/E12
Vertical position (inches)
Entries : 49
XMean : 0.41368
XRms : 8.3198
YMean : -0.39751
YRms : 8.2585
SumOfWeights : 1056850
Horizontal position (inches)


Muon 1. Q= 677.52 pC/E12
Vertical position (inches)
Entries : 81
XMean : 0.39514
YMean : -0.16724
YRms : 21.973
SumOfWeights : 19077
Horizontal position (inches)


Beam intensity. Latest = 28.16 E12, DT = 2.0 s, Total = 0.78 E17
Proton Intensity (E12)
TOR101
TORTGT
Sep 28, 2005
Time


Muon 2. Q= 113.87 pC/E12
Vertical position (inches)
Entries : 81
XMean : 0.91555
YMean : 0.27178
YRms : 21.876
SumOfWeights : 3206.5
Horizontal position (inches)


Muon 3. Q= 34.17 pC/E12
Vertical position (inches)
Entries : 81
XMean : 2.5792
YMean : 0.58345
YRms : 21.895
Horizontal position (inches)

Thoughts on In-beam Experience

- Online software is too arcane for the average shifter.
- The muon monitors are extremely sensitive
  - Proton beam spot size
  - Proton beam position
  - Horn current
  - other?
- Problems detected using the mu-mons usually require us to consult other instrumentation to understand
  - Always an effect of primary beam position or spot
  - Amost too sensitive – it's a non-specific alarm
  - Crying wolf syndrome
  - Becomes an offline analysis effort
- We've let ourselves be bit by rookie gas mistakes – twice
- Low helium flow can a problem for atmospheric variations (back-diffusion).


Can Muon Monitors
be Used to Measure
Neutrino Fluxes?

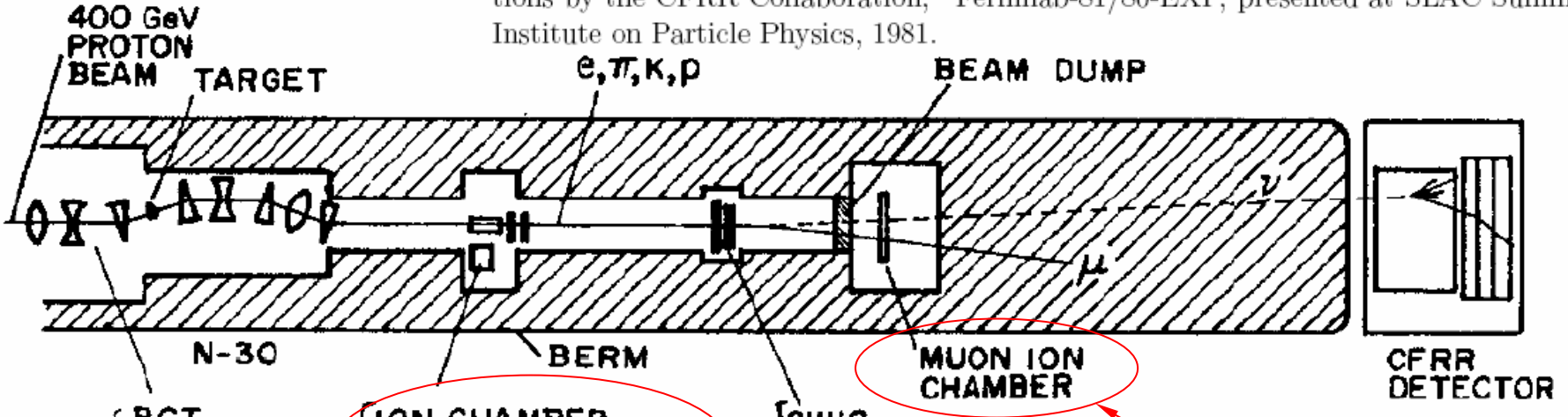
The Problem

- With some alarm, however, I have heard claims that we may be able to measure *fluxes* with our chambers to ±5%.
- Worse, I have heard presentations at conferences that other wide band beams will similarly know their fluxes to 5%.
- NuMI muon monitors are indeed responsive to various beam effects, variations, but while stable they were not designed to determine *fluxes*!

- Sooo, I wanted to investigate just how possible or impossible it would be to measure a flux using the NuMI chambers.

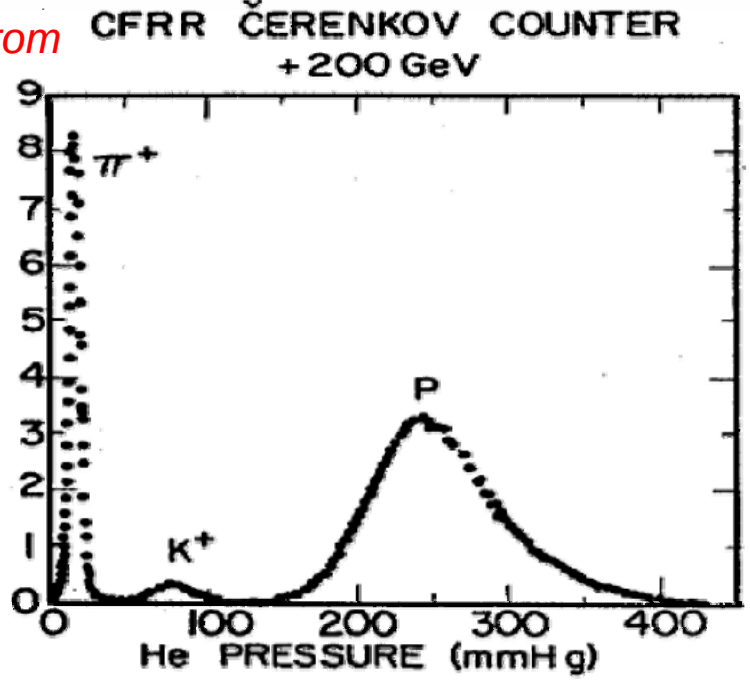
FNAL NBB

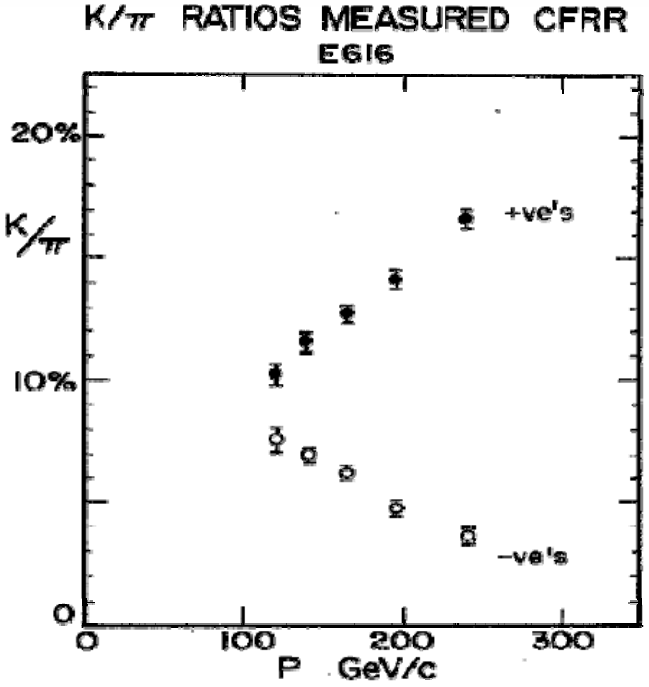
B.C. Barish *et al.*, "Recent Results on Total Neutrino and Antineutrino Cross Sections by the CFRR Collaboration," Fermilab-81/80-EXP, presented at SLAC Summer Institute on Particle Physics, 1981.



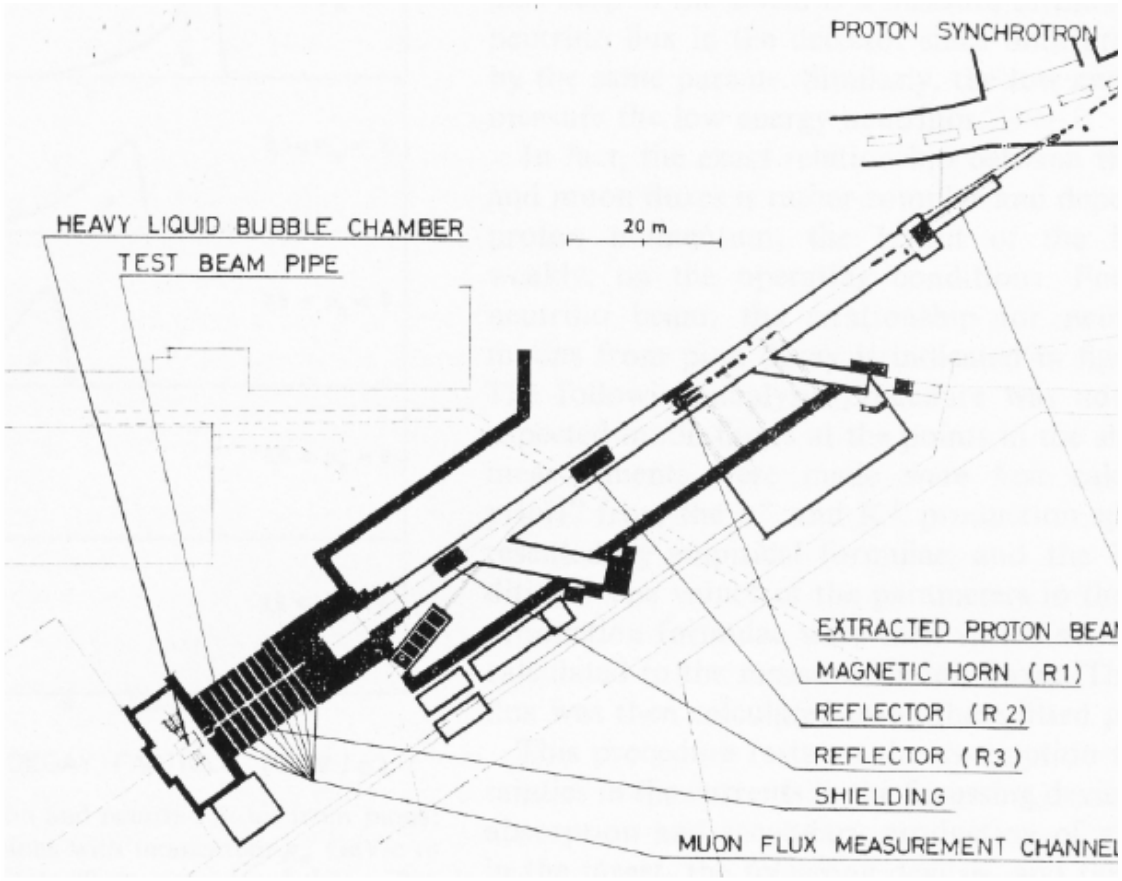
Fluxes came from these

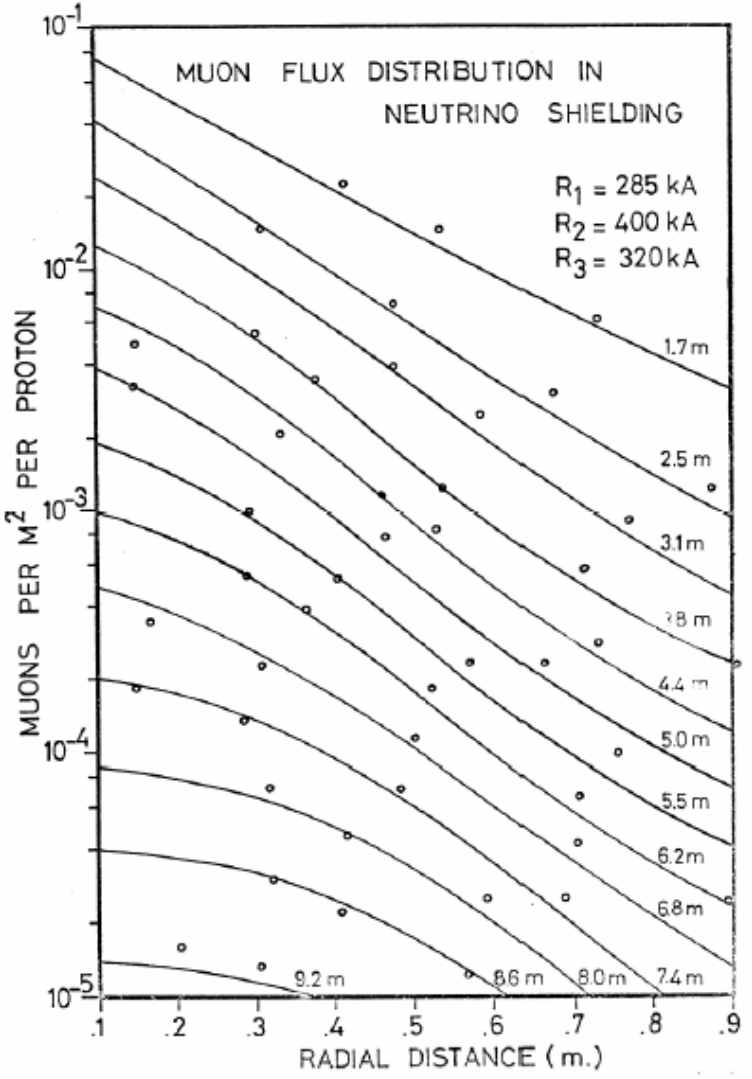
NB: Apparently μMon not used because of backgrounds





Experience from the CERN PS

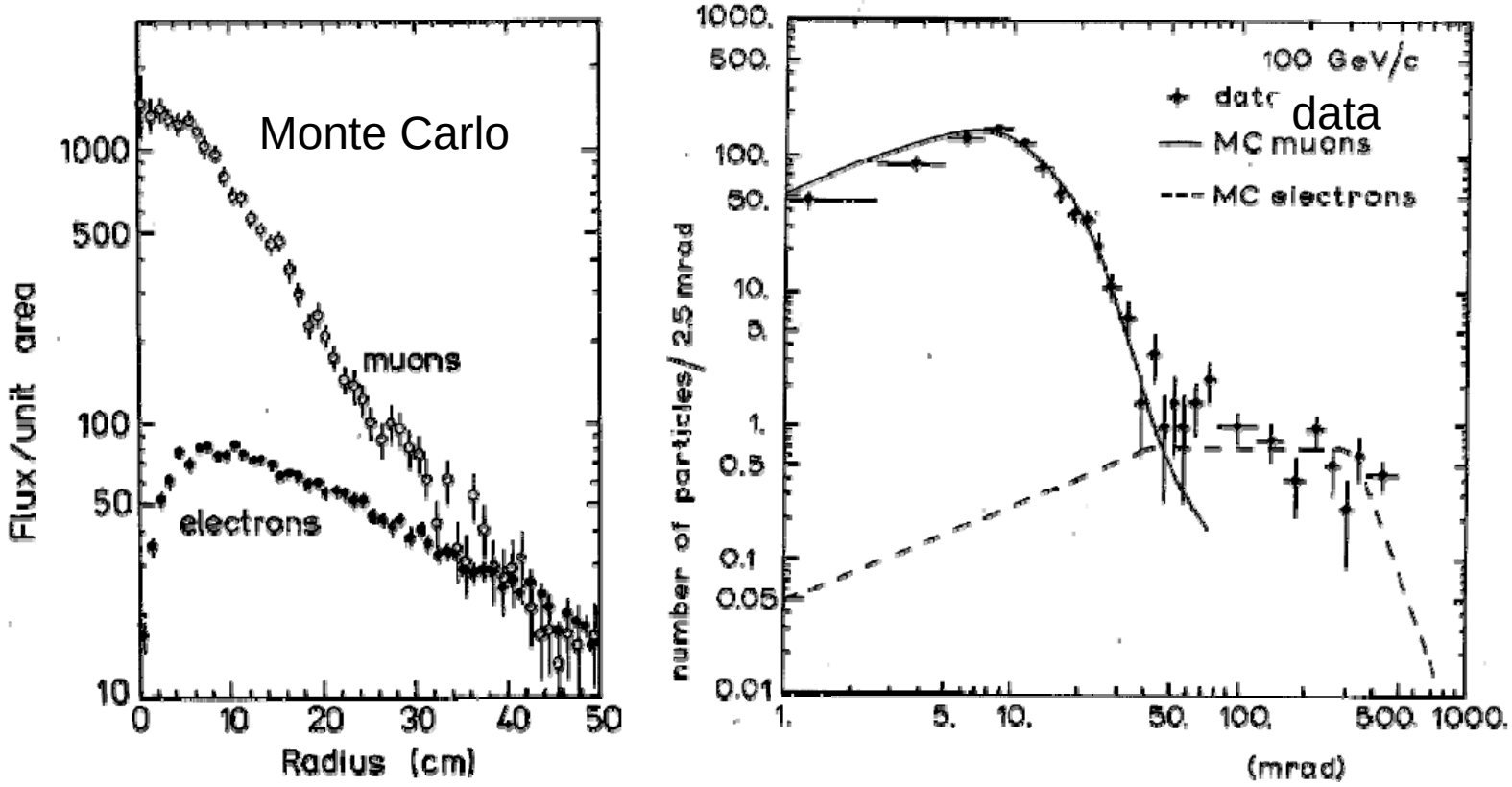




- Very similar system adopted by IHEP-Serpukhov

D. Bloess *et al.*, "Determination of the Neutrino Spectrum in the CERN 1967 Neutri
Experiment," Nucl. Instr. Meth. **91**, 605 (1971).

CERN SPS

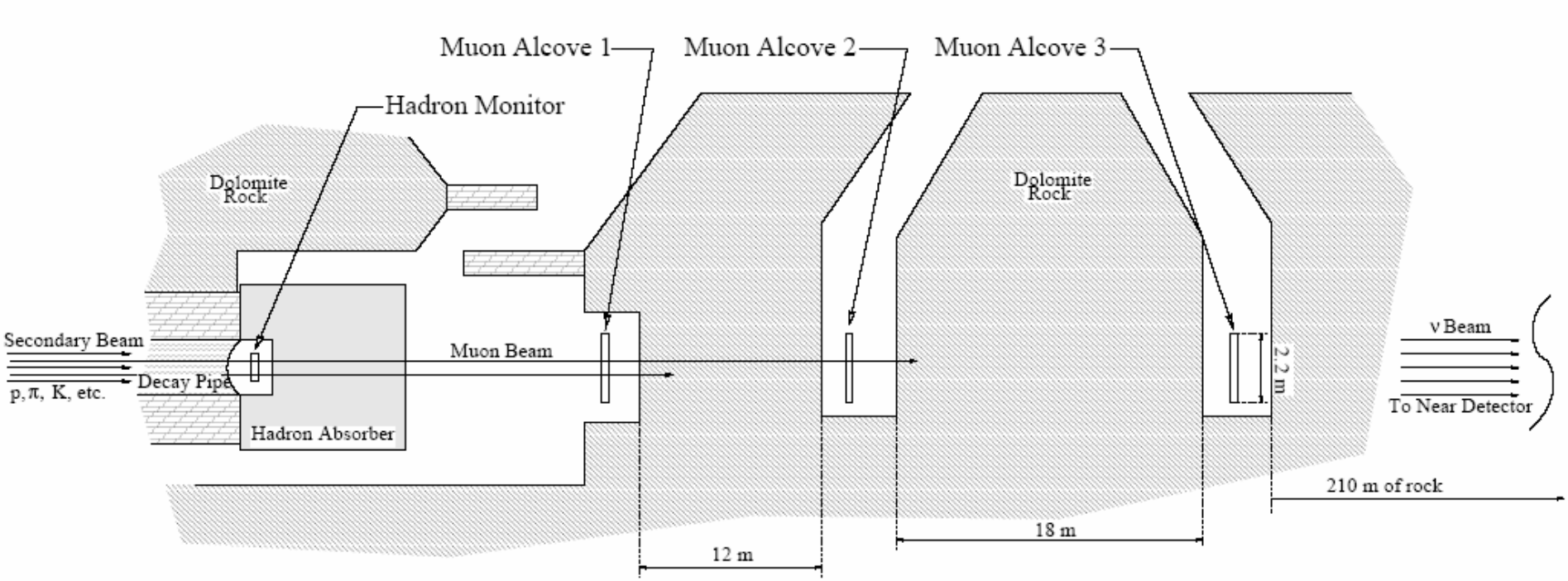


- At the PS, delta rays were “not significant” (~5%)
- CERN SPS made 10-30% corrections (high p_μ and high-Z shielding)
- Emulsions used to determine δ-ray fraction

E.H.M. Heijne, “Muon flux measurement with silicon detectors in the CERN neutrino beams,” CERN-83-06 (1983).

I. Abt and R. Jongejans, “An absolute calibration of the solid state detectors in the narrow band neutrino beam at CERN,” Nucl. Instr. Meth. **A235**, 85 (1985).

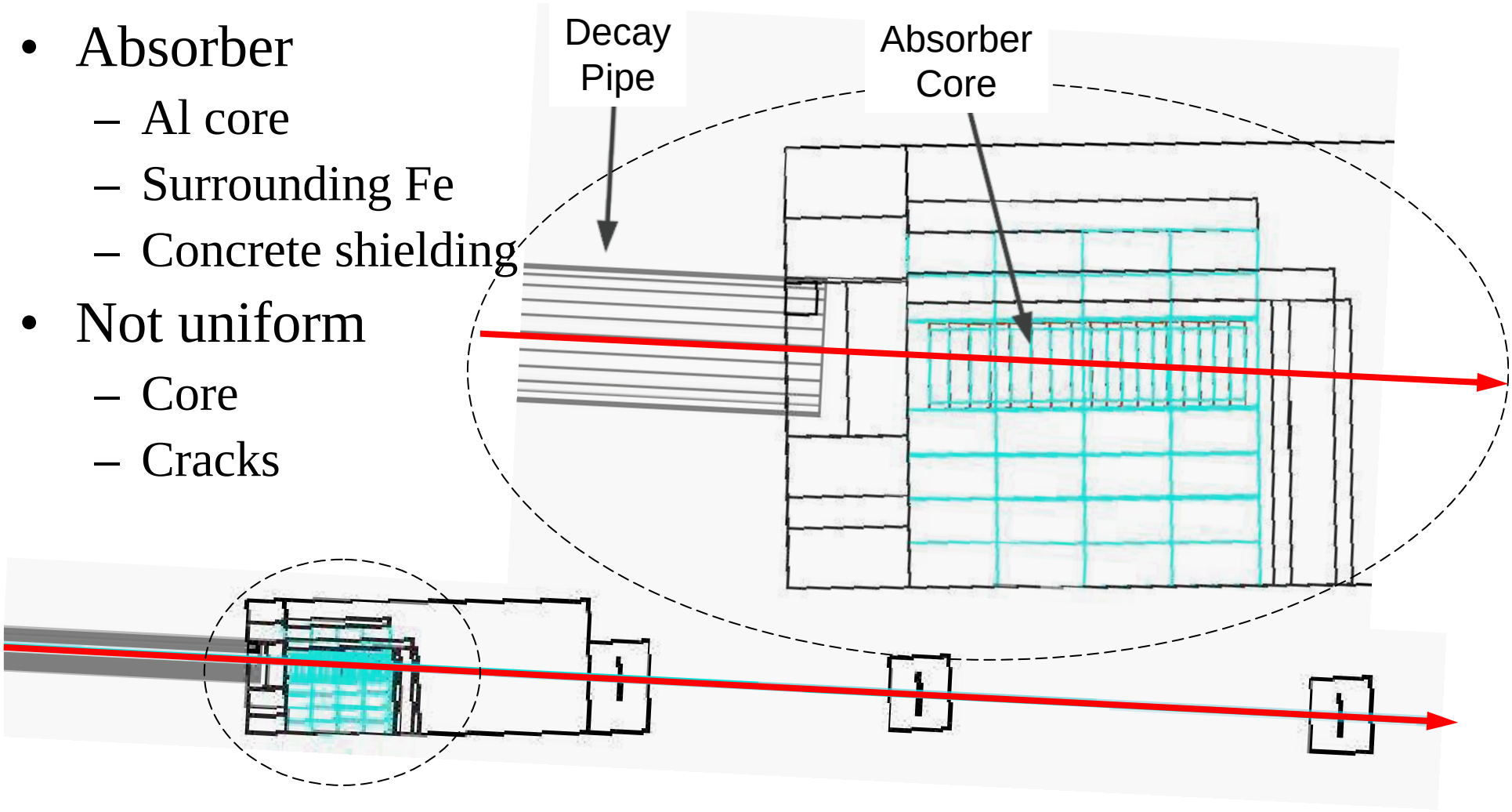
NuMI Muon Monitors



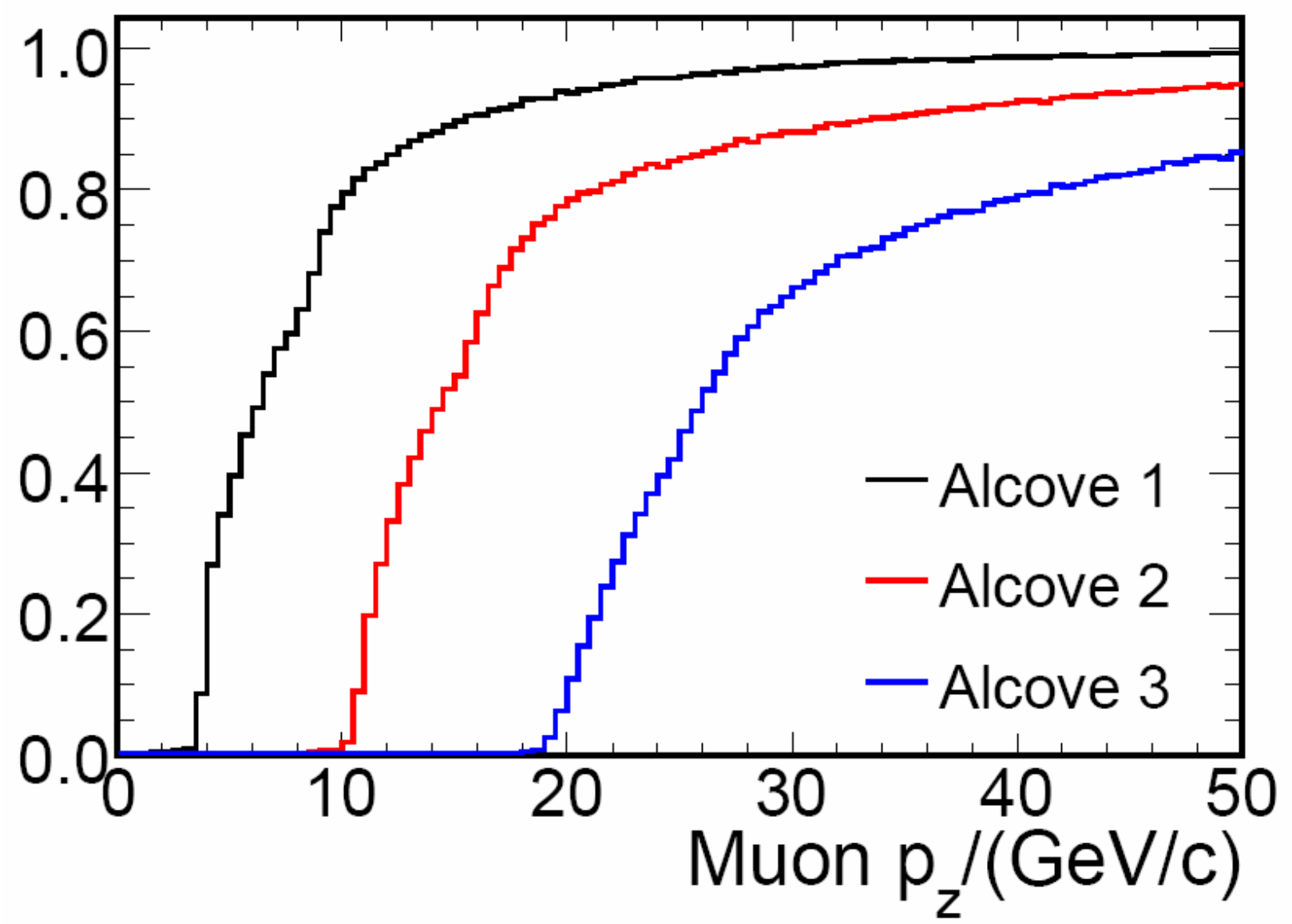
- Radially small (2m transverse size)
- Just 3 alcoves, first rather deep in shielding
- No provisions yet for δ-ray measurements
- Sooo, what can be done?

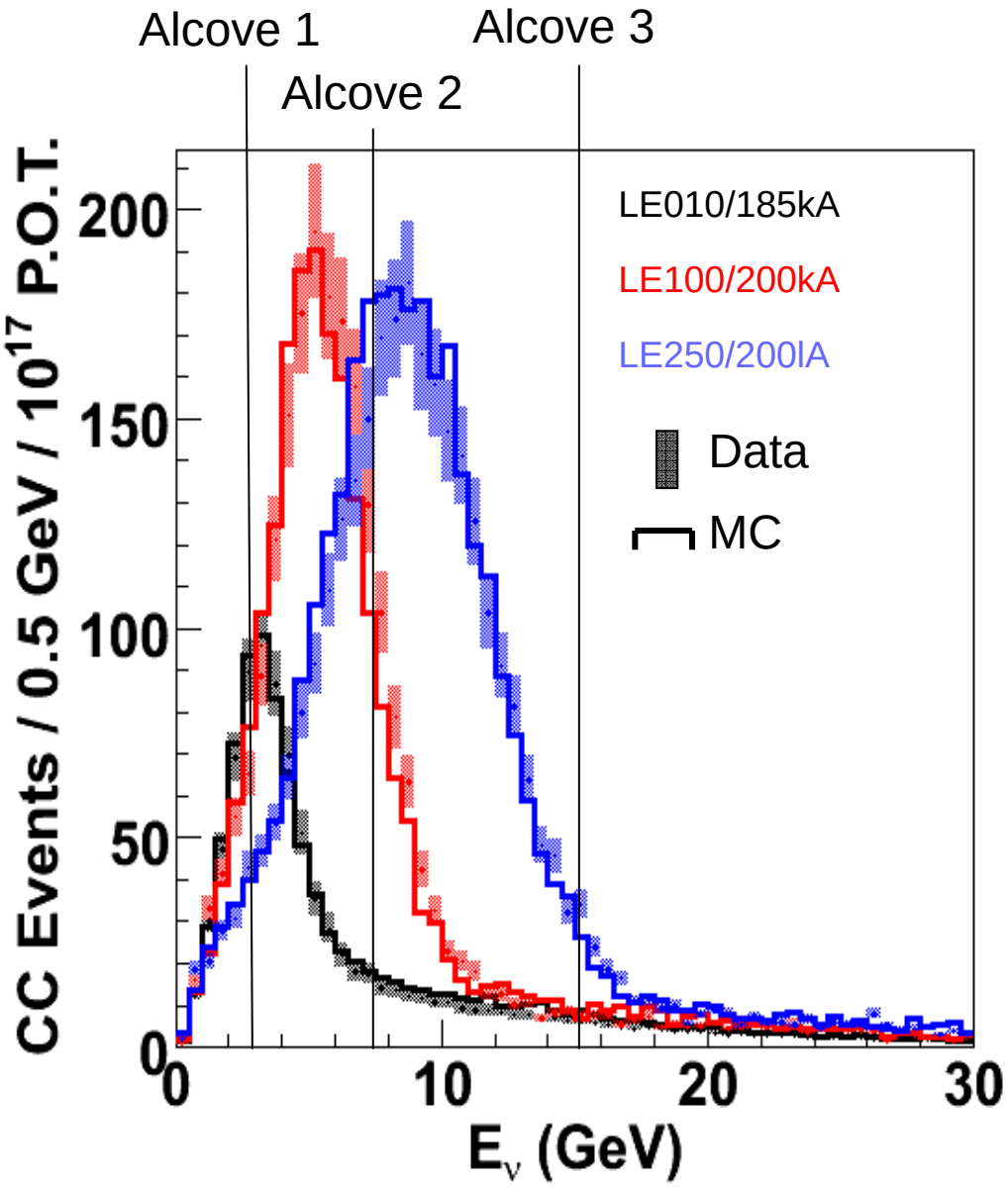
Upstream Shielding

- Absorber
  - Al core
  - Surrounding Fe
  - Concrete shielding
- Not uniform
  - Core
  - Cracks



Alcove Efficiency due to Shielding



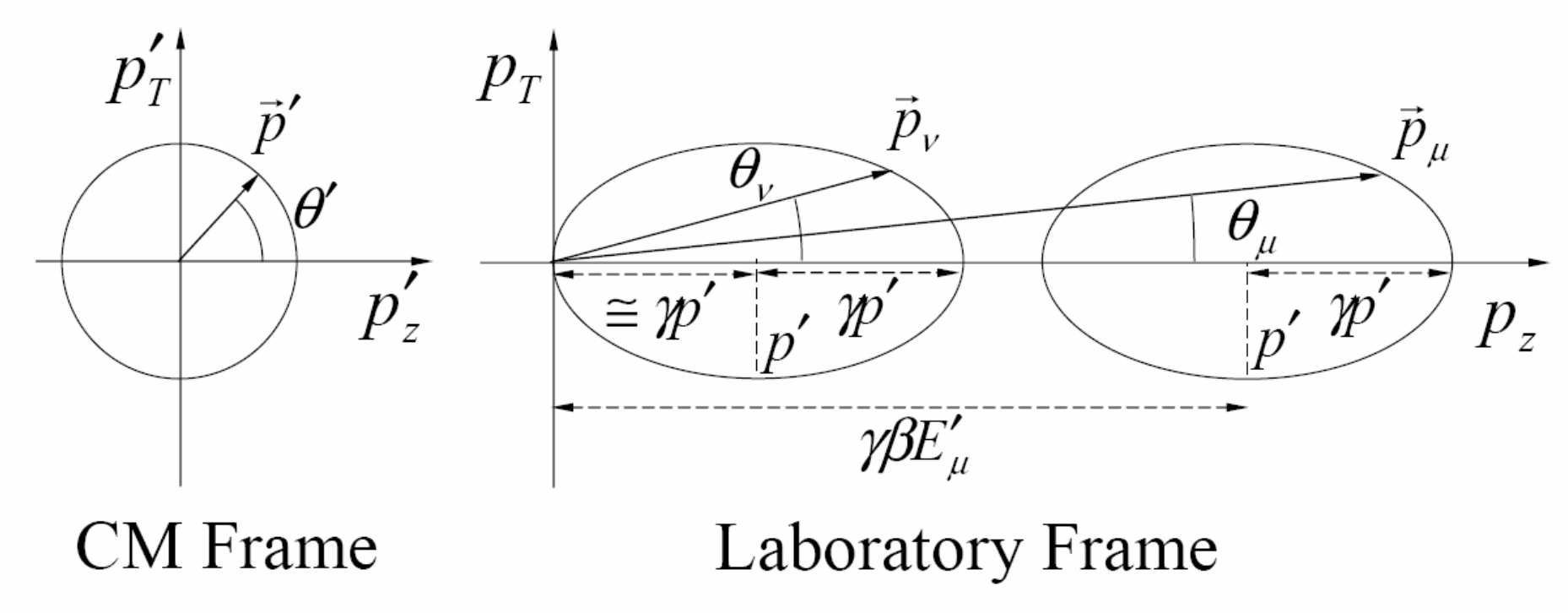


Naïve Estimation of Alcove Efficiency

$$E_\nu \cong \frac{\left(1-\frac{m_\mu^2}{m_\pi^2}\right)E_\pi}{1+\gamma^2\theta_\nu^2} \approx 0.43E_\pi$$

$$p_\mu \approx 0.57E_\pi$$

Calculating Alcove Acceptances

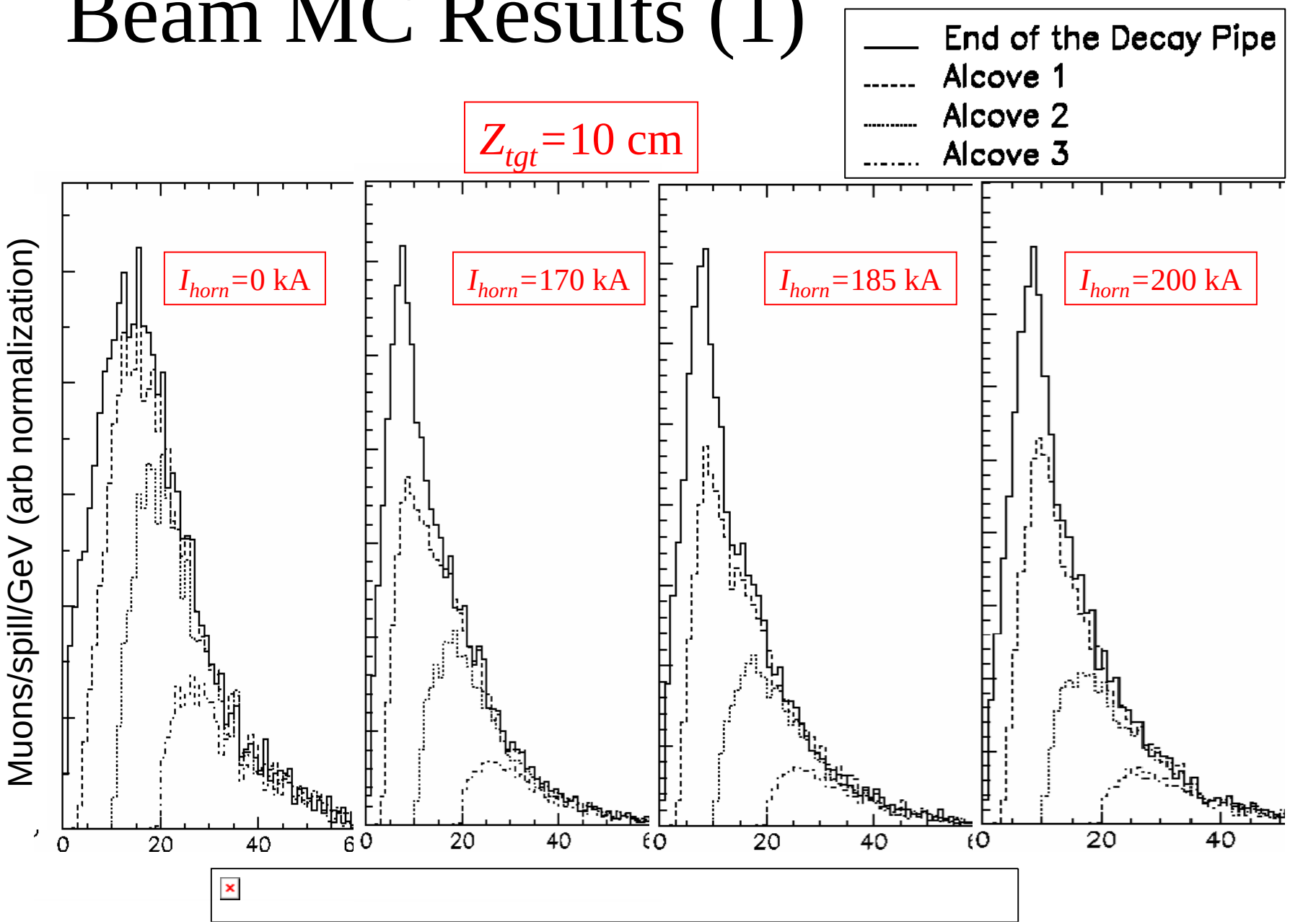


$$\tan\theta_{lab}^{\max} = \frac{\beta'}{\beta_\pi \gamma_\pi}$$

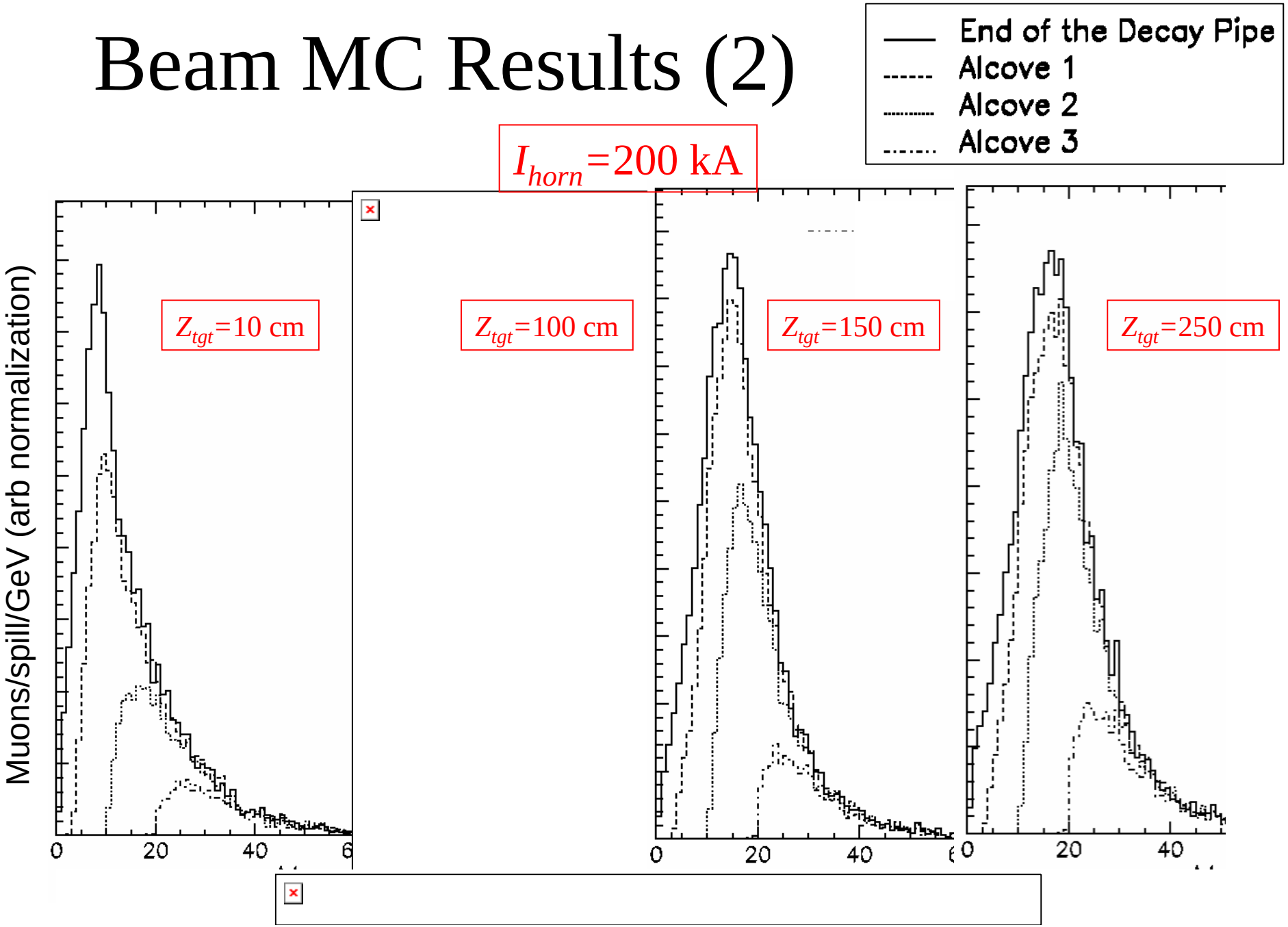
$$\beta' = \frac{p'}{E'} = \begin{cases} 0.28\ (muon\ ) \\ 1.0\ (neutrino\ ) \end{cases}$$

$$p_z^\mu \cong \frac{\gamma[E'_\mu \pm \sqrt{p'^2 - \gamma^2 m_\mu^2 \tan^2\theta_\mu}\,]}{1+\gamma^2\tan^2\theta_\mu}$$

Beam MC Results (1)

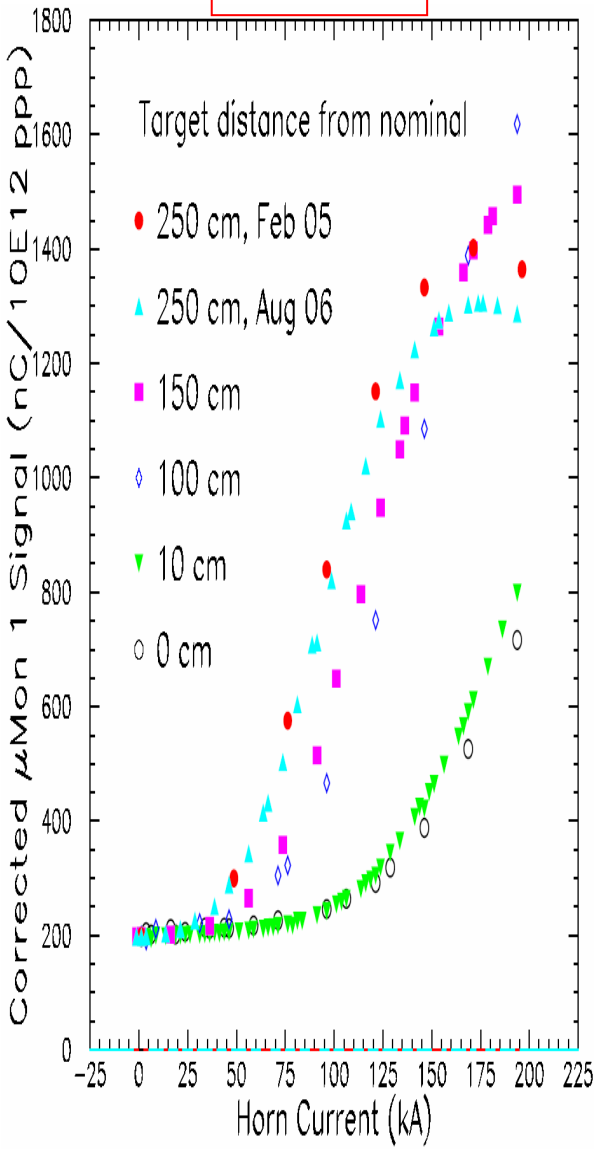


Beam MC Results (2)

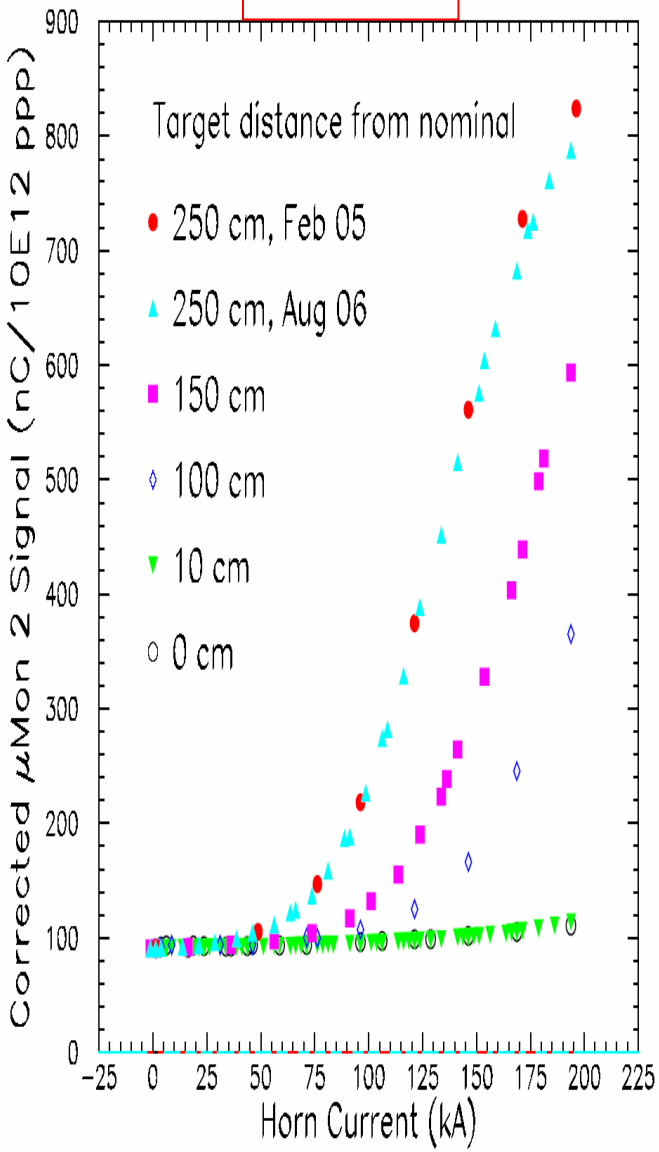


Results in Beam Data

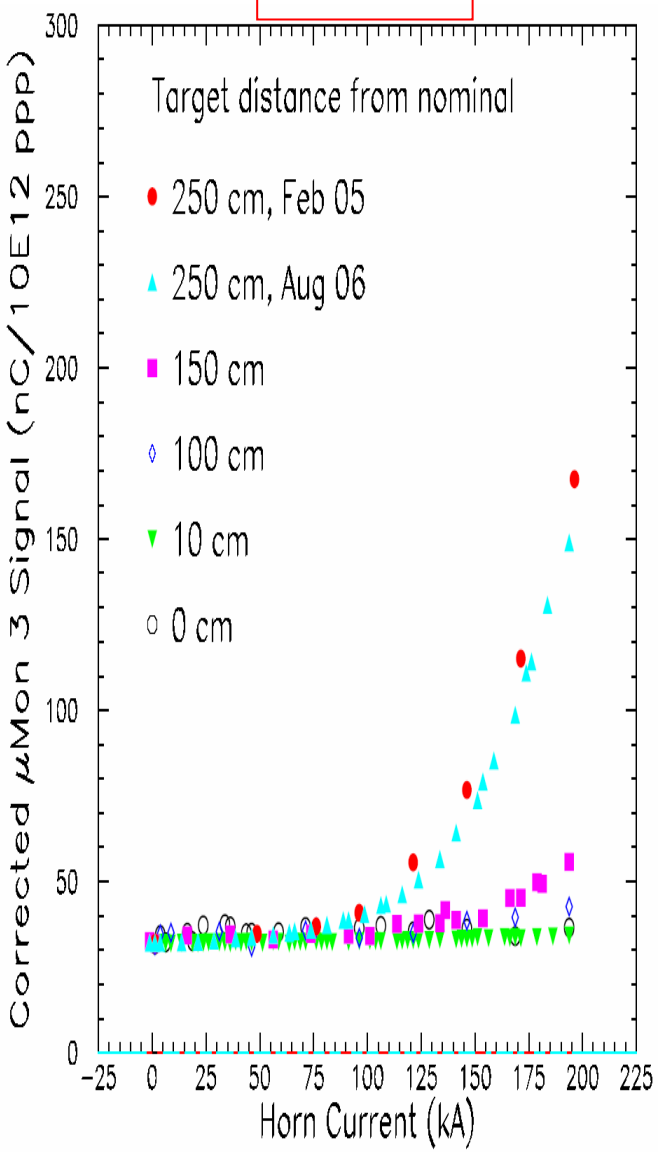
Alcove 1



Alcove 2



Alcove 3



Desires for Future

- Better knowledge of the shielding
  - Only preliminary understanding of beam absorber
  - Density/content of the rock?
- Roving ‘calibration chamber’
  - Internal sources
  - Moves amongst 3 alcoves
  - Demonstration that alcove-to-alcove calibration is correct
- Studies of upstream material
  - Delta rays in the monitors?
  - CCFR – place varying amts of material
  - CERN – emulsions

Closing Thoughts

- We'd lacked a serious MC for the muon monitors, only solving this now after 1.5 years!
- Monitor hardware performs well (2GRads!), and I'm thankful I don't have any photos of it after irradiation in the beam (must look worse than Jim's horn?!)
- Hadron monitor has very useful online role, not so useful offline (rates difficult to predict) – acts as an alarm and diagnostic tool.
- Muon monitors have tendency to be ignored online because we lack crisp interpretation for the data – some utility shown offline, however.

- Fluxes are *difficult* to measure, but essential for cross section experiments. Key issues
  - muon monitors' sensitivity/overlap with the ν flux
  - backgrounds from δ-rays, neutrons
  - Shielding geometry

References

- S. Kopp *et al*, “The Secondary Beam Monitoring System for the NuMI Facility at FNAL,” accepted in *Nucl. Instr. Meth.*
- R. Zwaska *et al*, “Beam-based Alignment of the Target Station Components of the NuMI Facility at FNAL,” accepted in *Nucl. Instr. Meth.*
- D. Indurthy *et al*, “Study of Neutron-Induced Ionization for Helium and Argon Chamber Gases,” *Nucl. Instr. Meth.* A528, 731 (2003)
- R. Zwaska *et al*, “Beam Tests of Ionization Chambers for the NuMI Beam at Fermilab,” *IEEE Trans. Nucl. Sci.* **50**, 1129 (2003).
- D. Naples *et al*, “Ionization Chambers for Monitoring in High-intensity Charged Particle Beams,” *Nucl. Instr. Meth.* **A496**, 293 (2003).
- S. Kopp, “Accelerator Neutrino Beams,” submitted to *Physics Reports*, (available in SPIRES).


Thank You!