Photoproduction of ϕ-meson off proton Using Linearly-Polarized Photons at Threshold Energies

Julian Salamanca, Philip L Cole and the CLAS Collaboration

NSTAR 2009
Beijing, CHINA
April 19, 2009

ISU PHYSICS

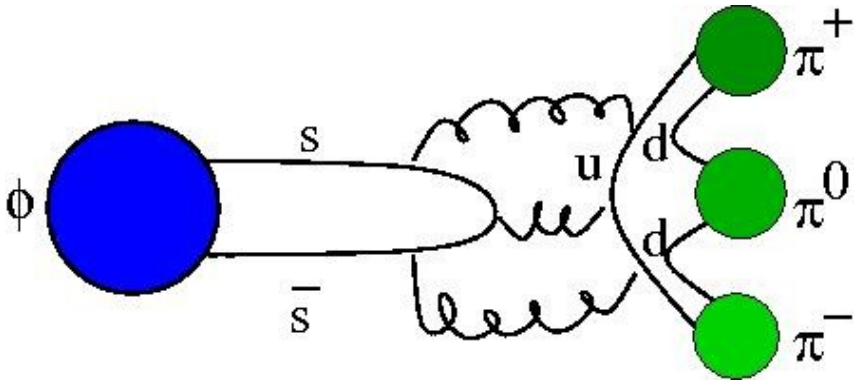
Jefferson Lab
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

Outline

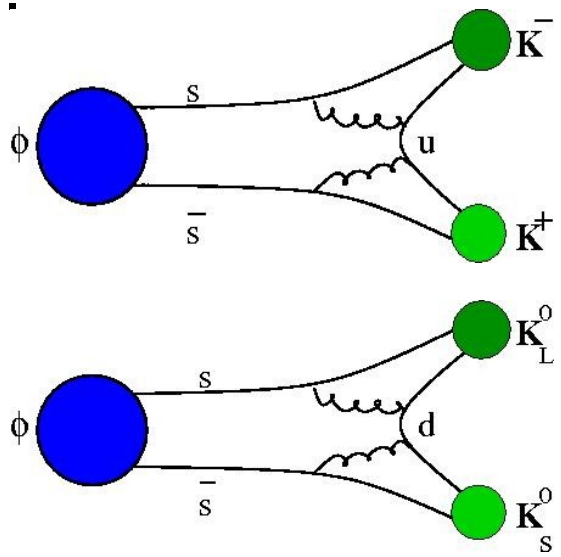
- Motivation
  - OZI evading/respecting
  - VMD (Vector Meson Dominance)
  - Spin Density Matrix Elements
- ϕ-meson Photoproduction
  - CEBAF (Continuous Electron Beam Accelerator Facility)
  - Coherent Bremsstrahlung Facility at CLAS
    (CEBAF Large Acceptance Spectrometer)
  - Event Selection
  - Background Subtraction
- Results for the 2.1 GeV Coherent-Edge Data

OZI evading/respecting process

- Okubo Zweig Iizuka rule: In strong interaction processes where final states can only be reached via quark-antiquark annihilation are suppressed. You cannot cut gluon lines in the OZI picture.



- **Experimentally this decay mode is: (15.3 ± 0.4)%**

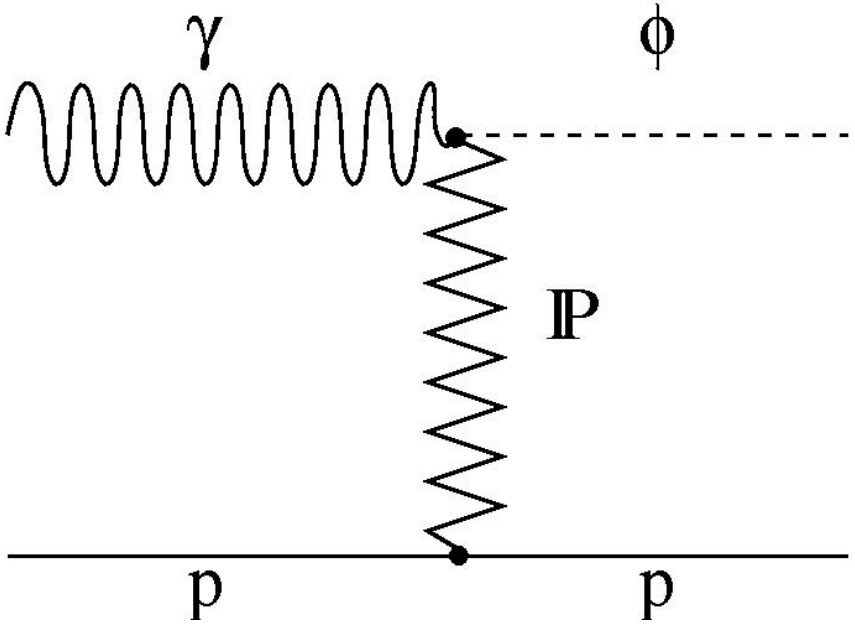


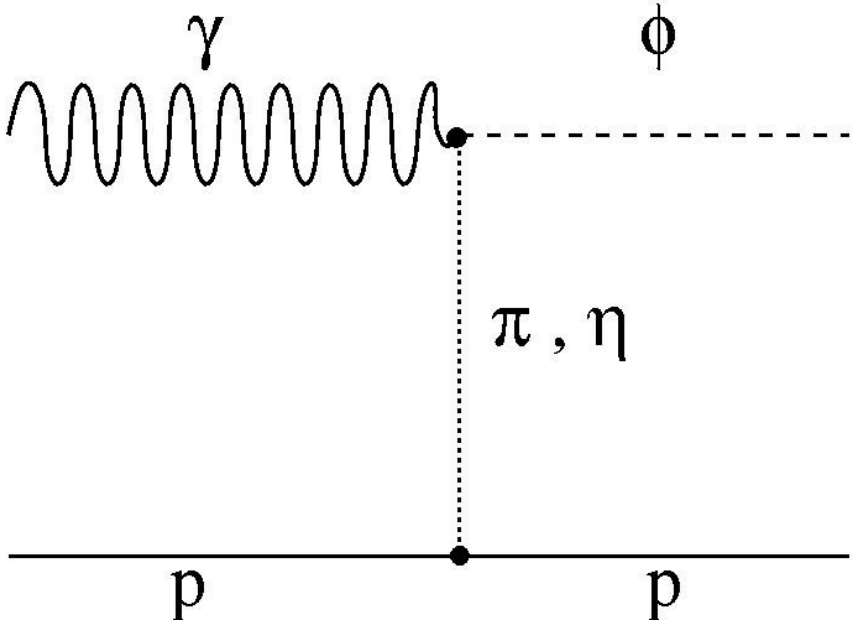
(49.2 ± 0.6) %

(34 ± 0.5)%

~84% of the Φ decay is OZI respecting.

VMD





Previous Measurements

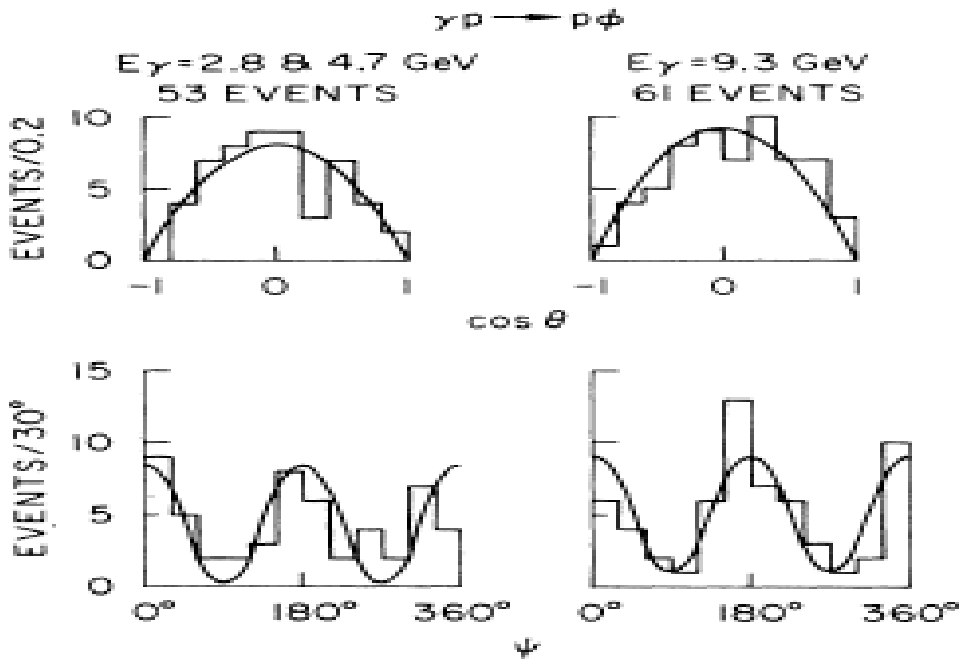


FIG. 29. Reaction $\gamma p \to p\phi$ at 2.8, 4.7, and 9.3 GeV. Decay angular distribution of $K\bar{K}$ pairs in the helicity system in the ϕ mass region $1.00 \leq M_{K\bar{K}} \leq 1.04$ GeV and in the momentum-transfer interval $0.02 \leq |t| \leq 0.8$ GeV^2. The curves are calculated for an s-channel helicity-conserving ϕ production amplitude.

J. Ballam, G. B. Chadwick *et al.,* Phys. Rev. D **7** 3150 (1972).

Previous Measurements

Spring-8 used a beam of linearly polarized photons (forward direction $|t|<0.4$ GeV ^{2})

- T. Mibe, "Measurement of ϕ meson photoproduction near production threshold with linearly polarized photons," PhD Thesis, Osaka University, Japan (2004), unpublished.
- T. Mibe *et al.*, Phys. Rev. Lett. 95, 182001 (2005).

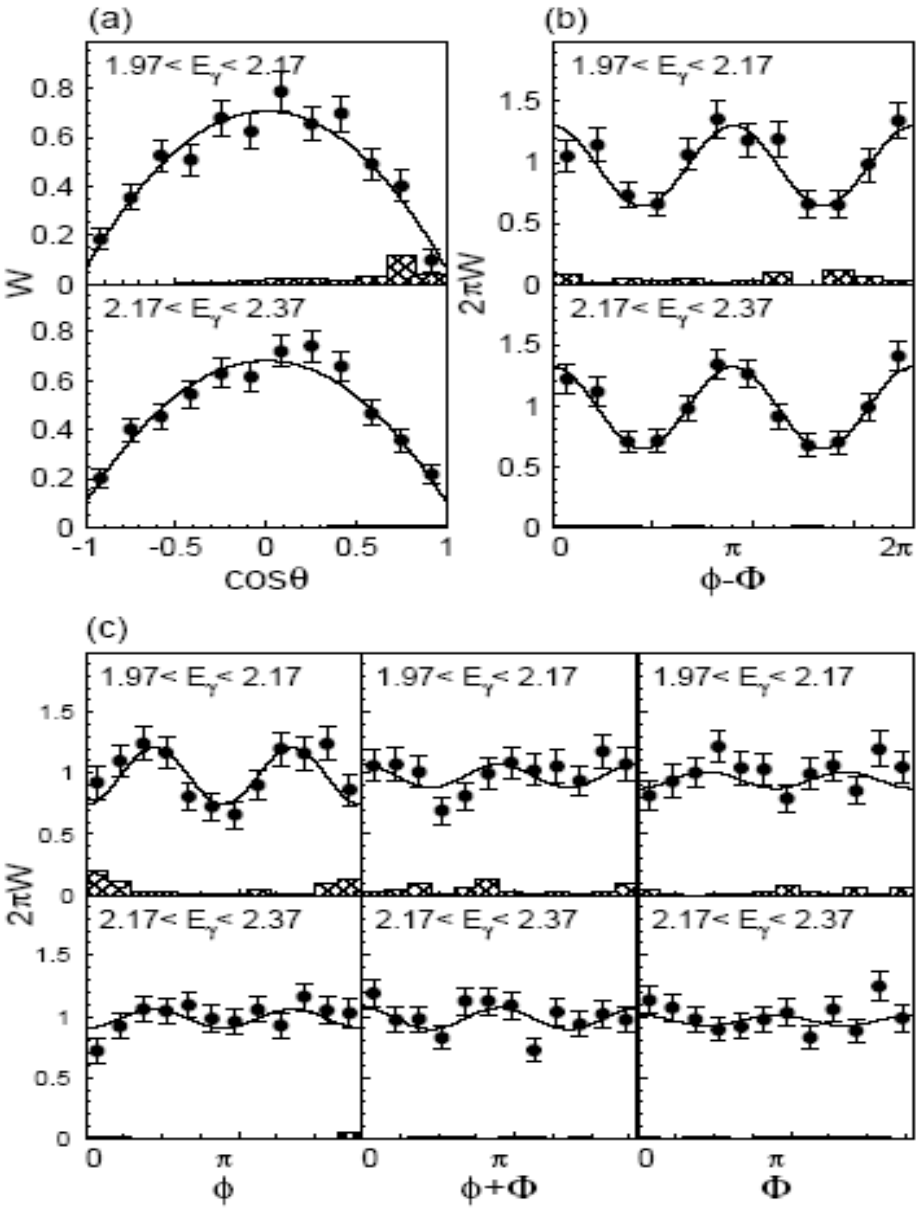


FIG. 4: Decay angular distributions for $-0.2< t+|t|_{min}$ in the Gottfried-Jackson frame. The solid curves are the fit to the data. The hatched histograms are systematic errors.

VMD

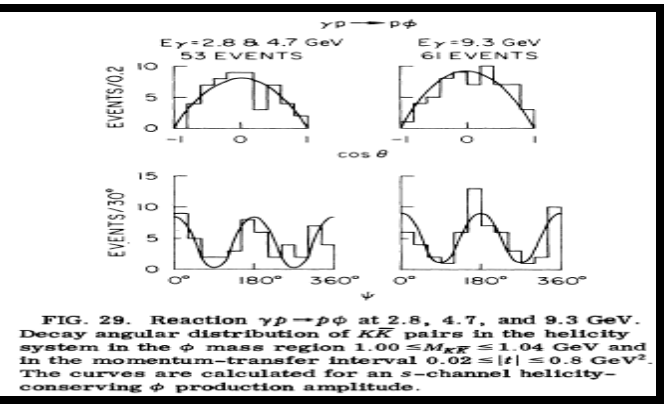
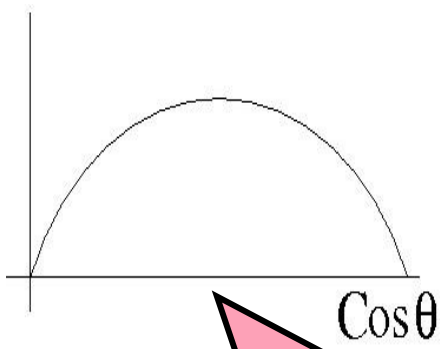
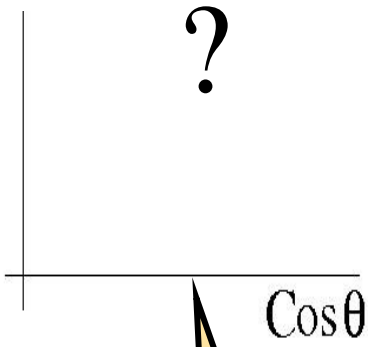


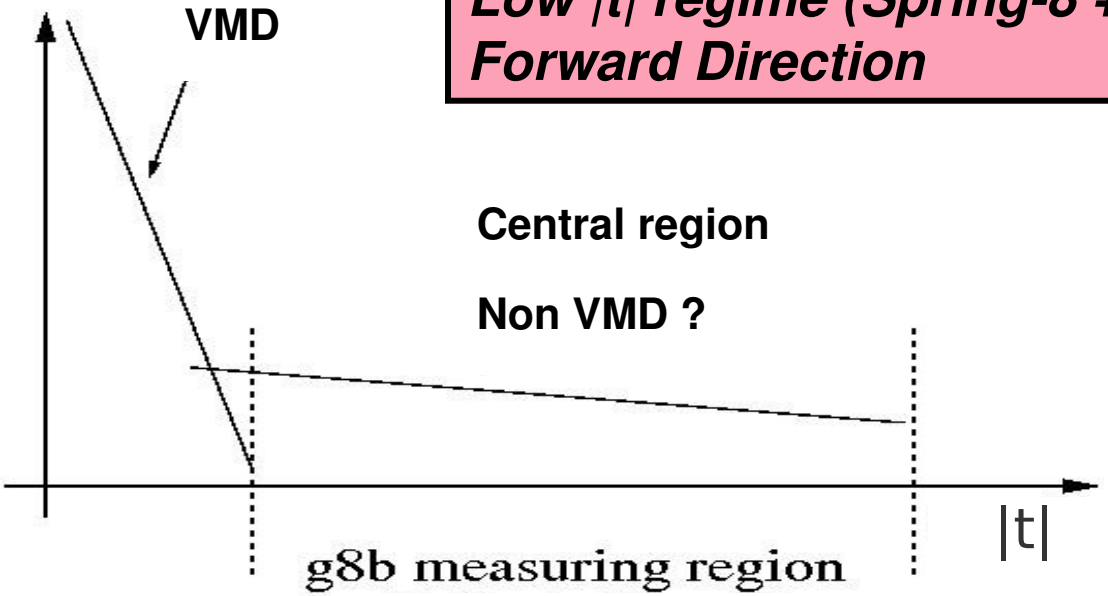
FIG. 29. Reaction $\gamma p \to p\phi$ at 2.8, 4.7, and 9.3 GeV. Decay angular distribution of $K\bar{K}$ pairs in the helicity system in the ϕ mass region $1.00 \leq M_{K\bar{K}} \leq 1.04$ GeV and in the momentum-transfer interval $0.02 \leq |t| \leq 0.8$ GeV^2. The curves are calculated for an s-channel helicity-conserving ϕ production amplitude.





Low |t| regime (Spring-8 + SLAC)
Forward Direction

High |t| regime g8b
Central Region



The Decay Angular Distribution Spin Density Matrix Elements

$$W(\cos\theta,\phi,\Phi) = W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) - P_\gamma\cos 2\Phi\, W^1(\cos\theta,\phi,\rho^1_{\alpha\beta}) - P_\gamma\sin 2\Phi\, W^2(\cos\theta,\phi,\rho^2_{\alpha\beta})$$

where

$$W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) = \frac{3}{4\pi}\left[\frac{1}{2}\sin^2\theta + \frac{1}{2}(3\cos^2\theta - 1)\rho^0_{00} - \sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\sin 2\theta\cos\phi - \rho^0_{1-1}\sin^2\theta\cos 2\phi\right]$$

$$W^1(\cos\theta,\phi,\rho^1_{\alpha\beta}) = \frac{3}{4\pi}\left[\rho^1_{11}\sin^2\theta + \rho^1_{00}\cos^2\theta - \sqrt{2}\,\mathrm{Re}\,\rho^1_{10}\sin 2\theta\cos\phi - \rho^1_{1-1}\sin^2\theta\cos 2\phi\right]$$

$$W^2(\cos\theta,\phi,\rho^2_{\alpha\beta}) = \frac{3}{4\pi}\left[\sqrt{2}\,\mathrm{Im}\,\rho^2_{10}\sin 2\theta\sin\phi + \mathrm{Im}\,\rho^2_{1-1}\sin^2\theta\sin 2\phi\right]$$

Linearly polarization gives access to six more density matrix elements

***Those are calculated in ϕ rest frame (Helicity Frame)**

Spin Density Matrix Elements

IF VMD:

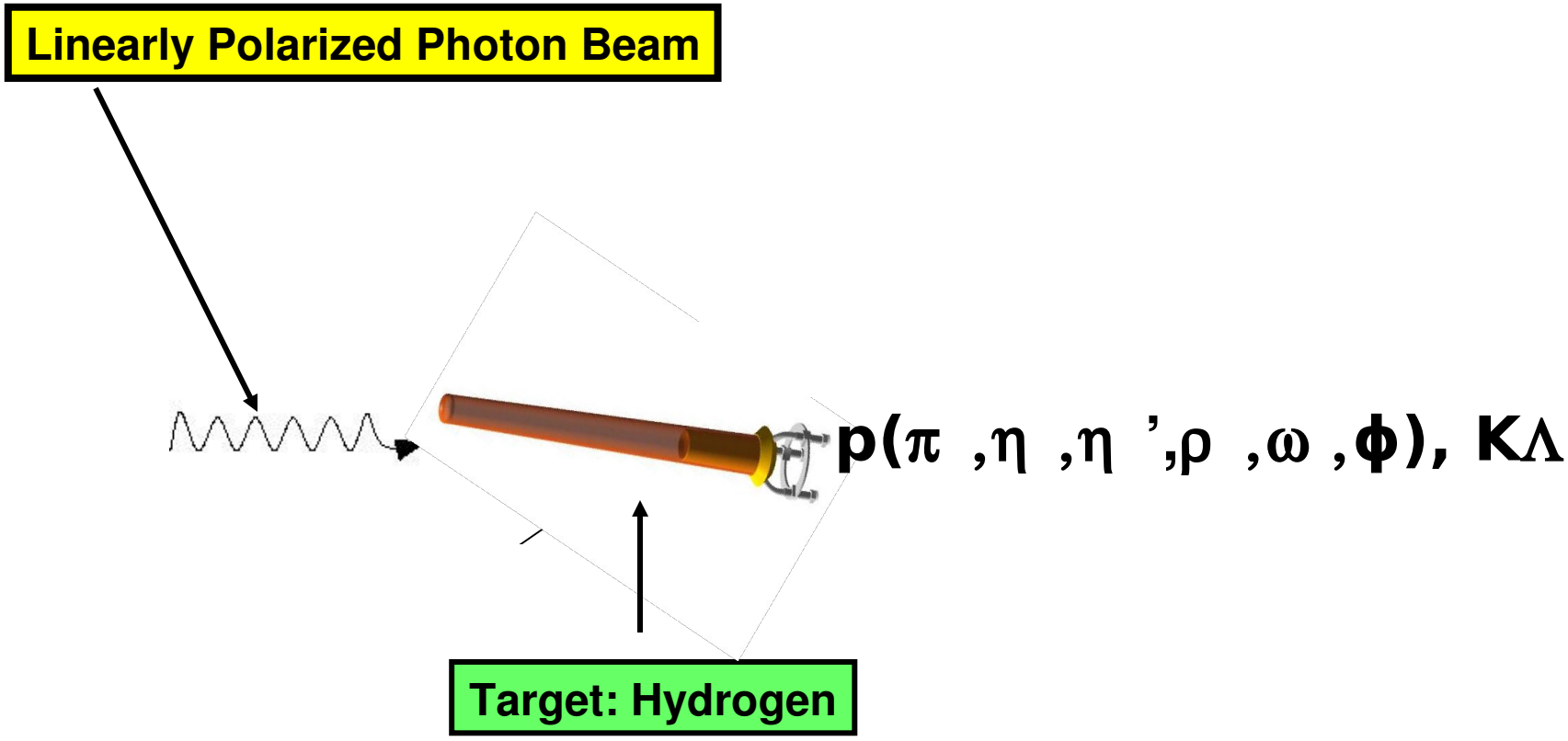
- **Density matrix elements should be equal to ZERO but ρ^1_{1-1} and $Im\{\rho^2_{1-1}\}$**
- **ρ^1_{1-1} , $Im\{\rho^2_{1-1}\}$ = (1/2, 1/2 : Pomeron)**

- **ρ^1_{1-1} , $Im\{\rho^2_{1-1}\}$ = (-1/2, 1/2 : Meson)**

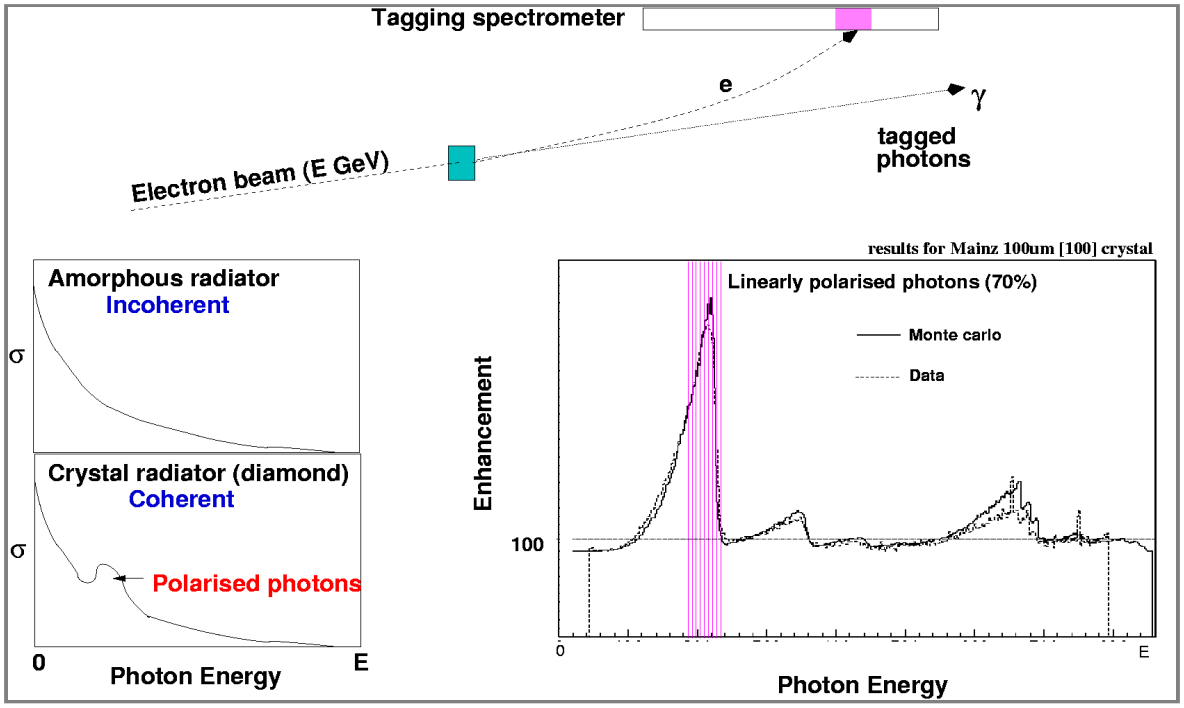
If not:

- **Knockout processes take place**
- **Interesting physics beyond VMD**

ϕ–Photoproduction: g8b experiment

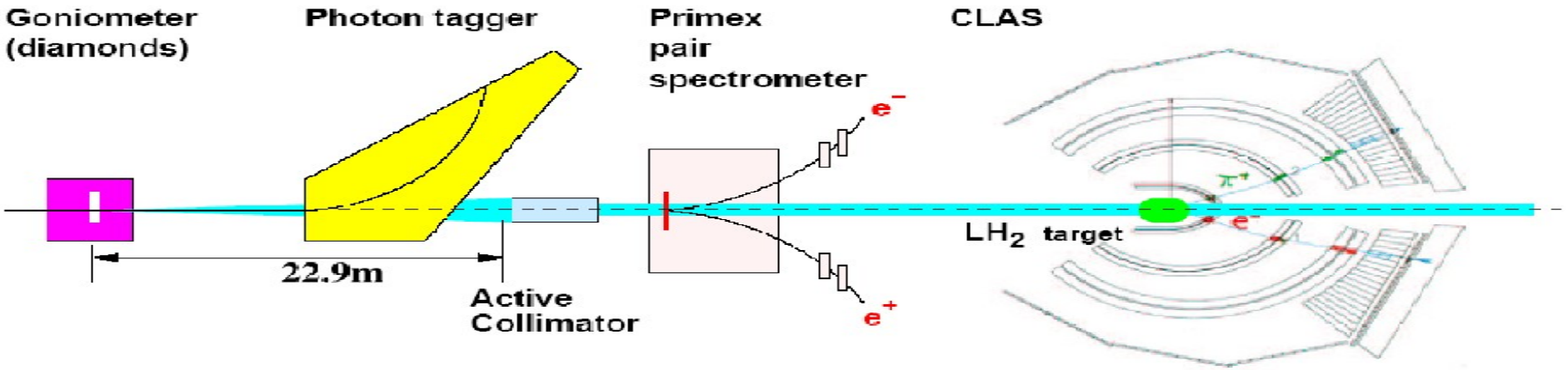


The Coherent Bremsstrahlung Facility at CLAS

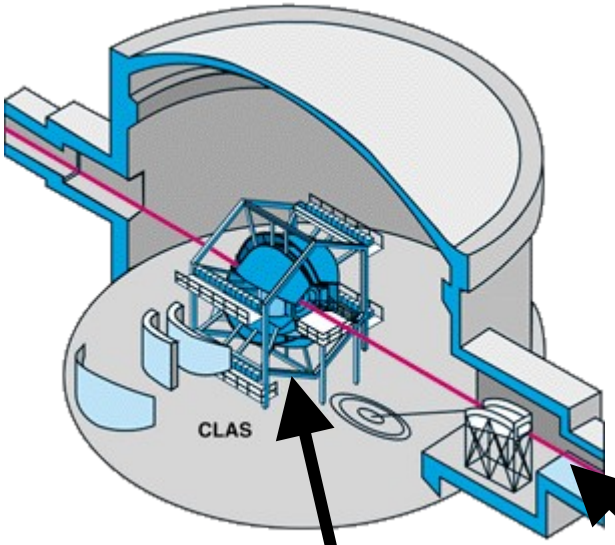


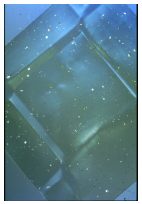
Requirements for Coherent Bremsstrahlung

- ❑ Low emittance, stable beam
- ❑ High quality thin crystal
- ❑ Collimation < 0.5 characteristic angle

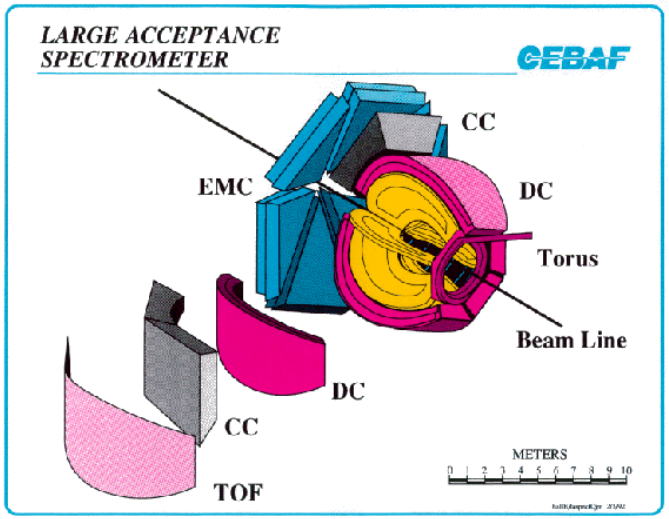


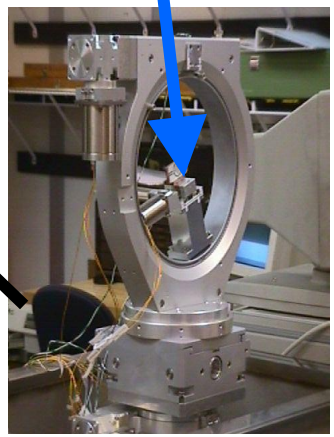
The Coherent Bremsstrahlung Facility at CLAS





Diamond



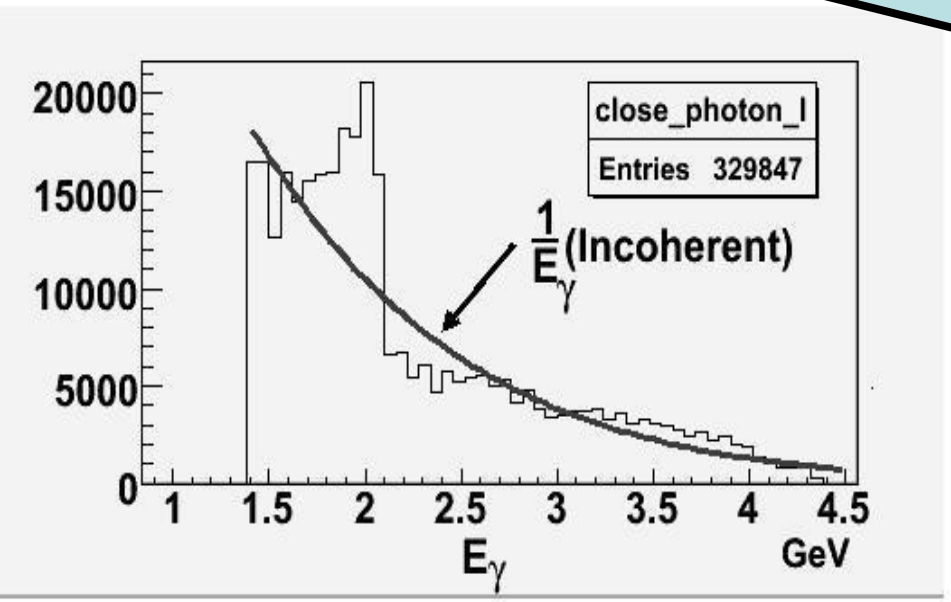


Goniometer,

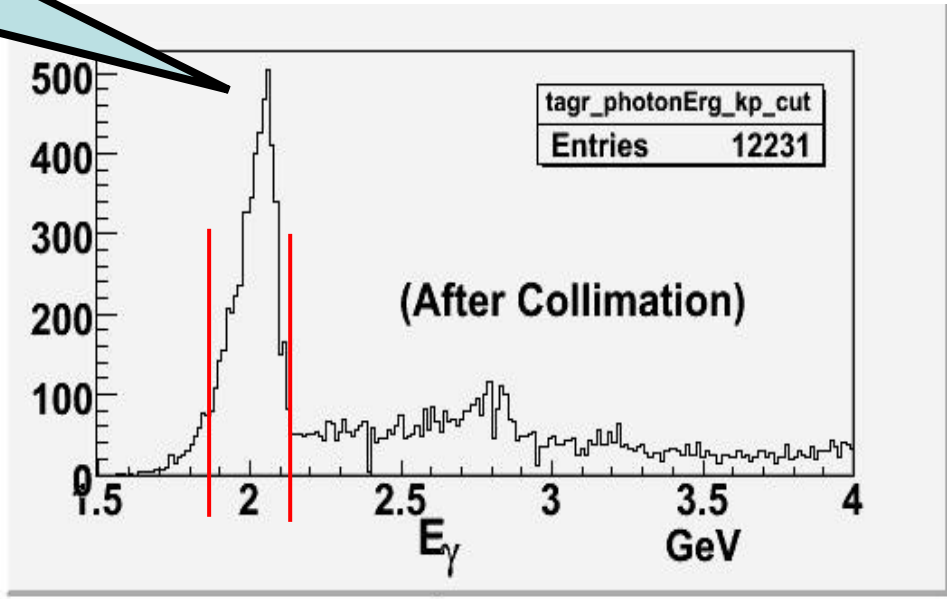
George Washington University

Linearly Polarized Photons

i. e. Coherent Peak at 2.1 GeV



a



b

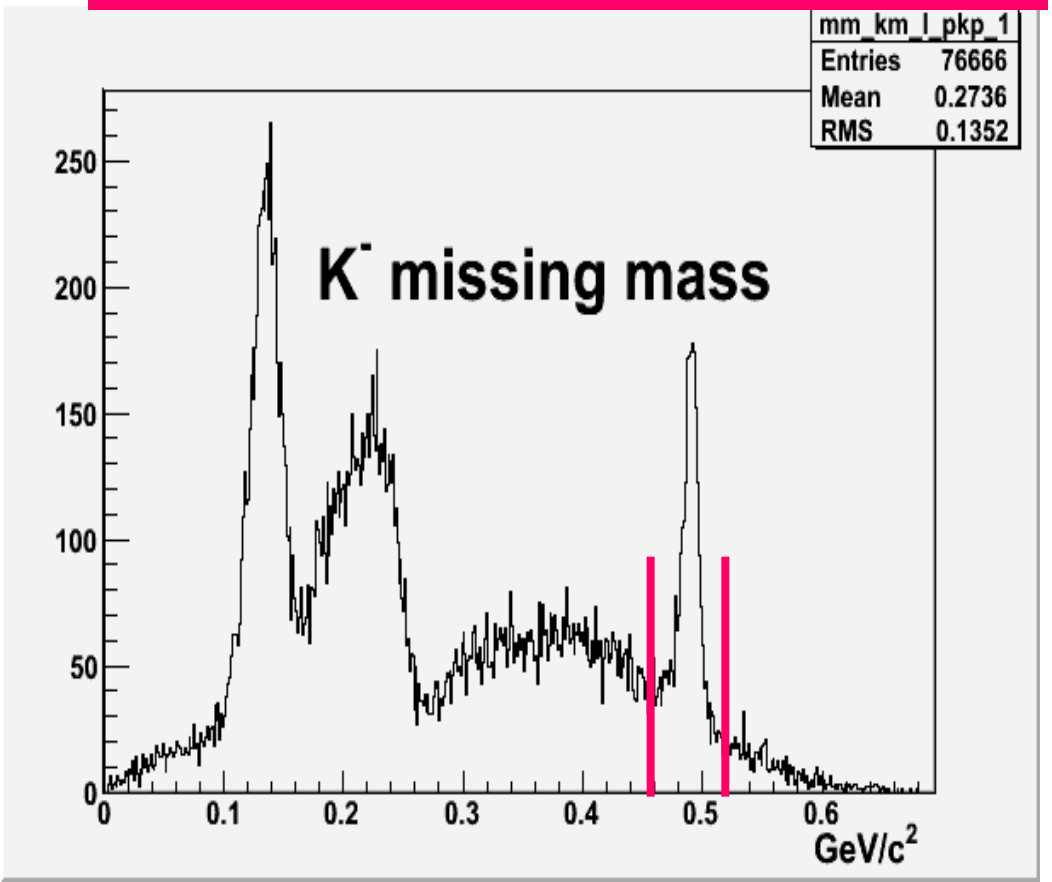
- **Mean polarization estimated to be ~70% from comparison with the coherent bremsstrahlung calculation***

* A. Natter. http://www.pit.physik.uni-tuebingen.de/grabmayr/software/brems/brems-analytic.html

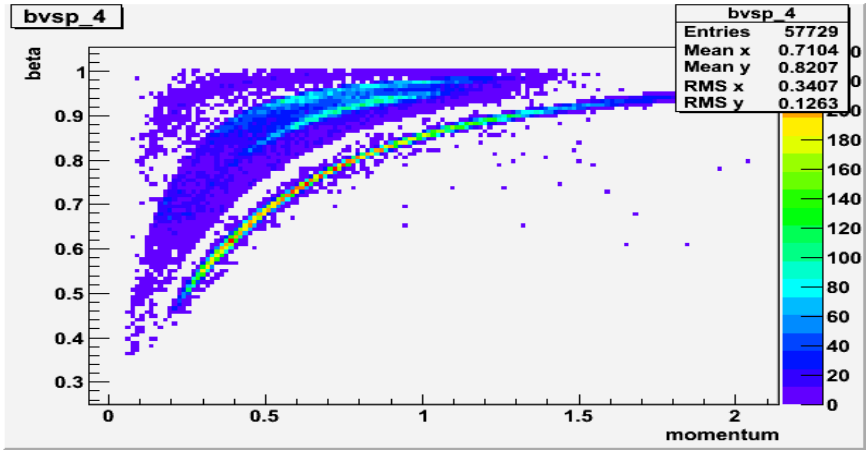
Event Selection

$\vec{\gamma}\, p \rightarrow p\phi \rightarrow pK^+K^-$

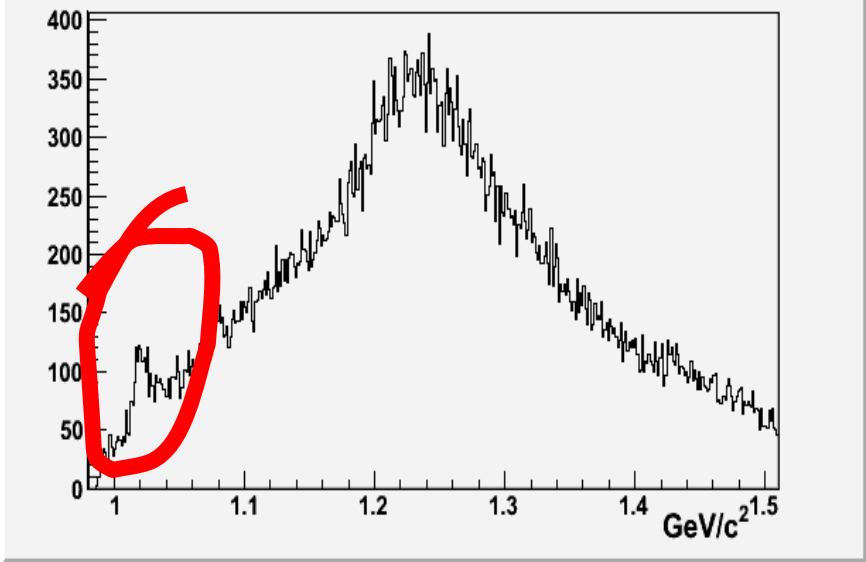
Mode: $(pK^+)K^-$



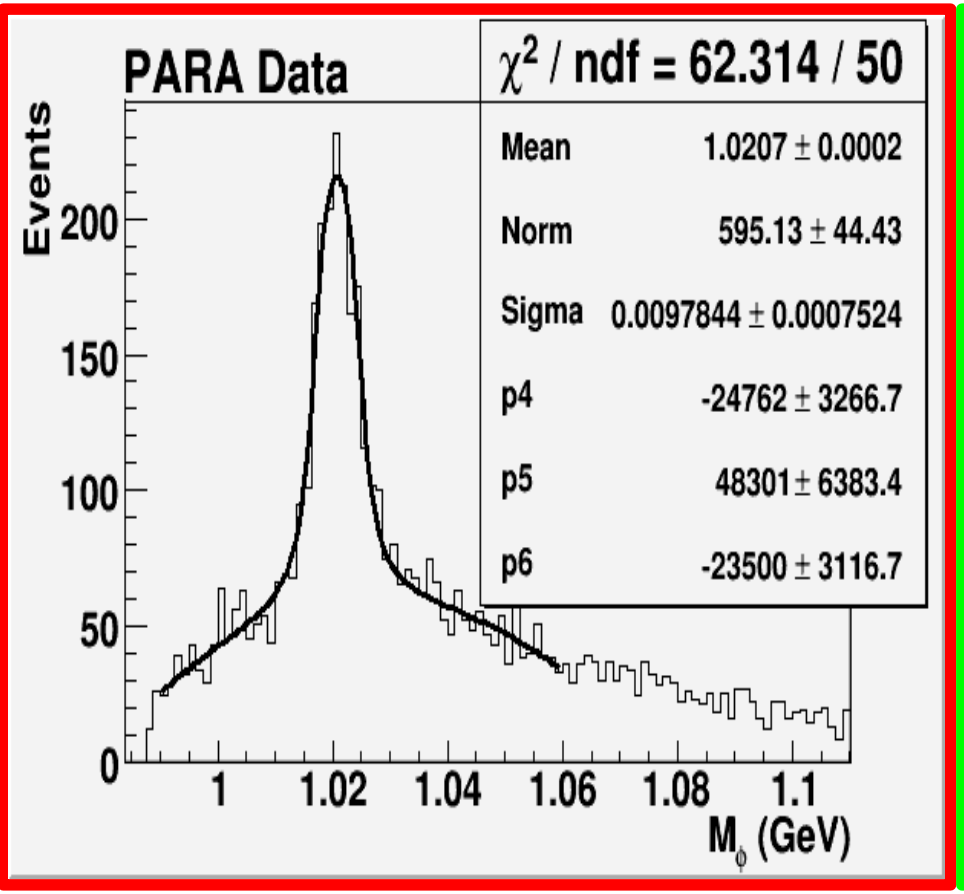
Before K^- missing mass cut

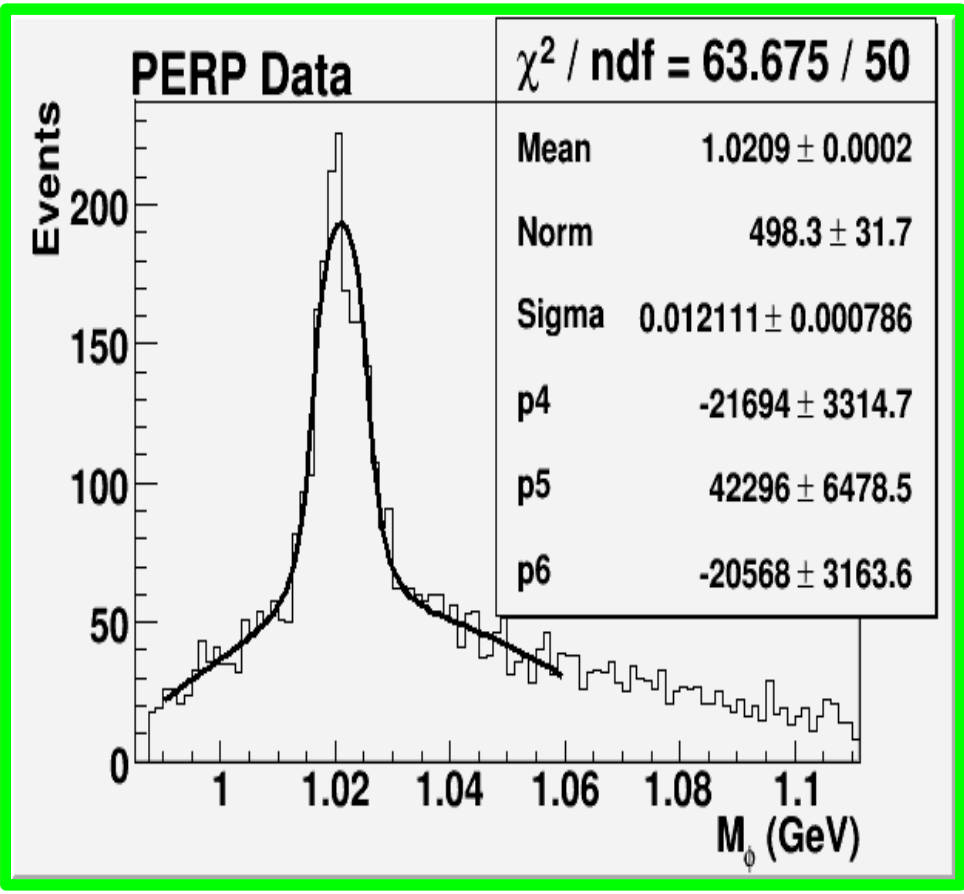


$\phi \rightarrow K^+K^-$ Invariant mass (before)



Event Selection



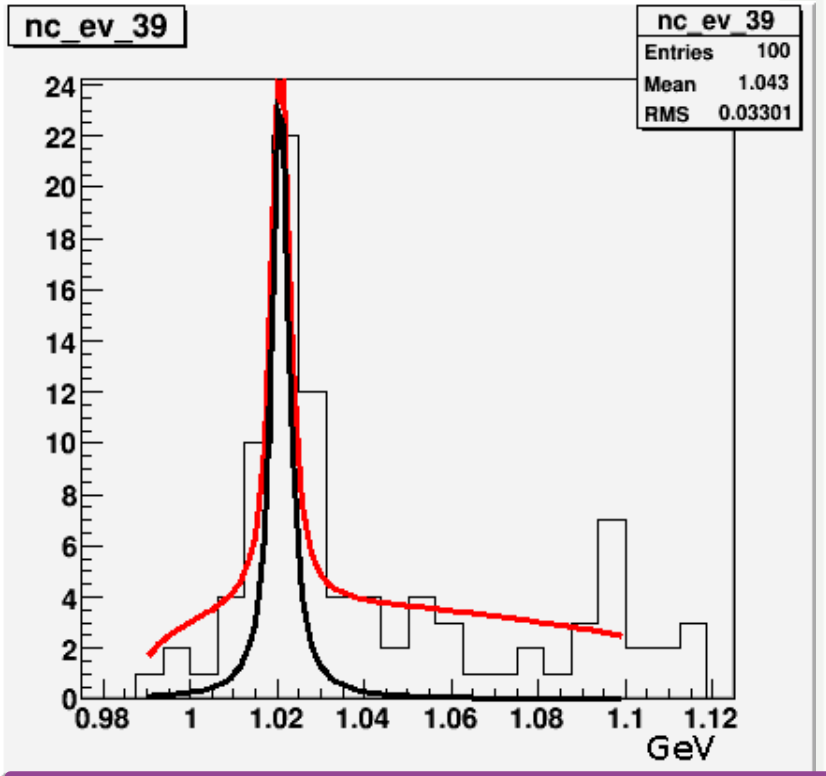


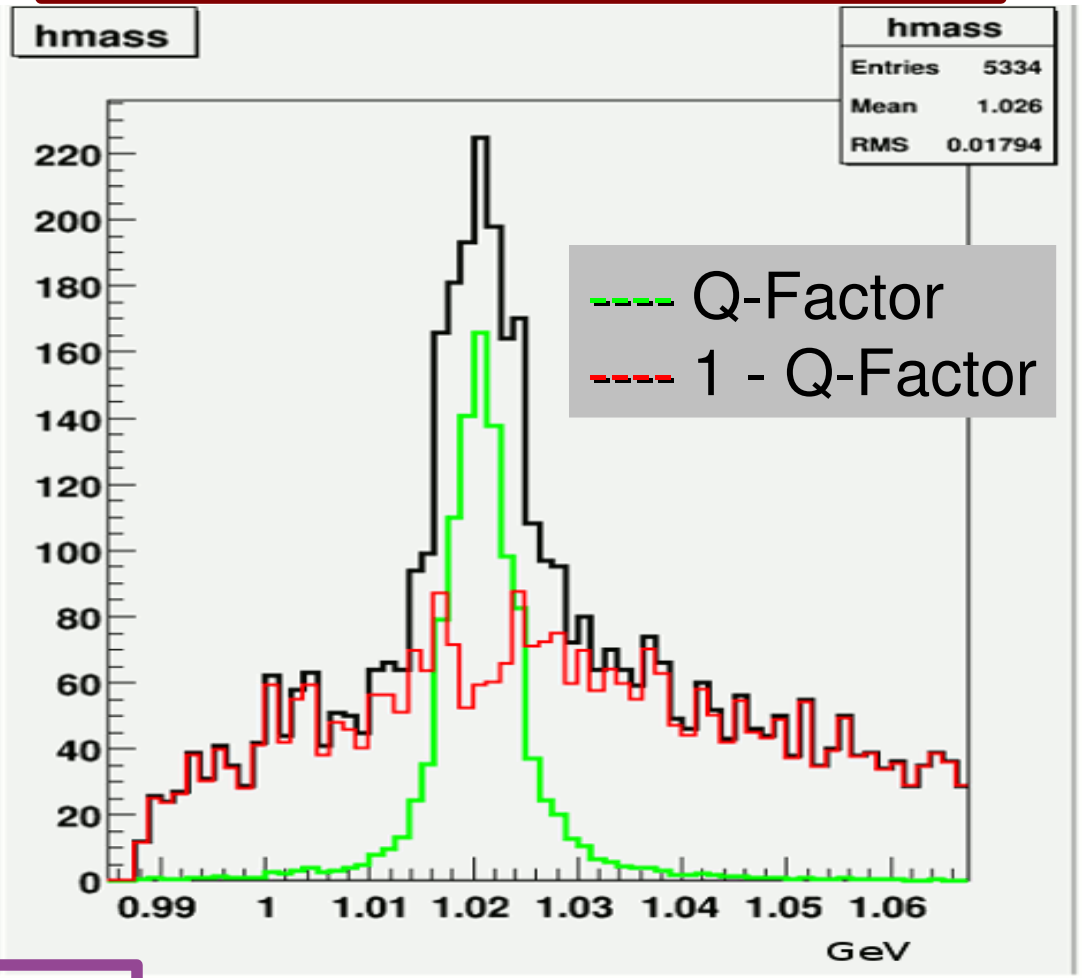
→ PARA: Polarization || to the floor

→ PERP: Polarization ⊥ to the floor

Background Subtraction

- Probabilistic Event Weighting*
- Q-factor = Fs/(Fs+Fb)
- Fs (Signal): Voigtian
- Fb (Background): 2nd order polynomial





* M. Williams, M. Bellis and C.A. Meyer arXiv: 0804.3382v1

Results @ 2.1 Coherent Edge

$$W(\cos\theta) = N[\tfrac{1}{2}(1 - \rho^0_{00})\sin^2\theta + \rho^0_{00}\cos^2\theta] \qquad \rho^0_{00} = \rho^1$$

$$W(\phi) = N[1 - 2\rho^0_{1-1}\cos 2\phi] \qquad \rho^0_{1-1} = \rho^2$$

$$W(\phi - \Phi) = N[1 + 2P_\gamma(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})\cos 2(\phi - \Phi)] \qquad \tfrac{1}{2}(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1}) = \rho^3$$

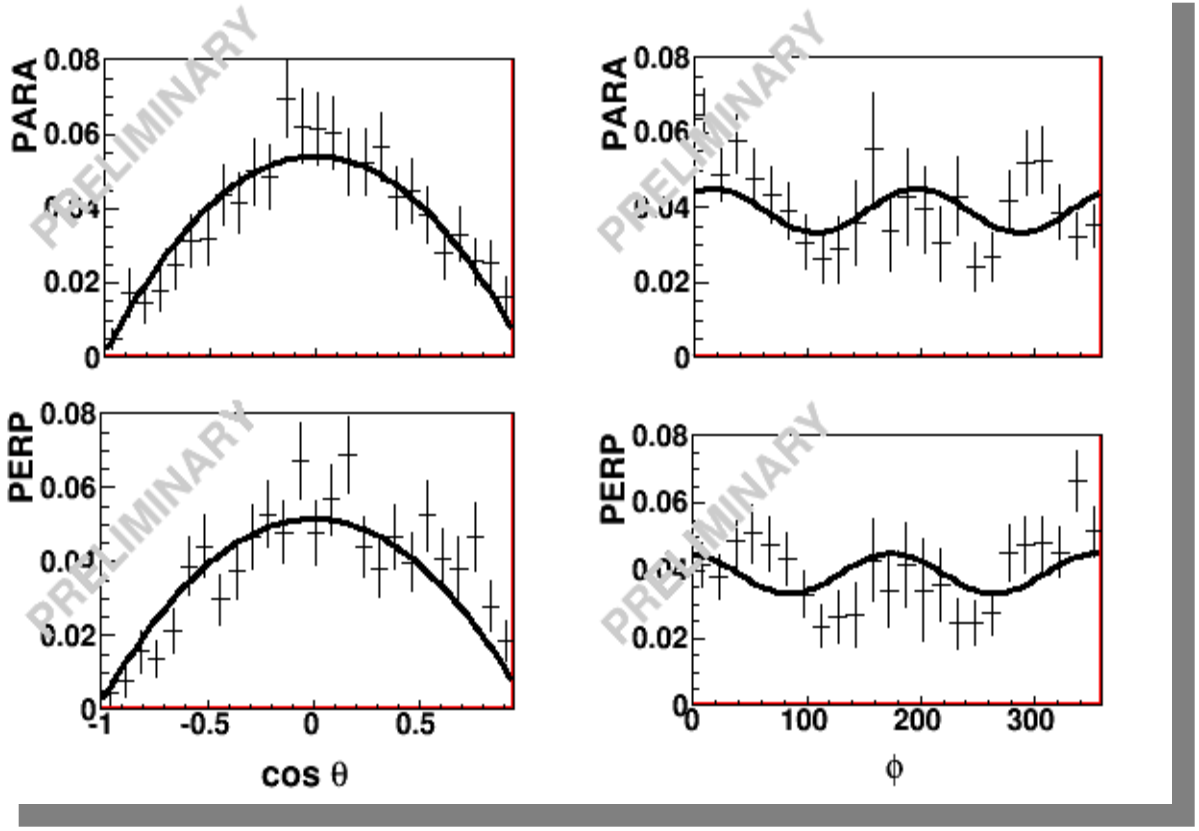
$$W(\phi + \Phi) = N[1 + 2P_\gamma(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1})\cos 2(\phi + \Phi)] \qquad \tfrac{1}{2}(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1}) = \rho^4$$

$$W(\Phi) = N[1 - P_\gamma(2\rho^0_{1-1} + \rho^1_{00})\cos 2\Phi] \qquad 2\rho^1_{11} + \rho^1_{00} = \rho^5$$

$$P_\gamma\rho^5\cos 2\Phi = \frac{W_{PARA} - W_{PERP}}{W_{PARA} + W_{PERP}}$$

Results @ 2.1 Coherent Edge

$1.9 < E_\gamma < 2.1$ GeV



PARA	
χ^2 / ndf	16 / 24
p0	0.1096 ± 0.0044
ρ^1	0.01385 ± 0.02132

PARA	
χ^2 / ndf	35.92 / 21
p0	0.03918 ± 0.00163
ρ^2	-0.0742 ± 0.0298
p2	-16.82 ± 11.54

PERP	
χ^2 / ndf	38.23 / 24
p0	0.1051 ± 0.0044
ρ^1	0.02041 ± 0.02367

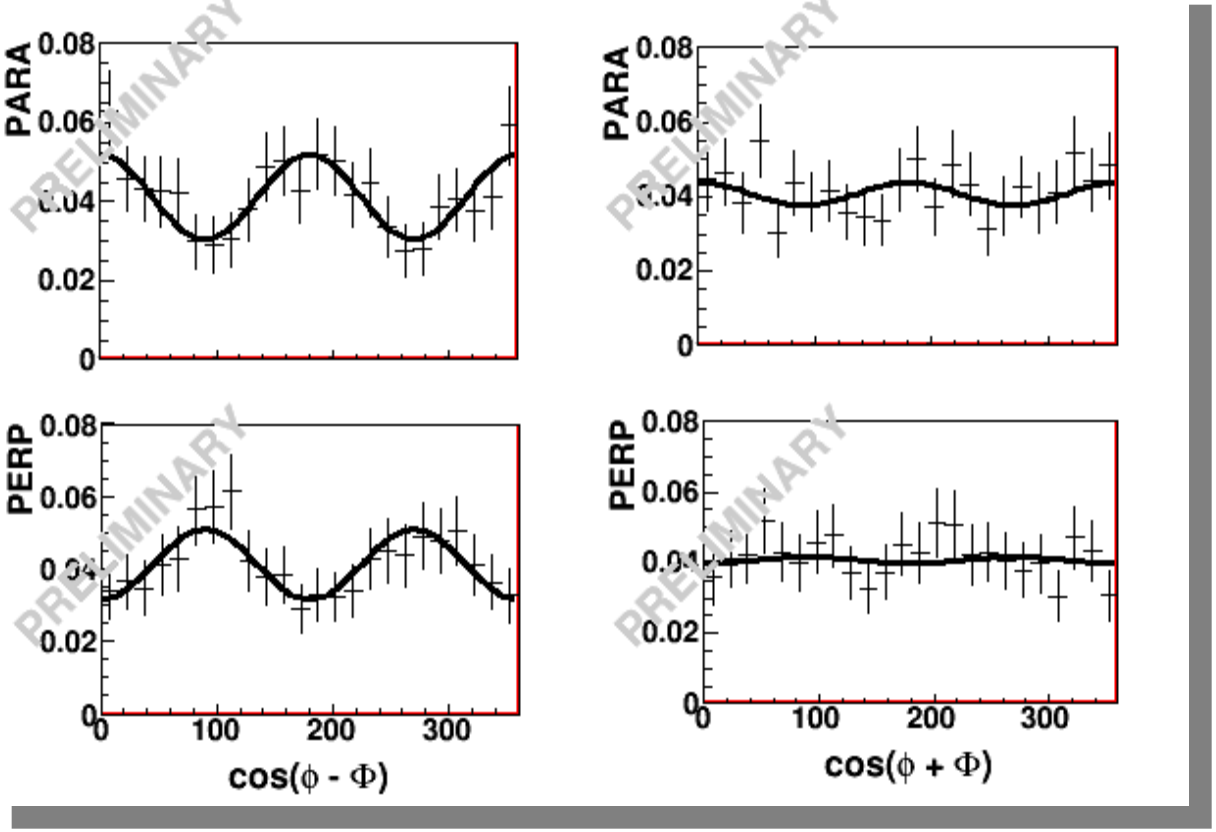
cos θ

PERP	
χ^2 / ndf	38.39 / 21
p0	0.03913 ± 0.00165
ρ^2	-0.07575 ± 0.02907
p2	5.425 ± 11.595

φ

Results @ 2.1 Coherent Edge

$1.9 < E_\gamma < 2.1$ GeV



PARA	
Entries	1476
χ^2 / ndf	8.155 / 22
p0	0.0411 ± 0.0016
ρ^3	0.1899 ± 0.0396

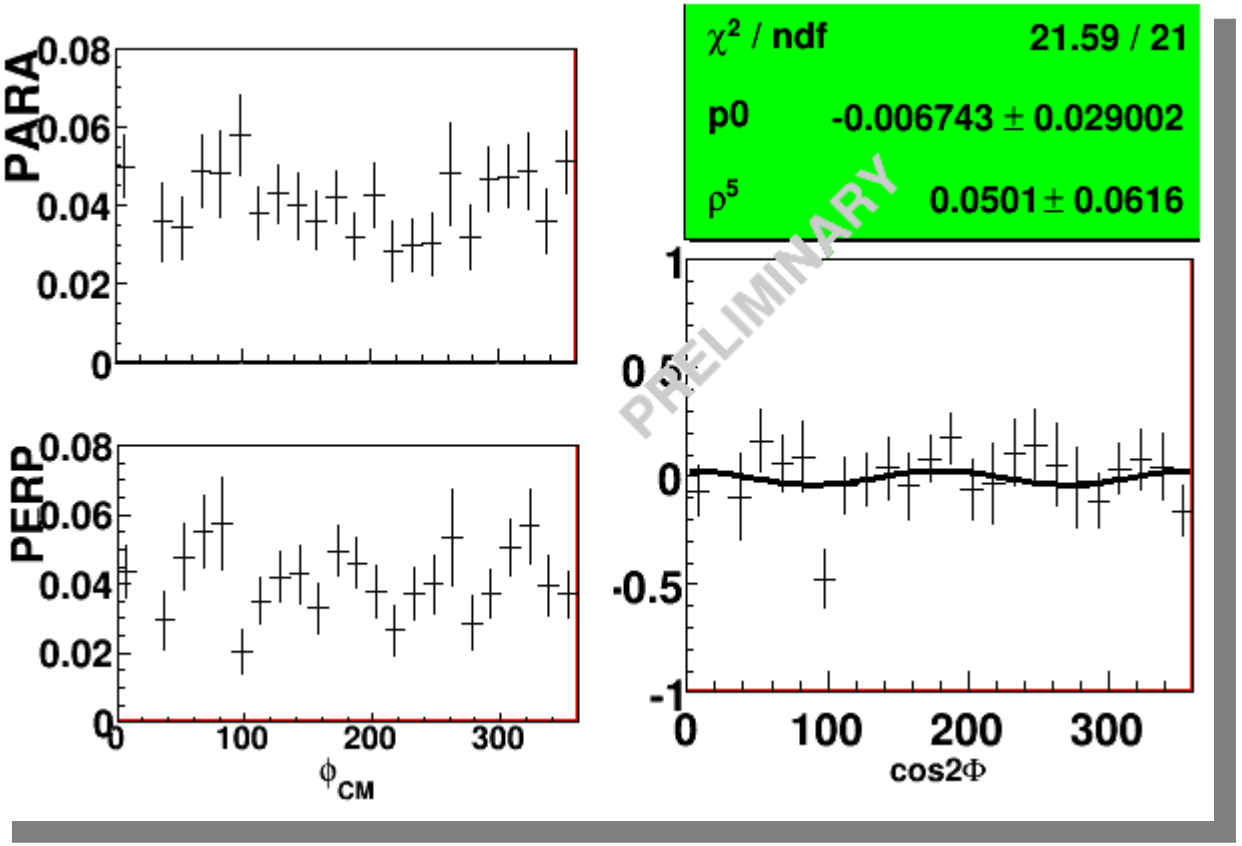
PARA	
Entries	1476
χ^2 / ndf	13.1 / 22
p0	0.04073 ± 0.00163
ρ^4	0.05535 ± 0.04108

PERP	
Entries	1433
χ^2 / ndf	5.987 / 22
p0	0.04117 ± 0.00167
ρ^3	0.18 ± 0.04

PERP	
Entries	1433
χ^2 / ndf	12.4 / 22
p0	0.04072 ± 0.00166
ρ^4	0.01697 ± 0.04417

Results @ 2.1 Coherent Edge

$1.9 < E_\gamma < 2.1$ GeV

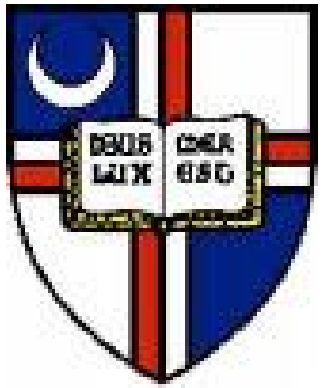


Conclusions

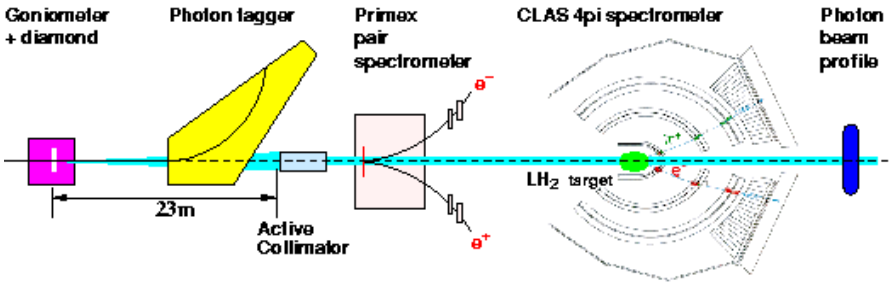
- Polarization 70%
- Over 11000 ϕ-meson events were analyzed
- Next step: Compare to $1.7 < E_\gamma < 1.9$ GeV data set (g8b data)
- Extract Spin Density Matrix Elements (SDMEs)
- Compare to Spring-8[1] data as well as J. Ballam *et al*.

- [1] T. Mibe *et al*., Phys. Rev. Lett. 95, 182001 (2005).
- [2] J. Ballam, G. B. Chadwick, *et al*., Phys. Rev. D 7 3150 (1972).

g8 history so far…



Jefferson Lab
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

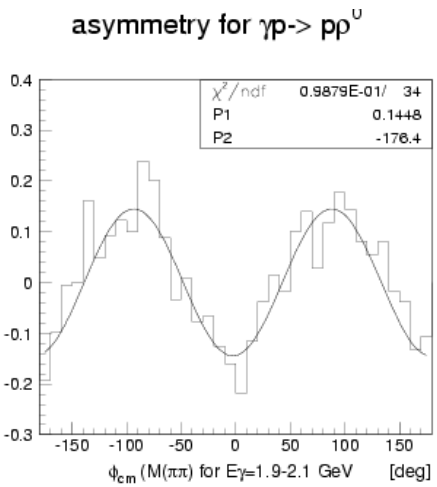


g8b (6/20 – 9/01/05)

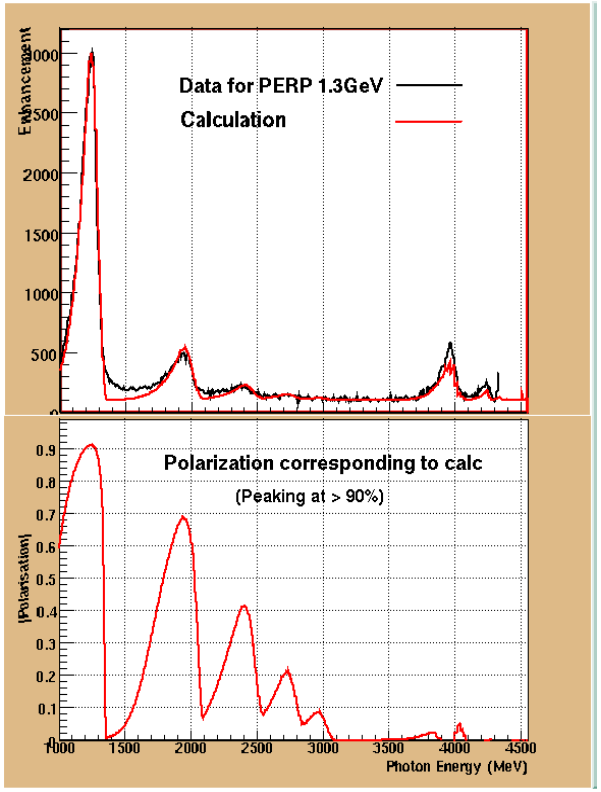
Tagged and Collimated $\bar{\gamma}$ beam in Hall B
for beam-asymmetry studies for the reactions:

$$\gamma p \rightarrow p(\pi,\eta,\rho,\omega,\varphi),K\Lambda$$

Coh. Peak	good evts
1.3 GeV	(1.4 Billion)
1.5 GeV	(2.0 Billion)
1.7 GeV	(1.8 Billion)
1.9 GeV	(1.2 Billion)
2.1 GeV	(0.9 Billion)
Amorphous	(1.8 Billion)



ρ^0 at low $|t|$ (< 0.30 GeV^2)



Photon Polarization

Thanks!!!

ARIZONA STATE UNIVERSITY
Idaho Accelerator Center
UNIVERSITY of GLASGOW
ISU