Precision Measurement of d_2^n: A Probe of the Color Force

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for the E06-014 Collaboration

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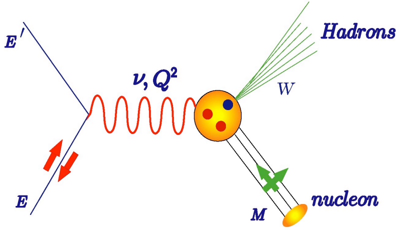
12/10/12

Outline

Polarized DIS

- Probes the spin content of the nucleon



$$\frac{d^2\sigma^{(\downarrow\Uparrow-\uparrow\Uparrow)}}{dE'd\Omega} = \frac{4\alpha^2}{MQ^2}\frac{E'}{\nu E}\left[\left(E+E'\cos\theta\right)g_1\left(x,Q^2\right)-\frac{Q^2}{\nu}g_2\left(x,Q^2\right)\right]$$

$$\frac{d^2\sigma^{(\downarrow\Rightarrow-\uparrow\Rightarrow)}}{dE'd\Omega} = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1\left(x,Q^2\right)+2Eg_2\left(x,Q^2\right)\right]$$

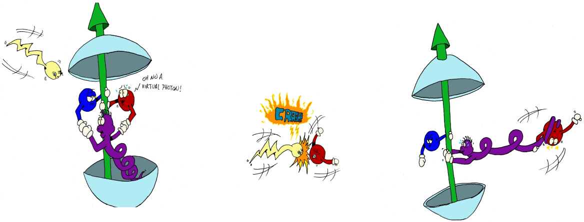
Probing Quark-Gluon Dynamics in the Nucleon

- d_2^n gives access to quark-gluon correlations

$$d_2^n = \int_0^1 x^2 \left(2g_1\left(x, Q^2\right) + 3g_2\left(x, Q^2\right)\right) dx$$

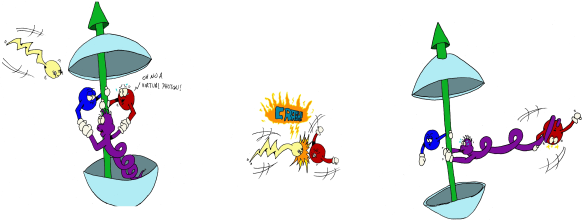
- What is d_2^n?
  - Average transverse Lorentz color force acting on a quark immediately after being struck by a virtual photon (M. Burkardt, hep-ph/0905.4079v1)
  - d_2^n is dominated by large x contributions

What is d_2^n?



What is d_2^n?

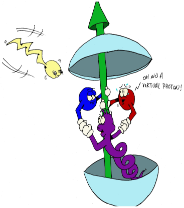
So d_2^n is. . .

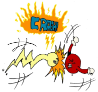


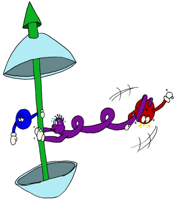
- A measure of quark-gluon correlations

What is d_2^n?

So d_2^n is...

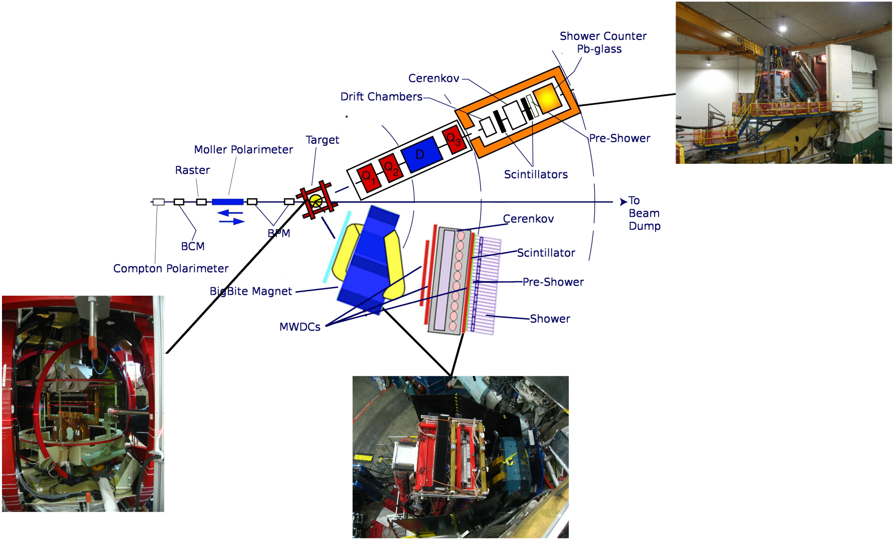






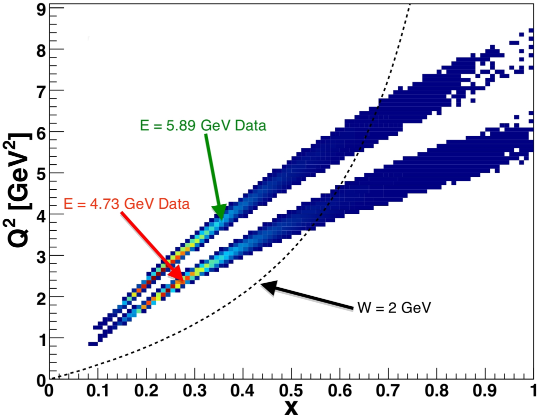
- A measure of quark-gluon correlations
- A force felt between the quark struck by the virtual photon and the spectator quarks

The E06-014 Experiment (1)



The E06-014 Experiment (2)

Kinematic Coverage



From Raw to Physics Asymmetries

- For the physics asymmetry, we have:

$$A_{\mathrm{phys}} = \frac{1}{P_b P_t D} A_{\mathrm{raw}}$$

where corrections are made for:

  - Imperfect beam and target polarizations (P_b, P_t)
  - Nitrogen dilution in the target (D)
  - Pair-produced electrons

Electron Physics Asymmetries on ^{3}He

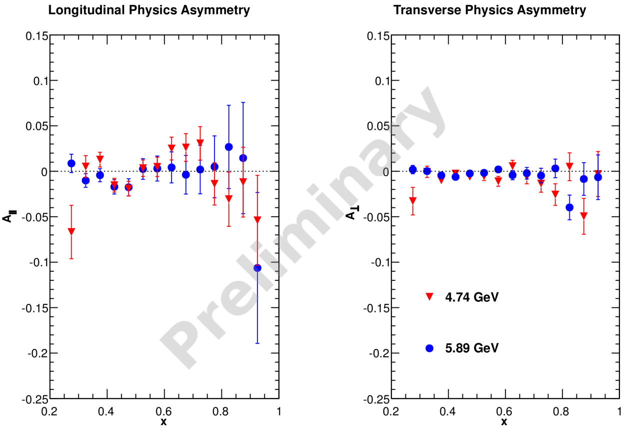
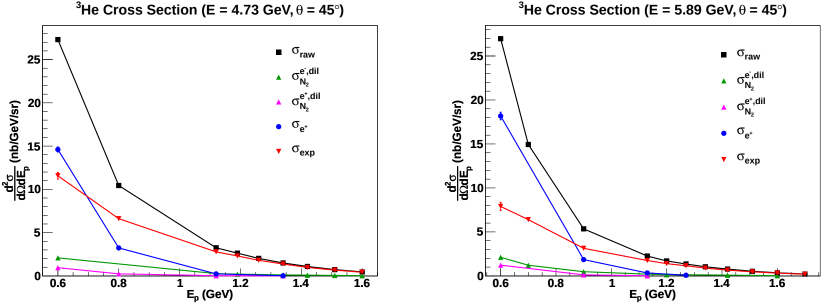


Figure: Preliminary electron asymmetries on ^{3}He in the DIS and resonance regions. W = 2 GeV for E = 5.89 GeV is at x = 0.62 and x = 0.52 for E = 4.74 GeV. Radiative corrections not yet applied.

Cross Sections

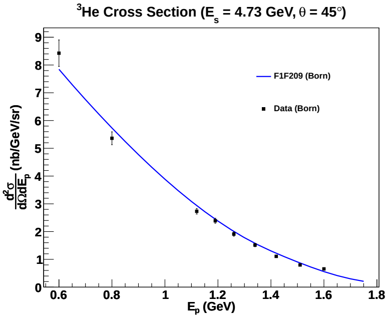


(a) E = 4.74 GeV

(b) E = 5.89 GeV

Figure: Raw ^{3}He cross section and positron and nitrogen background cross sections. Background-subtracted cross section shown in red. Lines are drawn to help guide the eye. Statistical errors only.

Born Cross Sections



(a) E = 4.74 GeV (b) E = 5.89 GeV

Figure: Born cross section. Error bars include statistical and systematic. Blue curve is P. Bosted's F1F209 inclusive cross section model.

$g_1^{^3He}$ Compared to Selected World Data

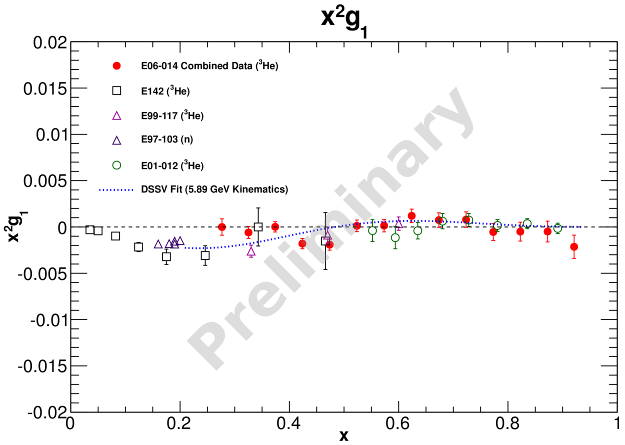


Figure: Preliminary $x^2 g_1$ structure function on ^{3}He in DIS and resonance regions. Radiative corrections to asymmetries not yet applied.

$g_2^{^3He}$ Compared to Selected World Data

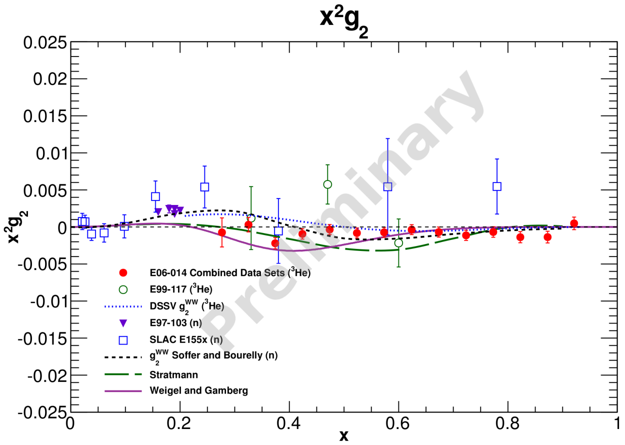


Figure: Preliminary $x^2 g_2$ structure function on ^{3}He in DIS and resonance regions. Radiative corrections to asymmetries not yet applied.

Current d_2 Uncertainty

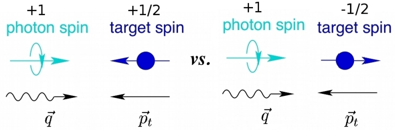
Data Set	Q^2 [GeV^2]	δd_2^{3He}
4.74 GeV	3.20	1.13×10^{-3}
5.89 GeV	4.32	8.26×10^{-4}
Combined	3.73	6.50×10^{-4}
Lattice QCD	5.00	1.50×10^{-3}

Table: Current statistical uncertainty on d_2^{3He} for $0.27 \leq x \leq 0.92$

But wait, there is more...

A_1 Asymmetry

$$A_1\left(x, Q^2\right) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



- We measure A_1^n through the electron asymmetries $A_\parallel$ and $A_\perp$:

$$A_1^n = \frac{1}{D\left(1+\eta\xi\right)} A_\parallel^n - \frac{\eta}{d\left(1+\eta\xi\right)} A_\perp^n$$

  - The asymmetries are given by:

$$A_\parallel \equiv \frac{\sigma_{\downarrow\Uparrow} - \sigma_{\uparrow\Uparrow}}{\sigma_{\downarrow\Uparrow} + \sigma_{\uparrow\Uparrow}} \quad \text{and} \quad A_\perp \equiv \frac{\sigma_{\downarrow\Rightarrow} - \sigma_{\uparrow\Rightarrow}}{\sigma_{\downarrow\Rightarrow} + \sigma_{\uparrow\Rightarrow}}$$

  - D, η, ξ and d are kinematic factors

$A_1^{^3\mathrm{He}}$ Compared to World Data

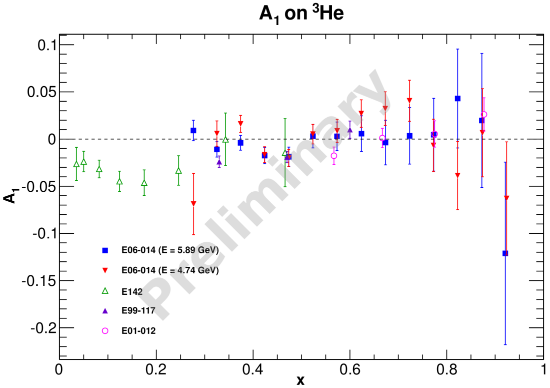


Figure: World $A_1^{^3\mathrm{He}}$ data with E06-014 DIS and resonance data. No radiative corrections to E06-014 data.E142: Phys. Rev. D **54**: 6620 (1996). E99-117: Phys. Rev. C **70**: 065207 (2004). E01-102: Phys. Rev. Lett. **101** 182502 (2008).

Summary

- Summary
  - Exploit transverse spin interactions through g_2 structure function, to study higher twist effects
  - Gain insight into the Lorentz color force inside the nucleon through the matrix element d_2
  - Good statistical precision on the data will provide a direct test of lattice QCD
- Current/Future Work
  - Radiative corrections to asymmetries are underway
  - BigBite simulations also well underway
  - Wally Melnitchouk is looking into neutron extraction of $d_2^{^3He} \rightarrow d_2^n$ and $A_1^{^3\mathrm{He}} \rightarrow A_1^n$

Acknowledgements

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- Thanks to P. Solvignon, K. Slifer, V. Sulkosky, E. Schulte, C. Dutta, K. Allada, X. Qian and the rest of the d_2^n, Transversity and the Hall A Collaborations, and the Hall A Staff at Jefferson Lab for their advice, suggestions, and continued support.
- Thank you to Temple University and Carnegie Mellon University.
- Primary analysis team: B. Sawatzky, D. Parno, D. Flay, M. Posik, Y. Zhang, G. Franklin, Z.-E. Meziani
- This work is supported by:
  DOE Award from Temple University $\#$DE-FG02-94ER40844.

Backup

Pair Production Correction (1): Positron-Electron Ratio

$$R = \left(\frac{N_p^{e+}}{N_n^{rawe-}}\right) = \kappa\left(\frac{N_n^{e+}}{N_n^{rawe-}}\right)$$

$$\kappa = \left(\frac{N_p^{+}}{N_n^{+}}\right)$$

- κ measured during 4-pass running, assumed to have same values at 5-pass running (verifying with GEANT4)
- Where p, n mean BigBite is in positive or negative polarity. $rawe-$ is measured electron with electron cuts applied
- We assume $\frac{N_p^{e+}}{N_n^{rawe-}}$ is closer to reality based on LHRS $\frac{\sigma_{e+}}{\sigma_{e-}}$ measurements

Backup

Pair Production Correction (2): Asymmetry Correction

$$N_n^{e-} = N_n^{rawe-} - N_n^{e+}$$

$$A_n^{e-} = \left(\frac{N_n^{rawe-}}{N_n^{e-}}\right) A_n^{rawe-} - \left(\frac{N_n^{e+}}{N_n^{e-}}\right) A_n^{e+}$$

$$\frac{N_n^{e-}}{N_n^{rawe-}} = 1 - R$$

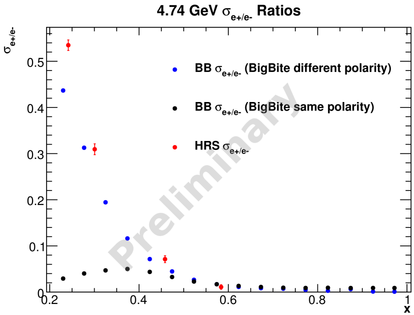
$$A_n^{e-} = \frac{A_n^{rawe-} - RA_n^{e+}}{1 - R}$$

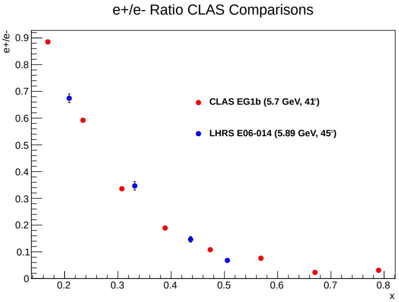
$$\delta A_n^{e-} = \sqrt{\left(\frac{\delta A_n^{rawe-}}{1 - R}\right)^2 + \left(\frac{R\delta A_n^{e+}}{1 - R}\right)^2}$$

assumes $\delta R = 0$

Backup

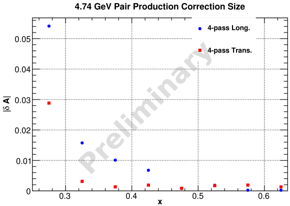
Pair Production Correction (4): Ratio Comparison





Backup

Pair Production Correction (4): 4.74 GeV Results



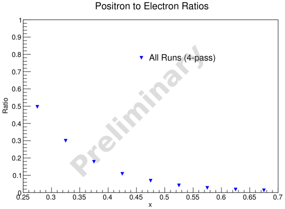
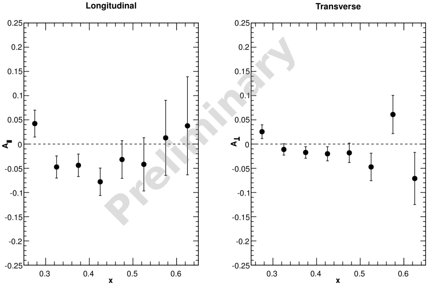
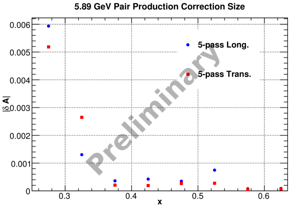


Figure: Positron asymmetries



Backup

Pair Production Correction (5): 5.89 GeV Results



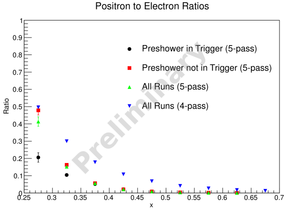
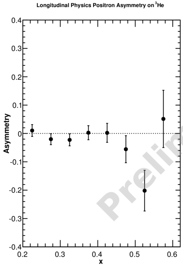
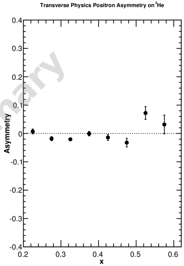


Figure: Positron asymmetries





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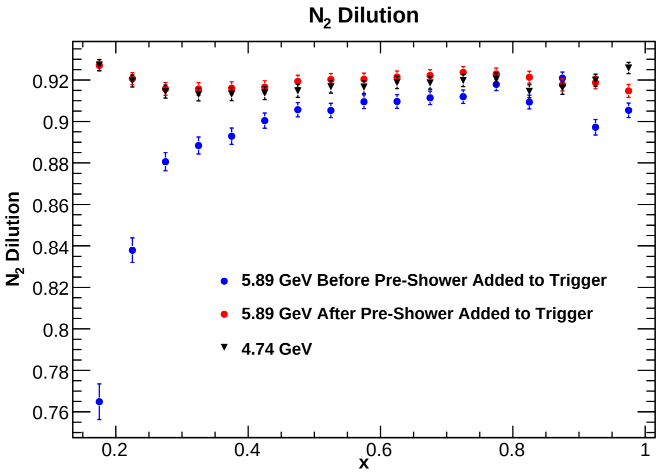
Nitrogen Dilution



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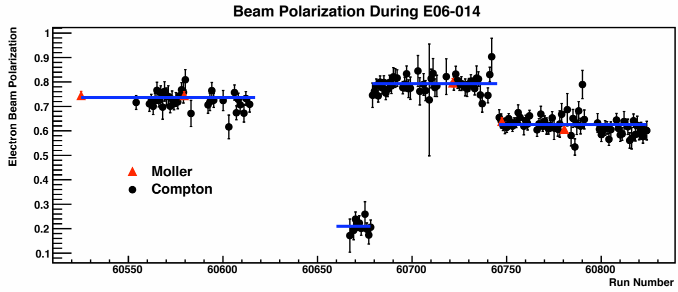
Electron Beam Polarization

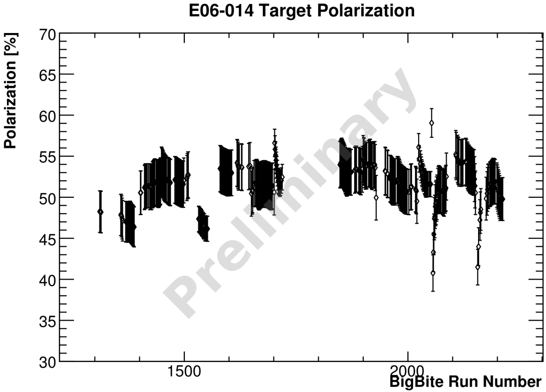
- Two methods: Møller and Compton measurements
- Combine both methods to achieve an error of $\sim 1.6\%$



Backup

^{3}He Target Polarization

- NMR measurement every four hours (target chamber)
- EPR at every spin rotation (pumping chamber)



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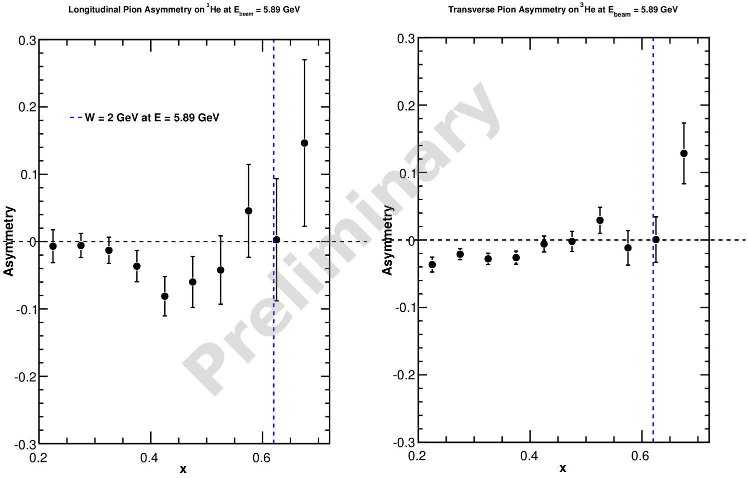
Pion Asymmetries



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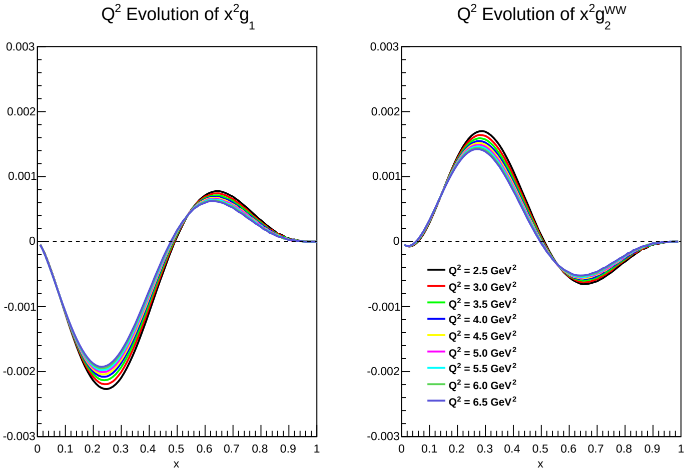
Spin Structure Functions

- The spin structure functions:

$$
\begin{aligned}
g_1 &= \frac{MQ^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\sigma_0\left[A_\parallel + \tan(\theta/2)\, A_\perp\right] \\
g_2 &= \frac{MQ^2}{4\alpha^2}\frac{y^2}{(1-y)(2-y)}\sigma_0\left[-A_\parallel + \frac{1+(1-y)\cos\theta}{(1-y)\sin\theta} A_\perp\right]
\end{aligned}
$$

Backup

Q^2 Dependence: DSSV Fit



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Q^2 Dependence: Selected Experiments

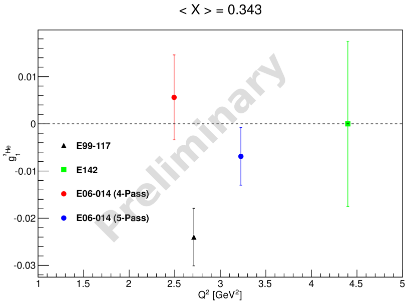


Figure: g_1^{3He} vs. Q^2

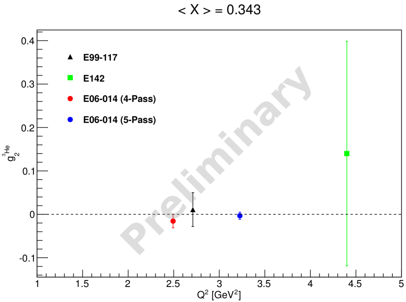


Figure: g_2^{3He} vs. Q^2

Backup

Q^2 Dependence: Interpolation

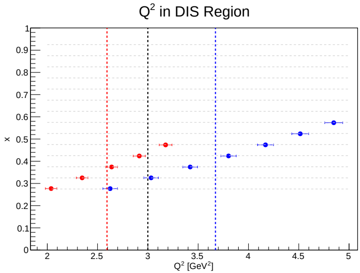


Figure: x vs Q^2 for 4 and 5 pass data. Red dashed line shows average Q^2 in the DIS region for the 4 pass data, the blue dashed line shows average Q^2 in the DIS region for the 5 pass data and the black dashed line shows the average Q^2 value in the DIS region over the entire data set.

- 3 overlapping data points
- $< Q^2 >$
  - 2.594 GeV^2 (4-pass)
  - 3.672 GeV^2 (5-pass)
  - 3.078 GeV^2 (4+5 pass)
- (4+5 pass) Drawn at Q^2 = 3.0 GeV^2 here to get more data points for interpolation

Backup

Q^2 Dependence: Interpolation Comparison

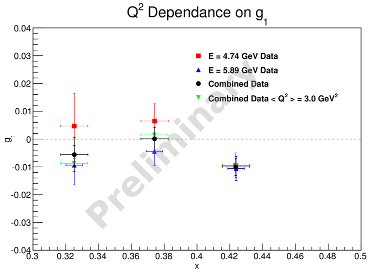


Figure: g_1 on ^{3}He as a function of x in a selected DIS region for various Q^2 treatments.

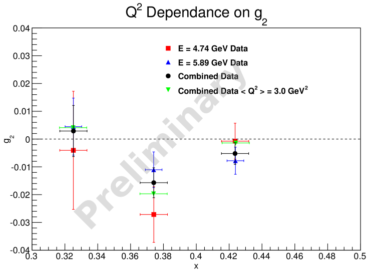
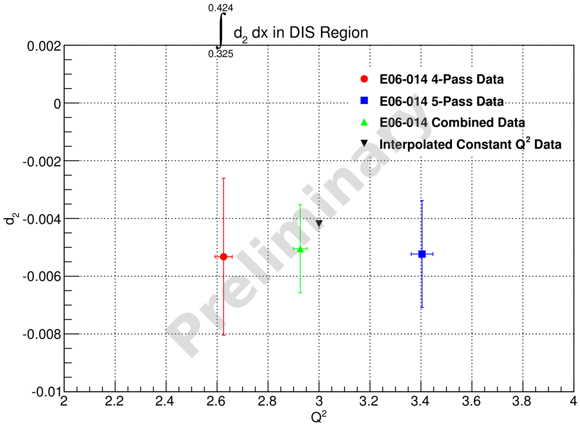


Figure: g_2 on ^{3}He as a function of x in a selected DIS region for various Q^2 treatments.

Backup

Q^2 Dependence: d_2 Comparison



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