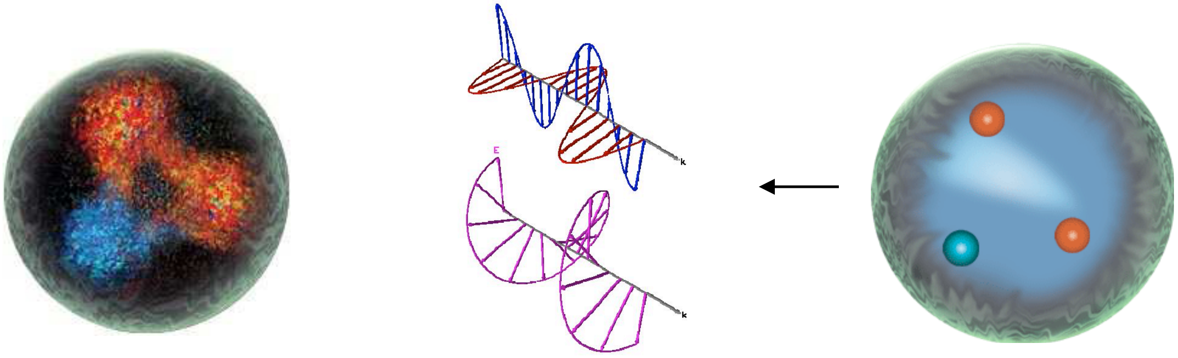
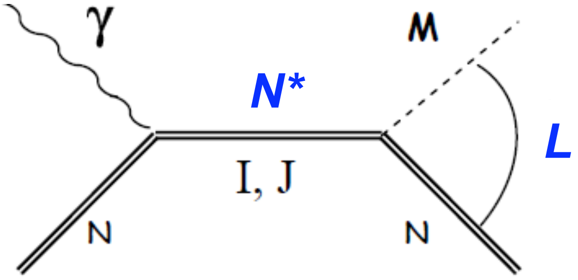
Excited baryons in electroproduction, photoproduction and J/ψ production

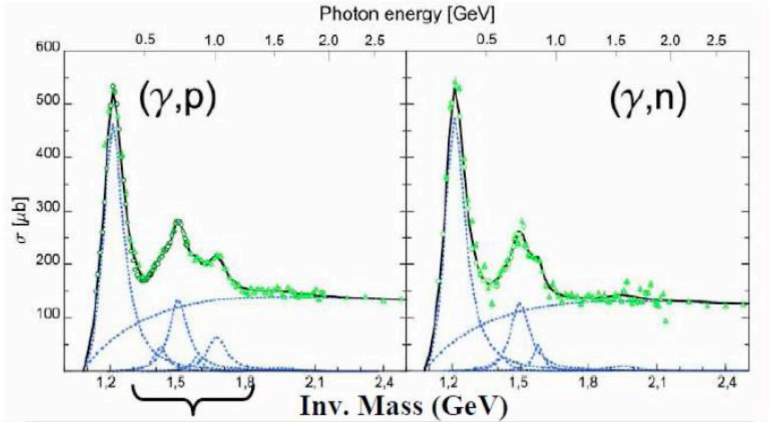
VIII Latin American
Symposium for
Nuclear Physics
and Applications



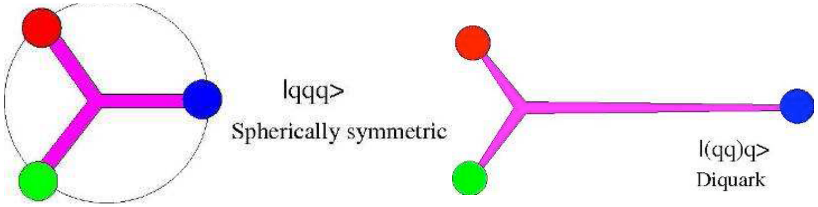
Philip Cole
Idaho State University
December 17, 2009.

Motivation





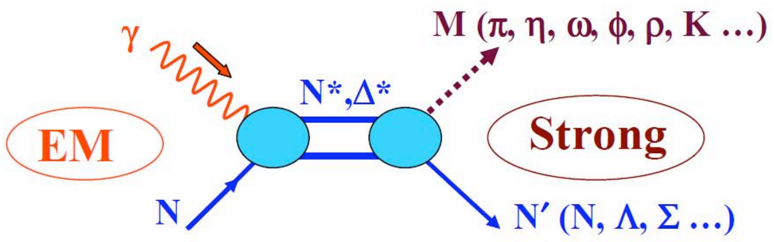
Second resonance region: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$

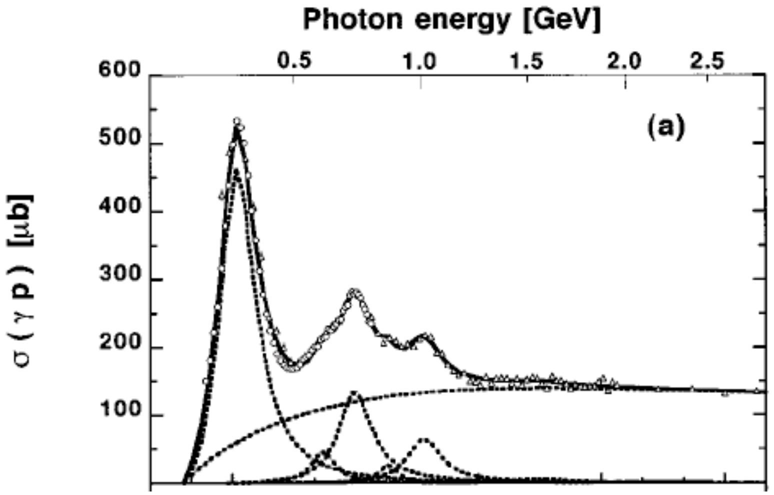


$L_{2I\ 2J}$

N*	Status	SU(6) ⊗ O(3)	Parity	Δ*	Status	SU(6) ⊗ O(3)
P11(938)	****	$\boxed{(56,0^+)}$	+	P33(1232)	****	$\boxed{(56,0^+)}$
S11(1535)[c]	****	$\boxed{(70,1^-)}$	−			
S11(1650)	****	$\boxed{(70,1^-)}$		S31(1620)	****	$\boxed{(70,1^-)}$
D13(1520)[c,d]	****	$\boxed{(70,1^-)}$		D33(1700)	****	$\boxed{(70,1^-)}$
D13(1700)	***	$\boxed{(70,1^-)}$				
D15(1675)	****	$\boxed{(70,1^-)}$				
P11(1520)	****	$\boxed{(56,0^+)}$	+	P31(1875)	****	$\boxed{(56,2^+)}$
P11(1710)[b]	***	$(70,0^+)$		P31(1835)		$(70,0^+)$
P11(1880)		$(70,2^+)$				
P11(1975)		$(20,1^+)$				
P13(1720)[b,c]	****	$\boxed{(56,2^+)}$		P33(1600)	***	$\boxed{(56,0^+)}$
P13(1870)[b]	**	$(70,0^+)$		P33(1920)	***	$\boxed{(56,2^+)}$
P13(1910)[a]		$(70,2^+)$		P33(1985)		$(70,2^+)$
P13(1950)		$(70,2^+)$				
P13(2030)		$(20,1^+)$				
F15(1680)[c,d]	****	$\boxed{(56,2^+)}$		F35(1905)	****	$\boxed{(56,2^+)}$
F15(2000)[a]	**	$(70,2^+)$		F35(2000)	**	$(70,2^+)$
F15(1995)		$(70,2^+)$				
F17(1990)	**	$(70,2^+)$		F37(1950)	****	$\boxed{(56,2^+)}$

Photo & Electroproduction





- Difficulties
  - Perturbative QCD cannot be applied
  - A lot of resonances could be present in a relatively narrow energy region
  - Nonresonance background is almost equally complicated
- Experiments
  - Jefferson Lab (USA)
  - MAMI (Germany)
  - ELSA (Germany)
  - ESRF (France)
  - SPring-8 (Japan)
  - BES (China) ¶

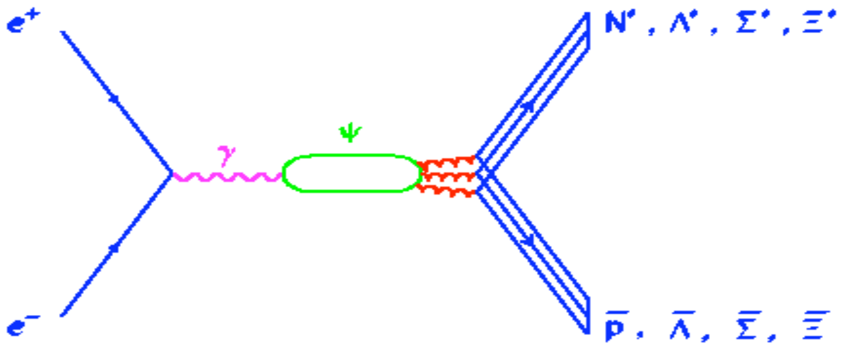
¶ A unique way of studying baryon spectrum is via BES: J/ψ → N*,…

Baryon spectroscopy from J/ψ decays:

Beijing Electron Spectrometer / Beijing Electron-Positron Collider

(BES/BEPC)

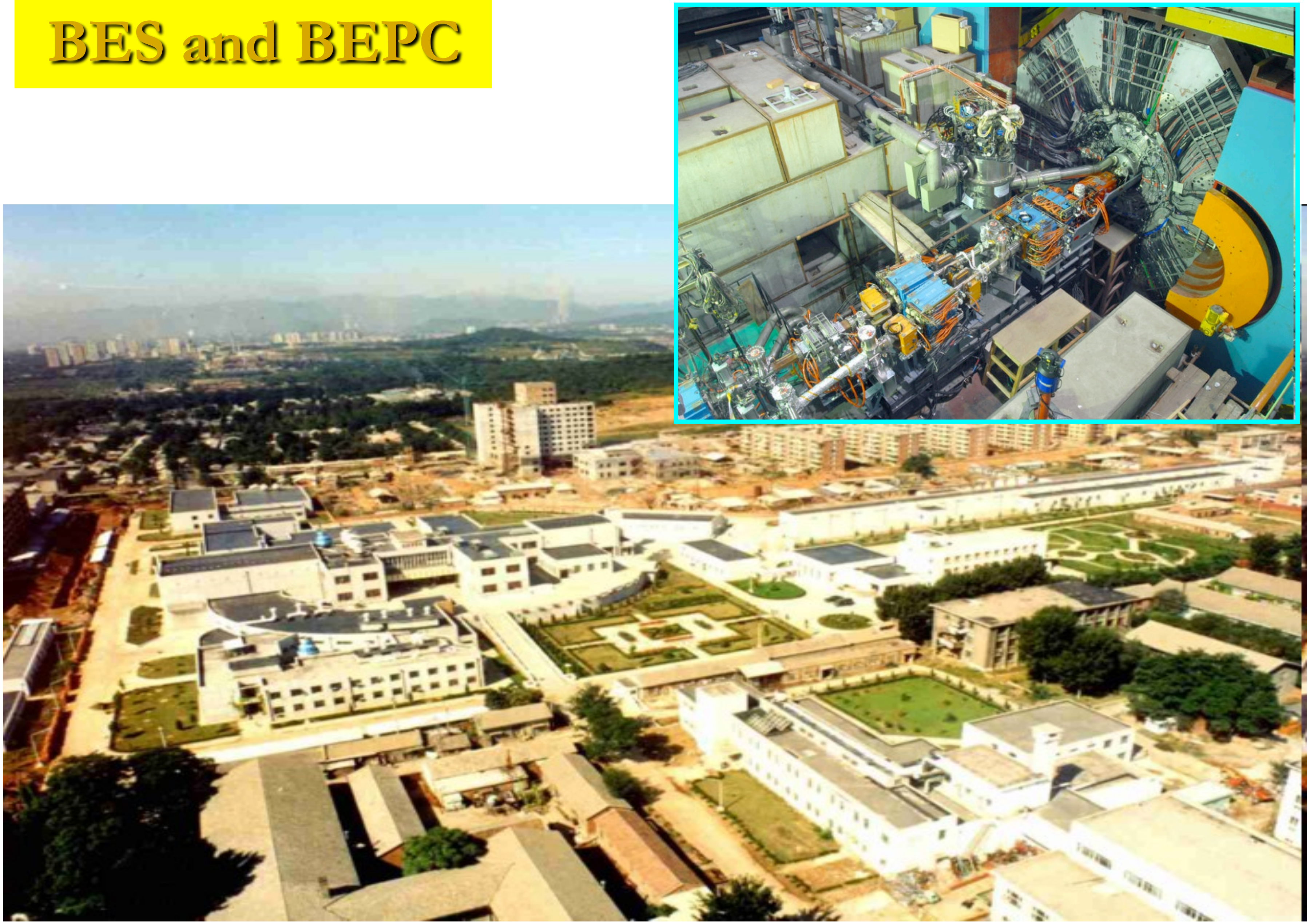
$$J/\Psi \to \overline{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$$



New mechanism for baryon production & an ideal isospin filter

BingSong Zou MENU 07

BES and BEPC



J/ψ → N* Production in e^-e^+ collisions at BES

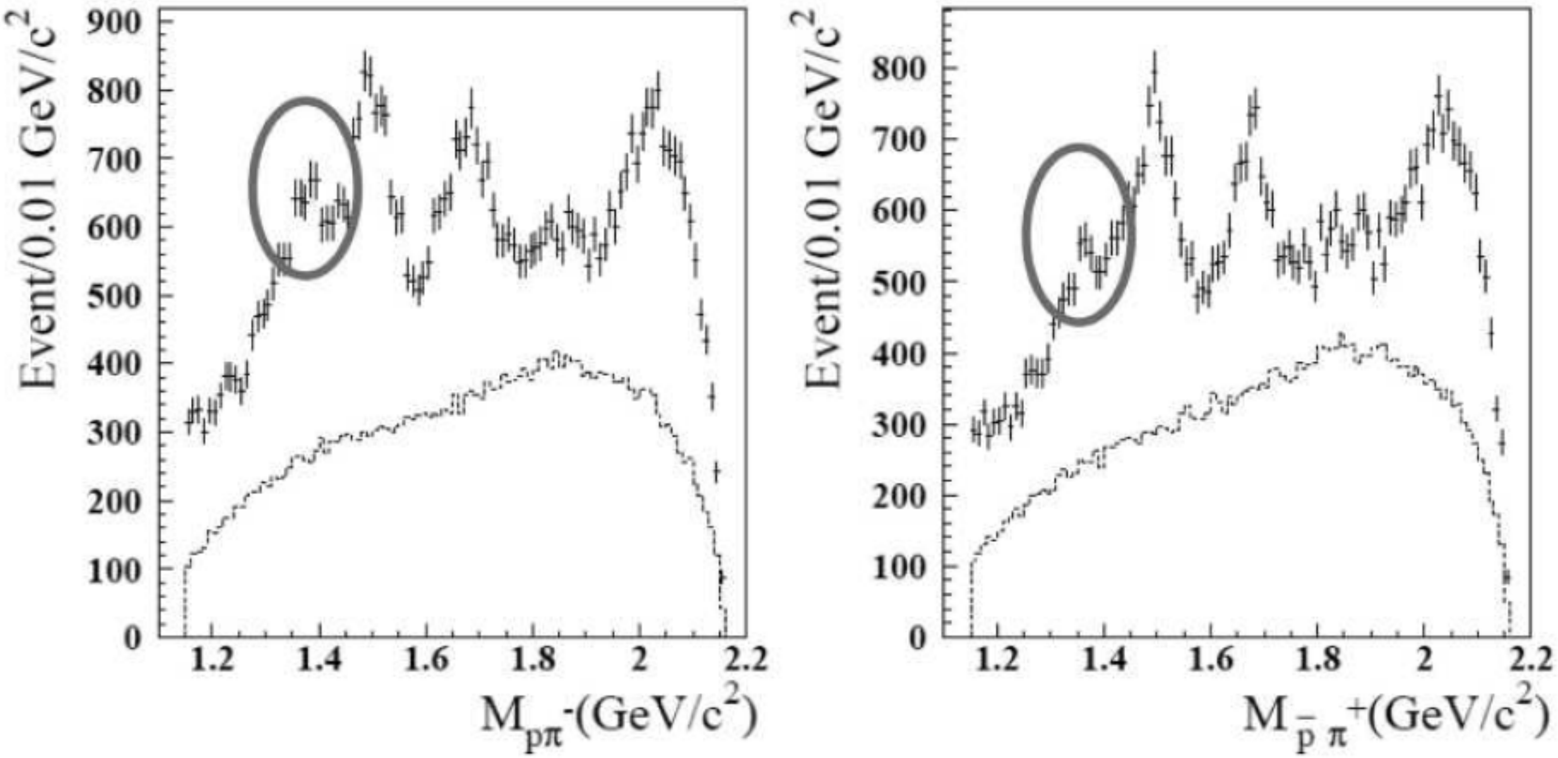


Fig. 3. The above plots come from Fig. 5 in the BES collaboration paper: Observation of Two New N* Peaks in $J/\psi \to p\pi^-\bar{n}$ and $\bar{p}\pi^+n$ Decays.[65] The $p\pi^-$ and $\bar{p}\pi^+$ invariant mass spectra for $J/\psi \to p\pi^-\bar{n}$ (left) and $\bar{p}\pi^+n$ (right), compared with phase space. The circled peak around 1360 MeV/c^2 marks the first direct observation of the Roper Resonance, i.e. the $N(1440)P_{11}$. From the IHEP partial wave analysis (in units of MeV): $M = 1358 \pm 17$ and $\Gamma = 179 \pm 56$.

$J/\psi \to N^*$ Production in e^-e^+ collisions at BES

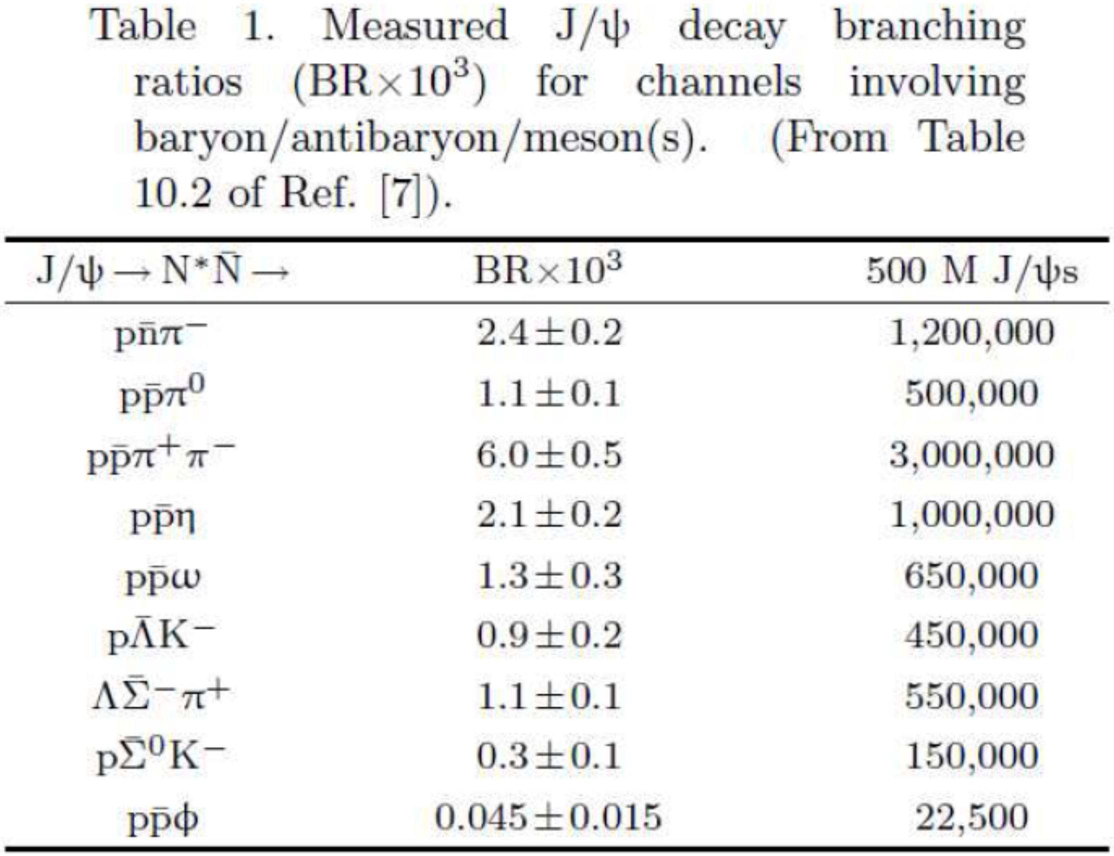
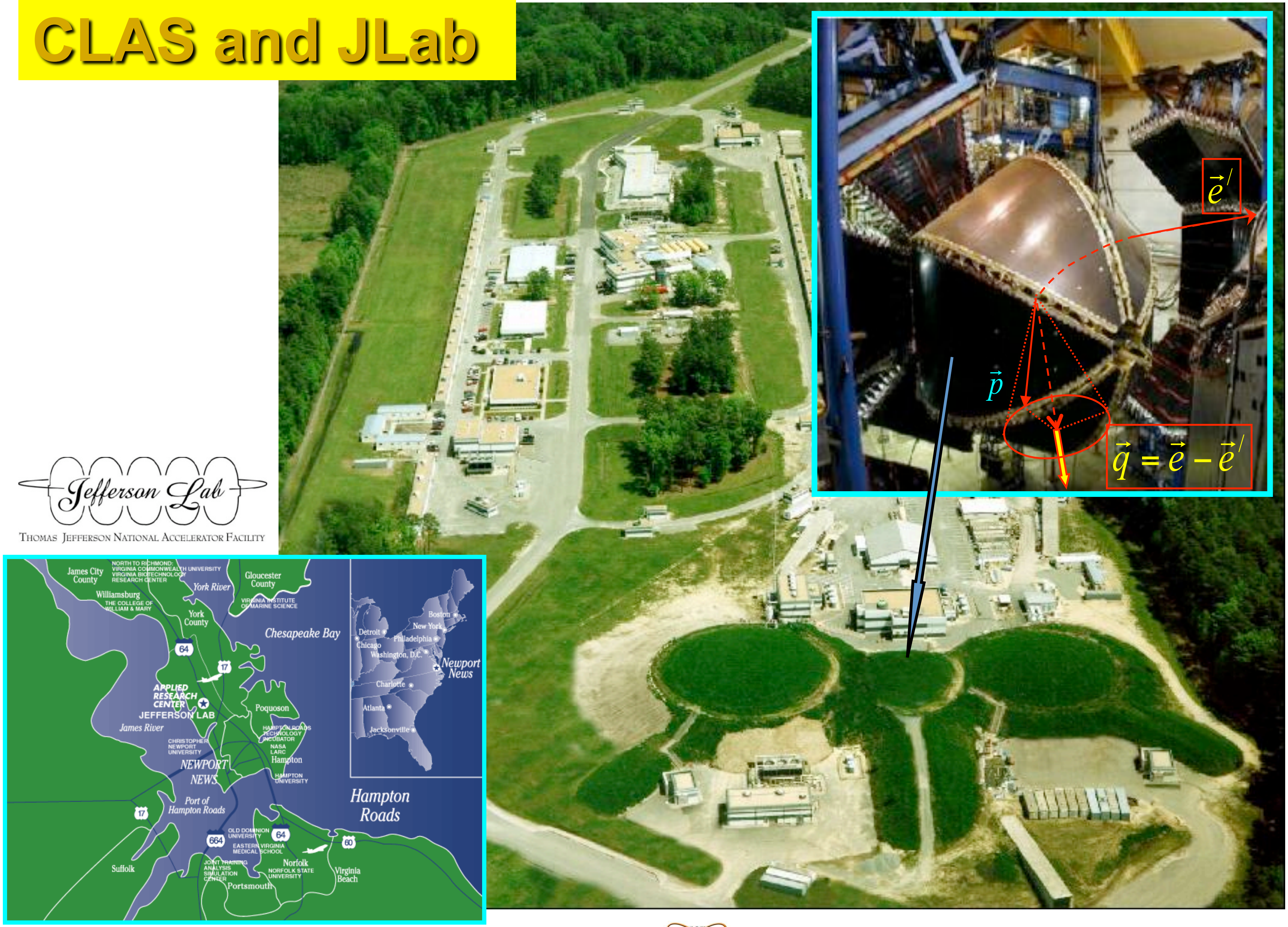


Table 1. Measured J/ψ decay branching ratios ($BR\times10^3$) for channels involving baryon/antibaryon/meson(s). (From Table 10.2 of Ref. [7]).

$J/\psi \to N^*\bar{N} \to$	$BR\times10^3$	500 M J/ψs
$p\bar{n}\pi^-$	2.4 ± 0.2	1,200,000
$p\bar{p}\pi^0$	1.1 ± 0.1	500,000
$p\bar{p}\pi^+\pi^-$	6.0 ± 0.5	3,000,000
$p\bar{p}\eta$	2.1 ± 0.2	1,000,000
$p\bar{p}\omega$	1.3 ± 0.3	650,000
$p\bar{\Lambda}K^-$	0.9 ± 0.2	450,000
$\Lambda\bar{\Sigma}^-\pi^+$	1.1 ± 0.1	550,000
$p\bar{\Sigma}^0K^-$	0.3 ± 0.1	150,000
$p\bar{p}\phi$	0.045 ± 0.015	22,500

CLAS and JLab



Jefferson Lab

Thomas Jefferson National Accelerator Facility

Issues (1)

BES and CLAS datasets

- They have very different contributions to the production background.
  - electron-positron collider
  - electron (photon) beam onto fixed target

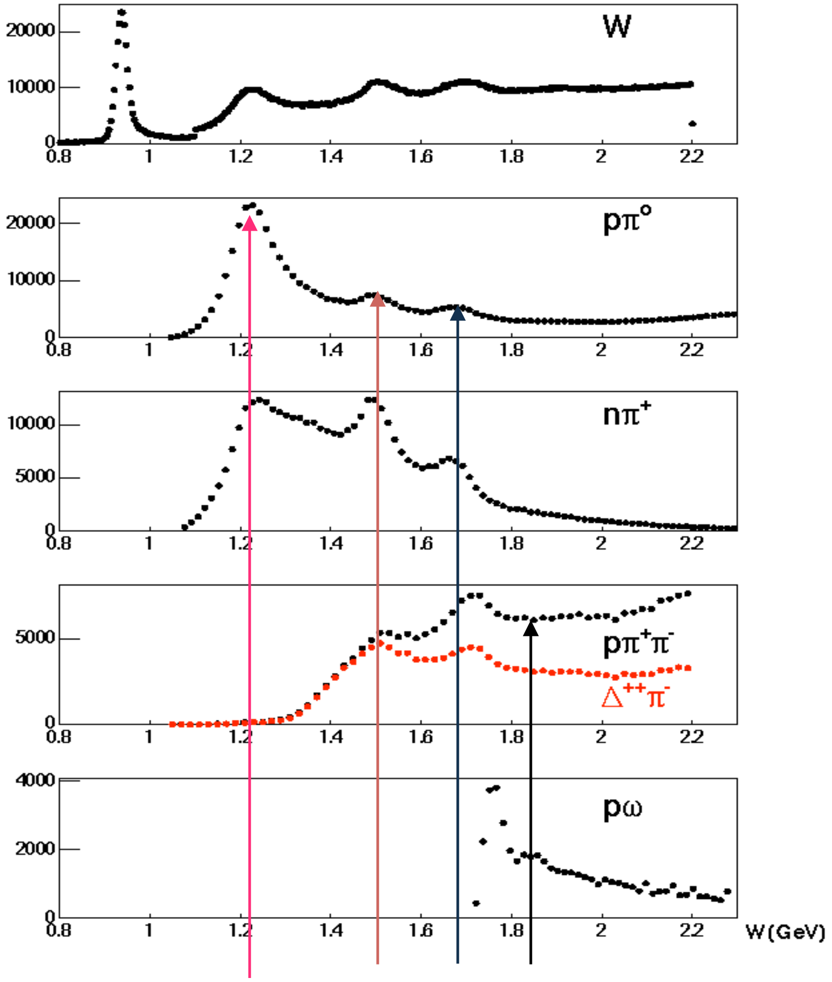
- They separately have unique N^* signatures
  - BES: $J/\psi \to \bar{B}N^* \to \bar{B}BM$ (e.g. $\bar{N}N\pi$, $\bar{N}Nn$)
  - CLAS: $N^* \to BM/BMM$ (e.g. $N\pi/N\pi\pi$)

Why Nπ/Nππ electroproduction channels are important

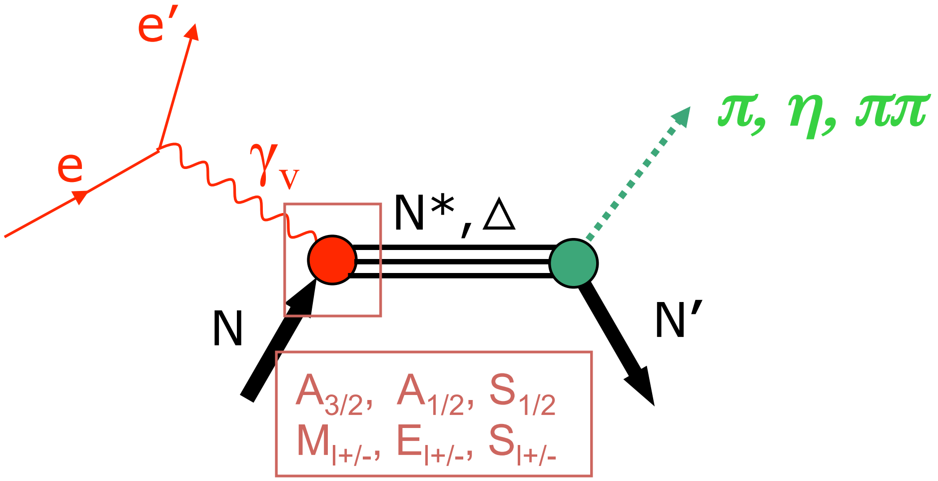
- **Nπ/Nππ channels are the two major contributors in N* excitation region;**
- **these two channels combined are sensitive to almost all excited proton states;**
- **they are strongly coupled by πN→ππN final state interaction;**
- **may substantially affect exclusive channels having smaller cross sections, such as ηp,KΛ, and KΣ.**

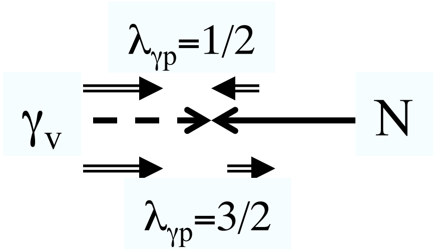
Therefore knowledge on Nπ/Nππ electroproduction mechanisms is key for the entire N* Program

CLAS data on meson electroproduction at $Q^2 < 4.0$ GeV^2



Electromagnetic Excitation of N*s





DOE Milestone 2012

Measure the electromagnetic excitations of low-lying baryon states (<2 GeV) and their transition form factors over the range $Q^2 = 0.1 - 7\ \mathrm{GeV}^2$ and measure the electro- and photo-production of final states with one and two pseudo-scalar mesons.

Electromagnetic Excitation of N*s

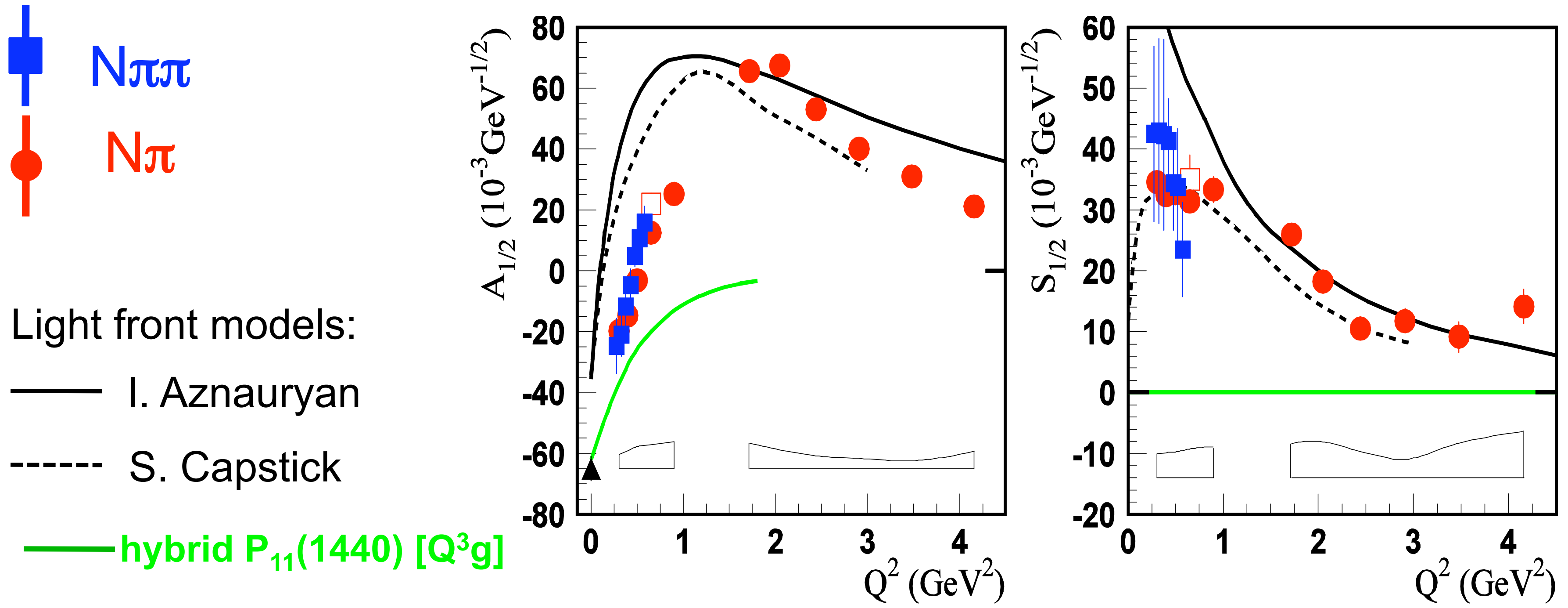
The experimental N* Program has two major components:

1) Transition form factors of known resonances to study their internal structure and the interactions among constituents, which are responsible for resonance formation.

2) Spectroscopy of excited baryon states, search for new states.

Both parts of the program are being pursued in various meson photo- and electroproduction channels, e.g. $N\pi$, $p\eta$, $p\pi^+\pi^-$, $K\Lambda$, $K\Sigma$, $p\omega$, $p\rho^0$ using cross sections and polarization observables.

$P_{11}(1440)$ electrocouplings from the CLAS data on $N\pi/N\pi\pi$ electroproduction



- **Good *agreement* between the electrocouplings obtained from the *$N\pi$ and $N\pi\pi$ channels*: Reliable measure of the electrocouplings.**
- **The electrocouplings for $Q^2 > 2.0$ GeV^2 are consistent with *$P_{11}(1440)$* structure as a *3-quark radial excitation*.**
- ***Zero crossing for the $A_{1/2}$* amplitude has been observed for the first time, indicating an importance of light-front dynamics.**

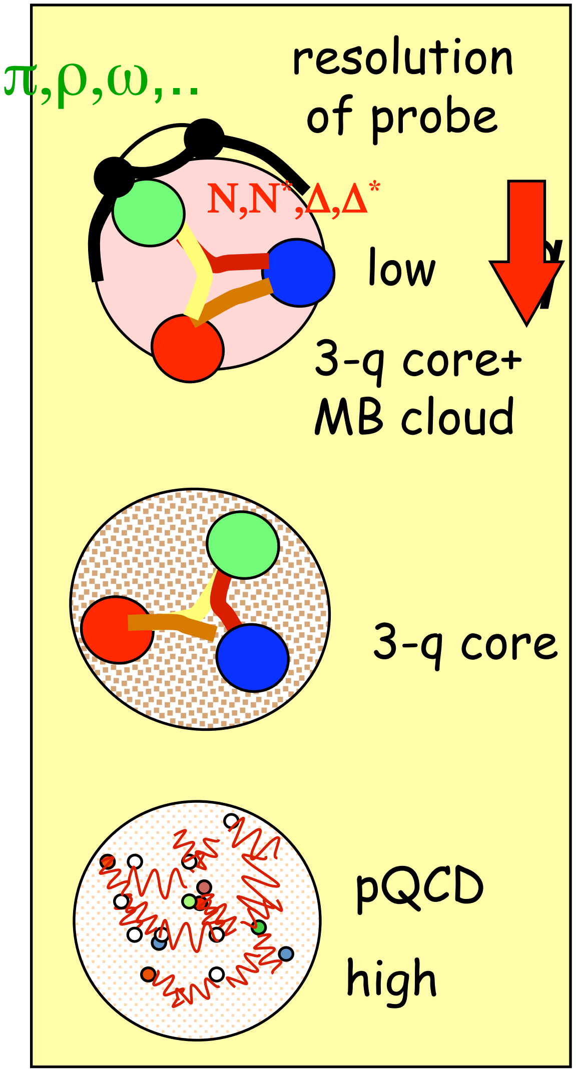
Issues (2)

BES tells where to dig and CLAS has the steam shovel

- **BES** at **BEPC** has collected high statistics data on J/ψ production. Its decay into baryon-antibaryon channels offers a unique and complementary way of probing nucleon resonances (N*).
- **CLAS** at **JLab** has access to N* form factors at high Q^2, which is advantageous for the study of structure of nucleon resonances,
- The low-background **BES** results will be able to provide guidance for the search for less-dominant excited states at **JLab**.
- Several N* states have been seen at **BES** in the mass region of 2 GeV.
  M. Ablikim *et al*., (BES Collaboration), Phys. Rev. Lett. **97**, 062001 (2006).
- With the precision electron and photon beams afforded by **JLab**, not only would the existence of these new N* states be confirmed, but it would further allow for their properties to be precisely mapped out at various distances or Q^2.

Coordination of efforts between BES and CLAS is timely

Hadron Structure with Electromagnetic Probes



π,ρ,ω,..

resolution of probe

N,N*,Δ,Δ*

low

3-q core+ MB cloud

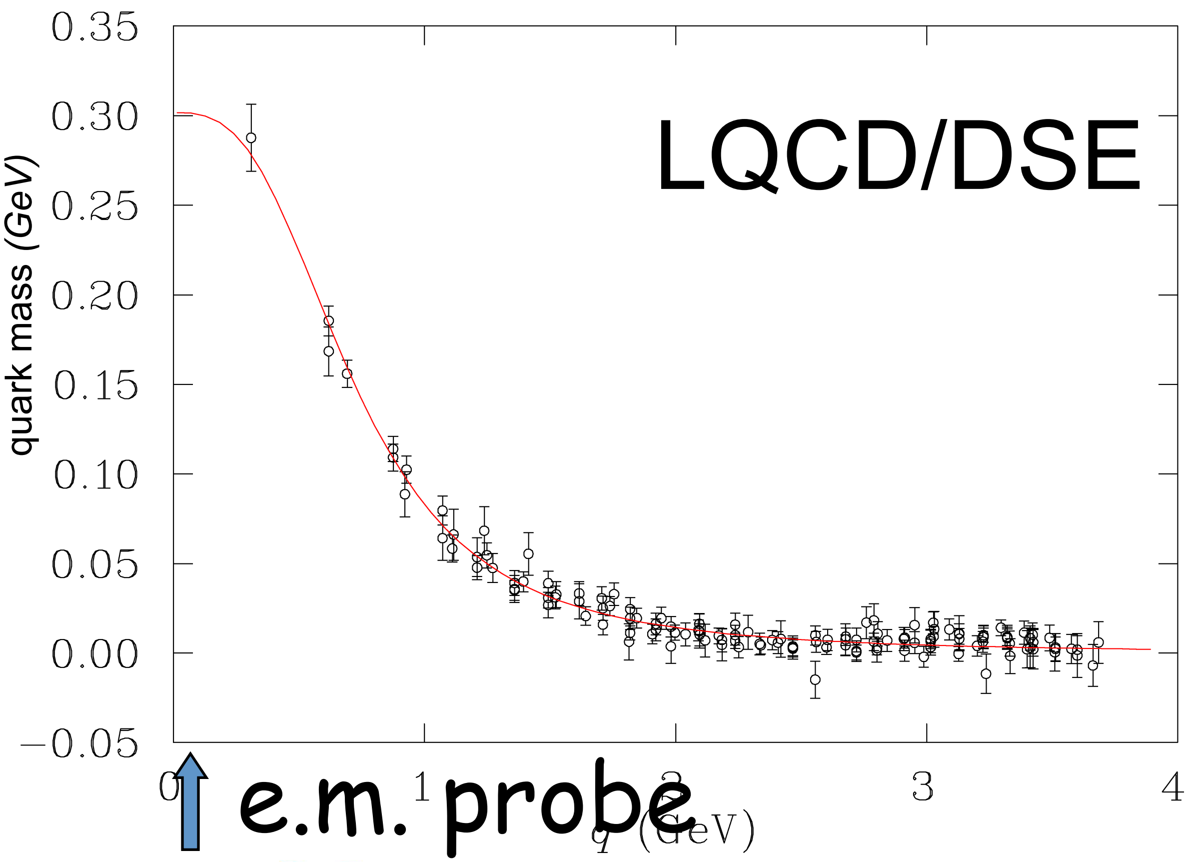
3-q core

pQCD

high

Allows to address central question:

What are the relevant degrees-of-freedom at varying distance scale?

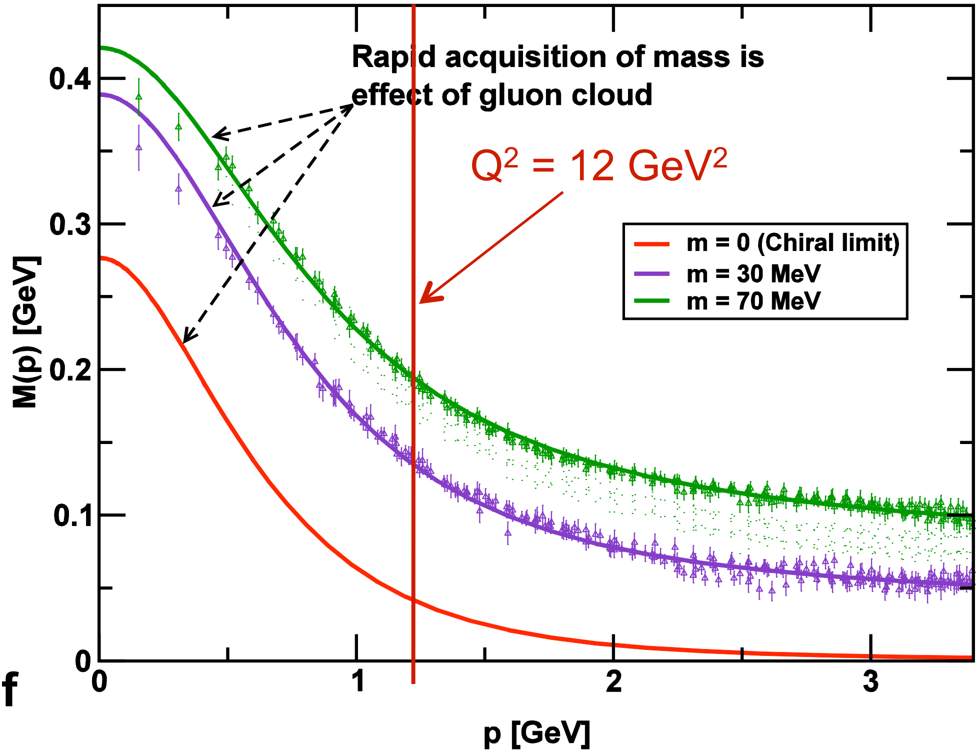


e.m. probe

Physics Objectives in the N* Studies with CLAS12

- **explore the interactions between the dressed quarks, which are responsible for the formation for both ground and excited nucleon states.**
- **probe the mechanisms of light current quark dressing, which is responsible for >97% of nucleon mass.**

Approaches for theoretical analysis of N* electrocouplings: LQCD, DSE, relativistic quark models. See details in the White Paper of EmNN* JLAB Workshop, October 13-15, 2008: http://www.jlab.org/~mokeev/white_paper/



Rapid acquisition of mass is effect of gluon cloud

$Q^2 = 12\ GeV^2$

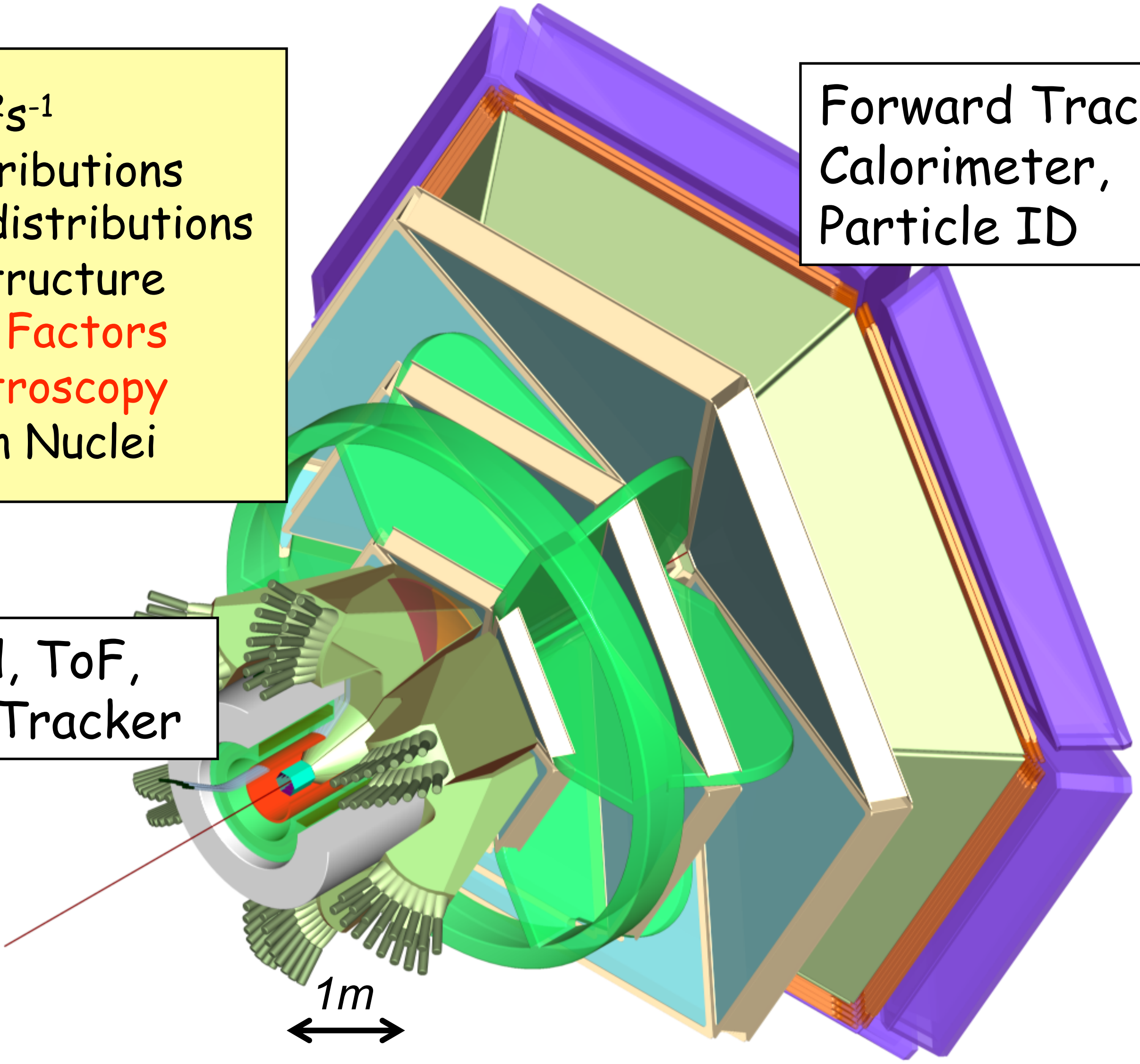
Independent QCD Analyses
Line Fit: DSE Points: LQCD

Need to multiply by $3p^2$ to get the Q^2 per quark

CLAS12 JLab Upgrade to 12 GeV

Luminosity > $10^{35} cm^{-2} s^{-1}$

- General Parton Distributions
- Transverse parton distributions
- Longitudinal Spin Structure
- N* Transition Form Factors
- Heavy Baryon Spectroscopy
- Hadron Formation in Nuclei

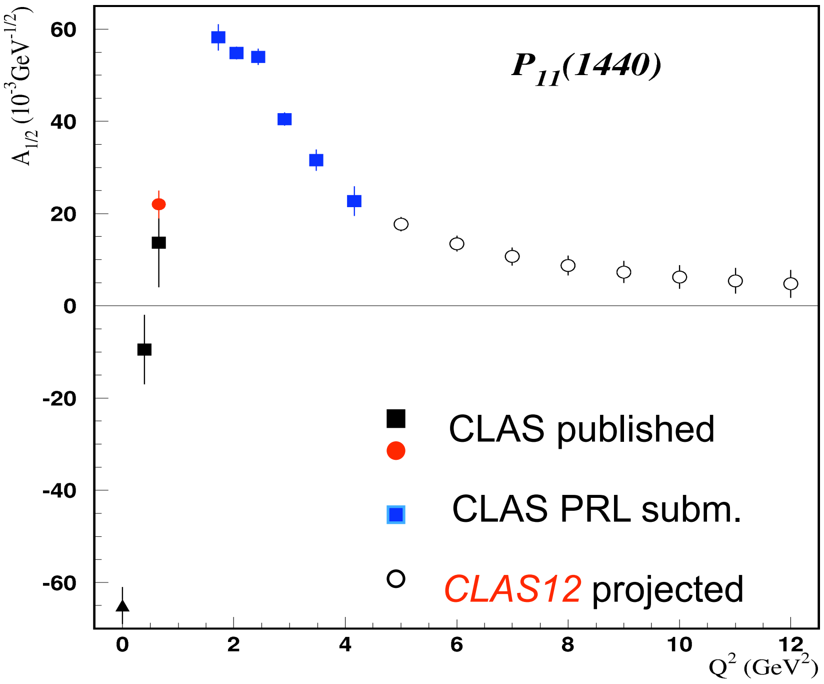


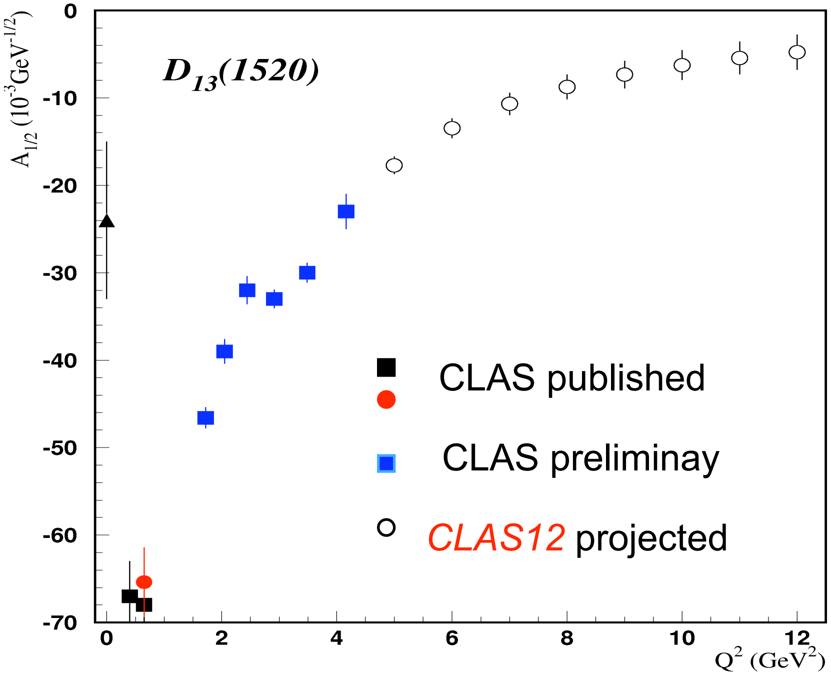
Forward Tracker,
Calorimeter,
Particle ID

Solenoid, ToF,
Central Tracker

CLAS12 Projections for N* Transitions

For the foreseeable future, CLAS12 will be the only facility worldwide, which will be able to access the N* electrocouplings in the Q^2 regime of 5 GeV^2 to 10 GeV^2, where the quark degrees of freedom are expected to dominate. Our experimental proposal "*Nucleon Resonance Studies with CLAS12*" was approved by PAC34 for the full 60-day beamtime request. http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.





Nucleon Resonance Studies with CLAS12

D. Arndt[4], H. Avakian[6], I. Aznauryan[11], A. Biselli[3], W.J. Briscoe[4], **V. Burkert[6]**,
V.V. Chesnokov[7], **P.L. Cole[5]**, D.S. Dale[5], C. Djalali[10], L. Elouadrhiri[6], G.V. Fedotov[7],
T.A. Forest[5], E.N. Golovach[7], **R.W. Gothe*[10]**, Y. Ilieva[10], B.S. Ishkhanov[7],
E.L. Isupov[7], **K. Joo[9]**, T.-S.H. Lee[1,2], **V. Mokeev*[6]**, M. Paris[4], K. Park[10],
N.V. Shvedunov[7], G. Stancari[5], M. Stancari[5], S. Stepanyan[6], **P. Stoler[8]**,
I. Strakovsky[4], S. Strauch[10], D. Tedeschi[10], M. Ungaro[9], R. Workman[4],
and the CLAS Collaboration

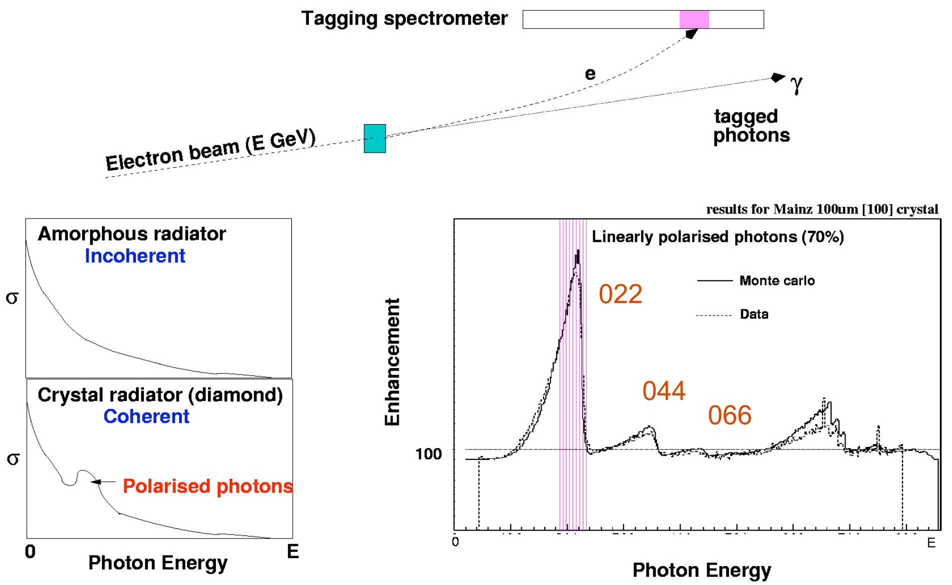
JLab PAC 34, January 26-30, 2009
Approved for 60 days beamtime

Argonne National Laboratory (IL,USA)[1], Excited Baryon Analysis Center (VA,USA)[2],
Fairfield University (CT, USA)[3], George Washington University (DC, USA)[4],
Idaho State University (ID, USA)[5], Jefferson Lab (VA, USA)[6],
Moscow State University (Russia)[7], Rensselaer Polytechnic Institute (NY, USA)[8],
University of Connecticut (CT, USA)[9], University of South Carolina (SC, USA)[10],
and Yerevan Physics Institute (Armenia) [11]

Spokesperson
Contact Person*

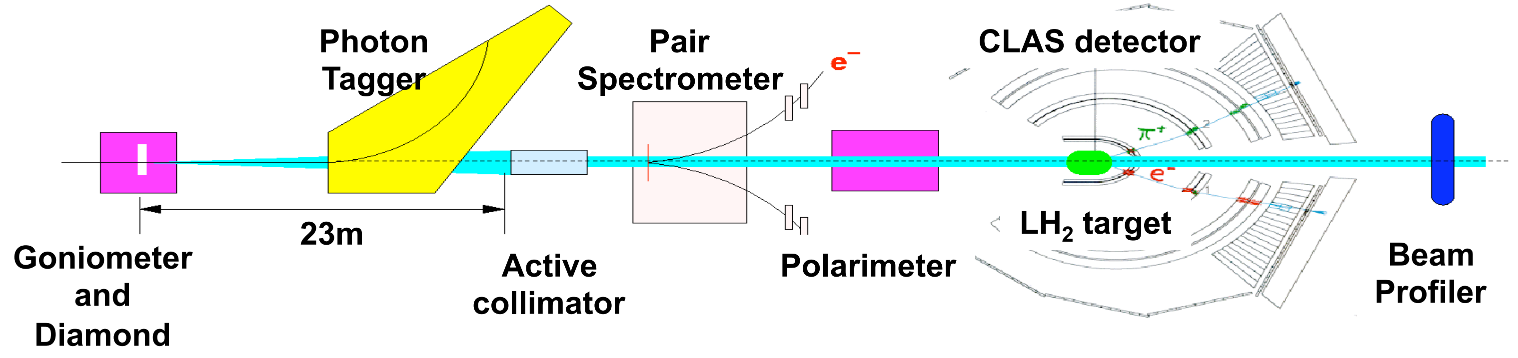
There be Photons, too!

The Coherent Bremsstrahlung Facility at CLAS



Requirements for coherent brem

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



Tagged and Collimated γ Beam on Target

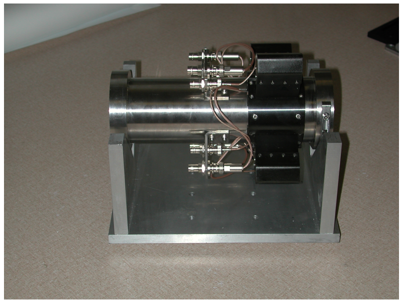
Photon Polarization

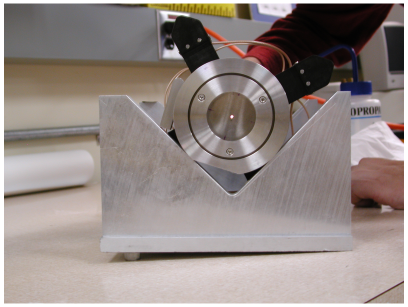
exceeds 90% in the peak

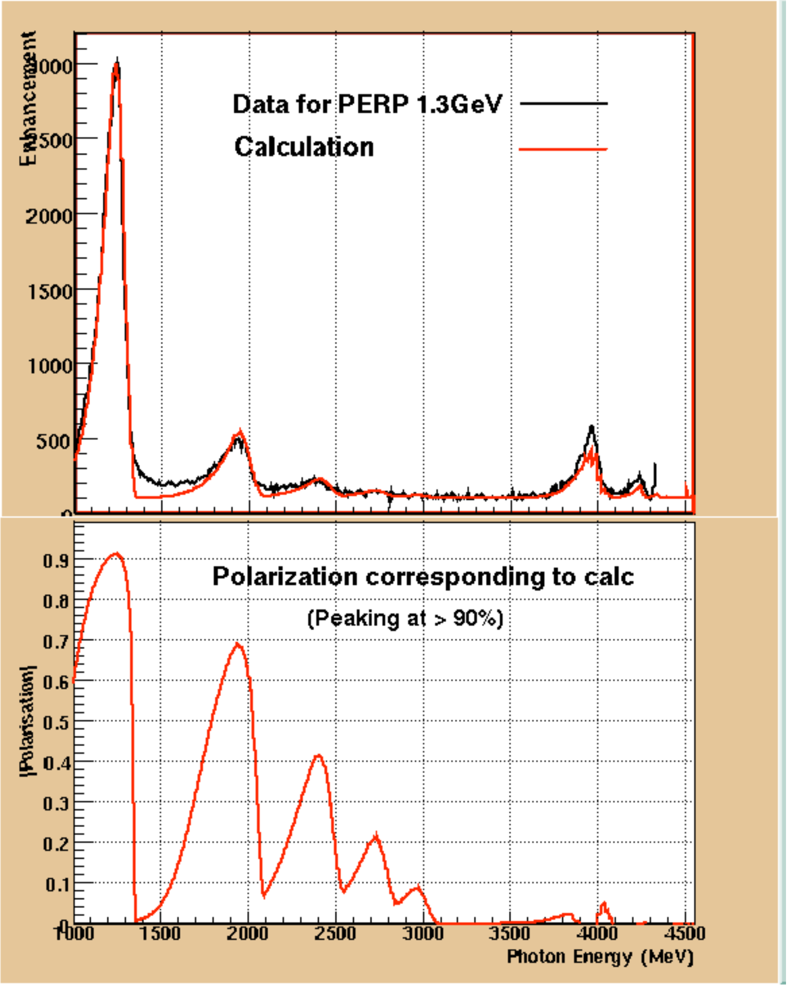
Tightly and Actively Collimated:

~½ of a characteristic angle

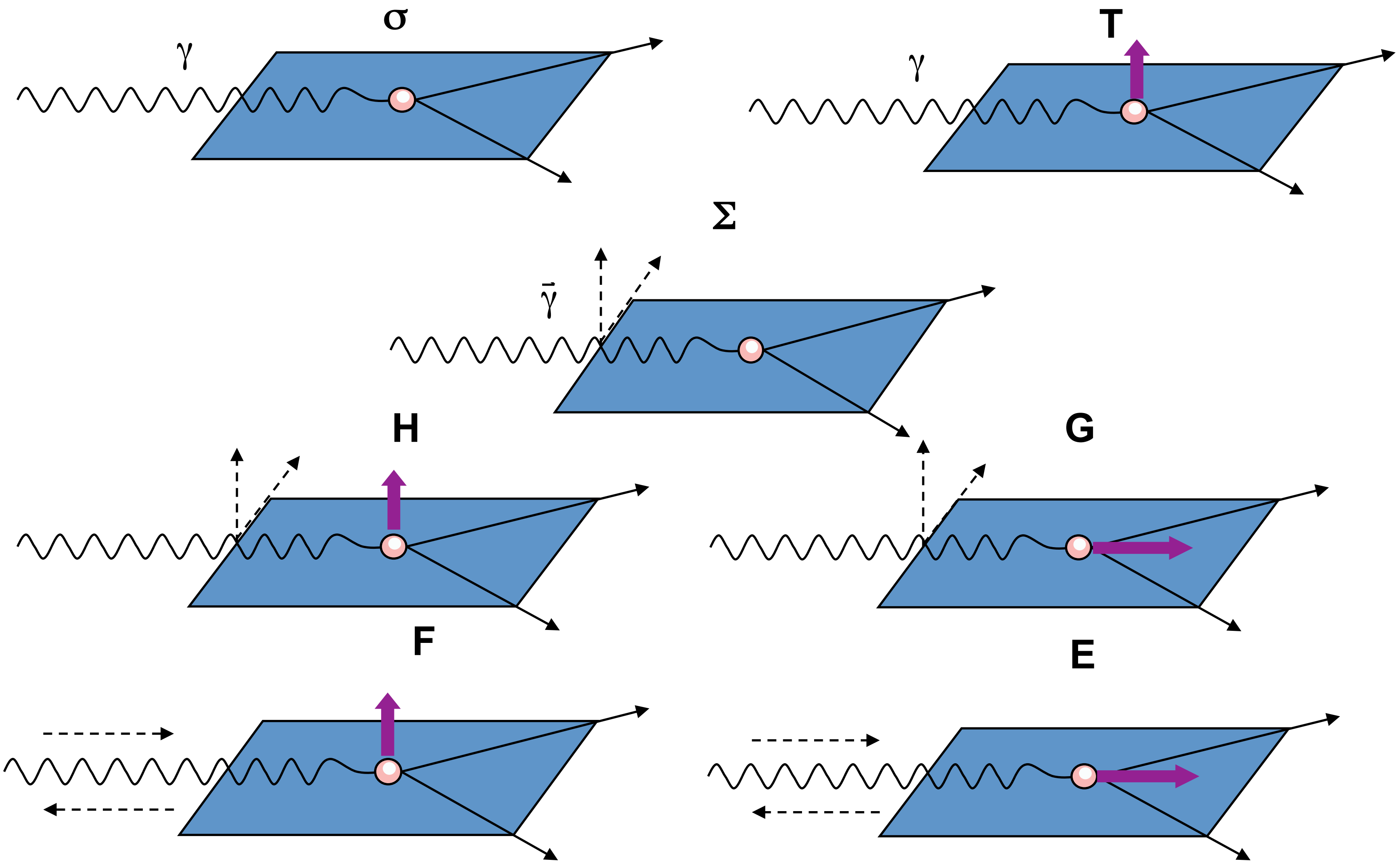
(Collimator subtends 44 μrad)







Photon and Target Polarization



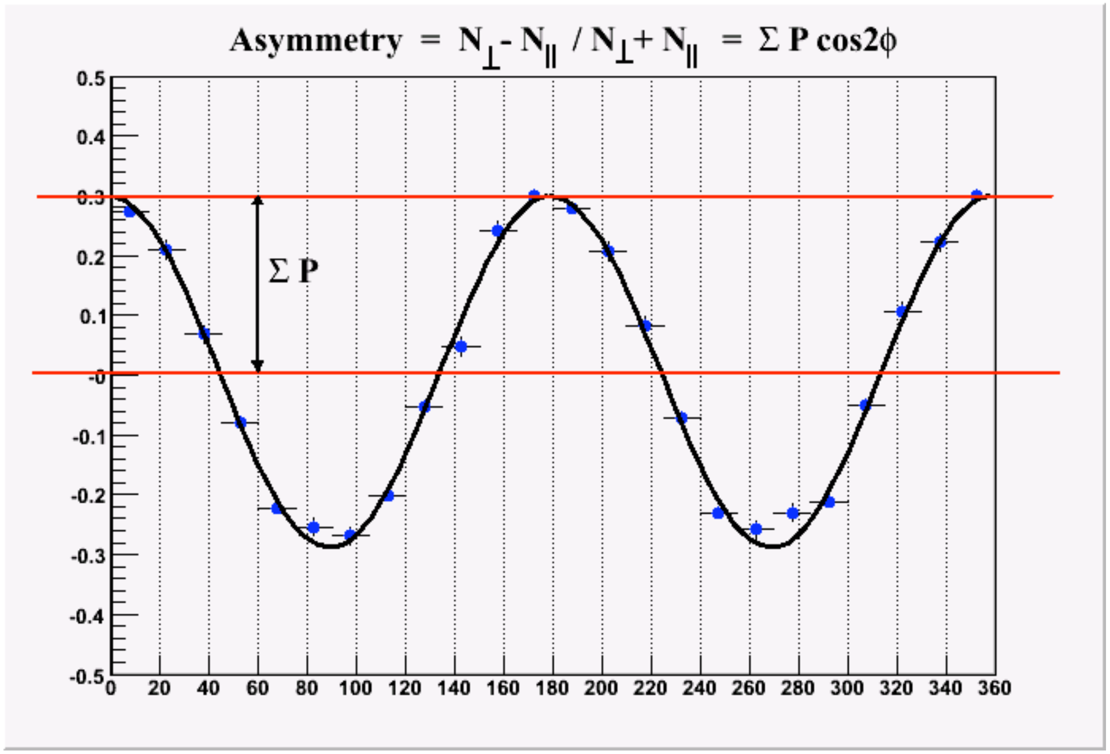
Polarization Observables in K Photoproduction

- Single-polarization observables
  - Cross section (σ_0)
  - Recoil polarization (P)
  - Beam asymmetry (Σ)
  - Target asymmetry (T)
- Double-polarization observables
  - Beam + Recoil ($C_{x'}, C_{z'}, O_{x'}, O_{z'}$)
  - Beam + Target (E, F, G, H)
  - Recoil + Target ($T_{x'}, T_{z'}, L_{x'}, L_{z'}$)
- No observable requires triple polarization
- The first 8 can be measured without a polarized target
  - *T* is accessed as a double-polarization observable
- 16 observables in total - but they are not independent!

$$\begin{aligned}\frac{d\sigma}{d\Omega} = {} & \sigma_0 \{1 - P_{lin}\Sigma \cos 2\varphi \\ & +\alpha \cos\theta_{x'} \left(-P_{lin} O_{x'} \sin 2\varphi - P_{\odot} C_{x'}\right) \\ & -\alpha \cos\theta_{y'} \left(-P + P_{lin} T \cos 2\varphi\right) \\ & -\alpha \cos\theta_{z'} \left(P_{lin} O_{z'} \sin 2\varphi + P_{\odot} C_{z'}\right)\}\end{aligned}$$

Polarization observables – the photon asymmetry parameter, Σ

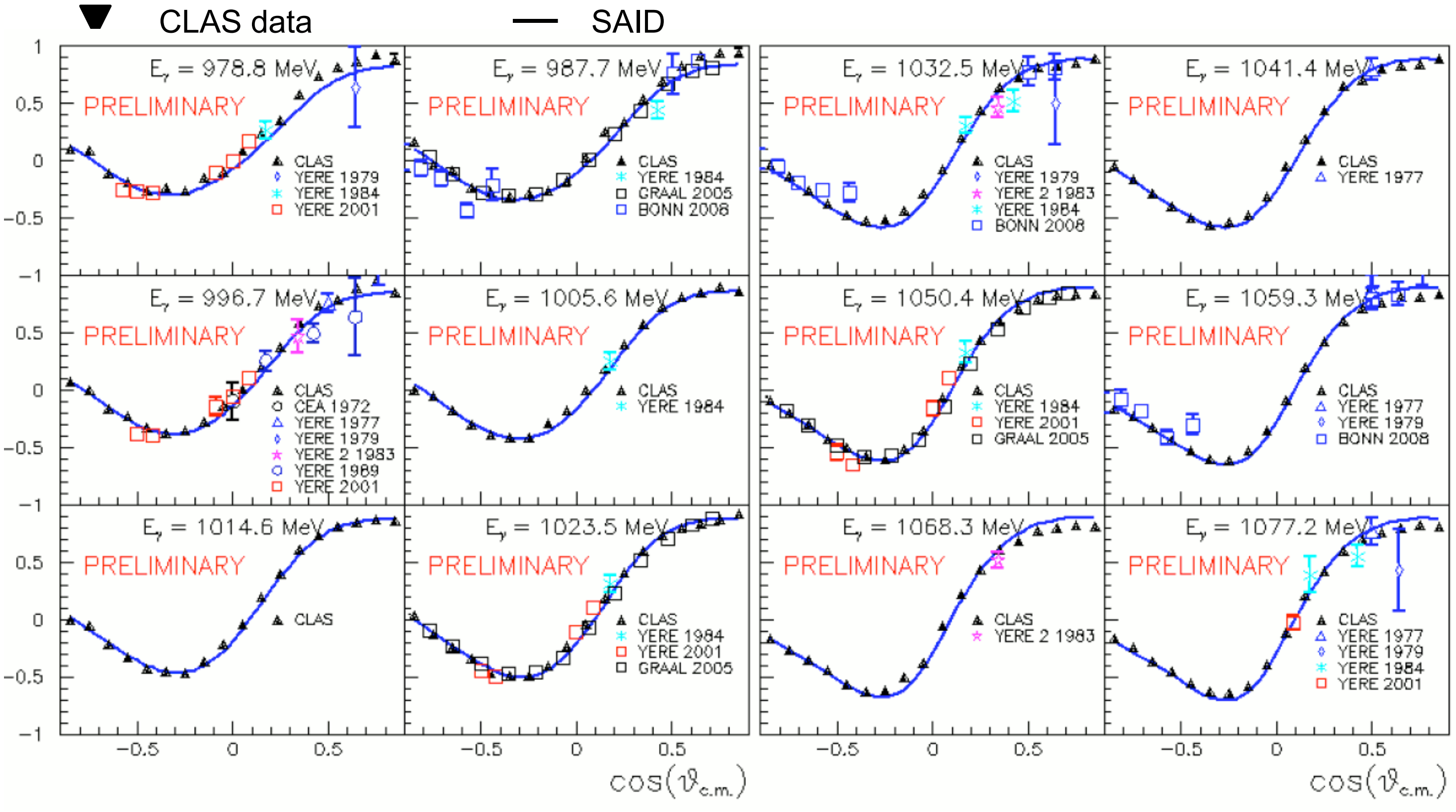
$\rho_f \frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{unpol}\{1 - P_\gamma^{lin}\Sigma\cos 2\phi$



- Systematics of detector acceptance cancel out.
- “Only” need to know P_{lin}, the degree of linear polarization.

g8b: July 2005

Polarized photon energy range: 1.3 – 2.1 GeV
Events (single charged particle in CLAS): 10 billion
preliminary results: $\pi^0 p$, Mike Dugger, ASU



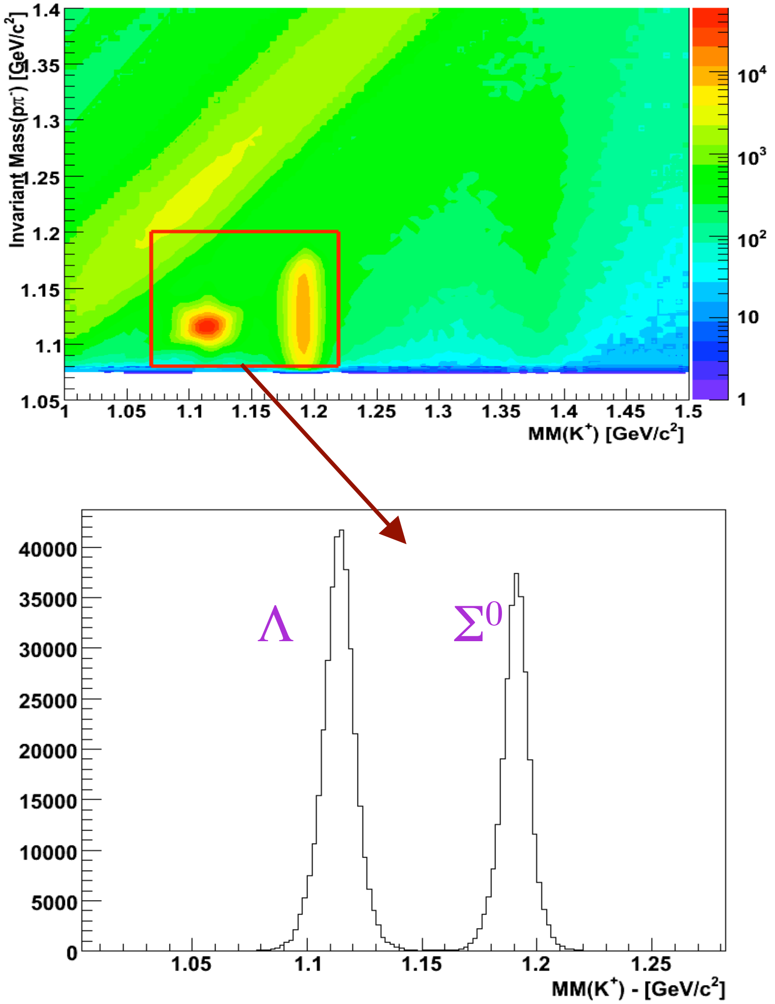
High statistics. Good agreement with previous measurement. We have P well determined.

From Brem. Calculation and πN results we expect 3% systematic error in P

g8b preliminary results - $K^+\Lambda$ and $K^+\Sigma^0$

Craig Paterson, Glasgow

$\gamma p \rightarrow K^+\Lambda \rightarrow K^+p\pi^-$



$\gamma p \rightarrow K^+\Sigma^0 \rightarrow K^+\Lambda\gamma \rightarrow K^+p\pi^-\gamma$

Single polarization observables

Σ Photon asymmetry

P Recoil polarization (induced pol. along y)

T Target asymmetry

Double polarization observables

O_x Polarization transfer along x

O_z Polarization transfer along z

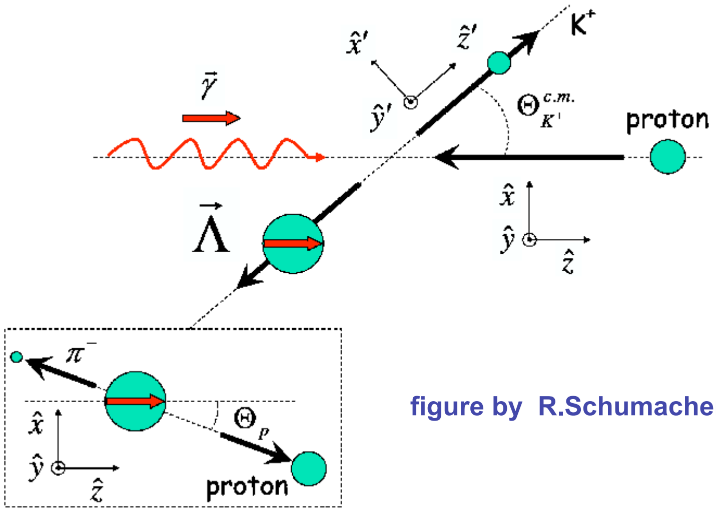
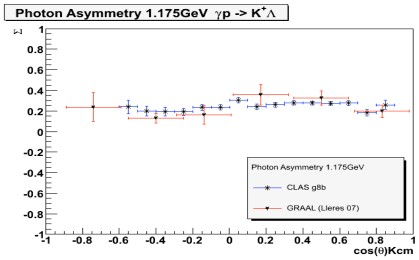
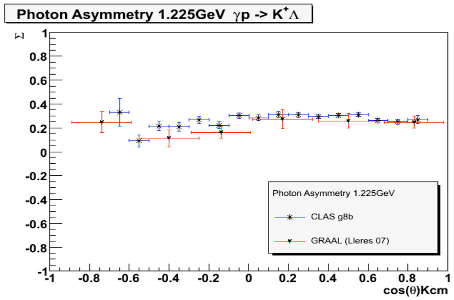


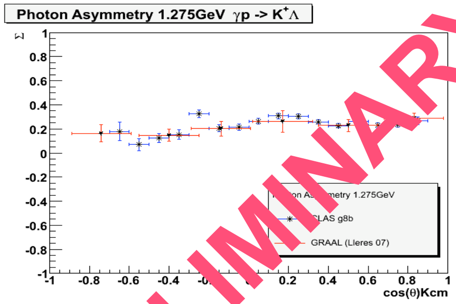
figure by R.Schumacher, CMU

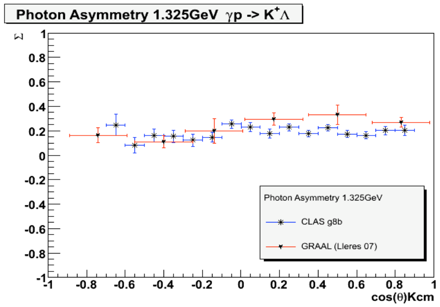
g8b preliminary results - $K^+\Lambda$

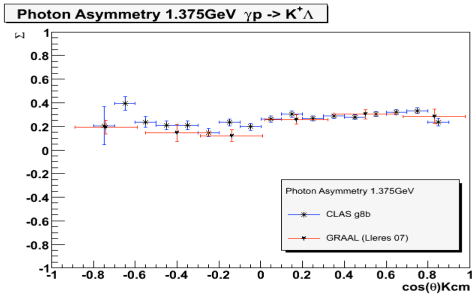
- Results compared with previous results from GRAAL
  - 7, 50-MeV Energy bins
  - 1175 → 1475 MeV
  - Good agreement with previous results

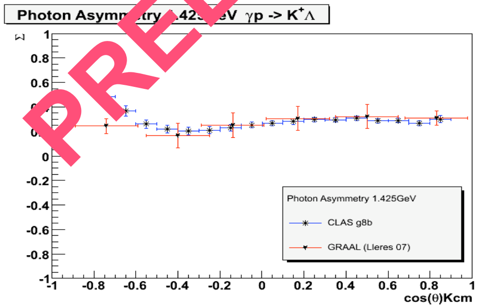

Photon Asymmetry 1.175GeV γp -> $K^+\Lambda$

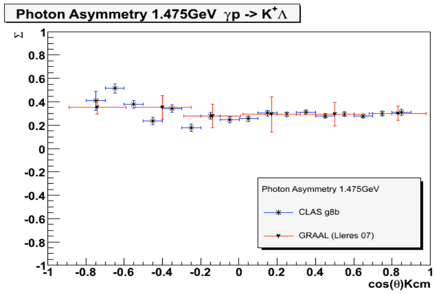

Photon Asymmetry 1.225GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.275GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.325GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.375GeV γp -> $K^+\Lambda$

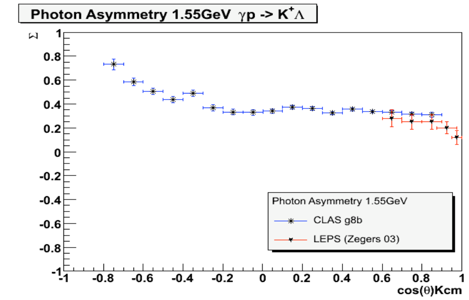

Photon Asym try 42 eV γp -> $K^+\Lambda$

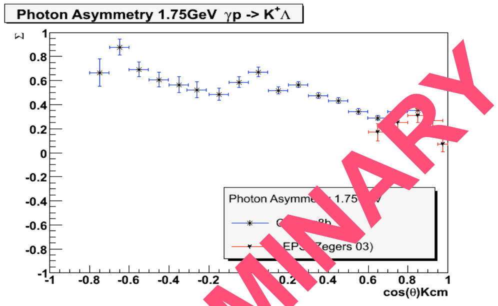

Photon Asymmetry 1.475GeV γp -> $K^+\Lambda$

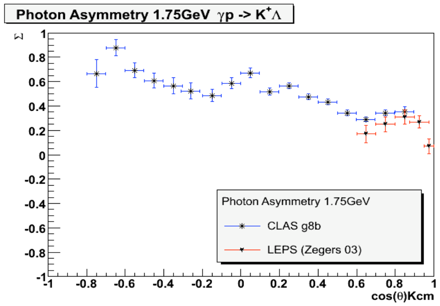
g8b preliminary results - $K^+\Lambda$

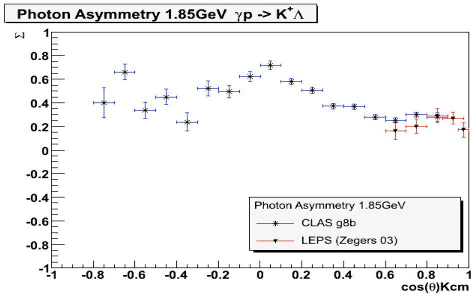
- Results compared with previous results from LEPS
  - 6, 100-MeV Energy bins
  - 1550 → 2050 MeV
  - More bins for our data

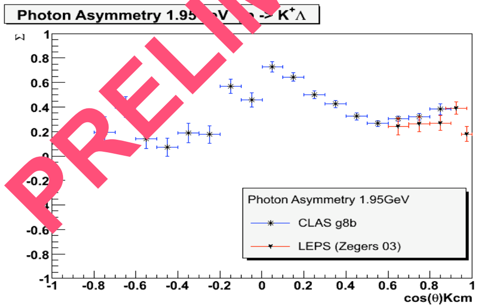
Increase the angular coverage to backward angles

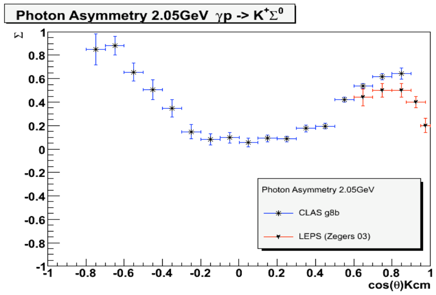

Photon Asymmetry 1.55GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.75GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.75GeV γp -> $K^+\Lambda$


Photon Asymmetry 1.85GeV γp -> $K^+\Lambda$

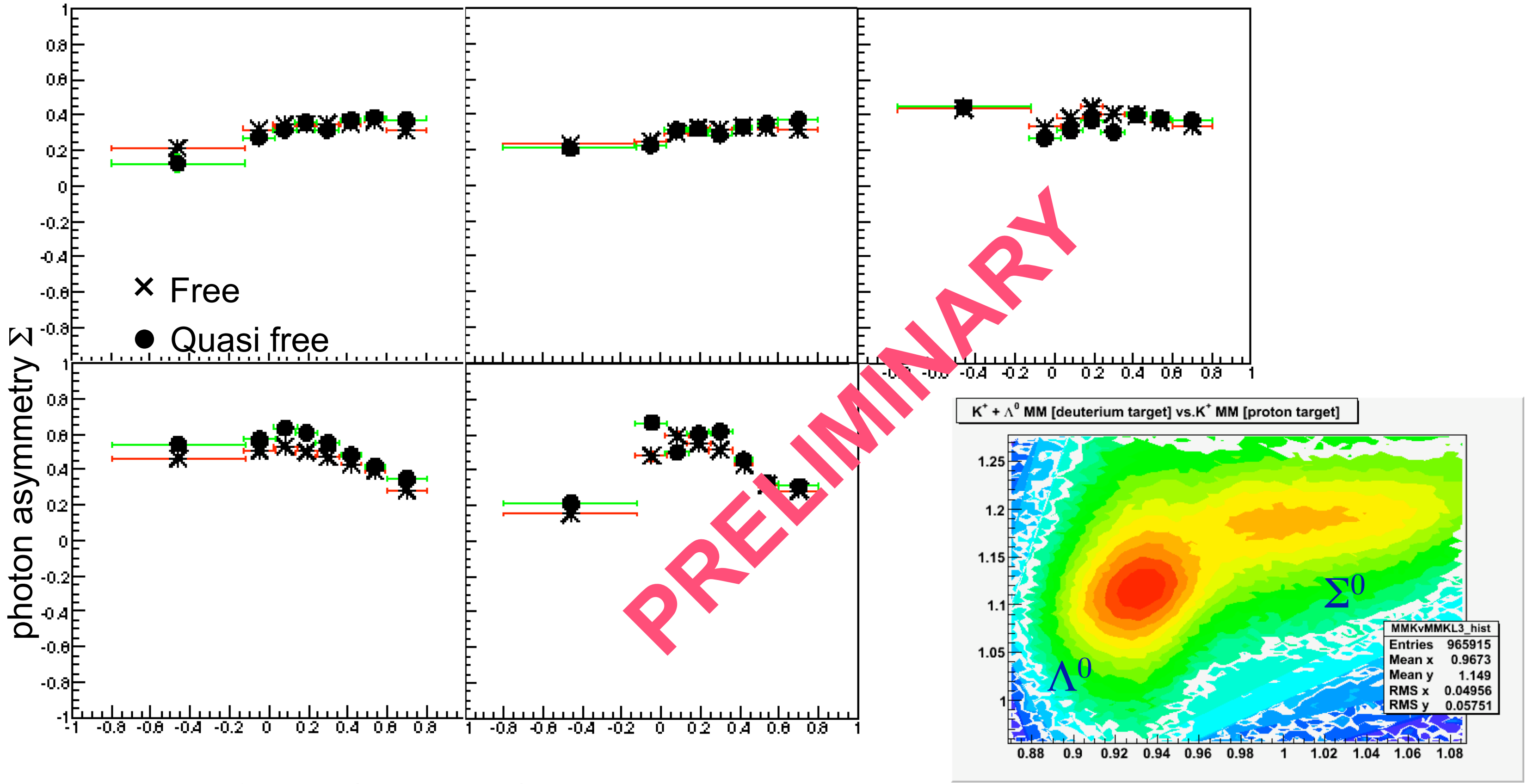

Photon Asymmetry 1.95GeV γp -> $K^+\Lambda$


Photon Asymmetry 2.05GeV γp -> $K^+\Sigma^0$

K production on n. g13 with Deuterium target

- How good a “free” neutron target is Deuterium ?
- Compare photon asymmetry of γp (n) -> $K^+\Lambda^0$ (n) with γp -> $K^+\Lambda^0$ (free and bound p)

γp (n) -> $K^+\Lambda^0$ (n) Russell Johnstone, Glasgow

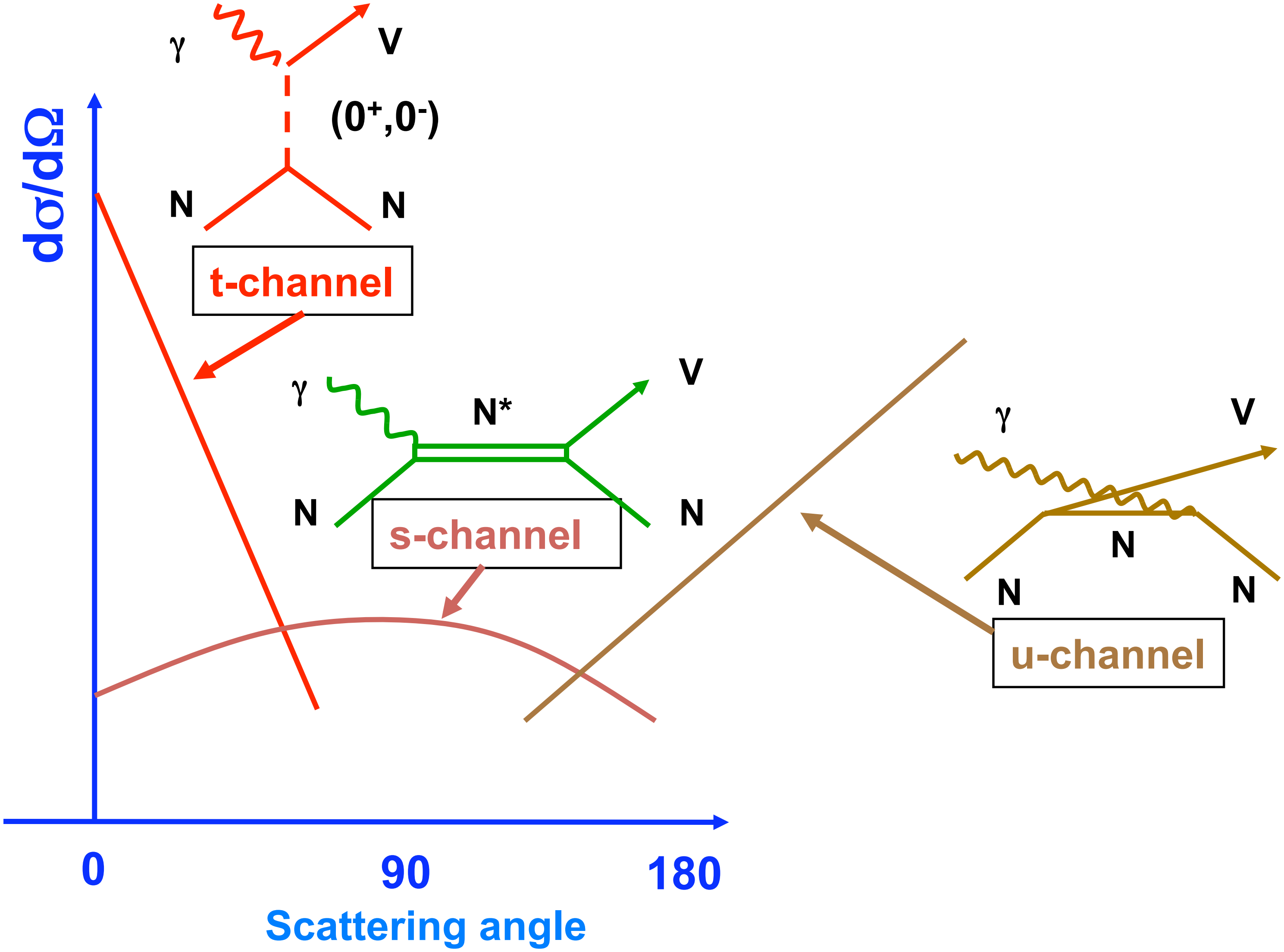


$\cos\theta_{cm}$ (-1.0 - +1.0)

Each plot is 200-MeV photon energy bin
1100-2150MeV

- Free and quasi-free proton
- Quasi free neutron good approx. to free, here.

Kinematic features of the production mechanism



Motivation – vector meson production

Extraction of spin density matrix elements

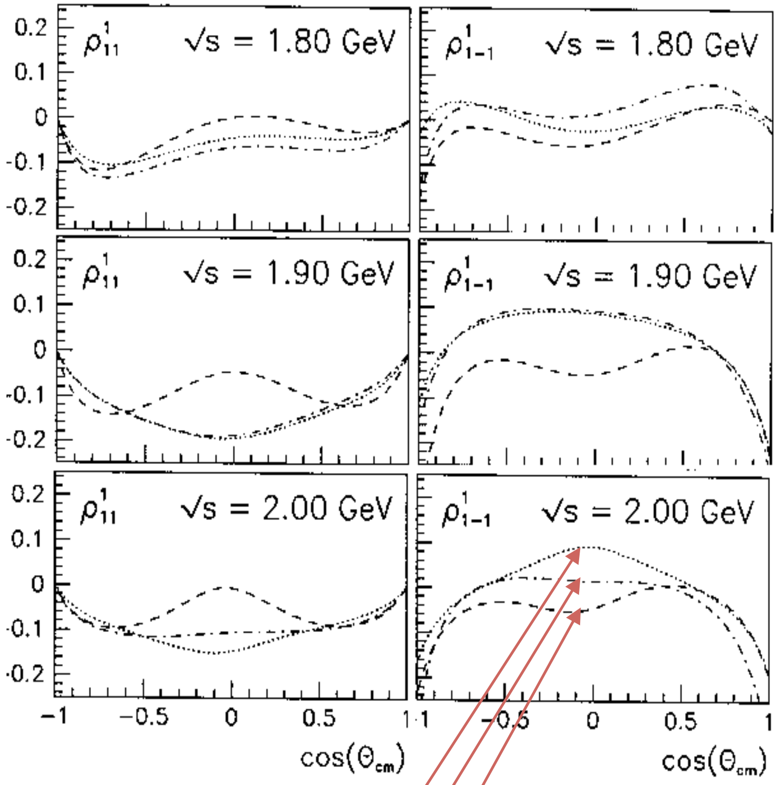
$$W(\cos\theta,\phi,\Phi) = W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) - \boxed{P_\gamma}\cos 2\Phi\, W^1(\cos\theta,\phi,\rho^1_{\alpha\beta}) - \boxed{P_\gamma}\sin 2\Phi\, W^2(\cos\theta,\phi,\rho^2_{\alpha\beta})$$

where

$$\begin{aligned}
W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) &= \frac{3}{4\pi}\Big[\frac{1}{2}\sin^2\theta + \frac{1}{2}(3\cos^2\theta - 1)\rho^0_{00} \\
&\quad -\sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\sin 2\theta\cos\phi - \rho^0_{1-1}\sin^2\theta\cos 2\phi\Big] \\
W^1(\cos\theta,\phi,\rho^1_{\alpha\beta}) &= \frac{3}{4\pi}\Big[\boxed{\rho^1_{11}}\sin^2\theta + \boxed{\rho^1_{00}}\cos^2\theta \\
&\quad -\sqrt{2}\,\mathrm{Re}\,\boxed{\rho^1_{10}}\sin 2\theta\cos\phi - \boxed{\rho^1_{1-1}}\sin^2\theta\cos 2\phi\Big] \\
W^2(\cos\theta,\phi,\rho^2_{\alpha\beta}) &= \frac{3}{4\pi}\Big[\sqrt{2}\,\mathrm{Im}\,\boxed{\rho^2_{10}}\sin 2\theta\sin\phi + \mathrm{Im}\,\boxed{\rho^2_{1-1}}\sin^2\theta\sin 2\phi\Big]
\end{aligned}$$

- ☐ **Helicity reference frame**
- ☐ **Linear polarization gives access to 6 more matrix elements than unpolarized data.**
- ☐ **g8 aims to do this for ρ^0, Φ and ω.**

Calculations for ρ^0 decay (Roberts)

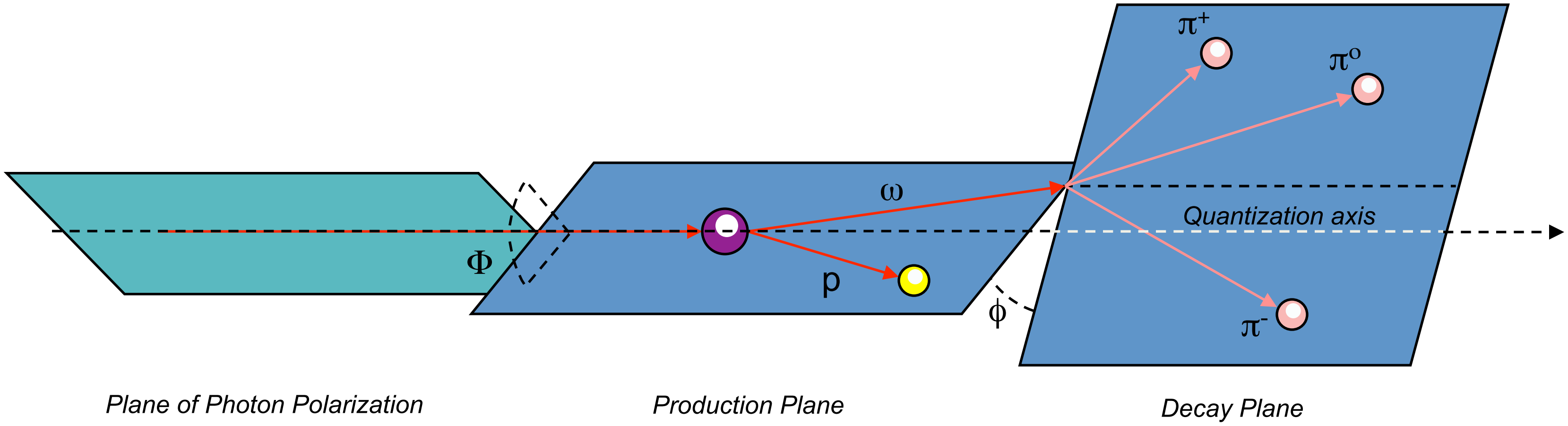


26 resonances

$N^{3/2+}$(1910)

26 – $N^{3/2+}$(1910)

The Decay Angular Distribution



P_γ = degree of polarization of the photon

Φ = the angle of photon polarization vector w.r.t the production plane

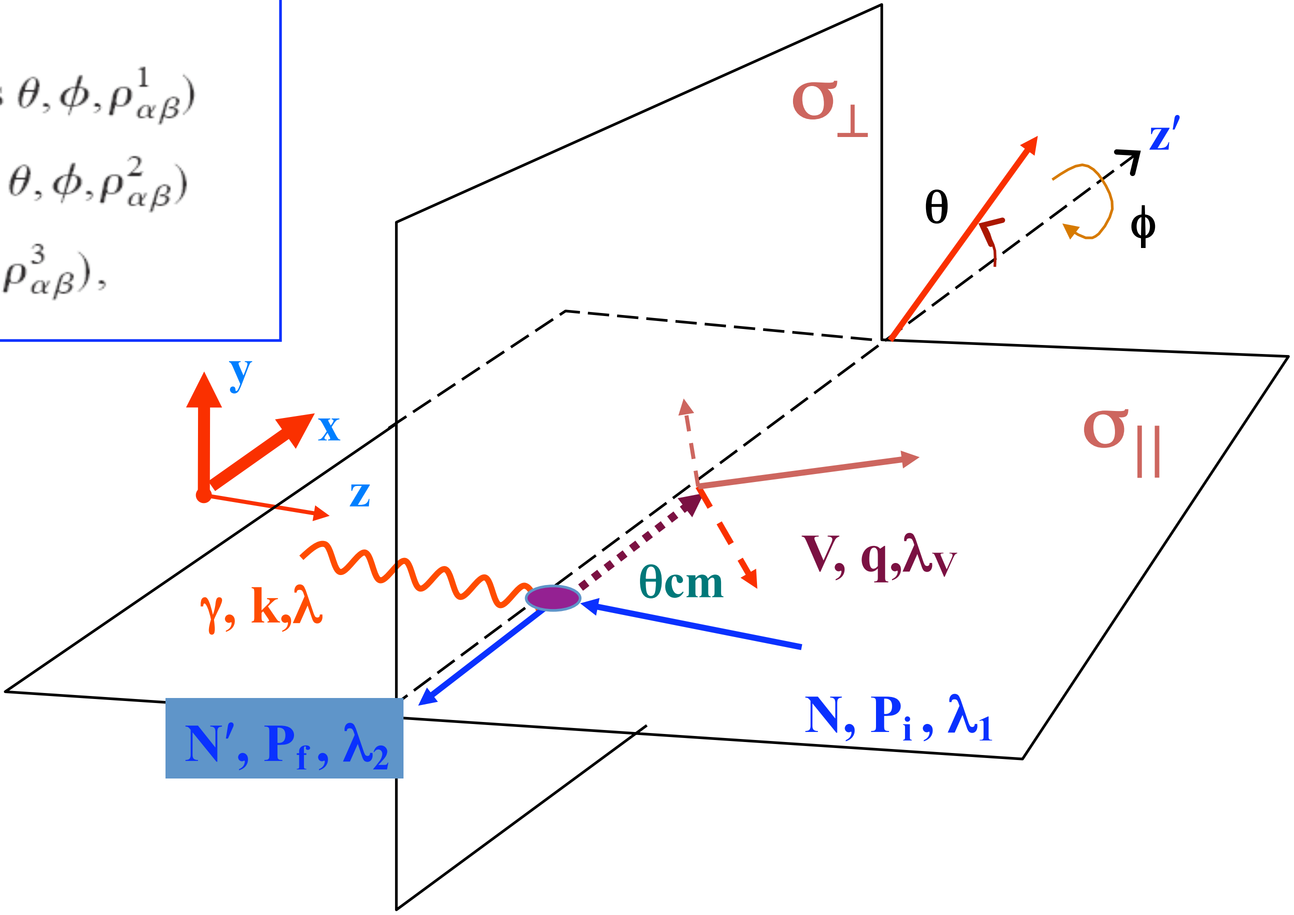
θ = polar angle of the decay plane

ϕ = azimuthal angle of the decay plane

Spin observables in terms of density matrix elements

Vector meson decay distribution:

$$
\begin{aligned}
&W(\cos\theta,\phi,\Phi)\\
&\quad = W^0(\cos\theta,\phi,\rho^0_{\alpha\beta})\\
&\qquad - P_\gamma \cos 2\Phi\, W^1(\cos\theta,\phi,\rho^1_{\alpha\beta})\\
&\qquad - P_\gamma \sin 2\Phi\, W^2(\cos\theta,\phi,\rho^2_{\alpha\beta})\\
&\qquad + \lambda_\gamma P_\gamma W^3(\cos\theta,\phi,\rho^3_{\alpha\beta}),
\end{aligned}
$$



Unpolarized decay distribution:

$$\begin{aligned} W^0(\cos\theta,\phi,\rho^0_{\alpha\beta}) = \frac{3}{4\pi}\Bigg(& \frac{1}{2}\sin^2\theta + \frac{1}{2}(3\cos^2\theta - 1)\rho^0_{00} \\ & - \sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\,\sin 2\theta\cos\phi \\ & - \rho^0_{1-1}\,\sin^2\theta\cos 2\phi\Bigg), \end{aligned}$$

Linearly-polarized decay distribution:

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

$$\left\{ \begin{aligned} \rho^0_{ik} &= \frac{1}{A}\sum_{\lambda\lambda_2\lambda_1} H_{\lambda_{v_i}\lambda_2,\lambda\lambda_1} H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1}, \\ \rho^1_{ik} &= \frac{1}{A}\sum_{\lambda\lambda_2\lambda_1} H_{\lambda_{v_i}\lambda_2,-\lambda\lambda_1} H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1}, \\ \rho^2_{ik} &= \frac{i}{A}\sum_{\lambda\lambda_2\lambda_1} \lambda H_{\lambda_{v_i}\lambda_2,-\lambda\lambda_1} H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1}, \\ \rho^3_{ik} &= \frac{i}{A}\sum_{\lambda\lambda_2\lambda_1} \lambda H_{\lambda_{v_i}\lambda_2,\lambda\lambda_1} H^*_{\lambda_{v_k}\lambda_2,\lambda\lambda_1}, \end{aligned} \right.$$

e.g. The polarized beam asymmetry:

$$\boxed{\Sigma \equiv \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{2\rho^1_{11} + \rho^1_{00}}{2\rho^0_{11} + \rho^0_{00}}}$$

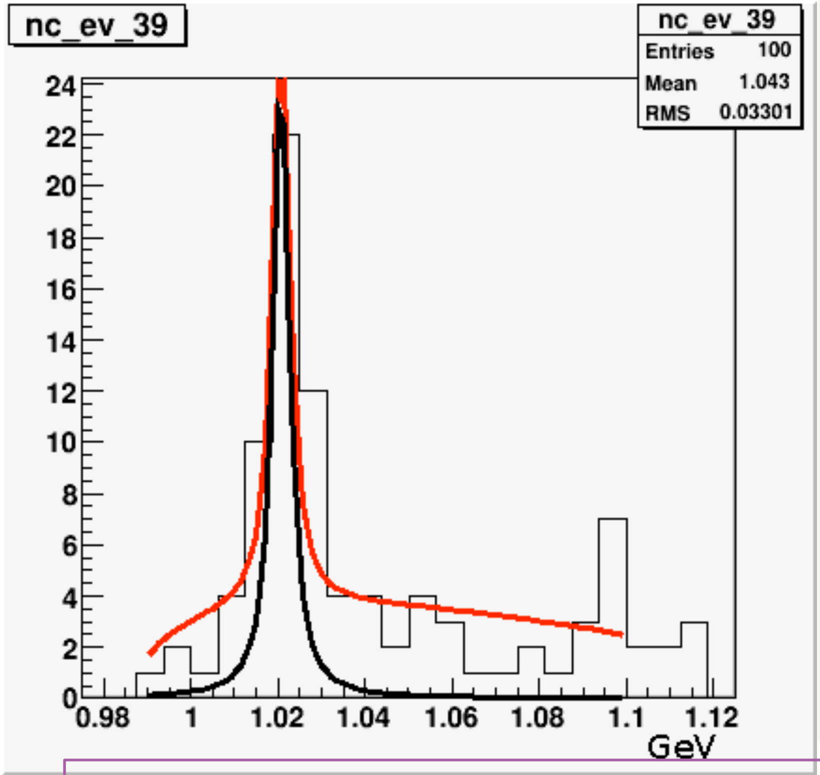
$$\begin{aligned} \epsilon_\perp &= \hat{y} = i(\epsilon_{\gamma+} + \epsilon_{\gamma-})/\sqrt{2} \\ \epsilon_\parallel &= \hat{x} = -(\epsilon_{\gamma+} - \epsilon_{\gamma-})/\sqrt{2} \end{aligned} \quad \Rightarrow \quad \left\{ \begin{matrix} \sigma_\perp \\ \sigma_\parallel \end{matrix} \right.$$

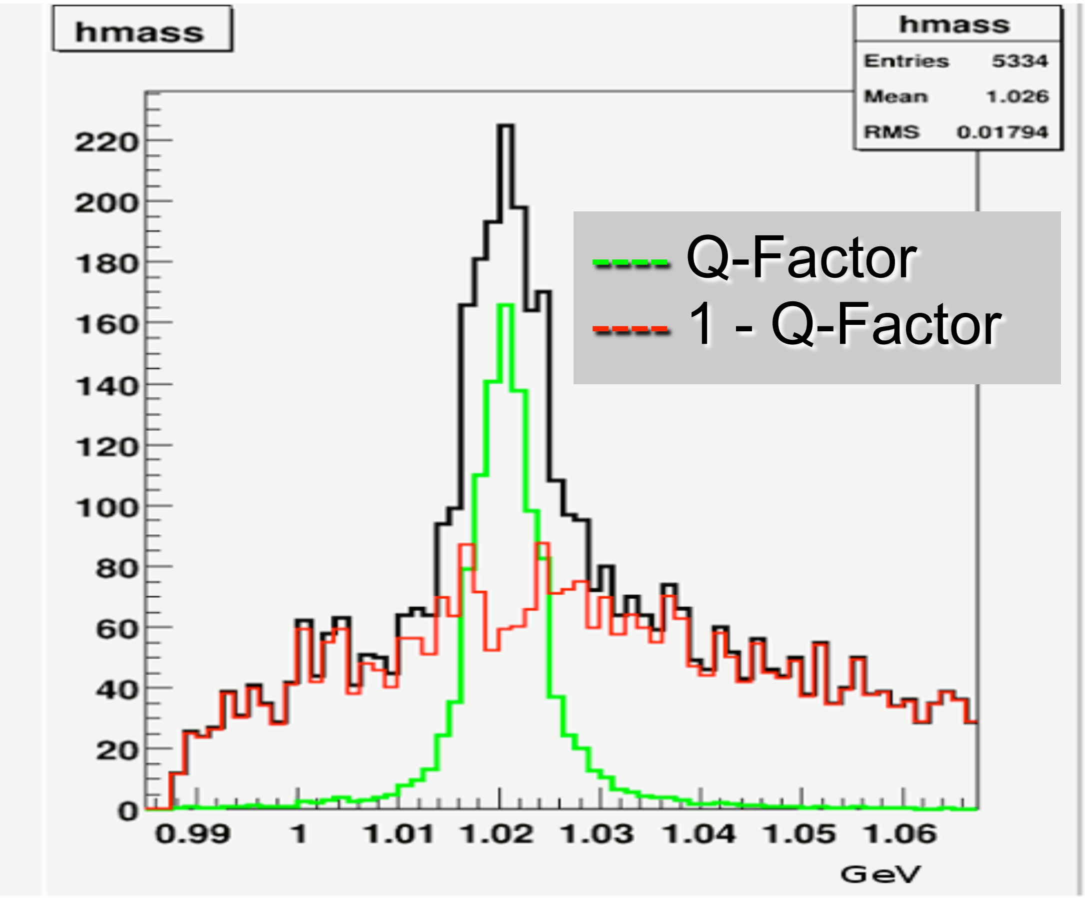
Zhao, Al-Khalili & Cole, PRC71, 054004 (2005); Pichowsky, Savkli & Tabakin, PRC53, 593 (1996)

Julian Salamanca (ISU) Phi Meson Photoproduction

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

Background Subtraction

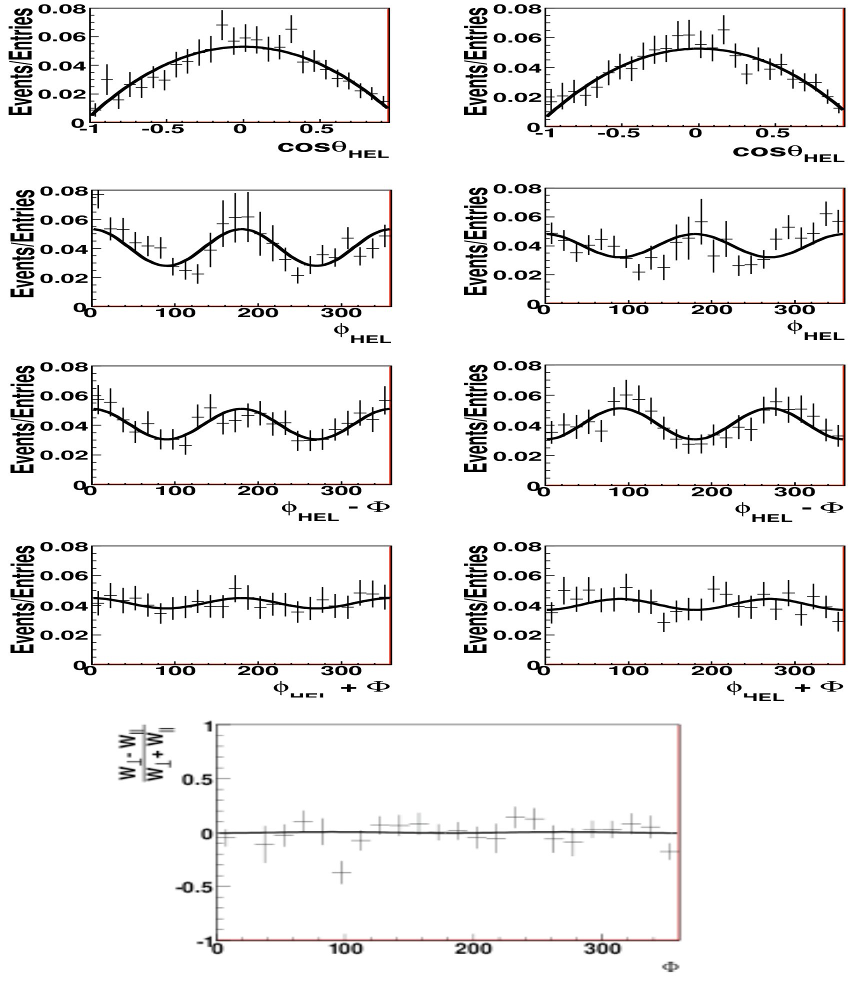




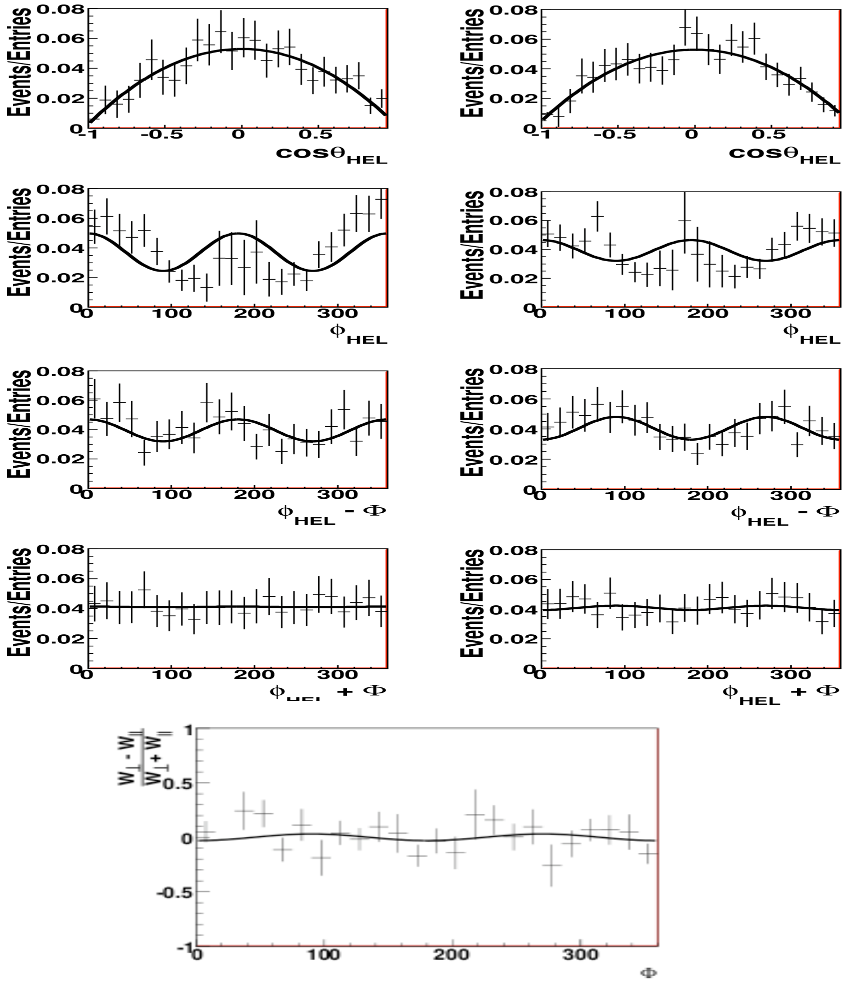
*** M. Williams, M. Bellis and C.A. Meyer arXiv: 0804.2548 accepted in JINST**

Julian Salamanca (ISU) Phi Meson Photoproduction – Dec. 2009

Results @ 2.1 GeV Coherent Edge



Results @ 1.9 GeV Coherent Edge



SDMEs parametrization

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

$$W(\phi) = N[1 - 2\rho^{0}_{1-1}\cos2\phi] \qquad \rho^{0}_{1-1} = \rho^{2}$$

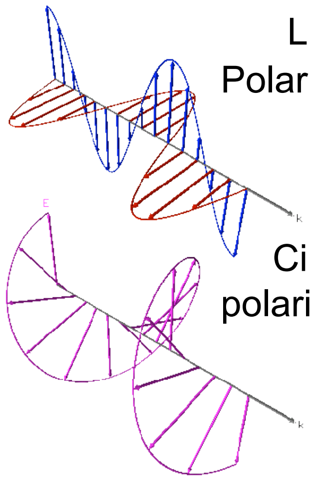
$$W(\phi - \Phi) = N[1 + 2P_{\gamma}(\rho^{1}_{1-1} - \mathrm{Im}\rho^{2}_{1-1})\cos2(\phi - \Phi)] \qquad \tfrac{1}{2}(\rho^{1}_{1-1} - \mathrm{Im}\rho^{2}_{1-1}) = \rho^{3}$$

$$W(\phi + \Phi) = N[1 + 2P_{\gamma}(\rho^{1}_{1-1} + \mathrm{Im}\rho^{2}_{1-1})\cos2(\phi + \Phi)] \qquad \tfrac{1}{2}(\rho^{1}_{1-1} + \mathrm{Im}\rho^{2}_{1-1}) = \rho^{4}$$

$$W(\Phi) = N[1 - P_{\gamma}(2\rho^{0}_{1-1} + \rho^{1}_{00})\cos2\Phi] \qquad 2\rho^{1}_{11} + \rho^{1}_{00} = \rho^{5}$$

$$P_{\gamma}\rho^{5}\cos2\Phi = \frac{W_{PARA} - W_{PERP}}{W_{PARA} + W_{PERP}}$$

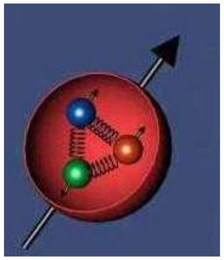
Frost – g9



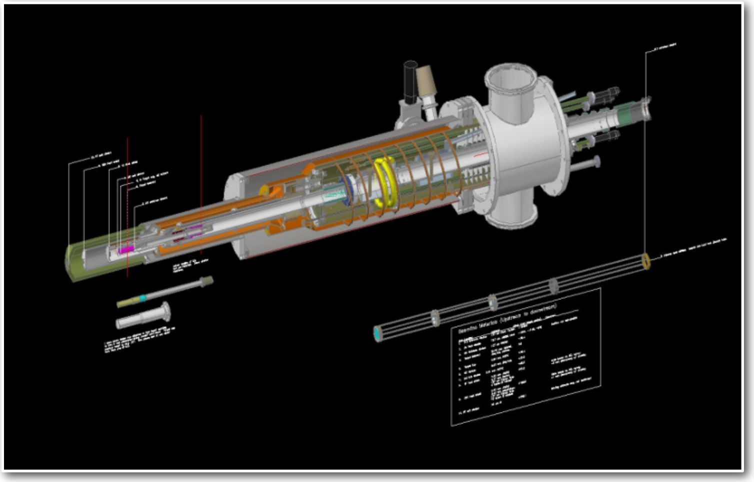
Linear Polarization ✓

Circular polarization ✓

$$\gamma + N \rightarrow N + m$$
$$\rightarrow Y + K$$

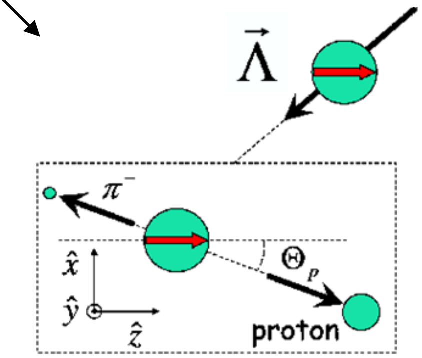


Nucleon recoil polarimeter x



Longitudinally polarized nucleon targets ✓

Transverse polarized nucleon targets ✓



Hyperons are “self analyzing” ✓

Gracias