The MINOS Experiment

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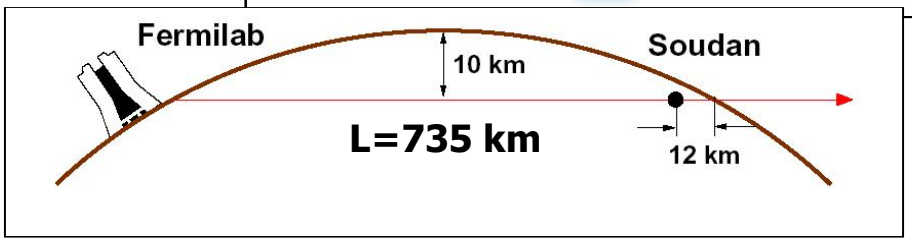
MINOS concept

High power ν_μ beam produced by 120 GeV protons from the FNAL main injector

Compare spectra:

near(1kT) $\Longleftrightarrow$ far(5.4kT)

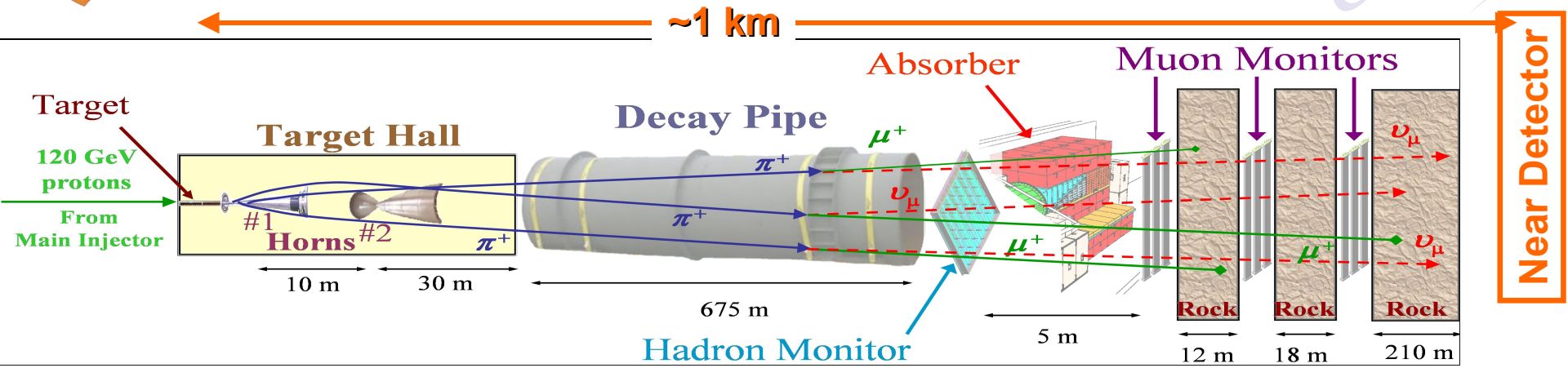
unoscillated $\Longleftrightarrow$ oscillated



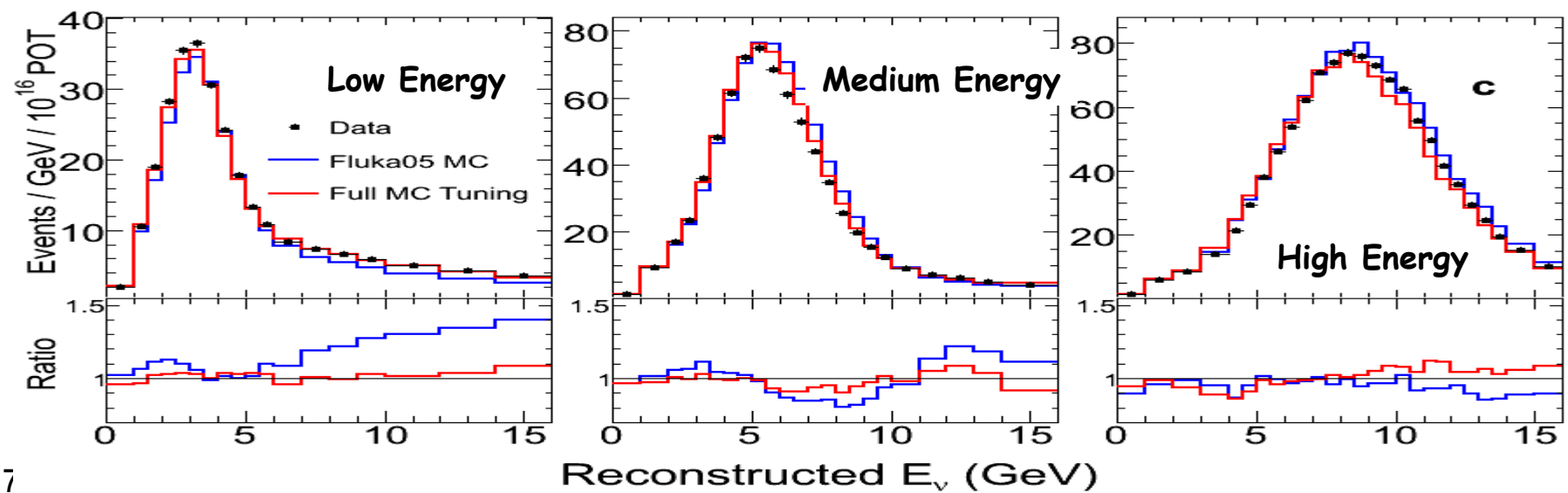
BNL group:

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

NuMI Beamline



- 120GeV protons incident on 1m graphite target with 2 magnetic focussing horns.
- Tunable ν_μ beam energy by moving target/horn



MINOS Physics Goals

- Test the $\nu_\mu \to \nu_\tau$ oscillation hypothesis

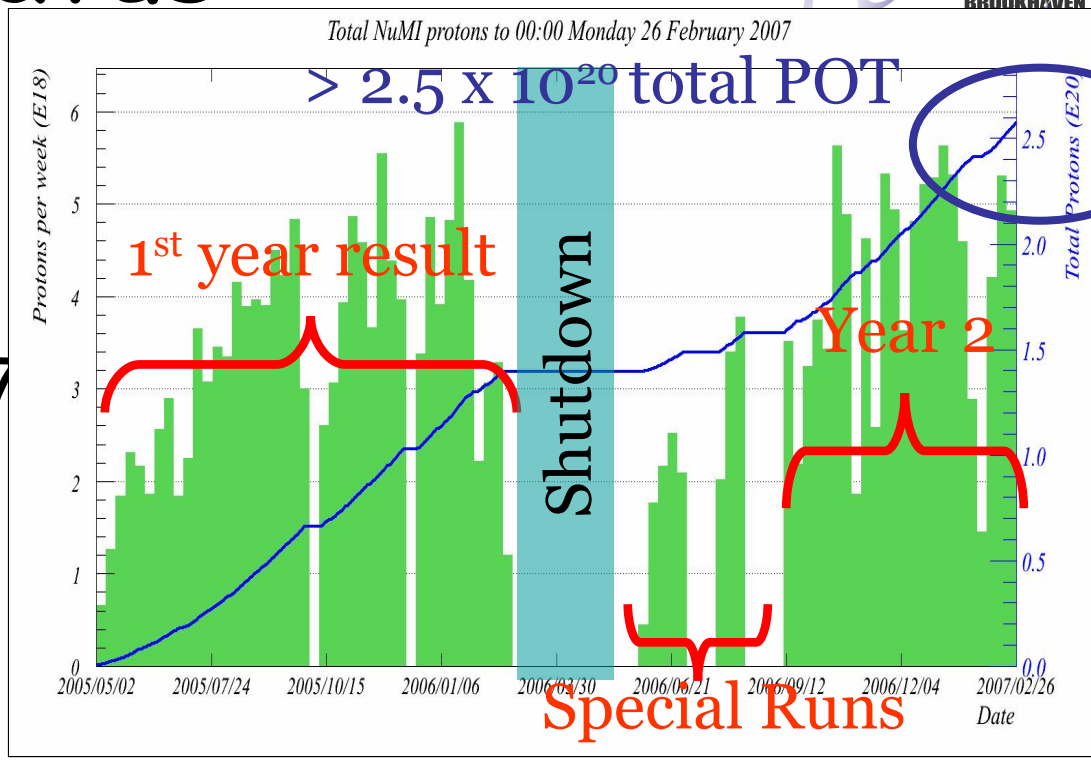
  (First year results: Phys.Rev.Lett. **97** (2006) 191801)

  - Measure $|\Delta m^2_{32}|$ and $\sin^2 2\theta_{23}$ more precisely
- Search for sub-dominant $\nu_\mu \to \nu_e$ oscillations
  - Limit $\sin^2 2\theta_{13}$
- Search for or constrain exotic phenomena
  - Sterile ν, $\bar{\nu}$ decay, $\nu \to \nu$ transitions, ν time-of-flight
- Compare ν, $\bar{\nu}$ oscillations
  - Test of CPT violation
- Atmospheric neutrino oscillations
  - **Phys. Rev. D73, 072002 (2006)**

MINOS Status

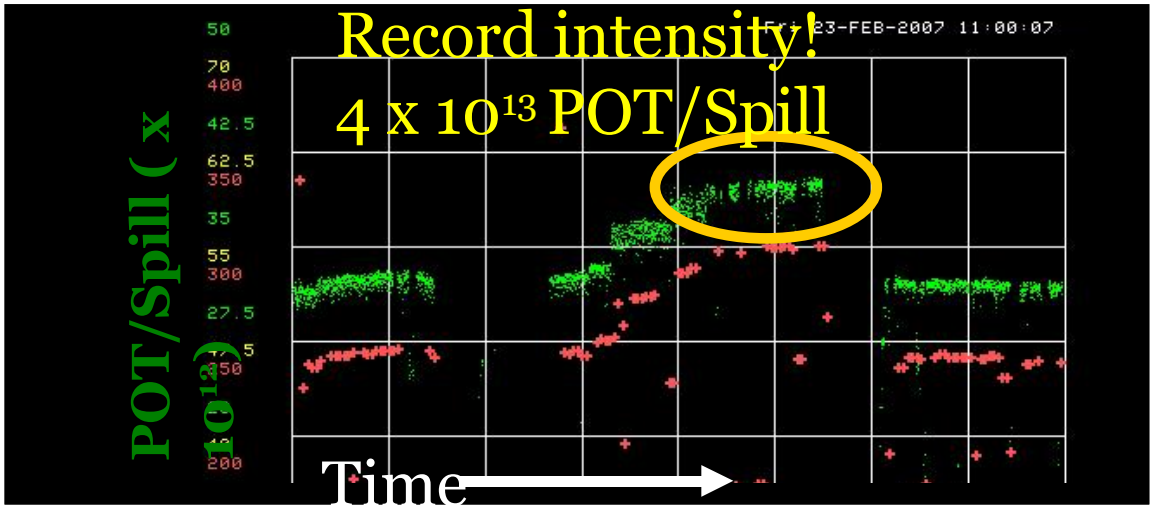
Second run in progress since Sept2006.

Expect at least 2.5×10^{20} POT by July07 shutdown.



Increasing intensity/spill

Design:
4×10^{13} POT/spill
at 1.9s rep.rate
with 10 μs spill length:
400kW



BNL Contributions

- Strong on-site presence during 1st year beam commissioning
- Developed & maintain extensive & complete beamline monitoring tools (M.Bishai,M.Dierckxsens,B.Viren)
- Beam monitoring on-call experts (M.Bishai,B.Viren)
- Support & maintain offline software framework (B.Viren)
- Analysis of the geometry & physics of the beam simulation (D.Jaffe)
- Analysis of muon decay-in-flight (M.Dierckxsens)

BNL Contributions(cont.)

- Provided offline tools to ensure beam data quality and count protons-on-target. Allows spill-by-spill analysis and normalization. Used for published ν_μ disappearance analysis, essential for all oscillation analyses requiring normalization. (M.Dierckxsens->H.Zhang)

BNL Responsibilities

- M.Dierckxsens: official MINOS database czar. Oversee & assist in filling of databases
- M.Bishai: co-convenor of beam systematics working group.
- M.Diwan: co-convenor of ν_e appearance working group

Publications & Presentations

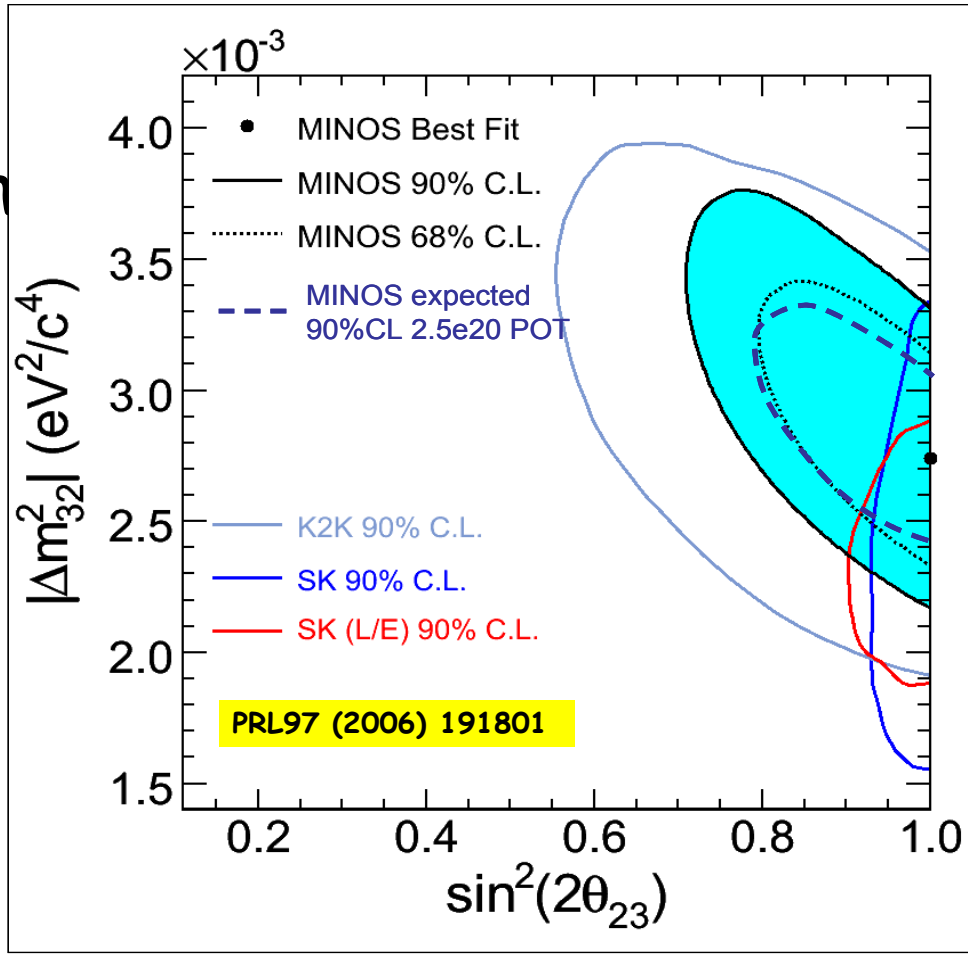
- *"Beam-Based Alignment of the NuMI Target Station Components at FNAL"* NIM **A568** (2006) 548 (M.Bishai, B.Viren)
- *"Secondary beam monitors for the NuMI facility at FNAL"* NIM **A568** (2006) 503 (M.Bishai, M.Dierckxsens, M.Diwan, B.Viren)
- *"Primary Proton Beamline for the Fermilab Main Injector Neutrino Program"*, draft NIM paper (M.Bishai, B.Viren)
- M.Dierckxsens, *"Recent Results from the MINOS Experiment"*,APS-DPF+ JPS 2006, Nov2006,Hawaii.
- M.Bishai, *"The Neutrino Beamline for the MINOS Experiment"*, APS, Dallas, April2006; *"New Results from MINOS"*, SUSY 2006, Irvine, June 2006; *"The Neutrino Beamline for the MINOS Experiment: Year 1"*, NuFACT 06, Irvine, August2006
- D.Jaffe, *"Latest Results from MINOS"*, HQL06, Munich, Oct2006

MINOS Physics

Update to published ν_μ disappearance analysis with ~twice as much data (~2.5×10^{20} POT) by July 2007

Incremental improvements

- Improve signal selection efficiency
- Larger FD fiducial volume
- Inclusion of $\overline{\nu}_\mu$



ν_e Appearance Sensitivity

SIXTY YEARS OF DISCOVERY 1947-2007
BROOKHAVEN NATIONAL LABORATORY

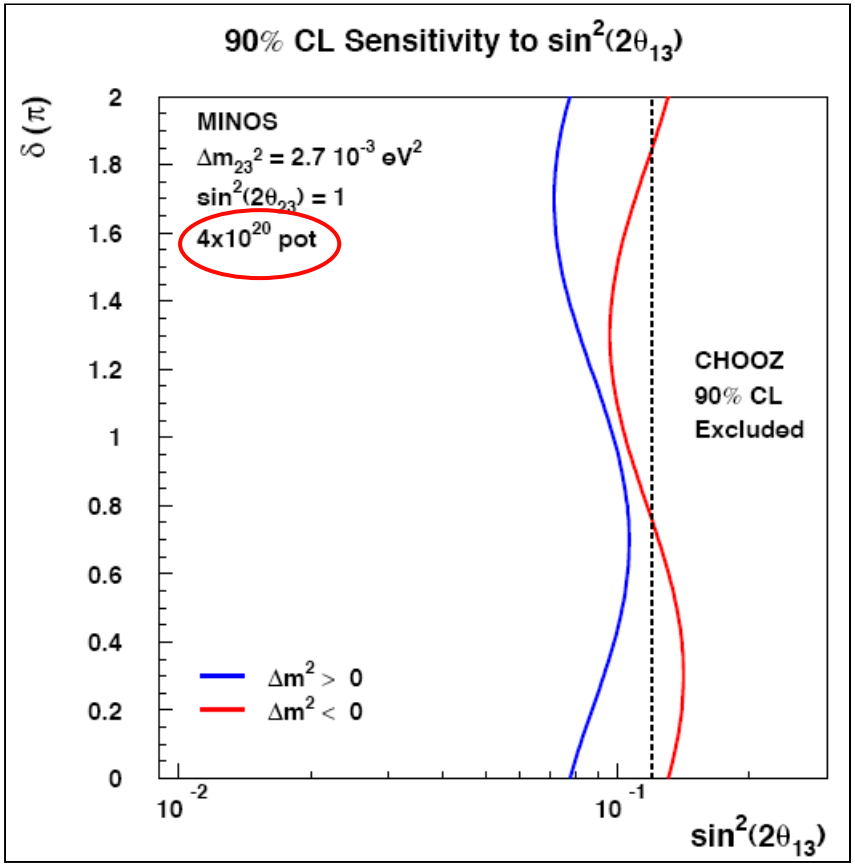
Backgrounds

NC events (primary background) π^0 final states in hadronic system produce EM showers

Intrinsic beam ν_e are identical to signal

High-y ν_μ CC Hadronic shower dominates; muon track is very short or buried

FD: Oscillated ν_τ generally shower-like; τ^- decays to e^- ~20% of the time



Neural Net selection results

Assumptions:

$\sin^2(2\theta_{13}) = 0.1$

$|\Delta m_{32}|^2 = 2.7\times10^{-3} eV^2$

$\sin^2(2\theta_{23}) = 1$

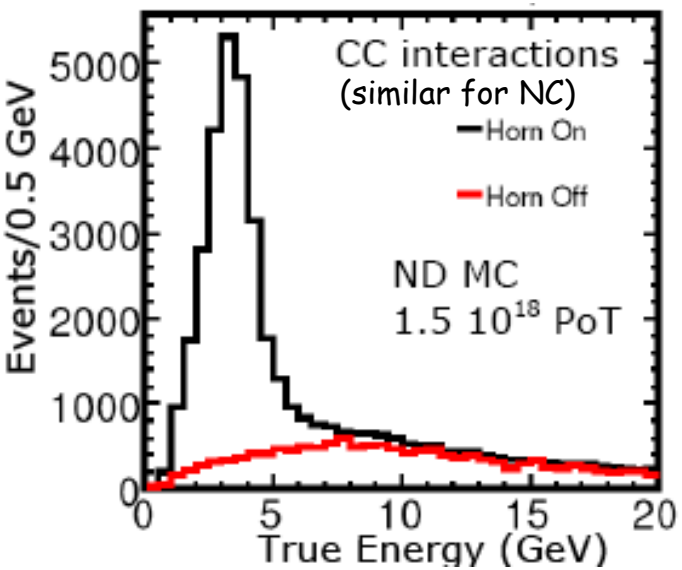
POT = 4×10^{20}

Expected results (number of events)

ν_μ CC	NC	ν_e^{beam}	ν_τ CC	Total	ν_e^{osc}
1.4	9.75	2.2	1.2	14.5	7.3

ν_e Appearance Sensitivity

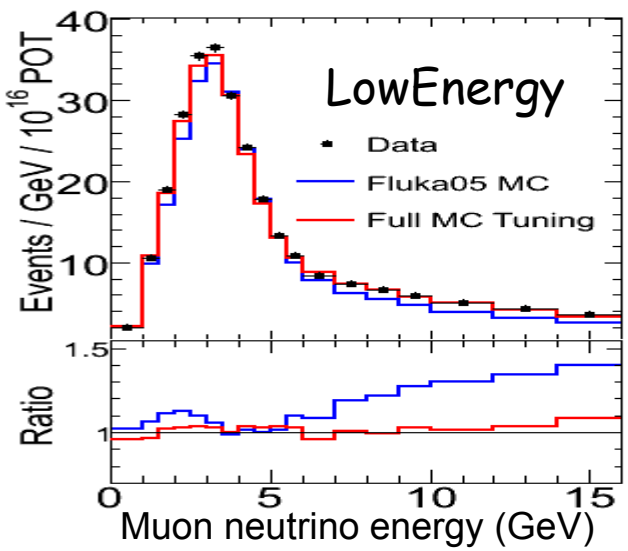
- Reliable & robust background estimation essential. Establish 2 methods to estimate **major backgrounds** from data.
- Most NC bkgd from high energy tail that remains with horn-off. Use horn-off running to separate NC & CC
- Remove muon from reconstructed CC ν_μ interactions to estimate NC contamination



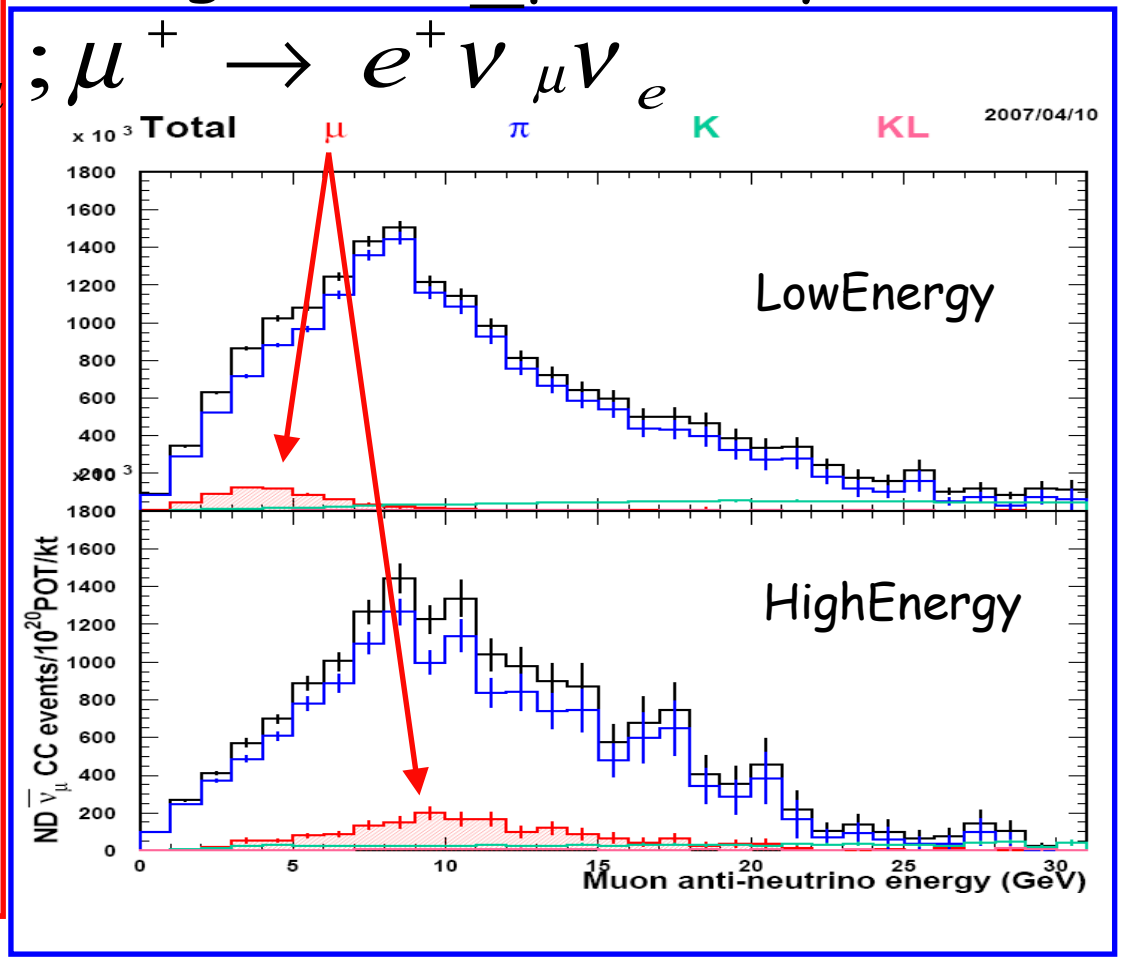
ν_e Appearance Analysis

- Low energy beam ν_e background is primarily due to

$$\pi^+ \rightarrow \mu^+ \nu_\mu ; \mu^+ \rightarrow e^+ \nu_\mu \nu_e$$



1. Adjust π^+ spectrum to agree with measured ν_μ spectrum and infer resulting ν_e spectrum



2. Use difference between $\bar{\nu}_\mu$ spectra for LowEnergy and HighEnergy beam configurations to extract the ν_e component in LowEnergy configuration (D.Jaffe).

Conclusions

- BNL continues to provide MINOS beamline monitoring and ensure offline beam data quality for reliable spill-by-spill normalization
- Expect ν_μ disappearance results after summer 2007 shutdown
- BNL has a lead role in ν_e appearance analysis; expect results summer 2008