Asymmetry Measurement of the Electric Form Factor of the Neutron at $Q^2 = 1.16\ \mathrm{GeV}^2$

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UCONN

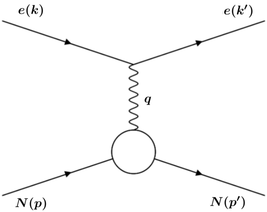
INTRODUCTION

- A brief introduction to the physics goals of E02-013, otherwise known as G_E^n
- Overview of the experimental apparatus
- Summary of the analysis
- Preliminary results of G_E^n/G_M^n at $Q^2 = 1.16\ \mathrm{GeV}^2$

NUCLEON FORM FACTORS

- Nucleon form factors arise by generalizing the typical vertex factor $-ie\gamma^{\mu}$ in OPEX:

$$\Gamma^{\nu} = \gamma^{\nu} F_1(q^2) + \frac{i\sigma^{\nu\alpha} q_{\alpha}}{2M} F_2(q^2)$$



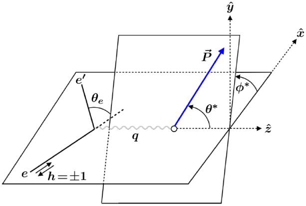
- An unpolarized calculation incorporating the nucleon structure results in the Rosenbluth formula:

$$\left.\frac{d\sigma}{d\Omega}\right|_{\mathrm{LAB}} = \frac{\alpha^2 \cos^2 \frac{\theta_e}{2}}{4E_e^2 \sin^4 \frac{\theta_e}{2}} \frac{E'_e}{E_e} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2 \frac{\theta_e}{2} \right],$$

where $\tau = \frac{Q^2}{4M^2}$, $G_E = F_1 - \tau F_2$ and $G_M = F_1 + F_2$.

BEAM-TARGET ASYMMETRY

Polarize beam and target, and an asymmetry arises by flipping the beam helicity $h = \pm 1$:



$$A_{\text{phys}} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

$$= -\frac{2\sqrt{\tau(1+\tau)}\tan\frac{\theta_e}{2}}{\frac{\tau}{\epsilon} + \Lambda^2}\left\{P_x\Lambda + \sqrt{\tau\left[1 + (1+\tau)\tan^2\frac{\theta_e}{2}\right]}P_z\right\},$$

$$= \frac{\mathcal{B}\Lambda + \mathcal{C}}{\mathcal{D} + \Lambda^2}.$$

- $\Lambda \equiv G_E/G_M$, $P_x = \sin\theta^* \cos\phi^*$ and $P_z = \cos\theta^*$
- At leading order, $A_{\text{phys}} \propto \Lambda$ if $\theta^* = \pi/2$ and $\phi^* = 0$ or $180°$

INTRODUCTION TO E02-013

- Extract G_E^n via a beam-target helicity asymmetry measurement using the semi-exclusive reaction $^3\vec{\mathrm{He}}(\vec{e}, e'n)pp$
- Ran in JLab's Hall A, and production took place from 3/01/2006 - 5/09/2006
- The double-arm coincidence experiment took data at four Q^2 configurations:

Q^2 [GeV^2]	Days	E_b [GeV]	θ_{BB} [deg]	θ_{NA} [deg]
1.16	8	1.519	-56.3	35.74
1.72	9	2.079	-51.6	35.74
2.48	19	2.640	-51.6	30.25
3.41	33	3.291	-51.6	25.63

Table: Kinematic configurations of E02-013, red is unpublished.

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Measurements of the Electric Form Factor of the Neutron up to $Q^2 = 3.4\ \mathrm{GeV}^2$ Using the Reaction $^3\vec{\mathrm{He}}(\vec{e}, e'n)pp$

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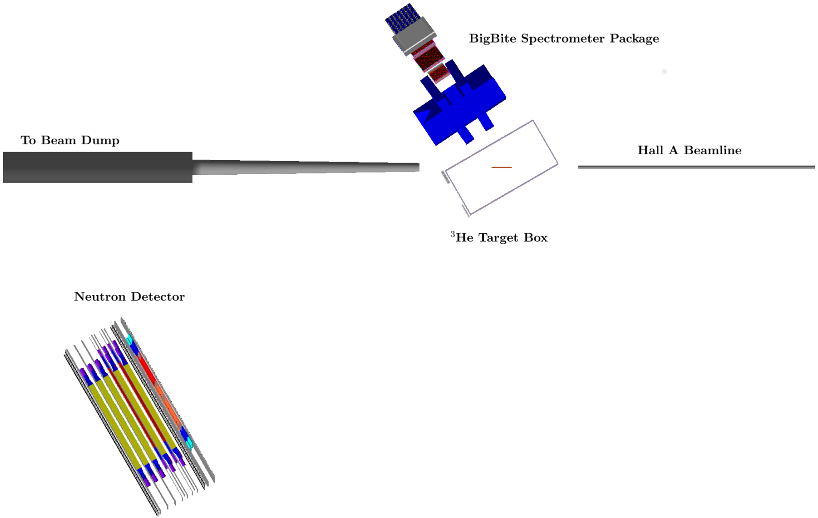
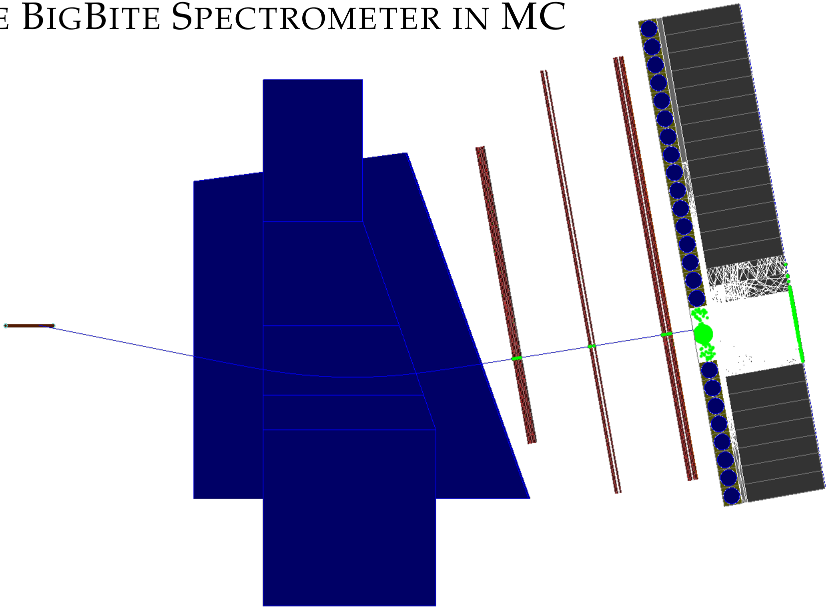
EXPERIMENTAL APPARATUS OVERVIEW



THE BIGBITE SPECTROMETER IN MC



MAJOR GOALS OF THE ANALYSIS

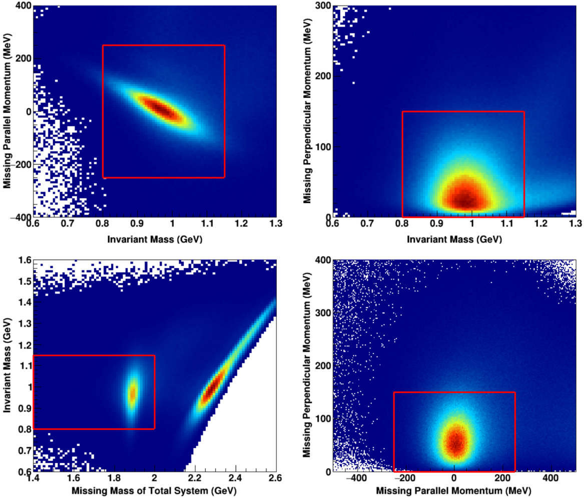
Major tasks:

1. Find electron tracks, reconstruct the vertex and momentum
2. Reconstruct the nucleon cluster and calculate the momentum via ToF
3. Separate quasielastic events with a set of cuts
4. Identify the charge of the nucleon cluster

Then we may...

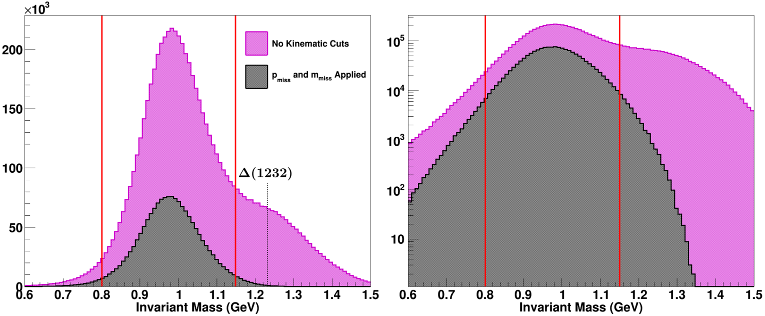
- Construct the raw asymmetry
- Correct for all appreciable experimental realities, *i.e.* events that contaminate (or dilute) the quasielastic neutral sample

Quasielastic Event Selection



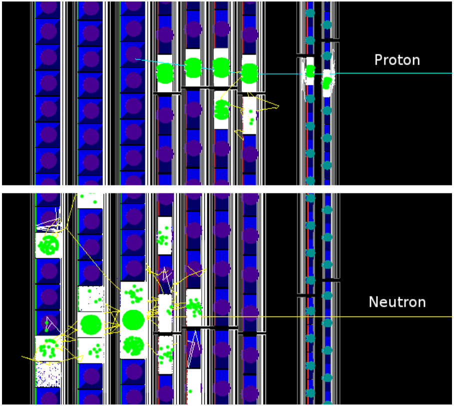
Cuts on the invariant mass, the missing momentum components and the missing mass largely select the QE region for $Q^2 = 1.16\,\text{GeV}^2$.

QUASIELASTIC EVENT SELECTION



- The inelastic region is heavily suppressed by the cut selection, resulting in negligible inelastic corrections to A_{raw}.
- A final cut of $0.8 < W < 1.15$ GeV is applied

Nucleon Charge Identification



Side view of the neutron detector depicting the ideal scenario of charge identification within MC. The recoiling nucleons have a kinetic energy of 1.3 GeV prior to entering the detector.

Major Corrections to the Raw Asymmetry

The raw asymmetry for the QE neutral sample:

$$A_{\text{raw}} = \frac{N^+ - N^-}{N^+ + N^-},$$

where $N^{\pm}$ denotes the QE neutral count for $\pm$ beam helicity.

A summary of the largest dilution factors:[1]

- Accidental background: 5%
- Nitrogen in ^{3}He target cell: 5%
- Protons misidentified as neutrons: 20%
- Nuclear effects + FSI (GEA): 10%

[1] If interested, more details may be found in the Appendix.

CHARGE MISIDENTIFICATION

Notation: $\eta_{\text{true}}^{\text{obs}}$ where true is particle that left the target and obs is the result of charge ID $\Rightarrow \eta_p^p$ protons correctly ID'ed as protons

Simulation:

- Generate elastic eN coincidence events and compare to the results of the charge identification procedure (prev. slide)
- Calculate the probability that the true nucleon gets correctly identified

Data:

- Analyze the QE uncharged to charged ratio for three targets (H_2, ^{3}He, C) to constrain the three η ratios
- Need all three ratios to calculate the misidentification correction to A_{raw} for the uncharged and charged samples

CHARGE MISIDENTIFICATION COMPARISON

Parameter	Data	Simulation	Description
$\frac{\eta_p^n}{\eta_p^p}$	0.021 ± 0.002	0.020 ± 0.001	Protons observed as neutrons
$\frac{\eta_n^p}{\eta_p^p}$	Undetermined	0.384 ± 0.001	Neutrons observed as protons
$\frac{\eta_n^n}{\eta_p^p}$	0.559 ± 0.027	0.636 ± 0.001	Neutrons observed as neutrons
D_p	0.812 ± 0.017	0.839 ± 0.001	Proton dilution factor

Table: Charge ID results for the data and the simulation.

The multiplicative correction to the neutral A_raw due to proton misidentification is given by D_p.

PRELIMINARY RESULT FOR $\mu_n G_E^n / G_M^n$

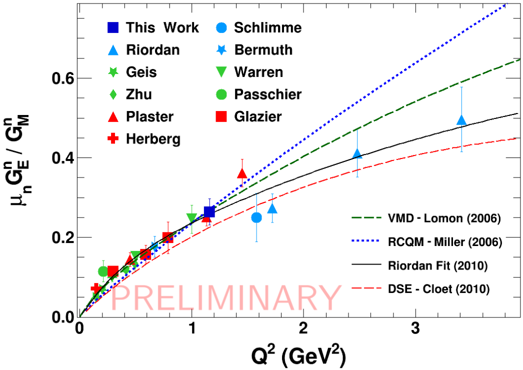


Figure: Double polarization data: $^3\vec{He}(\vec{e}, e'n)$ (blue markers), $\vec{d}(\vec{e}, e'n)$ (green markers), and $d(\vec{e}, e'\vec{n})$ (red markers). Largest contributions to systematic uncertainty come from target and beam polarization measurements. The error bar in this work is the total uncertainty.

SYSTEMATIC ERROR BUDGET

Quantity	δ/G_E^n	**Comments**
δG_E^n	0.126	Total uncertainty contribution
δ_{sys}	0.105	Systematic
δ_{stat}	0.070	Statistical
$\delta P_{^3\text{He}}$	0.077	Target polarization
δP_{beam}	0.040	Beam polarization
δD_{bk}	0.028	Background dilution
δD_{p}	0.028	Proton dilution
δG_M^n	0.025	Error from chosen G_M^n
δD_{FSI}	0.025	Nuclear corrections
δ_{other}	0.023	Sum of remaining contributions

Contributions to the systematic uncertainty of G_E^n from individual sources, and presented as a fraction of G_E^n.

Appendix

MAJOR CORRECTIONS: $A_{\mathrm{RAW}} \rightarrow A_{\mathrm{PHYS}}$

$\langle Q^2 \rangle$ [GeV^2]	1.16	**Remarks**
W [GeV]	$0.8 - 1.15$	Invariant Mass
$\mathbf{p}_\perp$ **[GeV]**	< 0.150	Missing $\perp$ momentum
$\mathbf{p}_\parallel$ **[GeV]**	< 0.250	Missing $\parallel$ momentum
$\mathbf{m}_{\mathbf{miss}}$ **[GeV]**	< 2	Missing mass
$\langle \mathbf{P_e} \rangle$	0.870 ± 0.020	Longitudinal beam polarization
$\langle \mathbf{P_{He}} \rangle$	0.416 ± 0.019	Polarization ^{3}He nucleus
$\mathbf{D_{bkgr}}$	0.949 ± 0.029	Accidental background
$\mathbf{D_{N_2}}$	0.954 ± 0.005	Nitrogen in target
$\mathbf{D_p}$	0.812 ± 0.017	Proton contamination
$\mathbf{D_{in}}$	0.980 ± 0.011	Inelastic contamination
$\mathbf{D_{FSI}}$	0.896 ± 0.013	Nuclear effects + FSI (GEA)

$$A_{\mathrm{phys}} = \frac{1}{P \cdot D} \left(A_{\mathrm{raw}} - \sum A_{\mathrm{corr}} \right),$$

where A_{corr} are corrections to A_{raw} which are associated to a dilution factor D within the table, and $P = P_e P_{\mathrm{He}}$.

TARGETS OF E02-013

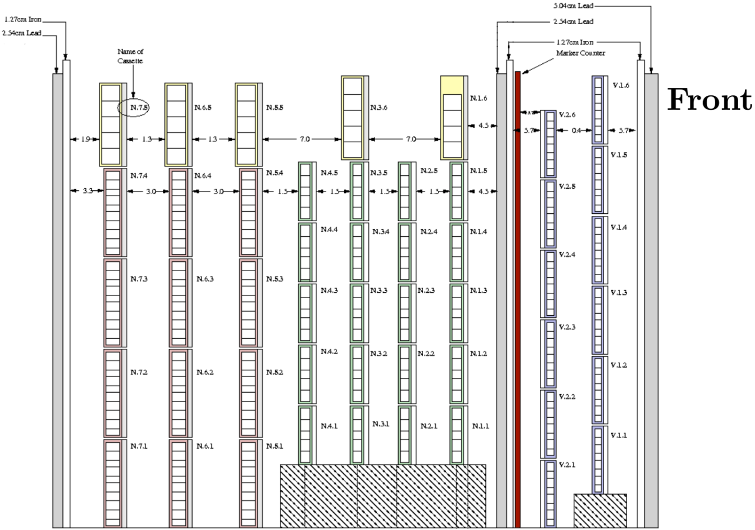
- Polarized ^{3}He is used as an effective neutron target as the symmetric S-state dominates the ground-state in which proton spins tend to cancel
  $\Rightarrow \sim 86\%$ of the nuclear spin is carried by the neutron
- Hybrid spin-exchange optical pumping (alkali vapors Rb and K) was used to polarize the ^{3}He target
- Target cells exceeded polarizations of 50%, operating at a pressure of ~ 10 atm with a beam current of 8μA
- Other targets included BeO-C foils and an empty ref. cell that may be filled with H_2 / N_2
- Targets are mounted to a ladder which is suspended in a 0.25″ thick iron "target-box"

THE BIGBITE SPECTROMETER

- The purpose is to measure the four momentum of the quasielastically scattered electron
- BigBite is a large dipole magnet that subtends $\sim$ 76 msr and accepts scattered e^- in the range $0.6 < p < 1.8$ GeV.
- Three multiwire drift chambers (15 wire planes) reconstruct the scattered track post magnetic deflection
- A segmented lead-glass preshower + shower package for triggering and pion rejection. Can reconstruct track energy and is used to confine search region of track recon.
- A hodoscope consisting of 13 scintillator paddles (resolution of 35 ps/channel) is used for event timing information

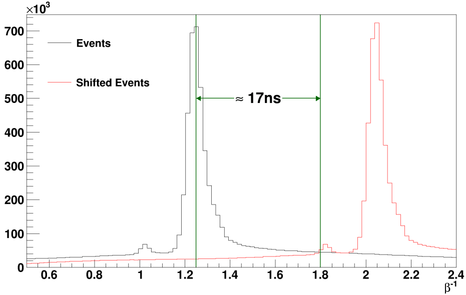
THE NEUTRON DETECTOR

- The purpose is to measure the momentum of the recoiling nucleons in coincidence via ToF and to identify the charge
- Designed to match the acceptance of BigBite at the largest Q^2 point
- A time of flight resolution of 300 ps has been obtained
- Detector consists of two "veto" layers (charge ID) and seven neutron layers (ToF)
- The veto layers are built out of 48 rows of long/short scintillating bars with two PMTs per row
- The neutron layers consist of rows of scintillating bars (1 per row) with two PMTs per row



The two veto layers (charge identification) and the seven neutron layers (nucleon ToF)

BACKGROUND SUBTRACTION



- Shift data in time before QE cuts are applied ⇒ adjust β:

$$\beta_{\text{bk}} = \frac{1}{\frac{1}{\beta_{\text{QE}}} + 0.8} \approx 0.5 \quad \Rightarrow \quad \beta_{\text{bk}}^{-1} = 2$$

where 0.8 is a shift parameter and $\beta_{\text{QE}} = 0.8$.

- Apply QE cuts, and the result is random background

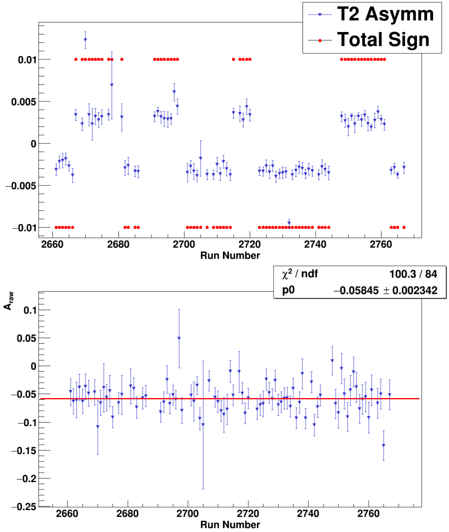
Raw Asymmetry

Top Panel:

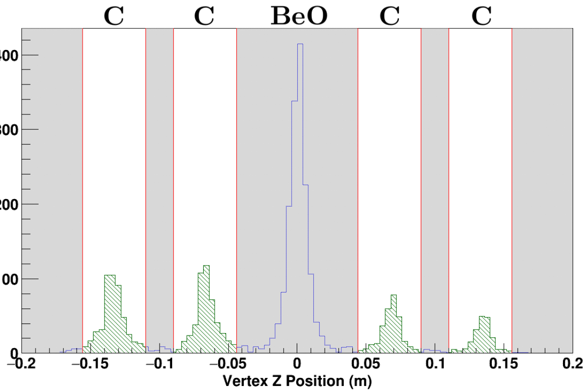
- BB single arm trigger rate T2 is sensitive to beam helicity
- Total sign = (target sign)×(precession sign)×(HWP sign)

Bottom Panel:

- Background corrected raw asymmetry
- Need to apply additional corrections to remove unwanted events



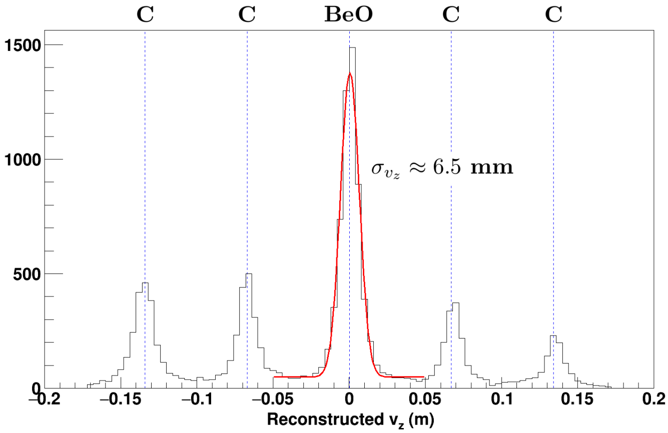
Nitrogen Dilution



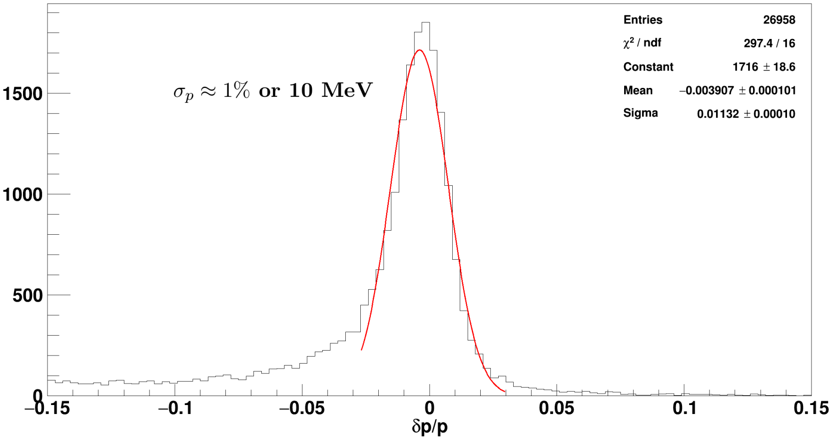
- No N_2 data $\Rightarrow$ use C foils and exclude the BeO foil

$$D_{N_2} = 1 - \frac{\Sigma(\mathrm{C}) - \Sigma_{\mathrm{back}}(\mathrm{C})}{\Sigma - \Sigma_{\mathrm{back}}} \frac{Q(^3\mathrm{He})}{Q(\mathrm{C})} \frac{\rho_{N_2}(^3\mathrm{He})}{\rho_{\mathrm{C}}(\mathrm{C})} \frac{t_{^3\mathrm{He}}}{t_{\mathrm{C}}}$$

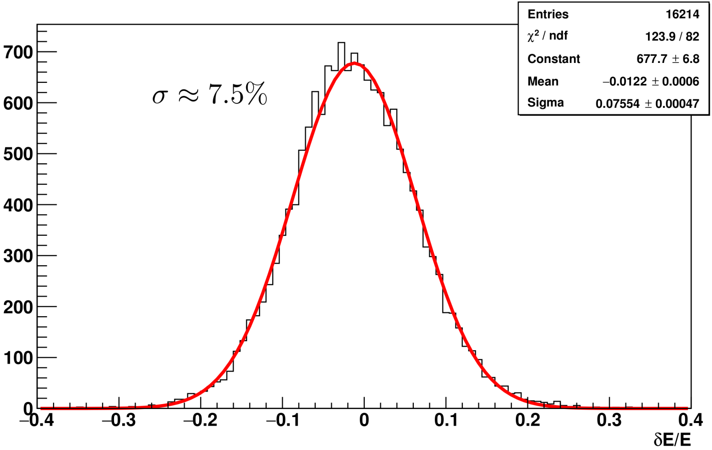
Vertex Resolution



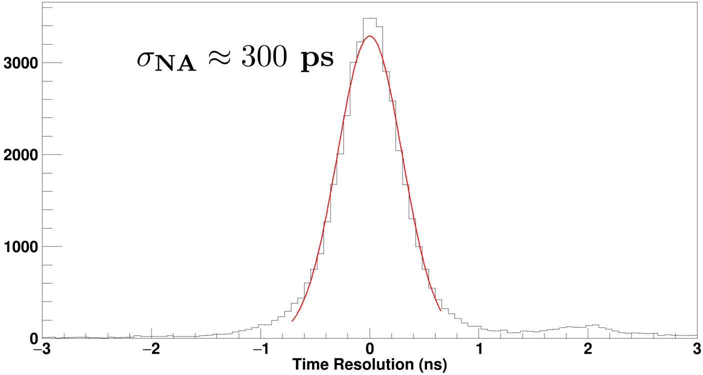
Momentum Resolution



BB Energy Resolution



NA ToF Resolution



Corrections

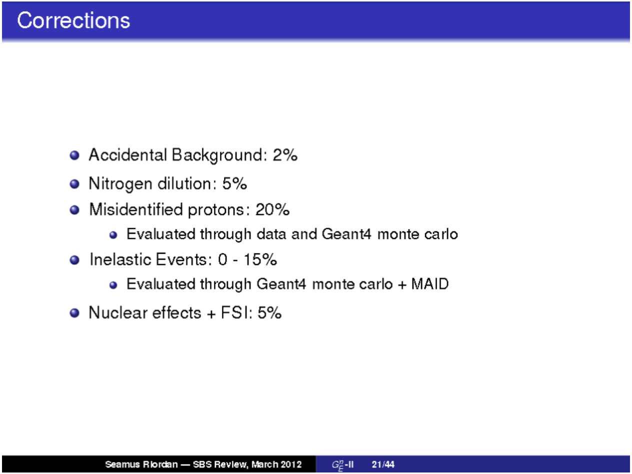


Figure: S. Riordan 2012 SBS Review

IN CASE I FORGET...

$$t_{\text{ToF,ex}} = \frac{\ell}{c}\sqrt{1 + \left(\frac{M}{|\vec{q}\,|}\right)^2}$$

$$\beta = \frac{v}{c} = \frac{|\vec{\ell}\,|}{c\ t_{\text{ToF}}}$$

$$p_{\text{na}} = \frac{M\beta}{\sqrt{1-\beta^2}}$$

$$\delta p = \frac{Mc\beta^2}{\ell}\left(\frac{1}{(1-\beta^2)^{\frac{3}{2}}}\right)\delta t$$