Precision Measurement of the Neutron Asymmetry A^n_1 at Large x_{Bj} using CEBAF at 11 GeV

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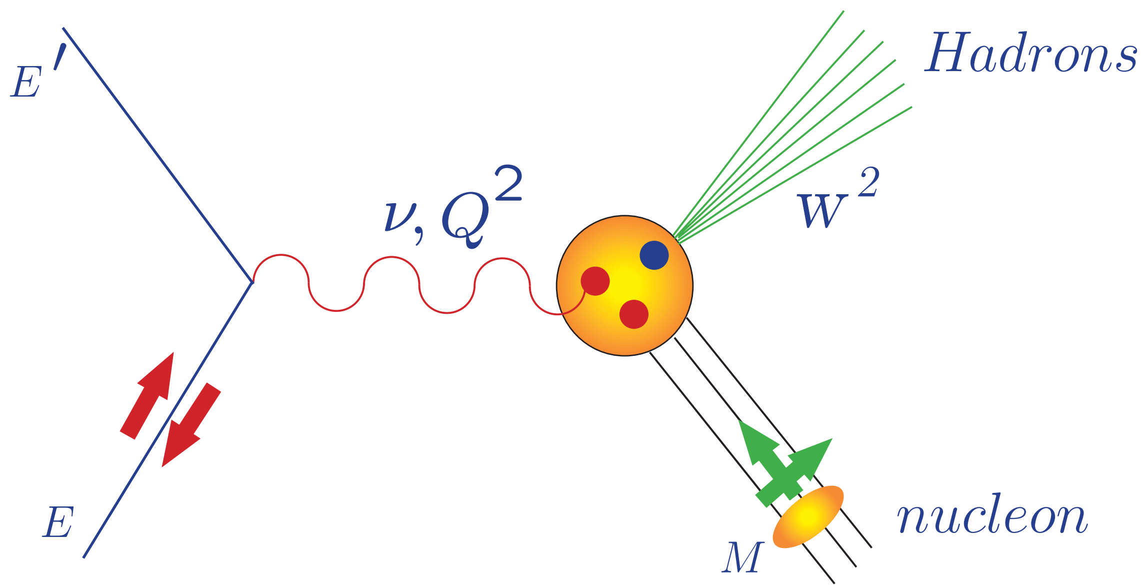
Z.-E. Meziani (contact person), X. Ji

- Physics motivation.
- CEBAF uniqueness.
- Experimental procedure.
- Projected results.
- Summary.

Polarized Deep Inelastic Electron Scattering



$x = \dfrac{Q^2}{2M\nu}$ Fraction of nucleon momentum carried by the struck quark

Q^2 = 4-momentum transfer of the virtual photon, ν = energy transfer, θ = scattering angle

- All information about the nucleon vertex is contained in

F_2 and F_1 the unpolarized (spin averaged) structure functions,

and

g_1 and g_2 the spin dependent structure functions

Quark-Parton Model

In the Bjorken scaling limit

$$F_1(x) = \frac{1}{2} \; {}_{i} \; e_i^2 f_i(x) \qquad g_1(x) = \frac{1}{2} \; {}_{i} \; e_i^2 \quad q_i(x)$$

$$f_i(x) = \quad q_i(x) + q_i(x)$$

$$q_i(x) = \quad q_i(x) \quad q_i(x)$$

$q_i(x)$ quark momentum distributions of flavor i

( ) parallel (antiparallel) to the nucleon spin

Observables of interest

$$A_1(x) = \frac{g_1(x)}{F_1(x)} = \frac{q_i(x)}{f_i(x)}$$

$$R^{np}(x) = \frac{F_2^n(x)}{F_2^p(x)}$$

Photon-Nucleon Asymmetry

Parallel Asymmetry

$$\frac{\sigma_{\uparrow\Downarrow} - \sigma_{\uparrow\Uparrow}}{\sigma_{\uparrow\Downarrow} + \sigma_{\uparrow\Uparrow}} = A_{//} = D\,(A_1 + \eta A_2)$$

Perpendicular Asymmetry

$$\frac{\sigma_{\uparrow\Leftarrow} - \sigma_{\downarrow\Leftarrow}}{\sigma_{\uparrow\Leftarrow} + \sigma_{\downarrow\Leftarrow}} = A_{\perp} = d\,(A_2 - \zeta A_1)$$

Kinematics Factors

$$D = (1 - E'\varepsilon / E)/(1+\varepsilon R)\,, \quad R(x,Q^2) = \sigma_T/\sigma_L$$

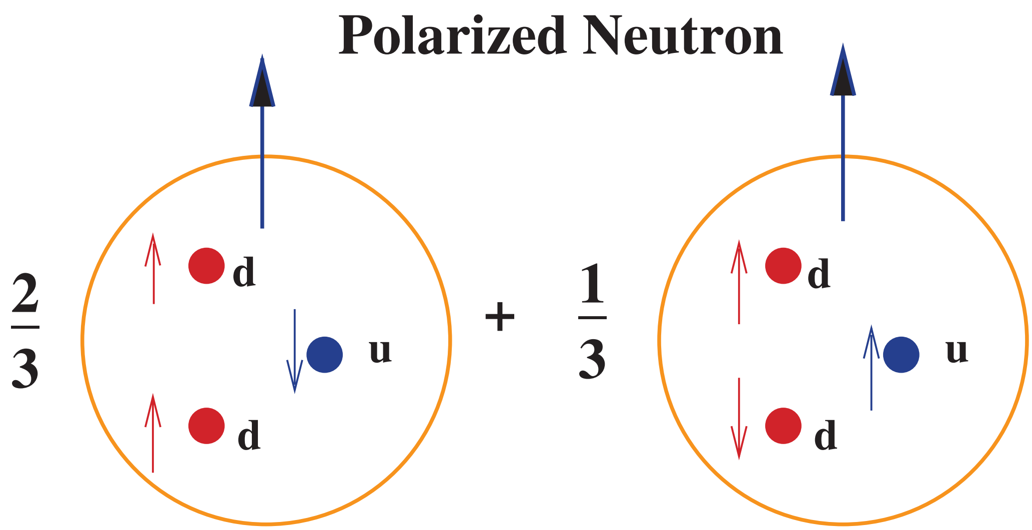
$$d = D\sqrt{2\varepsilon/(1+\varepsilon)}$$

$$\eta = \varepsilon\sqrt{Q^2}\,/\,(E - E'\varepsilon)$$

$$\zeta = \eta\,(1+\varepsilon)/2\varepsilon$$

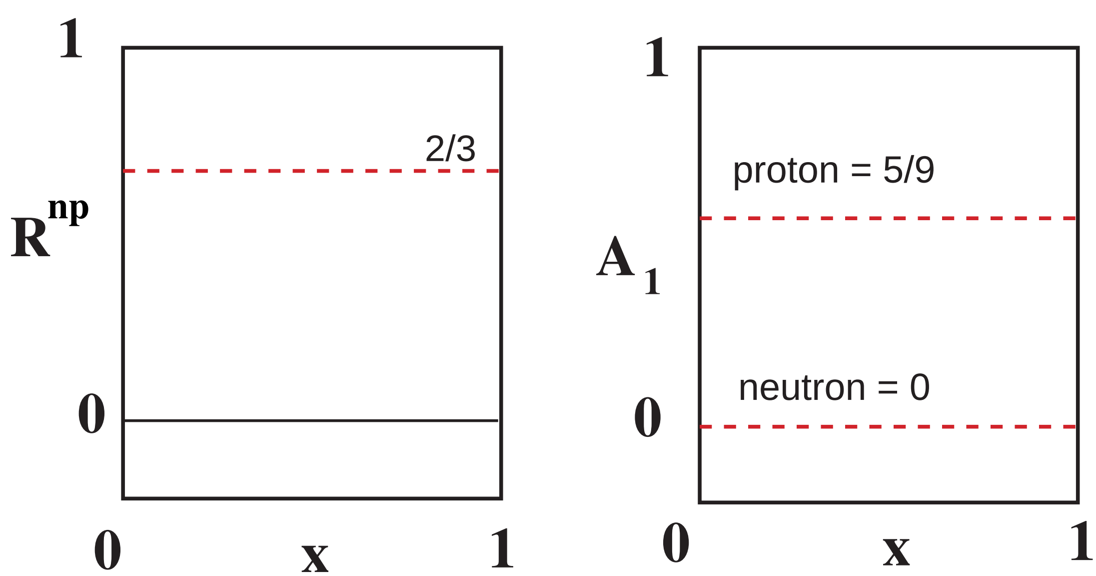
SU(6) Predictions

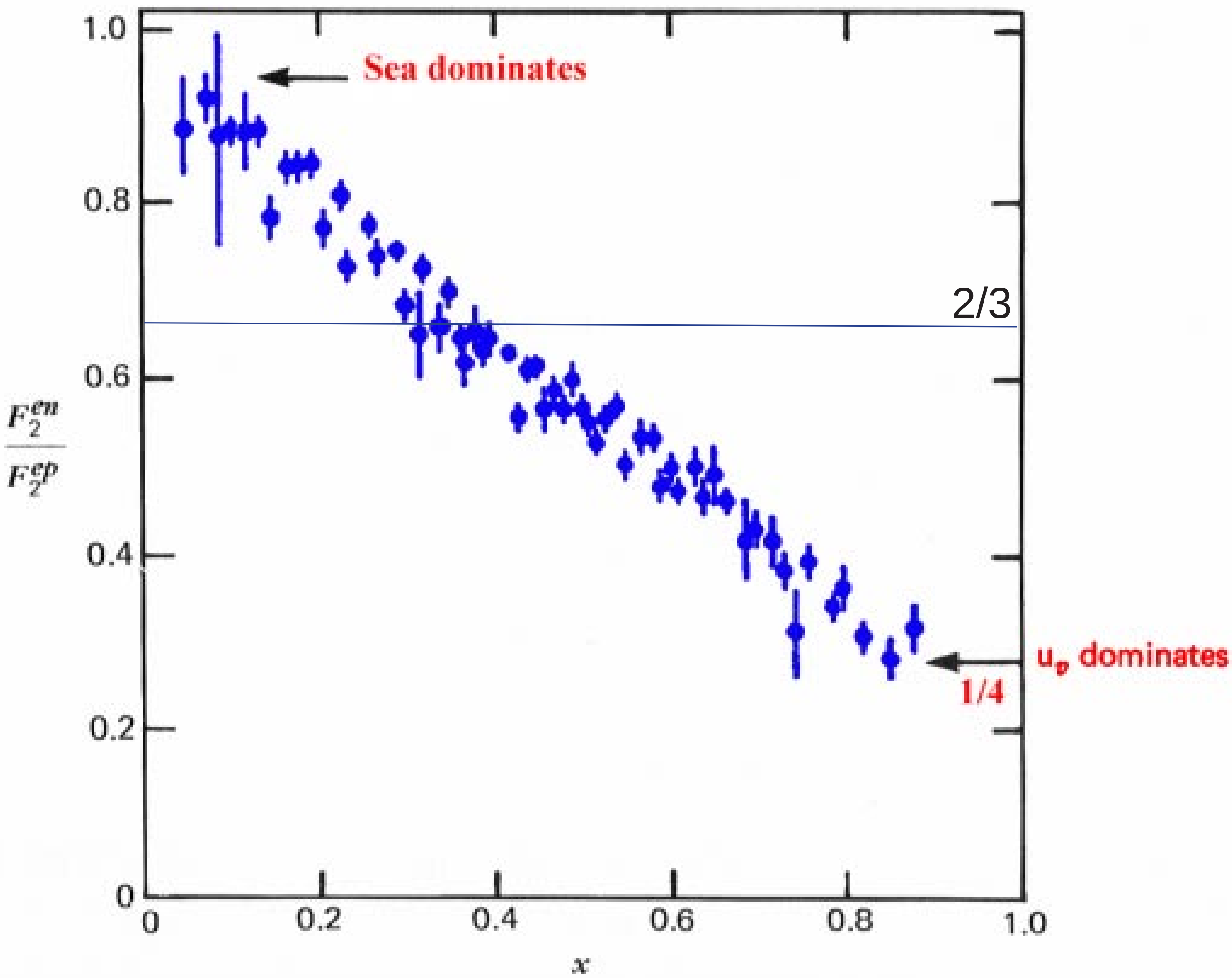
Polarized Neutron Static Wave Function in SU(6)



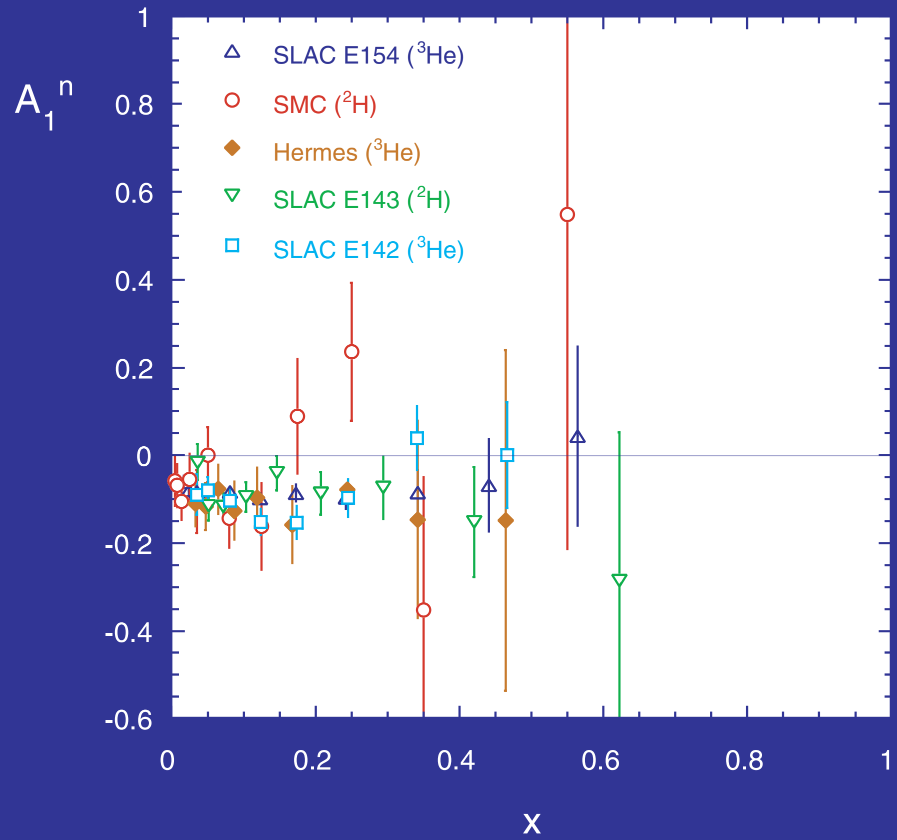
S=0 and S=1 components of the wave function are equiprobable leading to the following predictions

$$R^{np} = 2/3, \quad A_1^p = 5/9, \quad A_1^n = 0$$

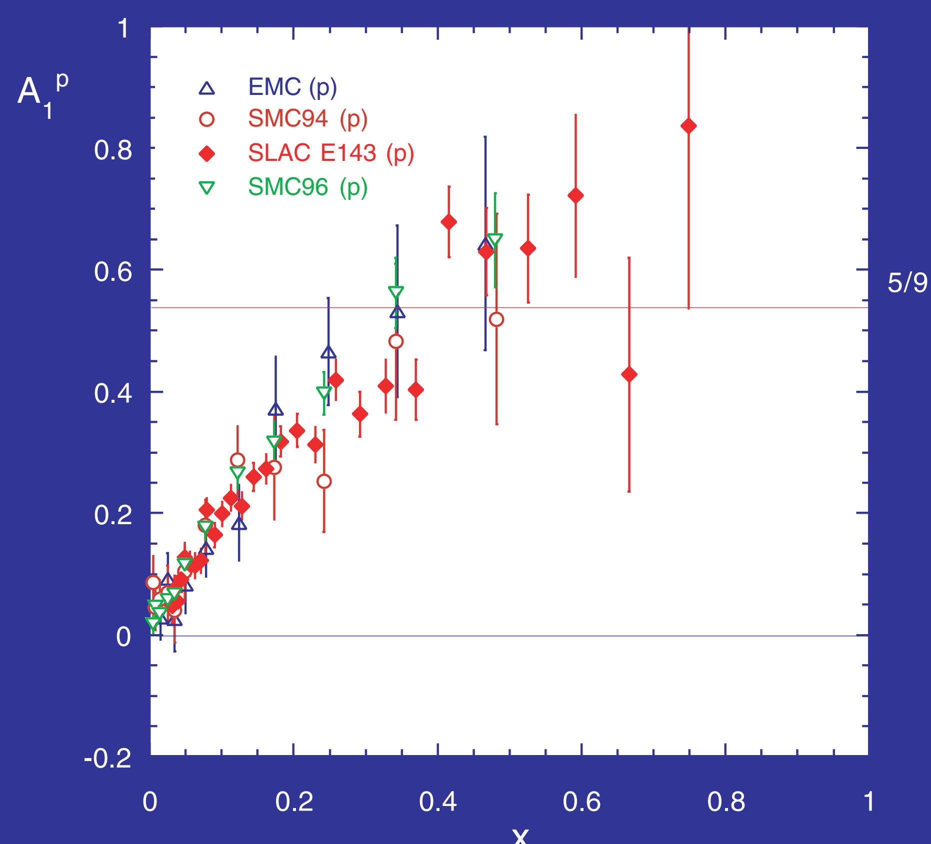



Sea dominates
2/3
u_v dominates
1/4
$\frac{F_2^{en}}{F_2^{ep}}$
x
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0

Neutron



Proton



Broken SU(6) Predictions

- Low x region : Dominated by sea quarks . Quantitative predictions are difficult.

- High x region: Dominated by valence quarks. Predictions are possible.

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

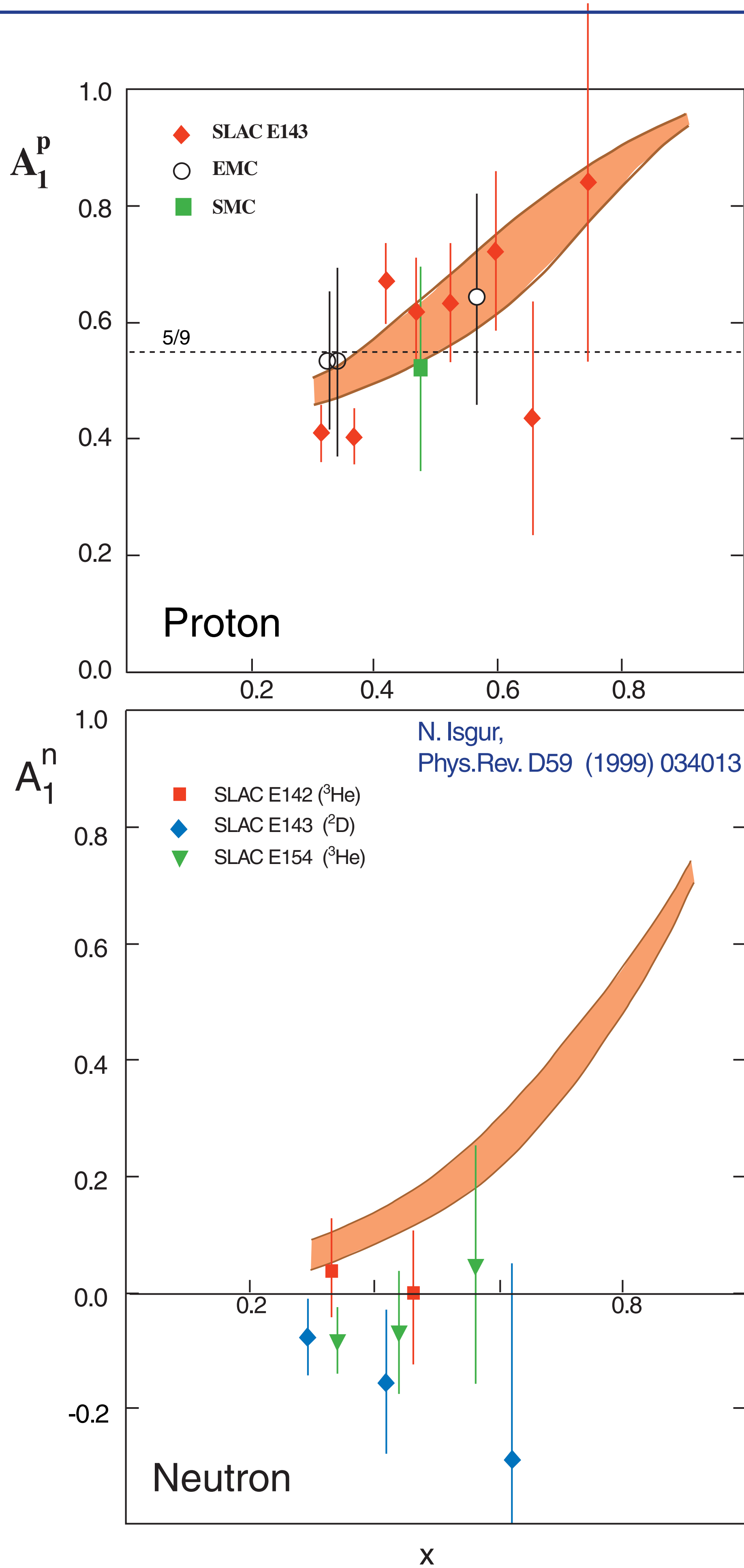
SU(6) symmetry breaks:

- $R^{np} \rightarrow 1/4$ as $x \rightarrow 1$.
- $\vec{S}_i \cdot \vec{S}_j \delta^3(\vec{r}_{ij})$ interaction (N - Δ mass splitting, etc...)

Both ⟶ $|d\uparrow(du)_{S=0}\rangle$ dominates.

What about $A_1^{n,p}$?

Recent paper by N. Isgur



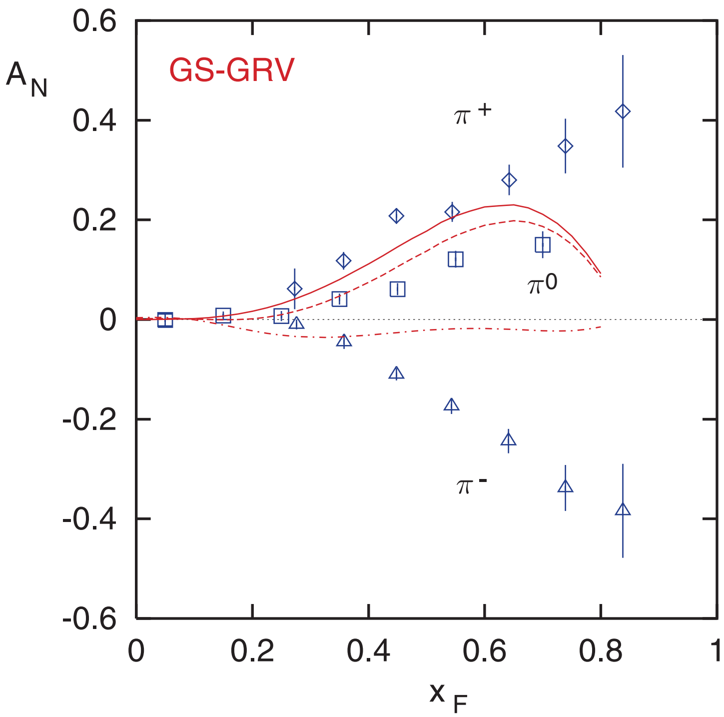
A_1^p
SLAC E143
EMC
SMC
5/9
Proton
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
A_1^n
N. Isgur,
Phys.Rev. D59 (1999) 034013
SLAC E142 (^{3}He)
SLAC E143 (^{2}D)
SLAC E154 (^{3}He)
-0.2
Neutron
x

Single-Spin Semi-Inclusive Pion Production Asymmetries: $p\uparrow p \longrightarrow \pi X$

Data are from Fermilab E704 experiment:

D. L. Adams *et al.*, *Phys. Lett.* **B264** (1991); *Phys. Rev. Lett.* **77** (1996) 2626

Calculations are by M. Boglione and E. Leader
Phys. Rev. **D61** (2000) 114001



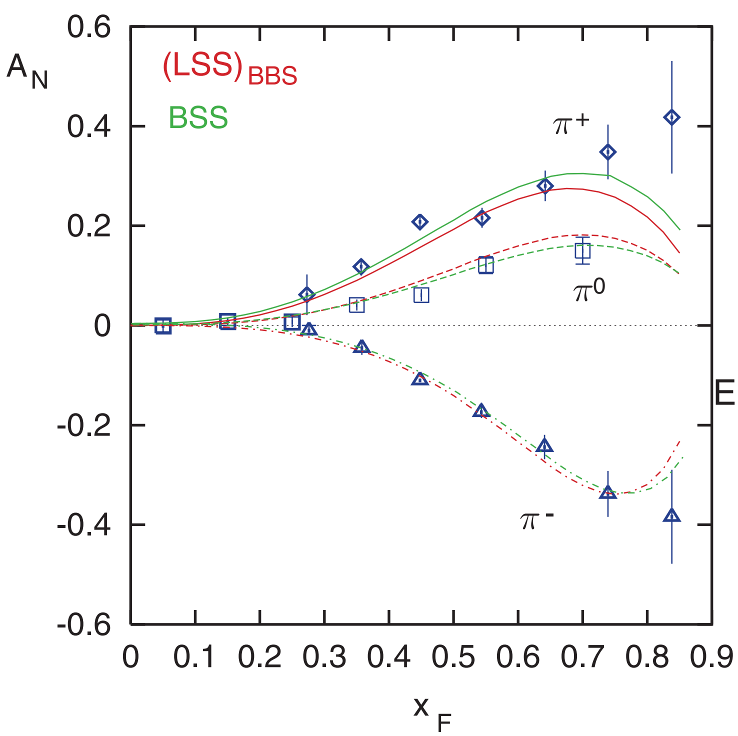
$$A_N = \frac{d\sigma\Uparrow - d\sigma\Downarrow}{d\sigma\Uparrow + d\sigma\Downarrow}$$

Soffer Bound

$$|\Delta_T q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)]$$

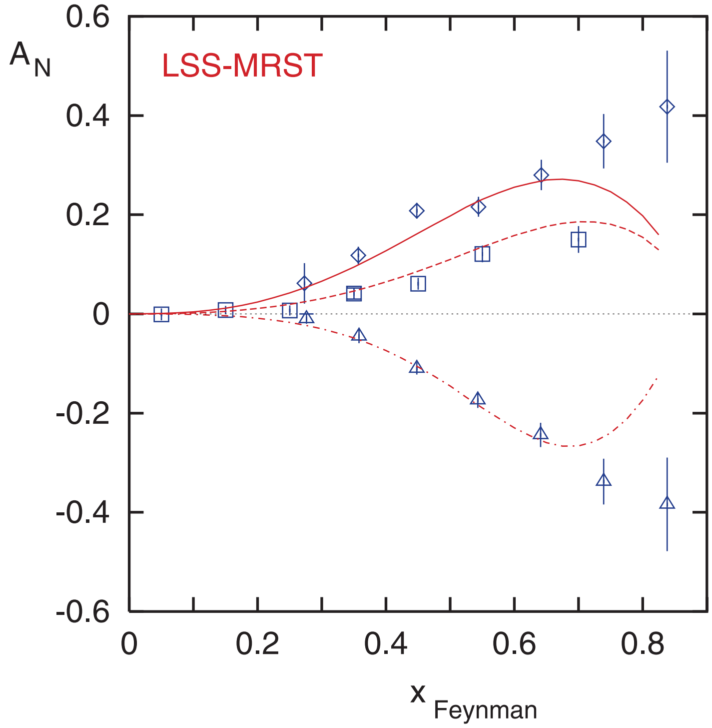
pQCD

$$\frac{\Delta q(x)}{q(x)} \rightarrow 1$$



GS-GRV
T. Gehrmann and W. J. Stirling
Phys. Rev. **D53** (1996)6100,
and
M. Glück, E. Reya and W.Vogelsang
Z. Phys. **C67** (1995) 433.

LSS-BSS
E. Leader, A. V. Sidorov, and D. B. Stamenov
Int. J. Mod. Phys. **A13**, N0.32, (1998) 5573
and
S. Brodsky, M. Burkhardt and I. Schmidt,
Nucl. Phys. **B441** (1995) 197.



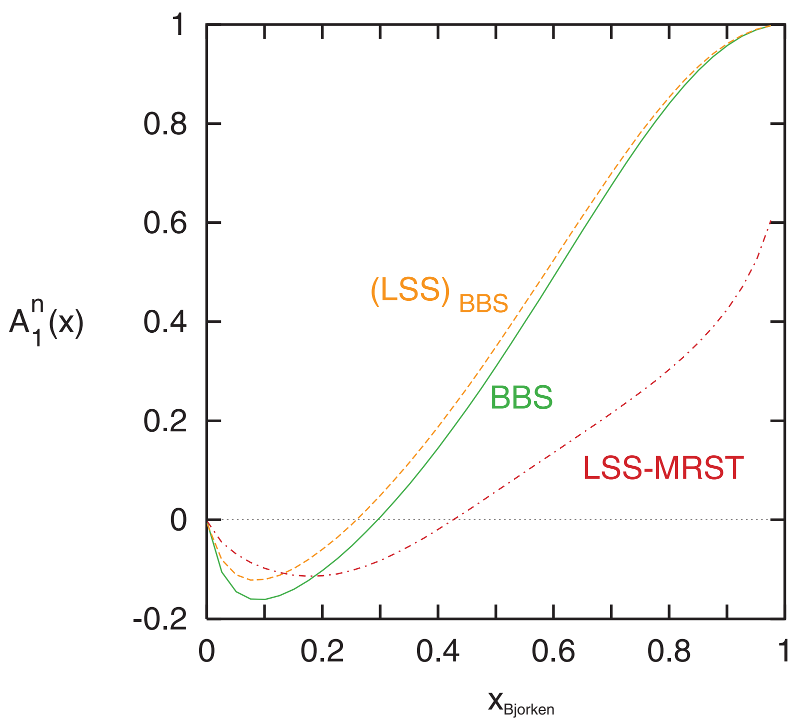
MRST

A.D. Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne

Eur. Phys. J. **C4** (1998) 5573

LSS for polarized distributions
MRST for the unpolarized distributions

Predictions for the Neutron Asymmetry A^n_1



Physics Overview as x----> 1

Diquark Spin State	F^n_2/F^p_2	A^p_1	A^n_1
S=1 and S=0 equiprobable: SU(6)	2/3	5/ 9	0
	d/u=1/2	$\frac{u}{u}$ --->2/3	$\frac{d}{d}$ --->-1/3
S=1 suppressed, S=0 retained F. Close, Phys. Lett. 43B (1973) 422. F. Close, An introduction to Quarks and Partons (1979).	1/4	+ 1	+1
	d/u=0	$\frac{u}{u}$ --->1	$\frac{d}{d}$ --->-1/3
S = 1, S_Z = 1 suppressed S = 1, S_Z = 0 and S = 0 retained G. Farrar, D. Jackson, Phys. Rev. Lett. 35(1975)1416 G. Farrar, Phys. Lett. 70B (1977)34	3/7	+1	+1
	d/u=1/5	$\frac{u}{u}$ --->1	$\frac{d}{d}$ --->1
Instantons! N. Kochelev, hep-ph/9711226			~0

SUMMARY

- In most approaches A_1^n large and positive as x becomes large (x > 0.3)
- At present all data are consistent with $A_1^n(x) \leq 0$
- If A_1^n stays negative the constituent quark picture is in jeopardy! New degrees of freedom might need to be considered, for example, Instantons??

This has been an important question for 25 years!

Experiment is believed to be possible with

- An intense polarized $\vec{e}$ beam
- A dense polarized $^3\vec{H}e$ target
- A beam energ y E $>6\ GeV$, a MAD spectrometer, etc...

CEBAF at 11GeV is by far the best facility to measure A_1^n at high x

Proposed Measurements

Measure $A_{//}^{^3He}$ & $A_{\perp}^{^3He}$

- 3 incident energies: $E_i = 6.6$, 8.8 and 11GeV
- 3 scattering angles: $\theta = 35°$, 27° and 25°
- 3 **MAD** momentum settings covering the range:

$$0.1 < x < 0.75$$

$$2.0 < Q^2 < 10 \text{ GeV}^2$$

$$W^2 \geq 4 \text{ GeV}^2$$

- Perform radiative corrections on

$$A_{//}^{^3He} \quad \& \quad A_{\perp}^{^3He}$$

- Determine

$$A_1^{^3He} = (A_{//}/D - \eta A_{\perp}/d)/(1+\eta\zeta)$$

- Correct for nuclear effects to extract

$$A_1^n(x,Q^2)$$

Uniqueness of CEBAF

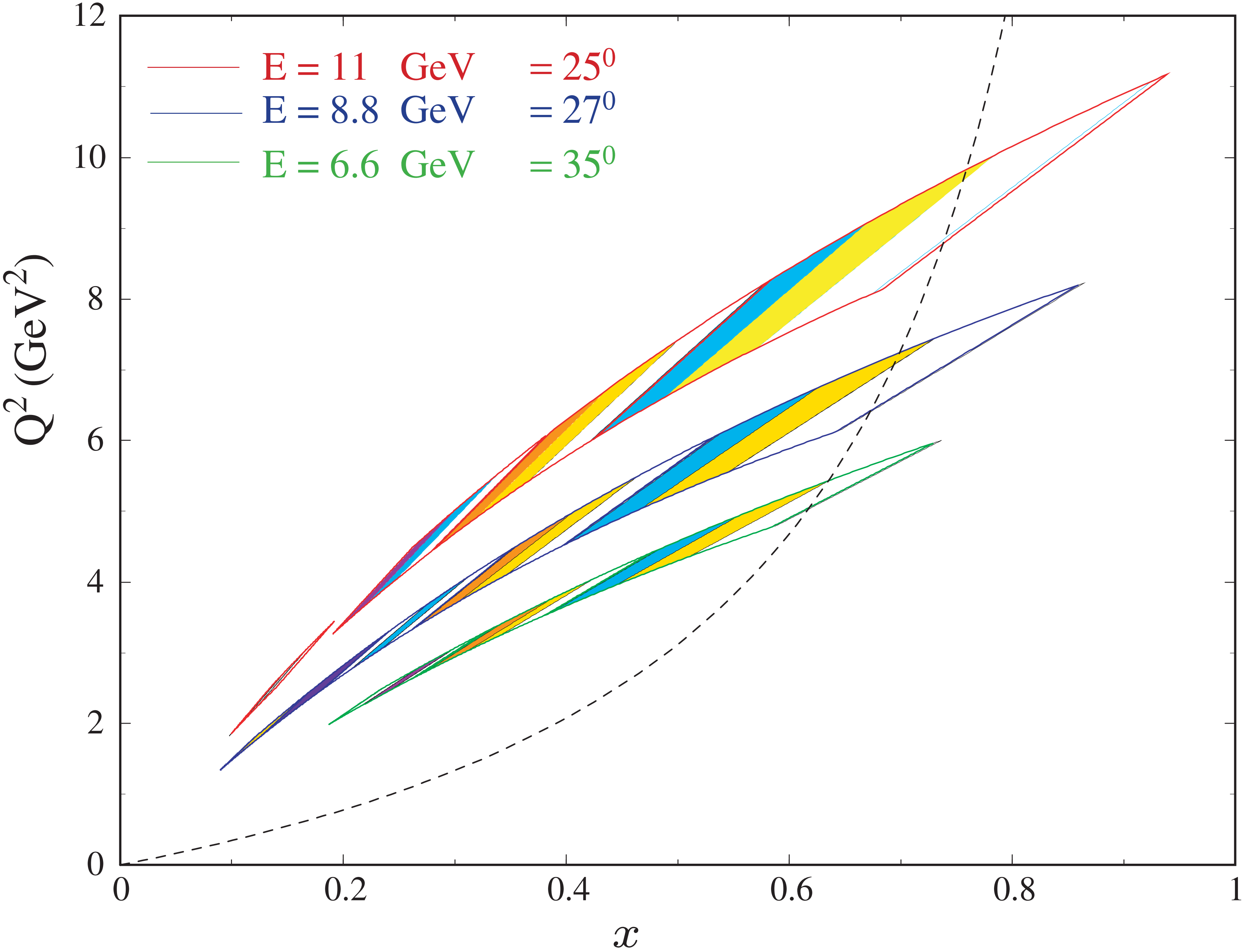
- Depolarization factor typically about 0.7 compared to 0.3 in most experiments performed at the high energy facilities ($A_1 \approx A_{//}/D$).

- Scattered electrons detected at large angle lead to high x, high Q^2 and low scattered energy (E'< 6 GeV). A large acceptance spectrometer like **MAD** matches the kinematics efficiently.

- High beam and target polarizations and high beam current provide for a good polarized luminosity.

- Target reconstruction reduces entrance and exit windows background thus, dilution of the asymmetry.

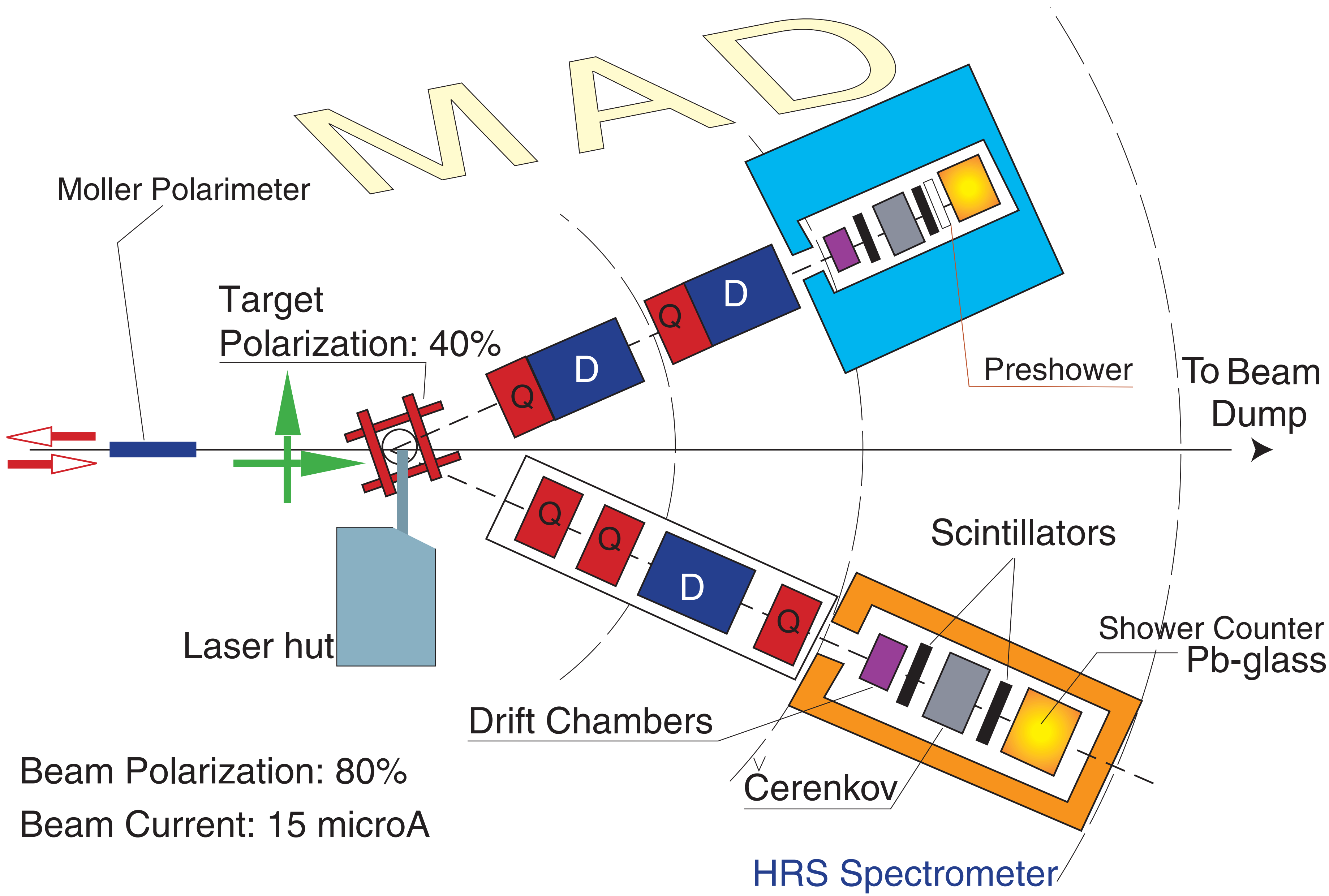
Kinematic Coverage for an A_1^n measurement using MAD



Comparison of some relevant parameters between CERN, HERA, SLAC and CEBAF. Note the difference in the D factor and size of the *x* bin.

Expt. Name	E_i *GeV*	E' *GeV*	θ *deg*	*x* bin	Q^2 GeV^2	D	$P_{e,\mu}$	Rate (Hz)
HERMES	35	17.0	5.2	0.6-0.7	9.1	0.22	0.50	0.05
SLAC E142	23	16.5	7.0	0.4-0.6	5.2	0.27	0.35	7.0
SLAC E143	29	25.5	7.0	0.6-0.7	9.1	0.29	0.84	0.3
SMC	190	161	1.8	0.4-0.7	29.5	0.14	0.80	0.005
CEBAF	11	4.4	25	0.7-0.75	10	0.67	0.80	1.3

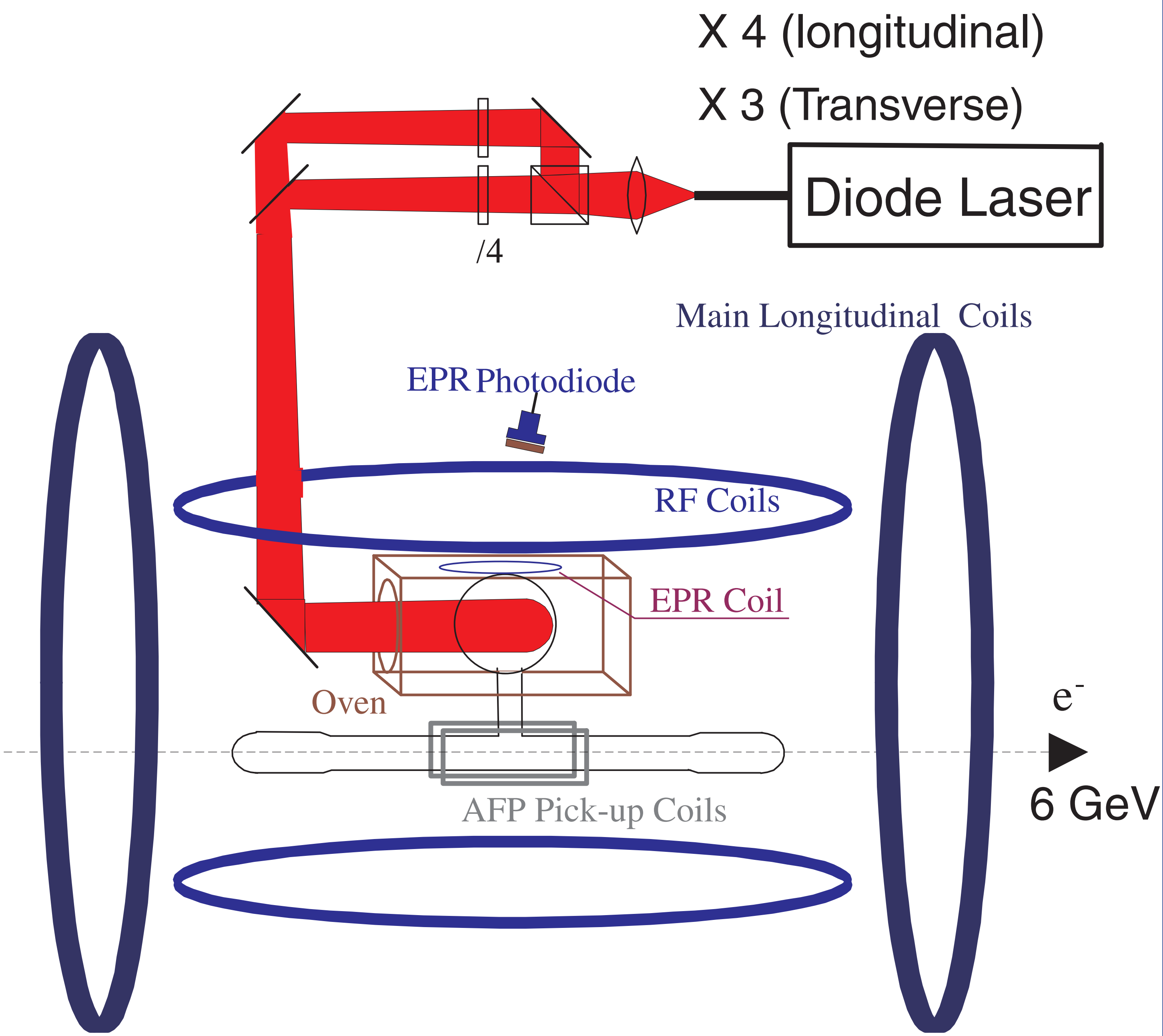
Hall A Floor Configuration with MAD



Beam Polarization: 80%

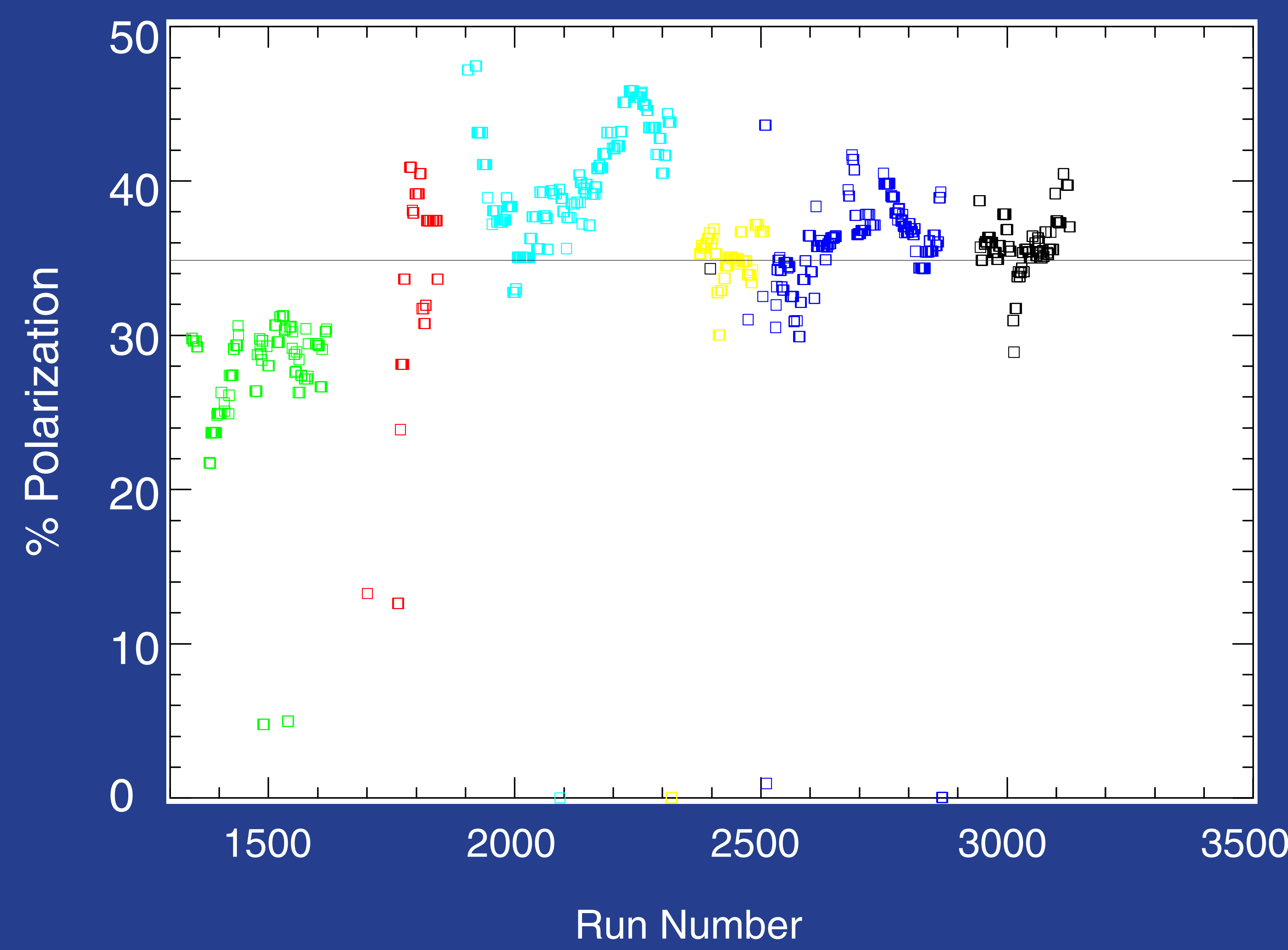
Beam Current: 15 microA

Jlab Hall A polarized ^{3}He Target



- NMR and EPR techniques for polarization monitoring.
- Elastic scattering for current induced depolarization.
- Target used successfully in E94-010 and E95-001.
- Target length will be 25 cm.

E94-010 ^{3}He Target Polarization



From ^{3}He to the Neutron

- Extract an effective $\tilde{A}_1^n$
  - Wave function includes S, S' and D waves.
  - Fermi motion not included.
  - binding effects not included

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

$$f_{p(n)} = \frac{F_2^n}{F_2^{^3He}}$$ &

$$\rho_p = -2\Delta' = -2.7 \pm 0.3\%$$
$$\rho_n = 1 - 2\Delta = 87 \pm 2\%$$

$$\Delta = (\rho_{S'} + 2\,\rho_D)/3 \qquad \rho_{S'} = 1.55 \pm 2\%$$
$$\Delta' = (\rho_D - \rho_{S'})/6 \qquad \rho_D = 9.1 \pm 0.9\%$$

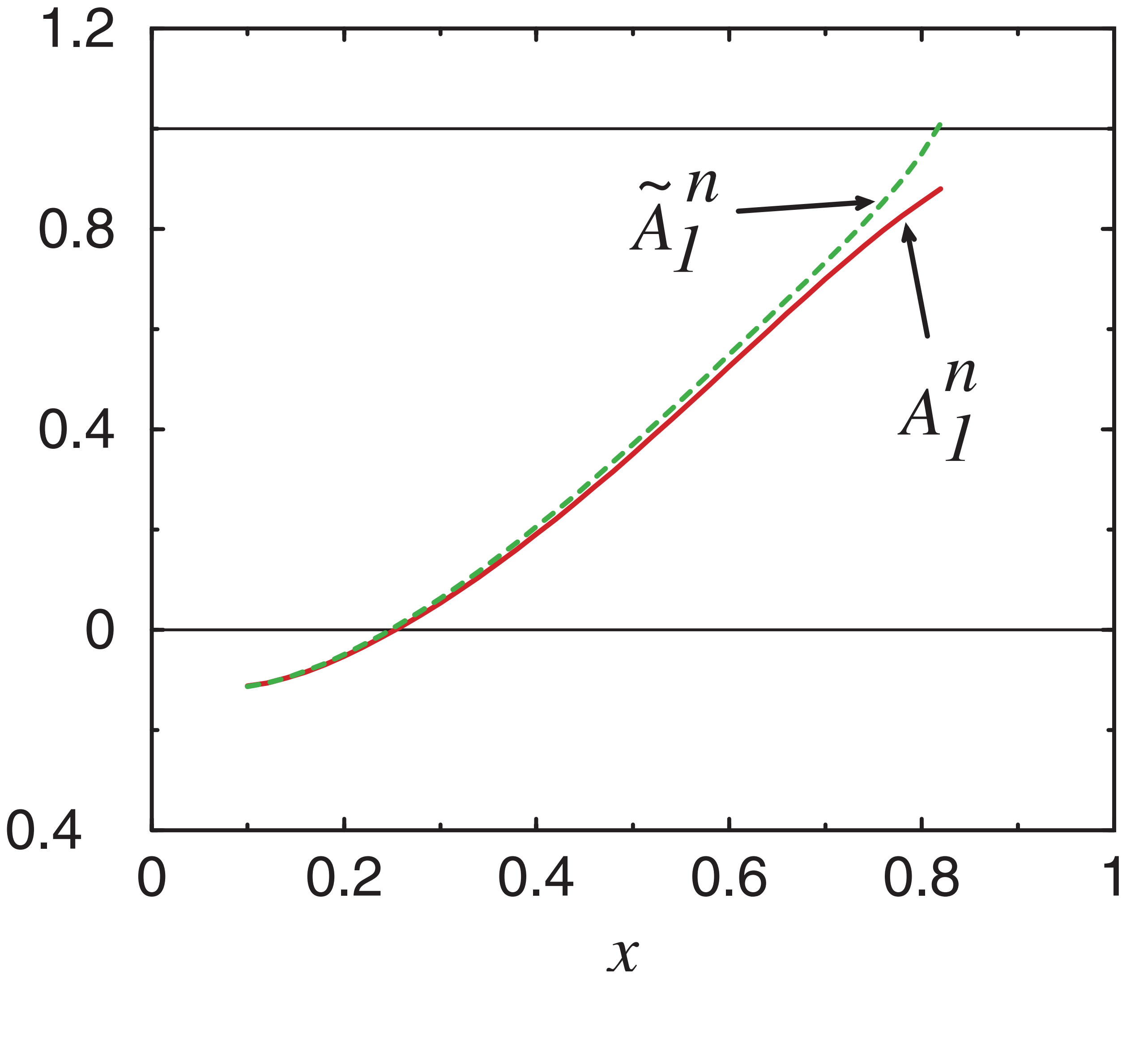
Very good approximation according to

C. Cioffi Degli Atti, S. Scopetta, E. Pace and G. Salme *University of Perugia report DFUPG 75/92.*

R. W. Shulze and P.U. Sauer, Phys. Rev. C48(1993)38.

W. Melnitchouk et al., Private communication

Residual of Nuclear corrections to extract the Neutron from ^3He



W. Melnitchouk *et al., private communication*

Rates and Times for parallel and perpendicular measurements which optimize the statistical uncertainty on A^n_1

E_i = 11 GeV $\theta = 25^0$

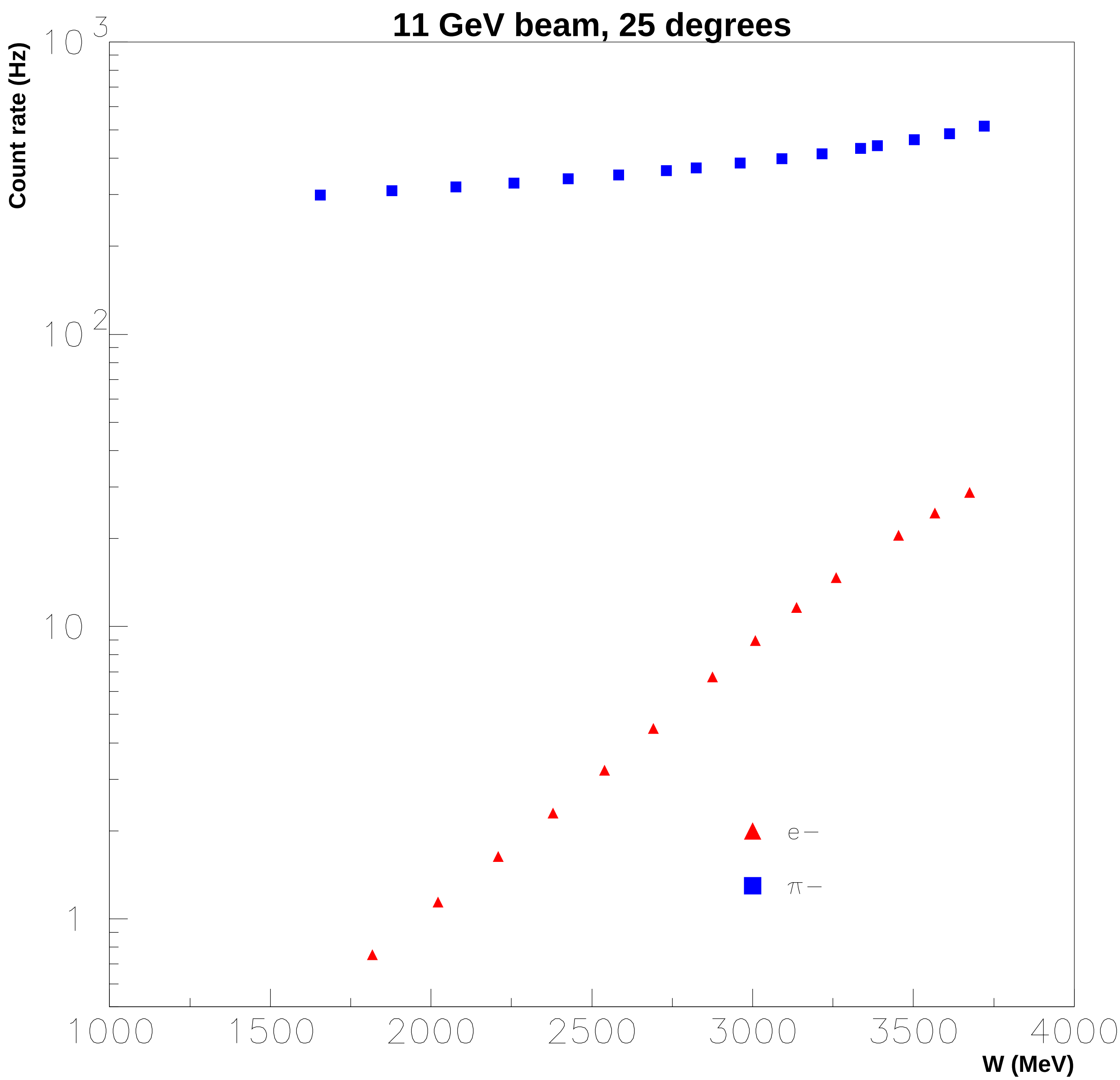
E' (GeV)	x	Q^2 $(\text{GeV})^2$	W (GeV)	D	$A_1^{^3He}$	$\Delta A_1^{^3He}$	$A_2^{^3He}$	$\Delta A_2^{^3He}$	Rate Hz	$\text{time}_{\parallel}$ Hours	$\text{time}_{\perp}$ Hours
4.40	.732	9.07	2.05	0.67	0.072	0.0046	0.0330	0.0159	1.26	**540**	**22**
3.98	.623	8.20	2.42	0.71	0.050	0.0041	0.0205	0.0155	2.69	252	10
3.60	.534	7.42	2.71	0.75	0.036	0.0036	0.0132	0.0153	4.21	161	6
3.26	.463	6.72	2.95	0.78	0.022	0.0033	0.0075	0.0152	5.56	**122**	**4.9**
2.95	.403	6.08	3.15	0.81	0.010	0.0030	0.0031	0.0152	6.66	102	4.1
2.67	.352	5.50	3.32	0.83	0.000	0.0028	-0.0001	0.0153	7.47	91	3.6
2.40	.307	4.95	3.47	0.86	-0.009	0.0027	-0.0024	0.0154	8.06	**84**	**3.3**
2.20	.275	4.53	3.59	0.87	-0.015	0.0026	-0.0037	0.0156	8.38	81	3.2
2.00	.244	4.12	3.69	0.89	-0.020	0.0025	-0.0045	0.0159	8.58	79	3.2
1.35	.154	2.78	4.03	0.93	-0.028	0.0022	-0.0049	0.0175	8.56	**79**	**3.2**
1.20	.135	2.47	4.10	0.94	-0.028	0.0022	-0.0046	0.0182	8.41	81	3.2
1.10	.122	2.27	4.15	0.95	-0.028	0.0022	-0.0043	0.0187	8.28	82	3.3

Each color represents one momentum setting for MAD

E' = 4.05 GeV
E' = 3.00 GeV
E' = 2.20 GeV
E' = 1.25 GeV

Each momentum bin in the table corresponds to:

$\Delta\Theta$ = +/– 35 mrd
$\Delta\Phi$ = +/– 150 mrd
$\delta p/p$ = +/- 5%



11 GeV beam, 25 degrees
Count rate (Hz)
10^3
10^2
10
1
1000
1500
2000
2500
3000
3500
4000
W (MeV)
e−
π−

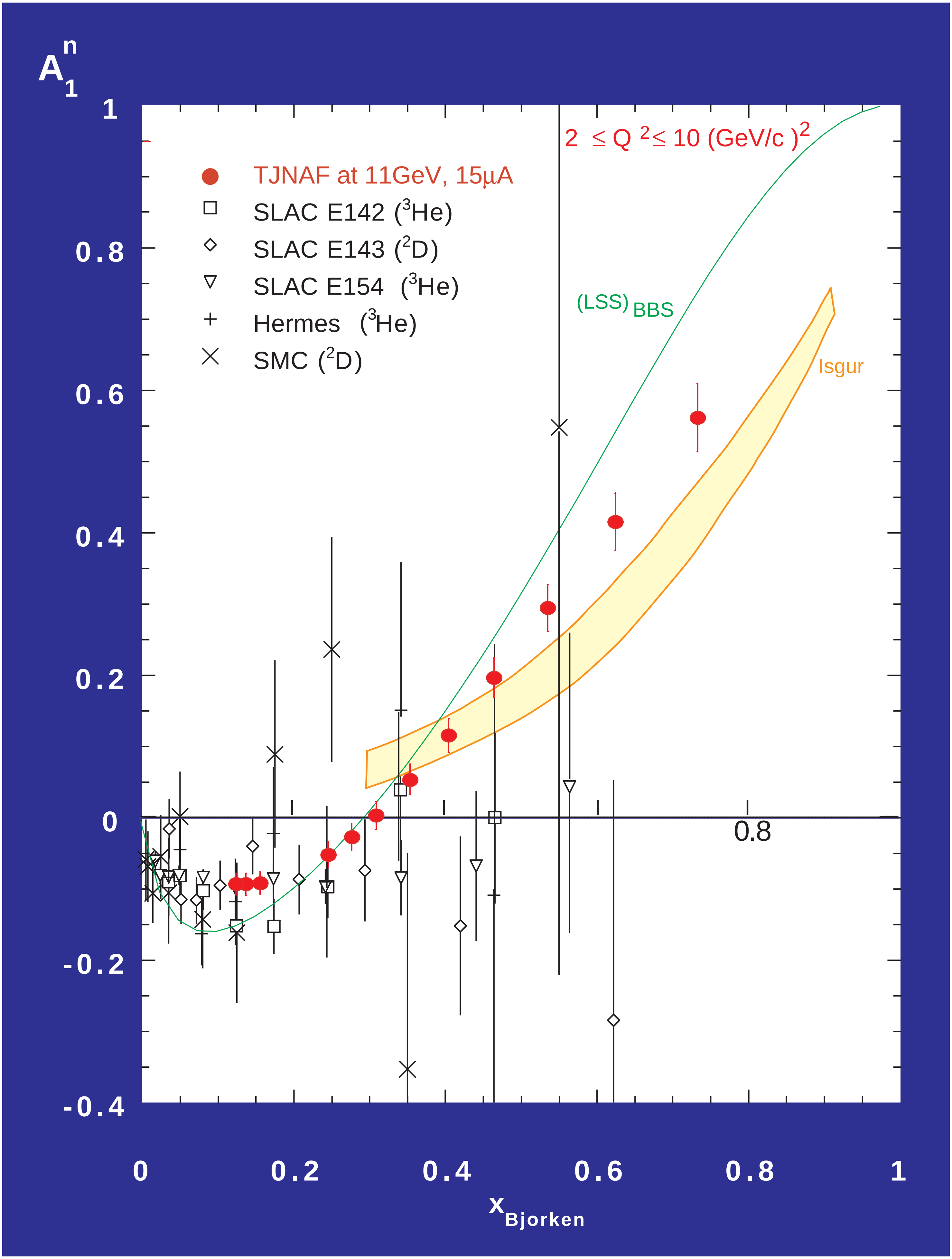
Total uncertainty of the neutron asymmetry A^n_1 extracted from that of ^{3}He

E_i = 11 GeV $\theta = 25^0$

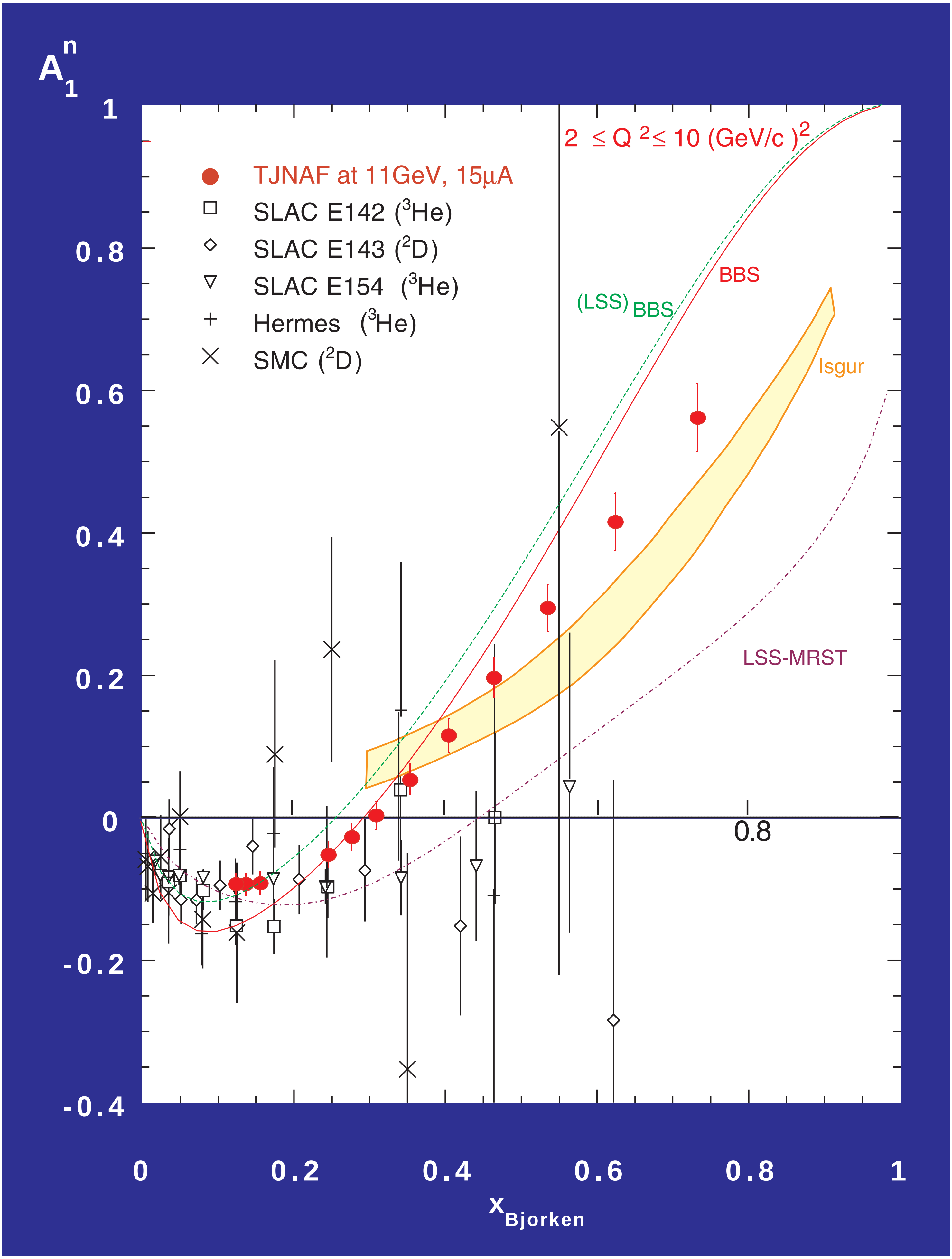
E' (GeV)	x	Q^2 $(GeV)^2$	W (GeV)	D	$A_1^{^3He}$	$\Delta A_1^{^3He}$ (stat.)	$\Delta A_1^{^3He}$ (syst.)	$\Delta A_1^{^3He}$ (total)	A_1^n	ΔA_1^n (total)
4.40	.732	9.07	2.05	0.67	0.072	0.0046	0.0042	0.0062	0.561	0.048
3.98	.623	8.20	2.42	0.71	0.050	0.0041	0.0029	0.0050	0.415	0.040
3.60	.534	7.42	2.71	0.75	0.036	0.0036	0.0021	0.0042	0.294	0.033
3.26	.463	6.72	2.95	0.78	0.022	0.0033	0.0013	0.0035	0.196	0.028
2.95	.403	6.08	3.15	0.81	0.010	0.0030	0.0058	0.0031	0.115	0.024
2.67	.352	5.50	3.32	0.83	0.000	0.0028	0.0021	0.0028	0.053	0.022
2.40	.307	4.95	3.47	0.86	-0.009	0.0027	0.0005	0.0027	0.002	0.020
2.20	.275	4.53	3.59	0.87	-0.015	0.0026	0.0009	0.0027	-0.028	0.019
2.00	.244	4.12	3.69	0.89	-0.020	0.0025	0.0012	0.0027	-0.053	0.018
1.35	.154	2.78	4.03	0.93	-0.028	0.0022	0.0016	0.0028	-0.093	0.016
1.20	.135	2.47	4.10	0.94	-0.028	0.0022	0.0016	0.0027	-0.094	0.016
1.10	.122	2.27	4.15	0.95	-0.028	0.0022	0.0016	0.0027	-0.094	0.015

Each color corresponds to a different momentum setting of the MAD spectrometer.

E' = 4.05 GeV
E' = 3.00 GeV
E' = 2.20 GeV
E' = 1.25 GeV



A_1^n
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
$2 \leq Q^2 \leq 10\ (GeV/c)^2$
TJNAF at 11GeV, 15µA
SLAC E142 (^{3}He)
SLAC E143 (^{2}D)
SLAC E154 (^{3}He)
Hermes (^{3}He)
SMC (^{2}D)
$(LSS)_{BBS}$
Isgur
0.8
0
0.2
0.4
0.6
0.8
1
$x_{Bjorken}$



A_1^n
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
$2 \le Q^2 \le 10$ (GeV/c)^2
TJNAF at 11GeV, 15μA
SLAC E142 (^{3}He)
SLAC E143 (^{2}D)
SLAC E154 (^{3}He)
Hermes (^{3}He)
SMC (^{2}D)
BBS
(LSS) BBS
Isgur
LSS-MRST
0.8
0
0.2
0.4
0.6
0.8
1
$x_{Bjorken}$

Conclusion

- Precision measurement of the deep inelastic asymmetry A^n_1 in the region $0.10 \leq x < 0.75$ and $2 \leq Q^2 \leq 10$ GeV^2
- 865 hours of beam on target for the 11 GeV beam energy measurement.
- A period of 2 months of beam on target should allow us to measure all energies incident beam energies leading to a Q^2 dependence and a W^2 dependence investigation.
- CEBAF at 11 GeV is the best place to perform this measurement. Further observables of great interest can be obtained at the same time. An example d_2^n, a quark-gluon correlation matrix element.

MEASURING g_2^n AT 11 GeV

- g_2 is one of the few clean places to measure higher twist effects which provide *direct* information about quark-gluon interactions.
- The leading twist contribution can be cleanly subtracted away using g_1 data.

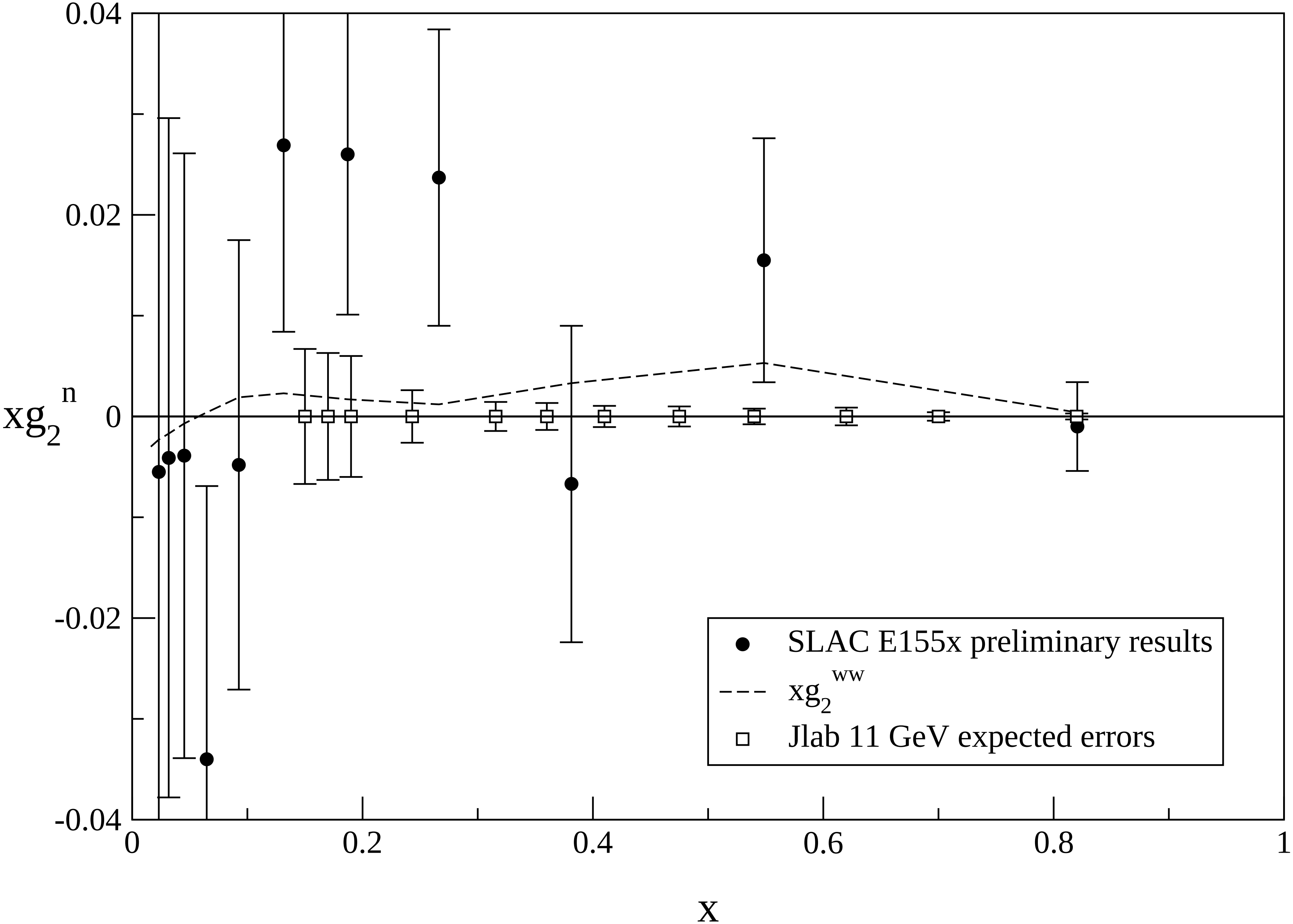
$$g_2(x,Q^2) = -\frac{F_1(x,Q^2)}{D'}\frac{\nu}{2E\sin\theta}\left[\sin\theta A_\parallel - \frac{E+E'\cos\theta}{E'}A_\perp\right]$$

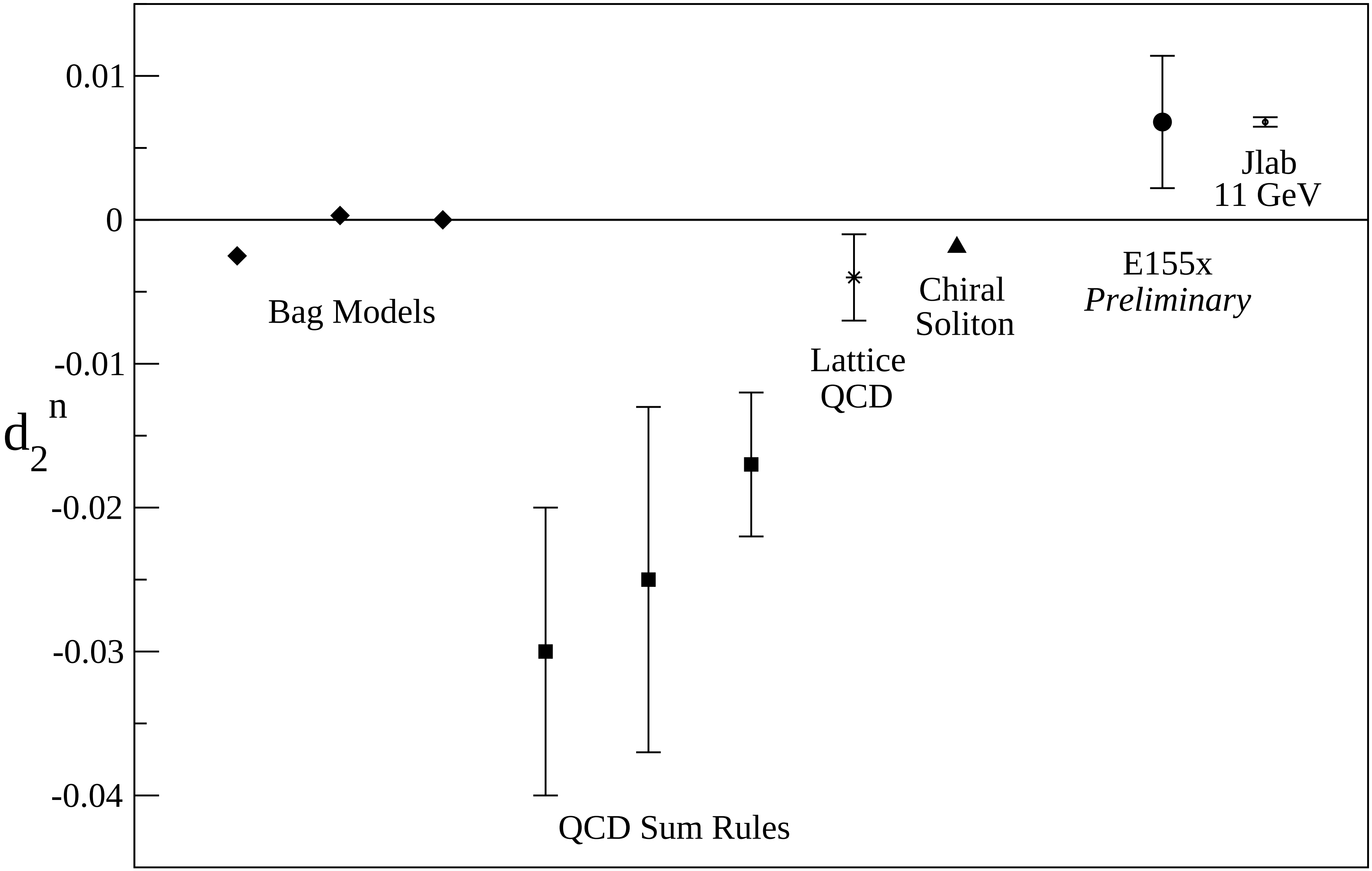
$$d_2^n(Q^2) = 2\int_0^1 x^2\left[g_1^n(x,Q^2)+\frac{3}{2}g_2^n(x,Q^2)\right]dx$$

- d_2^n is a twist-3 matrix element which is uniquely sensitive to quark-gluon correlations and can be related to the color electric and magnetic polarizabilities in the nucleon.

$$d_2 = (2\chi_B + \chi_E)/3$$

- This integral is dominated by the high-x region and is well-suited to JLab at 11 GeV.
- Can improve error on d_2^n by a factor of 10 in less than 1000 hours.


0.04
0.02
0
-0.02
-0.04
xg_2^n
0
0.2
0.4
0.6
0.8
1
x
SLAC E155x preliminary results
xg_2^{ww}
Jlab 11 GeV expected errors


0.01
0
-0.01
-0.02
-0.03
-0.04
d_2^n
Bag Models
QCD Sum Rules
Lattice QCD
Chiral Soliton
E155x *Preliminary*
Jlab 11 GeV