The Fermilab Neutrino Program

Presented by

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on Neutrino Factories and Superbeams
Laboratori Nazionali di Frascati

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Outline of this Talk

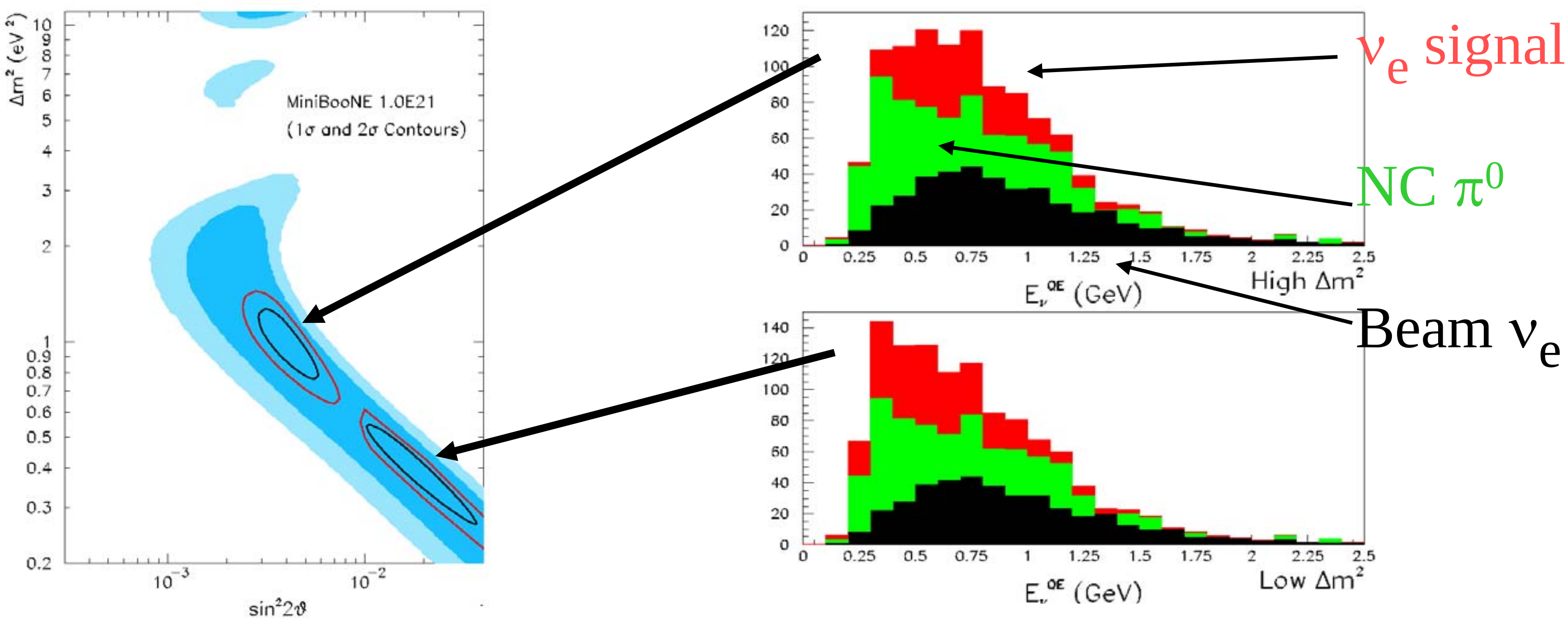
- Fermilab - an exciting present program
  - MiniBoone
  - MINOS
- Moving agressively into the future
  - NOvA
  - Minerva
- Varied and diverse additional efforts
  - More detector efforts and collaborative plans
  - Other types of facilities (reactors, DUSEL)
- Laboratory plans and direction
- Conclusions

MiniBoone – testing LSND at Fermilab

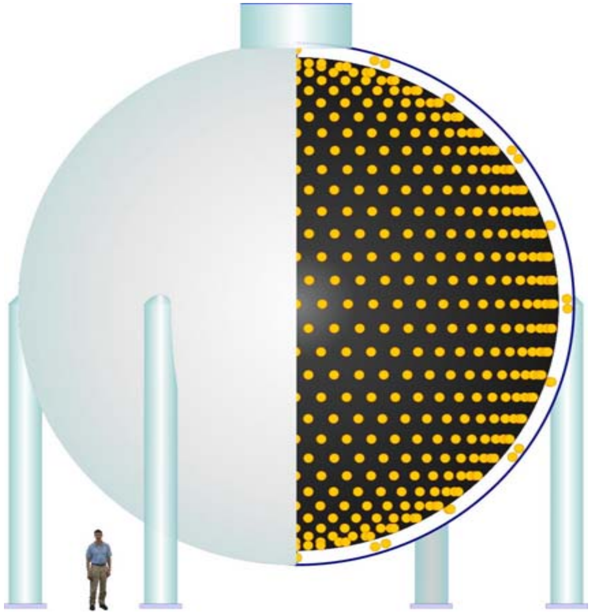
Check/confirm LSND oscillation signal at Fermilab Booster

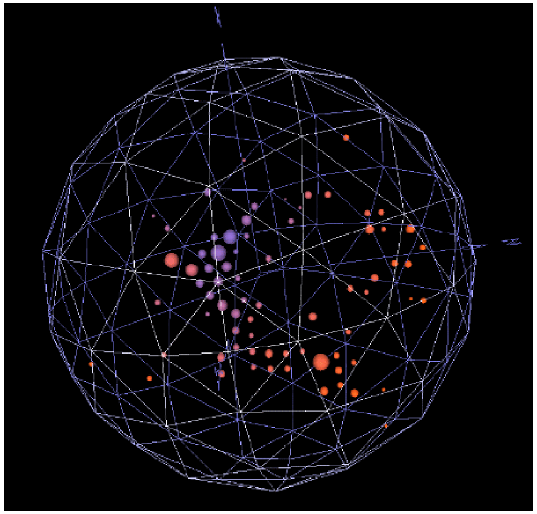
Different systematics from previous experiment

- L=540 m ~10x LSND
- E~500 MeV ~10x LSND



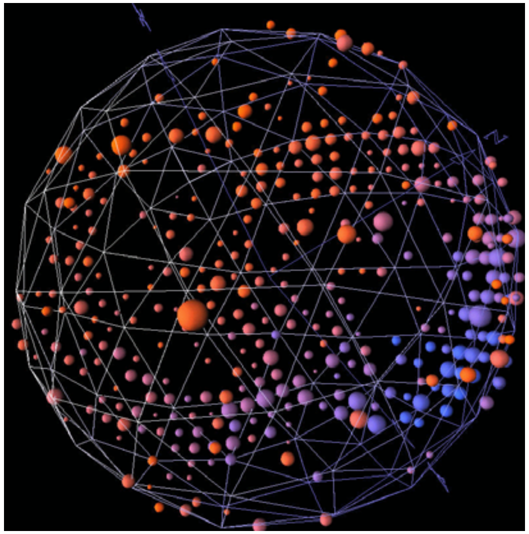
MiniBoone detector – an instrumented tank





Michel e from μ decay candidate.

Ragged outer edge of ring from scattering, brems.



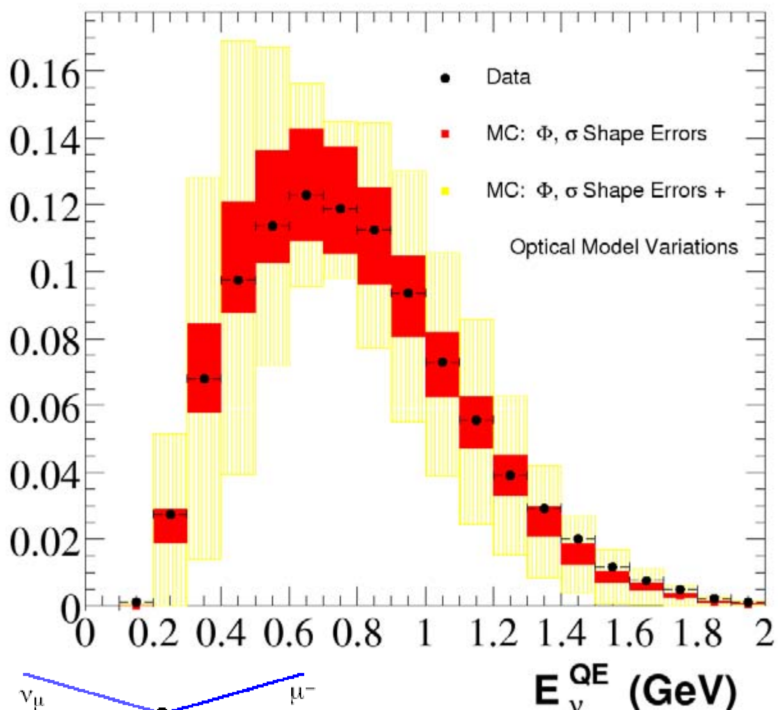
π^0candidate – overlapping rings,

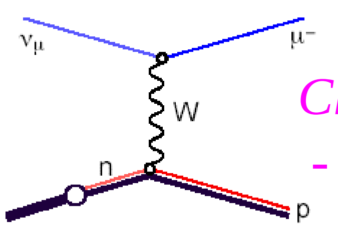
12 m sphere, 950 K liters of oil.

1280 PMT's - 8" diameter

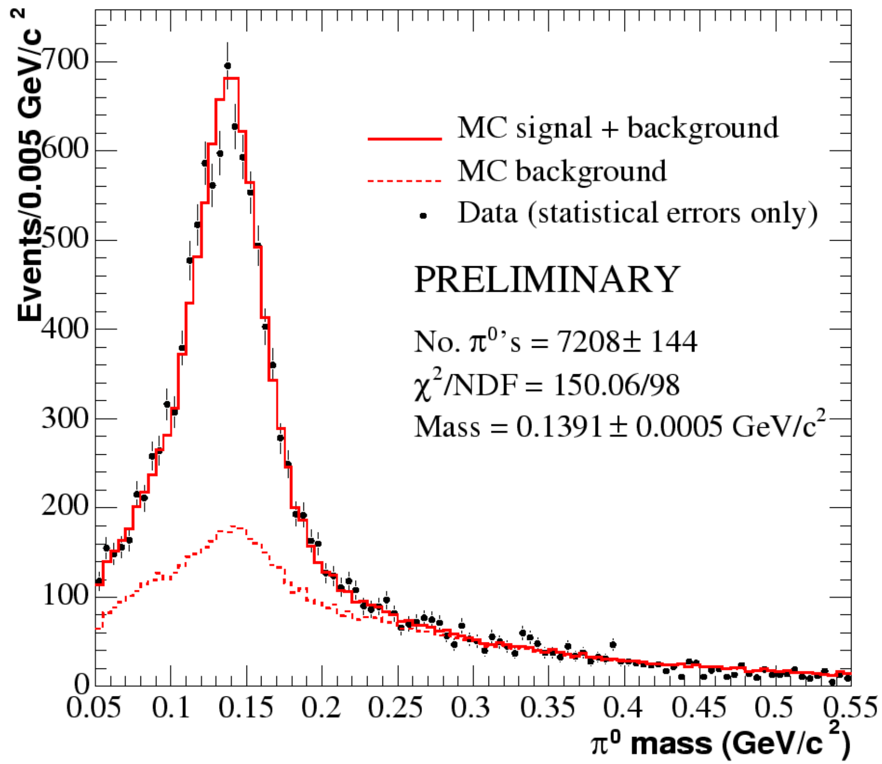
Cerenkov and Scintillation light

MiniBoone physics checks (and intrinsically interesting)

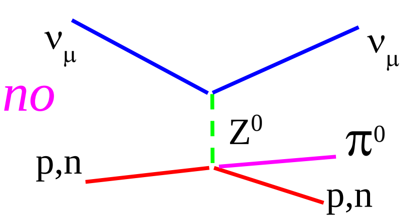




Charged Current QE
- single μ-like ring



Neutral Current π^0
- 2 rings, E threshold, no Michel electron

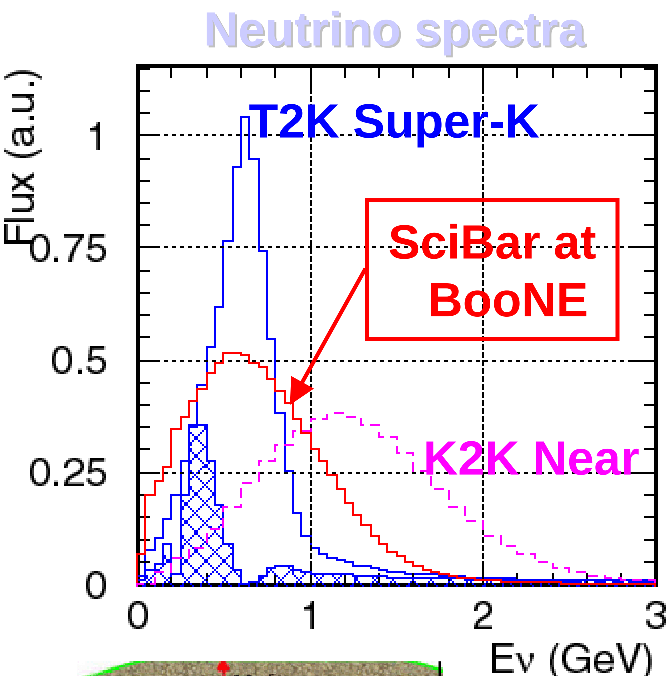


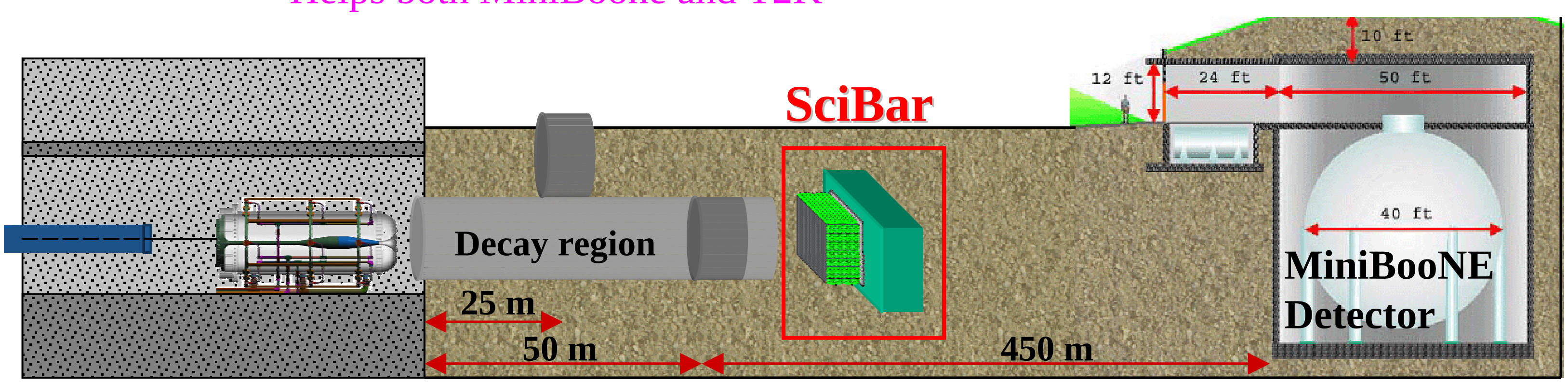
SciBar at FNAL

–K2K SciBar detector became available available because of end of K2K operations.

–Collaborative effort to bring the SciBar SciBar detector to the MiniBooNE beamline.

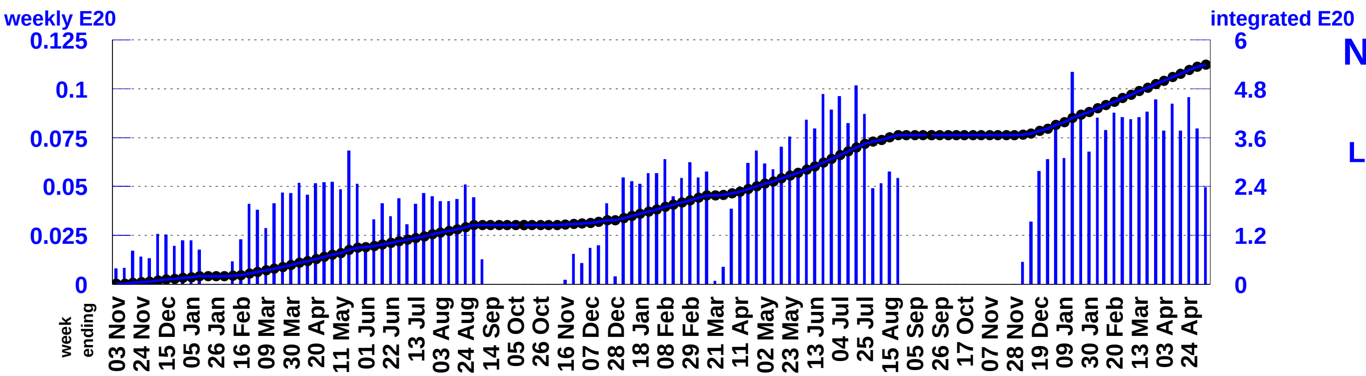
- –Measure beam contaminations
- –Measure cross-sections for beam and backgrounds
- –Helps both MiniBoone and T2K





MiniBoone status and plans

- World's largest ν dataset in ~1GeV range
  – Using 5.4 x 10^{20} protons on target
- Approved to run through USFY 2006
- Goal: ν_e appearance analysis ready in late 2005.
- Future running mode (including anti-ν) will depend on what the oscillation analysis reveals.
- Chance of SciBar+MiniBooNE physics



Number of Protons on Target

To date: 5.3977 E20

Largest week: 0.1084 E20

Latest week: 0.0495 E20

MINOS Long-Baseline Experiment: Physics Goals

★ **Demonstrate oscillation behaviour**

- confirm flavour oscillations describe data
- provide high statistics discrimination against alternative models:
  decoherence, ν decay, extra dimensions, etc.

★ **Precise Measurement of Δm^2_{23}**

- ~10 %

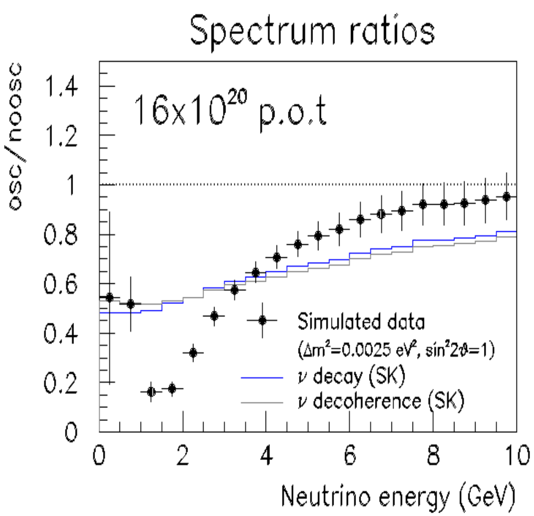
★ **Search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations**

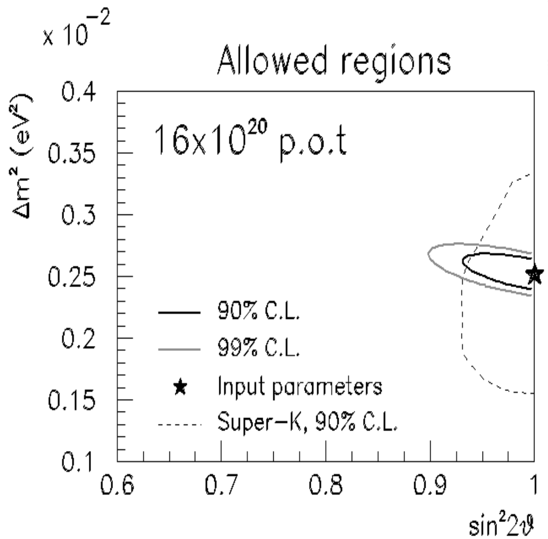
- first measurements of θ_{13} ?

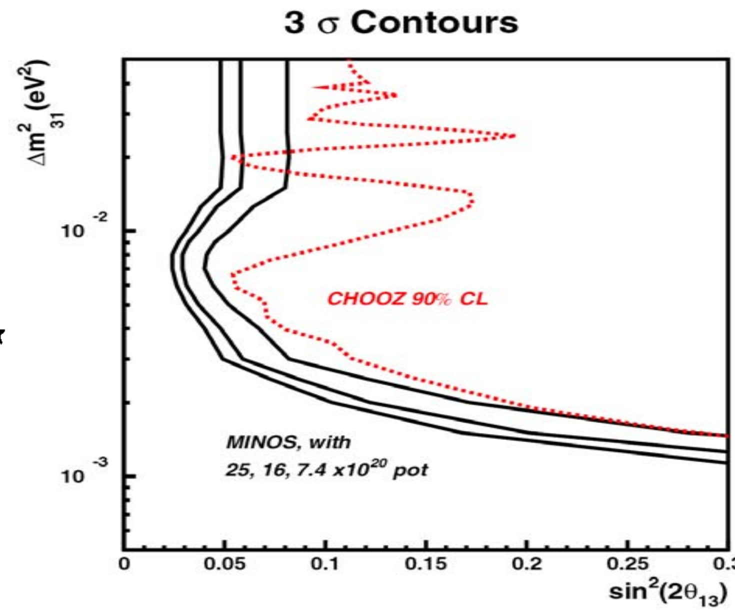
\+ **MINOS is the 1st large deep underground detector with a B-field**

- first direct measurements of ν vs $\bar{\nu}$ oscillations from atmospheric neutrino events

Expected MINOS Sensitivities







ν_e appearance =>non-zero θ_{13}

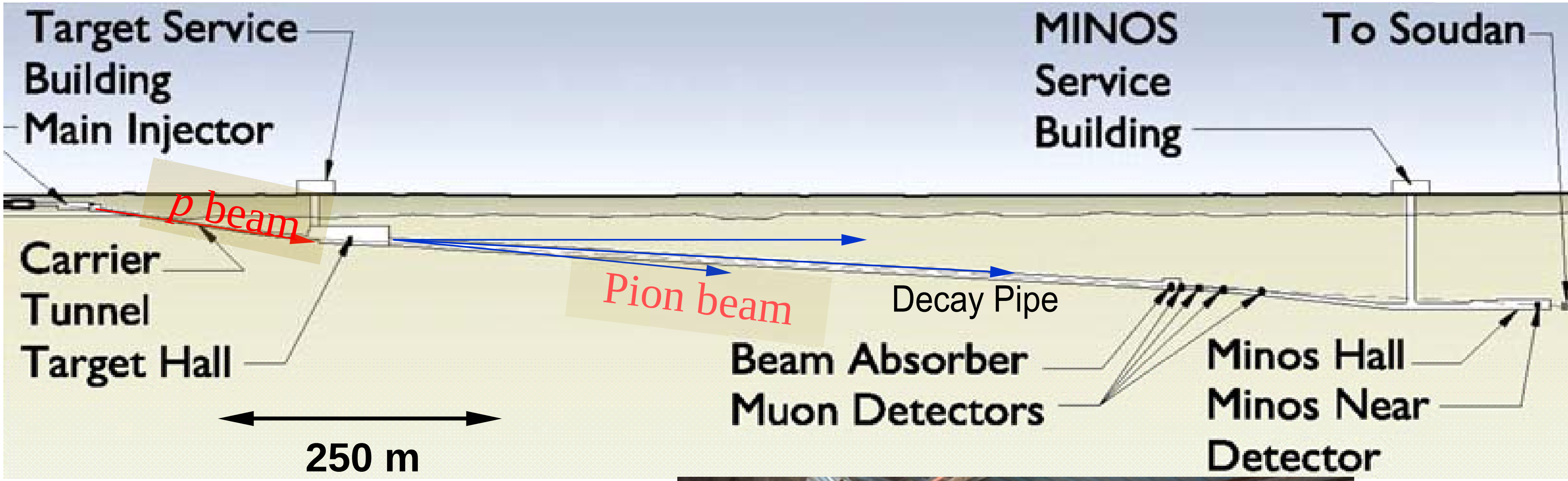
Δm^2 and $\sin^2 2\theta$

Can improve CHOOZ limit by ~2 with adequate protons

Greatly improve existing measurement;
excellent test against alternative hypotheses

MINOS measurements improve with more protons

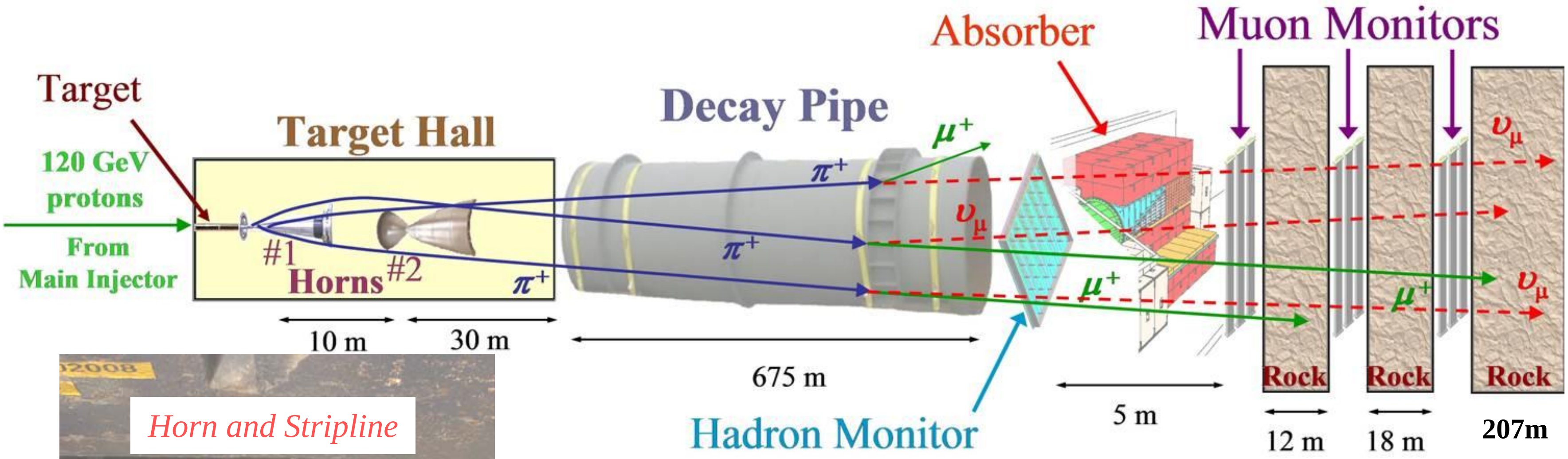
NuMI Tunnels and Facility

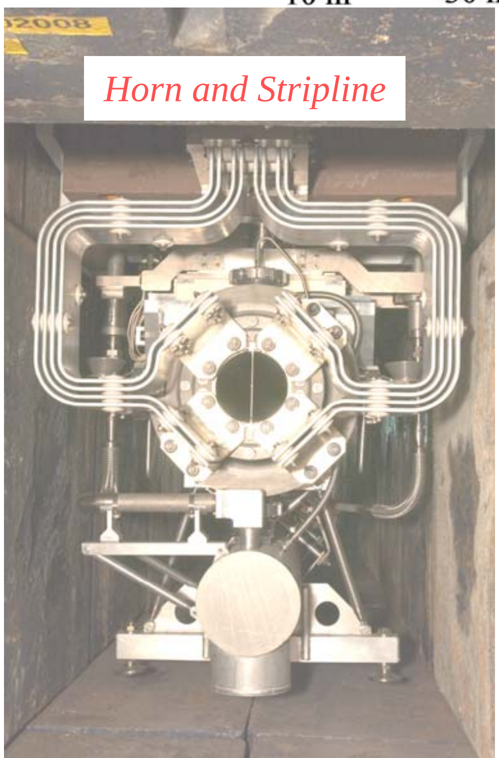


NuMI Components in Main Injector

NuMI Pretarget Area

NuMI Neutrino Beam





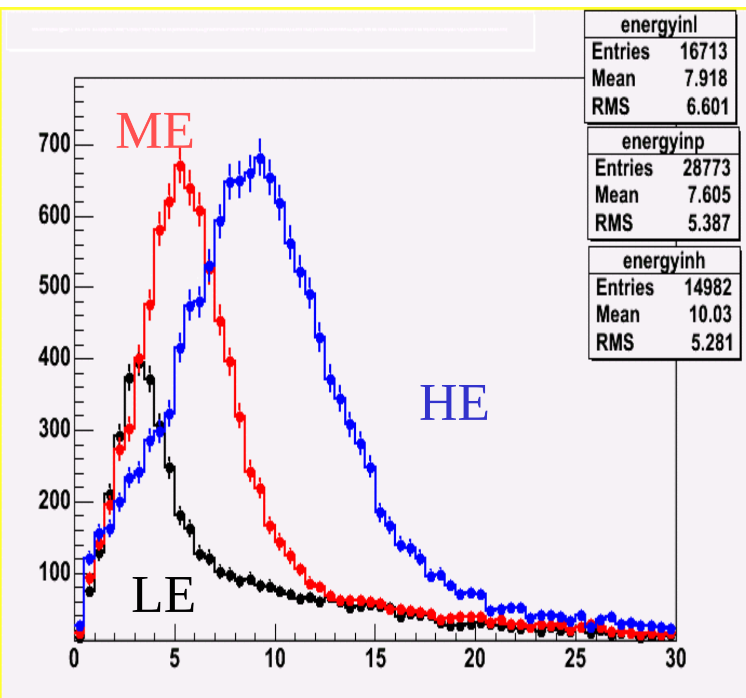
Horn and Stripline

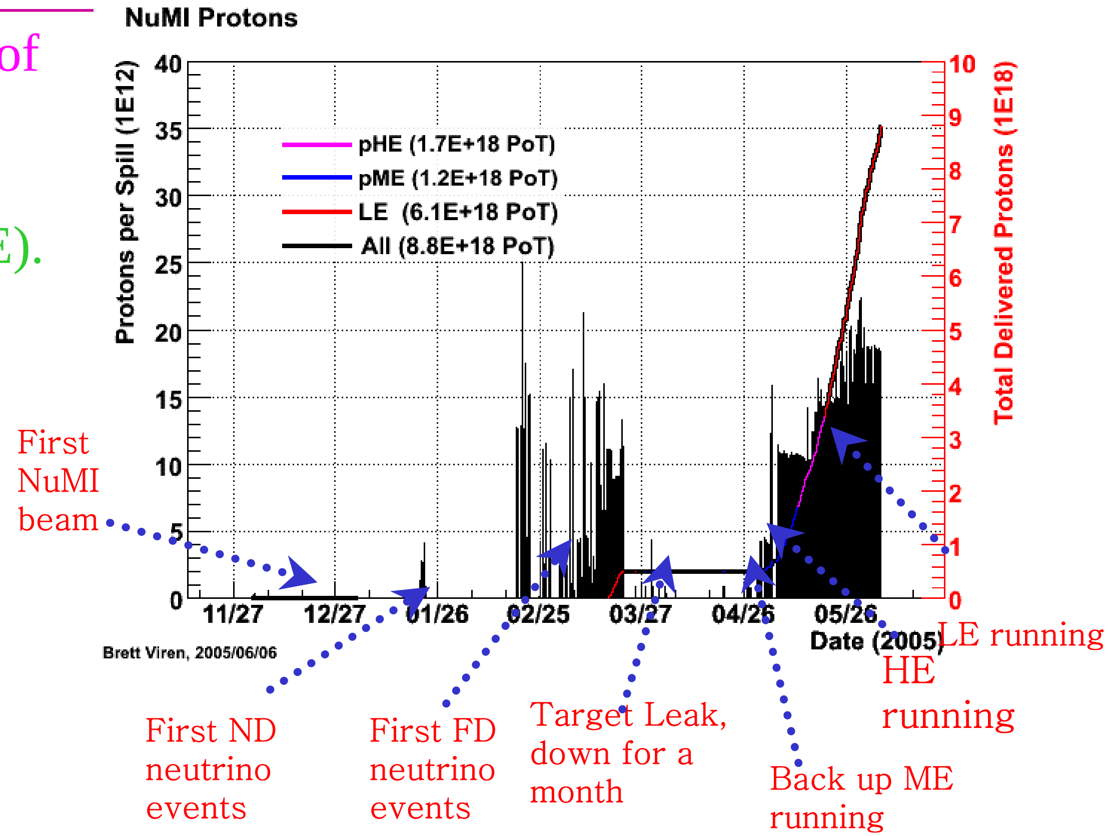
- 120 GeV protons strike the graphite target
- Nominal Intensity $2.4\text{x}10^{13}$ ppp with ~2 sec cycle time.
- Initial intensity ~2.5 x 10^{20} protons/year
- Ultimate intensity ~ 3.4 x 10^{20} protons/year (2008-9)

NuMI Beam Energy and Running

Beam energy tunable by motion of target.

Have run at three positions, high (HE), medium (ME) and low (LE).





Preliminary

Visible Neutrino Energy in Near Detector (GeV)

The MINOS Detectors

NuFact 05
June 21, 2005
R. Plunkett

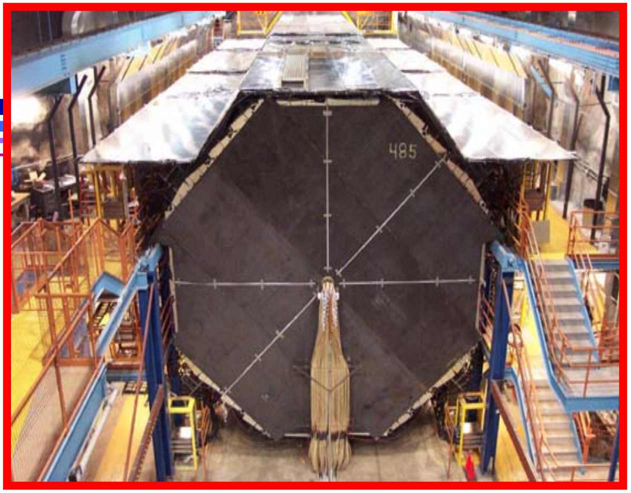
NEAR

0.98 Kton

MINOS Detector Hall, Fermilab

FAR

5.4 Kton

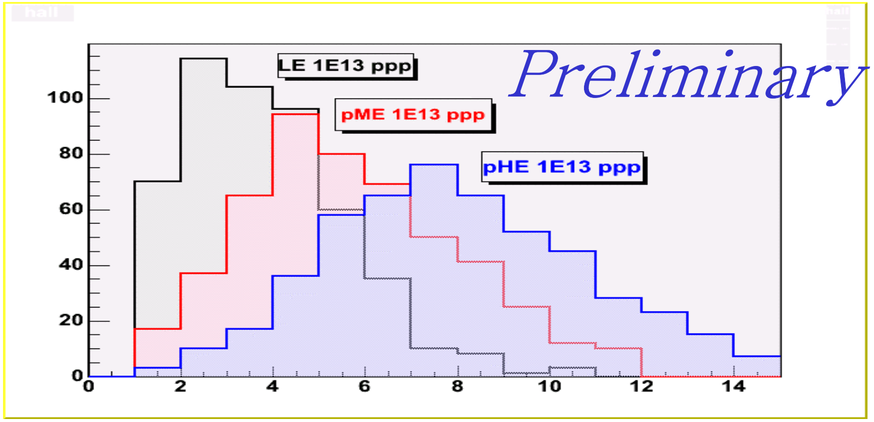


Soudan Underground Lab, Minnesota

Both detectors are tracking calorimeters composed of interleaved planes of steel and scintillator – uptimes routinely exceed 95%.

- 2.54 cm thick steel planes
- 4.1 cm wide scintillator strips
- 1.5 T toroidal magnetic field.
- Multi-Anode Hamamatsu PMTs (M16 Far & M64 Near)
- Near electronics optimized for high occupancy (~20) during 10 μs spill
- Energy resolution: 55%/√E for hadrons, 23%/√E for electrons
- Muon momentum resolution ~ 6 % from range (~ 12 % from curvature)

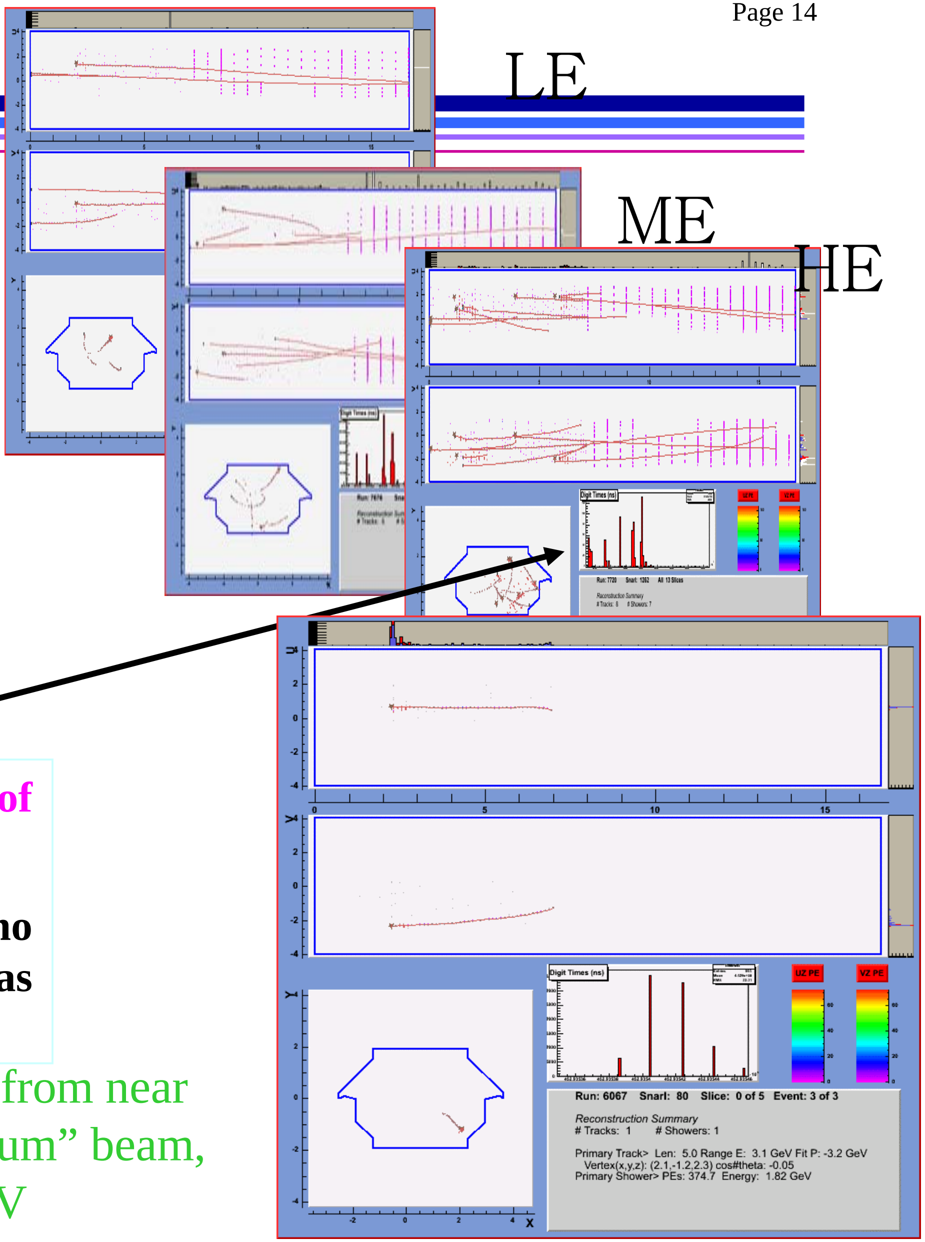
Near Detector neutrino events



Event/spill distribution for various beam configurations

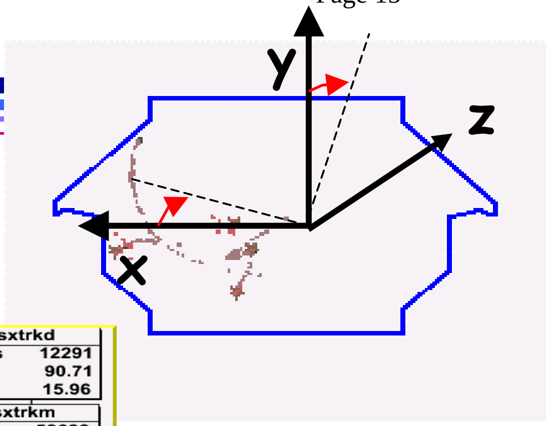
Events are separated for analysis on the basis of timing.

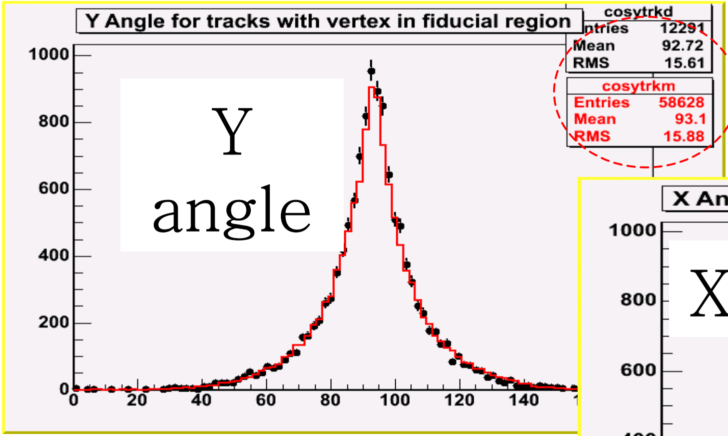
For constant intensity the number of neutrino events scales with neutrino energy (scaling factor as expected from MC).



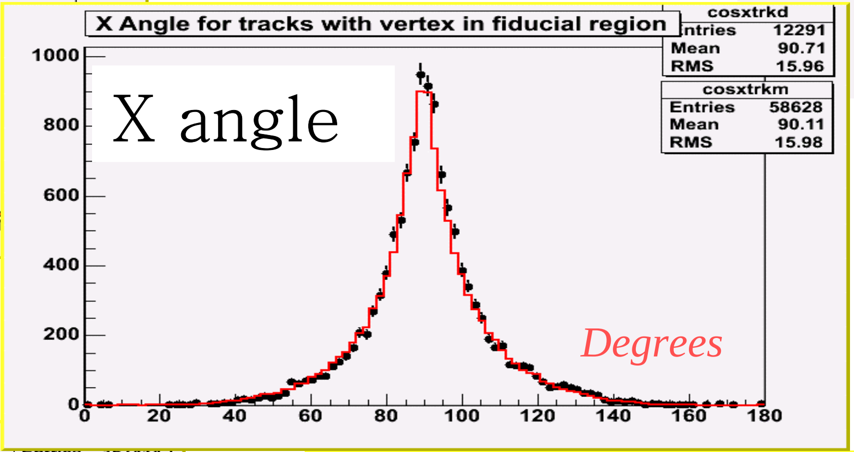
Medium energy track from near peak in “pseudo-medium” beam, track energy ~ 3.1 GeV

Characteristics of near detector events



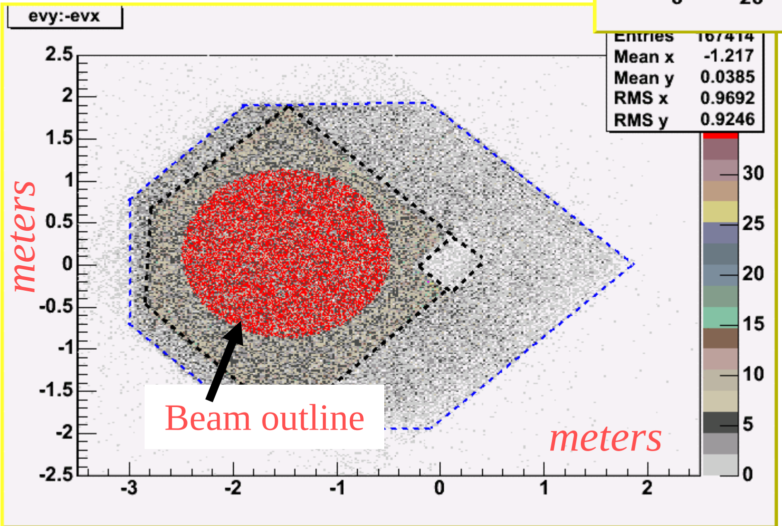


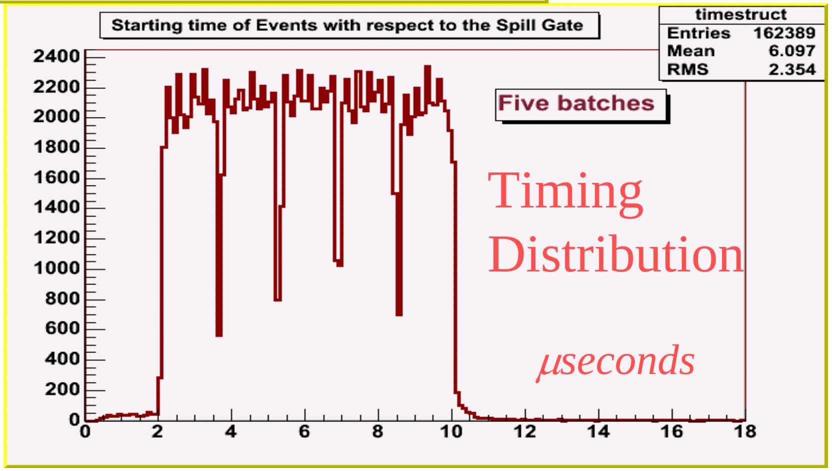
Degrees



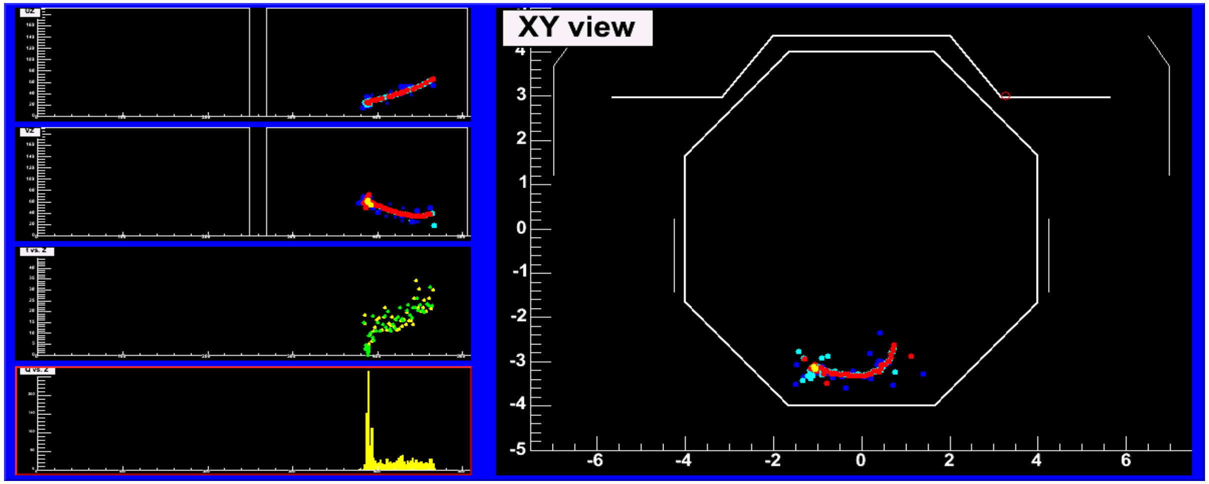
Preliminary

Vertex Distribution

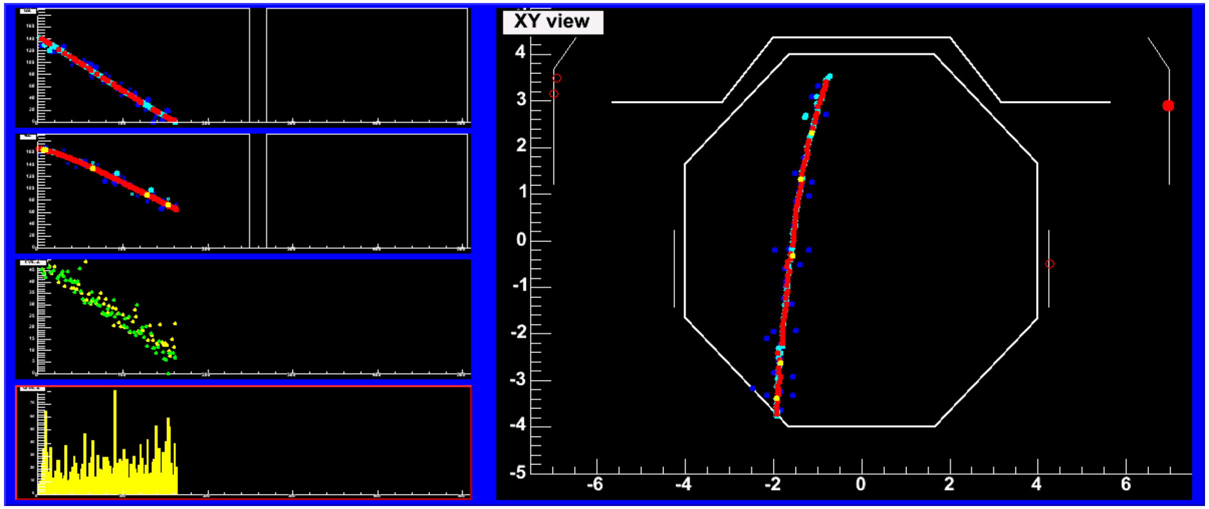




Minos Far Detector Events

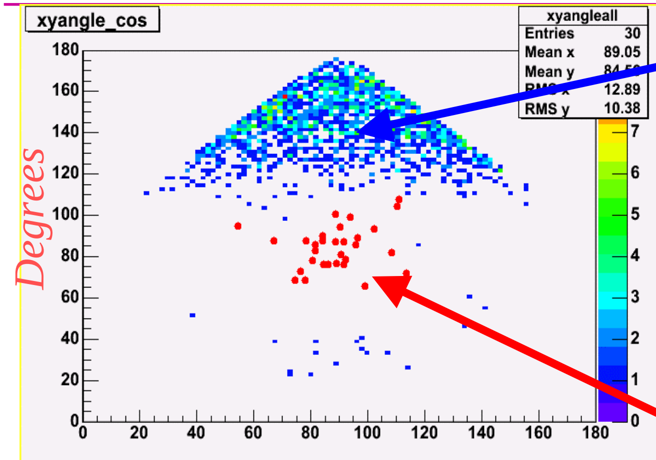


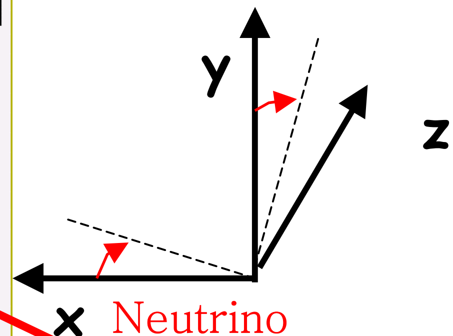
Contained CC event
Expected rate ~3/day



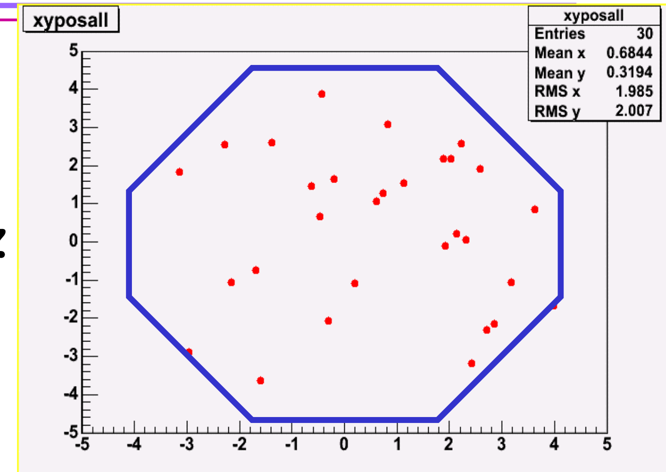
Up-going muon
Rate ~0.25/day

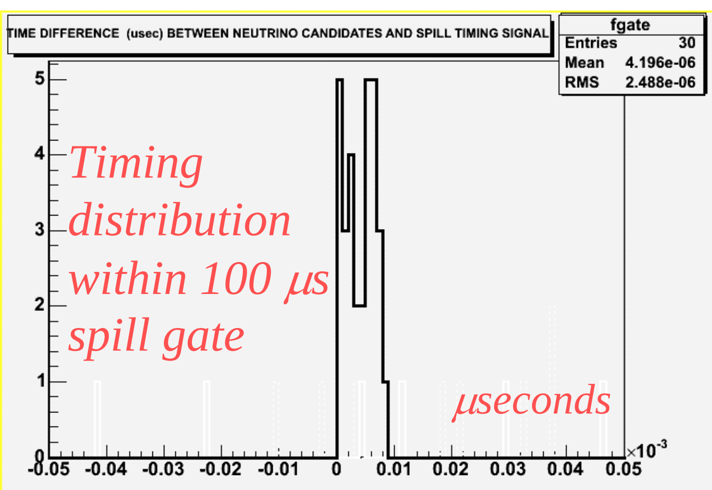
Characteristics of far detector events
High energy running => no oscillation





Preliminary



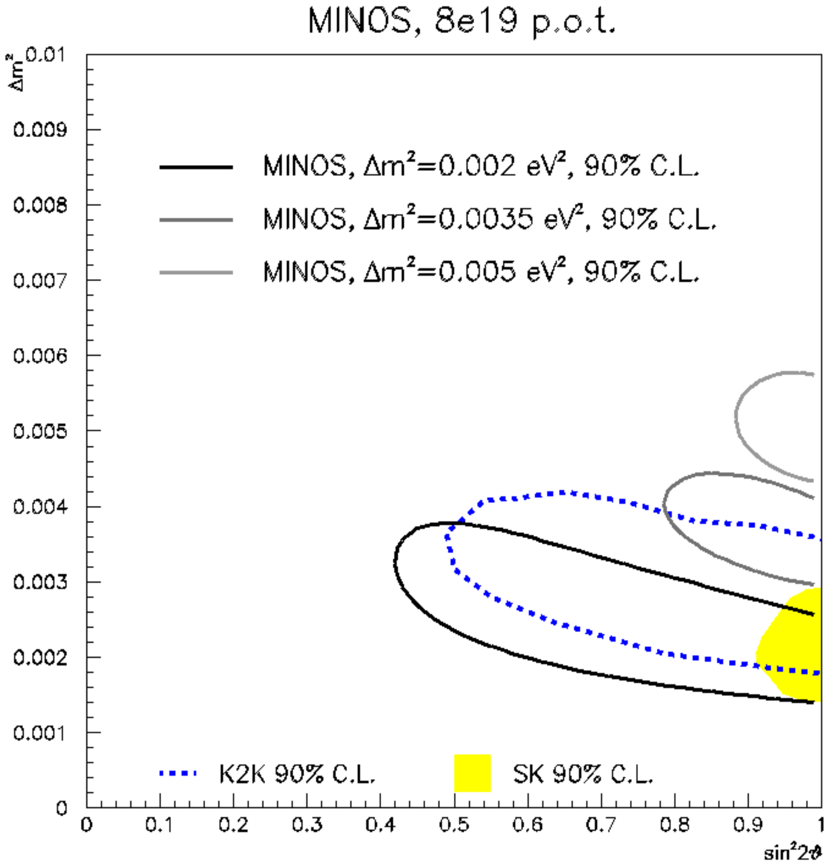


Visual scan of <100 in-time events with track (out of >150000 spills).

- Contained CC-like Events (21)
- Rock muon (9)
- Cosmics (6) (expect 7)

Minos Plans and Expectations

- Datataking run underway!
  - All MINOS measurements improve with more beam.
- Atmospheric results from > 400 live-days under analysis, first results soon.
  - Approximately 100 each of up-going muons and contained events.
- Will be able to use first 10^{20} protons data to verify choice of low-energy (LE) beam as operating point.

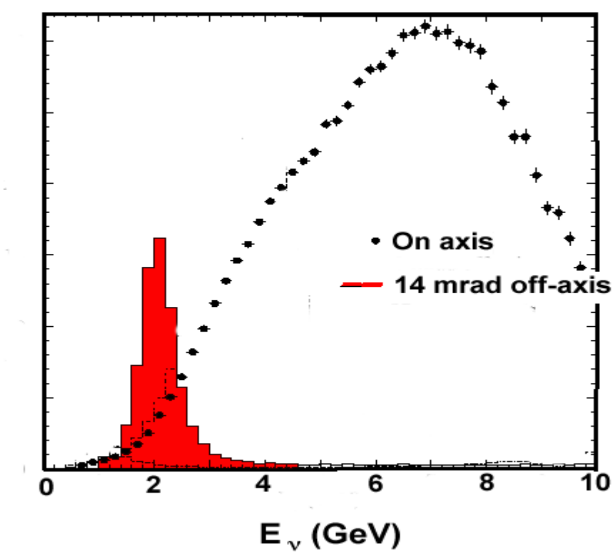


Off-axis beams and NOvA

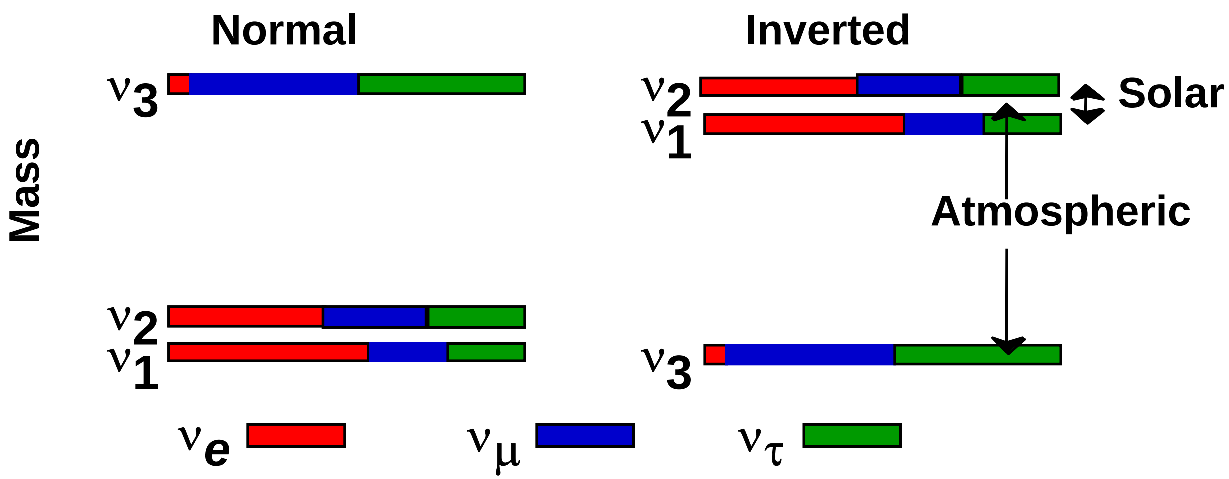
- Off-axis neutrino beams provide narrow-band kinematics
  - Reduces backgrounds

    mis-id NC

    ν_e's from K decay (wrong kinematics)
- Increases flux at oscillation maximum.
- This provides a good setting for ν_e appearance exeriments
  - Will be focus of Japanese T2K effort.
- NuMI beam already exists, can be exploited by construction of new detector.
  - NOvA proposal addresses this need.



NOvA Physics Objectives



Resolve the mass hierarchy in atmospheric oscillations

Requires matter effects and therefore a long-baseline experiment.

Measure θ_{13}, the unknown mixing angle in $\nu_\mu \rightarrow \nu_e$

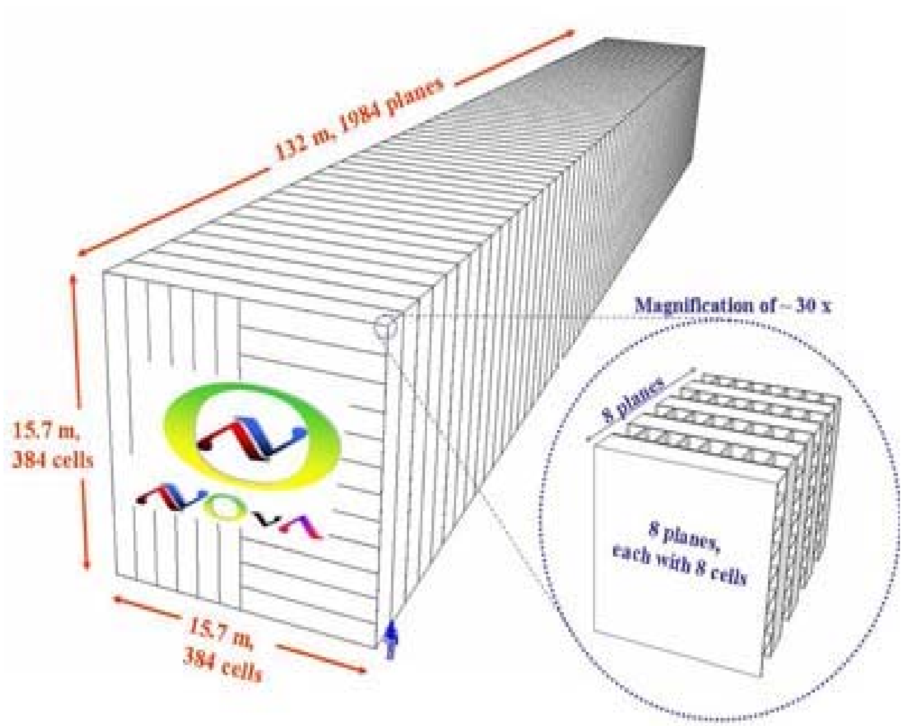
Better than benchmark reactor experiements, competitive with best proposed.

Begin the study of CP violation effects in the neutrino sector.

Especially in conjunction with proton driver or equivalent high-power beam.

Additionally, improve knowledge of $\sin^2\theta_{23}$ and Δm_{23}^2

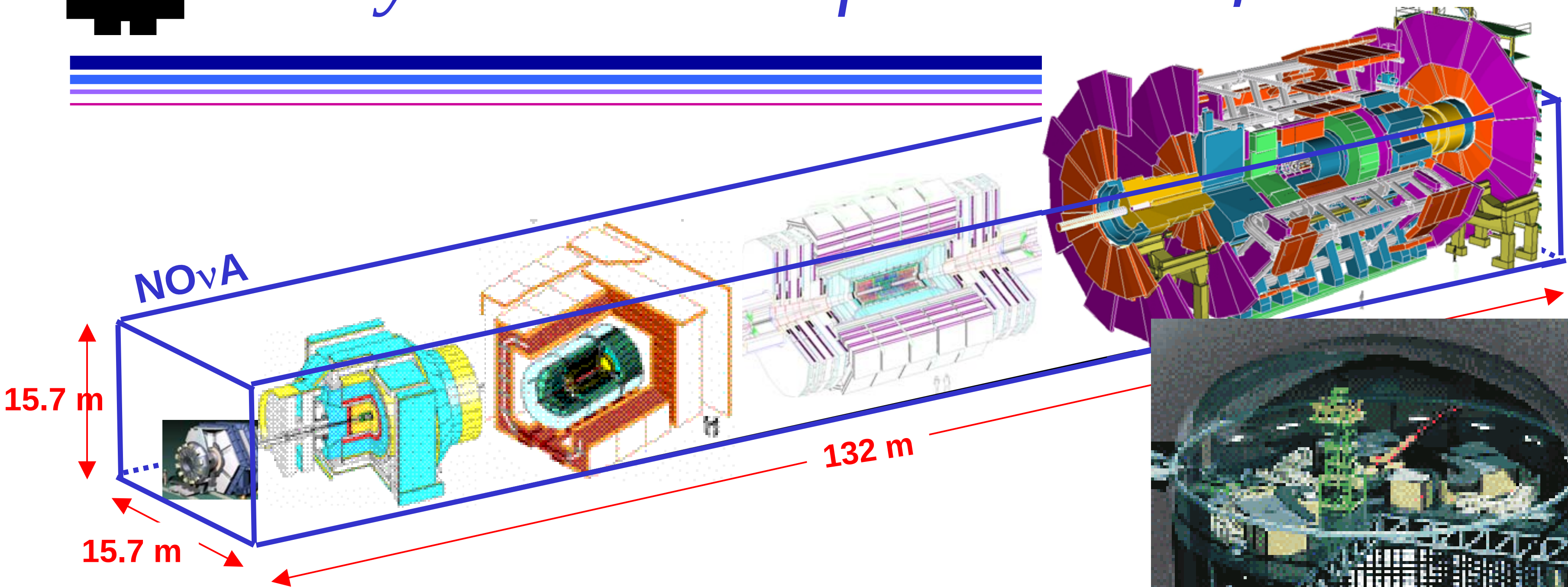
The NOvA Detector Proposal

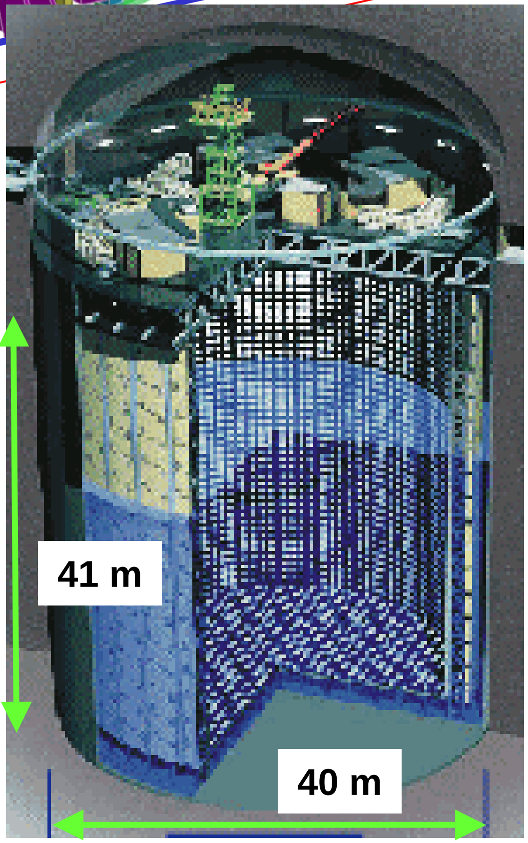


Large, “totally active” structure, fine segmentation

- 30 kton detector
  - ♦23,808 Titanium dioxide loaded PVC extrusions (6 kton)
    - 761,856 cells
    - 3.9 cm wide, 6-cm deep
  - ♦Active material liquid scintillator (24 kton).
  - ♦Looped wavelength-shifting fiber in each cell.
  - ♦32 pixel Avalanche photodiode readout
- ~2000 ν_μ CC events per 7e20 POT ($\Delta m^2 = 2.5 \times 10^{-3}$)
- Electron ID efficiency 24%
- For $\sin^2 2\theta_{13} \sim 0.1$ would see ~150 ν_e interactions in 5 years

Physical Scale of NOvA Project

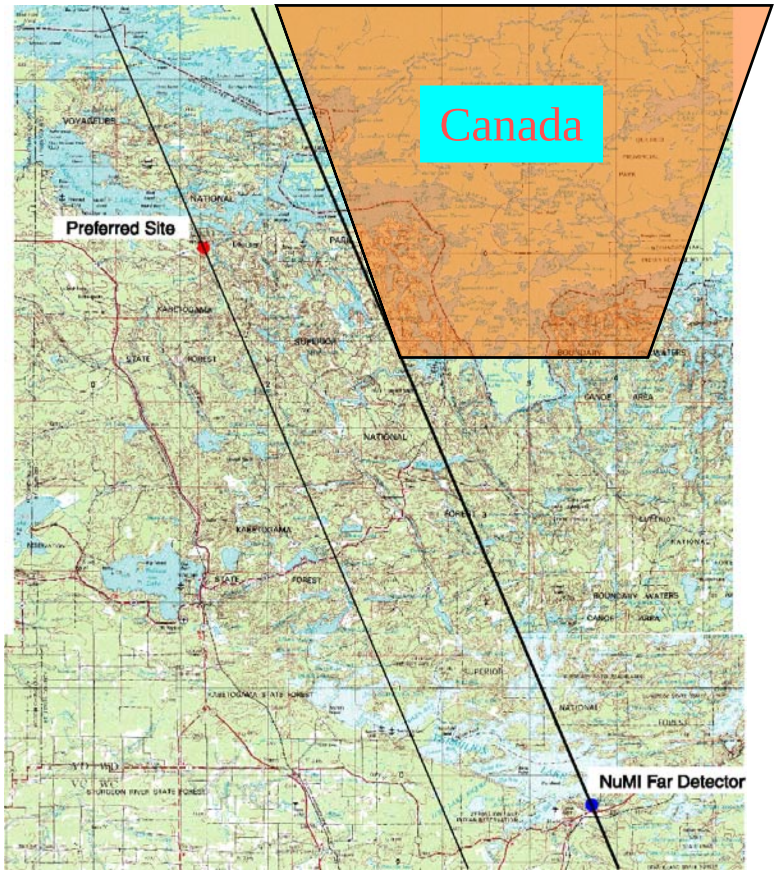


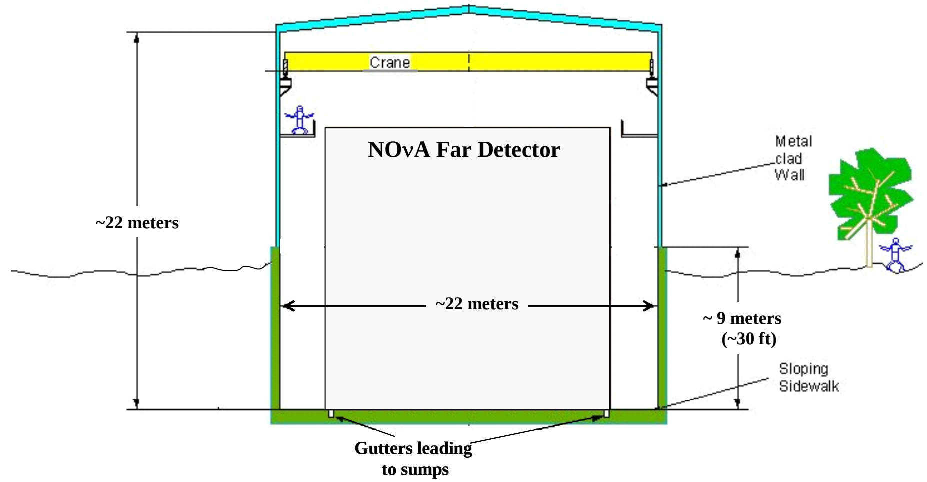


Proposed NOvA detector compared with BaBar,, CDF, D0, CMS, Atlas, and Super-K detectors on one scale.

Assembly: 32 cell modules epoxied together to make a 24 ton, 8 plane “block” which is then brought vertical (while empty) and secured to previous blocks.

NOvA Site and Building Concepts



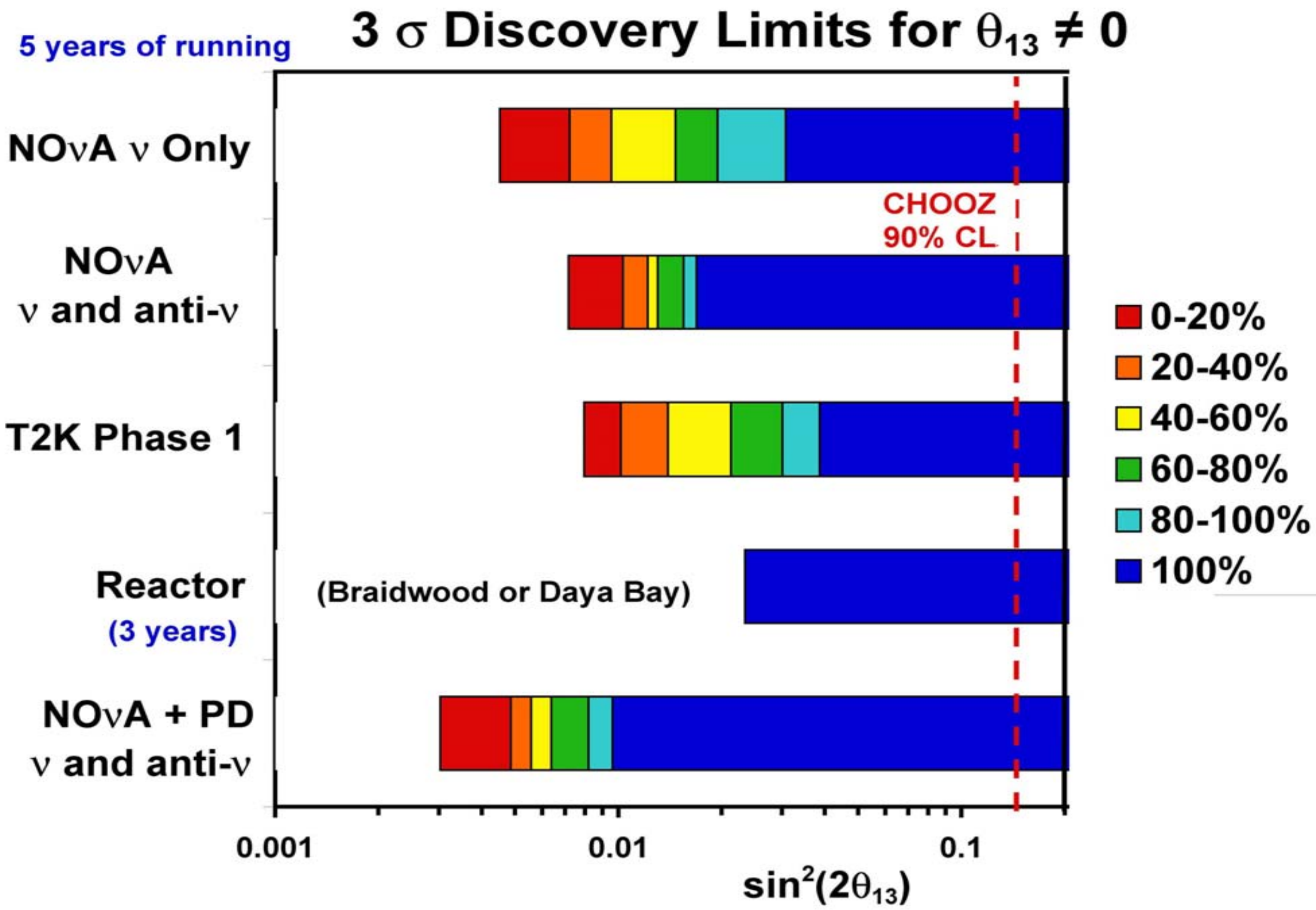


- Ash River near Voyageur's Nat'l Park
  - Center of NuMI beam is 4.2 km in the air here
  - This is 810 km from Fermilab
  - Backup site ~ 35 km further south
- Building designed for full secondary containment of liquid scintillator.
- Also investigating alternative building design with 3 m overburden on a 1 m concrete roof
  - Excavated area slightly deeper.

Protons for NOvA

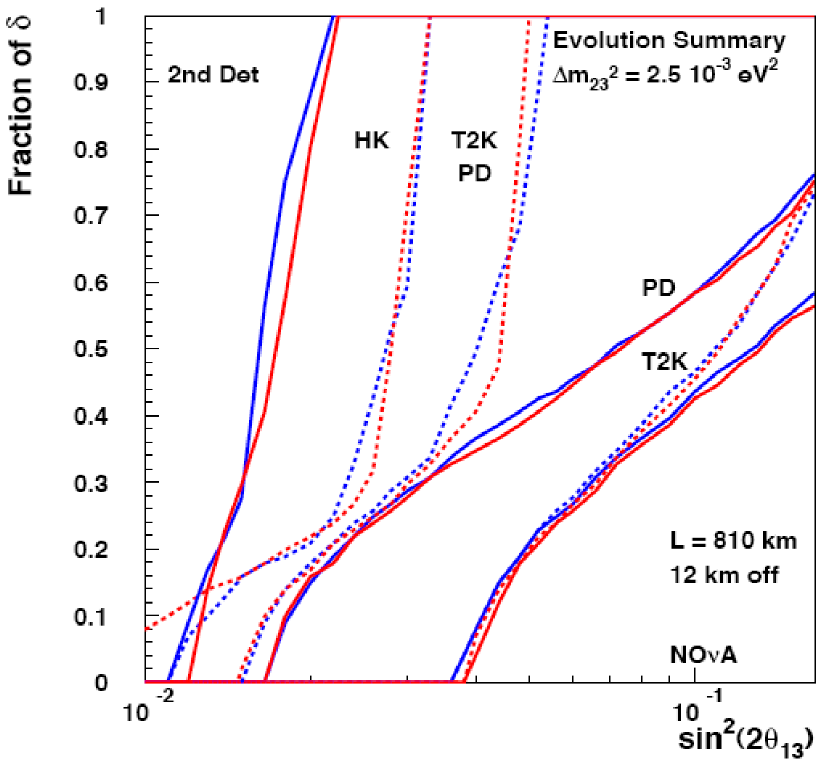
- Fermilab Proton Plan (Nov 2004) anticipates 3.4×10^{20} protons/year for NuMI by 2008.
- Expected end of Fermilab Collider program in 2009 frees up protons for neutrino program.
  - No antiproton creation or injection downtime. (factor ~ 1.4)
  - Use Recycler ring to buffer protons from booster, gaining cycle time. (factor ~ 1.5)
  - Total protons/year for neutrino programs become 6.5×10^{20}.
    - This is 0.65 MW source.
- Proton Driver or (conceivable) further reuse of complex will increase this flux.
  - This talk uses 25×10^{20} protons per year for such (PD) projections.

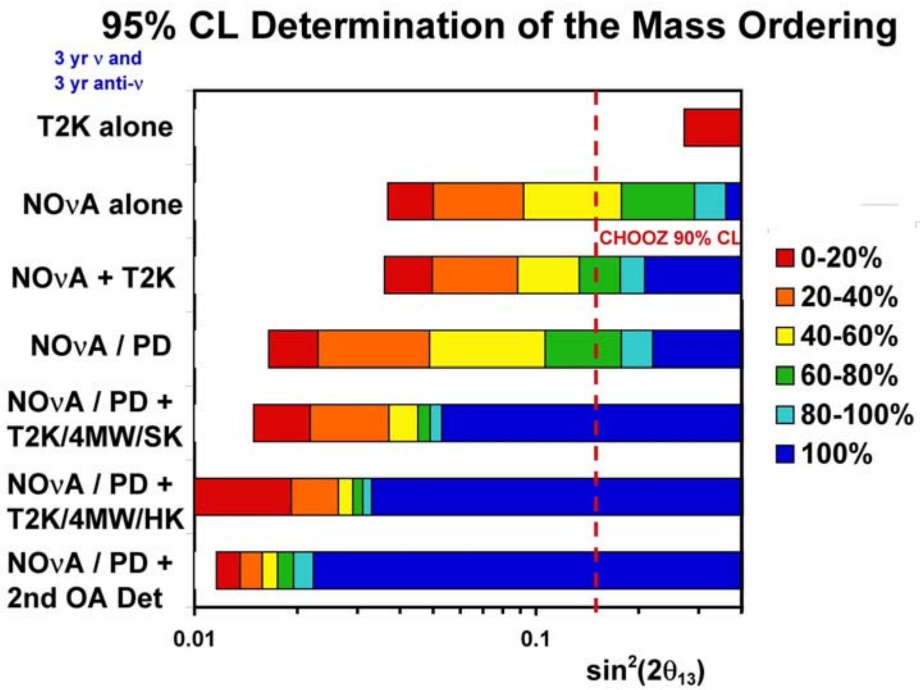
NOvA θ_{13} Sensitivity



Presented as % coverage in CP phase δ

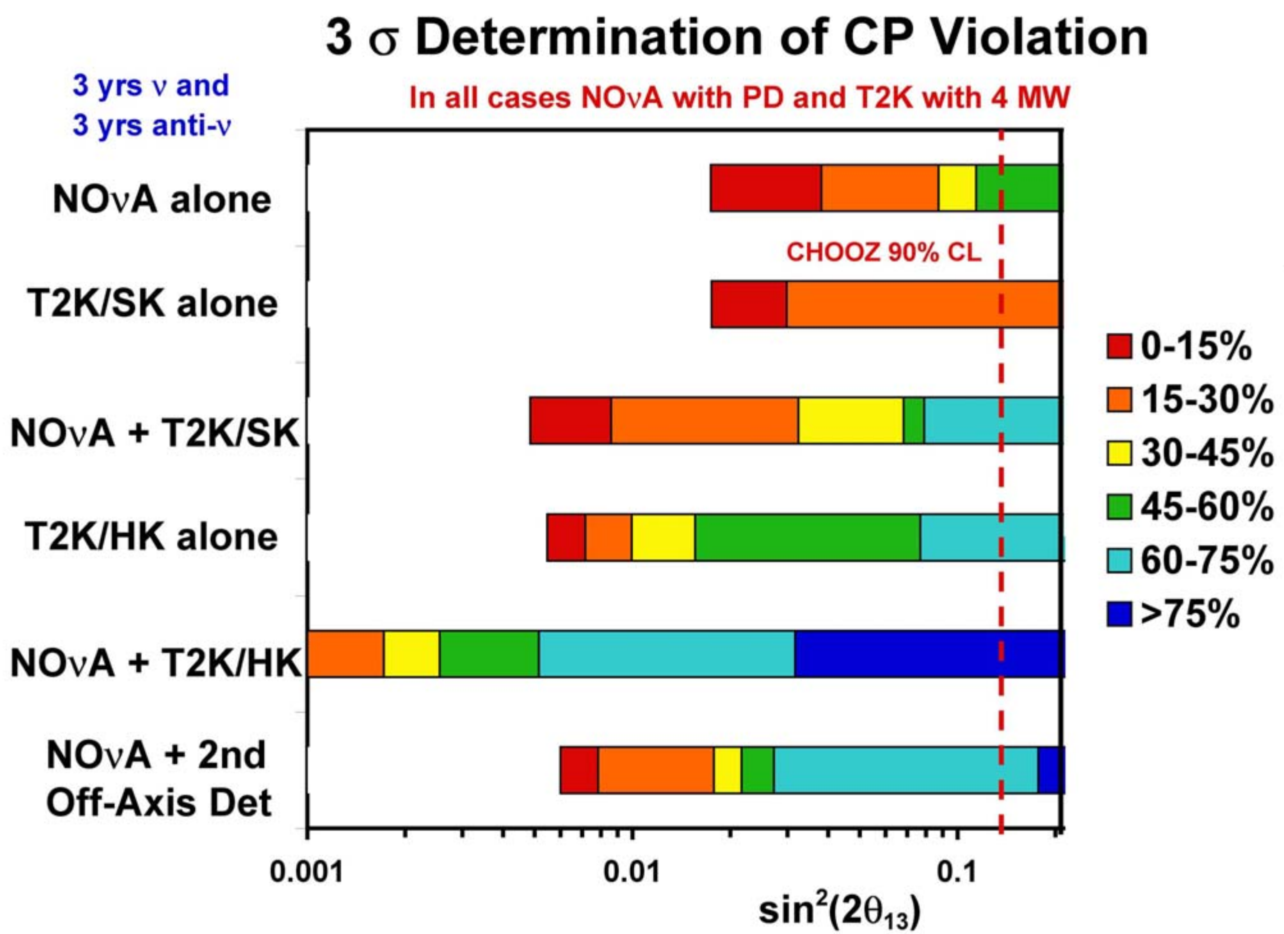
NOvA Mass Ordering Determination





Presented as % coverage in CP phase δ

NOνA and CP Violation

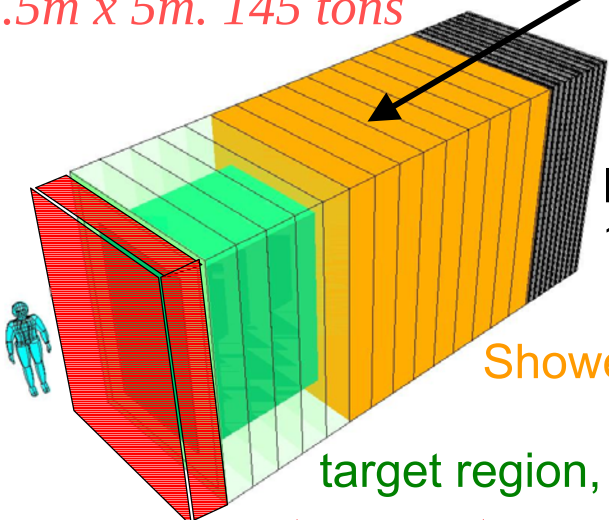


Presented as % coverage in CP phase δ

NOvA near detector, in current underground tunnels

3.5m x 5m. 145 tons

Each section
is an 8-plane block

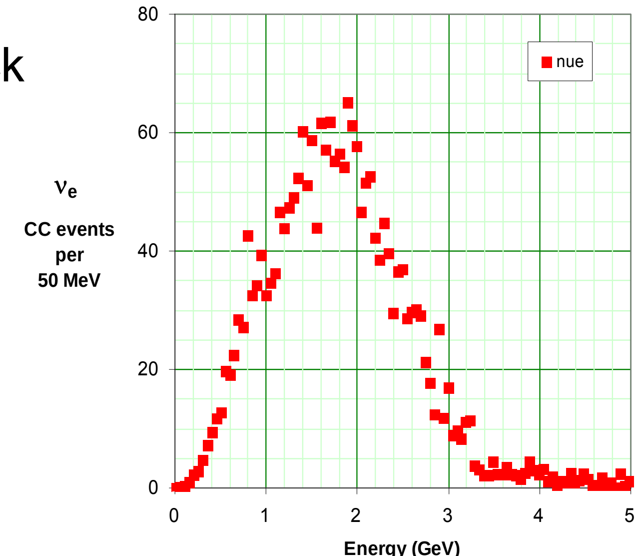


Muon catcher
1m steel + 10 planes

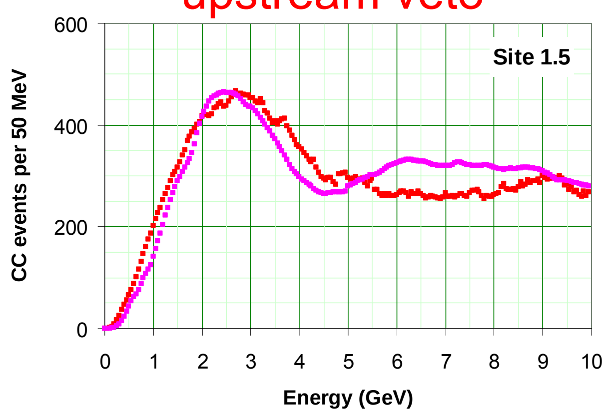
Shower containment

target region, 20 tons

upstream veto



ν_e spectrum from proposed ND prototype in MINOS surface building



Beam ν_e background shape, compared to far detector (pink)

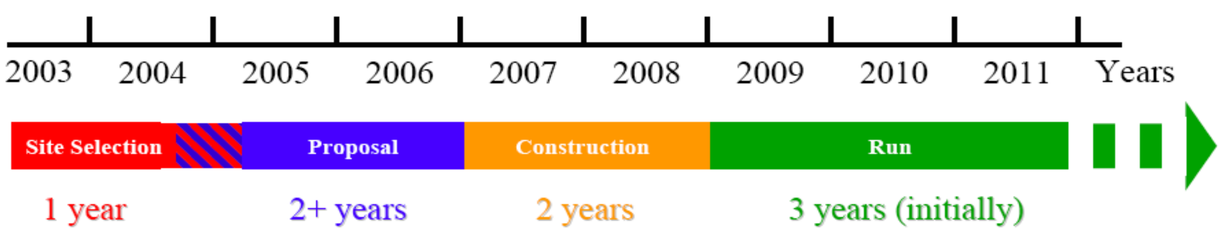
Detector response and energy calibration

Backgrounds to a ν_e signal in the Far Detector

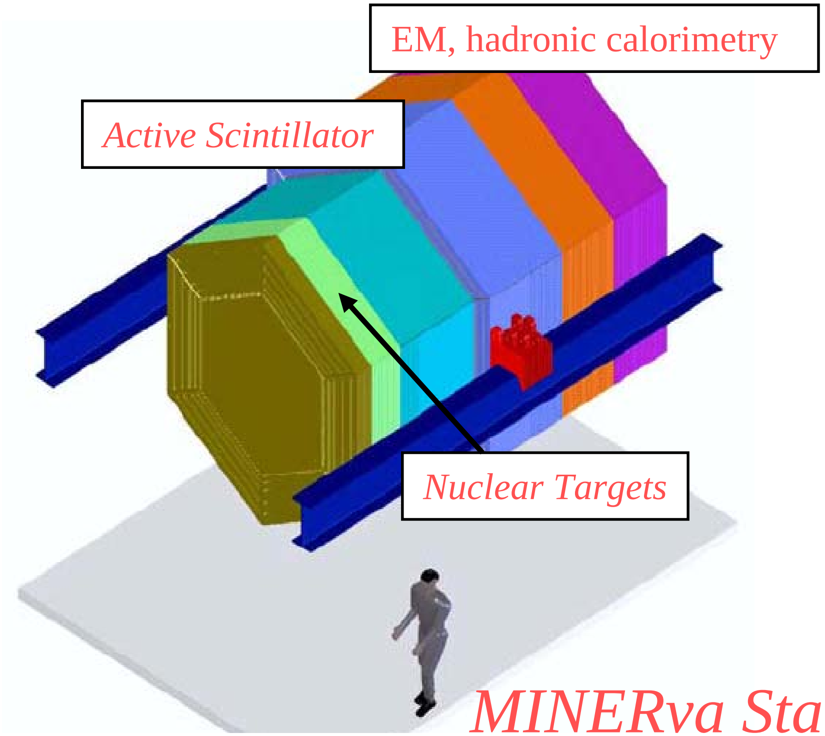
NOvA status and proposed schedule

- NOνA is the first step in a process to investigate θ_{13}, mass hierarchy, CP violation
  - Fits well in proton driver, second detector, world program scenarios.
- Fermilab collider program cessation increases protons approximately twofold.
- Proposal in system, first level of Fermilab approvals granted.
  - Now with funding agencies – a complex process
  - Project management team being assembled.

Experiment Timeline



MINERvA, a fine-grained neutrino scattering experiment

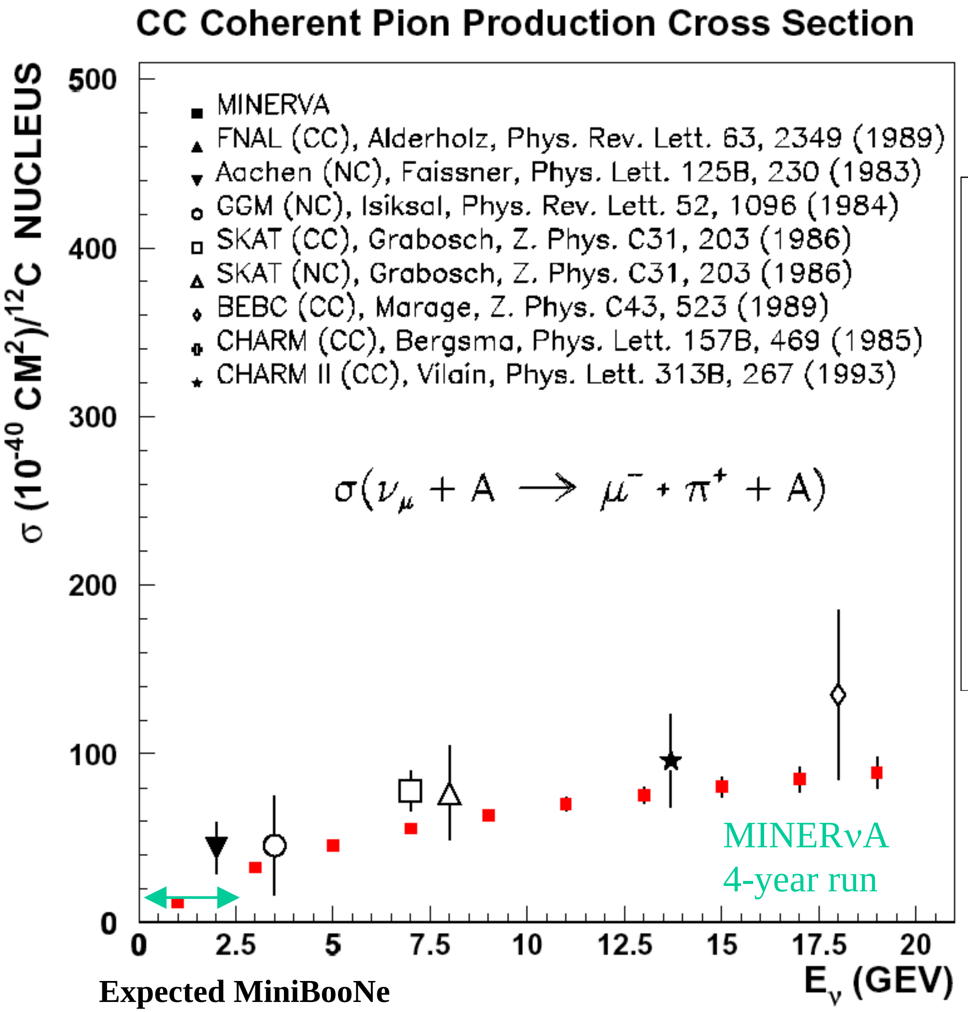


- Precision study of ν - nucleus scattering.
- Important for minimizing systematic errors of neutrino oscillation experiments
- To be located just upstream of MINOS Near Near Detector
- High-granularity, fully-active (~6T) scintillator strip based design.
- ~1 T of nuclear targets (C,Fe,Pb) form first detector section.

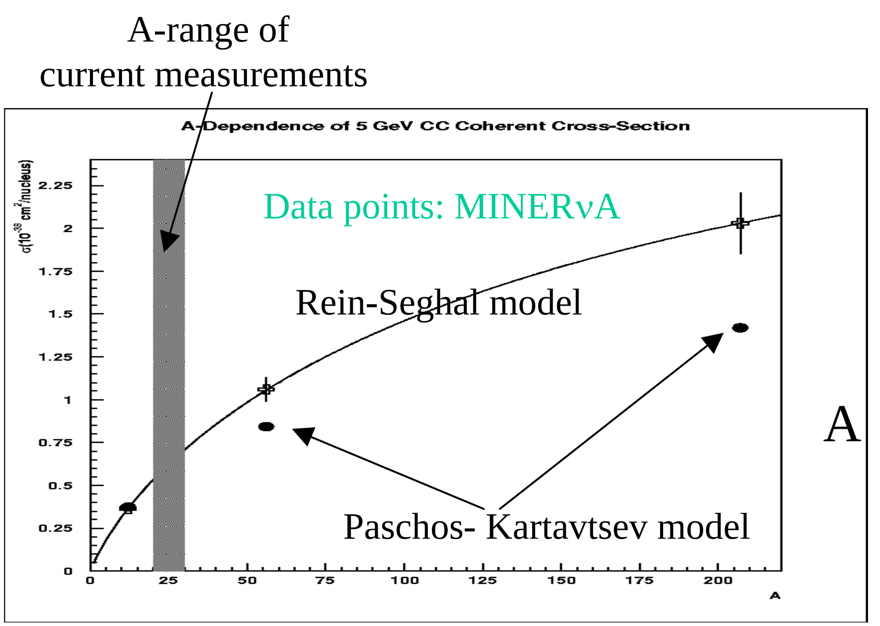
MINERva Status

- Vigorous collaboration including nuclear physicists.
- First approvals in April 2004 – moving towards cost and schedule baseline approvals.
- Projected construction & installation schedule: completed Fall of 2008 with physics data-taking at the start of 2009.

Example of MINERνA's Analysis Potential
Coherent Pion Production



Expected MiniBooNe and K2K measurements



MINERνA's nuclear targets allow the first measurement of the A-dependence of σ_{coh} across a wide A range

Other Neutrino Initiatives

- Fermilab scientists are also participating in conceptual design studies for future facilities and detector technologies, i.e.
  - Large scale Liquid Argon TPC (e.g. FLARE)
  - Small scale exposure of OPERA bricks in the MINOS Near Hall (PEANUT)
  - Reactor experiments to measure θ_{13}
  - Deep underground facilities at large distances (DUSEL)
    - Eye towards developing a synergy between a super neutrino beam-long baseline experiment with a super detector which could do proton decay and super nova physics

A bit more detail

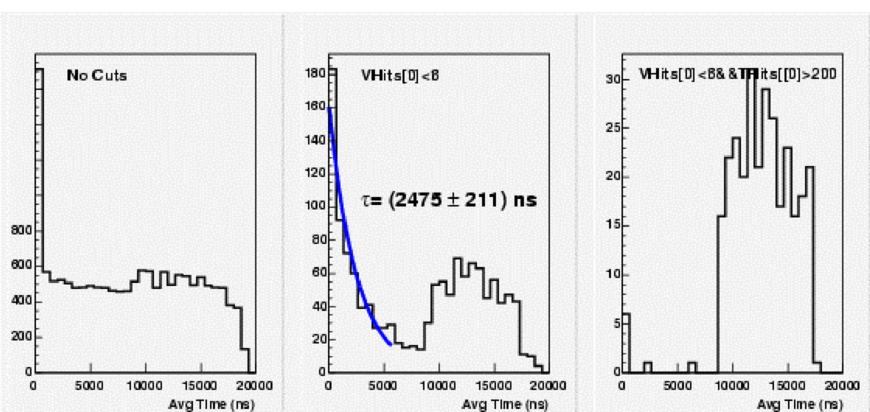
- Liquid Argon TPC Research and Development
  - Aim is to produce a viable design for a real multi-kton detector.
  - Investigating commercial tank technology.
  - Developing appropriate organizations, including outside collaborators.
- DUSEL
  - Appropriate in a world with a proton driver
  - Energy/flux optimizations may have impacts on layouts of the proton driver which need to be addressed early.
  - Help Evaluate appropriate sites; work within the on going process for site selection of an Underground Laboratory. Exploit synergy of these efforts.

Development of Fermilab Program

- A clear vision for the future was laid out by Pier Oddone at his presentation to the EPP2010 panel of the National Academy of Sciences.
  - http://www7.nationalacademies.org/bpa/EPP2010_Presentation_Oddone.pdf
- Current neutrino program is one of Fermilab's "ships of the line".
- R&D continuing for proton driver and alternatives.
- Further developments strongly impacted by ILC.
- After ILC CDR (~2 years), then evaluate options.
  - Proton driver
  - Extensions of Fermilab complex (e.g. recycler reuse).

Conclusions

- Fermilab neutrino program is vibrant and healthy.
  - Running experimental program
  - Active program for the future
  - Breadth of program addresses many of the issues of neutrino physics
  - Integrated, coordinated organization.
- Interesting results will come on a short timescale.
- The next generation of experiments and beam upgrades are massive and powerful.
  - Fermilab is actively involved in all areas, with principal efforts dedicated to accelerator-based
  - Inspirational, but require careful planning.



Cooperation at its best.

NuMI beam neutrinos as observed in MiniBoone detector.