The MINOS experiment

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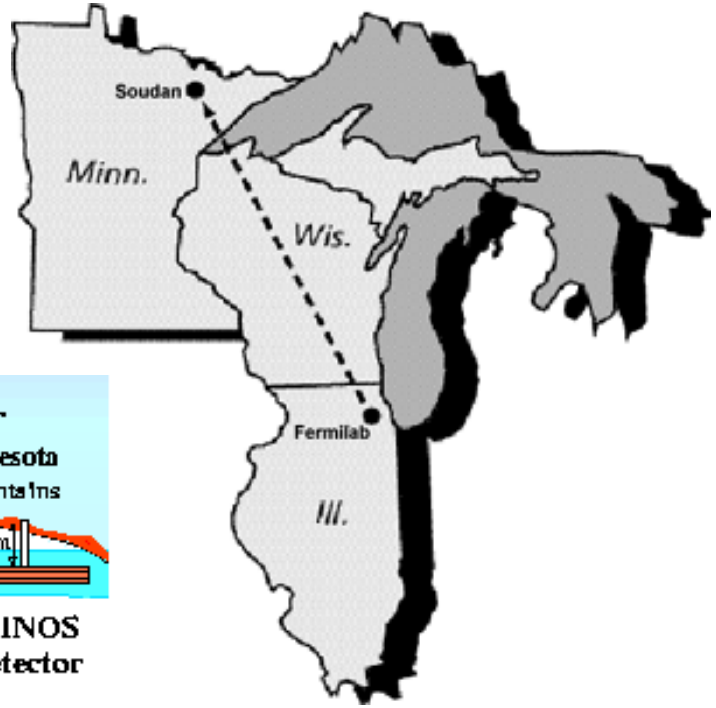
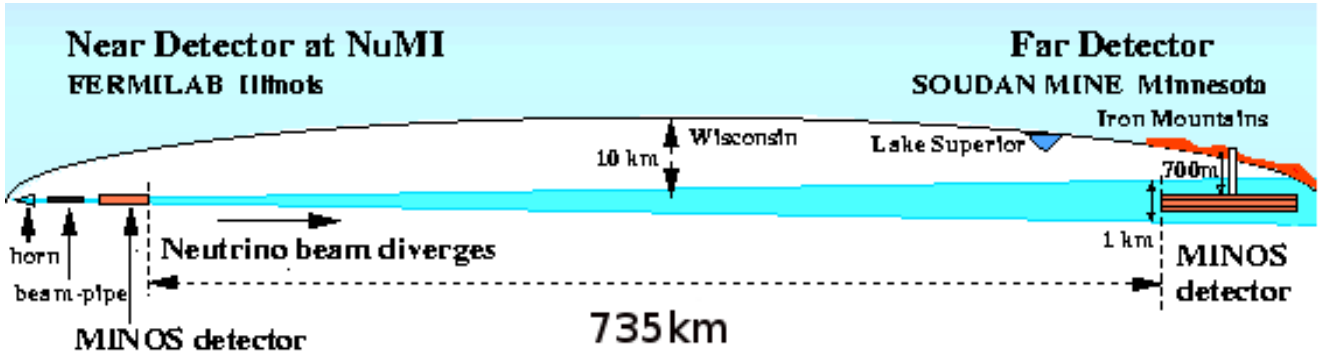
BROOKHAVEN NATIONAL LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

The Concept

High intensity ν_μ beam from Fermilab to Soudan (MN)





compare spectrum:

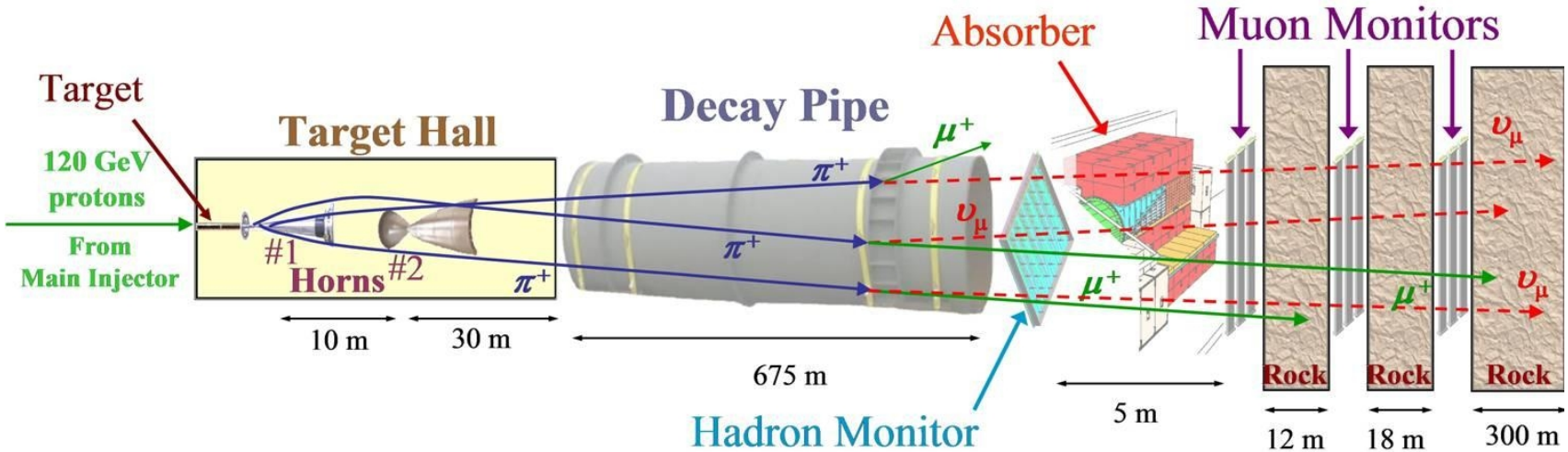
near (1kT) ⇔ far (5.4kT)

unoscillated ⇔ oscillated

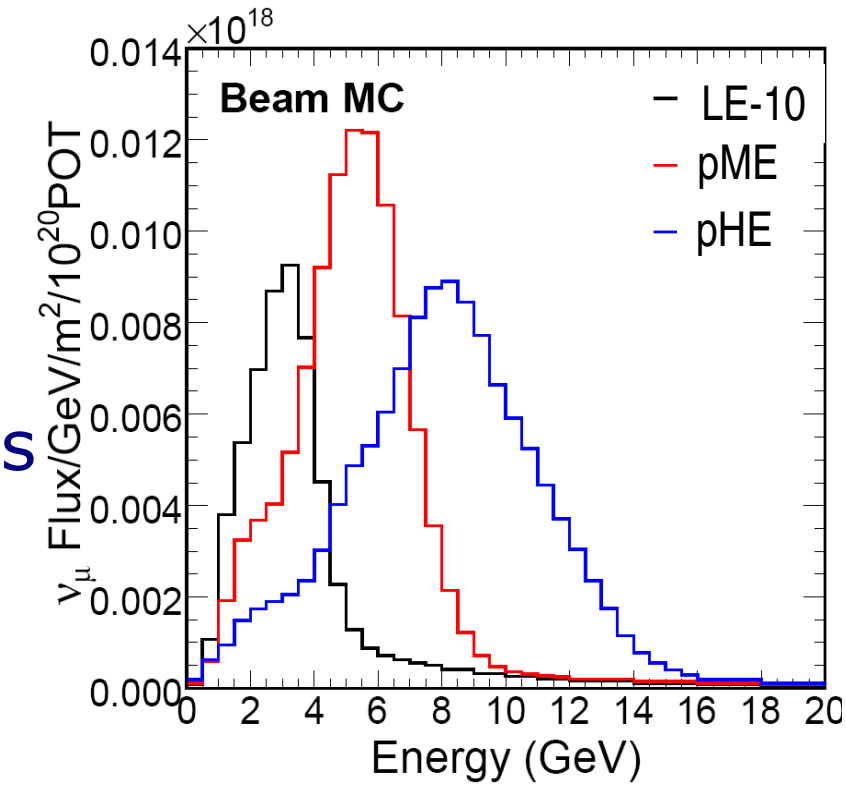
BNL group:

- M. Diwan
- B. Viren
- M. Bishai
- D. Jaffe
- M. Dierckxsens

NuMI Beamline

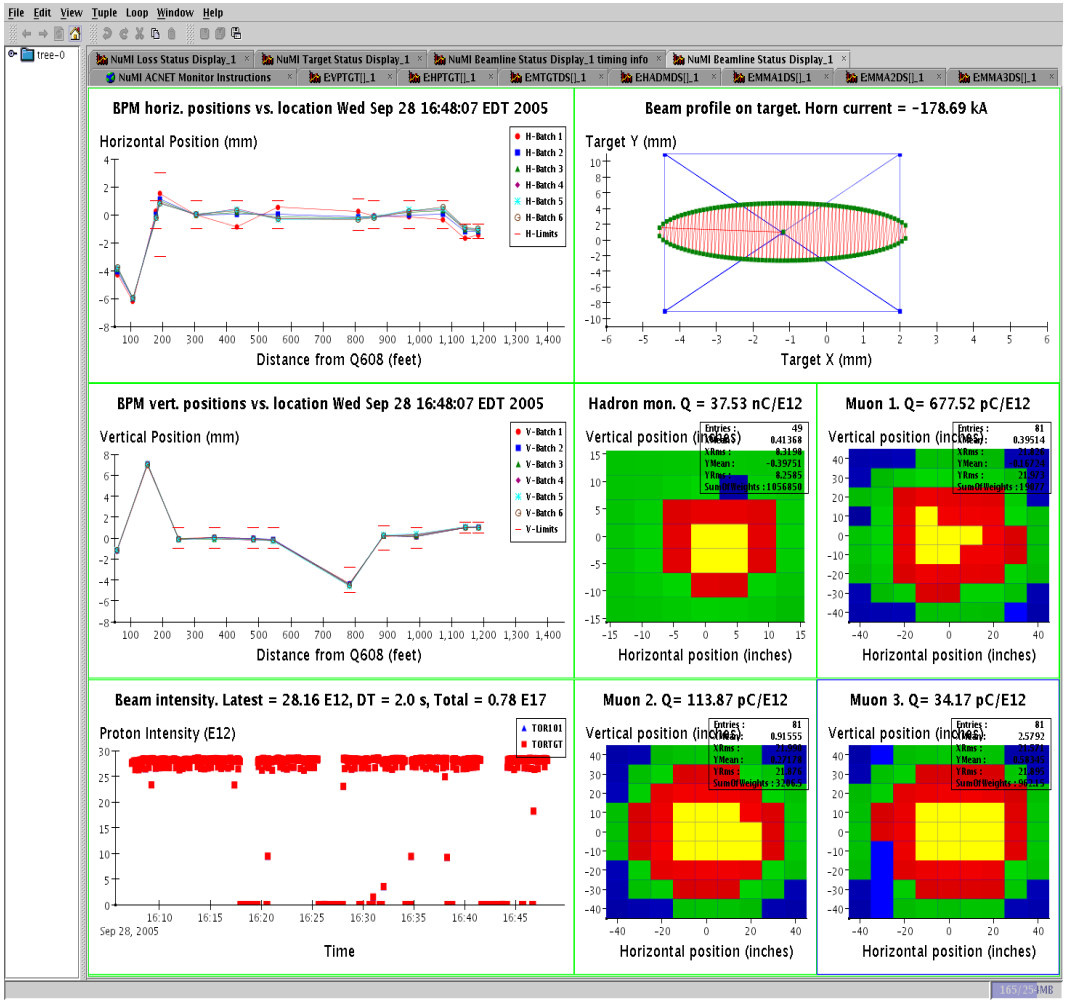


- 120 GeV protons
- graphite target
- 2 magnetic focusing horns
- tunable beam energy by modifying target/horn positions
- design: 4.0 10^{13} protons on target (PoT)/spill, 1.9s rep. rate, ~10 μs spill ⇒ 400 kW



BNL Contributions

- Raw beam monitoring data stream (B. Viren)
- Online beam monitoring (M. Bishai, B. Viren)



- Processing beam data (B. Viren, M. Bishai, M. Dierckxsens)
- Beam stability studies (M. Bishai, M. Dierckxsens)
- Strong presence at FNAL during commissioning
- BNL has 24h on-call duties for beam monitoring data taking

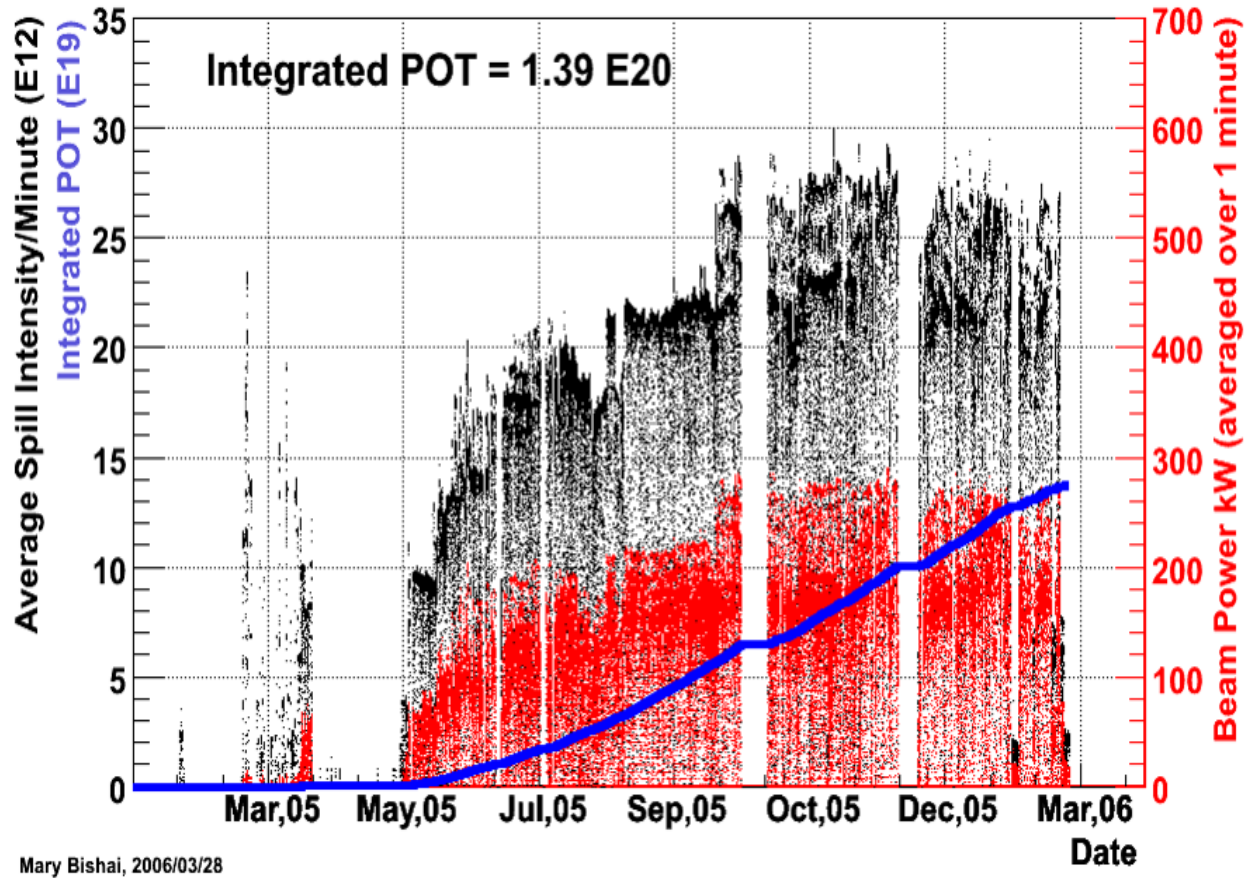
Counting Protons

- Beam Monitoring Database Framework (B. Viren, M. Bishai, M. Dierckxsens)
  - database on spill-by-spill basis
  - provides easy, robust, reliable interface to match detector data with beam monitoring data
- Incorporation of beam mon. info, such as PoT per spill, into standard analyses (M. Dierckxsens)
- Interface for applying beam quality cuts (M. Dierckxsens, Minos-doc-1486)
- Systematics of counting protons on target (M. Bishai, Minos-doc-1491)

First year of running

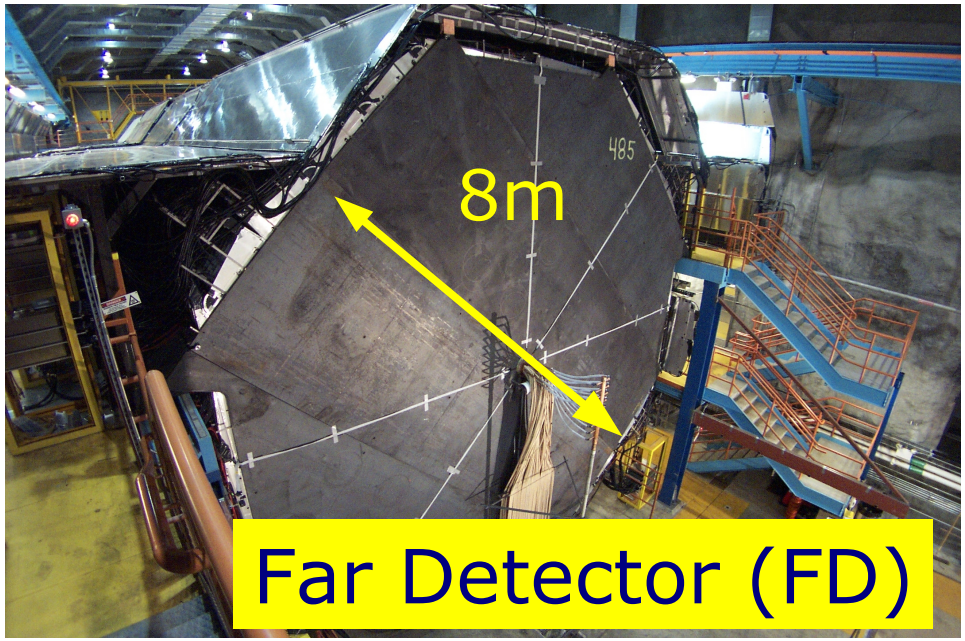
- First neutrino interaction in ND: Jan. 21, 2005
- Physics run: March 05 – Feb. 06: 1.4×10^{20} PoT

  Most at Low Energy configuration for maximum sensitivity to atmospheric oscillations result
- Achieved:
  - ✓ 3×10^{13} PoT/spill
  - ✓ 270 kW (~30 min)



MINOS Detectors

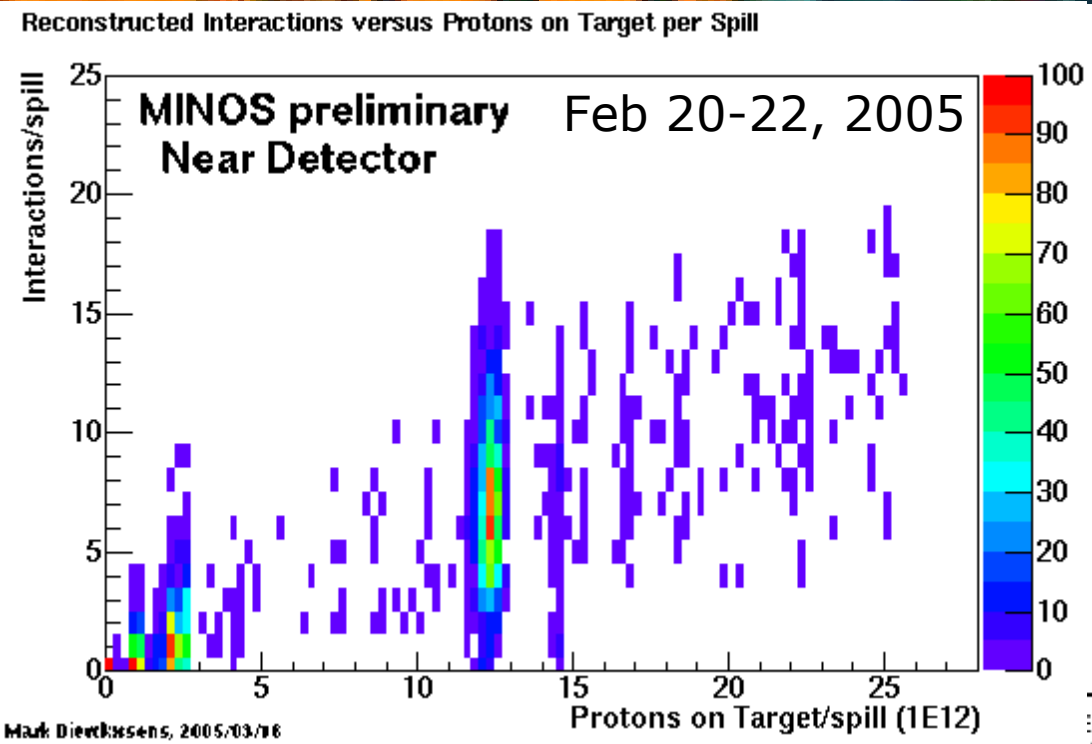
- 1 inch steel planes, magnetized ~1.2T
- 4.1x1cm^2 scintillator strips
- 1.2mm wavelength shifting fiber
- Hamamatsu multi-channel PMTs



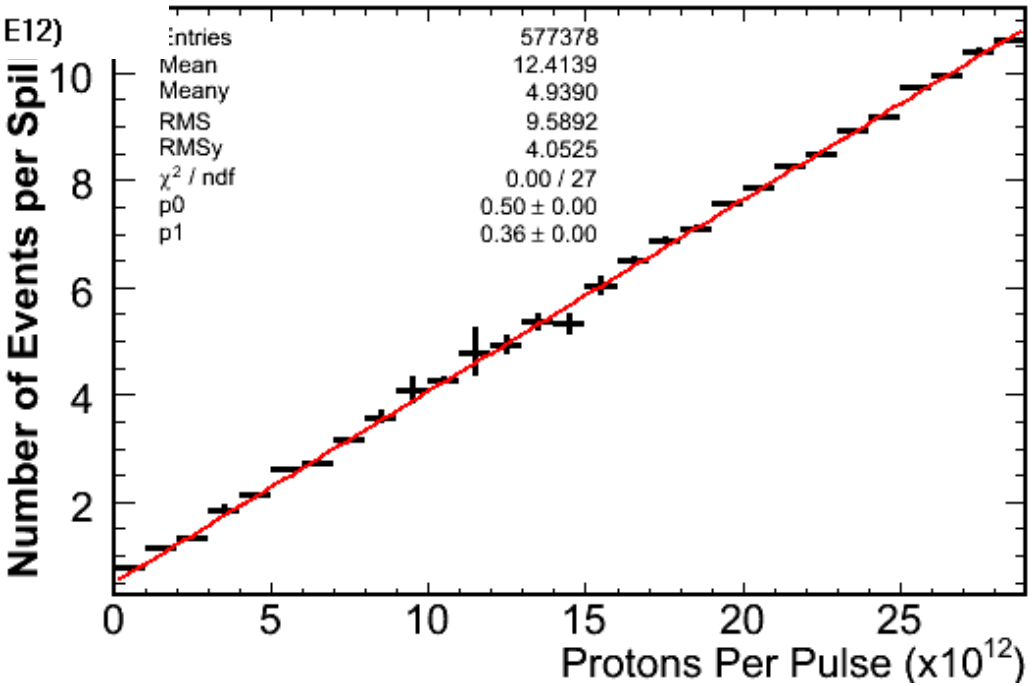
- 100m underground
- 282 planes: 0.98 kton
- high-rate electronics

- 700m underground
- 486 planes: 5.4 kton
- veto shield for cosmics

ND data vs. PoT

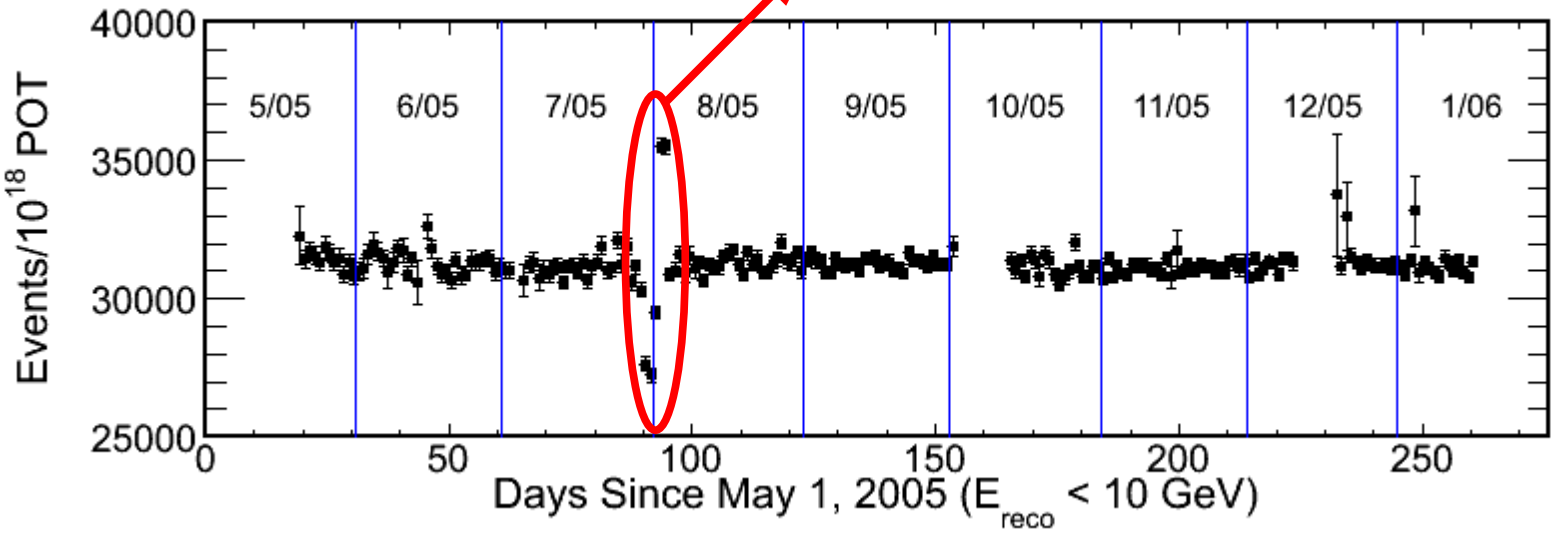


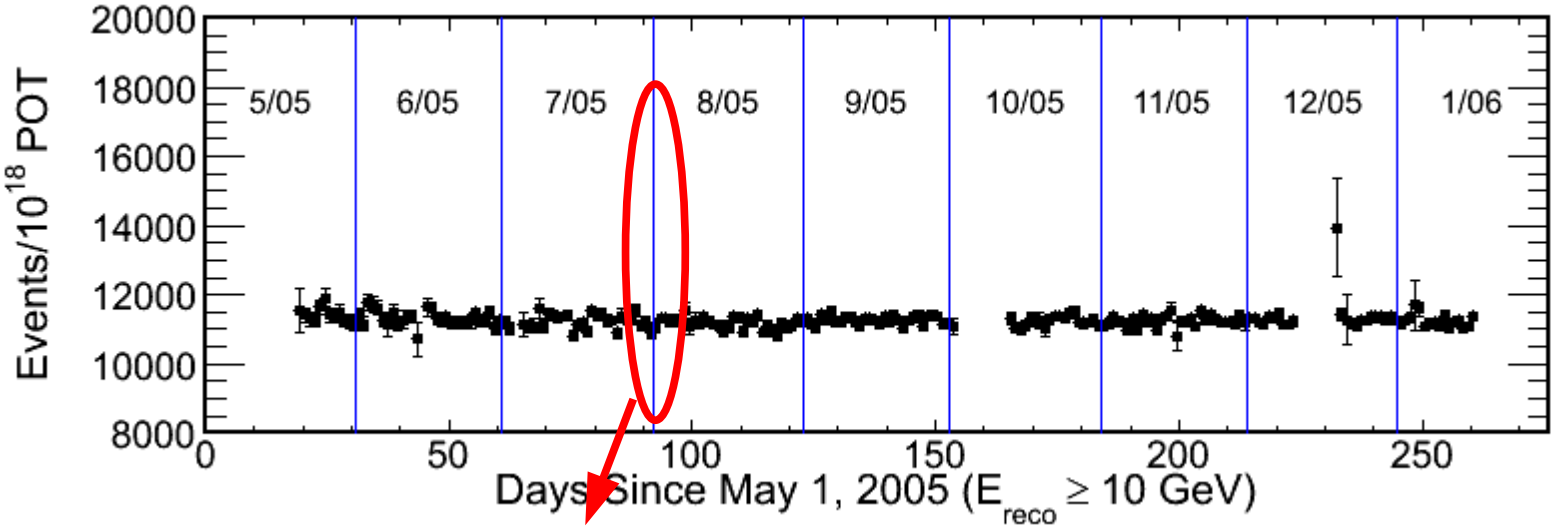
- Correlating beam monitoring with ND data (M. Dierckxsens)



ND event rate vs. time

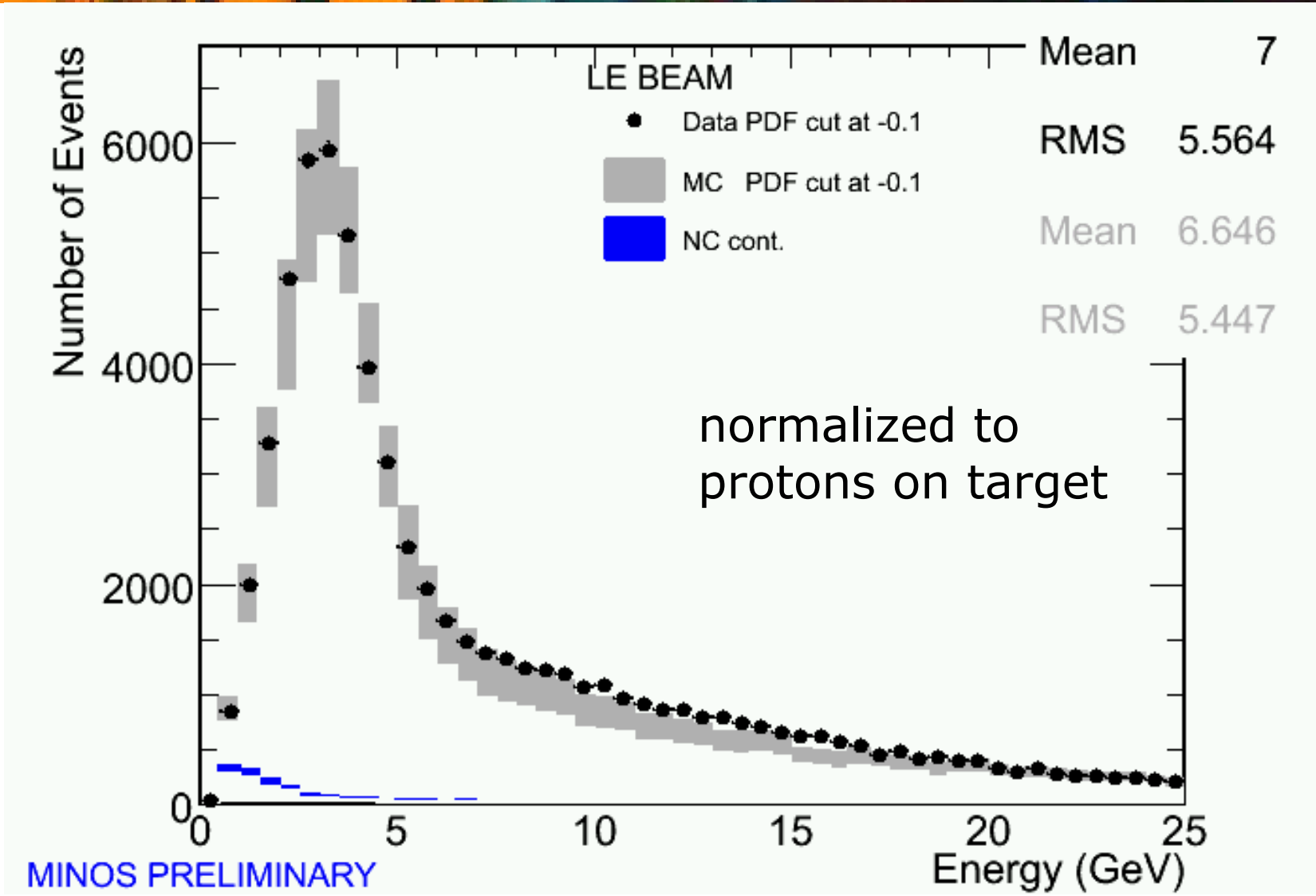
Horn Current Test Runs





High energy spectrum not affected

ND LE Spectrum



- MC error envelope: uncertainties due to cross section modeling, beam modeling and calibration

Hadron Production Tuning

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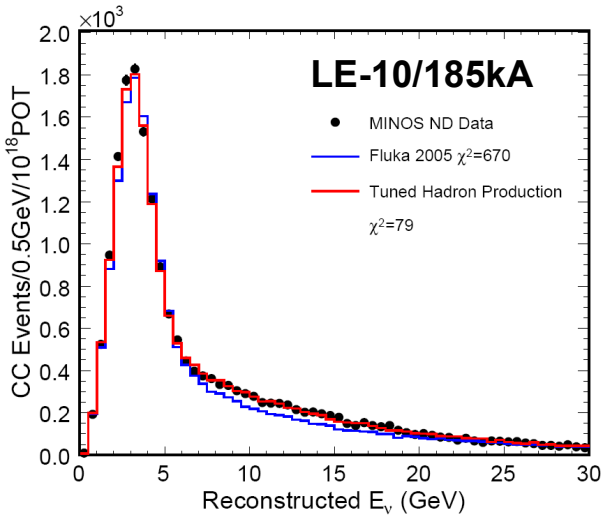
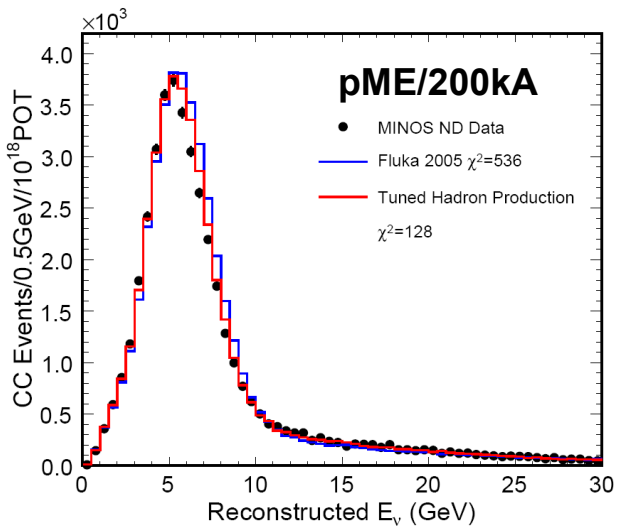
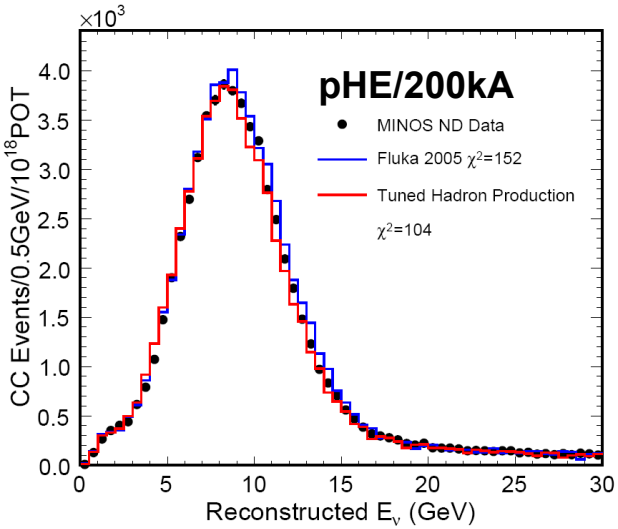
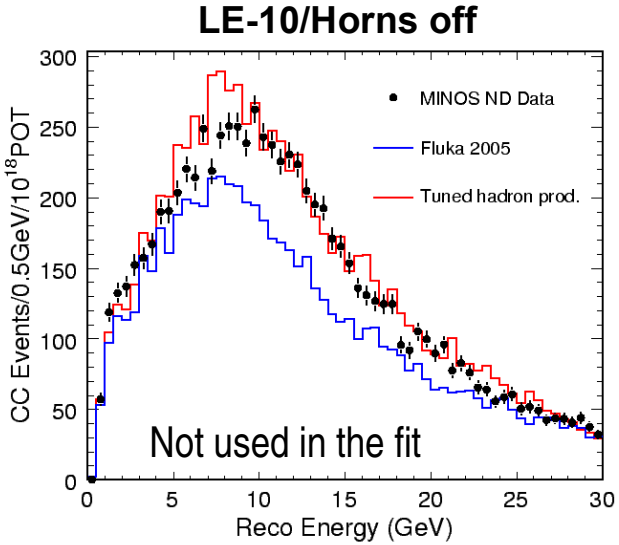
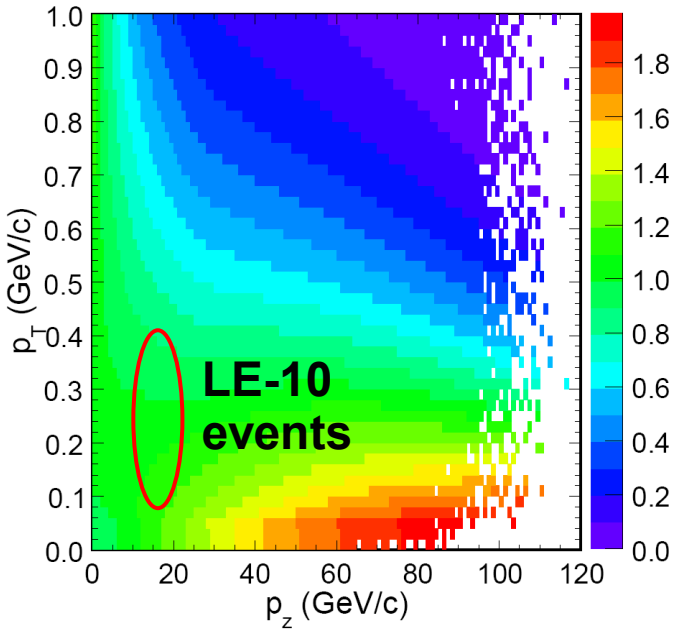
Good agreement data - Fluka05 Beam MC, tuning MC by fitting to hadronic x_F and p_T, improves agreement.







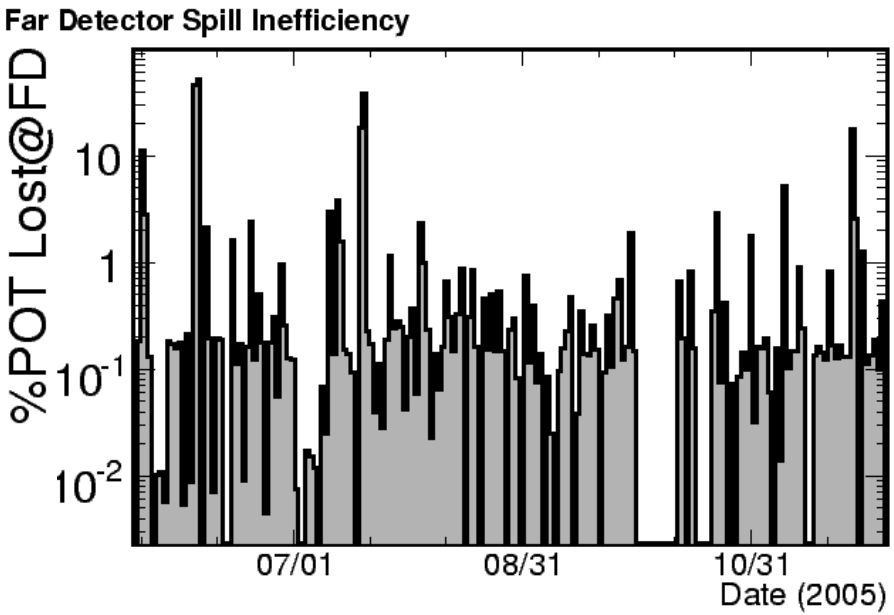


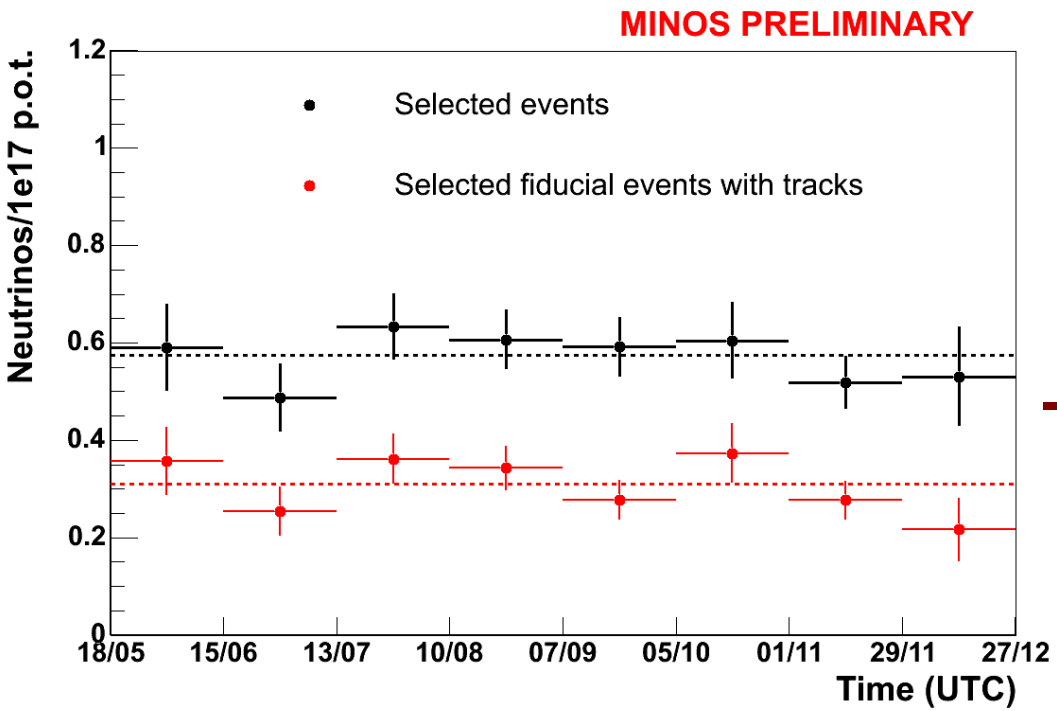


Weights applied as a function of hadronic x_F and p_T.

FD data sample

- Data sample: May 20th 2005 – Dec. 6th 2005
  - Integrated PoT: 0.93×10^{20}
  - Far detector livetime: 98.9% (PoT weighted)





→ event rate consistent over time

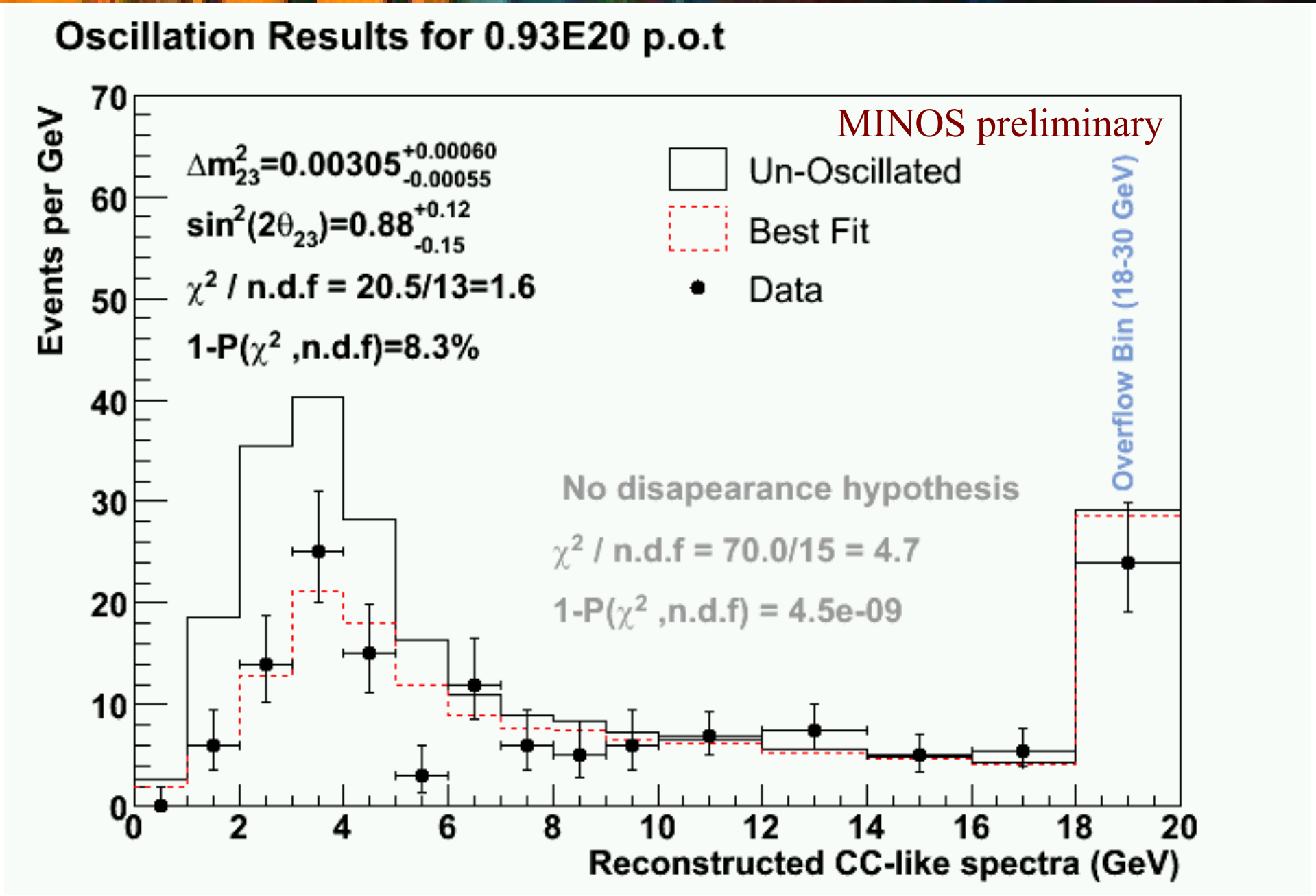
FD event selection

Cut	Events	Efficiency	Expected	Significance
all events in fid. vol.	331	-		
CC selection	204	61.6%	298±23	4.1σ
negative track charge	186	91.2%		
visible energy < 30 GeV	166	89.2%	249±21	4.0σ
visible energy < 10 GeV	92	55.4%	177±17	5.0σ

Main BNL contributions are: normalization & error, beam quality cuts, software support

contains statistical & systematic uncertainty

FD spectrum


Oscillation Results for 0.93E20 p.o.t
MINOS preliminary
$\Delta m^2_{23}=0.00305^{+0.00060}_{-0.00055}$
$\sin^2(2\theta_{23})=0.88^{+0.12}_{-0.15}$
χ^2 / n.d.f = 20.5/13=1.6
1-P(χ^2 ,n.d.f)=8.3%
Un-Oscillated
Best Fit
Data
No disapearance hypothesis
χ^2 / n.d.f = 70.0/15 = 4.7
1-P(χ^2 ,n.d.f) = 4.5e-09
Overflow Bin (18-30 GeV)
Events per GeV
Reconstructed CC-like spectra (GeV)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20

Electron Appearance

- BNL has strong interest in ν_e appearance
  - First sensitivity study (M. Diwan, B. Viren et al., Numi-714, 2001)
- M. Diwan is co-convener of ν_e analysis group
- Plan to have first results by Dec. 2006
- Expected events for 1.4×10^{20} PoT:

NC	3.21	(67%)
CC	0.54	(11%)
Beam ν_e	0.70	(15%)
ν_τ ($\Delta m^2 = 3 \times 10^{-3}$ eV^2)	0.36	(7%)
total background	4.81	

$\sin^2 2\theta_{23} = 1.0$

$\Delta m^2_{32} = 0.003$ eV^2

$\sin^2 2\theta_{13} = 0.12$

↓

3.6 signal events

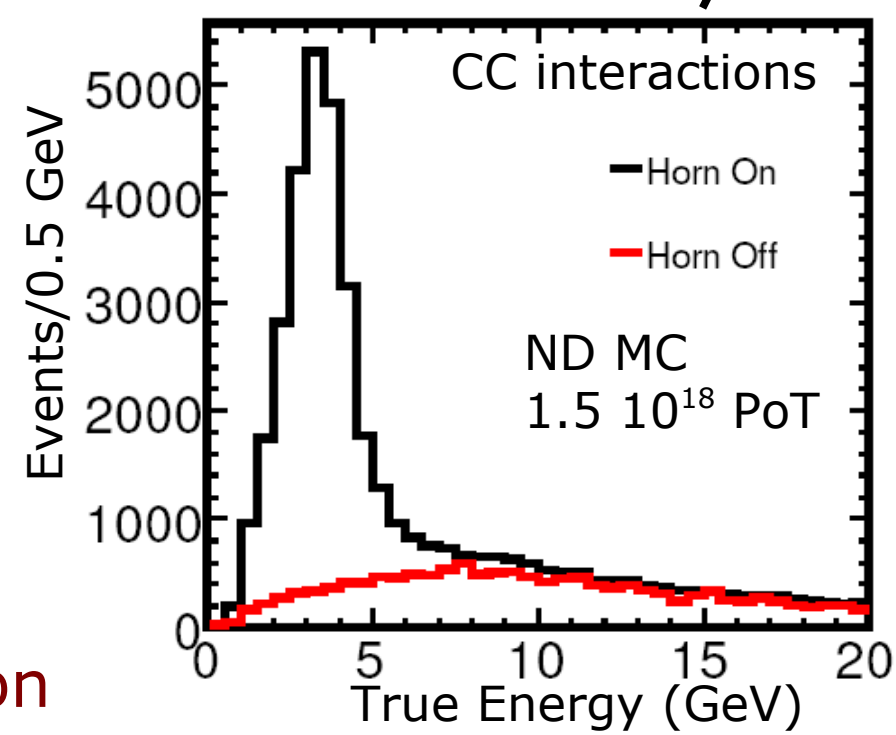
Electron Appearance

- Recently developed complete analysis strategy:
  Try to estimate all backgrounds from data.
  → uncertainty better than 30%

- Horn off running: disentangle NC from CC:
  - horn off eliminates the peak, high energy tail remains
    ⇒ high purity NC sample (~85%)

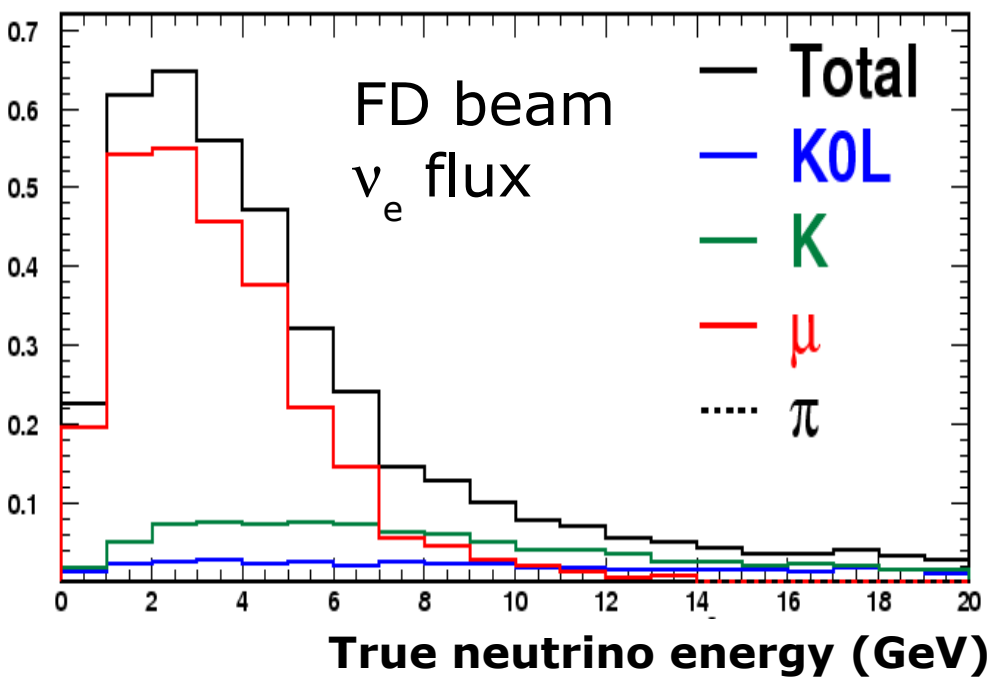
- Muon removal from reconstructed CC ν_μ interactions:
  - estimate the NC contamination

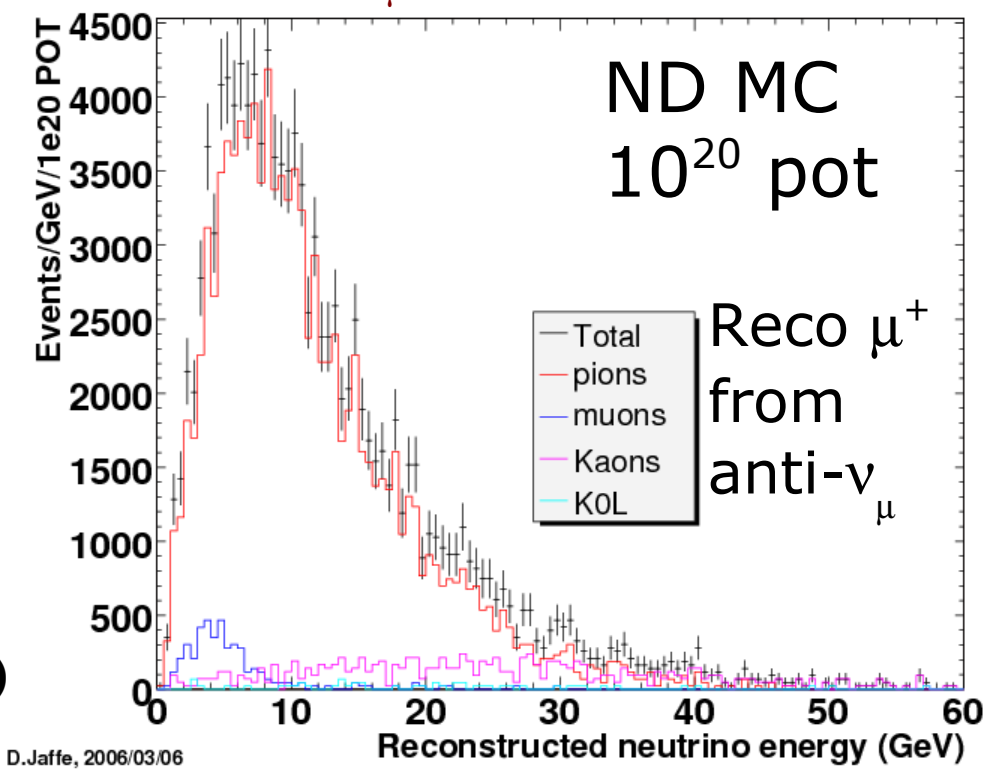
similar for NC



Electron Appearance

- Estimate ν_e FD flux from $\bar{\nu}_\mu$ in ND (D. Jaffe)
  - FD ν_e flux dominated by $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$
  - Measure μ^+ decay component in ND $\bar{\nu}_\mu$ event rate





- Incorporating ν_μ disappearance fit (M. Dierckxsens)
  - normalization from Δm^2

Conclusions

- MINOS finished first year of data taking collecting in total 1.4×10^{20} protons on target
- BNL has contributed substantially to the commissioning, in particular to beam monitoring readout and data analysis
- Preliminary ν_μ disappearance result (0.93×10^{20} PoT):

$$\Delta m^2_{32} = 3.05^{+0.60}_{-0.55}(stat) \cdot 10^{-3}\ eV^2$$

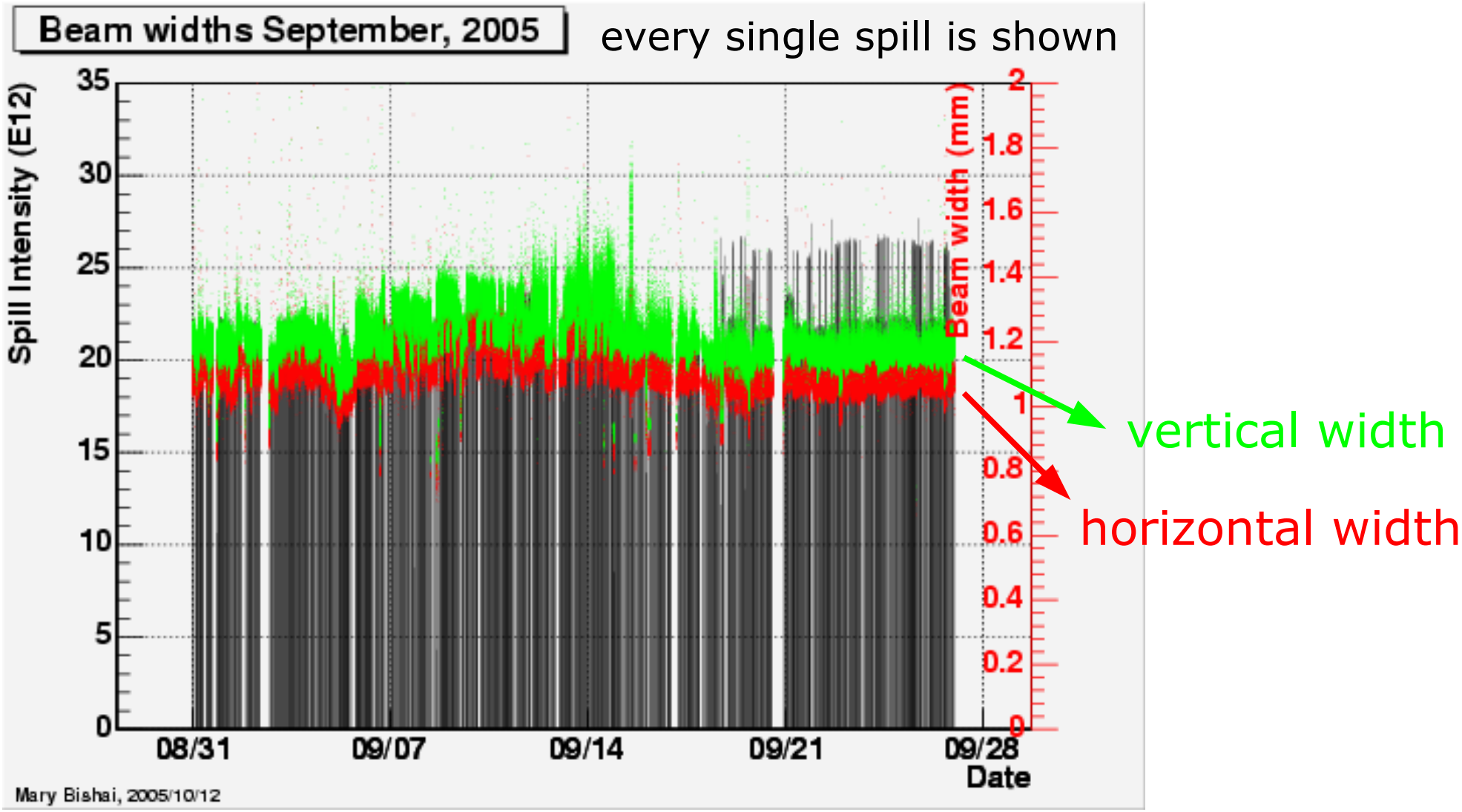
$$\sin^2 2\theta_{23} = 0.88^{+0.12}_{-0.15}(stat)$$

- Solid ν_e appearance analysis in development with large BNL involvement, expect results by the end of the year

Backup slides

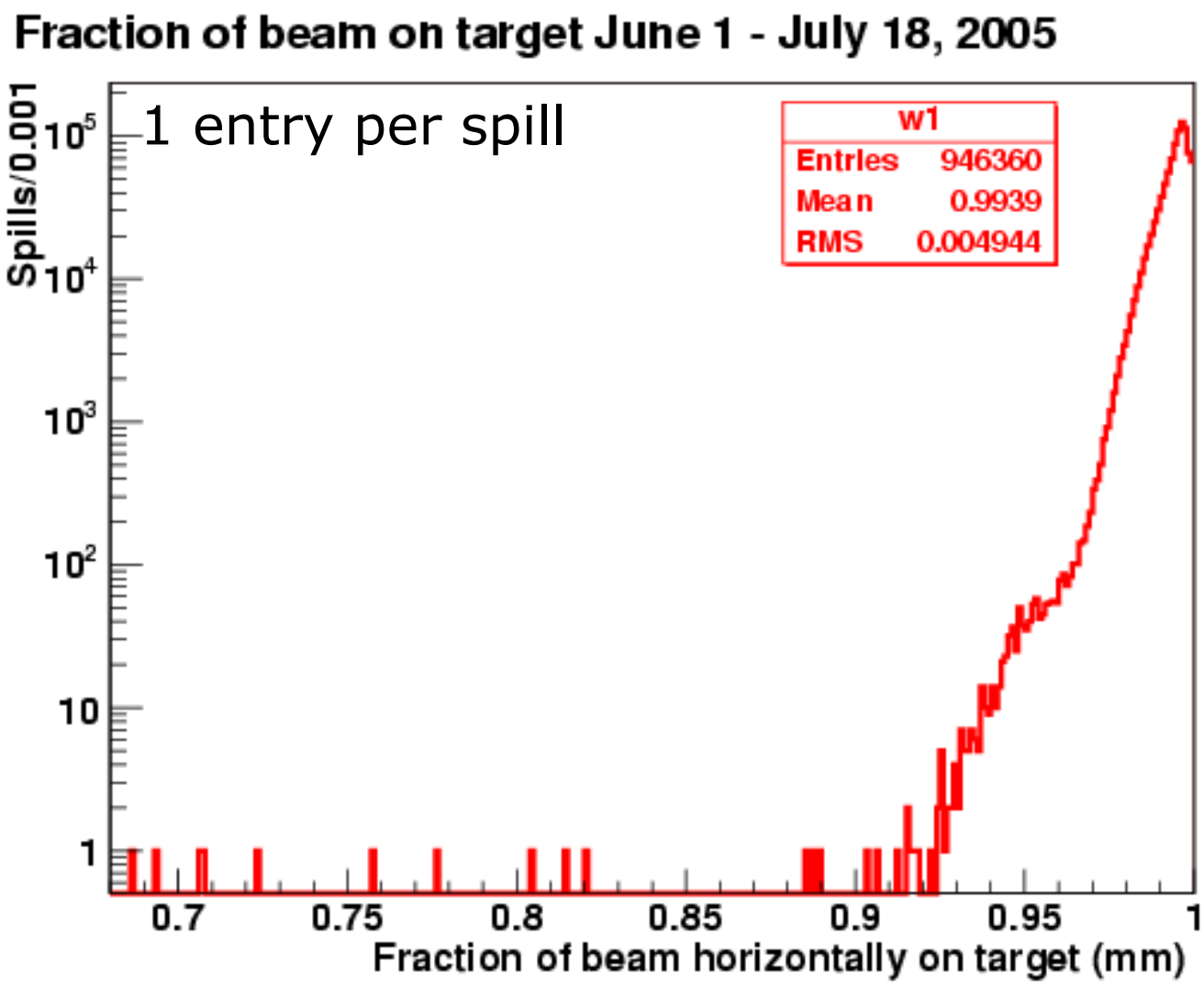
Beam Stability

- Very stable run conditions most of the time



Beam Stability

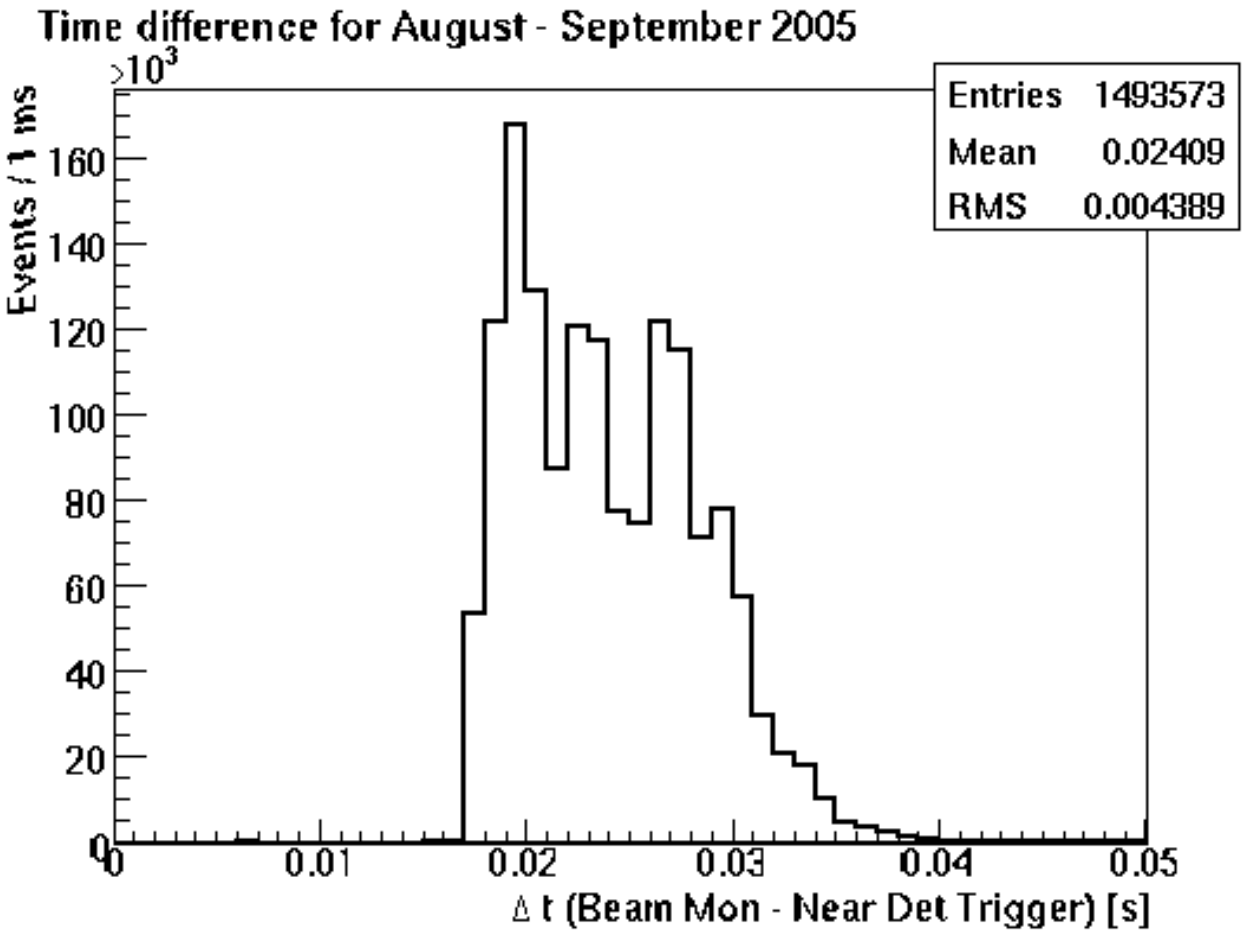
- Can calculate fraction of the beam hitting the target accurately using beam instrumentation



- Less than 0.5% of the protons are off the target

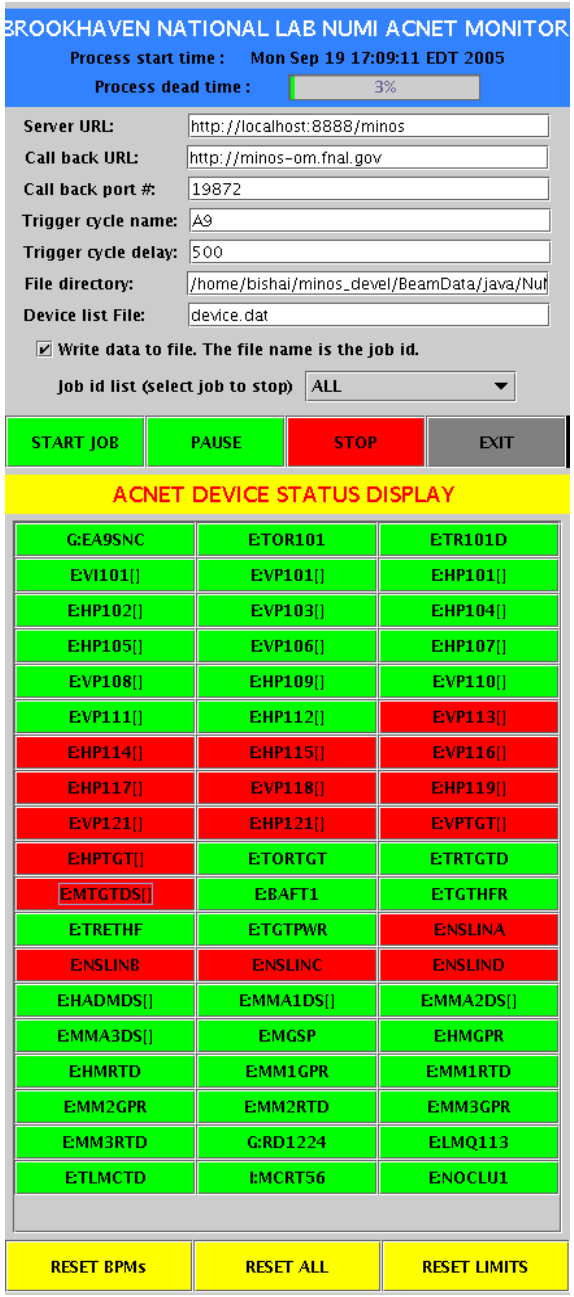
Beam Monitoring Timing

- Time difference between beam monitoring devices and near detector trigger time



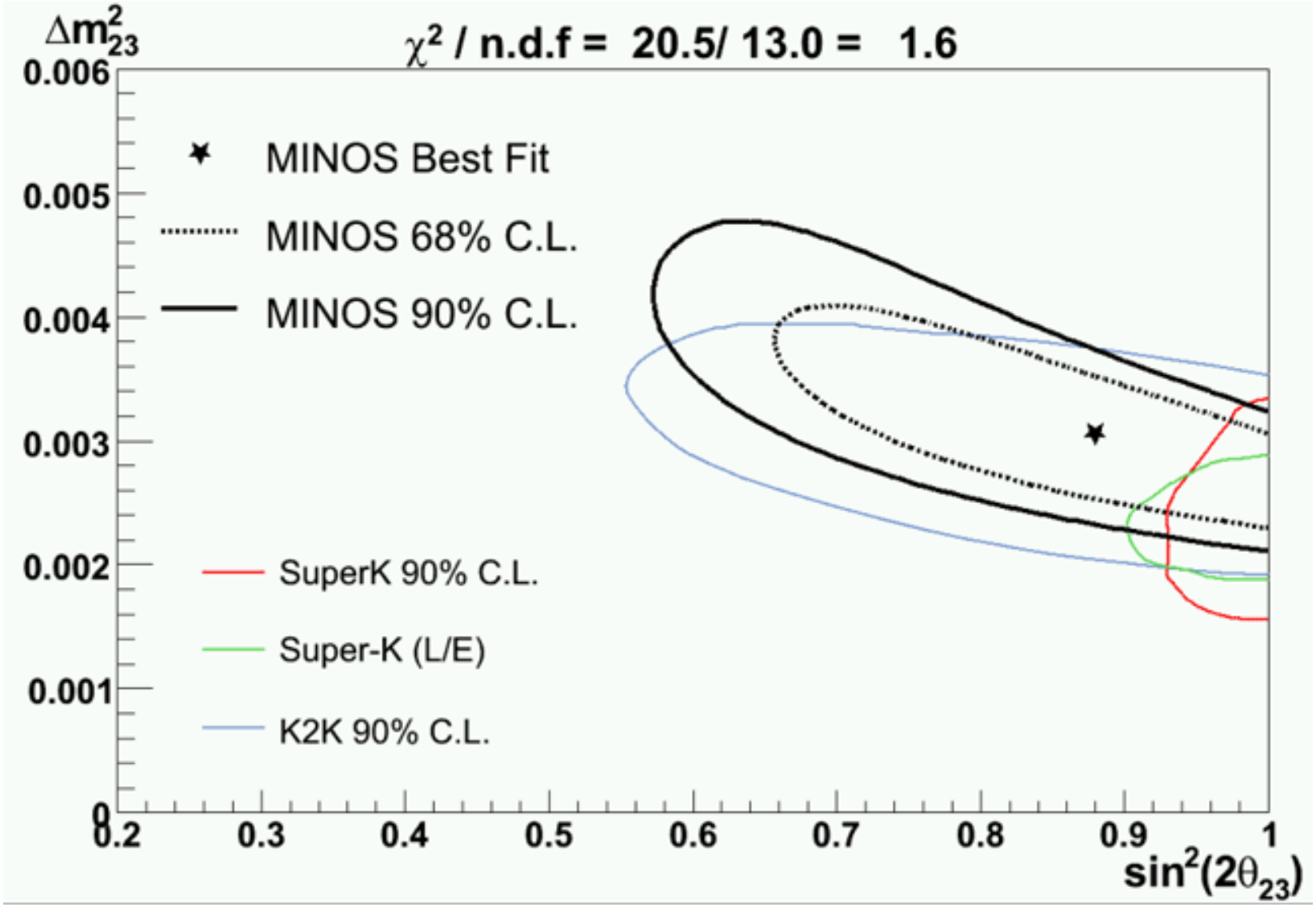
- Time difference well within 30ms
- Much smaller than spill repetition rate
- Allows unambiguous matching of beam info with near and far detector data

Online Monitoring



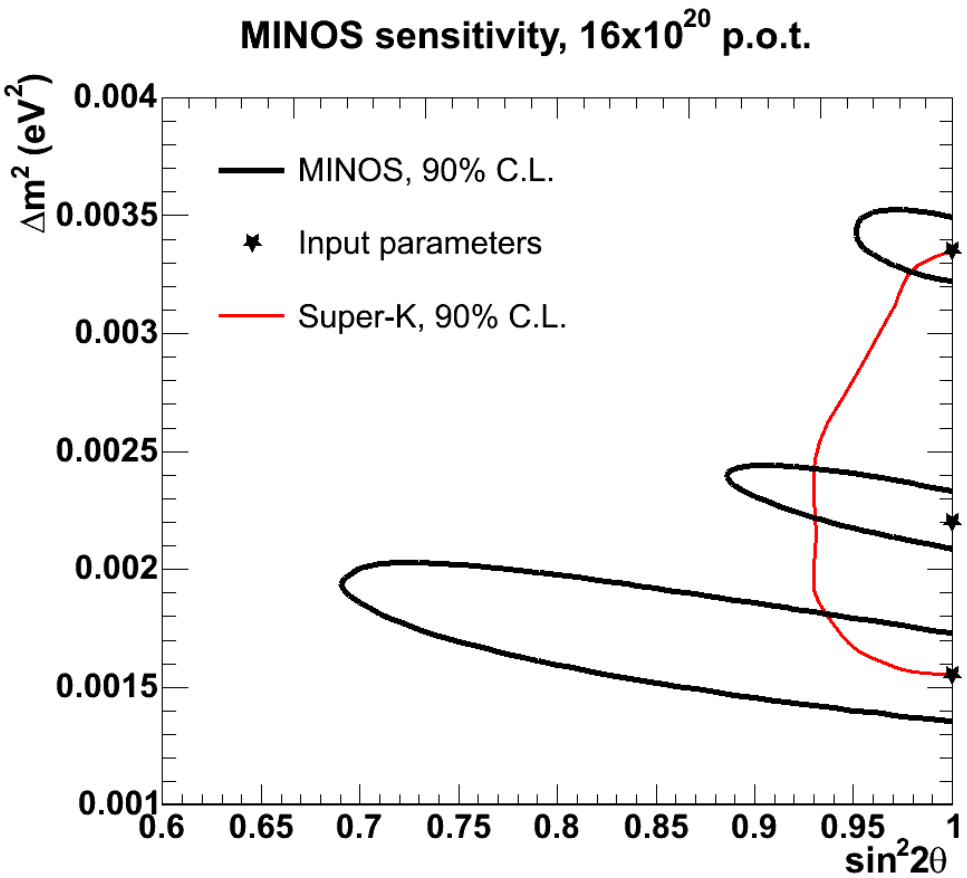
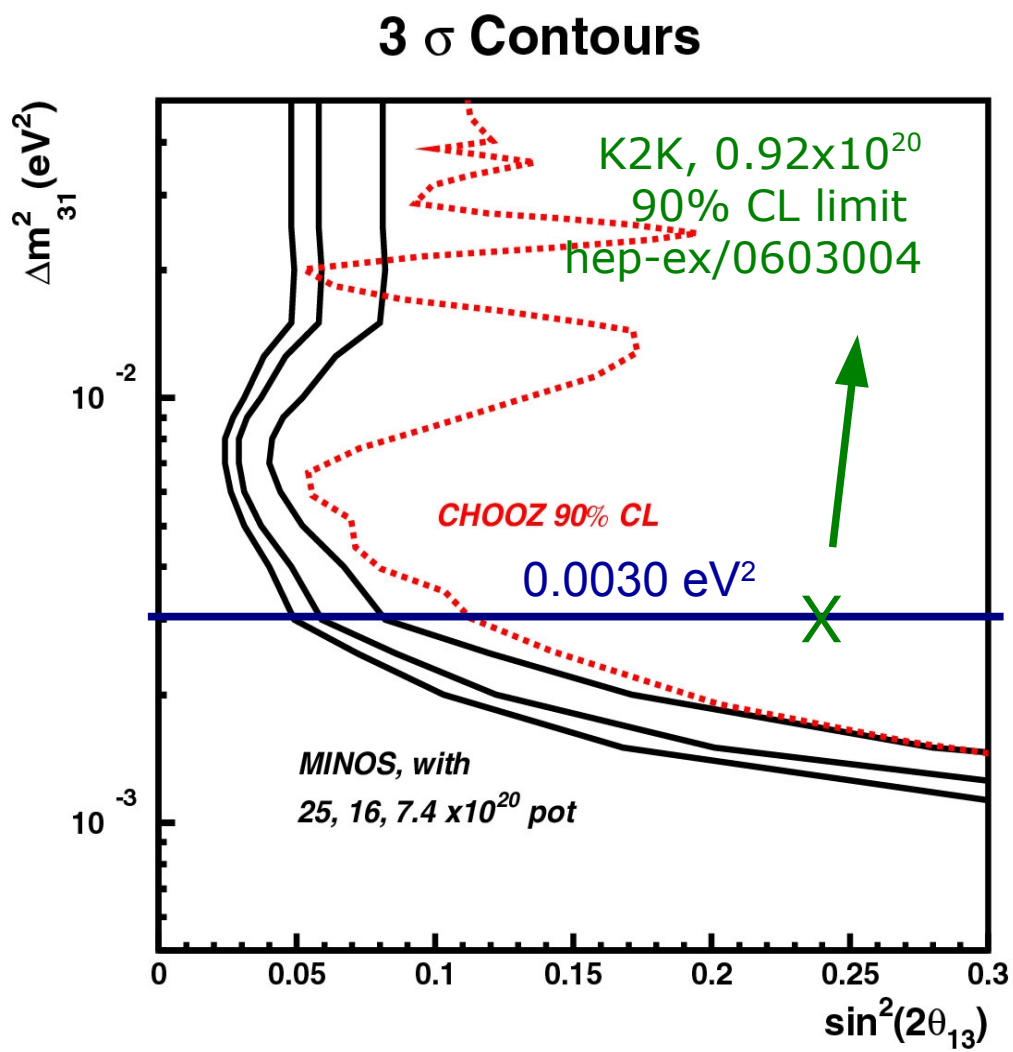
- Screen shot of the alarm system that is part of the beam instrumentation online monitoring display
- Shifters can spot problems with the beam stability and readout of the devices very quickly, usually before the Main Control Room does

FD fit results



Projected Sensitivities

ν_μ disappearance



ν_e appearance