NOνA

Leslie Camilleri
CERN, PH

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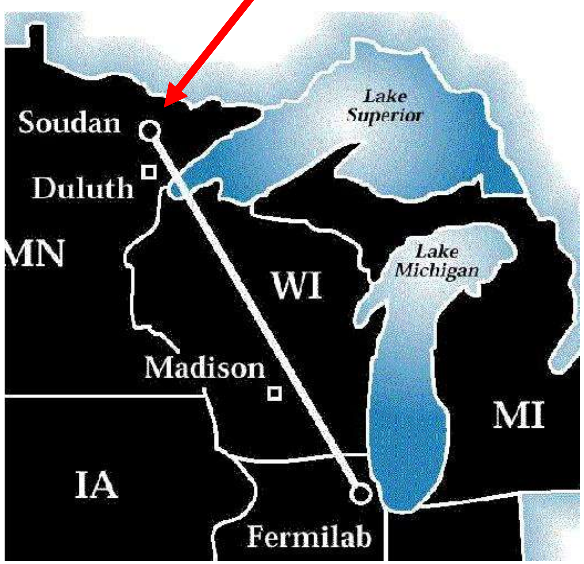
NOνA is a Long Baseline experiment using the NUMI beam from Fermilab

Now being used for MINOS (732km) away.

It will be located 810 km from Fermilab at Ash River.



$\nu_\mu \rightarrow \nu_e$ oscillations θ_{13} and the mass hierarchy.

Correlations

In vacuum and without CP violation:

$$P(\nu_\mu - \nu_e)_{vac} = \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\Delta_{atm}$$

with $\Delta_{atm} = 1.27\,\Delta m^2_{32}\,(L/E)$

For $\Delta m^2_{32} = 2.5 \times 10^{-3}\ eV^2$ and for maximum oscillation

We need: $\Delta_{atm} = \pi/2$ → $L(km)/E(GeV) = 495$

For L = 800km E must be 1.64 GeV, and for L = 295km E = 0.6 GeV

Introducing matter effects, at the first oscillation maximum:

$$P(\nu_\mu - \nu_e)_{mat} = [1 +\!- (2E/E_R)]\,P(\nu_\mu - \nu_e)_{vac}$$

with $E_R = [12\ GeV][\Delta m^2_{32}/(2.5\times10^{-3})][2.8\ gm.cm^{-3}/\rho] \sim 12\ GeV$

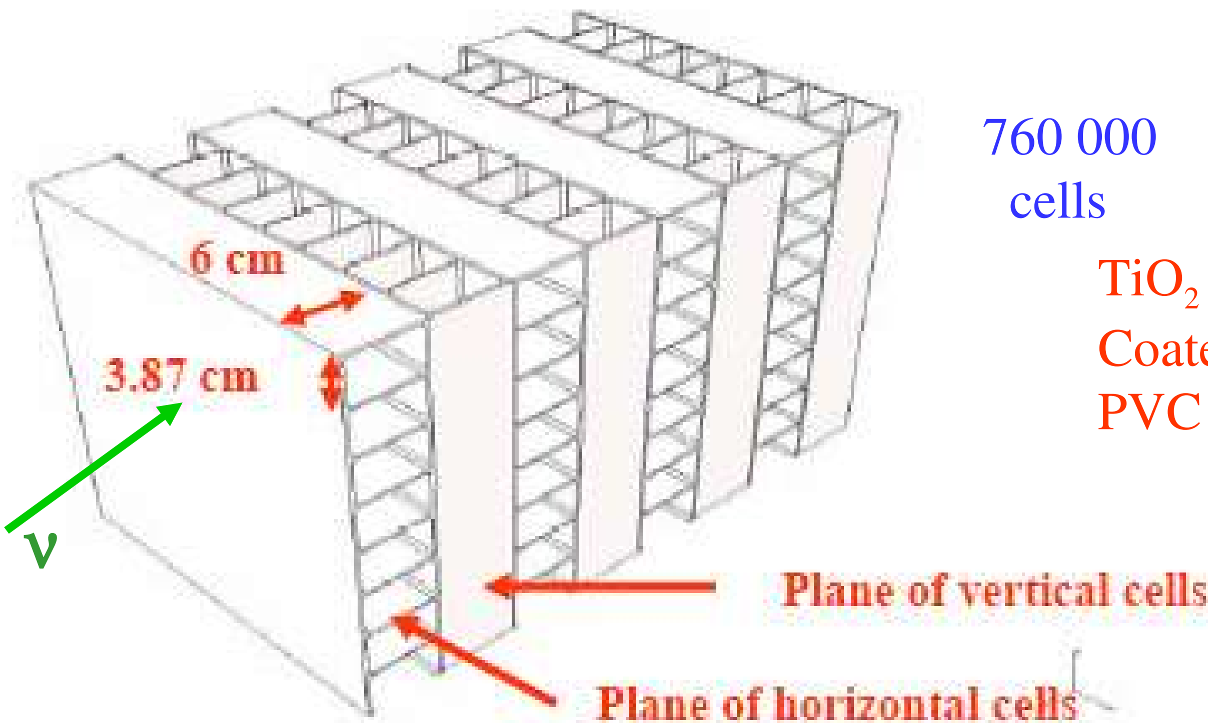
+- depends on the mass hierarchy.

Matter effects grow with energy and therefore with distance.

3 times larger (27%) at NOνA (1.64 GeV) than at T2K (0.6 GeV)

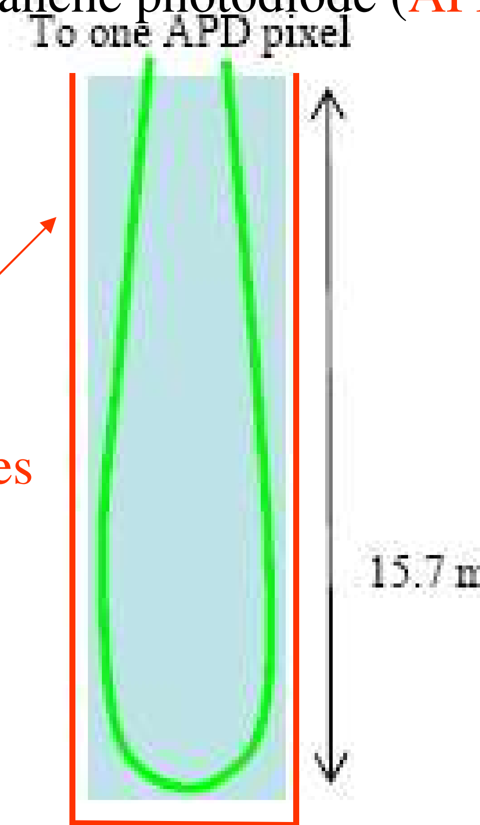
NOνA Detector

Given relatively high energy of NUMI beam,
decided to optimize NOνA for resolution of the mass hierarchy
Detector placed 14 mrad (12 km) Off-axis of the Fermilab NUMI beam (MINOS).
At Ash River near Canadian border (L = 810km) : New site. Above ground.
Fully active detector consisting of 15.7m long plastic cells filled
with liquid scintillator: Total mass 30 ktons.
Each cell viewed by a looped WLS fibre read by an avalanche photodiode (APD)



760 000 cells

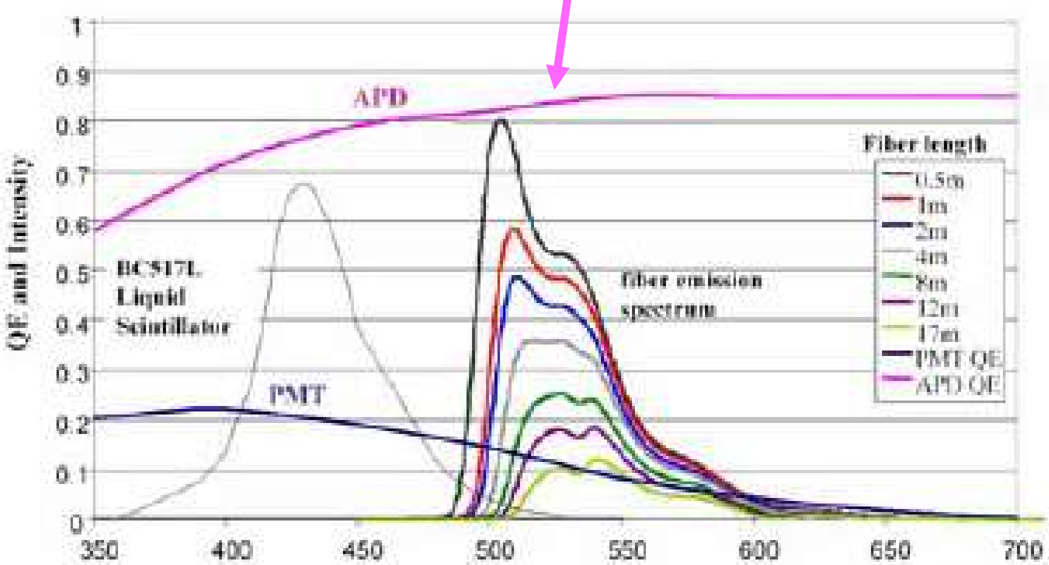
TiO_2 Coated PVC tubes

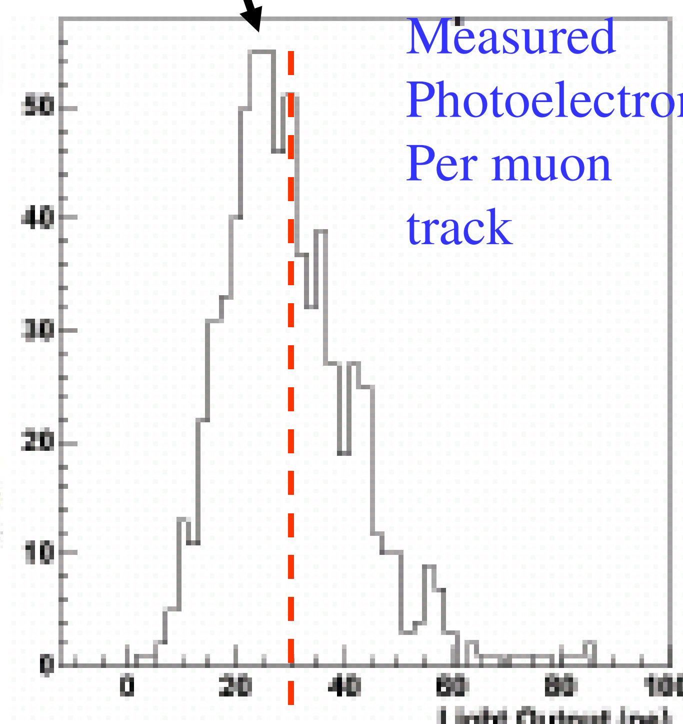


NOνA

The quantum efficiency of APD's is much higher than a pm's: ~80% . Especially at the higher wave lengths surviving after traversing the fibre.

After15.7m still **30 photoelectrons/mip** with looped fibre. Coating:15% TiO_2



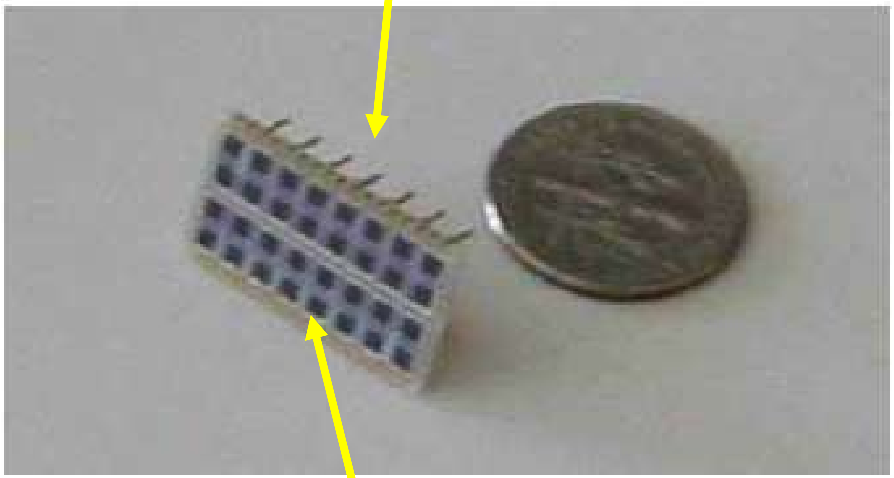


Measured Photoelectrons Per muon track

Asic for APD's: 2.5 pe noise
→ S/N ~ 12

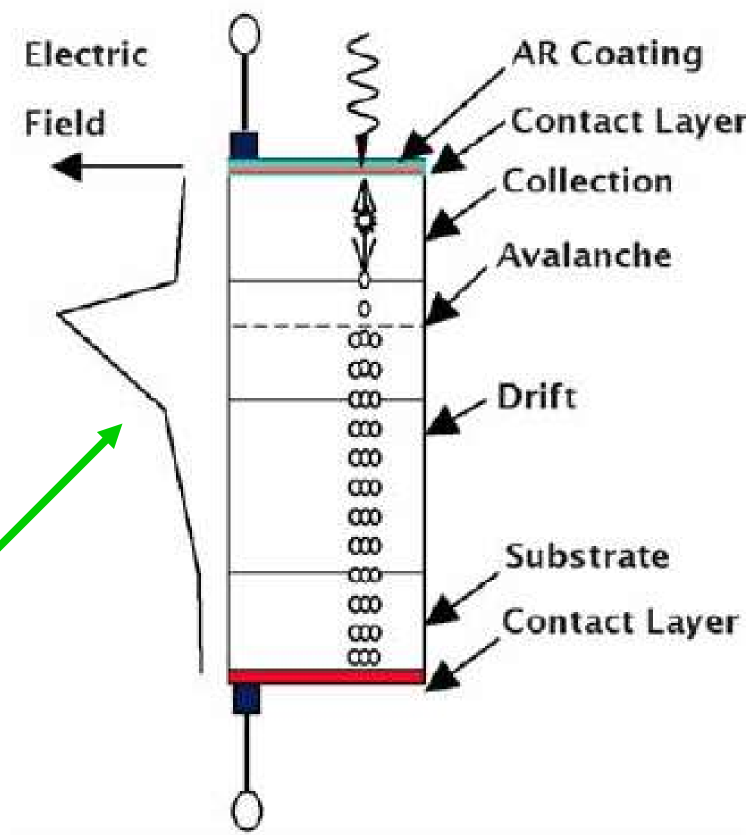
Avalanche Photodiode

- Hamamatsu 32 APD arrays



- Pixel size 1.8mm x 1.05mm (Fibre 0.8mm diameter)
- Operating voltage 400 Volts
- Gain 100
- Operating temperature: -15^{o} C (reduces noise)

Photon

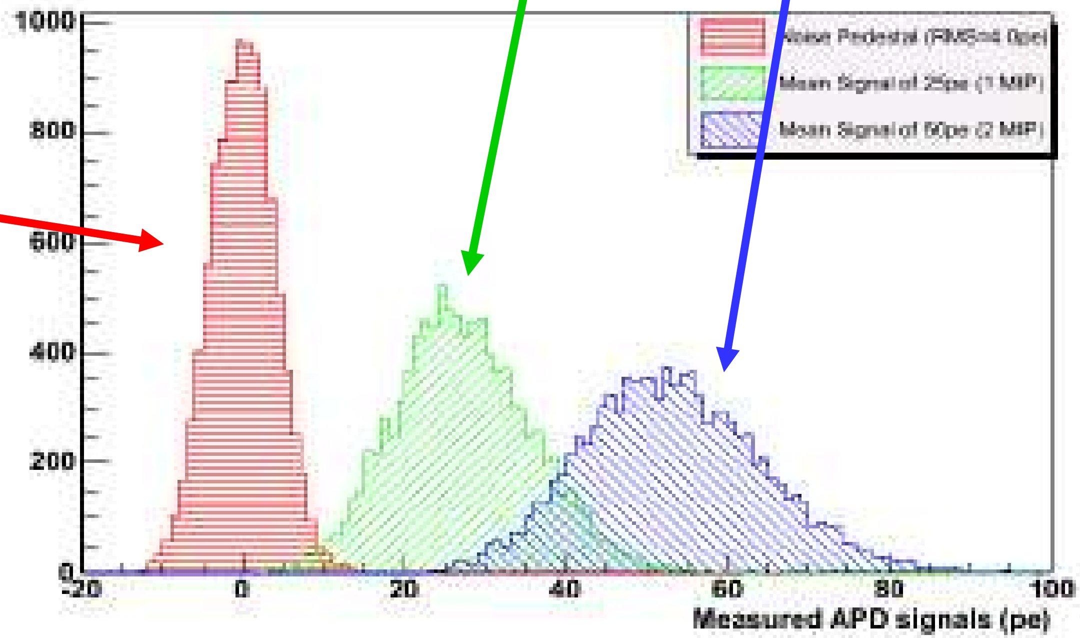


Asic for APD's: 2.5 pe noise
→ S/N ~ 30/2.5 = 12

APD response

Measured with light equivalent to one and two mip's

Noise



Signal well separated from noise

0 20 40 60 80 pe

The Beam

PROTONS: 6.5 x 10^{20} protons on target per year.

Greatly helped by

- Cancellation of BTeV
- Termination of Collider programme by 2009.

A gain of a factor of > 2 in numbers of protons delivered.

Longer term: Construction of an 8 GeV proton driver: x 4

↓

25.2 x 10^{20} protons on target per year is the goal.

The Beam: x 2

- No antiproton production batches in Main Injector: x 11/9 = 1.22

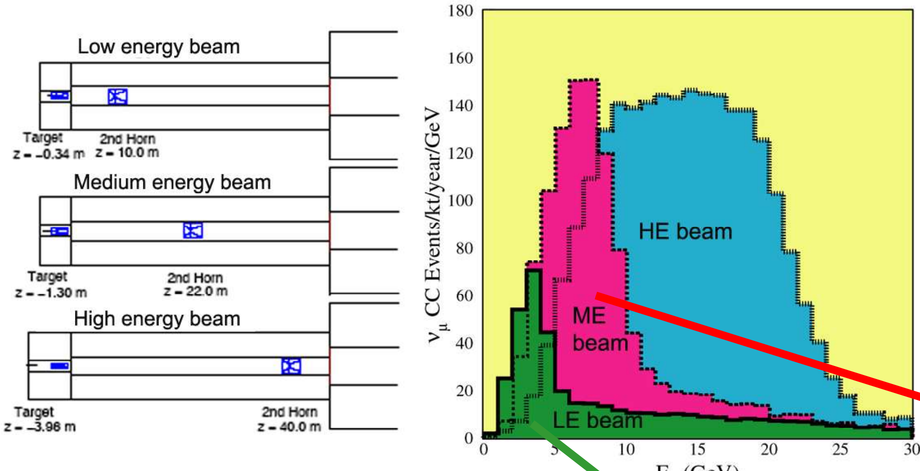
- No downtime for preparing collider shot.
  No time for antiproton transfer from accumulator to recycler. x 1.176

- Transfer time of 12 booster batches to Main Injector (0.8 sec).
  Instead transfer them to recycler during Main Injector cycle,
  and then transfer in one go (0.067 sec) from recycler to Main Injector. :
  2.2 sec/1.467 sec = 1.5

1.22 x 1.176 x 1.5 x 3.4 x 10^{20} protons/year = 7.3 x 10^{20} protons/year

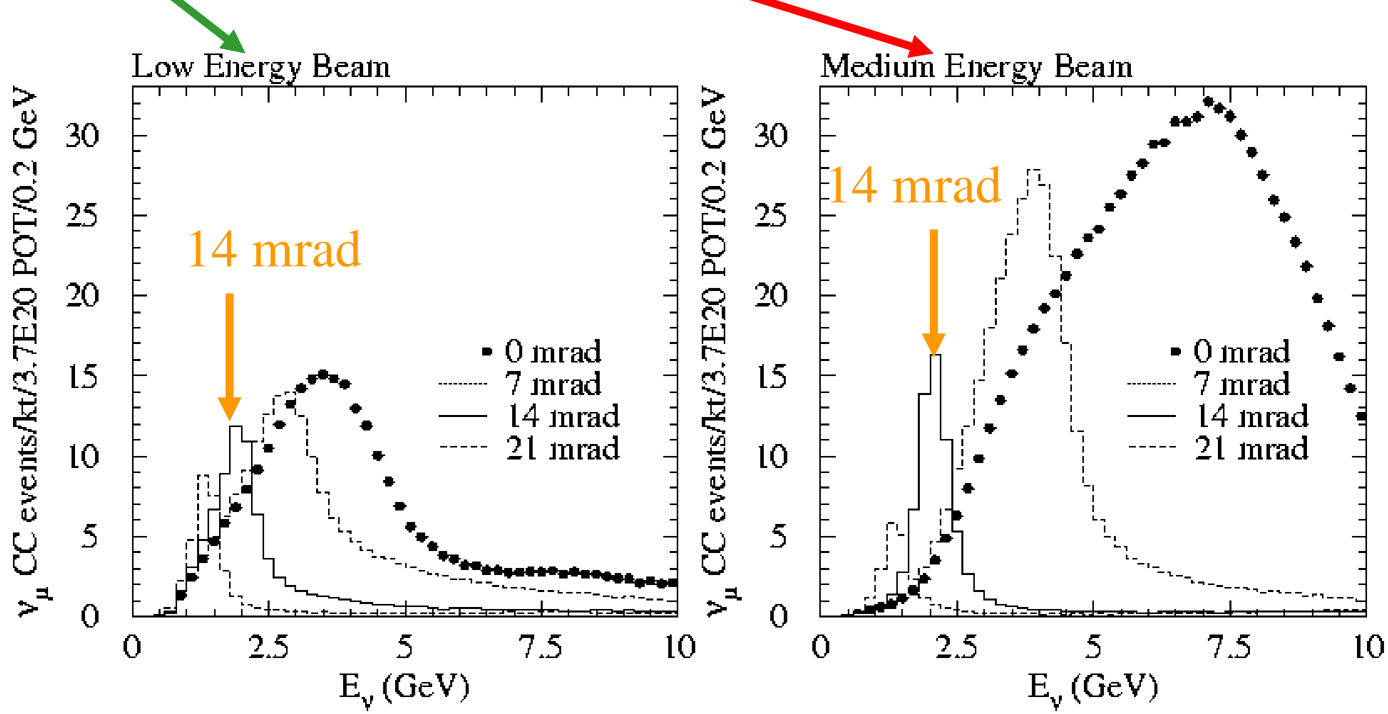
Negotiated 6.5 x 10^{20} protons/year with Fermilab management.

The Beam: Same NUMI beam as MINOS

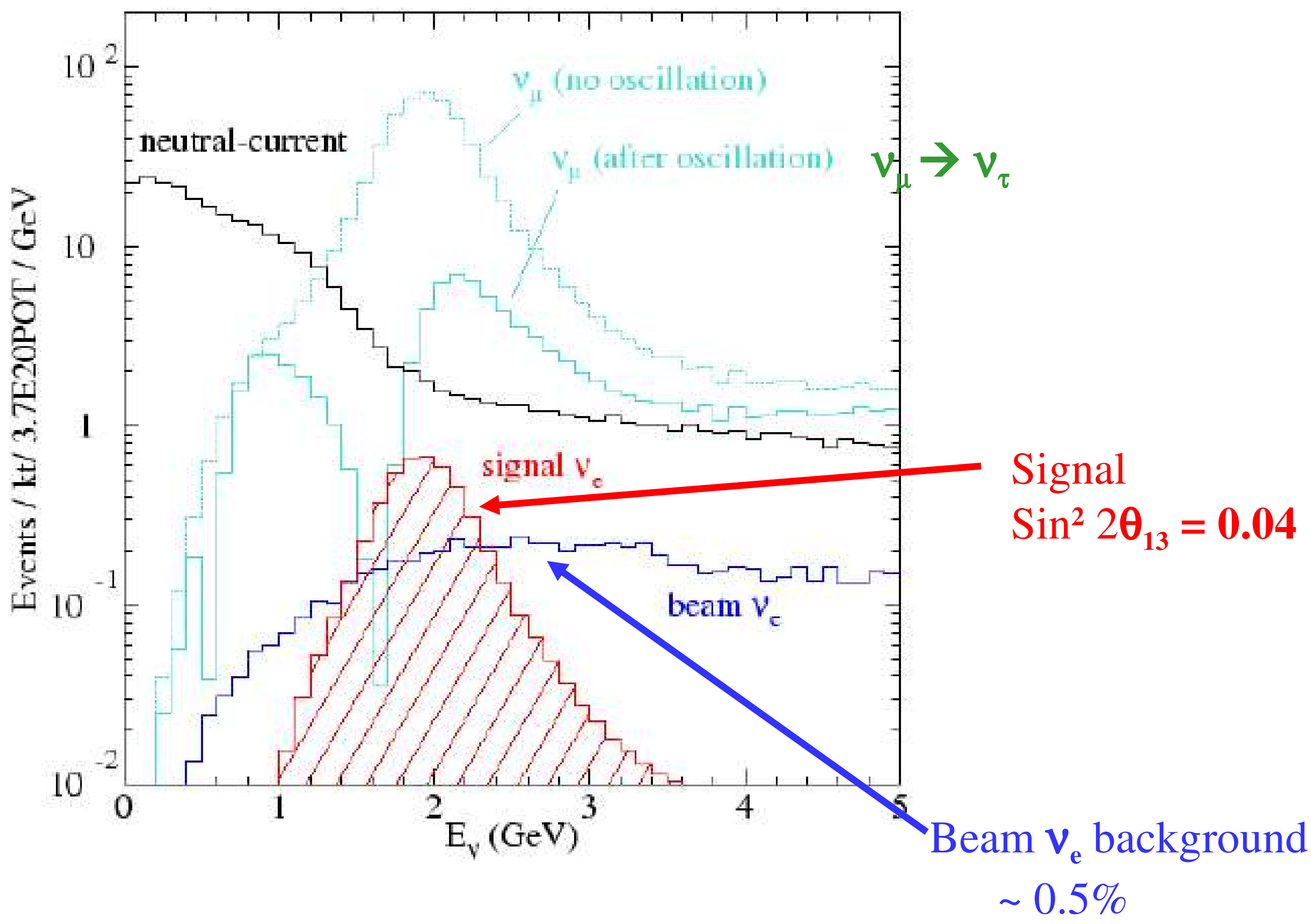


Can select low, medim and high energy beams by moving horn and target
Best is the
Medium energy beam

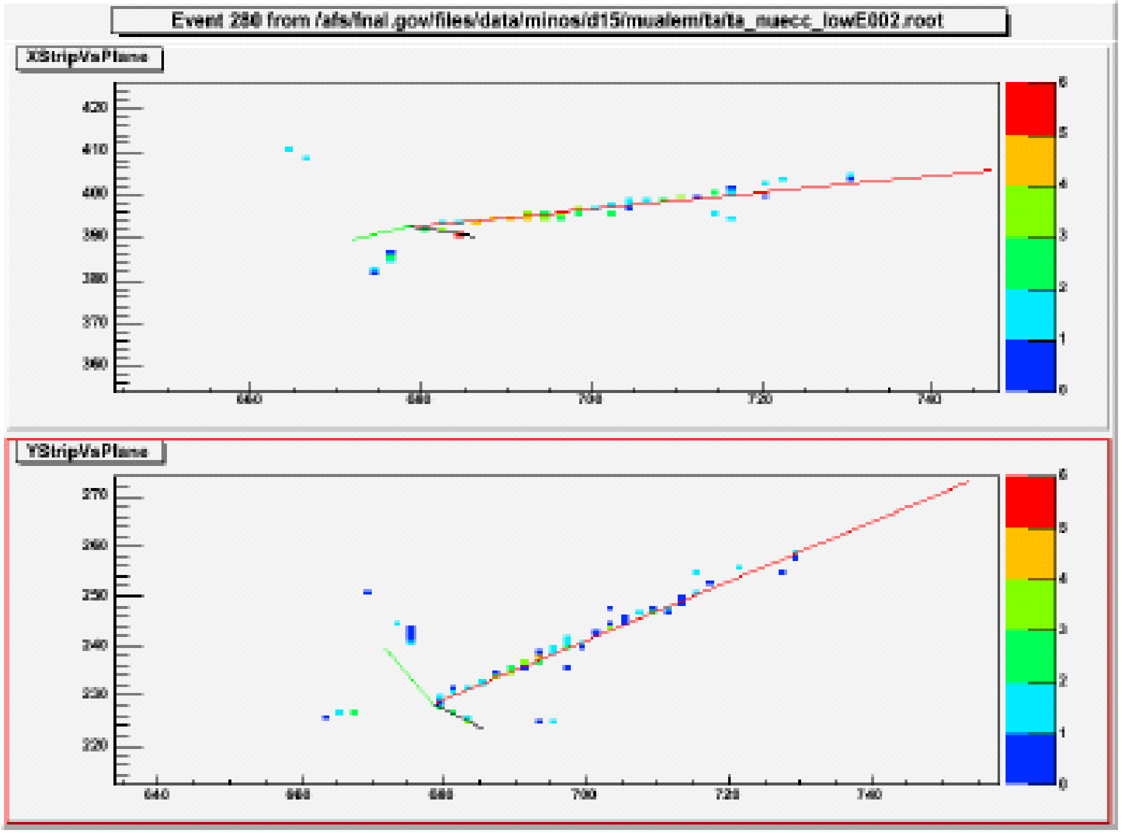
Off-axis detector:
14 mrad



Beam spectra

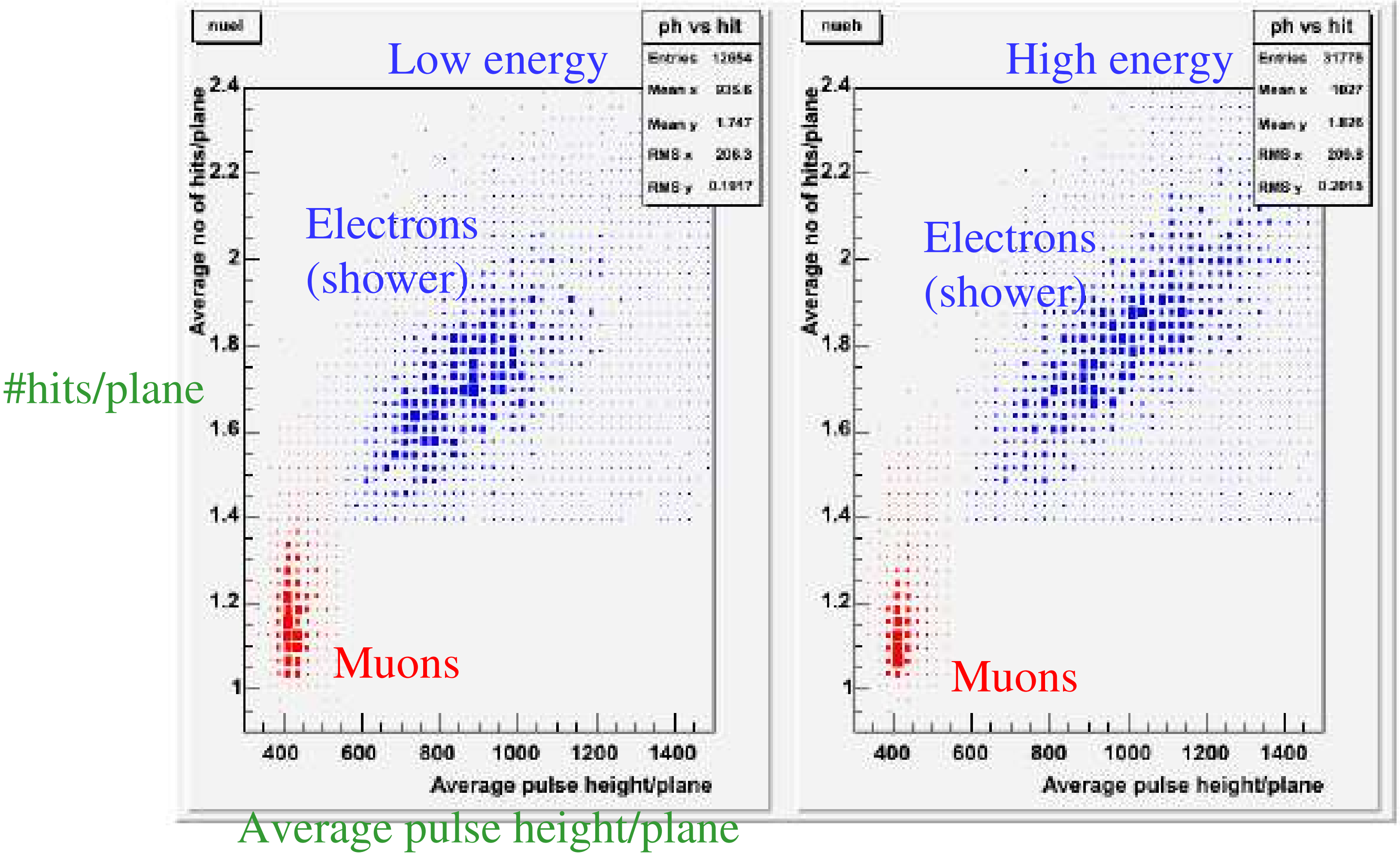


Accepted CC event: $\nu_e A \rightarrow p e \pi^o$



Electrons shower: many hits/plane.
Muons do not: just one hit/plane.

$\nu_\mu - \nu_e$ separation



π^o in NC also a problem.

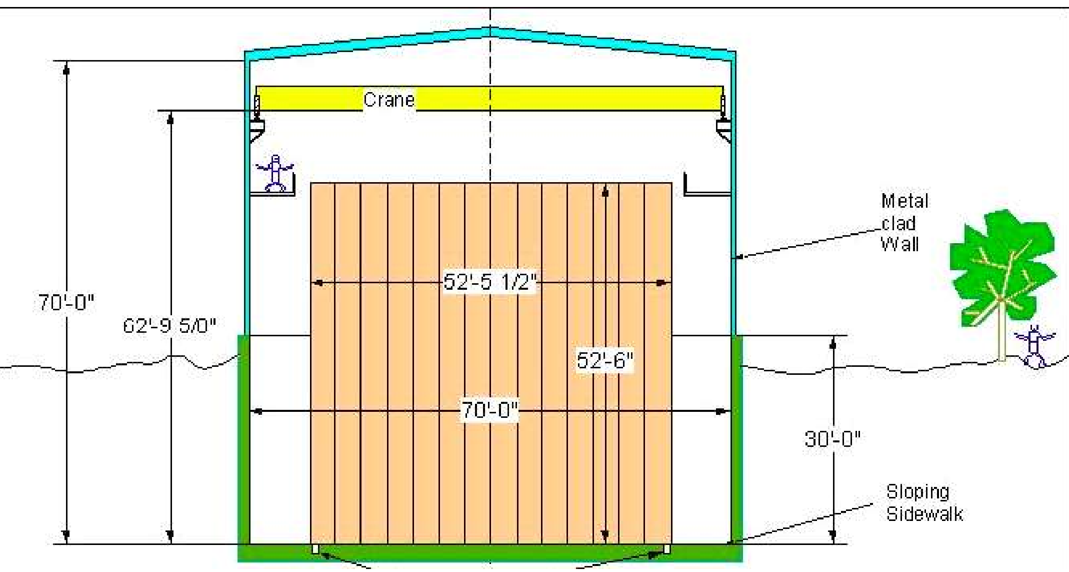
Signal ν_e efficiency: 24%. ν_μ CC background 4×10^{-4}

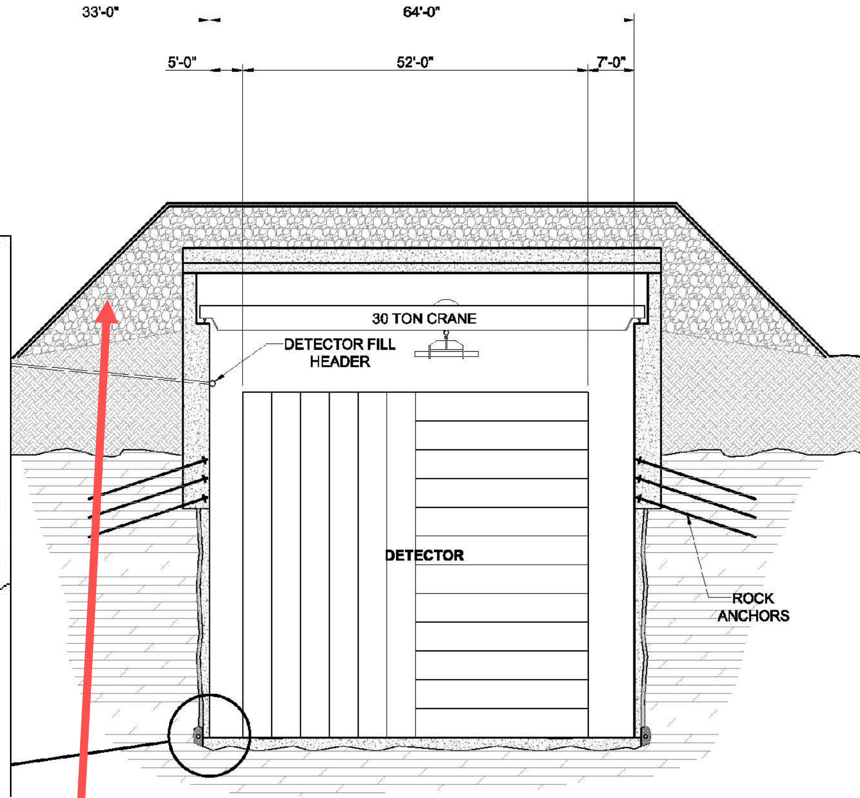
ν_μ NC background 2×10^{-3}

Summary of backgrounds

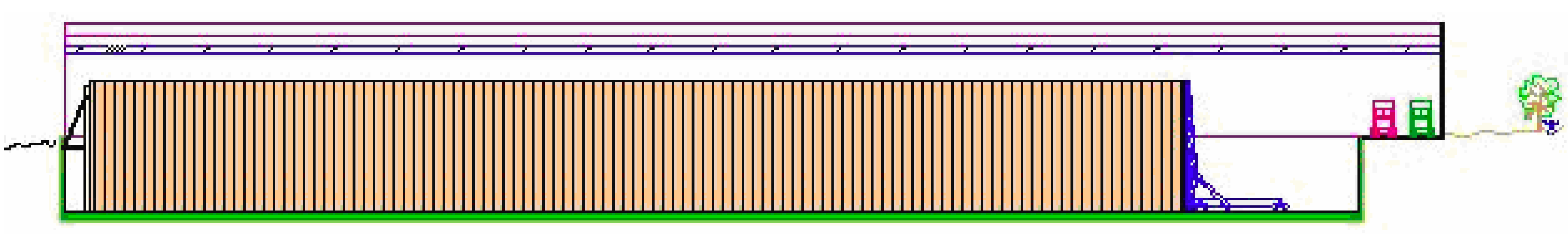
Background	Events	% Error	Error
Beam ν_e	11.9	7%	0.8
N_μ CC	0.5	15%	0.08
NC	7.1	5%	0.4
Total	19.5	5%	0.9

Location



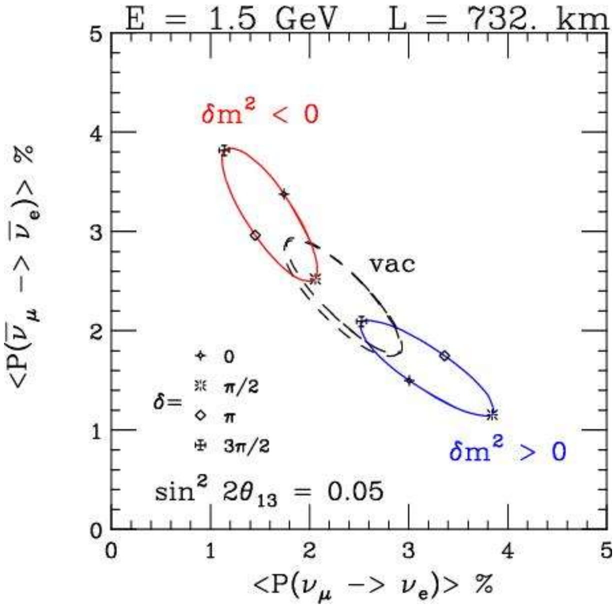


Surface detector with about 3m overburden to reduce
The em component of cosmic rays.



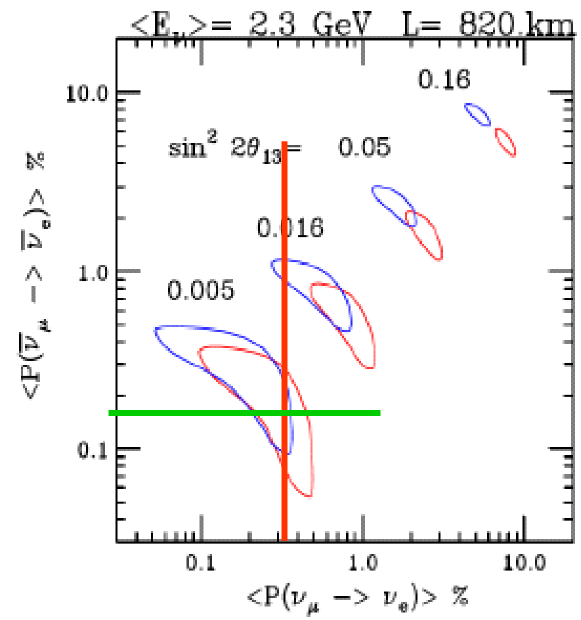
8-fold degeneracies

- θ_{13} - δ ambiguity.
- Mass hierarchy two-fold degeneragy



A measure of $P_{\mu e}$ can yield a whole range of values of θ_{13}

Measuring with $\bar{\nu}$'s as well reduces the correlations

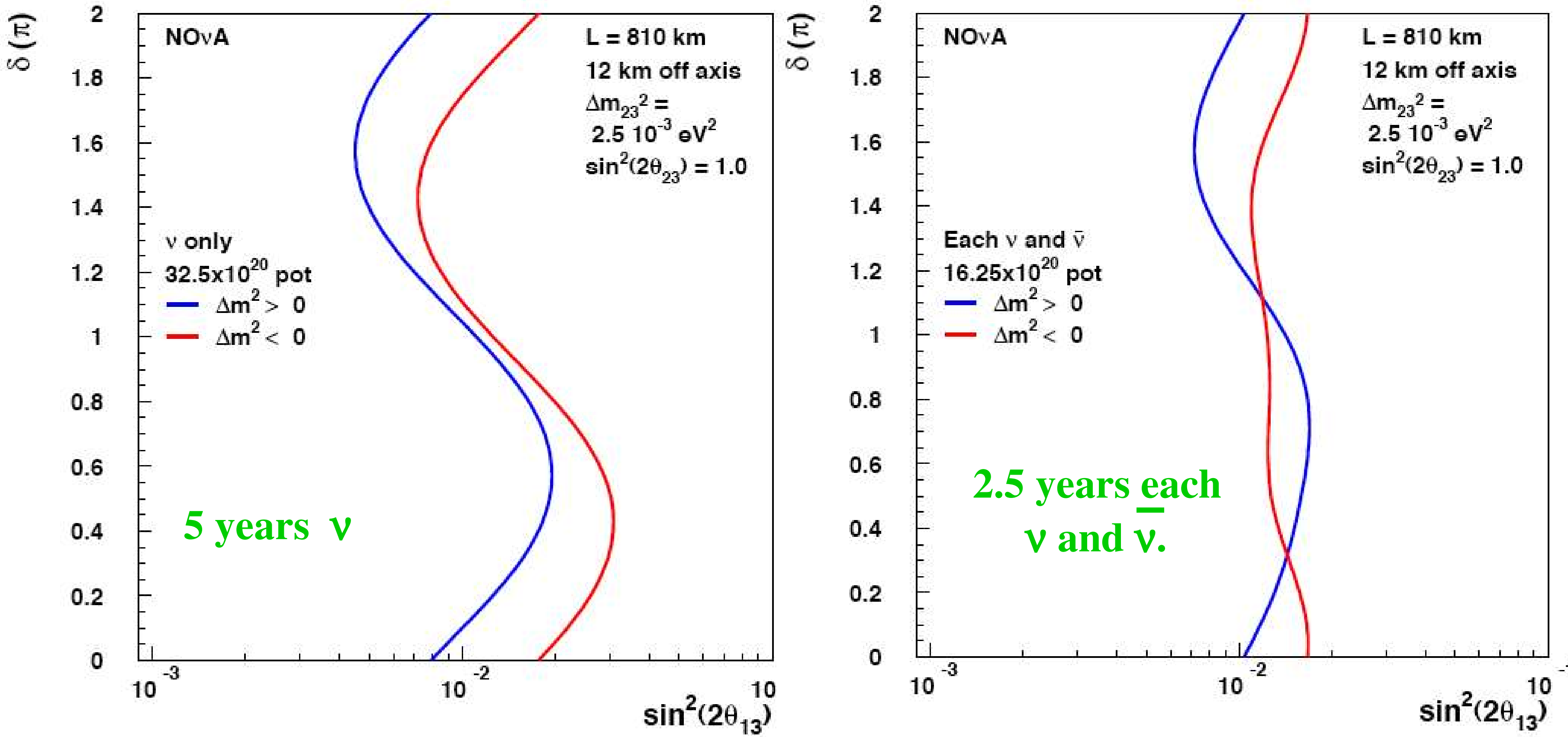


- θ_{23} degeneracy:

For a value of $\sin^2 2\theta_{23}$, say 0.92, $2\theta_{23}$ is 67° or 113 ° and θ_{23} is 33.5° or 56.5

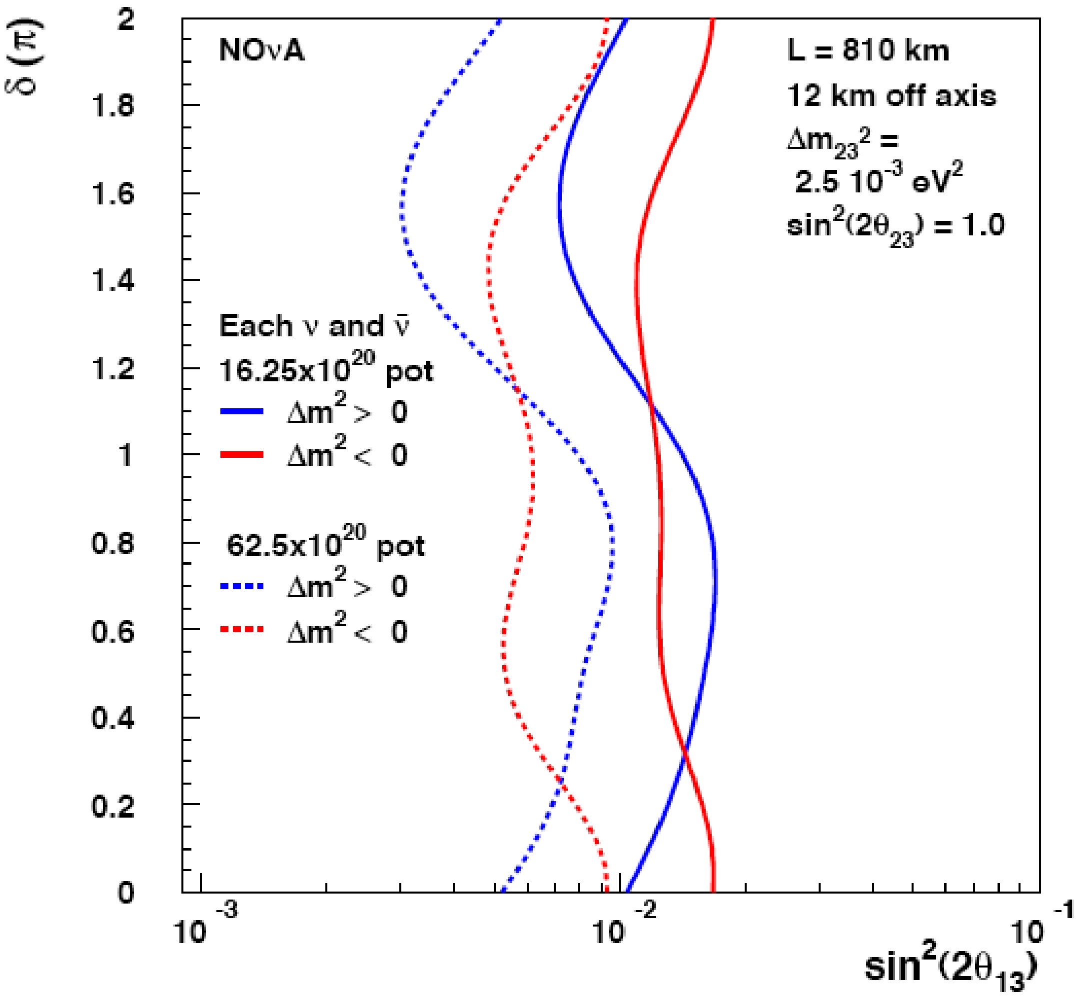
- In addition if we just have a lower limit on $\sin^2 2\theta_{23}$, then all the values between these two are possible.

3 σ discovery limits for $\theta_{13} \neq 0$



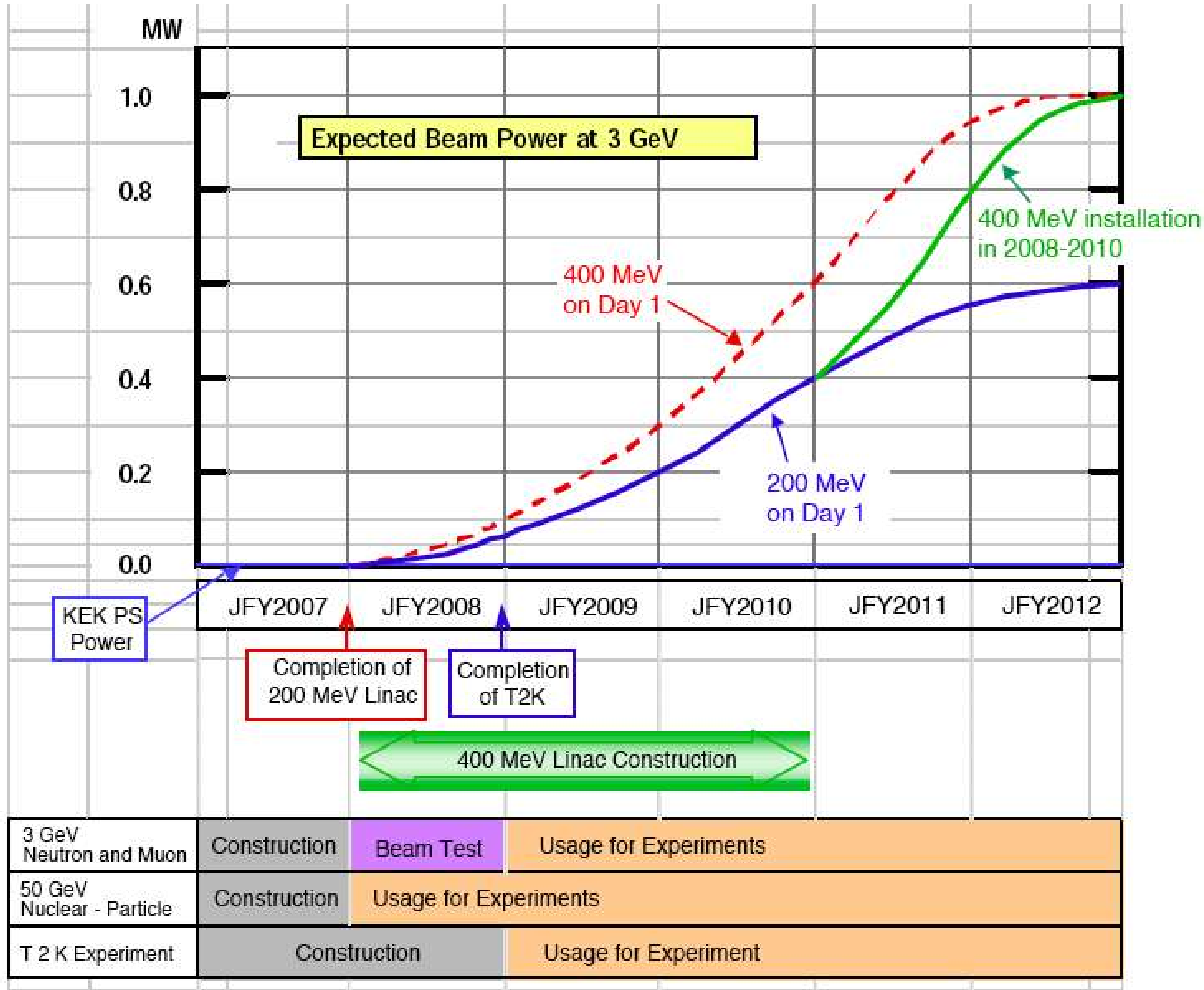
Discovery limit is better than 0.02 for ALL δ's and BOTH mass hierarchies.

3 σ discovery limits for $\theta_{13} \neq 0$
Comparison with Proton Driver

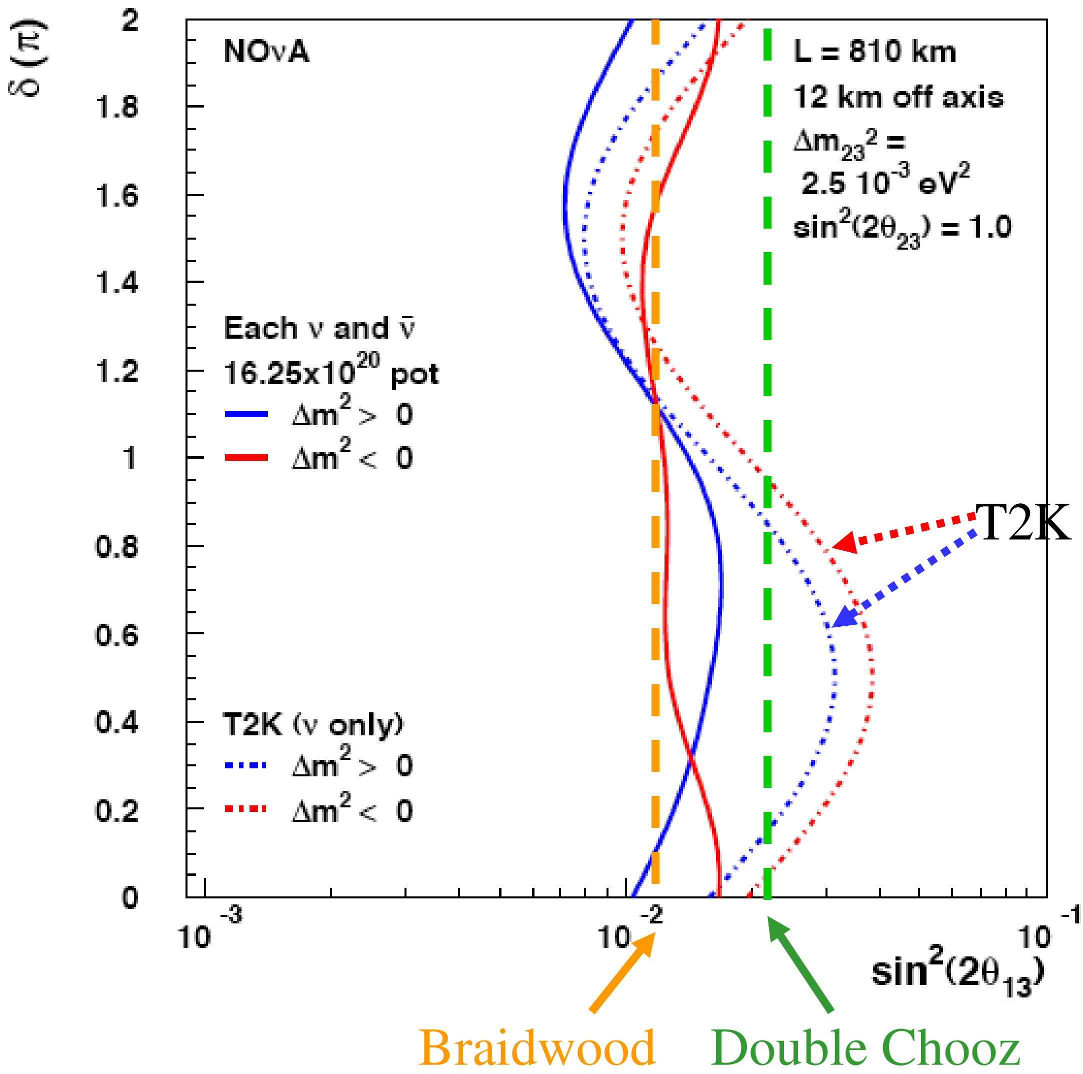


2.5 years each ν and ν.

T2K schedule



3 σ discovery limits for $\theta_{13} = 0$
Comparison with T2K and 2 Reactor experiments

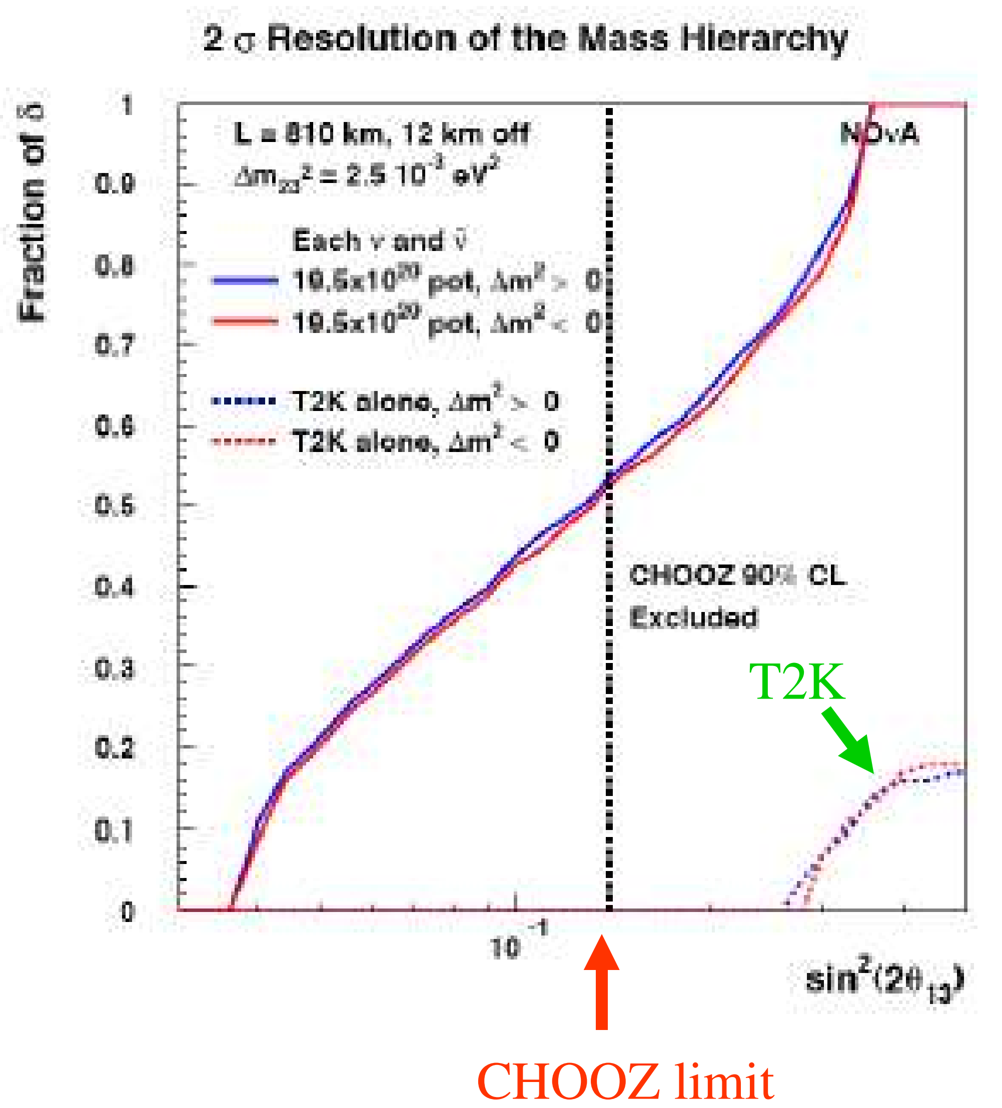


Sensitivity vs time

Resolution of mass hierarchy

- Fraction of δ over which the mass hierarchy can be resolved at 2σ.
- Equal amounts of neutrino and antineutrino running: 3 years each assuming Phase I.
- Near the CHOOZ limit the mass hierarchy can be resolved over 50% of the range of δ.
- T2K Phase I can only resolve the hierarchy in a region already excluded by CHOOZ.

  Because of its lower energy.
- Some small improvement if we combine T2K and NOνA results



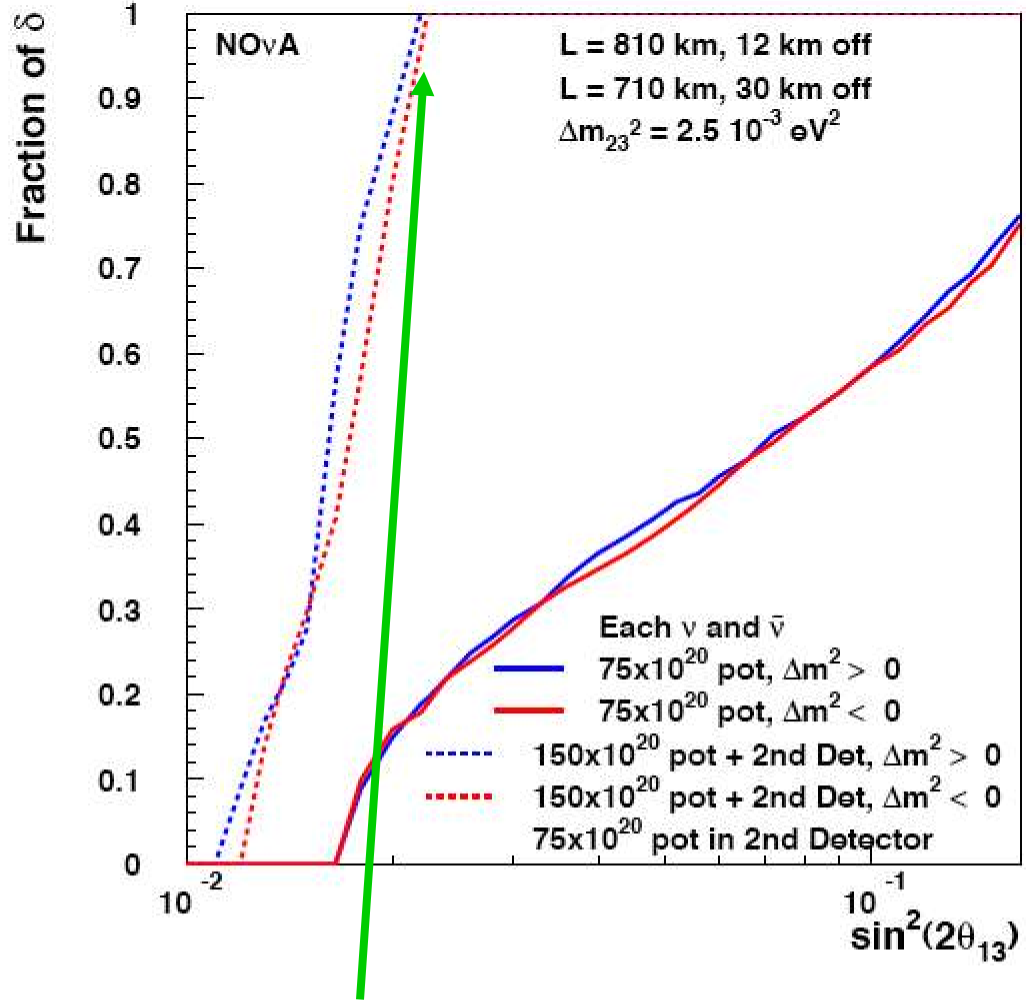
Looking further ahead

- With a proton driver, Phase II, the mass hierarchy can be resolved over 75% of **δ** near the CHOOZ limit.

- In addition to more protons in Phase II, to resolve hierarchy a second detector at the second oscillation maximum can be considered:

- $\Delta_{atm} = 1.27\ \Delta m^2_{32}\,(L/E) = 3\pi/2$.
  L/E = 1485, a factor of 3 larger than at 1st max.
  For ~ the same distance, E is 3 times smaller:
  matter effects are smaller by a factor of 3

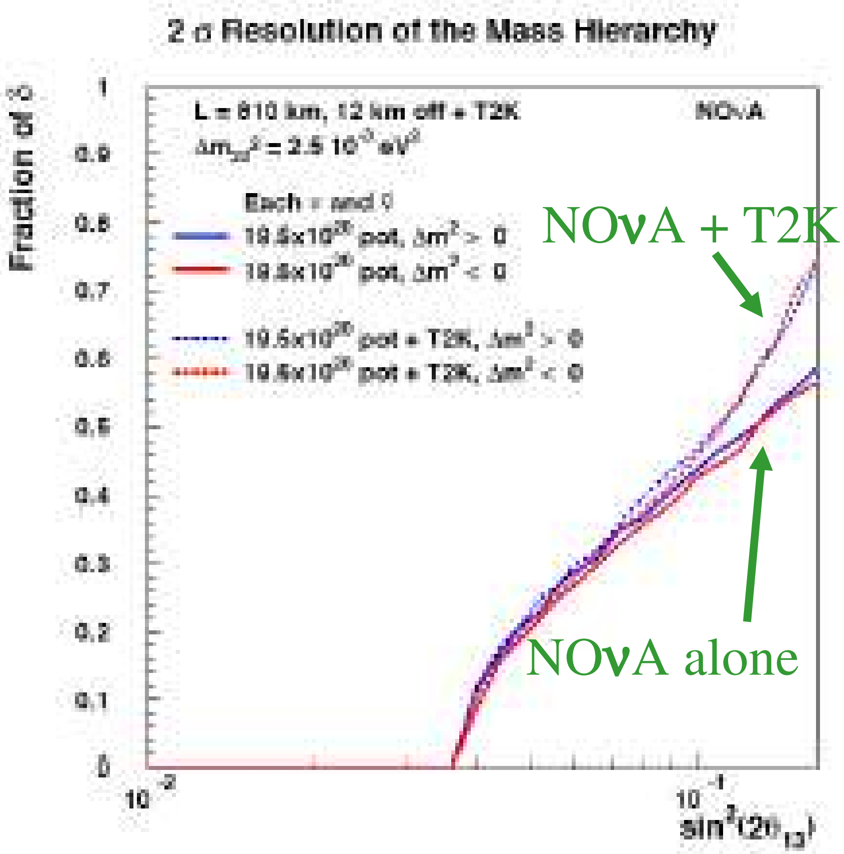
- 50 kton detector at 710 km.
- 30km off axis (second max.)
- 6 years (3 **ν** + 3 **ν**)



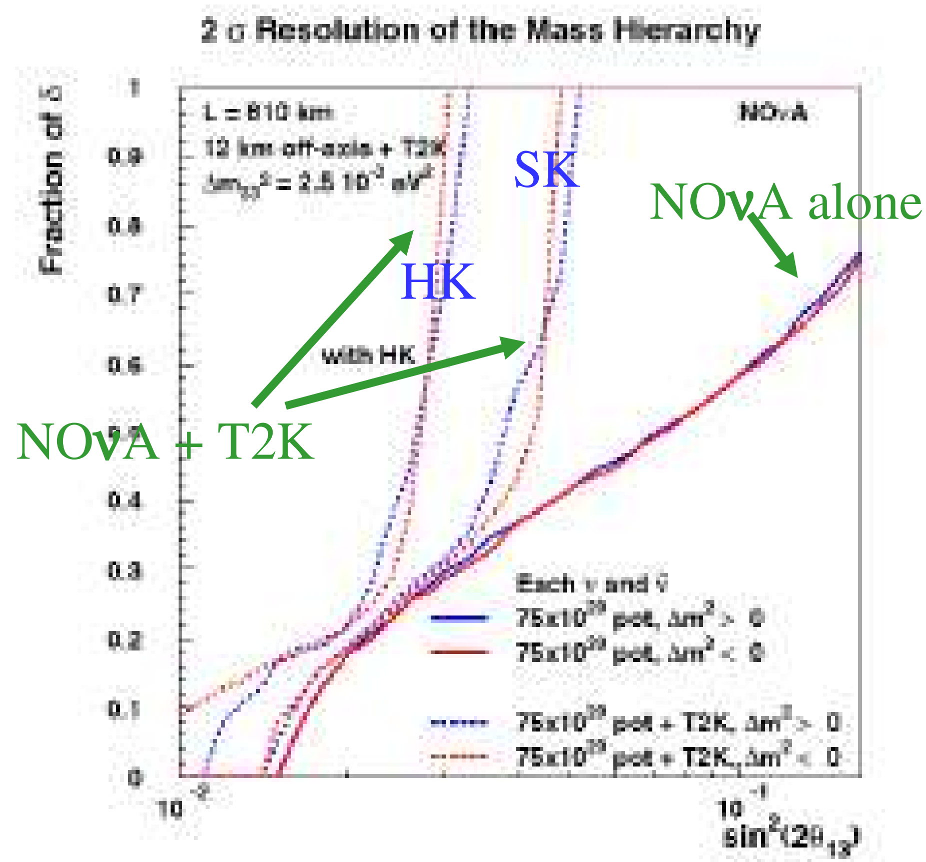
Determines mass hierarchy for all values of **δ** down to $\sin^2 2\theta_{13} = 0.02$

Synergy of NOνA and T2K

NOνA Phase 1

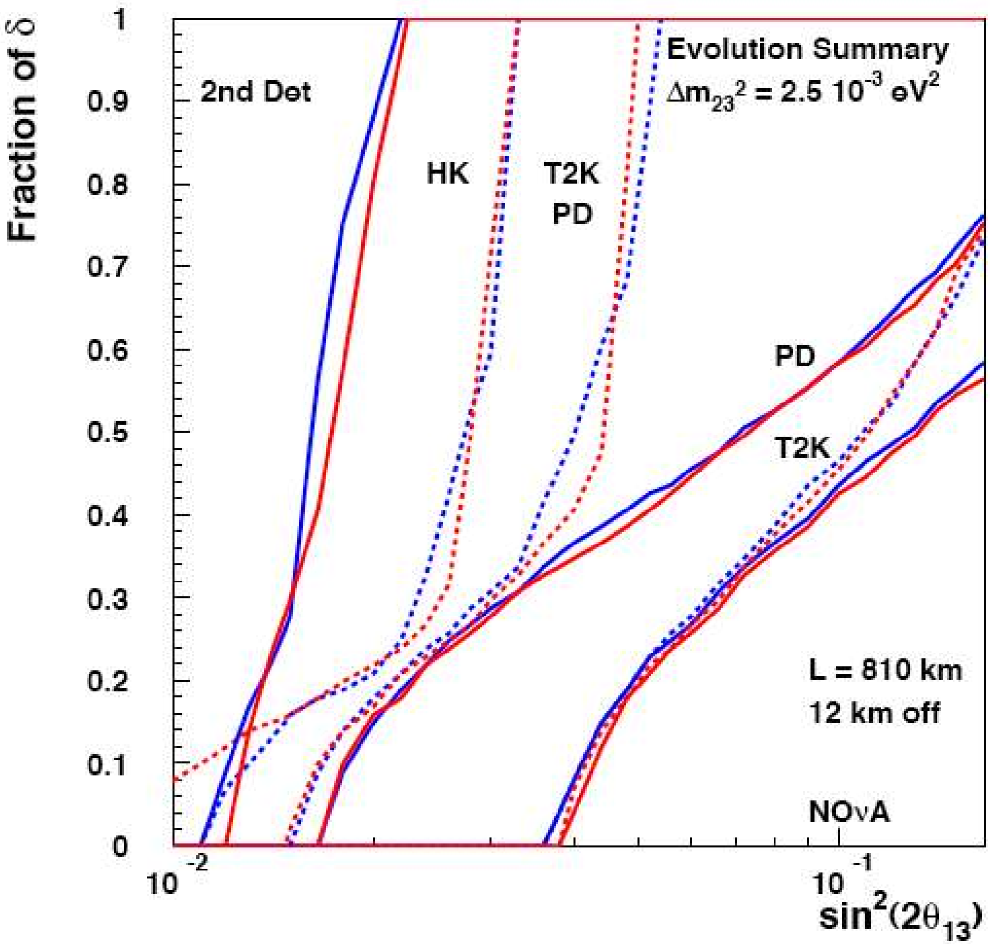


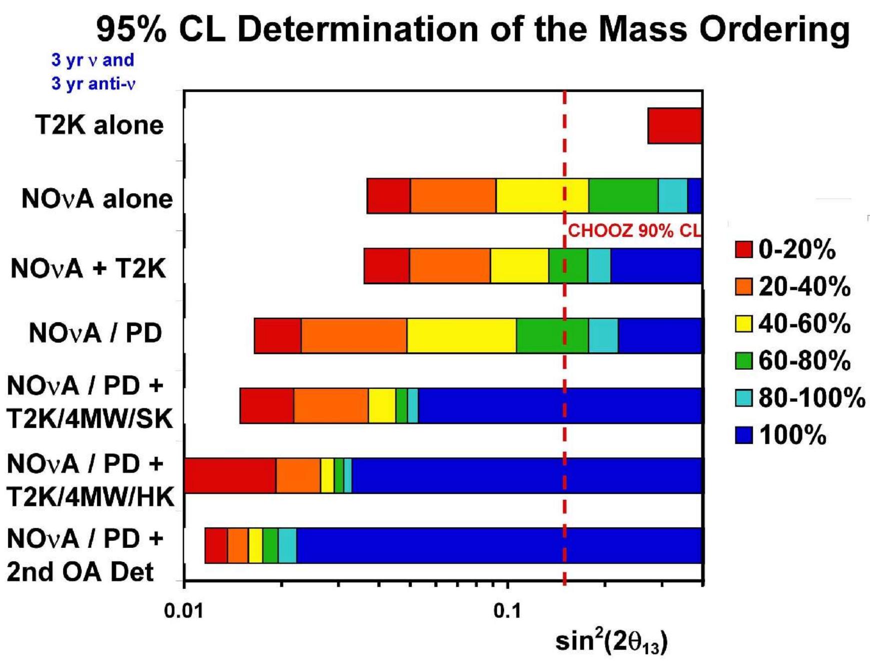
NOνA with PD



3 years each of **ν** and **$\bar{\nu}$** in both NO**ν**A and T2K

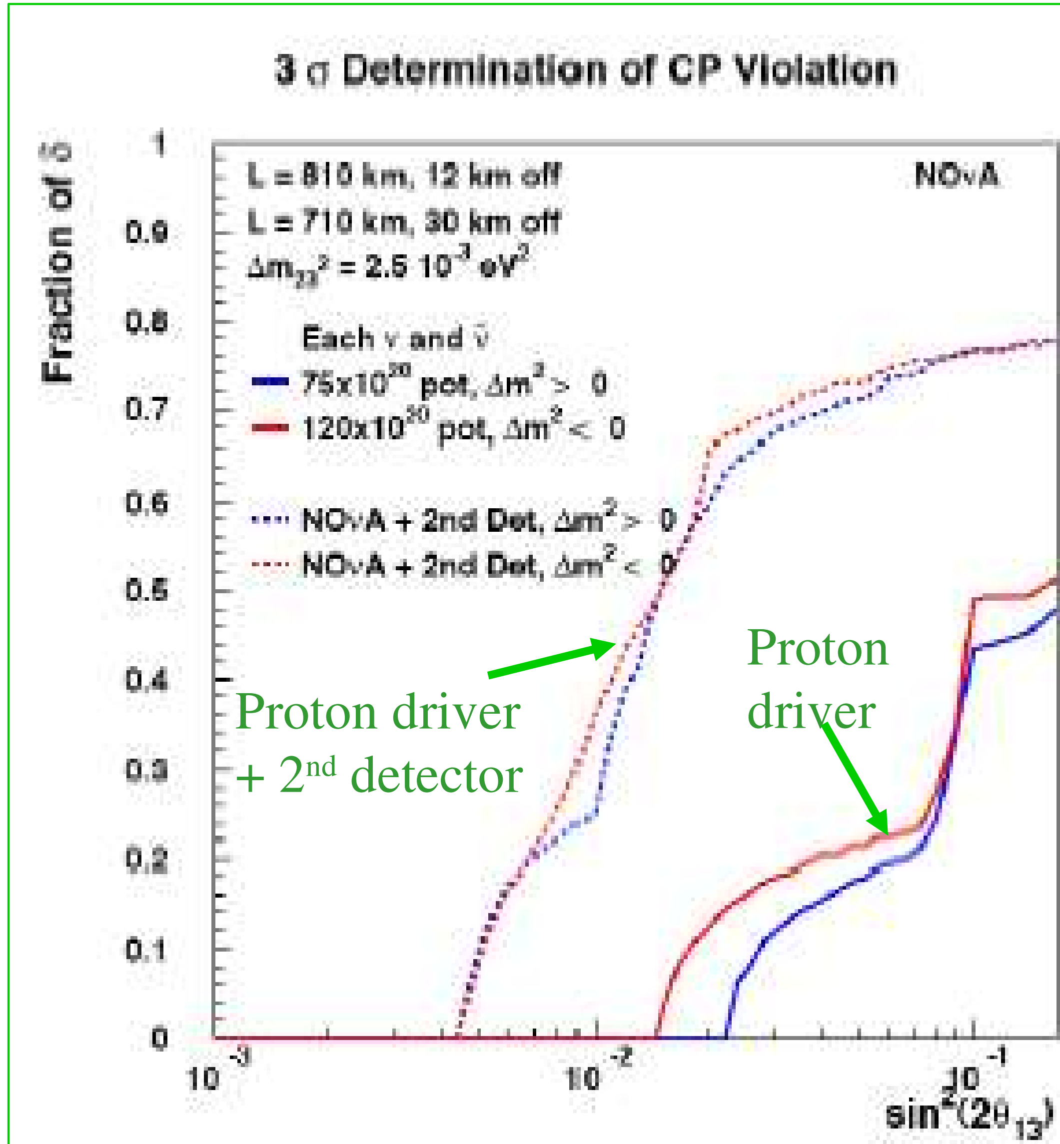
Summary of mass hierarchy reach



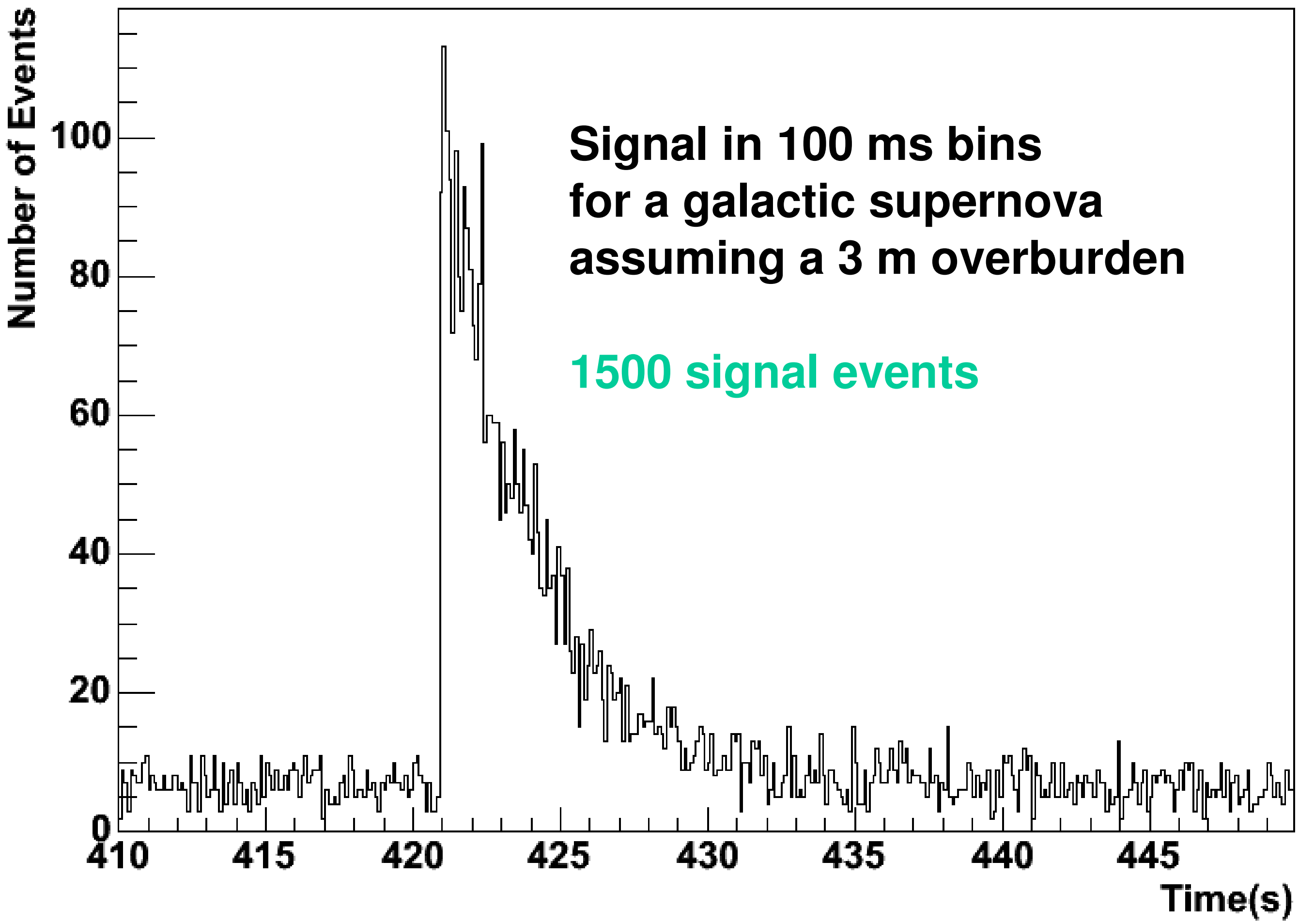


CP reach

- To look for CP violation requires the proton driver.
- But combining with a second detector is what really becomes SIGNIFICANT.



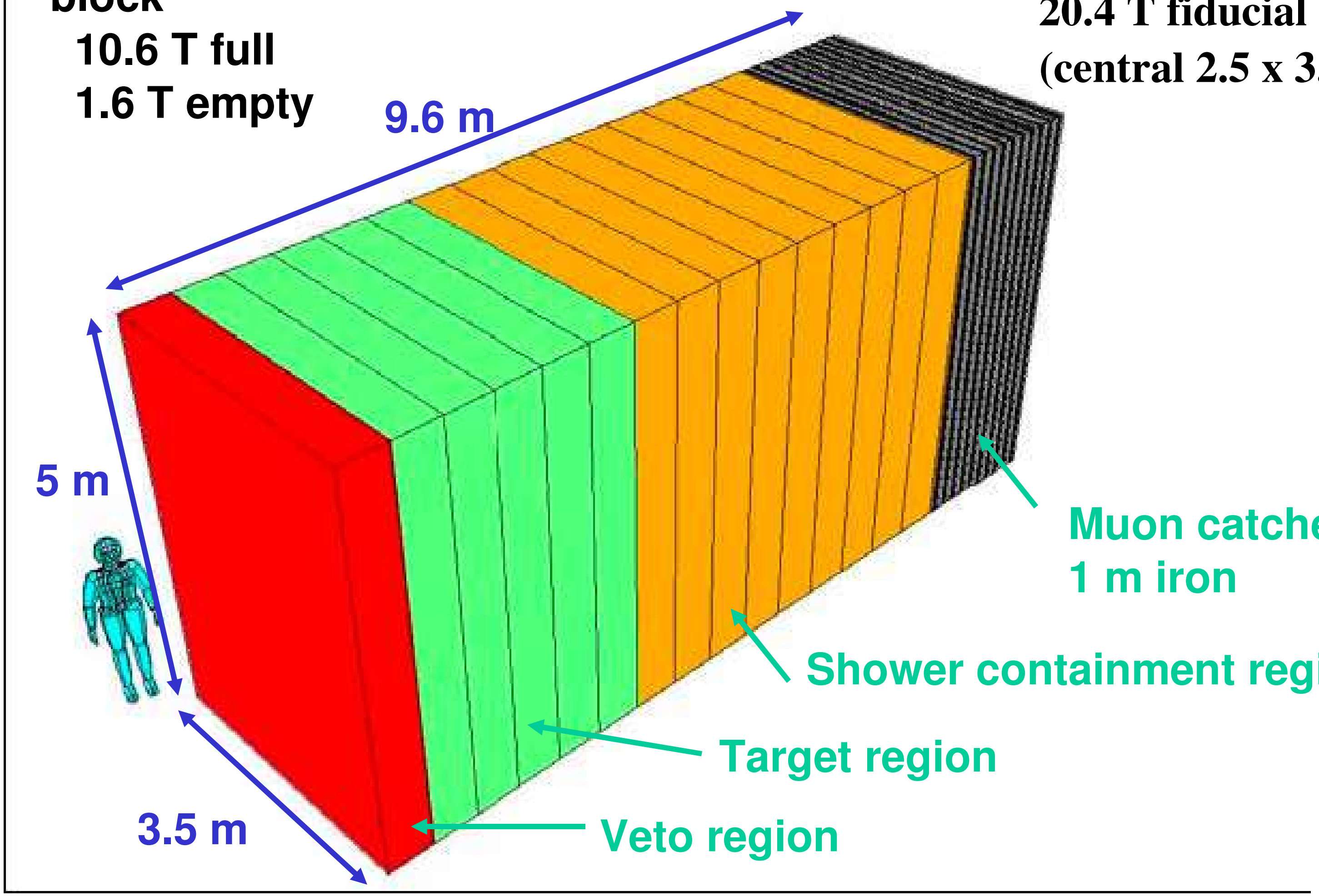
Super Nova signal with overburden



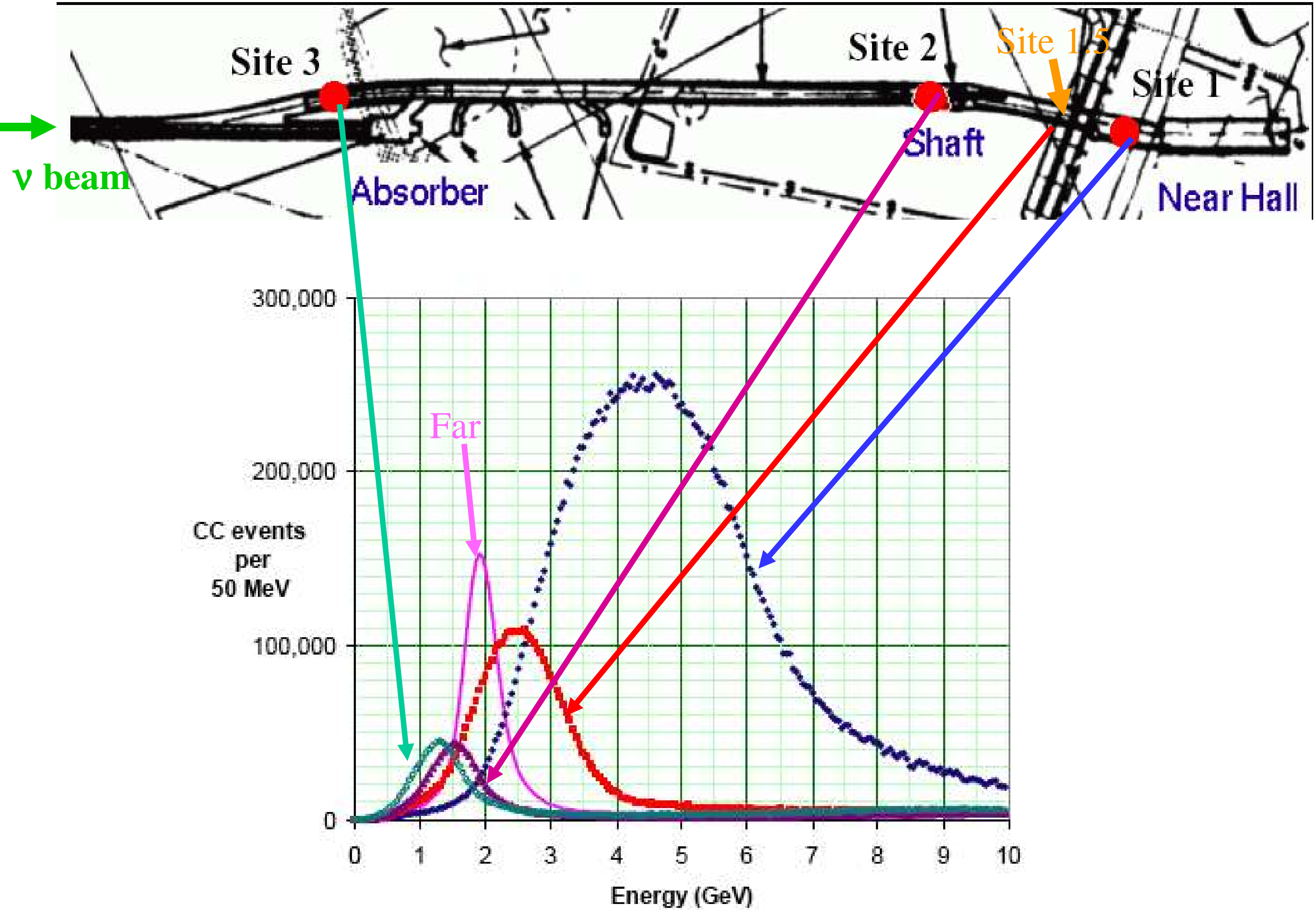
Near Detector to understand the beam

8-plane block
10.6 T full
1.6 T empty

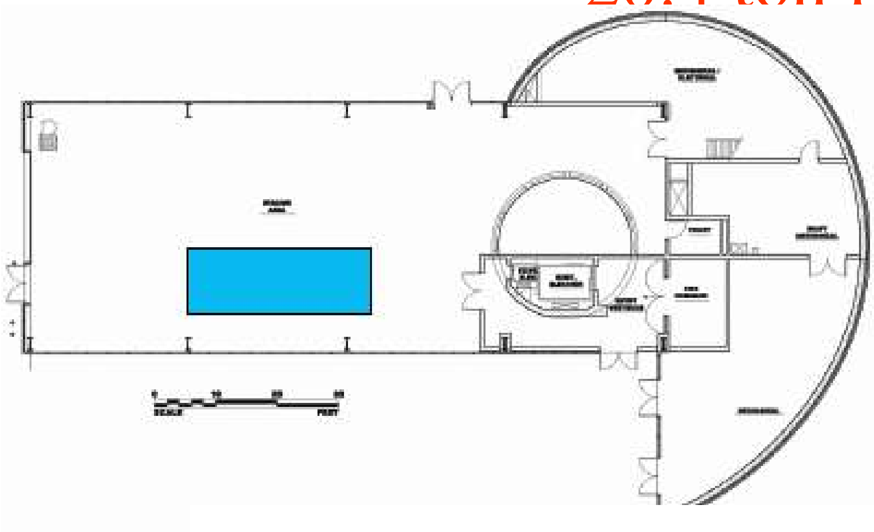
262 T
145 T totally active
20.4 T fiducial
(central 2.5 x 3.25 m)



Near detector locations



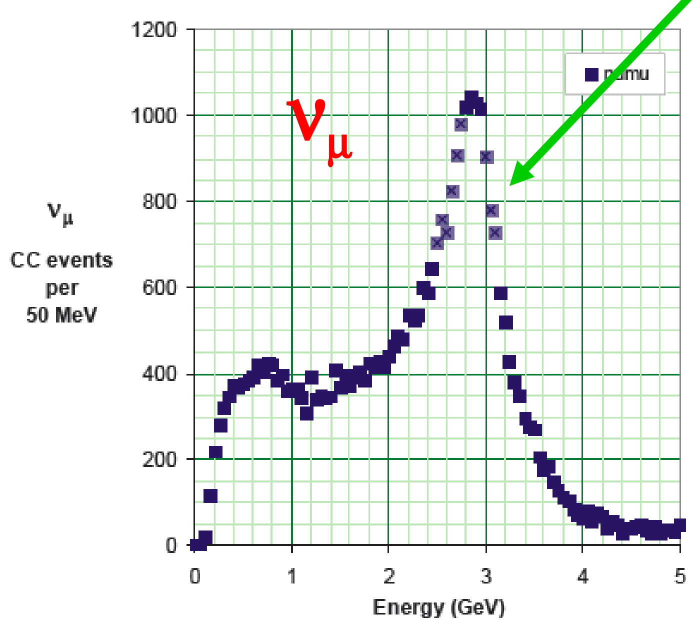
In Surface building: Test in 2007?
20.4 ton fid.volume

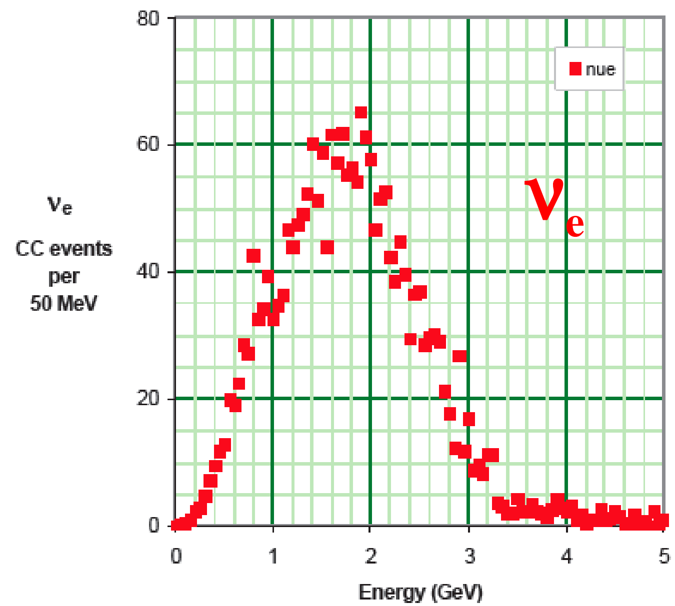


MINOS Surface Building

Extremely off-axis: 75 mrad. (105m)

Peak from kaon decays in ν_μ spectrum





45 000 CC events (2200 ν_e) for 6.5 x 10^{20} protons per year

Cost and schedule

- Total cost (Far and near detectors, building, admin etc…)
  164 M$ (including 50% contingency)

Status

- Approved by Fermilab Program Advisory Committee
- Going through reviews

Schedule

- Assumption: Approval in 2006.
- Building ready: May 2009.
- First kiloton: October 2009.
- Completion: July 2011.

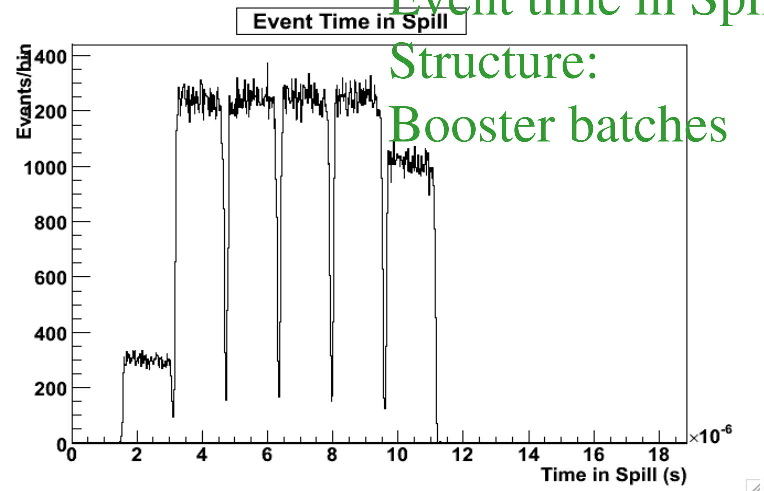
NOνA would welcome European groups

- Possible CERN participation ? (LC interested).
- European groups already in NOνA:
  Athens, College de France, Tech. Univ. Munich, Oxford, Rutherford
- Several Italian groups interested.

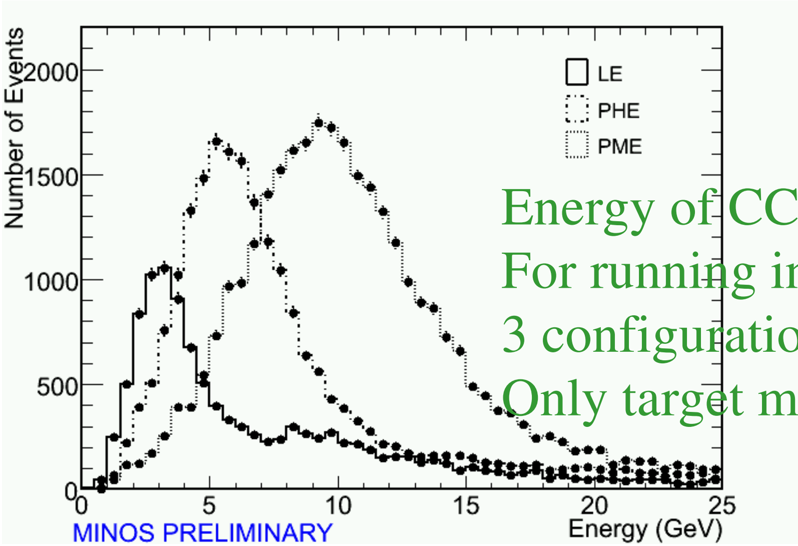
Status of NUMI/MINOS: Near detector

They get ~ 2.5 x 10^{13} protons/spill
Spill: either 2.2 or 3.8 secs.
(Depends on antiproton cooling)
Delivered so far: 0.8 x 10^{20}.

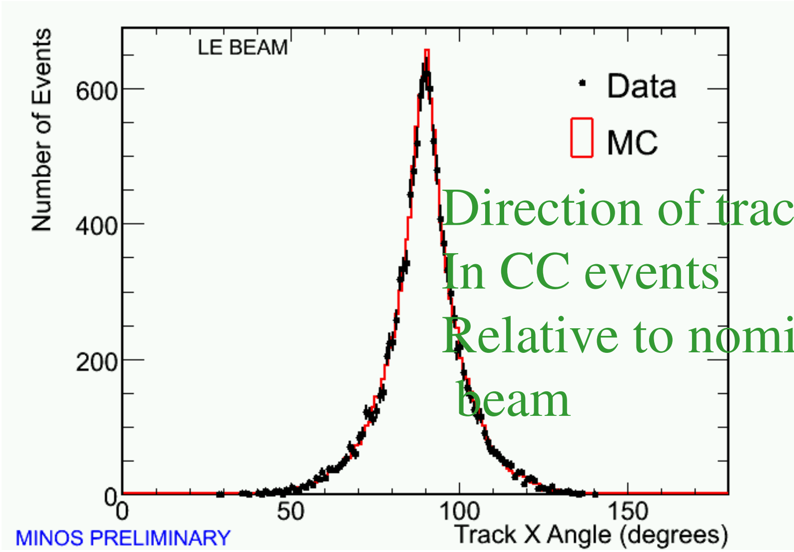
With 2.5 x 10^{13} and 2 sec spill → 2.5 x 10^{20}/year
With a factor of ~ 2 from stopping collider
~ 5 x 10^{20}
Not Far off NOvA target…!



Event time in Spill
Structure:
Booster batches

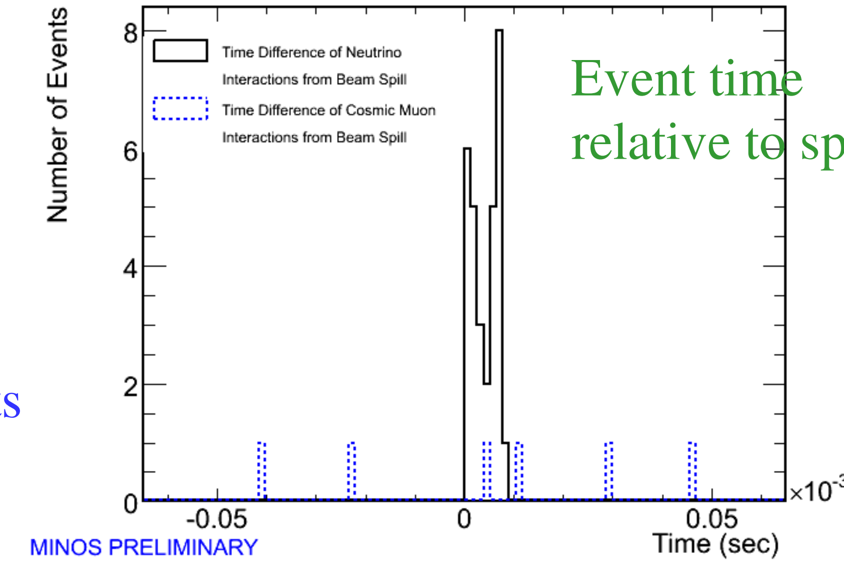


Energy of CC events
For running in
3 configurations:
Only target moved



Direction of track
In CC events
Relative to nominal
beam

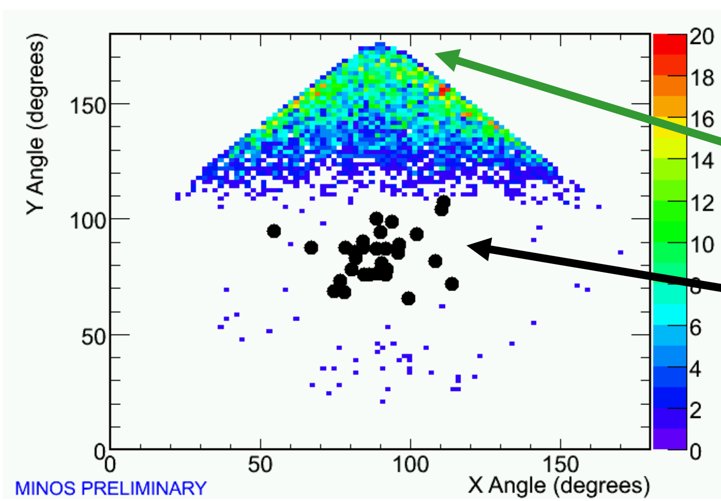
Status of NUMI/MINOS: Far detector



Event time relative to spill

Blind analysis.
Plots are for 1 week running.

Should have about 500 CC events if no oscillations



Cosmic rays: from above 180º

Beam events: 90º

Conclusions

- The neutrino oscillation programme is very rich.
- The smallness of neutrino masses is fascinating.
- The mass hierarchy must be determined.
- Is there any CP violation in the neutrino sector?
- The road to these is the observation of a non-zero θ_{13}.
- The NUMI beam is functioning well.
- NOνA has a well-developed long term research programme.