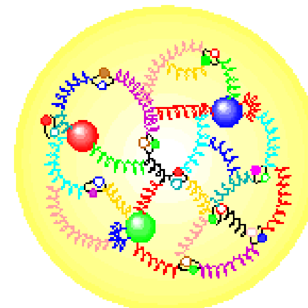
$\vec{^3He}$ Measurements using HMS+SHMS at 12 GeV

Xiaochao Zheng
Univ. of Virginia
August 19, 2011

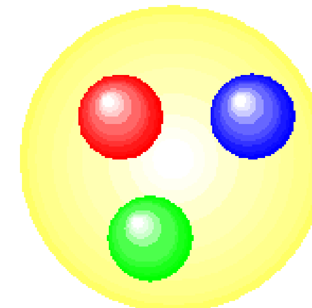
- Physics Motivation of A_1^n and E12-06-110 with HMS+SHMS
- Physics Motivation of g_2^n and d_2^n and E12-06-121 with HMS+SHMS
- Summary

Nucleon valence structure provides testing ground for theories (more than Q^2 evolution from perturbative QCD)

- 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

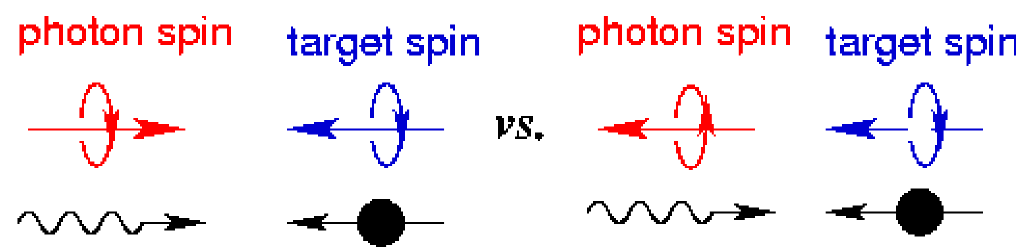


vs



- Virtual photon asymmetry:

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



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

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

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).

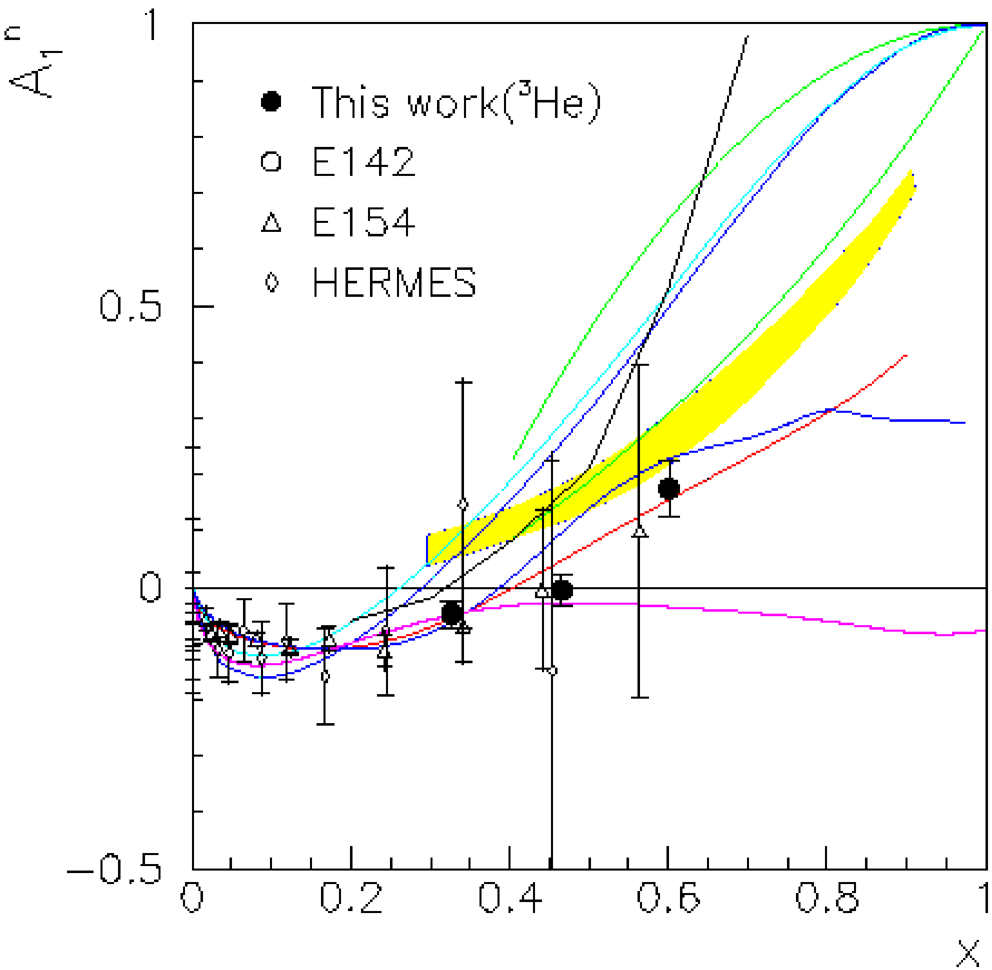
Predictions for A_1 and $\Delta q/q$ at large x

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

Model	F_2^n/F_2^p	d/u	Δ u/u	Δ 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 (and many other models) can make absolute predictions for structure functions.

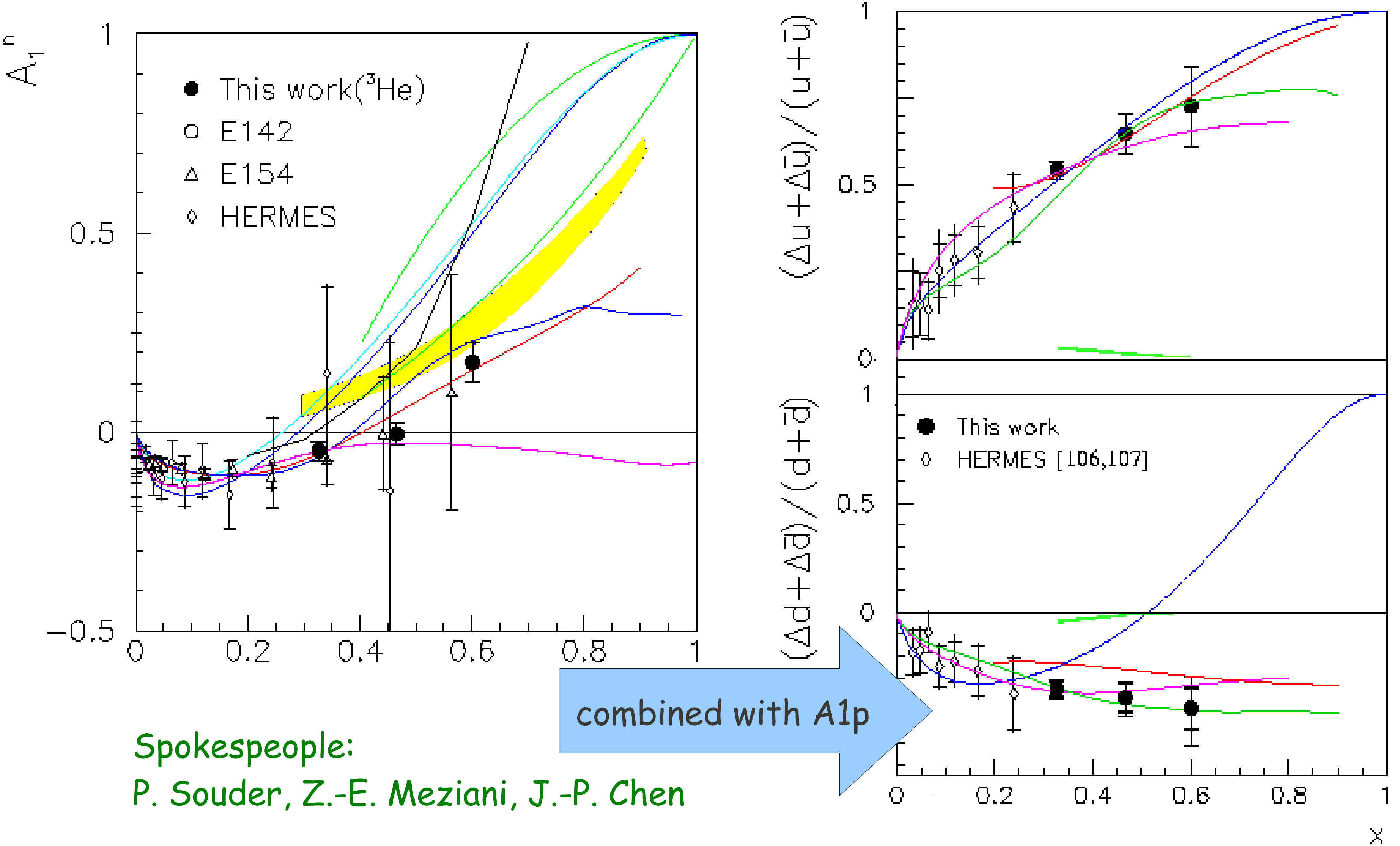
The 6 GeV Hall A Measurement (21 PAC days, 2001)



Spokespeople:
P. Souder, Z.-E. Meziani, J.-P. Chen

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

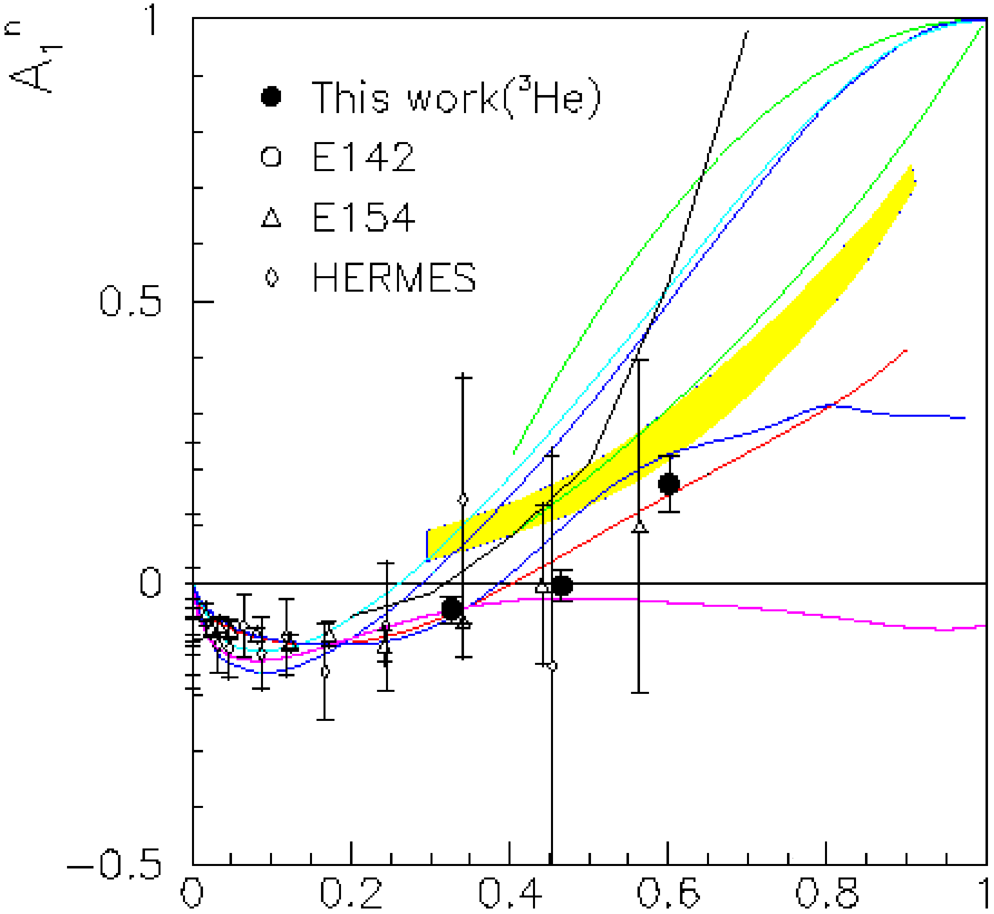
The 6 GeV Hall A Measurement (21 PAC days, 2001)

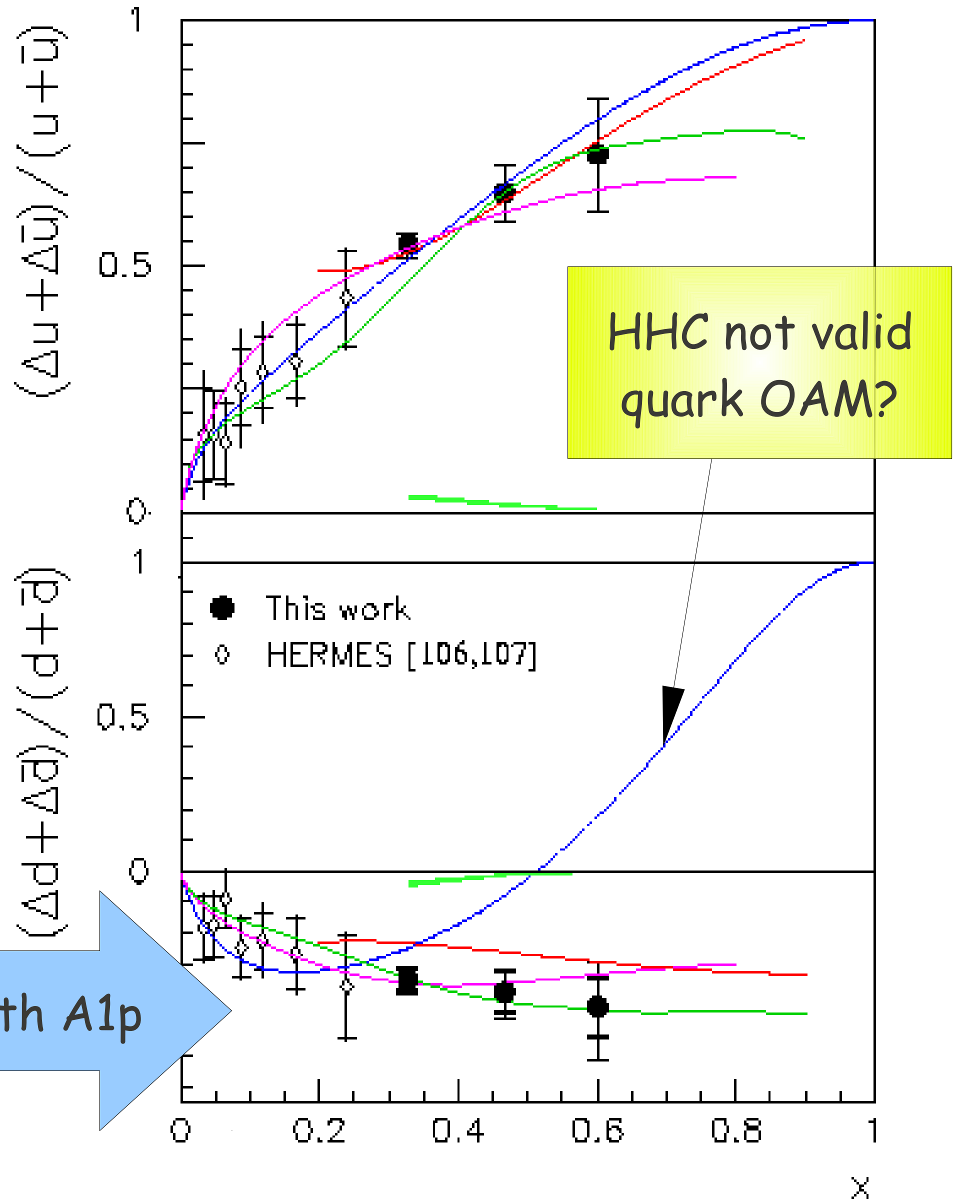


Spokespeople:
P. Souder, Z.-E. Meziani, J.-P. Chen

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

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



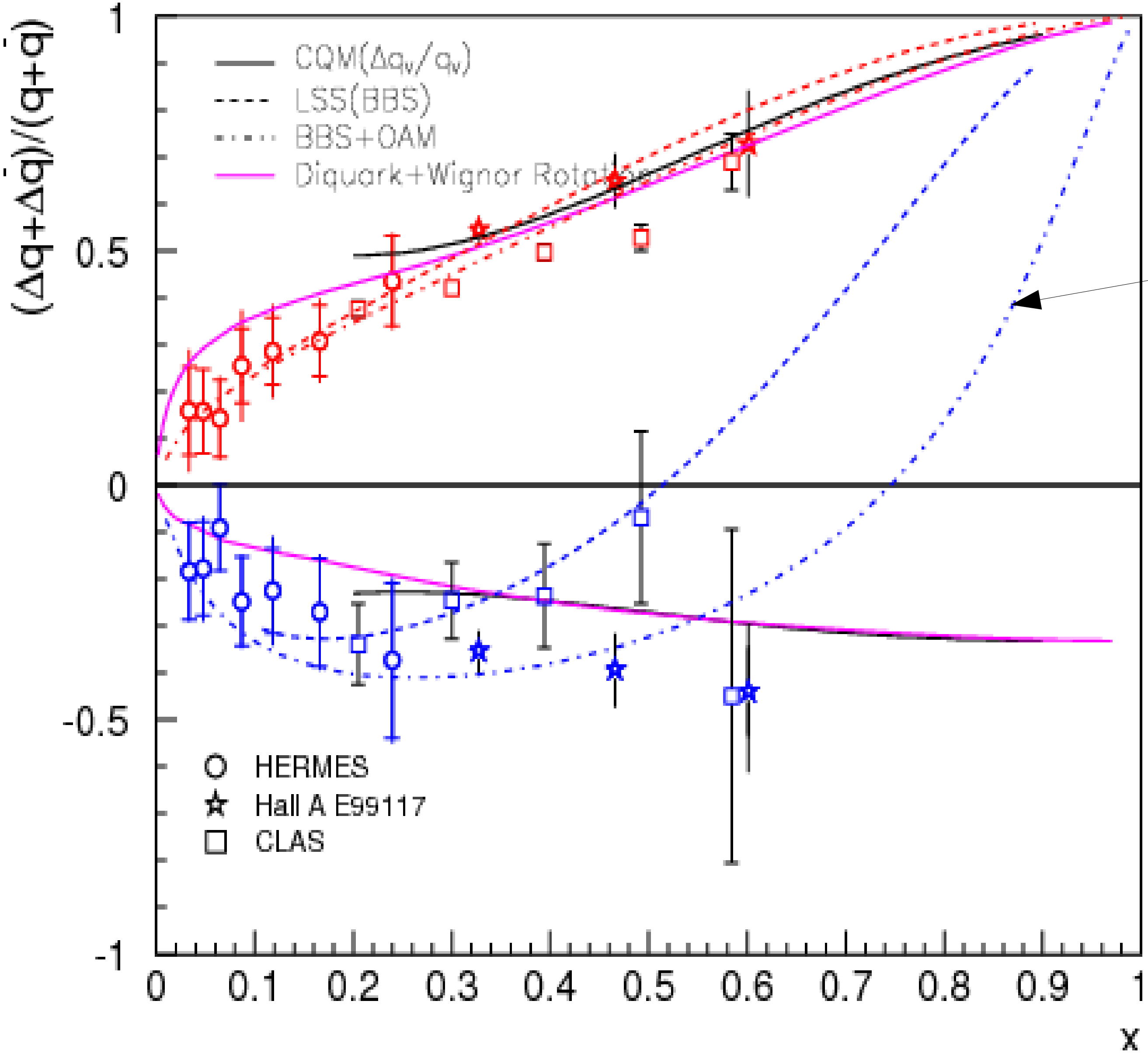


combined with A1p

Spokespeople:
P. Souder, Z.-E. Meziani, J.-P. Chen

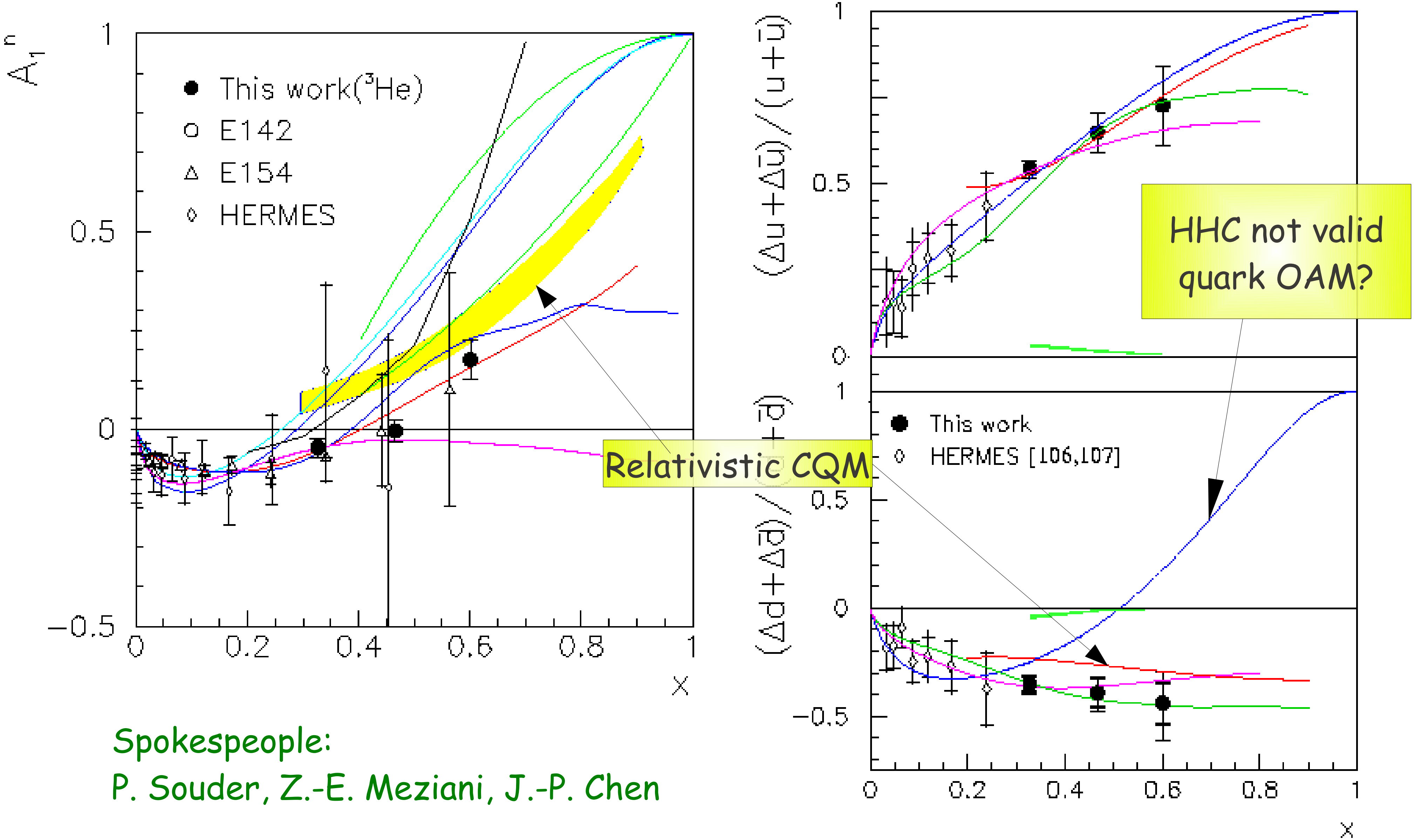
X. Zheng *et al.*, Phys. Rev. Lett. 92, 012004 (2004); Phys. Rev. C 70, 065207 (2004)

Polarized DIS and Nucleon Spin Structure



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

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



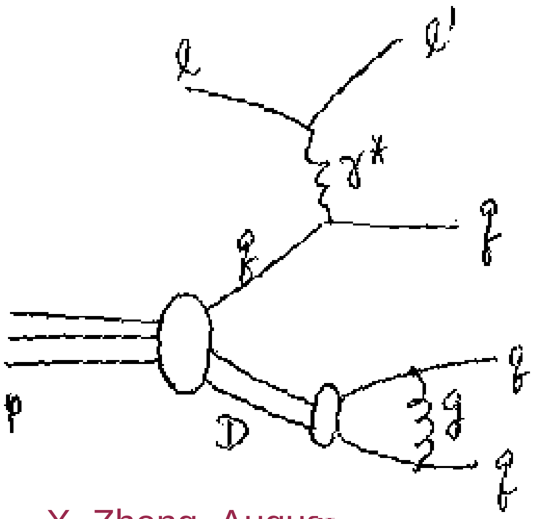
Spokespeople:
P. Souder, Z.-E. Meziani, J.-P. Chen

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

How Does Relativistic Effect Alter Δq?

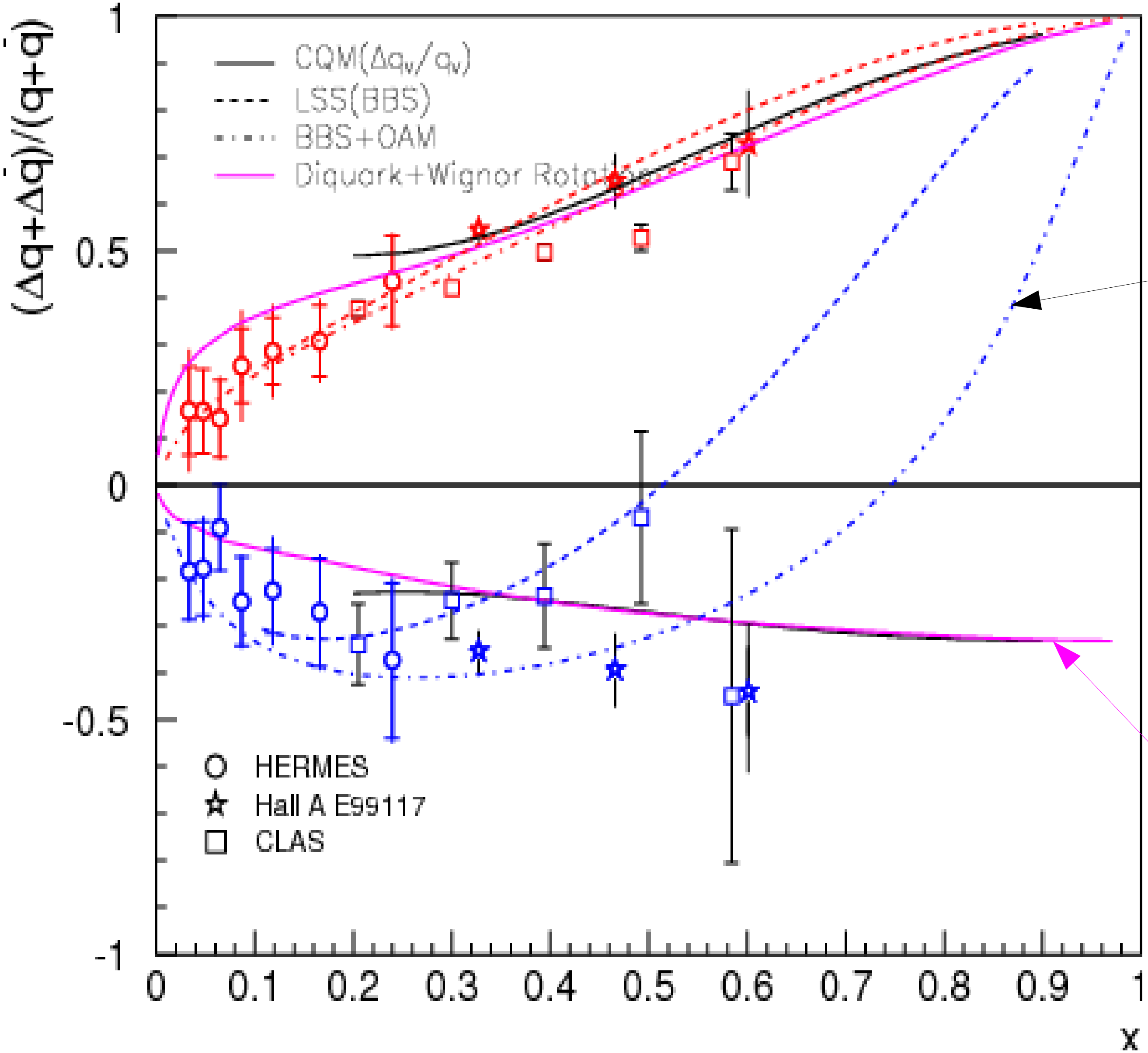
- The Δq measured in DIS is calculated from the matrix element. It has the physical implication as helicity distribution in the IMF (light-cone).
- From IMF to the nucleon rest frame, Δq is not invariant. So we should NOT expect the Δq of DIS to add up to the nucleon spin ($\frac{1}{2}$), as expected from the naïve quark model.
- To relate the two, one can use the Melosh-Wigner rotation, which is basically a relativistic transformation that bring in the quark transverse motions (or, "bring in the lower component of Dirac spinors").

A light cone quark-diquark model can be used to calculate A1



(The "proton spin crisis" can be reconciled with introductory-level physics?)

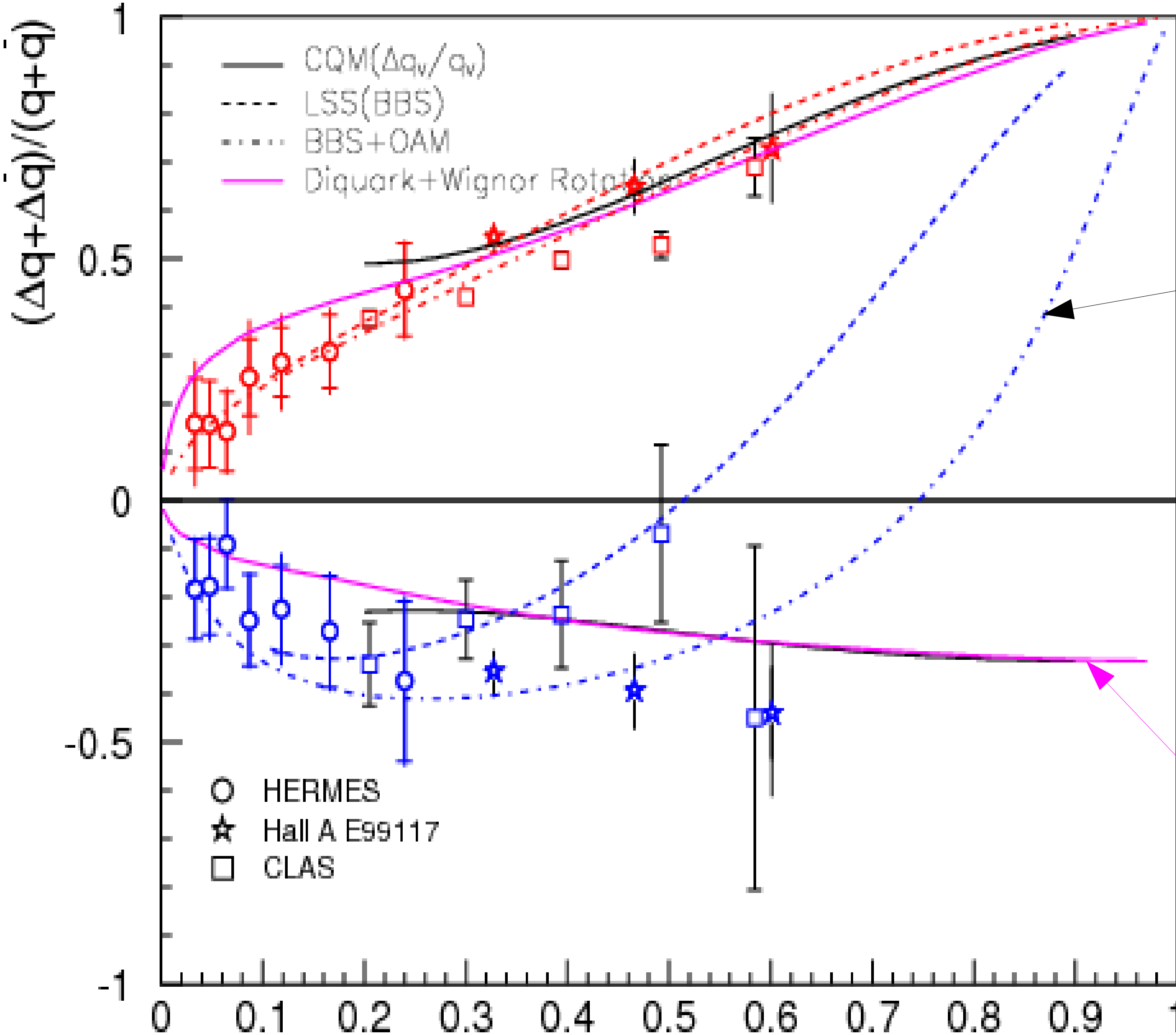
Polarized DIS and Nucleon Spin Structure



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

light-cone quark/diquark model
X. Chen, Y. Mao, B.-Q. Ma, Nucl. Phys. A 759, 188 (2005)

Polarized DIS and Nucleon Spin Structure



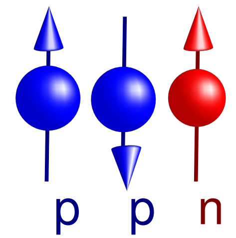
H. Avakian, S. Brodsky, A. Deur, F. Yuan, Phys. Rev. Lett.99:082001(2007)

light-cone quark/diquark model
X. Chen, Y. Mao, B.-Q. Ma,
Nucl. Phys. A 759, 188 (2005)

- **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.

E12-06-110 Measurement of A_1^n using SHMS+HMS

spokespeople: : J.P. Chen, Z.E. Meziani, G.D. Cates, X. Zheng



- Measure A_1^n in DIS from $^3\vec{He}(\vec{e},e')$ using $^3\overrightarrow{He} \approx \vec{n}$
  - 11 GeV beam, P_{beam}=80% (dP/P=1% Compton, Moller)
  - HMS+SHMS to detect e', measure both $A_{\parallel}$ and $A_{\perp}$:
  - Will use the same target design as GEN-II (11 GeV):
    - alkali-hybrid mixtures to increase the spin-exchange efficiency;
    - narrow-lined high-power diode lasers;
    - use of convection to overcome depolarization;
    - metal-based target chamber to resist radiations and avoid cell rupture;
    - overall, R&D to better understand the target polarizations
    - **Goal: 60-cm long target chamber, 12 amg density, up to 60uA beam with 60% polarization**
- **Total: 843h (35 days) + Target Installation**
- Will reach ΔA_1^n=±0.029(stat) ±0.034(syst) at x=0.77

Kinematics

10[4]:1 π rejection is needed

- Production (DIS and resonance)

Kine		E_b GeV	E_p GeV	θ (°)	(e,e') rate (Hz)	π^-/e	e^+/e^-	x (Q^2, in GeV^2) (W, in GeV) coverages
DIS								
1	HMS	11.0	5.70	12.5	2300.75	< 0.5	$< 0.1\%$	0.25-0.35 (2.78- 3.17) (2.6- 3.0)
2	HMS	11.0	6.80	12.5	1768.35	< 0.1	$< 0.1\%$	0.35-0.55 (3.26- 3.78) (2.0- 2.6)
3	HMS	11.0	2.82	30.0	5.03	< 7.0	$< 0.9\%$	0.50-0.60 (7.84- 8.87) (2.6- 3.0)
4	HMS	11.0	3.50	30.0	0.94	< 1.6	$< 0.1\%$	0.65-0.77 (9.59-10.54) (2.0- 2.5)
5	HMS	11.0	7.50	12.5	598.43	< 0.1	$< 0.1\%$	0.45-0.55 (3.59- 3.78) (2.0- 2.3)
A	SHMS	11.0	5.80	12.5	2817.72	< 0.6	$< 0.1\%$	0.25-0.55 (2.71- 3.77) (2.0- 3.0)
B	SHMS	11.0	3.00	30.0	9.61	< 9.4	$< 1.4\%$	0.45-0.77 (7.52-10.54) (2.0- 3.2)
C	SHMS	11.0	2.25	30.0	28.20	< 42.3	$< 10.1\%$	0.35-0.55 (5.94- 8.21) (2.8- 3.5)
D	SHMS	11.0	7.50	12.5	857.47	< 0.1	$< 0.1\%$	0.40-0.55 (3.40- 3.78) (2.0- 2.4)
Resonances								
5	HMS	11.0	7.50	12.5	666.78	–	–	0.55-0.83 (3.84- 4.26) (1.3- 2.0)
D	SHMS	11.0	7.50	12.5	440.74	–	–	0.55-0.89 (3.84- 4.36) (1.2- 2.0)

- Elastic e-^{3}He(ll) and Δ(1232) (⊥) 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	$A_{\parallel} = 0.0589$	5.1
Δ(1232)	2.200	1.815	12.5	-	-	$A_{\perp} \sim$ a few %	6

Projected A_1^n Uncertainties

- DIS

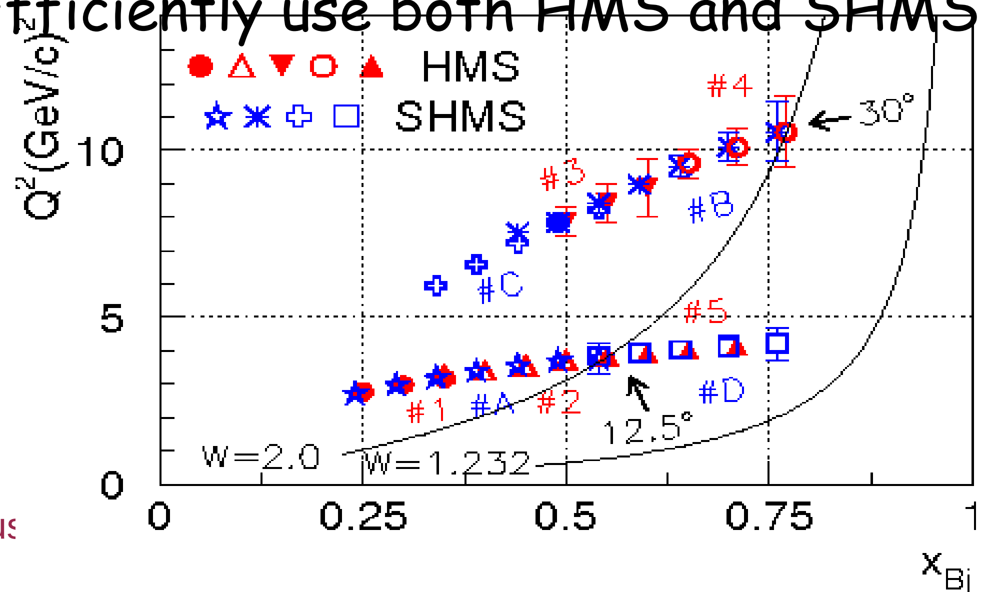
x	ΔA_1^n(stat.) low Q^2	ΔA_1^n(stat.) high Q^2	ΔA_1^n(stat.) two Q^2 combined	ΔA_1^n(syst.)	ΔA_1^n(total)
0.25	0.0022	–	0.0022	0.0054	0.0059
0.30	0.0020	–	0.0020	0.0063	0.0066
0.35	0.0025	0.0109	0.0024	0.0074	0.0078
0.40	0.0030	0.0084	0.0028	0.0089	0.0093
0.45	0.0029	0.0106	0.0028	0.0105	0.0109
0.50	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

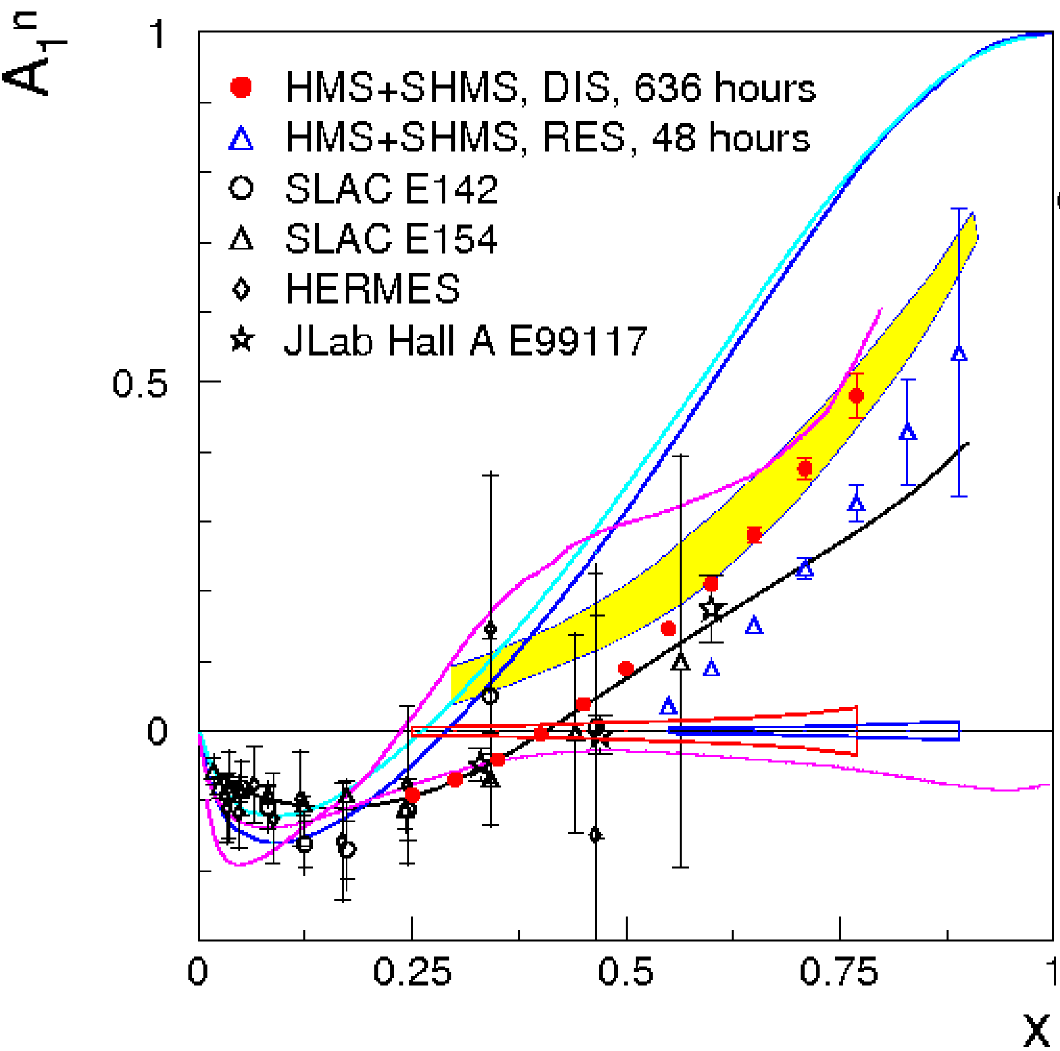
x	ΔA_1^n(stat.)	ΔA_1^n(syst.)	ΔA_1^n(total)
0.55	0.0072	0.0145	0.0162
0.60	0.0061	0.0169	0.0180
0.65	0.0074	0.0197	0.0210
0.71	0.0095	0.0242	0.0260
0.77	0.0138	0.0323	0.0352
0.83	0.0302	0.0530	0.0610
0.89	0.0593	0.1003	0.1165

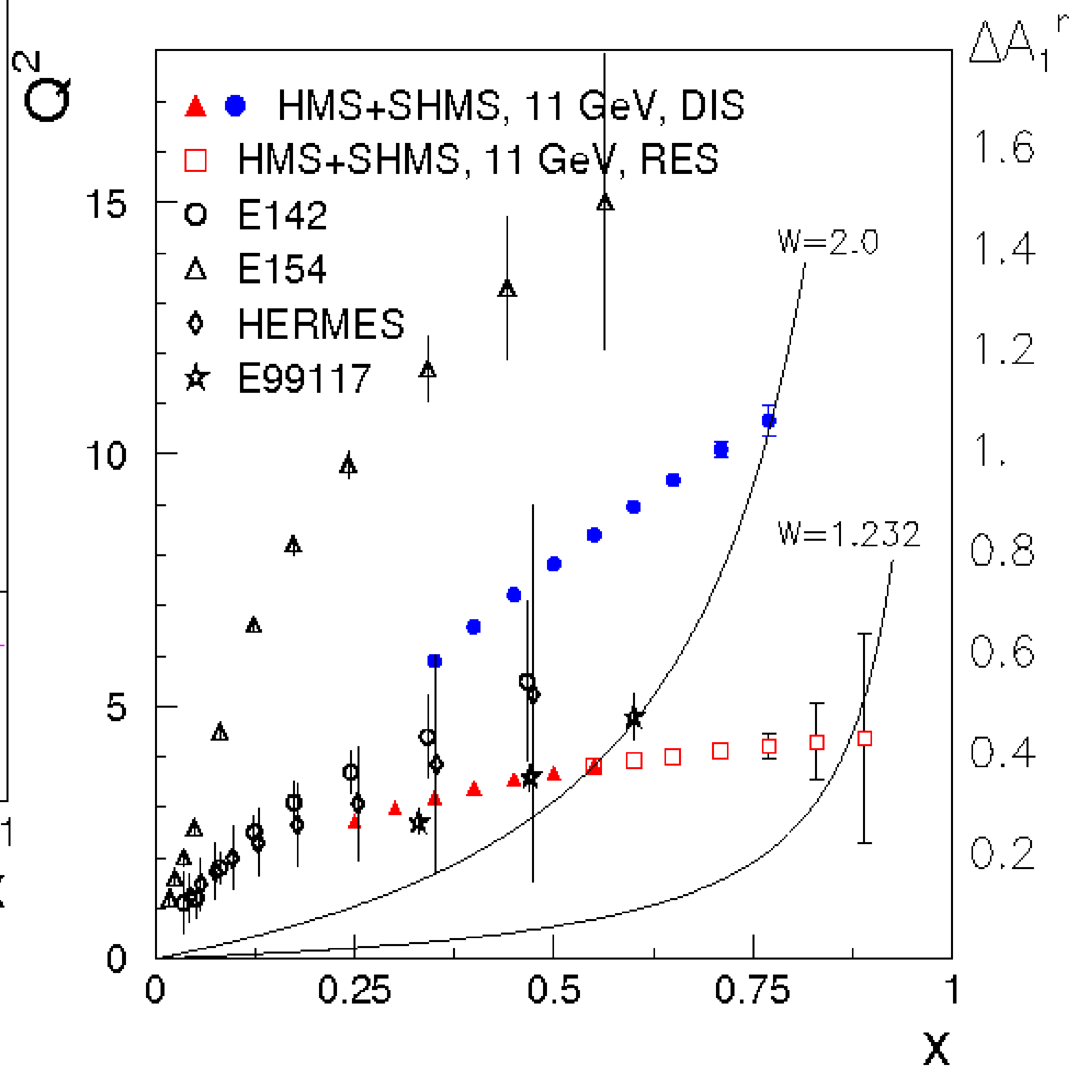
gus

Efficiently use both HMS and SHMS



Expected Results

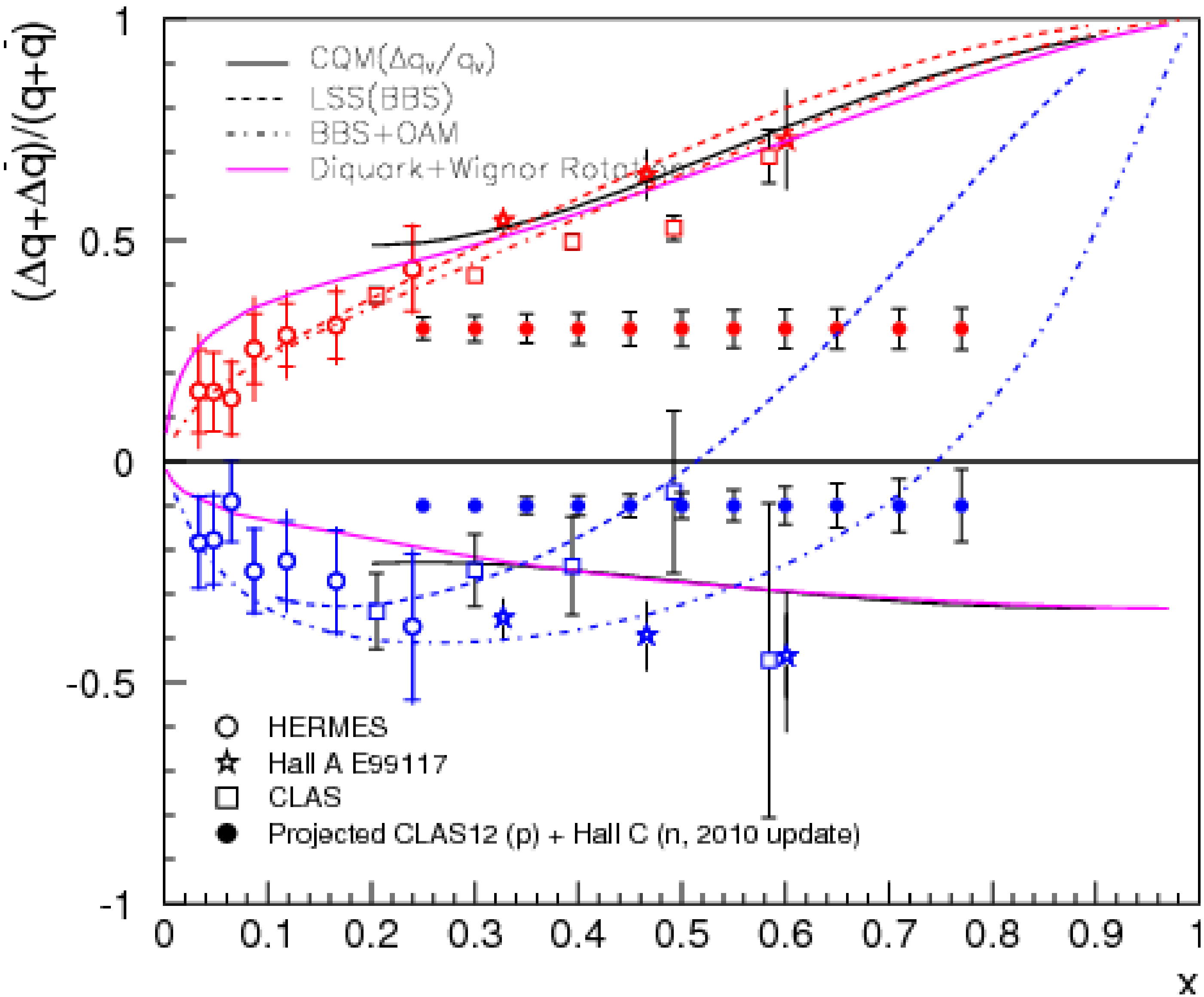




study Q^2 dependence

Expected Results

- Combined with Hall B (proton) 11 GeV experiments

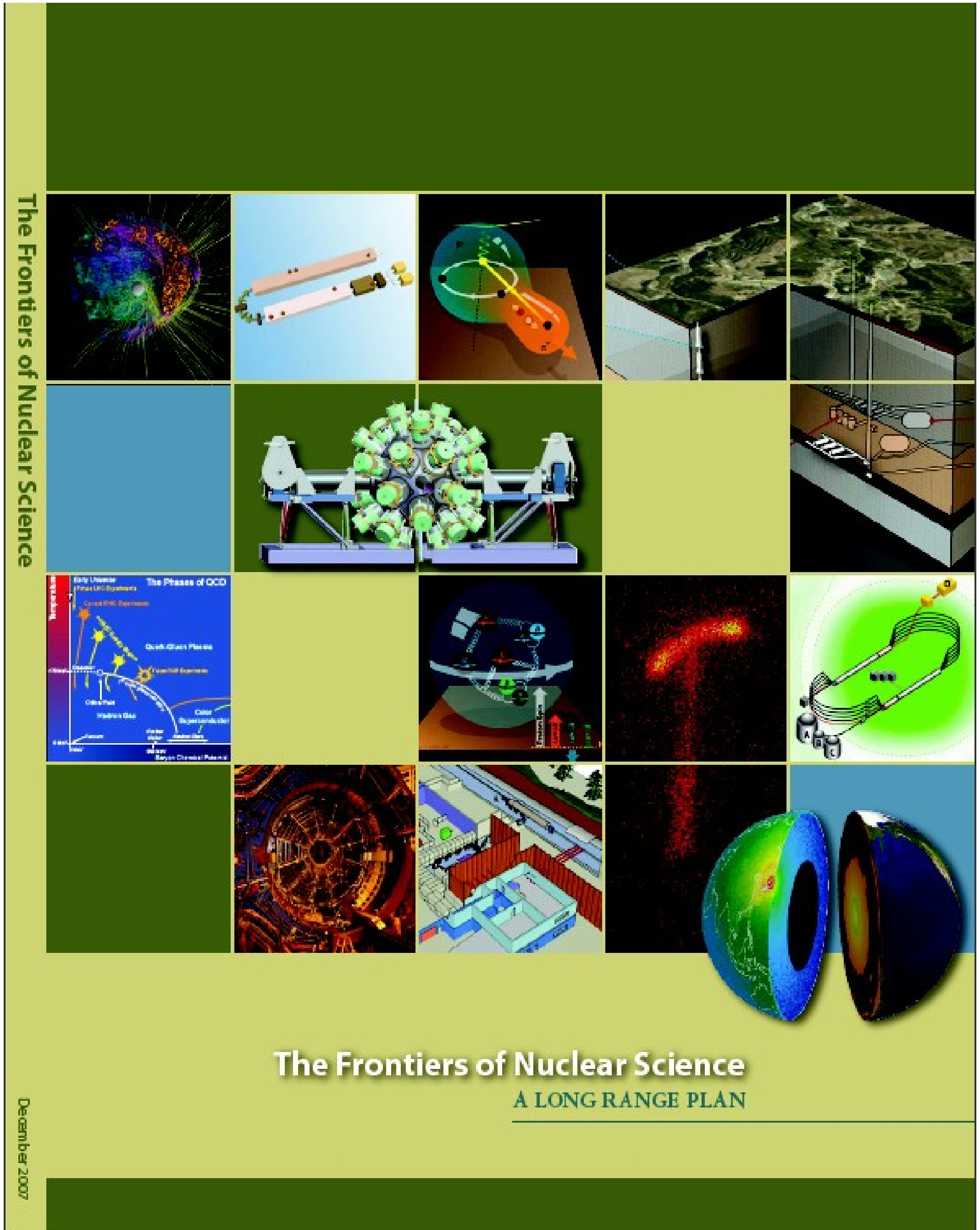


E12-06-121 Measurement of Neutron g2 and d2

(thanks to Brad S. for providing the slides)

Summary

Frontiers of Nuclear Science



"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."

E12-06-110 as a possible SHMS Commissioning Experiment

Extra slides

From ^{3}He to Neutron

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

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

- Other Inputs:
  - F_2^p, F_2^D – NMC fits and MRST/CTEQ
  - $P_n = 0.86^{+0.036}_{-0.020}$, $P_p = -0.028^{+0.009}_{-0.004}$

    dominant for high x

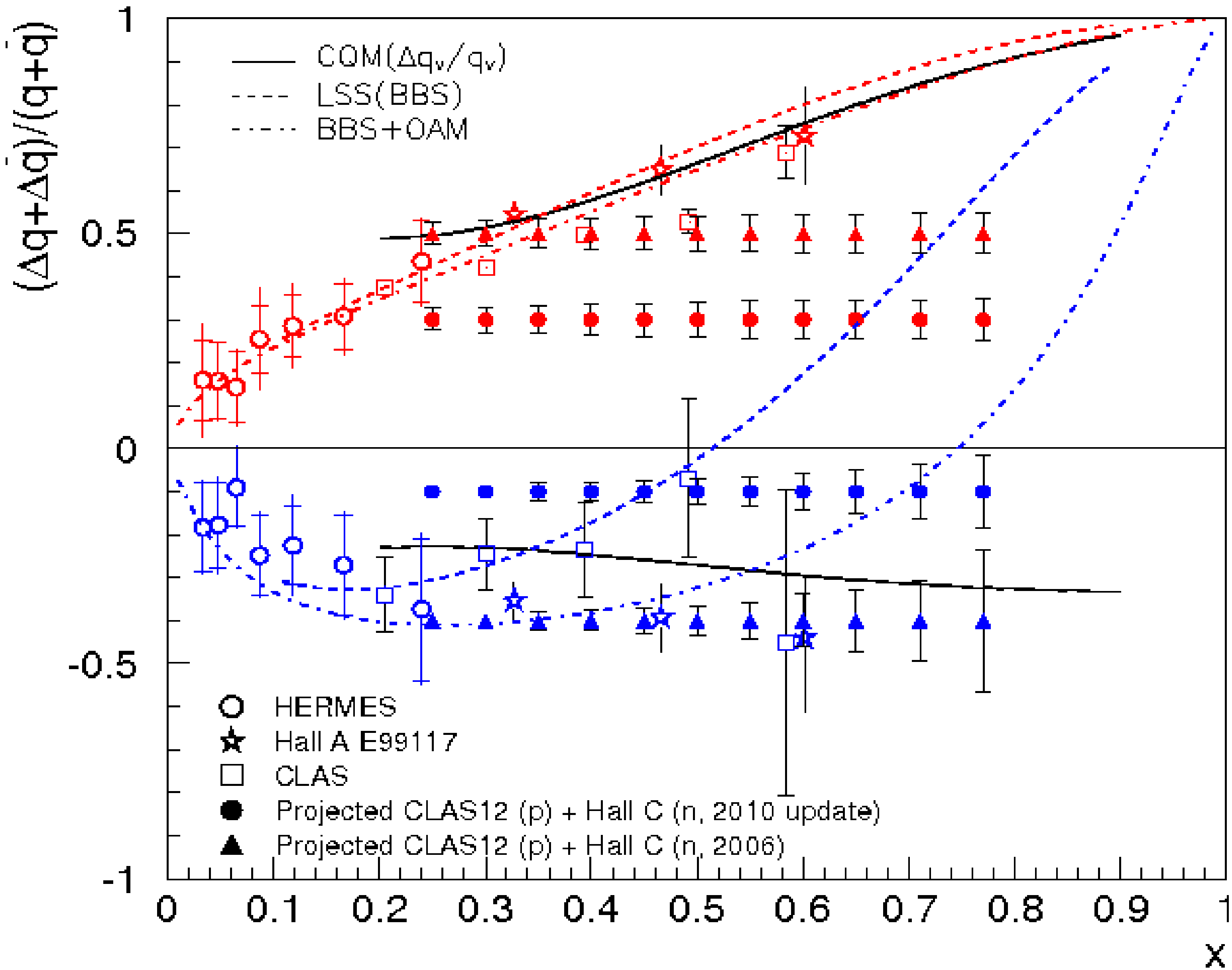
    Uncertainty on Pp expected to reduce by factor of 4 from Hall A Ax and Az measurements;
  - $R(x,Q^2)$ – R1998, PLB 452, 194 (1999)
  - EMC for F_2^{3He}, F_2^D Acta Phys.Polon. B27, 1407 (1996) (nucl-th/9603021)
  - A_1^p – from fit to world data (at large x also consistent with CLAS12 expected results) Phys. Rev. C 70, 065207 (2004)

Complementarity with the Hall A BigBite Proposal

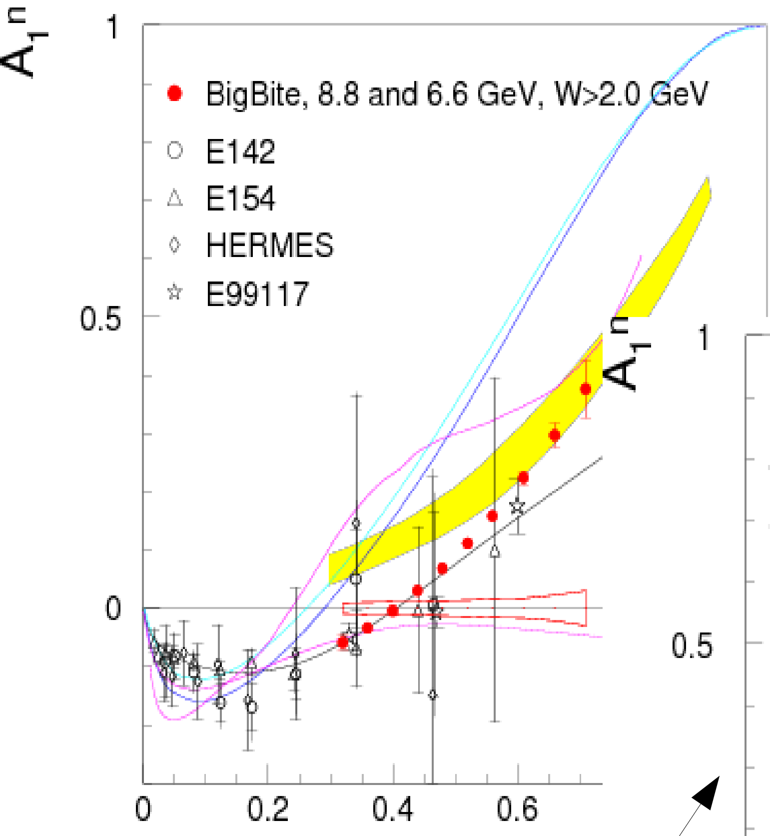
- The current version of Hall A proposal uses the BigBite spectrometer, will provide DIS data up to x=0.71 with a 8.8 GeV beam, with smaller uncertainties than this proposal. It is unknown yet whether it will work for 11 GeV; ← *condition of PAC30*
- Even if BigBite works for 11 GeV, it will be limited 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 Q2-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.

Expected Results

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

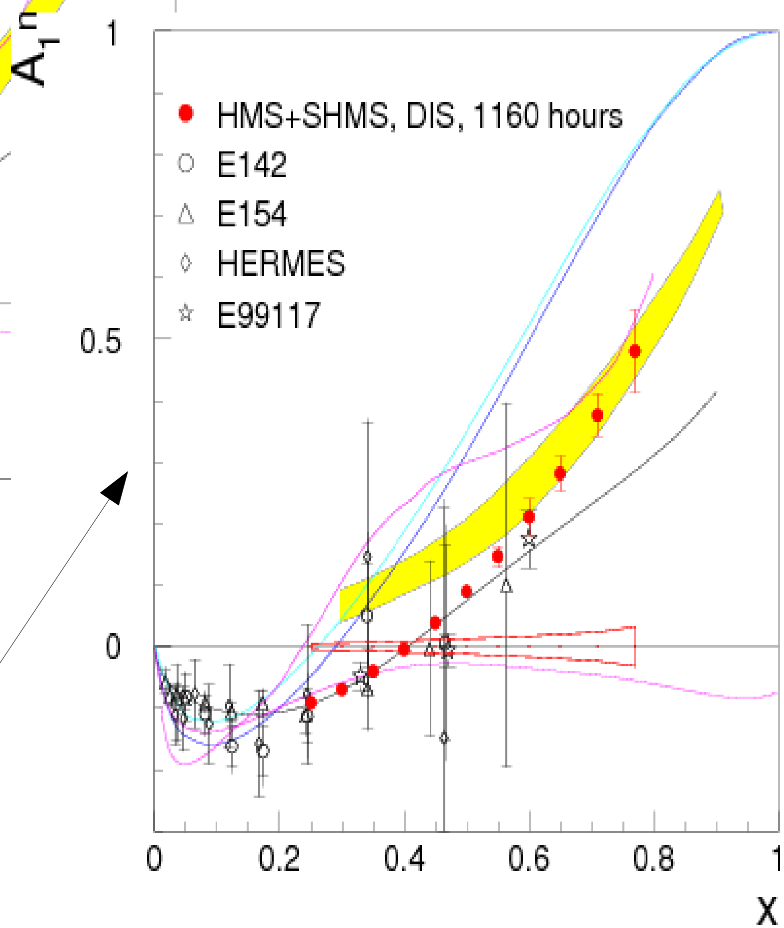


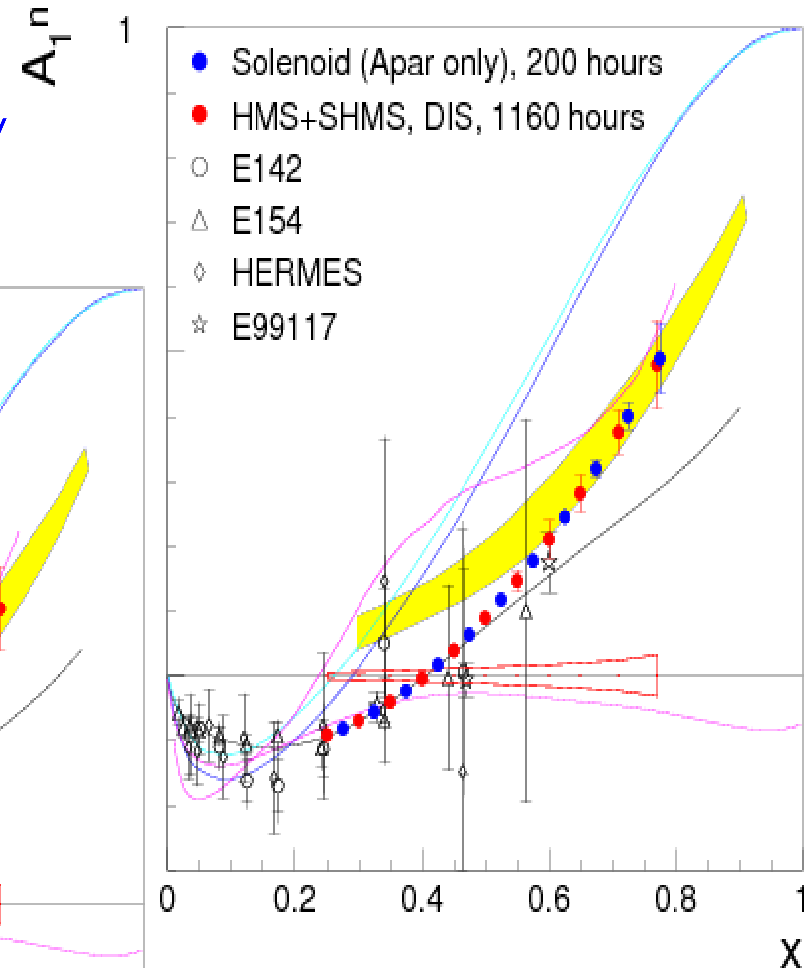
A_1^n in the Valence Quark Region at JLab 11 GeV



Hall A PR12-06-122: approved

Hall C: PR12-06-110: conditionally approved

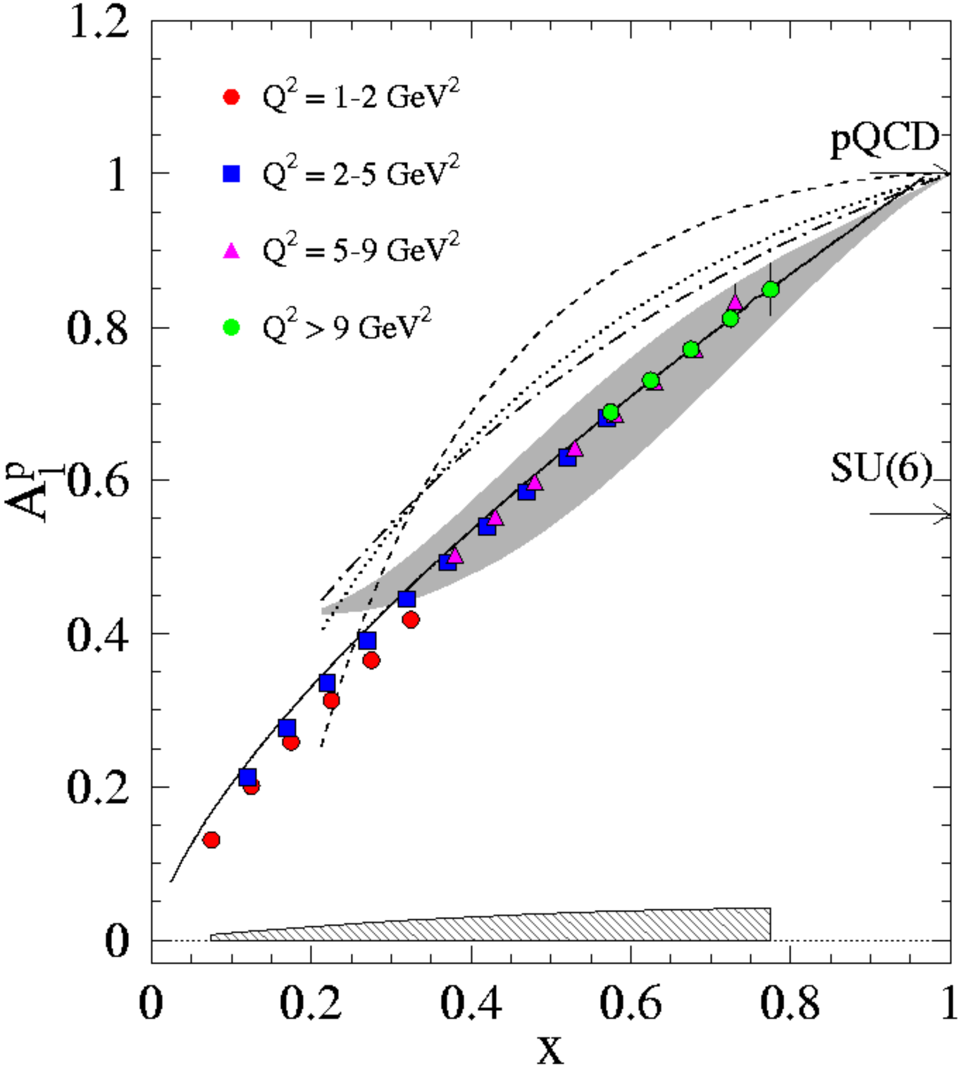




Hall A+SOLID: to be proposed

- To be rated August 2010

A_1^p at 11 GeV



1.2
1
0.8
0.6
0.4
0.2
0
A_1^p
$Q^2 = 1\text{-}2\ GeV^2$
$Q^2 = 2\text{-}5\ GeV^2$
$Q^2 = 5\text{-}9\ GeV^2$
$Q^2 > 9\ GeV^2$
pQCD
SU(6)
0
0.2
0.4
0.6
0.8
1
x

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; Δ(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