New Results on Testing Duality in Spin Structure from Jefferson lab

Nilanga Liyanage
University of Virginia
For Jefferson Lab Hall A, CLAS and RSS Collaborations

- DoF in the QCD Lagrangian are current quarks and gluons
- But the DoF observed in nature are Hadrons
- To understand hadron structure in QCD -in the confinement region -

  vital to understand the transition from partonic DoF to Hadronic DoF

Important clues from Quark-Hadron duality

Parton-Hadron duality

Scaling curve seen at high Q^2 is an accurate average over the resonance bumps at lower Q^2.

- First observed by Bloom and Gilman at SLAC in the 70's on the spin independent structure function F_2

E.D. Bloom and F.J. Gilman, Phys. Rev. D 4, 2901 (1971)

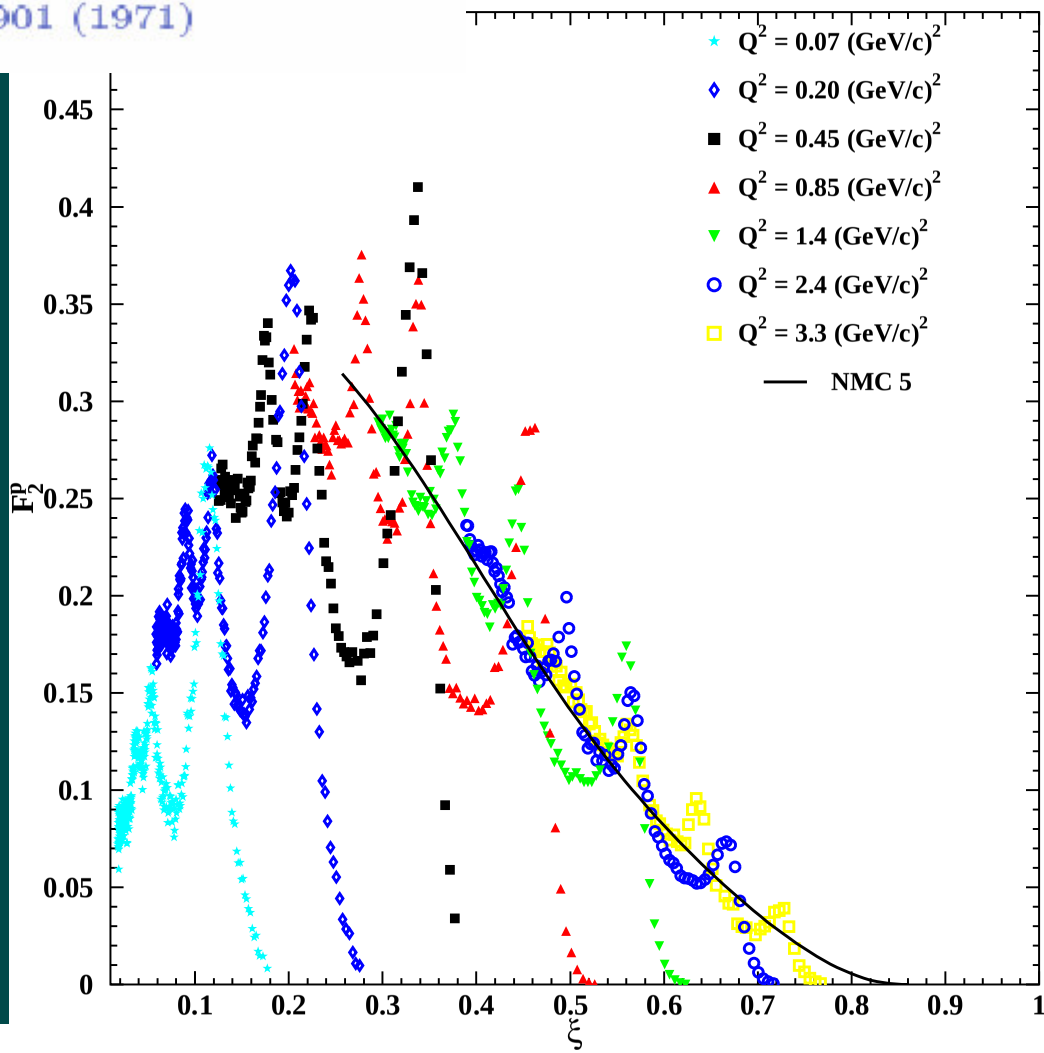
$$\xi = 2x/(1+\sqrt{1+4M^2x^2/Q^2})$$

I. Niculescu *et al.*

$$I(Res/DIS) = \frac{\int_{\xi_{min}}^{\xi_{max}} \nu W_2(\xi) d\,\xi}{\int_{\xi_{min}}^{\xi_{max}} F_2(\xi) d\,\xi}$$

I(Res/DIS) =1 to better than 5% for ***Q^2 >1 GeV^2***!

I. Niculescu *et al*, PRL, 86,Feb 2001



Duality in QCD

De Rujula, H Georgi, H. D. Politzer ('77) reinterpreted duality within QCD using OPE of moments

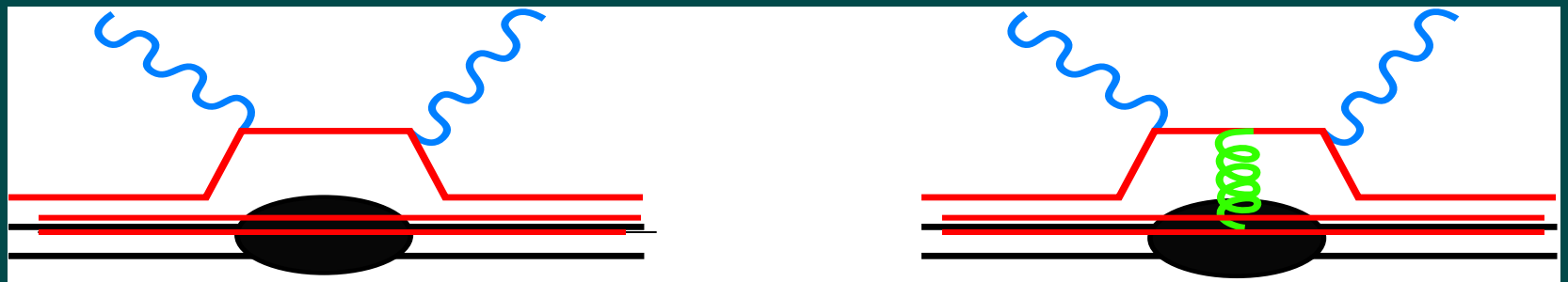
$$M_n(Q^2) = A_n^{(0)} + \frac{A_n^{(2)}}{Q^2} + \frac{A_n^{(4)}}{Q^4} + \ldots\ldots$$

- Leading terms ⇒ free quark scattering ⇒ scaling
- $1/Q^2$ terms ⇒ interactions between quarks and gluons

Not much Q^2 dep. Down to low Q^2

Higher twist terms are small or cancel each other

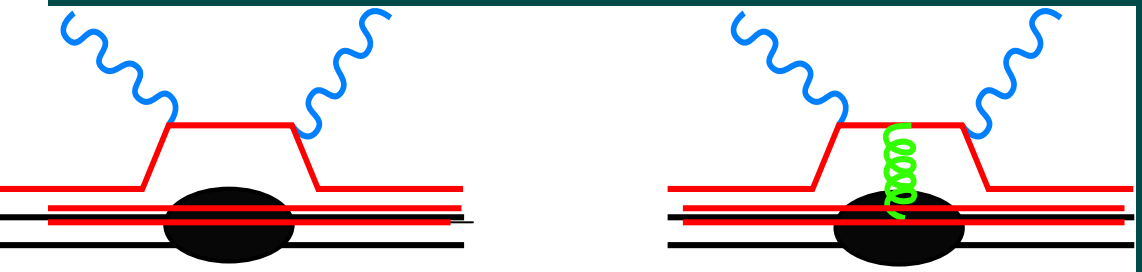
Why ?



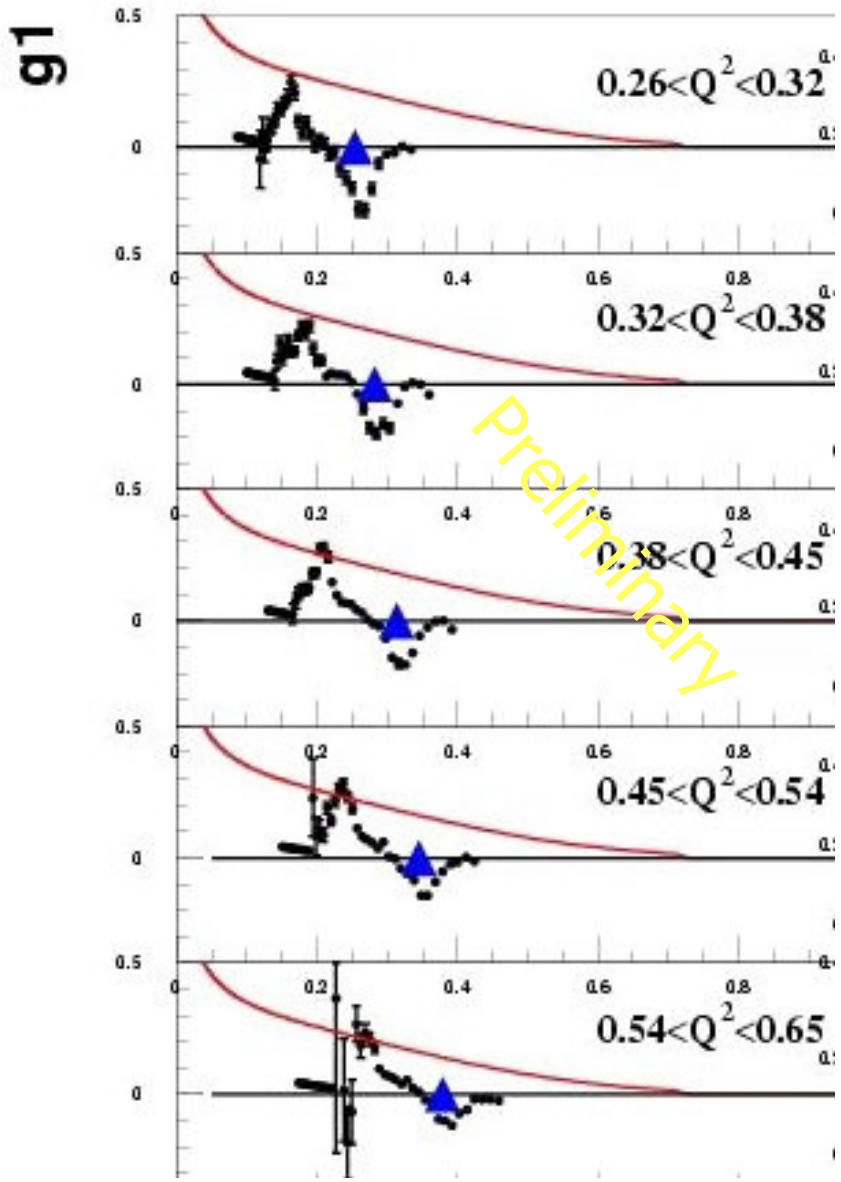
Twist–2 Twist–3

Duality in polarized structure functions

- Polarized structure functions come from cross section differences
- quark-quark interactions can change the sign of SSF
- Does duality still hold.
- Ex. g1p for Δ at low Q^2
  - spin 3/2 state
  - g1p negative at low Q^2
- No duality here !
- When do polarized SF start showing duality ?



Jefferson Lab Hall B (CLAS) Data for g1p
Y. Pork Ph.D thesis UVa



Was duality seen in F^2_p an accident or a global phenomena ?

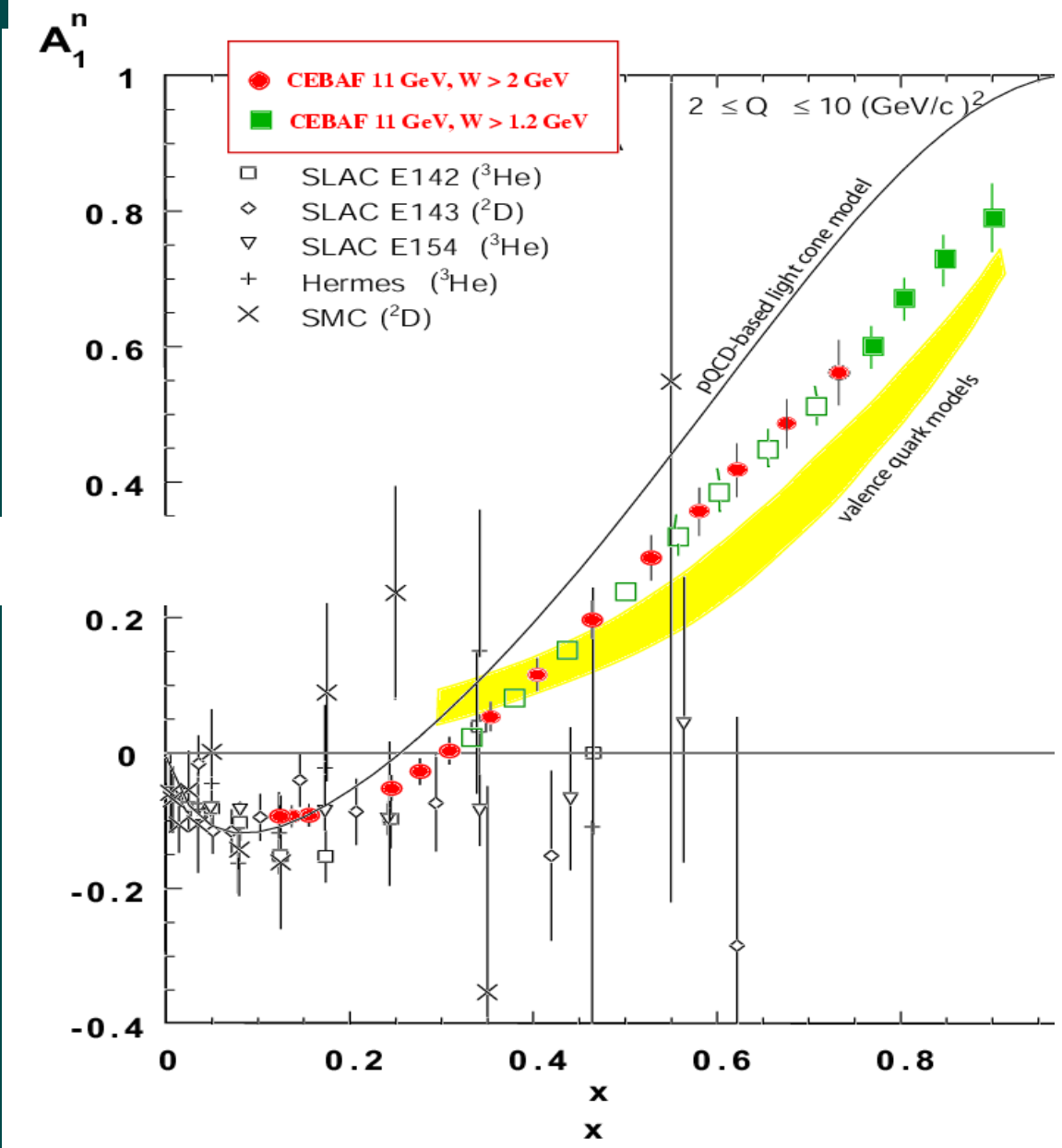
In order to gain a broad-based understanding of duality, need to explore duality in:

- Proton vs. Neutron
- Unpolarized vs. Polarized structure functions
- Duality in ratios of structure functions: R
- Duality in Semi-Inclusive reactions.

New Duality data in these areas are just coming in

An Application of Duality

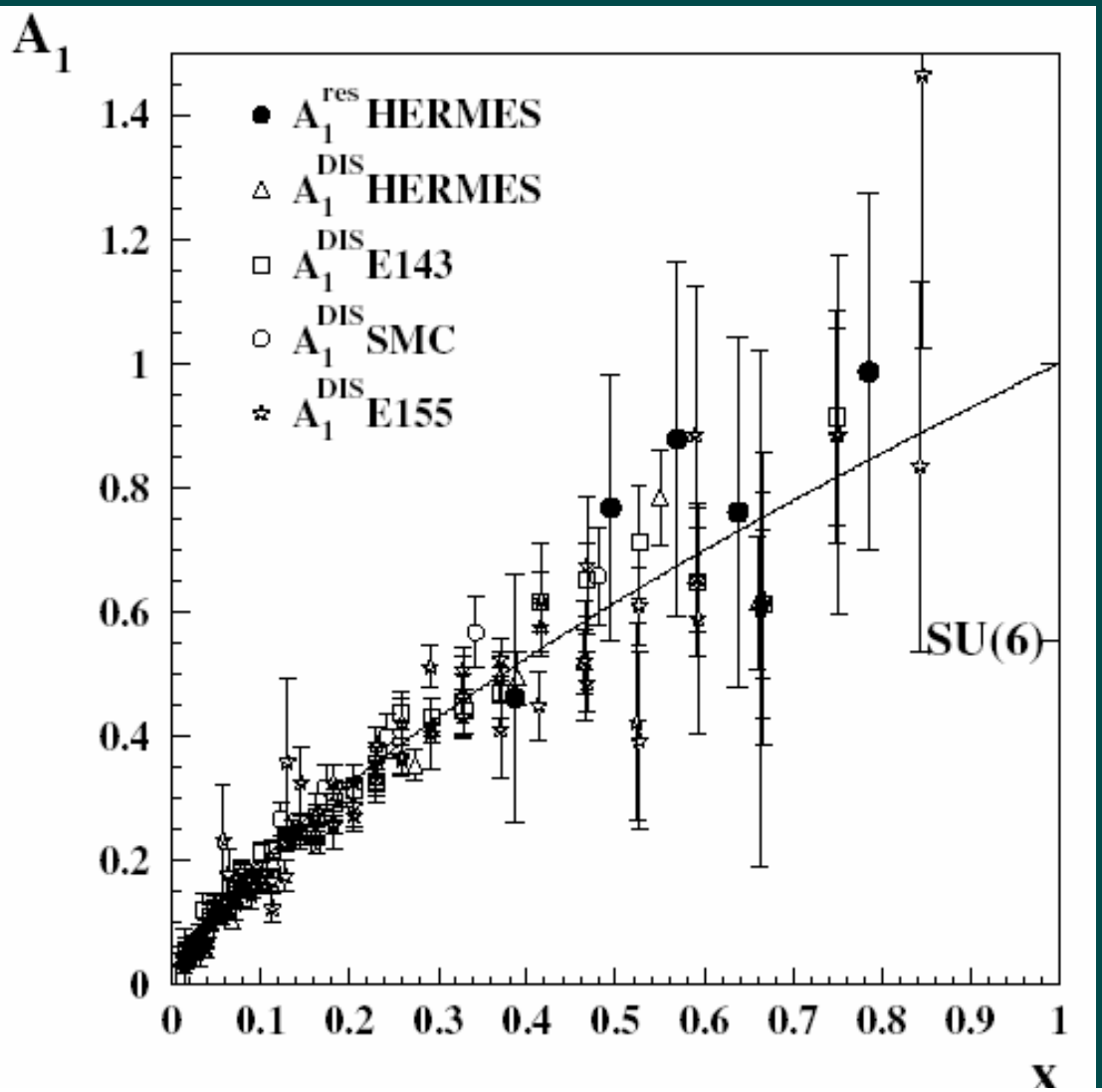
If duality established: a good way to access polarized quark distributions at high *x*



If works, will provide the only way to access parton distributions at very high x

- Indications of duality on spin structure functions:
  - HERMES for A_1^p

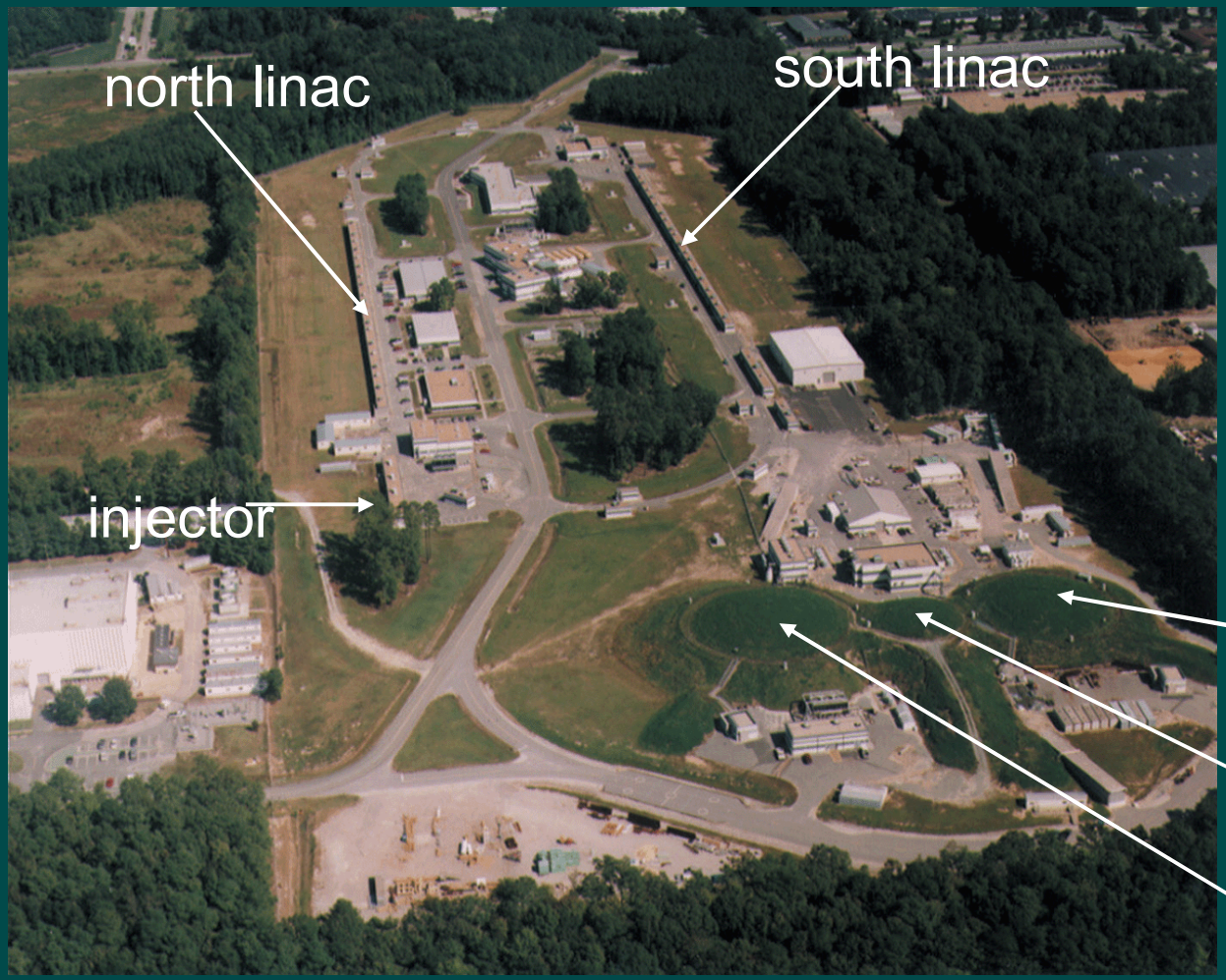
A.Airapetian et al., Phys. Rev. Lett. **90**, 092002 (2003)



Resonance data integrated over the whole resonance region

New precision resonance spin structure data from Jefferson Lab

- Hall B (CLAS) EG1 experiment: proton and deuteron
- Hall C E-01-006 (RSS) Experiment: proton and deuteron
- Hall A E-01-012 Experiment: neutron (pol. ^{3}He)



Spin structure Function Calculation

From Asymmetries:

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} \quad \text{and} \quad A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$

$$A_1 = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}, \qquad A_2 = \frac{\xi A_{\parallel}}{D(1+\eta\xi)} + \frac{A_{\perp}}{d(1+\eta\xi)}$$

$$g_1 = \frac{F_2}{2x\,(1+R)}\left(A_1 + \frac{2xM}{\sqrt{Q^2}}A_2\right)$$

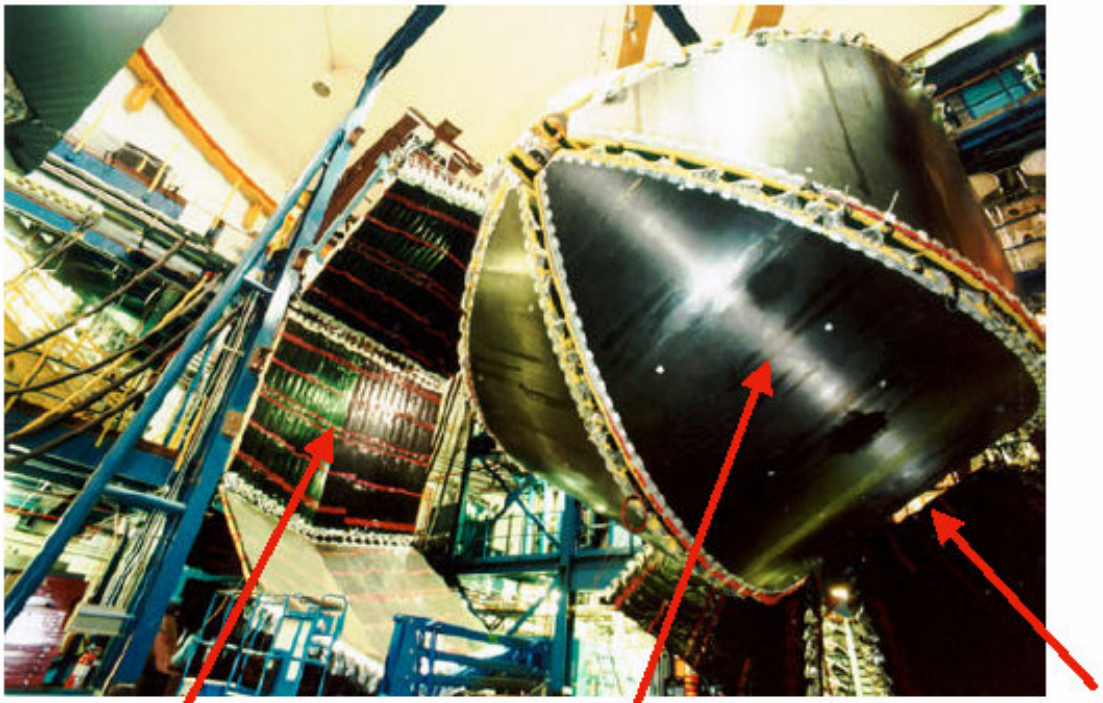
From Cross section differences:

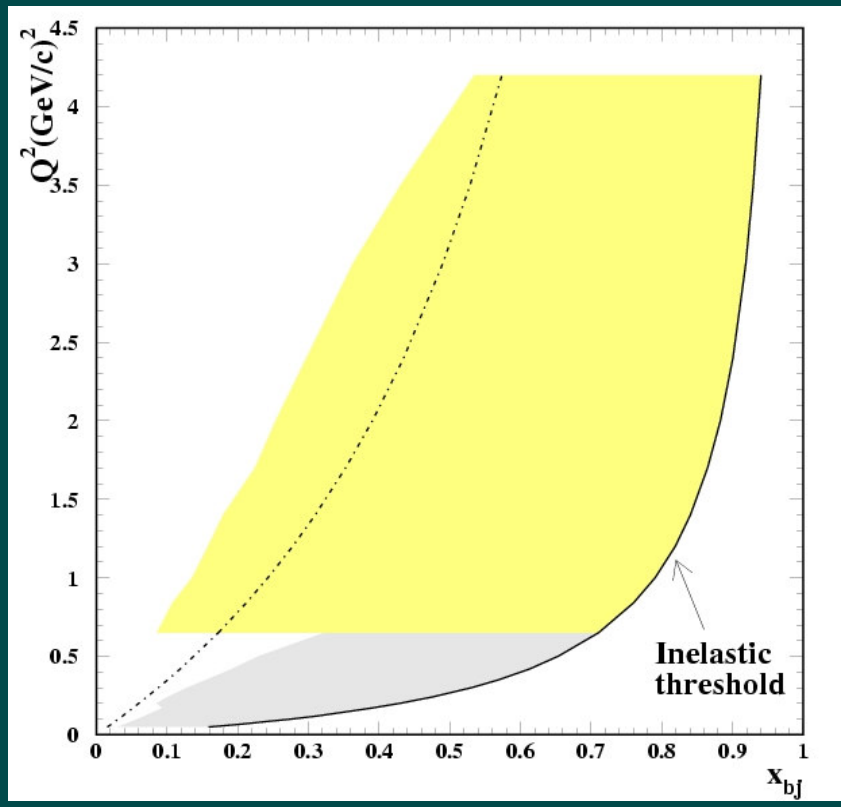
$$g_1 = \frac{MQ^2\nu}{4\alpha_e^2}\frac{E}{E'}\frac{1}{E+E'}\left[\Delta\sigma_{\parallel} + tan(\frac{\theta}{2})\Delta\sigma_{\perp}\right]$$

$$g_2 = \frac{MQ^2\nu^2}{4\alpha_e^2}\frac{1}{2E'(E+E')}\left[-\Delta\sigma_{\parallel} + \frac{E+E'cos\theta}{E'sin\theta}\Delta\sigma_{\perp}\right]$$

$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \quad \text{and} \quad A_2 = \frac{\gamma[g_1 + g_2]}{F_1}$$

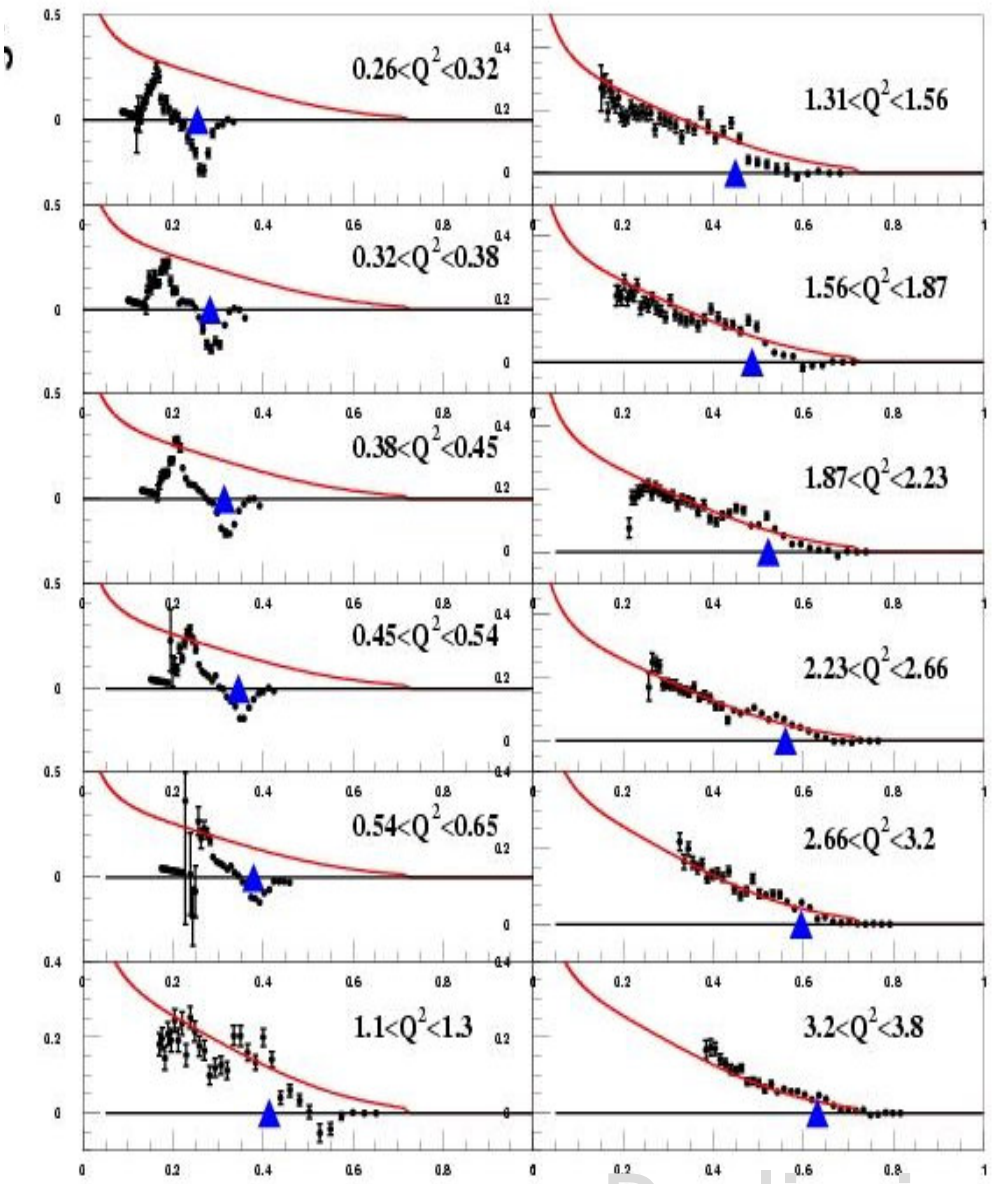
Hall B (CLAS) EG1 experiment: proton and deuteron





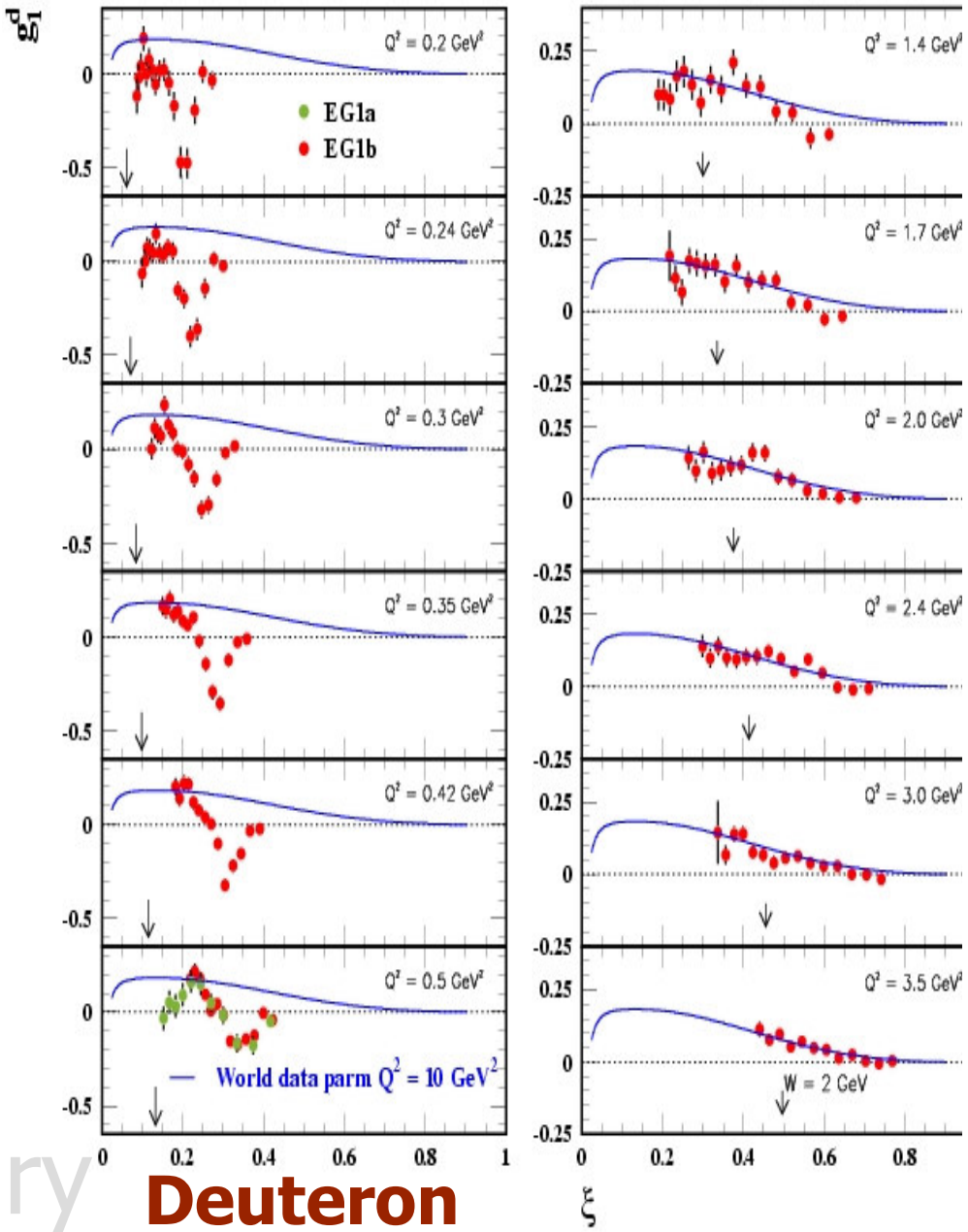
Targets:
NH_3(70-90%), ND_3(10-35%), ^{12}C,^{15}N, ^4He

1.6,2.5,4.2, and 5.7 GeV electrons polarized to ~70%



Proton

Preliminary

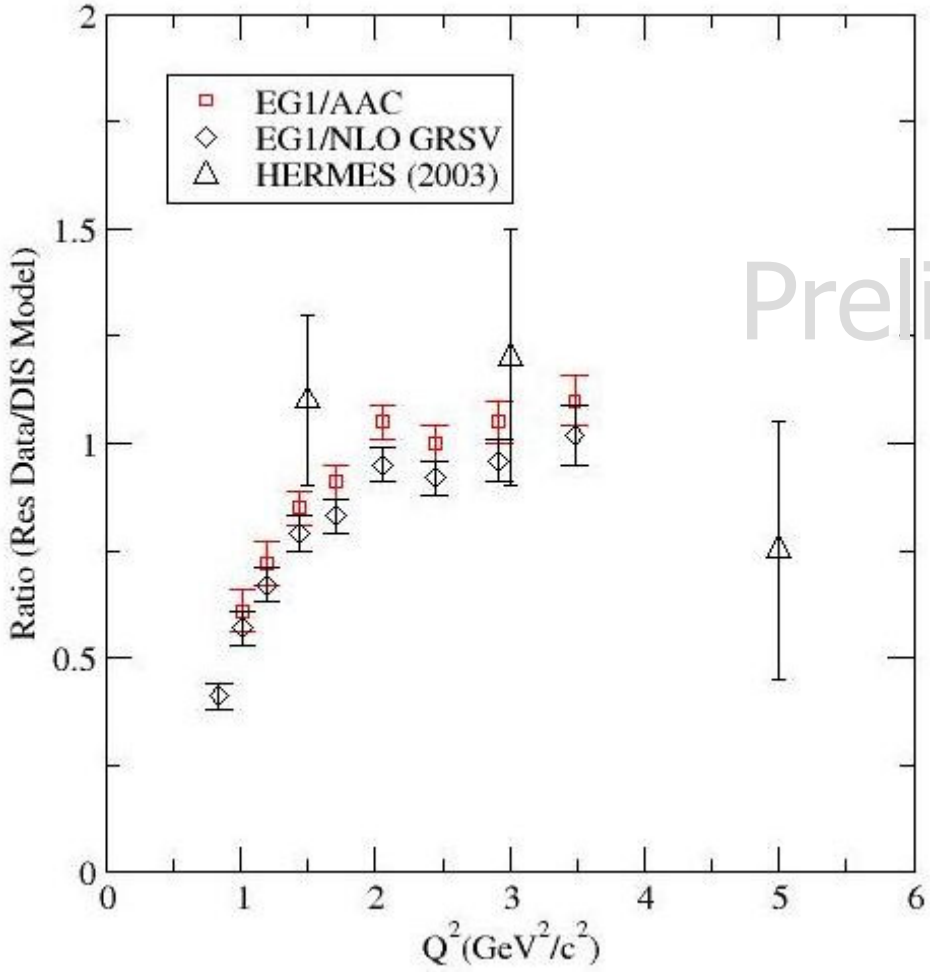


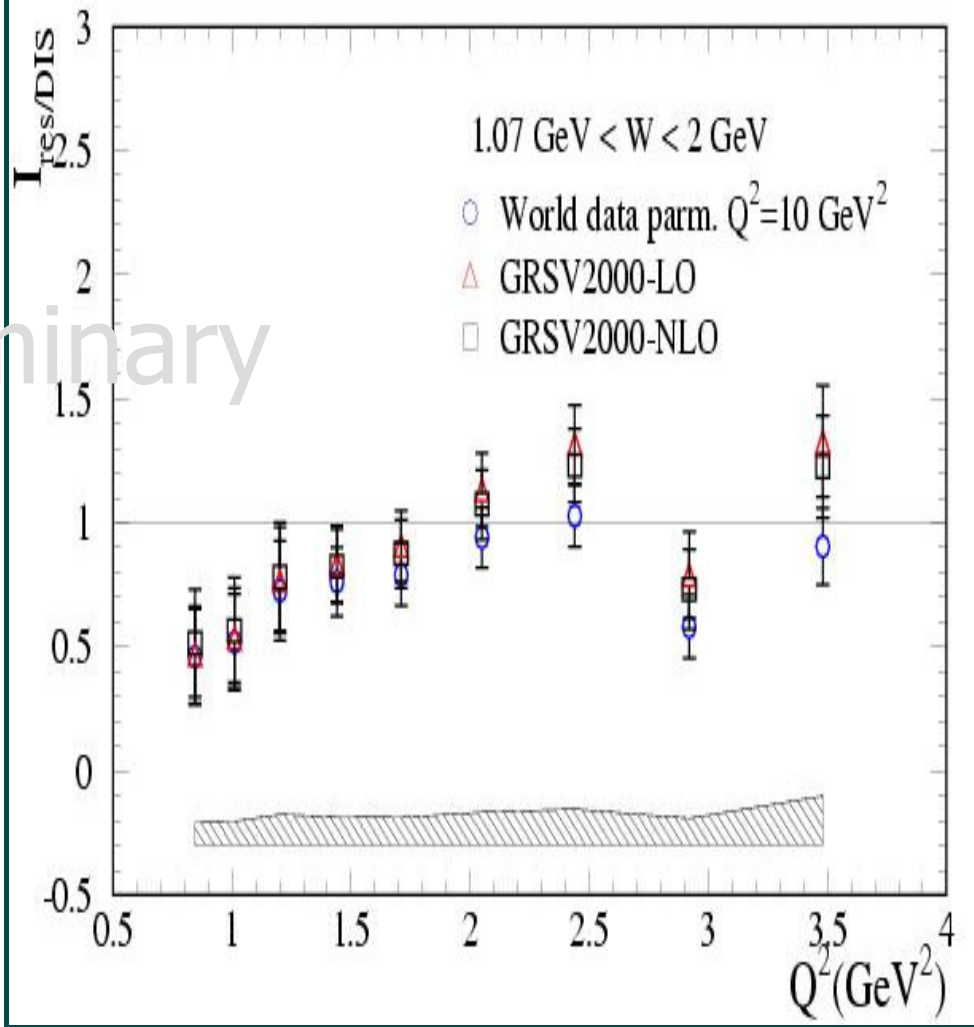
Deuteron

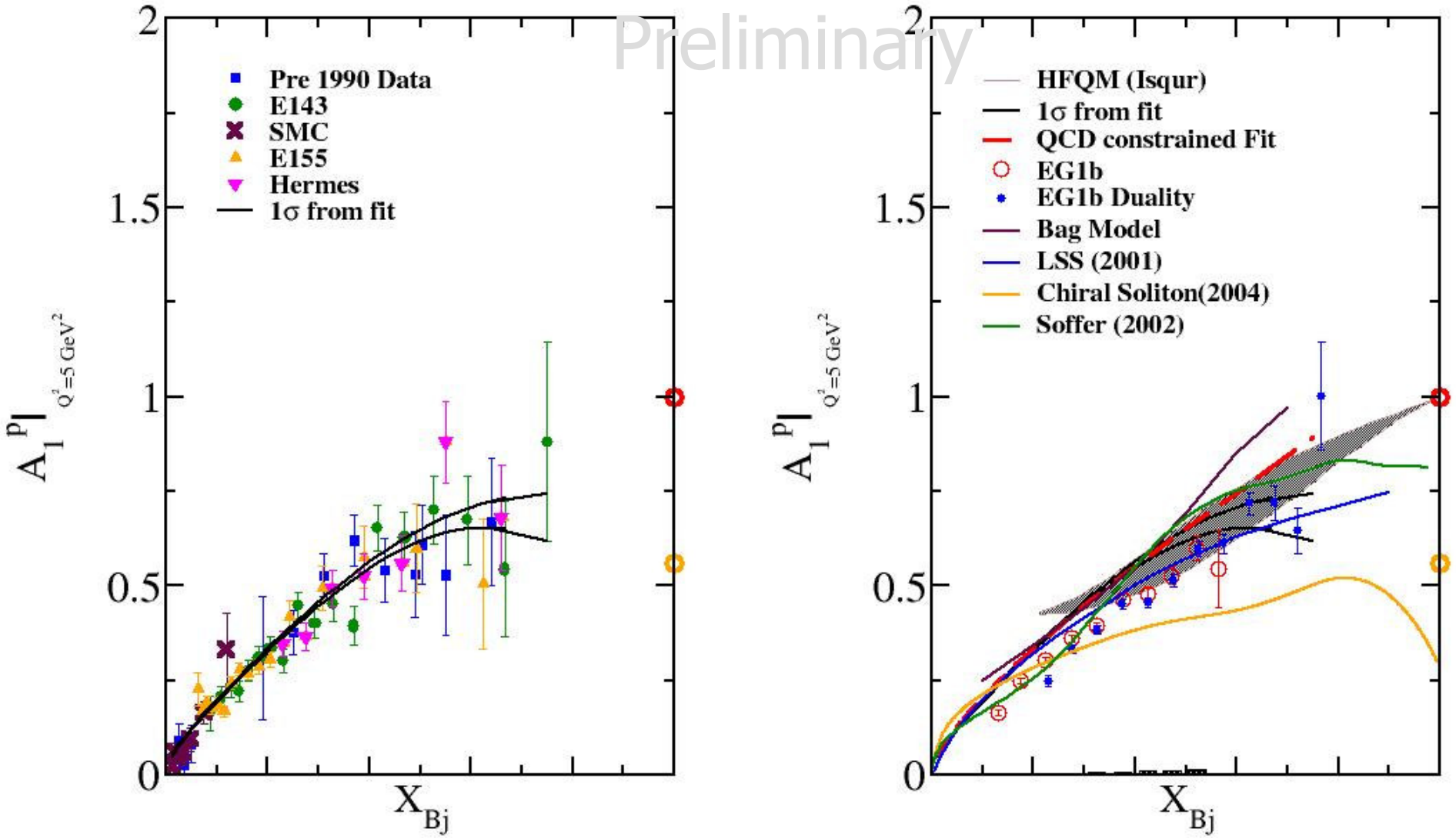
. Pork, Ph. D thesis UVa (2004), V. Dharmavardane, PhD Thesis. ODU (2004)

Since g1p > g1n at high x, g1d is mostly sensitive to g1p and not g1n

$$\Gamma^{res}/\Gamma^{DIS} \equiv \frac{\int_{x_{min}}^{x_{max}} g_1^{res}(x,Q^2)dx}{\int_{x_{min}}^{x_{max}} g_1^{DIS}(x,Q^2)dx}$$






Preliminary
Pre 1990 Data
E143
SMC
E155
Hermes
1σ from fit
HFQM (Isqur)
1σ from fit
QCD constrained Fit
EG1b
EG1b Duality
Bag Model
LSS (2001)
Chiral Soliton(2004)
Soffer (2002)
$A_1^p|_{Q^2=5\ GeV^2}$
X_{Bj}
0
0.5
1
1.5
2

JLab E-01-006
Resonances Spin Structure (RSS)

Precision Measurement of the Nucleon Spin Structure Functions in the Region of the Nucleon Resonances

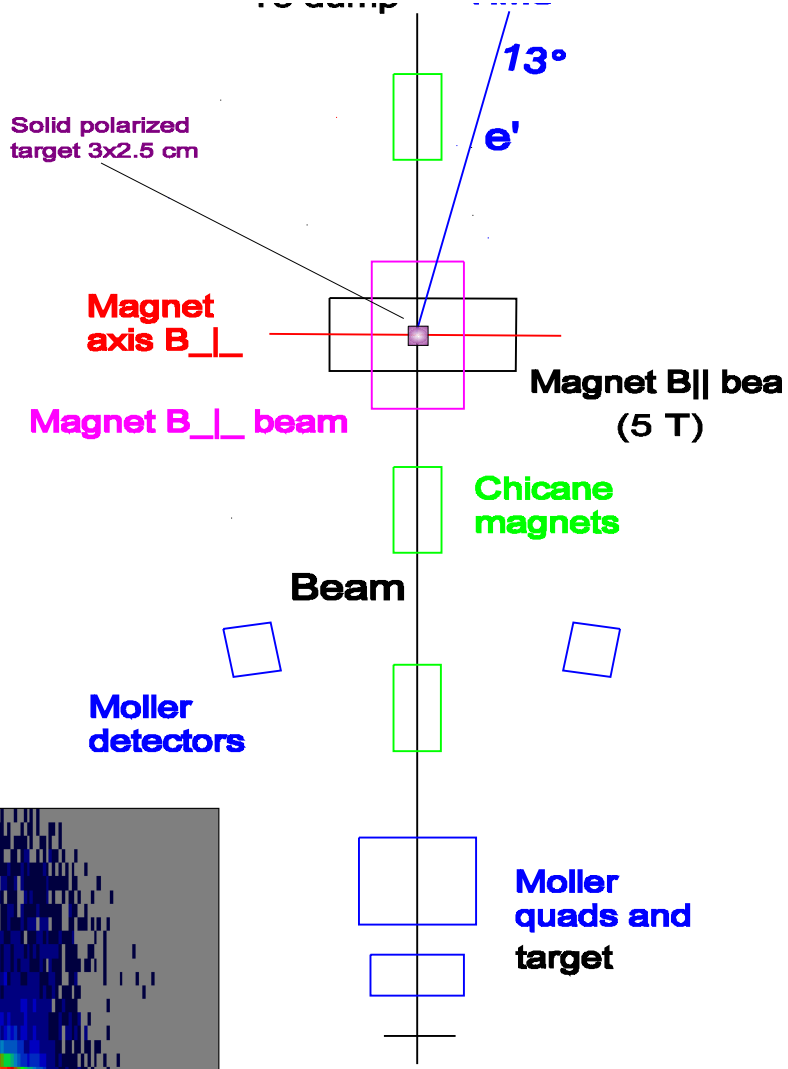
U. Basel, Florida International U., Hampton U., U. Massachusetts, U. Maryland, Mississippi S. U., North Carolina A&T U., U. of N. C. at Wilmington, Norfolk S. U., Old Dominion U., S.U. New Orleans, U. of Tel-Aviv, TJNAF, U. of Virginia, Virginia P. I. & S.U., Yerevan Physics I.

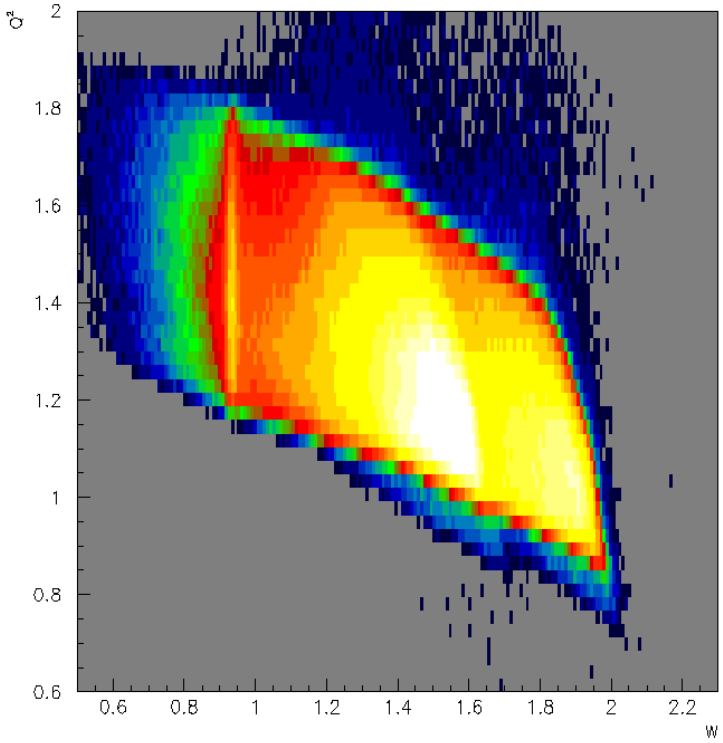
Spokesmen: Oscar A. Rondon (UVA) and Mark K. Jones (JLab)

Physics:

- Measure proton and deuteron spin asymmetries $\boldsymbol{A_1(W, Q^2)}$ and $\boldsymbol{A_2(W, Q^2)}$ at momentum transfer $Q^2 \approx 1.3$ GeV^2 and final state mass $0.8 \leq W \leq 2$ GeV.
- Study W dependence, onset of polarized local duality, twist-3 effects.
- Obtain asymmetries from inclusive polarized electron scattering on polarized nuclei.

- Measure count asymmetries $A_{\parallel}$, $A_{\perp}$ on protons and deuterons
- CEBAF polarized electron beam
  - 2 cm diameter raster at target
- Polarized ammonia target
  - Luminosity ~10^{35} Hz cm^{-2}
- **Hall C** High Momentum Spectrometer HMS
  - $\theta_{HMS} = -13.2°$
- Took data 1/21 to 3/3/2002
  - 160 M proton triggers
  - 350 M deuteron triggers

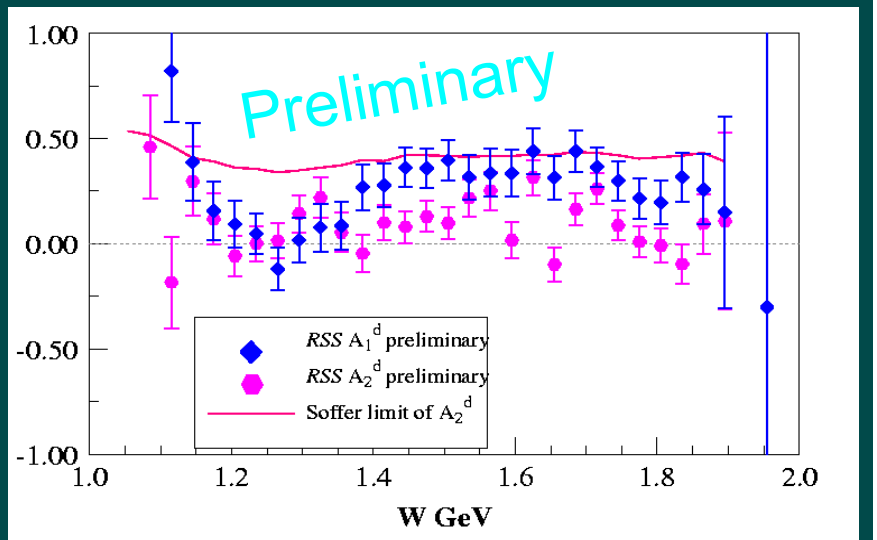


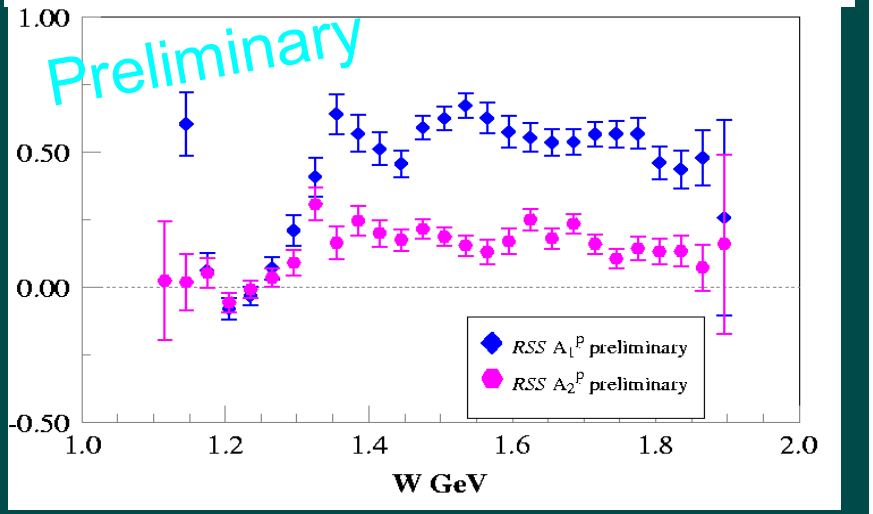


- Beam energy 5.755 GeV
- $\langle Q^2 \rangle = 1.3$ [GeV/c]^2

RSS preliminary results

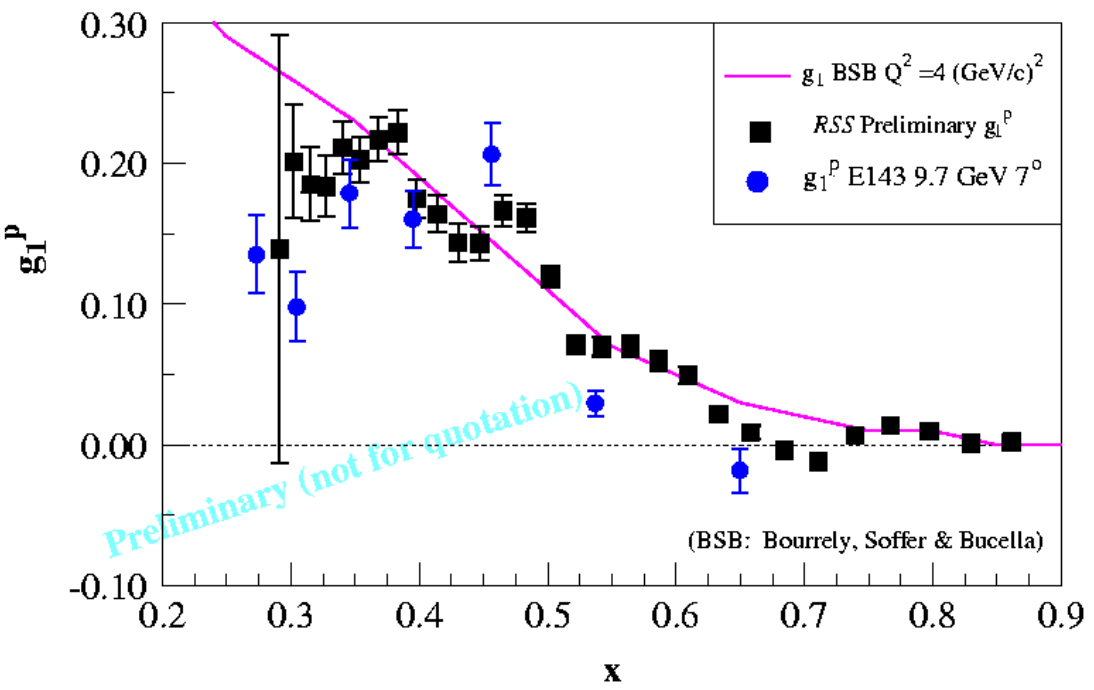
- A_1, A_2 for proton, deuteron in resonances are unique:
  - RSS is only experiment that can separate A_1, A_2 for proton
- Preliminary results
- No corrections applied yet
  - preliminary dilution factor
  - no radiative or nitrogen corrections.

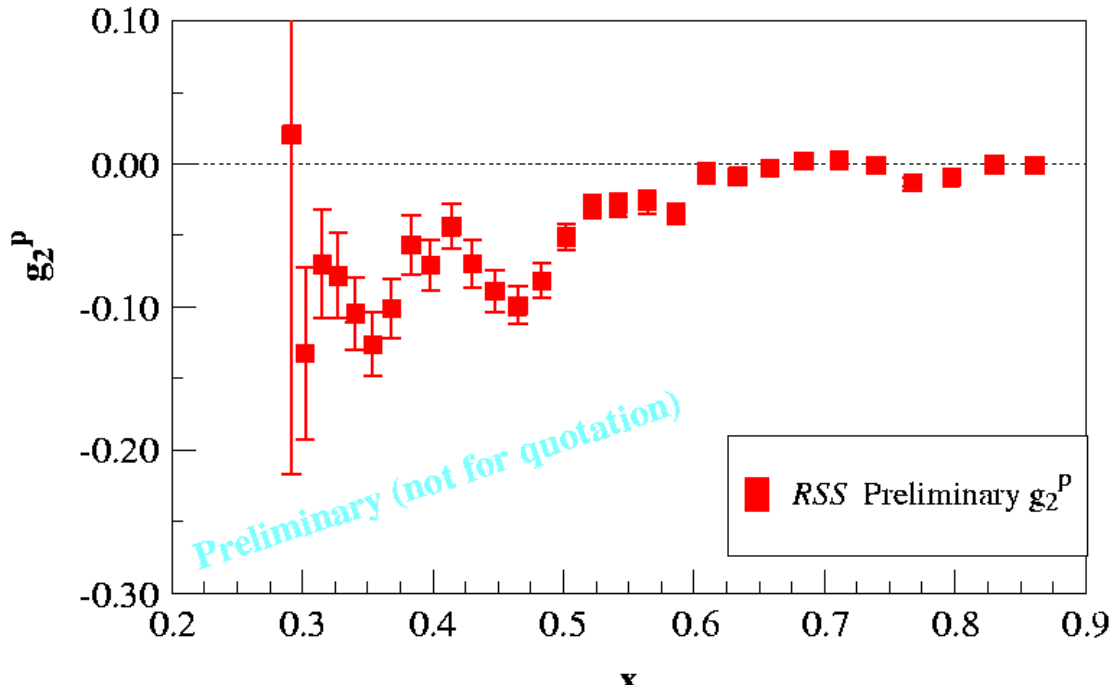




RSS preliminary results

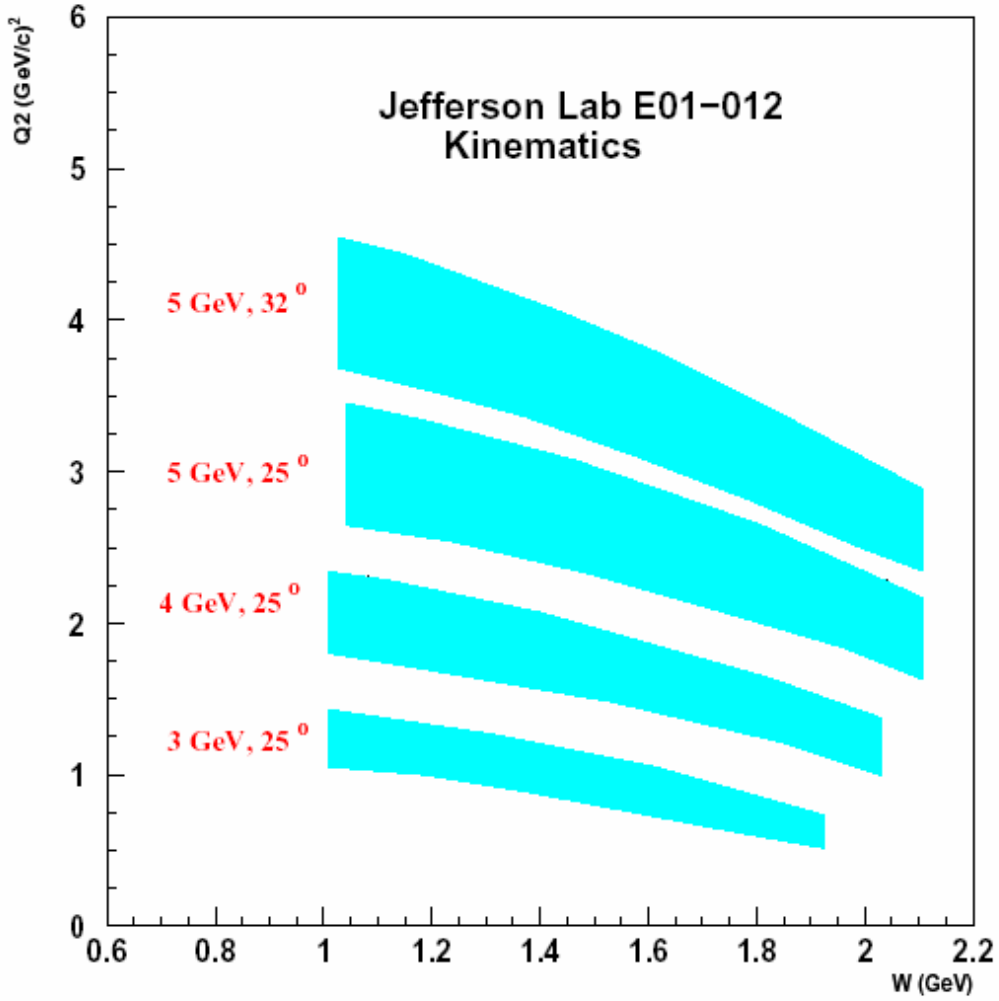
- High precision, high resolution measurement
- Only world data for g_2^p in the resonances
- Preliminary results
- No corrections applied yet
  - preliminary dilution factor
  - no radiative or nitrogen corrections.
- JLab Hall C F_2 and R in the resonances



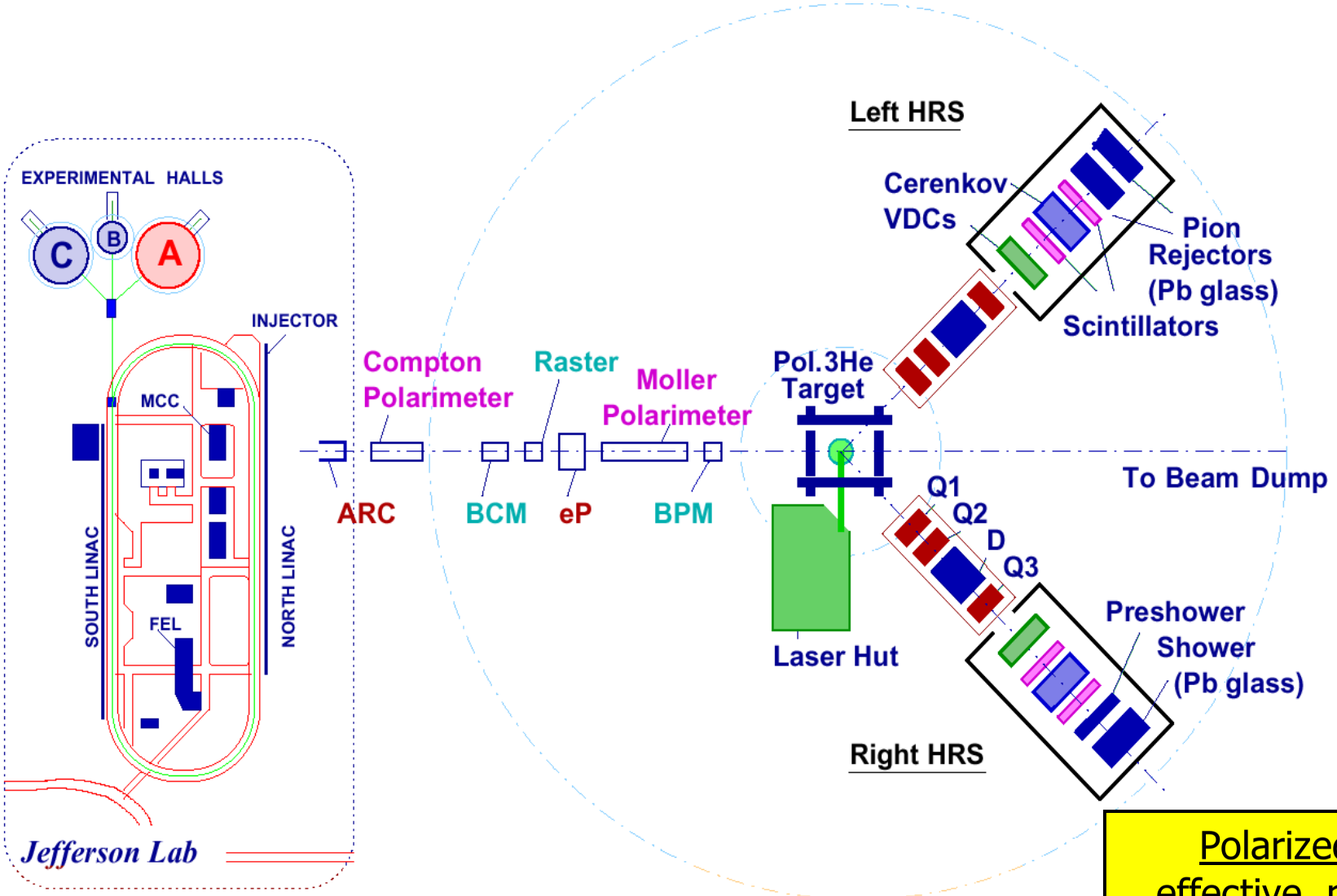


Jefferson Lab E01-012: neutron (3He) spin structure functions in the resonance region

Spokespersons: N. Liyanage, J. P. Chen, S. Choi; PhD student: P. Solvignon



- Measured g1n and A1n in the resonance region
  - $1.0 < Q2 < 4.0$ GeV^2.
- Asymmetries and Cross-section differences
- Longitudinal and Transverse target polarizations to separate A1 and A2
- Experiment ran in January and February, 2003.



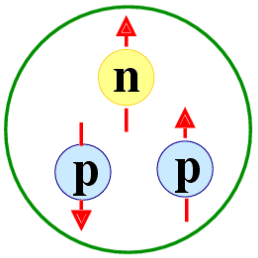
Polarized ^{3}He as an effective neutron target

→ 3 incident energies (3 GeV, 4 GeV and 5 GeV)

→ Average polarization: $(77 \pm 3)\%$

Hall A High Resolution Spectrometers:

→ Both HRS in a symmetric configuration at 25° and 32°.
⇒ double the statistics + check of the systematics



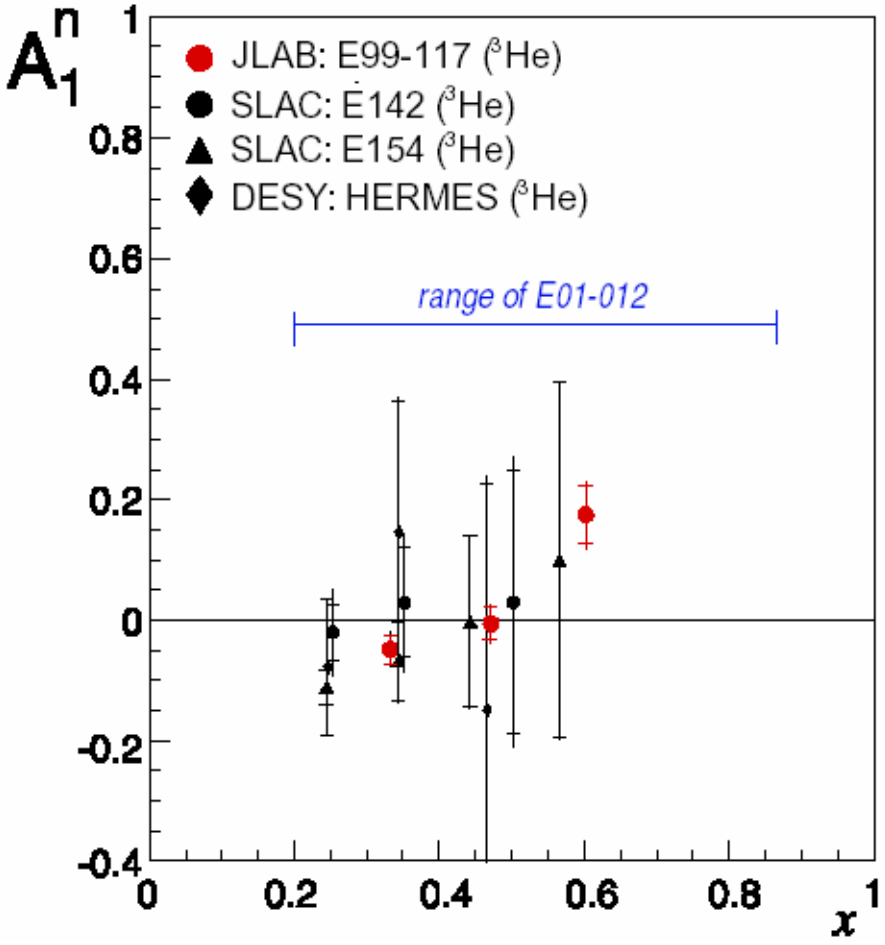
^{3}He (s state)

Test duality on the neutron spin structure functions:

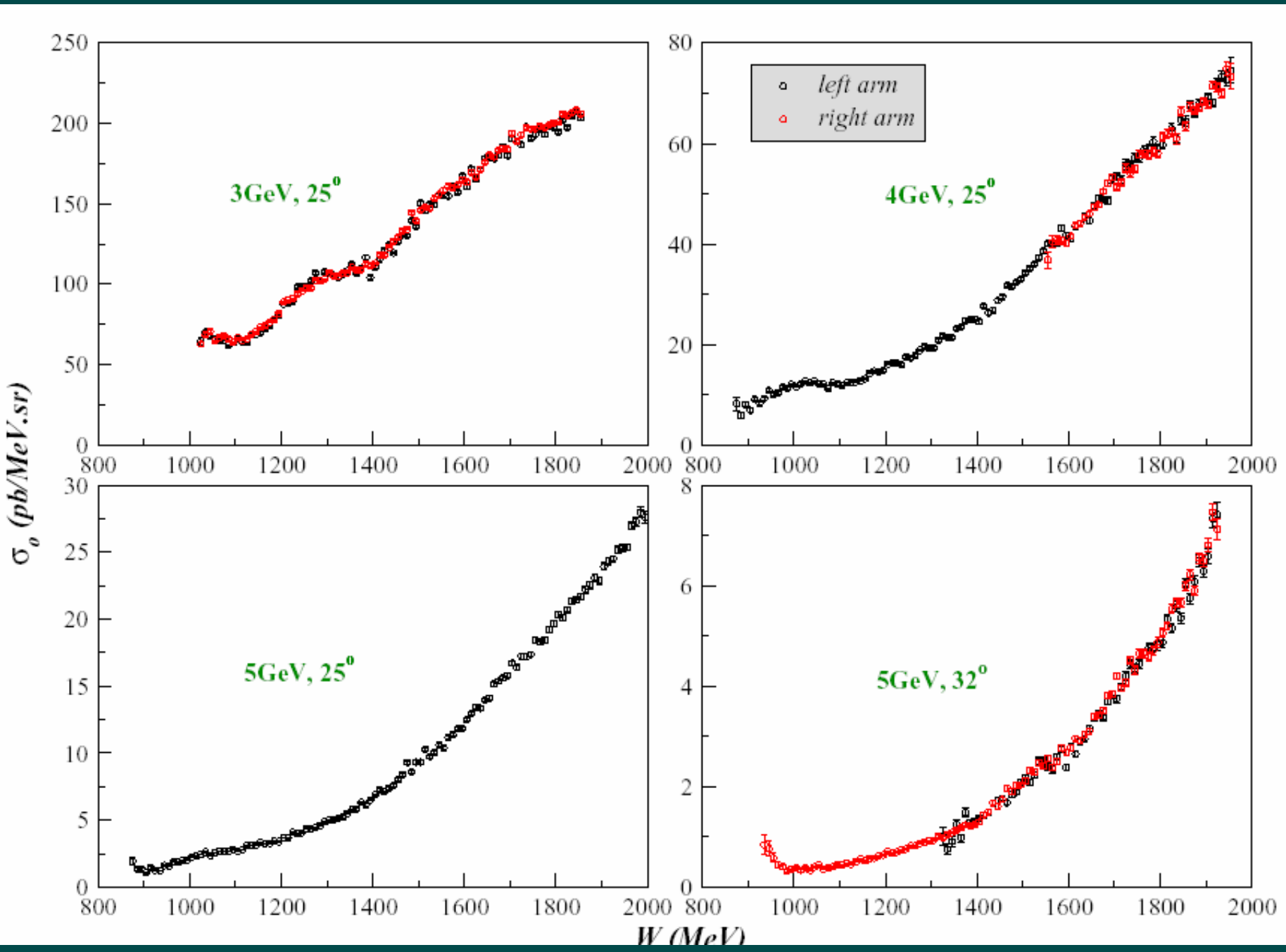
→ E01-012 data cover $0.2 < x < 0.87$.

→ For $x < 0.65$: test of duality with available DIS data.

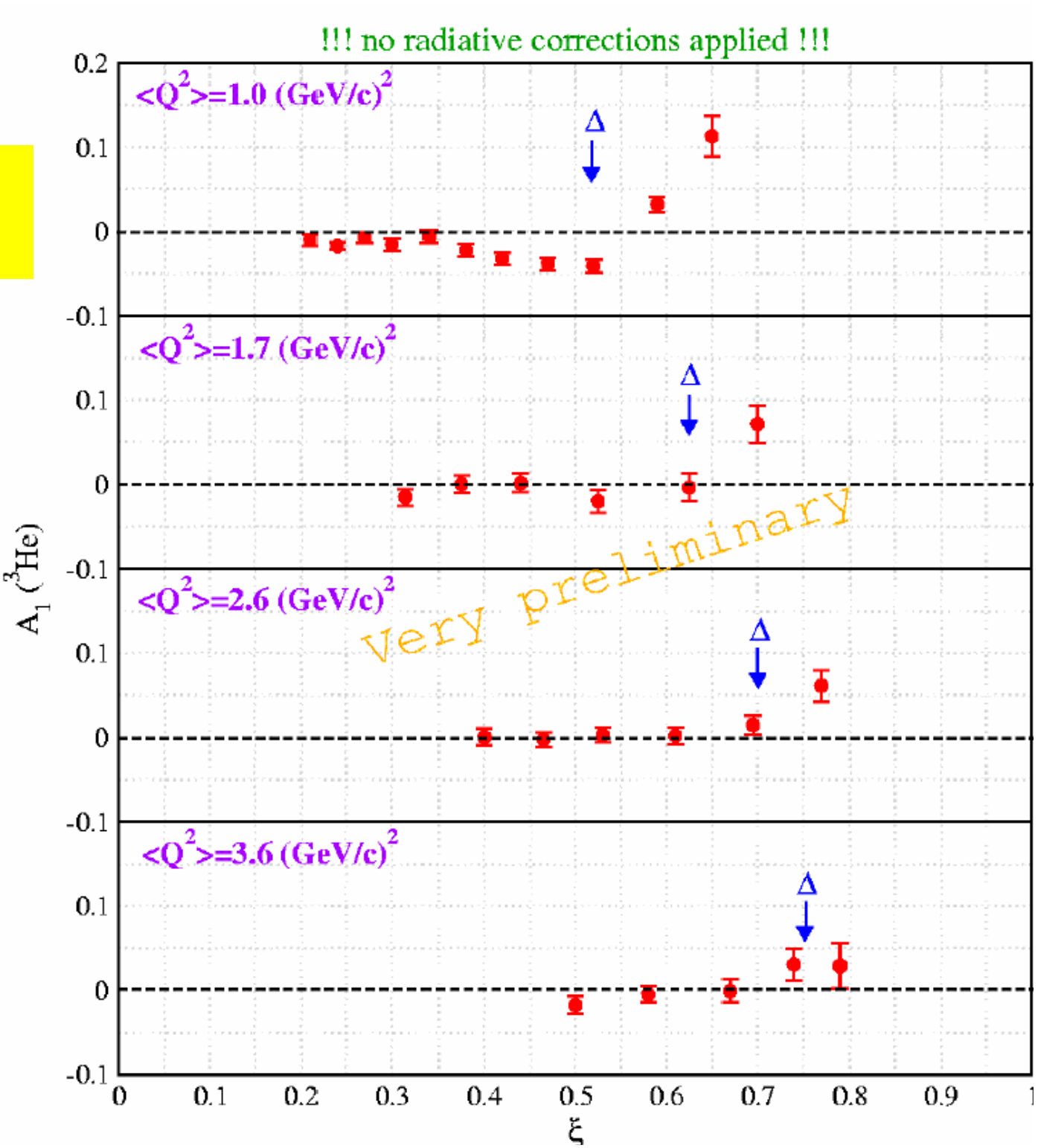
→ If duality is confirmed, resonance data will provide first precise measurement of g_1^n and A_1^n in the range $0.65 < x < 0.87$.



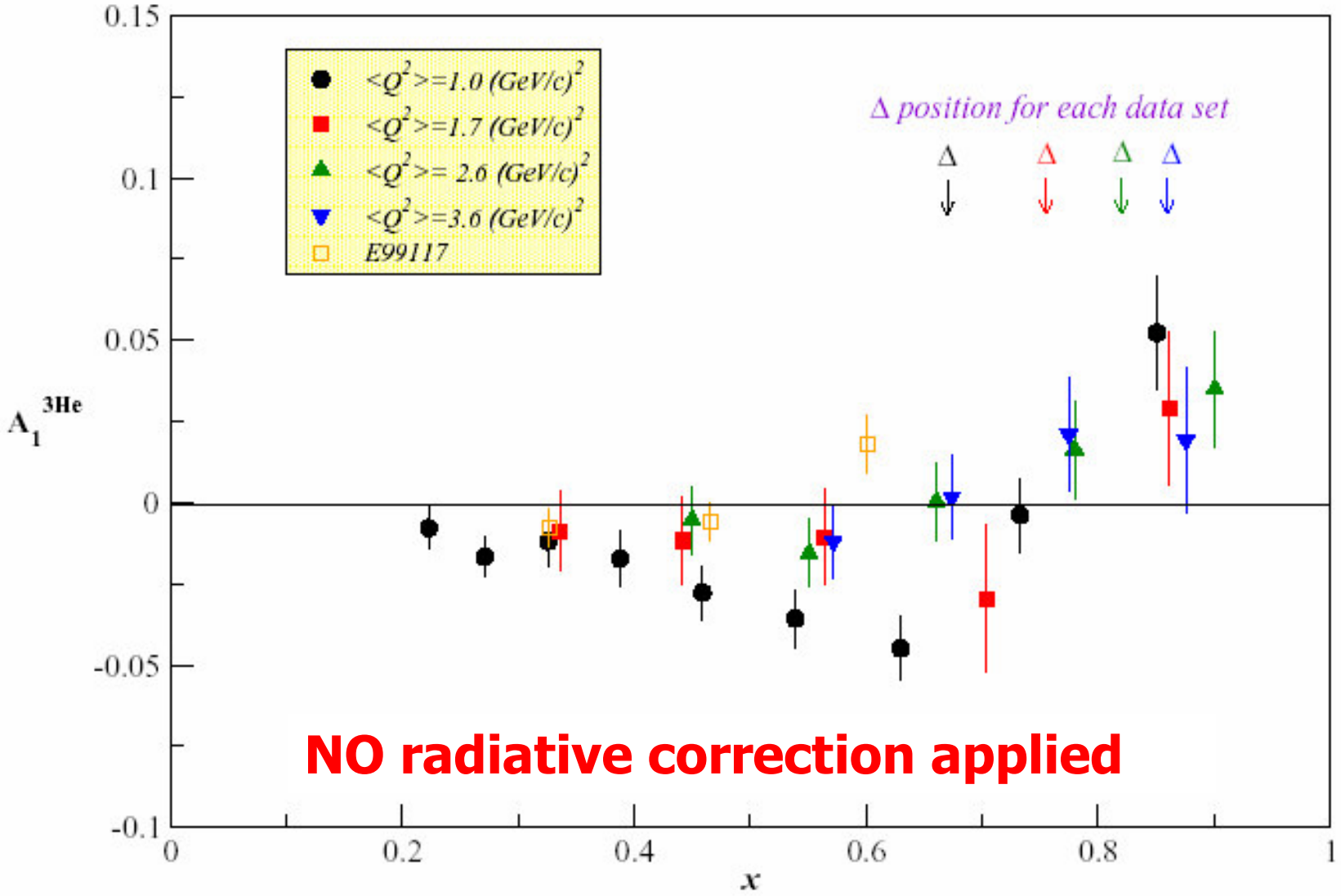
E01-012 preliminary results



E01-012: Preliminary results



E01-012 preliminary results



Summary and Outlook

• Three Jefferson Lab experiments will soon provide a comprehensive data set on p and n spin structure functions in the resonance region

- Hall B (CLAS) EG1 experiment: proton and deuteron
- Hall C E-01-006 (RSS) Experiment: proton and deuteron
- Hall A E-01-012 Experiment: neutron (pol. ^{3}He)

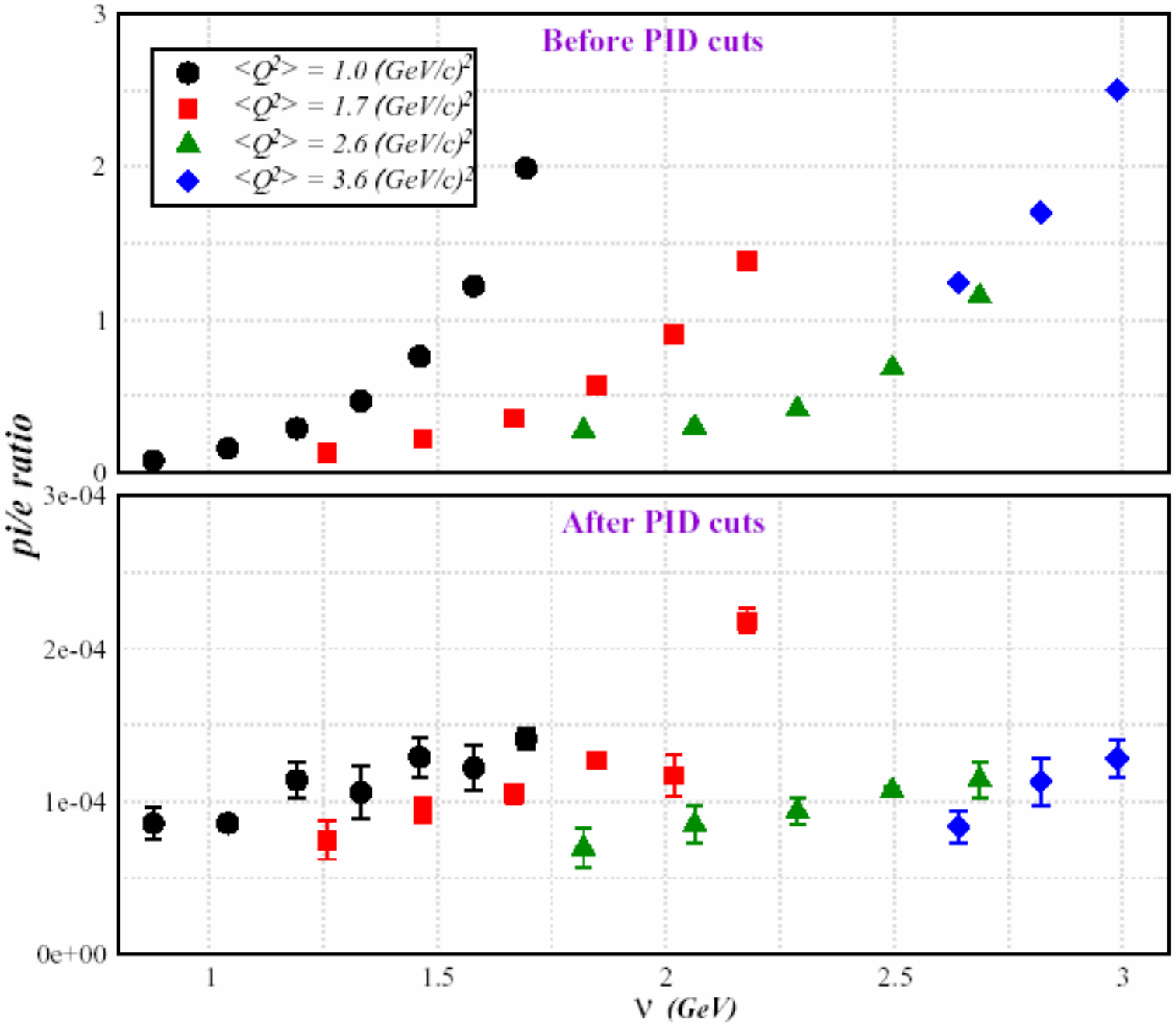
•Using overlap between resonance data and DIS data:

- **test of spin-flavor dependence of duality**

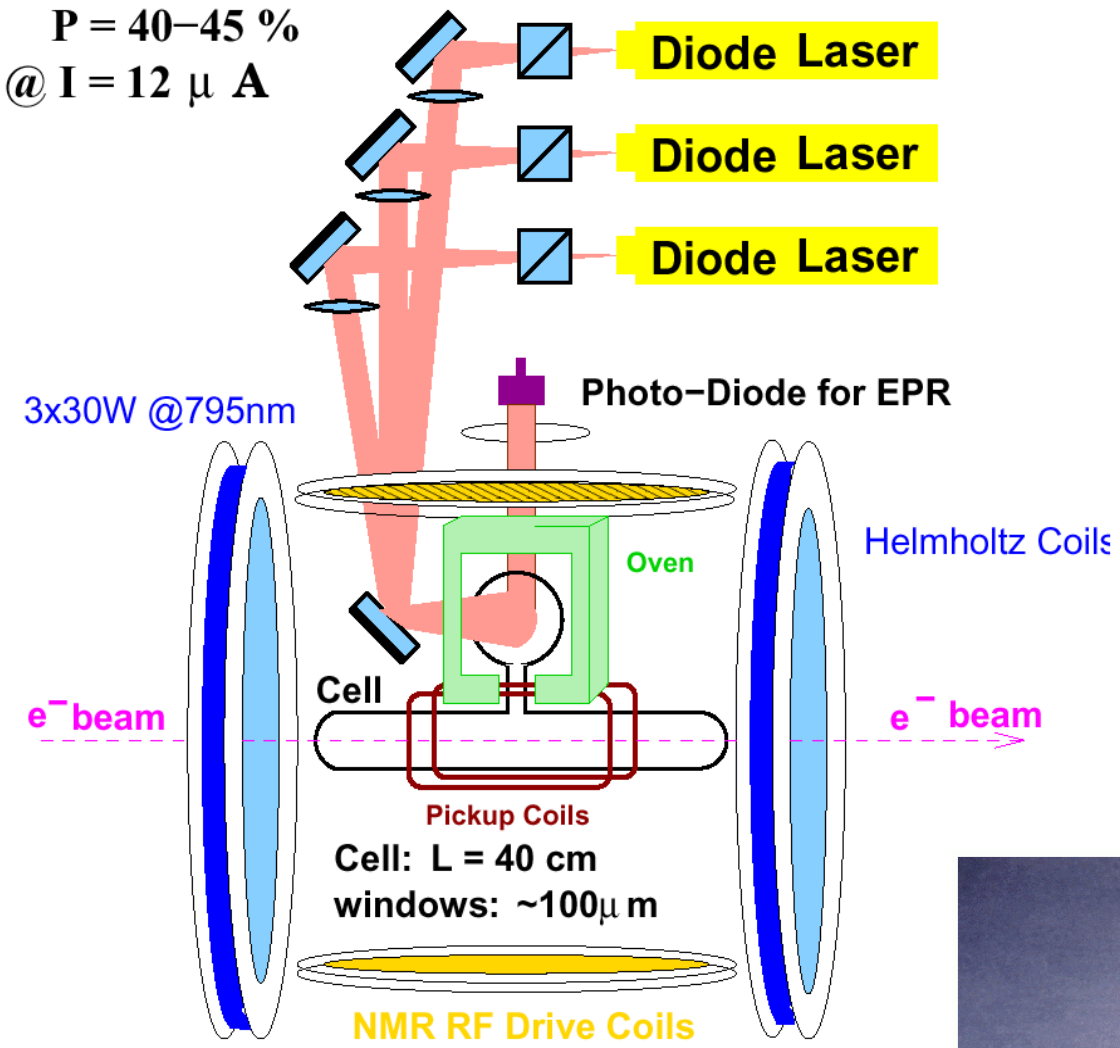
•With 12 GeV at Jefferson lab:

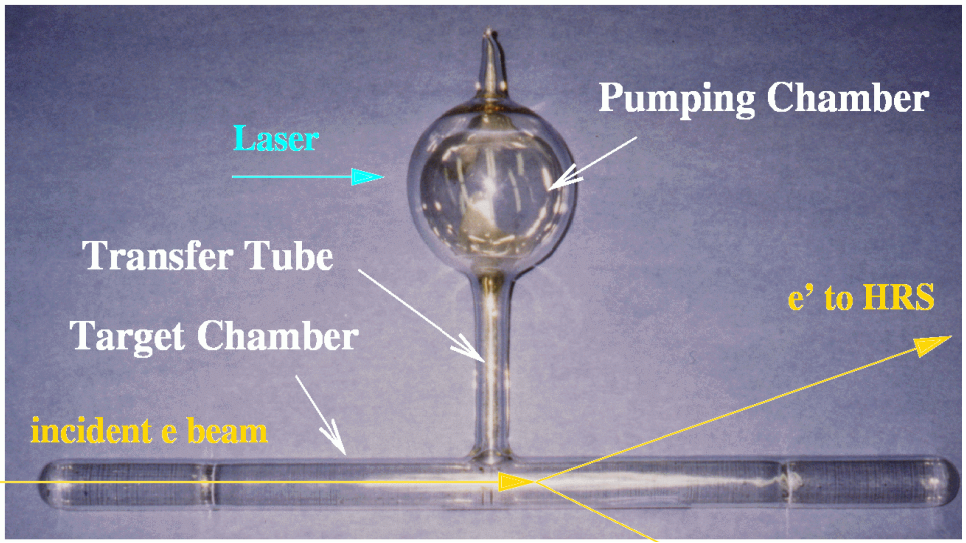
- **A precision test of spin-duality up to x ~ 0.75**
- **If duality established: polarized quark distributions up to x ~0.85**

→ Gas Cerenkov + lead glass → pion rejection > 10^4 with electron efficiency > 99%.

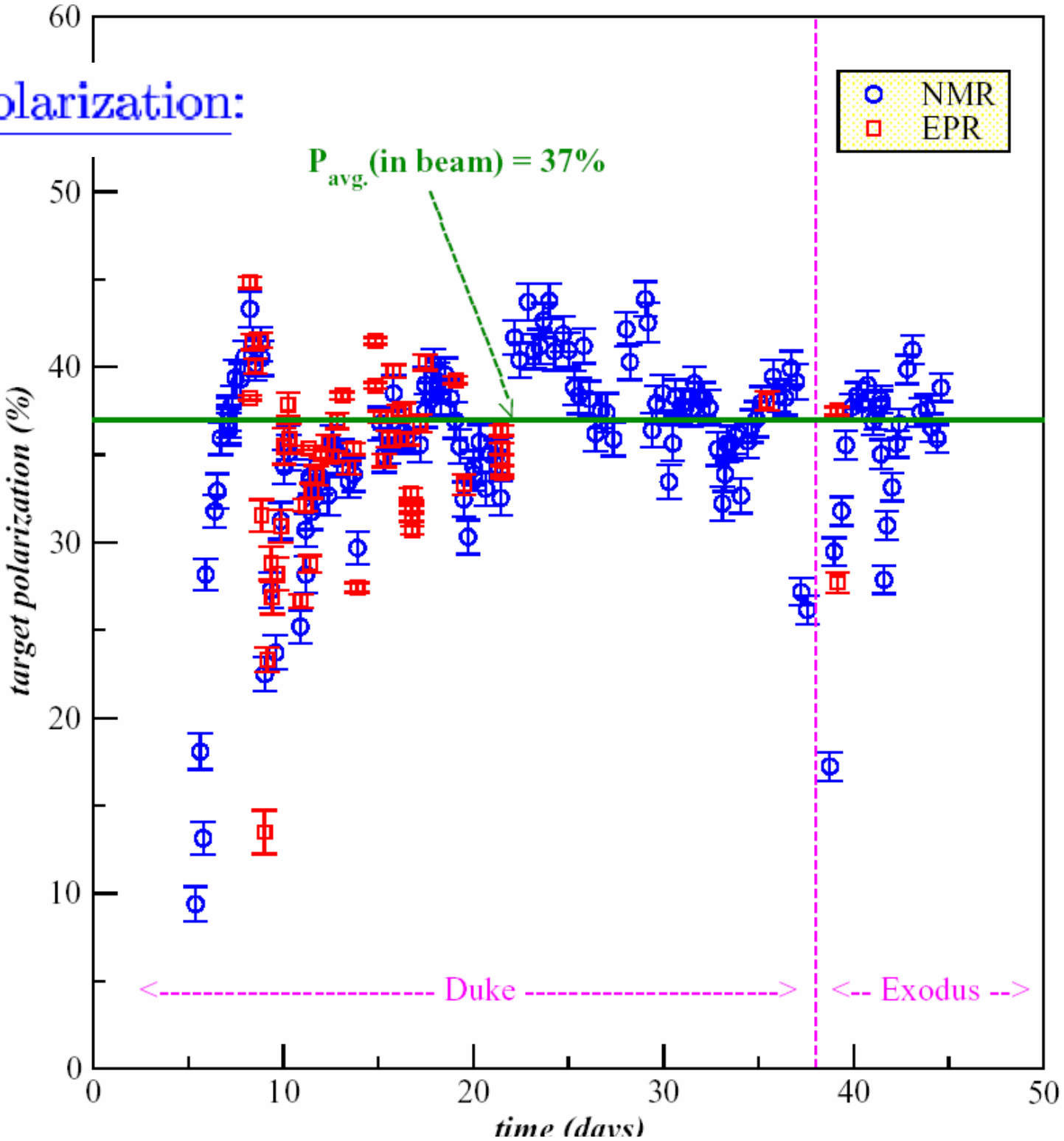


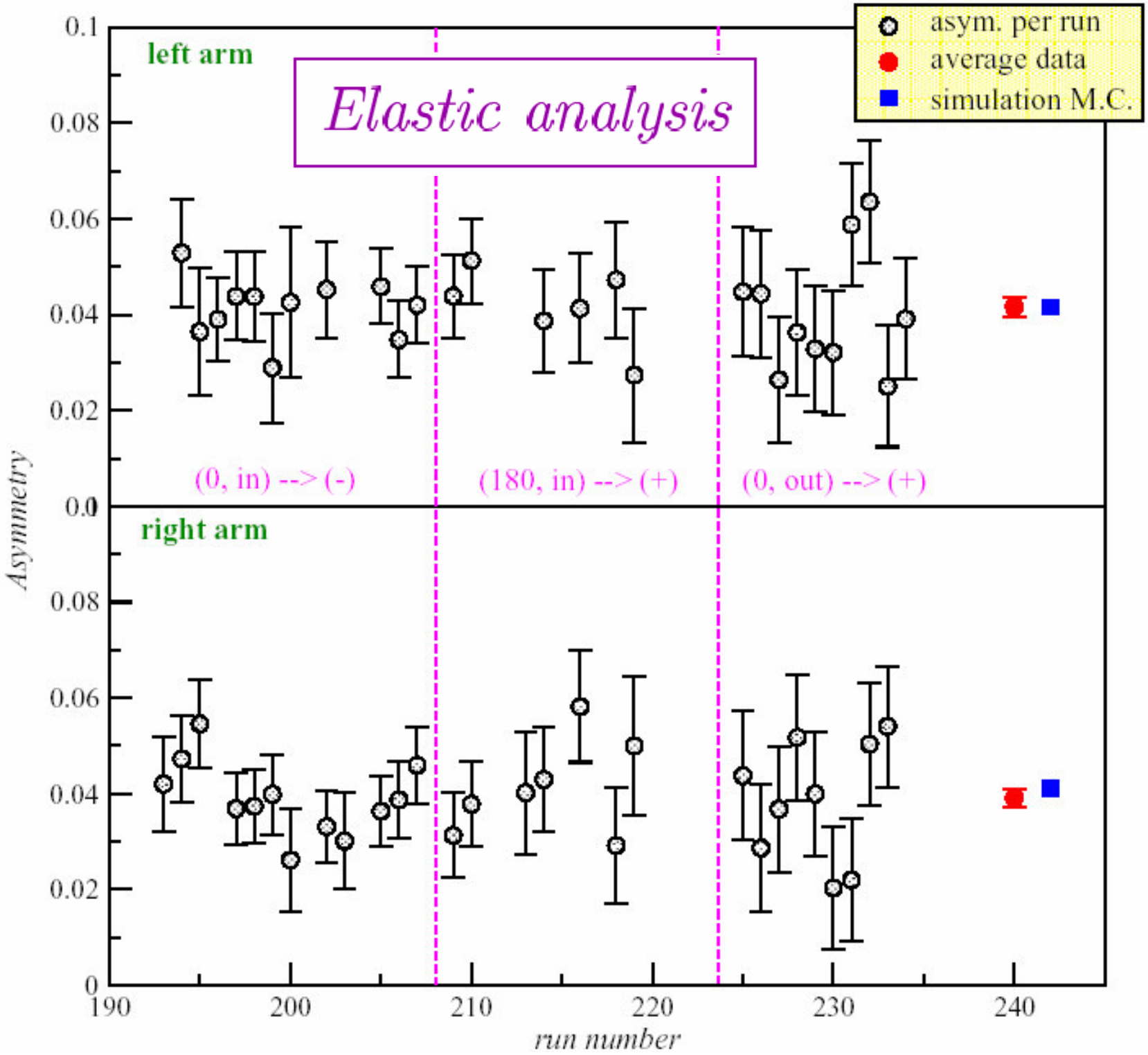
Hall A polarized ^{3}He target



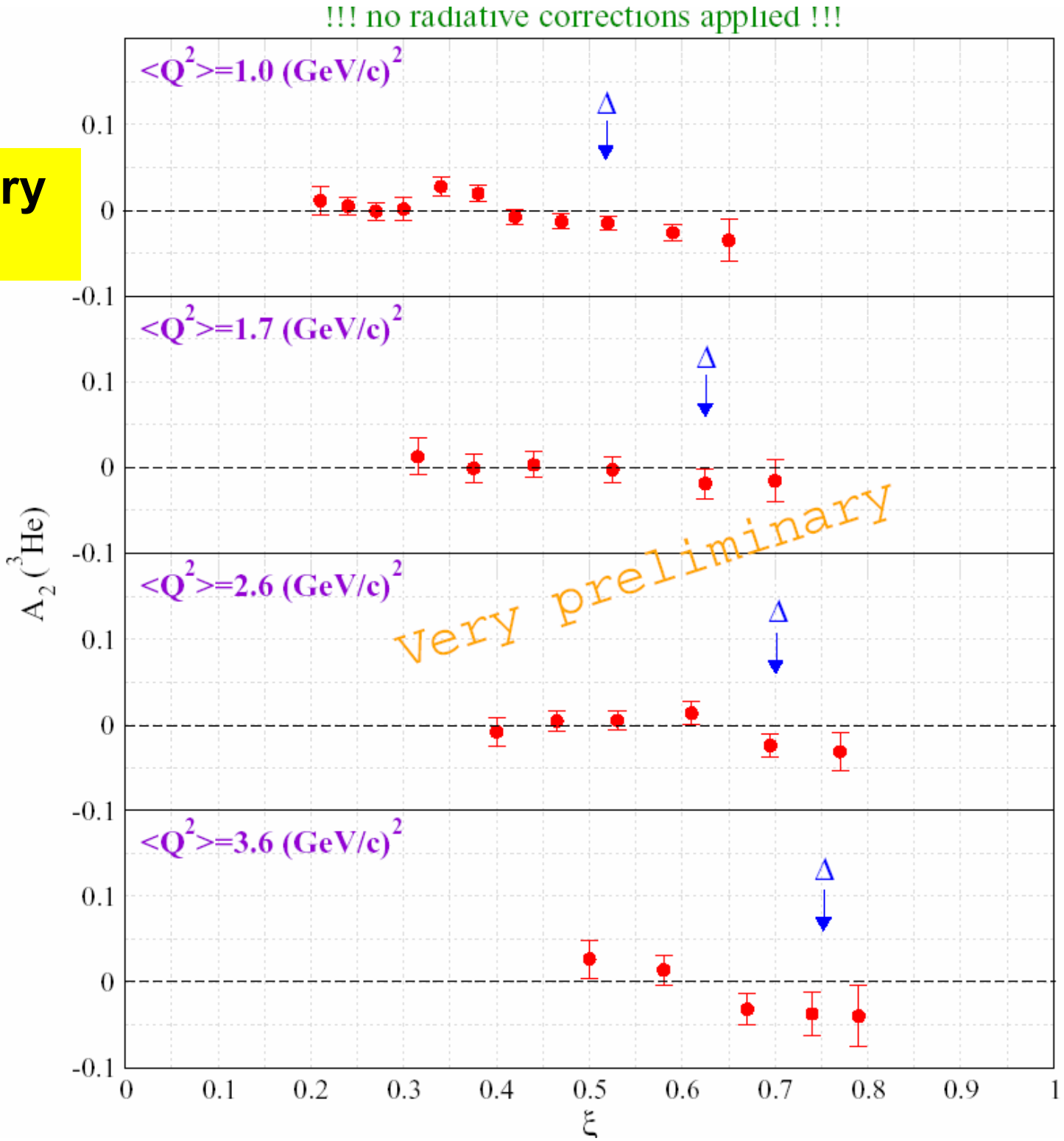


E01-012 target polarization:

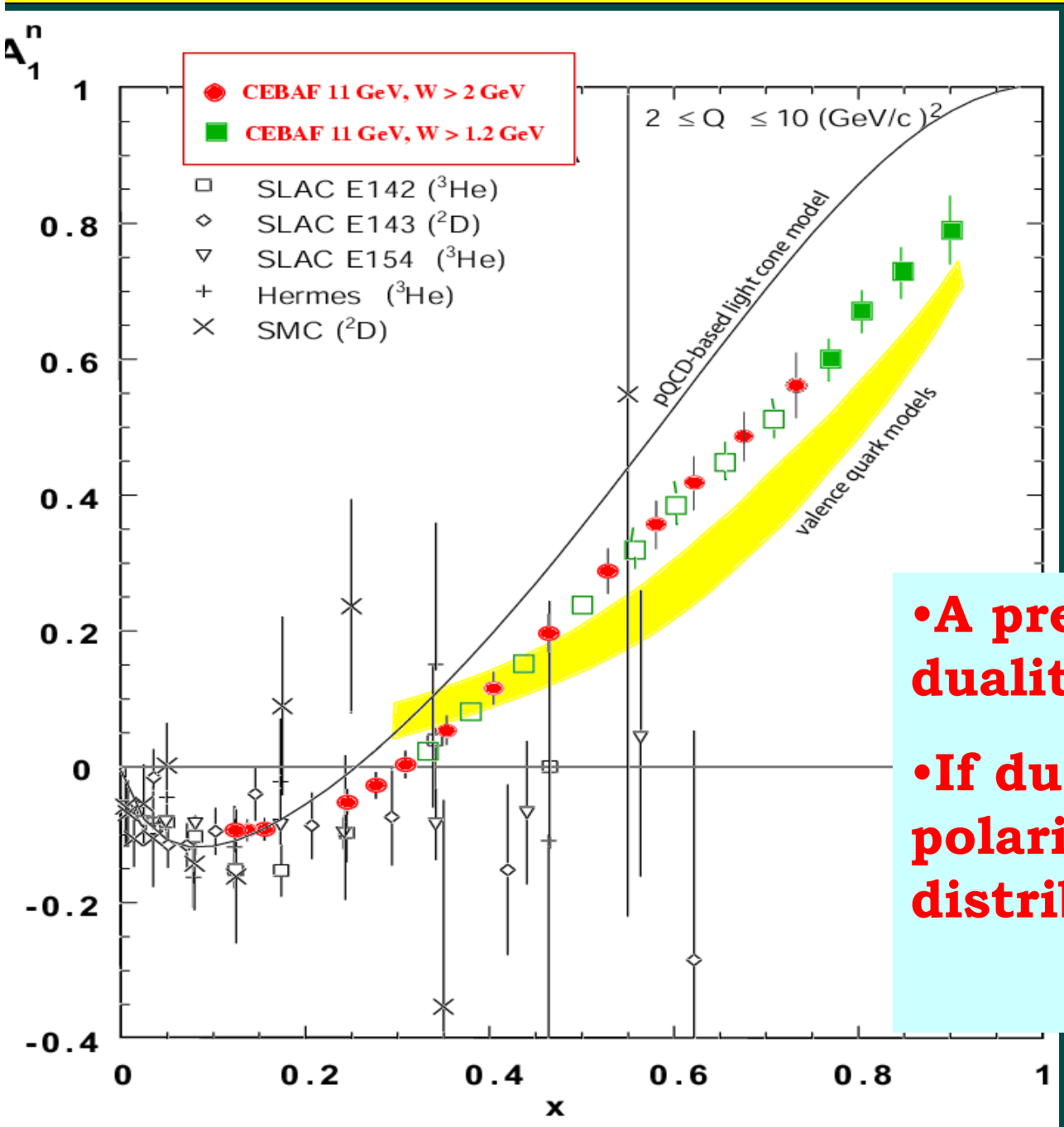



Elastic analysis
asym. per run
average data
simulation M.C.
left arm
right arm
(0, in) --> (-)
(180, in) --> (+)
(0, out) --> (+)
Asymmetry
run number
0.1
0.08
0.06
0.04
0.02
0
190
200
210
220
230
240

E01-012: Preliminary results



Spin-duality with Jefferson Lab at 12 GeV



- **A precision test of spin-duality up to x ~ 0.75**
- **If duality established: polarized quark distributions up to x ~0.85**

Summary and Outlook

- E01-012 provides precision SSF data on the neutron for $1<Q^2<4$ GeV^2
- Direct extraction of g_1 and g_2 (and A_1/A_2) from our data
- Data analysis is in progress: preliminary results expected by this Fall.
- Using overlap between E01-012 resonance data and DIS data:
  - test of spin-flavor dependence of duality
- With 12 GeV at Jefferson lab:
  - A precision test of spin-duality up to x ~ 0.75
  - If duality established: polarized quark distributions up to x ~0.85