Spin Physics

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University of Virginia

New Trends in High-Energy Physics
Yalta, Crimea, Ukraine
Sept. 17, 2007

Outline

1) Brief Spin Physics Backgrounder

2) Recent Experimental Results

Low Q^2 GDH Sum Rule, ChPT

EG4 : Hall B

E97-110 : Hall A

Medium Q^2 Spin Duality and Extended GDH

E01-012: Hall A

E94-010: Hall A, GDH

Large Q^2 d_2, Sum rules.

RSS : Hall C

SANE : Hall C

3) Summary

JLAB in Newport News, VA

CW Linear Accelerator

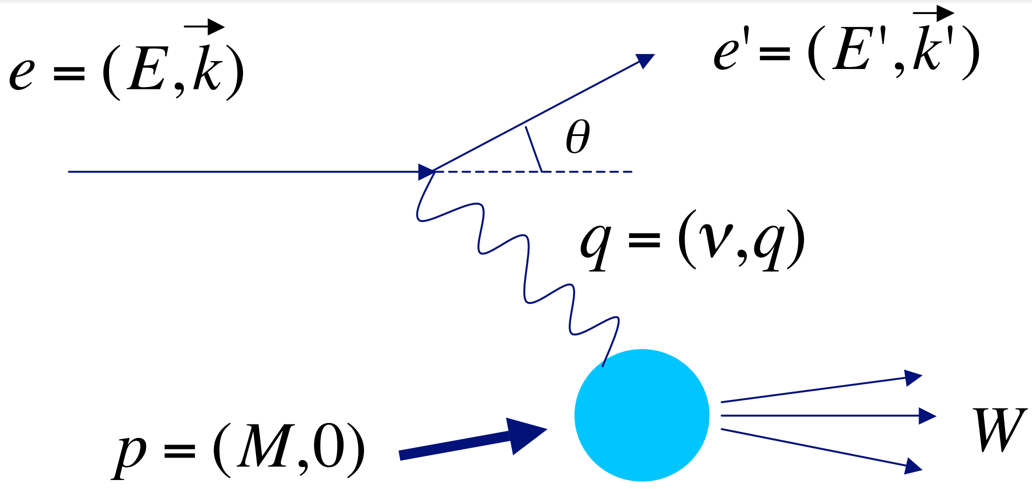
3 Fixed target Exp. Halls

Polarization ~ 80%

$E_0 \leq$ 5.8 GeV (5pass)

12 GeV Upgrade in 2011

Inclusive Electron Scattering



4-momentum transfer squared

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

Invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

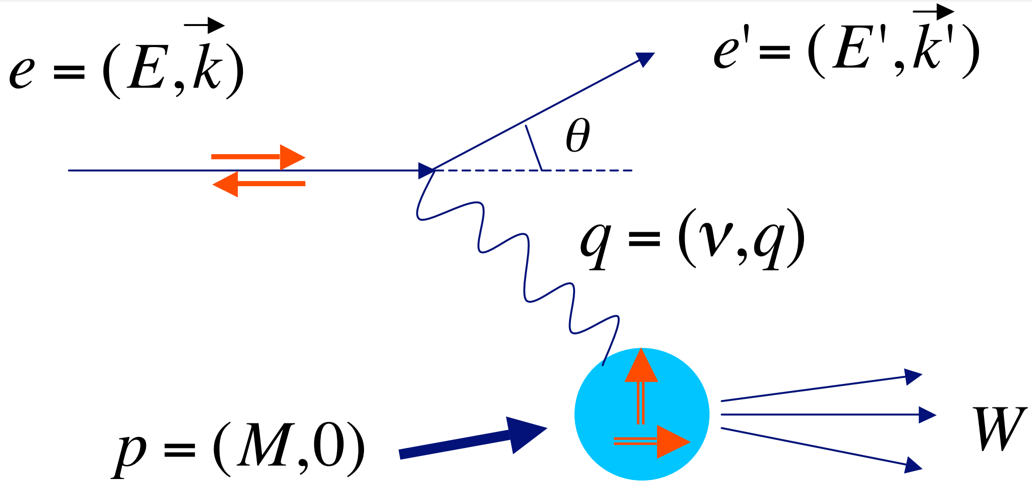
Bjorken variable

$$x = \frac{Q^2}{2M\nu}$$

Unpolarized case

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

Inclusive Electron Scattering



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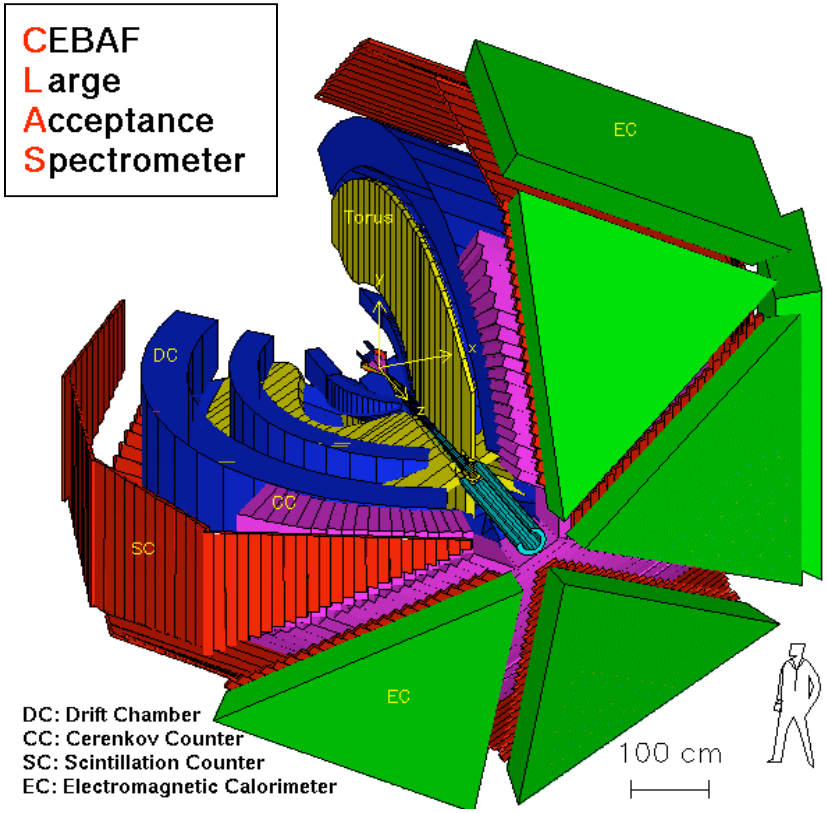
Polarized case

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

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

EG4



Ran in 2006

Measurement of g_1 at low Q^2

Test of ChPT as $Q^2 \longrightarrow 0$

Measured Absolute XS differences

Goal : Extended GDH Sum Rule
Proton
Deuteron

Spokespersons

NH_3: M. Battaglieri, A. Deur, R. De Vita, M. Ripani (Contact)
ND_3: A. Deur(Contact), G. Dodge, K. Slifer

PhD. Students

K. Adhikari, H. Kang, K. Kovacs

EG4

EG4: The GDH Sum Rule with Nearly Real Photons

$Q^2 = 0$

$$I(Q^2=0) = \frac{M^2}{8\alpha\pi^2}\int_{\nu_0}^{\infty}(\sigma_{1/2}-\sigma_{3/2})\frac{d\nu}{\nu} = -\frac{1}{4}\kappa^2$$

Finite Q^2

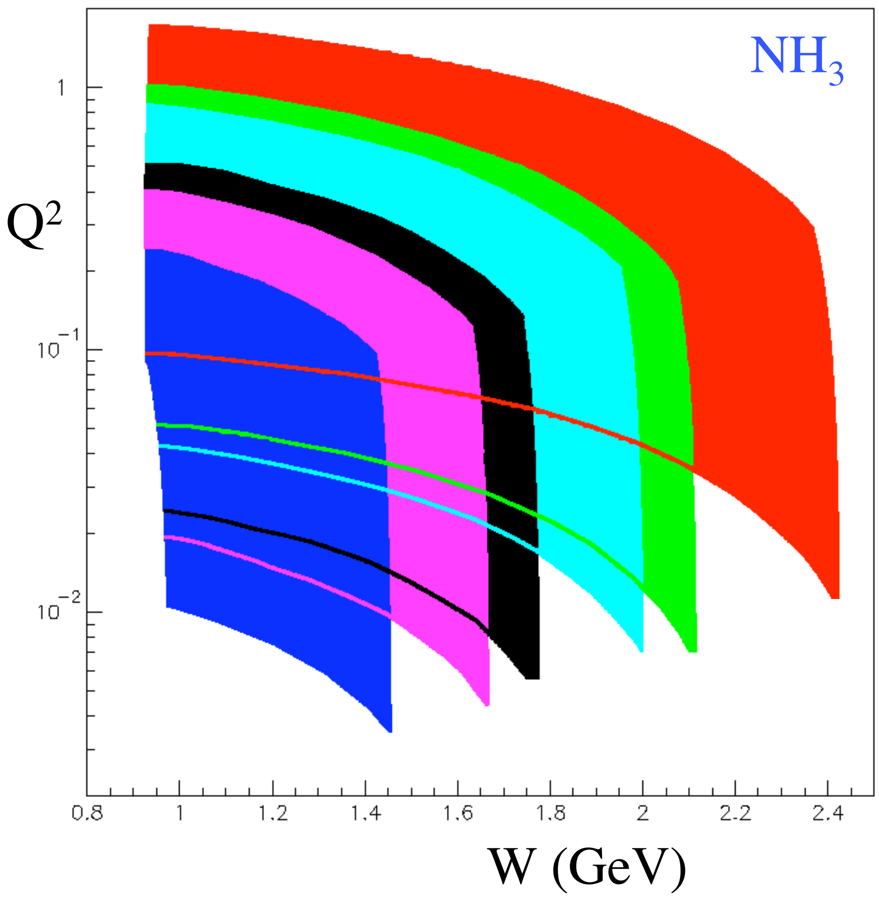
$$\Gamma_1(Q^2) = \int g_1(x,Q^2)dx \xrightarrow[Q^2\to 0]{} \left(\frac{Q^2}{2M^2}\right)I(Q^2)$$

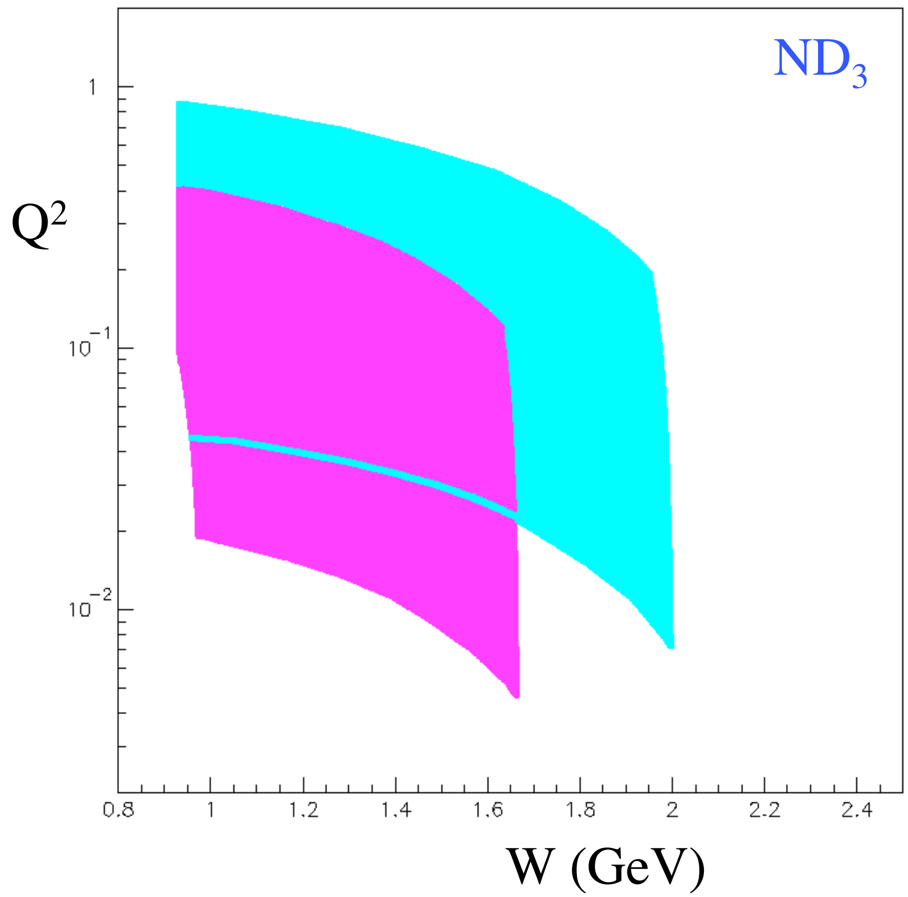
Method : Absolute cross section measurement

$$\left(\frac{d\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d\sigma^{\downarrow\Uparrow}}{d\Omega dE'}\right) = \frac{4\alpha^2 E'^2}{ME\nu Q^2}\left[(E-E'\cos\theta)g_1(x,Q^2) - 2Mxg_2(x,Q^2)\right]$$

g_2 contribution highly suppressed at low Q^2

EG4 Kinematics





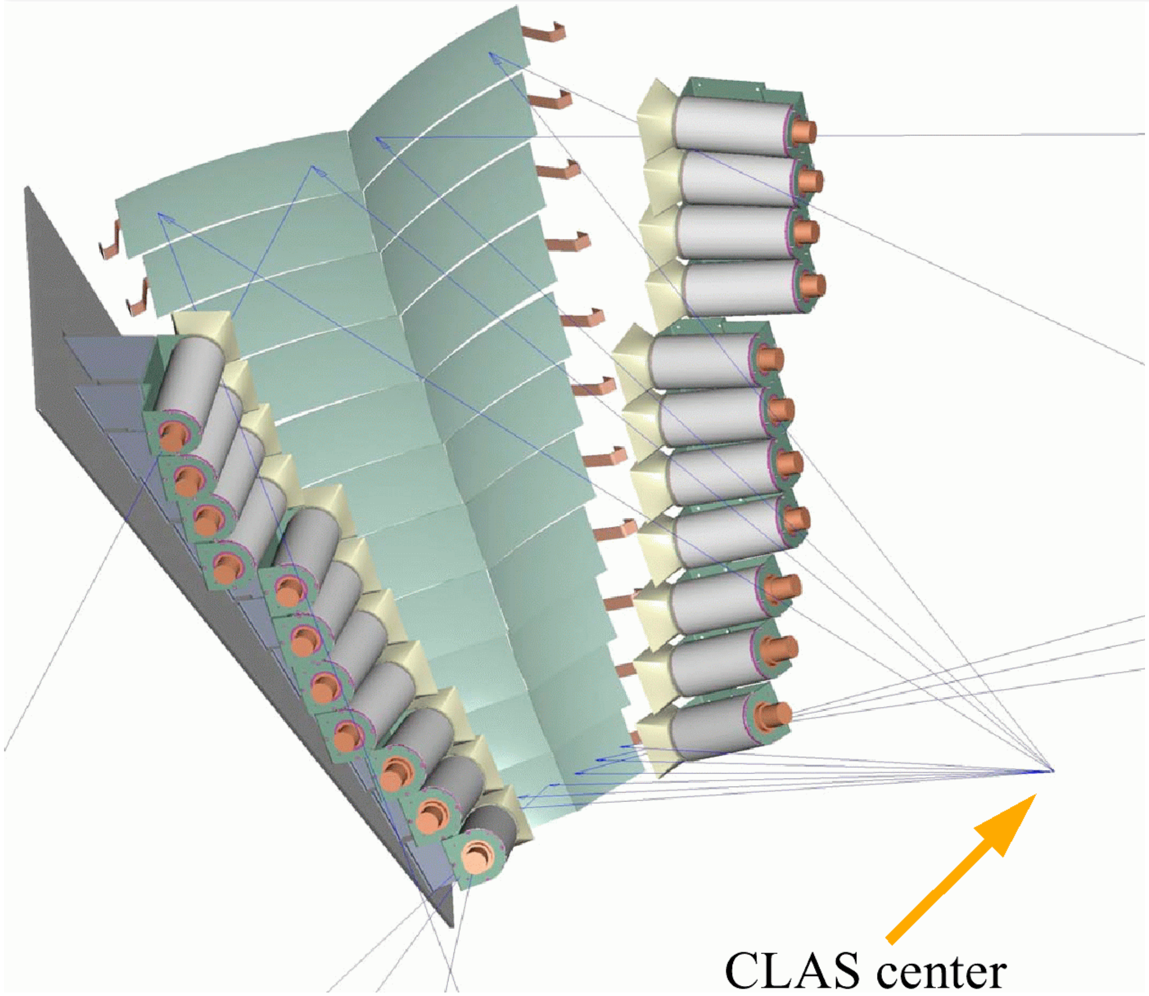
E_0 = 1.1,1.3,1.5,2.0,2.3,3.0 GeV

E_0 = 1.3, 2.0 GeV

$0.015 < Q^2 < 0.5$ GeV^2

Good coverage of the resonance region

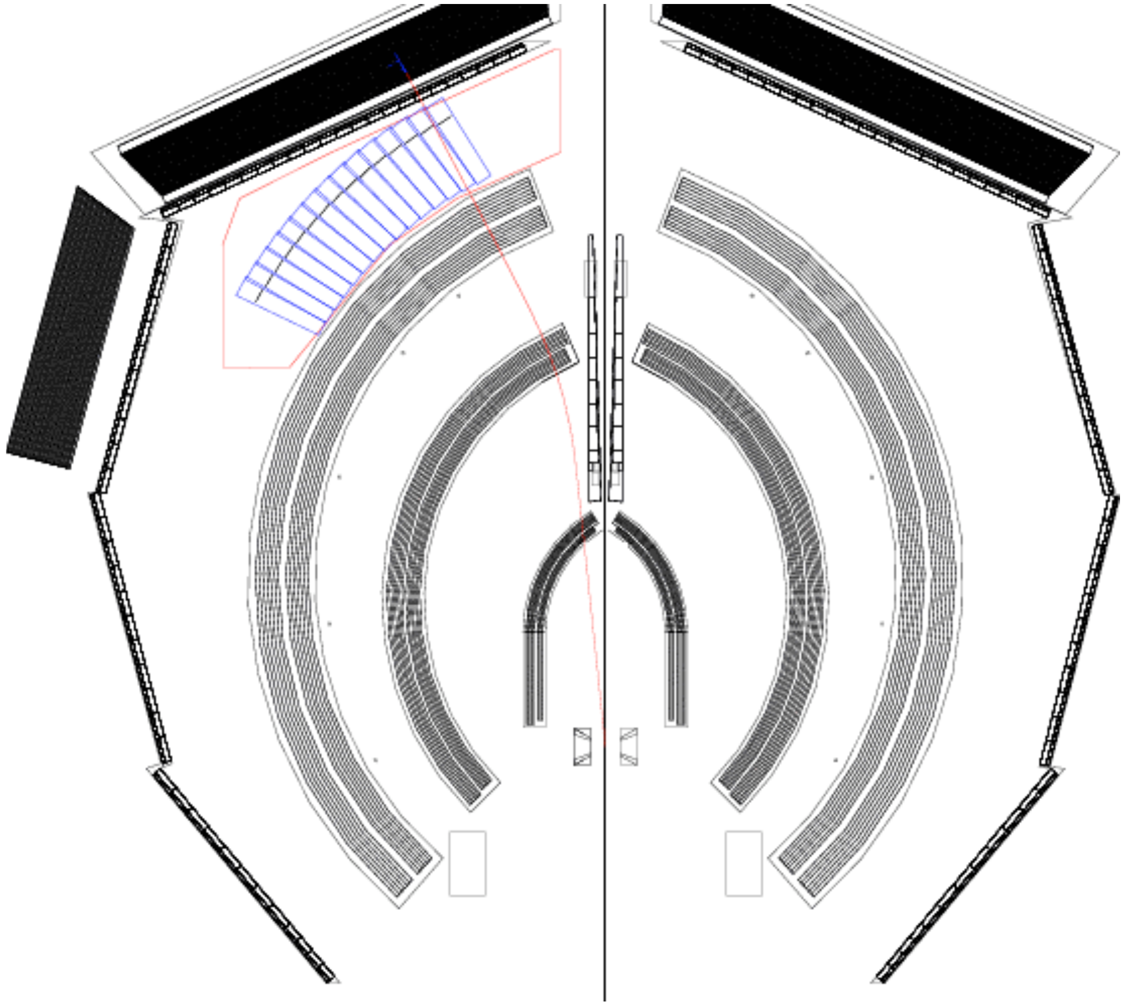
New Cerenkov Detector



Cross section measurement requires uniform detection efficiency at low Q^2

New Cerenkov (INFN-Genova) to detect scattered electrons down to 6 degrees.

New Cerenkov Detector



Overhead View of CLAS

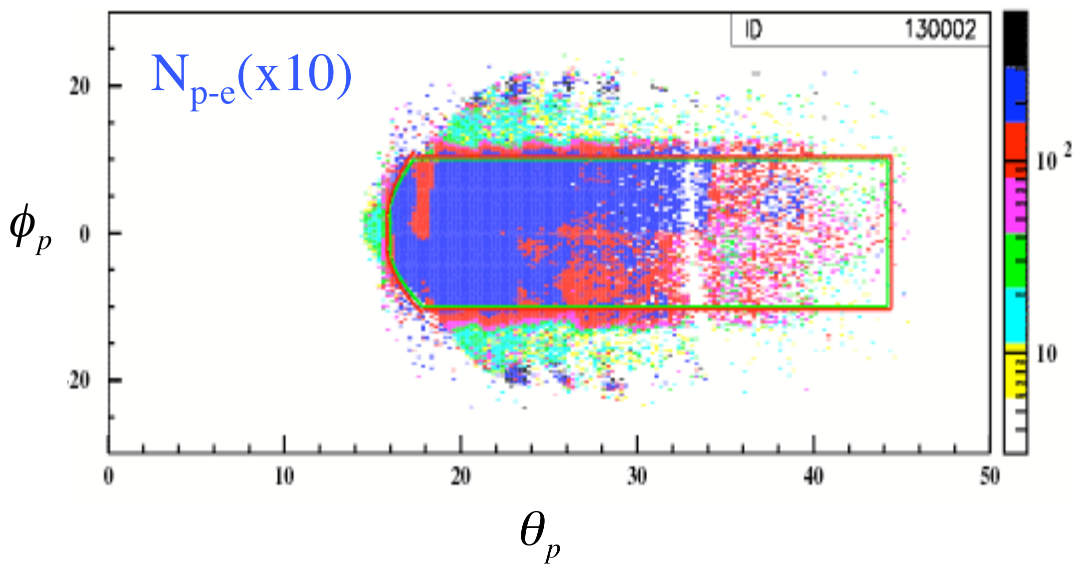
Cross section measurement requires uniform detection efficiency at low Q^2

New Cerenkov (INFN-Genova) to detect scattered electrons down to 6 degrees.

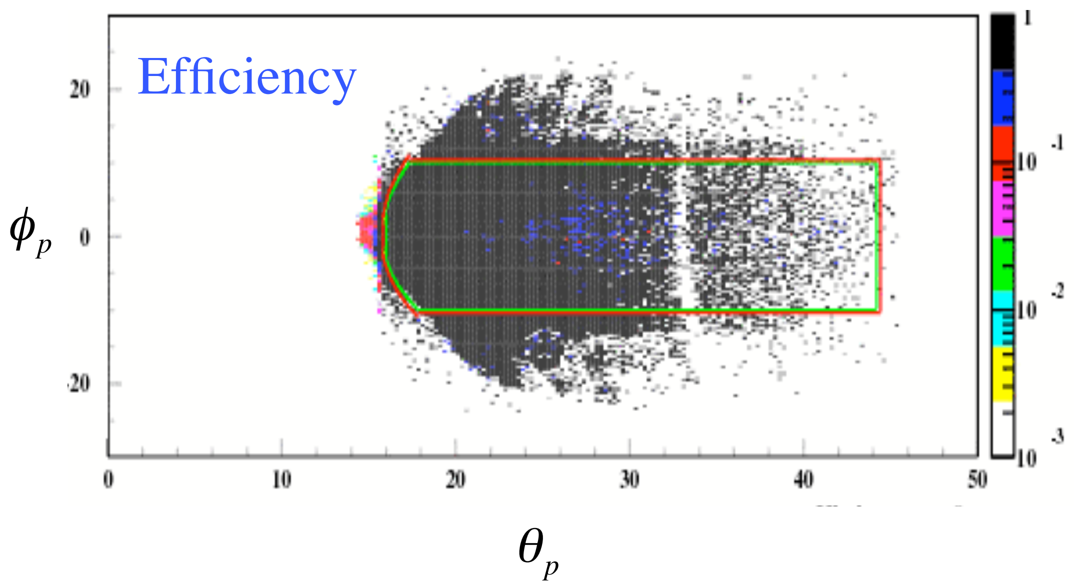
Single sector of CLAS used for inclusive trigger.

C_4F_{10}: perfluorobutane
n=1.00153
P_{pi}>2.5 Gev/c

New Cerenkov Performance



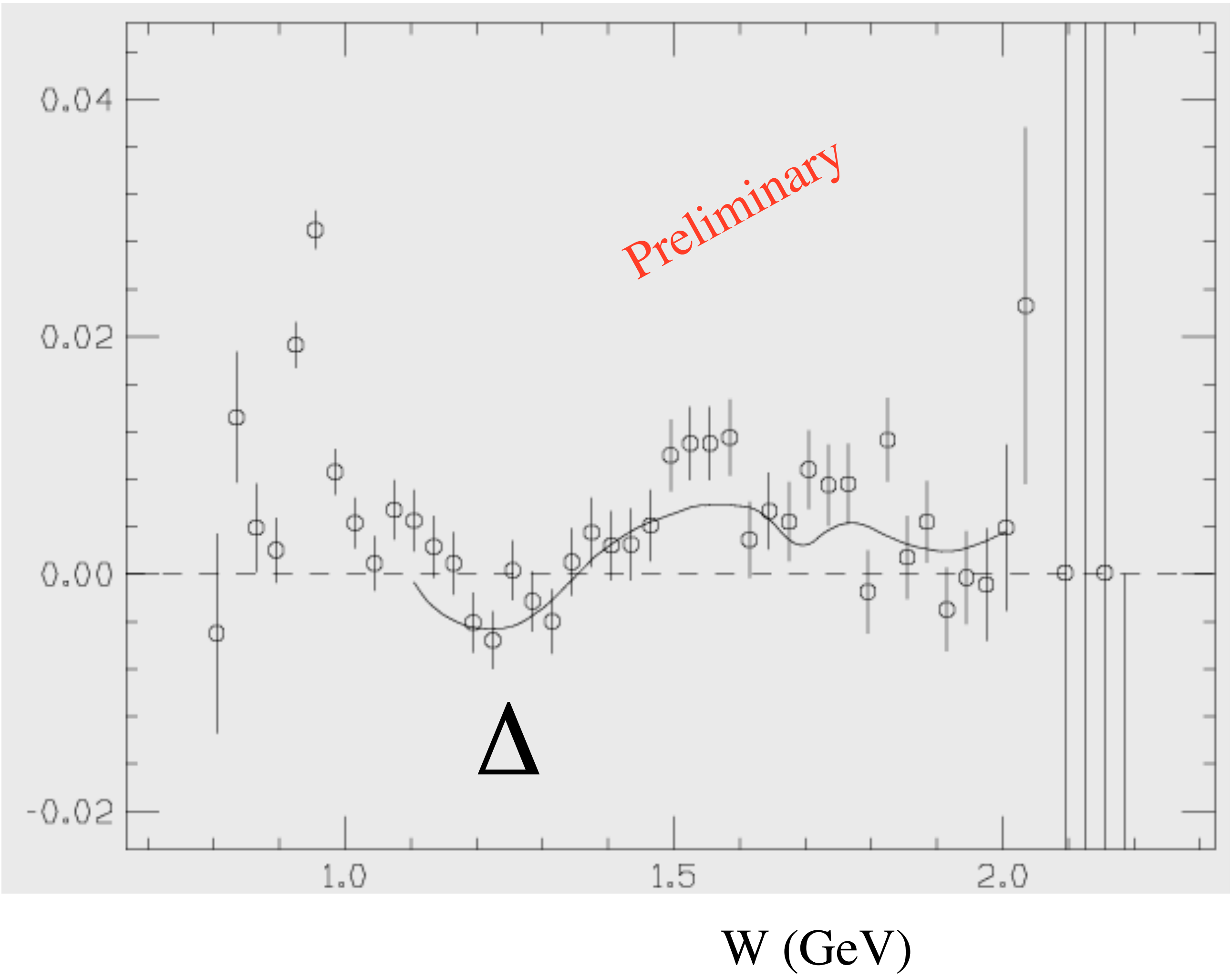
Large Number of photo-electrons.



Uniform detection efficiency.

Plot courtesy of X.Zheng

Raw Asymmetry



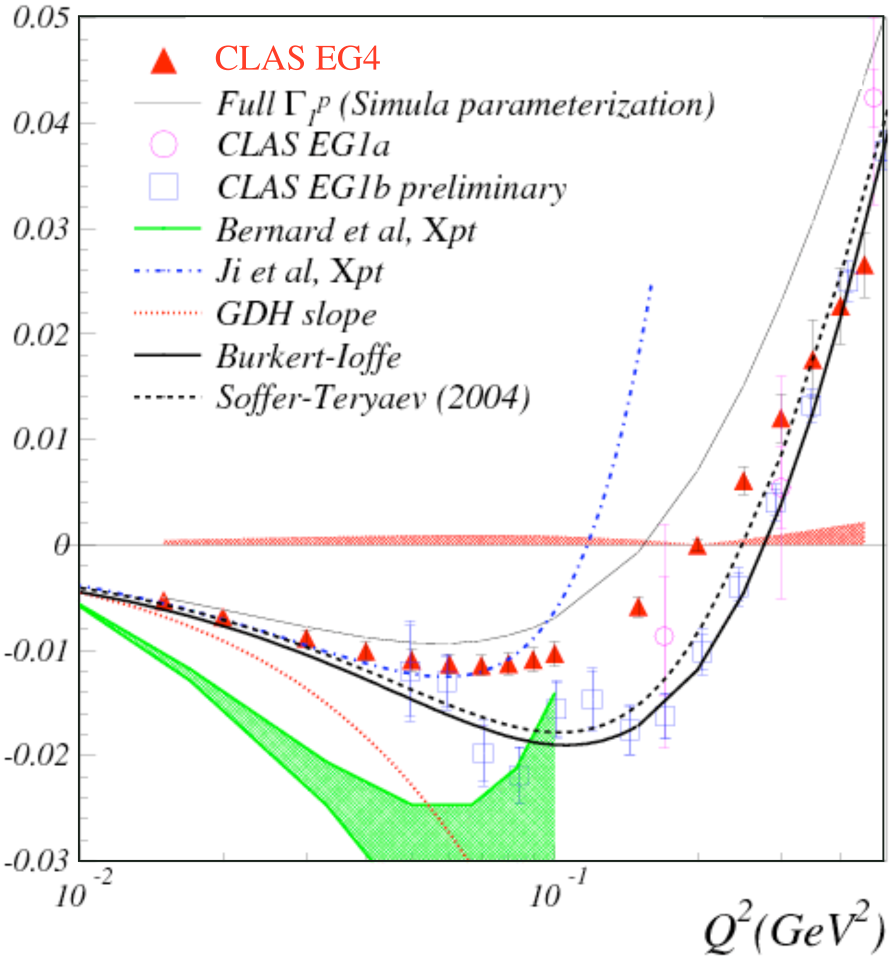
E_0 = 2.2 GeV

0.22 < Q^2 < 0.379

Plot courtesy of P. Bosted

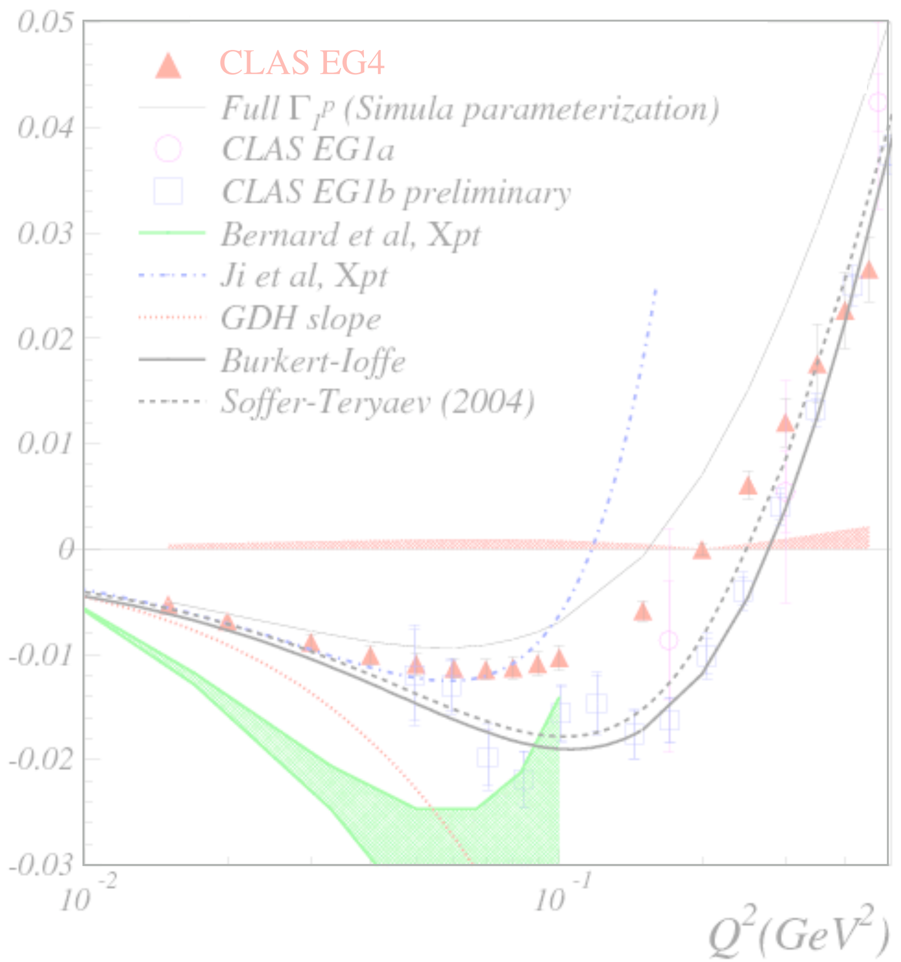
Expected Statistical Accuracy

Proton

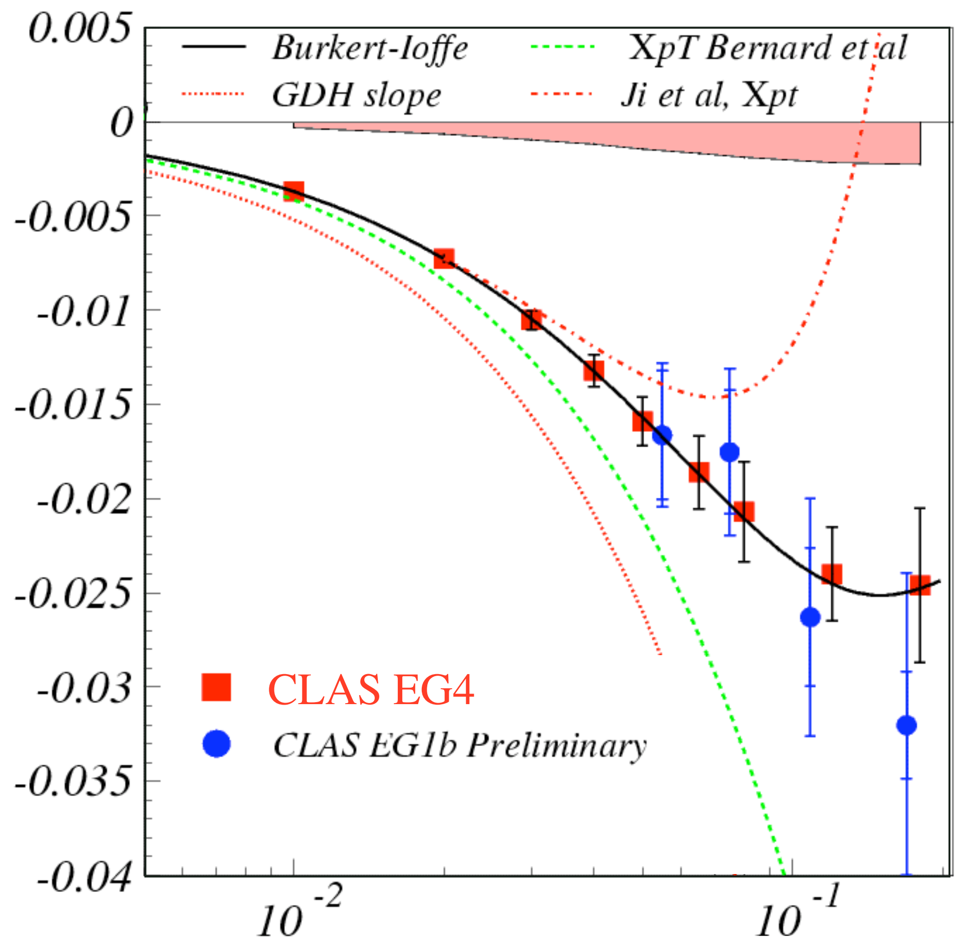


Expected Statistical Accuracy

Proton



Deuteron



Plot courtesy of A. Deur

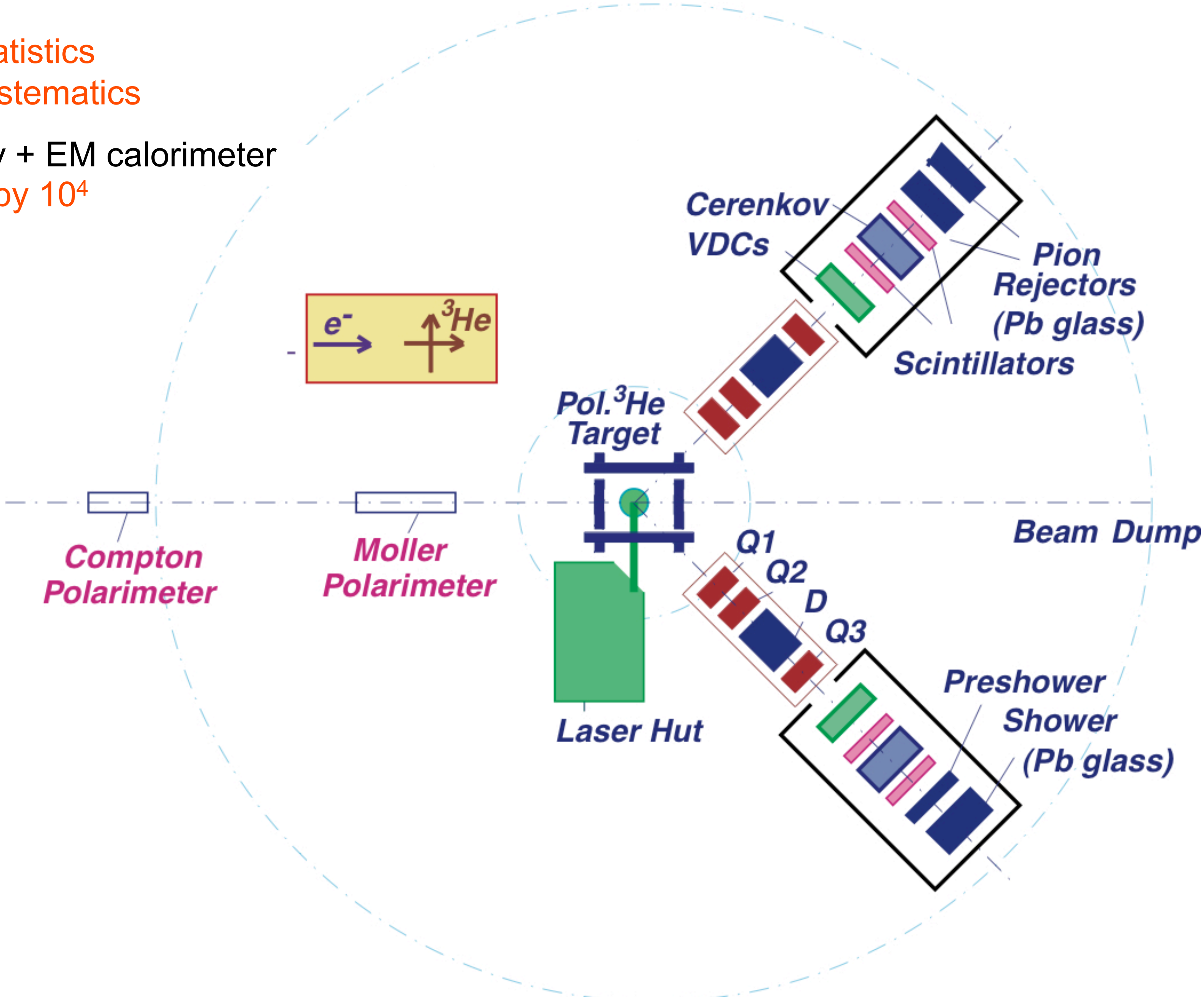
Hall A

Two HRS

- double the statistics
- control the systematics

PID = Cerenkov + EM calorimeter

- π/e reduced by 10^4



Hall A E97-110

Generalized GDH Integral at Low Q^2

Spokespersons:
J.P. Chen, A. Deur and F. Garibaldi

Students
J. Singh, V. Sulkosky and J. Yuan

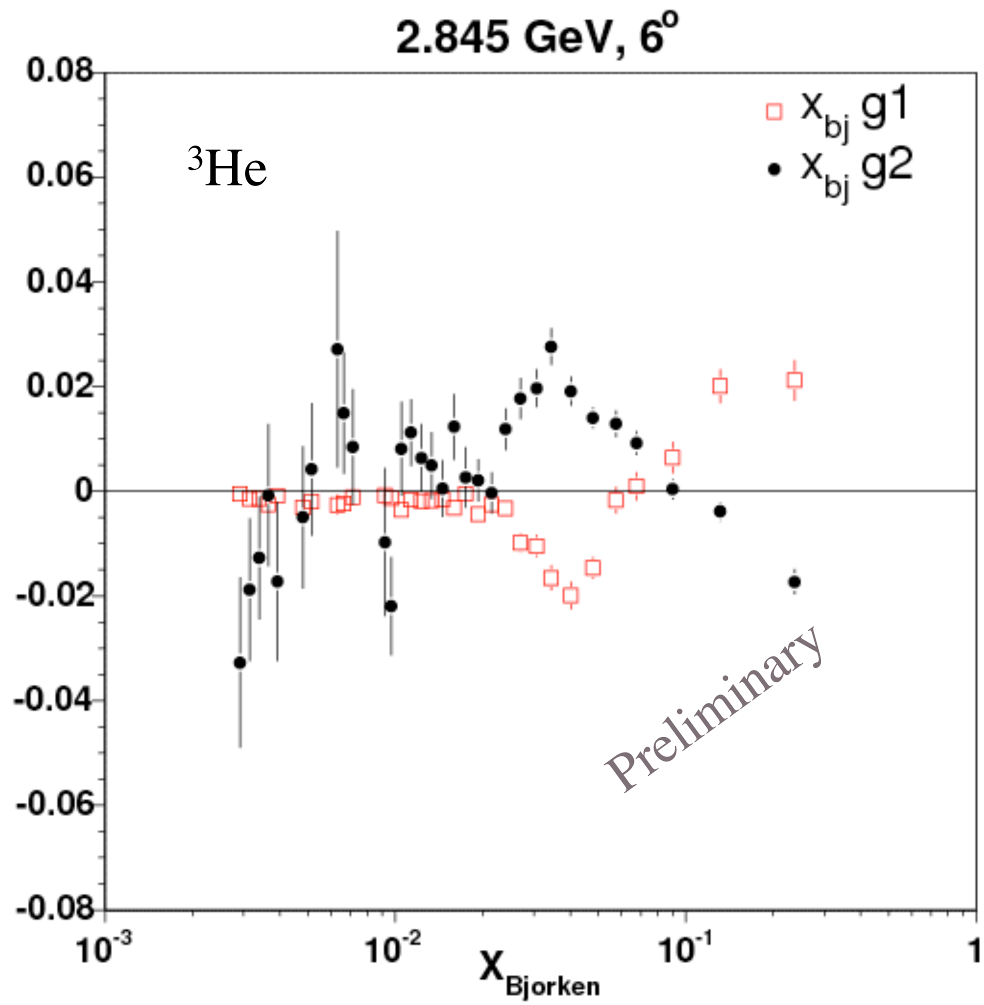
$$^3\overrightarrow{He}(\vec{e},e')X$$

^{3}He(neutron) g_1 and g_2

Kinematic Range

W : Resonance region

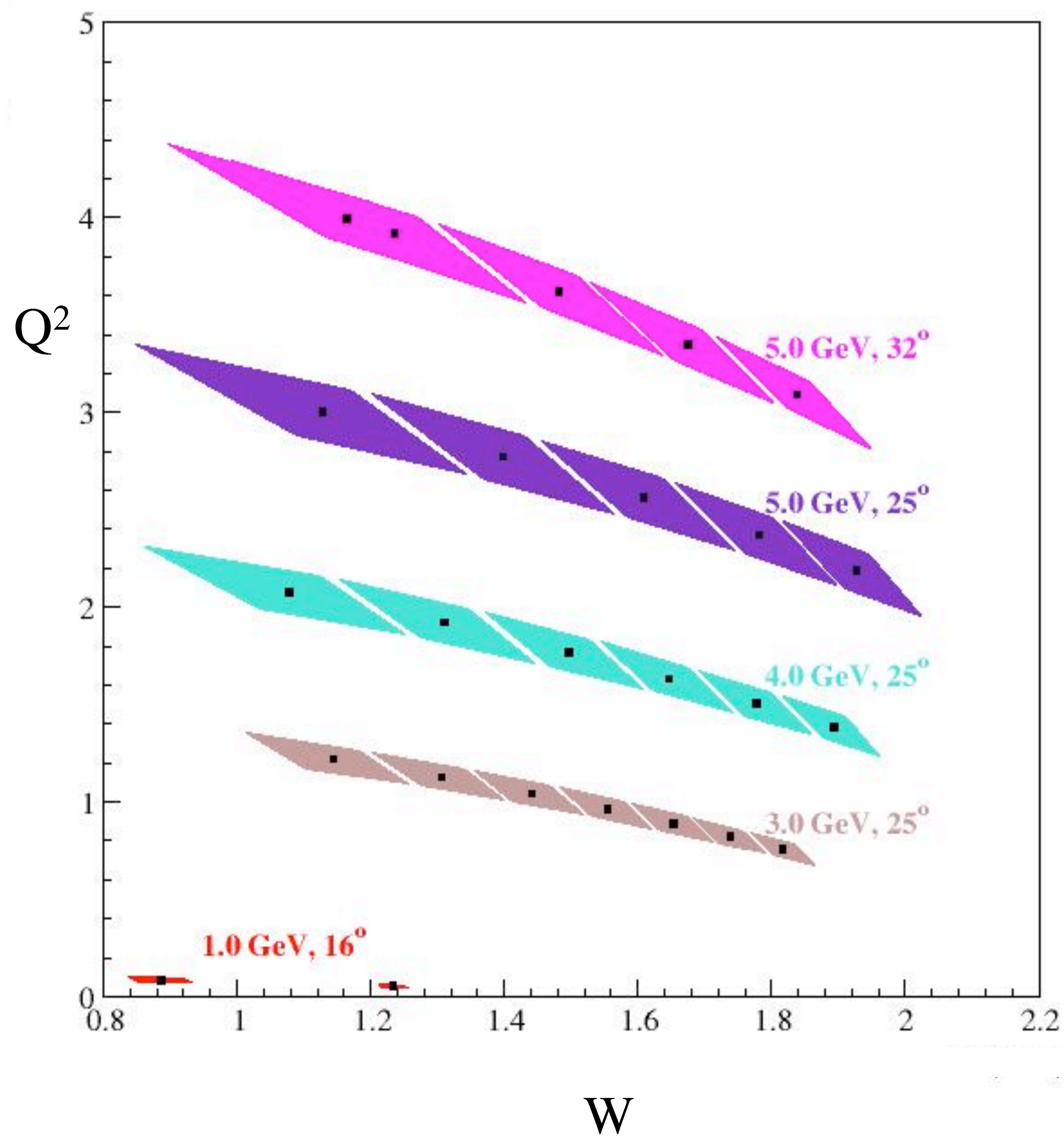
$0.02<Q^2<0.3\ GeV^2$



Plot courtesy of V. Sulkosky

E01-012

Test of Spin Duality on the neutron (and ^{3}He)



<u>Spokespersons:</u>
J.P. Chen, Seonho Choi, N. Liyanage

<u>PhD. Student</u>
P. Solvignon

Ran in 2003

$^3\overrightarrow{He}(\vec{e},e')X$

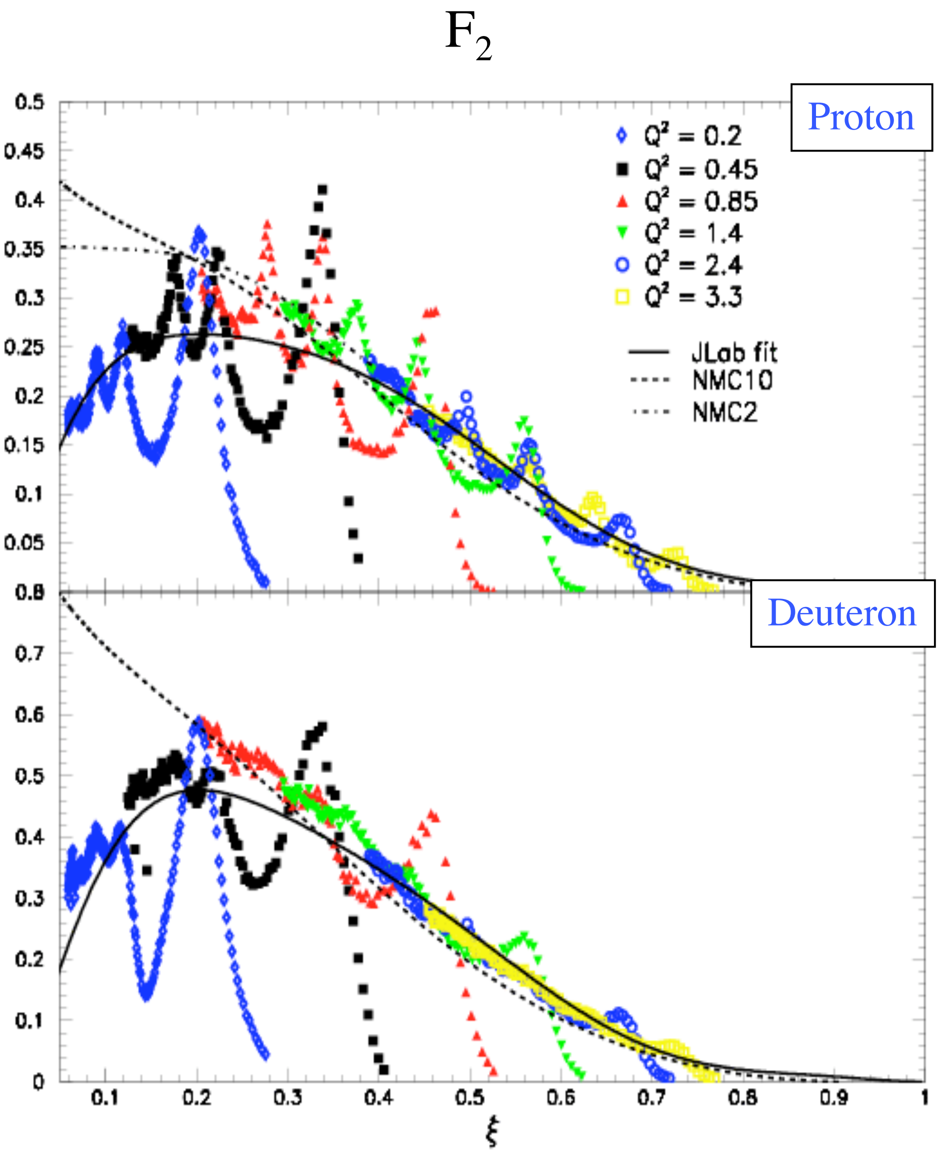
Polarized XS differences

Extract g_1 and g_2

<u>Kinematic Range</u>

$1.2 < Q^2 < 3.0$ GeV^2

Quark-Hadron Duality



Bloom-Gilman (1970)

F_2 measured in the resonance region averages to the large Q^2 scaling curve

PRL 25, 1140 (1970)
PRD 4, 2901 (1971)

JLAB Hall C

PRL 85 1182 (2000)

Global duality within 10%
Local duality within 10% for:
W=1232 MeV
W=1535 MeV
W=1680 MeV

Spin Duality

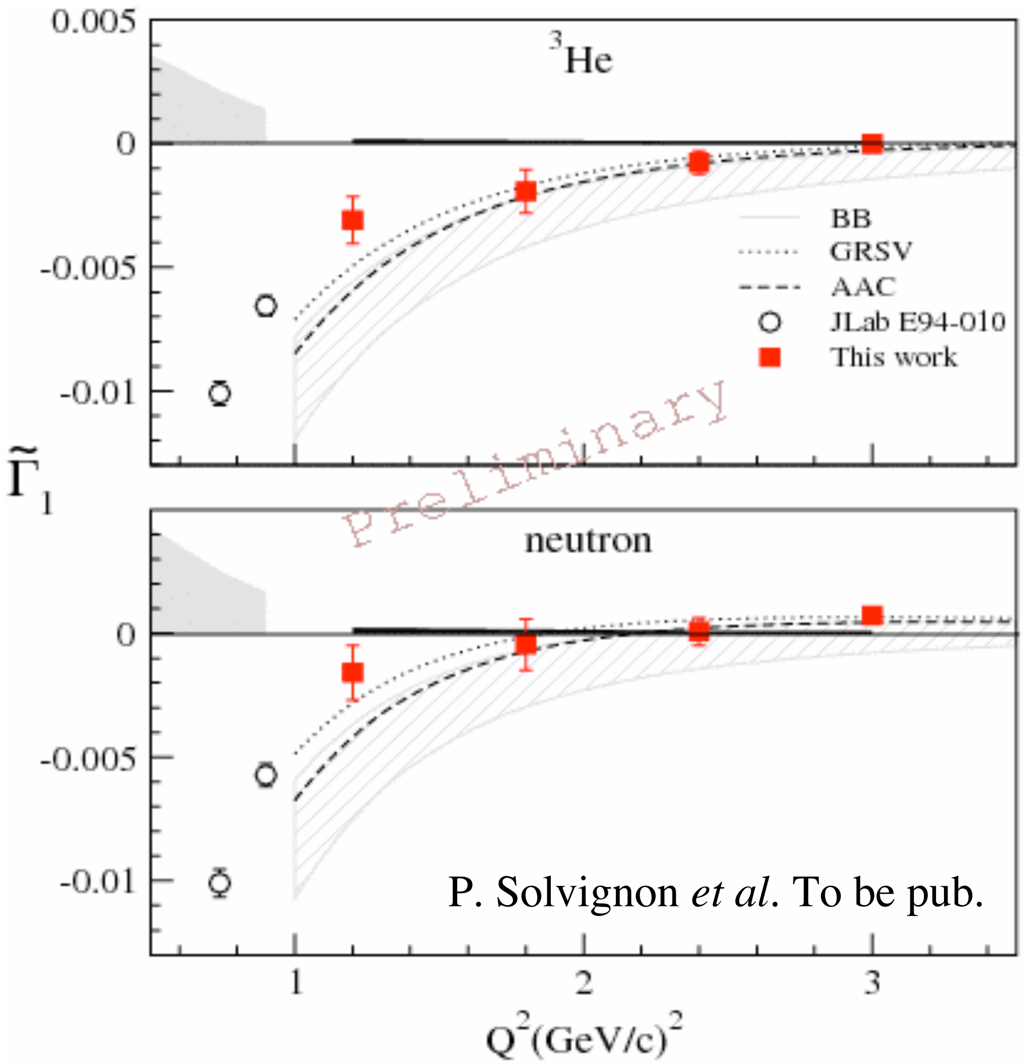
Bianchi, Fantoni and Liuti, PRD 69 014505 (2004)

1) Determine g_1^{res} at constant Q^2
2) Integrate over region of interest (local or Global)
3) Compare to DIS result evolved to same Q2

$$\Gamma_1^{res}(Q^2) \equiv \int_{x\min}^{x\max} g_1^{res}\, dx \qquad \Gamma_1^{dis}(Q^2) \equiv \int_{x\min}^{x\max} g_1^{dis}\, dx$$

$$\Gamma_1^{res}(Q^2) = \Gamma_1^{dis}(Q^2) \Rightarrow \quad \text{Duality}$$

Test of Duality on Neutron and ^{3}He



$$\tilde{\Gamma}_1^{dis} = \int_{x_{min}}^{x_{max}} g_1^{dis}(x,Q^2)dx$$

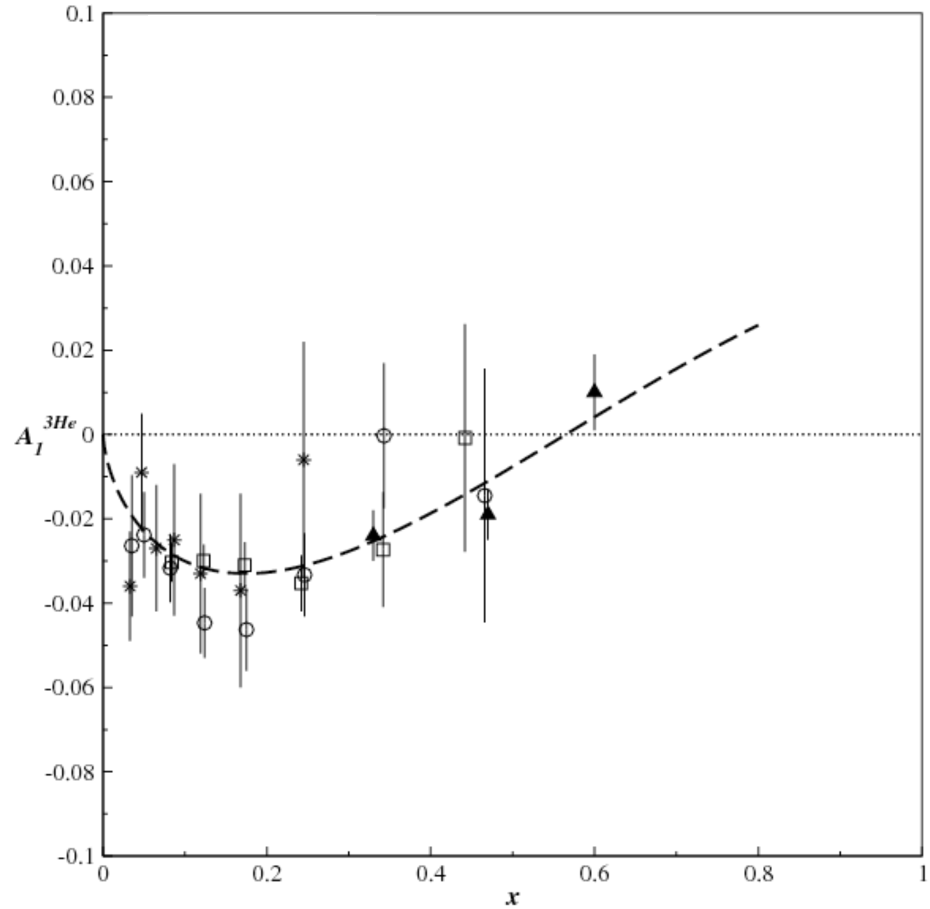
$$\tilde{\Gamma}_1^{res} = \int_{x_{min}}^{x_{max}} g_1^{res}(x,Q^2)dx$$

$$\tilde{\Gamma}_1^{res} = \tilde{\Gamma}_1^{dis} \quad ??$$

Global duality seems to work for $Q^2 > 1.8$ GeV^2

A_1 ^3He : World Data

Spin Asymmetry A_1



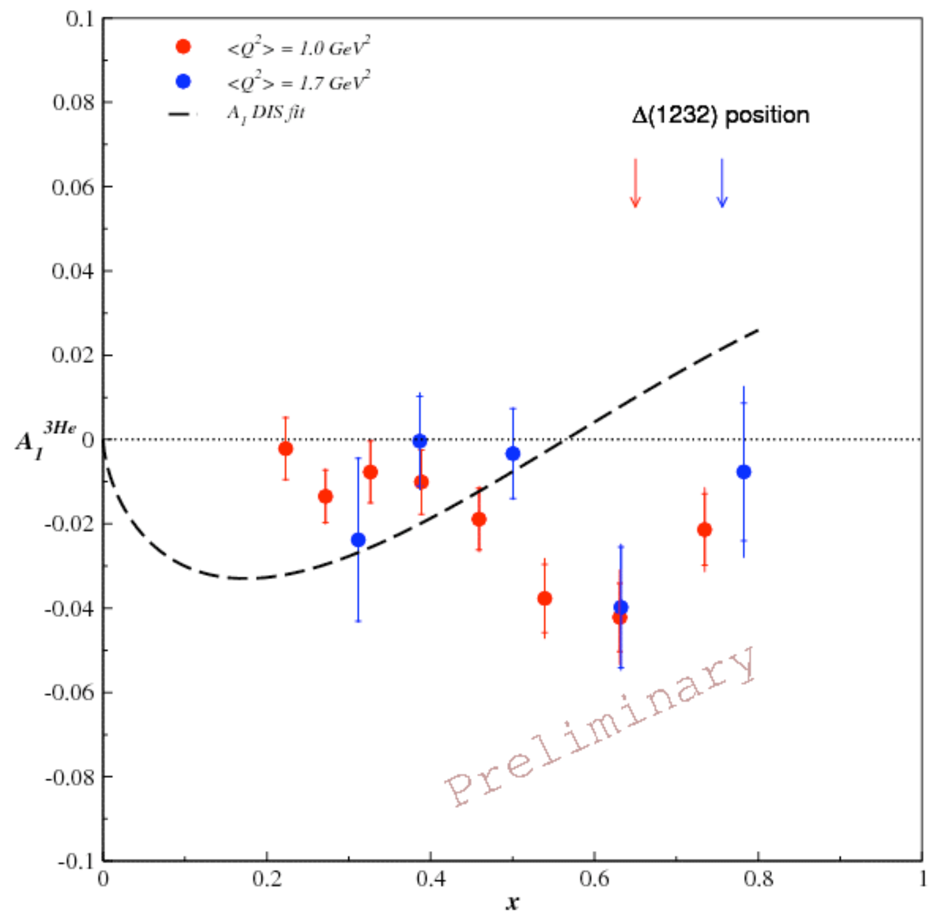
<u>Existing World DIS Data</u>

SLAC
HERMES
JLAB

A_1 ^3He : New results

<Q²> = 1.7 GeV²

<Q²> = 1 GeV²



For Q^2 = 1 and 1.7 GeV^2 prominent negative Δ peak – no duality

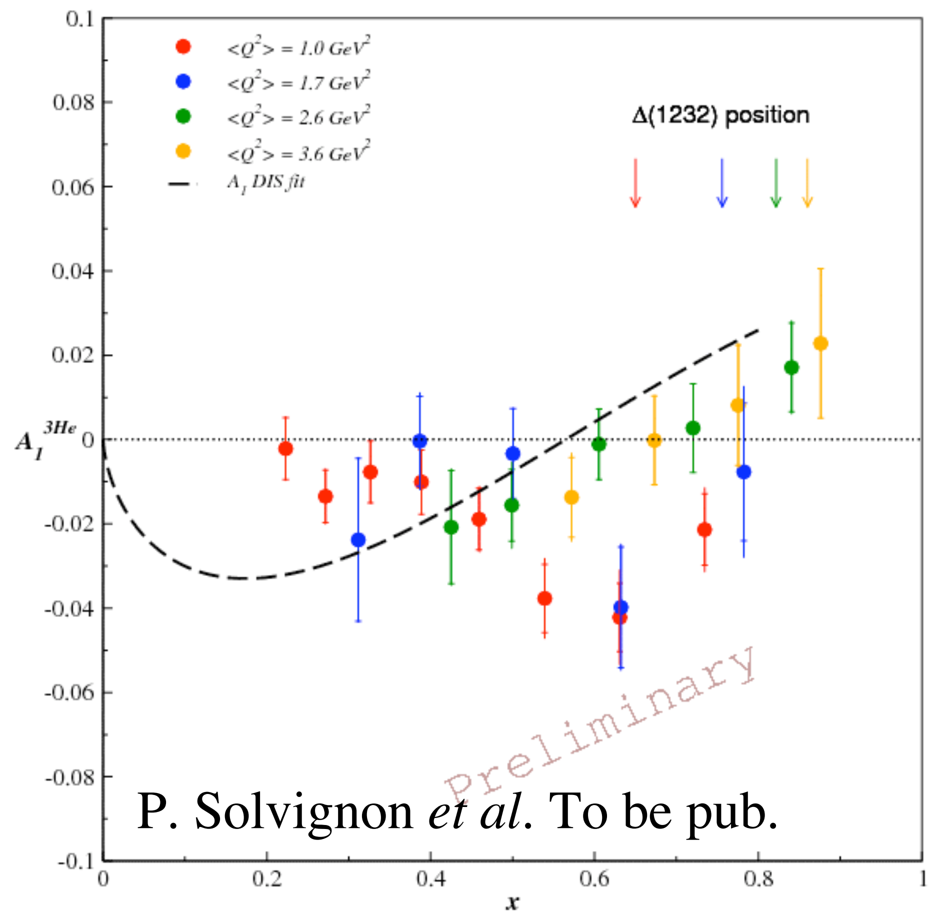
A_1 ^{3}He : New results

$\langle Q^2 \rangle = 3.6\ GeV^2$

$\langle Q^2 \rangle = 2.6\ GeV^2$

$\langle Q^2 \rangle = 1.7\ GeV^2$

$\langle Q^2 \rangle = 1\ GeV^2$



For Q² = 1 and 1.7 GeV² prominent negative Δ peak – no duality

For Q² = 2.6 and 3.6 GeV²,

- No Δ peak
- No Q² dependence
- DIS type behavior from resonance data – duality !

Resonant Spin Structure
of the
Proton and Deuteron

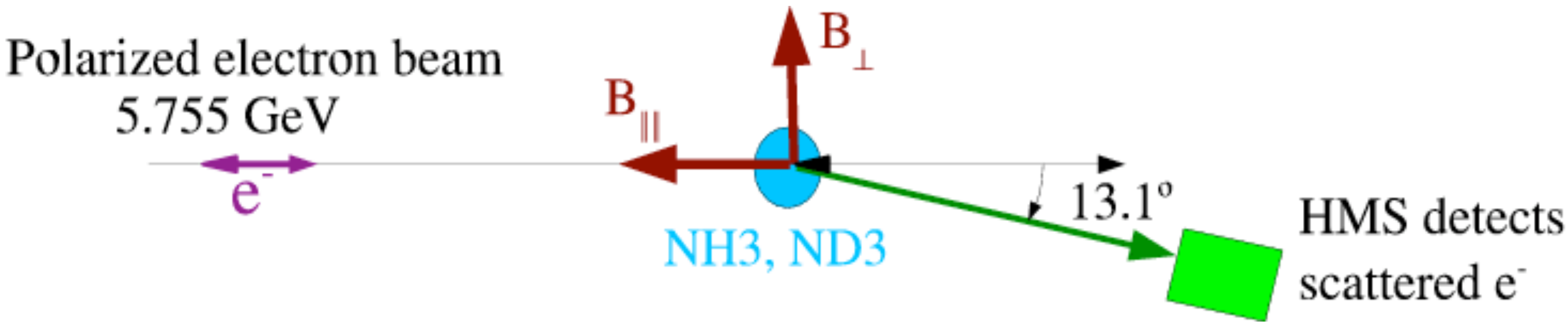
Mark K. Jones
JLAB

Oscar A. Rondon
UVA

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

The RSS Experiment



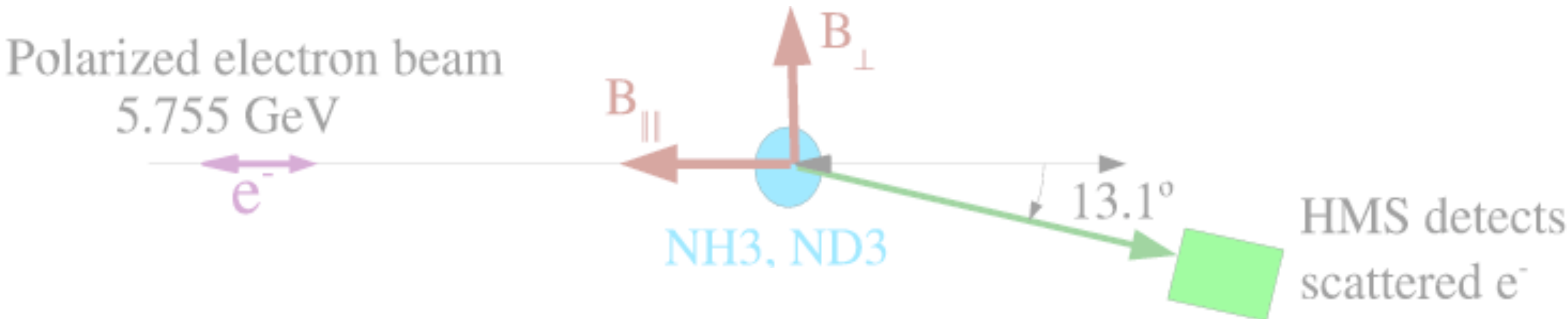
GOALS:

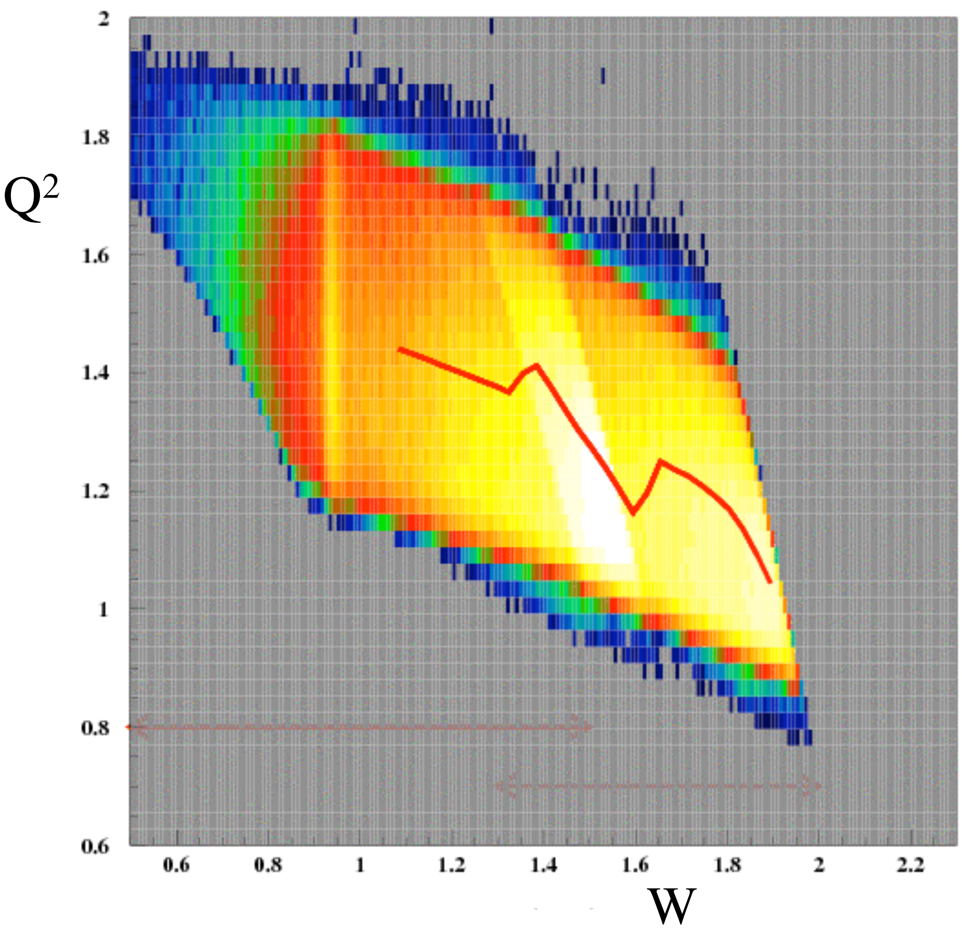
Proton & Deut Spin structure g_1 and g_2

Study onset of polarized local duality

Twist-3 effects

The RSS Experiment





<u>GOALS</u>:

Proton & Deut Spin structure g_1 and g_2

Study onset of polarized local duality

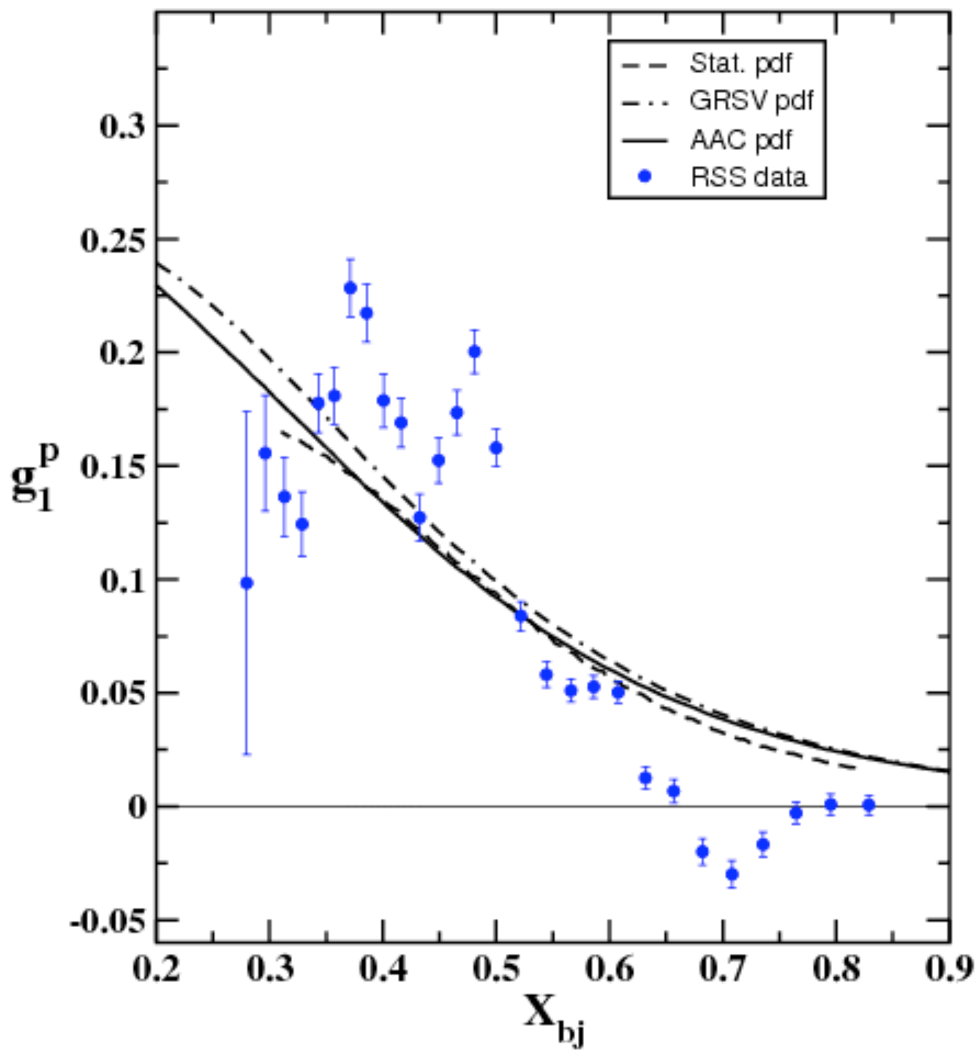
Twist-3 effects

<u>Kinematics</u>

$Q^2 \sim 1.3\ GeV^2$

$0.8 < W < 2.0\ GeV^2$

Test of Polarized Duality



PDFs

GRSV: Phys. Rev. D 53, (1996) 4775

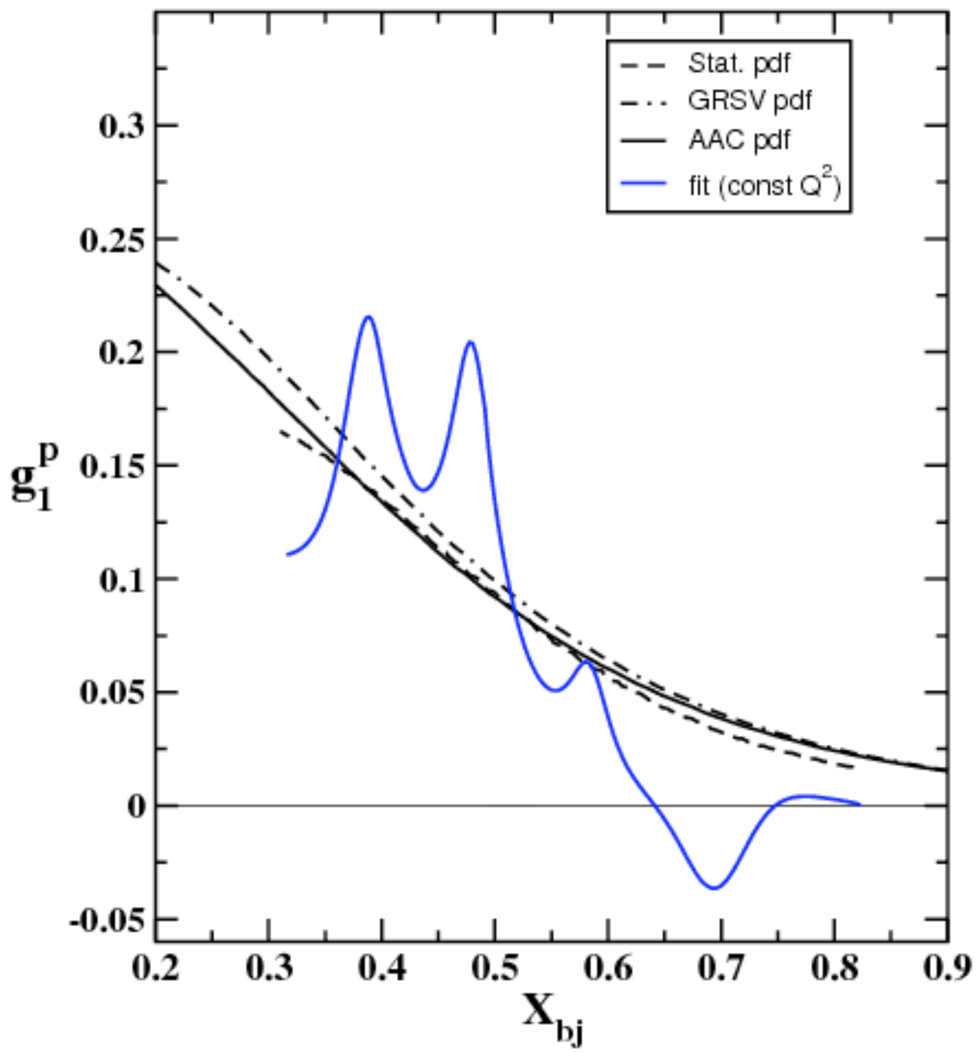
BSB : Eur. Phys. J. C 41, (2005) 327

AAC : Phys. Rev. D 62, (2000) 034017

All pdfs evolved to Q^2=1.279
Target mass corrections applied

$$\overline{\Gamma}_1^{DIS} / \overline{\Gamma}_1^{Res} = 1 \quad ??$$

Global Duality



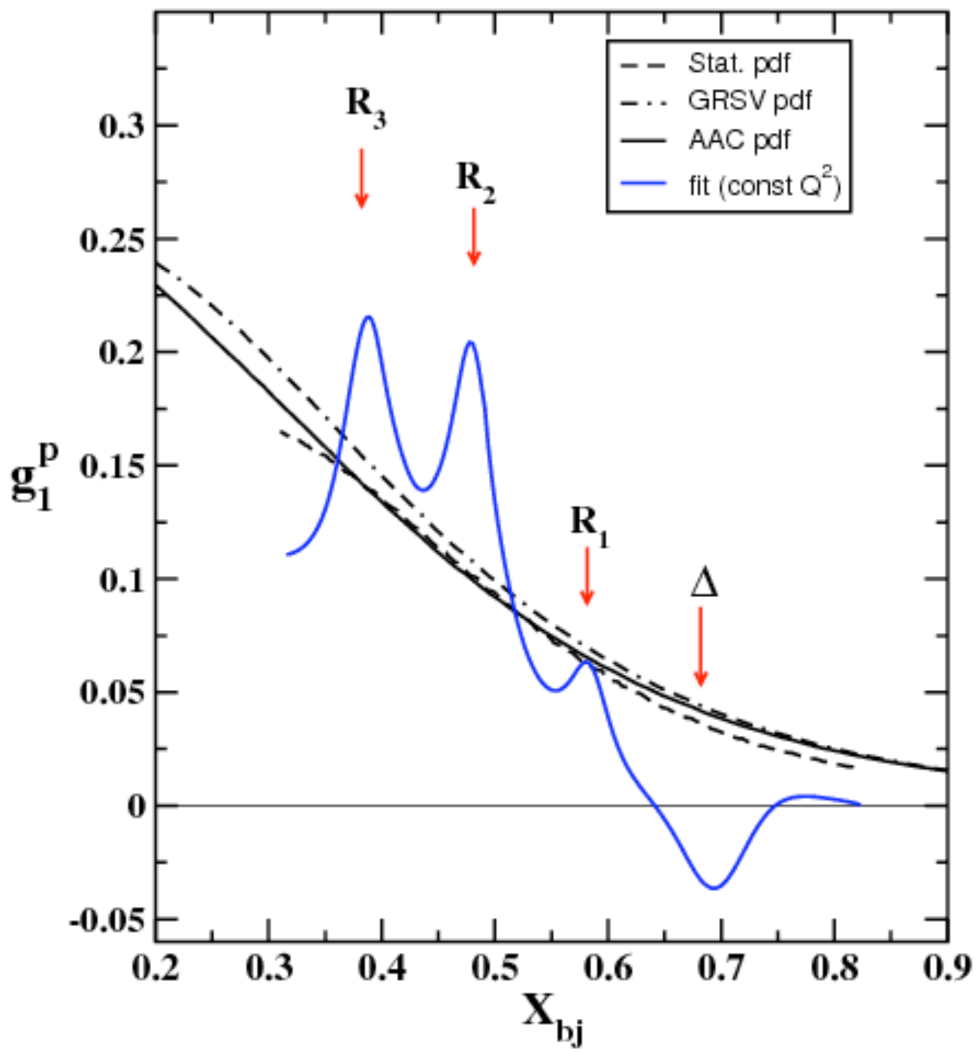
	BSB	GRSV	AAC	AVE
Global	1.11	1.23	1.14	1.17+-0.08

$$\overline{\Gamma}_1^{DIS} / \overline{\Gamma}_1^{Res} = 1 \quad ??$$

Almost….

Large x resummations
Increase discrepency by 1.3

g_1^p:Local Duality



Wesselmann, Slifer, Tajima, *et al*. (RSS Collab)
PRL 98, 132003 (2007)

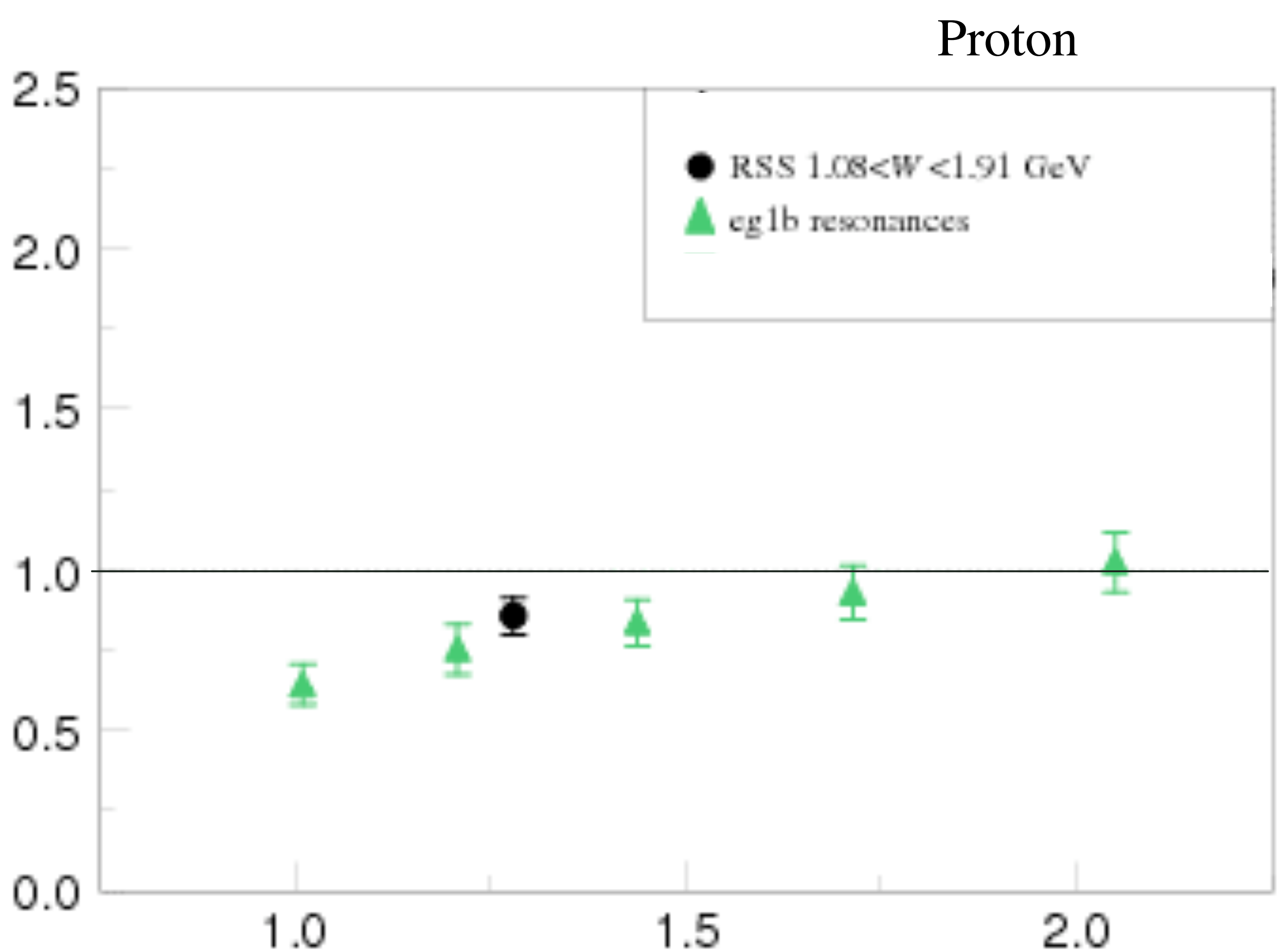
	BSB	GRSV	AAC	AVE
Delta	3.41	4.18	3.96	3.93+-0.58
R1	1.28	1.44	1.33	1.36+-0.10
R2	0.77	0.82	0.75	0.78+-0.05
R3	0.77	0.84	0.77	0.79+-0.06

$$\overline{\Gamma}_1^{DIS} / \overline{\Gamma}_1^{Res} = 1 \quad ??$$

Not locally

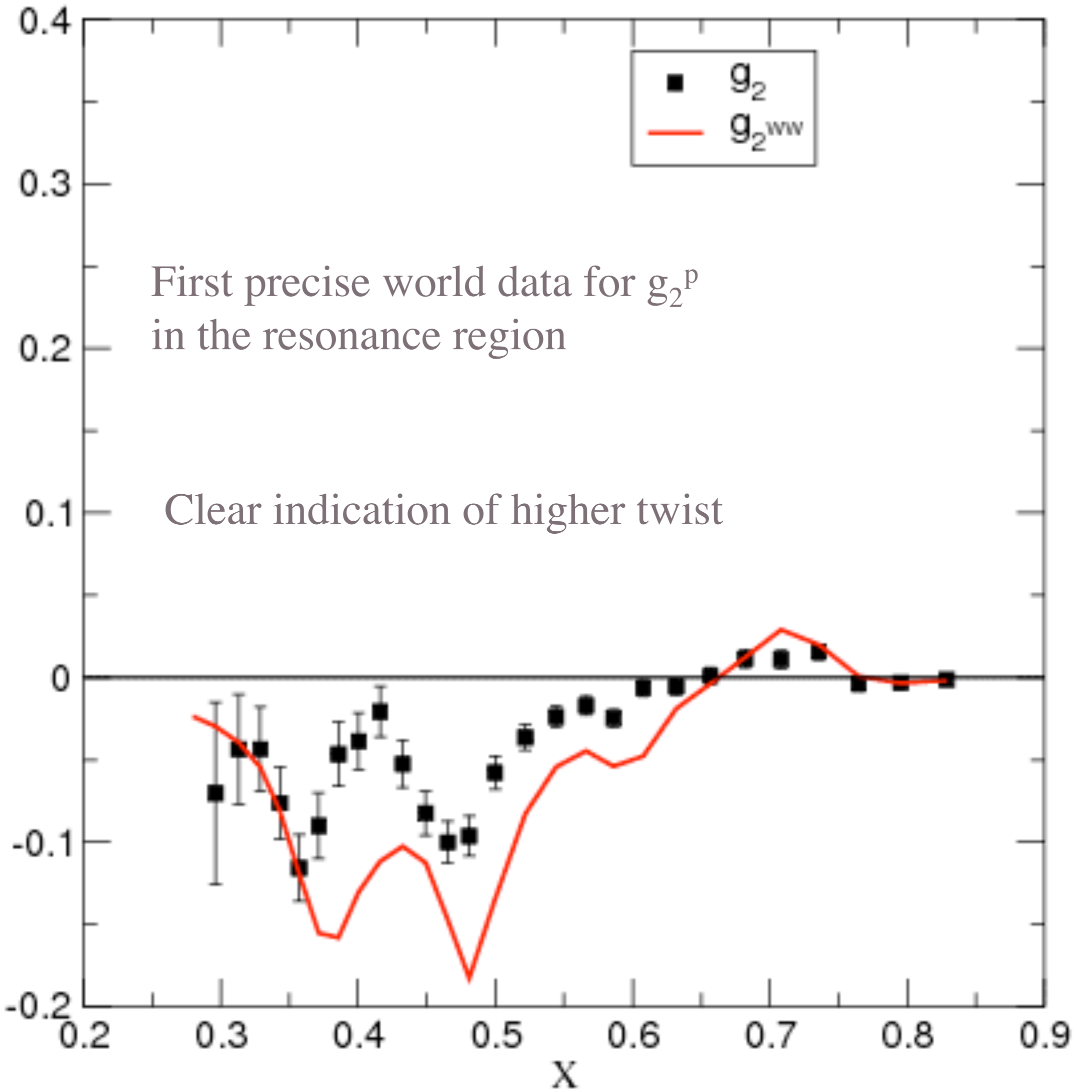
Onset of Global Duality

$$\frac{\Gamma_1^{\mathrm{Re}\,s}}{\Gamma_1^{DIS}}$$



Melnitchouk, Ent & Keppel,
Phys. Rep. 406, 127 (2005)

Higher Twist in g_2



Higher twist

$$g_2 = g_2^{WW} + \bar{g}_2$$

<u>Wandzura-Wilczek relation</u>

PLB 72, 195 (1977)

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

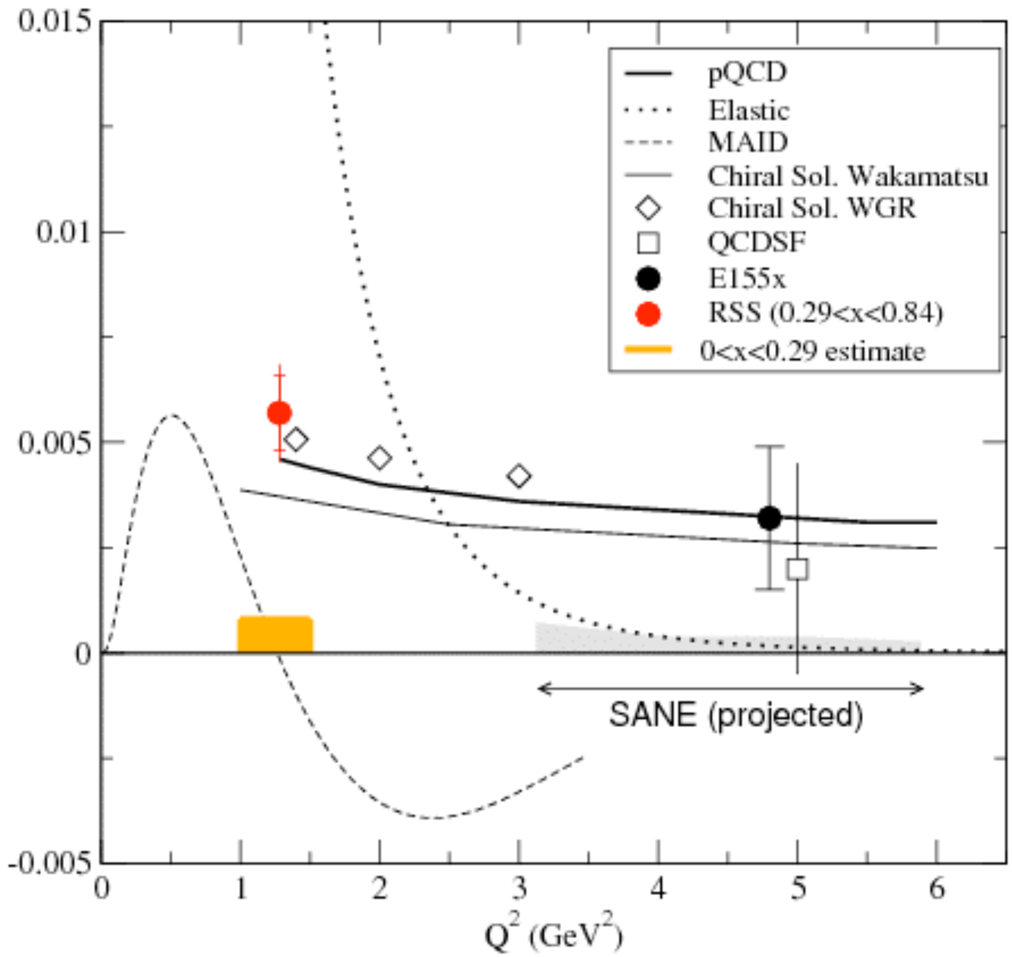
Leading twist determined by g_1

Twist-3

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

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

Cornwall-Norton moment



Measured: 0.29<x<0.84

$$d_2 = 0.0057 \pm 0.0009 \pm 0.0007$$

Unmeasured estimate: x<0.29

$$0.0008 \pm 0.0002$$

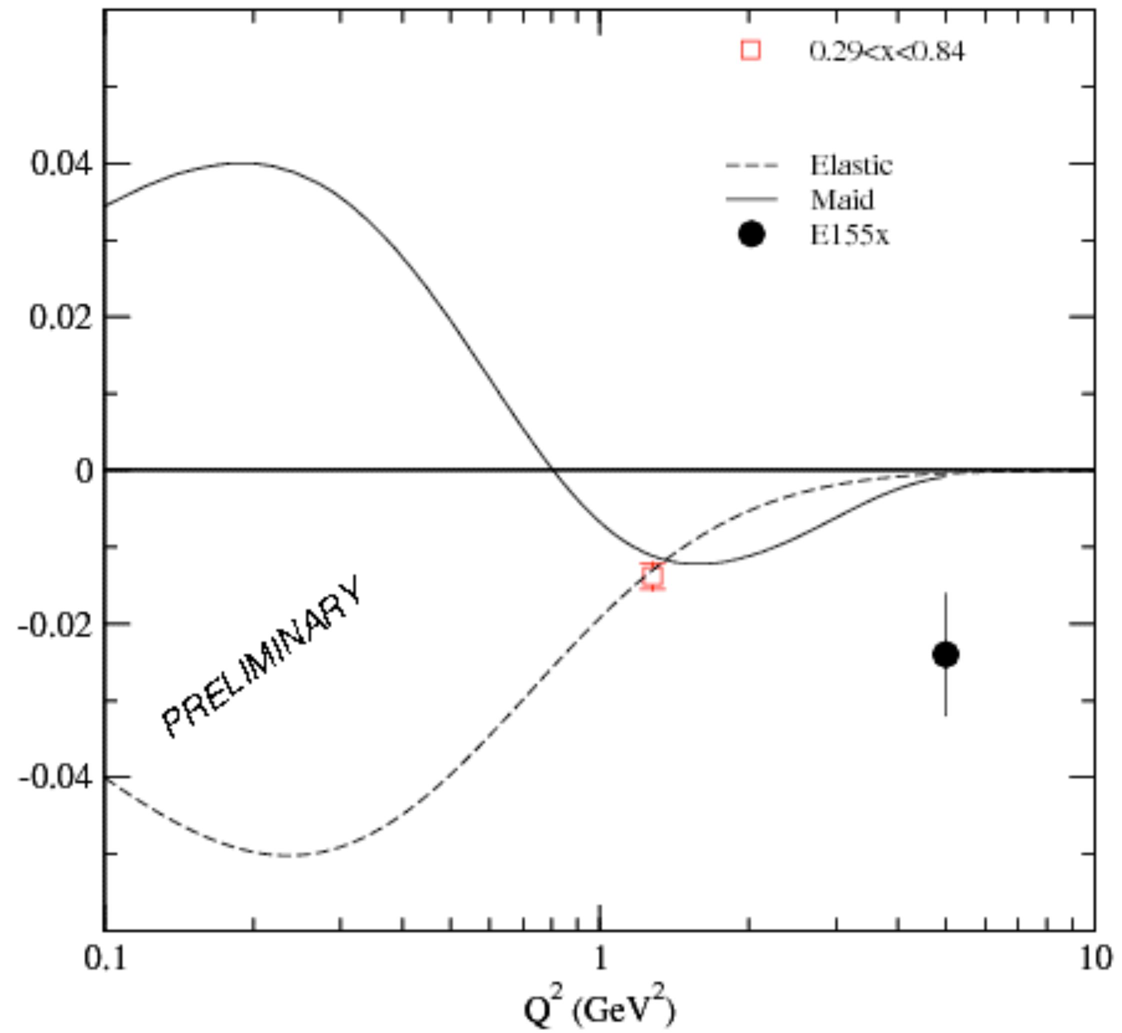
Wesselmann, Slifer, Tajima, *et al.* (RSS Collab)
PRL 98, 132003 (2007)

Burkhardt-Cottingham SR

$$\Gamma_2 = \int_0^1 g_2(x,Q^2)dx = 0$$

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

Resonance region
0.29<x<0.84



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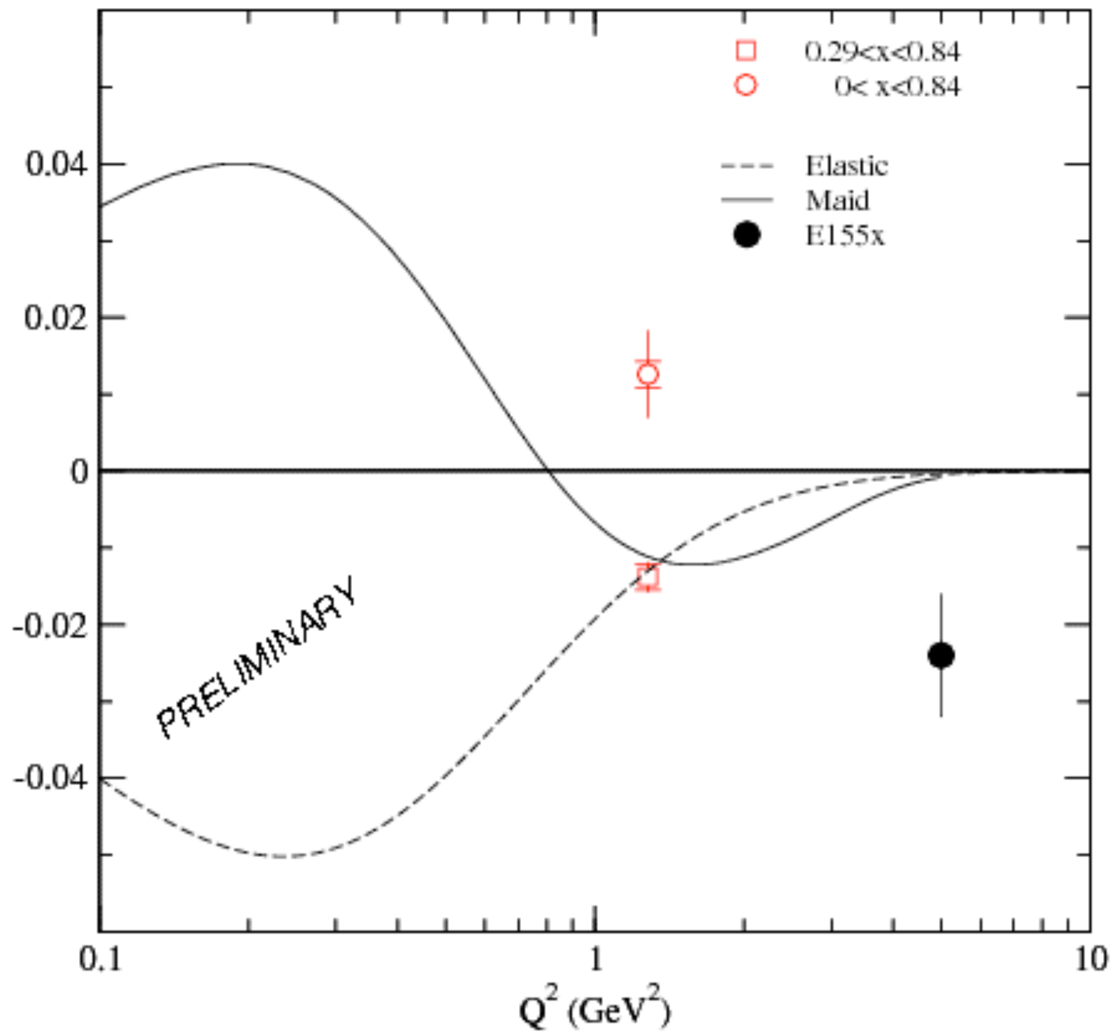
Resonance region+DIS
0<x<0.84

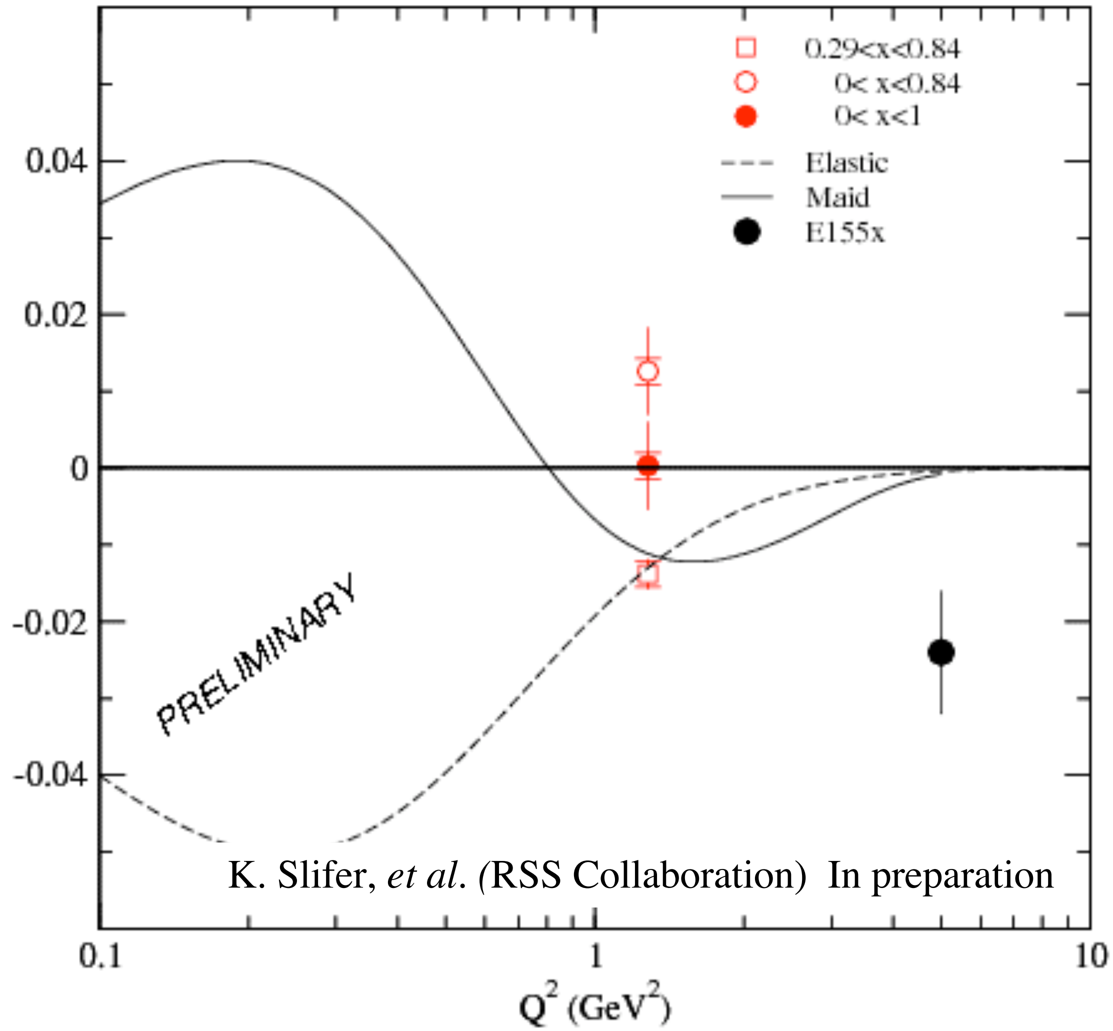


Burkhardt-Cottingham SR

$$\Gamma_2 = \int_0^1 g_2(x,Q^2)dx = 0$$

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

Resonance region+DIS+Elastic
0<x<1



K. Slifer, *et al.* (RSS Collaboration) In preparation

Neutron

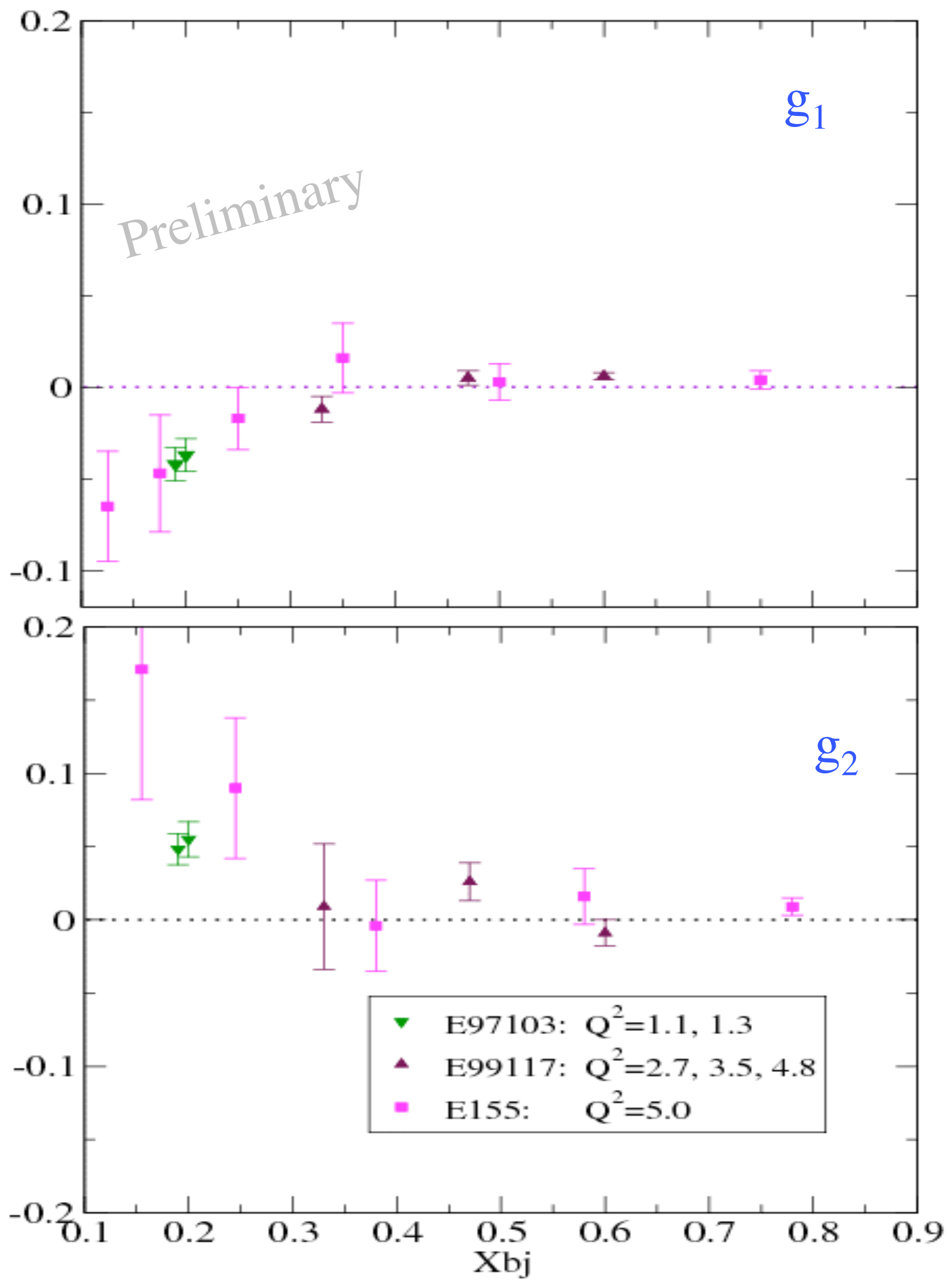
<u>Neutron from Proton and Deuteron</u>

Bodek-Ritchie version of Atwood-West smearing

Generate smeared proton DS by convolution
Of G_1 G_2 with nucleon momentum dist
To get g_1^s, g_2^s

Subtract smeared proton from deuteron to get smeared neutron quantities.

x-dependent D-state correction:
Melnitchouk, Piller, Thomas PLB 346, 165(1995)



Neutron

Neutron from Proton and Deuteron

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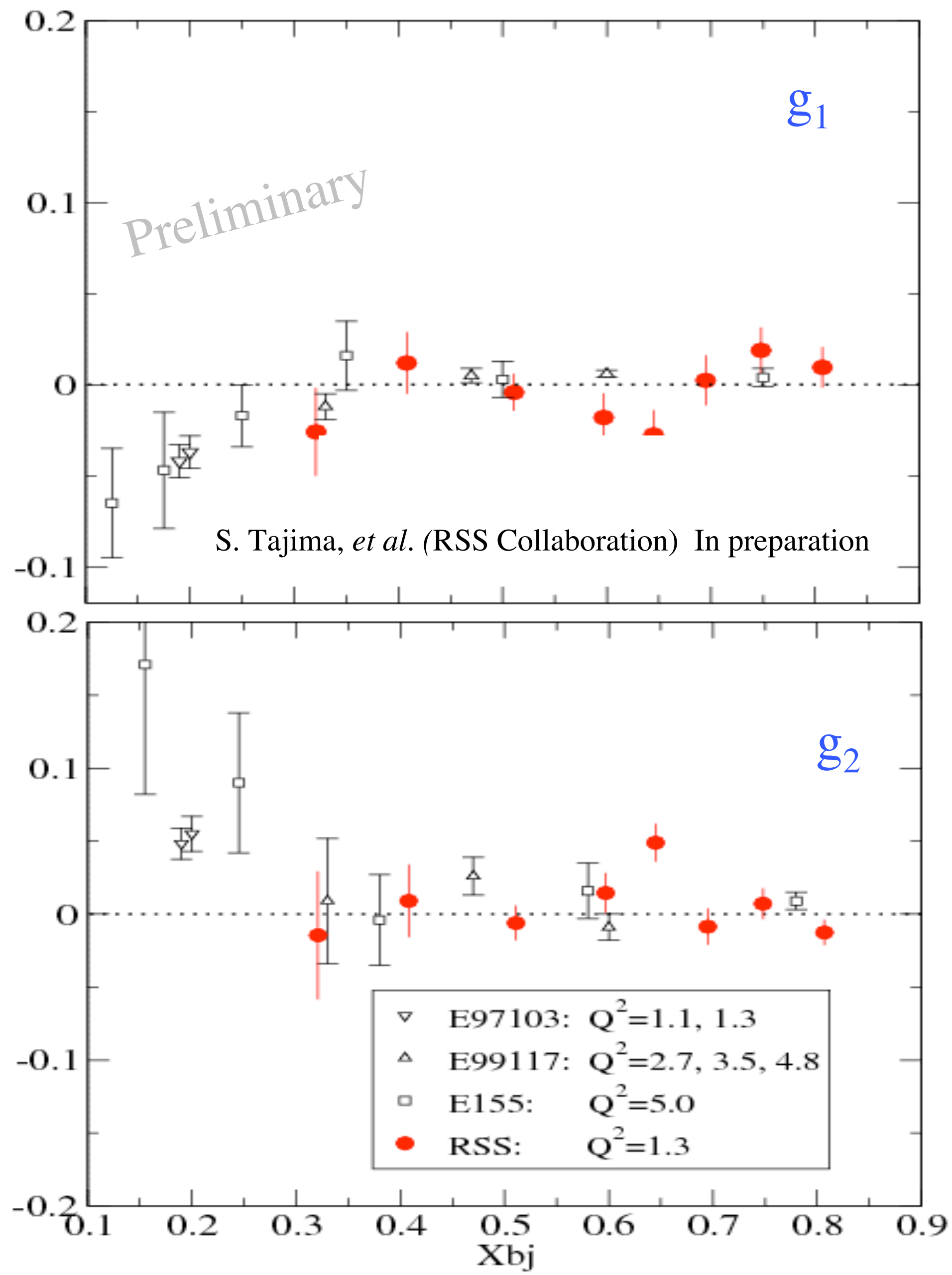


Spin Asymmetries of the Nucleon Experiment

SANE

Oscar A. Rondon
UVA

Seonho Choi
Seoul U.

Zein-Eddine Meziani
Temple U.

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

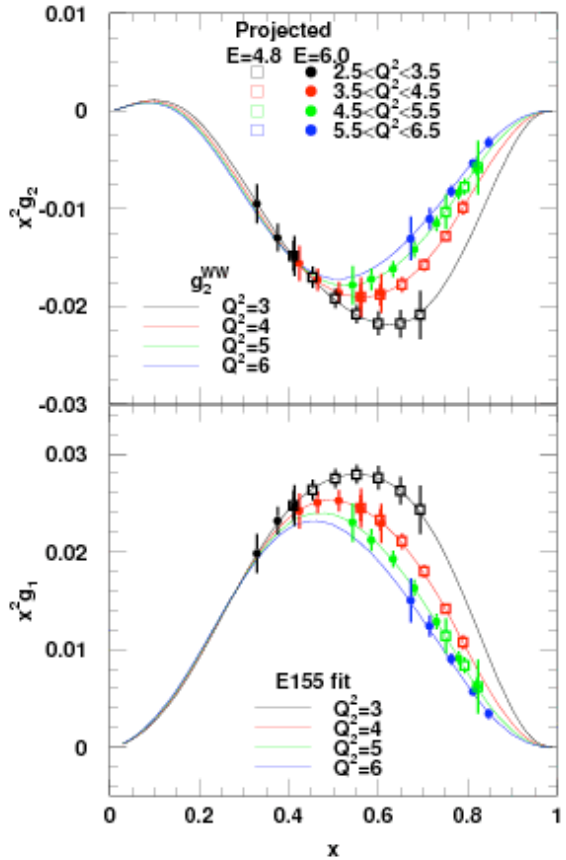
Inclusive double polarization measurement:

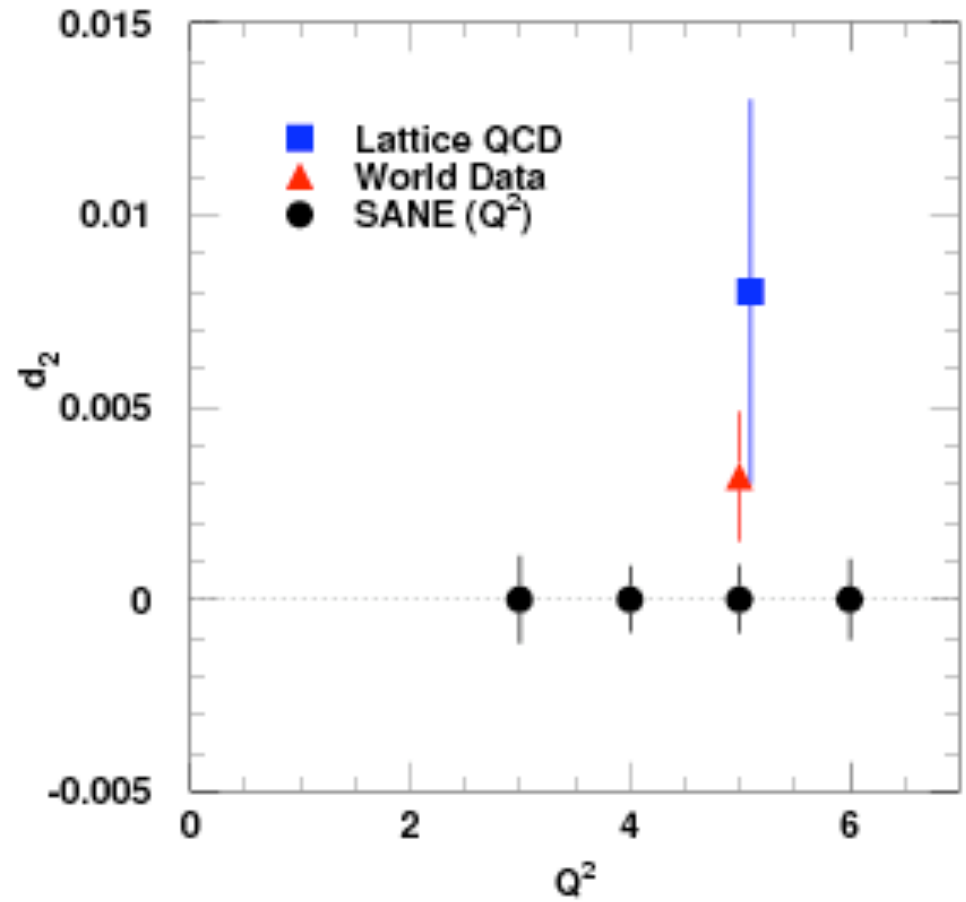
- Will Run in 2008
- Large Solid Angle Electron Telescope : BETA

Explore high x region:

- $2.5<Q^2<6.5$ GeV^2
- Twist-3 effects from moments of g_1 and g_2
- Comparison with LQCD, QCD Sum Rules, bag models, chiral quarks

SANE Projected





δ_{LT} Puzzle

Testing ChPT in the
Generalized Longitudinal-Transverse Spin Polarizability

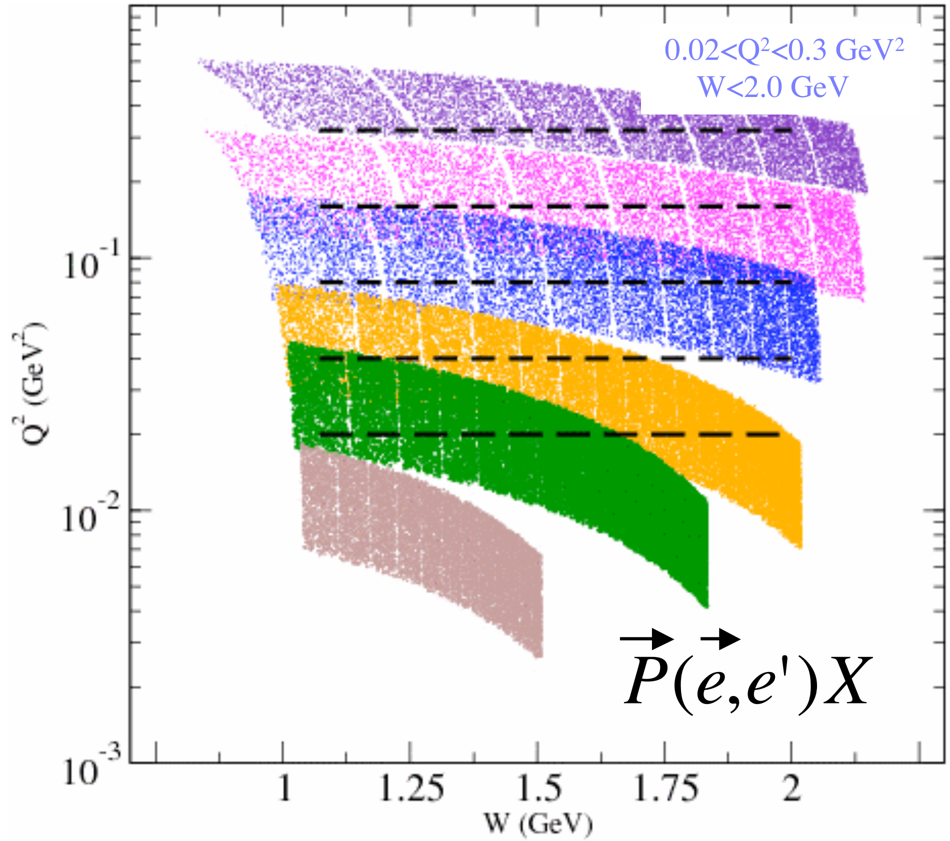
Spokespersons

A. Camsonne, J.P. Chen
JLab

K. Slifer (contact)
UVA

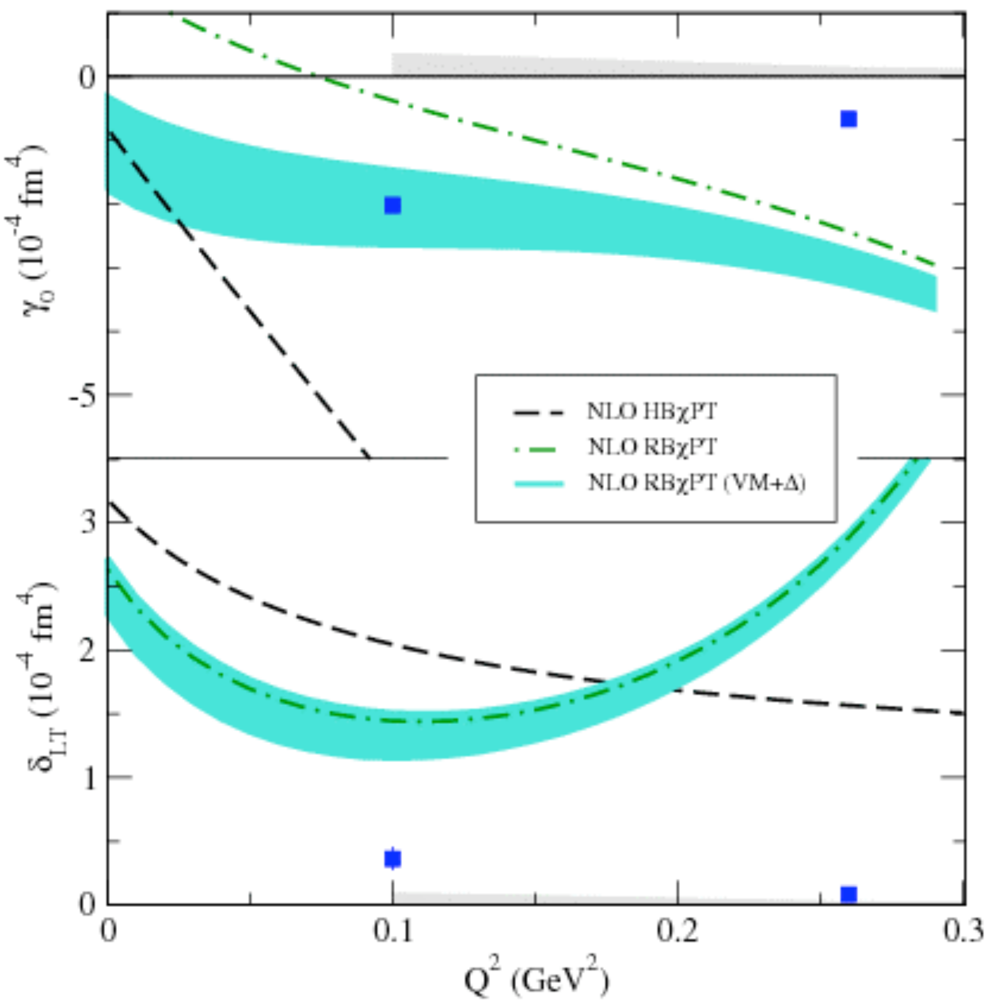
Measurement of g_2^p at low Q^2
--> LT Spin Polarizability

Conditional Approval by the PAC



The Issue

Neutron Spin Polarizabilities



$$\gamma_0(Q^2) = \left(\frac{1}{2\pi^2}\right)\int_{\nu_0}^{\infty}\frac{K(\nu,Q^2)}{\nu}\frac{\sigma_{TT}(\nu,Q^2)}{\nu^3}d\nu$$
$$= \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\left[g_1(x,Q^2) - \frac{4M^2}{Q^2}x^2 g_2(x,Q^2)\right]dx.$$
$$\delta_{LT}(Q^2) = \left(\frac{1}{2\pi^2}\right)\int_{\nu_0}^{\infty}\frac{K(\nu,Q^2)}{\nu}\frac{\sigma_{LT}(\nu,Q^2)}{Q\nu^2}d\nu$$
$$= \frac{16\alpha M^2}{Q^6}\int_0^{x_0} x^2\left[g_1(x,Q^2) + g_2(x,Q^2)\right]dx.$$

One issue of the chPT calcs is how to properly include the Delta resonance contribution.

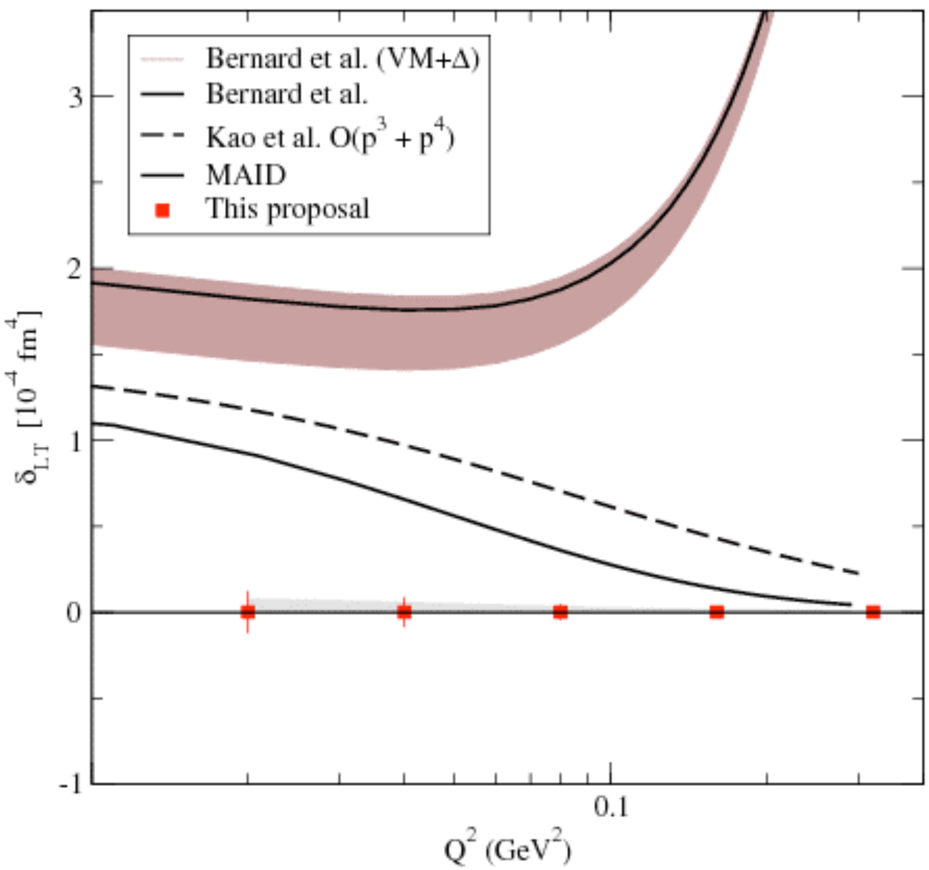
Expected that δ_{LT} would be good place to test chPT…

Instead find good agreement with γ_0

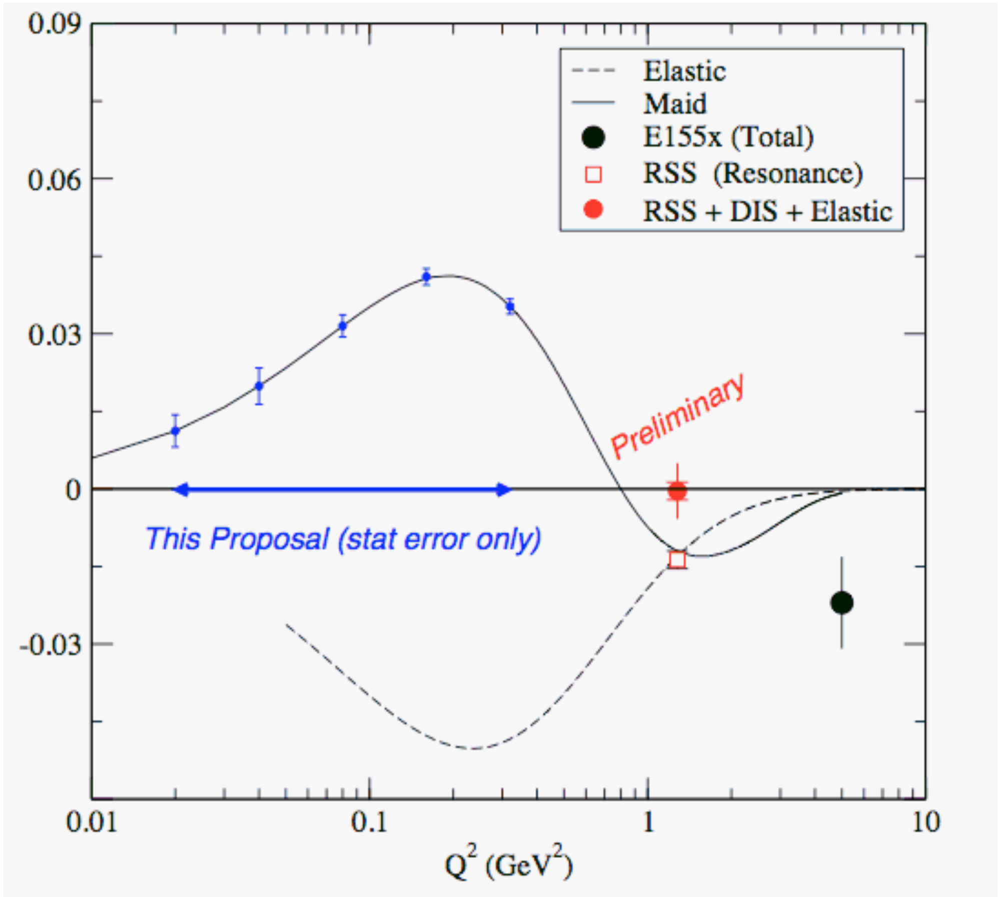
We need the isospin dependence to resolve this discrepency

Expected Precision

δ_{LT}



B.C Sum Rule



Conclusion

<u>Small sample of the JLab Spin Physics Program</u>

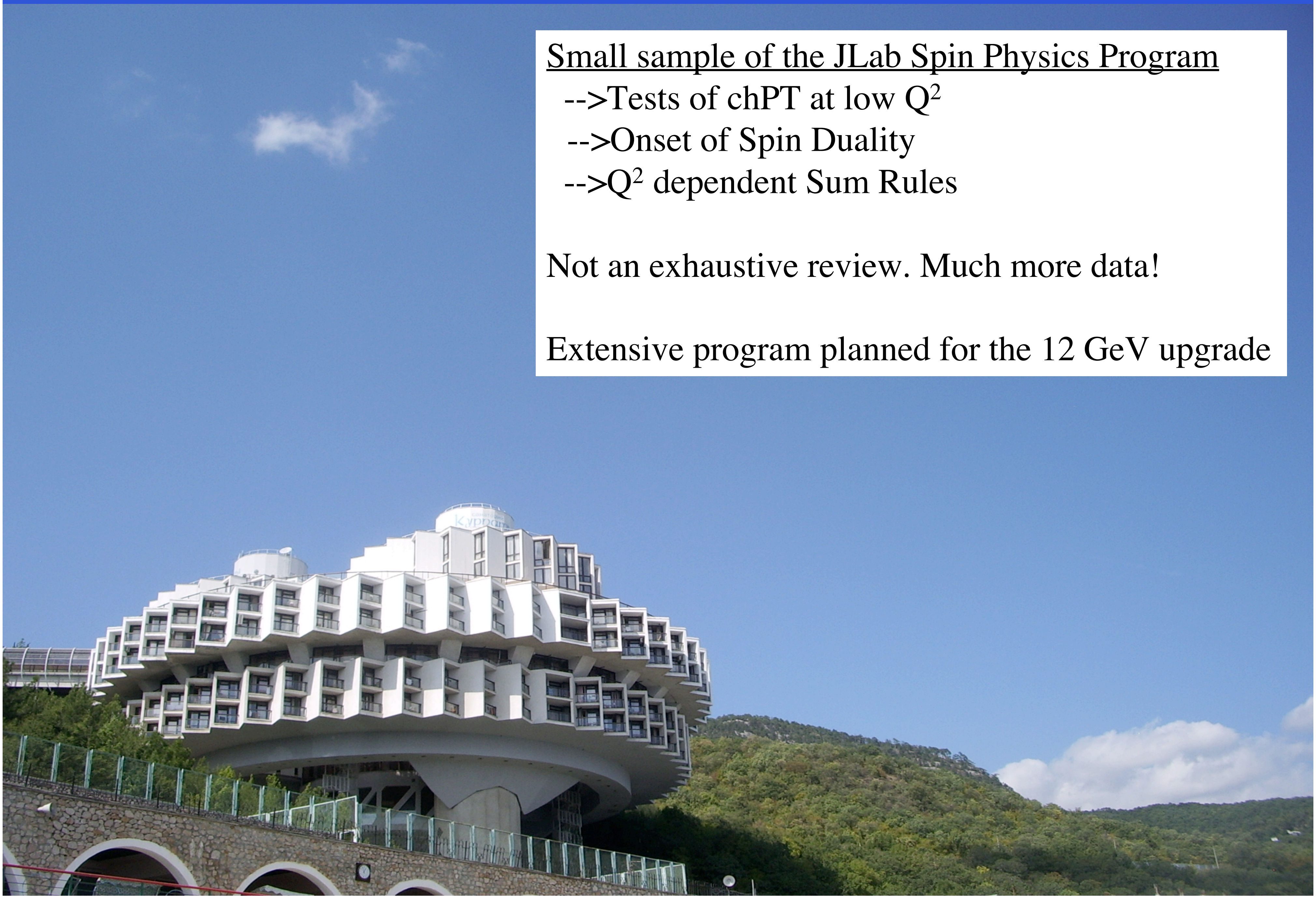
-->Tests of chPT at low Q^2

-->Onset of Spin Duality

-->Q^2 dependent Sum Rules

Not an exhaustive review. Much more data!

Extensive program planned for the 12 GeV upgrade



Target Mass Corrections

Purely kinematic effects from finite value of $4M^2x^2/Q^2$

$$g_1(x,Q^2) = g_1(x,Q^2,M=0)$$

From PQCD

$$+\frac{M}{Q^2} g_1^{(1)TMC}(x,Q^2)$$

Purely kinematical

$$+\frac{h(x,Q^2)}{Q^2} + \vartheta(1/Q^4)$$

Higher twist