Neutrino-Nucleon Neutral Current Elastic Interactions in MiniBooNE

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presented by:
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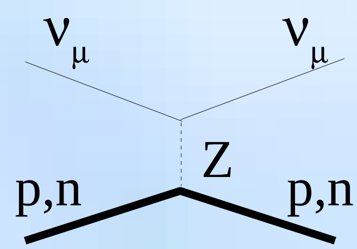
Nuint '09

Neutrino-Nucleon NC Elastic Scattering

neutral-current elastic (NCp,n)

$$\nu_\mu (p, n) \rightarrow \nu_\mu (p, n)$$



- The most fundamental NC probe of the nucleus/nucleon.

- Unlike CC quasielastic, sensitive to isoscalar component of nucleon (strange quarks)

- via isoscalar or “strange” axial-vector formfactor, $G_A^s(Q^2)$

- and $\Delta s = G_A^s(Q^2 = 0)$

axial nucleon weak neutral current

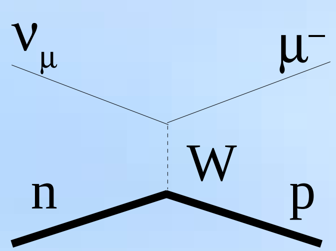
$$\langle N | A_\mu^Z | N \rangle = -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \langle N | \frac{1}{2}\{\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d - \bar{s}\gamma_\mu\gamma_5 s\} | N \rangle$$

$$\Delta u \qquad \Delta d \qquad \Delta s$$

$$= -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \langle N | \frac{1}{2}\{-G_A(Q^2)\gamma_\mu\gamma_5\tau_z + G_A^s(Q^2)\gamma_\mu\gamma_5\} | N \rangle$$

charged-current quasielastic (CCQE)

$$\nu_\mu n \rightarrow \mu^- p$$



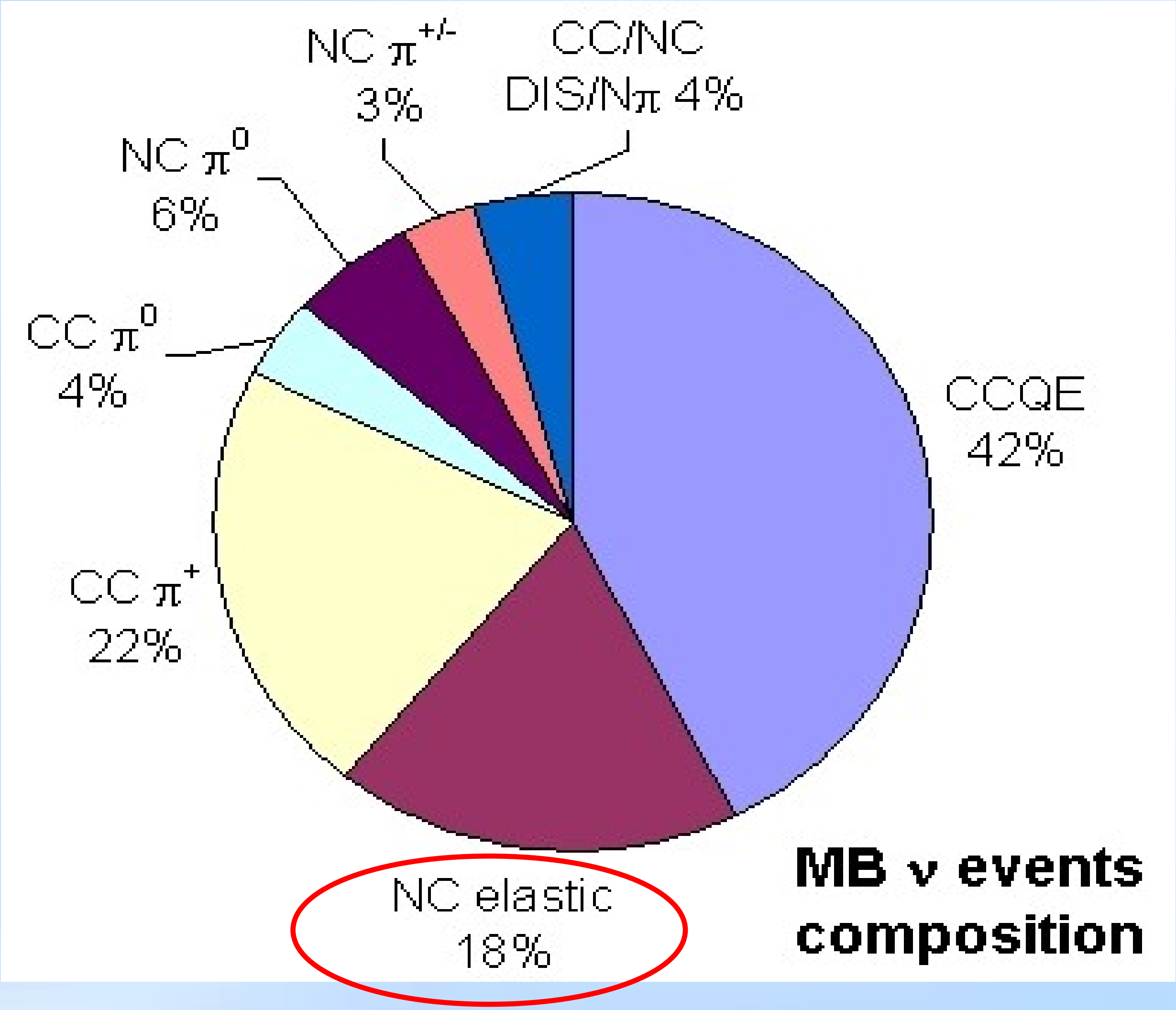
- Experimental sensitivity to isoscalar effects best via ratios:
  - NC(p)/NC(n), NC(p)/NC(p+n), NC(p)/CCQE

  as many systematics (flux, nuc. effects) should cancel.

- Another view:

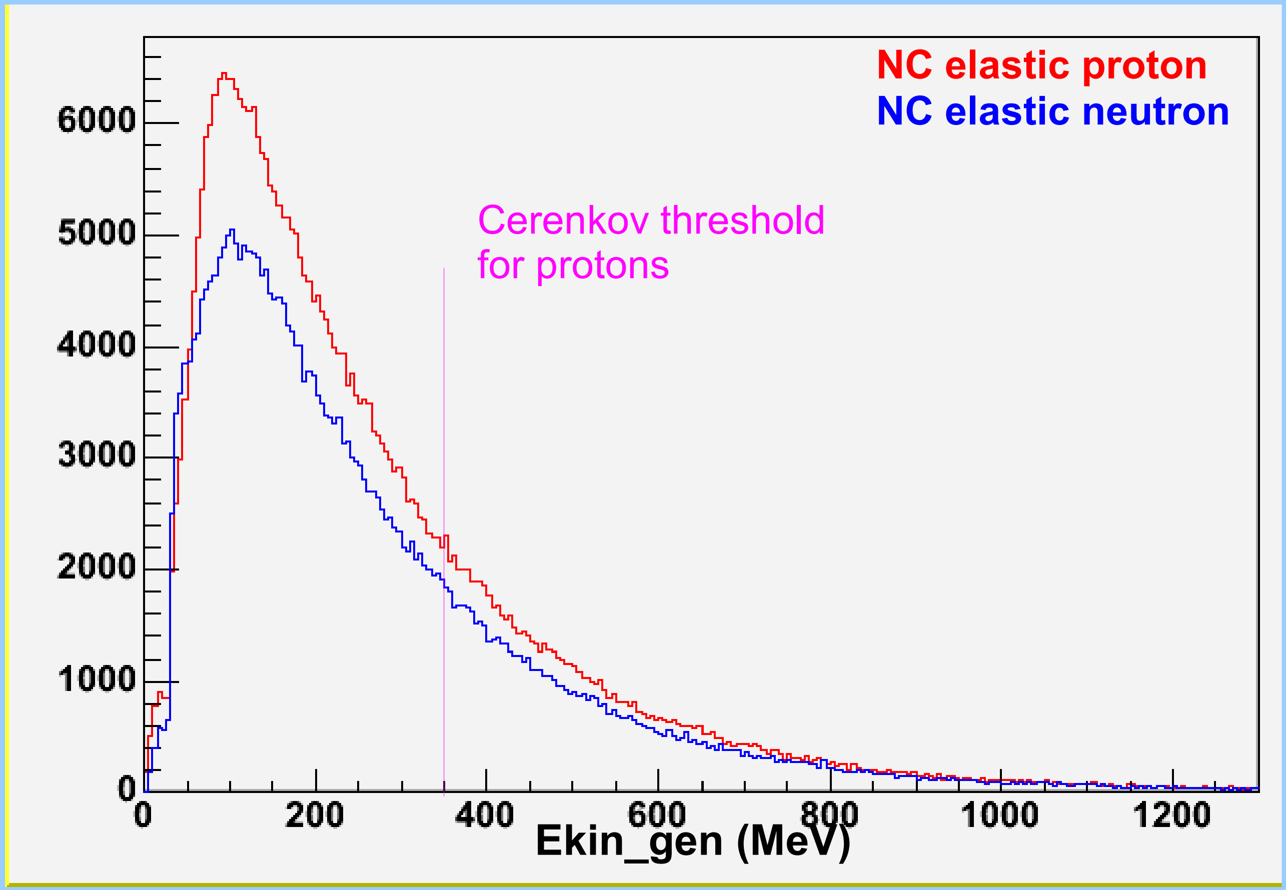
  Does our knowledge of CCQE (usually measured via muon) completely predict NCel (measured via recoil nucleon) for nuclear targets?

MiniBooNE Event Composition



NC elastic is the third largest sample of neutrino interactions in MiniBooNE

Kinetic energy of nucleons in the NC elastic (NCEL) events, Monte Carlo generated

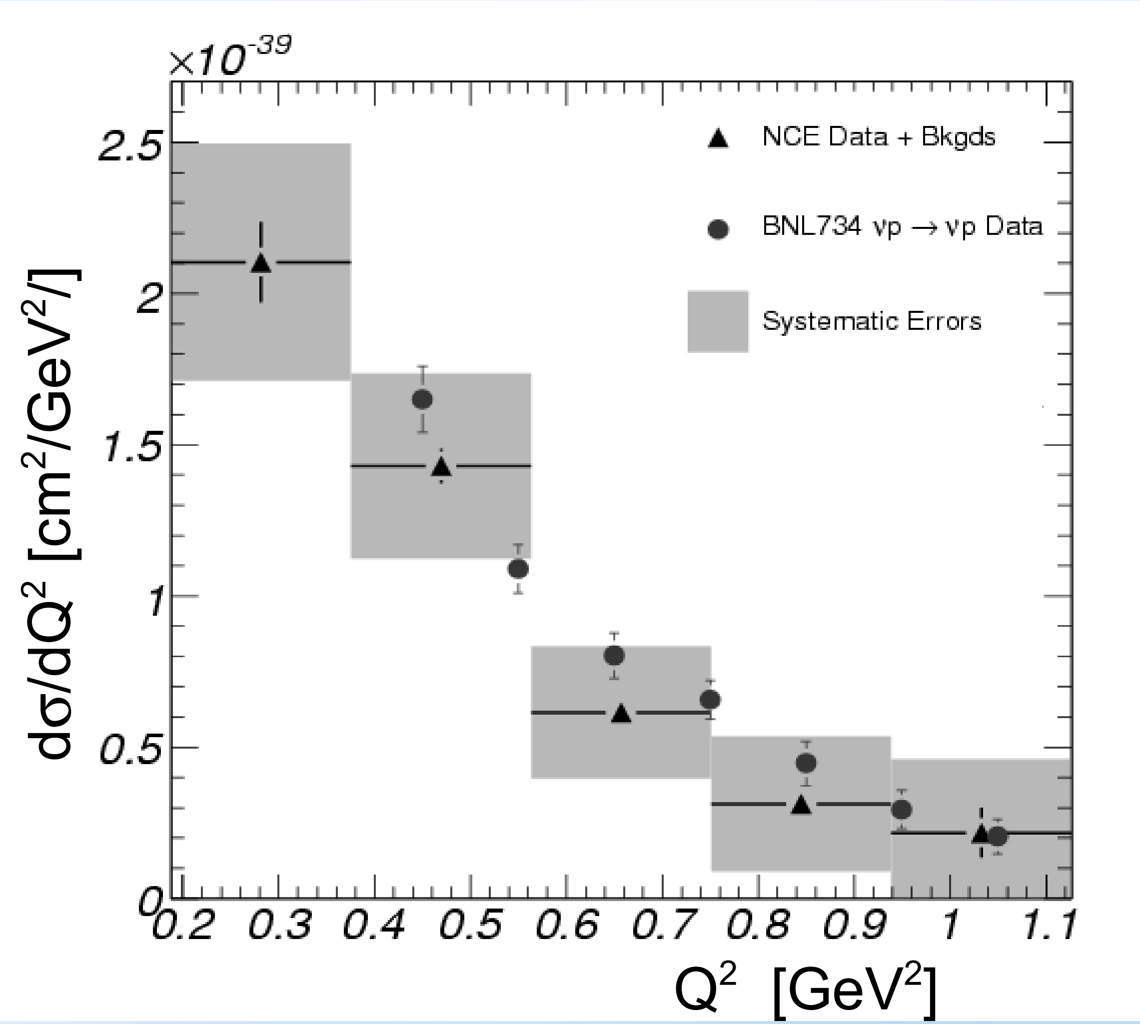


• **We measure the total nucleon (n+p) NCEL cross-section** (Most of the events are below Cerenkov threshold, where cannot separate NCEL protons from NCEL neutrons)

• However, above Cerenkov threshold for protons we may be able to measure proton/neutron NCEL channel separately.

From NuInt07...

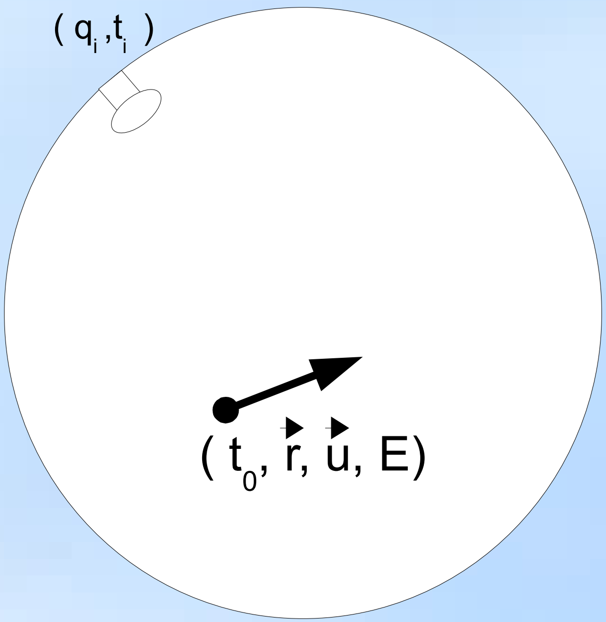
MiniBooNE Preliminary NC Elastic Flux-averaged Differential Cross-Section (using 10% MiniBooNE data) compared to BNL E734 νp Elastic (1987) Data

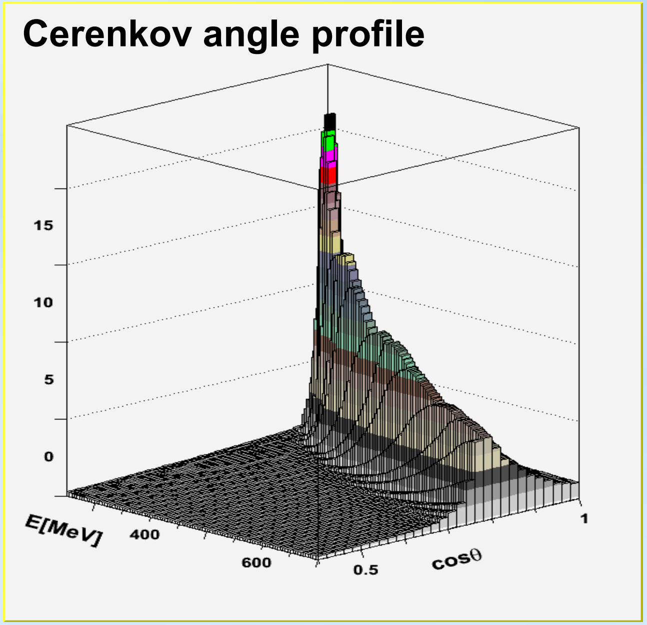


Ph.D. Thesis, Chris Cox,
Indiana University.

New Proton Fitter

In the early analysis we have used the electron hypothesis fitter for the NC elastic events reconstruction.





- Proton fitter features reconstruction of events assuming the event is a proton
- Cerenkov angle profile, Cerenkov and scintillation light fluxes and time likelihoods for proton events have been determined from MC
- Point-like event is assumed
- Reconstruction is done by maximizing Charge and Time likelihood functions

New Proton Fitter

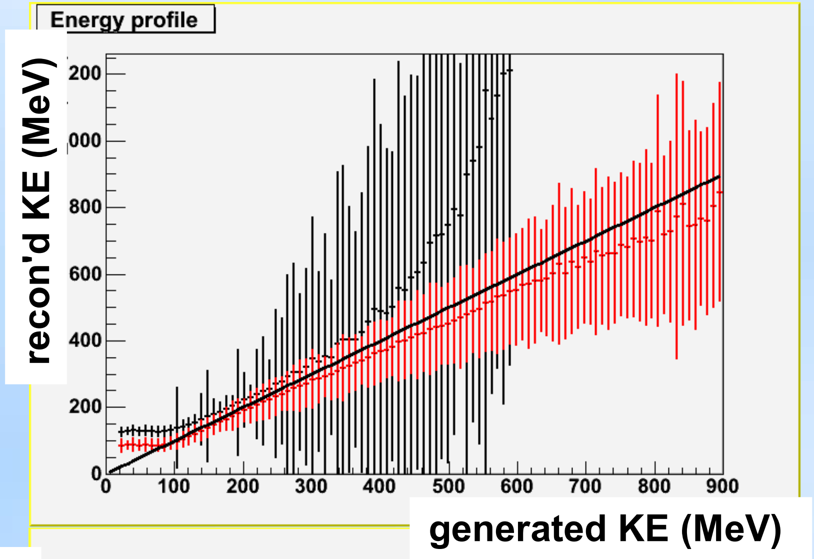
In the early analysis we have used the electron hypothesis fitter for the NC elastic events reconstruction.

With the proton hypothesis fitter we have improved the kinematicsreconstruction :

1. Position resolution: 1.3m → 0.7m for protons

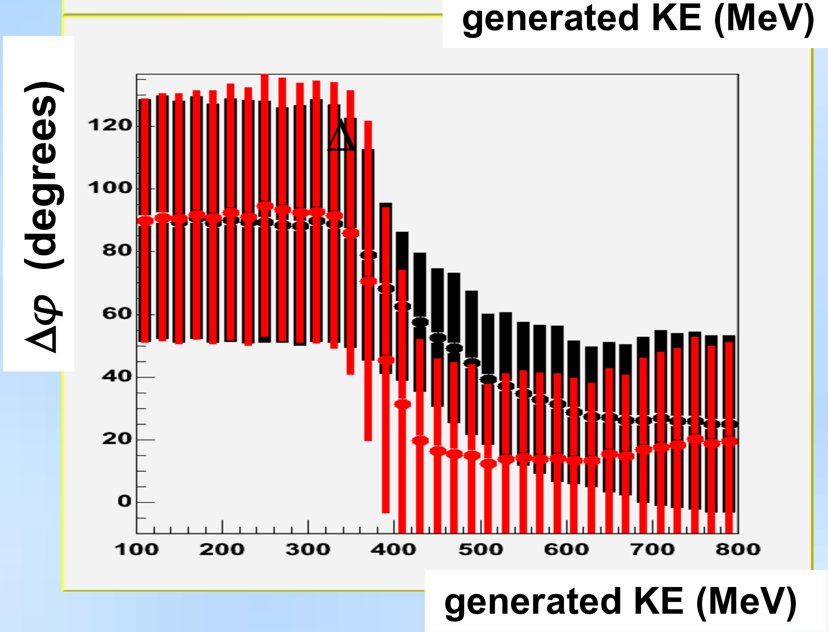
2. Energy reconstruction:
   substantial improvement at higher E

   MC protons reconstructed with
   -new proton fitter
   -electron fitter



3. Direction:
   improvement above Cerenkov threshold

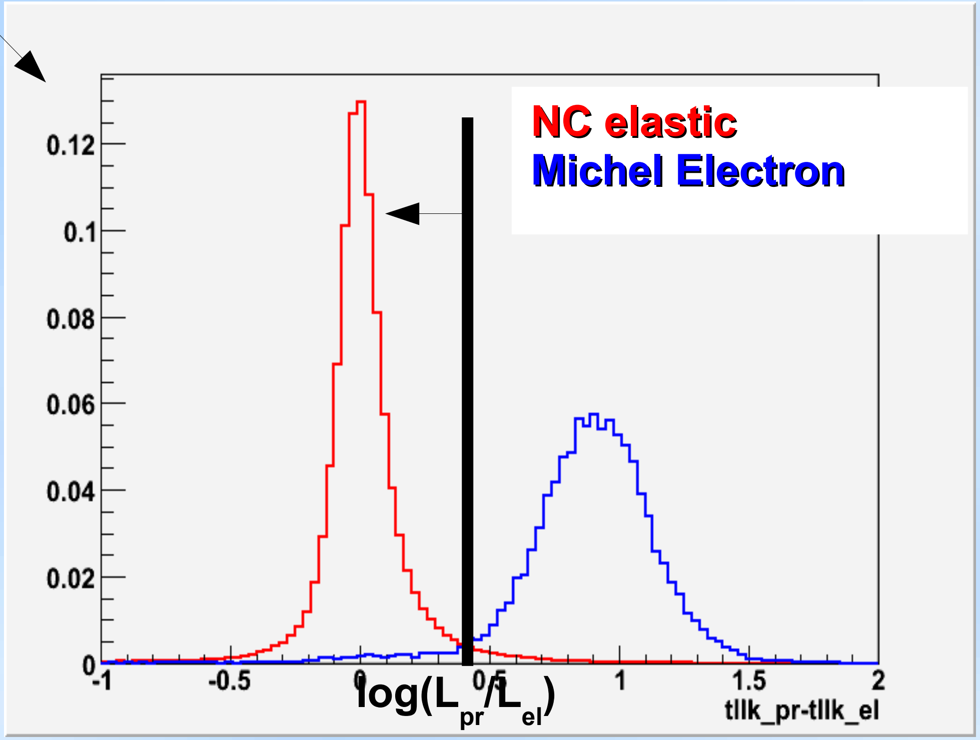
   MC protons reconstructed with
   -new proton fitter
   -electron fitter
   $\Delta\phi$ = true - reconstructed angle



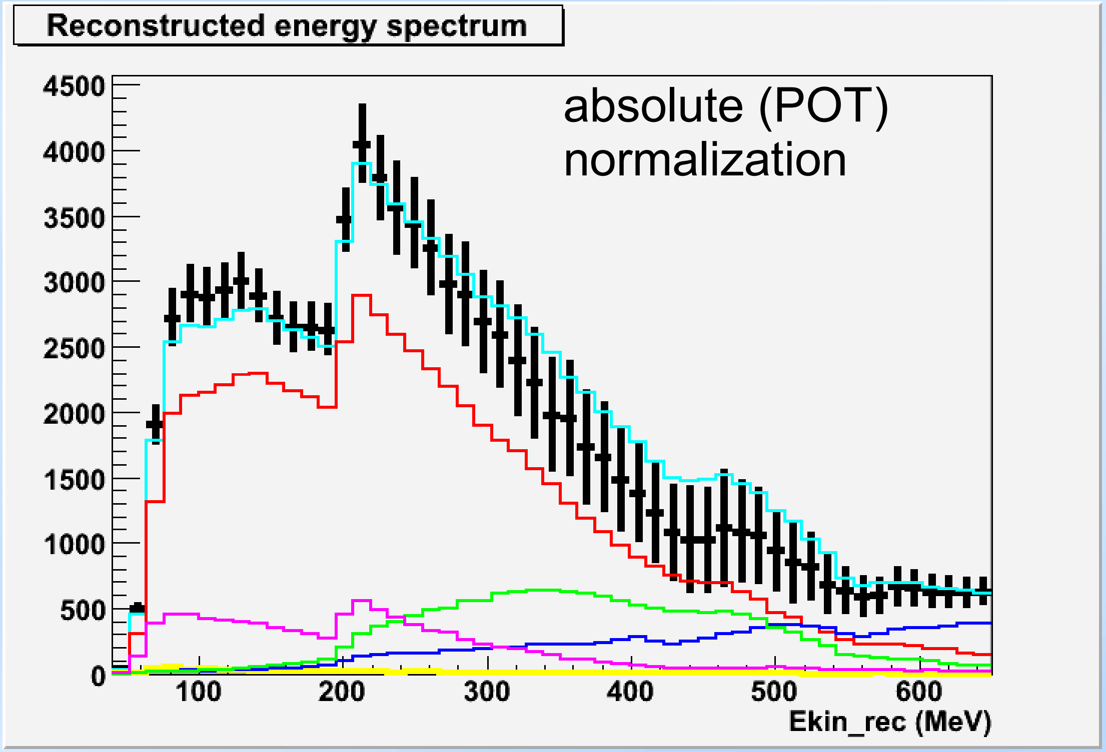
NC elastic event selection:

- **1 subevent** - Removes decaying particles (μ or π)
- **Veto PMT hits < 6** - Removes cosmic rays, external (dirt) events
- **Beam time window** - Neutrino induced events
- **Tank PMT hits > 24** - Reconstructible events
- **Reconstructed energy < 650 MeV** - Signal is of low-energy
- **Time likelihood ratio between proton and electron hypotheses** - proton-like events (removes beam-unrelated Michel electrons)
- **Fiducial volume =** - Removes dirt events, assures reconstructable events

$$\begin{cases} R<4.2\text{m if } Ekin_{rec}<200\text{MeV} \\ R<5.0\text{m if } Ekin_{rec}>200\text{MeV} \end{cases}$$



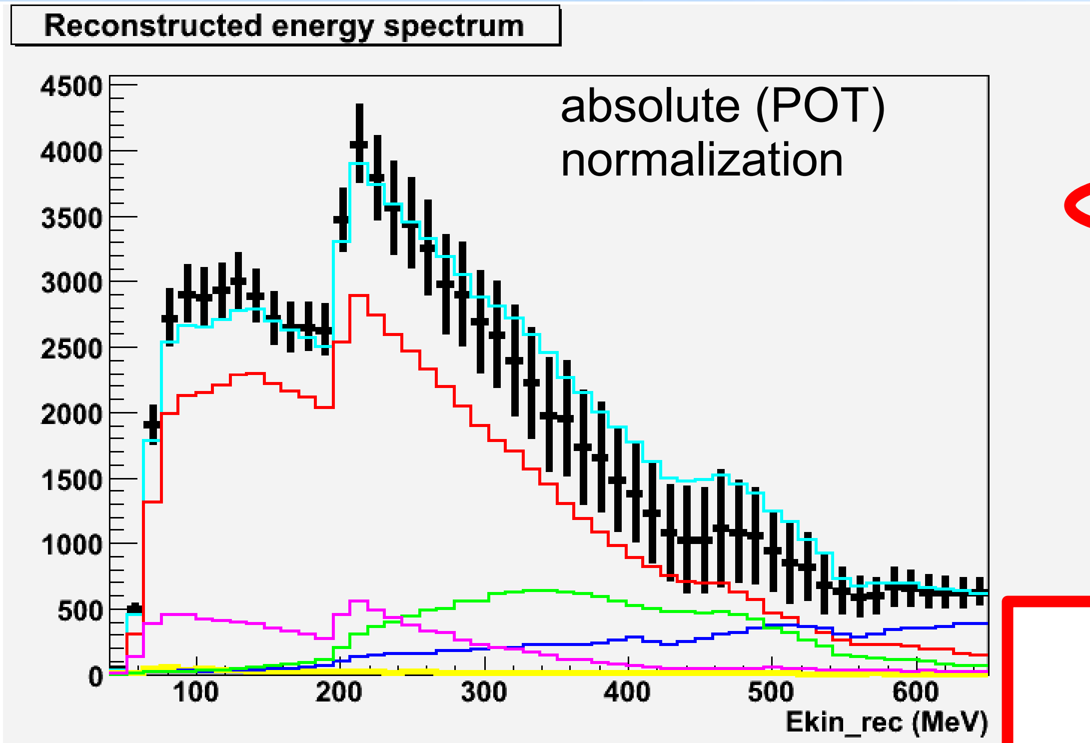
NC elastic events:

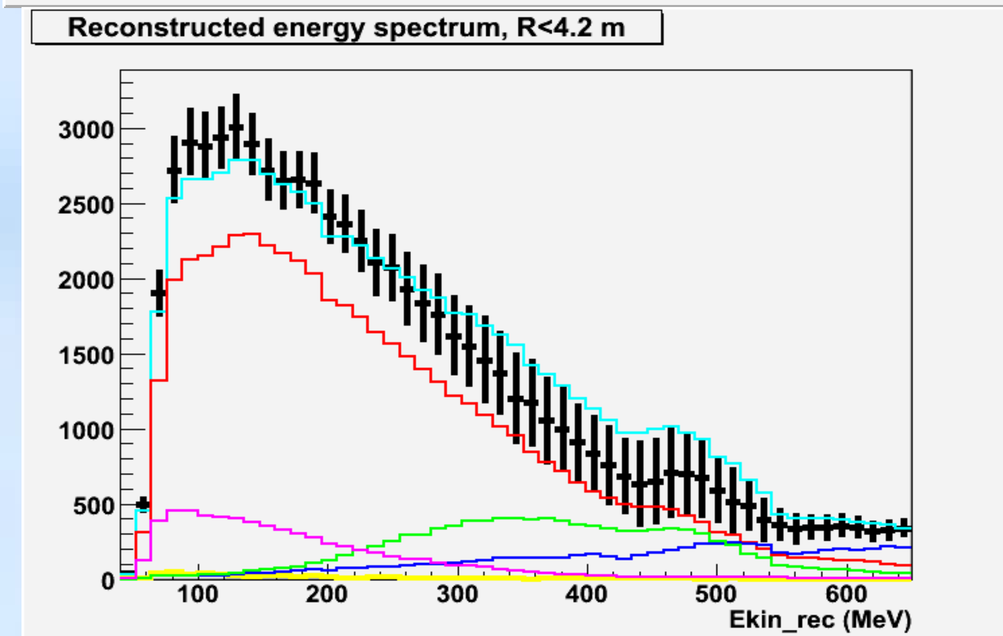


Data with total error
Total Monte Carlo
NC elastic (RFG, M_A=1.23 GeV)
Dirt
Irreducible
Beam unrelated
Other

94.5K data events from
6.46 10^{20} POT
NCel efficiency = 26%
NCel purity = 65%

NC elastic events:





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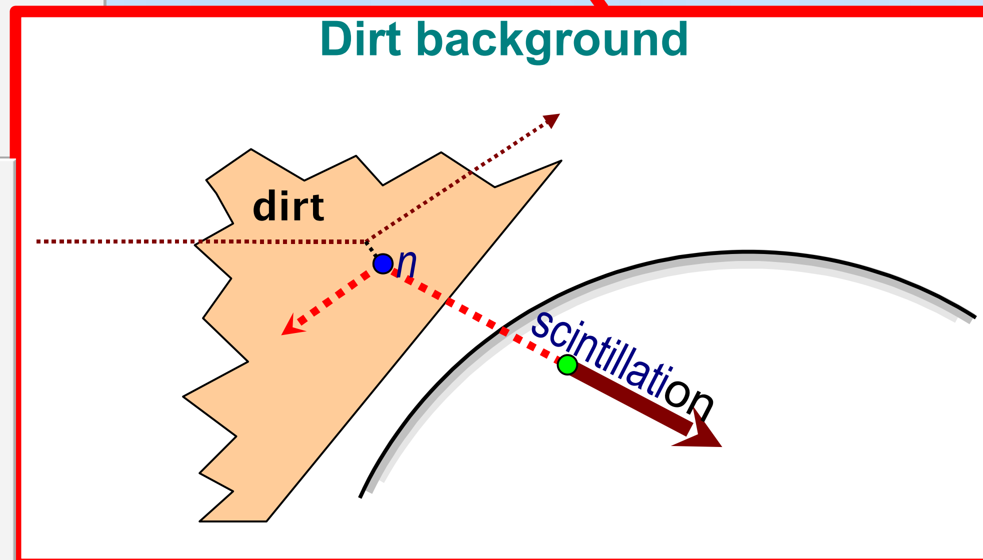
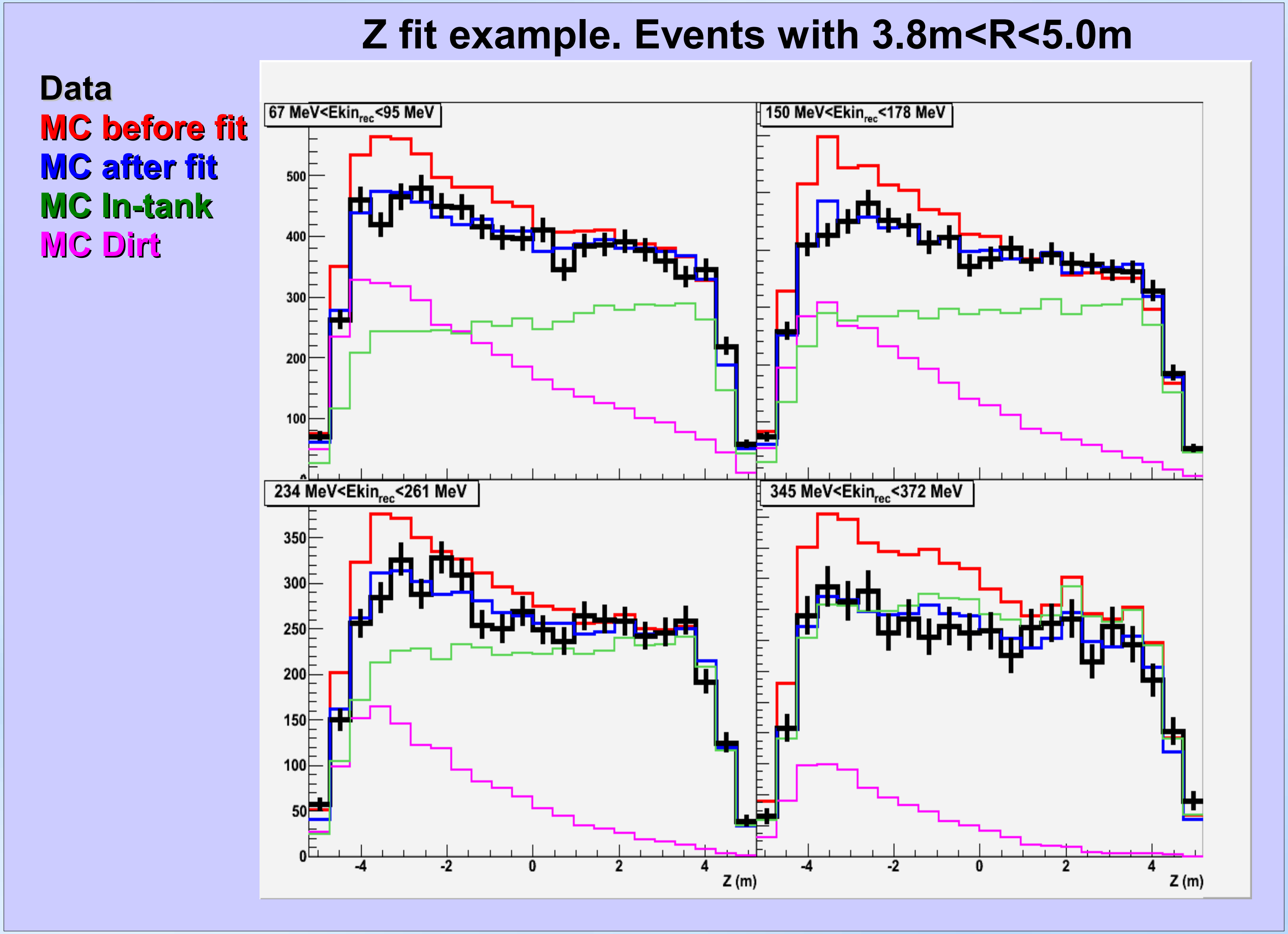


Low energy background

Dirt background measurement

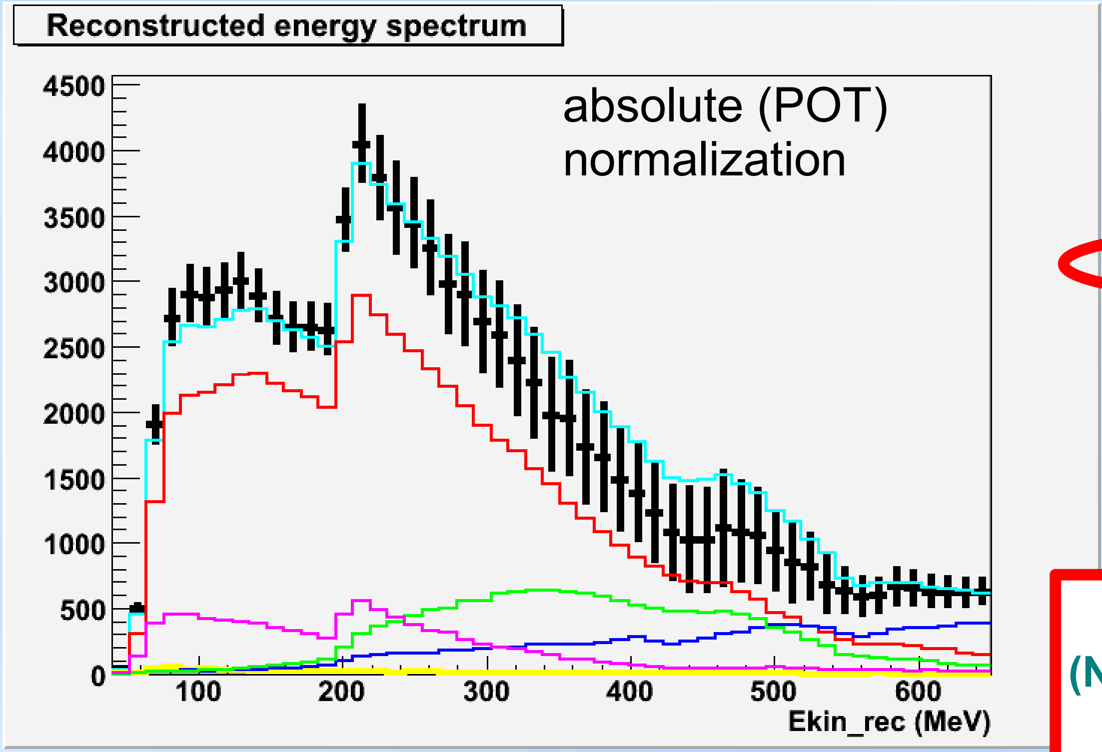
We have measure the dirt event energy spectrum by looking at the ***dirt-enriched samples*** and fitting **Z**, **R** and **Energy** distributions.



The three fits agree with each other, and MC/Data in Z and R distributions agreement is good after the fit.

We constrain dirt backgrounds to 10% error from MiniBooNE data.

NC elastic events:



Data with total error
Total Monte Carlo
NC elastic (RFG, M_A=1.23 GeV)
Dirt
Irreducible
Beam unrelated
Other

94.5K data events from 6.46 10^{20} POT

NCEL fraction	65%
Dirt background fraction	10%
Irreducible background fraction	15%

Irreducible background

(NC π channels with no pion in the final state)

$$\nu\, p \rightarrow \nu\, p\, \not{\pi}^0$$
$$\nu\, p \rightarrow \nu\, n\, \not{\pi}^+$$
$$\nu\, n \rightarrow \nu\, n\, \not{\pi}^0$$
$$\nu\, n \rightarrow \nu\, p\, \not{\pi}^-$$

intermediate energy background

Results: Flux-averaged MiniBooNE NC elastic differential cross-section

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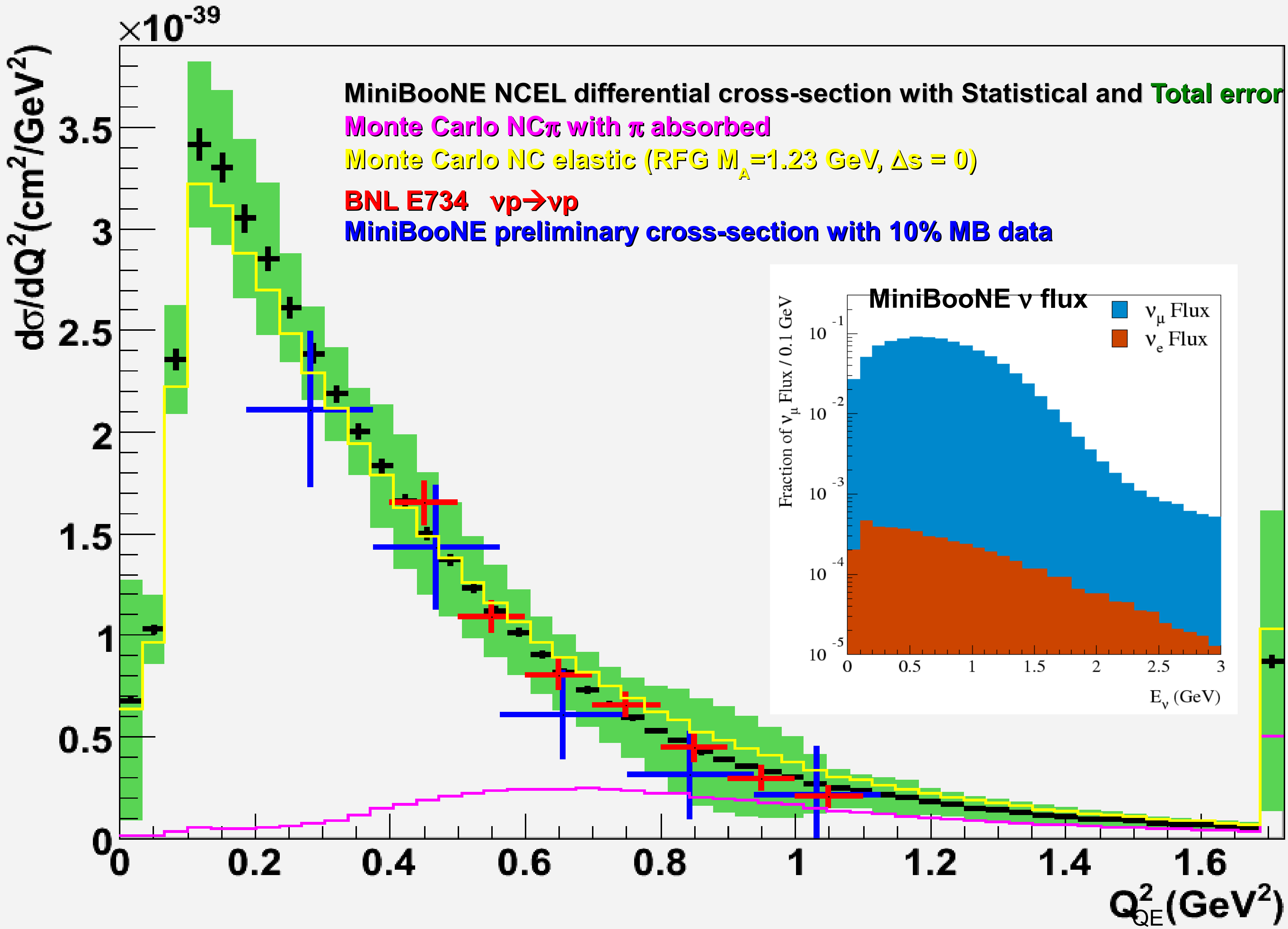
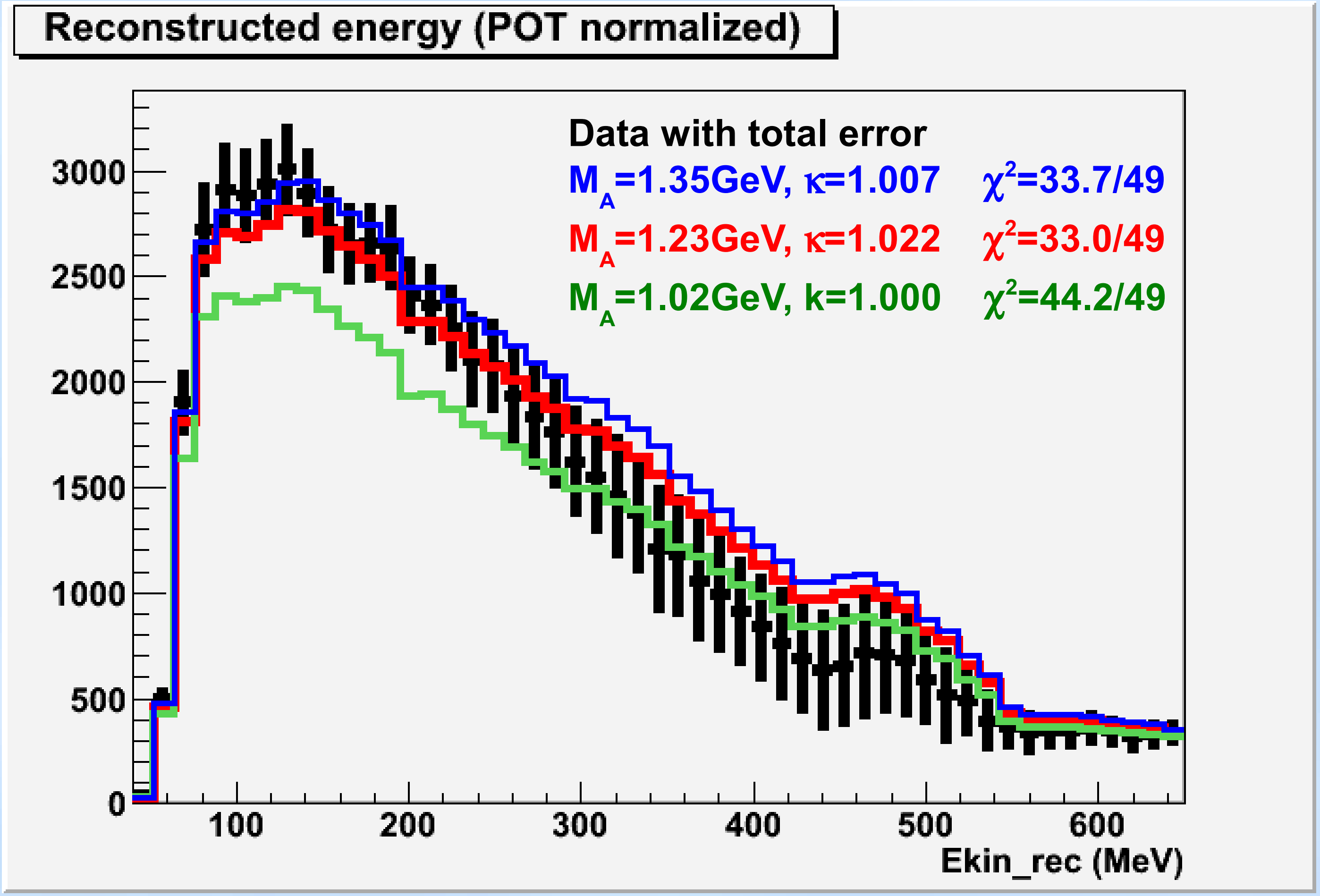


Note: "Q^2_{QE}" $= 2m_pT_p$

RFG model comparisons in reconstructed energy spectrum



NuInt09 MiniBooNE CCQE measurement

NuInt07 MiniBooNE CCQE measurement

World-averaged values before MiniBooNE

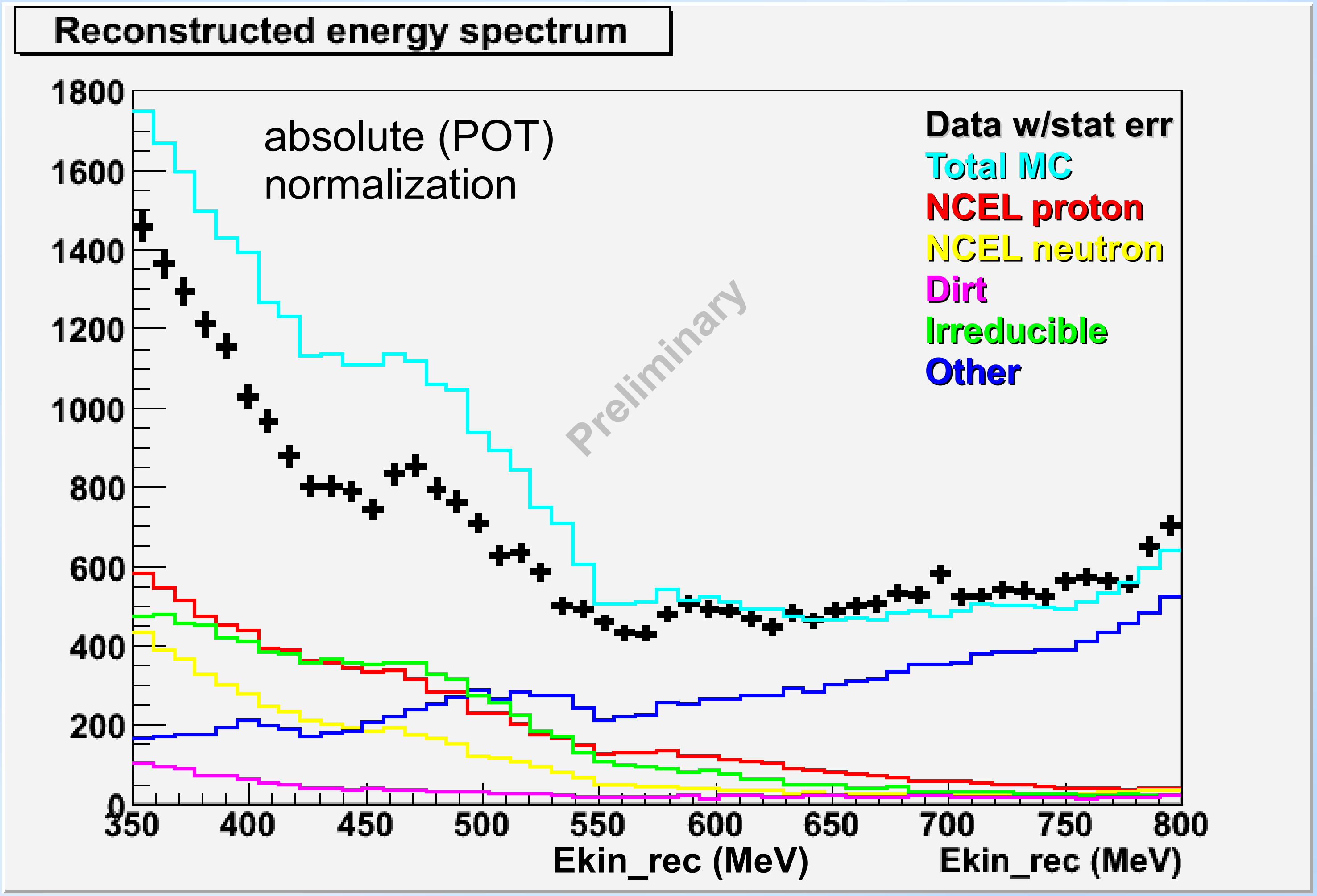
Monte Carlo with values of MA 1.23 GeV and 1.35 GeV gives a better fit to the data, than 1.02 GeV, especially at low energies.

NCEL (p+n) cross-section is not sensitive to the strange quark contribution to the nucleon spin (Δs).

High energy NC elastic proton sample (above Cerenkov threshold for protons)

NCelastic proton-enhanced sample

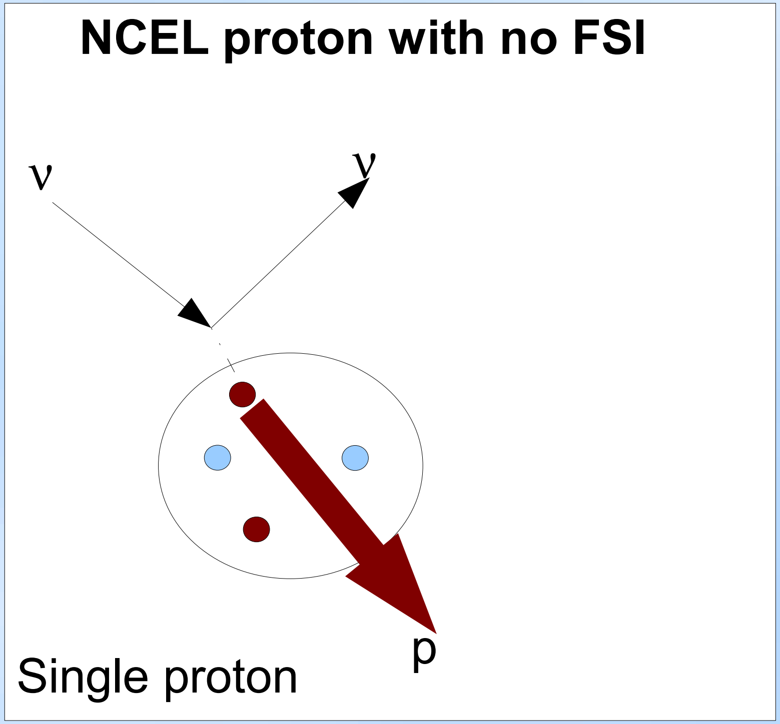
In order to investigate G_A^s (Δs), need a proton-enhanced NCel sample..
Start with the high energy NCEL reconstructed spectrum (after NCEL cuts are applied):

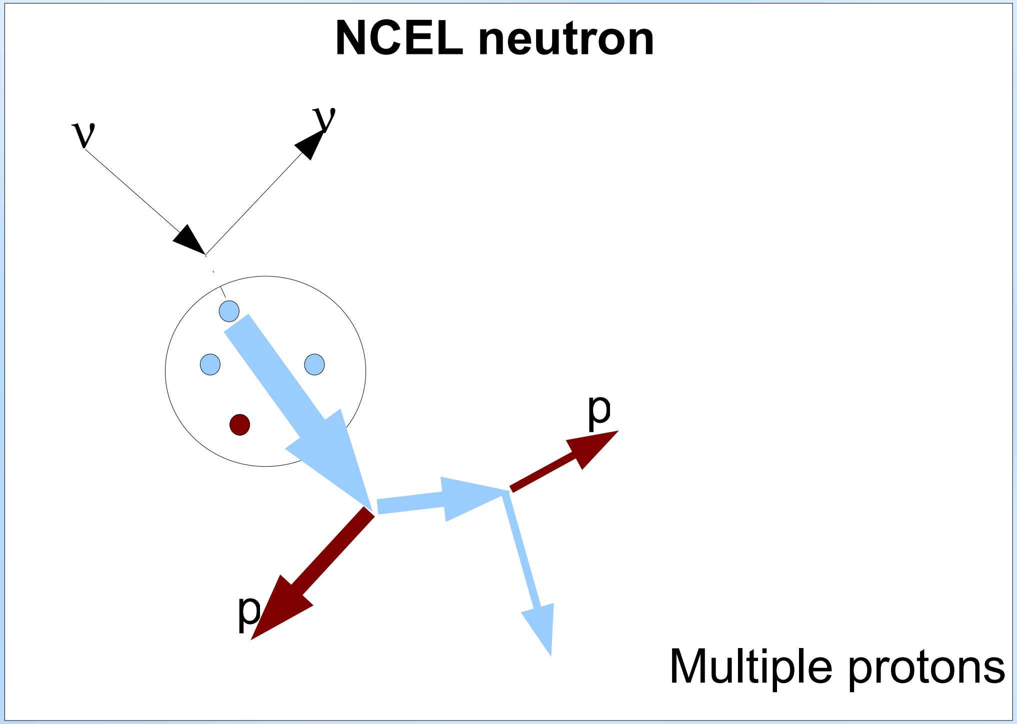


As one can see, much background. Signal (NCEL proton) is not strong.

NCelastic proton-enhanced sample

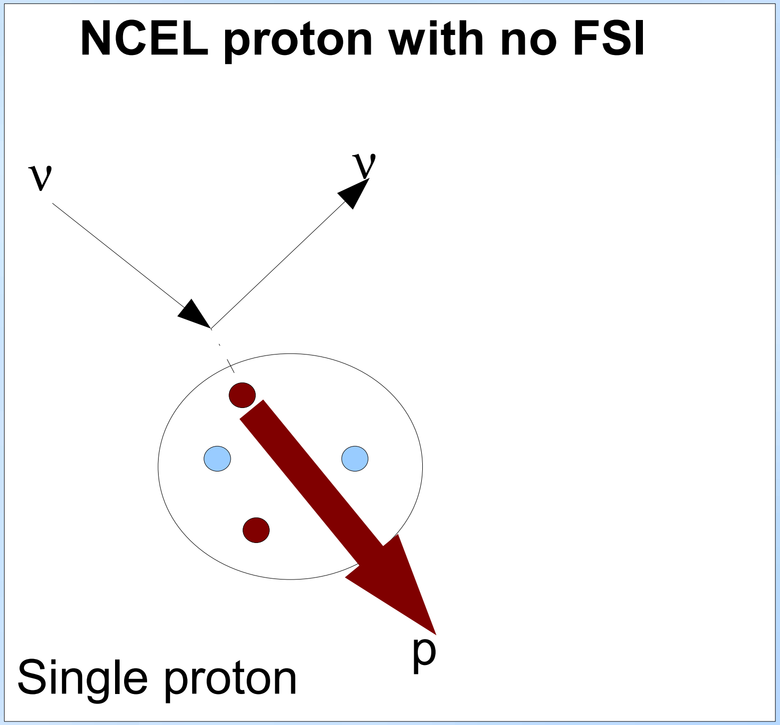
NC Elastic (NCEL) proton particle identification

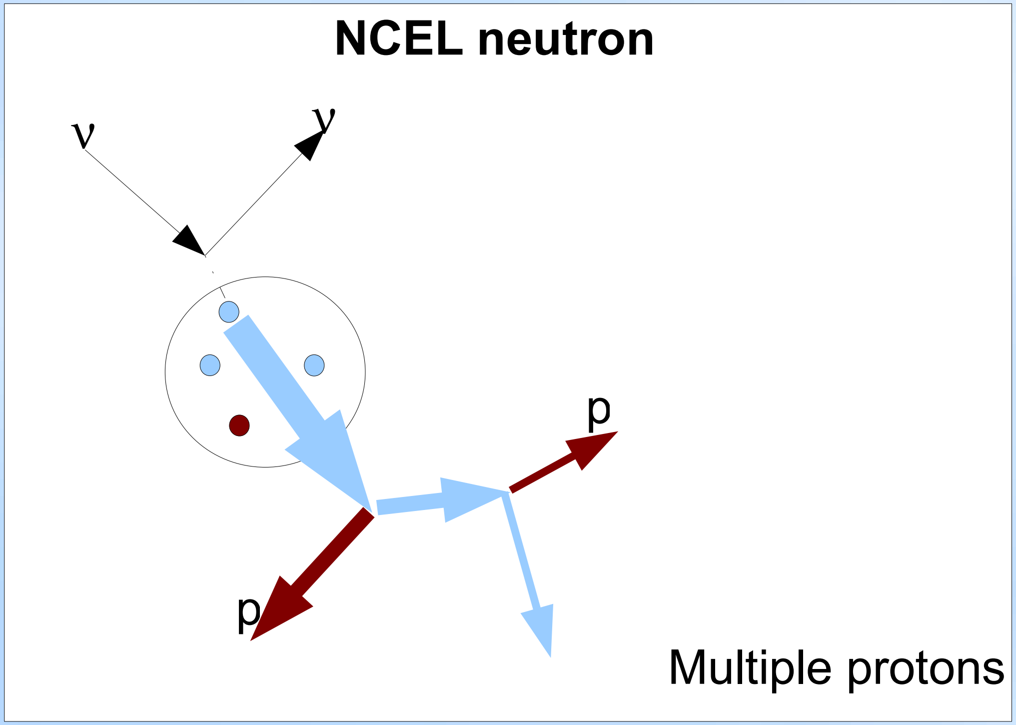


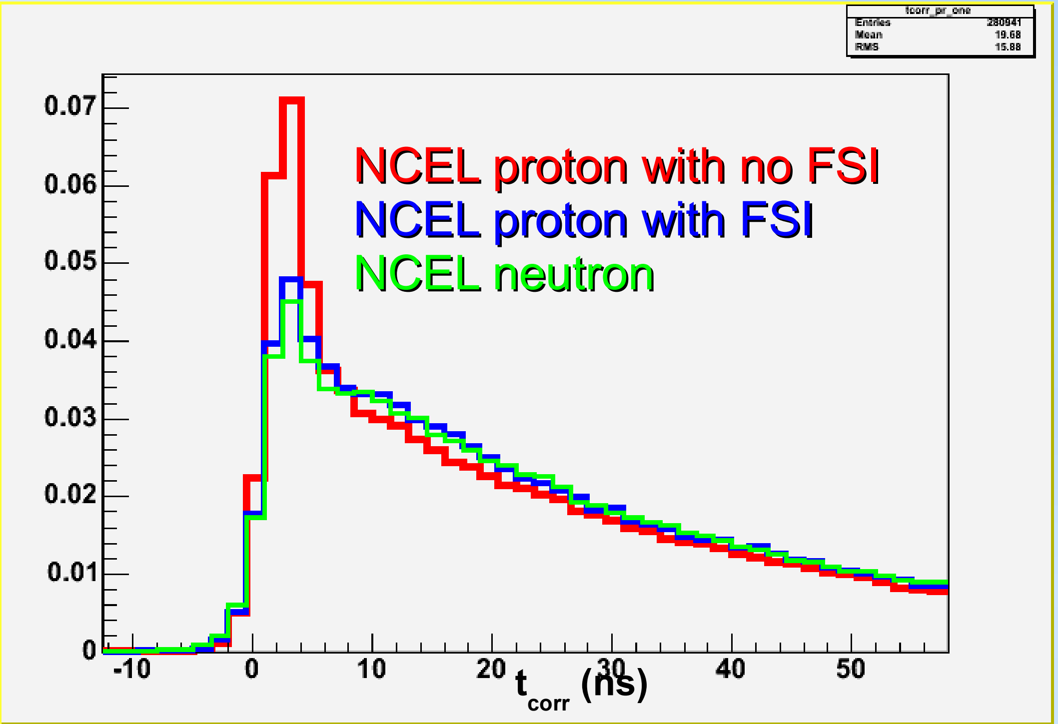


Single proton events should have more Cerenkov light fraction than multiple proton events (such as NCEL proton with FSI, NCEL neutron and Irreducible backgrounds)

NC Elastic (NCEL) proton particle identification

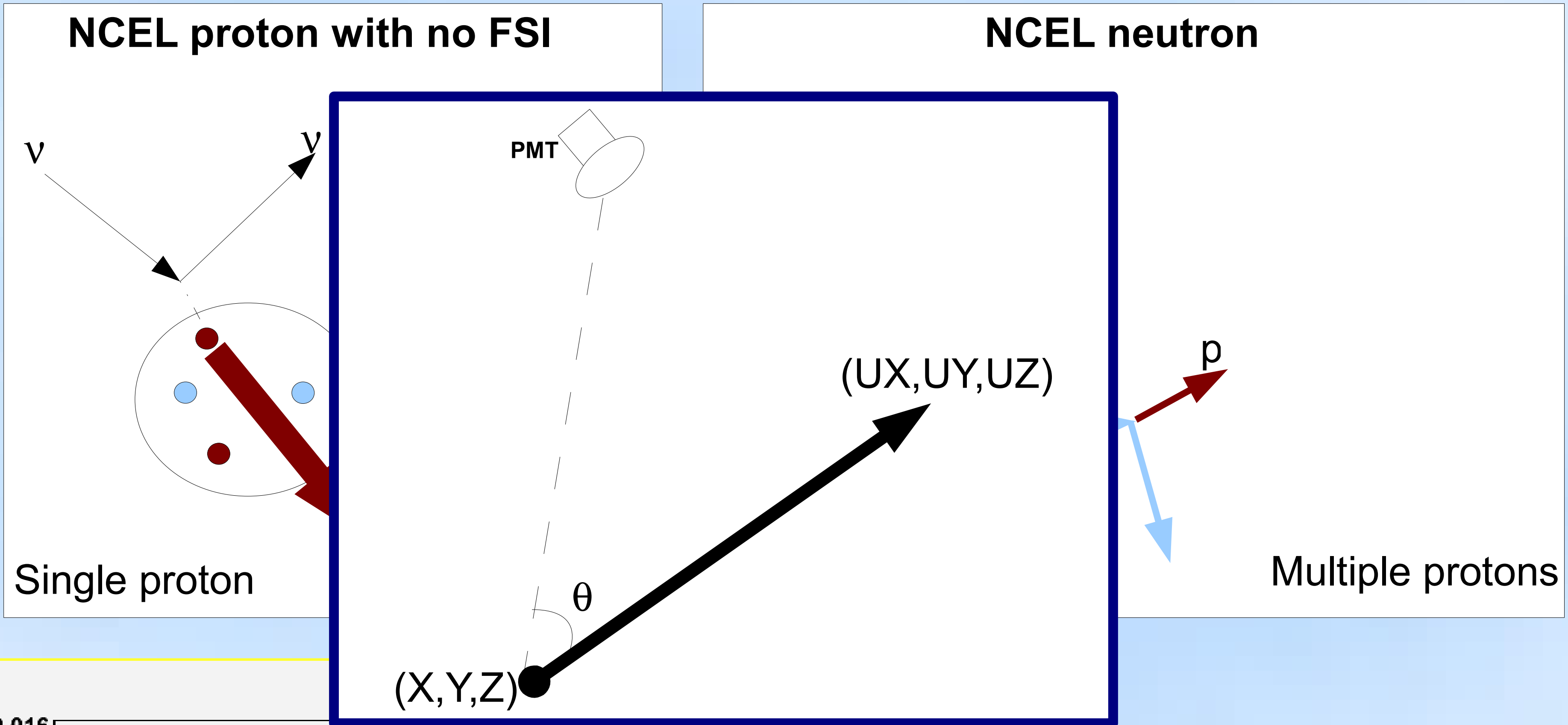


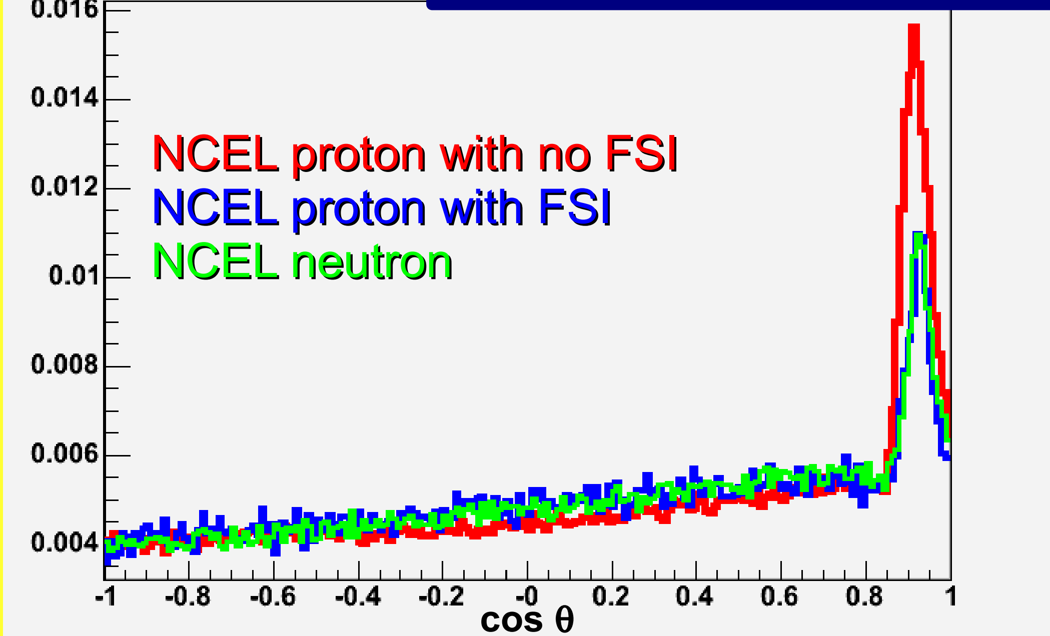




Single proton events have more prompt light

NC Elastic (NCEL) proton particle identification

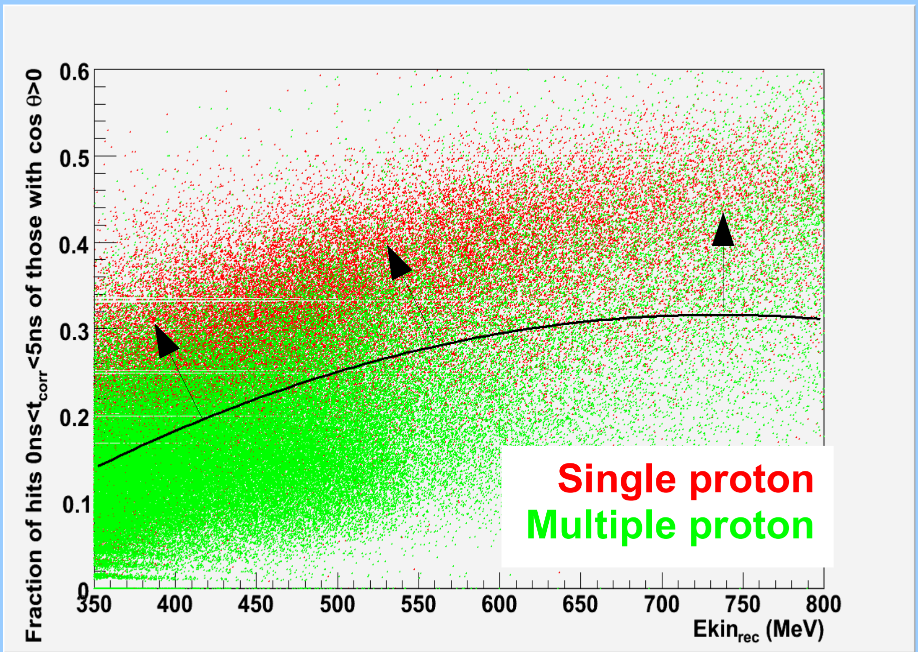


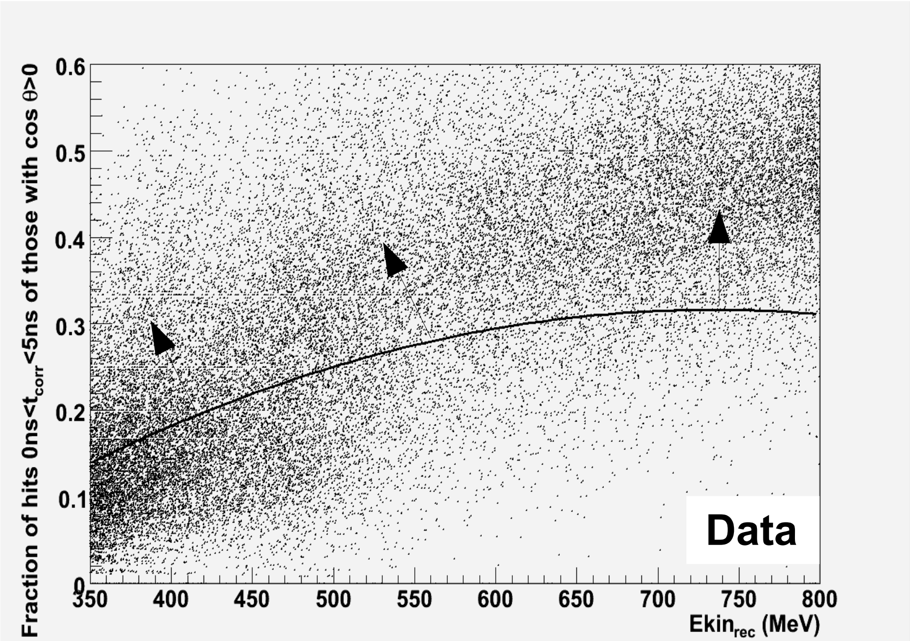


Single proton events have more directional light

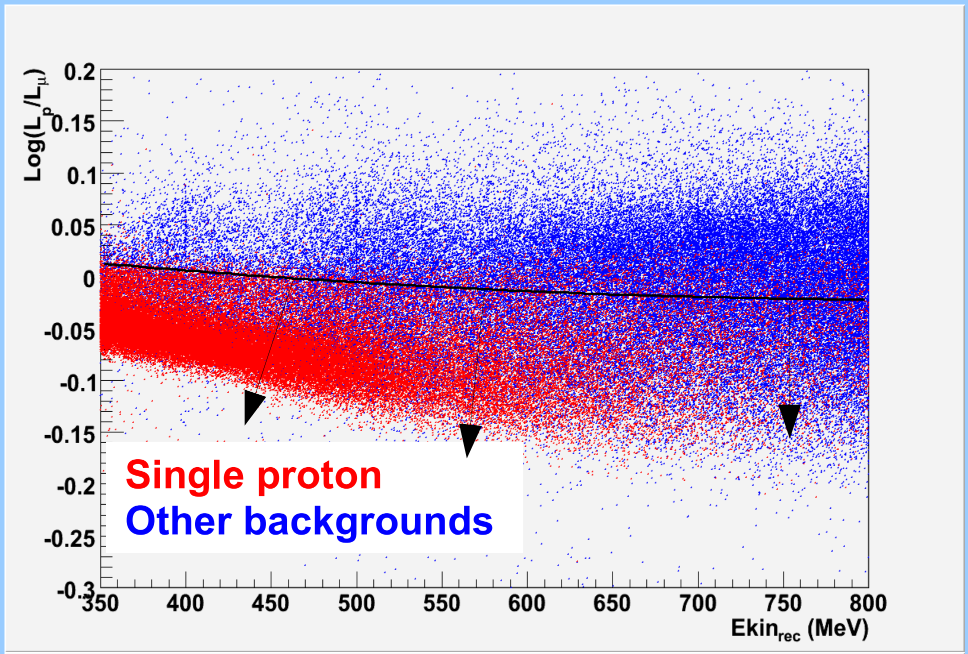
Two additional PID cuts
(arrows indicate side of the cut is kept in the analysis)

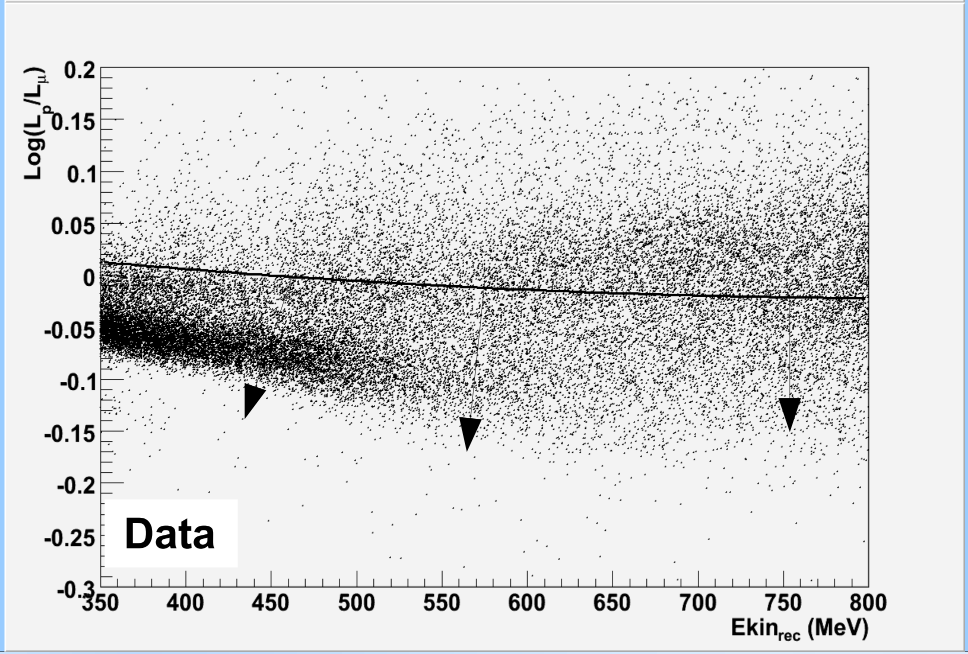
Fraction of prompt hits among PMTs that have cosθ > 0





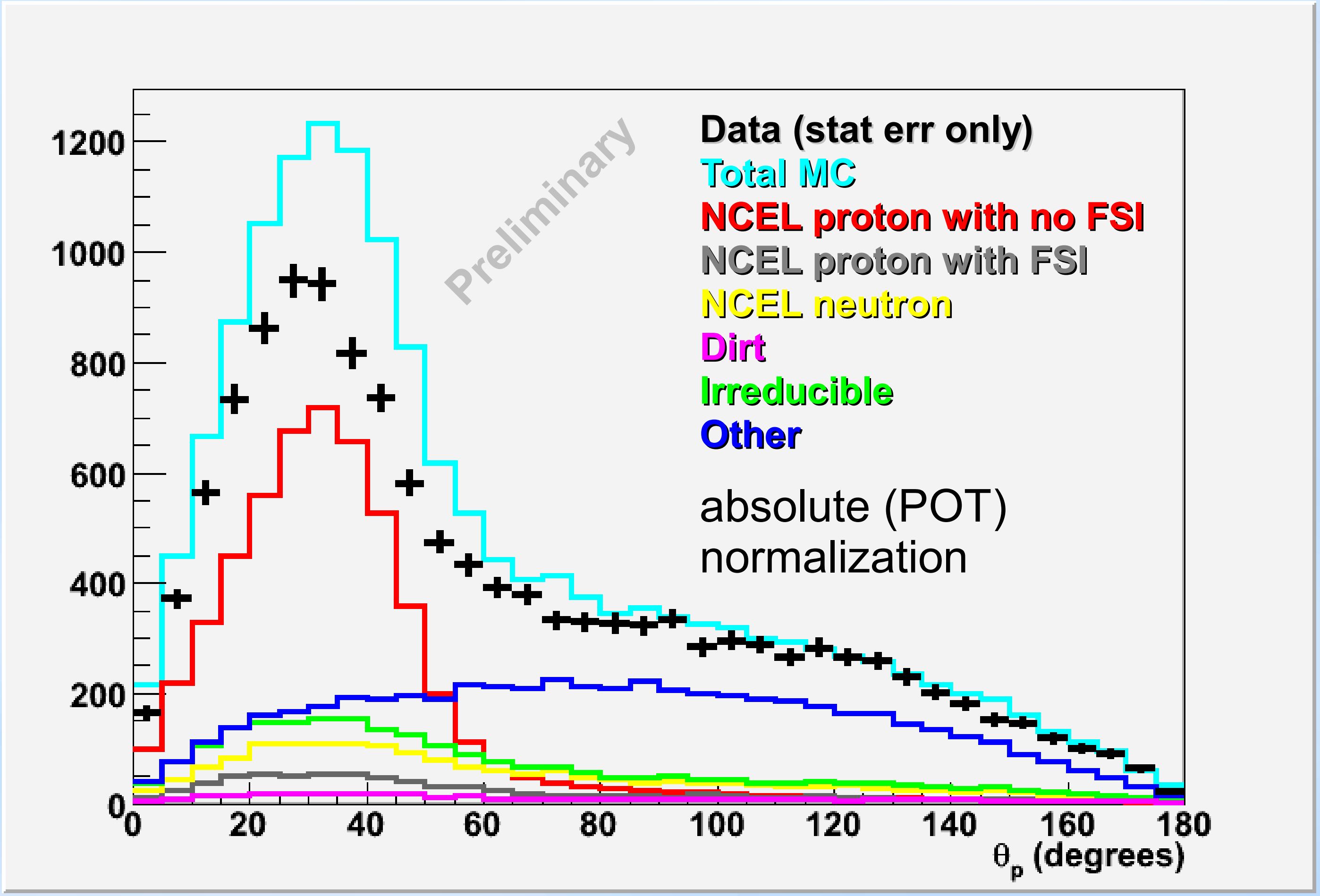
Likelihood ratio between proton and muon hypothesis





NCelastic proton-enhanced sample

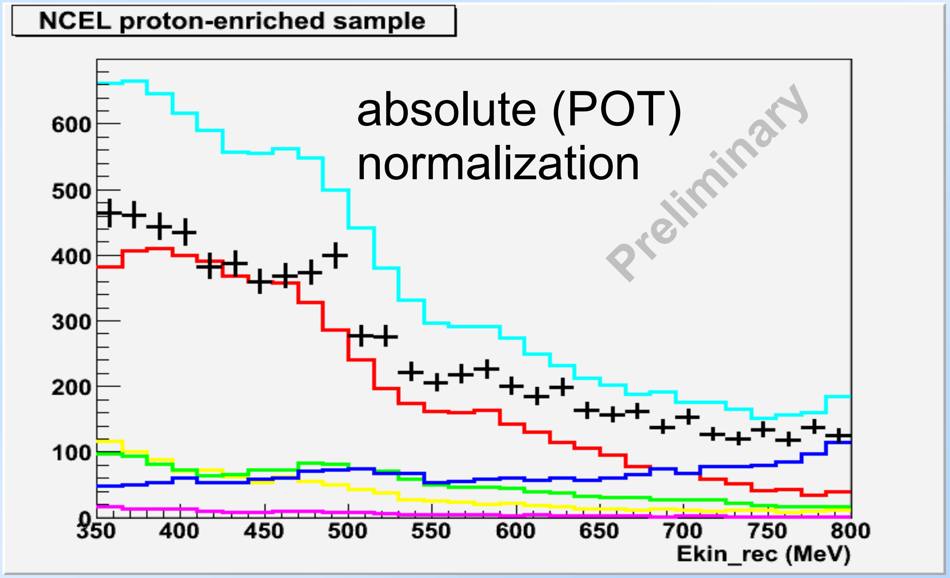
Reconstructed proton angle with respect to the beam direction

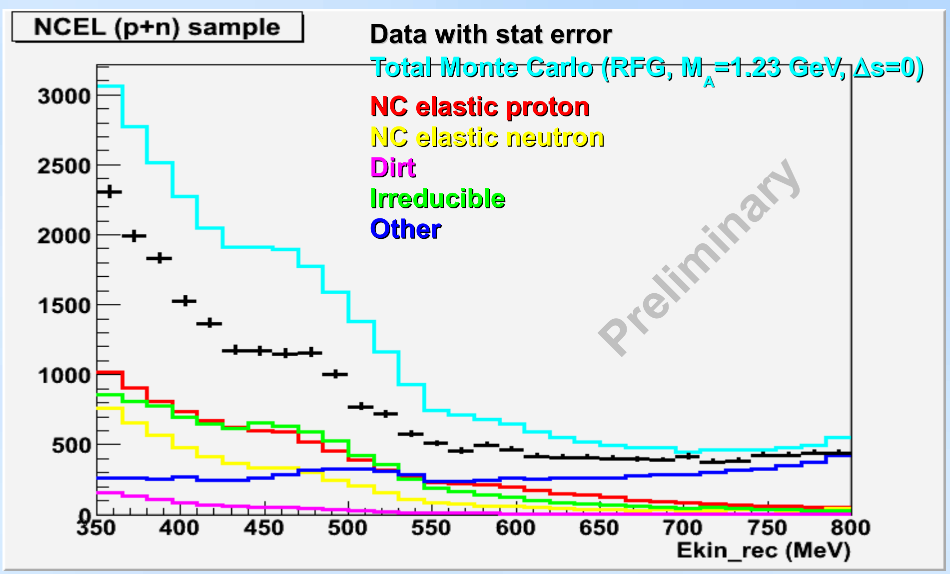


For the NCEL proton-enriched sample we make one more cut, θ_p<60°

NCelastic ratio

To reduce systematic errors, we form the ratio of
NCEL p / NCEL (p+n),
where the numerator – the NCEL proton-enriched sample,
the denominator has standard NCEL cuts, thus NCEL (p+n) sample





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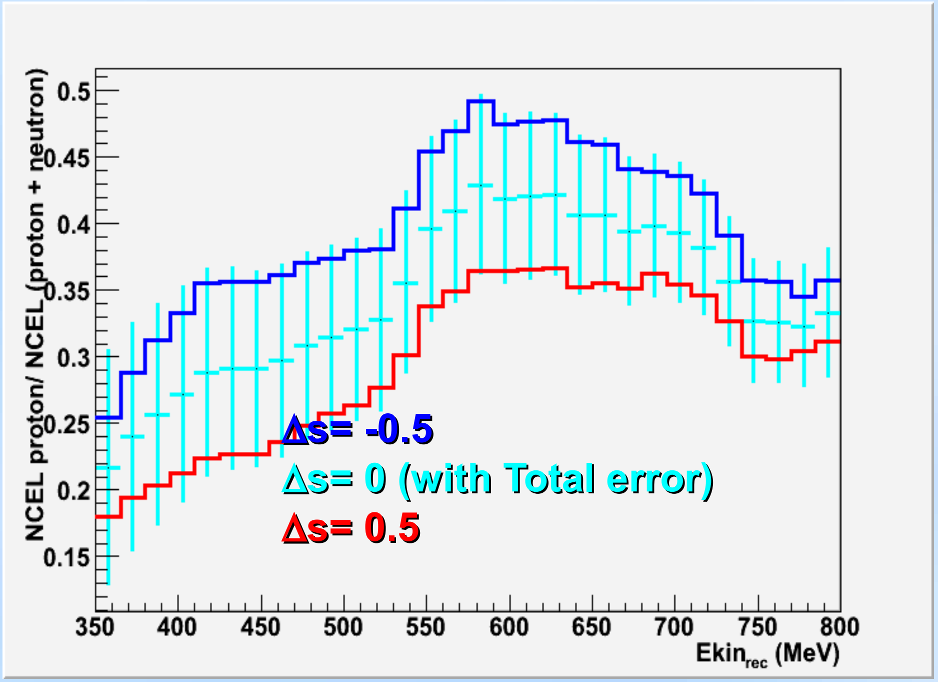

A measurement of Δs may be extracted from the ratio with data.
(a first NCel ratio measurement)

Summary

- MiniBooNE has extracted 95K NC elastic scattering event candidates from entire neutrino-mode data sample. A large sample of antineutrino NC elastic interactions also exists (to be analyzed).

- Since the preliminary results (of Nuint07), the NCelastic analysis has been improved:
  - a new Proton fitter
  - dirt backgrounds measured
  - all MiniBooNE neutrino data analyzed

- NC elastic differential cross-section measured.

- Nuclear model fits based on the NC elastic data
  - Axial vector mass (M_A) MC comparisons to data have been shown
    - The comparison shows a better Data/MC agreement with higher value of M_A, measured in MiniBooNE CCQE, than with M_A=1.02 GeV.
  - We are planning to measure the strange quark contribution to the nucleon spin (Δs) using high energy proton sample.

- Paper is currently in preparation.