Measuring particle momenta via Multiple Coulomb Scattering in the MicroBooNE Time Projection Chamber

Leonidas N. Kalousis (Virginia Tech)
for the MicroBooNE Collaboration

A maximum likelihood technique

Basic algorithm:
- Break up the particle track in segments of equal length ($\Delta s$)
- Find the direction (in $xy$ and $x_2$) of each segment
- Calculate the angular deflection ($\Delta \theta$) for two segments separated by $\ell$

\[ \Delta \theta = \theta_j - \theta_i \]

Say that you focus on the $i$-th and $j$-th segments, $\Delta \theta_{ij} = \theta_j - \theta_i$

The probability to measure $\Delta \theta_{ij}$ between $i$ and $j$ is:

\[ f_{ij} = f(\Delta \theta_{ij}, 0.0, \sigma_{ij}) \]

Find $E_0$ that maximizes:

\[ \mathcal{L}(E_0) = \prod_{(i,j)} f_{ij} \]

$\sigma_{ij}$ depends on the initial energy $E_0$ (momentum) since,

The energy at the $i$-th segment of the track can be found using the information on the wires, $E_i = E_0 - \Delta E_i$

Detector resolution:

The angular deflections ($\Delta \theta_i$) are smeared

by the intrinsic detector resolution (measurement errors)
- $\theta_i$ given by the Highland formula
- $\delta \theta_i$ corresponds to the measurement uncertainties

The likelihood becomes a function of both $E_0$ and $\delta \theta$:
- Measure $\delta \theta_i$ in situ, or estimate it through the Highland formula
- Fit simultaneously $E_0$ and $\delta \theta_0$

Experimental layout

MicroBooNE, just like MiniBooNE, will be installed along the Booster Neutrino Beam (BNB) at Fermi National Laboratory.

- Placed at a distance of ~470 m from the proton target, in the Liquid Argon Test Facility (LArTF).
- It will start data taking in the end of 2014 and run for 2 - 3 years in the neutrino mode accumulating $6.6 \times 10^{19}$ POT.

The MicroBooNE detector

Detection technique(s)
- Ionization electrons drifted along macroscopic distances (2.5 m, 1.6 ms)
- Scintillation photons (a few ns)

Characteristics
- Three planes of wires (3 mm pitch)
  - A collection plane at 0° from vertical
  - Two induction planes at ±6°
- Optical system of 32' cryogenic PMTs and 4 light guide prototypes
- Excellent energy resolution
- Robust tracking and PID capabilities

10.4 m x 2.5 m x 2.3 m Uniform E field, 500 V/cm
170 tons of purified LAr (83 m$^3$ of active volume)

Multiple Coulomb Scattering

- Whenever a particle is passing through matter it suffers a large number of small angle scatterers
  - Coulomb interactions with (mainly) atomic nuclei
- Large number of interactions, stochastic process

Modified Highland formula

\[ \theta_0 = \frac{13.6}{p^0} \sqrt{\frac{\sigma}{X}} \left( 1 + 0.038 \ln \left( \frac{X_0}{X} \right) \right) \]

References

H. A. Bethe, Phys. Rev. 89 (1953) 1256

Why Multiple Coulomb Scattering?

- Calorimetric information (wires) can be used to measure particle energy (and thus momentum) in MicroBooNE
- Adequate technique for fully contained events
- Excellent resolution, 2% at 1 GeV
- Fails when the particle exits the TPC (partially contained events)
- In the case of partially contained events, momentum and energy can be determined by means of Multiple Coulomb Scattering (MCS)
  - A technique employed within neutrino physics by DONUT, OPERA, MACRO and ICARUS
- In the MicroBooNE detector, a large number of charged current interactions will have a muon escaping the TPC
- No magnetic field or muon range detectors
- These events can be reconstructed using MCS

Results

- This technique has been applied to Monte-Carlo muons
  - Particle tracks taken from Monte-Carlo truth information, $\delta \theta_0 > 0$
  - Muons simulated upstream the MicroBooNE LArTPC with momenta between 0.5 to 5.0 GeV/c
  - Note though that the algorithm probably can not be used above 2.5 - 3 GeV/c due to the measurement errors

LAr, simulation, preliminary