NuMI-X: An Inter-Collaboration NuMI Beam Working Group

Raphaël Schroeter (Harvard University)
Alexander Radovic (College of William and Mary)
Ioana Anghel (Iowa State University, Argonne National Laboratory)

On behalf of the NuMI-X working group

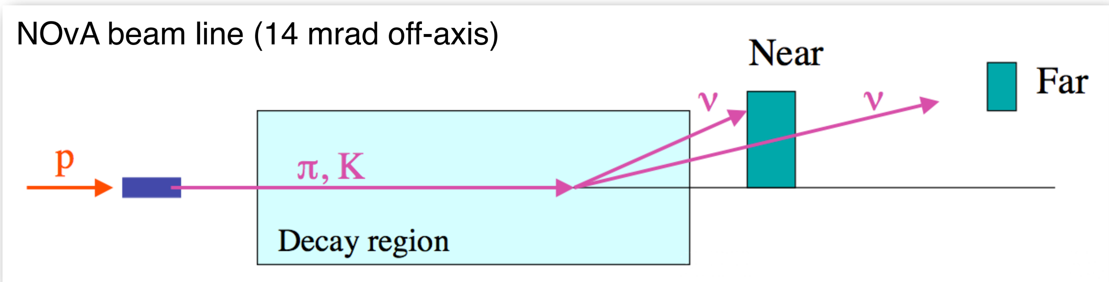
The NuMI-X Working Group

Joint effort between Fermilab's MINOS, MINOS+, MINERvA, NOvA, ArgoNeuT and MicroBooNE experiments on studying and modeling the NuMI beam.

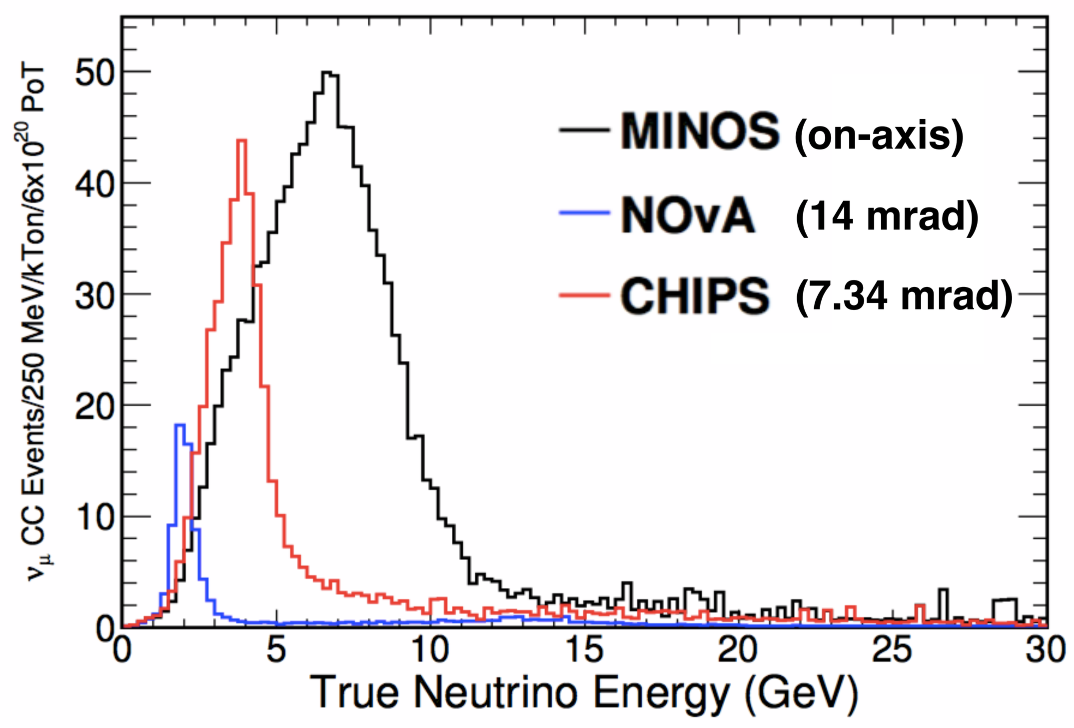
Goals:

- Develop and maintain the best knowledge about NuMI neutrino fluxes relevant to all NuMI experiments
- Produce neutrino flux Monte Carlo to be used by all
- Pioneer inter-collaboration tuning of the NuMI beam
- Use on- and off-axis data to constrain the beam modeling

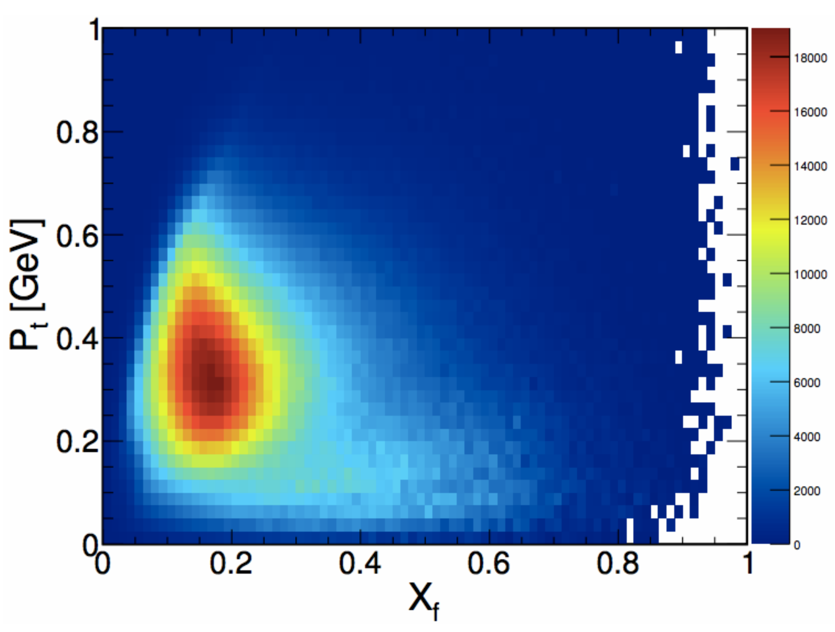
Multiple Views on the Same Beam



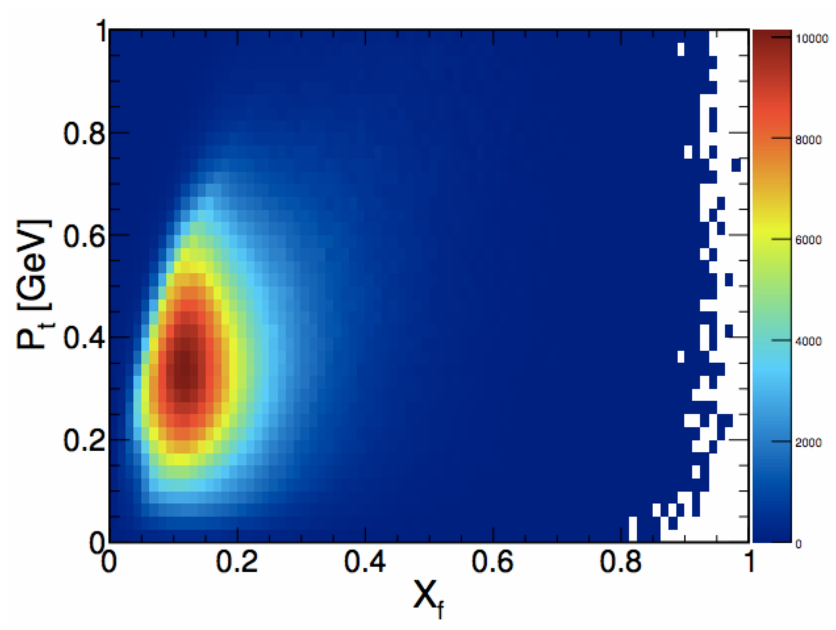
The NuMI beam forms the foundation of physics programs at MINOS+, MINERvA, NOVA, MicroBoone and MiniBoone. The isotropic decay of pions to produce muon neutrinos means that the spectra observed by each of these experiments is unique to the particular location of the experiments detector- the more "off-axis" the detector the more low energy and tightly peaked the observed spectra:



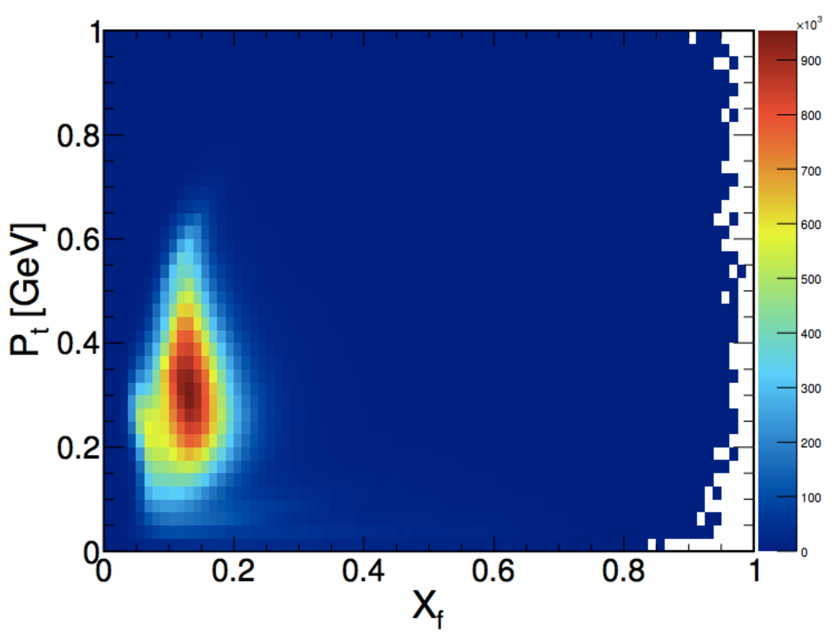
This also means that the pions and kaons contributing to the spectra at one experiment have different kinematics at production than those at another:



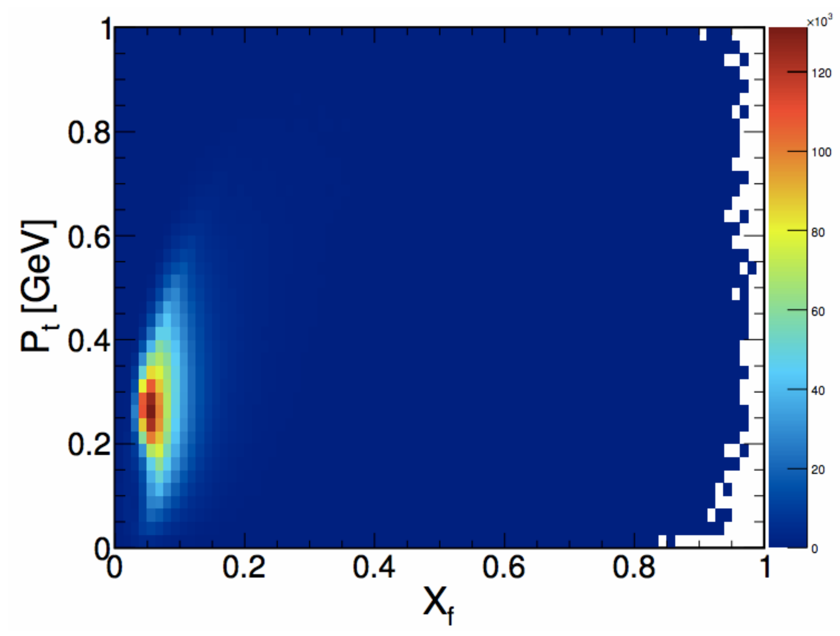
k+ MINOS



k+ NOvA



π+ MINOS



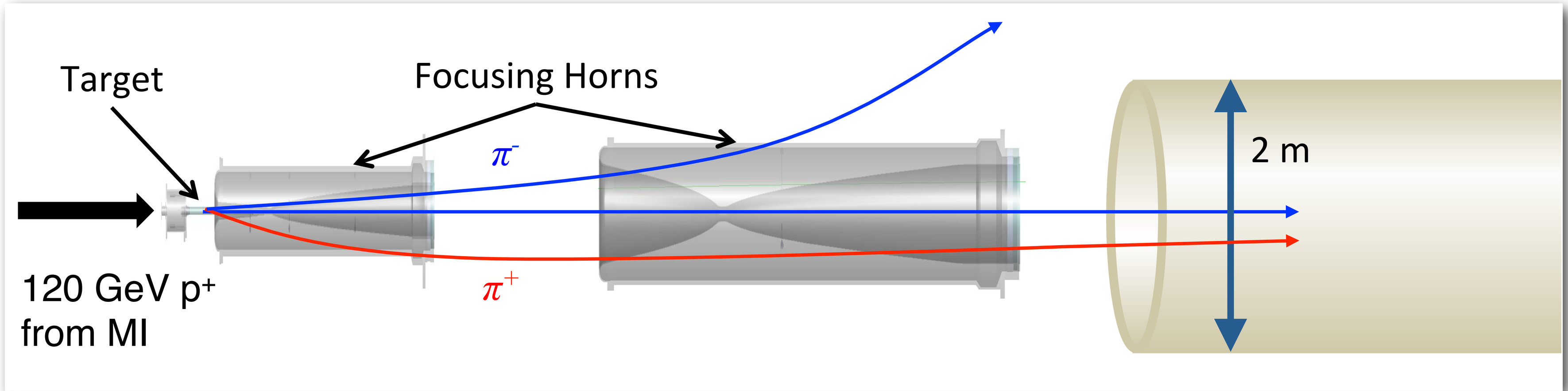
π+ NOvA

The NuMI-X Working Group

MINOS, MINOS+, MINERvA, NOvA, ArgoNeuT, MicroBooNE and Fermilab

[1] A. Ferrari, P.R. Sala, A. Fasso', and J. Ranft. FLUKA: a multi-particle transport code. CERN- 2005-10 (2005), INFN/TC_05/11, SLAC-R-773.
[2] The Fermilab GEANT4 Group, https://sharepoint.fnal.gov/project/geant4-pub/SitePages/ComposeG4PL.aspx

The NuMI Beam
Neutrinos At The Main Injector

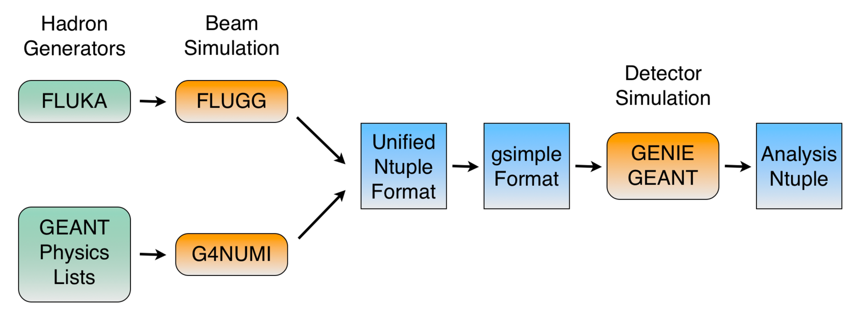


The NuMI beam upgrade:

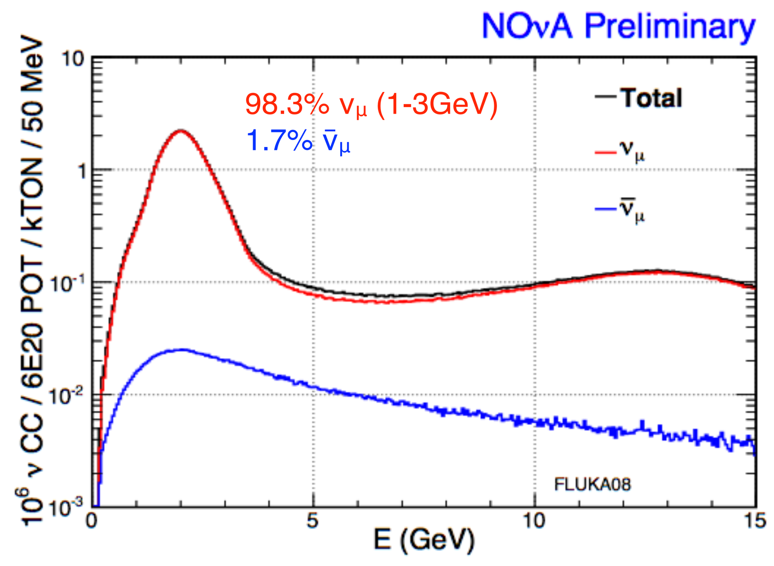
- Proton Improvement Plan (PIP), to bring beam power from 320 kW to 700 kW
- Runs in the medium energy target-horns configuration
- Target replacement:
  - New design for 700 kW
  - External to horn
- Target hall re-arrangement for higher energy
- Various shielding and magnet reconfigurations
- Plan 8+ years of operation for NOvA

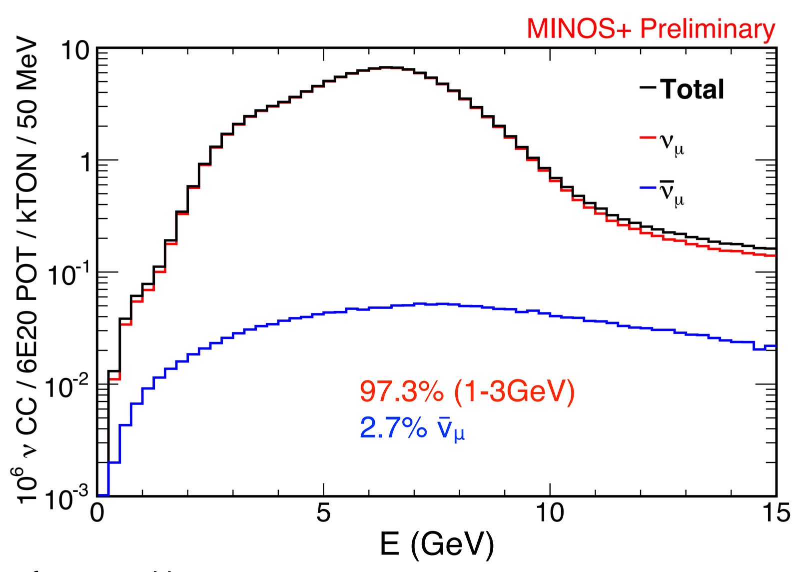
	NUMI / NOVA
Distance to far detector	810 km
Desired ν energy	2 GeV
Detector Off-beam-axis angle	14 mrad
Design beam power	700 kW
Energy per proton	120 GeV
Number of horns	2
Target length	1.2 m
Distance between target downstream end and horn	0.2 m (Not in horn)
Protons/spill	4.9 E13
Repetition rate	1.33 sec

Beam Modeling



- Two alternative hadron production models used in parallel:
  - GEANT - open code, but hadron production is tuned more for showers
  - FLUKA - best data agreement with neutrino experiments, closed code
- Both simulation chains share the same G4 target/beamline geometry
- Simulation output in unified ntuple format, containing full ancestry information



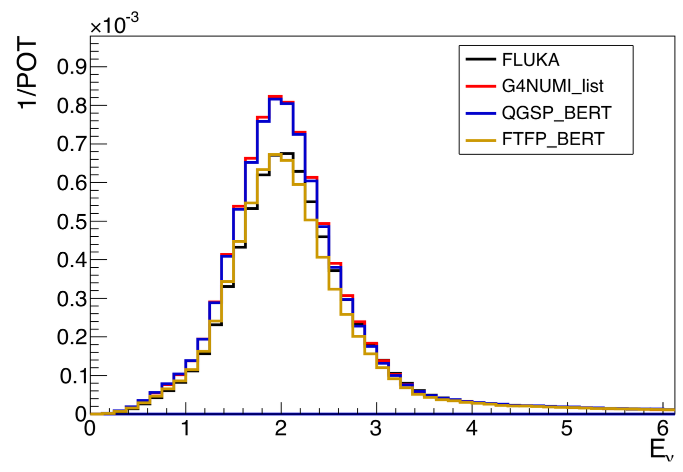


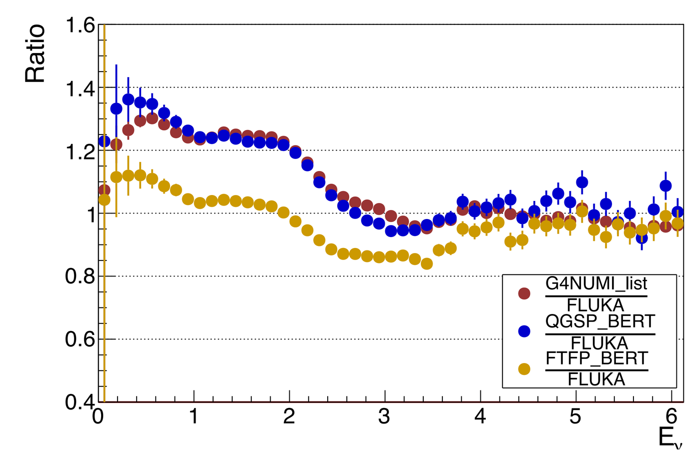
Neutrino mode: horns focus positives

Improving and Validating The Beam Modeling

Ongoing studies to compare the different hadron generators:

- FLUKA[1] for the FLUGG simulation
- G4 physics lists[2] (FTFP, QGSP, …) for the G4NuMI simulation
- Custom G4 physics list[2] specifically tuned to NuMI beam experiments developed by Fermilab's Geant4 group





Development of *FluxReader*, an extensive and flexible validation framework that:

- Reads unified ntuple flux files and allows users to create intuitive, reproducible, and consistent plots such as neutrino energy, neutrino parent energy, etc.
- Can perform "event by event" calculations, weight neutrino rays to different locations, and apply external weights

Longer term plans:

- Use of available external hadron production data (NA61/SHINE, NA49, MIPP, …) to:
  - Constrain simulations
  - Give direct input to experiments' flux estimation
- External data can be rescaled to NuMI proton energy for direct comparison and combined to maximally cover NuMI phase space
- Neutrino beam simulations greatly improved with dedicated and exhaustive program of hadron production measurements at NuMI proton energies such as USNA61