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Quark-Hadron Duality on the Neutron (^{3}He) Spin Structure

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Argonne National Laboratory

For the JLab E01-012 and Hall A collaborations

DNP meeting
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of Energy

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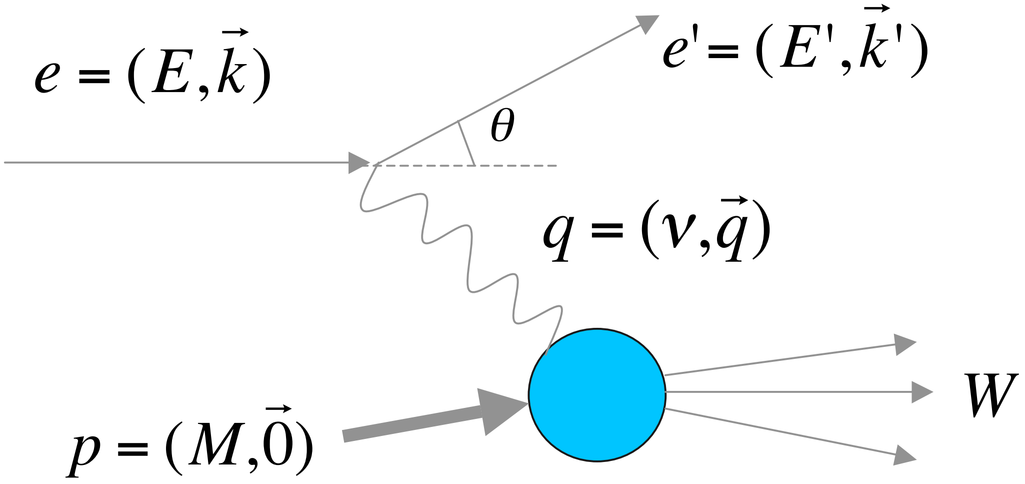
Inclusive electron scattering



4-momentum transfer squared

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

Invariant mass squared

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

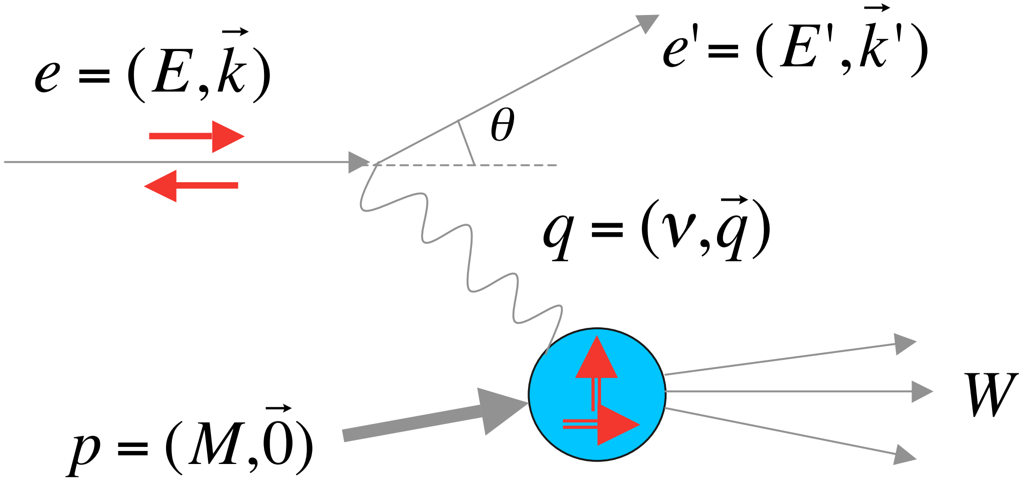
Bjorken variable

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

Unpolarized case

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

Inclusive electron scattering


$e = (E,\vec{k})$

$e' = (E',\vec{k}')$

θ

$q = (\nu,\vec{q})$

$p = (M,\vec{0})$

W

4-momentum transfer squared

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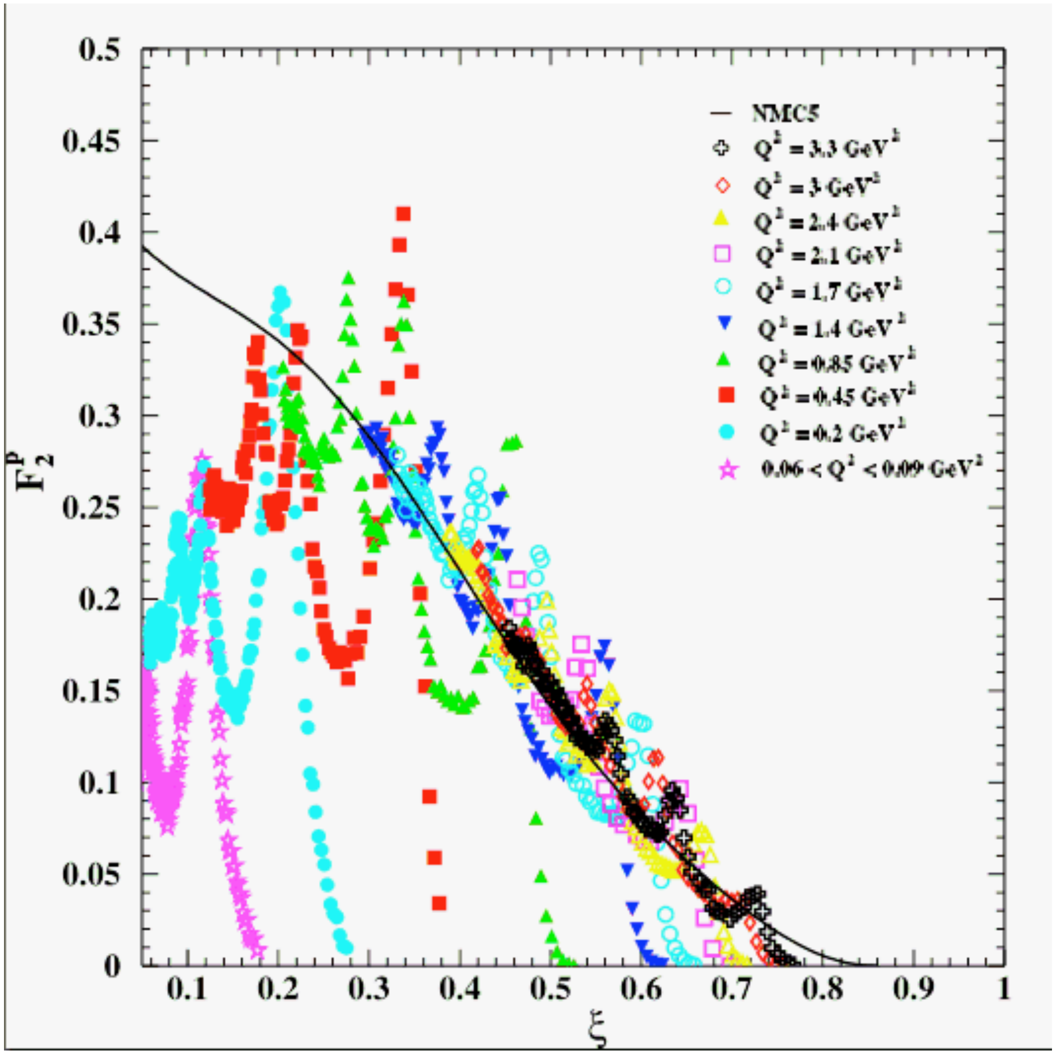
Polarized case

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

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

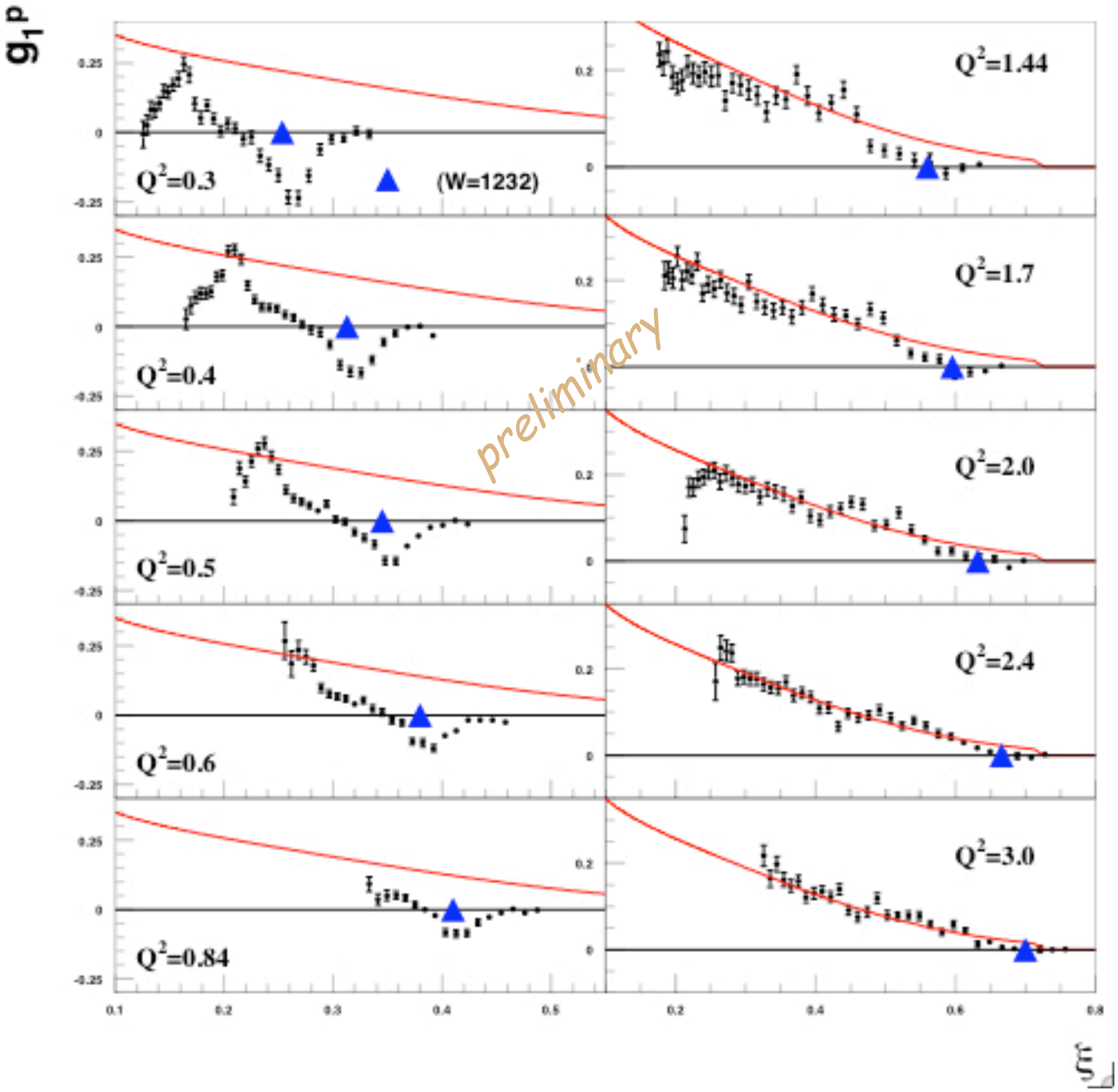
Quark-hadron duality

- 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
- Global and Local duality are observed for F_2



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

World data

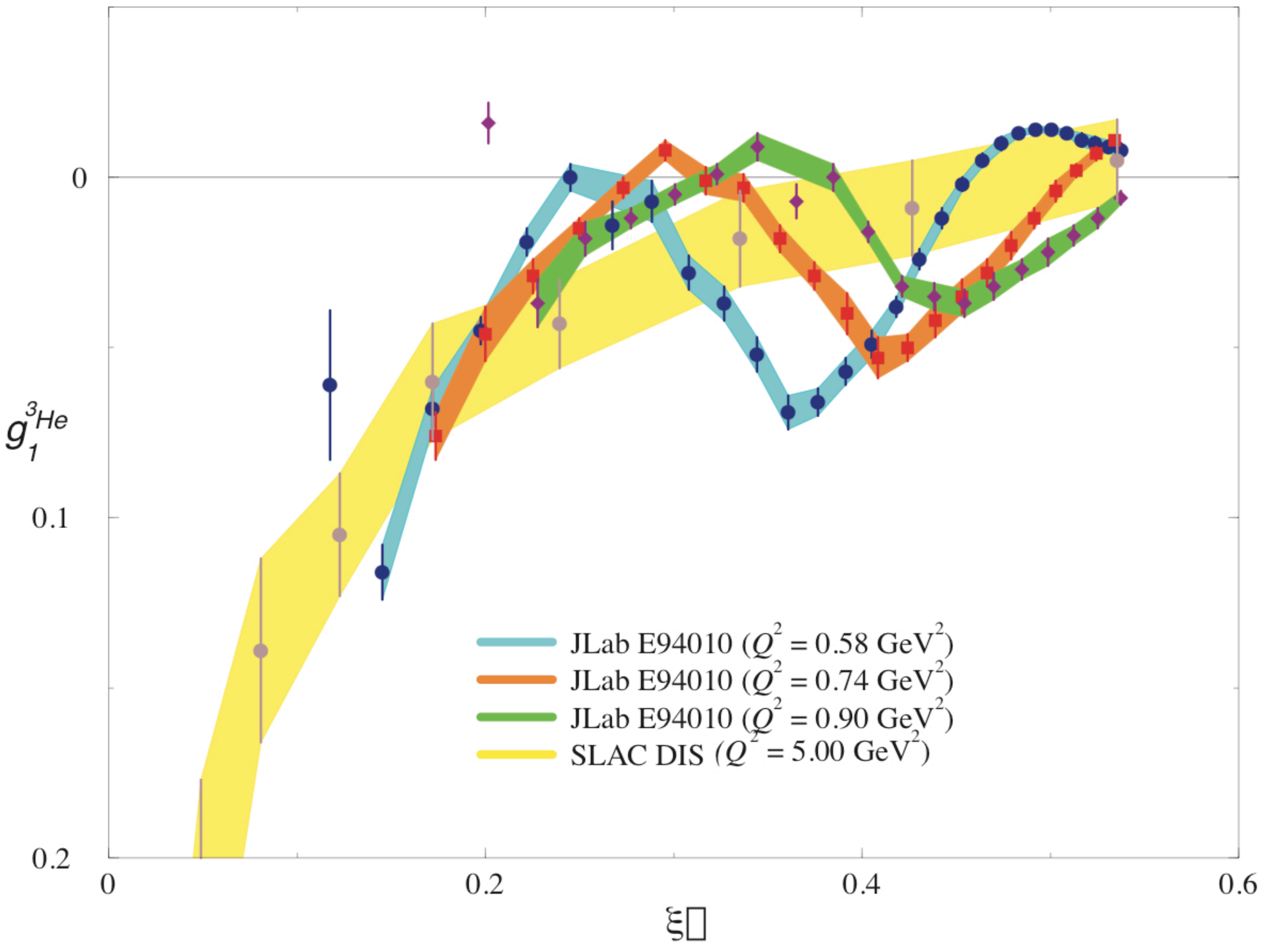


Jlab Hall B for g_1^p

From DIS 2005 proceedings

World data

Indication of duality from Jlab Hall A for g_1^{3He}

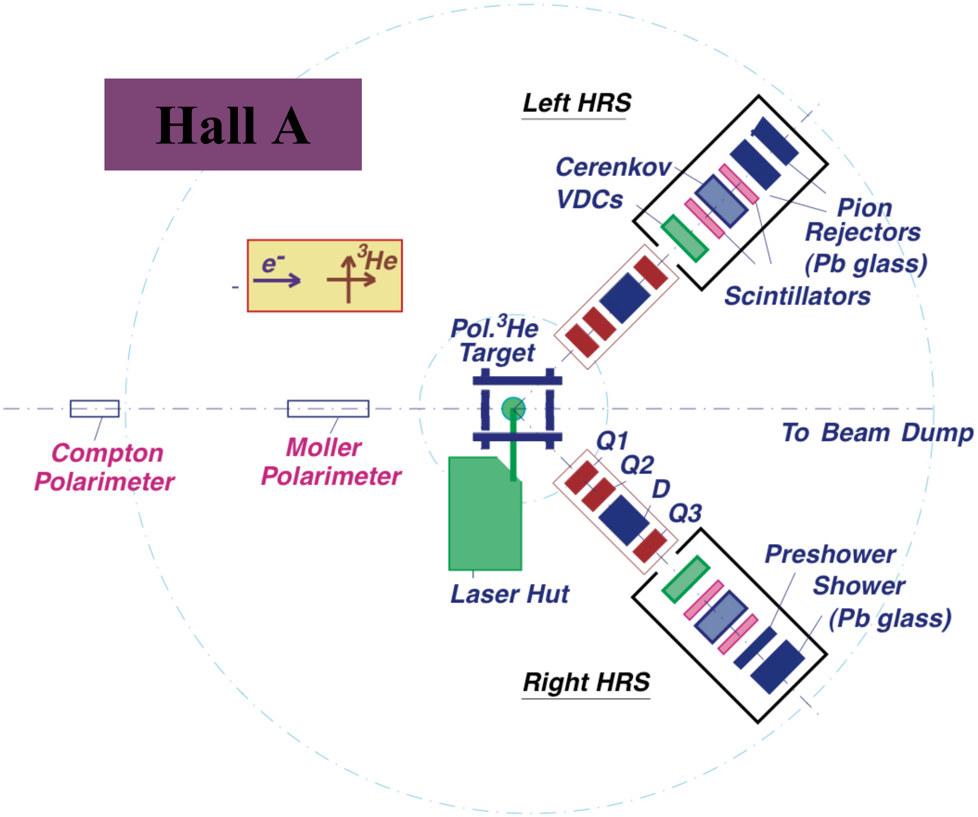


The experiment E01-012

- Ran in Jan.-Feb. 2003
- Inclusive experiment: $^{3}\vec{He}(\vec{e},e')X$
    - Polarized electron beam:

      $70 < P_{beam} < 85\%$
    - Hall A in standard equipment:
        - HRS in symmetric configuration
        - PID performance $\pi/e < 10^{-4}$
    - Pol. ^{3}He target (para and perp):

      $\langle P_{targ} \rangle = 37\%$



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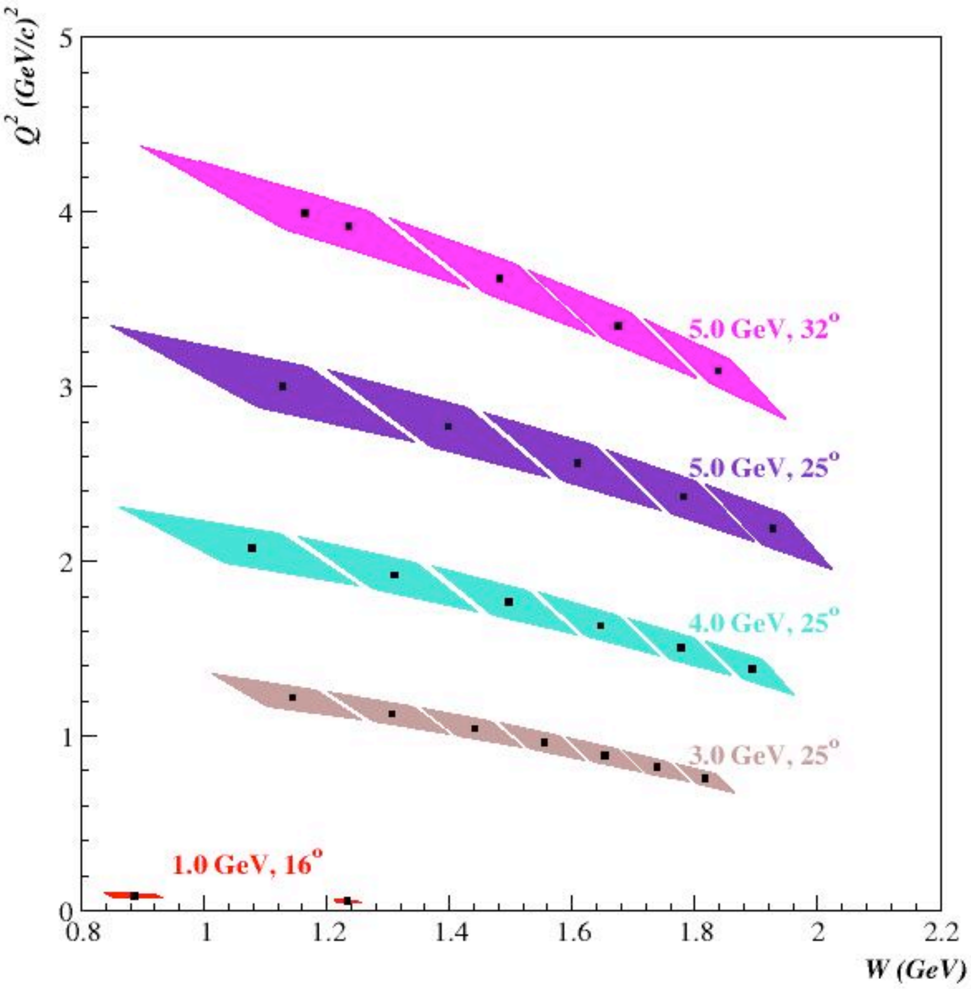
  - ➢ Hall A in standard equipment:
    - ↪ HRS in symmetric configuration
    - ↪ PID performance $\pi/e < 10^{-4}$
  - ➢ Pol. ^{3}He target (para and perp):
    $\langle P_{targ} \rangle = 37\%$
- Measured polarized cross section differences
- Form g_1 and g_2 for ^{3}He



↪ **Test of spin duality on the neutron (^{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,
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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,
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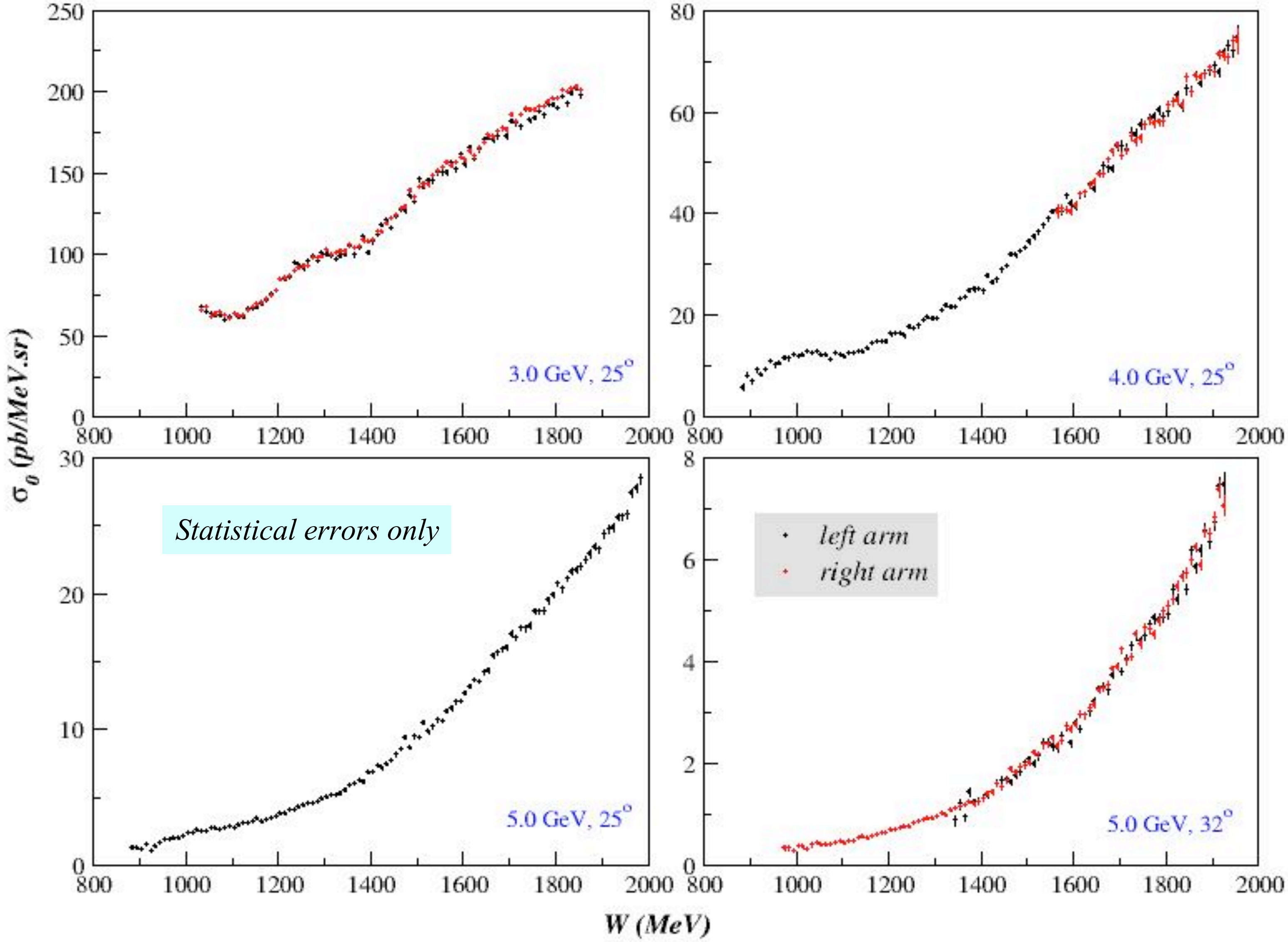
K. Wijesooriya, B. Wojtsekhowski, S. Woo, J.-C. Yang,
X. Zheng, L. Zhu

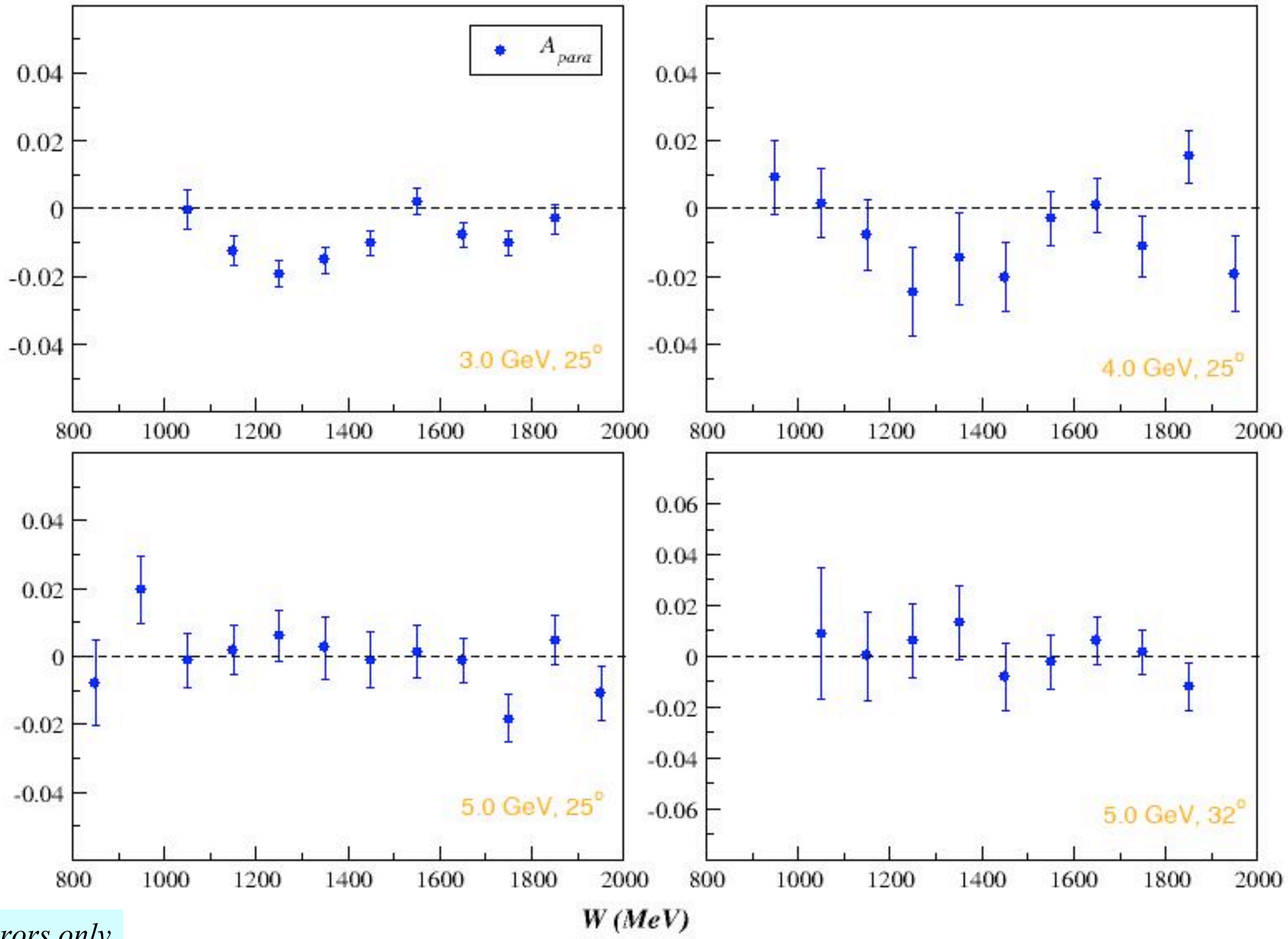
and the Jefferson Lab Hall A Collaboration

Unpolarized cross sections

Agreement between both HRS better than 2%

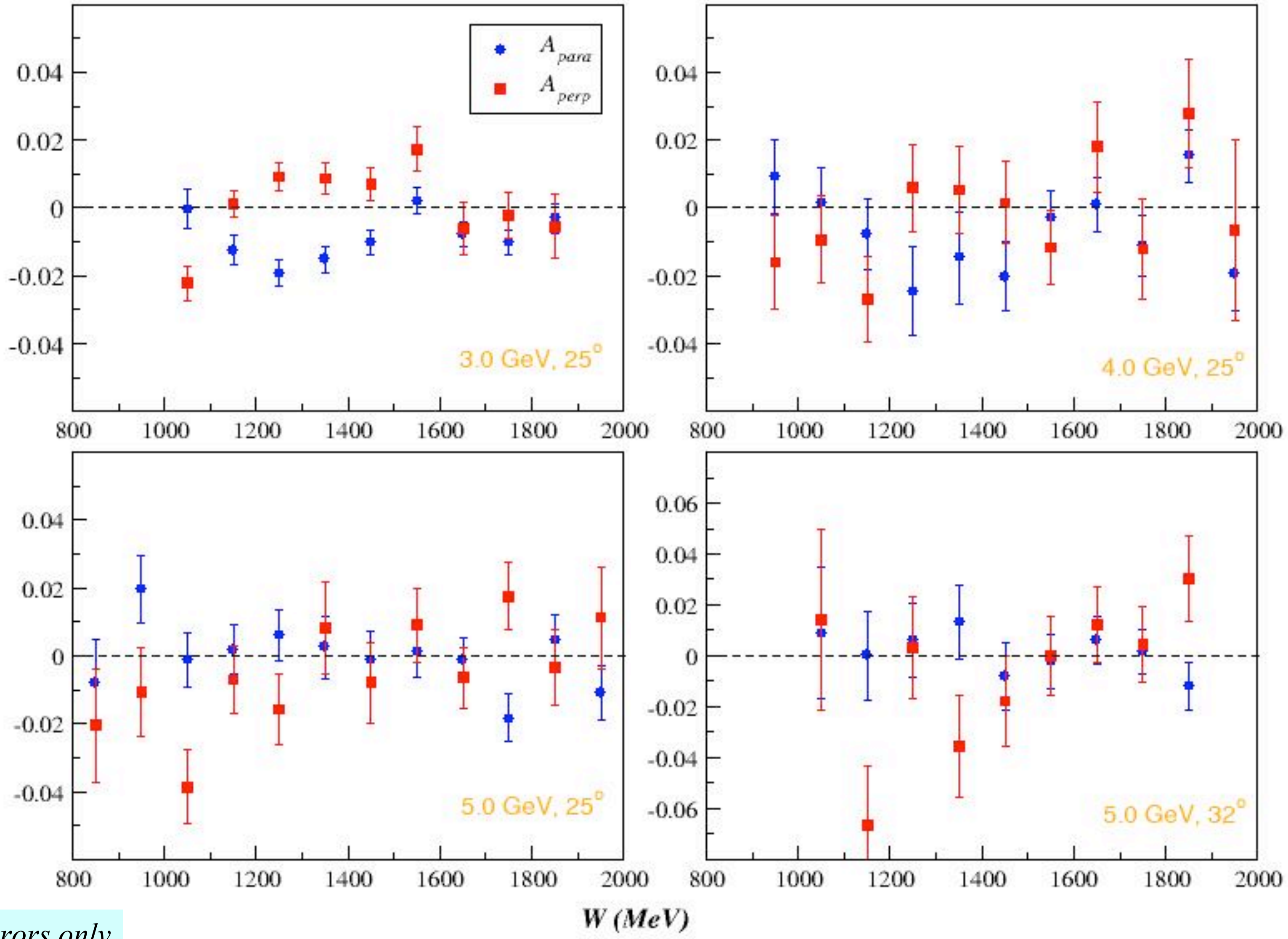


Asymmetries



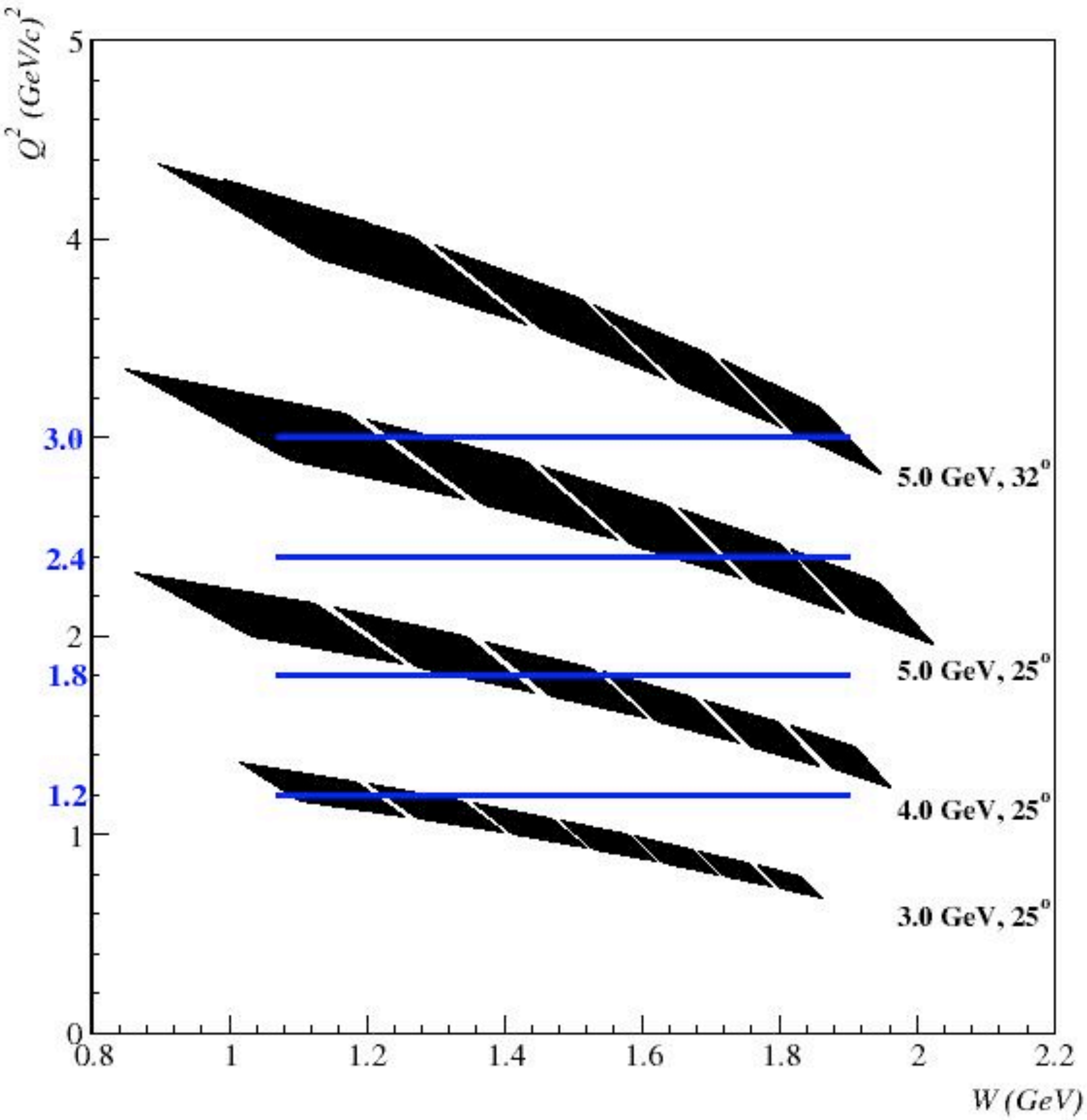
Statistical errors only

Asymmetries

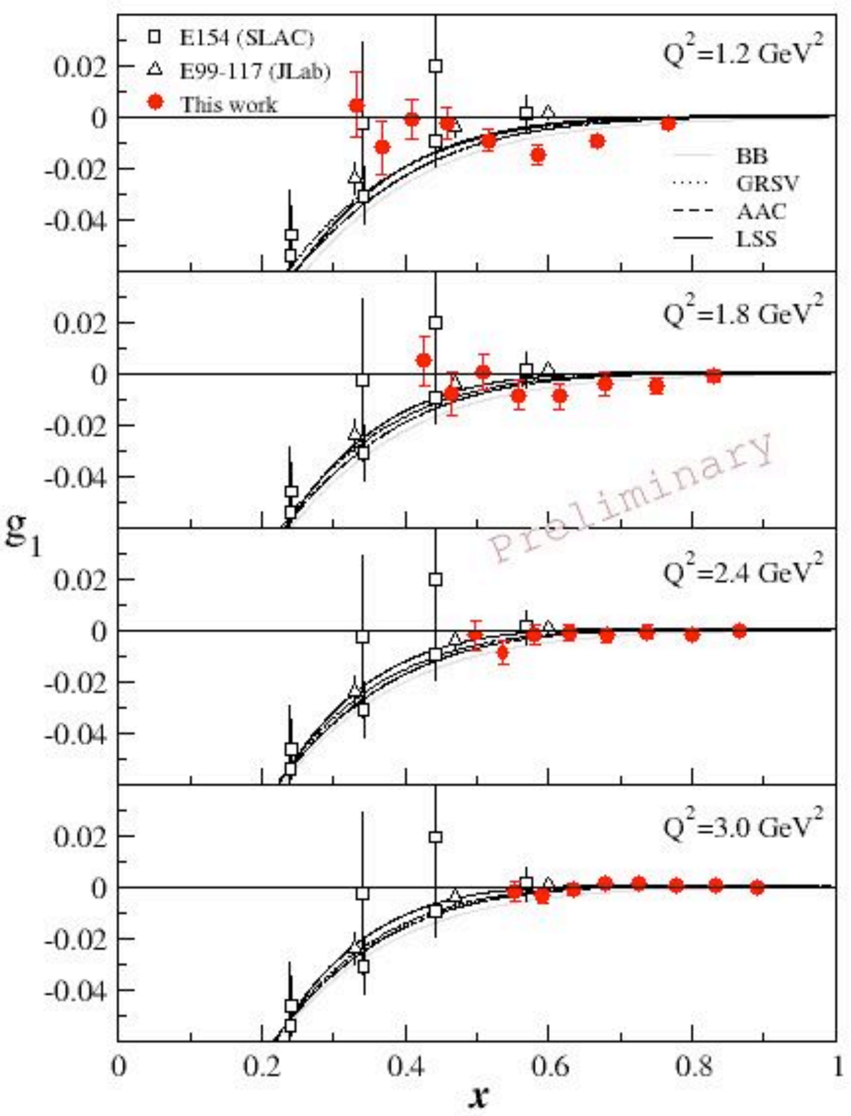


Statistical errors only

From constant E to constant Q^2

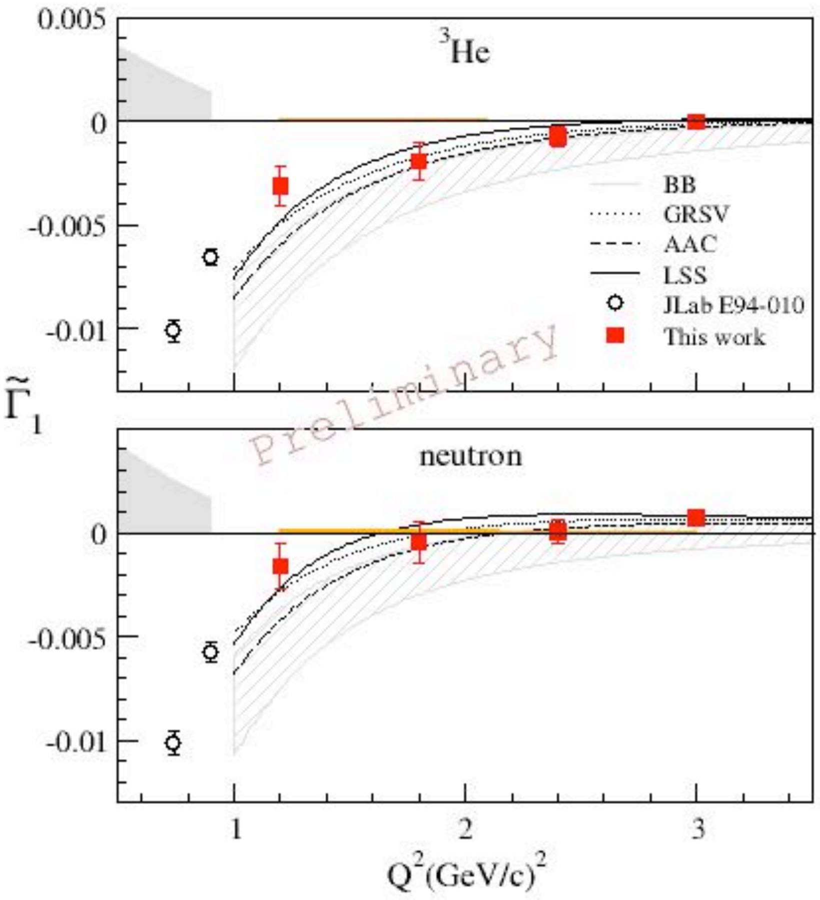


$g_1^{^3He}$ at constant Q^2



P. Solvignon et al, in preparation

g_1 in the resonance region



P. Solvignon et al, in preparation

Extract the neutron from effective polarization equation:

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

P_n=86%
P_p=-2.8%

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

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

If $\tilde{\Gamma}_1^{res} = \tilde{\Gamma}_1^{dis}$ **$\Rightarrow$ duality is verified**

Virtual photon-nucleon asymmetry

$$A_1(x,Q^2) = \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)}$$

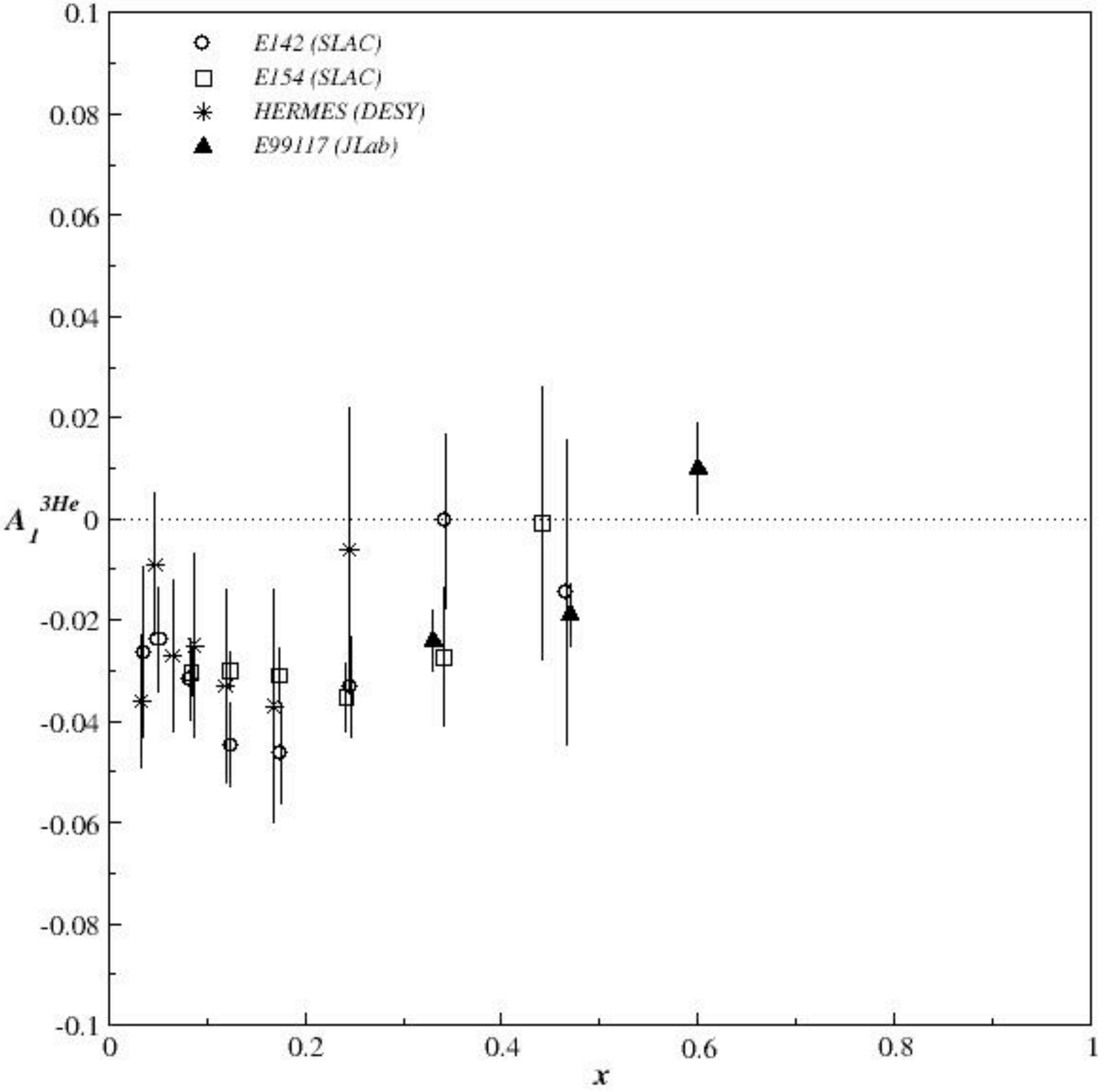
with $\gamma^2 = \frac{4M^2x^2}{Q^2}$

In the parton model:

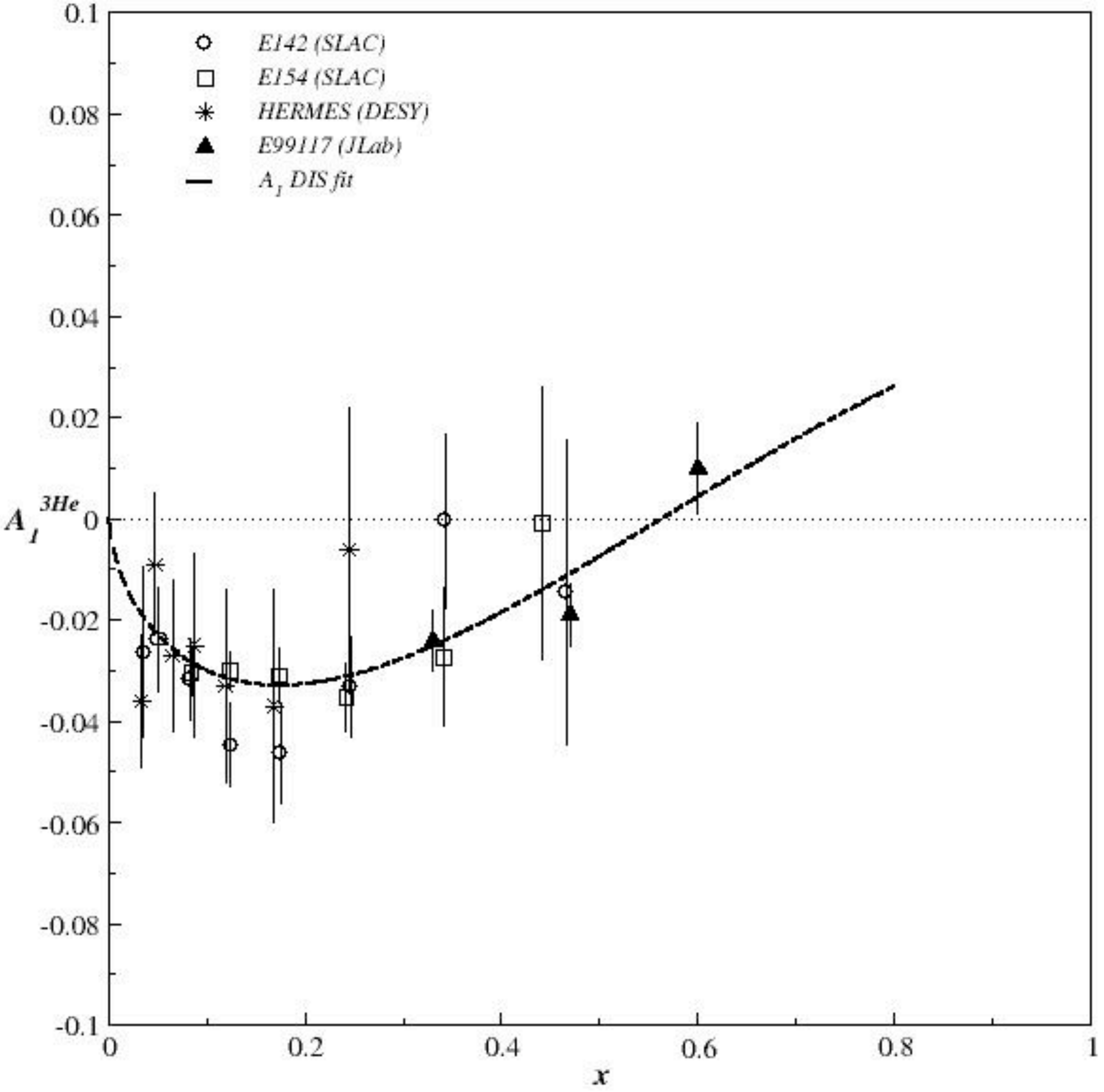
$$A_1 = \frac{g_1}{F_1}$$

If Q^2 dependence similar for g_1 and for F_1 ⇒ weak Q^2 dependence of A_1

A_1^{3He}


○ E142 (SLAC)
□ E154 (SLAC)
✳ HERMES (DESY)
▲ E99117 (JLab)
A_1^{3He}
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
0.2
0.4
0.6
0.8
1
x

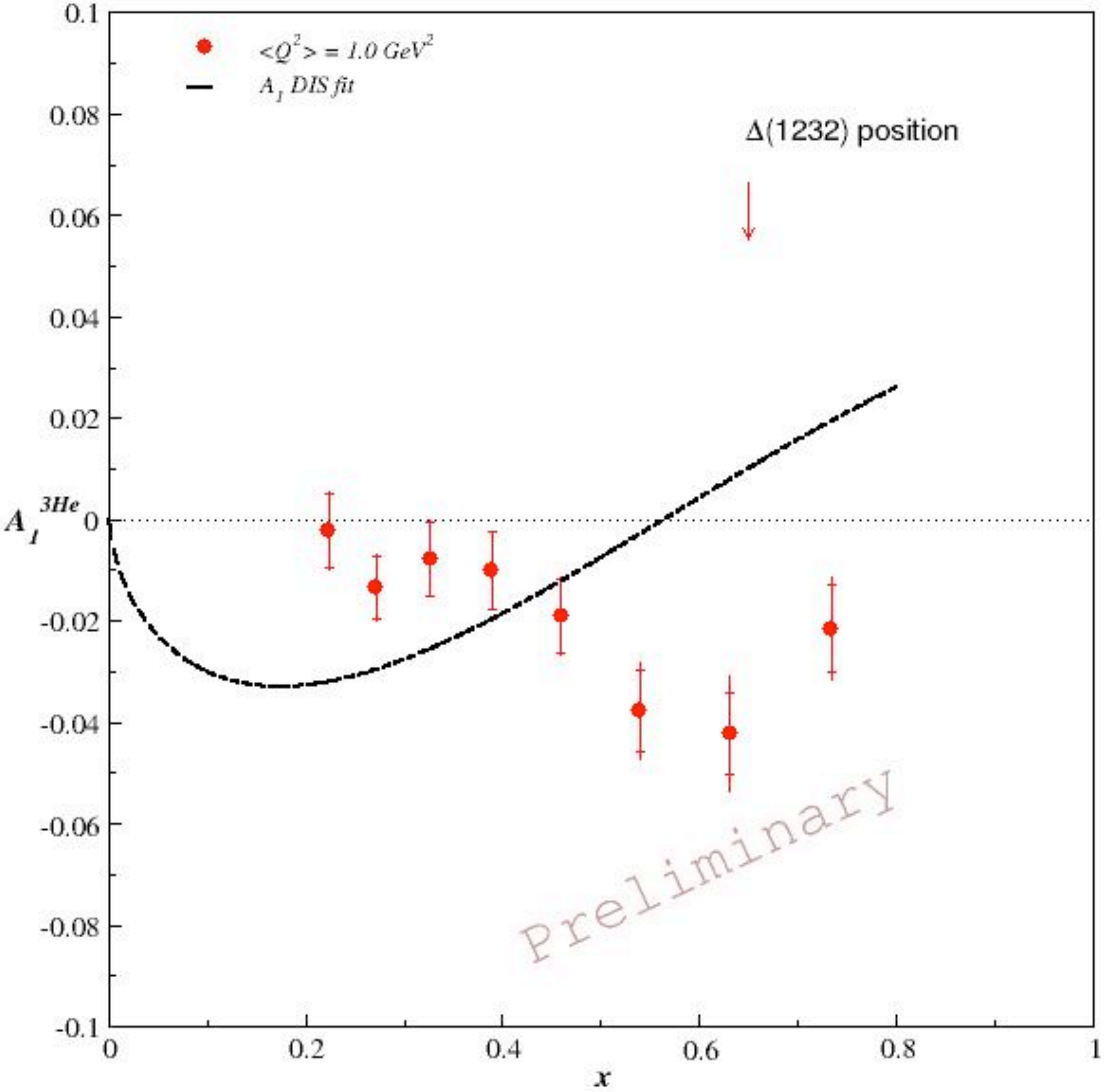
A_1^{3He}



○ E142 (SLAC)
□ E154 (SLAC)
✳ HERMES (DESY)
▲ E99117 (JLab)
— A_1 DIS fit
A_1^{3He}
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
0.2
0.4
0.6
0.8
1
x

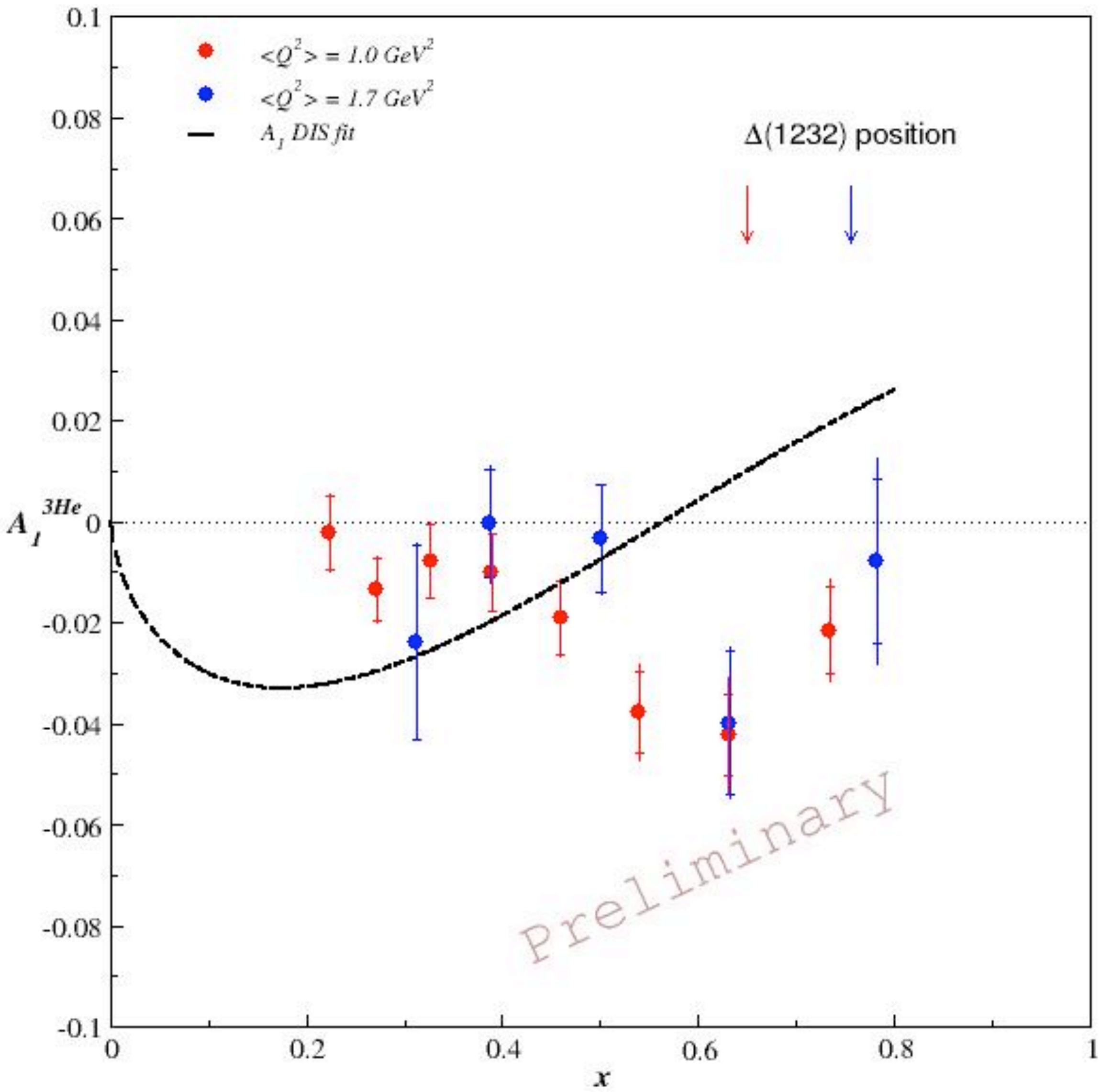
A_1^{3He}

P. Solvignon et al, in preparation



A_1^{3He}

P. Solvignon et al, in preparation



A_1^{3He}

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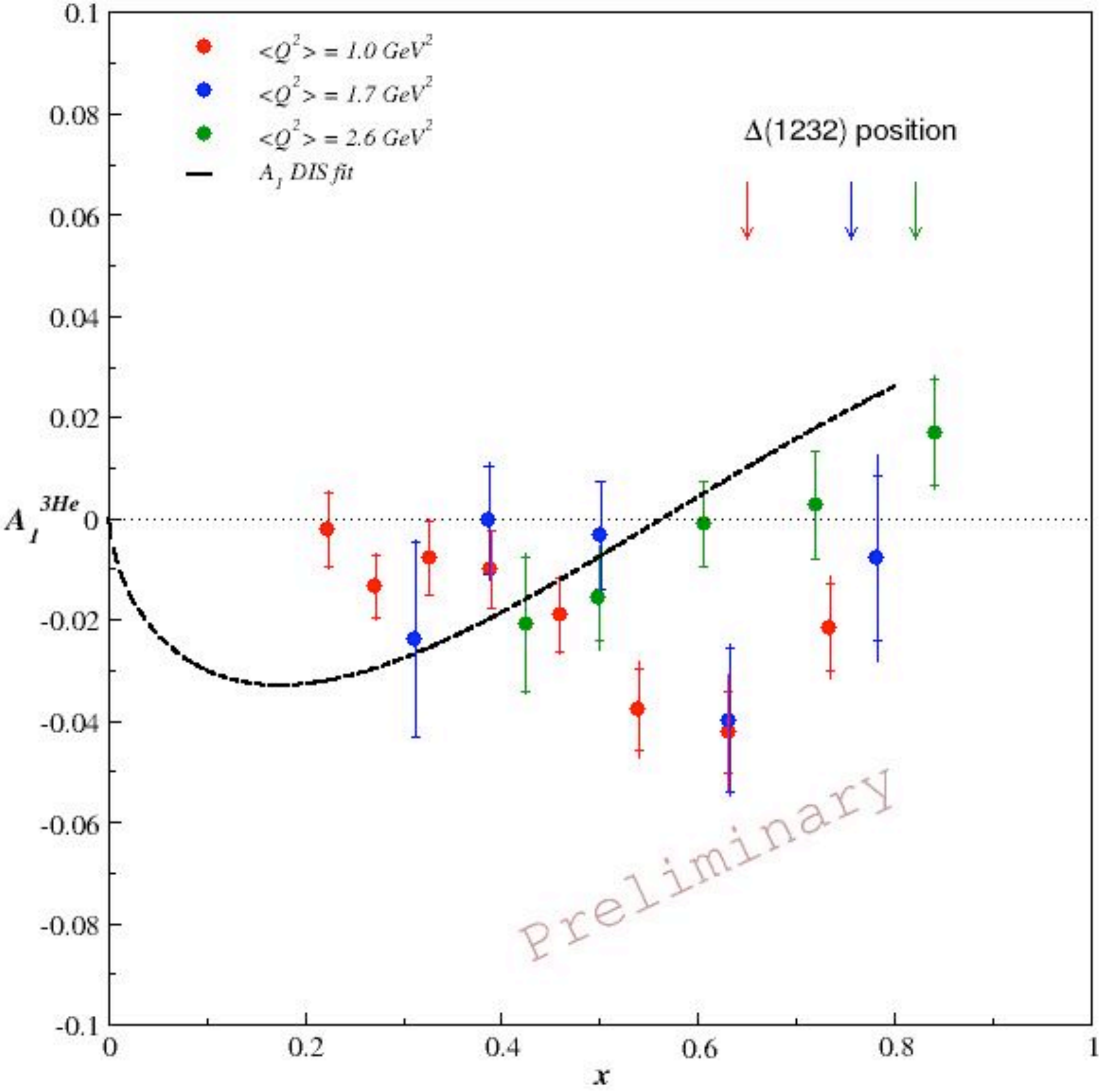
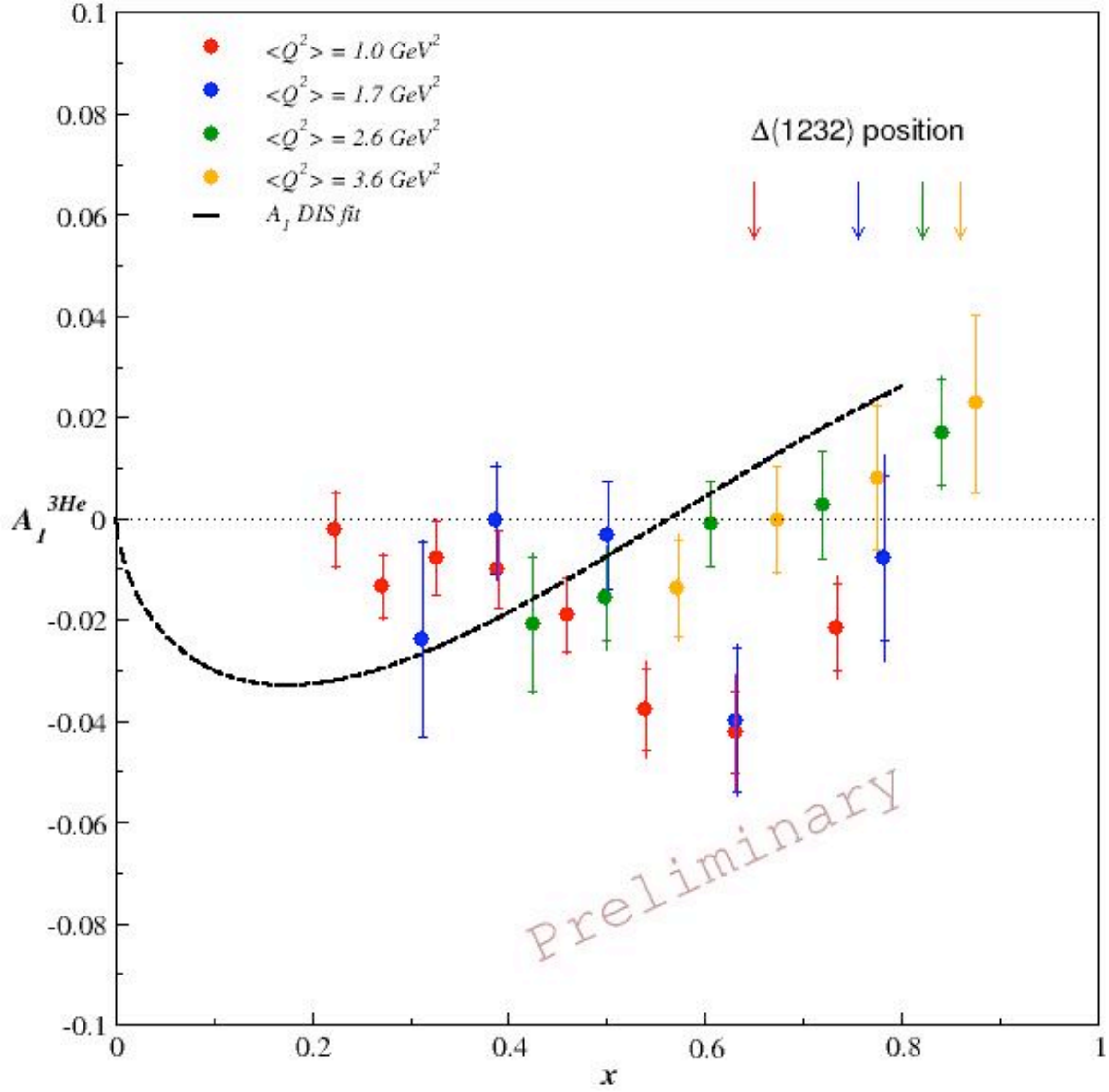


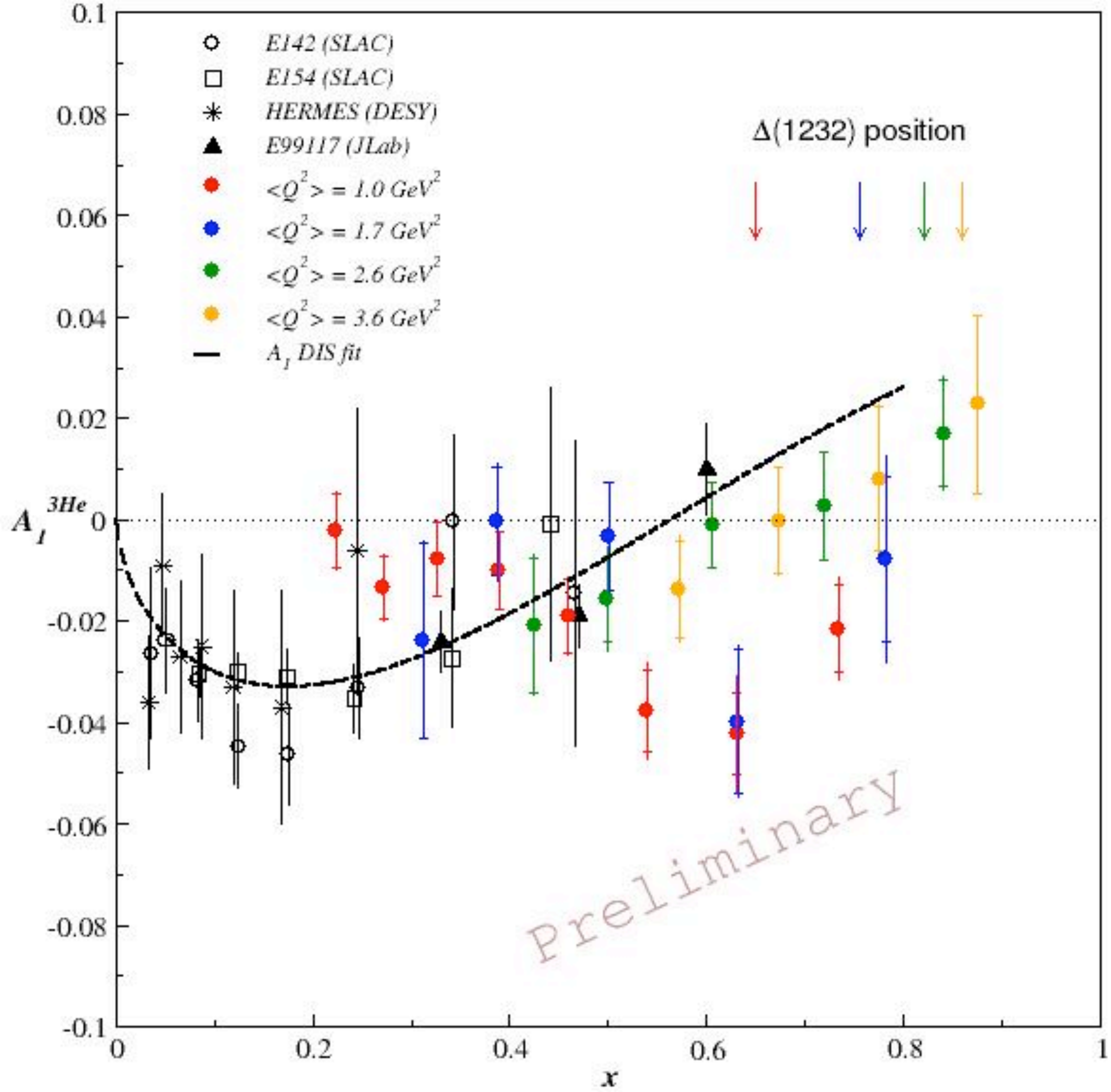
A_1^{3He}

P. Solvignon et al, in preparation



A_1^{3He}

P. Solvignon et al, in preparation



Summary

- E01-012 provides first data of Spin Structure Functions on neutron (^{3}He) in the resonance region for $1.0 < Q^2 < 4.0 GeV^2$

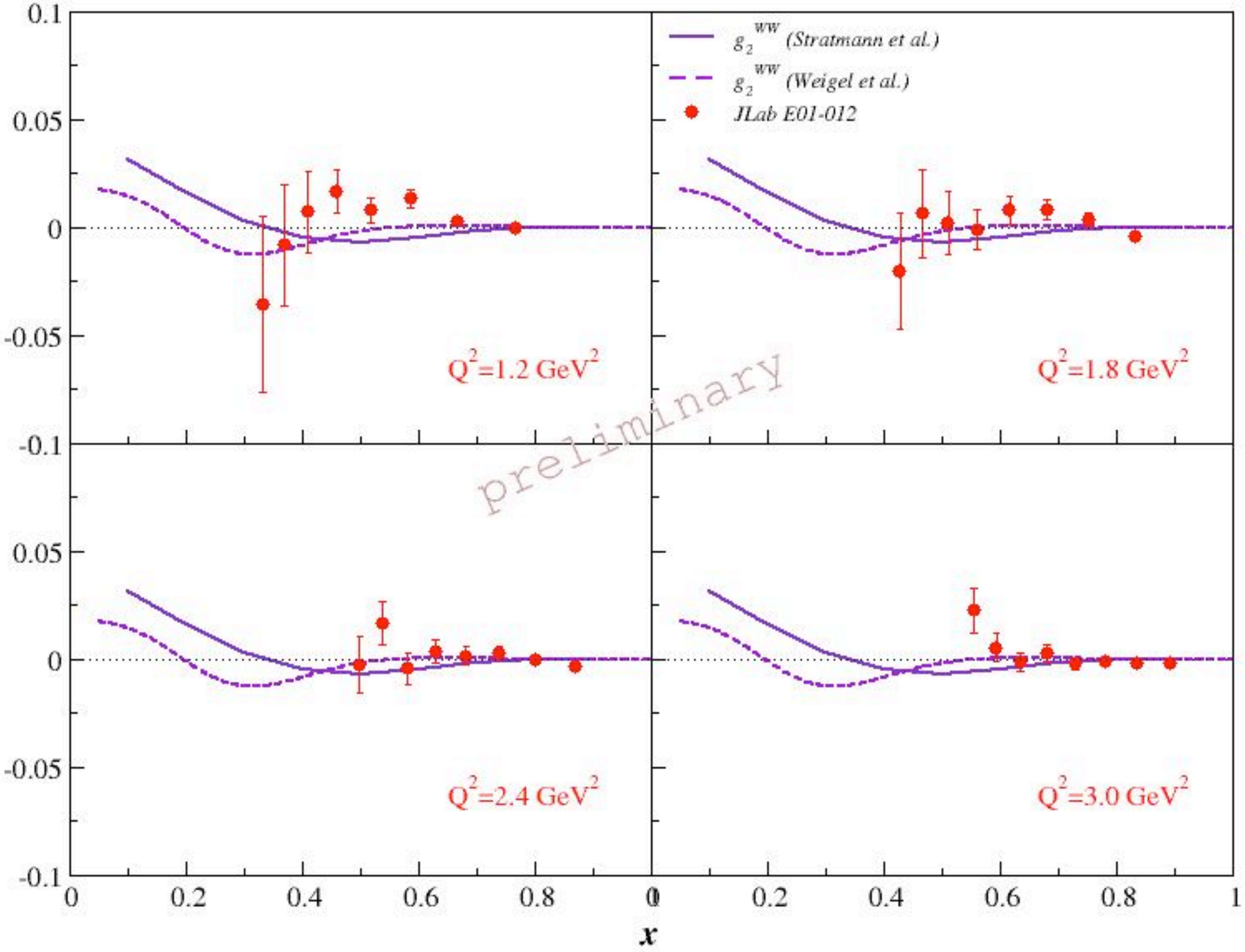
- Direct extraction of g_1 and g_2 from our data

- Overlap between E01-012 resonance data and DIS data:
  first dedicated test of Quark-Hadron Duality
  for neutron and ^{3}He SSF

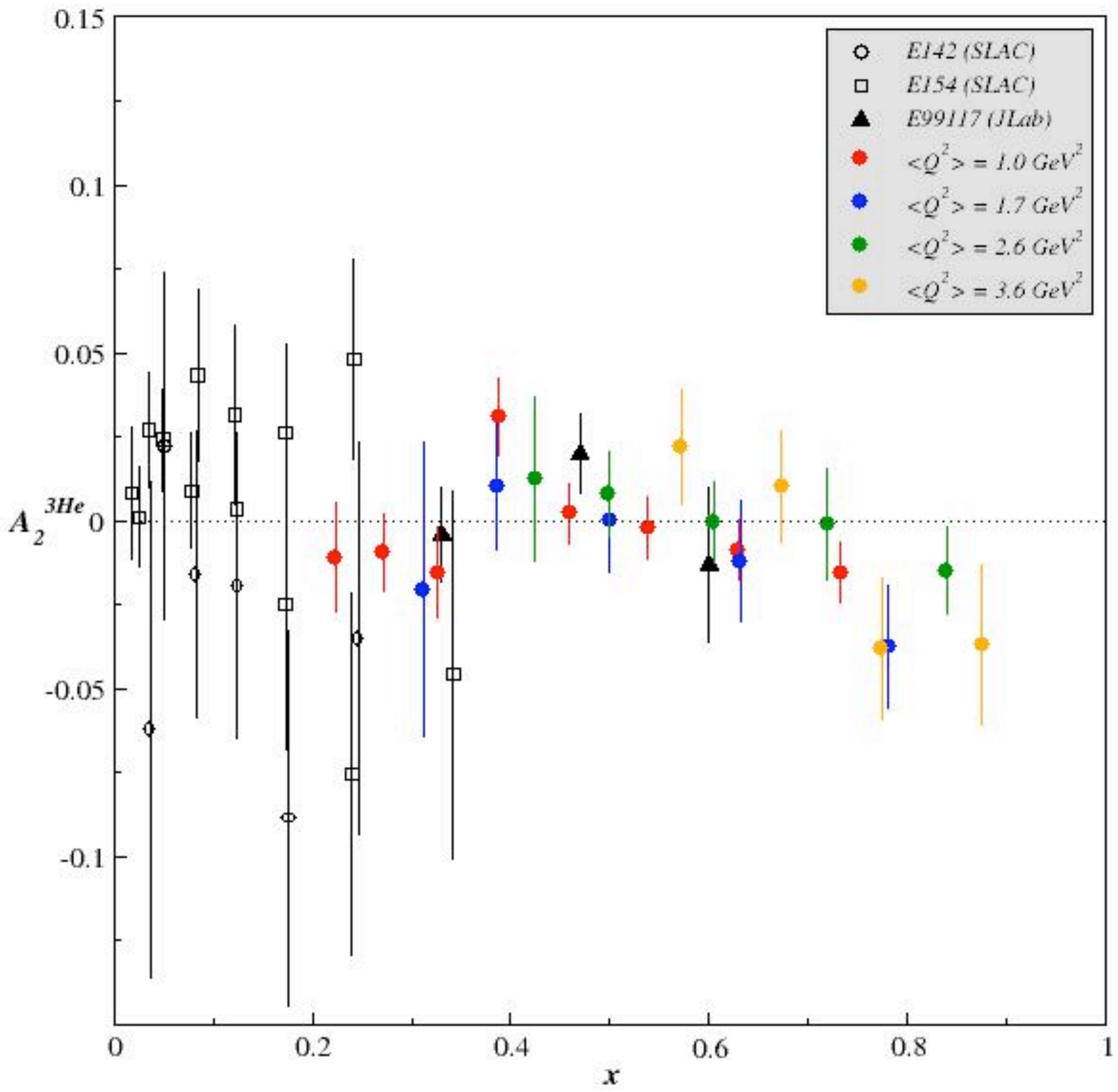
- Next: Extraction of A_1^n

Extra Slides

$g_2^{^3He}$ at constant Q^2



$A_2^{^3He}$



0.15
0.1
0.05
A_2^{3He} 0
-0.05
-0.1
0
0.2
0.4
0.6
0.8
1
x
○ E142 (SLAC)
□ E154 (SLAC)
▲ E99117 (JLab)
● $<Q^2> = 1.0$ GeV^2
● $<Q^2> = 1.7$ GeV^2
● $<Q^2> = 2.6$ GeV^2
● $<Q^2> = 3.6$ GeV^2

Target mass corrections

$$g_1(x,Q^2) = \boxed{g_1(x,Q^2;M=0)} + \frac{M^2}{Q^2} g_1^{(1)TMC}(x,Q^2) + \frac{h(x,Q^2)}{Q^2} + O(1/Q^4)$$

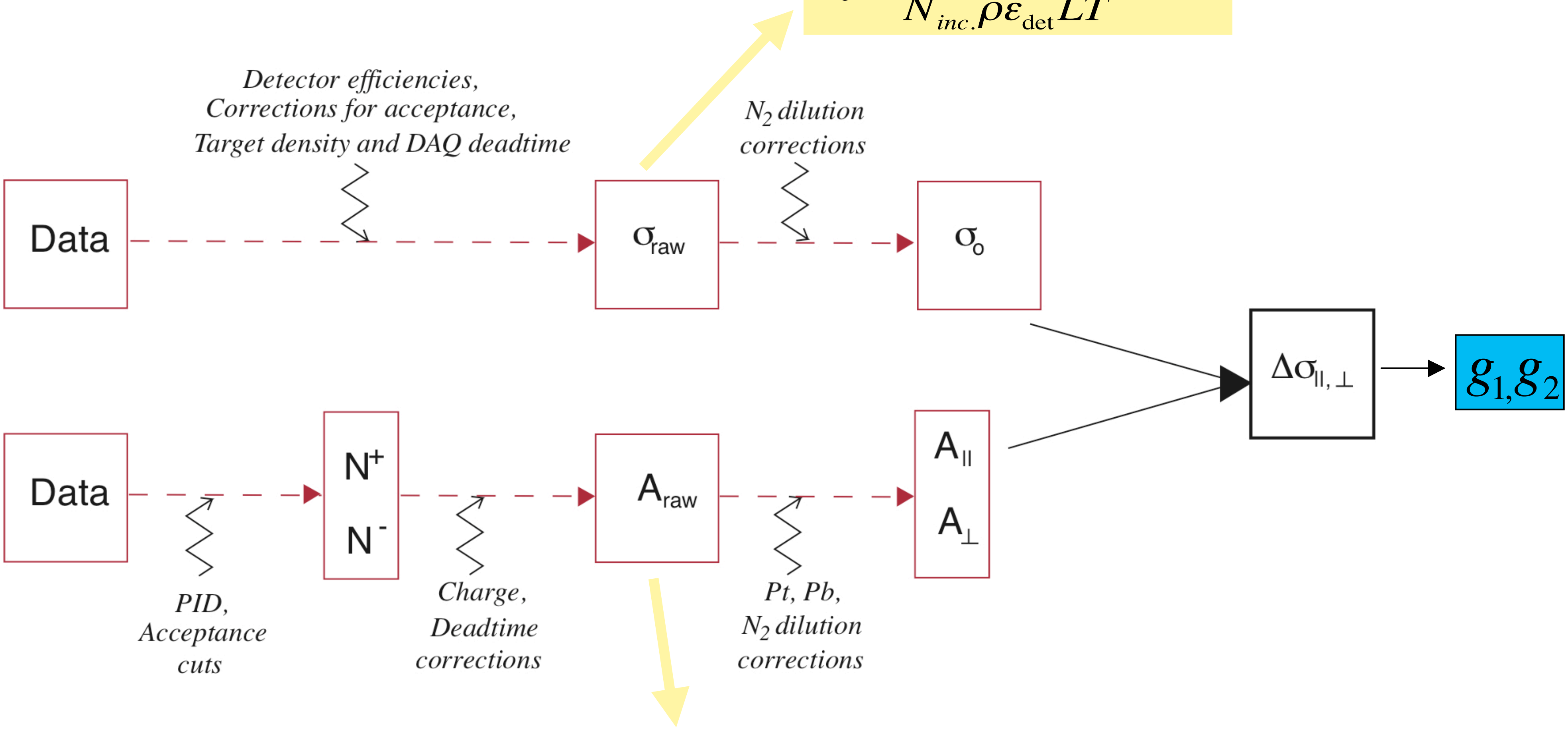
from experiments

from pQCD

- ➢ Purely kinematic effects: finite value of $4M^2x^2/Q^2$
- ➢ Need to be applied before calculating higher twist effects
- ➢ TMCs are expressed by higher moments of $g_1(x,Q^2;M=0)$

Analysis scheme

$$\sigma_0 = \frac{N_{cuts}}{N_{inc.}\rho\varepsilon_{\det}LT} * Acc.$$



Detector efficiencies,
Corrections for acceptance,
Target density and DAQ deadtime

N_2 dilution corrections

Data

σ_{raw}

σ_o

$\Delta\sigma_{\parallel,\perp}$

g_1, g_2

Data

N^+

N^-

A_{raw}

$A_\parallel$

$A_\perp$

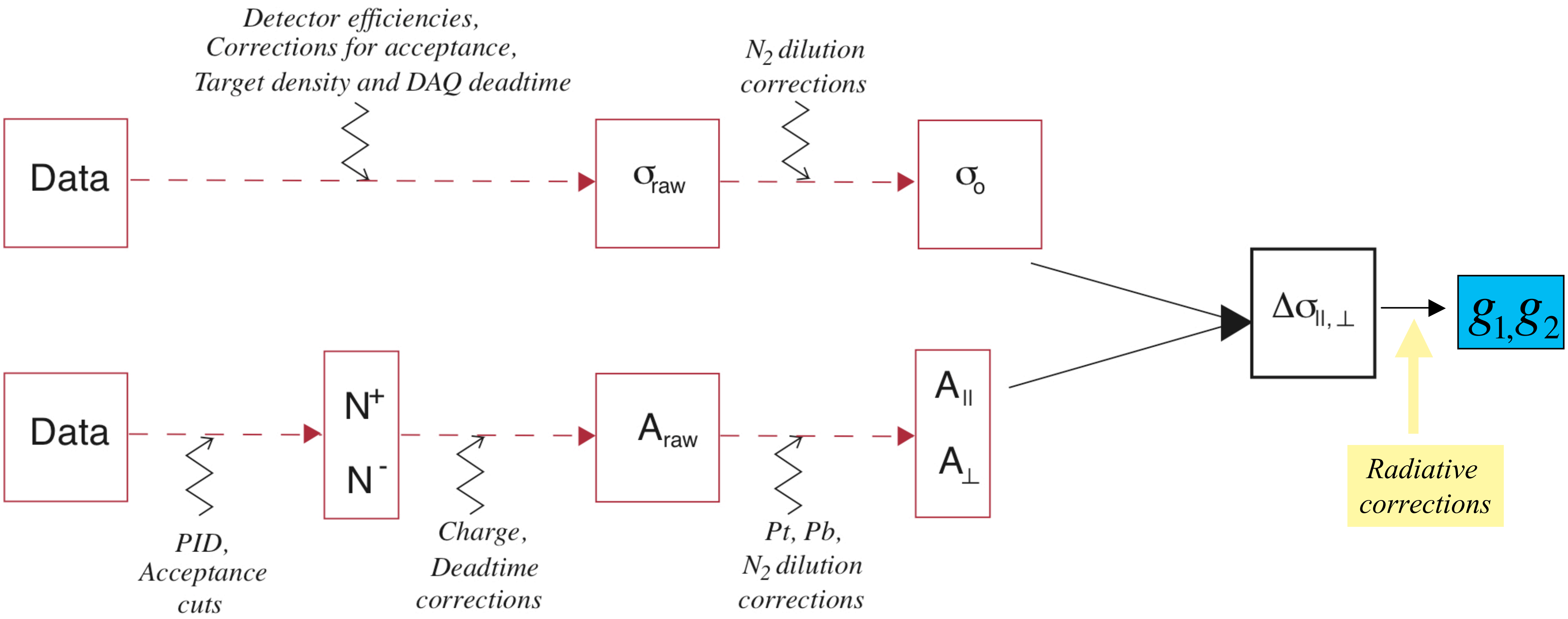
PID, Acceptance cuts

Charge, Deadtime corrections

Pt, Pb, N_2 dilution corrections

$$A_{\parallel,\perp} = \frac{\dfrac{N^+}{Q^+LT^+} - \dfrac{N^-}{Q^-LT^-}}{\dfrac{N^+}{Q^+LT^+} + \dfrac{N^-}{Q^-LT^-}}$$

Analysis scheme



Data

Detector efficiencies,
Corrections for acceptance,
Target density and DAQ deadtime

σ_{raw}

N_2 dilution
corrections

σ_o

Data

PID,
Acceptance
cuts

N^+

N^-

Charge,
Deadtime
corrections

A_{raw}

Pt, Pb,
N_2 dilution
corrections

$A_{\|}$

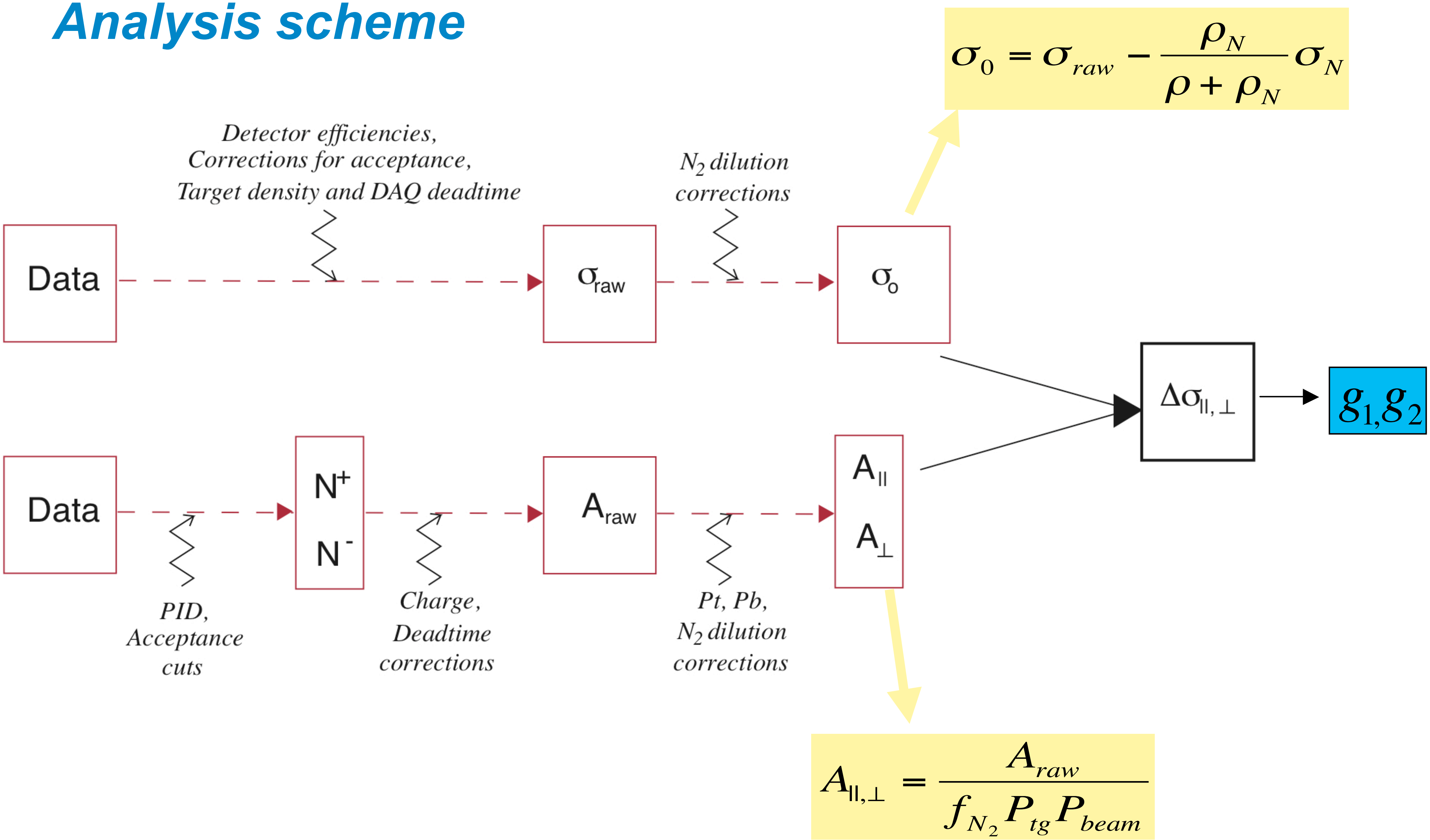
$A_{\perp}$

$\Delta\sigma_{\|,\perp}$

Radiative
corrections

g_1, g_2

Analysis scheme



$$\sigma_0 = \sigma_{raw} - \frac{\rho_N}{\rho + \rho_N}\sigma_N$$

Data

Detector efficiencies, Corrections for acceptance, Target density and DAQ deadtime

σ_{raw}

N_2 dilution corrections

σ_o

$\Delta\sigma_{\parallel,\perp}$

g_1, g_2

Data

PID, Acceptance cuts

N^+

N^-

Charge, Deadtime corrections

A_{raw}

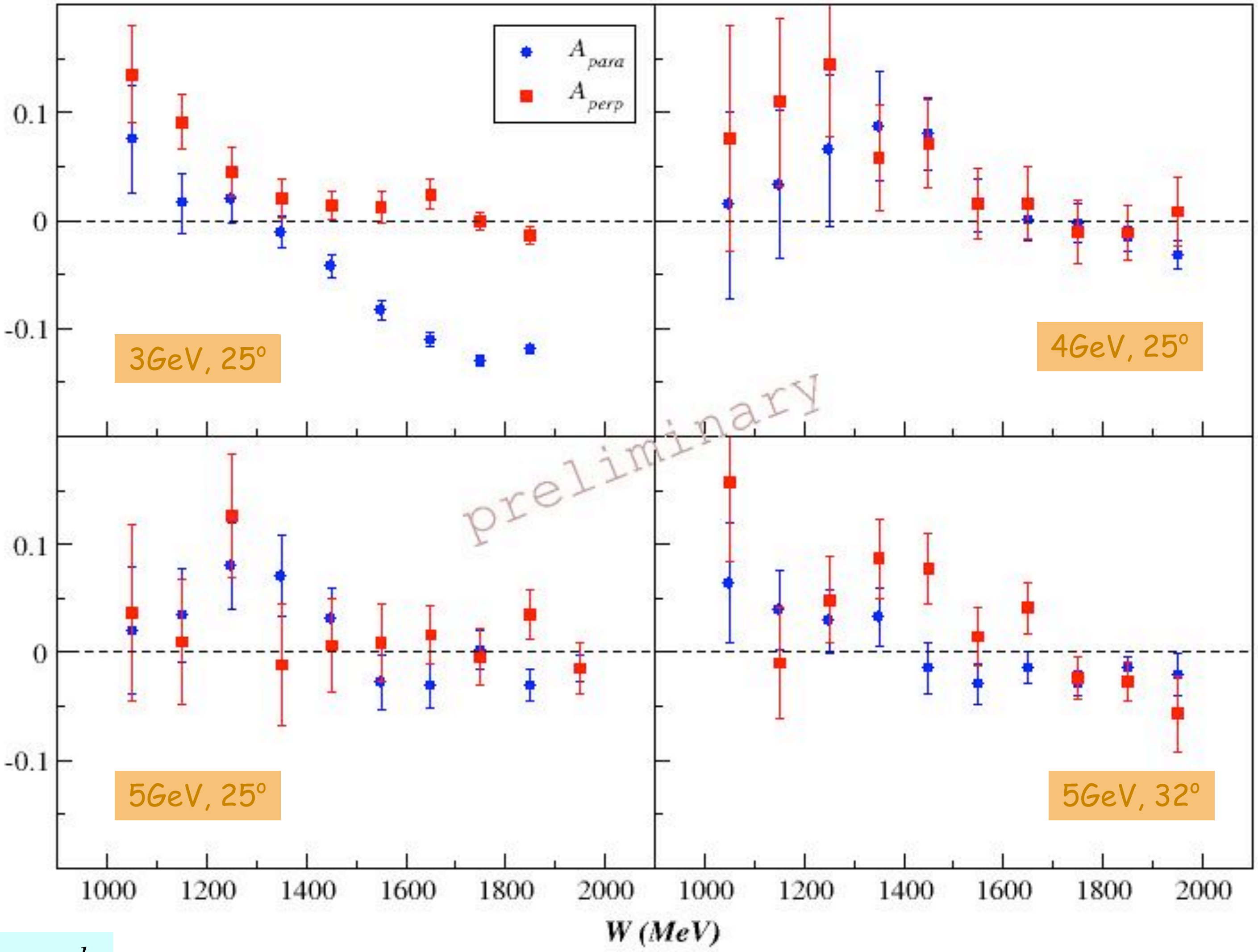
Pt, Pb, N_2 dilution corrections

$A_\parallel$

$A_\perp$

$$A_{\parallel,\perp} = \frac{A_{raw}}{f_{N_2} P_{tg} P_{beam}}$$

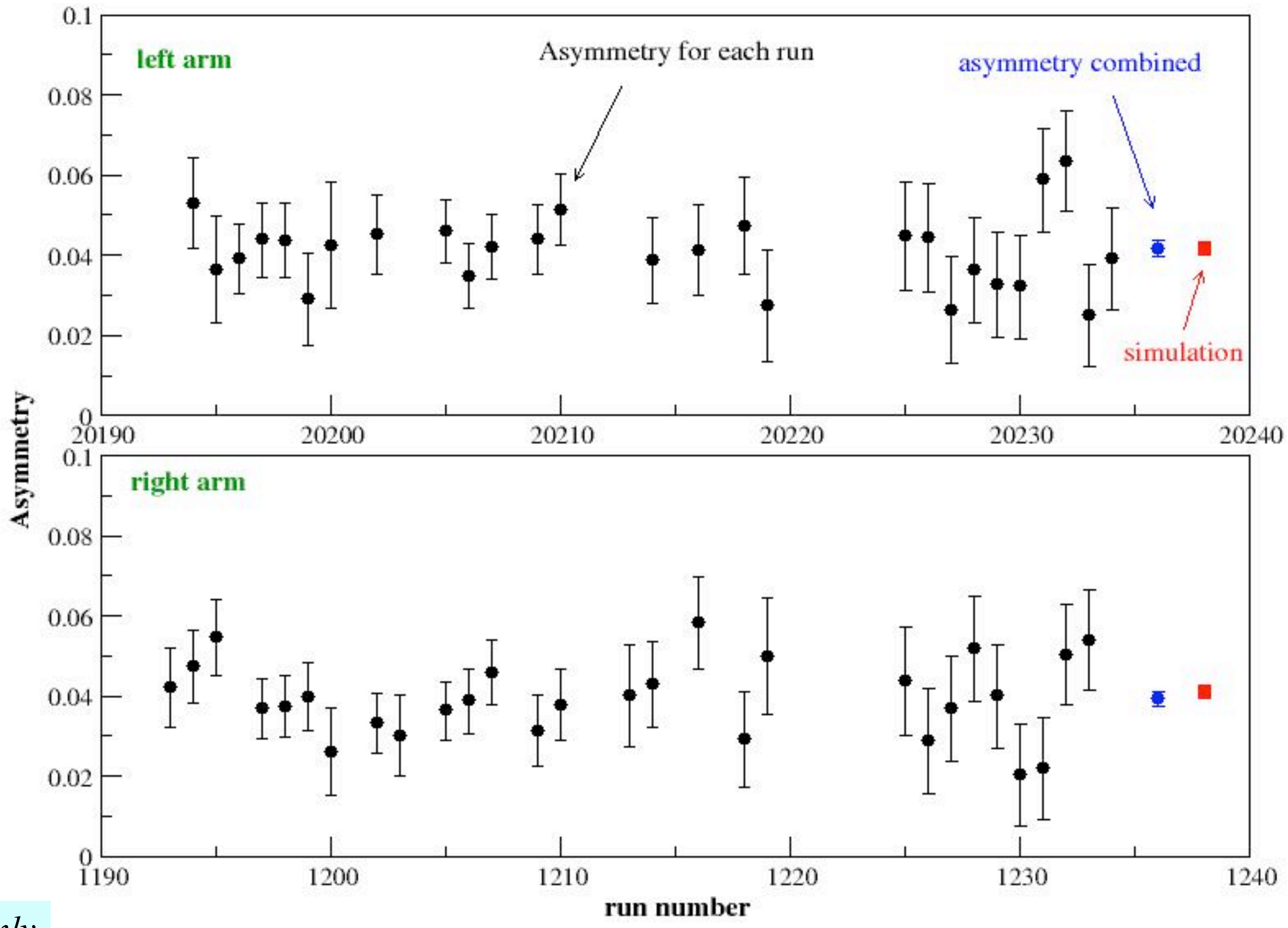
Pion asymmetries



Statistical errors only

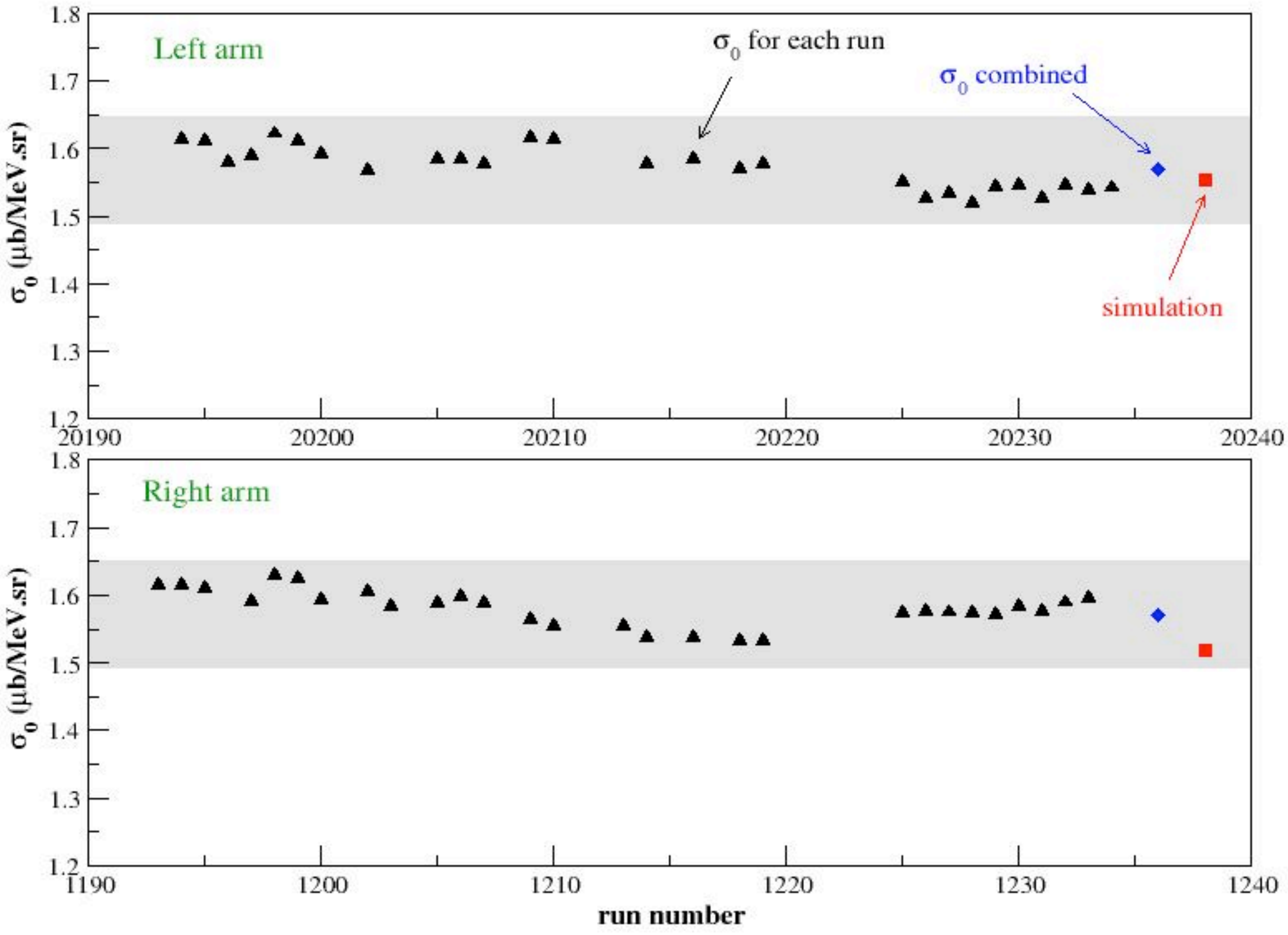
Elastic asymmetry

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



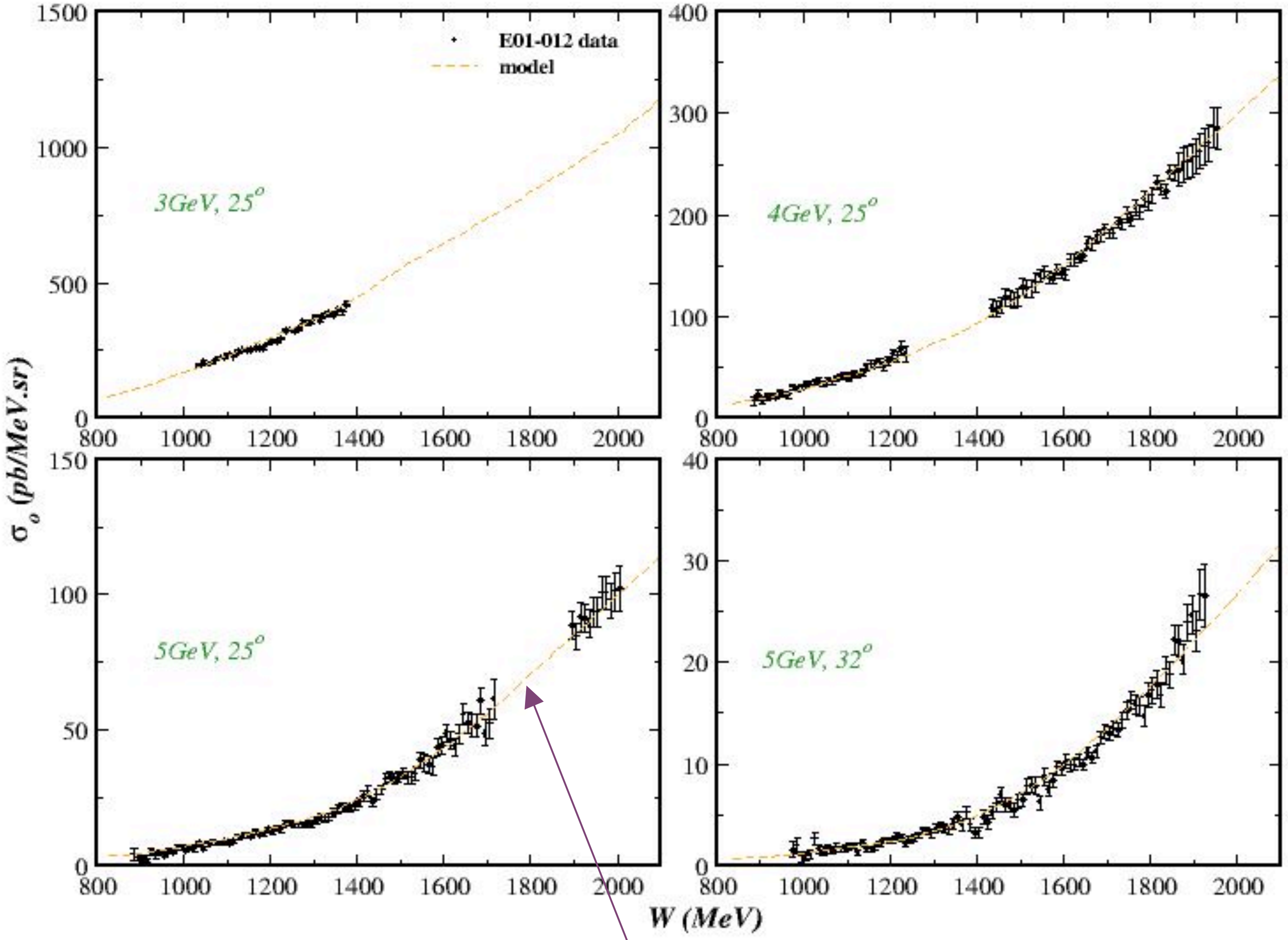
Statistical errors only

Elastic cross section



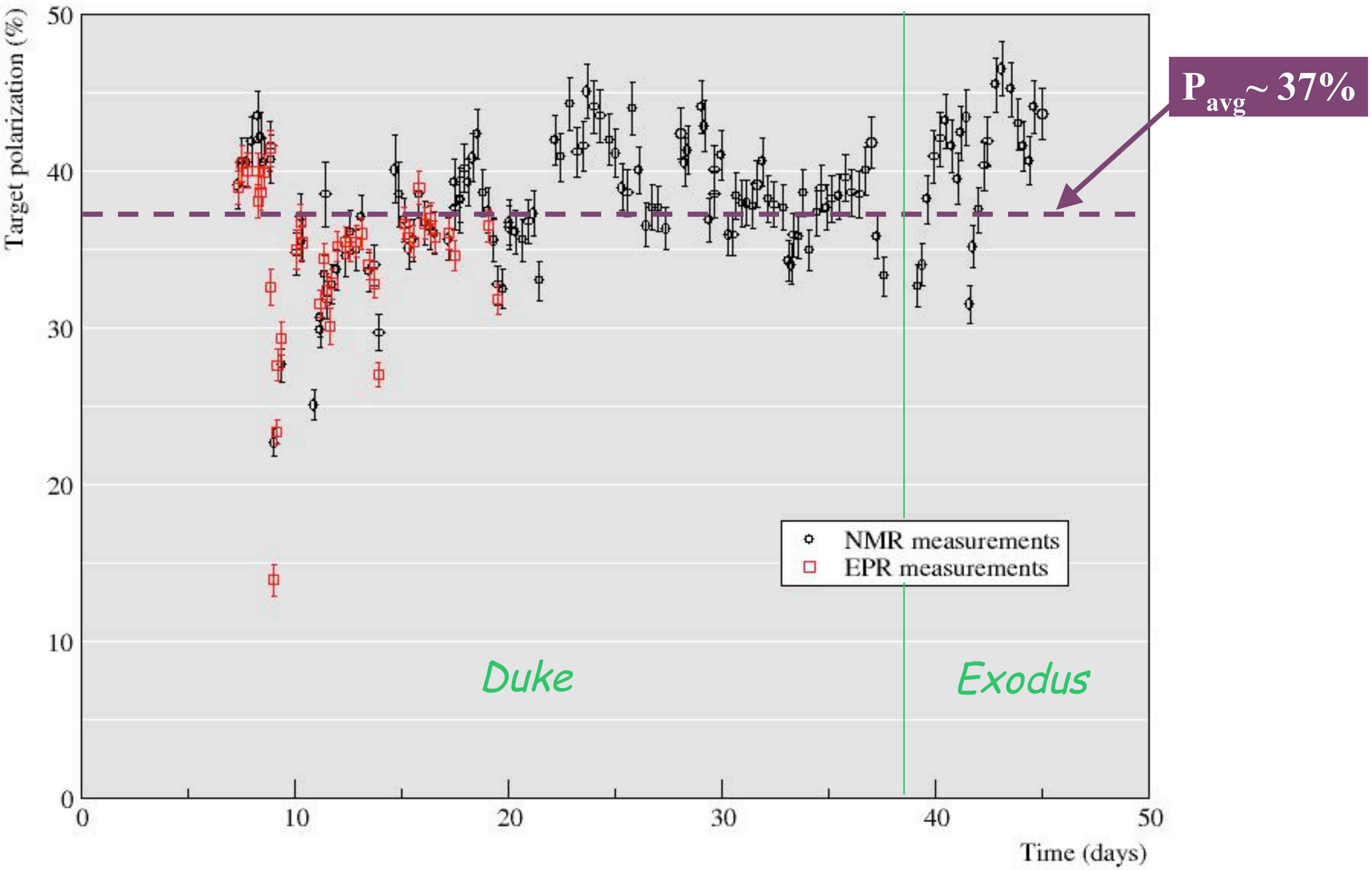
Statistical errors only

Nitrogen dilution



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

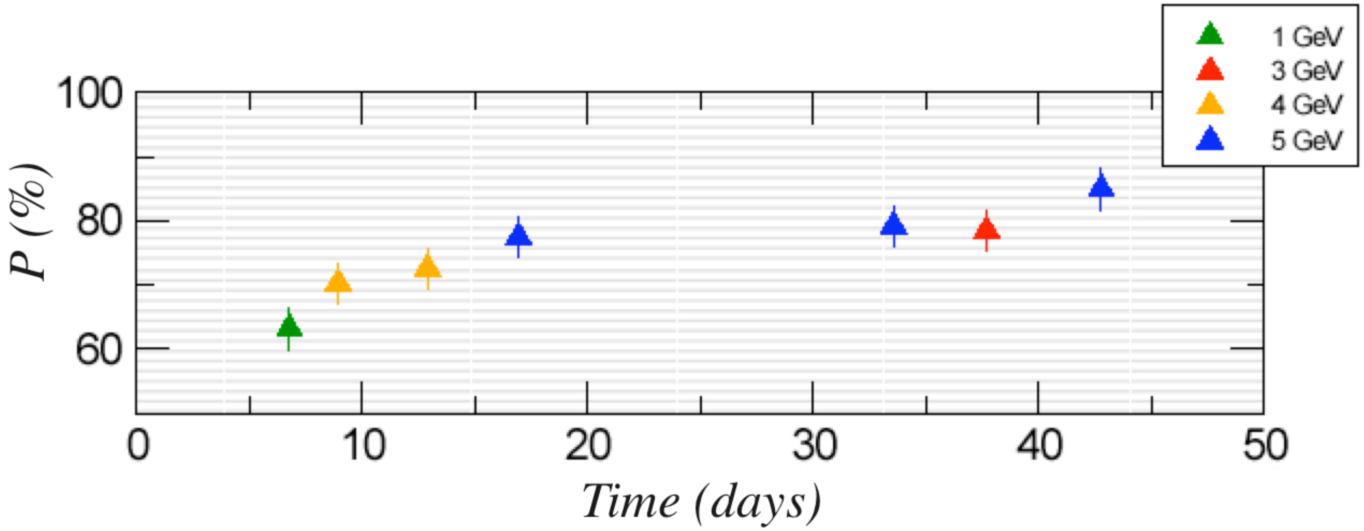
Target performance



$P_{avg} \sim 37\%$

Electron beam polarization

- Used Moller Polarimeter
- $70 < P_{beam} < 85\%$ for production data

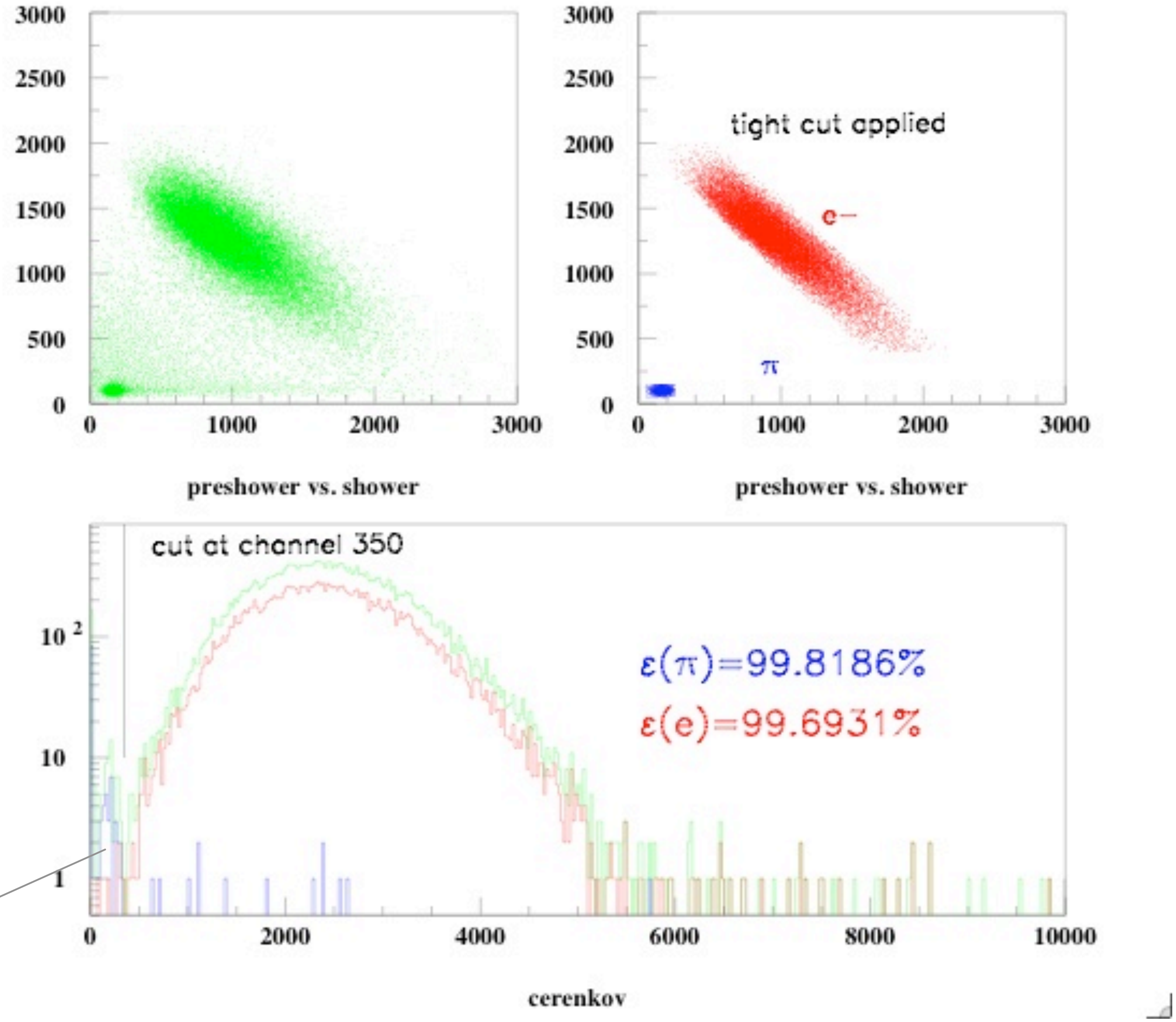


The CO_2 gas Cerenkov detector

Index of refraction:
n = 1.00041

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

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

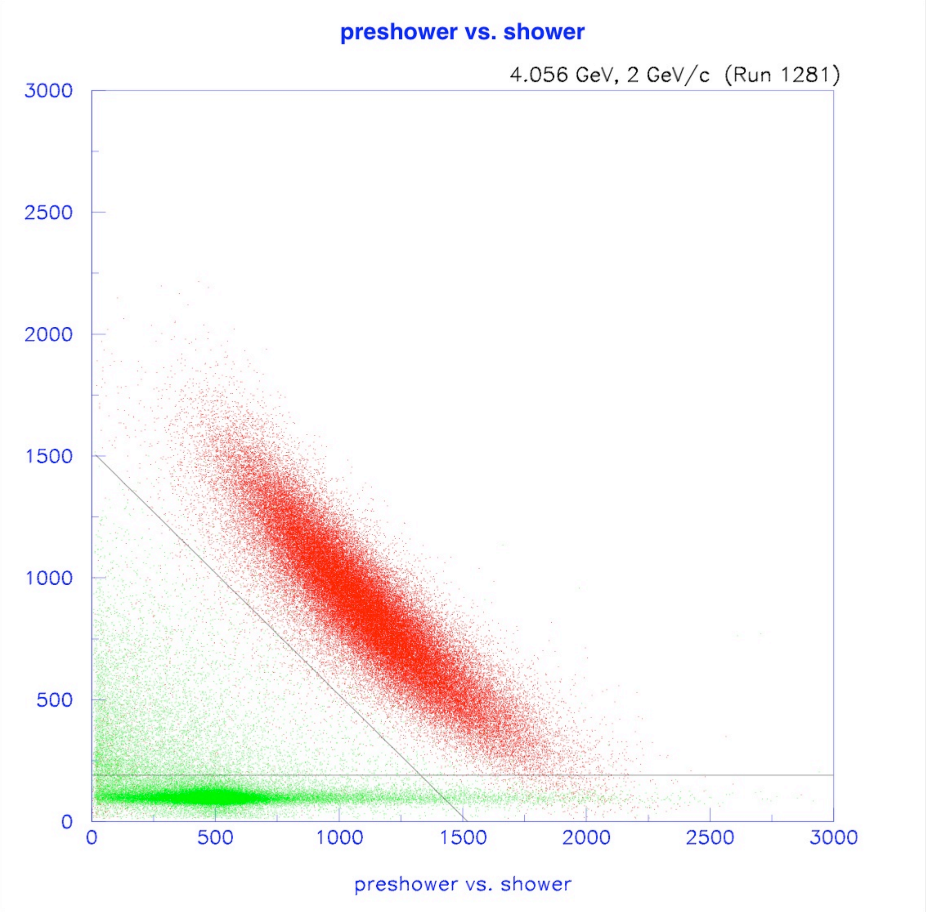


ε(π)=99.8186%

ε(e)=99.6931%

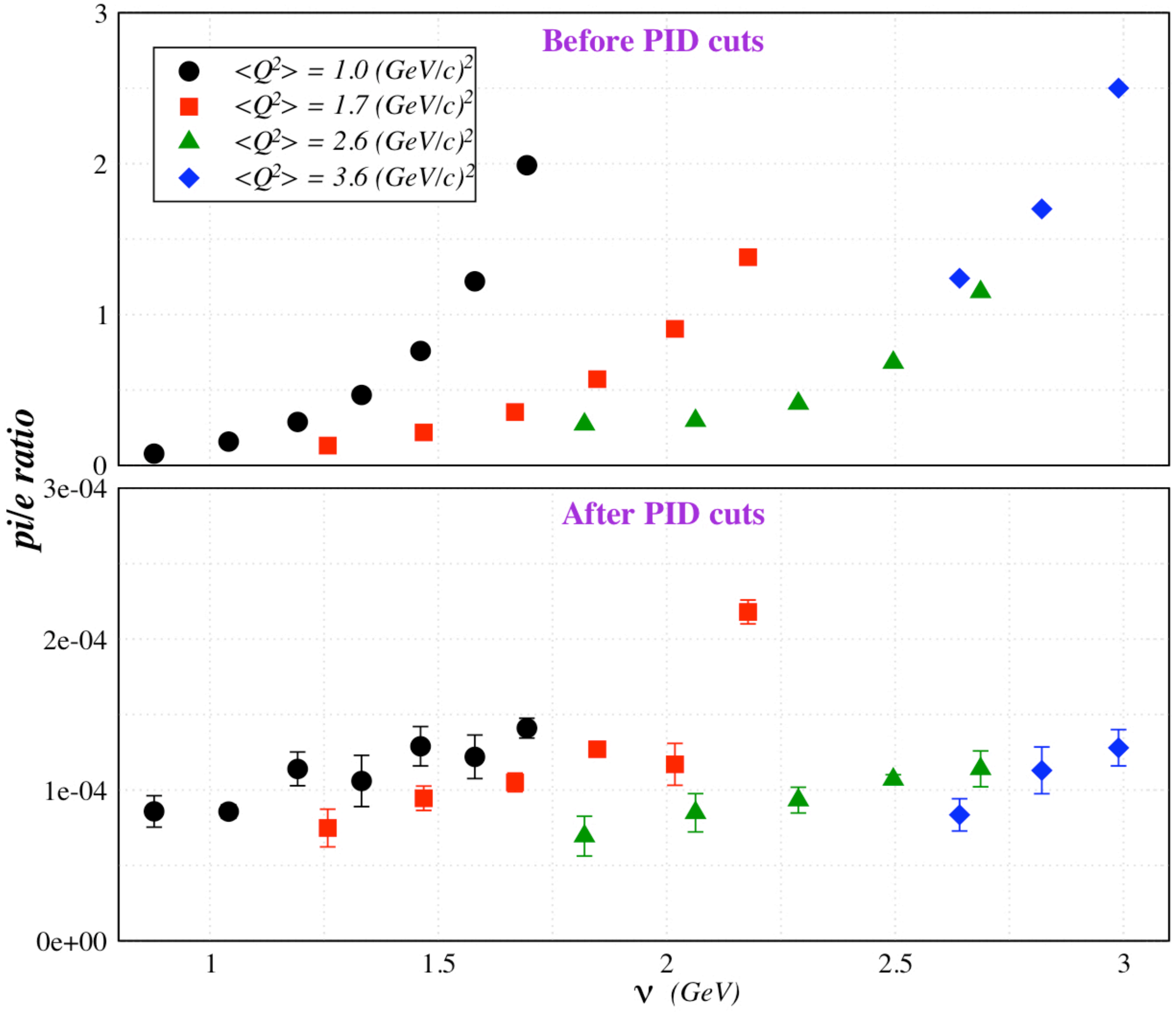
Knock-out e$^-$
&
Low energy e$^-$

Lead glass calorimeter



Cuts applied for electron efficiency > 99%

Particle identification performance



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

Systematics

Target	
density	2.6%
polarization	3.0-4.0%
Beam	
charge	1.0%
polarization	3.0%
energy	0.5%
N_2 dilution	0.5-1.0%
Detector efficiencies	2.5%
Acceptance	1.7-3.0%
Radiative corrections	3-10%