Extraction of Target and Double-Spin Asymmetries for $\vec{e}\,\vec{p} \rightarrow e'\pi^+(n)$ using CLAS EG4 data

Xiaochao Zheng

University of Virginia

June 16, 2016

Physics motivation, observables, formalism

EG4 run overview

Data analysis

Results and status of paper

Acknowledgment:

EG4 spokespeople: M. Battaglieri, R. De Vita, A. Deur, G. Dodge, M. Ripani, K. Slifer

EG4 students: K. Adhikari (inclusive ND3), H. Kang (inclusive NH3), K. Li-Kovacs (target)

CAA (HS07-02) review committee: D. Carman, P. Eugenio, C. Smith, M. Ungaro

Analysis note review committee: G. Niculescu, R. De Vita, D. Schott

Ad-hoc review committee: D. Sokhan, G. Niculescu, A. Celentano

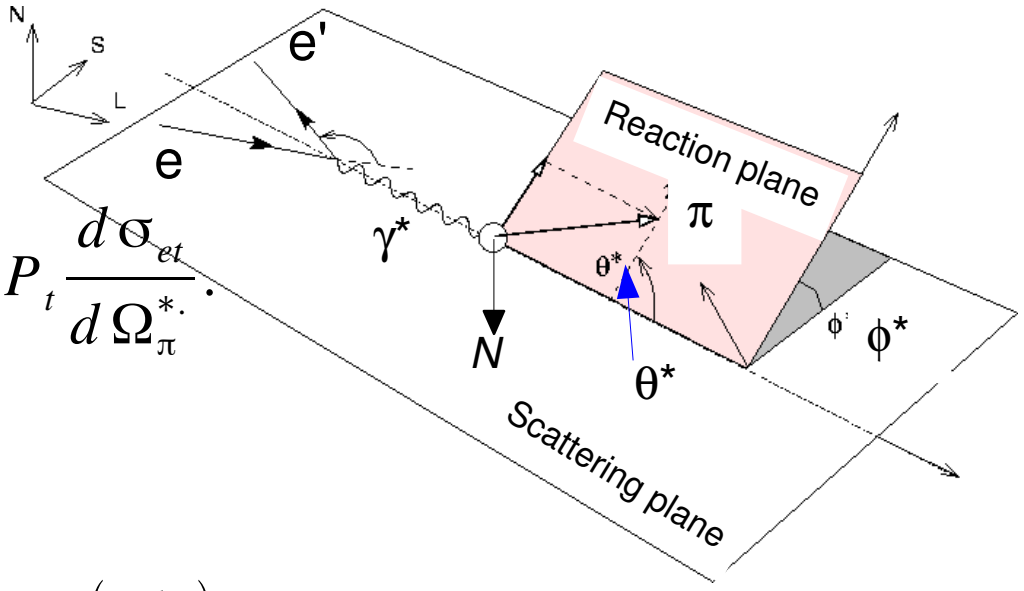
Physics Motivation

- Nucleon resonances form an important part of the strong interaction study:
  - Mostly non-perturbative, cannot use pQCD;
  - Too light for lattice calculation;
- Must use effective theories or models:
  - Constituent Quark Model: resonance amplitudes, helicity structure… (not on interference terms)
  - Phenomenology models: MAID, SAID, DMT, JANR, … …
  - *May compare to Chiral Perturbation Theory (very low Q^2 only).*
- Spin observables (asymmetries) provide constraints on: spin-dependent amplitudes, interference terms…

Observables

Cross section:

$$\frac{d\sigma}{d\Omega_\pi^{*.}} = \frac{d\sigma_{unp}}{d\Omega_\pi^{*.}} + P_e \frac{d\sigma_e}{d\Omega_\pi^{*.}} + P_t \frac{d\sigma_t}{d\Omega_\pi^{*.}} + P_e P_t \frac{d\sigma_{et}}{d\Omega_\pi^{*.}}.$$



Three independent asymmetries:

Single-beam $$A_e = \frac{d\sigma_e}{d\sigma_{unp}} = \frac{\sigma(+h_e) - \sigma(-h_e)}{\sigma(+h_e) + \sigma(-h_e)}$$ ← accessible from unpolarized target data

Single-target $$A_t = \frac{d\sigma_t}{d\sigma_{unp}} = \frac{\sigma(+h_N) - \sigma(-h_N)}{\sigma(+h_N) + \sigma(-h_N)}$$ ← only accessible from polarized target data

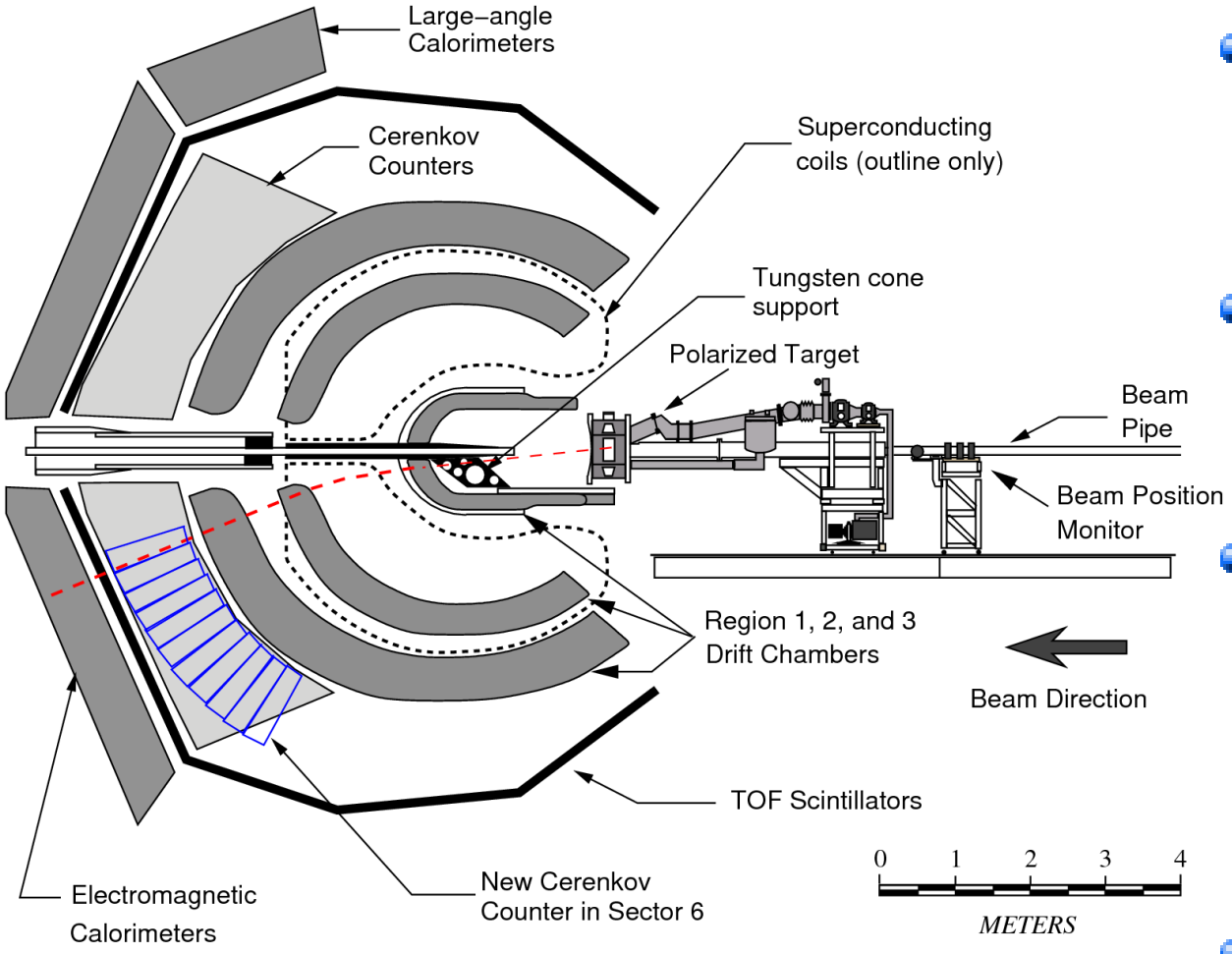
Double-spin

$$A_{et} = -\frac{d\sigma_{et}}{d\sigma_{unp}} = \frac{-\sigma(+h_e,+h_N) - \sigma(-h_e,-h_N) + \sigma(+h_e,-h_N) + \sigma(-h_e,+h_N)}{\sigma(+h_e,+h_N) + \sigma(-h_e,-h_N) + \sigma(+h_e,-h_N) + \sigma(-h_e,+h_N)}$$

EG4 Exclusive Channel Analysis

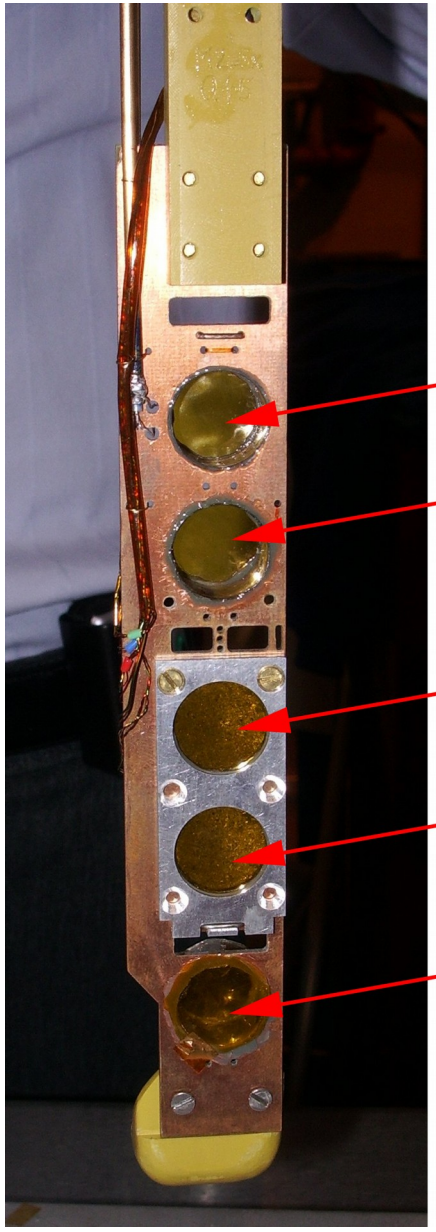
- Extracted *At* (A_{UL}) and *Aet* (A_{LL}) from EG4 NH3 data for: $\vec{e}\,\vec{p} \rightarrow e'\pi^+(n)$
- Study dependence on Q^2, W, ϕ^* and $\cos\theta^*$— (binned in 4 simultaneously);
- *Ae* (A_{LU}) and its $\sin\phi$ moment were extracted to check the beam HWP status for each run, and to provide the absolute beam helicity information;
- Previous/other analyses: EG1a (published), EG1b (in progress, see this morning's talk by P. Bosted);
- Our new results help to constrain models at low Q^2;
- Can compare to real photon experiment, study transition from virtual to real photons;

EG4 Overview



- Ran in Feb-Apr.2006
- Main goal is to extract inclusive g_1 and form GDH sum at low Q^2
- Polarized target installed at ~1m upstream of CLAS center
- Mostly electron outbending; new Cherenkov in sector 6 reached 6° scattering angle; electron trigger in sector 6 only.
- DC not always on in all sectors (zero or very small acceptance in some ϕ^* bins)

EG4 Target Insert



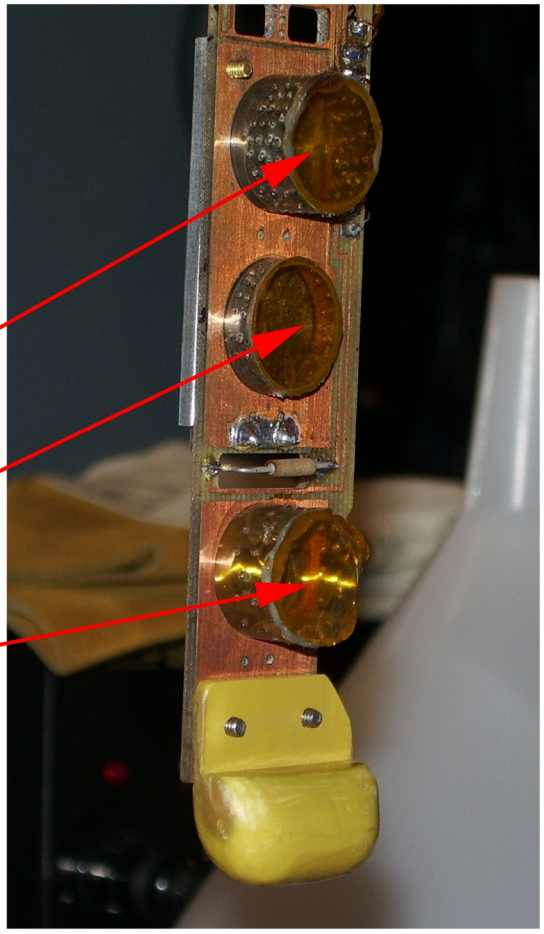
Long NH3 position (A)

Short NH3 position (B)

Long Carbon (C)

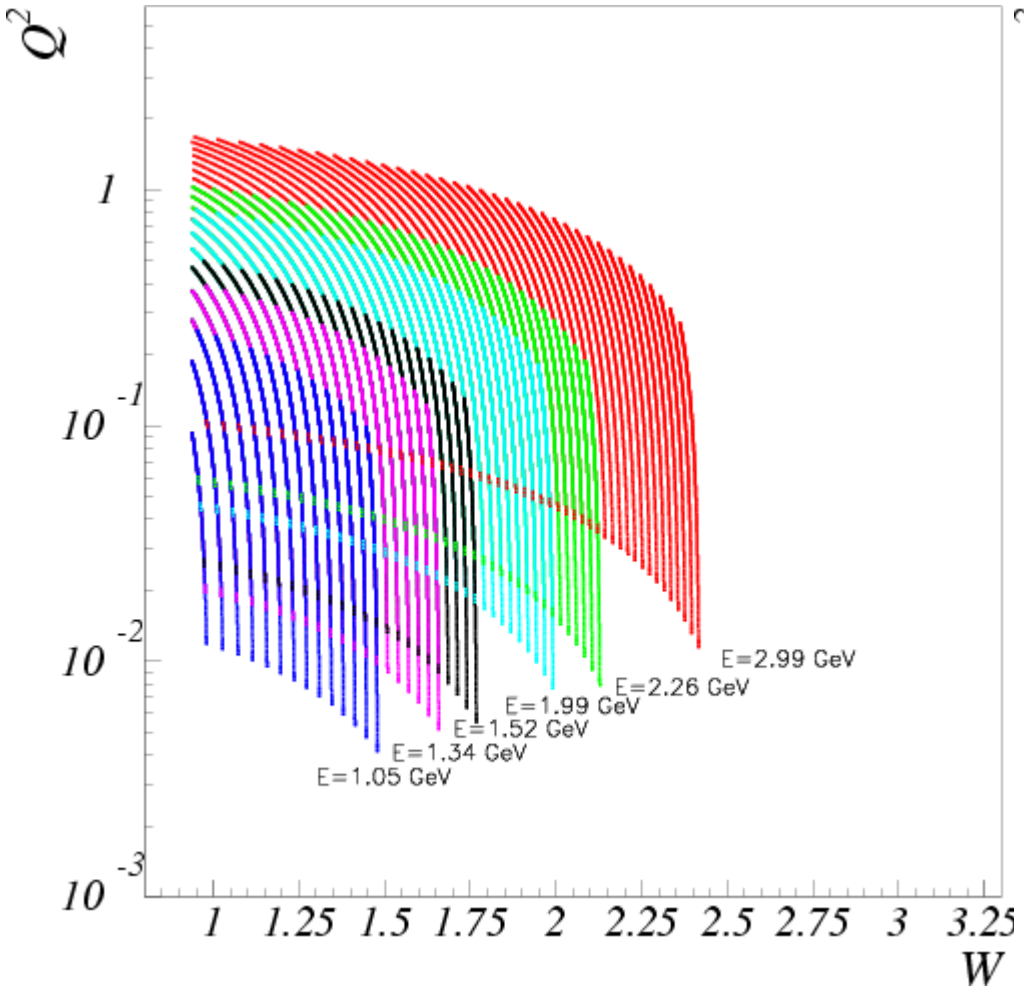
Short Carbon (D)

Empty Cell (E)

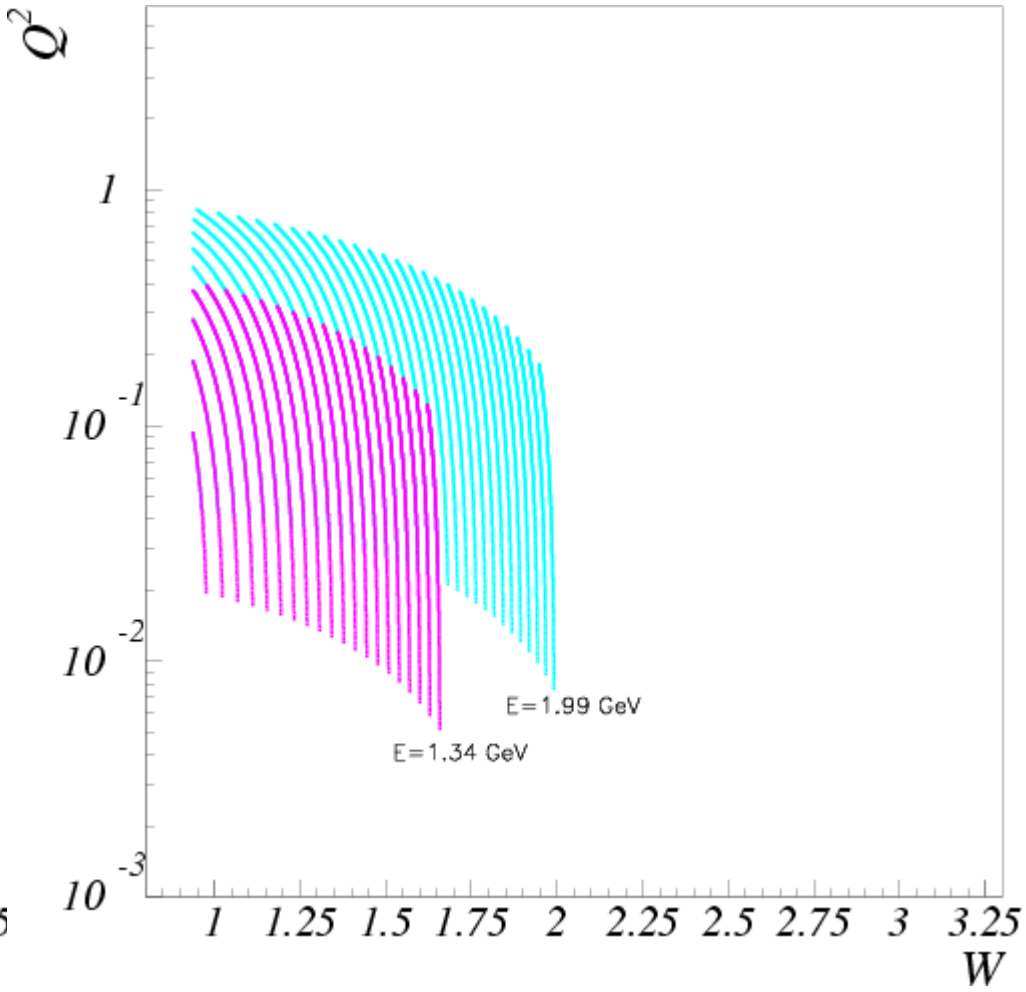


EG4 Kinematic Coverage

NH_3 target



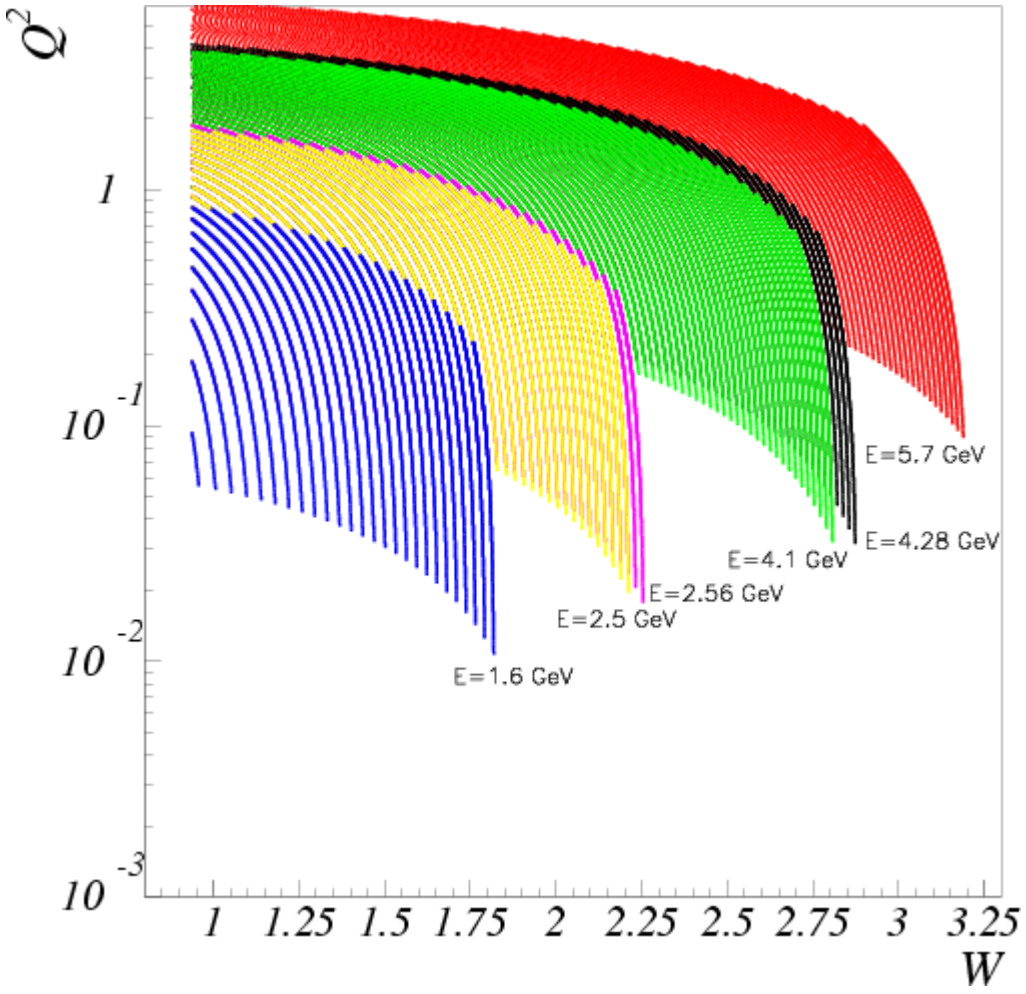
ND_3 target



The CAA originally included e'p(π^0), and ND3 e'π+(p) channel, but we no longer plan to analyze these because 1) poor acceptance for e'p(π^0); 2) the target spin was not flipped during the run.

EG4 Kinematic Coverage

eg1b coverage: (for comparison)

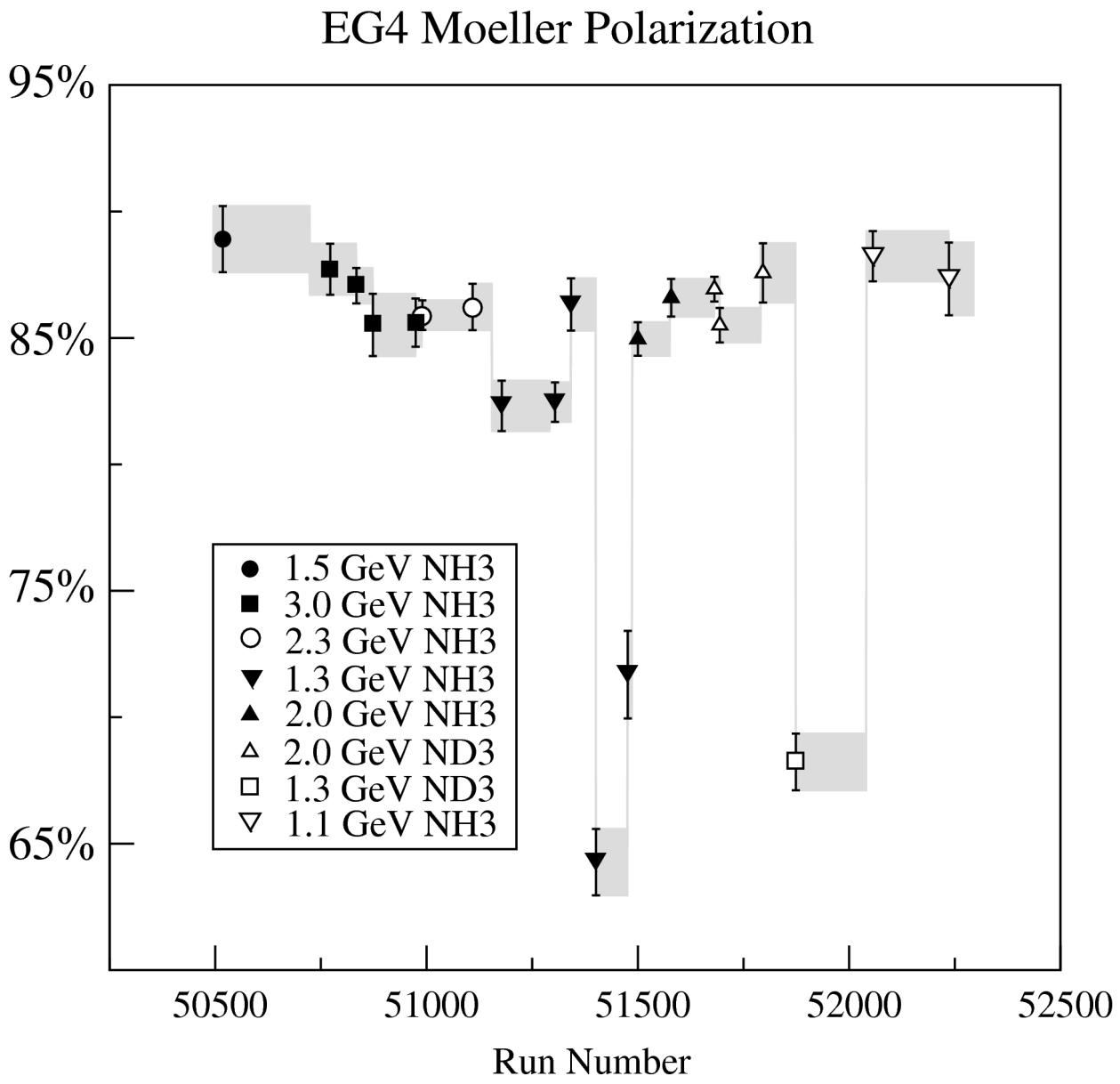


Lowest Eb: 1.6 GeV

Analysis Procedure for $\vec{e}\,\vec{p} \rightarrow e'\pi^+(n)$ using NH3 Data

- Beam polarization
- Event selection (electron and pion identification)
- Raster and momentum correction
- Dilution factor

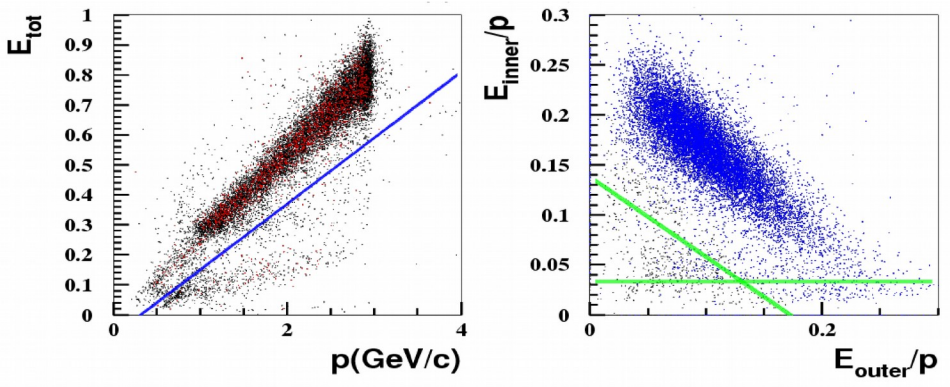
Beam Polarization

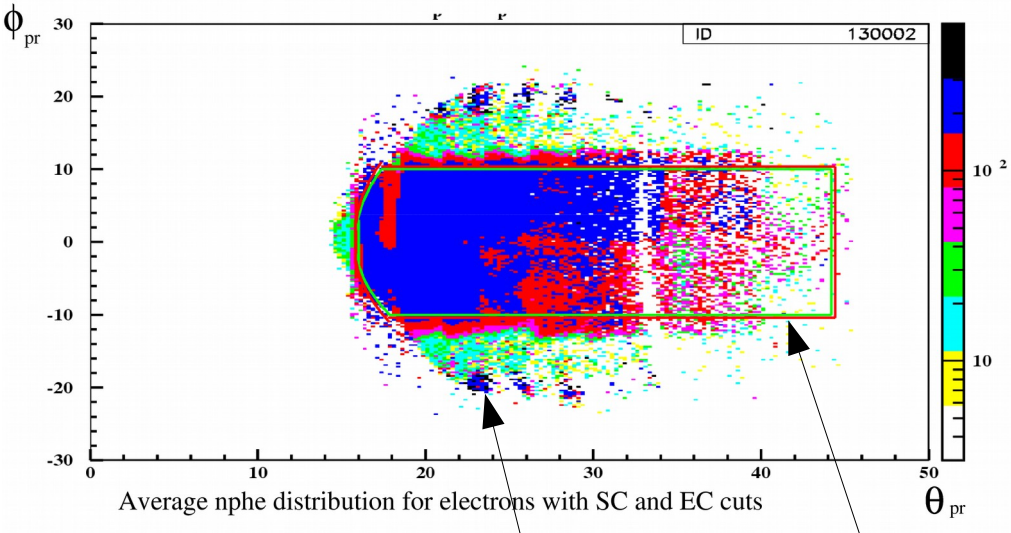


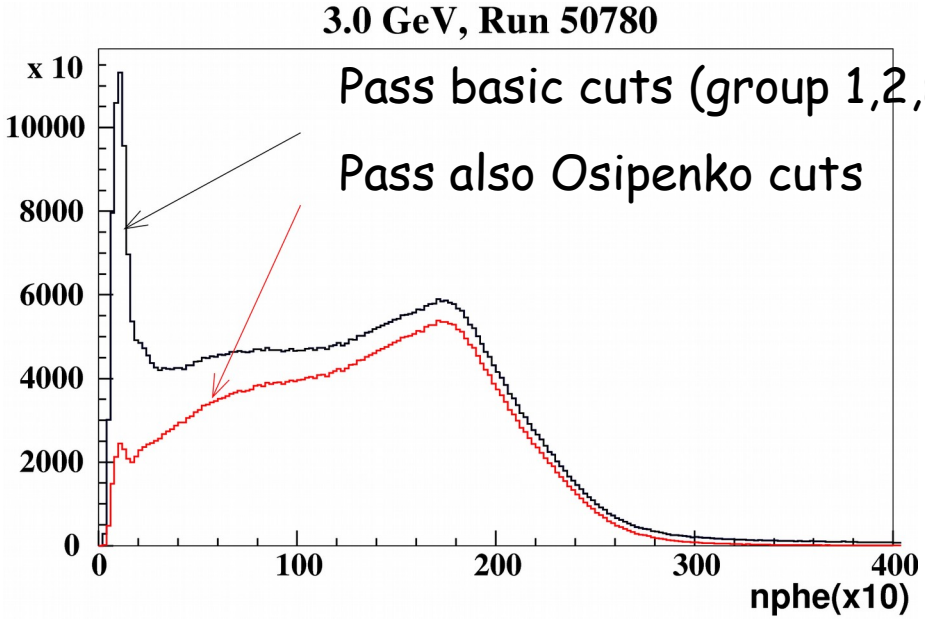
Electron Selection

$\vec{e}\,\vec{p} \rightarrow e'\pi^+(n)$

EG4 had a new Cherenkov and electron trigger in sector 6 only; we used EC cuts, and developed "Osipenko cuts" for the new CC:







Pass basic cuts (group 1,2,multihit)

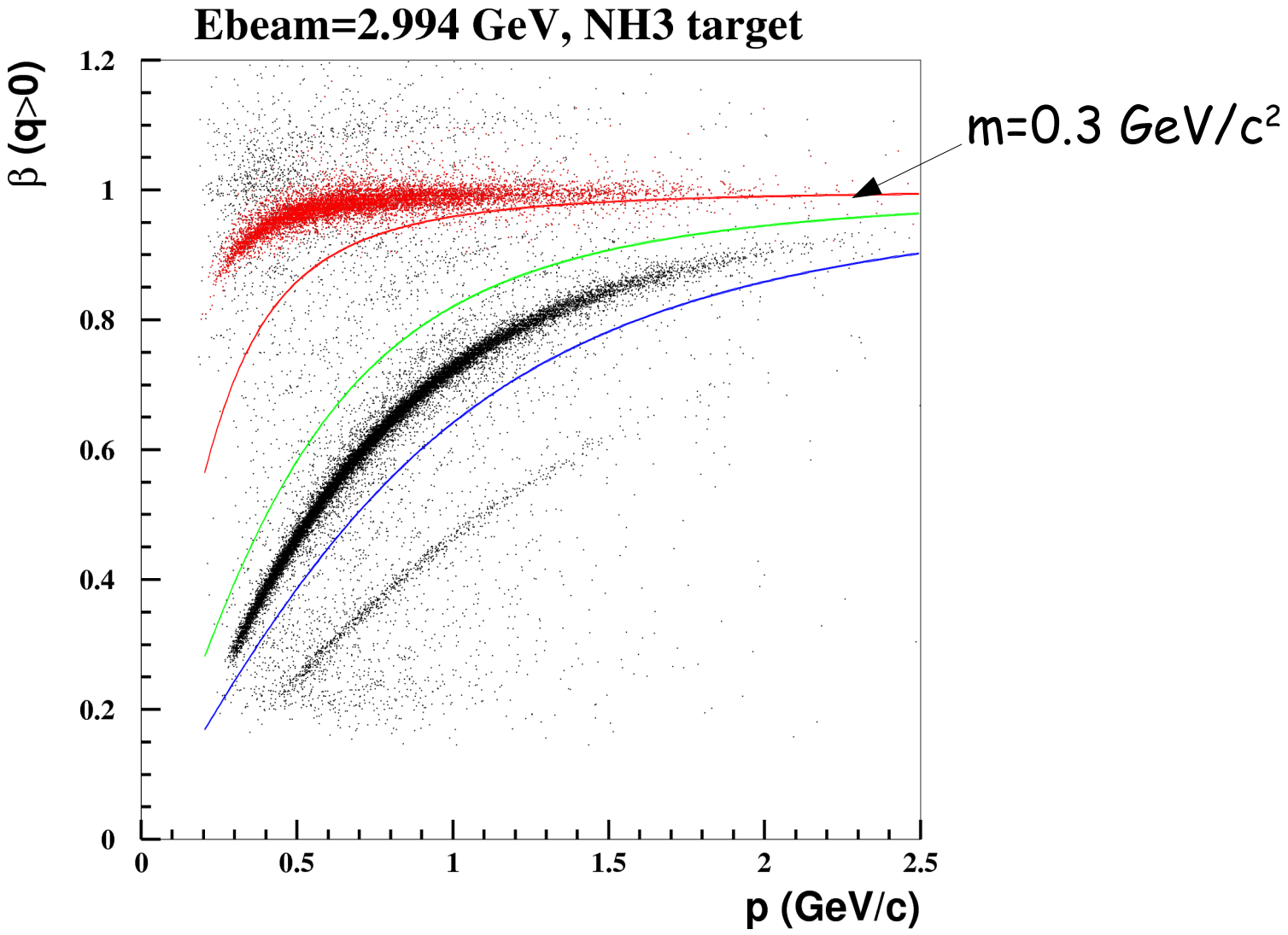
Pass also Osipenko cuts

Fiducial cut

Events that hit PMTs directly

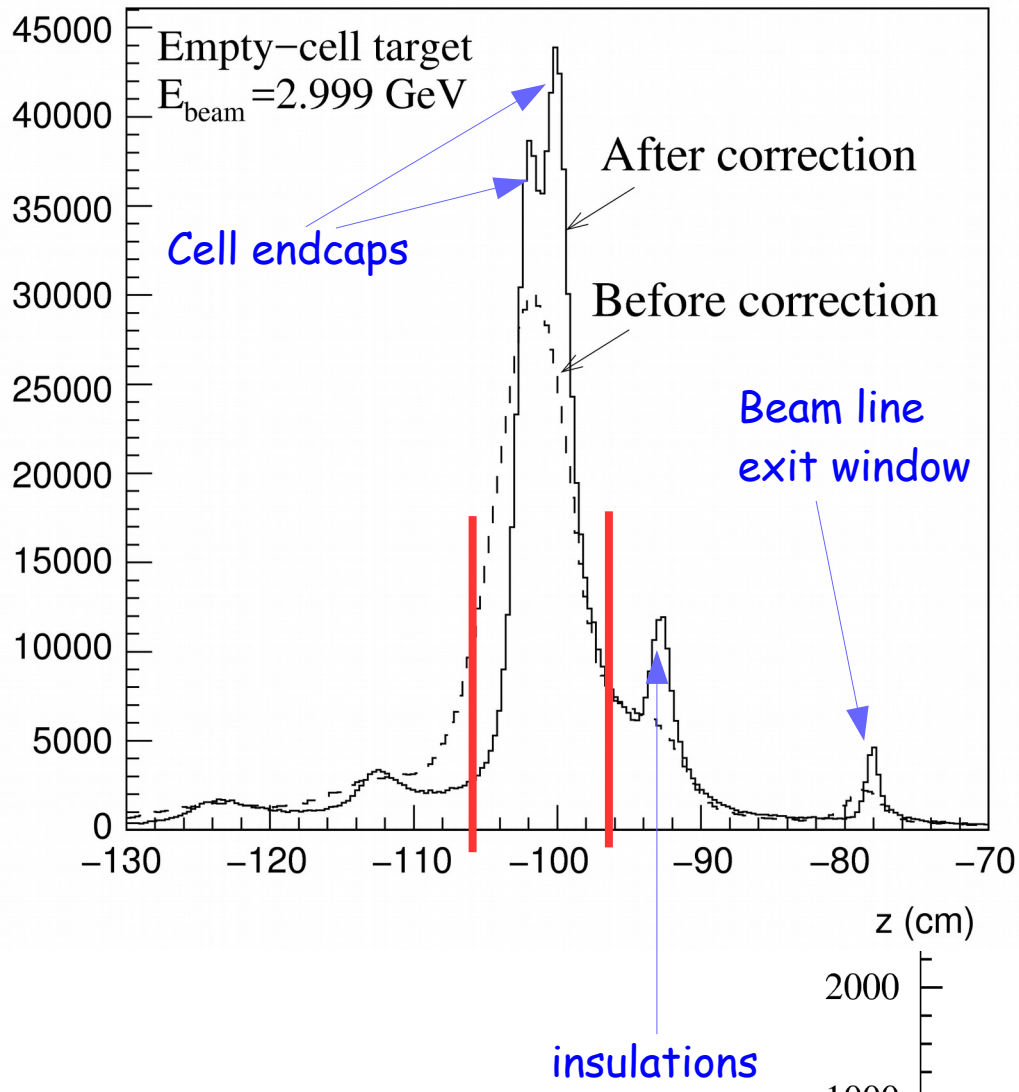
Pion Selection

Used TOF cut within +/- 1ns and mass=(0.01,0.3) GeV/c^2



Raster and Momentum Corrections

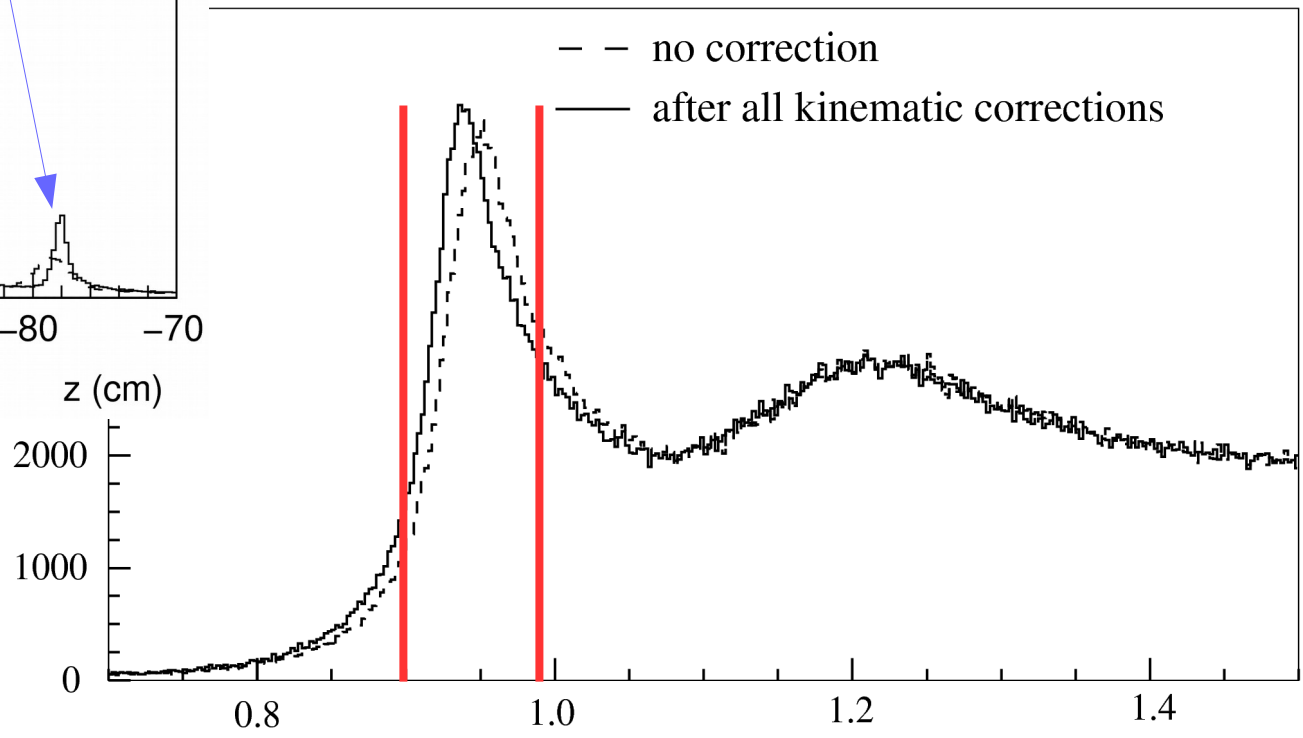
$\vec{e}\,\vec{p} \rightarrow e'\pi^+(n)$



Mx peak center:

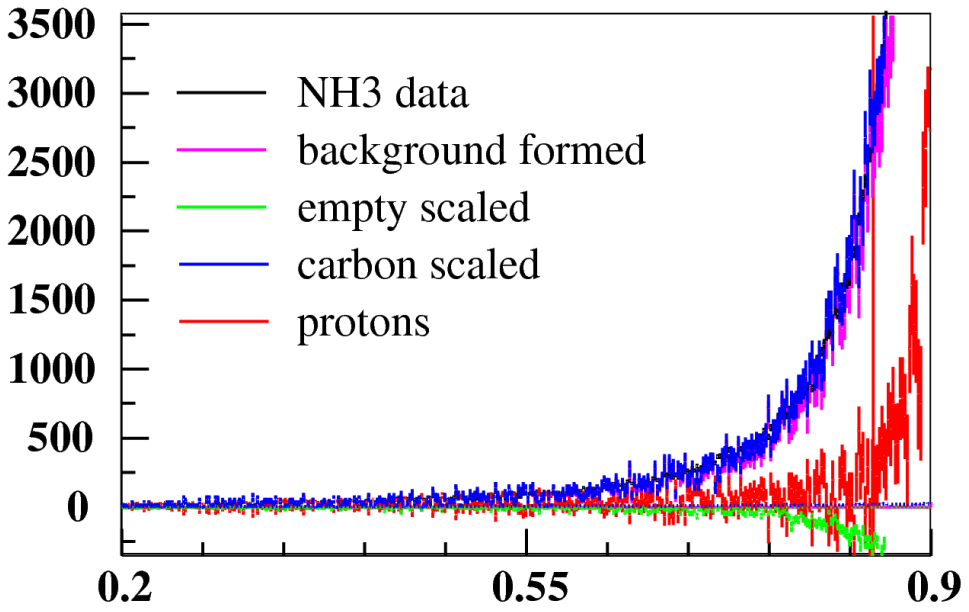
Before correction: (0.949 ± 0.020) GeV/c^2

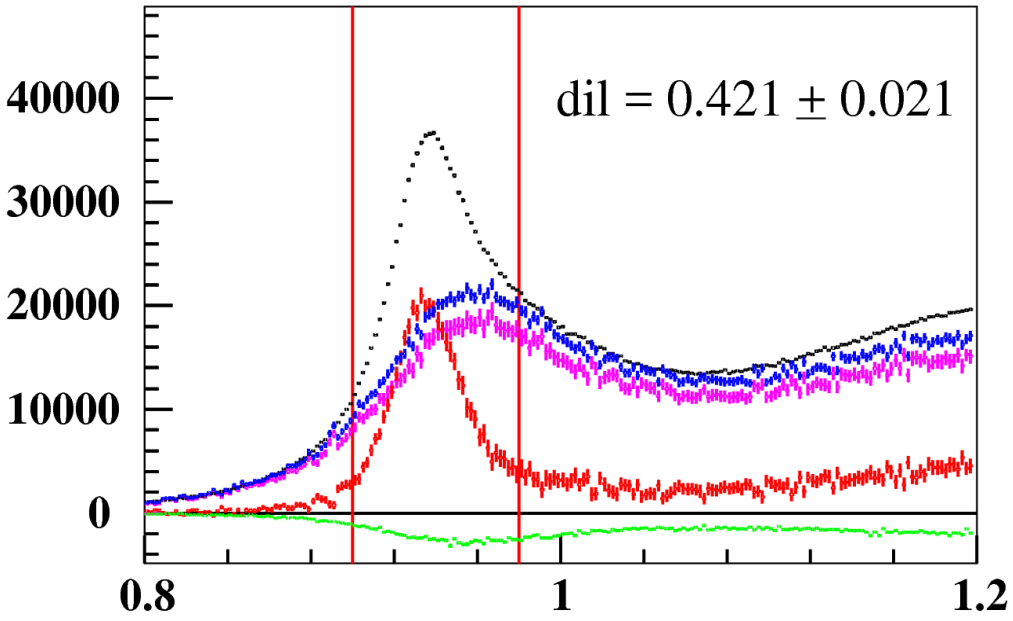
After correction: (0.937 ± 0.016) GeV/c^2



Dilution from Unpolarized Material

- Dilution factor describes fraction of events from polarized protons in the target
- For this analysis, extracted dilution using NH3, empty, and carbon target data, for fixed packing fractions (length of pure NH3 beads)
- Value of packing fraction and its uncertainty determined by examining low Mx spectrum, and from dilution of the e′π- channel
- 4D fit to the extracted dilution factor → used in the analysis





Extracting Asymmetries

$$\frac{d\sigma}{d\Omega_\pi^*} = \frac{d\sigma_{unp}}{d\Omega_\pi^*} + P_e \frac{d\sigma_e}{d\Omega_\pi^*} + P_t \frac{d\sigma_t}{d\Omega_\pi^*} + P_e P_t \frac{d\sigma_{et}}{d\Omega_\pi^*}.$$

$$N_{\uparrow\Uparrow} = D_1 \left[\sigma_0 + P_b^{\Uparrow}\sigma_e + f_{\rm dil}^{\pi} P_t^{\Uparrow}\sigma_t + P_b^{\Uparrow} f_{\rm dil}^{\pi} P_t^{\Uparrow}\sigma_{et}\right]$$

$$N_{\downarrow\Uparrow} = D_2 \left[\sigma_0 - P_b^{\Uparrow}\sigma_e + f_{\rm dil}^{\pi} P_t^{\Uparrow}\sigma_t - P_b^{\Uparrow} f_{\rm dil}^{\pi} P_t^{\Uparrow}\sigma_{et}\right]$$

$$N_{\uparrow\Downarrow} = D_3 \left[\sigma_0 + P_b^{\Downarrow}\sigma_e - f_{\rm dil}^{\pi} P_t^{\Downarrow}\sigma_t - P_b^{\Downarrow} f_{\rm dil}^{\pi} P_t^{\Downarrow}\sigma_{et}\right]$$

$$N_{\downarrow\Downarrow} = D_4 \left[\sigma_0 - P_b^{\Downarrow}\sigma_e - f_{\rm dil}^{\pi} P_t^{\Downarrow}\sigma_t + P_b^{\Downarrow} f_{\rm dil}^{\pi} P_t^{\Downarrow}\sigma_{et}\right]$$

$$A_{LU} = \frac{1}{P_b^{\Uparrow} P_b^{\Downarrow}} \times \left[\frac{\left(\frac{N_{\uparrow\Downarrow}}{D_3} - \frac{N_{\downarrow\Downarrow}}{D_4}\right) P_b^{\Uparrow} P_t^{\Uparrow} + \left(\frac{N_{\uparrow\Uparrow}}{D_1} - \frac{N_{\downarrow\Uparrow}}{D_2}\right) P_b^{\Downarrow} P_t^{\Downarrow}}{\left(\frac{N_{\uparrow\Uparrow}}{D_1} + \frac{N_{\downarrow\Uparrow}}{D_2}\right) P_t^{\Downarrow} + \left(\frac{N_{\uparrow\Downarrow}}{D_3} + \frac{N_{\downarrow\Downarrow}}{D_4}\right) P_t^{\Uparrow}}\right]$$

$$A_{UL} = \frac{1}{f_{\rm dil}^{\pi}} \frac{\left(\frac{N_{\uparrow\Uparrow}}{D_1} + \frac{N_{\downarrow\Uparrow}}{D_2}\right) - \left(\frac{N_{\uparrow\Downarrow}}{D_3} + \frac{N_{\downarrow\Downarrow}}{D_4}\right)}{\left(\frac{N_{\uparrow\Uparrow}}{D_1} + \frac{N_{\downarrow\Uparrow}}{D_2}\right) P_t^{\Downarrow} + \left(\frac{N_{\uparrow\Downarrow}}{D_3} + \frac{N_{\downarrow\Downarrow}}{D_4}\right) P_t^{\Uparrow}}$$

$$A_{LL} = \frac{1}{P_b^{\Uparrow} P_b^{\Downarrow} f_{\rm dil}^{\pi}} \times \left[\frac{\left(\frac{N_{\uparrow\Downarrow}}{D_3} - \frac{N_{\downarrow\Downarrow}}{D_4}\right) P_b^{\Uparrow} - \left(\frac{N_{\uparrow\Uparrow}}{D_1} - \frac{N_{\downarrow\Uparrow}}{D_2}\right) P_b^{\Downarrow}}{\left(\frac{N_{\uparrow\Uparrow}}{D_1} + \frac{N_{\downarrow\Uparrow}}{D_2}\right) P_t^{\Downarrow} + \left(\frac{N_{\uparrow\Downarrow}}{D_3} + \frac{N_{\downarrow\Downarrow}}{D_4}\right) P_t^{\Uparrow}}\right]$$

- D: normalization from beam charge, DAQ livetime, etc.
- PbPt extracted from inclusive elastic events
- Dilution for elastic PbPt evaluated the same way as exclusive channel
- For Pt, divided elastic PbPt by Moller Pb

Systematic Uncertainties

E_{beam} (GeV)	Target (NH_3)	$\Delta A_{UL}/A_{UL}$ (syst)	$\Delta A_{LL}/A_{LL}$ (syst)
3.0	top	7.0%	7.0%
2.3	top	6.2%	6.3%
	short	9.0%	9.0%
2.0	top	5.7%	5.8%
1.3	top	5.7%	5.9%
	bottom	5.5%	5.7%
1.1	bottom	11.1%	11.2%

- Dominated by the dilution factor/packing fraction
- ^{15}N: (1-2)%
- Radiative correction: ±0.03 (absolute)
- All others negligible

Results

Asymmetry results available for A_{LL}, A_{UL} in:

- 42 Q^2 bins between 0.00453 and 6.45 $(GeV/c)^2$, spaced logarithmically
- 38 W bins between 1.1 and 2.21 GeV/c^2 (0.03-GeV/c^2)
- 30 ϕ^* bins between 0^o and 360^o
- 20 $\cos\theta^*$ bins between -1 and 1

Not all bins have data, of course.

In the following slides, will show
(data uncertainties are statistical only)

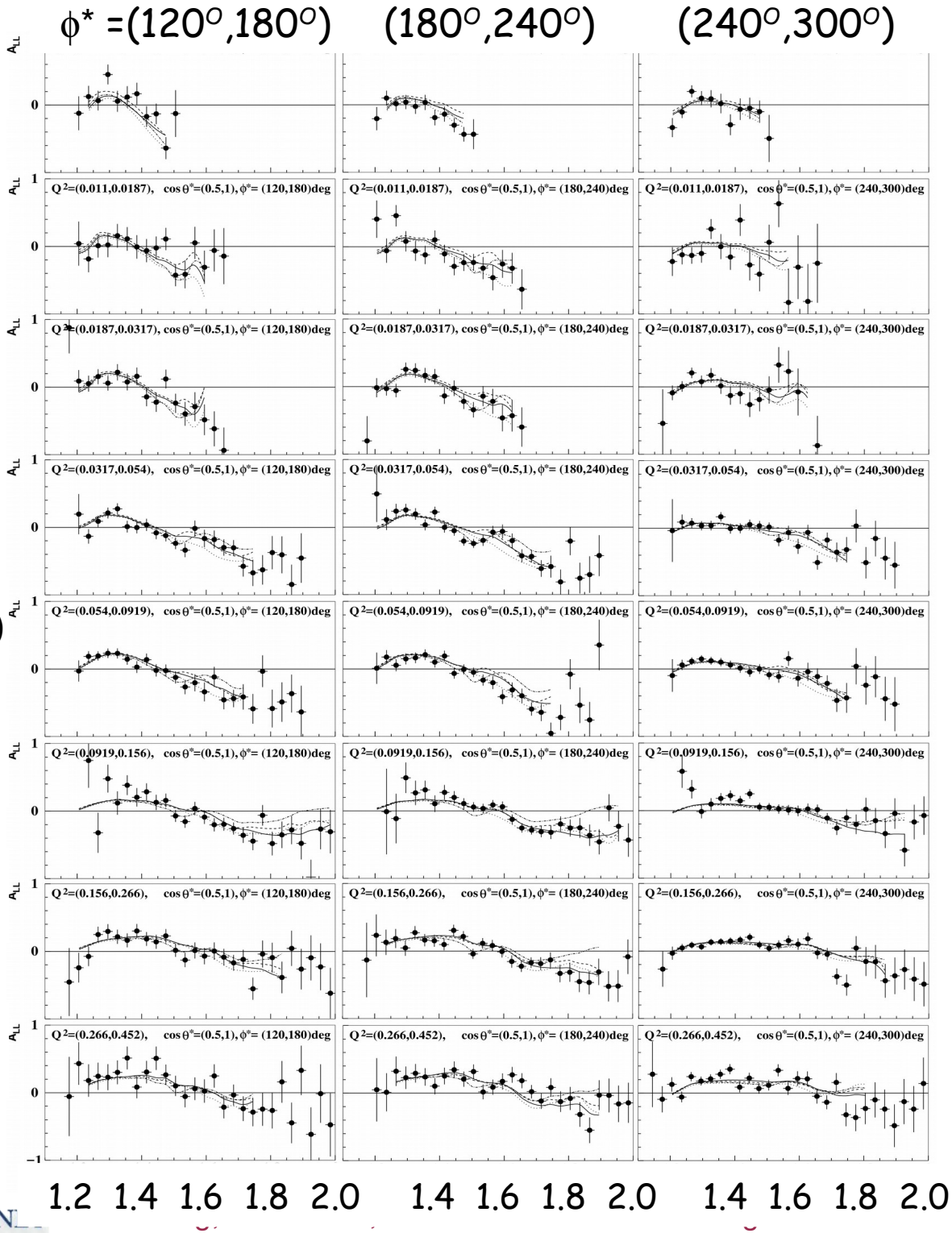
A_{LL} vs. W

A_{LL} vs. ϕ^*

A_{UL} vs. W

A_{UL} vs. ϕ^*

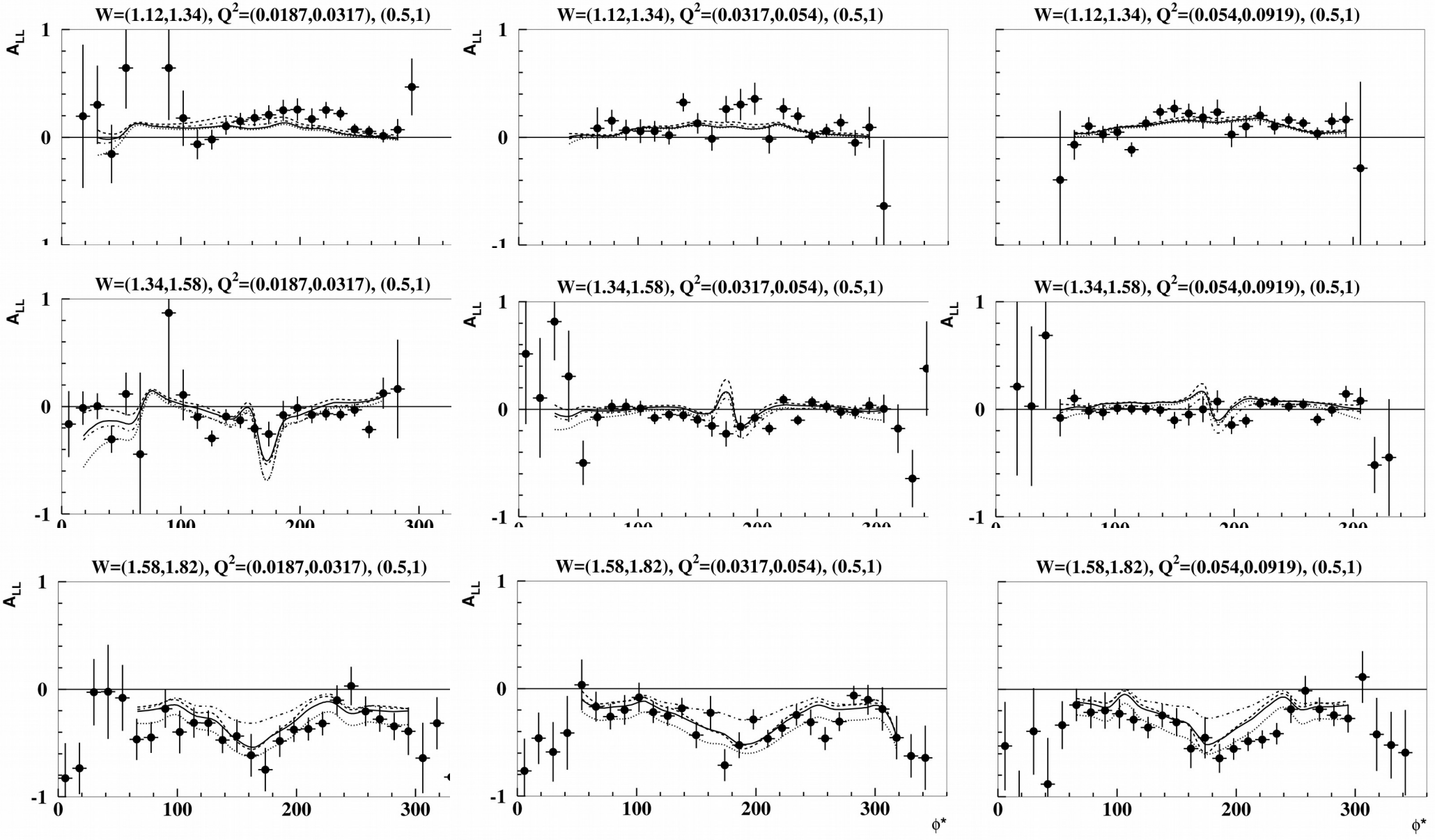
A_{LL} vs. W



MAID2007 (solid)
JANR(dashed)
SAID(dash-dotted)
DMT(dotted)

A_{LL} vs. ϕ^*

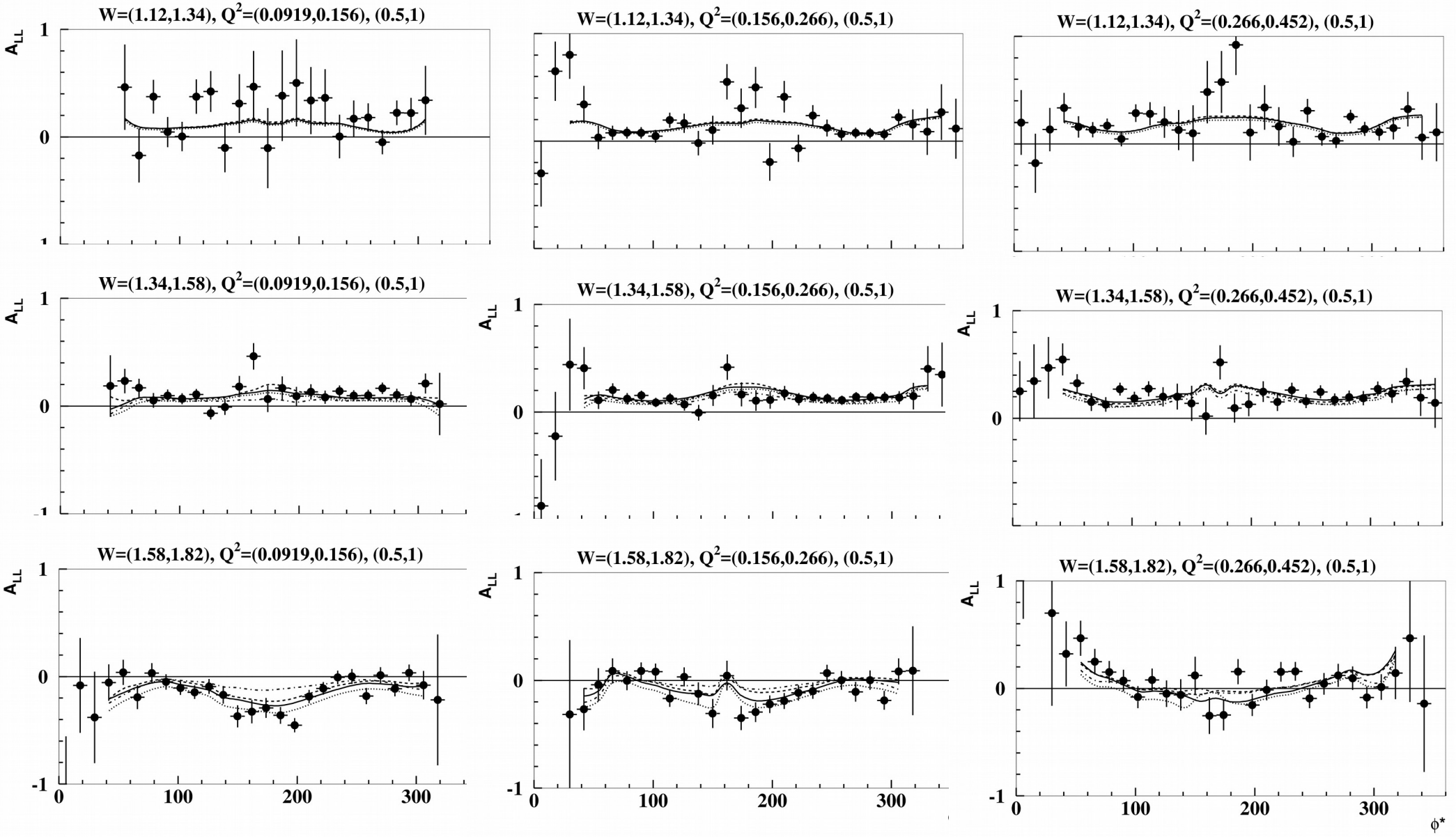
MAID2007 (solid) JANR(dashed)
SAID(dash-dotted) DMT(dotted)



3 Q2 bins

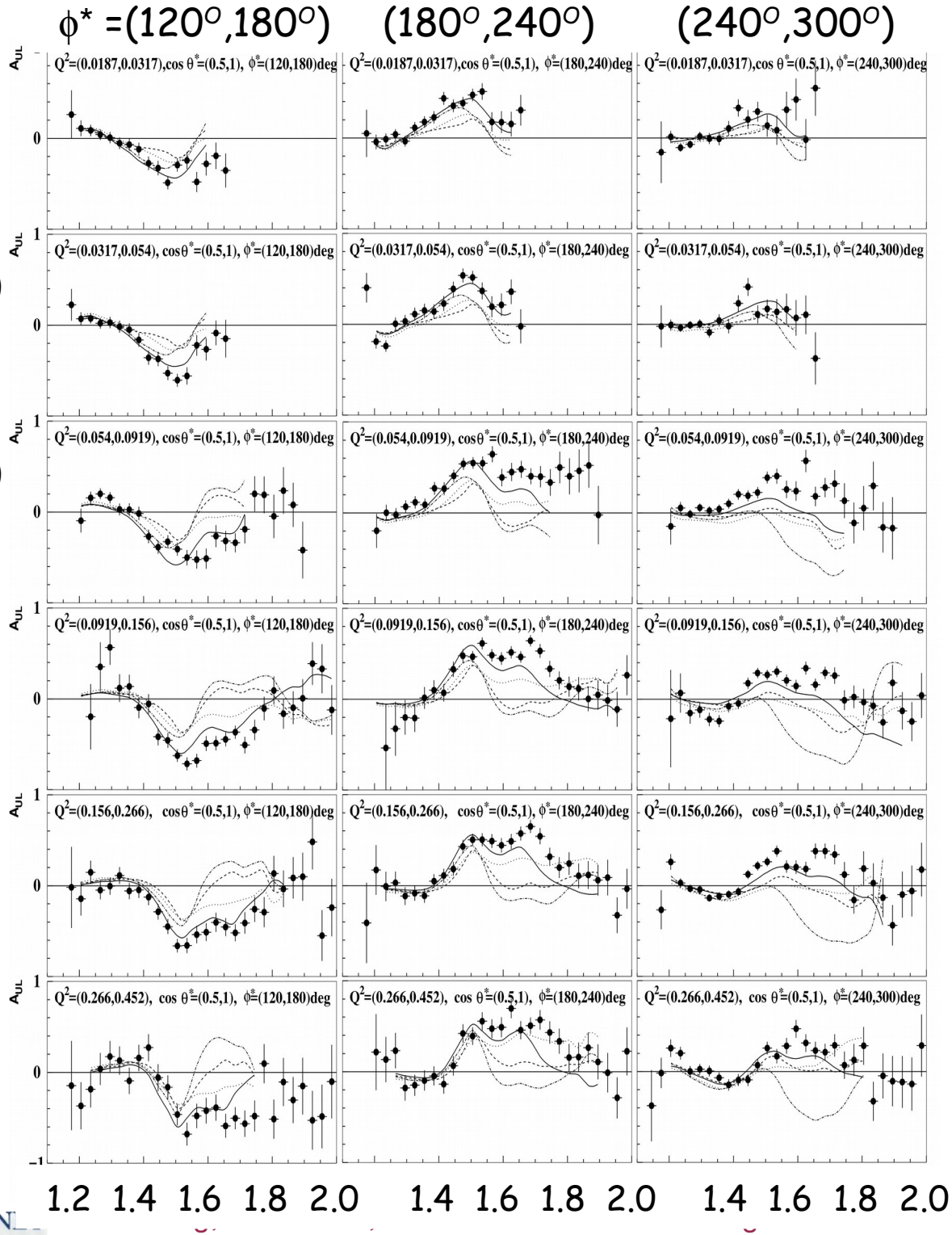
A_{LL} vs. ϕ^*

MAID2007 (solid) JANR(dashed)
SAID(dash-dotted) DMT(dotted)



3 Q2 bins

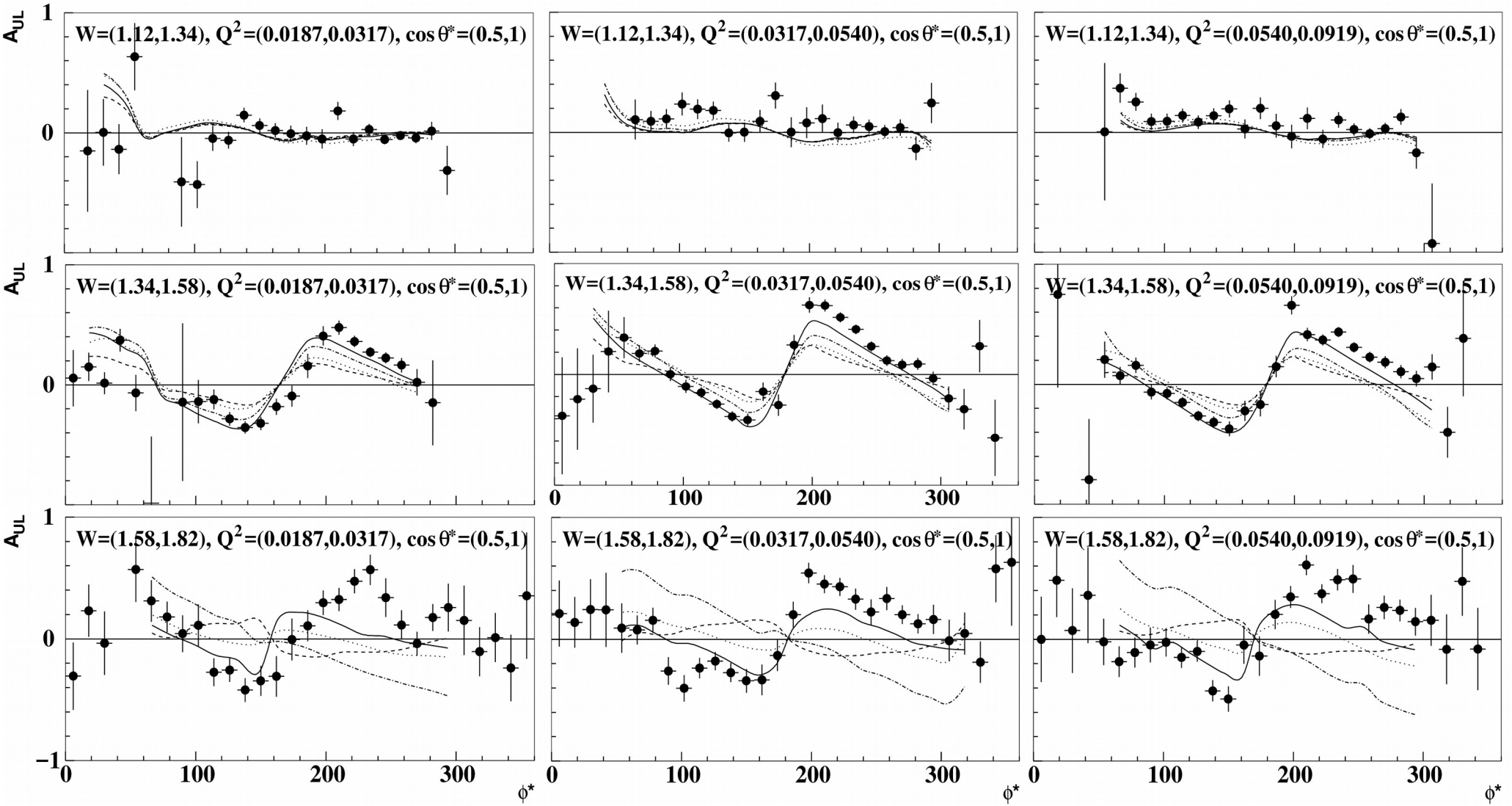
A_{UL} vs. W



MAID2007 (solid)
JANR(dashed)
SAID(dash-dotted)
DMT(dotted)

A_{UL} vs. ϕ^*

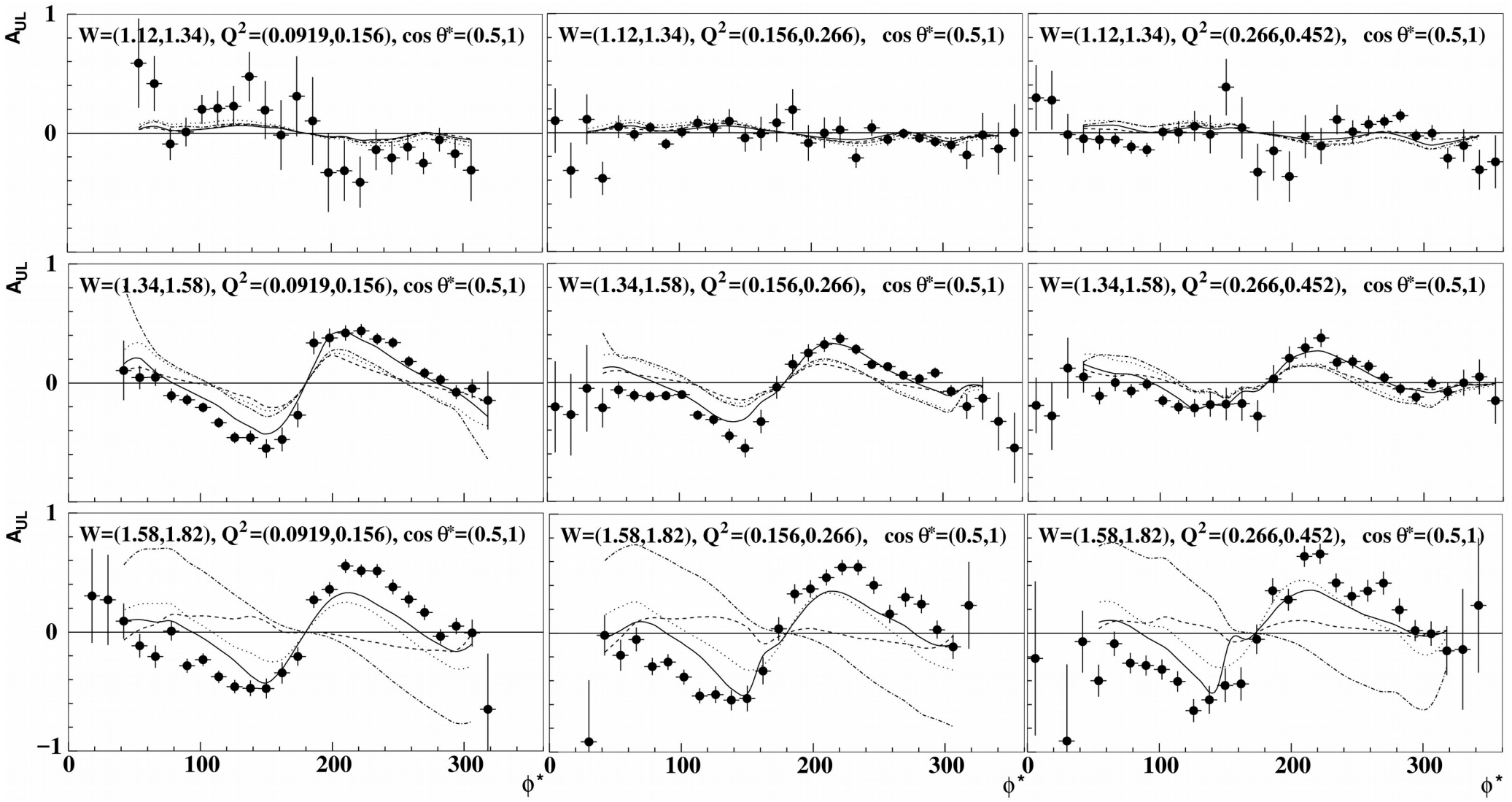
MAID2007 (solid) JANR(dashed)
SAID(dash-dotted) DMT(dotted)



3 Q2 bins

A_{UL} vs. ϕ^*

MAID2007 (solid) JANR(dashed)
SAID(dash-dotted) DMT(dotted)



3 Q2 bins

Summary

- Extracted asymmetry A_{LL}, A_{UL} for $\vec{e}\,\vec{p} \rightarrow e'\pi^{+}(n)$ from EG4's polarized NH3 data, down to Q^2=0.0064 GeV/c^2.
- A_{LL} agree very well with phenomenology calculations
- A_{UL} agree well with calculations for W<1.5 GeV/c^2, but calculations can improve for W>1.5 GeV/c^2 throughout all Q^2 measured, down to Q^2~0.02 (GeV/c)2
- Paper: collaboration-wide review is over, have accommodated all comments, working on improving the results figures and uploading all asymmetries to the CLAS database, almost ready to submit.
- This concludes the work of CAA HS-07-02
- Thank you!