A High Precision Measurement of the Deuteron Spin-Structure Function Ratio g_1/F_1

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Spin Structure at Long Distance Workshop, March 2009

- **Motivation**
- **Proposed Experiment**
- **Expeced Results**

$\Delta G(x)$

Spin Structure of the Nucleon

- **Spin sum rule: total spin 1/2 formed by quarks (small), gluons, and orbital angular momentum (sum of these must be big).**

- **How much carried by gluons?: major focus of large experimental program worldwide (RHIC, DESY, CERN, JLab…).**

- **One of DOE milestone for JLab is precision measurement of spin structure to Q^2=4 GeV^2**

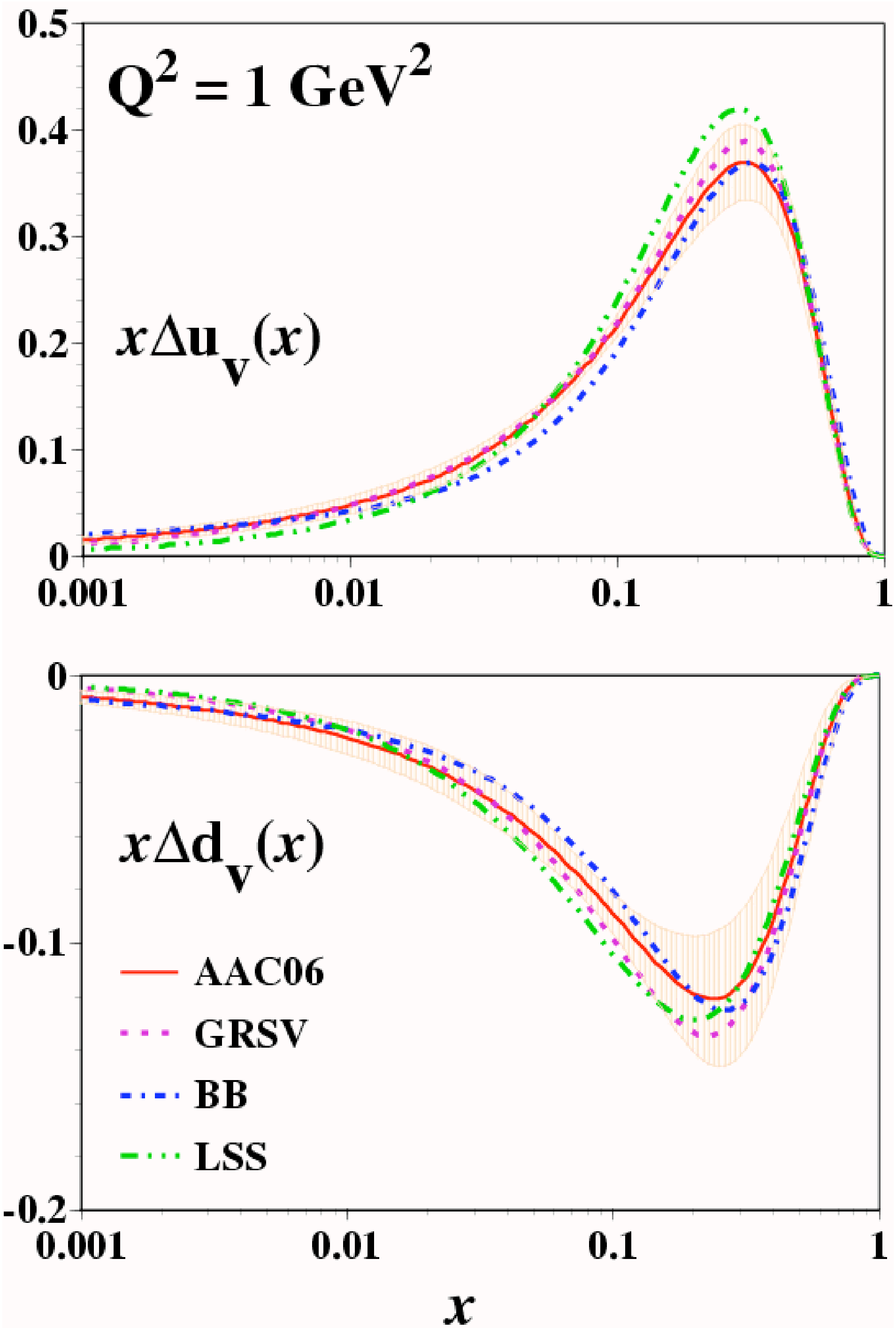
Polarized DIS

➢ Theoretically **cleanest** was to learn about polarized gluons is through pQCD evolution in deep inelastic scattering (DIS)

➢ **Q^2-dependence** at fixed x influenced by gluon radiation [log(Q^2)]. Wilson coefficients calculated to NLO in pQCD.

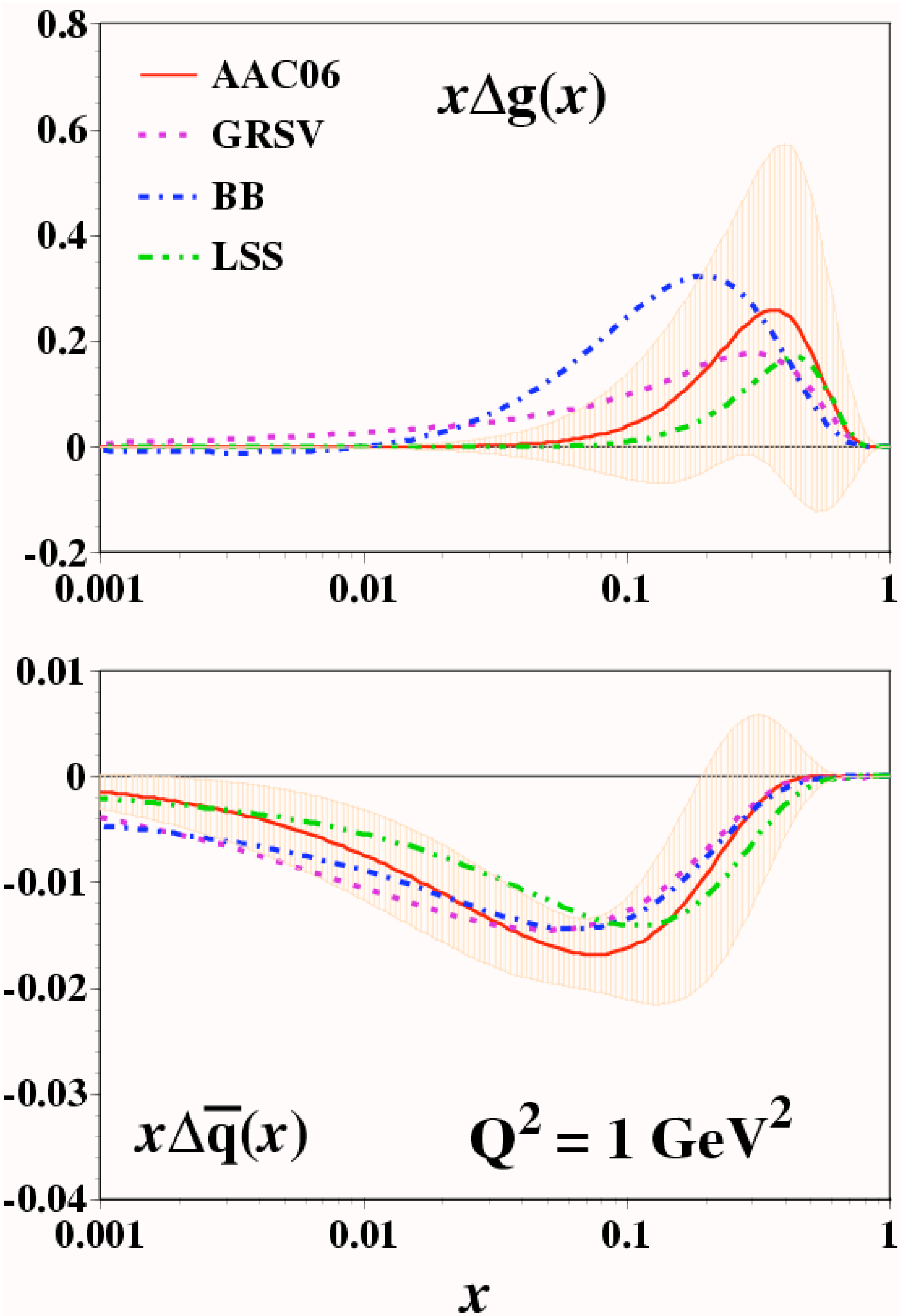
$$g_1(x,Q^2)_{\rm pQCD} = \frac{1}{2}\sum e_q^2 \left[(\Delta q + \Delta\bar{q}) \otimes \left(1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q\right) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \otimes \frac{\delta C_G}{N_f} \right]$$

➢ Largest sensitivity at **low Q^2** where α_s largest (but need to account for power law higher twist)



Valence Quarks

- Pretty **well known** now, primarily from measurements of proton and neutron g_1



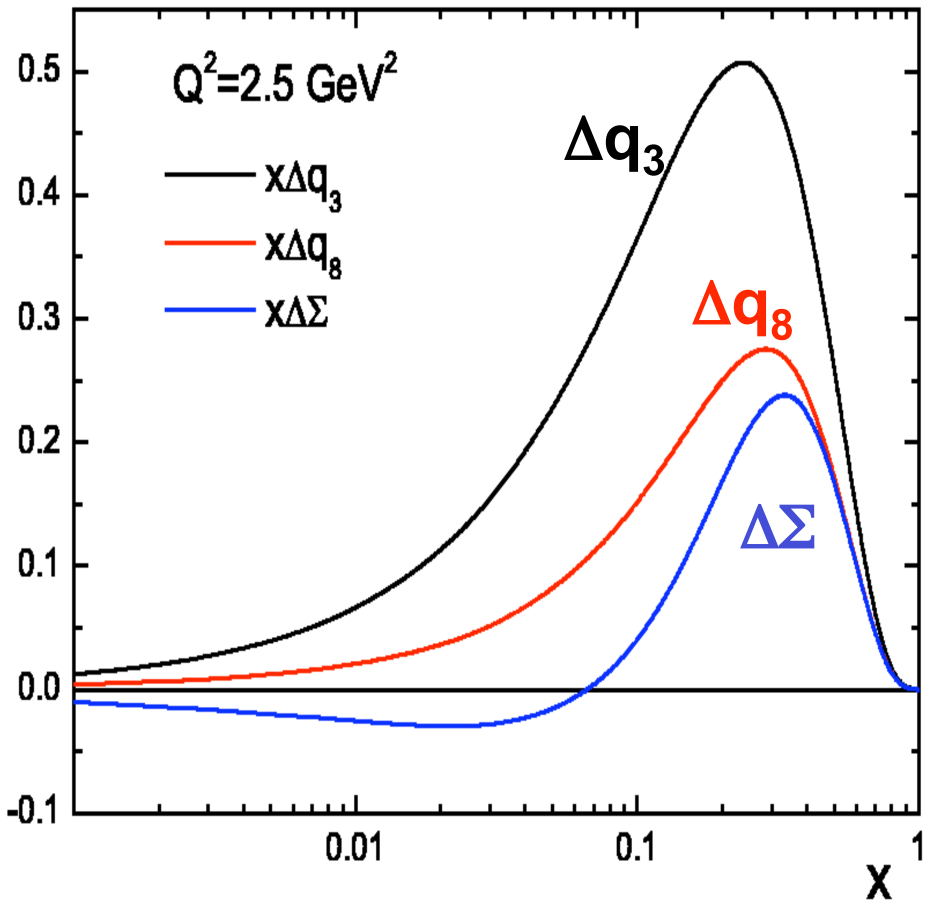
Gluons and Sea Quarks

- Gluon polarization **poorly known** (just that not maximal, probably positive). Need more precise data! **Main goal of this experiment.**

- Sea quark knowledge will improve with SIDIS studies in future.

Why deuteron best for ΔG(x)?

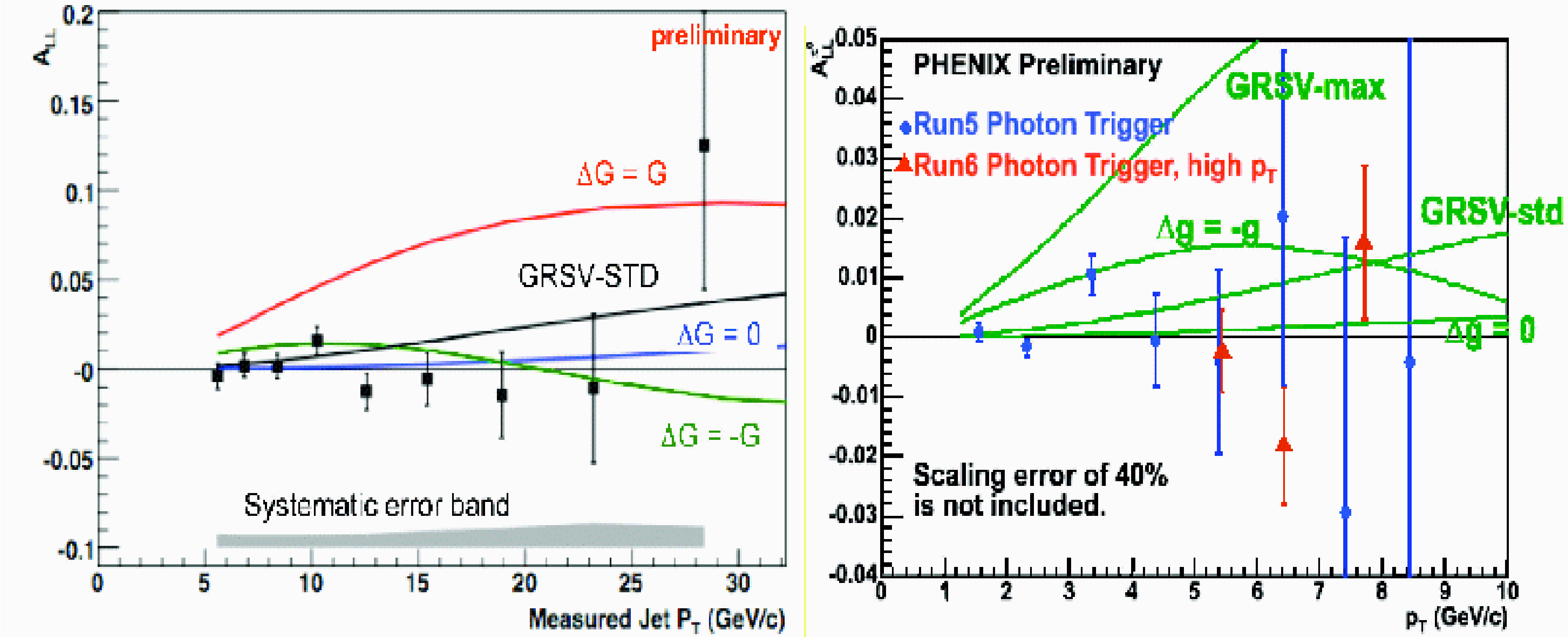
$$g_1^{p(n)}(x,Q^2) = \frac{1}{9}[(\pm\frac{3}{4}\Delta q_3 + \frac{1}{4}\Delta q_8 + \Delta\Sigma)\otimes(1+\frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \otimes \delta C_G]$$



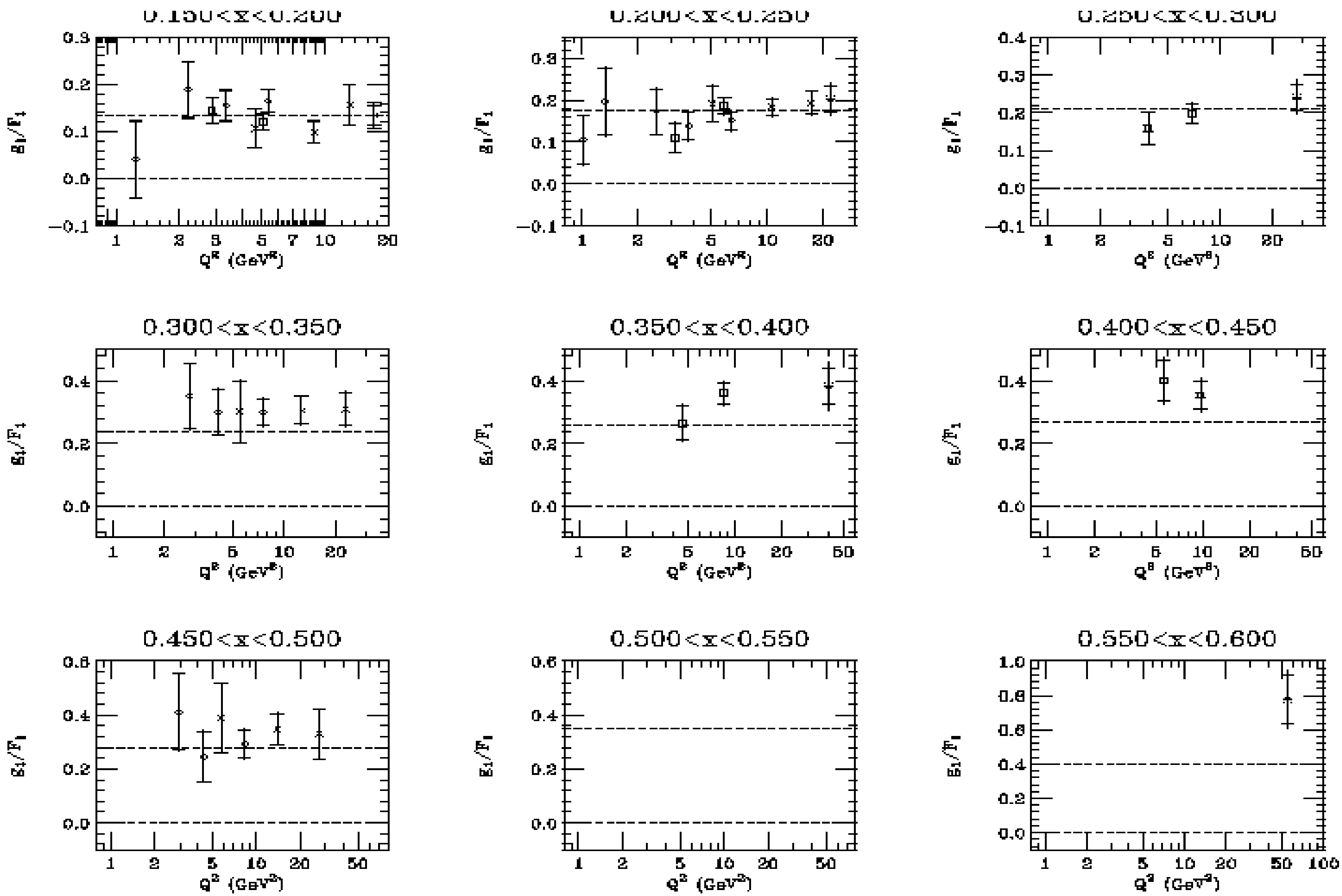
- The Δq_3 terms from p and n, about twice size of Δq_8 and $\Delta\Sigma$ terms, **cancels** in deuteron.
- **Relative** gluon contributions largest in deuteron: relevant as experimental errors dominated by syst. scale factors.

Complementary to RHIC-SPIN

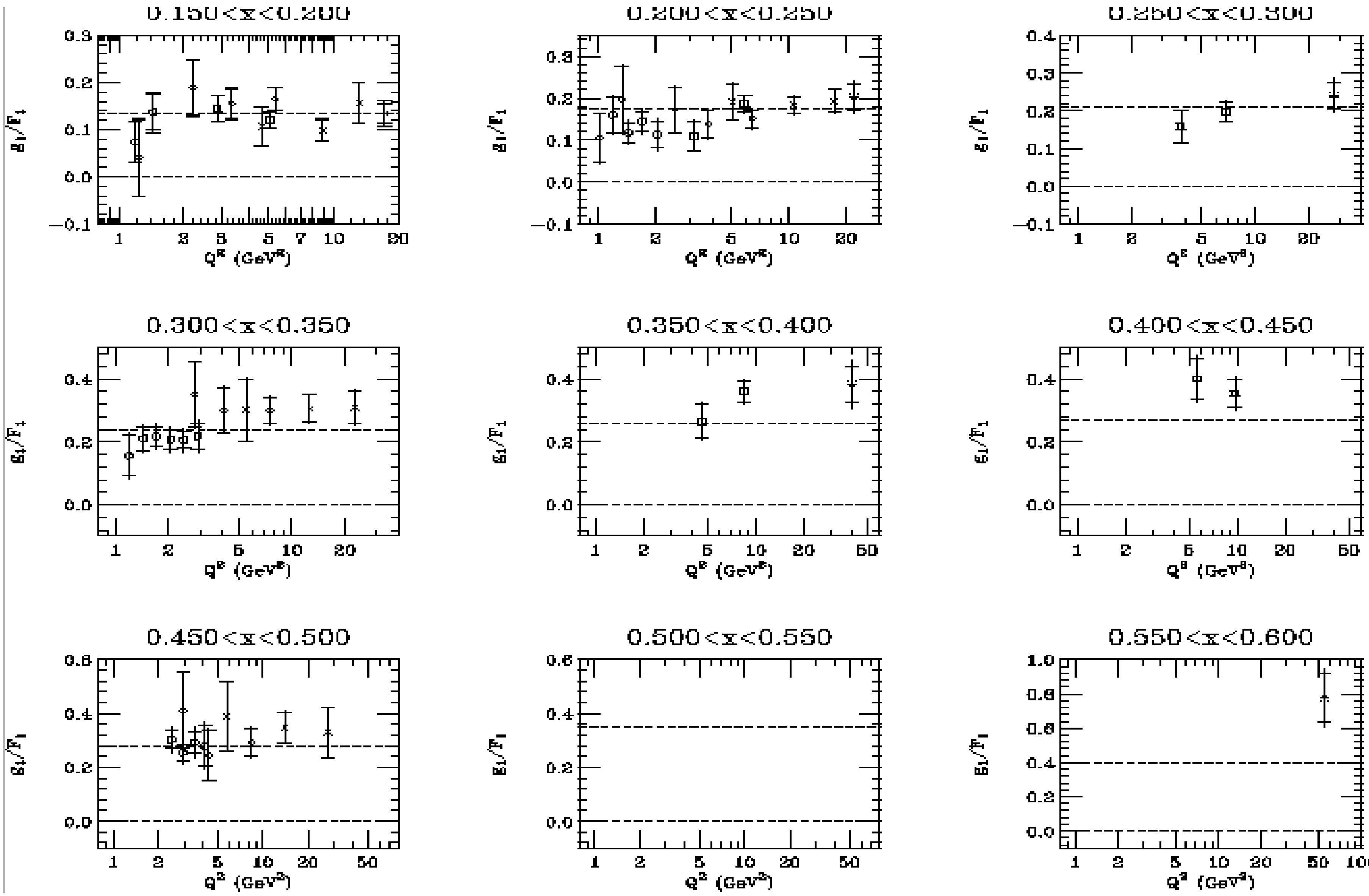
- Measurements such as π^0 from STAR (left) and PHENIX (right) as a function of p_t probe x<0.1.
- This proposal sensitive to x>0.1.
- Results so far rule out ΔG=G.



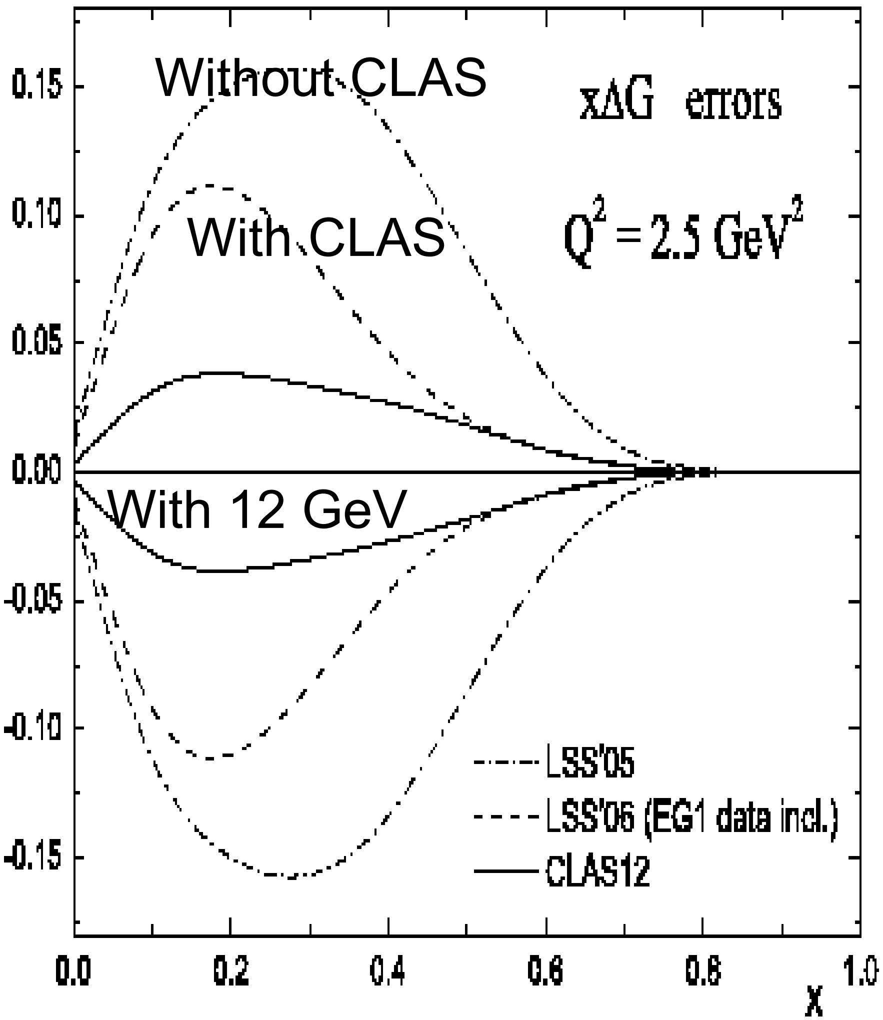
SLAC, DESY, CERN g_1/F_1 data x>0.1



Add recent DIS data CLAS Hall B



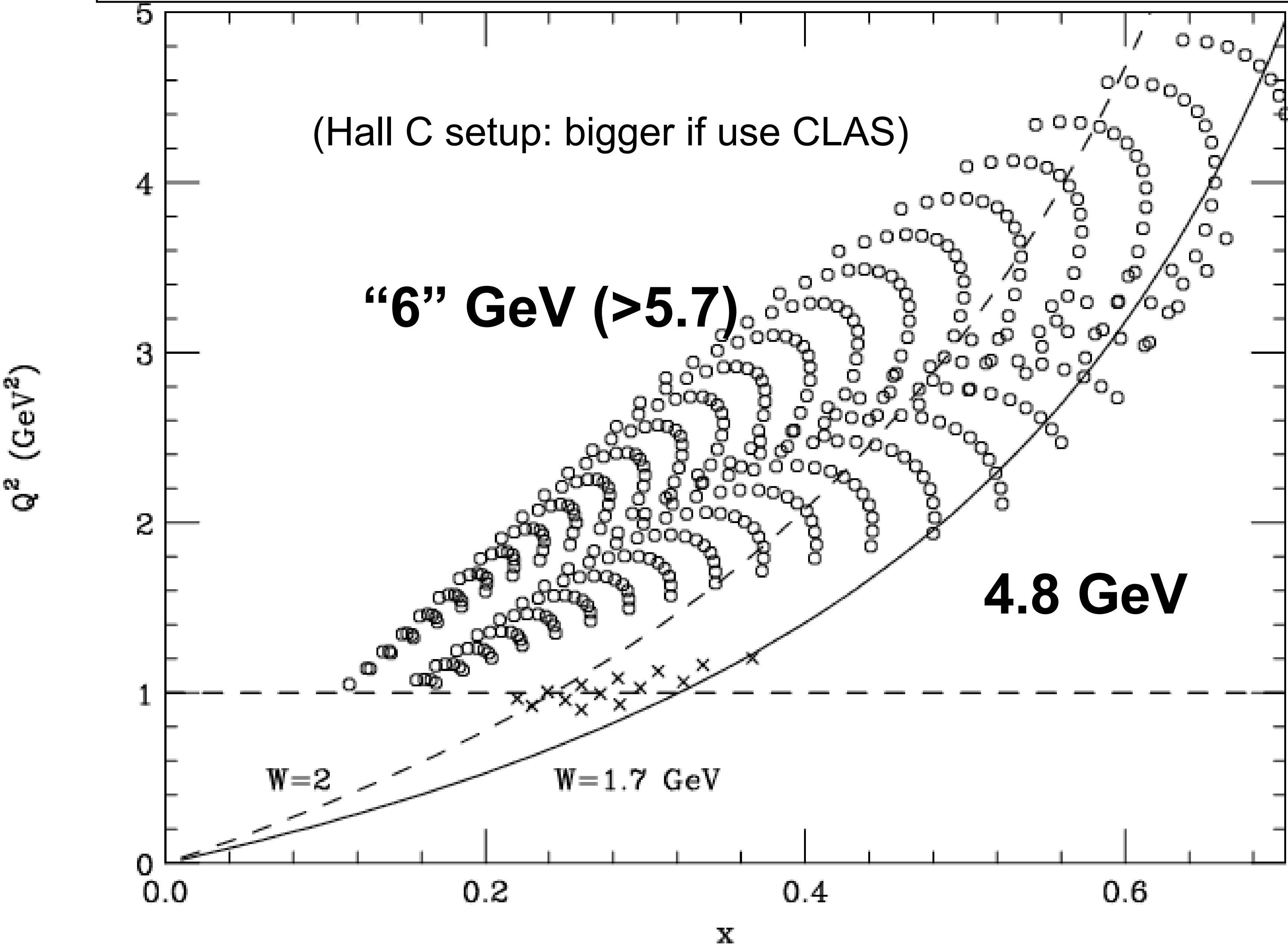
Physics Impact



Adding the CLAS data to the analysis of the LSS group (NLO plus Higher Twist) had a major impact on error band of ΔG(x)

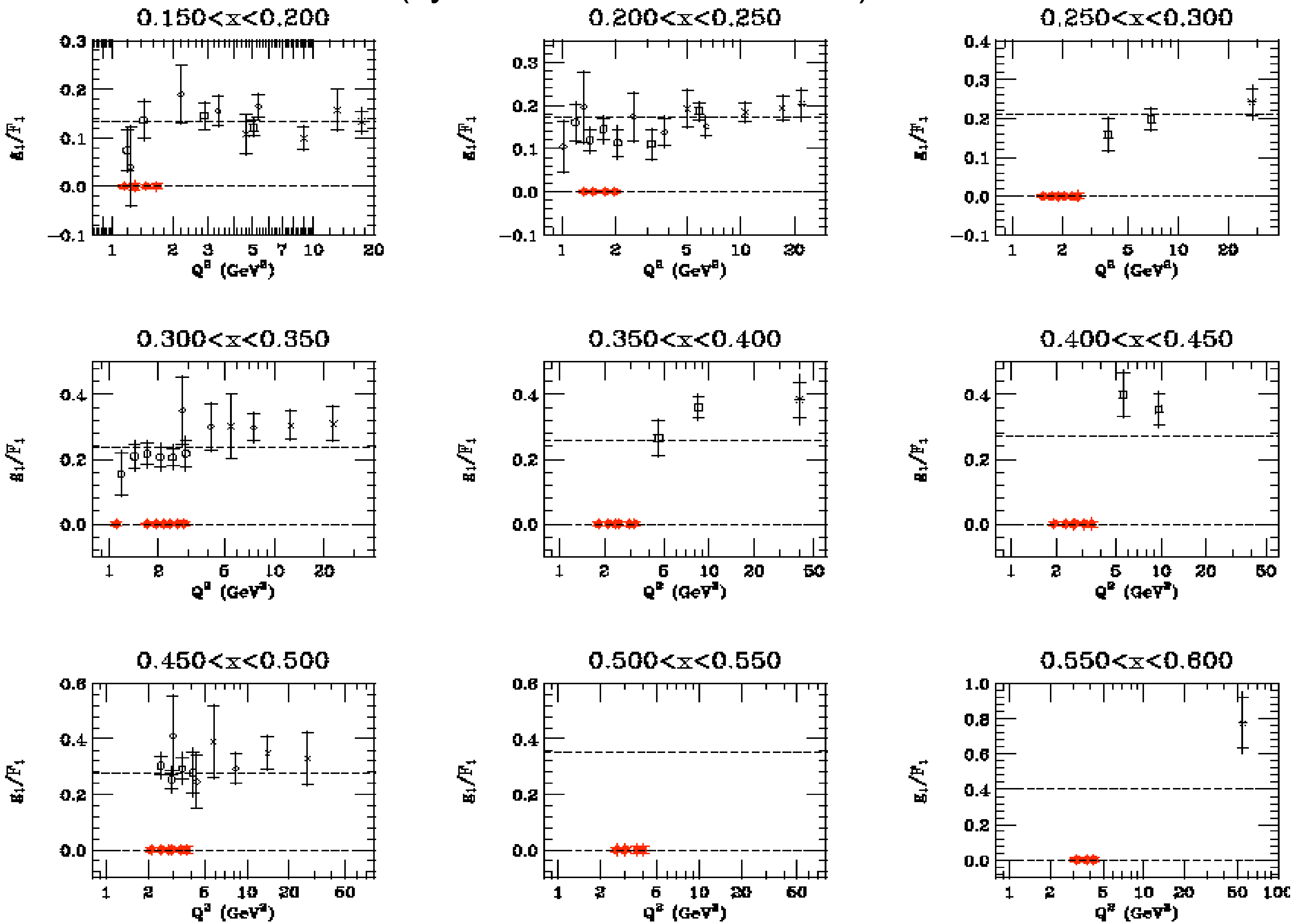
$$g_1^{HT}(x,Q^2) = g_1^{TM}(x,Q^2) + \frac{h(x)}{Q^2}$$

Proposed Kinematic Coverage



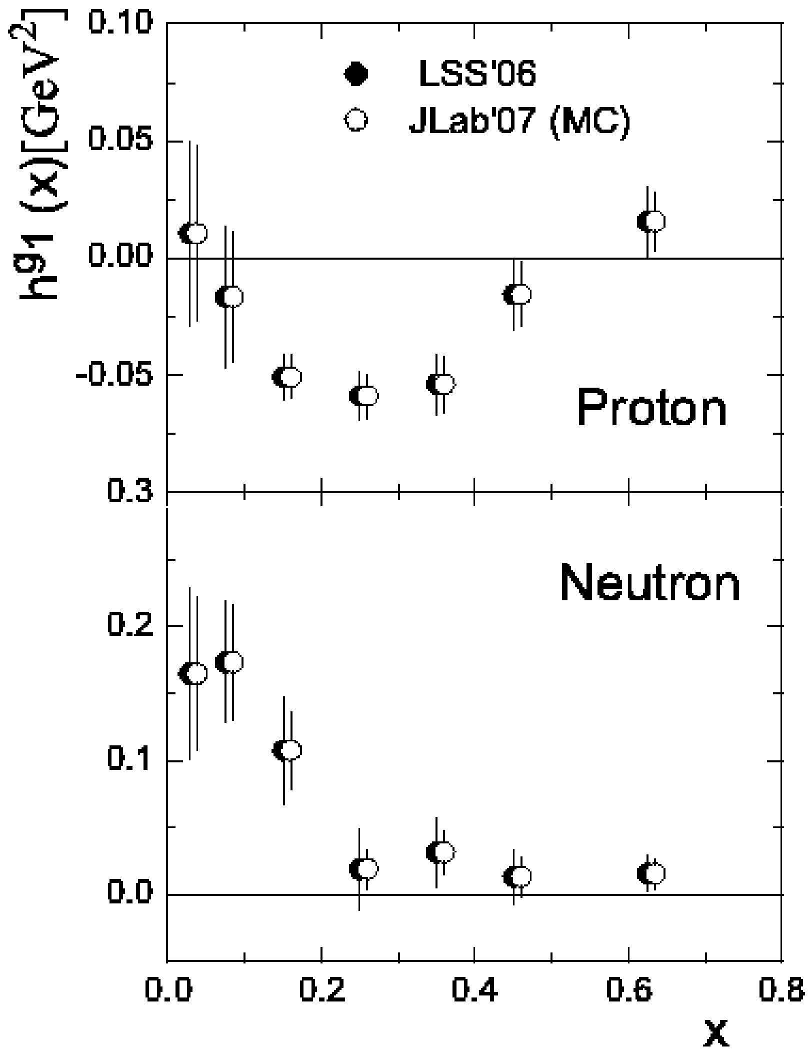
Proposed data shown in red

(systematic errors included)

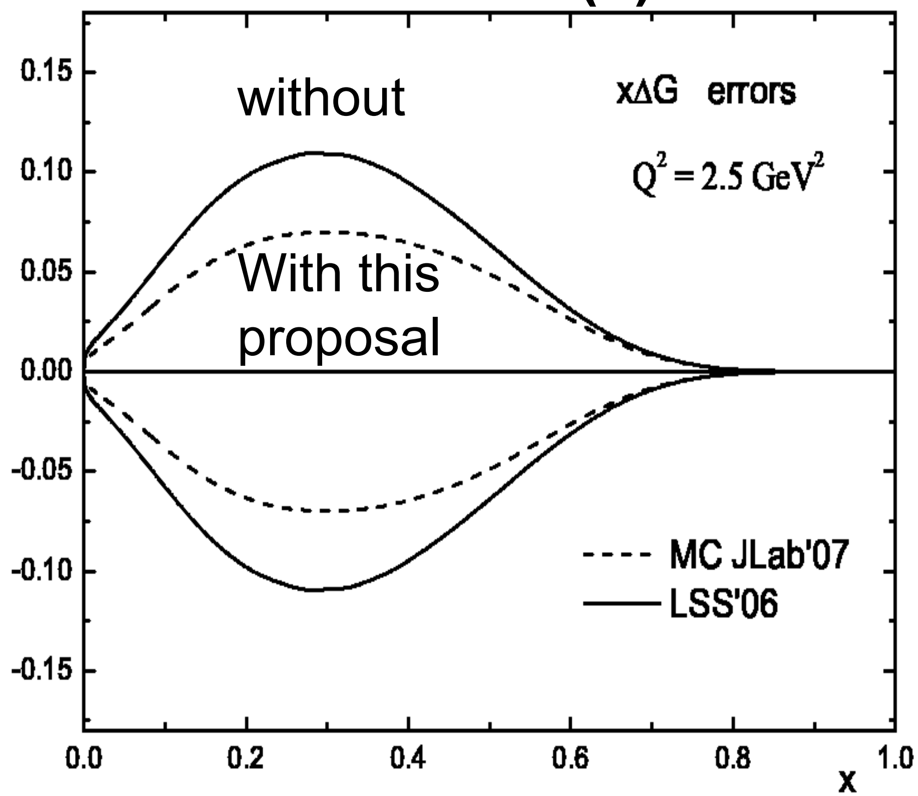


Physics Impact in LSS framework

HT coefficients



Error on ΔG(x)



Significant improvement in ΔG(x) and neutron HT

Physics Impact in AAC framework

Relative error on ΔG [first moment ΔG(x)]

1) World DIS without CLAS Eg1b: 2.08

2) World DIS with CLAS Eg1b: 1.48

3) With this Proposal: 0.96

4) With existing π^0 data RHIC: 0.91

Significant improvement in ΔG

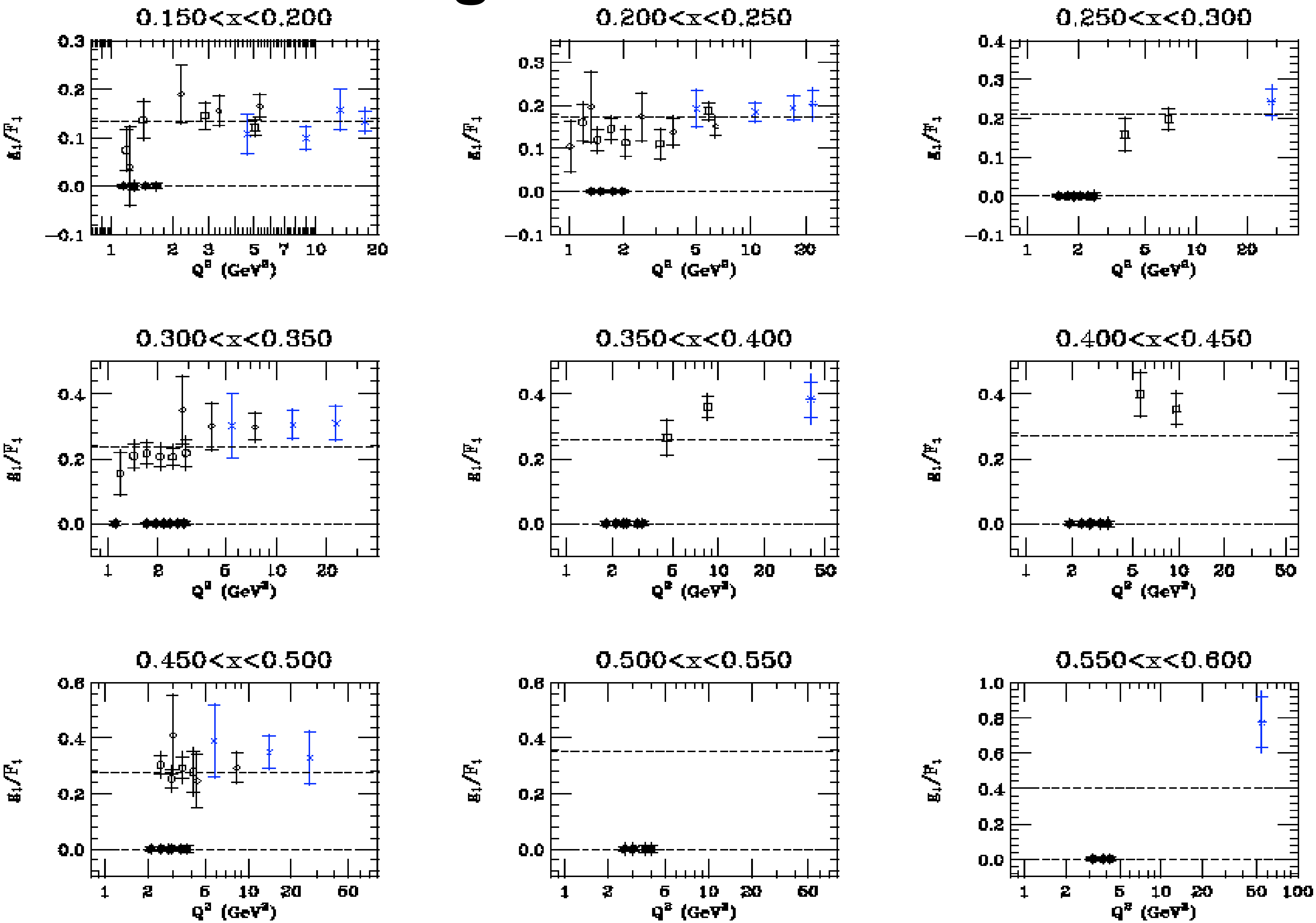
^{6}Li as Polarized Deuteron

- **Most high Q^2 experiments used (SLAC) or are using (COMPASS) ^{6}LiD as target (blue points on next slide).**

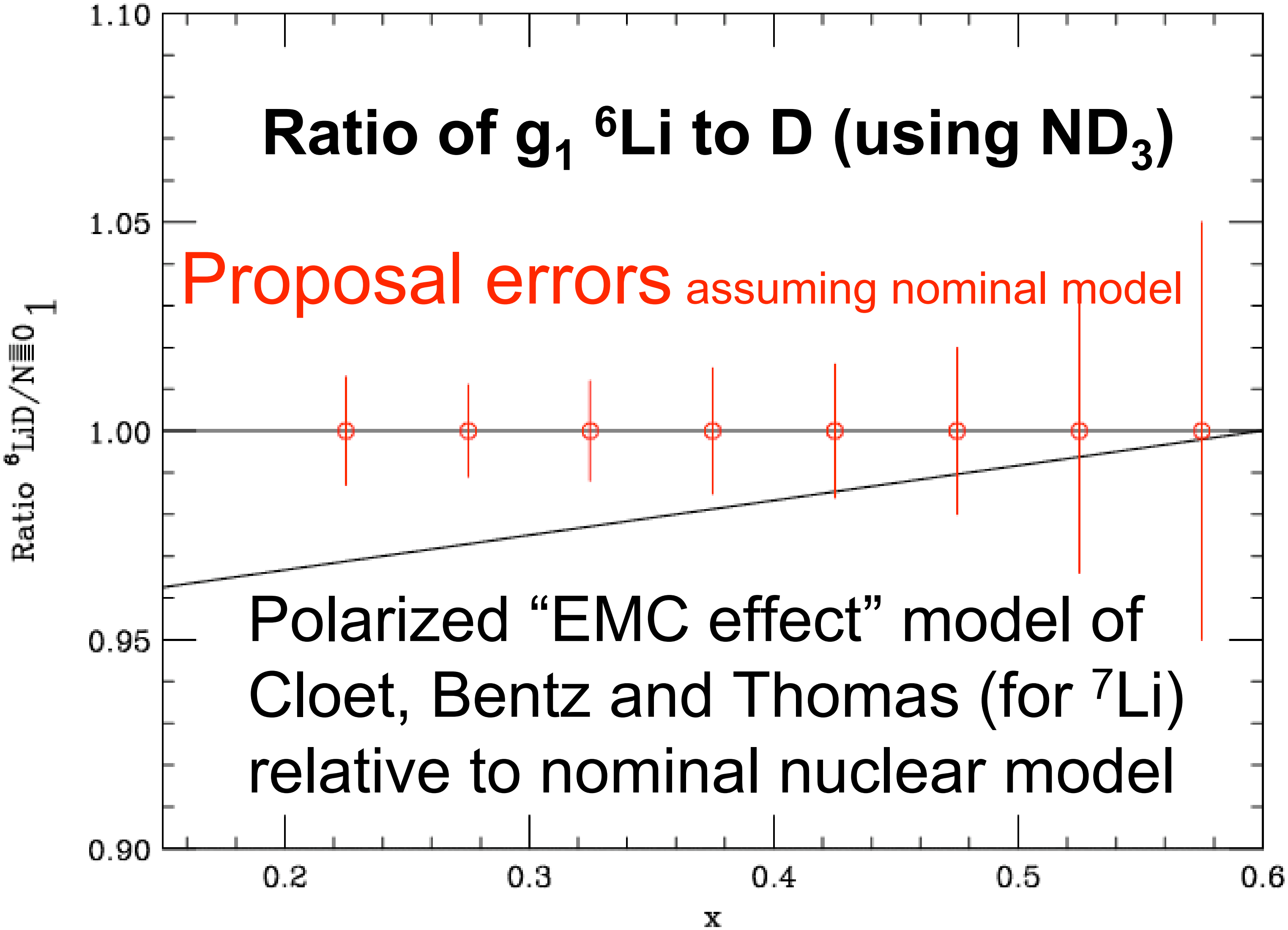
- **^{6}Li treated as unpolarized alpha particle plus deuteron with polarization 87% that of the free proton.**

- **If this wrong, will bias Q^2 dependence of g_1 and hence extracted gluon polarization. Global problem we can solve.**

Existing ^{6}LiD data in Blue



Nuclear effects in ^{6}Li



Experimental Setup

- Longitudinally polarized beam 4-pass and 5-pass (>5.7 GeV)

- Uva/Jlab or Hall B Polarized target setup with longitudinally polarized ND_3 and ^{6}LiD

- Inclusive electrons detected in BETA centered at 30 degrees (and HMS or HRS), or CLAS with angles 15 to 48 degrees.

- Dropped from Hall C schedule, but could be done in Hall B in about 2 to 3 calendar months, or possibly Hall A.

Systematic Errors

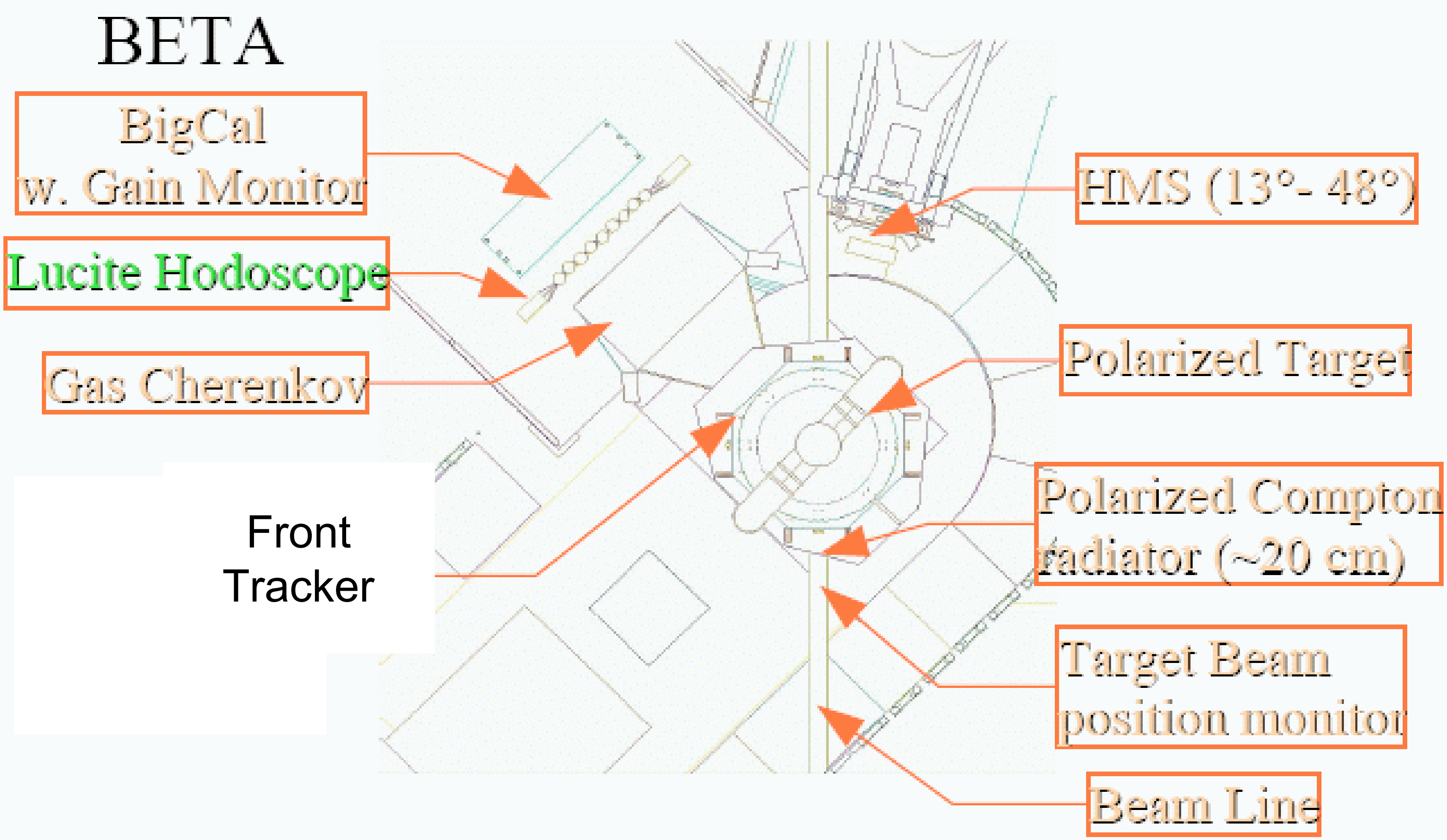
source	p-t-p	overall
$P_b\ P_t$	-	2.8%
dilution	1%	1.5%
pair-symmetric contribution	2%	-
pion contamination	2%	-
radiative corrections	1%	1.5%
^{7}LiD and ^{6}LiH	1%	2% (N/A for ND_3)
pile-up, dead time	1%	1%
Total		4.1%

Summary

- **Definitive measurements of deuteron g_1/F_1 in DIS range accessible at Jlab.**
- **Significant improvement in knowledge of fundamental polarized gluon distribution**
- **Improved measurements of Higher Twist**
- **Test of ^{6}Li as polarized deuteron: needed for interpretation of high Q^2 data.**
- **High impact physics: lets do it soon!**

Backup Slides

Experimental Setup



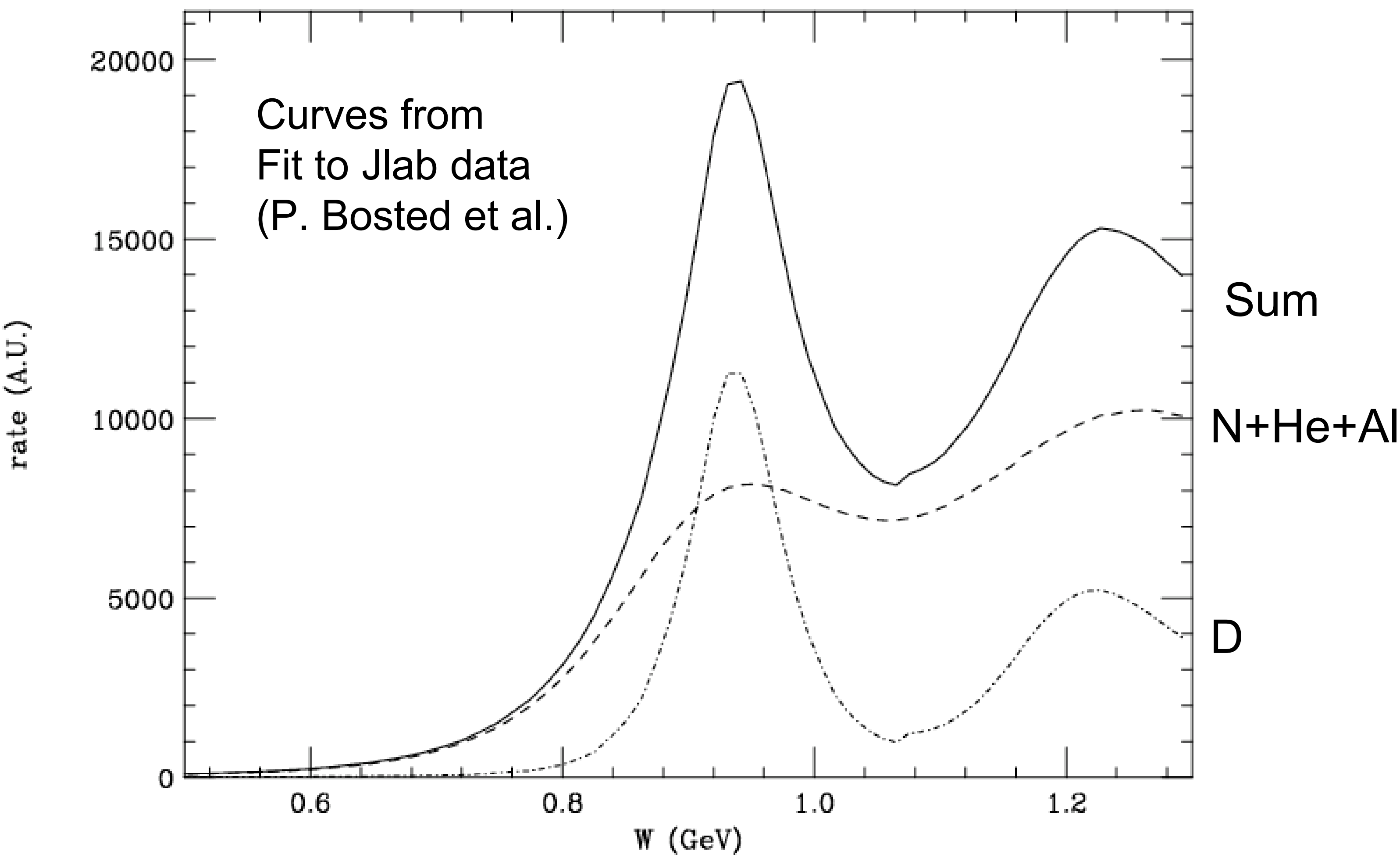
Quasi-elastic Measurement

- At low Q^2, deuteron quasi-elastic peak clearly visible in HMS spectrometer (see next slide).

- Use absolute cross sections to measure D content of the ND_3 target . Cross check of ratio of ND_3 to C rates in BETA and HMS.

- Use double-spin asymmetry to obtain product of beam and target polarization (compare with full calculation of Arenhoevel including MEC and FSI). Cross check with beam Moller and target NMR (two methods).

Quasi-elastic Measurement



Request

E (GeV)	target	θ_{BETA}	θ_{HMS}	P_{HMS}	days
6.	ND_3	30.	10.8	±2.71	8
6.	^{6}LiD	30.	10.8	±2.71	6
4.8	ND_3	30.	12.	-4.3	2
4.8	ND_3	30.	16.	-2.8	3

- **19 days production (12 shared with Semi-SANE, 7 new)**
- **5 days overhead (4 shared, 1 new)**
- **Only 8 new PAC days needed**
- **DAQ upgrade to 5 kHz (planned in any case)**

Readiness

> SANE expected to be ready by early 2008

>DAQ upgrade can be done by early 2008 also.

> This proposal could run immediately after SANE, with only a few shifts needed to change BETA angle from 40 to 30 degrees. Save on major installation time as well as need to re-calibrate BigCal.

Collaboration

- **79 collaborators from 22 institutions.**
- **Strong overlap with SANE, Semi-SANE, polarized Compton experiments**
- **Expertise in BigCal, BETA, HMS, polarized target, polarimetry, data analysis.**
- **Two young enthusiastic spokespersons (one did thesis on g_{1d}) that can carry polarized target physics into 12 GeV era.**

Thanks

- D. Stamenov and A. Sidorov of LSS group (motivation slides and physics impact study)
- M.Hirai, S. Kumano, and N. Saito of AAC group for detailed physics impact study.

Why Now?

- For $1<Q^2<10x$, 11 GeV has no advantage over 6 GeV: already systematic error limited in 8 PAC days.

- Combining with approved CLAS experiment at 11 GeV ($1<Q^2<20x$) will Improve $\Delta G(x)$, because both experiments orthogonally systematic error limited (different target, beam line)

- This is compelling physics with wide interest worldwide: a bird in the hand…

Why not Hall B?

> Main reason: would take approximately factor of 5 to 10 more beam time for same statistical errors (60x lower luminosity, 3x larger solid angle, 1.4x higher polarization), assuming current limited to 5 nA to 10 nA by drift chamber occupancy.

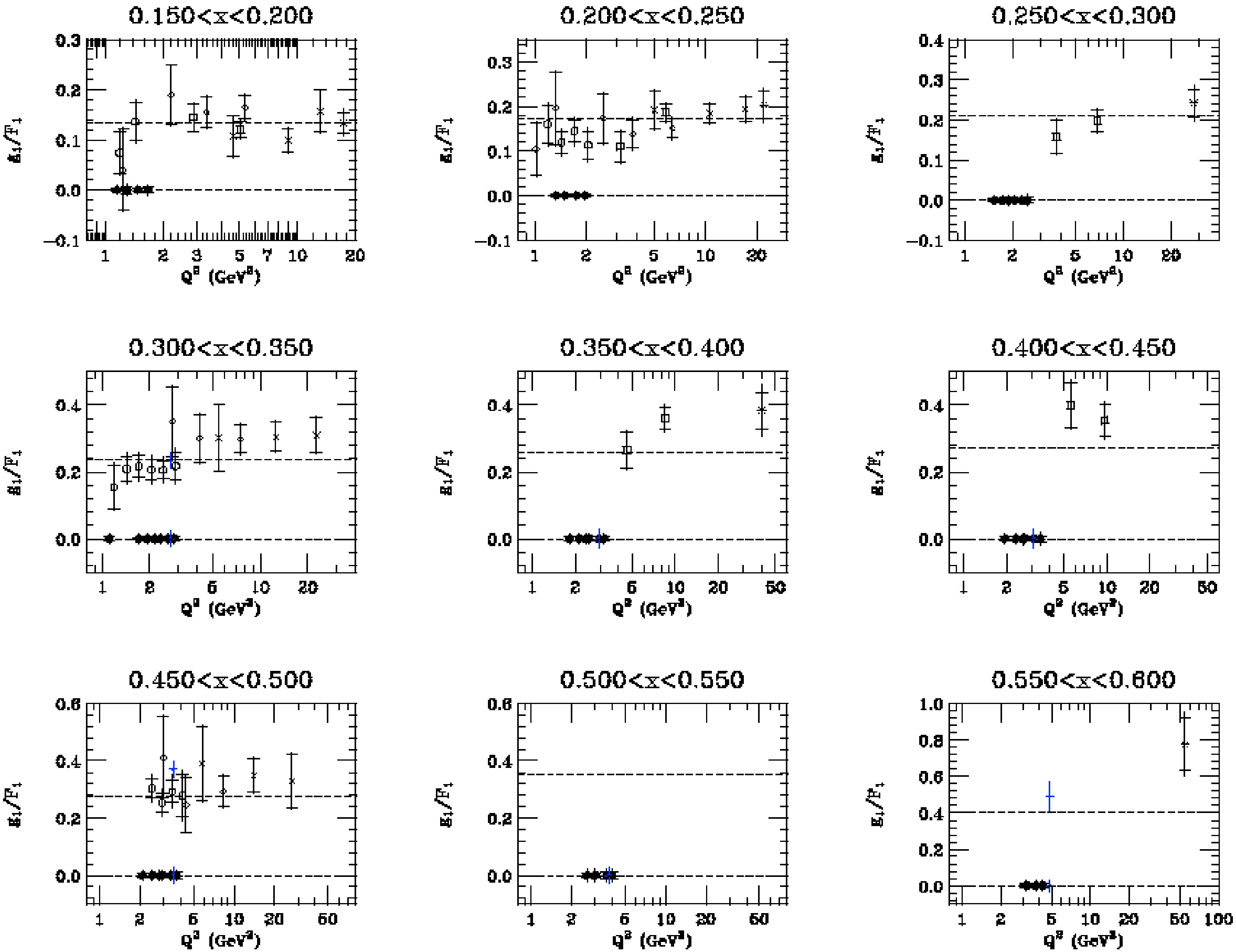
> Upgrade to target stick would be needed to embed NMR coils in target cell.

> BUT, would allow additional physics topics (i.e. polarized DVCS on deuteron).

Proton plus neutron as "deuteron"

- Alternative to deuteron target to obtain isoscaler combination is to add free proton plus neutron extracted from ^3He
- Due to scale factor systematic errors, resulting errors larger than for an actual deuteron target.
- Projected errors from SANE plus Hall A d_2 experiment shown on next slide (blue). Existing Hall B plus A data also shown.
- On other hand, allows test of ^3He as polarized neutron target

Proton plus neutron as “deuteron”



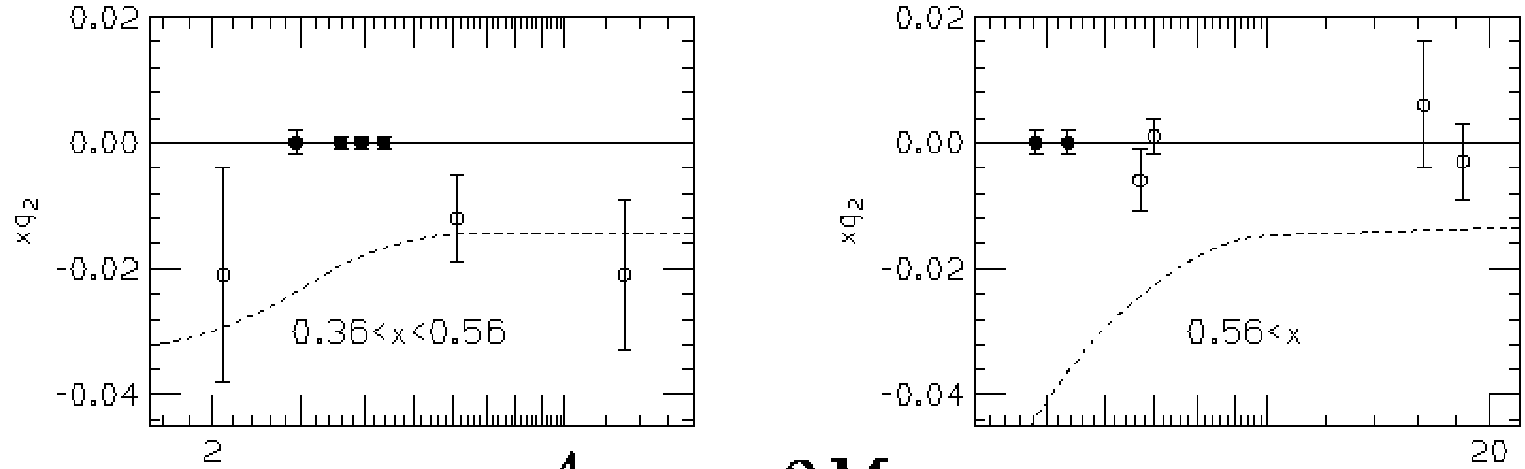
Pion, e+, radiative corrections

$<x>$	$< Q^2 >$	Pair symm.	π/e	f_{RC}	A_{RC}
0.175	1.4	15%	10%	0.90	-0.024
0.25	1.9	10%	8%	0.95	-0.019
0.35	2.5	6%	4%	0.97	-0.016
0.45	3.0	2%	1%	0.98	-0.012
0.55	3.7	1%	$< 1\%$	0.99	-0.007

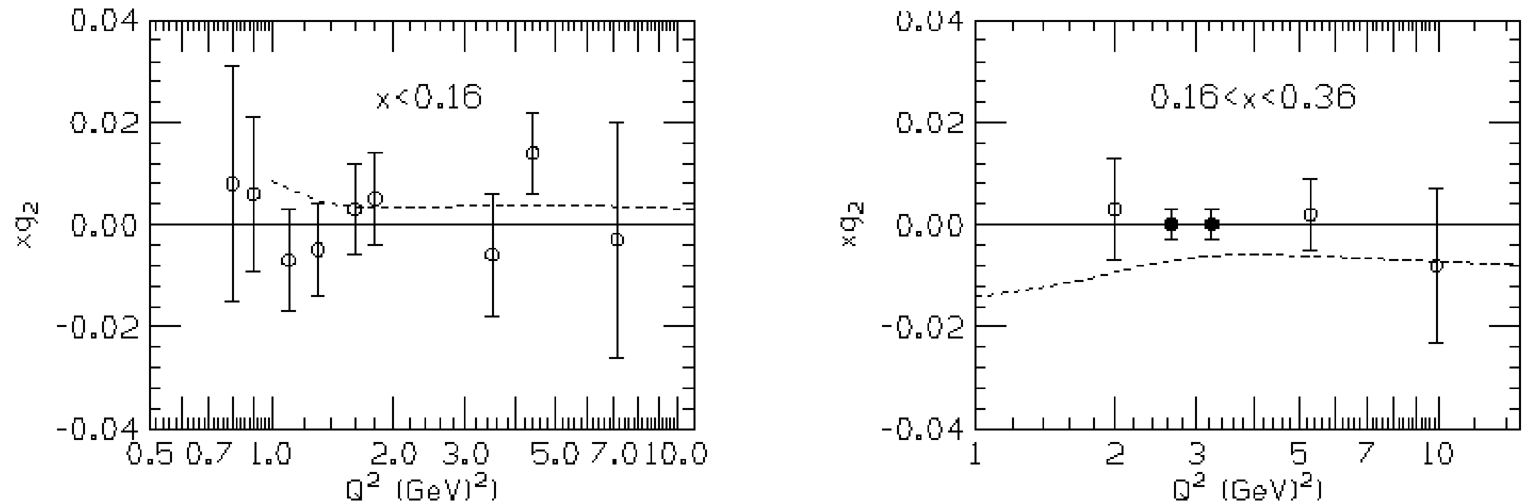
$$A_{\parallel} = \frac{A_{raw}}{f\, P_b\, P_t\, C_1} + C_2 \qquad \frac{g_1}{F_1} = \frac{A_{\parallel}}{d\, f_{RC}} + \frac{2Mx}{2E-\nu}\,\frac{g_2}{F_1} + A_{RC}$$

Correction from g_2

Will be sufficiently well known from SANE (p) and Hall A (n)



$$\frac{g_1}{F_1} = \frac{A_{\|}}{d\, f_{RC}} + \frac{2Mx}{2E-\nu}\,\frac{g_2}{F_1} + A_{RC}$$



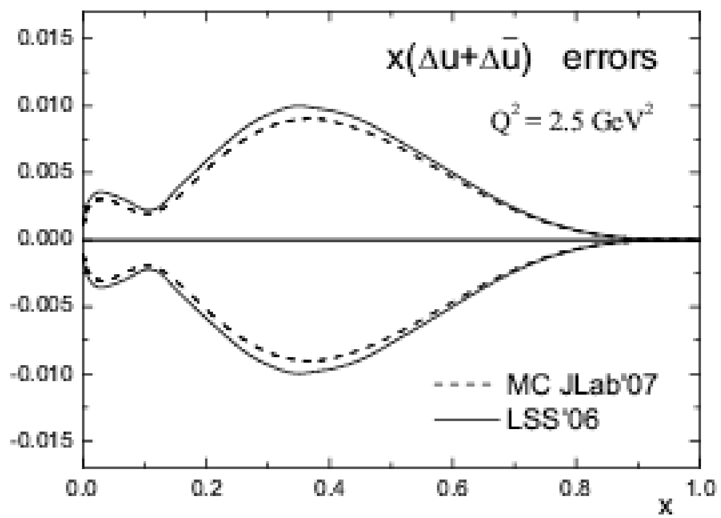
Statistical and Systematic Errors

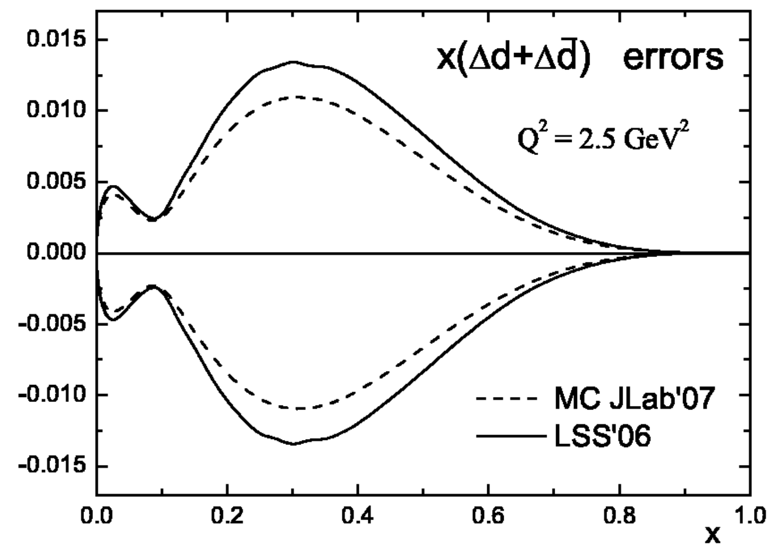
Well matched for study of Q^2 dependence

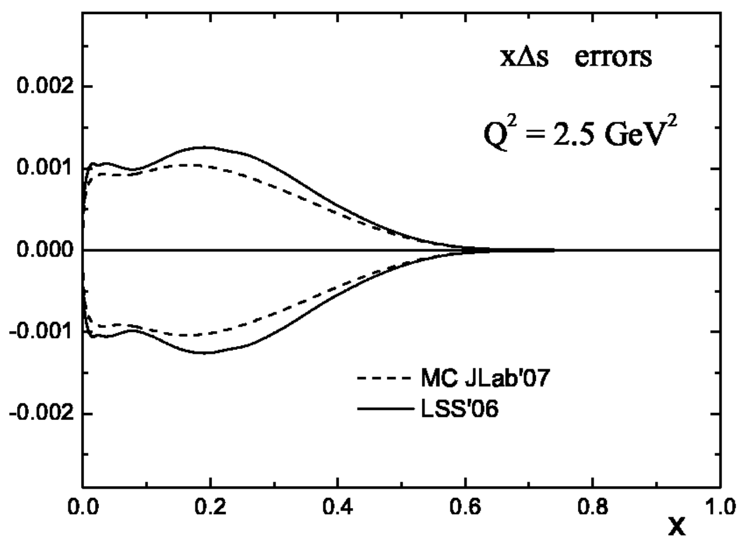
$<x>$	$<Q^2>$ [GeV^2]	$<W>$ [GeV]	g_1/F_1	$\delta g_1/F_1$ (stat.)	$\delta g_1/g_1$ (syst.)
BigCal with $E_{beam} = 6.0$ GeV					
0.13	1.19	3.04	0.0794	0.0032	0.0032
0.17	1.48	2.93	0.1030	0.0025	0.0041
0.22	1.77	2.77	0.1316	0.0030	0.0053
0.23	1.98	2.88	0.1350	0.0041	0.0054
0.27	2.07	2.62	0.1649	0.0032	0.0066
0.27	2.30	2.74	0.1648	0.0047	0.0066
0.28	2.48	2.82	0.1661	0.0063	0.0066
0.33	2.34	2.47	0.1983	0.0043	0.0079
0.33	2.62	2.61	0.1959	0.0054	0.0078
0.33	2.86	2.70	0.1969	0.0065	0.0079

$<x>$	$<Q^2>$ [GeV^2]	$<W>$ [GeV]	g_1/F_1	$\delta g_1/F_1$ (stat.)	$\delta g_1/g_1$ (syst.)
BigCal with $E_{beam} = 4.8$ GeV					
0.18	1.15	2.58	0.1063	0.0025	0.0043
0.22	1.34	2.43	0.1346	0.0026	0.0054
0.23	1.50	2.55	0.1353	0.0038	0.0054
0.27	1.73	2.43	0.1641	0.0042	0.0066
0.28	1.53	2.30	0.1653	0.0032	0.0066
0.28	1.89	2.49	0.1673	0.0061	0.0067
0.32	1.94	2.31	0.1938	0.0049	0.0078
0.33	1.70	2.17	0.1967	0.0035	0.0079
0.33	2.15	2.40	0.1964	0.0063	0.0079
0.37	1.83	2.07	0.2235	0.0054	0.0089

Physics Impact in LSS framework







Impact on polarized quark distributions relatively small