Test of Quark-Hadron Duality on Neutron and ^{3}He Spin Structure Functions

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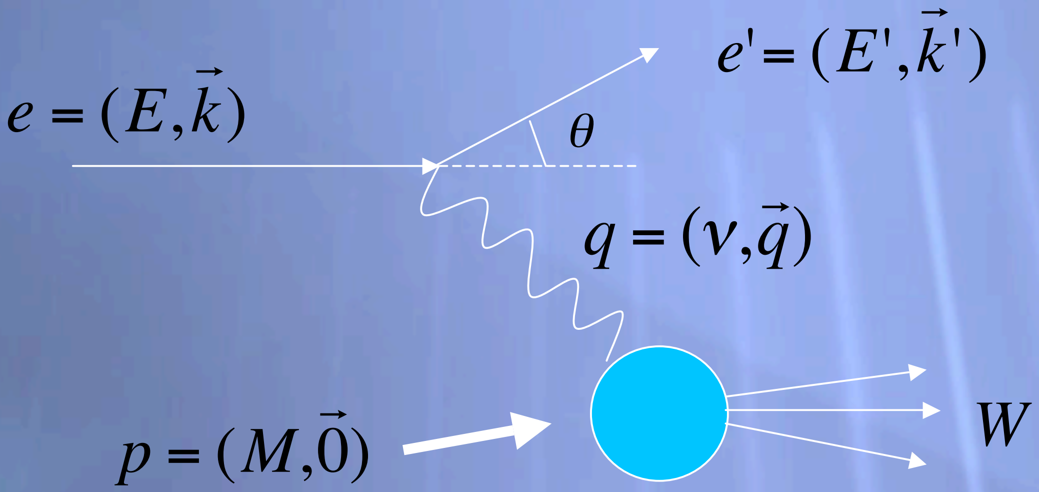
For the Jlab Hall A Collaboration

Graduate Student Lunch Seminar
Jefferson Lab
February 15, 2006

Outlines

- Brief theoretical description of Quark-Hadron Duality
- Experimental setup
- Analysis steps
- Preliminary results on the Spin Structure Functions
- Preliminary test of Quark-Hadron Duality on Neutron and ^{3}He

Inclusive Experiment



__Photon virtuality__

$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

__Invariant mass squared__

$$W^2 = M^2 + 2M\nu - Q^2$$

__Bjorken variable__

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

Unpolarized case

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\tfrac{\theta}{2}\right]$$

Polarized case

$$\frac{d^2\sigma^{\uparrow\Uparrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Uparrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{\nu E Q^2}\left[\left(E + E'\cos\theta\right)g_1(x,Q^2) - 2Mx\,g_2(x,Q^2)\right]$$

$$\frac{d^2\sigma^{\uparrow\Rightarrow}}{d\Omega dE'} - \frac{d^2\sigma^{\downarrow\Rightarrow}}{d\Omega dE'} = \frac{4\alpha^2 E'}{\nu E Q^2}\sin\theta\left[g_1(x,Q^2) + \frac{2ME}{\nu}g_2(x,Q^2)\right]$$

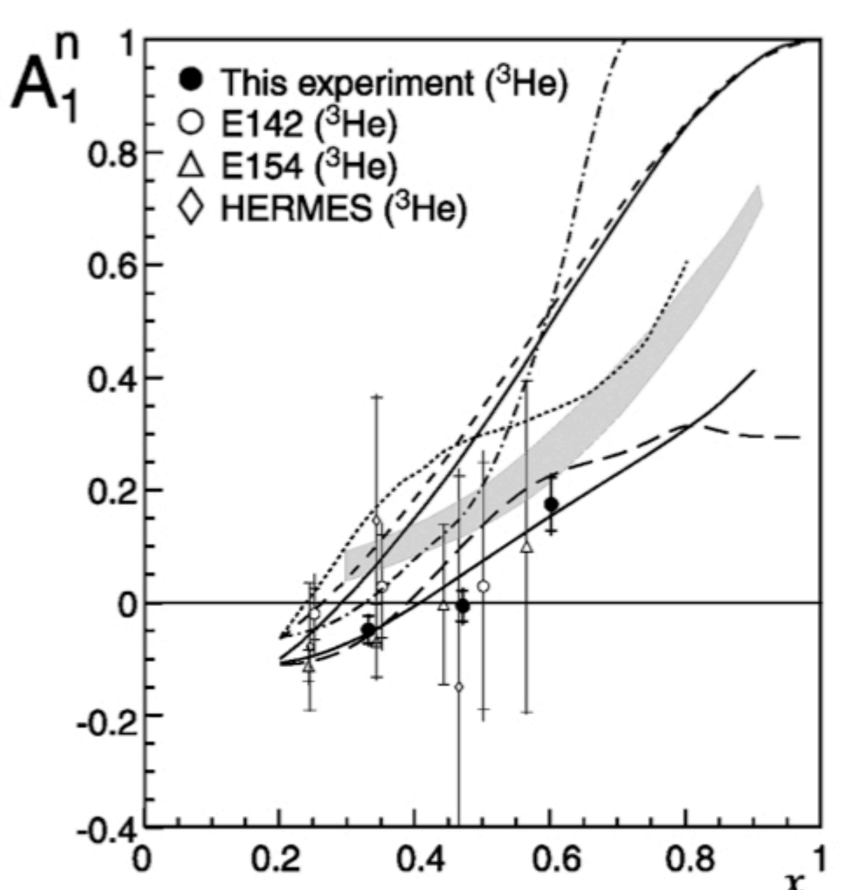
Structure functions in the parton model

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 q_i(x) = \frac{1}{2}\sum_i e_i^2 [q_i^{\uparrow}(x) + q_i^{\downarrow}(x)]$$

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x) = \frac{1}{2}\sum_i e_i^2 [q_i^{\uparrow}(x) - q_i^{\downarrow}(x)]$$

$$A_1(x) \approx \frac{g_1(x)}{F_1(x)}$$

Large x region: valence quarks dominate

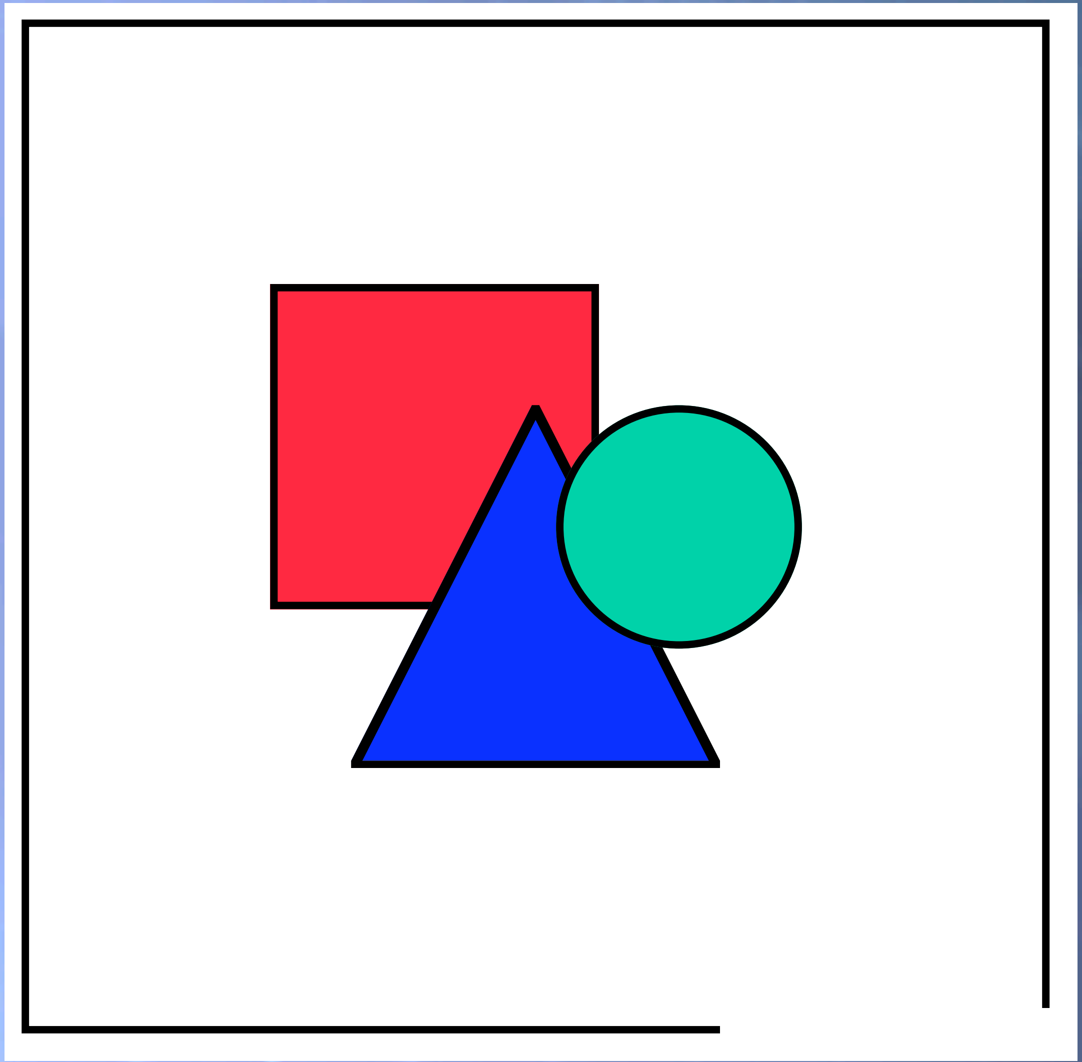


X. Zheng et al., PRL 91 (2004) 12004

Quark-hadron duality

- First observed by Bloom and Gilman in the 1970's on F_2

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

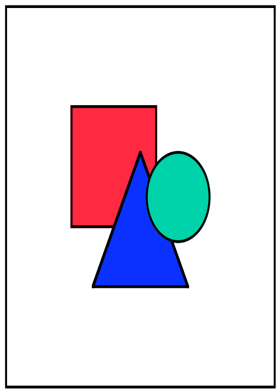


I. Niculescu et al., PRL 85 (2000) 1182

Quark-hadron duality (cont'd)

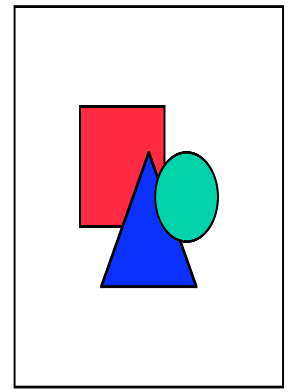
Short distance

W>2GeV



Asymptotic Freedom

Long distance



W<2GeV

Confinement

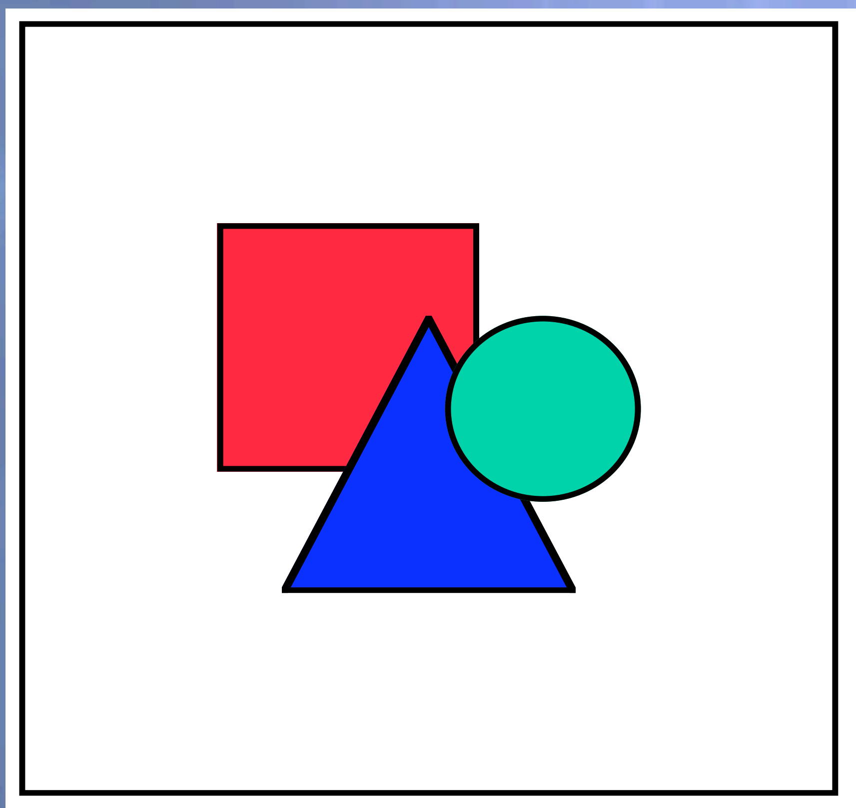
Two very different behaving in average the same way !

Resonance vs. scaling

Scaling ⇒ Q^2 independence of structure function moments
⇒ resonance region is a part of the scaling regime

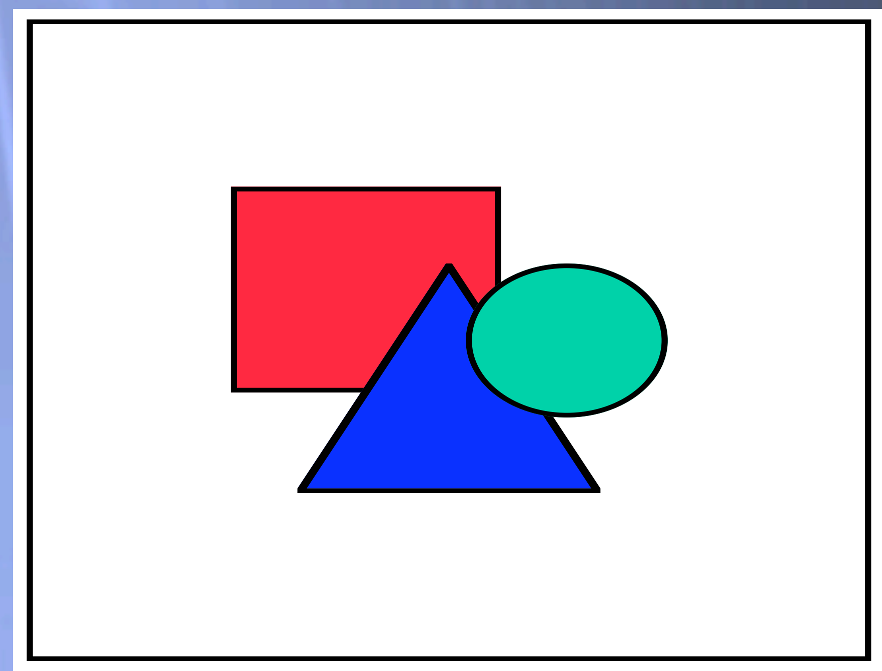
$$\Gamma_1(Q^2) = \int g_1(x,Q^2)dx$$

proton



R. fatemi et al., PRL 91 (2003) 222002

neutron



M. Amerian et al., PRL 859(2002) 242301

World data

Confirmation of duality for the spin-independent SF

- Jlab Hall C for F_2^p and F_2^d — I. Niculescu et al., PRL 85 (2000) 1182

Hint of duality for the spin-dependent SF

- HERMES for A_1^p

  A. Airapeian et al., PRL 90 (2003) 092002

- Jlab Hall B for g_1^p and g_1^d

- Jlab Hall A for g_1^{3He}

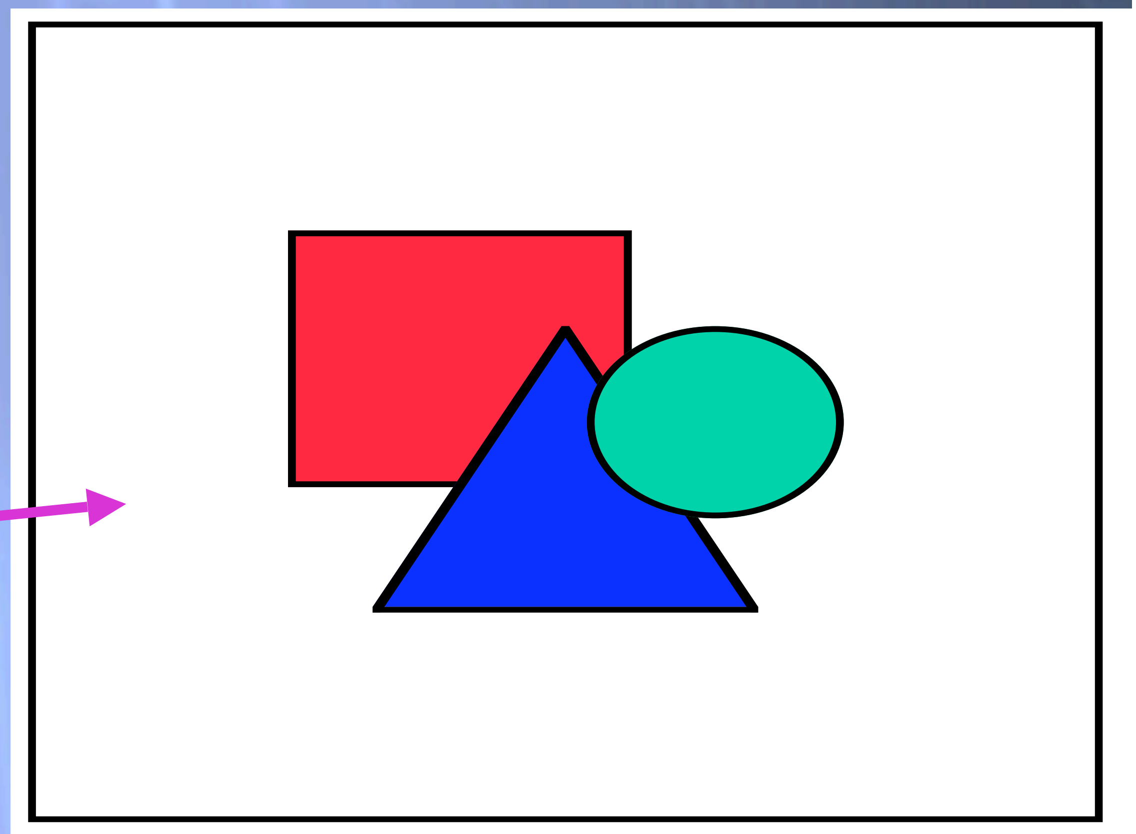


Figure from Seonho Choi

The experiment E01-012

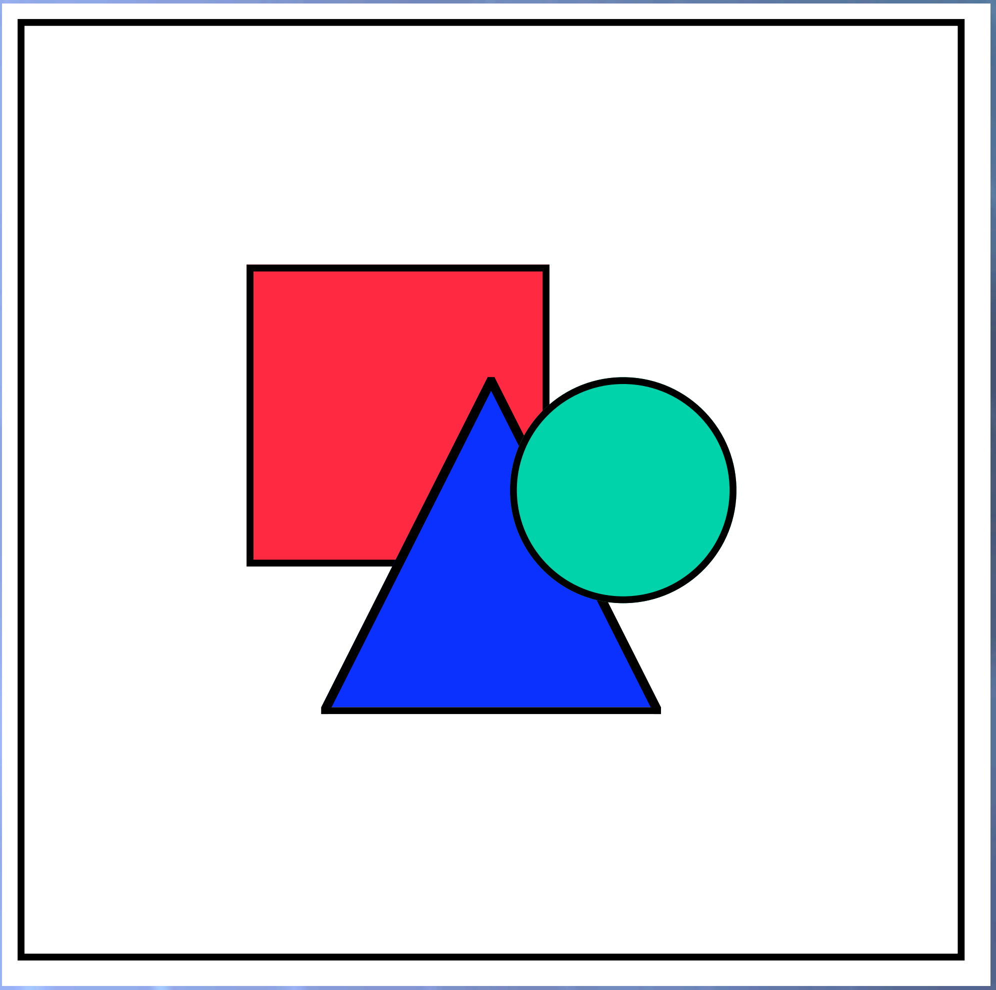
- Ran in Jan.-Feb. 2003

- Inclusive experiment:

  $^{3}\vec{He}(\vec{e},e')X$

- Measured polarized cross section differences

- Form g_1, g_2, A_1 and A_2



Test of spin duality on the neutron (and ^{3}He)

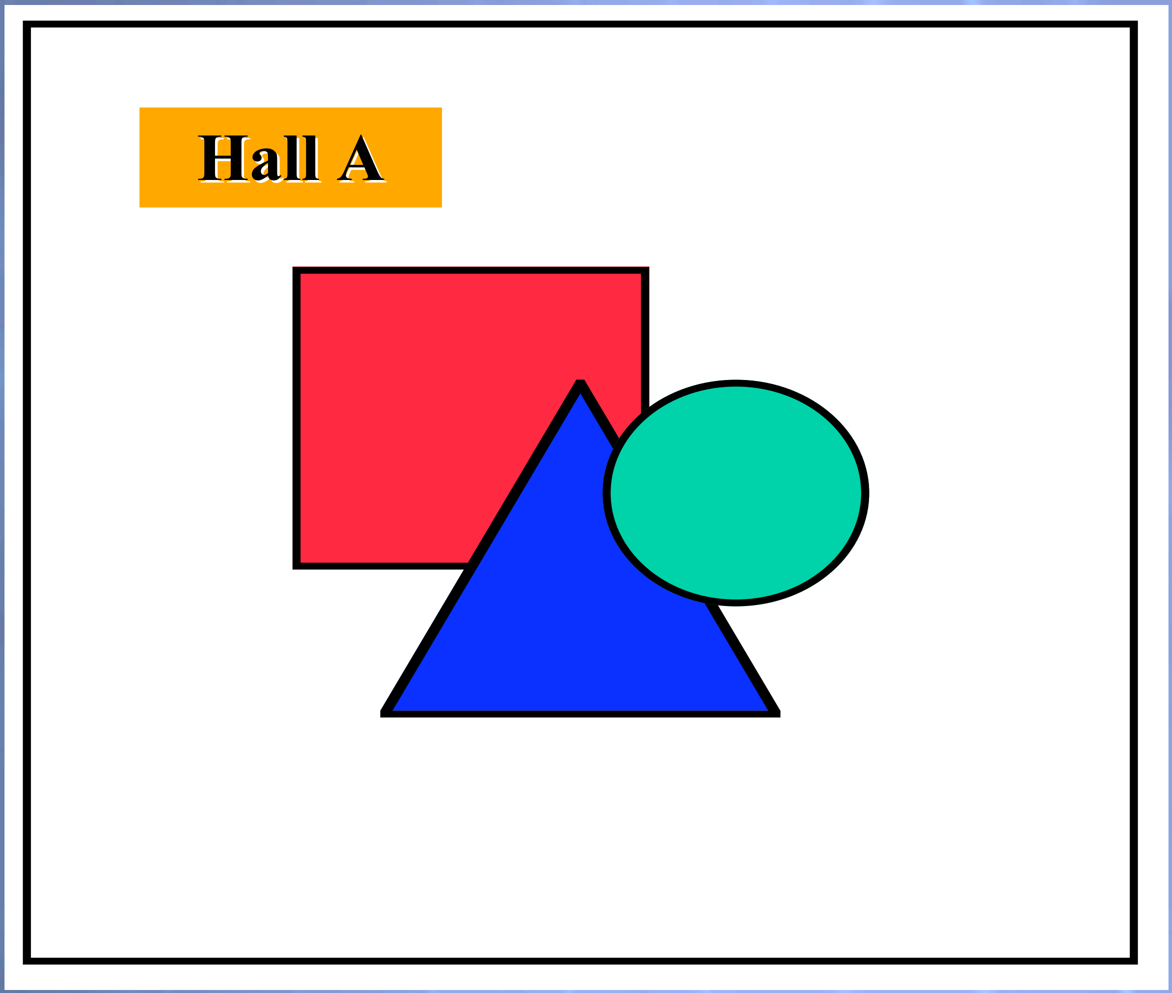
The E01-012 Collaboration

K. Aniol, T. Averett, W. Boeglin, A. Camsonne, G.D. Cates,
G. Chang, J.-P. Chen, Seonho Choi, E. Chudakov, B. Craver,
F. Cusanno, A. Deur, D. Dutta, R. Ent, R. Feuerbach,
S. Frullani, H. Gao, F. Garibaldi, R. Gilman, C. Glashausser,
O. Hansen, D. Higinbotham, H. Ibrahim, X. Jiang, M. Jones,
A. Kelleher, J. Kelly, C. Keppel, W. Kim, W. Korsch,K. Kramer,
G. Kumbartzki, J. LeRose, R. Lindgren, N. Liyanage, B. Ma,
D. Margaziotis, P. Markowitz, K. McCormick, Z.-E. Meziani,
R. Michaels, B. Moffit, P. Monaghan, C. Munoz Camacho,
K. Paschke, B. Reitz, A. Saha, R. Sheyor, J. Singh, K. Slifer,
P. Solvignon, V. Sulkosky, A. Tobias, G. Urciuoli, K. Wang,
K. Wijesooriya, B. Wojtsekhowski, S. Woo, J.-C. Yang,
X. Zheng, L. Zhu

and the Jefferson Lab Hall A Collaboration

Experimental setup

❖ Polarized e^- beam at 3.0, 4.0 and 5.0GeV



❖ Both HRS in symmetric configuration at 25° and 32°

→ double the statistics
→ control the systematics

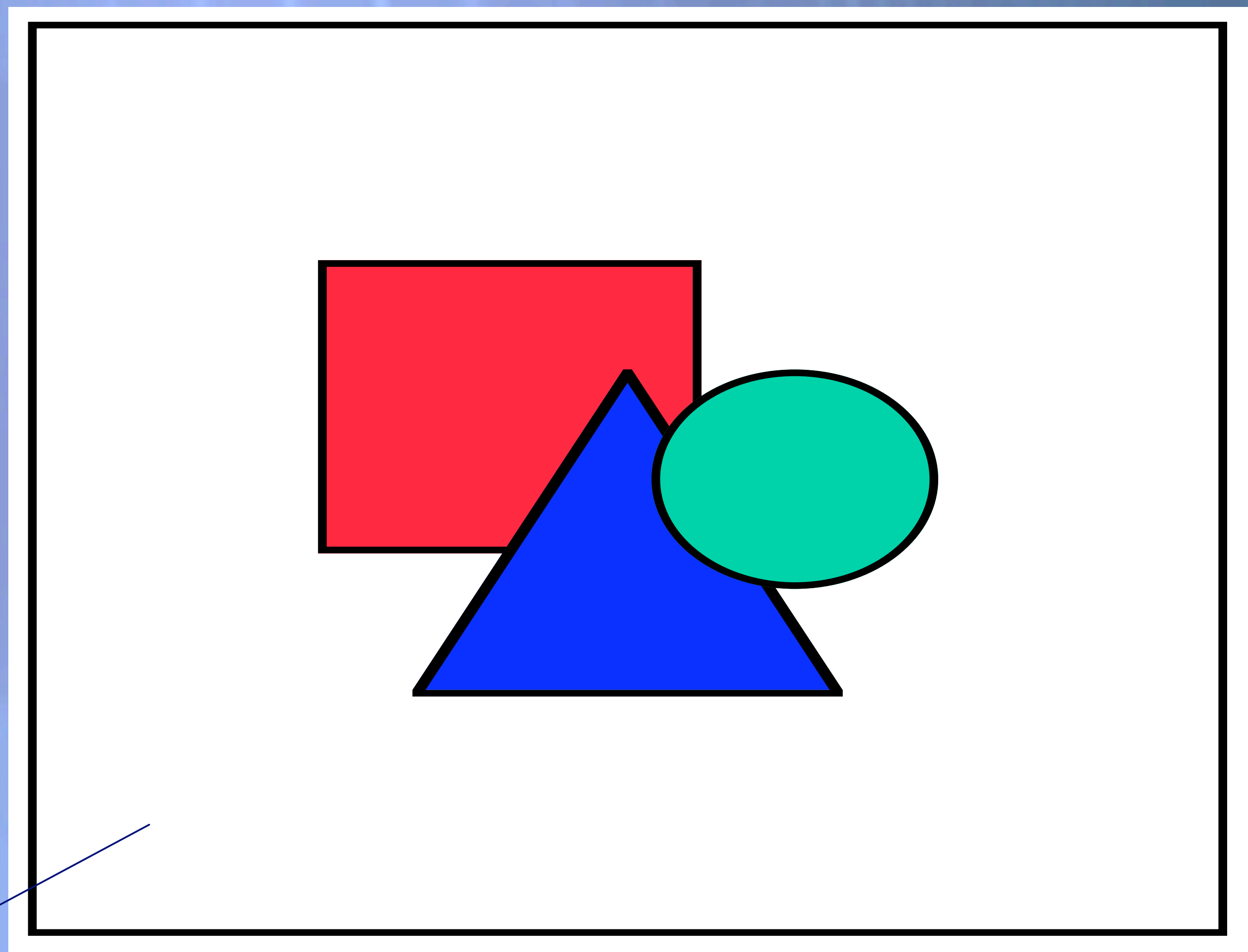
❖ Particle ID = Cerenkov + EM calorimeter

The CO_2 gas Cerenkov counter

Index de refraction:
n = 1.00041

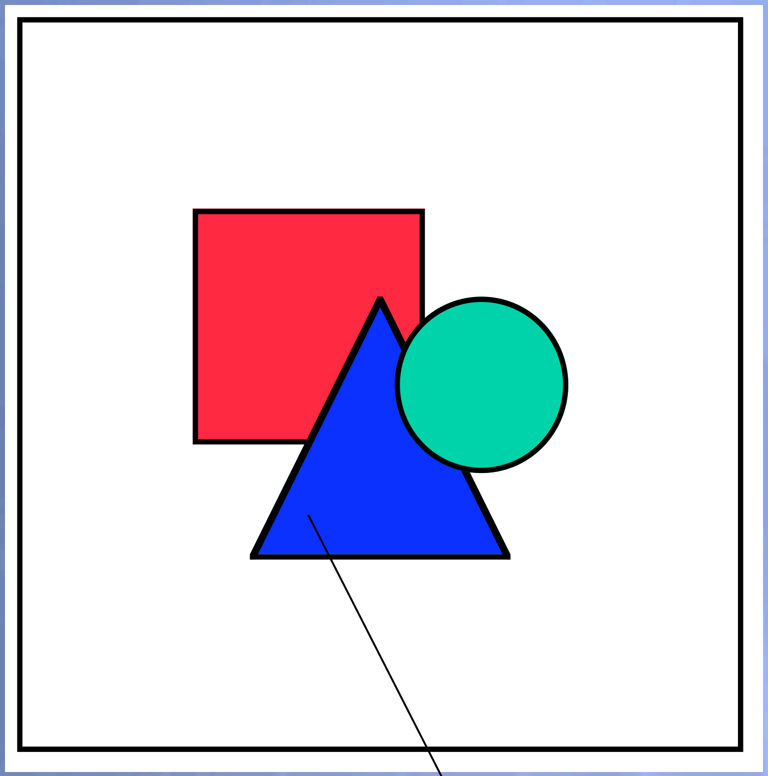
$$P^{e^-}_{thres.} = 18\,MeV$$

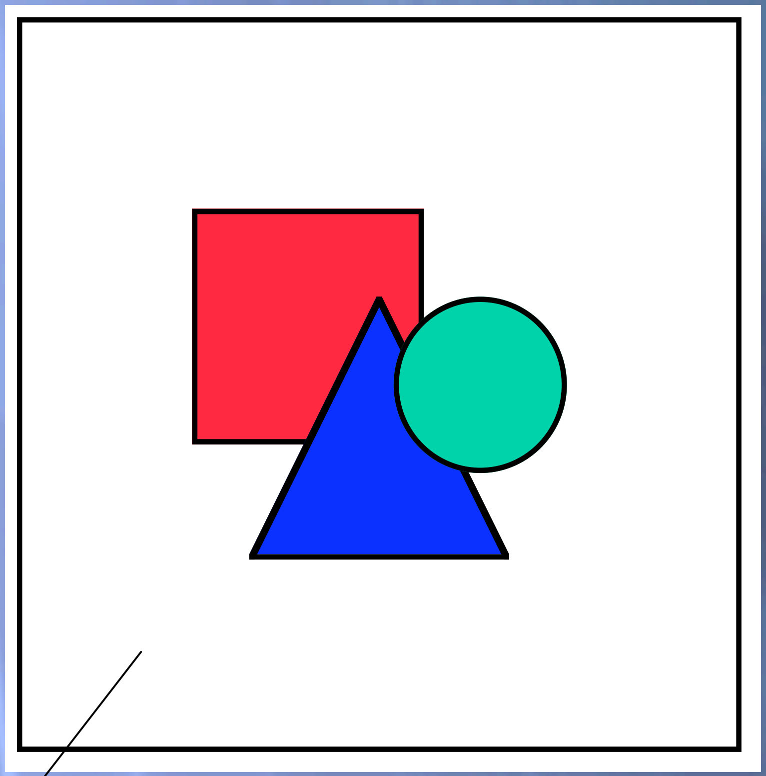
$$P^{\pi^-}_{thres.} = 4.9\,GeV$$



Knock-out e^-
&
Low energy e^-

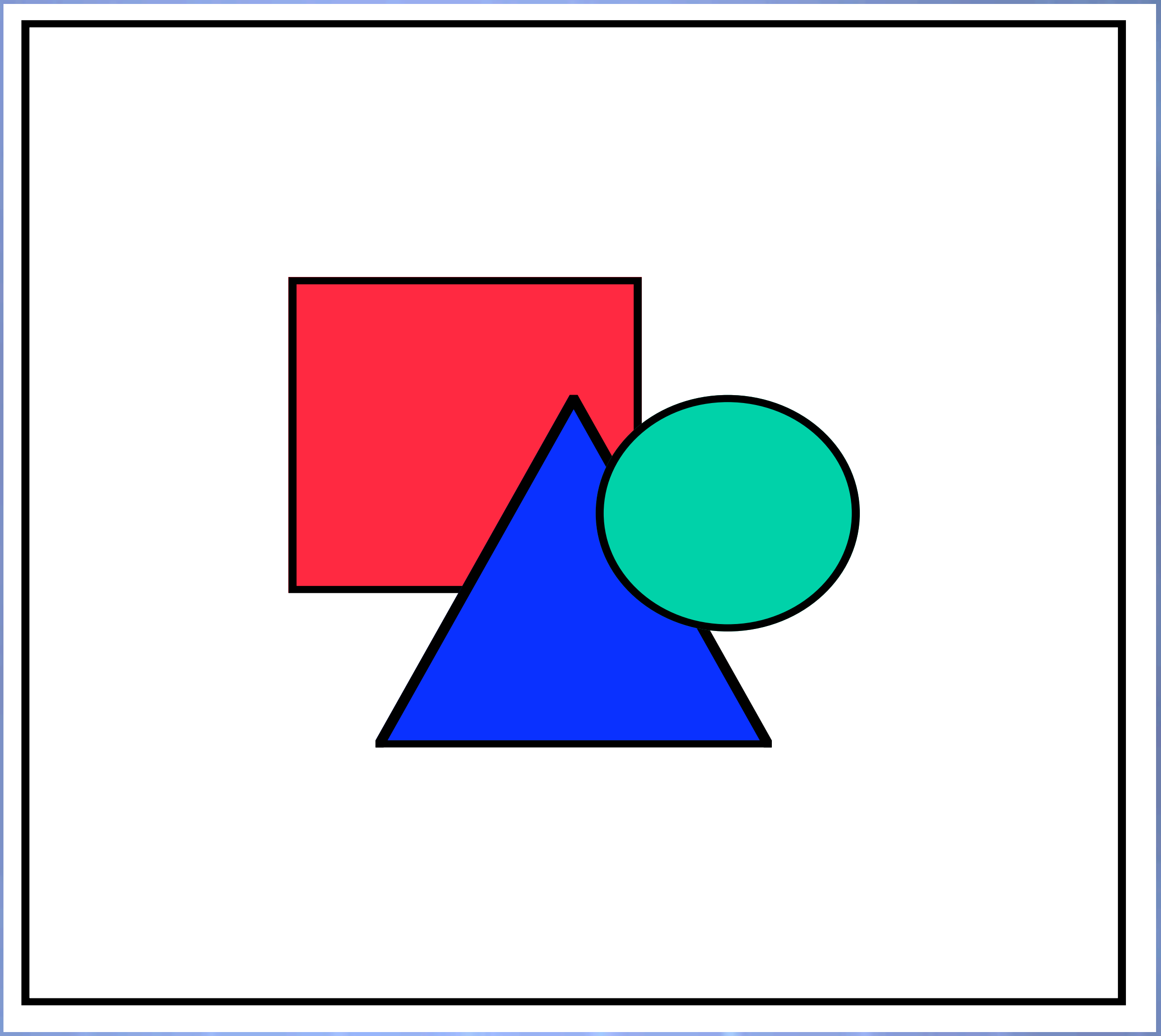
Lead Glass Calorimeter





Cuts applied for electron efficiency > 99%

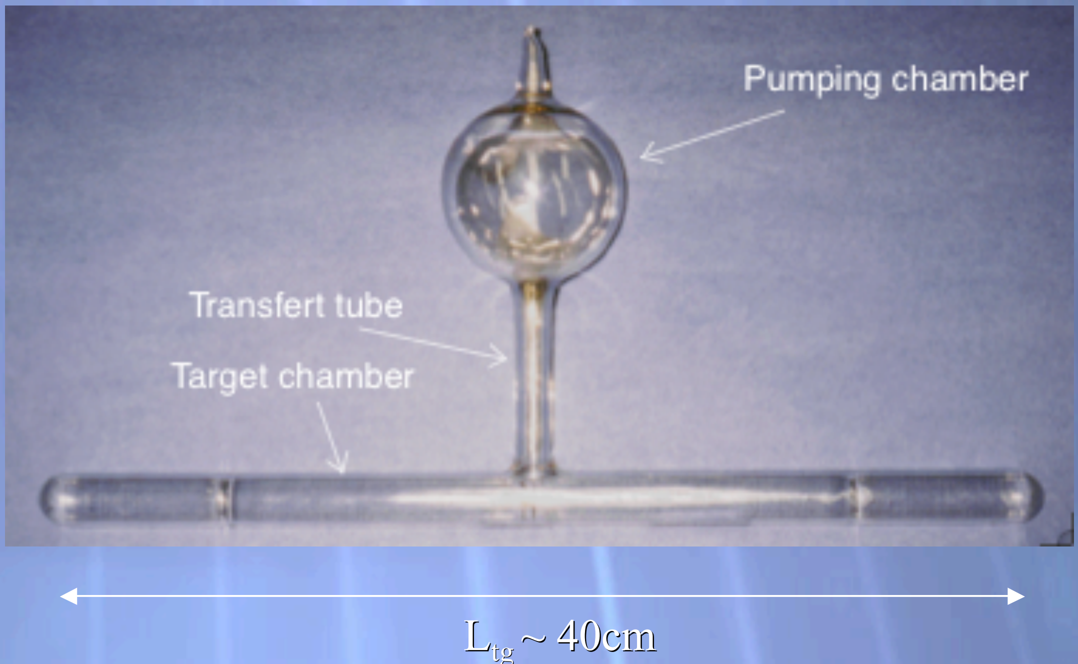
Particle identification performance



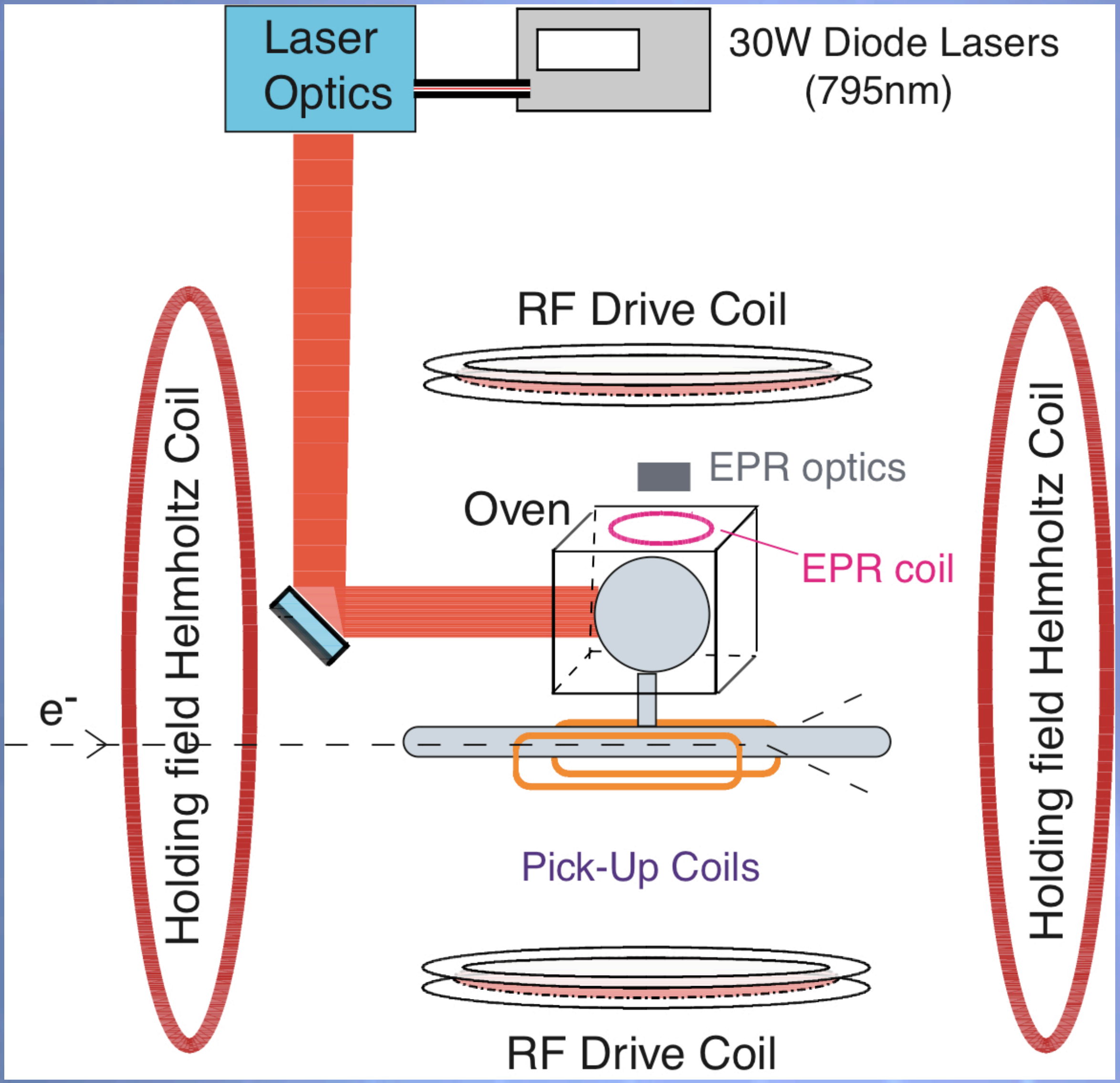
π/e reduced by 10^4 and electron efficiency kept above 98%

The polarized ^{3}He target

- Two chamber cell
- Pressure ~ 14 atm under running conditions
- High luminosity: 10^{36} $s^{-1}cm^{-2}$

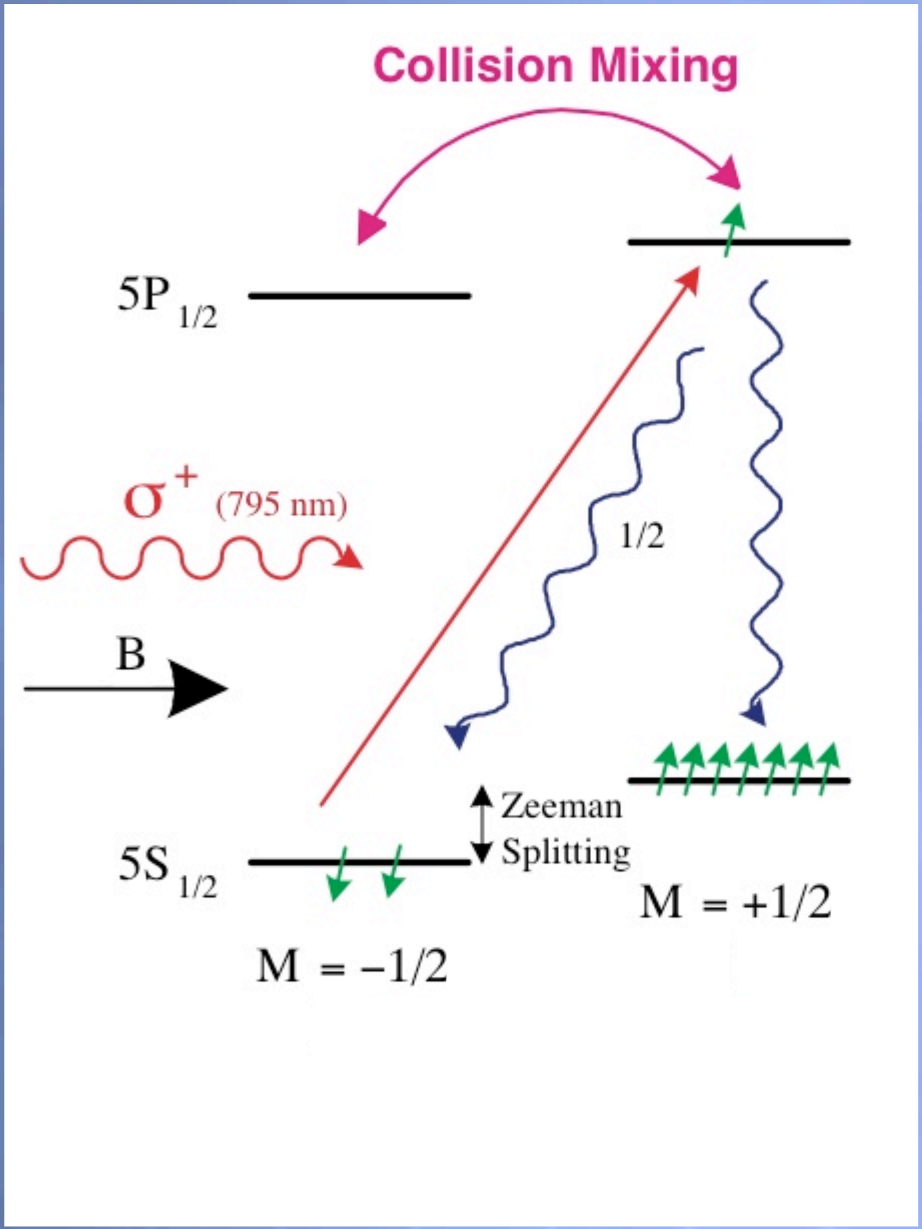


The polarized ^{3}He target



- ♦ Longitudinal and transverse configurations
- ♦ 2 independent polarimetries: NMR and EPR

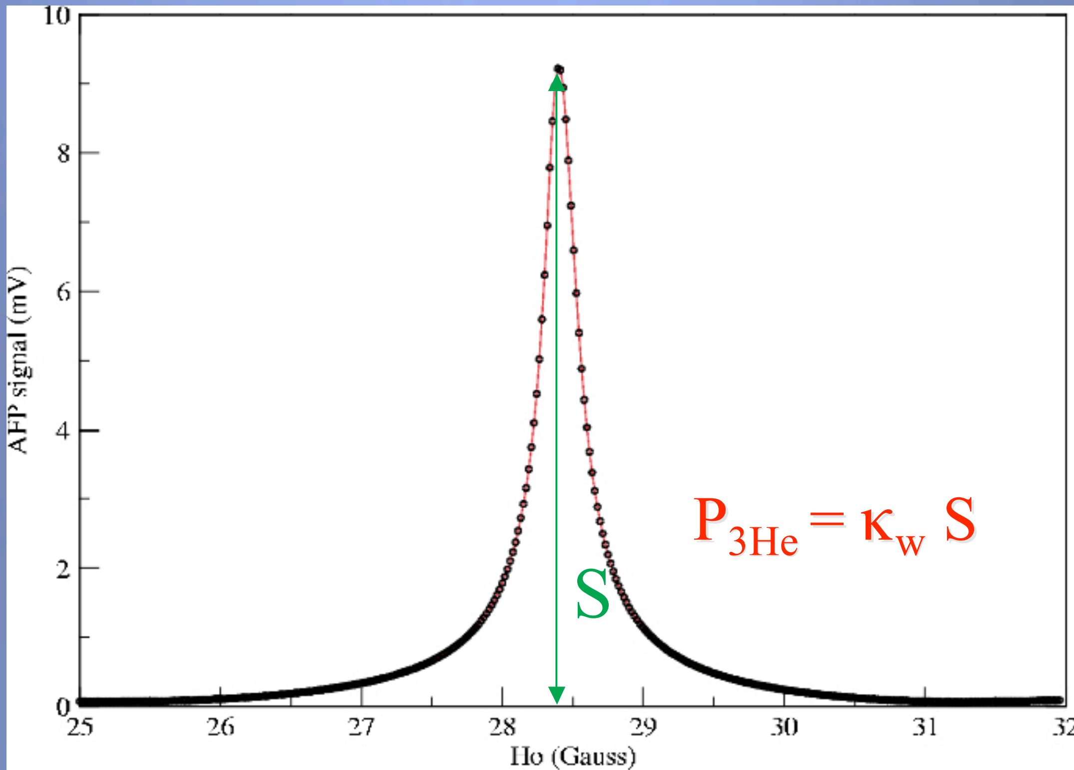
How to polarize ^{3}He ?



Two step process:

1. Rb vapor is polarized by optical pumping with circularly polarized light
2. Rb e^- polarization is transferred to ^{3}He nucleus by spin-exchange interaction

Nuclear Magnetic Resonance



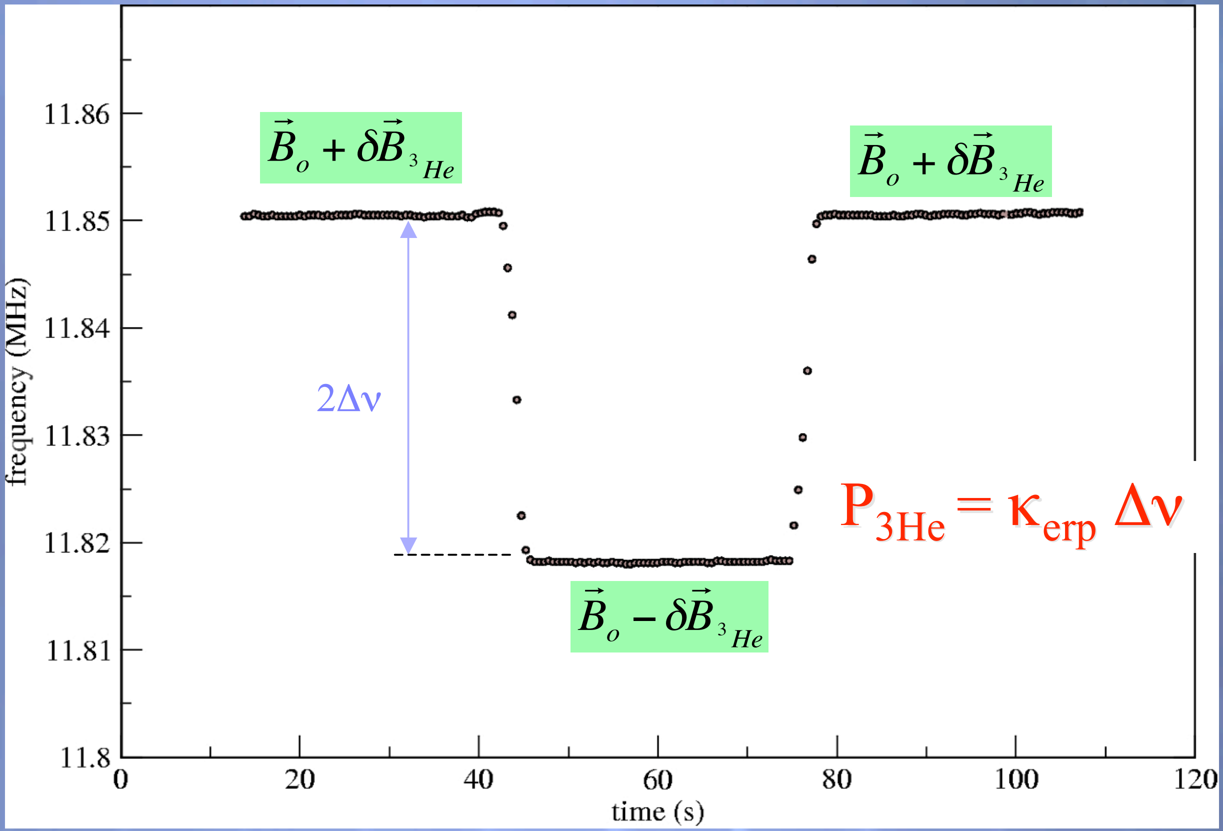
κ_w : from calibration with an identical target cell filled with water

1. Apply perpendicular RF field
2. Ramp holding field (H_0)

} flip the ^3He spins under AFP conditions

$$\frac{1}{T_2} << \frac{1}{H_1}\frac{dH_0}{dt} << \gamma H_1$$

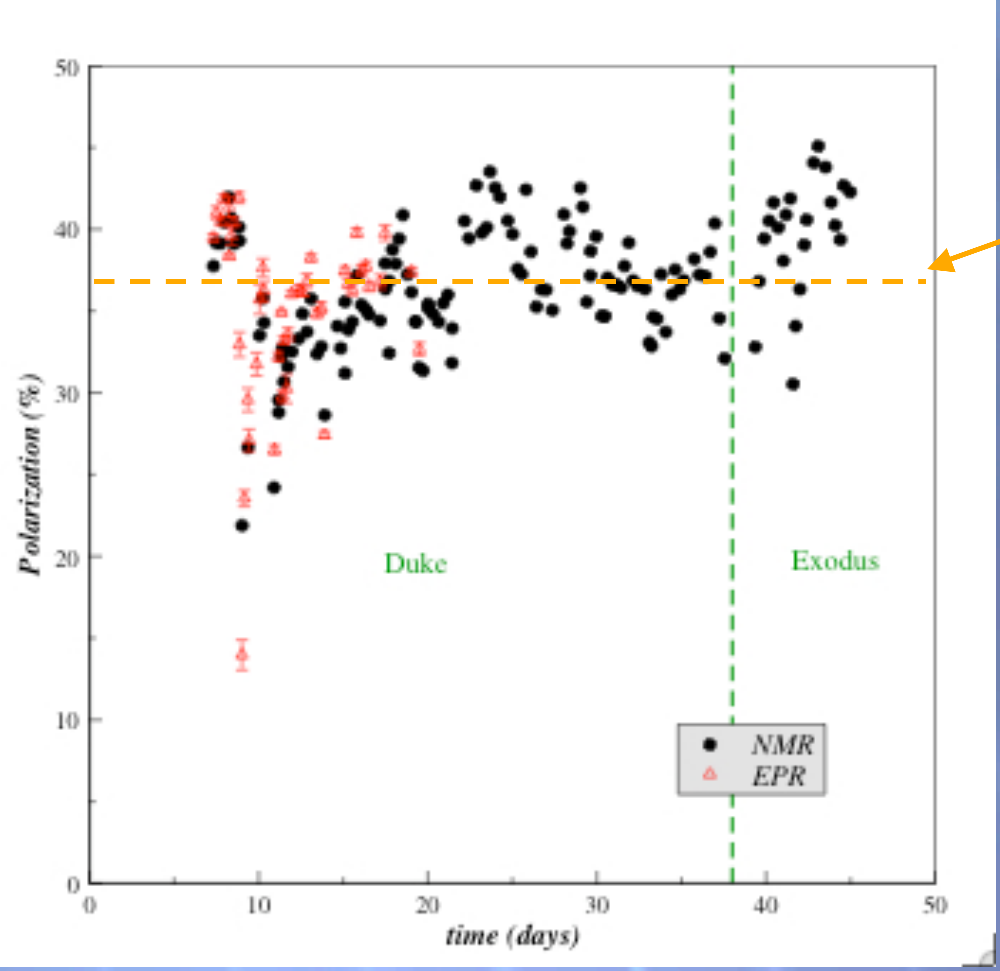
Electron Paramagnetic Resonance



1. Polarized ^{3}He creates an extra magnetic field: δB_{3He}
2. Measure the Zeeman splitting frequency when B_0 and δB_{3He} are aligned and anti-aligned.

κ_{epr} : depend of cell density

Target performance



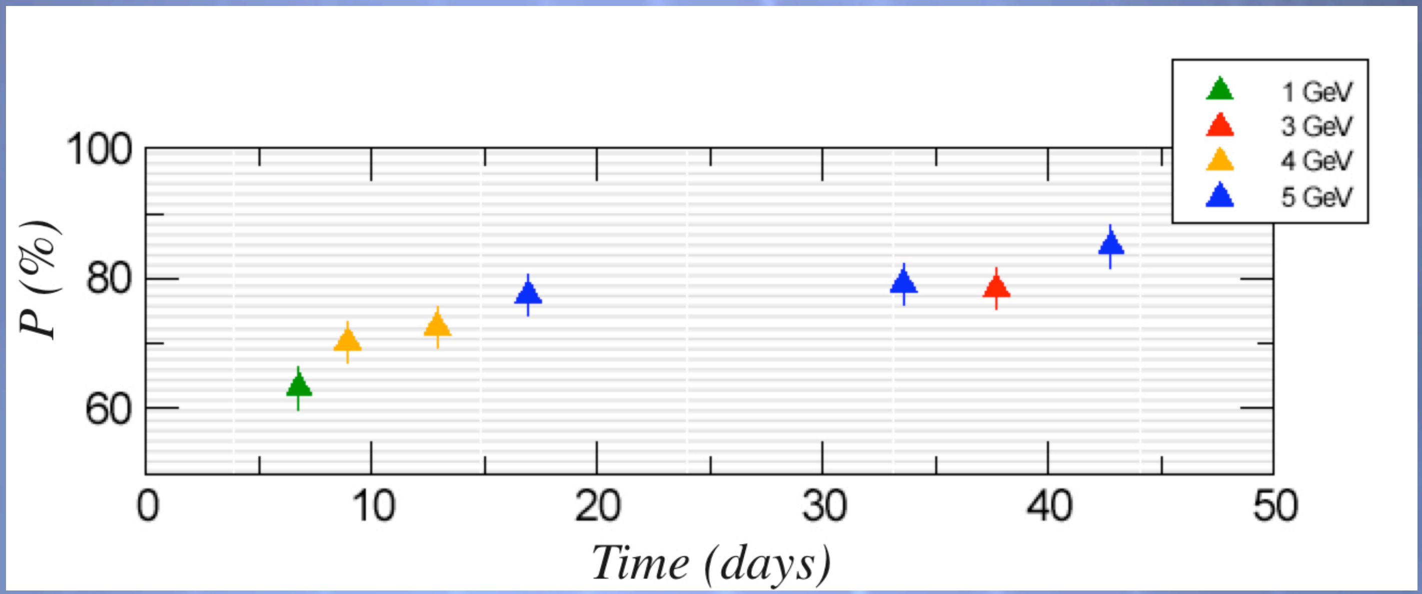
$P_{avg} \sim 37\%$

Statistical errors only

NMR analysis done by Vince Sulkosky

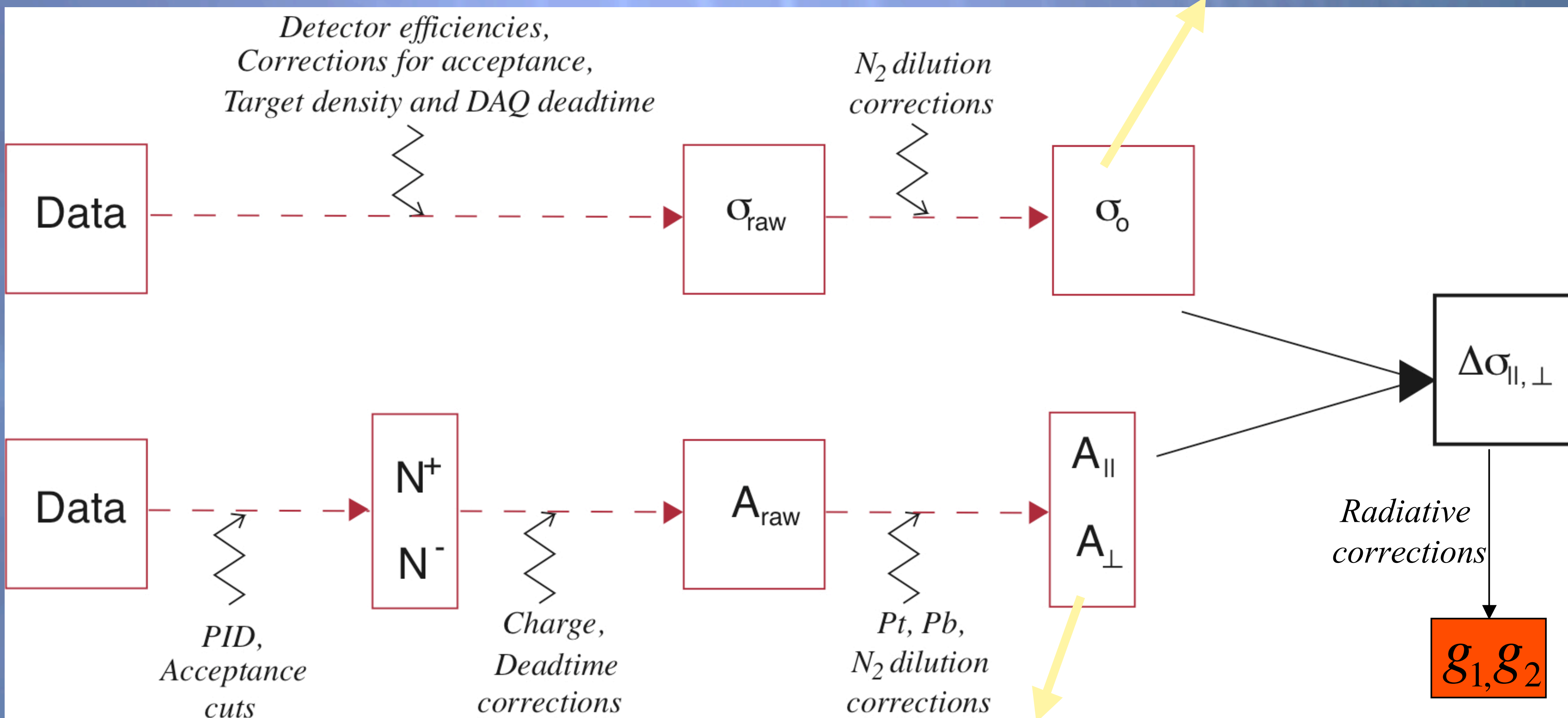
Electron Beam Polarization

- Used Moller Polarimeter: measurements performed by E. Chudakov et al.
- $70 < P_{beam} < 85\%$ for production data



Analysis scheme

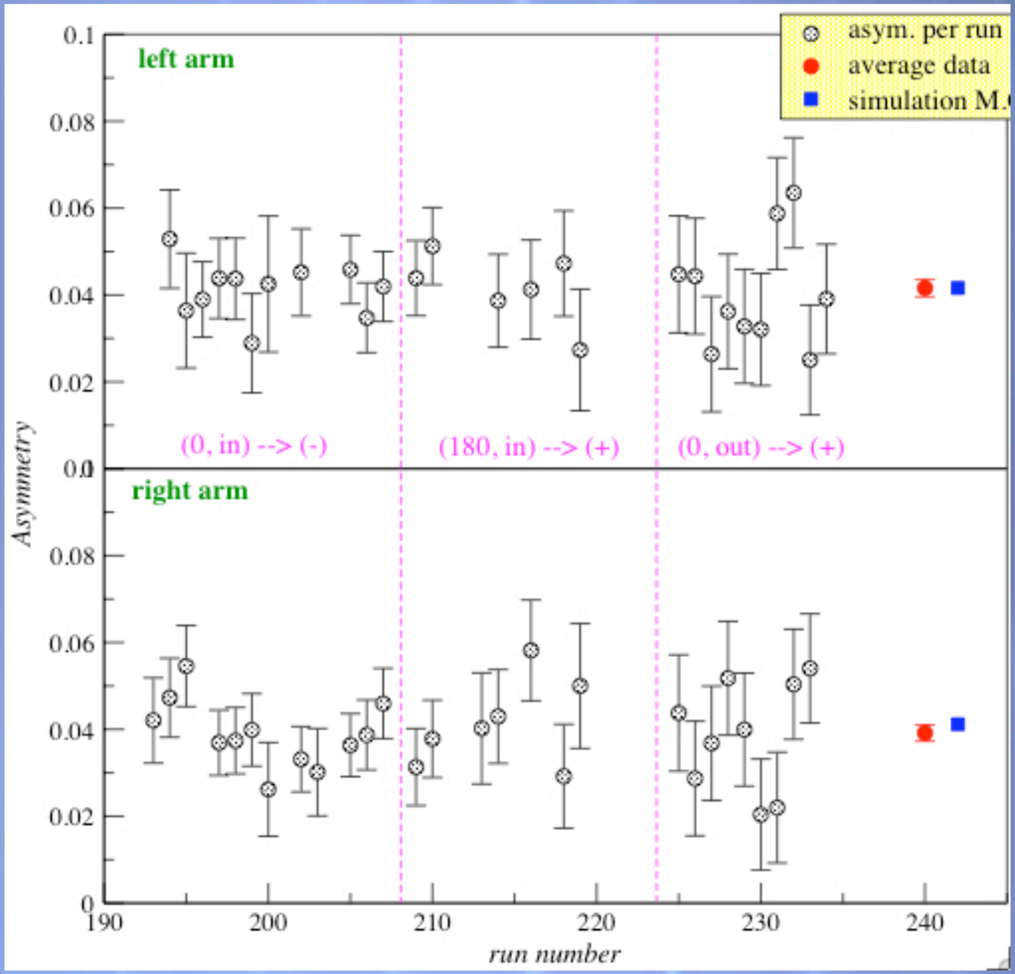
$$\sigma_0 = \frac{N_{cuts}}{N_{inc.}\rho\varepsilon_{\det}LT} * Acc. - \frac{2\rho_{N_2}}{\rho + \rho_{N_2}}\sigma_N$$



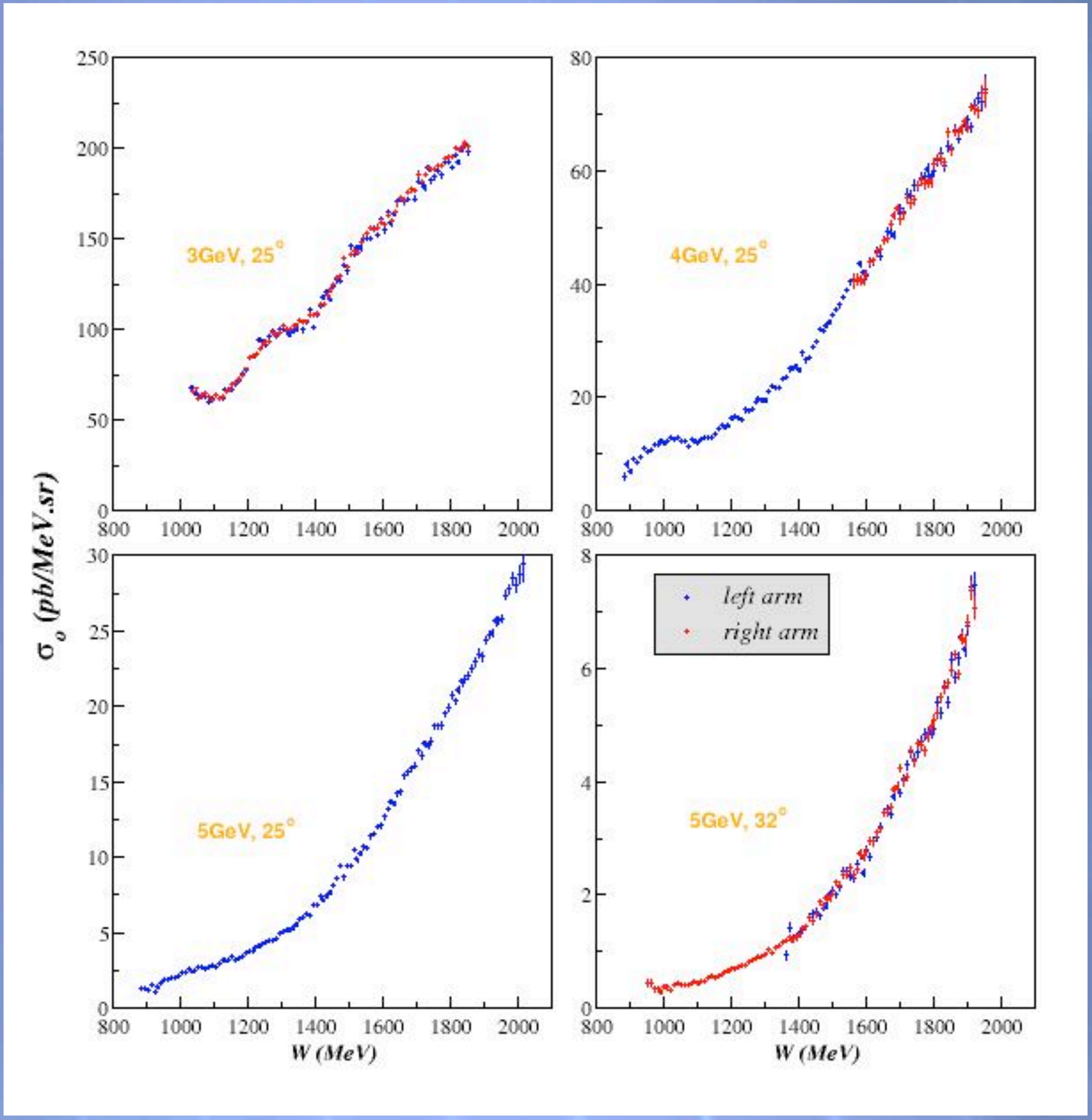
$$A_{\parallel,\perp} = \frac{1}{f_{N_2} P_{tg} P_{beam}} \frac{\frac{N^+}{Q^+LT^+} - \frac{N^-}{Q^-LT^-}}{\frac{N^+}{Q^+LT^+} + \frac{N^-}{Q^-LT^-}}$$

Elastic asymmetry

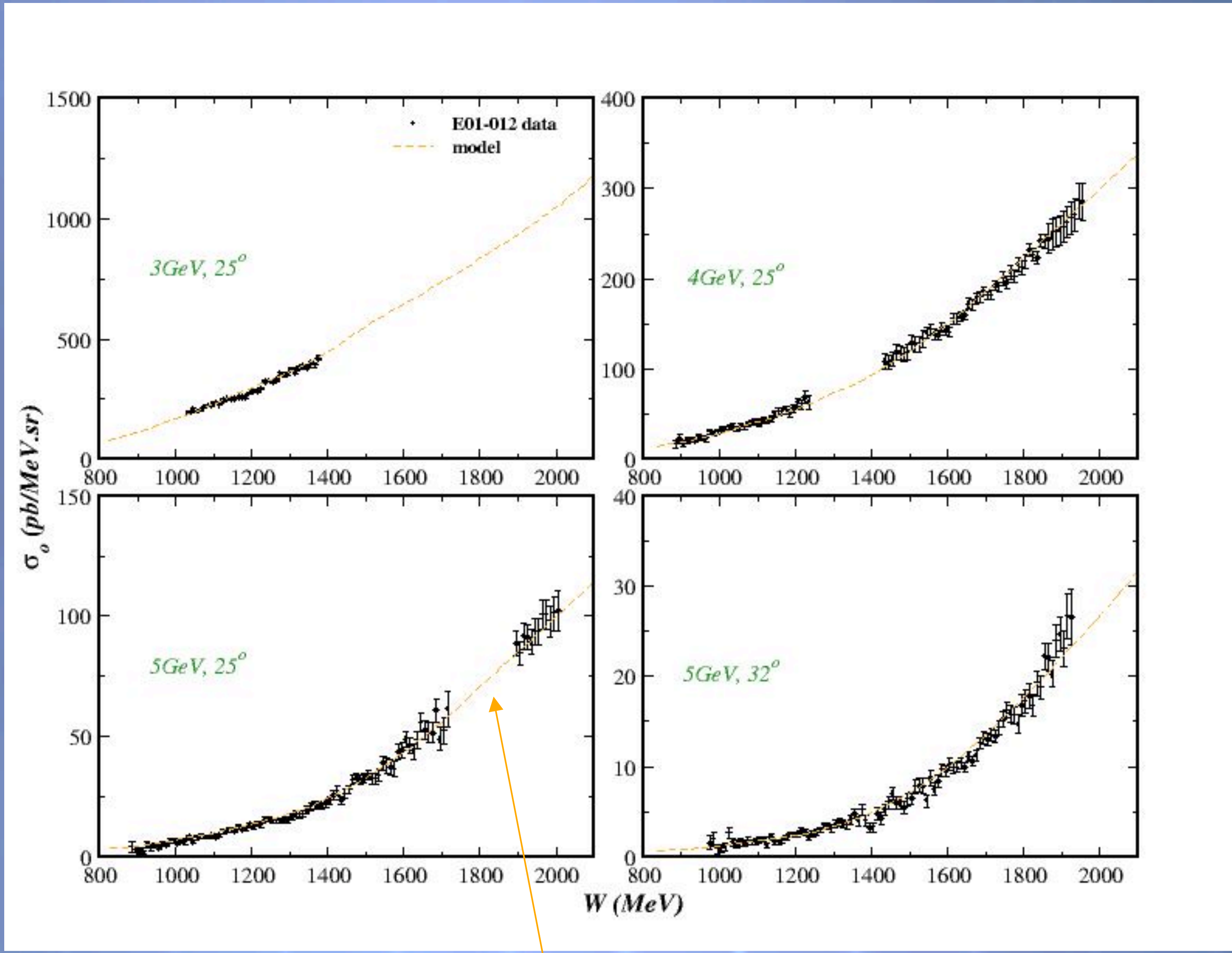
Check of the product: $f_{N_2} P_{tg} P_{beam}$



HRS cross section comparison

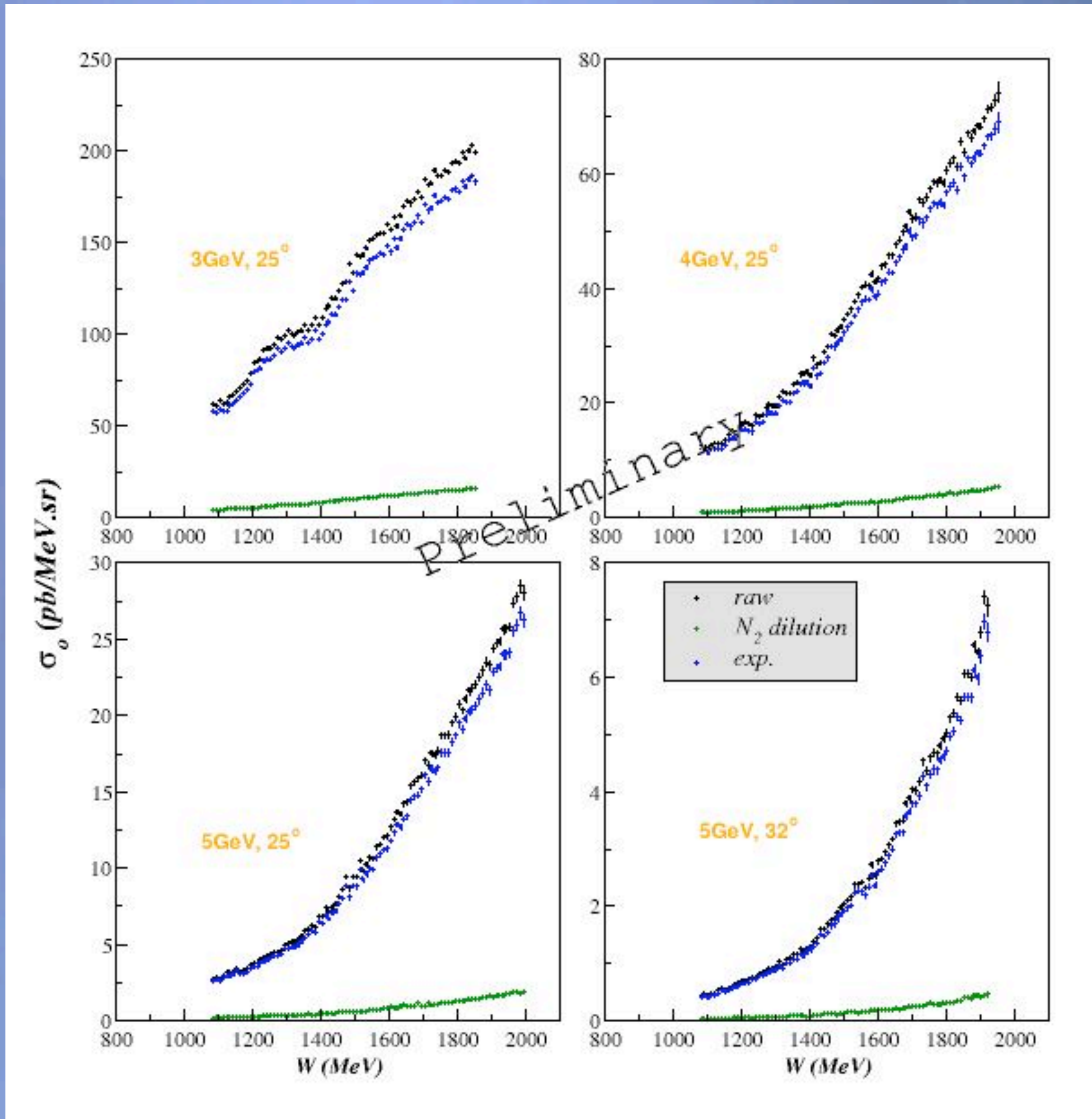


Nitrogen cross sections

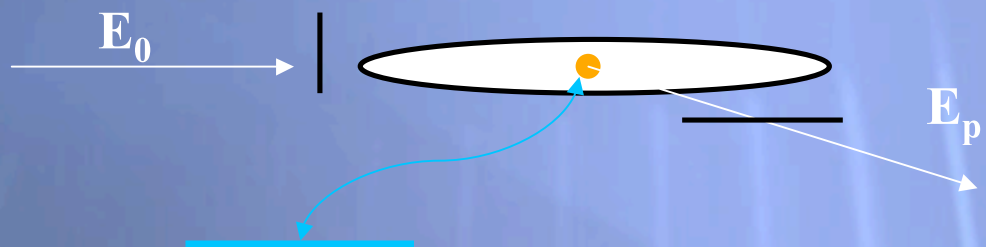


Modified the QFS model by adding energy dependence to the cross sections

^{3}He unpolarized cross sections



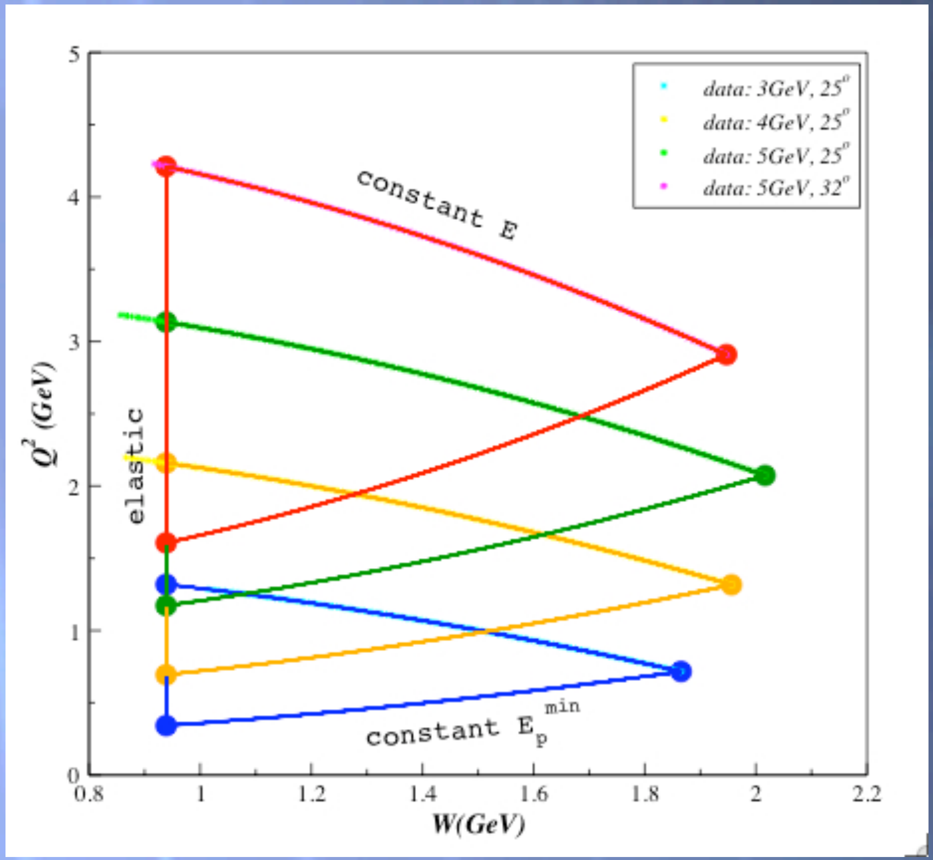
Radiative corrections



$$E_0^r < E_0$$

$$E_p^r > E_p$$

Computation to get the real reaction

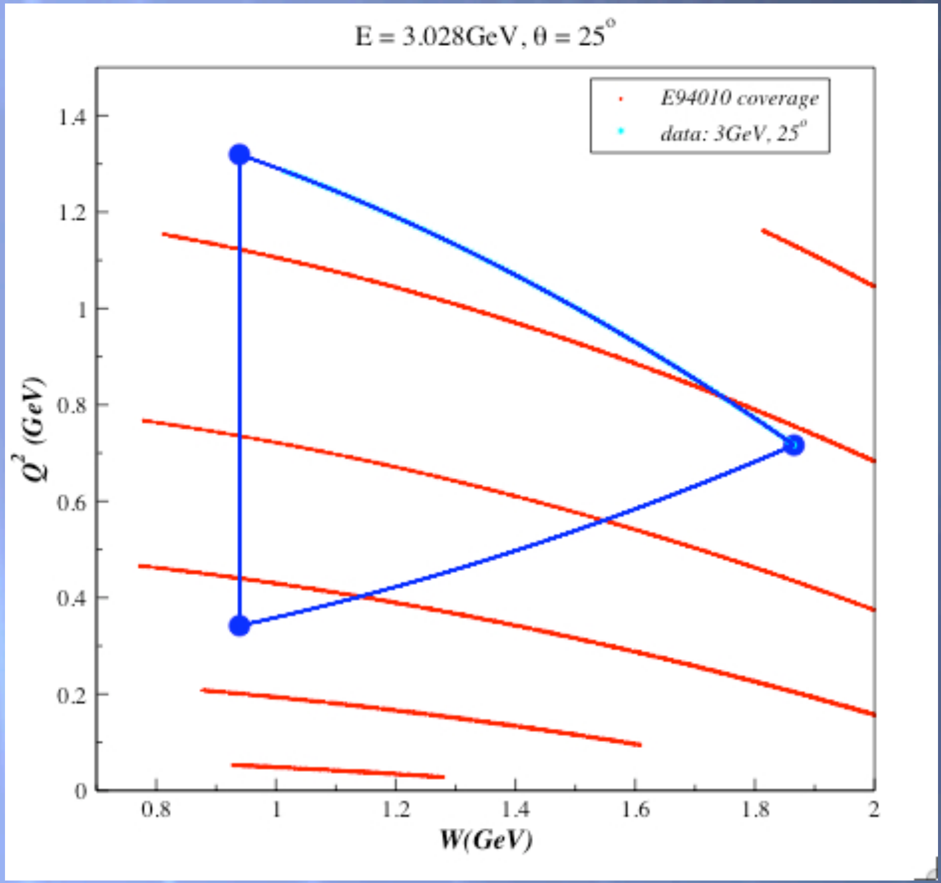


Radiative corrections

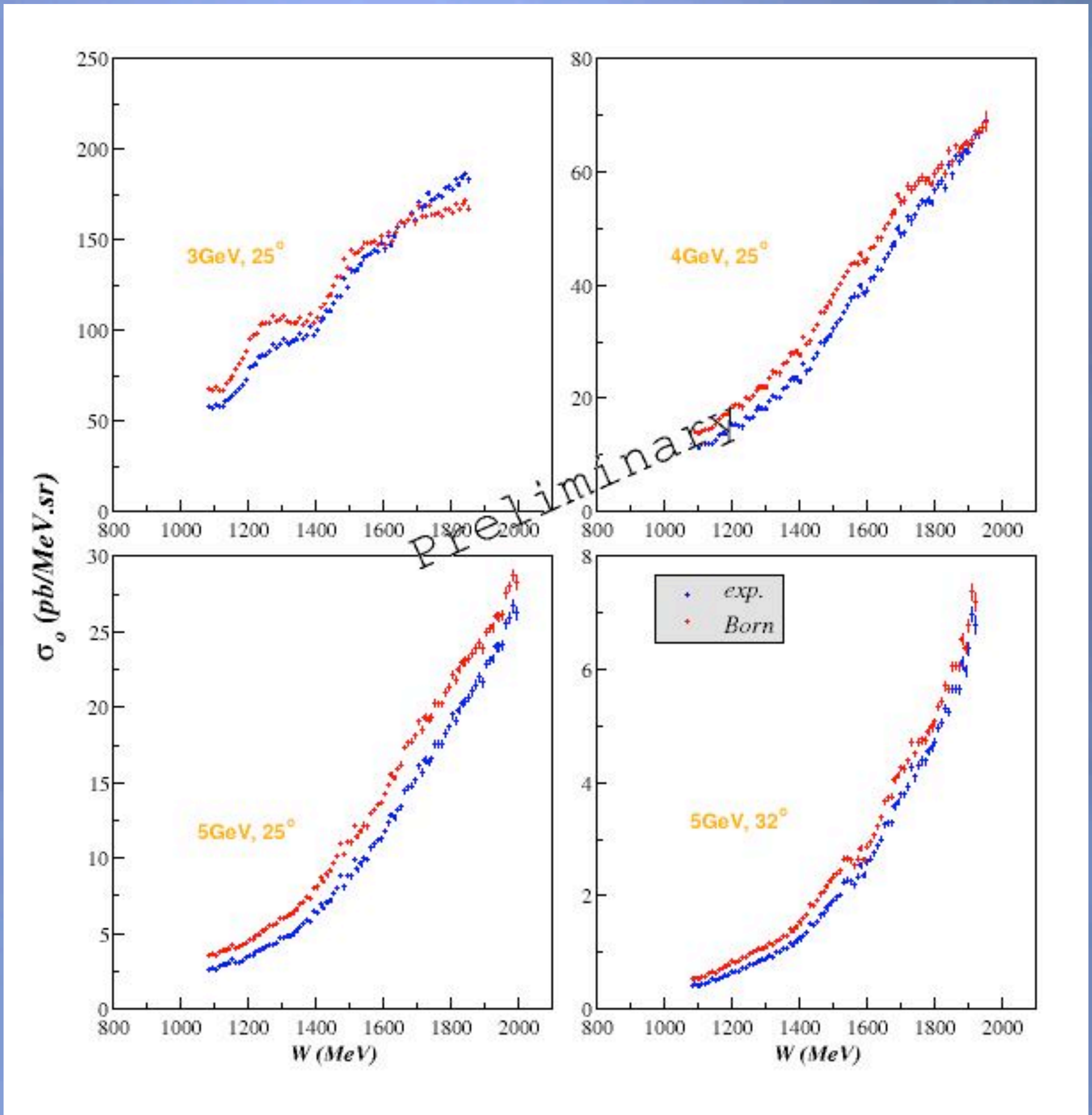
♦ Elastic tail negligible at all aour kinematics

♦ Used E94-010 data as a model for radiative corrections at the lowest energy:

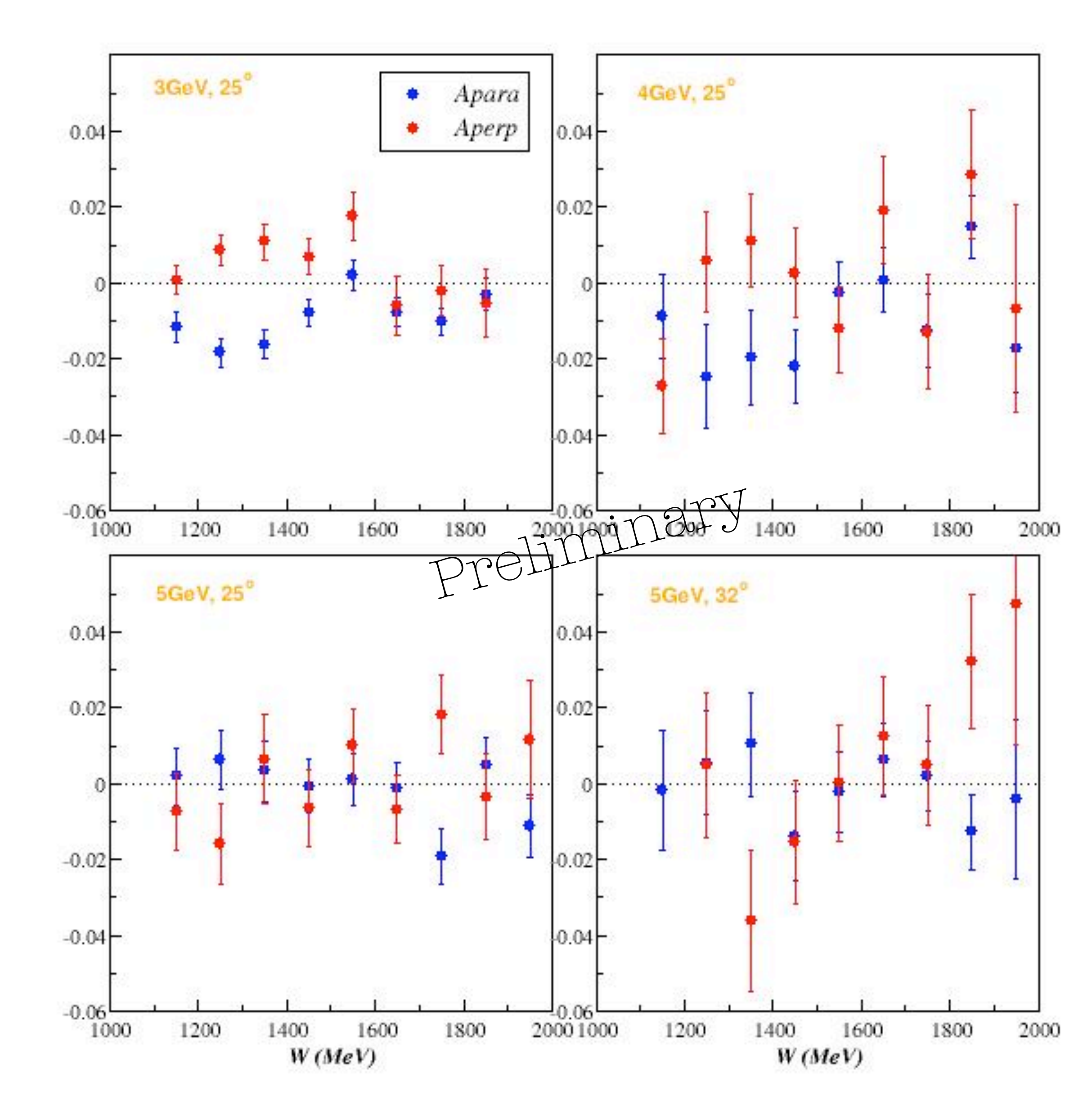
$$g_{1,2}(x,Q^2) \rightarrow \Delta\sigma_{\parallel,\perp}(E,E',\theta)$$



³He Born cross sections



Asymmetries



Test of Duality on Neutron and ^{3}He

Used method defined by N. Bianchi, A. Fantoni and S. Liuti on g_1^p PRD 69 (2004) 014505

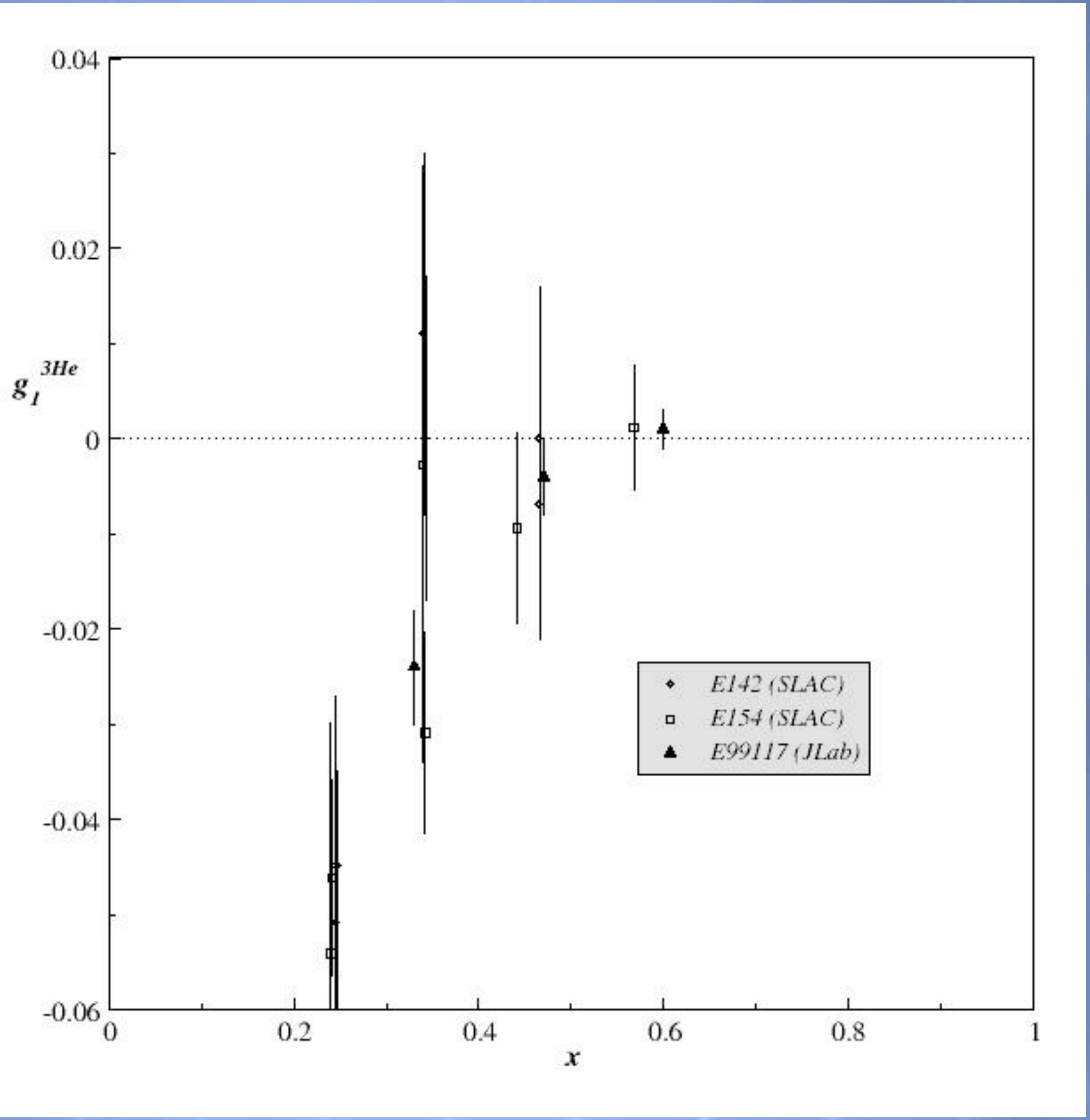
1. Get g_1 at constant Q^2
2. Define integration range in the resonance region in function of W
3. Integrate g_1^{res} and g_1^{dis} over the same x-range and at the same Q^2

$$\tilde{\Gamma}_1^{res} = \int_{x_{\min}}^{x_{\max}} g_1^{res}(x,Q^2)\,dx \qquad \tilde{\Gamma}_1^{dis} = \int_{x_{\min}}^{x_{\max}} g_1^{dis}(x,Q^2)\,dx$$

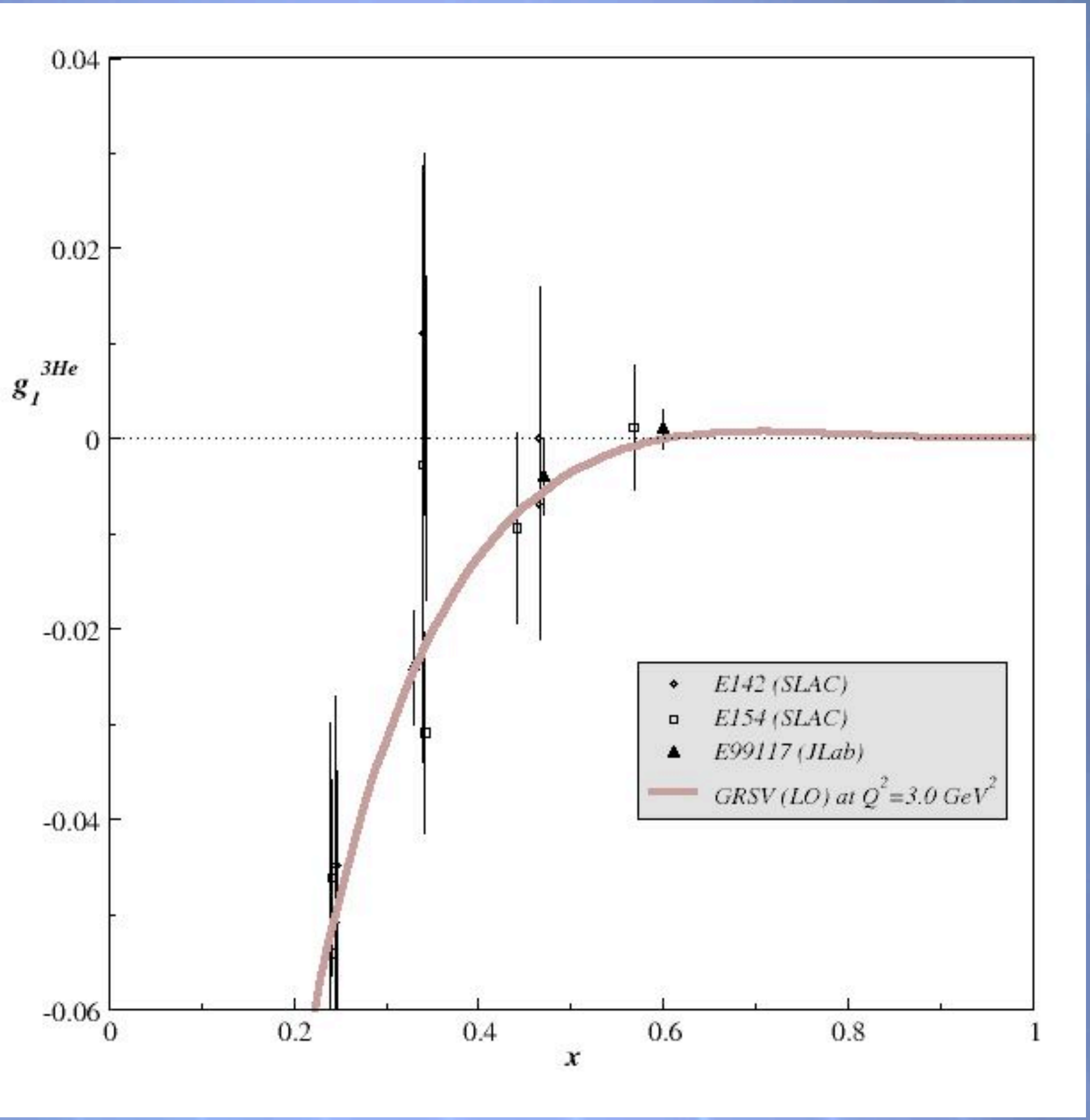
$$R = \frac{\tilde{\Gamma}_1^{res}}{\tilde{\Gamma}_1^{dis}}$$

if unity ⇒ duality is verified

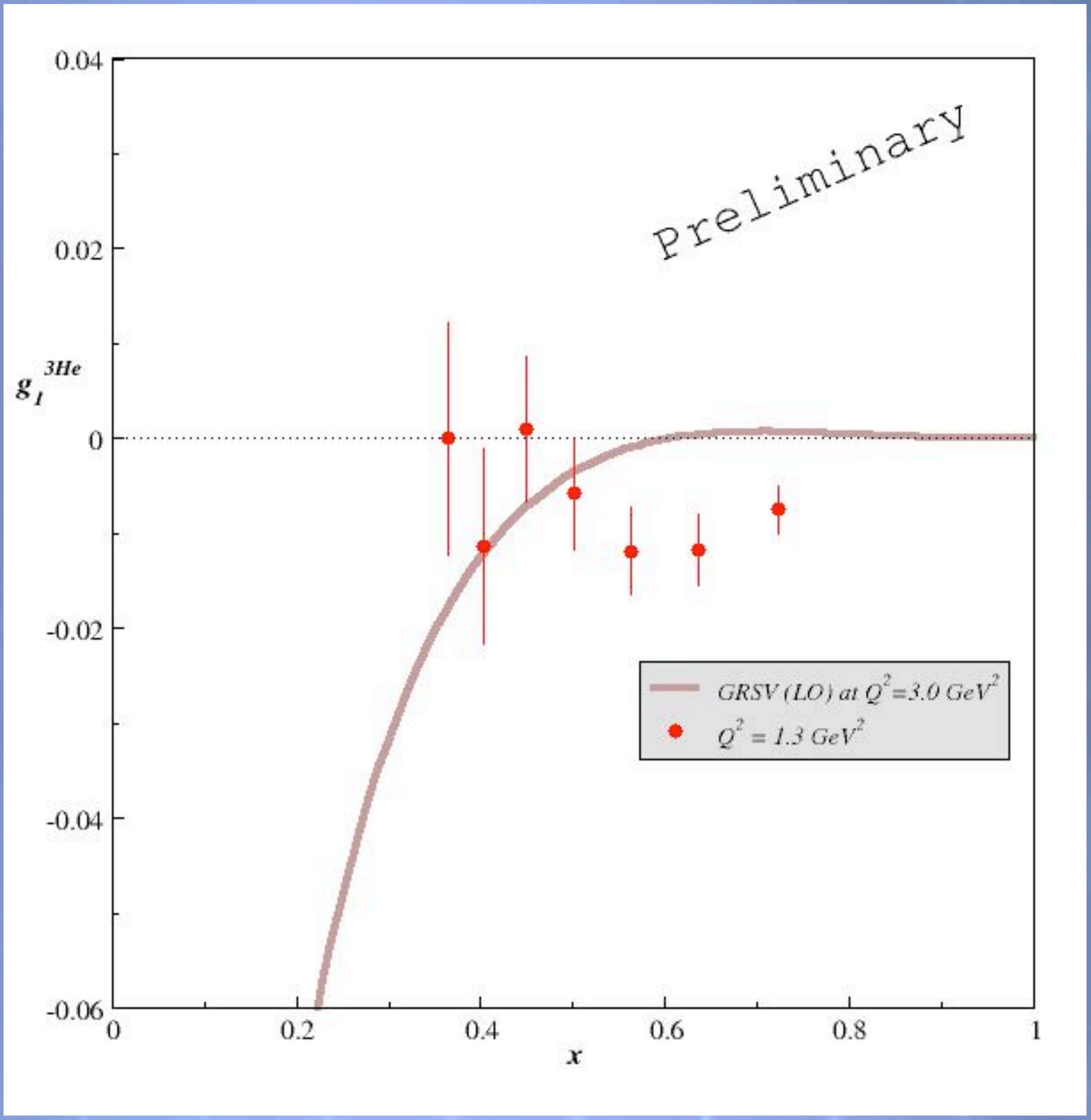
g_1^{3He} at constant Q^2



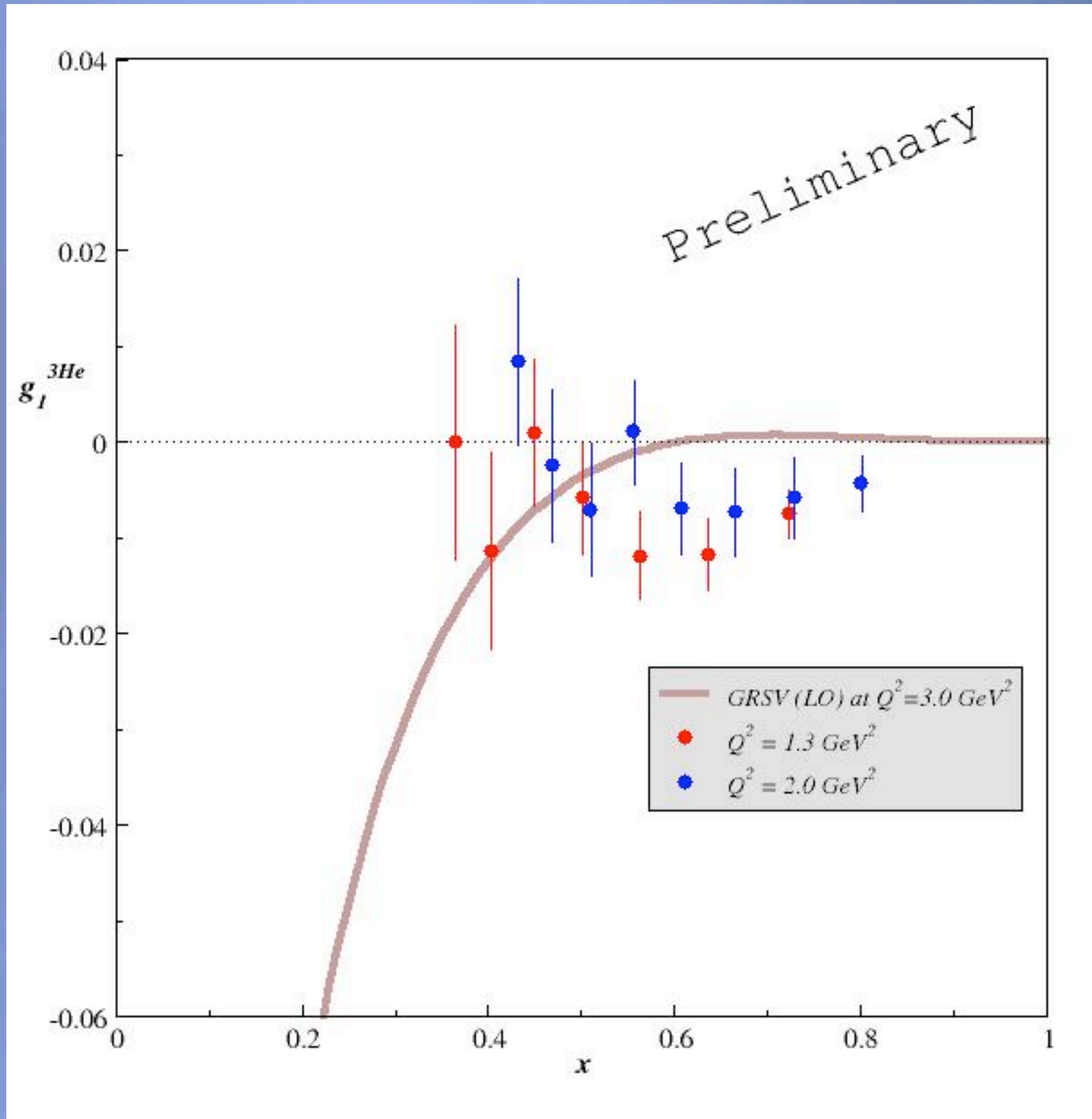
g_1^{3He} at constant Q^2



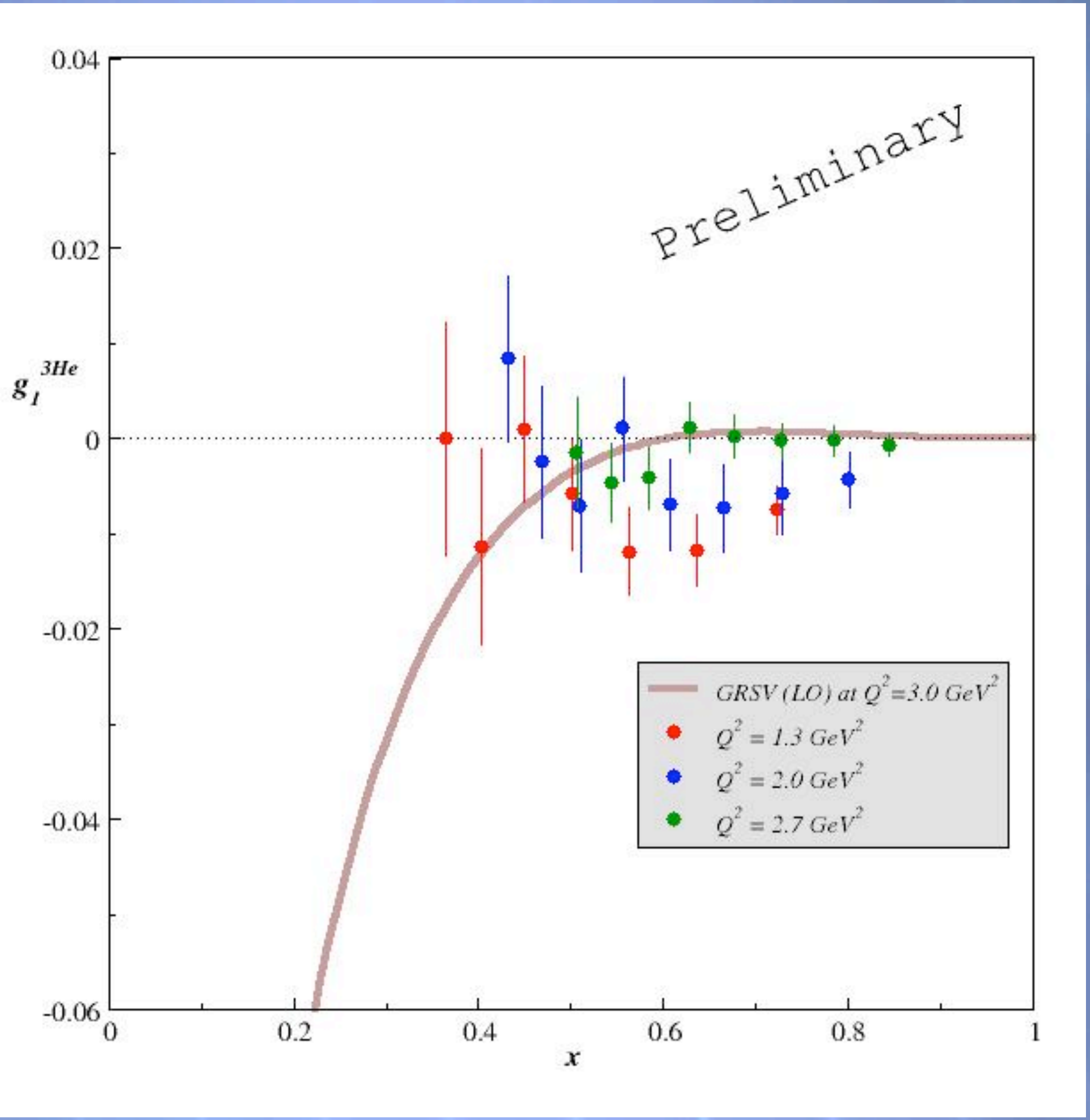
g_1^{3He} at constant Q^2



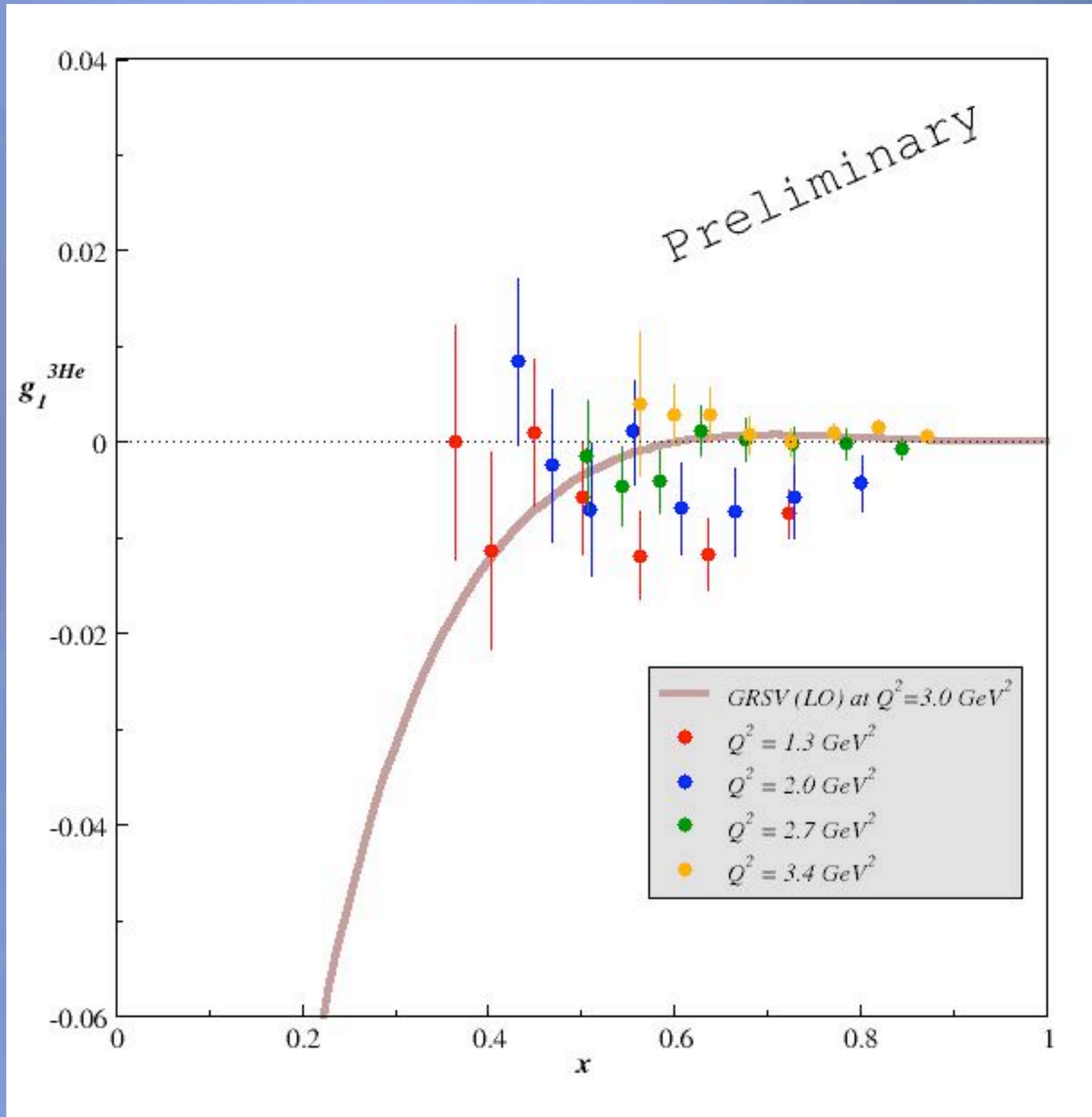
g_1^{3He} at constant Q^2



g_1^{3He} at constant Q^2



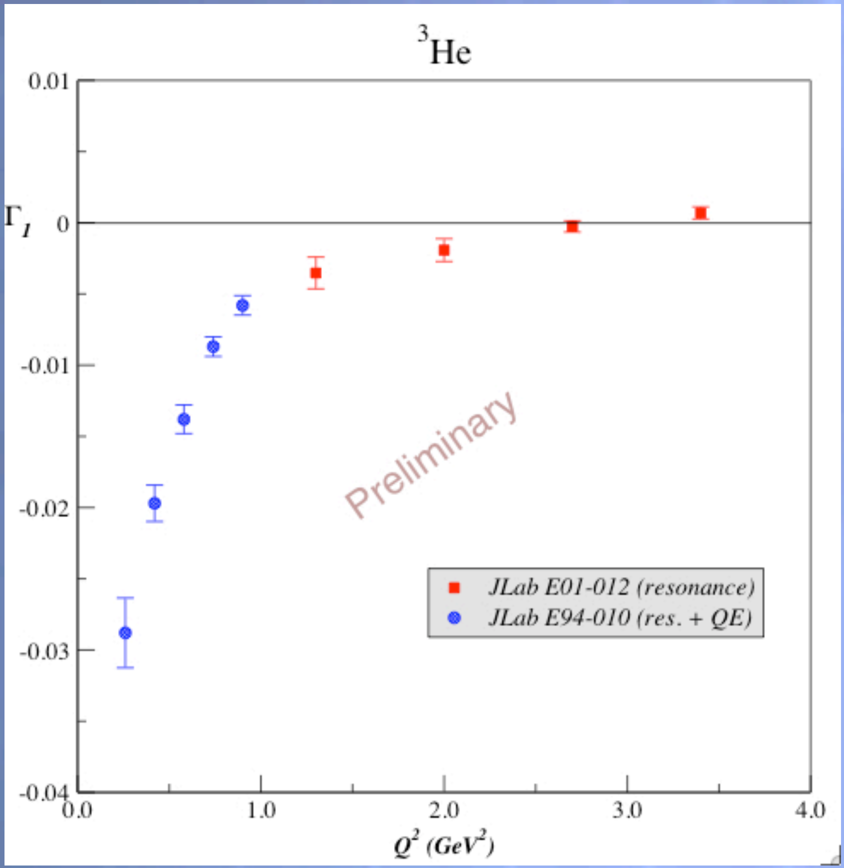
g_1^{3He} at constant Q^2

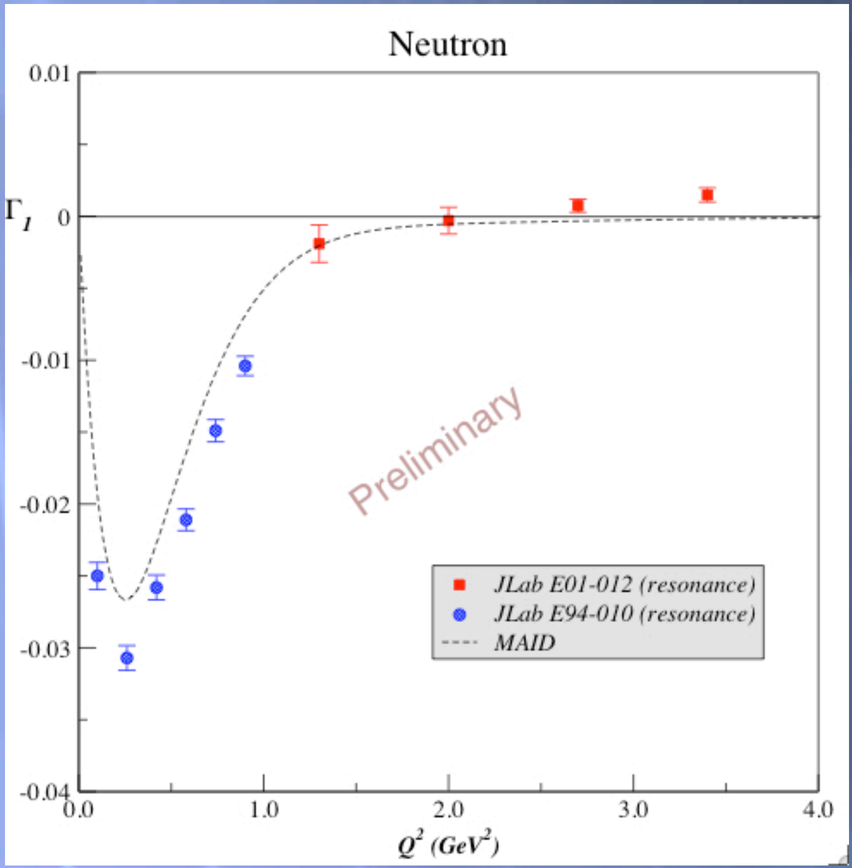


Γ_1^n in the resonance region

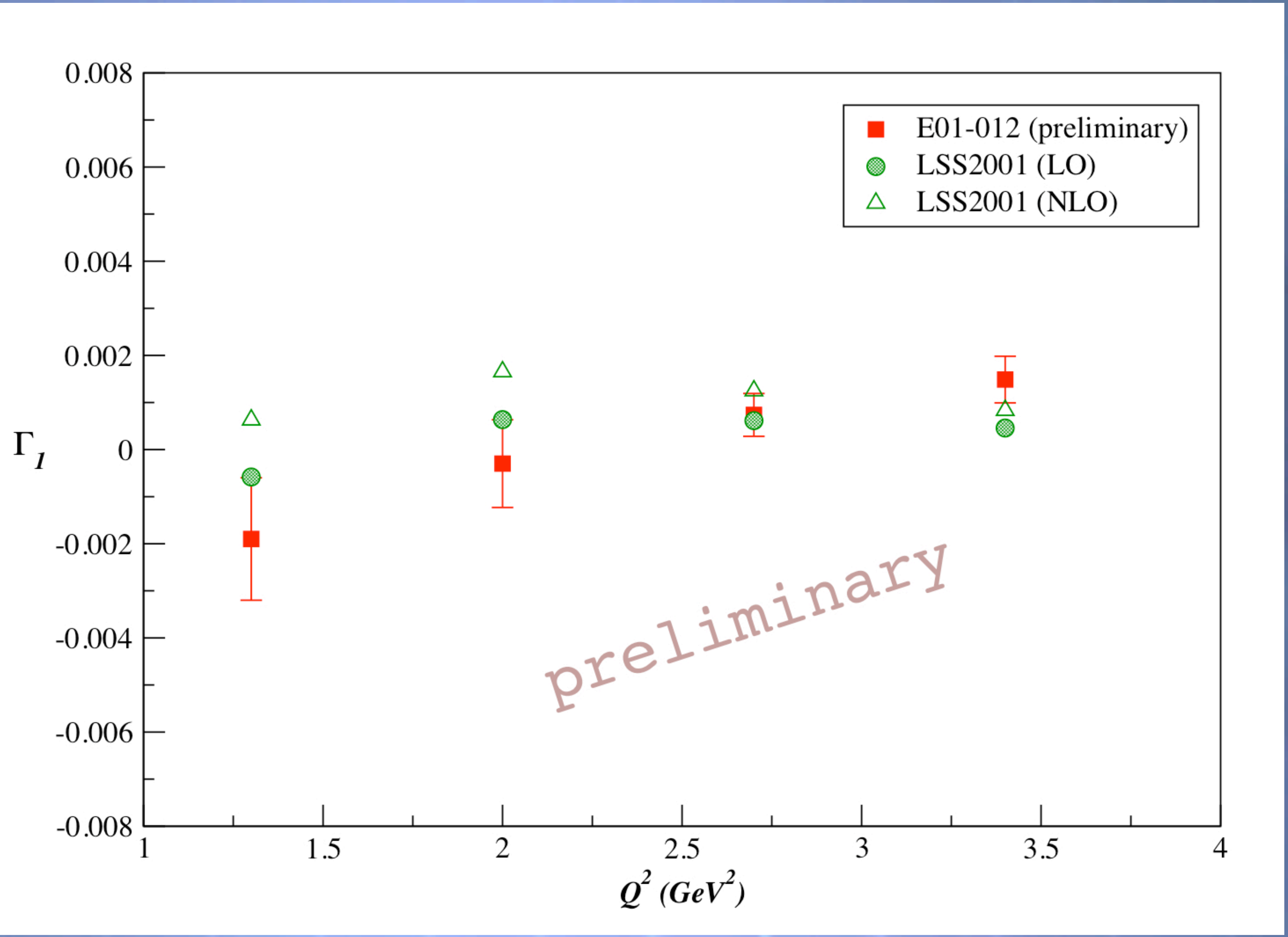
Extract the neutron from effective polarization equation:

$$\tilde{\Gamma}_1^{^3He} = P_n \tilde{\Gamma}_1^n + 2 P_p \tilde{\Gamma}_1^p$$





Test of duality on neutron



Spin asymmetries

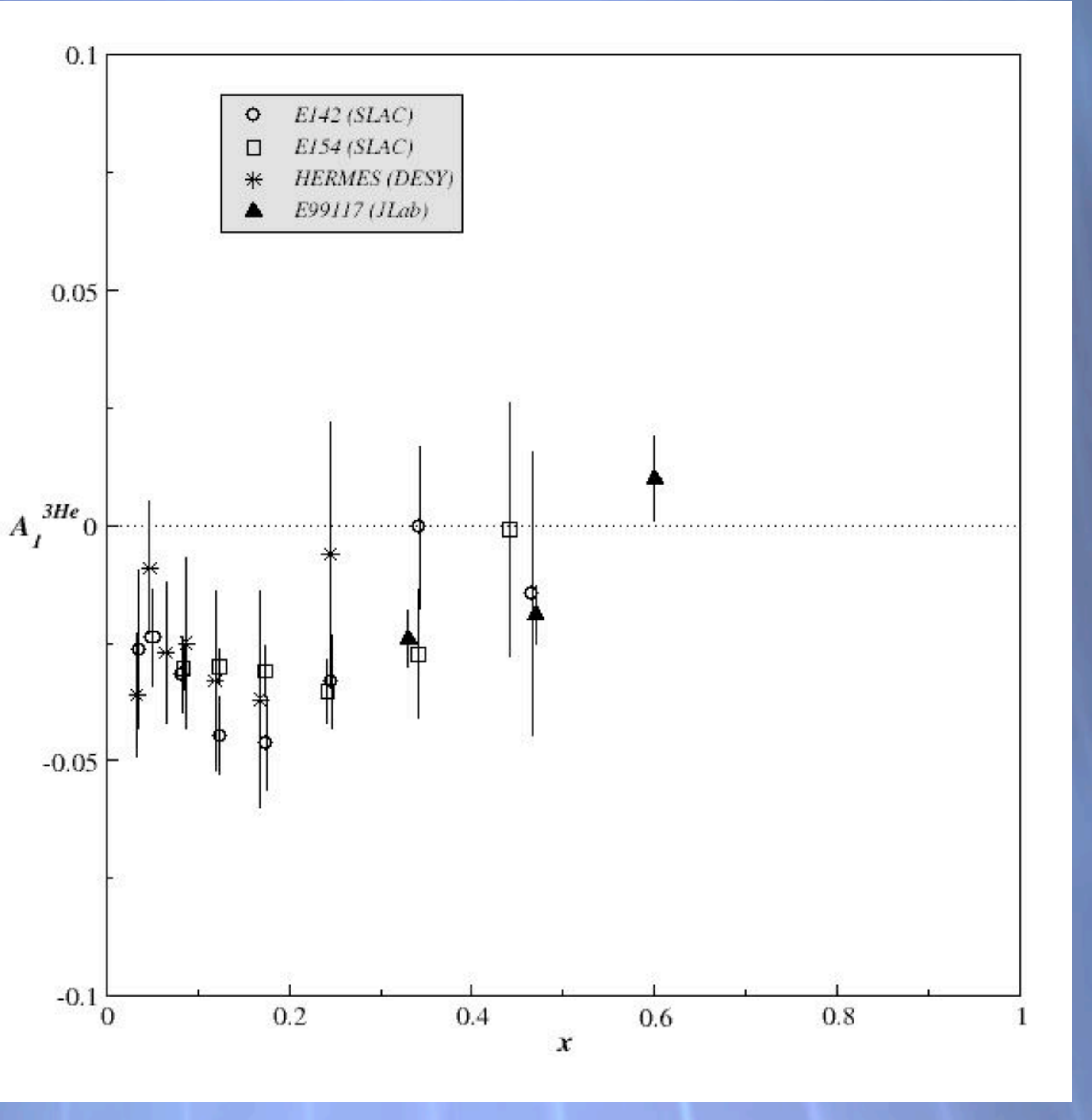
$$A_1 = \frac{A_{//}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$

$$A_2 = \frac{\xi A_{//}}{D(1+\eta\xi)} + \frac{A_{\perp}}{d(1+\eta\xi)}$$

η and ξ depend on kinematical variables

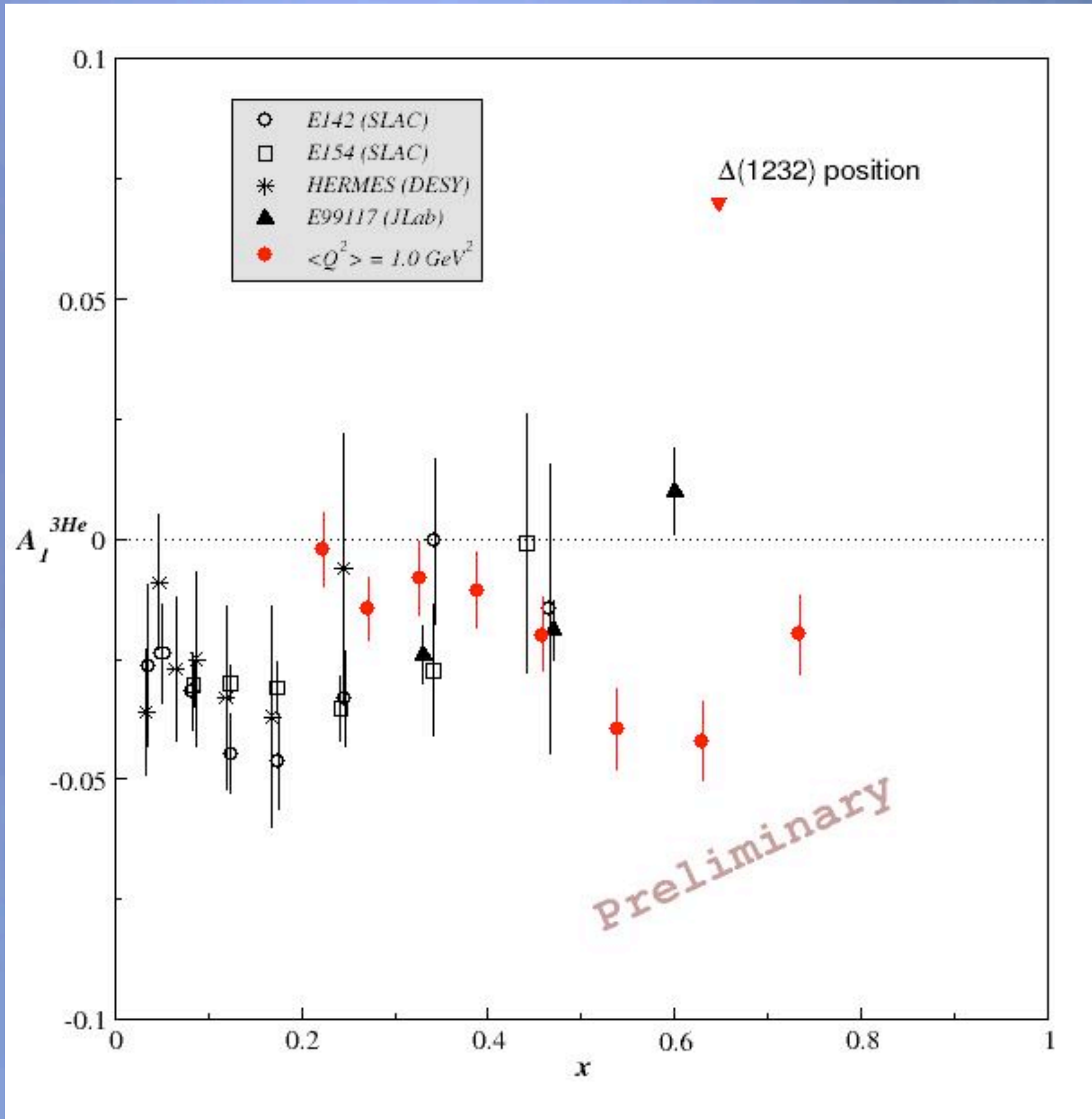
D and d depend on $R=\sigma_L/\sigma_T$ for ^3He

A_1^{3He}



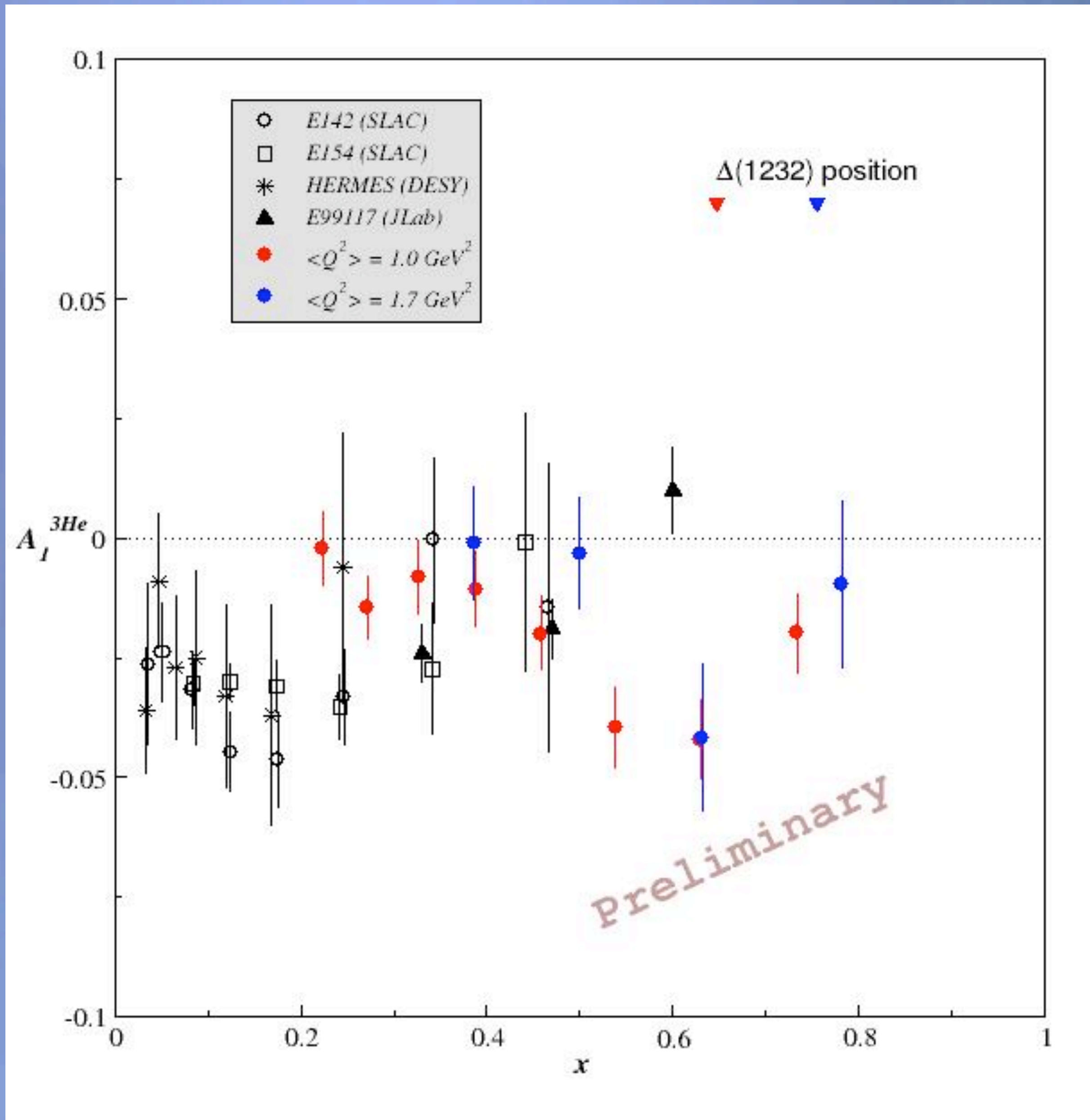
E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99117 (JLab)
0.1
0.05
0
-0.05
-0.1
0
0.2
0.4
0.6
0.8
1
A_1^{3He}
x

A_1^{3He}



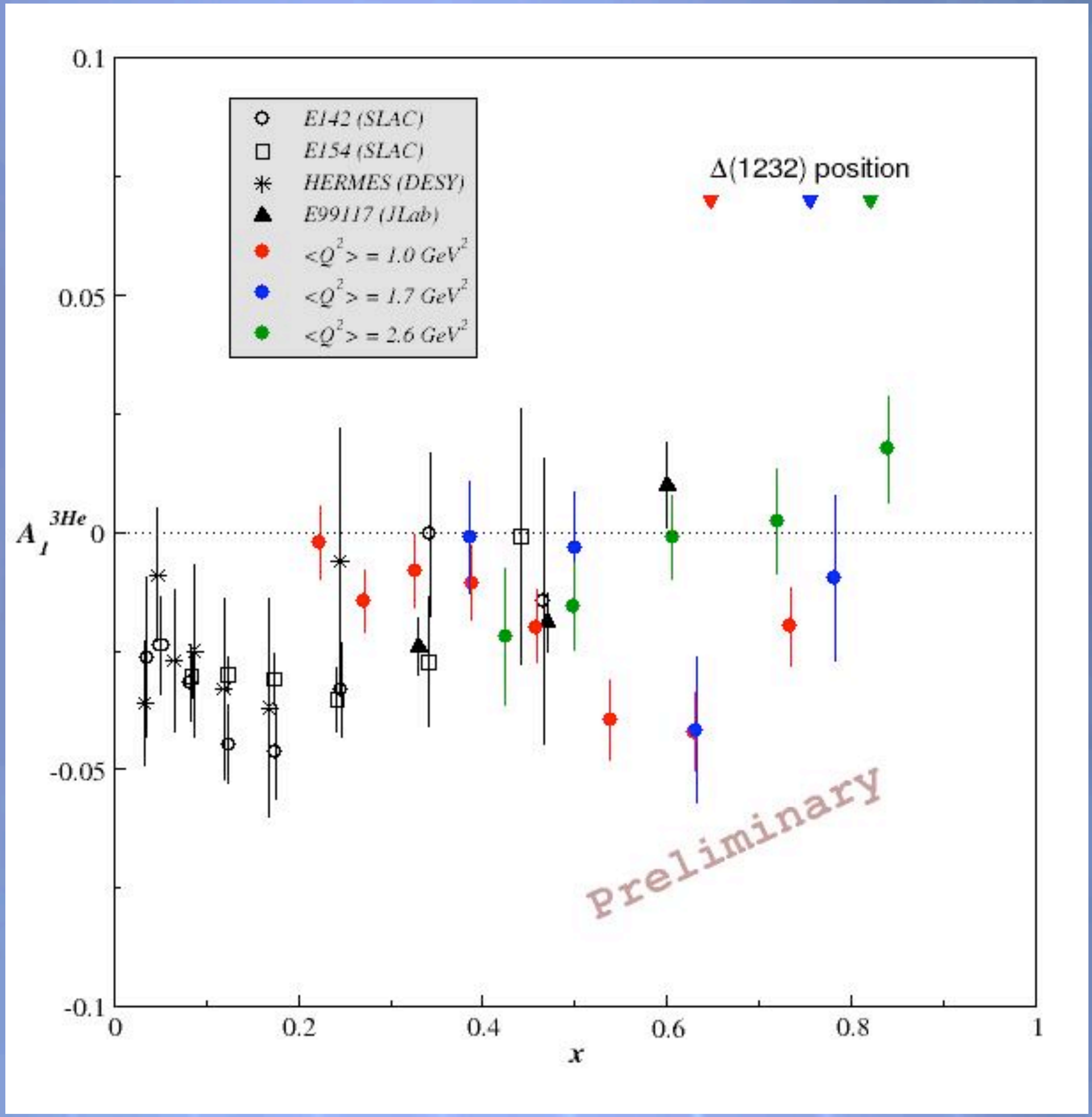
E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99117 (JLab)
<Q²> = 1.0 GeV²
Δ(1232) position
Preliminary
A1 3He
x
0.1
0.05
0
-0.05
-0.1
0
0.2
0.4
0.6
0.8
1

A_1^{3He}



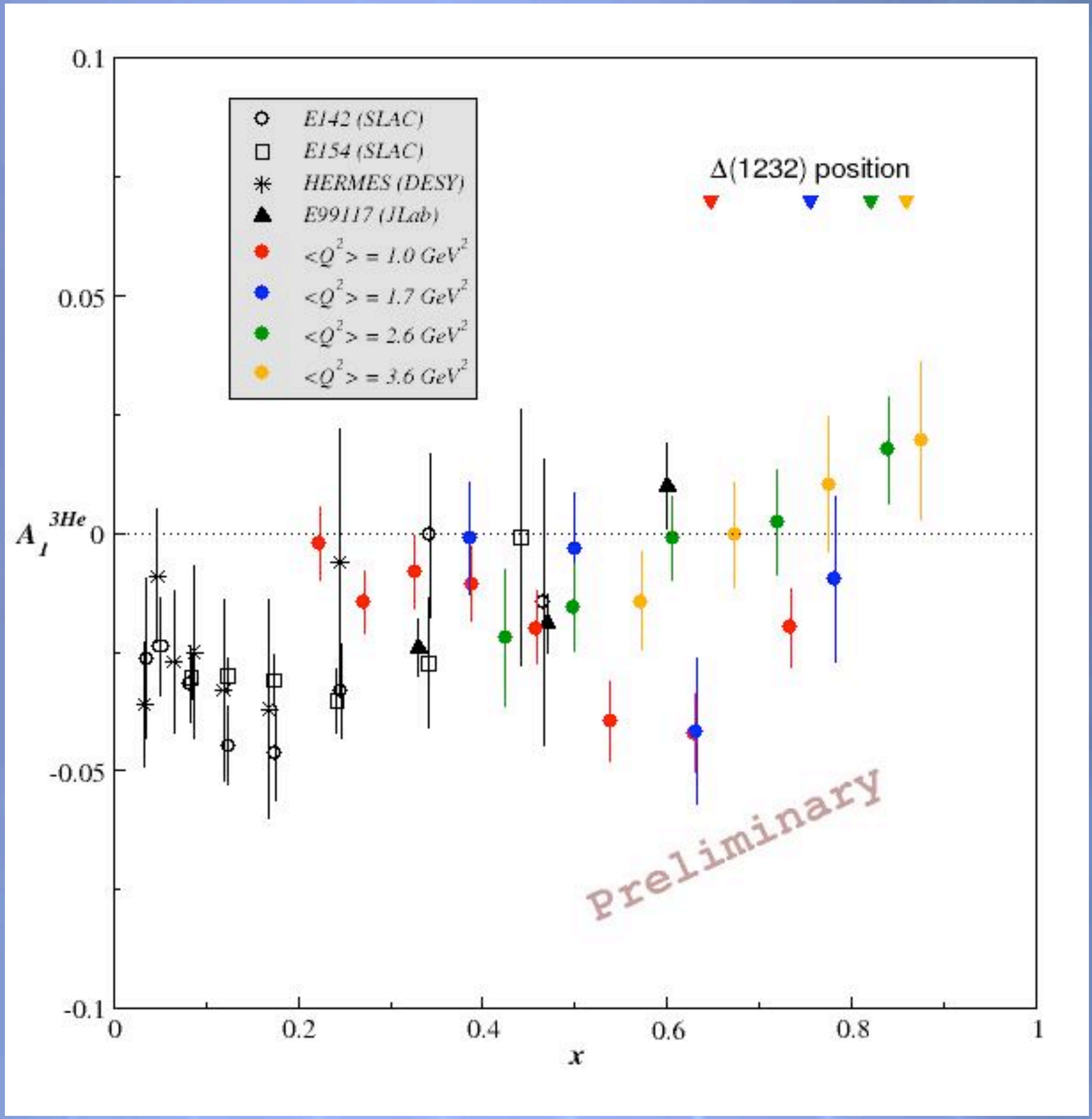
E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99117 (JLab)
<Q²> = 1.0 GeV²
<Q²> = 1.7 GeV²
Δ(1232) position
A₁^3He
x
0.1
0.05
0
-0.05
-0.1
0
0.2
0.4
0.6
0.8
1
Preliminary

A_1^{3He}



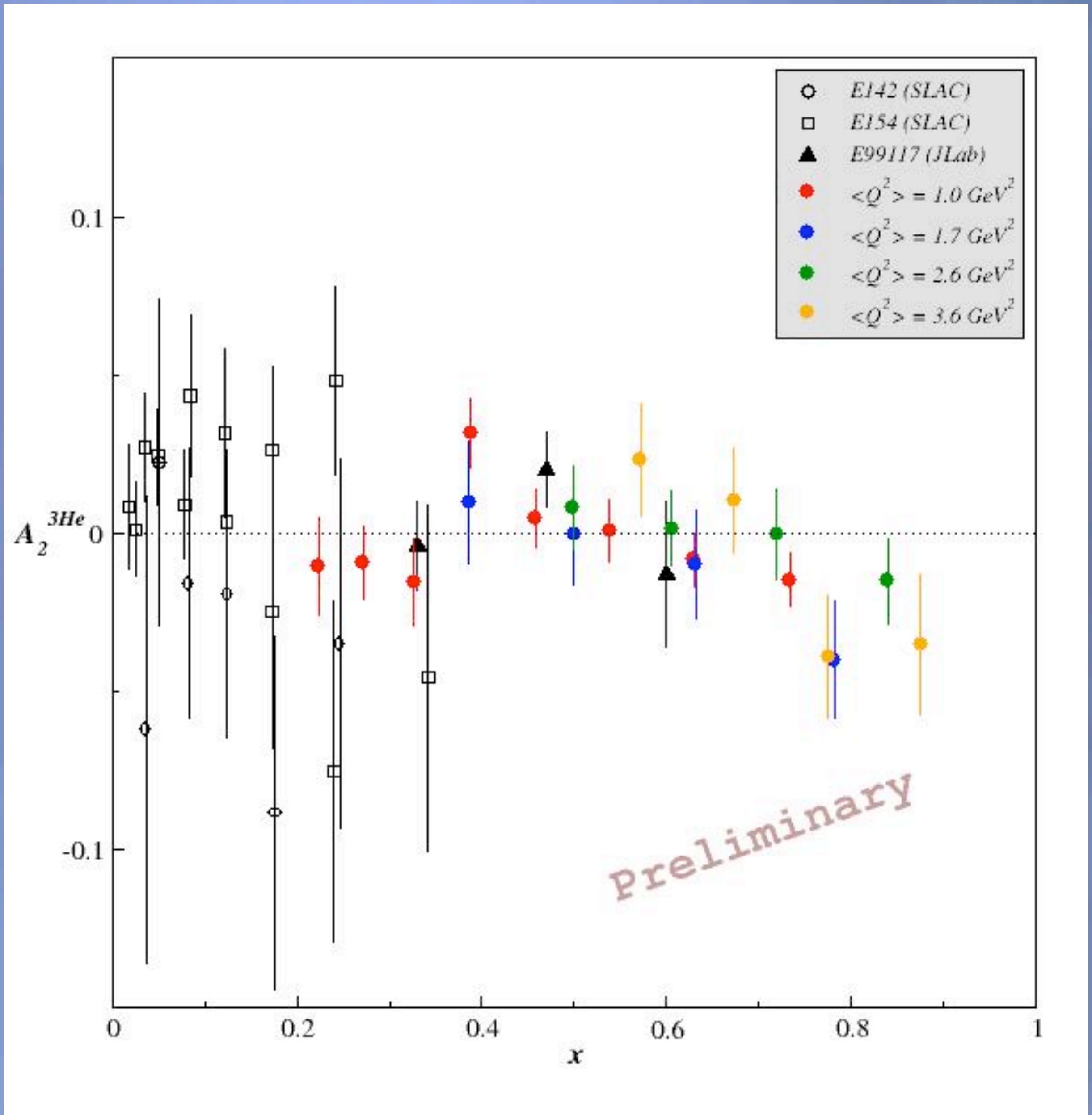
E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99117 (JLab)
<Q^2> = 1.0 GeV^2
<Q^2> = 1.7 GeV^2
<Q^2> = 2.6 GeV^2
Δ(1232) position
Preliminary
A_1^3He
x
0.1
0.05
0
-0.05
-0.1
0
0.2
0.4
0.6
0.8
1

A_1^{3He}



0.1
0.05
0
-0.05
-0.1
A_1^{3He}
0
0.2
0.4
0.6
0.8
1
x
E142 (SLAC)
E154 (SLAC)
HERMES (DESY)
E99117 (JLab)
$\langle Q^2 \rangle = 1.0\ GeV^2$
$\langle Q^2 \rangle = 1.7\ GeV^2$
$\langle Q^2 \rangle = 2.6\ GeV^2$
$\langle Q^2 \rangle = 3.6\ GeV^2$
Δ(1232) position
Preliminary

A_2^{3He}



E142 (SLAC)
E154 (SLAC)
E99117 (JLab)
<Q²> = 1.0 GeV²
<Q²> = 1.7 GeV²
<Q²> = 2.6 GeV²
<Q²> = 3.6 GeV²
0.1
0
-0.1
A_2^3He
0
0.2
0.4
0.6
0.8
1
x
Preliminary

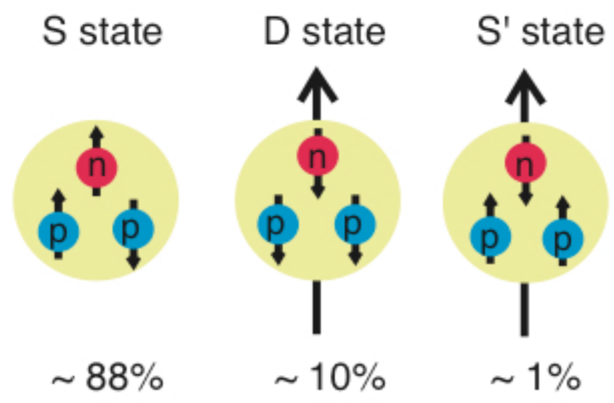
Summary

- E01-012 provides precision data of Spin Structure Functions on neutron (^3He) in the resonance region for $1.0<Q^2<4.0(GeV/c)^2$
- Direct extraction of g_1 and g_2 from our data
- Overlap between E01-012 resonance data and DIS data
→ test of Quark-Hadron Duality for neutron and nuclei SSF
- E01-012 data combined with proton data
→ test of spin and flavor dependence of duality
- Our data can also be used to extract moments of SSF (e.g. Extended GDH Sum Rule, BC Sum Rule)

Extra Slides

From ^{3}He to neutron

^{3}He as neutron target



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

NMR: water calibration