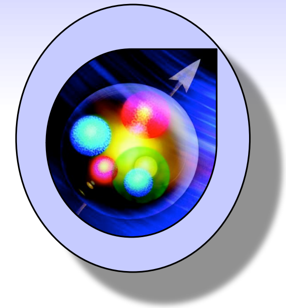
The g2p Experiment

ECT*. Nucleon Spin Structure
at Low Q^2
A Hyperfine View

Trento Italy
7/2/2018

Karl Slifer
University of New Hampshire

This Talk



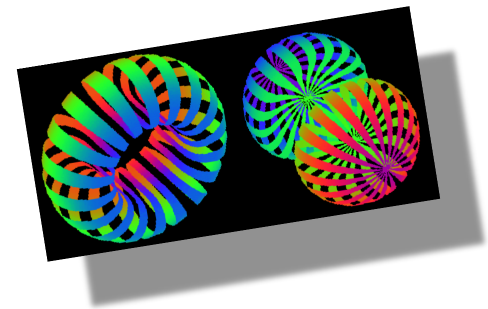
<u>The g2p experiment</u>

Physics Motivation for E08-027

Inclusive Scattering & Structure Functions

Spin Polarizabilities & Moments.

Hyperfine Contributions



<u>Tensor Structure Program</u>

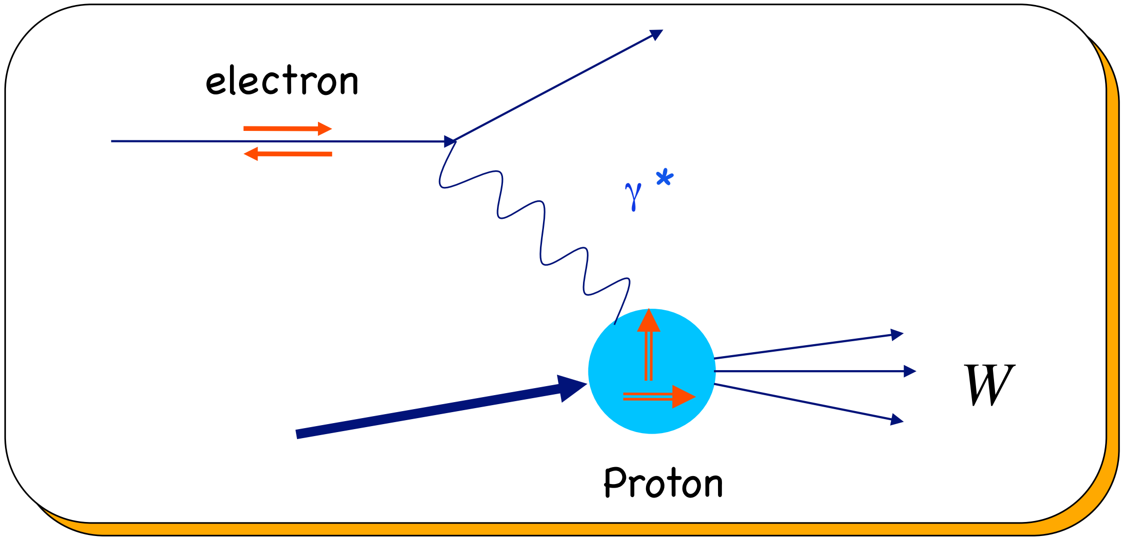
E12-13-011: "The b_1 experiment"

E12-15-005: "A_{zz} for $x>1$"

LOI-12-16-006: "Nuclear Gluometry"

Technical Developments

Inclusive Scattering



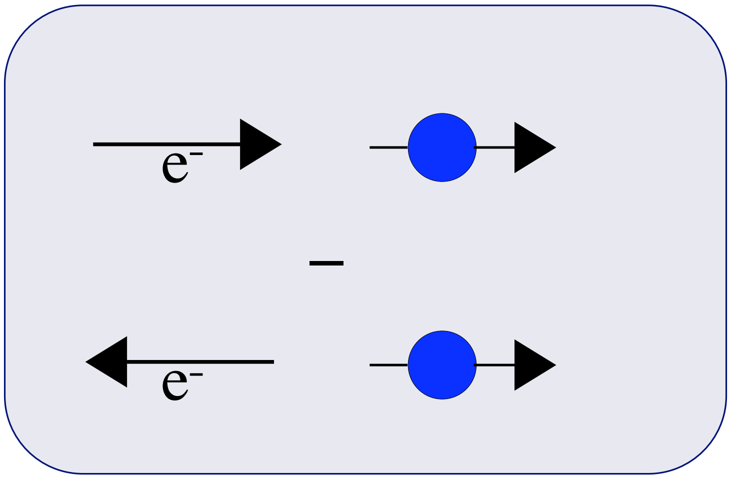
When we add spin degrees of freedom to the target and beam, 2 Additonal SF needed.

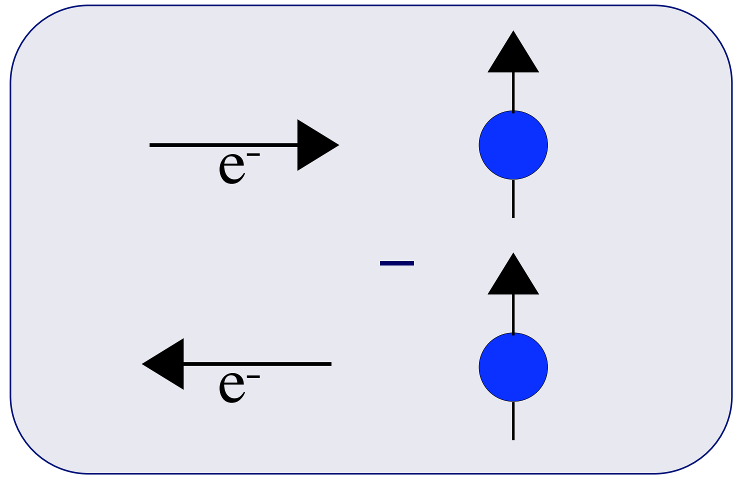
$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\frac{\theta}{2}\right]$$

$$+\,\gamma\, g_1(x,Q^2) + \delta\, g_2(x,Q^2)$$

Inclusive **Polarized**
Cross Section

Cross Section Differences

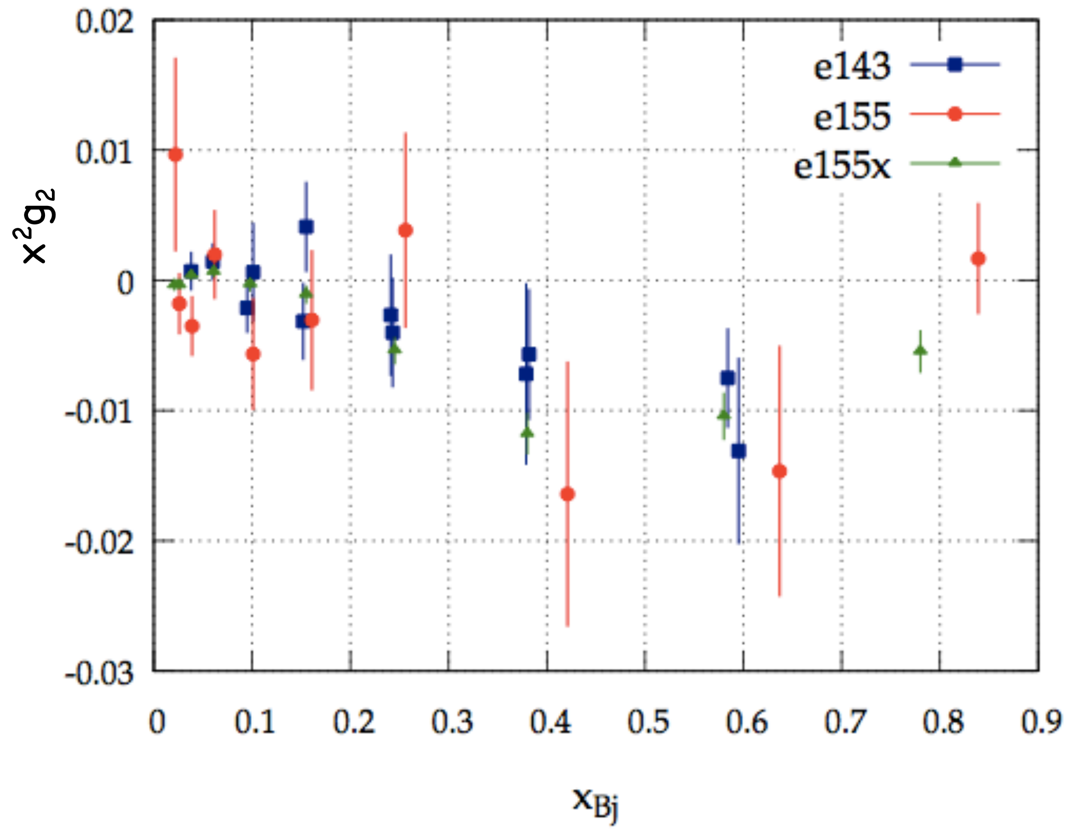




$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2}{\nu Q^2}\frac{E'}{E}\left[(E + E'\cos\theta)\, g_1 - 2Mx g_2\right]$$

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

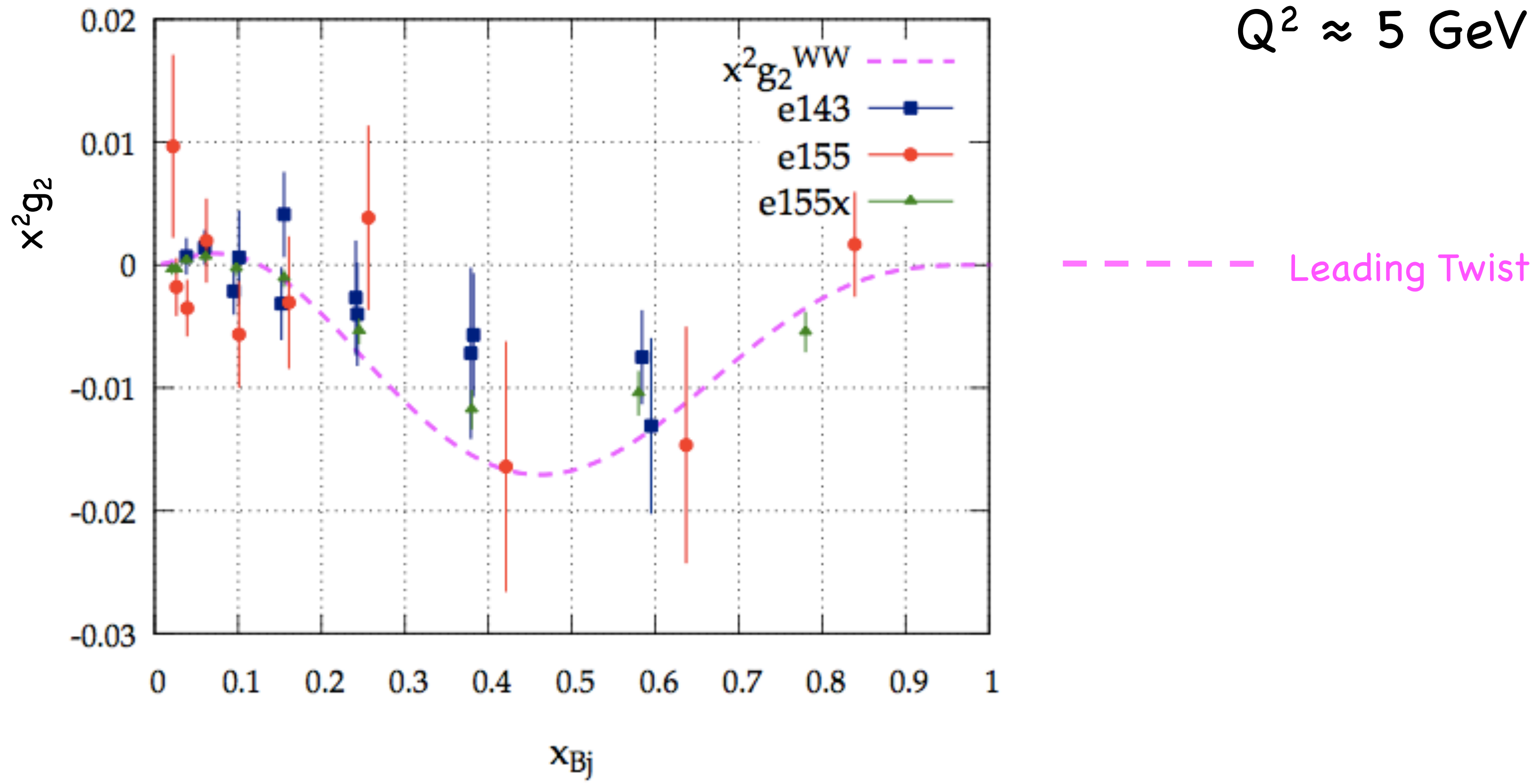
Proton g_2 data from SLAC



$Q^2 \approx 5\ \mathrm{GeV}^2$

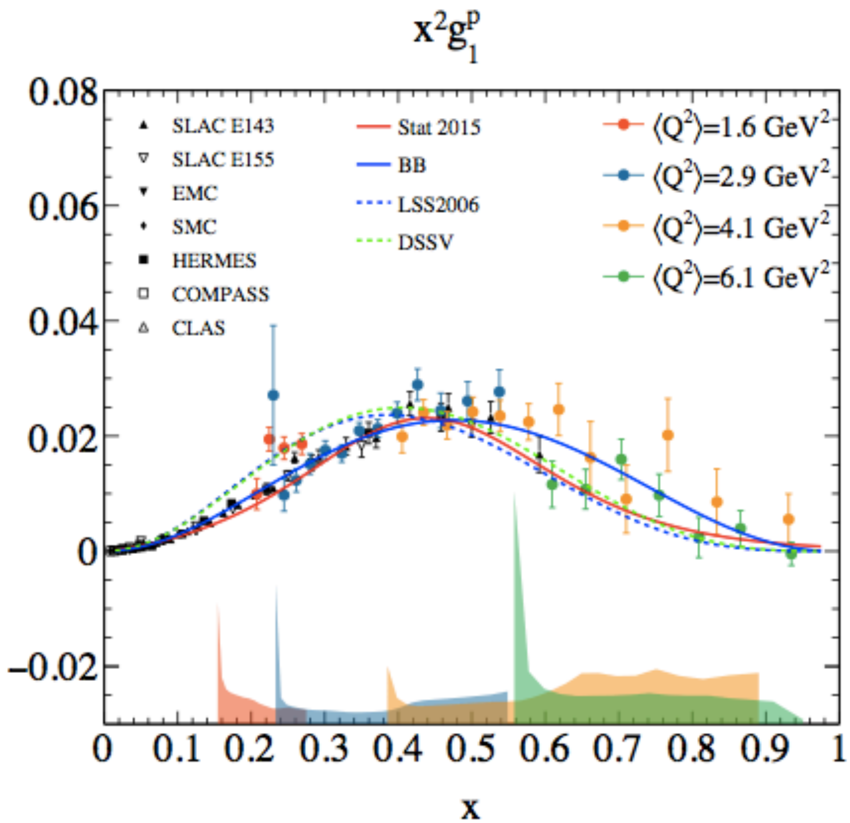
Proton g_2 data from SLAC

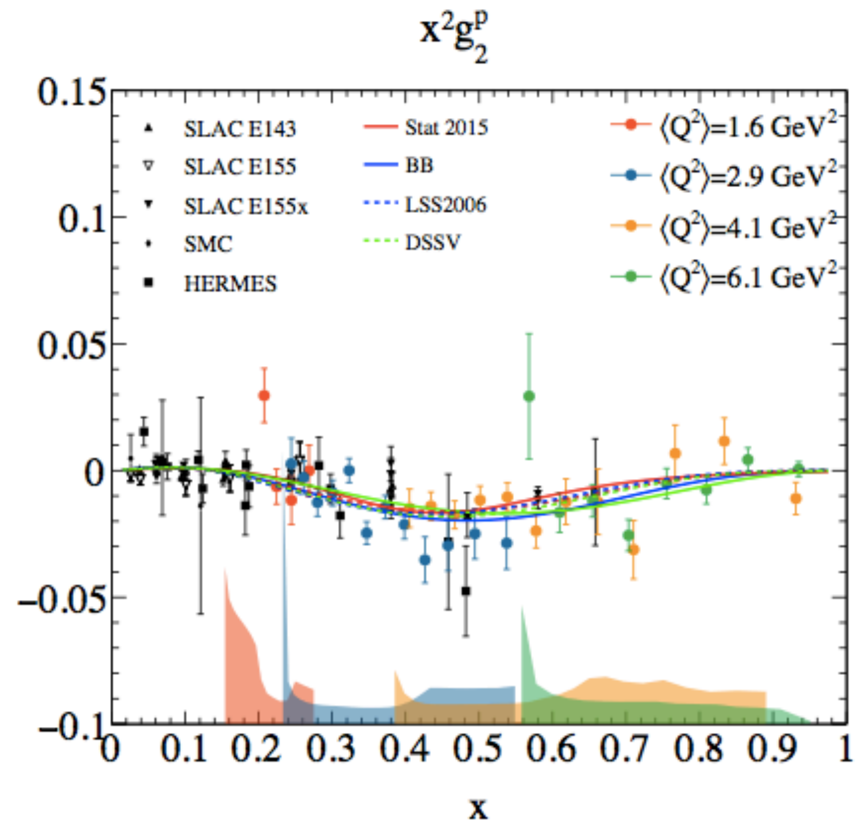
$Q^2 \approx 5\ GeV^2$



Precision does not allow unambiguous HT extraction

SANE $x^2g_1^p$ and $x^2g_2^p$





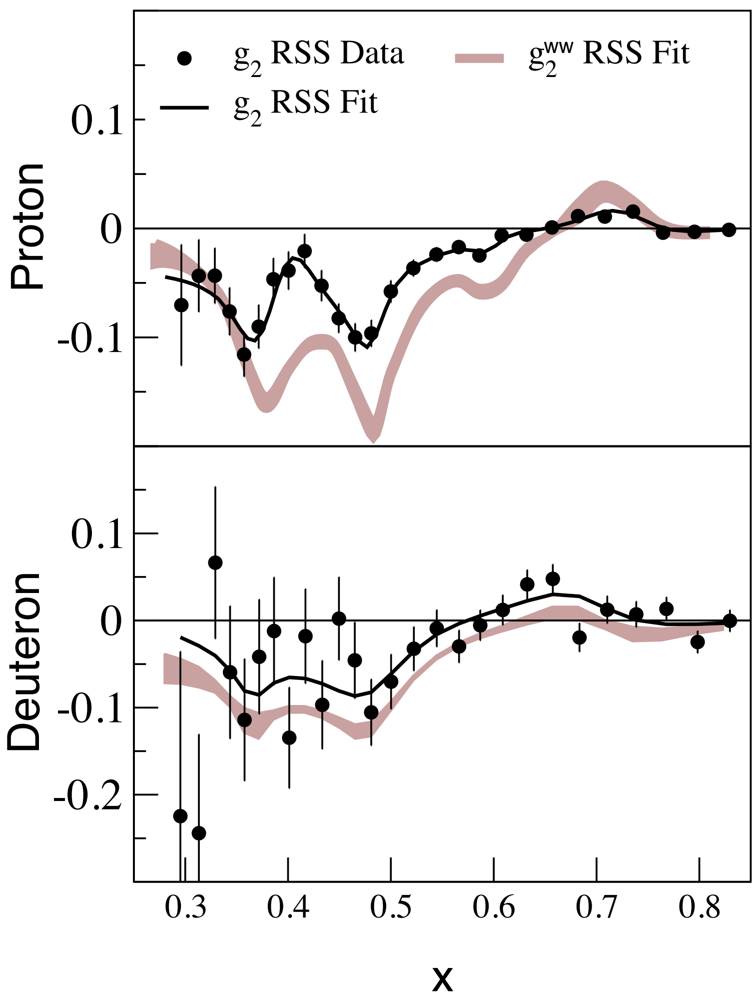
Models are showing g_2^{WW}.

Submitted to PRL

$Q^2 \approx 2\text{–}6$ GeV^2

RSS Experiment

$Q^2 = 1.3\ GeV^2$



$\overline{\Delta}\Gamma_2 = -0.0006 \pm 0.0021$ (proton)

consistent with zero
=> low x HT are small in proton.

$\overline{\Delta}\Gamma_2 = -0.0092 \pm 0.0035$ (neutron)

non-zero by 2.6σ

=>Significant HT at low x
needed to satisfy Neutron
BC sum rule.

K.Slifer., O. Rondon *et al.*
PRL 105, 101601 (2010)

SSF Moments

Generalized GDH Sum

$$\Gamma_1(Q^2) = \int_0^{x_0} \mathrm{d}x\, g_1(x, Q^2)$$

Burkhardt Cottingham

$$\Gamma_2(Q^2) = \int_0^{x_0} dx\ \ g_2(x, Q^2)$$

Generalized Forward Spin polarizabilities

$$\gamma_0(Q^2) = \frac{16\alpha M_N^2}{Q^6} \int_0^{x_0} \mathrm{d}x\, x^2 g_{TT}(x, Q^2),$$

$$\delta_{LT}(Q^2) = \frac{16\alpha M_N^2}{Q^6} \int_0^{x_0} \mathrm{d}x\, x^2 \left[g_1(x, Q^2) + g_2(x, Q^2)\right]$$

$$g_{TT} = g_1 - (4M_N^2 x^2/Q^2) g_2$$

E08-027 : Proton g_2 Structure Function

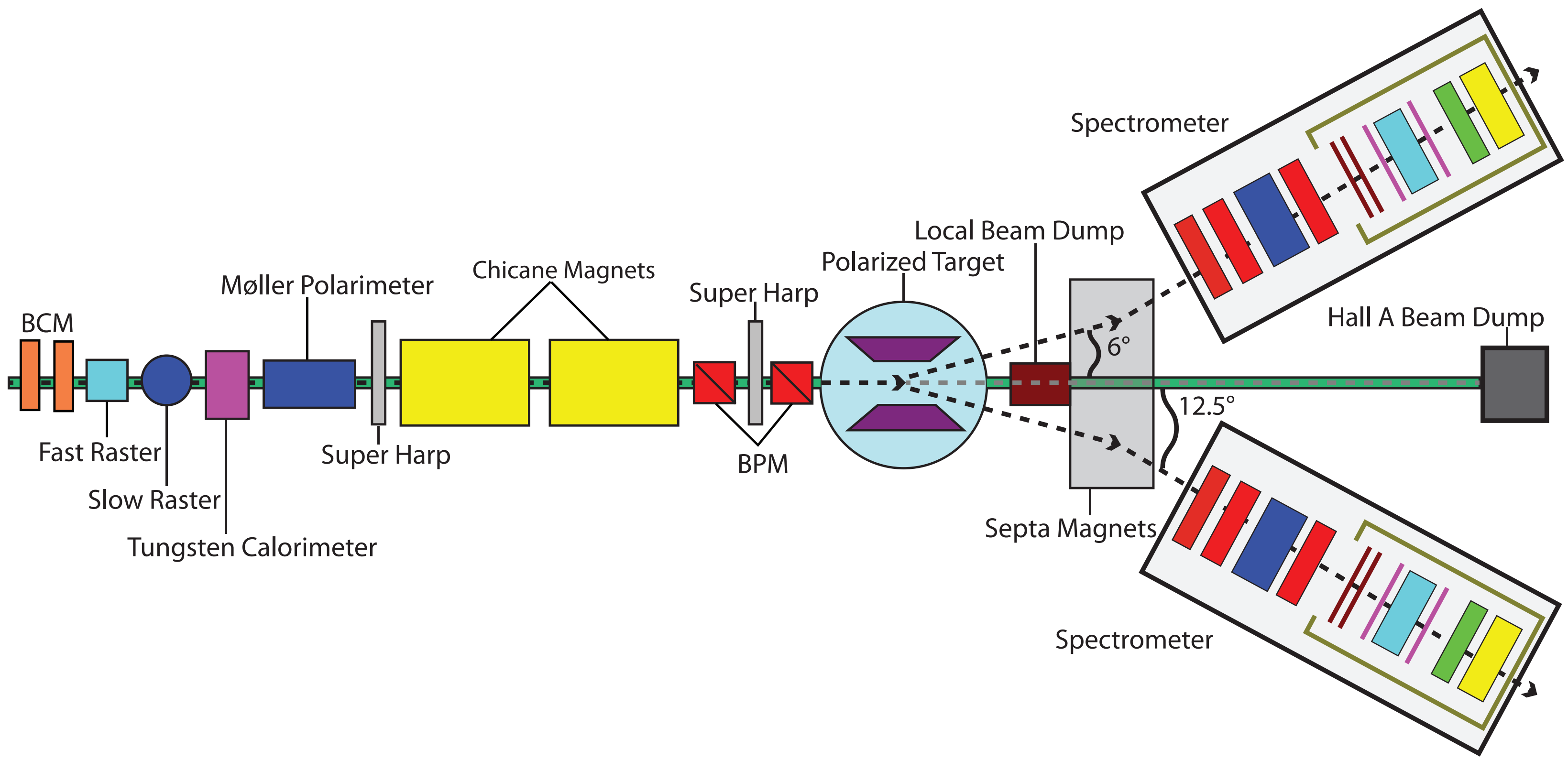
Camsonne, Crabb,

Chen, Slifer

BC Sum Rule : violation suggested for proton at large Q^2, but found satisfied for the neutron & ^{3}He.

Spin Polarizability : Major failure (>8σ) of χPT for neutron δ_{LT}

Hydrogen HFS: Structure dependent corrections



Largest Installation in Hall A History

Polarized proton target

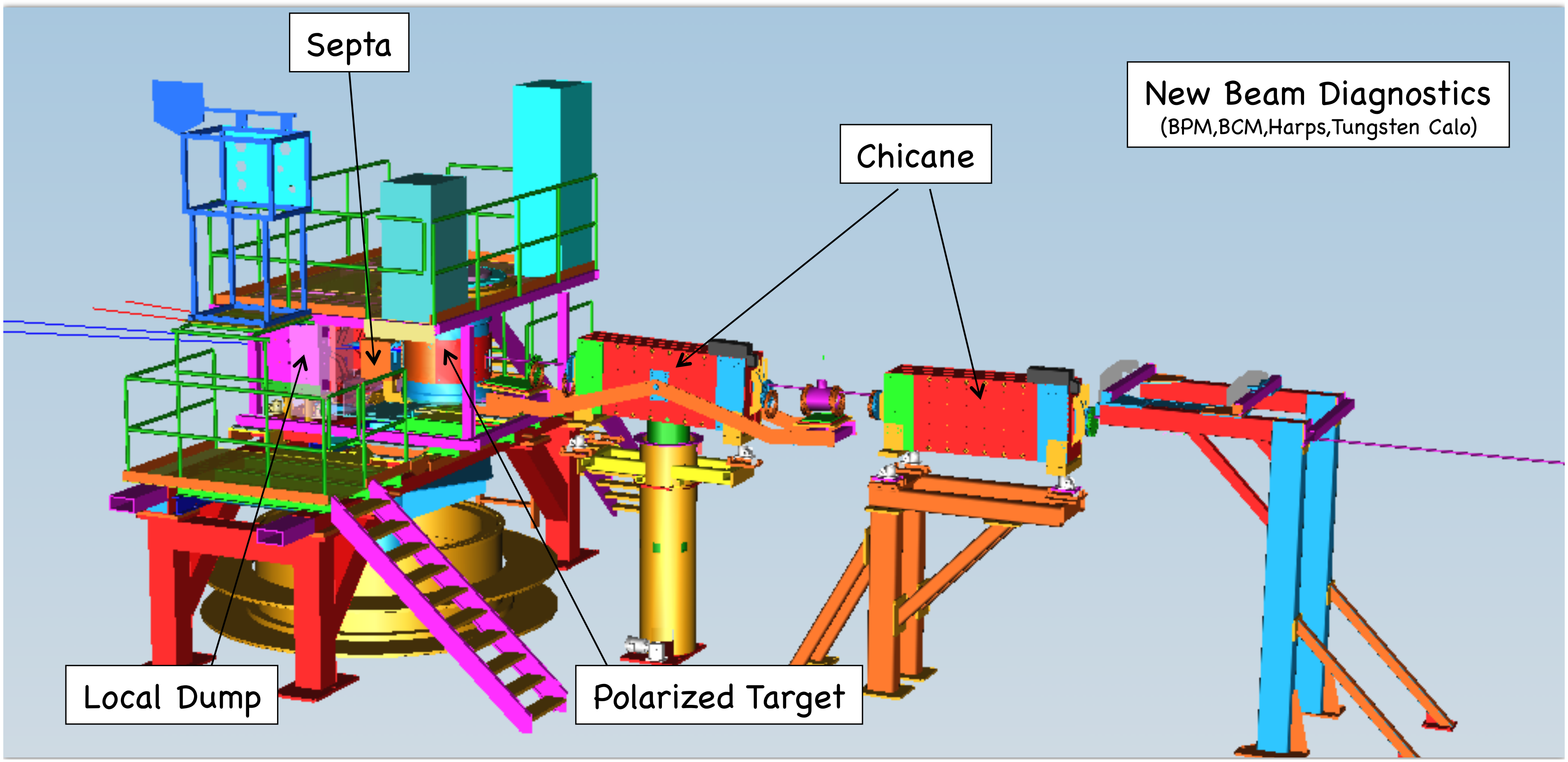
- upstream chicane
- downstream local dump

Low current polarized beam

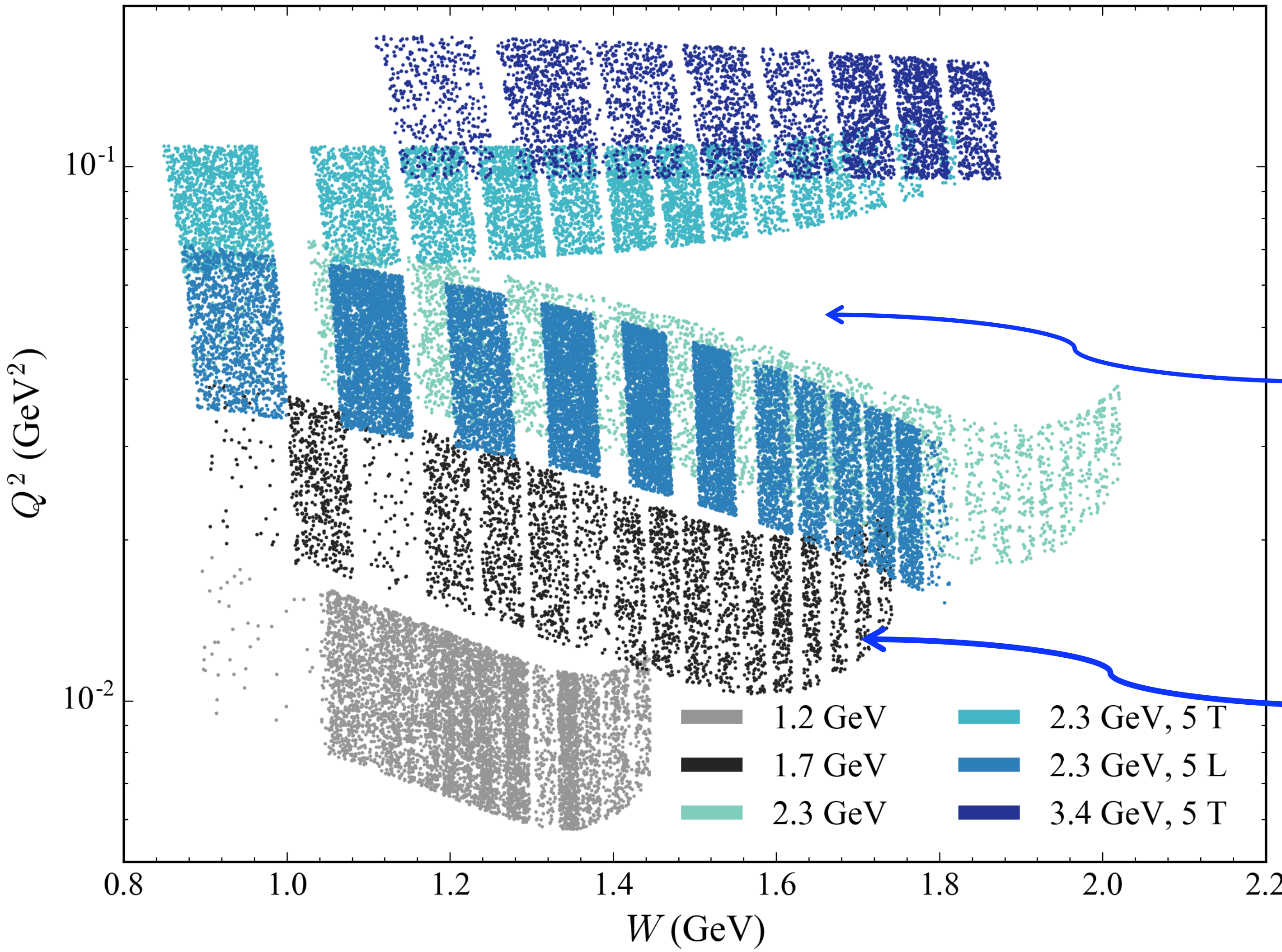
- Upgrades to existing Beam Diagnostics to work at 85 nA

Lowest possible Q^2 in the resonance region

- Septa Magnets to detect forward scattering



E08-027 : Proton g_2 Structure Function



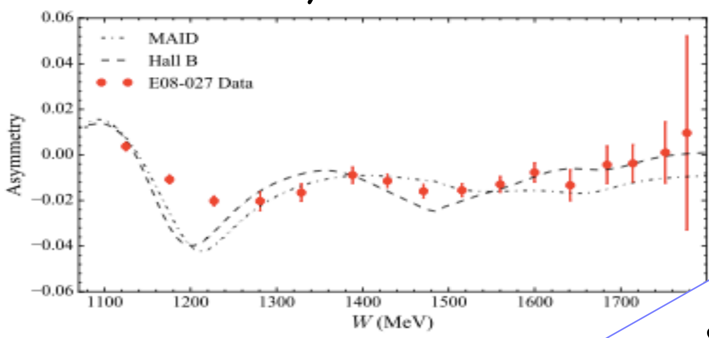
5T: Large Q^2 data
final
preparing for
publication

2.5T: Low Q^2 data
preliminary
finalizing
Packing Fraction

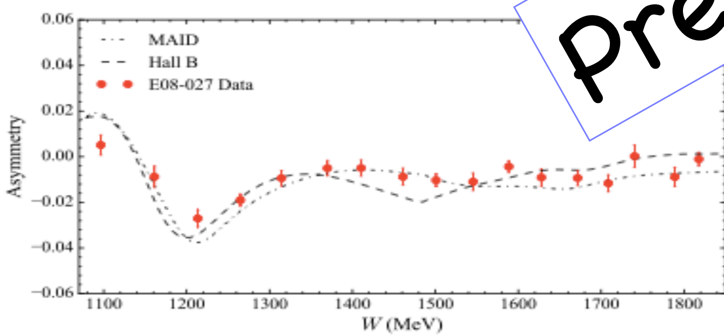
courtesy R. Zielinski

E08-027 Data

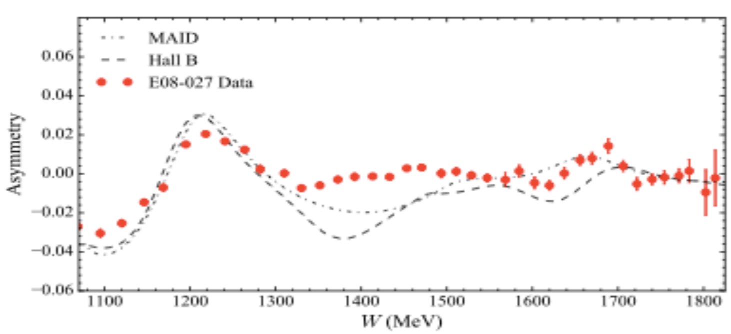
Asymmetries



(a) E_0 = 2254 MeV 5T Transverse



(b) E_0 = 3350 MeV 5T Transverse

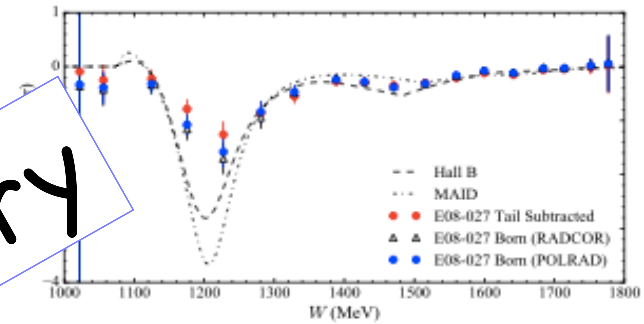


(c) E_0 = 2254 MeV 5T Longitudinal

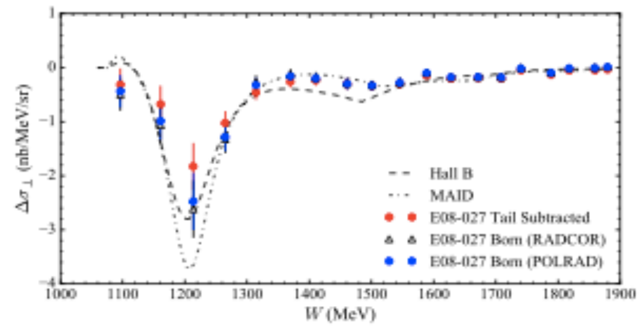
Figure 8-9: Final asymmetries for the 5 T settings.

Δσ

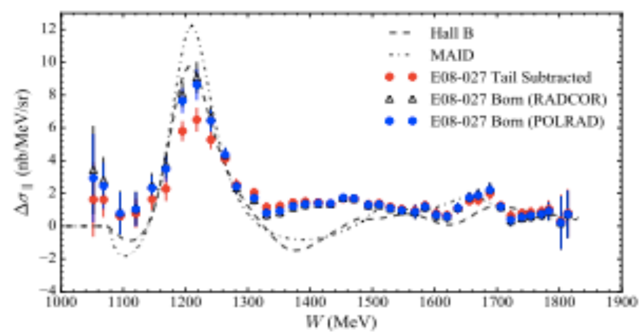
Preliminary



(a) E_0 = 2254 MeV 5T Transverse



(b) E_0 = 3350 MeV 5T Transverse



(c) E_0 = 2254 MeV 5T Longitudinal

Figure 8-19: Born polarized cr

courtesy R. Zielinski, UNH

E08-027 Structure Functions (5T data)

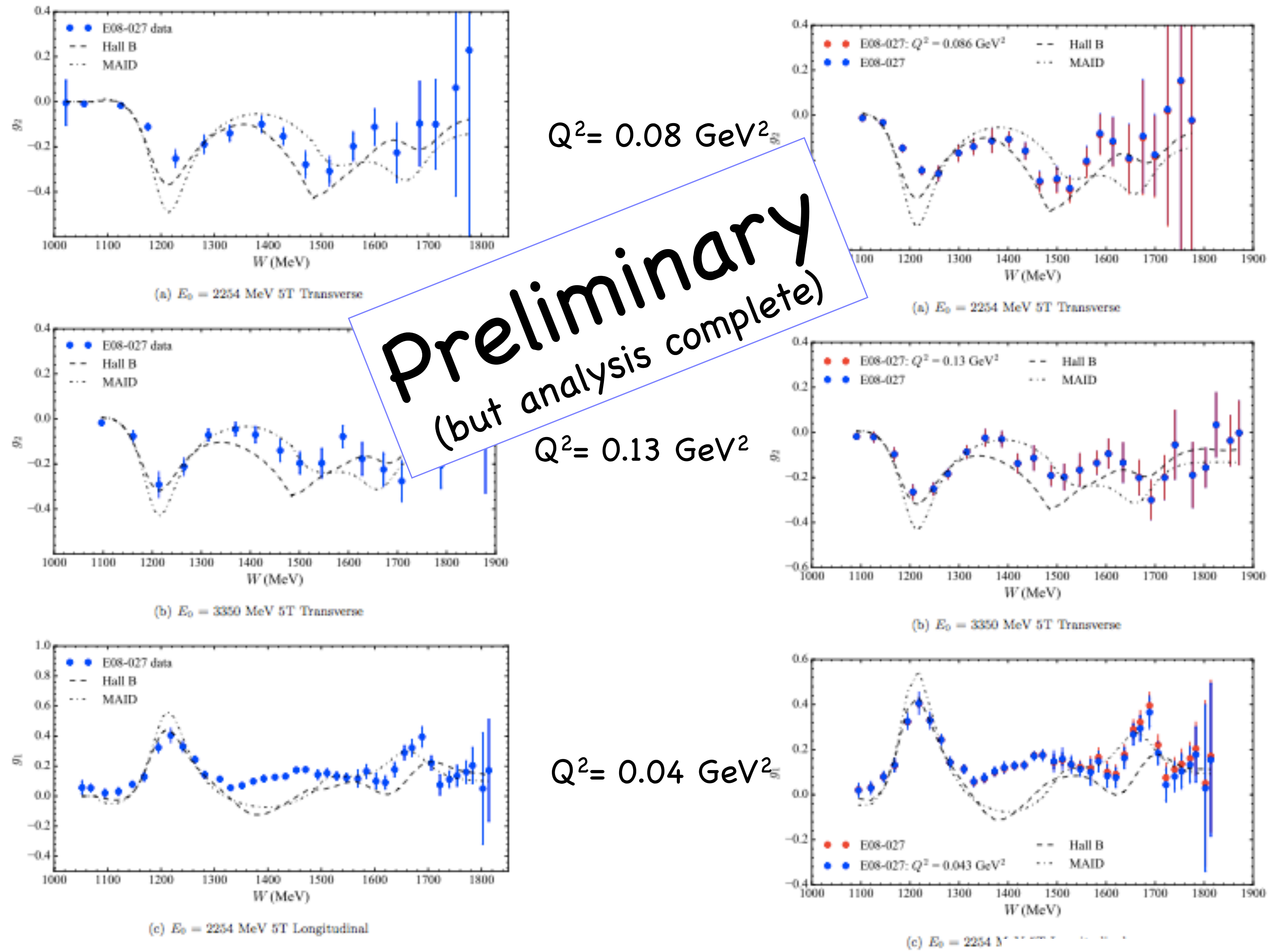
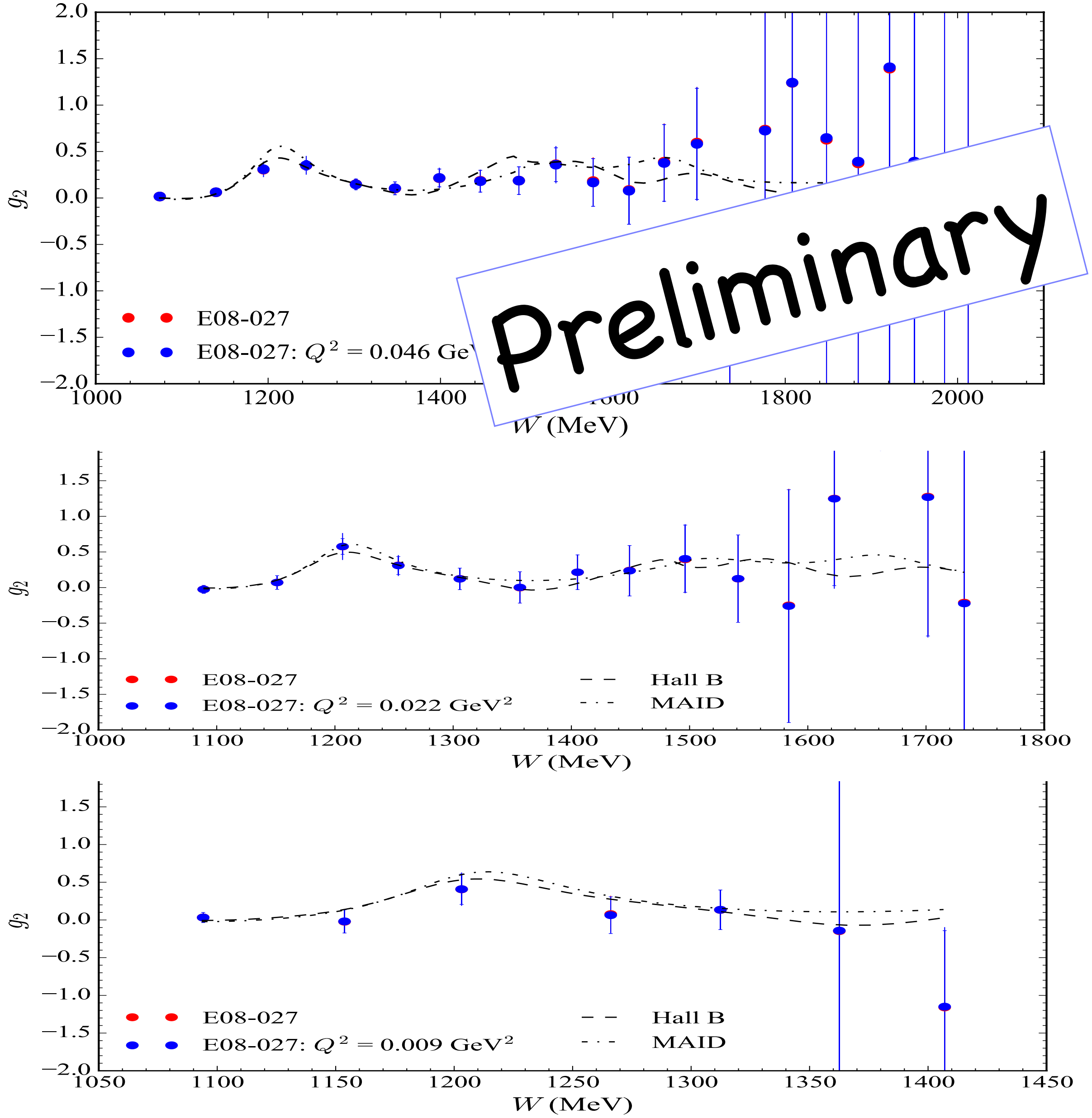


Figure 8-21: Born spin structure functions for the 5 T kinematic settings.

Figure 8-24: E08-027 spin structure functi

courtesy R. Zielinski, UNH

g2p 2.5T data



Q^2= 0.05 GeV^2

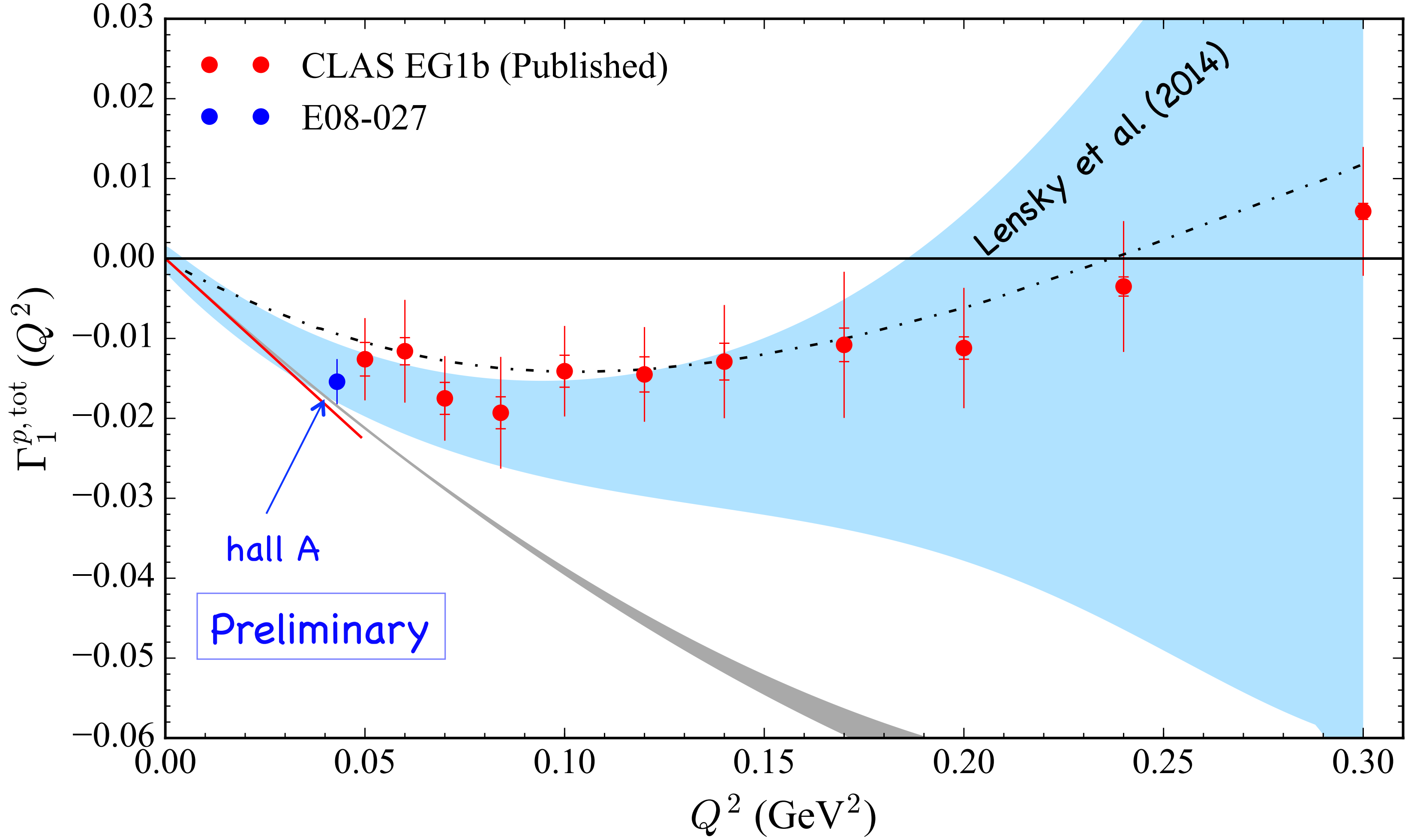
Q^2= 0.02 GeV^2

Q^2= 0.01 GeV^2

Finalizing df/pf

courtesy R. Zielinski, UNH

E08-027 Proton 1st Moment



courtesy R. Zielinski, UNH

BC Sum Rule

$$\int_0^1 g_2(x, Q^2)dx = 0$$

H.Burkhardt and W.N. Cottingham
Annals Phys. **56** (1970) 453.

Assumptions:

the virtual Compton scattering amplitude S_2 falls to zero faster than 1/x

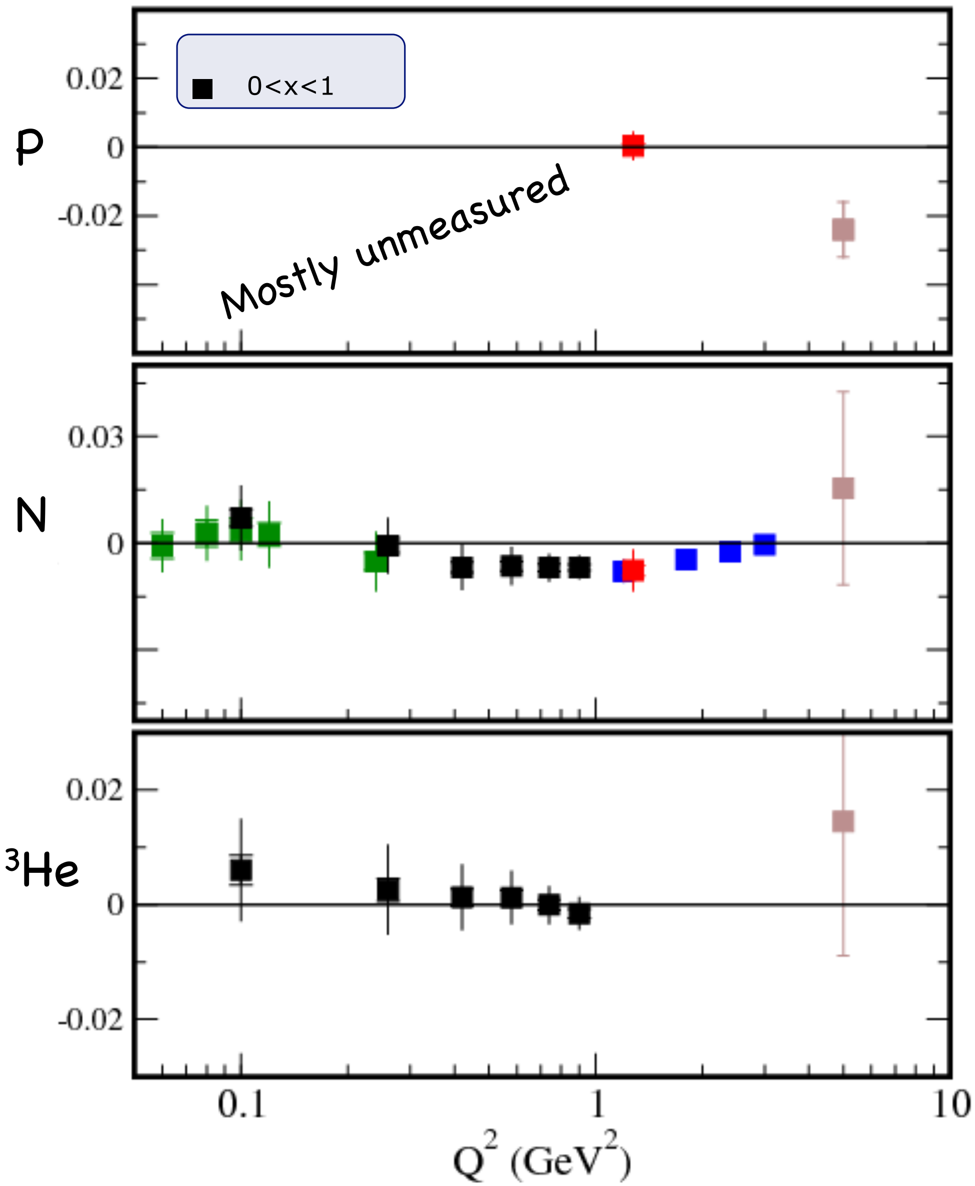
g_2 does not behave as $\delta(x)$ at x=0.

Discussion of possible causes of violations

R.L. Jaffe Comm. Nucl. Part. Phys. 19, 239 (1990)

"If it holds for one Q^2 it holds for all"

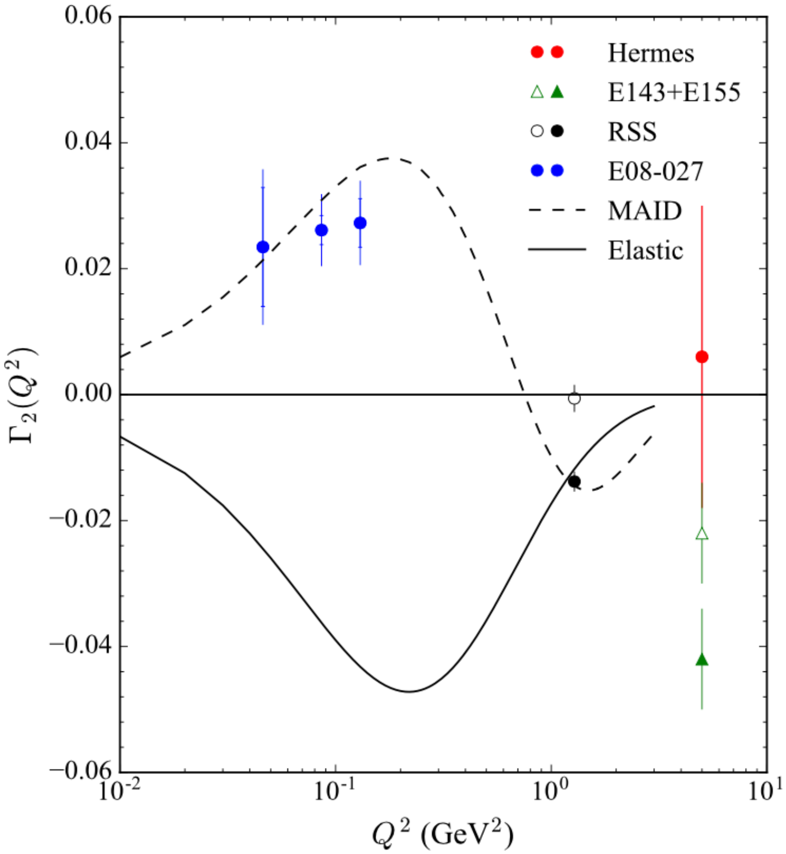
BC Sum Rule



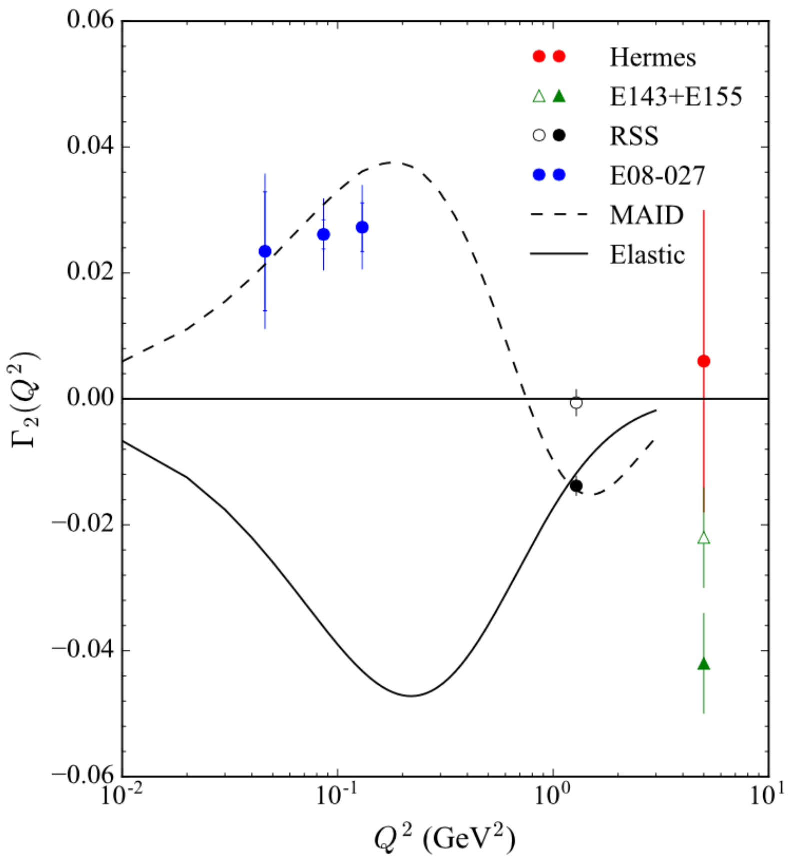
BC satisfied w/in errors for JLab Proton
2.8σ violation seen in SLAC data

← Nuclear Sum Rule

E08-027 Proton BC Integral



E08-027 Proton BC Integral



Source	x Integral $(0 < x < x_{\text{meas}})$	% contribution relative to measured region
CLAS	-0.003	12%
AAC PPDF	0.013	52%
GRSV PPDF	0.012	48%
Required	0.015	60%

TABLE V. Typical low x contributions to the first moment of g_2 at the E08-027 kinematics.

Unmeasured low x contribution has large uncertainty at low Q^2.

=>Difficult to make strong statement on BC with current low x estimates

We welcome theorist input!!!

Spin Polarizabilities

$$\gamma_0(Q^2) = \frac{16\alpha M_N^2}{Q^6}\int_0^{x_0} \mathrm{d}x\, x^2 g_{TT}(x,Q^2),$$

$$\delta_{LT}(Q^2) = \frac{16\alpha M_N^2}{Q^6}\int_0^{x_0} \mathrm{d}x\, x^2 \left[g_1(x,Q^2) + g_2(x,Q^2)\right]$$

$$g_{TT} = g_1 - (4M_N^2 x^2/Q^2) g_2$$

Good Test of ChPT.

Chpt respects all symmetries of QCD but its Lagrangian is constructed from hadron degrees of freedom

Heavy Baryon χPT : Treats the Baryon as a heavy static particle
Kao, Vanderhaeghen, et al

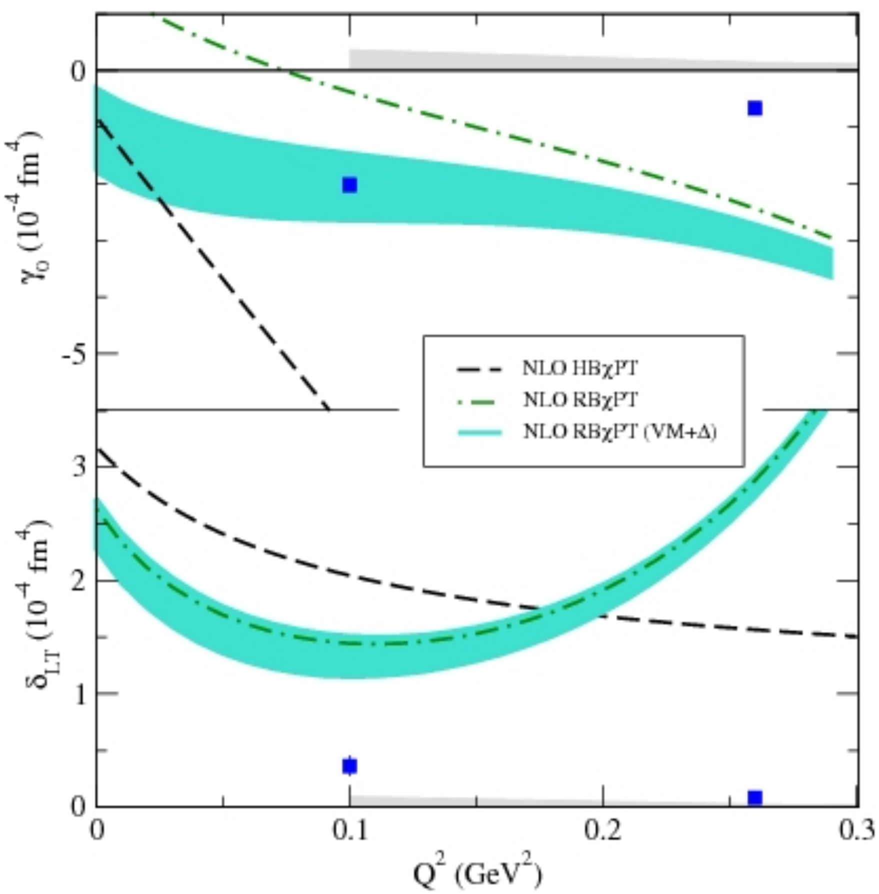
Relativistic Baryon : large momentum effects are absorbed in the low energy consts
Δ(1232) included explicitly. Other Resonances are included systematically through additional low energy constants

1: Meissner, Bernard, Krebs, Epelbaum
2: Lensky, Alarcon, Pascalutsa

δ_{LT} Puzzle

Neutron

PRL 93: 152301 (2004)



$$\gamma_0 = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 \left[g_1 - \frac{4M^2}{Q^2} x^2 g_2 \right]$$

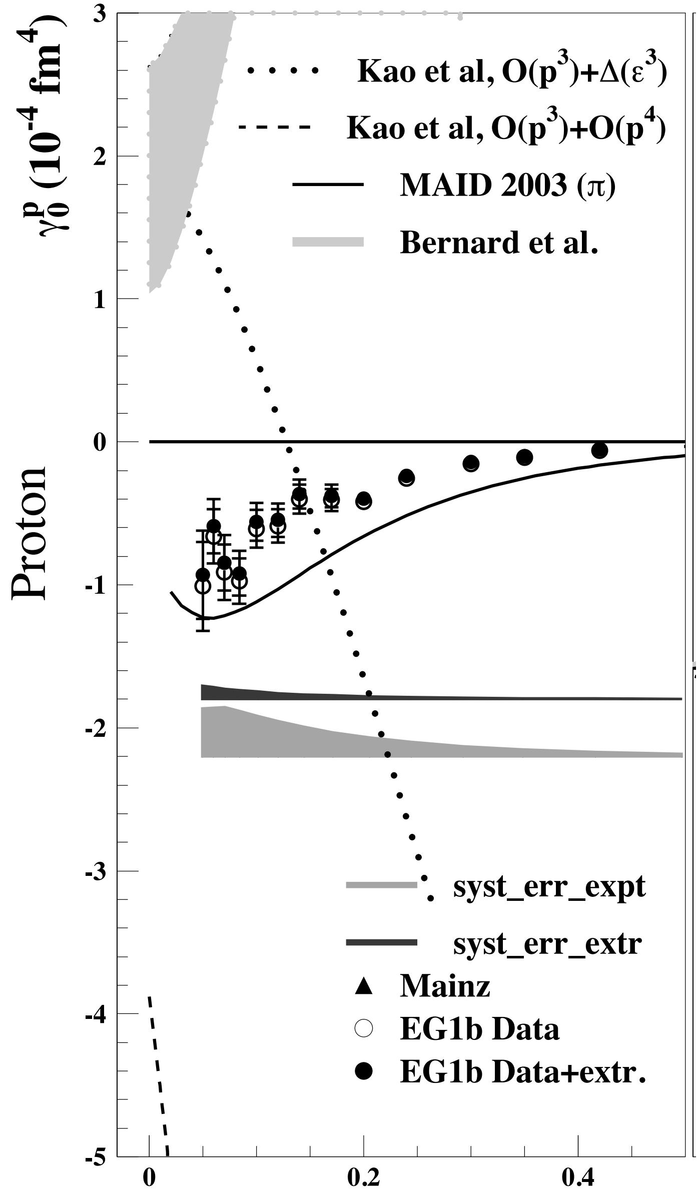
$$\delta_{LT} = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 \left[g_1 + g_2 \right]$$

Dramatic Discrepency
with χPT

Heavy Baryon ChPT Calculation
Kao, Spitzenberg, Vanderhaeghen
PRD 67:016001(2003)

Infrared Relativistic Baryon ChPT
Bernard, Hemmert, Meissner
PRD 67:076008(2003)

Proton γ_0



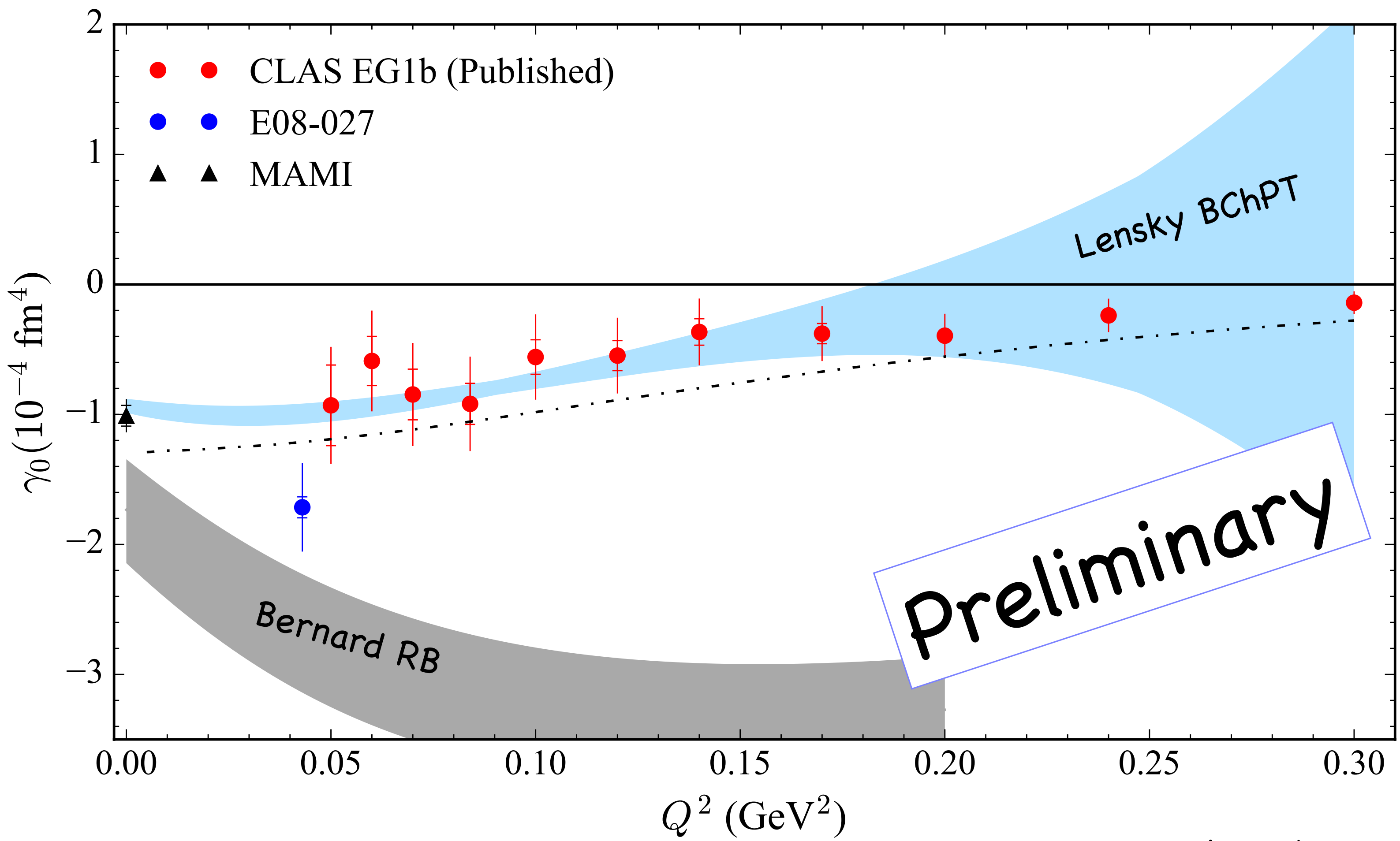
$$\gamma_0 = \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2 \left[g_1 - \frac{4M^2}{Q^2}x^2 g_2\right]$$

Older Calcs also failed for proton γ_0

PLB 672 12, 2009

published data goes down to about 0.06 GeV²

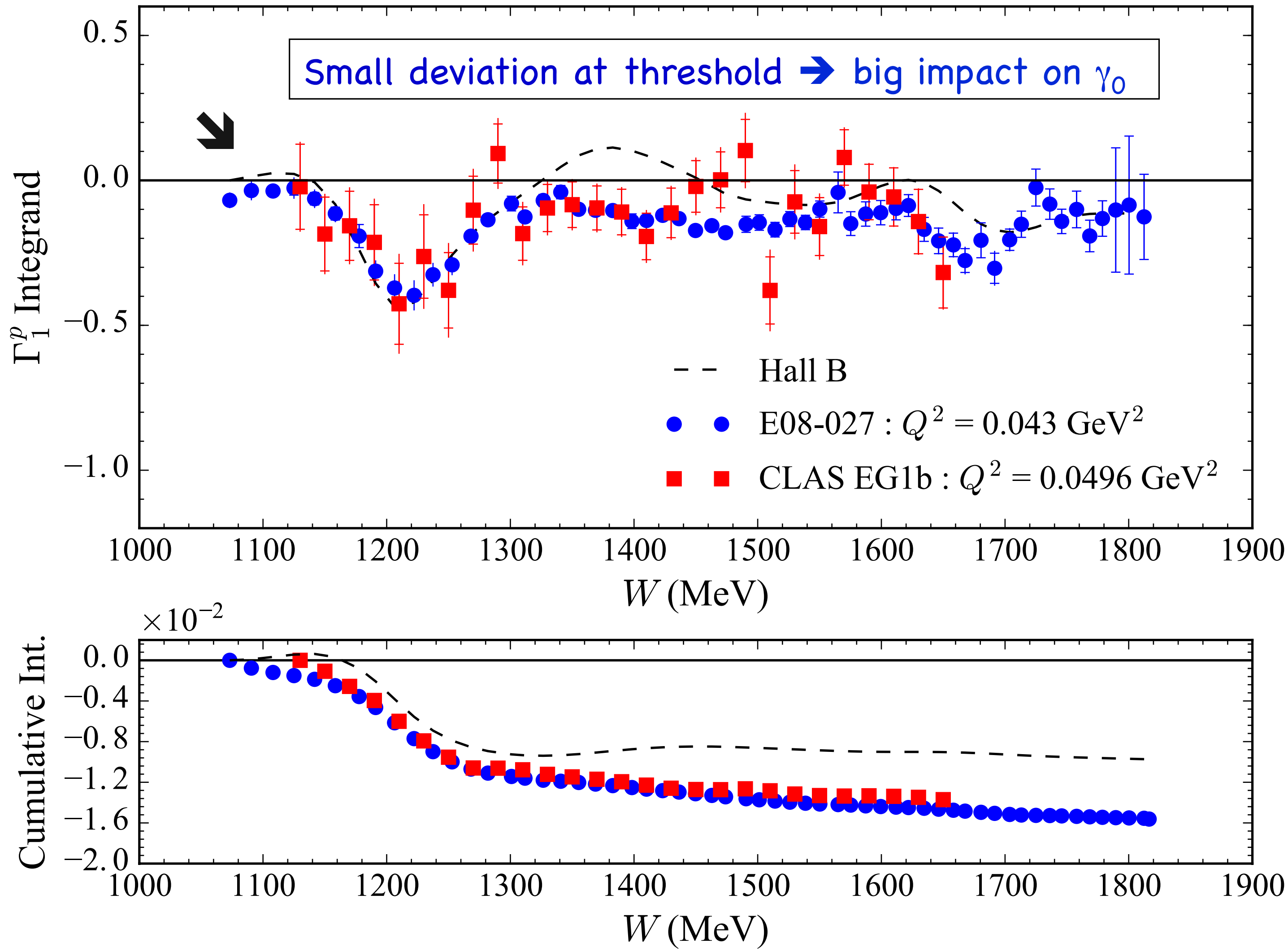
Proton γ_0 (latest data)



$$\gamma_0 = \frac{16\alpha M^2}{Q^6} \int_0^{x_0} x^2 \left[g_1 - \frac{4M^2}{Q^2} x^2 g_2 \right]$$

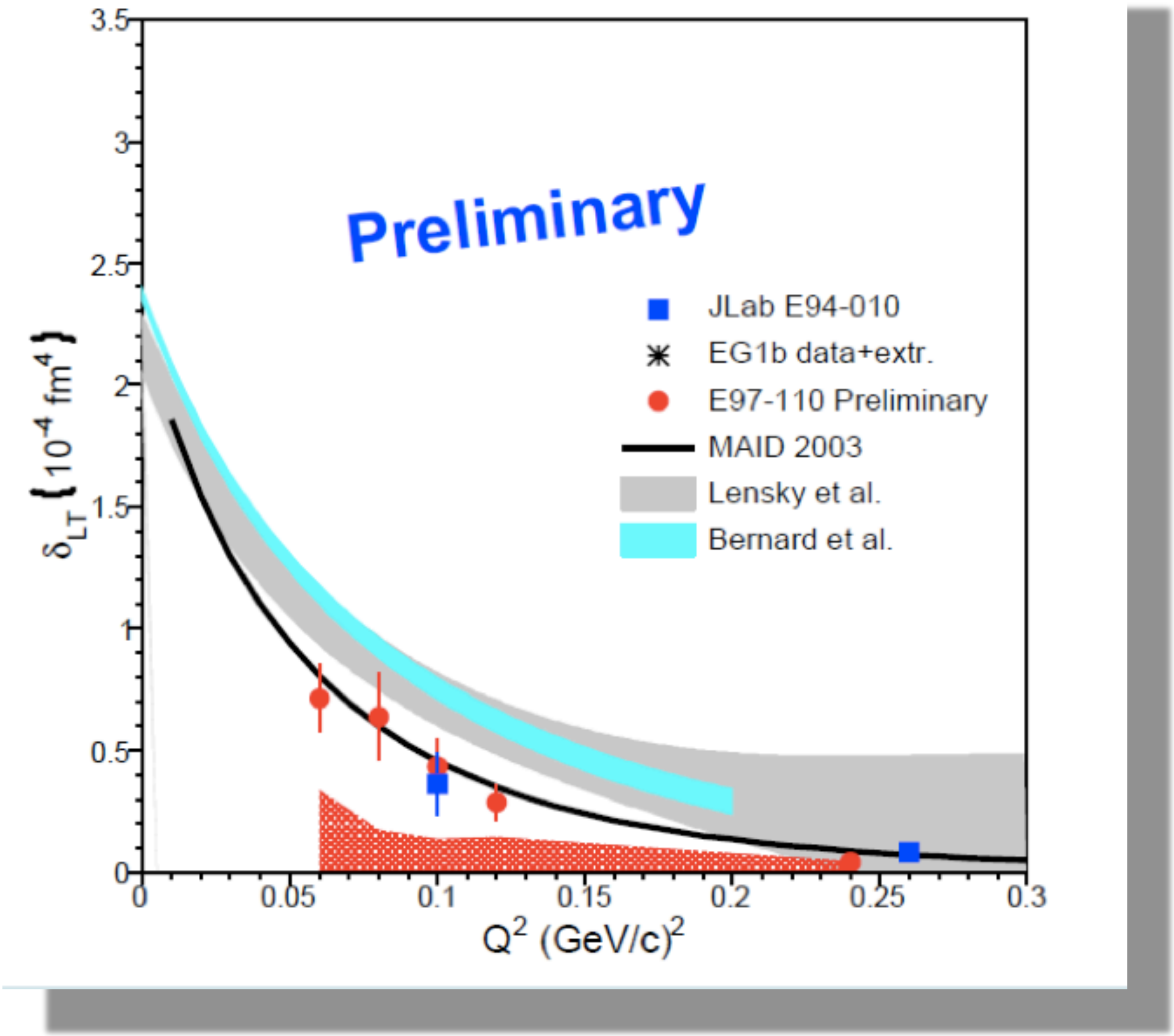
decent agreement
with BChpt
Small disagreeement
Between Hall A & B

Proton g1 (E08-027 vs. CLAS)



courtesy R. Zielinski, UNH

Neutron δ_{LT} (saGHD)



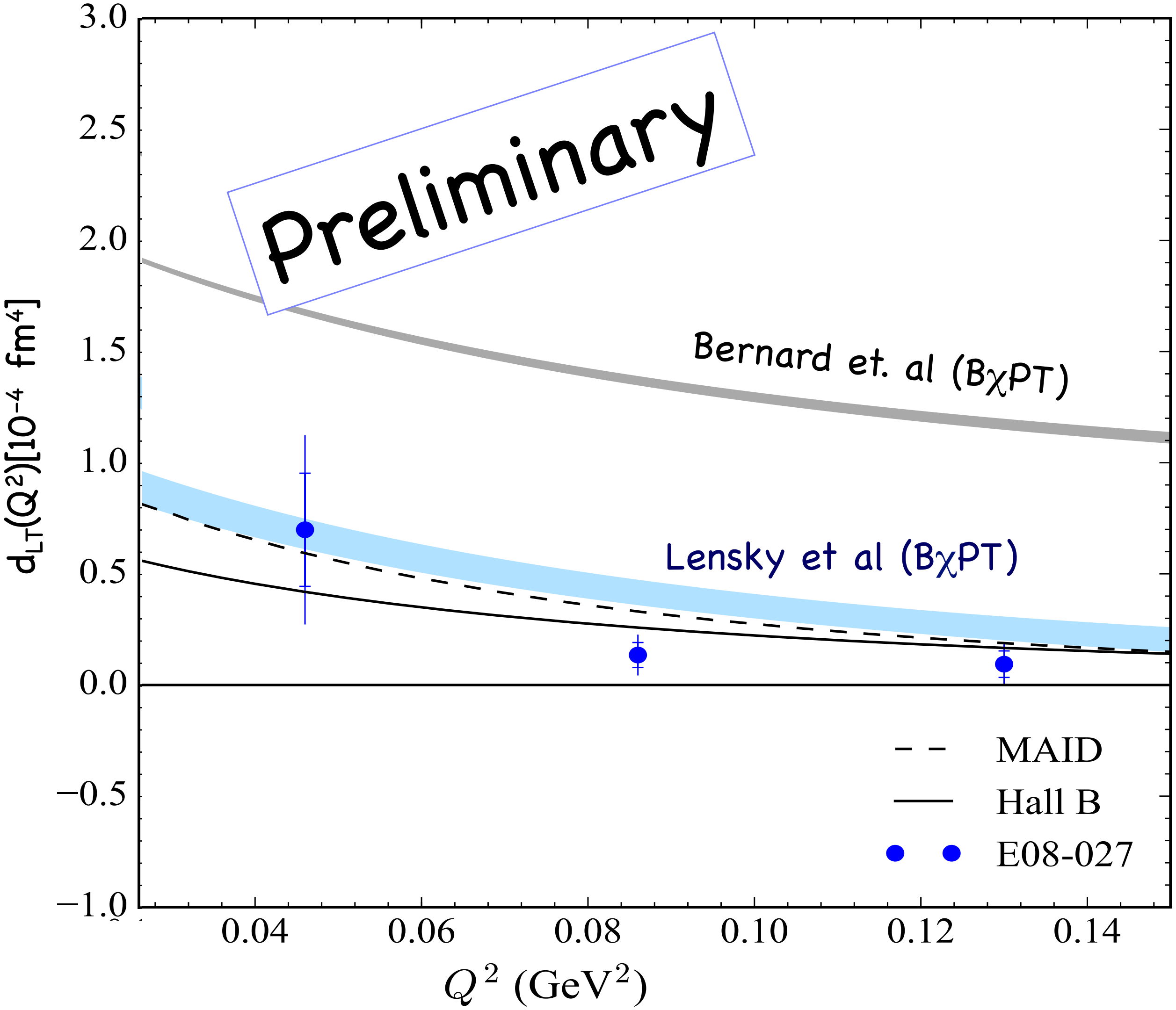
Good agreement
Now with χPT

See JP Chen's talk

BERNARD et al. PRD 87, 054032 (2013)

Lensky et al. PRC 90(2014) 055202

δ_{LT} Proton (E08-027)



χPT Comparison Summary

Γ_1 Pretty good agreement with χPT calculations

δ_{LT} Good agreement for neutron for all calcs
Proton data favors BχPT (Lensky et al)

γ_0 Good agreement for proton for BχPT (Lensky et al)
but perhaps an issue with the low nu data
needs further comm between HallA/HallB collabs

Can also evaluate the higher order polarizabilities....

Higher Order Polarizabilities

Next order terms in the expansions that lead to γ_0 and δ_{LT}

$$\mathrm{Re}\, f_{TT} = \sum_{n=0} \left(\frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{K(\nu', Q^2)\sigma_{TT}(\nu', Q^2)}{\nu'^{2n+2}} \nu^{2n+1} d\nu' \right),$$

$$\mathrm{Re}\, f_{LT} = \sum_{n=0} \left(\frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{K(\nu', Q^2)\sigma_{LT}(\nu', Q^2)}{\nu'^{2n+1}} \nu^{2n} d\nu' \right),$$

Higher Order Polarizabilities

Next order terms in the expansions that lead to γ_0 and δ_{LT}

$$\mathrm{Re}\, f_{TT} = \sum_{n=0} \left(\frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{K(\nu', Q^2)\sigma_{TT}(\nu', Q^2)}{\nu'^{2n+2}} \nu^{2n+1} d\nu' \right),$$

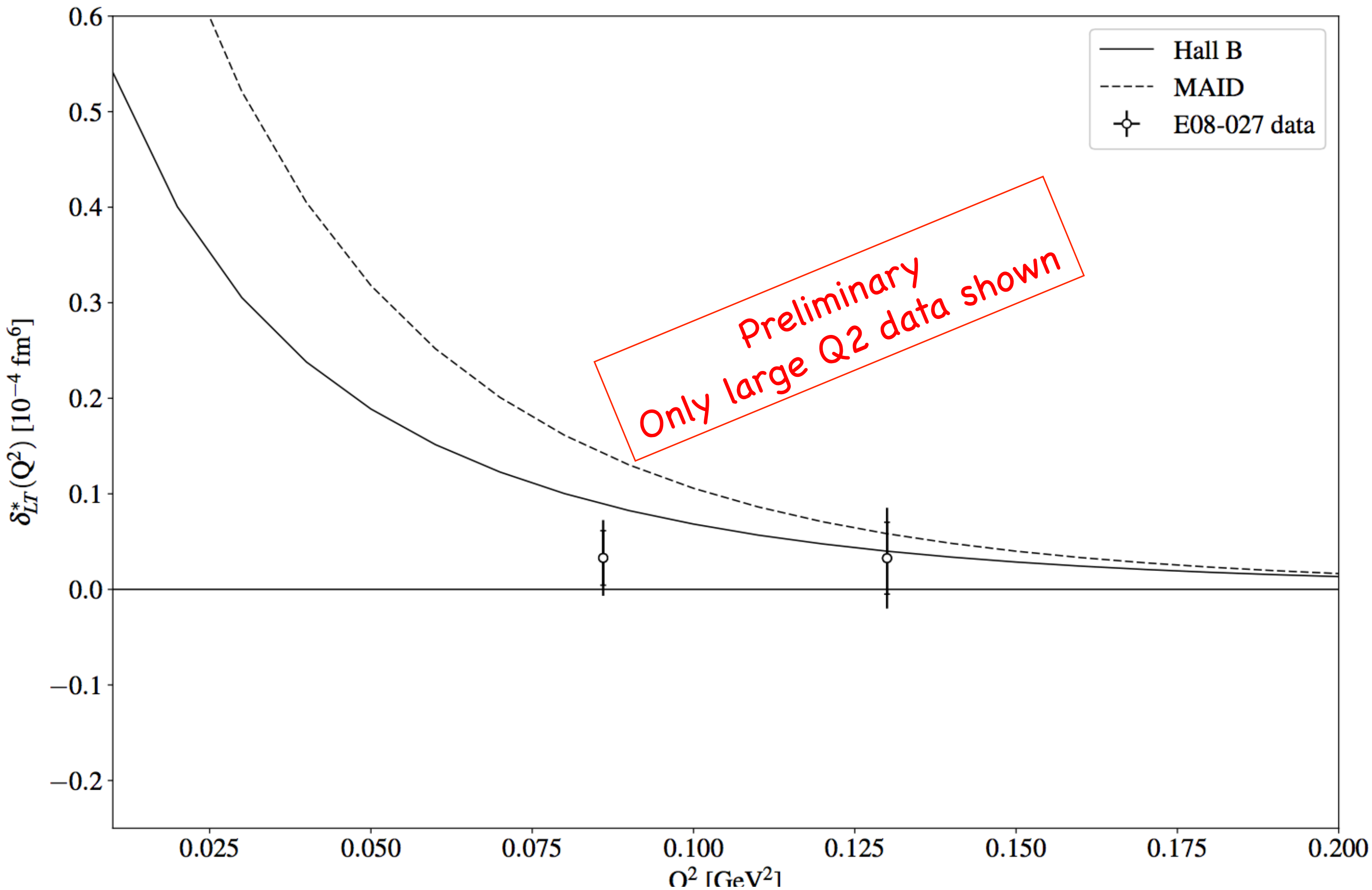
$$\mathrm{Re}\, f_{LT} = \sum_{n=0} \left(\frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{K(\nu', Q^2)\sigma_{LT}(\nu', Q^2)}{\nu'^{2n+1}} \nu^{2n} d\nu' \right),$$

Allow us to define higher order polarizabilities

$$\gamma_0^*(Q^2) = \frac{64 M^4 \alpha}{Q^{10}} \int_0^{x_0} x^4 \left(g_1(x, Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x, Q^2) \right) dx$$

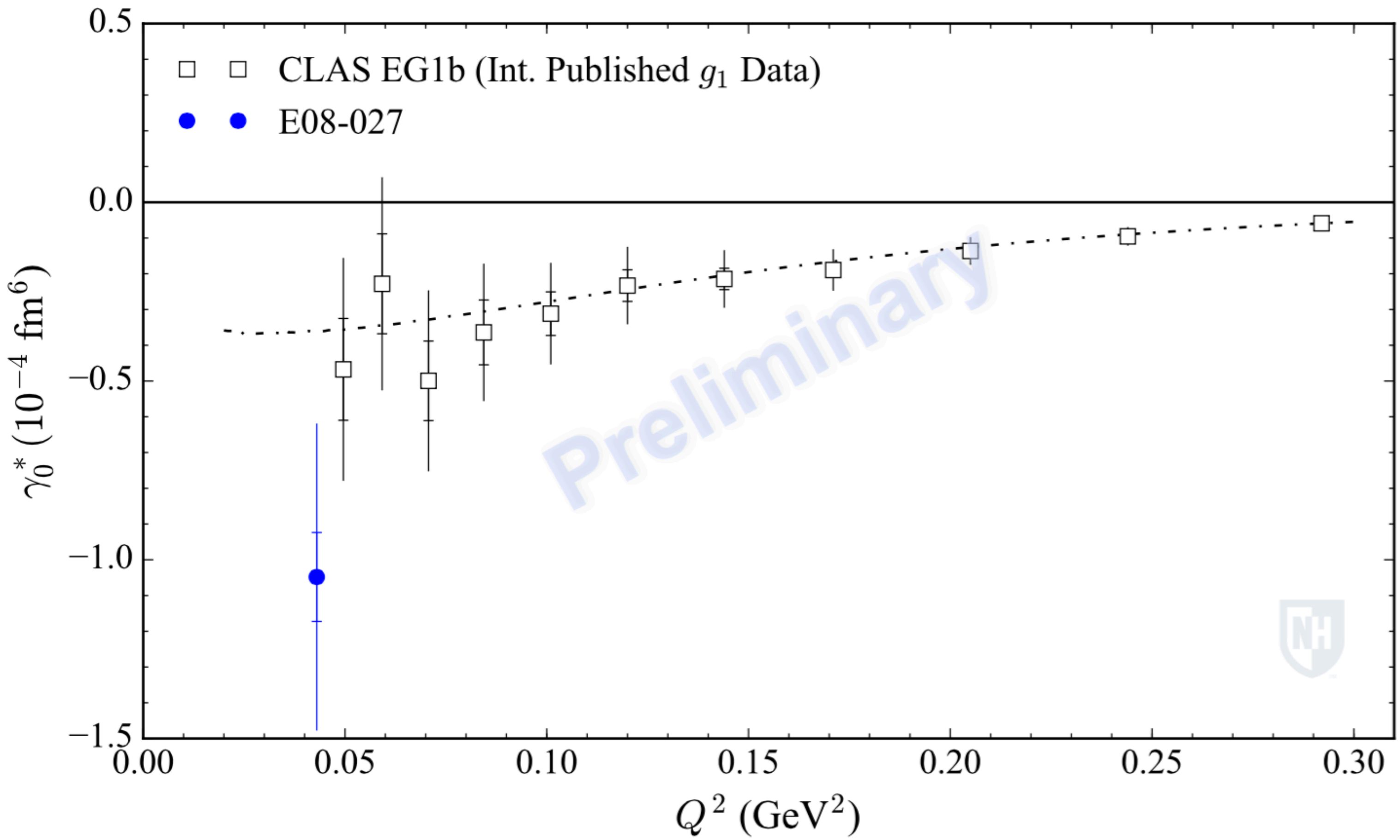
$$\delta_{LT}^* = \frac{64 \alpha M^4}{Q^{10}} \int_0^{x_0} x^4 \left(g_1(x, Q^2) + g_2(x, Q^2) \right) dx.$$

Higher Order Polarizabilities



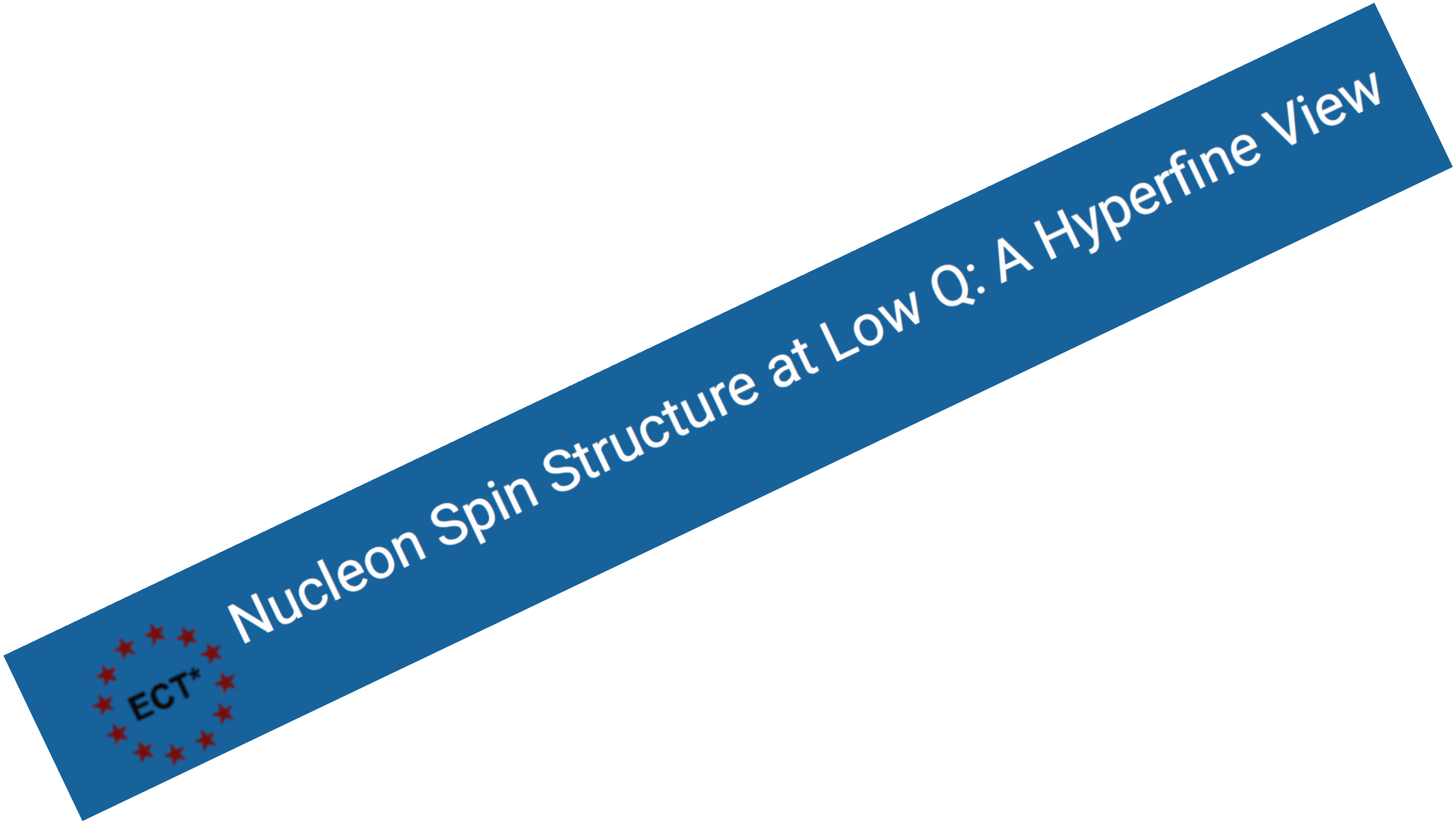
$$\delta^*_{LT} = \frac{64\alpha M^4}{Q^{10}} \int_0^{x_0} x^4 \left(g_1(x,Q^2) + g_2(x,Q^2)\right) dx.$$

Higher Order Polarizabilities

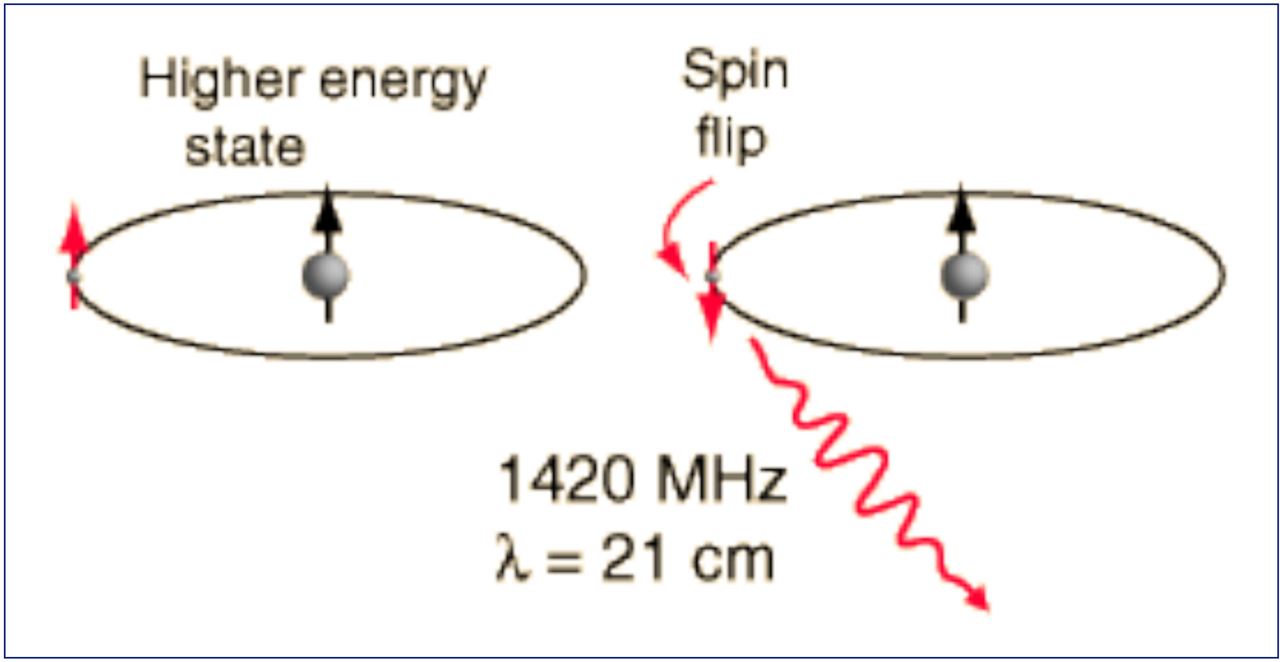


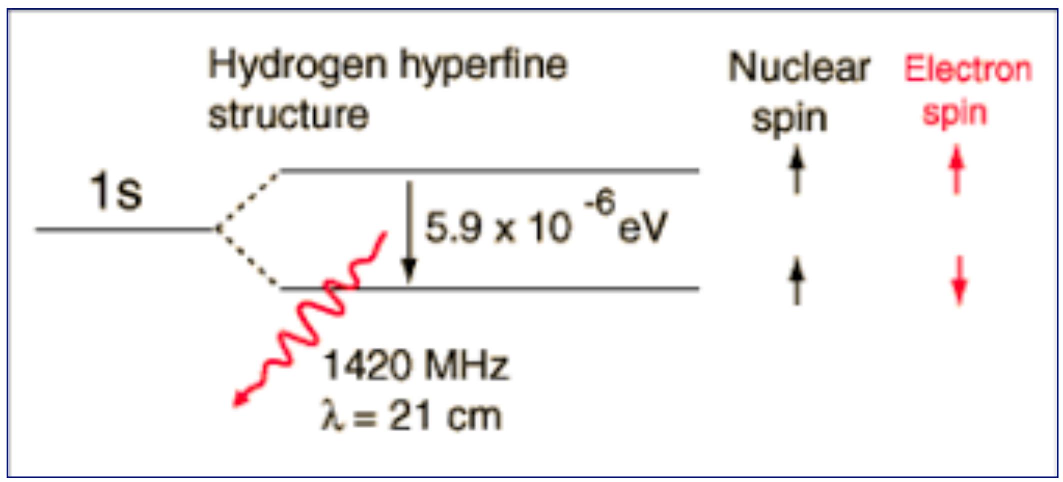
$$\gamma_0^*(Q^2) = \frac{64M^4\alpha}{Q^{10}} \int_0^{x_0} x^4 \left(g_1(x, Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x, Q^2)\right) dx$$

"A Hyperfine View…"

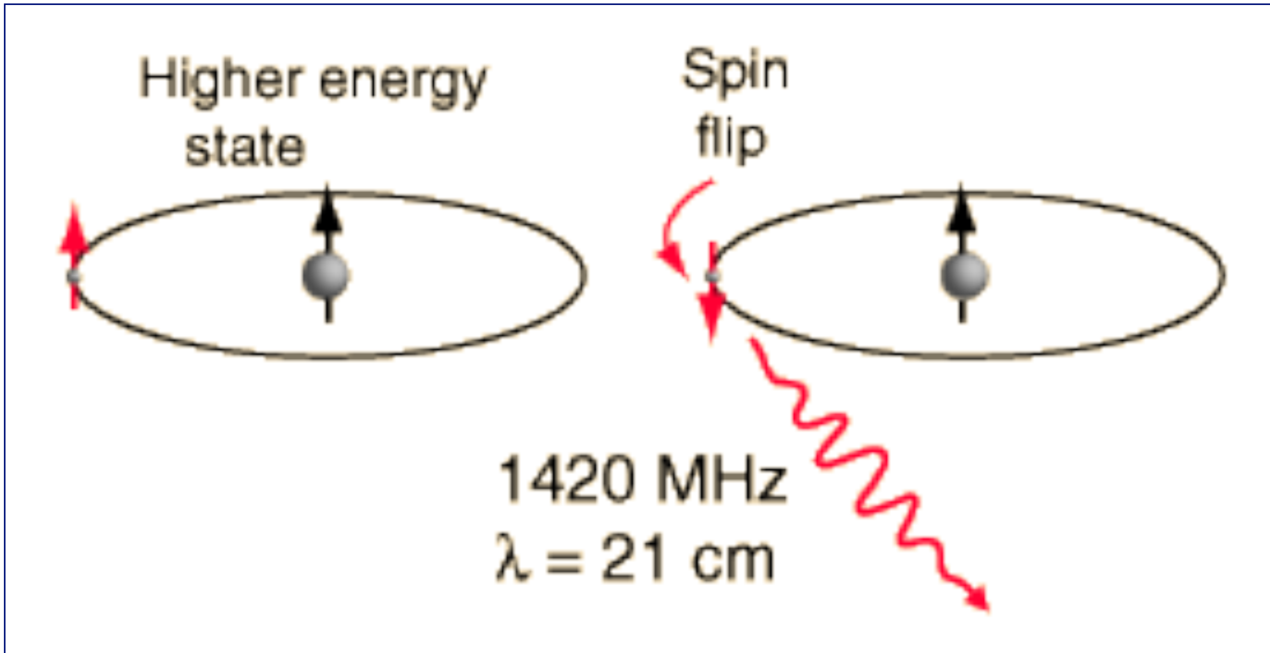


Hydrogen Hyperfine Splitting



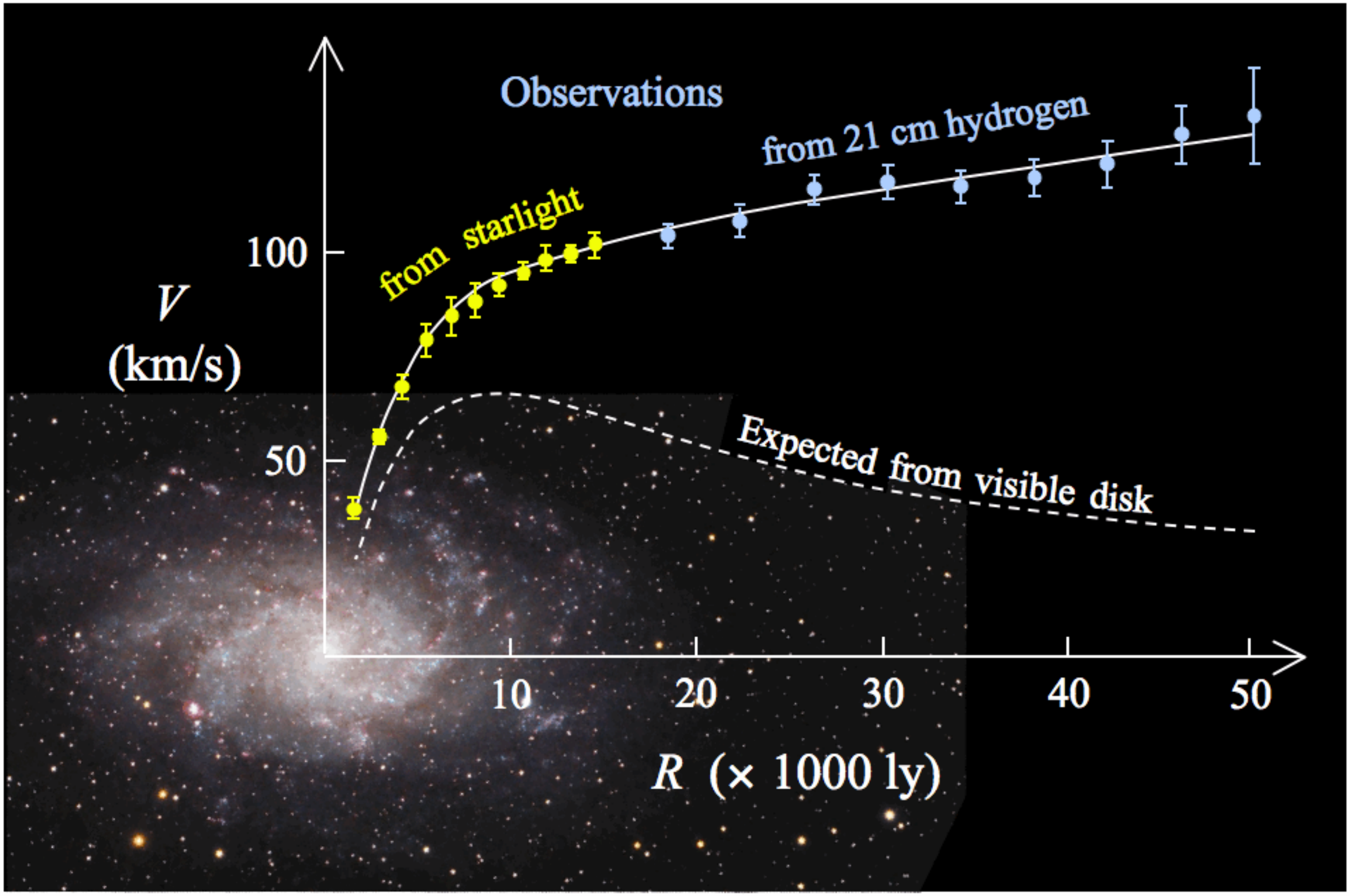


Hydrogen Hyperfine Splitting



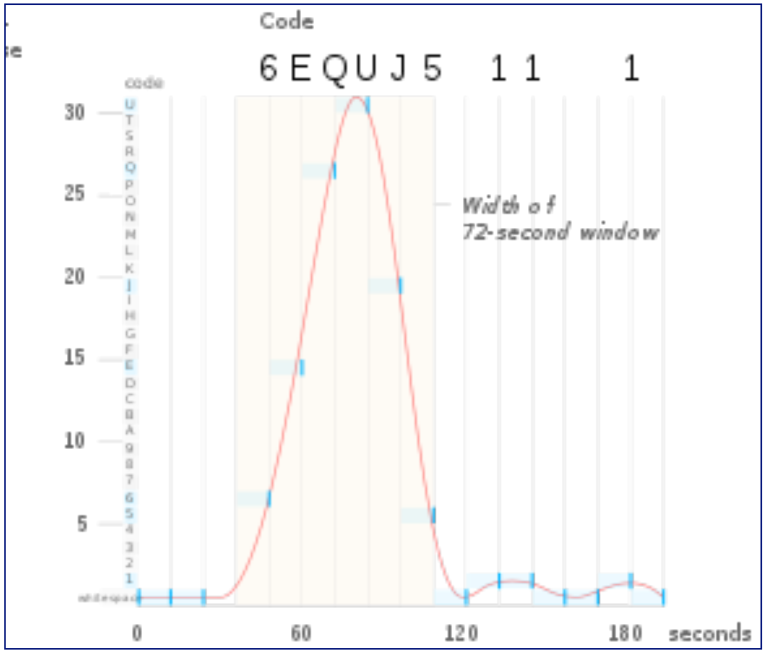
Discovery of 21 cm line → birth of radio astronomy

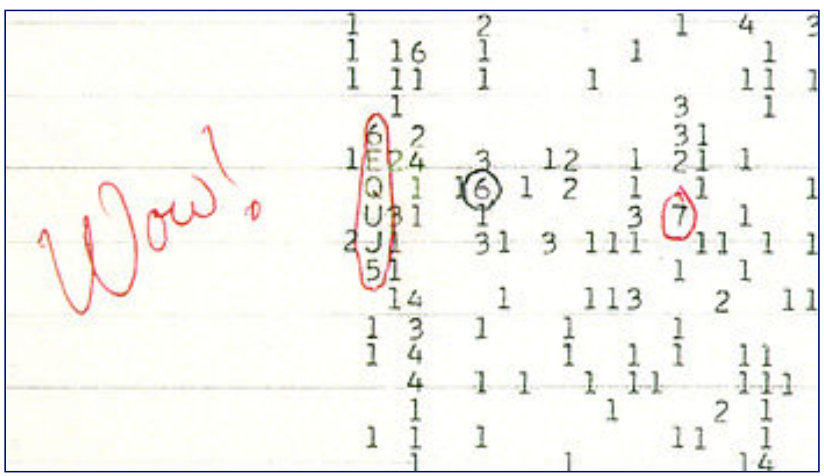
Hydrogen Hyperfine Splitting



First evidence for existence of dark matter

SETI Applications





The "WOW" 21 cm Signal

August 15, 1977

Ohio State Big Ear Radio Telescope

72 second blast of 21 cm radiation

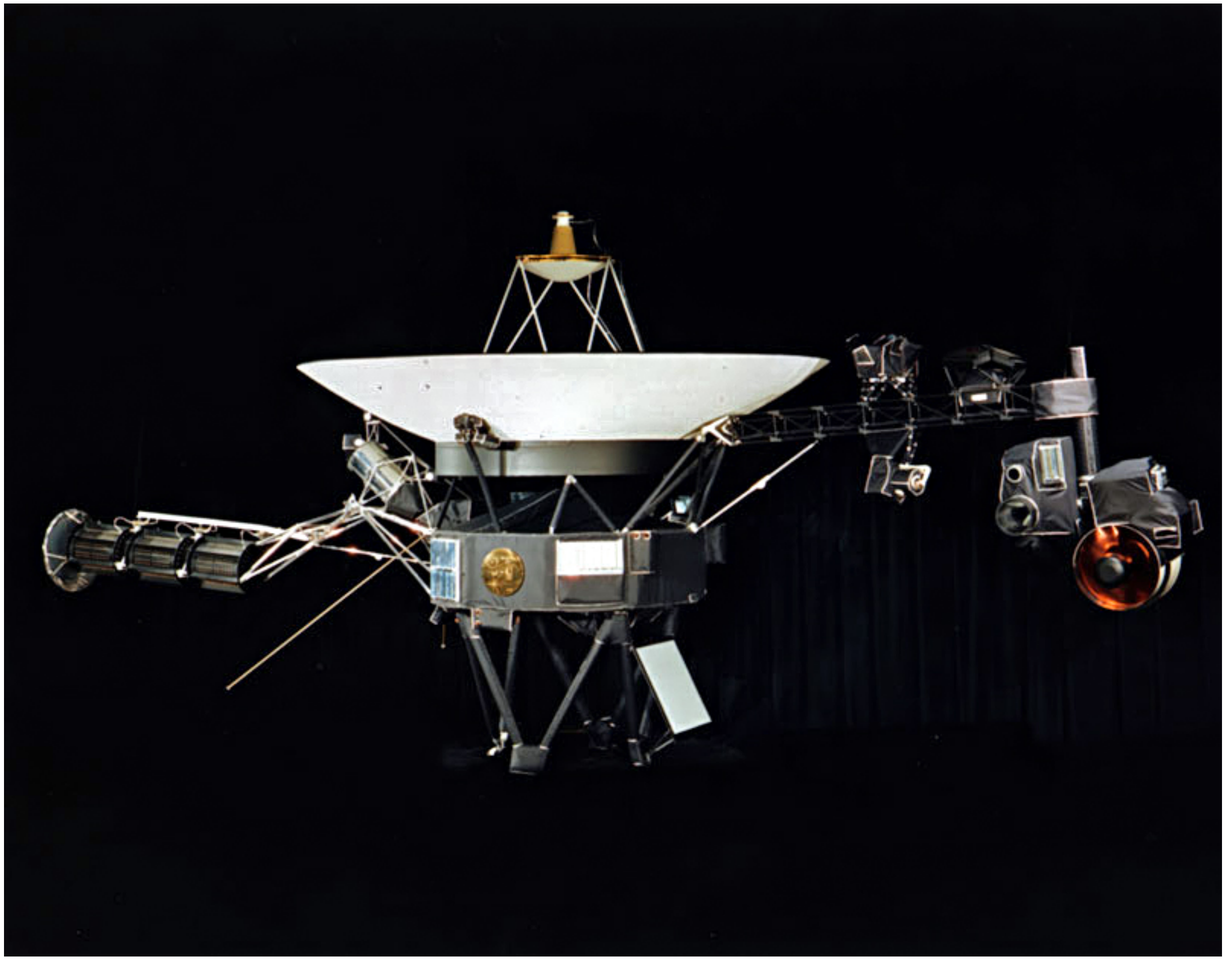
30X Background (SNR)

Constellation Sagittarius

Strongest candidate for SETI to date

Never Repeated ☹

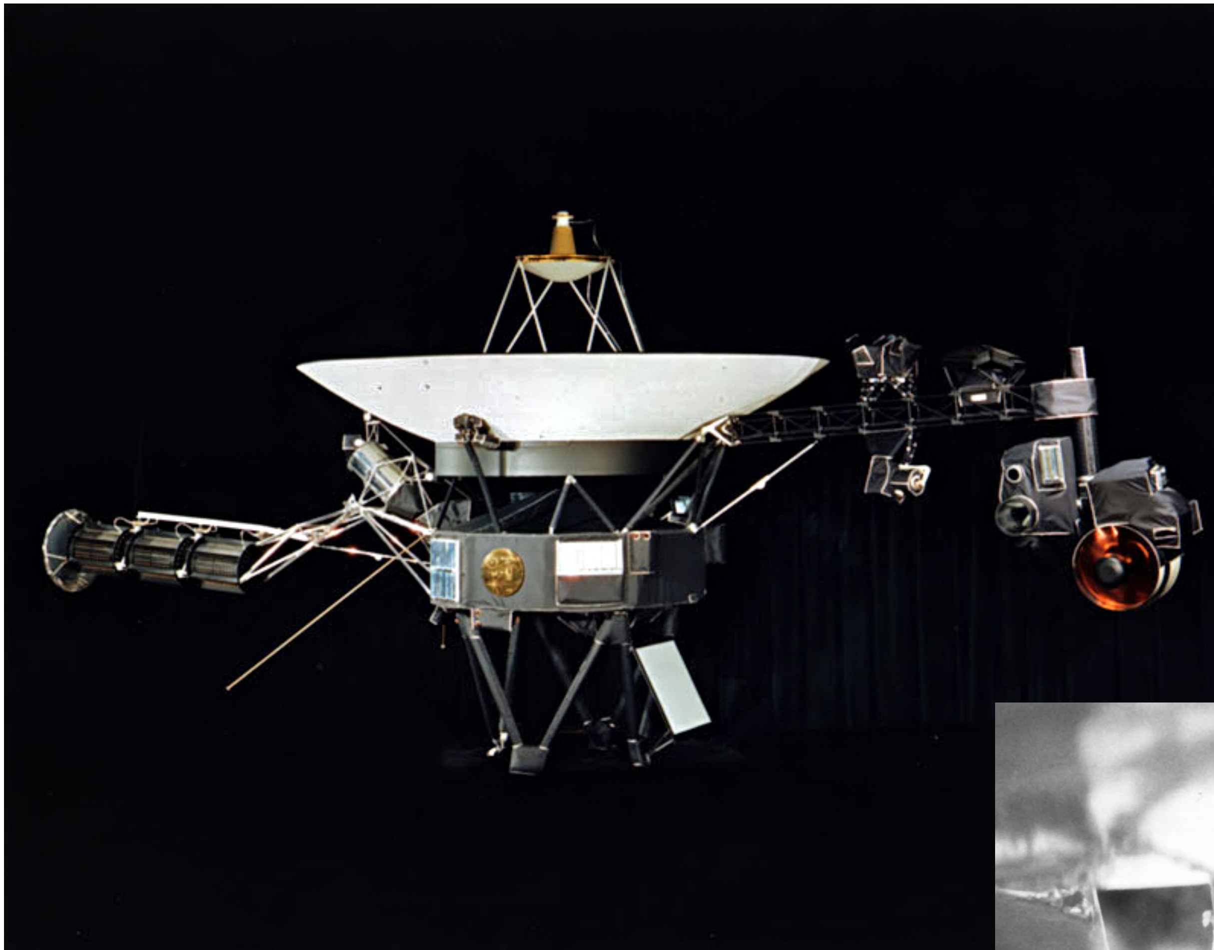
Hydrogen Hyperfine Splitting



Pioneer 10, 1972
Pioneer 11, 1973
Voyager, 1977

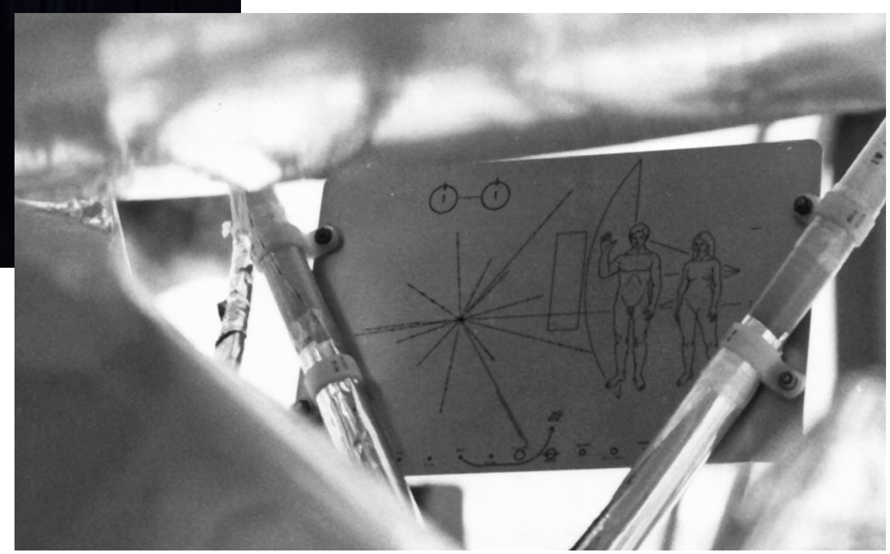
1st human objects
to exit the solar system

Hydrogen Hyperfine Splitting

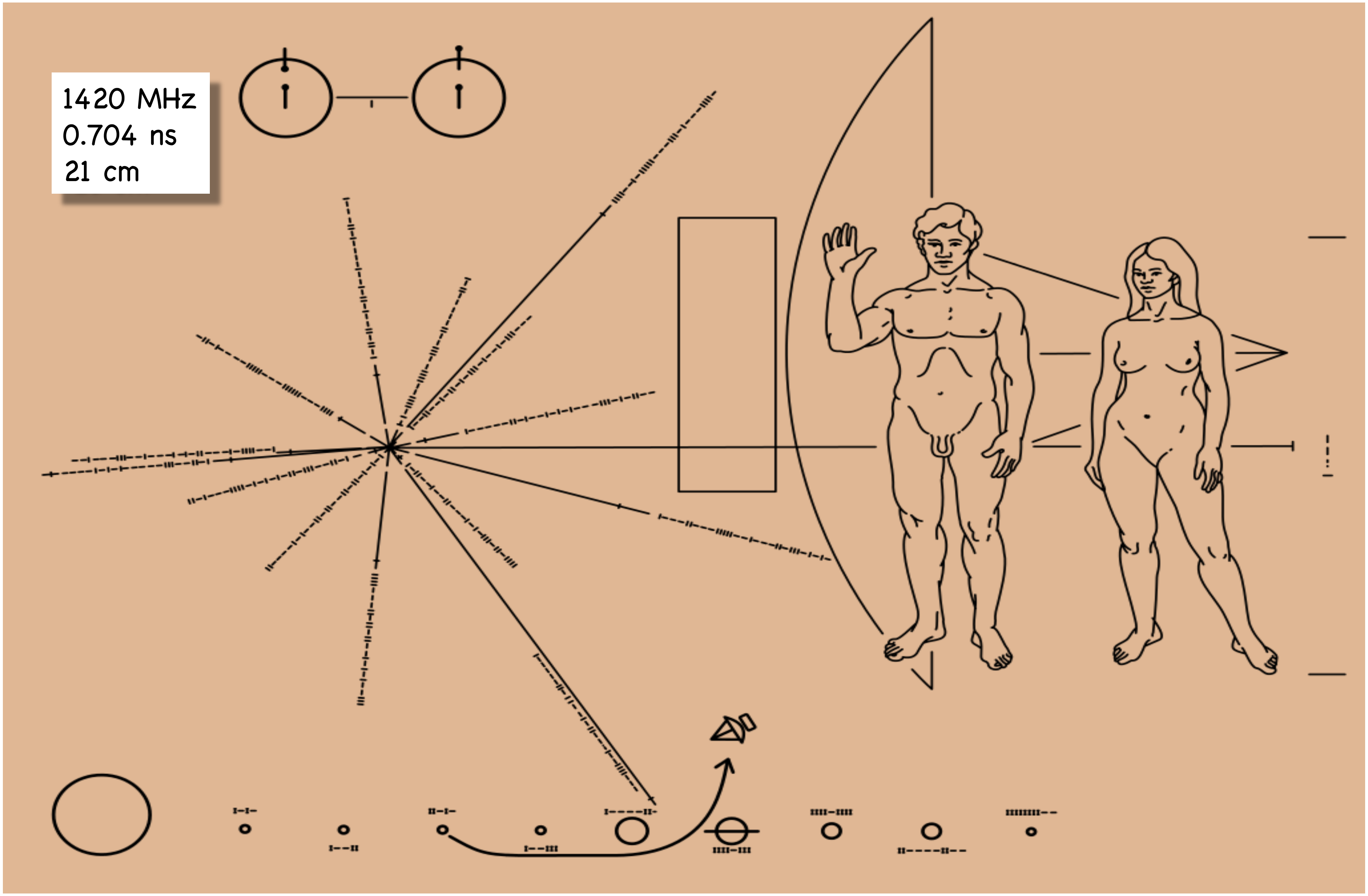


Pioneer 10, 1972
Pioneer 11, 1973
Voyager, 1977

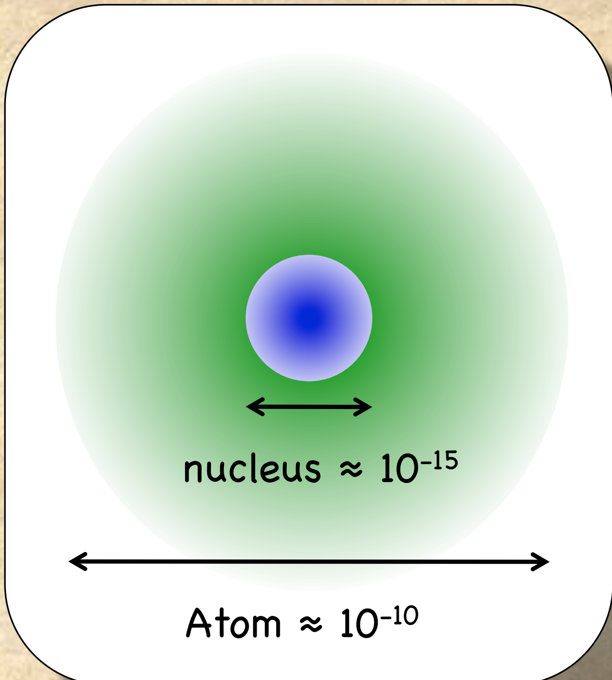
1st human objects
to exit the solar system



Hydrogen Hyperfine Splitting



Applications to Bound State Q.E.D.

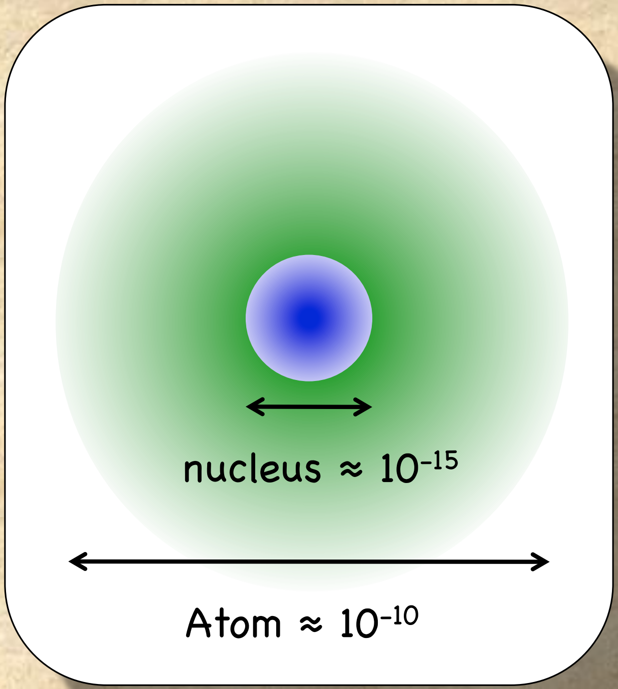


The finite size of the nucleus plays a small but significant role in atomic energy levels.

Hydrogen HF Splitting

$$\Delta E = 1420.405\,751\,766\,7(9) \text{ MHz}$$
$$= (1+\delta)E_F$$

Applications to Bound State Q.E.D.



Hydrogen HF Splitting

$$\Delta E = 1420.405\,751\,766\,7(9) \text{ MHz} = (1+\delta)E_F$$

$$\delta = (\delta_{QED} + \delta_R + \delta_{small}) + \Delta_S$$

The finite size of the nucleus plays a small but significant role in atomic energy levels.

Friar & Sick PLB **579** 285(2003)

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

Elastic Scattering

Δ_Z=-41.0±0.5ppm

$$\Delta_Z = -2\alpha m_e r_Z (1 + \delta_Z^{\text{rad}})$$

$$r_Z = -\frac{4}{\pi} \int_0^\infty \frac{dQ}{Q^2} \left[G_E(Q^2) \frac{G_M(Q^2)}{1 + \kappa_p} - 1 \right]$$

Structure dependence of Hydrogen HF Splitting

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

inelastic

Nazaryan,Carlson,Griffieon
PRL **96** 163001 (2006)

Δ_Z=-41.0±0.5ppm

$\Delta_{pol} \approx 1.3 \pm 0.3$ ppm

Elastic piece larger but with similar uncertainty

$$\Delta_{POL} = 0.2265 \quad (\Delta_1 + \Delta_2)\text{ppm}$$

integral of g_1 & F_1

pretty well determined from JLab data

Structure dependence of Hydrogen HF Splitting

$$\Delta_S = \Delta_Z + \Delta_{POL}$$

inelastic

Nazaryan,Carlson,Griffieon
PRL **96** 163001 (2006)

$\Delta_{pol} \approx 1.3 \pm 0.3$ ppm

Elastic piece larger but with similar uncertainty

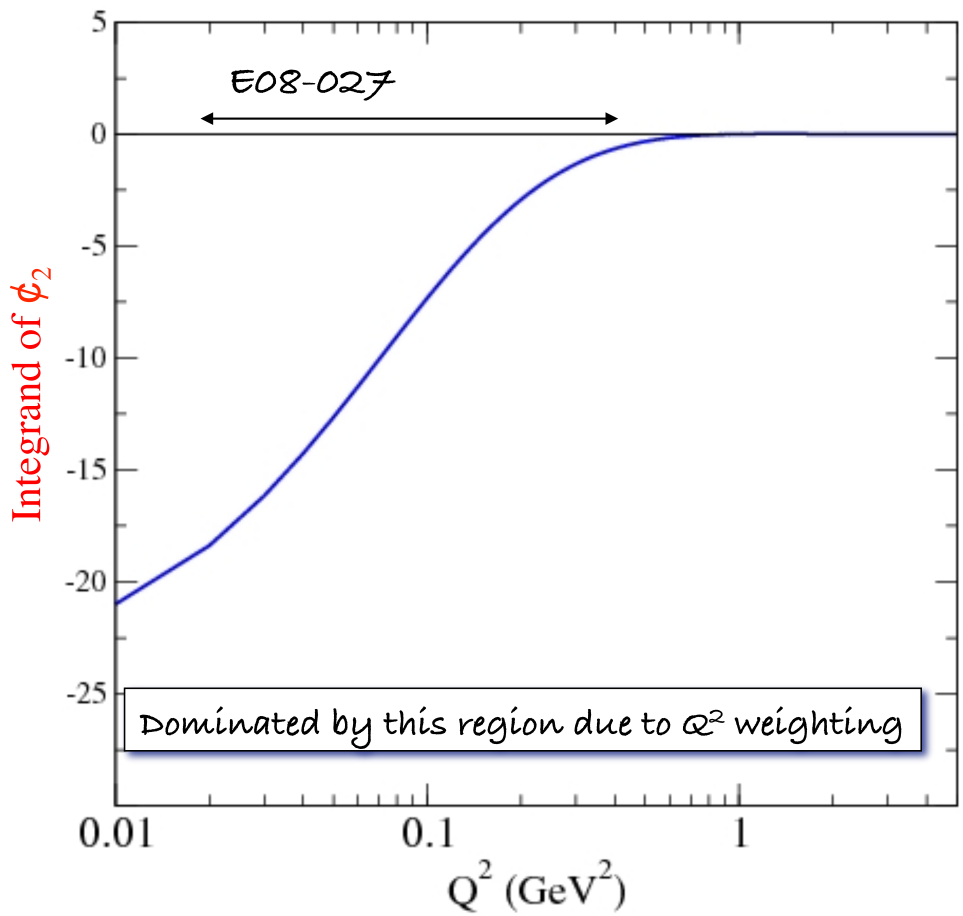
$$\Delta_{POL} = 0.2265 \quad (\Delta_1 + \Delta_2)\text{ppm}$$

$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$B_2(Q^2) = \int_0^{x_{th}} dx \beta_2(\tau) g_2(x, Q^2)$$

weighted heavily to low Q^2

Hydrogen Hyperfine Structure

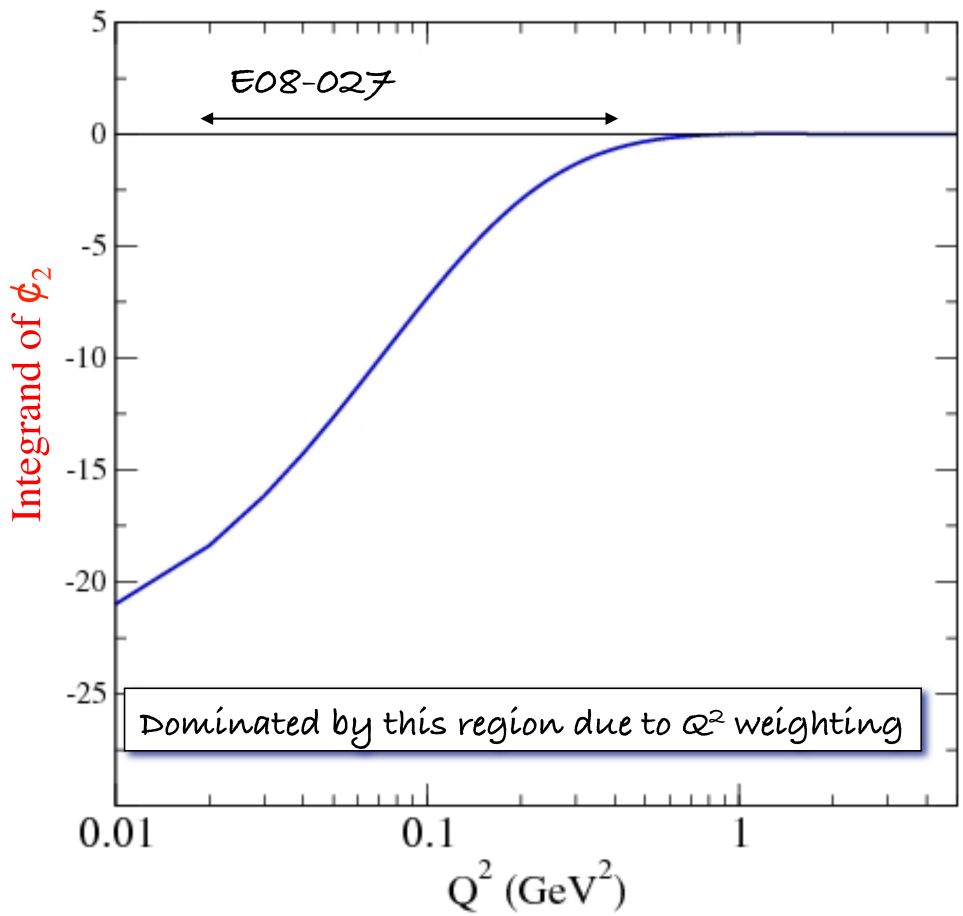


$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$= -0.57 \pm 0.57$$

assuming CLAS model with 100% error

Hydrogen Hyperfine Structure



$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$= -0.57 \pm 0.57$$

assuming CLAS model with 100% error

But, g_2^p unknown in this region:

$$\Delta_2 = -1.98 \quad \text{MAID Model}$$

$$\Delta_2 = -1.86 \quad \text{Simula Model}$$

So 100% error probably too optimistic

E08-027 will provide first real constraint on Δ_2

g1p contribution to the Hyperfine Splitting

Reminder of the integration:

$$\Delta_1 = \frac{9}{4}\int_0^\infty \frac{\mathrm{d}Q^2}{Q^2}\left[\left(\frac{G_M(Q^2)+G_E^2(Q^2)}{1+\tau}\right)^2 + \frac{8m_p^2}{Q^2}B_1(Q^2)\right]$$

- Use E08-027 data point to extend Q^2 range of CLAS data

$$B_1(Q^2) = \int_0^{x_{\mathrm{th}}} \mathrm{d}x\beta_1(\tau)g_1(x,Q^2)$$

$$\beta_1(\tau) = \frac{4}{9}\Big(-3\tau + 2\tau^2 + 2(2-\tau)\sqrt{\tau(\tau+1}$$

- Very close to one so this is almost Γ_1 (Q^2)
  - Except with a large $1/Q^4$ weighting!

g1p contribution to the Hyperfine Splitting

Reminder of the integration:

$$\Delta_1 = \frac{9}{4}\int_0^\infty \frac{dQ^2}{Q^2}\left[\left(\frac{G_M(Q^2)+G_E^2(Q^2)}{1+\tau}\right)^2 + \frac{8m_p^2}{Q^2}B_1(Q^2)\right]$$

Fill in low Q^2 part with a linear fit

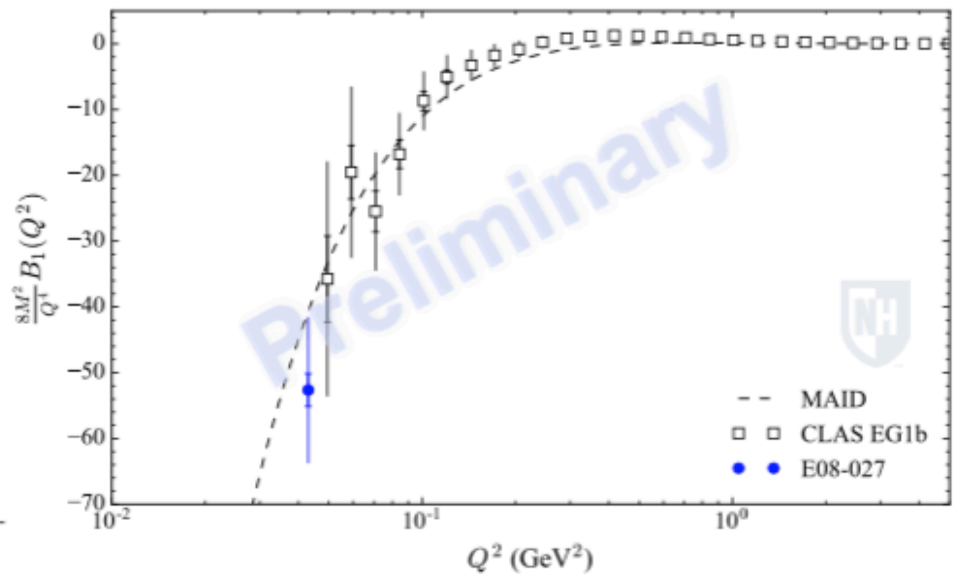
$$\Delta_1[0,Q_i^2] = \left(-\frac{3}{4}\kappa_p^2 r_p^2 + 18M^2 c_1\right)Q_i^2$$

charge radius

fit constant

Results (use model for high Q^2):

Term	Q^2 (GeV^2)	Contribution	Result	Stat	Sys
Δ_1	(0,0.043)	F_2 and g_1	1.28	0.20	0.83
	(0.043,5.0)	F_2	7.65	–	0.45
	(0.043,5.0)	g_1	−0.77	0.22	2.46
	(5.0,∞)	F_2	0.00	–	–
	(5.0,∞)	g_1	0.45	–	0.45
Total Δ_1			8.63	0.30	4.19



Compares favorably with published results

$$\Delta_1 = 8.85 \pm 0.30\ (\text{stat}) \pm 3.57^{10}\ (\text{sys})$$

Phys.Rev.A.78.022517

courtesy R. Zielinski, UNH

g_2 contribution to the Hyperfine Splitting

$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$B_2(Q^2) = \int_0^{x_{th}} dx \beta_2(\tau) g_2(x, Q^2)$$

$$\beta_2(\tau) = 1 + 2\tau - 2\sqrt{\tau(\tau+1)}$$

- Dev. from leading twist expected
- Agreement within uncertainty to two models

g_2 contribution to the Hyperfine Splitting

$$\Delta_2 = -24 m_p^2 \int_0^\infty \frac{dQ^2}{Q^4} B_2(Q^2)$$

$$B_2(Q^2) = \int_0^{x_{th}} dx \beta_2(\tau) g_2(x, Q^2)$$

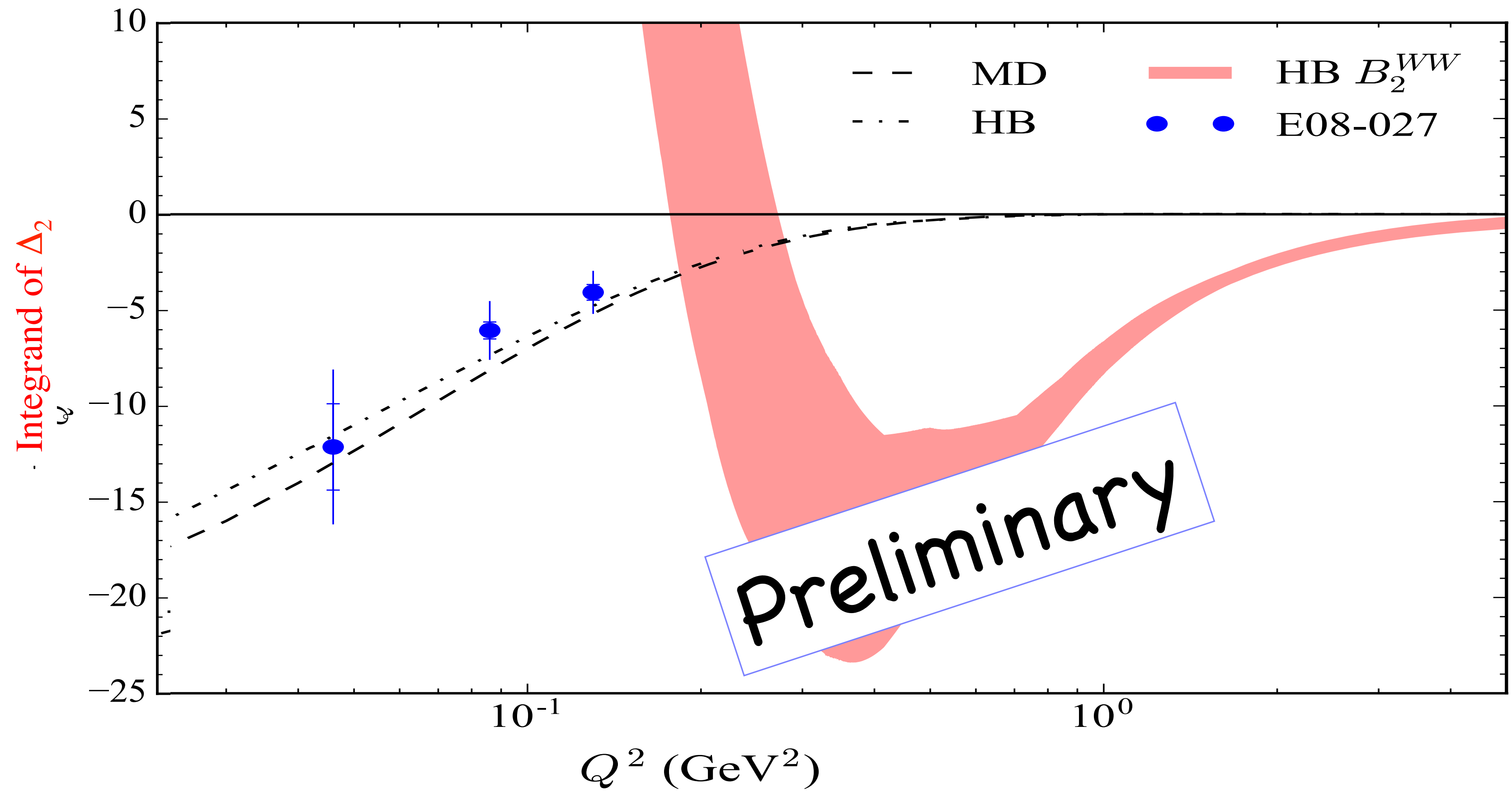
$$\beta_2(\tau) = 1 + 2\tau - 2\sqrt{\tau(\tau+1)}$$

- How do new models compare with previous publications?

Term	Q^2 (GeV^2)	MAID	Hall B	HB 2007
Δ_2	(0,0.05)	-0.87	−0.80	−0.23
	(0.05,20)	−1.26	−1.16	−0.33
	(20,∞)	0.00	0.00	0.00
Total Δ_2		−2.13	−1.96	−0.56

Phys.Rev.A.78.022517

g_2 contribution to Hyperfine Structure



good agreement with the MAID and *most recent* Hall B models

200% difference from Hall B 2007 model used in PRA78, 02251

E08-027 Summary

1) E08-027 was precision measurement of the proton structure functions at low Q^2

2) Longitudinal Data agrees with Hall B (mostly).
   Pushes the Q^2, slightly lower

3) δ_{LT} favors Lensky et al (BχPT)

4) Hyperfine splitting contributions from g_2 are very different from previous model based predictions.

5) Large Q^2 data finalized.
   Low Q^2 data we are still working on PF systematics.

Tensor Program

Jefferson Lab

UNIVERSITY OF VIRGINIA 1819

E12-13-011: "The b_1 experiment"

30 Days in Jlab Hall C
A- Physics Rating
Conditional Approval (Target Performance)

Contact : K. Slifer, UNH

E12-15-005: "A_{zz} for $x>1$"

44 Days in Jlab Hall C
A- Physics Rating
Conditional Approval (Target Performance)

Contact : E. Long, UNH

b_1 Structure Function

$$b_1(x) = \frac{q^0(x) - q^1(x)}{2}$$

measured in DIS (so probing quarks), but depends solely on the deuteron spin state

Investigate nuclear effects at the level of partons!

q^0 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

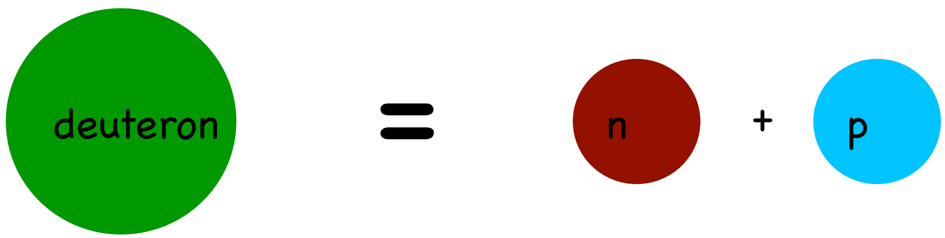
q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

b_1 Structure Function

Hoodbhoy, Jaffe and Manohar (1989)

b_1 vanishes in the absence of nuclear effects

i.e. if...



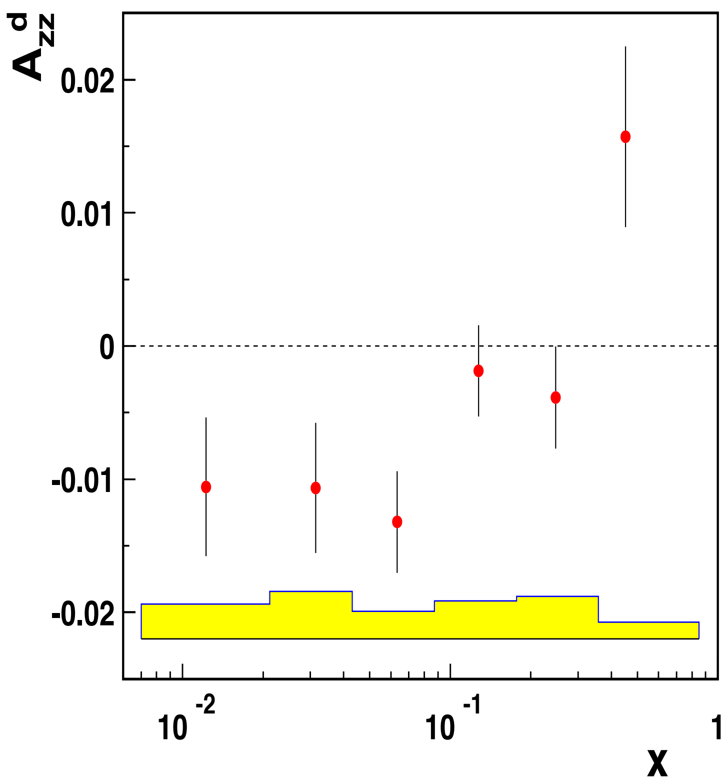
Proton Neutron in relative S-state

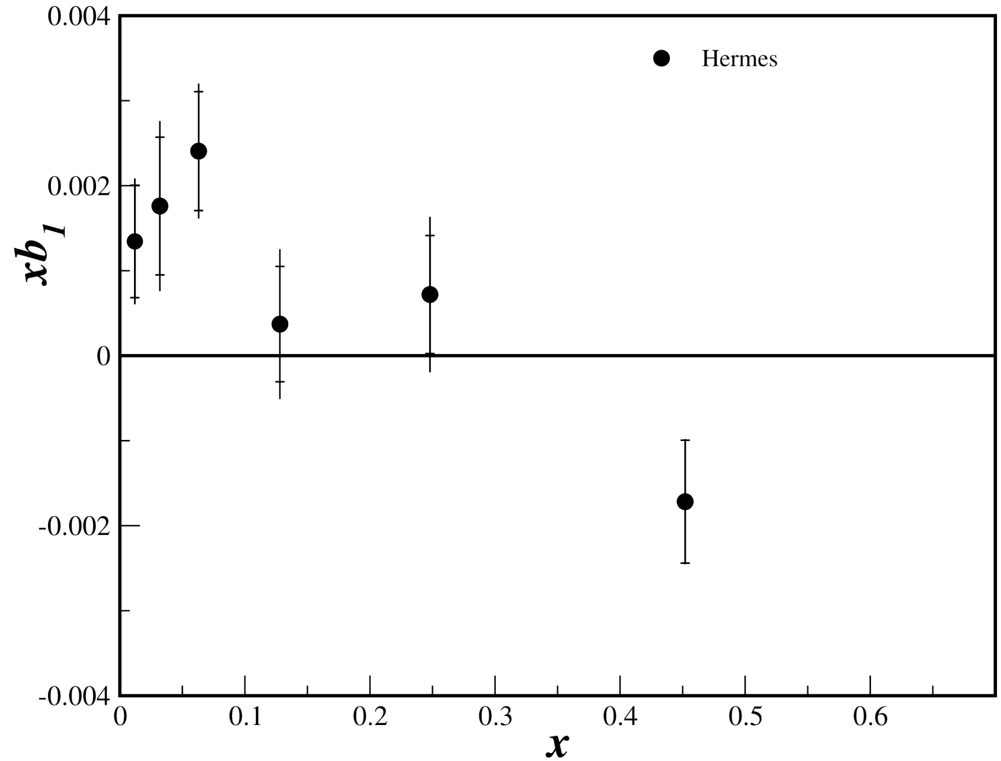
Even accounting for D-State admixture b_1 expected to be vanishingly small

Khan & Hoodbhoy, PRC 44 ,1219 (1991) : $b_1 \approx O(10^{-4})$
Relativistic convolution model with binding

Umnikov, PLB 391, 177 (1997) : $b_1 \approx O(10^{-3})$
Relativistic convolution with Bethe-Salpeter formalism

Data from HERMES

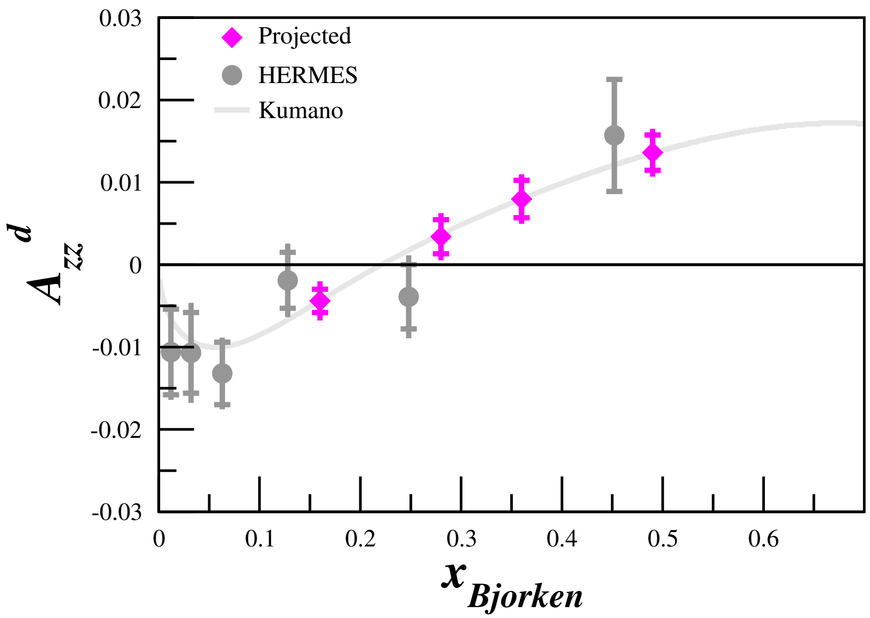




$$b_1 = -\frac{3}{2} F_1 A_{zz}$$

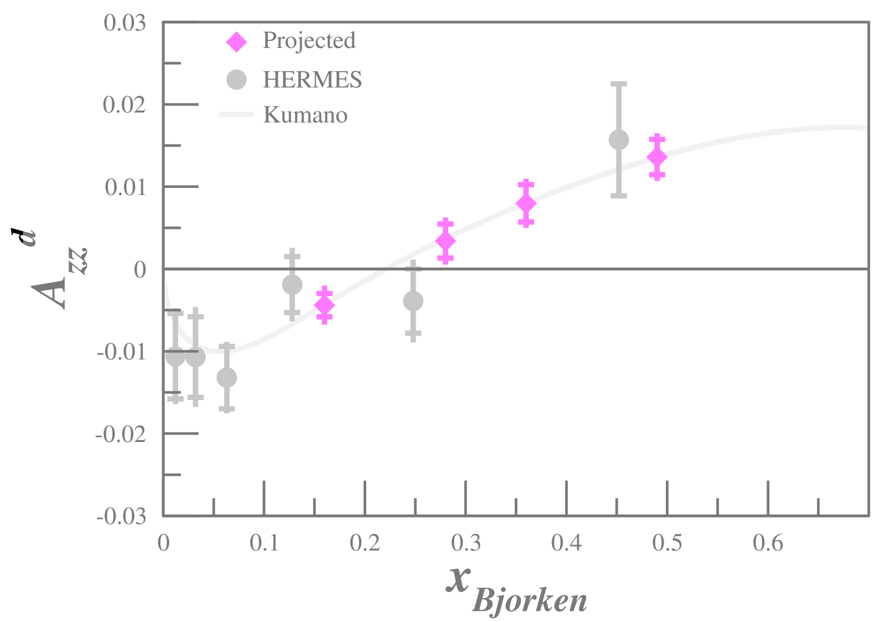
C. Reidl PRL **95,** 242001 (2005)

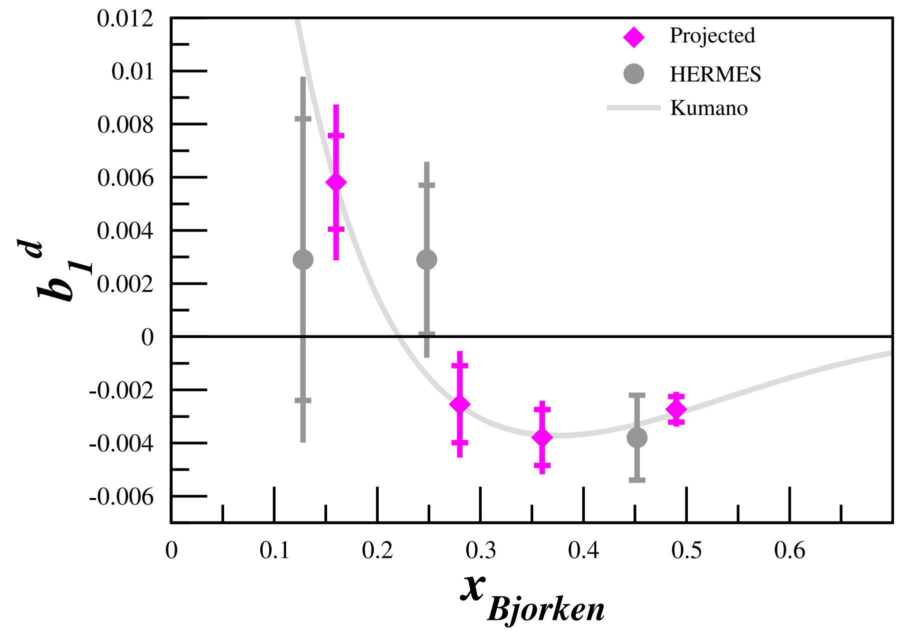
Projected Results for P_{zz} = 35%



30 Days in Jlab Hall C

Projected Results for P_{zz} = 35%





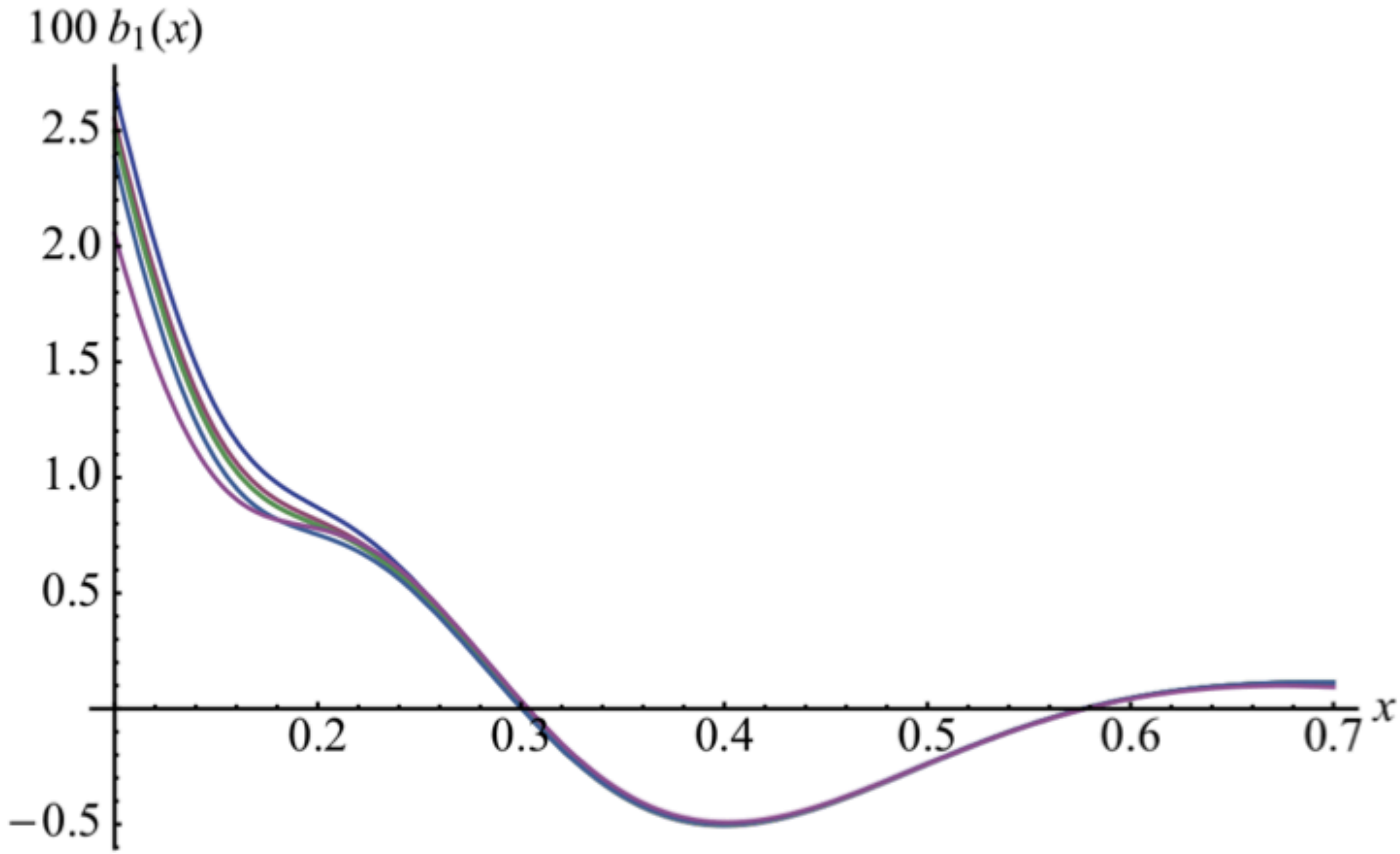
30 Days in Jlab Hall C

verification of zero crossing
essential for satisfaction of CK Sum

6-quark, Hidden Color

G. Miller **PRC89 (2014) 045203**

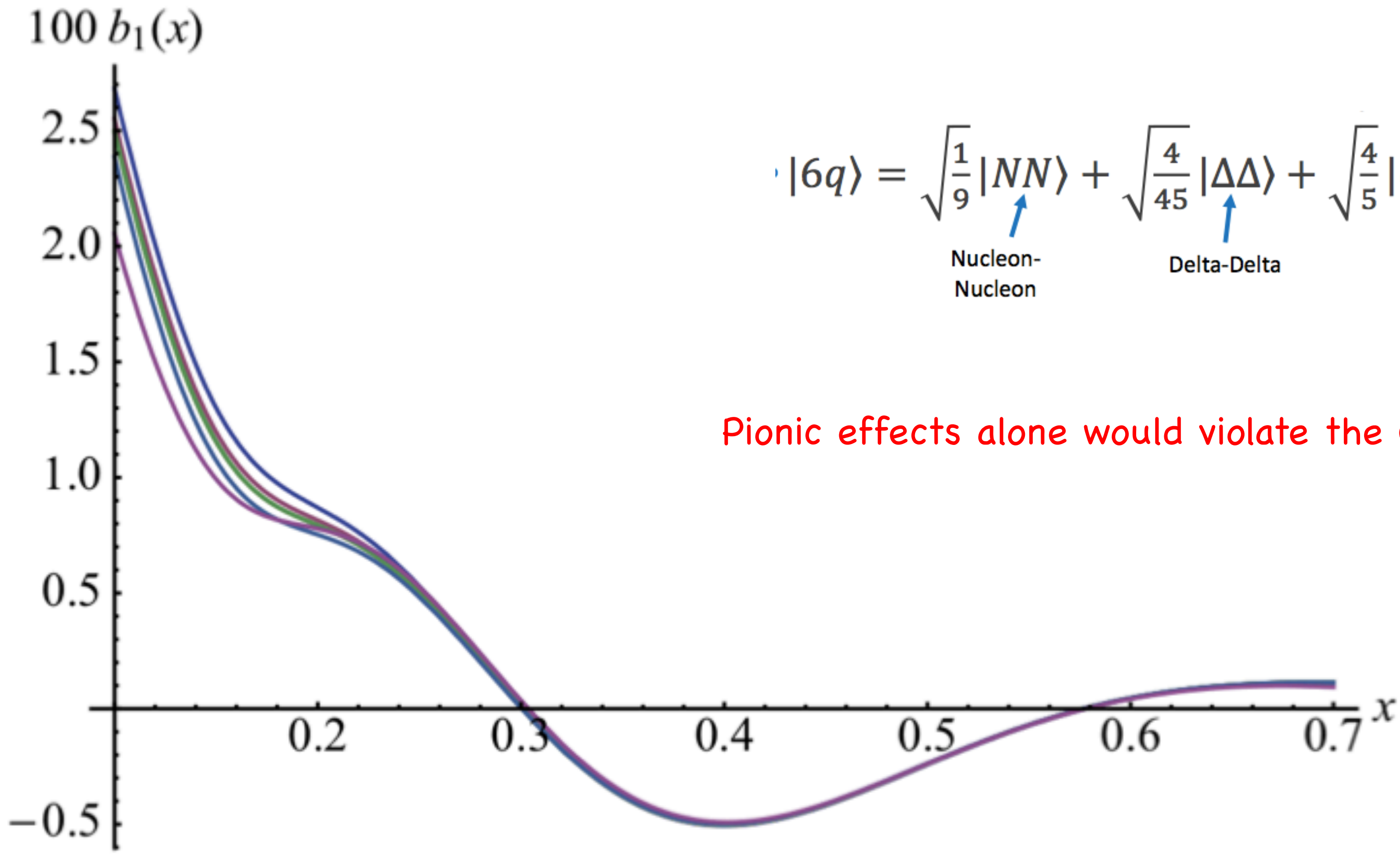
"Pionic and Hidden-Color, Six-Quark Contributions to the Deuteron **b1** Structure Function"



6-quark, Hidden Color

G. Miller **PRC89 (2014) 045203**

"Pionic and Hidden-Color, Six-Quark Contributions to the Deuteron **b1** Structure Function"



$$|6q\rangle = \sqrt{\frac{1}{9}}|NN\rangle + \sqrt{\frac{4}{45}}|\Delta\Delta\rangle + \sqrt{\frac{4}{5}}|CC\rangle$$

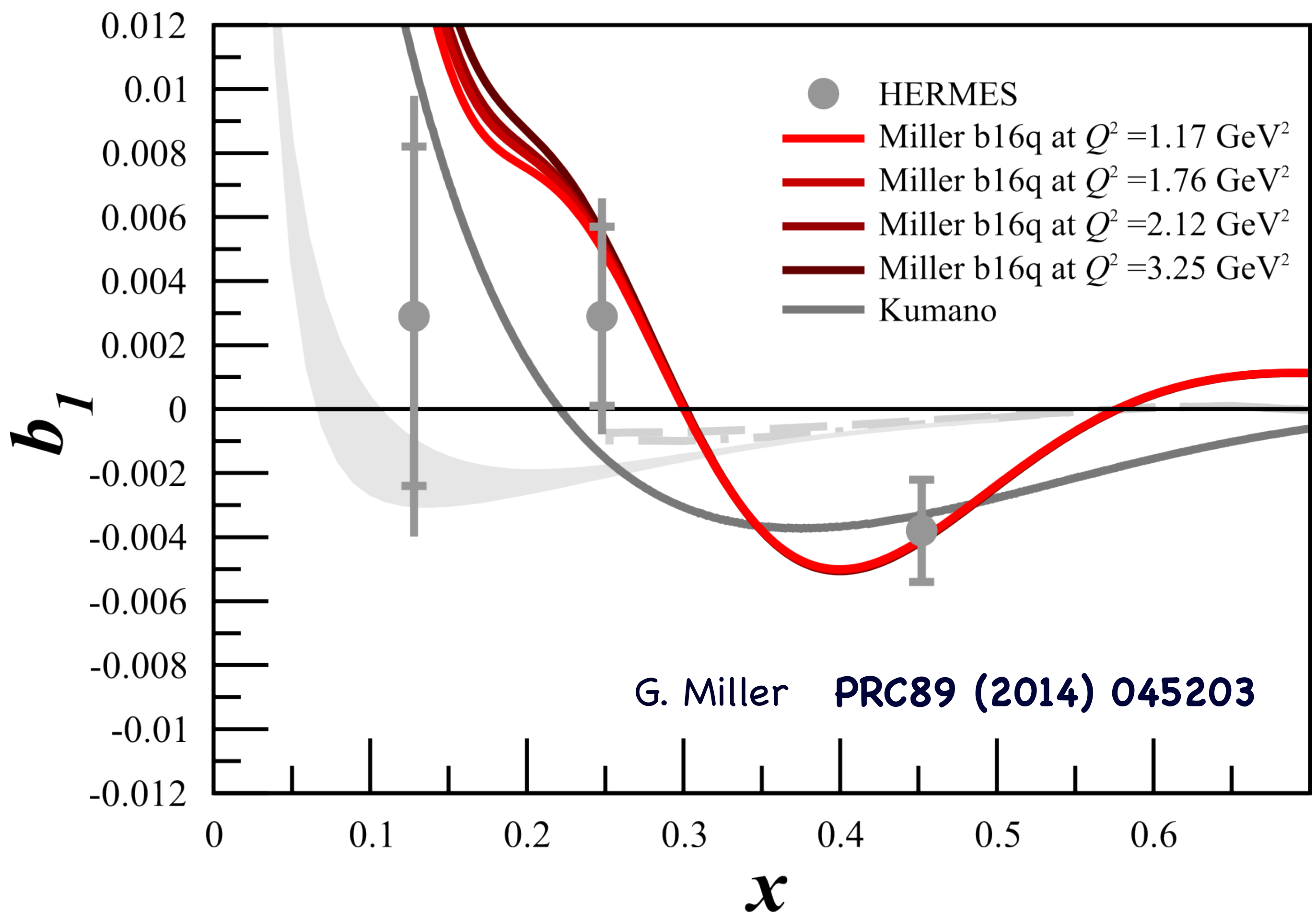
Nucleon-Nucleon

Delta-Delta

Hidden Color

Pionic effects alone would violate the Ck sum rule

Unique Signal of Hidden Color



no conventional nuclear mechanism can reproduce the Hermes data,

but that the 6-quark probability needed to do so (P_{6Q} = 0.0015) is small enough that it does not violate conventional nuclear physics.

Gluon Contribution to Tensor Structure

$$\int b_1(x)dx = 0$$

$$\int x b_1(x)dx = 0$$

Efremov and Teryaev (1982, 1999)

Gluons (spin 1) contribute to both moments

Quarks satisfy the first moment, but

Gluons may have a non-zero first moment!

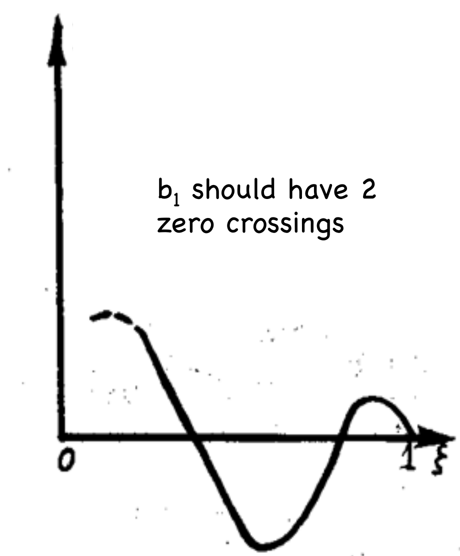


Рис.1

Efremov, Teryaev, JINR PreprintR2-81-857(1981), Yad. Phys. 36, 950 (1982)
A.V. Efremov, O. V. Teryaev JINR-E2-94-95 (1999)
Jaffe, Manohar Phys.Lett. B223 (1989) 218

Gluon Contribution to Tensor Structure

$$\int b_1(x)dx = 0$$

$$\int x b_1(x)dx = 0$$

Efremov and Teryaev (1982, 1999)

Gluons (spin 1) contribute to both moments

Quarks satisfy the first moment, but

Gluons may have a non-zero first moment!

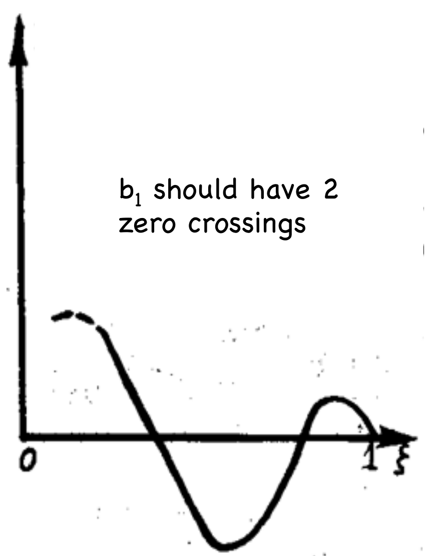


Рис.1

2^{nd} moment more likely to be satisfied experimentally since the collective glue is suppressed compared to the sea

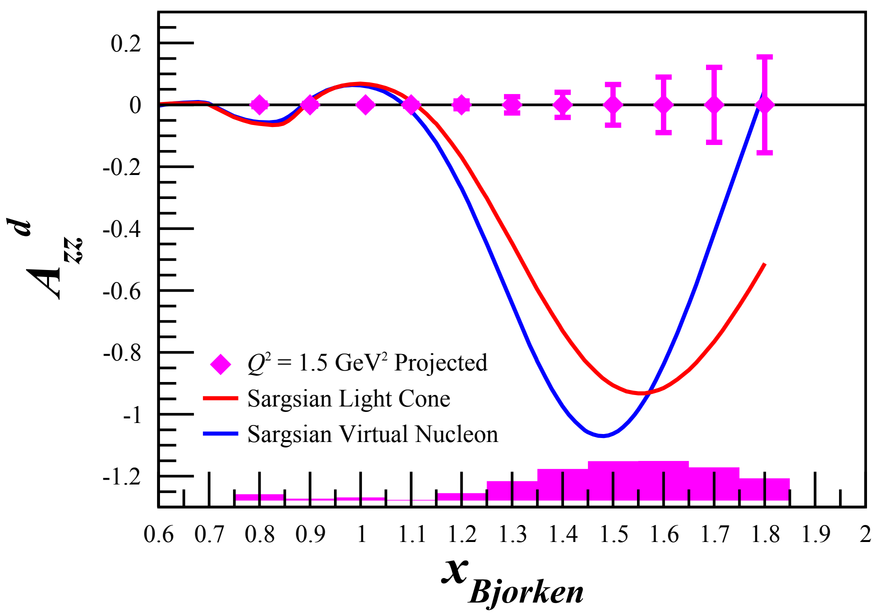
Study of b_1 allows to discriminate between deuteron components with different spins (quarks vs gluons)

Efremov, Teryaev, JINR PreprintR2-81-857(1981), Yad. Phys. 36, 950 (1982)
A.V. Efremov, O. V. Teryaev JINR-E2-94-95 (1999)
Jaffe, Manohar Phys.Lett. B223 (1989) 218

E12-15-005

A_{zz} in the x>1 Region

Ellie Long, Slifer, Solvignon,
Day, Higinbothan, Keller

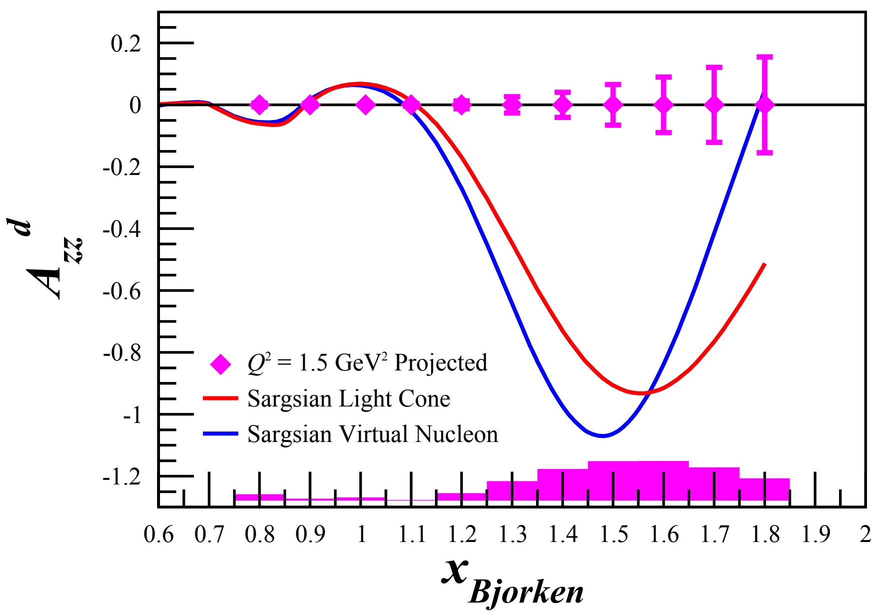


Very Large Tensor Asymmetries predicted

E12-15-005

A_{zz} in the x>1 Region

Ellie Long, Slifer, Solvignon,
Day, Higinbothan, Keller



Very Large Tensor Asymmetries predicted

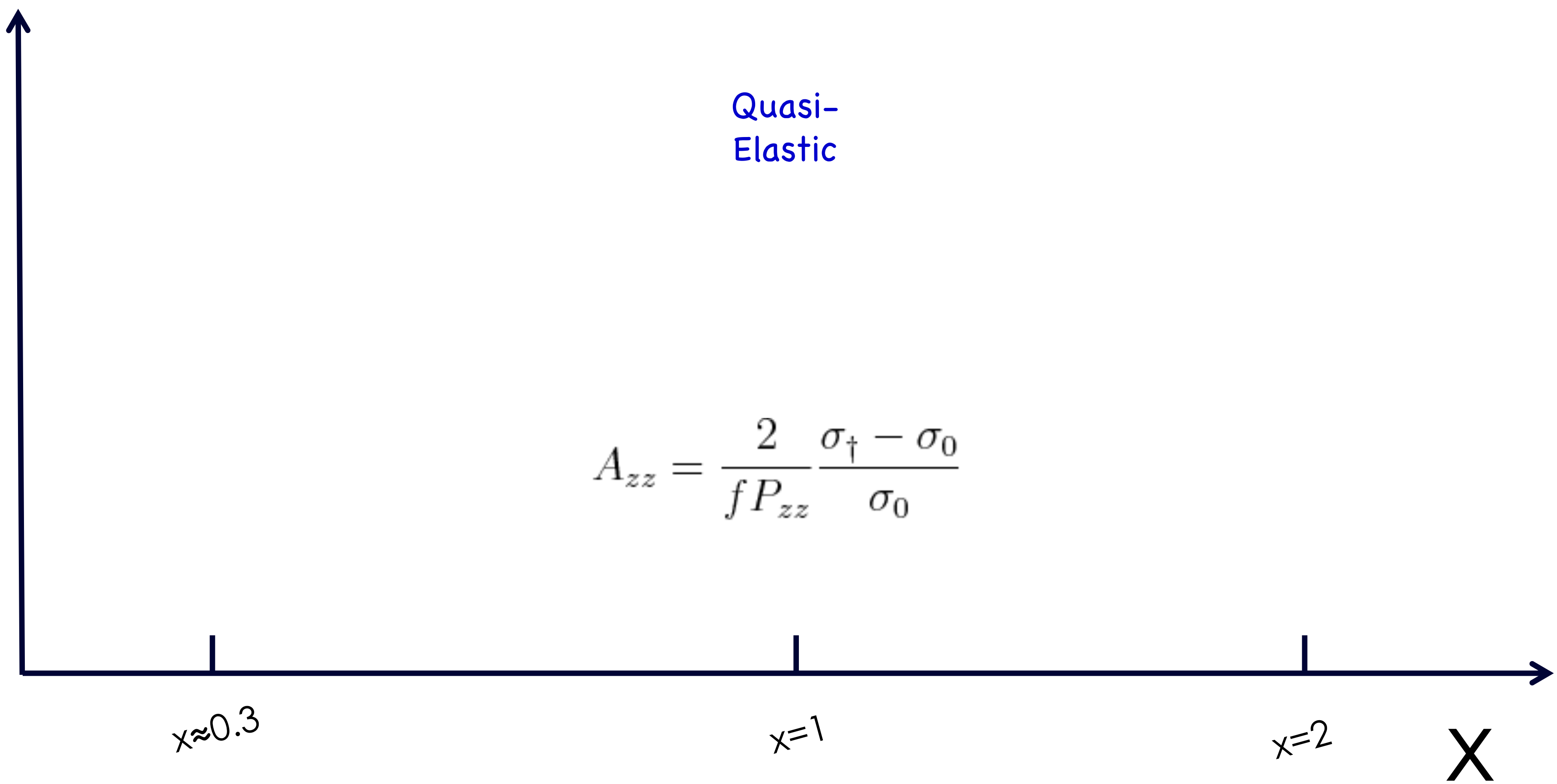
Sensitive to the S/D-wave ratio in the deuteron wave function

4σ discrim between hard/soft wave functions
6σ discrim between relativistic models

"further explores the nature of short-range pn correlations, the discovery of which was one of the most important results of the 6 GeV nuclear program."

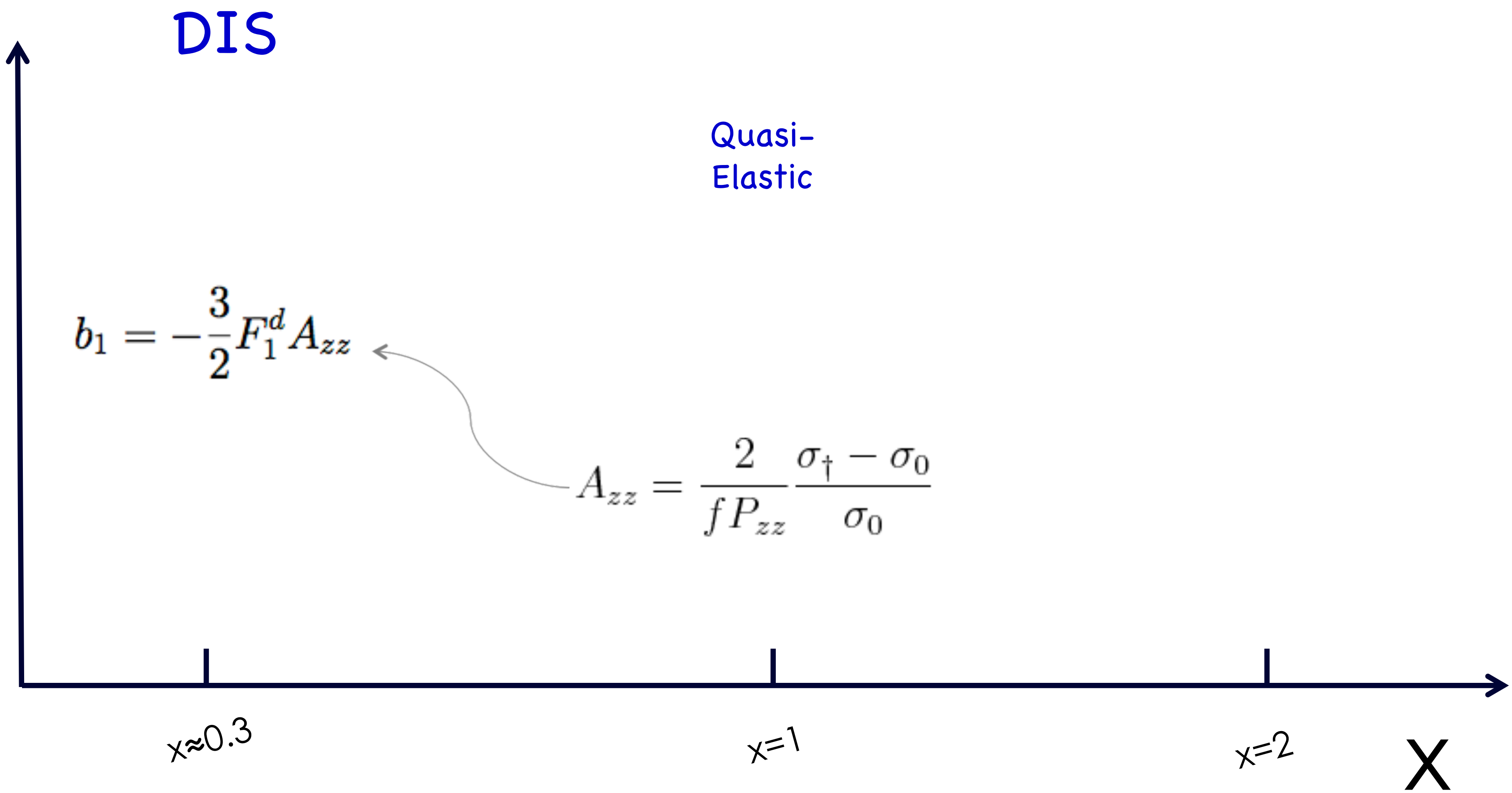
PAC44 Theory Report

Tensor Spin Observables



$$A_{zz} = \frac{2}{fP_{zz}} \frac{\sigma_{\dagger} - \sigma_0}{\sigma_0}$$

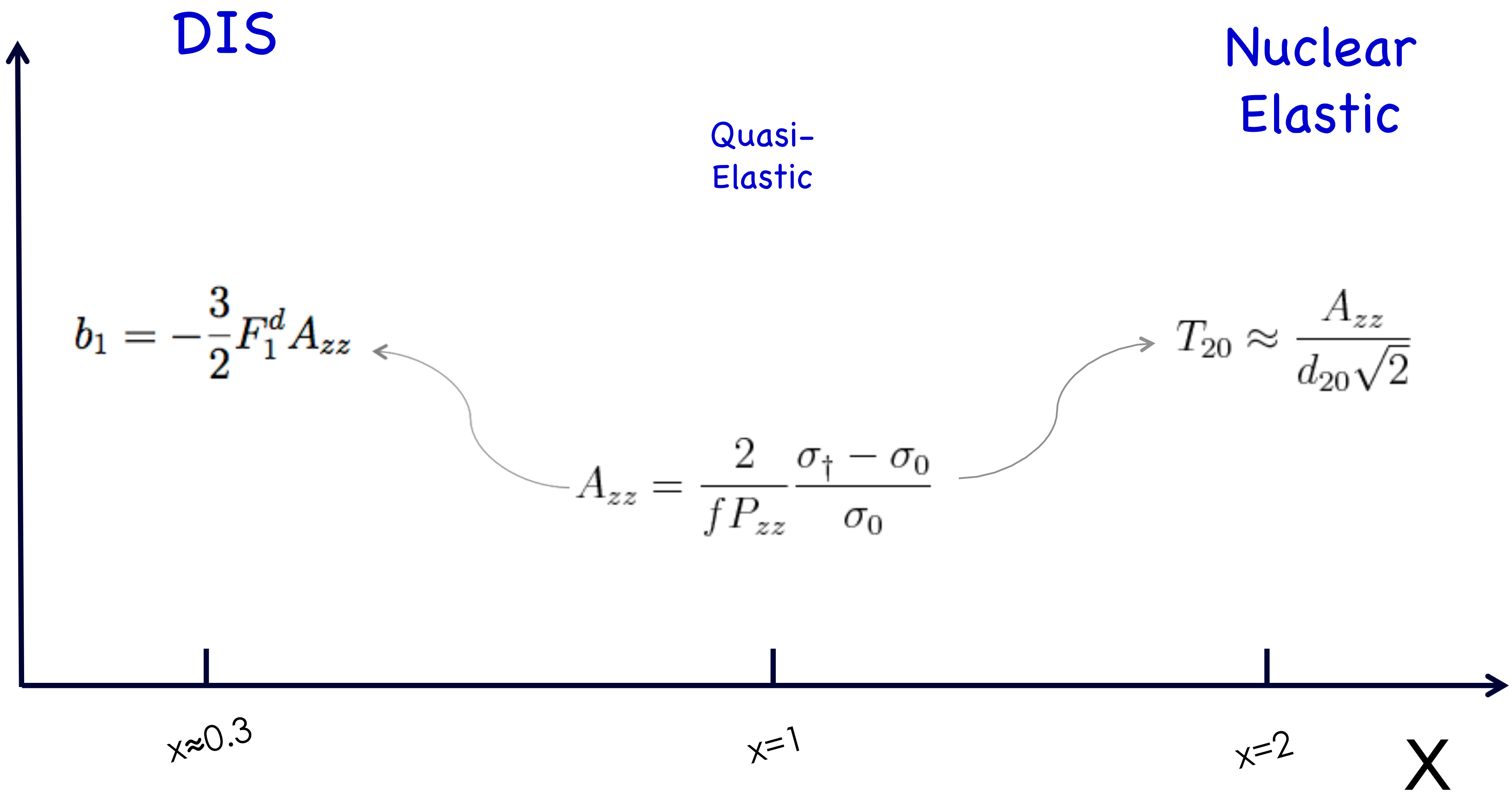
Tensor Spin Observables



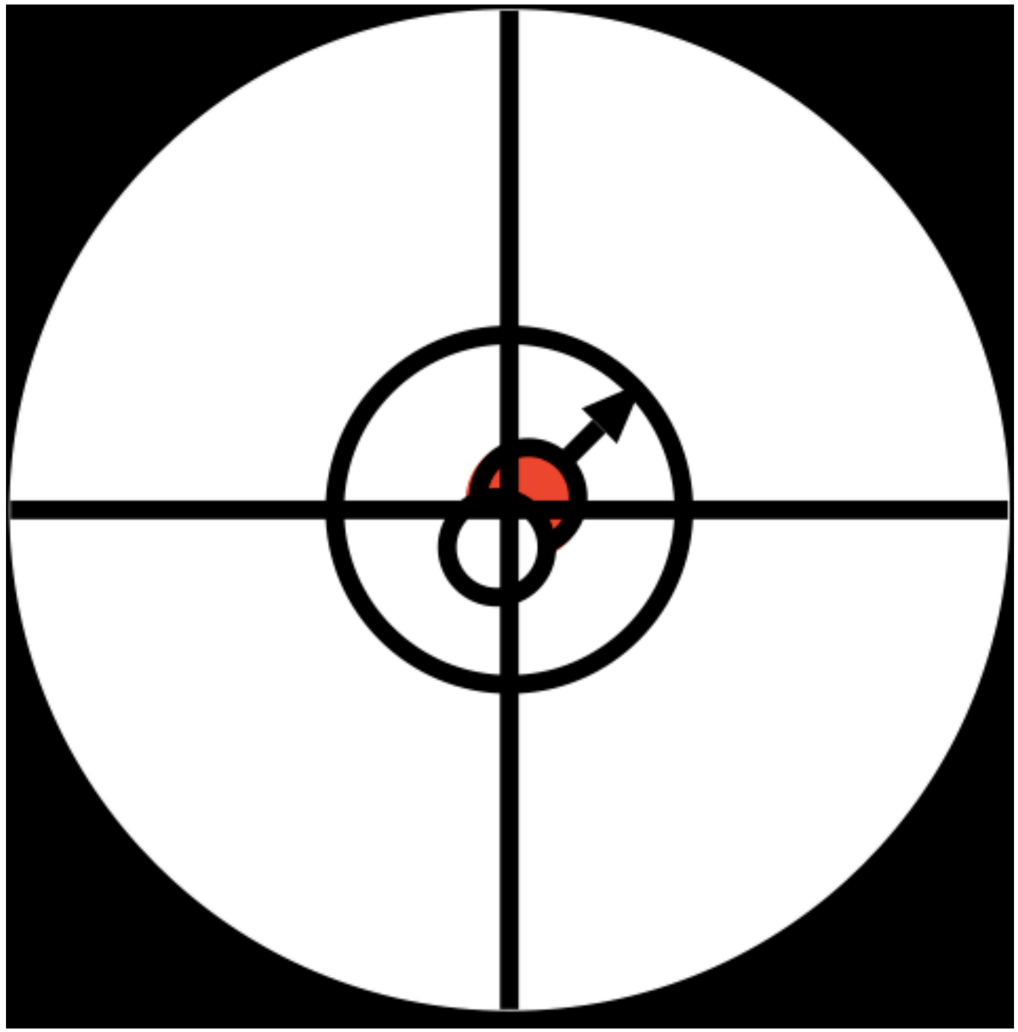
$$b_1 = -\frac{3}{2} F_1^d A_{zz}$$

$$A_{zz} = \frac{2}{f P_{zz}} \frac{\sigma_{\dagger} - \sigma_0}{\sigma_0}$$

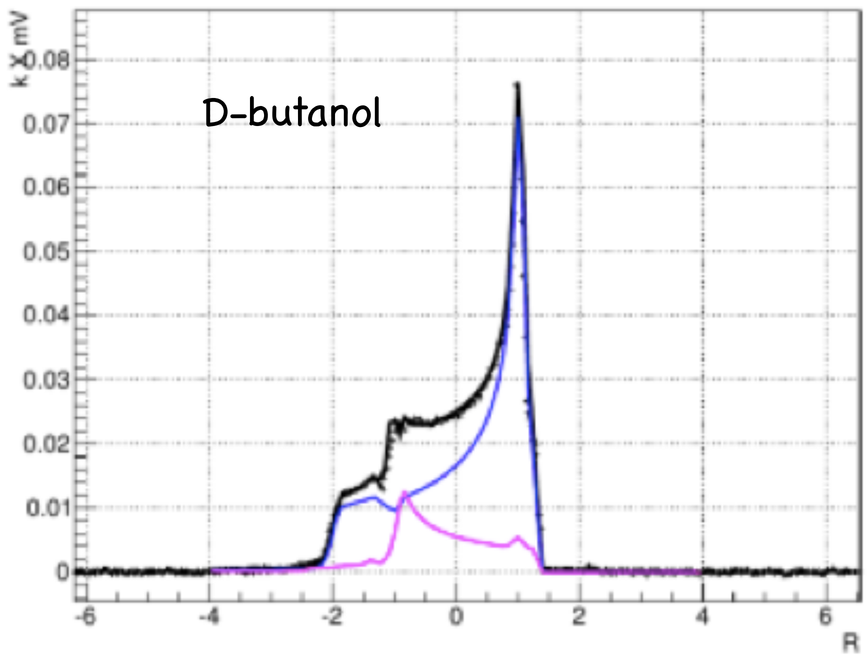
Tensor Spin Observables



Technical Developments



Tensor Polarized Target



MC overlap with d-but. NMR experimental points (Pn=51→45,Qn:20→31%)

Significant progress

Enhancing P_{zz} via semi-selective saturation

& understanding the NMR lineshape

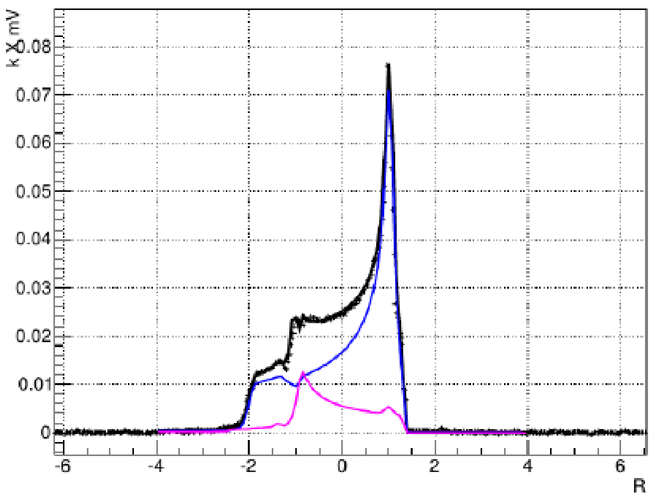
D Keller, Eur.Phys.J.A.,**53** no.7, 155 (2017)
D Keller, PoS, PSTP2015:014 (2016)
D Keller, J.Phys.Conf.Ser., **543**(1):012015 (2014)
D Keller, Int.J.Mod.Phys.Conf.Ser., **40**(1):1660105 (2016)

T_{20} measurement at Higs to verify NMR analysis

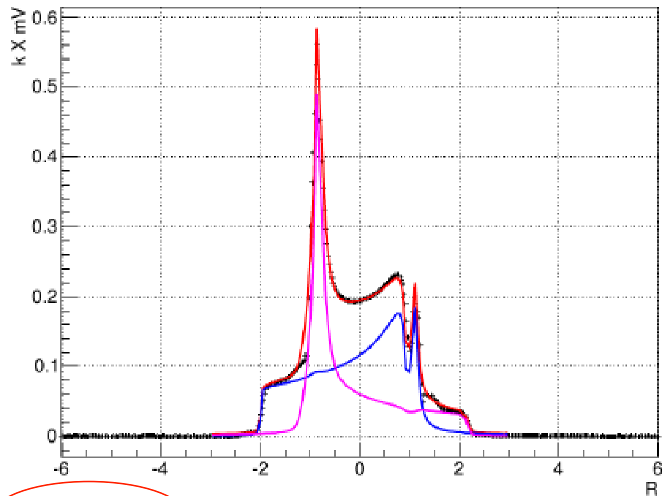
Selective Semi-saturation

(or just hole burning)

Dustin Keller
Hall A/C Collab



MC overlap with d-but. NMR experimental points (Pn=51→45,Qn:20→31%)



MC with fit and d-but. NMR experimental points (Pn=48→46,Qn:18→6%)

$$R = \frac{\omega - \omega_d}{3\omega_q}$$

DK Eur.Phys.J. A53 (2017) no.7, 155 arXiv:1707.07065

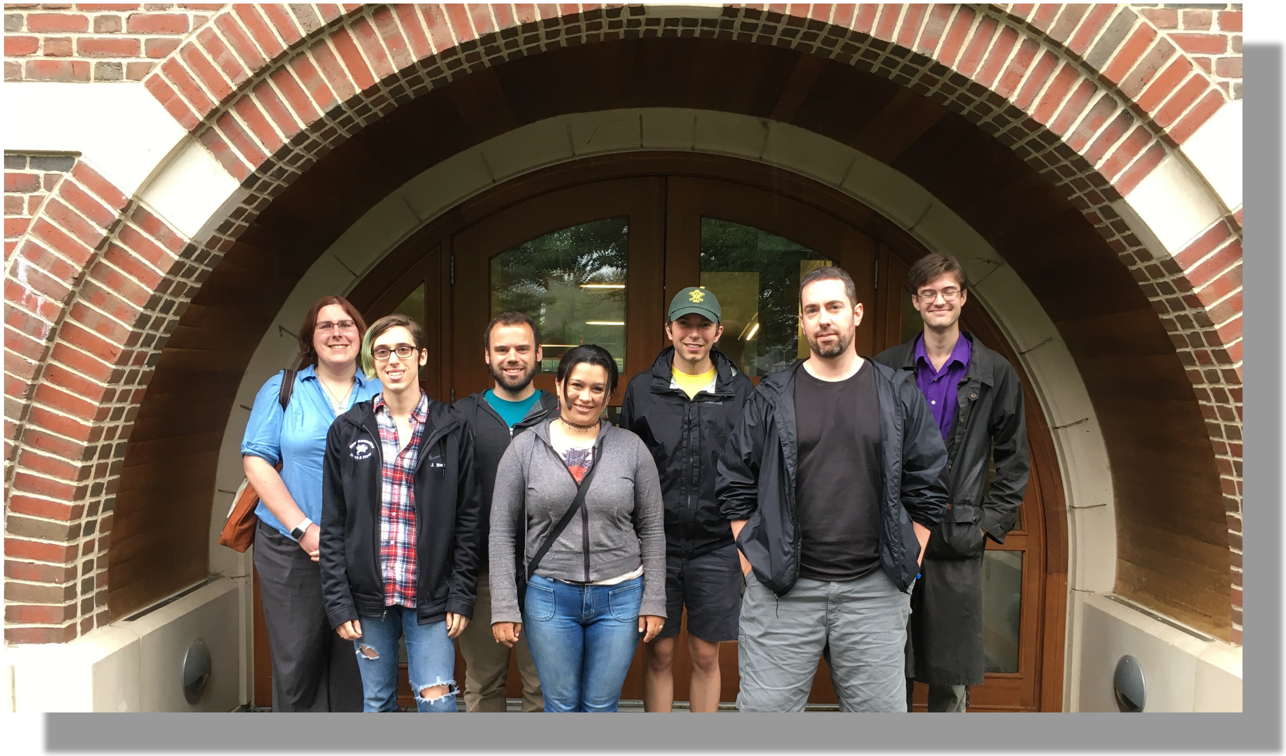
Dustin Keller
Hall A/C Collab

Achieved so far

- Before recent research (1984): ~20%
- Recent studies SSS (2014-2015): ~30%
- AFP with SSS (2016): ~34%
- Rotation SSS so far: ~38% (neg Q possible)

Still more to come, we can probably do much better than this by improving B/T should expect Q>>40%

UNH Polarized Target Lab



2 faculty
-K.Slifer & Ellie Long

1 post-doc to hire

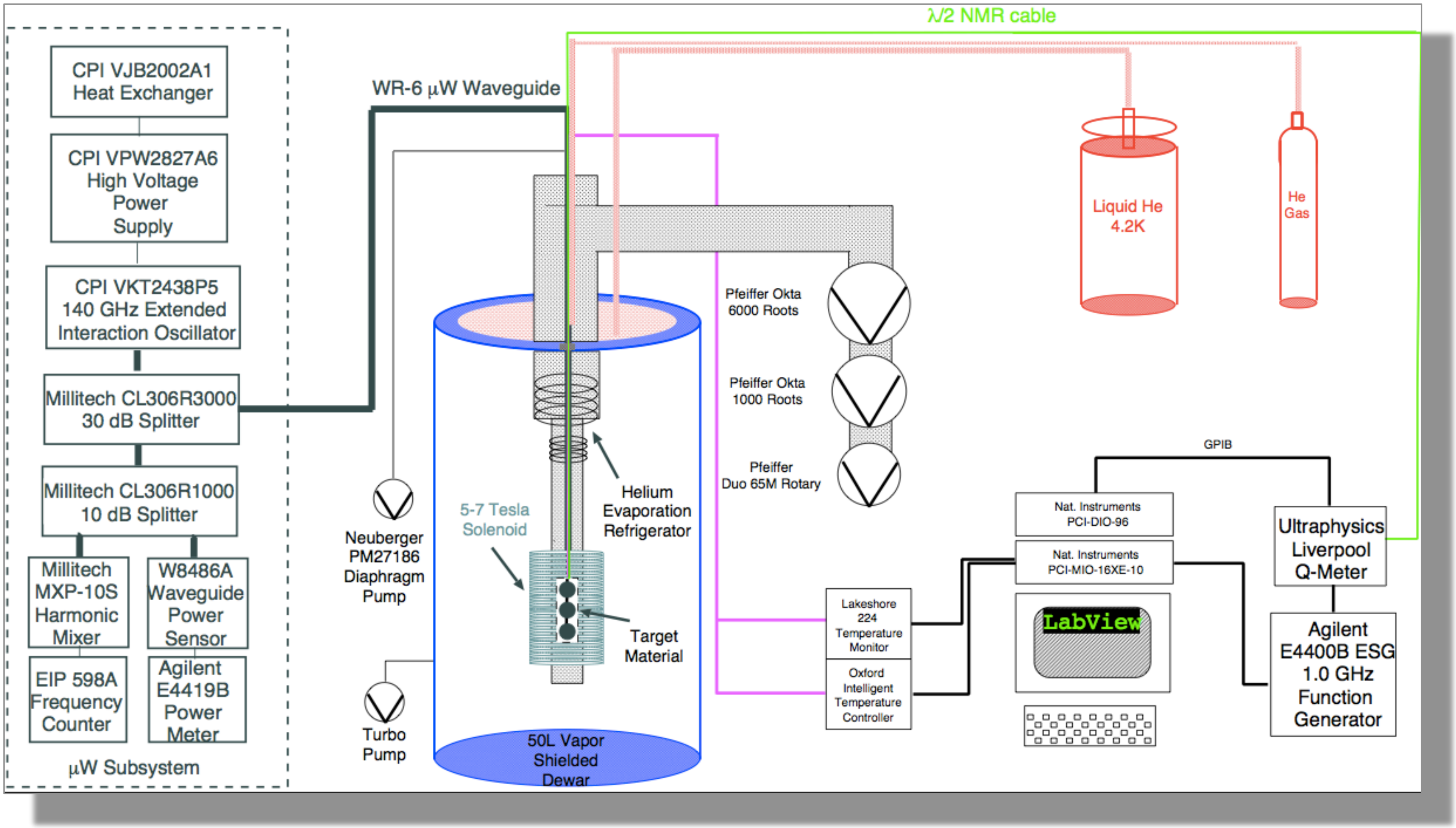
3 grad students:
--David R : significant time
--Nathalie S. : partial time
--Michael S. : full time

lots of undergrads

Projects

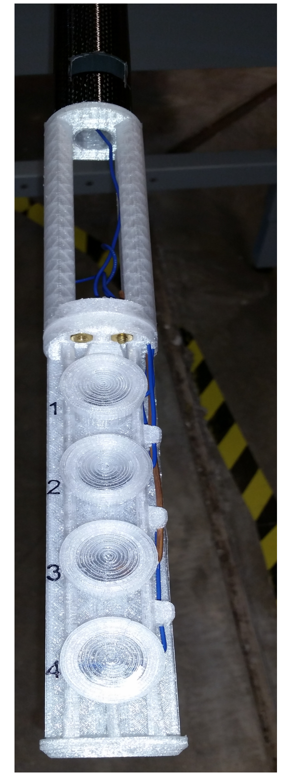
- Polarized Target Material Production & Labview controls for E1039
- Tensor Polarization R&D

UNH Polarized Target Lab



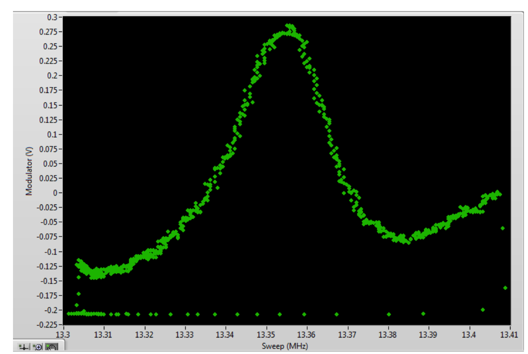
Very complicated / difficult system!

UNH Polarized Target Lab

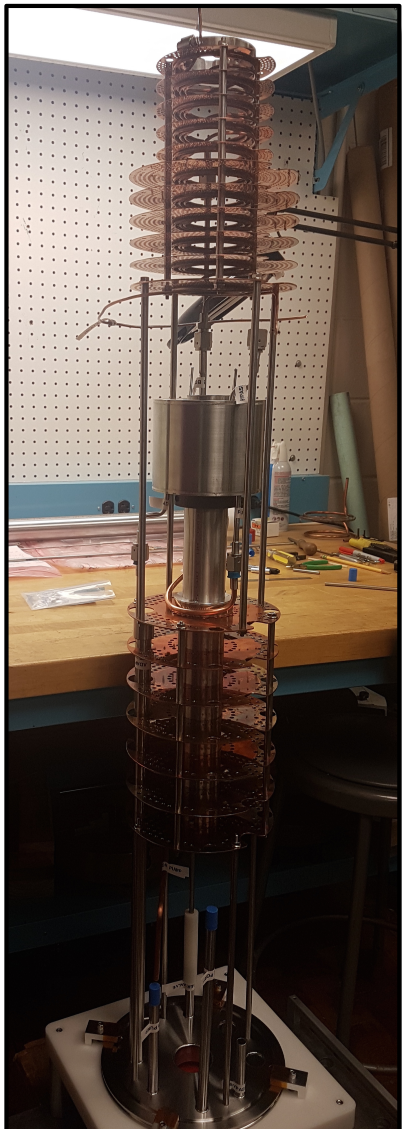


Reached 1K/7T
Have Working NMR system
Developed high vacuum expertise
Just Completed Commissioning of a new fridge
Still assembling the microwave subsystem

New Faculty hire (Elena Long)



UNH He Evaporation Refrigerator



(assemb "upside down")

UNH Machinist
Phil DeMaine

All Machining Complete

- ✓ Heat Exchanger
- ✓ Separator Pot
- ✓ Radiation Baffles
- ✓ Needle valves
- ✓ Vacuum Shells

December

1) Pre-Assembly at UNH (pictured) -complete

2) Leak testing new vacuum shells at UNH complete. 10^{-7} Torr

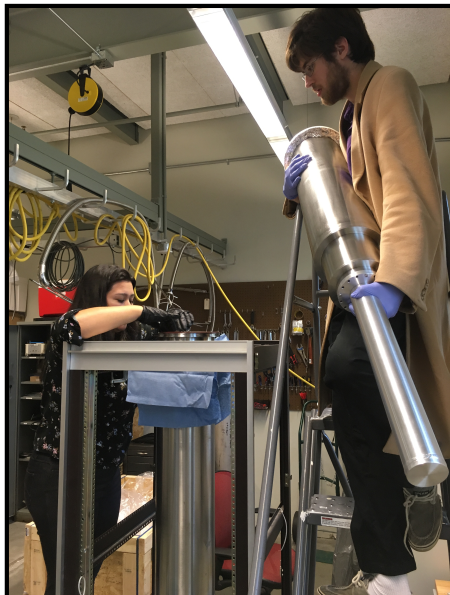
3) Final brazing/welding of needlevalves fittings @ Jlab completed in January

Successful LN2 Cooldown in January

Goals: test indium seals, vacuum
all good

UNH He Evaporation Refrigerator

Complete Fridge



Vacuum shells

All Machining Complete

- ✓ Heat Exchanger
- ✓ Separator Pot
- ✓ Radiation Baffles
- ✓ Needle valves
- ✓ Vacuum Shells

December

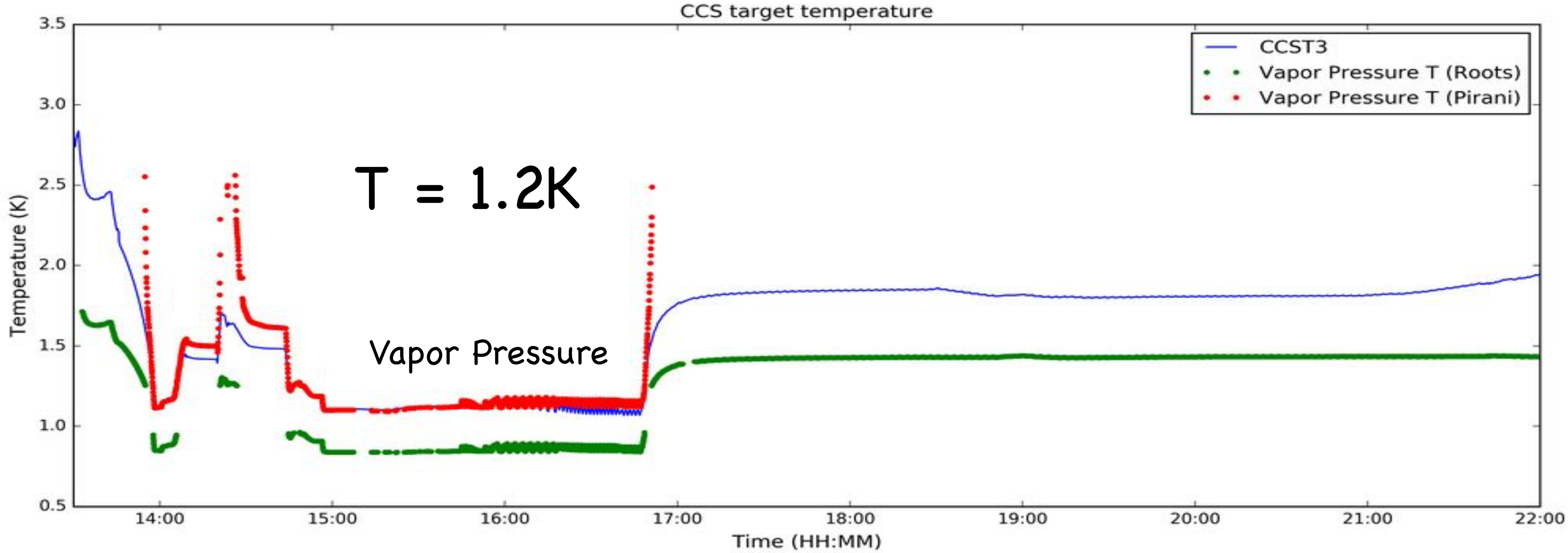
1) Pre-Assembly at UNH (pictured)
   -complete

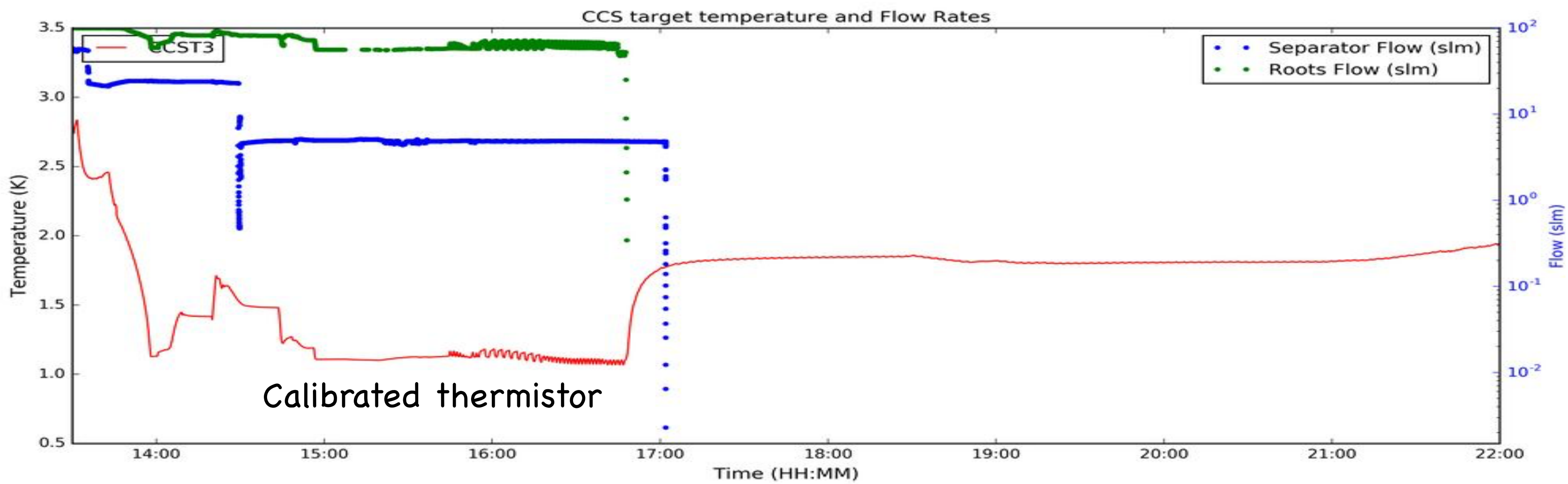
2) Leak testing new vacuum shells at UNH
   10-7 Torr

3) Final brazing/welding of swagelok
   fittings @ Jlab in January : complete

LHe Cooldown in Feb and Apr

Achieved 1 K in new fridge
Cross calibrate new NMR with QMeter


CCS target temperature
CCST3
Vapor Pressure T (Roots)
Vapor Pressure T (Pirani)
T = 1.2K
Vapor Pressure
Temperature (K)
Time (HH:MM)

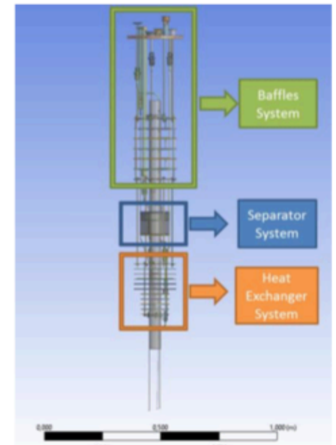

CCS target temperature and Flow Rates
CCST3
Separator Flow (slm)
Roots Flow (slm)
Calibrated thermistor
Temperature (K)
Flow (slm)
Time (HH:MM)

UNH and USM Valparaíso Collaboration

UNH – CCTVAL Collaboration on Cryogenic Fridge Design and Simulation

TEAM WORK USM: WILLIAM BROOKS
DAVID ALIAGA
PABLO BUNOUT

TEAM WORK UNH : KARL SLIFER
NATHALY SANTIESTEBAN
ELENA LONG

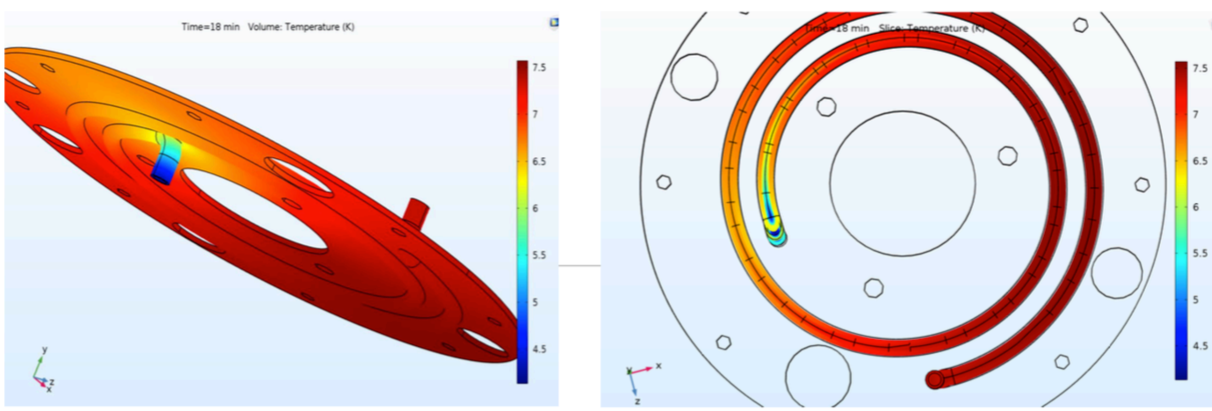


University of New Hampshire

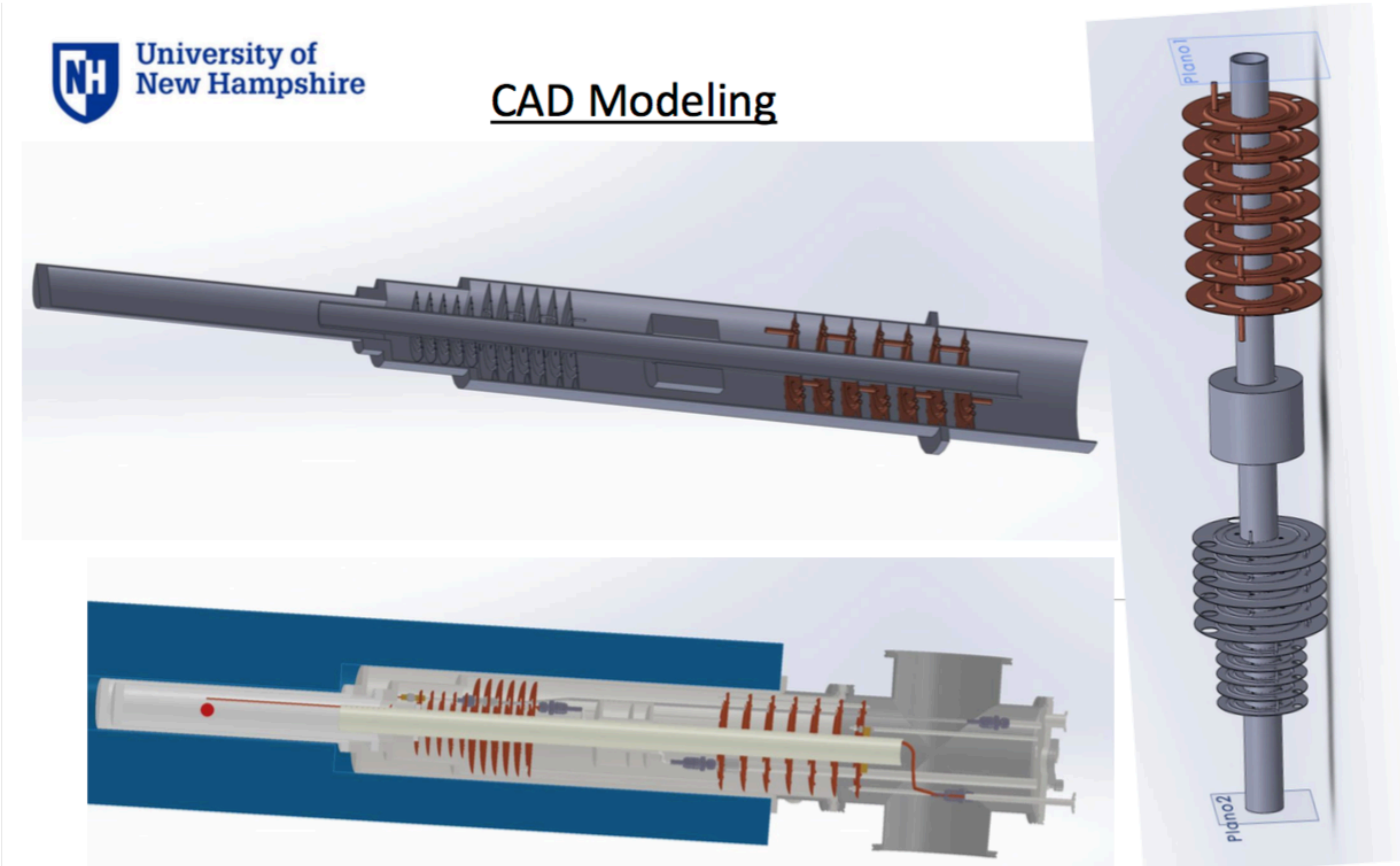
Baffles & HE Modeling : Results

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Temperature



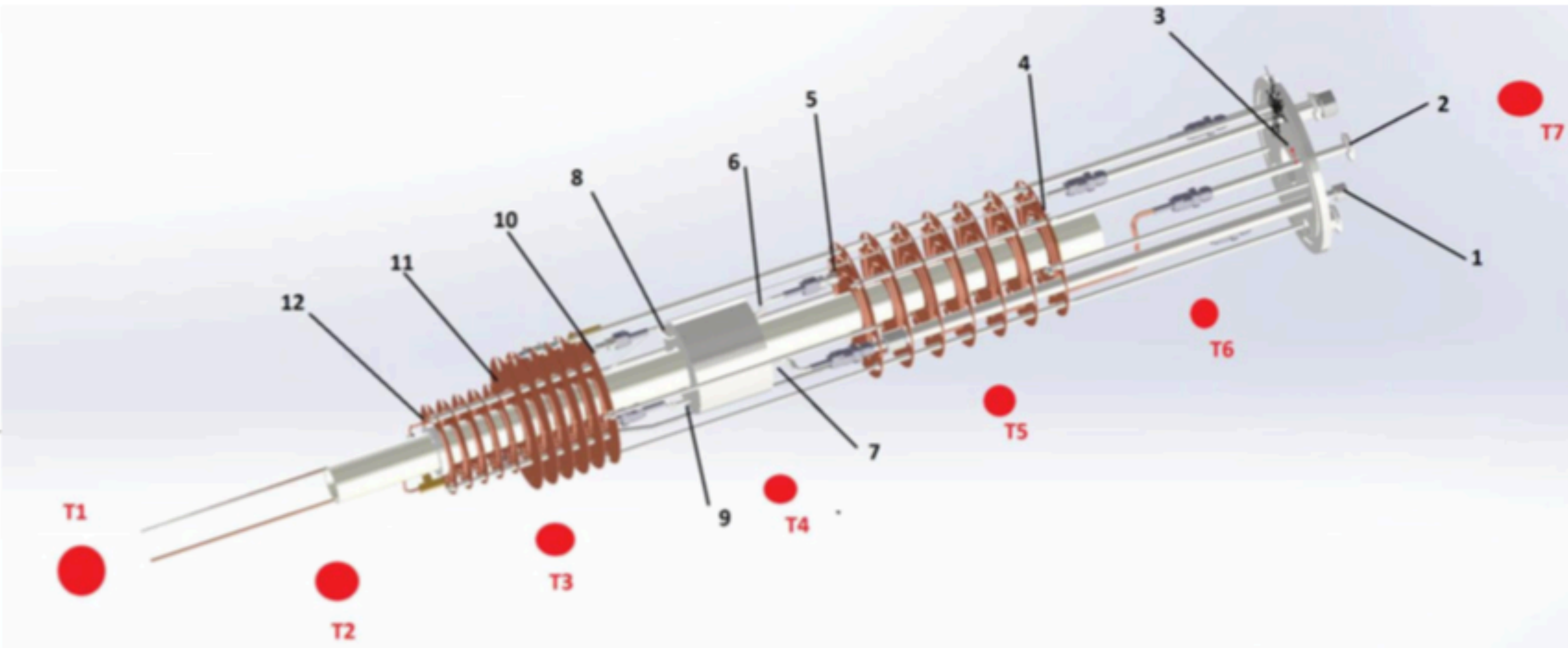
UNH and USM Valparaíso Collaboration



Courtesy David Aliaga, USM Valparaíso

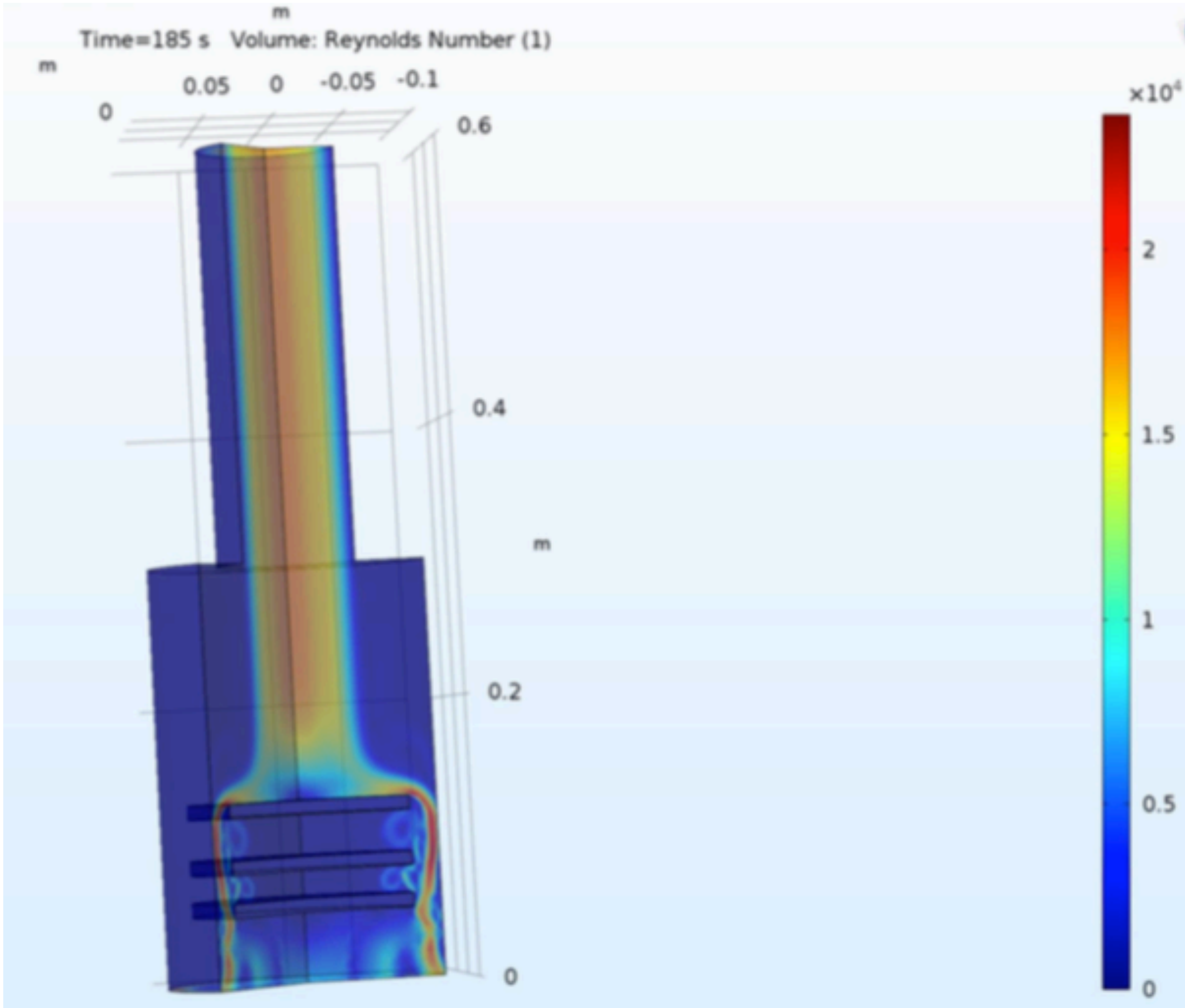
UNH and USM Valparaíso Collaboration

Temperature Zones (red points) : ** Locally Wall or Vapor bed Temperature measurements



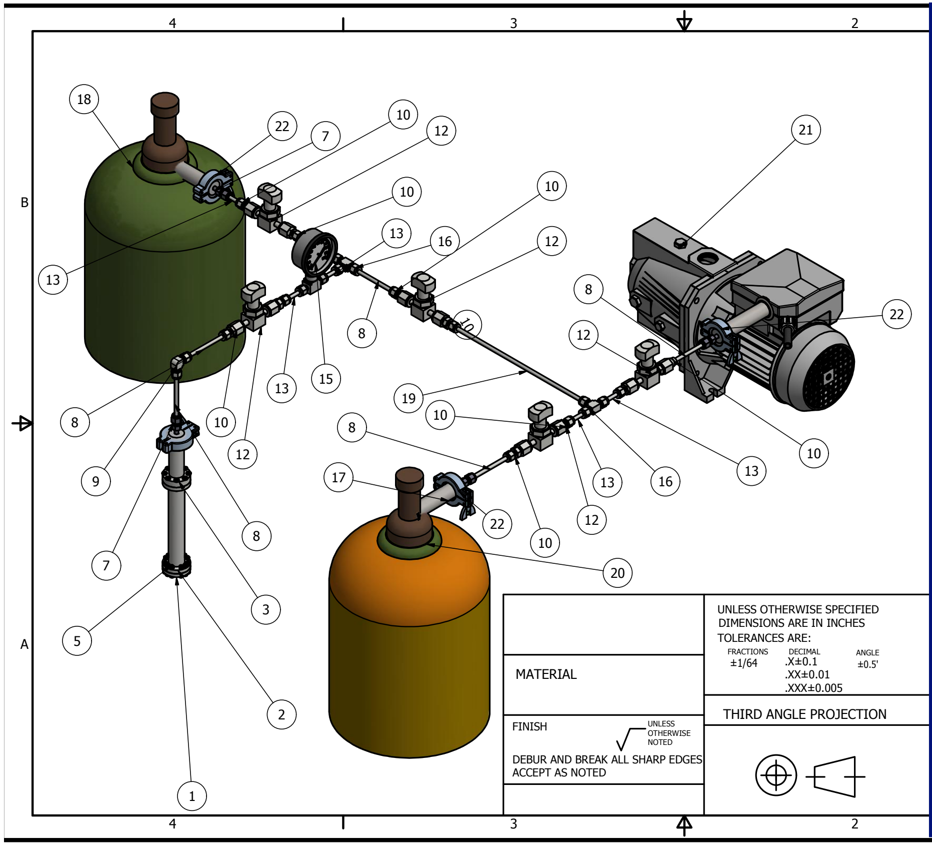
Courtesy David Aliaga, USM Valparaíso

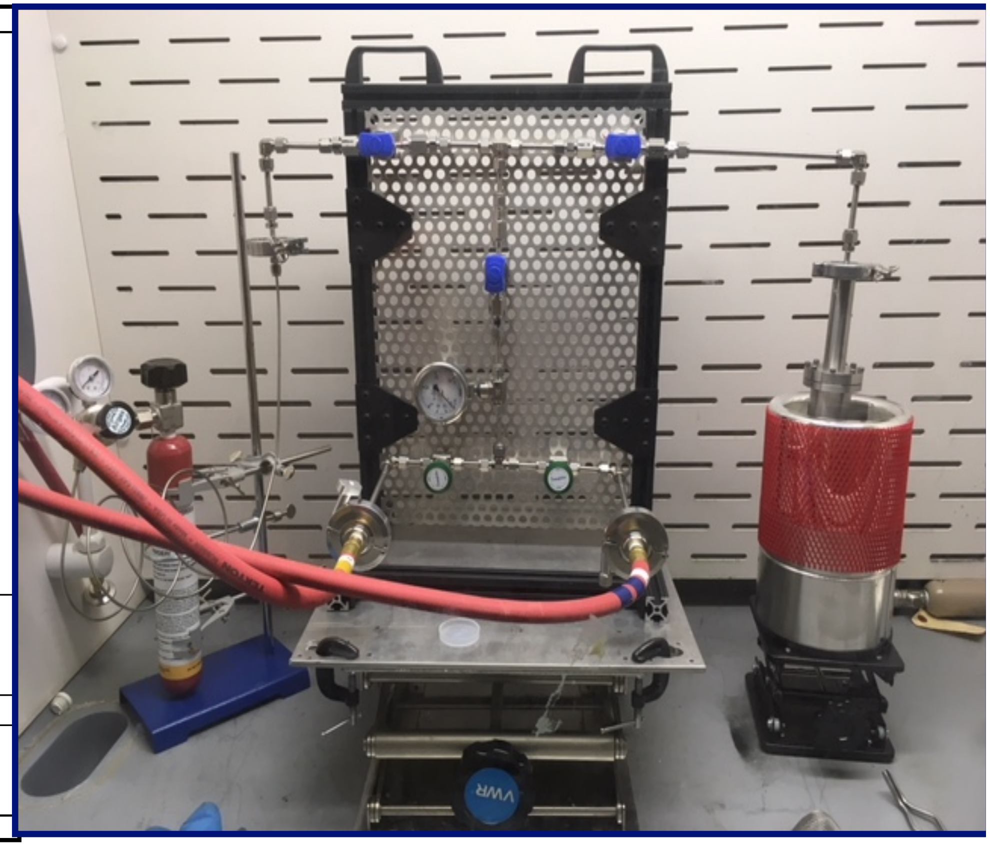
COMSOL Modeling of Helium Flow



Courtesy David Aliaga, USM Valparaíso

Target Material Production at UNH





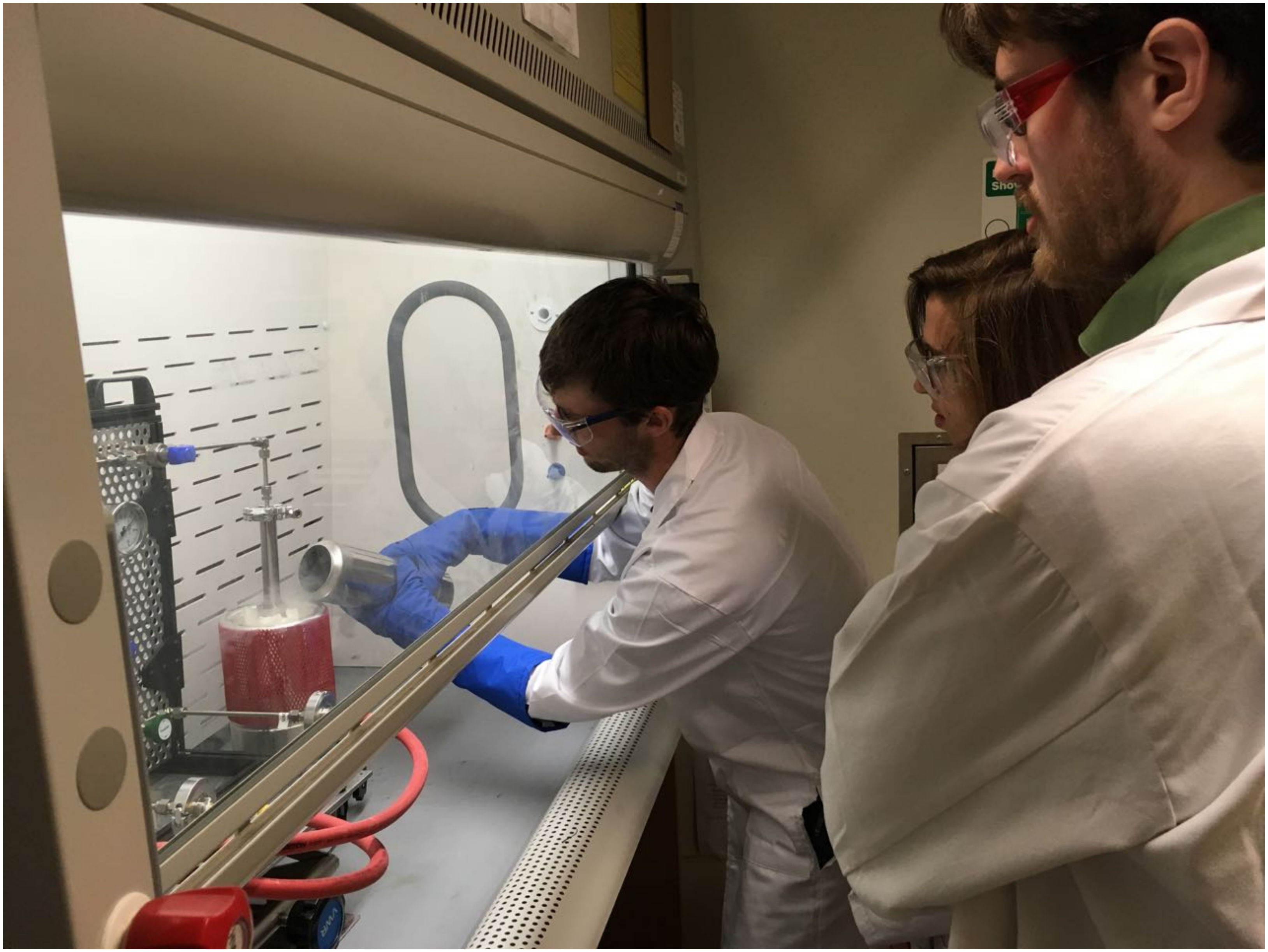
Status

-Gas line completed

-System completely contained in fume hood

-First milestone met : grade 5.5 NH_3 production

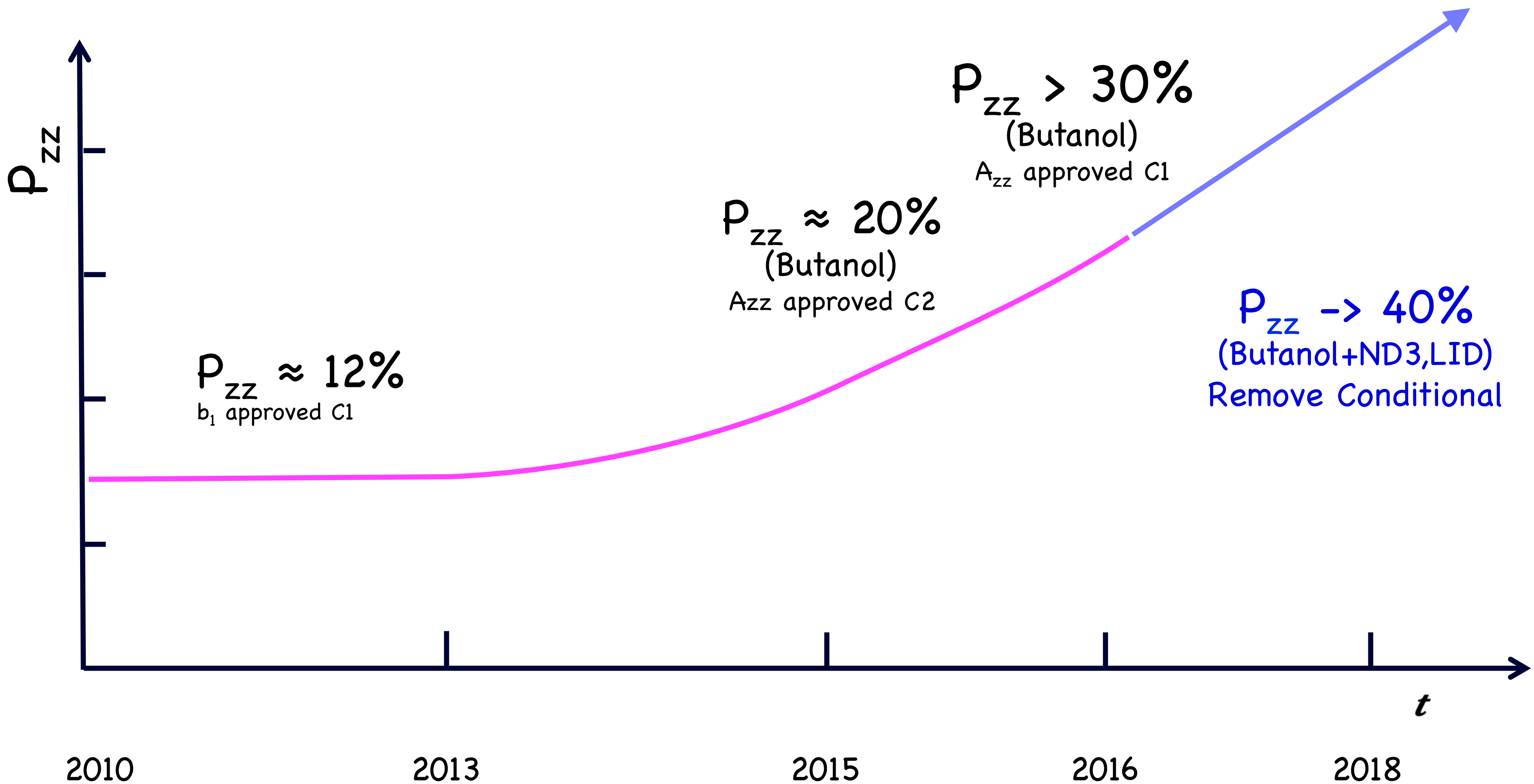
-Goal: 200 grams for E1039



Target Material Production at UNH

–Goal: 200 grams for E1039

Tensor Polarization progress



UNH Target Summary

1) LabView Controls and material production for E1039

2) New He Evaporation Fridge. Cooldowns in Feb&May reached 1K

3) Ammonia Line: Going into full production now.

4) microwave subsystem delivery expected in July.
   Probably take us a few mos to commission

Summary

g2p

Hyperfine splitting contributions from g2 very different from previous model pred

Large Q2 data finalized. Low Q2 data we are still working on PF systematics.

Tensor Program

E12-13-001: b_1 of the Deuteron (systematics suppressed by $1/P_{zz}$)

E12-14-002: A_{zz} for x>1 (HUGE asymmetries expected)

LOI12-14-001: Tensor Structure Function Δ

Other ideas : SIDIS, DVCS, Tensor polarized Drell Yan, …

Significant progress

High tensor polarizations demonstrated with SSS and rotation: P_{zz} -> 40%
Dramatic improvement in statistic and systematic uncertainties.

No reason this represents a limit. Much higher polarizations may be possible.

UNH target lab soon fully functional.