The NuMI-X Working Group

Joint effort between Fermilab’s MINOS, MINOS+, MINERνA, 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

The NuMI beam forms the foundation of physics programs at MINOS+, MINERνA, NOvA, MicroBooNE and MiniBoone. The isotropic decay of the NuMI beam forms the foundation of physics programs at MINOS+,

1. ArgoNeuT and MicroBooNE experiments on studying and modeling the NuMI beam.
2. Detector-the more “off-axis” the detector the more low energy and tightly peaked the observed spectra:

   - 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

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Multiple Views on the Same Beam

NOvA beam line (14 mrad off-axis)

Decay region

Near

Far

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

- Pion to be used by all
- Pioneer inter-collaboration tuning of the NuMI beam

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

Improving and Validating The Beam Modeling

Ongoing studies to compare the different hadron generators:
- FLUKA\textsuperscript{1} for the FLUGG simulation
- G4 physics list\textsuperscript{2} (FTFP, QGSP, …) for the G4NuMI simulation
- Custom G4 physics list 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