$\pi^0 p$ and $\pi^+ n$ photoproduction beam asymmetries from the proton

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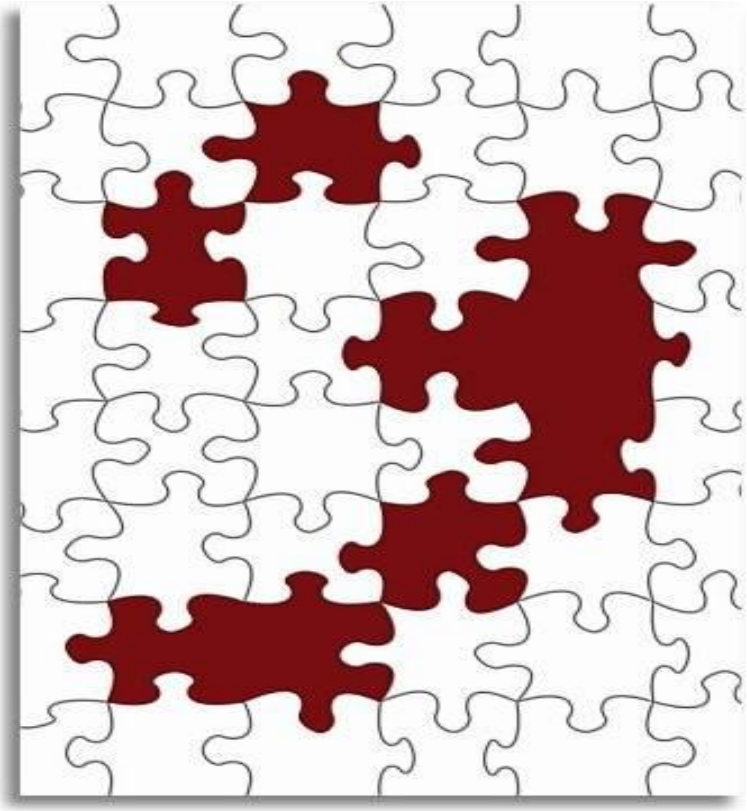
Several quark models of baryon masses

- ✦ Non-relativistic quark model
- ✦ Relativised quark model
- ✦ Goldstone-boson exchange
- ✦ Diquark and collective models
- ✦ Instanton-induced interactions
- ✦ Flux-tube models



Big Puzzle: Models predict too many resonance states!

Isospin overlaps for reactions involving π^0 and π^+

- Differing isospin overlaps of N^* and Δ^+ for the $\pi^0\, p$ and $\pi^+\, n$ final states
- The $\pi^0\, p$ and $\pi^+\, n$ final states can help distinguish between the Δ and N^*

$$\begin{array}{ccc} & \Delta^+ & N^* \\ & \downarrow & \downarrow \\ \pi^0 + p : & \sqrt{2/3}\left|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}\right\rangle & - \sqrt{1/3}\left|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}\right\rangle \\ \pi^+ + n : & \sqrt{1/3}\left|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}\right\rangle & + \sqrt{2/3}\left|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}\right\rangle \end{array}$$

Helicity amplitudes and observables

Spin observable	Helicity representation
$\check{\Omega}^1 \equiv \mathcal{I}(\theta)$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2+\lvert H_4\rvert^2)$
$\check{\Omega}^4 \equiv \check{\Sigma}$	$\mathrm{Re}(-H_1H_4^*+H_2H_3^*)$
$\check{\Omega}^{10} \equiv -\check{T}$	$\mathrm{Im}(H_1H_2^*+H_3H_4^*)$
$\check{\Omega}^{12} \equiv \check{P}$	$\mathrm{Im}(-H_1H_3^*-H_2H_4^*)$
$\check{\Omega}^3 \equiv \check{G}$	$\mathrm{Im}(H_1H_4^*-H_3H_2^*)$
$\check{\Omega}^5 \equiv \check{H}$	$\mathrm{Im}(-H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^9 \equiv \check{E}$	$\frac{1}{2}(\lvert H_1\rvert^2-\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^{11} \equiv \check{F}$	$\mathrm{Re}(-H_2H_1^*-H_4H_3^*)$
$\check{\Omega}^{14} \equiv \check{O}_x$	$\mathrm{Im}(-H_2H_1^*+H_4H_3^*)$
$\check{\Omega}^7 \equiv -\check{O}_z$	$\mathrm{Im}(H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{16} \equiv -\check{C}_x$	$\mathrm{Re}(H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^2 \equiv -\check{C}_z$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2-\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^6 \equiv -\check{T}_x$	$\mathrm{Re}(-H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{13} \equiv -\check{T}_z$	$\mathrm{Re}(-H_1H_2^*+H_4H_3^*)$
$\check{\Omega}^8 \equiv \check{L}_x$	$\mathrm{Re}(H_2H_4^*-H_1H_3^*)$
$\check{\Omega}^{15} \equiv \check{L}_z$	$\frac{1}{2}(-\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$

Differential cross section

Beam polarization

Target asymmetry

Recoil polarization

Double polarization observables

Need **at least** 4 of the double observables for a "complete experiment"

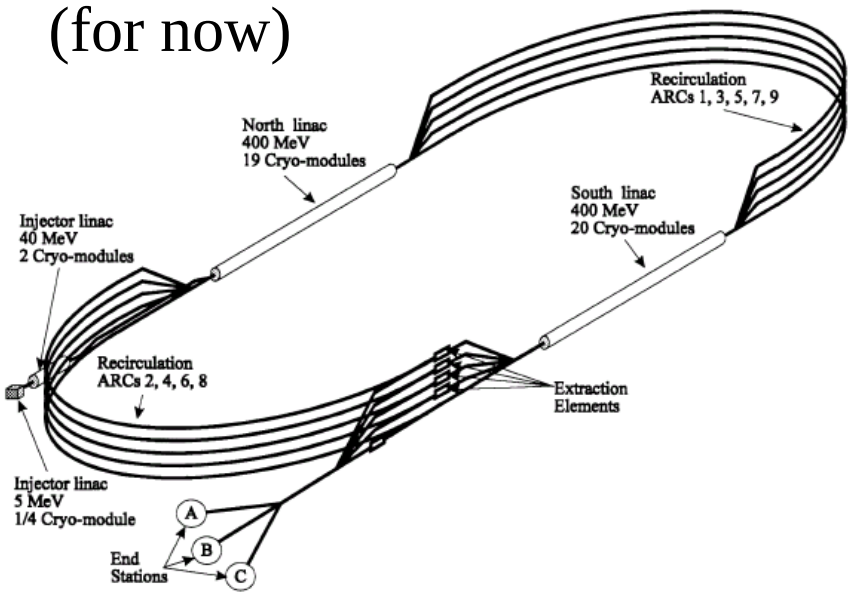
Finding missing resonances requires lots of different observables. Cross sections are not enough.

Experimental facility

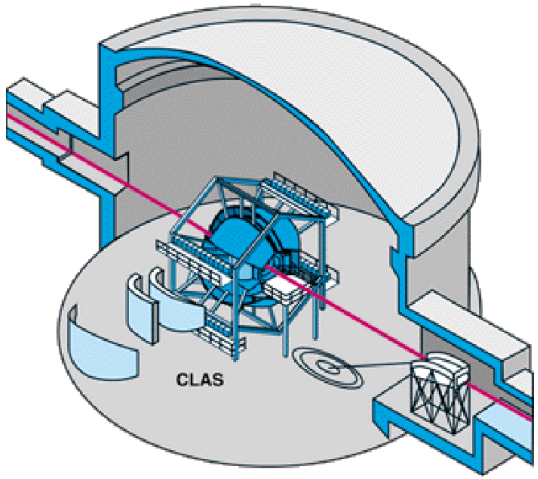
The Thomas Jefferson National Accelerator Facility (Jefferson Laboratory = JLab).

- ✦ Continuous Electron Beam Accelerator Facility (CEBAF)

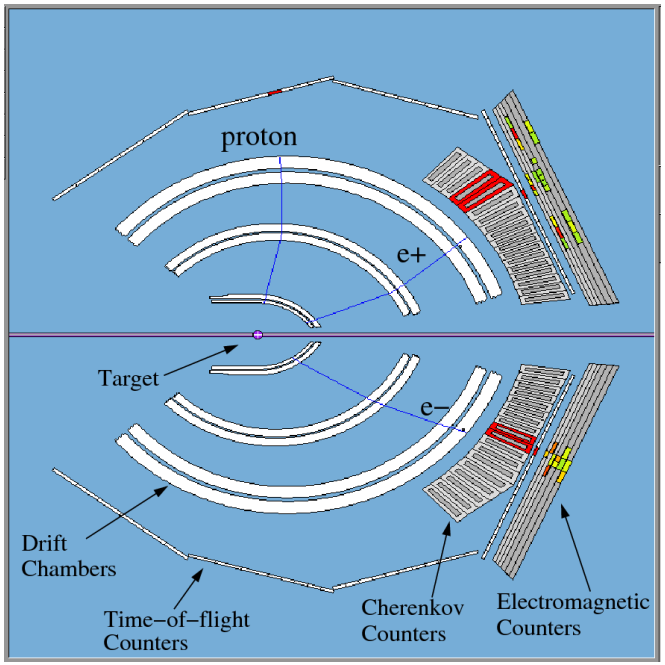
- ✦ Racetrack design
- ✦ Energies up to 6 GeV (for now)



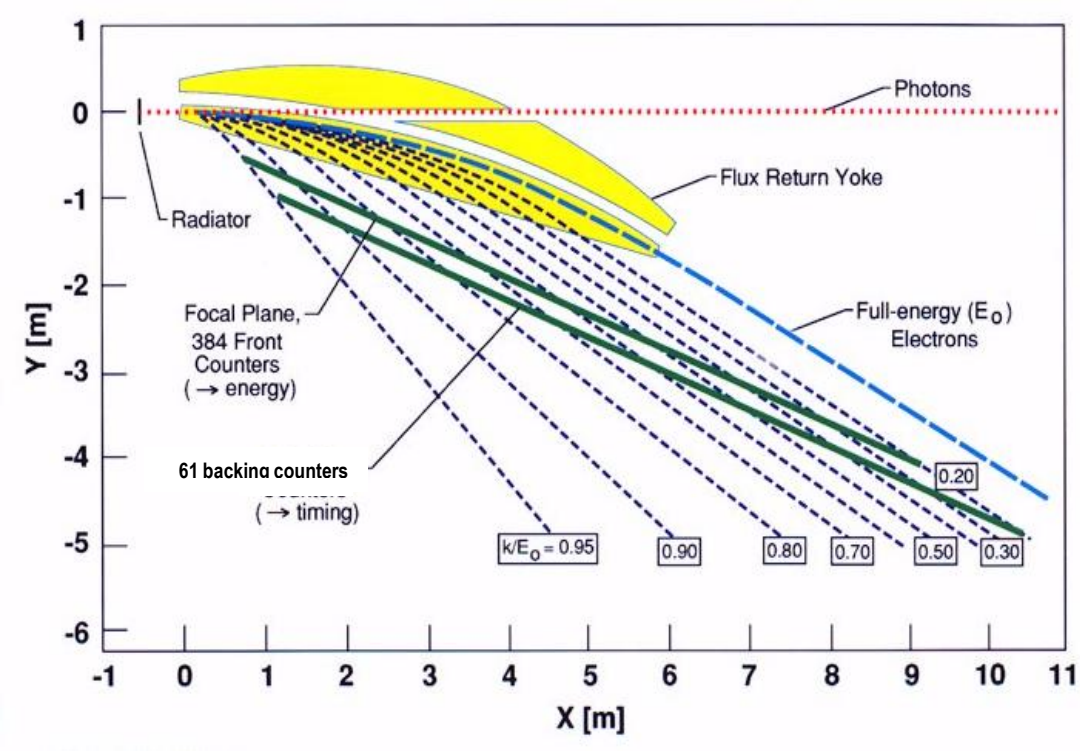
CLAS



- ✦ Good for charged particles
- ✦ Large acceptance



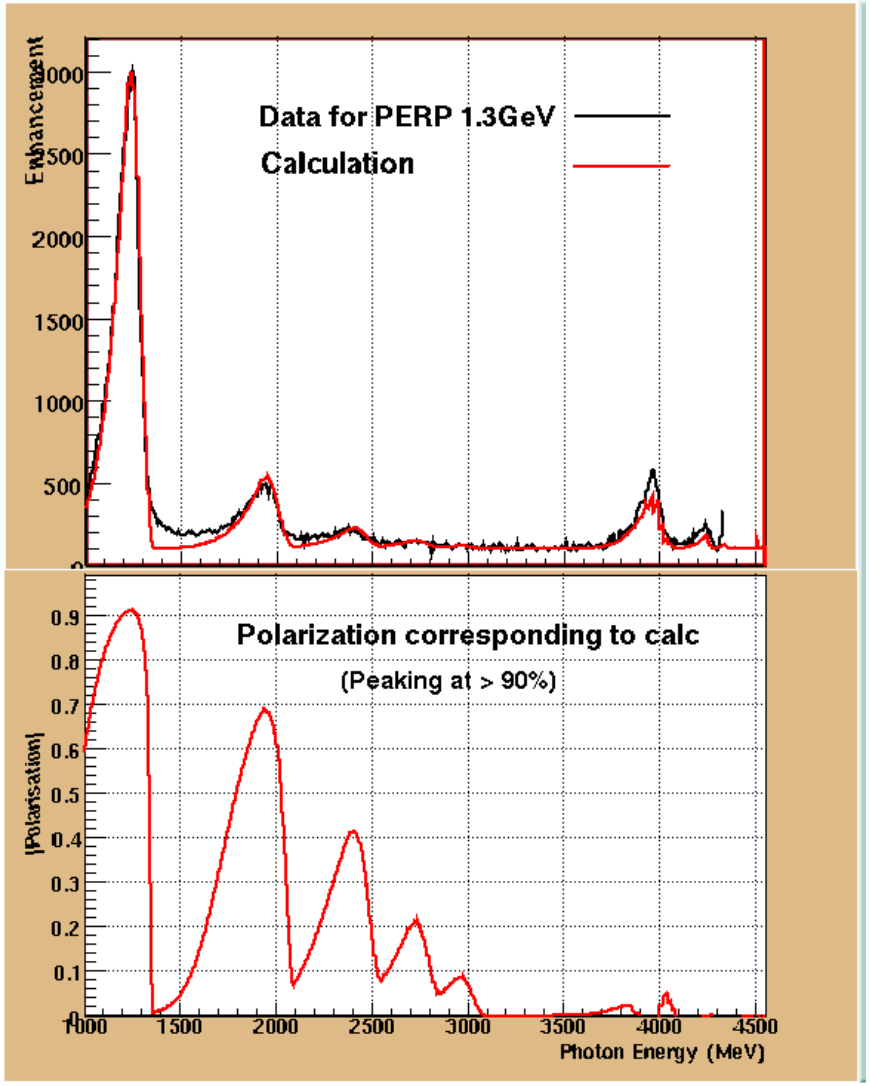
Experimental capabilities: Jefferson Lab Hall B



- Jefferson Lab Hall B bremsstrahlung photon tagger
  - E_γ = 20-95% of E_0
  - E_γ up to ~5.5 GeV
  - Circular polarized photons with longitudinally polarized electrons
  - Oriented diamond crystal for linearly polarized photons

Beam asymmetries from ASU/CLAS

Run period g8b (June 20- Sept 1, 2005)



- ✦ Coherent bremsstrahlung in 50 μ diamond
- ✦ Two linear polarization states (vertical & horizontal)
- ✦ Incident electron energy of 4.55 GeV
- ✦ Analytical QED coherent bremsstrahlung calculation fit to actual spectrum (Livingston/Glasgow) ☺
- ✦ ⊥ 1.3 GeV edge shown

Statistics for g8b

Coherent Edge	Billions of events
✦ Non-polarized (amorphous)	2.3
✦ 1.3 GeV (will show π^0 and π^+)	1.4
✦ 1.5 GeV (will show π^0 and π^+)	2.6
✦ 1.7 GeV (will show π^0 and π^+)	2.2
✦ 1.9 GeV (in progress)	1.2
✦ 2.1 GeV (in progress)	0.9

Fourier moment method

(CLAS Note 2008-35: Dugger and Ritchie, http://www1.jlab.org/ul/Physics/Hall-B/clas/public/2008-035.pdf)

- ✦ **Simultaneously uses full azimuthal φ acceptance of data set. ☺**
- ✦ **Only a few (in principle, only 2) histograms per kinematic bin need to be fit. ☺**
- ✦ **Statistical errors have to be evaluated carefully due to non-vanishing covariances. ☹**

Normalized yields

✦ **Define the normalized yield density $f^{i,j}$ for each kinematic bin *i,j***

$$f^{i,j}(\varphi) \equiv \rho L \int_{E_{i-1}}^{E_i} \int_{\cos\theta_{j-1}}^{\cos\theta_j} \varepsilon(E,\theta,\varphi) \frac{d^3\sigma}{d(\cos\theta)dEd\varphi} d(\cos\theta)dE$$

Integrated normalized densities

$$\left(\frac{Y^{i,j}}{N^{i,j}}\right)_a = \int_0^{2\pi} f_a^{\,i,j}(\varphi)d\varphi$$

Subscript denotes polarization:
a ↔ unpolarized
$\perp$ ↔ perpendicular
$\parallel$ ↔ parallel

$$\left(\frac{Y^{i,j}}{N^{i,j}}\right)_\perp = \int_0^{2\pi} f_\perp^{\,i,j}(\varphi)d\varphi = \int_0^{2\pi} f_a^{\,i,j}(\varphi)\left[1 + P_\perp \Sigma \cos(2\varphi)\right]d\varphi$$

$$\left(\frac{Y^{i,j}}{N^{i,j}}\right)_\parallel = \int_0^{2\pi} f_\parallel^{\,i,j}(\varphi)d\varphi = \int_0^{2\pi} f_a^{\,i,j}(\varphi)\left[1 - P_\parallel \Sigma \cos(2\varphi)\right]d\varphi$$

Moments of normalized yields

✦ **Expand the $f^{i,j}$ in Fourier series.**

$$f_a^{\,i,j}(\varphi) = a_0 + \sum_{m=1}^{\infty}\left[a_m \cos(m\varphi) + b_m \sin(m\varphi)\right]$$

Find the nth moment for the $f^{i,j}$ (called H_n):

$$H_{an} = \int_0^{2\pi} f_a^{\,i,j}(\varphi)\cos(n\varphi)d\varphi$$

orthogonality

$$H_{\perp n} = \int_0^{2\pi} f_\perp^{\,i,j}(\varphi)\cos(n\varphi)d\varphi = \int_0^{2\pi} f_a^{\,i,j}(\varphi)\left[1 + P_\perp \Sigma \underline{\cos(2\varphi)}\right]\underline{\cos(n\varphi)d\varphi}$$

$$H_{\parallel n} = \int_0^{2\pi} f_\parallel^{\,i,j}(\varphi)\cos(n\varphi)d\varphi = \int_0^{2\pi} f_a^{\,i,j}(\varphi)\left[1 - P_\parallel \Sigma \cos(2\varphi)\right]\cos(n\varphi)d\varphi$$

Solving these for Σ

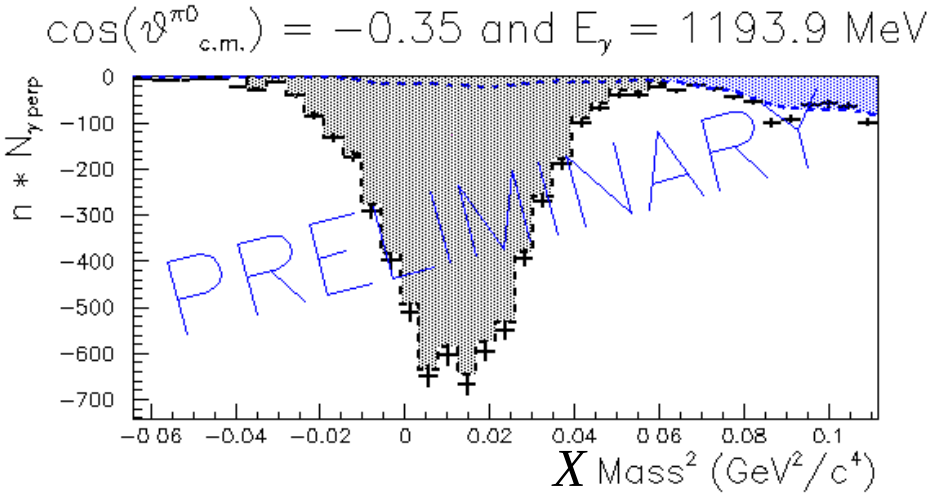
- **Putting the pieces together, for the *i,j* kinematic bin, we find:**

$$\Sigma = \left[\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel}\right] = \frac{2\left(H_{\perp 2} - H_{\parallel 2}\right)}{P_\parallel\left(H_{\perp 0} + H_{\perp 4}\right) + P_\perp\left(H_{\parallel 0} + H_{\parallel 4}\right)}$$

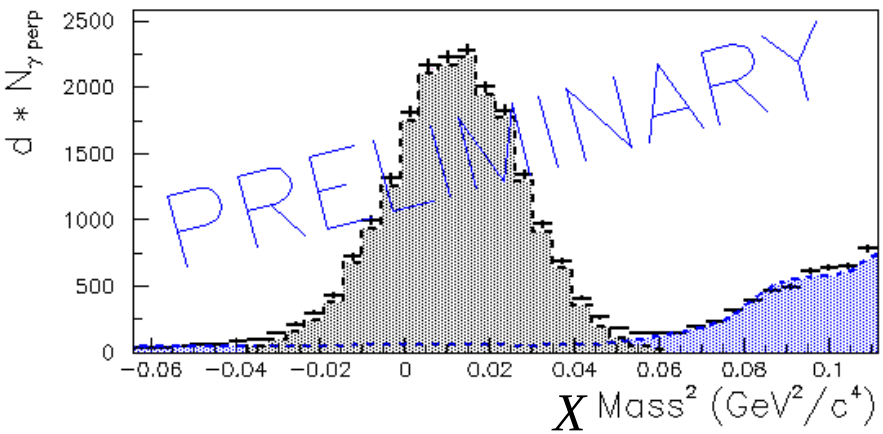
- **The H_n histograms are created by weighting each event by $cos(n\varphi)$ for each *i,j* kinematic bin.**

Fit Example: $\gamma\, p \rightarrow p\, X$, where X is identified as π^0

numerator



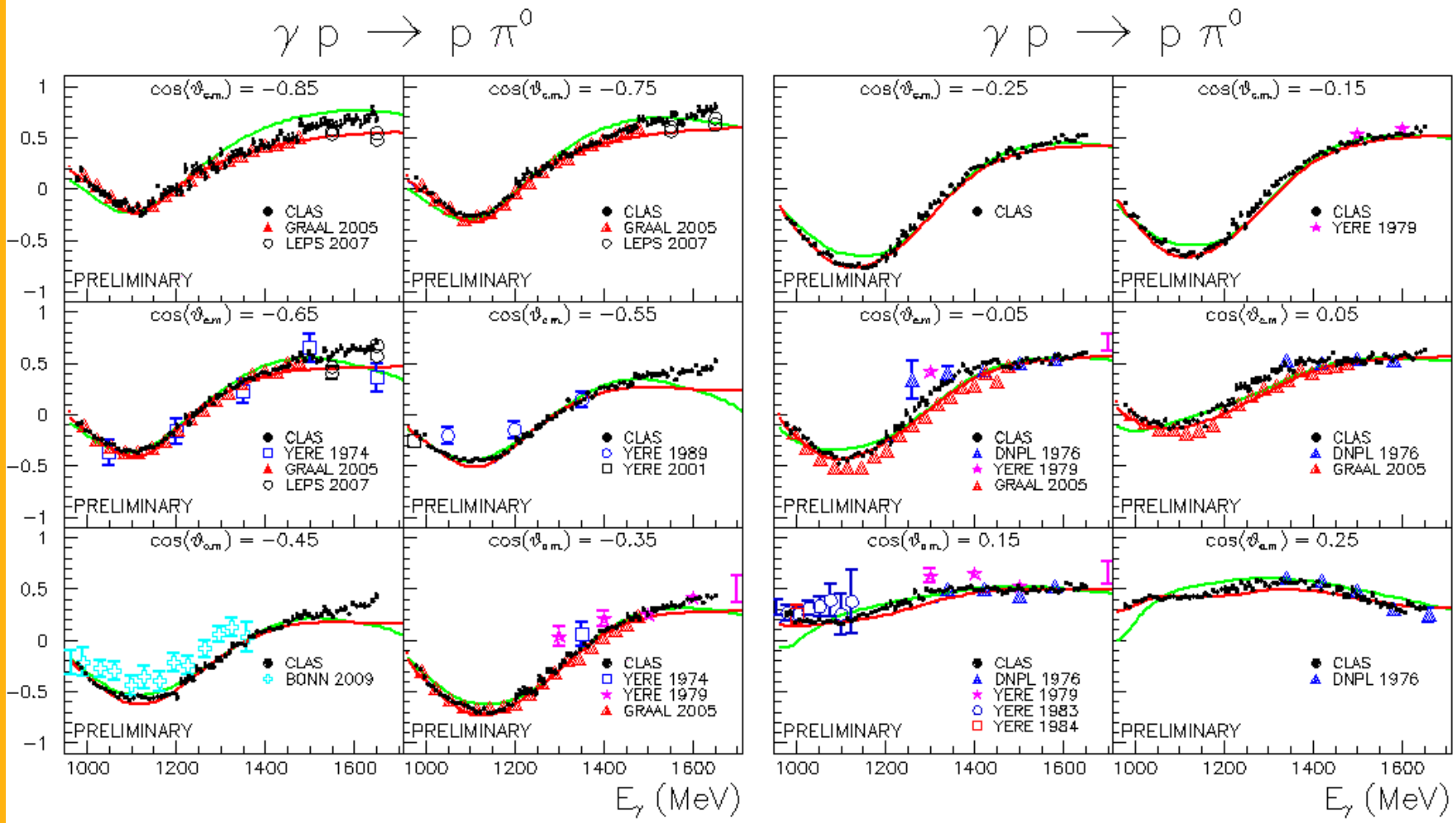
denominator



Preliminary Σ results for π^0

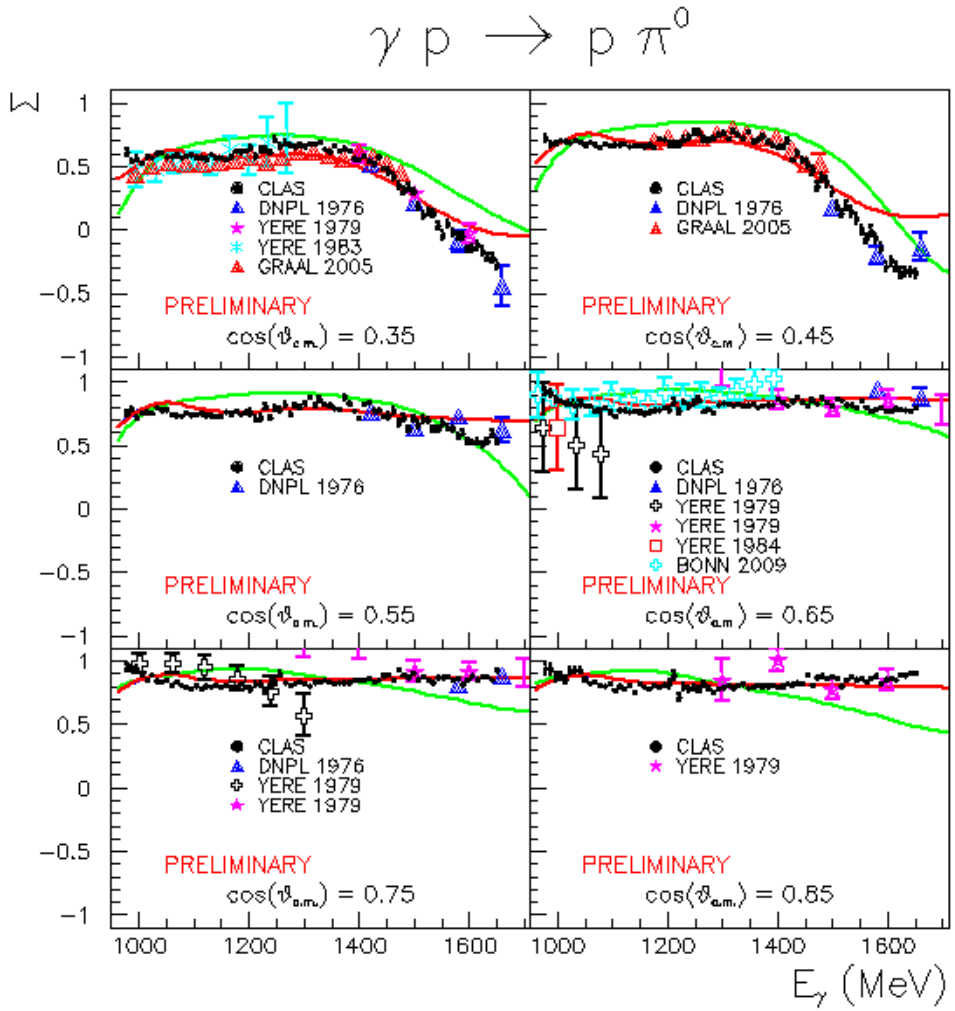
Fixed angle – 2 slides

Preliminary Σ results for π^0



Red lines are SAID. Green lines are MAID

Preliminary Σ results for π^0



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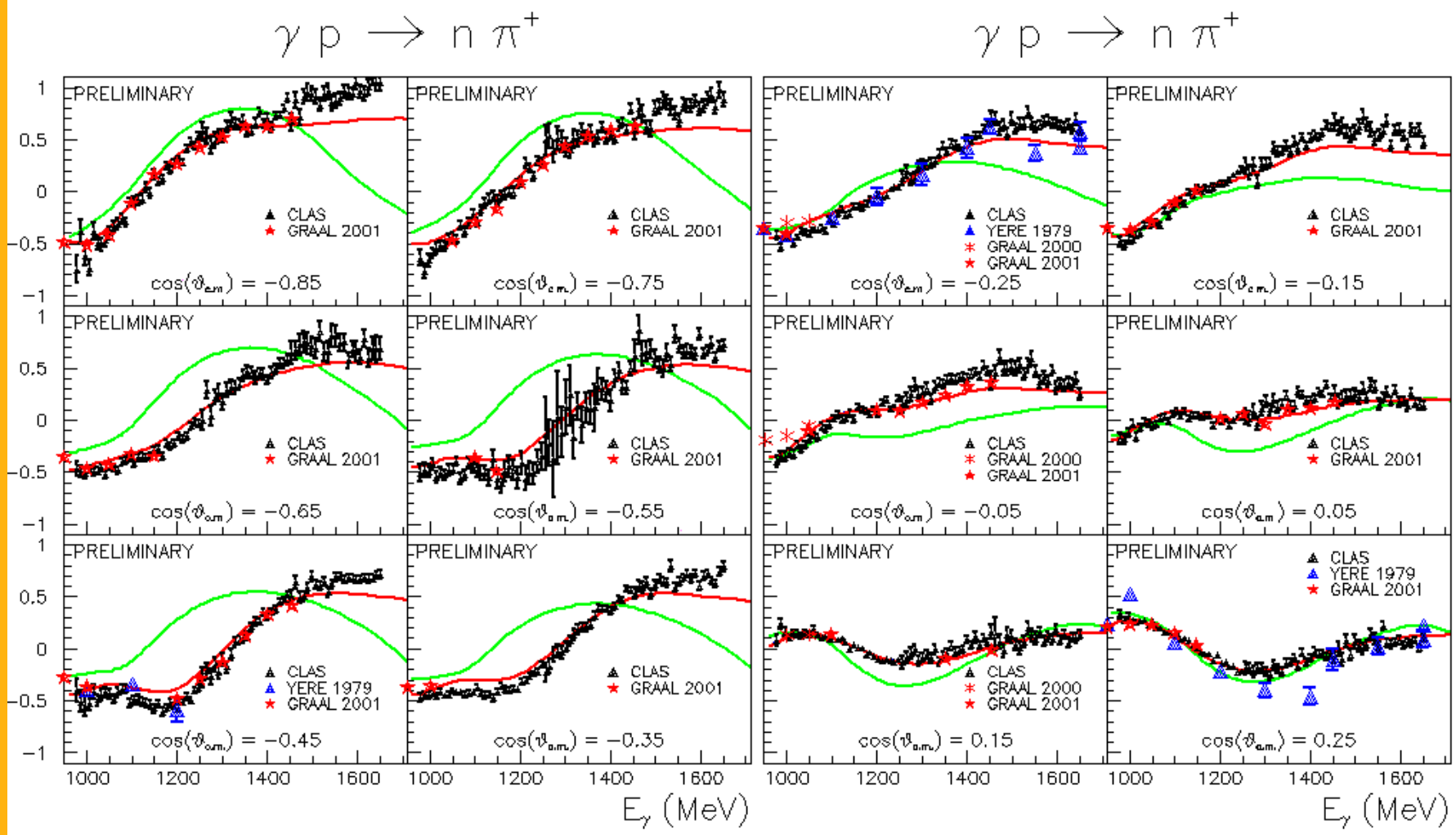
Preliminary Σ results for π^+

Fixed angle – 2 slides

Preliminary Σ results for π^+



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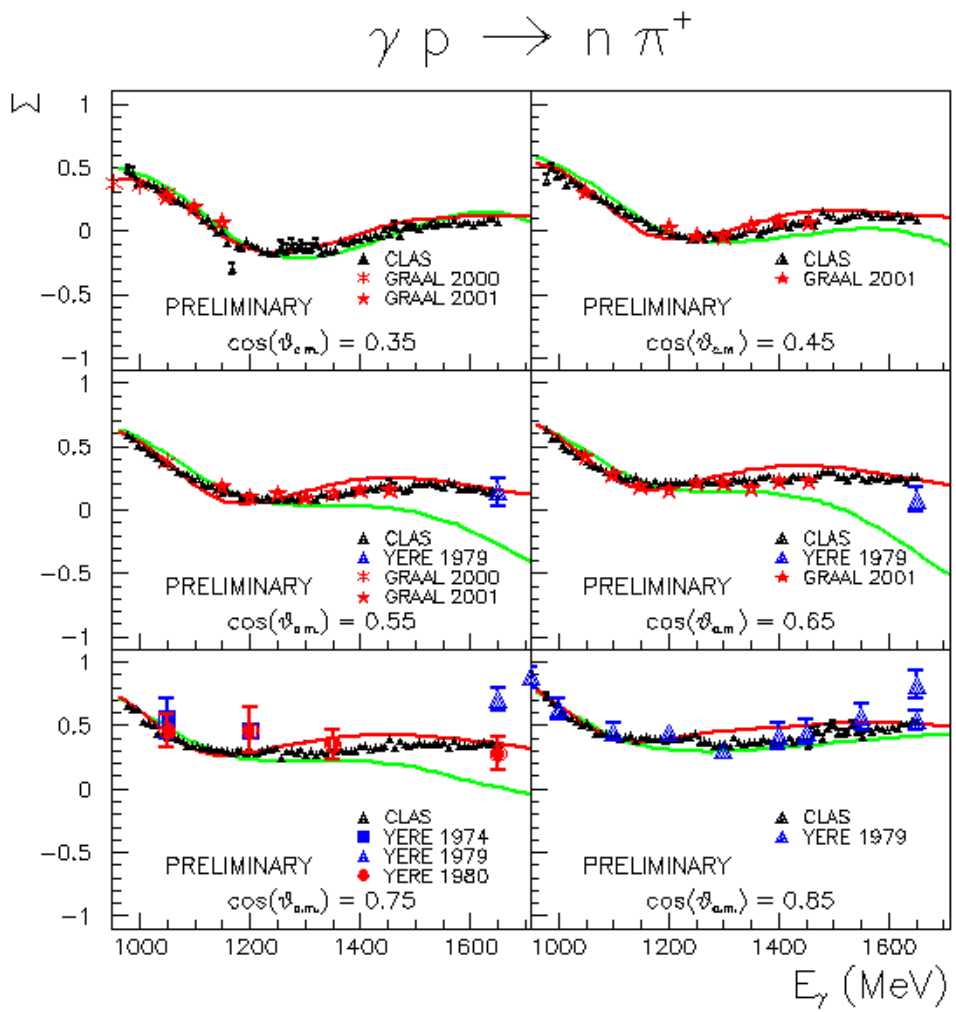
Preliminary Σ results for π^+



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CLAS generates lots of data on beam asymmetries for pion photoproduction.

Conclusions

✦ World database greatly enhanced during past several years

✦ Preliminary beam asymmetries from CLAS agree fairly well with previous measurements.

✦ Polarization observables from CLAS will be useful in determining between sets of included resonances in theoretical investigations

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