Measurements of the neutron spin asymmetry A1n at high Bjorken x after the CEBAF upgrade

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For the A1n collaborations from both Halls A & C

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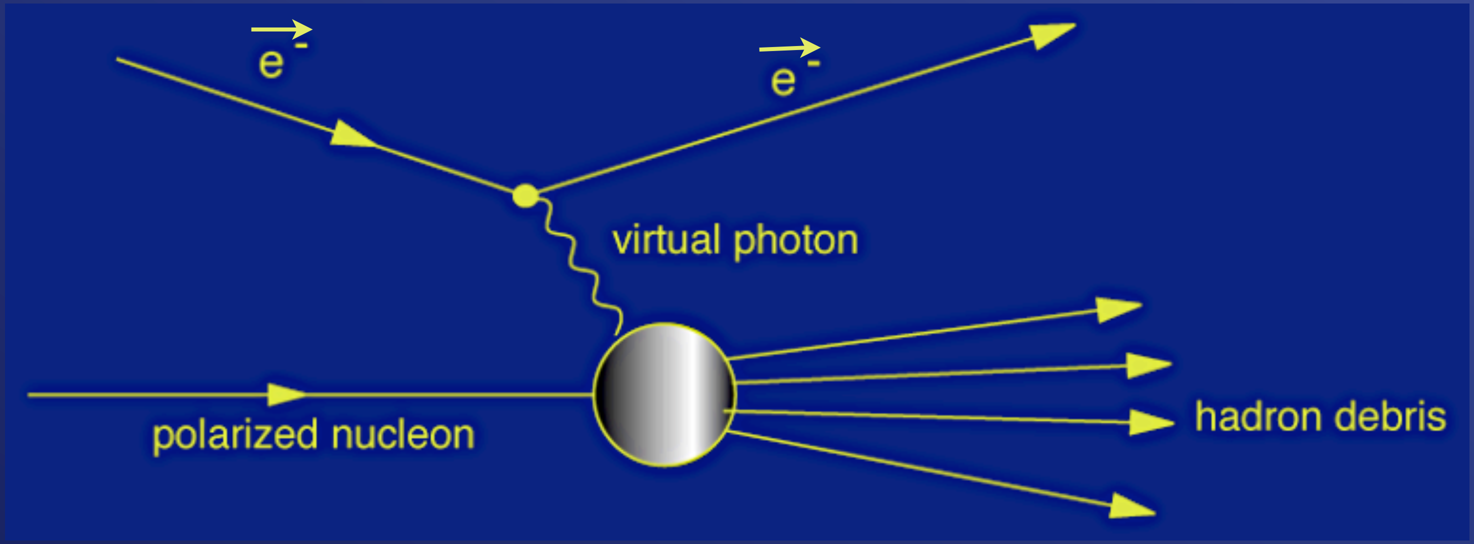
- Sensitive probe of nucleon structure in the valence quark region.
- Enormous new capability with CEBAF upgrade together with experimental advances

A1n at high x_{Bj}



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

The spin asymmetry in the virtual photo-absorption cross section

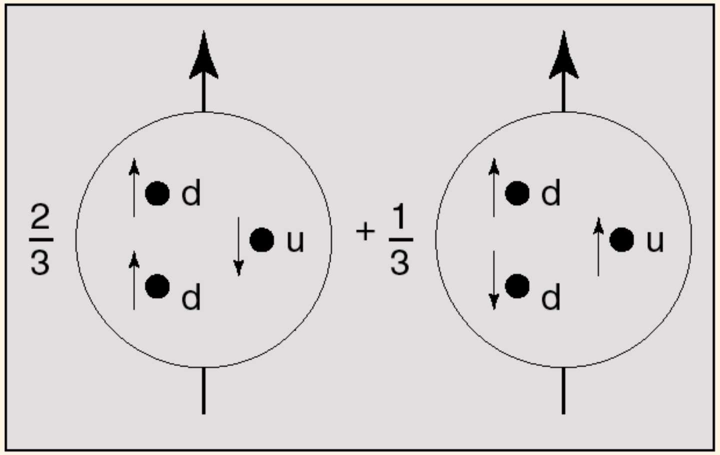
- At high x:
  - A1n is dominated by the valence quarks,
  - certain calculations of A1n are tractable, a rare opportunity in QCD.
- Among other things, A1n probes the role of quark orbital angular momentum.

A1n in SU(6)

SU(6) wavefunction of a polarized neutron

$$|n\uparrow\rangle = dduC^A\psi^S\left[-\sqrt{\frac{1}{6}}(\uparrow\downarrow\uparrow + \downarrow\uparrow\uparrow - 2\uparrow\uparrow\downarrow)\right]$$

The probabilities of the two possible spin configurations: →



The resulting distribution functions: $q_d^\uparrow = \frac{5}{9};\ q_d^\downarrow = \frac{1}{9};\ q_u^\uparrow = \frac{1}{9};\ q_u^\downarrow = \frac{2}{9}$

$$A_1^n = \frac{\Sigma e_i^2(q_i^\uparrow(x) - q_i^\downarrow(x))}{\Sigma e_i^2(q_i^\uparrow(x) + q_i^\downarrow(x))} = \frac{\frac{4}{9}\left(\frac{1}{9}-\frac{2}{9}\right)+\frac{1}{9}\left(\frac{5}{9}-\frac{1}{9}\right)}{\frac{4}{9}\left(\frac{1}{9}+\frac{2}{9}\right)+\frac{1}{9}\left(\frac{5}{9}+\frac{1}{9}\right)} = 0$$

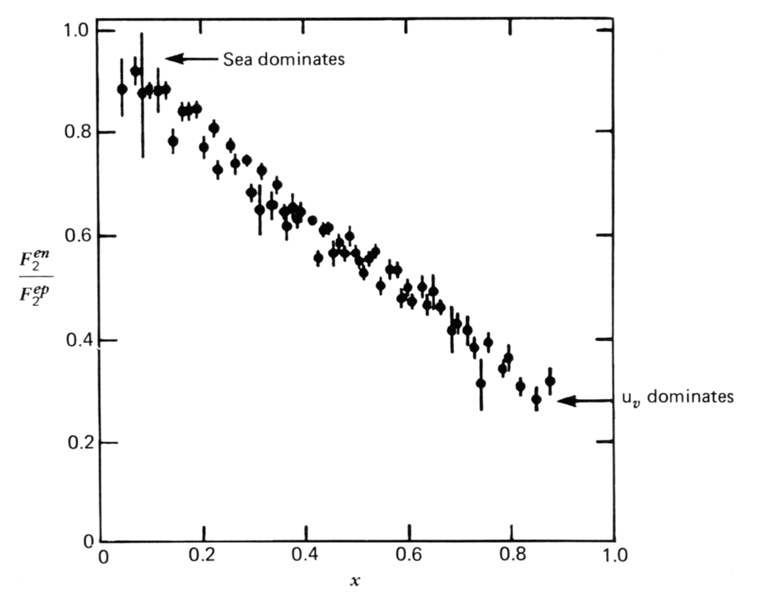
This was not considered an unreasonable expectation for many years.

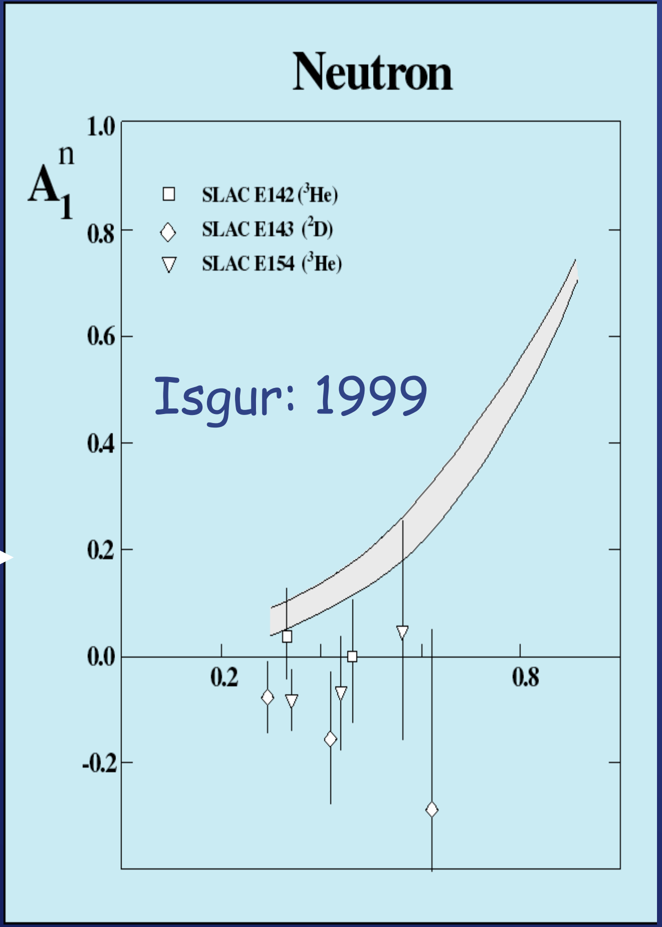
Broken SU(6): Isgur's analysis of relativistic constituent quark models (RCQM)

- Starts with an SU(6) quark model including relativistic effects.
- Next introduces hyperfine interactions.
  - For A_1, the exact form of u_v and d_v is not relevant, only their ratio matters.
- Finally, constrain d/u by using experimental data.

$$R^{np} = F_2^{en} / F_2^{ep}$$

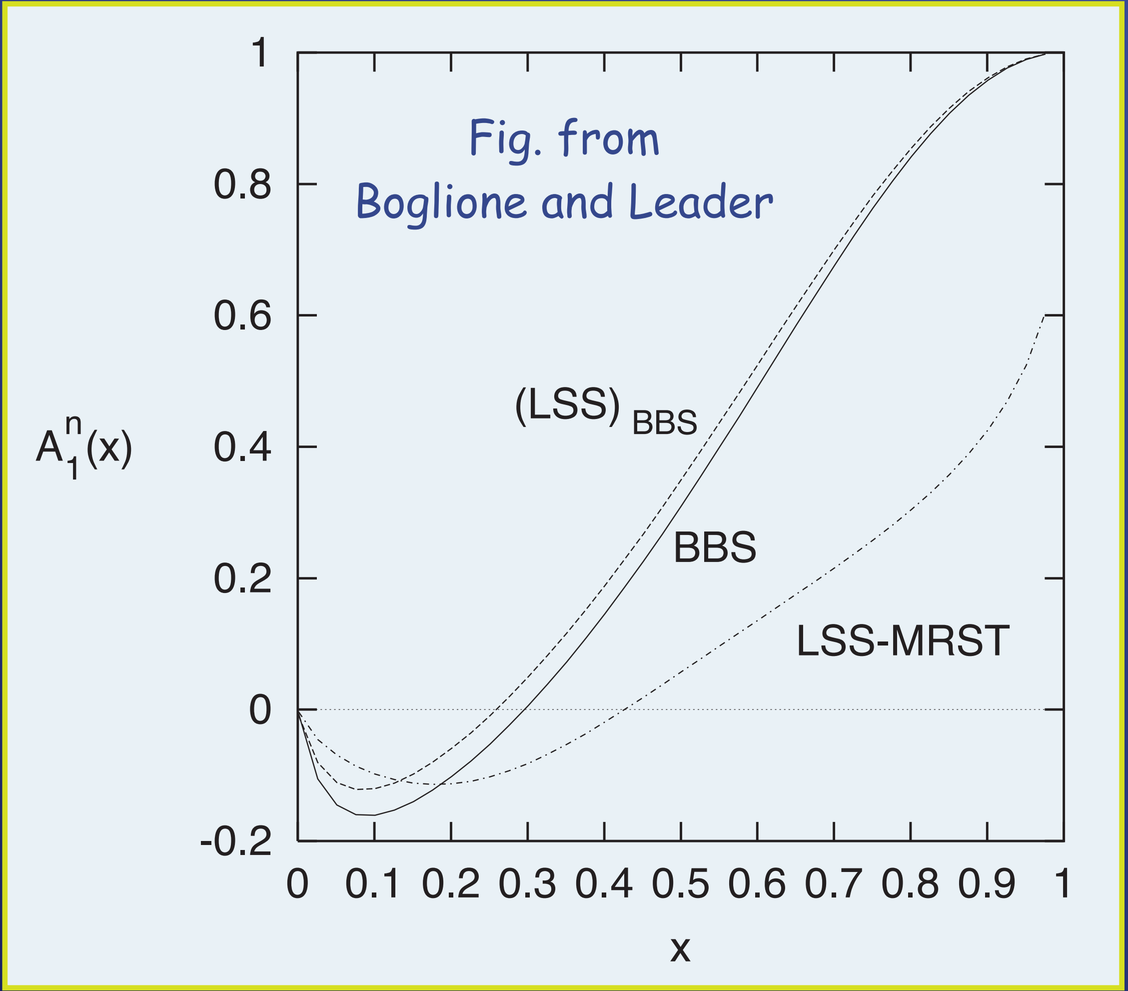
$$d(x)/u(x) = \frac{4R^{np} - 1}{4 - R^{np}}$$





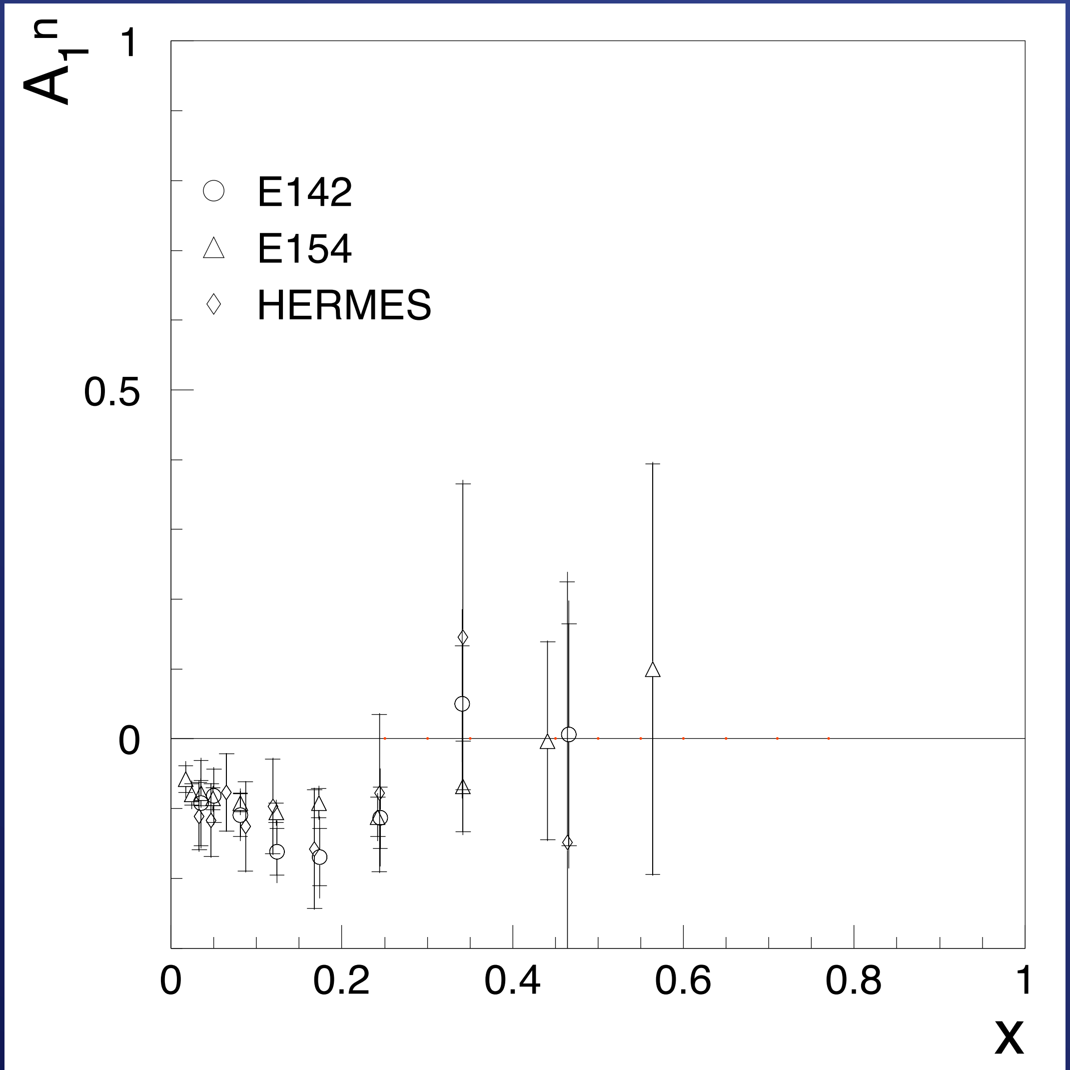
pQCD constrained BBS parameterization

- Brodsky, Burkardt and Schmidt (BBS) parameterization.
  - Incorporates behavior as $x \rightarrow 1$ that preserves $\Delta q/q \rightarrow 1$,hadron helicity conservation (HHC).
- Leader, Sidorov and Stamenov variant on BBS, LSS_{BBS}, incorporates for careful Q^2 evolution.
- LSS-MRST does not have the constraints in BBS



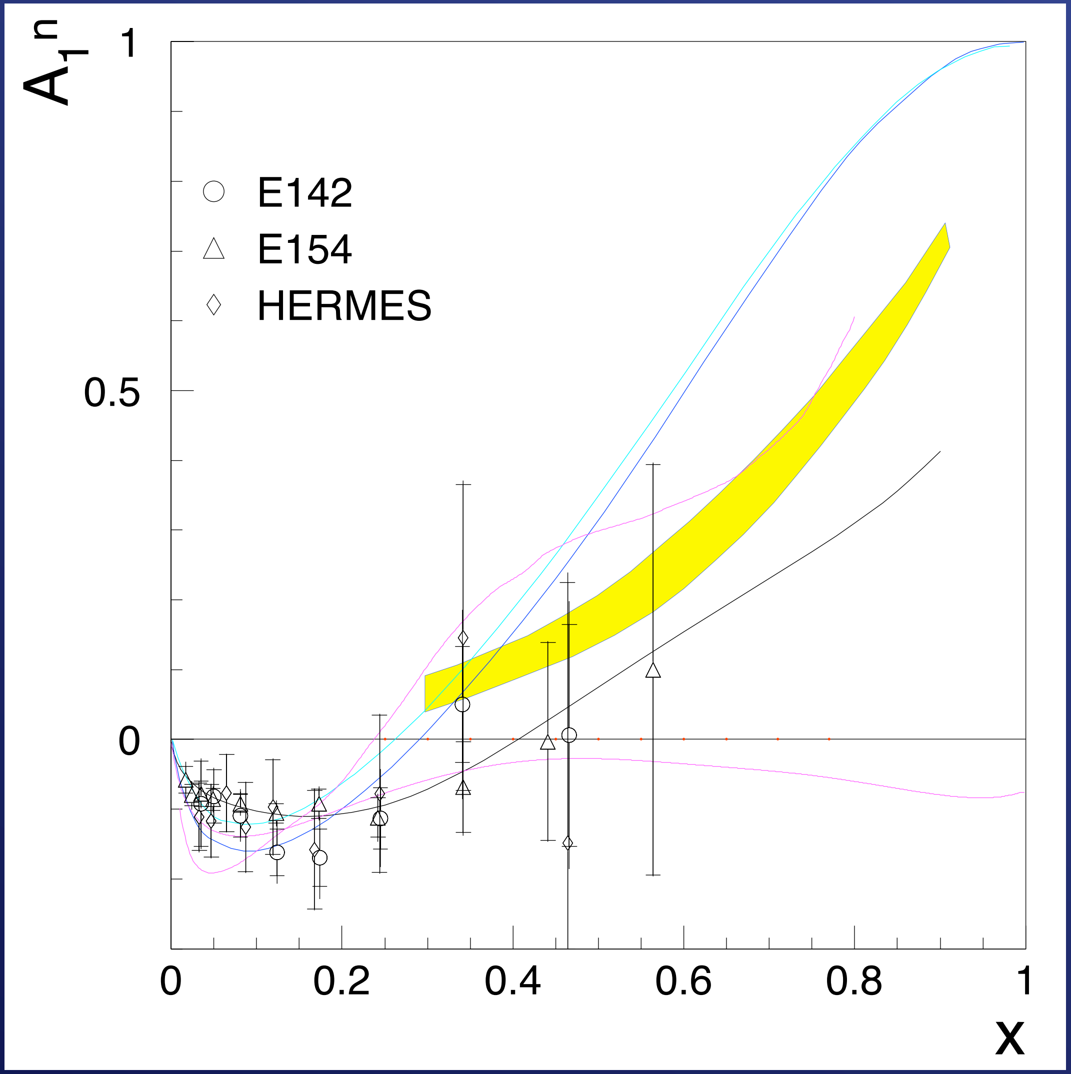
Boglione and Leader (2000): “The implications [of $\Delta q/q \rightarrow 1$] for the polarized DIS neutron longitudinal asymmetry A1n are dramatic”

A1n data and predictions at high-x



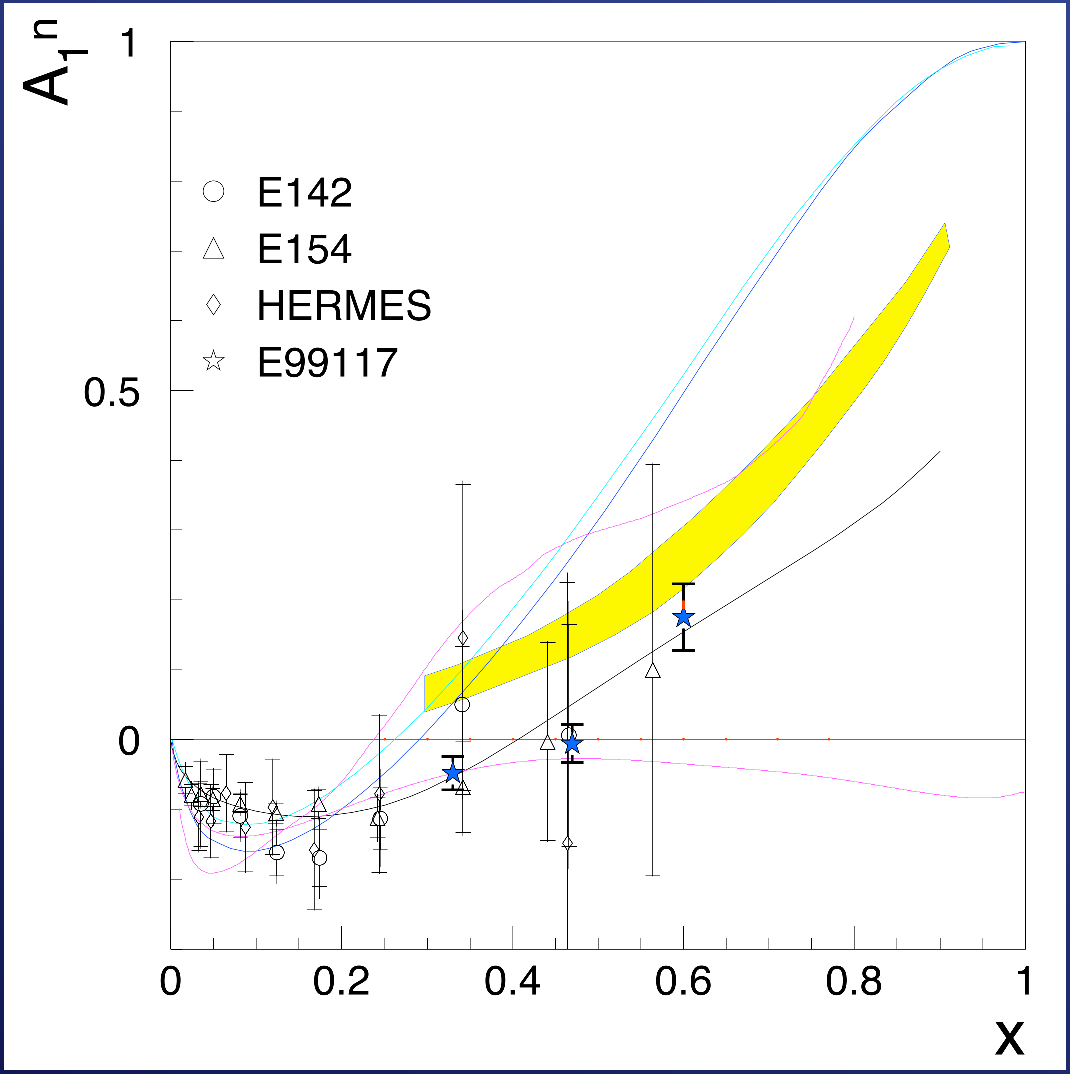
Early data were either negative or consistent with zero

A1n data and predictions at high-x



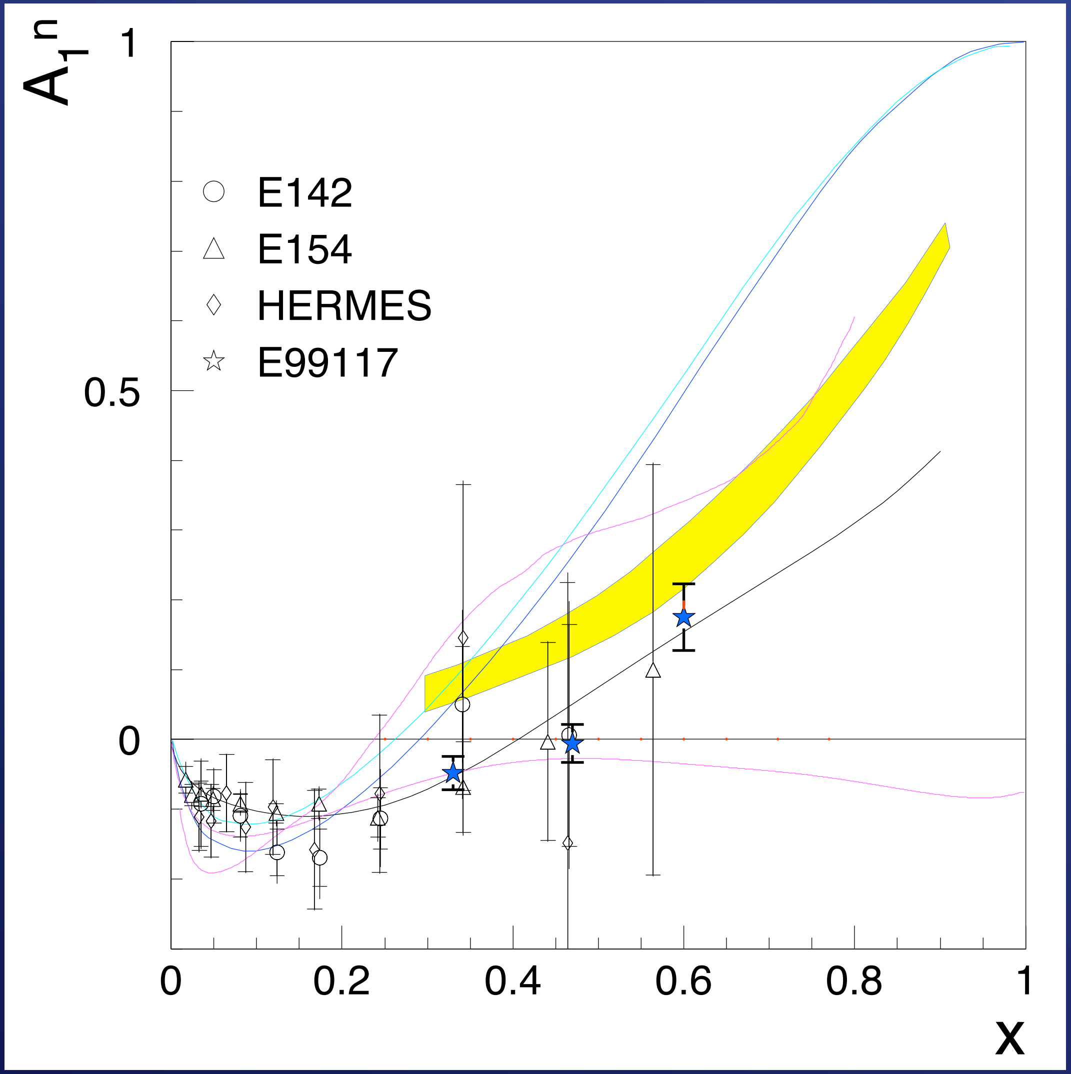
Both RCQM and pQCD constrained calculations predicted A1n → 1 as x → 1

A1n data and predictions at high-x



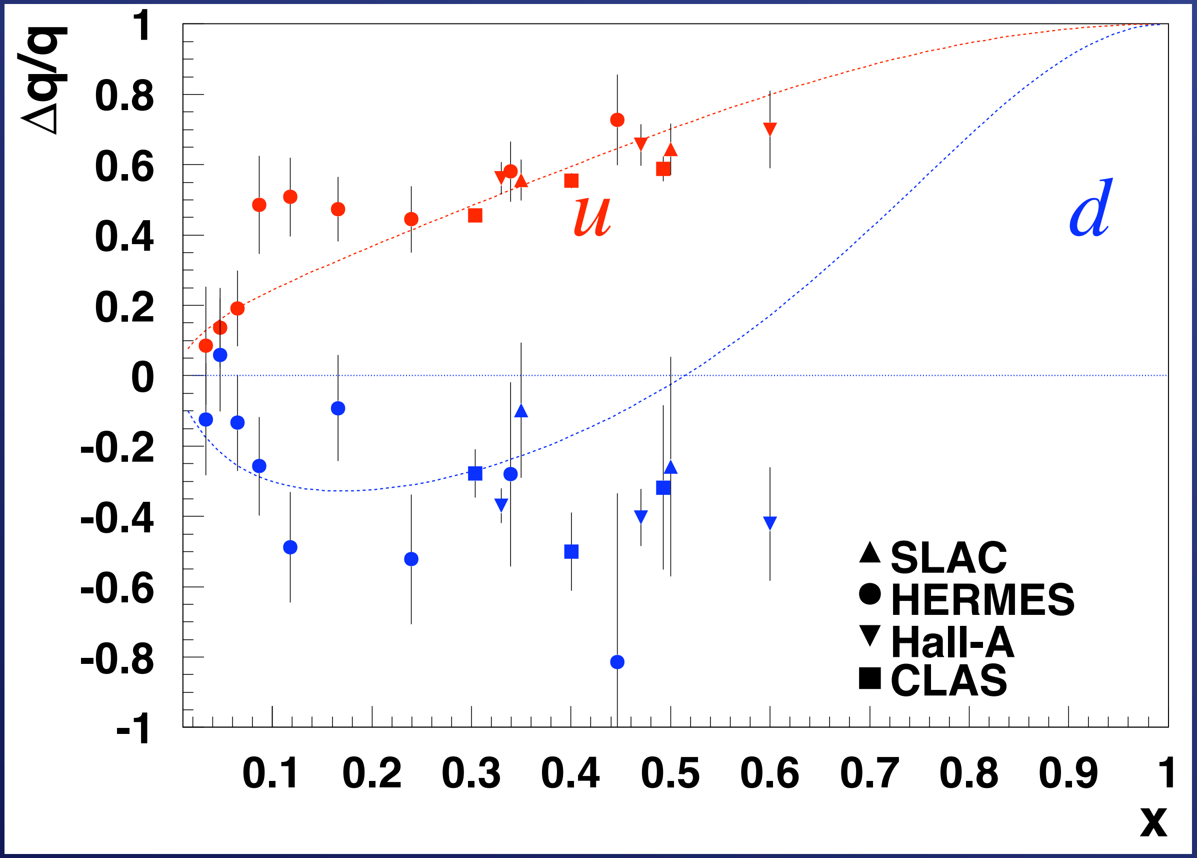
First precise data at relatively high x (0.6) showed A1n becoming positive.

A1n data and predictions at high-x



Disagreement with HHC constrained pQCD calculations represented early confirmation of the importance of quark orbital angular momentum.

Using both neutron and proton data, flavor decomposition of Δq/q is possible



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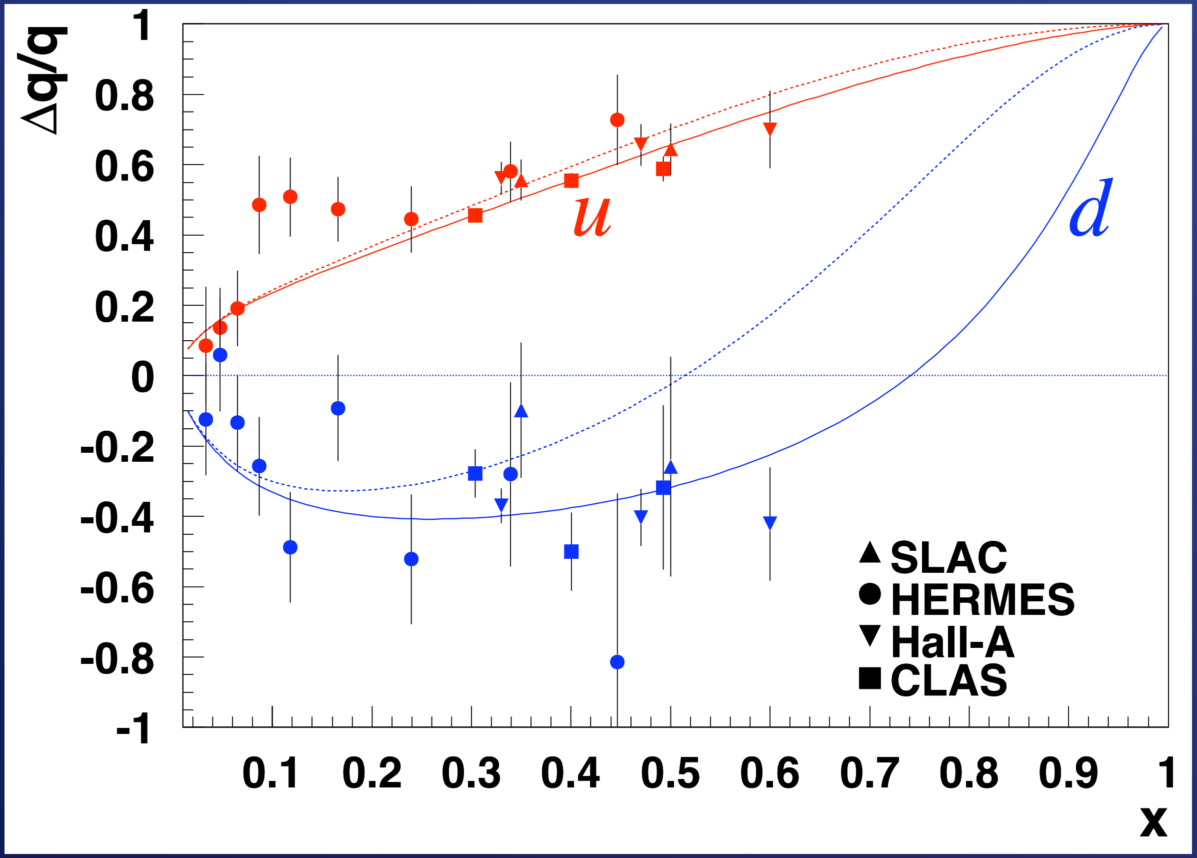


Analysis by Avakian, Brodsky, Deur and Yuan that includes Fock states with $L_z \neq 0$ provides better agreement (solid lines).

Achieving precision on A1n at even higher values of x

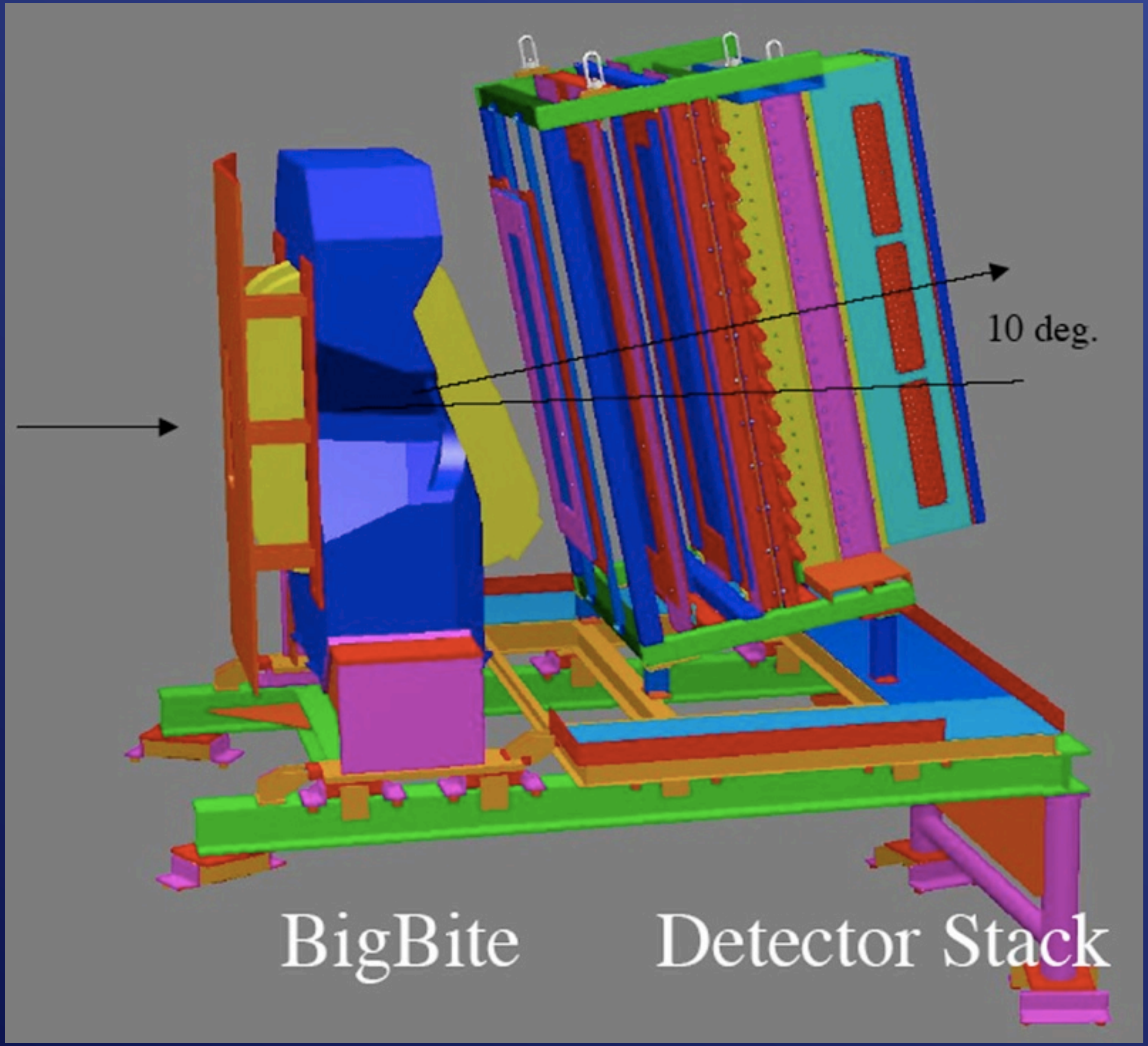
- Higher energies are needed to stay within DIS regime
- Cross sections are very small, so you need
  - High luminosity: 3 - 10 x 10^{36} $cm^{-2}s^{-1}$
  - High polarization
  - Large solid angle detection

➡ Next generation polarized 3He target

➡ BigBite in Hall A, SHMS and HMS in Hall C (both approved experiments)

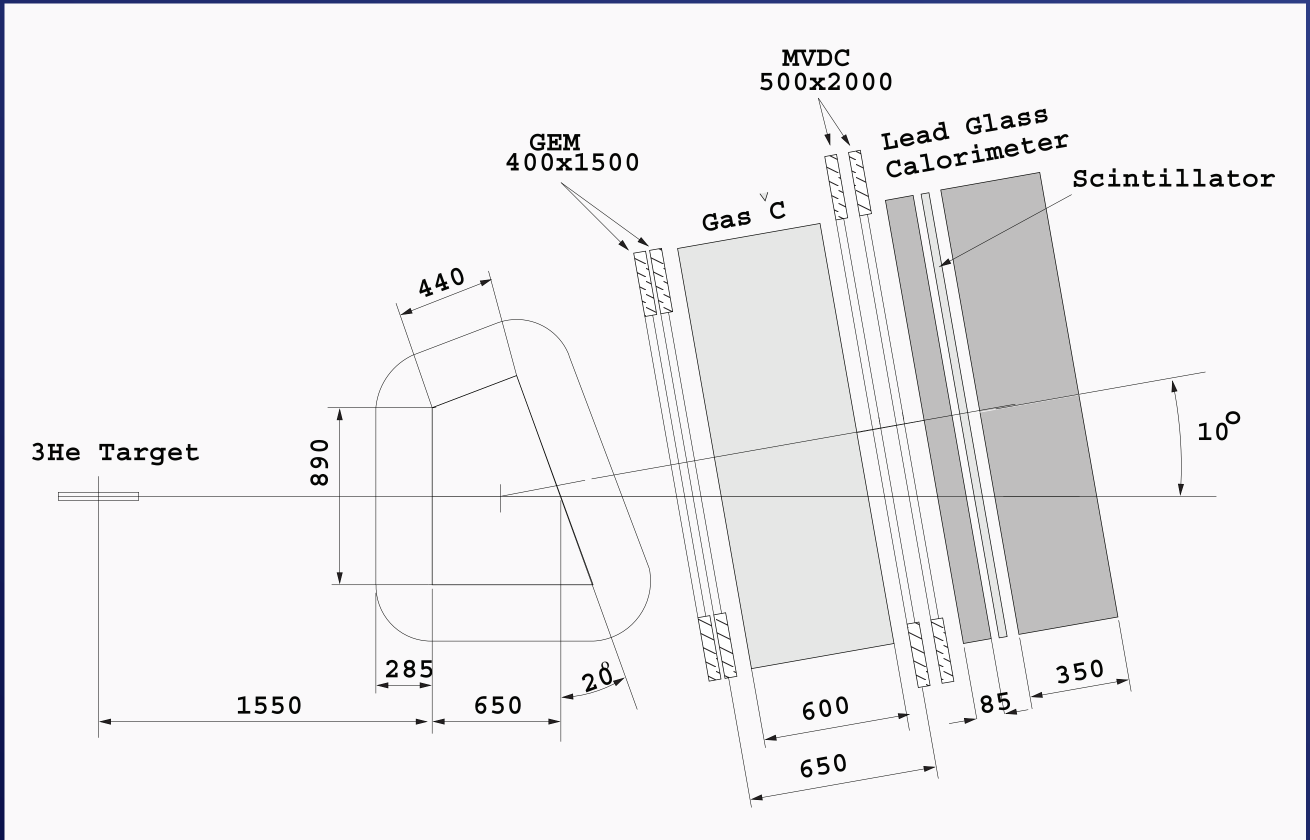
➡ Super Bigbite in future?

For Hall A A1n: BigBite



Shown in configuration used for the Hall A GEn experiment (E02-013)

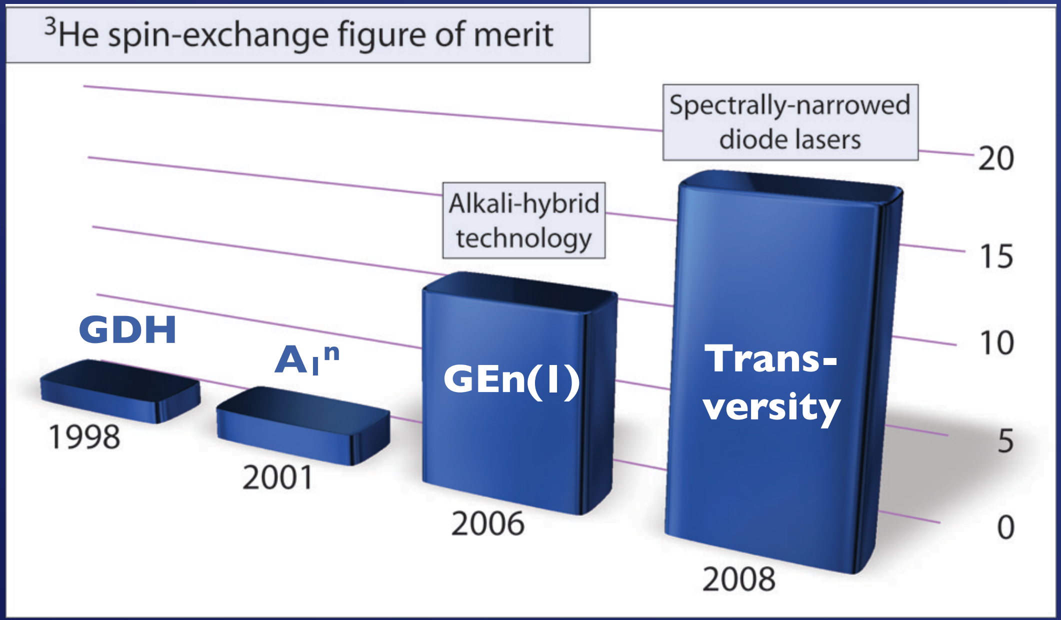
BigBite



Configuration used for
Hall A A1n Monte Carlo's

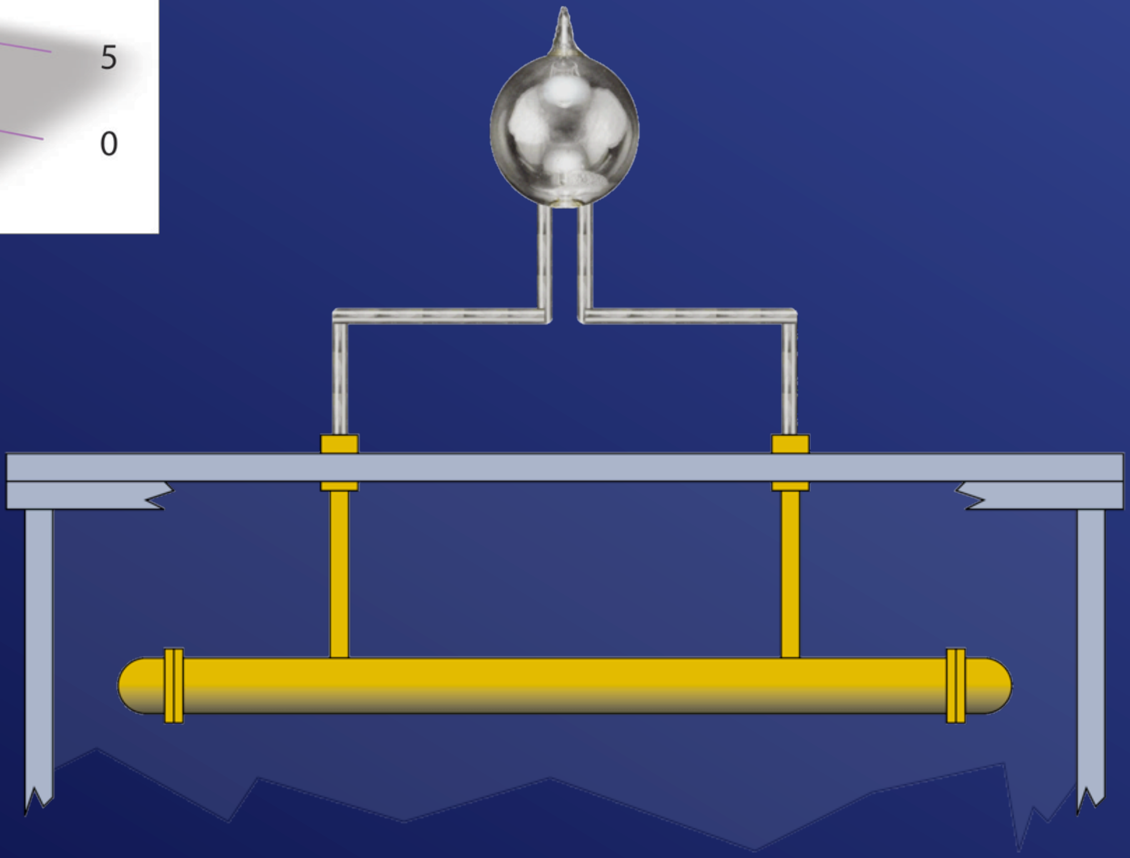
- Single dipole, open geometry
- 50 msr acceptance over 40 cm target.
- Front trackers: GEM detectors, with very high rate handling capability.
- Newly designed gas Cherenkov
- 1% momentum resolution
- double-layer lead-glass calorimeter for triggering on high-energy electrons.

Next-generation high-luminosity polarized ^{3}He target

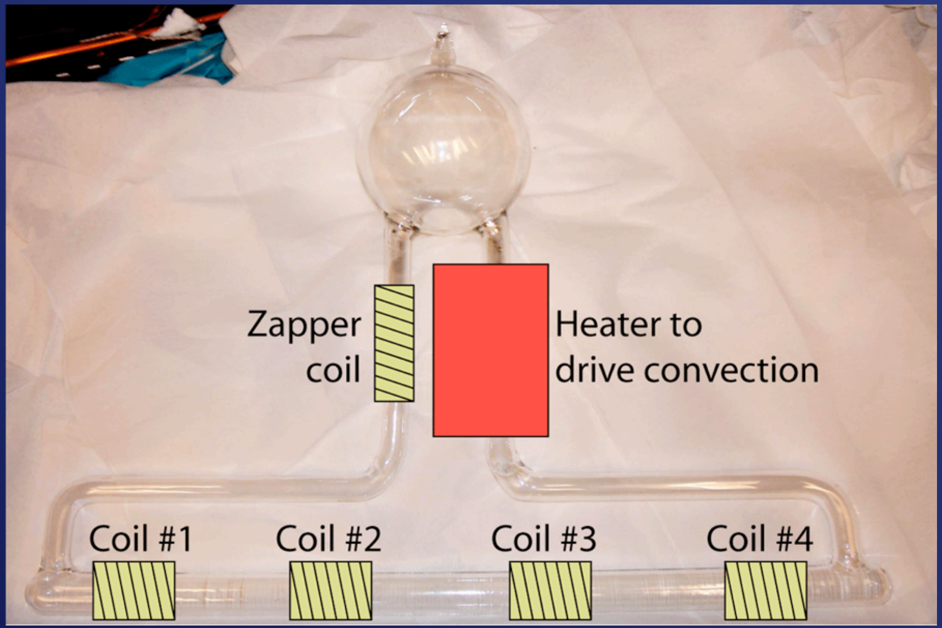


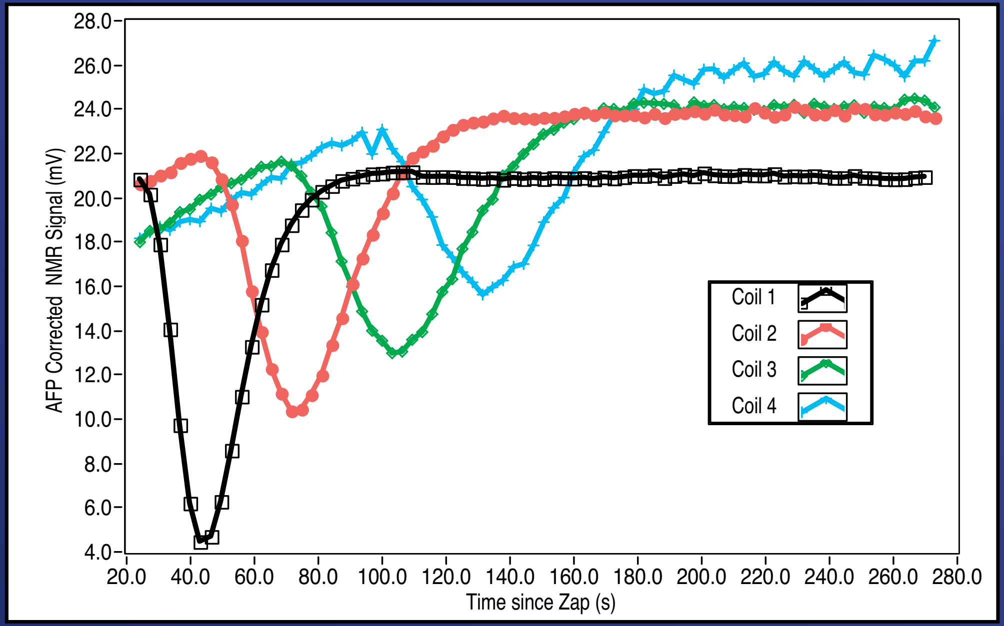
Rapid progress in target technology make it possible to design a next generation target that takes full advantage of advances.

- Convective flow is critical new feature.
- Luminosity - up to 10^{37} cm^{-2}s^{-1} at 100 μA
- Polarization over 60%
- Target length - 60 cm
- Target density - 11 amagats
- Amount of polarized gas - 6 STP liters
- Target chamber partially metal
- Can run in vacuum or air.
- No moving parts

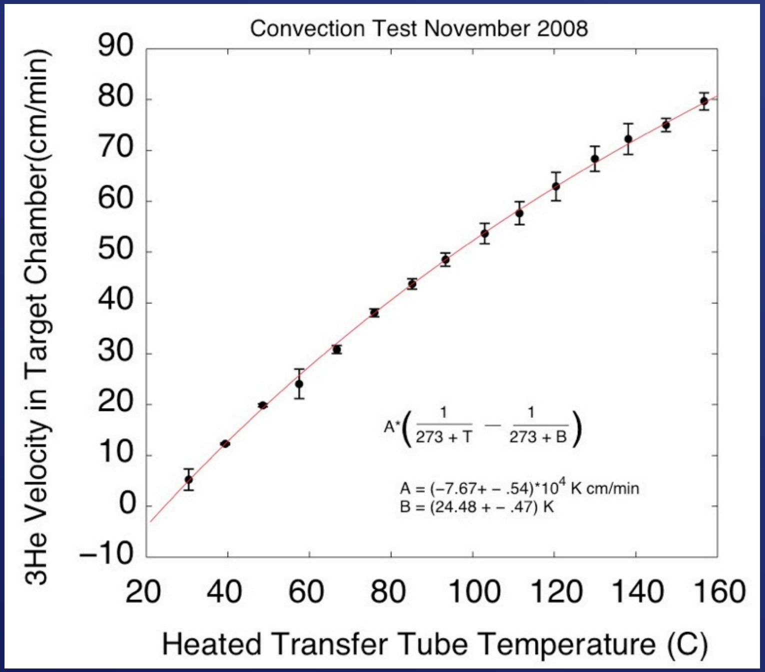


Convection-driven gas-flow test

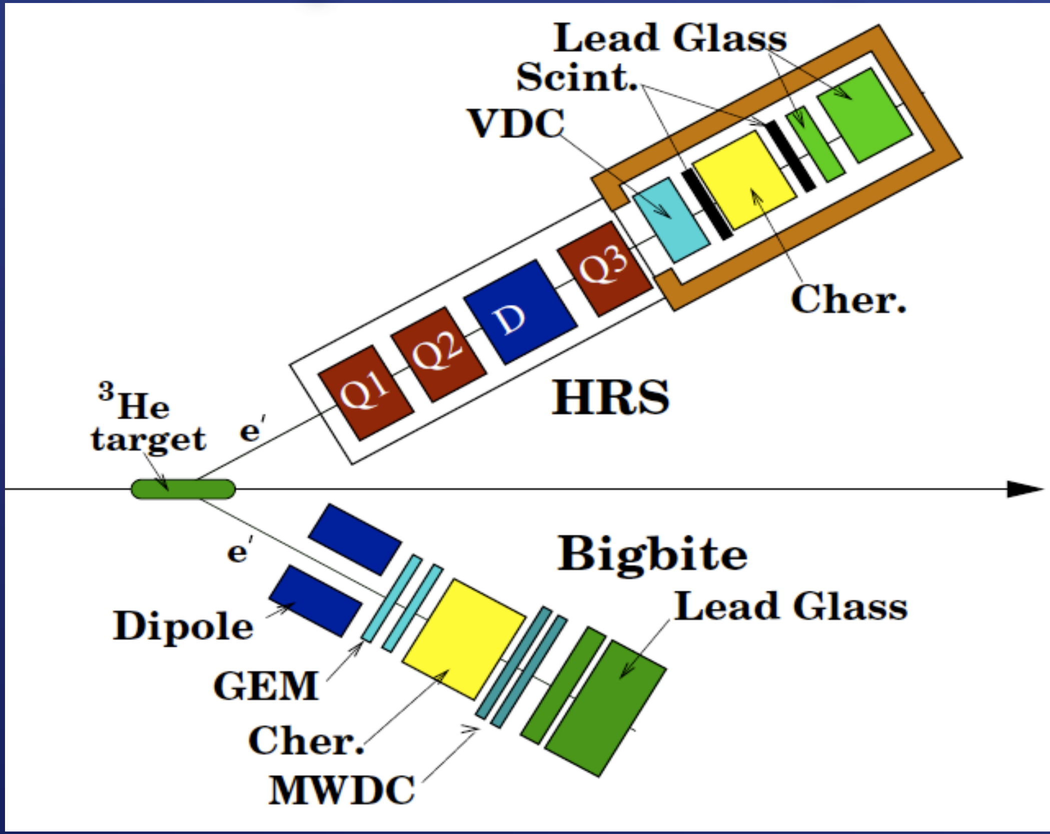




- Heater drives convection
- Zapper coil depolarizes slug of gas
- Coils #1 - #4 monitor passage of depolarized slug.
- Heater temperature can be changed to adjust speed of gas.
- Plot shows speeds up to 80 cm/min.

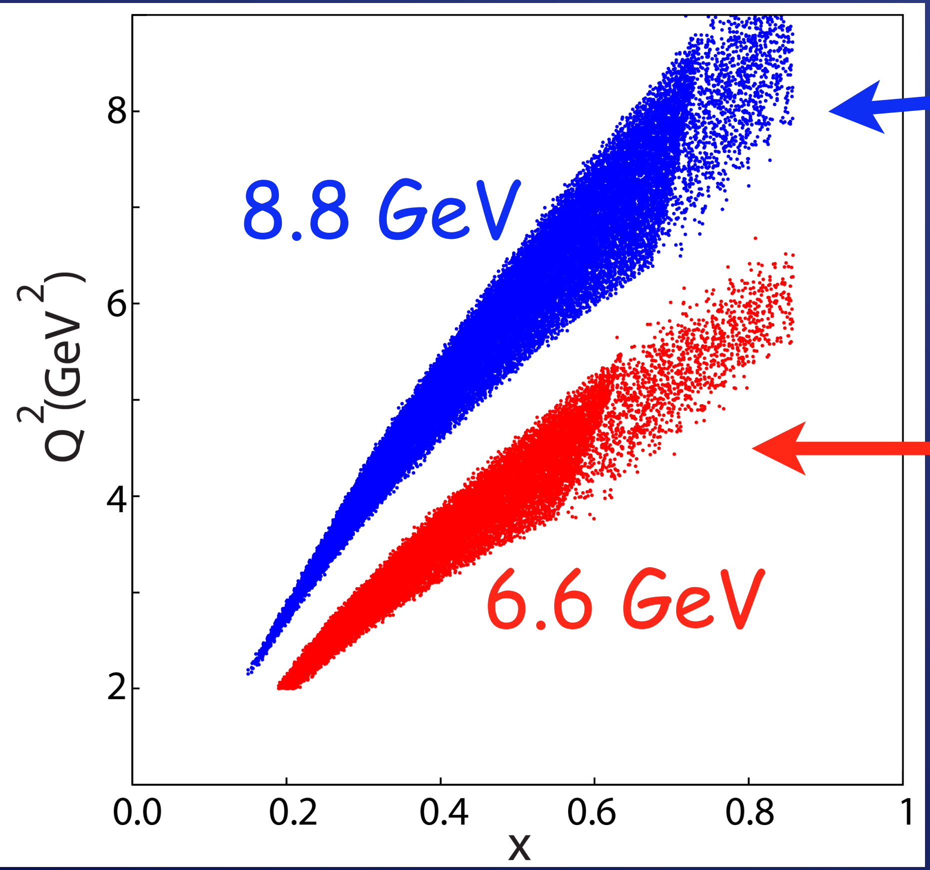


Hall A A1n Experiment (E12-06-122)



- Bigbite Spectrometer at 30°, two energies, 8.8 and 6.6 GeV
- Hall A HRS also set at 30° to provide cross checks of data.
- Next-generation polarized 3He target, 30µA (well below max. luminosity)
- 360 hours of production running.
- Beam and target requirements modest, making E12-06-122 an excellent choice for the first experiment following the CEBAF upgrade.

Kinematic Coverage: Hall A A1n

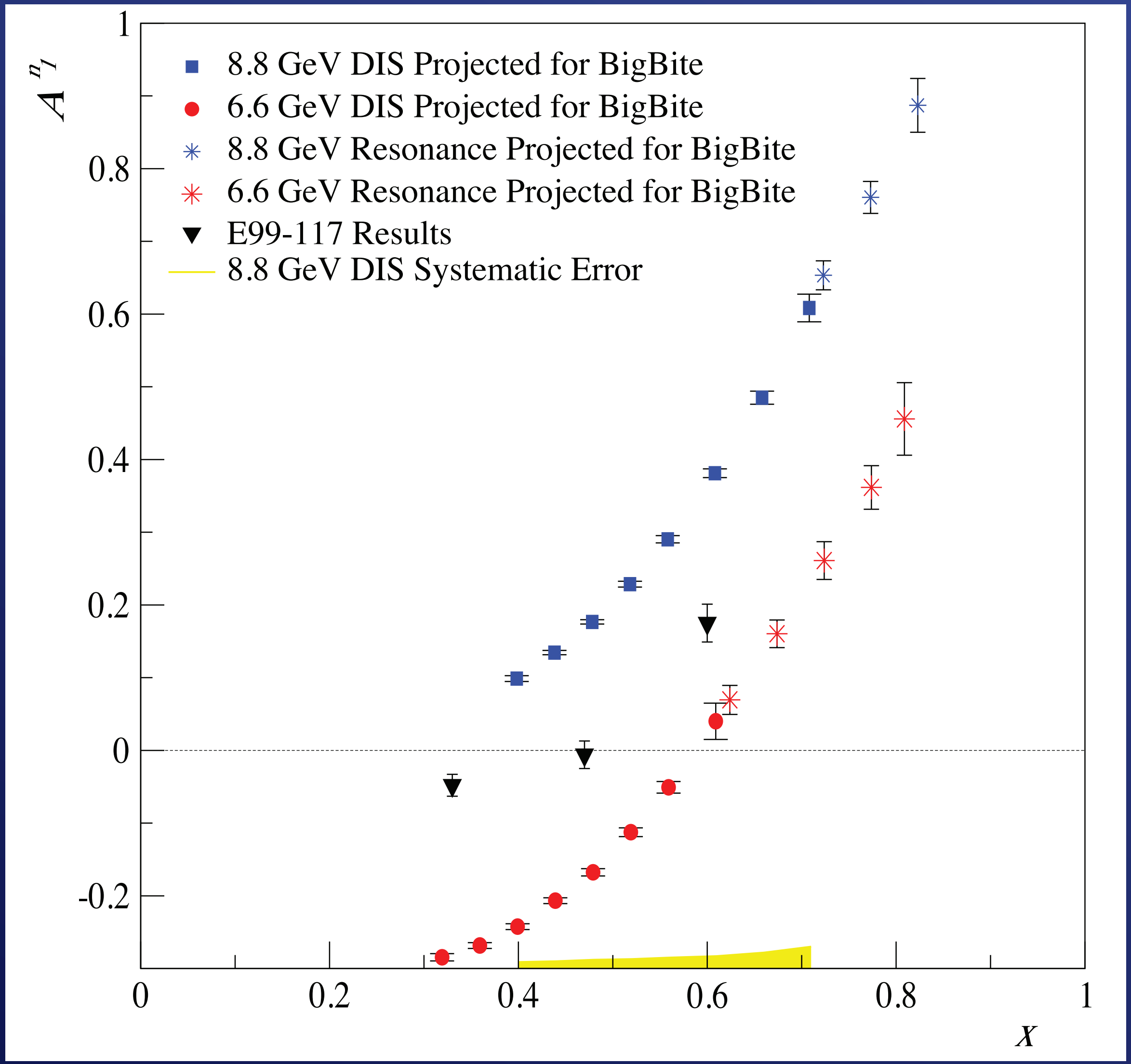


270 hrs production with BigBite at 30°

90 hrs production with BigBite at 30°

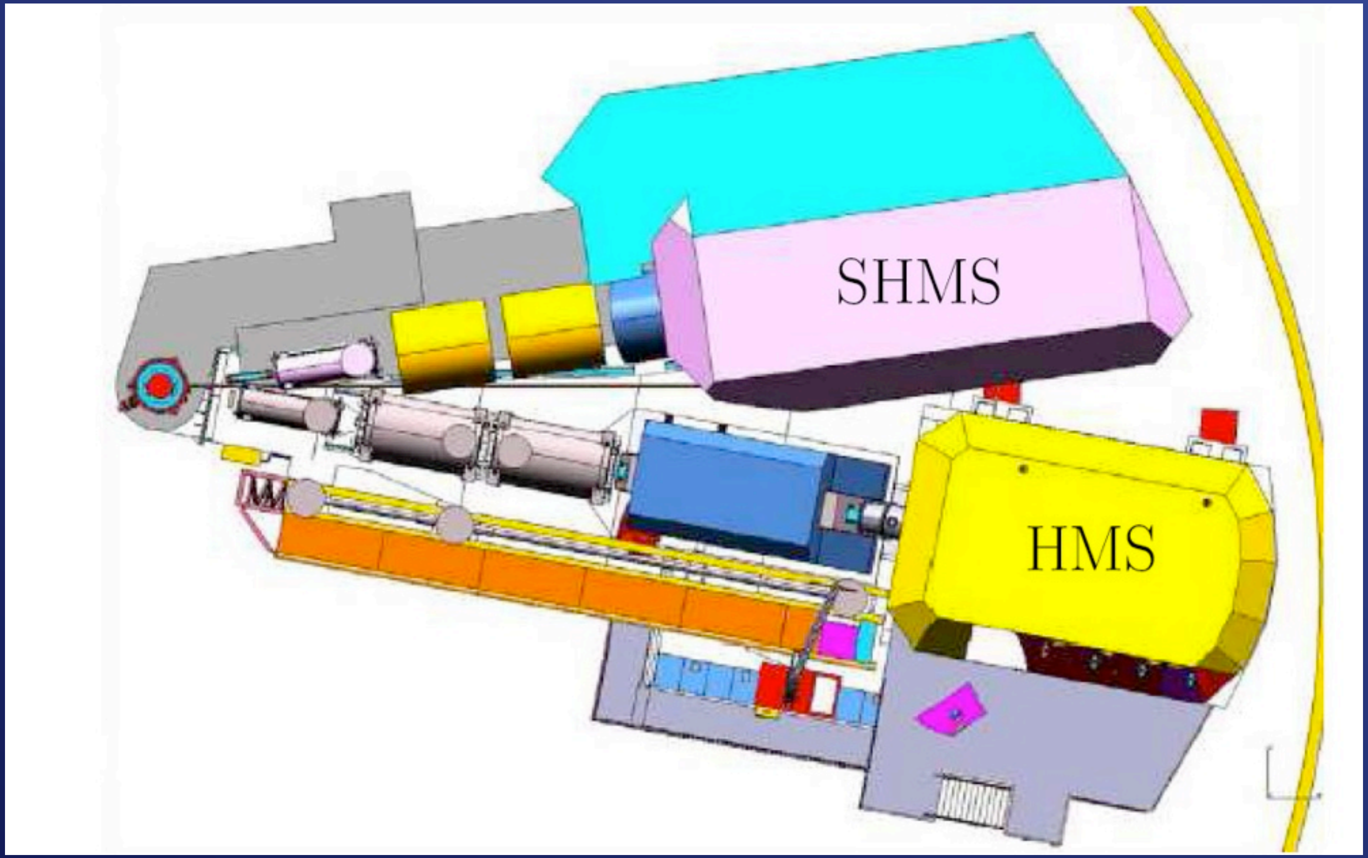
All production running at the same angle and two energies

Hall A A1n projected errors



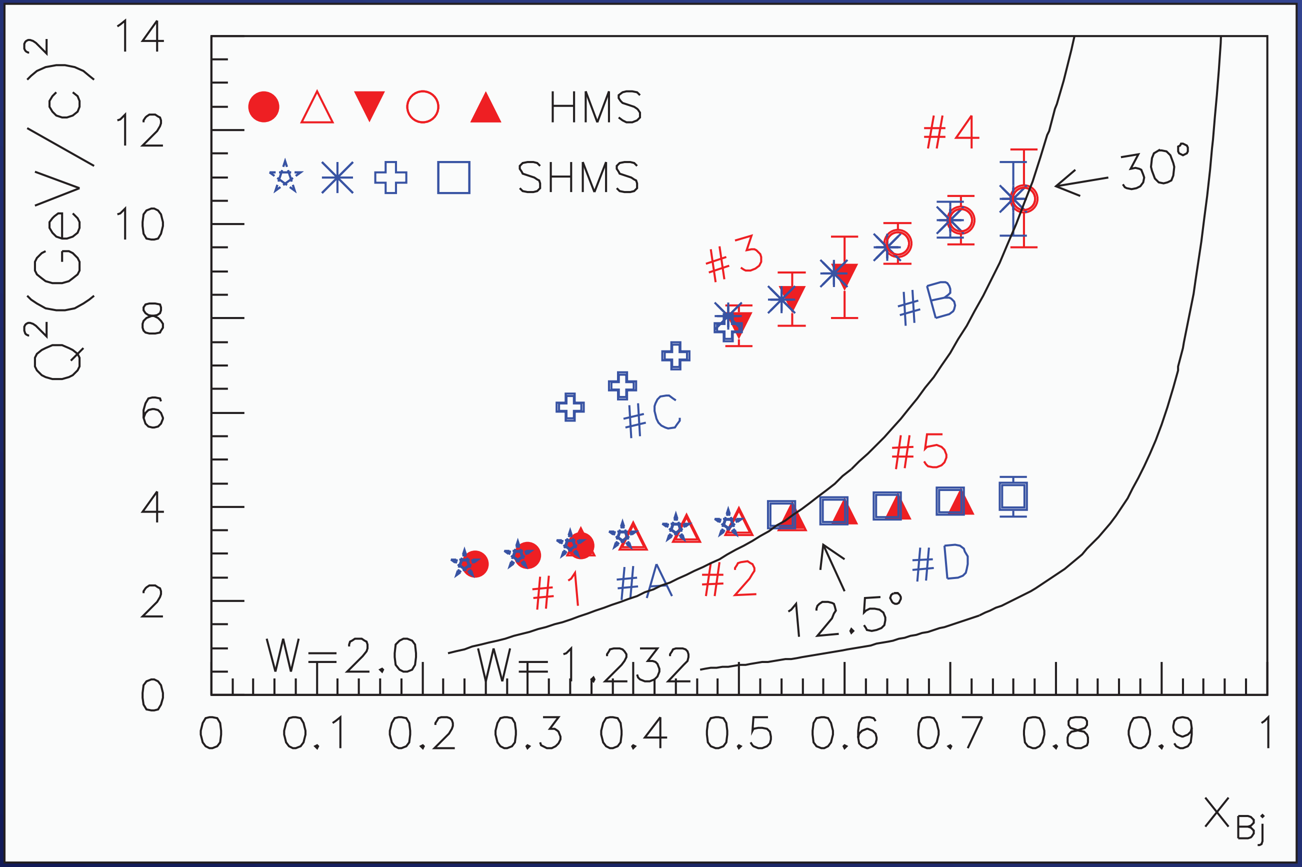
Dramatic improvement over E99-117 (which itself was a huge step) up to x_{Bj} = 0.71 in DIS region, higher with resonance data.

Hall C A1n Experiment (E12-06-110)



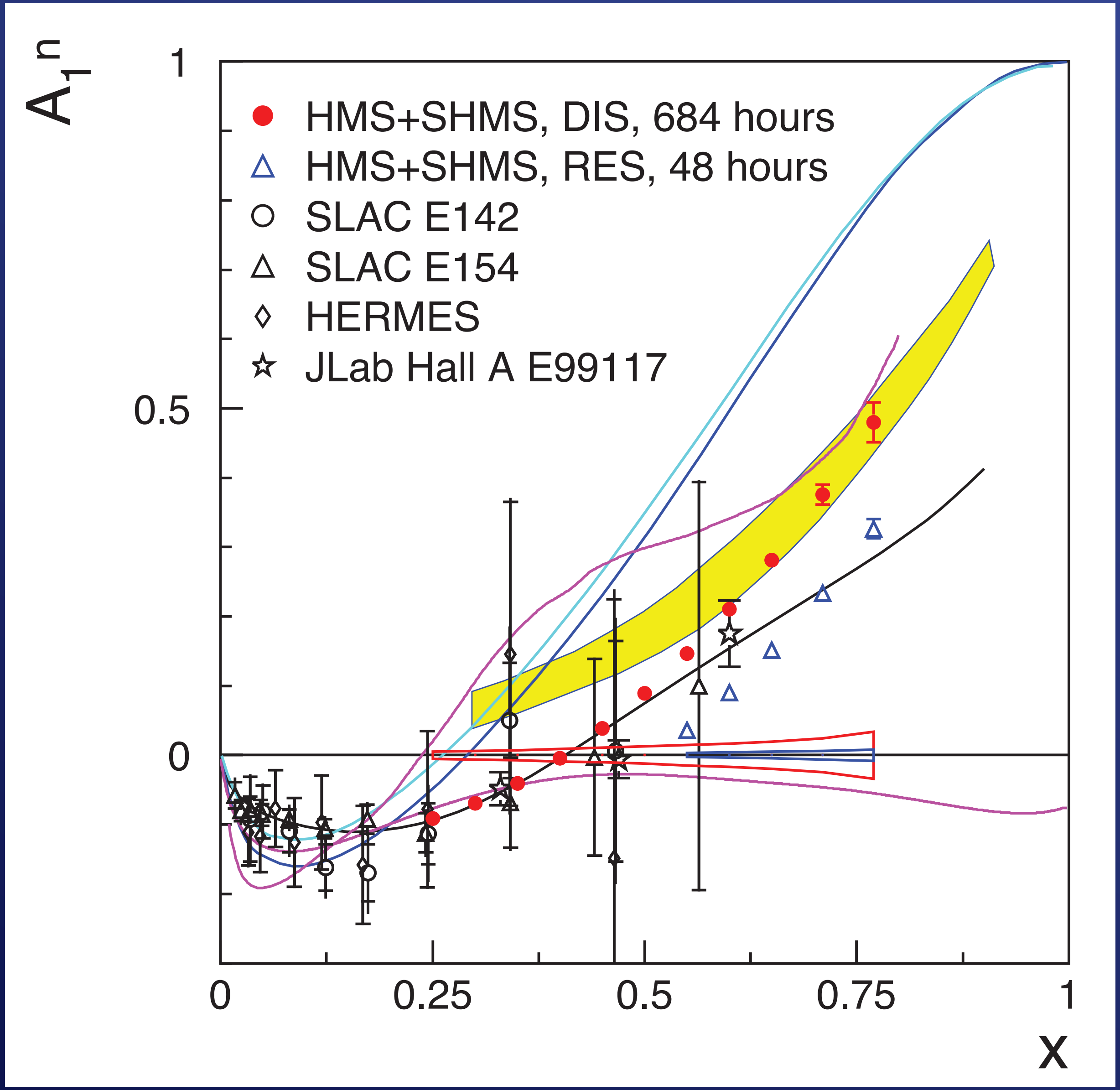
- Use the SHMS and the HMS at a mix of 12.5° and 30° with 11 GeV beam.
- Next-generation polarized 3He target with 60μA polarized beam.
- Clean data, excellent compliment to Hall A experiment.
- Production running time of 636 hours.

Kinematic Coverage: Hall C A1n



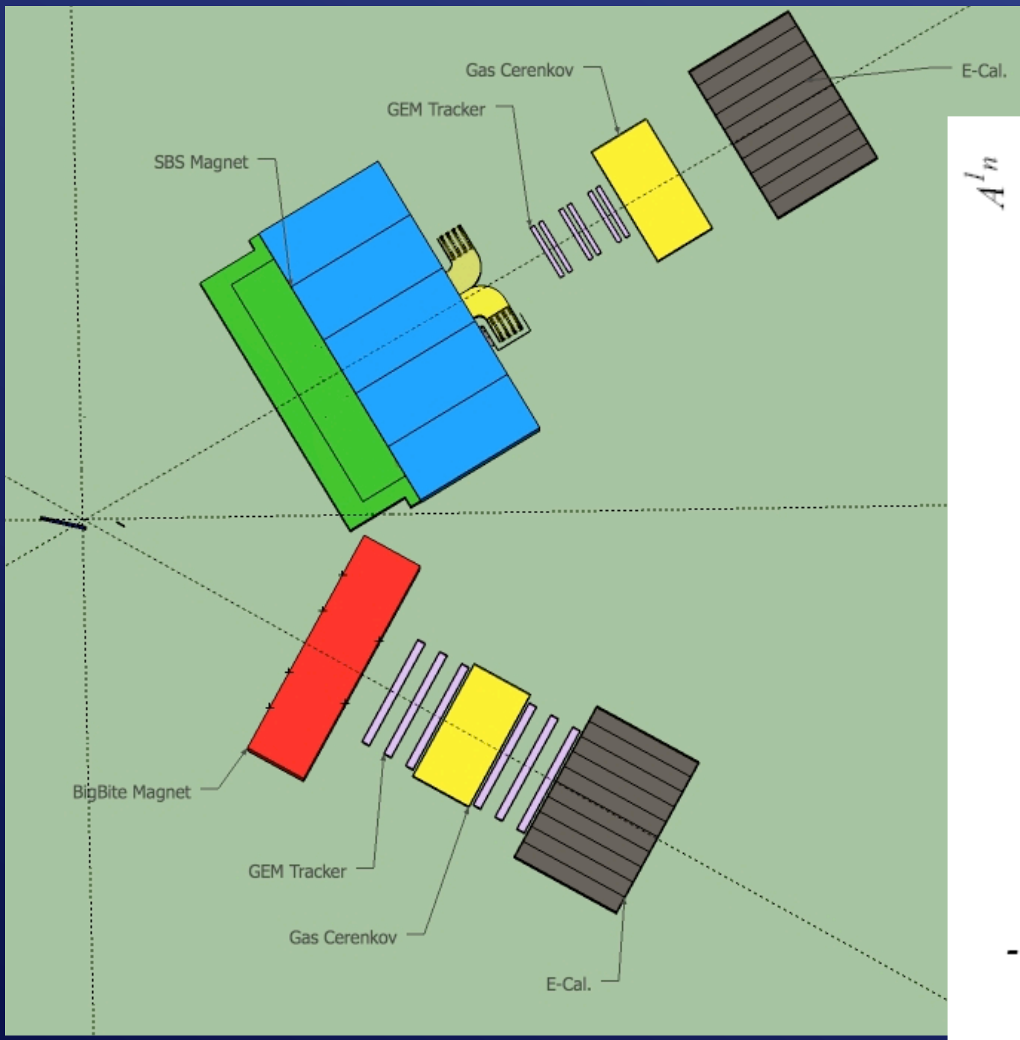
- Total production running of 636 hours.
- Good statistics at two Q^2 values to look for Q^2 dependence.
- Data in resonance region will provide test of duality in this context.

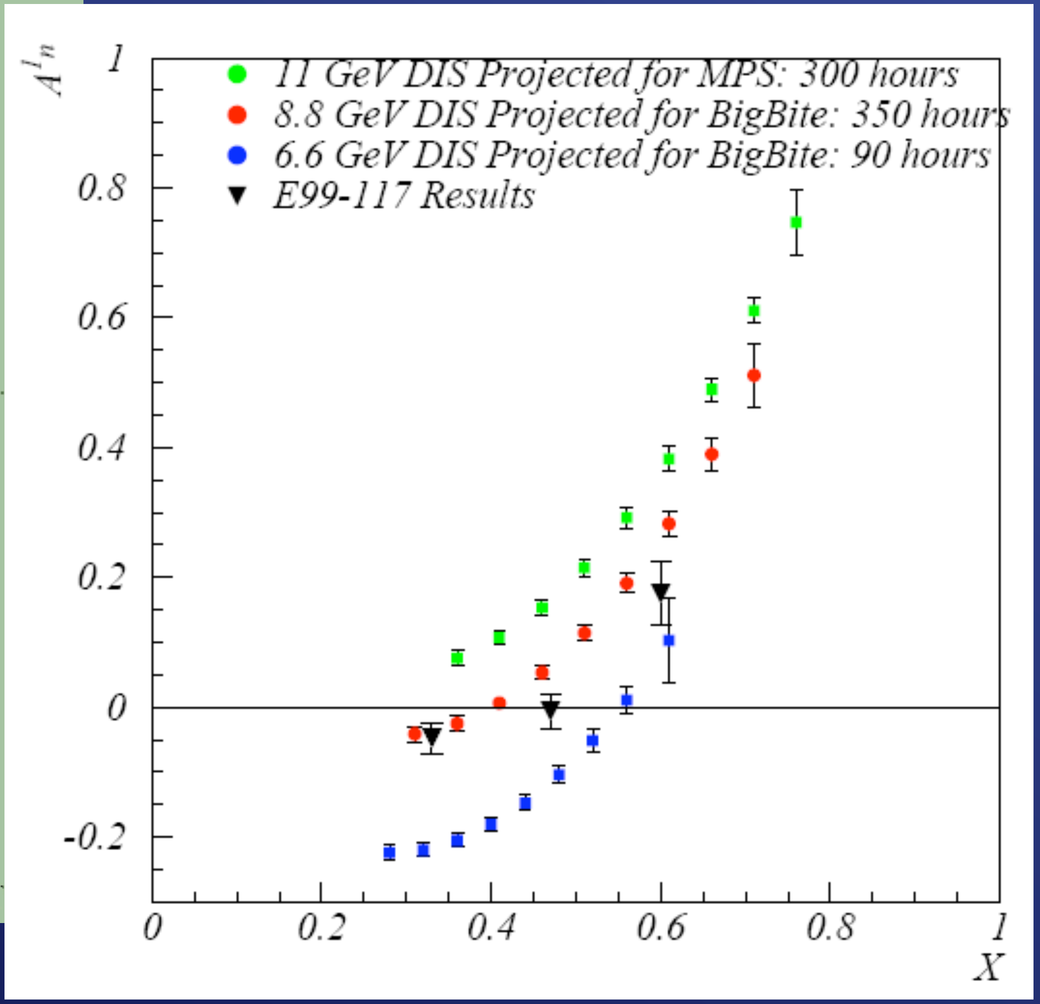
Hall C A1n projected errors



Covers up to x_{Bj} = 0.77 in DIS region, higher with resonance data.

Super Bigbite A1n





The best statistics, the only way to reach x_{Bj} = 0.8

Summary

- A1n provides an excellent probe of nucleon structure of the valence quark region where calculations are reasonably tractable.
- An upgraded CEBAF brings us cleanly into the regime where high-x measurements are possible.
- Performance of EXISTING polarized 3He targets suggests that a next-generation target is possible capable of up to 100 μA and a luminosity of $10^{37}/cm^2s^{-1}$ is conservatively achievable.
- New appropriate spectrometers are available, including an upgraded BigBite, SHMS, and Super Bigbite.
- A1n, a key part of the 12 GeV-era program, looks very exciting.

Backup Slides

Hall A A1n Running times (E12-06-122)

Task	Time (hours)
Production data; parallel asymmetry	220
Production data; perpendicular asymmetry	60
N2 dilution runs	10
^{3}He elastic asymmetry runs (2.2 GeV on HRS)	15
^{3}He delta asymmetry runs (2.2 GeV on HRS)	10
Bigbite optics calibration runs using H(e,e′p) data	50
Beam and target polarization measurements	25
Total	390

Task	Time (hours)
Production data ; parallel asymmetry	70
Production data; perpendicular asymmetry	20
Total	90

Hall A A1n projected errors

x	E' (GeV)	Q2 (GeV^2)	W2 (GeV^2)	rate (Hz)	dA1n (Stat)	dA1n (Syst)
0.71	3.175	7.758	4.1	2.5	0.019	0.030
0.66	3.025	7.133	4.6	8.5	0.009	0.022
0.61	2.875	6.779	5.2	15	0.006	0.017
0.56	2.725	6.425	5.9	20	0.005	0.015
0.52	2.575	6.072	6.5	32	0.004	0.013
0.48	2.425	5.718	7.1	41	0.003	0.012
0.44	2.275	5.364	7.8	44	0.003	0.010
0.40	2.125	5.011	8.4	31	0.004	0.009

x	E' (GeV)	Q2 (GeV^2)	W2 (GeV^2)	rate (Hz)	dA1n (Stat)	dA1n (Syst)
0.61	2.587	4.576	3.8	6.5	0.025	0.022
0.56	2.462	4.355	4.2	40	0.008	0.017
0.52	2.337	4.134	4.7	60	0.006	0.015
0.48	2.212	3.913	5.2	85	0.005	0.013
0.44	2.087	3.692	5.6	115	0.004	0.012
0.40	1.962	3.471	6.1	150	0.004	0.012
0.36	1.837	3.250	6.5	150	0.004	0.010
0.32	1.712	3.028	7.0	85	0.005	0.009

Hall C kinematic points

	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	2994.47	< 0.5	< 0.1%	0.25-0.50 (2.79- 3.65) (2.1- 3.0)
B	SHMS	11.0	3.00	30.0	8.72	< 5.8	< 0.7%	0.50-0.77 (8.04-10.54) (2.0- 3.0)
C	SHMS	11.0	2.25	30.0	28.35	< 36.0	< 8.2%	0.35-0.50 (6.11- 7.81) (2.9- 3.5)
D	SHMS	11.0	7.50	12.5	581.08	< 0.1	< 0.1%	0.45-0.55 (3.57- 3.78) (2.0- 2.3)
					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	579.92	–	–	0.55-0.89 (3.84- 4.36) (1.2- 2.0)

Hall C A1n Running times (E12-06-110)

Table 6: 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	496	4	500
C	11.0	SHMS	30.0	2.25	93	7	100
				Resonances			
5	11.0	HMS	12.5	7.50	48	0	48
D	11.0	SHMS	12.5	7.50	48	0	48

Hall C A1n errors

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

BigBite Cherenkov Project for A_1^n Measurement in Hall A

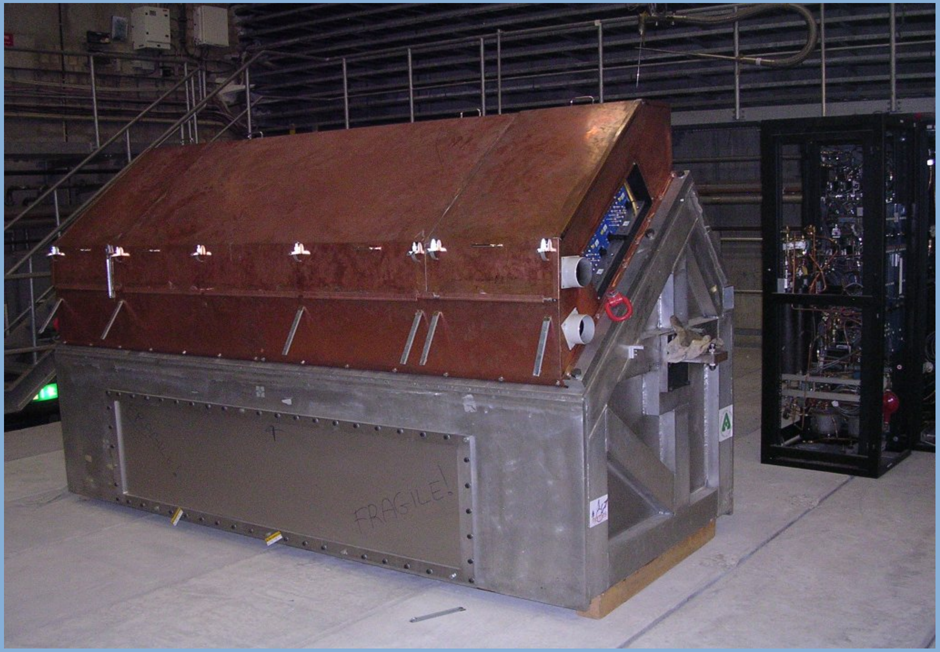
Todd Averett, William and Mary
Bogdan Wojtsekhowski, Jefferson Lab

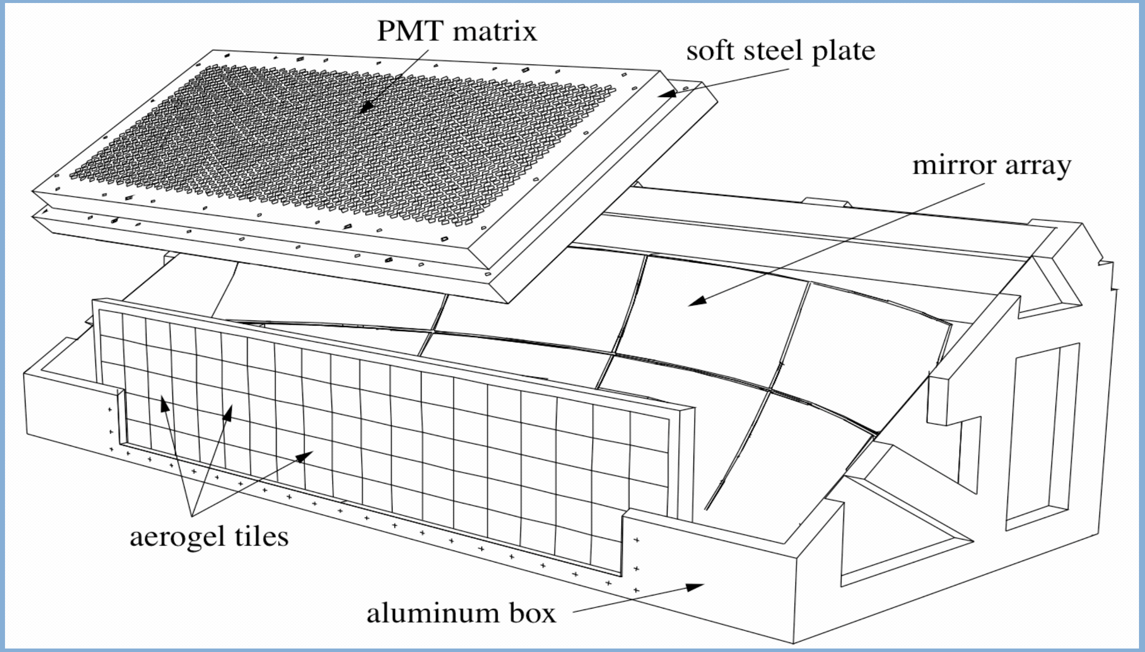
- Manpower behind project – W&M, Rutgers, ODU, Glasgow, Jlab.
- Milestones: analysis of d2n Cherenkov data, OPTICS design for one side, 25 PMT segment, front end boards
- Experimental test in hall A with BigBite - Spring 2011

- New design—Large array of 0.75" diameter PMT's
  - Find clusters using TDC's
  - Timing cut ~10 ns
- Expect to be able to handle 2 MHz or higher background rate per tube.
- Prototype—Build at W&M using spare Philips XP1911 PMT's
  - Assemble array of 25 PMT's
  - Test/optimize concept with cosmic rays—December 2010
  - Test in beam to study high rate capability—Spring 2011

Full Detector Concept

- Use PMT array from HERMES RICH; currently located at UVa storage.
- Move RICH to William and Mary High Bay Lab for PMT array removal and re-configuration.
- Construction of gas box and mirrors at W&M or Jefferson Lab
- Transport light to array using simple, 2-4 mirror design





Broken SU(6) symmetry, constrained by data

$$|n\uparrow\rangle = \frac{1}{\sqrt{2}}|d\uparrow(ud)_{S=0}\rangle + \frac{1}{\sqrt{18}}|d\uparrow(ud)_{S=1}\rangle - \frac{1}{3}|d\downarrow(ud)_{S=1}\rangle$$
$$-\frac{1}{3}|u\uparrow(dd)_{S=1}\rangle - \frac{\sqrt{2}}{3}|u\downarrow(dd)_{S=1}\rangle$$

Color hyperfine interaction breaks the SU(6) symmetry and causes the S=0 term to dominate at high x.