Spin Structure at High x

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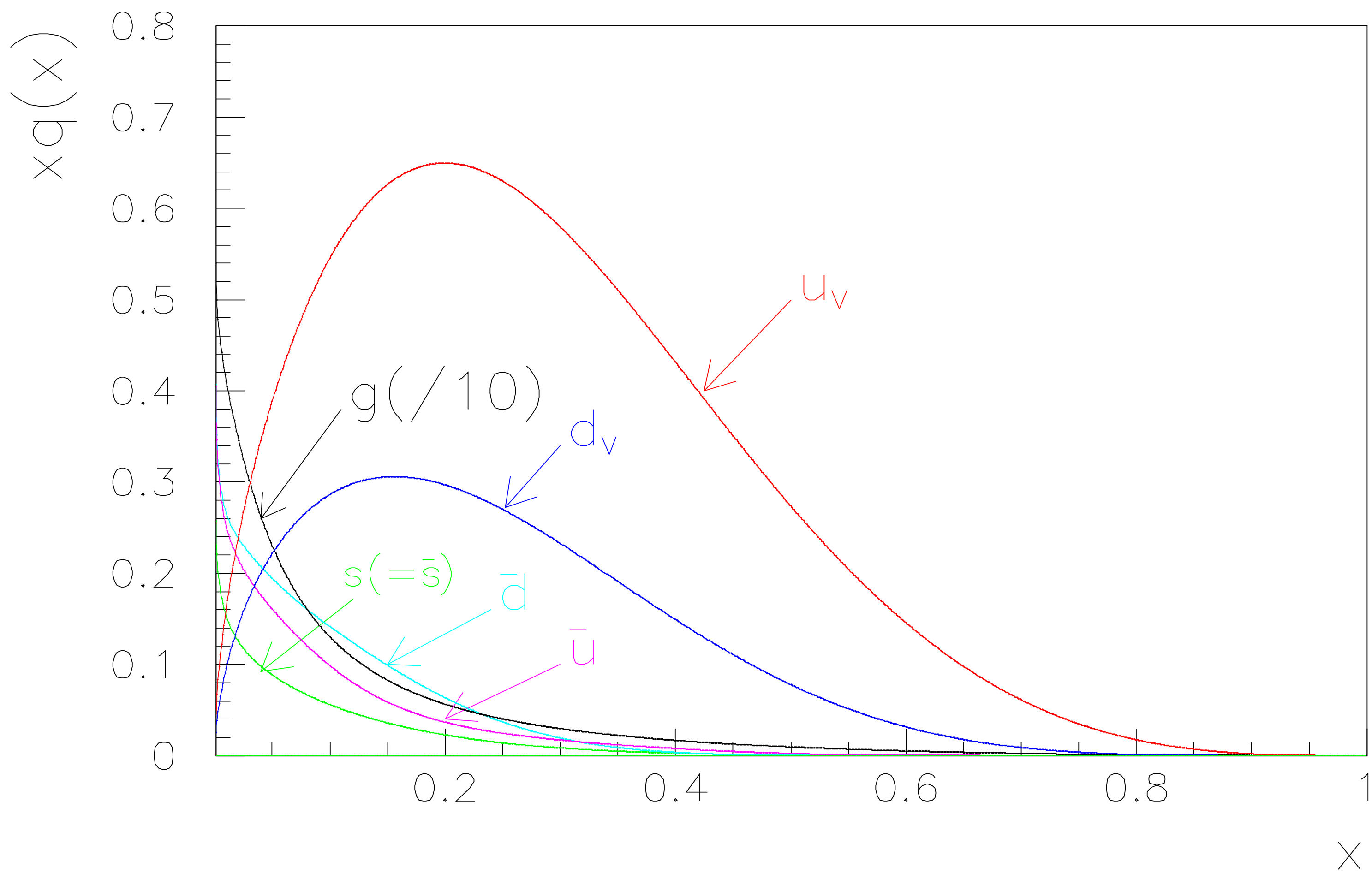
For the JLab Hall A, E99-117, E97-103 and CLAS Collaborations

DIS2005, Madison, April, 2005

- Introduction
- Valence quark neutron spin structure: A_1^n at high x
- Spin-flavor decomposition: $\Delta u/u$ and $\Delta d/d$
- Other neutron results: A_2^n, g_1^n, g_2^n, and d_2^n
- Preliminary A_1^p and A_1^d results
- Precision measurement of g_2^n and higher twist effects
- Summary

Unpolarized Parton Distributions (CTEQ6)

- After 40 years DIS experiments, unpolarized structure of the nucleon reasonably well understood.
- High x → valence quark dominating



Polarized Parton Distributions (BB)

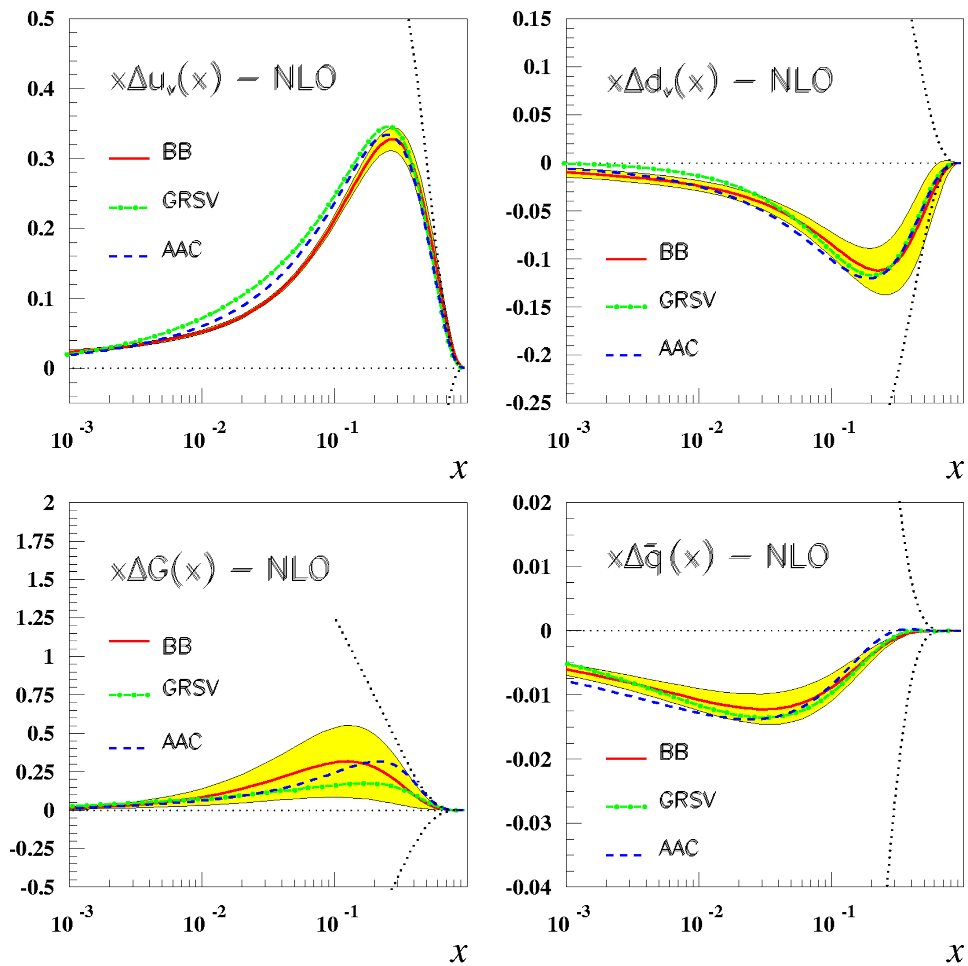


Figure 4: NLO polarized parton distributions at the input scale $Q_0^2 = 4.0\ \mathrm{GeV}^2$, `ISET=4`, (solid line) compared to results obtained by GRSV (dashed–dotted line) [16] and AAC (dashed line) [15]. The shaded areas represent the fully correlated 1σ error bands calculated by Gaussian error propagation. The dark dotted lines indicate the positivity bound if reference is taken to the distributions [27].

Valence Quark Spin Structure

A_1 at high x

Predictions for large x_{Bj}

Proton Wavefunction (Spin and Flavor Symmetric)

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

Nucleon Model	F_2^n/F_2^p	d/u	Δu/u	Δd/d	A_1^n	A_1^p
SU(6)	2/3	1/2	2/3	-1/3	0	5/9
Valence Quark	1/4	0	1	-1/3	1	1
pQCD	3/7	1/5	1	1	1	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	$\frac{\Delta u}{u}$ --->2/3	$\frac{\Delta d}{d}$ --->-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 d/u=0	+1 $\frac{\Delta u}{u}$ --->1	+1 $\frac{\Delta d}{d}$ --->-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)346	3/7 d/u=1/5	+1 $\frac{\Delta u}{u}$ --->1	+1 $\frac{\Delta d}{d}$ --->1
Instantons! N. Kochelev, hep-ph/9711226			~0

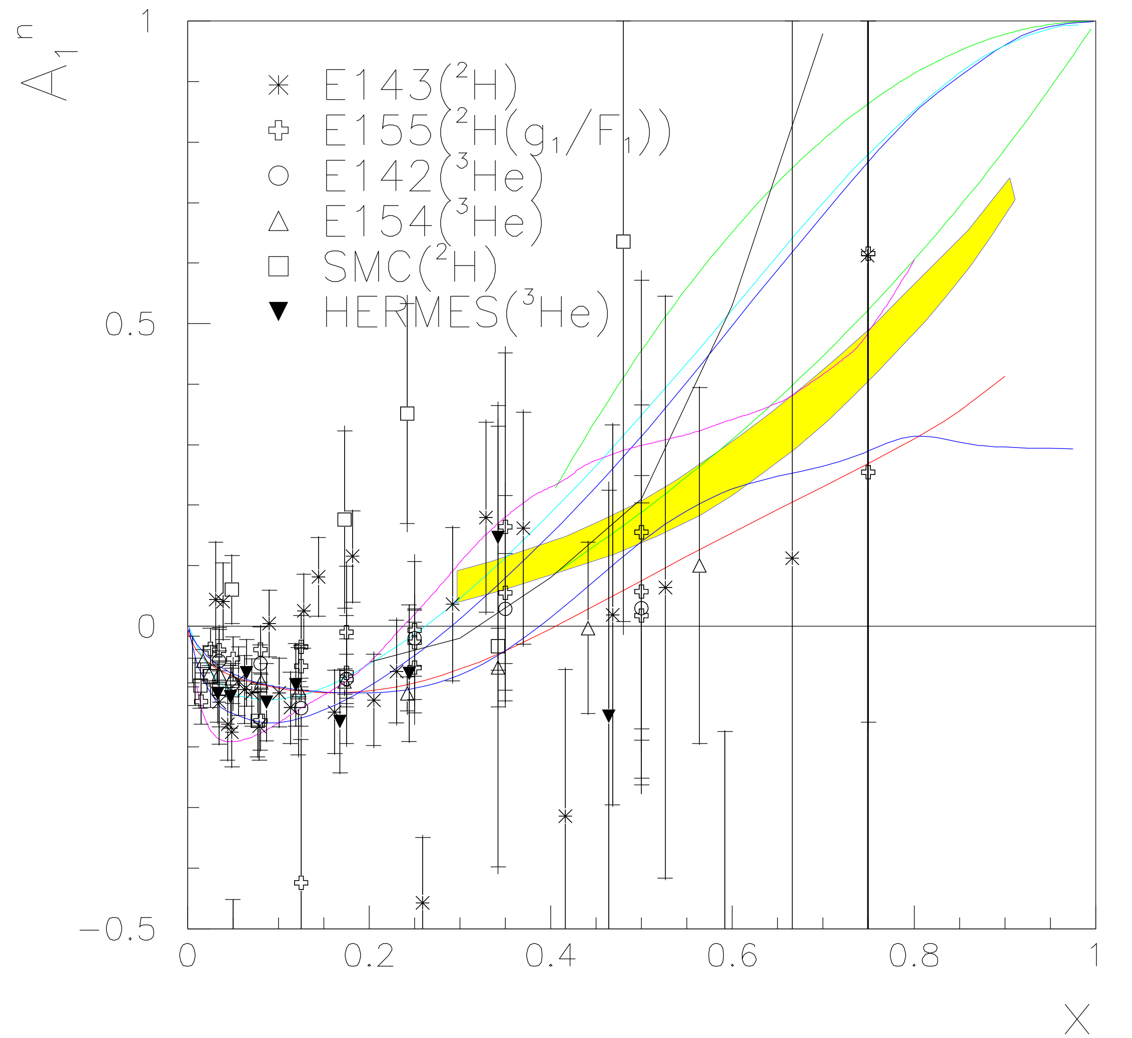
World Data on A_1^n and Models

- SU(6): $A_1^n=0$
- Valence quark models
- pQCD assuming HHC

(hadron helicity conservation)

- PDF fits (LSS)
- Statistical model
- Chiral Soliton model
- Local duality model
- Cloudy bag model

Need precision data at high x

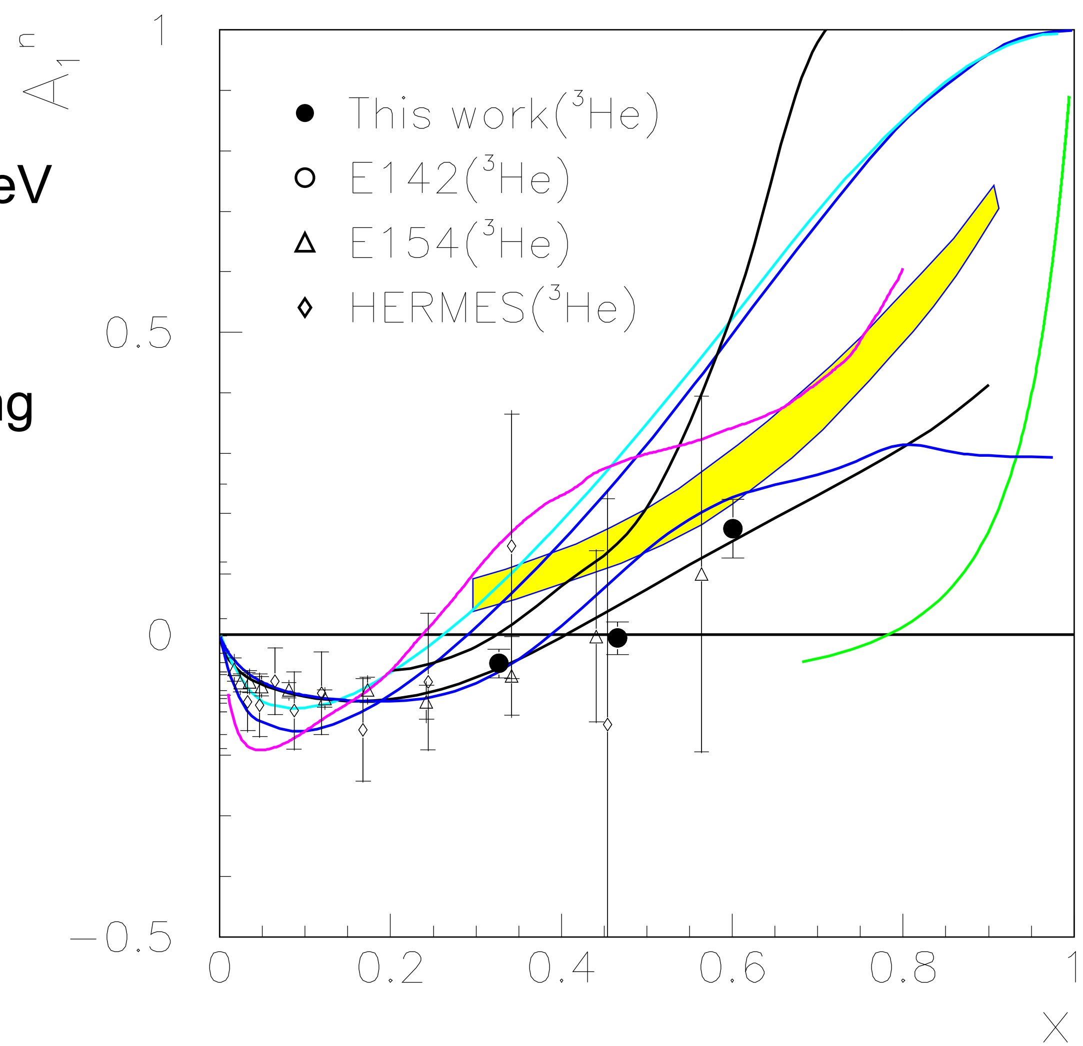


JLab E99-117

Precision Measurement of A_1^n at Large x

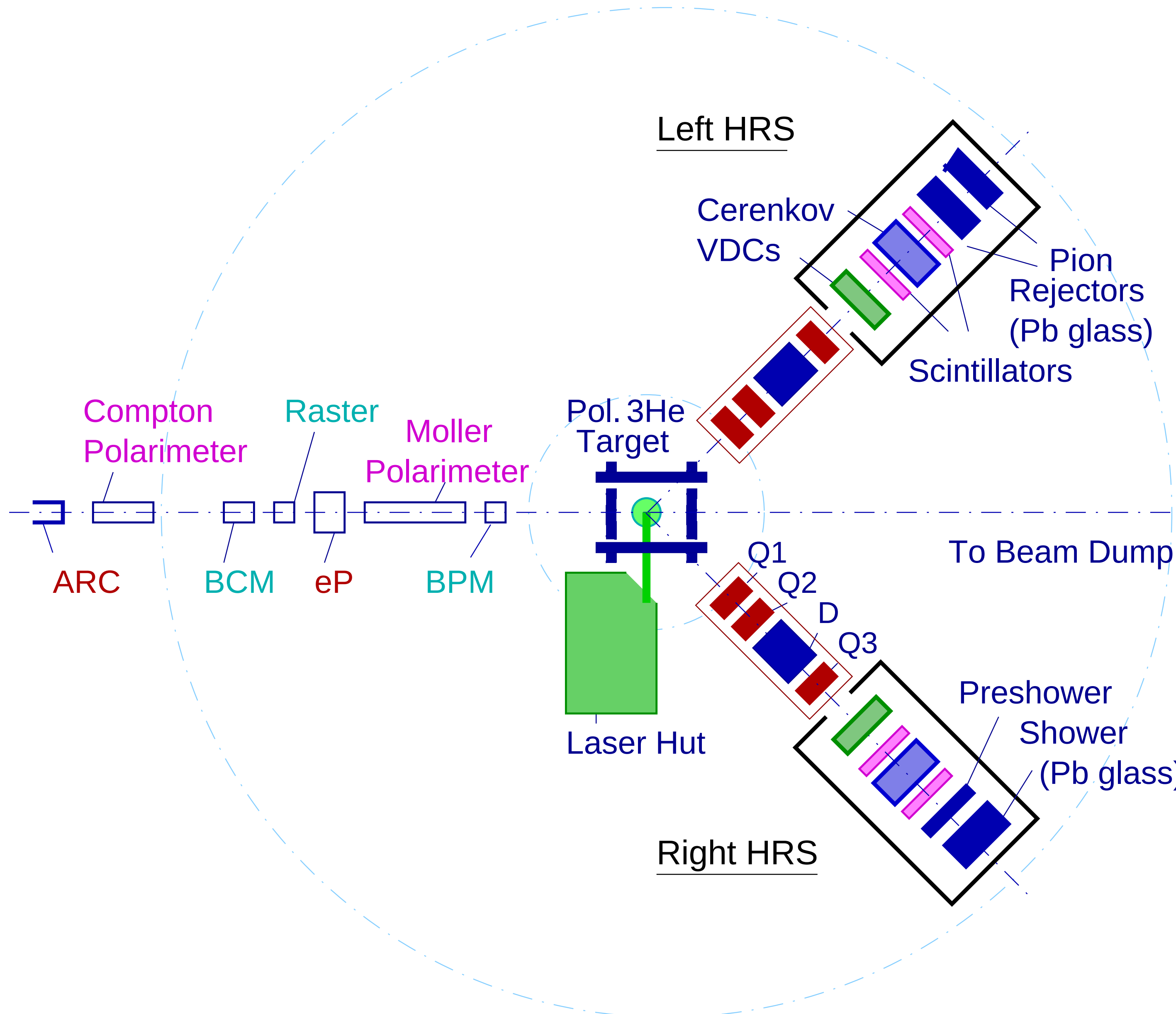
Spokespersons: J. P. Chen, Z. -E. Meziani, P. Souder, PhD Student: X. Zheng

- Precision A_1^n data at high x
  $2.7 GeV^2 < Q^2 < 4.8 GeV^2, W > 2 GeV$
- Extracting valence quark spin distributions
- Test our fundamental understanding of valence quark picture
  - SU(6) symmetry
  - Valence quark models
  - pQCD (with HHC) predictions
  - Other models: Statistical Model, Chiral Soliton Model, PDF fits, ….
- Quark orbital angular momentum
- Crucial input for pQCD fit to PDF



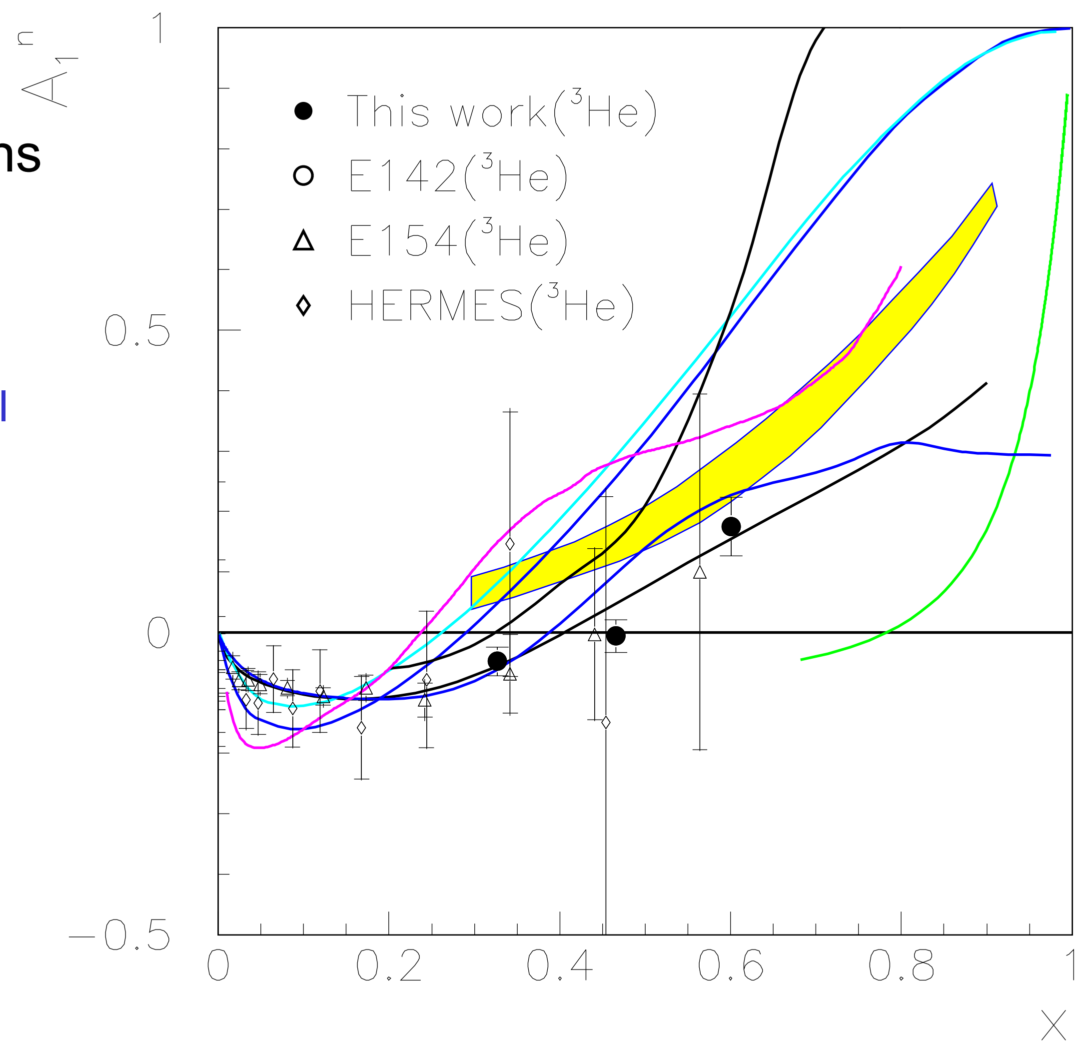
E99-117 Setup at JLab Hall A

5.7 GeV, 80% pc
electron beam
on 40% polarize
^{3}He target
Luminosity~10^{36}



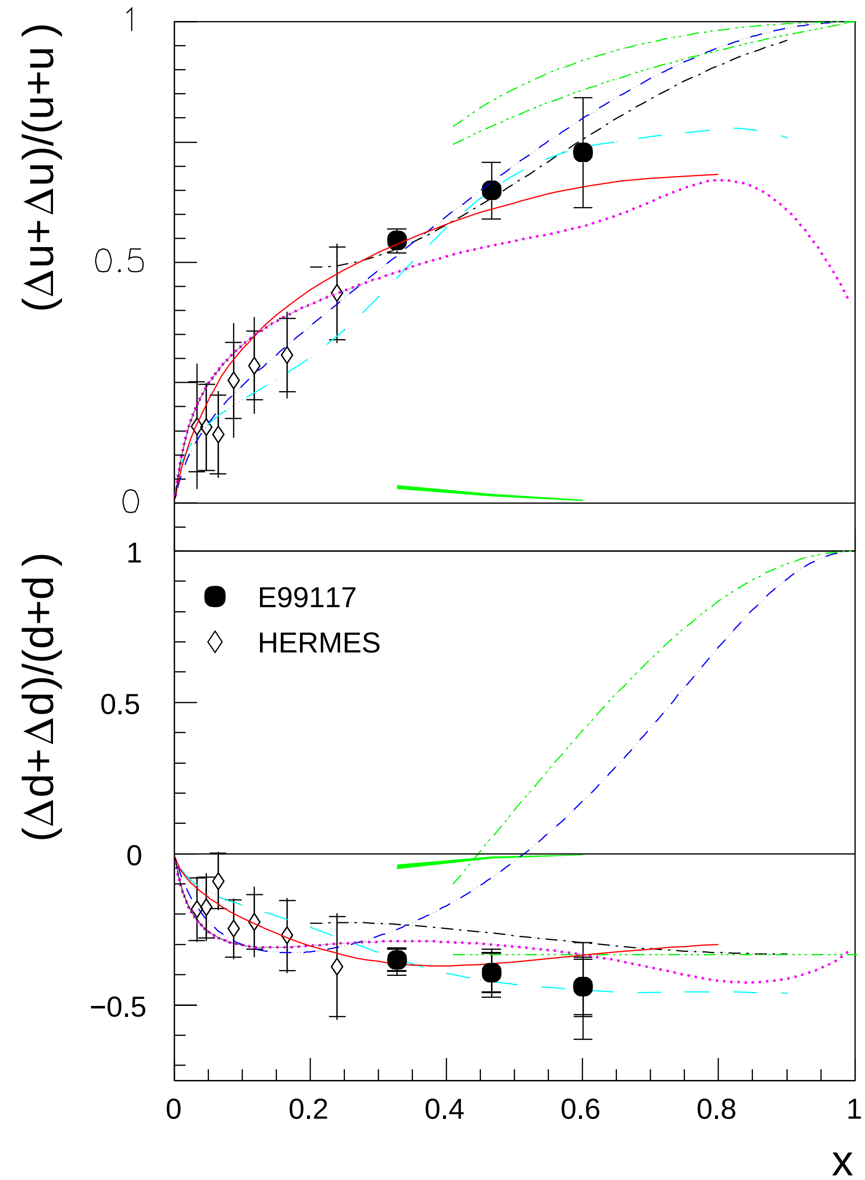
E99-117 A_1^n Results

- First precision A_1^n data at $x > 0.3$
- Comparison with model calculations
  - SU(6) symmetry
  - Valence quark models
  - pQCD (with HHC) predictions
  - Other models: Statistical model, Chiral Soliton model, PDF fits, …
- Crucial input for pQCD fit to PDF
- PRL 92, 012004 (2004)



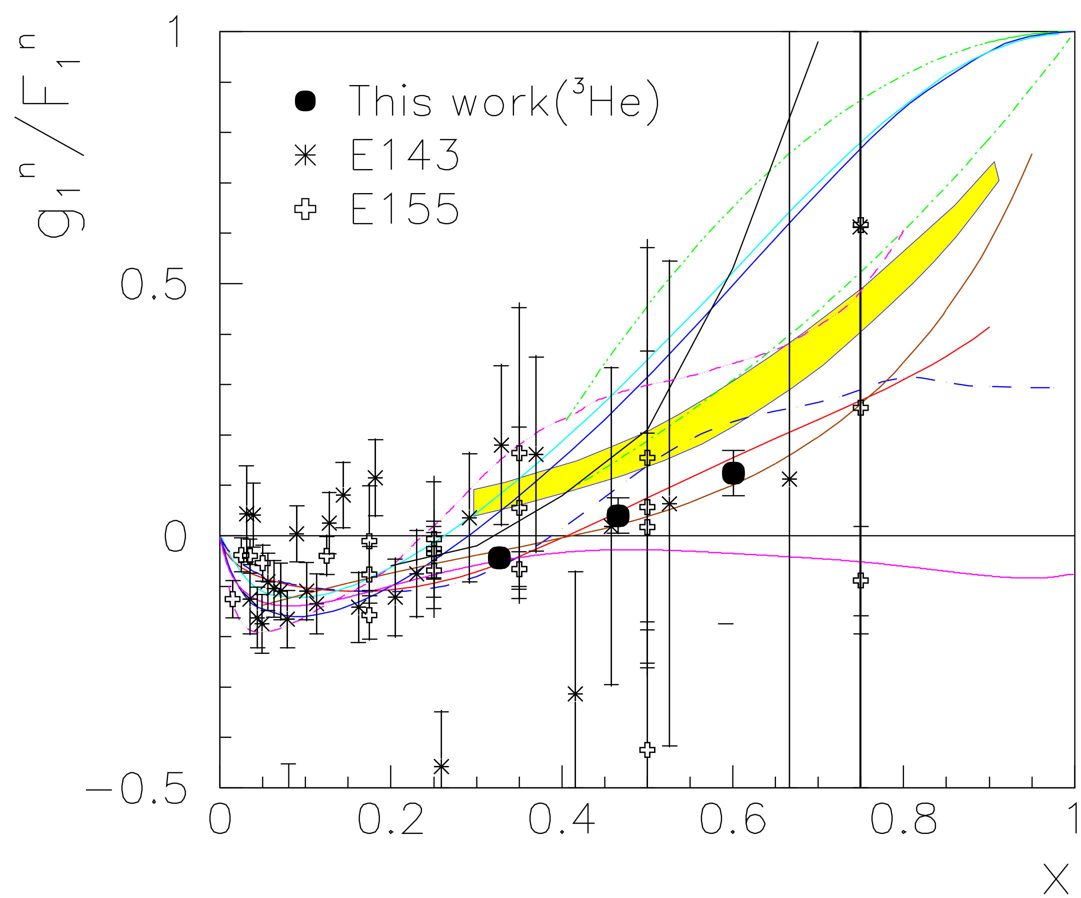
Polarized Quark Distributions

- Combining A_1^n and A_1^p results
- Valence quark dominating at high x
- u quark spin as expected
- d quark spin stays negative!
  - Disagree with pQCD model calculations assuming HHC (hadron helicity conservation)
  - Quark orbital angular momentum
- Consistent with valence quark models, statistical model or pQCD PDF fits



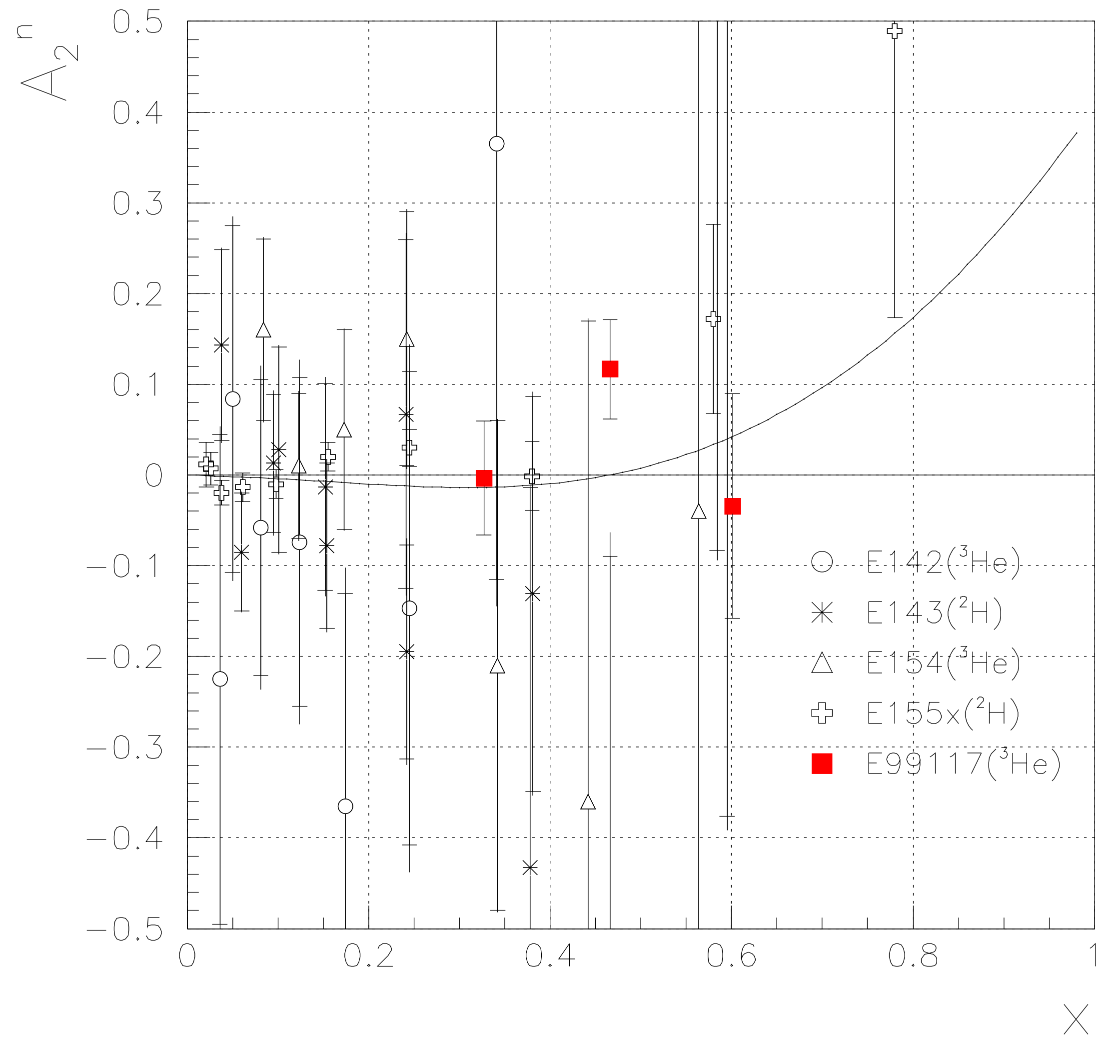
Comparison with models

- Chiral Soliton Models
- G.A. Miller's model with *quark orbital angular momentum*, which gives an explanation to the proton G_E^p/G_M^p results.
- pQCD: factorization at large x, NLO, Resummation, …?

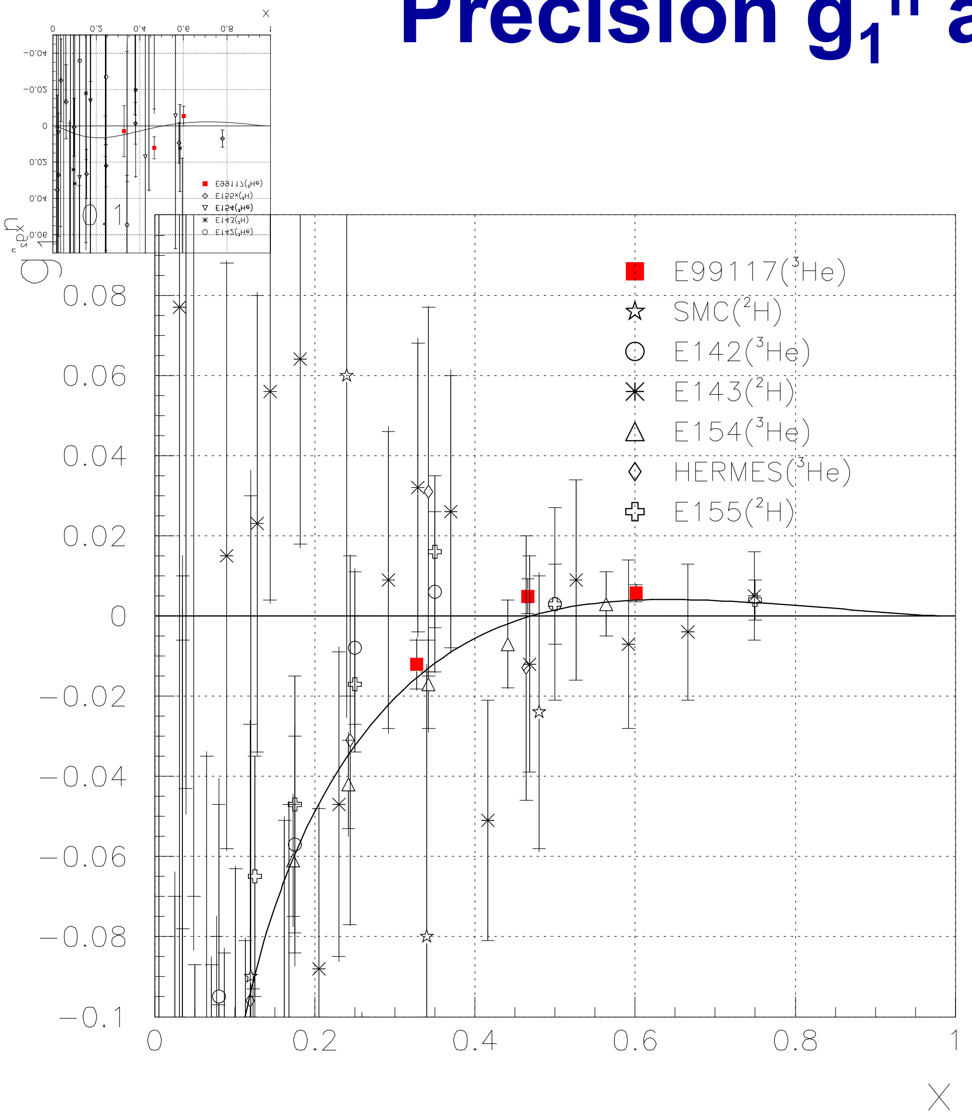


A_2^n results

- By-product
- Precision better than the world best results
- Also g_1^n and g_2^n results
- Improved d_2^n precision by a factor of 2:
  $d_2^n = 0.0062 \pm 0.0028$
- PRC 70, 065207 (2004)



Precision g_1^n and g_2^n results



Discussion

- Precision data of A_1^n and g_1^n at high x:

  A_1^n positive above x=0.5
- Extracted $\Delta u/u$ and $\Delta d/d$: $\Delta d/d$ stays negative!
- Disagree with leading order pQCD model (HHC)

  Quark orbital angular momentum important
- g_1^n, g_2^n, A_2^n data
- Extracted d_2^n, a factor of 2 improvement

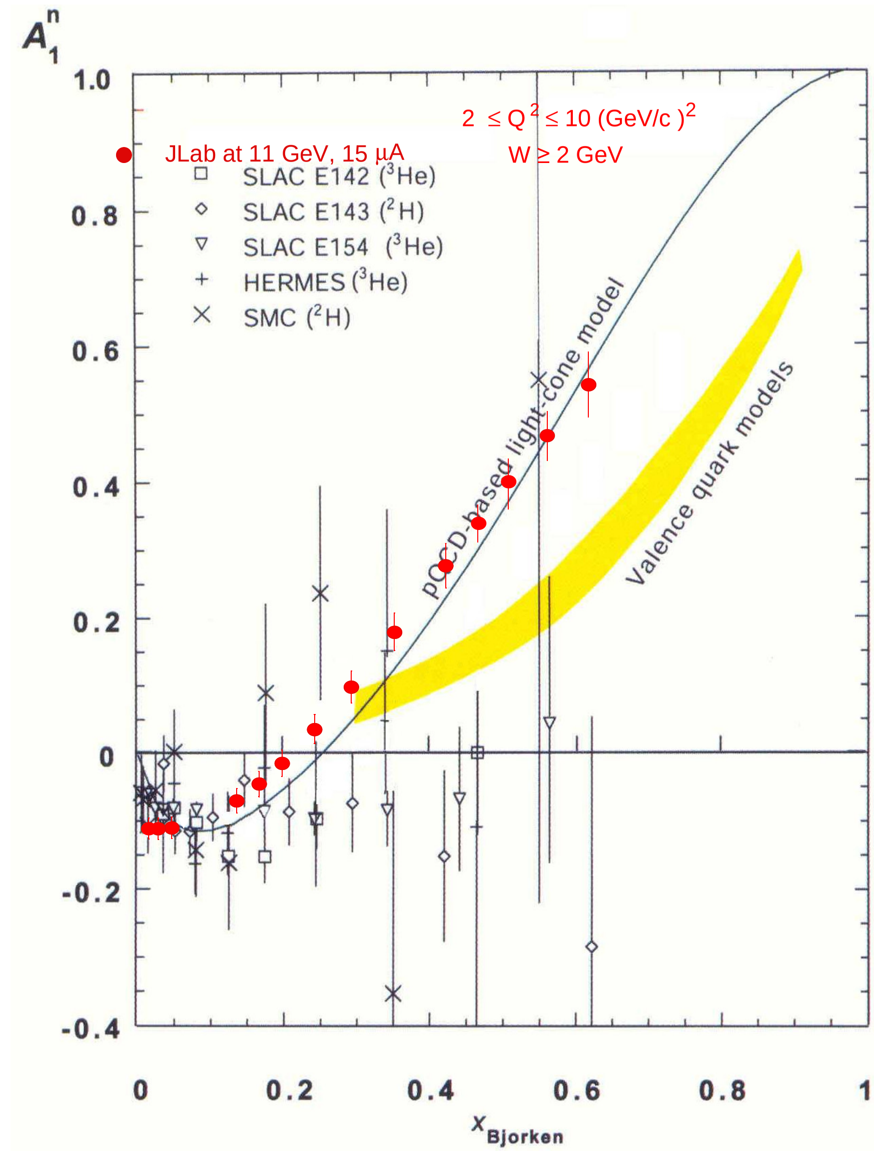
Results published in PRL 92, 012004 (2004), PRC 70, 065207(2004)
and in the news:

AIP Physics News Update, Physics Today Update,
Science online (Science Now), Science News,
DNP web featured article

A_1 with 12 GeV Upgrade

One of the flagship experiments:

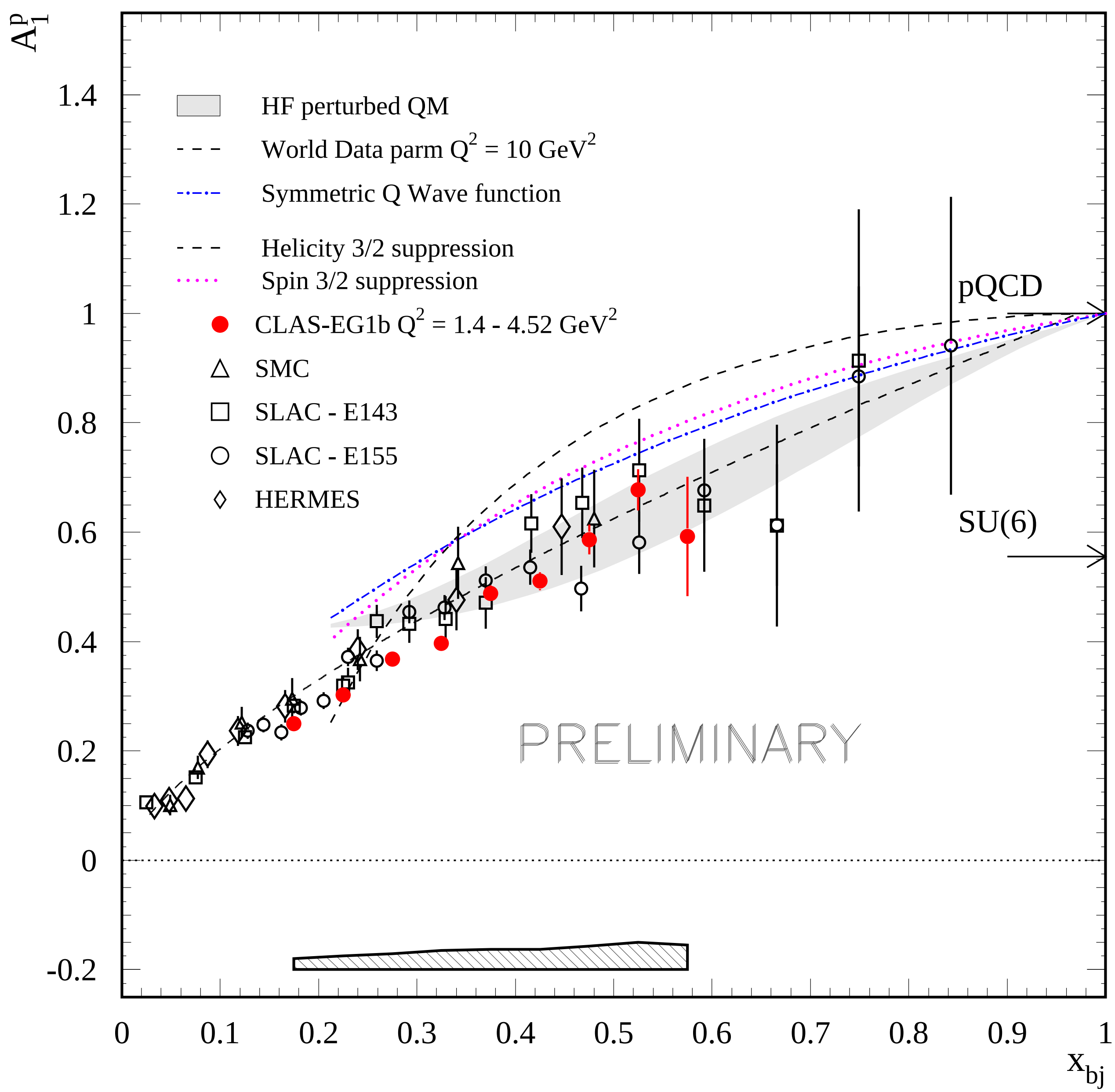
complete a chapter on the valence quark structure



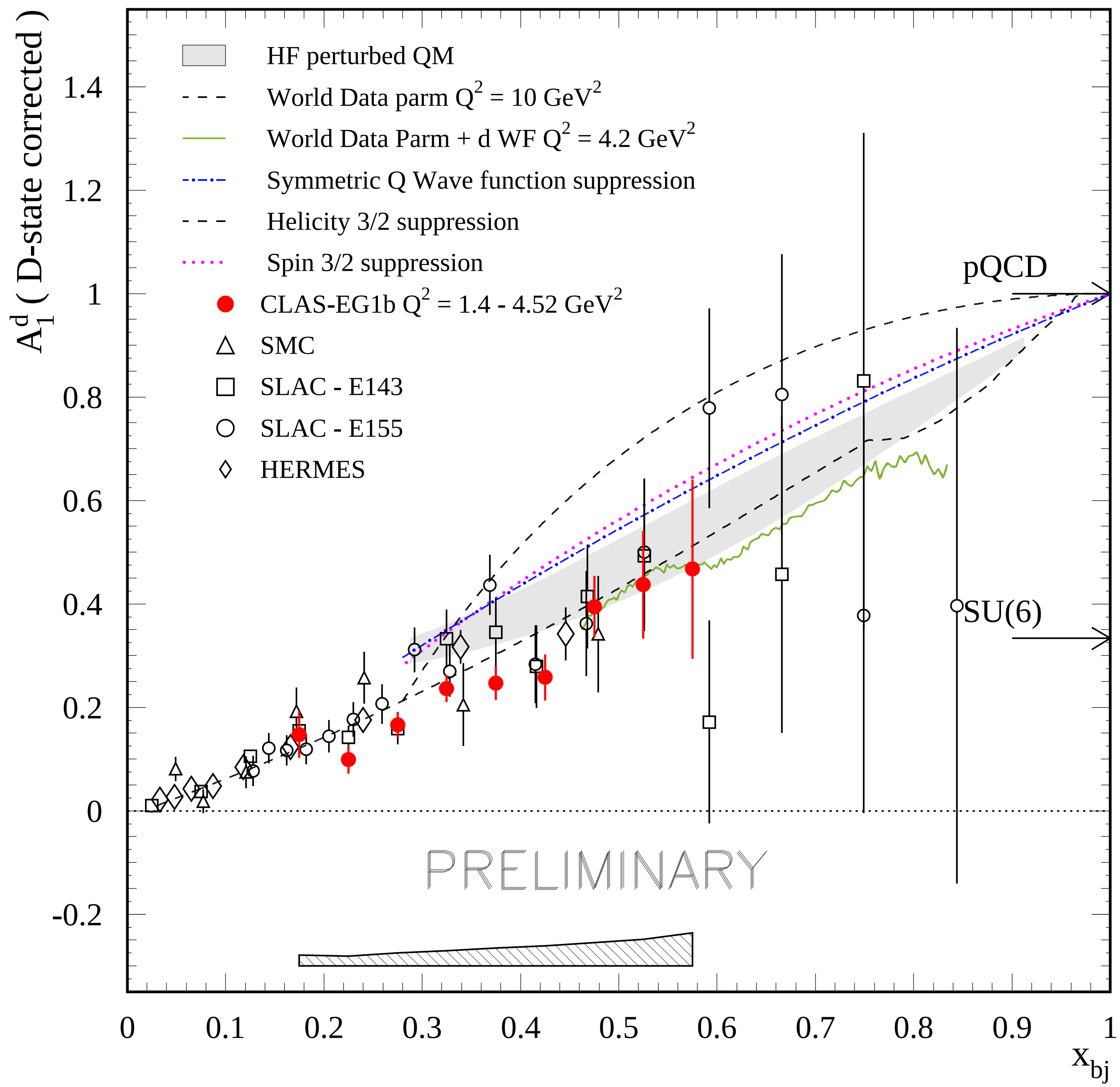
A_1^p, A_1^d at high x

Preliminary results from
JLab CLAS (S. Kuhn, *et al.*)

Preliminary CLAS A_1^p results: W>2



Preliminary CLAS A_1^d results: W>2



Precision measurement of g_2^n

Higher twist effects:
quark-gluon correlations

Quark-Gluon Correlations

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

- In simple partonic picture $g_2(x)=0$
- Wandzura and Wilczek have shown that g_2 can be written in two parts:
  - twist-2 contributions given by g_1
  - the other originating from quark-gluon correlations (twist-3)

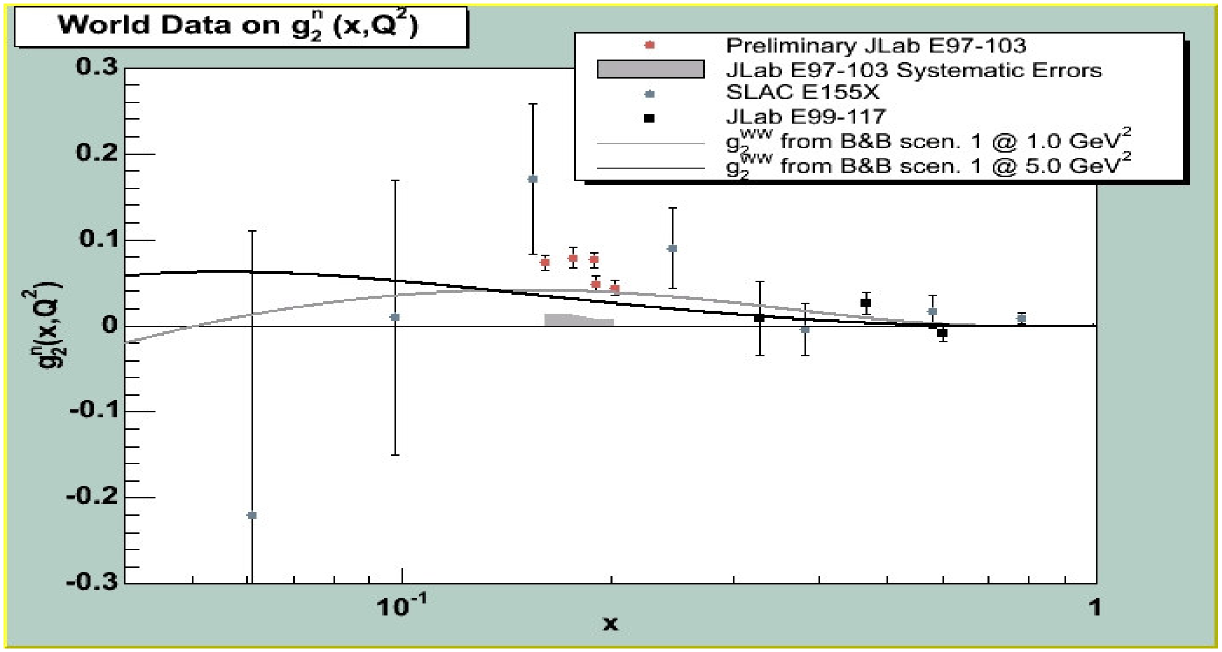
Twist–2 Twist–3

$$d_2^n(Q^2) = \int_0^1 x^2 \left[2g_1^n(x,Q^2) + 3g_2^n(x,Q^2)\right]dx \qquad d_2 = (2\chi_B + \chi_E)/3$$

Jefferson Lab Hall A Experiment E97-103

Precision Measurement of the Neutron Spin Structure Function $g_2^n(x,Q^2)$:
A Search for Higher Twist Effects

T. Averett, W. Korsch (spokespersons)   K. Kramer (Ph.D. student)



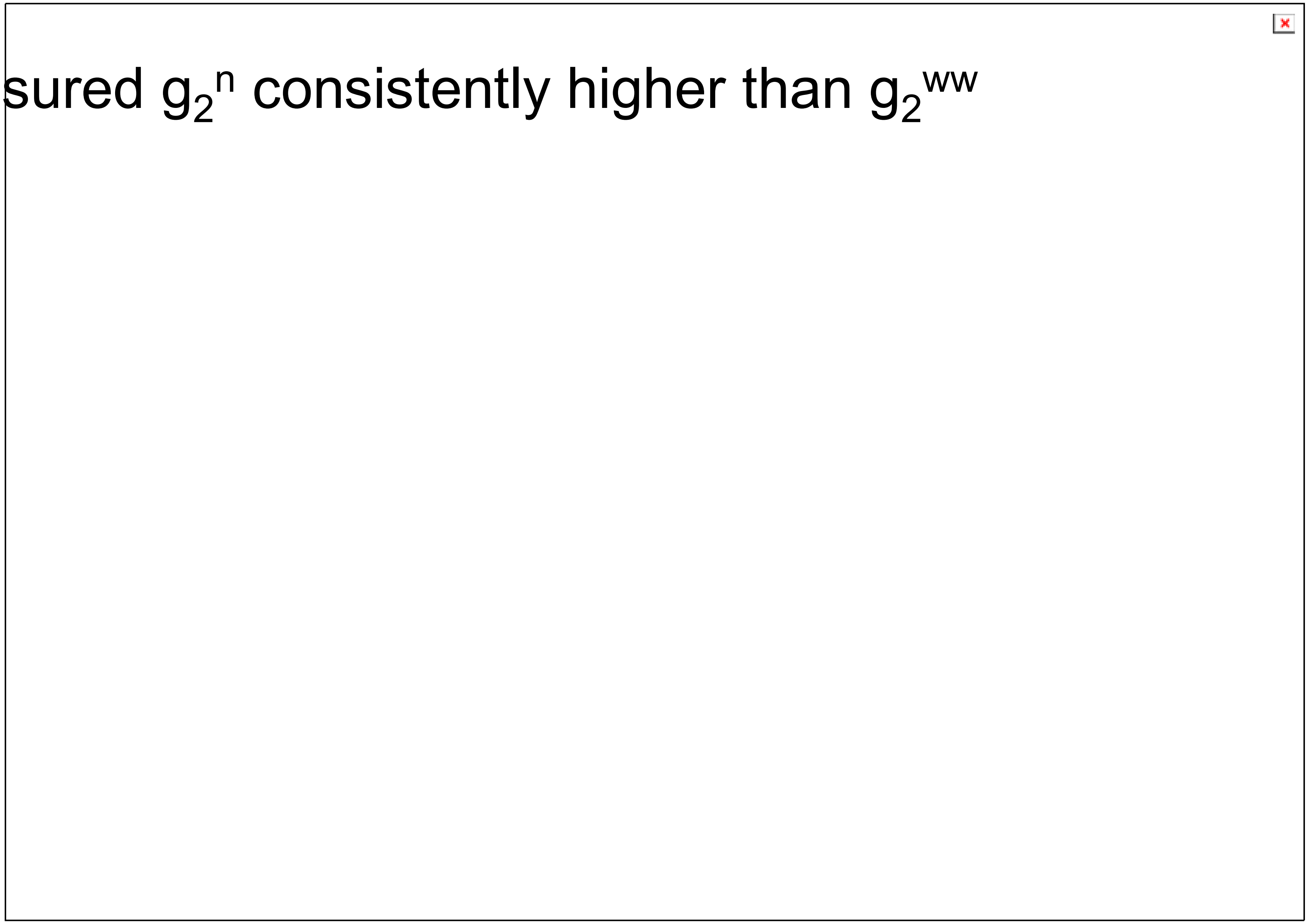
- Precision g_2^n, $0.57 < Q^2 < 1.34$ GeV^2, W > 2 GeV, at $x \sim 0.2$.
- Direct comparison to *twist-2* g_2^{WW} prediction using world g_1^n data.
- Quantitative measurement of higher twist effects provides information on nucleon structure beyond simple parton model (e.g. quark-gluon correlations).

E97-103 Results: g_2^n vs. x

Improved precision of g_2^n by an order of magnitude

E97-103 results: g_2^n vs. Q^2

- Measured g_2^n consistently higher than g_2^{ww}



E97-103 results: g_1^n

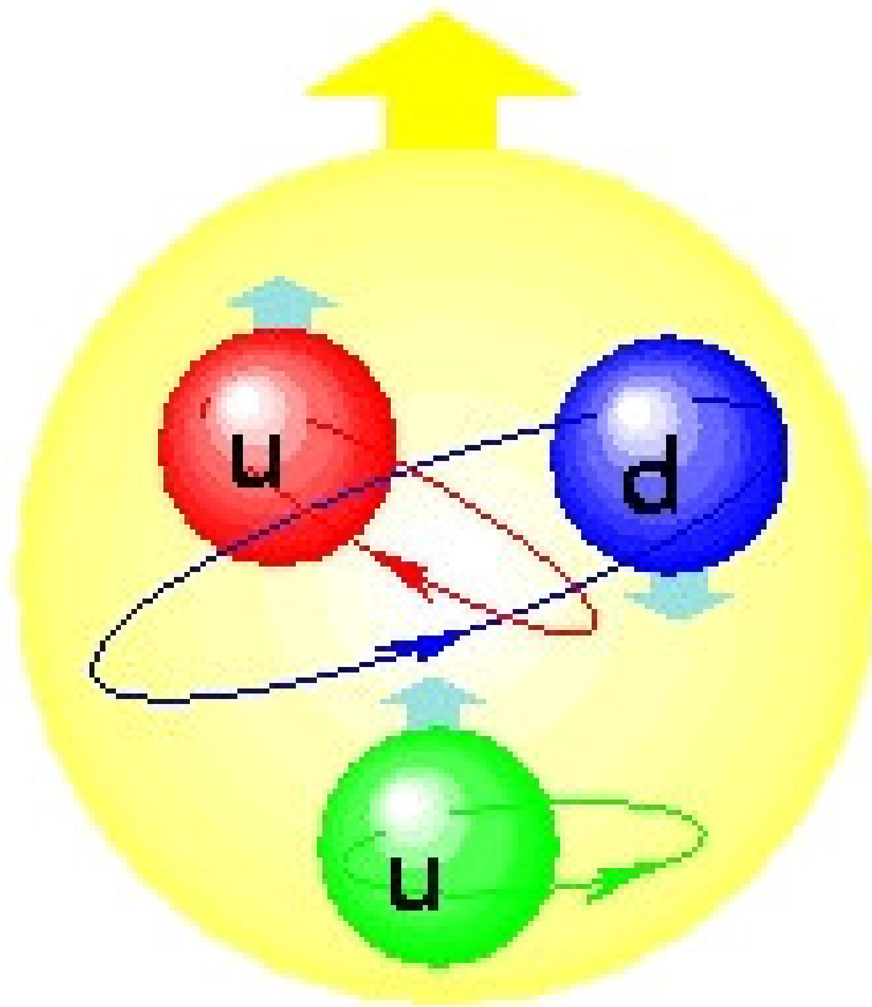
- Agree with NLO fit to world data, evolved to our Q^2

Summary

- Precision spin structure data at high x from JLab
  - Valence quark neutron spin structure
    - A_1^n at high x, an order of magnitude improvement:
    - Crucial input to fundamental understanding of valence quark picture: first time clearly goes positive
    - Valence spin-flavor decomposition: $\Delta u/u$, $\Delta d/d$
    - Disagreement with pQCD (HHC) → Quark OAM important
    - A_2^n, g_1^n, g_2^n
    - d_2^n: a factor of 2 improvement
  - Proton/deuteron results: A_1^p and A_1^d
- Precision measurement of g_2^n at low Q^2
  - An order of magnitude improvement in precision
  - g_2^n consistently higher than g_2^{WW}
  - Higher twist effects: quark-gluon correlations

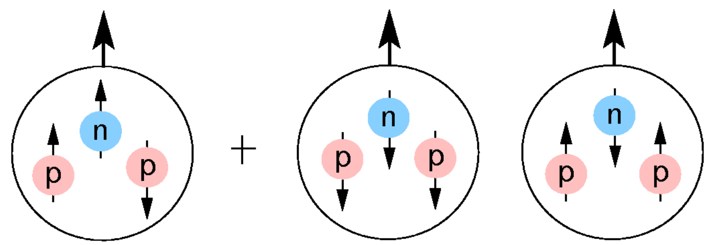
A_1^n and $\Delta u/u$, $\Delta d/d$ results in the news

- Physics News Update, 12/18/2003
  'Bringing the Nucleon into Sharper Focus'
- Science Now , 12/23/2003
  'Quarks in a Surprising Spin'
- Science News, 1/3/2004
  'Topsy Turvy'
- Physics Today Update, 2/2004
  'Spinning the Nucleon into Sharper Focus'
- APS-DNP current research topic, 5/5/2004
  'The Spin Structure of the Nucleon in the Valence Quark Region'



From ^{3}He to Neutron

POLARIZED ^{3}HE AS AN EFFECTIVE NEUTRON TARGET



S state (~88.2%) + D state (~9.8%) + S' state (~1.4%)

Effective nucleon polarizations:

$$P_n = 86\%,\ P_p = -2.8\%$$

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

Effective Neutron Target

From ^{3}He to Neutron (cont.)

CONVOLUTION APPROACH

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

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

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

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

COMPLETE ANALYSIS

F. Bissey et. al., hep-ph/0109069

- S, S', D, Δ isobar in ^{3}He wavefuntion

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