The Neutrino Beamline for the MINOS experiment

APS 2006, Dallas, April 21-25, 2006

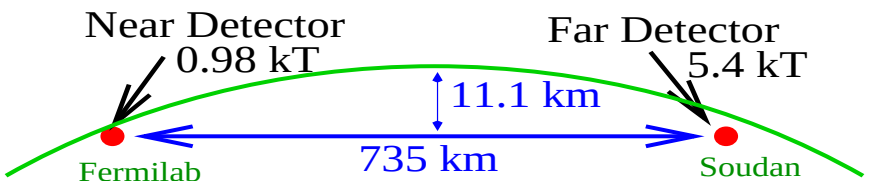
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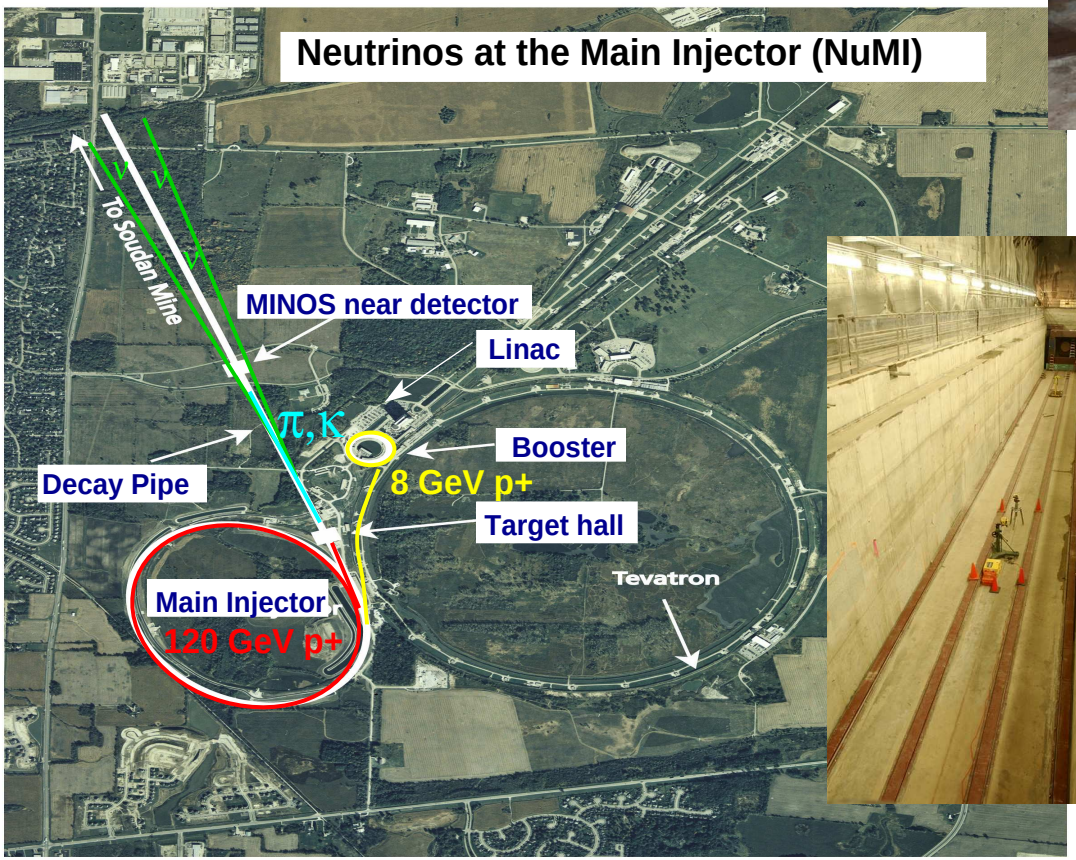
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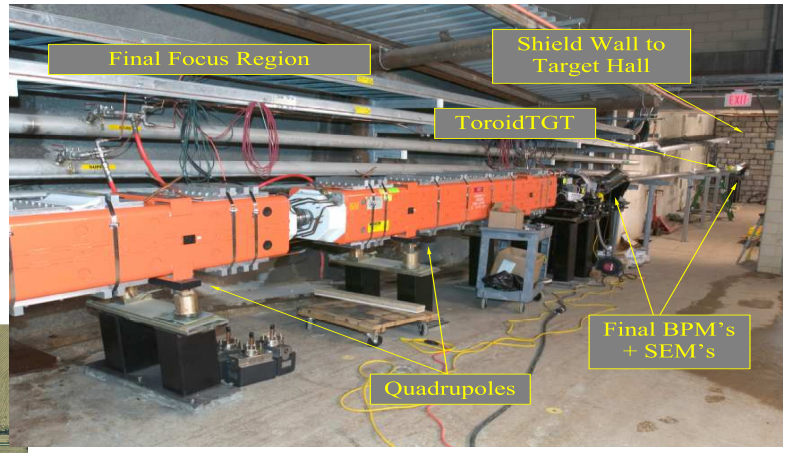


NuMI/MINOS Concept



Fermi Natl. Lab., IL **Soudan Underground Lab, MN**





Pretarget region

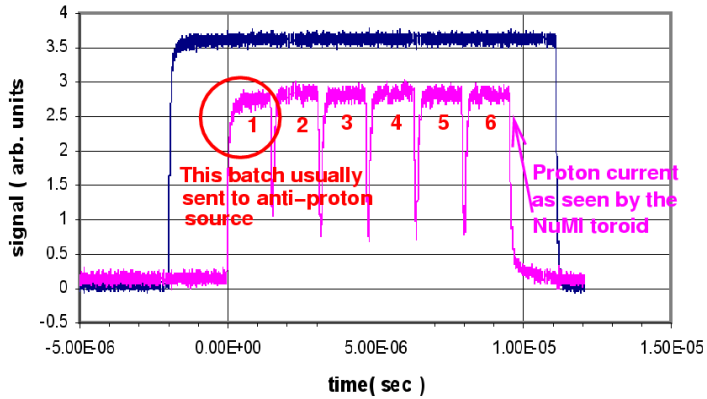
Target hall



Decay pipe

NuMI Specifications

NuMI Beamline specs:



- **Up to 4×10^{13} 120 GeV/c protons every 1.9 secs**

  $\Rightarrow$ 0.4 MW average beam power

- **Main injector can accept up to 6 booster batches/cycle. 5 to 6 batches sent to NuMI in a single turn extraction (10 μ sec).**

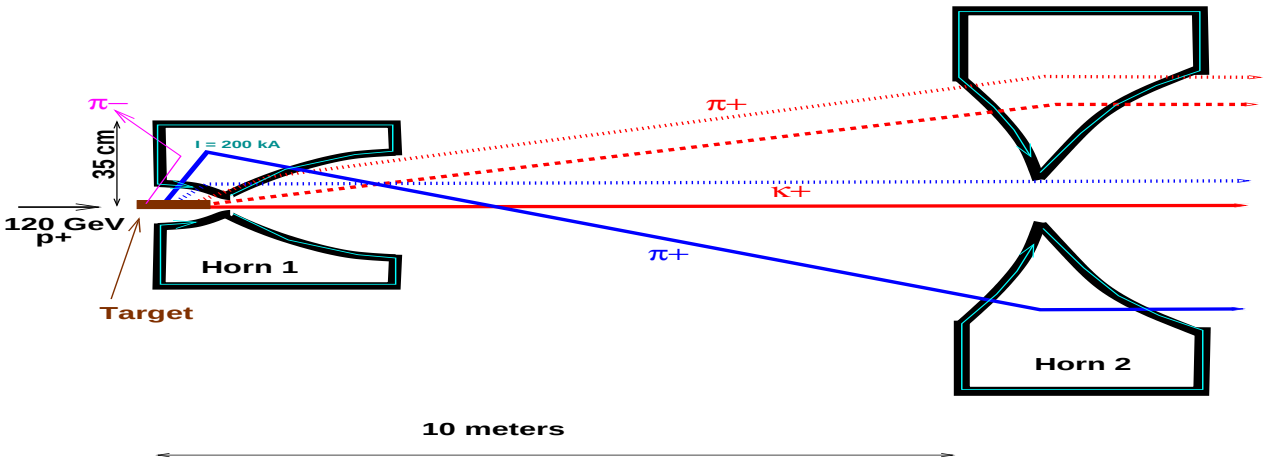
- **Losses not to exceed 0.01 watt/meter = very stable beam**

MINOS expt specs:

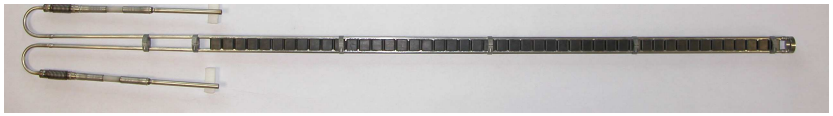
- **Minimize re-absorption of secondary hadrons in target = narrow target $\perp$ to beam (w=6.4mm) $\Rightarrow$ round beam profile with RMS width ~ 1mm**

- **Beam position stability on target ± 0.25 mm and angular stability $\sim 60\mu$ radians.**

Target Region Components



NuMI Target



6.4 x 15 mm^2 graphite segments.

1m long = 1.9 interaction lengths.

$\mathcal{O}(10)$ KW beam power at 1 mm beam width.

Water cooled.



Horn 1

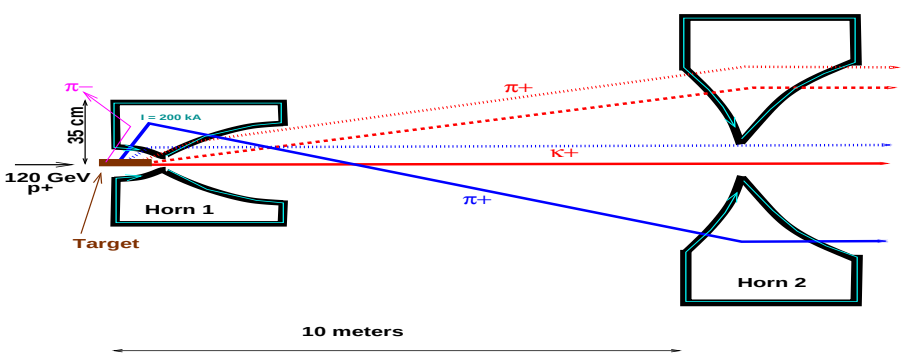


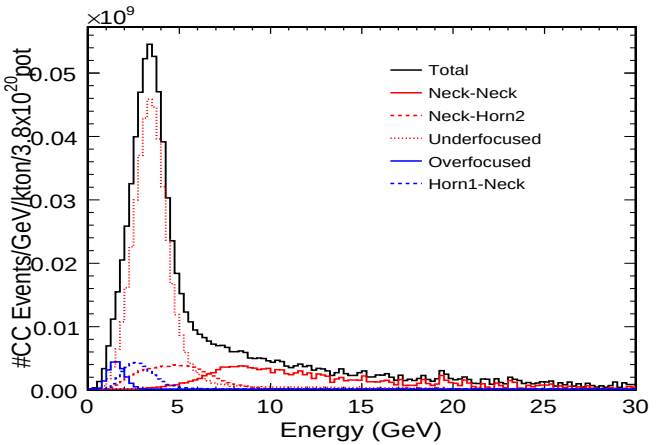
Horn 2

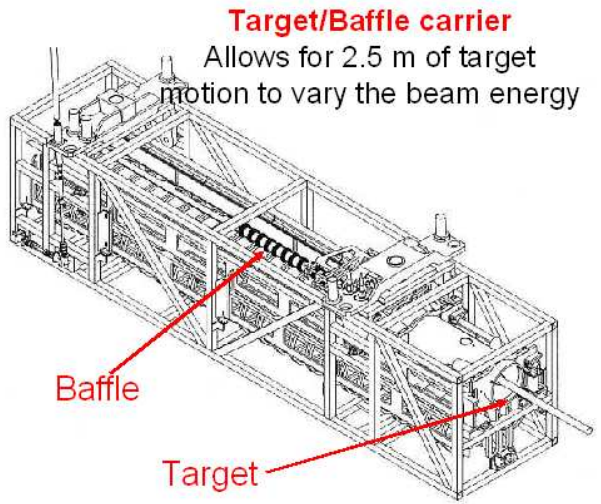
Parabolic magnetic lens.

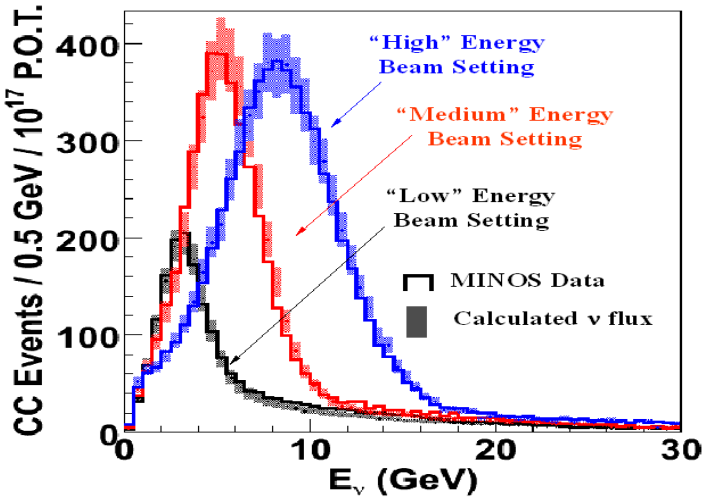
3T at 200 kA

NuMI Beam Spectrum







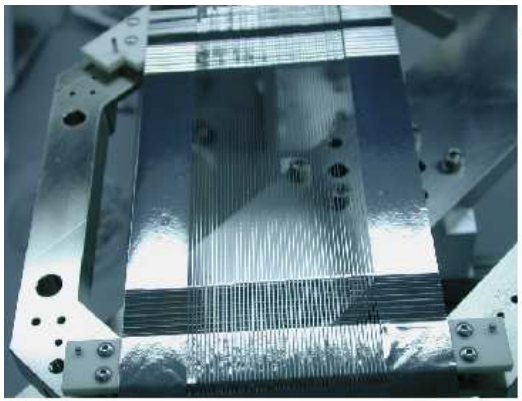


Move target w.r.t to Horn 1: -10cm (LE), -100cm (ME), -250cm (HE)

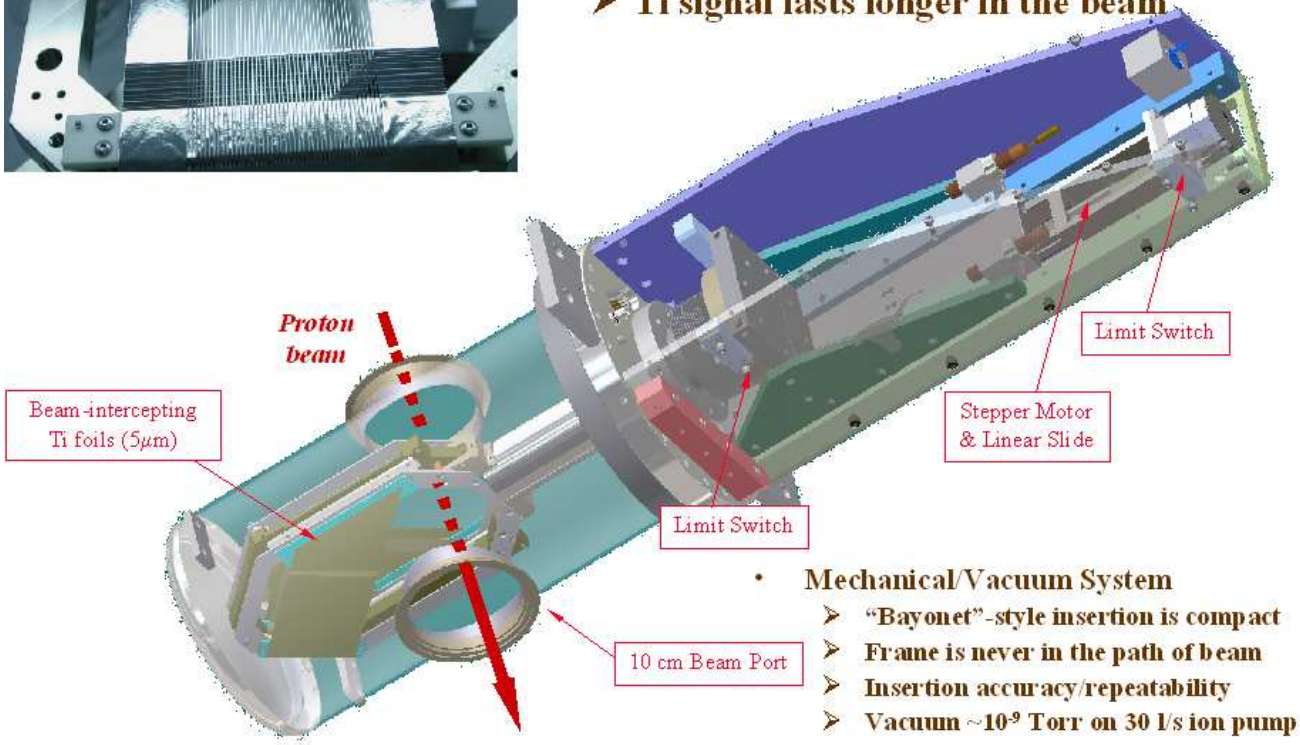
Beam is 92% ν_μ, 6.5% $\bar{\nu}_\mu$, 1.5% $\nu_e + \bar{\nu}_e$



Measuring the Beam Profile



- **Foil Secondary Emission Monitors**
  - **Beam profile + halo measurement**
  - **Very low mass (5 μm Ti)**
  - **Reduced Beam Heating problems**
  - **Ti signal lasts longer in the beam**



- **Mechanical/Vacuum System**
  - **"Bayonet"-style insertion is compact**
  - **Frame is never in the path of beam**
  - **Insertion accuracy/repeatability**
  - **Vacuum ~10^{-9} Torr on 30 l/s ion pump**

10 SEMS deployed along 360 m of beamline



Measuring the Beam Position

Characteristics of NuMI Beam Position Monitors:

- **Software algorithm to search 400 μsec to find the beam.**
- **NuMI bunches come in 6 batches from booster. Position is measured batch by batch.**
- **Linear over 15-20 mm. 50 μm accuracy in pretarget.**
- **11 vertical and 13 horizontal measurements over 360m.**

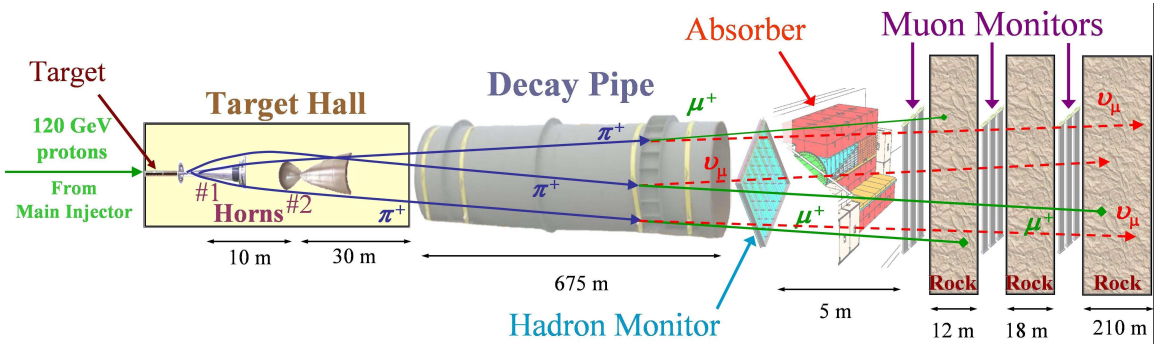


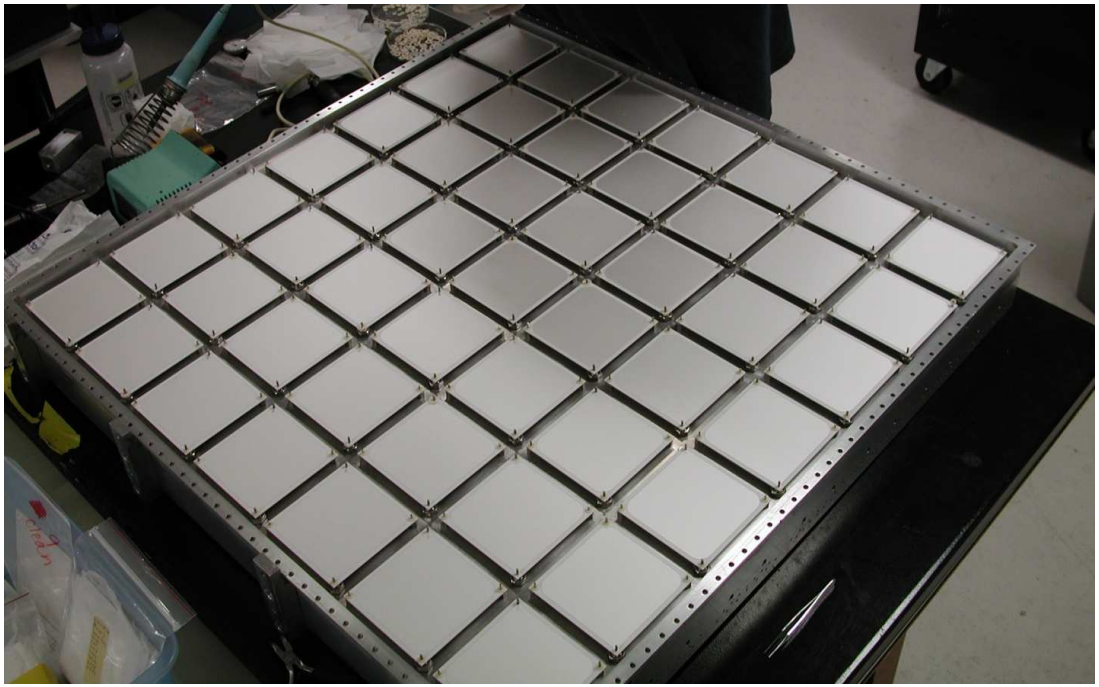


Feedback from BPMs used to auto-steer the beam to target center

Muon and Hadron monitors

Parallel-plate ionization chambers are used to monitor hadron and muon content of secondary beam.

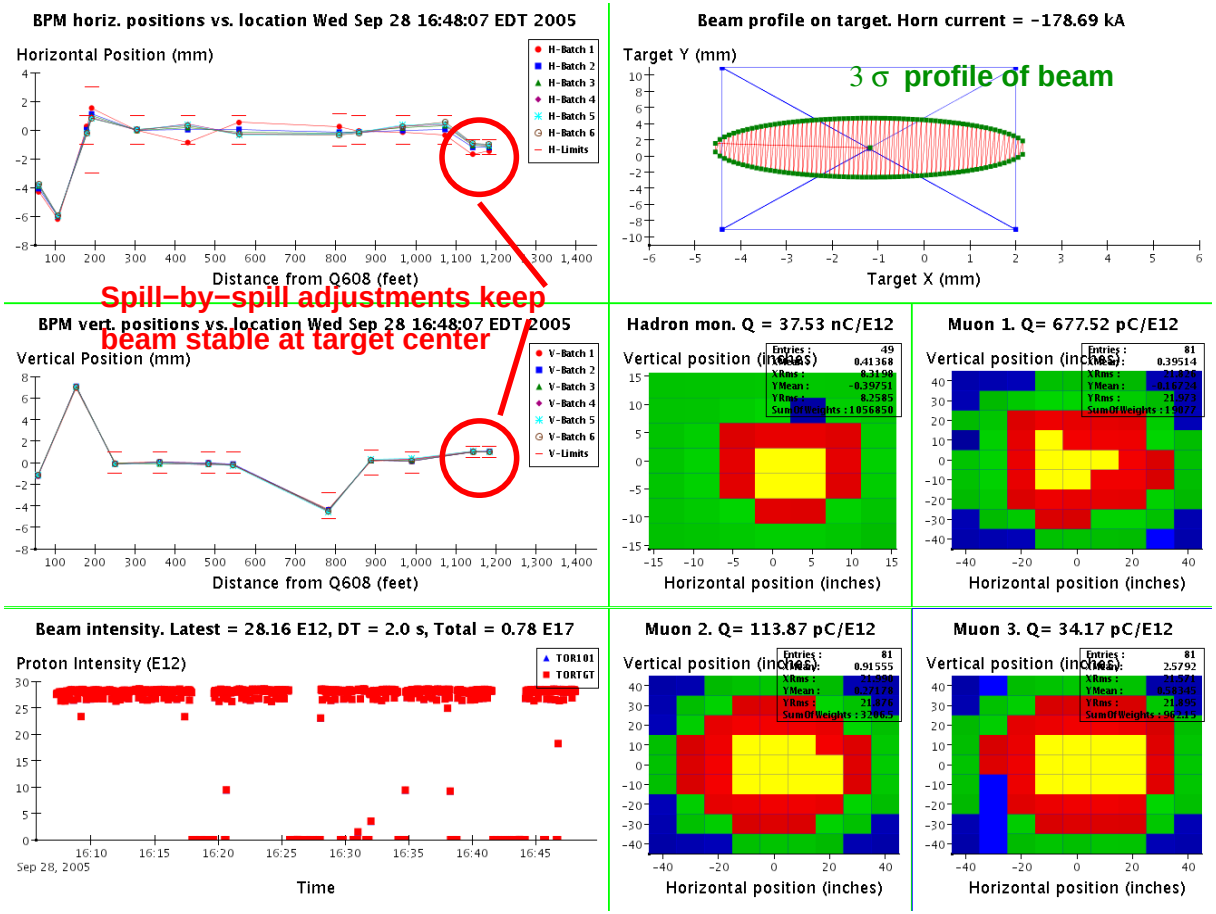






Beam monitoring/control

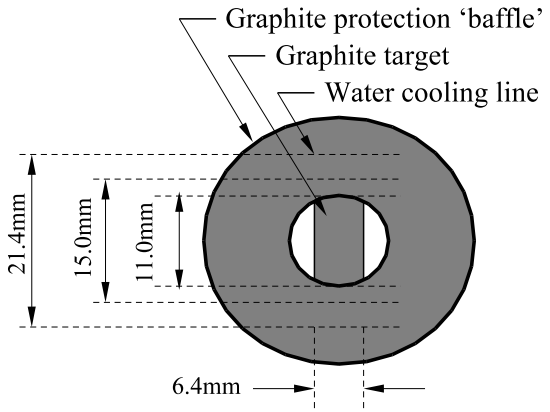
Automated beam steering using feedback from 10-H and 9-V BPMs every spill. Magnet trims adjusted as needed to keep beam trajectory stable.



Time-stamped spill-by-spill beam information available offline for MINOS.

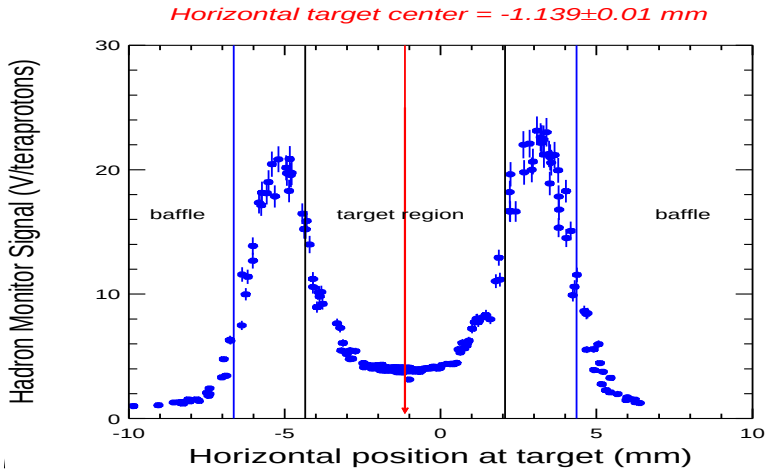
Target Alignment with Beam

Use low intensity beam and scan across target:

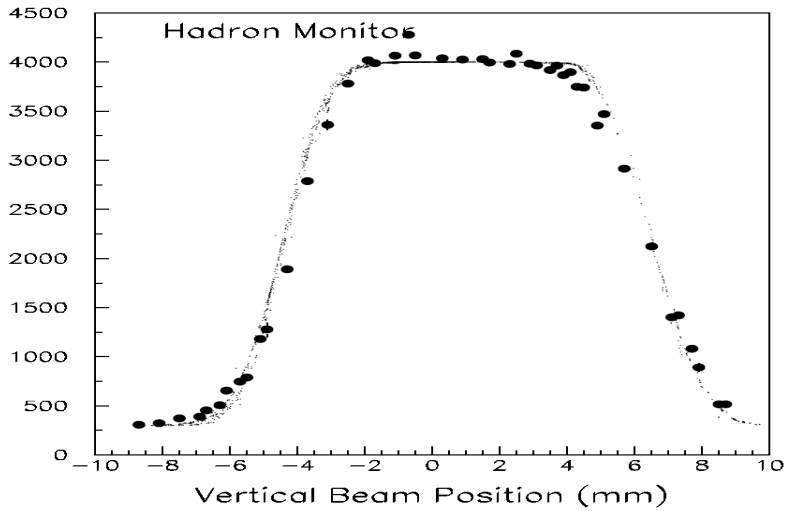


Maximum P.H. when beam passes between target and graphite protection baffle.

In-situ verification of beamline alignment with target hall components.

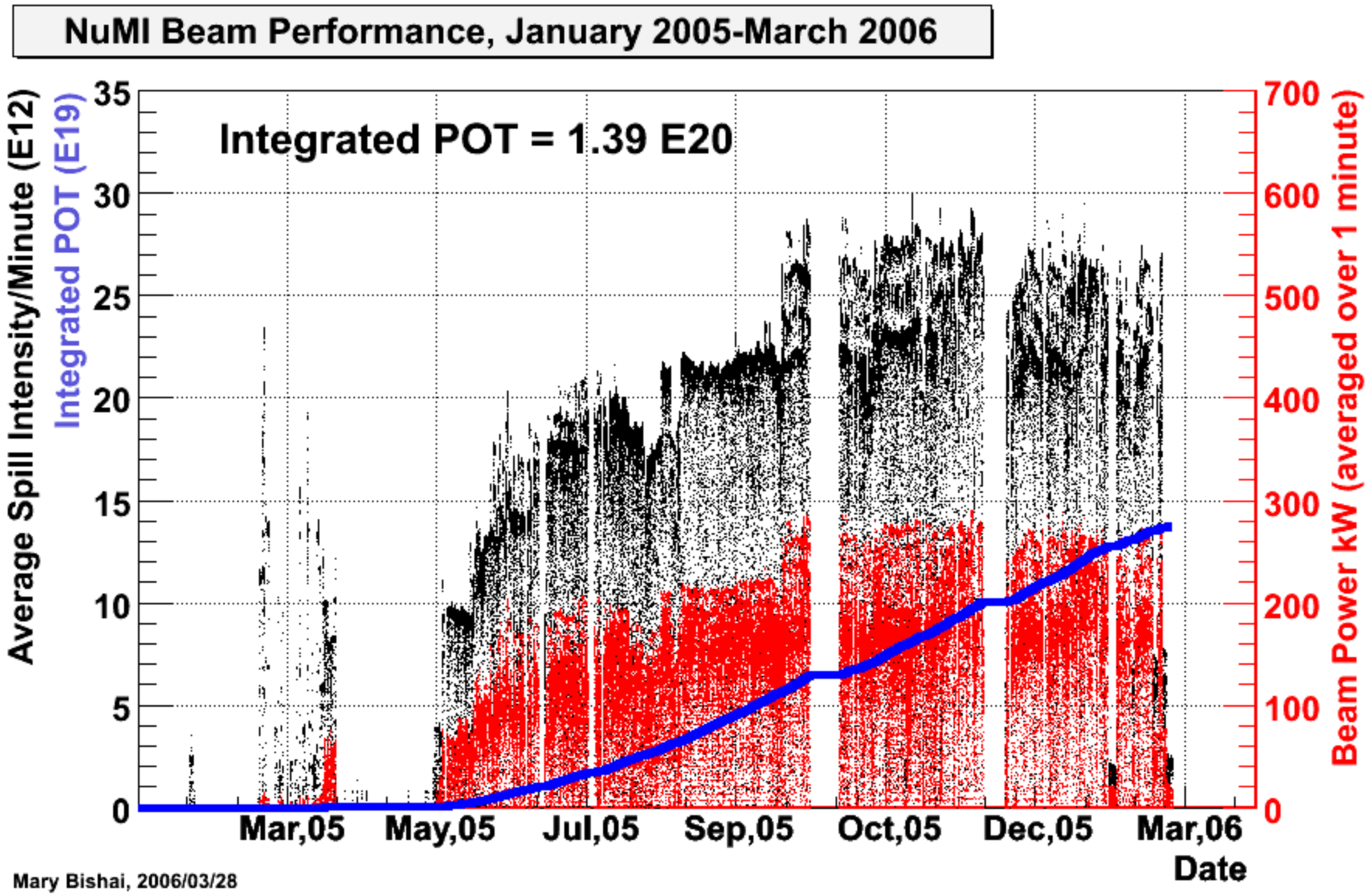


Horizontal scan (mm)

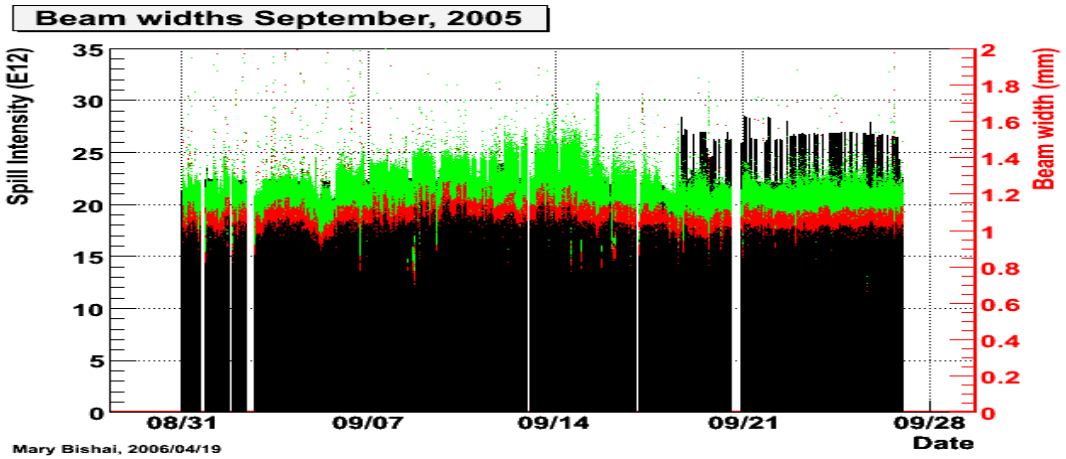


Vertical scan (mm)

Beam Performance - Power



Beam Performance - Stability



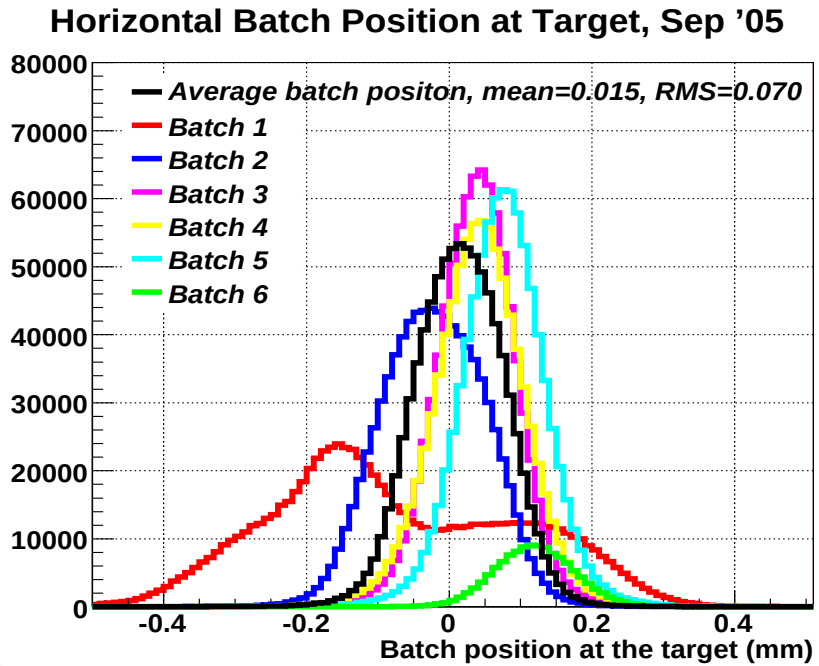
Beam width stable with RMS:

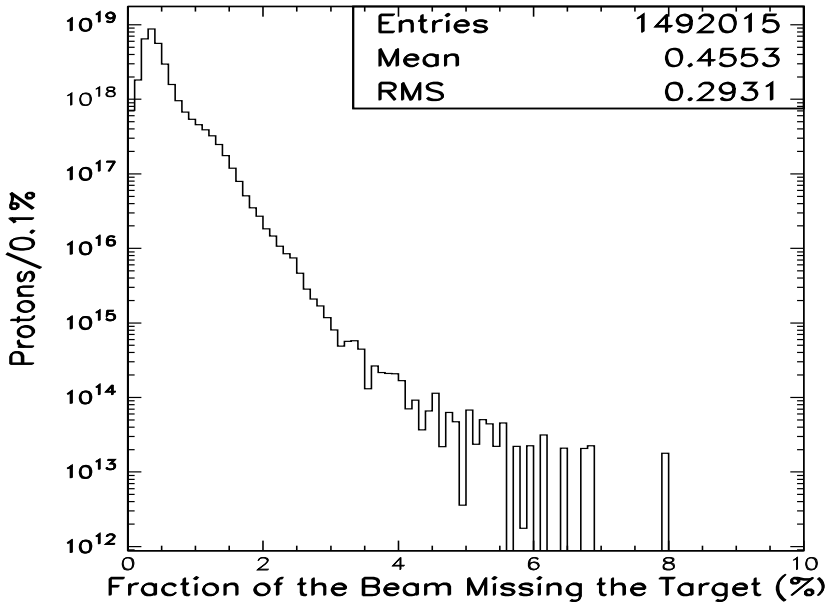
~ 1.1 mm horizontal

~ 1.25 mm vertical

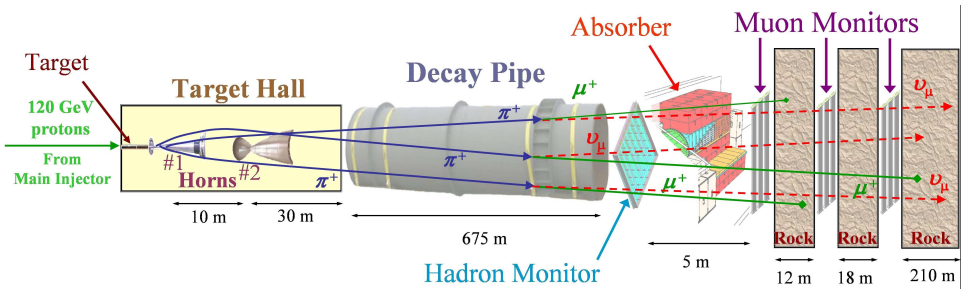
Beam position at target stable to ~ 0.1mm

$\geq$ 99.5% of beam is on target

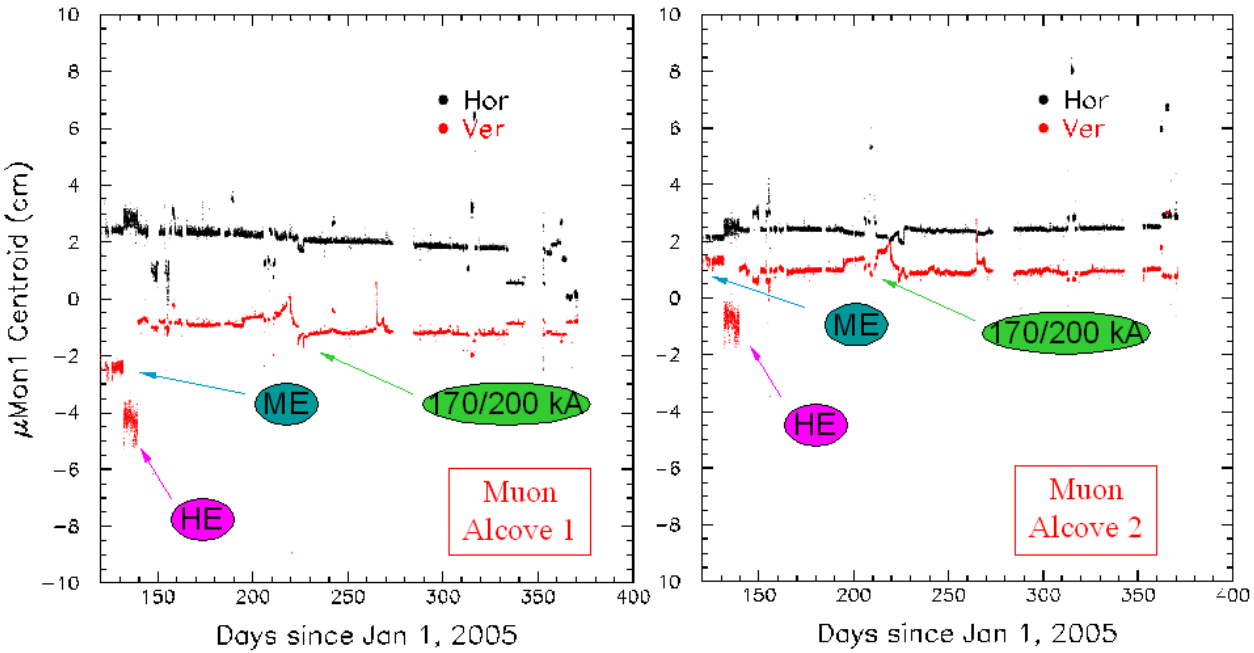




Beam Performance - Targeting



Shift in muon centroid position by ± 5 cm $\Rightarrow$ beam shift by $\pm 60\mu$rad.

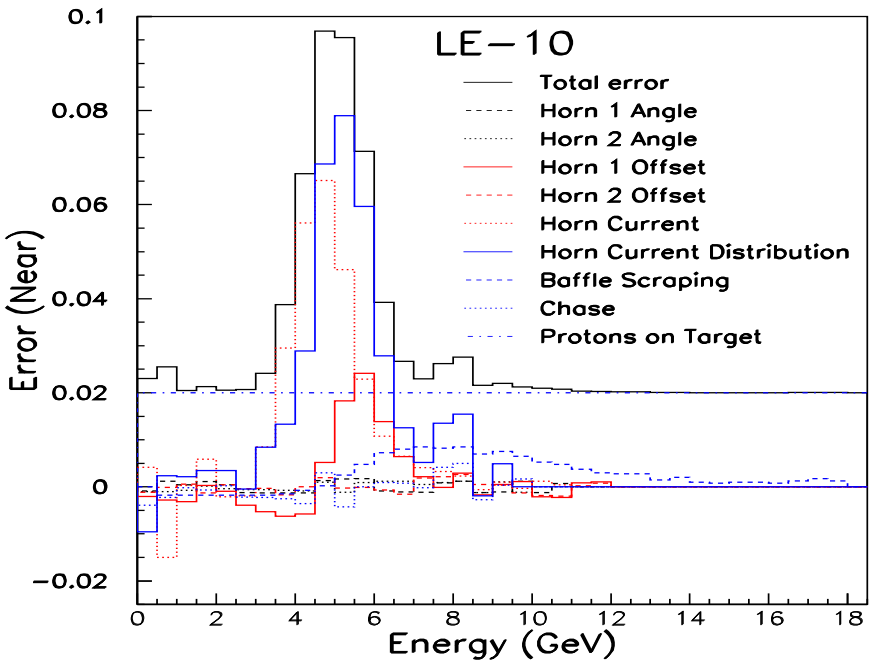


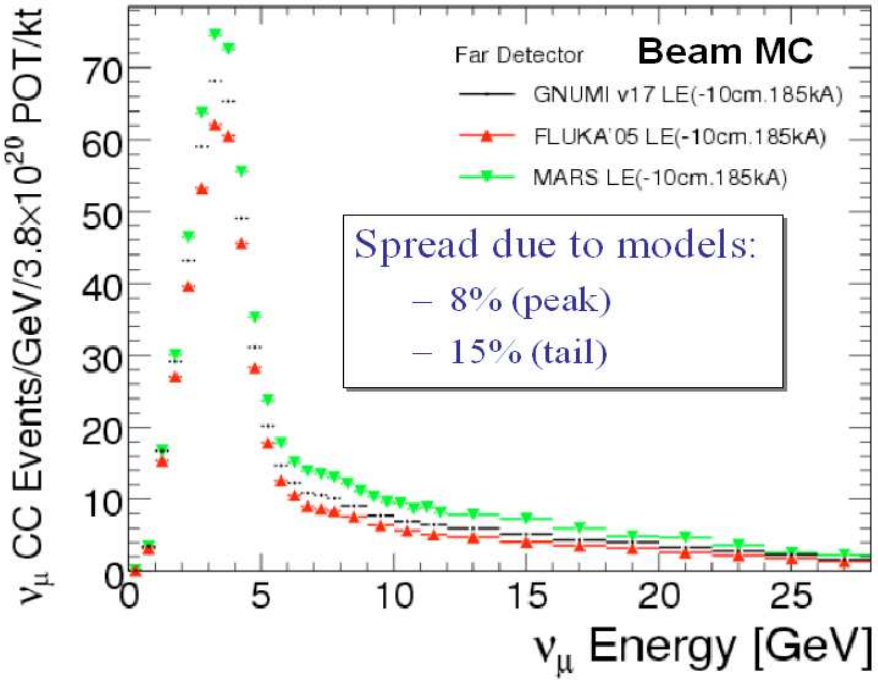
Targeting stability to $< 60\mu$rad maintained over run period.

Near Det. Flux uncertainties

Absolute p-beam intensity is known to better than 2%.

Dominant non-had. model uncertainty is from modeling skin-depth effect in horns. Overall beam performance uncertainties are $< 3\%$ in region of maximum sensitivity





Performance uncertainties $<<$ hadro-production model

Conclusions

MILESTONES:

- **Spill intensity of 3×10^{13} protons**
- **Average power of 270 kW maintained over ~ 1 hour**
- **Integrated 1×10^{20} protons-on-target in approx 6 mos.**
- **Automated operation fully commisioned = very stable beam with low losses**

2006 Goals:

- **Finish spare target and horns.**
- **Improved cycle time $\Rightarrow$ expect 2×10^{20} P.O.T. in 2006**
- **Booster batch stacking commisioning $\Rightarrow$ higher intensity in 2007+.**

