Photo shows my house on the south end of the Big Island of Hawaii where much of the anaysis

SPIN ASYMMETRIES IN ELECTRON SCATTERING USING CLAS AT JEFFERSON LAB

Presented by Peter Bosted for the CLAS Collaboration

OUTLINE

EXPERIMENTAL OVERVIEW

NEW VERY PRECISE RESULTS g_1^p and g_1^d

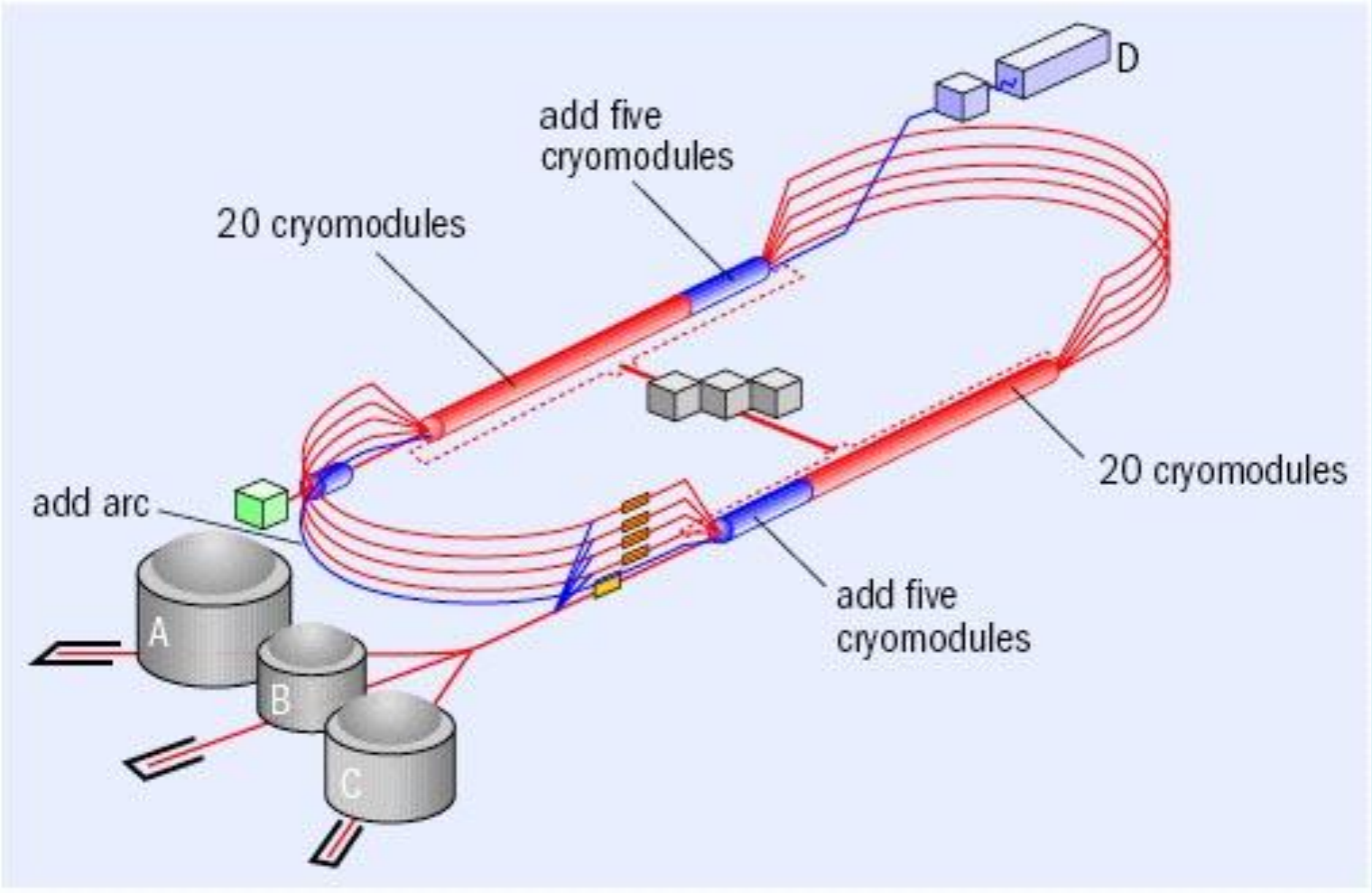
PRELIMINARY Pt DEPENDENCE SIDIS

EXCLUSIVE PION ELECTROPRODUCTION

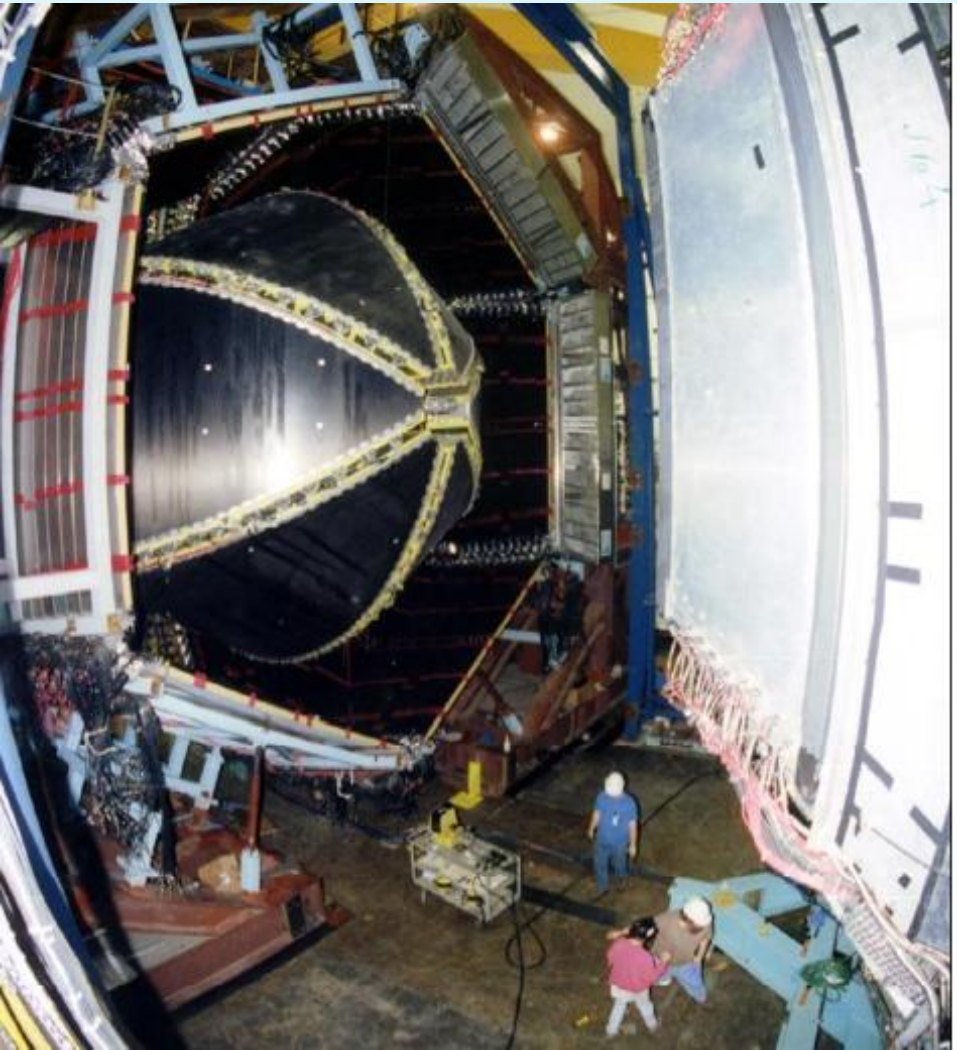
CEBAF AT JEFFERSON LAB

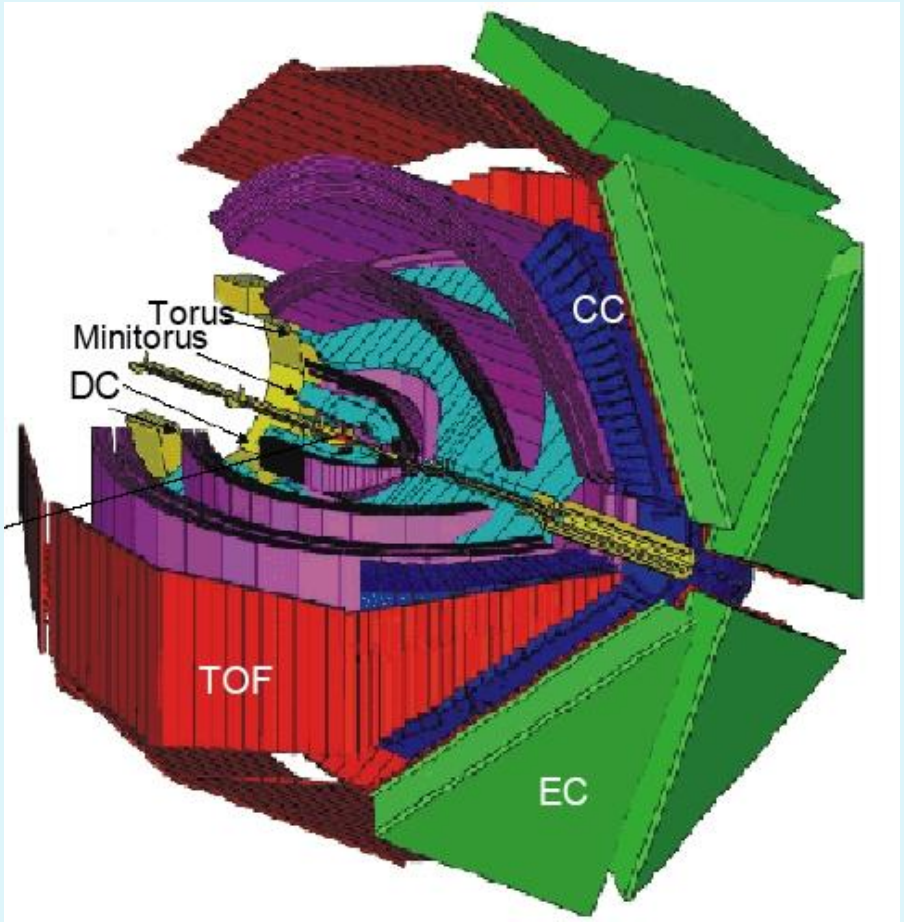
ELECTRON ENERGIES 1 TO 6 GEV

LONGITUDINAL POLARIZATION 70% TO 85%

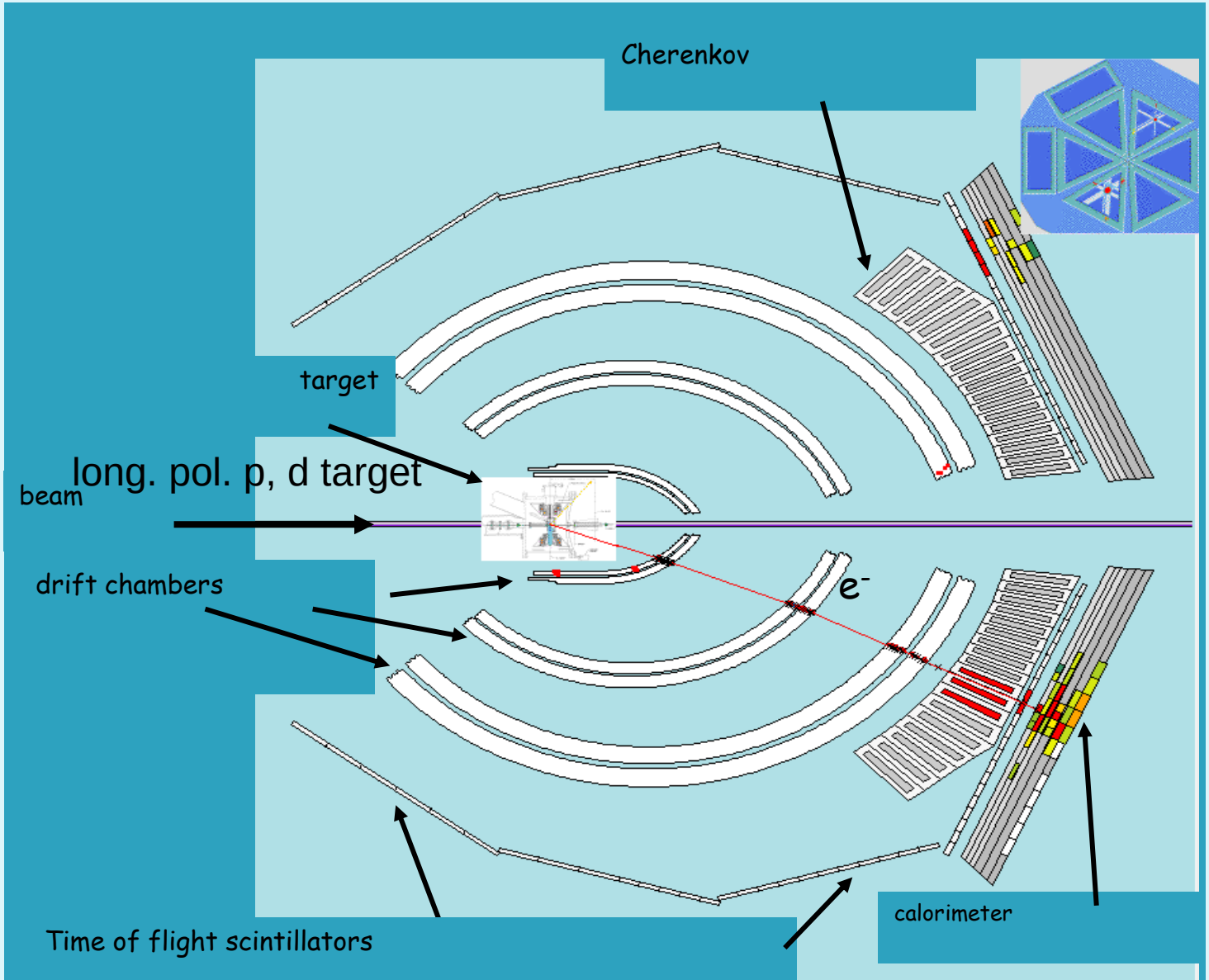


CLAS DETECTOR
In Hall B at Jefferson Lab



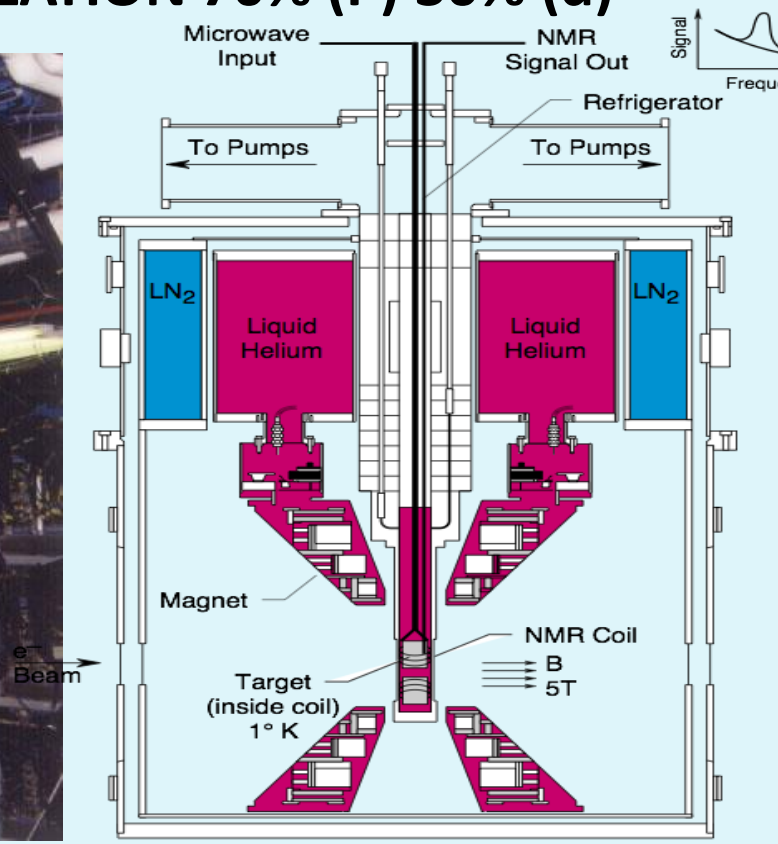


p(e, e')X EVENT IN CLAS



LONGITUDINALLY POLARIZED PROTON, DEUTERON TARGETS

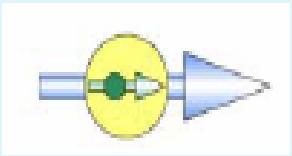
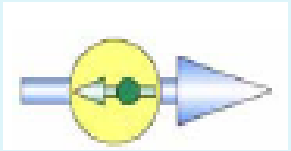
- 5 TESLA MAGNETIC FIELD
- 1 K LIQUID HELIUM
- AMMONIA TARGETS (NH_3, ND_3)
- POLARIZATION 70% (P) 30% (d)



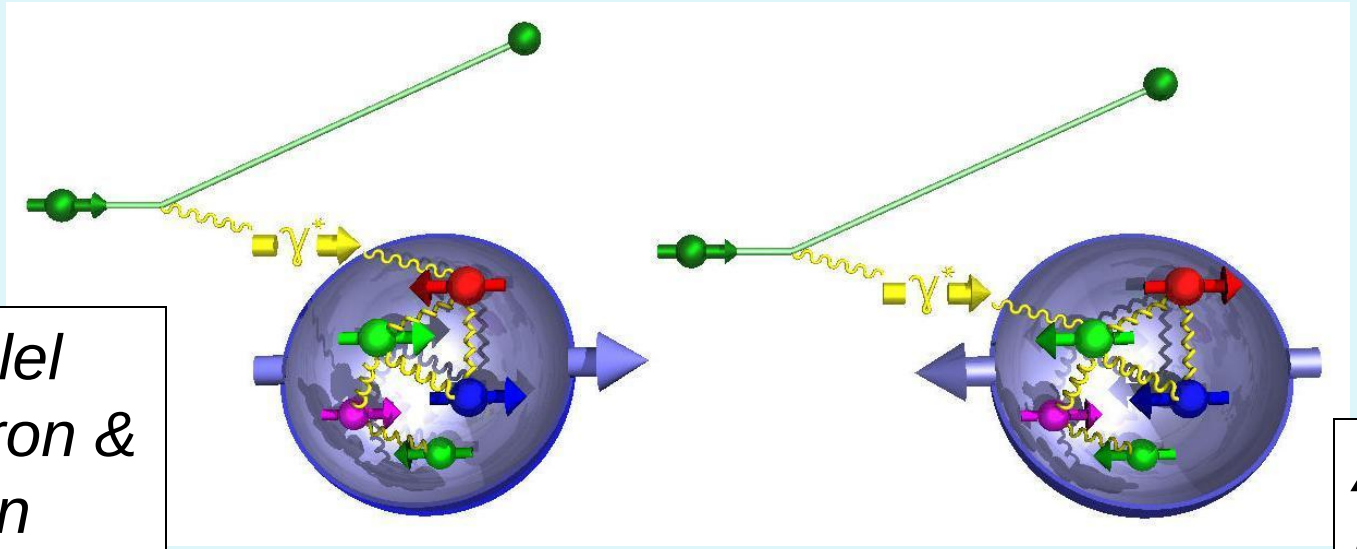
Purple beads are ammonia (NH_3); only the protons are polarized, the nitrogen makes for (big) background

Polarization of quarks

Quarks have spin, which can be aligned or anti aligned with proton spin

$q^+(x)$   q^-

Experiment: compare:



Parallel electron & proton spins

Anti-parallel electron & proton spins

EG1-DVCS experiment

5.9 GeV polarized electrons

Run in 2009: 4 months on NH_3
1.5 months on ND_3

Many improvements compared to 2001: equivalent to 30x more events

INCLUSIVE g_1/F_1 DETERMINATION

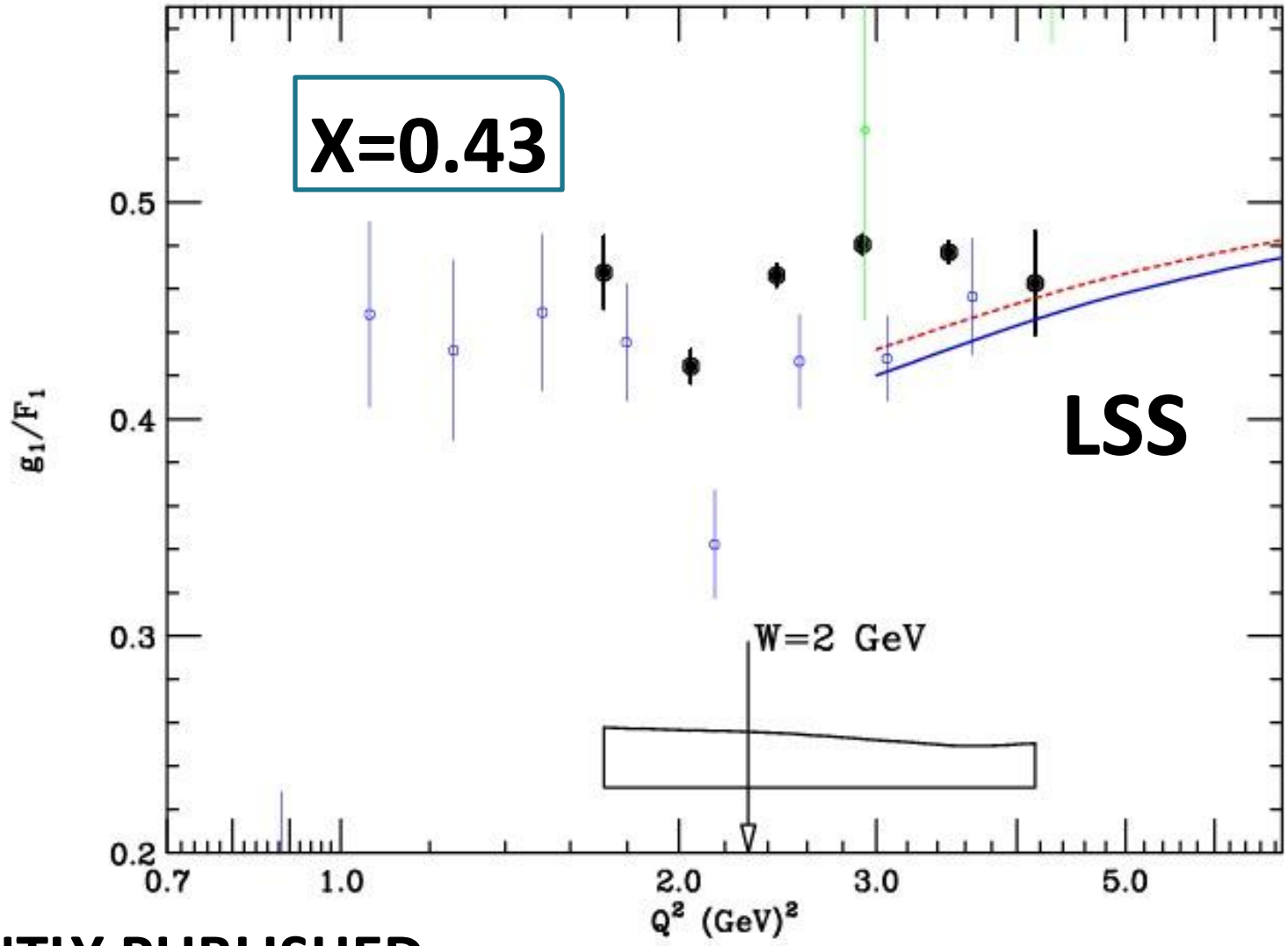
$$\frac{g_1}{F_1} \approx \frac{1}{P_B P_T f D_{LL}(y)} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

- **Beam polarization P_B about 0.8**
- **Target polarization 0.7 (p), 0.3 (d)**
- **Dilution factor f about 0.2**
- **Depolarization factor $D_{LL}(y)$ about 0.3**
- **Number cound N measured in billions**

ADDITIONAL CORRECTIONS g_1/F_1

-
- **RADIATIVE CORRECTIONS**
- **RADIATIVE DILUTION**
- **PAIR-SYMMETRIC BACKGROUND**
- **POLARIZATION OF NITROGEN**
- **CONTRIBUTION FROM g2**
- **ACCIDENTAL CONTAMINATION OF ND_3 TARGET WITH 10% NH_3**

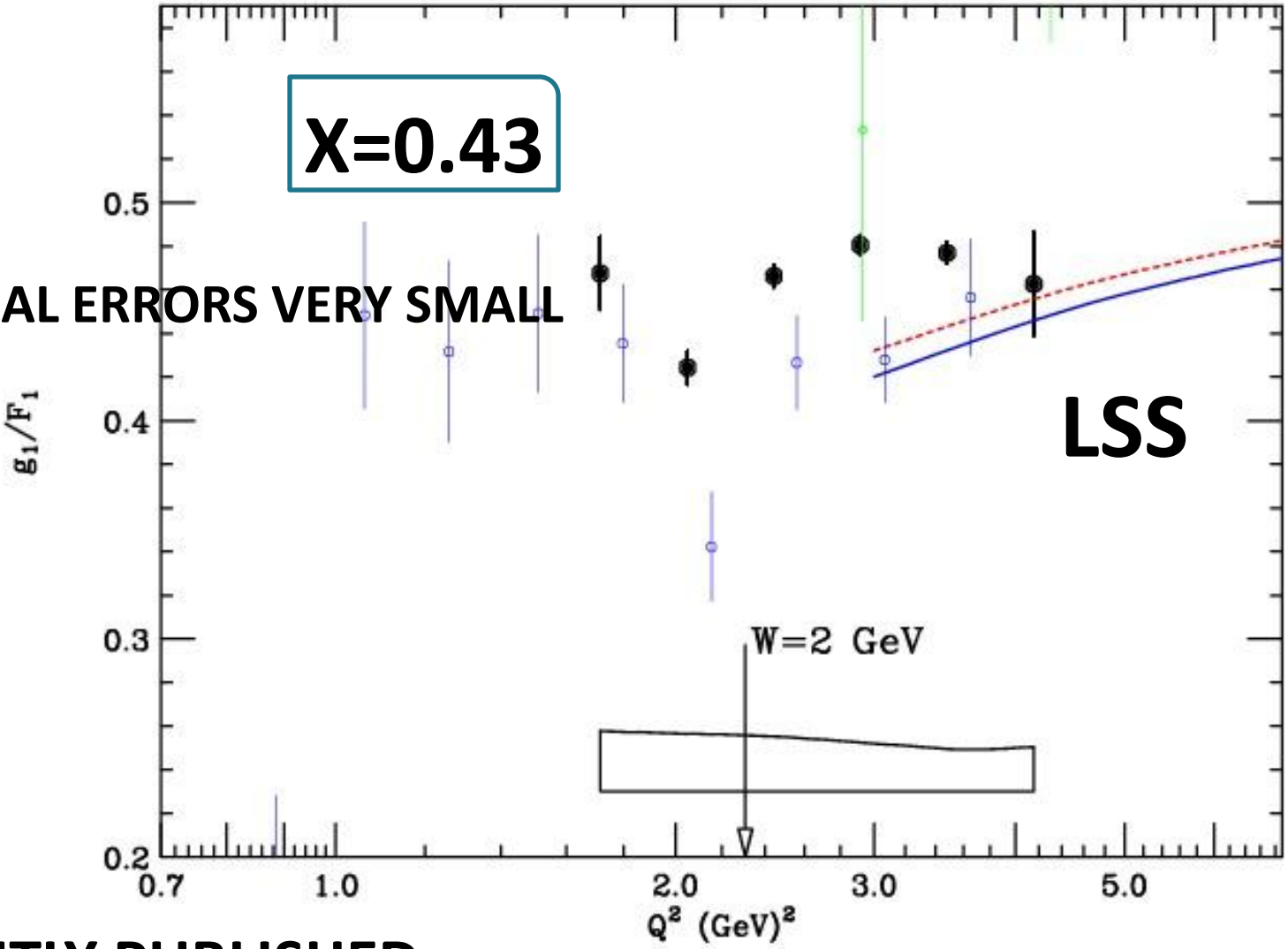
EG1-DVCS PROTON g_1/F_1



RECENTLY PUBLISHED:

Y. Prok, P. Bosted, N. Kvaltine et al (CLAS) Phys. Rev. C 90,025212 (2014).

EG1-DVCS PROTON g_1/F_1



STASTICAL ERRORS VERY SMALL

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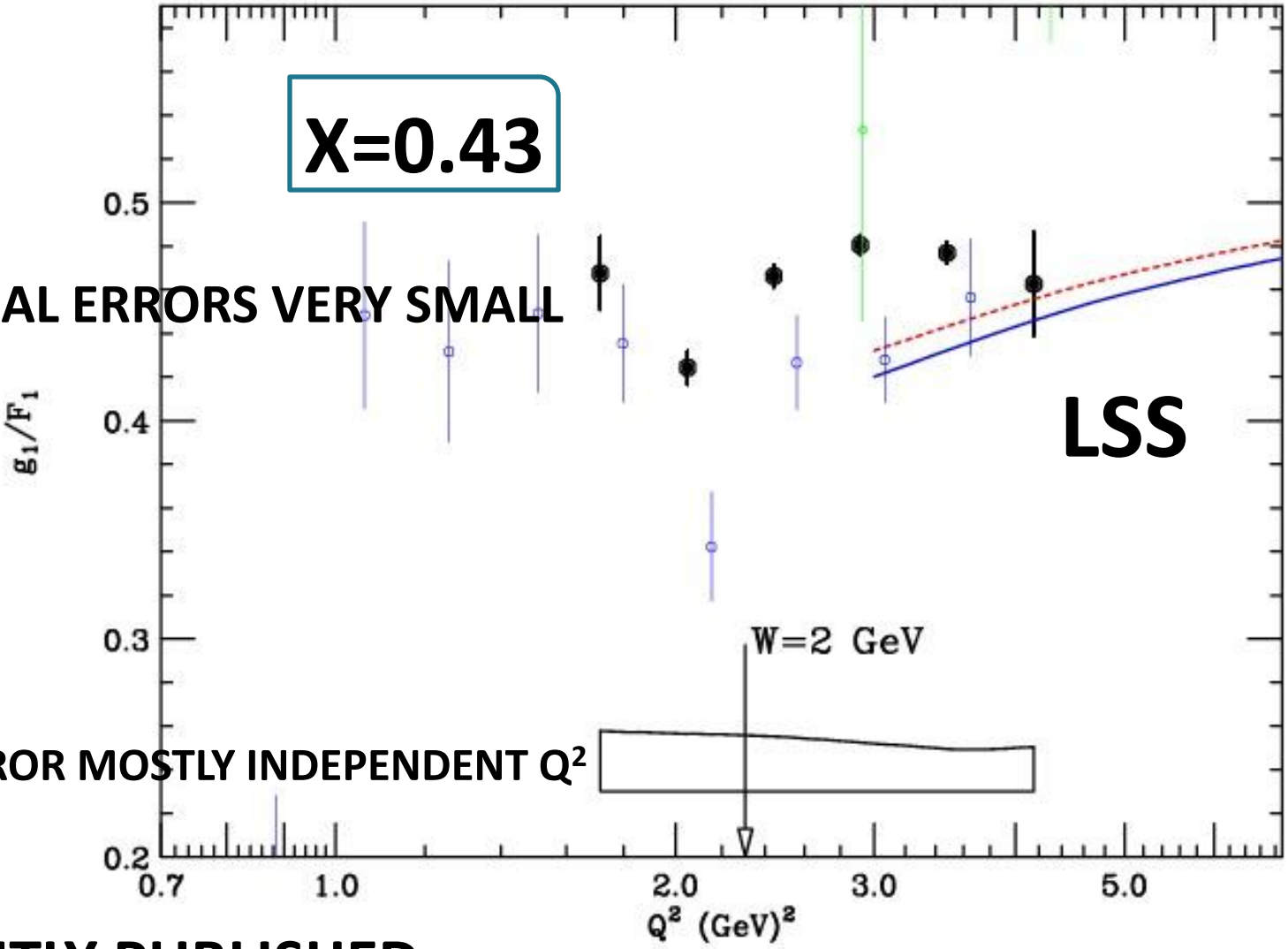
EG1-DVCS PROTON g_1/F_1



STASTICAL ERRORS VERY SMALL

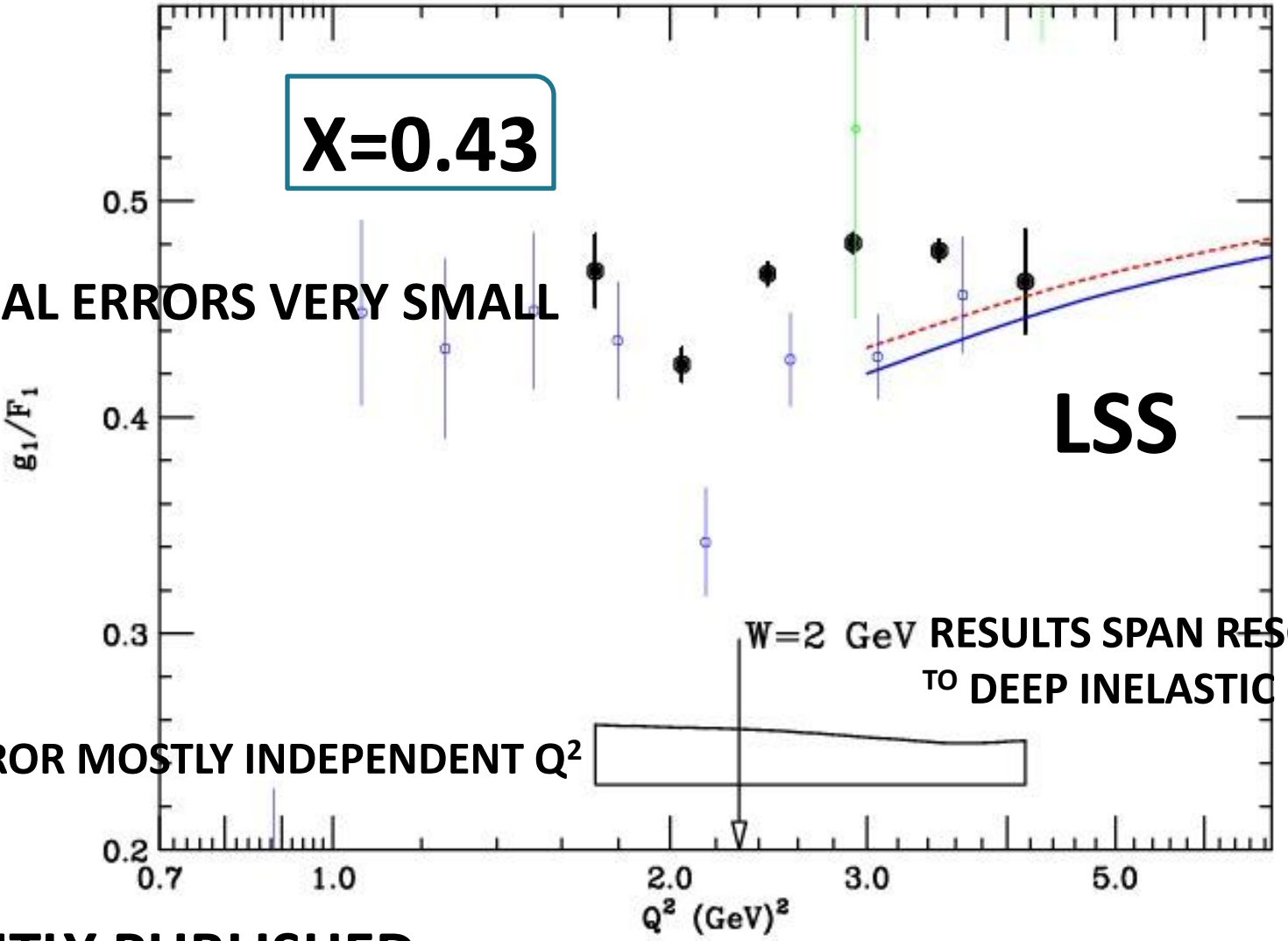
LSS

SYST. ERROR MOSTLY INDEPENDENT Q^2

RECENTLY PUBLISHED:

Y. Prok, P. Bosted, N. Kvaltine et al (CLAS) Phys. Rev. C 90,025212 (2014).

EG1-DVCS PROTON g_1/F_1



STASTICAL ERRORS VERY SMALL

LSS

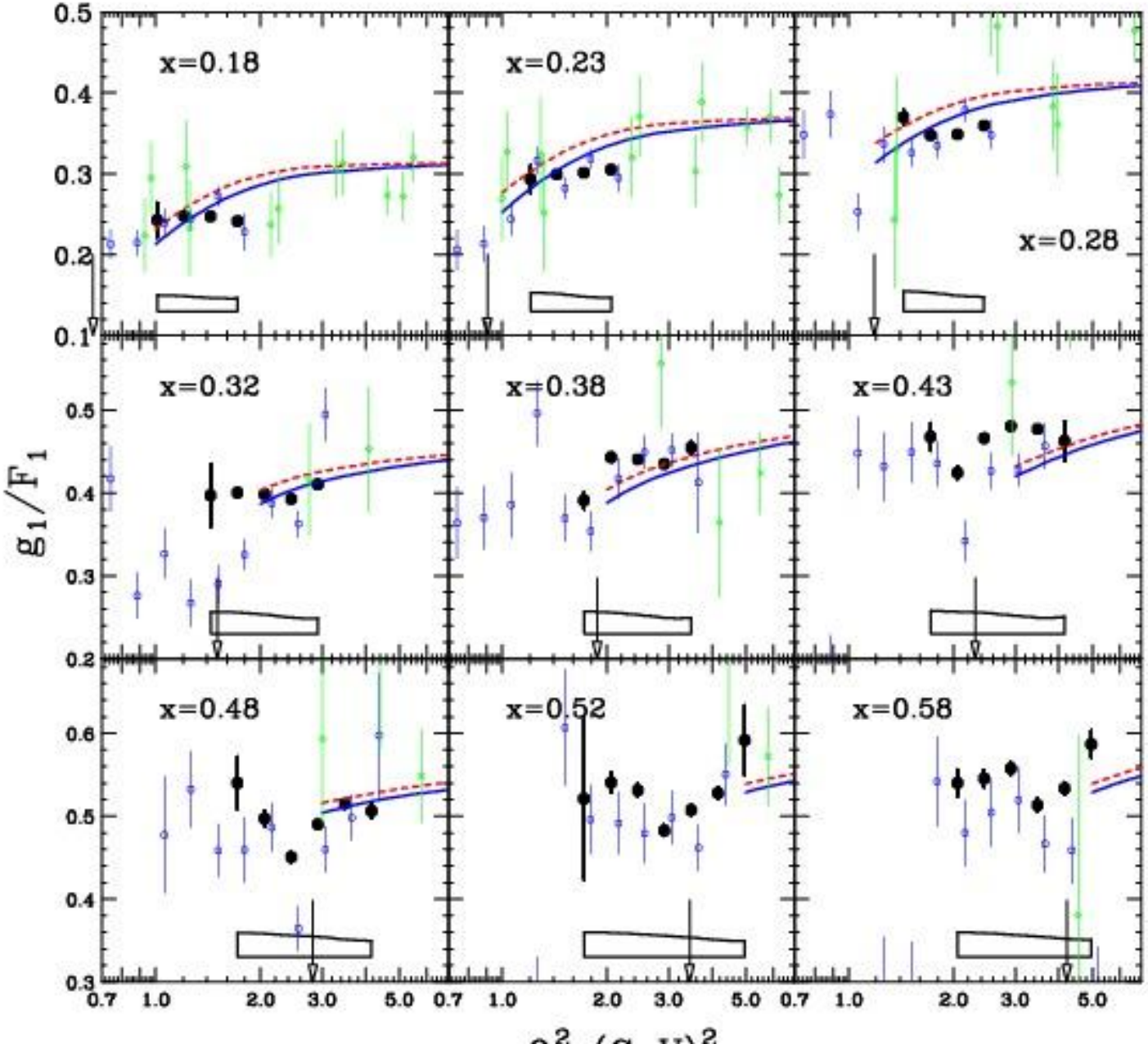
RESULTS SPAN RESONANCE TO DEEP INELASTIC REGIONS

SYST. ERROR MOSTLY INDEPENDENT Q^2

RECENTLY PUBLISHED:

Y. Prok, P. Bosted, N. Kvaltine et al (CLAS) Phys. Rev. C 90,025212 (2014).

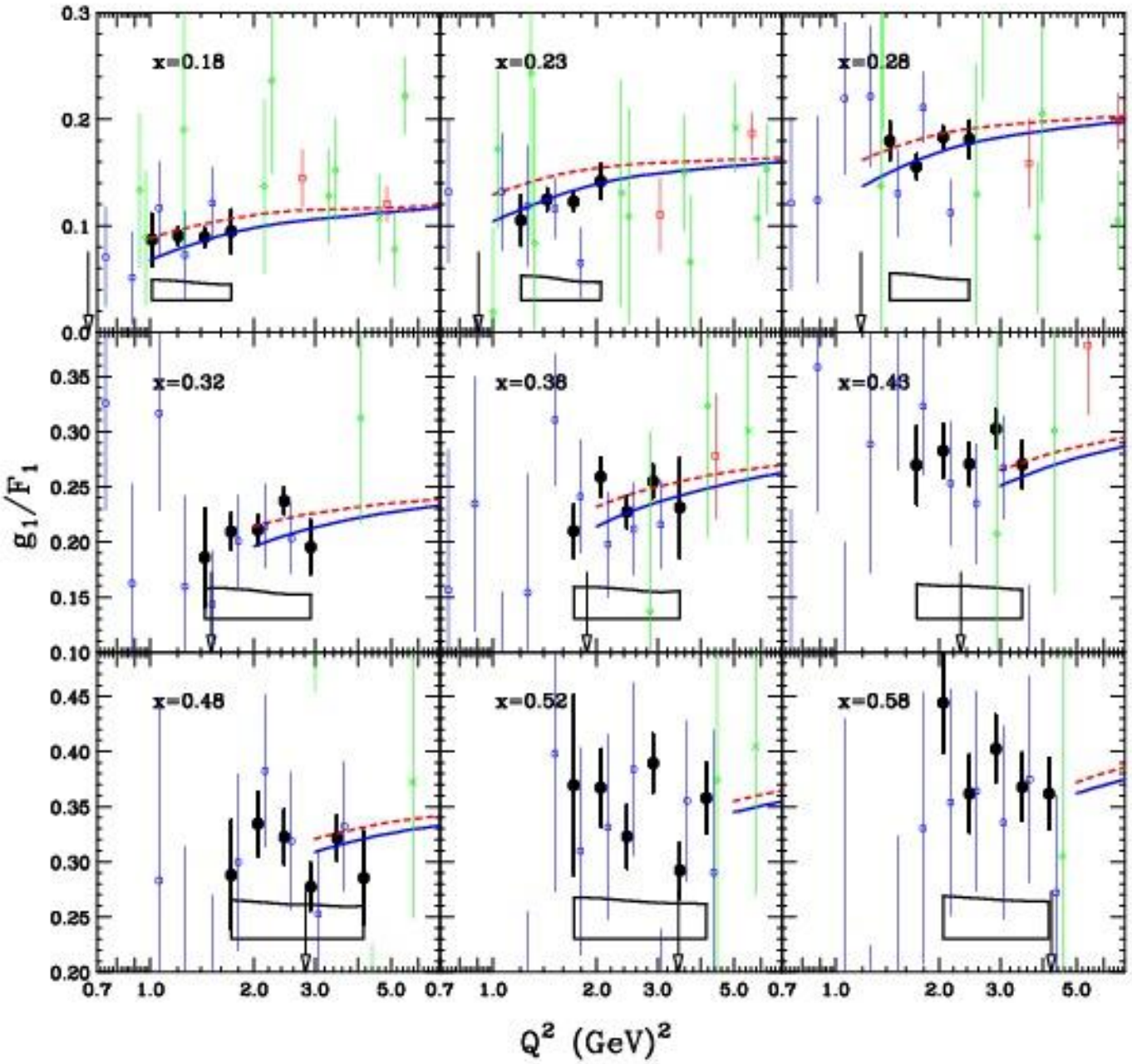
EG1-DVCS PROTON g_1/F_1



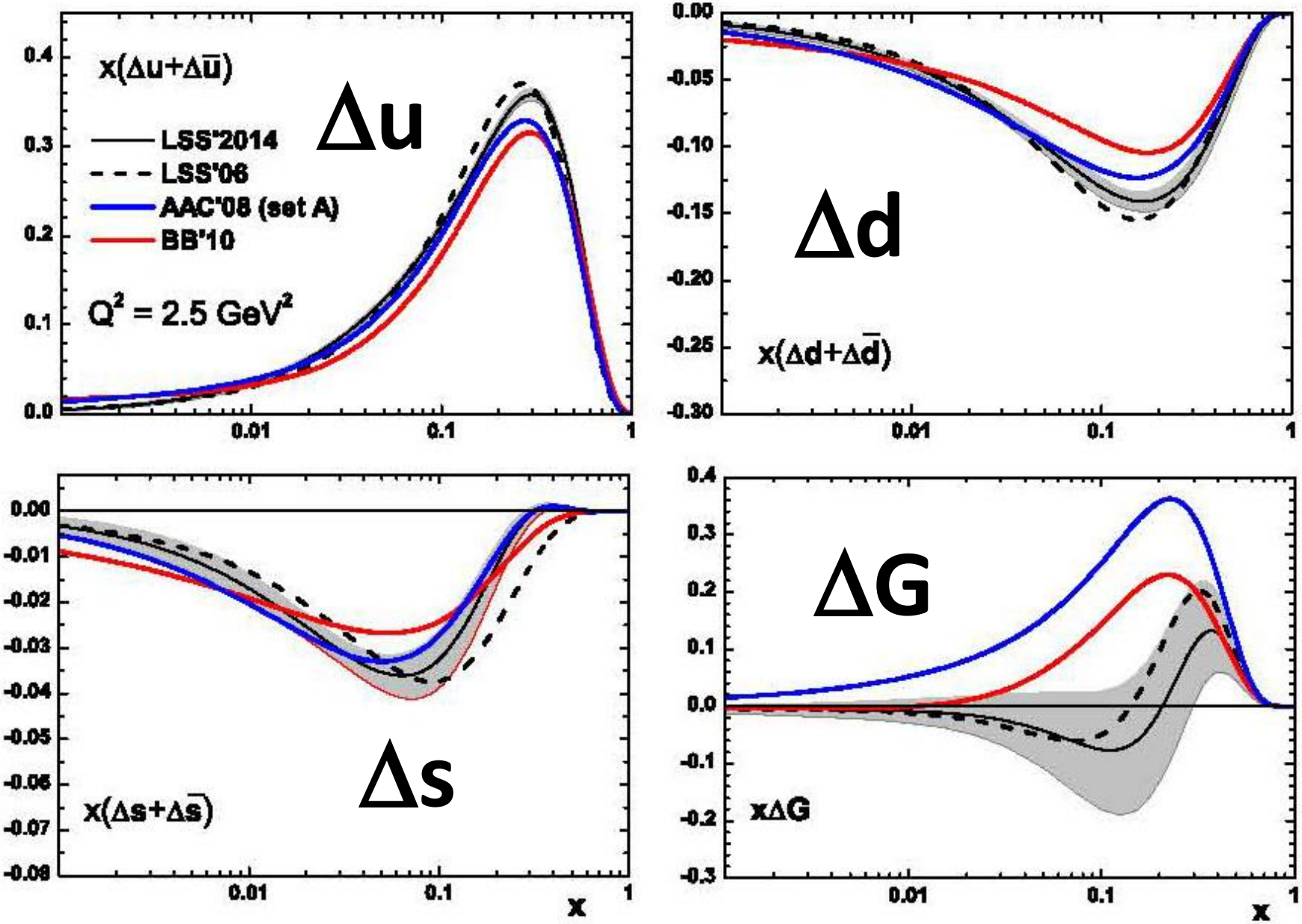
0.15<X<0.6

1<Q^2<5 GeV^2

EG1-DVCS DEUTERON g_1/F_1



LSS FIT USING EG1-DVCS NEW RESULTS



Leader, Siderov, and Staminov 1410:1657 (October 2014)

LSS FIT USING EG1-DVCS NEW RESULTS

"We have stressed that, in principle, the inclusive DIS data uniquely determine the strange quark polarization. Our new analysis of the inclusive world data, including for the first time the **extremely accurate JLab CLAS data on the proton and deuteron** spin structure functions and the recently published COMPASS proton data, despite allowing, in the parametrization, for a possible sign change, has confirmed the previous claim, namely, that the inclusive data **yield** **significantly negative values for the strange quark polarization**. The fundamental difference between the SIDIS and DIS analysis is the necessity in SIDIS to use information on the fragmentation functions, which are largely determined from multiplicity measurements."

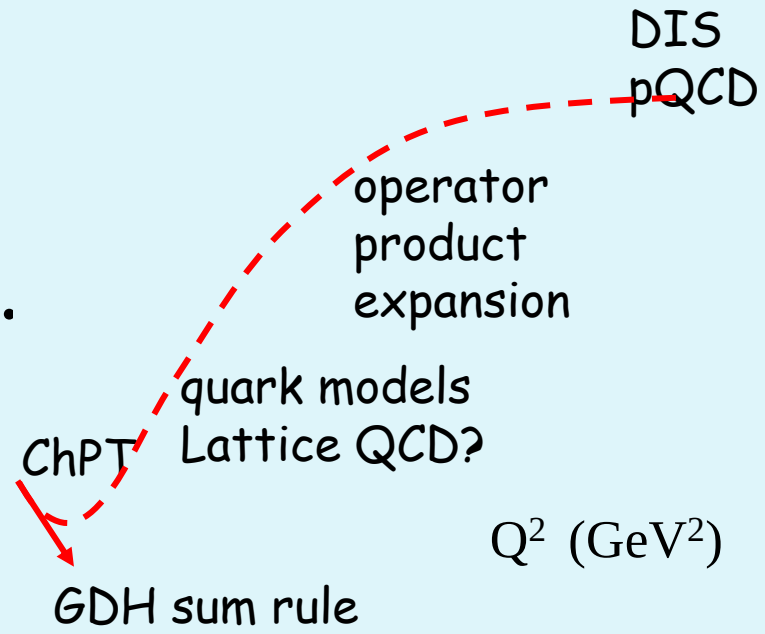
Leader, Siderov, and Staminov 1410:1657 (October 2014)

Moments of spin structure functions

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)\,dx$$

Bjorken Sum Rule:

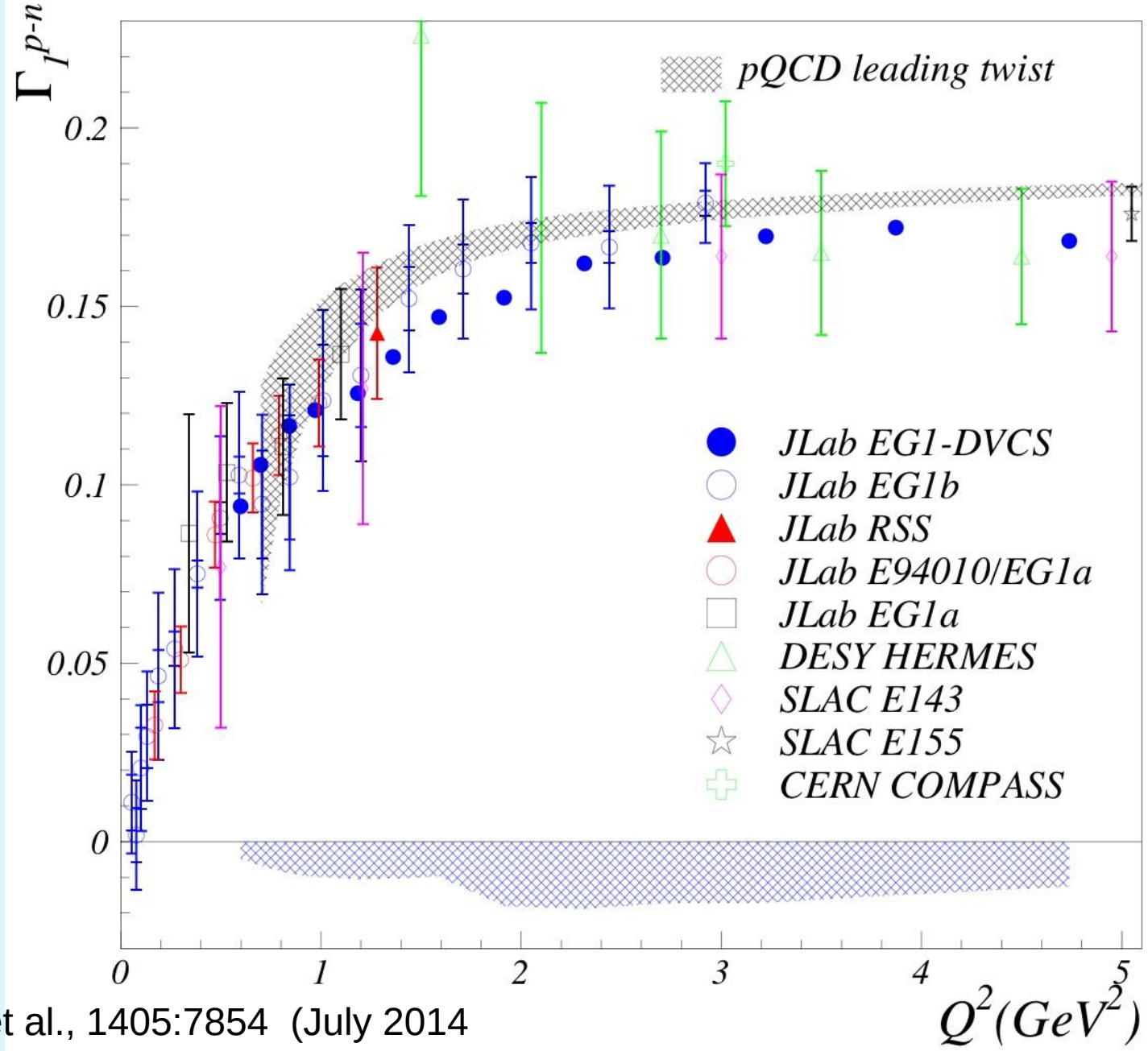
$$\Gamma_1^p - \Gamma_1^n = \frac{g_A}{6} + \text{QCD corr.}$$



GDH Sum Rule:

$$G_1(Q^2 \to 0) \to -\frac{Q^2}{2M^2}\frac{k^2}{4}$$

BJORKEN SUM RULE



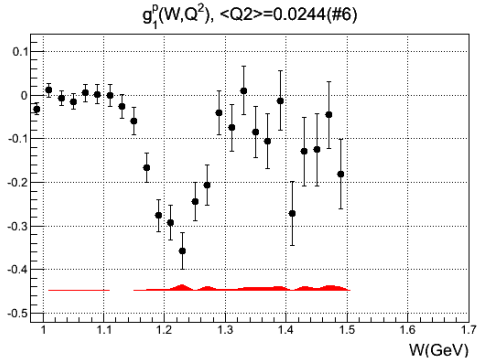
A. Deur et al., 1405:7854 (July 2014

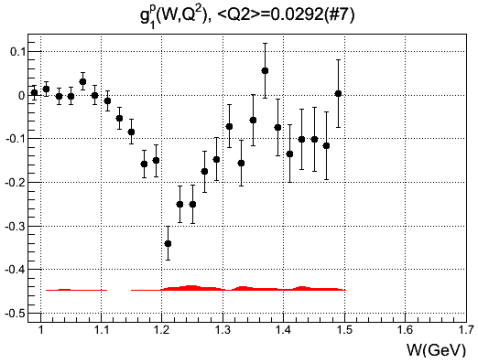
EG4 EXPERIMENT

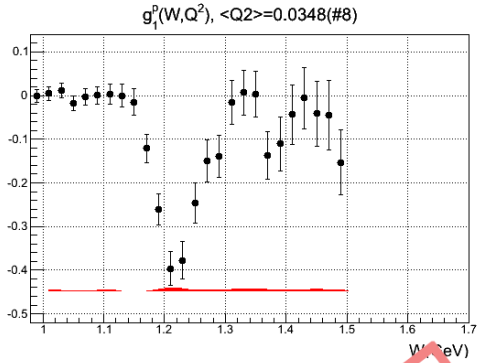
Scattering of 1 to 3 GeV polarized electrons off polarized NH_3, ND_3

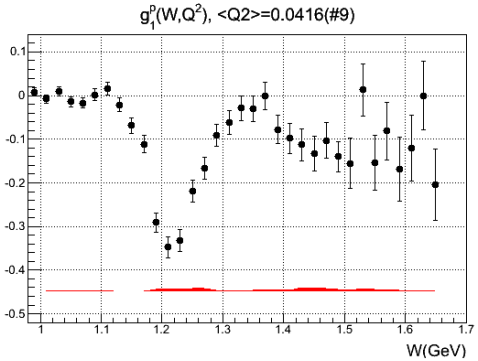
Took data in 2004

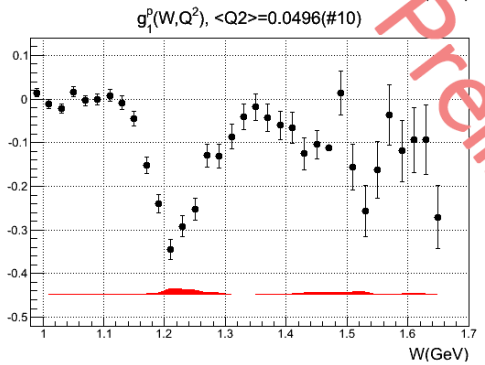
Small scattering angles (6 to 20 degrees) to focus on low Q^2 region

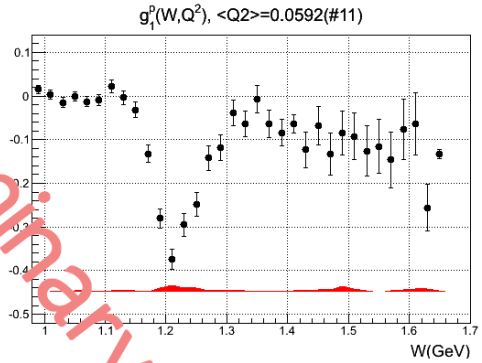


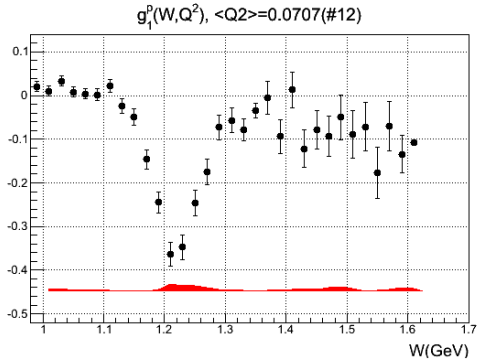












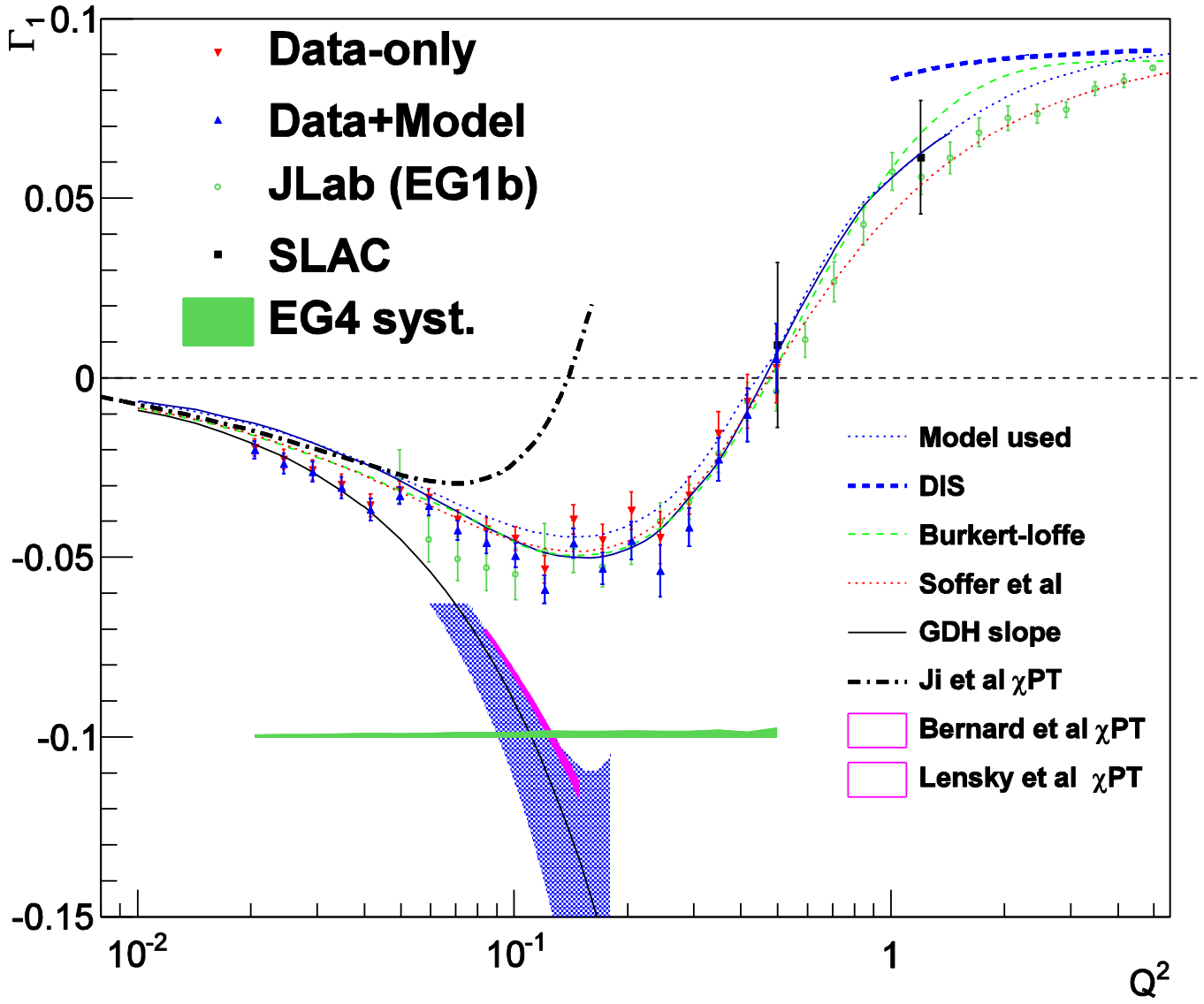
Preliminary

EG4 g_1 PROTON

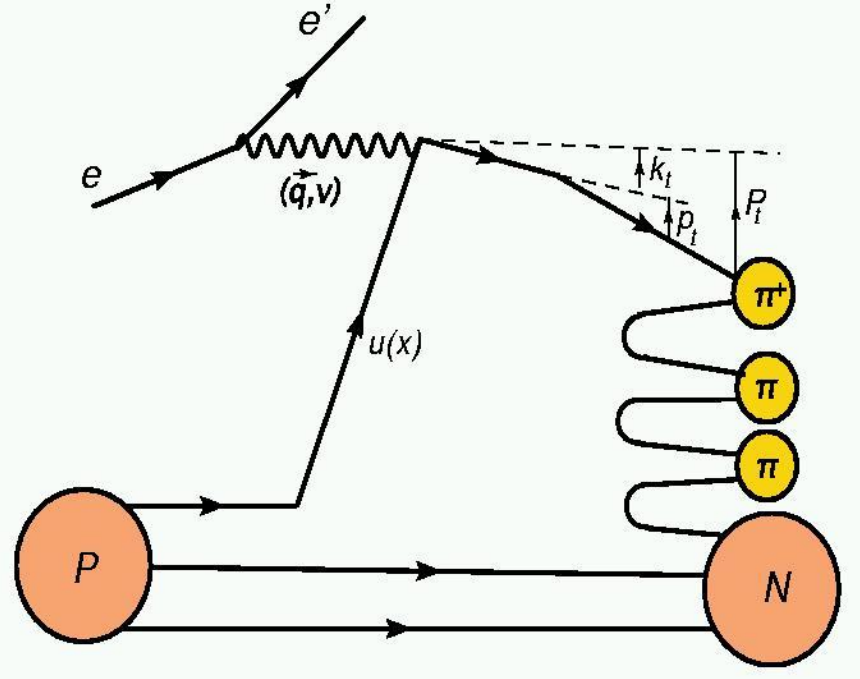
g_1 AS FUNCTION OF w IN 7 OF 20 Q^2 BINS.

$\Delta(1232)$ PROMINENT

Preliminary EG4 DEUTERON INTEGRAL Γ_1



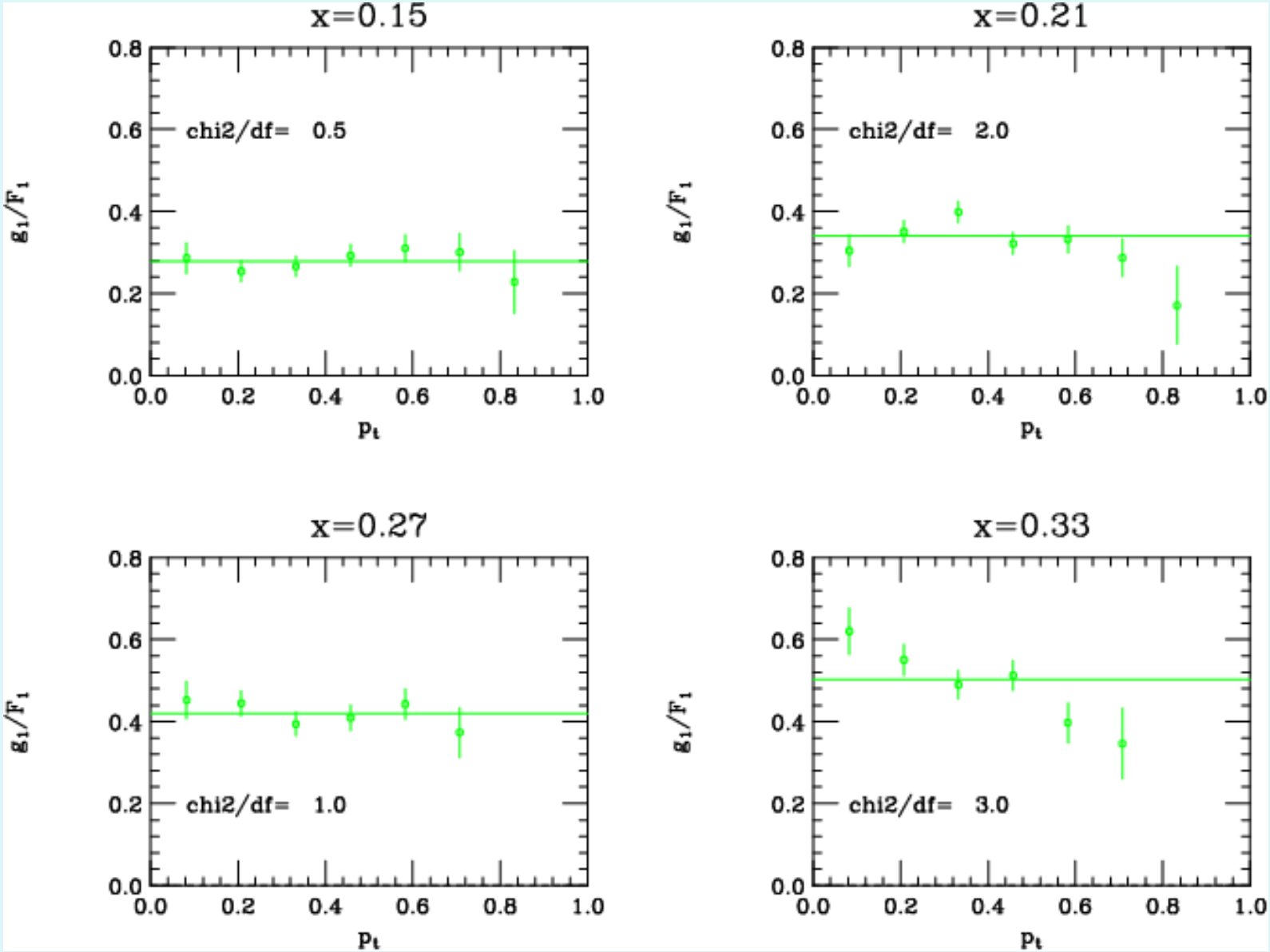
One Level deeper: k_T-dependent SIDIS



Assume P_t of observed pion is 3D vector sum of quark k_t and a fragmentation that generates extra vector p_t.

Does ratio g_1/F_1 depend p_T?

Very preliminary results for π^0 for g_1/F_1 versus p_T from eg1-dvcs



Results consistent with no p_T dependence

SIDIS STILL PRELIMINARY

QED RADIATIVE CORRECTION CAN BE LARGE AT HIGH PT.

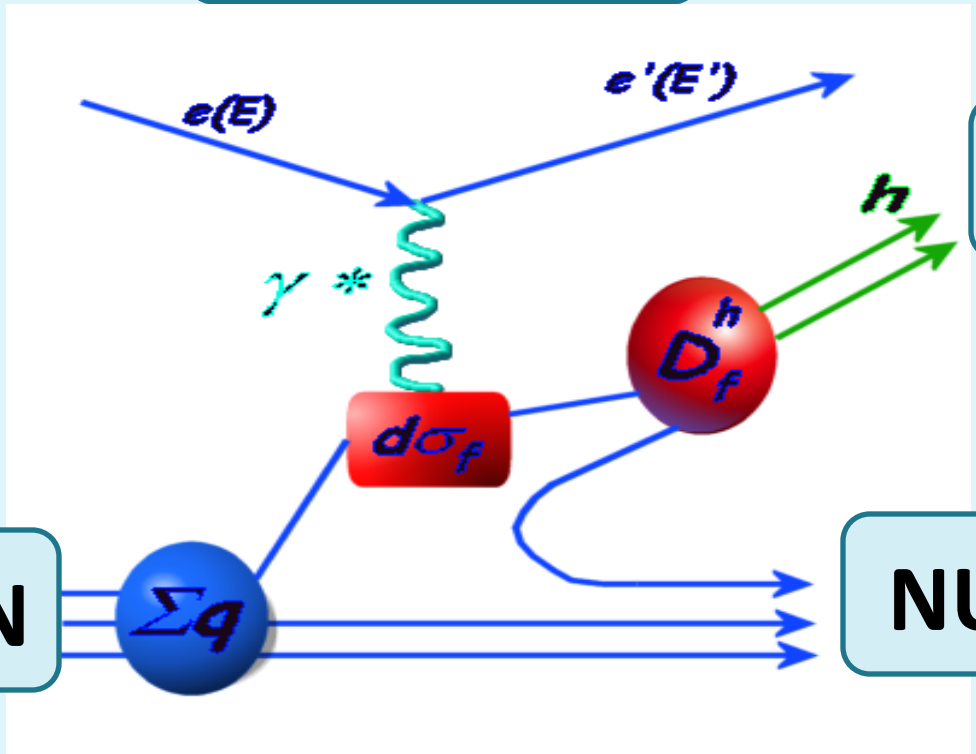
NEED RELIABLE FITS TO CROSS SECTIONS AND ASYMMETRIES FROM SGINLE PION AND DOUBLE PION ELECTROPRODUCTION

EMBARK ON PROJECT TO ANALYZE LARGE BODY DATA FROM 00 AND 2009

ONE LEVEL DEEPER YET:
EXCLUSIVE PION ELECTROPRODUCTION

$e\,p \rightarrow e\,n\,\pi^+$ $e\,p \rightarrow e\,p\,\pi^0$ $e\,n \rightarrow e\,p\,\pi^-$

ELECTRON



PION

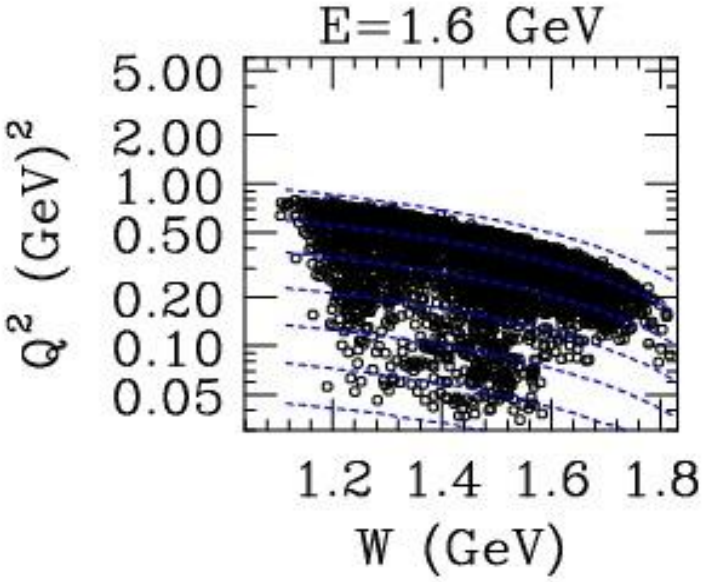
NUCLEON

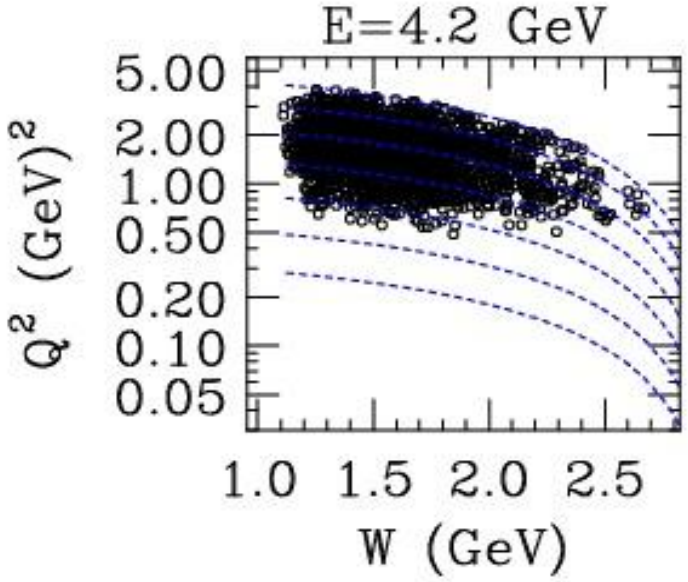
NUCLEON

NEW RESULTS EG1B (2000) AND EG1-DVCS (2009)

- 4 BEAM ENERGIES (1.6, 2.5, 4.2, 6 GEV)
- 40 BINS IN W FROM 1.1 TO 3.0 GEV (OR 0.1<X<1)
- 10 BINS IN Q^2 FROM 0.05 TO 5 GEV^2
- 10 BINS IN COS(θ^*) FROM -0.4 TO 1 (OR -1<t<0 GEV2)
- 12 BINS IN ϕ^* FROM 0 TO 360 DEGREES

CAN'T SHOW ALL IN 2 MINUTES!





BEAM-TARGET SPIN ASYMMETRY

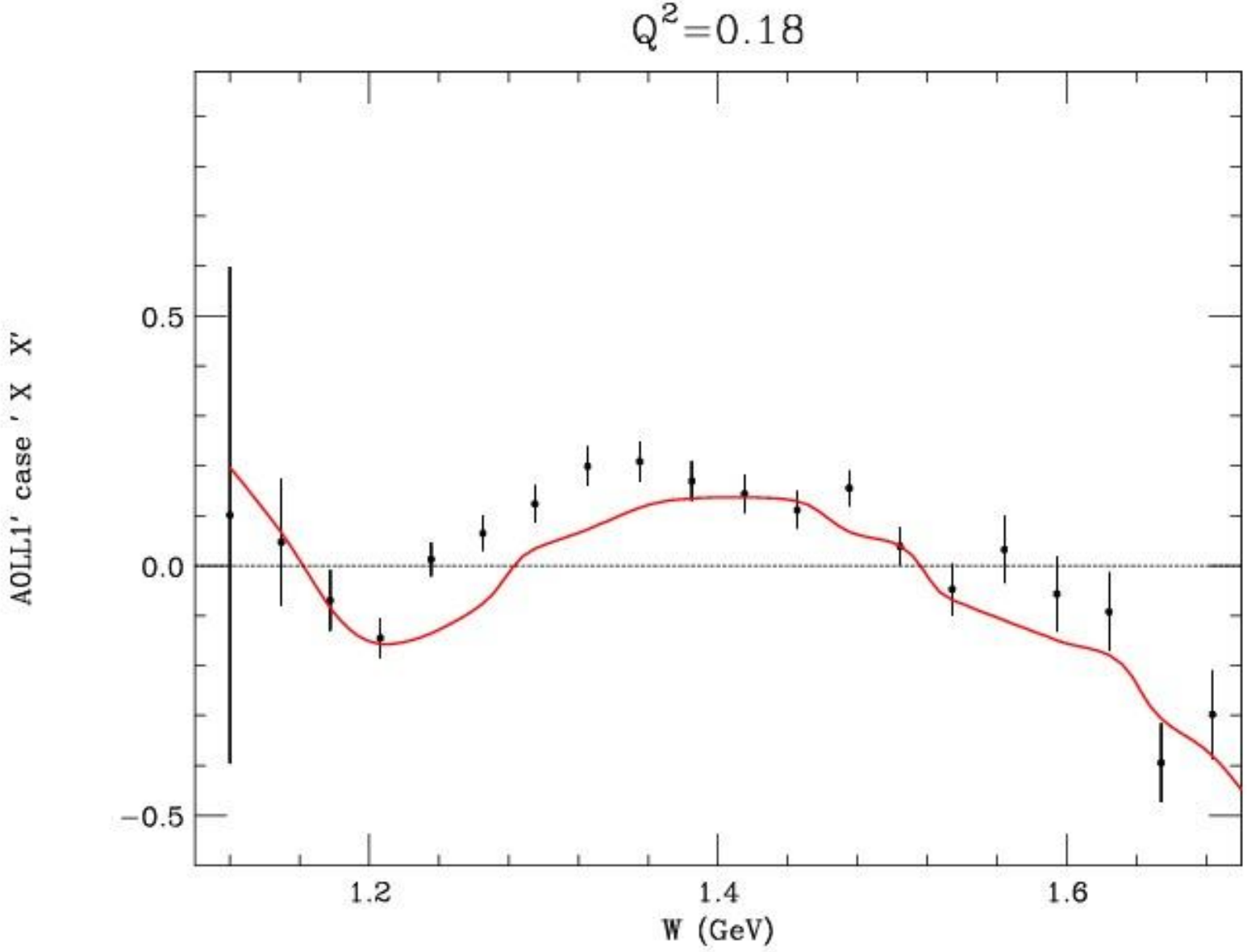
$$A_{LL}(W, Q^2, \cos(\theta^*), \phi^*) = \frac{1}{P_B P_T f} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

- **Leading term independent of ϕ^***
- **Related to g_1/F_1**
- **Related to $A_{1/2} - A_{3/2}$**

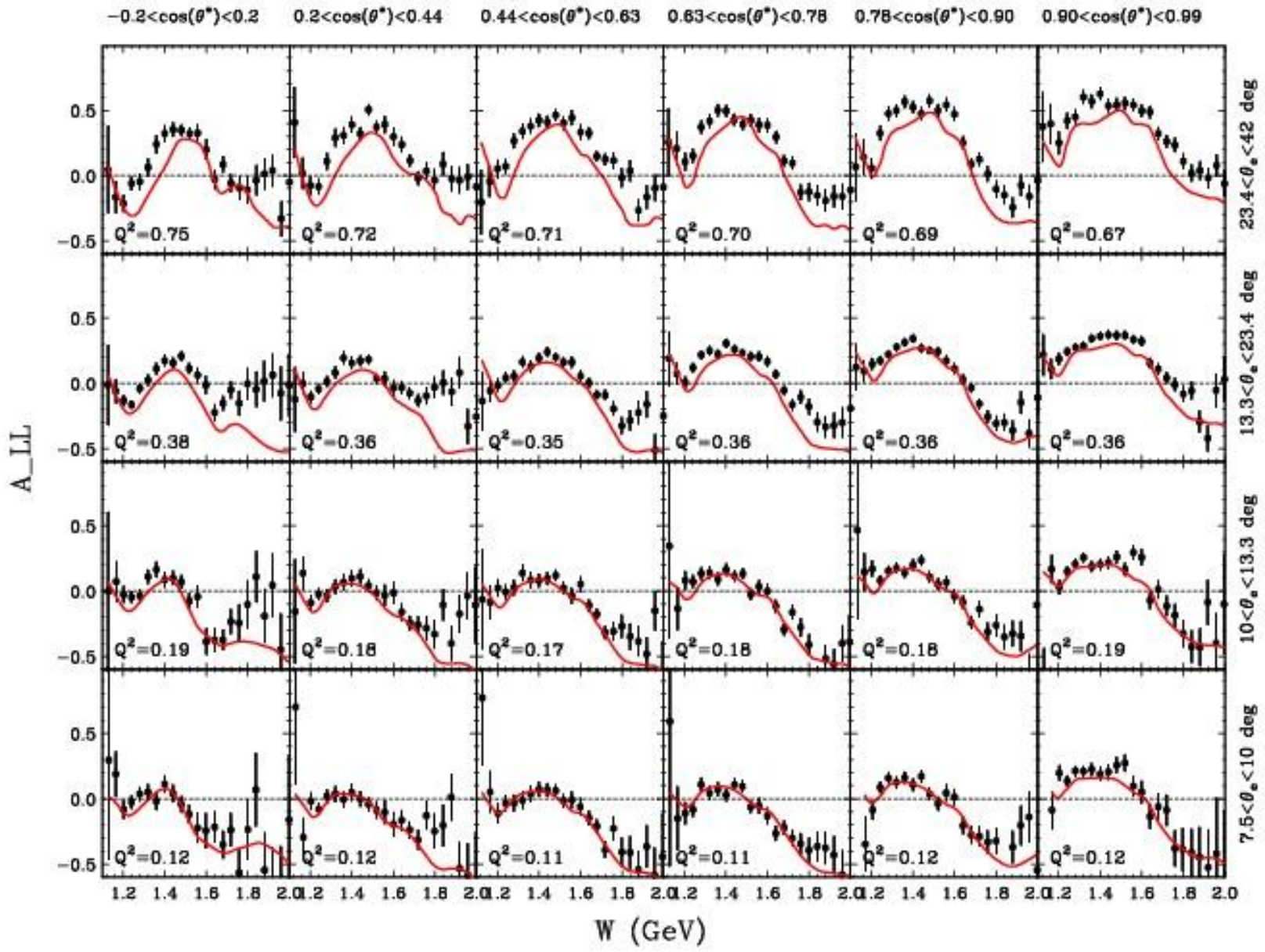
ALL RESULTS ARE PRELIMINARY

RED CURVES ON PLOTS ARE UNITARY ISOBAR FIT TO PREVIOUS WORLD DATA: MAID 2007

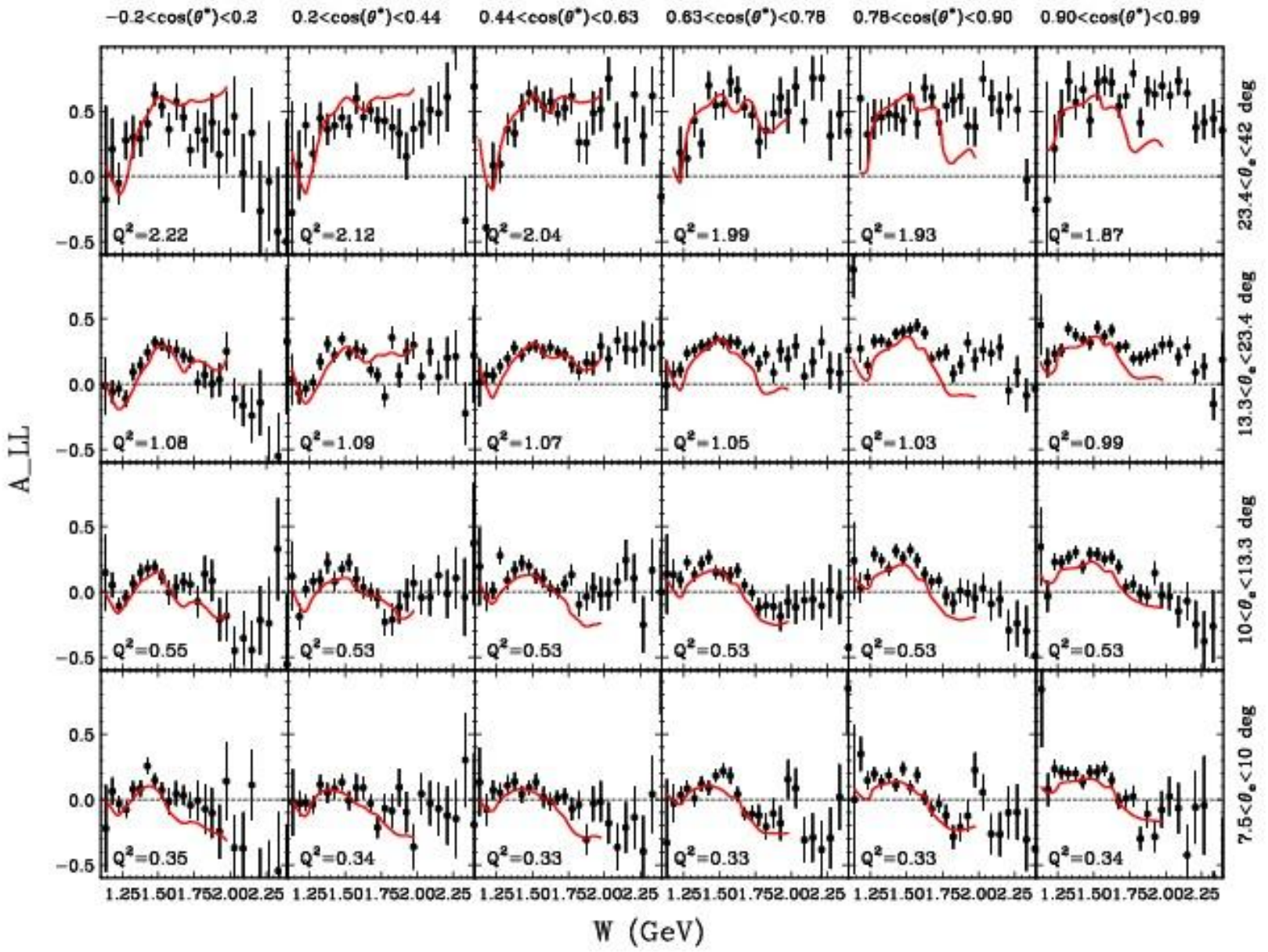
A_{LL} ϕ-average E=1.6 GeV ep→ e n π^+



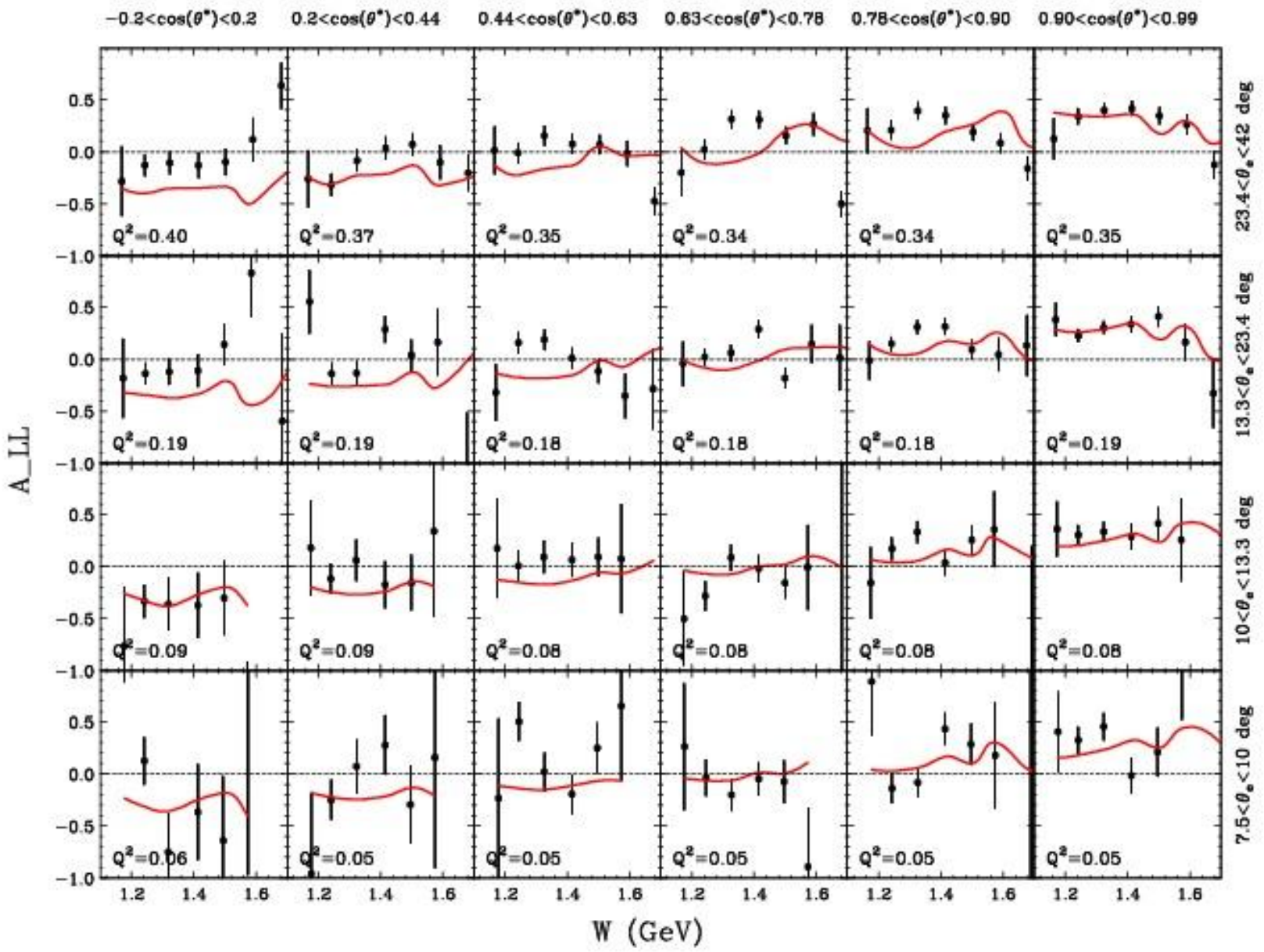
A_{LL} ϕ-average E=2.5 GeV ep→ e n π^+



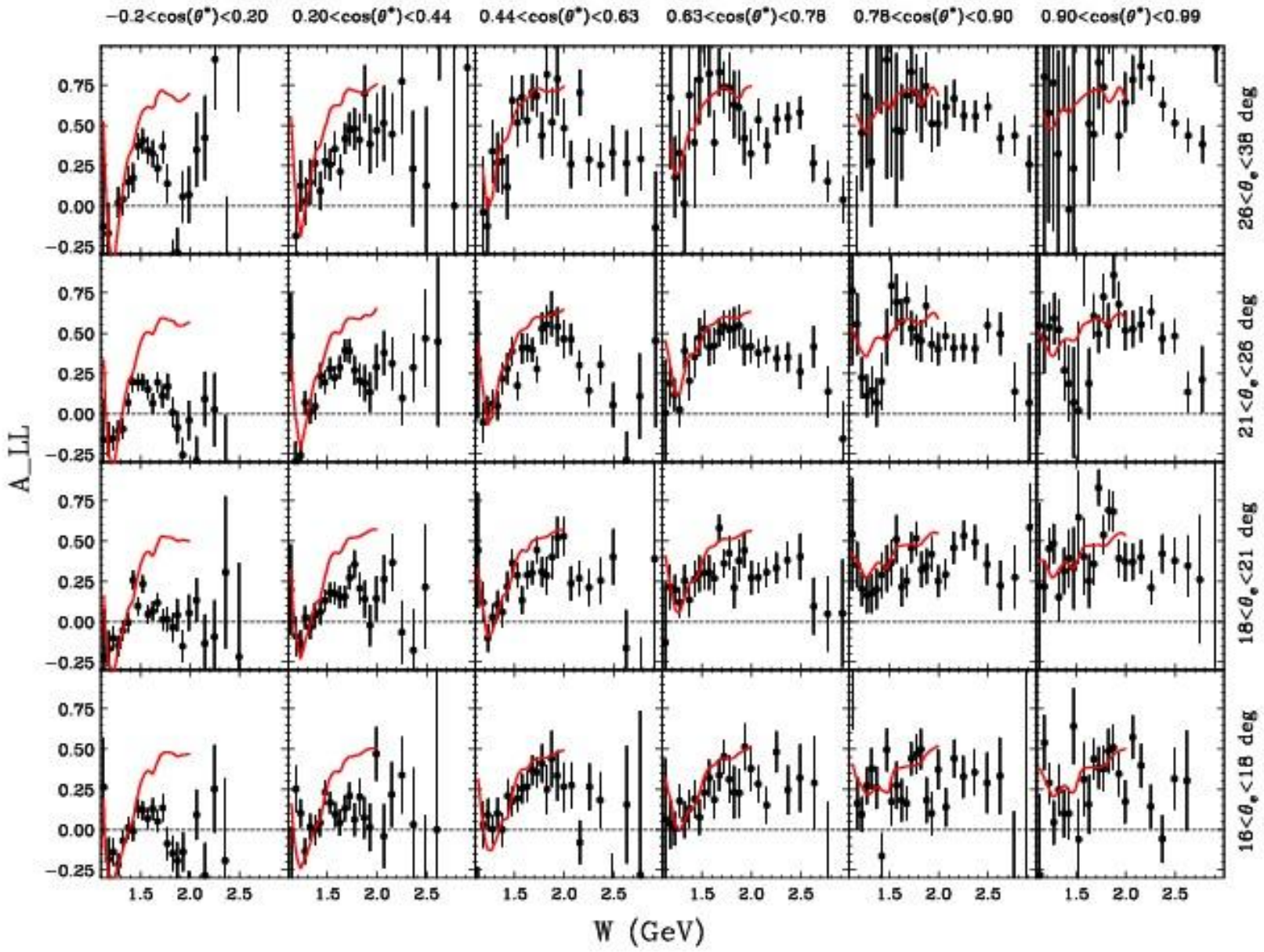
A_{LL} ϕ-average E=4.2 GeV ep→ e n π^+



A_{LL} ϕ-average E=1.6 GeV en→ e p π^-



A_{LL} ϕ-average E=5.7 GeV ep→ e p π^0

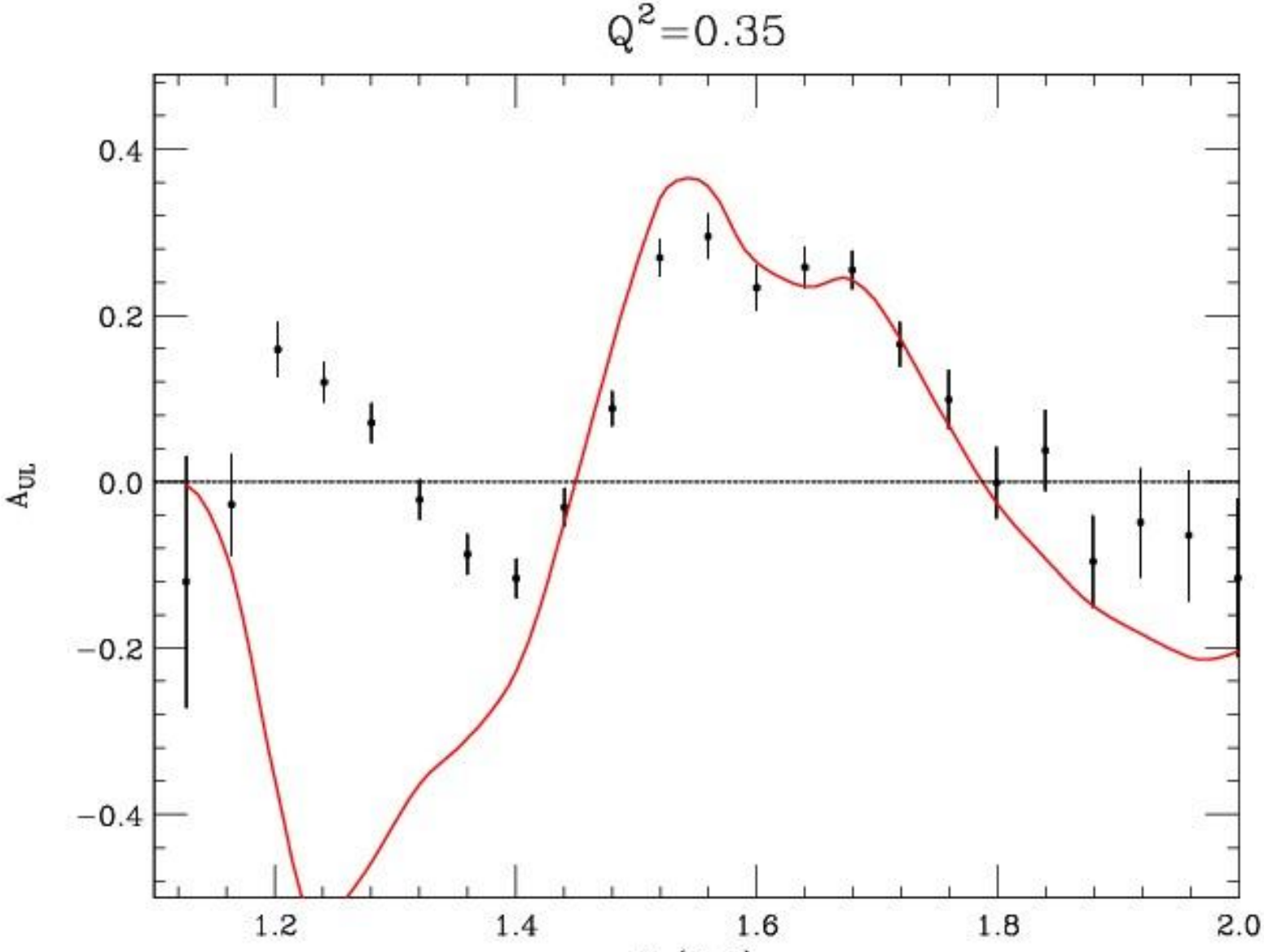


TARGET SPIN ASYMMETRY

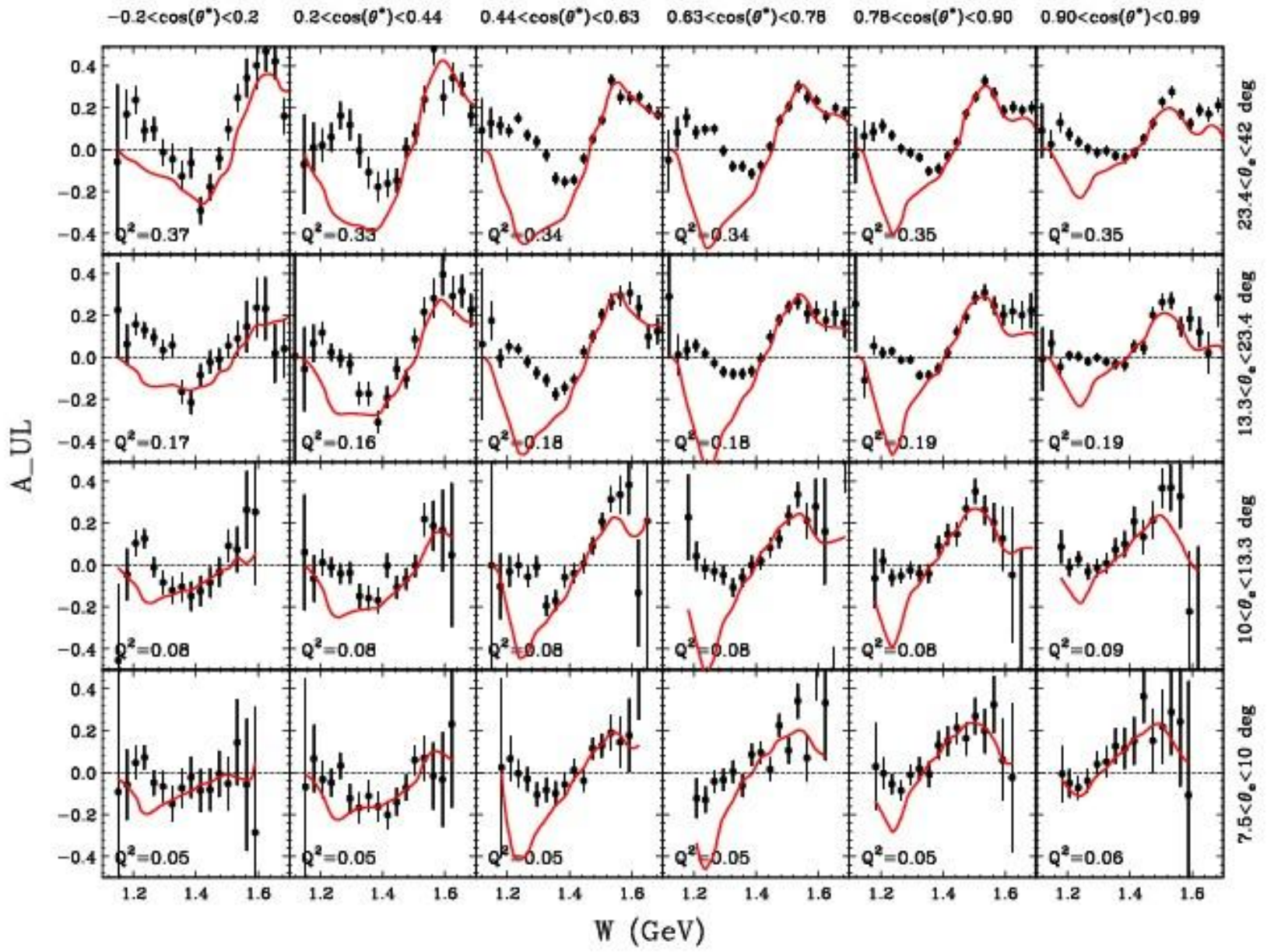
$$A_{UL}(W, Q^2, \cos(\theta^*), \phi^*) = \frac{1}{P_T f} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

- **Leading terms: sin(ϕ^*) and sin(2ϕ^*)**
- **Related to L-T and T-T interference and higher twist contributions**

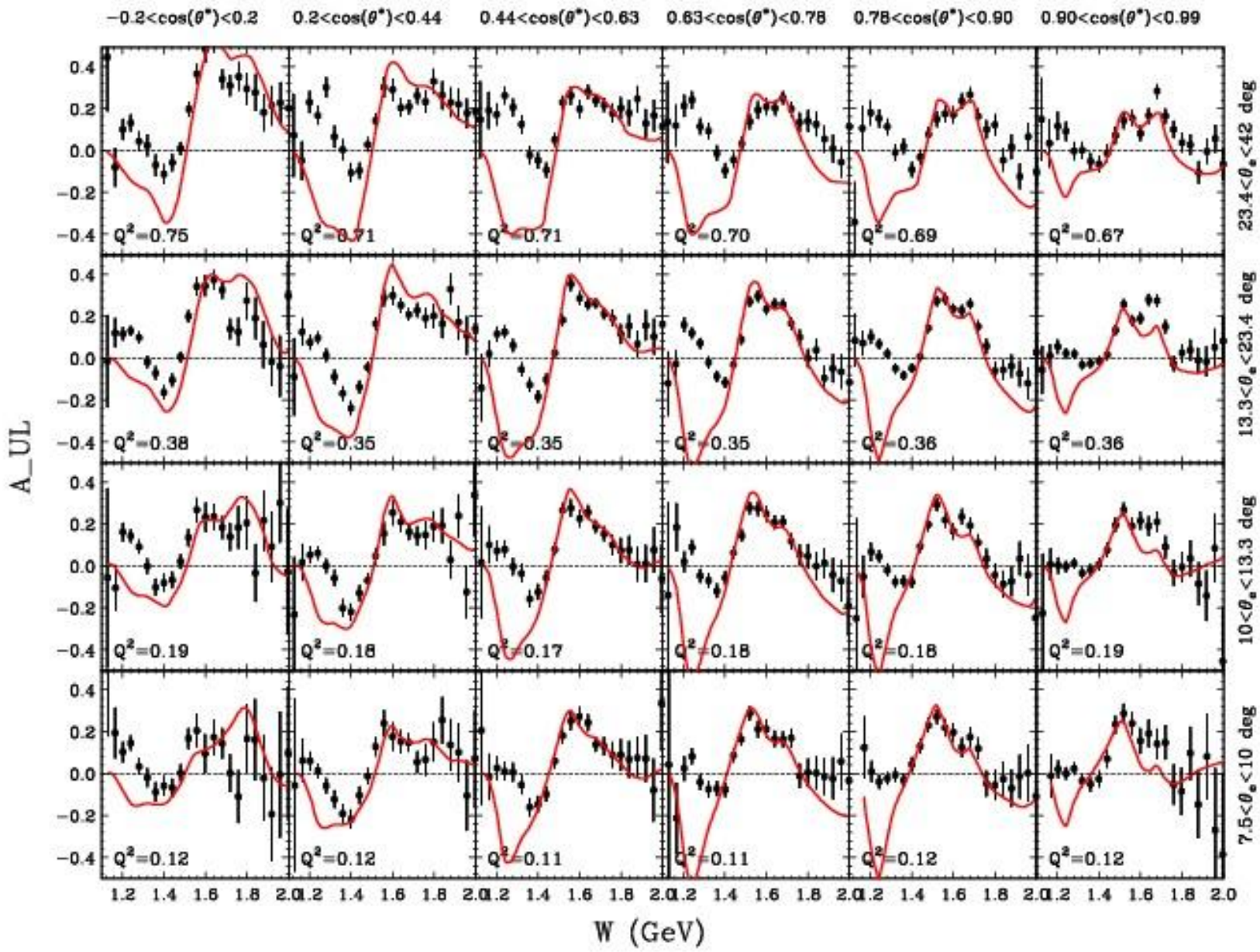
A_{UL} sin(ϕ)-moment E=1.6 GeV ep→ e n π^+



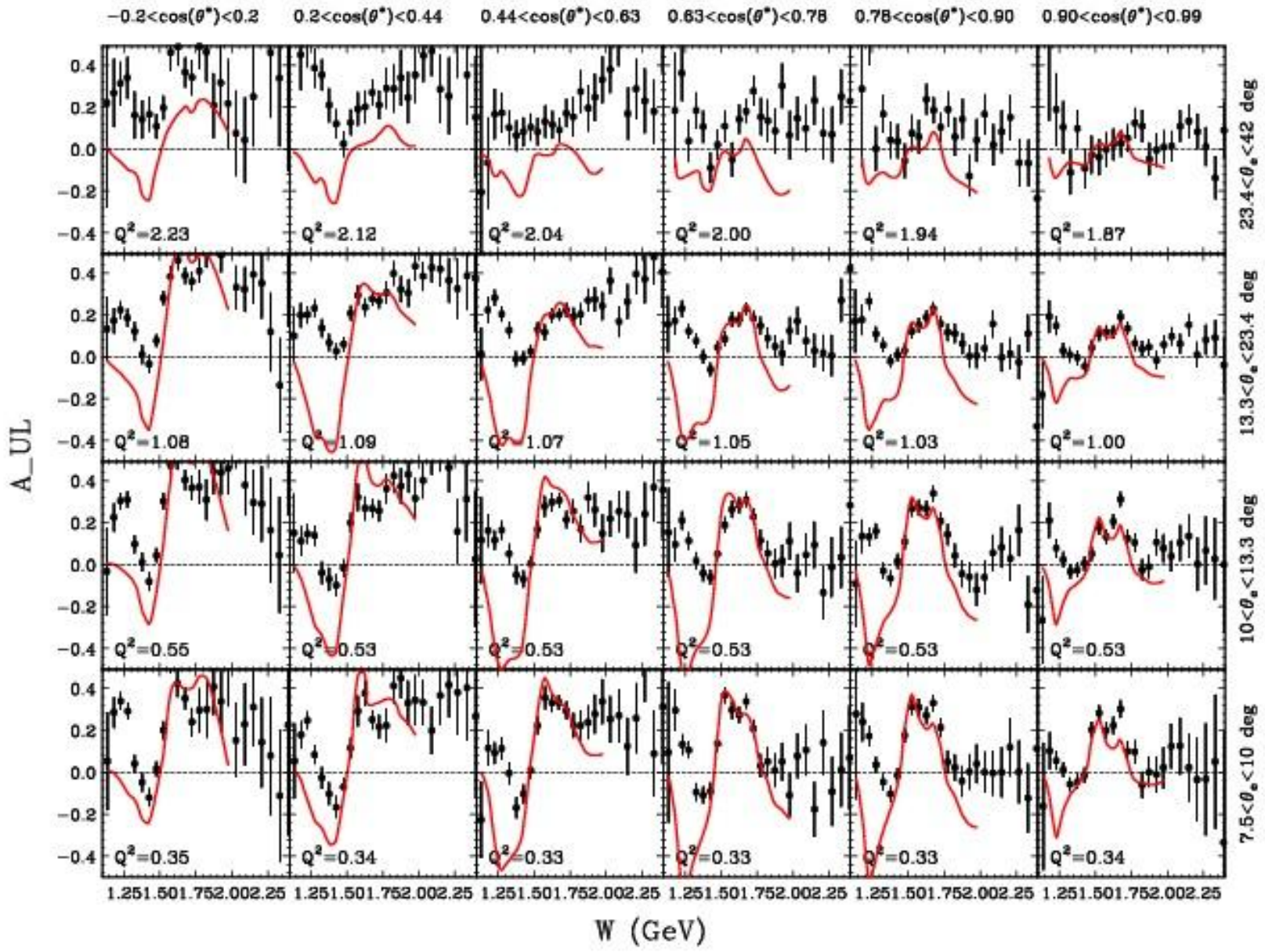
A_{UL} sin(ϕ)-moment E=1.6 GeV ep→ e n π^+



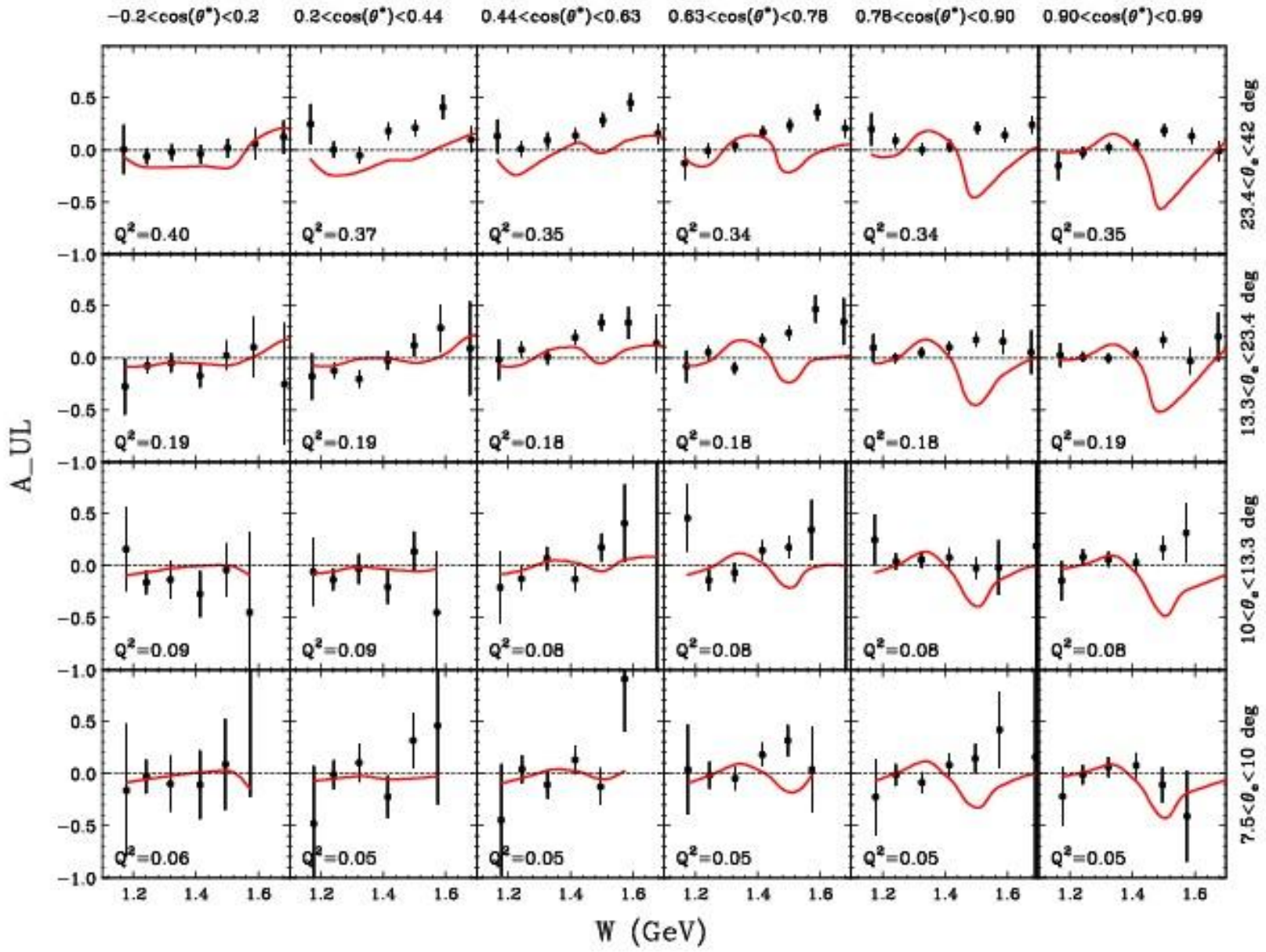
A_{UL} sin(ϕ)-moment E=2.5 GeV ep→ e n π^+



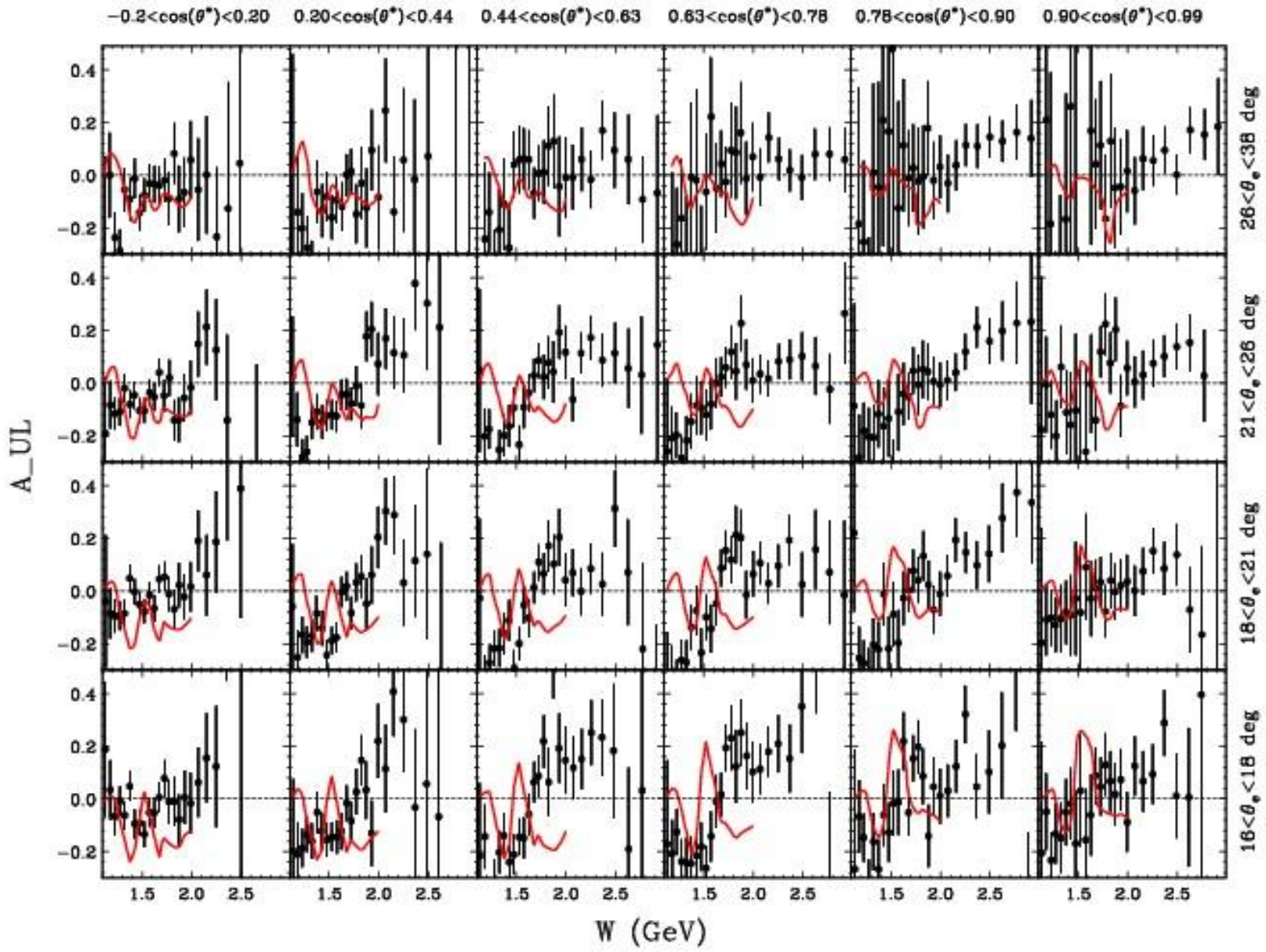
A_{UL} sin(ϕ)-moment E=4.2 GeV ep→ e n π^+



A_{UL} sin(ϕ)-moment E=1.6 GeV en→ e p π^-



A_{UL} sin(ϕ)-moment E=5.7 GeV ep→ e p π^0

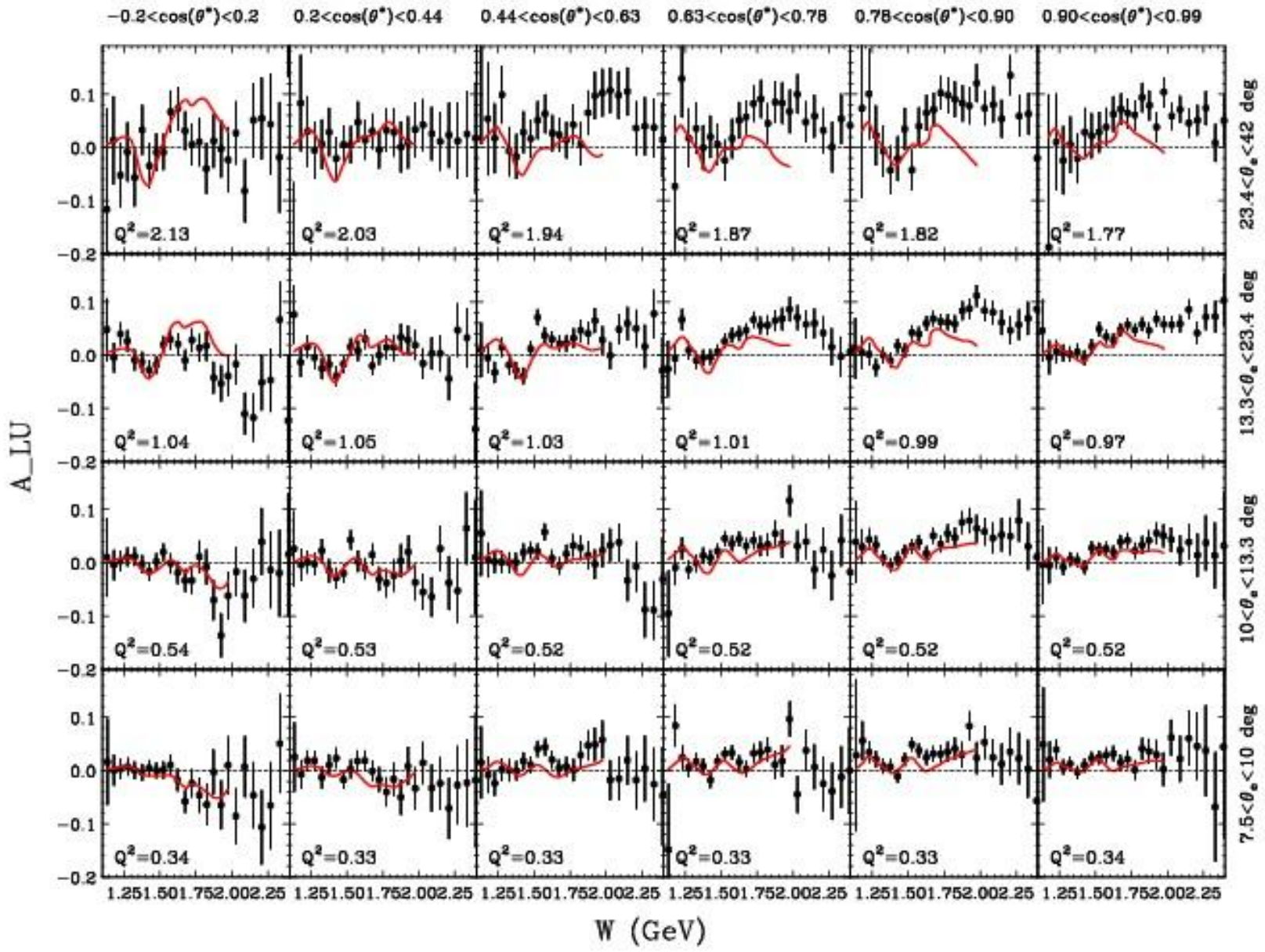


BEAM SPIN ASYMMETRY

$$A_{LU}(W, Q^2, \cos(\theta^*), \phi^*) = \frac{1}{P_B f} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$

- **Leading term: sin(ϕ)**
- **Related to L-T interference and higher twist contributions**

A_{LU} sin(ϕ)-moment E=4.2 GeV ep→ e n π^+



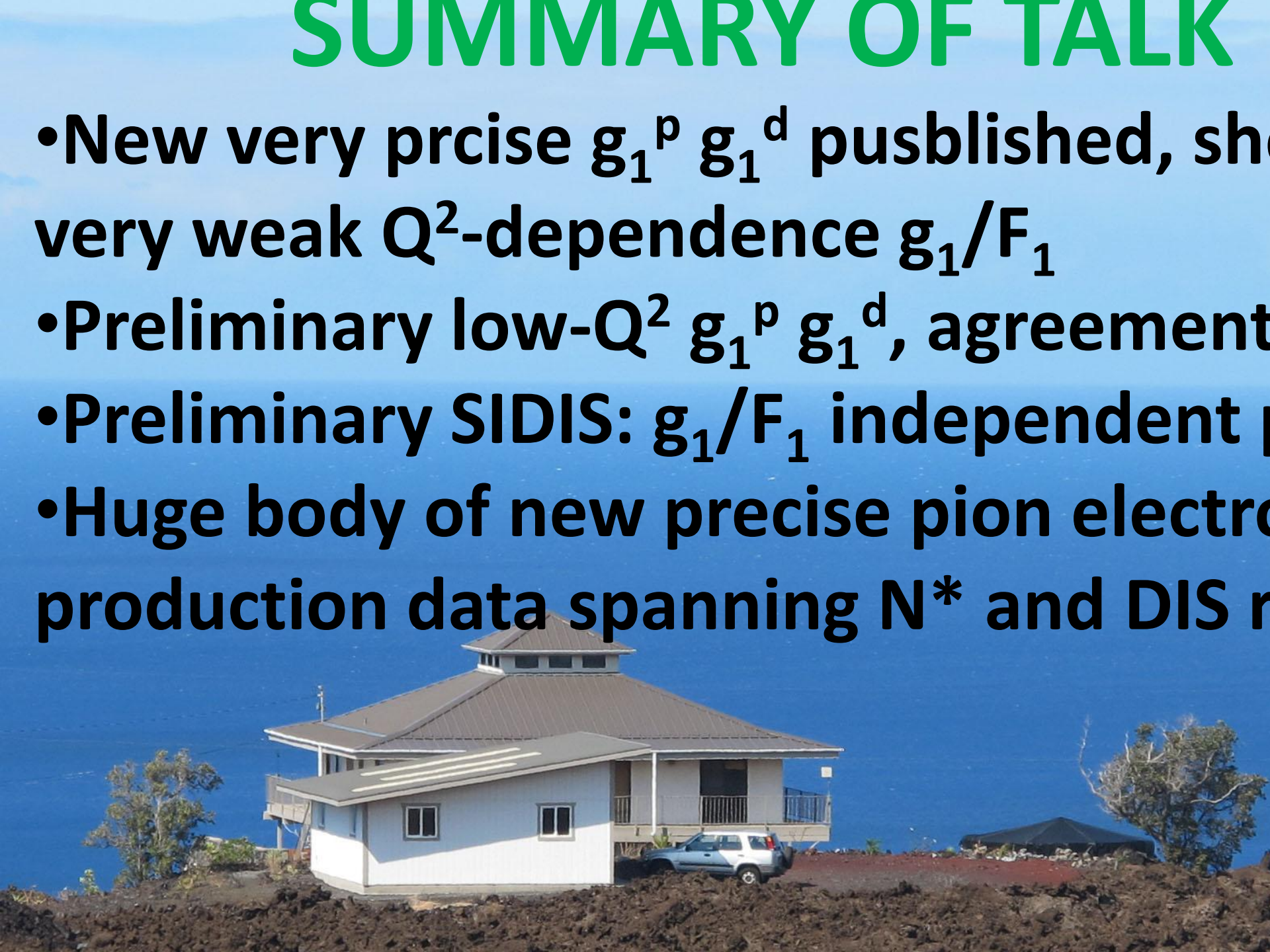
SUMMARY of EXCLUSIVE PION

- LOTS new data! (about 50,000 points)
- Three reactions for flavor dependence
- Three spin asymmetries
- Should help determine Q^2 dependece for resonant form factors and phases
- Should help study of GPDs using W>2 GeV results

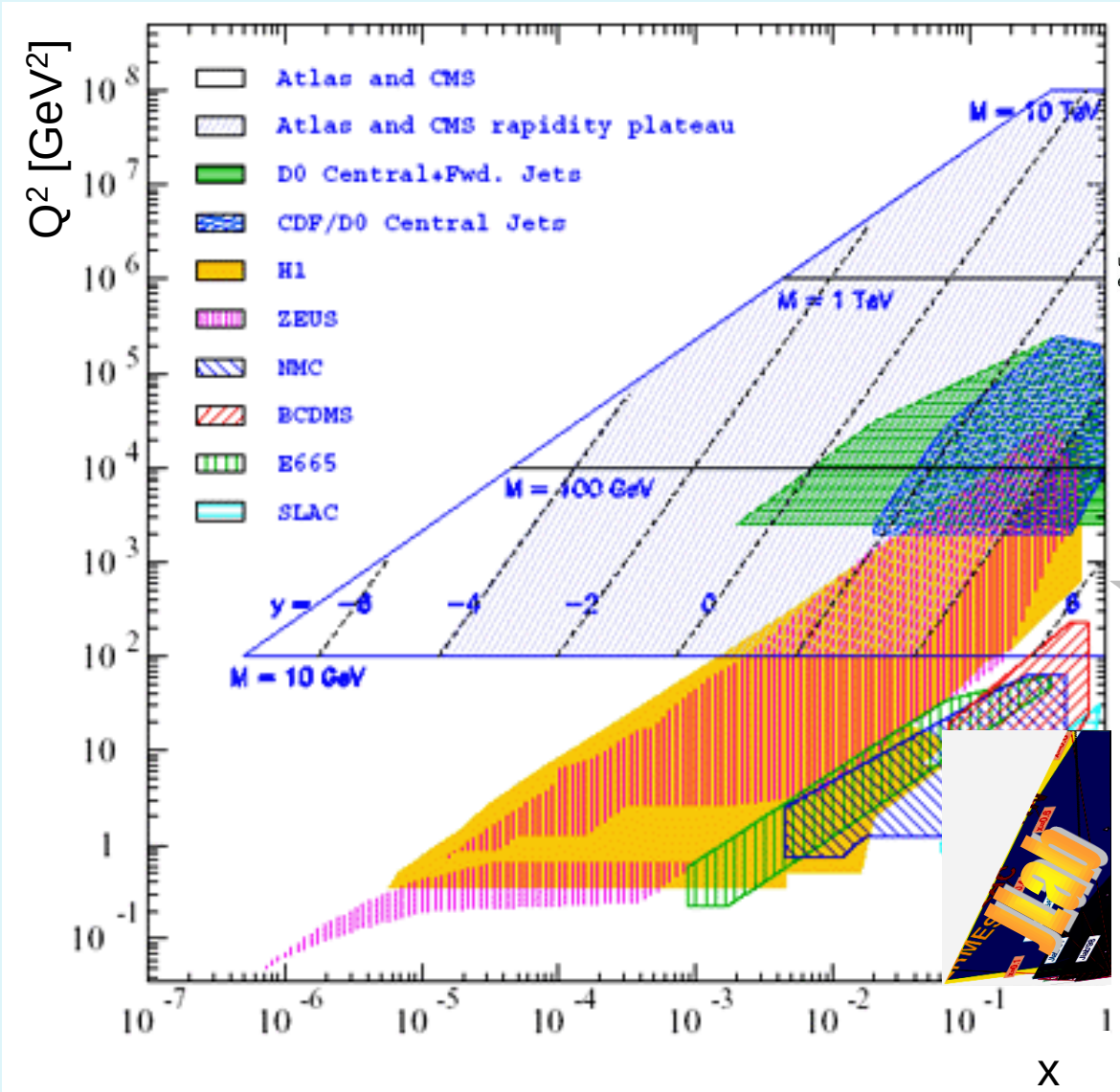
Acknowledgments:
- Andrey Kim (π^0 analysis 6 GeV)
- Josh Pierce (π^+ analysis 4.2 GeV)
- Sharon Creccia (π^- analysis 1.6-4.2 GeV)
- CLAS Collaboration

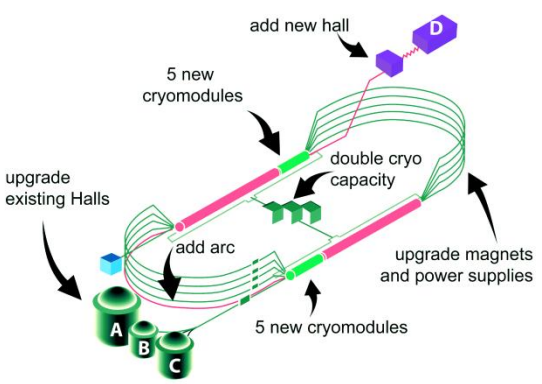
SUMMARY OF TALK

- New very prcise g_1^p g_1^d pusblished, sh
very weak Q^2-dependence g_1/F_1
- Preliminary low-Q^2 g_1^p g_1^d, agreement
- Preliminary SIDIS: g_1/F_1 independent
- Huge body of new precise pion electro
production data spanning N* and DIS r



Jefferson Lab in Perspective





JLab DIS

Future: 12 GeV

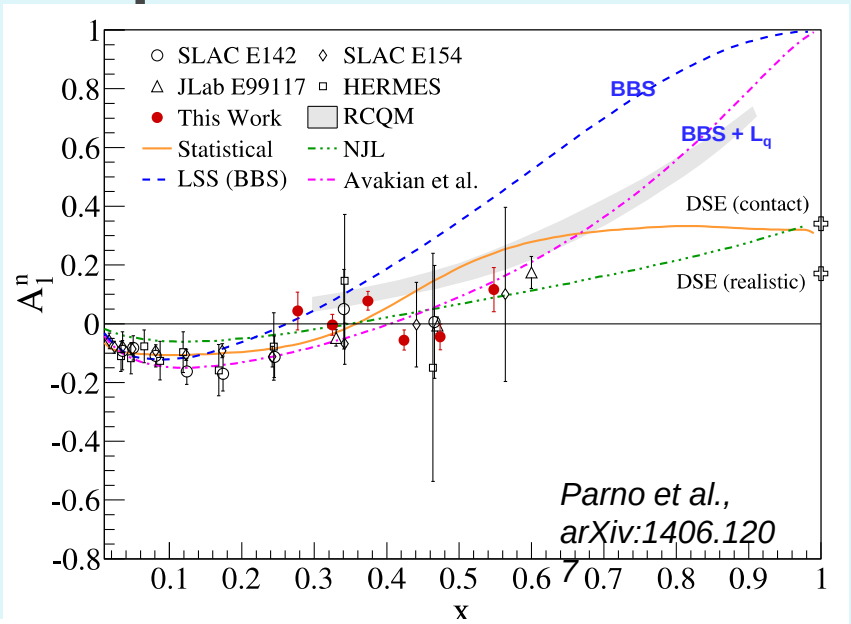
Q^2 = 1…13 GeV²

x = 0.06…0.8

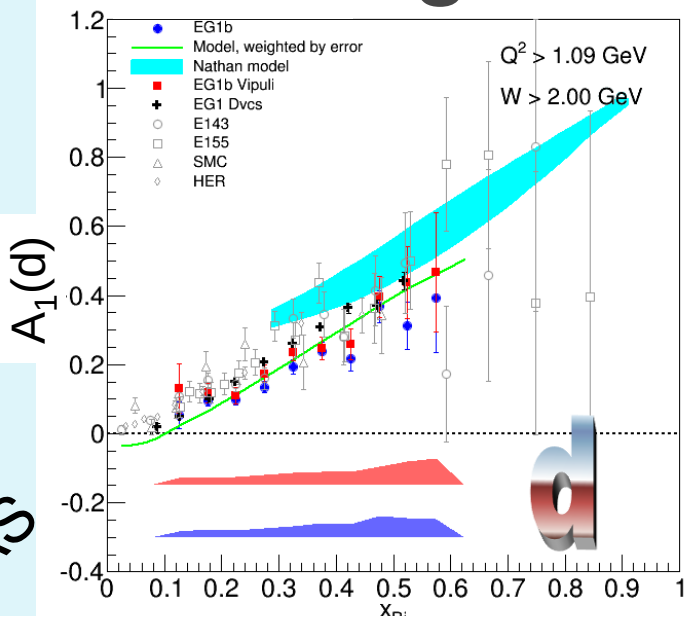
W = 0.94…4 GeV

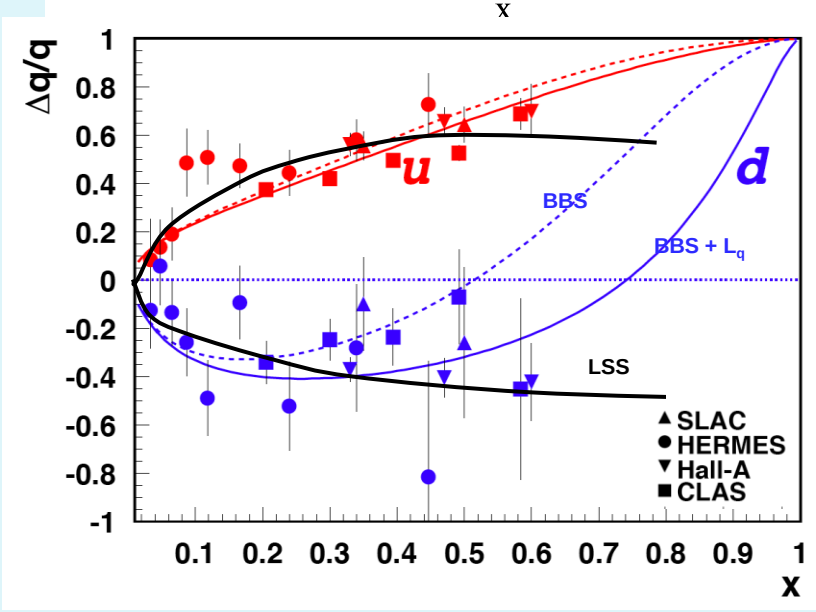
Spin structure functions at large *x*

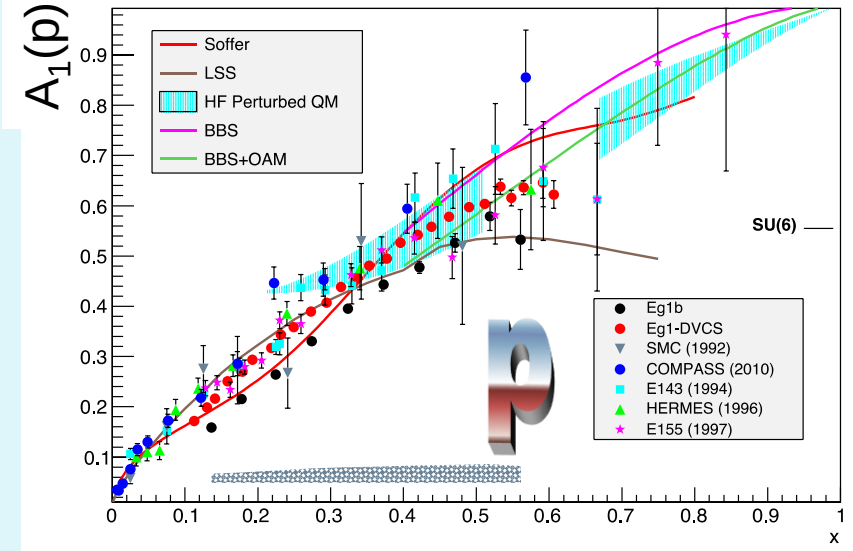
Hall A



CLAS

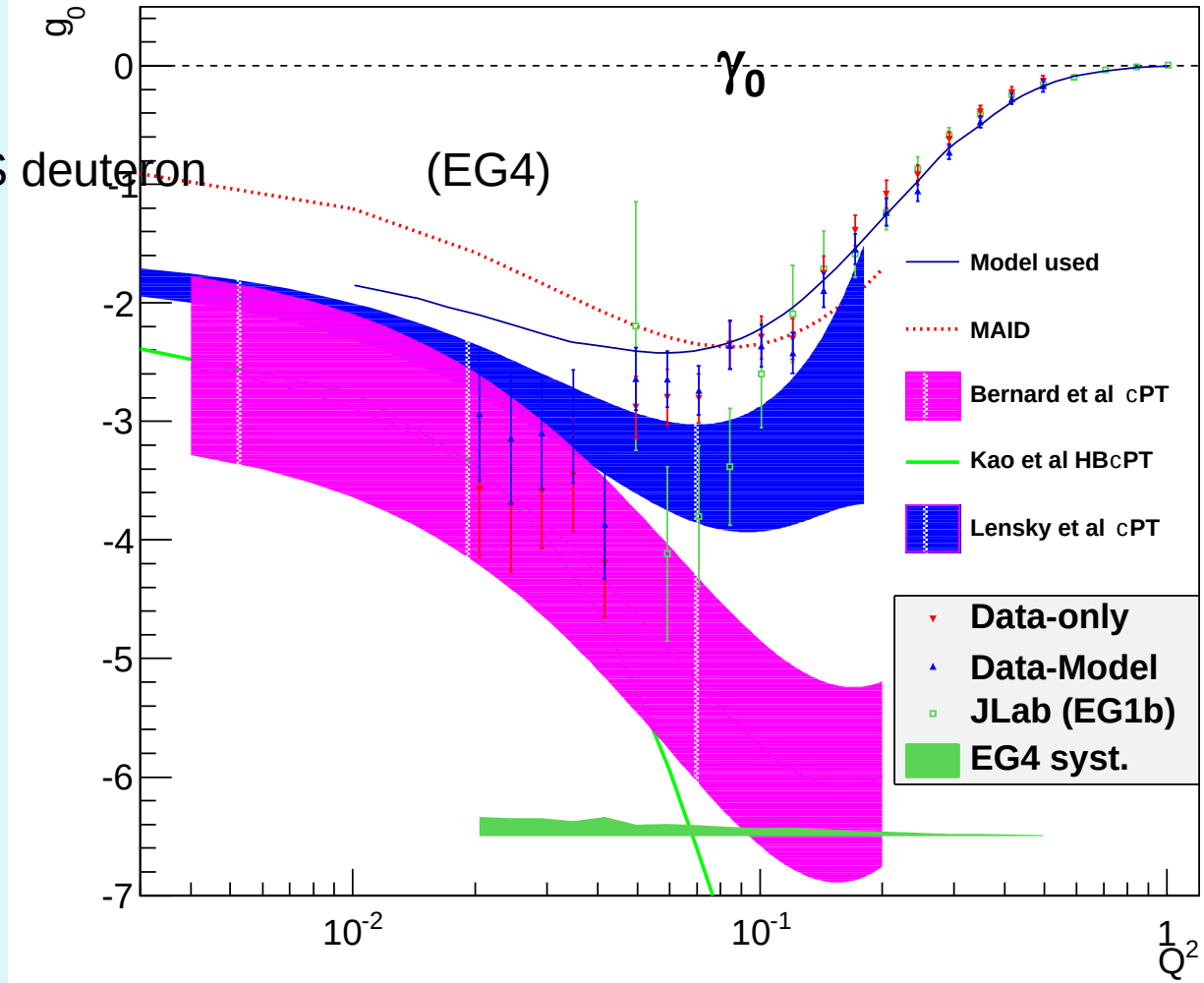






Spin Polarizabilities

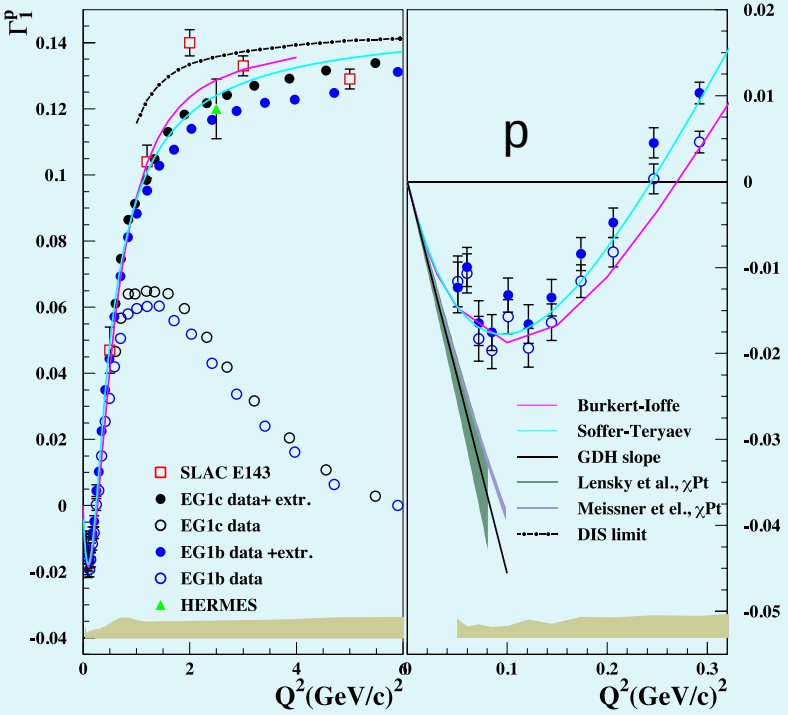
Sensitive Test of Chiral Perturbation Theory calculations



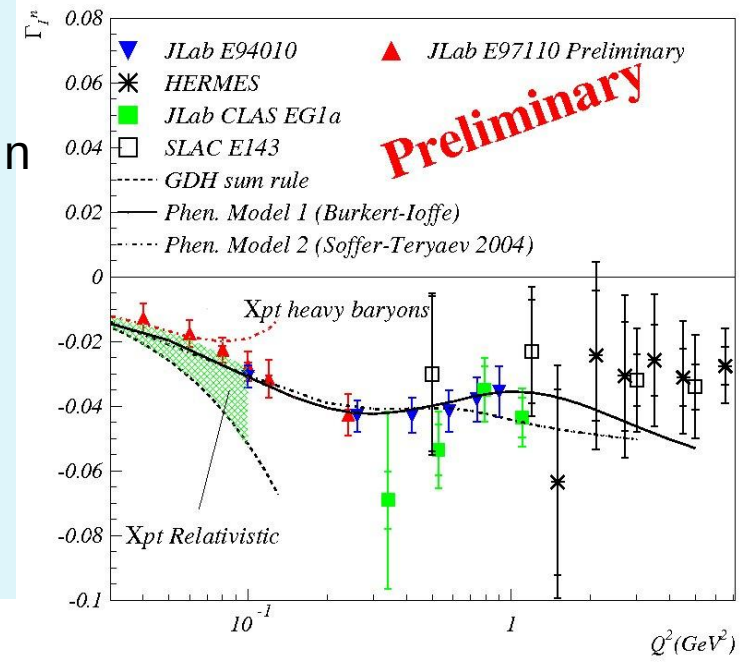
Q^2

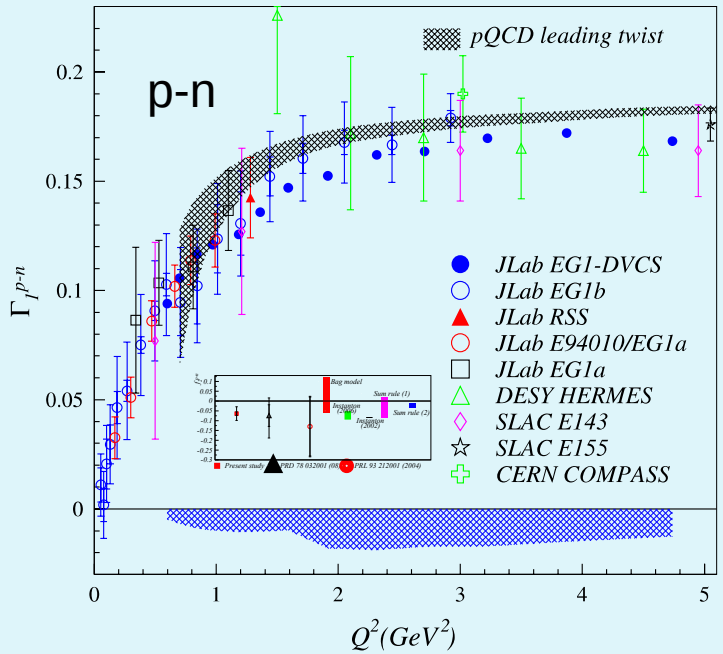
Q^2

Γ_1

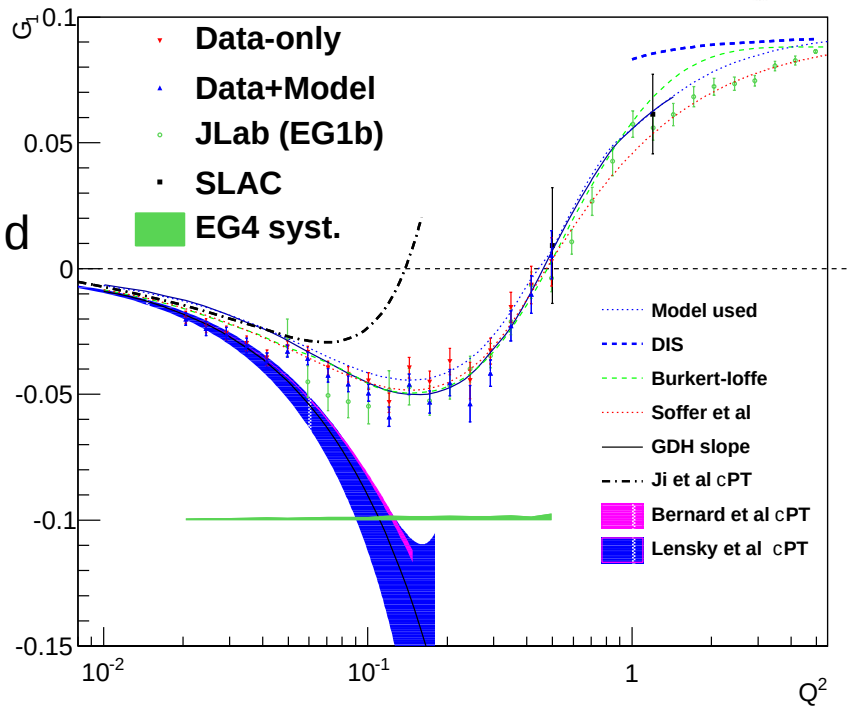

p
SLAC E143
EG1c data+ extr.
EG1c data
EG1b data +extr.
EG1b data
HERMES
Burkert-Ioffe
Soffer-Teryaev
GDH slope
Lensky et al., χPt
Meissner et el., χPt
DIS limit
Q²(GeV/c)²
Q²(GeV/c)²

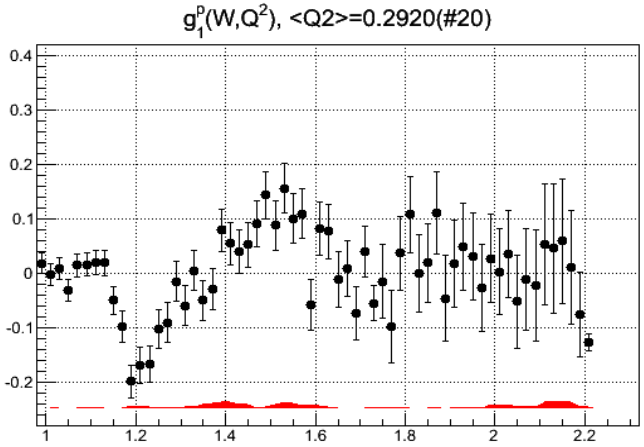
n

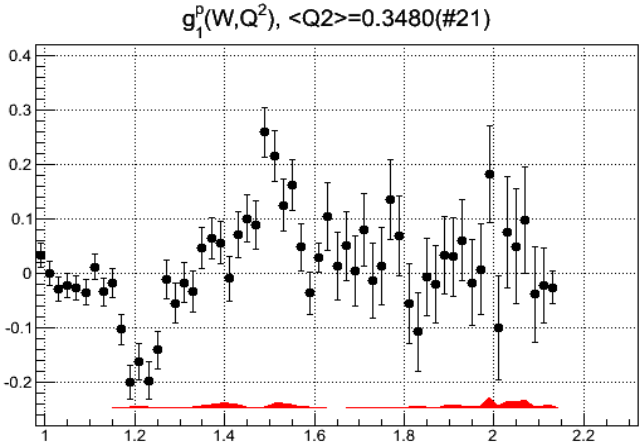

JLab E94010
HERMES
JLab CLAS EG1a
SLAC E143
GDH sum rule
Phen. Model 1 (Burkert-Ioffe)
Phen. Model 2 (Soffer-Teryaev 2004)
JLab E97110 Preliminary
Preliminary
Xpt heavy baryons
Xpt Relativistic
Q²(GeV²)

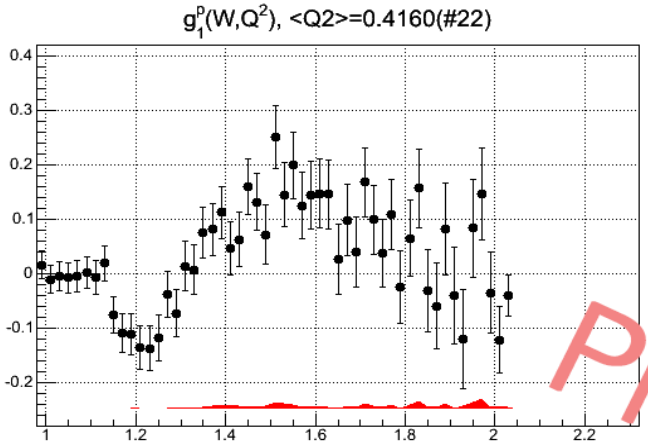

p-n
pQCD leading twist
JLab EG1-DVCS
JLab EG1b
JLab RSS
JLab E94010/EG1a
JLab EG1a
DESY HERMES
SLAC E143
SLAC E155
CERN COMPASS
Q²(GeV²)

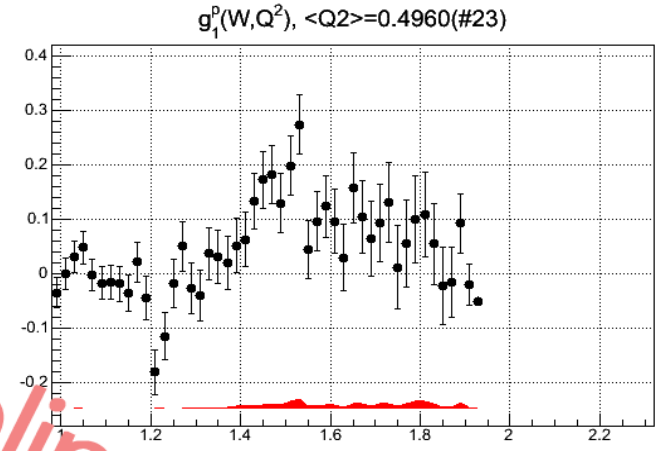
d

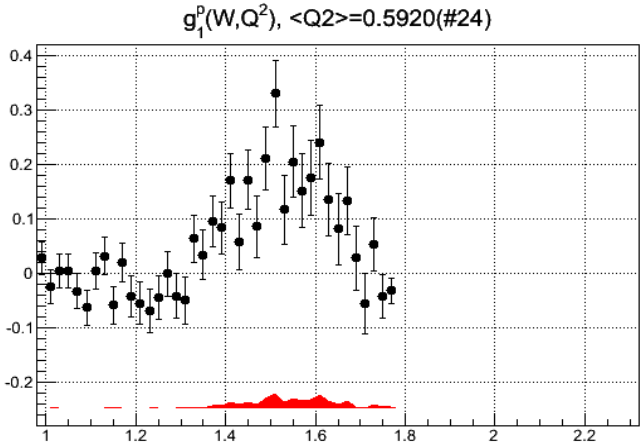

Data-only
Data+Model
JLab (EG1b)
SLAC
EG4 syst.
Model used
DIS
Burkert-Ioffe
Soffer et al
GDH slope
Ji et al cPT
Bernard et al cPT
Lensky et al cPT
Q²



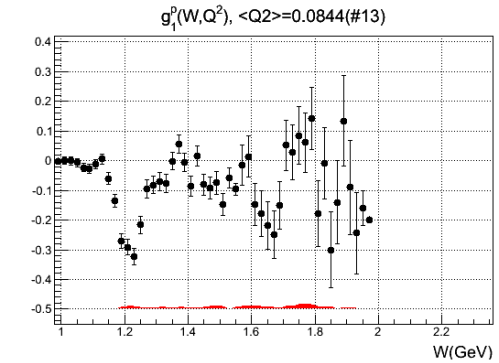


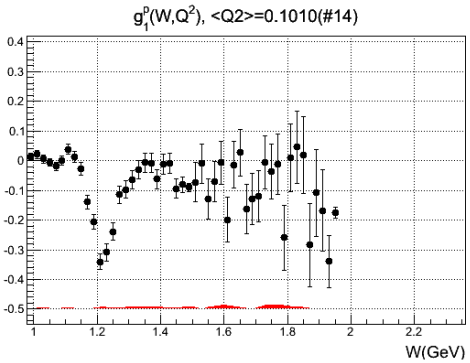


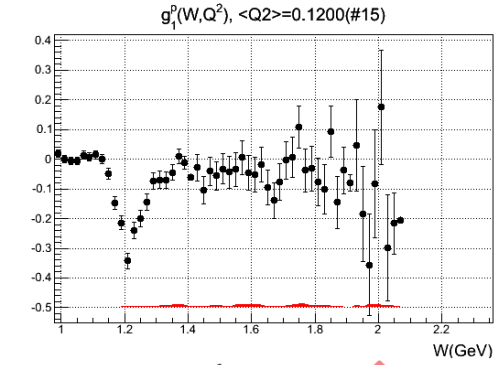


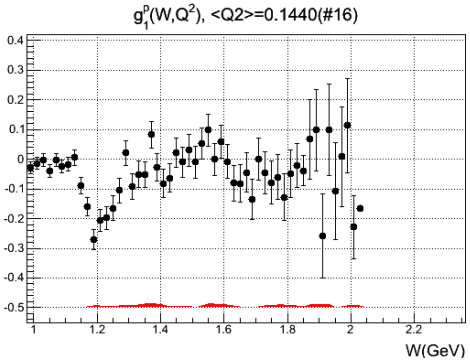


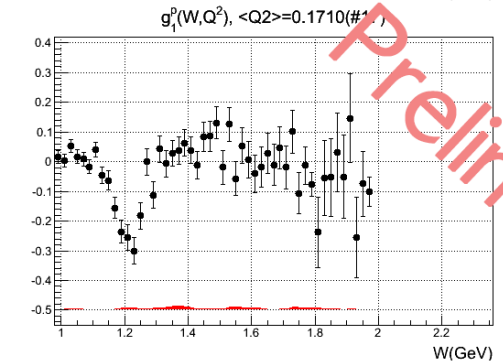
EG4 g_1 proton

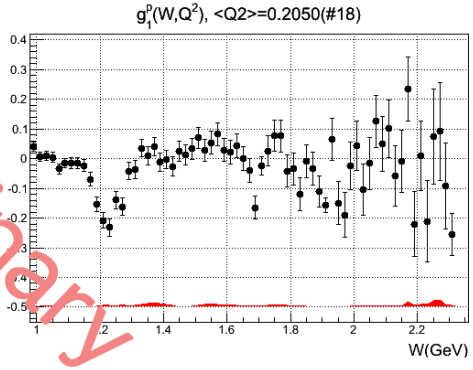


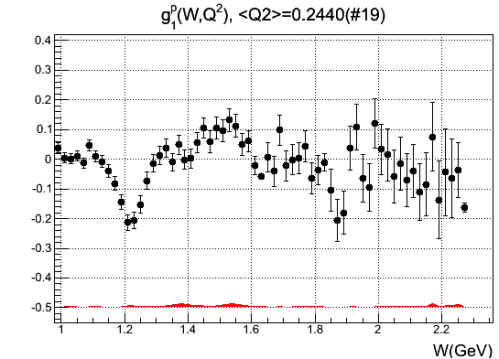








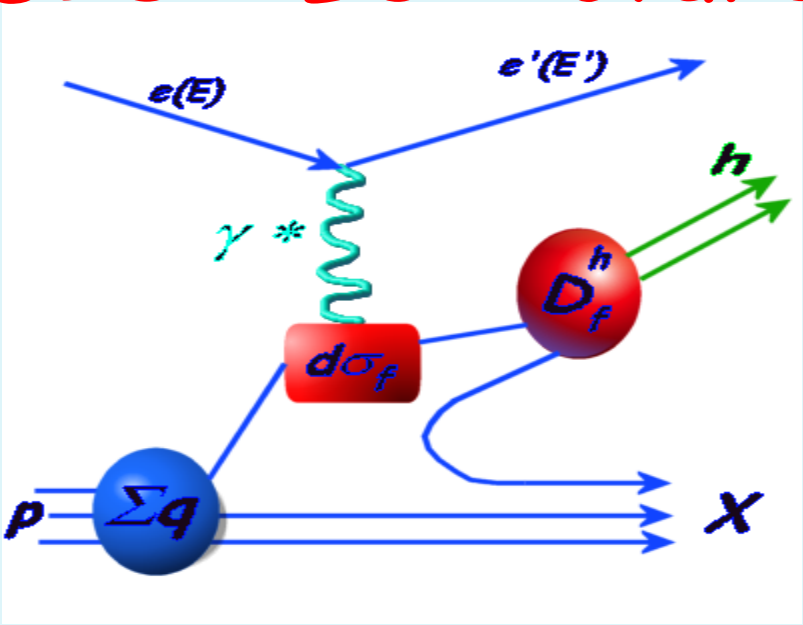




Preliminary

EG4 g_1 proton

SIDIS - LO Picture



Leading-order Picture: hit one Quark

(e,e') $M_x^2 = W^2 = M^2 + Q^2 (1/x - 1)$

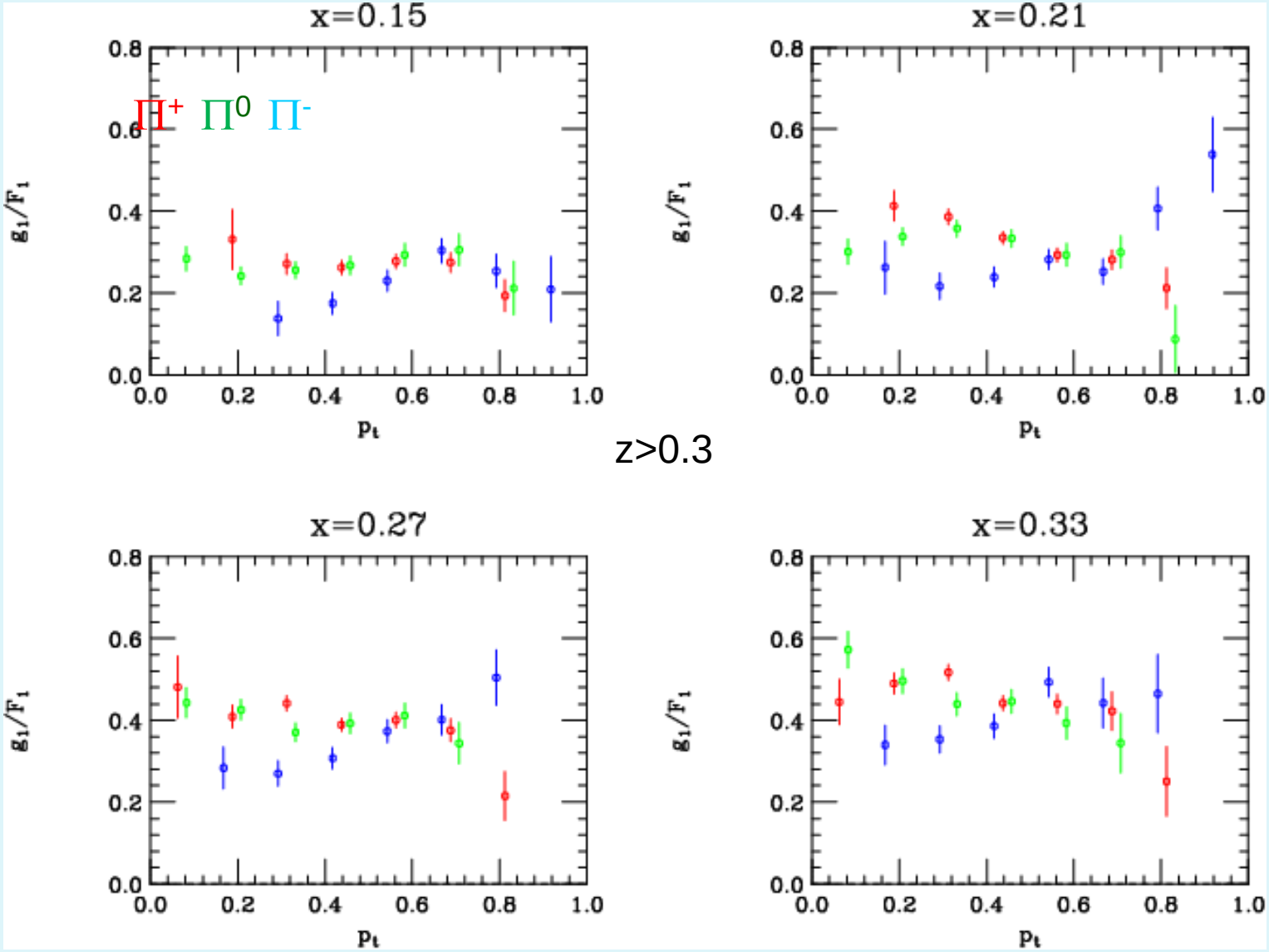
(For M_m small, $\vec{p}_m$ collinear with $\vec{\gamma}$, and $Q^2/\nu^2 << 1$)

(e,e'm) $M_x^2 = W'^2 = M^2 + Q^2 (1/x - 1)(1 - z)$

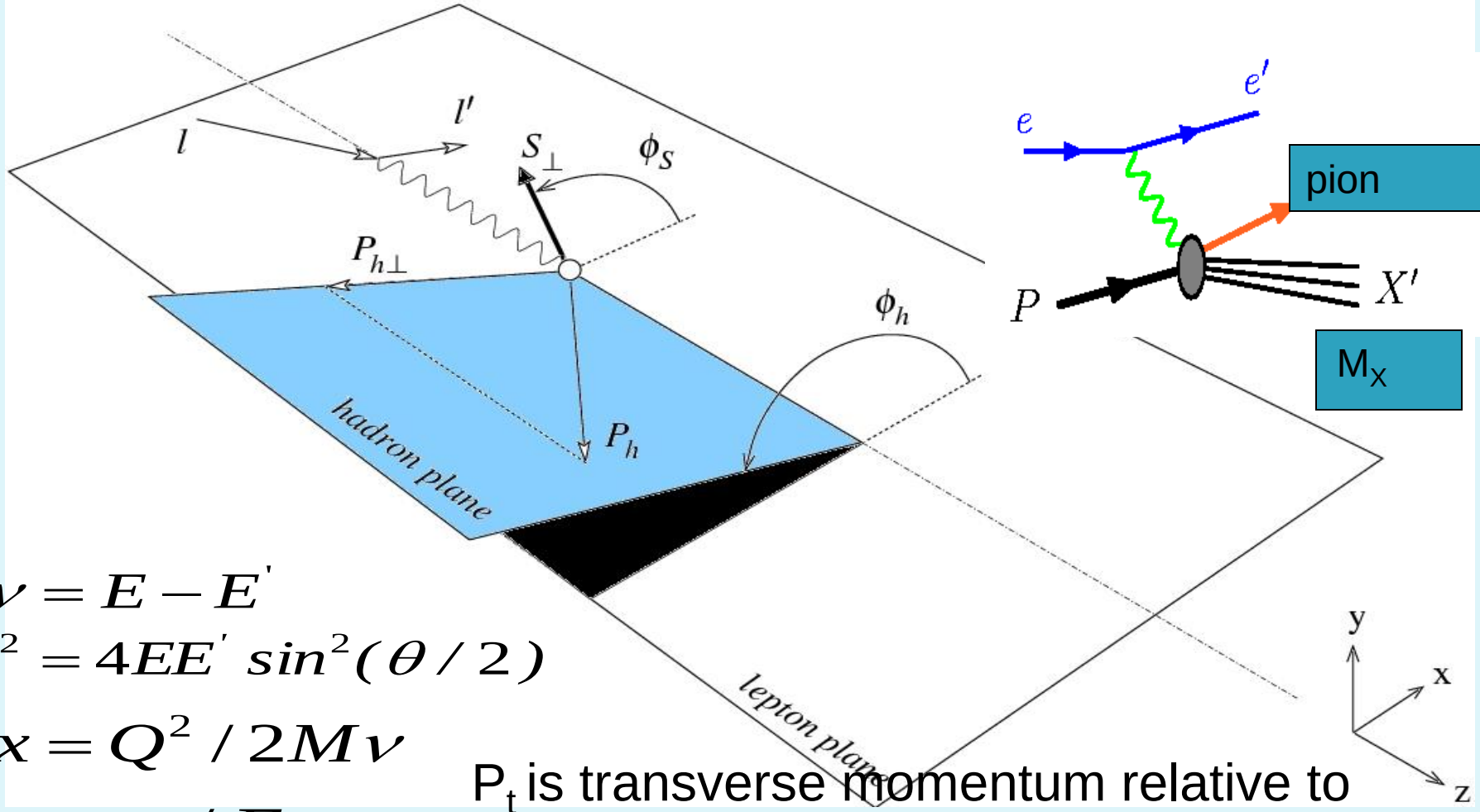
Want large Q^2 to keep M_x big

$z = E_m/\nu$

ONE LEVEL DEEPER: SIDIS
Very Preliminary results from eg1-dvcs



SIDIS kinematic plane and relevant variables



$$\nu = E - E'$$

$$Q^2 = 4EE' \sin^2(\theta/2)$$

$$x = Q^2 / 2M\nu$$

$$y = \nu / E$$

$$z = E_h / \nu$$

P_t is transverse momentum relative to virtual photon

$M_x^2 = M^2 + Q^2(1/x - 1)$ is invariant mass of total hadronic final state