

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

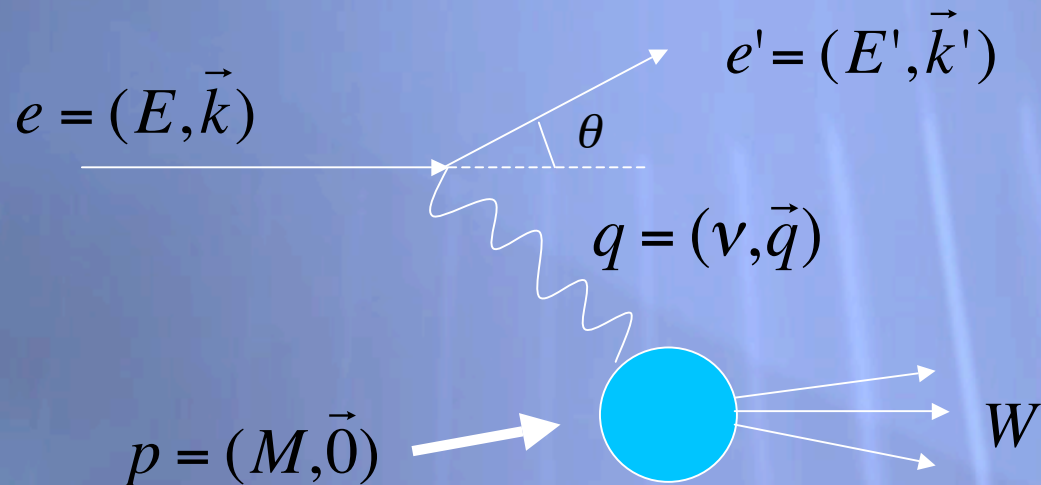
Patricia Solvignon
Temple University
For the Jlab Hall A Collaboration

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 ^3He

Inclusive Experiment



Photon virtuality

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

Invariant mass squared

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

Bjorken variable

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

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

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

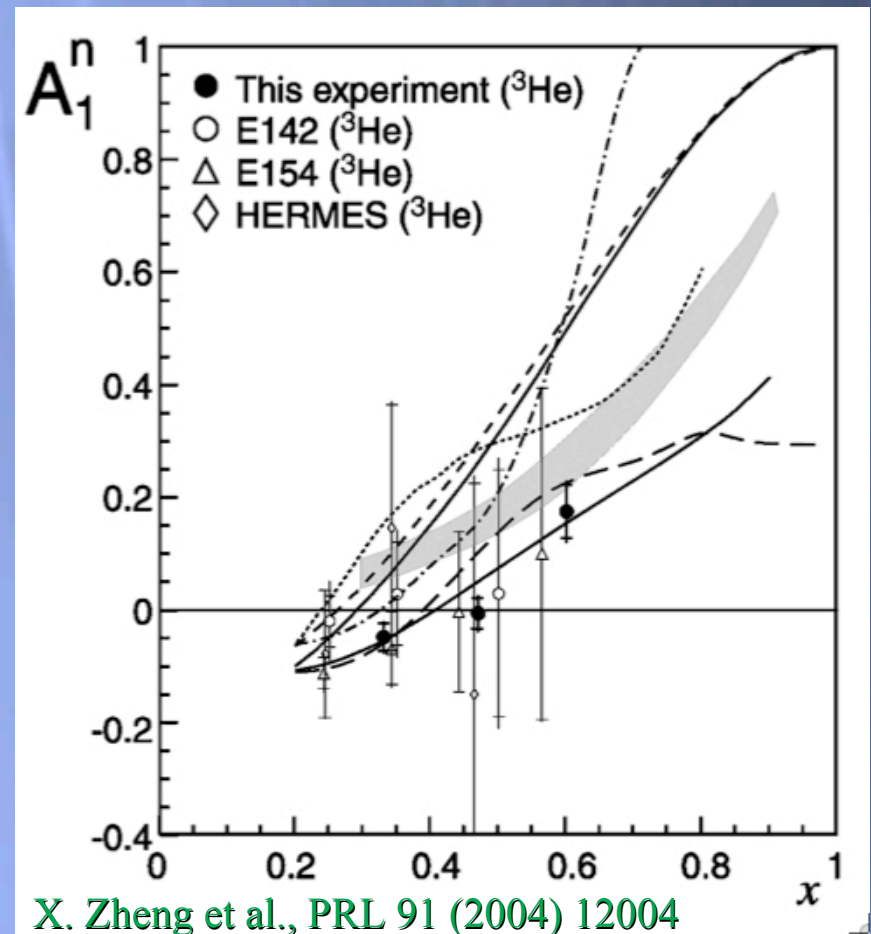
Structure functions in the parton model

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

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

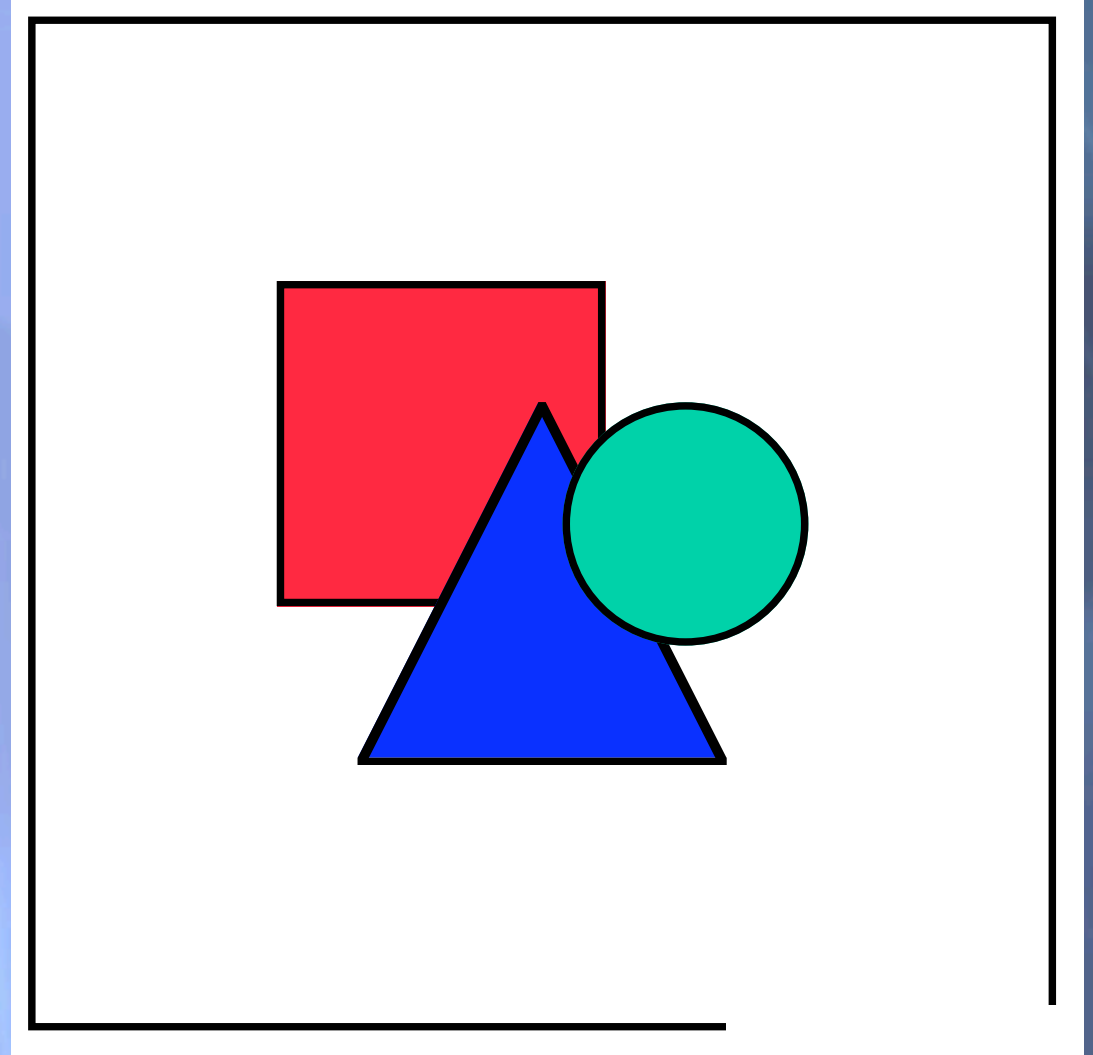
$$A_1(x) \approx \frac{g_1(x)}{F_1(x)}$$

Large x region: valence quarks dominate



Quark-hadron duality

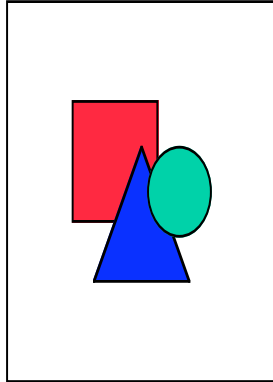
- First observed by Bloom and Gilman in the 1970's on F_2
- **Scaling curve** seen at high Q^2 is an accurate **average** over the **resonance region** at lower Q^2



Quark-hadron duality (cont'd)

Short distance

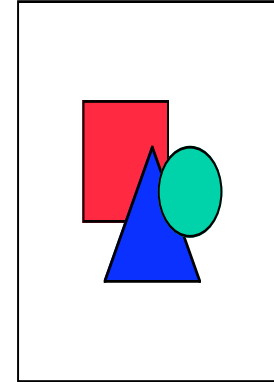
$W > 2\text{GeV}$



**Asymptotic
Freedom**

Long distance

$W < 2\text{GeV}$



Confinement

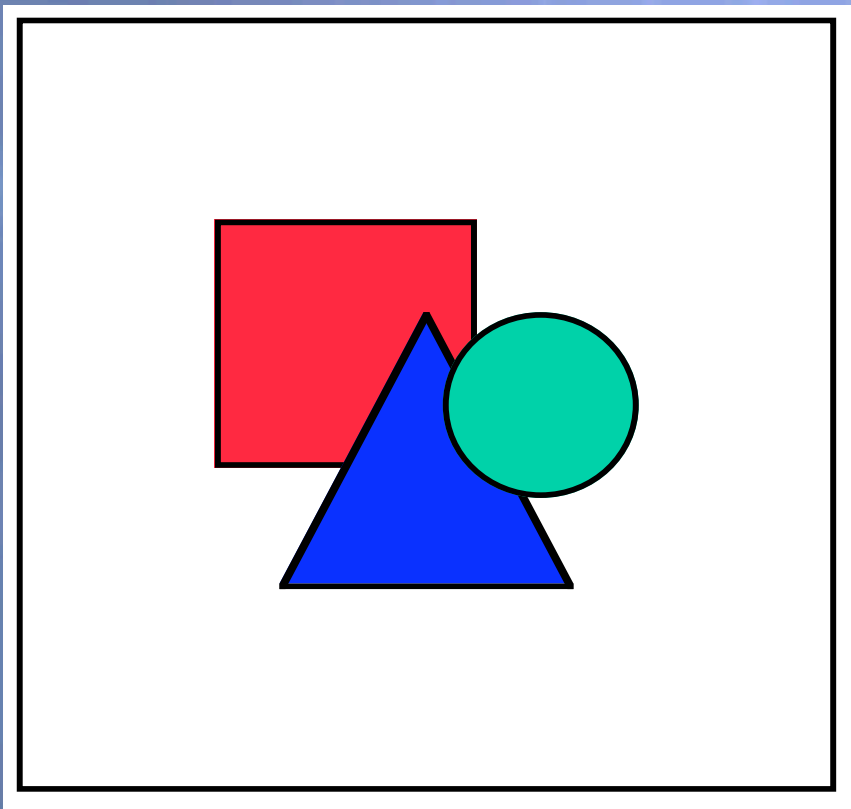
Two very different behaving in average the same way !

Resonance vs. scaling

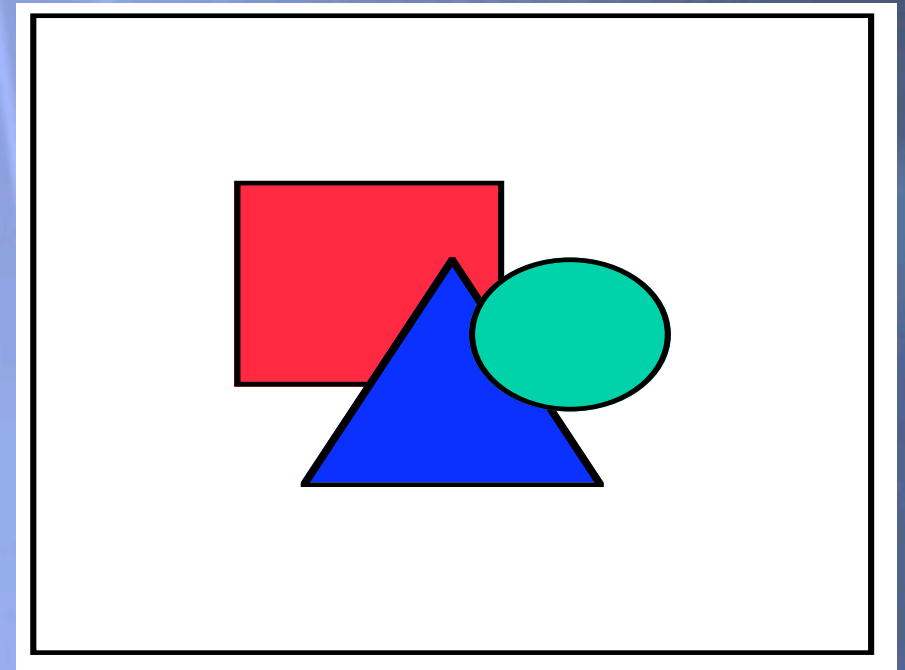
Scaling $\Rightarrow Q^2$ independence of structure function moments
 \Rightarrow resonance region is a part of the scaling regime

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

proton



neutron



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

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

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 $g_1^{3\text{He}}$

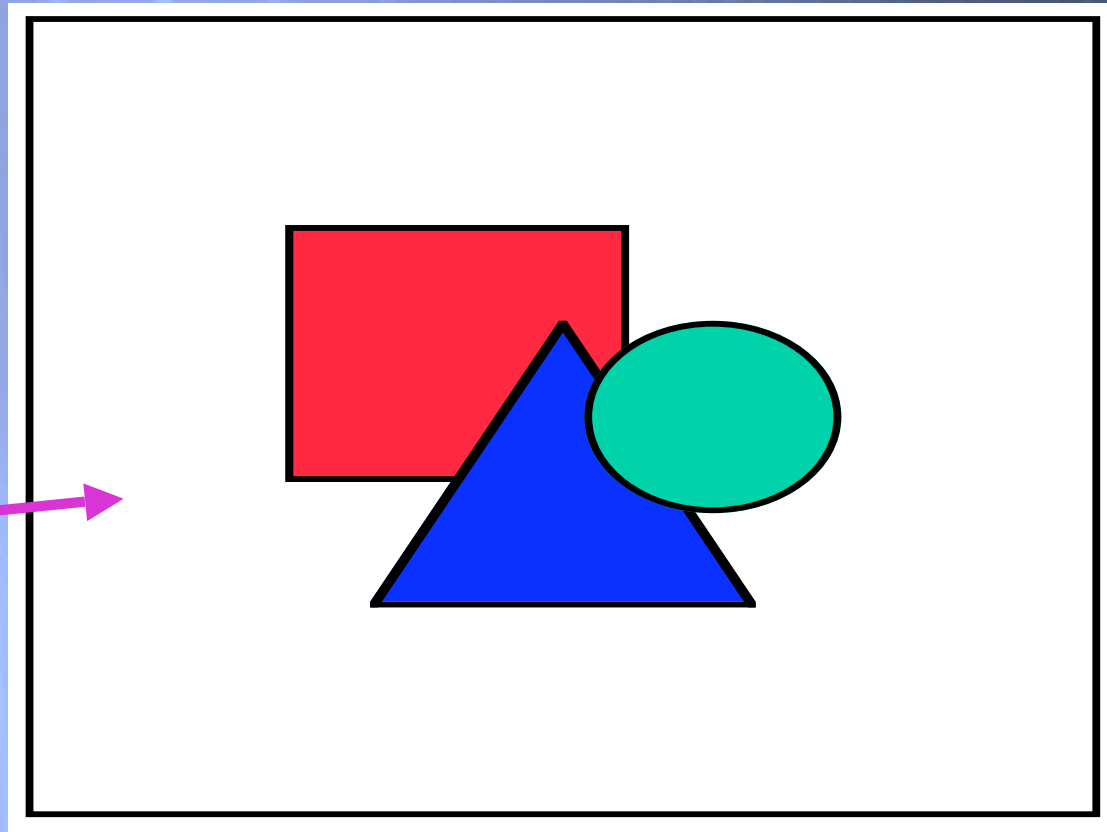
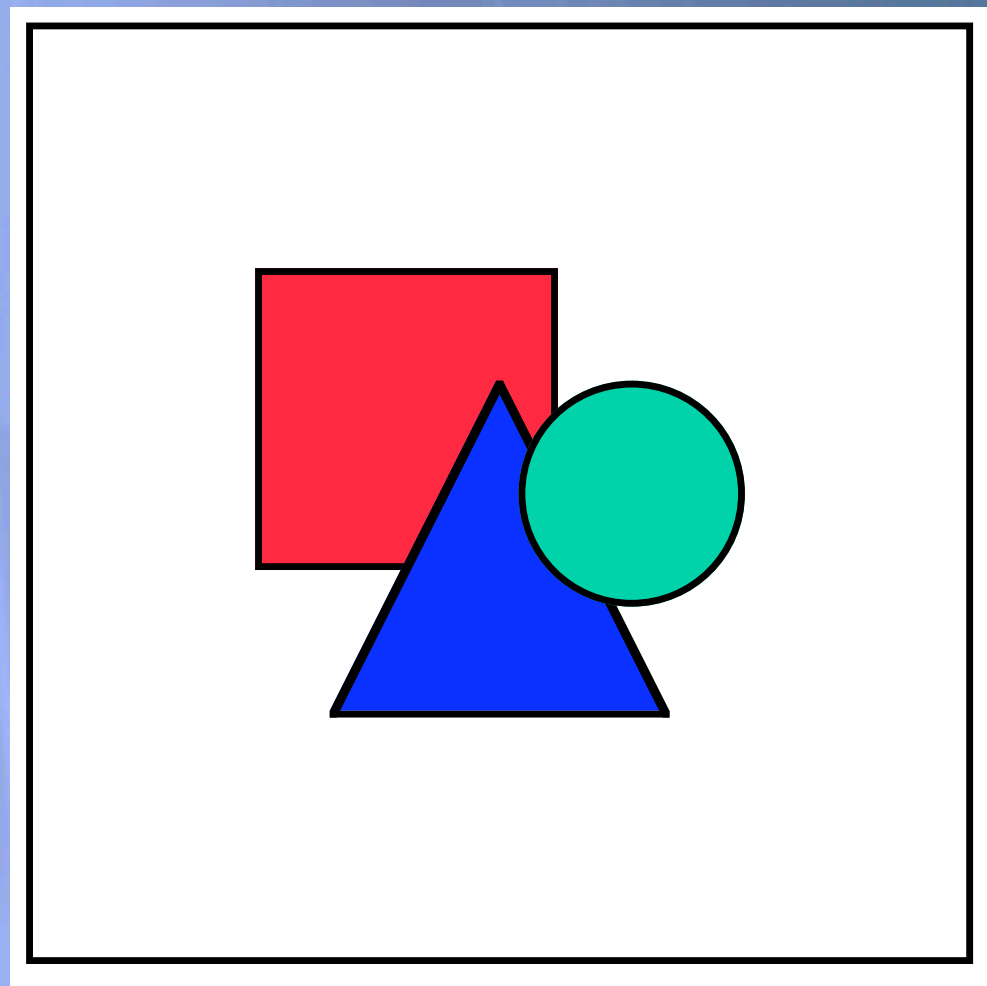


Figure from Seonho Choi

The experiment E01-012

- Ran in Jan.-Feb. 2003
- Inclusive experiment:
 ${}^3\vec{\text{He}}(\vec{e}, e')X$
- Measured polarized cross section differences
- Form g_1 , g_2 , A_1 and A_2



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

The E01-012 Collaboration

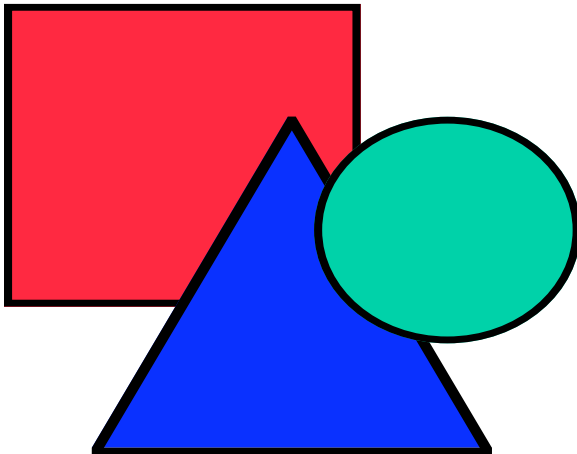
K. Aniol, T. Averett, W. Boeglin, A. Camsonne, G.D. Cates,
G. Chang, J.-P. Chen, Seonho Choi, E. Chudakov, B. Craver,
F. Cusanno, A. Deur, D. Dutta, R. Ent, R. Feuerbach,
S. Frullani, H. Gao, F. Garibaldi, R. Gilman, C. Glashauser,
O. Hansen, D. Higinbotham, H. Ibrahim, X. Jiang, M. Jones,
A. Kelleher, 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 5.0 GeV

Hall A



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

→ double the statistics
→ control the systematics

❖ Particle ID = Cerenkov + EM calorimeter

The CO₂ gas Cerenkov counter

Index de refraction:

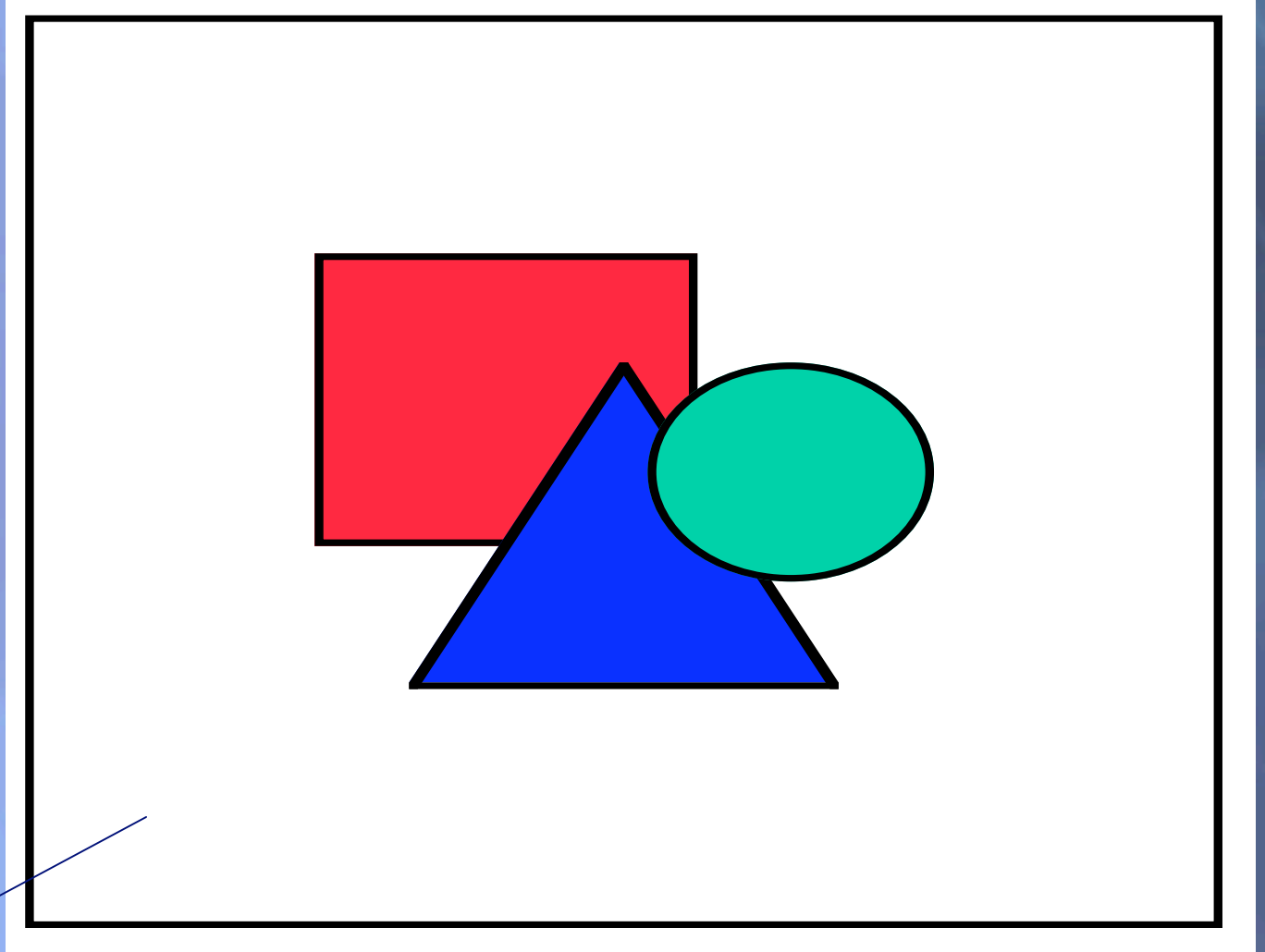
$$n = 1.00041$$



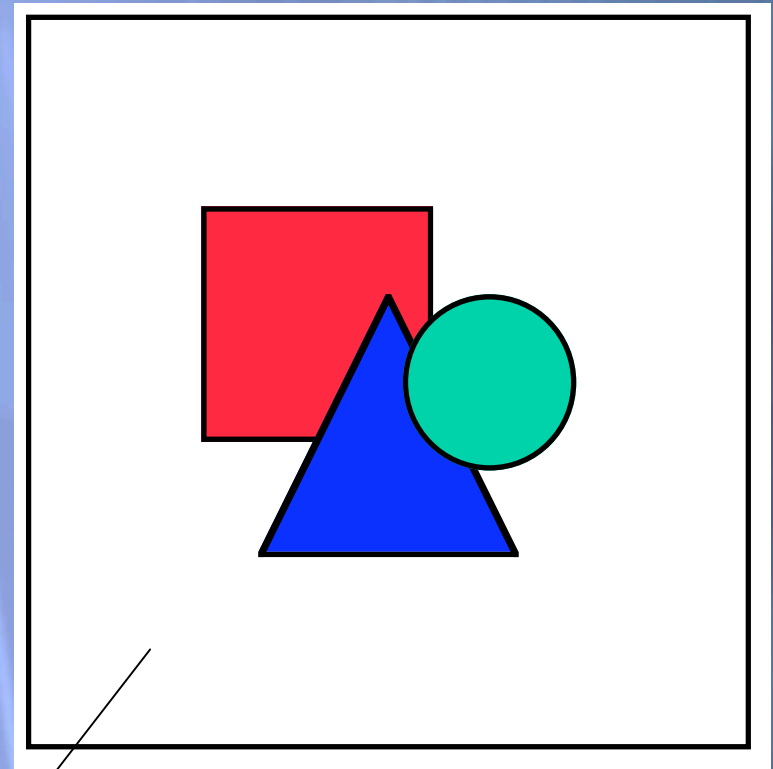
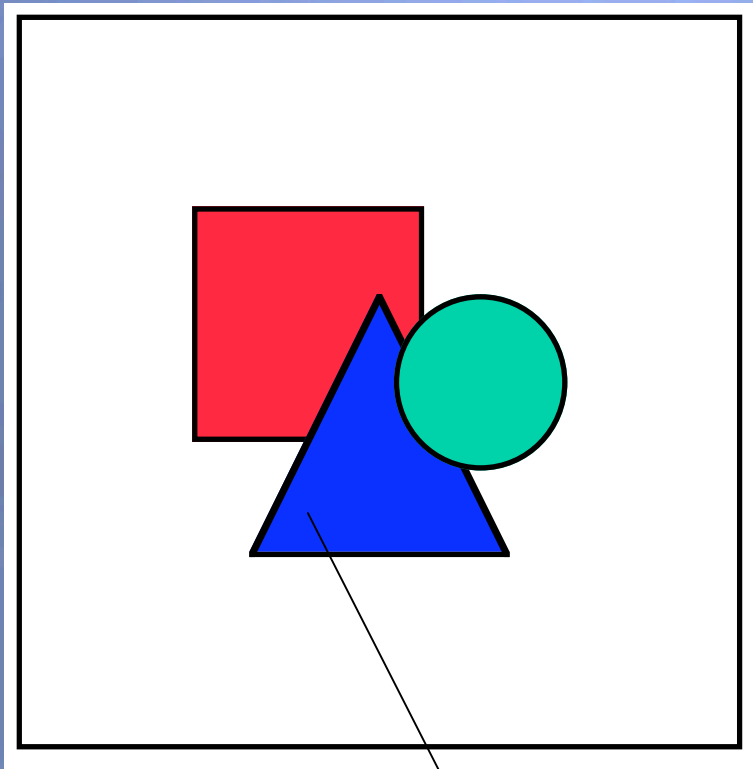
$$P_{thres.}^{e^-} = 18 MeV$$

$$P_{thres.}^{\pi^-} = 4.9 GeV$$

Knock-out e⁻
&
Low energy e⁻

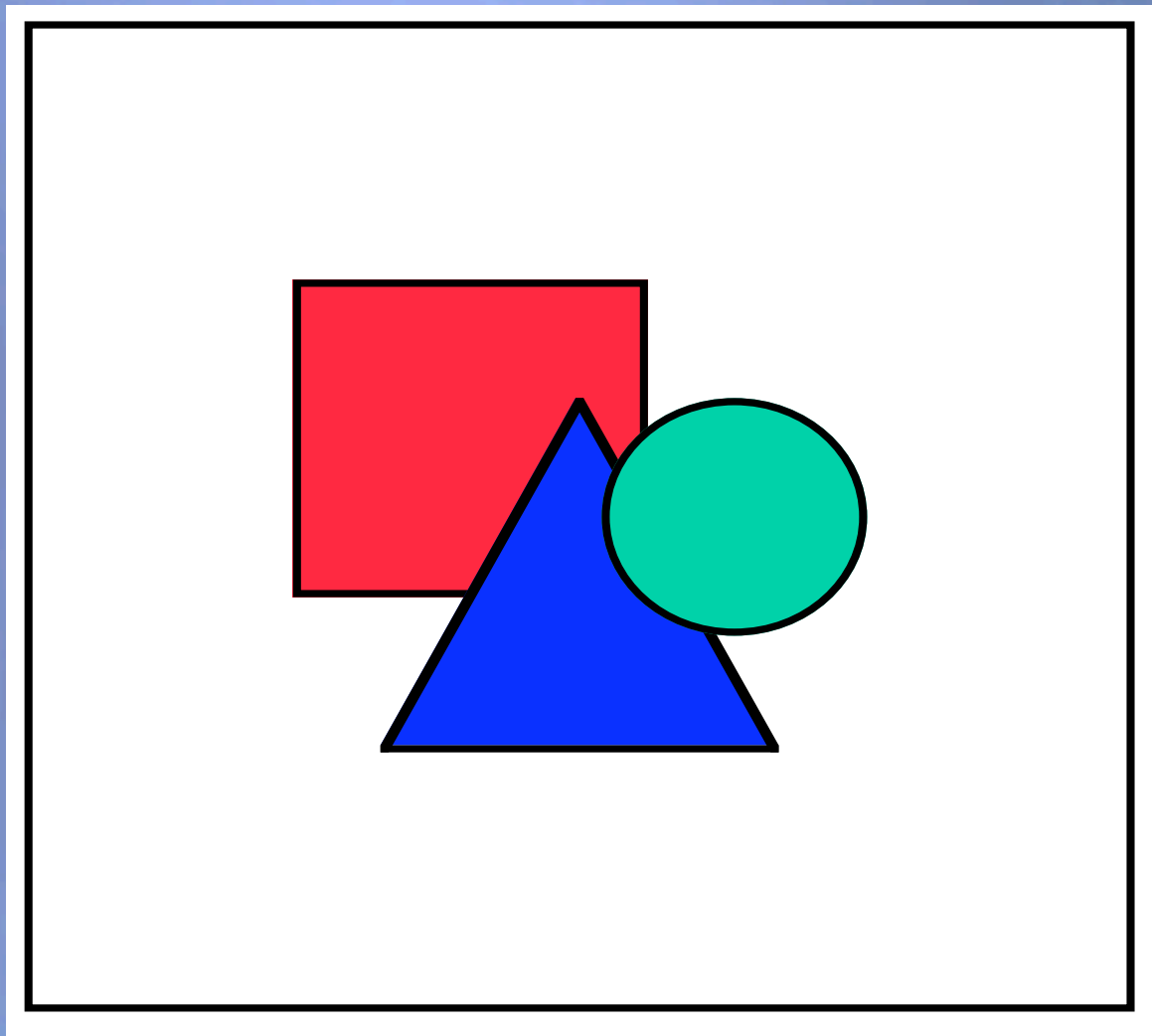


Lead Glass Calorimeter



Cuts applied for electron efficiency $> 99\%$

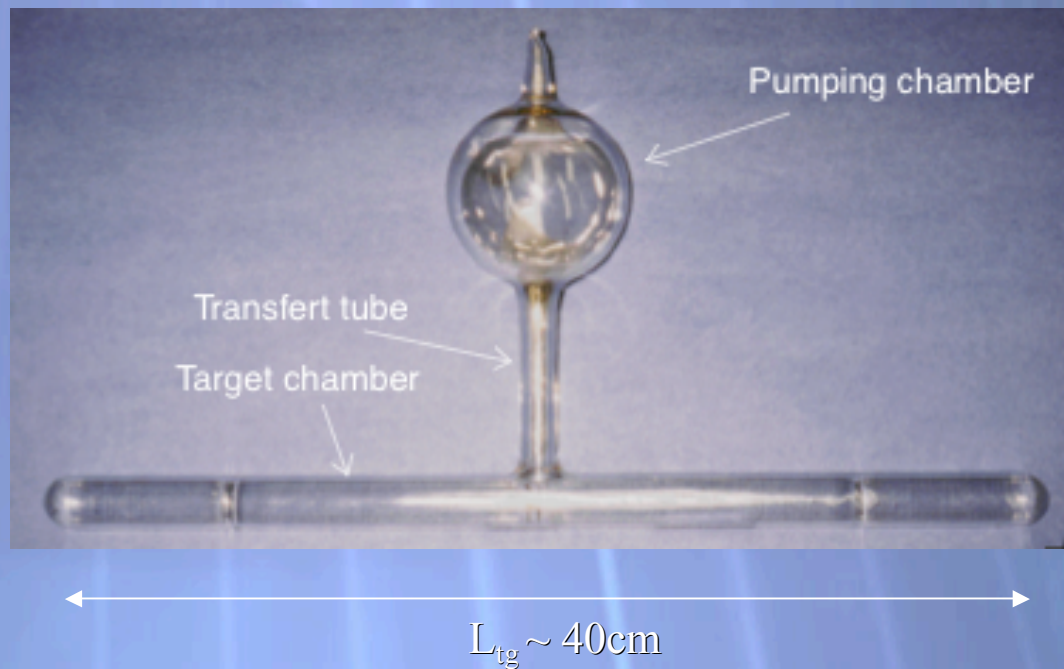
Particle identification performance



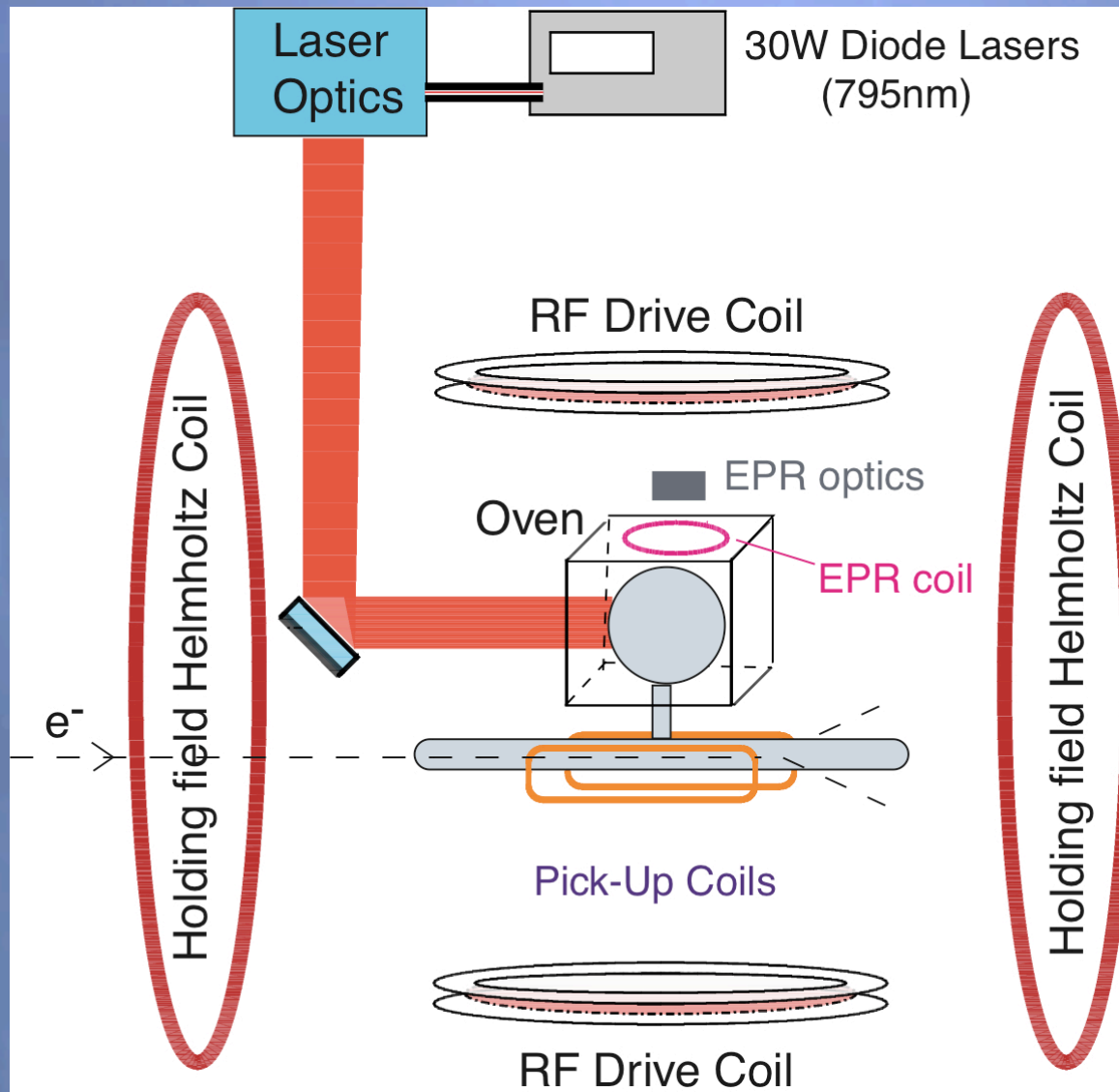
π/e reduced by 10^4 and electron efficiency kept above 98%

The polarized ^3He target

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



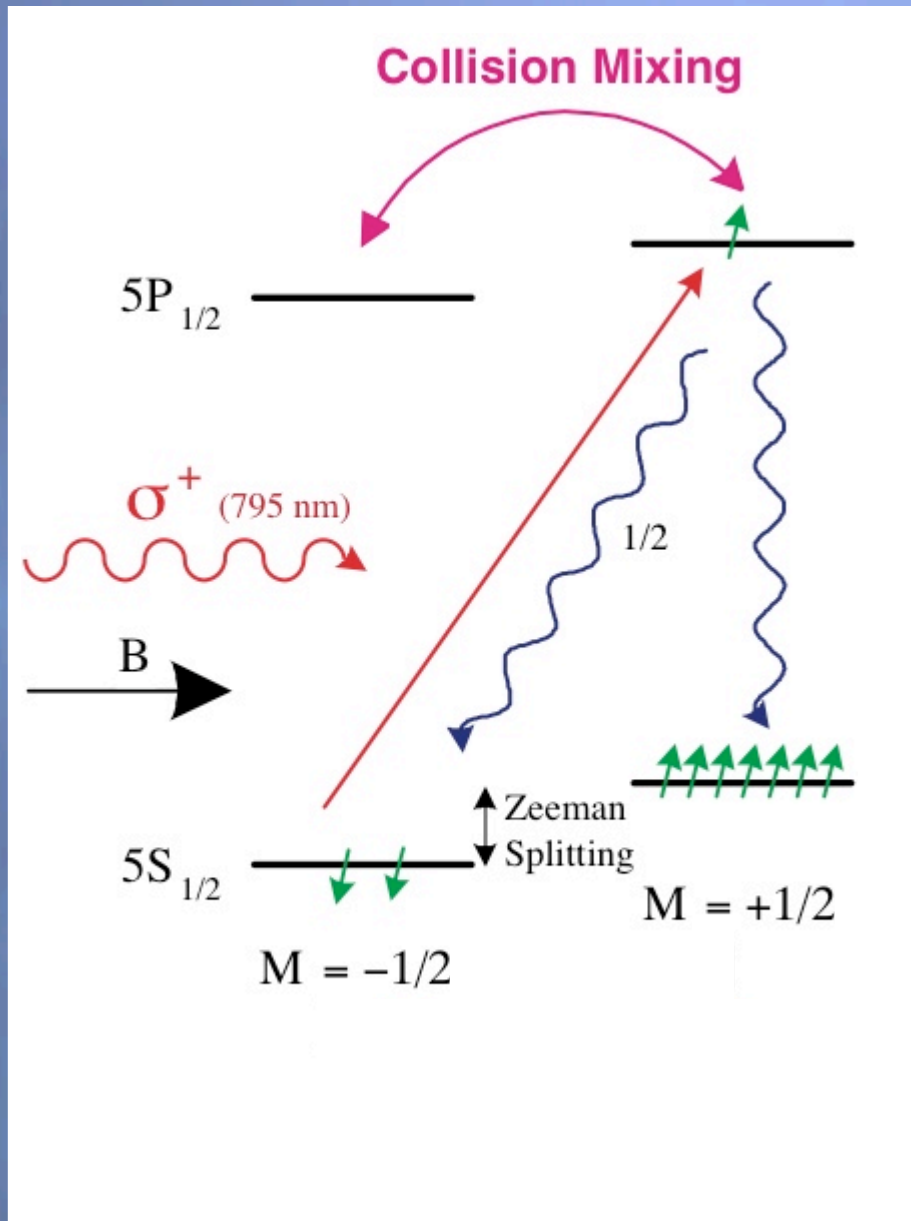
The polarized ^3He target



◆ Longitudinal and transverse configurations

◆ 2 independent polarimtries:
NMR and EPR

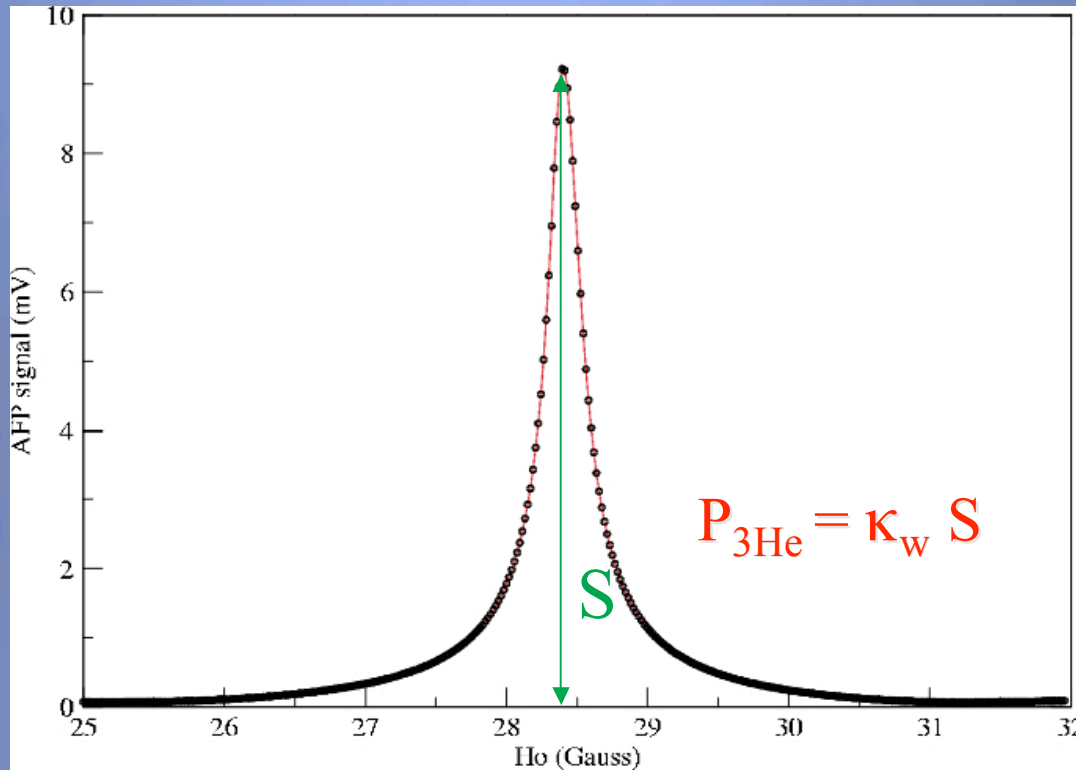
How to polarize ^3He ?



Two step process:

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

Nuclear Magnetic Resonance



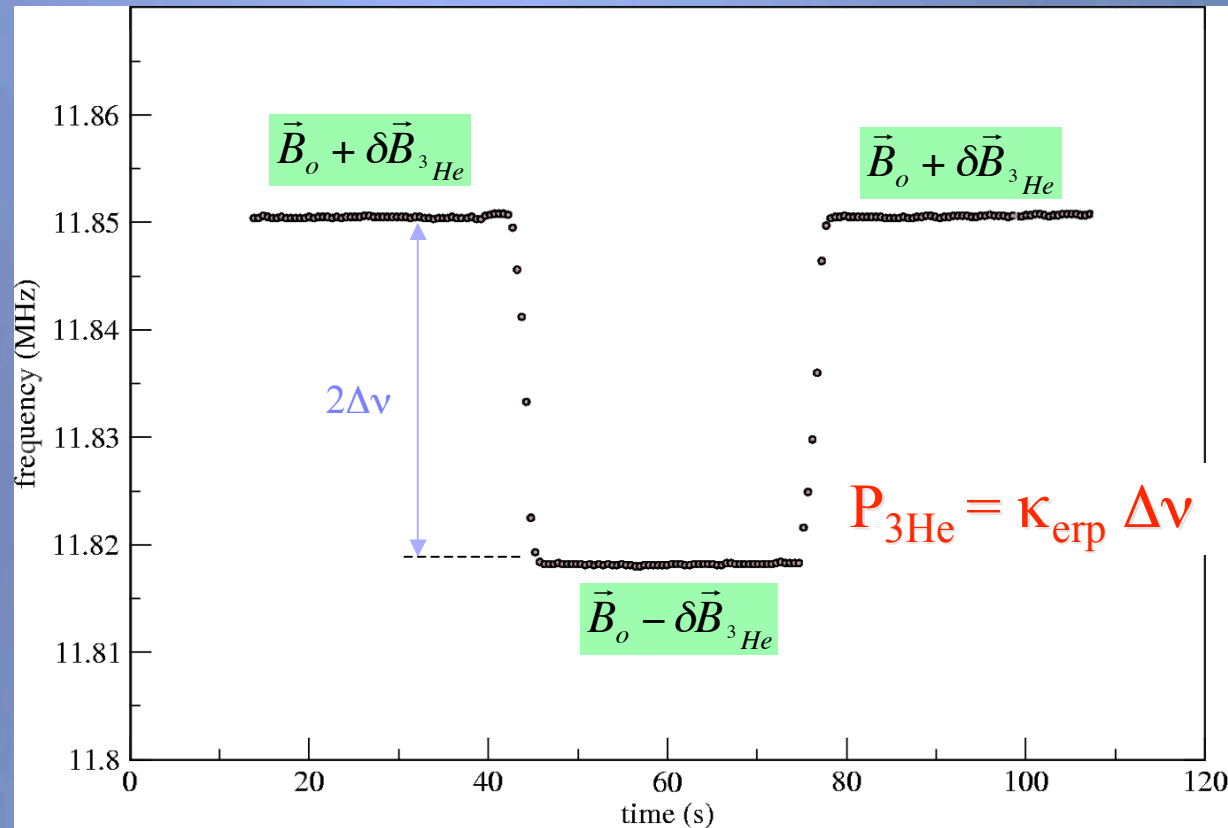
κ_w : from calibration with an identical target cell filled with water

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

} flip the ^3He spins under AFP conditions

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

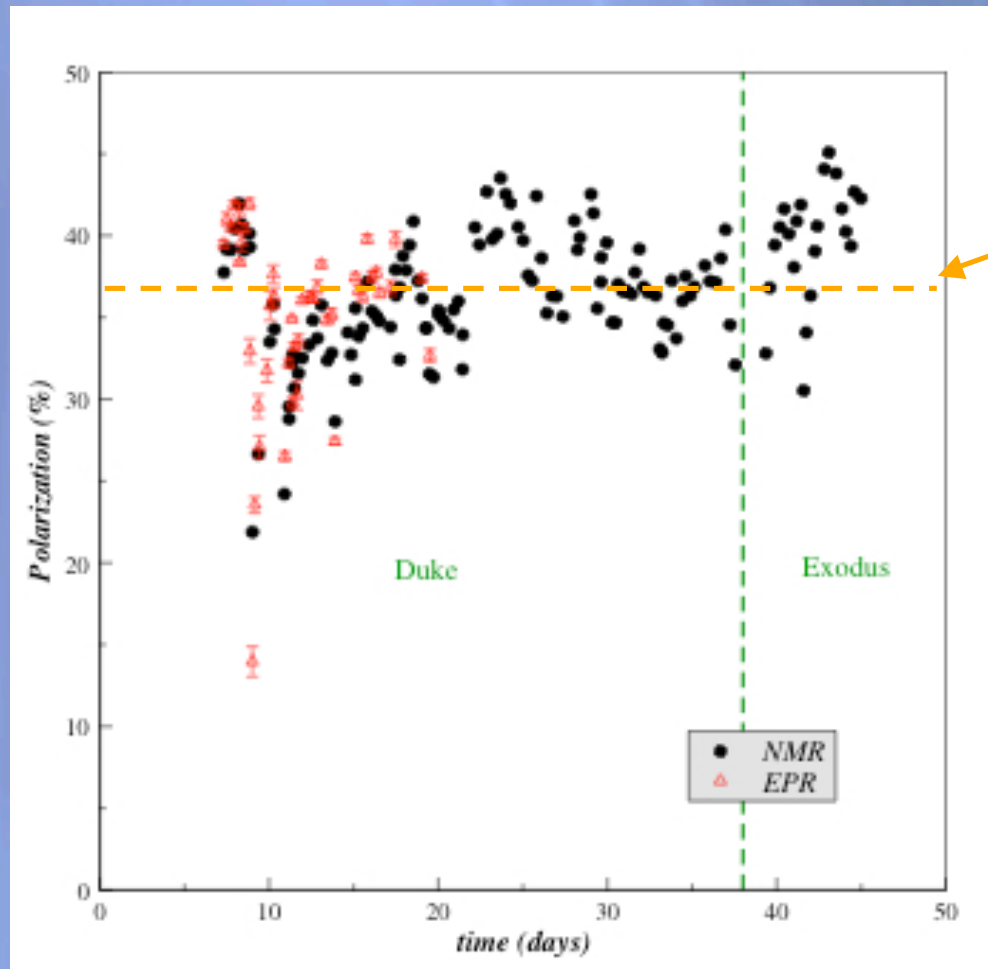
Electron Paramagnetic Resonance



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

κ_{erp} : depend of cell density

Target performance

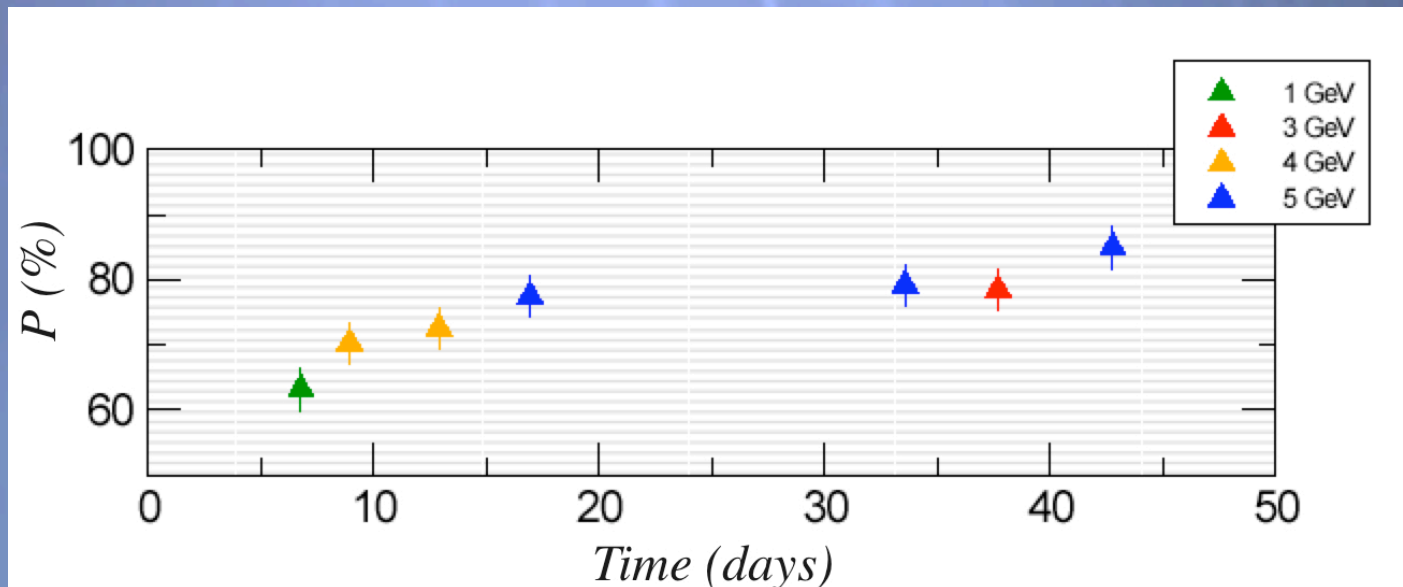


Statistical errors only

NMR analysis done by Vince Sulkosky

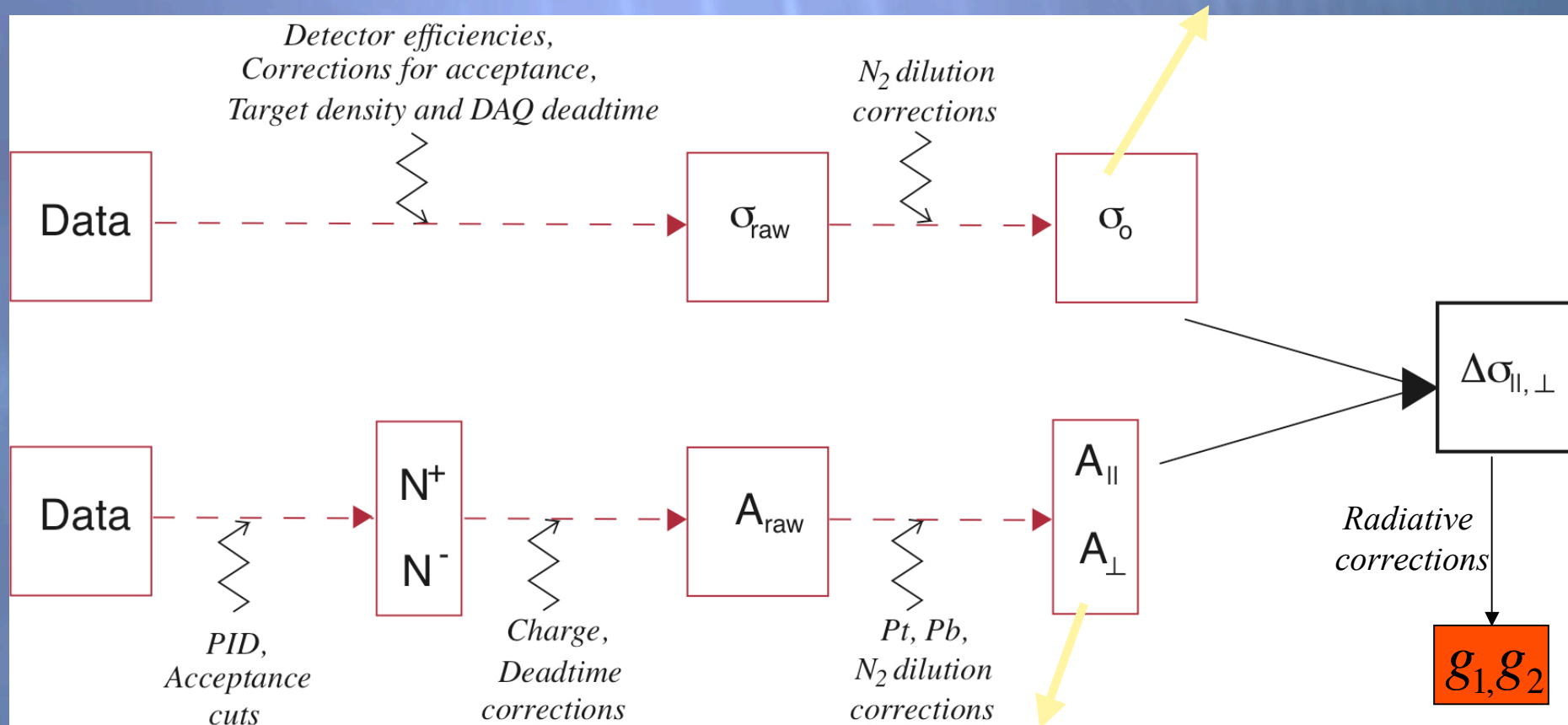
Electron Beam Polarization

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



Analysis scheme

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

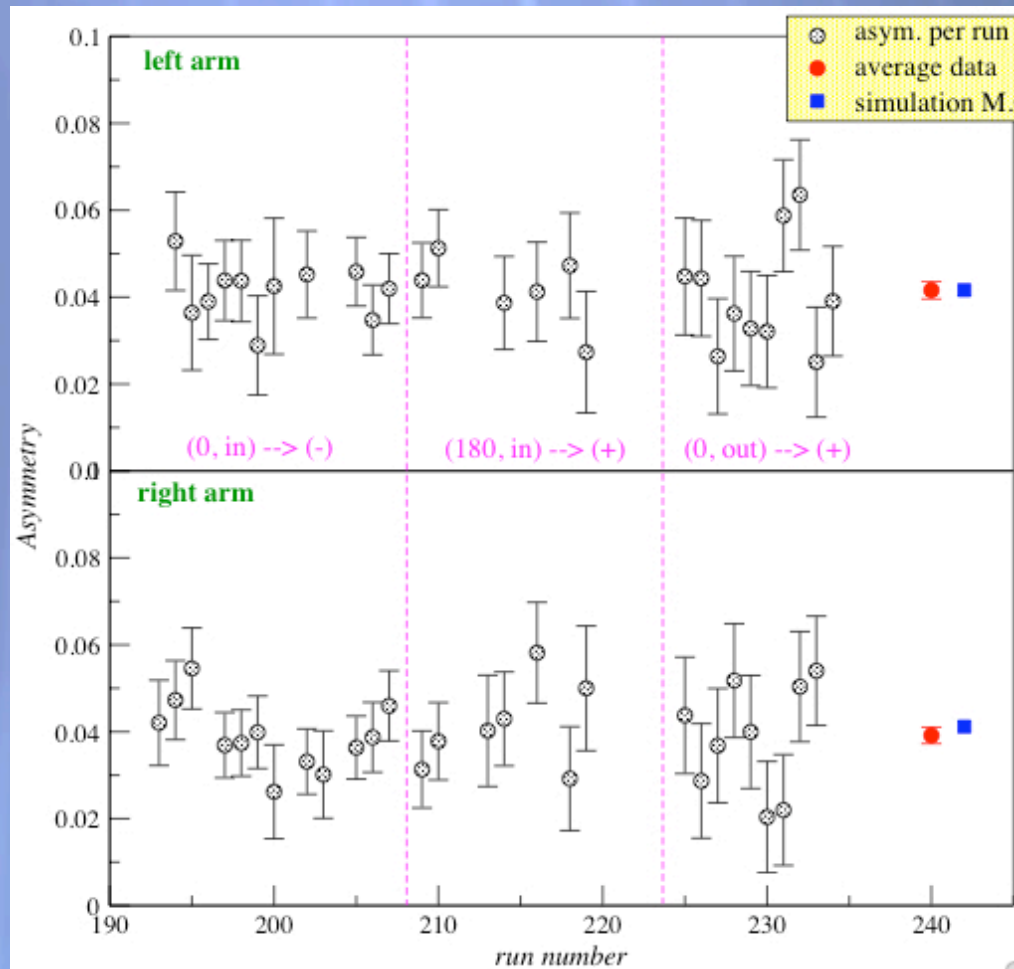


$$A_{||, \perp} = \frac{1}{f_{N_2} P_{tg} P_{beam}} \frac{\frac{N^+}{Q^+ LT^+} - \frac{N^-}{Q^- LT^-}}{\frac{N^+}{Q^+ LT^+} + \frac{N^-}{Q^- LT^-}}$$

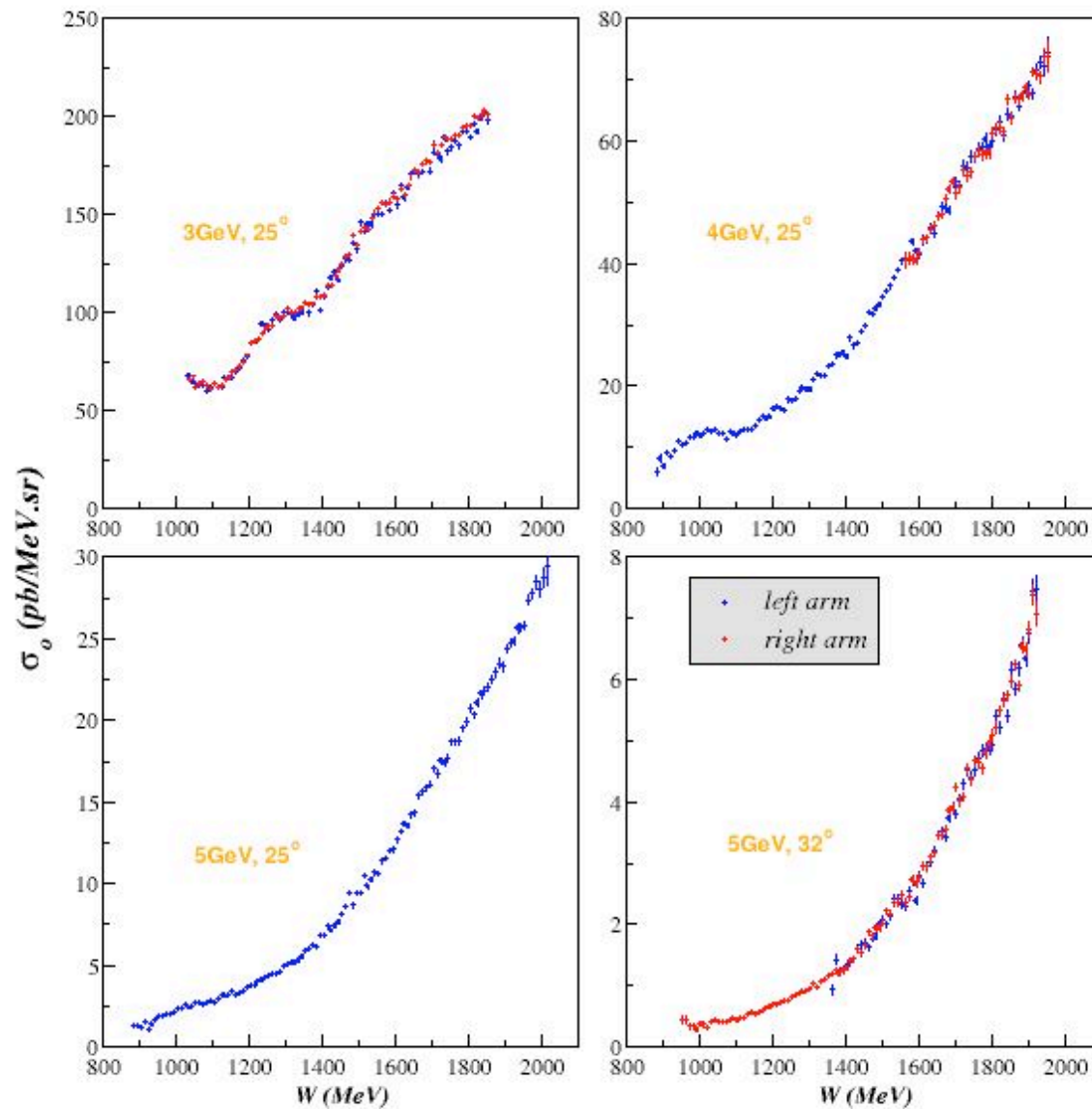
Elastic asymmetry

Check of the product:

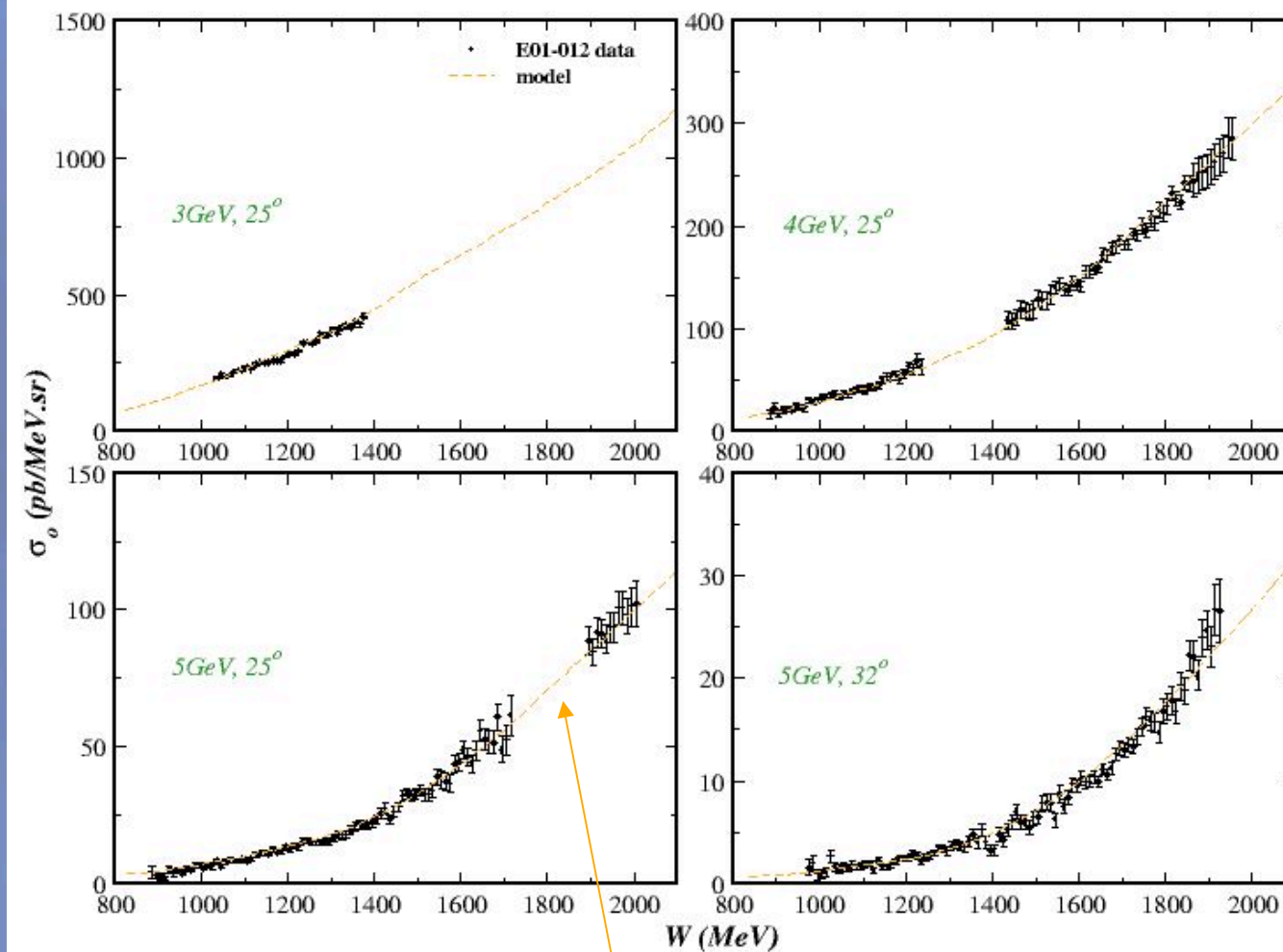
$$f_{N_2} P_{tg} P_{beam}$$



HRS cross section comparison

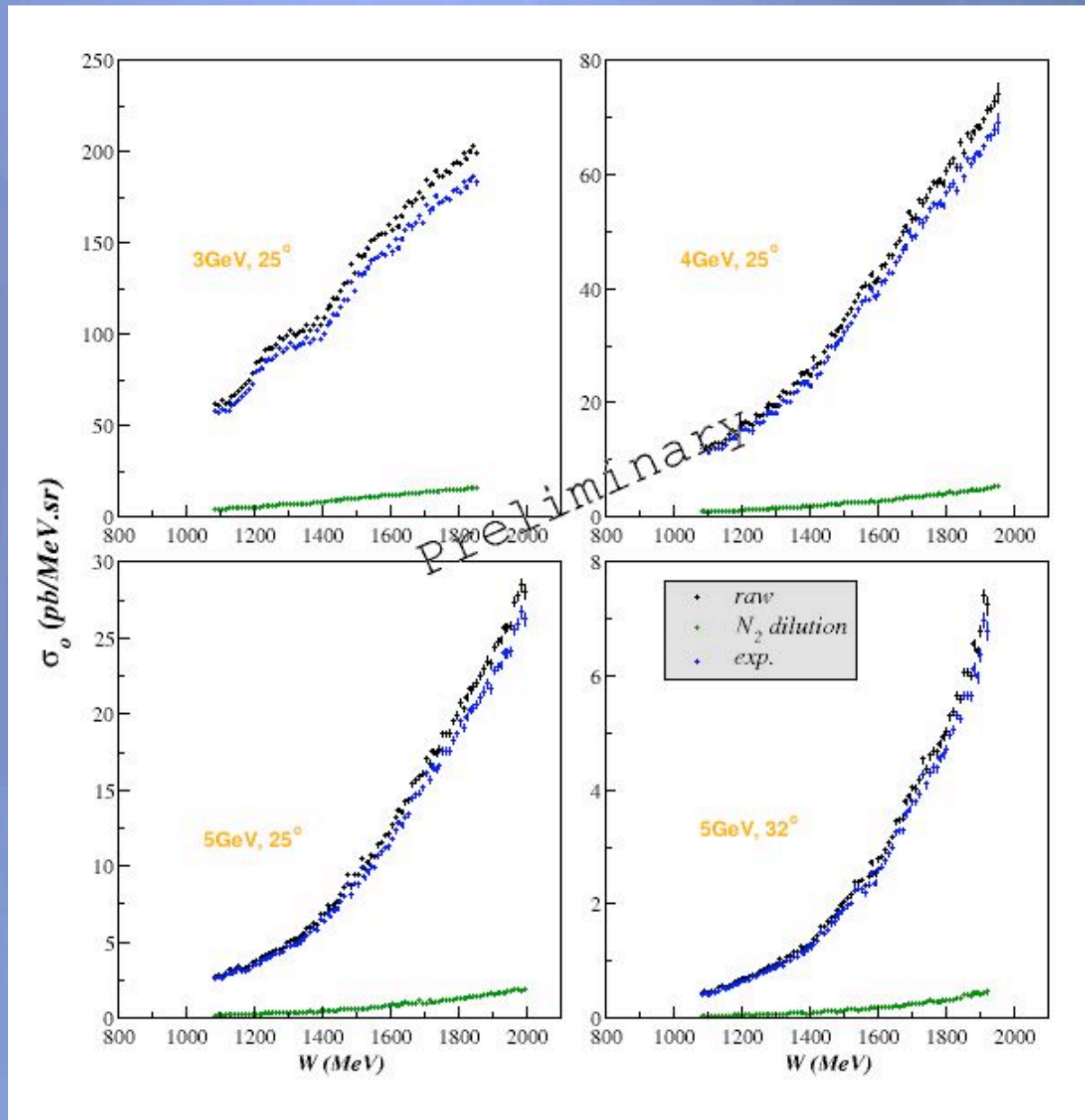


Nitrogen cross sections

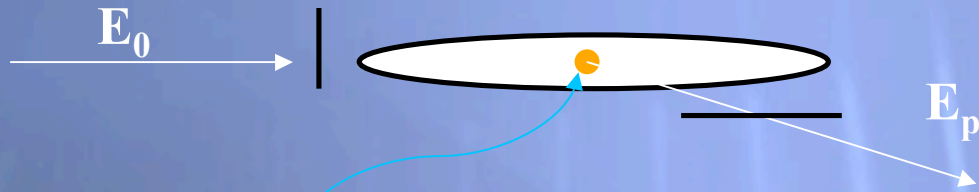


Modified the QFS model by adding energy dependence to the cross sections

^3He unpolarized cross sections



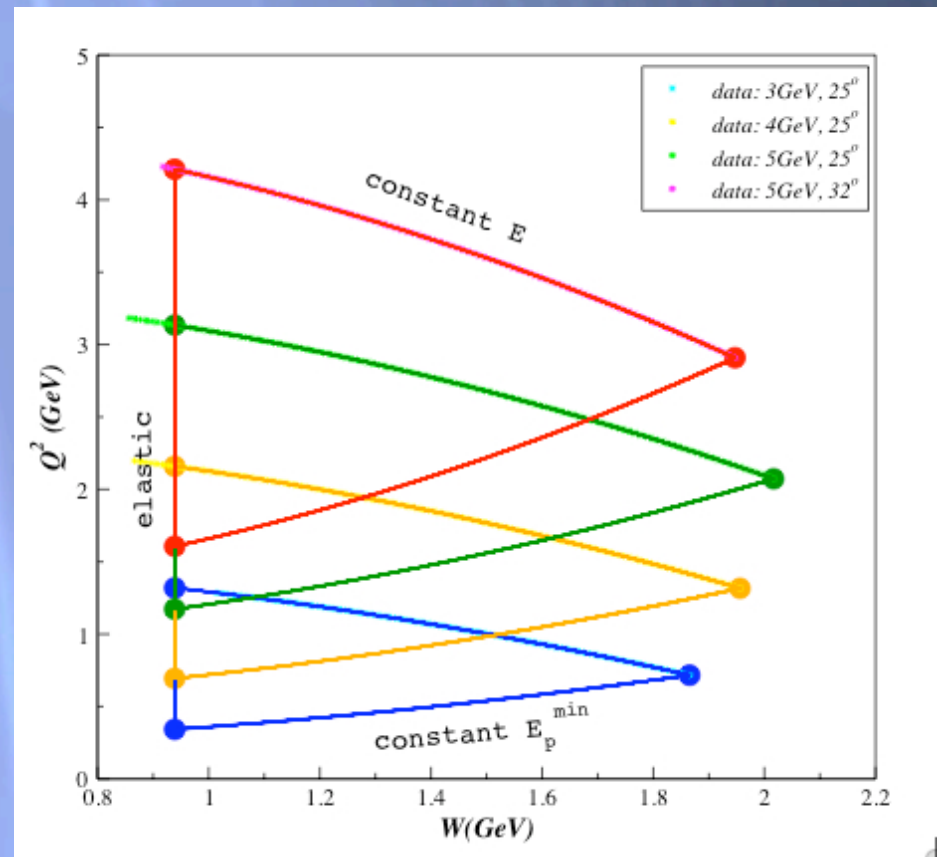
Radiative corrections



$$E_0^r < E_0$$

$$E_p^r > E_p$$

Computation to get the
real reaction

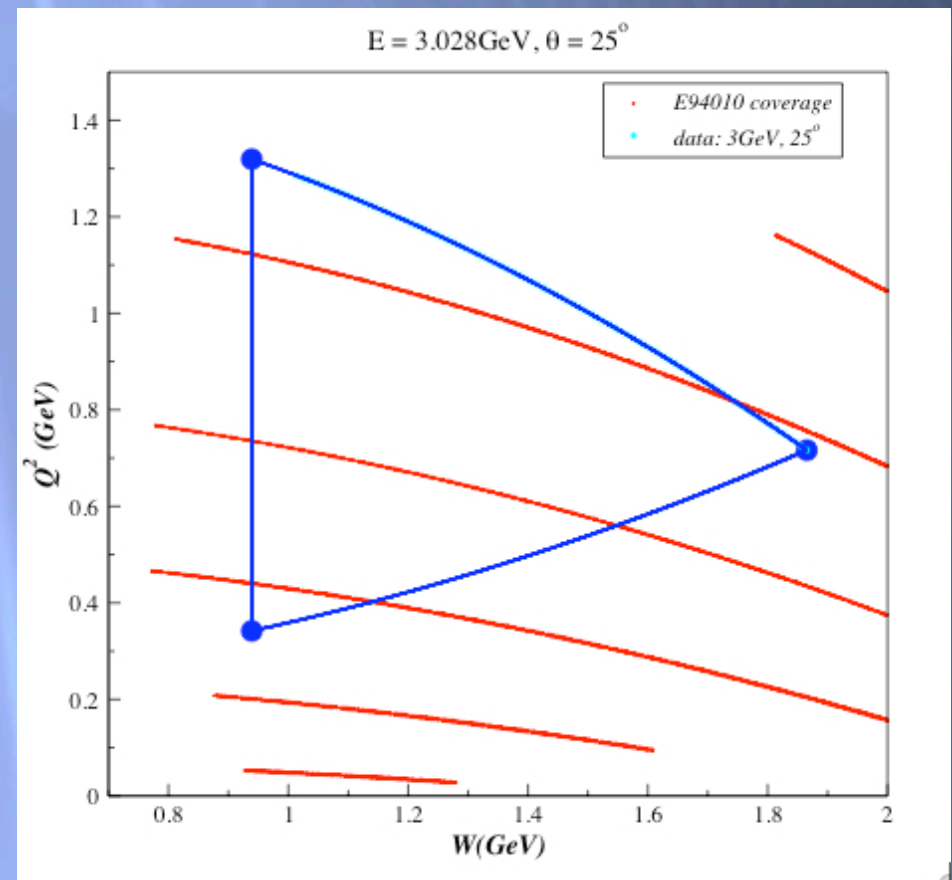


Radiative corrections

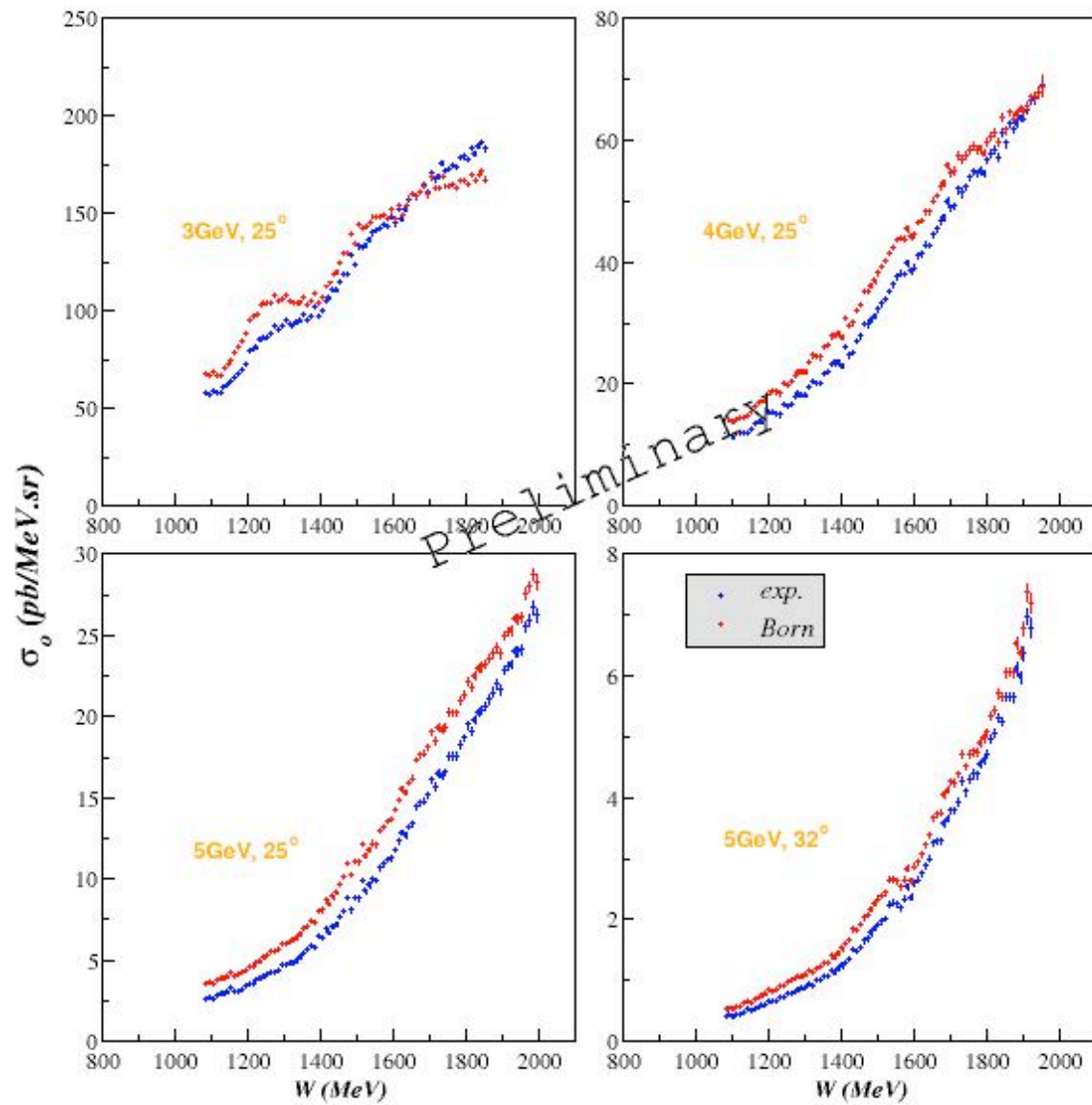
◆ Elastic tail negligible at all our kinematics

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

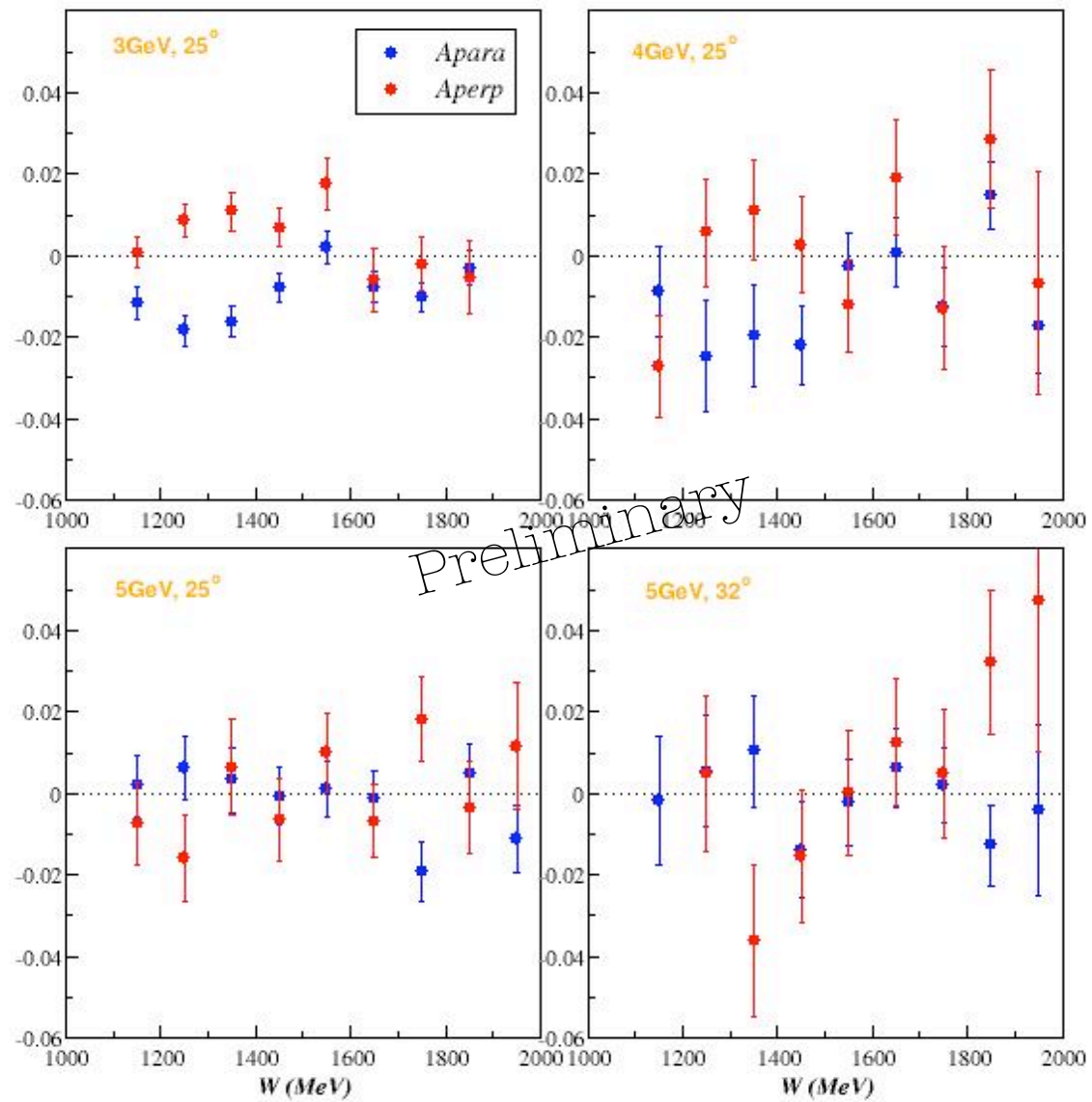
$$g_{1,2}(x, Q^2) \rightarrow \Delta\sigma_{\parallel, \perp}(E, E', \theta)$$



^3He Born cross sections



Asymmetries



Test of Duality on Neutron and ^3He

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

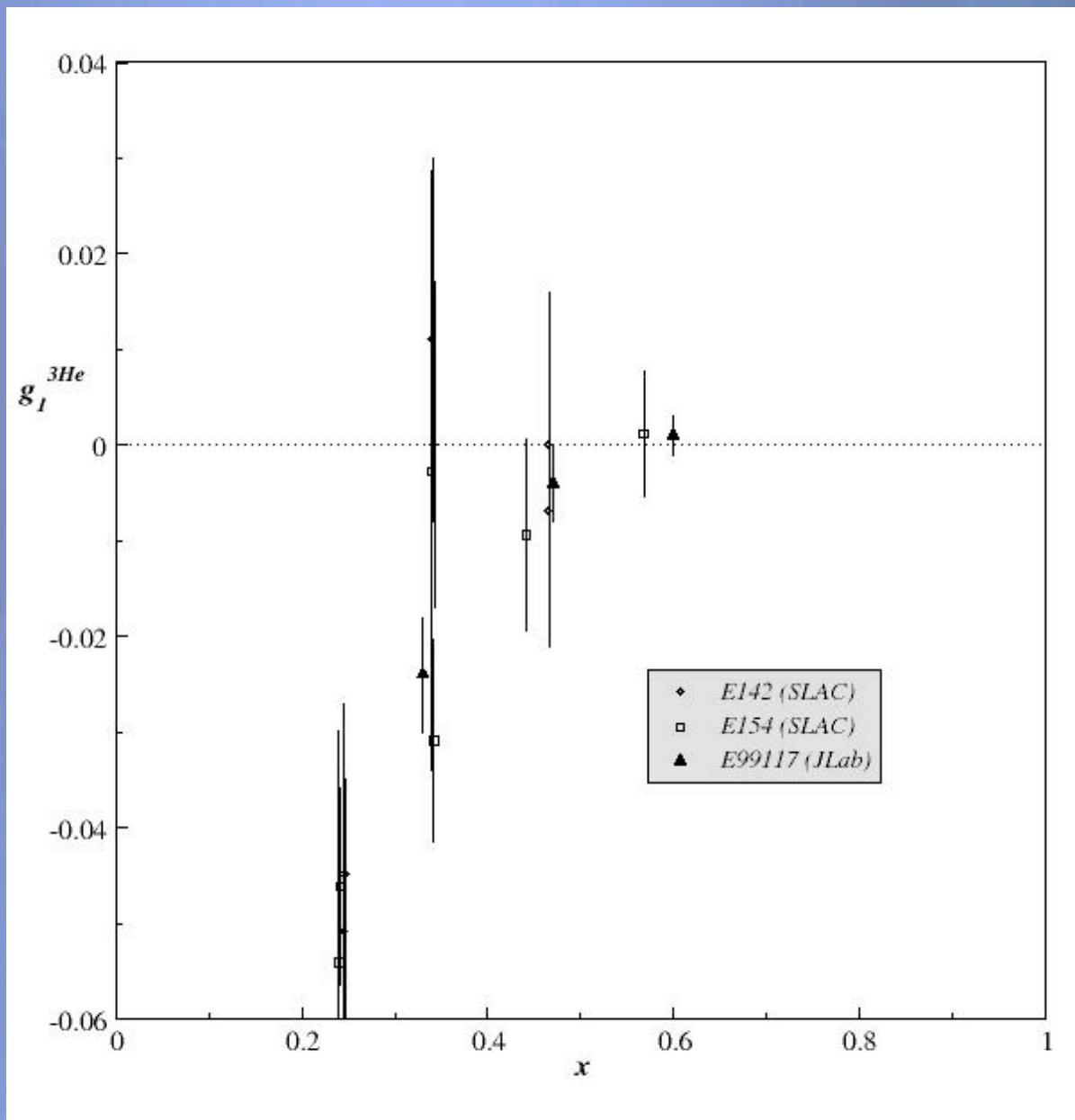
$$\tilde{\Gamma}_1^{res} = \int_{x_{min}}^{x_{max}} g_1^{res}(x, Q^2) dx$$

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

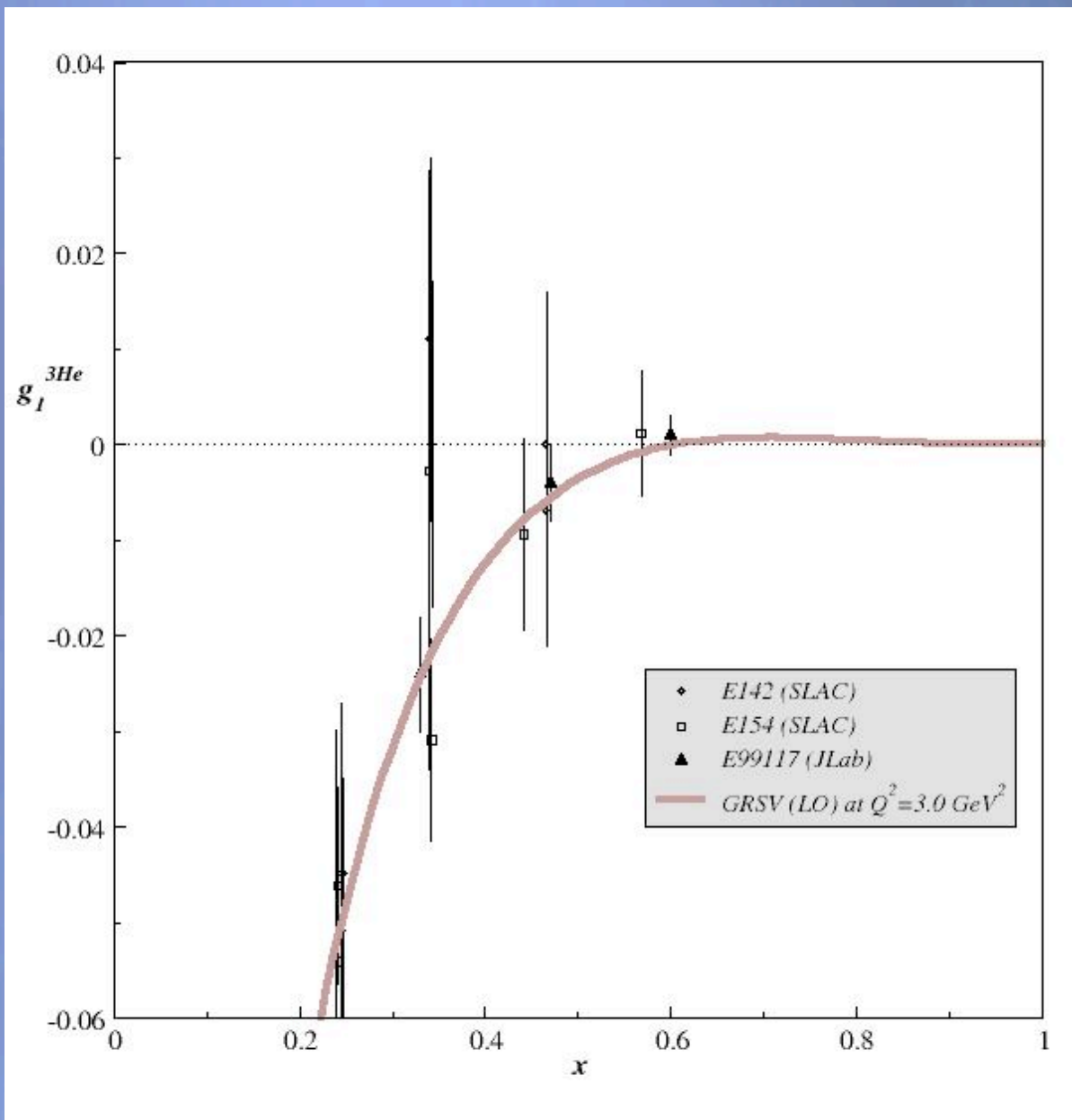
$$R = \frac{\tilde{\Gamma}_1^{res}}{\tilde{\Gamma}_1^{dis}}$$

if unity \Rightarrow duality is verified

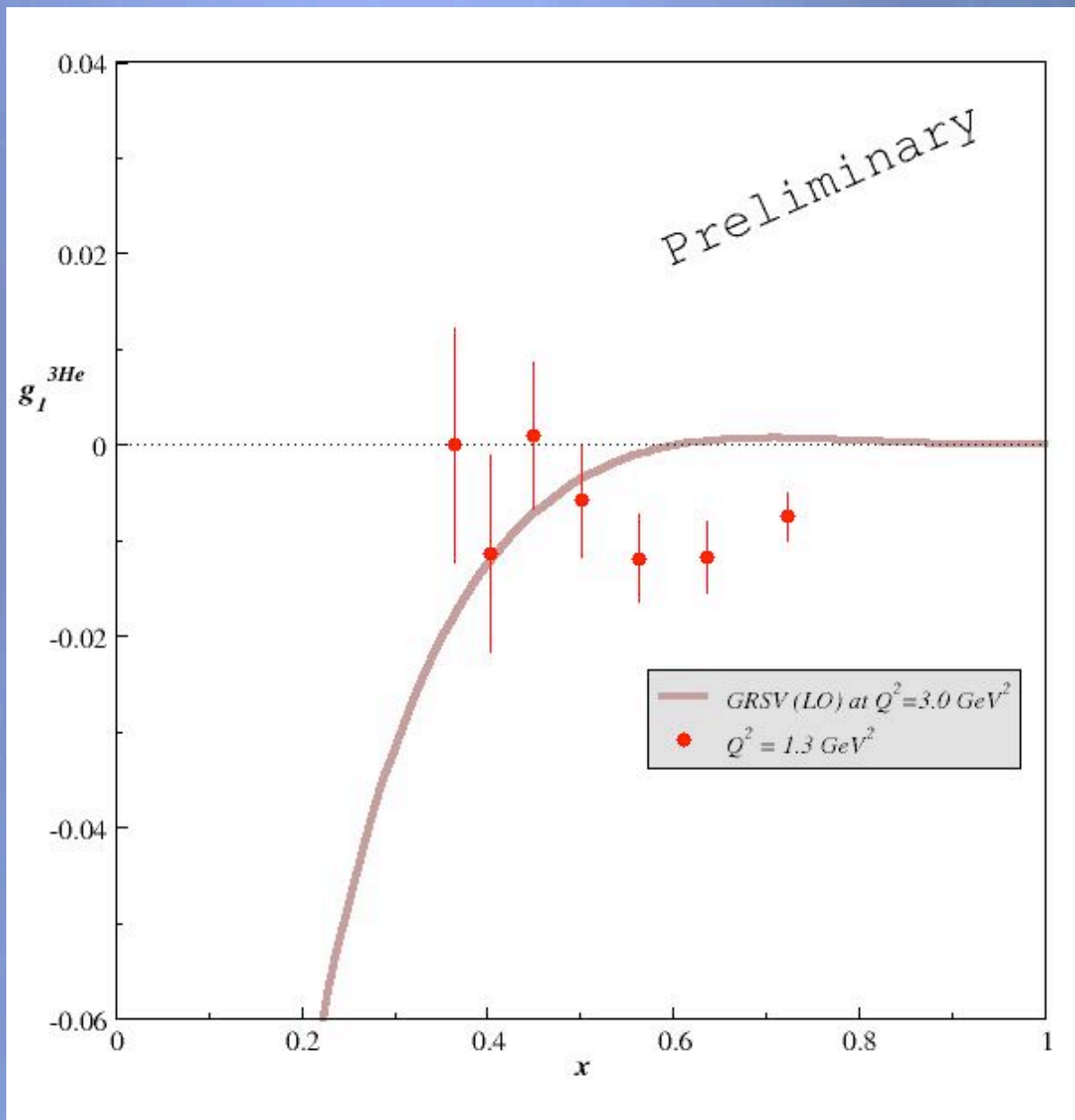
$g_1^{3\text{He}}$ at constant Q^2



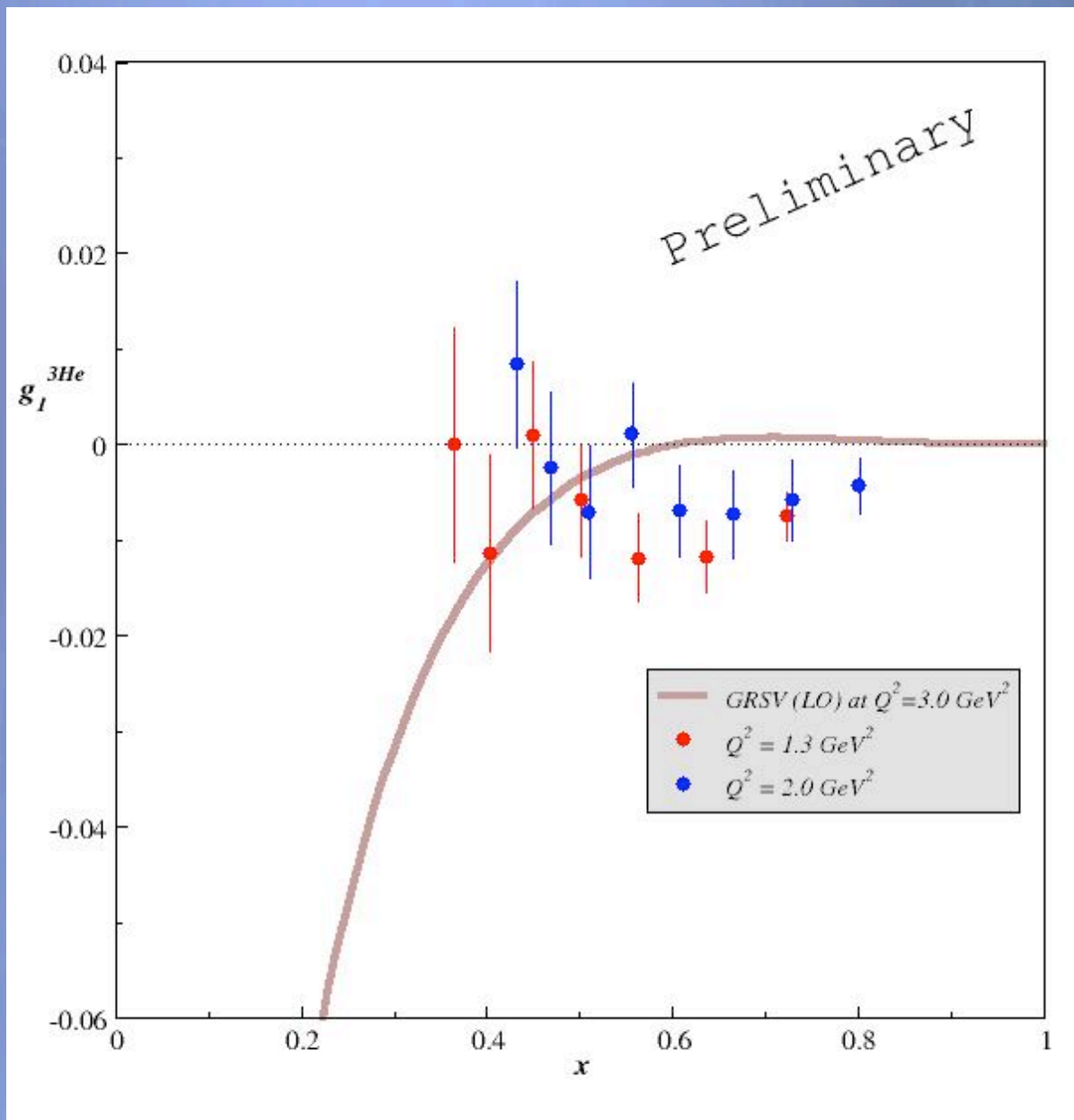
$g_1^{3\text{He}}$ at constant Q^2



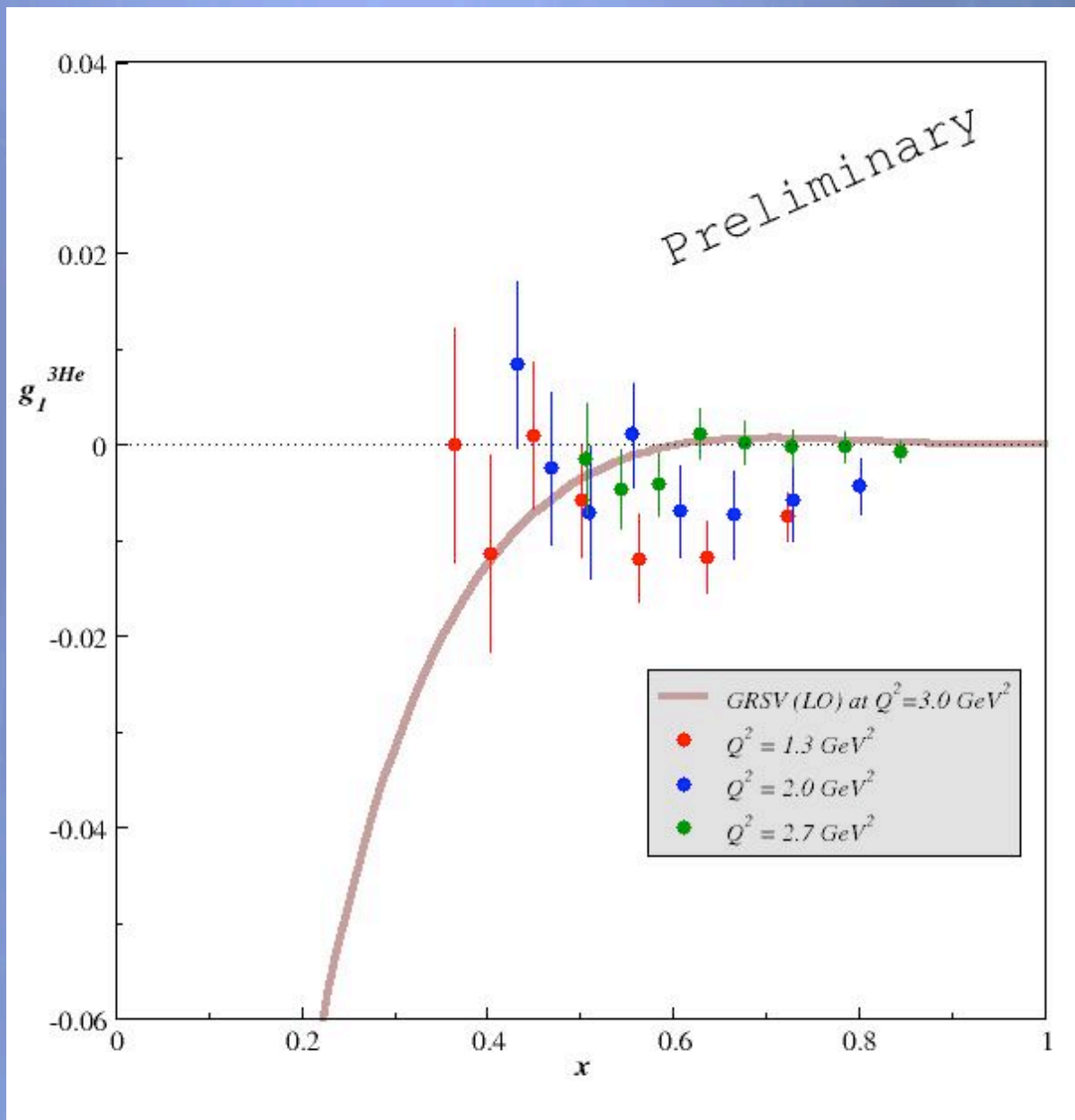
$g_1^{3\text{He}}$ at constant Q^2



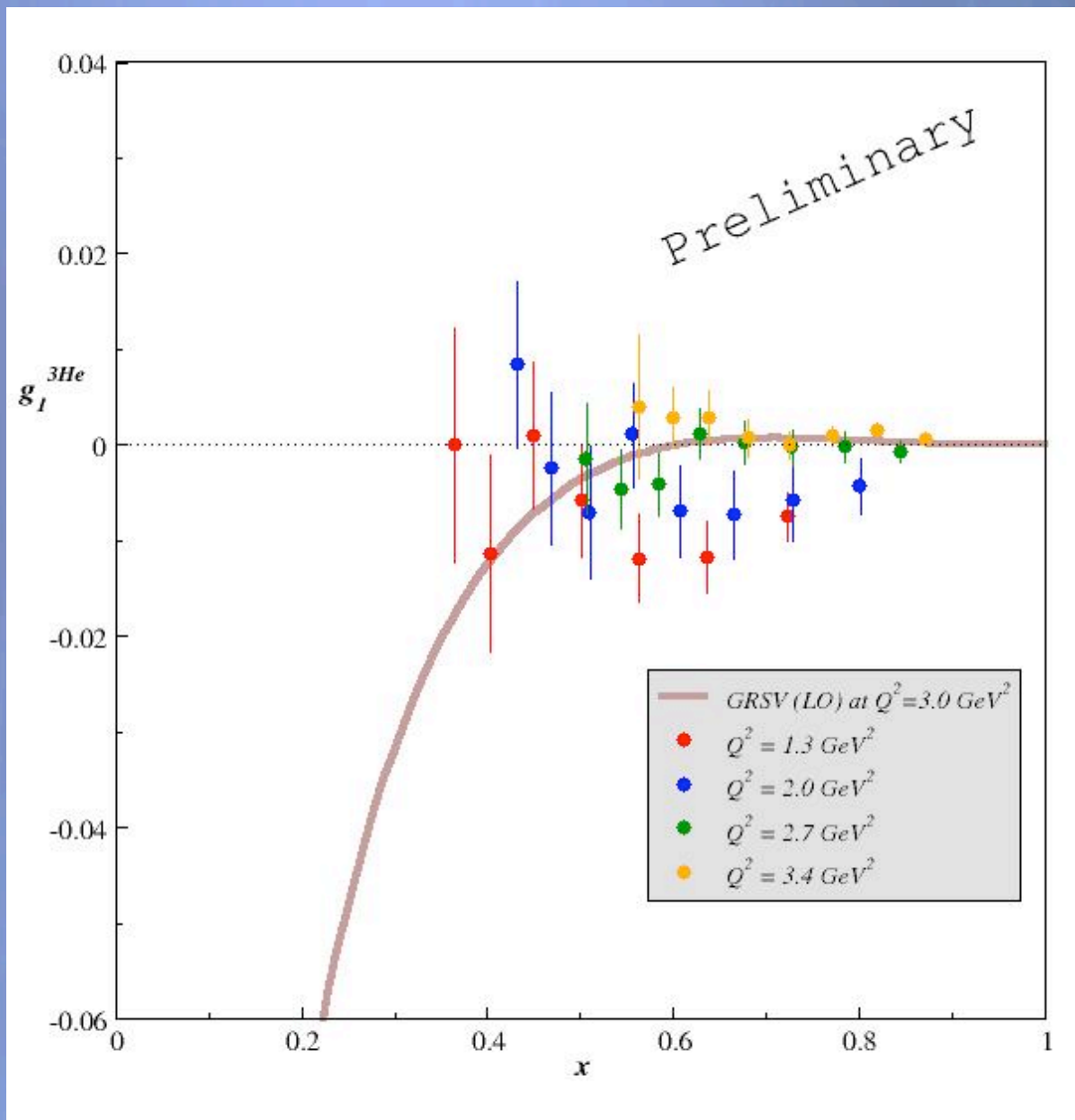
$g_1^{3\text{He}}$ at constant Q^2



$g_1^{3\text{He}}$ at constant Q^2



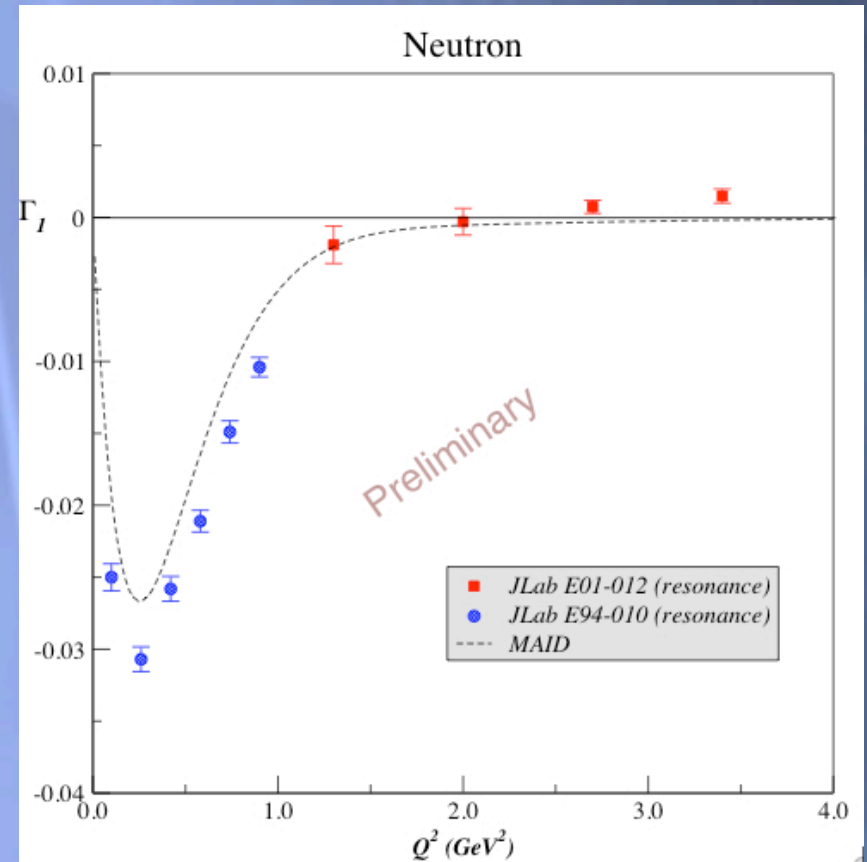
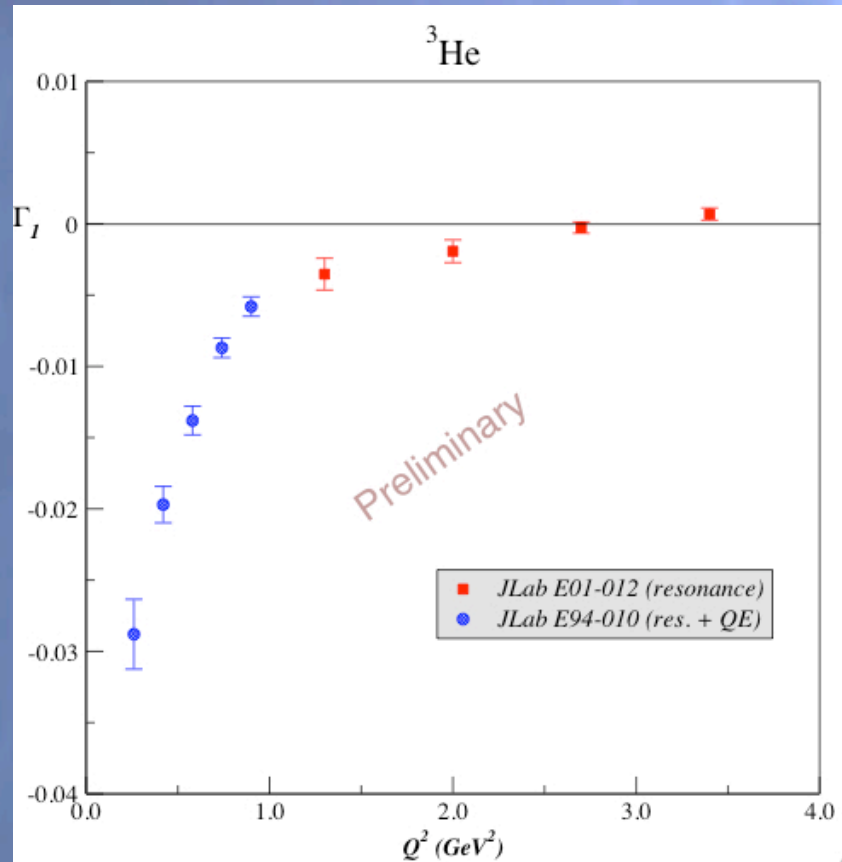
$g_1^{3\text{He}}$ at constant Q^2



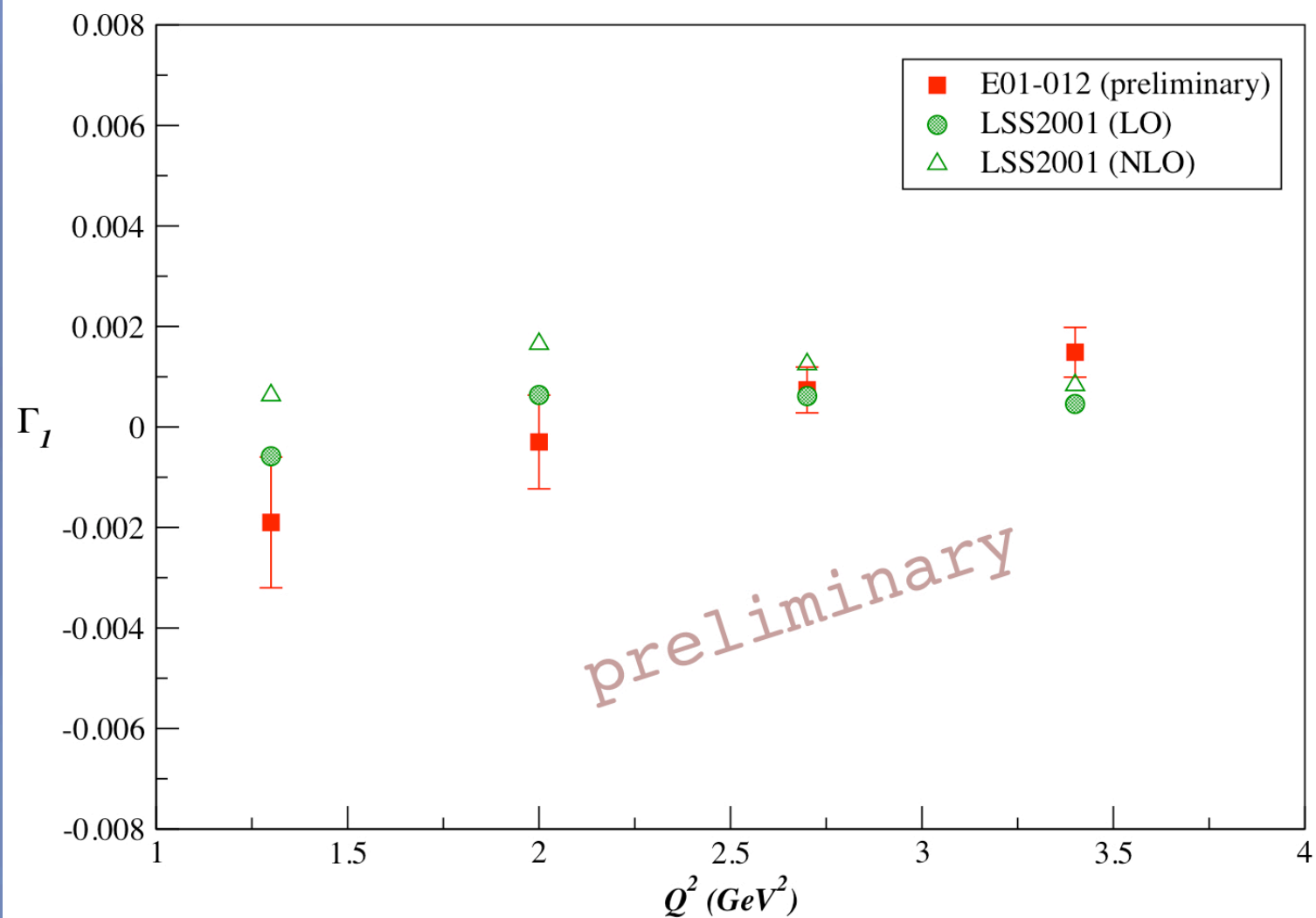
Γ_1^n in the resonance region

Extract the neutron from effective polarization equation:

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



Test of duality on neutron



Spin asymmetries

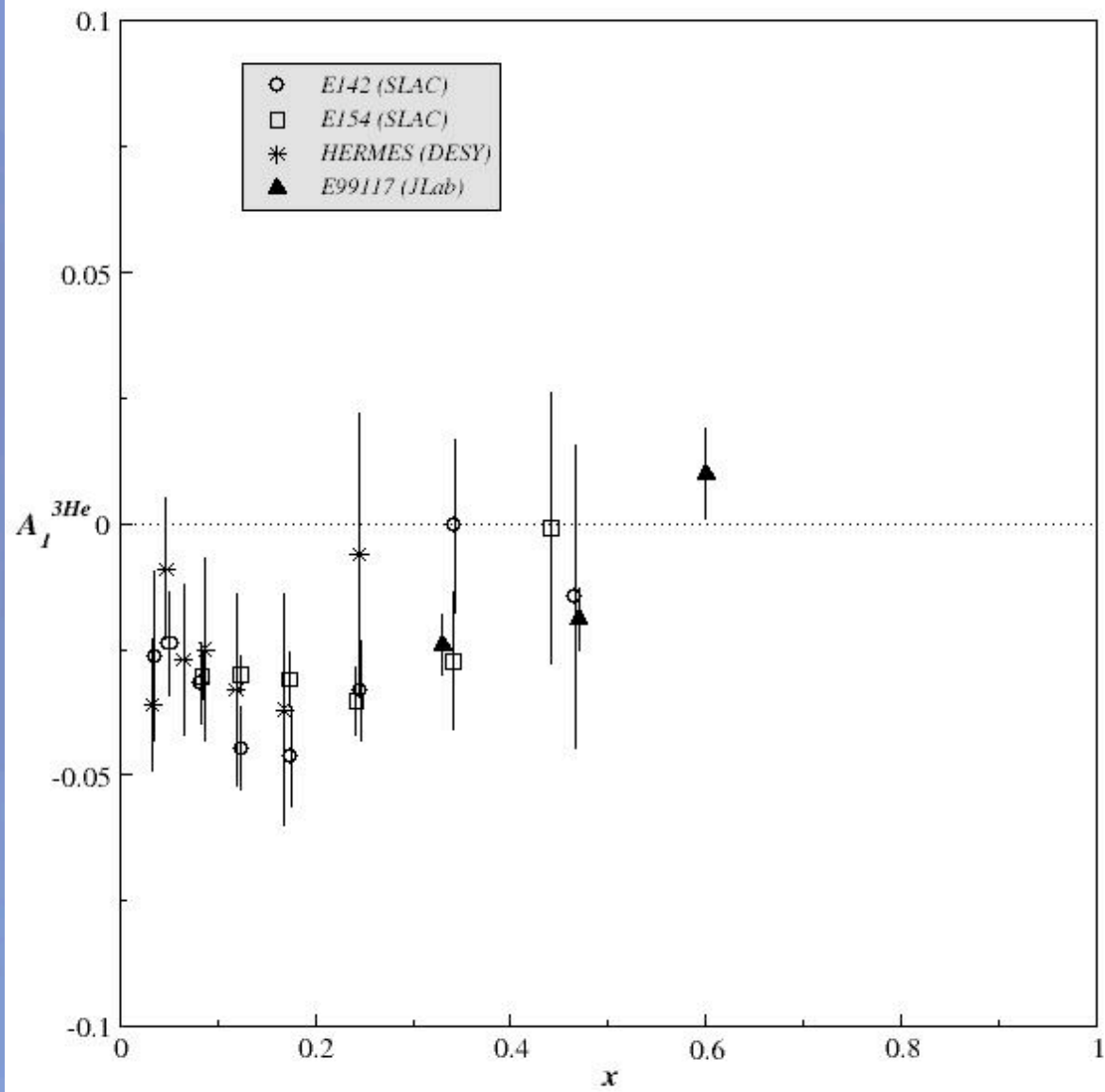
$$A_1 = \frac{A_{//}}{D(1 + \eta\xi)} - \frac{\eta A_{\perp}}{d(1 + \eta\xi)}$$

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

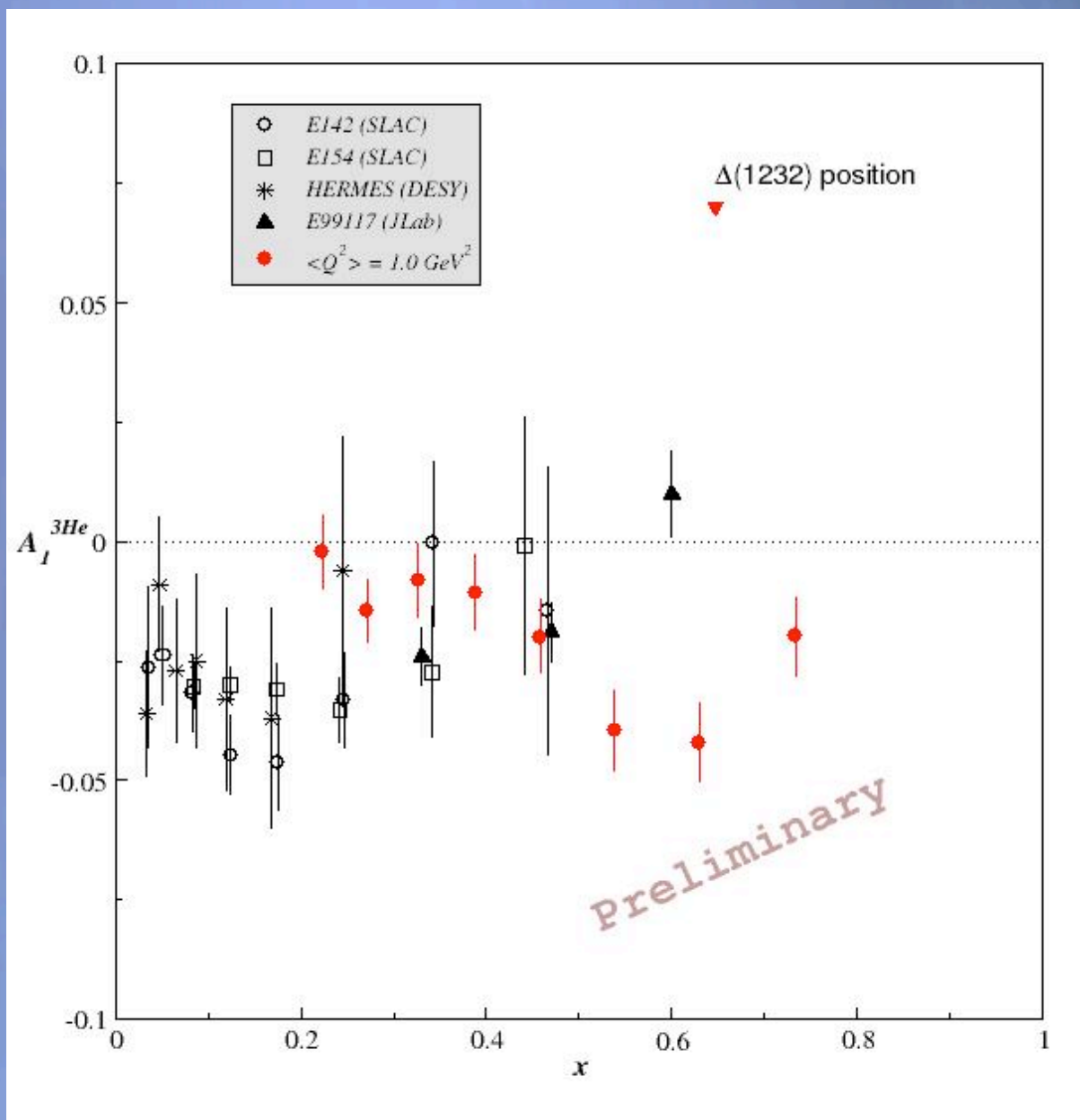
η and ξ depend on kinematical variables

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

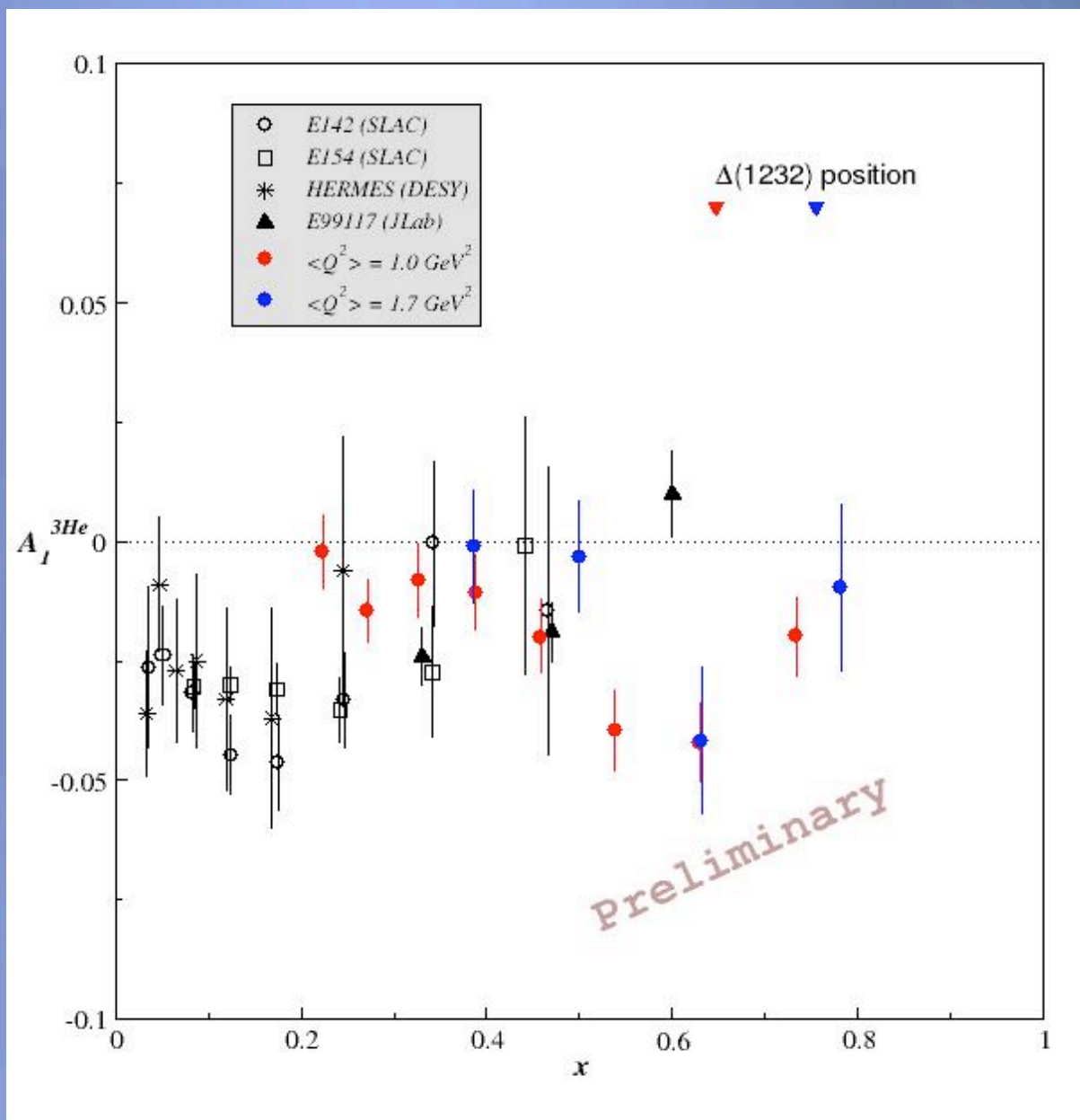
A₁ 3He



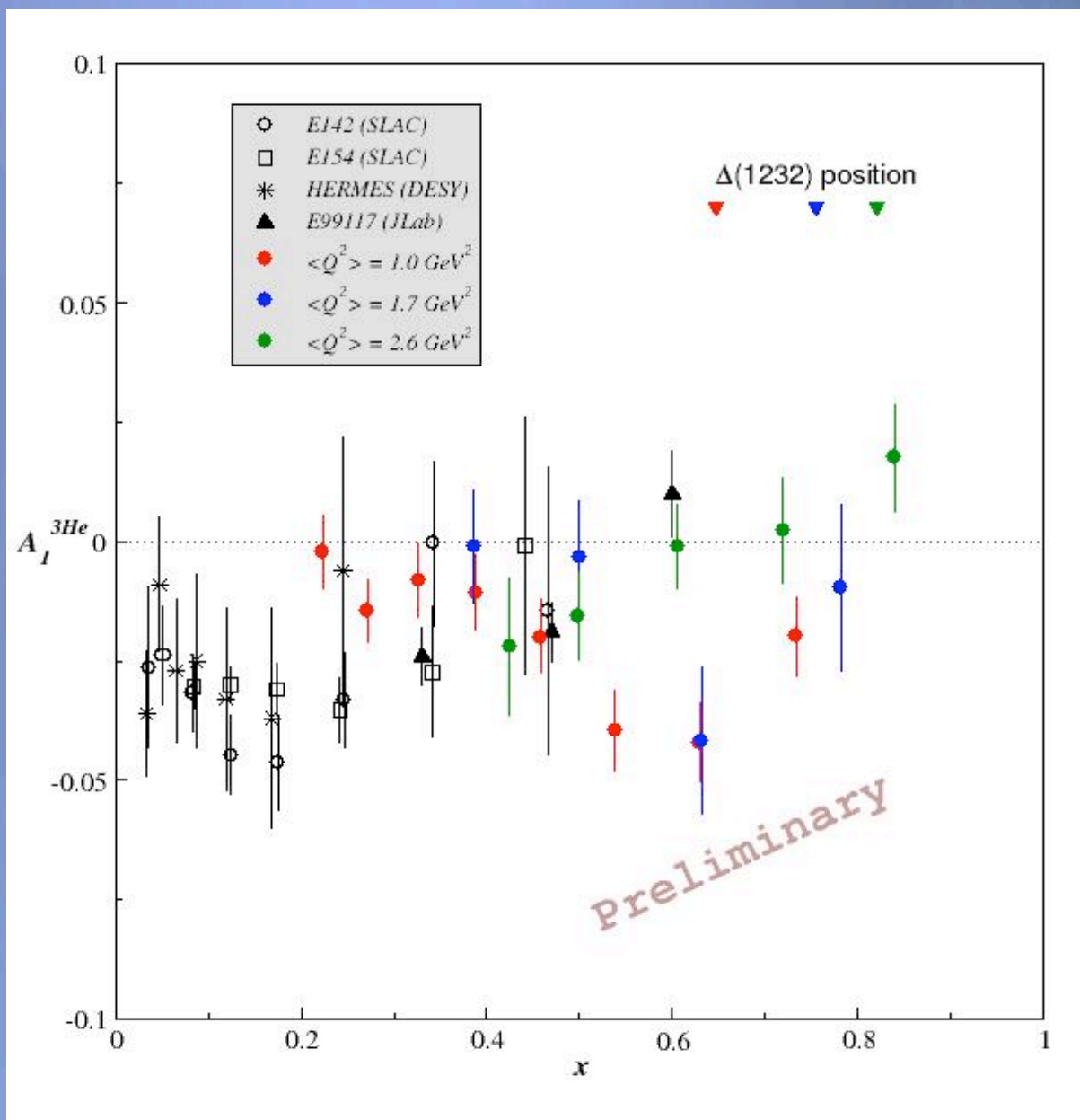
$A_1^{3\text{He}}$



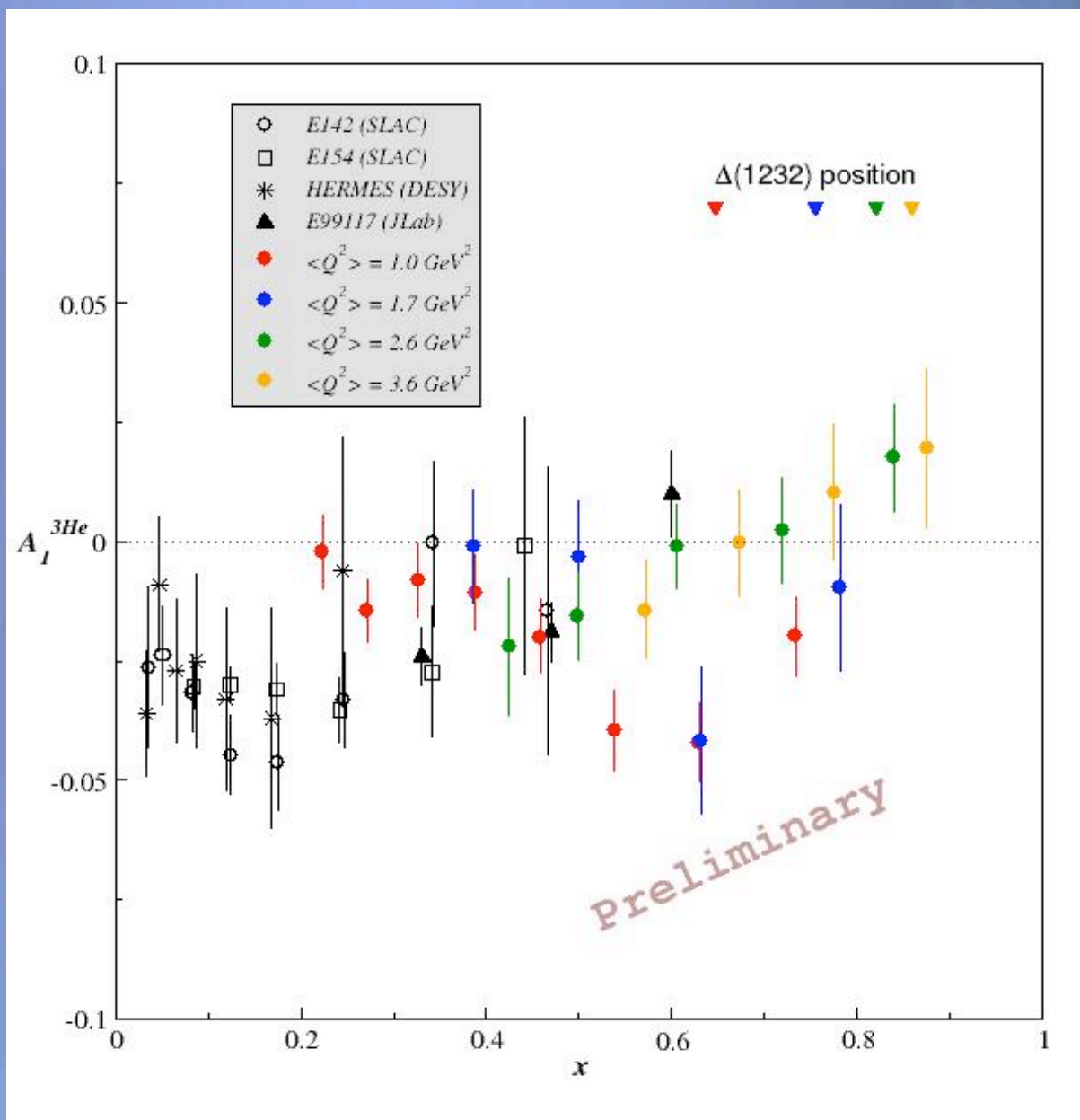
$A_1^{3\text{He}}$



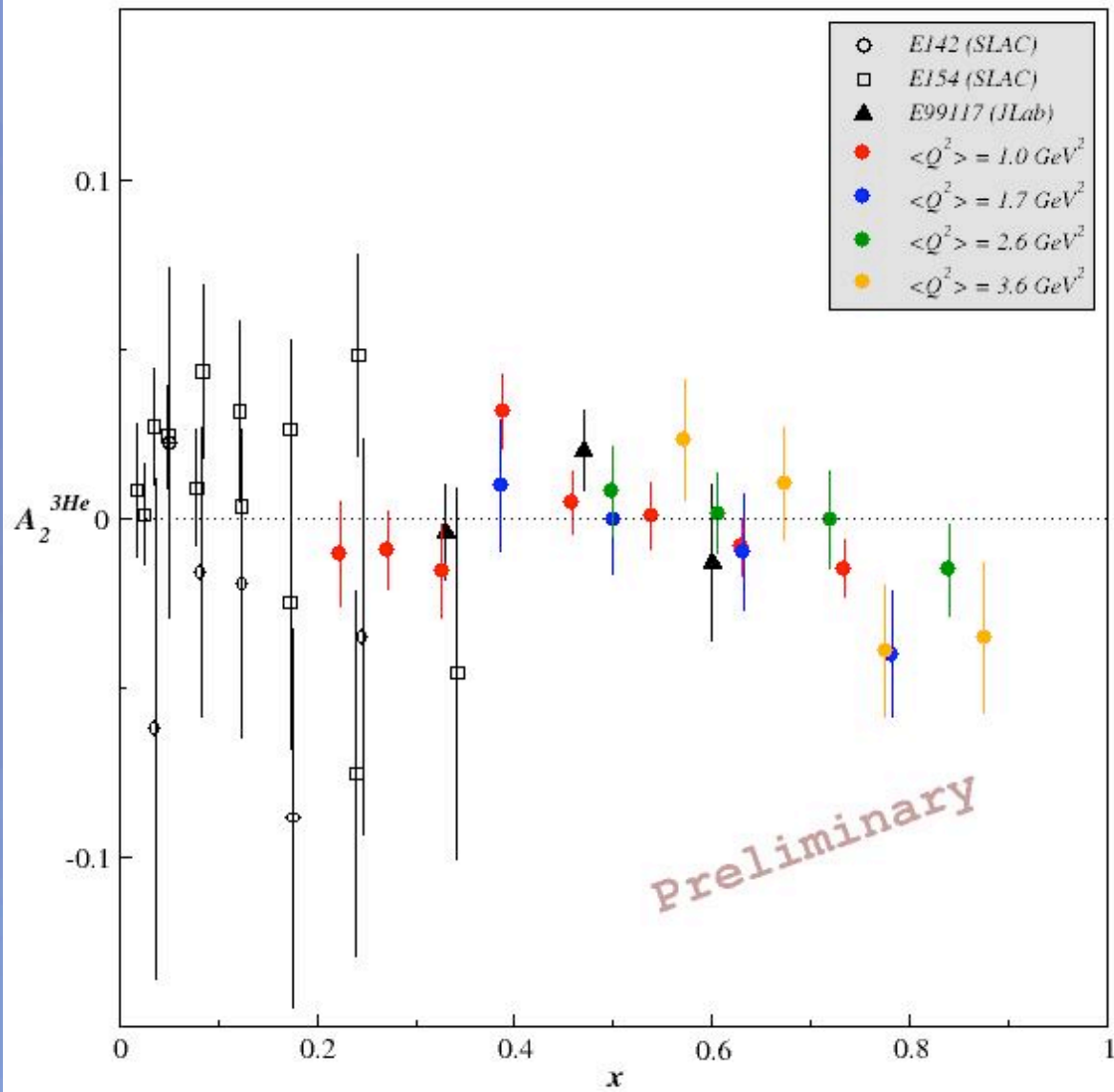
$A_1^{3\text{He}}$



$A_1^{3\text{He}}$



$A_2^{3\text{He}}$



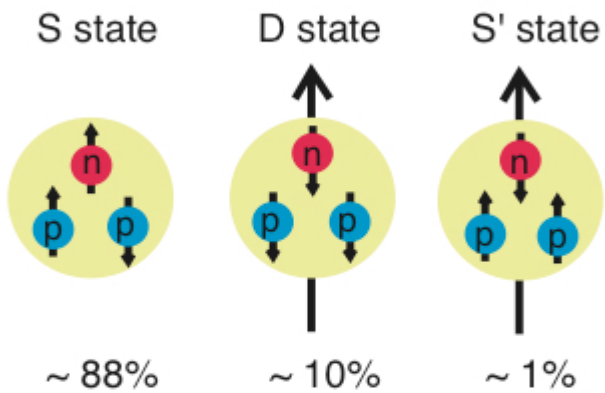
Summary

- E01-012 provides precision data of **Spin Structure Functions** on **neutron (^3He)** in the resonance region for $1.0 < Q^2 < 4.0 (\text{GeV}/c)^2$
- 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 ^3He to neutron

^3He as neutron target



$$R_n = 86\% \text{ and } R_p = -2.8\%$$

NMR: water calibration

