

Measurement of the Neutron Spin Asymmetry A_1^n using HMS+SHMS at 12 GeV

Xiaochao Zheng

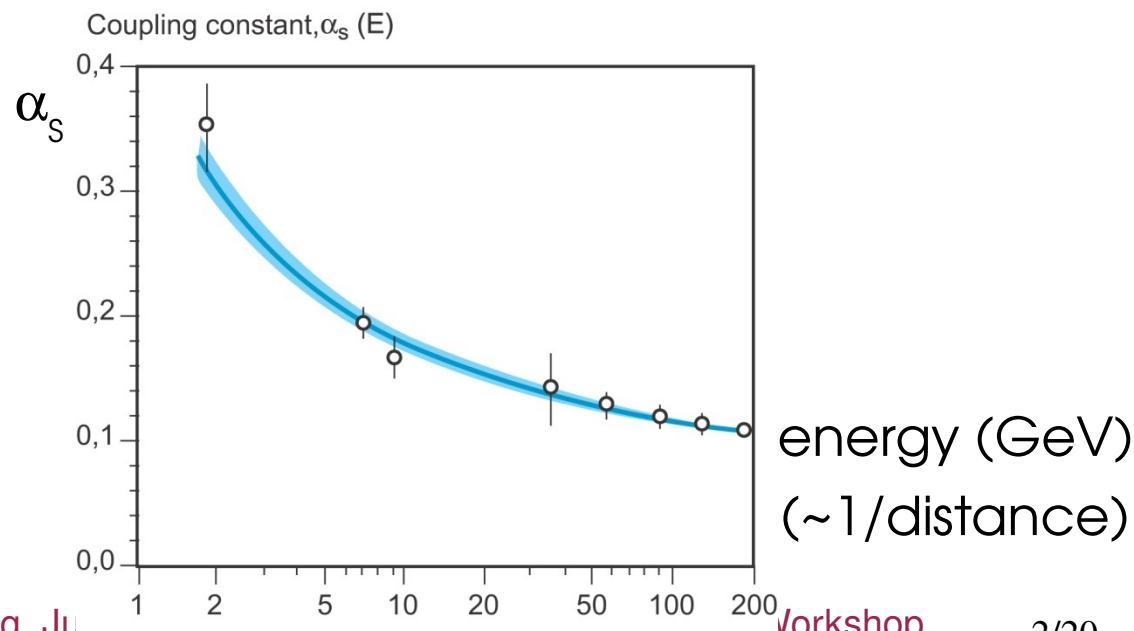
Univ. of Virginia

June 17, 2010

- Physics Motivation
- A_1^n measurements at JLab 6 GeV in Hall A in 2001
- Proposal for the A_1^n measurement with HMS+SHMS (2010 vs. 2006 versions)
- Summary

Standard Model of Particle Physics (Strong Interaction Sector)

- Success of the Standard Model
 - ✚ QCD tested in the high energy (perturbative) region
- Major Challenges **within** the Standard Model
 - ✚ Understand and test QCD in extreme conditions (RHIC, LHC)
 - ✚ Understand and test QCD in “strong” interaction region (non-perturbative)
 - ✚ Understand the nucleon structure, how quarks and gluons form the nucleon's mass, momentum, and spin



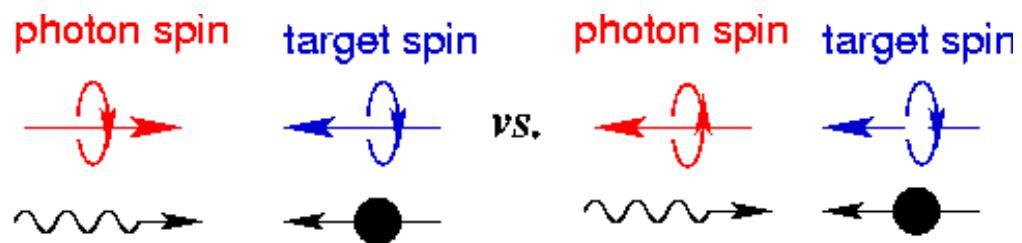
Data vs. Theory – How do we test QCD?

- ★ For most cases, QCD cannot predict (be used to calculate) the value of structure functions because of their non-perturbative nature.
- ★ However, there are a couple of exceptions:

- F_2^P/F_2^n and d/u at large x
- A_1^P, A_1^n , or $\Delta u/u$ and $\Delta d/d$ at large x

④ Virtual photon asymmetry:

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

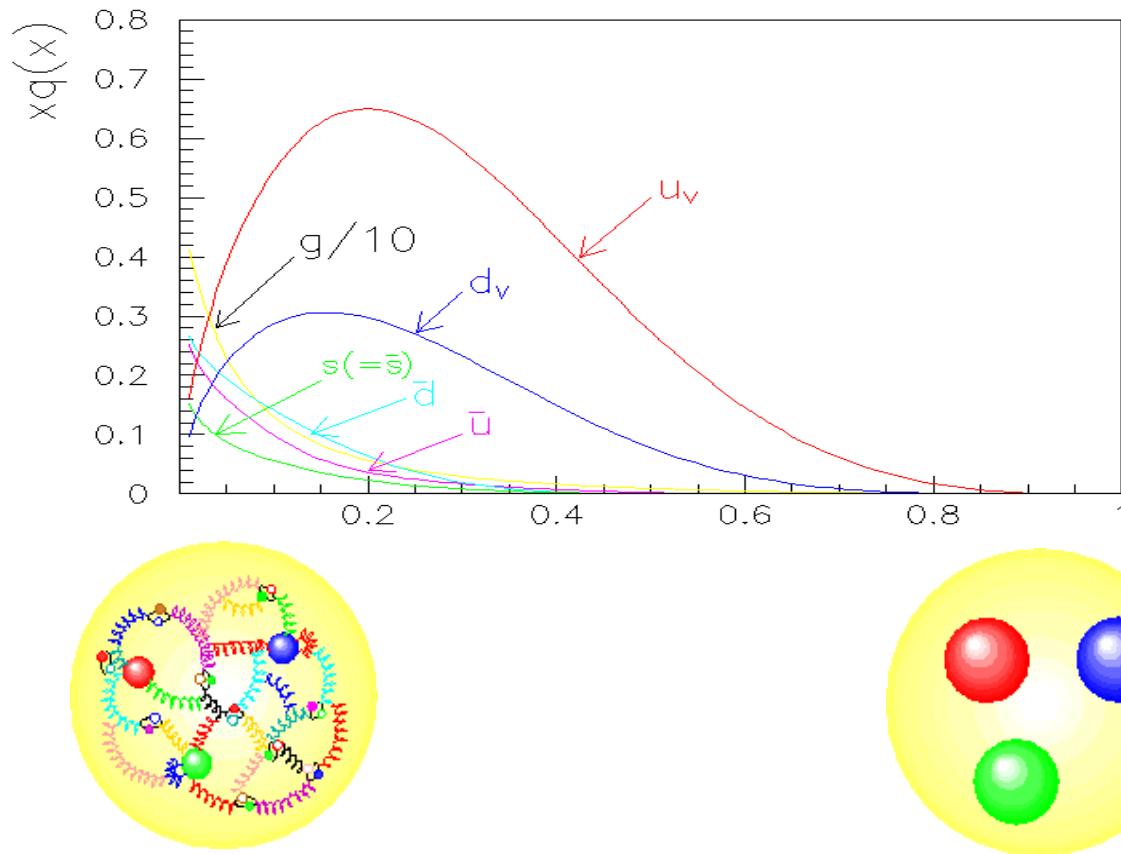


$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1} \quad \text{at large } Q^2$$

$$\gamma^2 = \frac{Q^2}{v^2} = \frac{4 M^2 x^2}{Q^2}$$

At large Q^2 , A_1 has only weak-dependence on Q^2 (g_1 and F_1 follow the same LO and NLO evolutions, but not in higher orders or higher twists).

Why Large x ?



- At large x , valence quarks dominate, easier to model;
- Less contribution from $q-q\bar{q}$ sea and gluons — a relatively clean region to study the nucleon structure;
- To understand the nucleon spin, high x is a good place to start with.

Predictions for A_1 and $\Delta q/q$ at large x

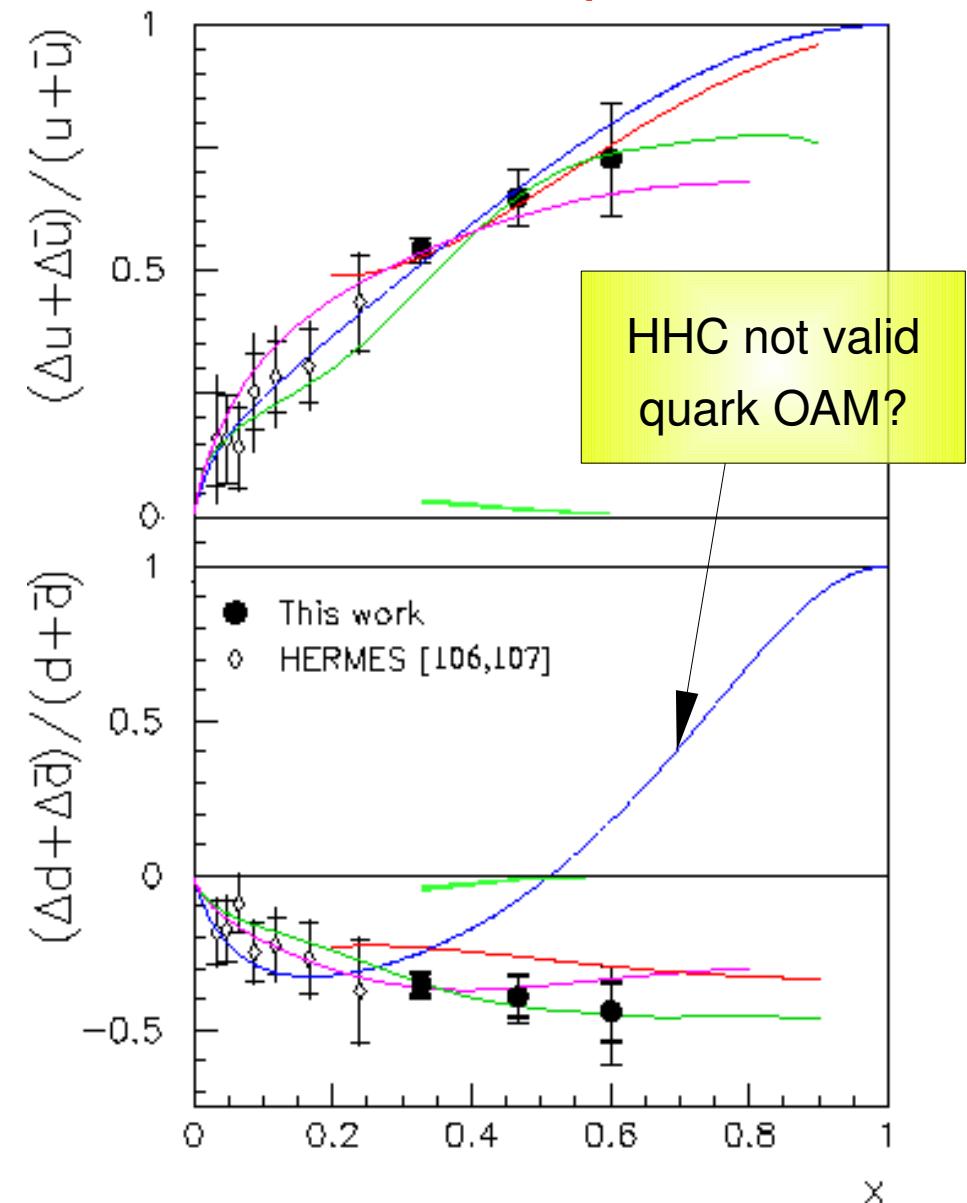
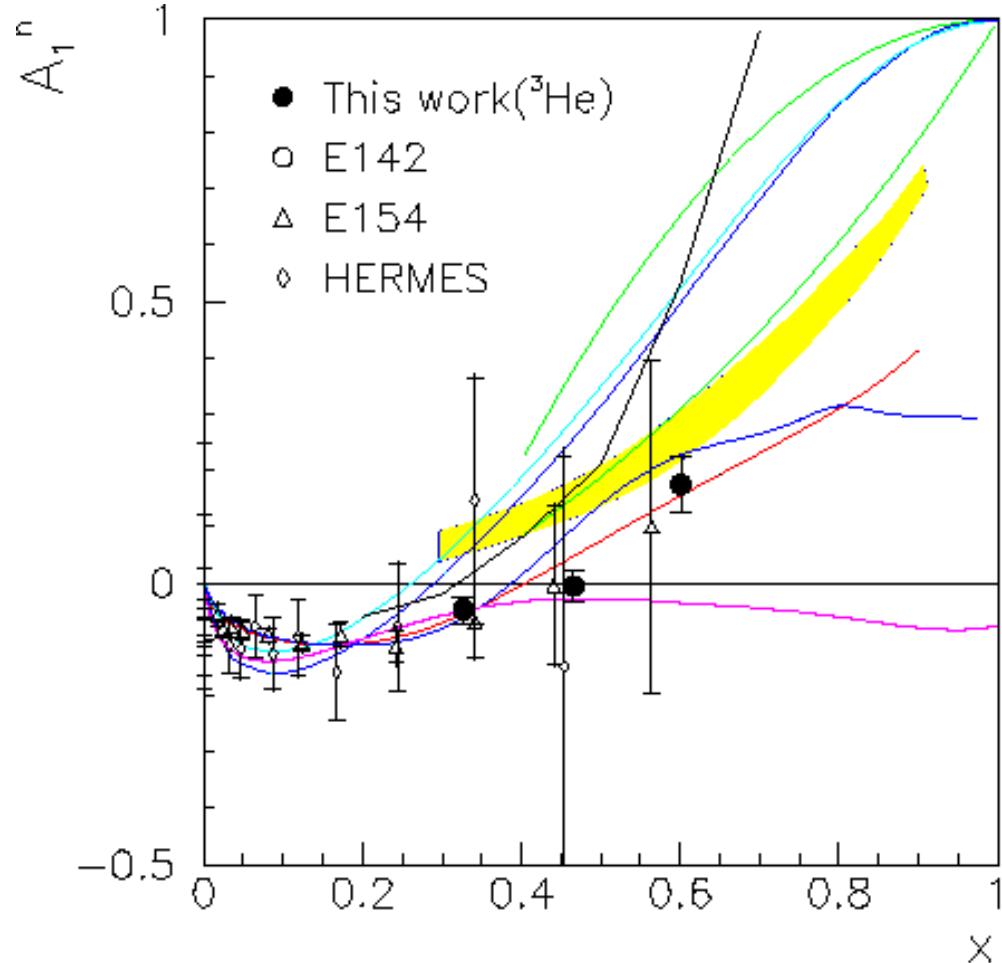
$$|p^\uparrow\rangle = \frac{1}{\sqrt{2}} |u^\uparrow(ud)_{00}\rangle + \frac{1}{\sqrt{18}} |u^\uparrow(ud)_{10}\rangle - \frac{1}{3} |u^\downarrow(ud)_{11}\rangle$$

$$- \frac{1}{3} |d^\uparrow(uu)_{10}\rangle - \frac{\sqrt{2}}{3} |d^\downarrow(uu)_{11}\rangle$$

Model	F_2^n/F_2^p	d/u	$\Delta u/u$	$\Delta d/d$	A_1^n	A_1^p
SU(6) = SU3 flavor + SU2 spin	2/3	1/2	2/3	-1/3	0	5/9
Valence Quark + Hyperfine	1/4	0	1	-1/3	1	1
pQCD + HHC	3/7	1/5	1	1	1	1

- The only place QCD can make absolute predictions for structure functions.

The 6 GeV Hall A Measurement (21 PAC days, 2001)

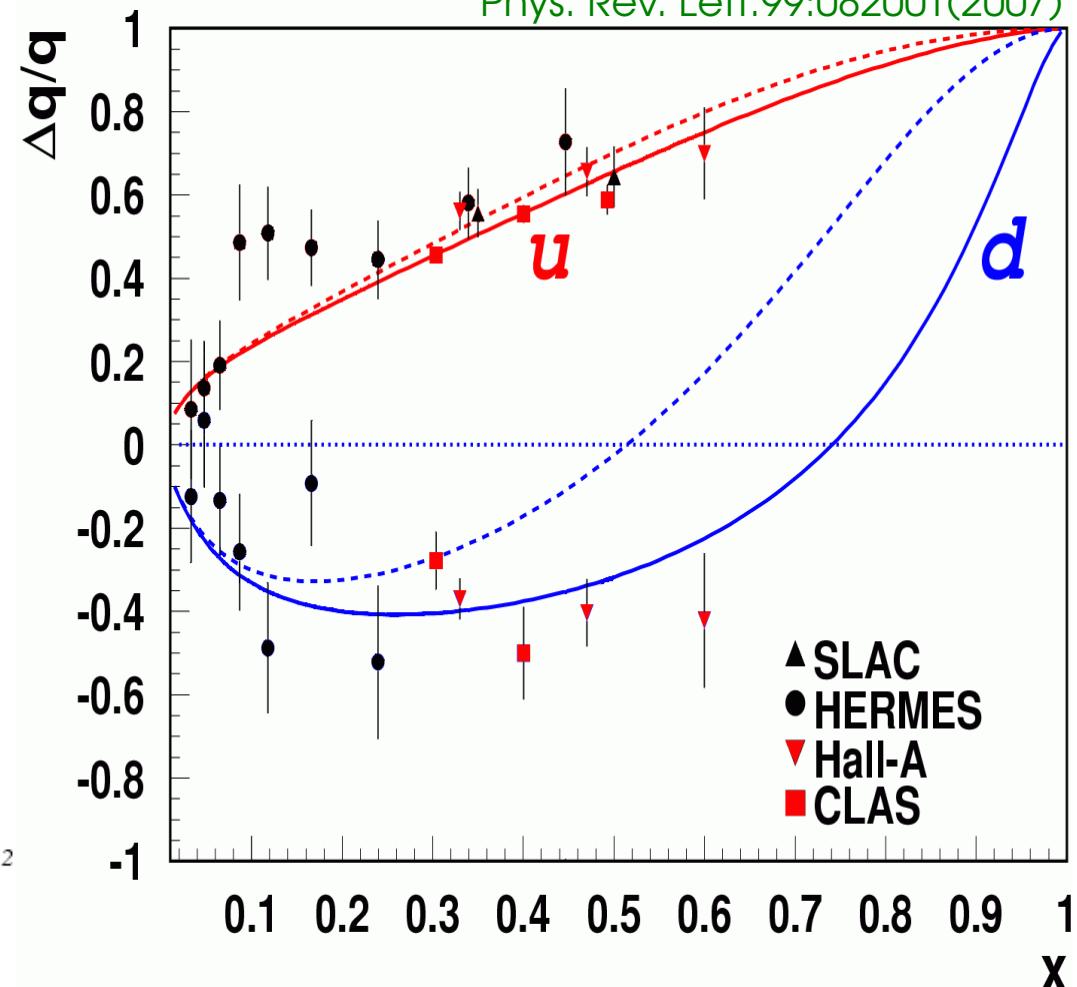
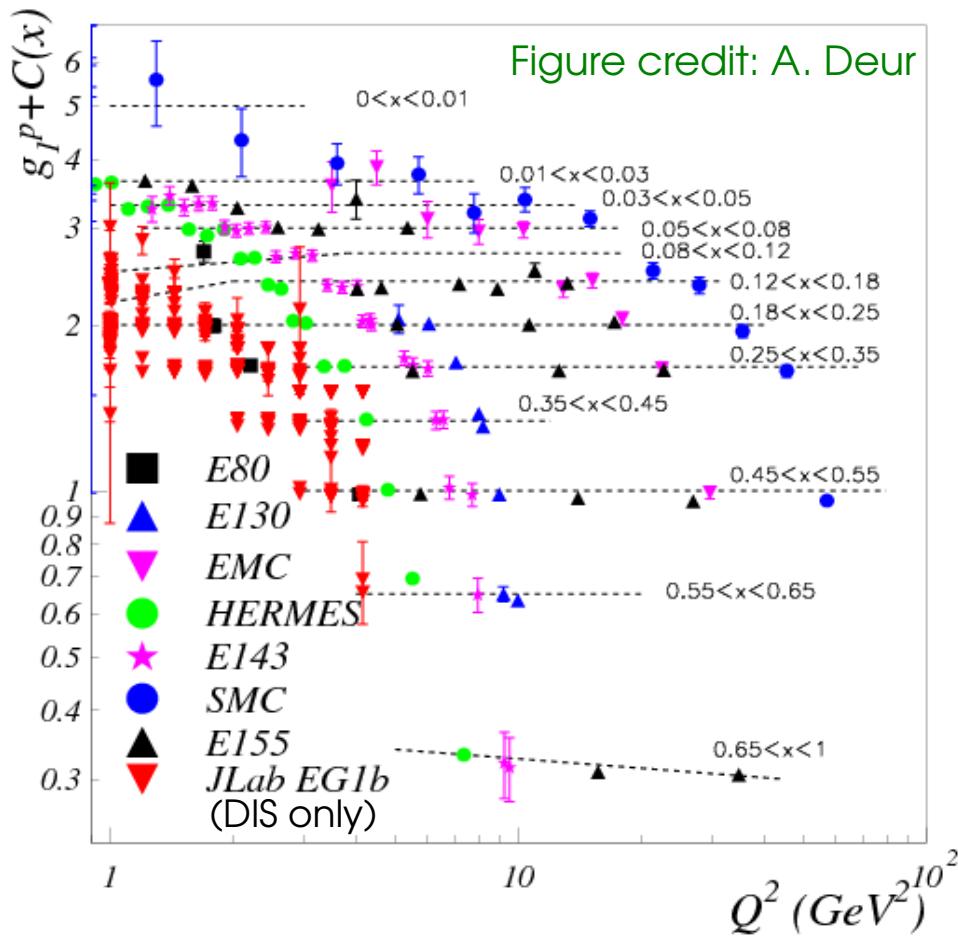


X. Zheng *et al.*, Phys. Rev. Lett. 92, 012004 (2004); Phys. Rev. C 70, 065207 (2004)

Polarized DIS and Nucleon Spin Structure

$$g_1(x) = \frac{1}{2} \sum e_i^2 [q_i^\uparrow(x) - q_i^\downarrow(x)] = \frac{1}{2} \sum e_i^2 [\Delta q_i(x)]$$

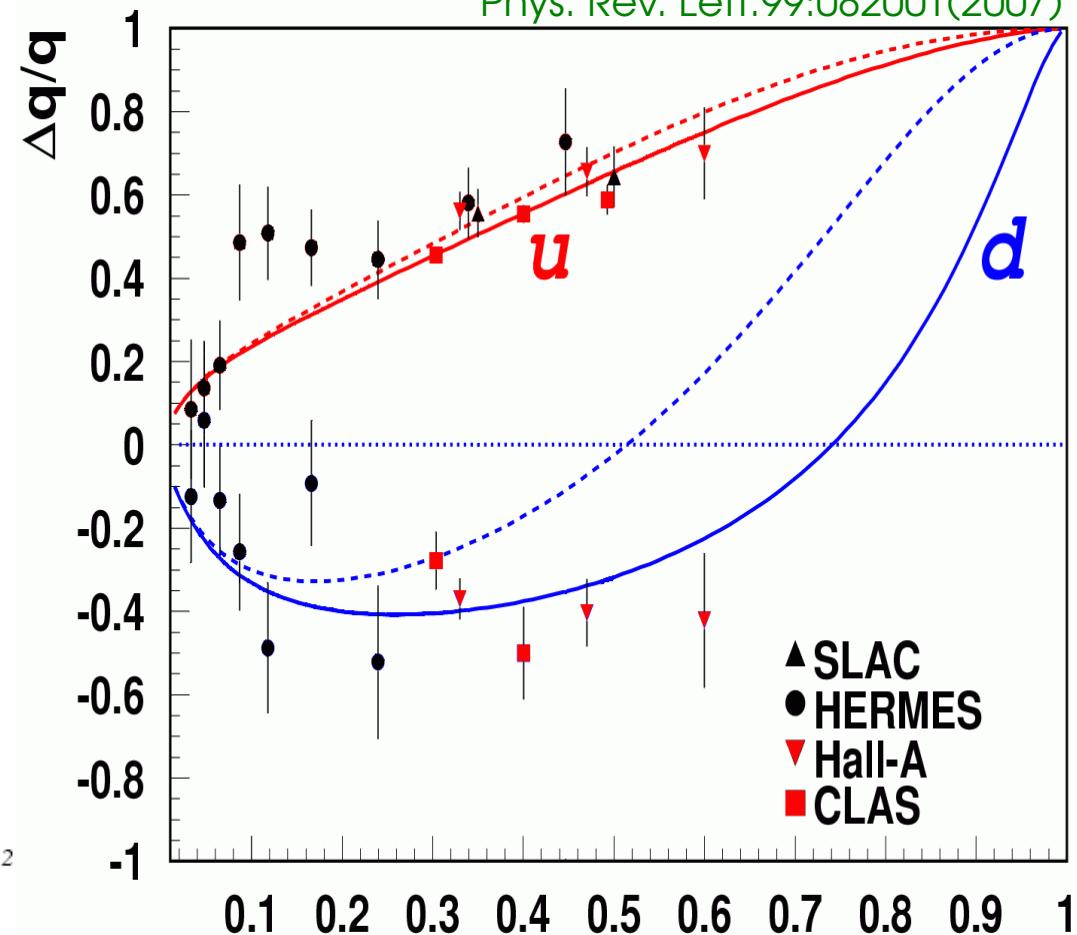
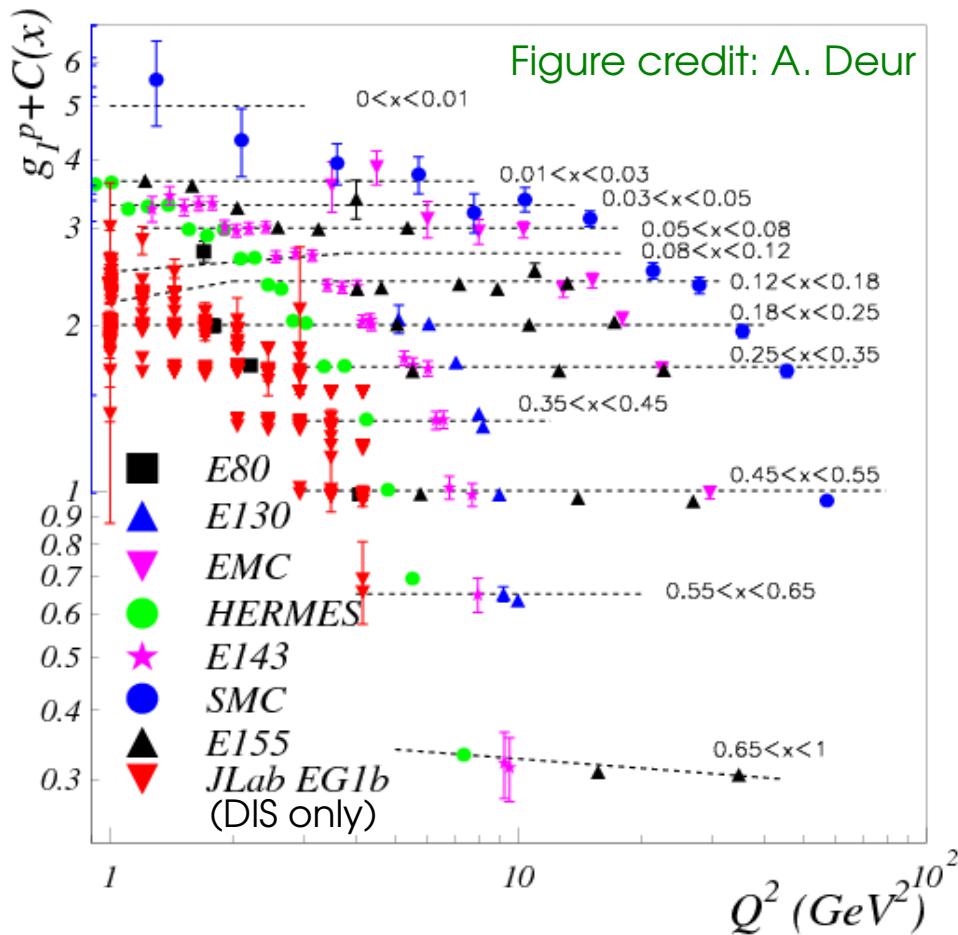
H. Avakian, S. Brodsky, A. Deur, F. Yuan,
Phys. Rev. Lett. 99:082001(2007)



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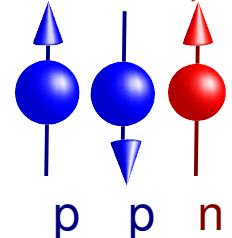


- ★ The JLab Hall A data were quoted by the 2007 NSAC long range plan as one of the “most important accomplishments since the 2002 LRP”;
- ★ Extensions of these measurements are flag-ship experiments for JLab 11 GeV.

Original Proposal for PAC-30 (Conditionally approved)

- Measured A_1^n in DIS from ${}^3\vec{He}(\vec{e}, e')$ using

$${}^3\vec{He} \approx \vec{n}$$



- + 12 GeV polarized e^- beam, $P_{beam}=80\%$ ($dP/P=1\%$ Compton, Moller)
- + Polarized ${}^3\text{He}$ target, hybrid pumping, 40cm, 14 atm @ 50°C , $P_{Targ}=50\%$ ($dP/P = 3\%$) — (GE0 E02-013 has achieved 55% in beam)
- + HMS+SHMS to detect e' , measure both $A_{||}$ and A_{\perp} :
- + Total: 1908h (79 days) + Target Installation
- + Will reach $\Delta A_1^n = \pm 0.071(\text{stat}) \pm 0.032(\text{syst})$ at $x=0.77$

Improvements on the Polarized 3He Target (2010)

- Will use the same design as GEN-II (11 GeV):
 - ✚ use of alkali-hybrid mixtures to increase the spin-exchange efficiency;
 - ✚ use of narrow-lined high-power diode lasers;
 - ✚ study of polarimetries for both 3He and alkali-metal vapor and their densities to improve understanding of the target performance;
 - ✚ use of convection to overcome beam and other depolarization effects;
 - ✚ metal-based target chamber to resist radiations and avoid cell rupture;
- ★ **Goal: a 60-cm long target chamber, 12 amg density, up to 60uA beam with 60% polarization**
- Overall, provide a factor of 8 improvement in luminosity!
 - ✚ allow the use of less beam time to achieve higher precision (now set statistical uncertainty = systematic at $x=0.77$)
 - ✚ added resonance measurements (with little extra beam time)

Kinematics

- Production (DIS and resonance)

$10^4:1 \pi^-$ rejection is needed

Kine	E_b GeV	E_p GeV	θ (°)	(e, e') rate (Hz)	π^-/e	e^+/e^-	$x (Q^2, \text{in GeV}^2) (W, \text{in GeV})$ coverages
DIS							
1	HMS	11.0	5.70	12.5	2300.75	< 0.5	< 0.1%
2	HMS	11.0	6.80	12.5	1768.35	< 0.1	< 0.1%
3	HMS	11.0	2.82	30.0	5.03	< 7.0	< 0.9%
4	HMS	11.0	3.50	30.0	0.94	< 1.6	< 0.1%
5	HMS	11.0	7.50	12.5	598.43	< 0.1	< 0.1%
A	SHMS	11.0	5.80	12.5	2817.72	< 0.6	< 0.1%
B	SHMS	11.0	3.00	30.0	9.61	< 9.4	< 1.4%
C	SHMS	11.0	2.25	30.0	28.20	< 42.3	< 10.1%
D	SHMS	11.0	7.50	12.5	857.47	< 0.1	< 0.1%
Resonances							
5	HMS	11.0	7.50	12.5	666.78	-	-
D	SHMS	11.0	7.50	12.5	440.74	-	-

- Elastic $e^-{}^3\text{He}(\text{ll})$ and $\Delta(1232)$ (\perp) at low Q^2 to check $P_b P_t$ and beam helicity:

Kine	E_b GeV	E_p GeV	θ (°)	elastic x-sec (nb/sr)	elastic rate (Hz)	Asymmetry	Time (hours)
Elastic	2.200	2.160	12.5	106.986	2840.3	$A_{ } = 0.0589$	5.1
$\Delta(1232)$	2.200	1.815	12.5	-	-	$A_{\perp} \sim \text{a few \%}$	6

From ${}^3\text{He}$ to Neutron

- S, S', D, Δ isobar in ${}^3\text{He}$ wavefunction: Phys. Rev. C65, 064317 (2002)

$$A_1^n = \frac{F_2^{{}^3\text{He}}}{P_n F_2^n (1 + \frac{0.056}{P_n})} \left[A_1^{{}^3\text{He}} - 2 \frac{F_2^p}{F_2^{{}^3\text{He}}} P_p A_1^p \left(1 - \frac{0.014}{2 P_p} \right) \right]$$

- Other Inputs:

- F_2^p, F_2^D – NMC fits and MRST/CTEQ dominant for high x
- $P_n = 0.86^{+0.036}_{-0.020}, P_p = -0.028^{+0.009}_{-0.004}$ Uncertainty on Pp expected to reduce by factor of 4 from Hall A Ax and Az measurements;
- $R(x, Q^2)$ – R1998, PLB 452, 194 (1999)
- EMC for $F_2^{{}^3\text{He}}, F_2^D$ Acta Phys. Polon. B27, 1407 (1996) (nucl-th/9603021)
- A_1^p – from fit to world data (at large x also consistent with CLAS12 expected results) Phys. Rev. C 70, 065207 (2004)

Projected A_1^n Uncertainties

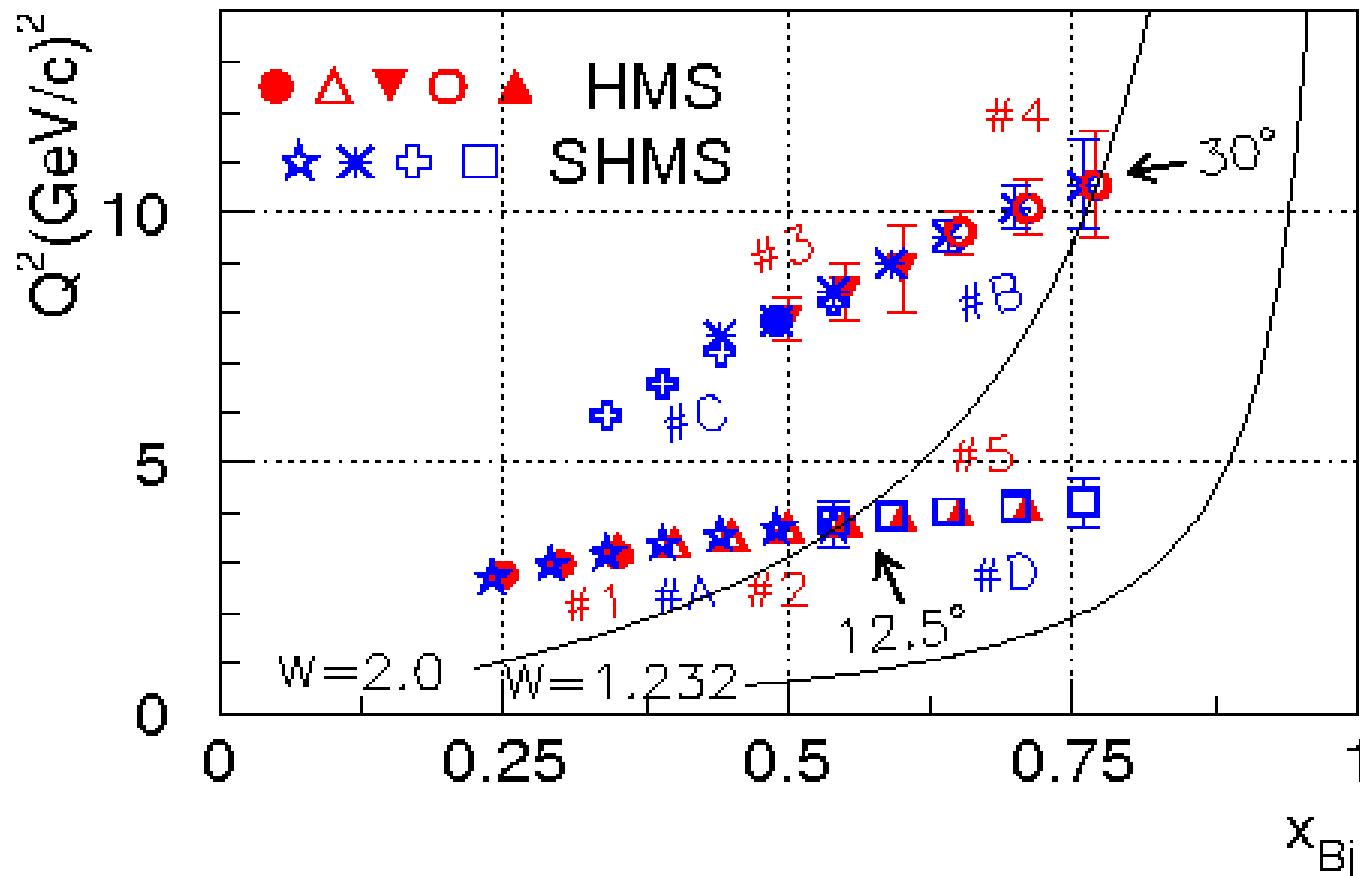
DIS

x	$\Delta A_1^n(\text{stat.})$ low Q^2	$\Delta A_1^n(\text{stat.})$ high Q^2	$\Delta A_1^n(\text{stat.})$ two Q^2 combined	$\Delta A_1^n(\text{syst.})$	$\Delta A_1^n(\text{total})$
0.25	0.0022	—	0.0022	0.0054	0.0059
0.30	0.0020	—	0.0020	0.0063	0.0066
0.35	0.0025	0.0109	0.0024	0.0074	0.0078
0.40	0.0030	0.0084	0.0028	0.0089	0.0093
0.45	0.0029	0.0106	0.0028	0.0105	0.0109
0.50	0.0033	0.0081	0.0031	0.0124	0.0127
0.55	—	0.0069	0.0047	0.0145	0.0152
0.60	—	0.0092	0.0092	0.0168	0.0192
0.65	—	0.0105	0.0105	0.0197	0.0223
0.71	—	0.0143	0.0143	0.0246	0.0285
0.77	—	0.0288	0.0288	0.0340	0.0446

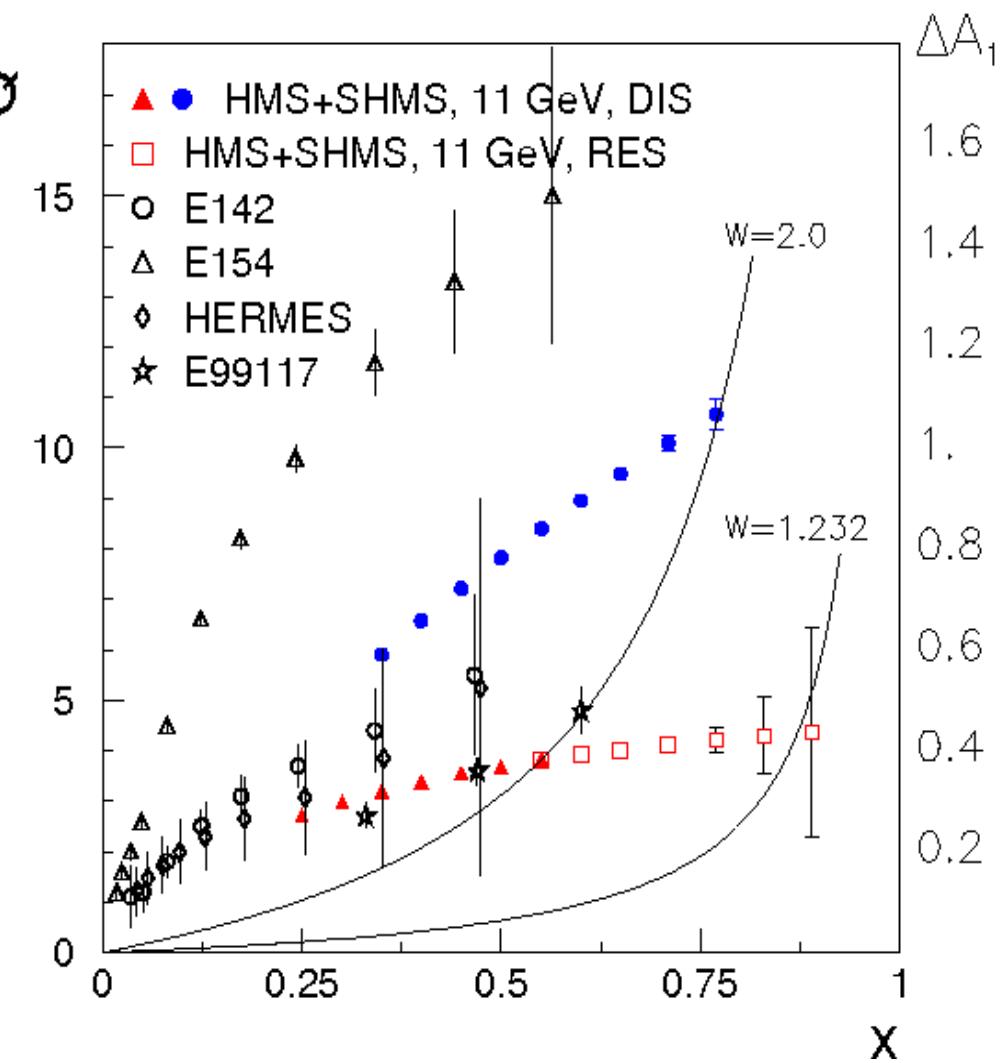
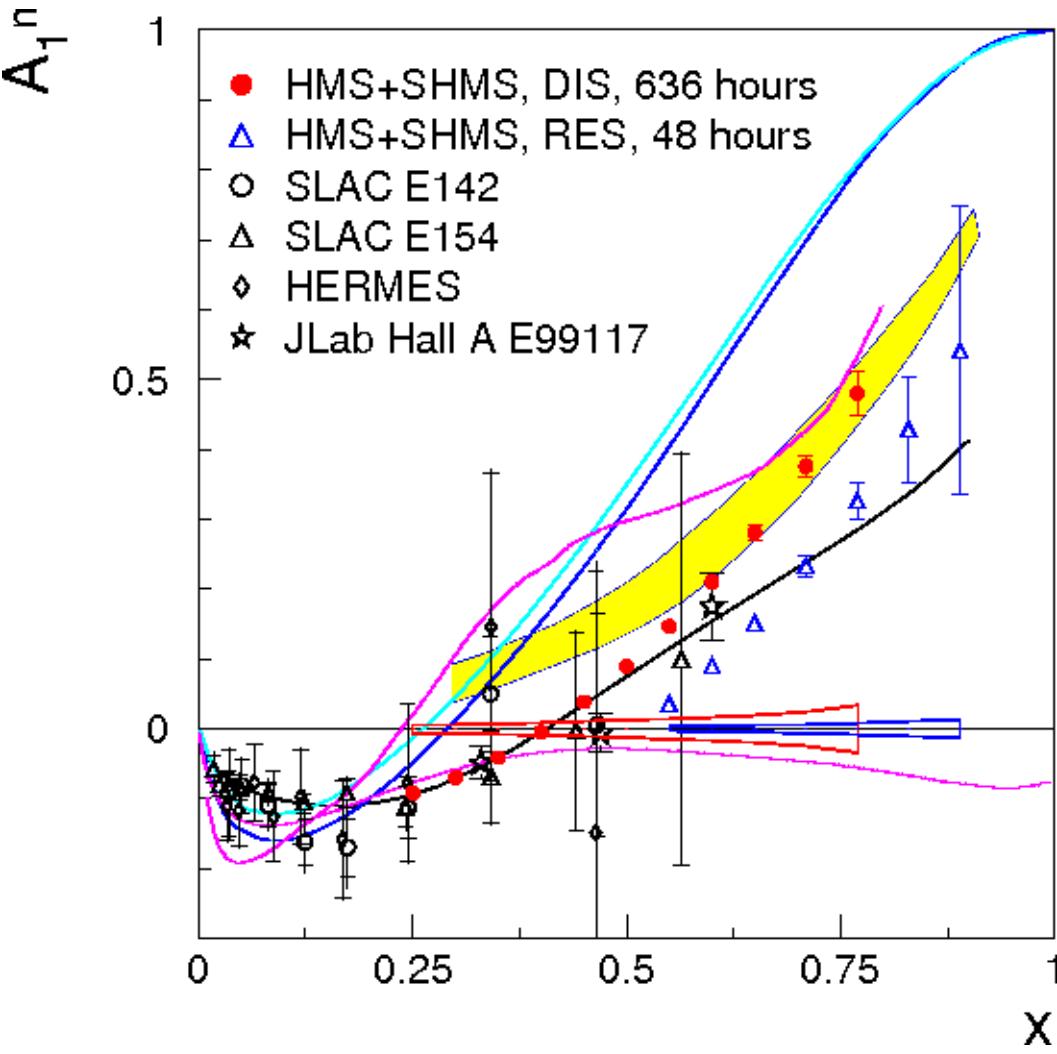
Resonance

x	$\Delta A_1^n(\text{stat.})$	$\Delta A_1^n(\text{syst.})$	$\Delta A_1^n(\text{total})$
0.55	0.0072	0.0145	0.0162
0.60	0.0061	0.0169	0.0180
0.65	0.0074	0.0197	0.0210
0.71	0.0095	0.0242	0.0260
0.77	0.0138	0.0323	0.0352
0.83	0.0302	0.0530	0.0610
0.89	0.0593	0.1003	0.1165

Expected Results



Expected Results



Beam Time Request

◆ Production: 684 hours

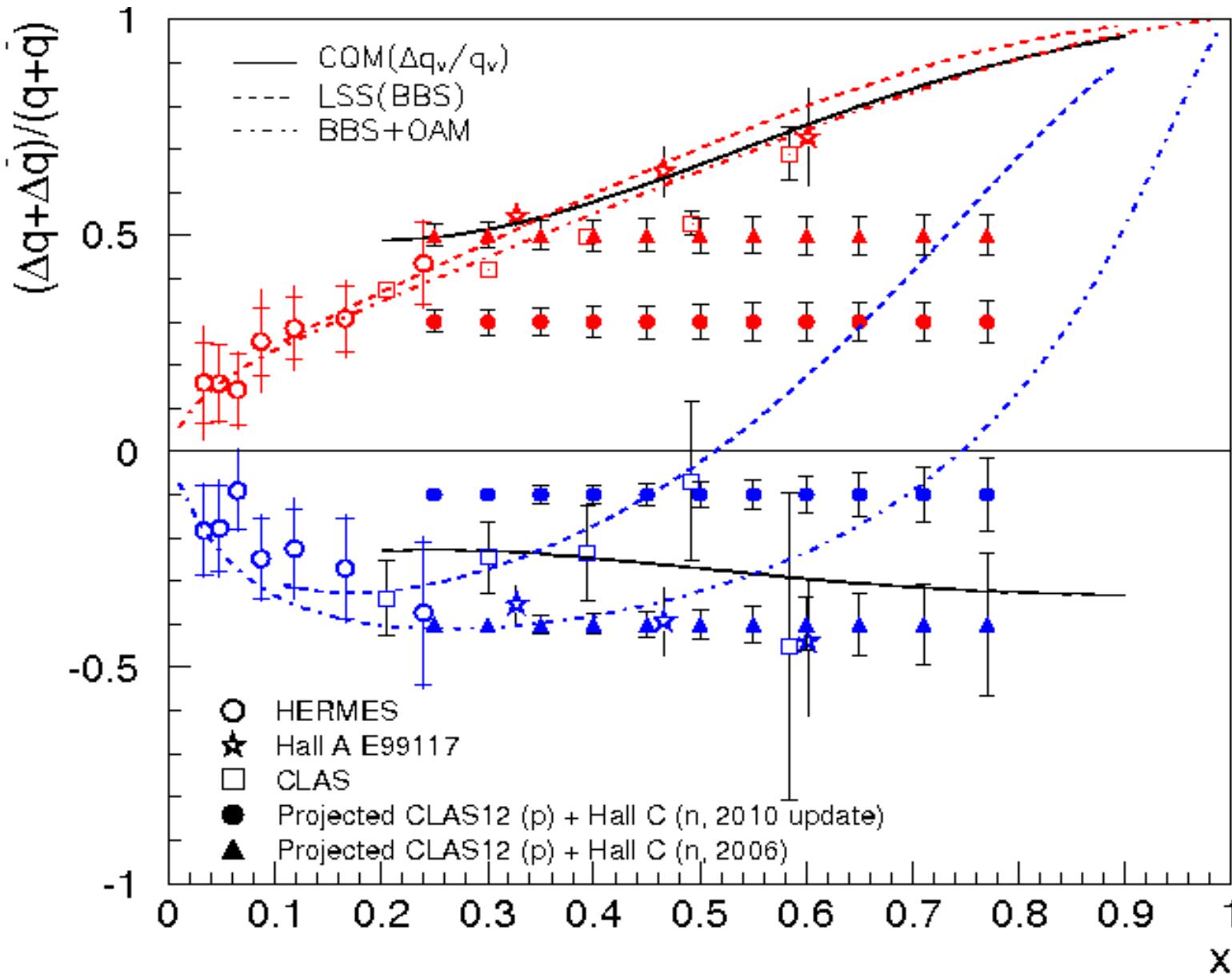
Table 5: Beam time for DIS (636 hours) and resonance (48 hours) measurements. We have reduced the beam time by 45% compared to our original proposal.

Kine	E_b (GeV)		θ (°)	E_p (GeV)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
DIS							
1	11.0	HMS	12.5	5.70	12	0	12
2	11.0	HMS	12.5	6.80	24	0	24
3	11.0	HMS	30.0	2.82	59	1	60
4	11.0	HMS	30.0	3.50	539	1	540
A	11.0	SHMS	12.5	5.80	36	0	36
B	11.0	SHMS	30.0	3.00	493	7	500
C	11.0	SHMS	30.0	2.25	91	9	100
Resonances							
5	11.0	HMS	12.5	7.50	48	0	48
D	11.0	SHMS	12.5	7.50	48	0	48

- ◆ Commissioning: 3 days if not including the target, longer if include target.
- ◆ Elastic; $\Delta(1232)$; Reference Cell (N_2 run)
- ◆ Configuration changes; Beam pass change;
- ◆ Moller; Target polarimetry;
- ◆ **Total: 843h (35 days) + Target Installation, ~45% of our 2006 request**

Expected Results

- Combined results from Hall A (neutron) and B (proton) 11 GeV experiments



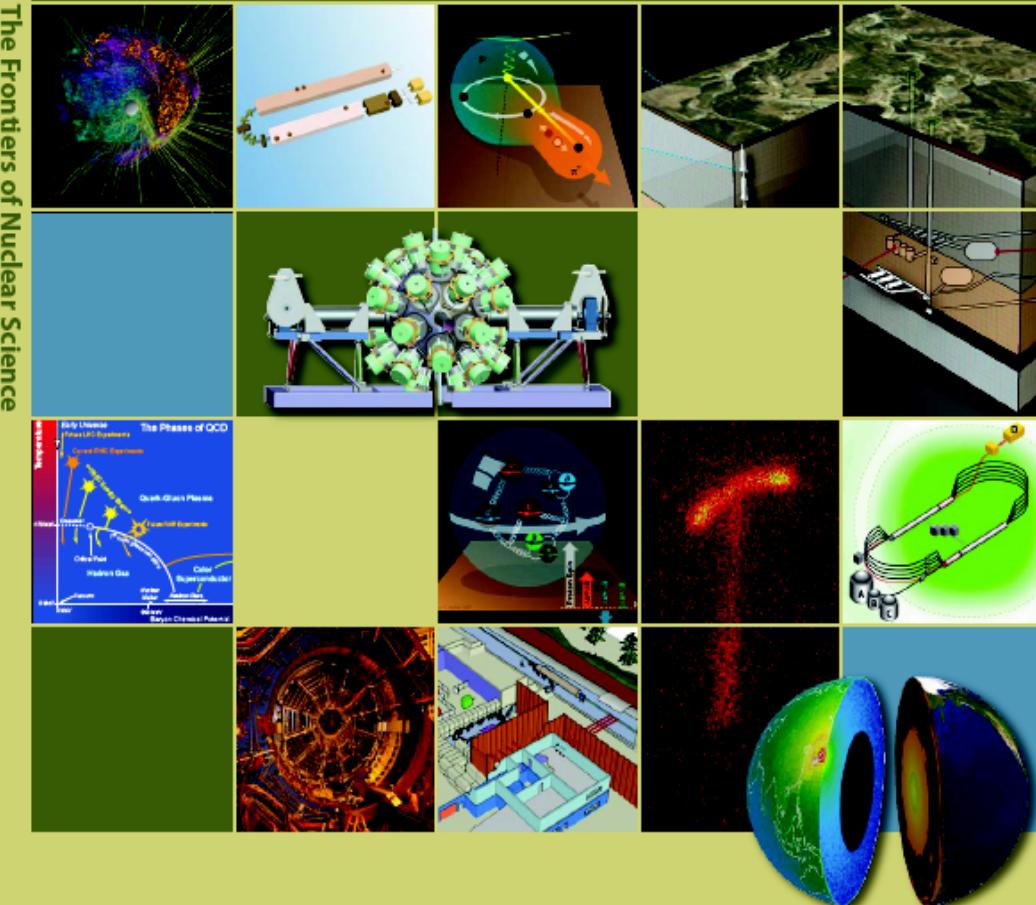
Complementarity with the Hall A BigBite Proposal

- The current version of Hall A proposal uses the BigBite spectrometer, will provide DIS data up to $x=0.71$ with a 8.8 GeV beam, with smaller uncertainties than this proposal. It is unknown yet whether it will work for 11 GeV; ← *condition of PAC30*
- Even if BigBite works for 11 GeV, it will be limited by systematics at $x=0.77$. And
 - The physics of A_1^n at large x is important enough that it's worth more than one measurement;
 - A combination of the Hall A and C measurement will allow the study of the Q^2 -dependence of A_1^n up to $x=0.71$.
 - The use of HMS+SHMS (close spectrometers) will allow clean measurements of A_1^n with less systematics than open spectrometers. As a result, reliable and fast online and/or offline data analysis will be possible, allowing fast turn-out of physics results.

Summary

- Will measure A_{1^n} up to $x=0.77$ in DIS, **test of CQM, pQCD and the role of quark OAM;**
- Wide Q^2 coverage allows the study of Q^2 -dependence up to $x=0.55$;
- Requires: pol3He target in Hall C + SHMS + HMS w/ $10^4:1$ π rejection;
 - ✚ Compare to the 2006 version: Added resonance data to test quark-hadron duality; Recent development in the target allows significant reduction of the beam time and increased physics outcome.
- Beam time request: 35 days total (not including target commissioning)
- Complementary to the Hall A BigBite proposal, Use of HMS/SMS spectrometers allows clean studies of A_{1^n} and fast offline (even online) analysis;
- Will combine with CLAS12 proton data to extract $\Delta q/q$; provide further tests of predictions.

Frontiers of Nuclear Science



The Frontiers of Nuclear Science
A LONG RANGE PLAN

"Building on the foundation of the recent past, nuclear science is focused on three broad but highly related research frontiers: (1) QCD and its implications and predictions for the state of matter in the early universe, quark confinement, the role of gluons, and the structure of the proton and neutron; (2) the structure of atomic nuclei and nuclear astrophysics, which addresses the origin of the elements, the structure and limits of nuclei, and the evolution of the cosmos; and (3) developing a New Standard Model of nature's fundamental interactions, and understanding its implications for the origin of matter and the properties of neutrinos and nuclei."

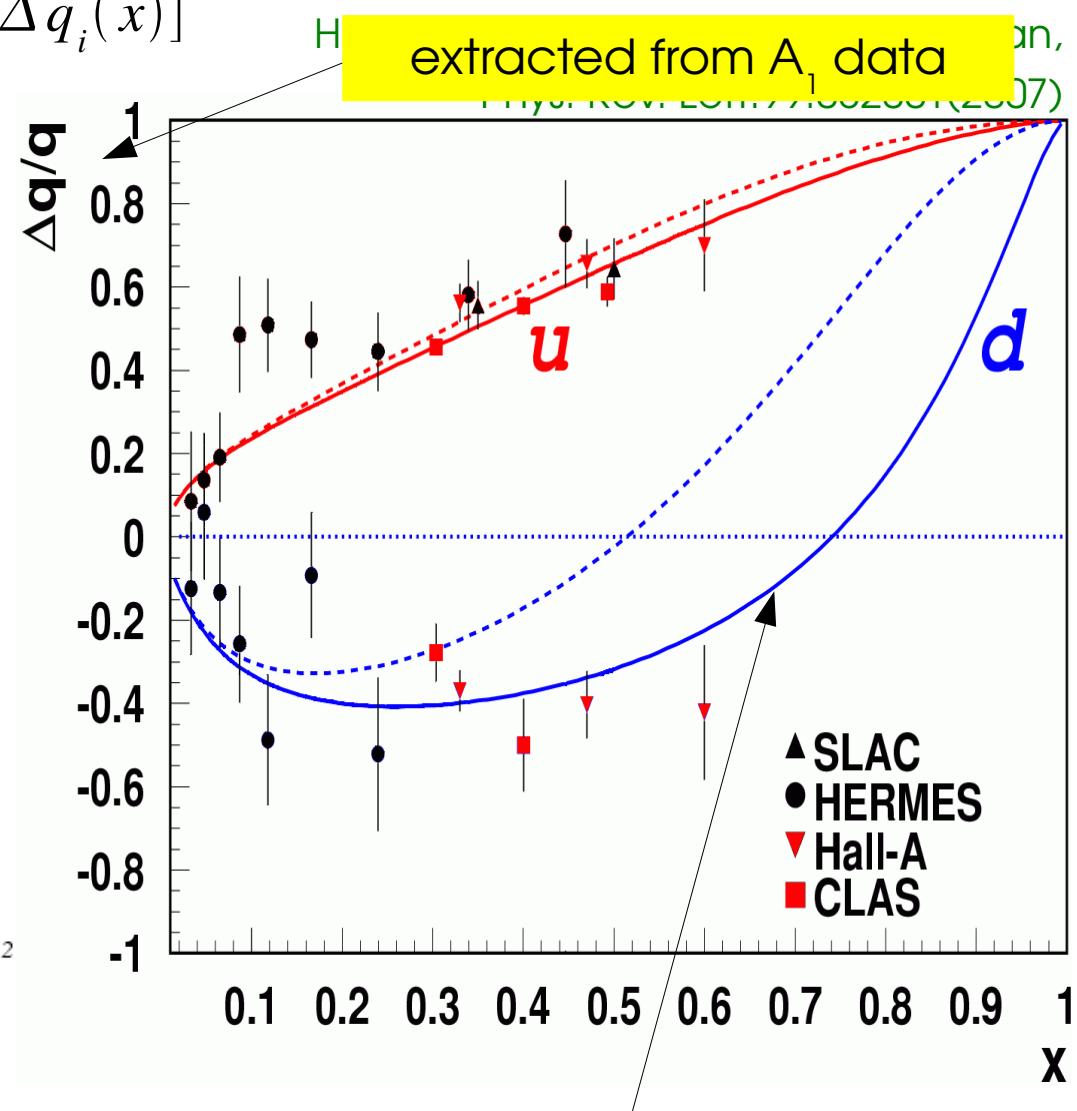
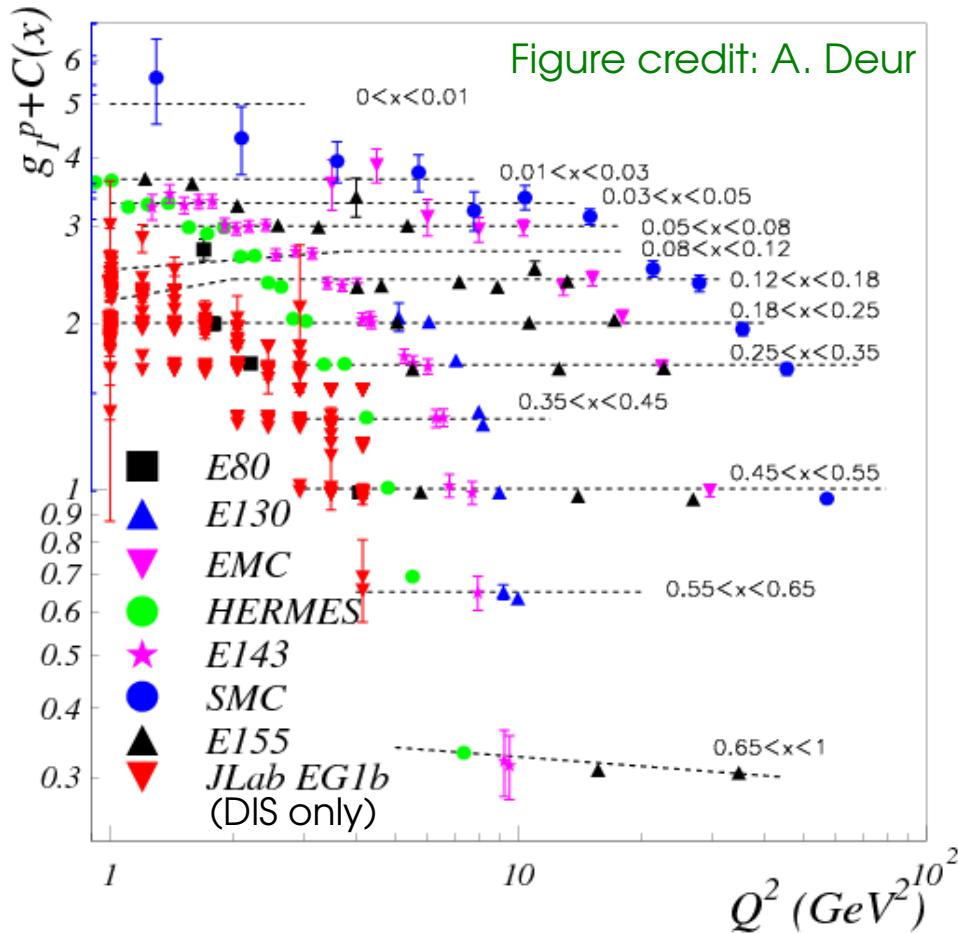
Extra slides

- Major Challenges **to** the Standard Model
 - ✚ Higgs mechanism yet to be tested (observed);
 - ✚ Cannot explain the observed non-zero mass of ν 's;
 - ✚ Does not include gravity, neither does it explain dark matter/energy;
 - ✚ Requires too many parameters;
 - ✚ Conceptually, there is always “room” for New Physics.
 - ✚ Parity violation in lepton/electron scattering can help to test the Standard Model by looking for “signs” of new physics.

Nucleon Spin Structure in the Valence Quark Region

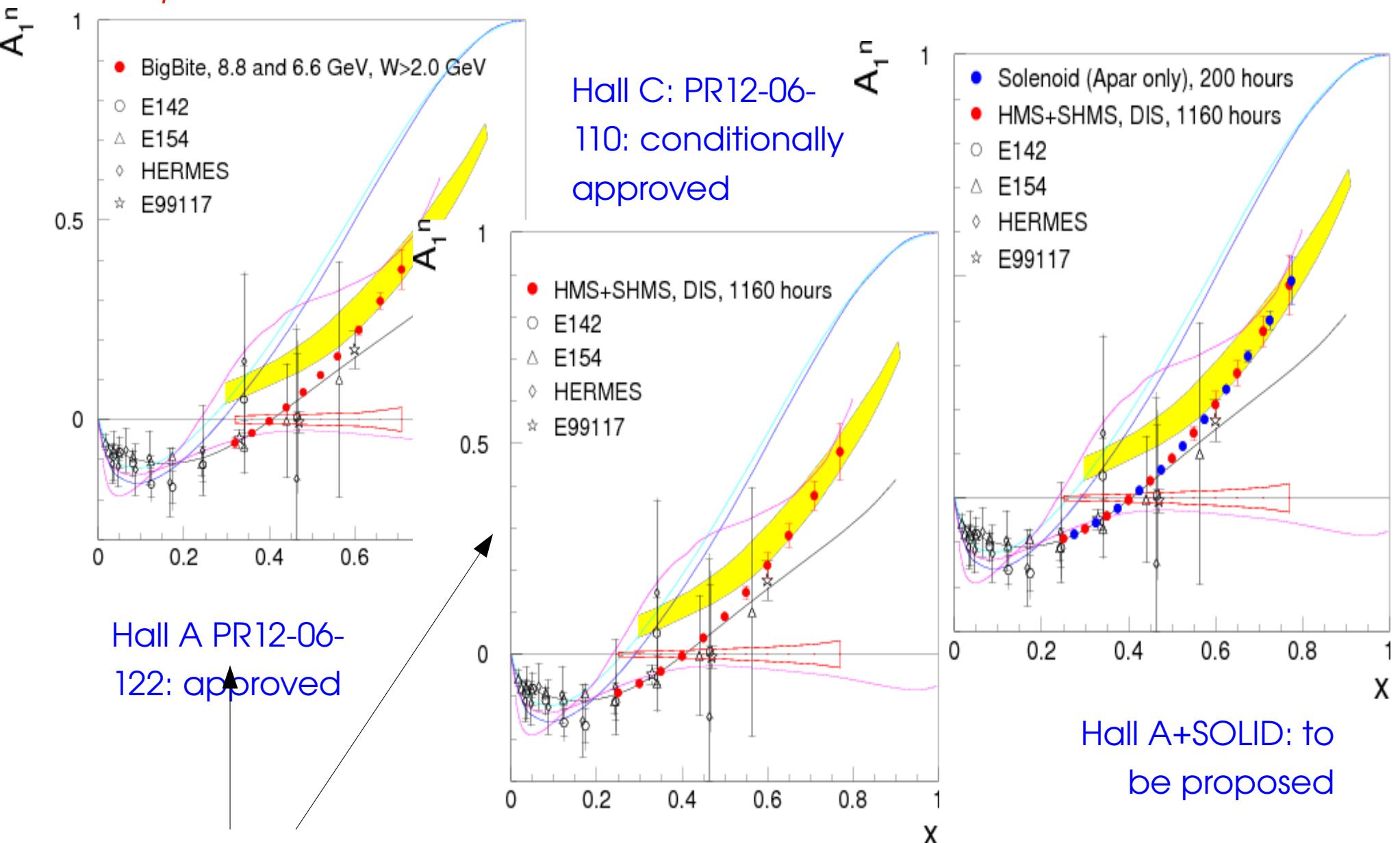
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Will pQCD predictions
(with quark OAM) work?

A_1^n in the Valence Quark Region at JLab 11 GeV



To be rated August 2010

A_1^p at 11 GeV

