Simulation & Neutrino Flux Studies for NOvA Experiment

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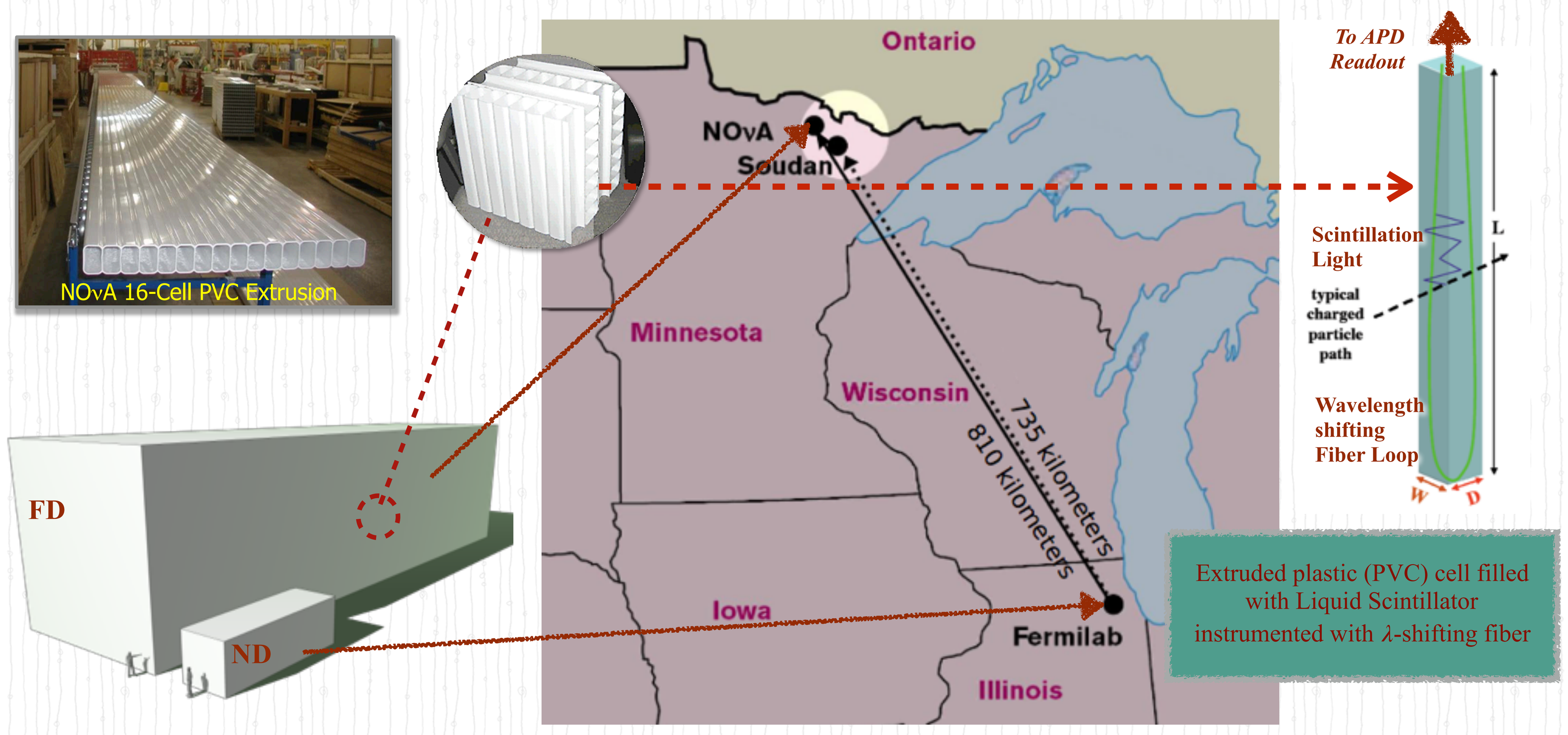
for NOvA Collaboration

NOvA:

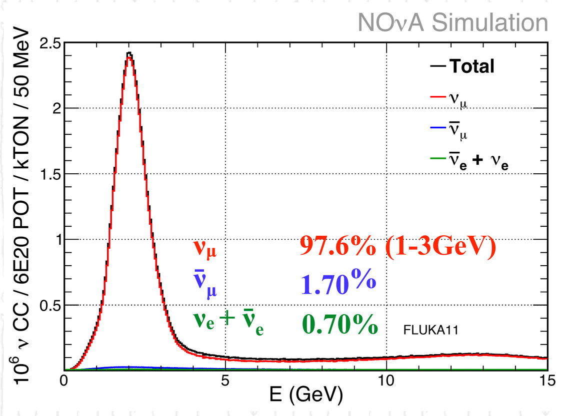
NuMI: Neutrinos at the Main Injector (ν_μ), Off-Axis: narrow band beam (2GeV), ν_e Appearance



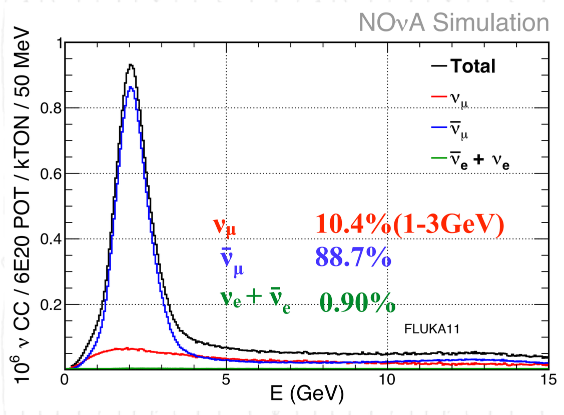
The experiment can count on two detectors, both located 14.6 mrad off the axis of the NuMI (Neutrinos at the Main Injector) beam line:

- The Near Detector (ND), 330 tons, 100m underground, 4.2m X 4.2m X 15.8m 214 planes 20,192 channels 1km from the source, used to measure composition of the un-oscillated beam
- Far Detector (FD), on surface, 14 kt, 15.5m X 15.5m X 60m, 896 planes 344,064 channels , 810km from the source, observes the oscillated spectra

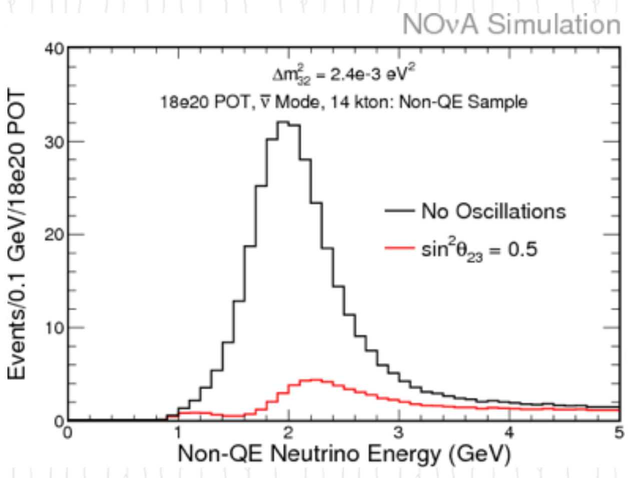
Motivation



Neutrino mode: horns focus

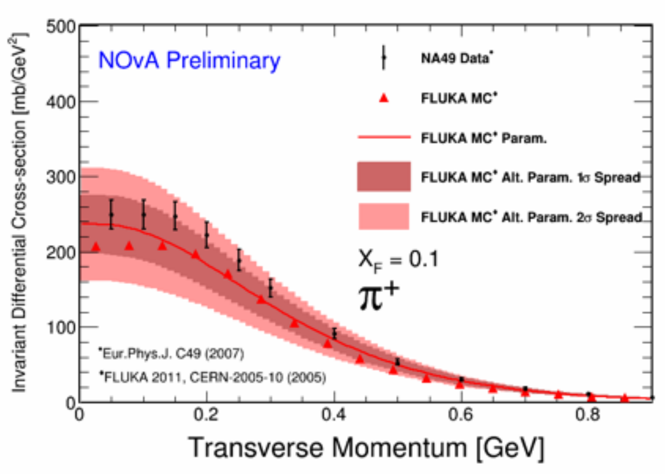


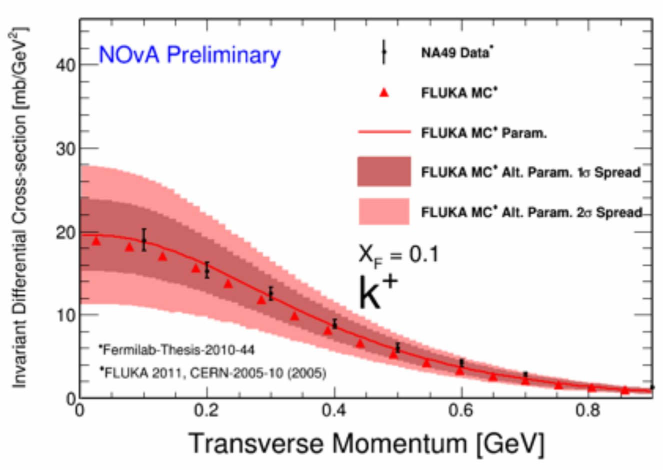
Anti-neutrino mode: horns focus negatives



- The sensitivity of the oscillation studies critically depends upon precise prediction of un-oscillated ν_μ, $\bar{\nu}_\mu$, $\nu_e+\bar{\nu}_e$ flux-ratio: FD/ND(E_ν).
- Uncertainties in FD/ND come from the proton-nucleon hadron production and the beam transport simulation
- Needed are data-driven methods to constrain the uncertainties. The most important is the NOvA-ND data. Other constraints include MINOS, NDOS (Near Detector Prototype On Surface) data, and Hadron-production data (MIPP, NA49...)

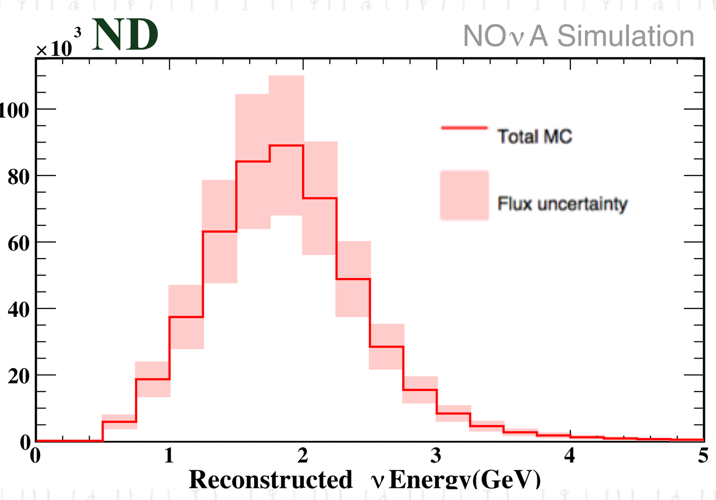
Uncertainties in hadron production based on NA49 data



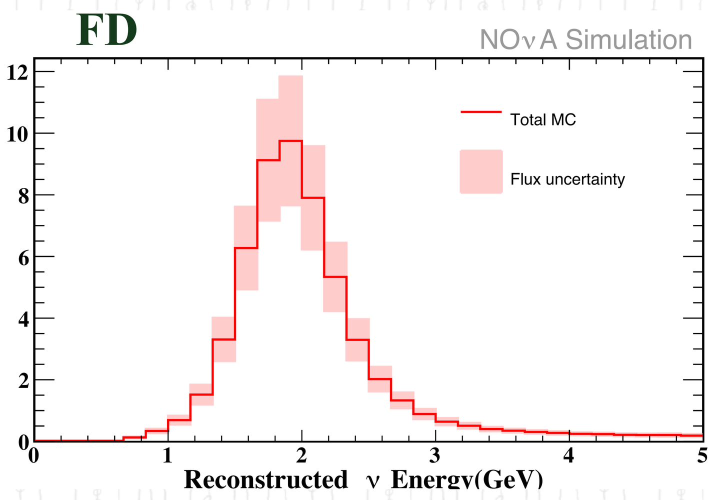


Invariant differential cross section for an X_F of 0.1 and as a function of P_T for Pions & Kaons produced in p+C collisions at 158-GeV/c beam momentum on thin target.

Beam Transport Errors, including NA49 Hadroproduction Uncertainty on Reconstructed neutrino energy[GeV] in NOvA ND & FD for 6e20 POT



Flux uncertainty is ±23.9%

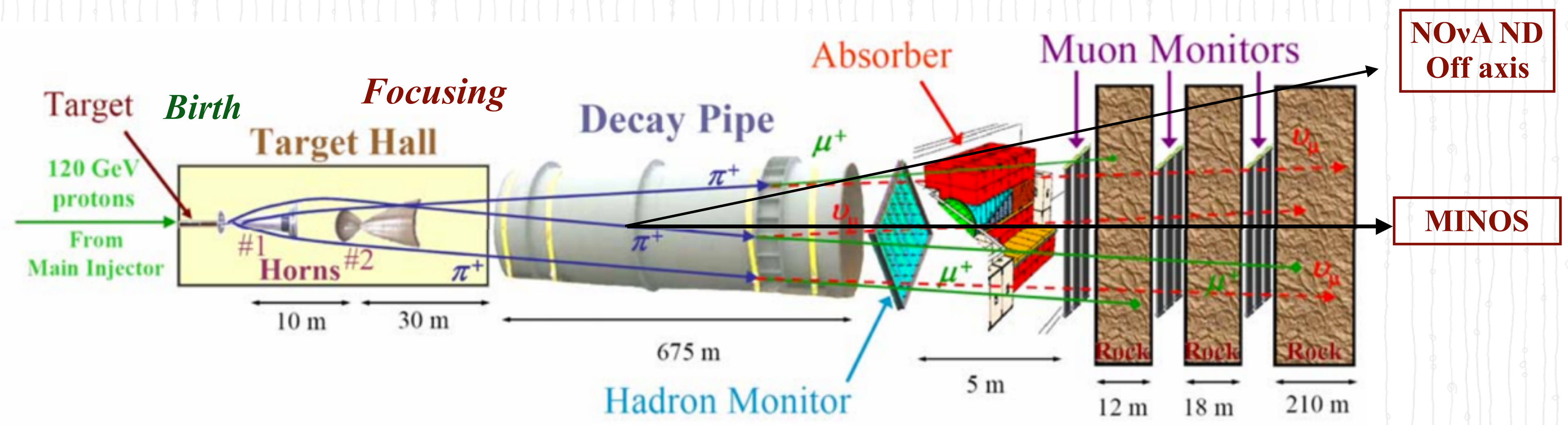


Flux uncertainty is ±20.9%

The error band represents a ±1 sigma shift of all beam systematics: including NA49 Hadroproduction Uncertainty, Spot size, Beam position on the target (X/Y), Target position, Horn current, Horn-positions, & the modeling of horn's B-field.

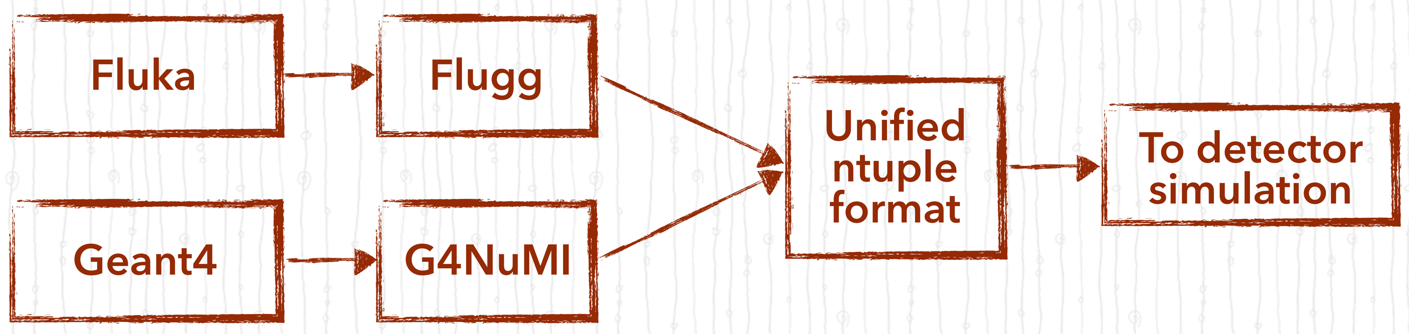
The NuMI Beam Line

A beam of 120 GeV **protons** is delivered from the Main Injector at Fermilab. These protons are then made collided against a graphite **target**. Secondary particles produced in the target are focused, thanks to two **horns** where a strong magnetic field is present. Of all these secondary particles, most important are **pions** and **kaons**, because they will decay in a muon and a **neutrino**. After being focused, they are left free to decay in a **decay pipe**. At the end of the decay pipe, remains a beam of neutrinos, muons and hadrons. The latter are then absorbed by a **hadron absorber**.



NOvA uses two softwares to simulate the beam line:

- **G4NuMI**: a pure Geant4 simulation
- **Flugg**: uses the same G4NuMI geometry, but interfaces to Fluka (version 11.2b.6) for the actual particle physics. It gives best data agreement with neutrino experiments



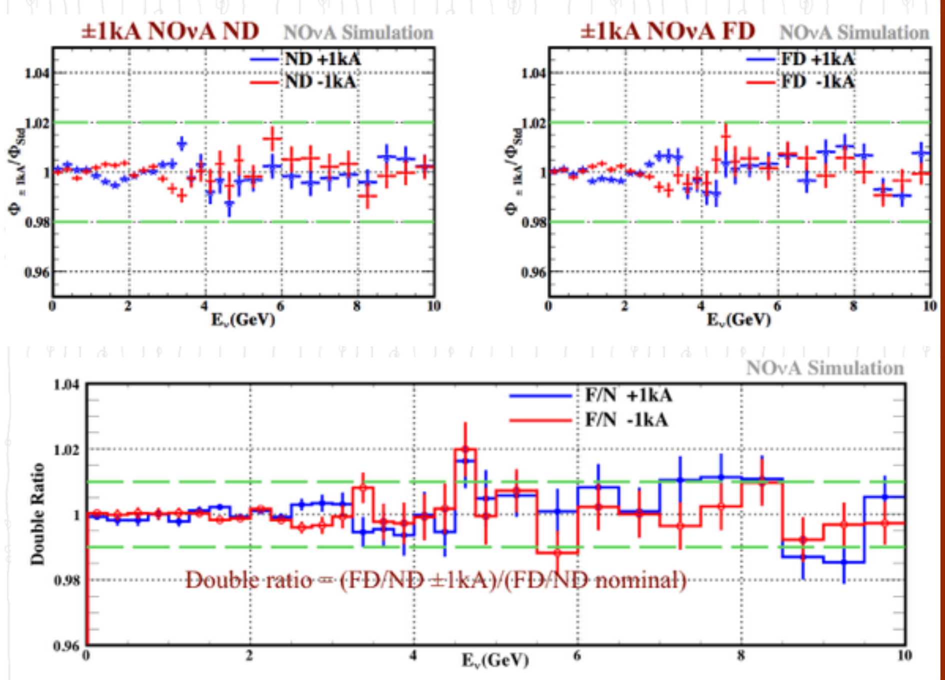
Beam Transport Systematic Variations

The 'Standard Flux' is based on FLUKA 2011.2b.6 (Flugg 2009-3d)

A. Horn Current
B. Beam spot size
C. Horn1 & Horn 2 position
D. Target position shift
E. Shifted beam positions on Target
F. B-field modeling in skin of horn: Exponential Magnetic field

An example of Beam-Transport parameter variation:

Horn Current Variation ±1kA:



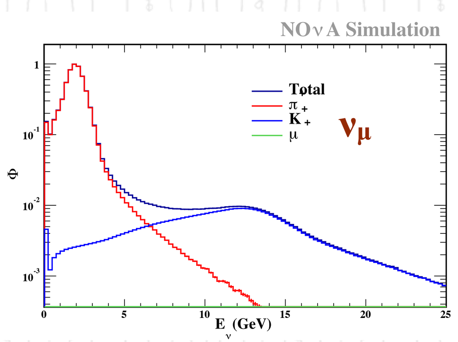
Variation in # of νμ at NOvA ND &FD

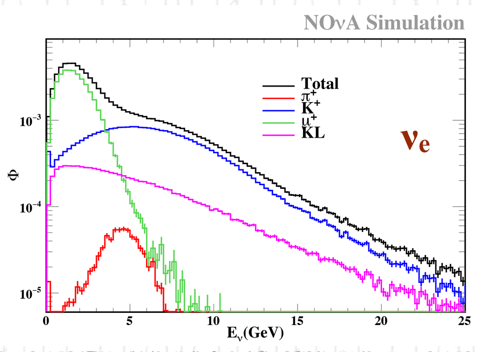
Model	Delta(%) ND	Delta(%) FD
Std	0	0
+1kA	-0.2	-0.16
-1kA	0.16	0.1
BposX+.5mm	-0.66	-0.68
BposX-.5mm	0.26	0.24
BposY+.5mm	0.13	0.18
BposY-.5mm	-0.35	-0.45
BmSptp +.2mm in X & Y	-0.77	-0.81
BmSptm -.2mm in X & Y	0.29	0.29
H1 +2mm X & Y	-0.44	-0.39
H1 -2mm X & Y	-1.7	-1.79
H2 +2mm in X & Y	-0.51	-0.47
H2 -2mm in X & Y	0.37	0.3
Exp B field	-4.3	-4.32
Target position +2mm	-0.08	-0.09
FTFP	-3.65	-3.76

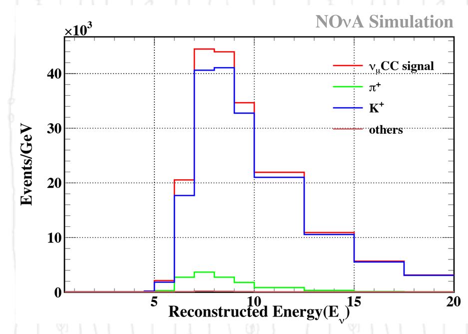
δ(%) for ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$ is ~3% for ND & FD(1-3GeV), Energy variation for ν_μ, $\bar{\nu}_\mu$, ν_e, $\bar{\nu}_e$ <1%

Constraints using ND Data

- $\pi\rightarrow\nu_\mu+\mu$; 97% of ν_μ at the ND are from the π
- Use ND-Data (E_ν>7.5 GeV) to constrain K^+ (for ν_e)
- Use ND-Data (0.5<Ev<5) to constrain π^+ <=> μ^+ (for ν_e) i.e $\pi\rightarrow\nu_\mu+\mu$, $\mu\rightarrow\nu_\mu+e+\nu_e$







Future Plans:

- We will use Mipp Experiment thick target data for hadro-production uncertainties.
- K^+ & π^+ Normalization from ND CC-Data
- Absolute flux from ν_e NC interaction
- Constraining the shape (relative-flux) using Low-Nu0 method

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