Neutral Current Elastic Interactions at MiniBooNE

-Ranjan Dharmapalan

for the MiniBooNE collaboration

NuInt '11

Dehradun, India.

THE UNIVERSITY OF ALABAMA

Outline:

1. The MiniBooNE Experiment

2. Neutral current Elastic scattering (theory)

3. Neutral current Elastic scattering in MiniBooNE (expt)

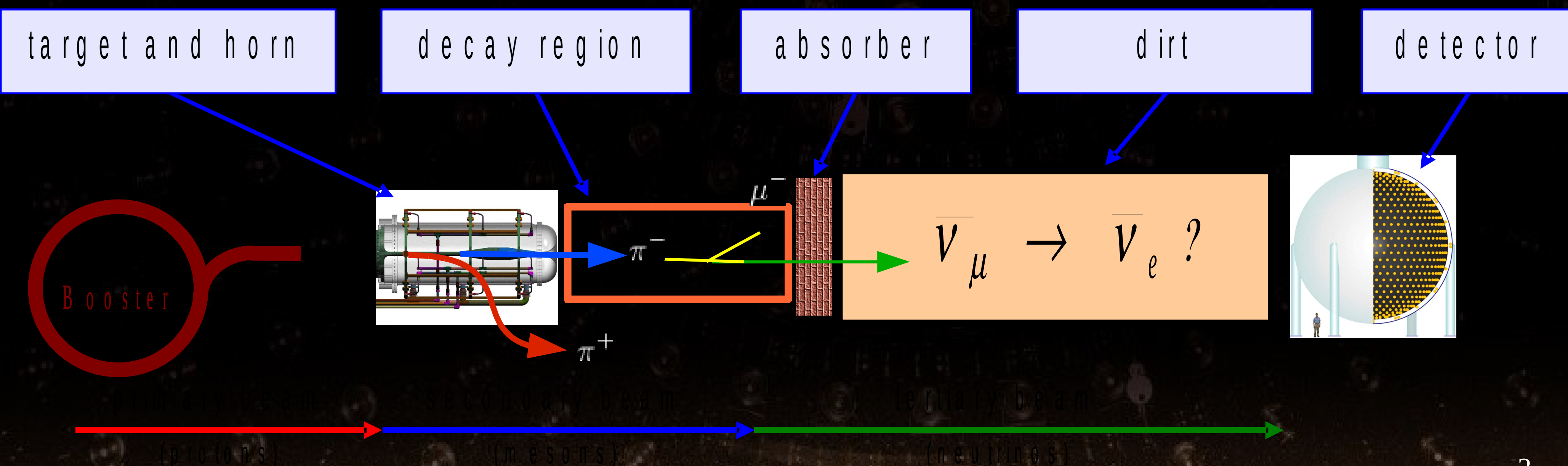
4. ν mode results

5. First look at $\bar{\nu}$ data

6. Future plans and conclusion

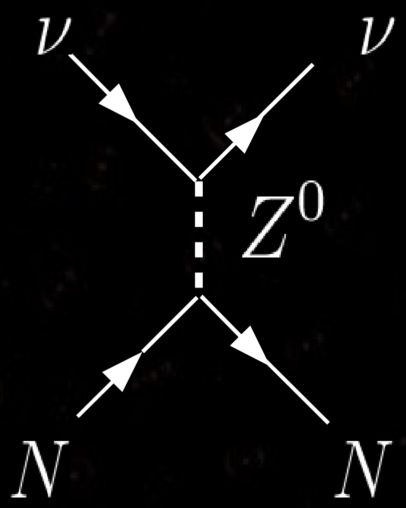
The MiniBooNE Experiment

- designed to have same L/E as LSND experiment
  average neutrino energy ~800 MeV
- 800 ton Cerenkov detector
- target mineral oil (CH_2)



Neutrino-nucleus Neutral Current Elastic (NCE) scattering

- Unique nuclear probe
- Sensitive to nucleon axial mass (M_A)
- Sensitive to measure of strange quark spin component of nucleus (Δs)



Axial nucleon weak neutral current

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

$$= -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \left\langle N \left| \frac{1}{2}\left\{-G_A(Q^2)\gamma_\mu\gamma_5\tau_5 + G_A^s(Q^2)\gamma_\mu\gamma_5\right\}\right| N \right\rangle$$

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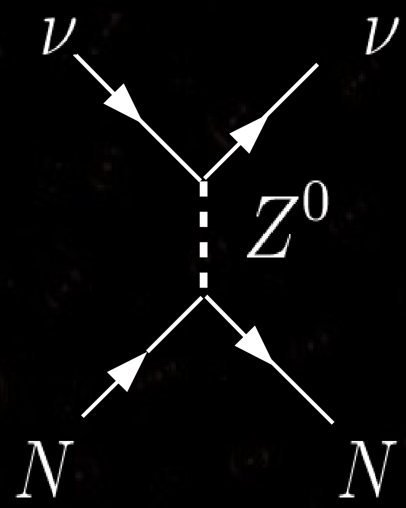


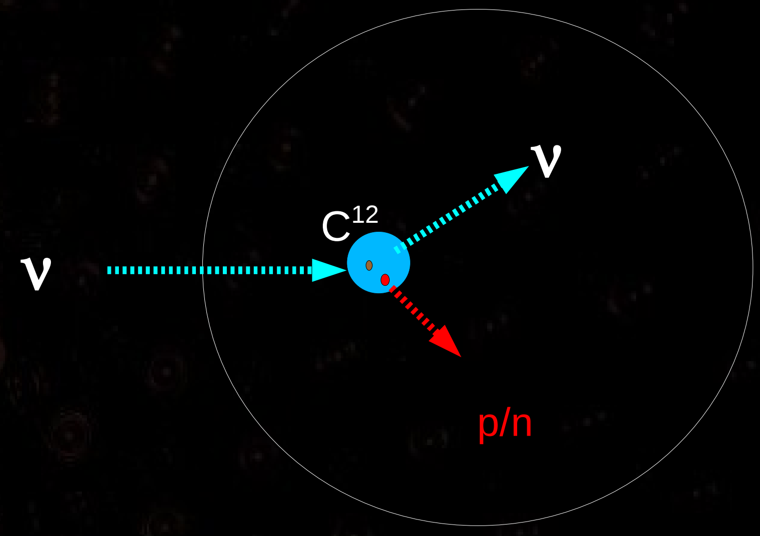
Axial nucleon weak neutral current

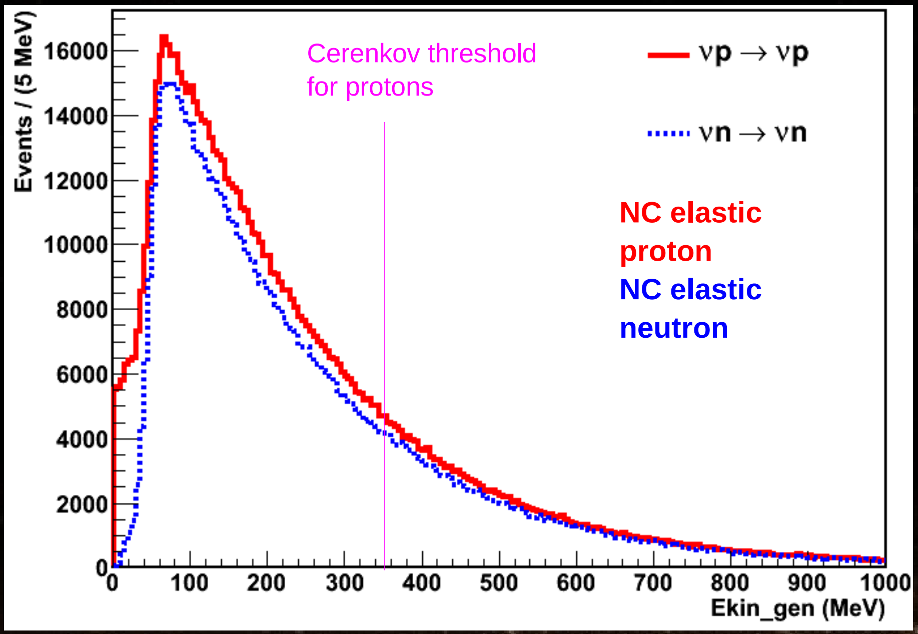
$$G_A(Q^2) = \frac{1.2671}{(1+Q^2/M_A^2)^2}\tau_5 \qquad G_A^s(Q^2) = \frac{\Delta s}{(1+Q^2/M_A^2)^2}$$

$$= -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \left\langle N \left| \frac{1}{2}\left\{-G_A(Q^2)\gamma_\mu\gamma_5\tau_5 + G_A^s(Q^2)\gamma_\mu\gamma_5\right\} \right| N \right\rangle$$

Neutral Current Elastic (NCE) in MiniBooNE

- A Neutral current event results in an energetic nucleon that interacts with the detector media, ionizing and exciting atoms which emit photons that can be detected by the (PMTs).
- Experimental signature: activity in the detector with no μ^+ or π
- Dedicated NC Fitter-assumes outgoing nucleon is a proton.





nucleon KE (MeV)

- Below Cerenkov threshold p/n separation not possible.Reconstruction via. scintillation

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ν mode results:

*Dissertation work of Denis Perevalov, published Phys. Rev. **D82**, 092005 (2010)*

Sample size: 94,531 NCE events   efficiency:35%   purity:65%

1) Flux averaged differential cross section

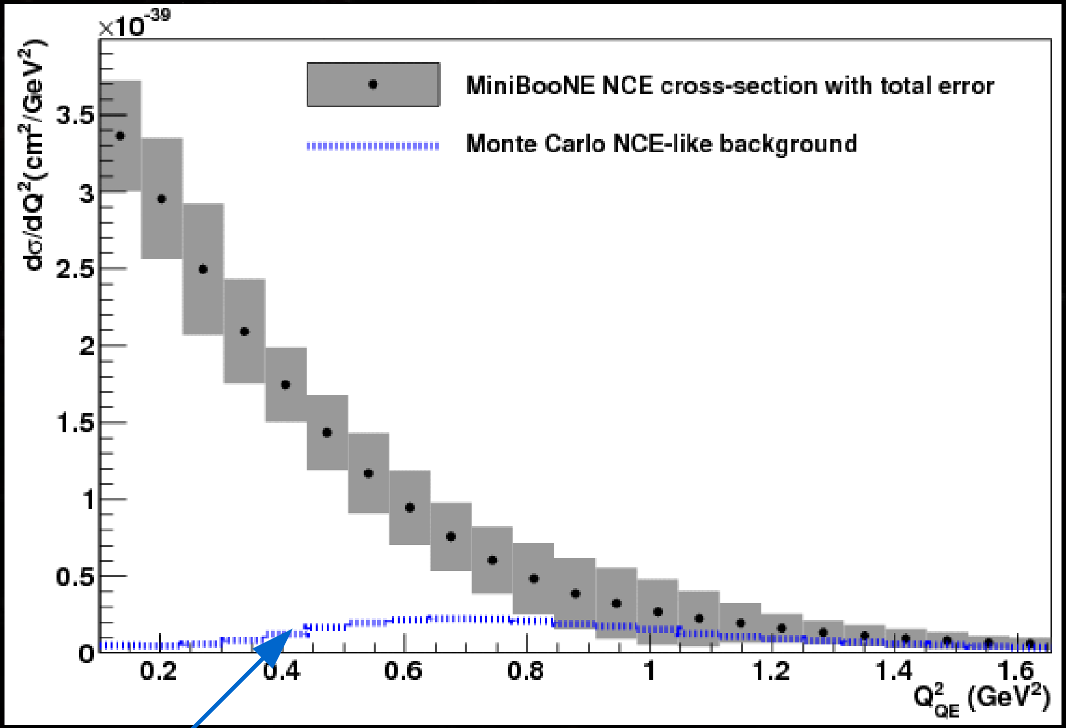
- As a function of Q^2 for $0.1\ GeV^2 < Q^2 < 1.65\ GeV^2$

Note: In MiniBooNE, $Q^2 = 2m_n \sum_i T_i$

T is the kinetic energy of outgoing nucleon

Less sensitive to FSI

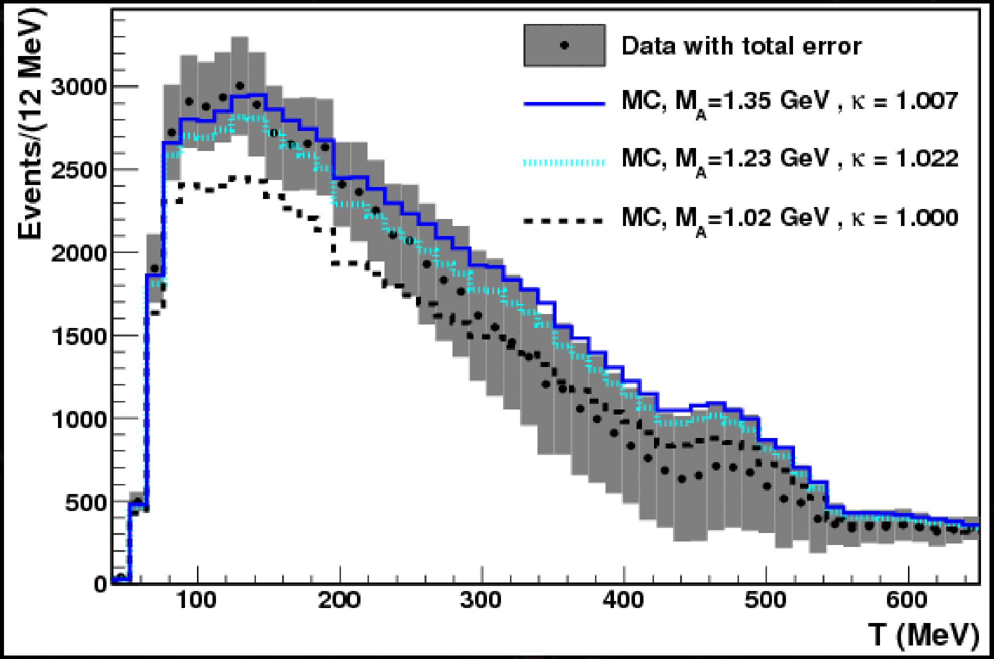
- Scattering from nucleons- both bound (carbon) and free (hydrogen)



'NCE-like' background

ν mode results:

2. Axial vector mass (M_A):



- Via a goodness of fit test to find the value of M_A that best matches data. (normalization and shape fit)

$$M_A = 1.39 \pm 0.11 GeV$$

- Agrees with the shape-only fits from MiniBooNE CCQE data

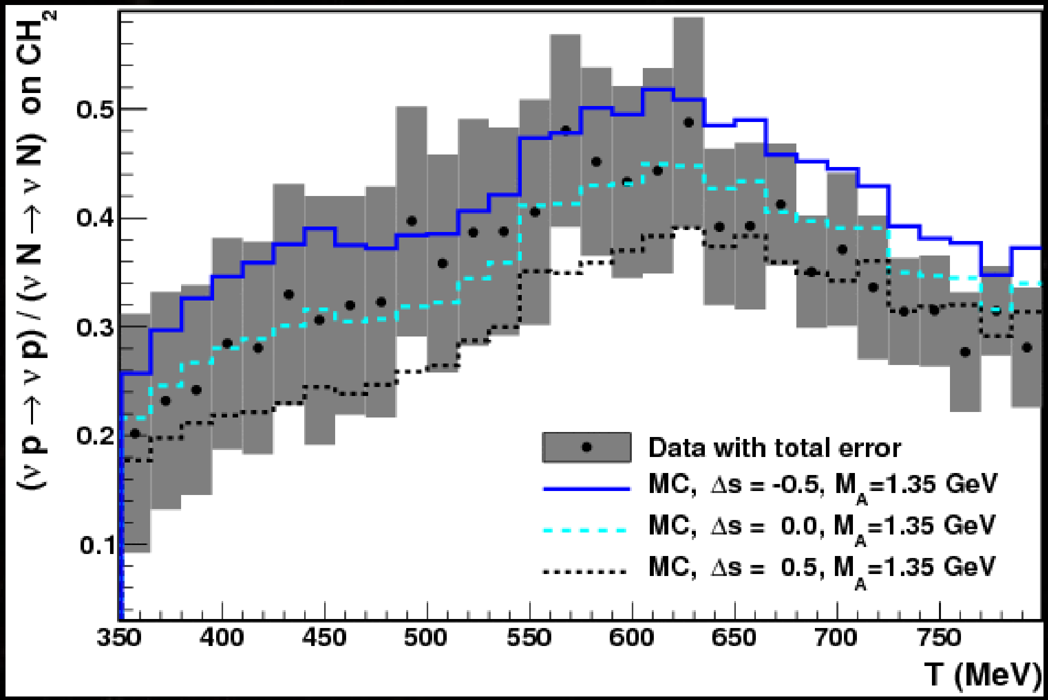
3. Strange quark spin (Δs) :

- Above 350 MeV
- Assuming M_A= 1.35 GeV for $\frac{\nu p \rightarrow \nu p}{\nu N \rightarrow \nu N}$

$$\Delta s = 0.08 \pm 0.26$$

- In agreement with BNL E734 experiment (*PRD* ***35****, 785 (1987)*)

$$\Delta s = -0.15 \pm 0.09$$



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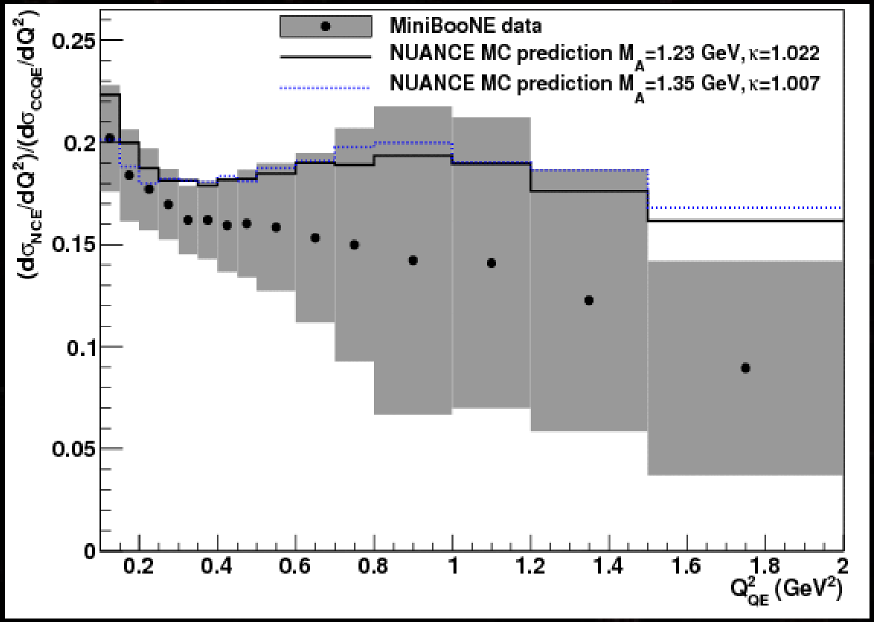
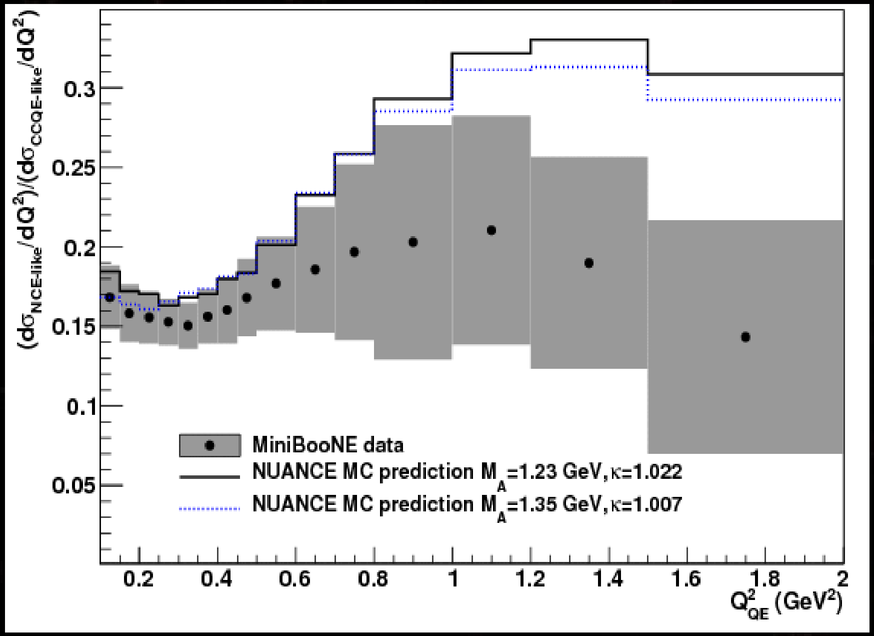


4. NCE/CCQE cross section ratio:

(First time such a ratio attempted)

- cross section measured differently for the two processes
- per target nucleon (14-NCE, 6-CCQE)

ν mode results:



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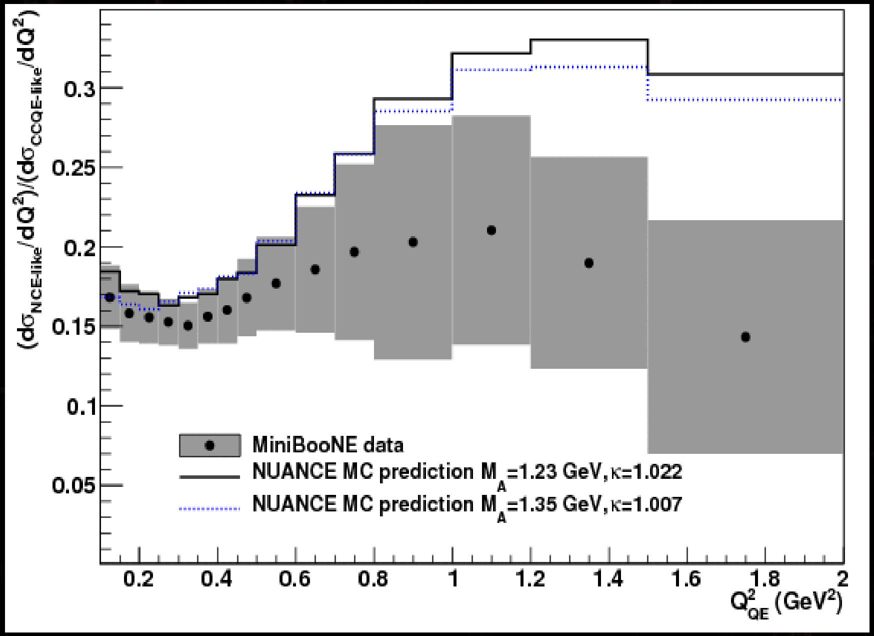

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Look at the same ratio in $\bar{\nu}$ mode.

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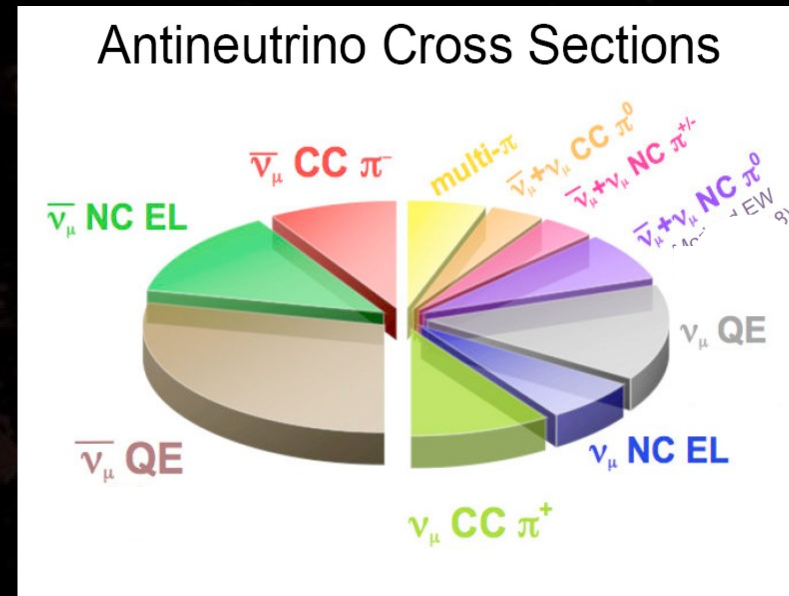
$\bar{\nu}$ mode

Challenges in the $\bar{\nu}$ mode:

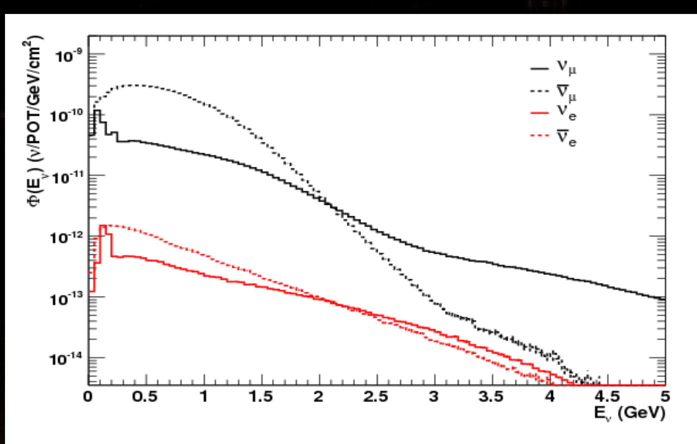
- Lower statistics

  -leading particle effect
  -lower cross section

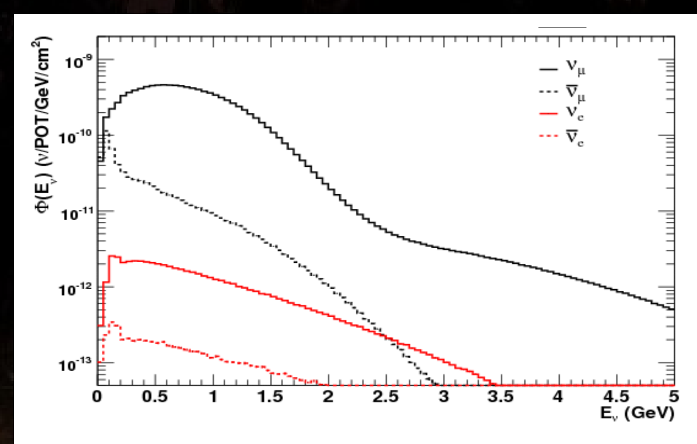
- ν background: Wrong sign (WS)



$\bar{\nu}$ flux



ν flux



$\bar{\nu}$ mode

NCE Event Selection

1. One subevent
2. Veto hits < 6
3. Tank hits >12
4. Event in beam window(4400ns to6500ns)
5. Particle ID cut: $\ln(L_e/L_p)<0.42$
6. Fiducial volume cut:R<5.0m

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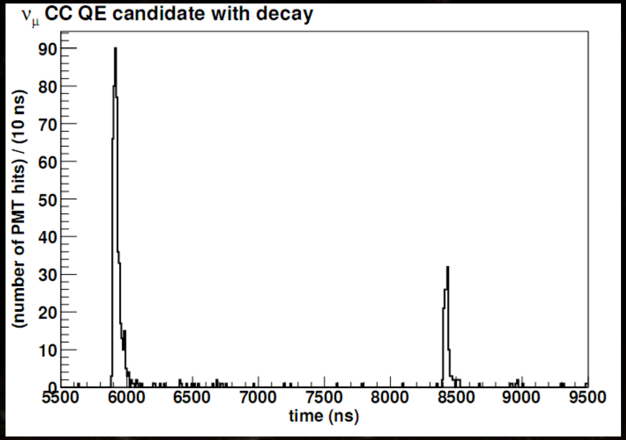
$$\bar{\nu} + N \xrightarrow{1} \bar{\nu} + N$$

As opposed to

$$\nu_\mu + n \xrightarrow{1} \mu^- + p$$

2

$$e^- + \bar{\nu}_e + \nu_\mu$$



$\bar{\nu}$ mode

NCE Event Selection

1. One subevent
2. Veto hits < 6

Remove cosmic ray background

3. Tank hits >12
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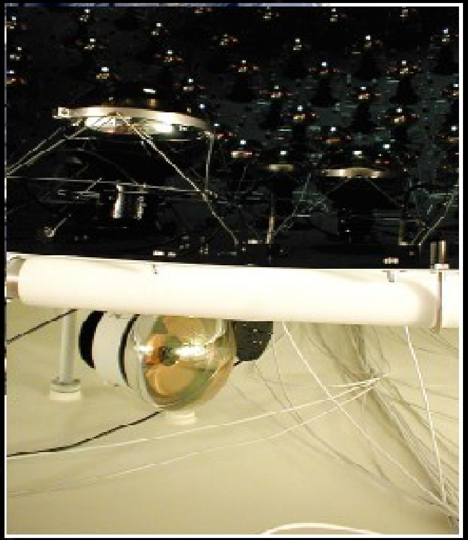

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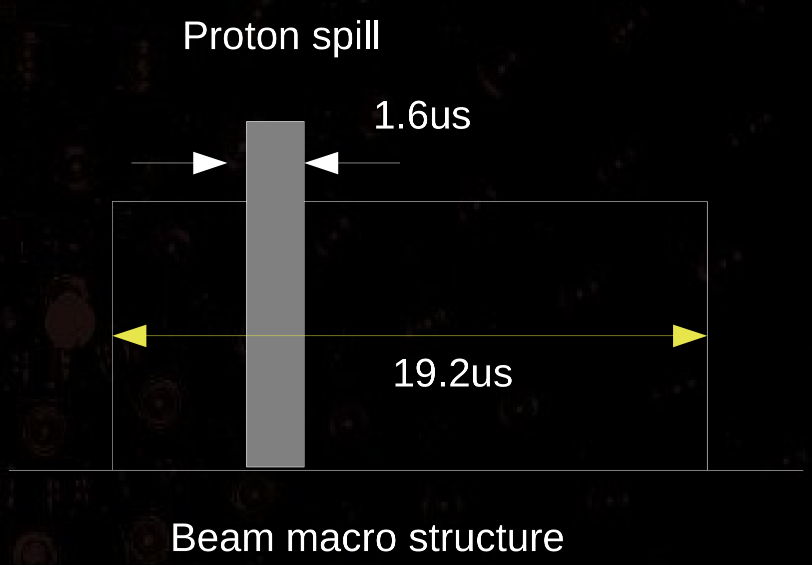

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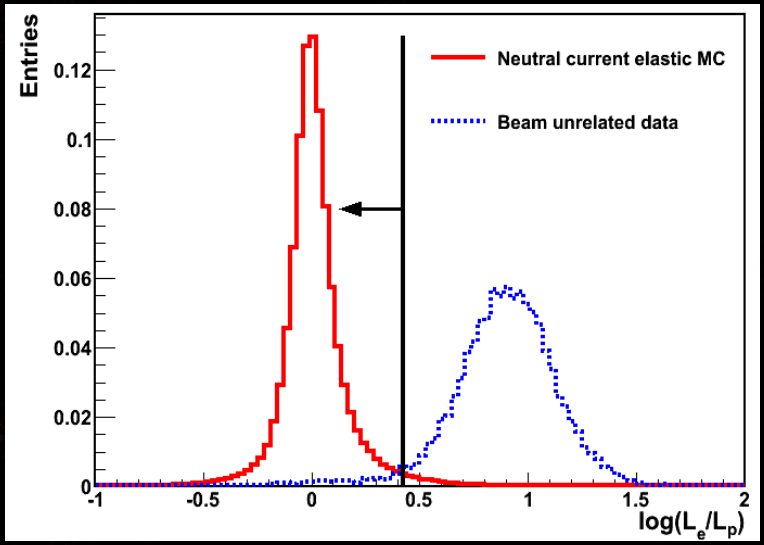

Select proton like events

Time likelihood ratio between proton and electron hypotheses

NCE Event Selection

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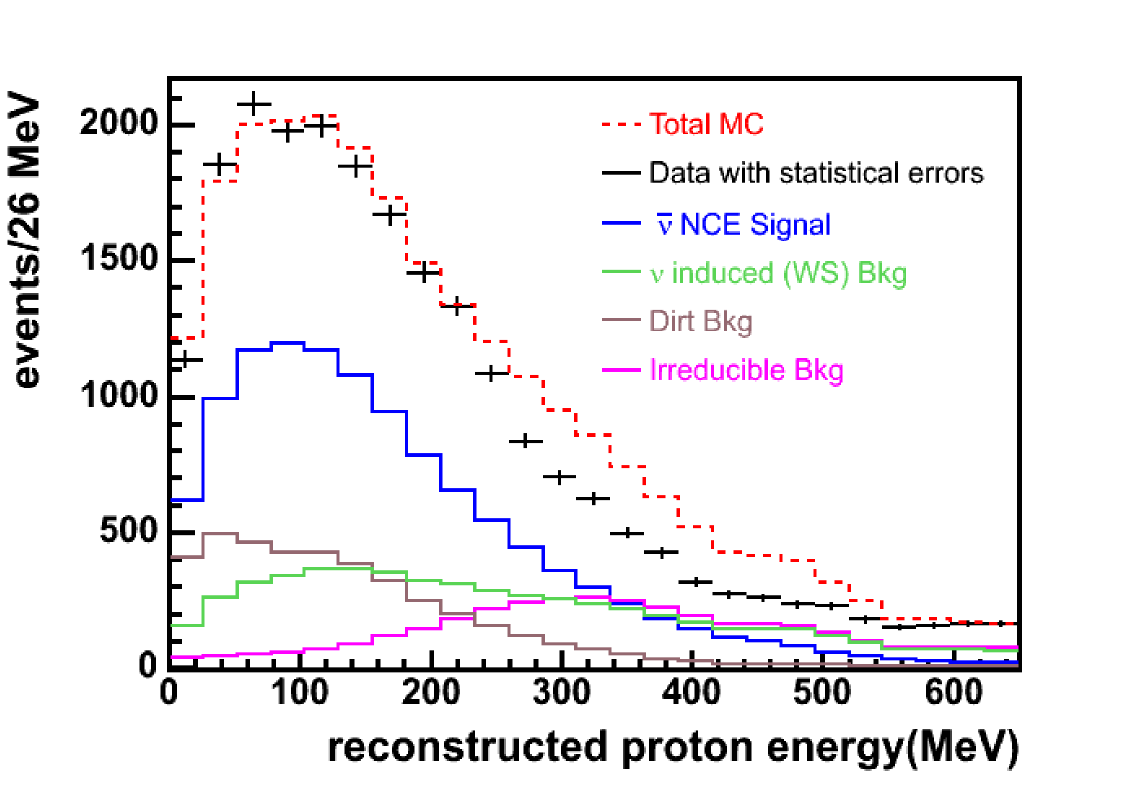
Look at reconstructed energy spectrum



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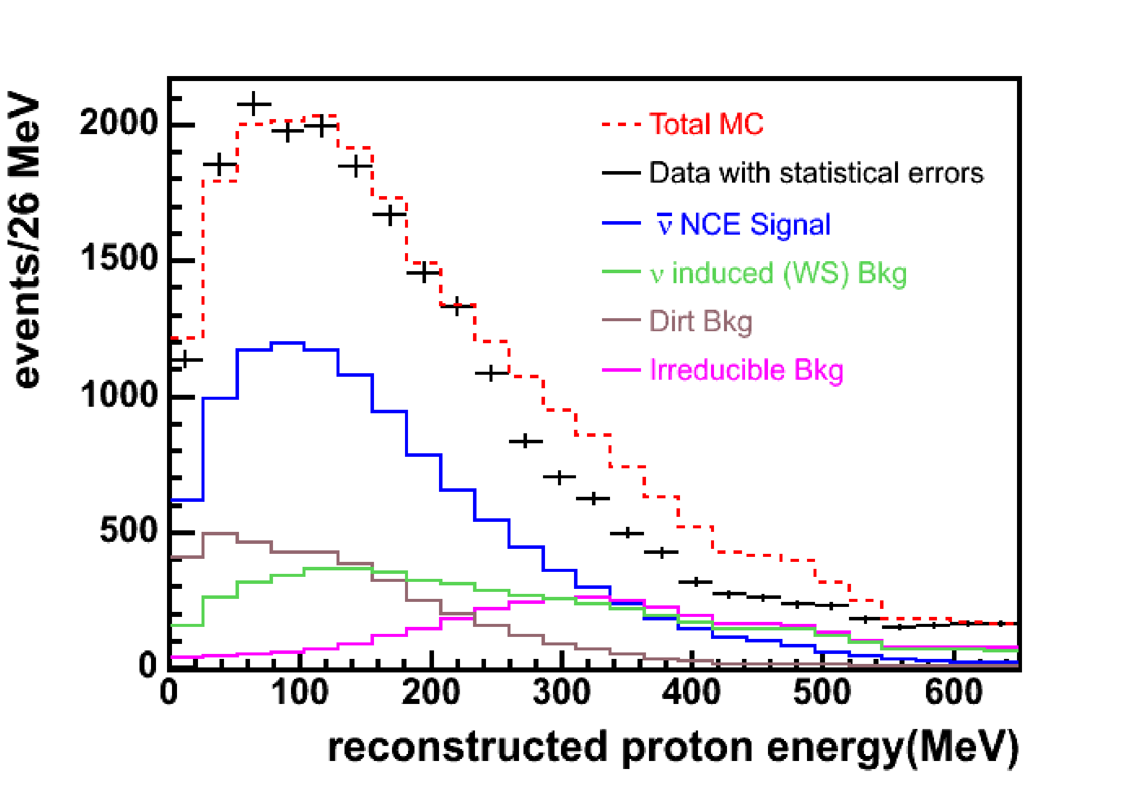
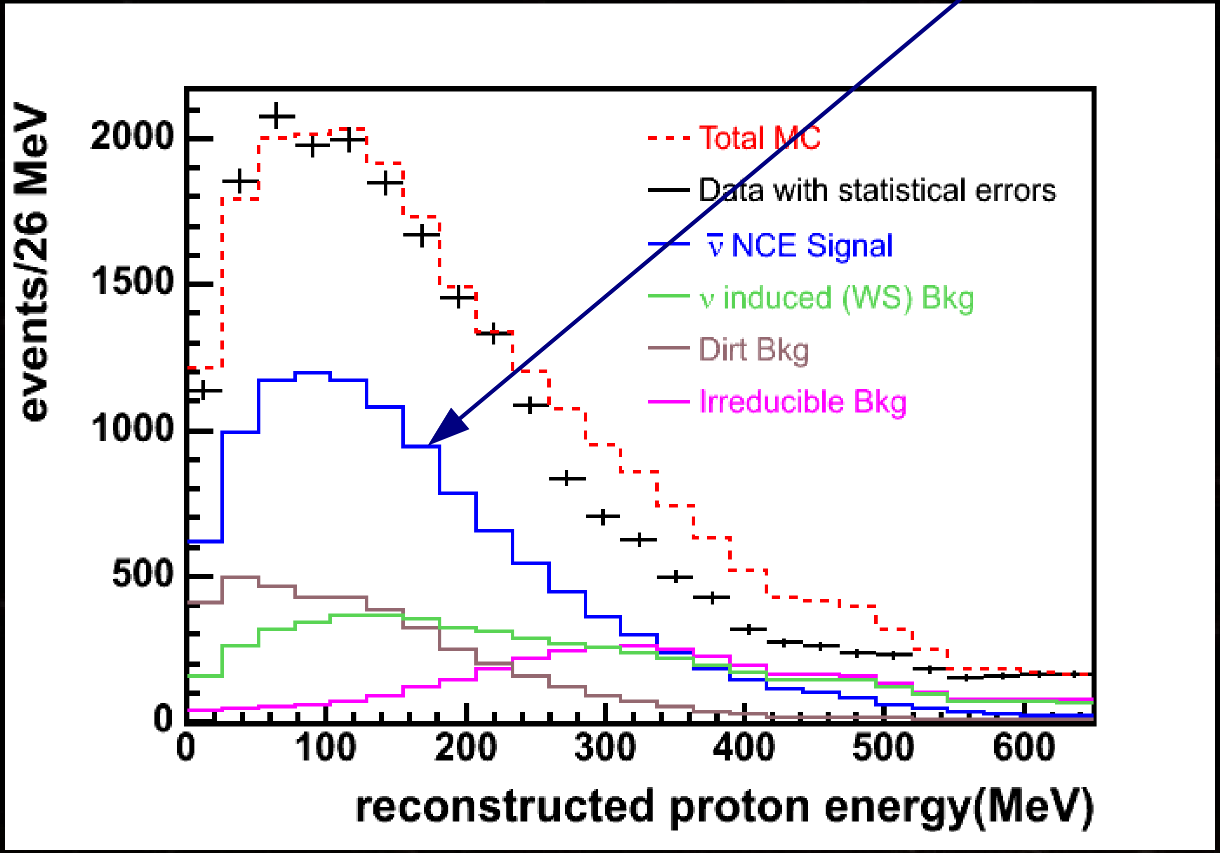


- 21,500 NCE events corresponding to 4.48E20 POT.
- purity: 57%
- efficiency: 33%

} $\bar{\nu}$ NCE

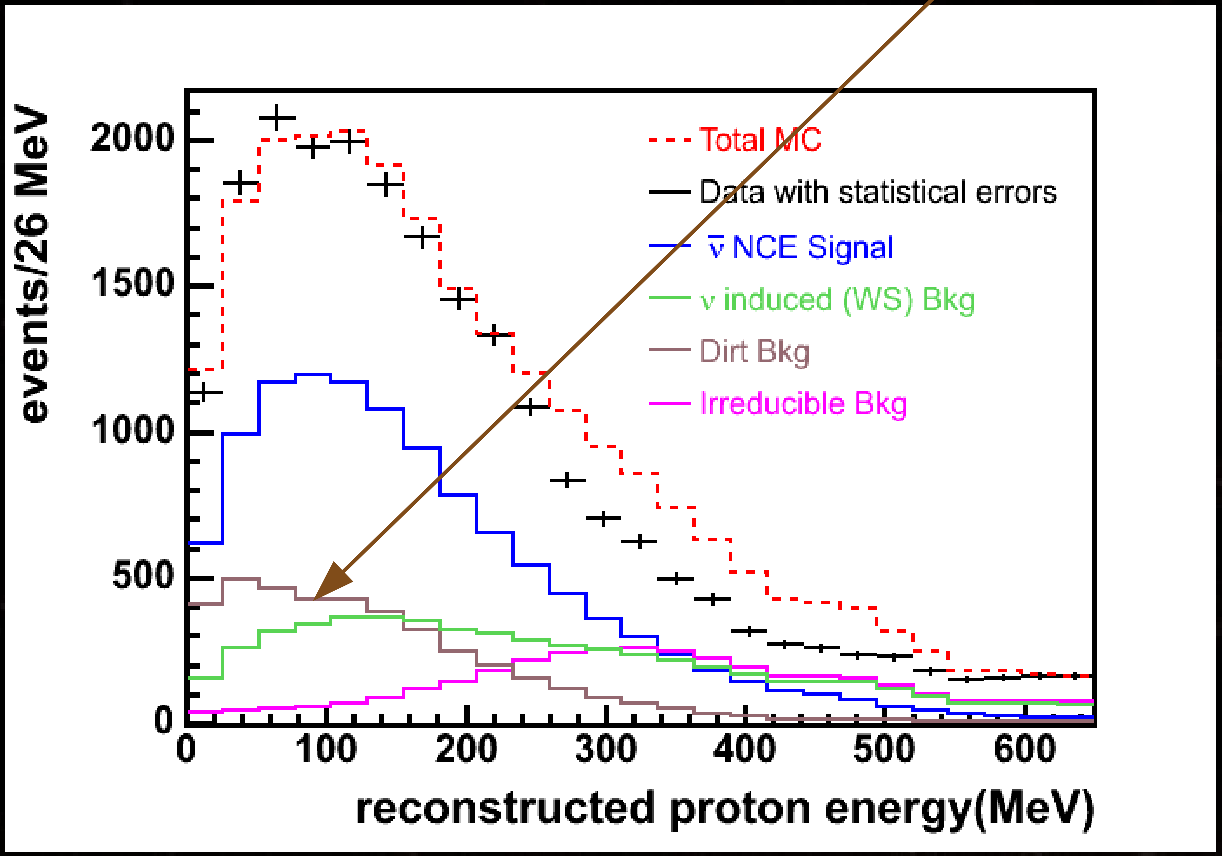
$\bar{\nu}$ mode

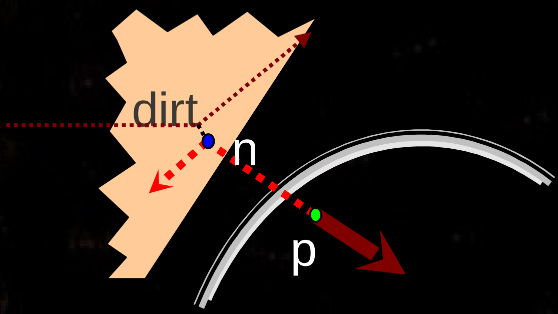
- $\bar{\nu}$ neutral current elastic (NCE) signal.
- MC generated using RFG model M_A=1.23, κ=1.022



$\bar{\nu}$ mode

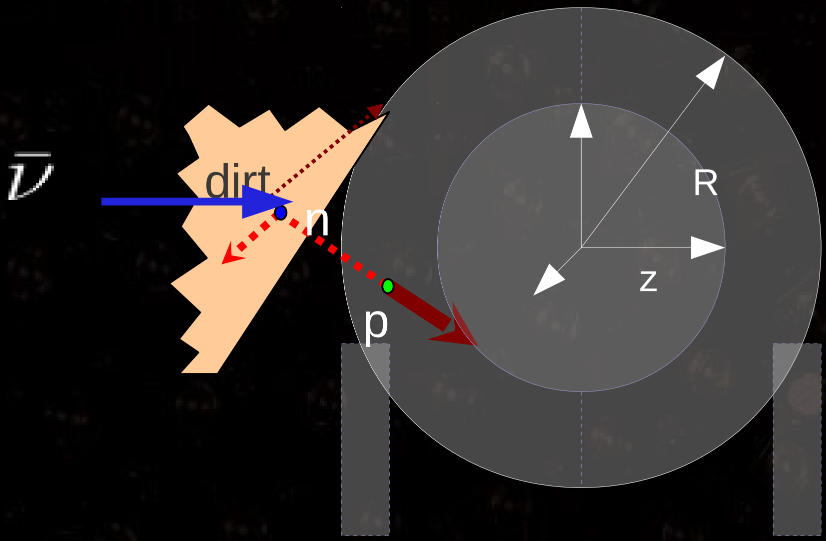
- Mostly low energy neutrons sneaking past veto PMTs
- Difficult to model
- Constrained by MiniBooNE dirt measurement





$\bar{\nu}$ mode

MiniBooNE Dirt Measurement



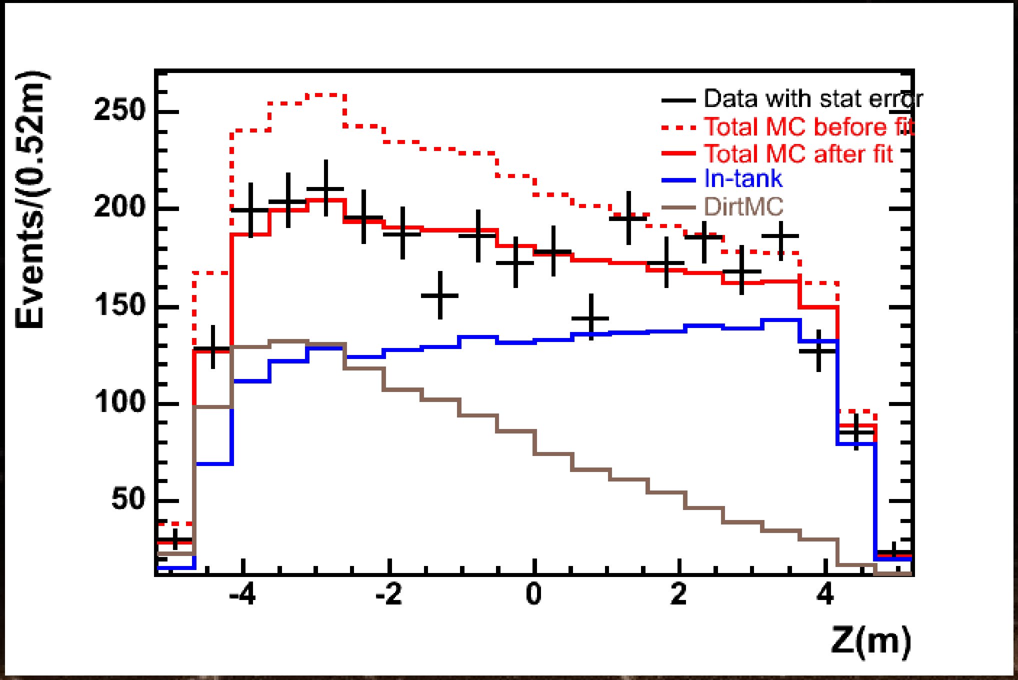
- Make 'dirt enriched' samples

Sample	Cuts
Z	3.8m <R< 5.2m
R	Z<0m
E	3.8m <R< 5.2m & Z<0m

- compare with data in bins of 61 MeV. (40Mev to 650MeV)

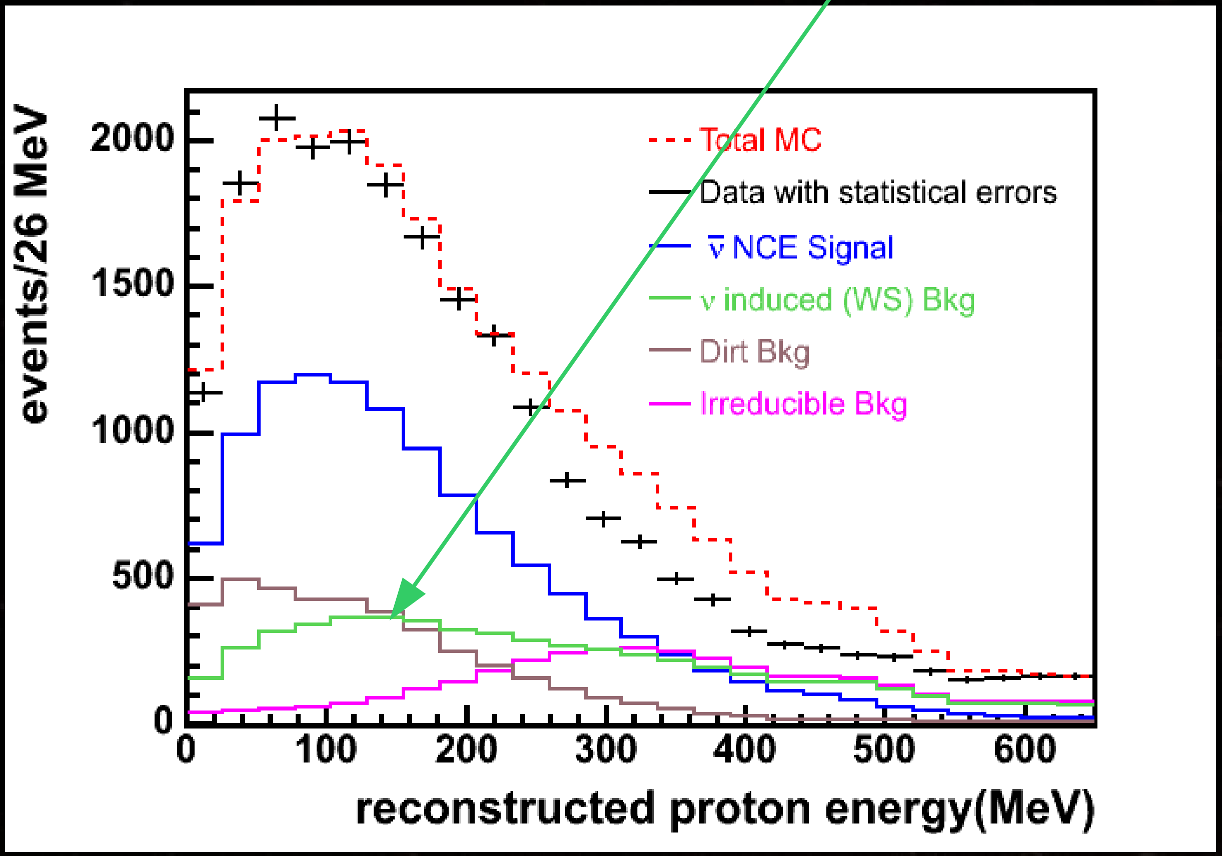
- good agreement between fits in 3 samples

- constrain dirt to within 10% error



$\bar{\nu}$ mode

- ν (wrong sign) induced events
- constrained by MiniBooNE wrong sign measurement



MiniBooNE Wrong Sign (WS) Measurement *arXiv:1102.1964v1 [hep-ex]*

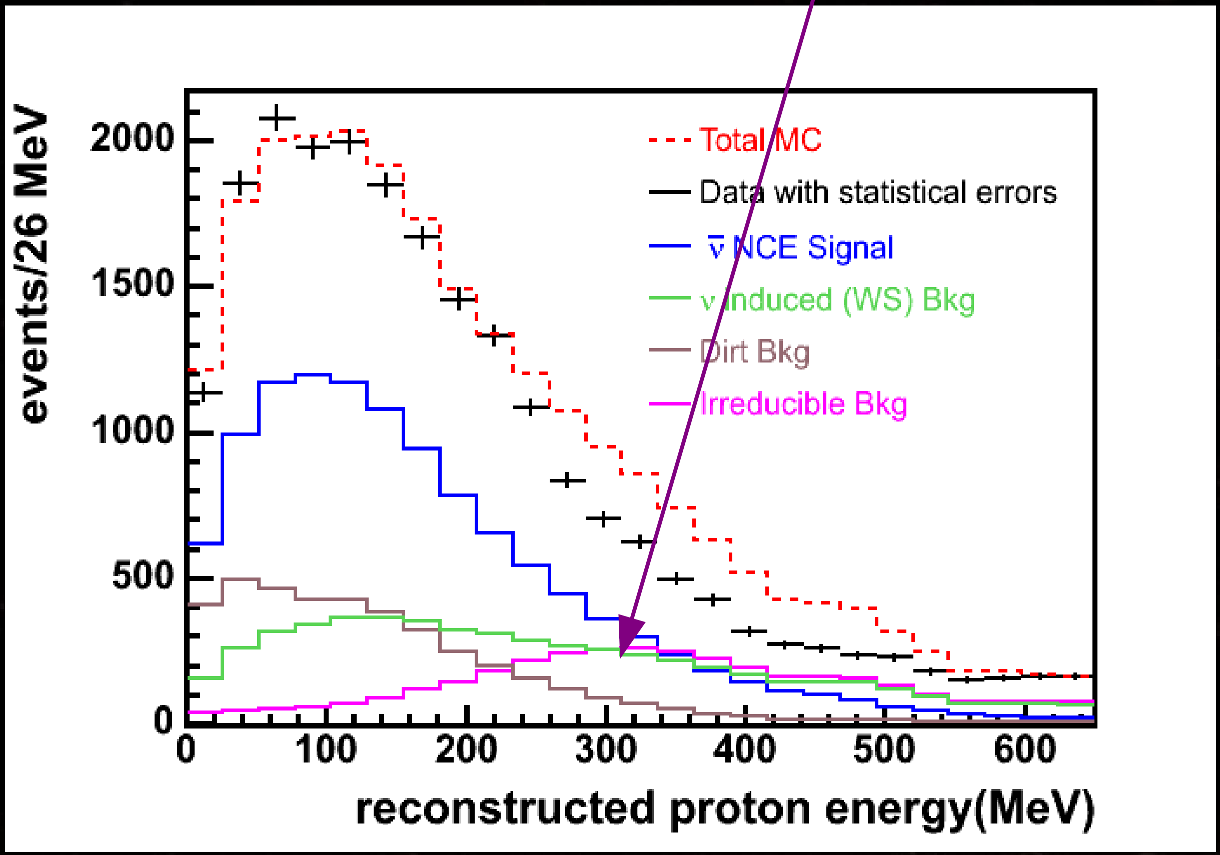
- ν induced events in $\bar{\nu}$ mode
- Not significant in ν mode but significant background in $\bar{\nu}$ mode
- constrained using 3 independent methods (refer to previous talk by Joe Grange)
- WS constrained to within 14% error

$\bar{\nu}$ mode

- Intermediate energy, NCπs with no pion in final state

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

- 'Irreducible' NCE-like



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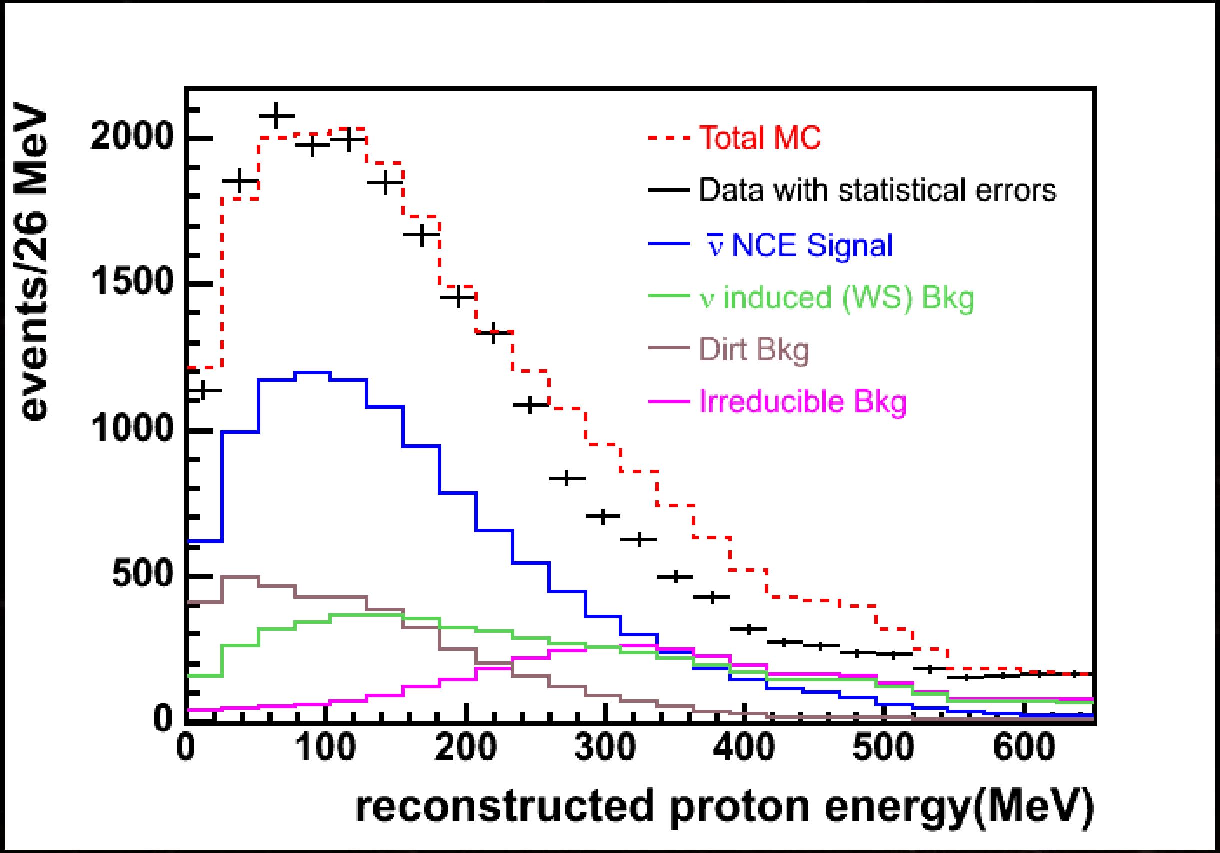


Backgrounds:

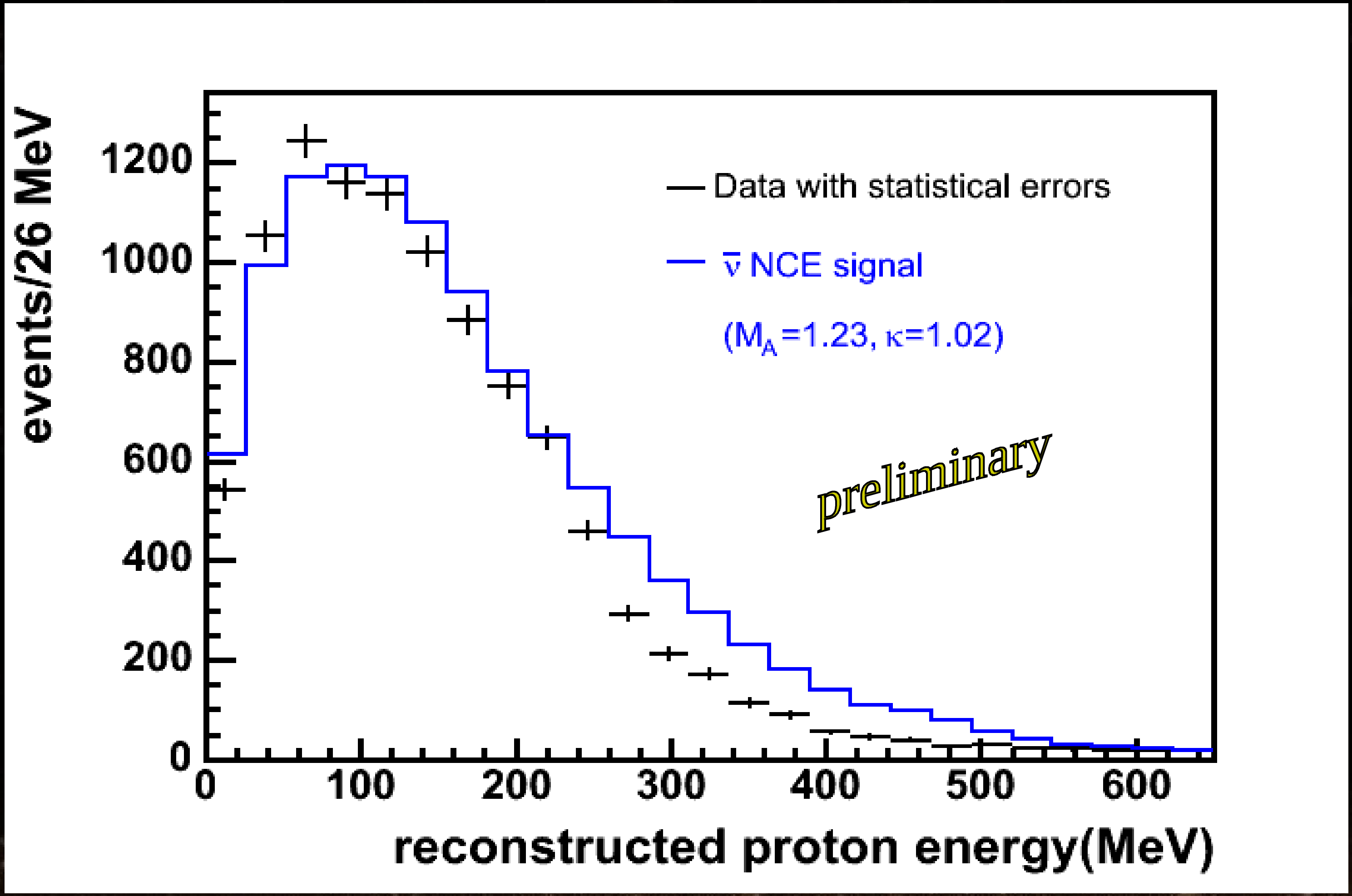
Dirt √

Neutrino (WS) √

Irreducible NCE-like √

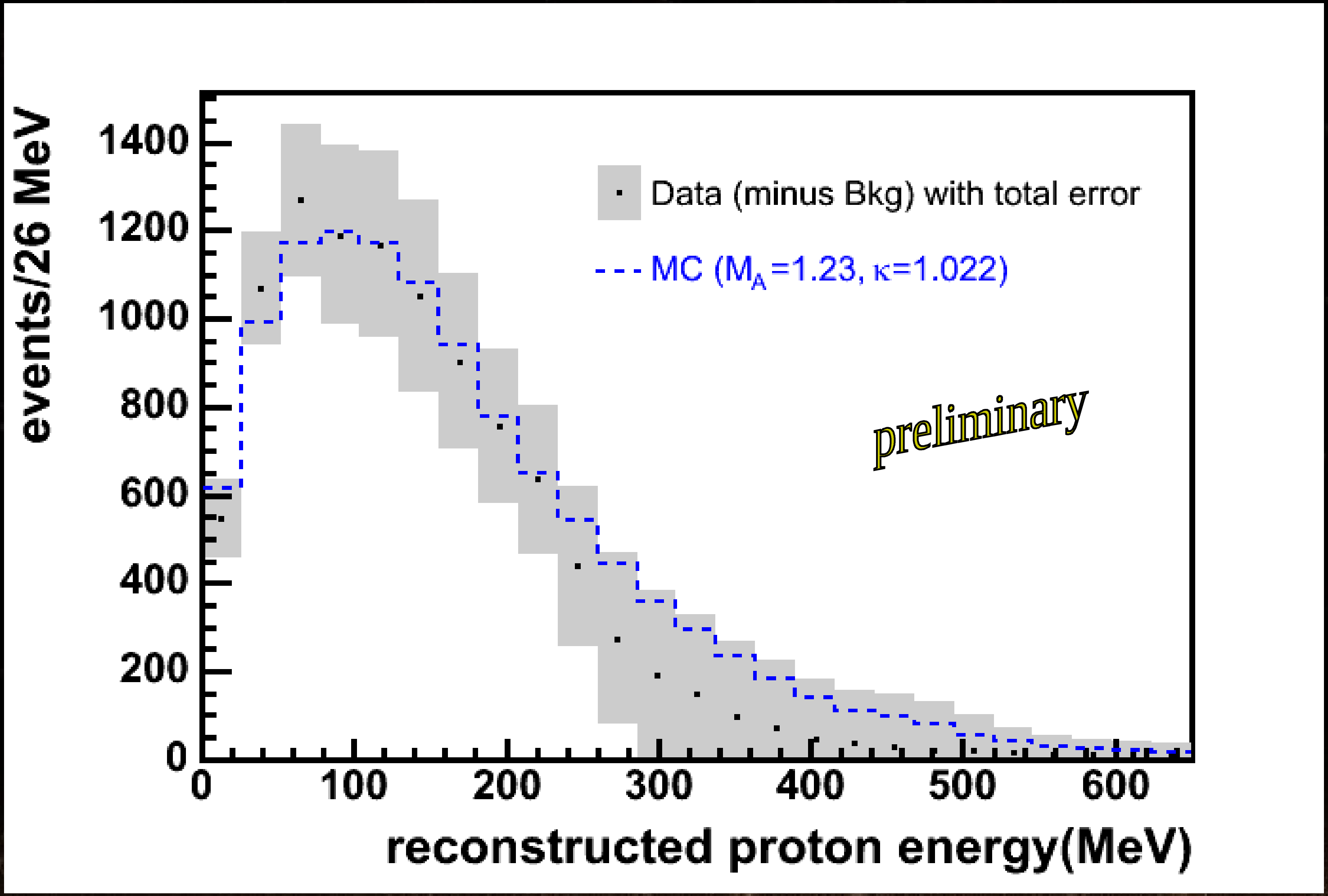
$\bar{\nu}$ mode

- Comparing data to MC (after background subtraction)
- MC model (RFG with M_A=1.23, κ=1.022)



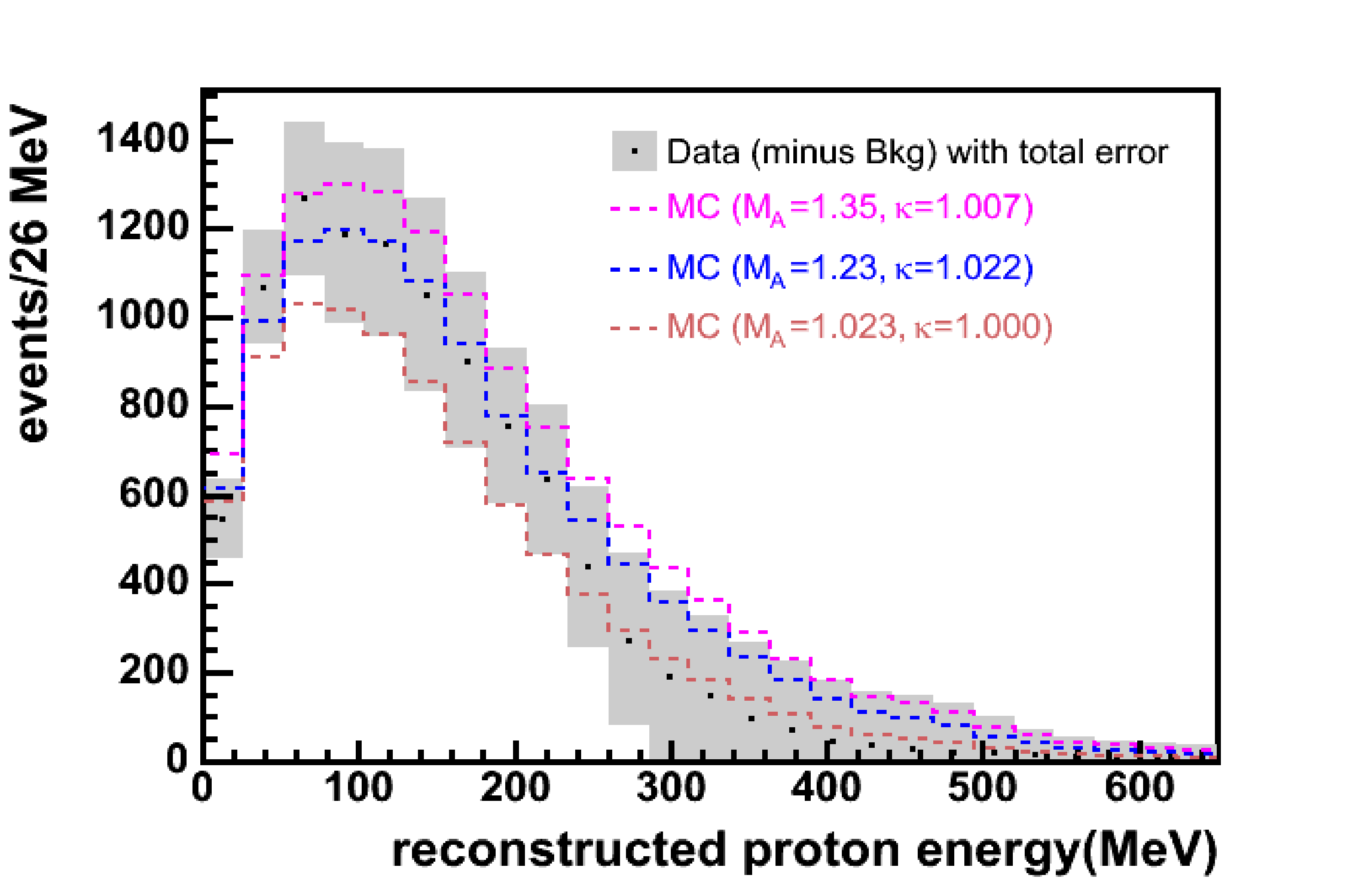
$\bar{\nu}$ mode

- Comparing data to MC (after background subtraction)
- MC model (RFG with M_A=1.23, κ=1.022)
- data shown with total errors



$\bar{\nu}$ mode

- Comparison of data with MC of different M_A and κ values
- Data shown with all errors(statistical + systematic)



$\bar{\nu}$ mode

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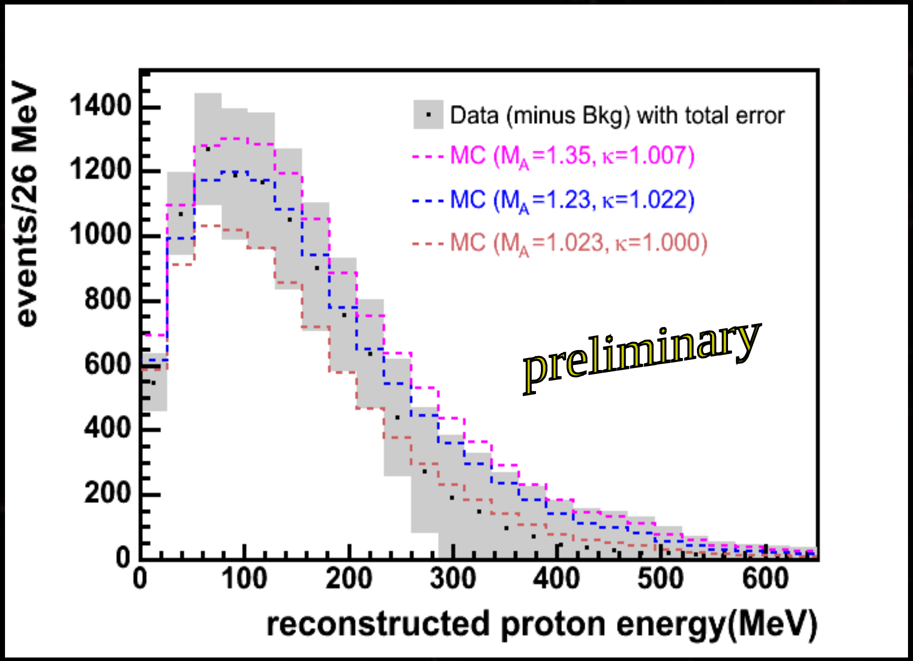
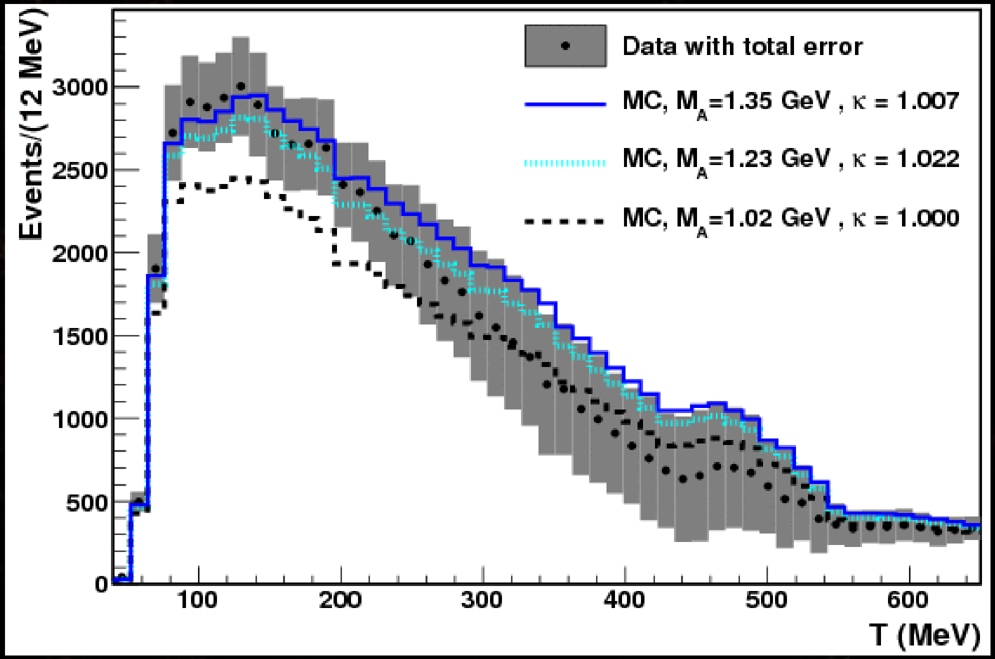
Comparing with neutrino mode

$\bar{\nu}$



ν



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Future plans...

- Correct for detector effects and produce a flux averaged differential cross section
  - This is the largest $\bar{\nu}$ sample to date
- produce a 'best fit' for the axial mass M_A
  - Interesting to compare with $\bar{\nu}$ CCQE and also ν NCE and CCQE
- Extract Δs – the strange quark spin in the nucleus
  - best to look at ratios as systematics are canceled

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$$R(p/n) = \frac{\sigma(\bar{\nu}p \rightarrow \bar{\nu}p)}{\sigma(\bar{\nu}n \rightarrow \bar{\nu}n)}$$ → Most sensitive but a difficult measurement

$$R(NCE/CCQE) = \frac{\sigma(\bar{\nu}p \rightarrow \bar{\nu}p)}{\sigma(\bar{\nu}p \rightarrow \mu^+ n)}$$ → Compare NCE with CCQE

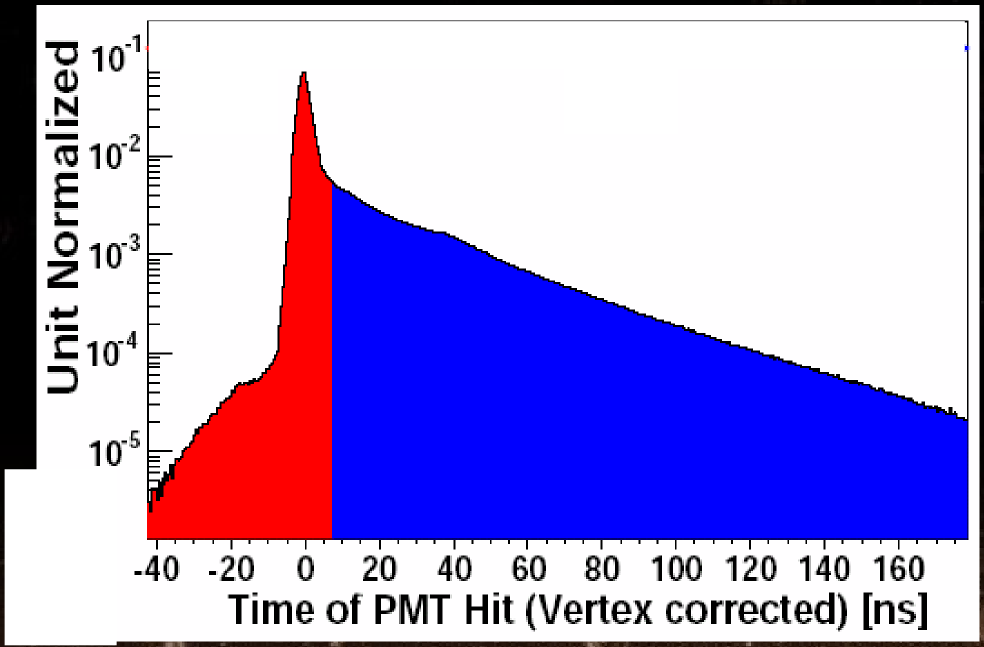
$$R(NCE/NCE) = \frac{\sigma(\bar{\nu}p \rightarrow \bar{\nu}p)}{\sigma(\nu p \rightarrow \nu p)}$$ → Compare ν and $\bar{\nu}$

Conclusion:

- Extracting $\bar{\nu}$ neutral current events is challenging, particularly in a Cerenkov detector.
- However this is possible due to a number of complimentary analyses (ν mode, WS, CCπ etc.) and understanding of the detector
- with the largest $\bar{\nu}$ sample in hand we plan to report (in addition to the cross section) M_A, Δ s , NCE/CCQE offering a uniqe opportunity to compare $\bar{\nu}$ and ν.

Thank you

Backups

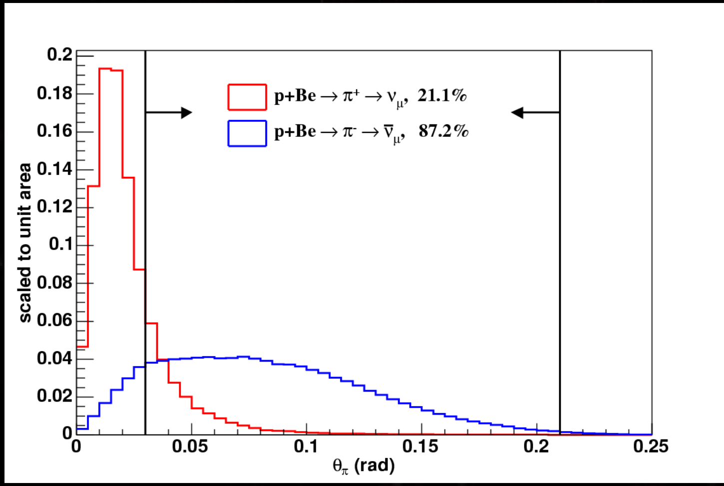


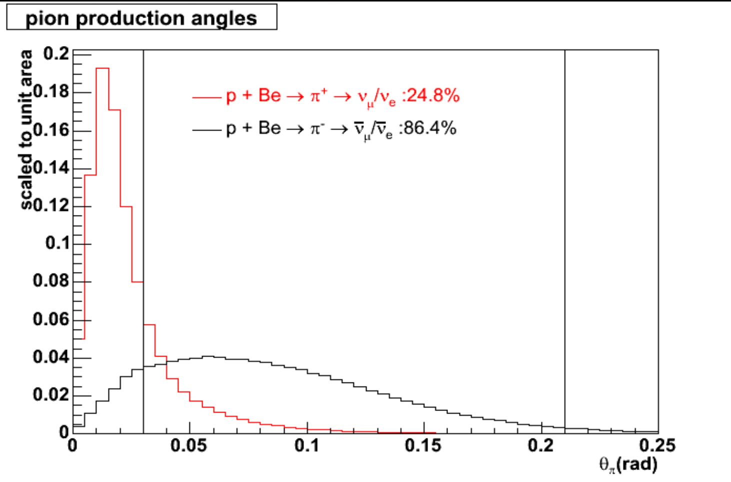
Unit Normalized
10-1
10-2
10-3
10-4
10-5
-40 -20 0 20 40 60 80 100 120 140 160
Time of PMT Hit (Vertex corrected) [ns]

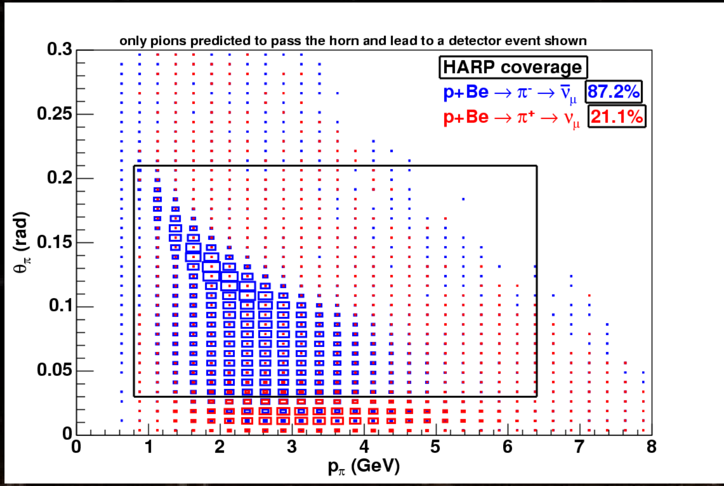
Step 5: Estimate Wrong Sign (WS) i.e. neutrino component in my sample

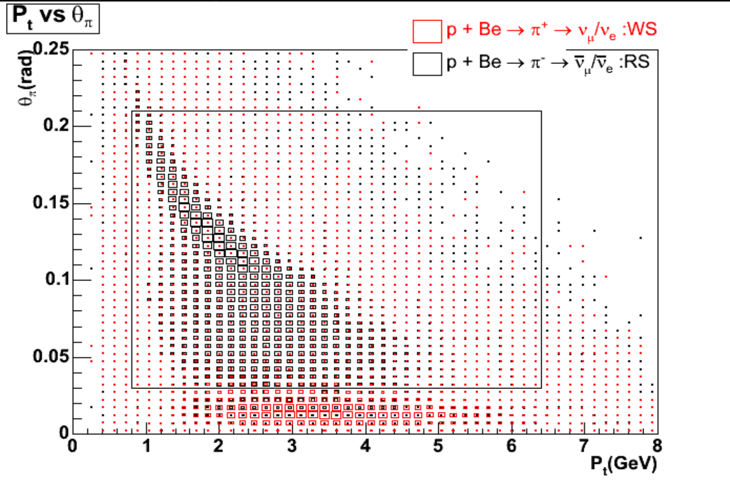
Quick check before I use Joe's numbers

With CCQE cuts | with NCE cuts









Error	%
Statistical	3.75
Optical model	18.83
Discriminator threshold	2.68
Q-t correlation	4.91
POT	1.69
Cross sections	6.65
Beam unisims	6.96
pi- production	4.40
K- production	0.30
Hadronic	0.06
Total	23.57