Measurement of A_1^n Using HMS/SHMS at 12 GeV

(A new proposal for PAC-30)

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- Motivation: Neutron Spin Asymmetry A_1^n at large x_{Bj}
- This Proposal
  - Kinematics and Rates
  - Systematic Uncertainties and Projected Results
  - Complementarity with "A_1^n using BigBite"
- Summary

Draft: http://www.jlab.org/~xiaochao/12gev/HALLC/PR12_a1n_hallc.pdf

All Hall A collaborators are invited to join!

Polarized DIS and Spin Structure of the Nucleon

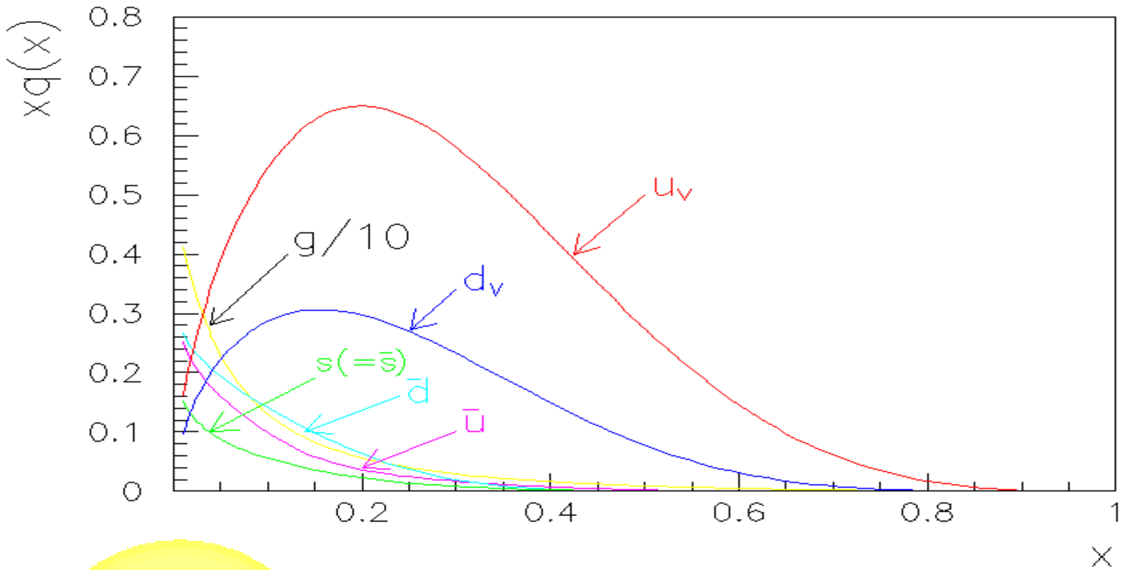
Spin observables provide testing ground of QCD, the "Standard Model" of strong interactions

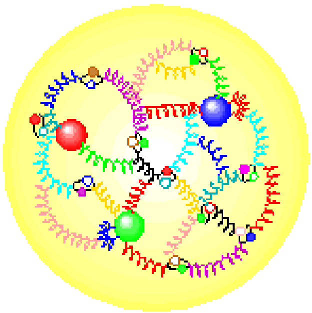
- 1988-1989: data showed quarks' spin contributes (12±17)% to the proton spin — "The Proton Spin Crisis"
- Current understanding of the nucleon spin:

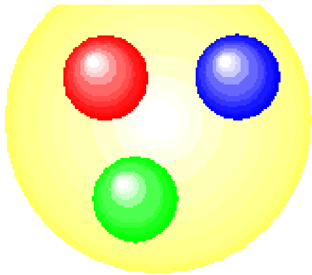
$$\frac{1}{2} = S_Z^N = S_Z^q + L_Z^q + J_Z^g \quad \text{(the spin "sum rule")}$$

  - Quark spin contributes about (20~30)% to the nucleon spin
  - Little data exist on L_z^q and J_Z^g.
- Understanding spin structure of the nucleon requires measurements of all three components, and to answer *the* question: *"CAN WE UNDERSTAND THESE DATA from the first principles in QCD?"*
- However, the region where we can test QCD is limited due to the complication in QCD calculations — moments, structure func. at high x.

Why Large *x* ?







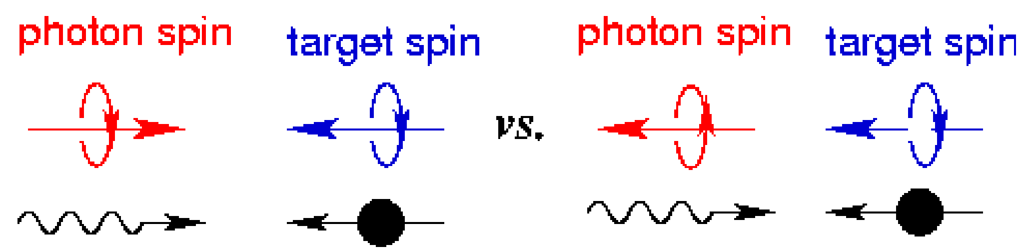
- At large *x*, valence quarks dominate, easier to model;
- Less contribution from q-qbar sea and gluons — a relatively clean region to study the nucleon structure;
- To understand the nucleon spin, high x is a good place to start with.

Polarized DIS and Virtual Photon Asymmetries

- Longitudinal target:
$$\frac{d^2\sigma^{\uparrow\downarrow}}{d\Omega\, dE'} - \frac{d^2\sigma^{\uparrow\uparrow}}{d\Omega\, dE'} \propto \sigma_{point-like}[\alpha' g_1(x,Q^2) + \beta' g_2(x,Q^2)]$$

- Transverse target:
$$\frac{d^2\sigma^{\uparrow\leftarrow}}{d\Omega\, dE'} - \frac{d^2\sigma^{\uparrow\leftarrow}}{d\Omega\, dE'} \propto \sigma_{point-like}[\alpha'' g_1(x,Q^2) + \beta'' g_2(x,Q^2)]$$

- Virtual photon asymmetry:
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$



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

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

- A_1 nearly independent 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

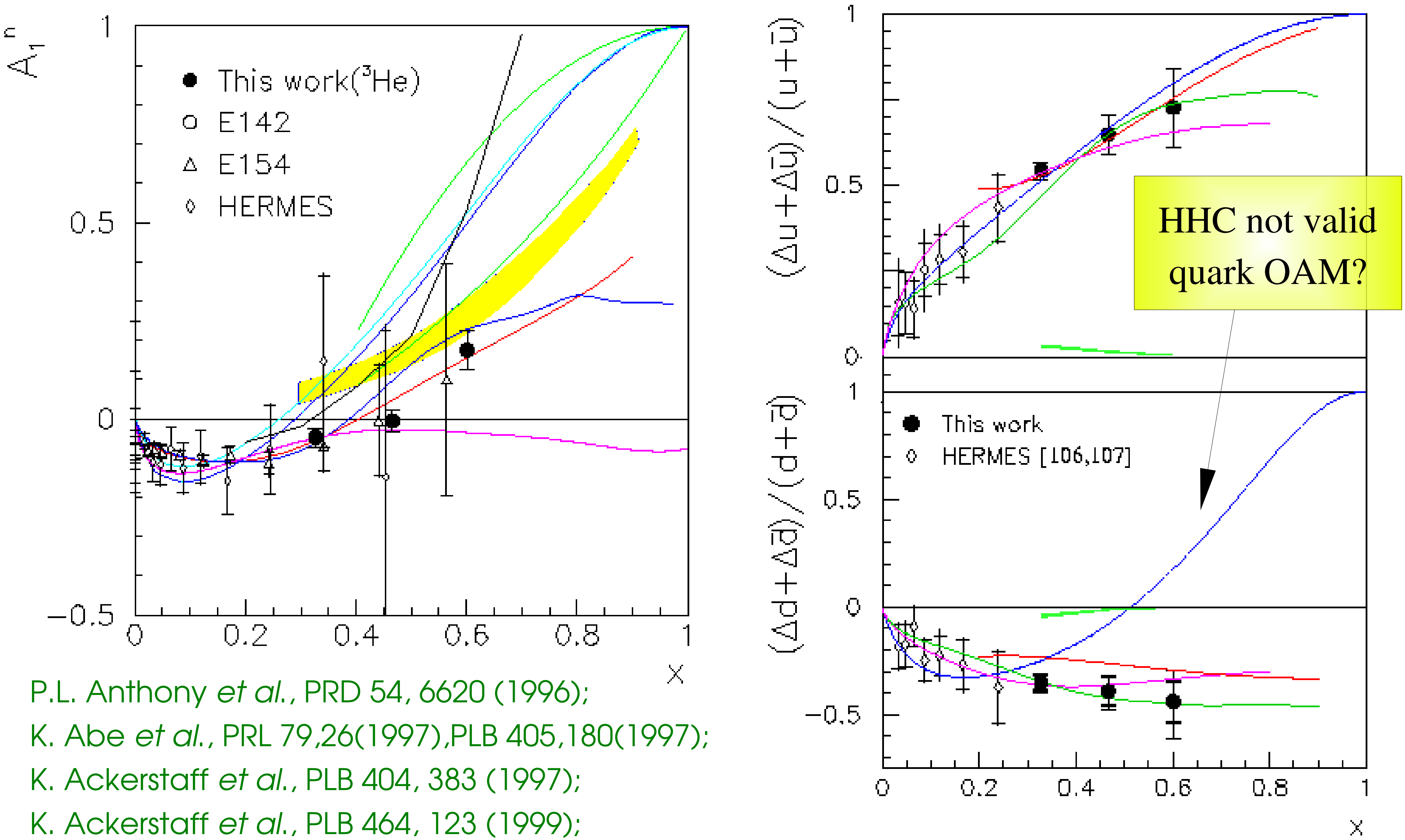
$$|p^{\uparrow}\rangle = \frac{1}{\sqrt{2}}|u^{\uparrow}(ud)_{00}\rangle + \frac{1}{\sqrt{18}}|u^{\uparrow}(ud)_{10}\rangle - \frac{1}{3}|u^{\downarrow}(ud)_{11}\rangle$$

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

Model	F_2^n/F_2^p	d/u	$\Delta u/u$	$\Delta d/d$	A_1^n	A_1^p
SU(6) = SU(3) flavor + SU(2) 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.

Present World Data on A_1^n and $\Delta q/q$



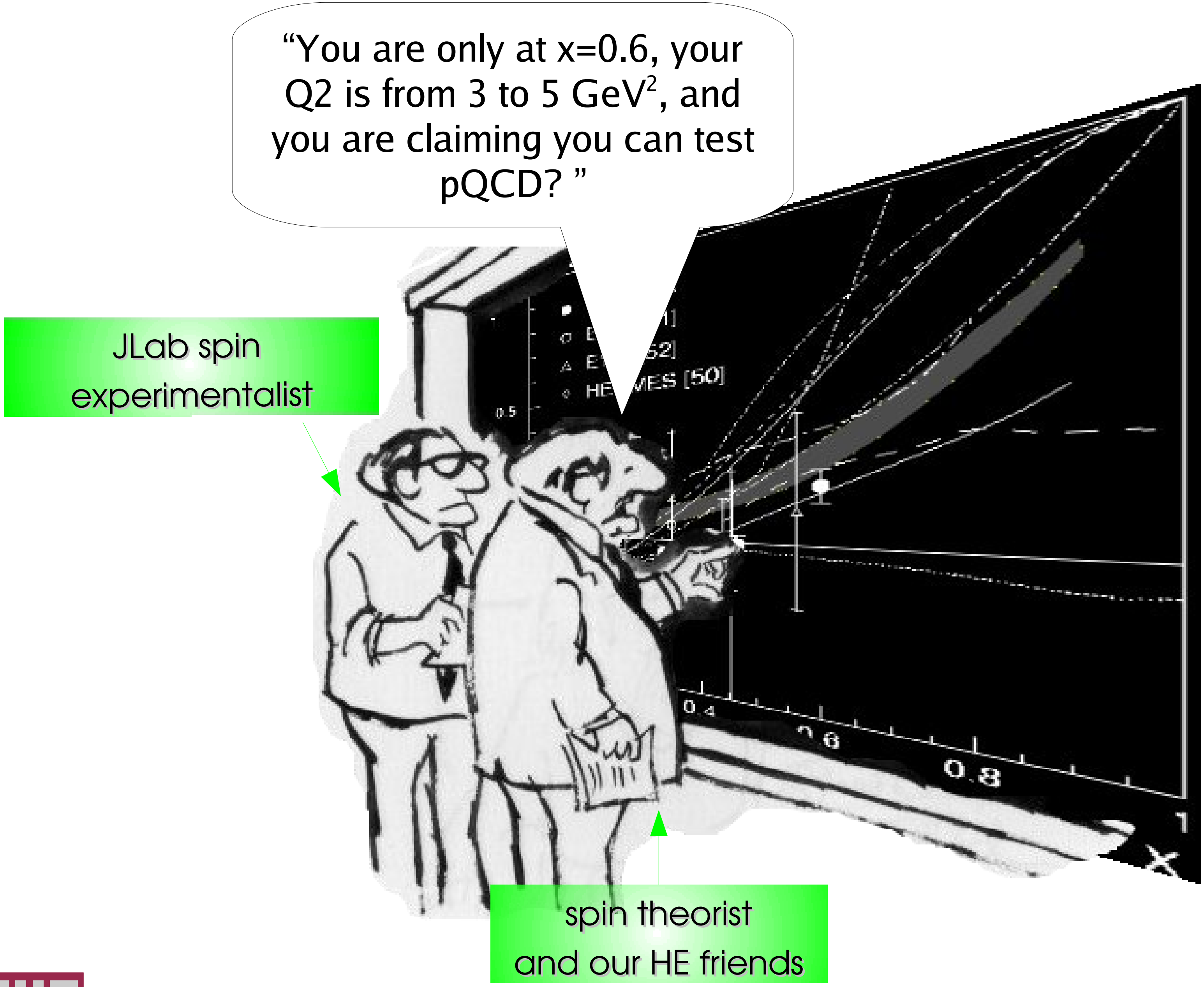
P.L. Anthony *et al.*, PRD 54, 6620 (1996);
K. Abe *et al.*, PRL 79,26(1997),PLB 405,180(1997);
K. Ackerstaff *et al.*, PLB 404, 383 (1997);
K. Ackerstaff *et al.*, PLB 464, 123 (1999);
X. Zheng *et al.*, PRL 92, 012004 (2004);

Figures from PRC 70, 065207 (2004)

Public Media Articles on A_1^n Results

- CERN Courier http://www.cerncourier.com/main/article/44/10/16
- APS — DNP website http://dnp.nscl.msu.edu/current/spin.html
- Physics Today Update
  http://www.physicstoday.org/vol-57/iss-2/p9.shtml
- Science On-line article
  http://sciencenow.sciencemag.org/cgi/content/full/2003/1223/2
- Science News article
  http://www.sciencenews.org/20040103/fob1.asp
- Physics News Update:
  http://www.aip.org/enews/physnews/2003/split/666-1.html

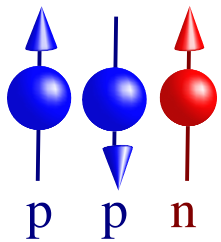
Are We Close to pQCD, Valence Quark Regime?



New Proposal for PAC-30

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

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



  - 12 GeV polarized e^- beam, P_{beam}= 80% (dP/P=1% Compton, Moller)
  - Polarized ^{3}He target, hybrid pumping, 40 cm, 14 atm @ 50^{o}C, P_{Targ}=50% (dP/P = 3%) — (E02-013 has achieved 55% in beam)
  - HMS+SHMS to detect e', measure both $A_{\parallel}$ and $A_{\perp}$:

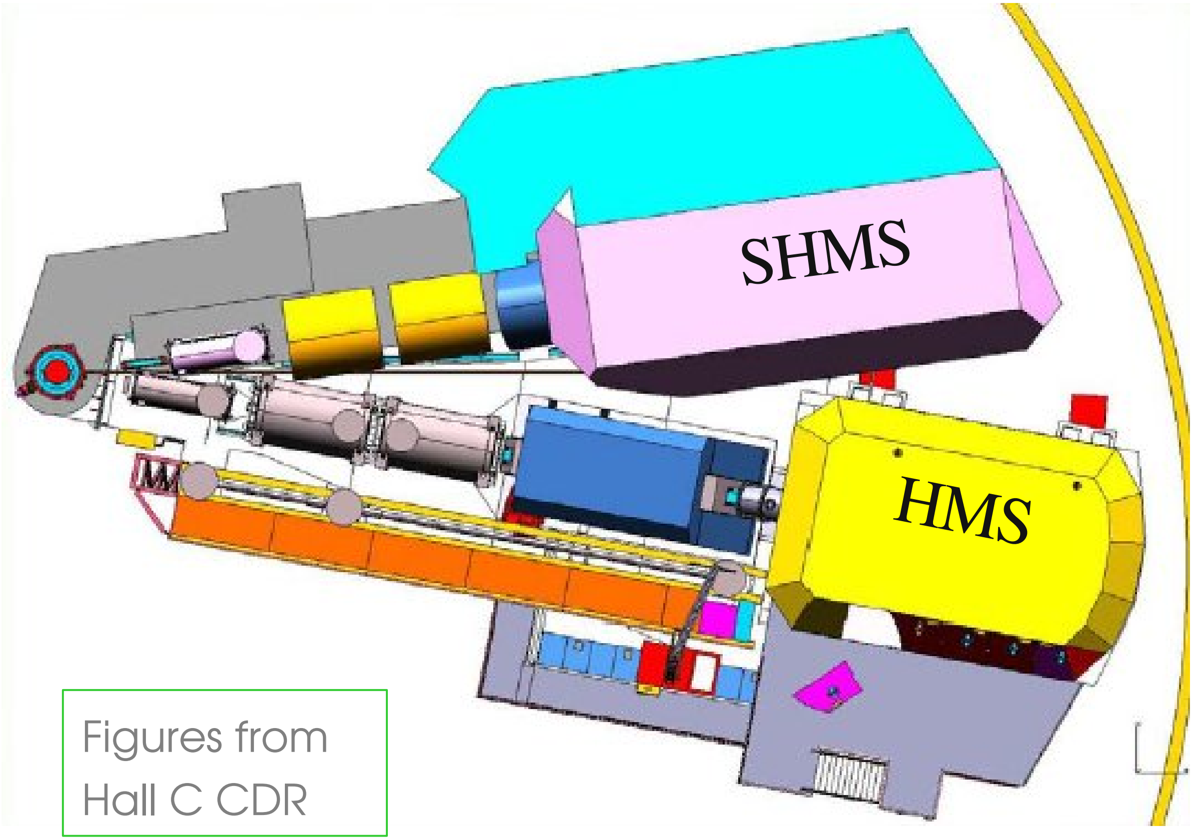
Hall C at 11 GeV

HMS spectrometer

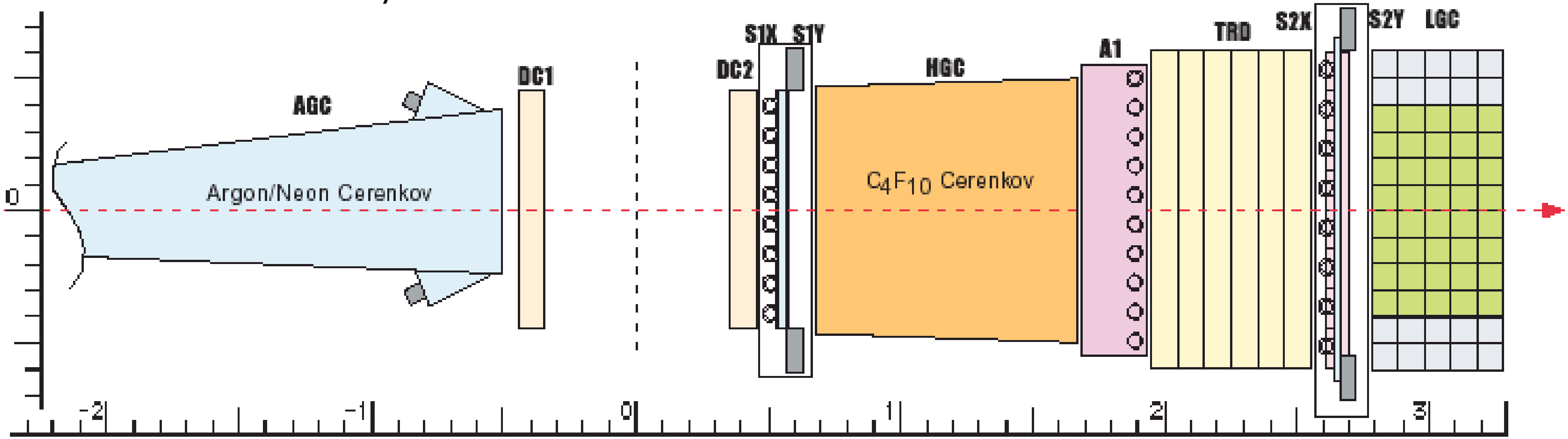
- P_{max}=7.5 GeV/c,
- $\Delta P/P$=(-9%,9%)
- $\Delta\Omega$= 8.0 msr, Δy=±5 cm

SHMS spectrometer:

- Design in progress
- P =(2-10.4) GeV/c,
- $\Delta P/P$=(-15%,25%)
- $\Delta\Omega$= 3.8 msr, Δy=±15 cm



Figures from Hall C CDR



Kinematics

- DIS

Kine		E_b GeV	E_p GeV	θ (°)	DIS (e,e') rate (Hz)	π^-/e	e^+/e^-	x (Q^2, in GeV^2) coverages for DIS
1	HMS	11.0	5.70	12.5	498.17	< 0.5	$< 0.1\%$	0.25-0.35 (2.78- 3.17)
2	HMS	11.0	6.80	12.5	370.41	< 0.1	$< 0.1\%$	0.35-0.55 (3.26- 3.78)
3	HMS	11.0	2.82	30.0	1.22	< 7.1	$< 0.7\%$	0.50-0.60 (7.84- 8.87)
4	HMS	11.0	3.50	30.0	0.22	< 1.7	$< 0.1\%$	0.65-0.77 (9.59-10.54)
A	SHMS	11.0	5.80	12.5	465.54	< 0.6	$< 0.1\%$	0.25-0.55 (2.71- 3.77)
B	SHMS	11.0	3.00	30.0	1.54	< 9.5	$< 0.8\%$	0.45-0.77 (7.52-10.54)
C	SHMS	11.0	2.25	30.0	4.69	< 41.9	$< 9.2\%$	0.35-0.55 (5.94- 8.21)

- DIS (e,e') cross-section: using average of MRST and CTEQ (NMC95 no longer valid above x=0.6)
- π background: Wiser's code;
- e+ background: Wiser (π^0) + π^0 decay (Bosted code)
- HMS and SHMS must have 10^4:1 π rejection factor;

From ^{3}He to Neutron – Complete Analysis

- 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 – average of MRST and CTEQ
  - $P_n = 0.86^{+0.036}_{-0.020}$, $P_p = -0.028^{+0.009}_{-0.004}$
    Uncertainty on Pp expected to reduce by factor of 4 from Hall A Ax and Az measurement on pol 3He;
  - $R(x,Q^2)$ – 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 – fit to world data, PRC70, 065207 (2004)

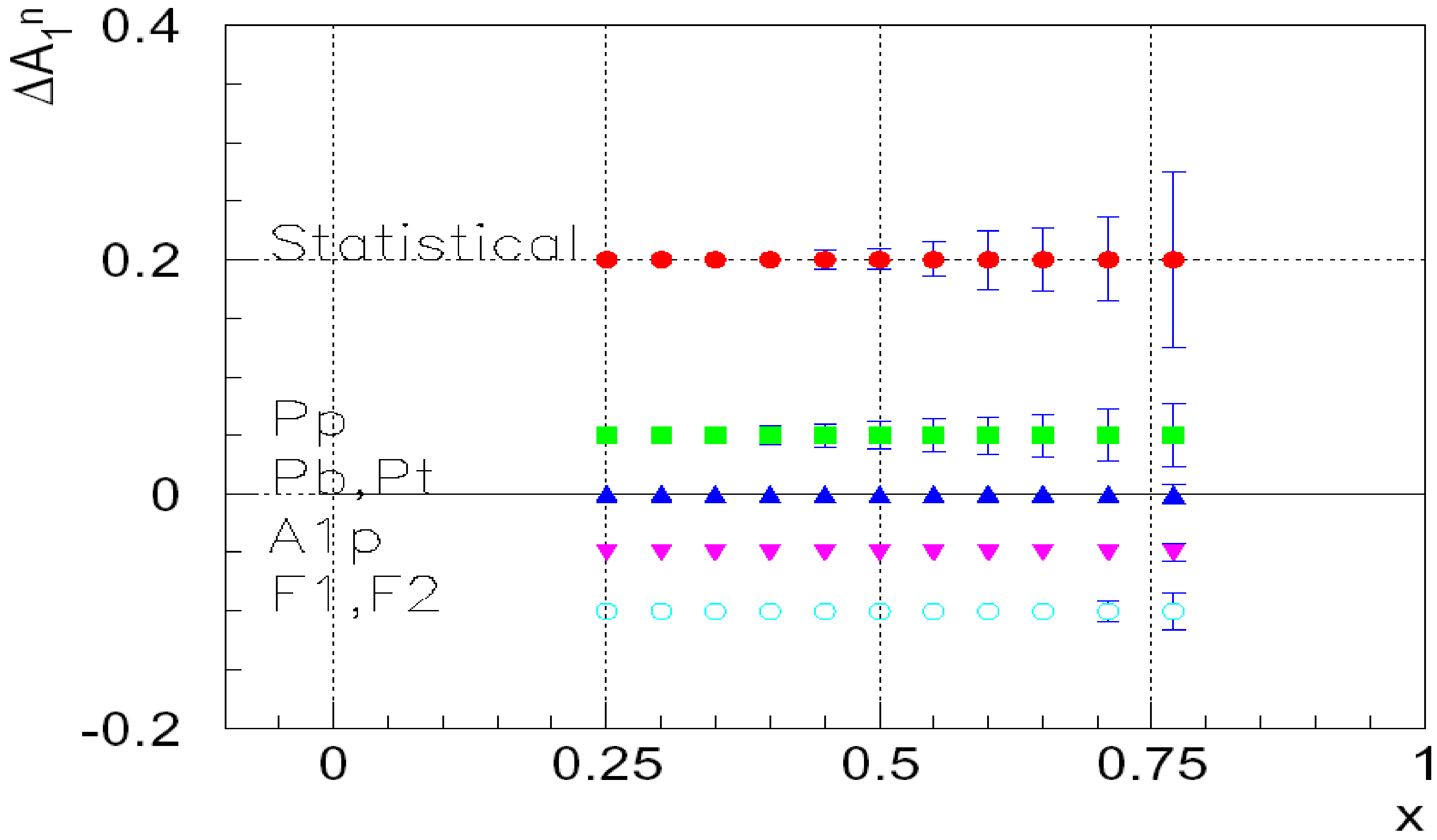
Projected A_1^n Uncertainties

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	0.0039	–	0.0039	0.0050	0.0063
0.30	0.0045	–	0.0045	0.0060	0.0075
0.35	0.0055	0.0182	0.0052	0.0072	0.0089
0.40	0.0065	0.0214	0.0062	0.0086	0.0106
0.45	0.0087	0.0262	0.0083	0.0102	0.0131
0.50	0.0118	0.0129	0.0087	0.0120	0.0148
0.55	–	0.0178	0.0143	0.0141	0.0201
0.60	–	0.0251	0.0251	0.0166	0.0302
0.65	–	0.0267	0.0267	0.0198	0.0333
0.71	–	0.0361	0.0361	0.0251	0.0440
0.77	–	0.0744	0.0744	0.0327	0.0813

- N_2 dilution factor: 0.92 (N_2 contributes to 8% of total yield)

Breakdown of A_1^n Uncertainties

- Systematic uncertainty dominated by:
  - Effective nucleon polarizations (Pn) Pp;
  - F1, F2;



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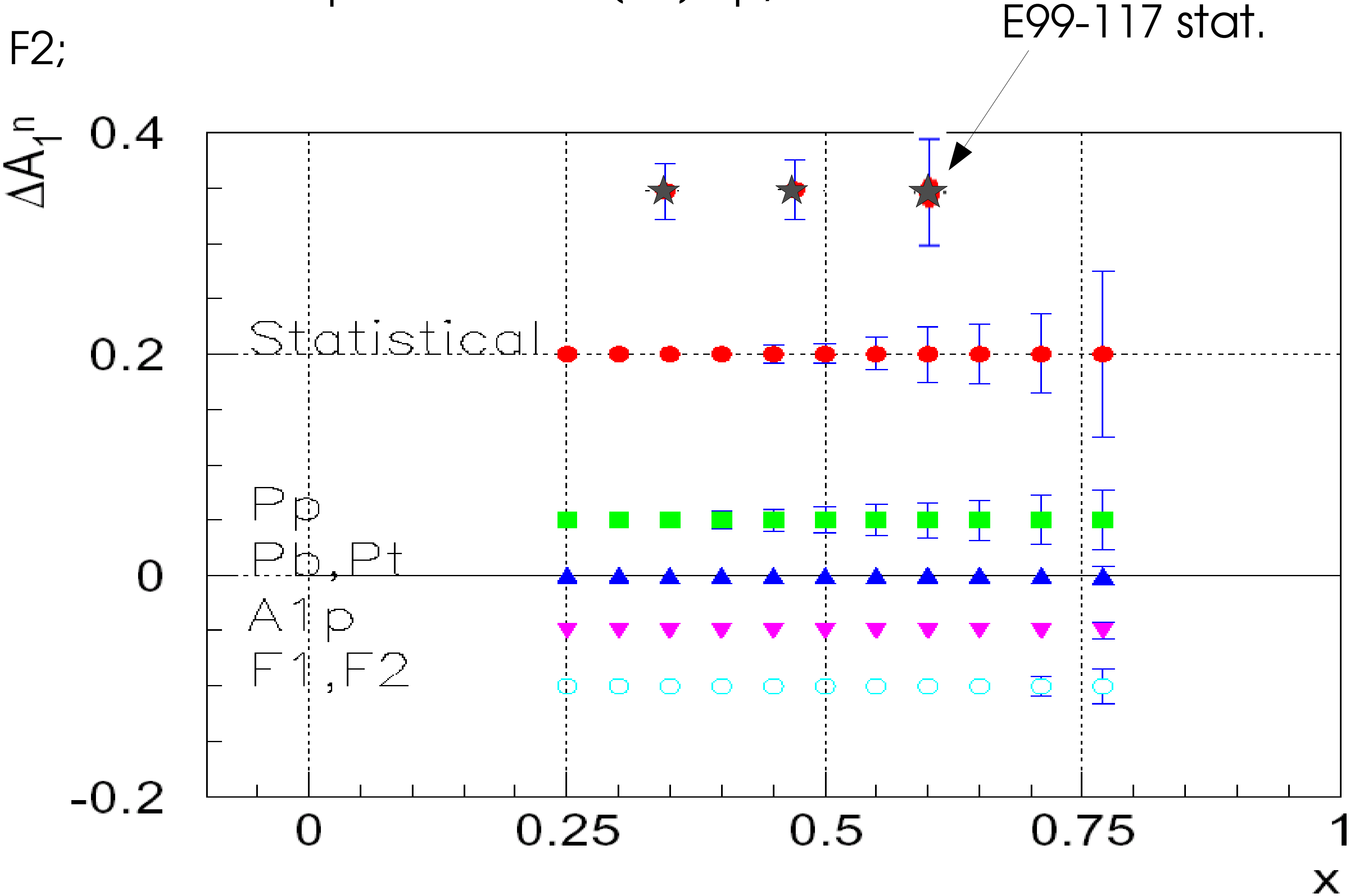
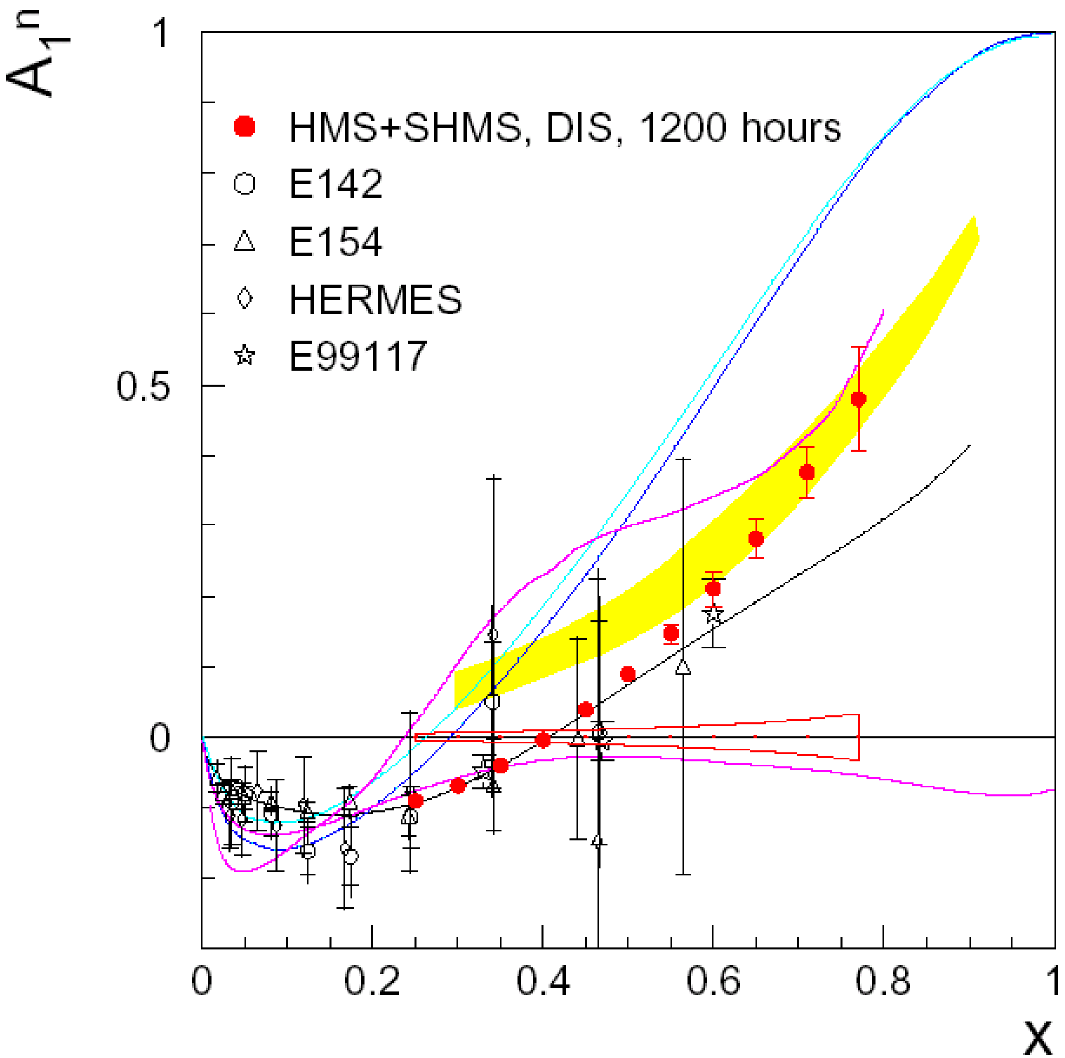
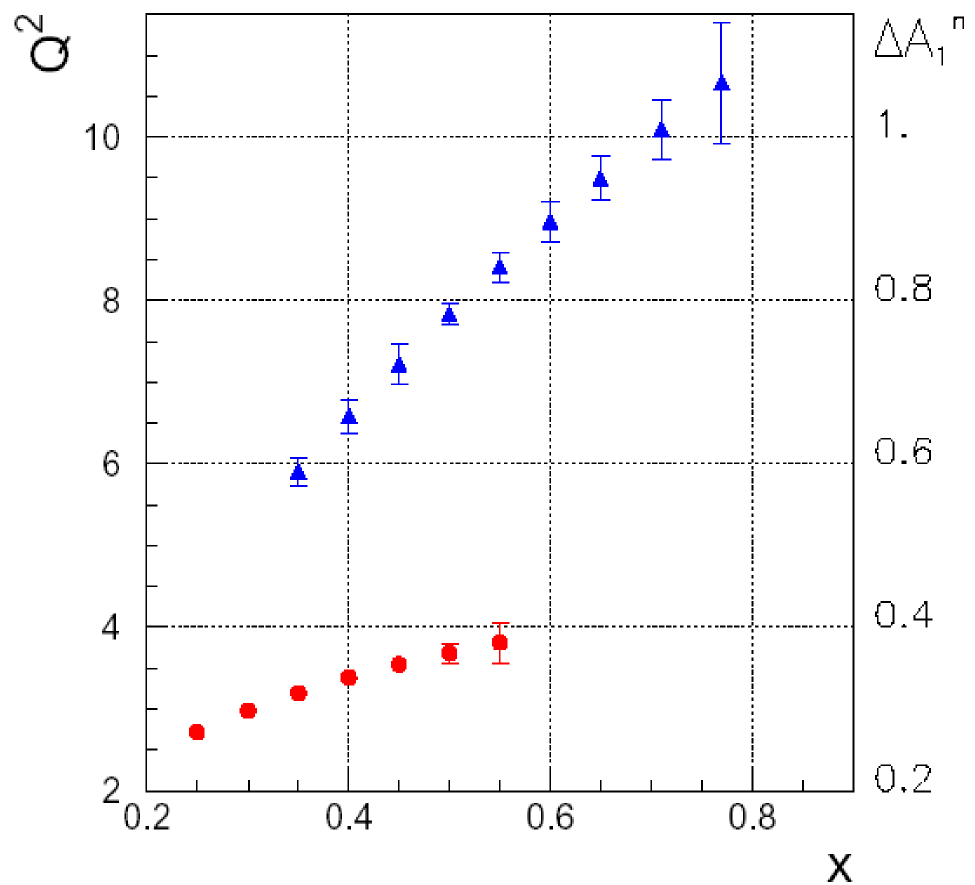


Projected A_1^n Data at 12 GeV in Hall C

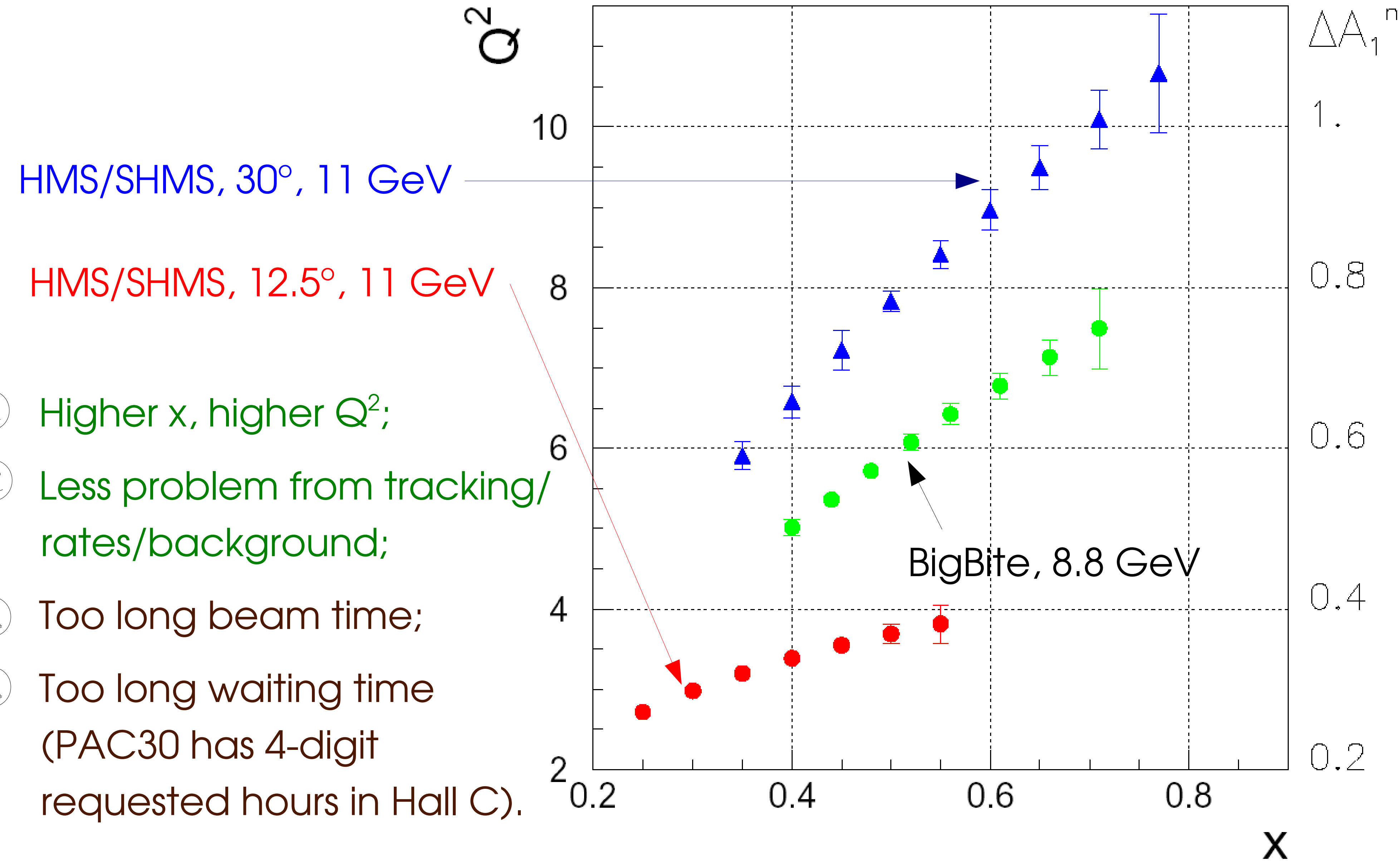


Q^2-dependence of A_1^n:



- To think about: $\Delta q/q$ — need d/u (BONUS? PVDIS?) and g_1^p/F_1^p (fit or projected 12 GeV data from Hall B or C???)

Complementarity with BigBite in Hall A



- Higher x, higher Q^2;
- Less problem from tracking/ rates/background;
- Too long beam time;
- Too long waiting time (PAC30 has 4-digit requested hours in Hall C).

Beam Time Request

- DIS (total 1192 hours):

Kine	E_b (GeV)		θ ($^\circ$)	E_p (GeV)	e^- production (hours)	e^+ prod. (hours)	Tot. Time (hours)
1	11.0	HMS	12.5	5.70	24	0	24
2	11.0	HMS	12.5	6.80	48	0	48
3	11.0	HMS	30.0	2.82	119	1	120
4	11.0	HMS	30.0	3.50	999	1	1000
A	11.0	SHMS	12.5	5.80	72	0	72
B	11.0	SHMS	30.0	3.00	913	7	920
C	11.0	SHMS	30.0	2.25	184	16	200

Beam Time Request

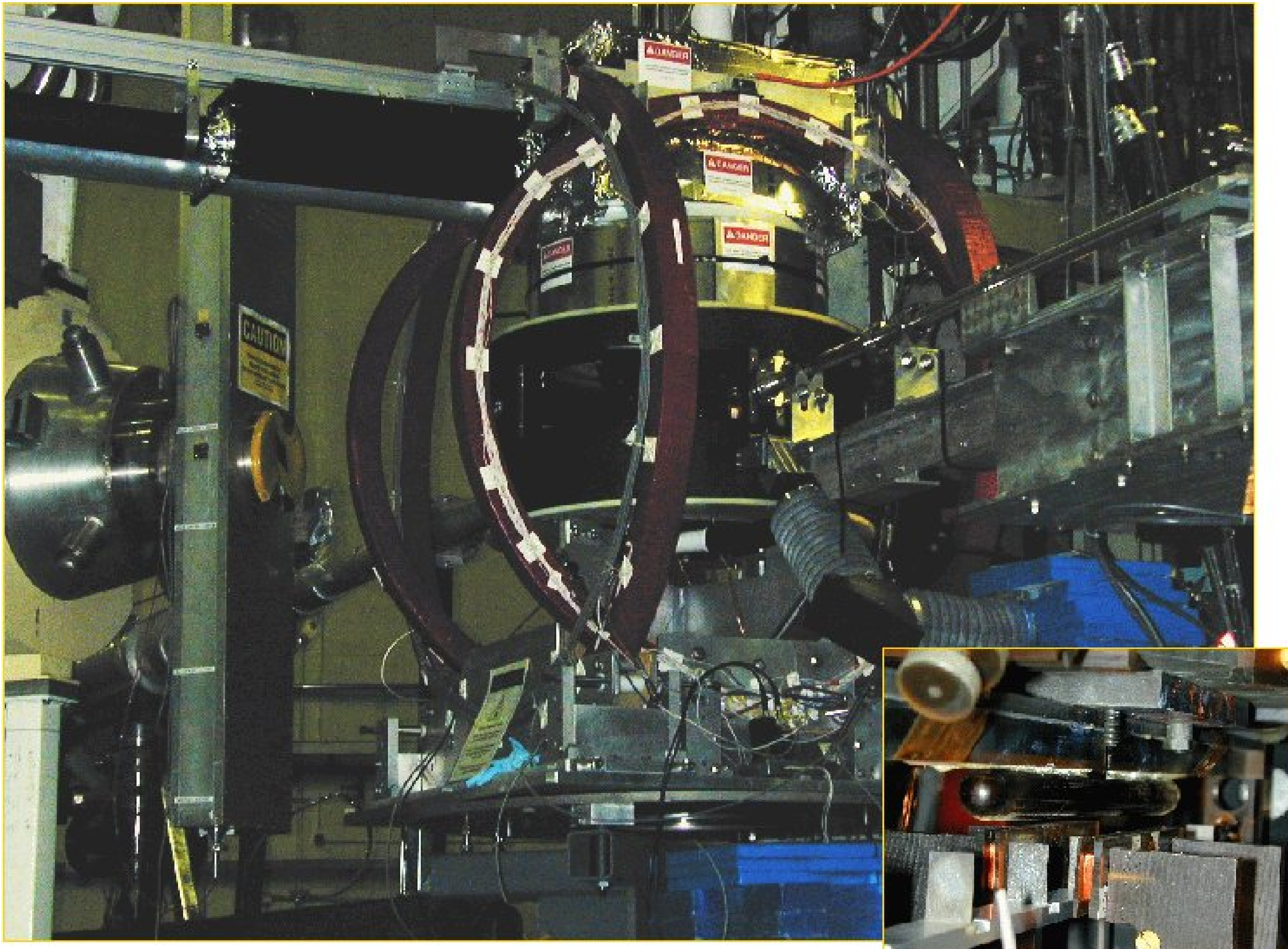
- Elastic e-^{3}He(ll) and Δ(1232) ($\perp$) at low Q^2 to check P_bP_t and beam helicity:

Kine	E_b GeV	E_p GeV	θ ($^\circ$)	elastic x-sec (nb/sr)	elastic rate (Hz)	Asymmetry	Time (hours)
Elastic	2.200	2.160	12.5	106.986	710.1	$A_{\parallel} = 0.0589$	8.3
$\Delta(1232)$	2.200	1.815	12.5	-	-	$A_{\perp} \sim$ a few %	6

- Reference Cell (N_2 run): 16h;
- Configuration change: 13h;
- Beam pass change, 8h; Moller: 8h; Target polarimetry: 40min/day;

- Total: 1288h (53 days) + Target Installation

Polarized 3He Target in Hall C?



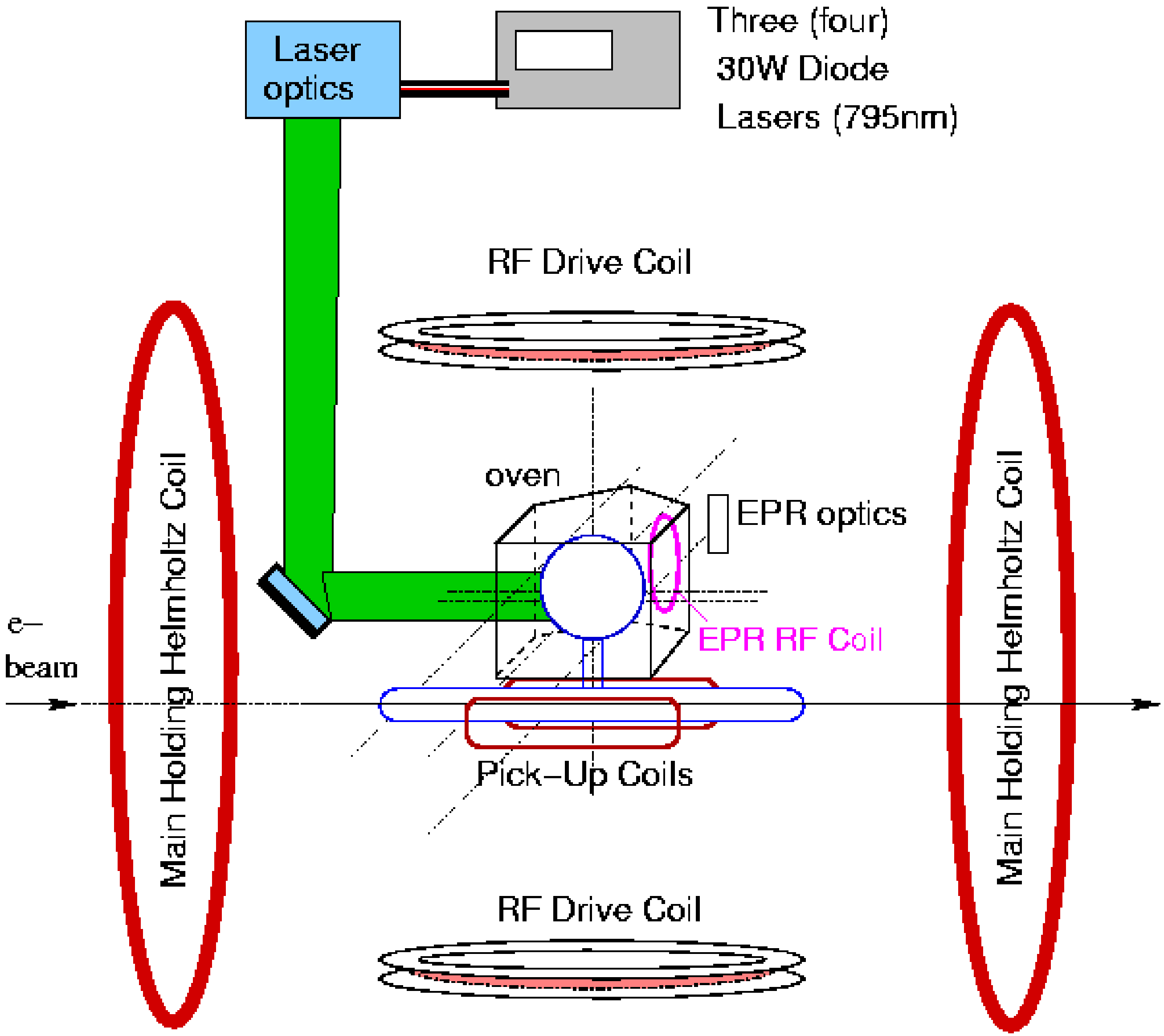
Contribution to Hall C Baseline Equipment?

- Only proposals including the intension of making a significant contribution to the baseline equipment will be considered for the upcoming PAC30
  - Is polarized 3He target enough? (not in Hall C CDR)
  - Other possibilities under investigation.

Summary

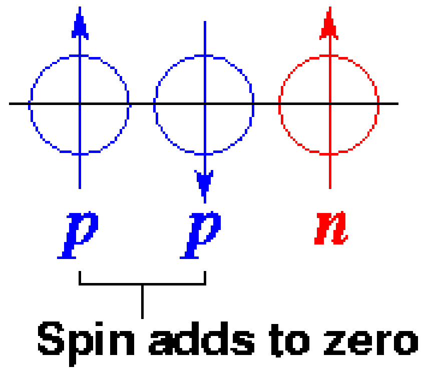
- Propose to measure A_1^n up to x=0.77, wide Q^2 coverage (3-10 GeV^2);
- Require: pol3He target in Hall C + SHMS + HMS; Commitment to baseline equipment under study;
- Complimentary to "A_1^n using BigBite" in Hall A;
- Beam time request: 53 days total;
- Provide important data in the unexplored large x region:
  - Improve world polarized PDF fits;
  - Study Q^2 dependence;
  - Test pQCD/HHC and quark OAM in a "deeper" valence quark region;
- May combine with proton spin and d/u data (if planned) to extract $\Delta q/q$.

Target Setup



From ^{3}He to neutron

- Polarized ^{3}He as Effective polarized neutron:



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

Effective Neutron Target

- Convolution Approach
  - ^{3}He consists S, S', D states;
  - Three body calculation using Fadeev wavefunction

Ciofi degli Atti *et al.*,
Phys. Rev. C48, 968 (1993);
Phys. Lett. B404, 223 (1997)

$$\tilde{g}_1^n = \frac{1}{\rho_n}\left(g_1^{3\mathrm{He}} - 2\rho_p g_1^p\right)$$

$$\tilde{A}_1^n = \frac{W_1^{3\mathrm{He}}}{W_1^n}\frac{1}{\rho_n}\left(A_1^{3\mathrm{He}} - 2\frac{W_1^p}{W_1^{3\mathrm{He}}}\rho_p A_1^p\right)$$