NOvA's Short-baseline Tau Neutrino Appearance Search

New Perspectives 2018

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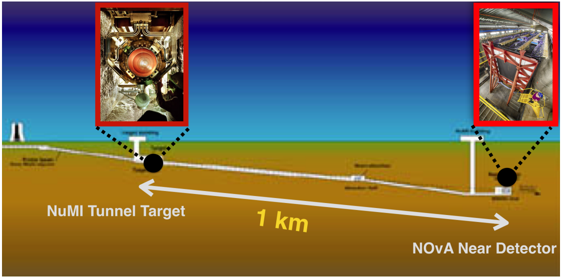
The NOvA Experiment

- Off-axis long-baseline neutrino oscillation experiment
- A narrow energy flux peaks at 2 GeV with a high energy tail, as the detectors are located 0.8^{o} off NuMI beam axis

- **Near Detector:**
  105 m underground
  1 km from target
  0.3 kton



Sterile Neutrinos

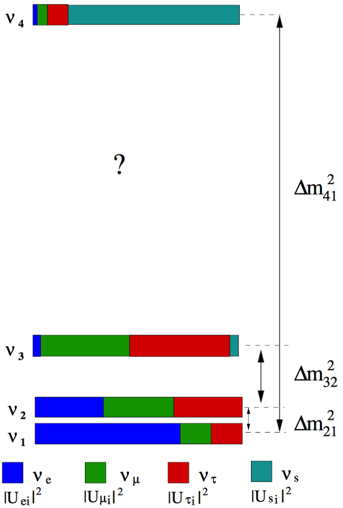
The probability for ν_τ appearance and ν_μ disappearance using a 3+1 neutrino oscillation model in Short-BaseLine(SBL) approximation:

$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\tau} = \sin^2 2\theta_{\mu\tau} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

where $\sin^2 2\theta_{\mu\tau} \equiv 4|U_{\mu 4}|^2 |U_{\tau 4}|^2$
$= \cos^4 \theta_{14} \sin^2 2\theta_{24} \sin^2 \theta_{34}$

$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu} = 1 - \sin^2 2\theta_{\mu\mu} \sin^2 \frac{\Delta m^2_{41} L}{4E}$$

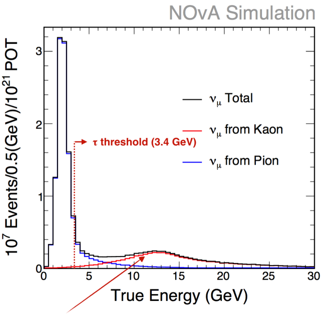
where $\sin^2 2\theta_{\mu\mu} = \cos^2 \theta_{14} \sin^2 \theta_{24}$



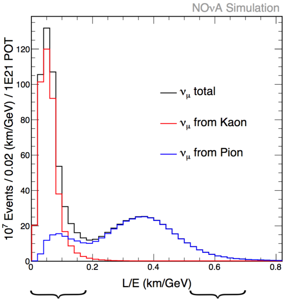
Analysis Overview

- Neutrinos in narrow-band beam peaked at 2 GeV predominantly created by pion decays
- But τ threshold is $\sim$3.4 GeV

- Looking at the high energetic neutrinos coming from kaons above τ treshold
- Search for $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_\tau$ oscillations



SBL ν_τ Appearance

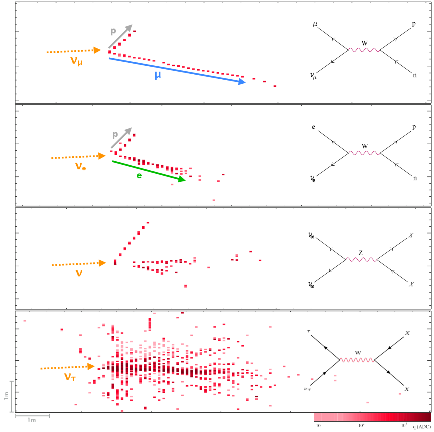


SBL ν_τ Appearance

LSND sensitive region(0.4 -1.4)

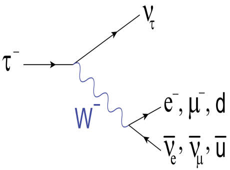
Neutrino Interactions in NOvA

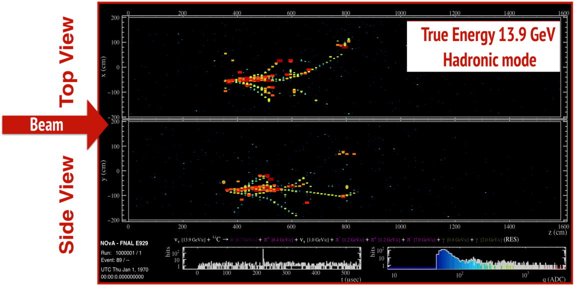
- ν_μ CC : Long Track
- ν_e CC : Electronic Shower
- NC : Hadrons
- ν_τ CC : τ Decay



τ Decay Modes

- hadronic ($\sim$ 65%) and leptonic:

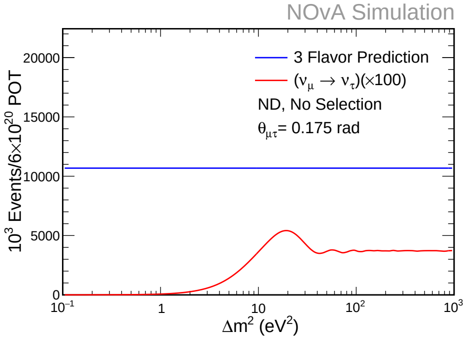




- This analysis looks only for hadronic mode τ decays.

Joint ν_μ -ν_τ Fit

- ν_τ event rates are maximized for $\Delta m^2 = 22eV^2$ as looking at high energy region with low L/E.

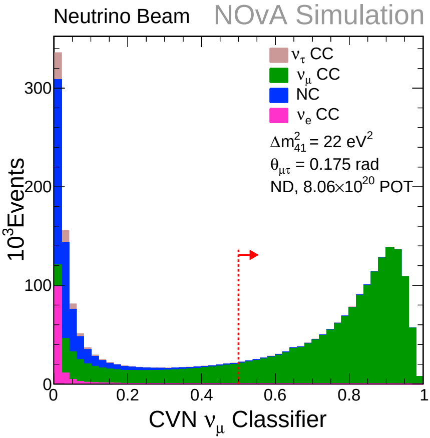


- Use convolutional neural network based PIDs and BDTs as primary selectors.
- A joint ν_μ-ν_τ fit to constrain huge systematic uncertainties.
- Rate only fit to the 3+1 oscillation parameters: $\Delta m^2{}_{41}, sin^2 2\theta_{\mu\tau}$ and $\sin^2\theta_{24}$.

ν_μ Event Selection

$\nu_\mu \rightarrow \nu_\mu$ Selection

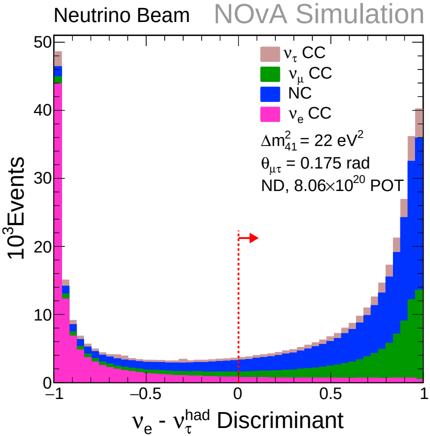
- A convolutional neural network based PID (ν_μ CVN) is used as a primary selector.
- Preselection cuts: To ensure the event quality and to remove the interactions in the surroundings of the detector



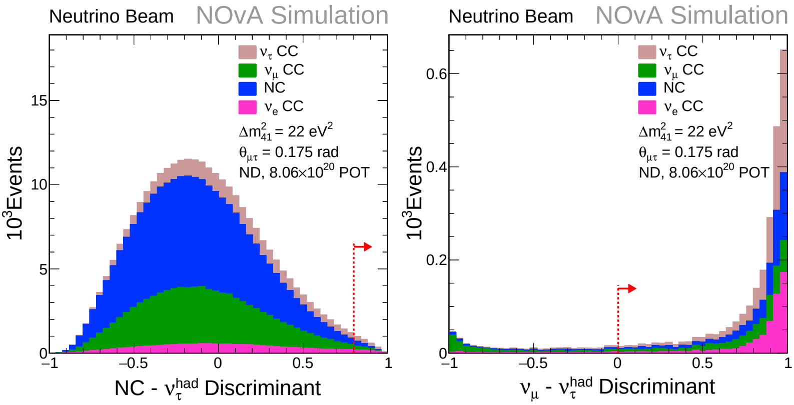
ν_τ Event Selection

$\nu_\mu \rightarrow \nu_\tau$ Selection

- 3 BDTs are used as the primary selectors ($\nu_\mu, \nu_e, NC - \nu_\tau^{had}$ Discriminants)
- Preselection cuts: To ensure the event quality and to remove the interactions in the surroundings of the detector



$\nu_\mu \rightarrow \nu_\tau$ Selection



Signal Predictions

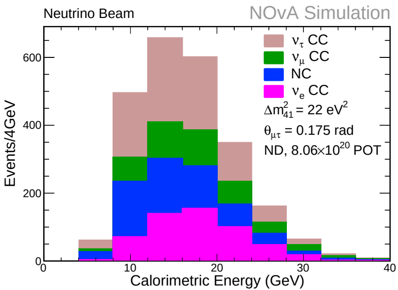


Figure: ν_τ Prediction

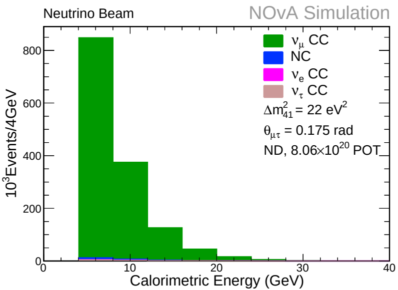
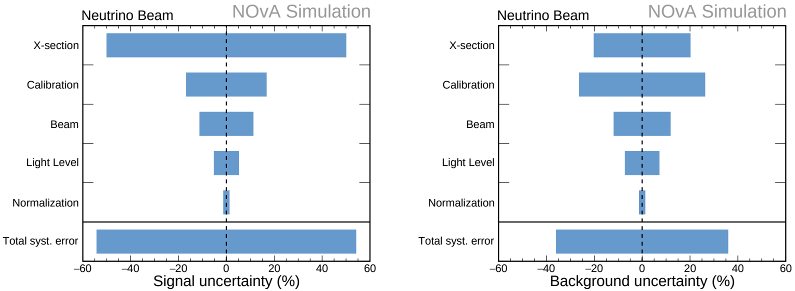


Figure: ν_μ Prediction

Selection	ν_μ CC	NC	ν_e CC	ν_τ CC
$\nu_\mu \to \nu_\tau$	460	591	541	866
$\nu_\mu \to \nu_\mu$	1.52e+06	14252	2063	6694

Table: Scaled to 8.06 $\times$ 10^{20} POT. The predictions are for fixed parameters, Δm^2_{41} = 22 eV^2 and θ_{μ_τ} = 0.175 rad.

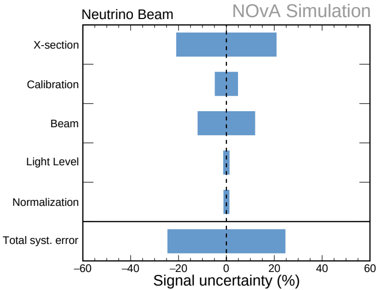
ν_τ Selection

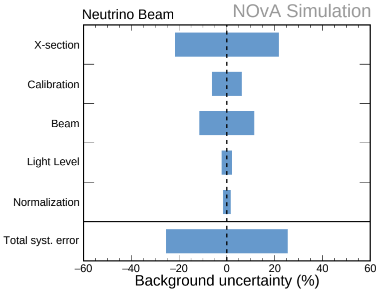


- ν_τ cross-sections are not well constrained yet, so we added a 50% normalization uncertainty on just ν_τ cross-section.

Systematic Uncertainties

ν_μ Selection

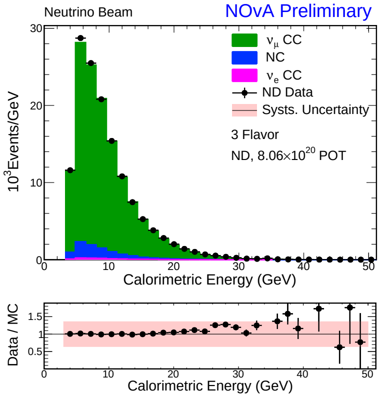


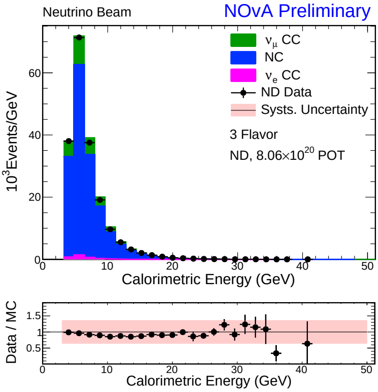


- Cross-section uncertainty and beam uncertainty are the dominant uncertainties for ν_μ selection.

Sideband Studies

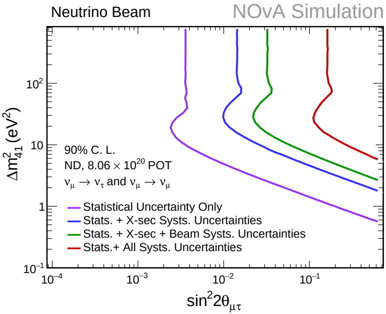
ν_μ and ν_τ Sidebands



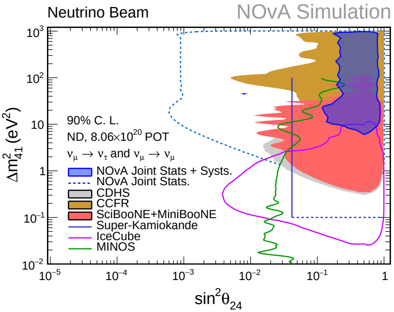


- A mid ν_μ CVN sideband region for ν_μ Selection
- A high NC CVN sideband region for ν_τ selection

ν_μ-ν_τ Joint Fit



- Marginalized over $sin^2\theta_{34}$ and $sin^2 2\theta_{24}$



- Marginalized over $sin^2\theta_{34}$.

Summary & Conclusions

- The NOvA SBL $\nu_\mu - \nu_\tau$ joint analysis is promising.
- We conducted the systematic uncertainty studies for both the ν_μ and ν_τ selections used in this joint analysis.
- We looked at the data in two different side-band regions for ν_τ and ν_μ selections.
- The data and MC are in good agreement in those regions within the systematic uncertainty.

Thank You

http://novaexperiment.fnal.gov