# Polarized Structure Functions:
# Proton/Deuteron Measurements in the Resonance Region

*Mark K. Jones, Jefferson Lab*

## Measurement of $A_{\parallel}^{p,d}$ and $A_{\perp}^{p,d}$ at Jefferson Lab in Hall C

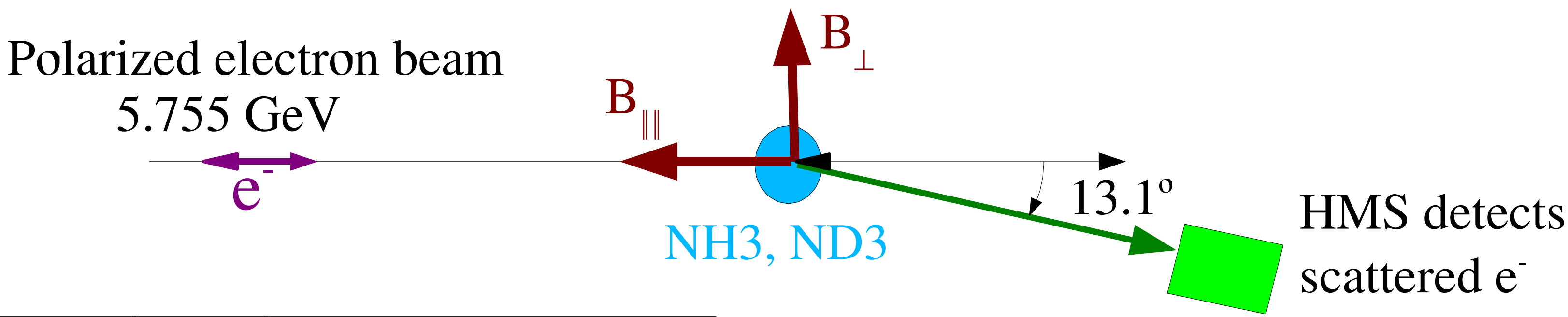
## Collaboration

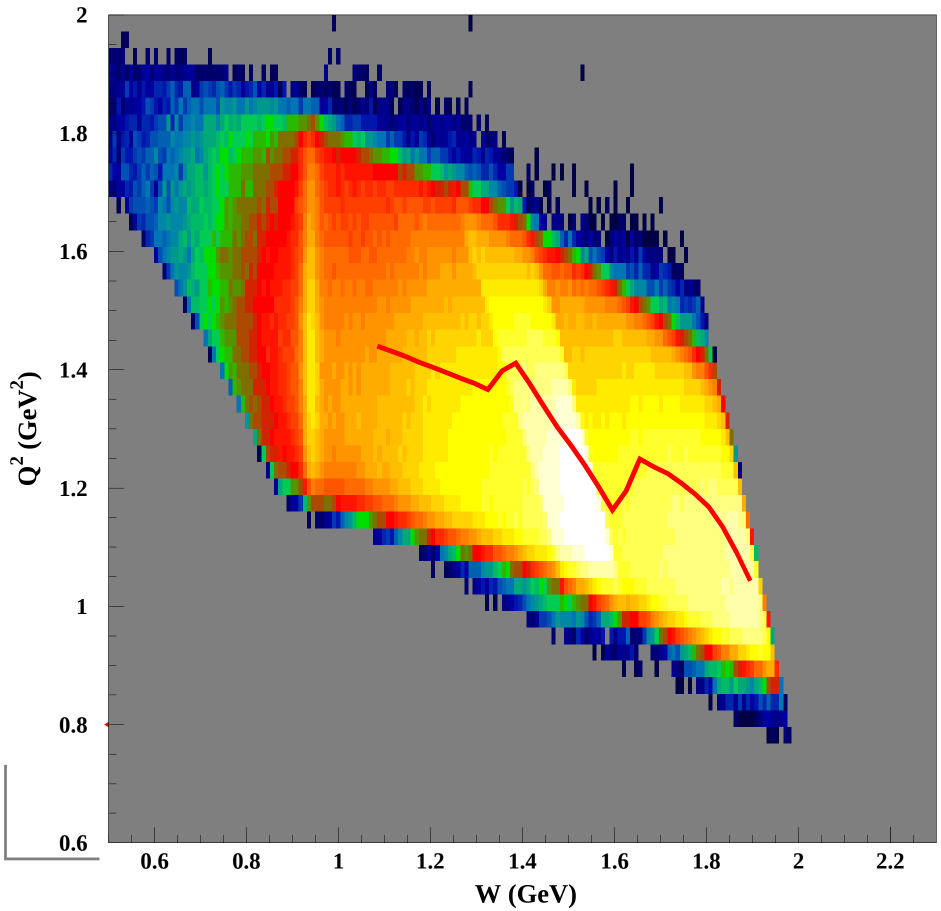
*Univ. Basel, Florida International Univ., Hampton Univ., Univ. of Massachusetts, Univ. of Maryland, Mississippi State Univ.,North Carolina A&T Univ., Univ. of N. C. at Wilmington, Norfolk State Univ.,Old Dominion Univ.,S.U. at New Orleans, Univ. of Tel-Aviv, Jefferson Lab, Univ. of Virginia, Virginia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

Spokesmen: Oscar A. Rondon (Univ. of Virginia) and Mark K. Jones (Jefferson Lab)

*Acknowledge the hard work of Paul McKee, Karl Slifer, Shige Tajima, Frank Wesselmann, Junho Yun and Hongguo Zhu*

# Experimental set-up in Hall C

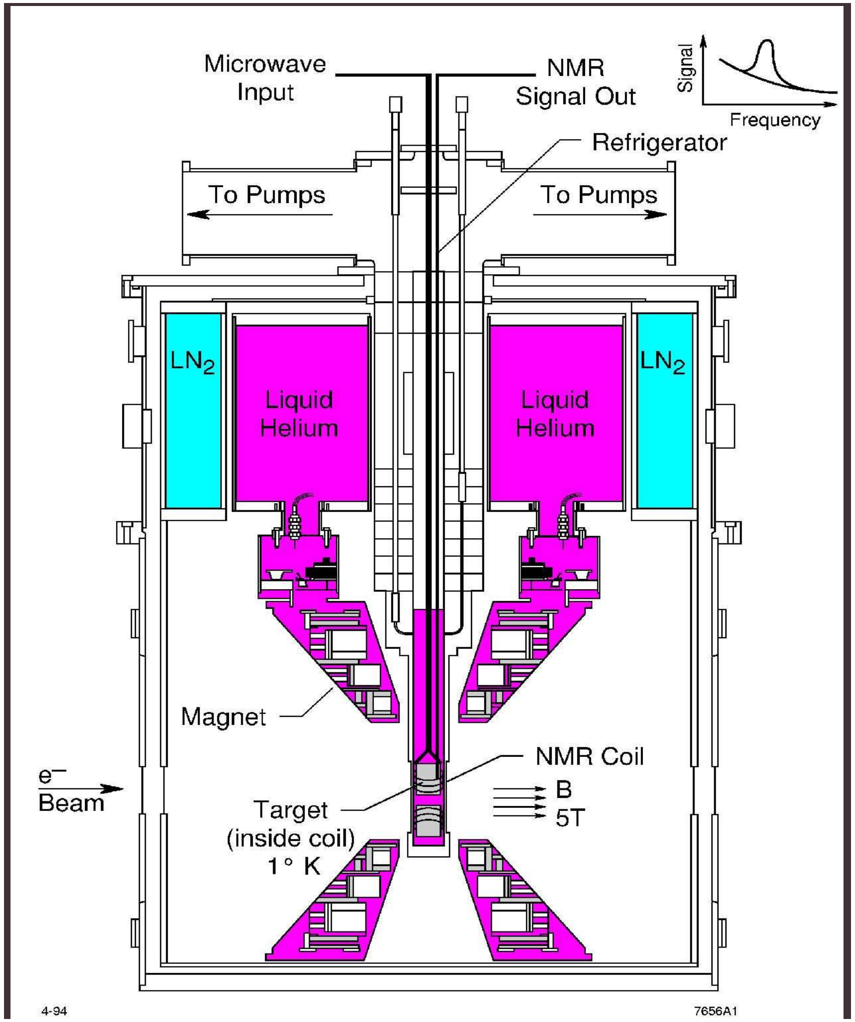



- Two HMS momentum settings: 4.7, 4.1 GeV/c
- $Q^2 \approx 1.3$ GeV$^2$ for 0.8$< W <$ 2 GeV
- $I \approx$ 100nA for $NH_3$, $ND_3$
- Beam polarization, $P_b$ measured by Moller
  $P_b$ = 65.6 $\pm$ 2.6 for $B_{\parallel}$
  $P_b$ = 70.9 $\pm$ 1.7 for $B_{\perp}$
- Beam charge asym. < 0.1%

# Polarized Target

Dynamic Nuclear polarized ammonia ($NH_3$) and deuterated ammonia ($ND_3$)




- Target ladder contained carbon (7mm), two $NH_3$ ( or $ND_3$) cups
- Rotate target can to switch from parallel, $B_{\parallel}$, to perpendicular, $B_{\perp}$, field.
- Polarization can be flipped by 180°. Ran $\pm$ for equal times.
- Average polarization

| | $NH_3$ | $ND_3$ |
|---|---|---|
| $B_{\parallel}$ | 68% | 15% |
| $B_{\perp}$ | 70% | 20% |

- Relative systematic error of 4% for $ND_3$ and 2.5% for $NH_3$

# Extracting Asymmetry

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

  in which $N^+, N^-$ are the number of counts normalized by the charge and deadtime for opposite beam helicities.

- Parallel and perpendicular asymmetries

$$A_{\|,\perp} = \frac{1}{C_N f_{rc}} \left( \frac{A_{raw}}{f P_b P_t} - C_D \right) + A_{rc}$$

  - $f$ = dilution factor ; ratio of rates from polarized nucleons to all nucleons
  - $P_b, P_t$ = beam and target polarizations
  - $C_N, C_D$ = corrections for $^{15}$N asymmetry (not applied yet)
  - $f_{rc}, A_{rc}$ = radiative corrections (sofar applied to proton only)

    Use code for polarized scattering in resonances

    ( I. Akusevich *et al.*)

# 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

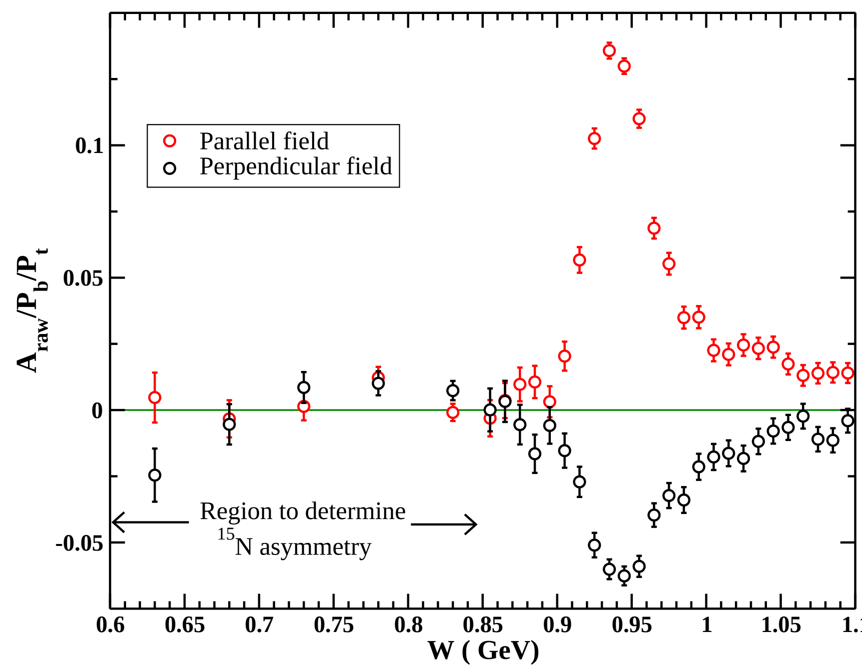
| | $B_{\parallel}$ | $B_{\perp}$ |
|---|---|---|
| $\theta^\star, \phi^\star$ | $129^\circ, 180^\circ$ | $41^\circ, 162^\circ$ |
| $\frac{\Delta A_{el}/A_{el}}{\Delta \frac{G_E}{G_M} / \frac{G_E}{G_M}}$ | 0.02 | 1 |

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

$$A_{el} = \frac{A_{raw}}{f P_b P_t} - C_N$$

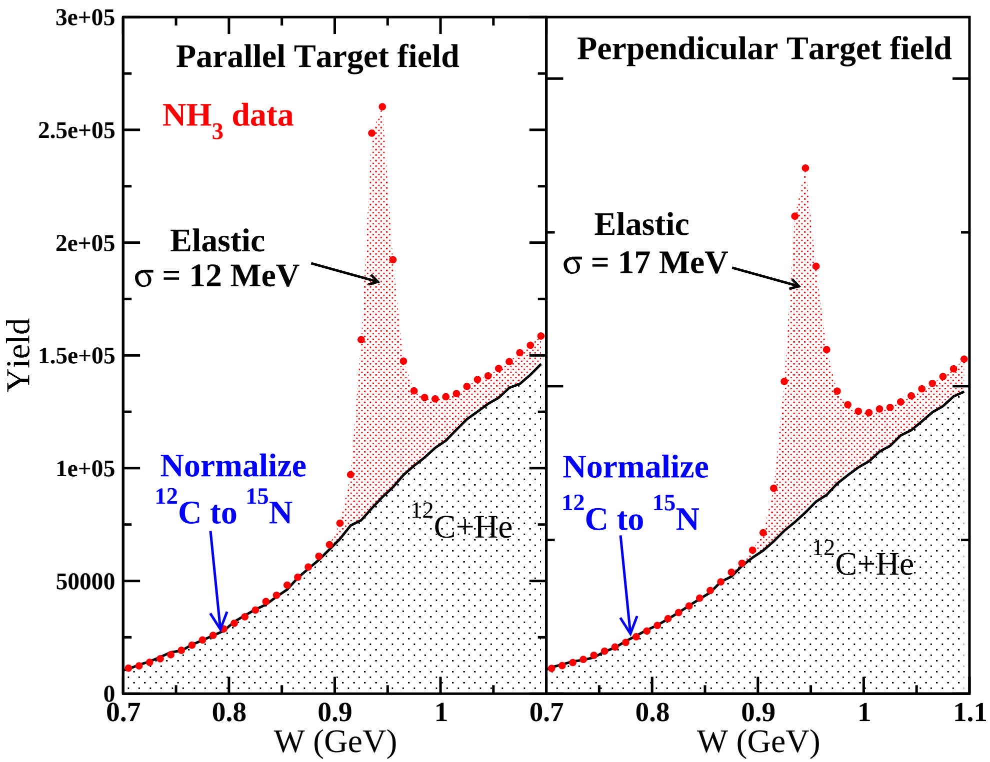
$C_N$ = 0.003 $\pm$ 0.001 for $B_{\perp}$

$C_N$ = 0.0015 $\pm$ 0.0015 for $B_{\parallel}$

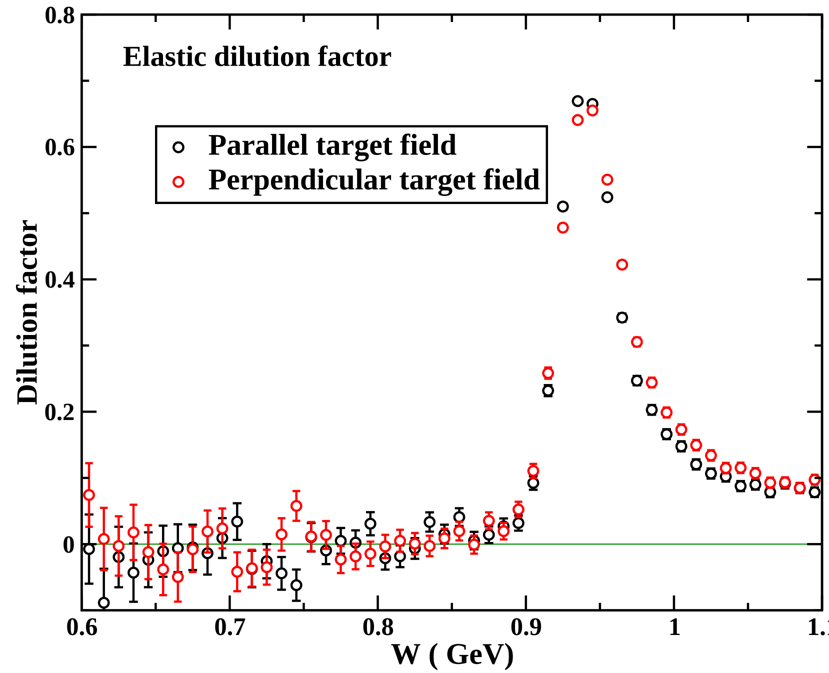


# Dilution factor for elastic peak

Use carbon for background shape under the elastic peak

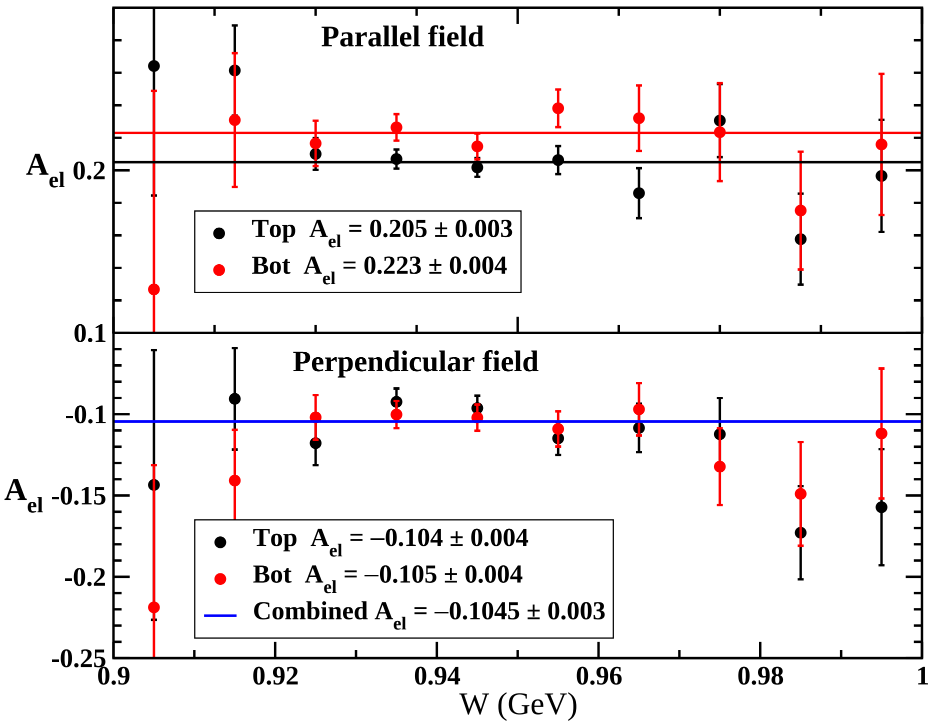



Dilution factor



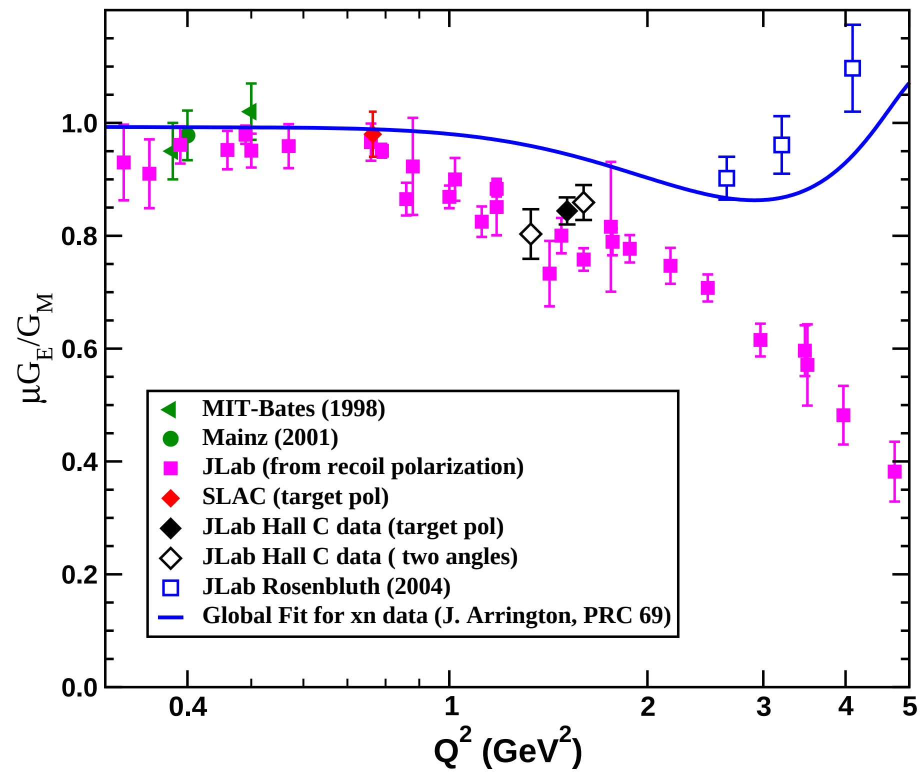
# Measured proton $A_{el}$

- For $B_{||}$, predict $A_{el}$ = 0.215
- For $B_{||}$, top and bottom $A_{el}$ disagree.




- Use predicted $A_{el}$ to normalize $B_{||}$ target polarizations for top ( 1.05) and bottom (0.96) cups.

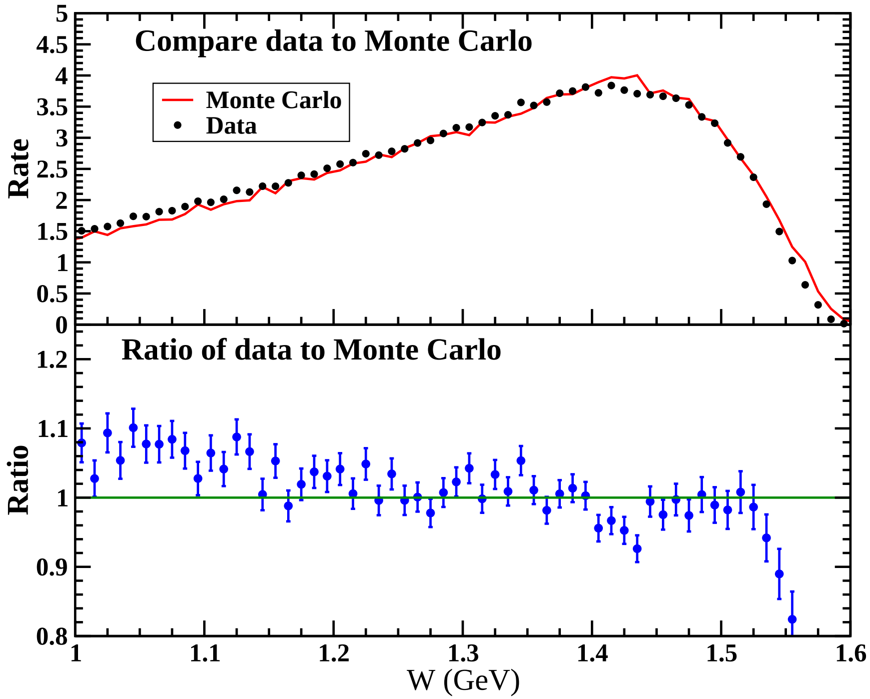
- For $B_{\perp}$, top/bottom $A_{el}$ agree
- Extract proton $\frac{G_E}{G_M}$

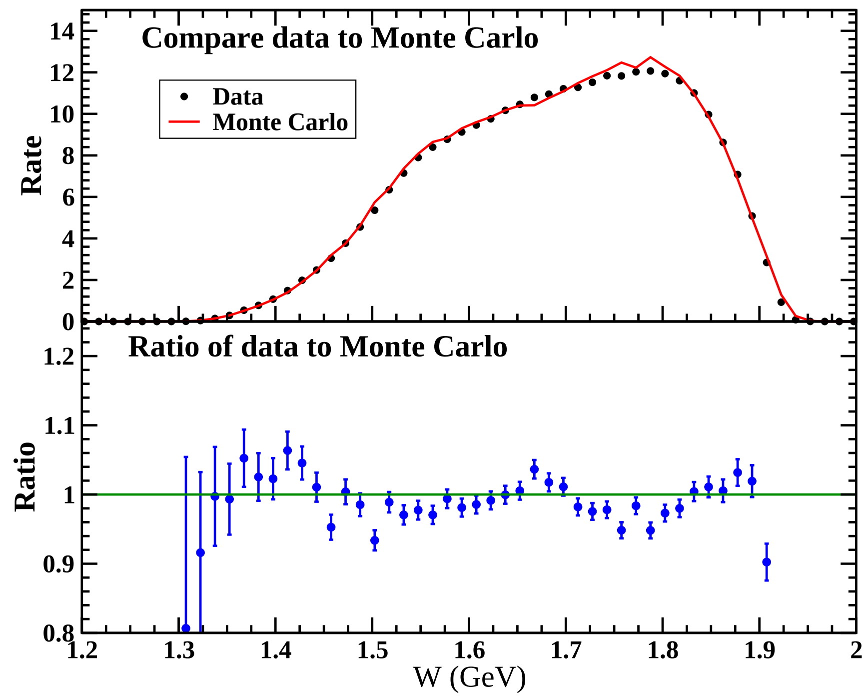


# Comparisons to carbon data

Use carbon data to test QFS model.
Example for parallel field.

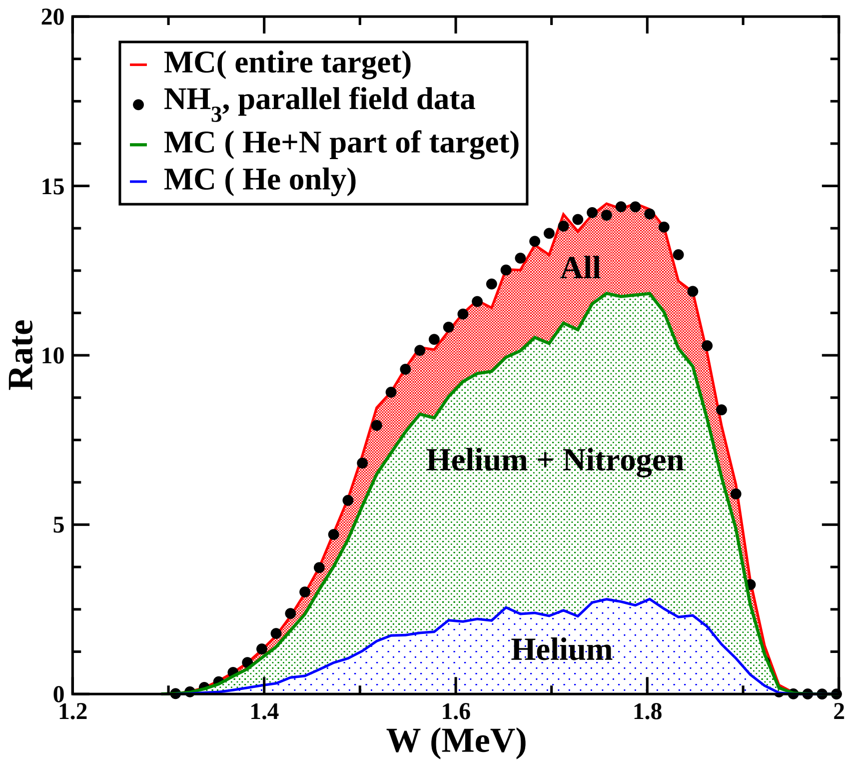
- Central HMS $p$ = 4.7 GeV/c
- Central HMS $p$ = 4.1 GeV/c

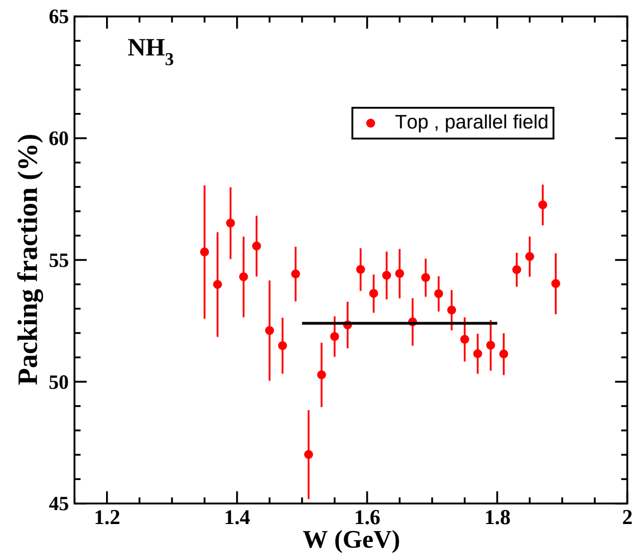


# Packing fractions

Packing fraction is ratio of $NH_3$ (or $ND_3$) to $NH_3$ + He in cup.



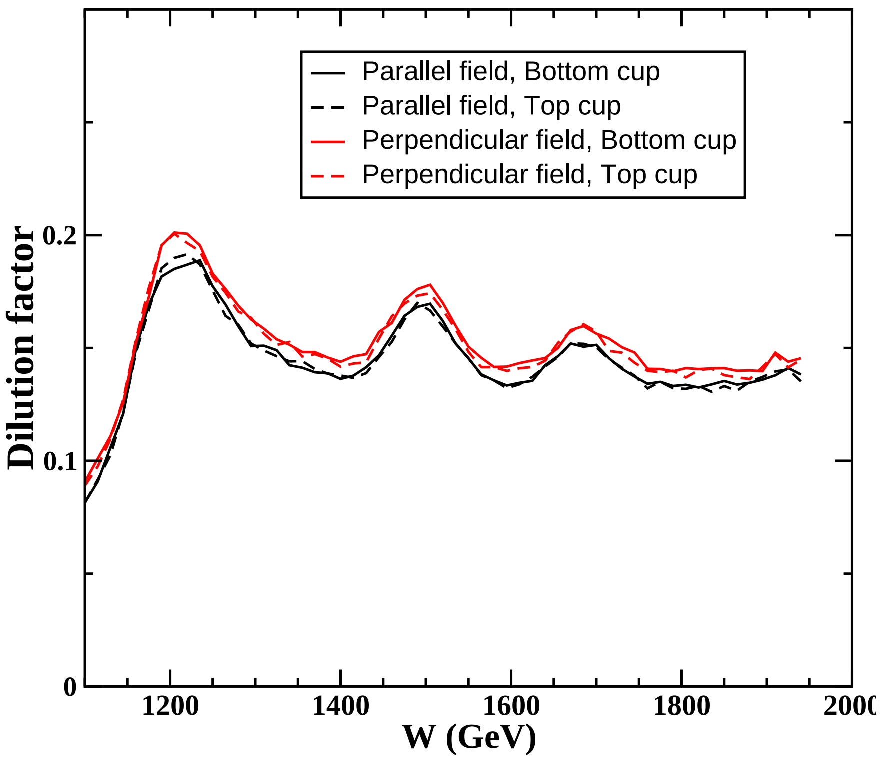




## Packing Fractions

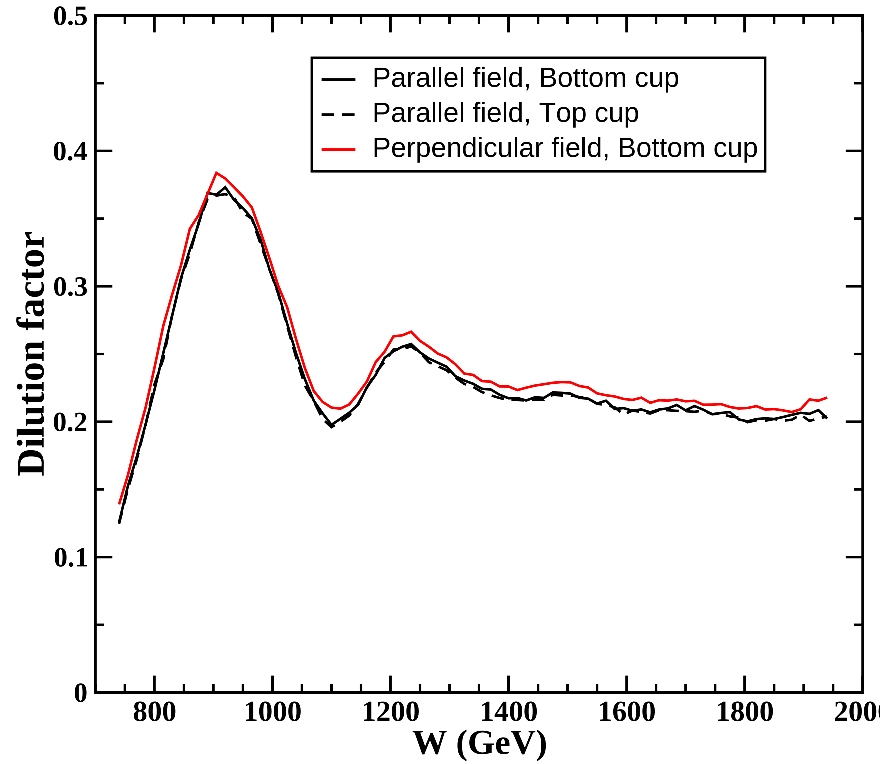
| | $NH_3$ | | $ND_3$ | |
|---|---|---|---|---|
| | $B_{\|\|}$ | $B_{\perp}$ | $B_{\|\|}$ | $B_{\perp}$ |
| Top | 52.4% | 58.9 | 55.2 | – |
| Bottom | 53.2 | 60.7 | 56.0 | 62.1 |

# Dilution factors

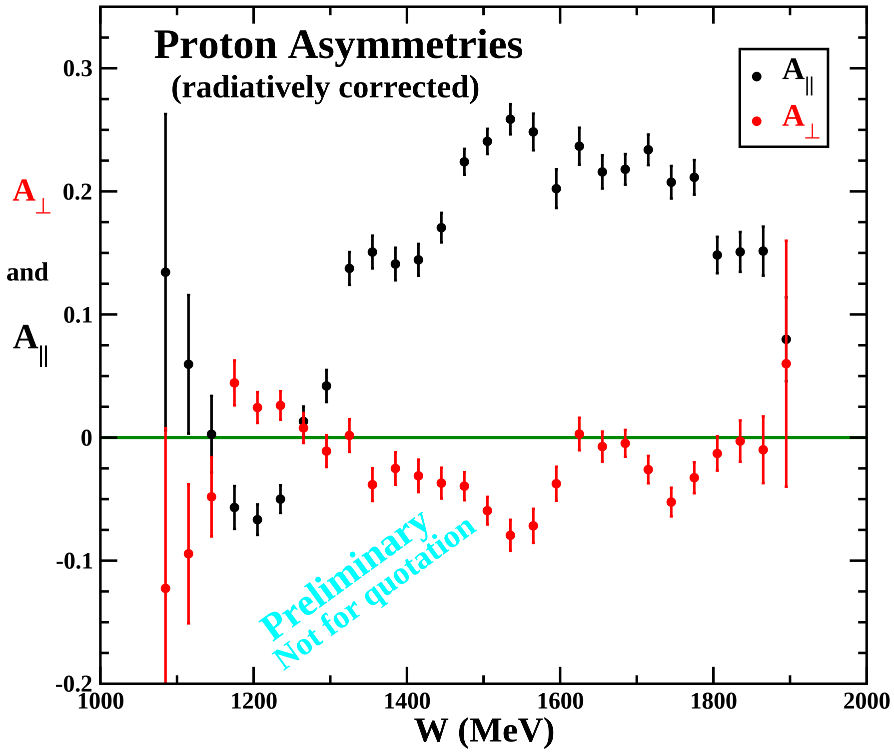
- $NH_3$
- Hall C fit for $F_2$ and R.(*M. E. Christy*)
- QFS for A $>$ 2

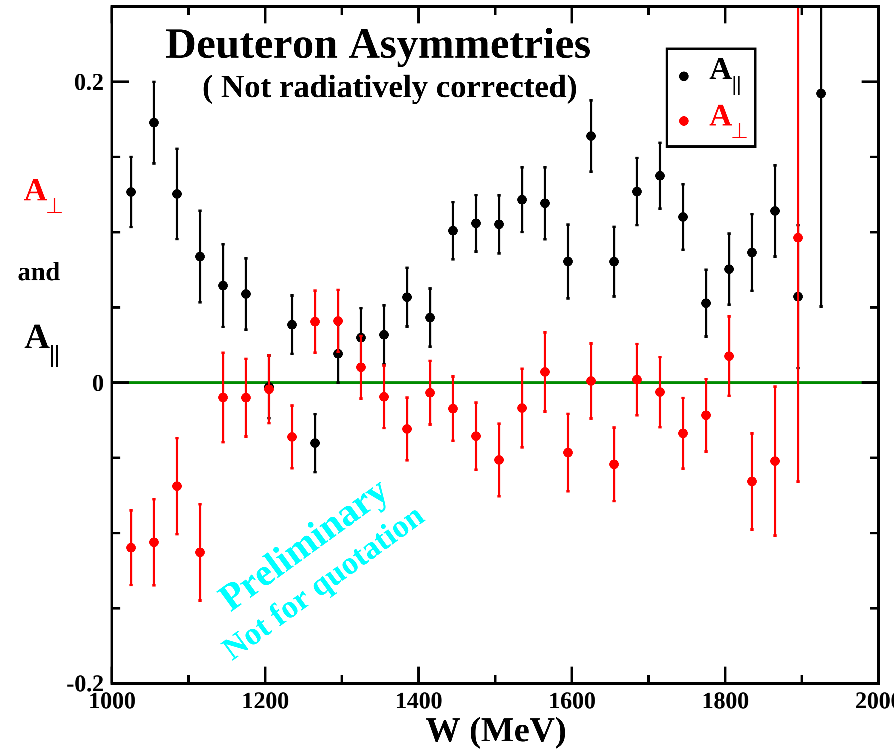



- $ND_3$
- Hall C fit for $F_2^d$ and $R^d$. (*I. Niculescu*)
- QFS for A $>$ 2 , deuteron quasi-elastic



# Proton and Deuteron Asymmetries



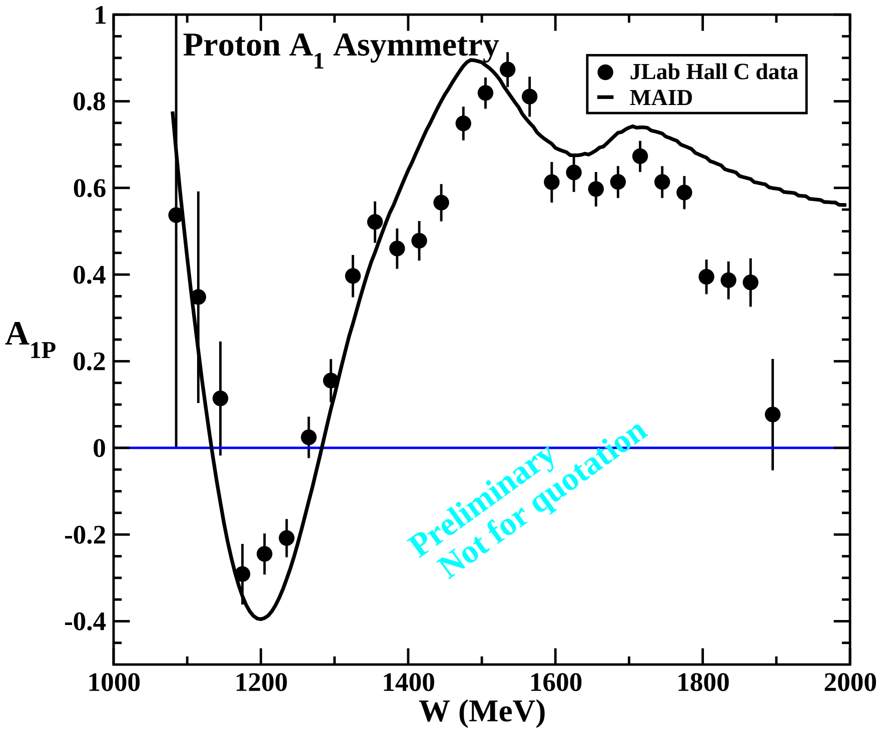



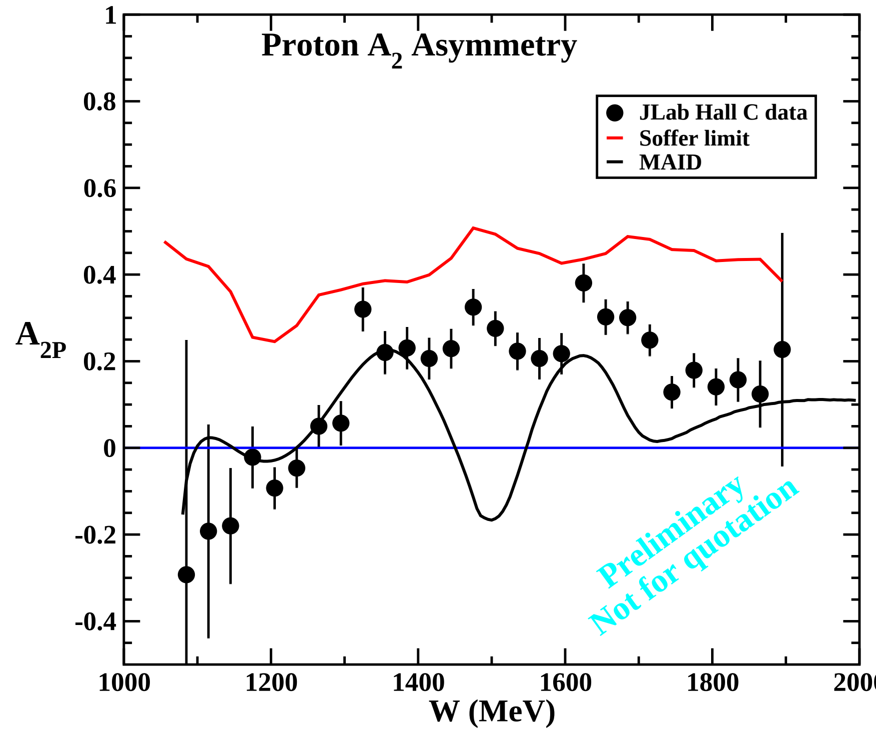

No correction for $^{15}$N asymmetry applied

Work on radiative correction for deuteron in progress

Relative Systematic errors of 6% and 8% for $NH_3$ and $ND_3$

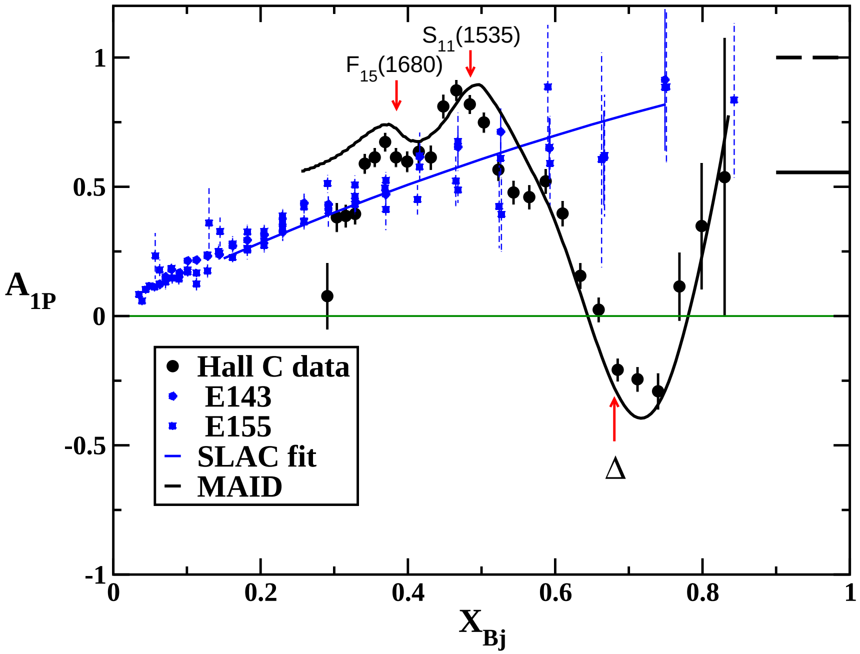
# Proton $A_1$ and $A_2$ versus W

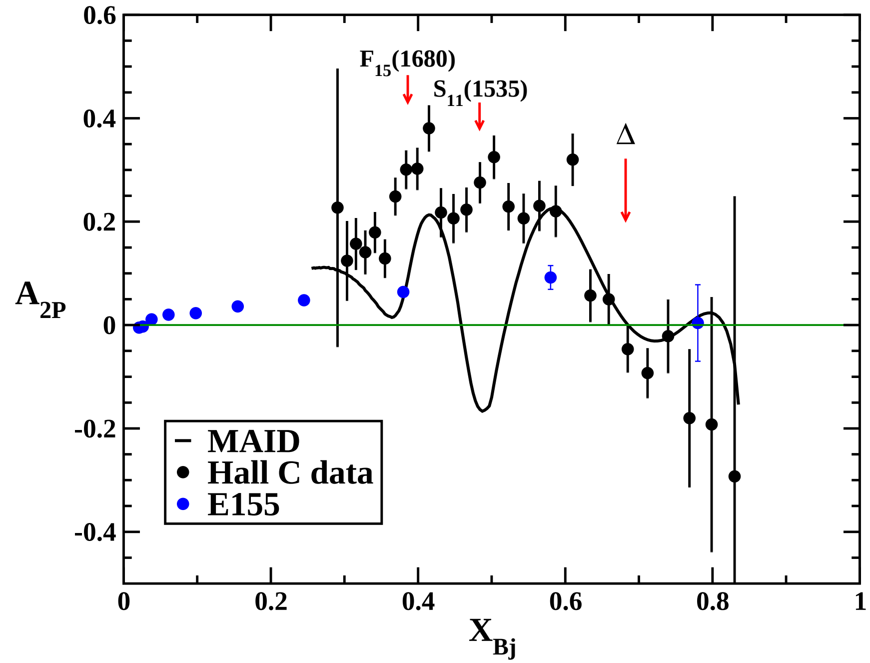


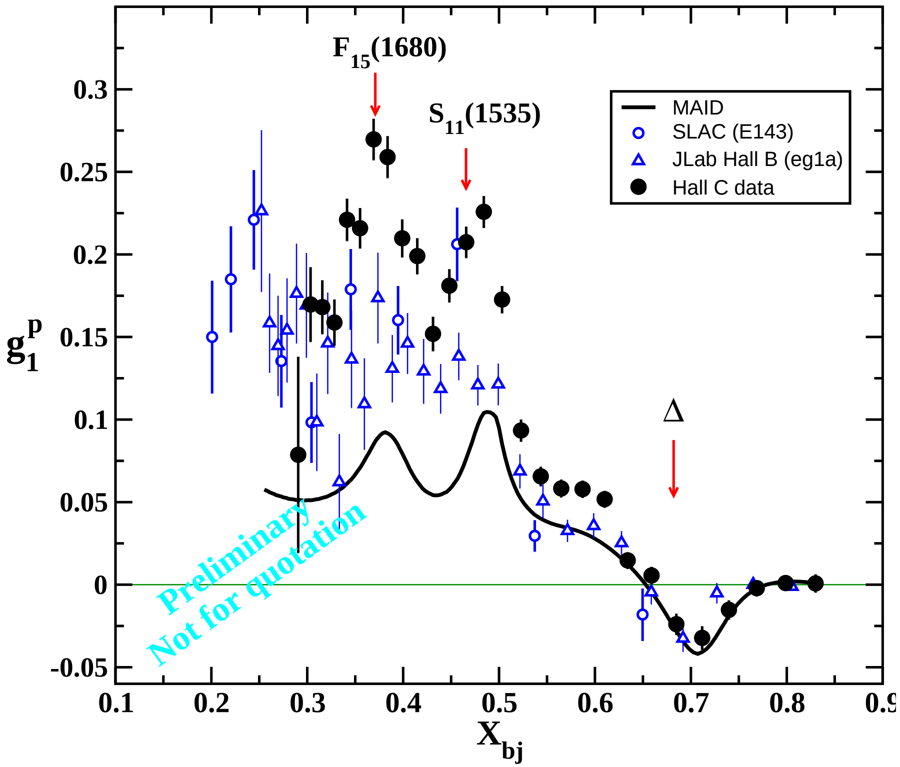

$A_{\|}$ and $A_{\perp}$ transformed using Hall C $F_2$ and $R$ fit (M. E. Christy)

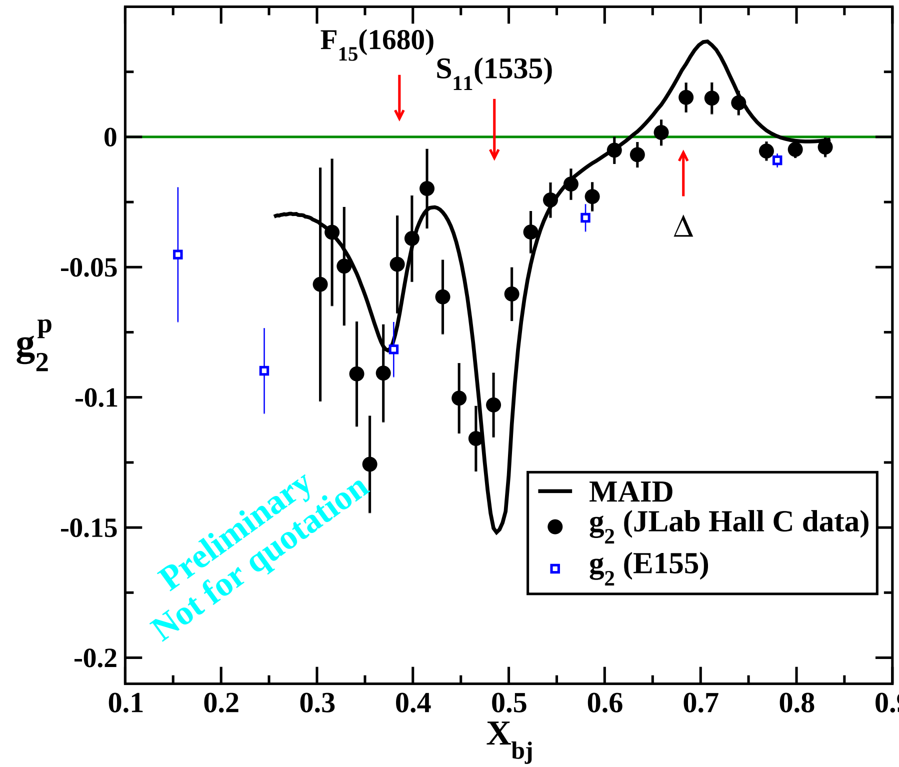
# Proton $A_1$ and $A_2$ versus x



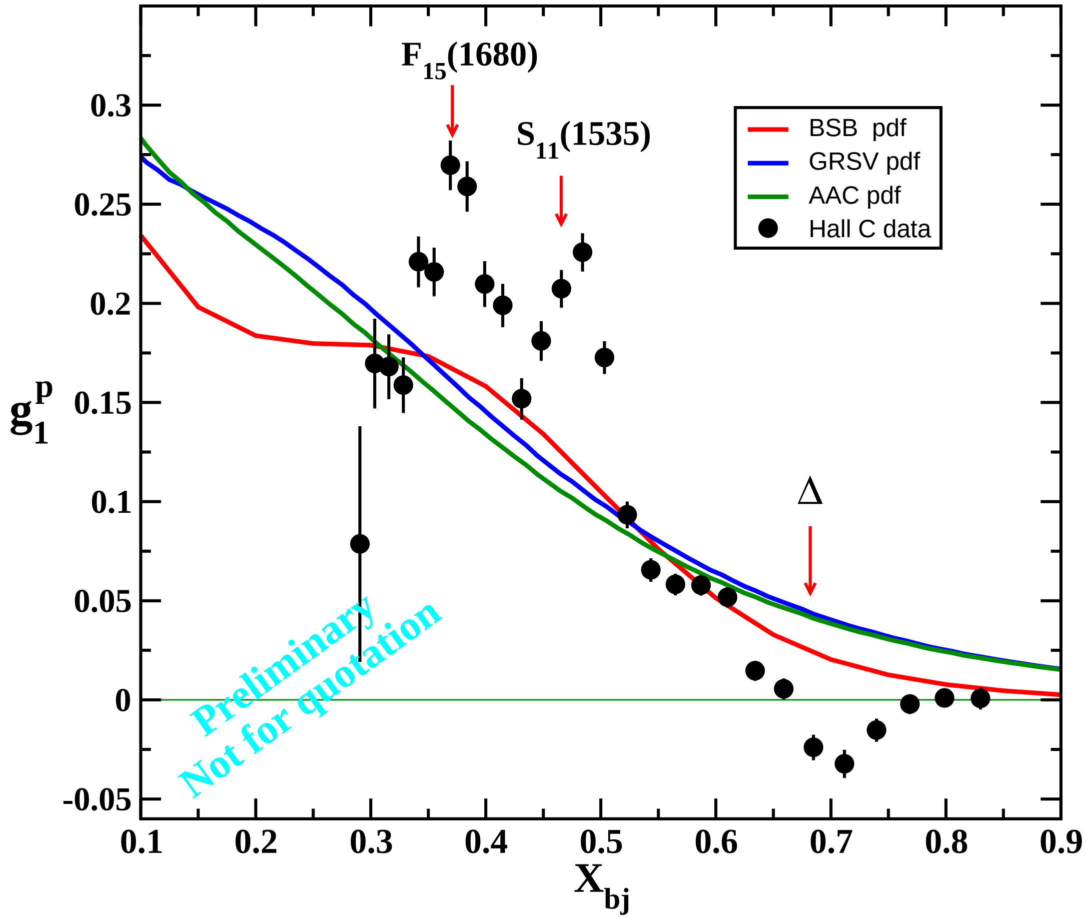



# Proton $g_1^p$ and $g_2^p$



# Compare PDFs to $g_1$

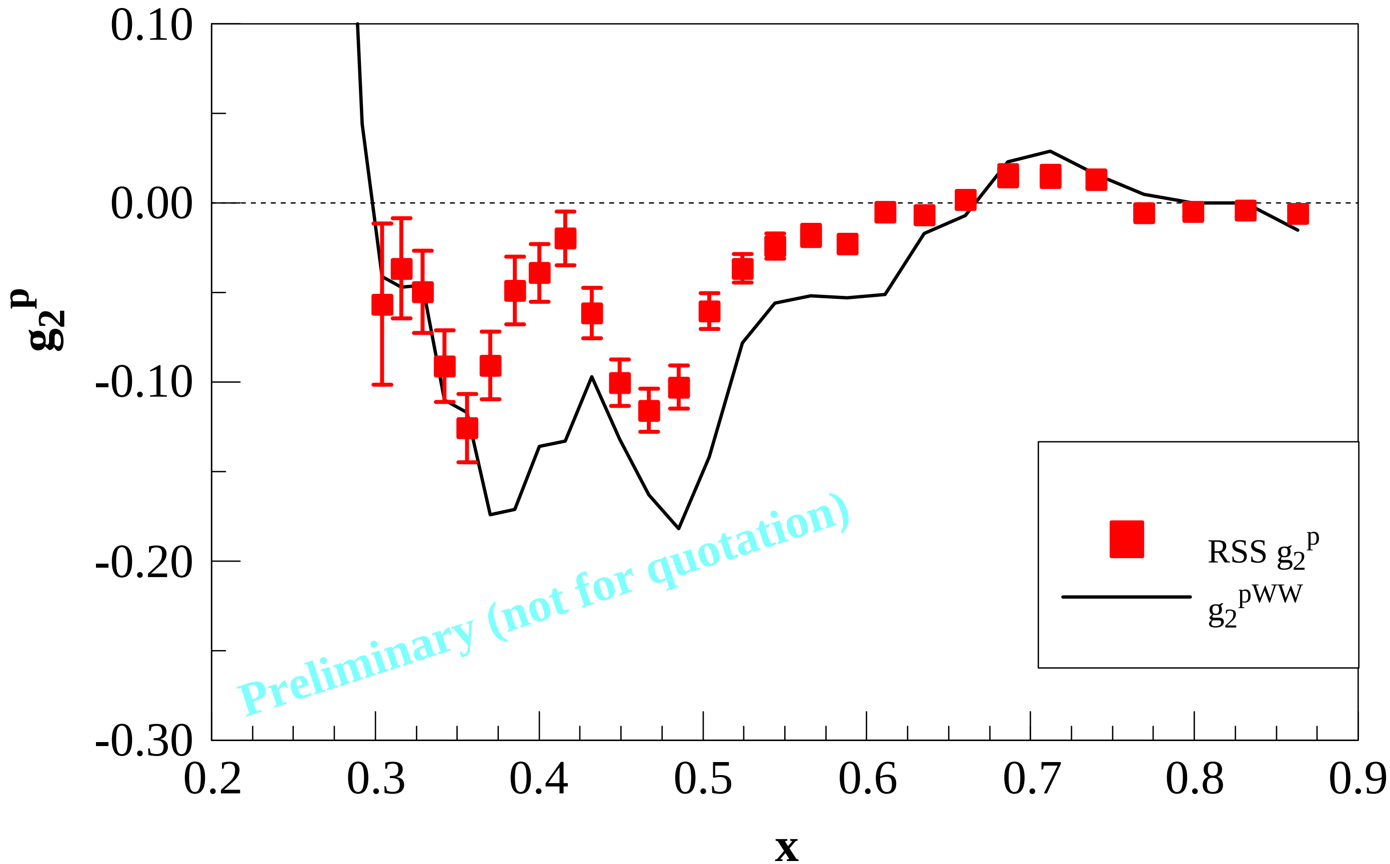



*GRSV, AAC pdfs evolved to $Q^2$ = 1.3 and have target mass correction.*

*BSB statistical pdfs evolved to $Q^2$ = 1.3*

Need to do quantitative comparison. In progress

# Higher twist in $g_2$



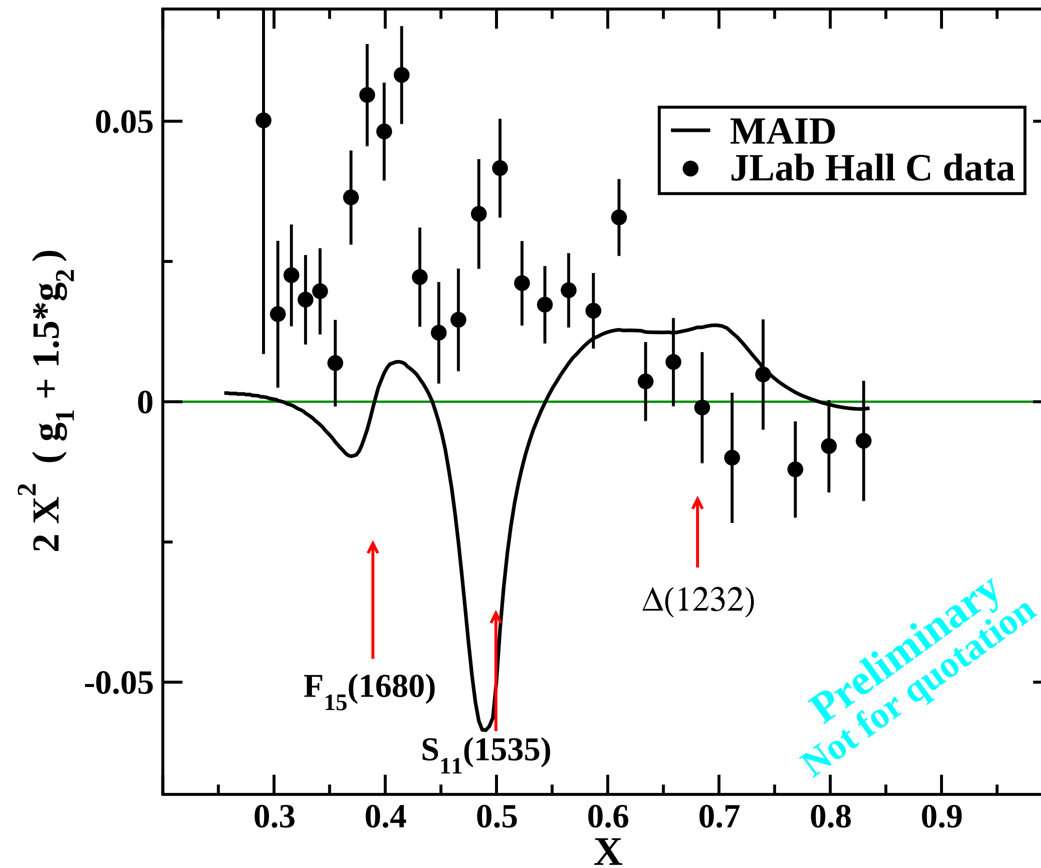

$g_2 = g_2^{WW} + \overline{g}_2$   Twist-2 $g_2^{WW} = -g_1 + \int_x^1 \frac{g_1}{y} dy$

Use measured $g_1$ to calculate $g_2^{WW}$

# Twist-3 matrix element $d_2$

$$d_2 = \int_0^1 x^2(2g_1 + 3g_2)dx$$

- 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
- 1/Q dependence of twist-3 implies that SLAC $d_2$
  would increase by 2.



# Summary

- Measured proton and deuteron $A_{||}$ and $A_\perp$ at $Q^2 \approx 1.3$ and $0.8 < W < 2.0$ .
  - Proton analysis done. Deuteron analysis almost done. RC in progress. ➡ Extract neutron.
- Extracted proton $A_1$,$A_2$,$g_1$,$g_2$ .
  - MAID predicts $A_1$ well,$A_2$ less well
  - MAID predicts $g_1$ well at $\Delta$, badly above. $g_2$ well !?!
  - Polarized duality: Qualitative comparison of $g_1$ to PDFs is promising. ➡ Quantitative comparison in progress.
- Positive $d_2$ measured with 10% error !
- Future ➡ Approve experiment at JLab in Hall C to measure proton $A_{||}$ and $A_\perp$ at $2.5 < Q^2 < 6.5$ *(O. Rondon, Z. E. Meziani, S. Choi)*