University of New Hampshire
Nuclear & Particle Physics Group

A Measurement of the Proton's Spin Structure Functions in the Truly Strong Region
2022 Winter Status Update

David Ruth

Hall A Collaboration Meeting

February 11, 2022

1. Experiment Background
    - First low Q^2 measurement of transverse proton spin structure
2. Recent Progress
    - Sanity checks on data
    - Detailed investigation into model input
    - Publication writing and revision
3. Publication Progress:

University of New Hampshire

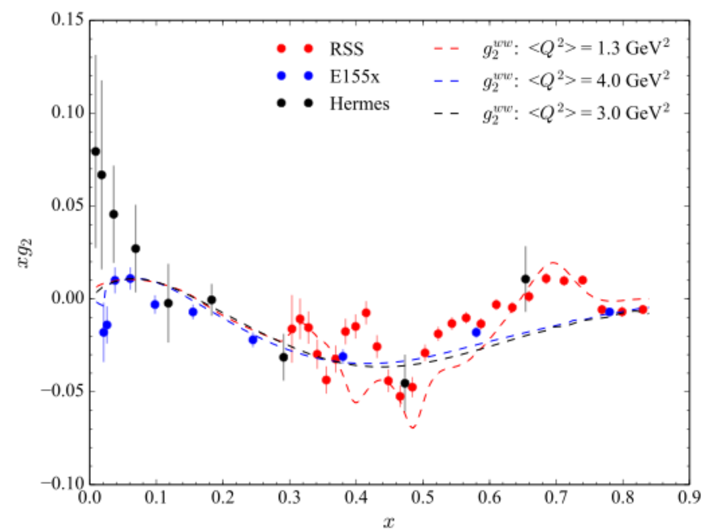
Motivation:

Measure a fundamental spin observable (g_2) in the region $0.02 < Q^2 < 0.20$ GeV^2 for the first time

$$\frac{d^2\sigma^{\pm}}{d\Omega dE'} = \sigma_{\mathrm{Mott}}\left[\alpha F_1(x,Q^2) + \beta F_2(x,Q^2) \pm \gamma g_1(x,Q^2) \pm \delta g_2(x,Q^2)\right]$$

g_1 and g_2 related to spin distribution

- Measurements at Jefferson Lab:
  - RSS – medium Q^2 (1-2 GeV^2) (published)
  - SANE – high Q^2 (2-6 GeV^2) (analysis)
  - **g_2p – low Q^2 (0.02-0.20 GeV^2) (analysis)**

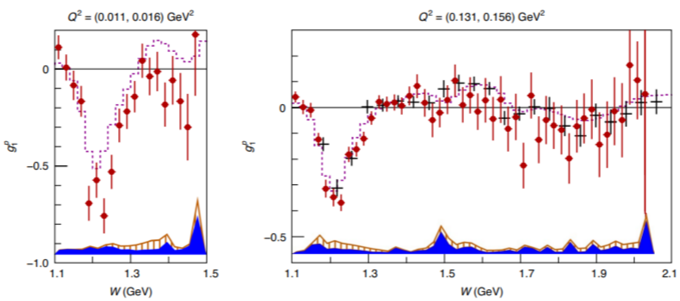


- **Low Q^2 is difficult**:
  - Electrons strongly influenced by target field
  - Strong kinematic dependence on observables
- **Low Q^2 is useful**:
  - Test predictions of Chiral Perturbation Theory (χPT)
  - Test sum rules and measure moments of g_2
  - Study finite size effects of the proton

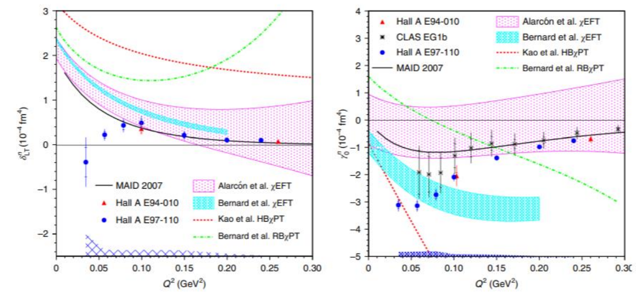
University of New Hampshire

Recent Spin Structure Studies

- EG4: Published in Nature Physics in April 2021
  - Low+Medium Q^2 measurement of g_1 and longitudinal moments for Proton
- Small-Angle GDH: Published in Nature Physics in May 2021
  - Low+Medium Q^2 measurement of g_1 and g_2 for Neutron
- New χPT Calculations: Bernard et. al calculation in 2013 gave closer agreement to results of E94010
- Alarcon et. al calculation has been updated several times, most recently in 2020
- These calculations disagree at low Q^2 for the proton, showing that there are unanswered questions about QCD in the chiral domain



X. Zheng et al. Nature Physics 17, 736-741



V. Sulkosky et al. Nature Physics 17, 687-692

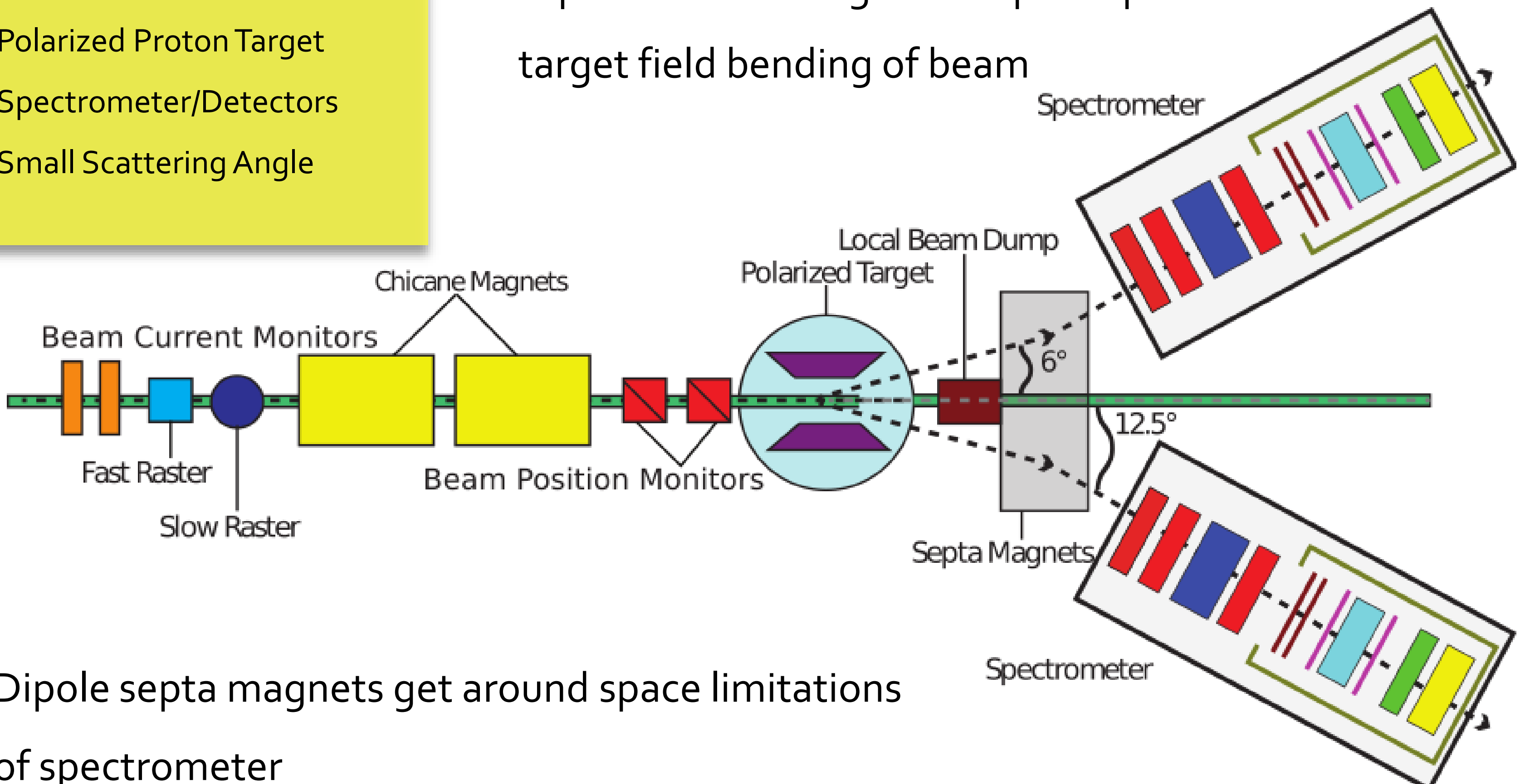
University of New Hampshire

Hall A Experimental Setup:

Measuring g_2^p

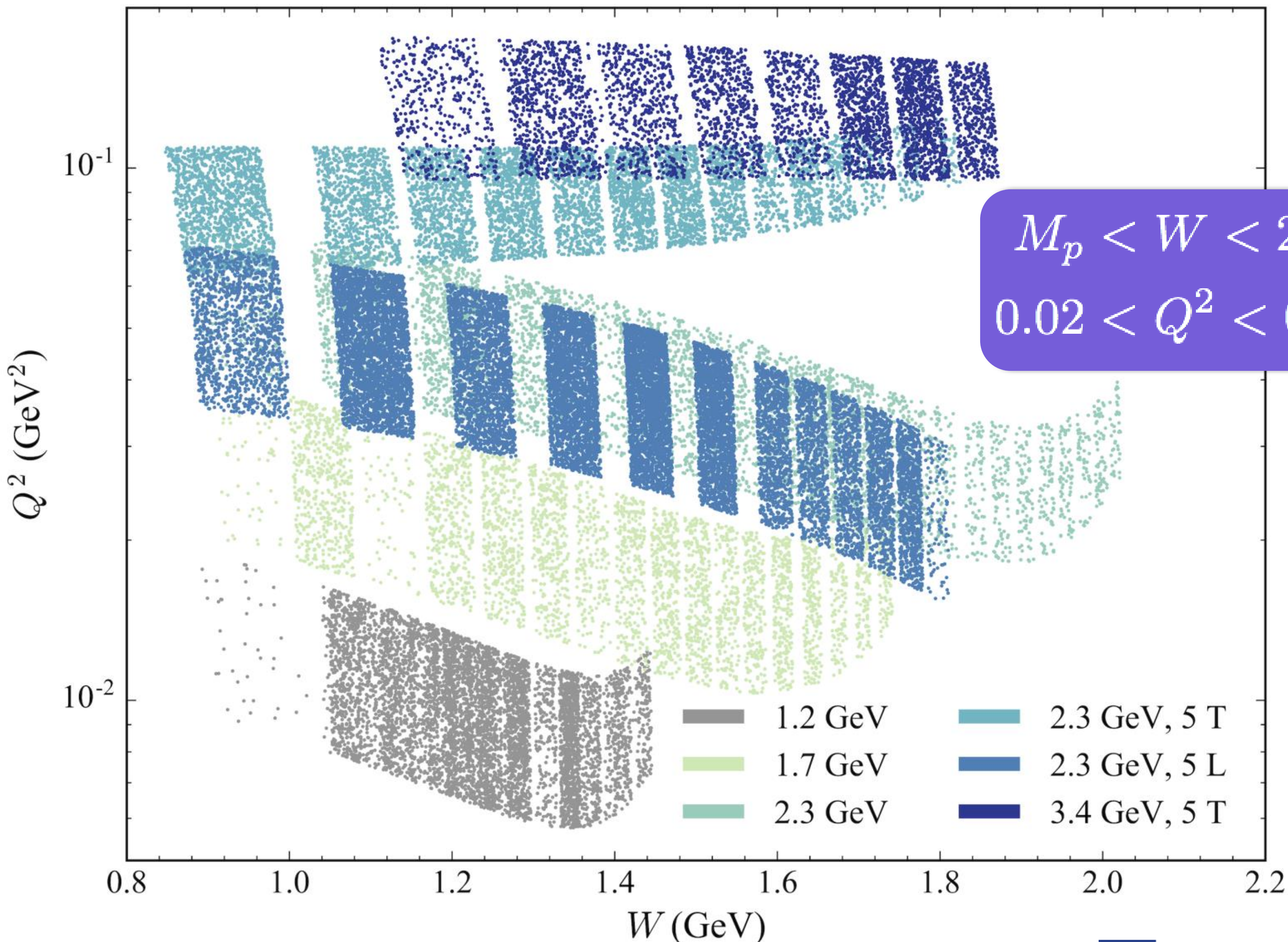
- Electron Beam
- Polarized Proton Target
- Spectrometer/Detectors
- Small Scattering Angle

- g_2p experiment ran spring 2012 in Hall A
- Transverse polarized NH_3 target (2.5/5.0T)
- Dipole chicane magnets help compensate for target field bending of beam



- Dipole septa magnets get around space limitations of spectrometer

g_2p Kinematic Coverage

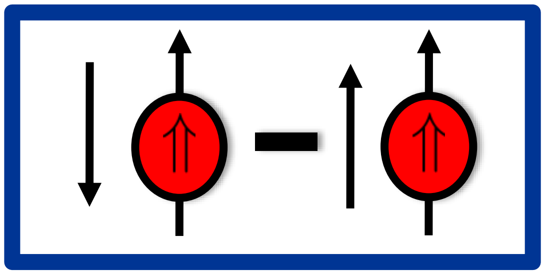


$$M_p < W < 2\,\mathrm{GeV}$$

$$0.02 < Q^2 < 0.20\,\mathrm{GeV}^2$$

University of New Hampshire

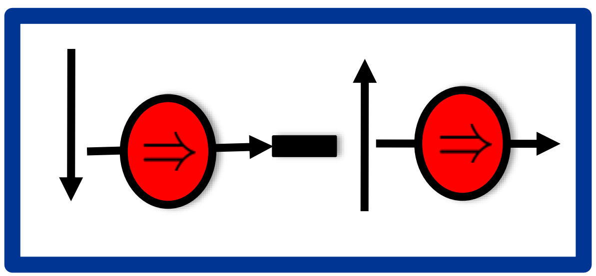
Extracting Spin Structure by Looking at Cross Section Differences



Parallel

Inclusive *polarized* cross sections

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



Perpendicular

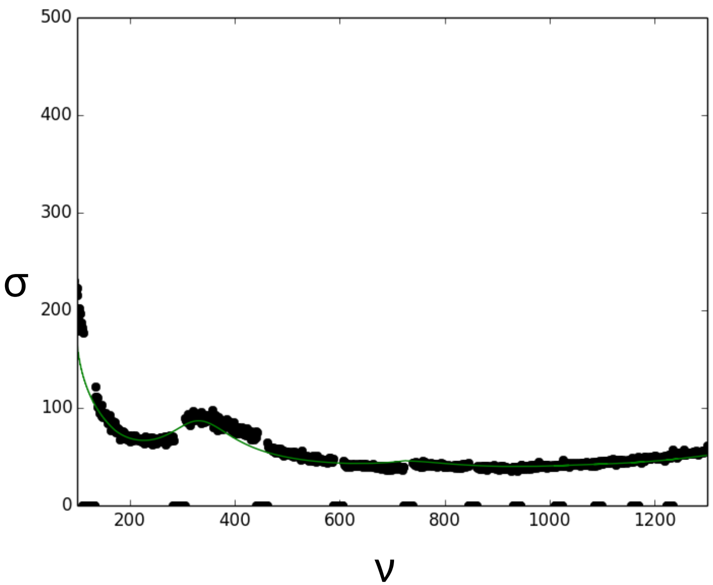
$$\frac{d^2\sigma^{\uparrow\Rightarrow}}{dE'd\Omega} - \frac{d^2\sigma^{\downarrow\Rightarrow}}{dE'd\Omega} = \frac{4\alpha^2}{M\nu Q^2}\frac{E'^2}{E}\sin\theta\left[\nu g_1(x,Q^2) + 2E g_2(\nu,Q^2)\right]$$

$$\Delta\sigma_\perp = \frac{d^2\sigma}{d\Omega dE'}(\downarrow\rightarrow - \uparrow\rightarrow) = 2\cdot A_\perp \sigma_0$$

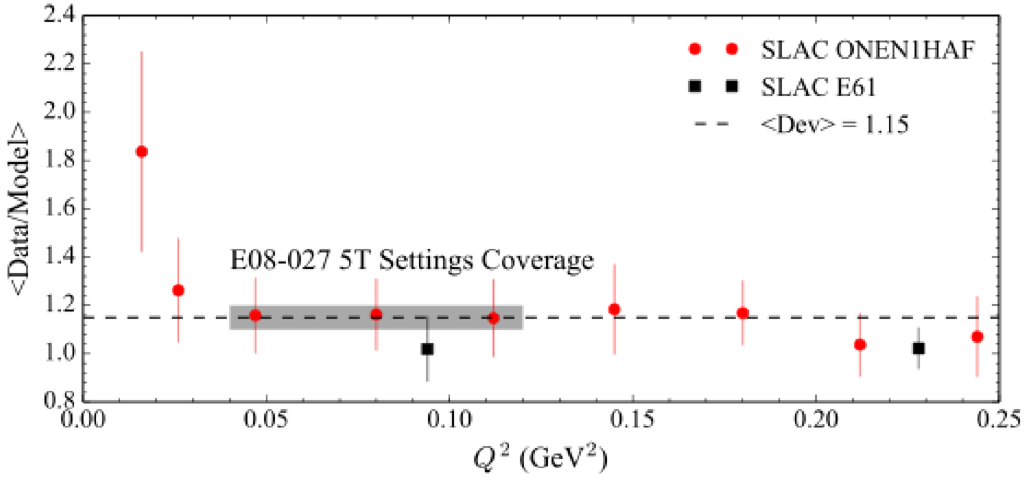
From Model

From Data

Recent Updates: Model Cross Section



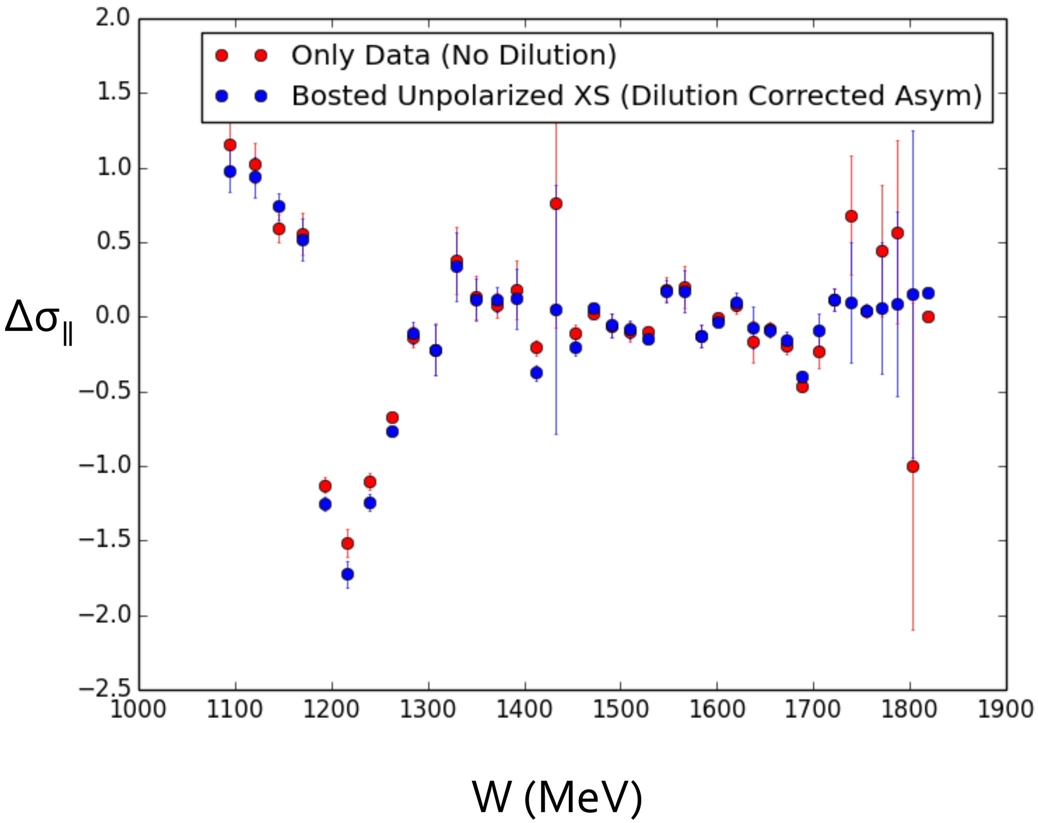
- g2p data has good agreement with Bosted-Christy Model if a scaling of 1.15 is used
- We investigated this scaling in depth and determined its impact on the moments is less than 6%
- Transverse acceptance forces us to use model cross section



- Bosted-Christy model in this region is based on E61, while g2p and onen1haf require a similar scaling factor
- However all three experiments agree within error

University of New Hampshire

Recent Updates: Longitudinal Sanity Checks



- Compared polarized cross section difference from data, to $\Delta\sigma_{\parallel}$ from model and dilution-corrected asymmetry
- Good agreement is a sanity check on the dilution and the use of the model for the transverse settings

First publication nearly finished

- We have been hard at work on a paper focused on the transverse results with the intention of submission to Nature Physics, following the success of the EG4 and Small-Angle GDH Experiments in that journal
- Paper is nearly complete and has been sent to our core group for comments
- We aim to send our draft to the Hall A collaboration for comments and the C.C. for approval **within a few weeks**.

Moments of the Proton Spin Structure Function g_2 in the Truly Strong Region

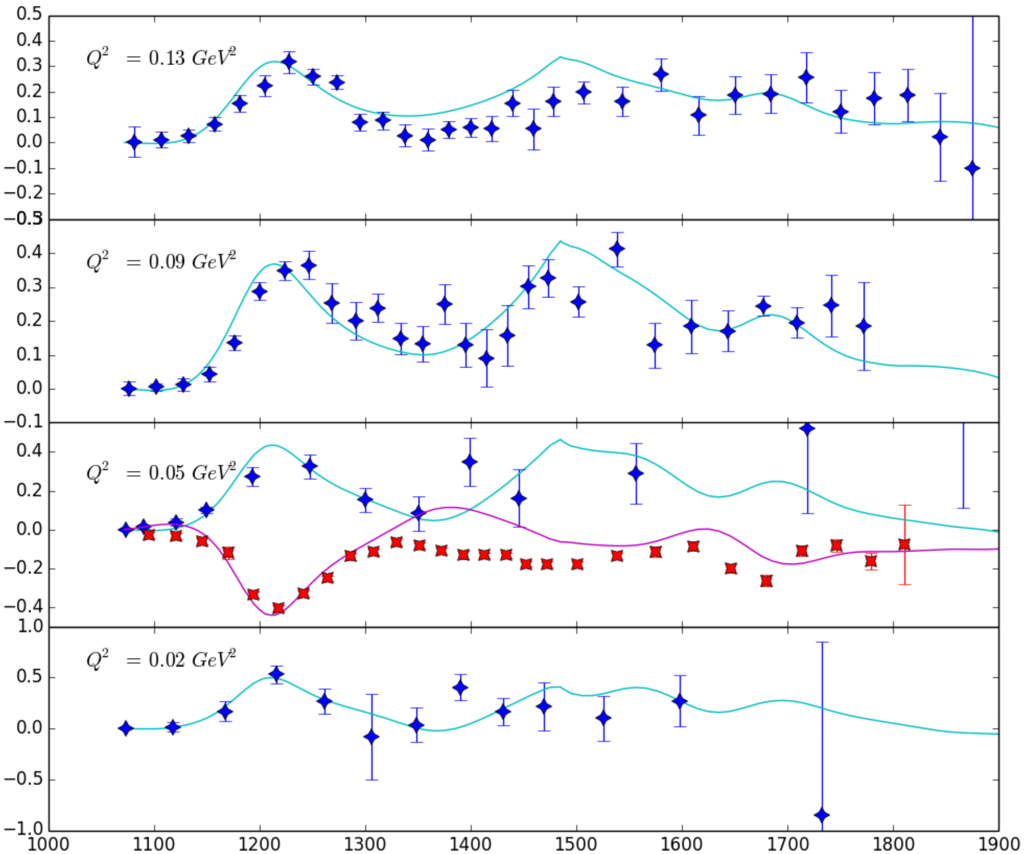
D. Ruth,[1] R. Zielinski,[1] C. Gu,[2] T. Badman,[1] M. Cummings,[3] M. Huang,[4] J. Liu,[2] P. Zhu,[5] K. Allada,[6] J. Zhang,[7] A. Camsonne,[7] J.P. Chen,[7] K. Slifer,[1] K. Aniol,[8] J. Annand,[9] T. Averett,[3] H. Baghdasaryan,[2] V. Bellini,[10] W. Boeglin,[11] J. Brock,[7] C. Carlin,[7] C. Chen,[12] E. Cisbani,[13] D. Crabb,[2] D. Day,[2] L. Elfassi,[14] M. Friedman,[15] E. Fuchey,[16] H. Gao,[4] M. Hafez,[17] Y. Han,[12] O. Hansen,[7] M. Hashemi Shabestari,[2] D. Higinbotham,[7] S. Iqbal,[8] E. Jensen,[18] H. Kang,[19] H. Kang,[19] C.D. Keith,[7] A. Kelleher,[6] D. Keller,[2] H. Khanal,[11] I. Korover,[20] G. Kumbartzki,[14] J. Lichtenstadt,[20] E. Long,[1] S. Malace,[21] J. Maxwell,[1,7] D.M. Meekins,[7] C. McLean,[3] R. Michaels,[7] M. Mihovilovic,[22] N. Muangma,[6] C. Munoz Camacho,[23] K. Myers,[14] Y. Oh,[19] M. Pannunzio Carmignotto,[24] C. Perdrisat,[3] S. Phillips,[1] J. Pierce,[7,25] V. Punjabi,[26] Y. Qiang,[7] P. Reimer,[27] O. Rondon,[2] G. Russo,[10] K. Saenboonruang,[2] B. Sawatzky,[7] A. Shahinyan,[28] R. Sheyor,[20] S. Sirca,[22] J. Sjoegren,[9] P. Solvignon-Slifer,[1] N. Sparveris,[16] V. Sulkosky,[6] F. Wesselmann,[29] Z. Ye,[2] M. Yurov,[2] Y. Zhang,[14] Y. Zhao,[5] and X. Zheng[2]
(The E08-027 Collaboration)

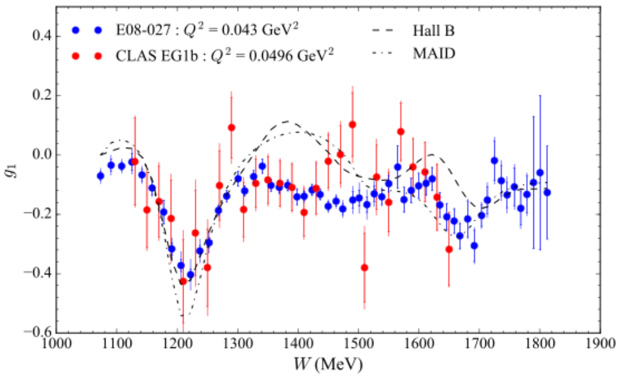
[1] *University of New Hampshire, Durham, New Hampshire 03824, USA*
[2] *University of Virginia, Charlottesville, Virginia 22903, USA*
[3] *The College of William and Mary, Williamsburg, Virginia 23187, USA*
[4] *Duke University, Durham, NC 27708, USA*
[5] *University of Science and Technology, Hefei 230000, China*
[6] *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

Author list is **not final** and is under careful review

Structure Function Results

Blue Stars – g_2 (Transverse Setting)
Red Xs – g_1 (Longitudinal Setting)





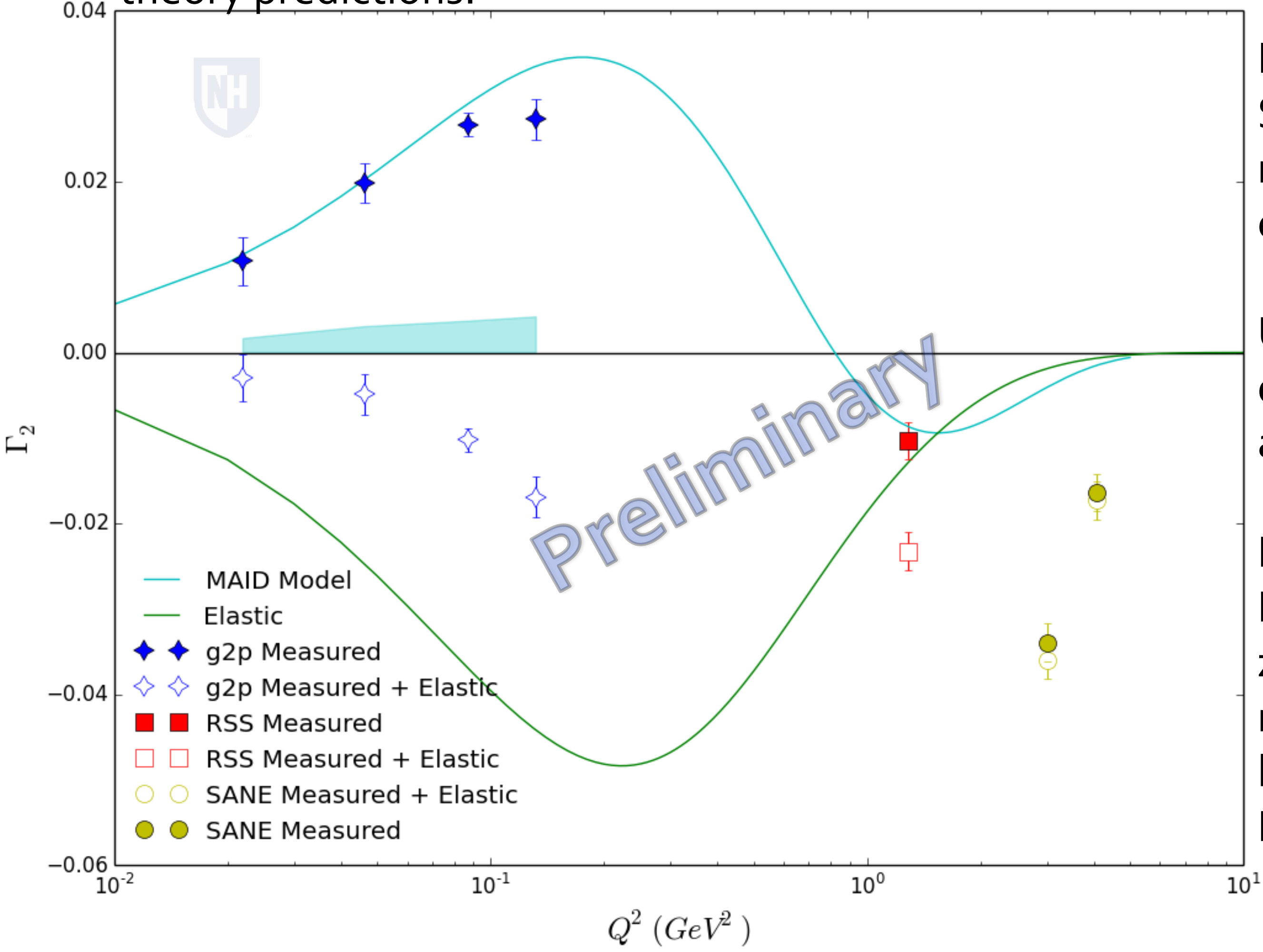
- E08-027 data is consistent with previously published data from CLAS
- But with much better statistics!!

University of New Hampshire

First Moment of $g_2(x,Q^2)$

$$\Gamma_2 = \int_0^{x_{th}} g_2(x,Q^2)dx$$

Moments provide a useful quantity that can be related back to theory predictions!



Burkhardt-Cottingham Sum rule says this moment should be zero everywhere…

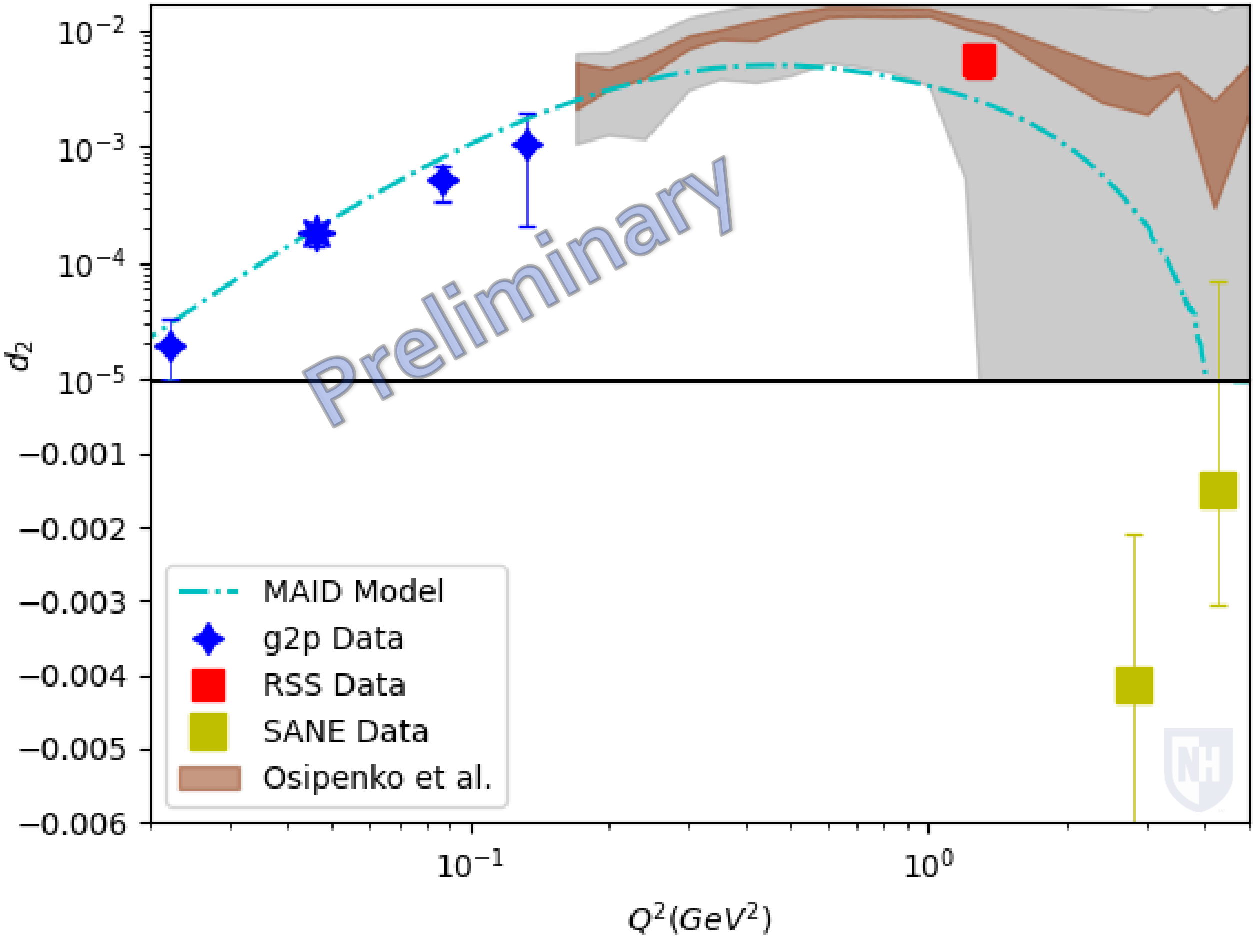
Unmeasured, low x part difficult to calculate accurately at low Q^2

Distance between Measured+elastic and zero can be taken as measurement of this hard to measure region if BC sum rule is followed

University of New Hampshire

d2 Higher Matrix Element

$$\overline{d_2} = \int_0^{x_{th}} x^2 [2\, g_1(x, Q^2) + 3\, g_2(x, Q^2)] dx$$



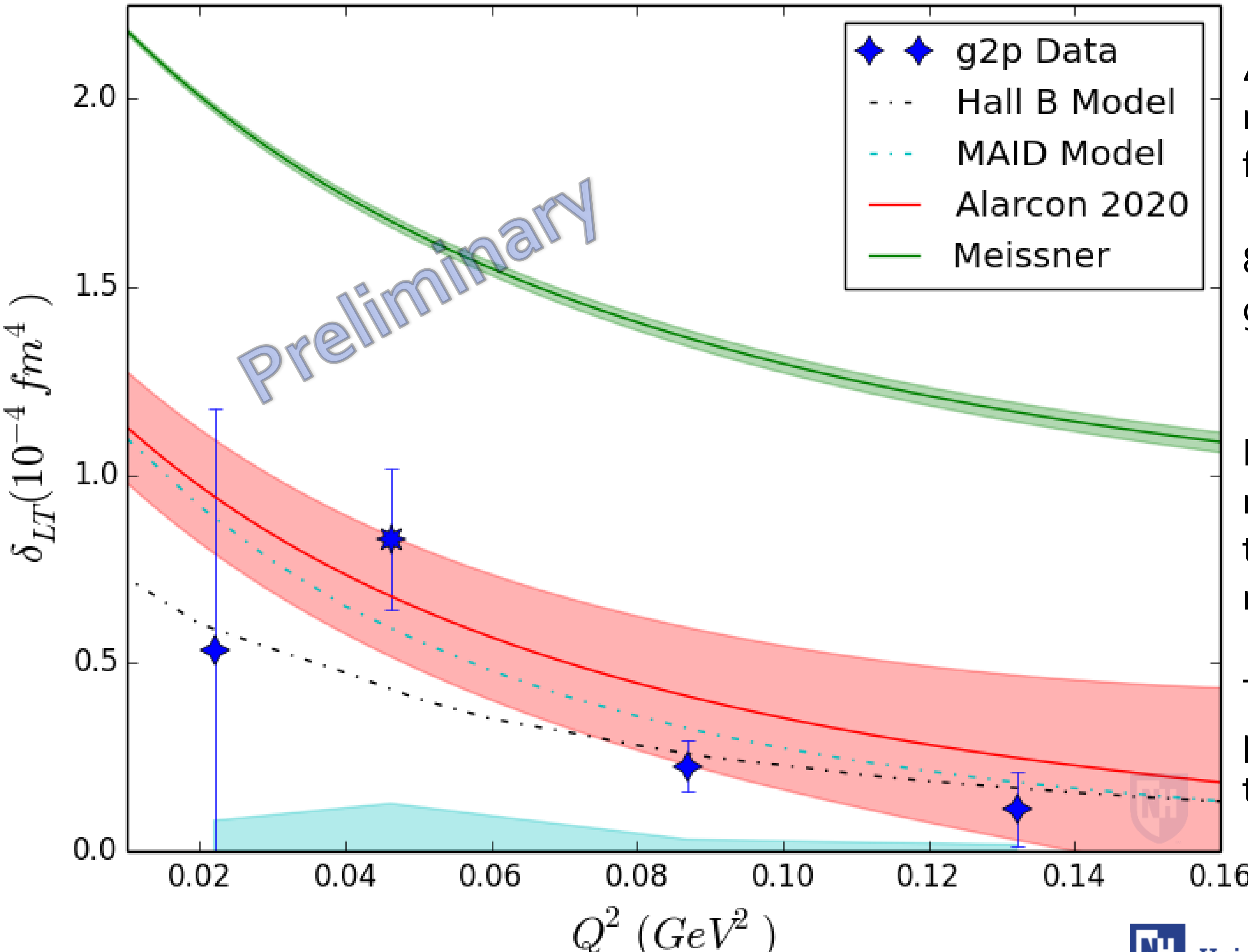
Data agrees with sign and trend of MAID model

Moment is an interesting way to probe quark-gluon correlations at low Q^2

University of New Hampshire

Transverse-Longitudinal Spin Polarizability

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



4 pt star – g2 measured with g1 from Hall B model

8 pt star – g1 and g2 both measured

First ever measurement of this quantity in this region!

Test of chiral perturbation theory

University of New Hampshire

Conclusion

- The g_2p experiment was a precision measurement of proton g_2 in low Q^2 region **for the first time!**
- Analysis is **complete**!
- First publication is **almost done** and nearly ready to be shared with all of our collaborators

University of New Hampshire

Acknowledgements

g2p Analysis Team

Spokespeople:
J.P. Chen
Karl Slifer
Alexandre Camsonne
Don Crabb

Post-Docs:
Kalyan Allada
James Maxwell
Vince Sulkosky
Jixie Zhang

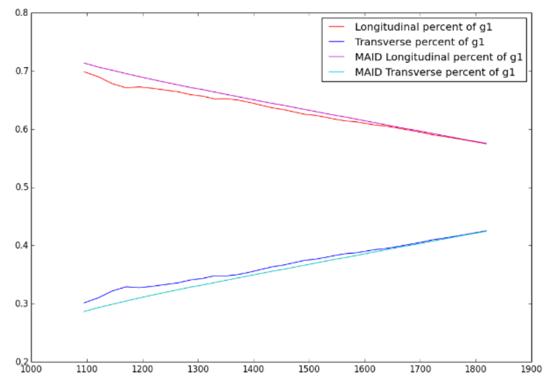
Graduate Students:
Ryan Zielinski
Chao Gu
Toby Badman
Melissa Cummings
Min Huang
Jie Liu
Pengjia Zhu

Additional Slides: Model Scaling Factor Impact

$$g_1(x,Q^2) = K_1\left[\Delta\sigma_{\parallel}\left(1+\frac{1}{K_2}\tan\frac{\theta}{2}\right)\right] + \frac{2g_2(x,Q^2)}{K_2 y}\tan\frac{\theta}{2}$$

Input from Hall B model

Combination of data & Bosted model



- Scaling factor is on Bosted-Christy XS
- Hall B has different systematics
- Input term is a significant part of the SSF: ~30%

- Propagate through Bosted-Christy with scaling of 1.0 vs scaling of 1.15 for Longitudinal setting
- Everything else stays the same
- Form a 'zeroeth order' and 'second order' moment:

$$M_0 = \int g_1 dx \qquad M_2 = \int x^2 g_1 dx$$

- Zeroeth order difference is suppressed by Hall B term
- 2nd order difference is further suppressed by x^2 weighting
- Highest difference is ~6%

University of New Hampshire