The Double Spin Asymmetry in Exclusive π^+ Electro-production with CLAS

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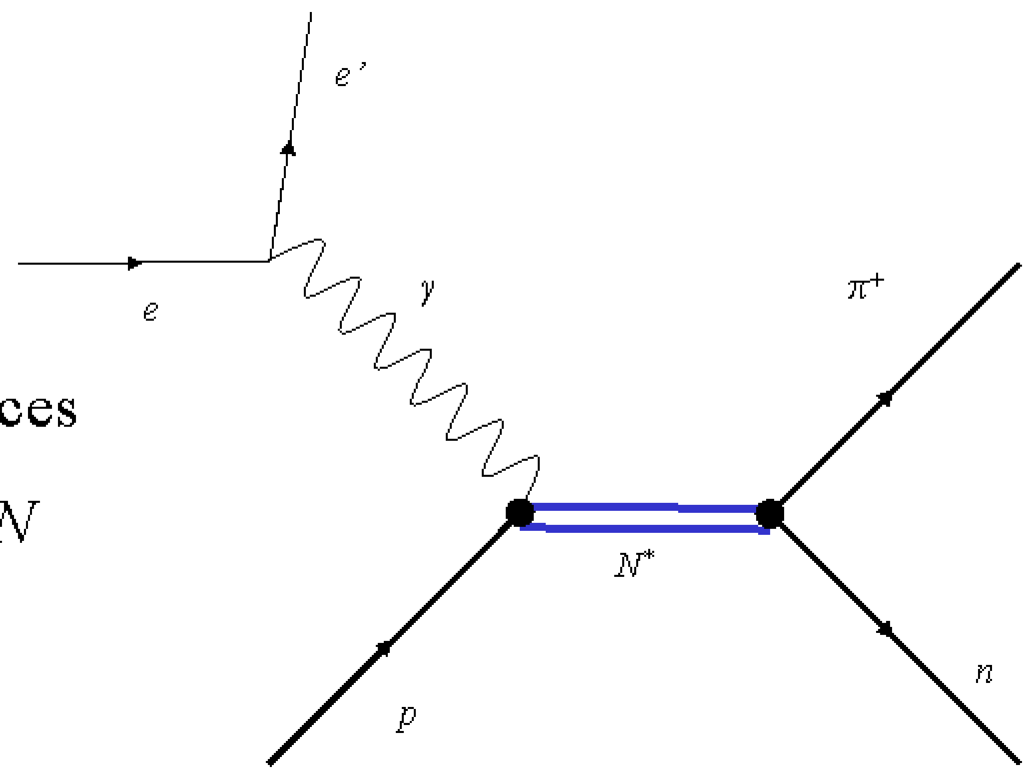
Single π^+ electro-production

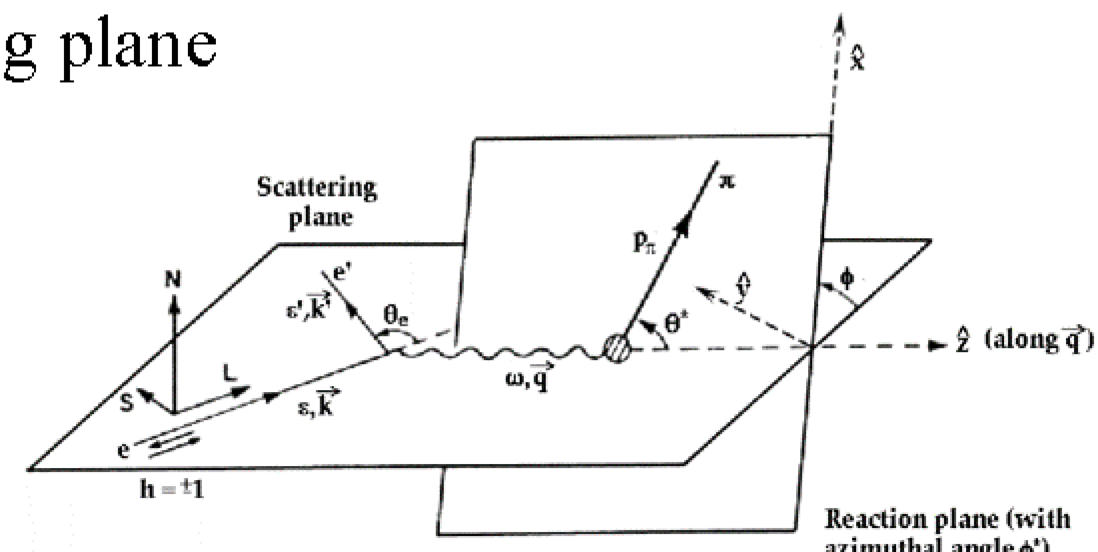
- Polarization dependence of the exclusive reaction
  - by measuring the asymmetry
- Measured as a function of four variables.
- Can give insight into the spin structure of the resonances
  - large branching ratios into πN
    - $P_{11}(1440)$
    - $D_{13}(1520)$
    - $F_{15}(1680)$
    - others

$$ep \rightarrow e\pi^+ N$$



Kinematic Variables

- W, Q^2, θ^*, and φ^*
  - θ^* and φ^* are calculated in the rest frame of the pion/neutron system
  - θ^* is the angle between the pion production angle and the four momentum transfer $\vec{q}$
  - φ^* is the angle between the lepton scattering plane and the hadron scattering plane



Cross Section

$$d\sigma = \frac{\varepsilon_i}{k_i}\frac{m_e}{\varepsilon_i}\frac{m_N}{E_i}\frac{m_e}{\varepsilon_f}\frac{d^3\mathbf{k_f}}{(2\pi)^3}\frac{1}{2E_\pi}\frac{d^3\mathbf{p}_\pi}{(2\pi)^3}\frac{d^3\mathbf{p_f}}{(2\pi)^3} *$$

$$2\pi\delta^{(4)}(p_i + q - p_\pi - p_f)\left|\langle p_f, p_\pi | J^\mu | p_i\rangle q^{-2}\langle k_f | j_\mu | k_i\rangle\right|^2$$

$$\frac{d\sigma}{dE'\, d\Omega_e d\Omega_\pi} = \Gamma \frac{d\sigma_v}{d\Omega_\pi}$$

← Virtual Photon Cross Section

Virtual Photon Flux →

$$\Gamma = \frac{\alpha}{2\pi^2}\frac{W^2 - m_p^2}{2m_p Q^2}\frac{E'}{E_0}$$

Response Functions

$$
\begin{aligned}
\frac{d\sigma_\nu}{d\Omega_\pi} &= \frac{|\vec{q}|}{q_\gamma^{CM}}[R_T + P_y R_T^y + \epsilon_L (R_L + P_y R_L^y) \\
&+ \sqrt{2\epsilon_L(1+\epsilon)}((R_{LT} + P_y R_{LT}^y)\cos\phi^* + (P_x R_{LT}^x + P_z R_{LT}^z)\sin\phi^*) \\
&+ \epsilon((R_{TT} + P_y R_{TT}^y)\cos 2\phi^* + (P_x R_{TT}^x + P_z R_{TT}^z)\sin 2\phi^*) \\
&+ h\sqrt{2\epsilon_L(1-\epsilon)}((R_{LT'} + P_y R_{LT'}^y)\sin\phi^* + (P_x R_{LT'}^x + P_z R_{LT'}^z)\cos\phi^*) \\
&+ h\sqrt{1-\epsilon^2}(P_x R_{TT'}^x + P_z R_{TT'}^z)]
\end{aligned}
$$

$$
(P_x, P_y, P_z) = P_t(\sin\theta_\gamma \cos\phi^*, -\sin\theta_\gamma \sin\phi^*, \cos\theta_\gamma)
$$

$$
\begin{aligned}
\frac{d\sigma_{et}}{d\sigma_0} &= \sqrt{2\varepsilon_L(1-\varepsilon)}\left[\sin\theta_\gamma\left(R_{LT'}^x \cos^2\phi^* - R_{LT'}^y \sin^2\phi^*\right) + R_{LT'}^z \cos\theta_\gamma \cos\phi^*\right] \\
&+ \sqrt{1-\varepsilon^2}\left[R_{TT'}^x \sin\theta_\gamma \cos\phi^* + R_{TT'}^z \cos\theta_\gamma\right]
\end{aligned}
$$

Cross Section (cont.)

$$\frac{d\sigma_v}{d\Omega_\pi^*} = \frac{|\mathbf{q}|}{q_\gamma^{CM}} \left\{ \frac{d\sigma_0}{d\Omega_\pi^*} + P_B \frac{d\sigma_e}{d\Omega_\pi^*} + P_T \frac{d\sigma_t}{d\Omega_\pi^*} - P_B P_T \frac{d\sigma_{et}}{d\Omega_\pi^*} \right\}$$

Polarization independent part of cross section

Part of the cross section that depends on both beam and target polarization

$$\frac{\sigma_{et}}{\sigma_0} = A_{et} = \frac{(\sigma(+,-)-\sigma(+,+))+(\sigma(-,+)-\sigma(-,-))}{\sigma(+,+)+\sigma(-,-)+\sigma(+,-)+\sigma(-,+)}$$

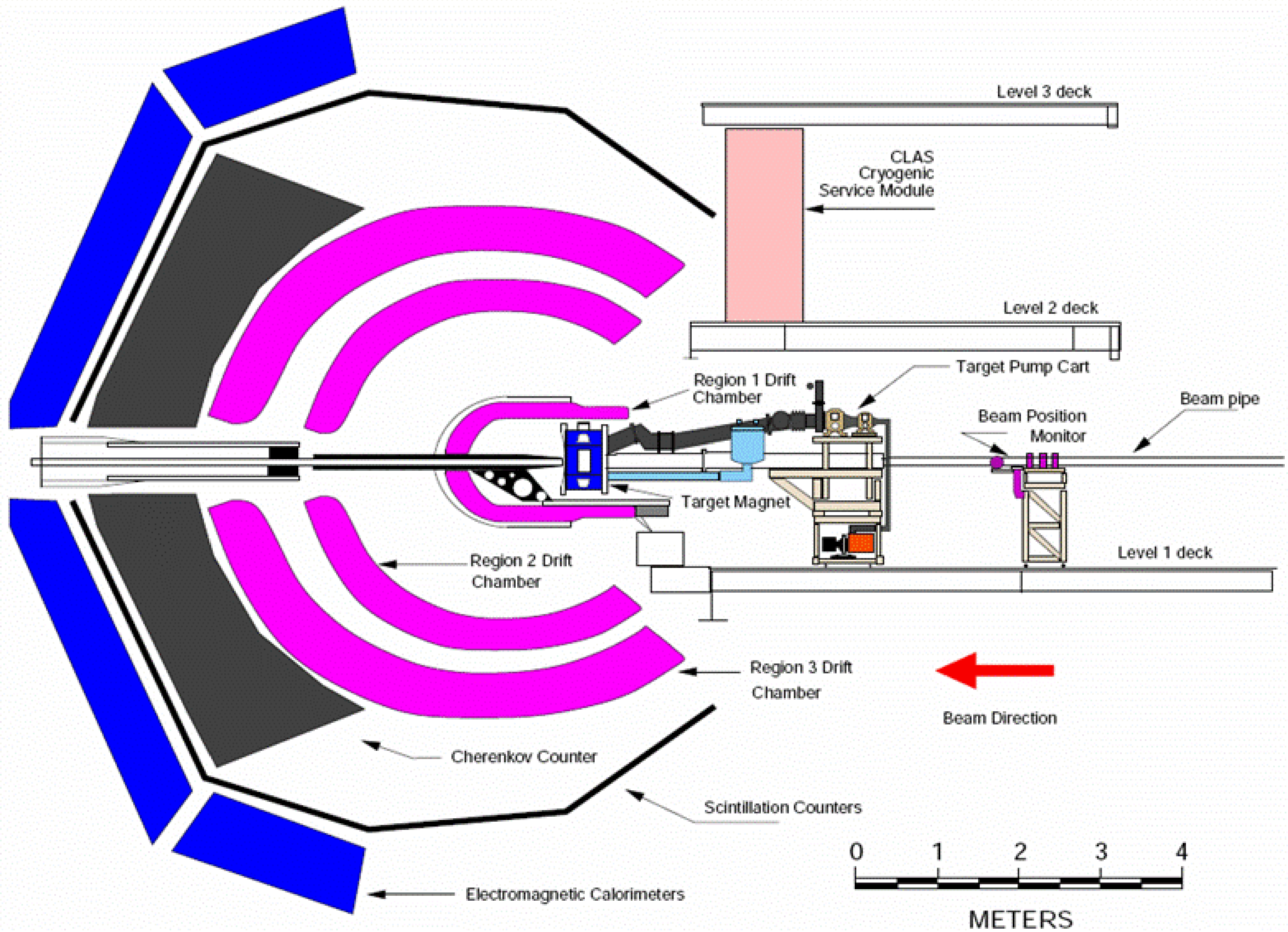
Double spin Asymmetry

$$A_{et} = \frac{1}{f_D P_B^{\uparrow} P_T^{\downarrow}} \frac{N'_{\downarrow\uparrow} - N'_{\uparrow\uparrow} + r_B \left(N'_{\uparrow\downarrow} - N'_{\downarrow\downarrow}\right)}{N'_{\downarrow\uparrow} + N'_{\uparrow\uparrow} + r_T \left(N'_{\uparrow\downarrow} + N'_{\downarrow\downarrow}\right)}$$

eg1b aka EG2000

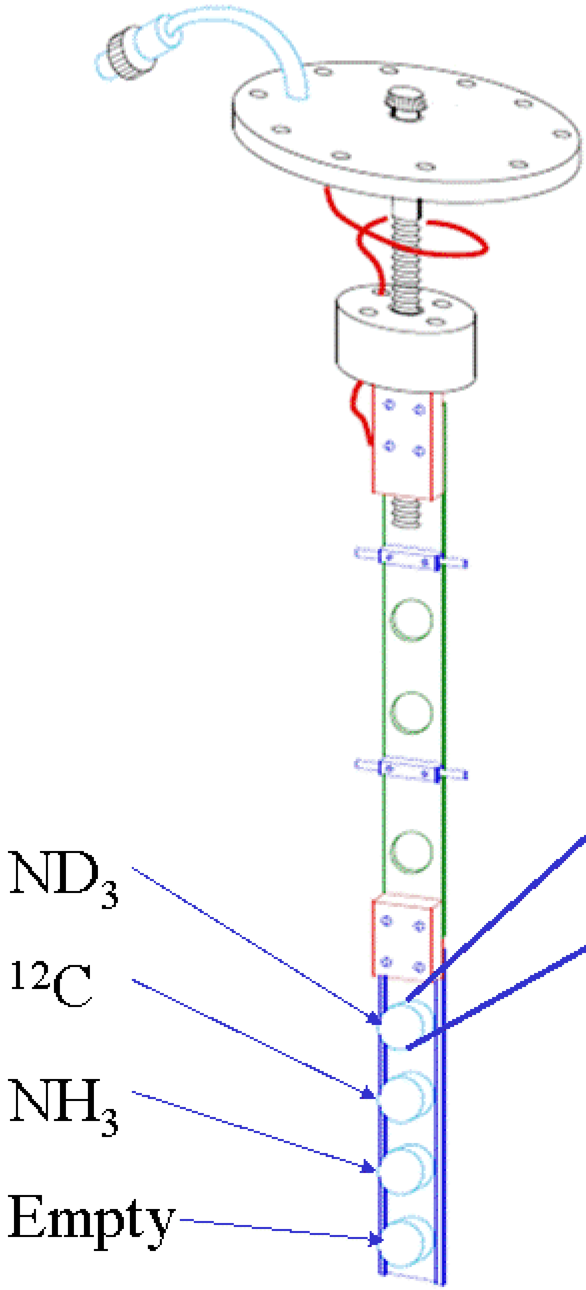
- Hall B at Jefferson Lab (CLAS)
- Polarized electron beam
  - Four different beam energies (1.6, 2.5, **4.2**, 5.6 GeV)
- Polarized nuclear target
  - Polarized NH_3 as a proton target
  - Polarized ND_3 as an effective neutron target
  - Carbon and Nitrogen targets for background studies

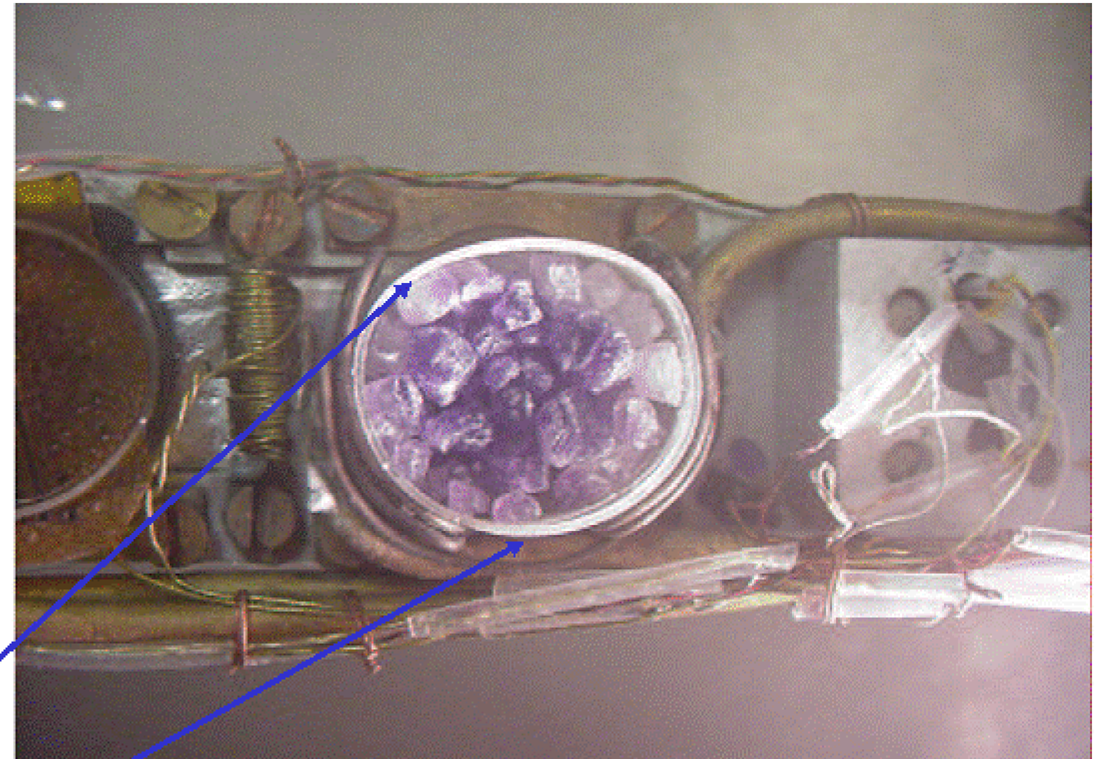
EG1 Target in CLAS



CEBAF Large Acceptance Spectrometer

Polarized Target





- DNP used to polarize target
  - Super-conducting magnet (5T)
  - Microwaves (140 GHz)
  - He evaporation refrigerator (1K)

Asymmetry Instead of Cross Sections

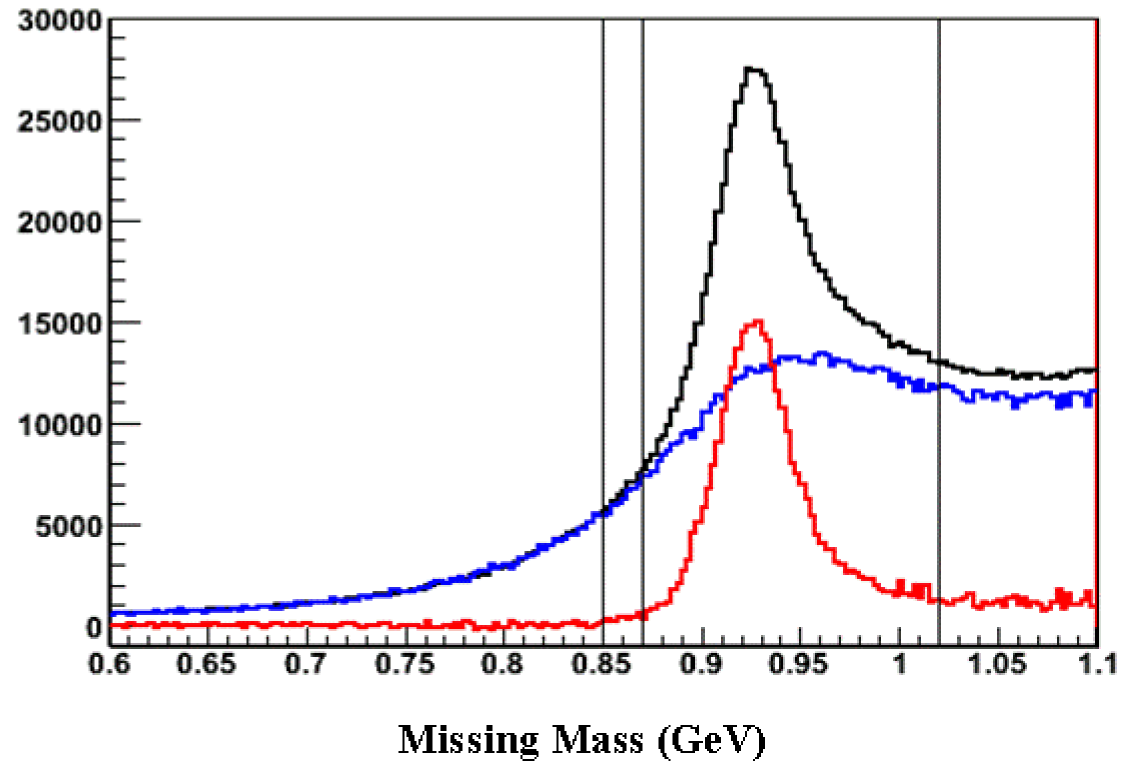
- Insensitive to acceptance
  - The acceptance cancels in the asymmetry
- Only relative luminosities are important
- Limited background contribution
  - Spin independent backgrounds enter as a dilution
- Interference terms allow relatively small quantities to be measured more easily

Asymmetry

- Fast flipping of electron helicity (pseudo-random sequence at 1 Hz)
  - Polarization is nearly identical for both helicities (~70%)
- Slow flipping of proton helicity (once per E_0)
  - Large, systematic difference in polarizations for different helicities (~70% with fairly large variations for two helicities)
- Define two data groups
  - Data taken with positive target helicity and data taken with negative target helicity
  - Data from the second group normalized by the ratio of the polarizations from the two groups.

Event Selection

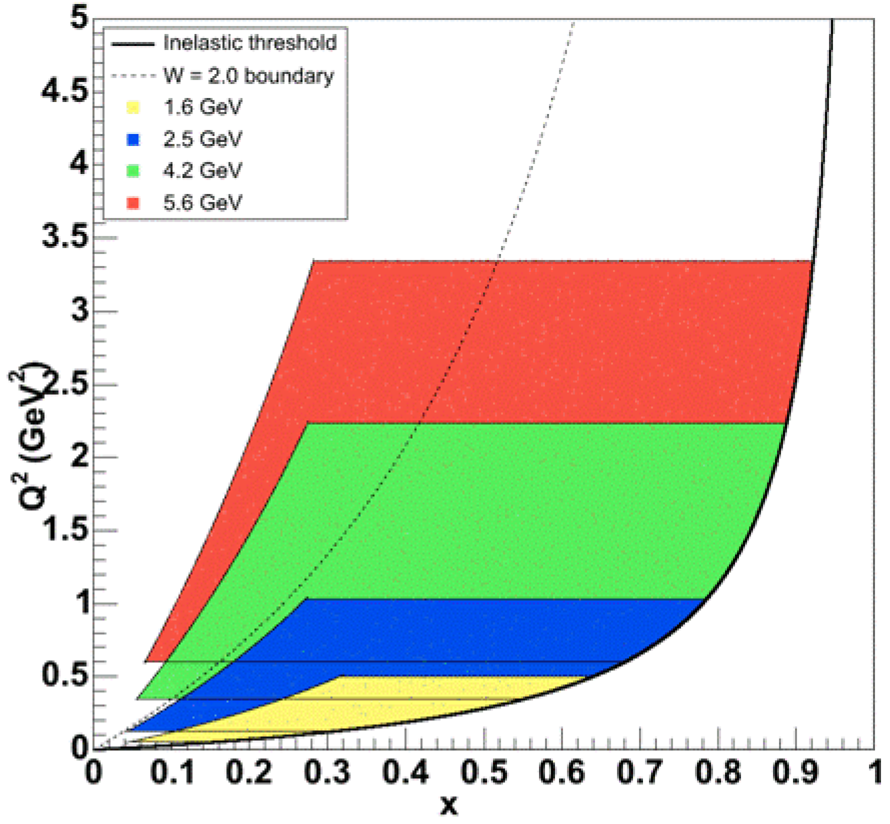
- Events require the detection of scattered electron and the pion
- Neutron not detected, but channel determined by a cut on missing mass of undetected particle



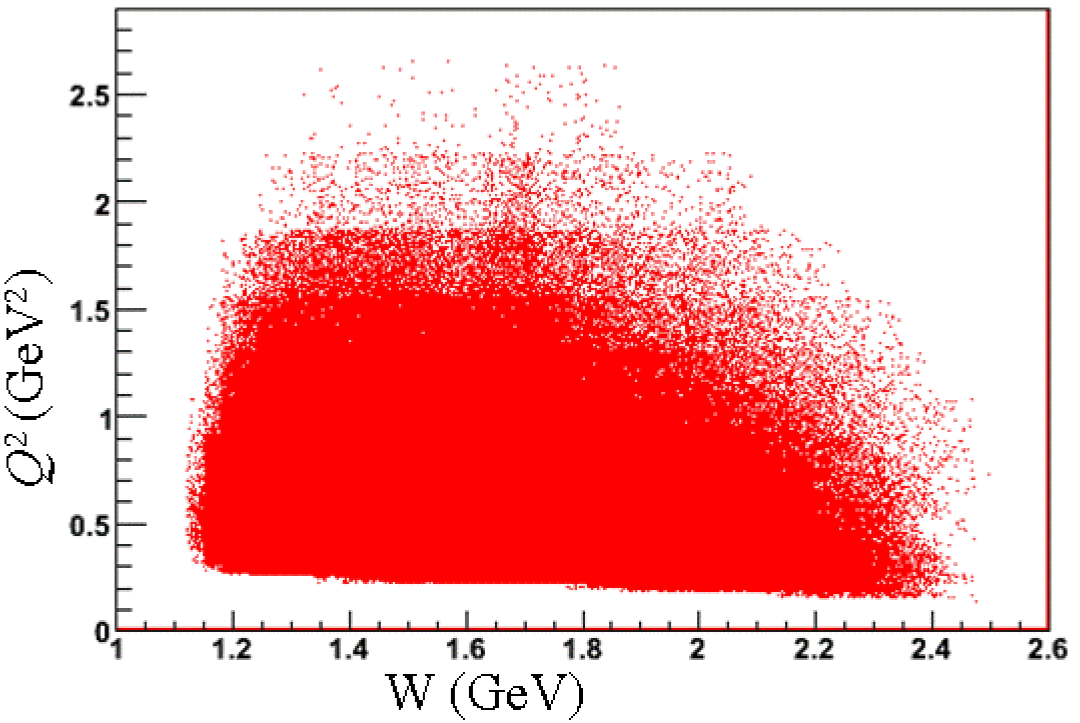
  - Necessary due to low efficiency in detection of neutrons

eg1b Kinematic Coverage

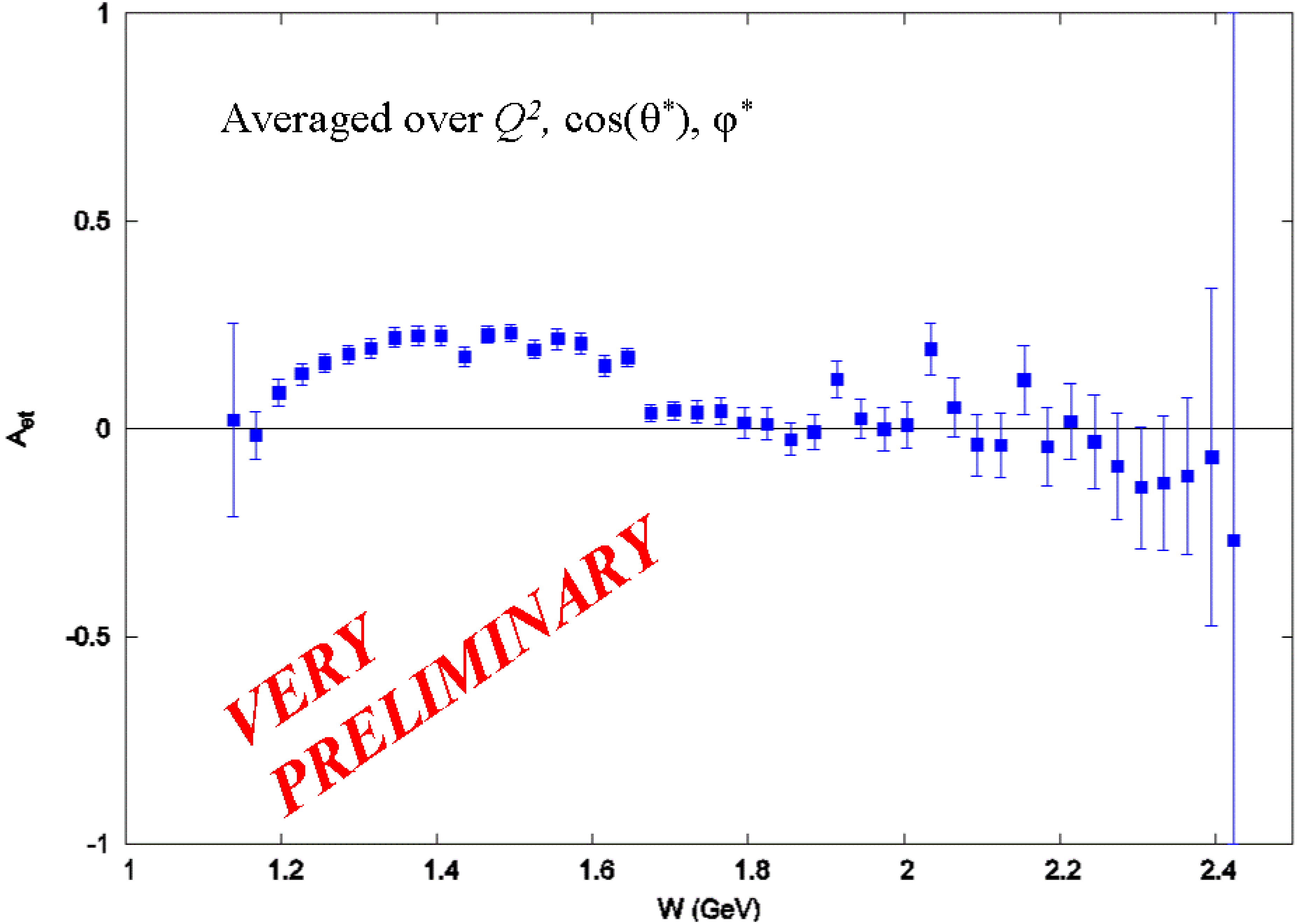
Coverage for inclusive events



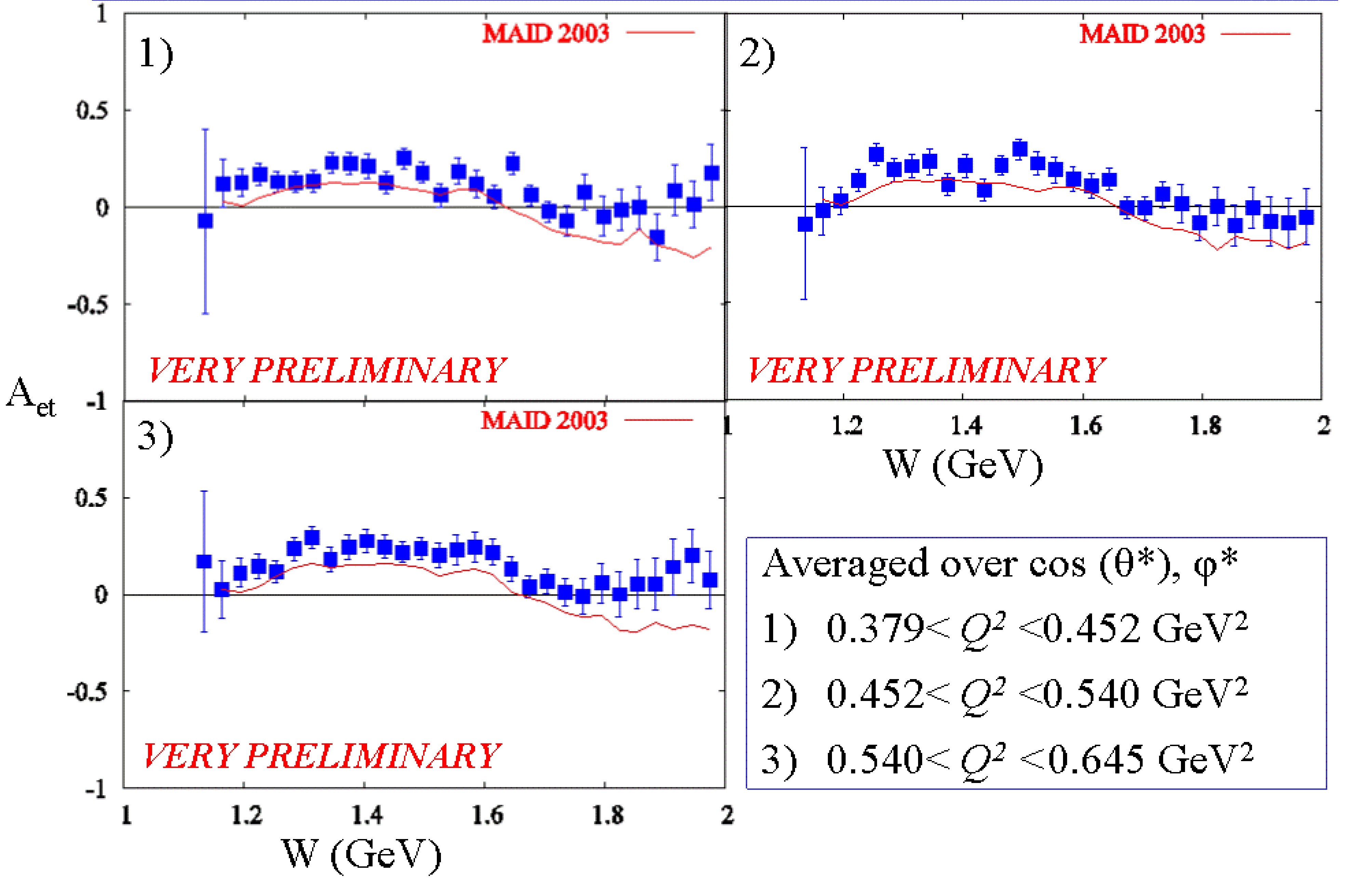
Coverage for exclusive **π**+ electro-production events. E_0=4.2GeV



A_{et} as a Function of W



A_{et} as a Function of W for fixed Q^2



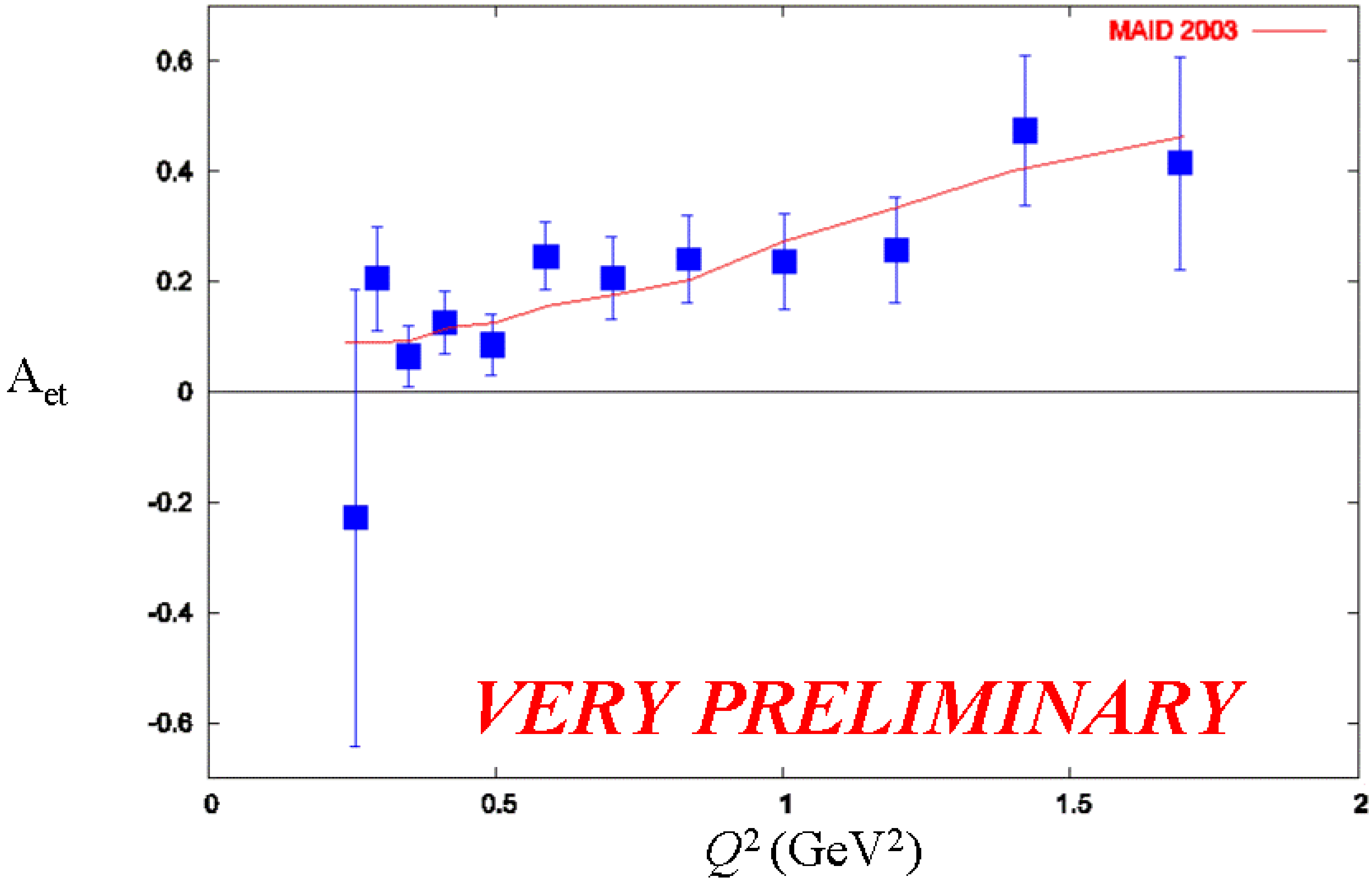
Averaged over cos (θ*), φ*

1) $0.379 < Q^2 < 0.452$ GeV^2

2) $0.452 < Q^2 < 0.540$ GeV^2

3) $0.540 < Q^2 < 0.645$ GeV^2

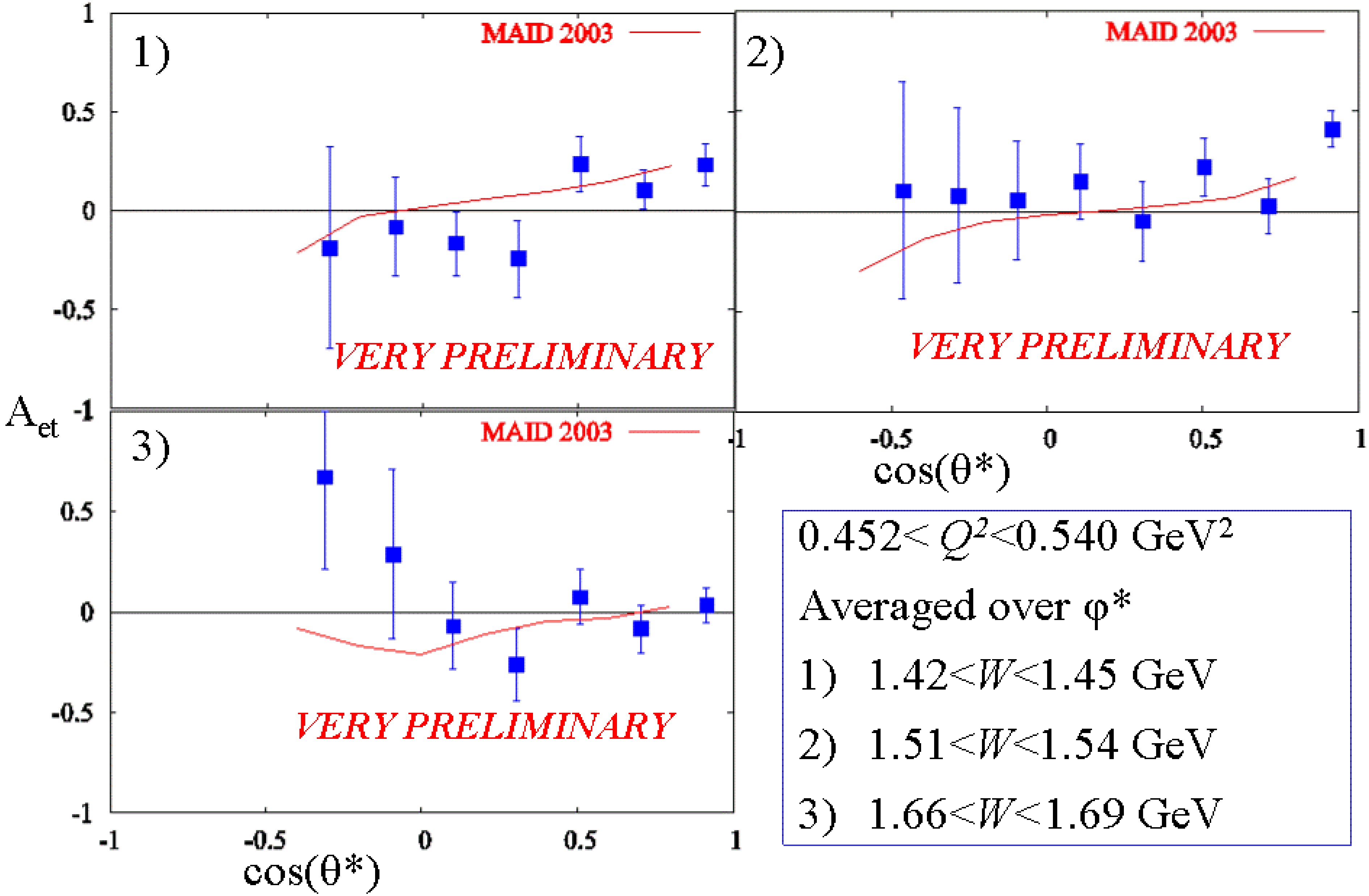
A_{et} as a Function of Q^2 for fixed W



Averaged over $\cos(\theta^*)$, φ^*

$1.420 < W < 1.450$ GeV

A_{et} as a Function of $\cos(\theta^*)$ for fixed W and Q^2



$0.452 < Q^2 < 0.540$ GeV^2

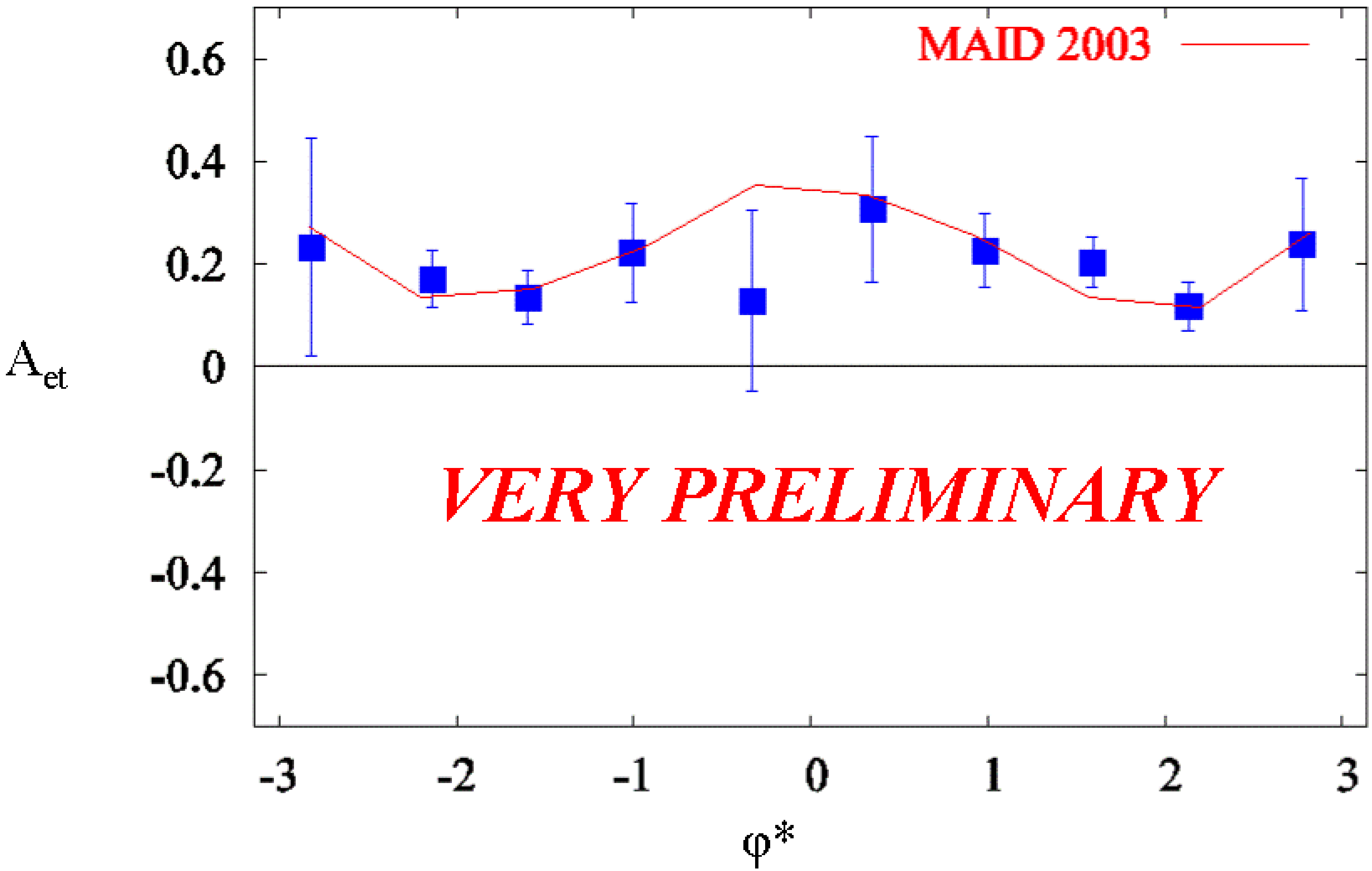
Averaged over φ^*

1) $1.42 < W < 1.45$ GeV

2) $1.51 < W < 1.54$ GeV

3) $1.66 < W < 1.69$ GeV

A_{et} as a Function of φ^* for fixed W



Averaged over Q^2, $\cos(\theta^*)$

$1.420<W<1.450$

Summary

- Spin Dependence of $ep \rightarrow e\pi^+ N$ is useful in determining the spin structure of the resonances
- The double spin asymmetry has been measured as a way to show this dependence
- The double spin asymmetry has been measured as a function of W, Q^2, θ^*, and φ^*
- Analysis of single spin asymmetries are also underway
- More energy settings, much more data
- Analysis of other channels