NuMI Hadron and Muon Monitoring

Fermilab *UWisconsin* *UTexas -- Austin*

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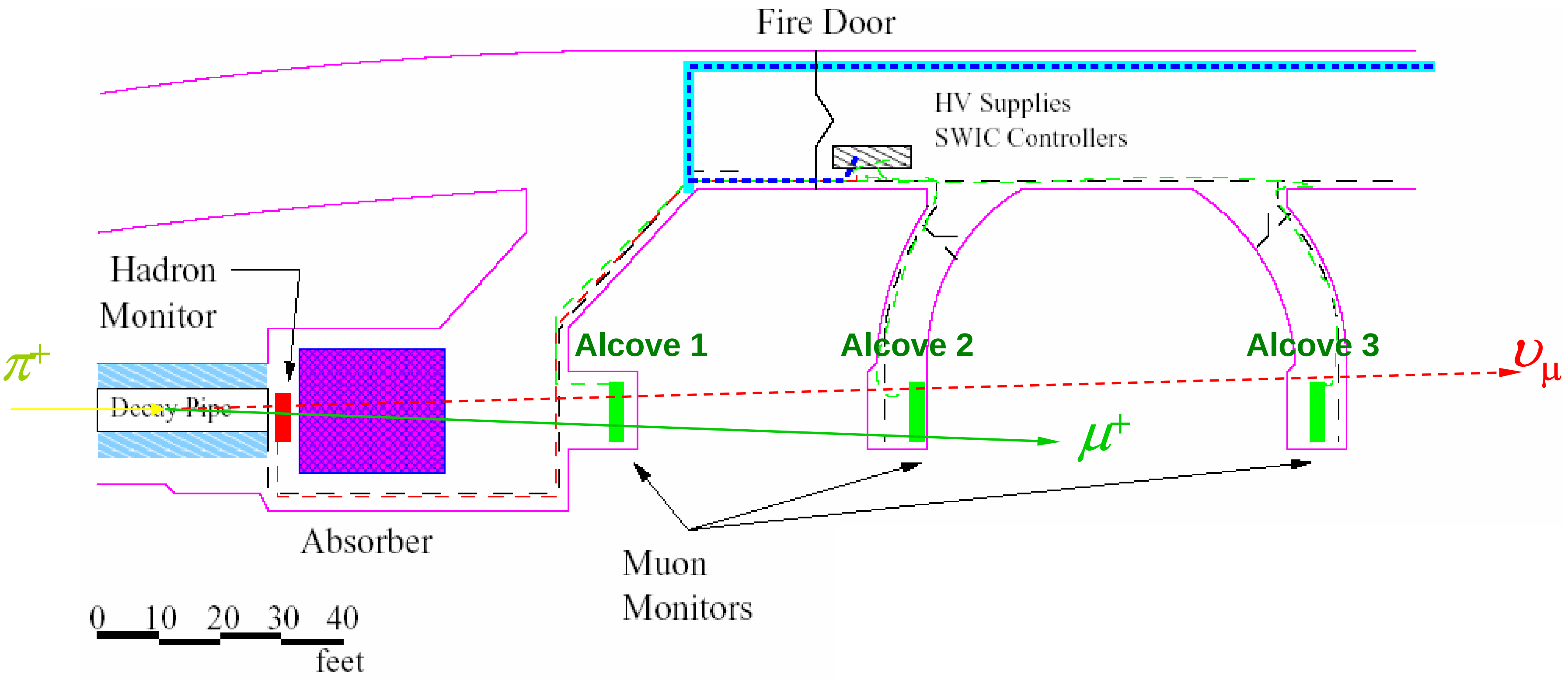
University of Texas at Austin

NBI 2003
November 10, 2003

System Geography



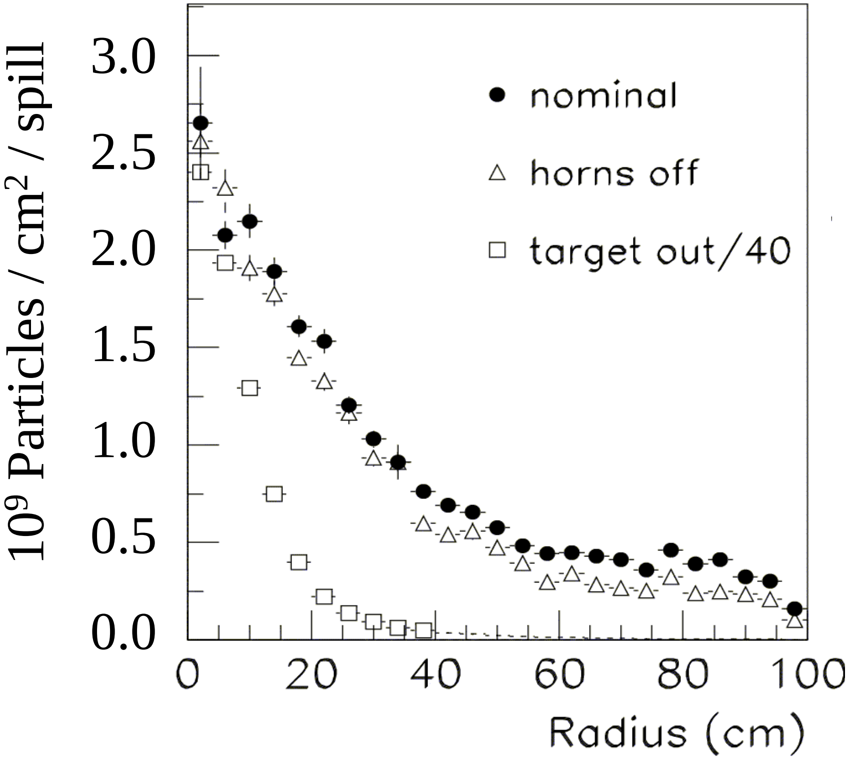
Hadron Monitor

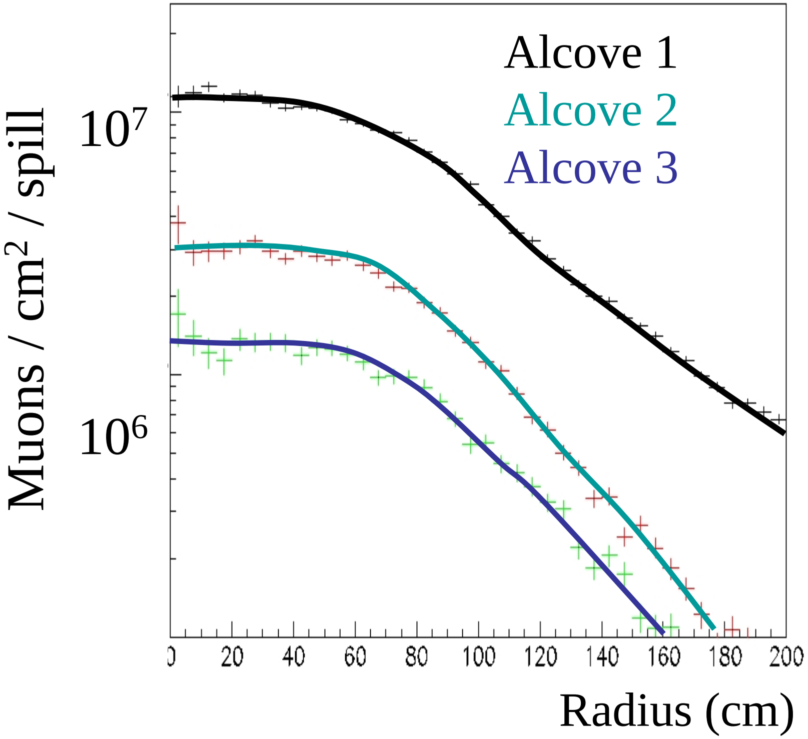
- Max fluxes $10^9/\text{cm}^2/\text{spill}$
- Rad levels ~2×10^9 Rad/yr.

Muon Monitors

- Max fluxes $4\ 10^7/\text{cm}^2/\text{spill}$
- Rad levels ~ 10^7 Rad/yr.

Particle Fluences





- Neutron fluences are ~ 10× that of charged particles at Hadron Monitor & Alcove 1 locations
- Hadron Monitor insensitive to horn focusing
- Muon Monitor distributions flat

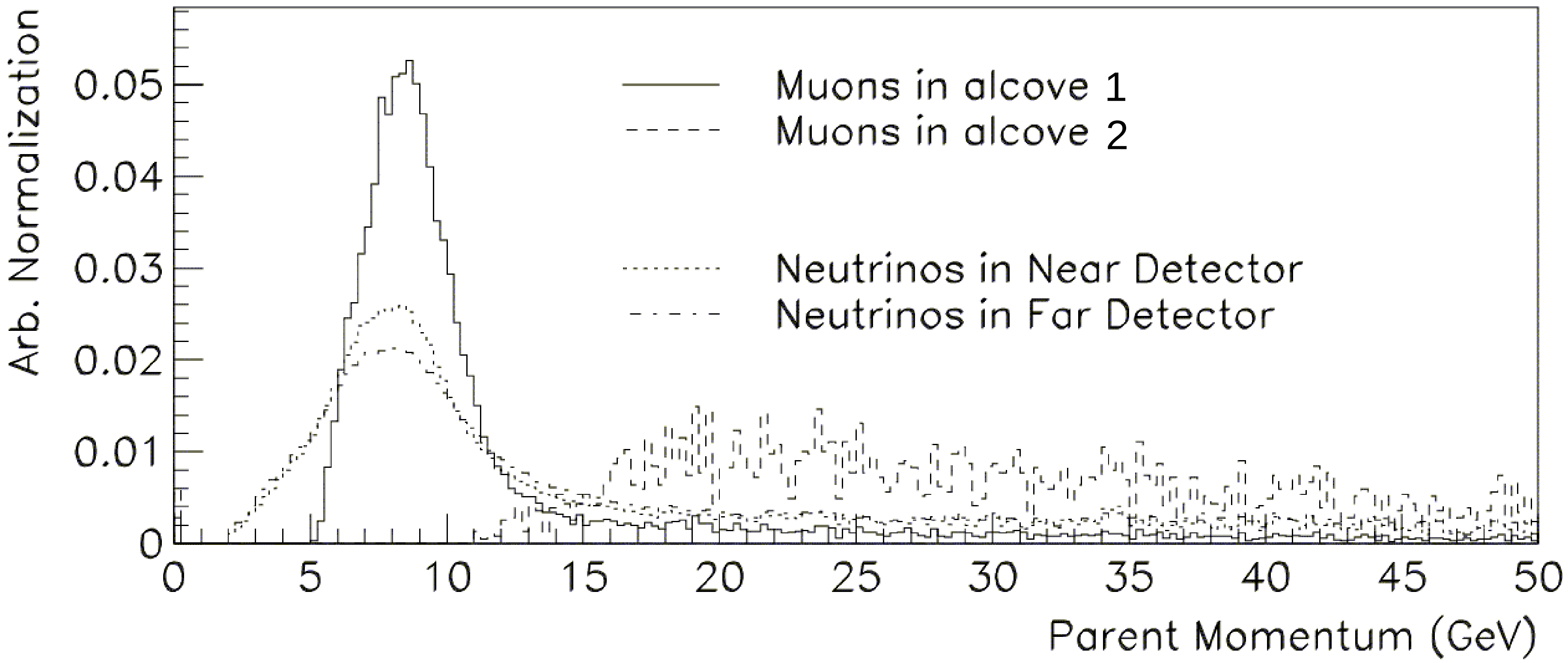
Role of Monitors

- Commissioning the beam – check of alignment
  - Proton beam – Hadron Monitor
  - Neutrino beam – Muon Monitor

- Normal beam operations – ensure optimal beam
  - Proton beam angle – Hadron Monitor
  - Target integrity – Hadron Monitor
  - Horn integrity, position – muon monitor

- Re-commissioning the beam if optics moved

Information in Alcoves

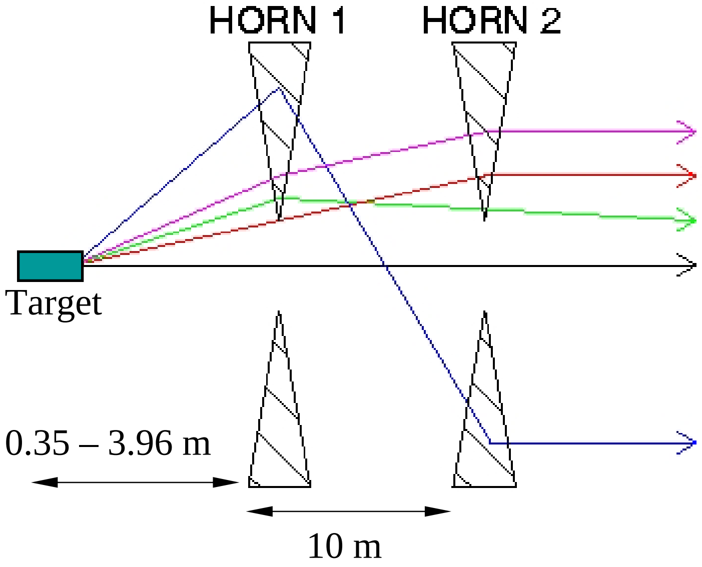


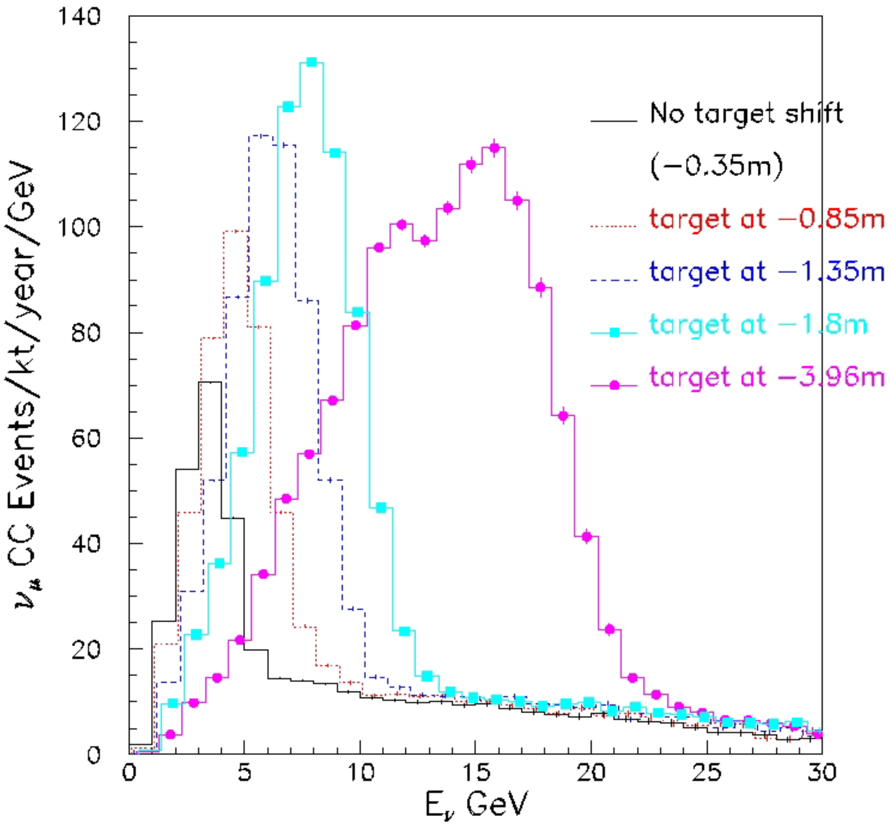
- Hadron Monitor swamped by π's, protons, e^+e^-
- Alcoves have sharp cutoff energies
- Even Alcove 1 doesn't see softest parents

Flexible Energy Beam

- Low E_ν beam flat, hard to monitor relevant parent particles.
- Best way to focus higher energy pions: focus smaller angles.
- Place target on rail system for remote motion capability.

M. Kostin, S. Kopp, M. Messier,
D. Harris, J. Hylen, A. Para

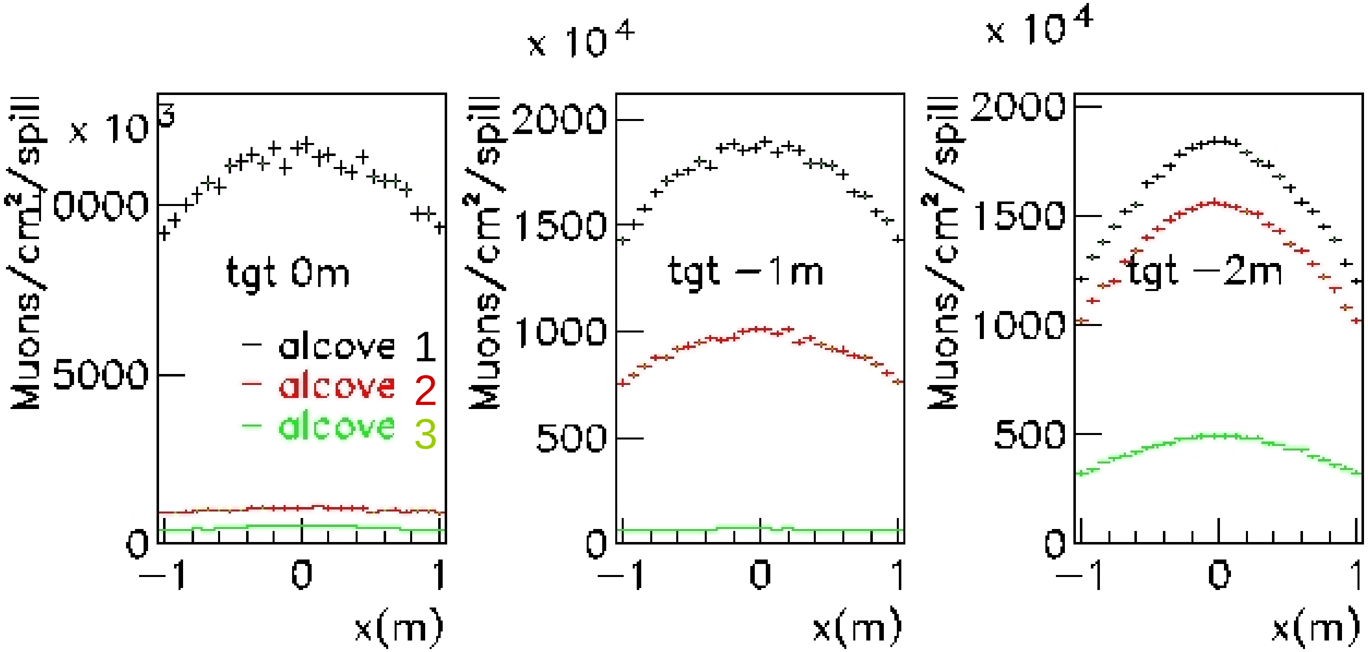




Variable Beam as Monitoring Tool

- Muon alcoves have narrow acceptance (long decay tube!)
- As E_ν increased, decay products boosted forward
- See peak in particle fluxes as energy increases

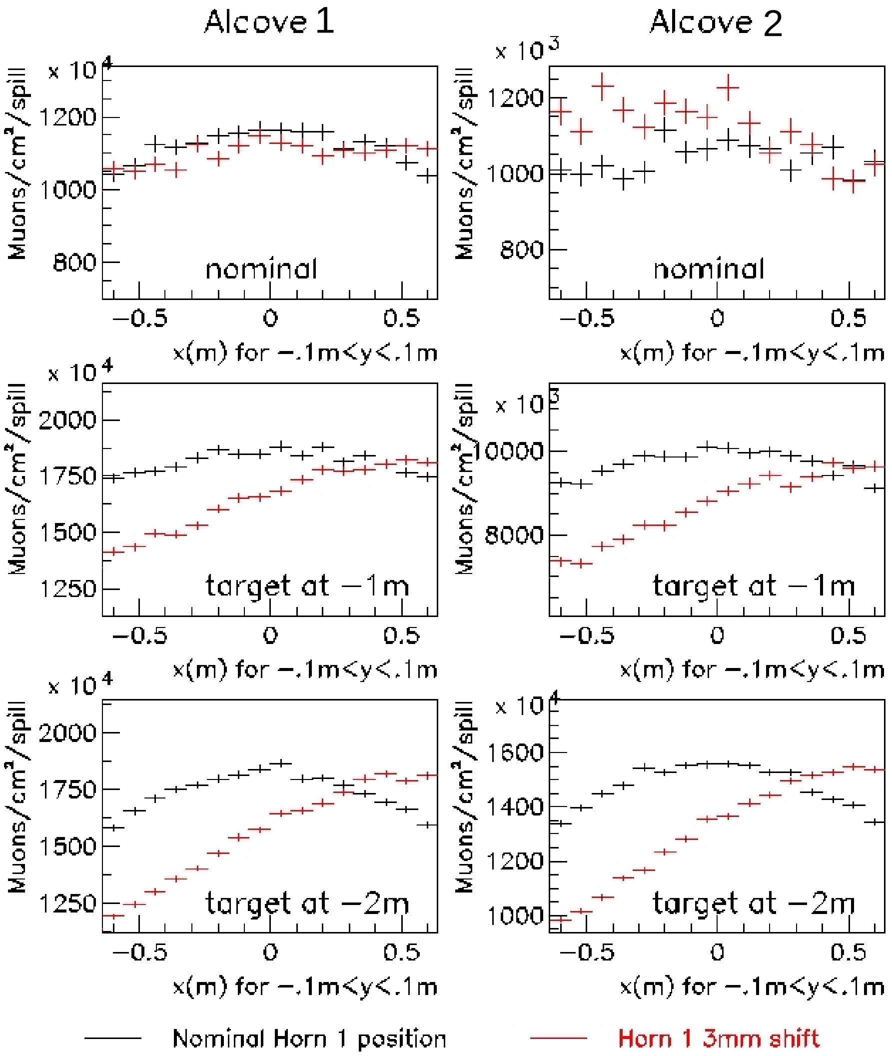
- Use variable beam as periodic monitoring diagnostic



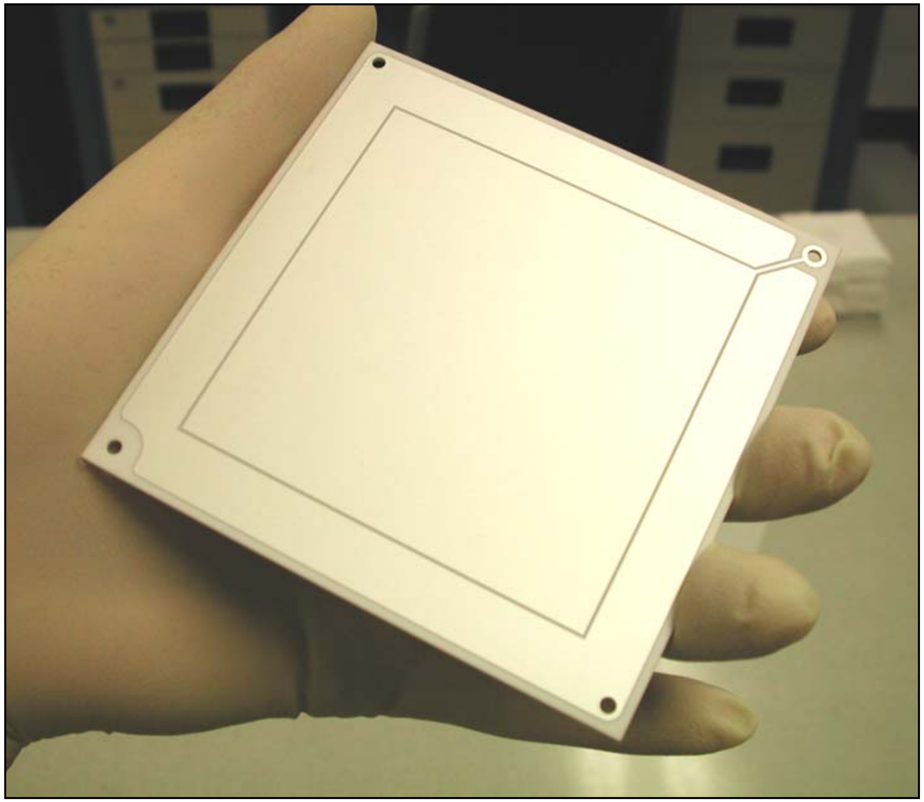
-D. Harris

Muon Monitors

- Alignment of ν beam
  - ➢ Beam center to ~ few cm
  - ➢ Lever arm is 740, 750, 770 m
  - ➢ ν beam direction to ~ 100 μrad
  - ➢ Can measure in 1 beam spill
  - ➢ Requires special ME/HE running
- As beam monitor
  - ➢Rates sensitive to targeting
  - ➢Centroid sensitive to horn focusing
  - ➢Centroid requires ME/HE run (1 spill)



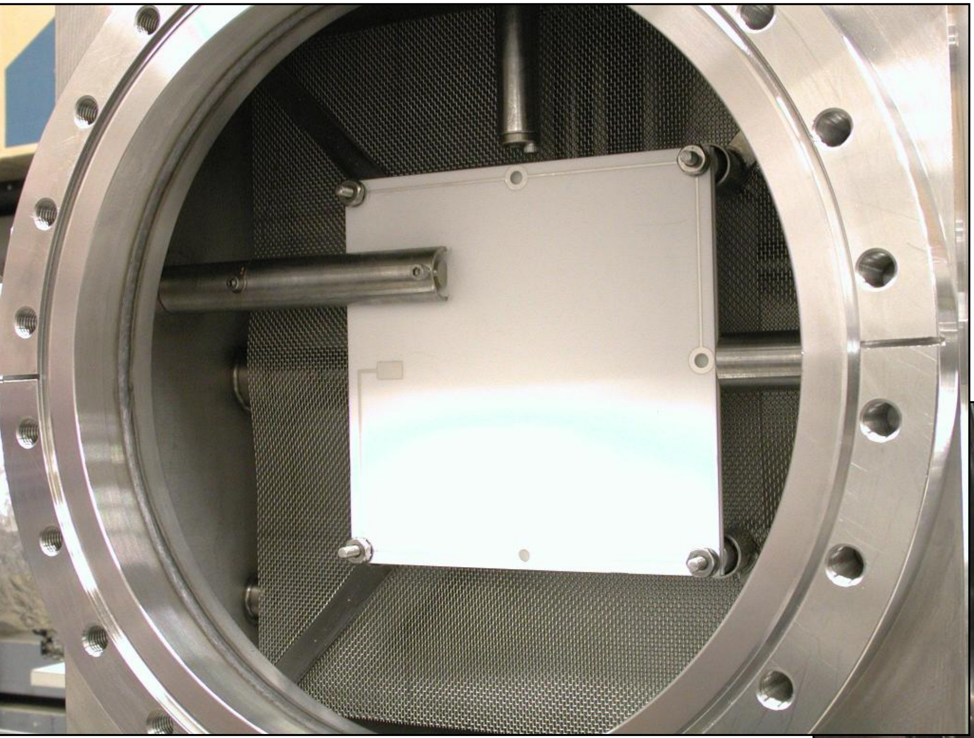
Parallel Plate Ion Chambers



Sense wafer, chamber side

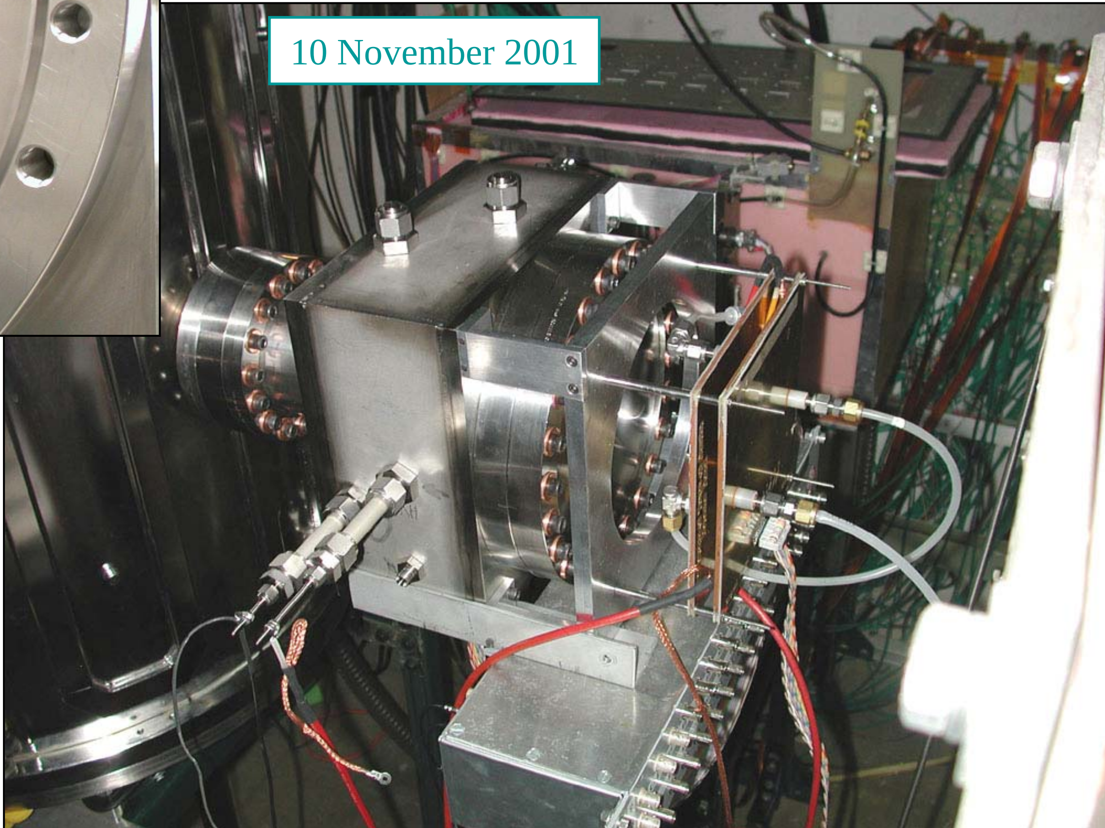
- 11.4 × 11.4 cm^2 Al_2O_3 ceramic wafers
- Ag-plated Pt electrodes
- Similar HV ceramic wafer
- Holes in corners for mounting
- Vias to solder pads on reverse side.
- Separate mechanical support and electrical contacts
- Adopt design with electrical & mechanical contacts in corner holes Chamber gap depends on station
- Ionization medium: Helium gas at atmospheric pressure

Booster Beam Test



Fermilab Booster Accelerator

8 GeV proton beam
5×10^{9} - 5×10^{12} protons/spill
5 cm^{2} beam spot size



10 November 2001

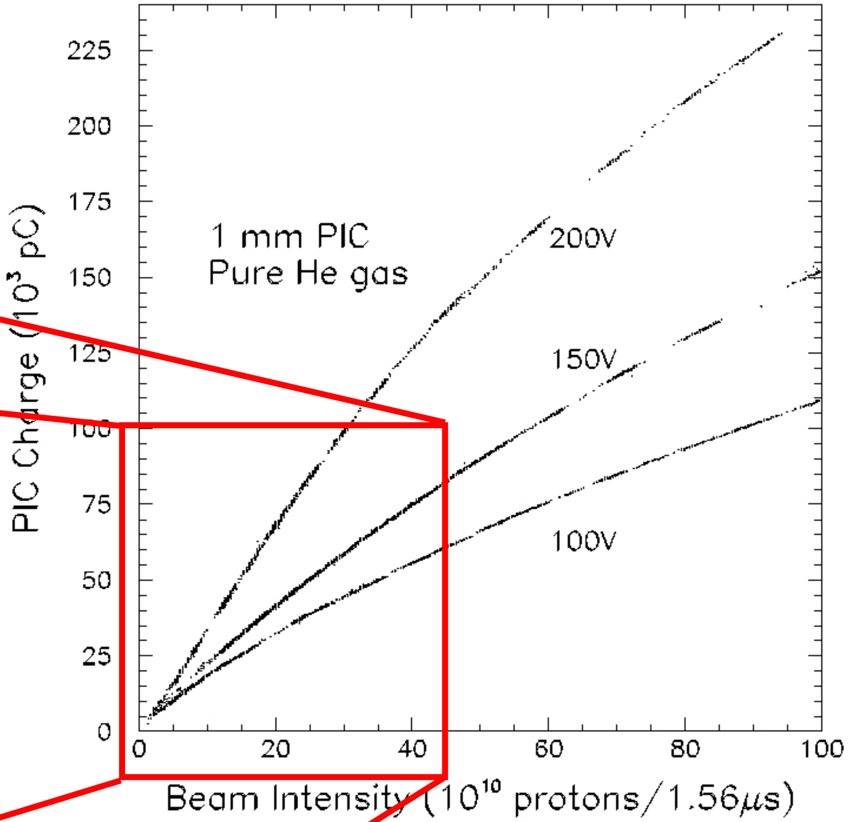
- Two chambers tested (1mm & 2mm gas gap)
- 2 PCB segmented ion chambers for beam profile.
- Toroid for beam intensity

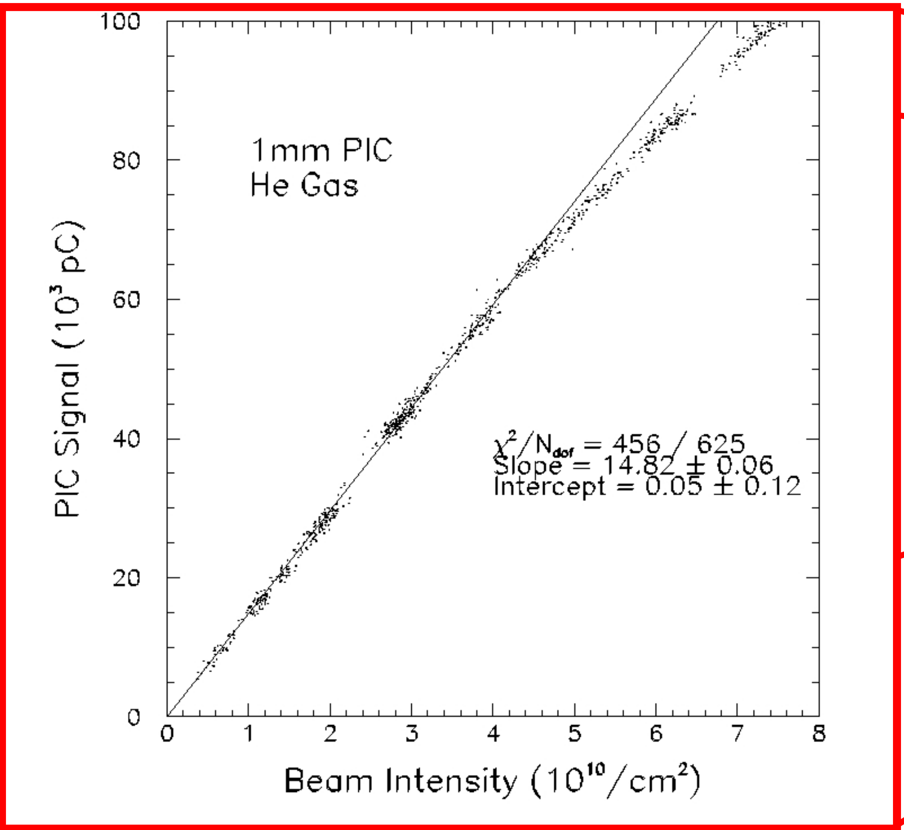
High-Intensity Beam Test

R. Zwaska et al., IEEE Trans. Nucl. Sci. ***50****, 1129 (2003)*

Fermilab Booster

8 GeV proton beam
5×10^{9} - 5×10^{12} protons/spill
5 cm^{2} beam spot size
1mm and 2mm chamber gaps tested



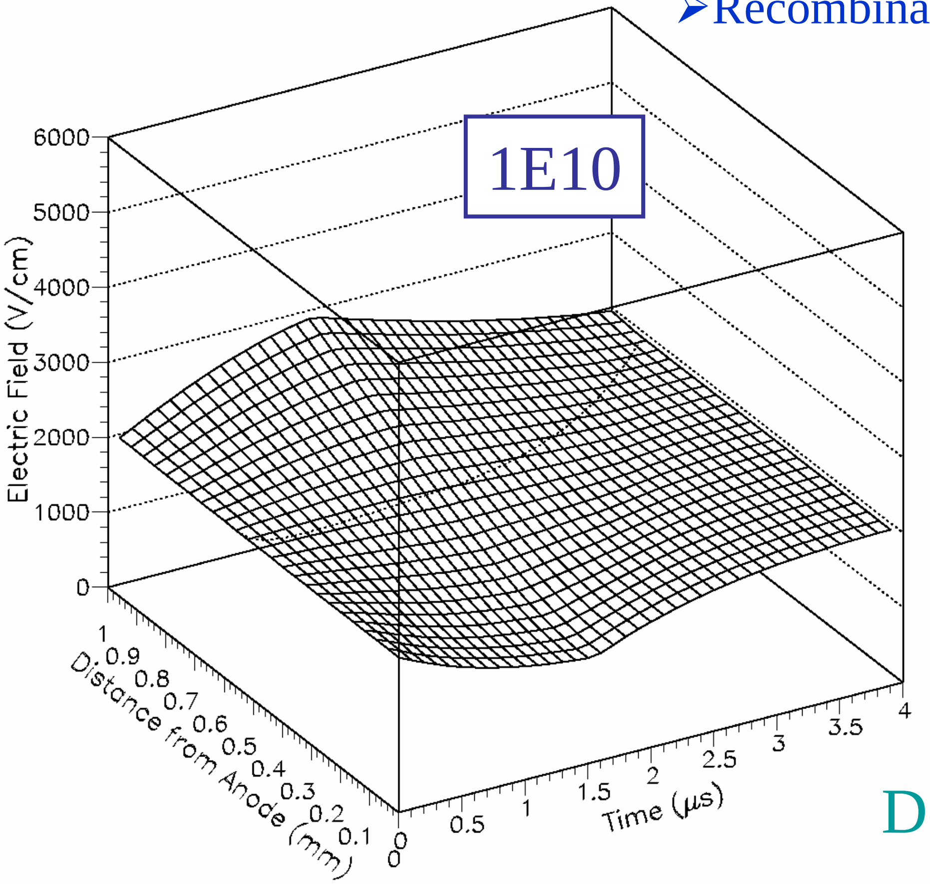


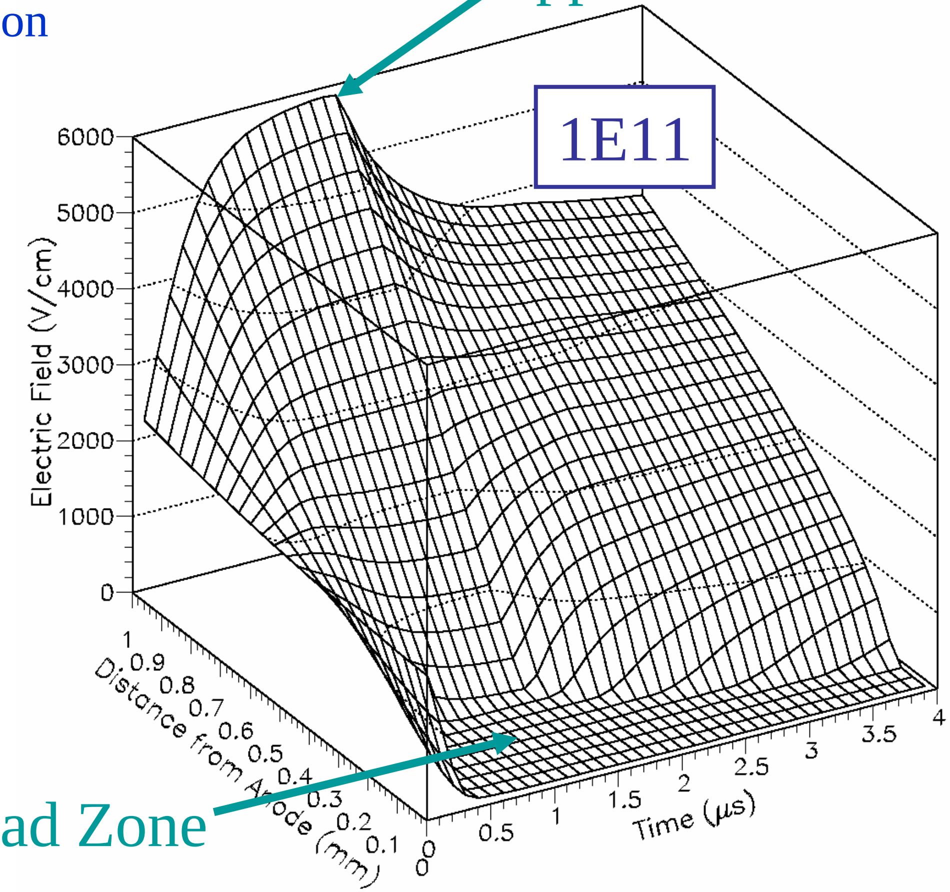
- See onset of charge loss at 4×10^{10} protons/cm^{2}/spill.
- Effect of recombination as chamber field is screened by ionization.

Simulating a Chamber

- Predict Behavior seen in beam test
- 1 Dim. finite element model incorporating:
  - Charge Transport
  - Space Charge Build-Up & Dead Zone
  - Gas Amplification
  - Recombination

1 mm separation
200 V applied
1.56 μs spill


1E10


1E11

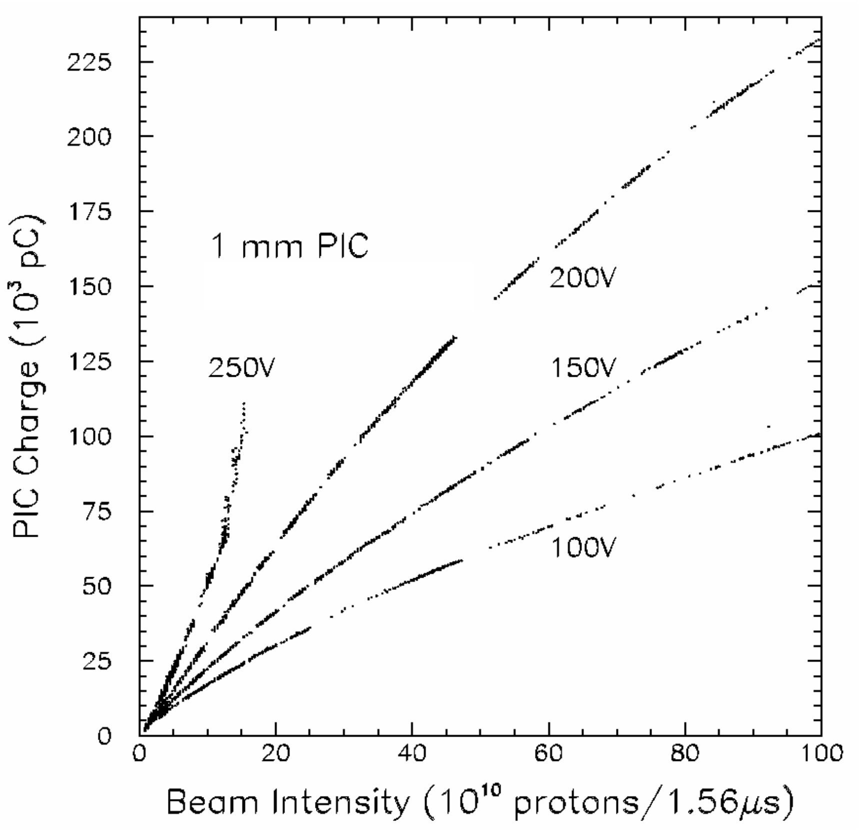
3x Applied Field!

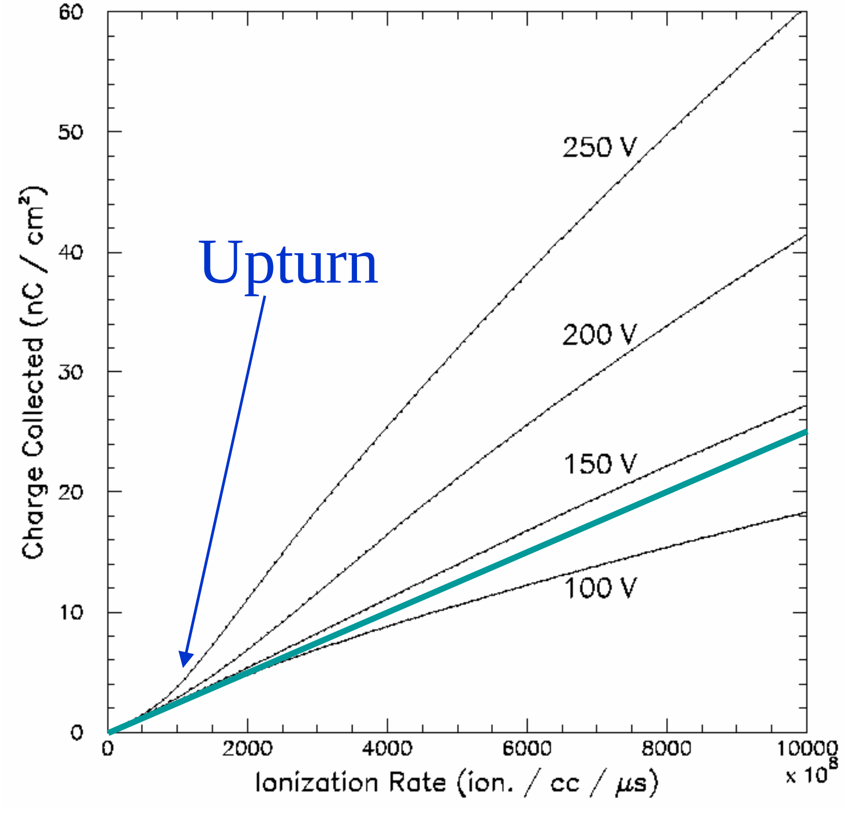
Dead Zone

Simulate Multiplication and Recombination

- Use the same volume recombination: $\frac{dn}{dt} = -kn_+n_-$
- Include gas multiplication: $\frac{dN}{dx} = N\alpha \quad \frac{\alpha}{P} = A\exp\left[-\frac{B}{(E/P)}\right]$
- Space Charge creates an electric field larger than the applied field

Data ⇔ Simulation

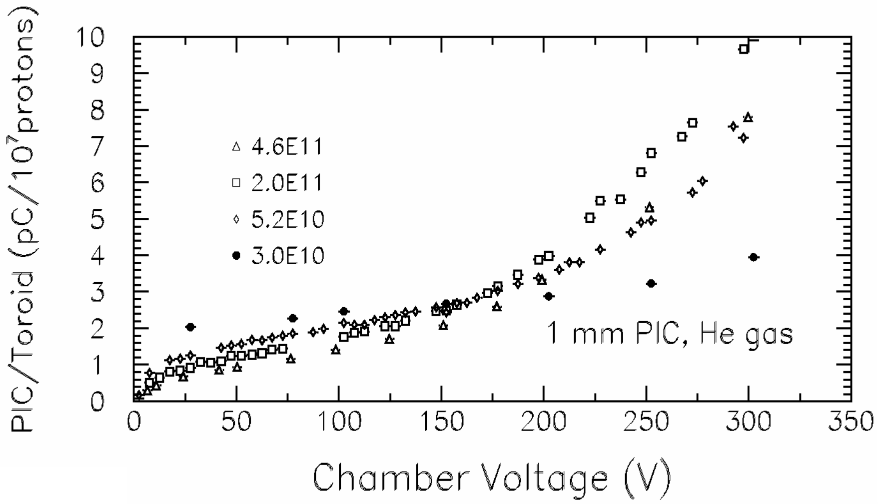


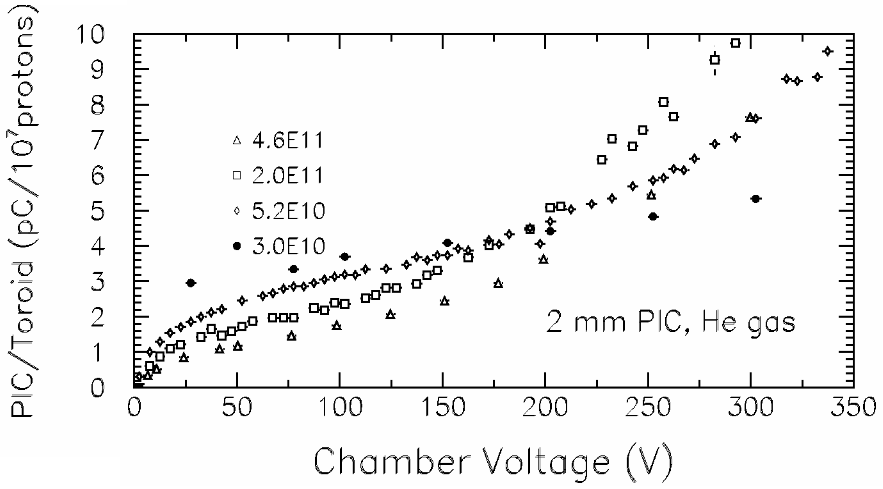

Upturn

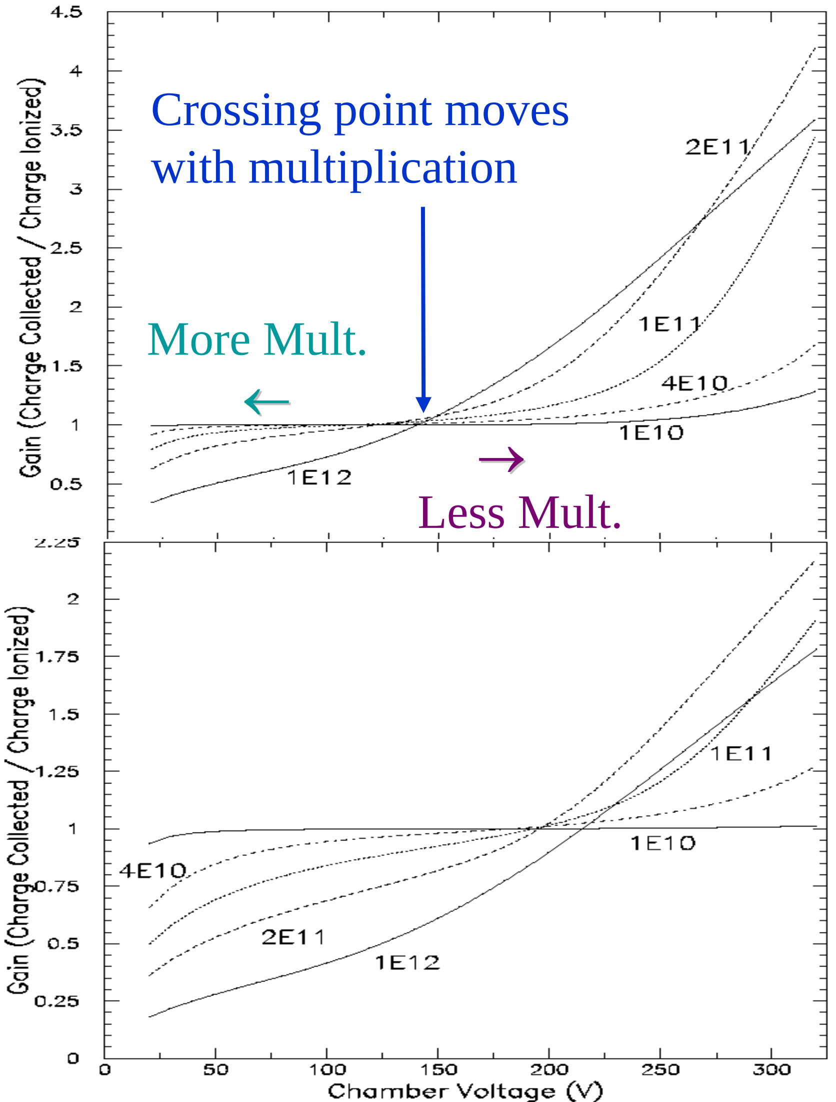
Plateau Curves

- ➢Curves converge in a region of voltage near a gain of 1
  - ➢Data suggests 15-20 electron-ion pairs / cm

Data ⇔ Simulation







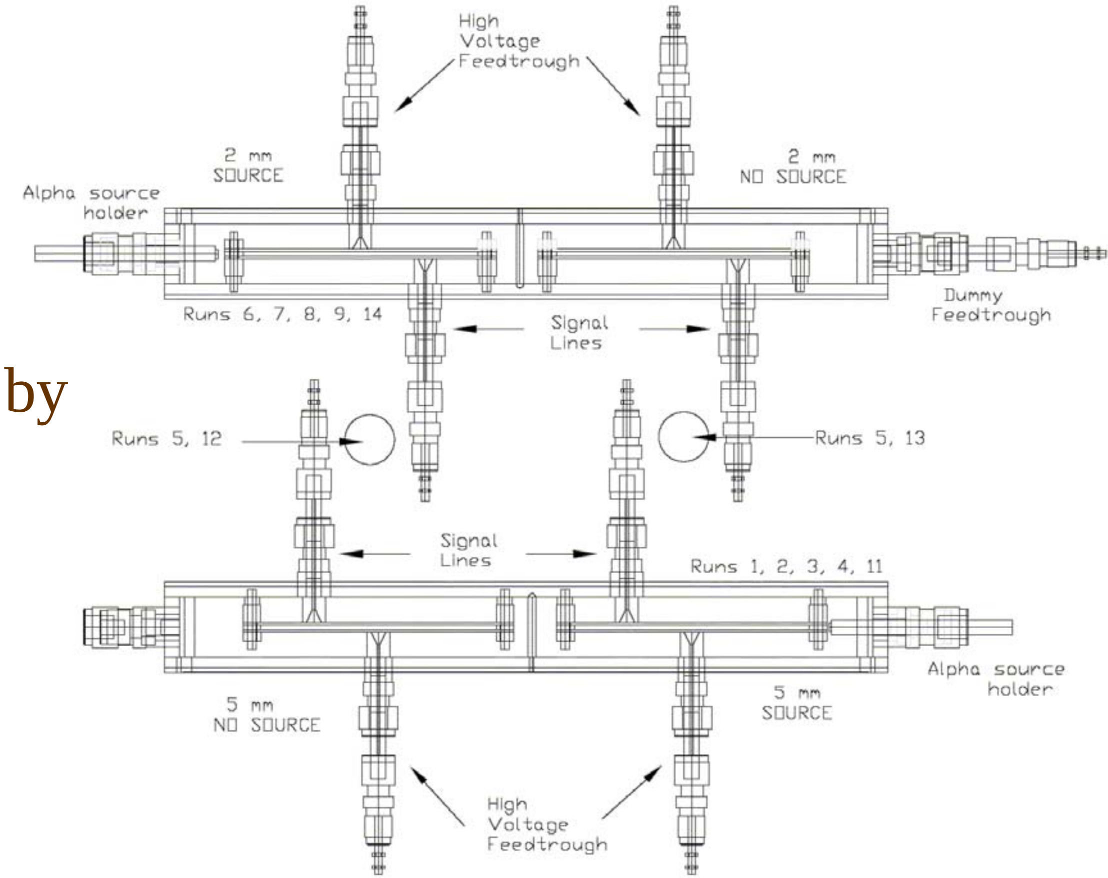
Crossing point moves with multiplication

More Mult. ←

→ Less Mult.

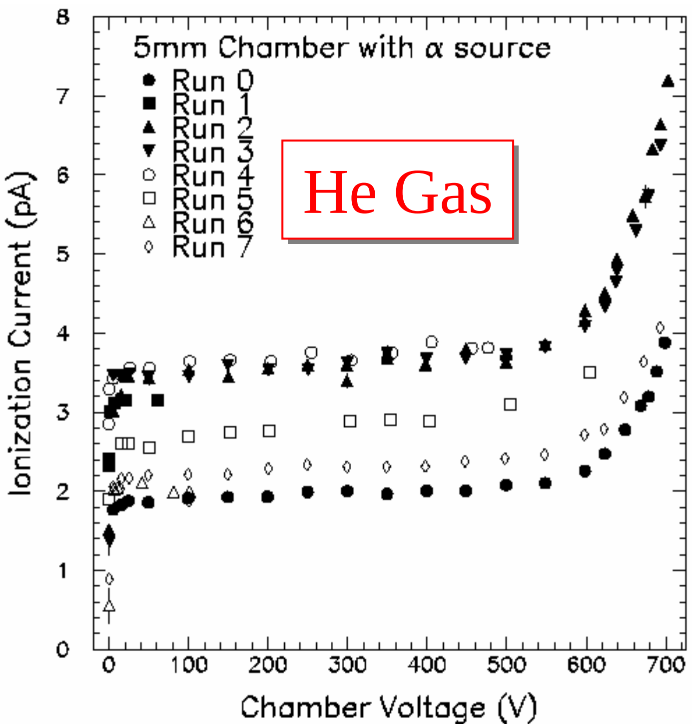
Neutron Backgrounds

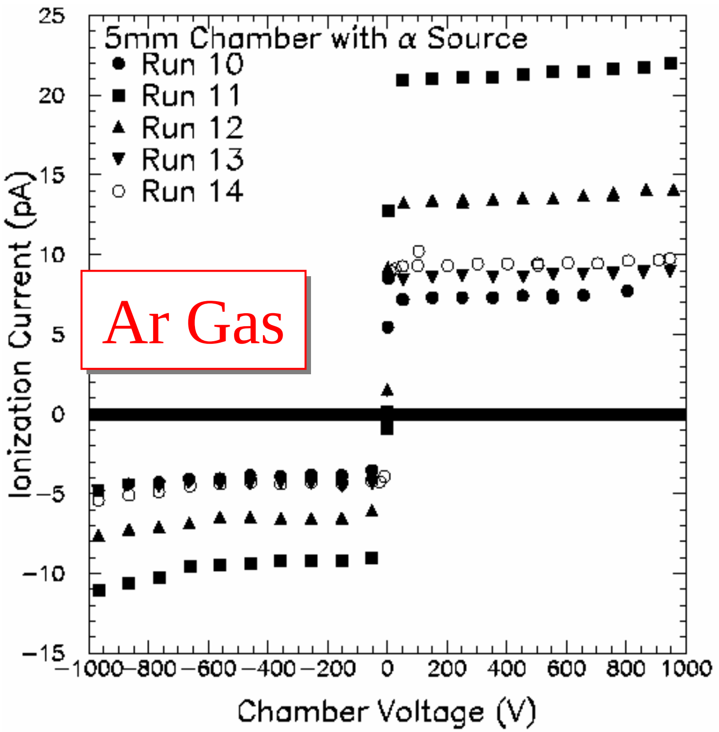
- Neutron Fluxes are comparable to charged particle fluxes
  - ➢ 10x in Hadron Monitor
  - ➢ 10x in Muon Monitor 1
    - From Beam Dump
  - ➢ Smaller in other locations
- Neutrons create ionization by nuclear recoils
- Measured ionization from PuBe neutron sources
  - ➢ 1-10 MeV
  - ➢ 55 Ci



Neutron Signals

D. Indurthy et al, submitted to Nucl. Instr. Meth.





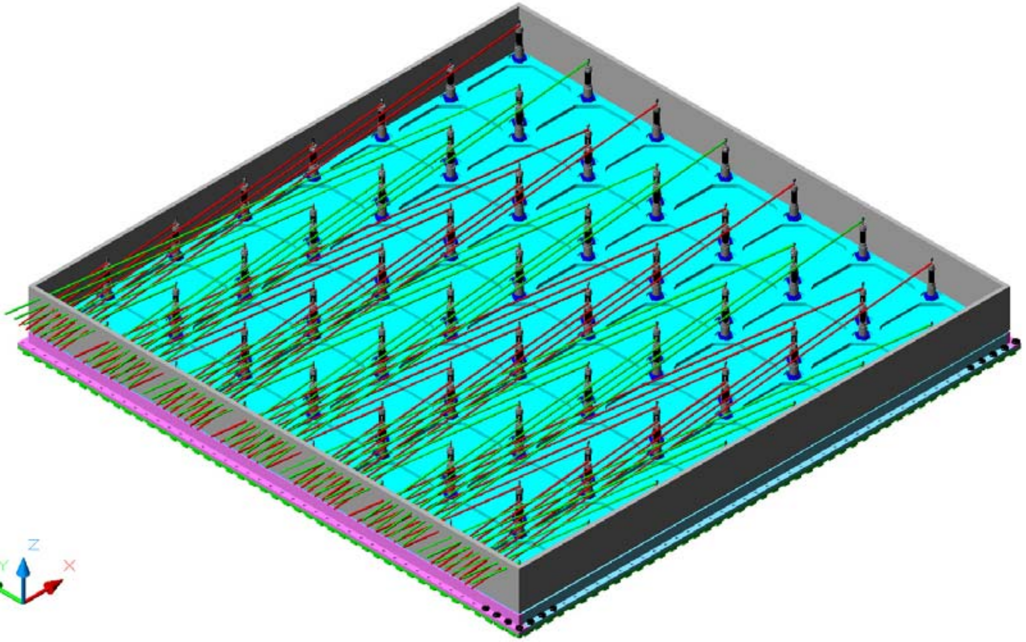
Ion Pairs / cm	He Gas	Ar Gas
Neutrons	1.1 ± 0.2	9.6 ± 2.6
Charged Particles	16	120

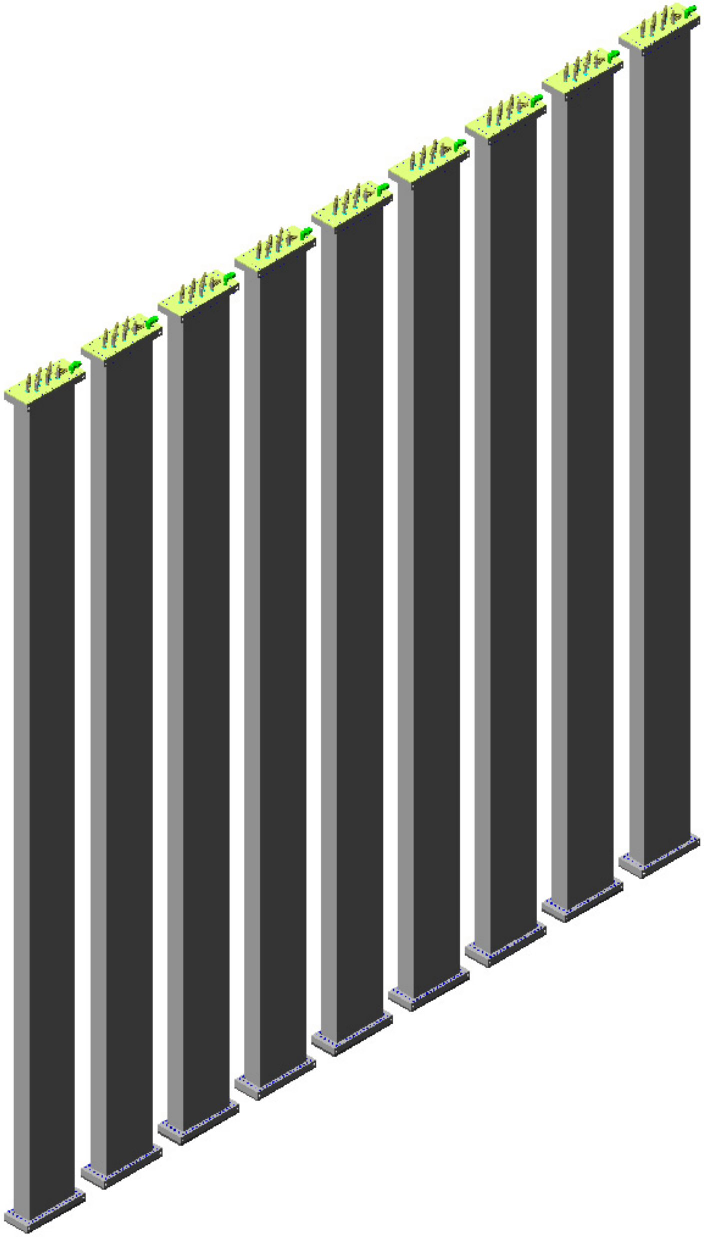
Results ⇒ signal:noise is 1:1 in monitors?

-preliminary-

System Design

- Hadron Monitor
  - 7x7 grid → 1x1 m^2
    - 1 mm gap chambers
  - Radiation Hard design
  - Mass minimized for residual activation
    - 57 Rem/hr
- Muon Monitors
  - 9 tubes of 9 chambers each → 2.2x2.2 m^2
    - 3 mm gap chambers
  - Tube design allows repair
- High Voltage (100-500 V) applied over He gas
  - Signal acquired with charge-integrating amplifiers

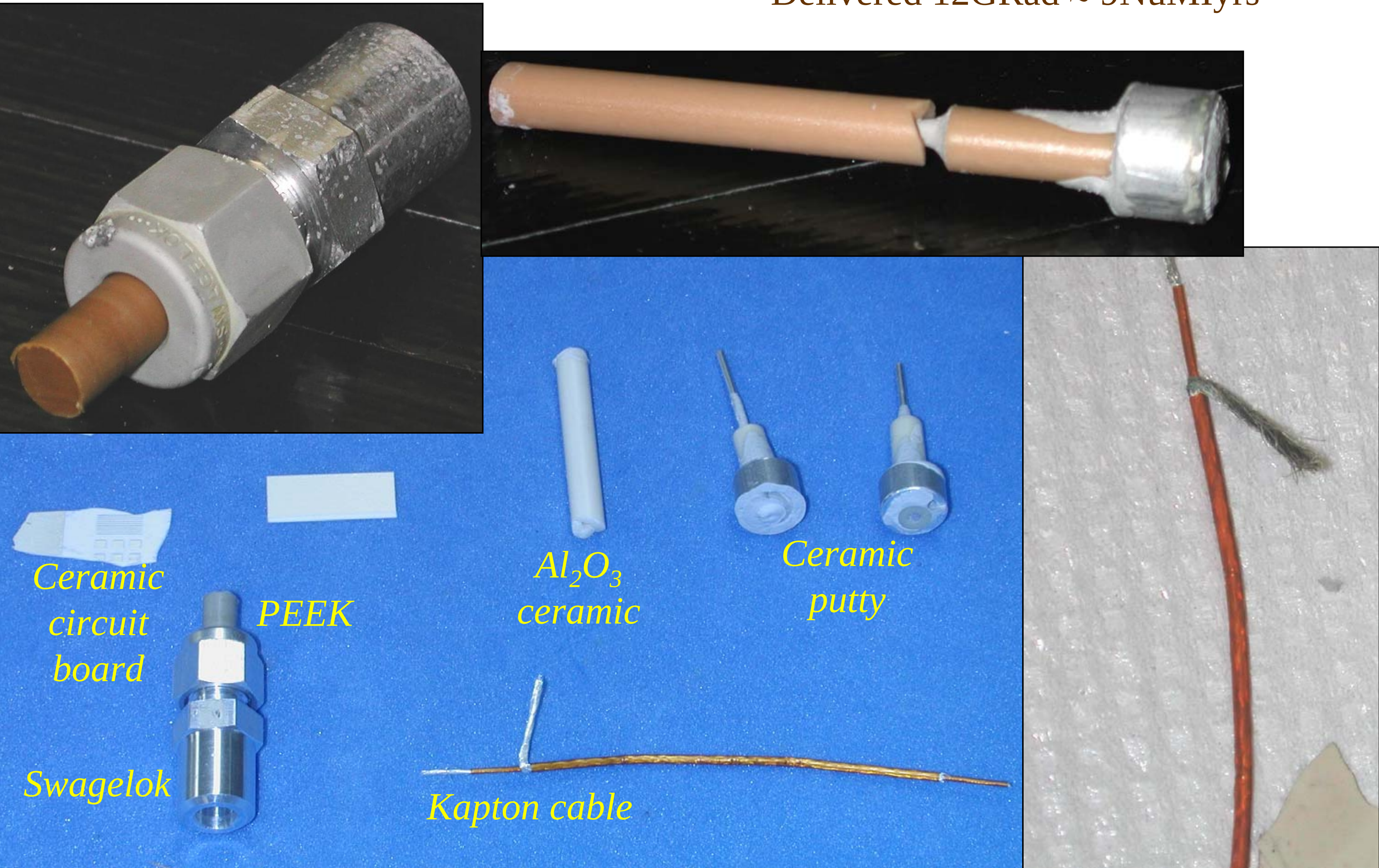




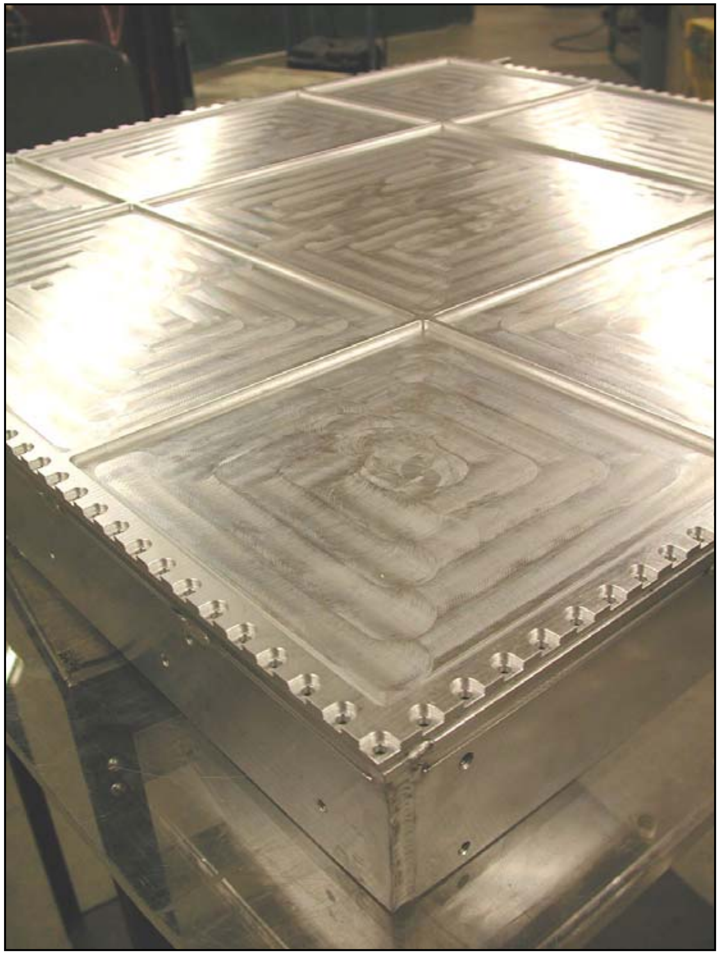
Radiation Damage Tests

@ UT Nuclear Engineering Teaching Lab Reactor

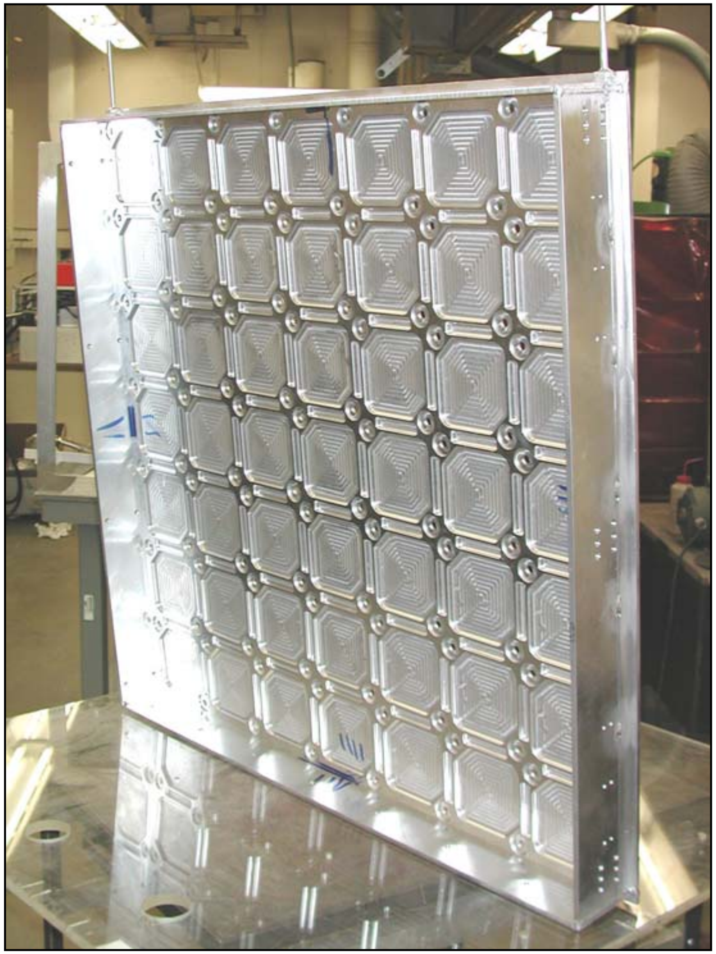
- Delivered 12GRad ≈ 9NuMIyrs



Hadron Monitor Construction

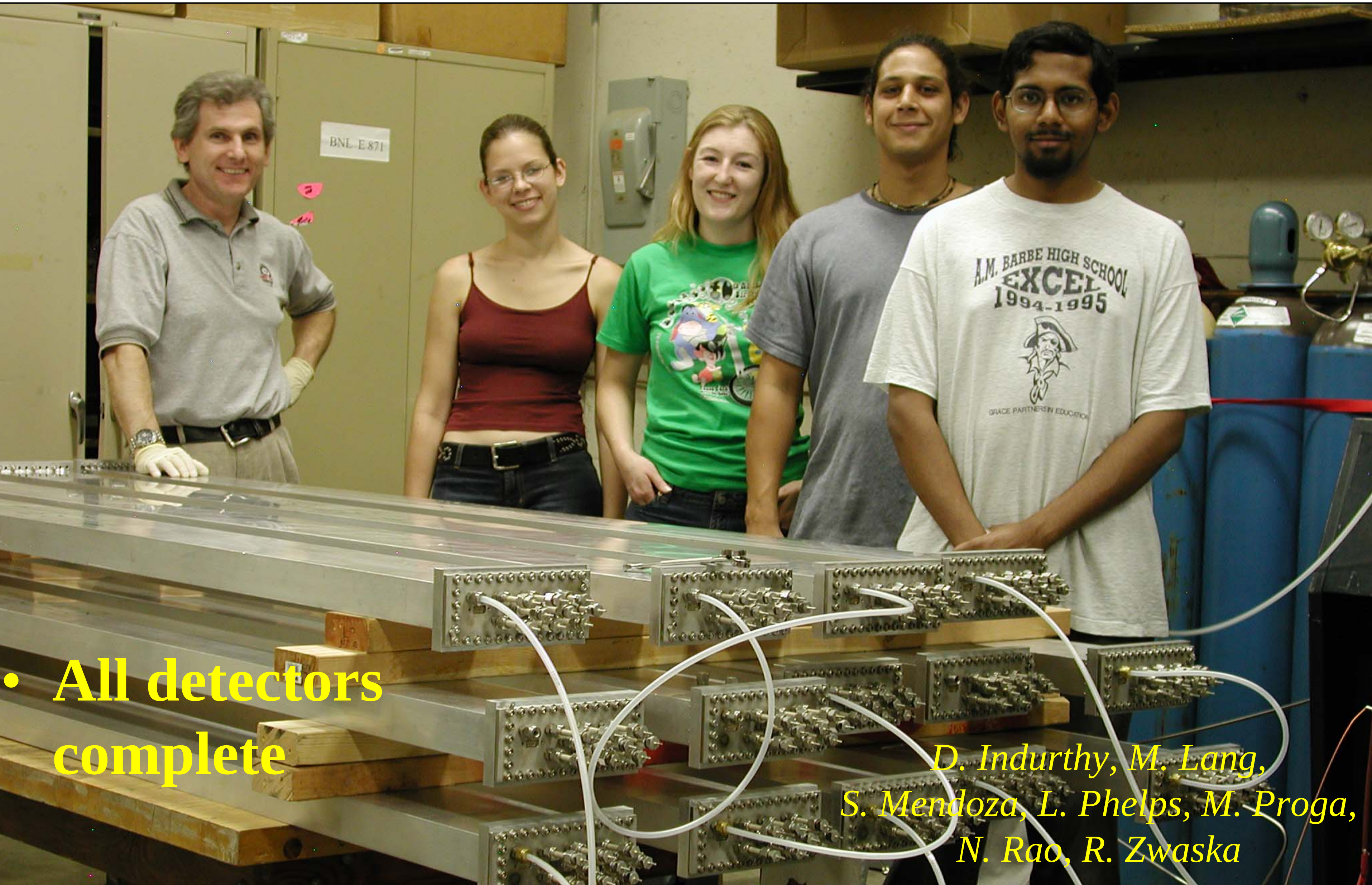


front window



rear feedthrough base

Muon Monitor Construction



- **All detectors complete**

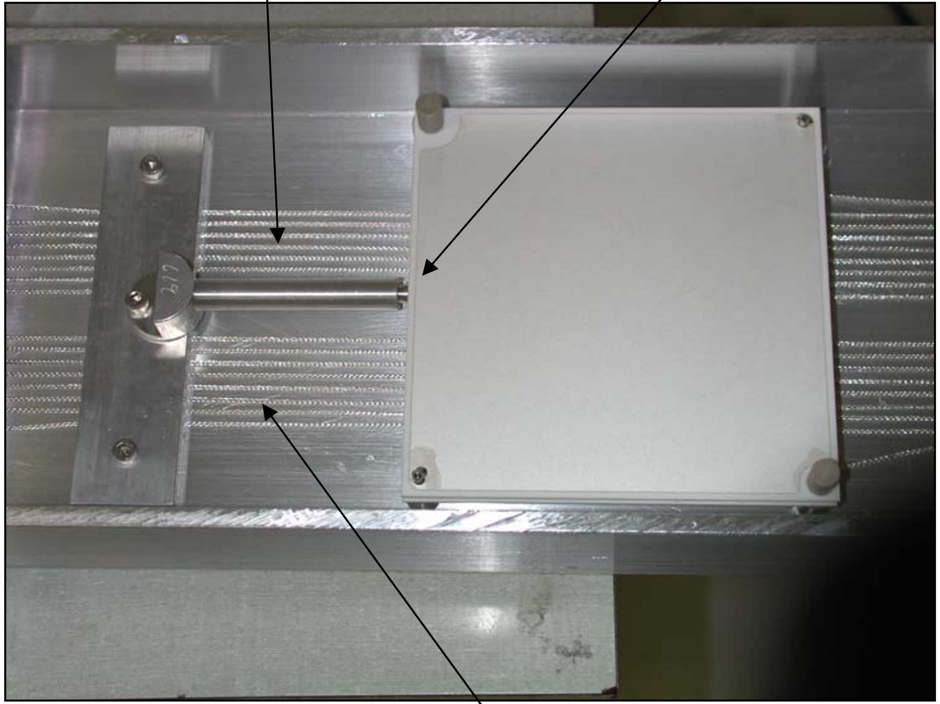
D. Indurthy, M. Lang,
S. Mendoza, L. Phelps, M. Proga,
N. Rao, R. Zwaska

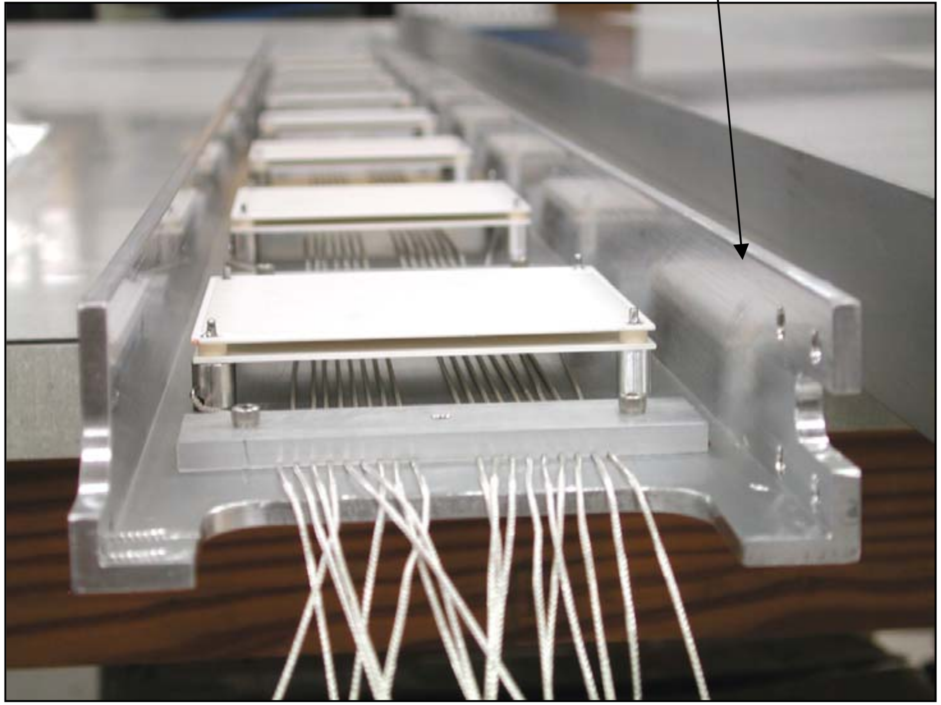
Assembly

Signal Cables

1 μCi ^{241}Am α
Calibration Source

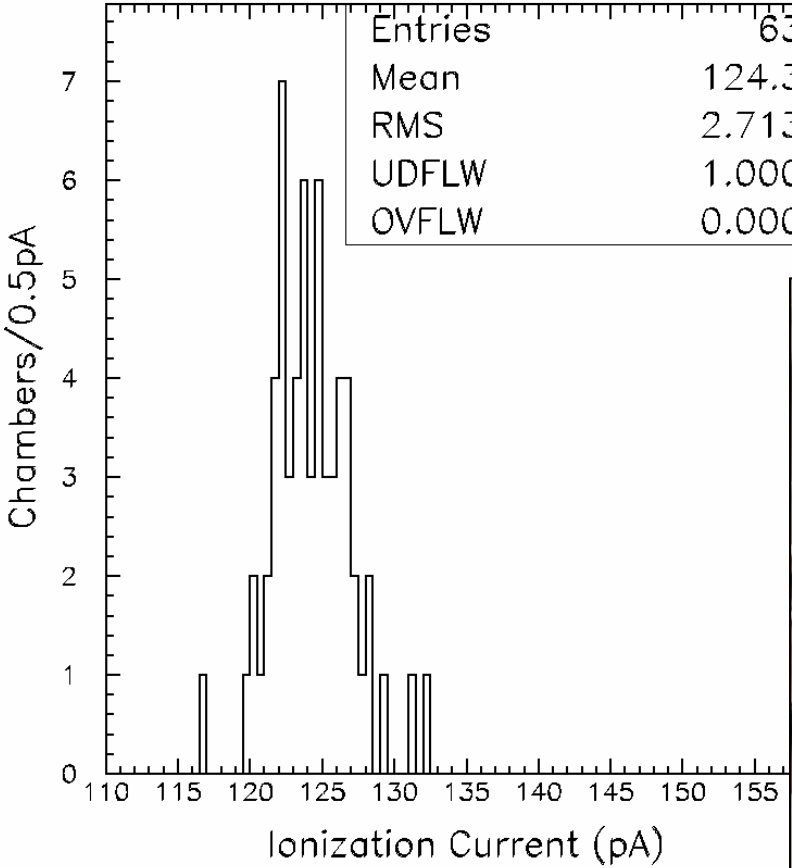
Tray



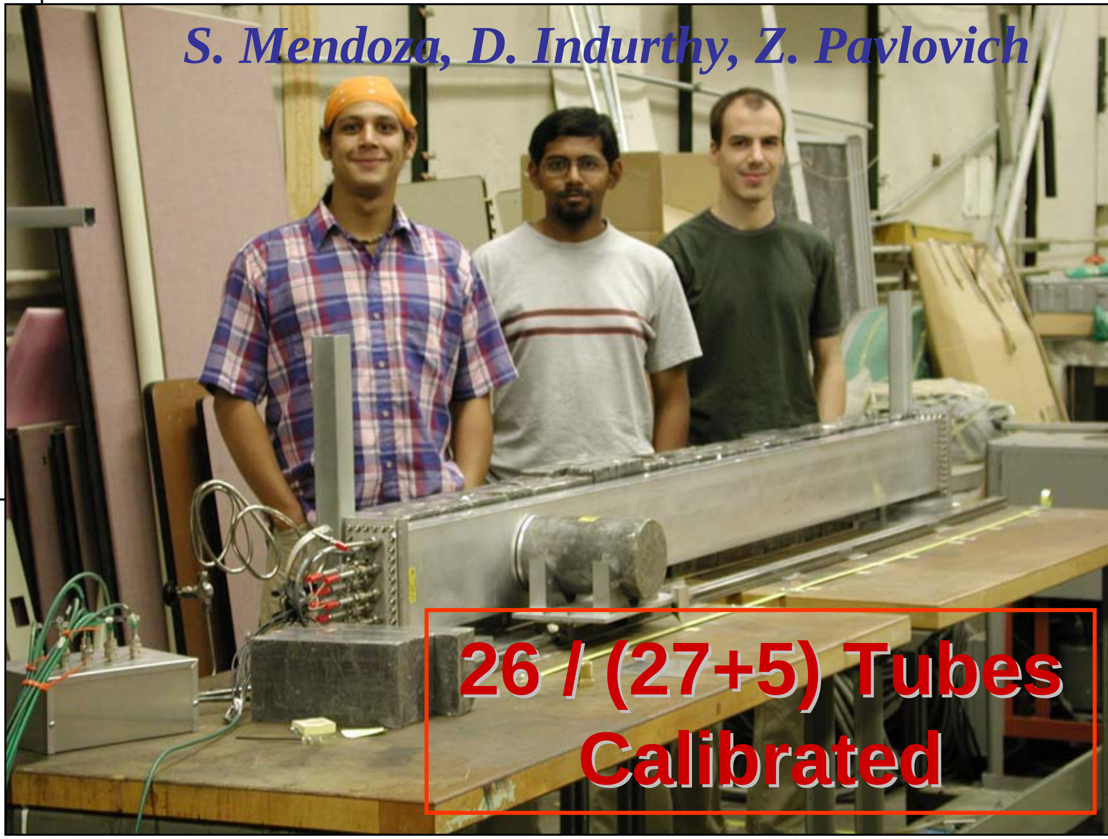


HV cables

Muon Monitor Calibration



- Establish relative calibration of all 270 chambers to <1%.
- Irradiate every chamber with 1Ci Am^{241} source (30-60 keV γ's)



S. Mendoza, D. Indurthy, Z. Pavlovich

26 / (27+5) Tubes Calibrated

- Precision of ion current ~0.1pA
- Results show ~10% variations due to construction variations

Summary

- Hadron & Muon Monitors provide information on:
  - Beam alignment (proton & secondary)
  - Target Integrity
  - Optics Quality
- Signals come from hadrons, muons, and neutrons
- Variable energy beam allows more information to be collected
- Detector hardware tested at high intensity
  - Linearity is adequate
  - Behavior is understood through simulation
- Neutron backgrounds estimated & characterized
  - Neutron signal might be comparable to (other) hadron signal
- Systems designed, built, & calibrated
  - Components tested for radiation damage