Generalized GDH Sum Rules for Neutron and ^{3}He at Low Q^2

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For E97-110 and Hall A Collaborations

HALL A/C COLLABORATION MEETING, JUNE 08, 2021

Outline

Introduction

Experiment E97-110

E97-110 Results

Generalized GDH Sum Rules

Virtual Compton amplitudes are related to moments of spin dependent structure functions

- Connect moments of spin-dependent structure functions with the Compton amplitudes

$$I_{TT}(Q^2) = \frac{M^2}{4\pi^2\alpha}\int_{\nu_{th}}^{\infty}\frac{K\sigma_{TT}(\upsilon, Q^2)}{\upsilon^2}d\upsilon$$

$$= \frac{2M^2}{Q^2}\int_0^{x_{th}}\left[g_1(x, Q^2) - \frac{4M^2x^2}{Q^2}g_2(x, Q^2)\right]dx$$

g_1 and g_2 are experimentally accessible, $I_{TT}(Q^2)$ predictions are given by theories

- Chiral Effective Field Theory (ChEFT)
- Lattice QCD (not available yet)

Generalized Spin Polarizabilities

Longitudinal-Transverse (LT) interference polarizability

$$\delta_{LT}(Q^2) = \frac{16\alpha M^2}{Q^6} \int_0^{x_{th}} [g_1(x, Q^2) + g_2(x, Q^2)] x^2 dx$$

- Quantifies the spin precession from LT interference (analogous in classical view)
- Arises because of virtual photon $(Q^2 \neq 0)$ can be longitudinally polarized
- "Gold-plated" observable for ChEFT because of suppression in $\Delta(1232)$ contributions

Forward spin polarizability

$$\gamma_0(Q^2) = \frac{16\alpha M^2}{Q^6} \int_0^{x_{th}} \left[g_1(x, Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x, Q^2) \right] x^2 dx$$

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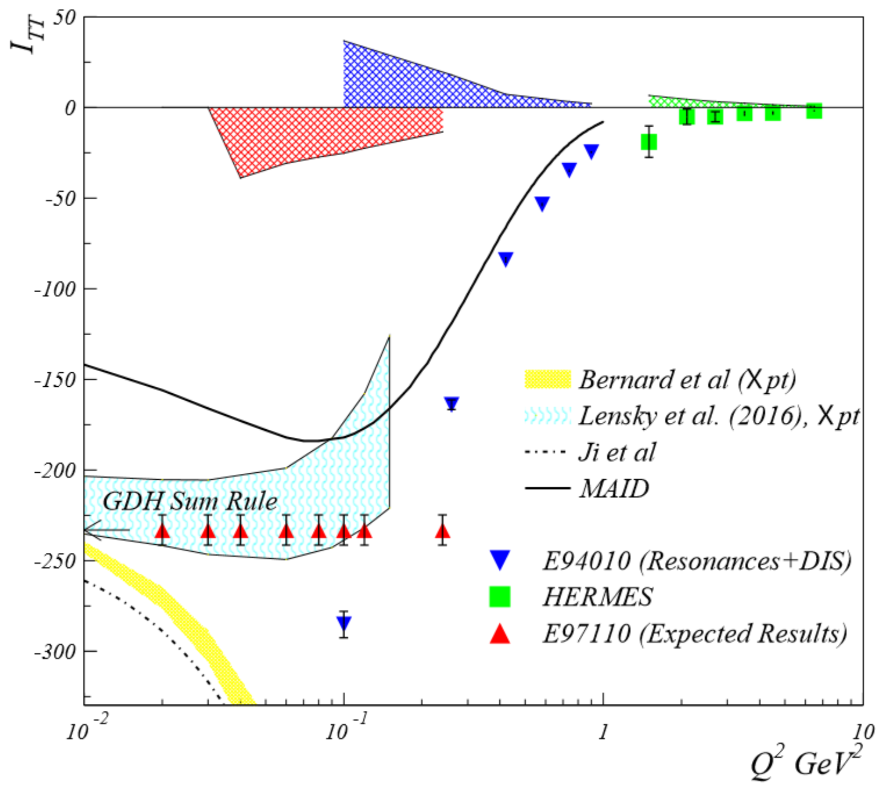
E97-110 at Jefferson Lab



Inclusive measurement, ${}^{3}\vec{\mathrm{He}}(\vec{e},e')X$

- Scattering angles: 6º and 9º
- Polarized electron beam, P_{beam} = 75%
- Polarized ^{3}He target, P_{target} = 40%

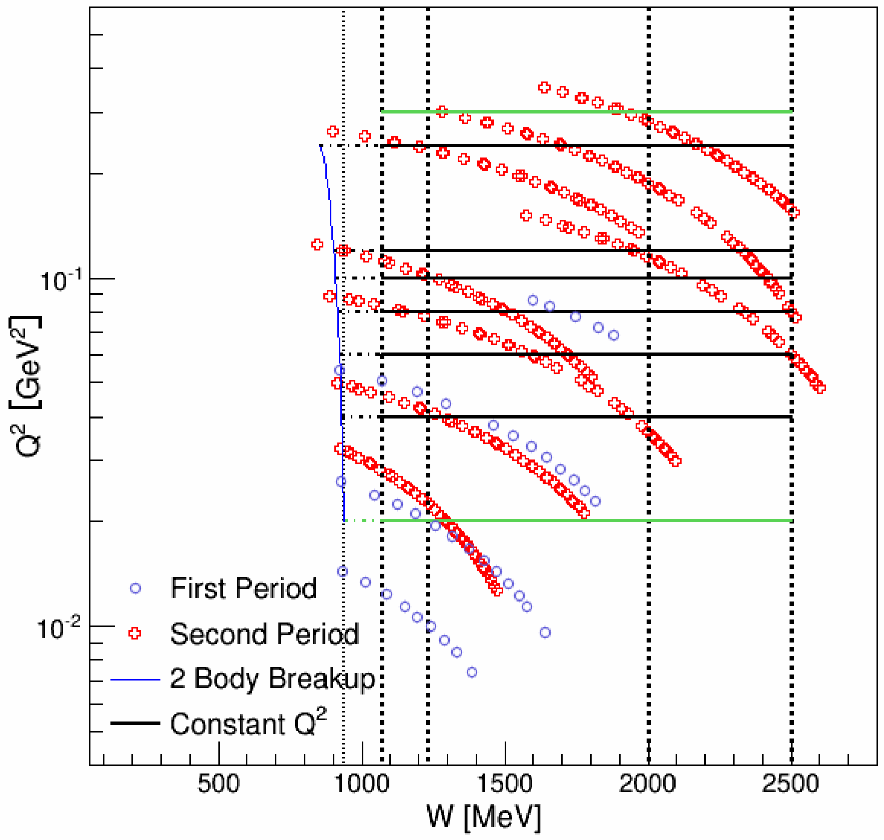
Measured the differences of polarized cross sections

- Parallel (anti-parallel)
- Perpendicular

Spokespersons: J.-P. Chen, A. Deur, F. Garibaldi

Graduate students: J. Singh, V. Sulkosky, J. Yuan, C. Peng, N. Ton

E97-110 at Jefferson Lab

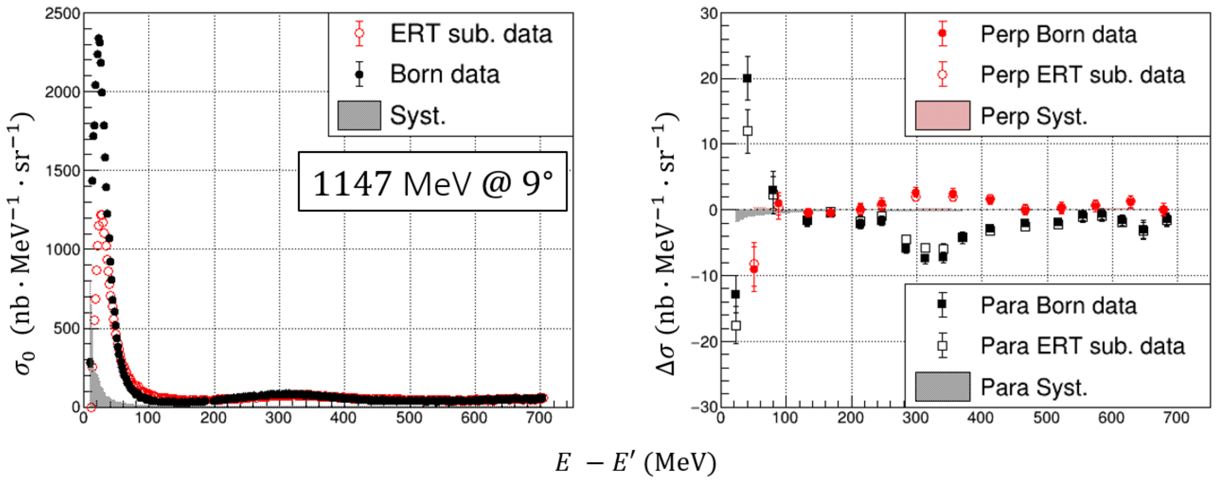


Target Cell	Angle	Beam Energy (MeV)
Penelope	6.10°	2134.2
Priapus	6.10°	2134.9
Priapus	6.10°	2844.8
Priapus	6.10°	4208.8
Priapus	9.03°	1147.3
Priapus	9.03°	2233.9
Priapus	9.03°	3318.8
Priapus	9.03°	3775.4
Priapus	9.03°	4404.2

Radiative Correction

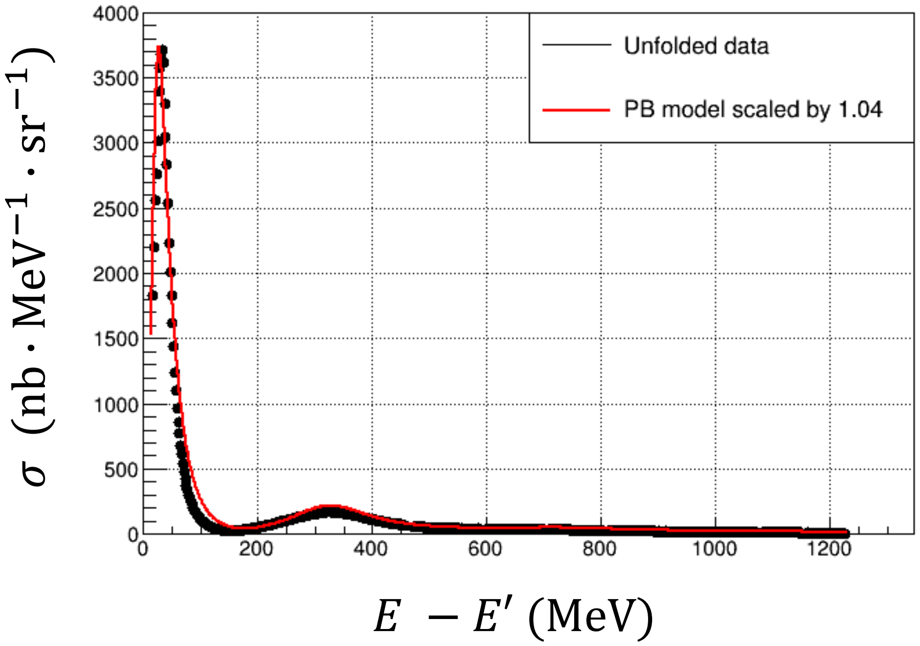
Iterative correction

- Build pseudo-model with experimental data
- Interpolation and extrapolation (or filled by other models) for unmeasured points
- Calculate radiative effects with this pseudo-model
- Unfold Born cross sections, and then update the pseudo-model
- Repeat until results are converged

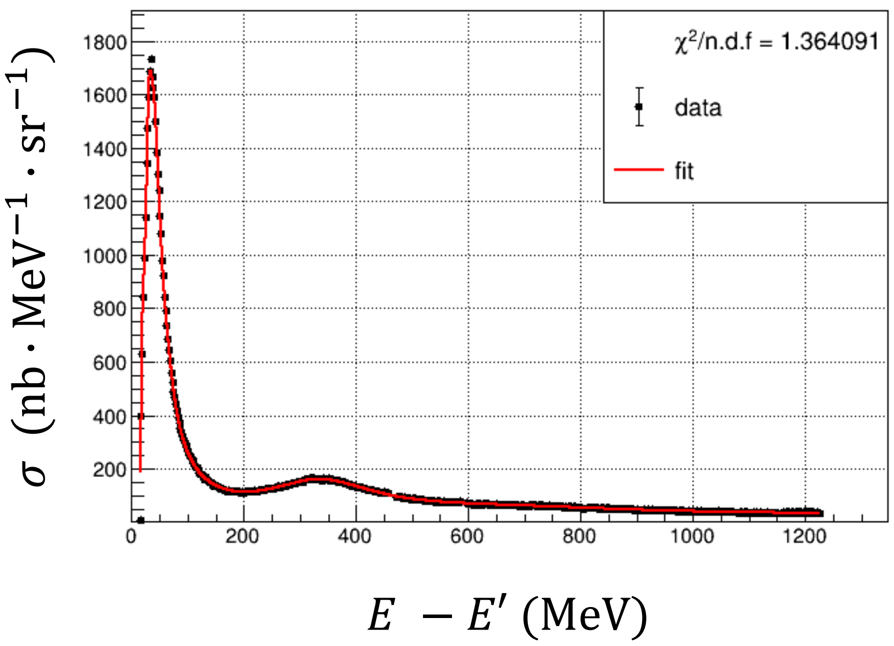


Radiative Correction

Peter-bosted model for unmeasured extrapolation



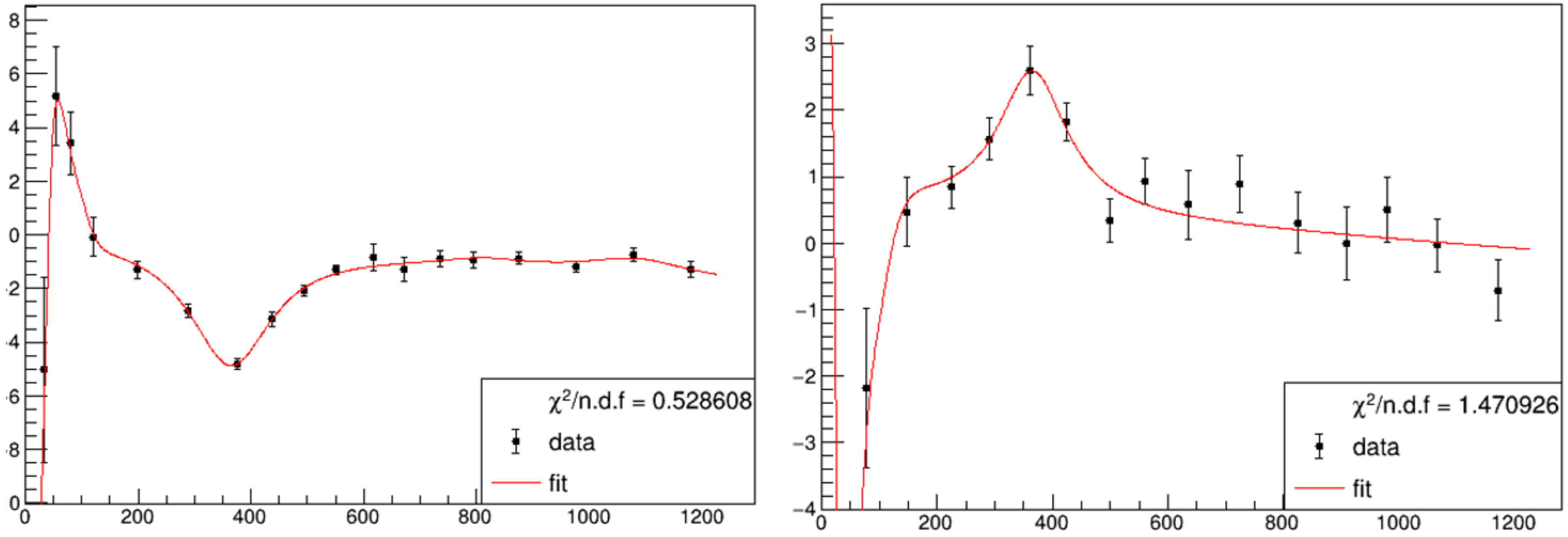
Fit for interpolation



Radiative Correction

2135 MeV @ 6°

$\Delta\sigma\ (\mathrm{nb \cdot MeV^{-1} \cdot sr^{-1}})$

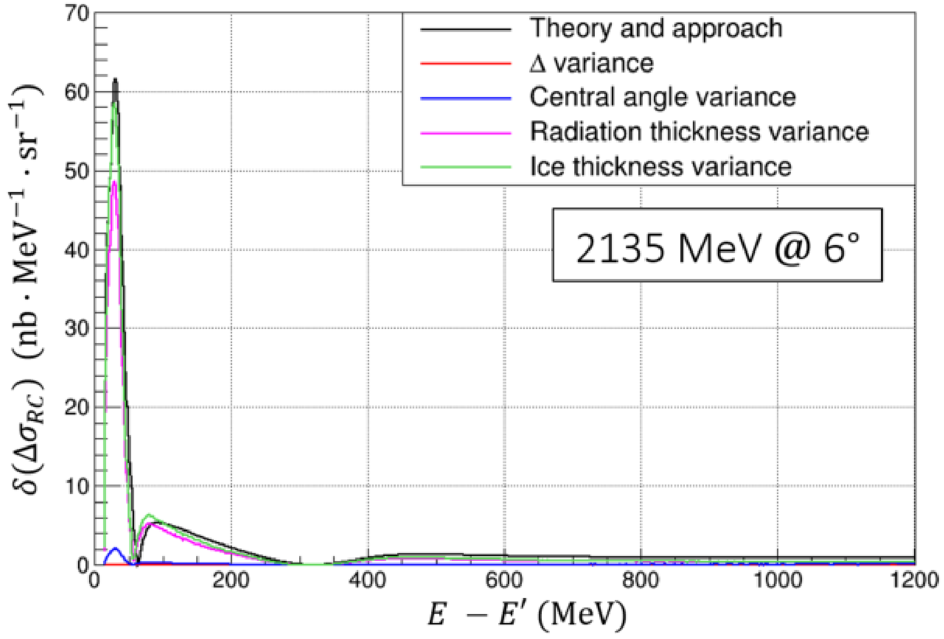


$E\ - E'\ (\mathrm{MeV})$

Radiative Correction

Systematic uncertainties

- Internal effects by comparing different approaches < 3%
- Extrapolation or model dependency for the unmeasured region
  - Cross-check with each other < 3%
- Free parameter Δ for singular integral of $I(E, E', l)$
  - $\Delta = 1 \pm 0.5$ MeV tested, negligible
- Material thickness uncertainty
- Particle trajectory uncertainty
  - Varied the central angle by $\pm 0.1^{\circ}$



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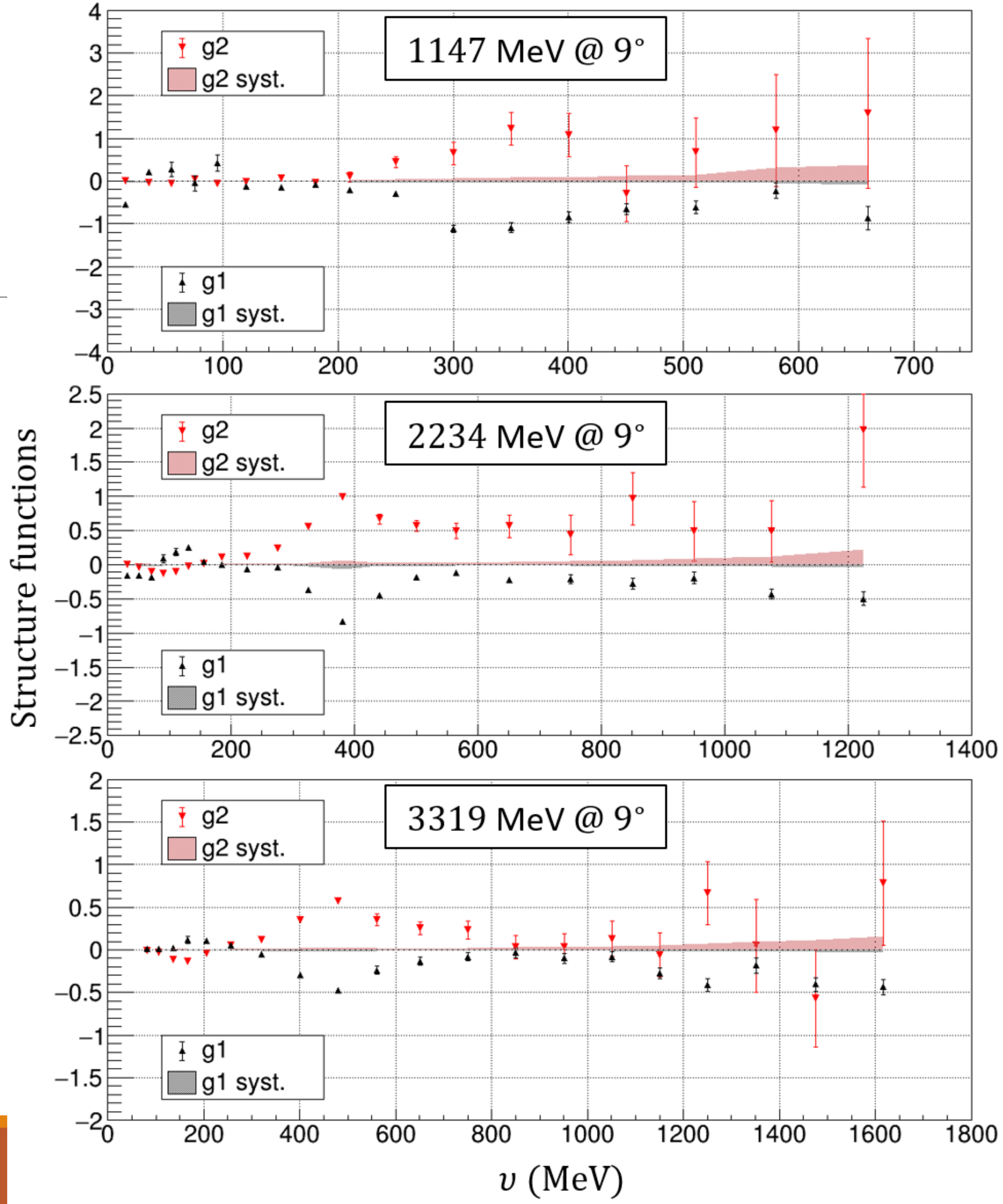
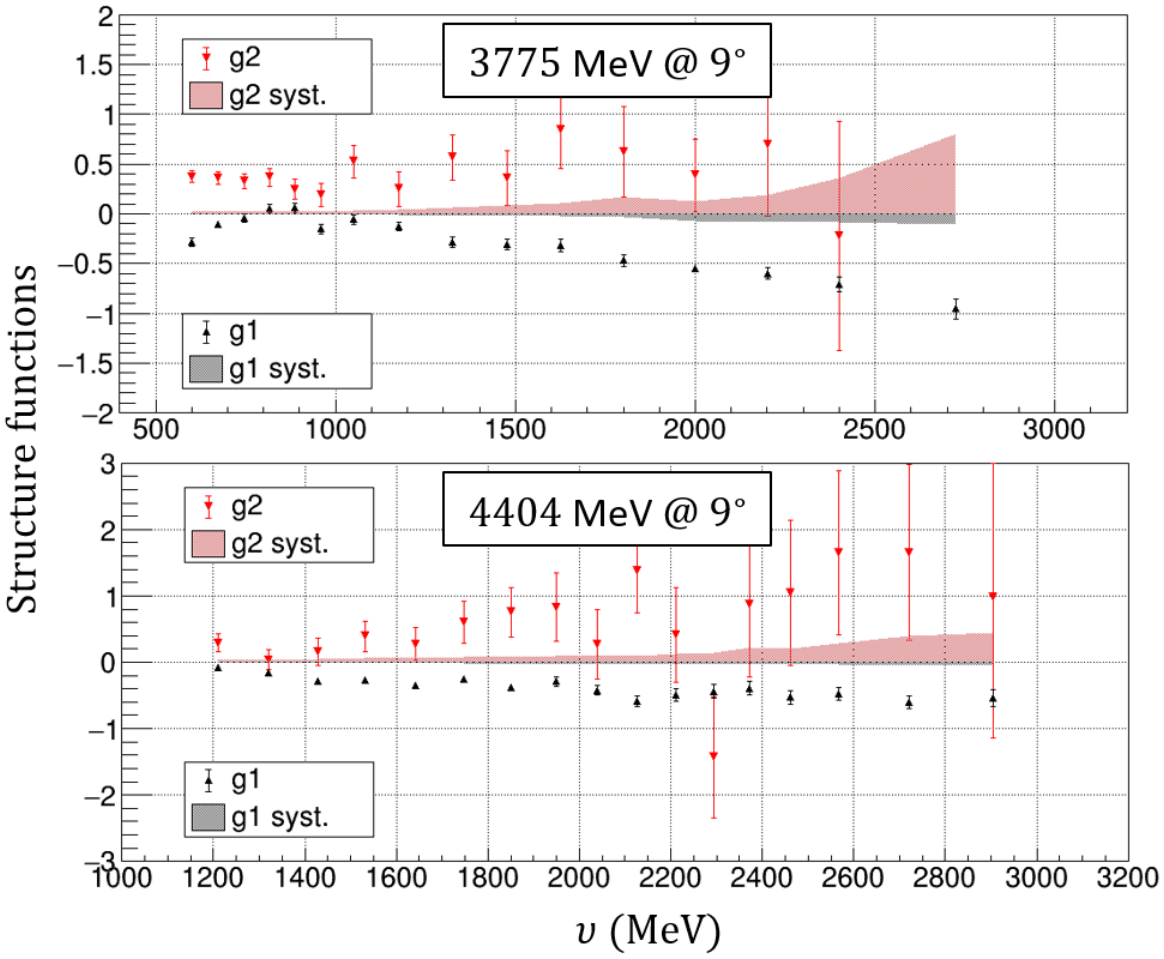
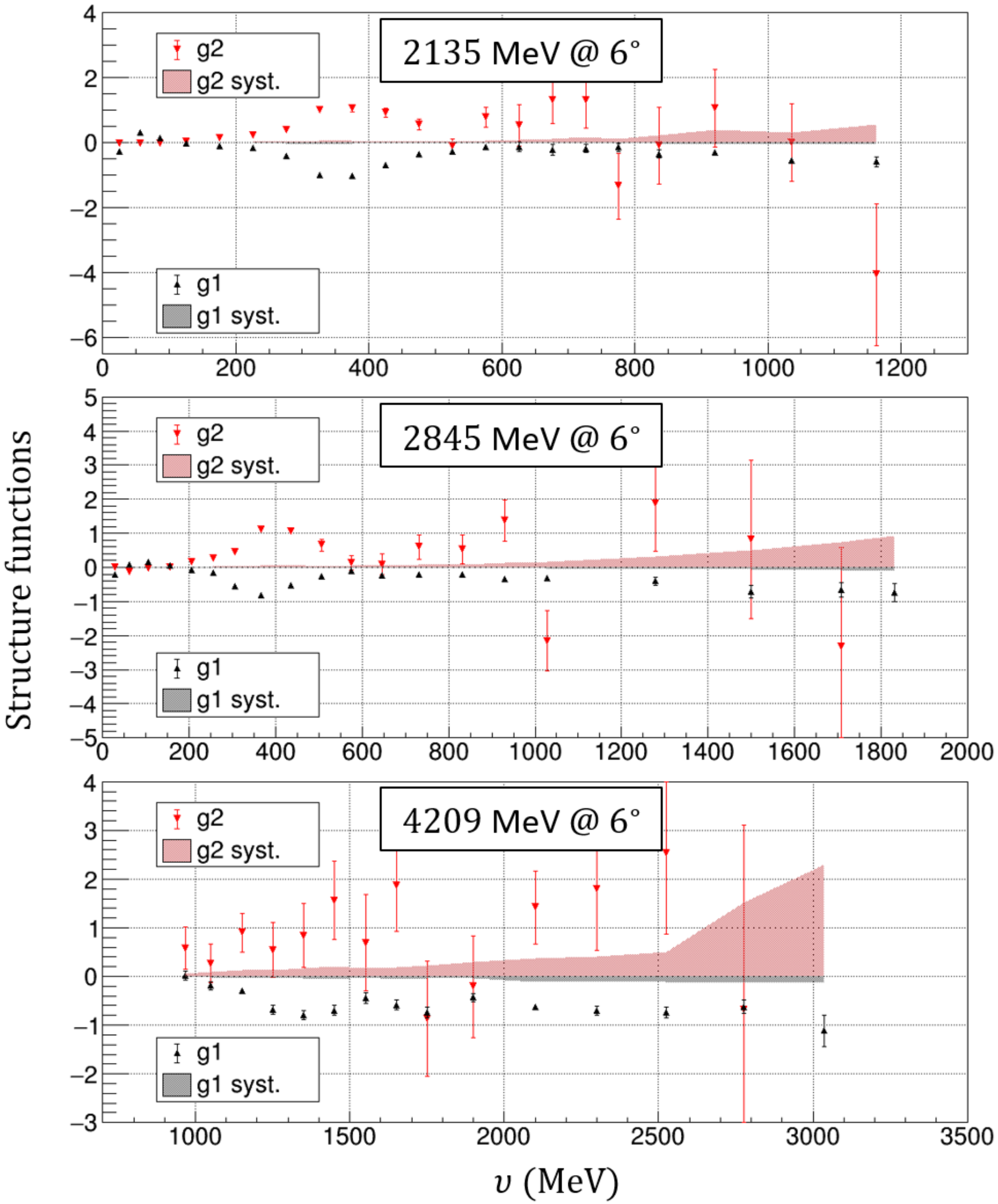
^{3}He
Spin-dependent
Structure
functions



^{3}He Spin-dependent Structure functions

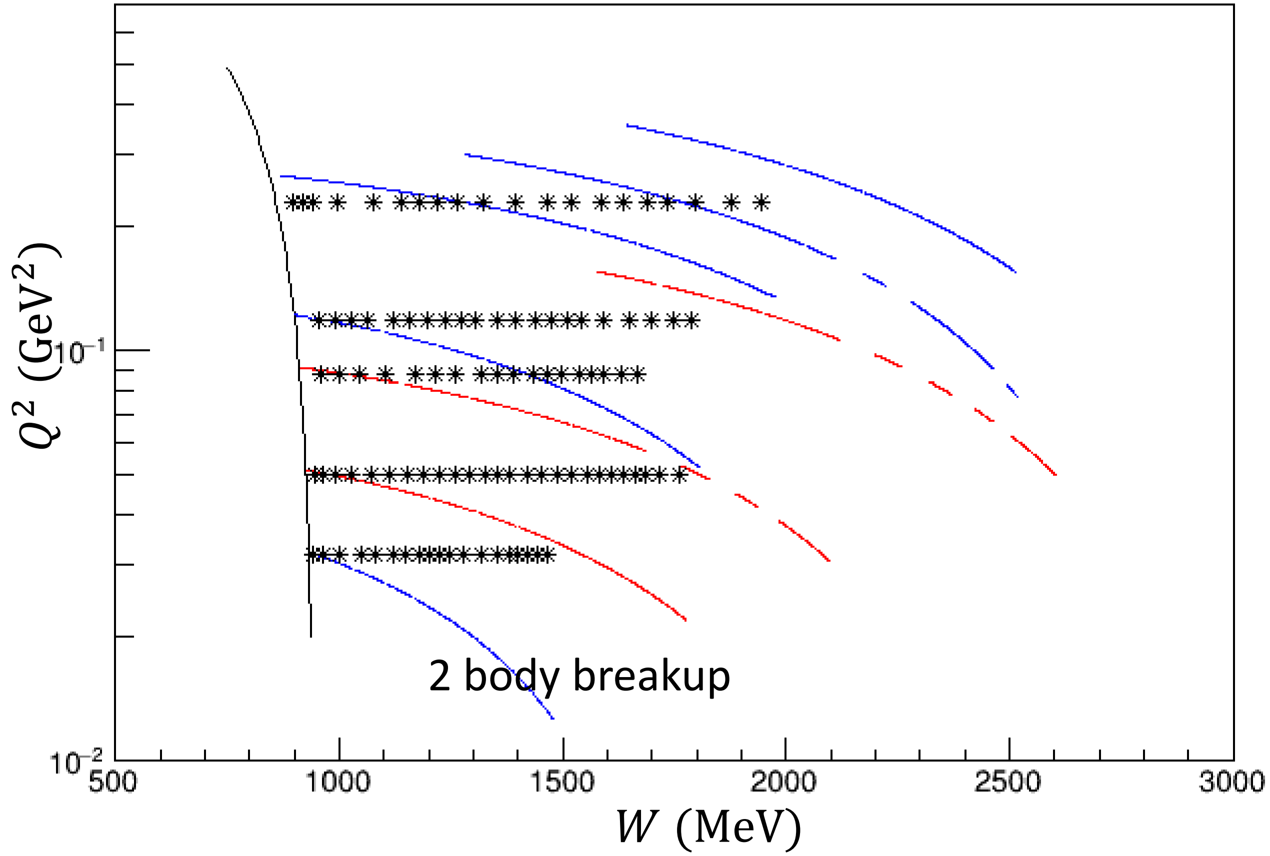


^{3}He Spin-dependent Structure functions



Interpolation to constant Q^2

$Q^2 = 0.032 \sim 0.23 \text{ GeV}^2$

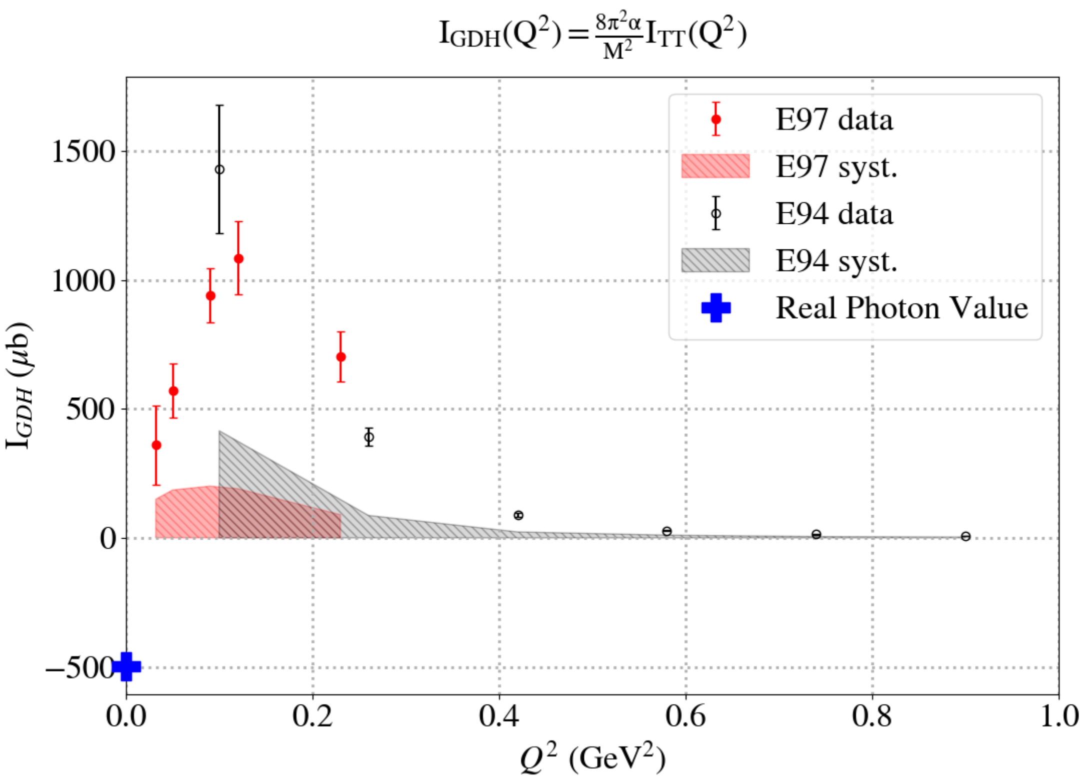


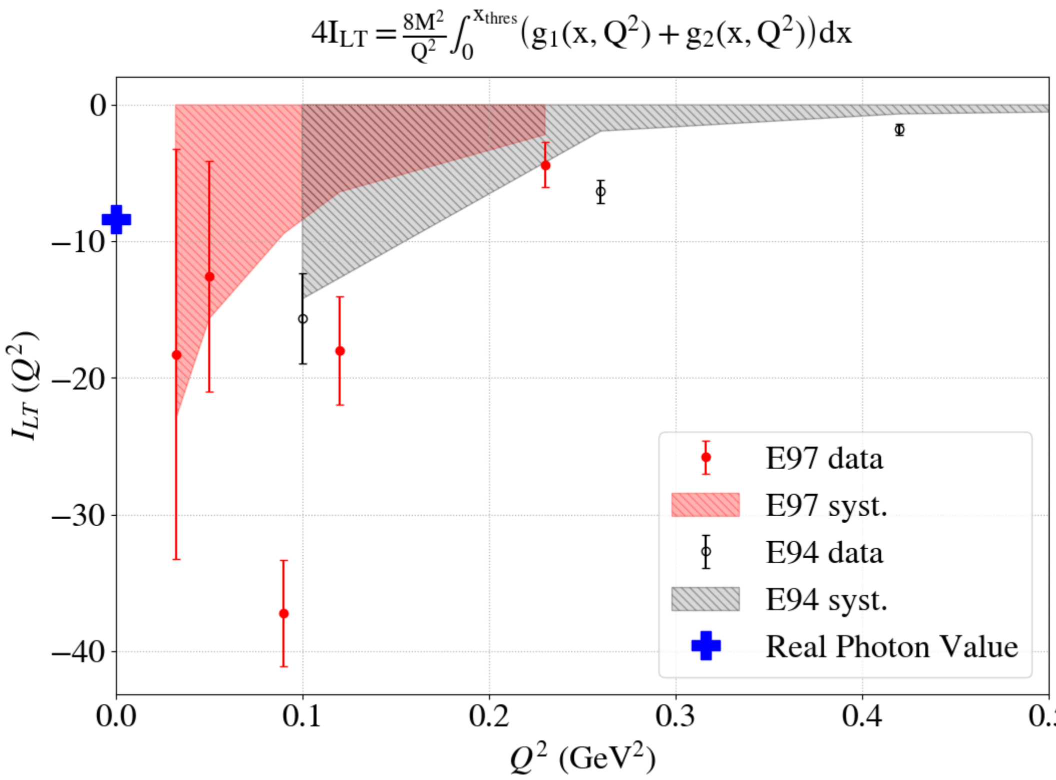
Blue: 9 degree

Red: 6 degree

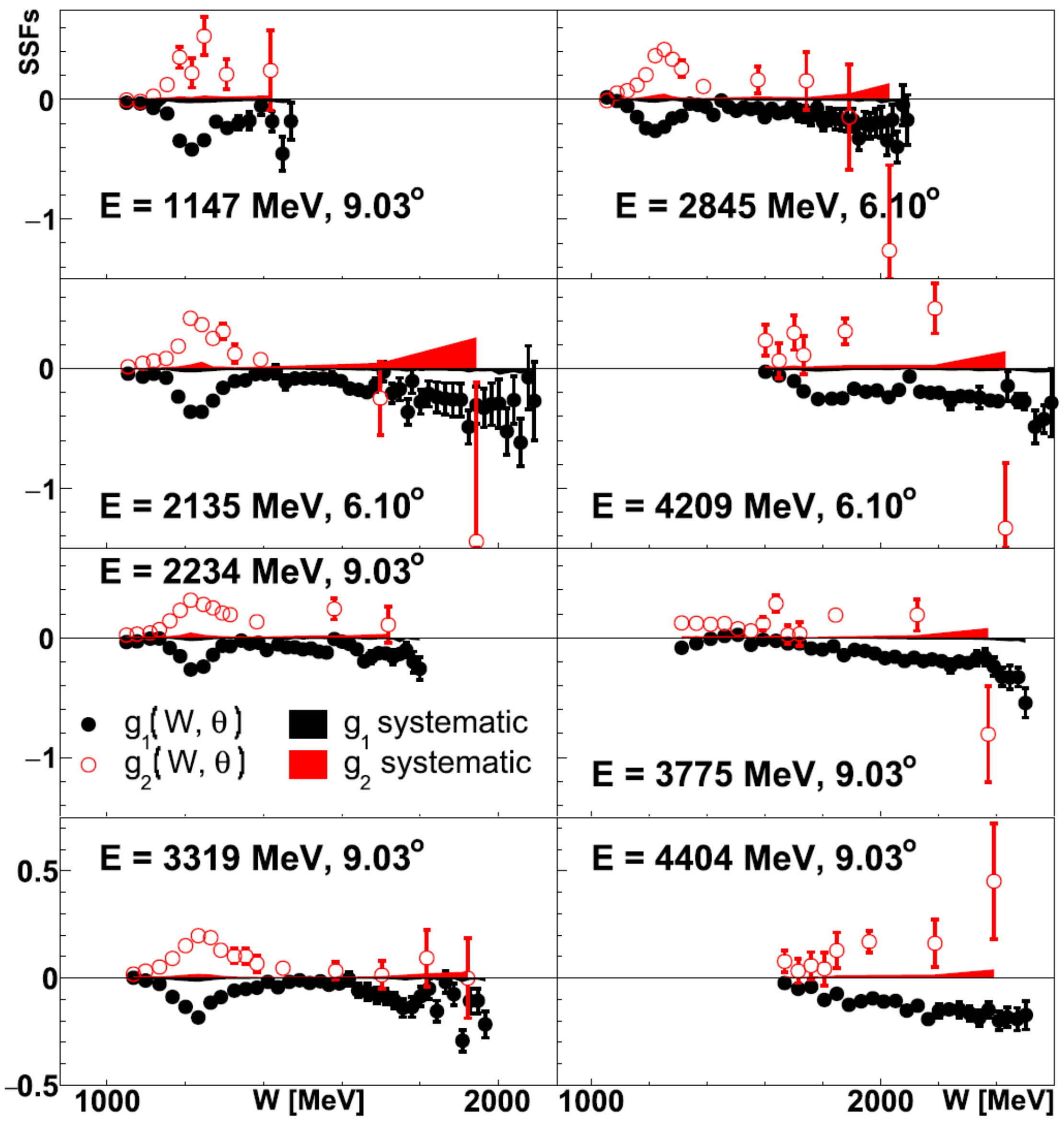
Black points: interpolated data points

^{3}He Results


$I_{GDH}(Q^2) = \frac{8\pi^2\alpha}{M^2} I_{TT}(Q^2)$
1500
1000
500
0
−500
0.0
0.2
0.4
0.6
0.8
1.0
I_{GDH} (μb)
Q^2 (GeV^2)
E97 data
E97 syst.
E94 data
E94 syst.
Real Photon Value

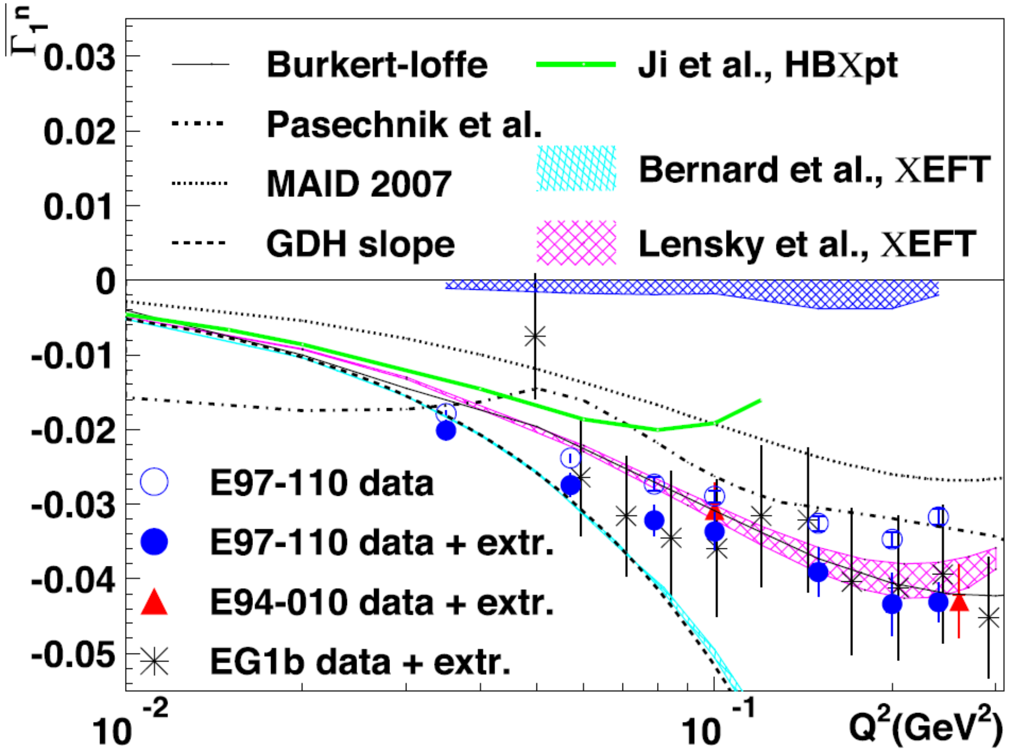

$4I_{LT} = \frac{8M^2}{Q^2} \int_0^{x_{thres}} (g_1(x, Q^2) + g_2(x, Q^2))dx$
0
−10
−20
−30
−40
0.0
0.1
0.2
0.3
0.4
0.5
$I_{LT}(Q^2)$
Q^2 (GeV^2)
E97 data
E97 syst.
E94 data
E94 syst.
Real Photon Value

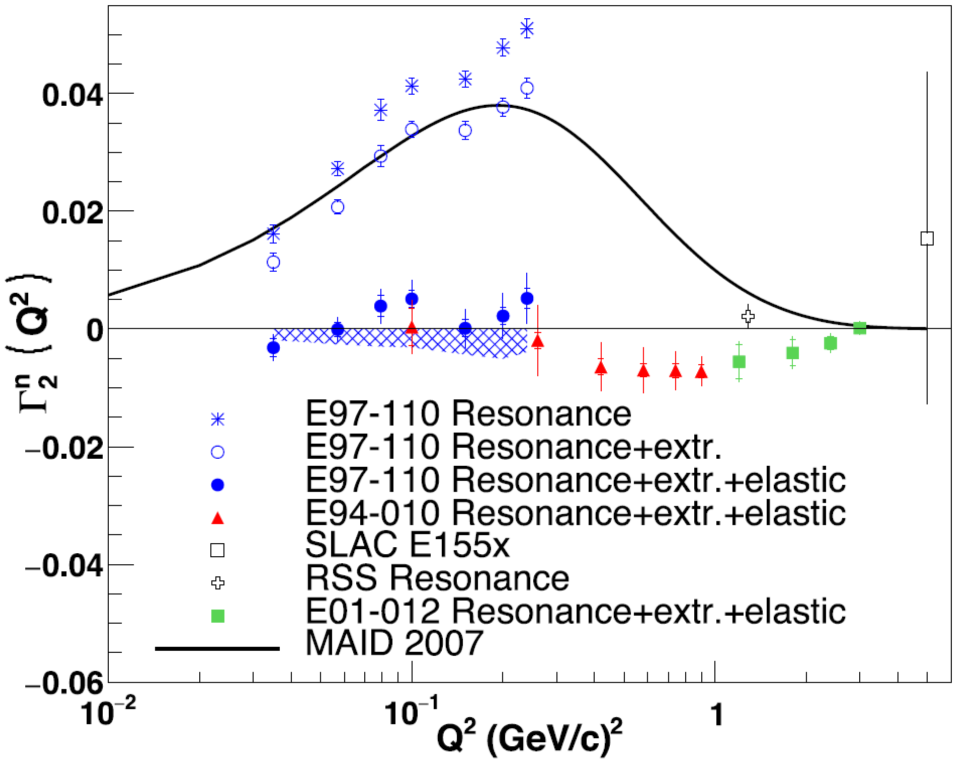
^{3}He
Spin-dependent
Structure
functions
QE subtracted



V. Sulkosky *et al.*, Phys. Lett. B 805 (2020) 135428

Neutron Results





Nuclear corrections follow the recipe from C. Ciofi degli Atti and S. Scopetta (1997)

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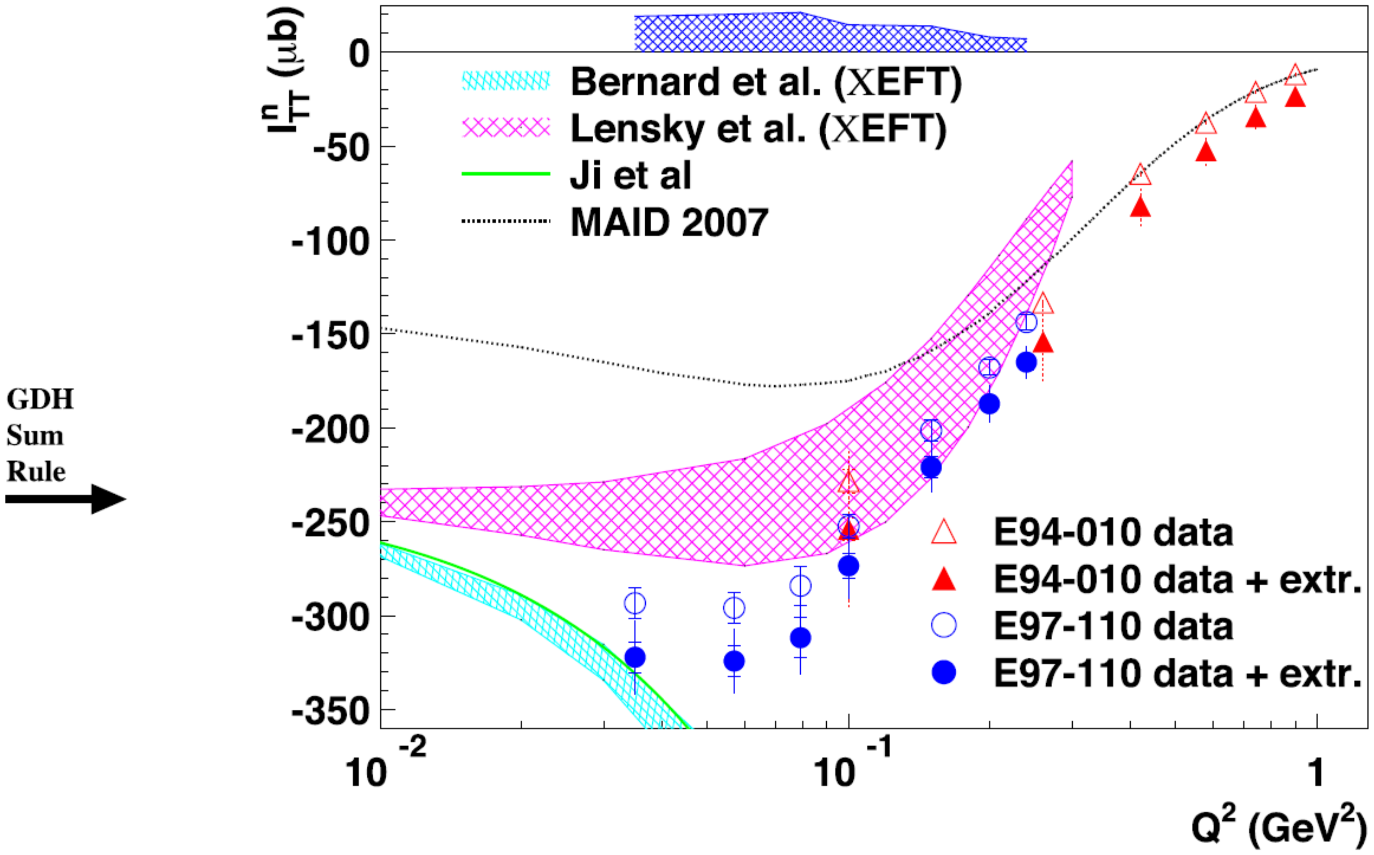
Neutron Results

GDH
Sum
Rule



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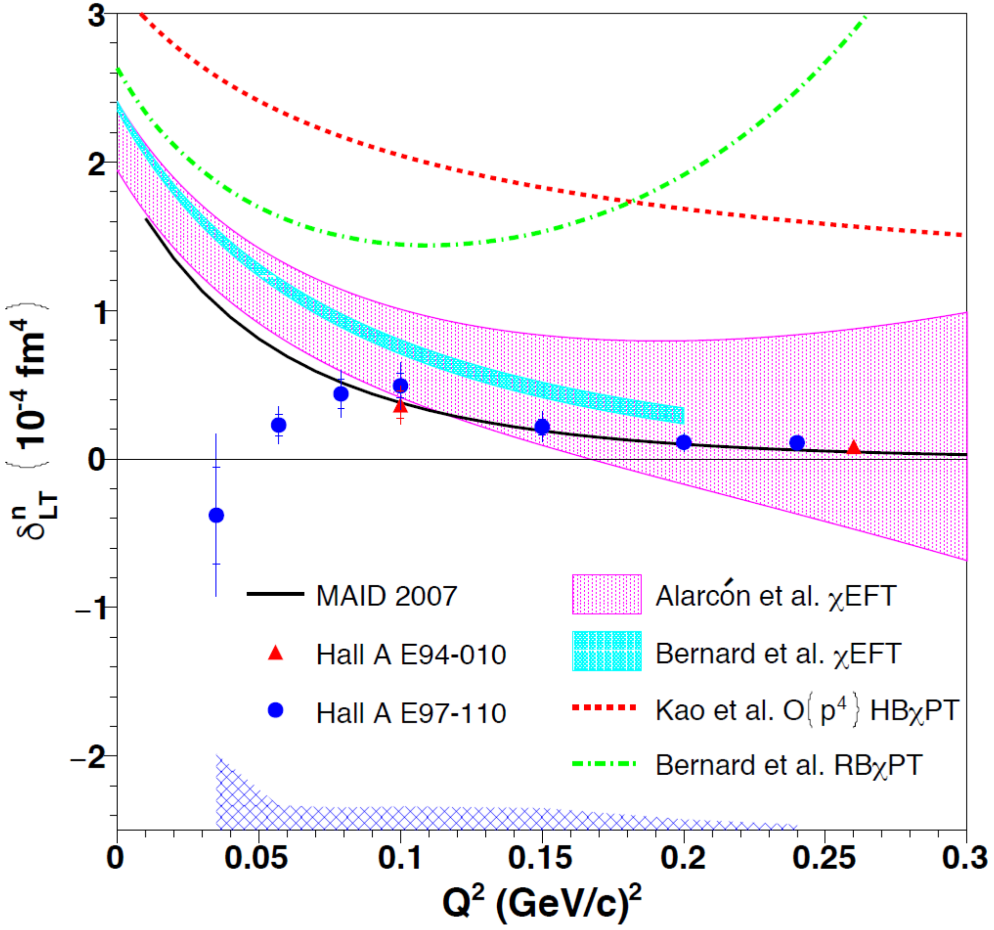
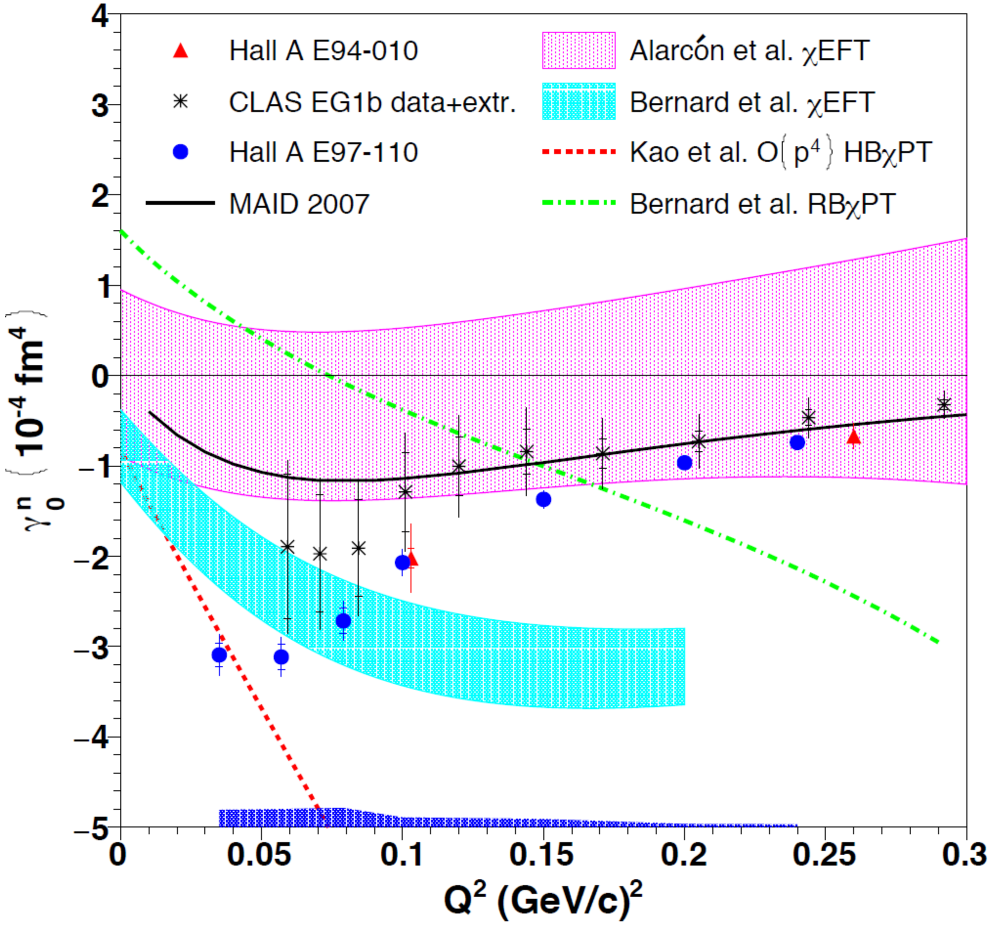
Neutron Spin Polarizabilities





V. Sulkosky *et al.*, *Nature Physics* volume 17, p687–692 (2021)

Summary

Generalized GDH integrals are extracted at low Q^2

- Neutron GDH shows reasonable agreement with ChEFT calculations
- ^{3}He GDH integral exhibits a turning point to recover real photon point

Spin polarizabilities for neutron

- Surprising disagreement with ChEFT calculations at lowest Q^2
- Motivates lattice QCD calculations

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