

MINOS Update

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❖ **The components of the MINOS experiment**

- Main Injector and primary proton beam-line
- NuMI ν beam and monitoring instrumentation
- The Near and Far neutrino detectors

❖ **NuMI beam commissioning**

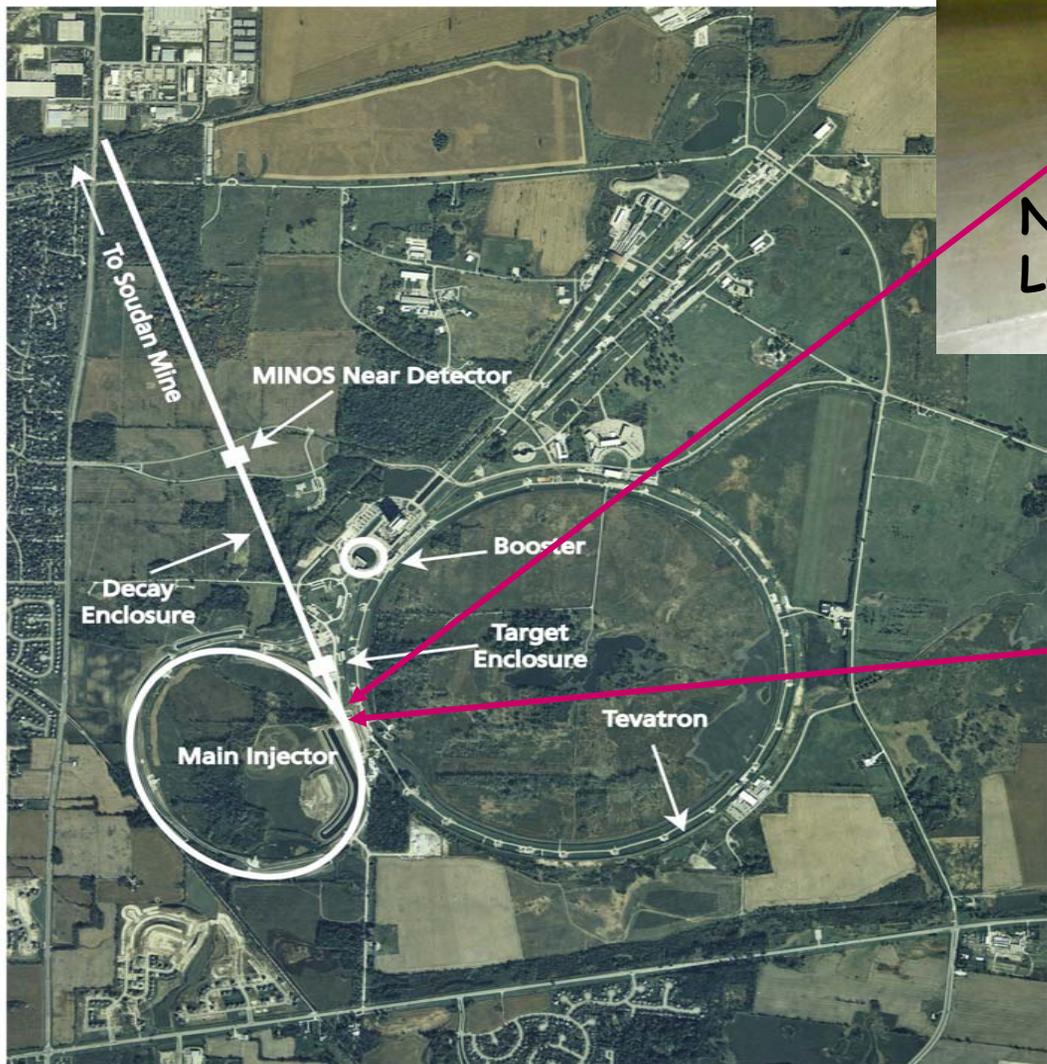
- commissioning of the primary proton line
- commissioning of the neutrino beam and observation of ν interactions in the Near Detector
- commissioning of high intensity beam in Main Injector
- start of MINOS operation
- target failure and plans

❖ **Conclusions**

Main Injector supporting NuMI operation

- ❖ **One additional extraction region at MI60 for NuMI**
 - additional kickers and Lambertson magnets installed
- ❖ **Anti-proton stacking and NuMI share a same Main Injector cycle (mixed-mode operation), with a flattop energy of 120 GeV**
 - from single batch to multi-batch mode operation
 - 2 separate single-turn extractions in a same cycle
- ❖ **The goal for 2005**
 - run NuMI at a **2 s cycle time with 2.5×10^{13} protons/cycle** (0.24 kW beam power)
 - NuMI design is for 4×10^{13} protons every 1.9 s (0.4 MW)
 - a **2 s long Main Injector cycle** accommodates injections of 6 batches, with a **total intensity of 3.3×10^{13} protons/cycle**
 - the Anti-proton Source requires 1 batch of 0.8×10^{13} protons (via slip-stacking)
 - 5 batches, for a total intensity of 2.5×10^{13} protons, are single-turn extracted to the NuMI target in $\sim 8 \mu\text{s}$

Main Injector & NuMI



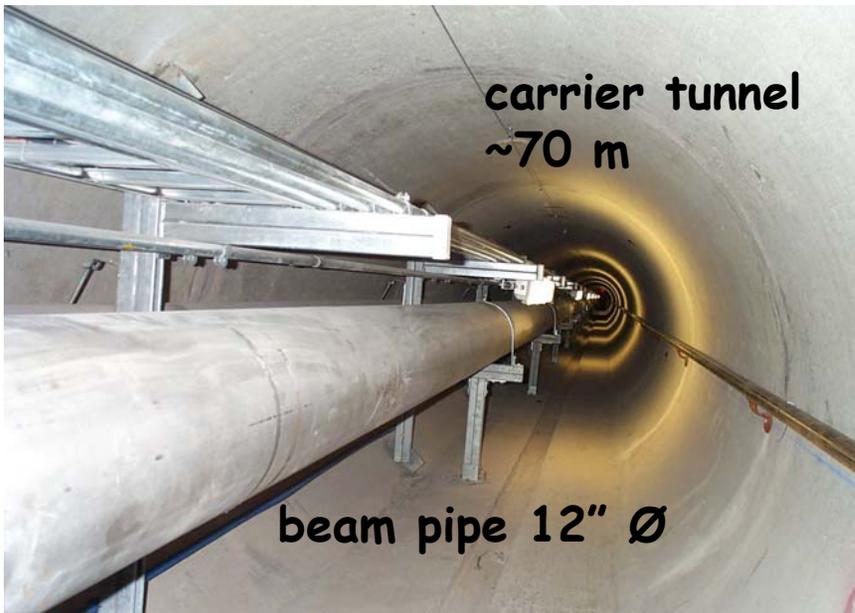
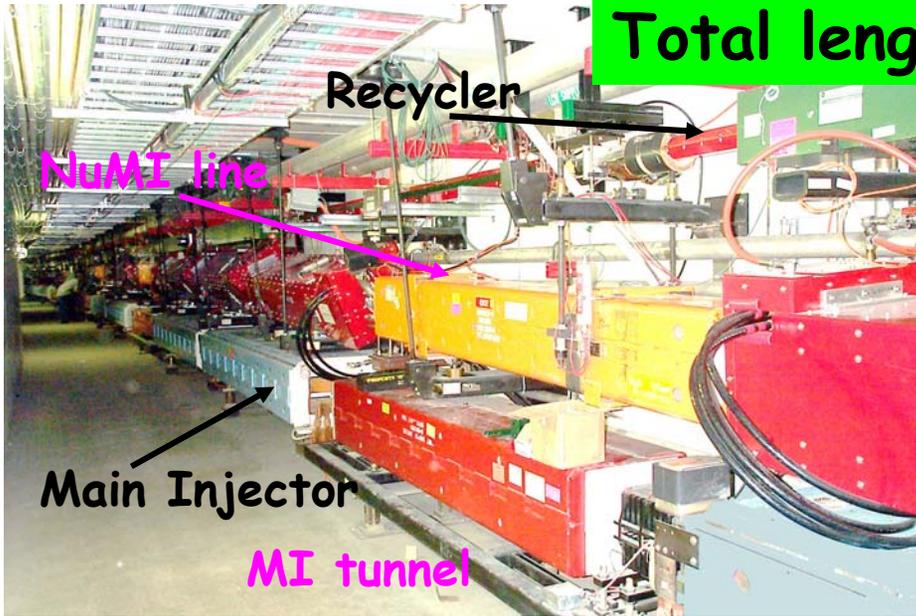
**NuMI extraction
Lambertsons**



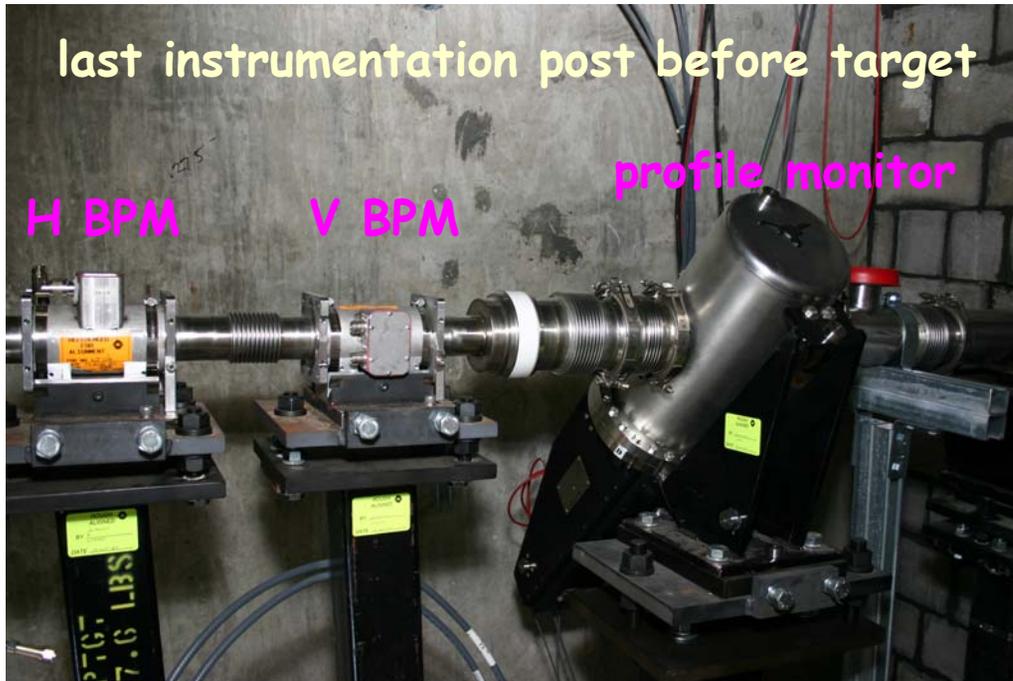
**NuMI kickers
allow extraction of
up to 6 batches**

The primary proton line

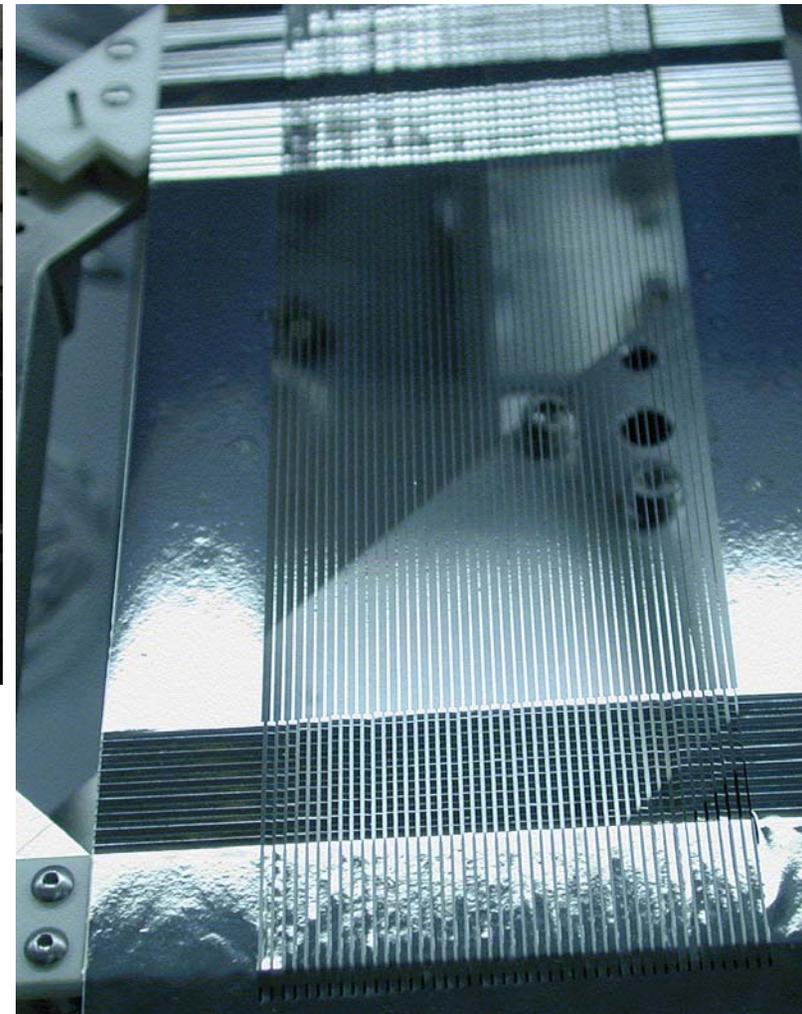
Total length ~ 350 m



Primary beam-line instrumentation

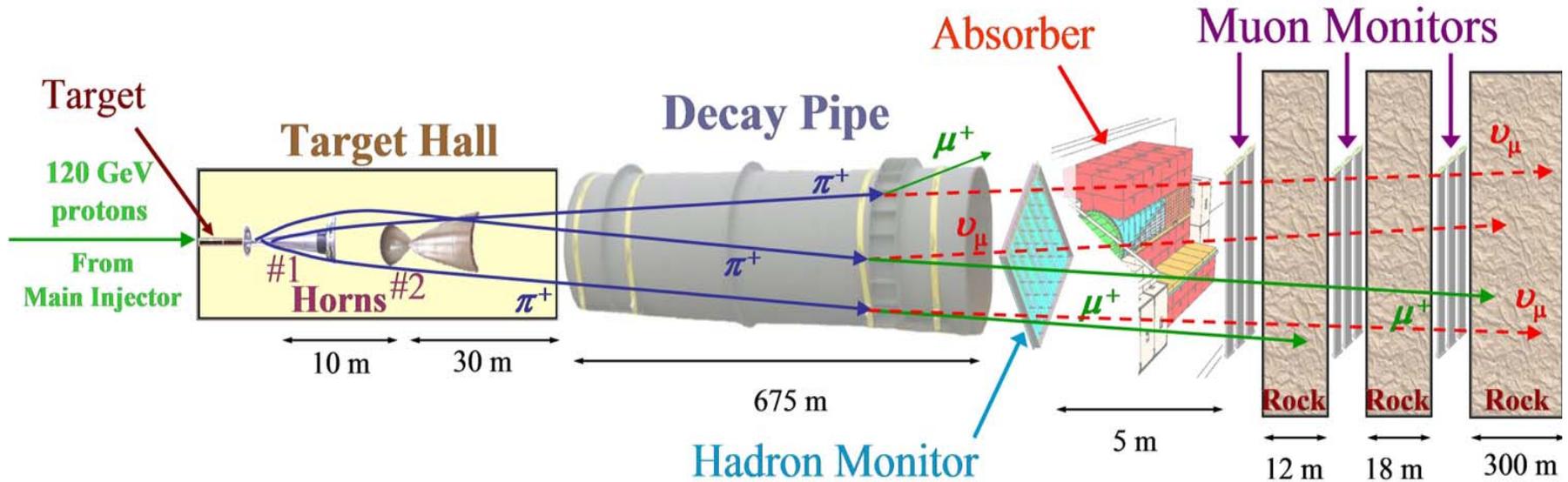


- 2 beam toroids
- 24 beam position monitors
- 54 loss monitors
- 10 thin-foil profile monitors (SEM) developed at U. Texas
 - 5 micron Titanium foils
 - Pitch 1 mm (8 units) or 0.5 mm (2 units)



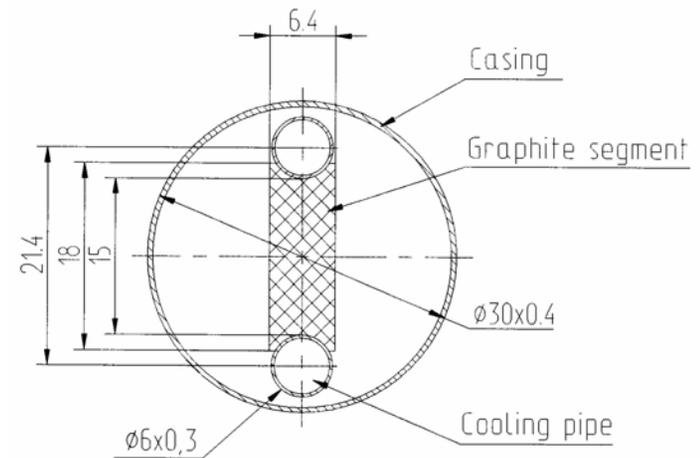
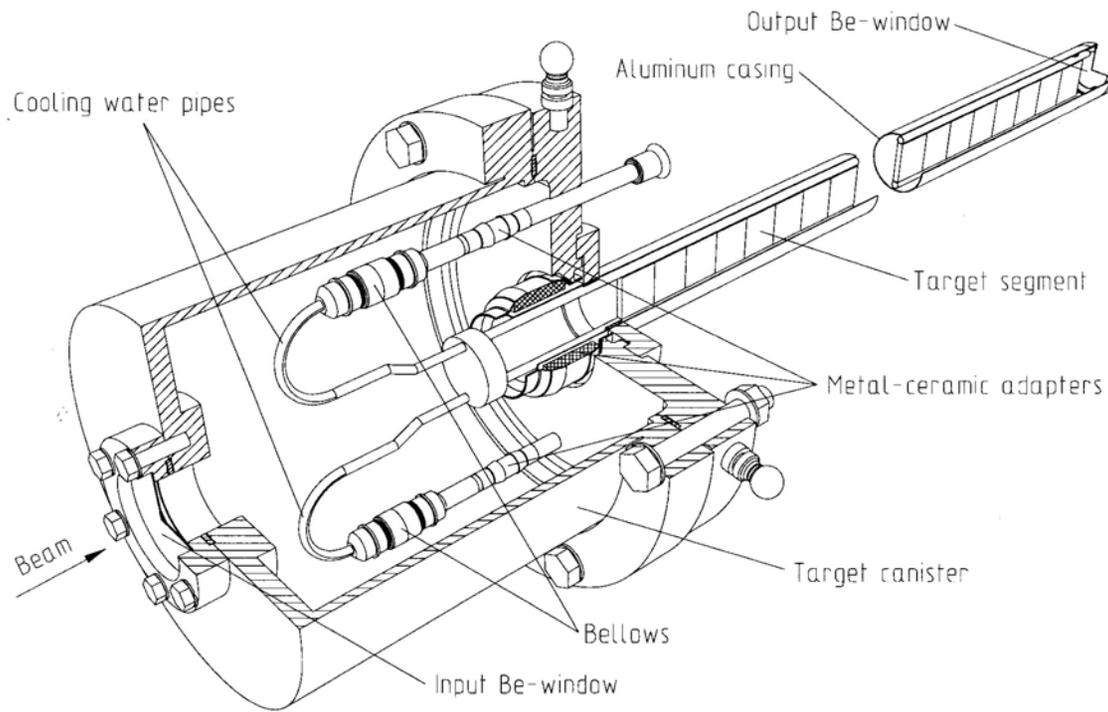
Profile monitor
1 mm pitch

NuMI ν beam and monitoring instrumentation



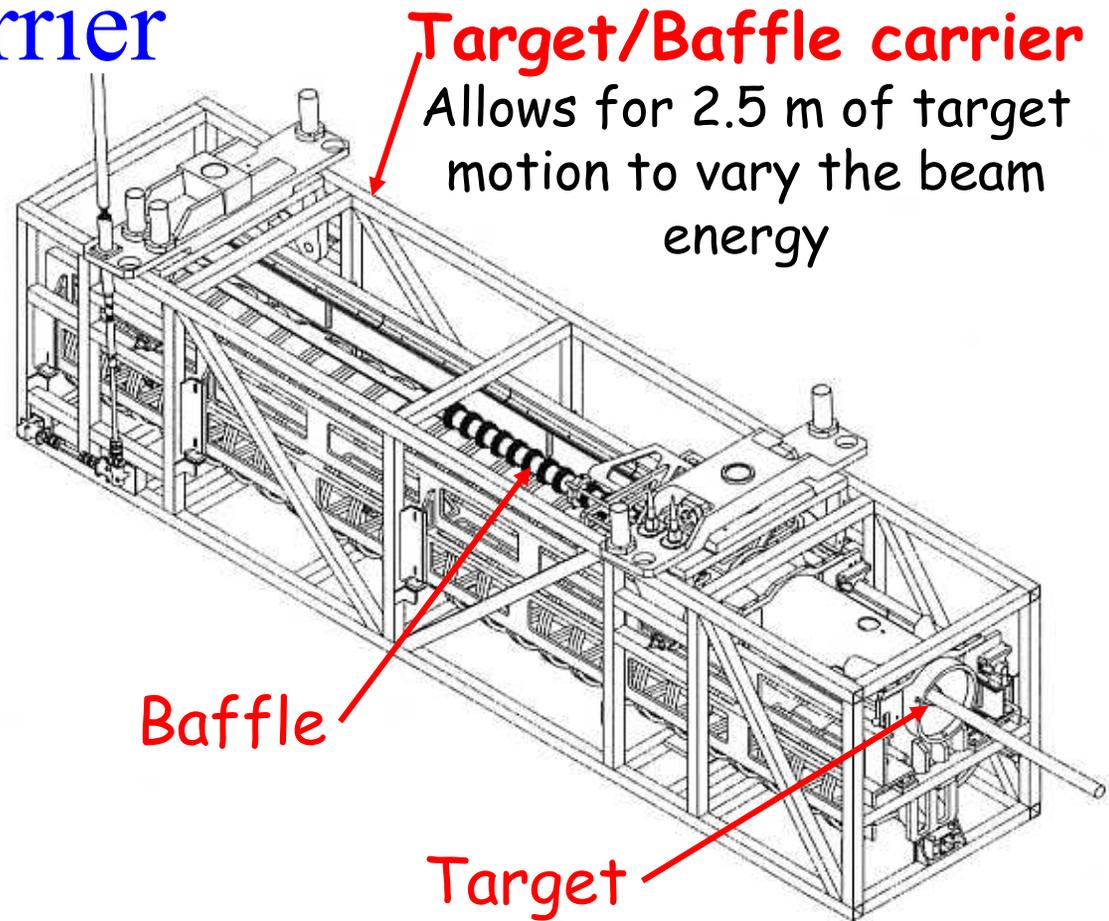
- ❖ water cooled graphite target, 2 interaction lengths, which provides absorption of $\sim 90\%$ of the primary protons
- ❖ target readily movable in beam direction
- ❖ flexible configuration of 2 parabolic horns, water cooled, pulsed with a 2.6 ms half-sine wave pulse of 200 kA
- ❖ 675 m long decay pipe with a radius of 1 m, evacuated to 1 Torr
- ❖ 1 hadron monitor and 3 muon monitor stations

The target



- 47 segments of graphite of 20 mm length and $6.4 \times 15 \text{ mm}^2$ cross section
- 0.3 mm spacing between segments, for a total target length of 95.4 cm

Target/Baffle carrier



- **Baffle: protection of horn neck and target cooling/support components**

- dimensions: 150 cm long, 11 mm \varnothing hole, 57 mm \varnothing graphite core, 61 mm \varnothing aluminum casing

Secondary Hadron and Muon Instrumentation

Hadron Monitor

Max flux $\sim 10^9$ part./cm²/spill



- 4"×4" parallel plate ion chambers made from ceramic wafers with Ag-Pt electrodes
- Hadron monitor 1 mm, Muon monitor 3 mm gap
- gas: He

3 Muon Stations in excavated alcoves

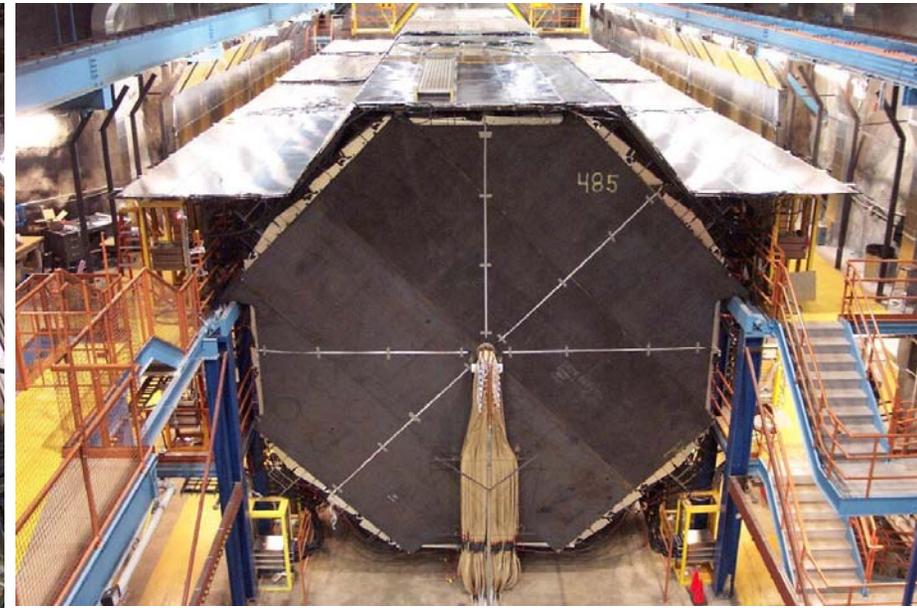
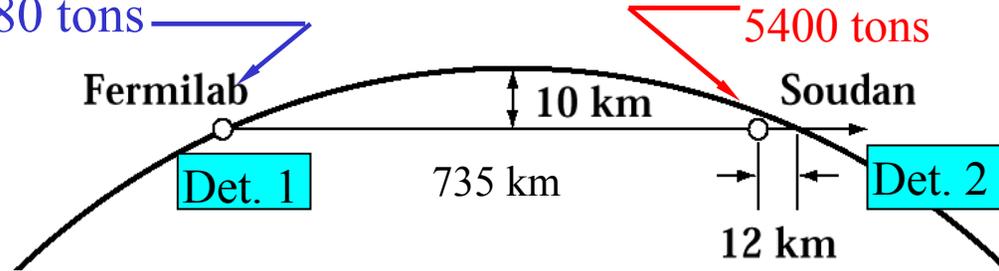
Max. flux $\sim 3 \times 10^7$ part./cm²/spill



The Near and Far neutrino detectors

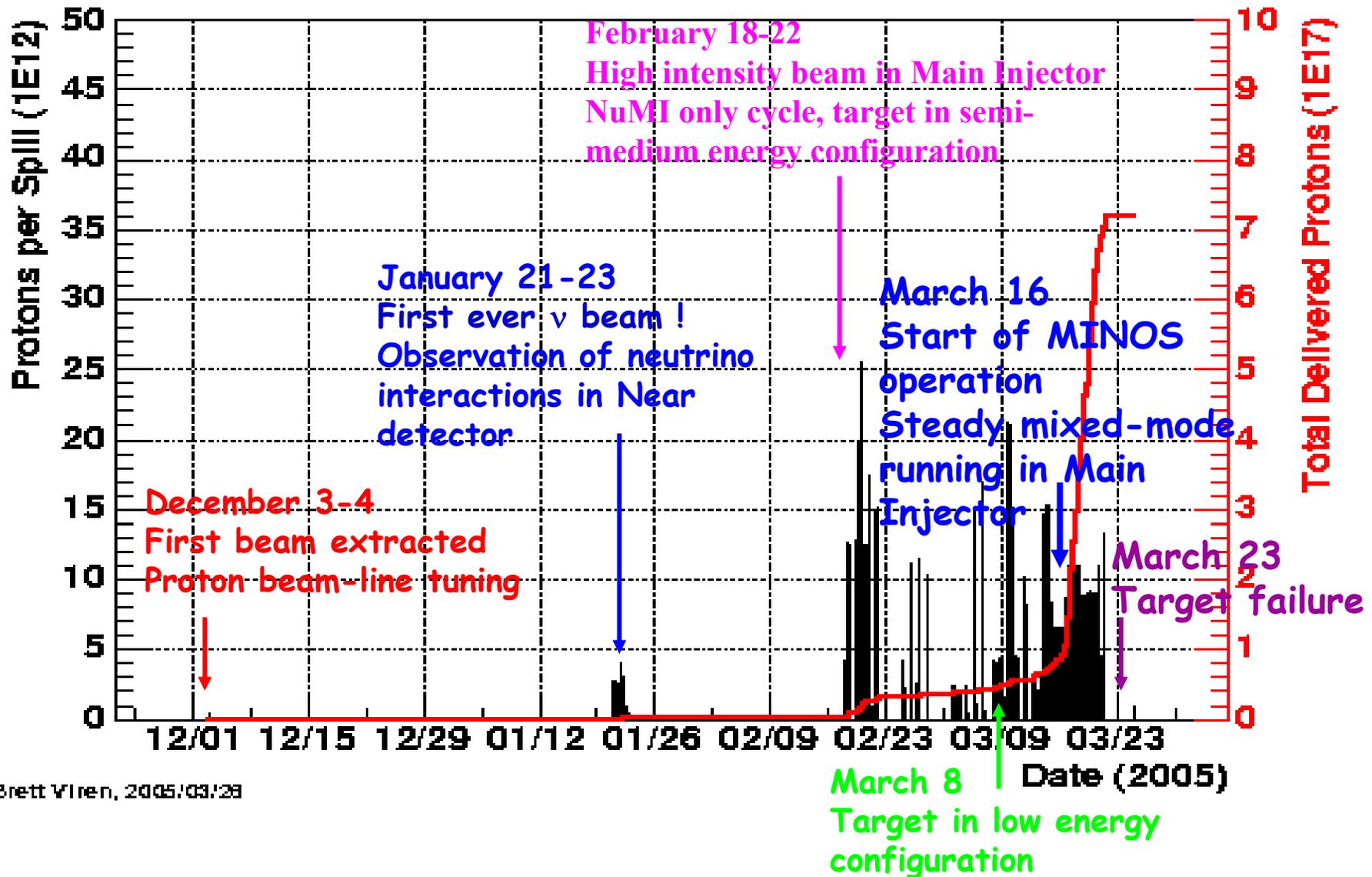
Near Detector:
980 tons

Far Detector:
5400 tons



NuMI beam commissioning

NuMI Protons

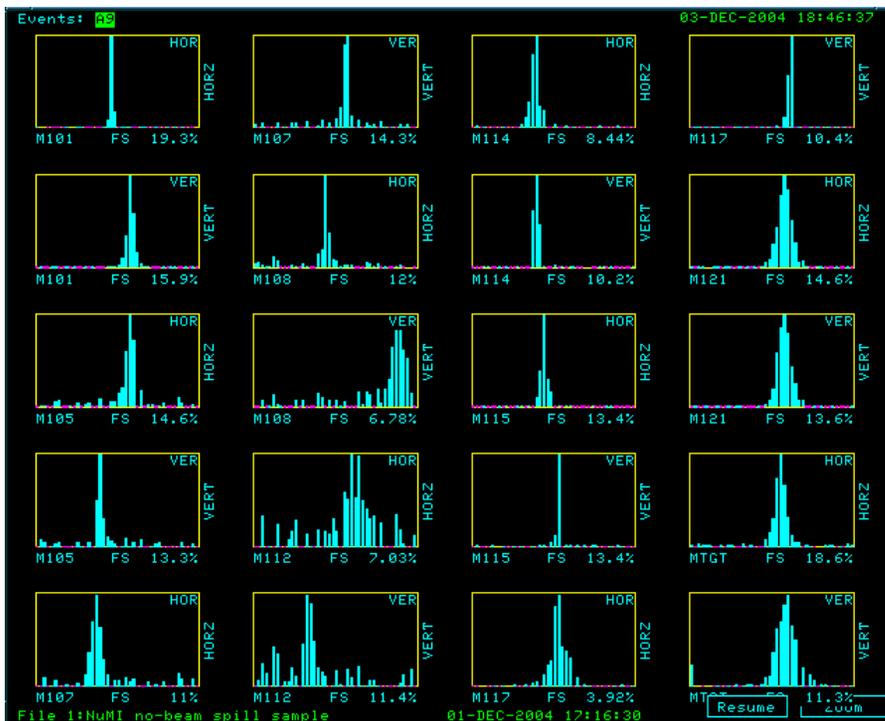


Commissioning of the primary proton line and of the neutrino beam

- ❖ **December 3-4 2004. Commissioning the primary proton beam**
 - target out, horns OFF
 - small number of low intensity (1 batch with 3×10^{11} protons) pulses carefully planned
 - beam extracted out of Main Injector on the 1st pulse
 - beam centered on the Hadron Absorber, 725 m away from the target, in 10 pulses
 - all instrumentation worked on the first pulse
- ❖ **January 21-23 2005. Commissioning of the neutrino beam**
 - target at $z = -1$ m from nominal \Rightarrow pseudo-medium energy beam
 - horns ON
 - MI operating on a dedicated NuMI cycle, at 1 cycle/minute, with a single batch of 2.6×10^{12} protons
 - few pulses up to 4×10^{12} protons
 - final tuning of the proton line
 - neutrino interactions observed in Near Detector
 - NuMI project met DoE CD4 goal

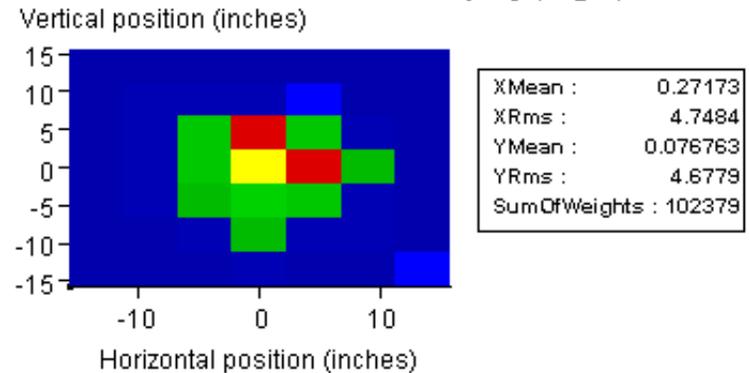
Beam centering on the Hadron Monitor

10th pulse !

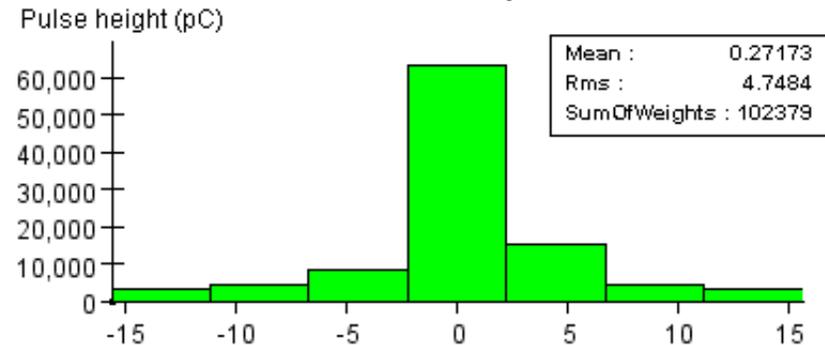


Beam points in the right direction within $\sim 20 \mu\text{rad}$

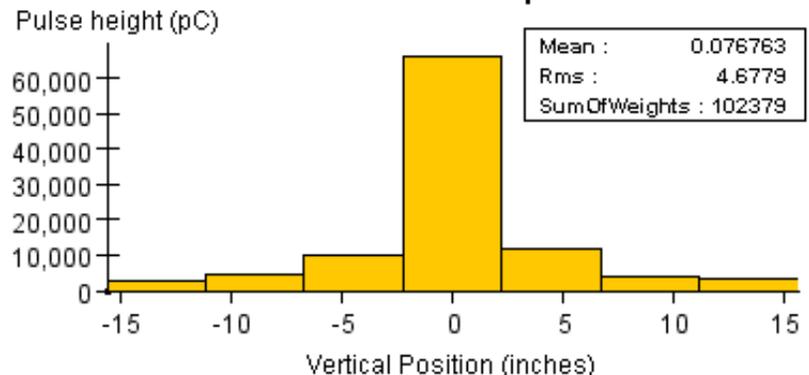
NuMI Hadron Monitor 2-D Display (log Z)



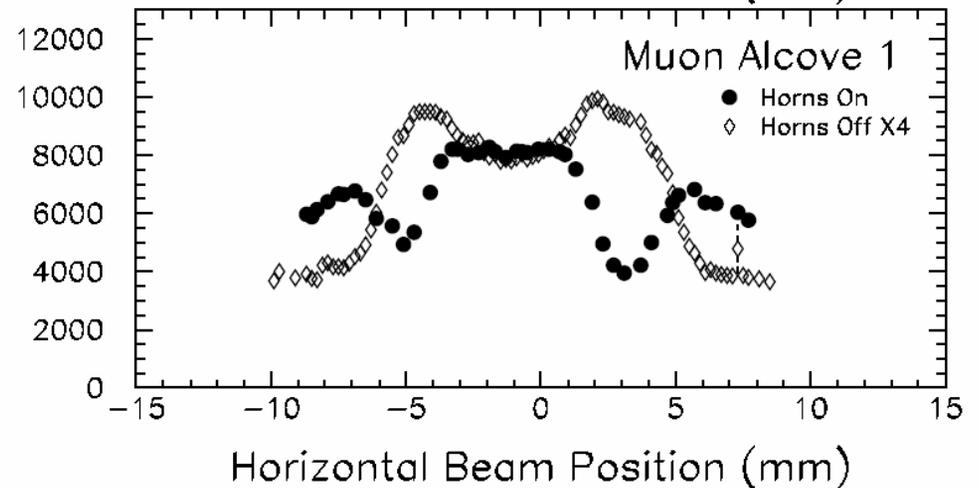
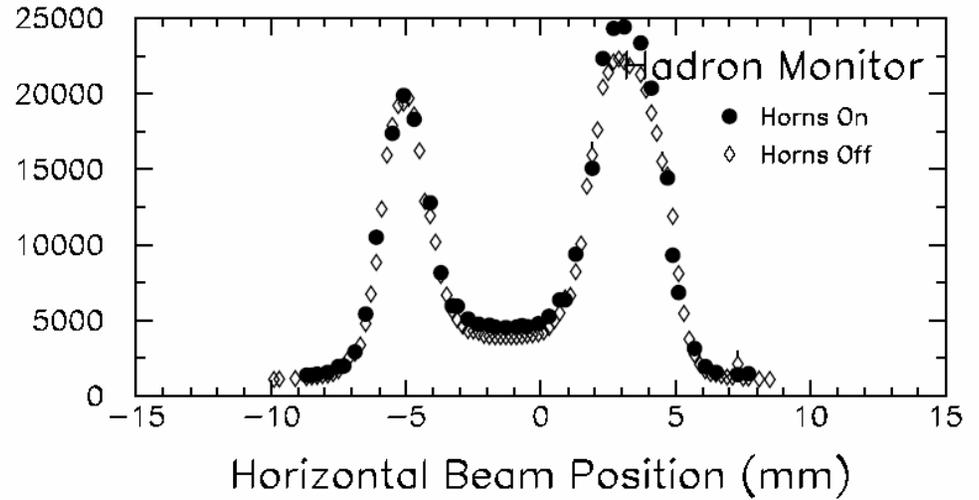
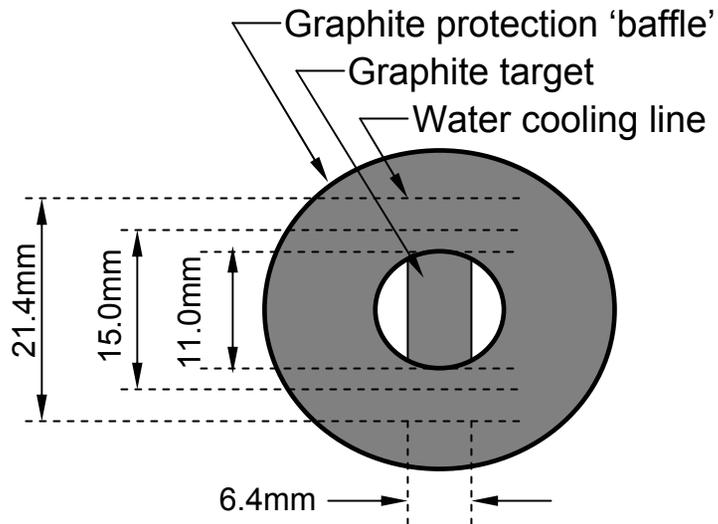
NuMI Hadron Monitor X-position



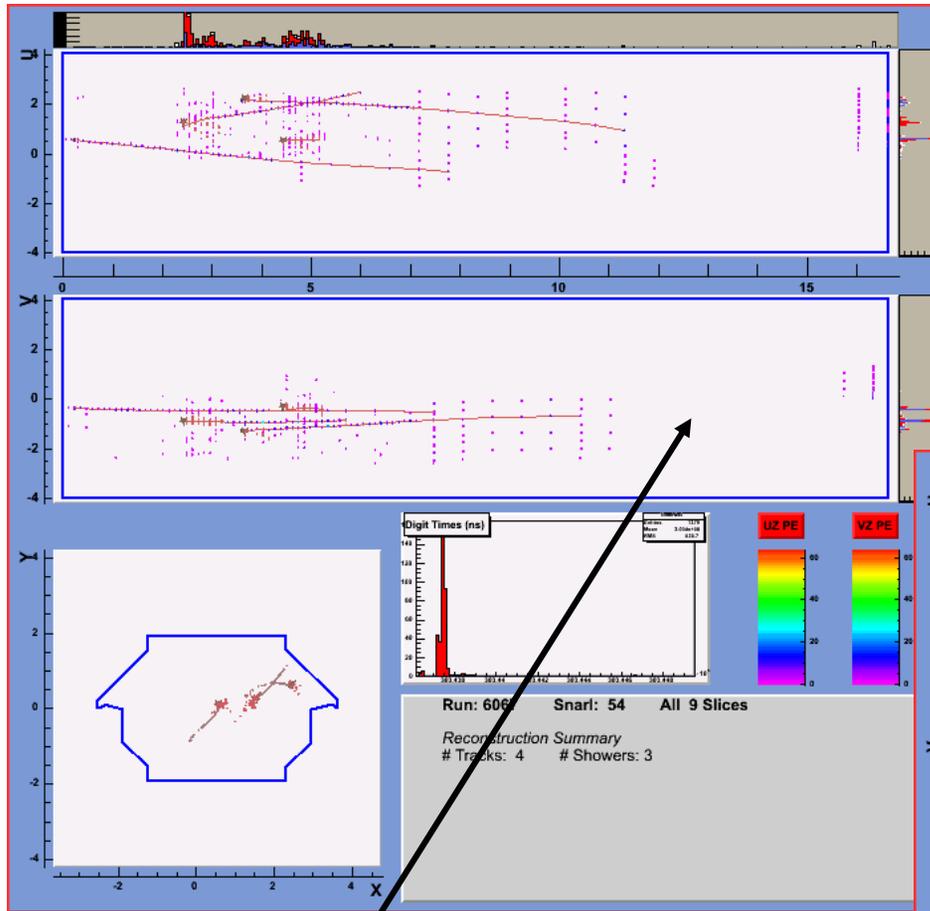
NuMI Hadron Monitor Y-position



Horizontal target scan



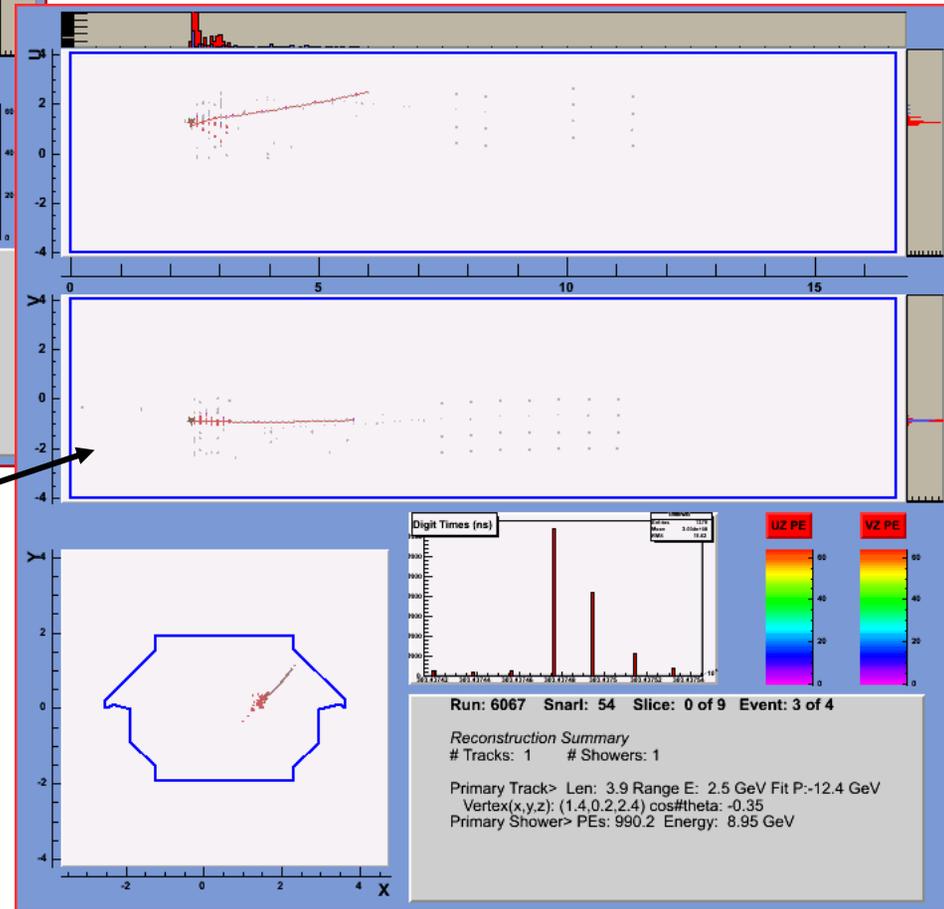
Observation of ν interactions in the Near Detector



1 full spill

one of the events after slicing

Detector read out in 19 ns buckets, allowing event separation



Commissioning of high intensity beam in Main Injector

❖ **Multi-batch studies in MI on dedicated study cycles started since early 2003**

➤ a few pulses just above 2×10^{13} protons were achieved in April 1999 during MI commissioning

➤ a bunch-by-bunch digital damper system, both transverse and longitudinal, installed in 2003, has proved to be essential for MI operation at high intensity

❖ **Achieved a max intensity of 2.9×10^{13} protons @ 120 GeV in Main Injector**

➤ *beam losses and beam quality issues still to be worked on above $\sim 2 \times 10^{13}$ protons*

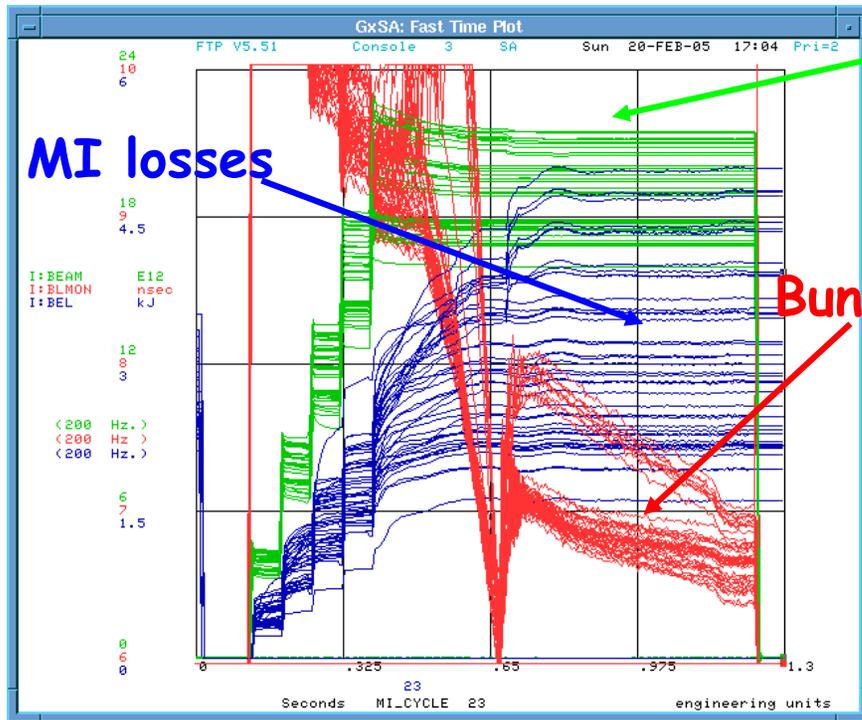
➤ presently implementing a longitudinal mode 1 damper system, using the same hardware of the digital damper system

➤ *special attention to beam losses in MI*

❖ **Relevant contributions from MINOS collaborators**

Commissioning of high intensity beam in the NuMI beam-line

February 18-22, 2005



Beam intensity

E:TORTGT $\sim 22.5 \times 10^{12}$ p

Booster @ 14 turns: $\sim 4.7 \times 10^{12}$ p

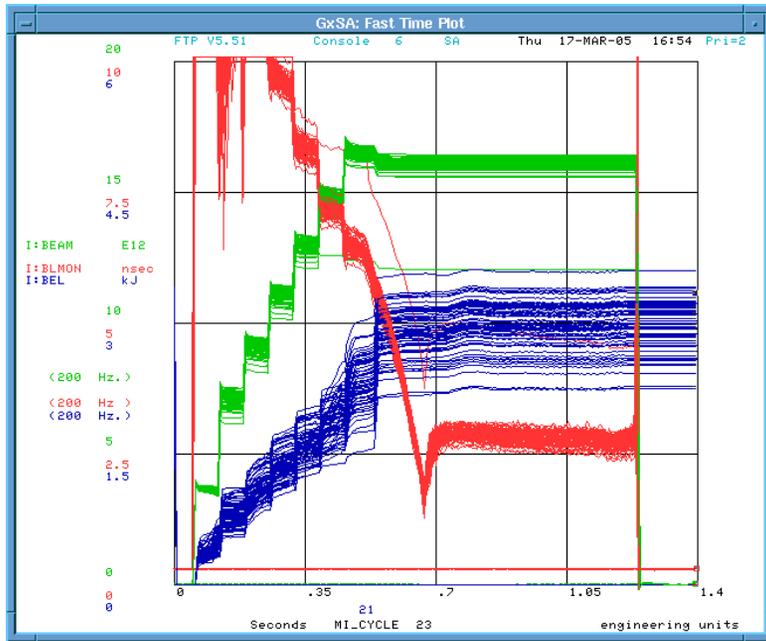
Bunch length monitor

- MI operating on a dedicated NuMI cycle, at 1 cycle/minute, in multi-batch mode
- with 6 batches, we achieved a maximum intensity of 2.5×10^{13} p/cycle

5 batches, 14 Booster turns
NuMI only cycle

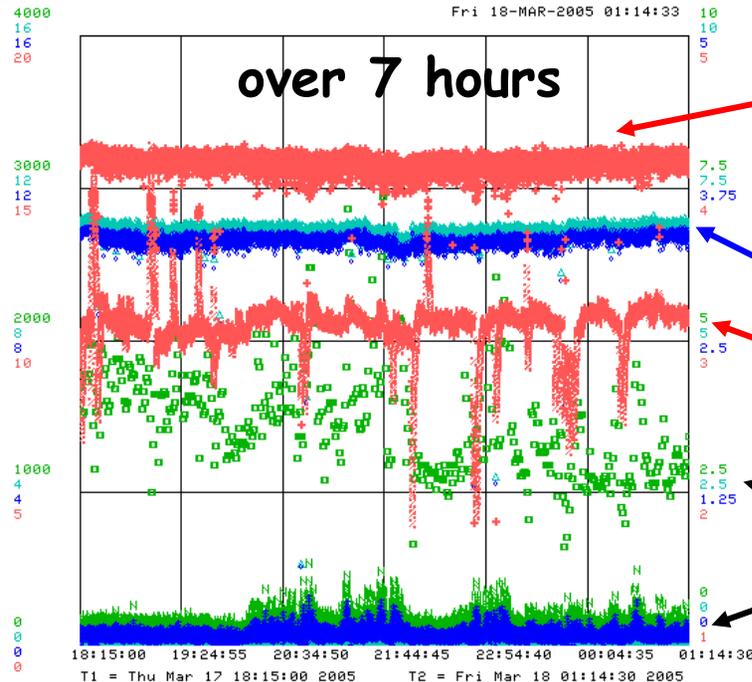
Start of MINOS operation

March 16, 2005



- Target in low energy position
- Steady mixed-mode (slip-stacking & NuMI) running in MI
- 5 Booster turns/NuMI batch
⇒ 10.7×10^{12} p/pulse on NuMI target
- Max. 20 pulses/min. ⇒ 1.3×10^{16} p/hr

over 7 hours



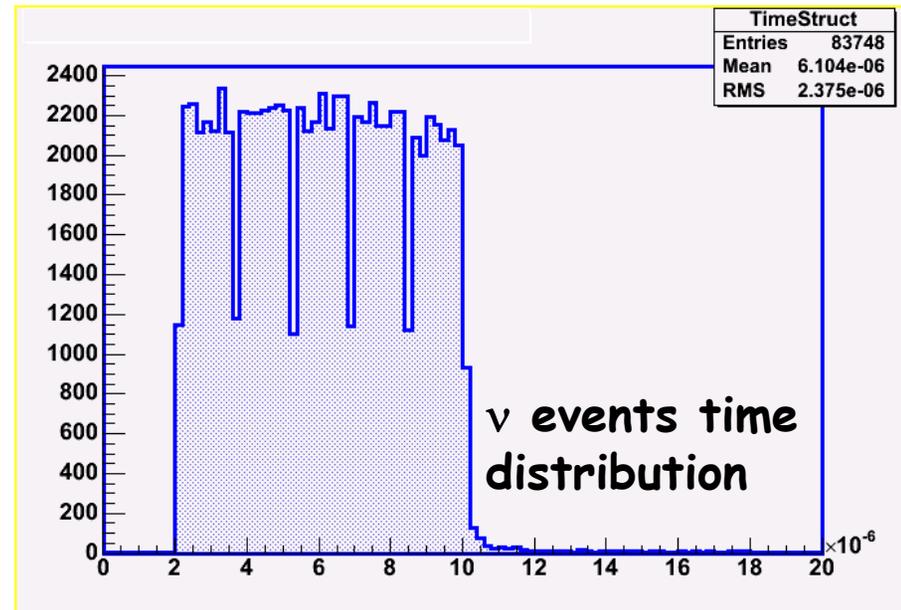
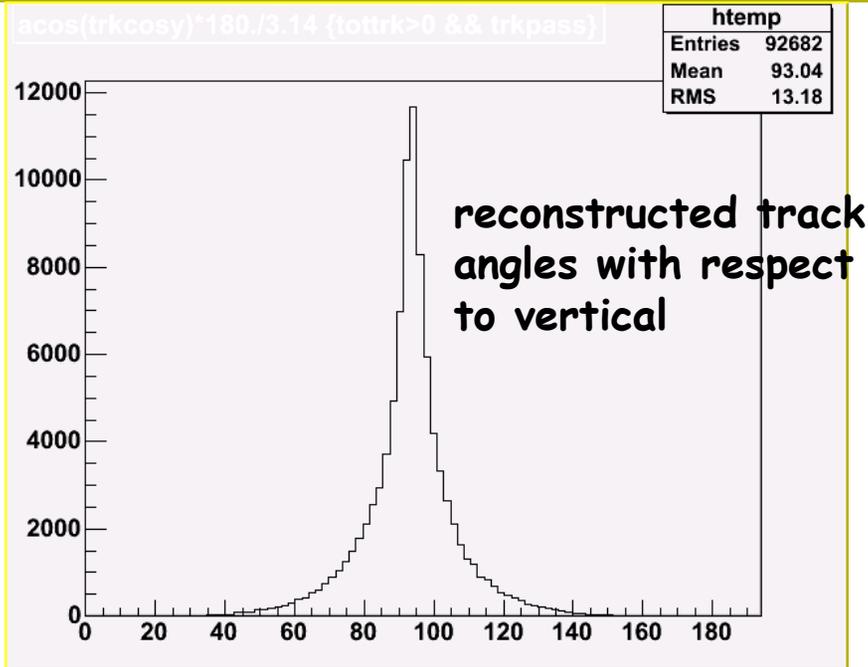
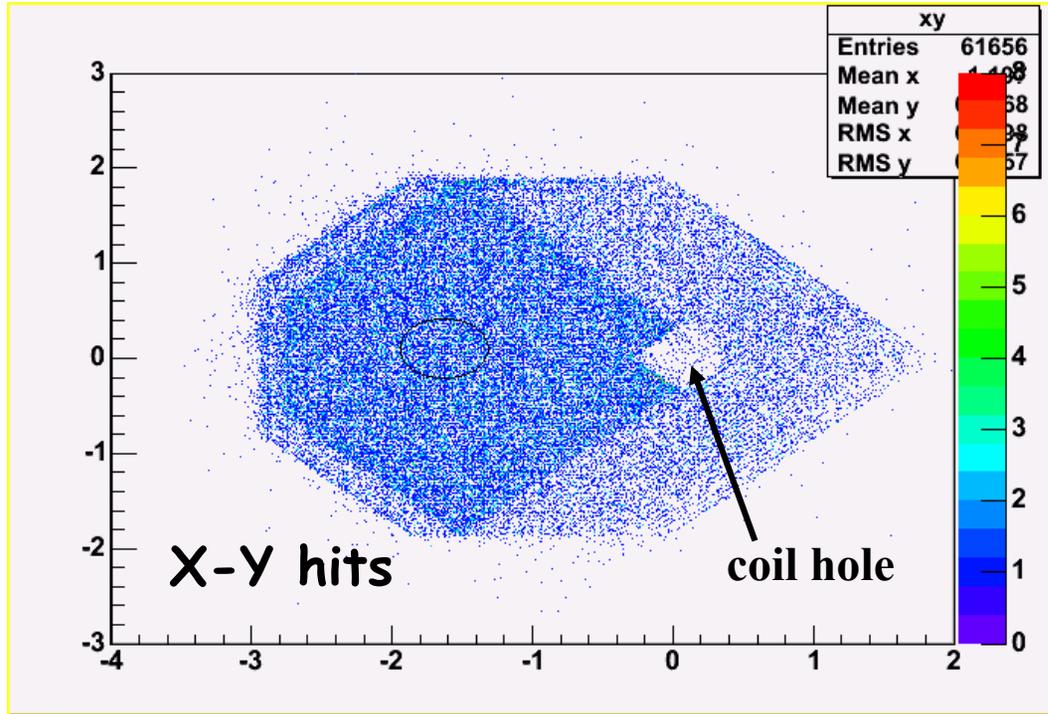
MI beam intensity $\approx 1.6 \times 10^{13}$ p

NuMI beam intensity $\approx 1.0 \times 10^{13}$ p

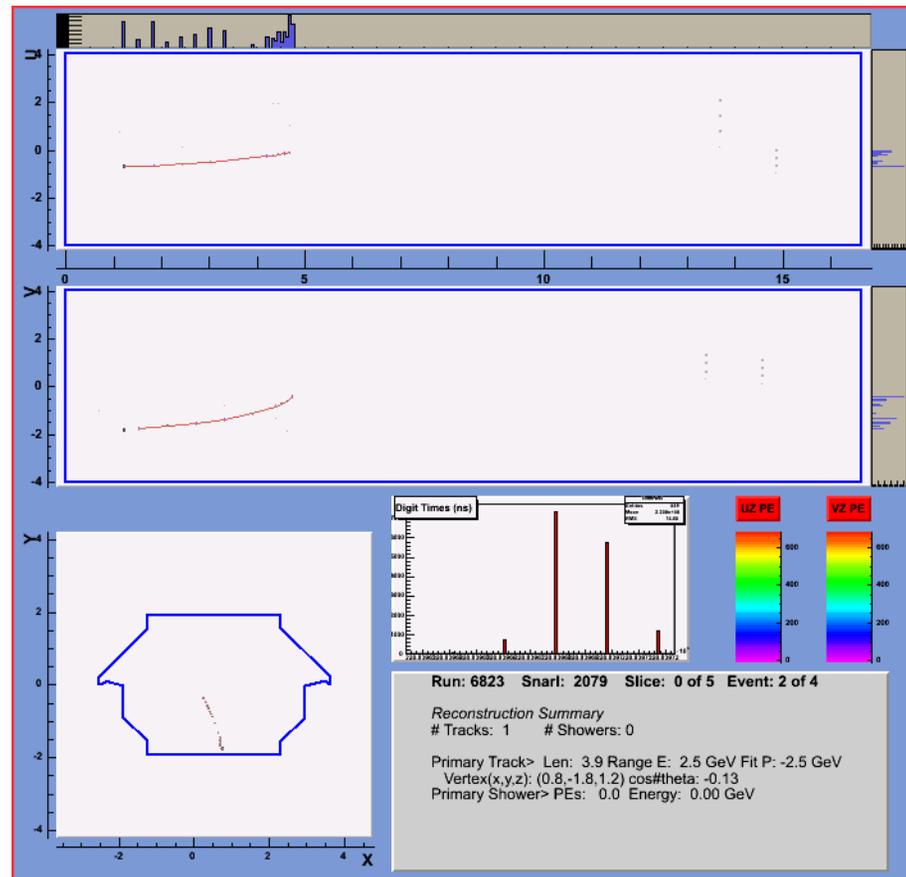
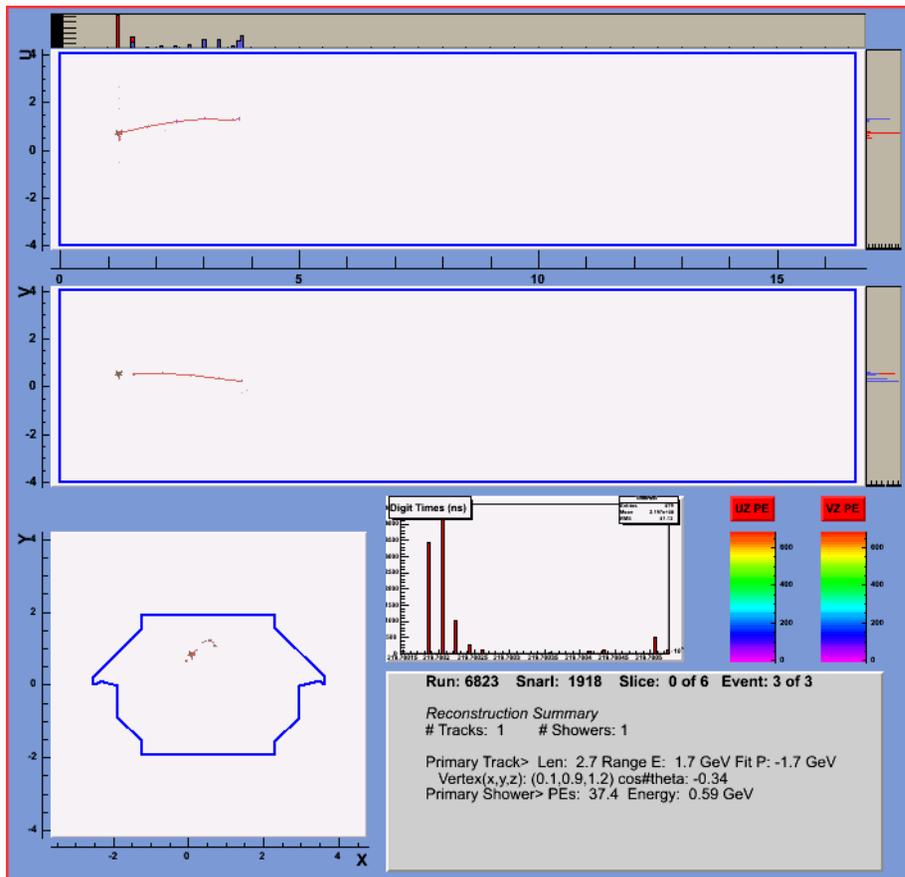
MI losses ≈ 3 kJ

NuMI beamline losses

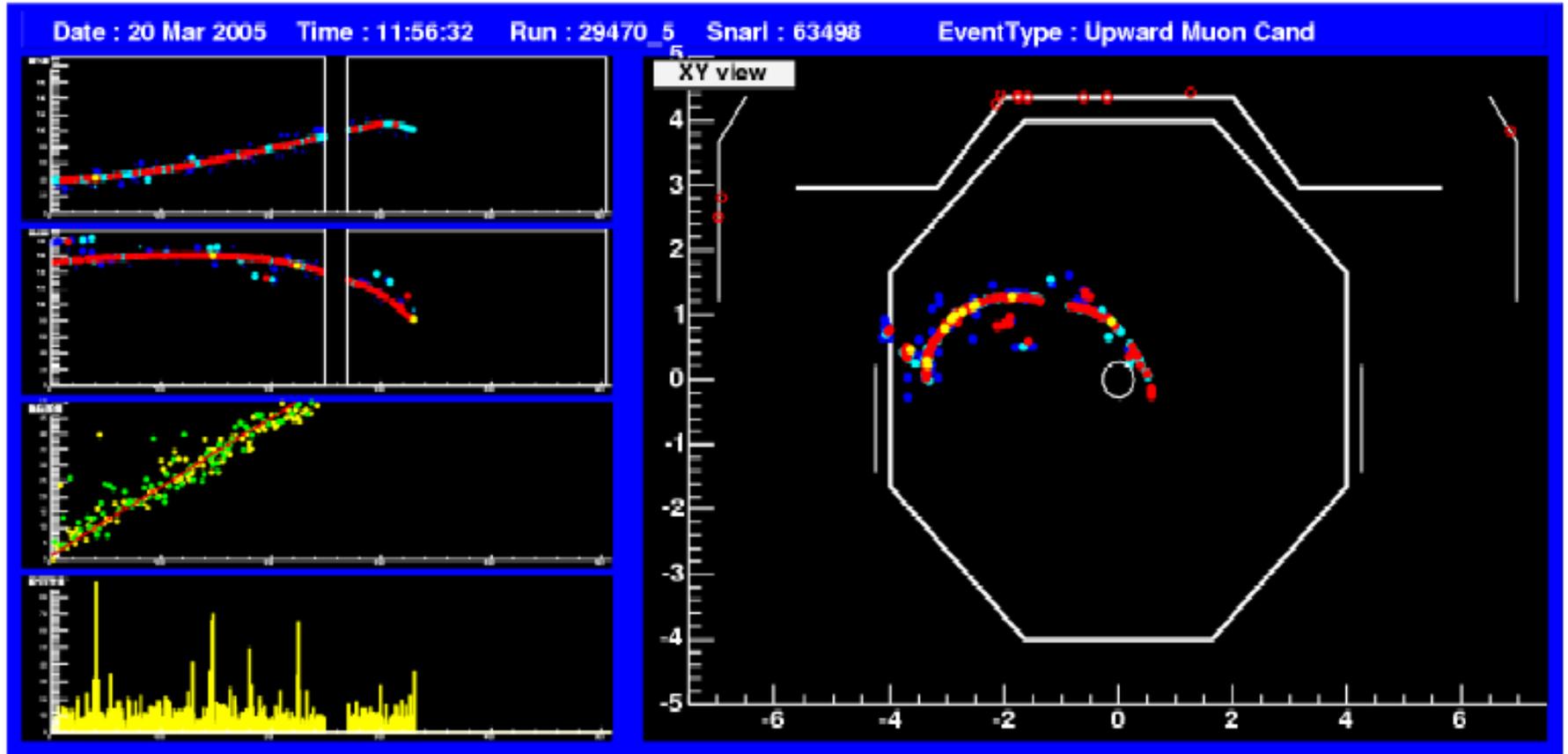
Event distributions in Near Detector



ND events in LE configuration

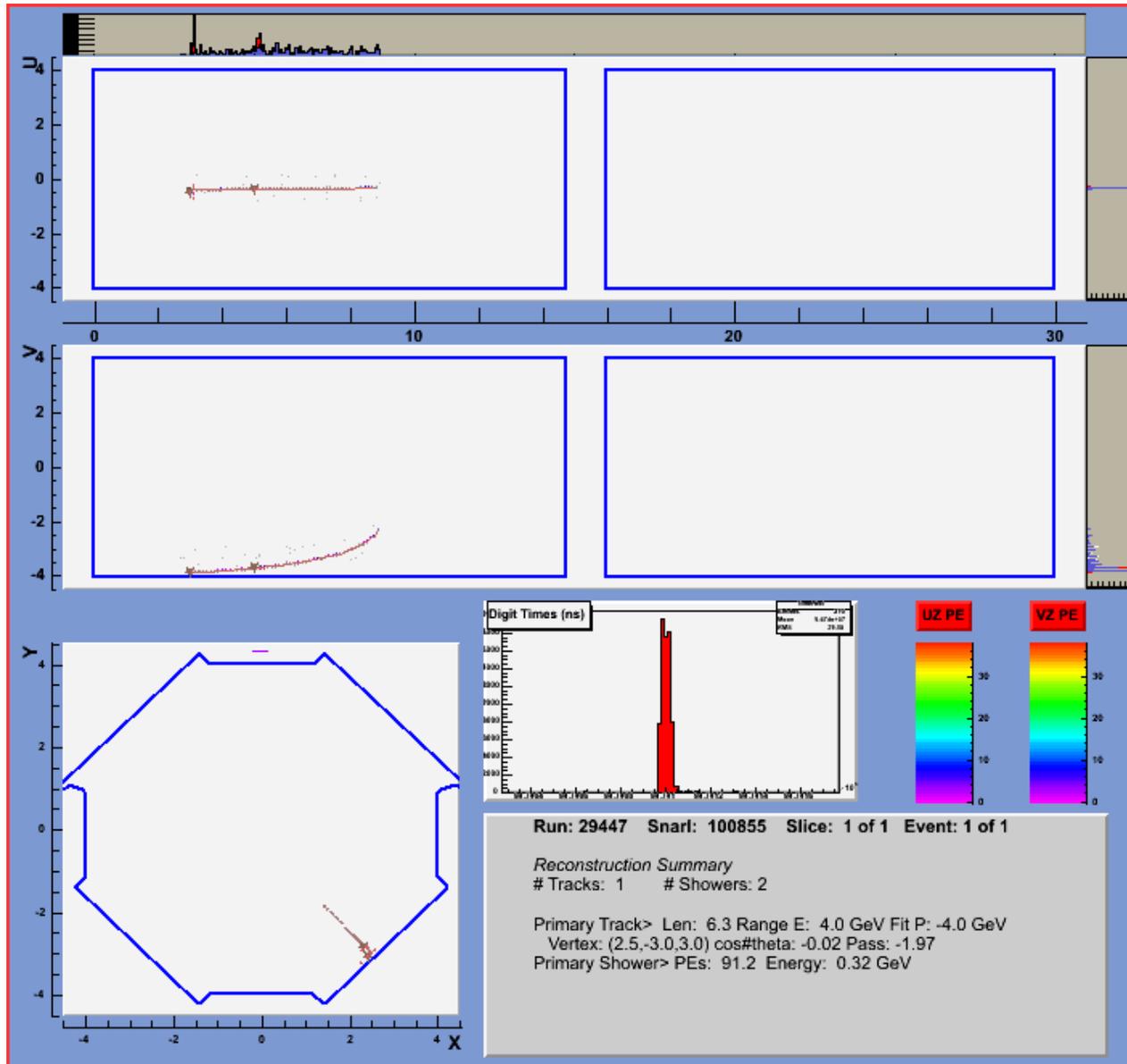


Rock muon candidate at the Soudan site

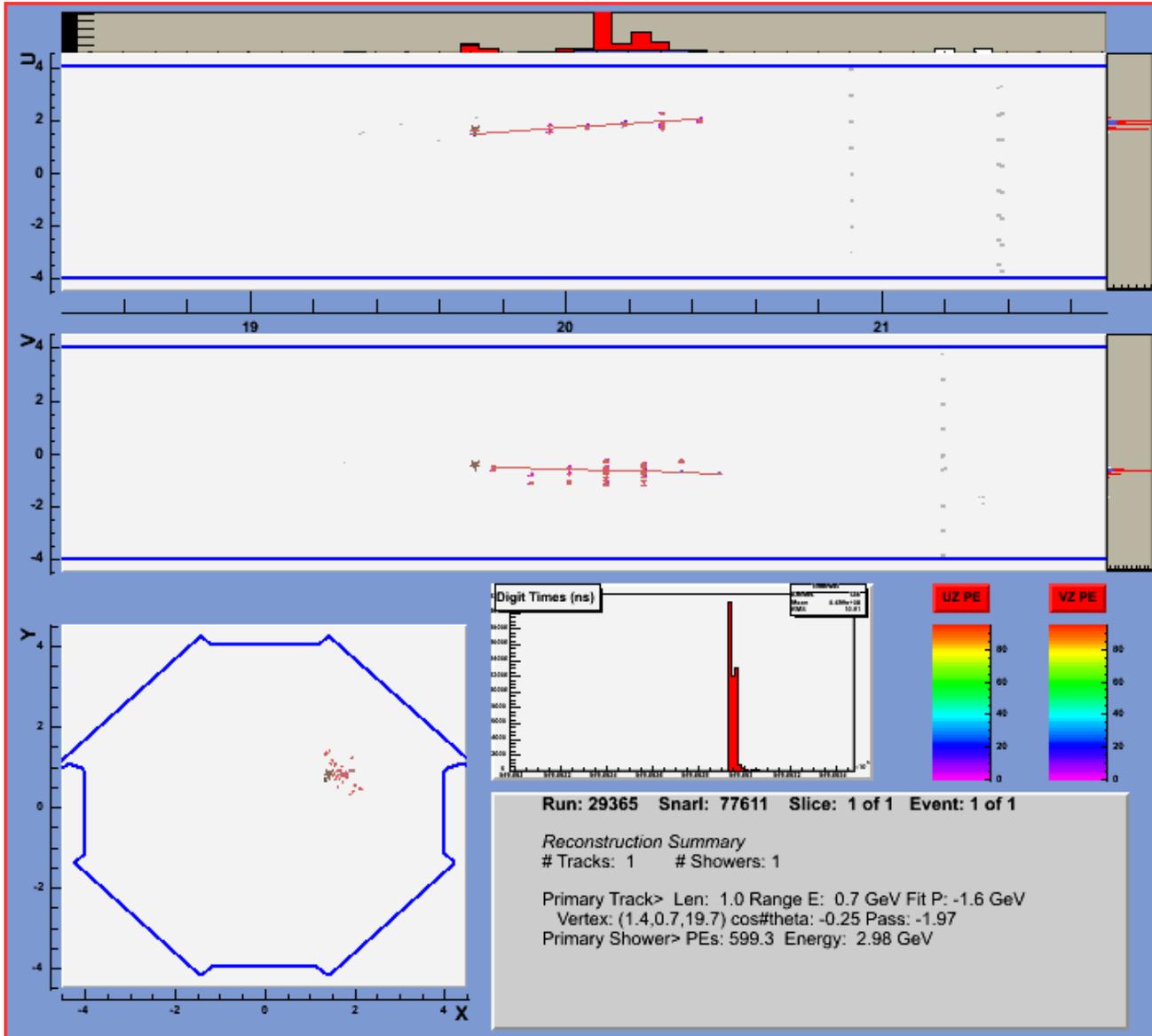


$$p_{\mu} = 13 \text{ GeV}$$

Another event in FD



Contained event in FD



This one is
inside the
fiducial volume !

Showering event

The target failure and the plan to resume operation

❖ **Data taking stopped on March 23 due to target failure**

- found water in the oil of the vacuum pump connected to the target
- target scans with beam confirmed the presence of water in the target and provide a way to measure quantitatively its amount
- observations are consistent with a leak present in the lower water pipe at the upstream end of the target
- there was an effort to drain the target by a combination of tilting, pressurizing and pumping, which reduced the column of water in the beam direction by about 30 %

❖ **baffle/target carrier is being moved to the work cell for target inspection/repair**

- the time estimate is 2 weeks + time for inspection/repair

❖ **A spare target is available, but not a spare carrier (expected in July)**

❖ **Large support from Accelerator Division: ~ 20 people involved in target activities**

- also proceeding on a parallel path to investigate alternative target designs

Conclusions

- ❖ **NuMI/MINOS construction project successfully completed**
- ❖ **Far and Near detectors working extremely well**
- ❖ **Successful commissioning of the NuMI line**
 - careful planning/installation and reliability of the instrumentation have been the key elements for success
 - relevant contributions from MINOS collaborators
- ❖ **Established steady running of MINOS, with mixed-mode cycles in MI (anti-proton stacking & NuMI), on March 16**
 - delivered up to 1.3×10^{16} protons/hour (28% of the 2005 goal)
- ❖ **Neutrino event distributions from the Near Detector !**
- ❖ **Observation of neutrino interactions in the Far Detector !**
- ❖ **Data taking stopped on March 23 due to target failure**
 - leak present in the water cooling conduits
 - baffle/target carrier is being moved to the work cell for target inspection/repair
 - about ~ 20 people involved in target activities