Exclusive Electroproduction of π^0 Mesons

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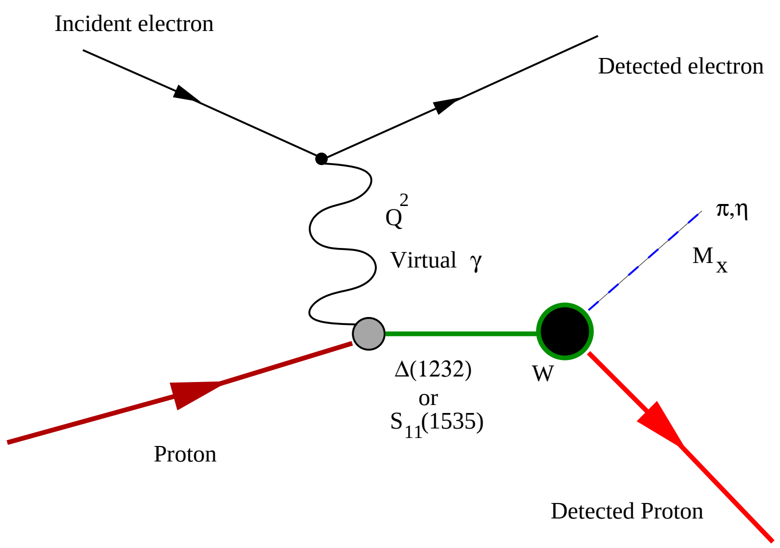
Overview

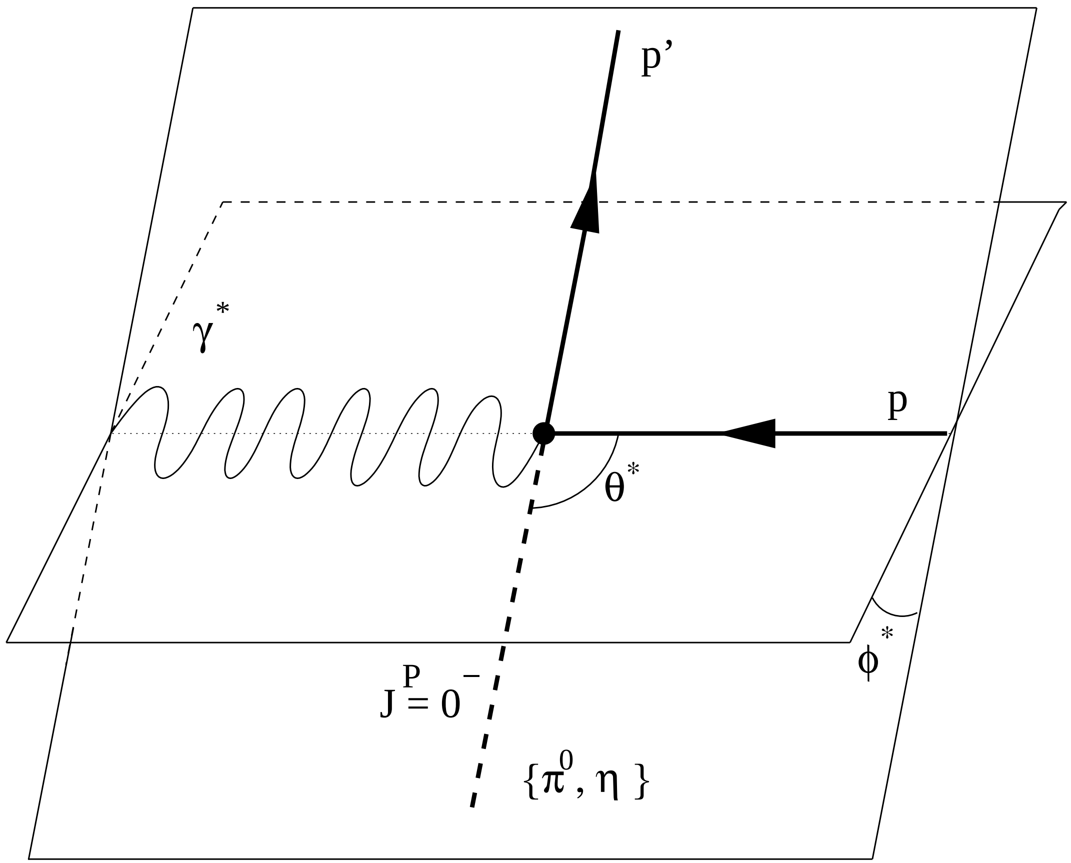
- Physical motivations
- Brief experimental overview
- Backgrounds, corrections, and data exclusions
- Differential cross sections

Exciting the Δ in E01-002



- Kinematic variables
  Q^2 = 6.3 GeV^2; 7.4 GeV^2
  W = Elastic $\rightarrow$ 1.8 GeV
- Single photon exchange
- Full angular coverage in COM

Center of Mass Kinematics



Center of Mass Cross Section

- The cross section can be written in the center of mass :

$$\frac{d\sigma}{dQ^2 dW d\Omega_{cm}} = \Gamma \frac{d\sigma_\nu}{d\Omega_{cm}}$$

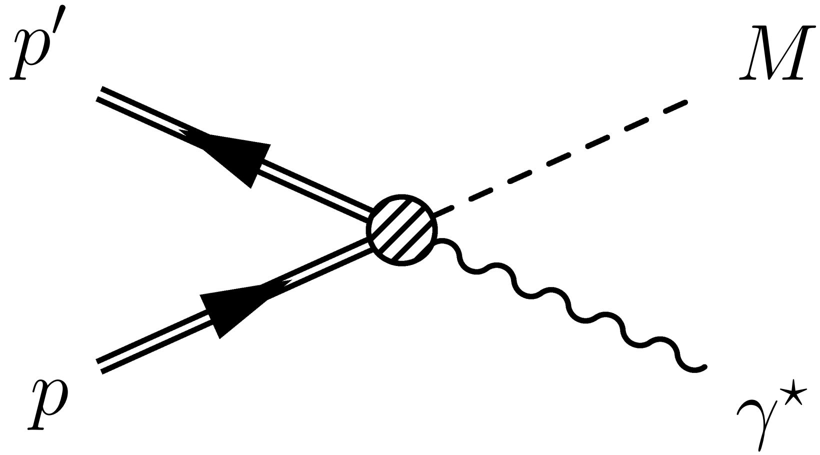
- The virtual photon flux factor Γ relates to kinematic quantites in center of mass

$$\Gamma = \frac{\alpha}{2\pi} \frac{E'}{E} \frac{W^2 - m_p^2}{2m_p Q^2} \frac{1}{1-\epsilon}$$

$$\epsilon = \frac{1}{1 + 2\tan^2\left(\frac{\theta_e}{2}\right)\frac{|\vec{q}|^2}{Q^2}}$$

- In *virtual* photoproduction one may have
  - virtual photons having "mass"
  - virtual photons having longitudinal polarization states

Virtual Photoproduction



- Virtual photoproduction amplitude can be written

$$\mathcal{M}_{ph} = \epsilon_\mu^\lambda \langle h_f | J^\mu_{had} | h_i \rangle$$

$$\frac{d\sigma}{d\Omega_{cm}} = \sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\phi^* + \sqrt{\frac{\epsilon(1+\epsilon)}{2}}\sigma_{LT}\cos\phi^*$$

Current Decomposition

- Current matrix element from virtual photoproduction amplitude can be decomposed

$$\langle p' M | J^\mu_{had} | p \rangle = i\bar{u}_f(p'_p)\gamma_5 \Big[\gamma^\mu \not{q} B_1 + (p_p + p'_p)^\mu B_2 + p_p^\mu B_3 + q^\mu B_4 + \gamma^\mu B_5 + (p_p + p'_p)^\mu \not{q} B_6 + q^\mu \not{q} B_7 + p_p^\mu \not{q} B_8 \Big] u_i(p_p)$$

- Scalar functions B_i can be expressed in terms of multipole expansions

$$B_1 \propto \sum_{l \geq 0} \left[(l M_{l+} + E_{l+}) P'_{l+1} + ((l+1) M_{l-} + E_{l-}) P'_{l-1} \right]$$

- Quantum numbers l and $\pm$ specify $J = |l \pm \frac{1}{2}|$ in final state

Multipoles from Atomic Physics

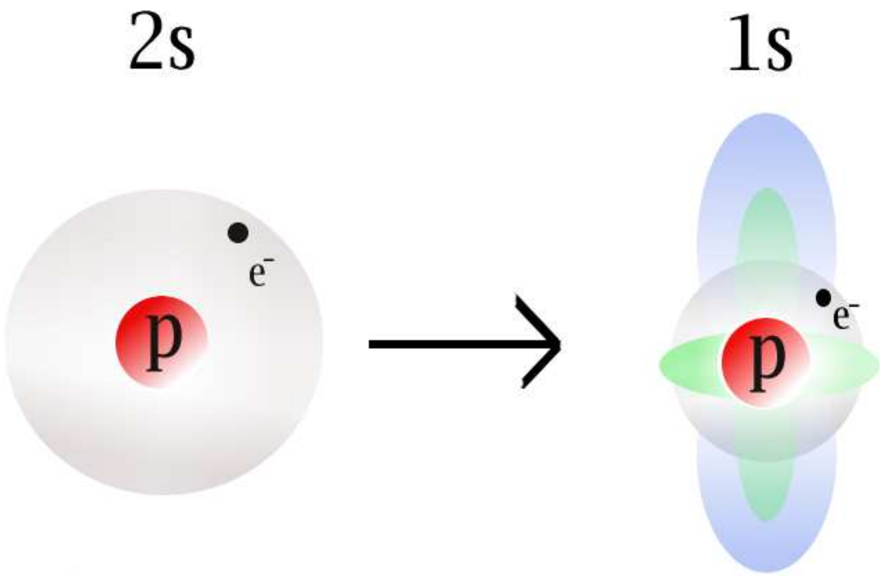
- Wave function of incident photon can be decomposed as vector spherical harmonics

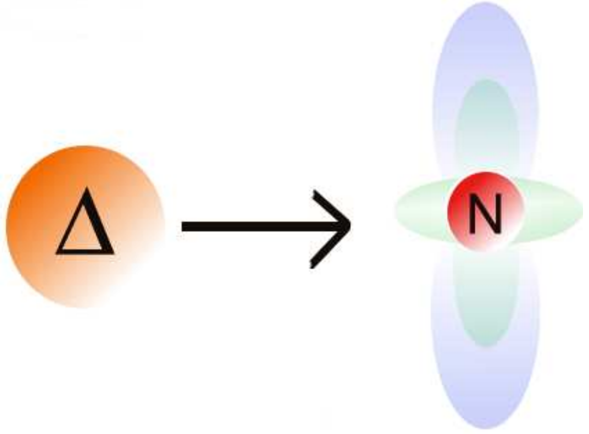
$$\mathbf{Y}_{\bar{l}LM} = \sum_{\nu} C(1\lambda, \bar{l}\nu|LM)\hat{e}_{\lambda} Y_{\bar{l}\nu}$$

- EL (electric) and CL (coulomb) type radiation are made of parity even combinations and ML (magnetic) is parity odd
- Since angular momentum is conserved one has $J = |l \pm \frac{1}{2}| = |L \pm \frac{1}{2}|$
- Parity arguments can then give the following relations
  $EL, CL : |L - l| = 1$

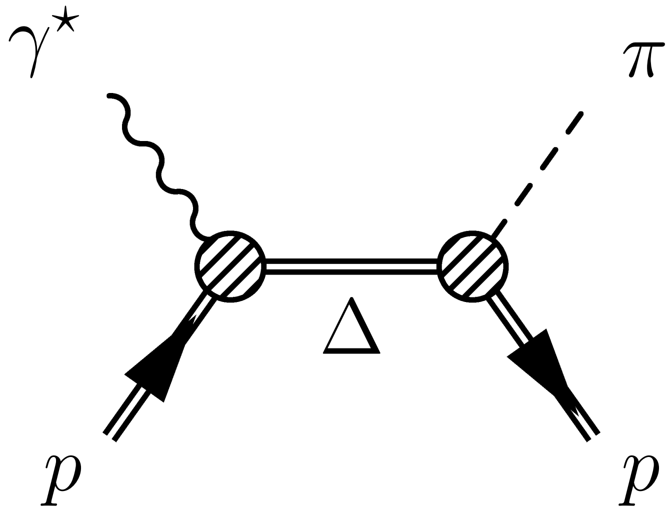
  $ML : L = l$

The Atomic Analog





Resonance Production (Δ)



- Restriction to Δ decreases the number of independent functions to three
- Functions can be represented:

$$G^{\pm,0} = \frac{1}{2M}\langle(\Delta), \lambda_{res}|\epsilon_\mu^{\pm,0} J^\mu_{had}|P, \lambda_p = \pm\frac{1}{2}\rangle$$

Multipole Definition

- Considering only Δ production reduces the number of multipoles

  $A_{\frac{1}{2}} \propto G^{+}$

  $A_{\frac{3}{2}} \propto G^{-}$

  $S_{\frac{1}{2}} \propto G^{0}$

- Also These can be related (through $E_{l\pm}$ and $M_{l\pm}$) to E2 and M1:

  $A_{\frac{1}{2}} = -\frac{1}{2}(M1 + 3E2)$

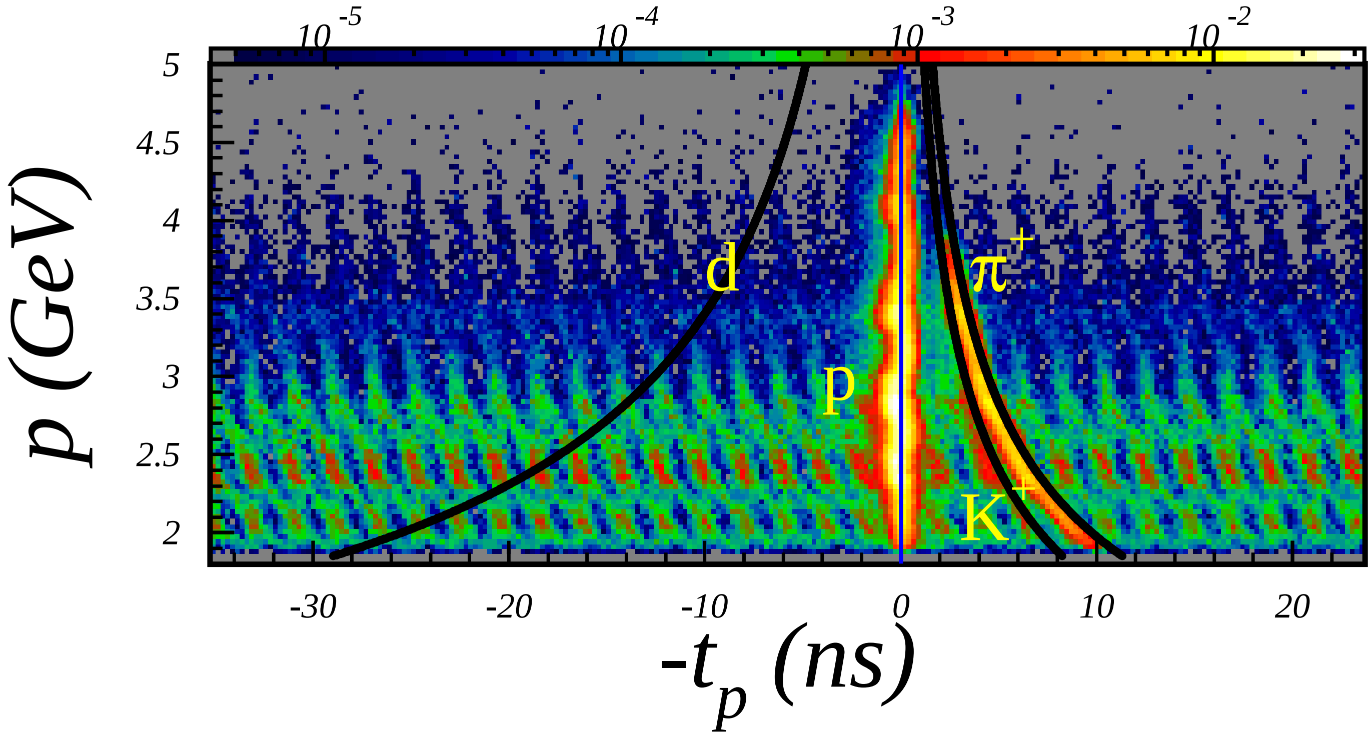
  $A_{\frac{3}{2}} = \frac{\sqrt{3}}{2}(E2 - M1)$

  $S_{\frac{1}{2}} = -C2$

Measurement and Prediction

- Measured Quantities
  - E_{1+}, M_{1+} and S_{1+} extracted for Δ
  - Above used to infer information about $\frac{E2}{M1}$
- Predictions
  - Perturbative QCD predicts that $\frac{E2}{M1} \rightarrow 1$ as Q^2 becomes large
  - Constituent quark model predicts $M1$ dominance because Δ transition is viewed as a simple spin flip excitation

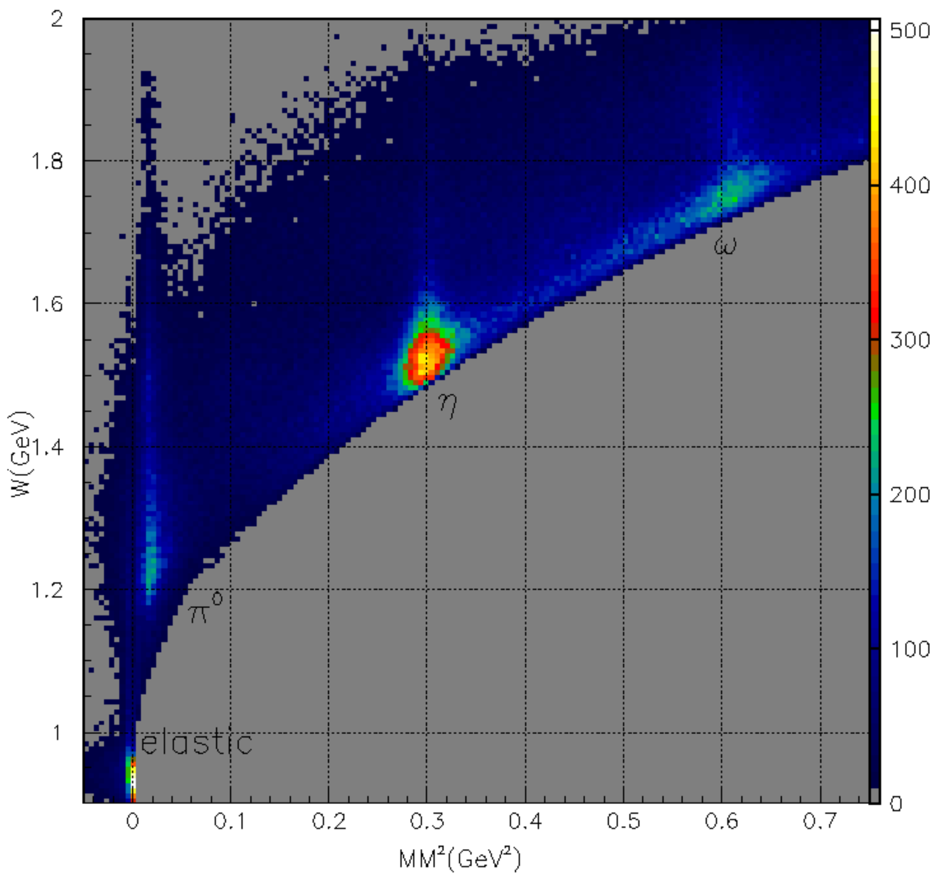
Particle Selection



- Clean separation of p and π^+ events
- Enough π^+ events for $\gamma^* p \to n\pi^+$

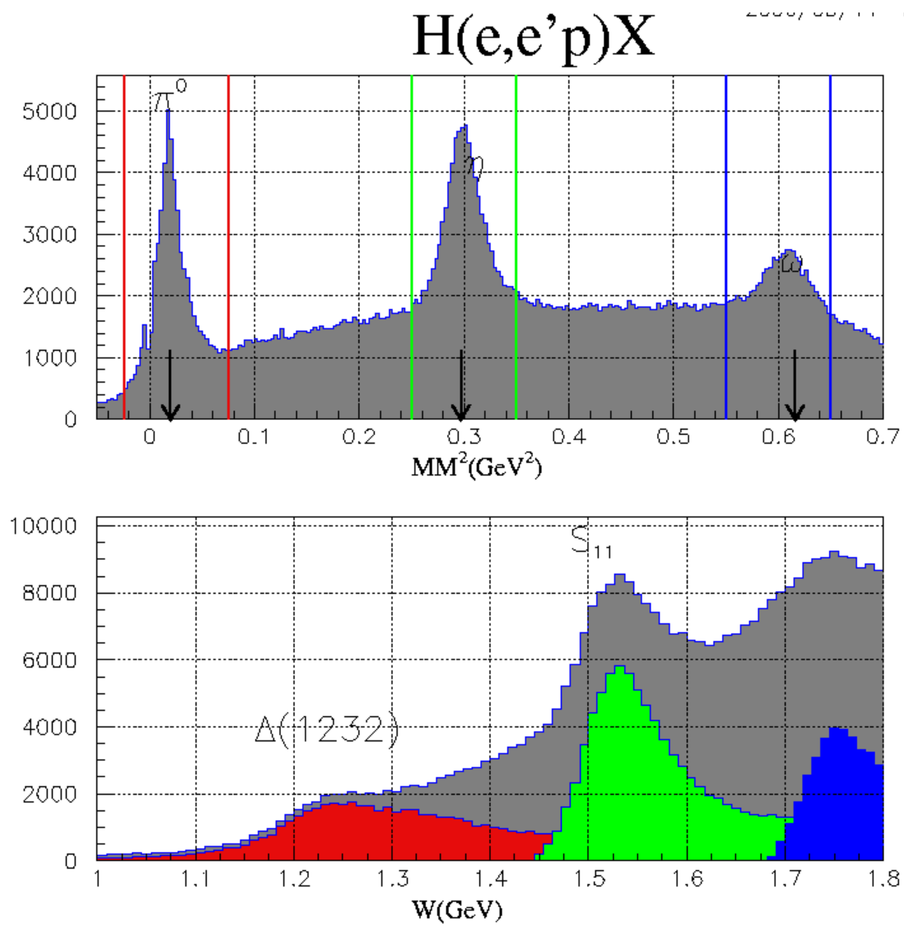
Baryon Resonances

- The $\Delta(1232)$ and S_{11} resonances are clearly correlated with the π^0 and η M_x^2 peaks
- The elastic events clearly come from lower W with some overlap into a higher W region due to pre or post radiation
- The ω meson comes from the largest W region for the experiment

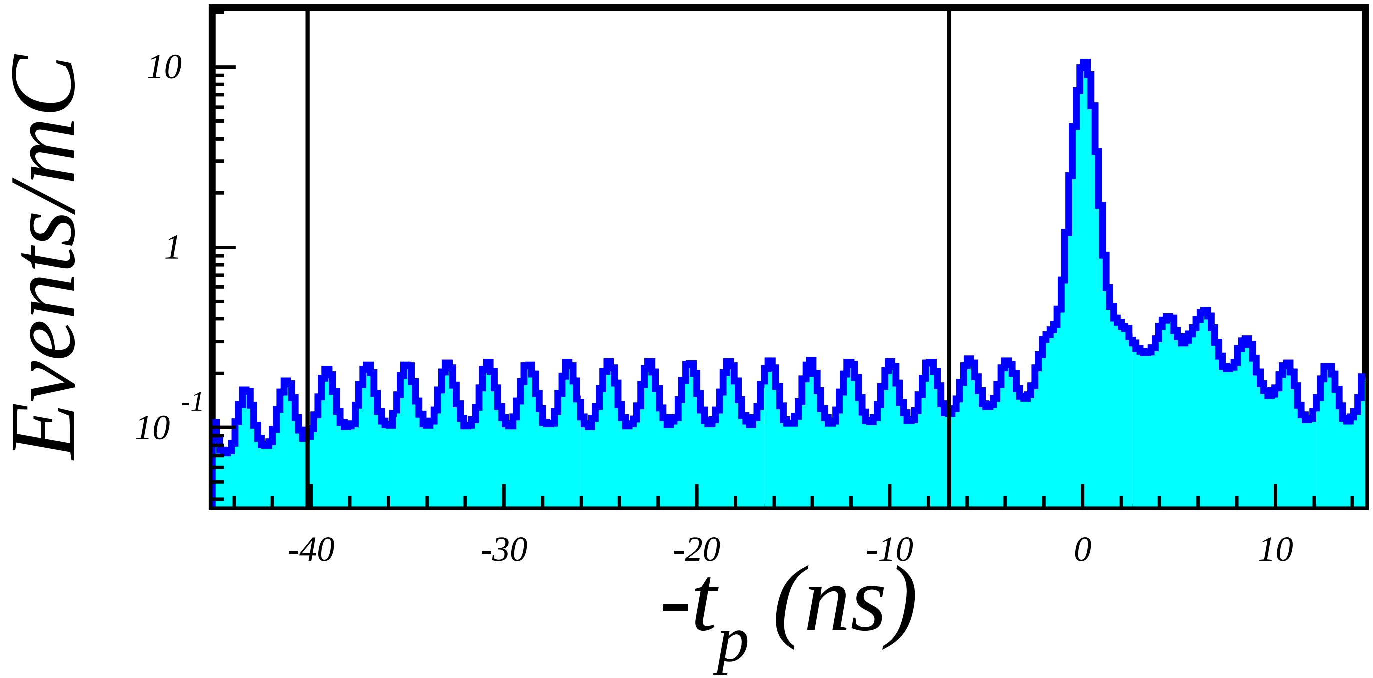


Exclusive Studies

- The M_x^2 peaks can be used to constrain the reaction and/or baryon resonance
- The M_x^2 resolution for the π^0 allows detailed study of the reaction $^1H(e,e'p)\pi^0$
- Exclusive cross sections and amplitudes will be compared to models and previous data

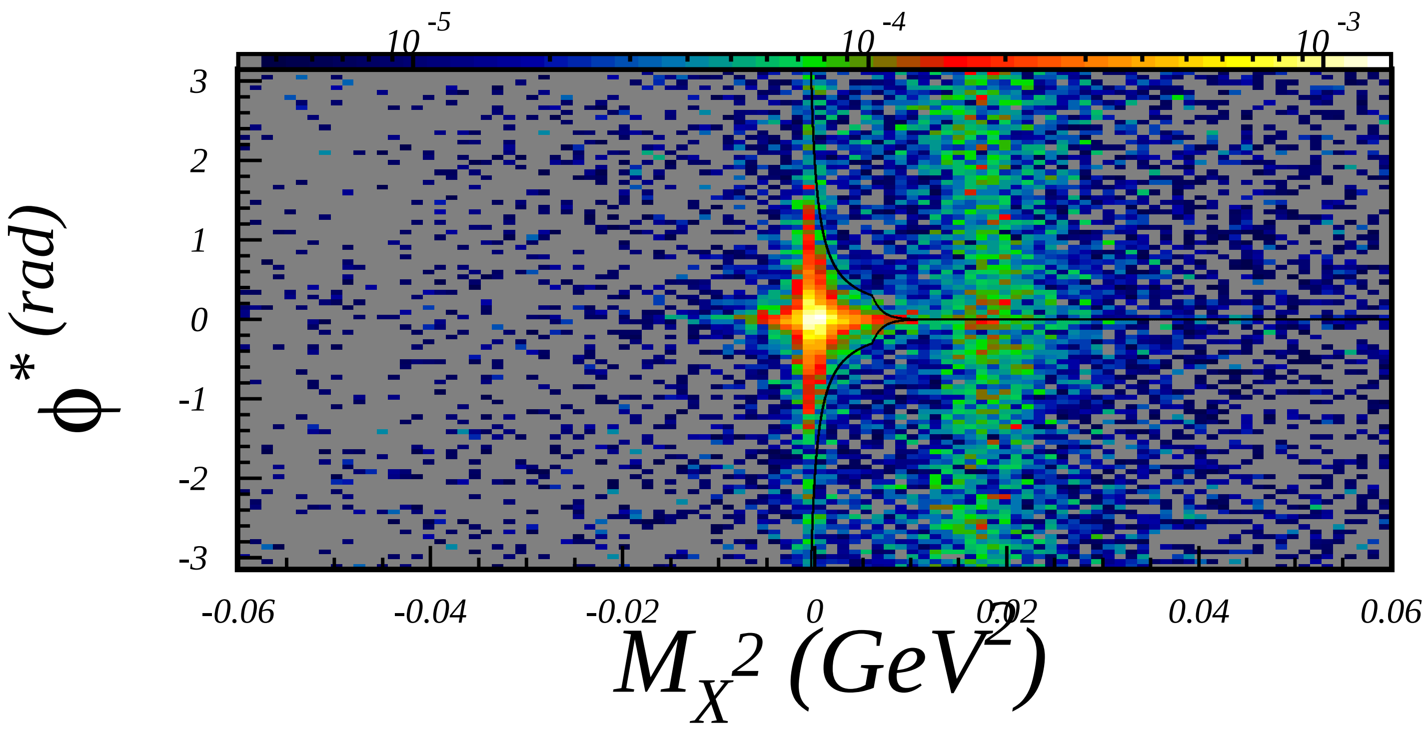


Accidental Corrections



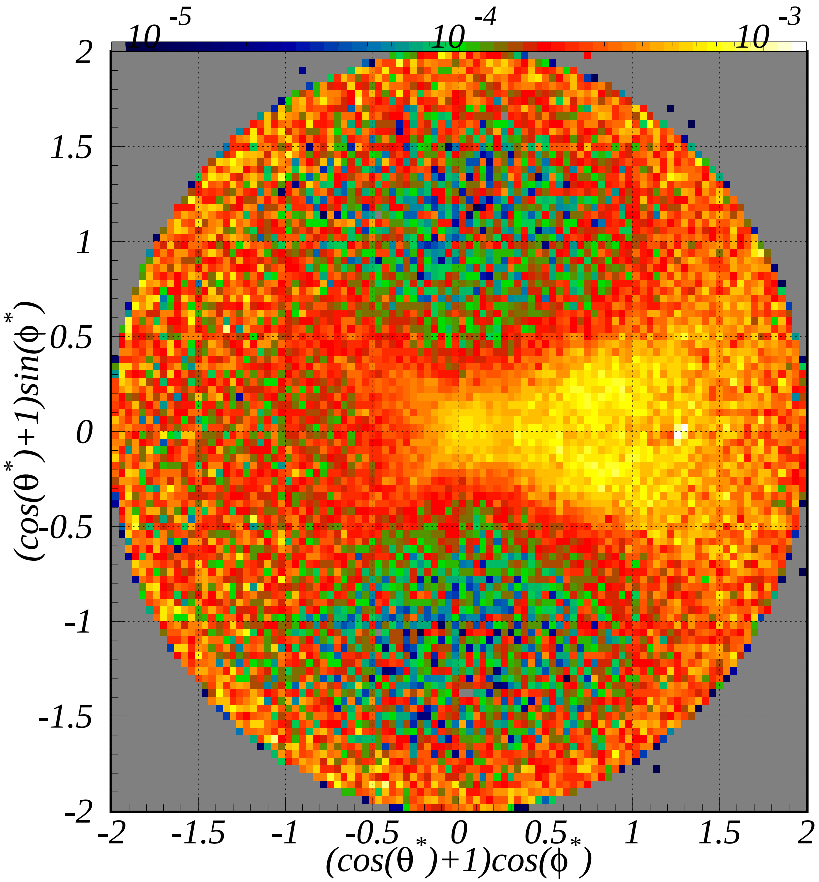
- Use the beam structure away from coincidence proton peak
- Extract angular distribution by above cut and subtract
- Low momentum hadrons dominate beam structure

Elastic Radiative



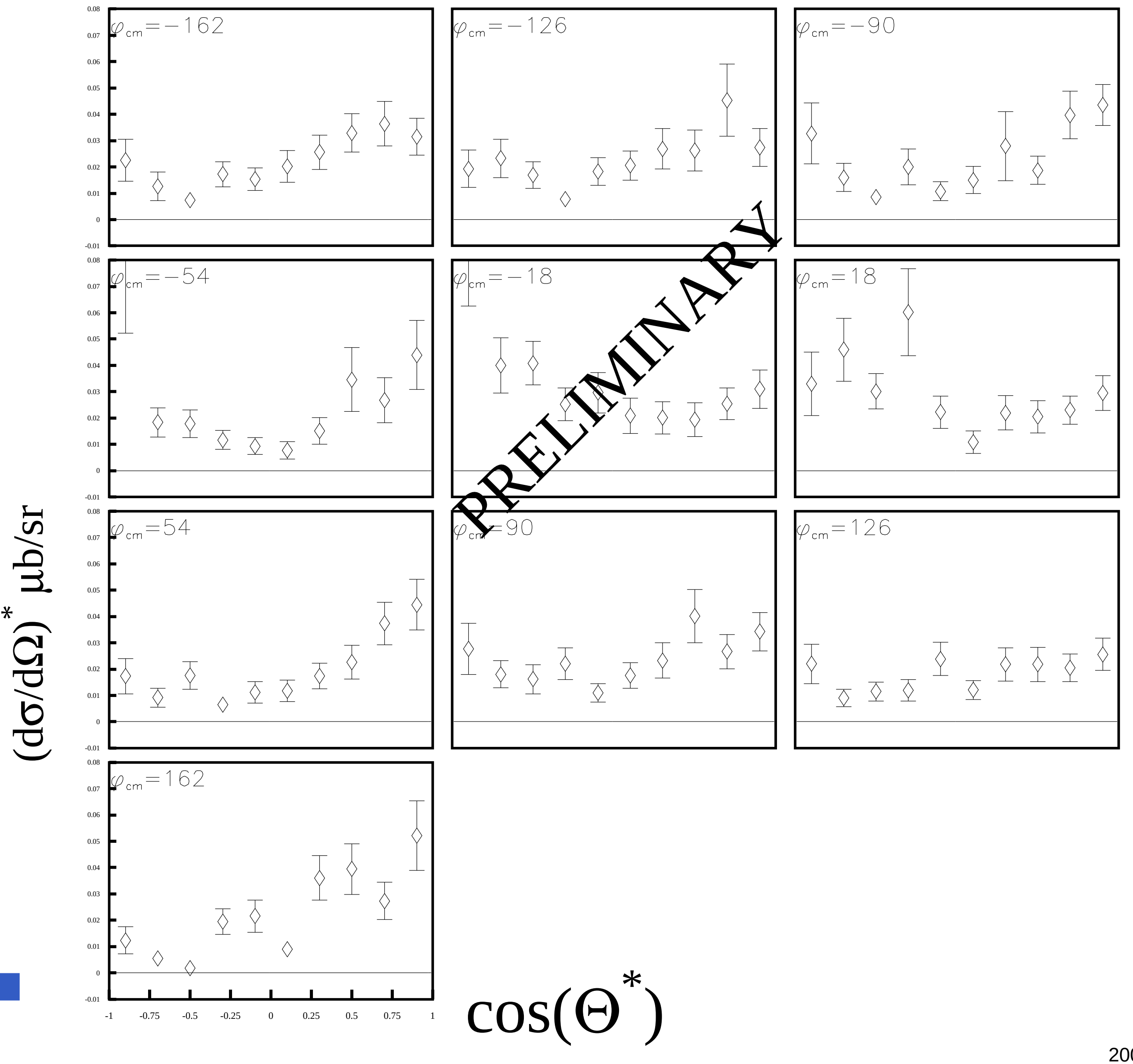
- Above example for $-1.0 \leq \cos\theta^* < -.6$
- For lowest $\cos\theta^*$ elastic radiative concentrated
- Use same form for other $\cos\theta^\star$ bins

Full Angular Coverage

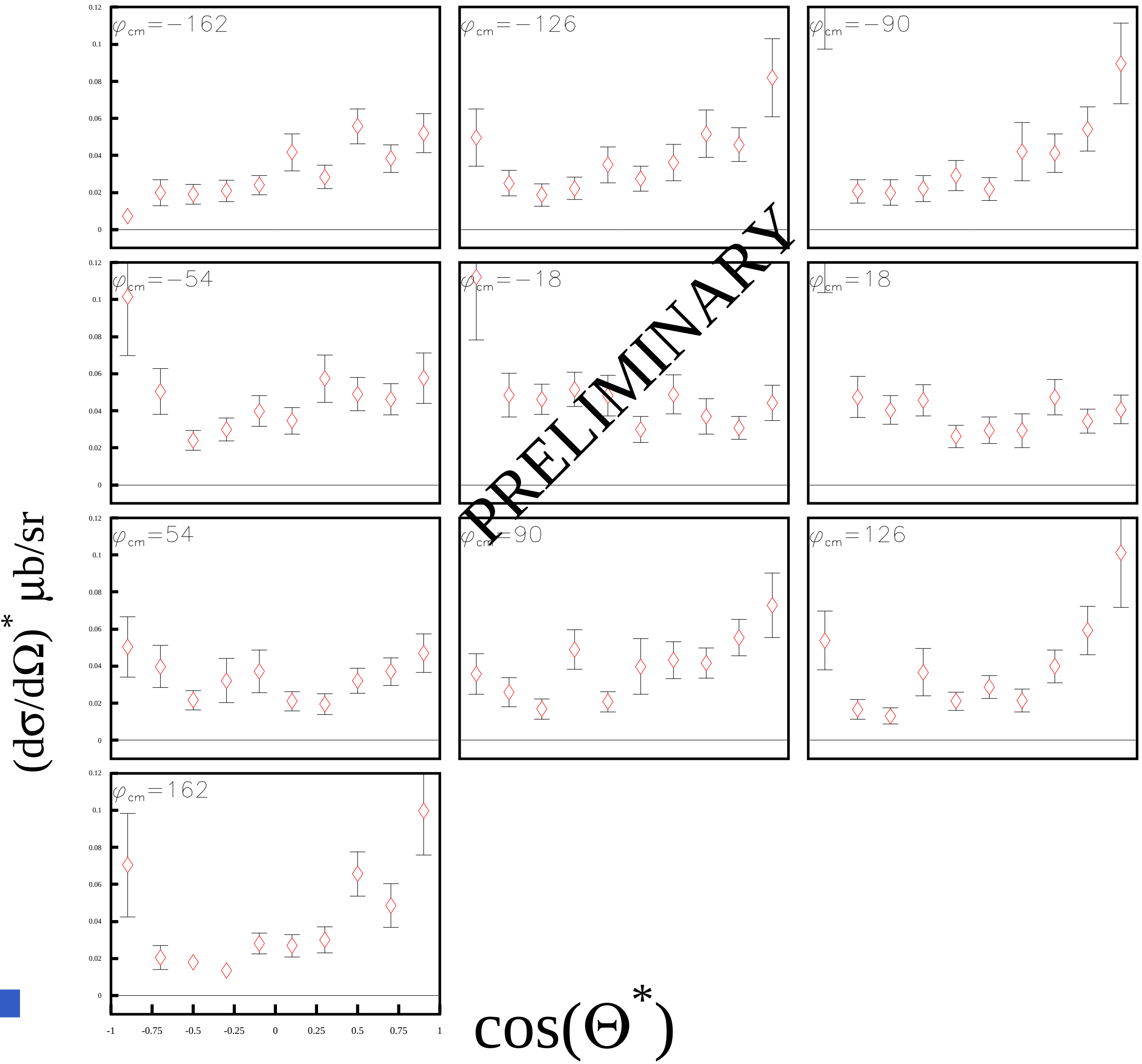


- Uniform coverage in the center of mass angles
- All W plotted
- Elastic radiative cut removes bad $\phi^* = 0$ data

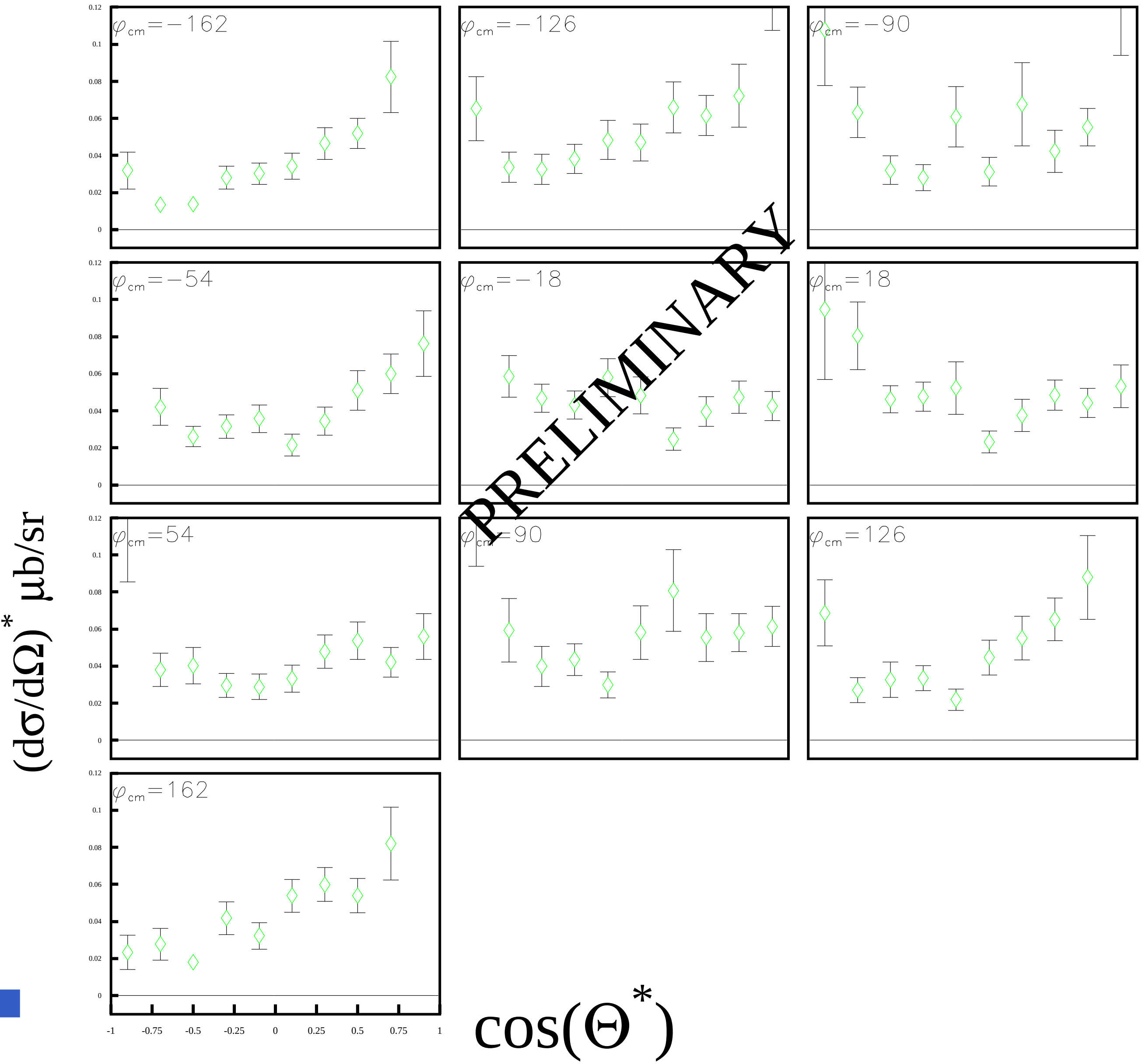
W=1.172 GeV ; 30 MeV Bin ; Q^2=6.3



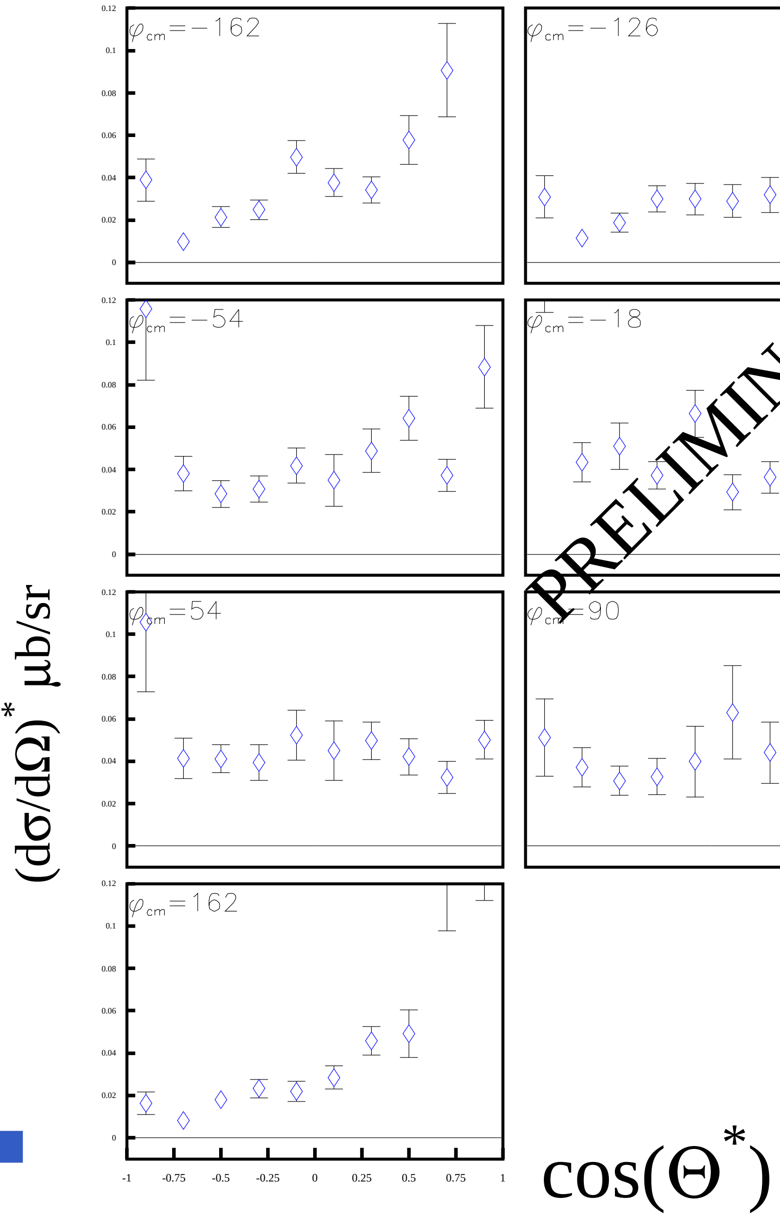
W=1.202 GeV ; 30 MeV Bin ; Q^2=6.3



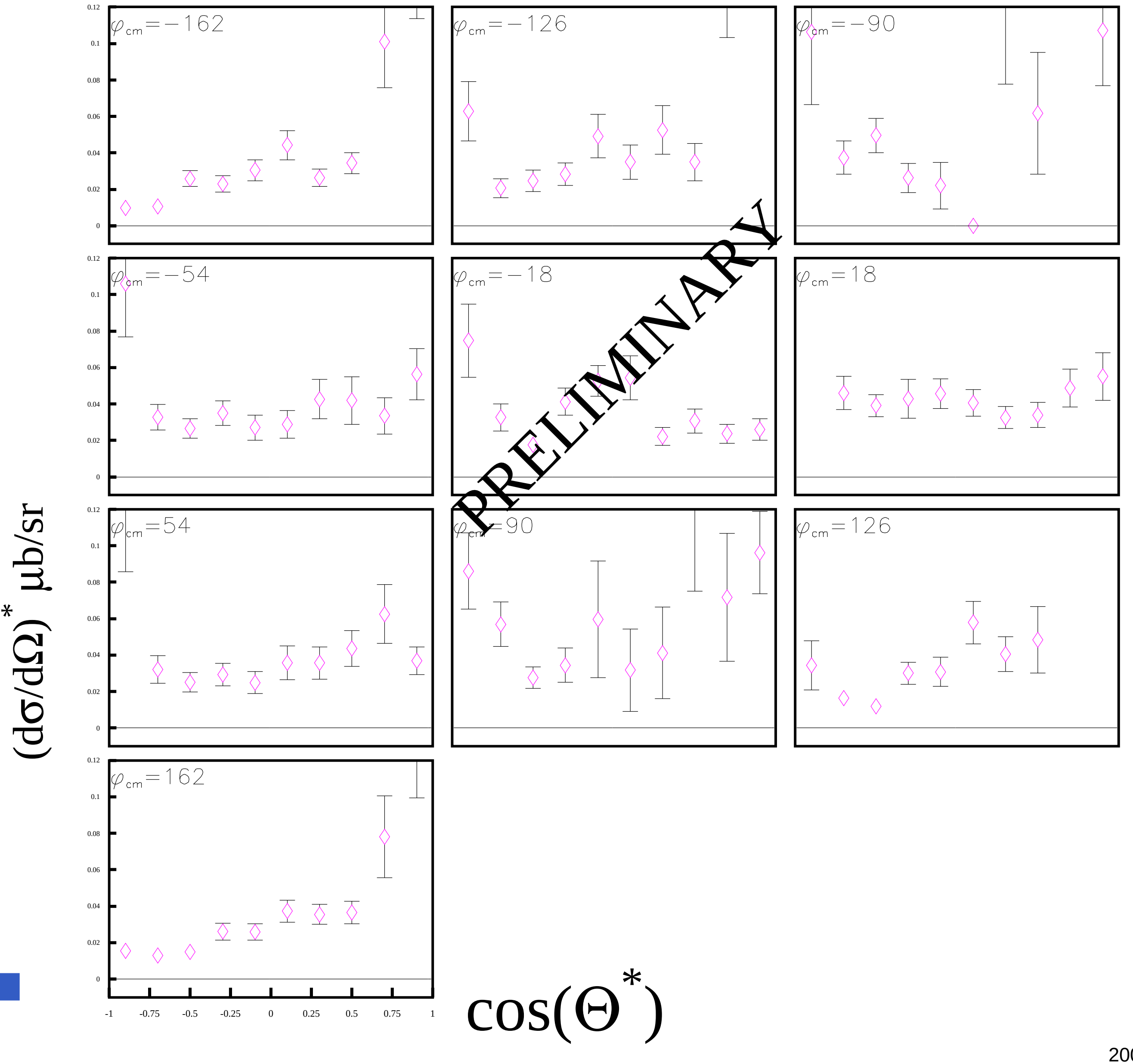
W=1.232 GeV ; 30 MeV Bin ; Q^2=6.3



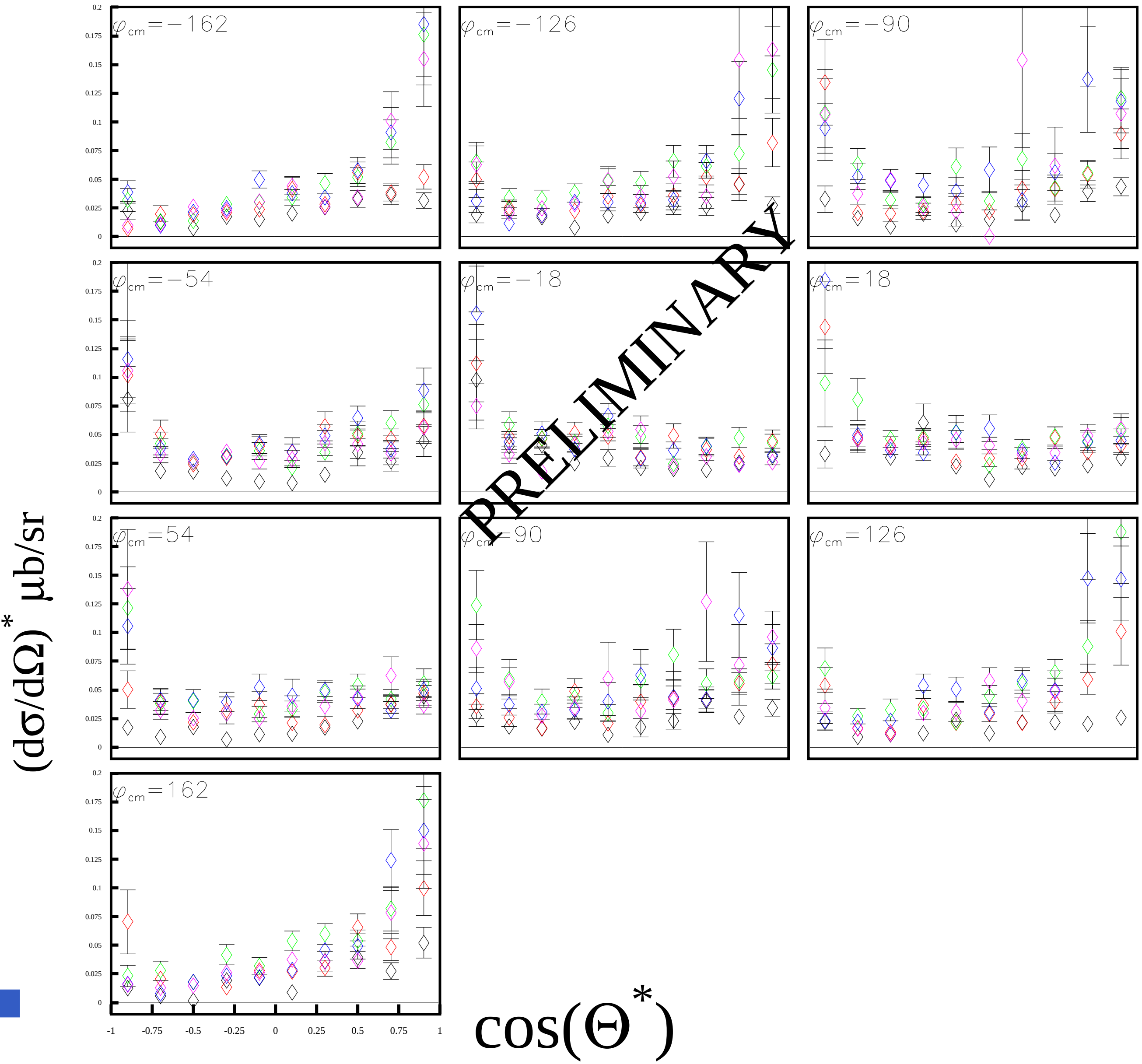
W=1.262 GeV ; 30 MeV Bin ; Q^2=6.3



W=1.292 GeV ; 30 MeV Bin ; Q^2=6.3



Exclusive Cross Section



Summary and Progress

- Beam energy of $5.5GeV$ with two Q^2 settings
  - Measure the cross sections for $^1H(e,e'p)X$, $X = \{\pi^0, \eta, \omega\}$
  - X identified by missing mass, M_x
  - Q^2 of 6.3 and $7.7GeV$ for Δ resonance
  - Varied proton arm angle and momentum to cover wide range of $\theta^\star$ and $\phi^\star$ bins for W up to $2GeV$
- Physics
  - Showed angular distributions for low Q^2
  - Distributions will be fit though it is not clear that the pure Δ multipoles will show
  - Systematic uncertainties need to be brought under control