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

ANOTHER SPIN PUZZLE: LARGE TARGET AND BEAM-TARGET SPIN ASYMMETRIES IN EXCLUSIVE PION ELECTROPRODUCTION

Peter Bosted

MY MOTIVATION

RADIATIVE CORRECTIONS TO SEMI-INCLUSIVE DEEP INELASTIC

NEED RELIABLE FITS TO CROSS SECTIONS AND ASYMMETRIES

EMBARK ON PROJECT TO ANALYZE LARGE BODY ASYMMETRY DATA FROM)

CEBAF AT JEFFERSON LAB

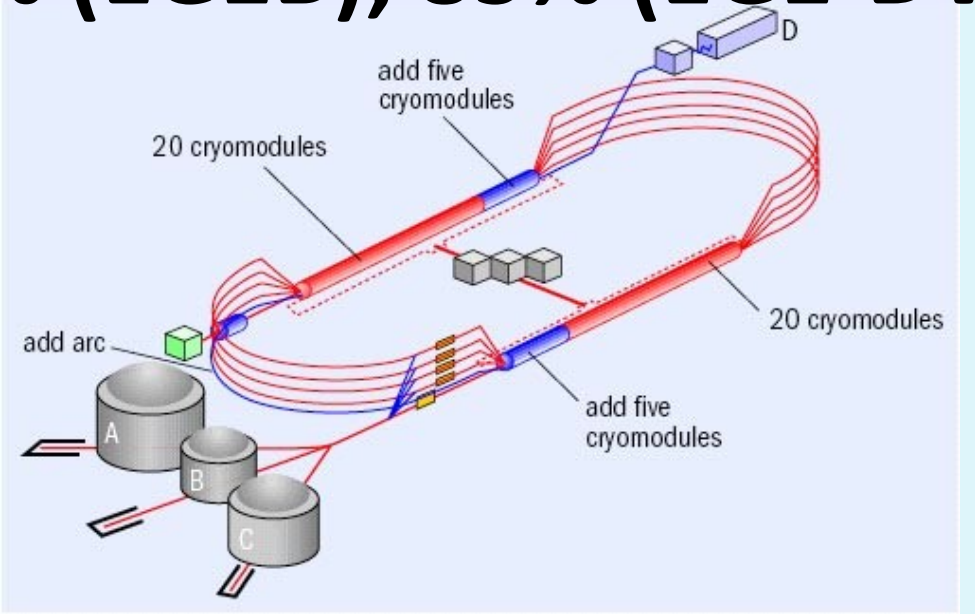
ELECTRON ENERGIES

1.7, 2.5, 4.2 GEV (EG1B IN 2000-2001)

6 GEV (EG1-DVCS IN 2009)

LONGITUDINAL POLARIZATION

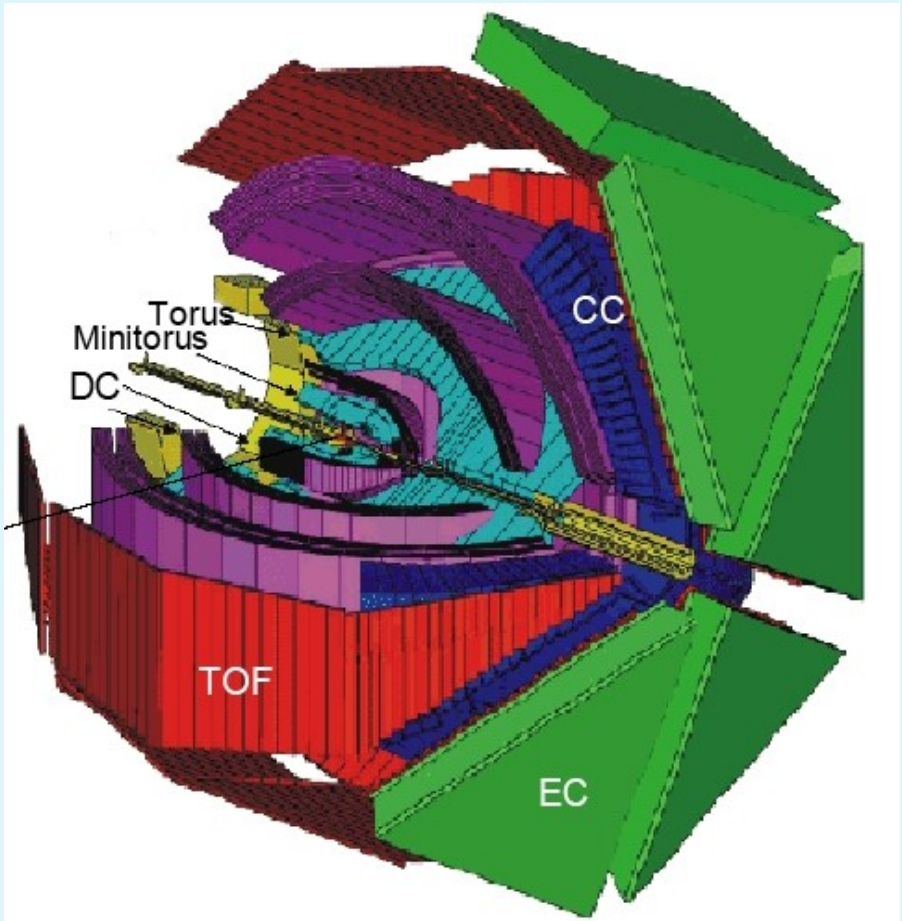
70% (EG1B), 85% (EG1-DVCS)



CLAS DETECTOR

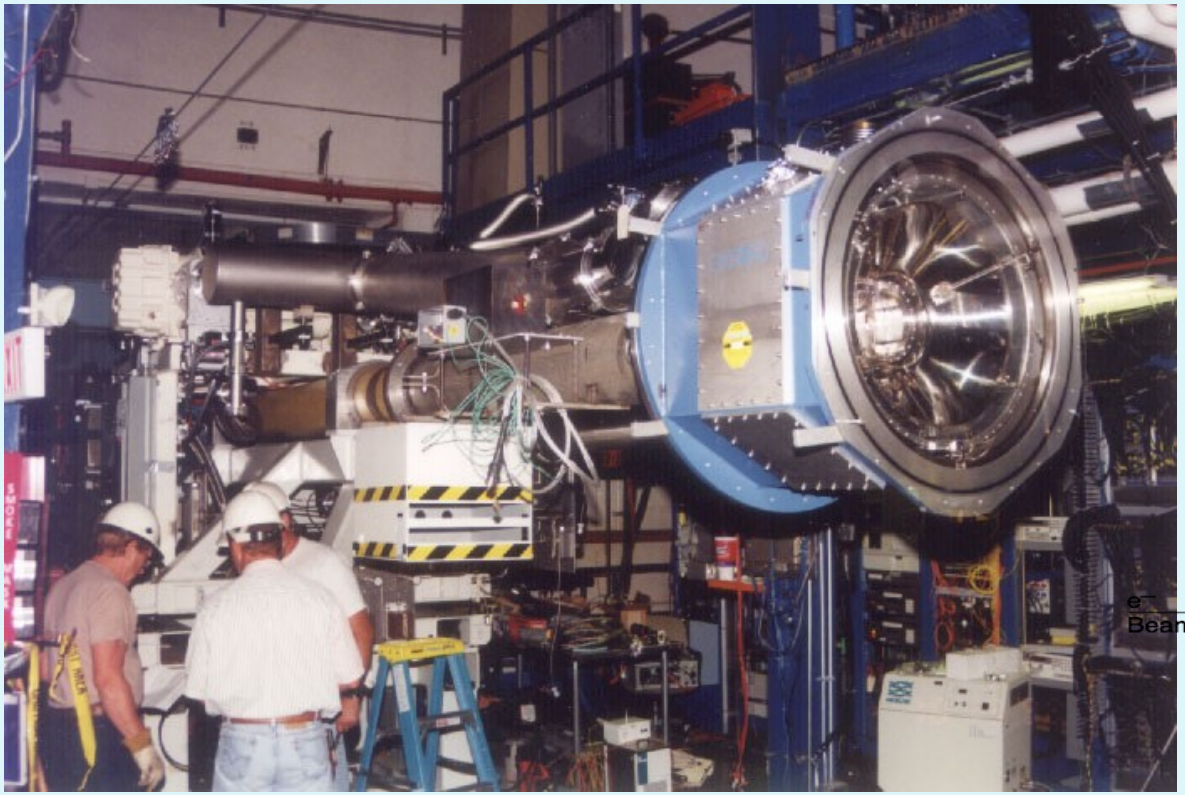
"Standard" for Eg1b (2000)

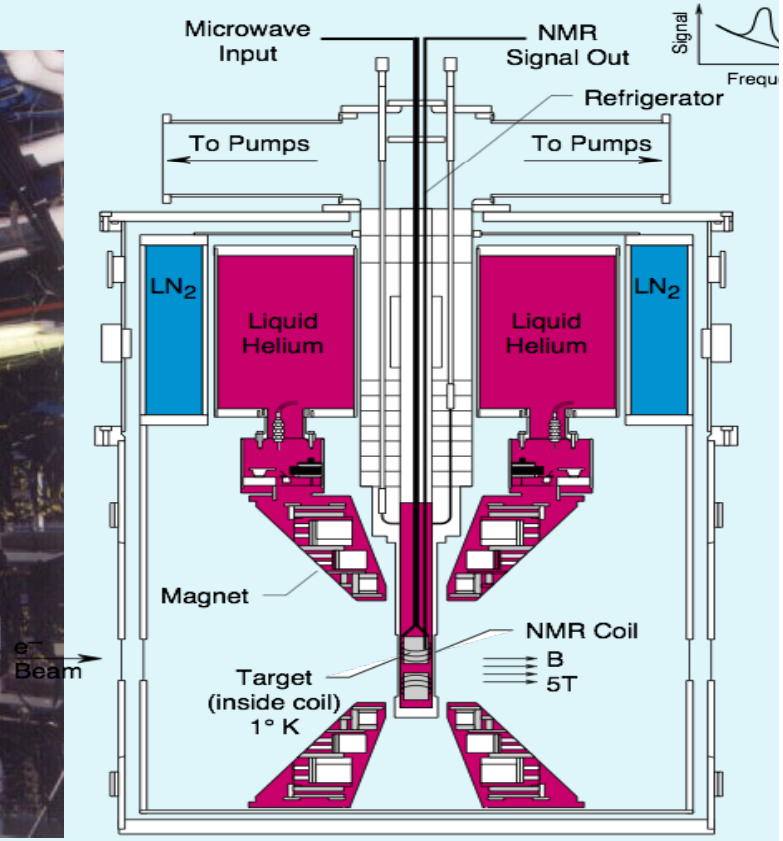
Inner Calorimeter added for eg1-dvcs (2009)



LONGITUDINALLY POLARIZED PROTON, DEUTERON TARGETS

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

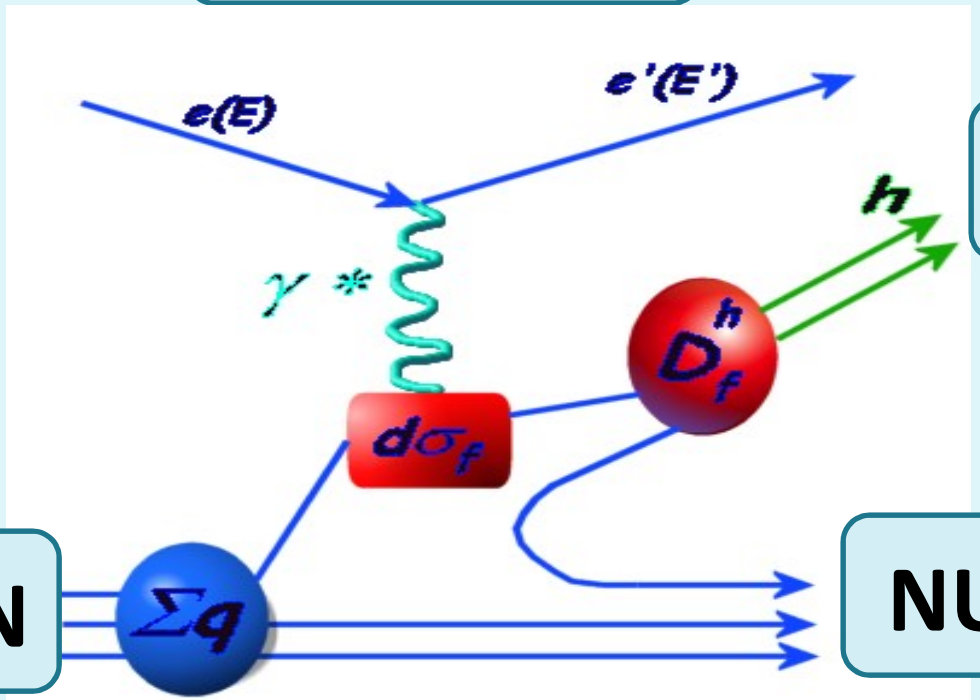




EXCLUSIVE PION ELECTROPRODUCTION

2000, and 2009	2009	2000
$e\ p \rightarrow e\ n\ \pi^+$	$e\ p \rightarrow e\ p\ \pi^0$	$e\ n \rightarrow e\ p\ \pi^-$

ELECTRON



PION

NUCLEON

NUCLEON

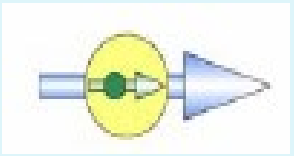
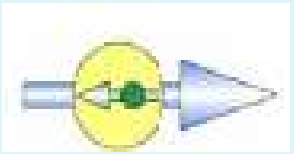
AVERAGED TWO TOPOLOGIES FOR EACH REACTION

$e\ p \rightarrow e\ n\ \pi^+$	$e\ p \rightarrow e\ p\ \pi^0$	$e\ n \rightarrow e\ p\ \pi^-$
$e\ p \rightarrow e\ n\ \pi^+$	$e\ p \rightarrow e\ p\ \gamma\gamma$	$e\ n \rightarrow e\ p\ \pi^-$
$e\ p \rightarrow e\ (n)\pi^+$	$e\ p \rightarrow e\ p\ \gamma(\gamma)$	$e\ n \rightarrow e\ (p)\ \pi^-$

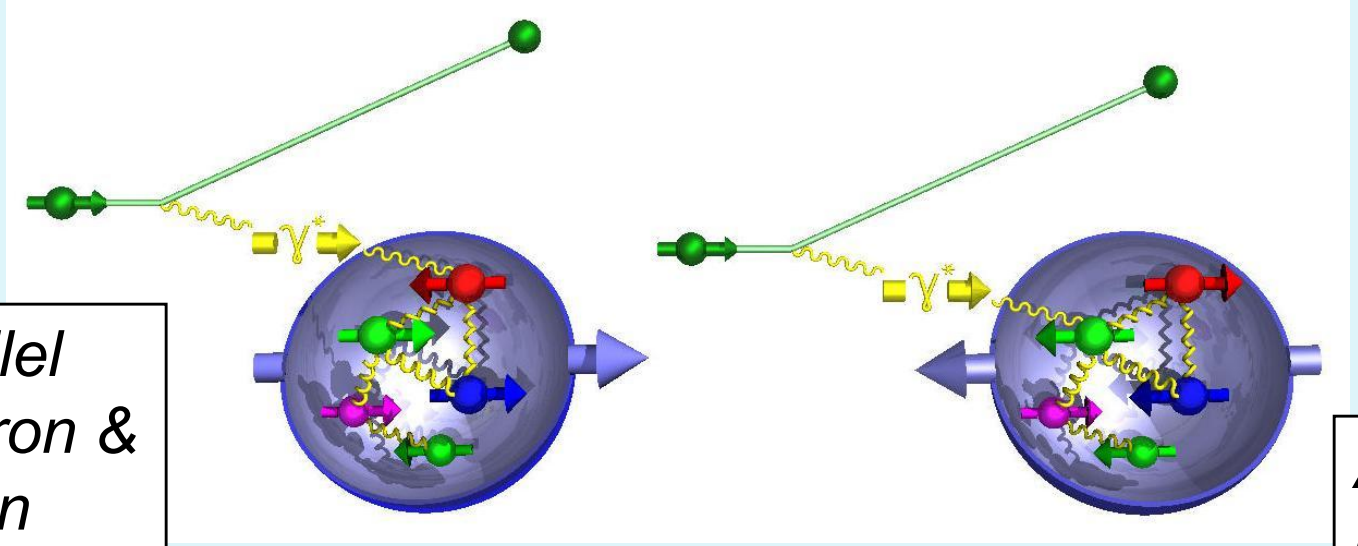
To be precise, last reaction is really $e\ d \rightarrow e\ (p)\ p\ \pi^-$

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

$$A_{LL} \approx \frac{1}{P_B P_T f} \frac{N^{+-} + N^{-+} - N^{++} - N^{--}}{N^{+-} + N^{+-} + N^{++} + N^{--}}$$

$$A_{UL} \approx \frac{1}{P_T f} \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

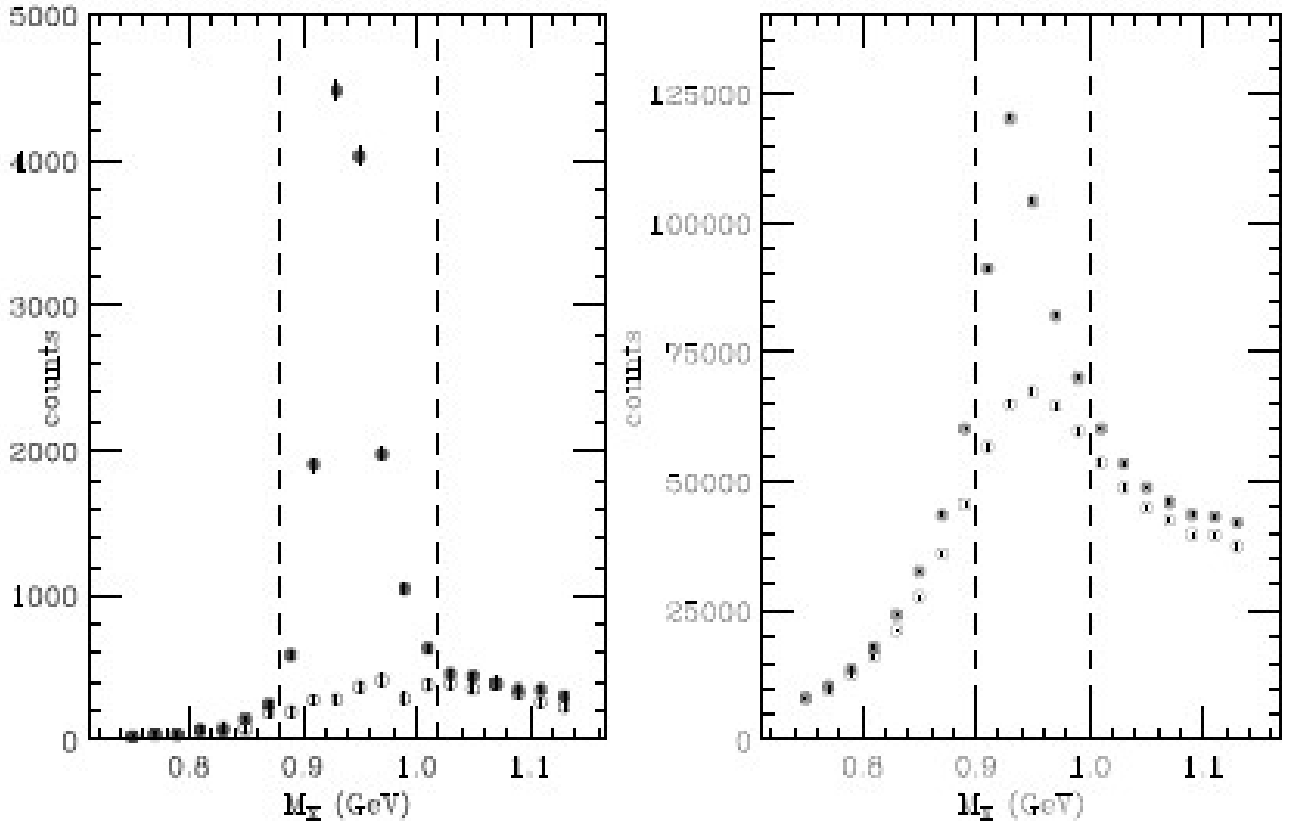
- **Beam polarization P_B 0.7 to 0.85**
- **Target polarization 0.7 (p), 0.3 (d)**
- **Dilution factor f ranges from 0.3 to 0.9 depending on topology and kinematics**

EXCLUSIVITY CUTS

EXAMPLE: ELECTRON-PION MISSING MASS

LEFT: NEUTRON DETECTED

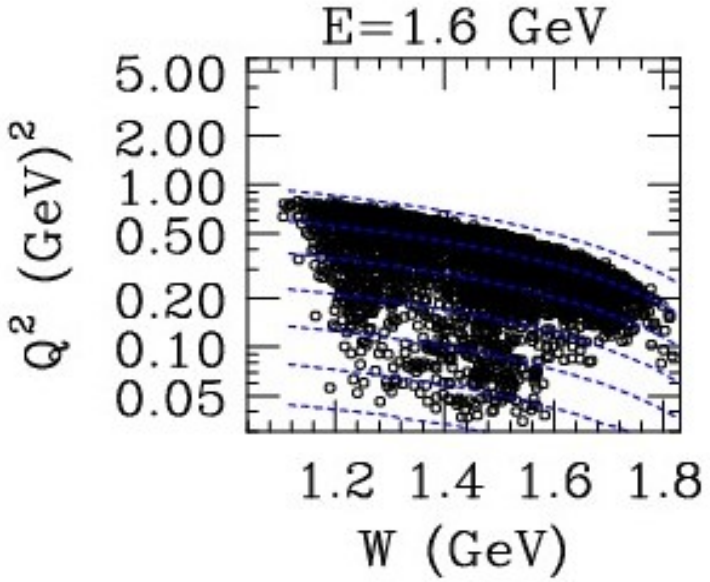
RIGHT: NO NEUTRON DETECTED)

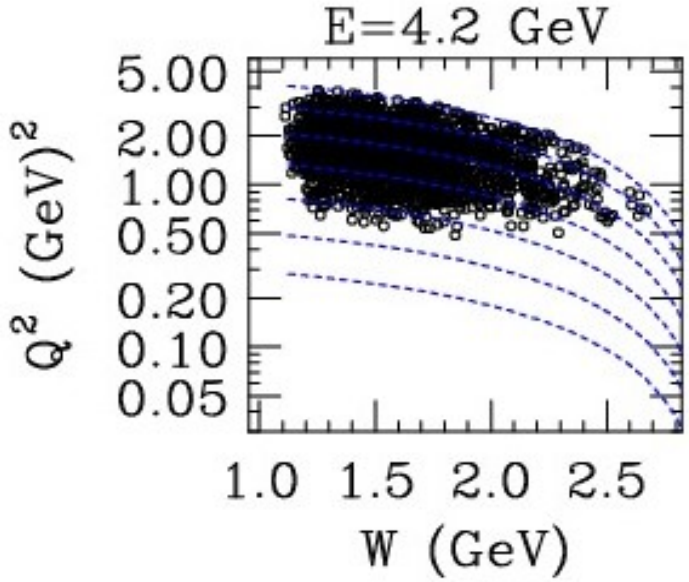


KINEMATIC COVERAGE AND BINNING

- 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

W^2 = s and t scales with cos(θ^*)





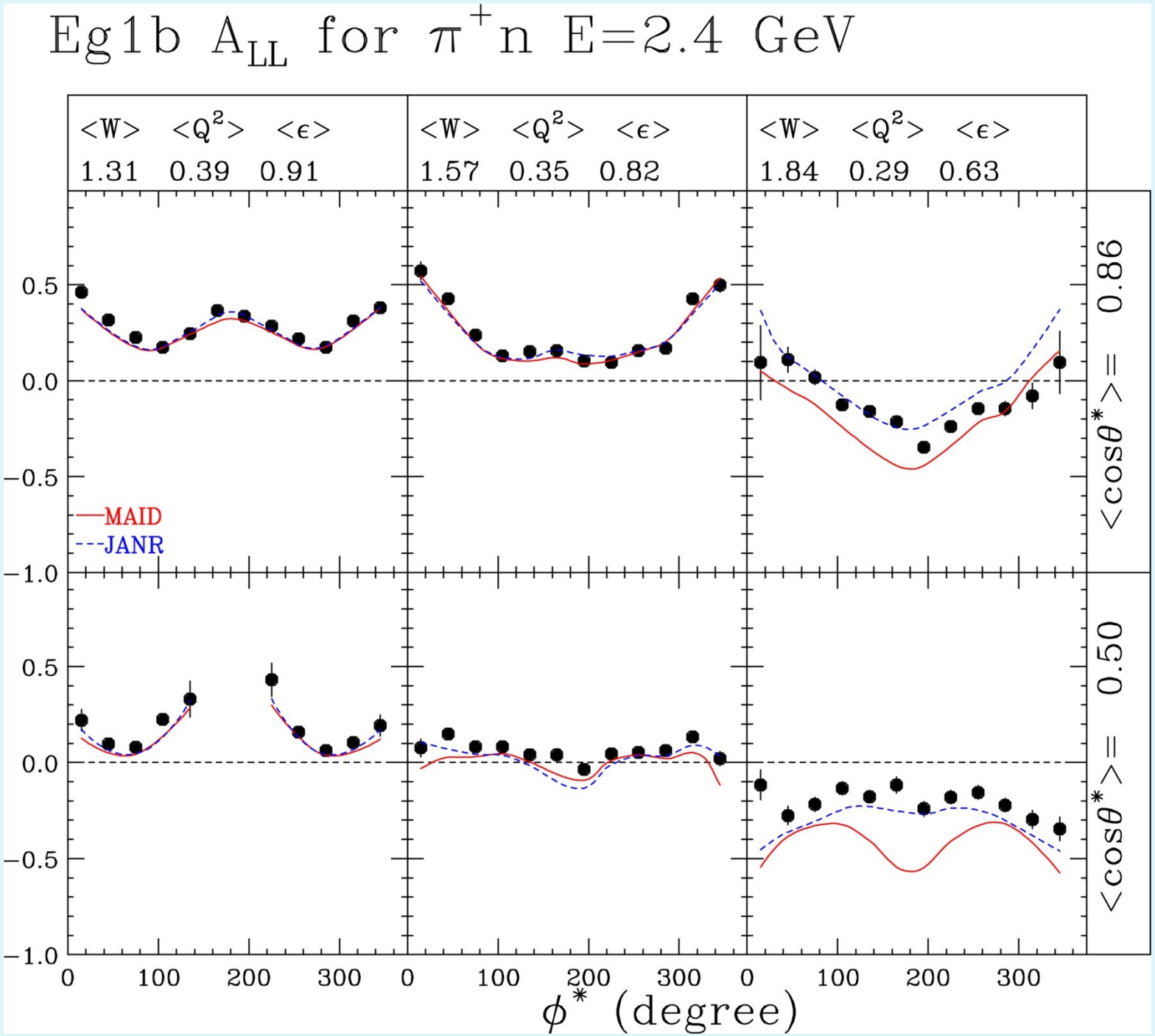
RESULTS WITH 2.4 Gev ELECTRONS

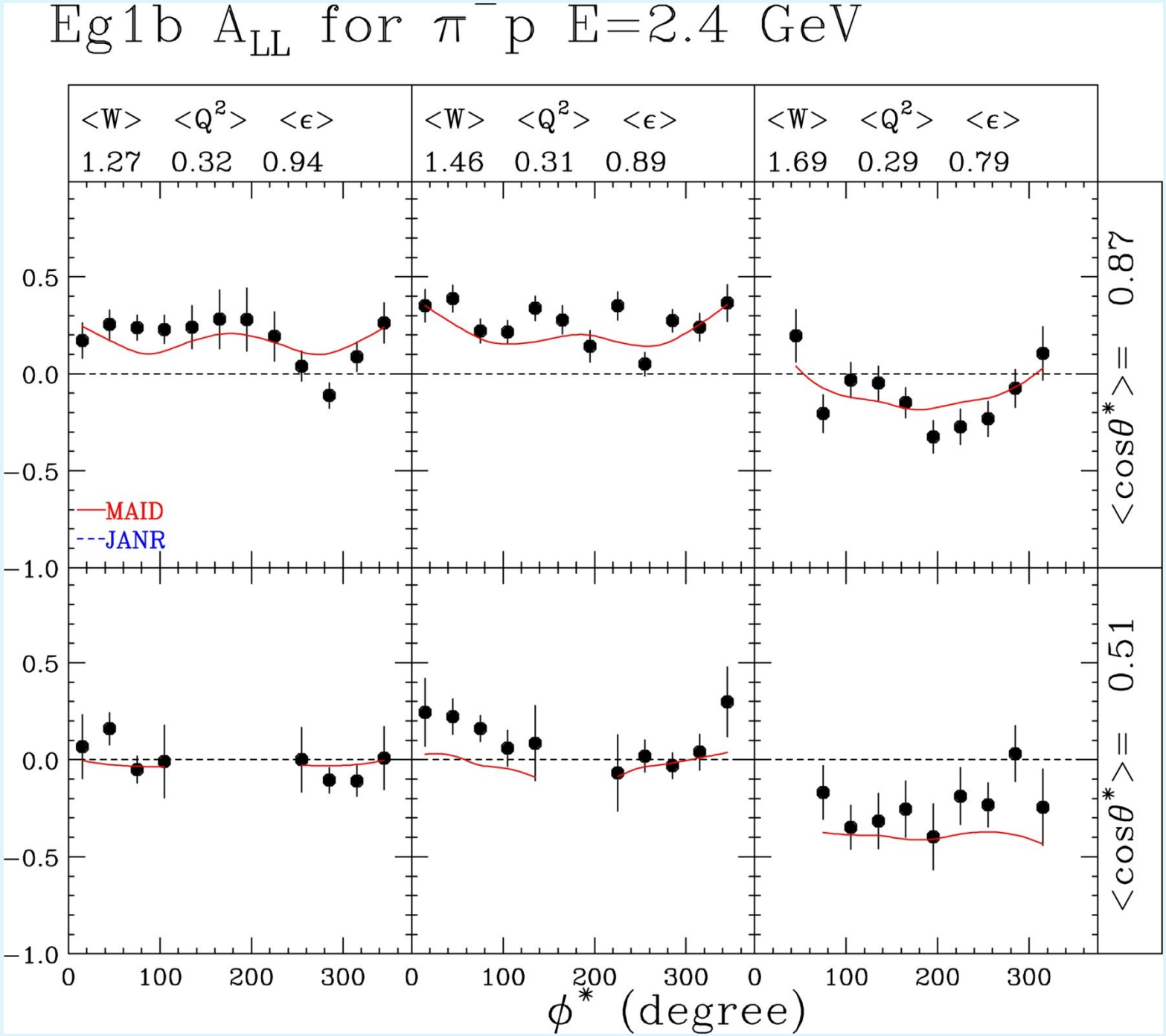
SPAN TRADITIONAL RESONANCE REGION (W<2 Gev)

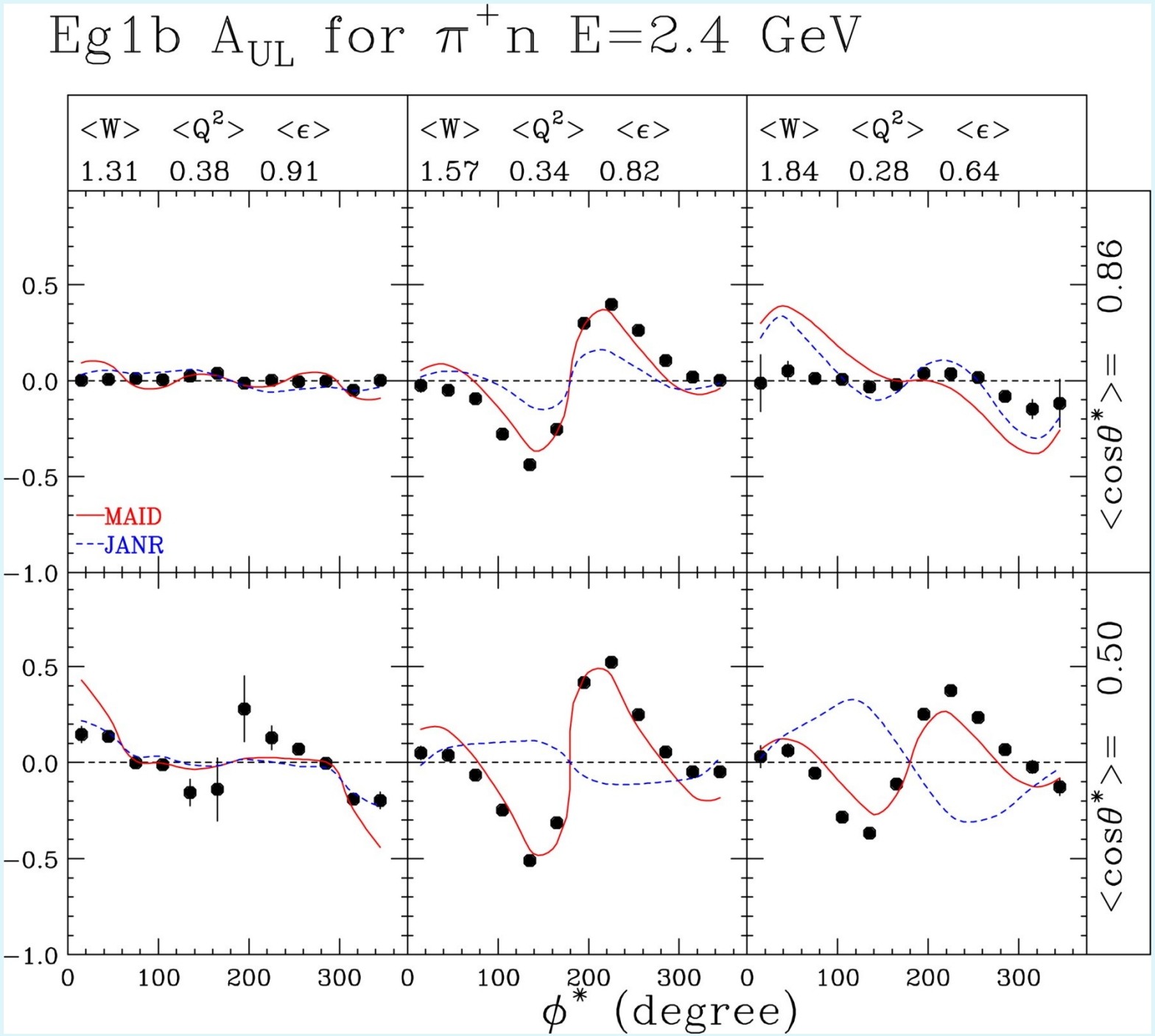
COMPARE TO TWO REPRESENTATIVE UNITARY ISOBAR FITS TO WORLD DATA

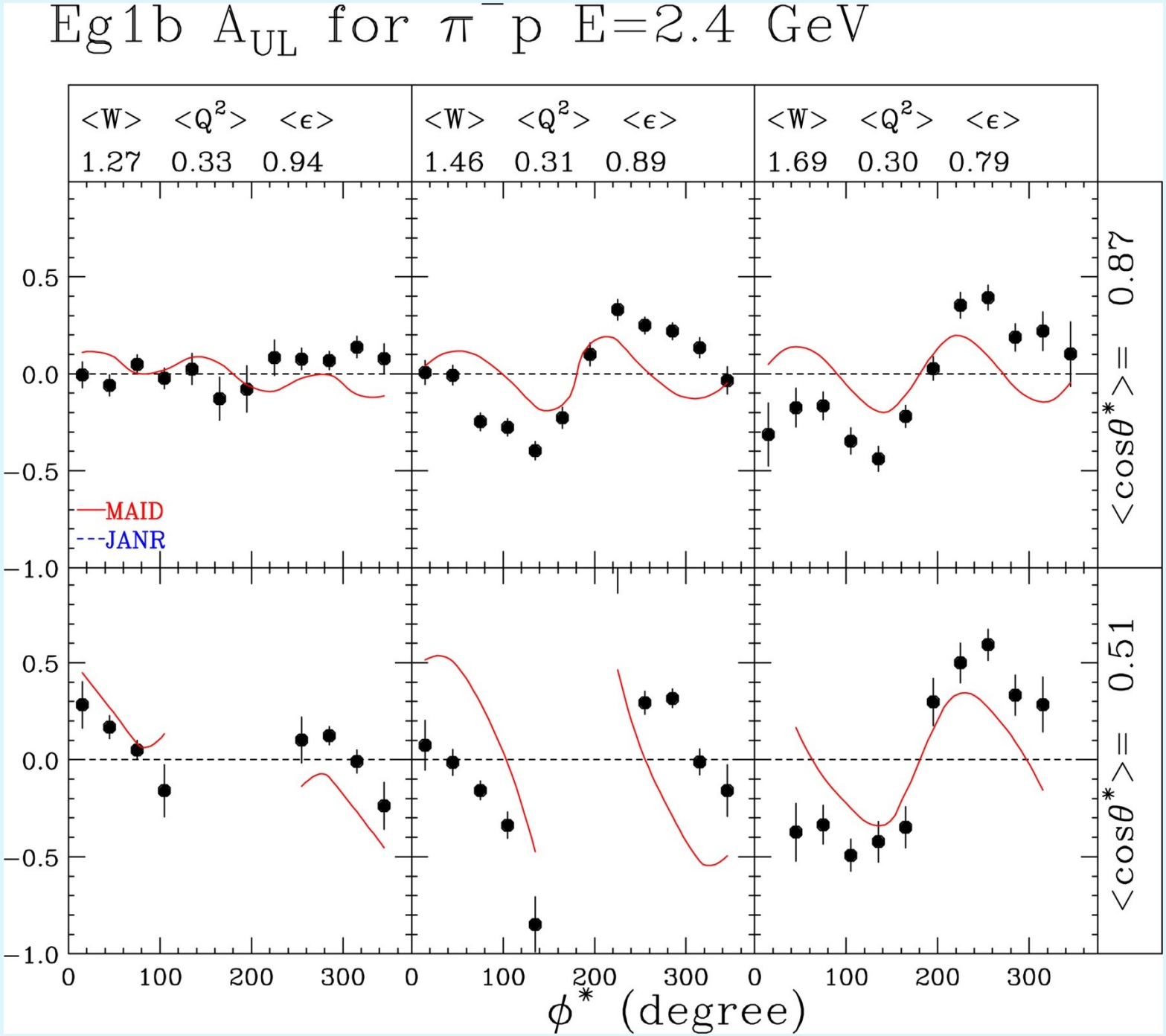
MAID

JANR


Eg1b A_{LL} for π^+n E=2.4 GeV
<W> <Q²> <ε>
1.31 0.39 0.91
<W> <Q²> <ε>
1.57 0.35 0.82
<W> <Q²> <ε>
1.84 0.29 0.63
MAID
JANR
<cosθ*> = 0.86
<cosθ*> = 0.50
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)


Eg1b A_{LL} for π^-p E=2.4 GeV
<W> <Q²> <ε>
1.27 0.32 0.94
<W> <Q²> <ε>
1.46 0.31 0.89
<W> <Q²> <ε>
1.69 0.29 0.79
MAID
JANR
<cosθ*> = 0.87
<cosθ*> = 0.51
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)


Eg1b A_{UL} for π^+n E=2.4 GeV
<W> <Q²> <ε>
1.31 0.38 0.91
<W> <Q²> <ε>
1.57 0.34 0.82
<W> <Q²> <ε>
1.84 0.28 0.64
MAID
JANR
<cosθ*> = 0.86
<cosθ*> = 0.50
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)

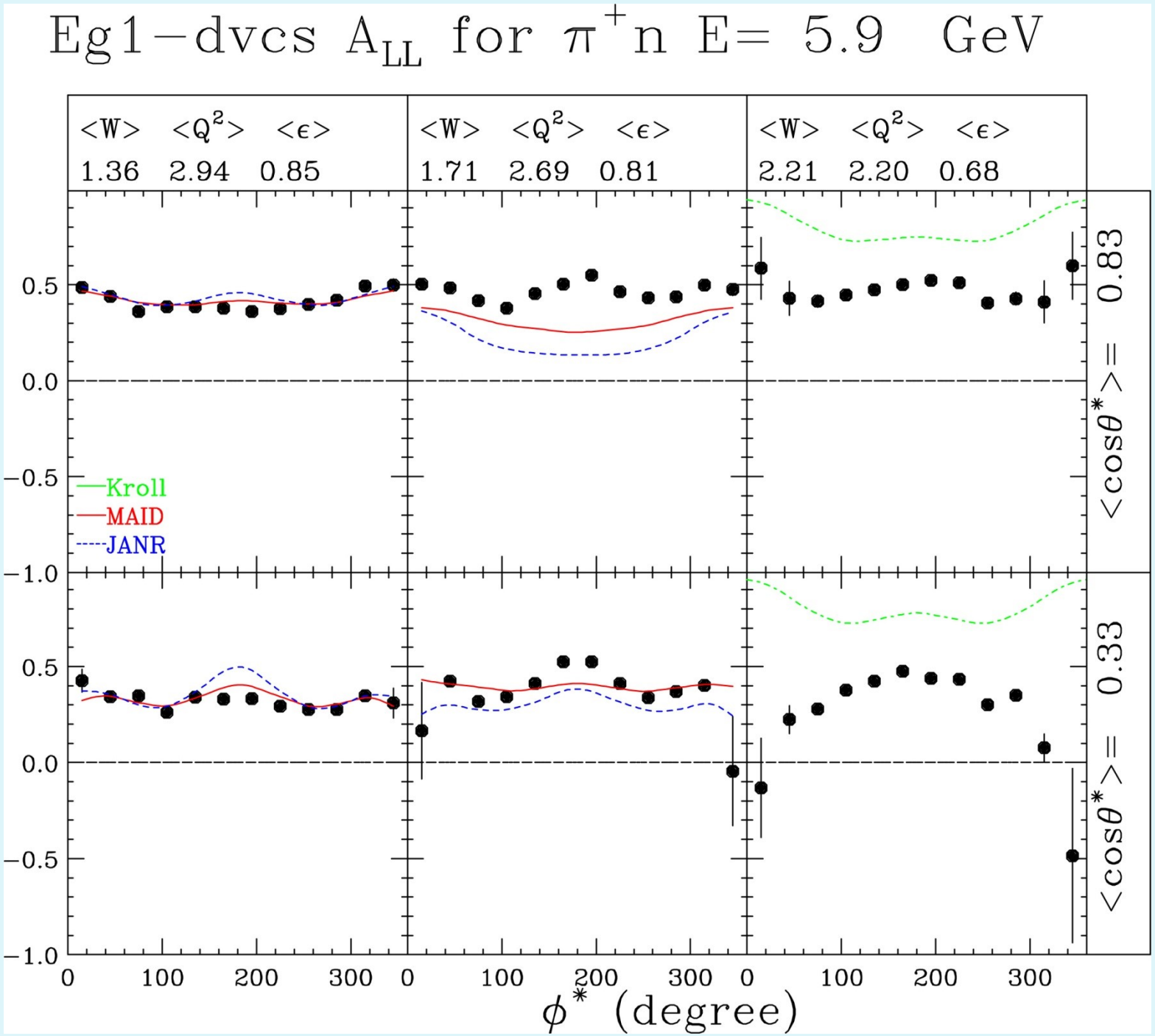

Eg1b A_{UL} for π^-p E=2.4 GeV
<W> <Q²> <ε>
1.27 0.33 0.94
<W> <Q²> <ε>
1.46 0.31 0.89
<W> <Q²> <ε>
1.69 0.30 0.79
<cosθ*> = 0.87
<cosθ*> = 0.51
MAID
JANR
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)

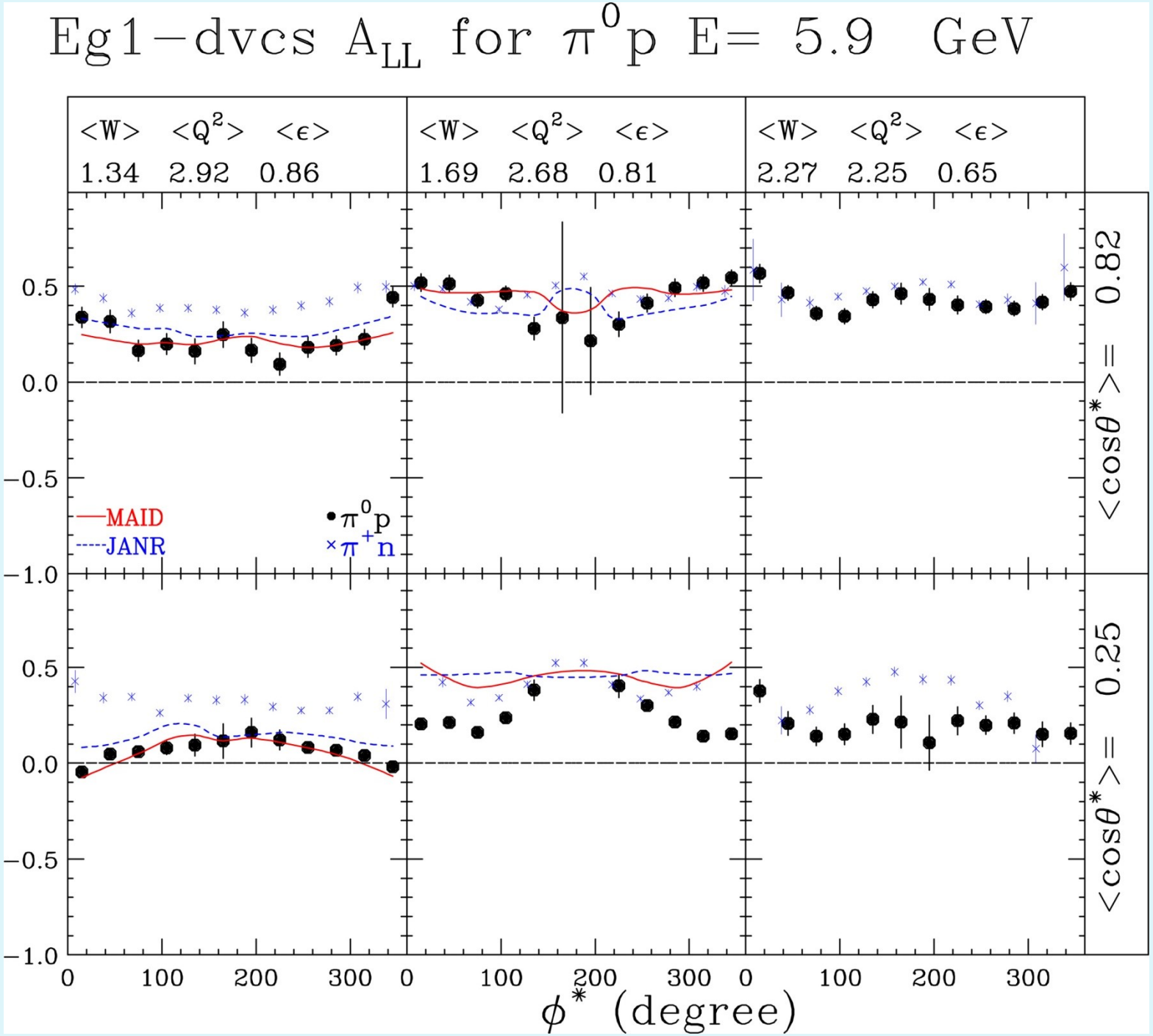
RESULTS WITH 6 Gev ELECTRONS

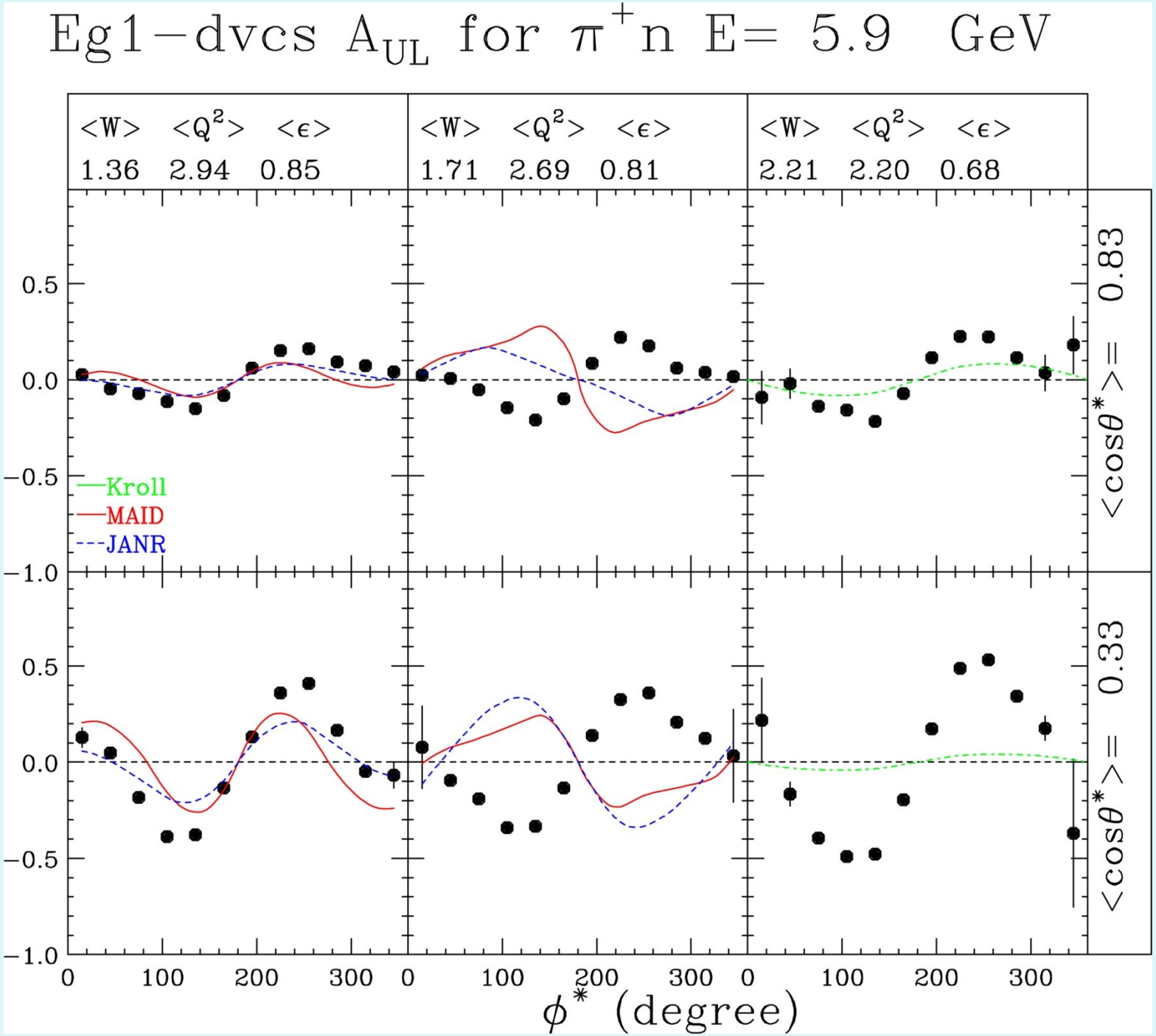
EXPAND INTO 4th RESONANCE REGION (1.1W<2.7 Gev)

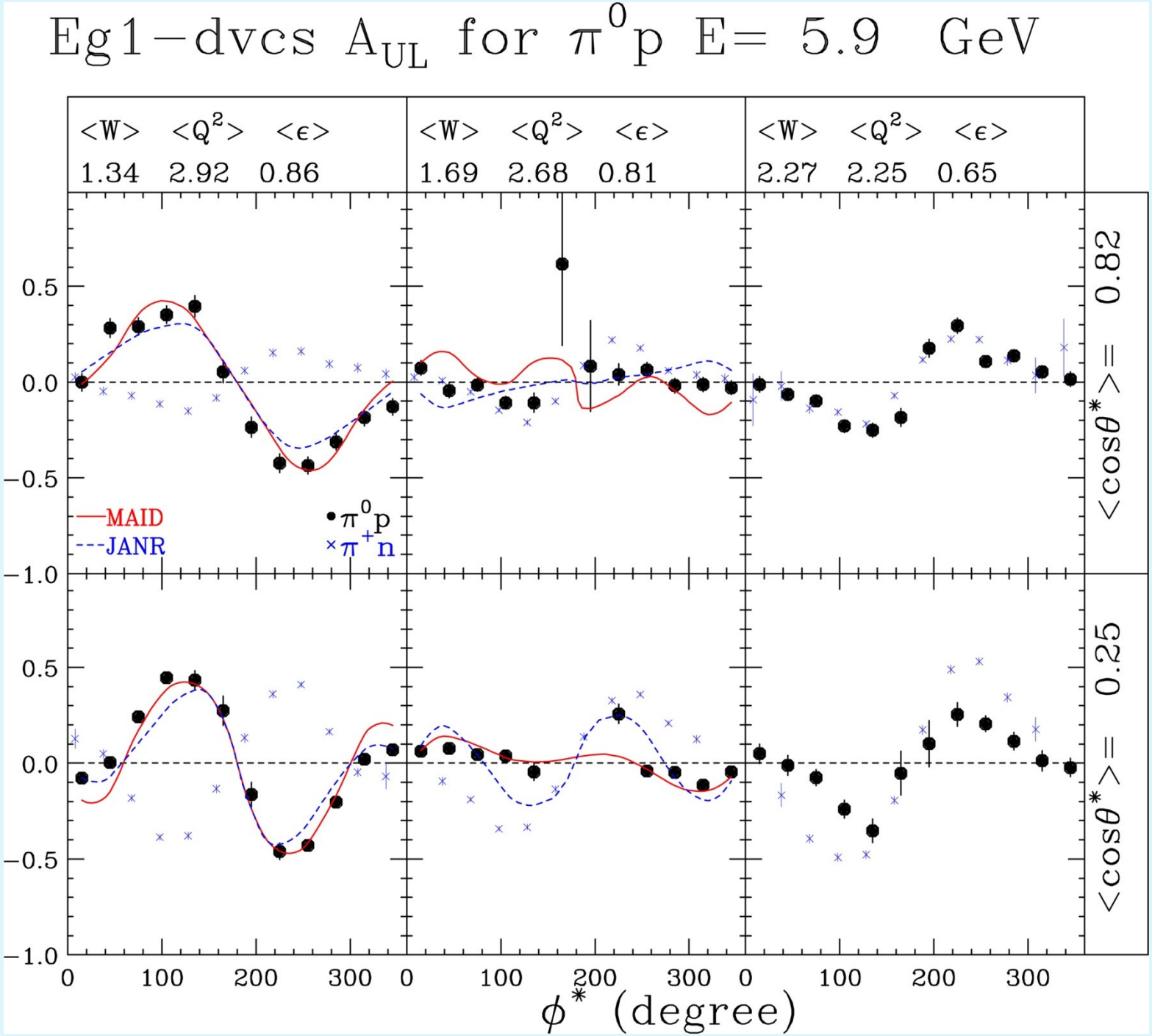
IS W>2 GeV “DEEP” (DUALITY)?

GREEN: A GPD MODEL


Eg1−dvcs A_{LL} for π^+n E= 5.9 GeV
<W> <Q²> <ϵ>
1.36 2.94 0.85
<W> <Q²> <ϵ>
1.71 2.69 0.81
<W> <Q²> <ϵ>
2.21 2.20 0.68
Kroll
MAID
JANR
<cosθ*> = 0.83
<cosθ*> = 0.33
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)


Eg1−dvcs A_{LL} for π^0p E= 5.9 GeV
<W> <Q²> <ϵ>
1.34 2.92 0.86
<W> <Q²> <ϵ>
1.69 2.68 0.81
<W> <Q²> <ϵ>
2.27 2.25 0.65
MAID
JANR
•π⁰p
×π⁺n
<cosθ*> = 0.82
<cosθ*> = 0.25
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)

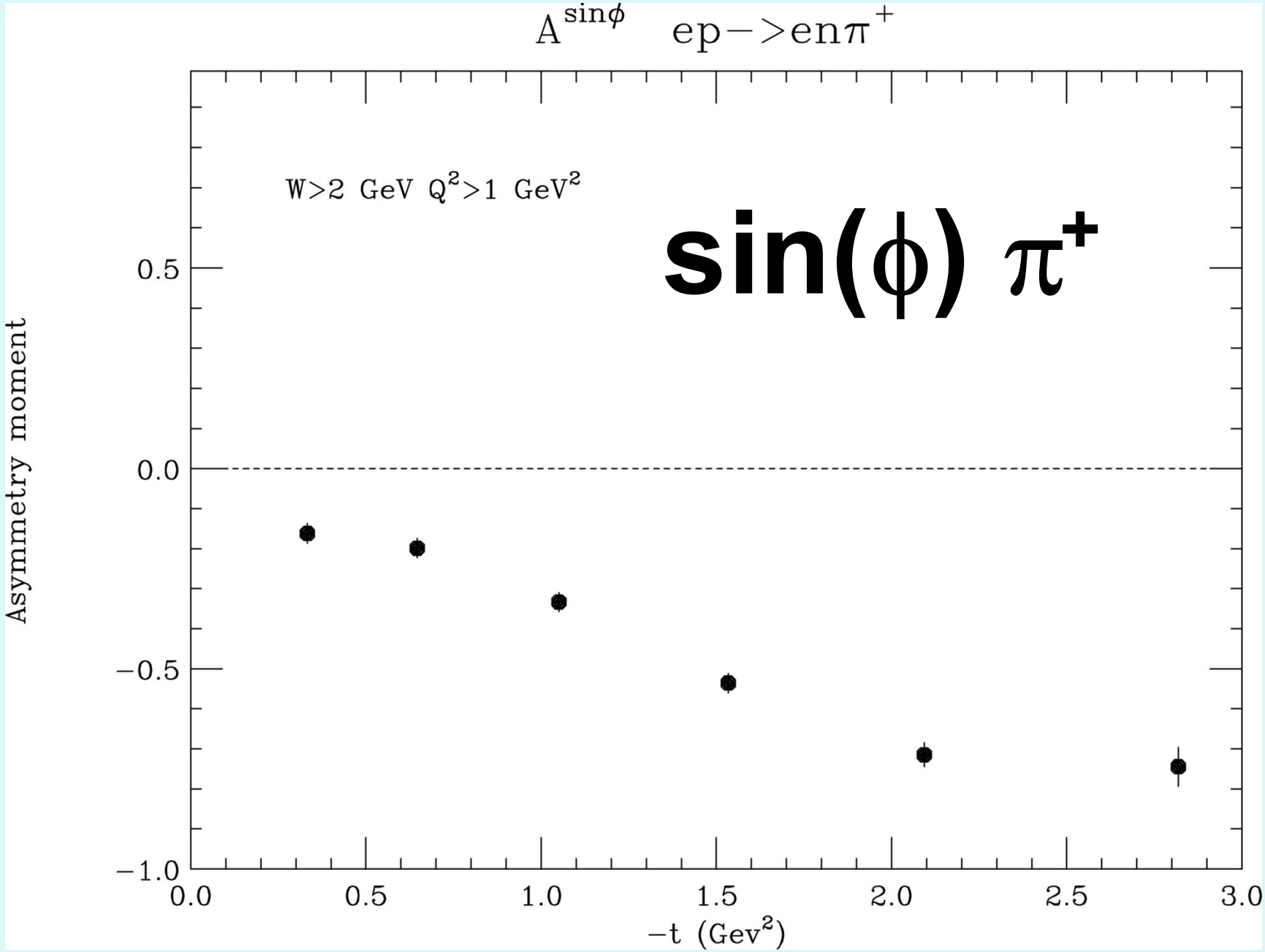

Eg1−dvcs A_{UL} for π^+n E= 5.9 GeV
<W> <Q²> <ϵ>
1.36 2.94 0.85
<W> <Q²> <ϵ>
1.71 2.69 0.81
<W> <Q²> <ϵ>
2.21 2.20 0.68
Kroll
MAID
JANR
<cosθ*> = 0.83
<cosθ*> = 0.33
0.5
0.0
−0.5
−1.0
0
100
200
300
ϕ^* (degree)

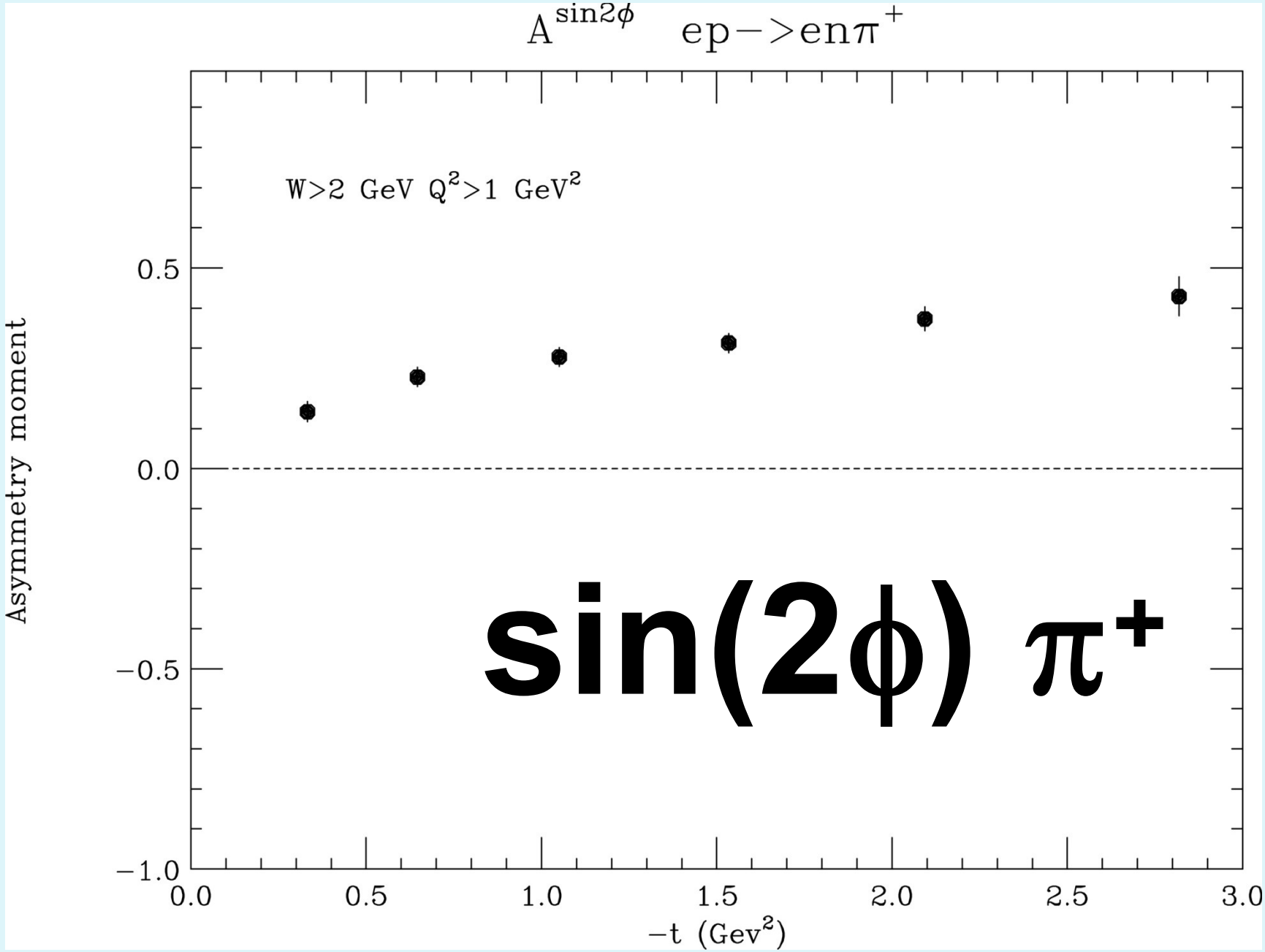

Eg1−dvcs A_{UL} for π^0p E= 5.9 GeV
<W> <Q²> <ϵ>
1.34 2.92 0.86
<W> <Q²> <ϵ>
1.69 2.68 0.81
<W> <Q²> <ϵ>
2.27 2.25 0.65
<cosθ*> = 0.82
<cosθ*> = 0.25
MAID
JANR
π⁰p
π⁺n
0.5
0.0
−0.5
−1.0
0
100
200
300
φ* (degree)

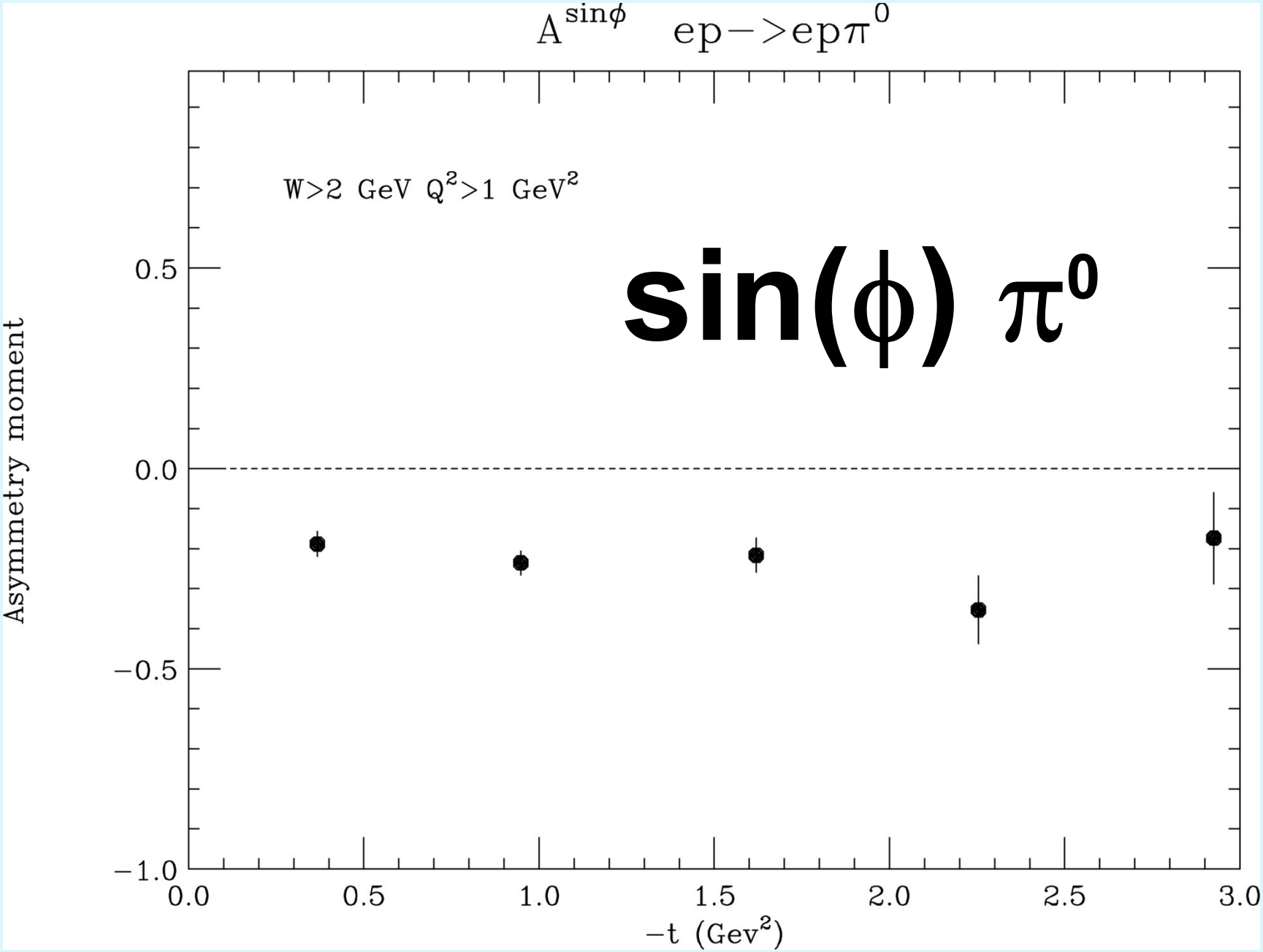
A_{LL} similar to DIS values

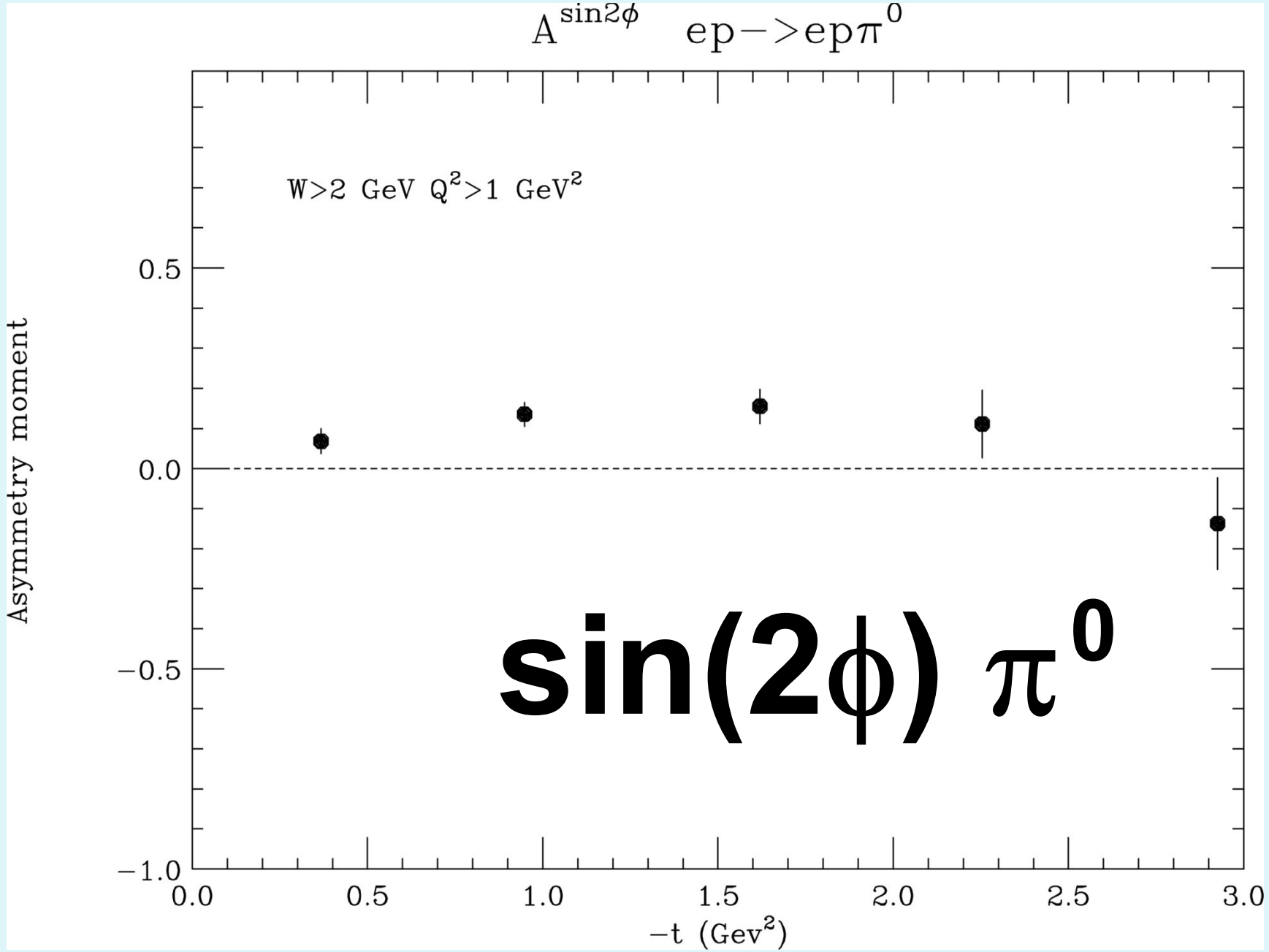
A_{UL} has HUGE Φ dependance (off my original scale!)

A_{UL} has two components
$\sin(\phi)$: transverse-longitudinal
$\mathrm{Sin}(2\phi)$: transverse-transverse


$A^{\sin\phi}$ $ep->en\pi^+$
W>2 GeV Q^2>1 GeV^2
sin(ϕ) π+
Asymmetry moment
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−t (Gev^2)


$A^{\sin 2\phi}$ $ep->en\pi^+$
W>2 GeV Q^2>1 GeV^2
Asymmetry moment
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−t (Gev^2)
sin(2ϕ) π+


$A^{\sin\phi}$ $ep->ep\pi^0$
W>2 GeV Q^2>1 GeV^2
sin(ϕ) π⁰
Asymmetry moment
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−t (Gev^2)


$A^{\sin 2\phi}$ $ep->ep\pi^0$
W>2 GeV Q^2>1 GeV^2
Asymmetry moment
0.5
0.0
−0.5
−1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−t (Gev^2)
sin(2ϕ) π⁰

SUMMARY

OVER 100,000 NEW ASYMMETRY RESULTS

SIGNIFICANT DIFFERENCES FROM PREVIOUS FITS (MAID, JANR, SAID….) AT w >1.6 GEV, $Q^2 > 1$ GeV^2

ALL DATA NOW PUBLISHED AND AVAILABLE TO EXPAND ISOBAR MODELS INTO FOURTH RESONANCE REGION ANDHIGH Q^2.

PUZZLE?

WHY A_{UL} SO LARGE IN "DEEP" REGION?

- PION POLE TERM (FOR π^+) ?
- HIGHER TWIST ?
- SPIN IN INITIAL STATE ?
- SPIN IN FINAL STATE ?
- BARYON RESONANCES ?

THANKS
COLLABORATORS
OFFICE OF SCIENCE
JEFFERSON LAB
APS / GHP