SBS Collaboration Meeting

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July 13, 2017

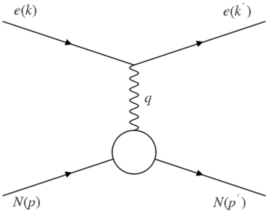
INTRODUCTION

- A brief introduction to the physics goals of E02-013, otherwise known as G_E^n
- Description of the experimental apparatus
- Brief discussion of selected calibration procedures
- Analysis of G_E^n
- Preliminary results of G_E^n at $Q^2 = 1.16\ \text{GeV}^2$

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:

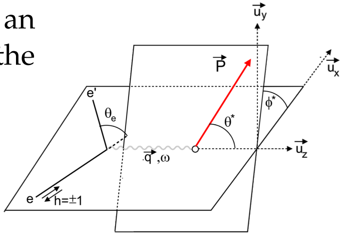
$$\left.\frac{d\sigma}{d\Omega}\right|_{\mathrm{LAB}} = \frac{\alpha^2 \cos^2 \frac{\theta_e}{2}}{4E_e^2 \sin^4 \frac{\theta_e}{2}} \frac{E_e'}{E_e} \left[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2 \frac{\theta_e}{2} \right]$$

$$G_E(Q^2) = F_1(Q^2) - \tau F_2(Q^2)$$
$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$$

BEAM-TARGET ASYMMETRY EXTRACTION

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

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



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

- $P_x = \sin\theta^* \cos\phi^*$ and $P_z = \cos\theta^*$
- Extract $\Lambda \equiv \frac{G_E}{G_M}$ if $\theta^* = \pi/2$ and $\phi^* = 0$ or $180°$

INTRODUCTION TO E02-013

- Goal is to extract G_E^n via a beam-target helicity asymmetry 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.

PRL 105, 262302 (2010) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2010

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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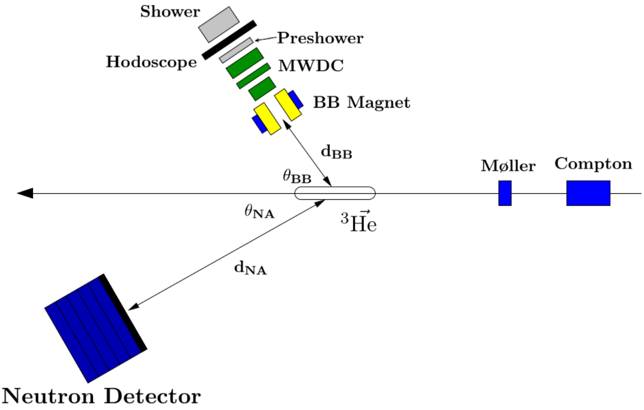
Spokespeople:

- Gordan Cates - University of Virginia
- Nilanga Liyanage - University of Virginia
- Bogdan Wojtsekhowski - Jefferson Lab

GEOMETRY OVERVIEW



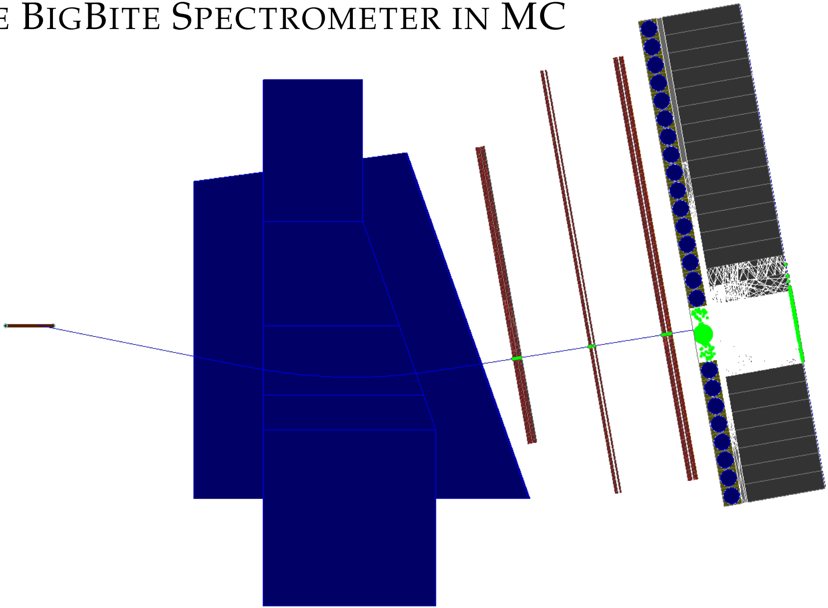
TARGETS OF E02-013

- 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

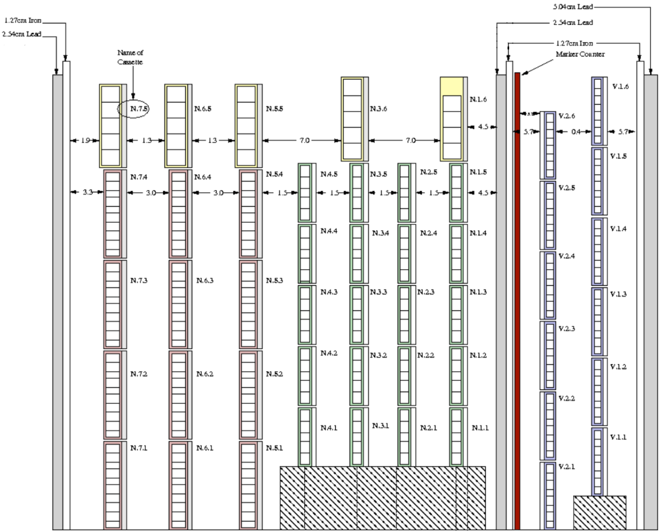
- The purpose is to measure the four momentum of the quasielastically scattered electron
- BigBite is a large dipole magnet that subtends ~ 76 msr and accepts scattered e^- in the range $0.6 < p < 1.8$ GeV.
- Three multiwire drift chambers (15 wire planes) reconstruct the scattered track post magnetic 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 BigBite Spectrometer in MC



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



Front

96 (= 2 × 48) modules in the veto layers (V1-V2) and 244 (= 29 + 25 + 30 + 25 + 3 × 45) neutron bars for a total of 340.

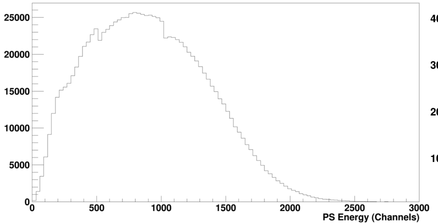
CALIBRATION OF BIGBITE CALORIMETER

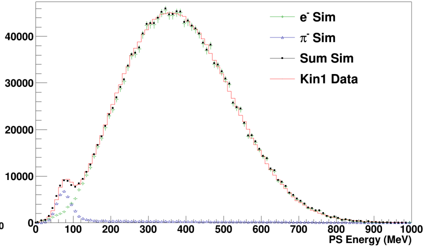
- There are 243 PS and SH blocks, 54 and 189, respectively.
- The best set of gain coefficients may be found by a χ^2-minimization procedure:

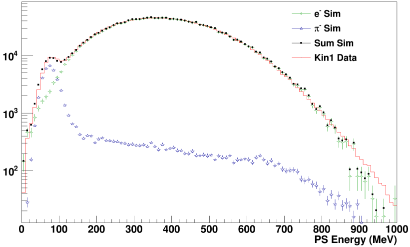
$$\chi^2 = \sum_{i=1}^{N} \left(E_e^i - \sum_{k=0}^{M} C_k A_k^i \right)^2$$

- E_e^i is the reconstructed BB optics energy for event i, A_k is the ADC amplitude for block k of cluster size M, and C_k are the desired coefficients in units of MeV/ADC
- Minimizing χ^2 with respect to C_k results in a system of 243 linear equations.

Before and After Calibrations

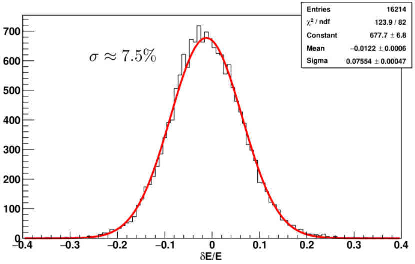


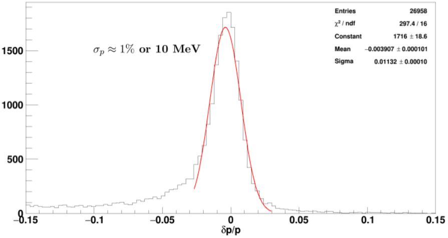




SELECTED CALIBRATIONS SUMMARY

1. Vertex resolution $\sigma_{v_z} \approx 6.5$ mm, BeO-C foil data
2. BigBite optics momentum resolution $\delta p/p = 1\%$, H_2 data
3. BigBite calorimeter resolution $\delta E/E = 7.5\%$, H_2 data
4. NA ToF resolution $\delta t = 300$ ps, H_2 + ^{3}He data





Major Goals of the Analysis

Q^2 [GeV^2]	p_{e^-} [GeV]	p_n [GeV]	β_n	ToF [ns]
1.16	0.86	1.3	0.8	37.5

- Find BigBite tracks and reconstruct the interaction vertex and momentum
- Reconstruct nucleon cluster, associate it to a NA track, and calculate the ToF
- Identify and select the quasielastic region
- Associate a nucleon cluster to veto hits and ID the charge
- Construct the raw asymmetry
- Remove contaminations or dilutions, *e.g.* accidental background, pions, inelastics, FSI, scattering from N_2 in the target cell, or events where the nucleon charge has been misidentified.

QUASIELASTIC SELECTION

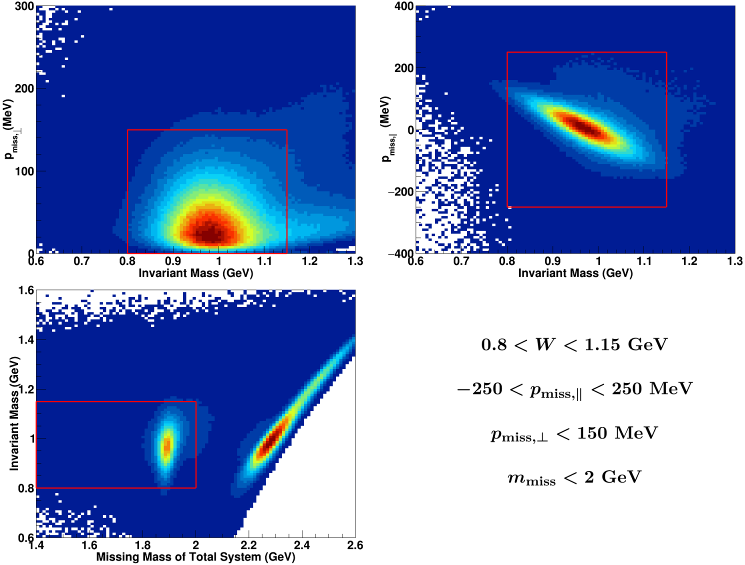
- Need to select the quasielastic region to the best of our ability, hints from H_2 data are invaluable
- Remove target cell windows with $-0.17 < v_z < 0.17$ m
- Suppress pion events with $E_{\text{preshower}} > 150$ MeV
- Invariant mass:

$$W^2 = (p_{\text{i,nuc}} + q)^2 \Rightarrow W = \sqrt{M^2 - Q^2 + 2M\left(E_e - E_e'\right)}$$

- $p_{\text{miss},\parallel} = (\vec{q} - \vec{p}_{\text{na}}) \cdot \hat{q}$
- $p_{\text{miss},\perp} = |\vec{q} - \vec{p}_{\text{na}} - p_{\text{miss},\parallel}\,\hat{q}|$
- $m^2_{\text{miss}} = (P_{\text{i,3He}} + q - p_{\text{NA}})^2$

Notes: For W, initial nucleon is at rest.
For missing mass, initial ^{3}He is free and at rest.

QUASIELASTIC SELECTION



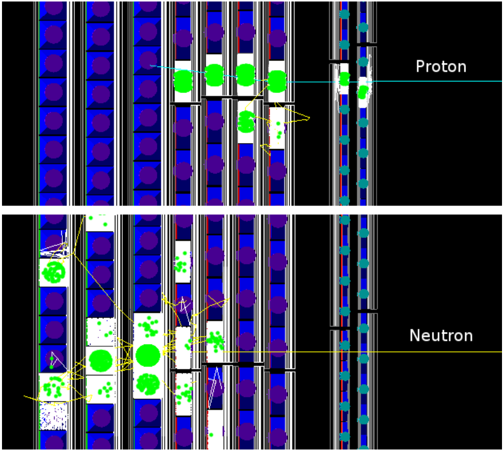
$$0.8 < W < 1.15 \text{ GeV}$$

$$-250 < p_{\text{miss},\parallel} < 250 \text{ MeV}$$

$$p_{\text{miss},\perp} < 150 \text{ MeV}$$

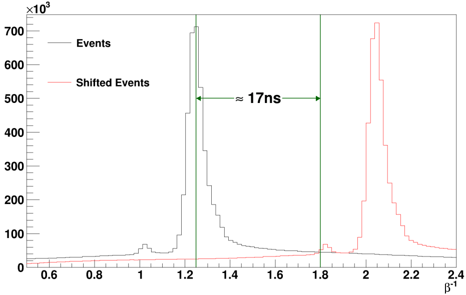
$$m_{\text{miss}} < 2 \text{ GeV}$$

Charge Identification



Side view of ND depicting the ideal scenario of charge ID. The recoiling nucleons have an energy of 1.3 GeV prior to entering the detector.

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

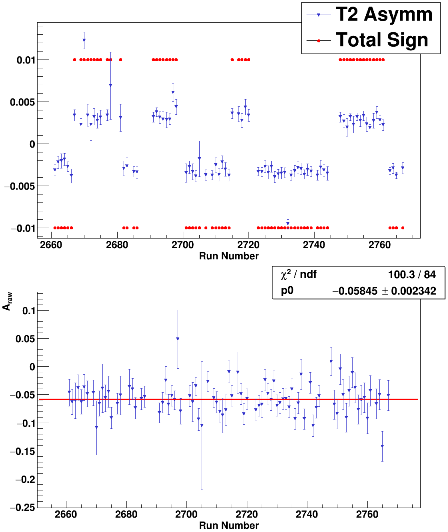
Raw Asymmetry

Top Panel:

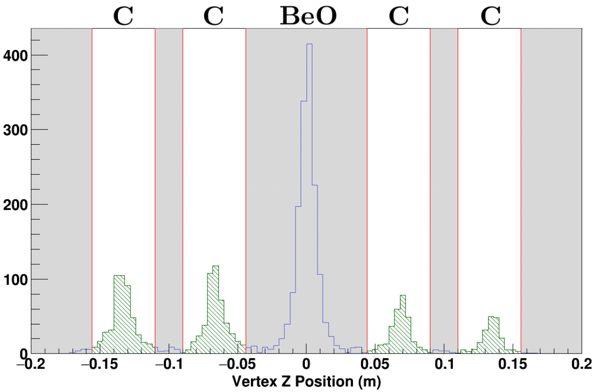
- BB single arm trigger rate T2 is sensitive to beam helicity
- Total sign = (target sign)×(precession sign)×(HWP sign)

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

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

Remaining Corrections

- Correct for target and beam polarization
- Proton contamination is evaluated by studying the uncharged-to-charged ratios of H_2, ^{3}He, and foil data
- Preshower pion contamination has been estimated with Monte Carlo
- Inelastic contribution is expected to be small (to do list)
- Final state interactions estimated with generalized eikonal approximation calculations (to do list)

$\langle Q^2 \rangle$ [GeV^2]	1.16	**Remarks**
W [GeV]	0.8 – 1.15	Invariant Mass
$\mathbf{p_\perp}$ **[MeV]**	< 150	Missing $\perp$ momentum
$\mathbf{p_{\|\|}}$ **[MeV]**	< 250	Missing $\|\|$ momentum
$\mathbf{m_{miss}}$ **[GeV]**	< 2	Missing mass
$\mathbf{D_{back}}$	0.949 ± 0.029	Accidental background
$\mathbf{D_{N_2}}$	0.947 ± 0.004	Nitrogen in target
$\mathbf{D_p}$	0.812 ± 0.016	Proton contamination
$\mathbf{D_{in}}$	0.980 ± 0.011	Inelastic contamination
$\mathbf{P_{beam}}$	0.852 ± 0.055	Beam polarization
$\mathbf{P_{He}}$	0.416 ± 0.019	Average polarization ^{3}He nuclei
$\mathbf{P_n}$	0.978 ± 0.010	Neutron polarization in target

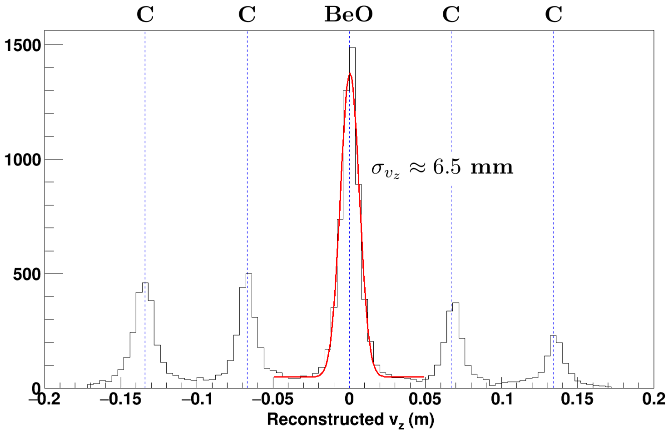
Table: Numbers used in preliminary calculation of G_E^n.

$\langle Q^2 \rangle$	1.16	1.72	2.48	3.41
$\mathbf{W}$	$0.8 - 1.15$	$0.7 - 1.15$	$0.65 - 1.15$	$0.6 - 1.15$
$\mathbf{p}_\perp$	< 150	< 150	< 150	< 150
$\mathbf{p}_\parallel$	< 250	< 250	< 250	< 400
$\mathbf{m_{miss}}$	< 2	< 2	< 2	< 2.2
$\mathbf{D_{back}}$	0.949 ± 0.029	0.970	0.981	0.975
$\mathbf{D_{N_2}}$	0.947 ± 0.004	0.948	0.949	0.924
$\mathbf{D_p}$	0.812 ± 0.016	0.782 ± 0.033	0.797 ± 0.036	0.807 ± 0.032
$\mathbf{D_{in}}$	0.980 ± 0.011	0.980 ± 0.011	0.963 ± 0.027	0.851 ± 0.060
$\mathbf{P_{beam}}$	0.852 ± 0.055	0.852 ± 0.055	0.850 ± 0.031	0.829 ± 0.026
$\mathbf{P_{He}}$	0.416 ± 0.019	0.470 ± 0.076	0.439 ± 0.059	0.462 ± 0.047
$\mathbf{P_n}$	0.978 ± 0.010	0.975 ± 0.033	0.975 ± 0.024	0.975 ± 0.016

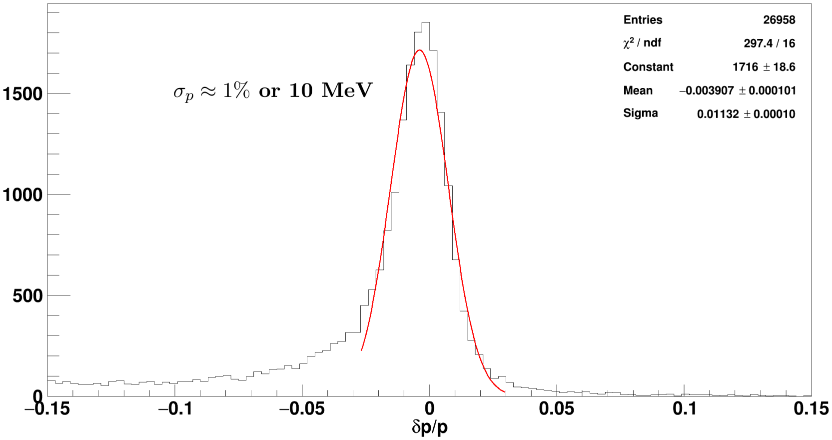
Table: Errors for higher Q^2 are systematic contributions as a fraction of the G_E^n value as seen in 2010 Riordan *et al.* PRL. Other ~ 0.025

Appendix

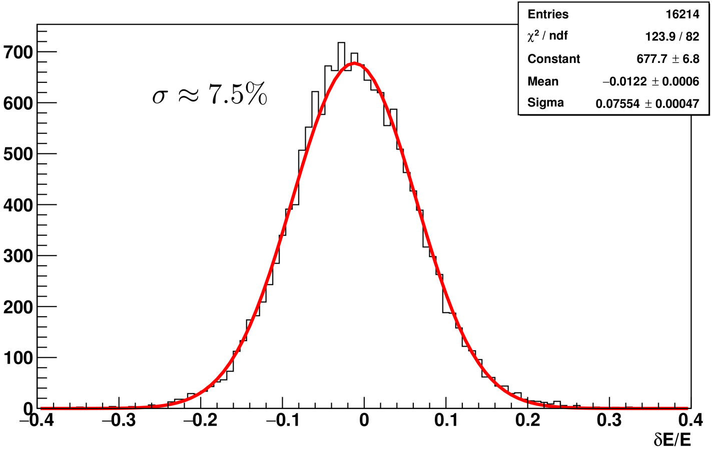
Vertex Resolution



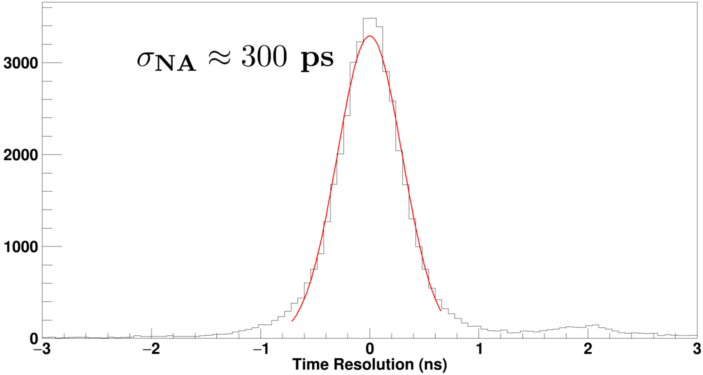
MOMENTUM RESOLUTION



BB Energy Resolution



NA ToF Resolution



CORRECTIONS

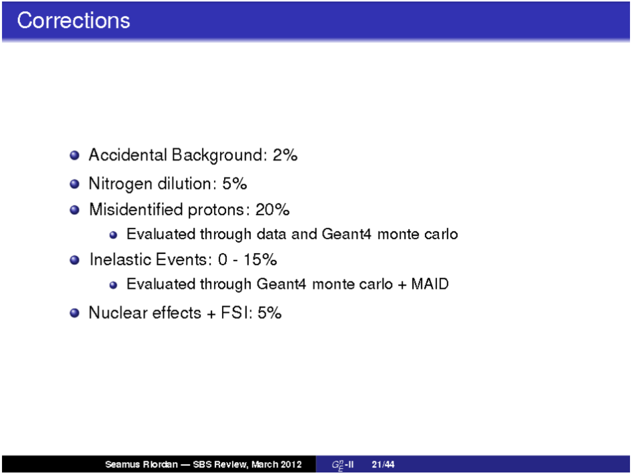


Figure: S. Riordan 2012 SBS Review

In case I forget...

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

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

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

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