Two-Photon Exchange Contribution to the Electron-Neutron Elastic Scattering Cross Section Using the Super BigBite Spectrometer in Hall A

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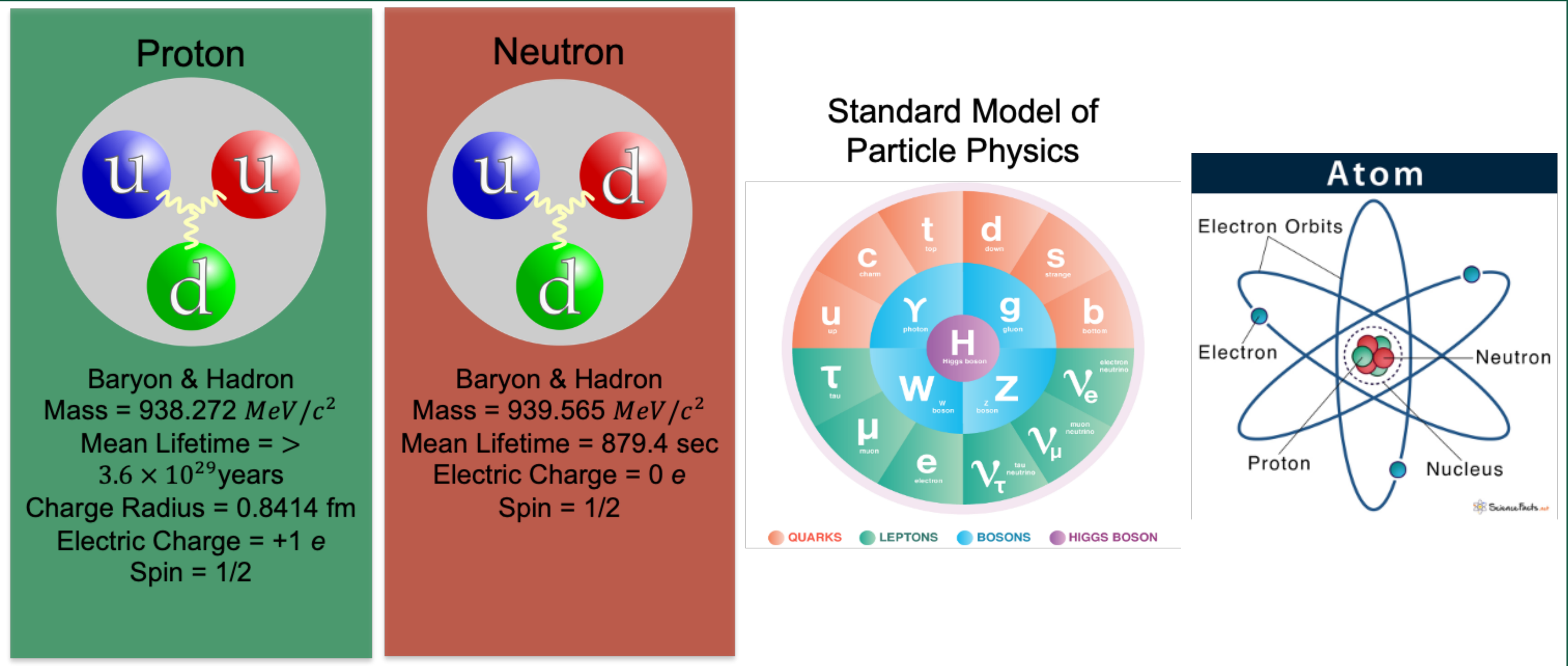
For the SBS Collaboration

What is Ordinary Matter?



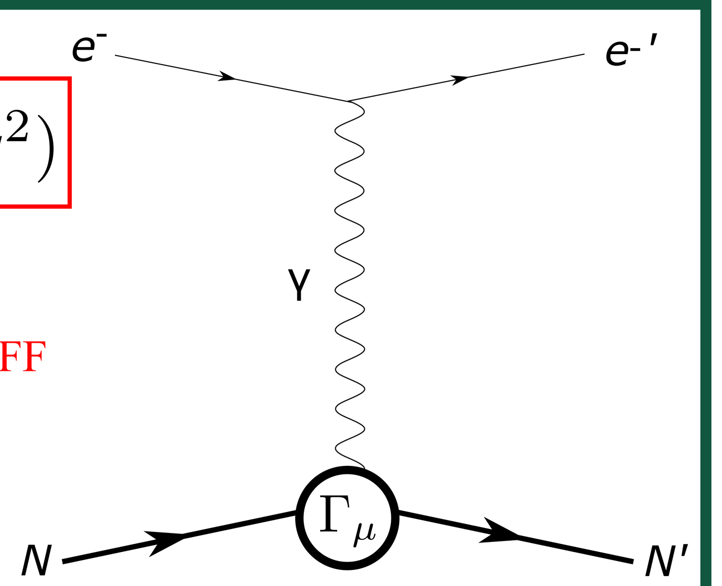
Ordinary matter in the universe is made of atomic nuclei which is a composite of subatomic particles known as protons/neutrons (the nucleon). Studying the building blocks of all nuclei provides a better fundamental understanding of the universe.

Elastic e-N scattering & FFs

Nucleon Vertex:

$$\Gamma_\mu(q) = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2M_N} F_2(q^2)$$

Dirac FF (F_1), Pauli FF (F_2)



Sachs Form Factors:

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

G_E, G_M are Electric and Magnetic Form Factors respectively

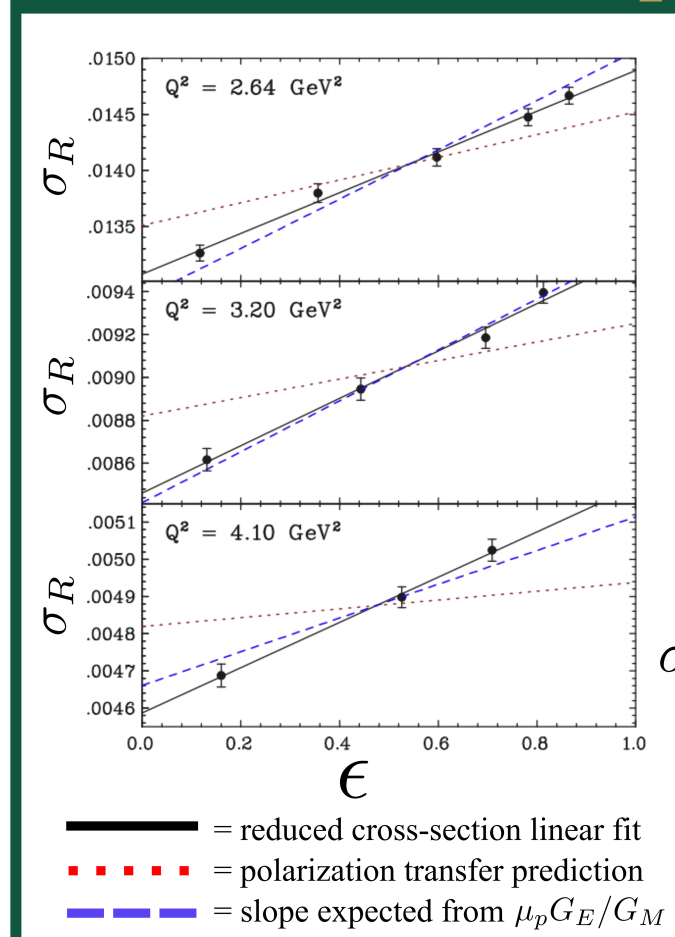
Differential Cross Section:

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\left(\epsilon G_E^2(Q^2) + \tau G_M^2(Q^2)\right)$$

$Q^2 = -q^2$
$\tau = Q^2/4M_N^2$
$\epsilon = \left(1 + 2(1+\tau)\tan^2(\theta/2)\right)^{-1}$

Elastic Electromagnetic Form Factors are some of the most basic observables and encode the internal electric charge and magnetic distributions of the nucleon.

Rosenbluth Separation for Nucleon FFs



$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha}{4M_N Q^2}\frac{E'}{E}\right)^2 |M_\gamma|^2$$
$$= \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\left(\epsilon G_E^2(Q^2) + \tau G_M^2(Q^2)\right)$$
$$= \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\sigma_R = \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\left(\epsilon\sigma_L + \sigma_T\right)$$

M_γ is invariant amplitude

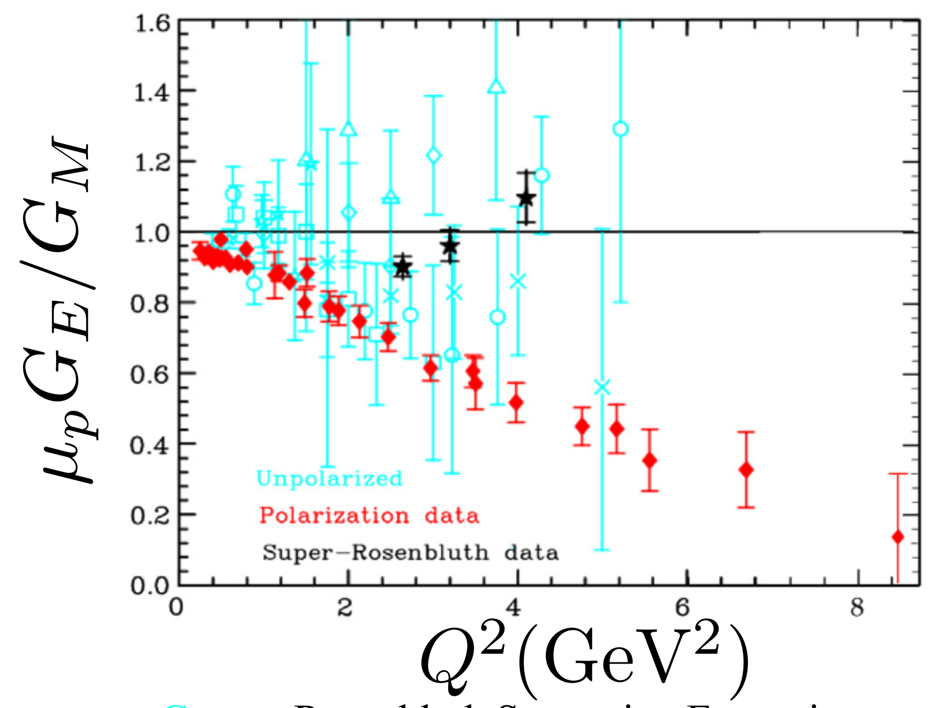
α is fine structure constant

σ_{Mott} is the scattering from a point-like particle

Method used extensively for studying proton

nTPE experiment will use this method for the first on neutron

Proton FF Ratio Discrepancy



Cyan = Rosenbluth Separation Extraction
Red = Polarization Transfer Measurements
Black = Super Rosenbluth

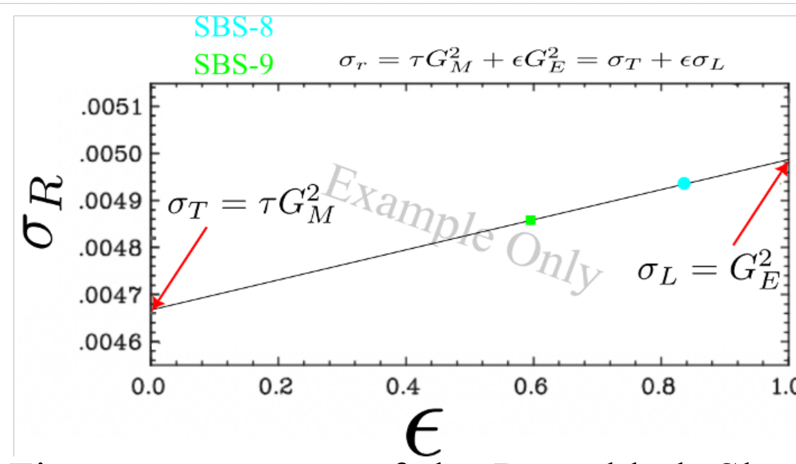
Two primary measurment methods:
1. Rosenbluth Separation (Cross-Section data)
2. Polarization Transfer

Rosenbluth:
1. Consistent with 1.0
2. Identical spatial dependences
3. Sensitive to TPE

Polarization Transfer:
1. Disagress by 3-4 sigma
2. Charge distribution is more spatially spread out than magnetization distribution
3. Insensitive to TPE

SBS nTPE Experiment

Name	Ebeam (GeV)	BigBite angle (deg)	BigBite Distance (m)	SBS angle (deg)	SBS distance (m)	HCAL "angle" (deg)	HCAL distance (m)	Q^2 (GeV^2)	Electron P (GeV)	Nucleon P (GeV)
SBS-8	5.965	26.5	2.00	29.9	2.25	29.4	11.0	4.5	3.58	3.2
SBS-9	4.015	49.0	1.55	22.5	2.25	22.0	11.0	4.5	1.6	3.2



First measurement of the Rosenbluth Slope (RS) for the neutron using the ratio method. Data taken January & February 2022 for a total of 19 days at 2 different kinematic values. Exploiting the linearity of the reduced cross section extracts neutron FFS.

Measured Observable:

$$R_{observed} = N_{e,e'n}/N_{e,e'p}$$

Nuclear & Radiative Corrections:

$$R_{corrected} = f_{corr} \times R_{observed}$$

Relation to Cross-Sections:

$$R_{corrected,\epsilon} = \frac{\sigma^n_{Mott}(1+\tau_p)}{\sigma^p_{Mott}(1+\tau_n)} \times \frac{\epsilon\sigma^n_L + \sigma^n_T}{\epsilon\sigma^p_L + \sigma^p_T}$$

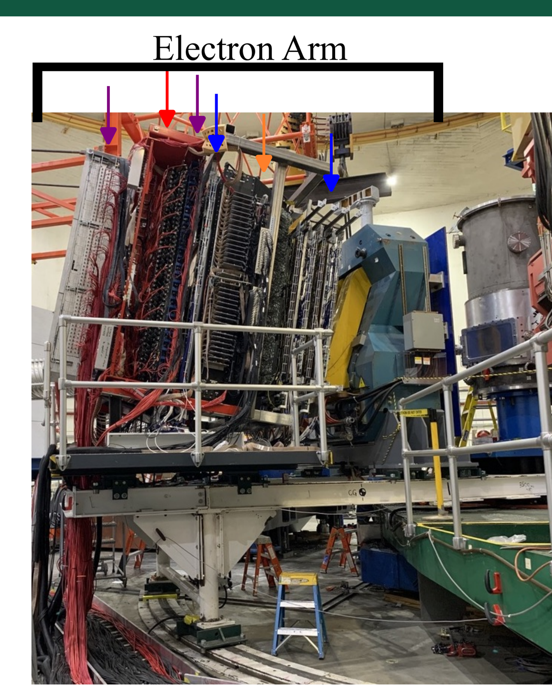
Physics result:

$$A \equiv \frac{R_{corrected,\epsilon_1}}{R_{corrected,\epsilon_2}} = B \times \frac{1+\epsilon_1 S^n_c}{1+\epsilon_2 S^n_c}$$
$$\approx B \times (1 + \Delta\epsilon \cdot S^n_c)$$

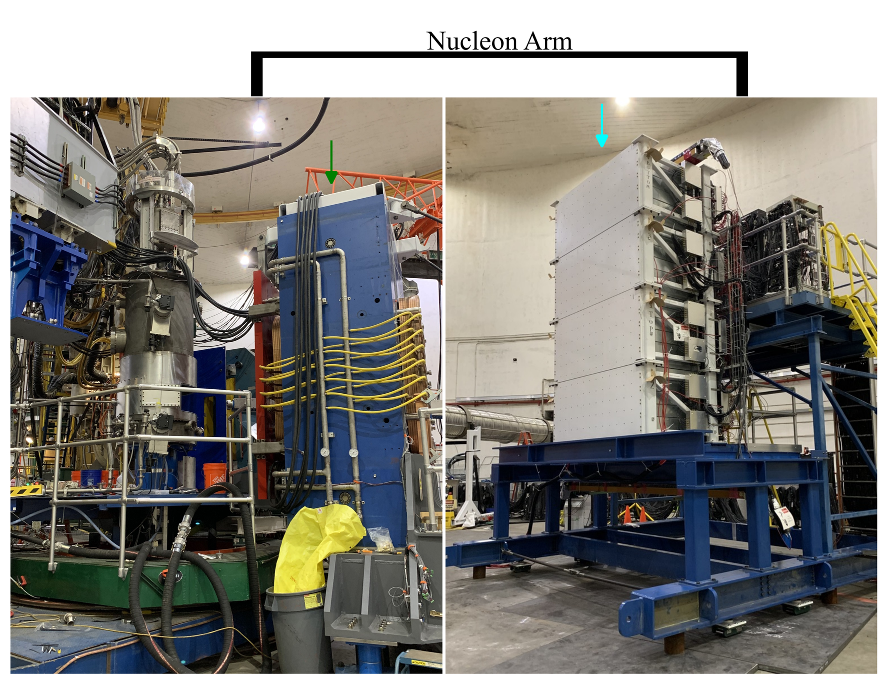
From Data, Proton Global data (from analysis of e-p cross-section take as known), kinematic info, Physics Result!

$$S^{n(p)}_c = \sigma^{n(p)}_L/\sigma^{n(p)}_T$$

SBS Apparatus

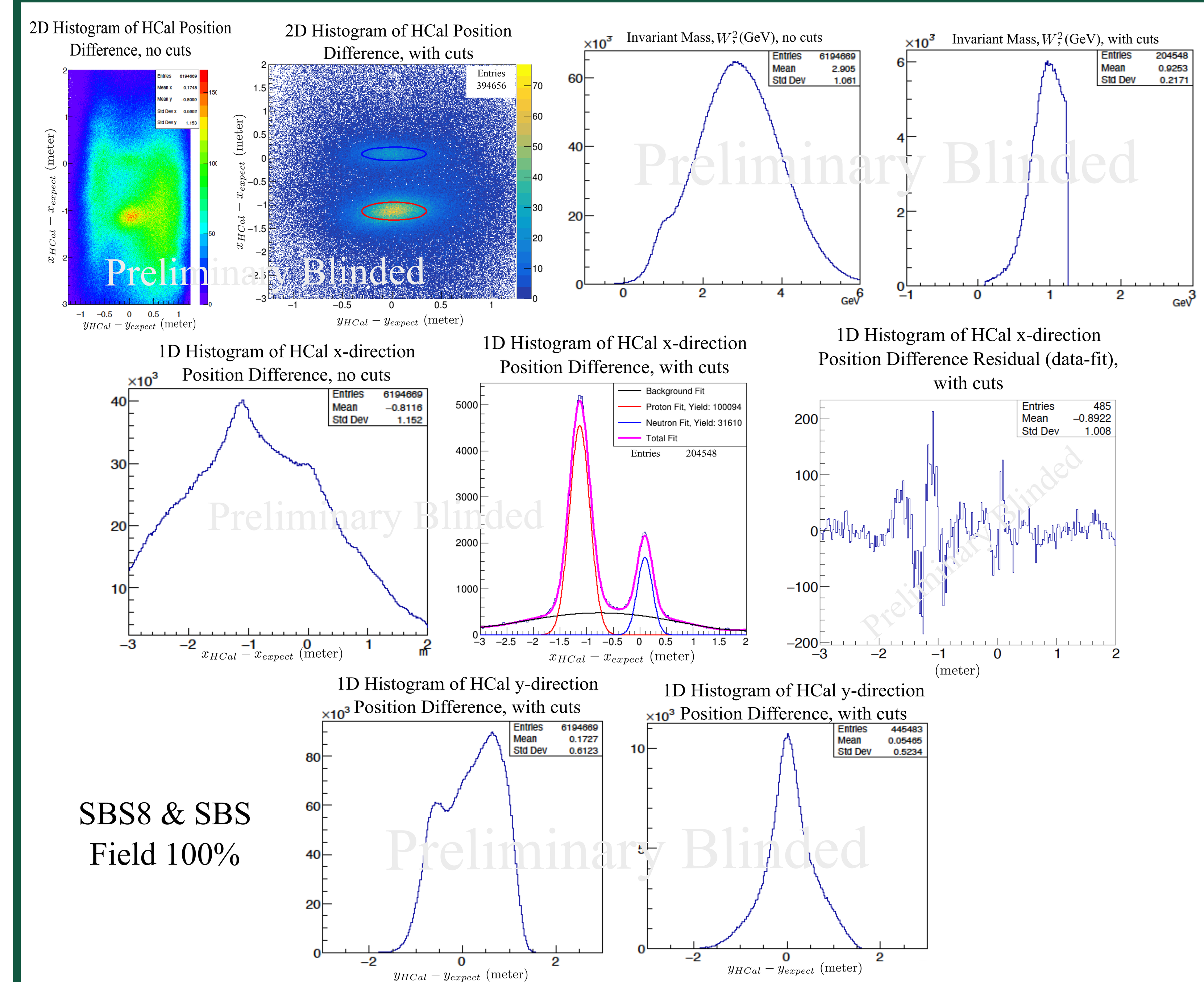


Dueteron target & BigBite Spectrometer includes Gas Electron Multipliers (GEMs), GRINCH, Timing Hodoscope, Calorimeters

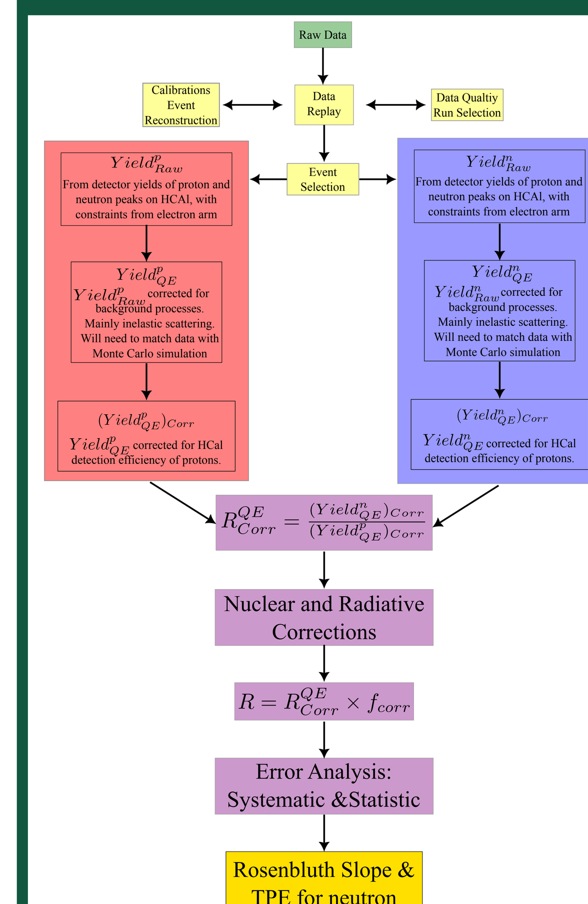


Super BigBite Spectrometer includes Super BigBite Magnet & Hadron Calorimeter (HCal)

Analysis Status



Outlook



In-progress (me):

Refine yields script by implementing interpolated functions and sideband analysis.
Refine HCal proton efficiency script and method.
Compare to Monte Carlo Simulation.
Created script for data & simulation comparison.
Implement method for backgrounds based on anticut.
Implement acceptance & fiducial cuts.
Create script for physics result.

In-progress (collaboration):

Dedicated effort to implement nuclear & radiative corrections.
Efforts for 2nd pass mass replay are underway, would be quality enough for preliminary result.
Determine error analysis, mainly systematics.

References & Acknowledgments

1. Afansev, A., et al. "Two-Photon exchange contribution in elastic electron-proton scattering" *Prog. Part Nucl.* Phy. 95, 245 (2017)
2. Alsalmi, S., et al. "Measurement of the Two-Photon Exchange Contribution to the Electron-Neutron Elastic Scattering Cross-Section." (2020). Proposal# E12-20-010

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