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

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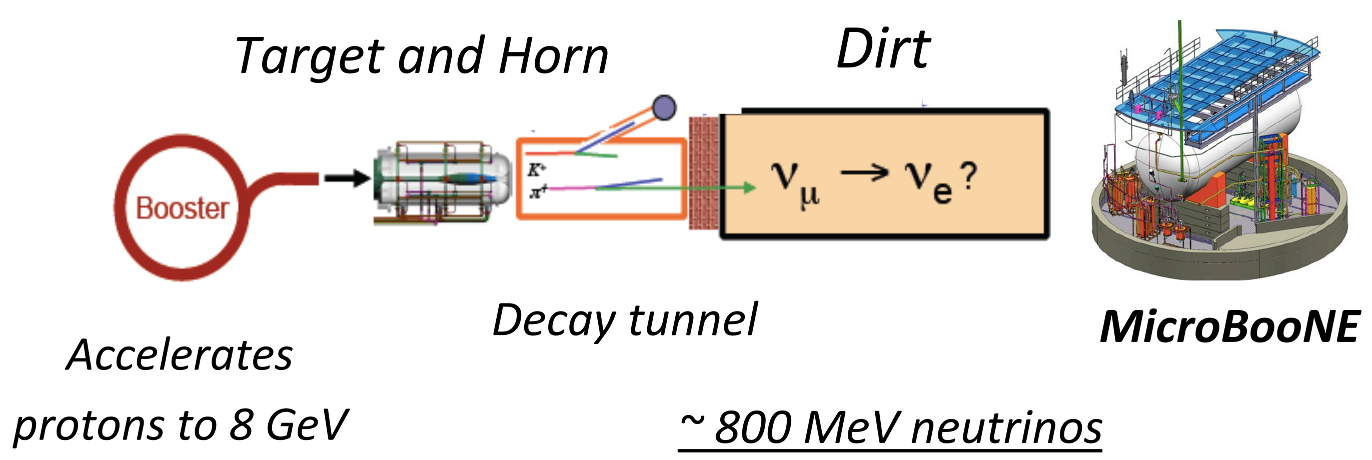
MicroBooNE

- The MicroBooNE detector will be the largest *Liquid Argon Time Projection Chamber* (LArTPC) operating in the United States, US.
- Main motivation for building MicroBooNE is the investigation of the ***MiniBooNE low-energy excess***
- Nonetheless, MicroBooNE will also:
  - ***Perform neutrino cross-section measurements on argon***
  - ***Study the background relevant for proton decay in LArTPCs***
  - ***And, of course, further advance the LArTPC technology***
- Additionally, it could contribute to more *exotic searches*
  - Neutrinos from Supernovae explosions
  - Burst neutrinos

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 is will start data taking in the end of 2014 and run for 2 - 3 years in the neutrino mode accumulating 6.6 10^{20} POT.

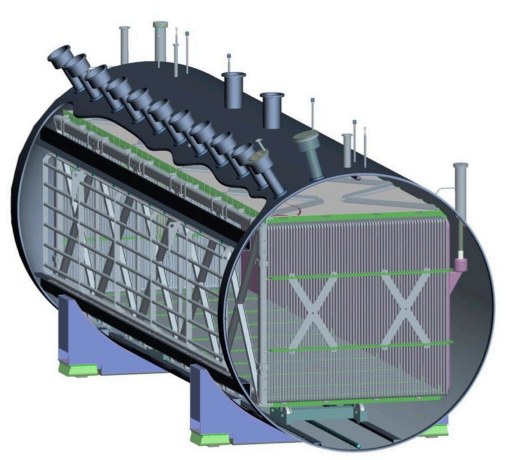
The MicroBooNE detector

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 (3mm pitch)
  - A collection plane at 0° from vertical
  - Two induction planes at ±60°
- Optical system of 32 8′ cryogenic PMTs and 4 light guide prototypes
- *Excellent energy resolution*
- *Robust tracking and PID capabilities*

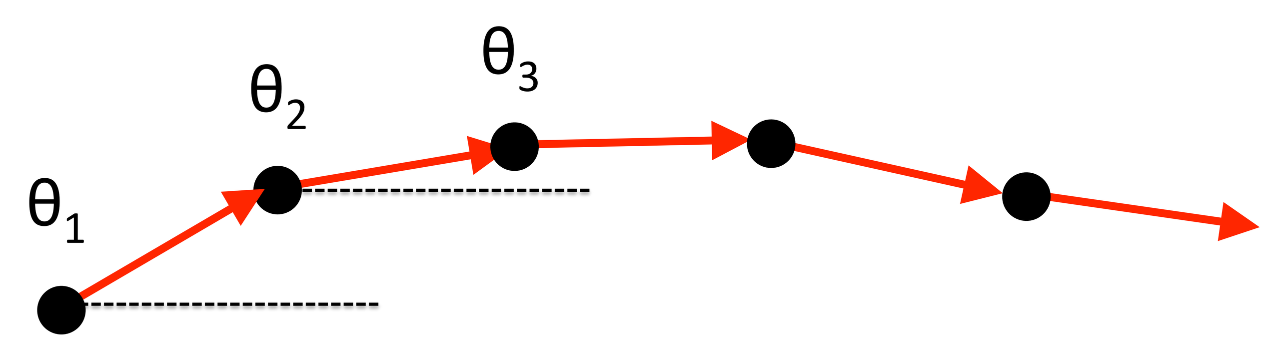


10.4 m × 2.5 m × 2.3 m
Uniform E field, 500 V/cm
170 tons of purified LAr
(83 m³ of active volume)

A maximum likelihood technique

Basic algorithm:

– *Break up the particle track in segments of equal length (Δs)*
– *Find the direction (in zy and zx) of each segment*
– *Calculate the angular deflection (Δθ) for two segments separated by ℓ*



– 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:

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

$$f(\ x,\ Q,\ \sigma\ ) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{(\ x - Q\ )^2}{2\sigma^2}}$$

Find E_0 that maximizes:

$$\mathscr{L}(\ E_0\ ) = \prod_{(i,j)} f_{ij}$$

– σ_{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 :

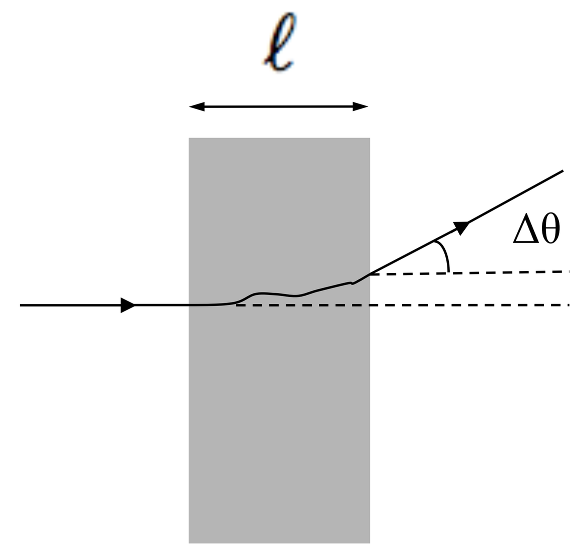
$$\sigma_{ij} = \sqrt{\theta_0^2\ +\ \delta\theta_0^2}$$

– The angular deflections ($\Delta\theta_{ij}$) are *smeared* by the intrinsic detector resolution (measurement errors)
- θ_0 given by the Highland formula
- $\delta\theta_0$ corresponds to the measurement uncertainties

– ***The likelihood becomes a function of both E_0 and $\delta\vartheta_0$***
- *Measure $\delta\vartheta_0$ in situ, or estimate it through Monte-Carlo*
- *Fit simultaneously E_0 and $\delta\vartheta_0$*

Multiple Coulomb Scattering

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



Modified Highland formula

$$\theta_0 = \frac{13.6}{p\beta}\sqrt{\frac{\ell}{X_0}}\left[1 + 0.038\ln\left(\frac{\ell}{X_0}\right)\right]$$

θ_0 : RMS of the Δθ distribution (mrad)
p : particle momentum (GeV/c)
ℓ : material thickness (cm)
X_0 : radiation length (cm)

References

J. Beringer *et al*., Phys. Rev. D **86** (2012) 010001
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, $\delta\vartheta_0 = 0$*
  - 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