MINOS Neutrino Flux

Using NuMI Muon Monitors for calculating flux for use in cross-section calculations

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Outline

- MINOS Experiment
- Beam Basics
- Using Muon Monitors for flux
  - NuMI beam line Monte Carlo
  - Minimize Monte Carlo and data differences
The MINOS Collaboration

32 institutions
175 scientists

Argonne • Athens • Benedictine • Brookhaven • Caltech • Cambridge • Campinas • Fermilab
College de France • Harvard • IIT • Indiana • ITEP-Moscow • Lebedev • Livermore
Minnesota-Twin Cities • Minnesota-Duluth • Oxford • Pittsburgh • Protvino • Rutherford
Sao Paulo • South Carolina • Stanford • Sussex • Texas A&M
Texas-Austin • Tufts • UCL • Western Washington • William & Mary • Wisconsin
The MINOS Experiment

- Main Injector Neutrino Oscillation Search
- Long-baseline neutrino oscillation experiment

Two Detectors
- Near Detector at Fermilab
- Far Detector in Tower, MN
- Both covered in more detail in later talks
Producing the neutrino beam (NuMI)

- **NuMI - Neutrinos at Main Injector**
- 120 GeV protons strike target
- 2 magnetic horns focus secondary Pions/Kaons
- Decay of Pions/Kaons produces neutrinos
- Moveable target & horn gives variable beam energy
Calculating Flux

Motivation for a method using Muon Monitors

- MINOS Cross section analysis
  - Direct, absolute flux measurement is crucial
  - Previous experiments have used muon monitors to directly measure the neutrino flux

- Oscillation analysis
  - A data driven flux uncertainty is preferable over the current Monte Carlo driven

- Neutrino flux is intrinsically tied to muon flux
  - Directly measurable
How-To

- Write a beamline Monte Carlo
- Use 3 downstream muon monitors for comparison to Monte Carlo
- Assume underlying model inaccuracies
  - Reweight MC to match data
    - Sanford-Wang, BMPT, SKZP
  - Minimize Data/MC difference via changes to model
Experience @ CERN PS (1967-1973)


- Tuned hadron production à la Sanford-Wang to match muon data
- Adjusted the neutrino flux by a FACTOR OF TWO!!!
Good

- Quick data taking ~hrs.
- Variable beam energy
- Similar to method using MINOS ND $\nu$'s

Bad

- Granularity
  - 3 Data points per beam configuration
- Background/Systematics
  - knock-on electrons, delta rays, rock density

Ugly

- Research for Monte Carlo inputs
  - Reading Sedimentary geology journals
Muon Monitors

Detection
- He Gas Ionization chambers
- 9 x 9 grid covering ~2.09m x 2.09m active area

Data
- 3 Different regions of muon momenta
  - Hadron Absorber and rock between alcoves
Simulation Tools

- **Fluka**
  - Hadron production off the target

- **gnumi**
  - Geant3 transport simulation from target to the decay point
  - Accommodates changes to target position and horn current

- **Weighting function**
  - Provides likelihood of muon to decay towards the end of Decay Pipe

- **g4numi**
  - Geant4 transport simulation of muons from the end of the Decay Pipe to the muon monitors
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**Muon Monitor Data (MC)**

- gnumi muons combined with muon weights give muon distribution at the end of the Decay Pipe (EODP)

**Muon p at EODP**

- Entries: 2537114
- Mean: 11.5032
- RMS: 11.2965

**Efficiency curve**
- Efficiency curves come from G4NuMI simulations
Full Monte Carlo chain produces Muon distribution in alcoves
Integrating Muon Distribution in MC Monitor approximates real Monitor response

- Muon energy deposition is flat (Bethe-Bloch)
The Job

Beat on MC/Data differences with a minimizing function (MINUIT)

- i.e. increase/decrease pion production by XX% to minimize chi-squared
  - include penalty terms
- Accounts for model discrepancies

Flux comes from the reweighted MC

Cross-section comes from flux and number of events
Conclusions

- Flux is essential for cross-section calculation
- Neutrino flux can be obtained from Muon Monitors
- NuMI beamline Monte Carlo works well
  - parameterized for ease of use
- Future possibility of combined flux analysis w/ MINOS neutrinos
Fluka ↔ gnumi → muon decay weights to Decay Pipe
Varying horn current probes different regions of parent (pion, kaon etc...) $p_z$ and $p_T$ space.
Varying horn current probes different regions of parent (pion, kaon etc...) $p_z$ and $p_T$ space

Muon Monitors sample 3 different regions of ($p_T$, $p_Z$) space per beam configuration
Muon Monitors provide a path to compare Monte Carlo data with real data

Data/MC Muon Monitor comparison

Real goal is still flux

- Examine muon parent hadrons
- Tune parents using a new model