Hall C Spin Results and Perspective

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Topics

Resonant Spin Structure

SANE

Semi-SANE

Resonant Spin Structure (RSS) of the Proton and Deuteron

Oscar A. Rondon (UVA)

Mark K. Jones (JLab)

Analysis

Paul McKee, Karl Slifer, Shige Tajima

Frank Wesselmann, Junho Yun, Hongguo Zhu

(*Eric Christy, Peter Bosted)*

E01-006 Collaboration

Univ. Basel, Florida International Univ., Hampton Univ., Univ. of Massachusetts, Univ. of Maryland,
Mississippi State Univ.,North Carolina A&T Univ., Univ. of N. C. at Wilmington,
Norfolk State Univ.,Old Dominion Univ.,S.U. at New Orleans, Univ. of Tel-Aviv,
Jefferson Lab, Univ. of Virginia, Virginia P. I. & S.U., Yerevan Physics Institute

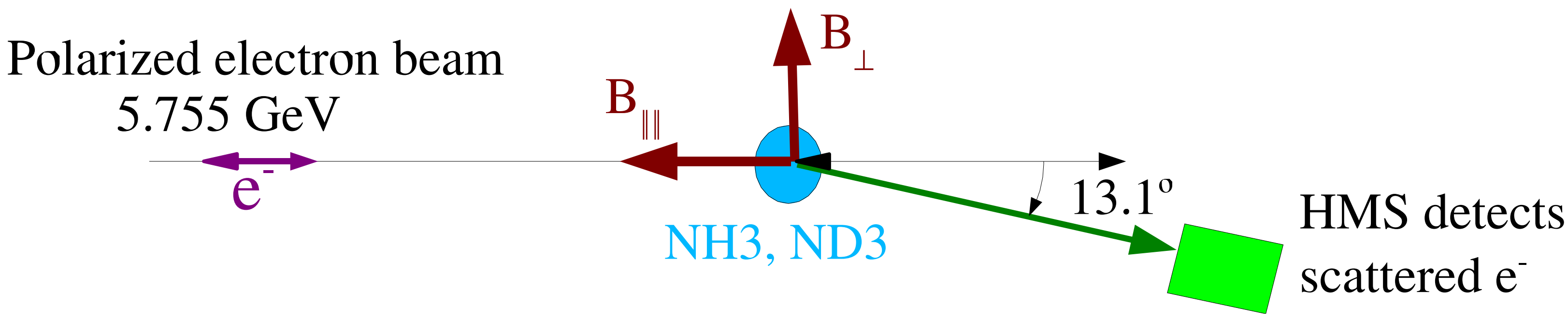
Goals

Measure proton and deuteron $A_1(W, Q^2)$ and $A_2(W, Q^2)$ in the resonance region at moderate Q^2.

Extract g_1 and g_2 structure functions and study:

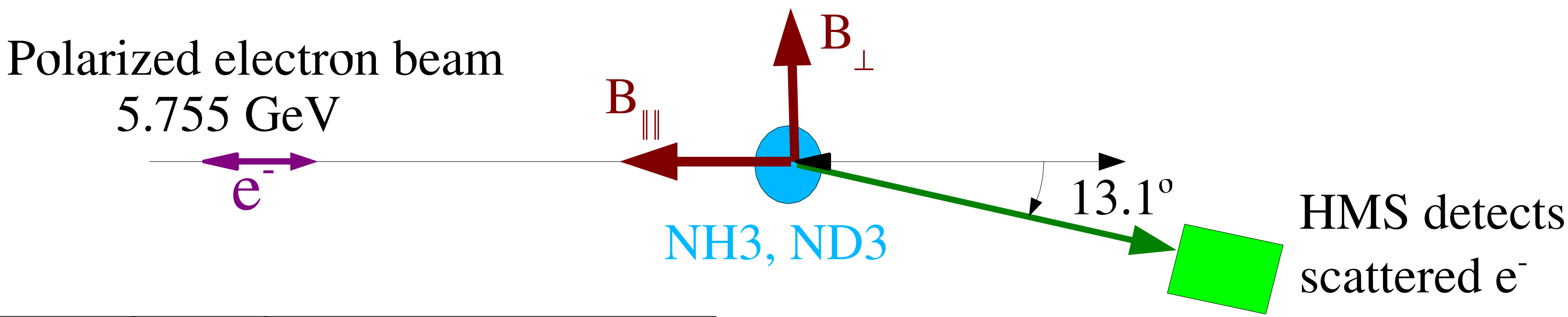
- W–dependence
- Onset of polarized local duality
- twist-3 effects in d_2 matrix element

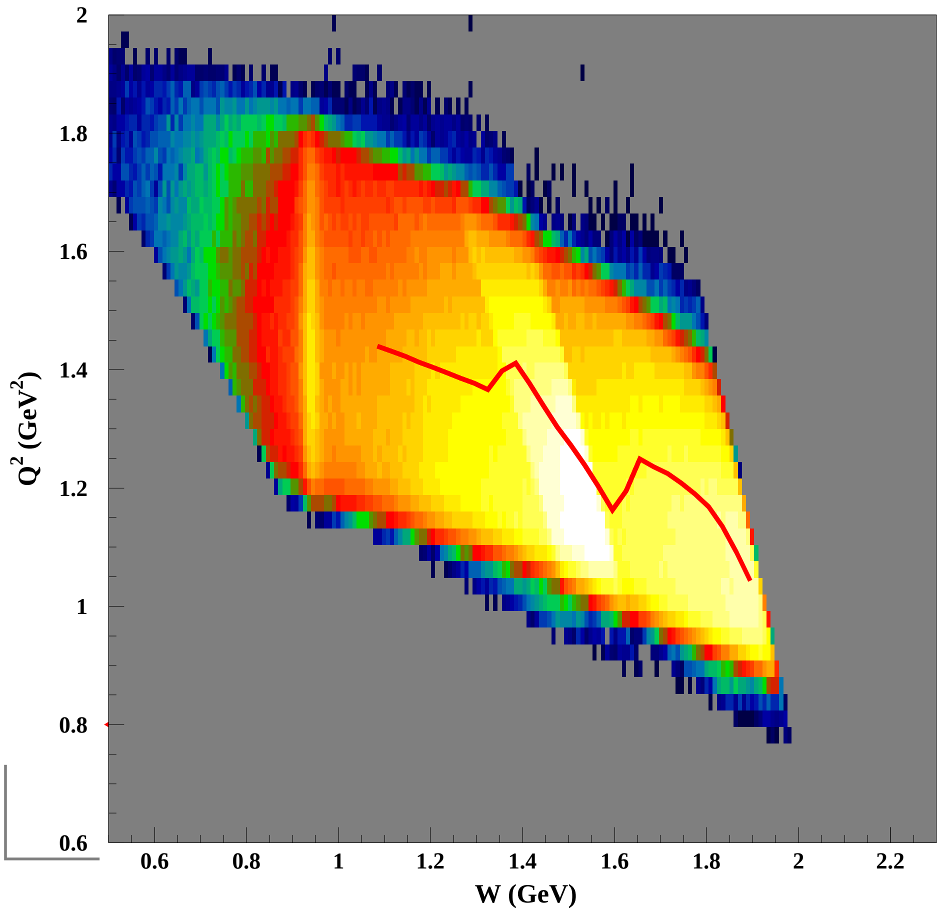
Experimental set-up in Hall C



P_0 = 4.7, 4.1 GeV/c

Experimental set-up in Hall C





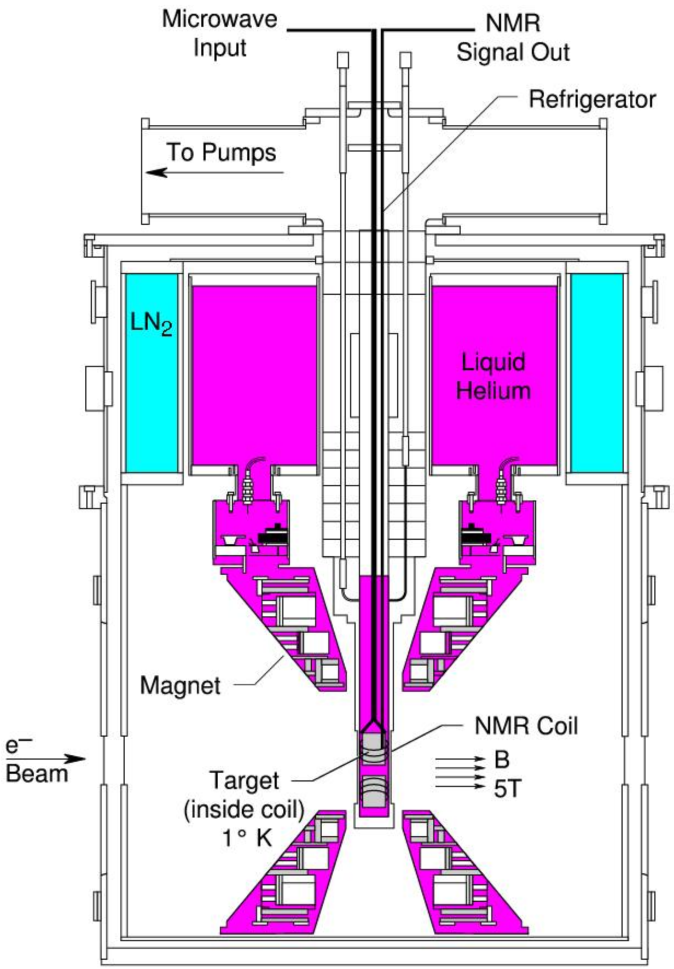
P_0 = 4.7, 4.1 GeV/c

$Q^2 \approx$ 1.3 GeV^2
W : 0.8 – 2.0 GeV

P_b = 65.6 $\pm$ 2.6 for $B_{\parallel}$
P_b = 70.9 $\pm$ 1.7 for $B_{\perp}$

$I \approx$ 100nA
Beam charge asym. < 0.1%

Polarized Target



Target Ladder

2 NH_3 cups

2 ND_3 cups

1 Carbon (7mm)

Target Field

5 Tesla

Para & perpendicular fields.

Polarization can be flipped by

180°. Ran $\pm$ for equal times.

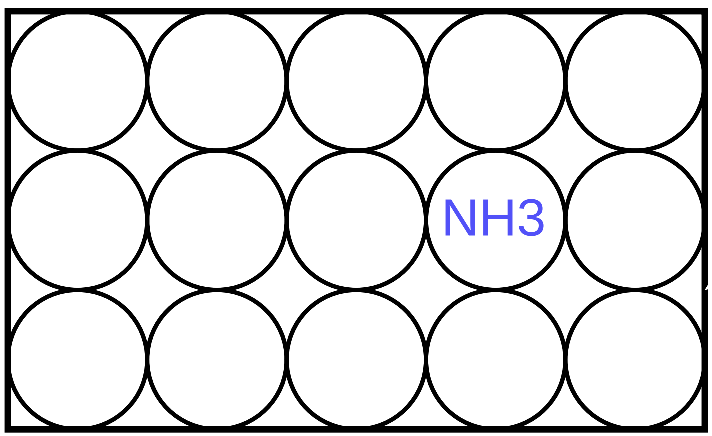
Target Polarization

NH_3 : $P_t \approx 0.68 \pm 0.017$

ND_3 : $P_t \approx 0.18 \pm 0.007$

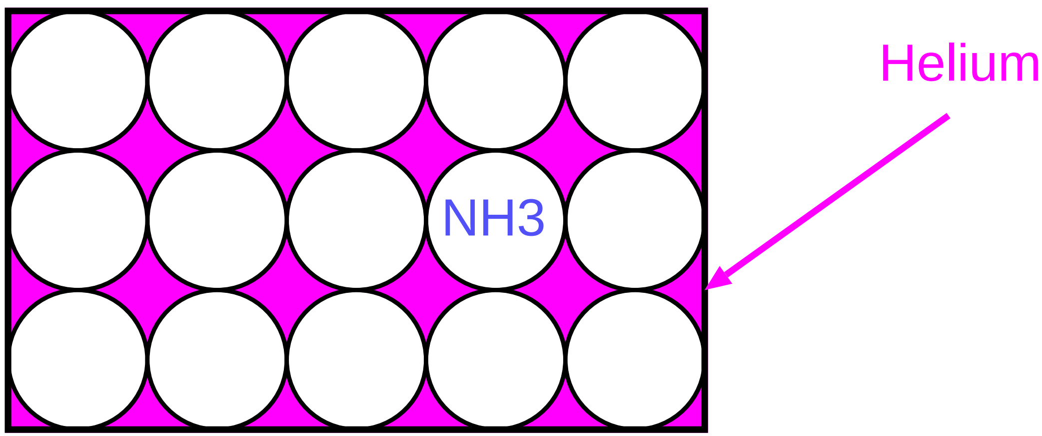
Packing fractions

Packing fraction is ratio of NH_3



Packing fractions

Packing fraction is ratio of NH_3 to (NH_3 + He).



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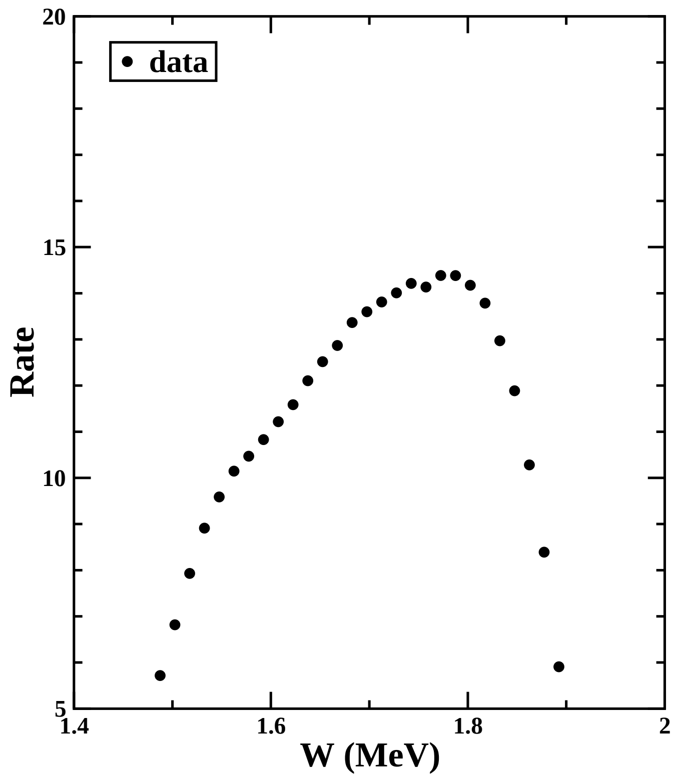

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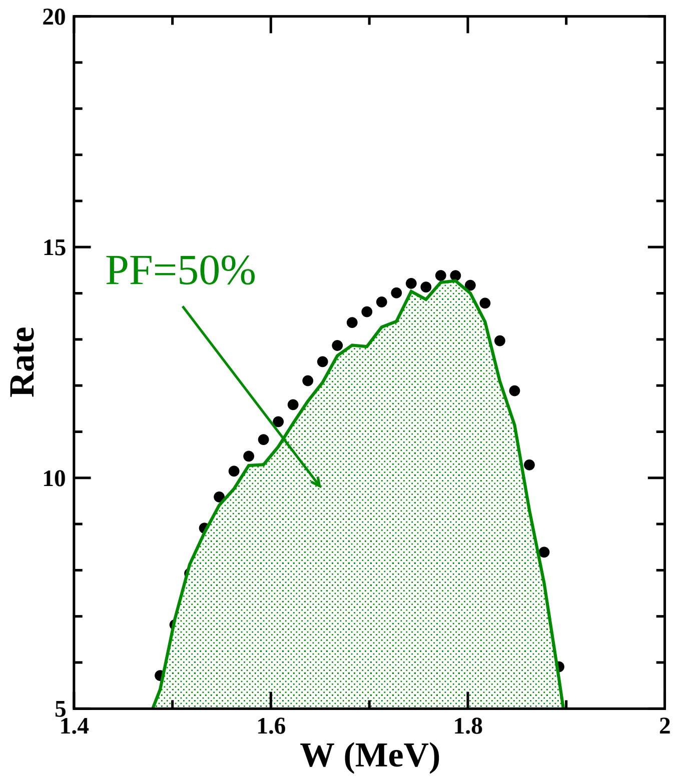

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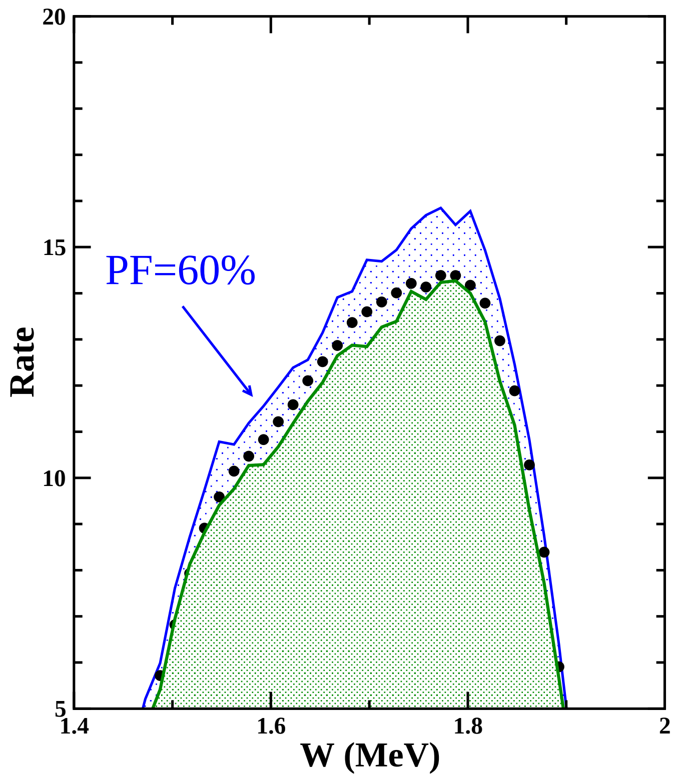

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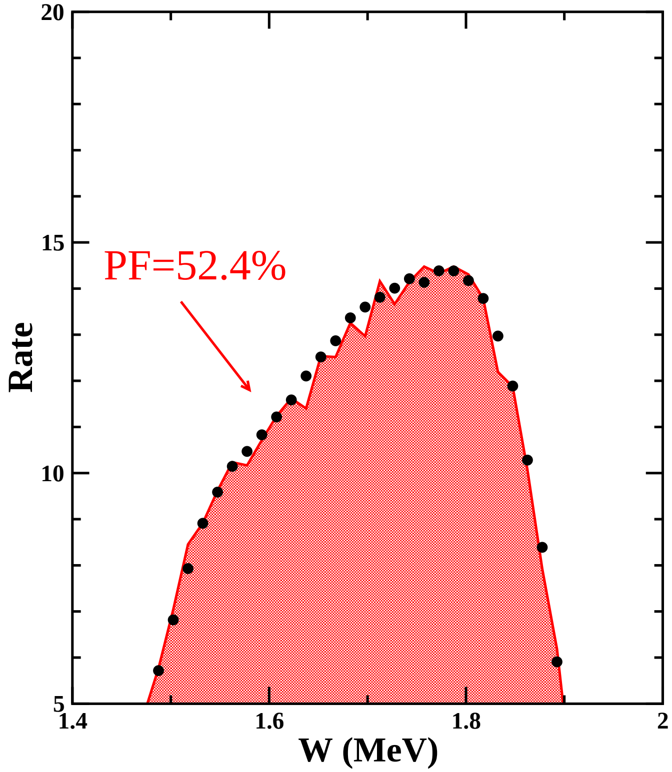

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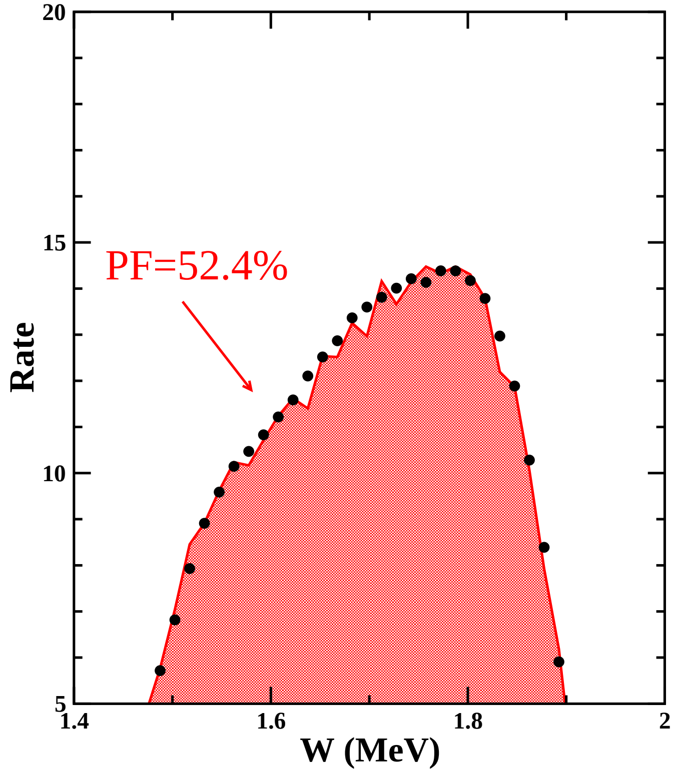
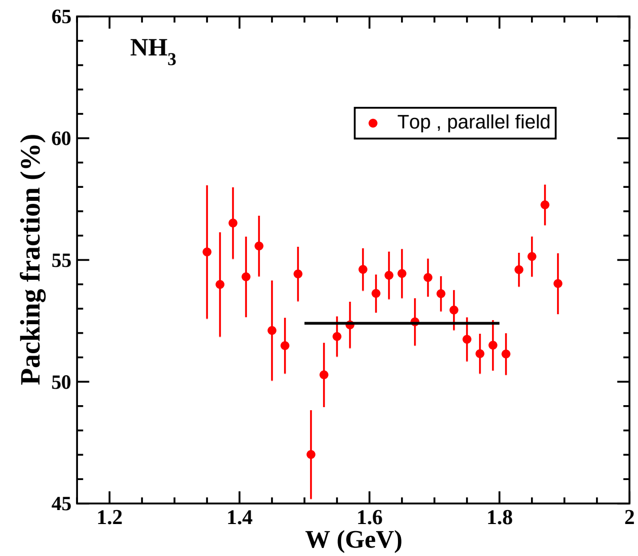




Packing Fractions

	NH_3		ND_3	
	$B_{\parallel}$	$B_{\perp}$	$B_{\parallel}$	$B_{\perp}$
Top	52.4%	58.9	55.2	–
Bottom	53.2	60.7	56.0	62.1

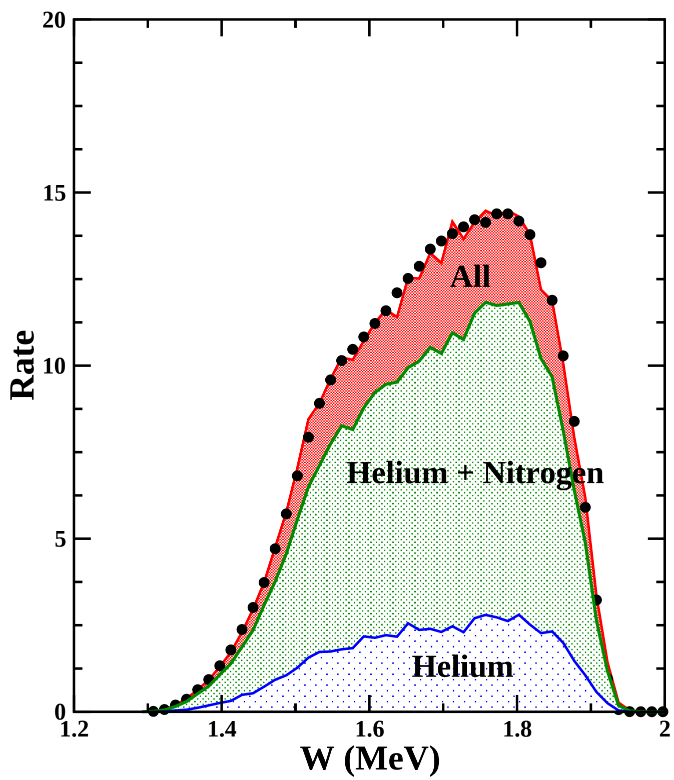
Dilution factors

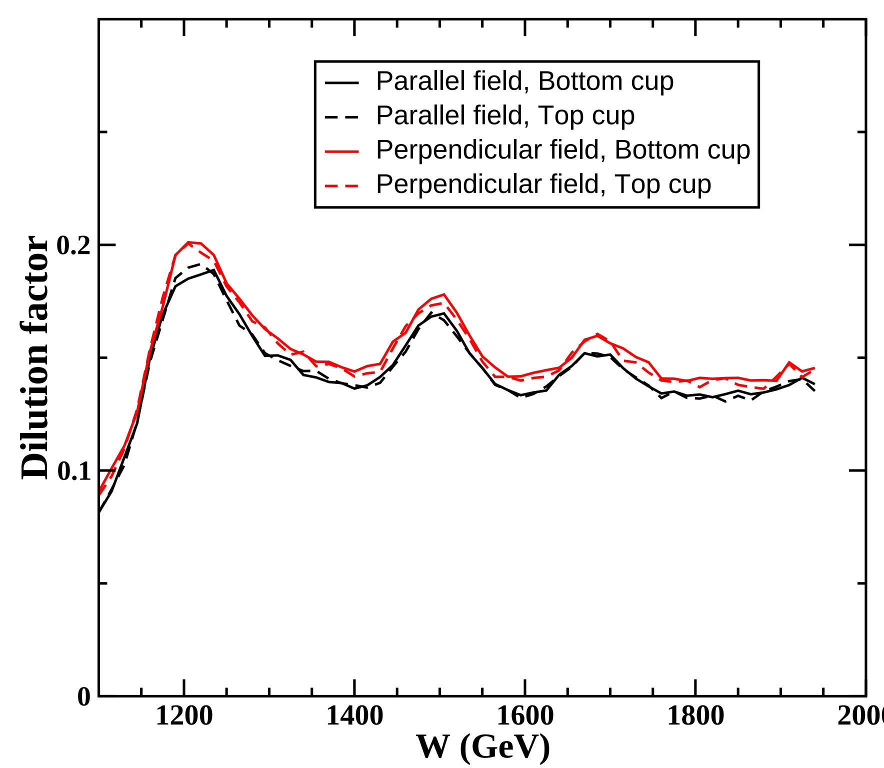
$$f = \frac{\dot{N}_{\text{Pol}}}{\dot{N}_{\text{Tot}}}$$

<u>NH_3</u>

Hall C fit for F_2 and R.(*M. E. Christy*)

QFS for A $>$ 2

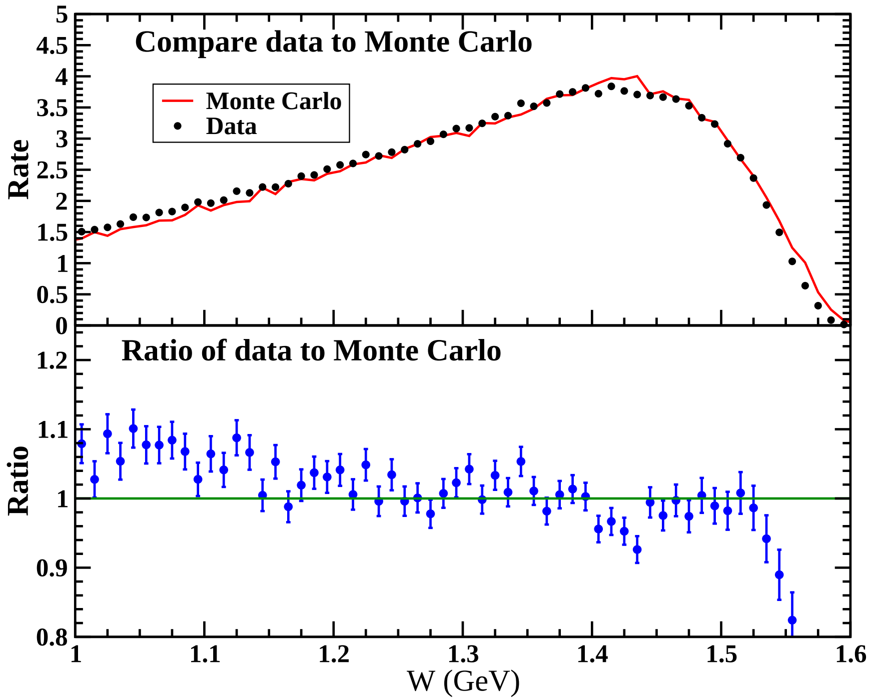




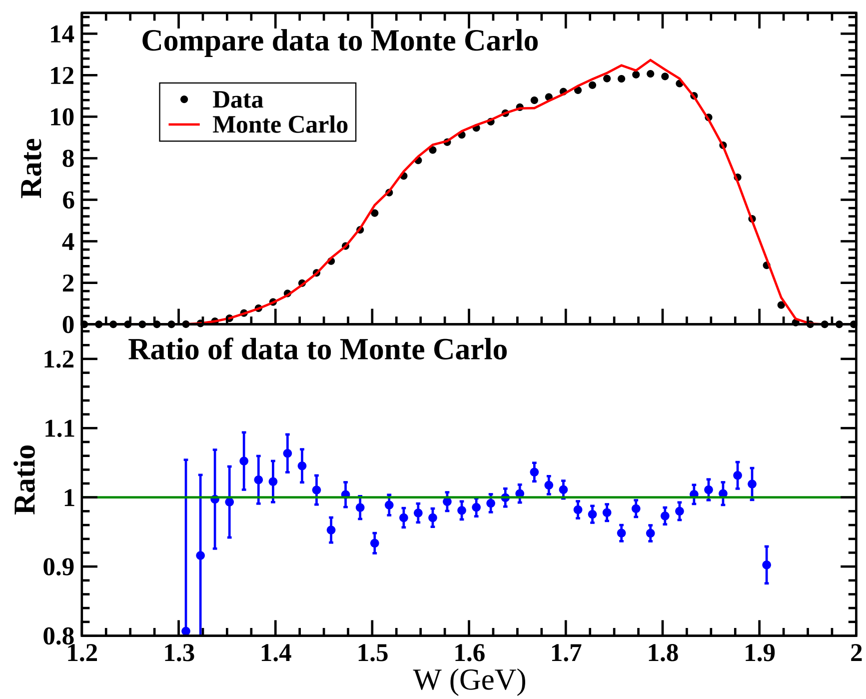
Comparisons to carbon data

Carbon data used to fit QFS model.

P_0 = 4.7 GeV/c



P_0 = 4.1 GeV/c



Extracting Asymmetry

- Raw Asymmetries

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

N^+, N^- : Helicity gated counts, normalized by the charge and deadtime

Extracting Asymmetry

- Raw Asymmetries

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

- Physics Asymmetries

$$A_{\|,\perp} = \frac{1}{C f_{rc}} \frac{1}{f P_b P_t} A_{raw} + A_{rc}$$

f : ratio of rates from polarized nucleons to all nucleons.

P_b, P_t : beam and target polarizations.

C : corrections for ^{15}N asymmetry (not applied yet).

f_{rc}, A_{rc} : radiative corrections

POLRAD (Akusevich *et al.*) modified to include our data as input.

Proton Elastic Asymmetry

$$A_{el} = \frac{K_1 \cos\theta^\star + K_2 \frac{G_E}{G_M} \sin\theta^\star \cos\phi^\star}{G_E^2/G_M^2 + \tau/\epsilon}$$

$\theta^\star, \phi^\star$ = polar and azimuthal angles between $\vec{q}$ and target spin

K_1, K_2 = kinematic factors

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Sensitivity	$\parallel$	$\perp$
$\frac{\Delta A_{el}/A_{el}}{\Delta \frac{G_E}{G_M} / \frac{G_E}{G_M}}$	0.02	1

- $A_{\parallel}$ used to determine $P_b P_t$
- $A_{\perp}$ measure $\frac{G_E}{G_M}$

Proton Elastic Asymmetry

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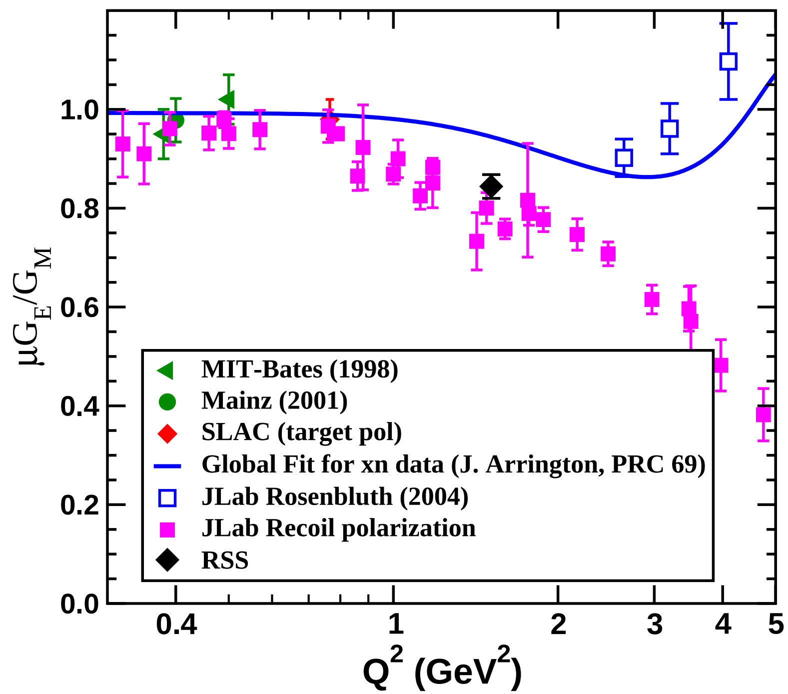


Sensitivity	$\parallel$	$\perp$
$\frac{\Delta A_{el}/A_{el}}{\Delta \frac{G_E}{G_M} / \frac{G_E}{G_M}}$	0.02	1

- $A_{\parallel}$ used to determine $P_b P_t$
- $A_{\perp}$ measure $\frac{G_E}{G_M}$

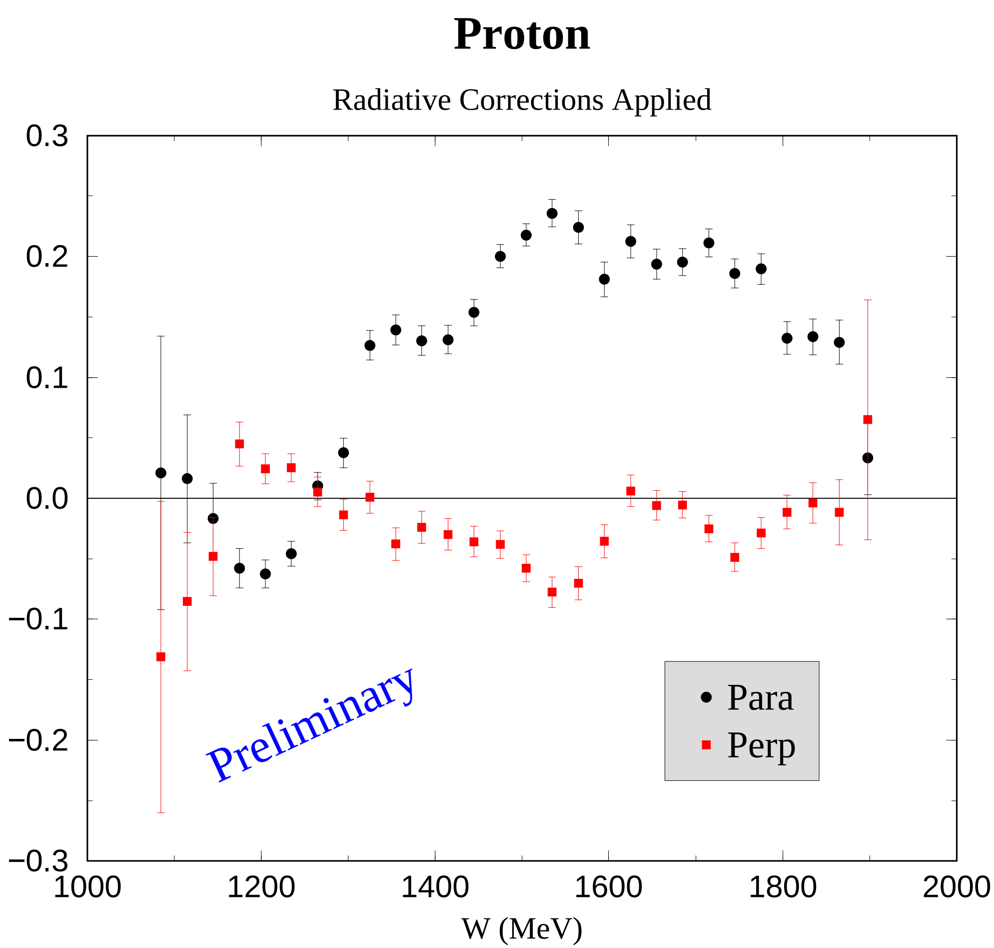
Inelastic Asymmetries

- ^{15}N asymmetry correction (≈ 1.02) not applied yet.
- Radiative corrections have been applied to proton data.
  Work on radiative correction for deuteron in progress.

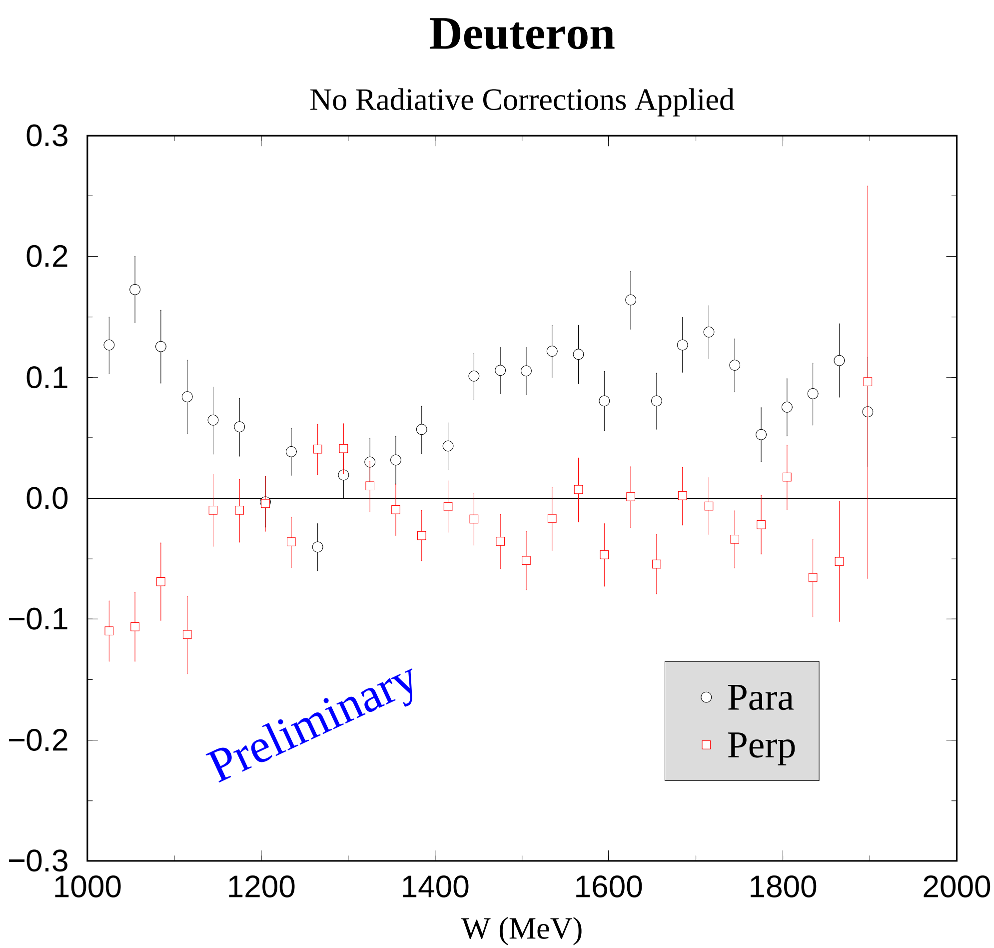
- Expected systematic errors:
  - NH_3 : 6% (relative)
  - ND_3 : 8% (relative)

- $A_{\|}$ and $A_{\perp}$ transformed to A_1 and A_2 using Hall C F_2 and R fi t (M. E. Christy)

Asymmetries

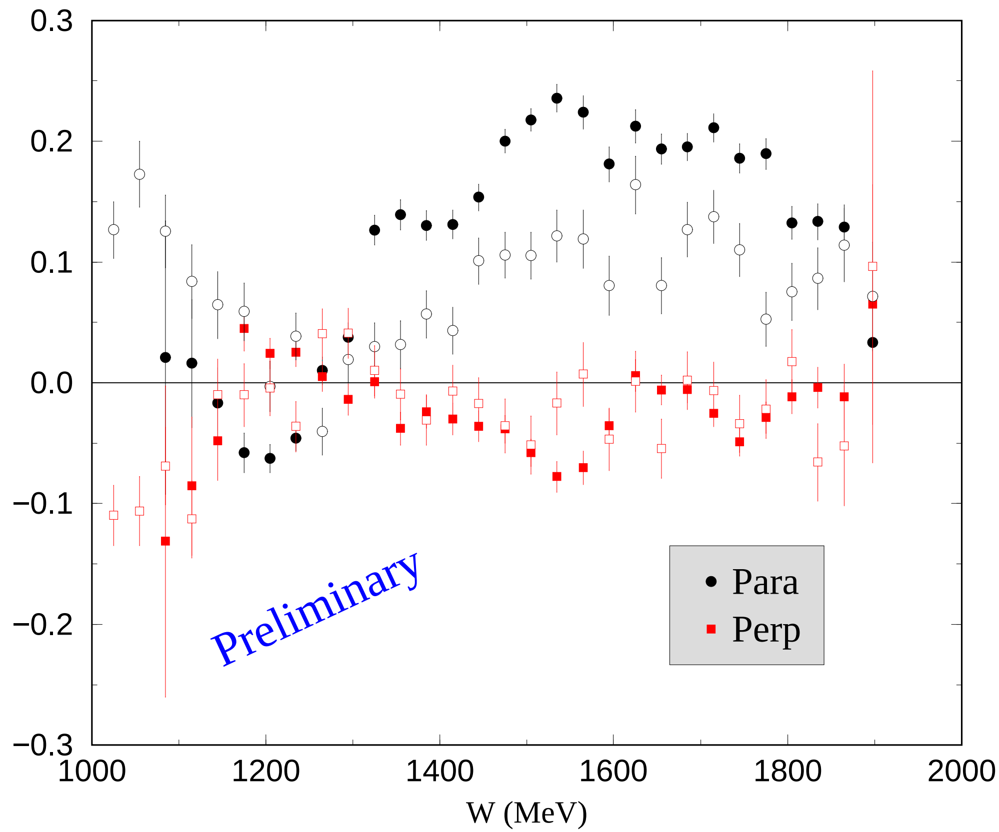


Asymmetries

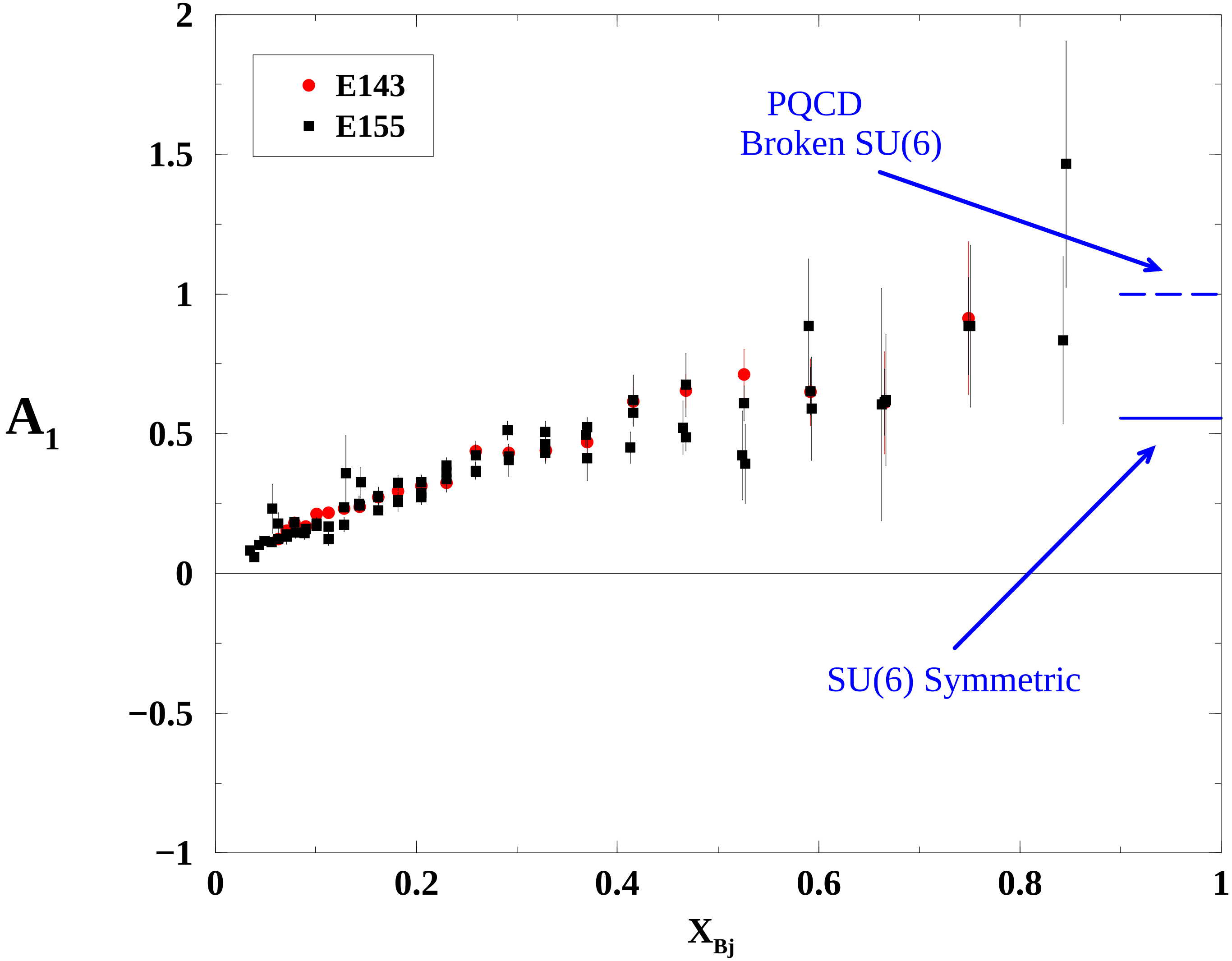


Asymmetries

Proton and Deuteron

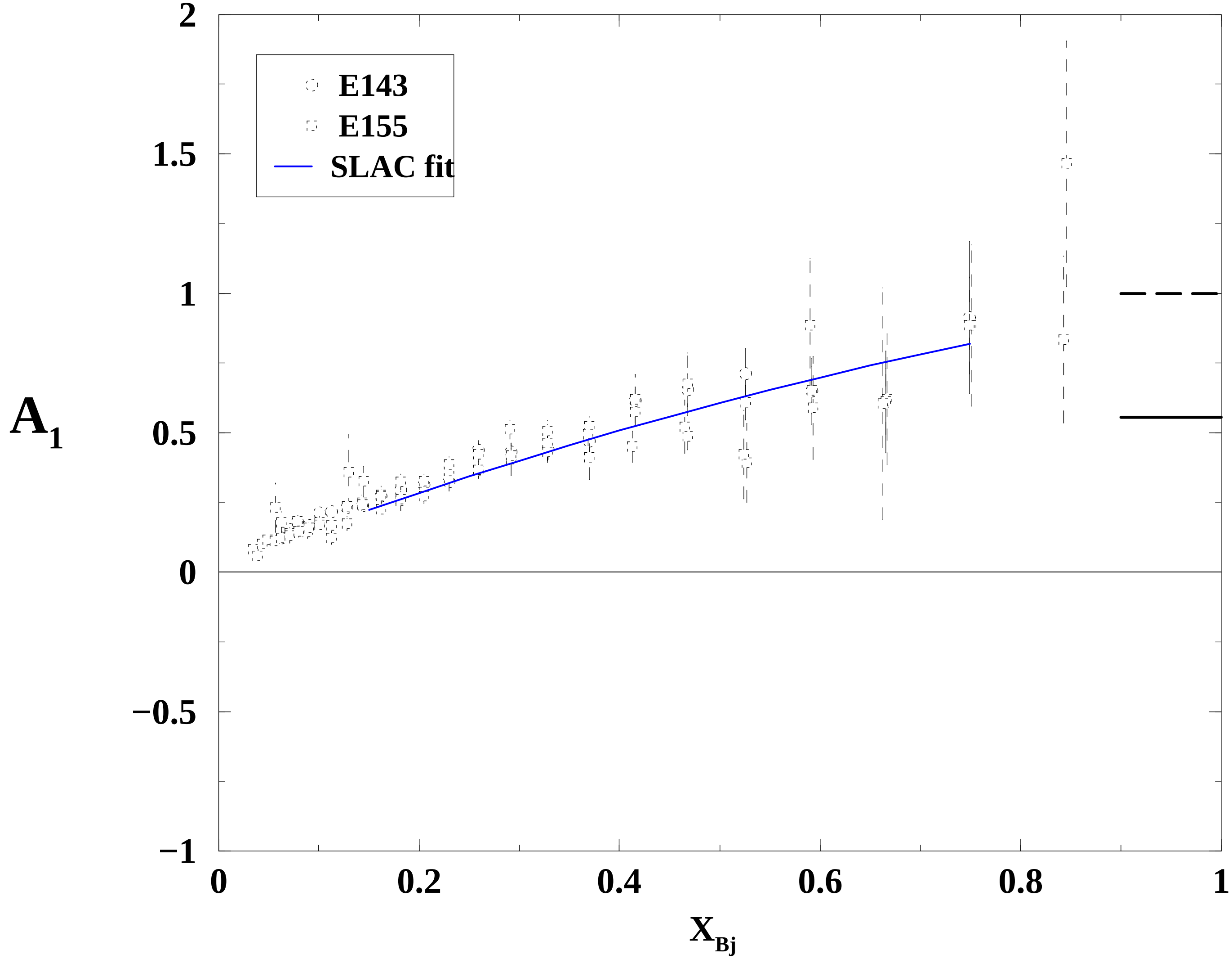


Proton A_1

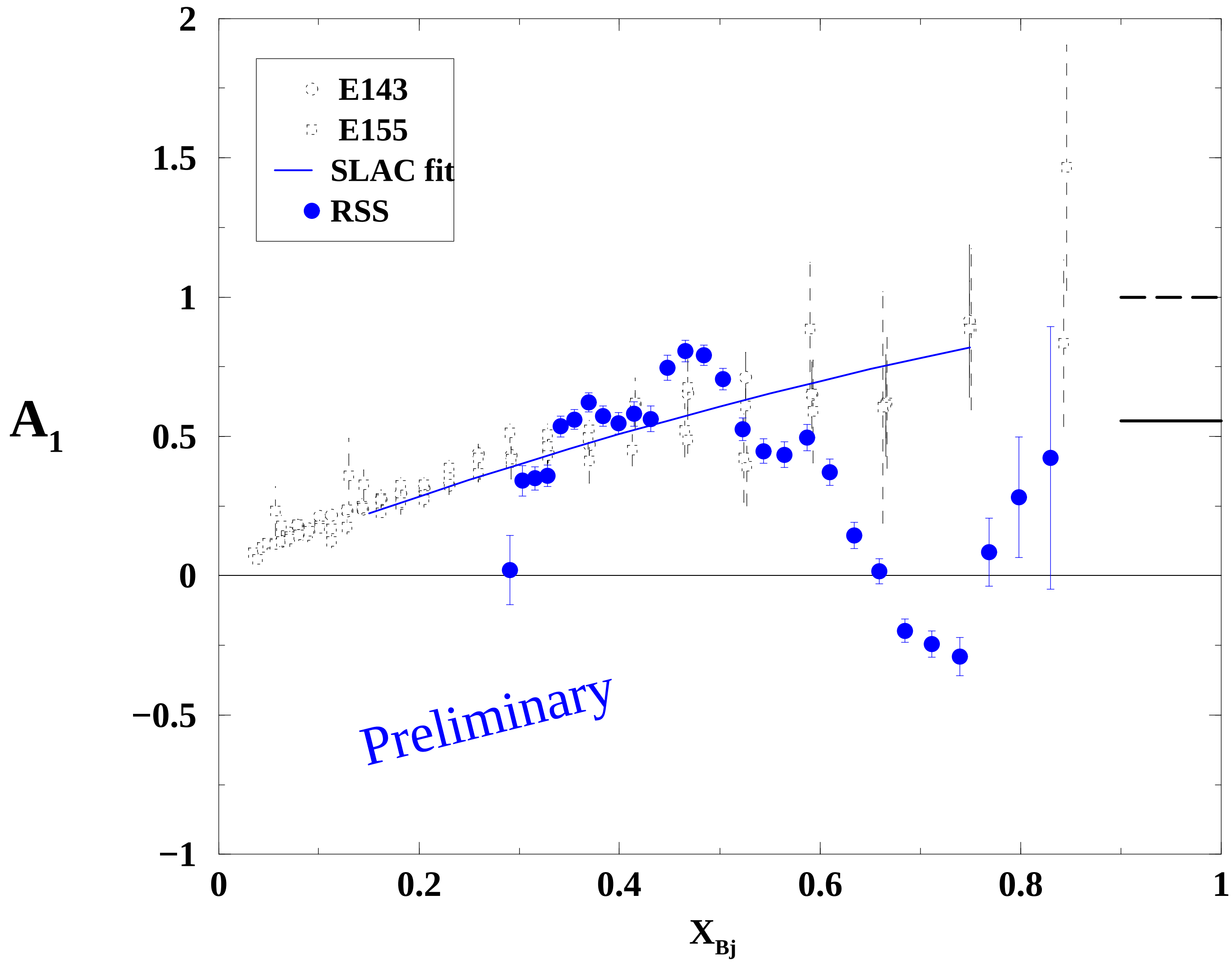


E143
E155
PQCD
Broken SU(6)
SU(6) Symmetric
A1
XBj
2
1.5
1
0.5
0
−0.5
−1
0
0.2
0.4
0.6
0.8
1

Proton A_1

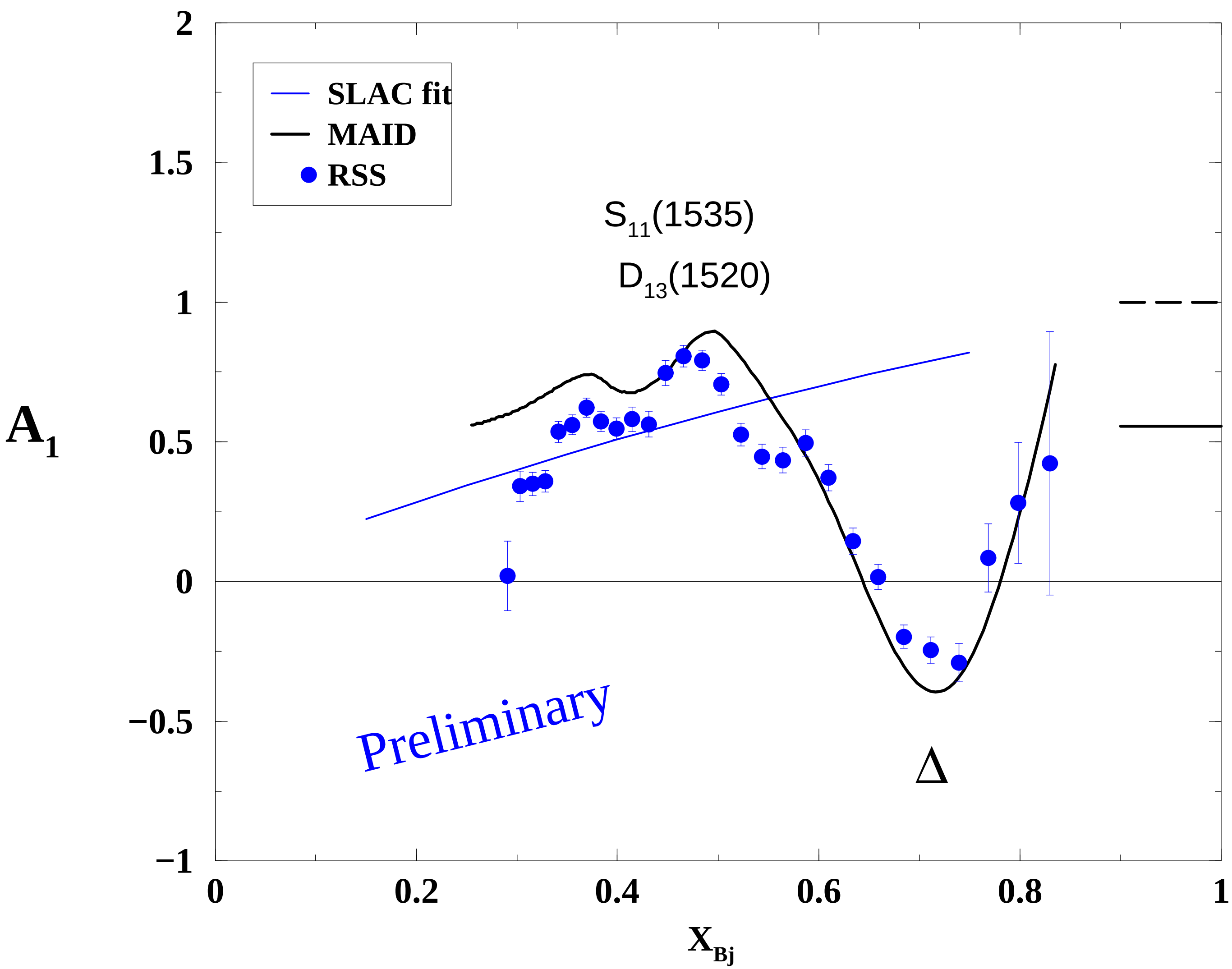


Proton A_1



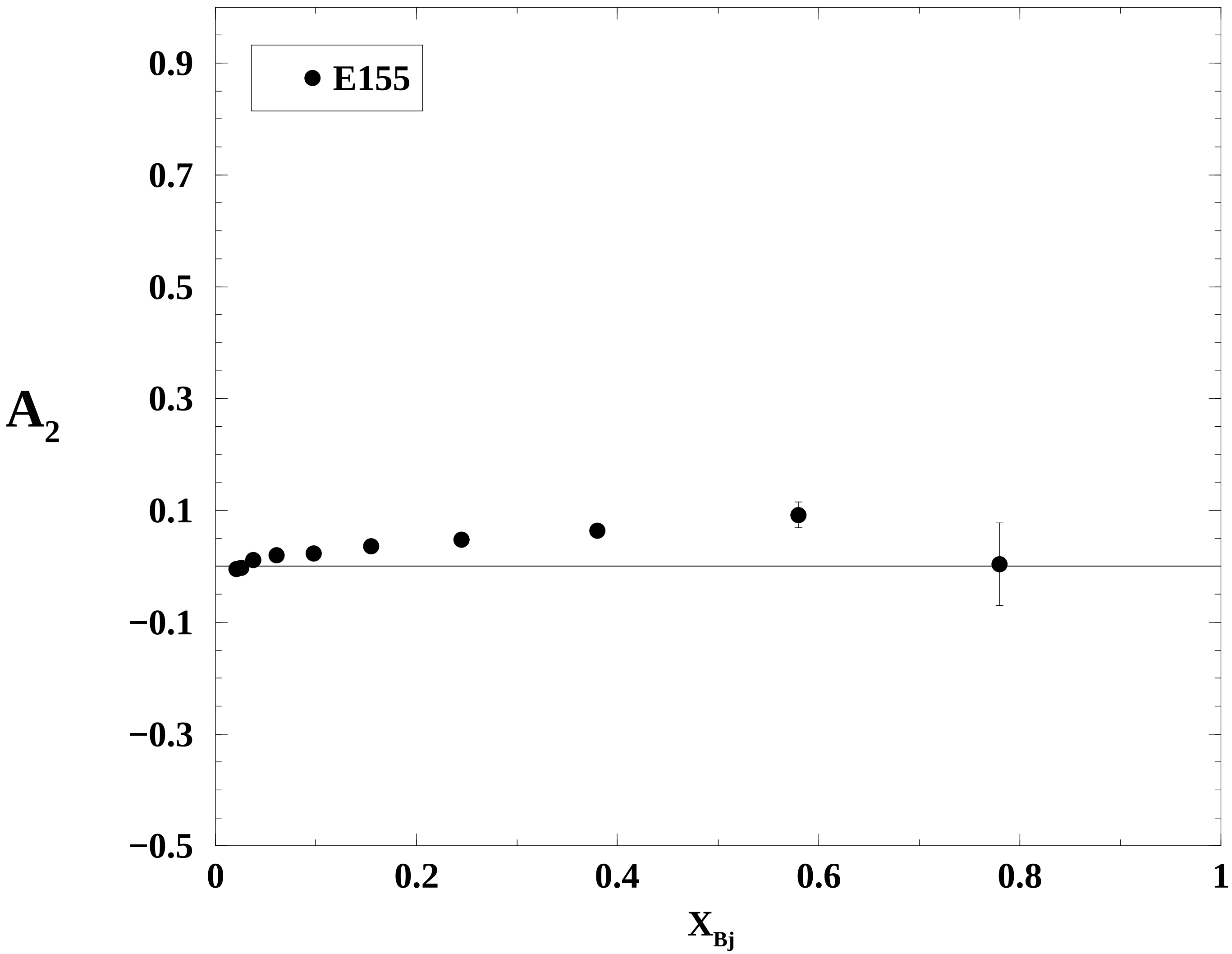
E143
E155
SLAC fit
RSS
Preliminary
A1
XBj
2
1.5
1
0.5
0
−0.5
−1
0
0.2
0.4
0.6
0.8
1

Proton A_1

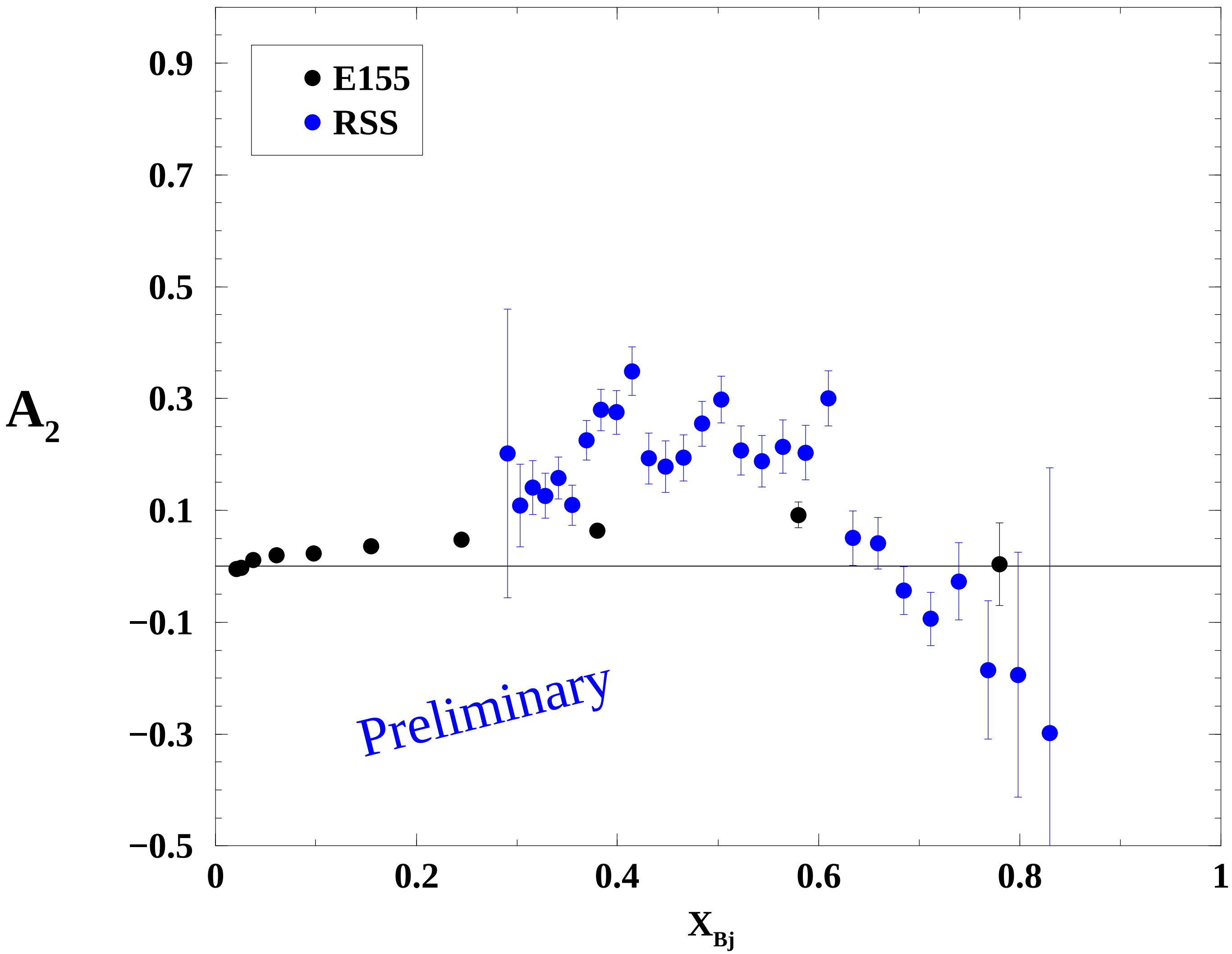


SLAC fit
MAID
RSS
S11(1535)
D13(1520)
Preliminary
Δ
A1
XBj
2
1.5
1
0.5
0
−0.5
−1
0
0.2
0.4
0.6
0.8
1

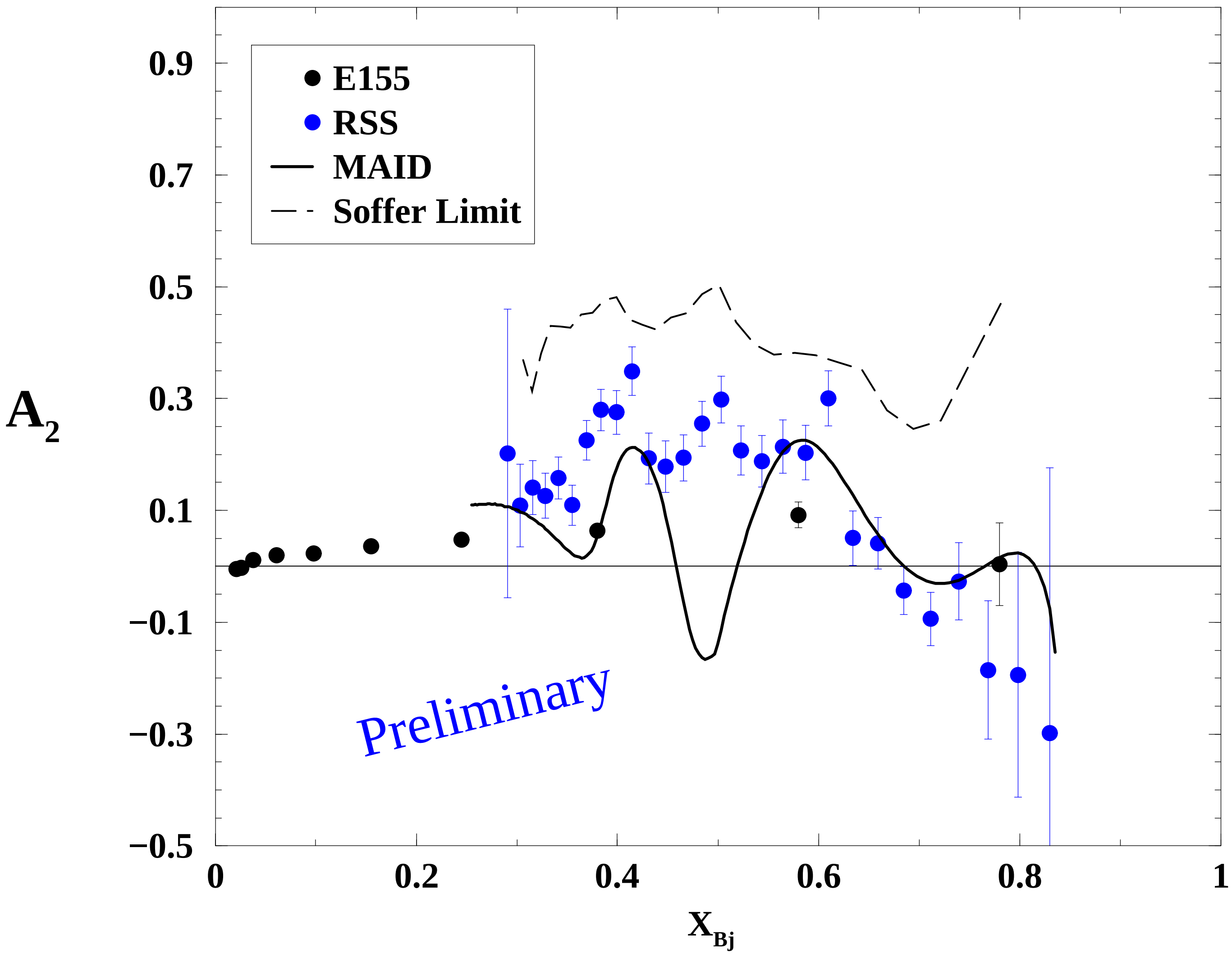
Proton A_2



Proton A_2

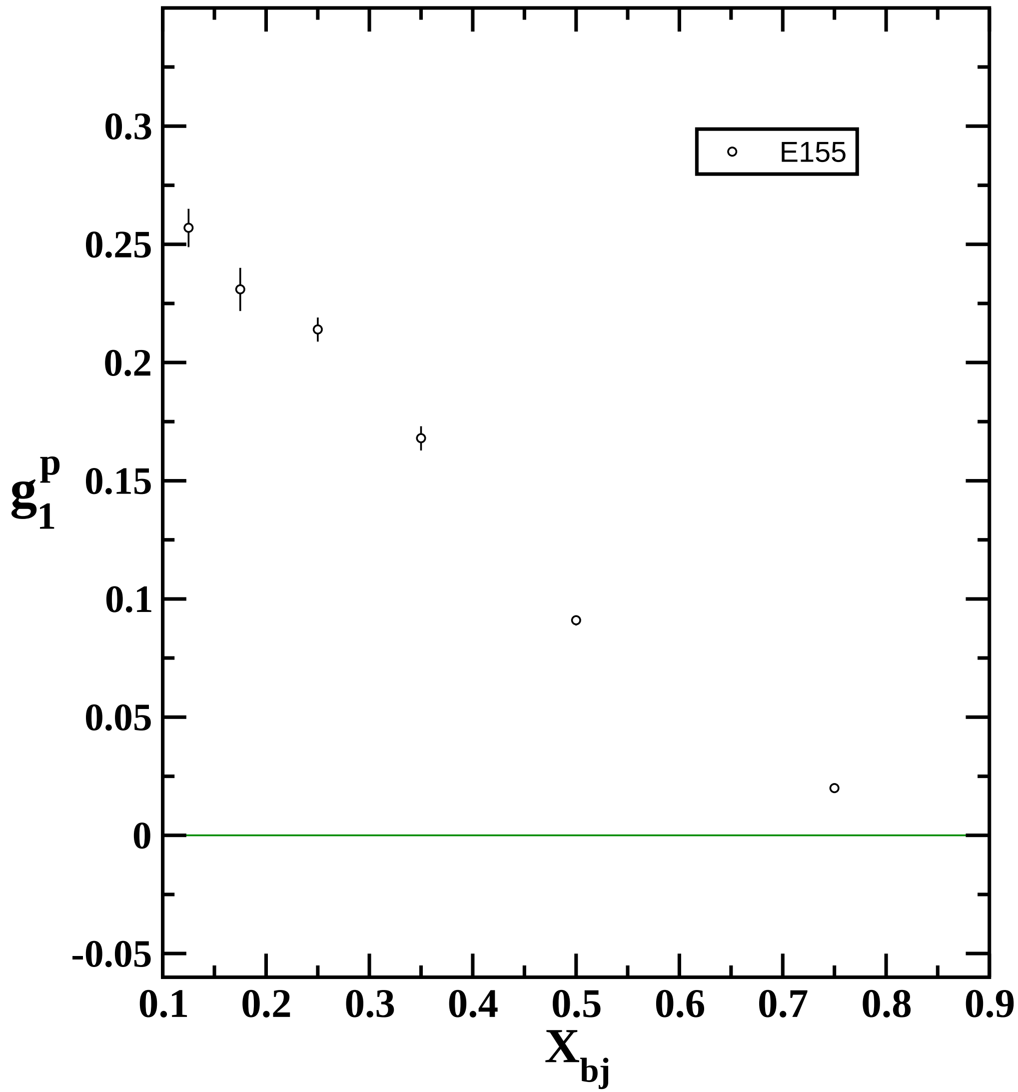


Proton A_2

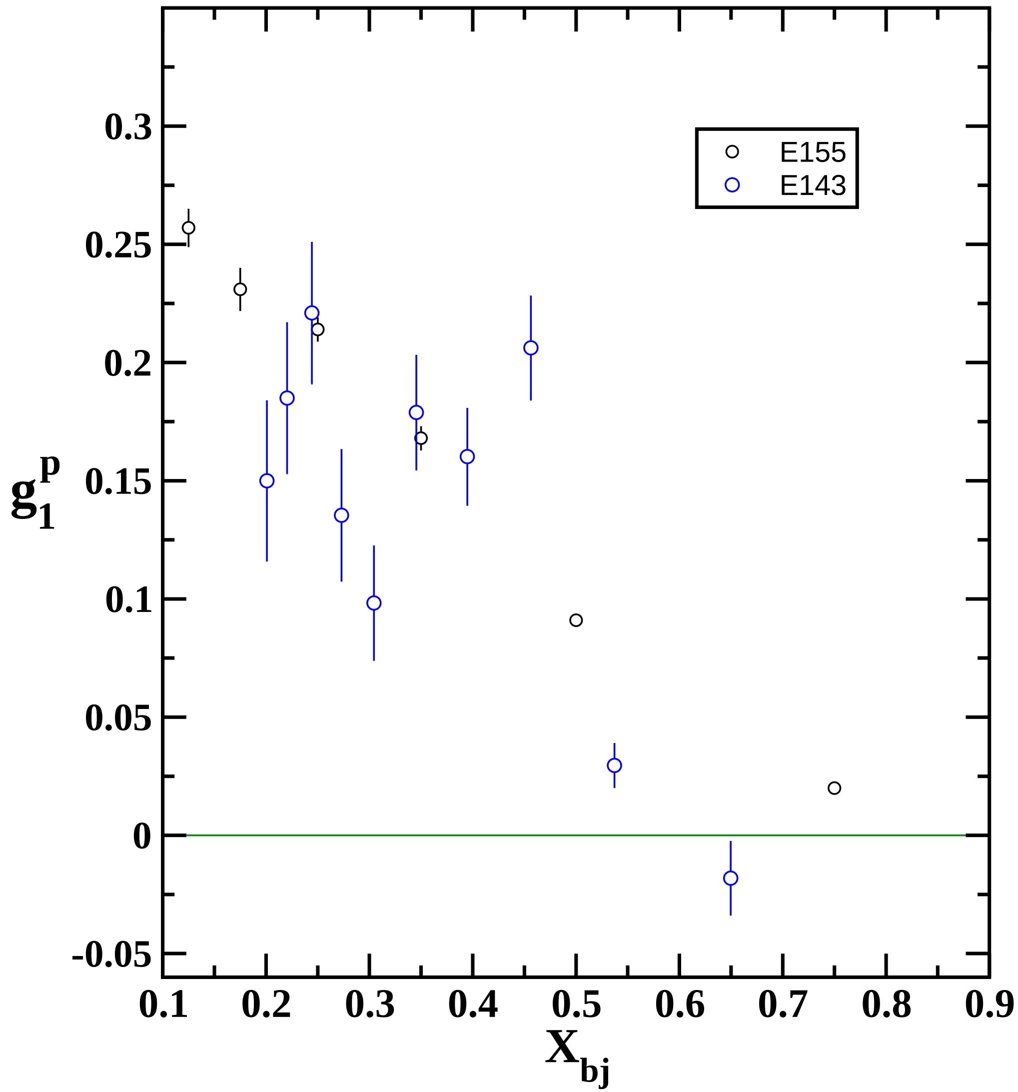


E155
RSS
MAID
Soffer Limit
0.9
0.7
0.5
0.3
0.1
−0.1
−0.3
−0.5
A_2
0
0.2
0.4
0.6
0.8
1
X_{Bj}
Preliminary

Proton g_1

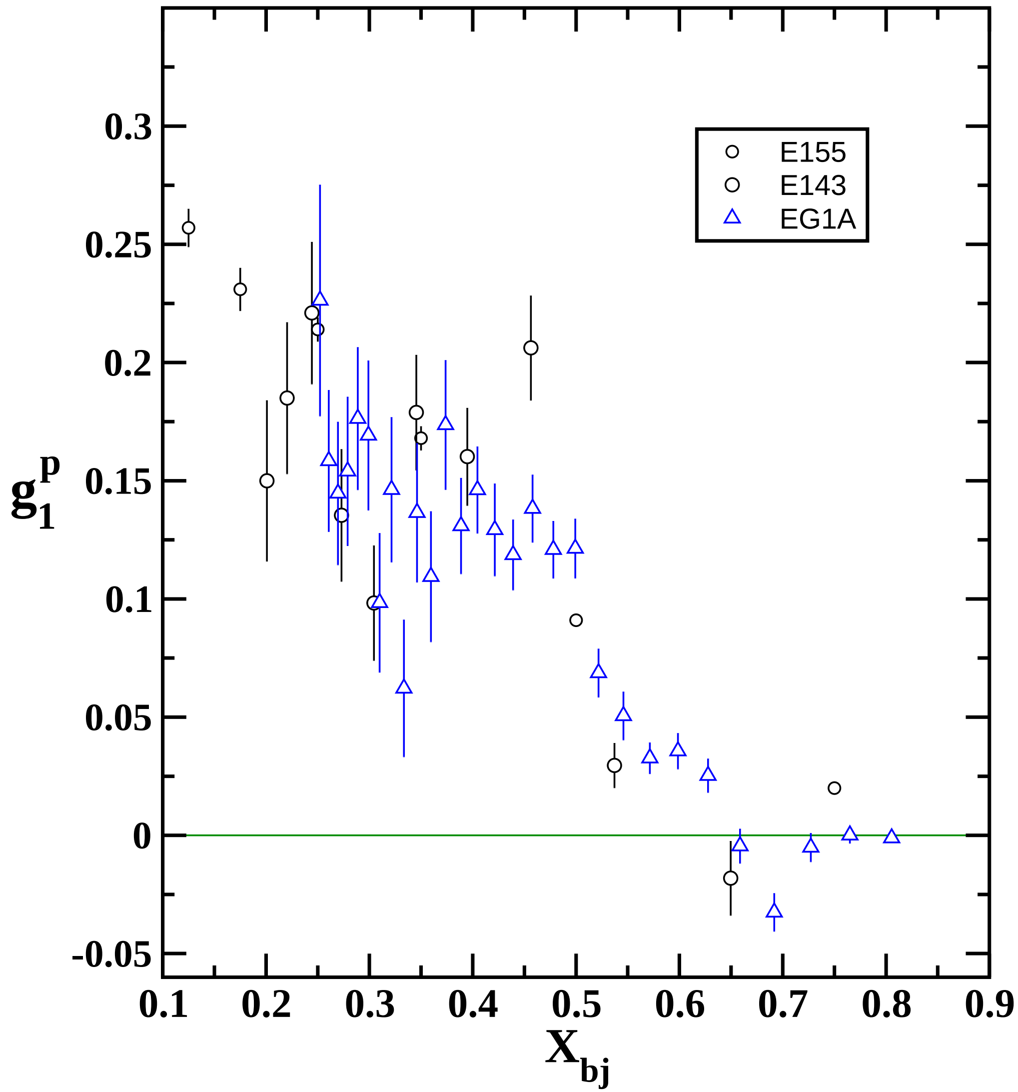


Proton g_1



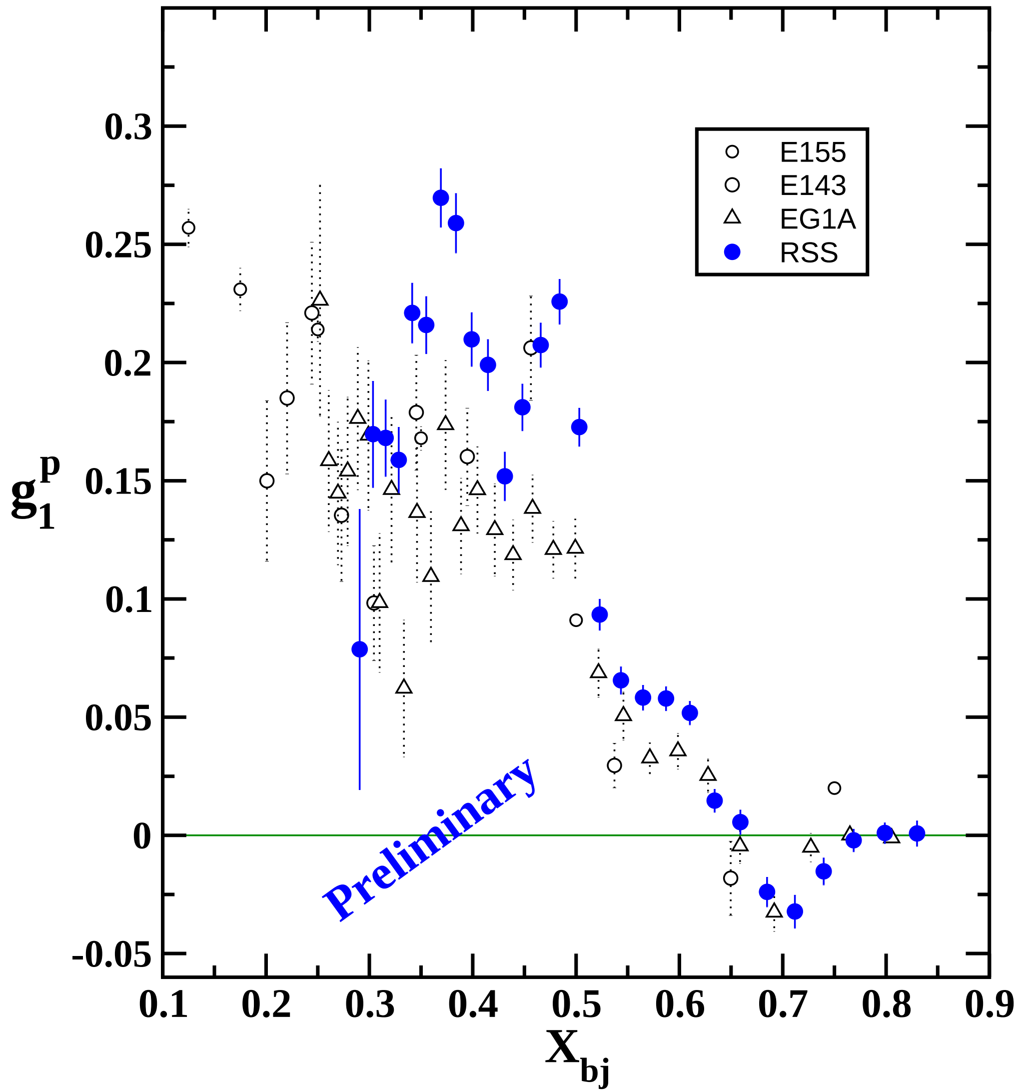
E155
E143
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
g_1^p
X_{bj}

Proton g_1

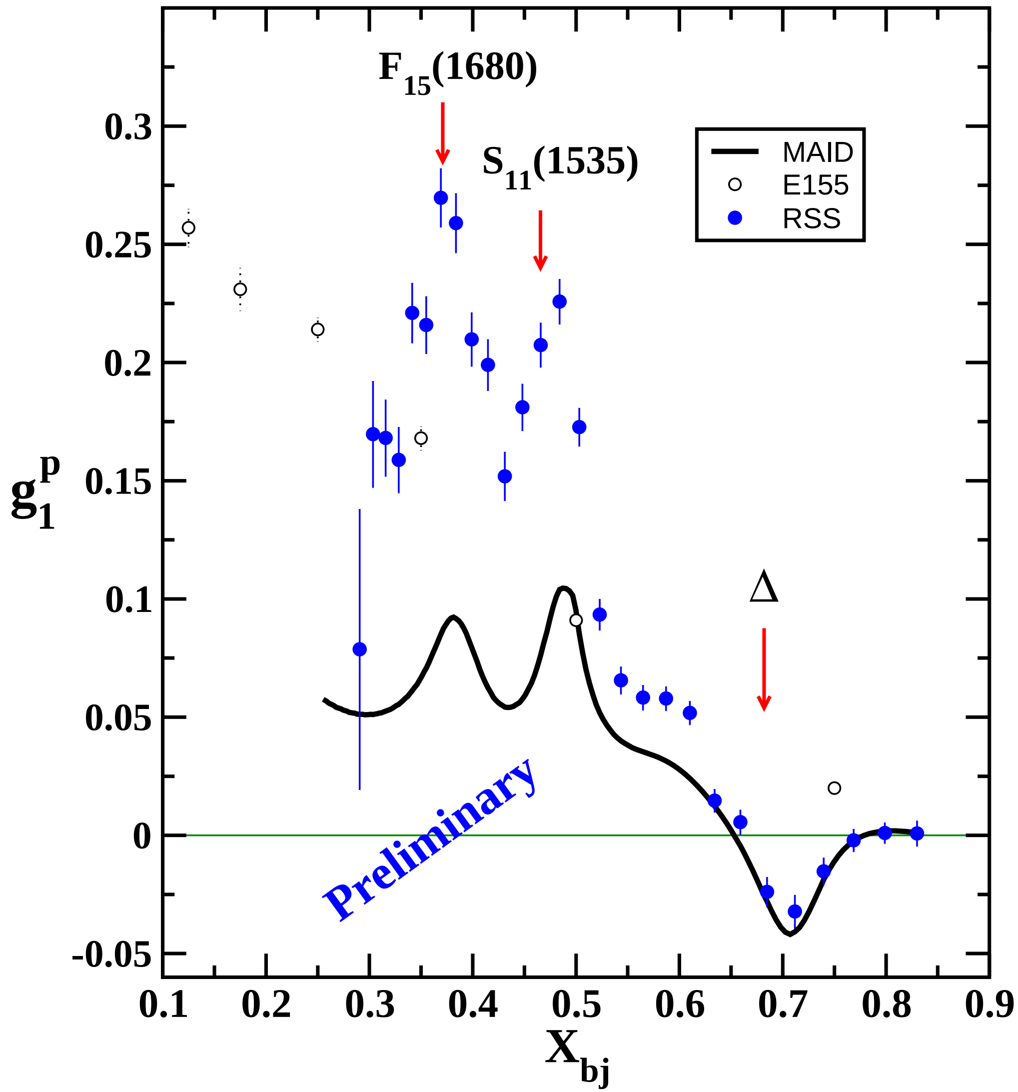


E155
E143
EG1A
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
g_1^p
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
X_{bj}

Proton g_1

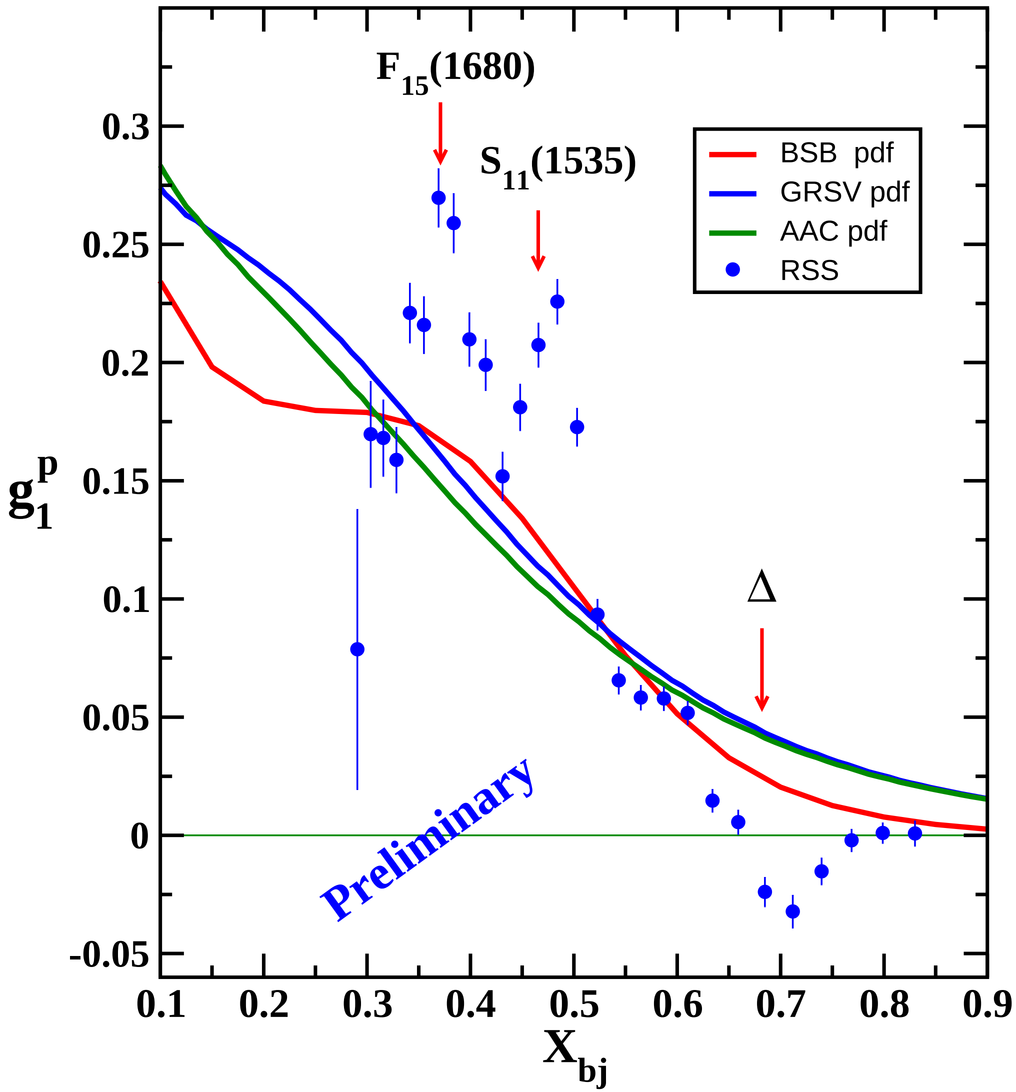

E155
E143
EG1A
RSS
Preliminary
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
g_1^p
X_{bj}

Proton g_1



F15(1680)
S11(1535)
MAID
E155
RSS
Δ
Preliminary
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
g1p
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Xbj

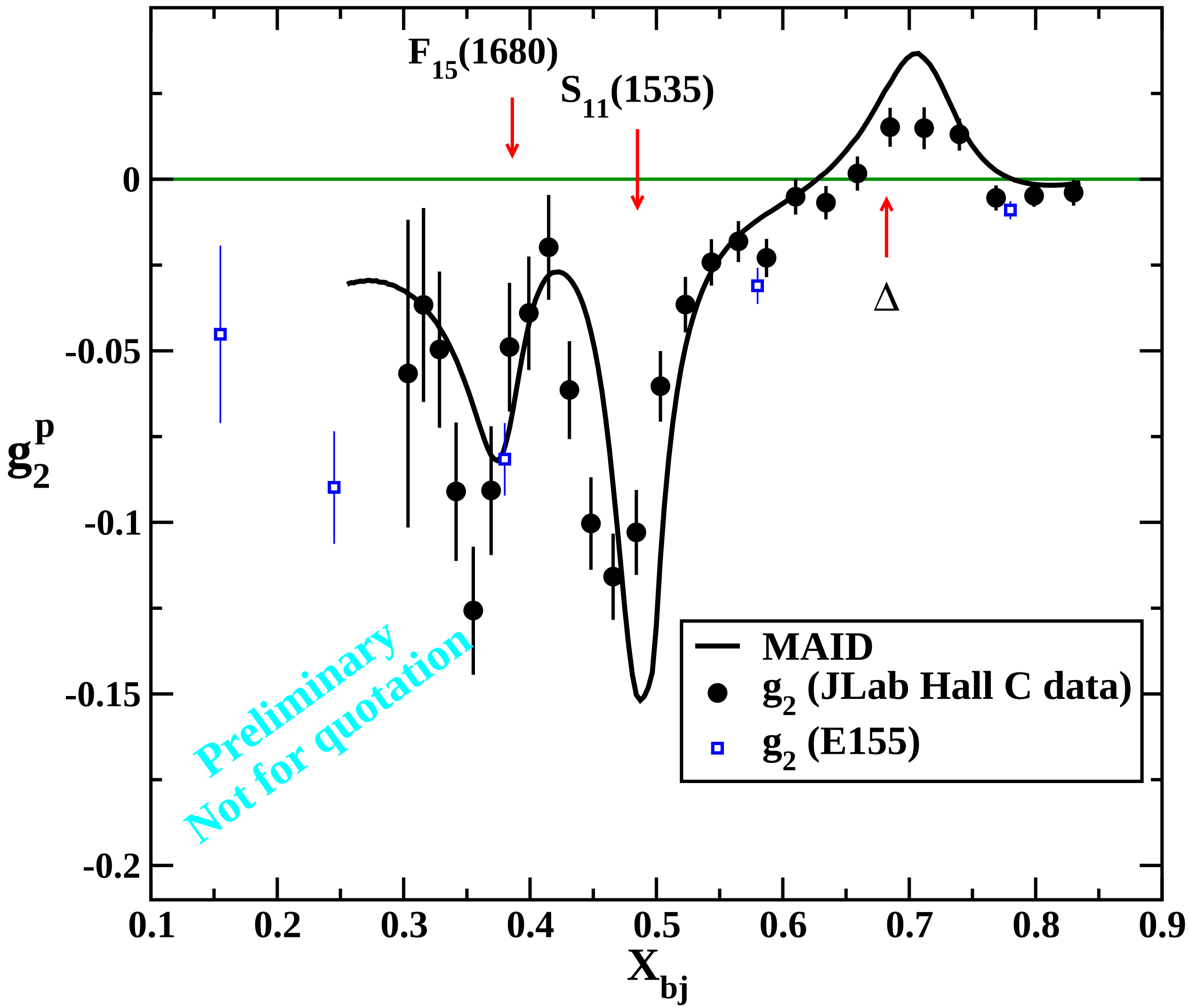
Proton g_1



All pdfs evolved to Q^2 = 1.3

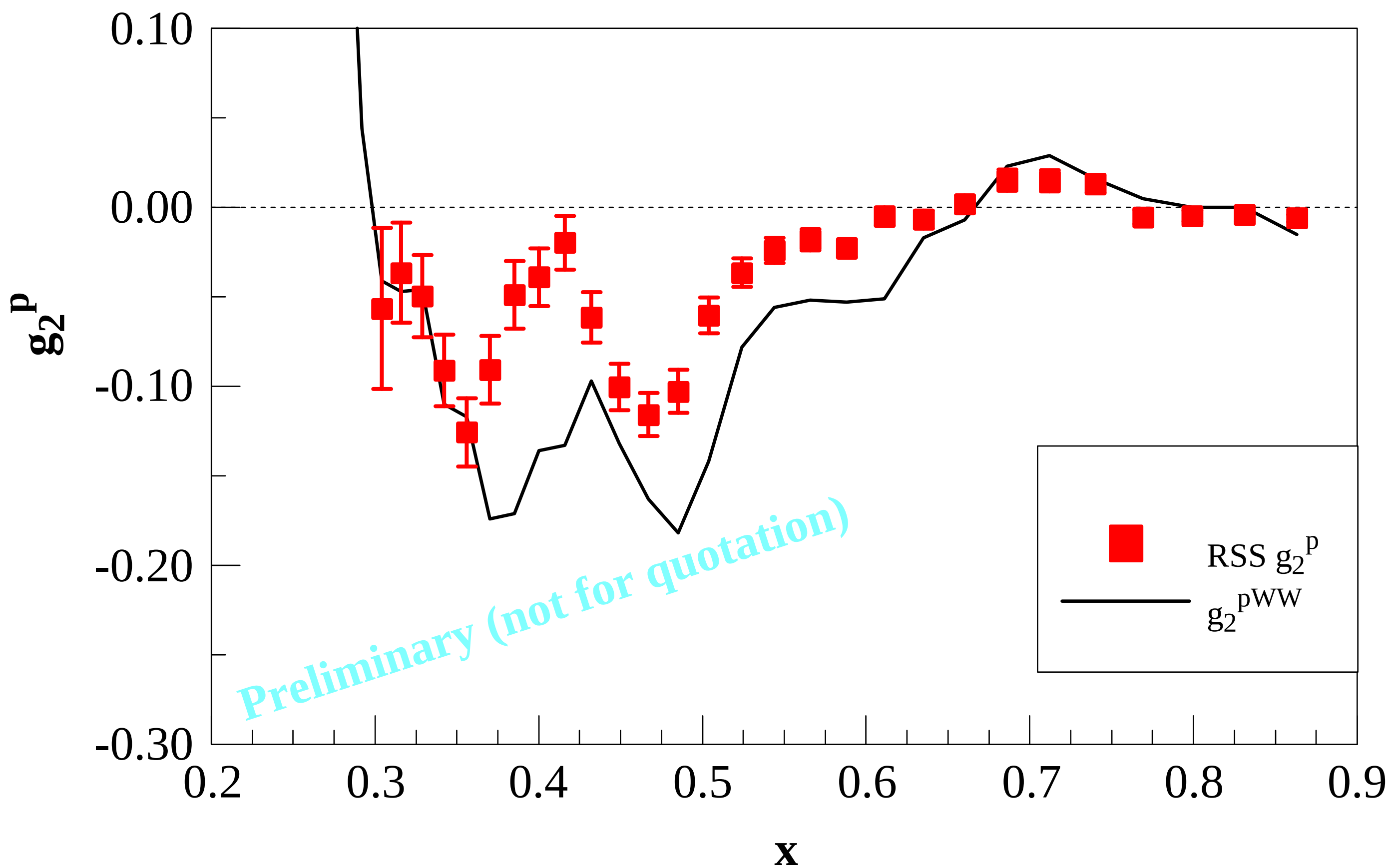
GRSV, AAC have target mass correction.

Proton g_2



F15(1680)
S11(1535)
Δ
0
-0.05
-0.1
-0.15
-0.2
g2p
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Xbj
MAID
g2 (JLab Hall C data)
g2 (E155)
Preliminary
Not for quotation

Higher twist in g_2



$$g_2 = g_2^{\mathrm{WW}} + \overline{g}_2$$

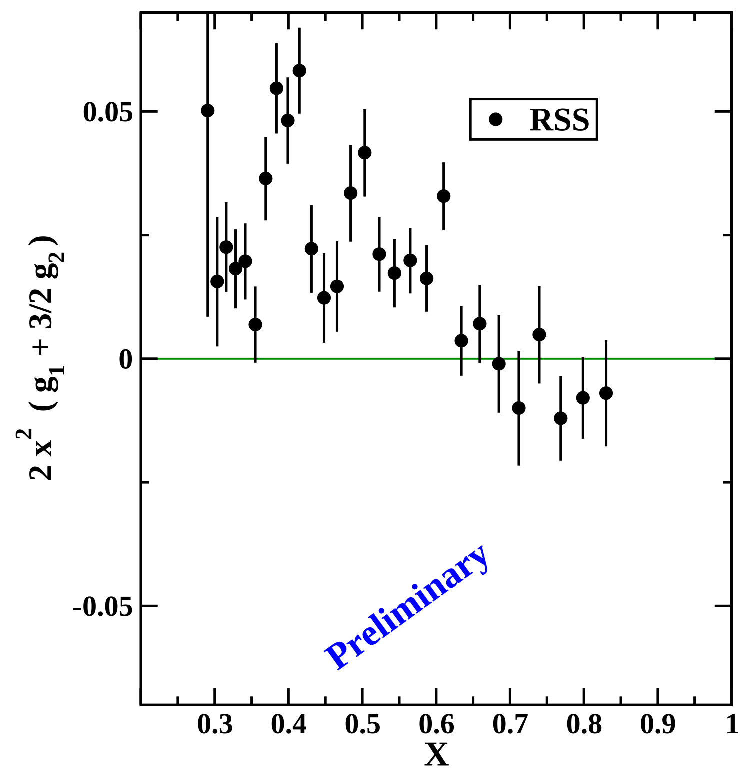
Twist-2 : $g_2^{\mathrm{WW}} = -g_1 + \int_x^1 \frac{g_1}{y} dy$

Twist-3 matrix element d_2

$$d_2 = 3\int_0^1 x^2(g_2 - g_2^{\mathrm{WW}})dx$$

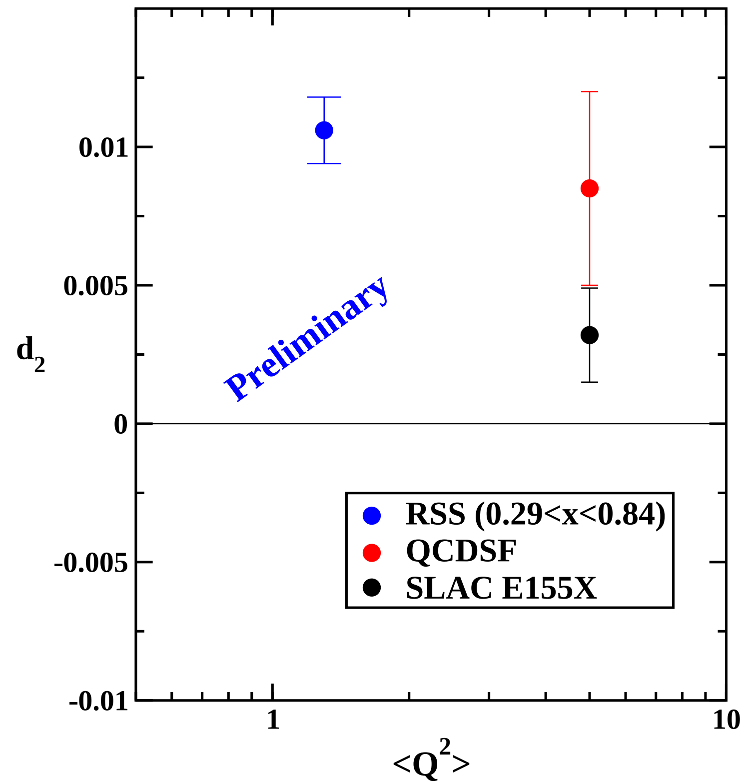
Twist-3 matrix element d_2

$$d_2 = 3\int_0^1 x^2(g_2 - g_2^{\text{WW}})dx$$
$$= 2\int_0^1 x^2(g_1 + \frac{3}{2}g_2)dx$$



Twist-3 matrix element d_2

- Integrated over
  0.29 $< x_{bj} <$ 0.84
  d_2 = 0.0106 $\pm$ 0.0012
- Lattice QCD at $Q^2 = 5$
  d_2 = 0.0085 $\pm$ 0.0035
  QCDSF group , hep-lat/0011091
- SLAC E155 at $< Q^2 >= 5$
  d_2 = 0.0032 $\pm$ 0.0017



RSS Summary

Measured proton/deuteron $A_{||}$ and $A_{\perp}$.

(Q$^2 \approx 1.3$ and $0.8 < W < 2.0$)

Proton analysis complete. Extracted A_1,A_2,g_1,g_2 d_2.

- Compared to MAID model.
- Compared to DIS data.
- Made a qualitative comparison of g_1 to PDFs.
- Positive d_2 measured with 10% error !

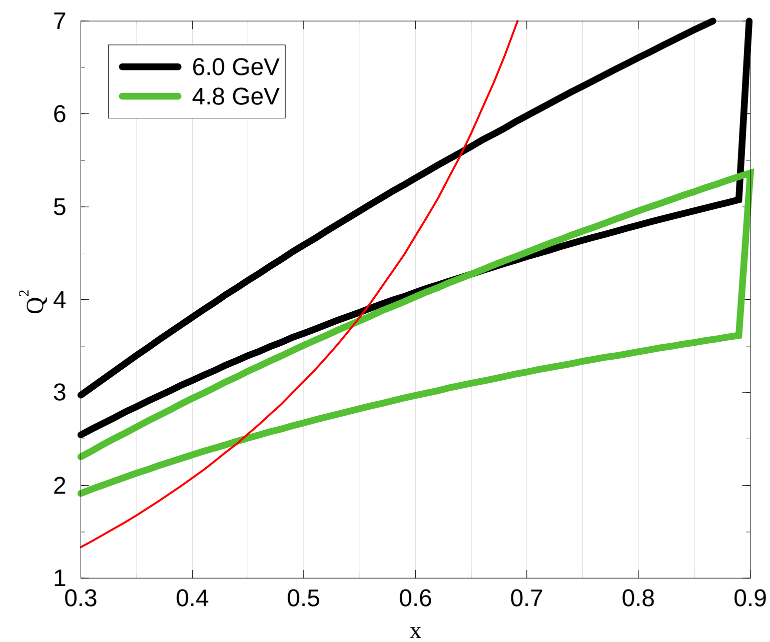
To Do:

- Deuteron radiative corrections (in progress).
- Quantitative duality analysis.
- Structure function moments.

Spin Asymmetries on the Nucleon Experiment

E03-109

Basel, F.I.U. , Hampton, IHEP Protvino, Kent State, Norfolk, N.C A&T, Rensselaer Polytechnic, St. Norbert, Temple, TJNAF, UVA, William & Mary, Yerevan



Spokesmen

Oscar A. Rondon (UVA)

Zein-Eddine Meziani (Temple)

Seonho Choi (Seoul)

- Proton spin structure function $g_2(x, Q^2)$ and spin Asymmetry $A_1(x, Q^2)$ $2.5 < Q^2 < 6.5$ GeV^2 and $0.3 < x < 0.8$.
- Study x and Q^2 dependence, twist-3 effects, moments of g_2 and g_1, comparison with Lattice QCD predictions, test polarized local duality for $W > 1.4$ GeV.

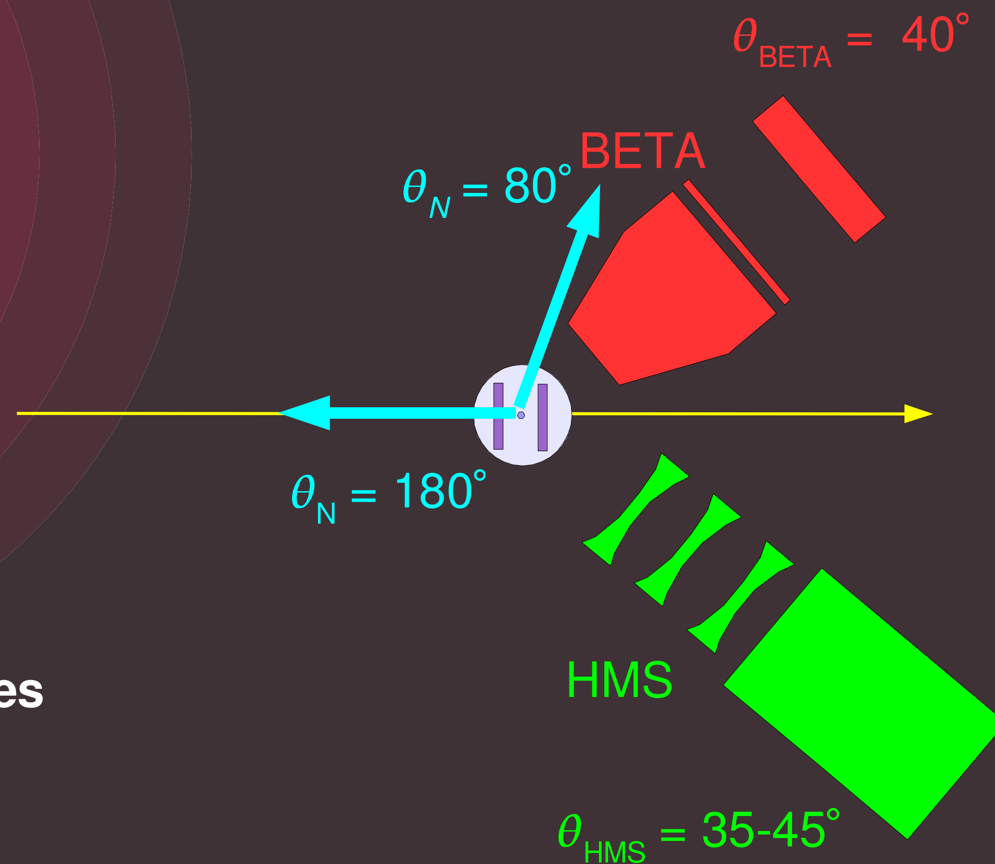
Experimental Setup

Target
- UVa NH3 target
- 5 T field

Beamline
- Chicanes
- SEM
- He Bag

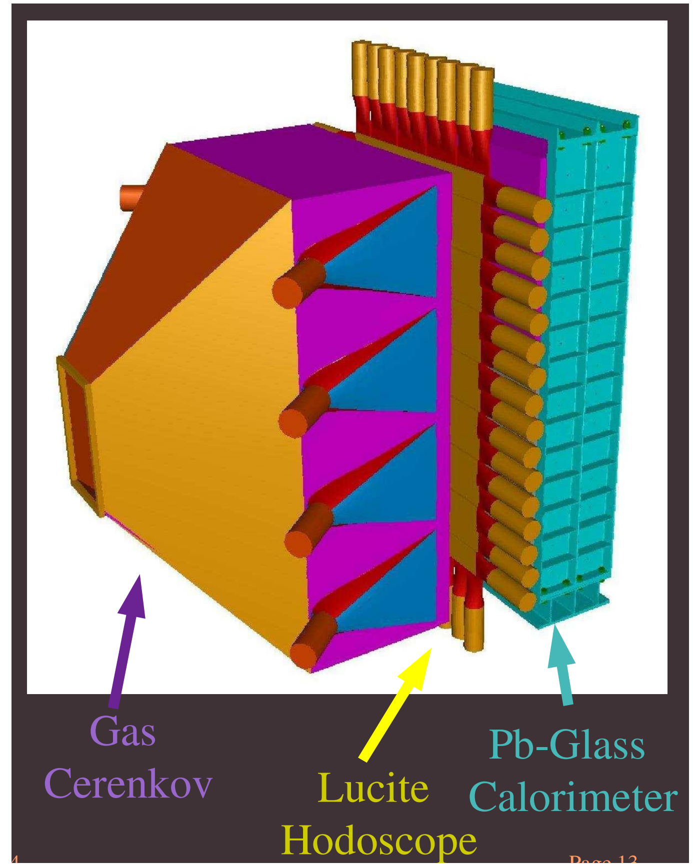
Electron Arm
- BETA

Background Studies
- HMS

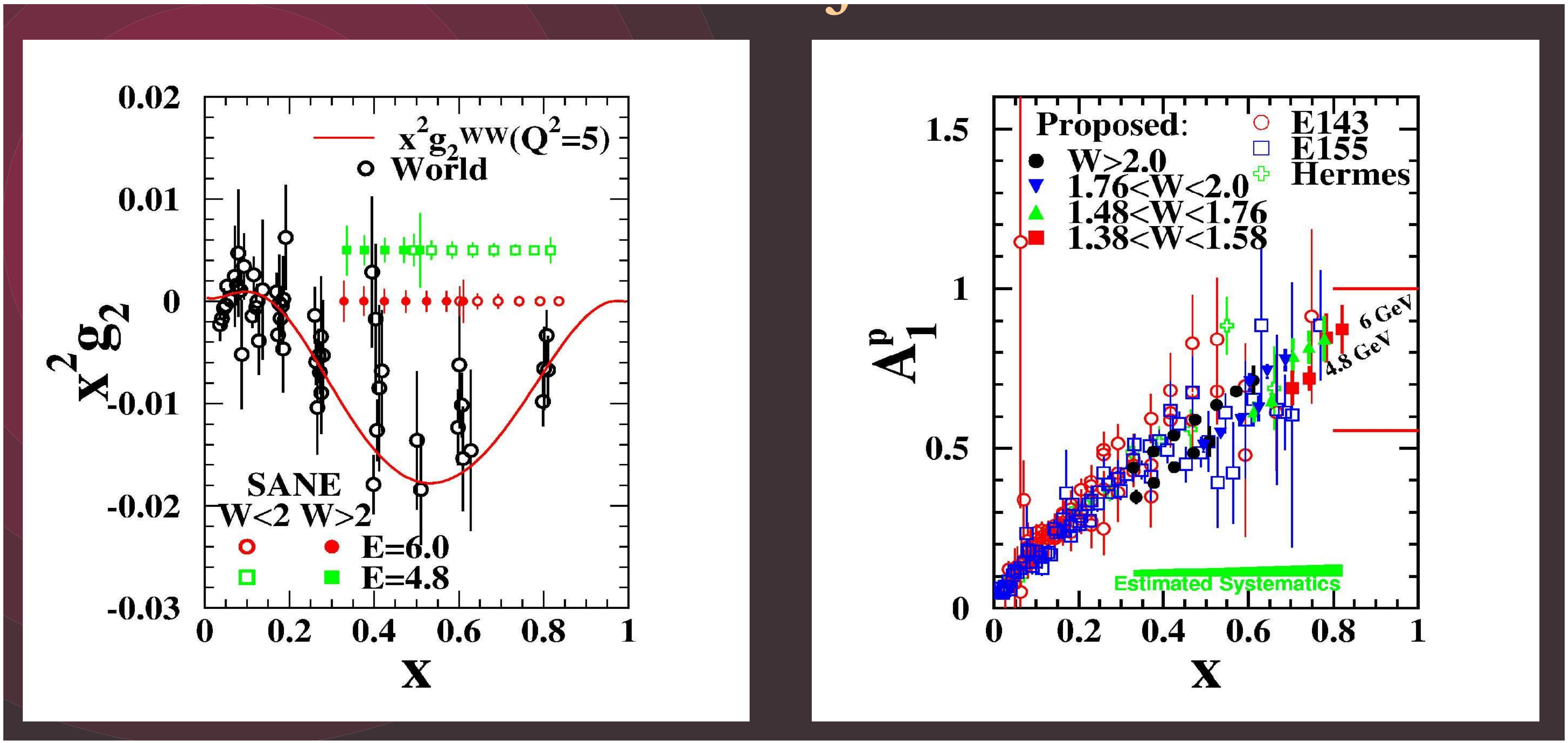


Big Electron Telescope Array (BETA)

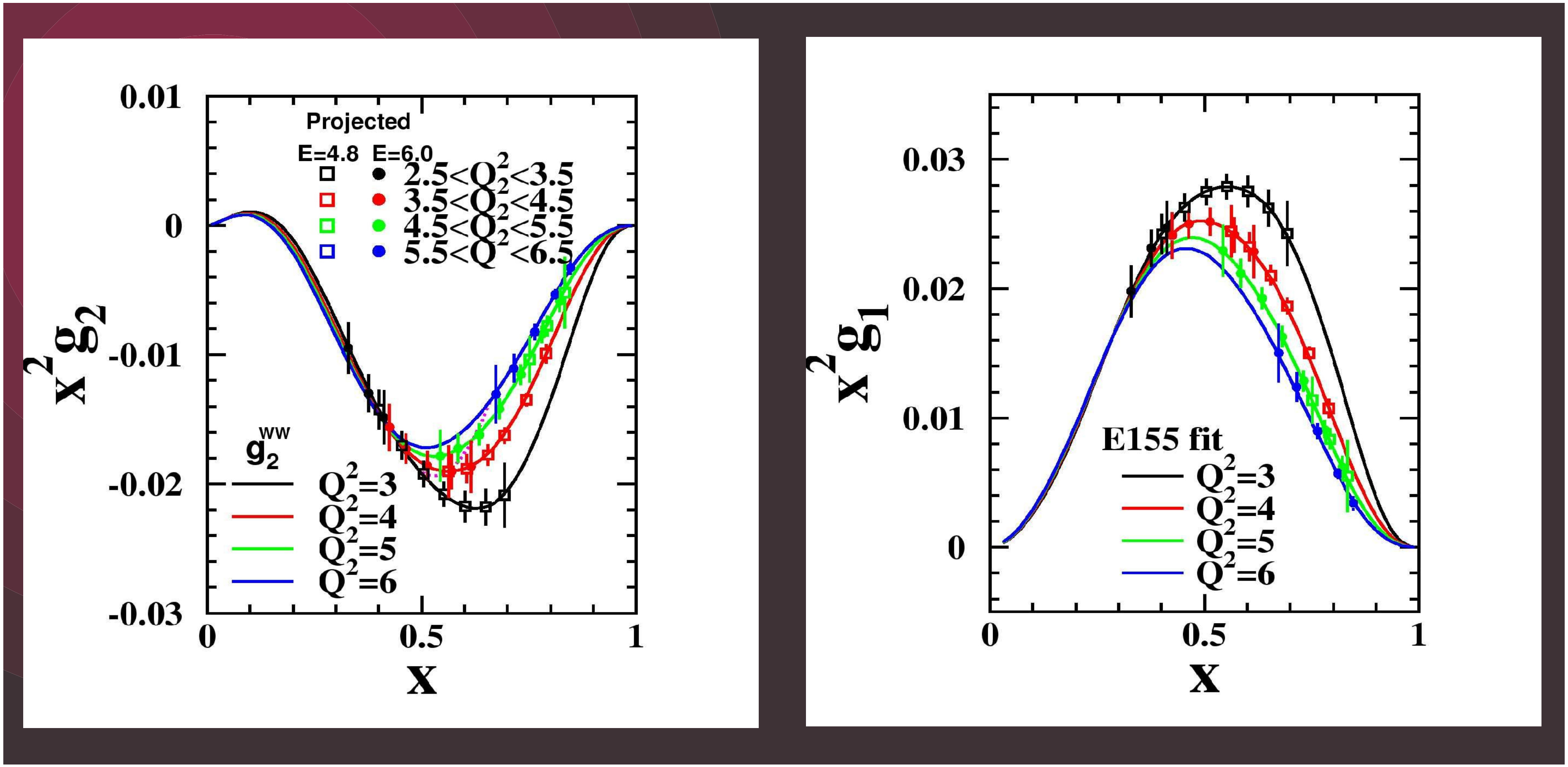
- 3 subsystems
  - Lead glass calorimeter
  - Gas Cherenkov
  - Lucite hodoscope
- Target field sweeps low E BG
- Characteristics
  - $\Delta\Omega \approx 194$ msr
  - $\Delta E \approx 5\%/\sqrt{E}$
  - $\Delta\theta \approx 2^\circ$
  - 1000:1 pion rejection



Expected Results for proton g_2 and A_1



Expected Results x and Q^2 dependence



Semi-Inclusive Spin Asymmetries on the Nucleon Experiment

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Proton and deuteron semi-inclusive longitudinal spin asymmetries

- Polarized DIS reactions $p(e, e'h)$ and $d(e, e'h)$ for h = $\pi^{\pm}$,$K^{\pm}$
- 1.2 $< Q^2 <$3.1 GeV^2
- 0.12 $< x <$ 0.43,

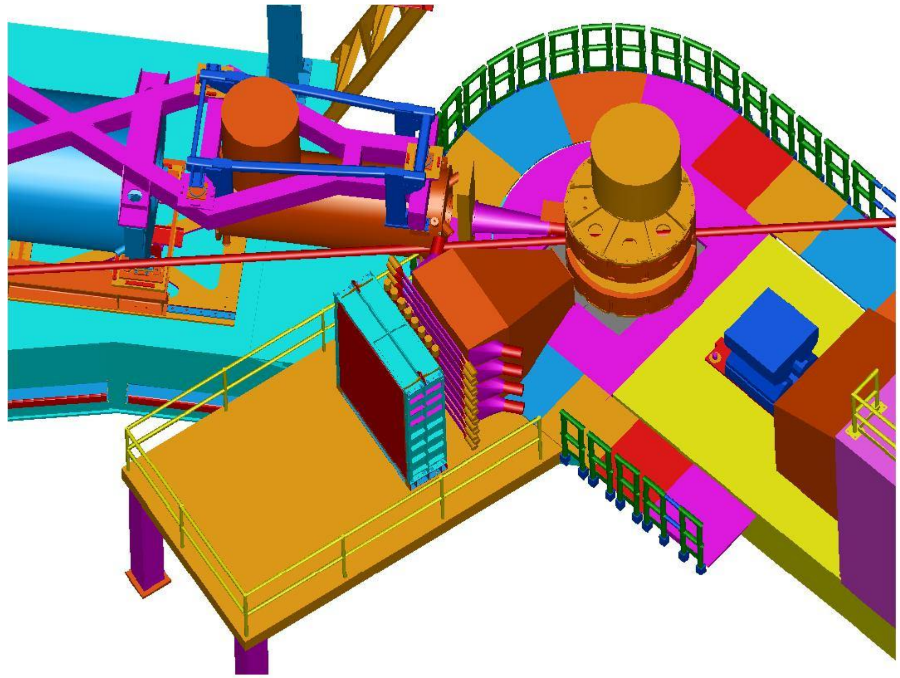
Spin flavor decomposition

- emphasis on NLO spin flavor decomposition to extract Δu_v, Δd_v and $\Delta\overline{u} - \Delta\overline{d}$
- based on measurement of combined asymmetry, $A_{1N}^{\pi^+-\pi^-}$.

Examine deviation from factorization

- by comparing combined asymmetry, $A_{1N}^{\pi^++\pi^-}$ with the inclusive asymmetry, A_{1N}.

Experiment Set-up



- Electrons detected in BETA at 30°
- Hadrons detected in HMS at 10.8° and p_{cent} = 2.7 GeV/c

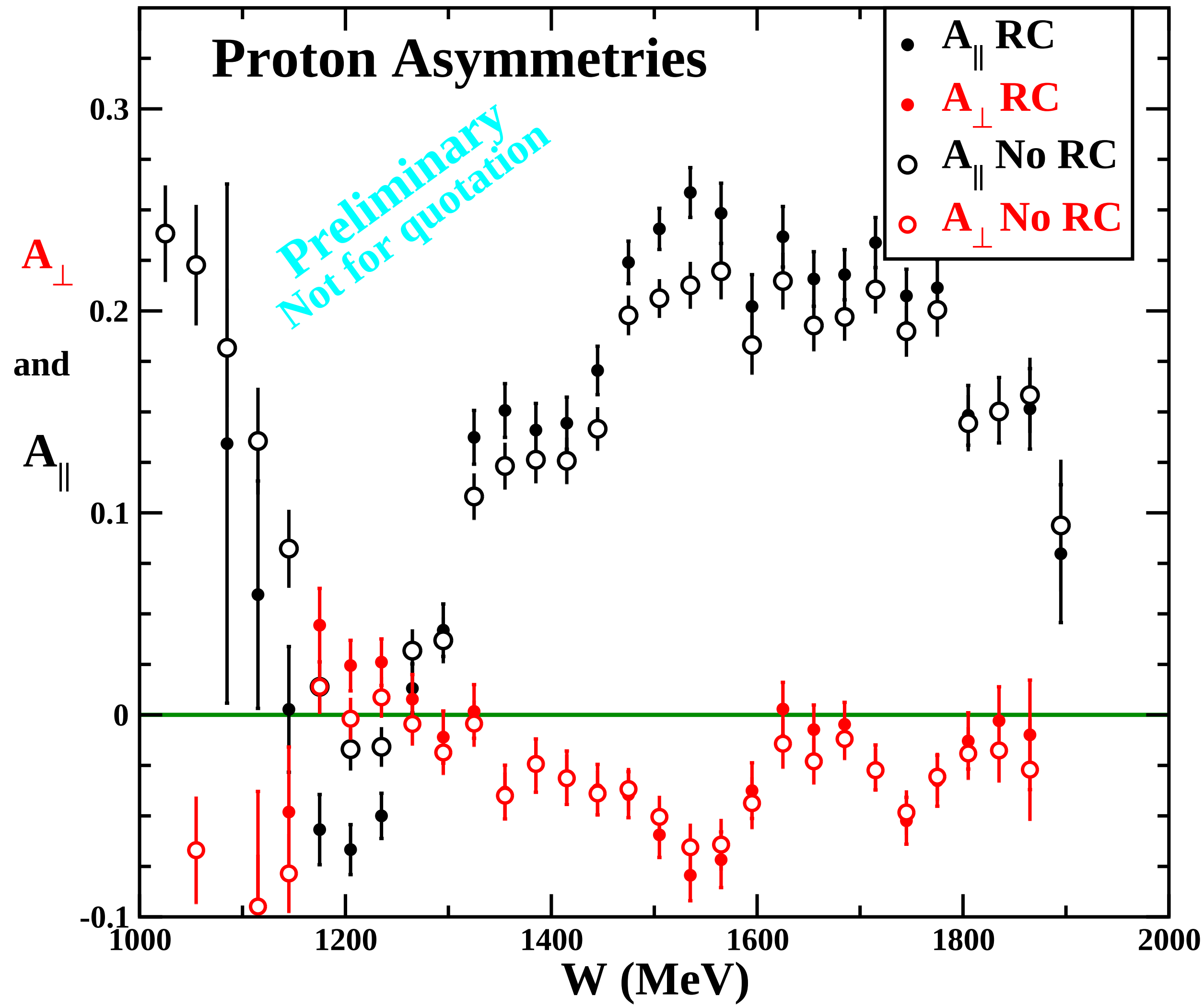
Summary of Hall C spin program

- RSS : $A_{||}$ and $A_{\perp}$ in inclusive electron scattering on protons and deuterons.
  - SF and Spin Asymmetries at $Q^2 = 1.3$ GeV^2 and 0.8 $< W <$ 2.0
- SANE: $A_{||}$ and $A_{\perp}$ in inclusive electron scattering on proton with large acceptance detector (BETA)
  - Extract g_1 and g_2 in range
  - 2.5 $< Q^2 <$ 6.5 and 0.3 $< x <$ 0.8
- Semi-SANE: SIDIS reactions $p(e, e'h)$ and $d(e, e'h)$ for h = $\pi^{\pm}$,$K^{\pm}$.
  - 1.2 $< Q^2 <$3.1 GeV^2, 0.12 $< x <$ 0.43, 0.5 $< z <$ 0.7
  - Spin flavor decomposition
  - “Test” of validity of factorization by checking if $A_{1N}^{\pi^{+}+\pi^{-}}$ equals the inclusive asymmetry, A_{1N}.

Sources of Systematic Error

	$^{15}NH_3$	$^{15}ND_3$
Nitrogen polarization	$<$1%	1%
Radiative corrections	2%	3%
Beam Polarization	1.5%	1.5%
Target polarization	2.5%	4%
Dilution factor	3%	3%
Pions, deadtime	1%	1%
Errors from R and F2	3%	3%
Total error	5.5%	6.8%

Compare proton $A_{\parallel}$ and $A_{\perp}$ w/o RC



$$
\begin{aligned}
A_1 &= \frac{C}{D}(A_\parallel - dA_\perp) \\
A_2 &= \frac{C}{D}(c'A_\parallel - d'A_\perp)
\end{aligned}
$$

- Kinematic variables
  $C, c', d, d'(E, E', \theta), D(E, E', \theta, R)(R = \sigma_L/\sigma_T)$
- $d' \approx 1, c' \approx d \leq 1$ (at RSS kinematics)

- g_1, g_2 can be extracted directly from $A_{\|}, A_{\perp}$ or A_1, A_2

$$g_1 = \frac{F_1}{1+\gamma^2}(A_1 + \gamma A_2)$$
$$g_2 = \frac{F_1}{1+\gamma^2}(\frac{A_2}{\gamma} - A_1) \; ; \; \gamma^2 = \frac{Q^2}{\nu^2}$$

  - Need $F_1 = F_2(1+\gamma^2)/2x/(1+R)$ in the resonance region. Measurement of F2 and R in resonance region