Ion Chambers for Monitoring the NuMI Neutrino Beam

Sacha E. Kopp,
University of Texas – Austin

for the

NuMI/MINOS Collaboration

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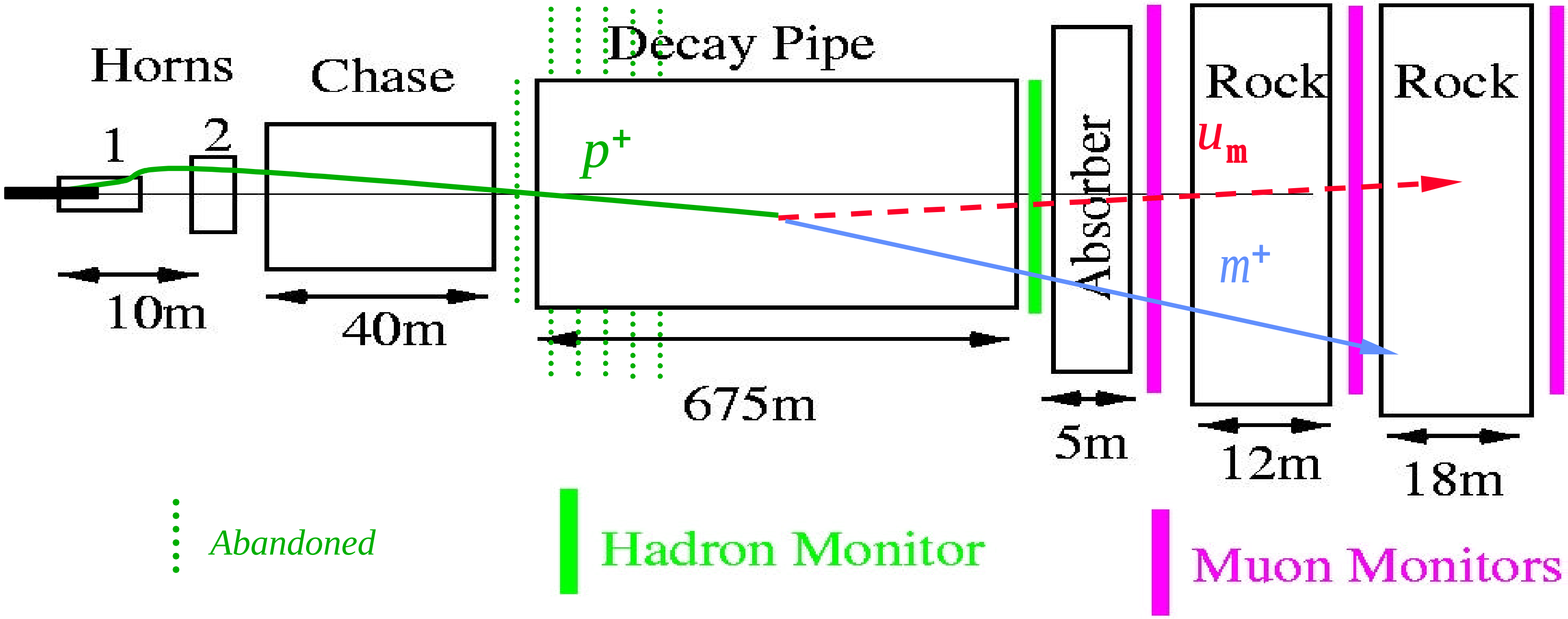
System Geography



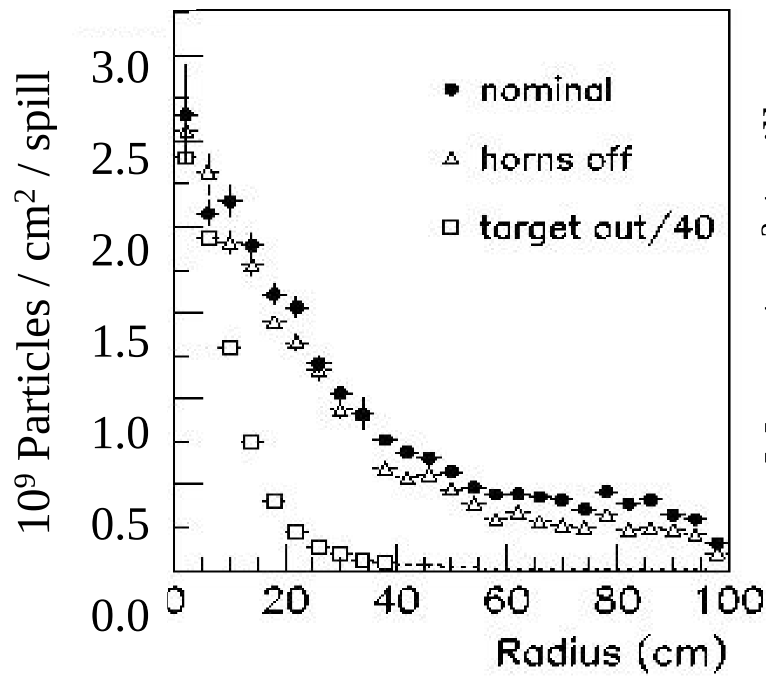
Downstream Hadron Monitors

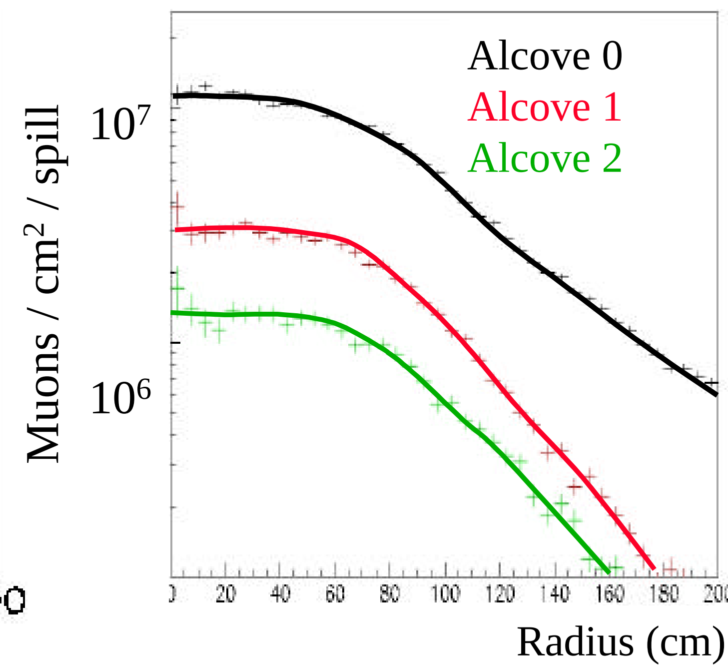
- Max fluxes 10^9/cm^2/spill
- Rad levels ~ 10^{10} Rad/yr.

Muon Monitors

- Max fluxes 4 10^7/cm^2/spill
- Rad levels ~ 10^7 Rad/yr.

Particle Fluences





- Neutron fluences ~ 10× chg'd ptlces at HadMon, Alcove 0
- *KEY POINT #1*: HadMon insensitive to horn focusing!
- *KEY POINT #2*: μMon distributions flat!

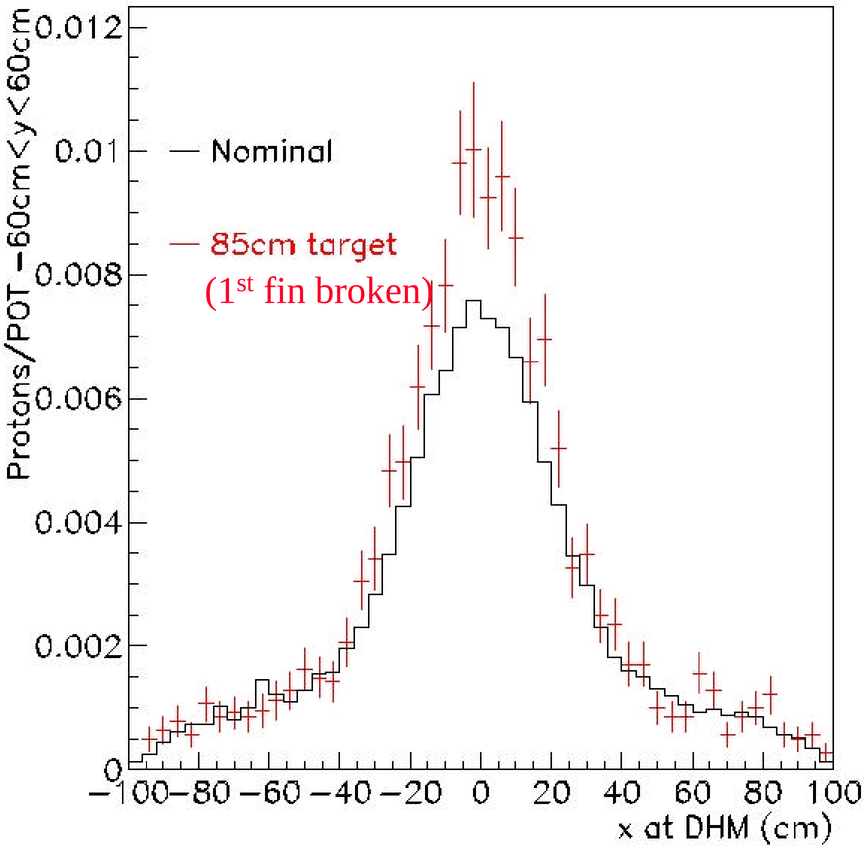
Role of Monitors

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

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

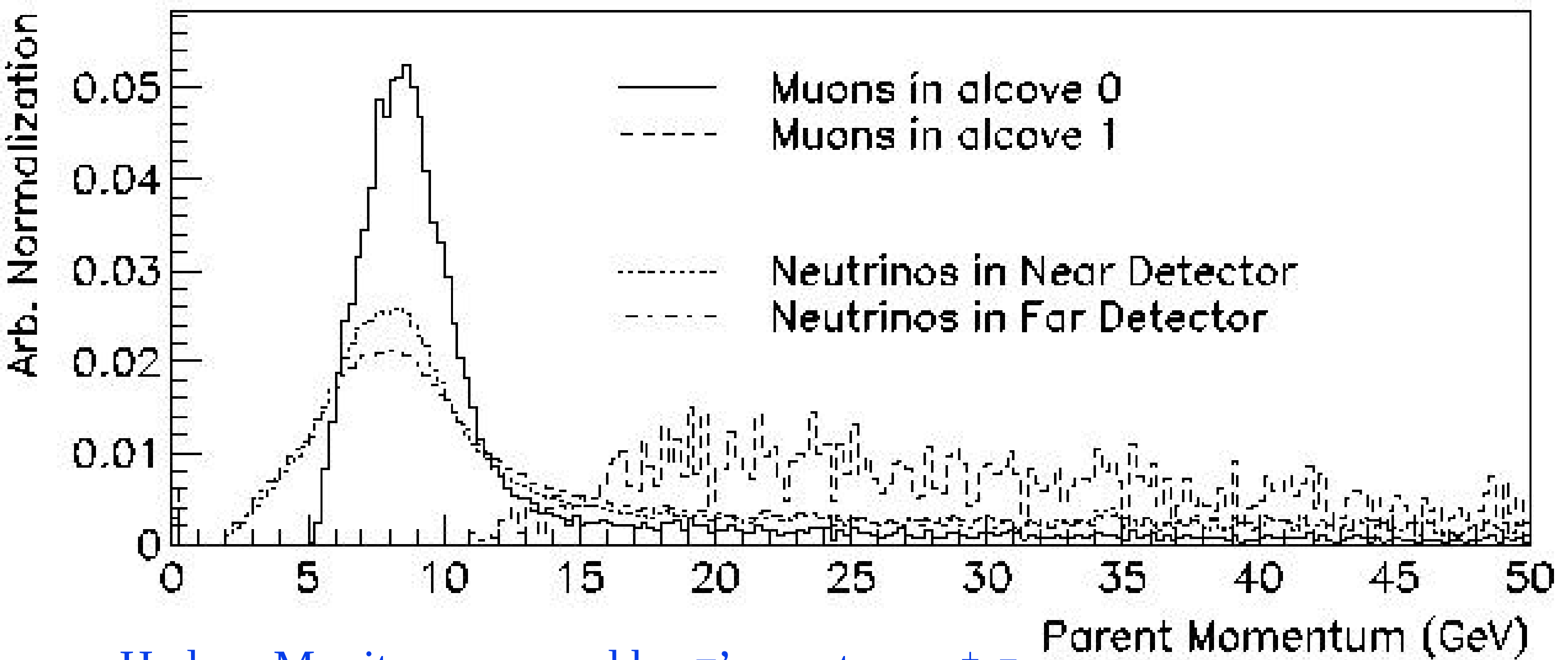
- Re-commissioning the beam if optics moved

Hadron Monitor



- As alignment tool:
  - » σ_{beam} ~ 10 cm (no target)
  - »Beam position to ~ 3 cm
  - »Had mon ~725m from target
  - »Proton angle to ~ 40 μrad
- As target monitor
  - » σ_{beam} ~ 10 cm (no target)
  - » σ_{beam} ~ 40 cm (target in)
- Excellent target monitor because insensitive to horns.

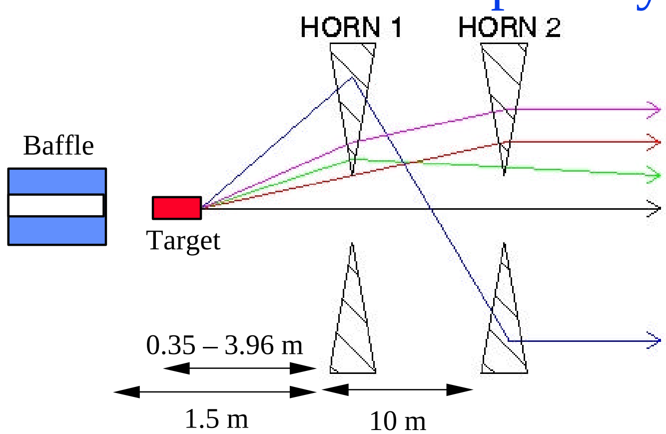
Information in Alcoves

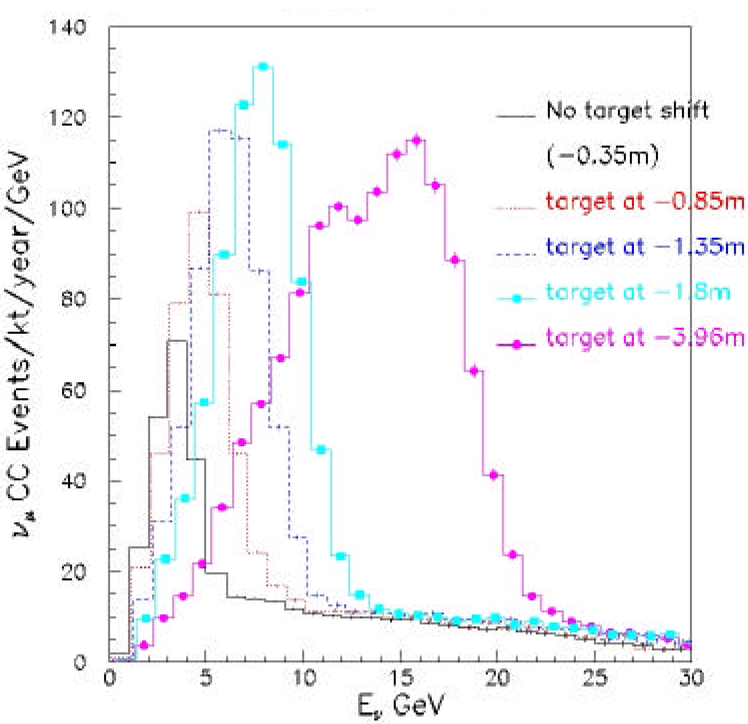


- Hadron Monitor swamped by π's, protons, e^+e^-.
- Alcoves have sharp cutoff energies
- *KEY POINT #3*: Even Alcove0 doesn't see softest parents.

Flexible Energy Beam

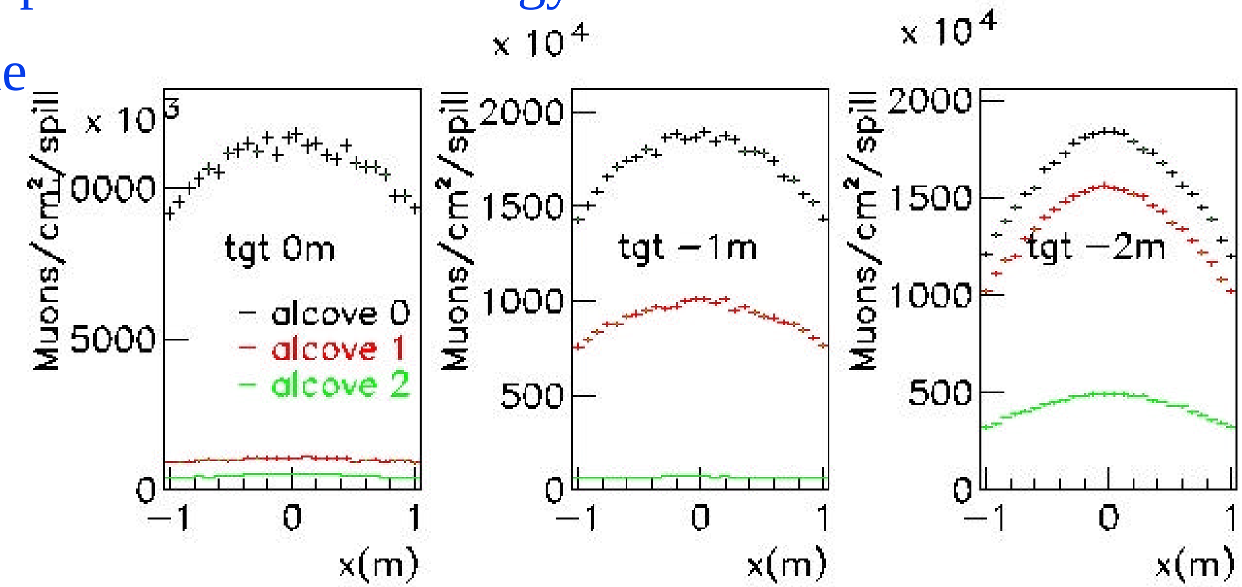
- Low E_ν beam flat, hard to monitor relevant parent particles.
- Best way to focus higher energy pions: focus smaller angles.
- Place target on rail system for remote motion capability.





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



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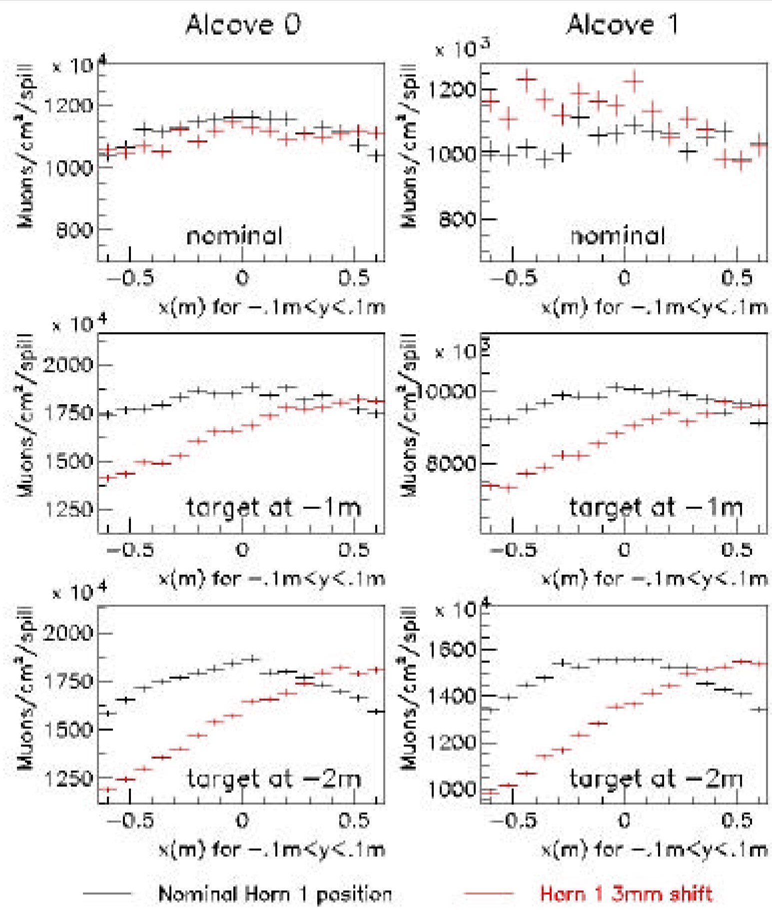
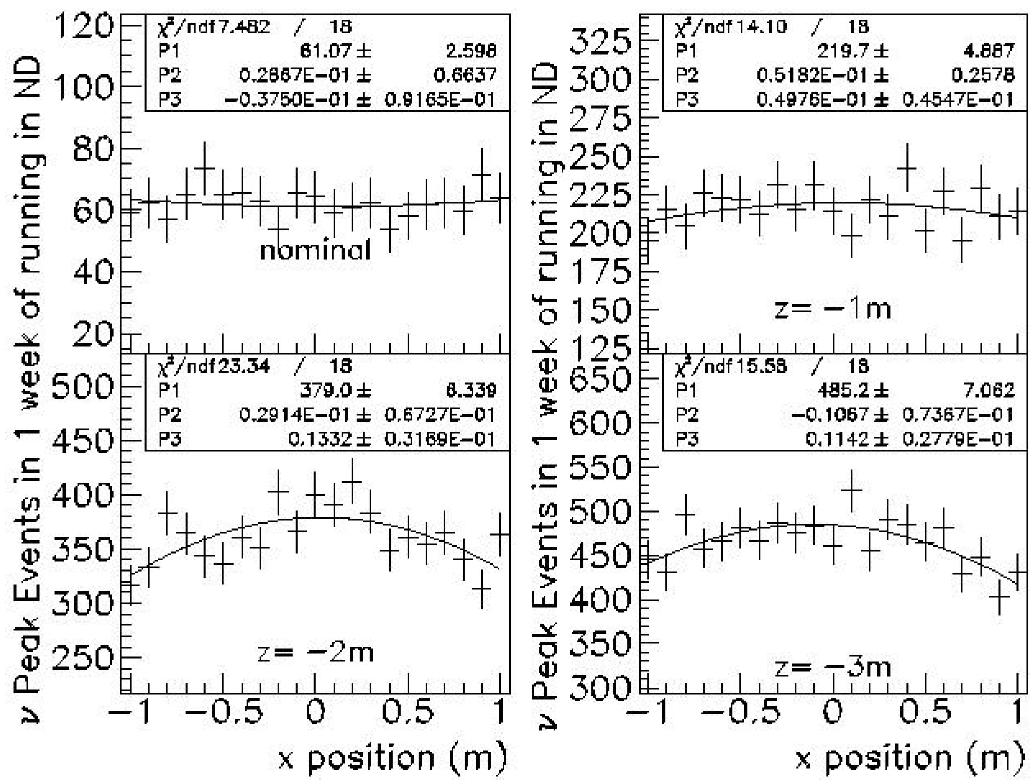
Muon Monitors

- 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)

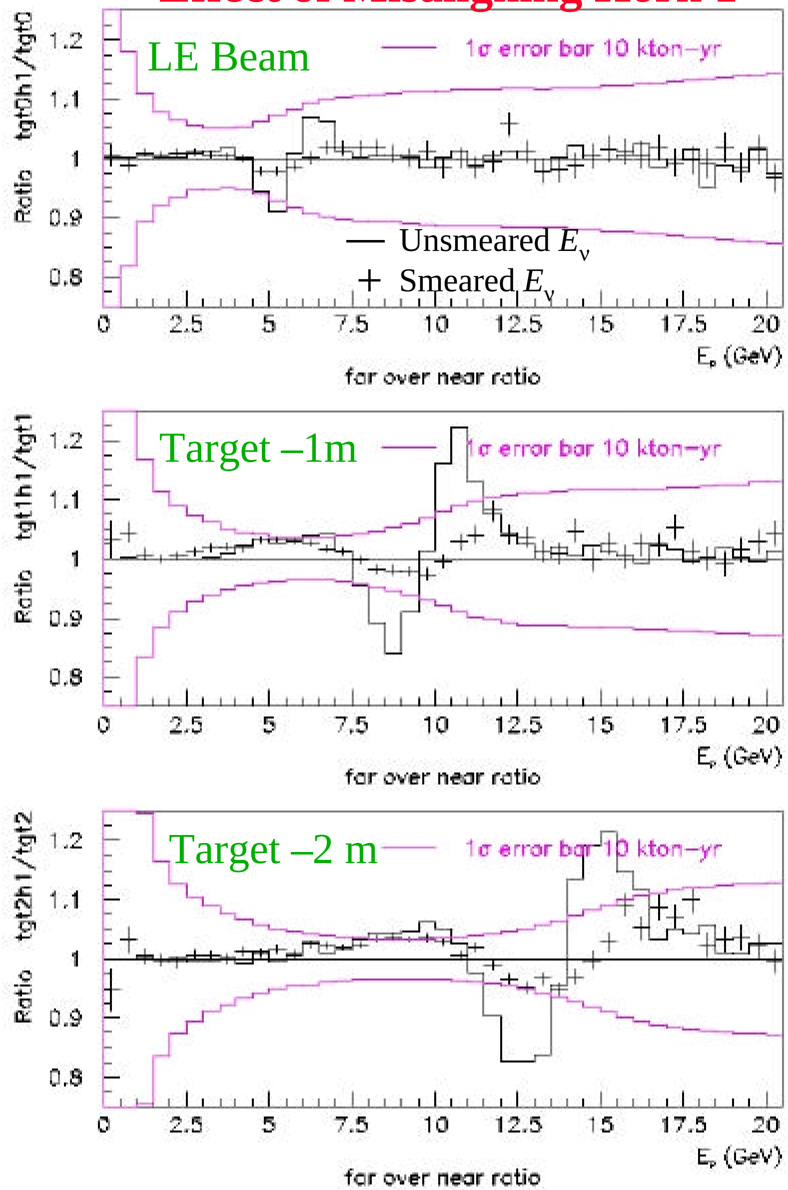


MINOS Near Detector

- Also locates neutrino beam
- Lever arm ~ 1040 m
- Neutrino beam center to ~ 10 cm (1 week's data)
- Align ν beam to 10 μrad
- Requires
  - »Special ME/HE run
  - »1 week's data



Effect of Misaligning Horn 1



Occasional Monitoring

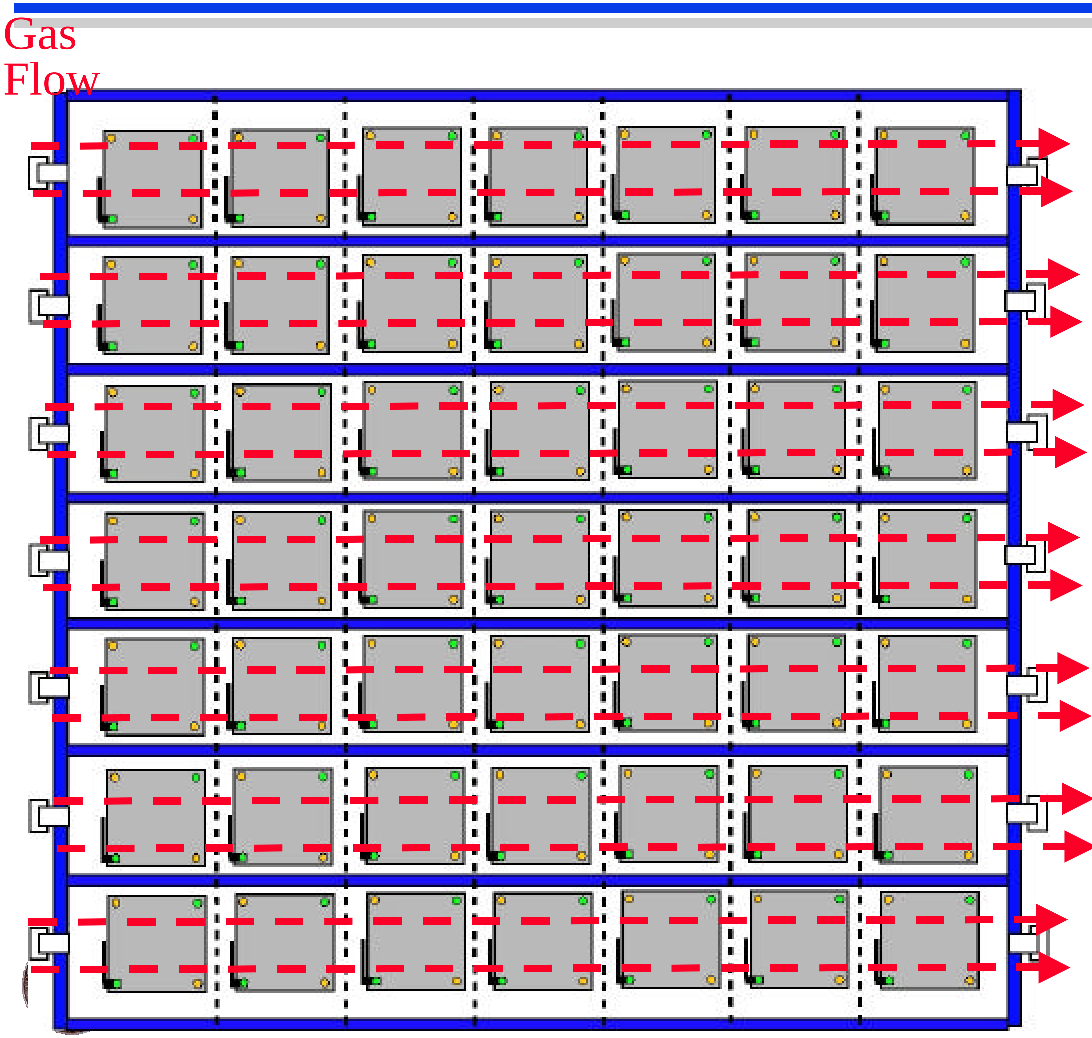
- NuMI low energy beam is *broad*!
  - » μMon acceptance small at DV end
  - » Investigated instrumenting upstream concrete around DV
- Some systematics barely show up
  - »Bad: hard to see in monitors
  - »Good: not as important for near-to-far extrapolation
- Therefore, some monitoring not as important to do spill-to-spill
  - »Periodic monitoring runs sufficient

Parallel Plate Ion Chambers

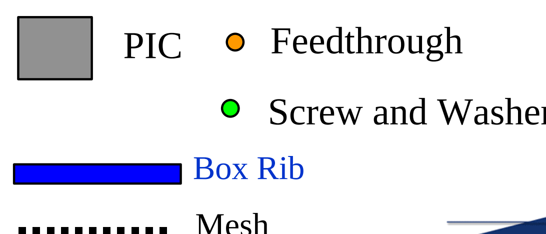
Sense wafer, chamber side

- 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 (HadMon and possibly MuMon?)
- Chamber gap depends on station

Beam's Eye Sketch for DHM

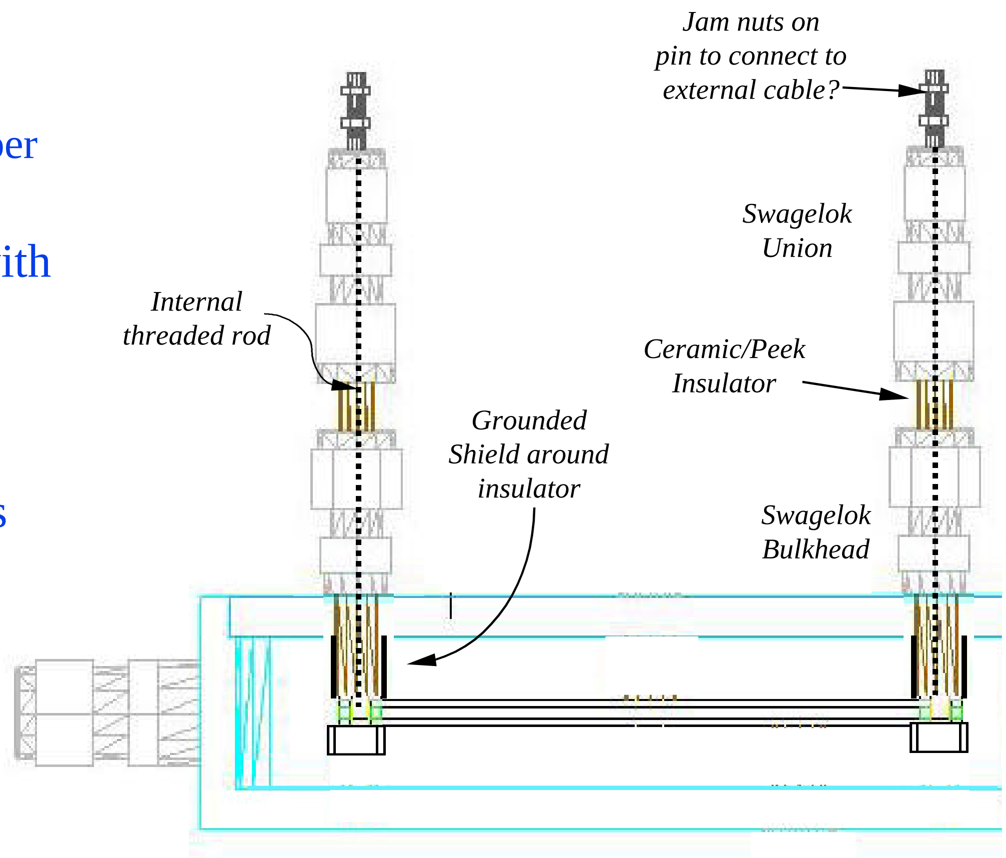


- Single box, multiple gas inlets/outlets.
- DHM ~ 1x1 m^2
- MuMon ~ 2x2 m^2, design still TBD
- Each PPIC has Am^{241} source for calibration signal between spills.
- Weld final lid or Cu/Indium wire seal.



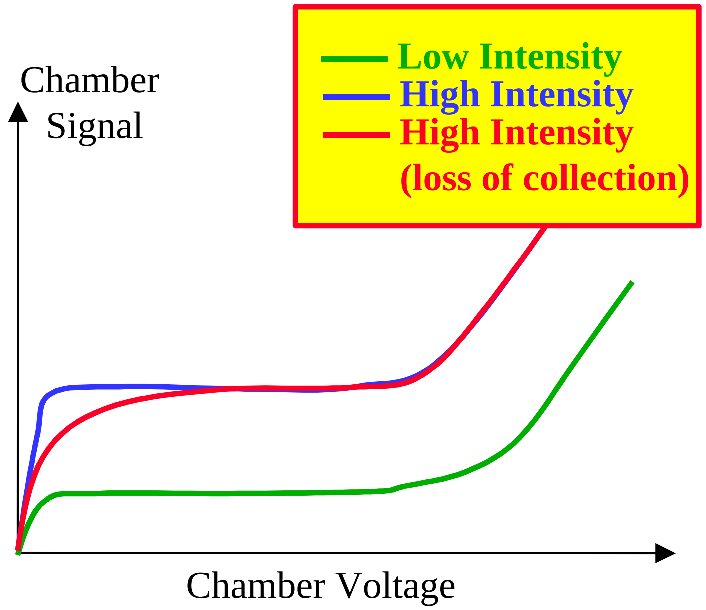
Electrical Feedthroughs

- Combine functions
  - »mechanical support of chamber
  - »electrical feedthrough
- Feedthroughs are shielded with grounded outer jacket
- Move feedthroughs to 'rear'
- Need to shield exteriors of feedthroughs from neighbors (kapton tape and Al foil).
- Design for DHM (MuMon TBD)



Ion Chambers at High Intensity

- Ionization proportional to particle number through gas.
- With large ionization, charges in gas ***screen chamber field***
- Lower field increases drift time, greater potential for ***recombination***.
- Can try to counteract this effect with
  »Larger chamber voltage
  »Smaller chamber gap
  »Different gas (larger *W* ⇒ lower ionization)
  »Gas additive (increase drift velocities – eg CO_2 or alcohol).

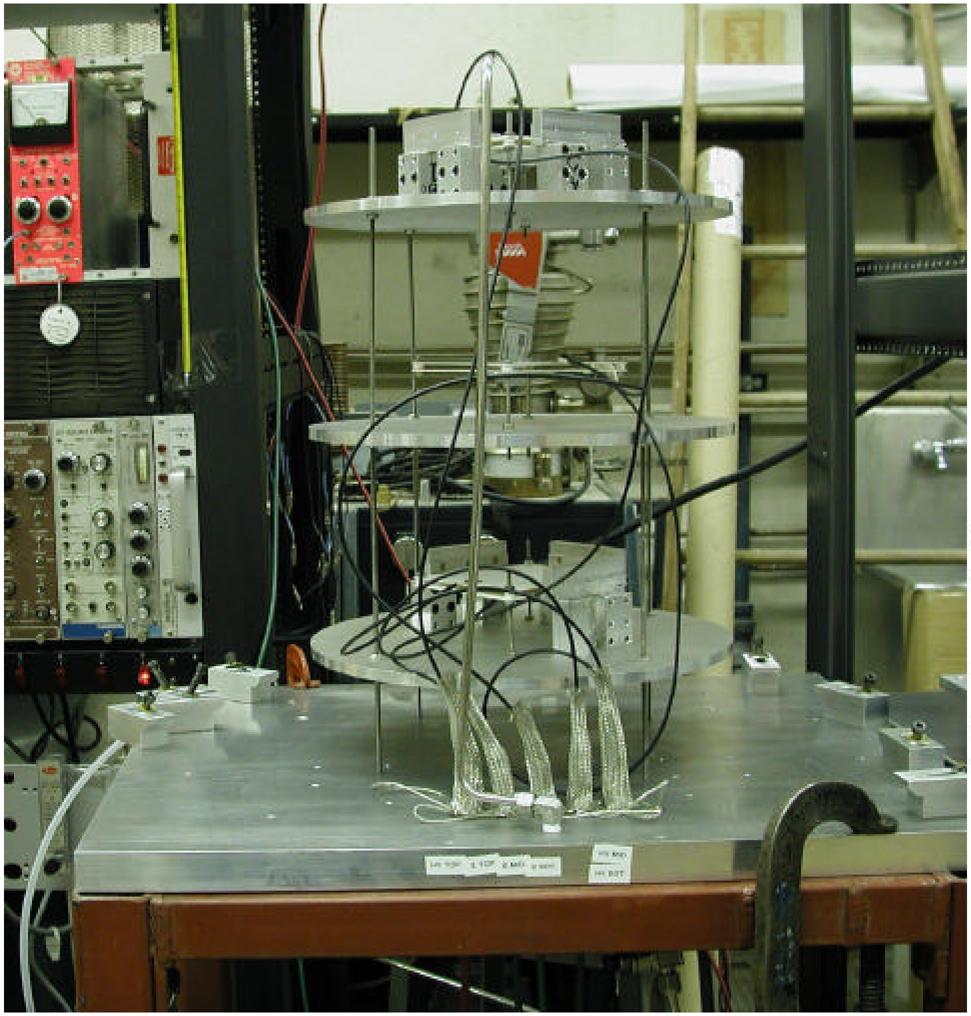


- Large voltage plateau is a helpful indicator of no loss of signal, but not required (just need linear *vs.* intensity at *some* voltage)

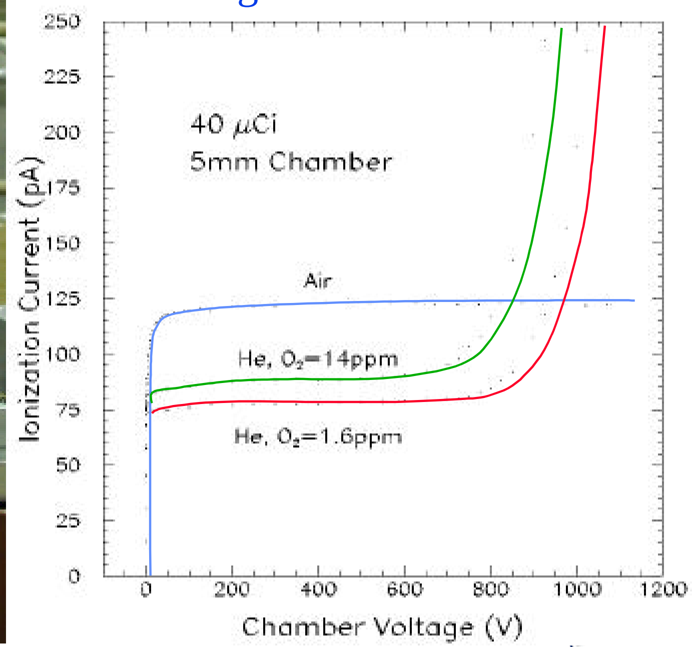
Hardware Tests

- Bench Tests with Alpha Sources
  - »Investigate plateau behavior
  - »Cross Talk
  - »Ion Attachment coefficient
- Fermilab Booster
  - »8 GeV/*c* protons
  - »1.56 μsec spill length, rep rate ~Hz
  - »$10^{10} - 5 \times 10^{12}$ protons per spill
- Brookhaven ATF
  - »40 MeV/*c* electrons
  - »50 psec spill length, rep rate ~ Hz
  - »$10^{7} - 10^{9}$ e^{-} per spill
- Neutron Irradiation
  - »50 Ci Pu-Be source ($E_n \sim 3 - 12$ MeV)
  - »1 MW fission reactor (10^{10} fast *n*'s/sec, 10^{13}/sec total)

Bench Tests



- 3 chambers, Am^{241} source (E_a =5.3 MeV)
- Setup useful to study
  - »Chamber plateau
  - »Electrostatic screening
  - »Cross talk
  - »Charge recombination



Ion Recombination

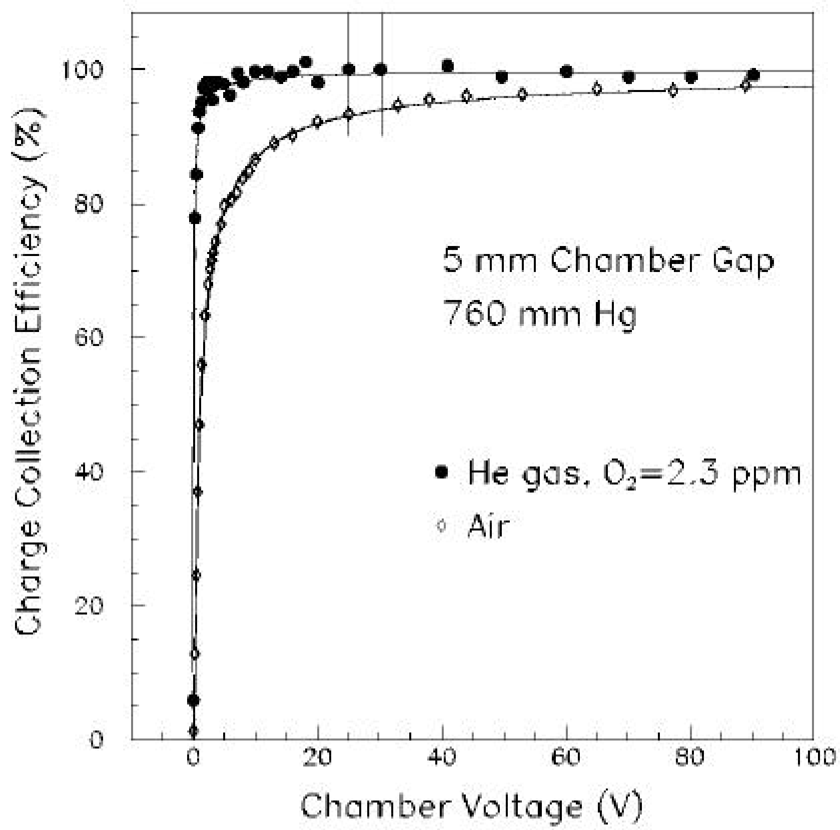
- Required to understand charge loss at high beam intensity
- Assume ion loss in time:

$$\frac{dn}{dt} \approx -an \Rightarrow n(t) = n_0 e^{-at}$$

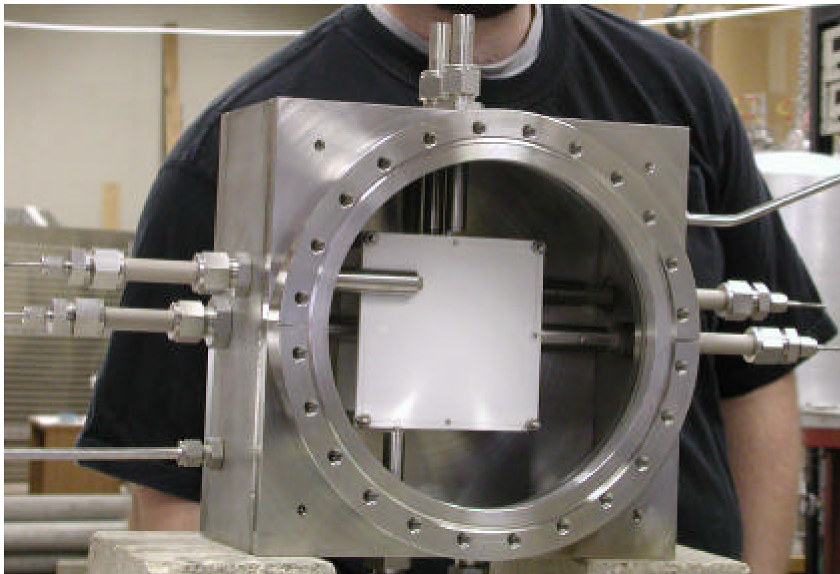
- Assume ion drift $v_d \sim K(E/p)^{\mathrm{m}}$ so that $t \sim (d/2)/v_d$.

$$\frac{n(t)}{n_0} = \exp\left(\frac{-ad^{m+1}p^m}{2KV^m}\right)$$

- Investigating scaling with
  - »Chamber voltage V
  - »Pressure p
  - »Chamber gas gap d
  - »Impurity level (O_2) in He gas

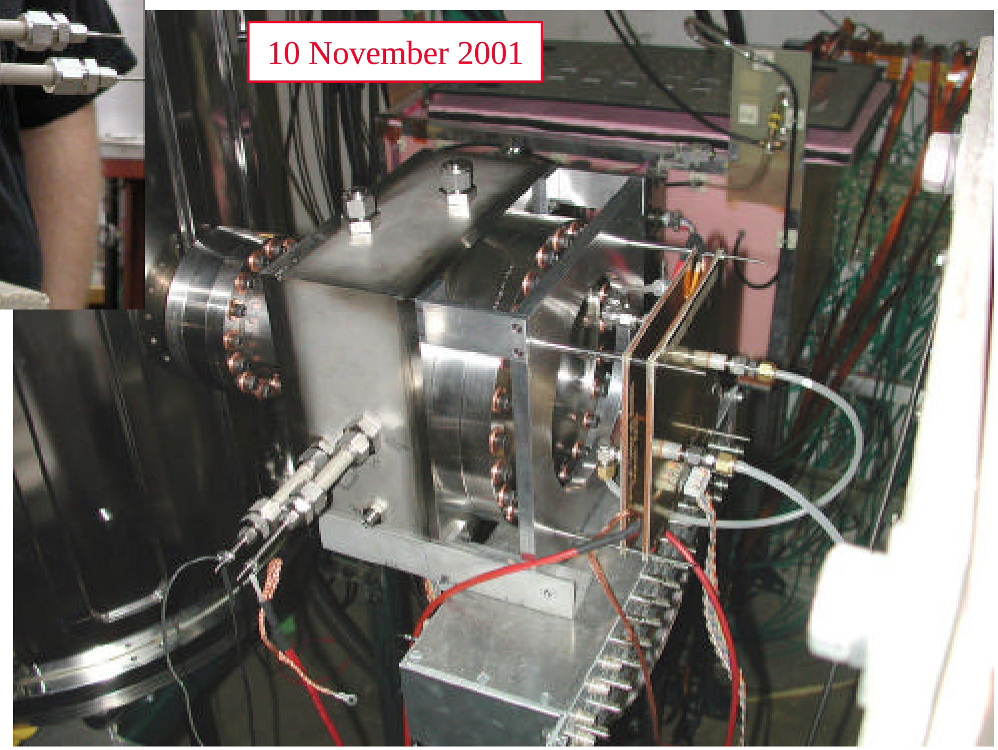


Booster Beam Test



Fermilab Booster Accelerator

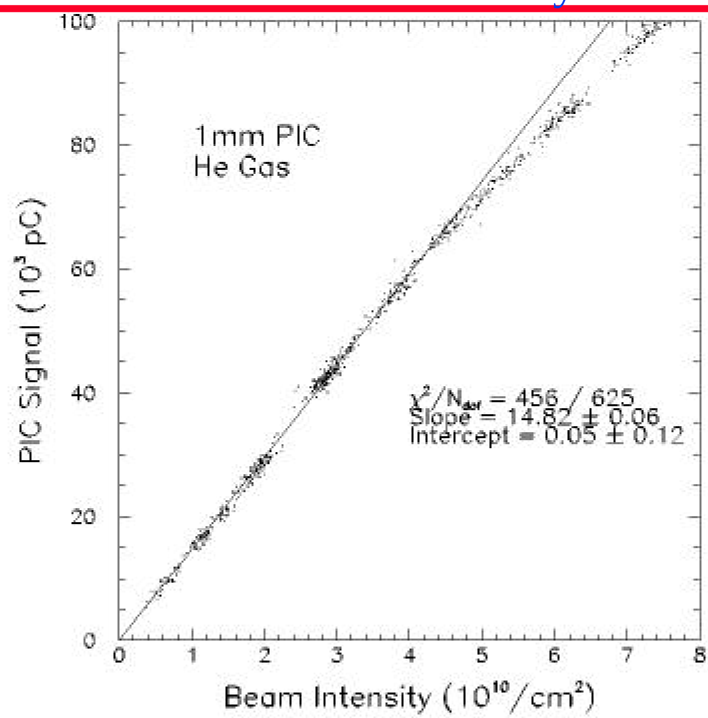
8 GeV proton beam
5×10^9 - 5×10^{12} protons/spill
5 cm^2 beam spot size

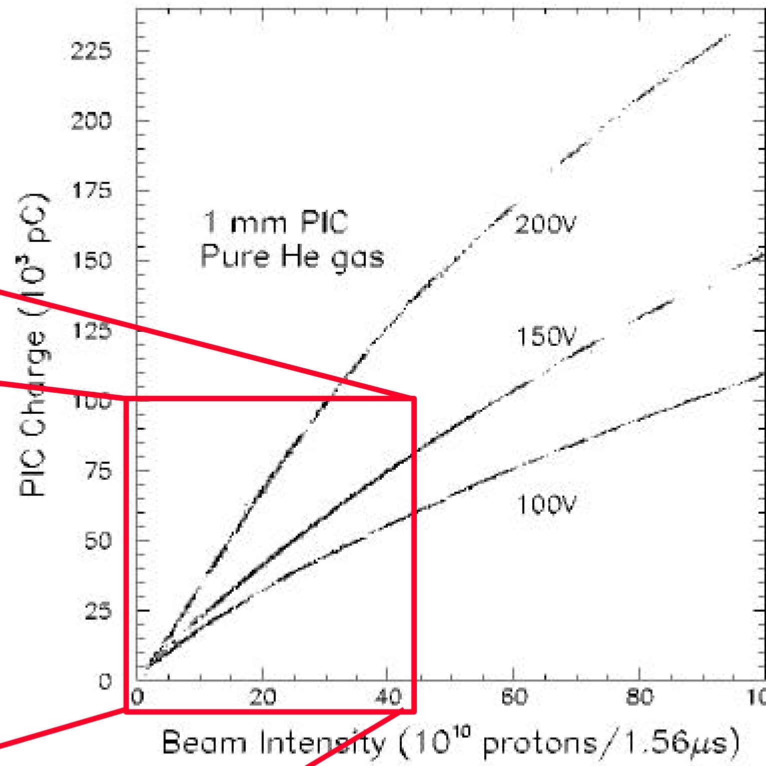


- Two chambers tested (1mm & 2mm gas gap)
- 2 PCB segmented ion chambers for beam profile.
- Toroid for beam intensity

Range of Linear Operation?

- Intensity scans at 3 chamber voltages
- See onset of charge loss at 4×10^{10} protons/cm^2/spill.
- Manifestation of recombination as chamber field screened by ionization.

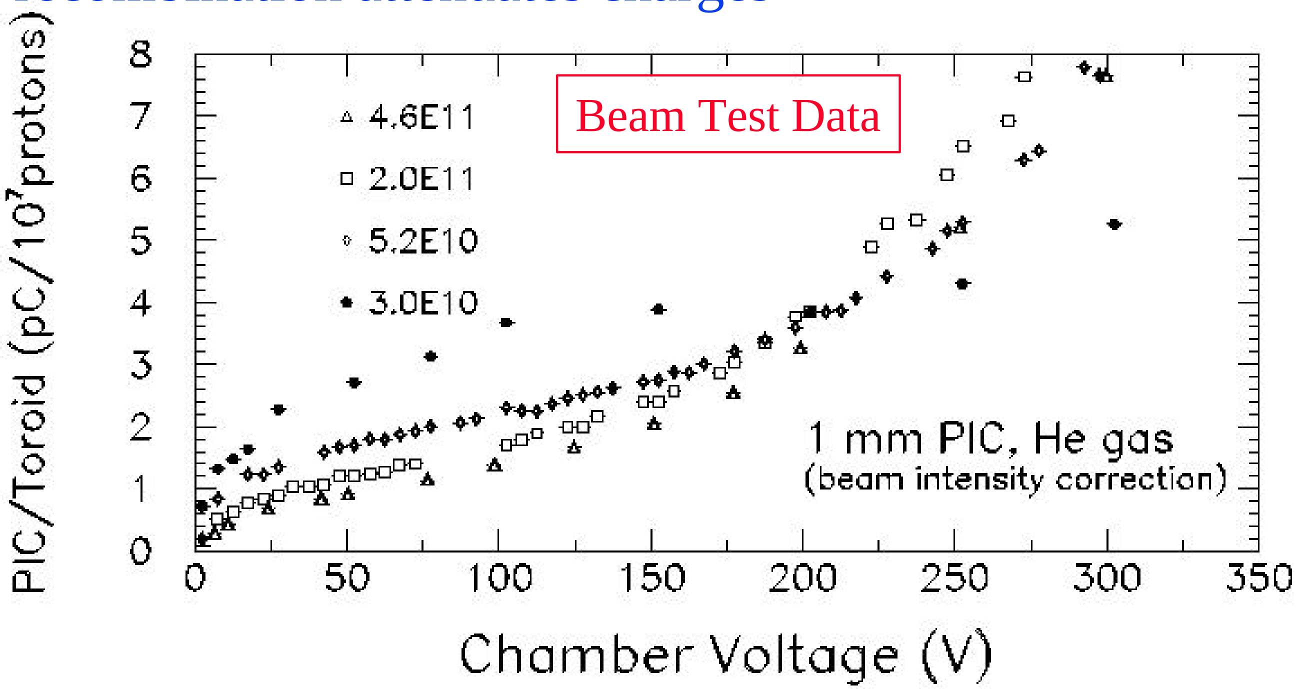




- Left plot is protons/area, as measured by beam chambers

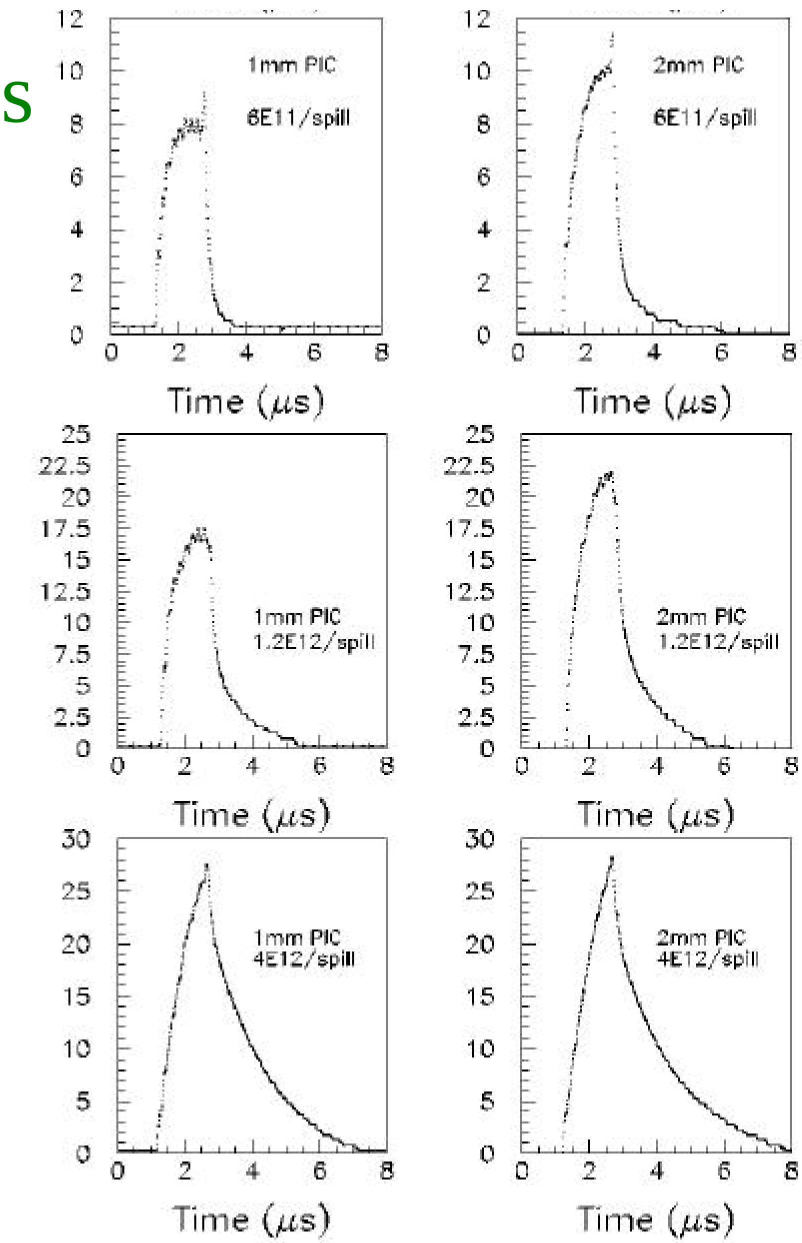
Effective Screening of Field

- Ionization density increases ⇒ charges screen chamber field.
- Apply larger bias, overcome reduced field before recombination attenuates charges

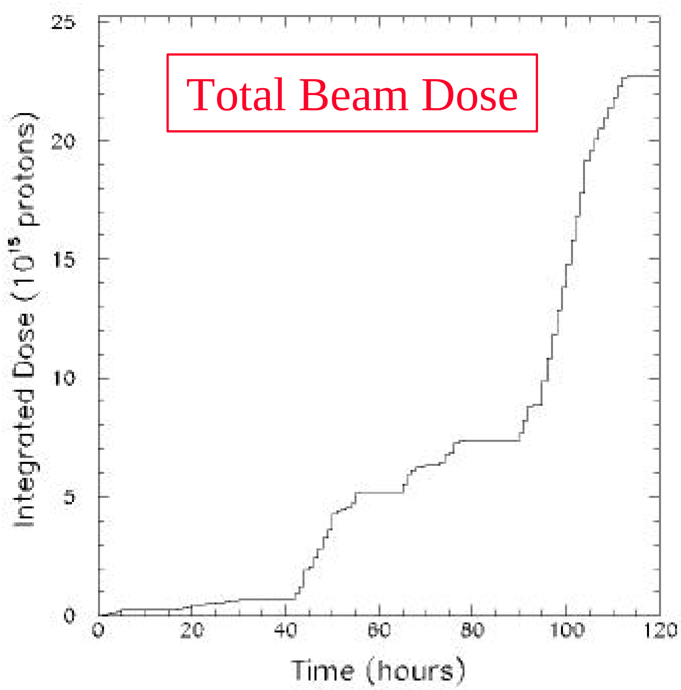


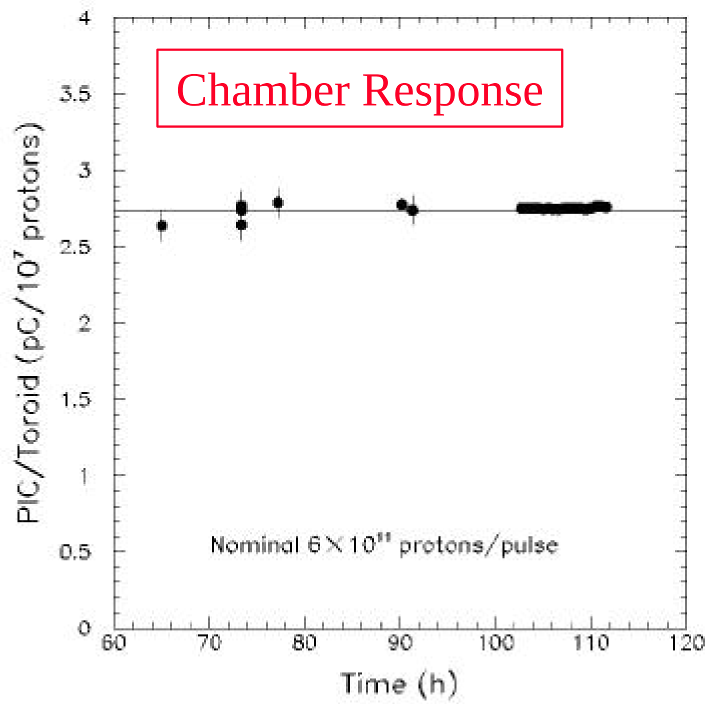
Slowing Charges

- Scope traces of chamber signal.
- Directly see longer drift time
- Develop finite element model to describe charge mobility,
  - »field screening,
  - »charge recombination



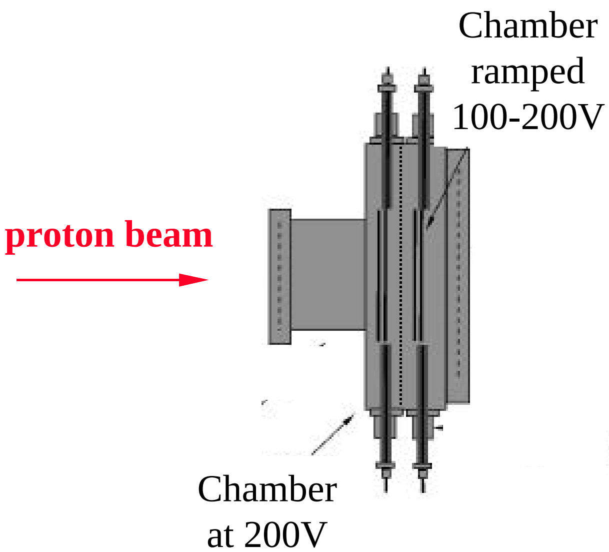
Aging Effects?



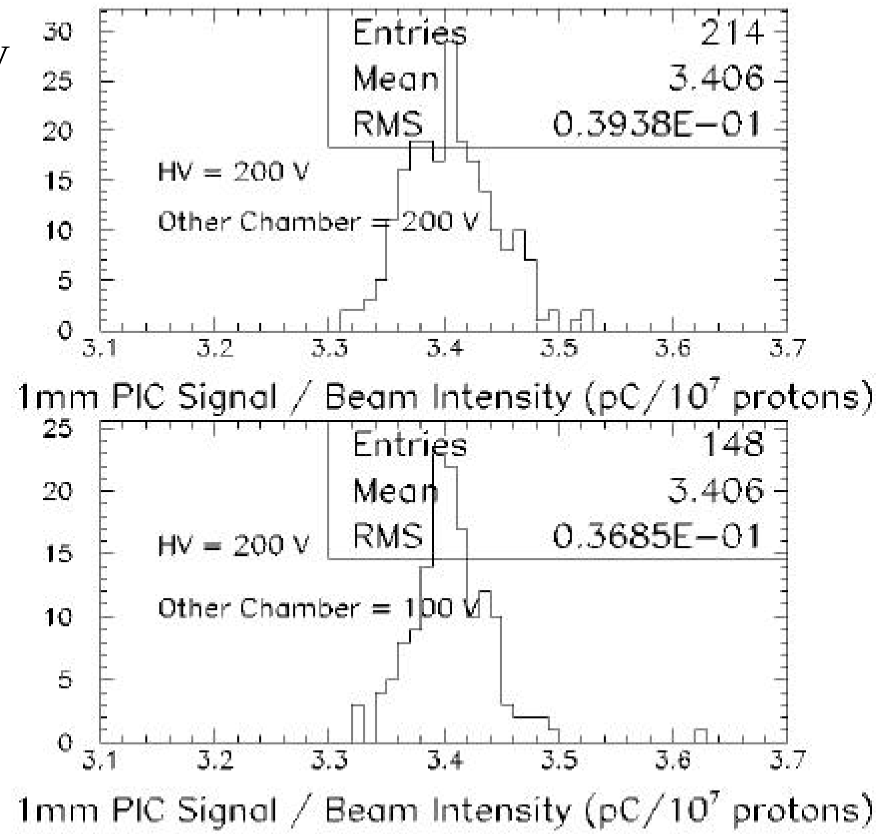


- No effect seen at the 1-2% level.
- Actual dose ~ 20-30% higher

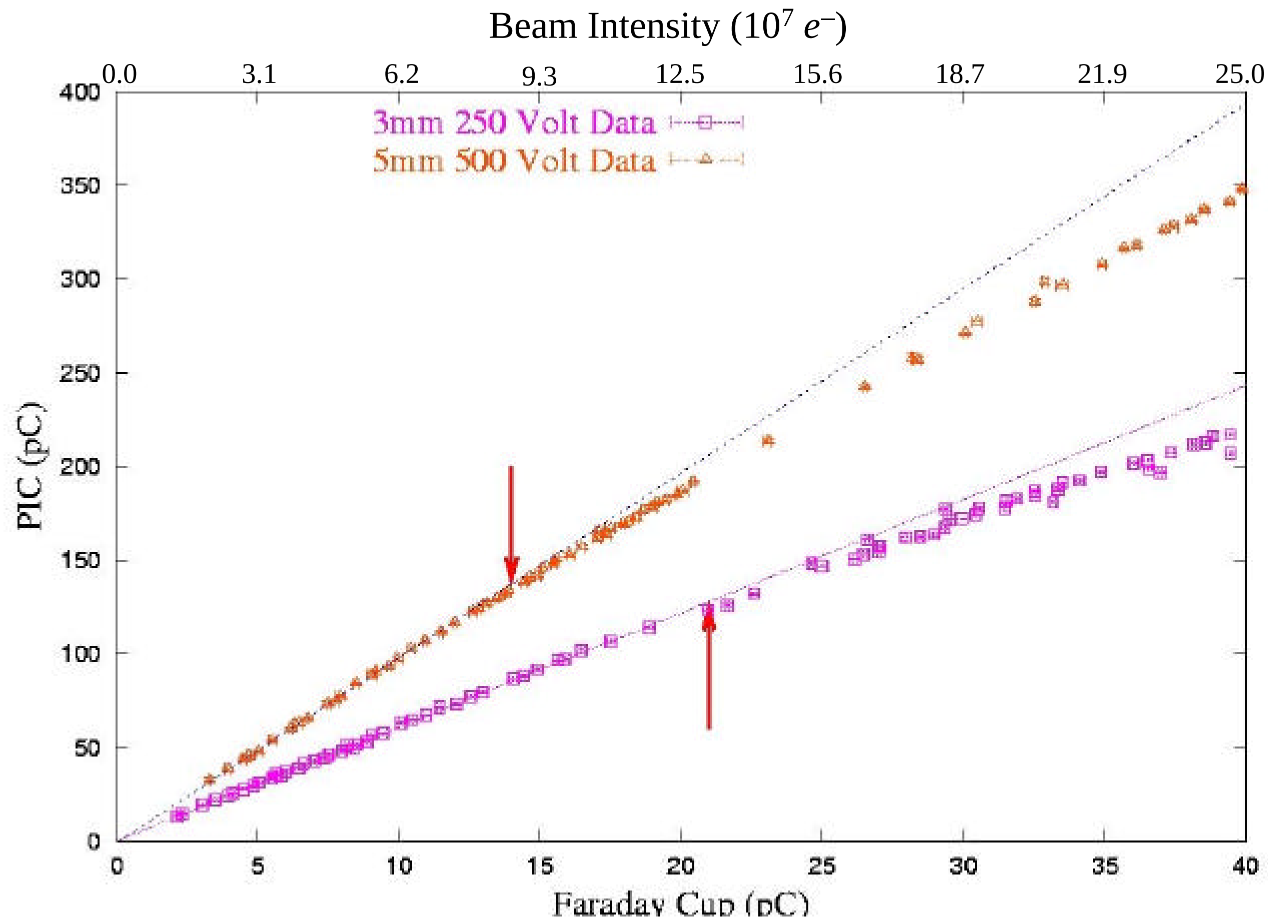
Signal Cross Talk?



- Feedthroughs + mesh screen, adequately shield signals



Tests at Brookhaven ATF



Explore beam intensity range relevant for μMon's

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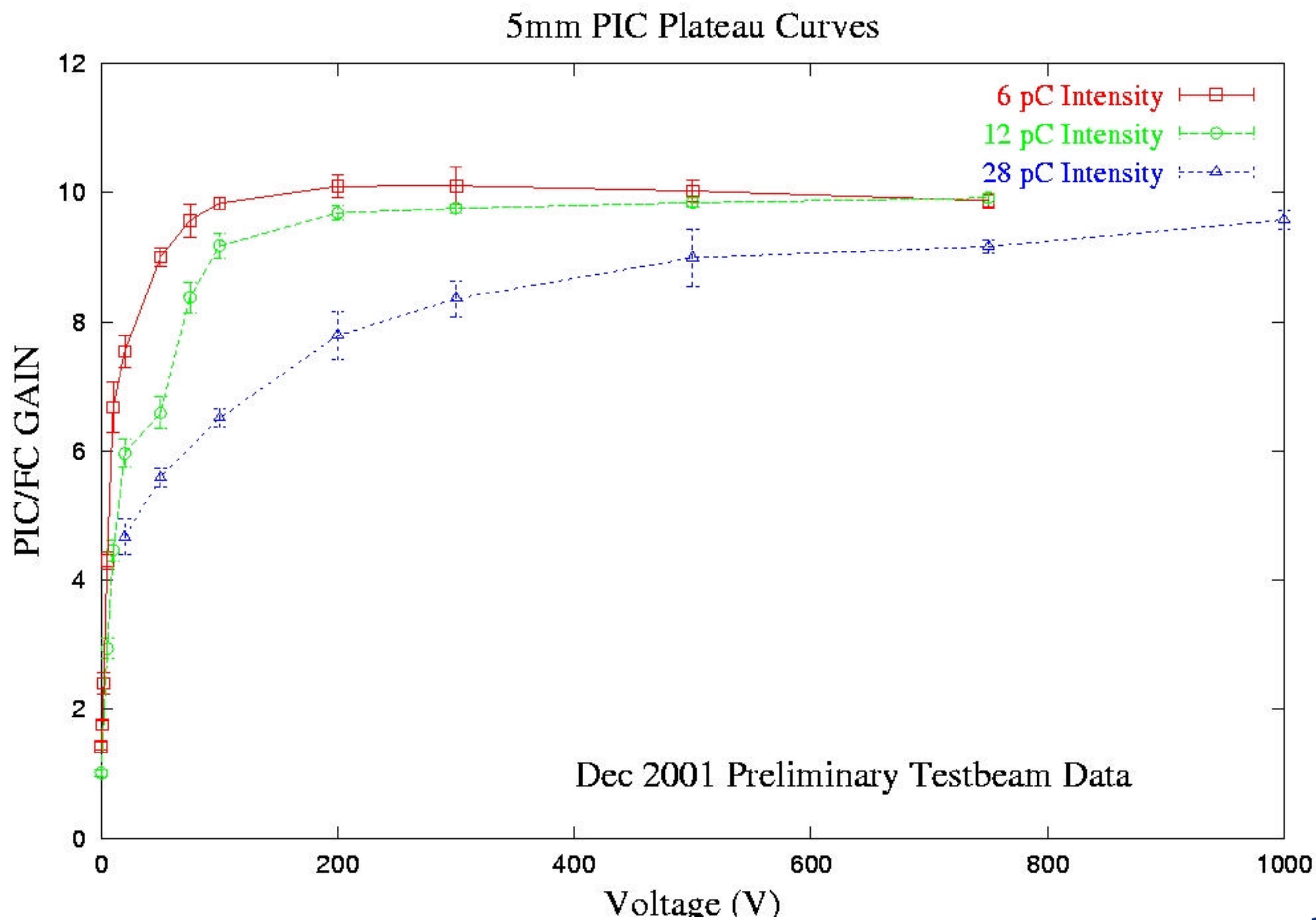
ATF Plateau Curves



Conclusions

- Monitoring system
  - »Rate capabilities spill-to-spill
  - »Detailed measurements in periodic dedicated runs
- Chambers will operate linearly at NuMI intensities
- Much study to do on
  - »Radiation hardness of materials, cables
  - »Coalescing beam test data
  - »Chambers already losing charge, compensated by gain?
- Engineering design of system being completed.
- Thanks to Konrad and all for a great workshop!