Preliminary Σ for $\gamma p \rightarrow p \pi^0, n \pi^+$, and $p \eta$ from CLAS g8b run period with 0.95 GeV < E_γ < 1.2 GeV

ASU Meson Physics Group* (and g8b friends)

University of Glasgow
The George Washington University, Washington DC
Florida State University 1851
Idaho State University
Jefferson Lab

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the National Science Foundation

ASU
NSF

Arizona State University

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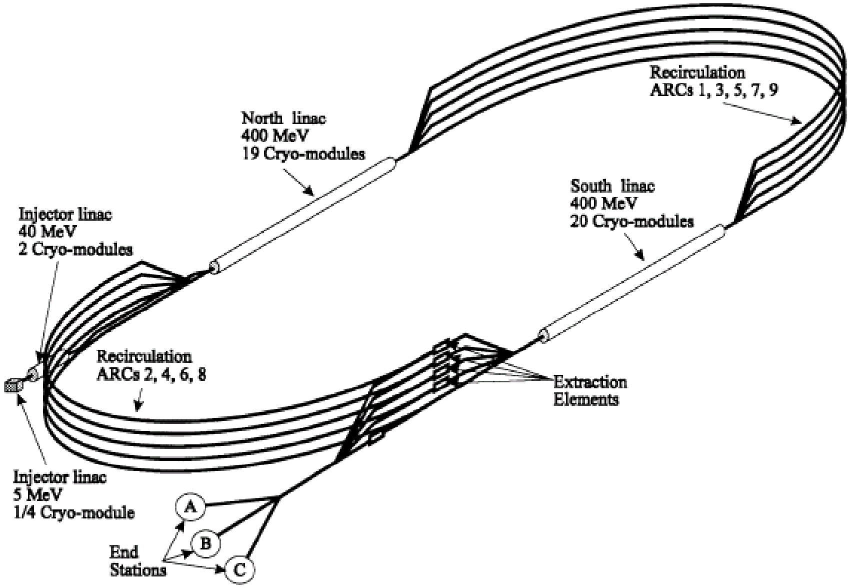
Experimental facility

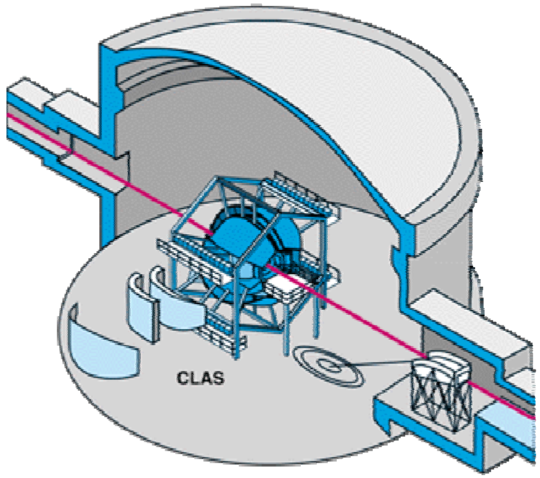
The Thomas Jefferson National Accelerator Facility

- **Continuous Electron Beam Accelerator Facility (CEBAF)**

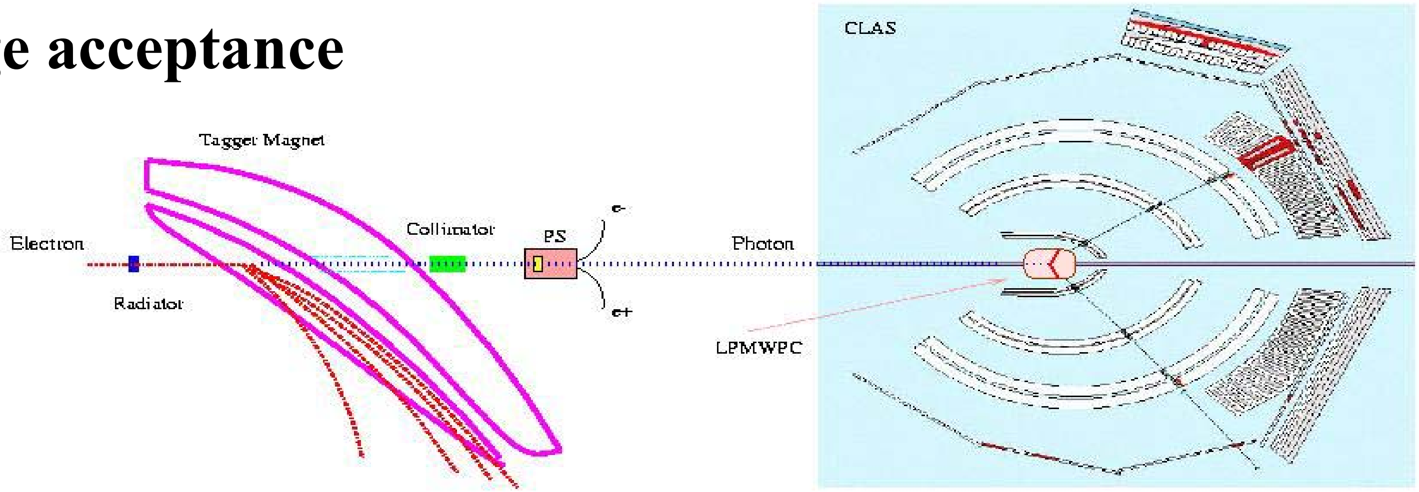
- **Racetrack design**
- **Energies up to 6 GeV (for now)**



CLAS

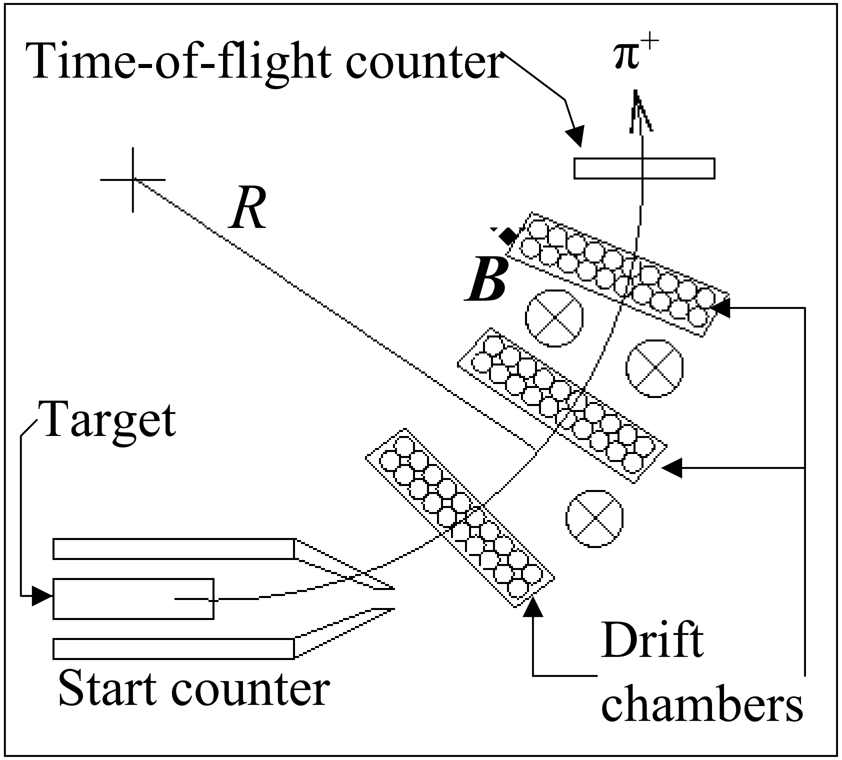


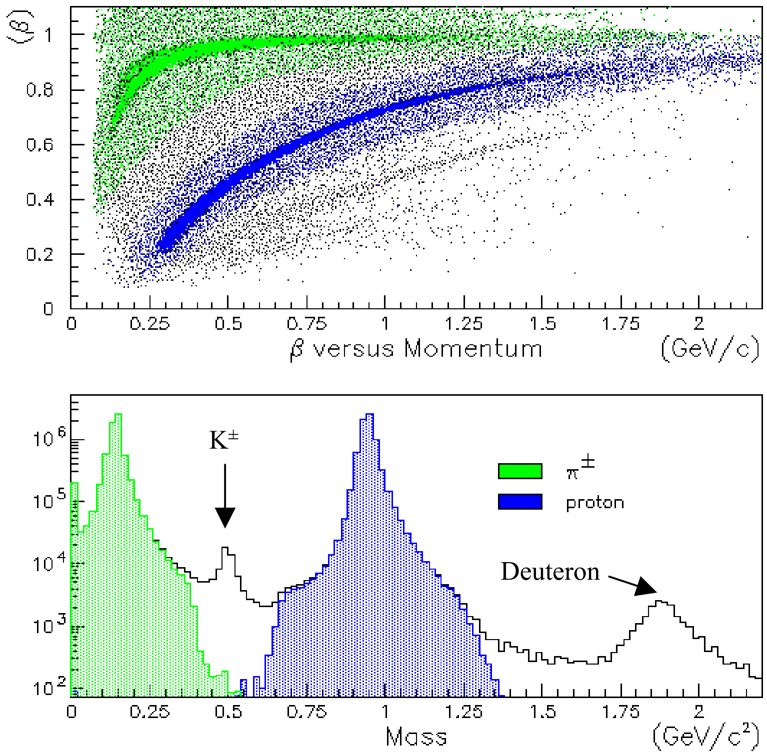
- **Good for charged particles**
- **Large acceptance**



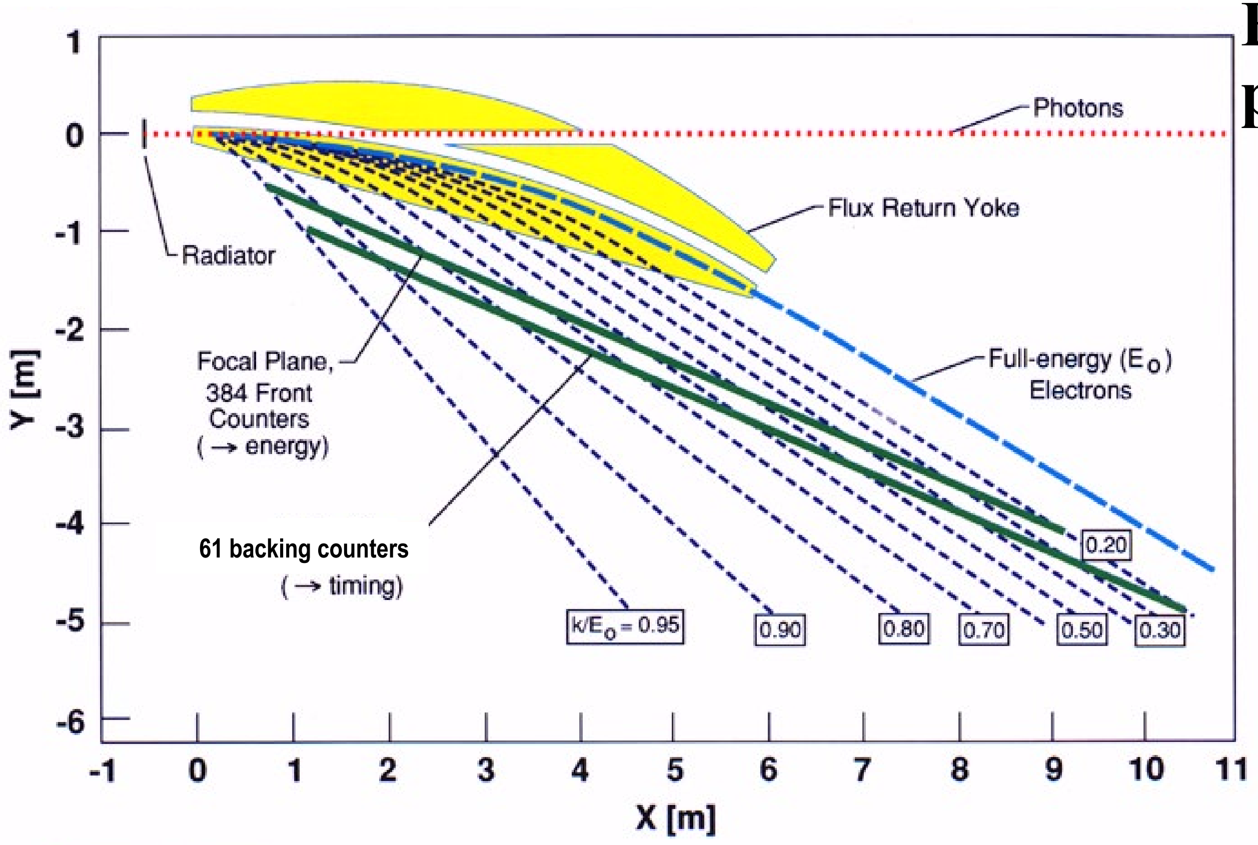
Charged particle identification

- The path length and curvature determined by tracking
- Time of travel determined by Time-of-flight and start counter
- ID determined by checking compatibility of measured velocity to known particles (given the measured momentum)



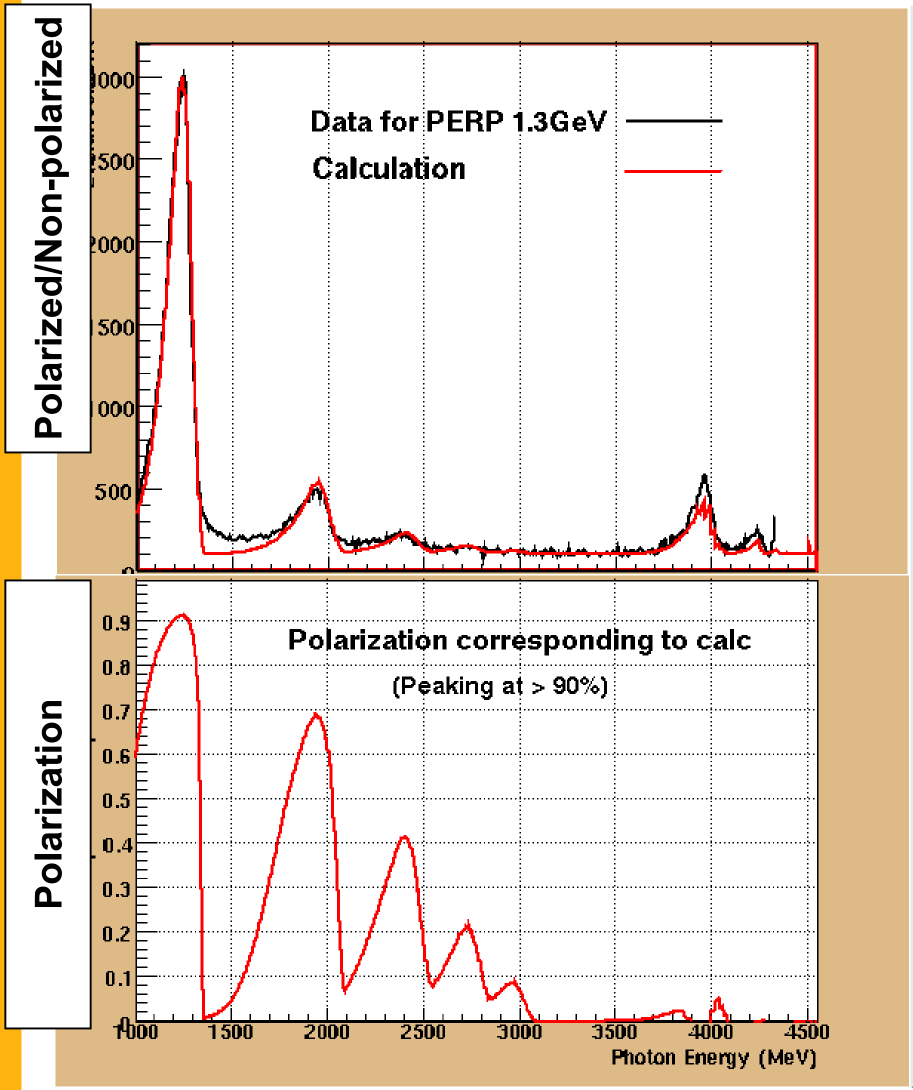


Experimental capabilities: Jefferson Lab Hall B



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

Photon beam polarization for g8b
(June 20- Sept 1, 2005)



- **Coherent bremsstrahlung in 50 μ diamond**
- **Analytical QED coherent bremsstrahlung calculation fit to actual spectrum (Livingston/Glasgow) ☺**
- **Estimated systematic uncertainty in *P*: ~3%**
- **⊥ 1.3 GeV edge shown**

Statistics for g8b

Coherent Edge	Billions of events
• Non-polarized	2.3
• 1.3 GeV	1.4
• 1.5 GeV	2.6
• 1.7 GeV	2.2
• 1.9 GeV	1.2
• 2.1 GeV	0.9

NOTE: Energy range from 0.95 to 1.2 GeV represents a small fraction of collected data and only from the 1.3 GeV data set

Fourier moment method

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

- **Simultaneously uses full azimuthal φ acceptance of data set. ☺**

- **Only 2 histograms per kinematic bin need to be fit. ☺**

Normalized yields

- **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 yield densities

$$\left(\frac{d\sigma}{d\Omega}\right)_{\perp/\parallel} = \left(\frac{d\sigma}{d\Omega}\right)_a \left[1 {}^{+}\!/\!_{-} \Sigma P \cos(2\varphi)\right]$$

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

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

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

Subscript denotes polarization:
a ↔ non-polarized
$\perp$ ↔ perpendicular
$\parallel$ ↔ parallel

Moments of normalized yields

- **Expand the $f^{i,j}$ in Fourier series with coefficients Y_m and Z_m:**

$$f_a^{\,i,j}(\varphi) = \frac{Y_0}{2\pi} + \frac{1}{\pi}\sum_{m=1}^{\infty}\left[Y_m \cos(m\varphi) + Z_m \sin(m\varphi)\right]$$

- **Find the coefficients Y_{an} , $Y_{\perp n}$, $Y_{||n}$ in terms of $f_a(\varphi)$:**

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

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

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

Finding Σ from the moment histograms

By using the orthogonality, we find relations between Y_a, $Y_{||}$, and $Y_\perp$ for $m=0,2,4$:

$$Y_{\perp 2} - Y_{||2} = \left(P_\perp + P_{||}\right)\Sigma\left(\frac{Y_{a0}}{2} + \frac{Y_{a4}}{2}\right)$$

$$P_{||}Y_{\perp 0} + P_\perp Y_{||0} = Y_{a0}\left(P_{||} + P_\perp\right)$$

$$P_{||}Y_{\perp 4} + P_\perp Y_{||4} = Y_{a4}\left(P_{||} + P_\perp\right)$$

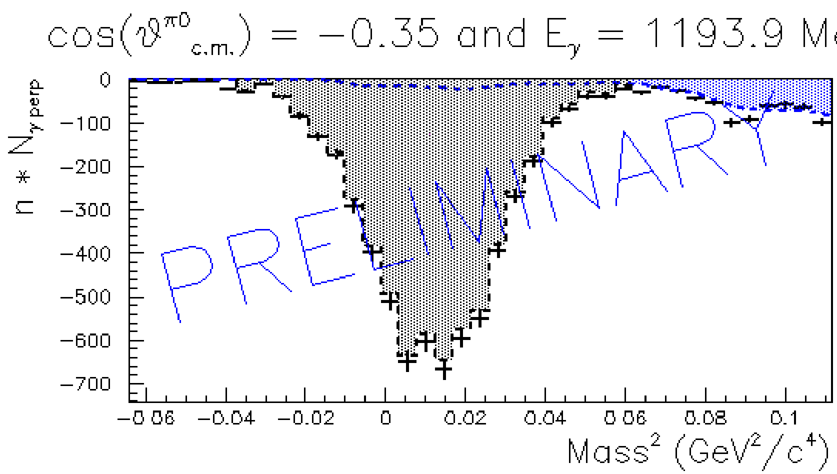
The Y_n histograms are created by weighting each event by *cos(nφ)* in a given *cos(θ), E_γ* bin.

$$\rightarrow \quad \Sigma = \frac{2\left(Y_{\perp 2} - Y_{||2}\right)}{P_{||}\left(Y_{\perp 0} + Y_{\perp 4}\right) + P_\perp\left(Y_{||0} + Y_{||4}\right)}$$

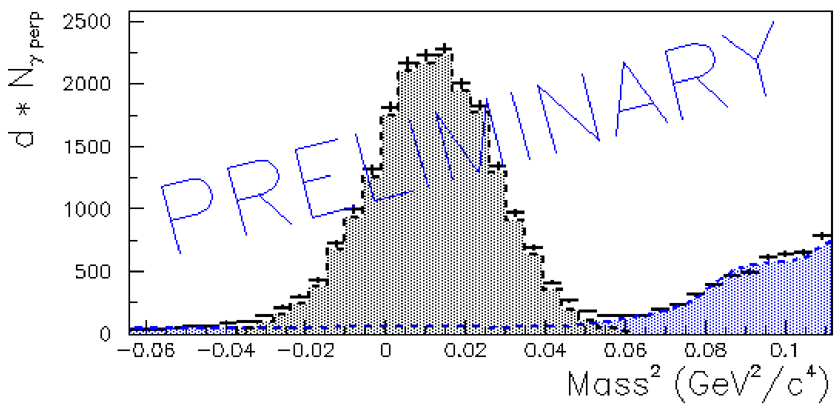
Fit Example: $\gamma\, p \rightarrow \pi^0\, p$

$$\Sigma = \frac{2\left(Y_{\perp 2} - Y_{\parallel 2}\right)}{P_{\parallel}\left(Y_{\perp 0} + Y_{\perp 4}\right) + P_{\perp}\left(Y_{\parallel 0} + Y_{\parallel 4}\right)}$$

numerator



denominator



Preliminary results for Σ from g8b

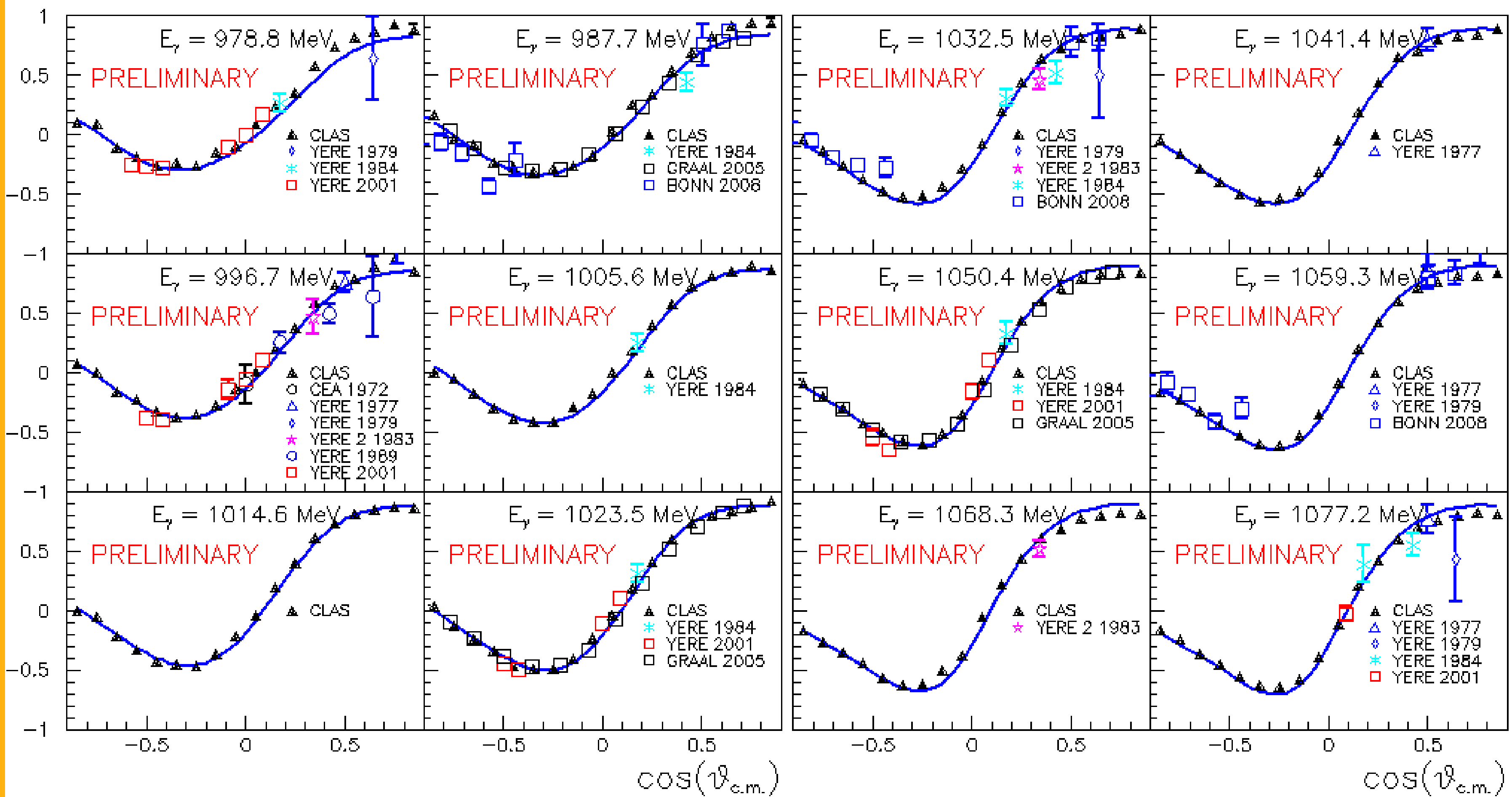
- Preliminary results: π^0, π^+, and η for 1.3 GeV coherent edge setting
  - Fourier moment method
  - Only showing results for $E_\gamma < 1.2$ GeV
- Two ways to view preliminary results
  - Fixed energy
  - Fixed angle

Preliminary Σ results for π^0

Fixed energy – 2 slides

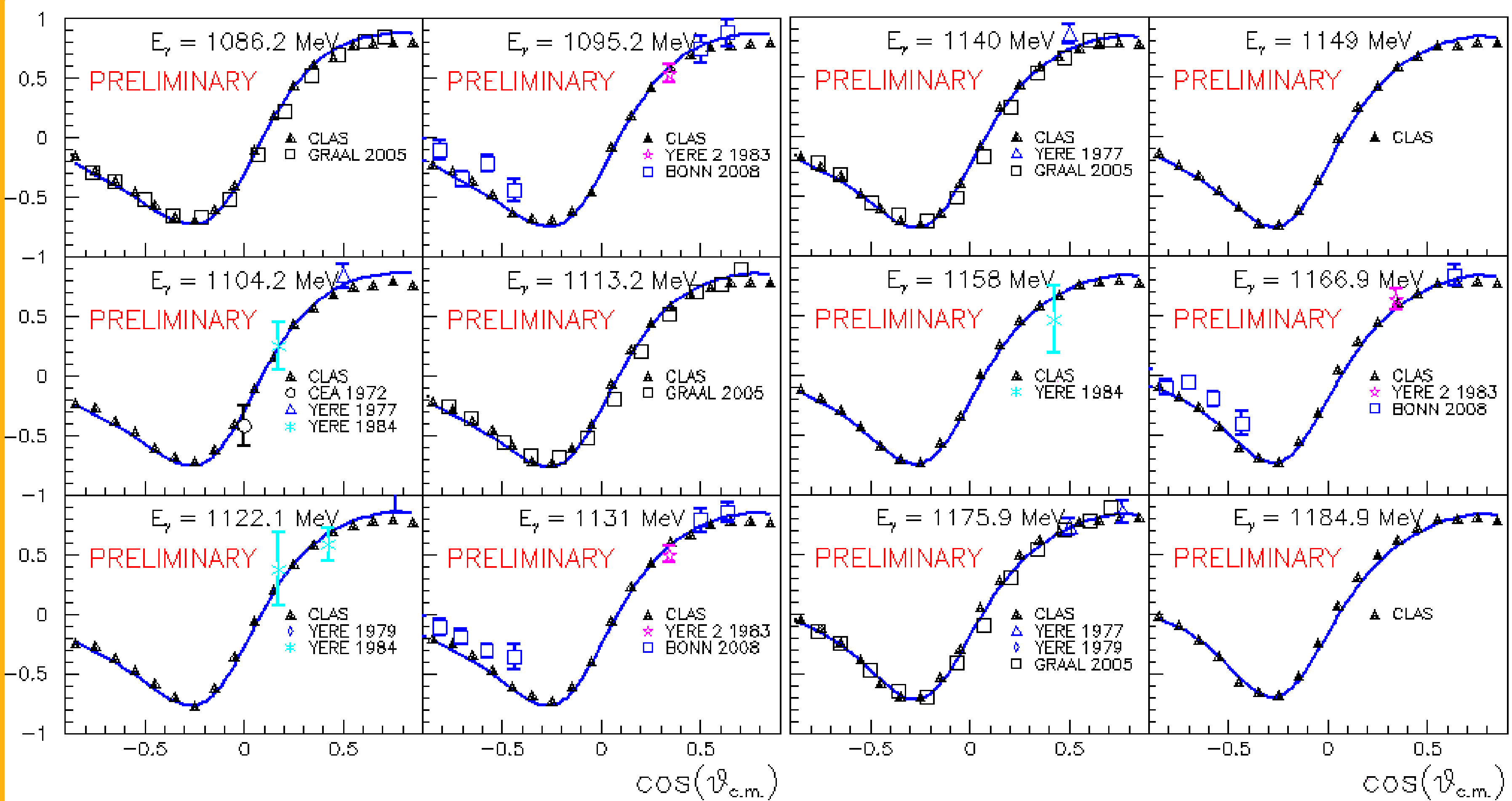
Fixed angle – 2 slides

Preliminary Σ results for π^0



Fixed energy slide 1, lines are SAID

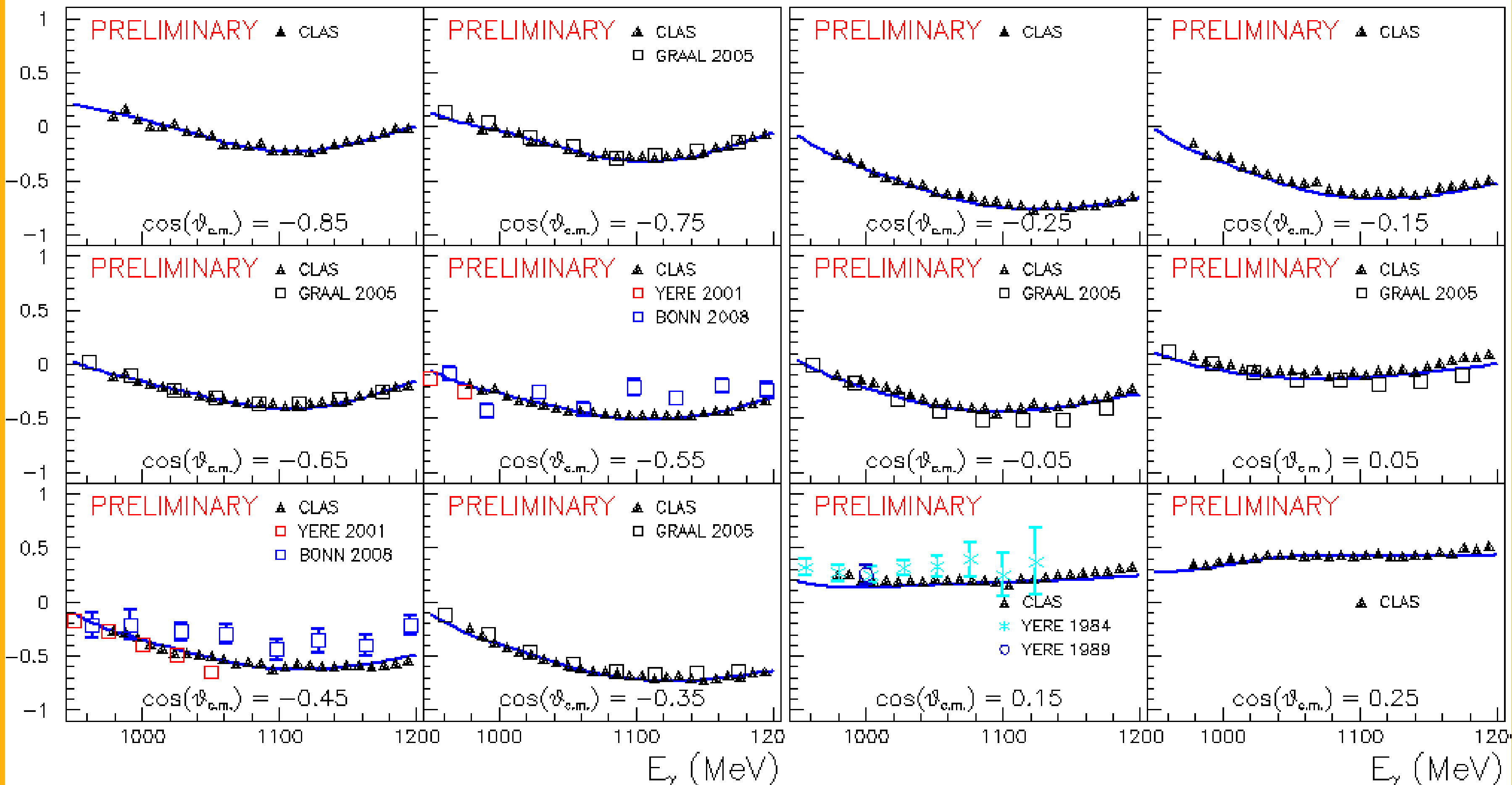
Preliminary Σ results for π^0



Fixed energy slide 2, lines are SAID

M. Dugger, NNR Workshop, June 2009

Preliminary Σ results for π^0



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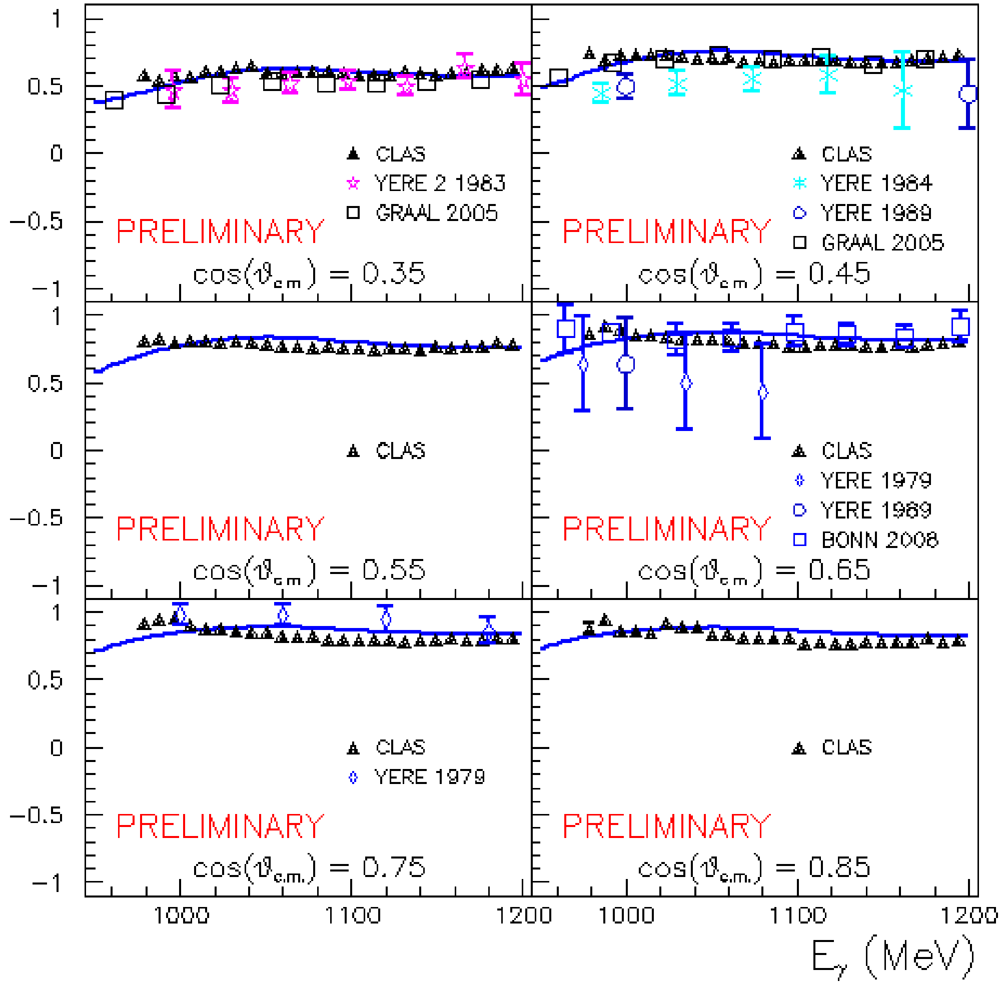
Preliminary Σ results for π^0



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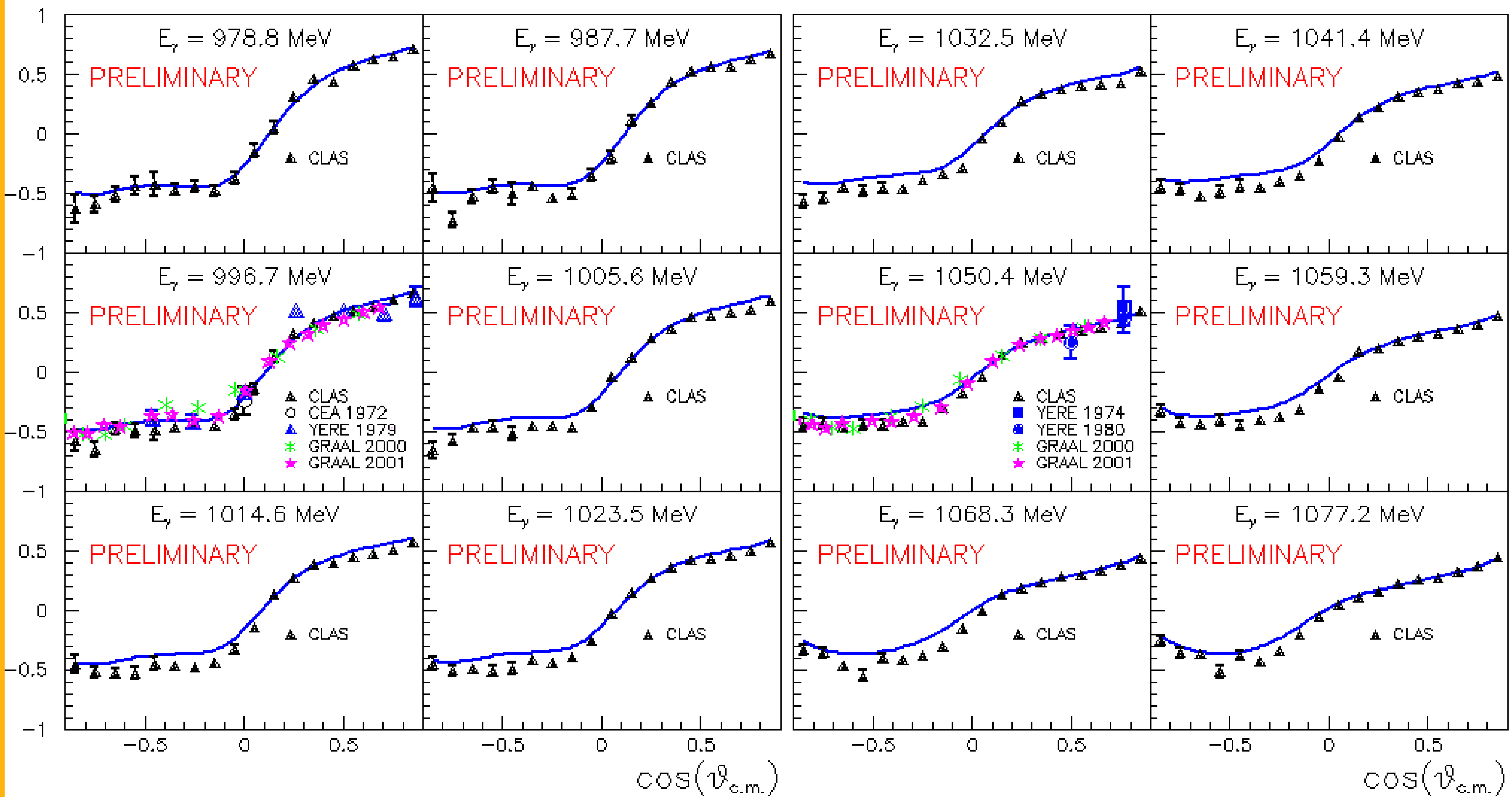
Preliminary Σ results for π^+

Fixed energy – 2 slides

Fixed angle – 2 slides

Preliminary Σ results for π^+



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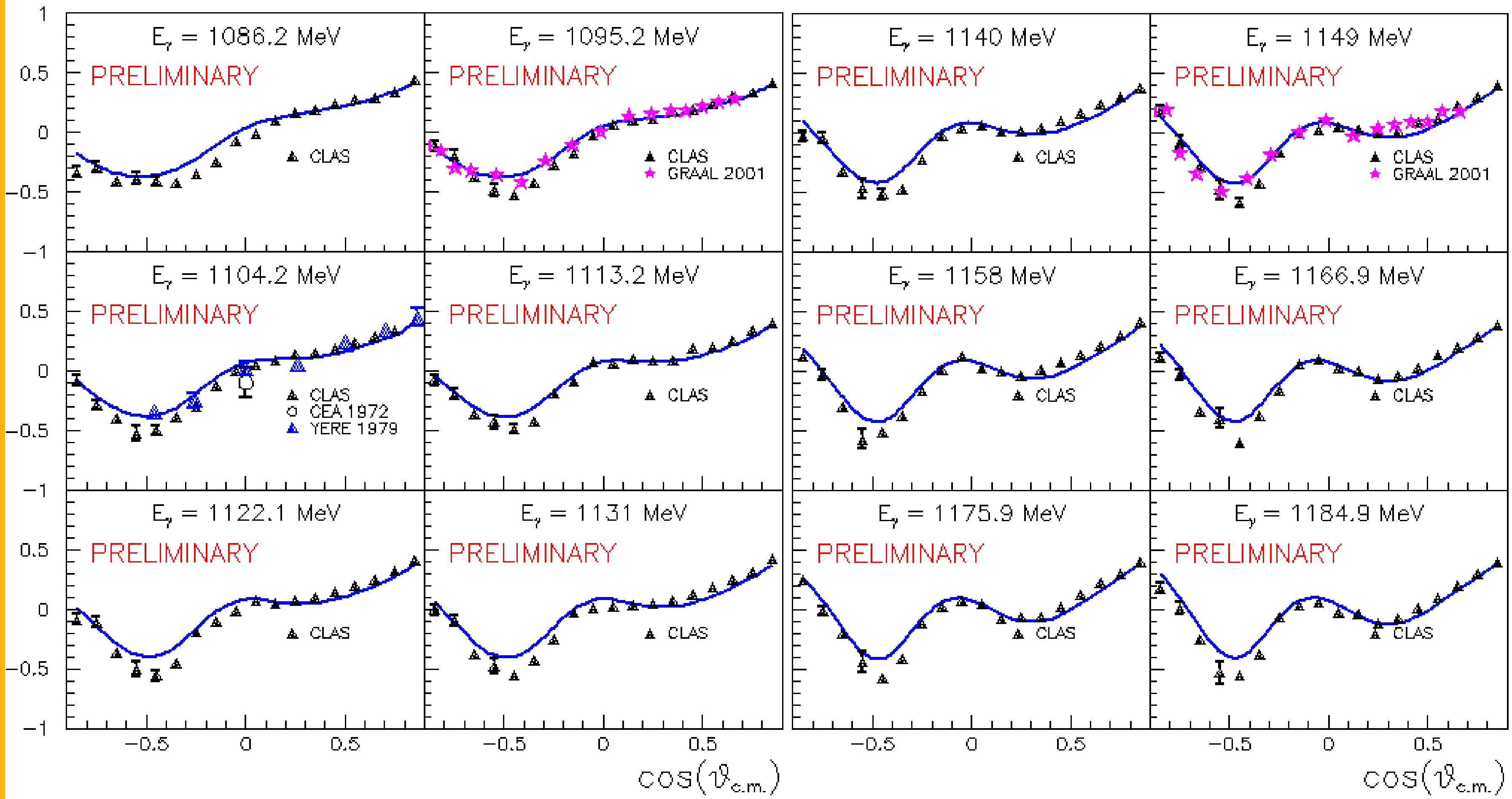
Preliminary Σ results for π^+



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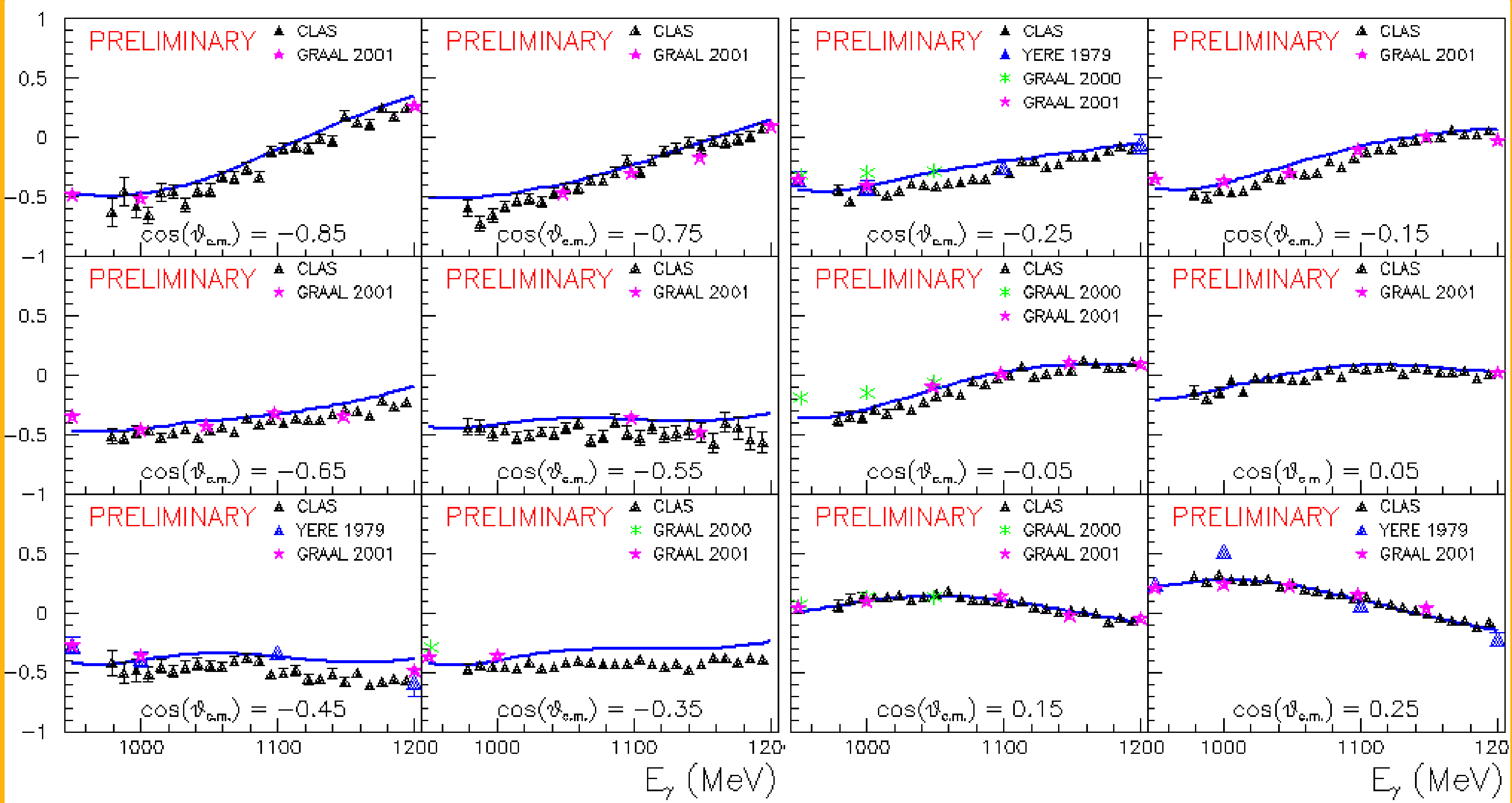
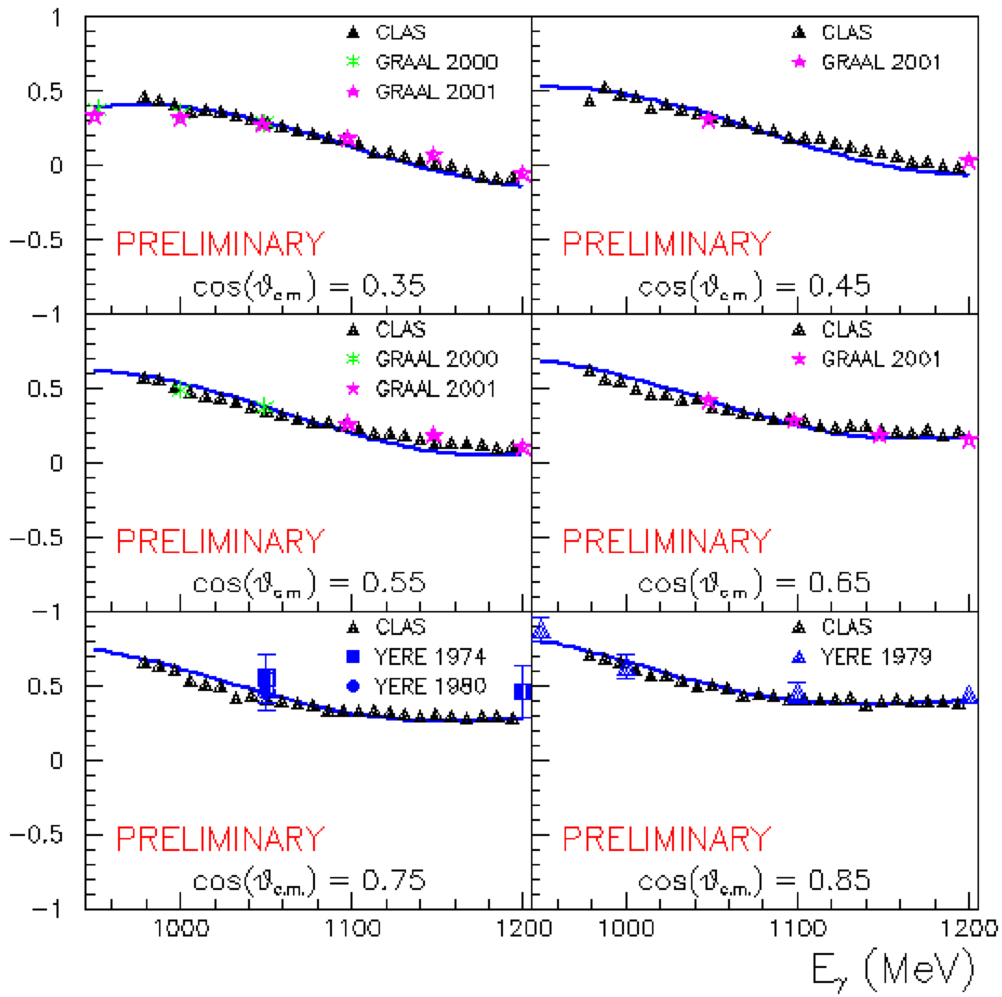
Preliminary Σ results for π^+



Fixed angle slide 1, lines are SAID

Preliminary Σ results for π^+

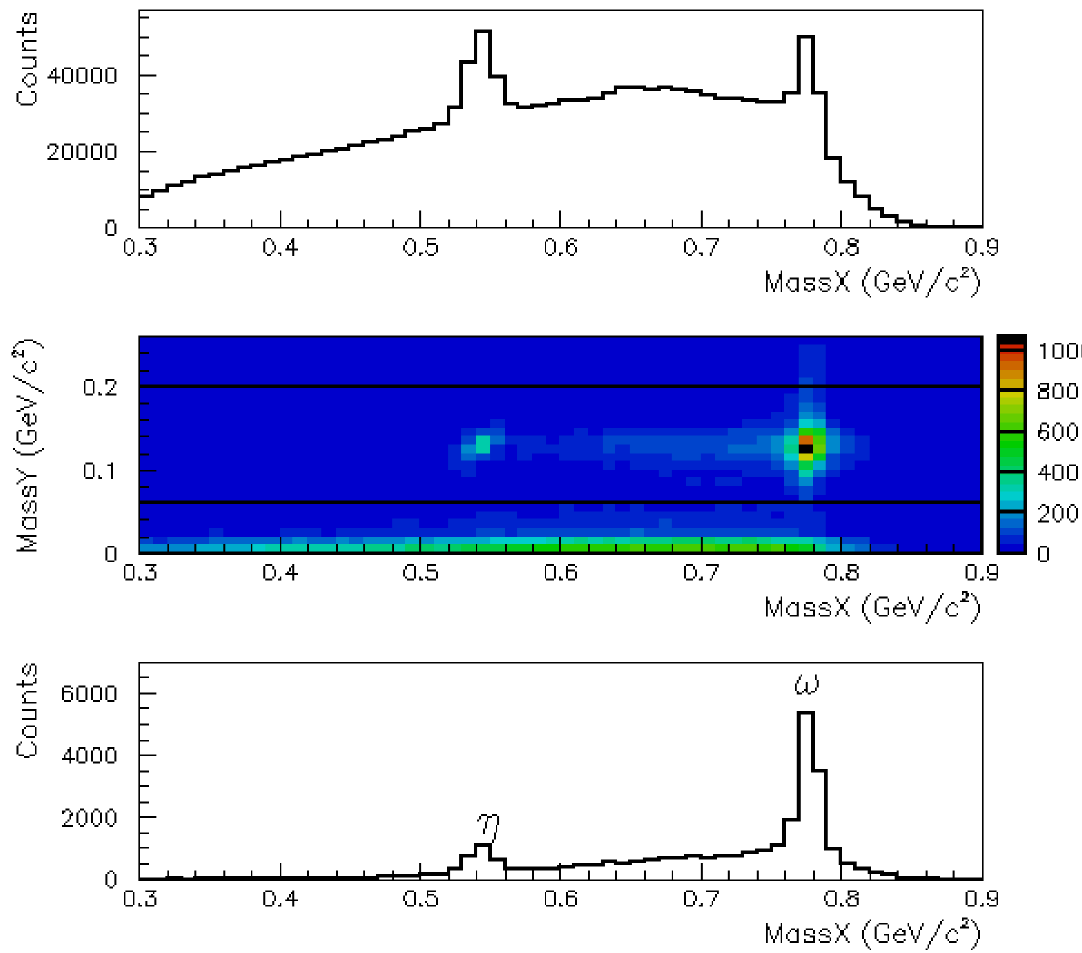


Fixed angle slide 2, lines are SAID

Preliminary Σ results for η

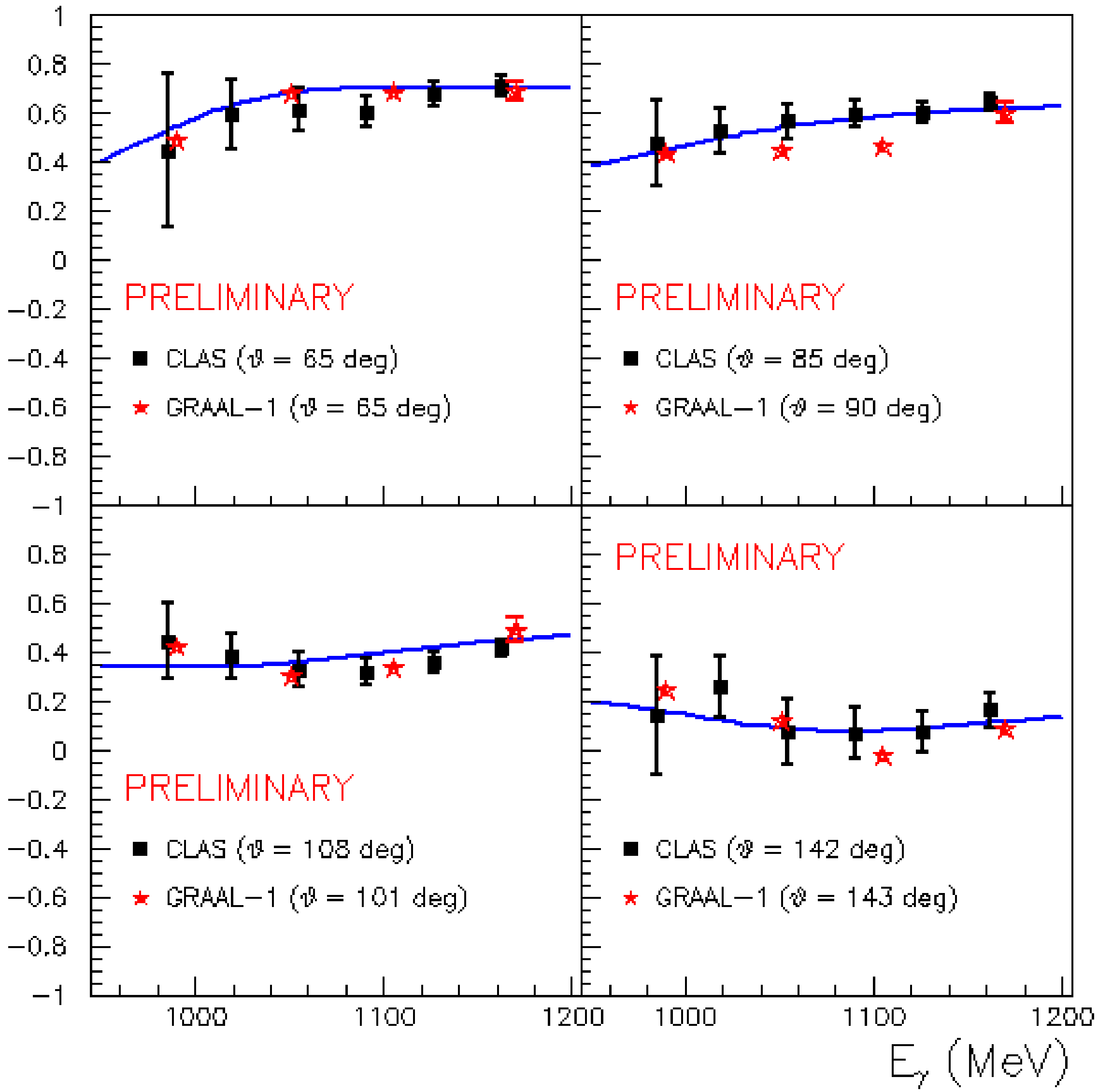
Chose a branch: $\eta \rightarrow \pi^+\pi^-\pi^0$ (Γ~22.7%)

- **Define *X*:**
  $\gamma p \rightarrow p X$
- **Define Y:**
  $p X \rightarrow p\ \pi^+\pi^- Y$
- **Cut on** $M_Y = M(\pi^0)$



Preliminary Σ results for η

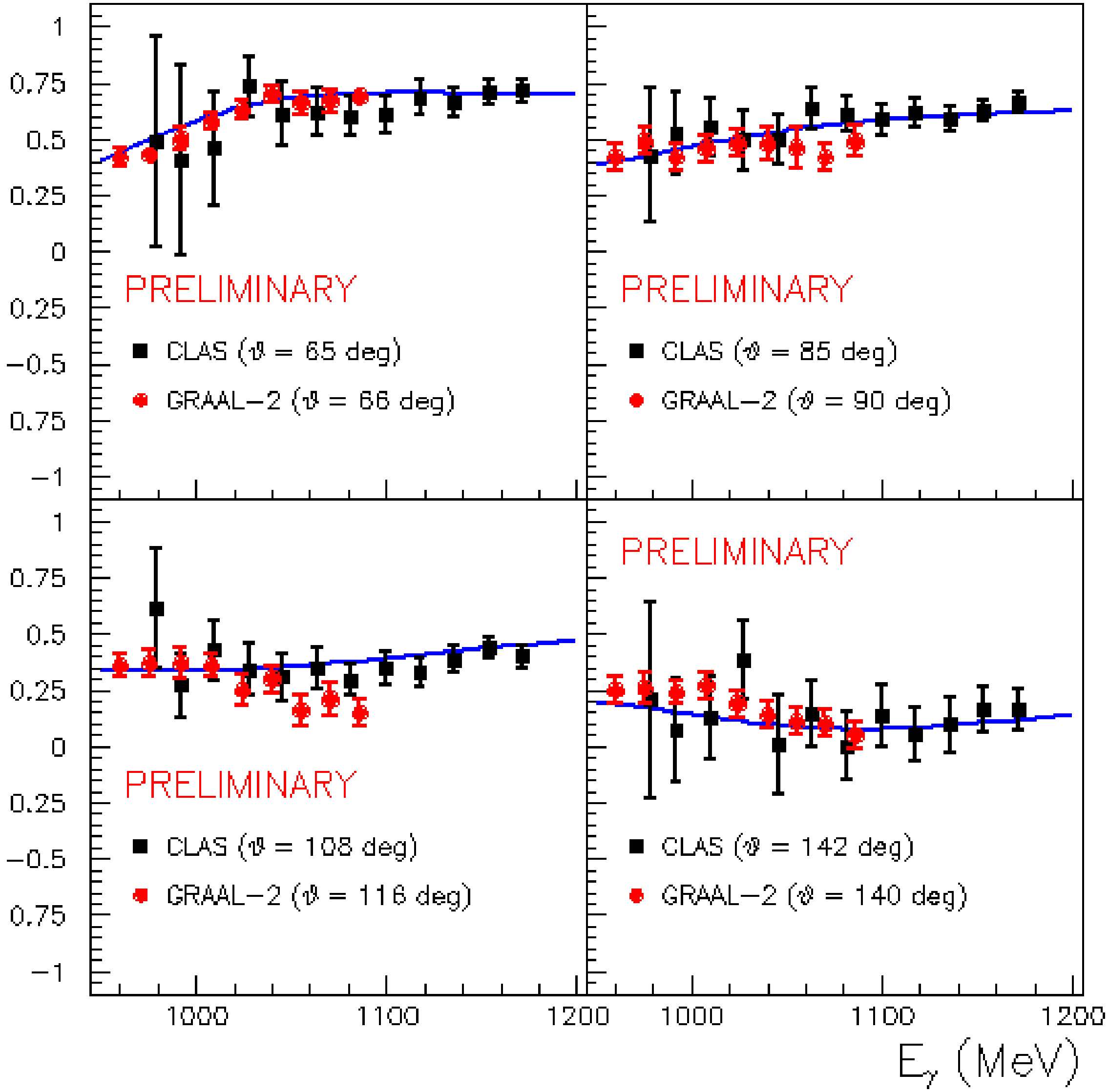
4 E-counters per bin



M. Dugger, NNR Workshop, June 2009

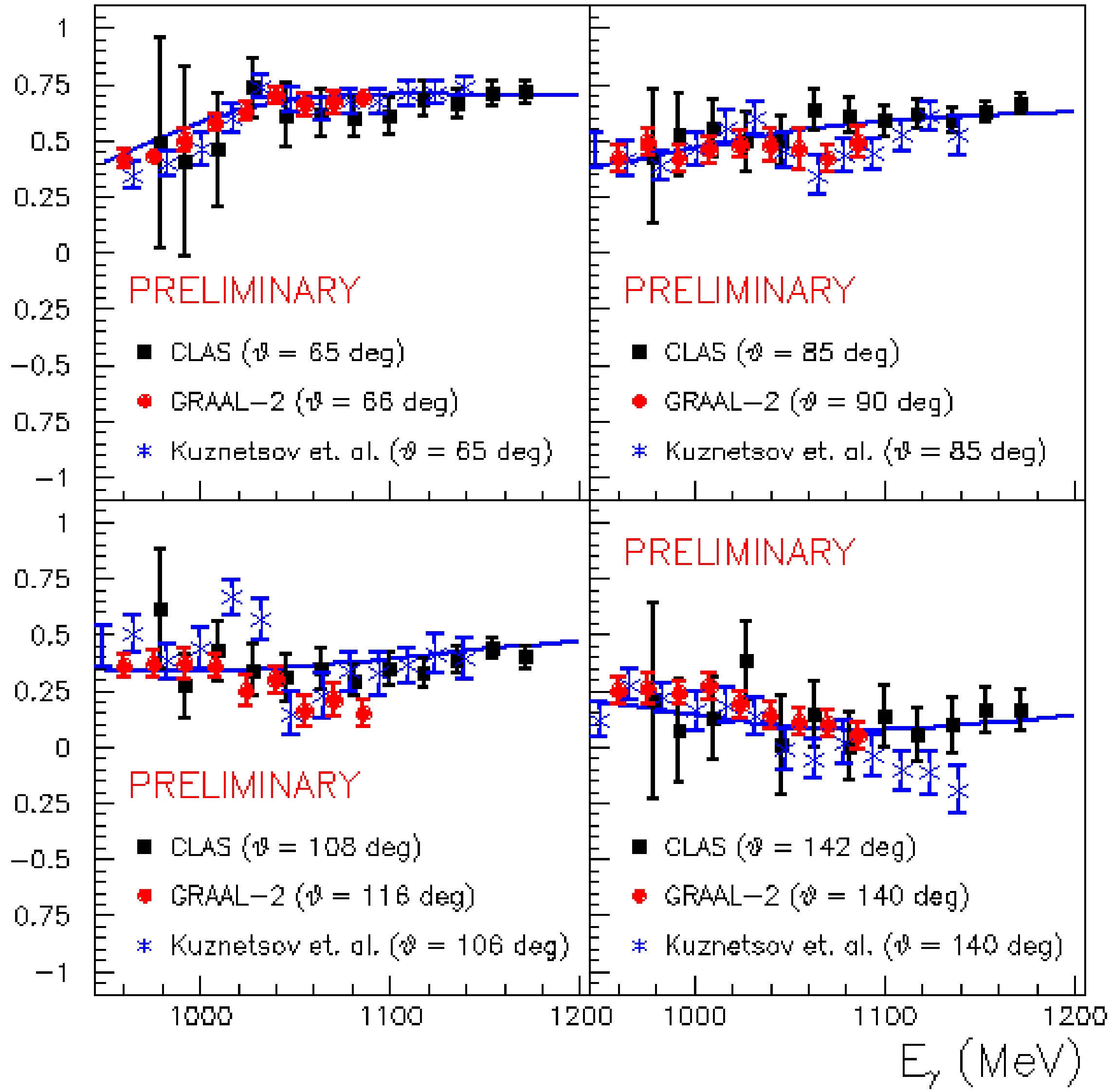
Preliminary Σ results for η

2 *E*-counters per bin



Preliminary Σ results for η

2 *E*-counters per bin



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 asymmetry

Target asymmetry

Recoil polarization

Single polarization

Double polarization

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

FROzen Spin Target "FROST"

- **Longitudinally polarized target**

- **Beam: Circular polarization; Linear polarization; Un-polarized**

- **Will measure σ, Σ, E, and G for η.**

Beam	Target	Observable
0	Longitudinal	$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}$
Circular	Longitudinal	$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left[1 - P_z P_{\square} E\right]$
Linear	Longitudinal	$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left[1 - P_T \Sigma \cos 2\phi - P_T P_z G \sin 2\phi\right]$

σ_0 = unpolarized cross section, P_T = transverse beam polarization
P_0= circular polarization, P_z= longitudinal target polarizaion

FROST statistics

- **Longitudinally polarized target**

Circularly polarized beam

E_0=1.645 GeV   1.1B events complete

E_0=2.478 GeV   2.3B events

Linearly polarized beam

0.7 GeV   300M events

0.9 GeV   500M events

1.1 GeV   500M events ← **Coherent edge for bump region**

1.3 GeV   600M events

1.5 GeV   600M events

1.7 GeV   850M events

1.9 GeV   720M events

2.1 GeV   800M events

2.3 GeV   780M events

Amorphous radiator 1.1B events

Grand Total: 10.1B events

Summary

- **Good progress for g8b data with the *first/worst 200 MeV* of photon energy range**
  - **Finish line is in sight for Σ for π^+, π^0, and η**

- **Goal: To have g8b analysis ready for collaboration review by end of year**

- **FROST data will give us access to the Σ, G, and E observables from threshold up to 2.3 GeV for $\gamma p \rightarrow p \eta$**

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