Using near detector(s) to predict far detector events in NOνA

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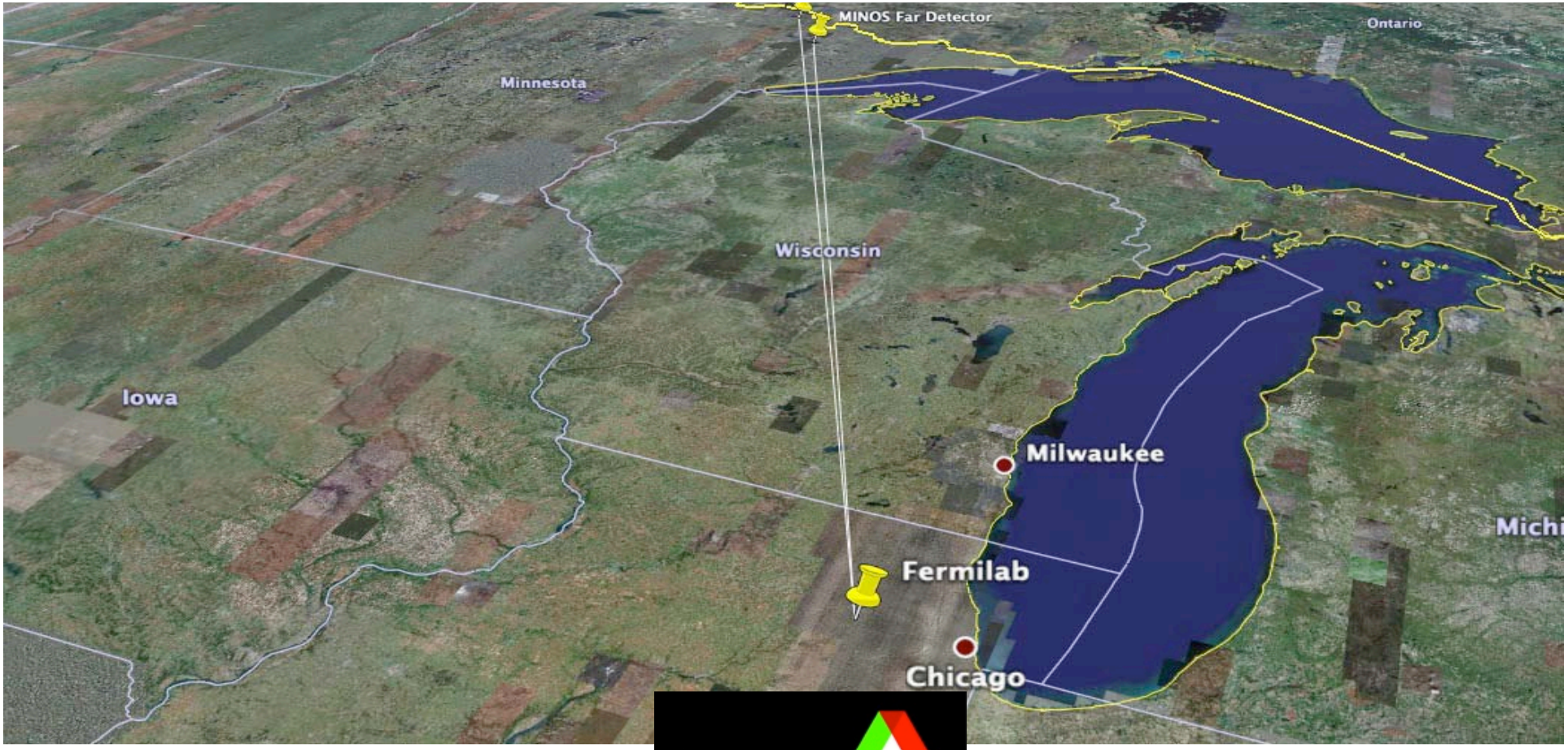


Argonne NATIONAL LABORATORY

October 20-25, 2010. Mumbai, India

NuFact2010: 12th International Workshop on Neutrino Factories, Superbeams and Beta Beams

-NOνA detector(s) construction is underway (see B. Rebel talk on NOνA status).

-Time to think how to use near detector(s) to predict events in far detector.

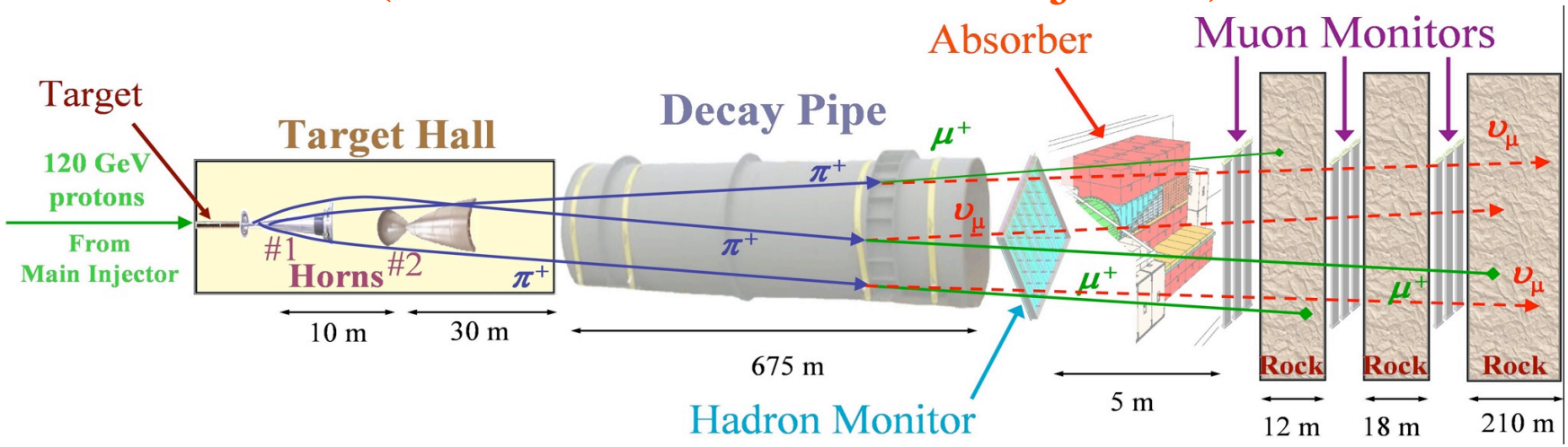
-NOνA is NuMI Off-Axis ν_e Appearance Experiment.

-NOνA will be using NuMI neutrino beam from Fermilab to Ash River in Minnesota (810km baseline).

-NOνA is two detector experiment where near detector is used to predict events in far detector.
  -Near and Far detector functionally identical.

-NOνA benefits from MINOS and MiniBooNE experience.

NuMI (Neutrinos at the Main Injector) Beam



-Beam spectrum tunable by horn currents, relative placement of target and horns.

-Can select ν or $\bar{\nu}$ predominant beam depending on horn current polarity.

-10μs beam spill (every 2.2 sec).

-Operating since 2005 (MINOS, MINERvA, ArgoNEUT)

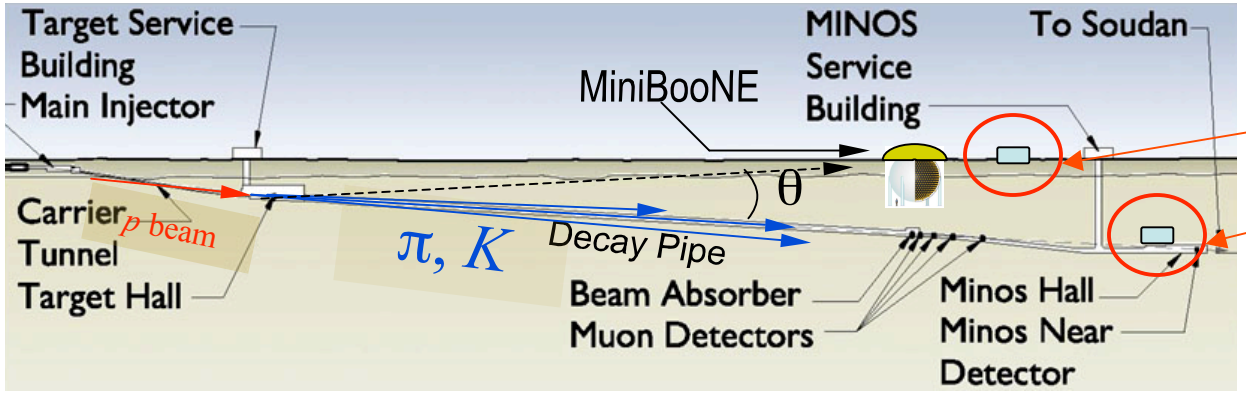
-Routinely delivers 280-300kW beam power.

-Most operations to-date in "Low Energy" mode optimized for MINOS on-axis location.

Future: -700 kW power to NuMI using existing accelerator complex.

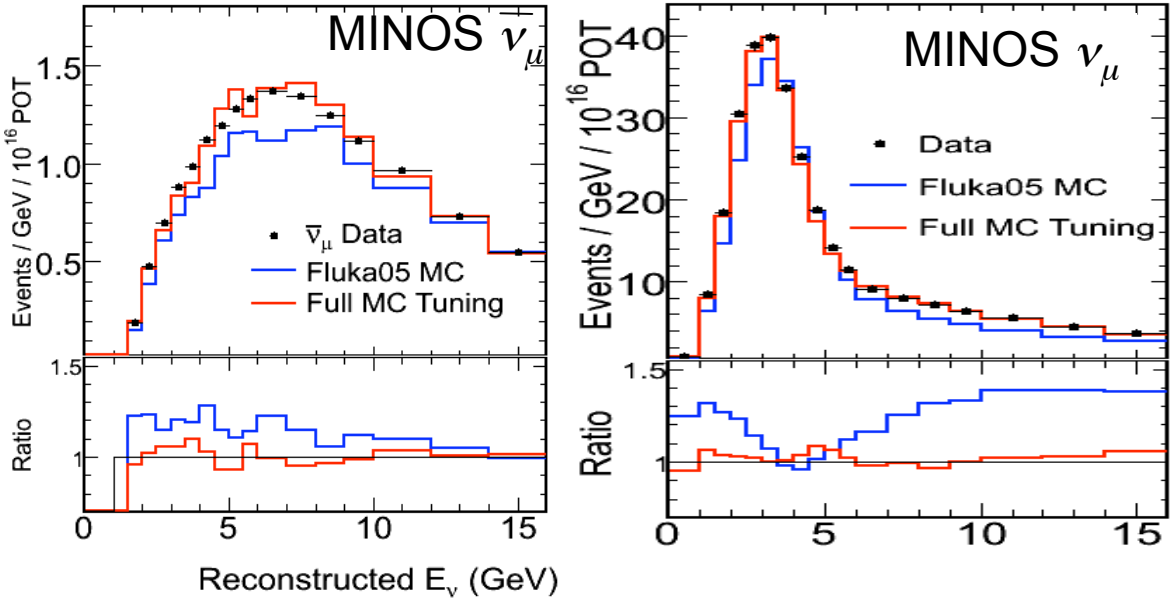
-Reduce cycle time from 2.2 to 1.33 seconds.

NuMI Neutrino Beam



NuMI spectrum is "calibrated".

Extensive experience with MINOS data.
MINOS acquired datasets in variety of NuMI configurations.
Tuned kaon and pion production (x_F,p_T) to MINOS data.



Same parent hadrons produce neutrinos seen by NDOS (MiniBooNE).

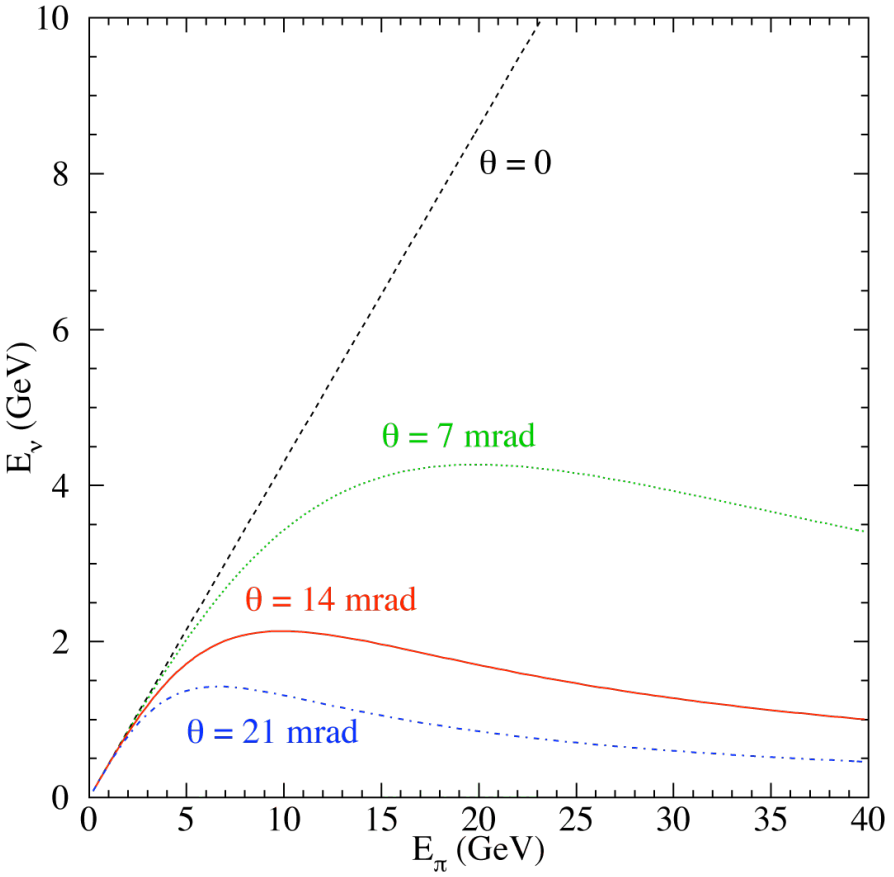
Flux at NDOS (MiniBooNE) should be well-described by NuMI beam MC.

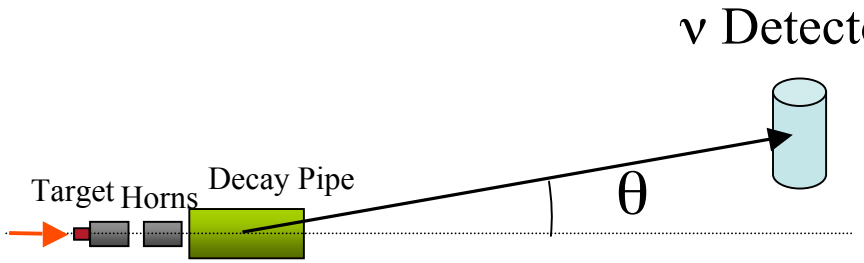
D.G. Michael et al, Phys. Rev. Lett. 97:191801 (2006)
D.G. Michael et al, arXiv:0708.1495 (2007)

NOνA uses an Off-Axis Beam

-On-axis, neutrino energy more tightly related to hadron energy.
-Off-axis, neutrino spectrum is narrow-band and "softened".
-Easier to estimate flux correctly: all mesons decay to ≈ same E_ν.

$$E_\nu \approx \frac{(1 - \frac{m_\mu^2}{m_{\pi,K}^2}) E_{\pi,K}}{1 + \gamma^2 \theta^2}$$





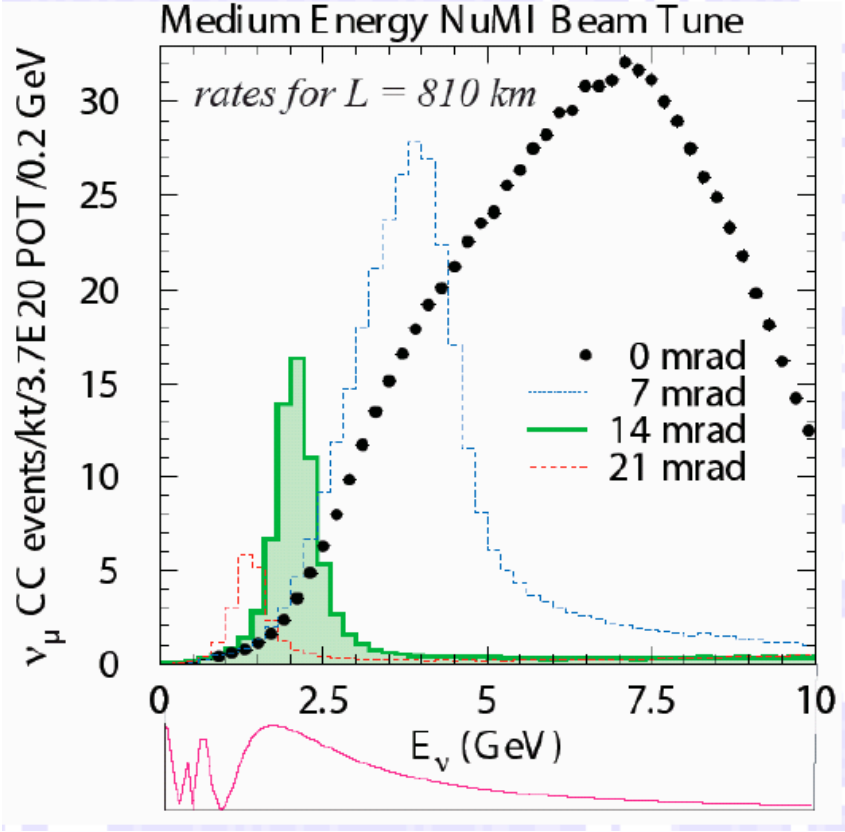
NOνA uses an Off-Axis Beam

-More flux near oscillation maximum

-Reduction of high energy tail reduces NC background.

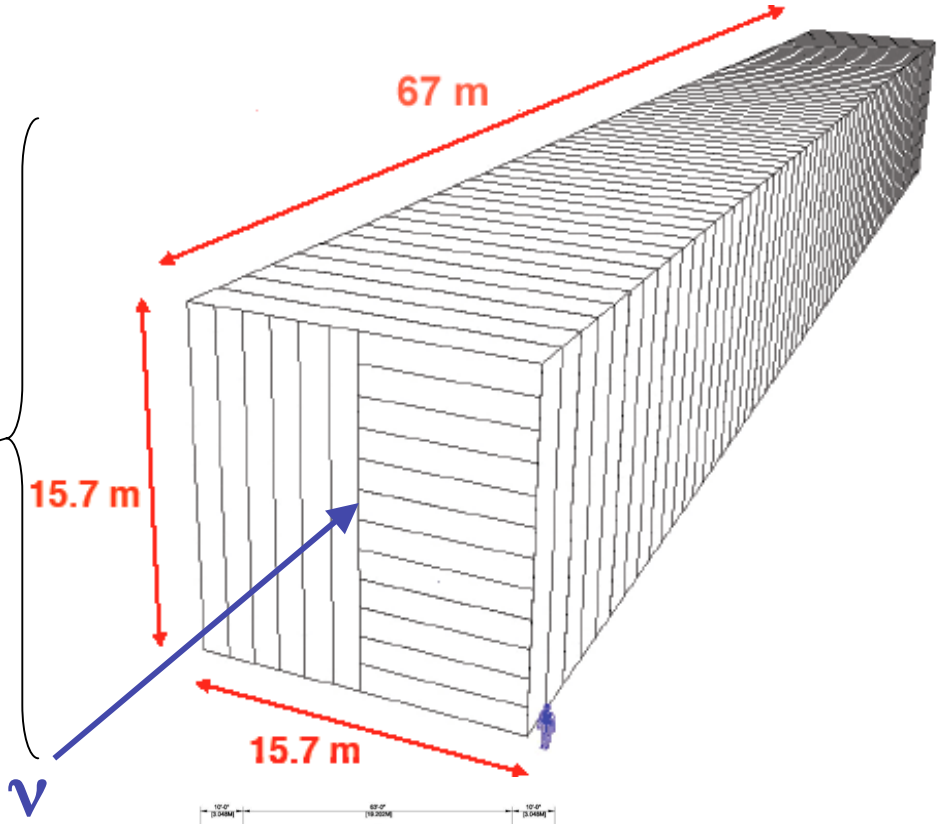
-Concentration of ν_e from oscillation relative to intrinsic beam ν_e (from 3-body K and μ decay).

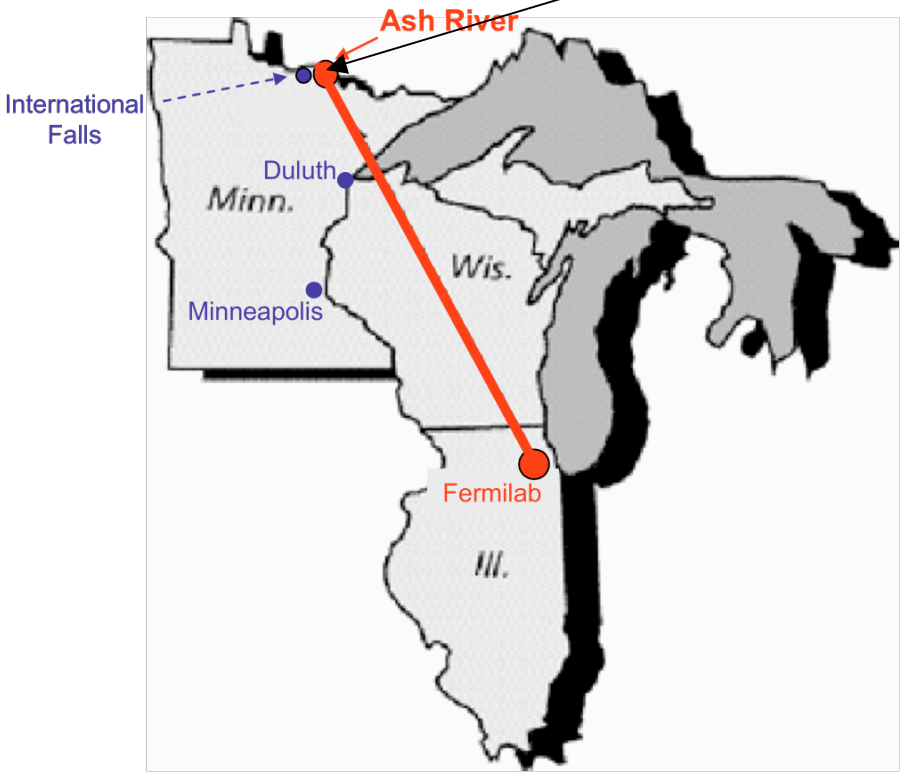
-NOνA will use Medium Energy NuMI Configuration (MINOS mostly used Low Energy mode).

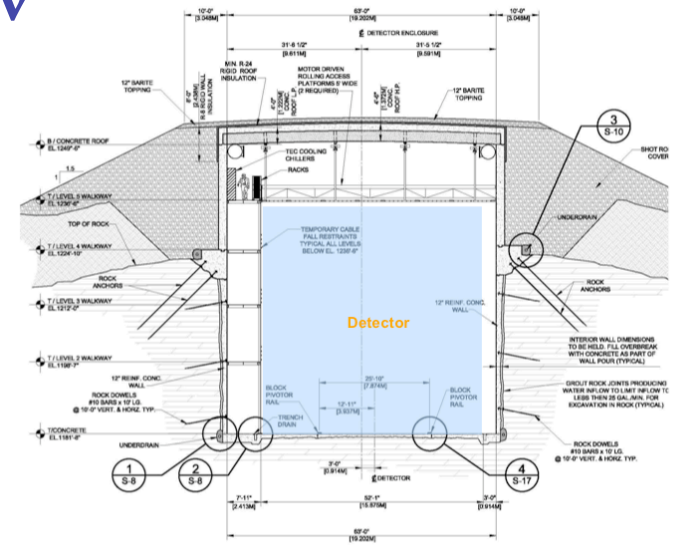


NOνA Far Detector

-810 km from Fermilab.
-14kT total mass (70% Scintillator).
-14.6 mrad off-axis.





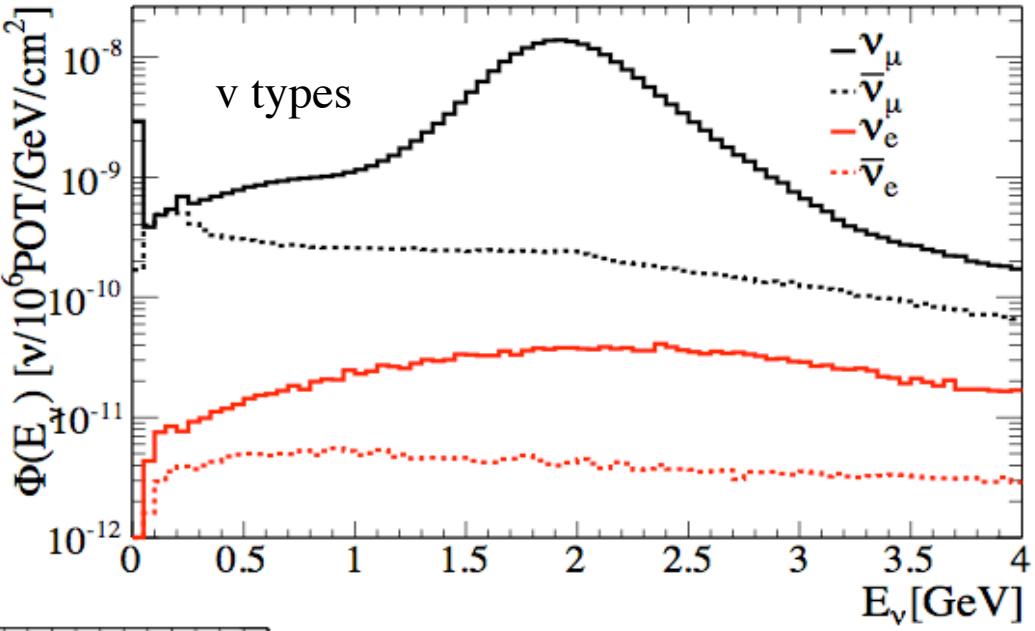


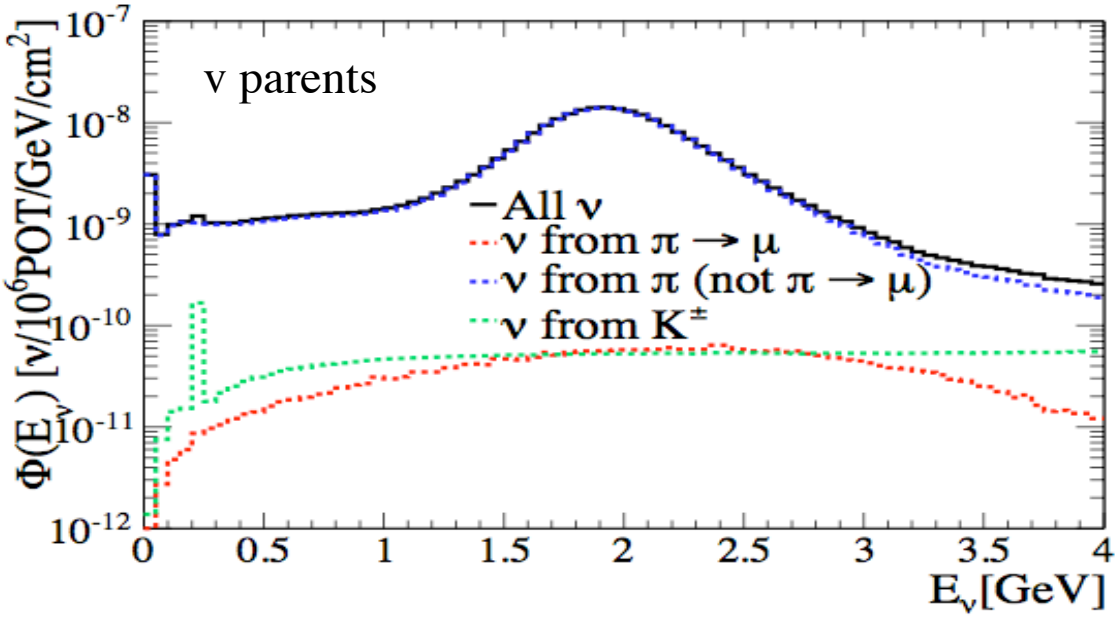
NOνA Far Detector

-NuMI flux simulation for Far detector in Medium Energy configuration.

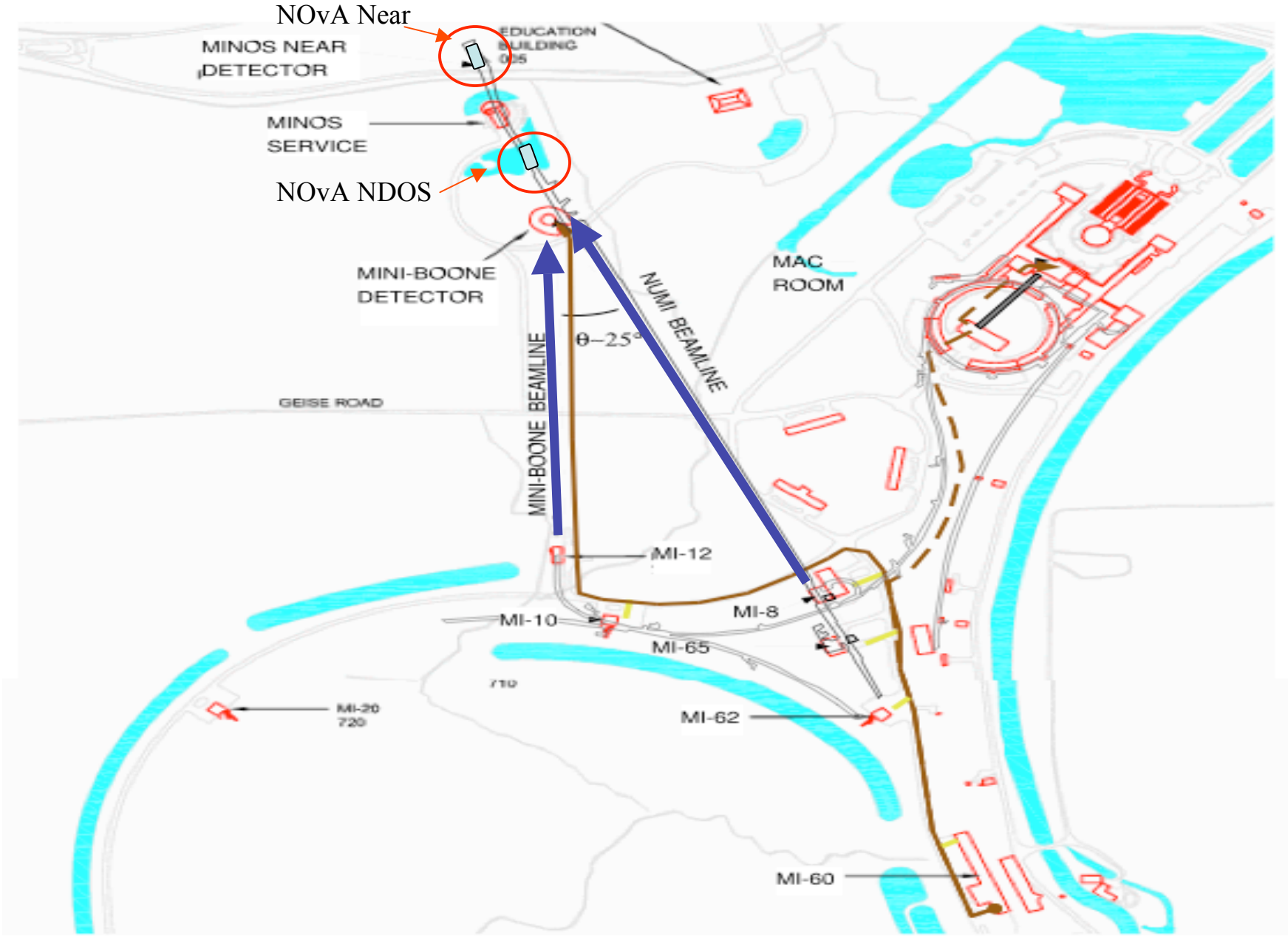
-Neutrino mode.

-Unoscillated spectra.





NOvA near detector(s) and Fermilab Neutrino Beams

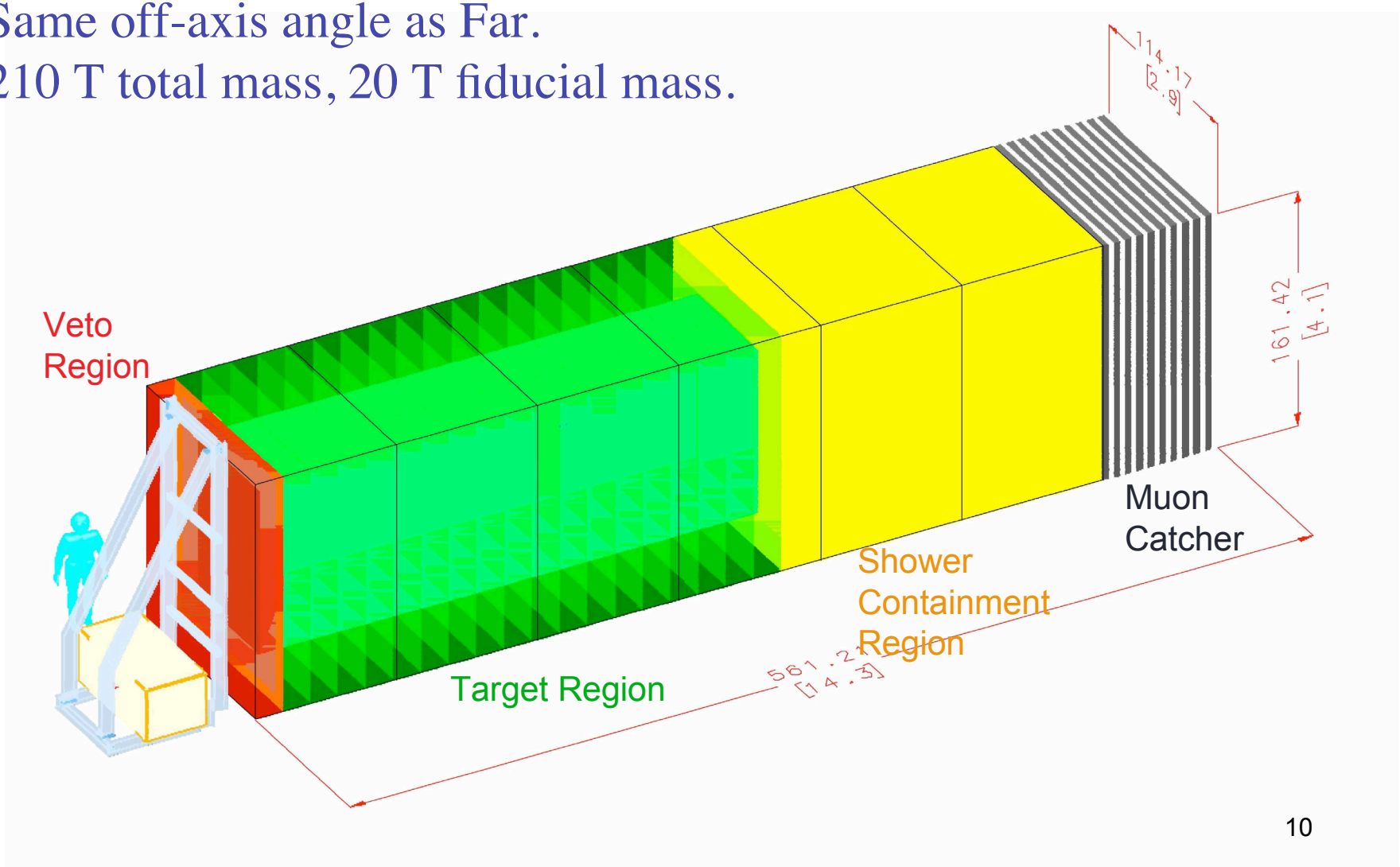


NOνA Near Detector

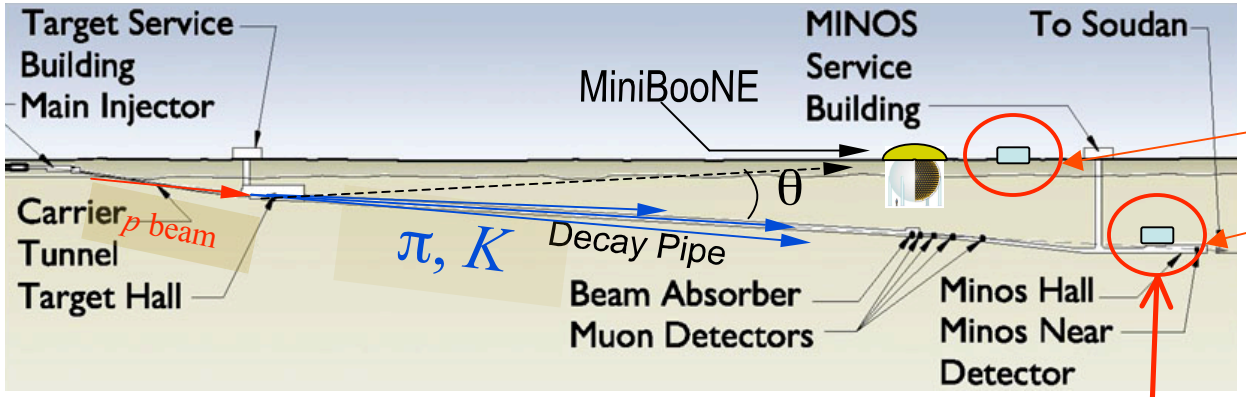
-Identical to Far Detector (in material, segmentation, and orientation), except smaller, with muon catcher.

-Same off-axis angle as Far.

-210 T total mass, 20 T fiducial mass.

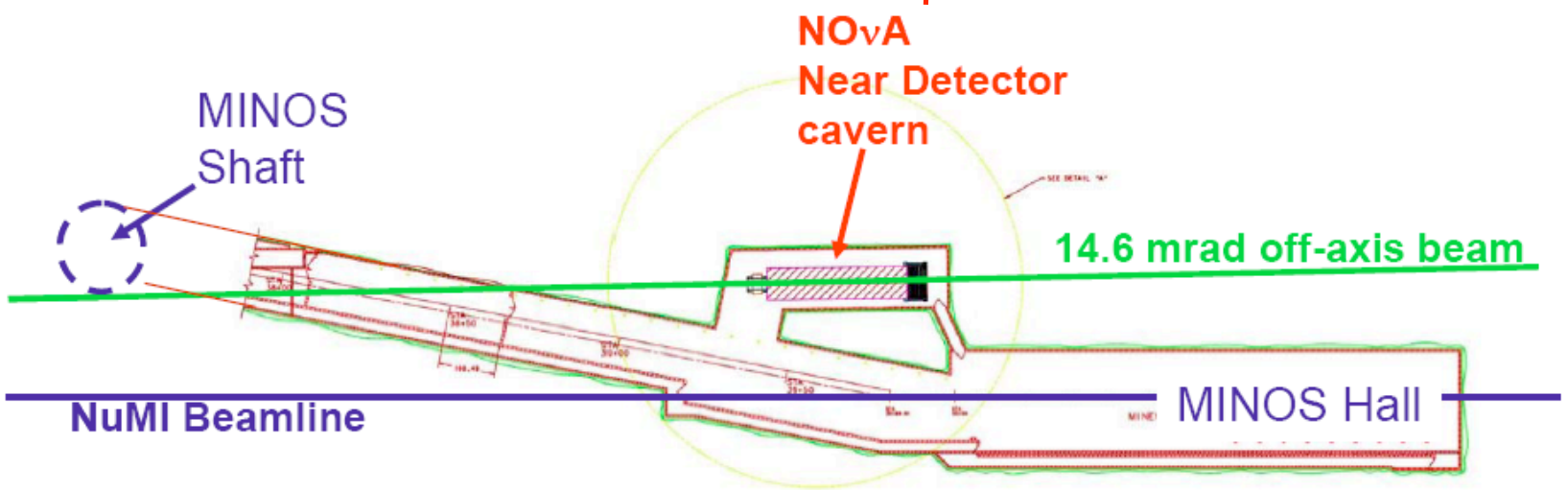


NOνA Near Detector



-Cavern for Near Detector to be excavated near MINOS Near Detector Hall.

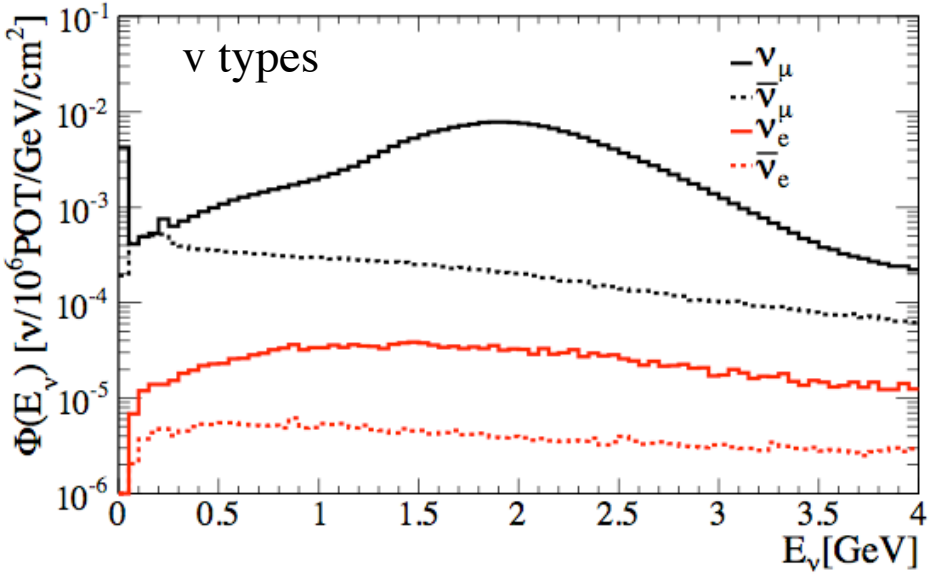
-1km from NuMI target.

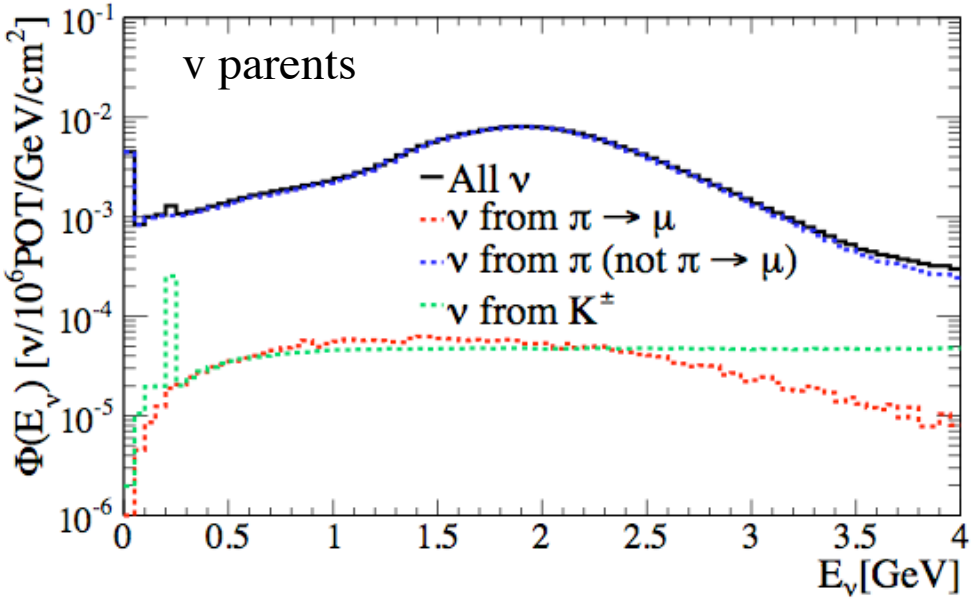


NOνA Near Detector

-NuMI flux simulation for Near detector in Medium Energy configuration.

-Neutrino mode.

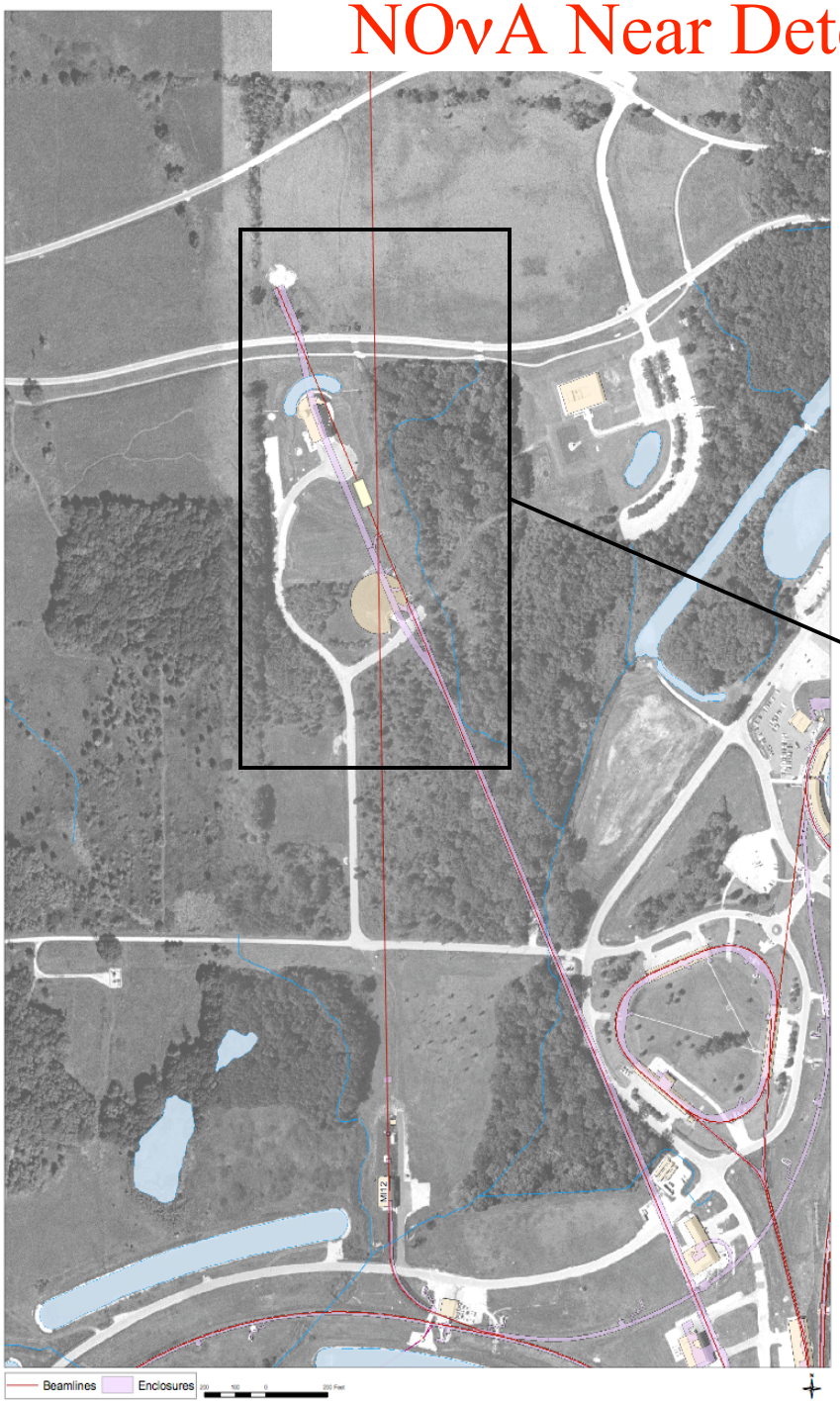


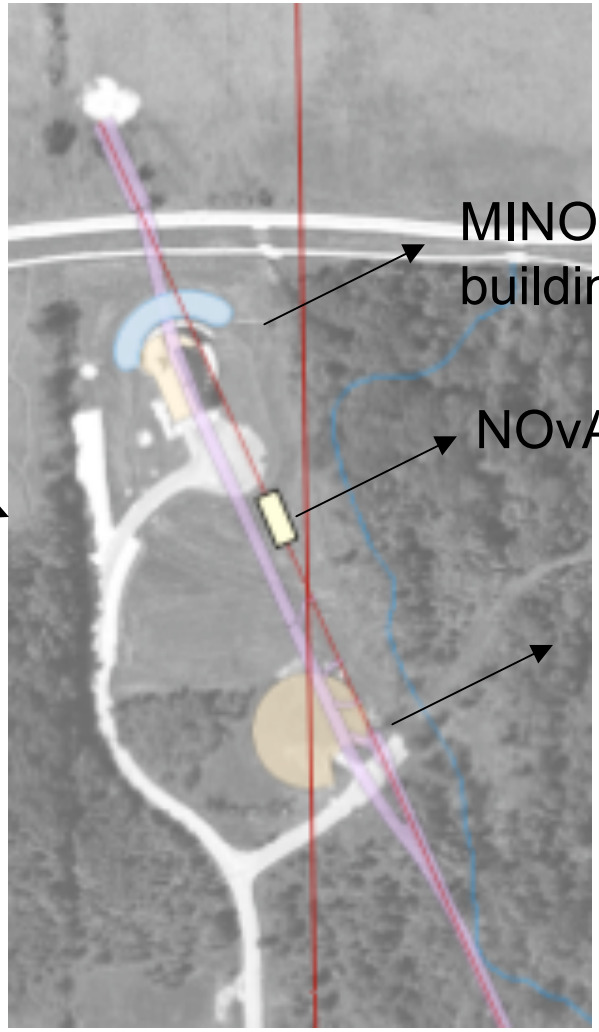


-Near detector sees ν's from π's.

-This component well measured at Near.

NOvA Near Detector On Surface (NDOS) (Under Commissioning)

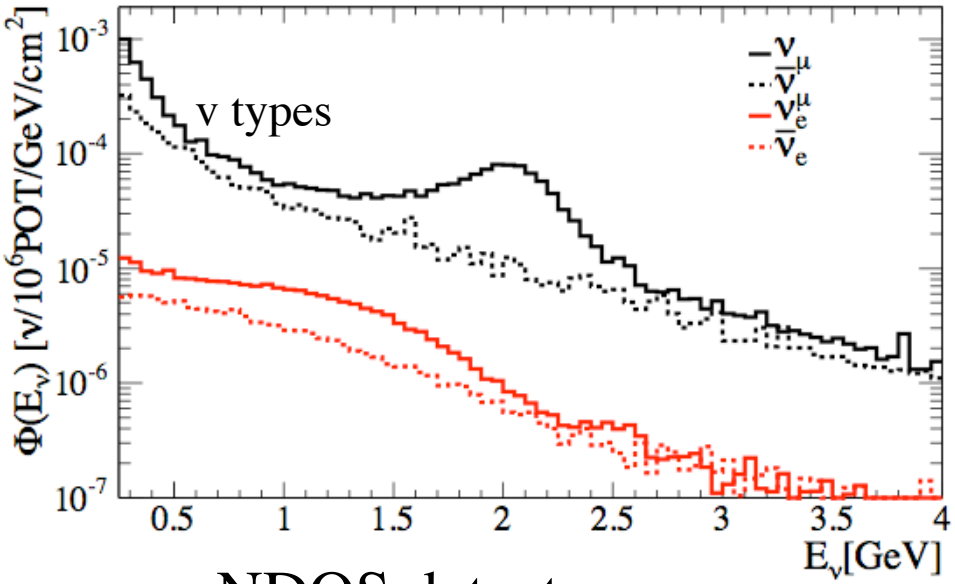


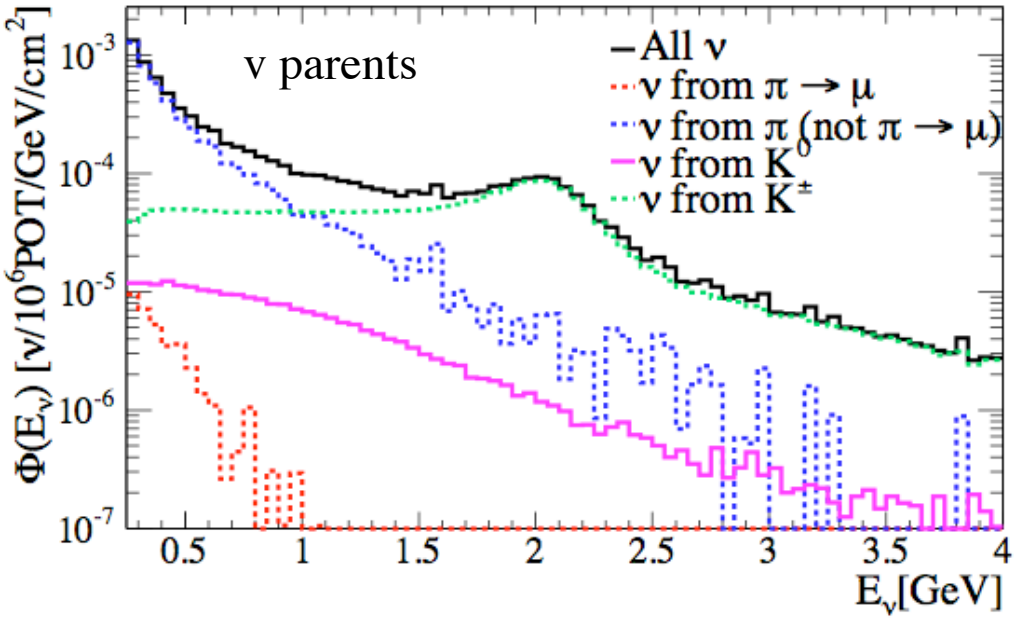


NOνA Near Detector On Surface (NDOS)

-NuMI flux simulation for NDOS detector in Low Energy configuration.

-Neutrino mode.





-NDOS detector sees ν's from K's.

-This component well measured at NDOS.

-Used to tune K's at Near.

-Study reconstruction and particle ID (enhanced ν_e component).

-Will measure Booster ν's.

NOνA Near Detector On Surface (NDOS)

-NuMI beam currently operates in neutrino mode, expect anti-neutrino mode early next year.

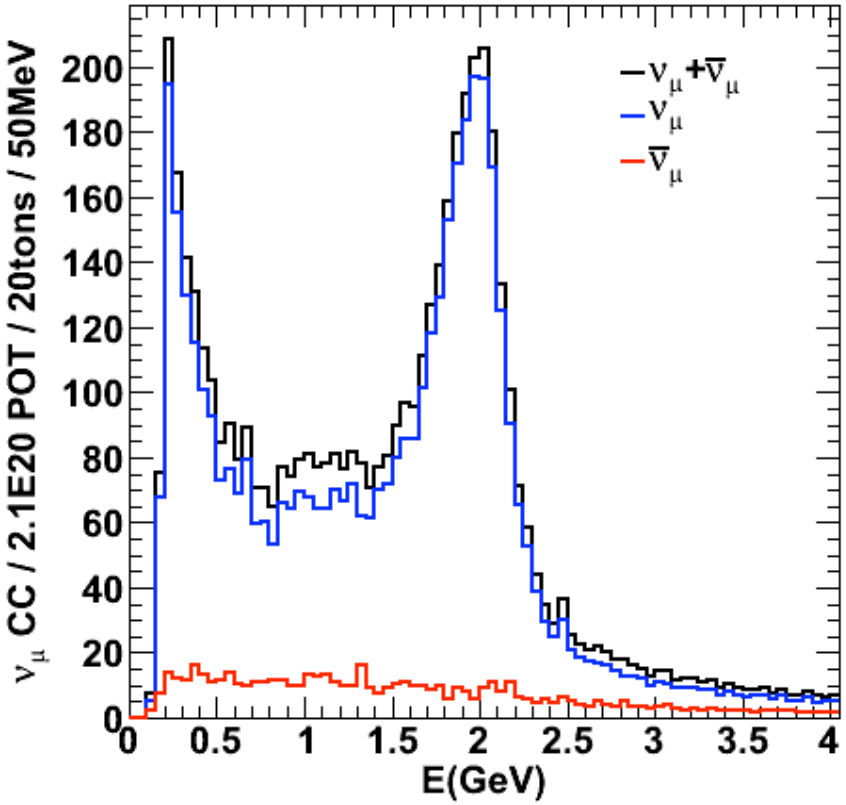
-NDOS may get measurement in both modes.

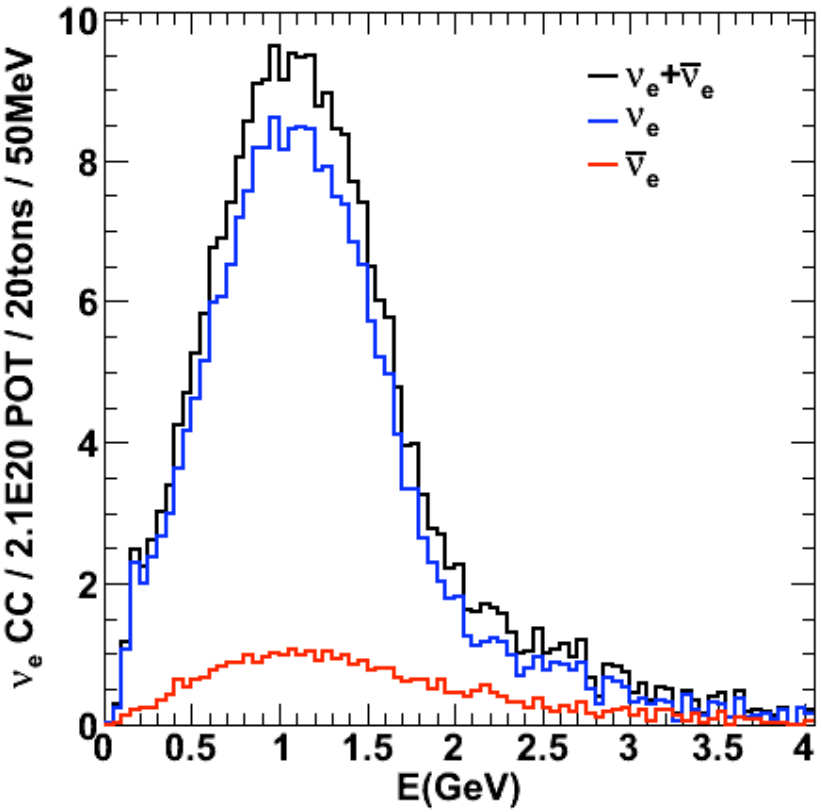
-Neutrino mode: 2.1×10^{20} POT.

GeV	Total CC	CC QE	CC RES	CC DIS	CC COH	NC
ν_μ Total 1.6-2.4	4751 1931	2288 559	1533 842	861 511	38 20	1911 699
ν_e Total	340	166	119	50		125
$\bar{\nu}_\mu$ Total 1.6-2.4	624 132	323 50	179 55	103 24	14	353 142
$\bar{\nu}_e$ Total	37	19	12	5		19

NOνA Near Detector On Surface (NDOS)

-Neutrino mode: 2.1×10^{20} POT.





NOνA Near Detector On Surface (NDOS)

-NuMI beam currently operates in neutrino mode, expect anti-neutrino mode early next year.

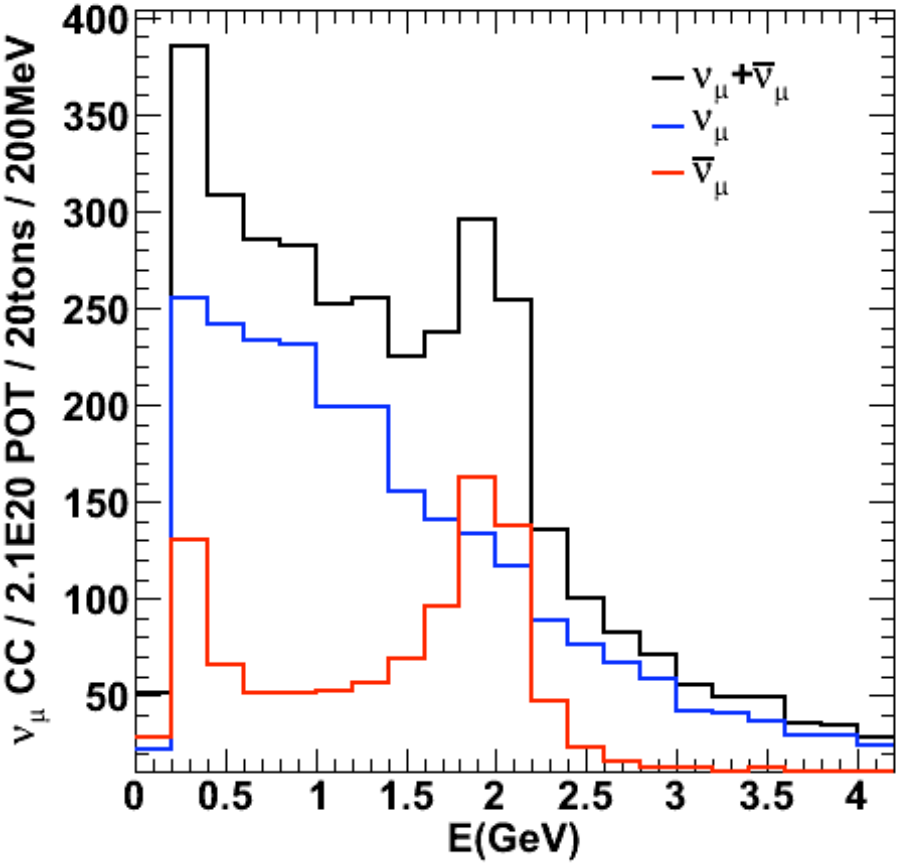
-NDOS may get measurement in both modes.

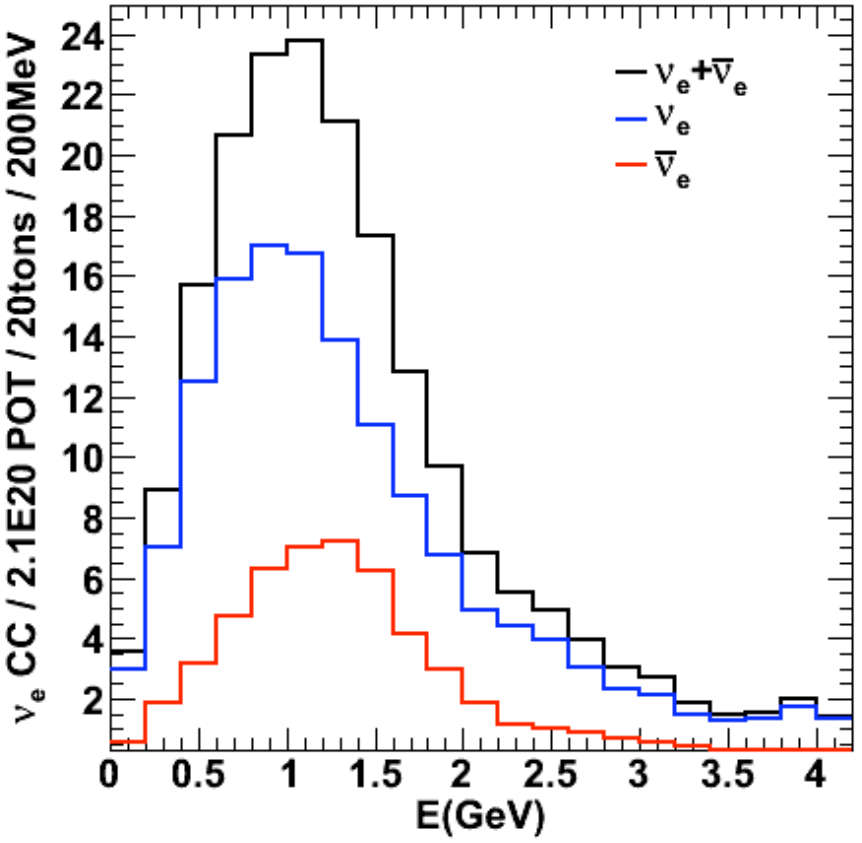
-Anti-neutrino mode: 2.1×10^{20} POT.

GeV	Total CC	CC QE	CC RES	CC DIS	CC COH	NC
ν_μ Total 1.6-2.4	2664 498	1259 143	789 216	505 134	21	1056 180
ν_e Total	306	148	106	48		113
$\bar{\nu}_\mu$ Total 1.6-2.4	873 363	471 139	262 151	119 65	19	507 170
$\bar{\nu}_e$ Total	52	28	17	6		28

NOνA Near Detector On Surface (NDOS)

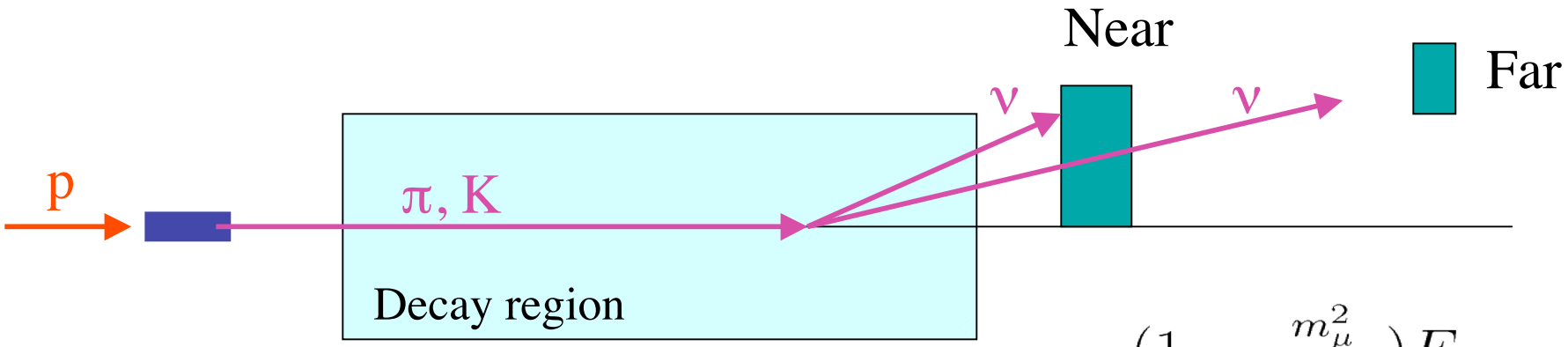
-Anti-neutrino mode: 2.1×10^{20} POT.





Near to Far Extrapolation

-Neutrino spectrum without oscillations at Far detector is similar but not identical to the Near spectrum.

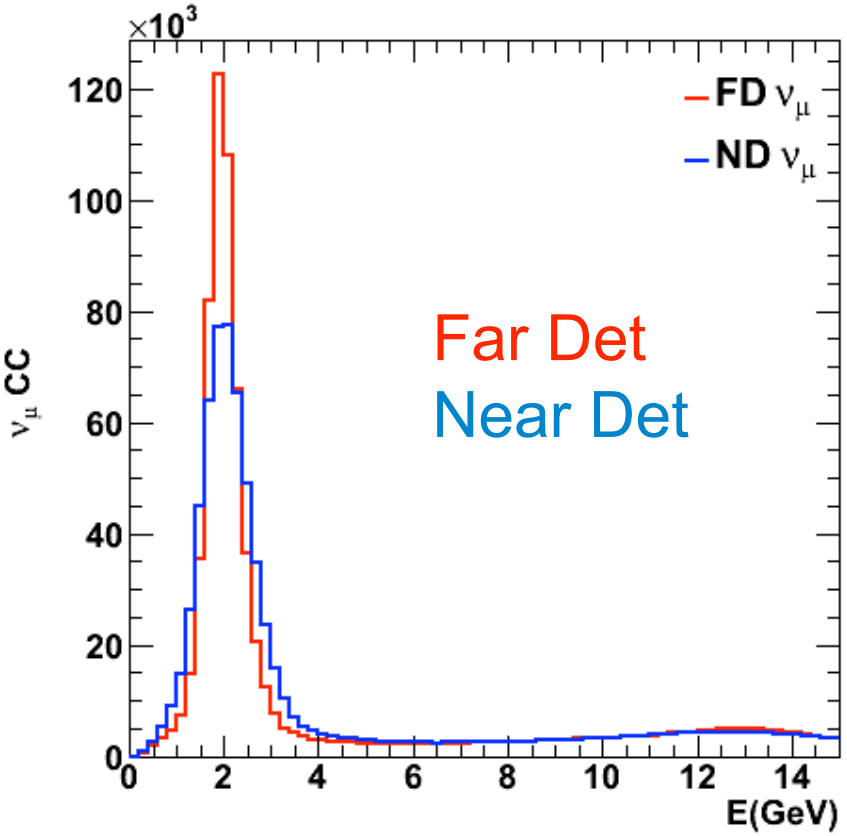


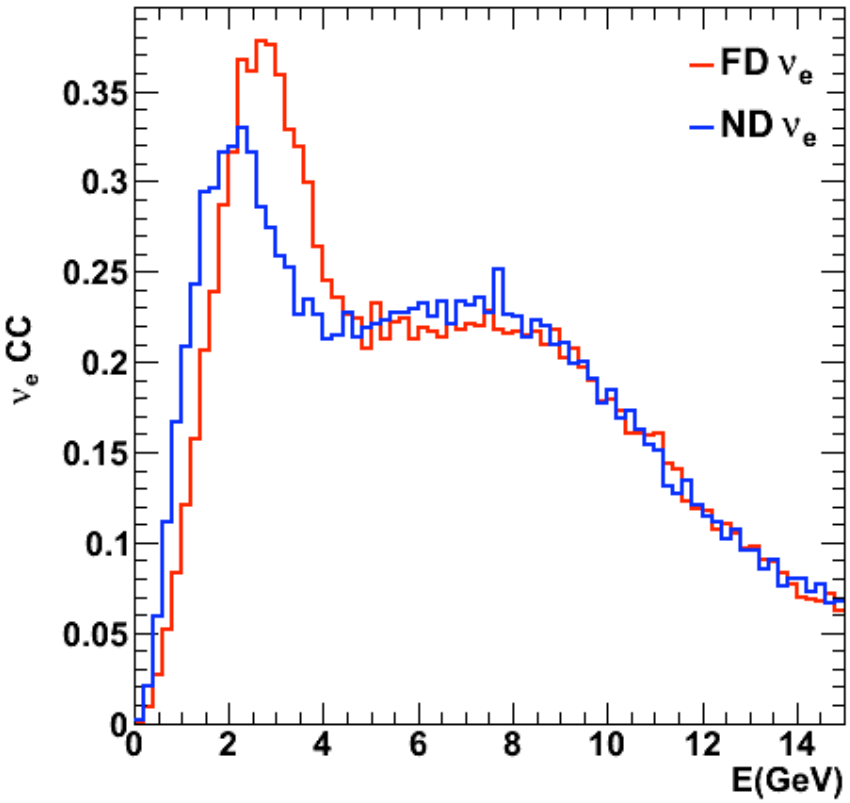
$$E_\nu \approx \frac{(1 - \frac{m_\mu^2}{m_{\pi,K}^2}) E_{\pi,K}}{1 + \gamma^2 \theta^2}$$

-Neutrino energy depends on angle wrt original meson direction and meson's energy.
-Higher energy pions decay further along decay pipe.
-Angular distributions different between neutrinos seen at Near and Far detectors.

Near to Far Extrapolation

-Comparison of Neutrino spectra at Near and Far detectors
-Neutrino mode.

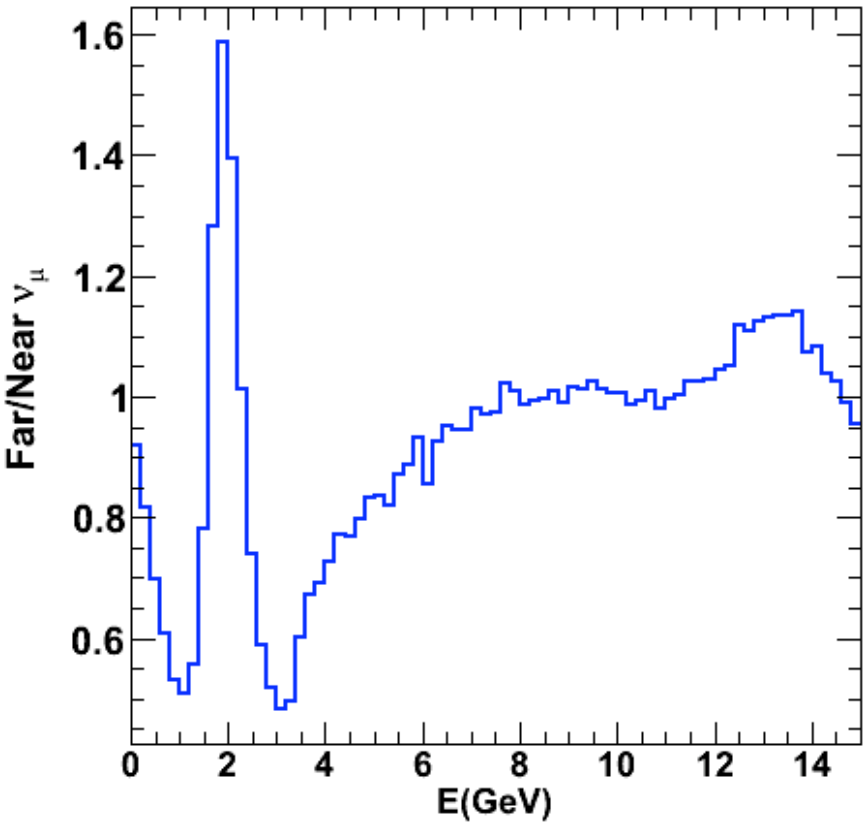


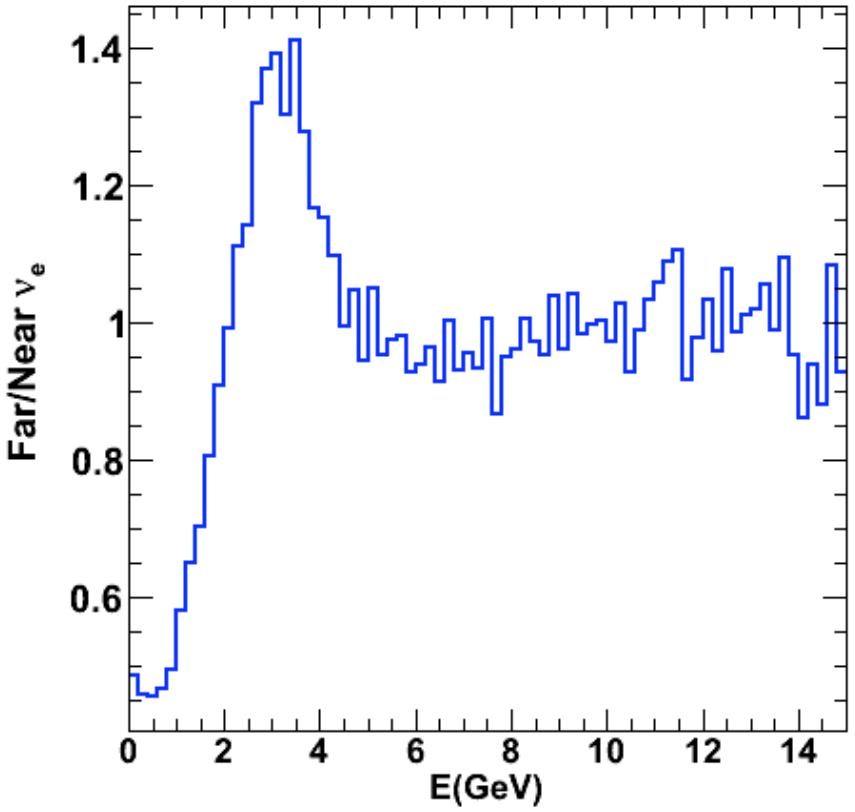


Normalized by area

Near to Far Extrapolation

-Ratio of Neutrino spectra at Near and Far detectors
-Neutrino mode.

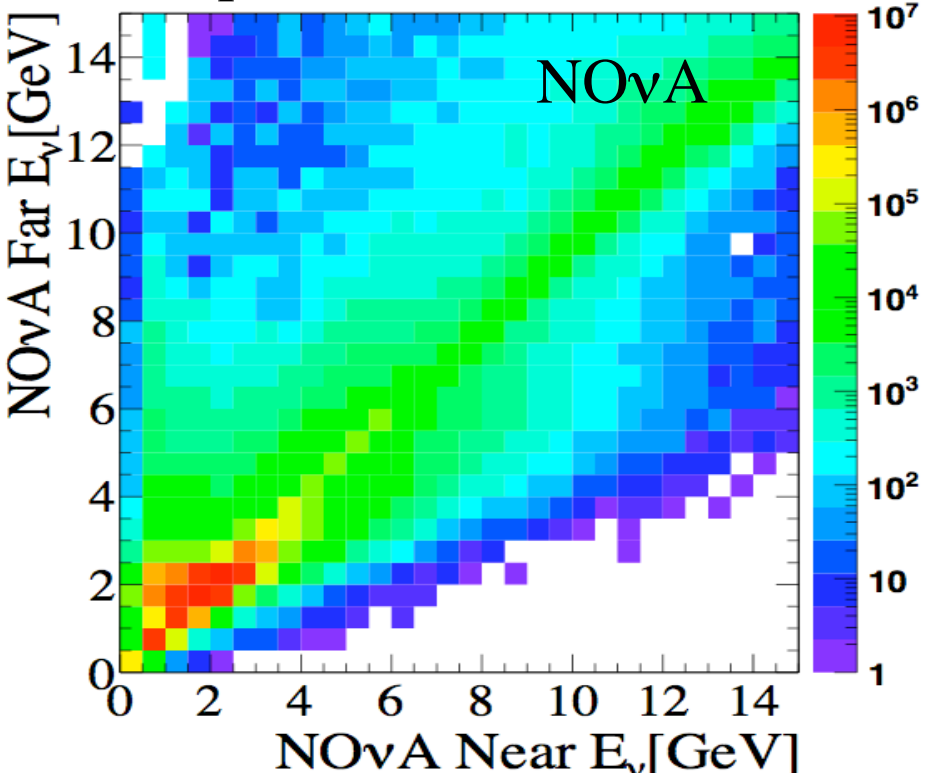


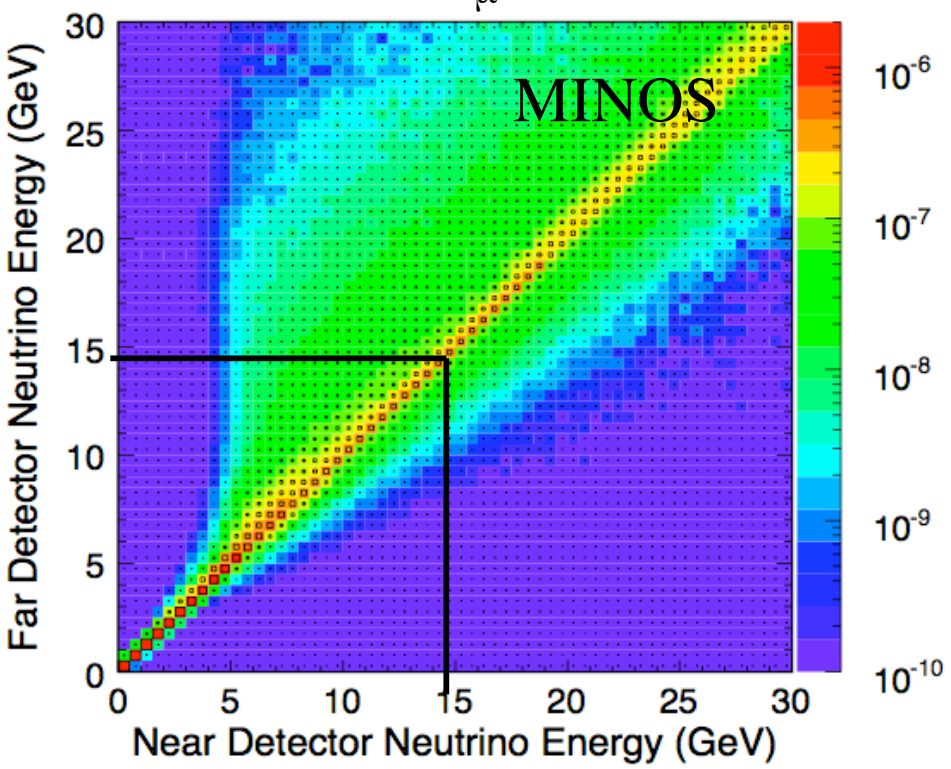


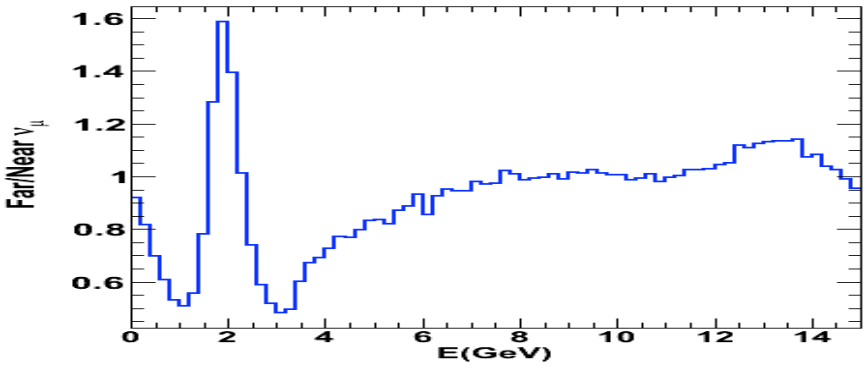
Near to Far Extrapolation

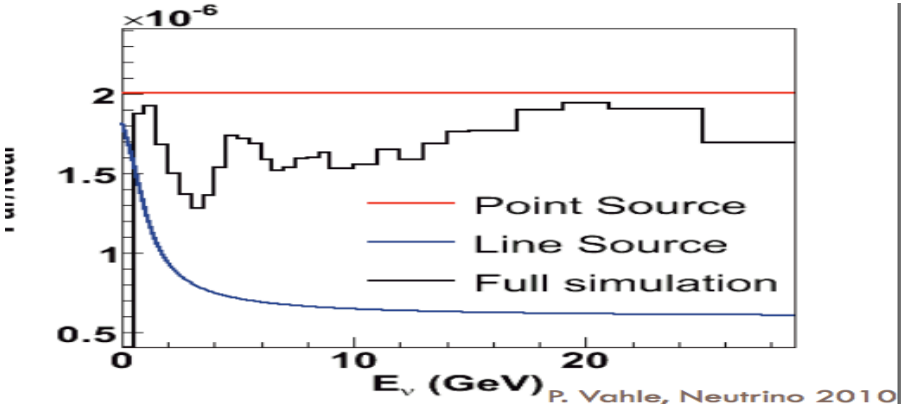
-Covariance Matrix correlating fluxes at Near and Far detectors.

-Compare NOνA beam matrix/ratio vs MINOS for ν_μ 's:





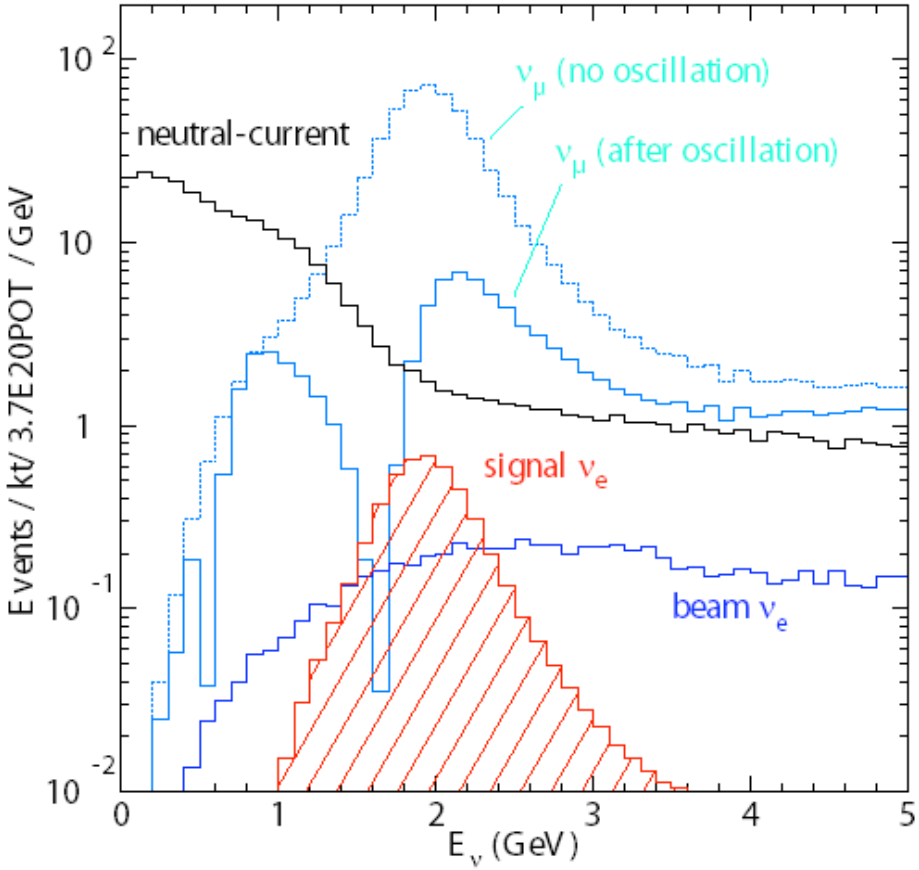




Near to Far Extrapolation

-For ν_e appearance analysis need extrapolation of backgrounds.

-Experience from MINOS:
- -used various beam configurations to enhance each background (NC, intrinsic ν_e 's, and ν_μ 's) in horn-off, HE, and LE configuration.
- -bkgd components decomposed and extrapolated independently.

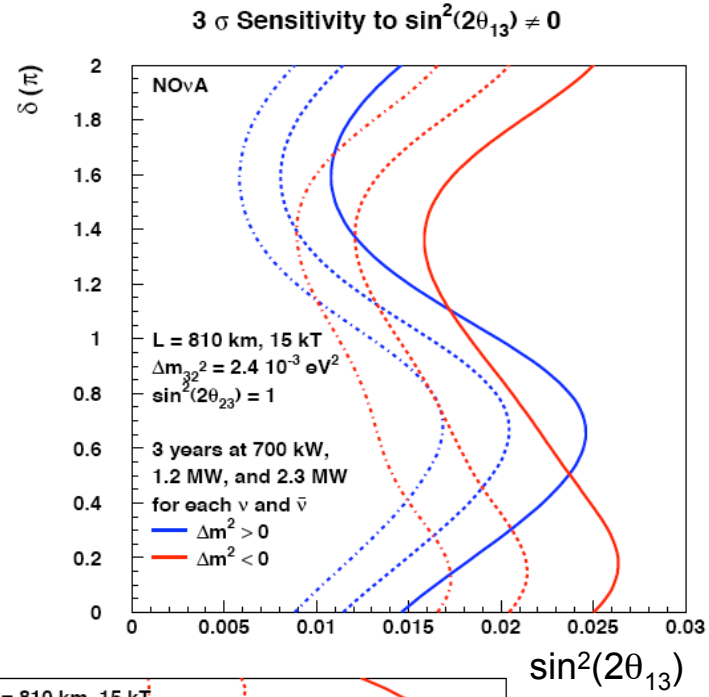


-However, off-axis beam more robust against change of beam configuration → less difference in bkgds.

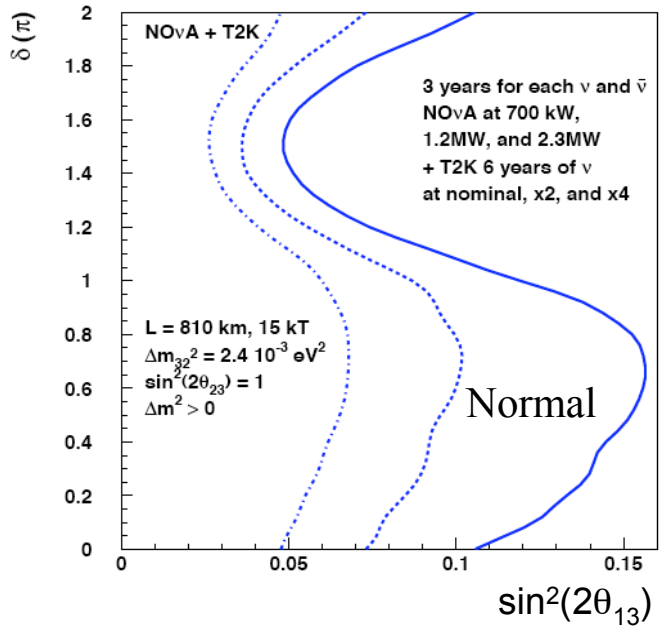
-shower reconstruction for NOνA being developed.
-one option to consider for NOνA is MRCC (muon removed shower reconstruction), used in MINOS as well.

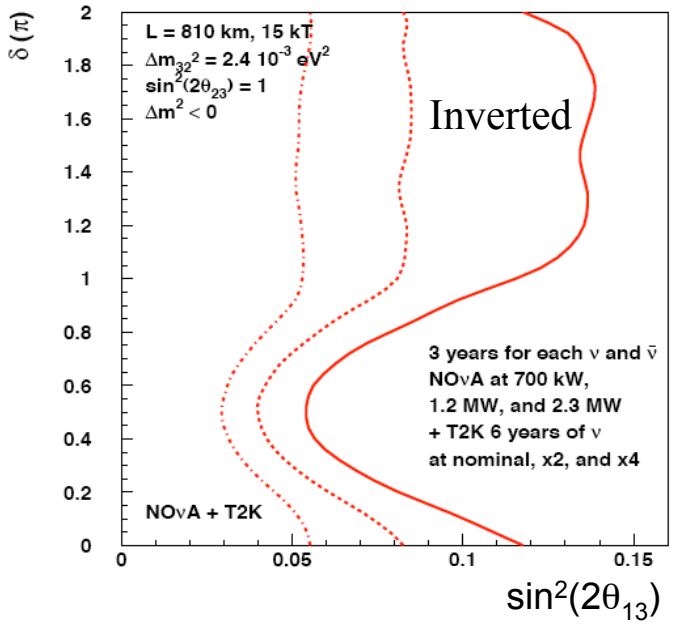
Near to Far Extrapolation

-Sensitivity calculations performed assuming a systematic uncertainty in the background extrapolation from the near to far detector of 10%.

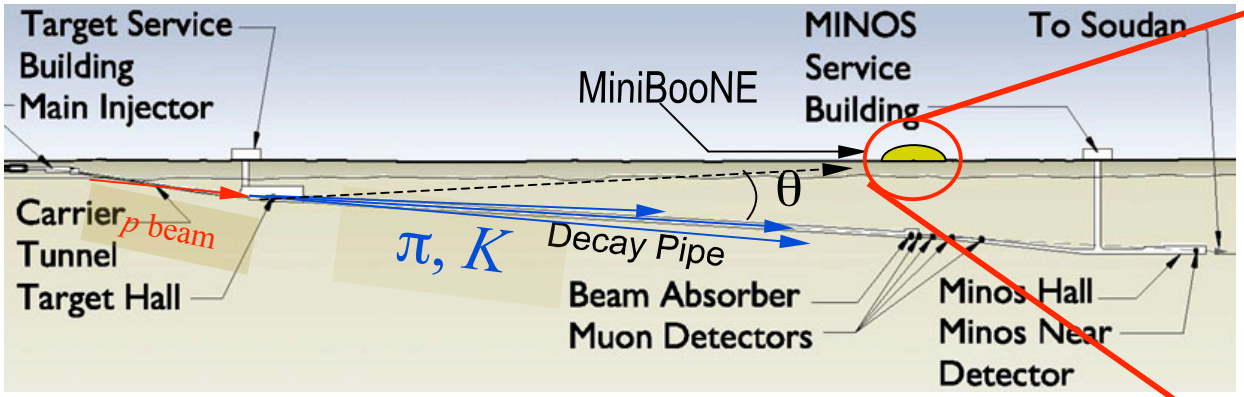


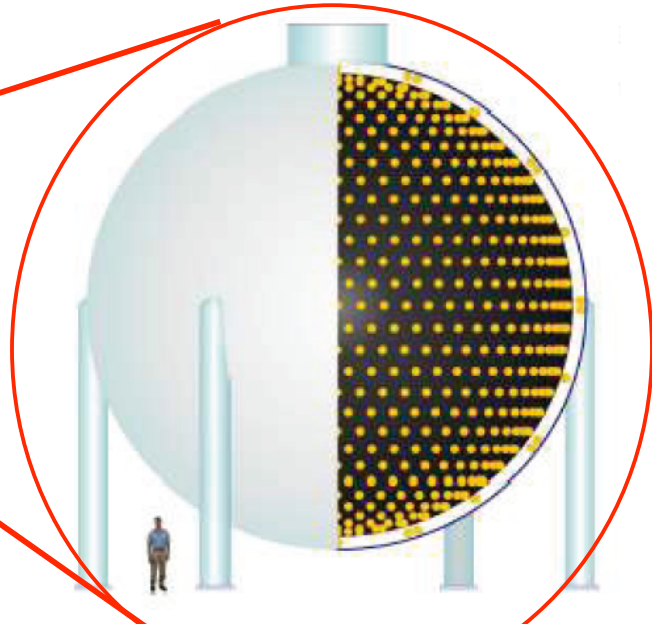
95% CL Resolution of the Mass Ordering





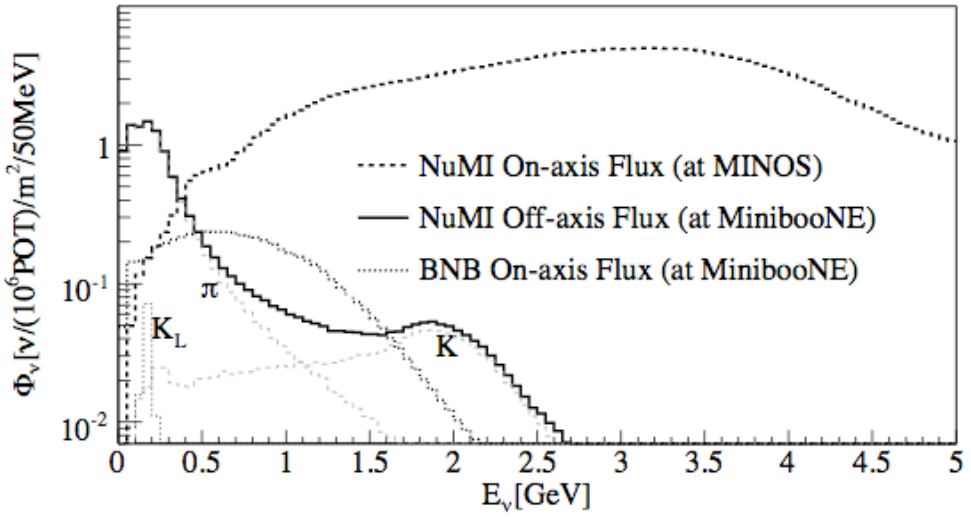
Events from NuMI detected at MiniBooNE





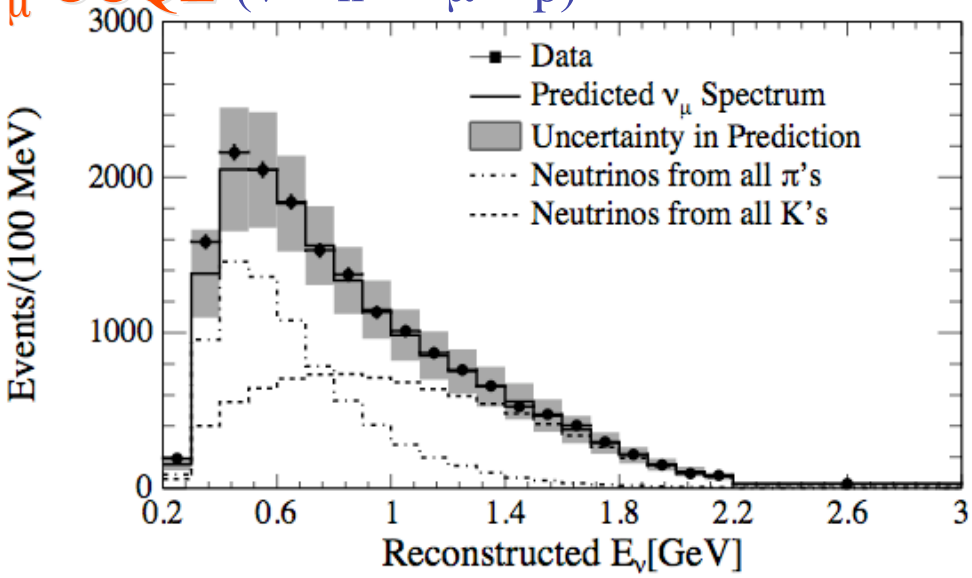
MiniBooNE detector is 745 m downstream of NuMI target.
MiniBooNE detector is 110 mrad off-axis wrt NuMI decay pipe.

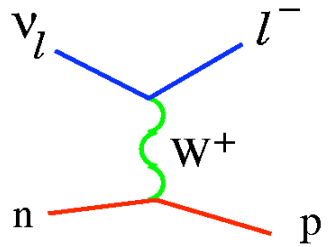
$$E_\nu \approx \frac{(1-\frac{m_\mu^2}{m_{\pi,K}^2})E_{\pi,K}}{1+\gamma^2\theta^2}$$



ν_μ CCQE and ν_e CCQE samples from NuMI at MiniBOONE

ν_μ CCQE ($\nu + n \rightarrow \mu + p$)



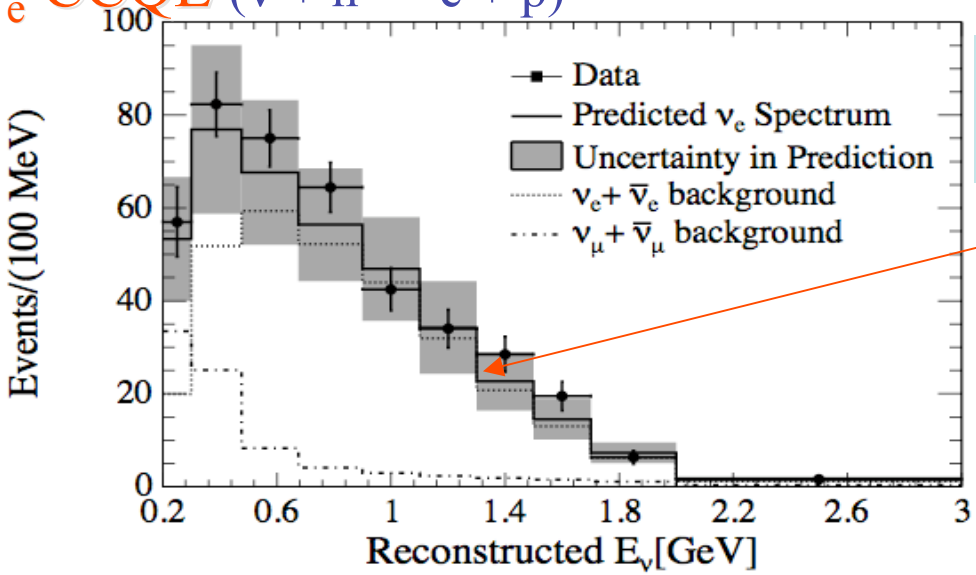


These results show that reliable predictions for an off-axis beam can be made.

Details

P.Adamson et al, PRL 102, 211801 (2009)
arXiv:0809.2447 [hep-ex].

ν_e CCQE ($\nu + n \rightarrow e + p$)



Very different backgrounds compared to BNB (Kaons vs Pions)!

Systematics not yet constrained!

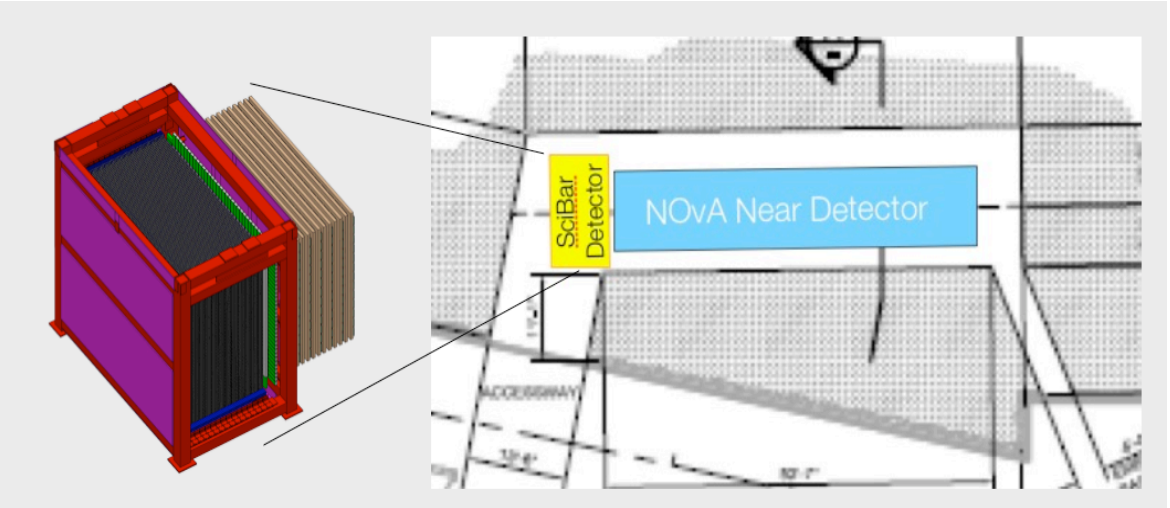
We collected more data from NuMI at MiniBooNE.

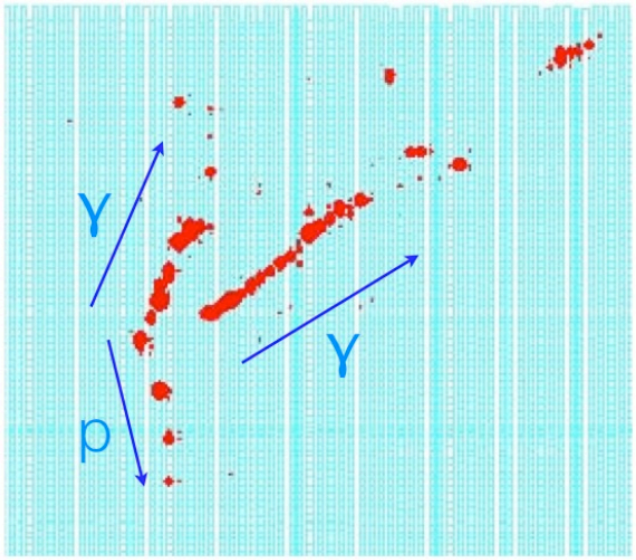
Proposed SciNOνA Project

-Place fine-grained detector (scint. strips, SciBar-like) in front of NOvA Near.

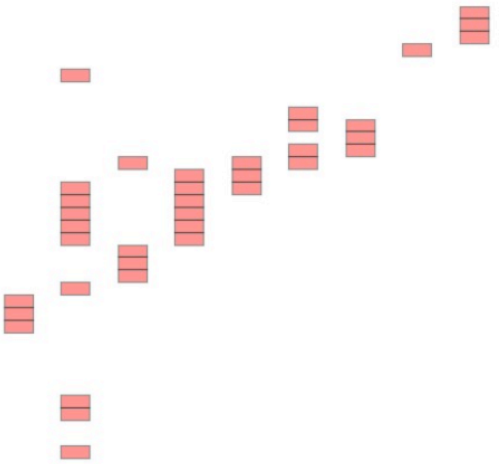
-Measurement of ν-nucleaus scattering in narrow-band beam.

-Enhance NOνA program by precise measurements of NC background.





p + π⁰ in SciBar



Same event resampled in NOvA

More fine-grained detector would enable a data-driven check of NCπ^0 background (i.e. efficiency).

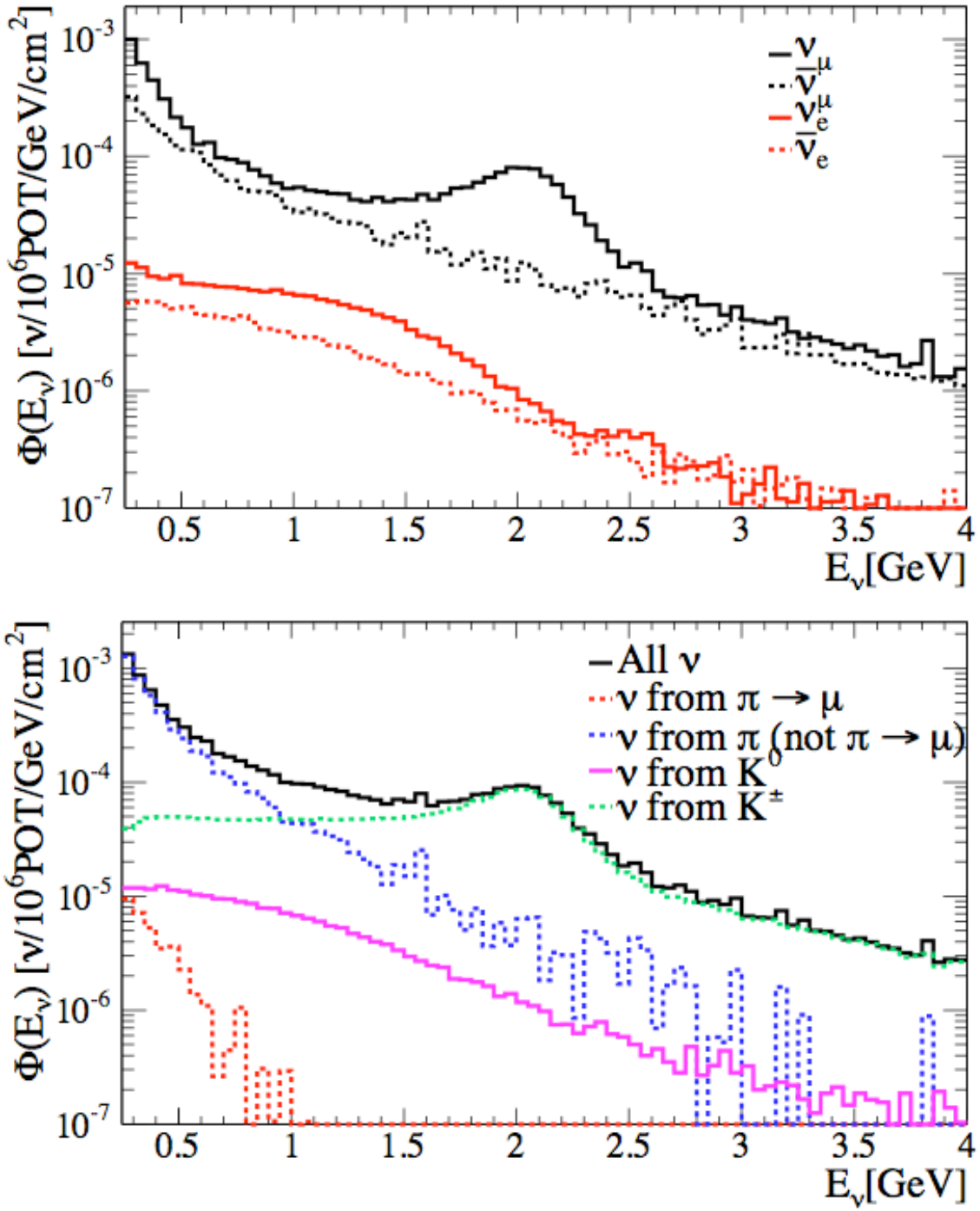
Summary

-NOνA is NuMI Off-Axis ν_e Appearance Experiment.
-NOνA will be using NuMI neutrino beam from Fermilab
to Ash River in Minnesota (810km baseline).
-NOνA is two detector experiment where near detector is
used to predict events in far detector.
  -Near and Far detector functionally identical.

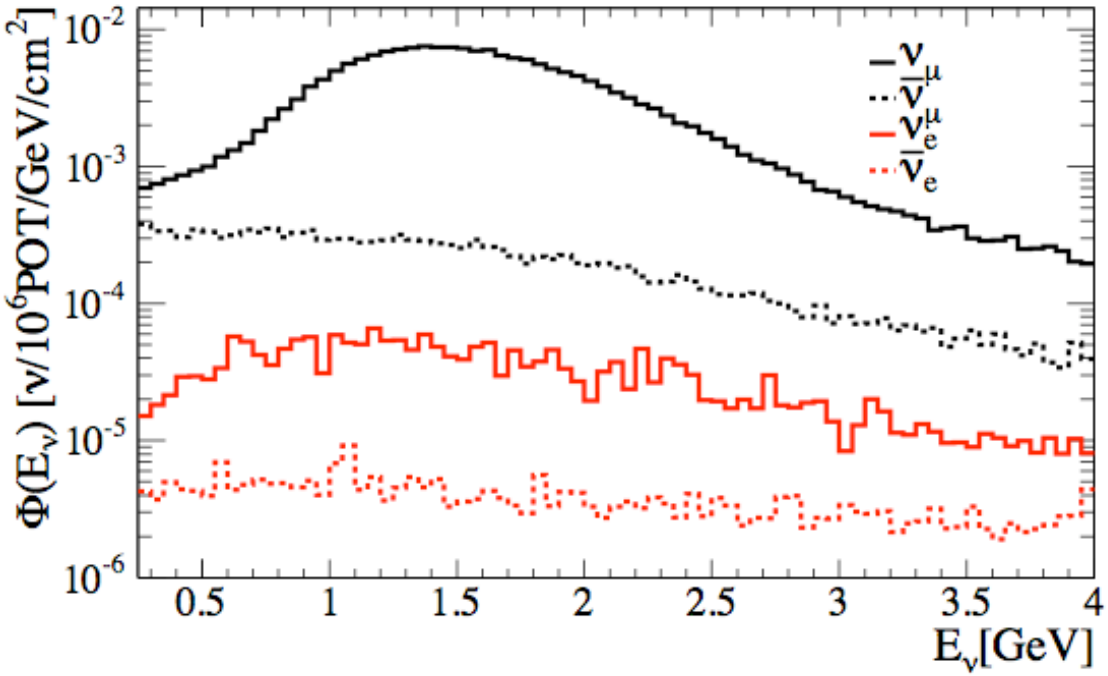
-NOνA near detector will be taking data at two different
locations and beam configurations (NDOS and Near location).
-NOνA will use input from MINOS experiment.
-NOνA will use input from MiniBooNE (and SciBooNE) experiments.
-Possible input from proposed SciNOνA experiment.

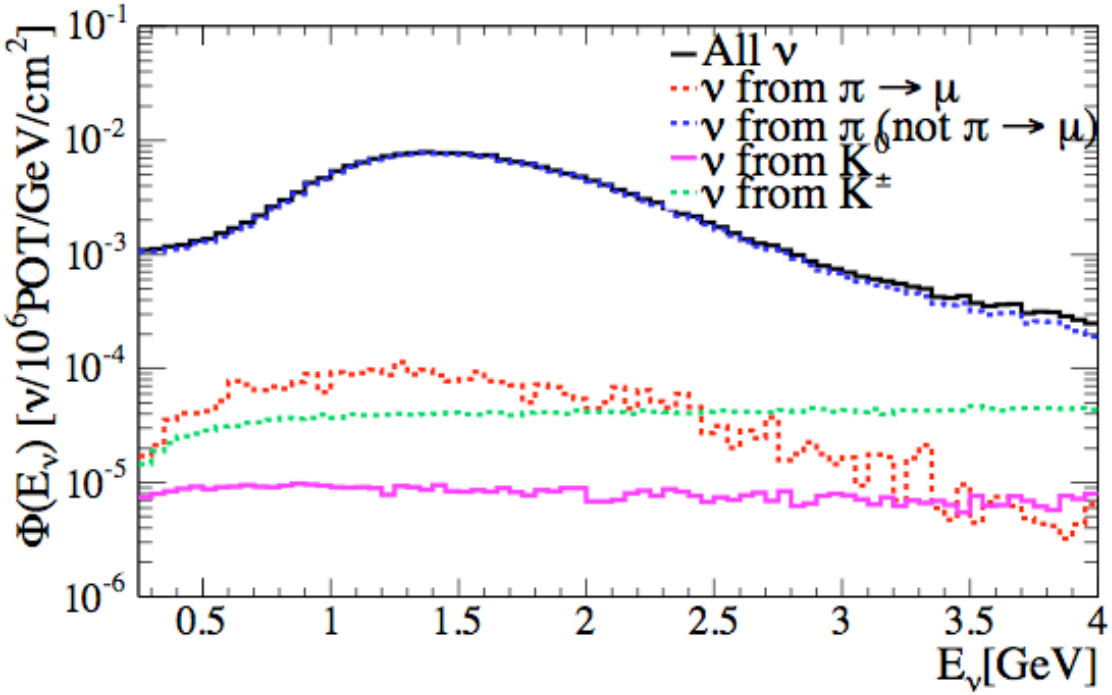
Backups

NDOS (LE):

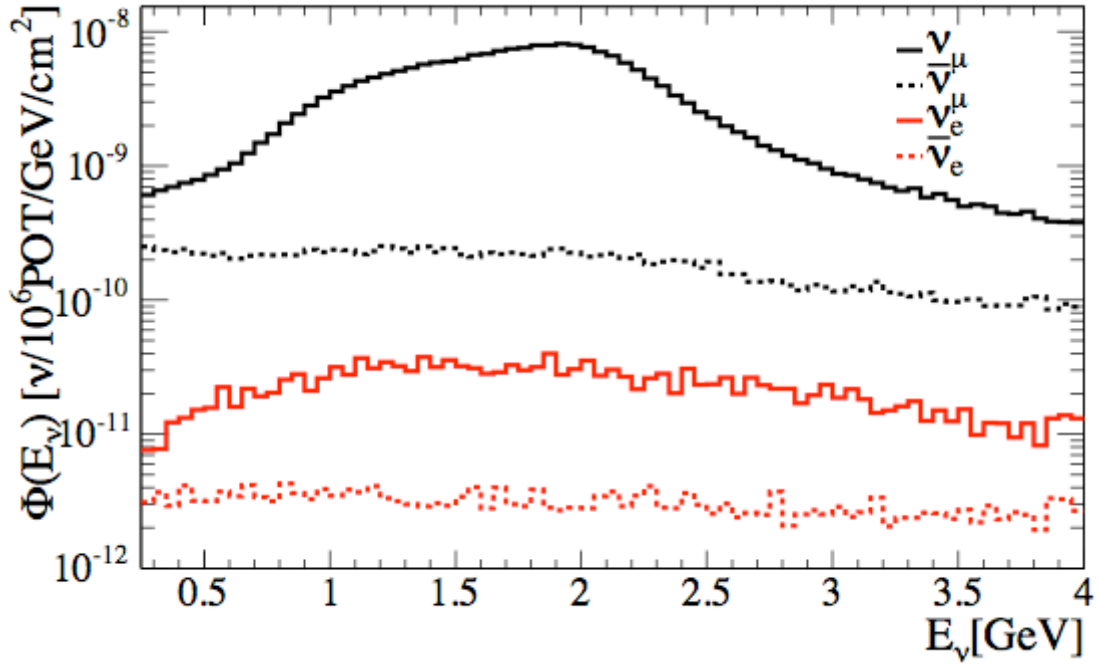

$\Phi(E_\nu)$ [$\nu/10^6$POT/GeV/cm^2]
E_ν[GeV]
ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
All ν
ν from $\pi \rightarrow \mu$
ν from π (not $\pi \rightarrow \mu$)
ν from K^0
ν from $K^\pm$

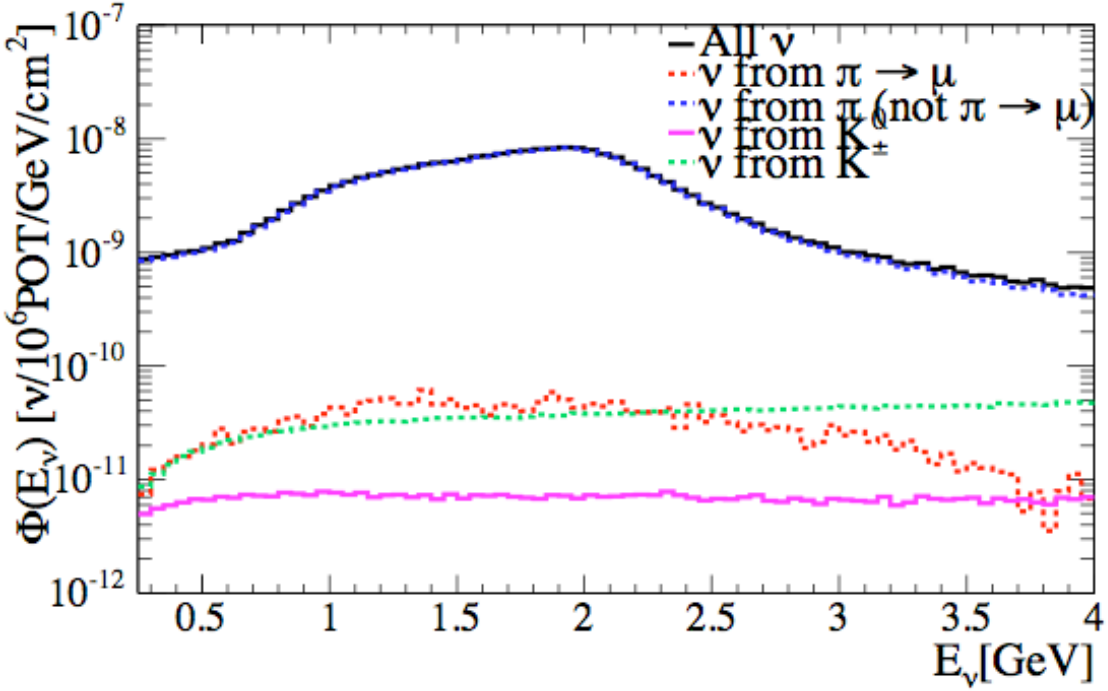
Near (LE):


ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
$\Phi(E_\nu)$ [ν/10^6POT/GeV/cm^2]
E_ν[GeV]


All ν
ν from $\pi \rightarrow \mu$
ν from π (not $\pi \rightarrow \mu$)
ν from K^0
ν from $K^\pm$
$\Phi(E_\nu)$ [ν/10^6POT/GeV/cm^2]
E_ν[GeV]

Far (LE):


ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
$\Phi(E_\nu)$ [$\nu/10^6$POT/GeV/cm^2]
E_ν[GeV]

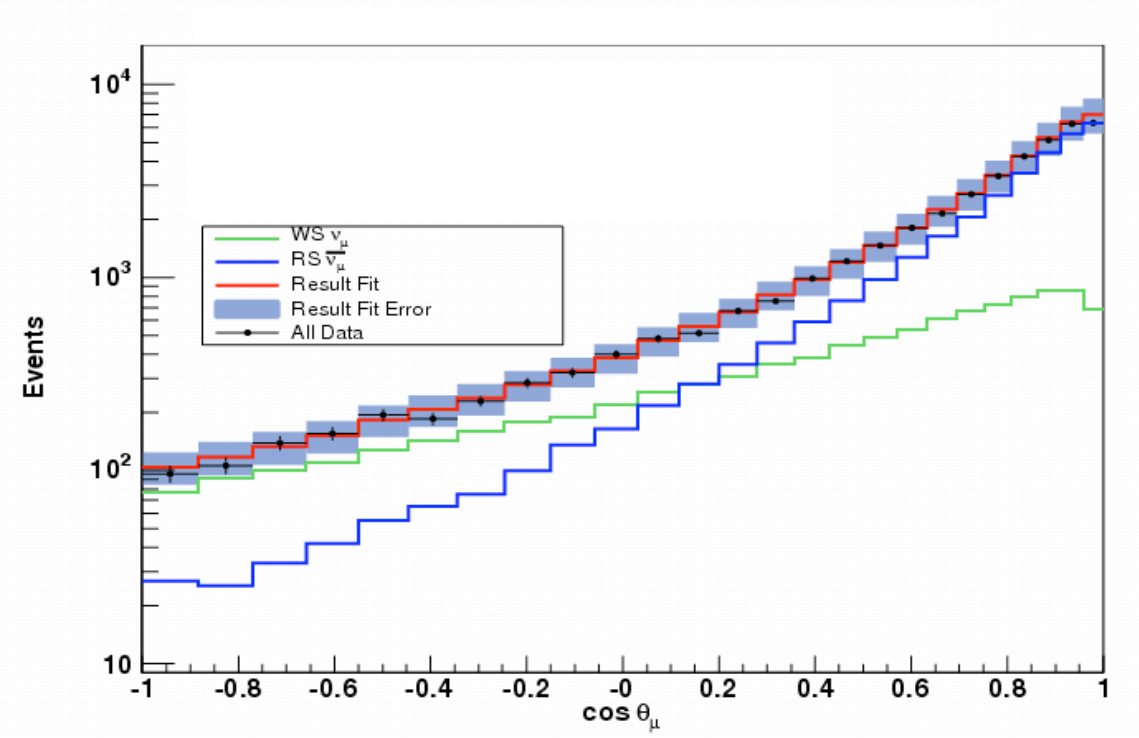

All ν
ν from $\pi \rightarrow \mu$
ν from π (not $\pi \rightarrow \mu$)
ν from $K^\pm$
ν from K^0
$\Phi(E_\nu)$ [$\nu/10^6$POT/GeV/cm^2]
E_ν[GeV]

Need to know wrong sign vs right sign.

We cannot separate ν_μ and bar-ν_μ on event-by-event basis.

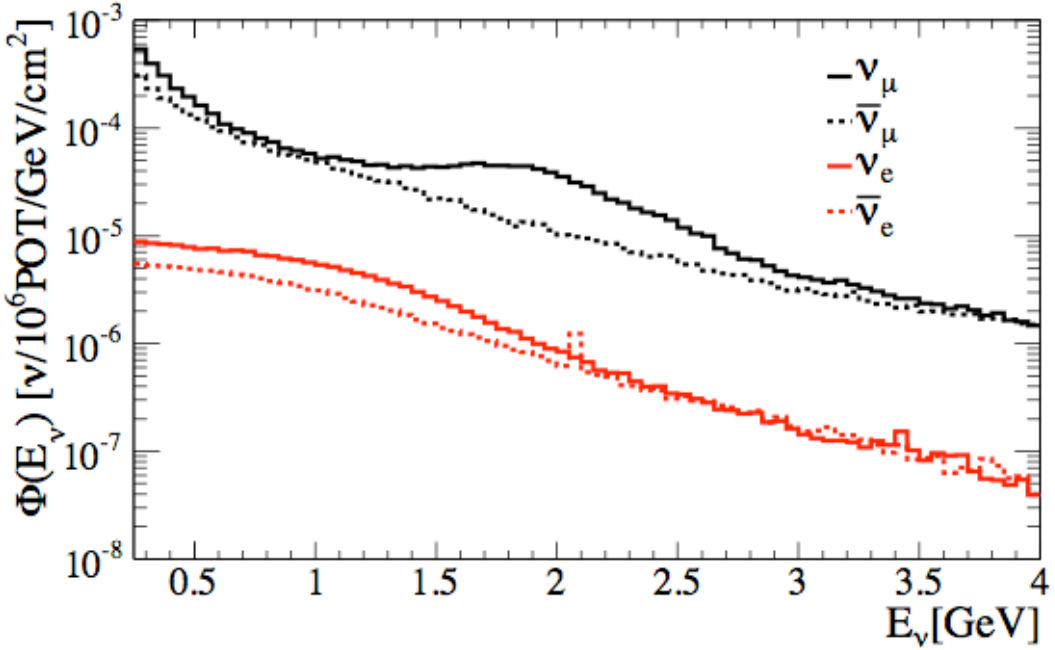
We measure it.

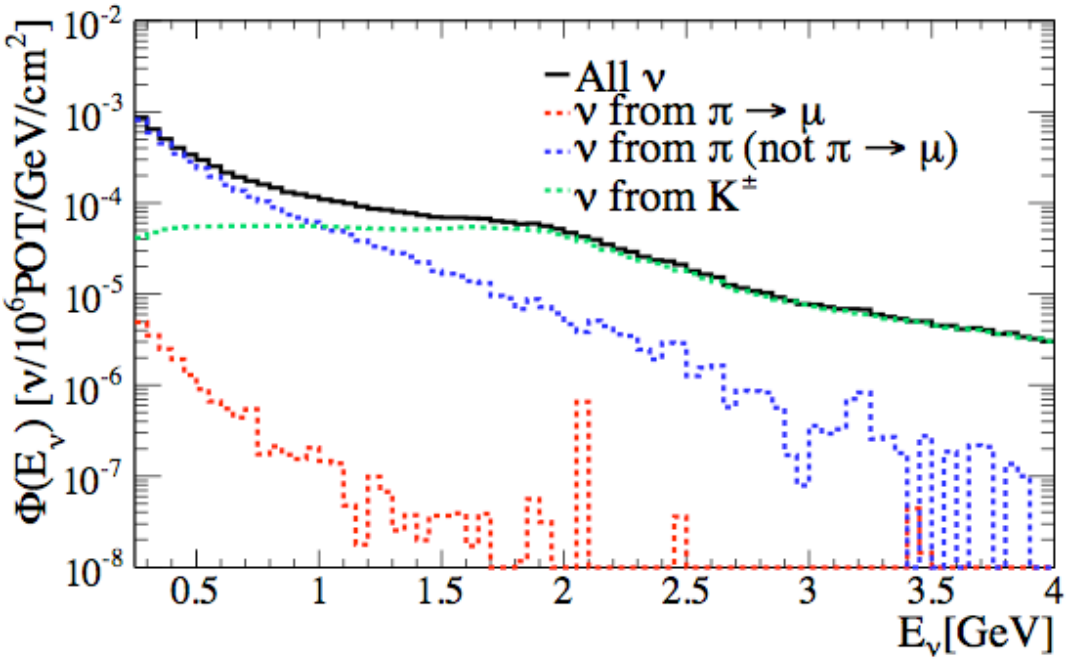
ν_μ CCQE gives more forward peaked muon.



From MiniBooNE

NDOS (ME):

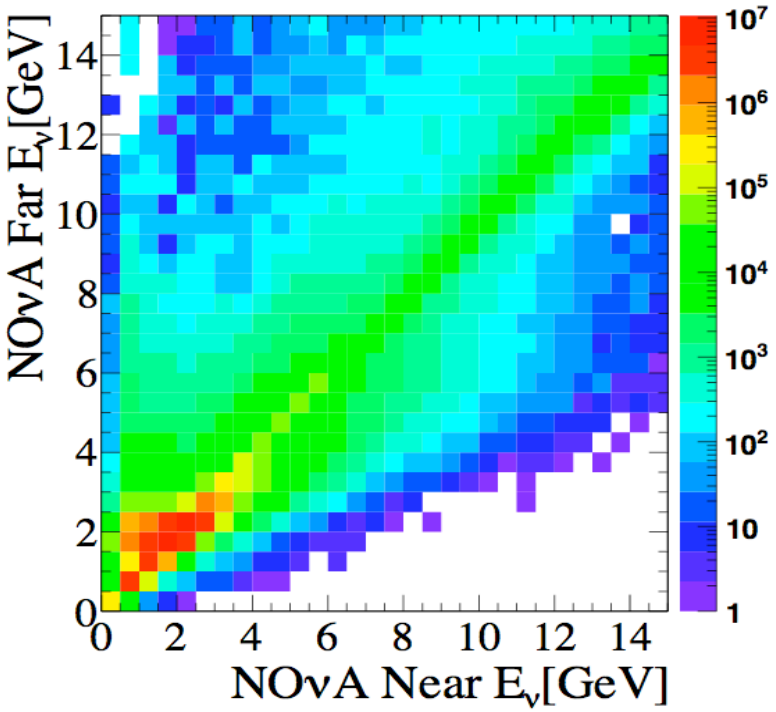

ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
$\Phi(E_\nu)$ [$\nu/10^6$POT/GeV/cm^2]
E_ν[GeV]


All ν
ν from $\pi \rightarrow \mu$
ν from π (not $\pi \rightarrow \mu$)
ν from $K^\pm$
$\Phi(E_\nu)$ [$\nu/10^6$POT/GeV/cm^2]
E_ν[GeV]

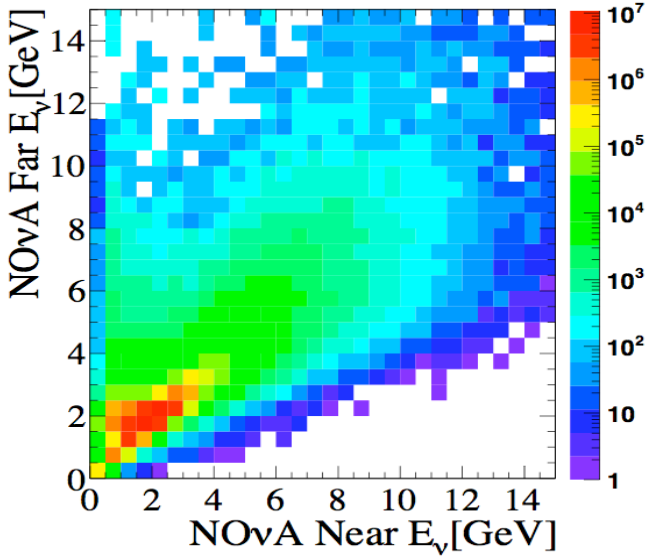
Near to Far Extrapolation

-Covariance Matrix correlating fluxes at Near and Far detectors

ν_μ 's:



ν_μ 's from π:



ν_μ 's from K: