Polarization as a tool to study baryon resonances at CLAS (JLab)

DIS 2007 Workshop
Munich, Germany

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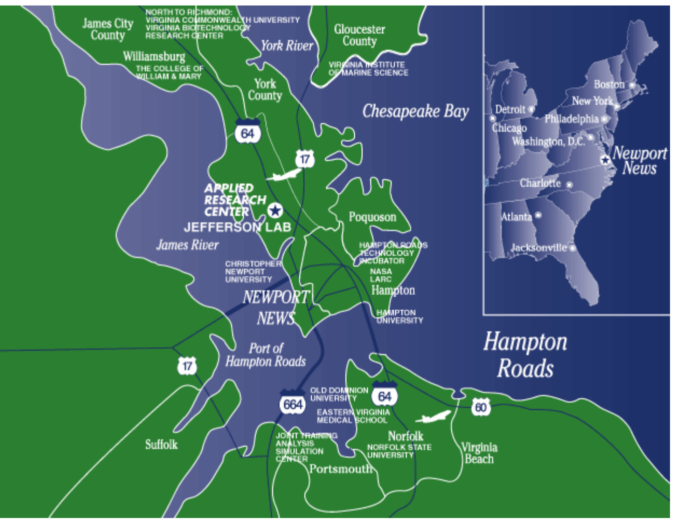
*For the CLAS Collaboration

CEBAF

(Continuous Electron Beam Accelerator Facility)

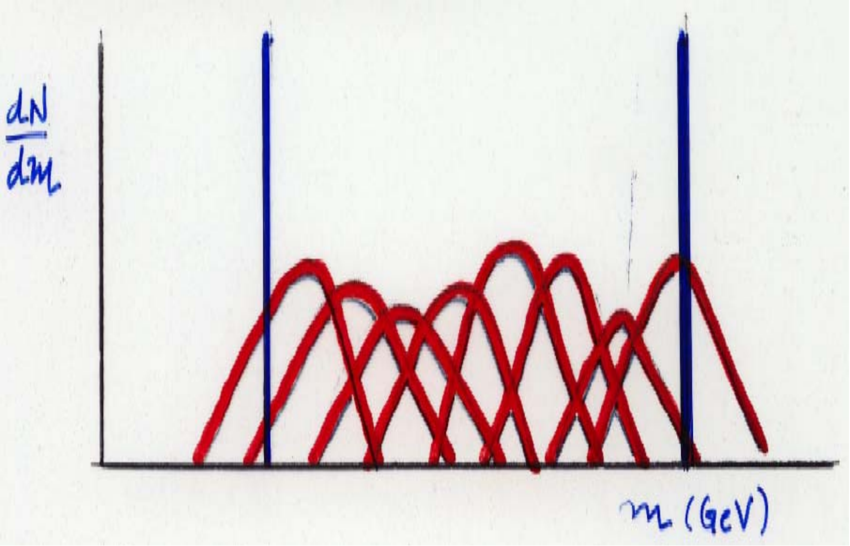


Jefferson Lab

THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

MOTIVATION

There are many (relatively unexplored) baryon resonances in the energy range of $1.5 < \sqrt{s} < 2.0$ GeV that decay through the vector-meson channel



- They are ***closely packed*** and have ***broad widths*** (~150MeV).
- Quark models predict:
  - Masses
  - Widths
  - J^P (spin/parity)
  - Decay angular distributions

Spin observables will provide a sensitive tool for testing the quark models

(more on this later…..)

Baryon Resonances and SU(6) x O(3)

$|\text{Baryon}\rangle : \ \alpha\, |qqq\rangle + \beta\, |qqq(q\bar{q})| + \gamma\, |qqqG\rangle + ..$

3 Flavors: $\{u,d,s\} \longrightarrow$ SU(3)

$\{qqq\}: \quad \mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1}$

Quark spin $s_q = ½ \longrightarrow$ SU(2)

$\{\vec{q}\vec{q}\vec{q}\}: \quad \mathbf{6} \otimes \mathbf{6} \otimes \mathbf{6} = \mathbf{56} \oplus \mathbf{70} \oplus \mathbf{70} \oplus \mathbf{20}$

SU(6) multiplets decompose into flavor multiplets:

$\mathbf{56} = {}^4\mathbf{10} \oplus {}^2\mathbf{8}$

$\mathbf{70} = {}^2\mathbf{10} \oplus {}^4\mathbf{8} \oplus {}^2\mathbf{8} \oplus {}^2\mathbf{1}$

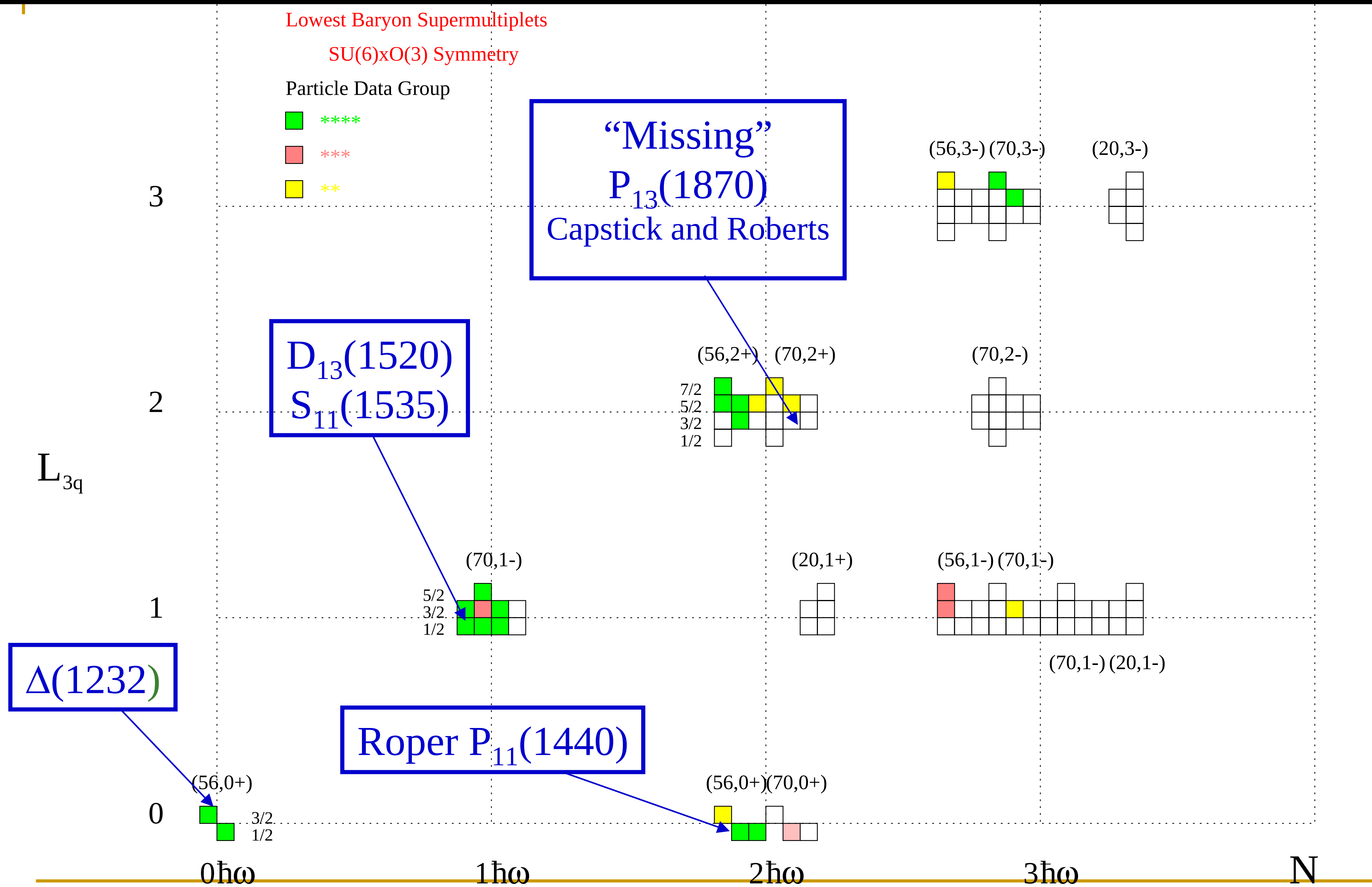
$\mathbf{20} = {}^2\mathbf{8} \oplus {}^4\mathbf{1}$

O(3)

Baryon spin: $\vec{J} = \vec{L} + \sum \vec{s}_i$

parity: $P = (-1)^L$

SU(6) x O(3) Classification of Baryons



Polarization observables

4 complex amplitudes

≥ 8 measurements required to completely determine the amplitudes

- γp: all 4 combinations of beam (lin,circ) and target (long,trans)
- γn: 2 combinations of beam (lin,circ) and long.pol. target
- for Λ, $\Sigma^{0,+}$ additionally recoil polar. → **complete set**
- all observables as functions of √s and cosθ
- use algebraic relations to check for systematics

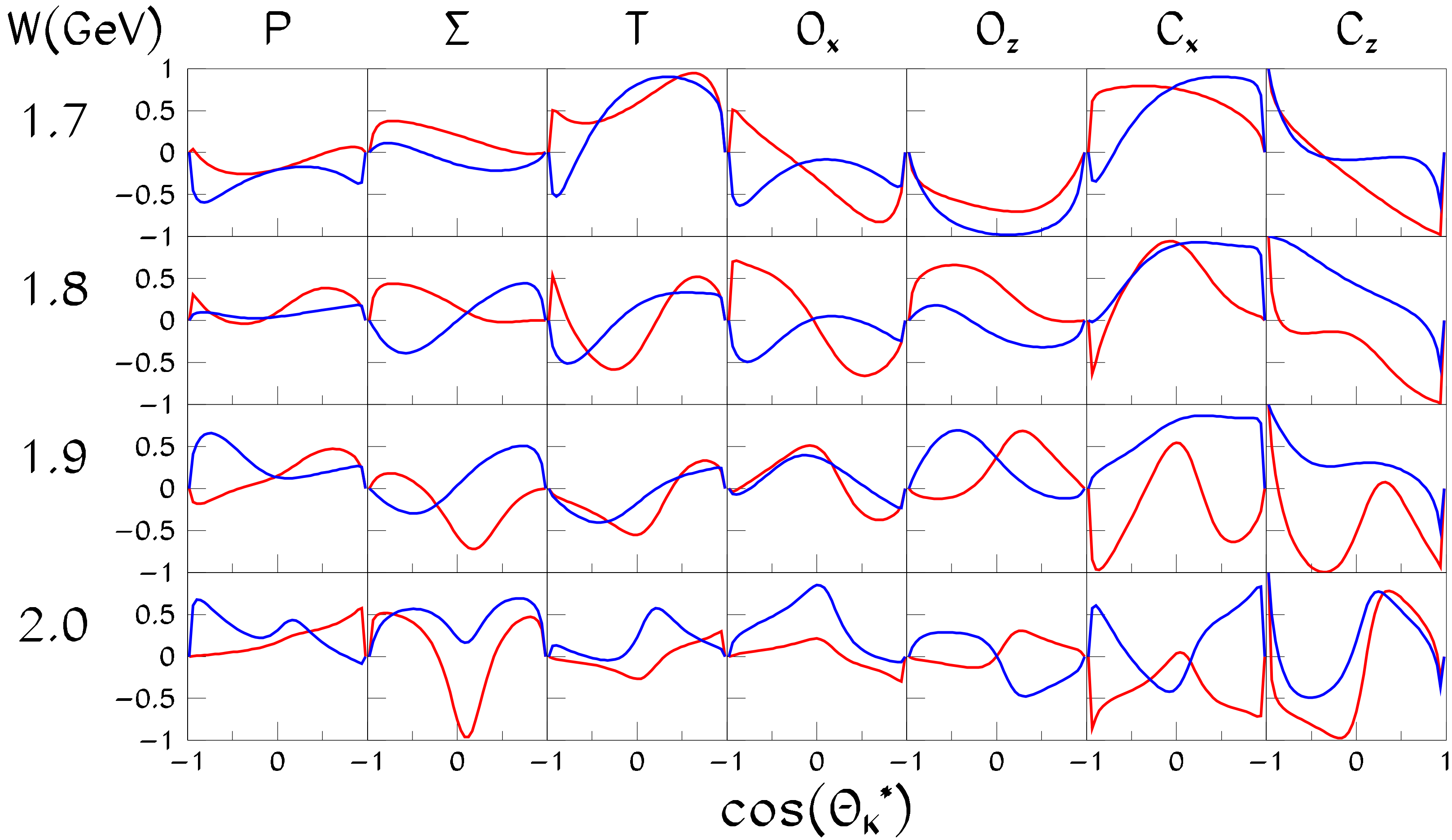
Photon		Target			Recoil			Target + Recoil			
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	($-L_{z'}$)	($T_{z'}$)	($-L_{x'}$)	($-T_{x'}$)
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

from CLAS g1, g2, **g8**, **g13**, (g10,g11) data

Relations among the observables

- R.A. Adelseck and B. Saghai, Phys. Rev. C **42**, 108 (1990):
  - Beam + Recoil
    - $C_{x'}^2 + C_{z'}^2 + O_{x'}^2 + O_{z'}^2 = 1 + T^2 - P^2 - \Sigma^2$
    - $C_{z'}O_{x'} - C_{x'}O_{z'} = T - P\Sigma$
  - Beam + Target
    - $E^2 + F^2 + G^2 + H^2 = 1 + P^2 - \Sigma^2 - T^2$
    - $FG - EH = P - \Sigma T$
  - Target + Recoil
    - $T_{x'}^2 + T_{z'}^2 + L_{x'}^2 + L_{z'}^2 = 1 + \Sigma^2 - P^2 - T^2$
    - $T_{x'}L_{z'} - T_{z'}L_{x'} = \Sigma - PT$

Sensitivity of polarization observables in the $K^0\Lambda$ channel to the presence of the missing $D_{13}(1900)$ resonance

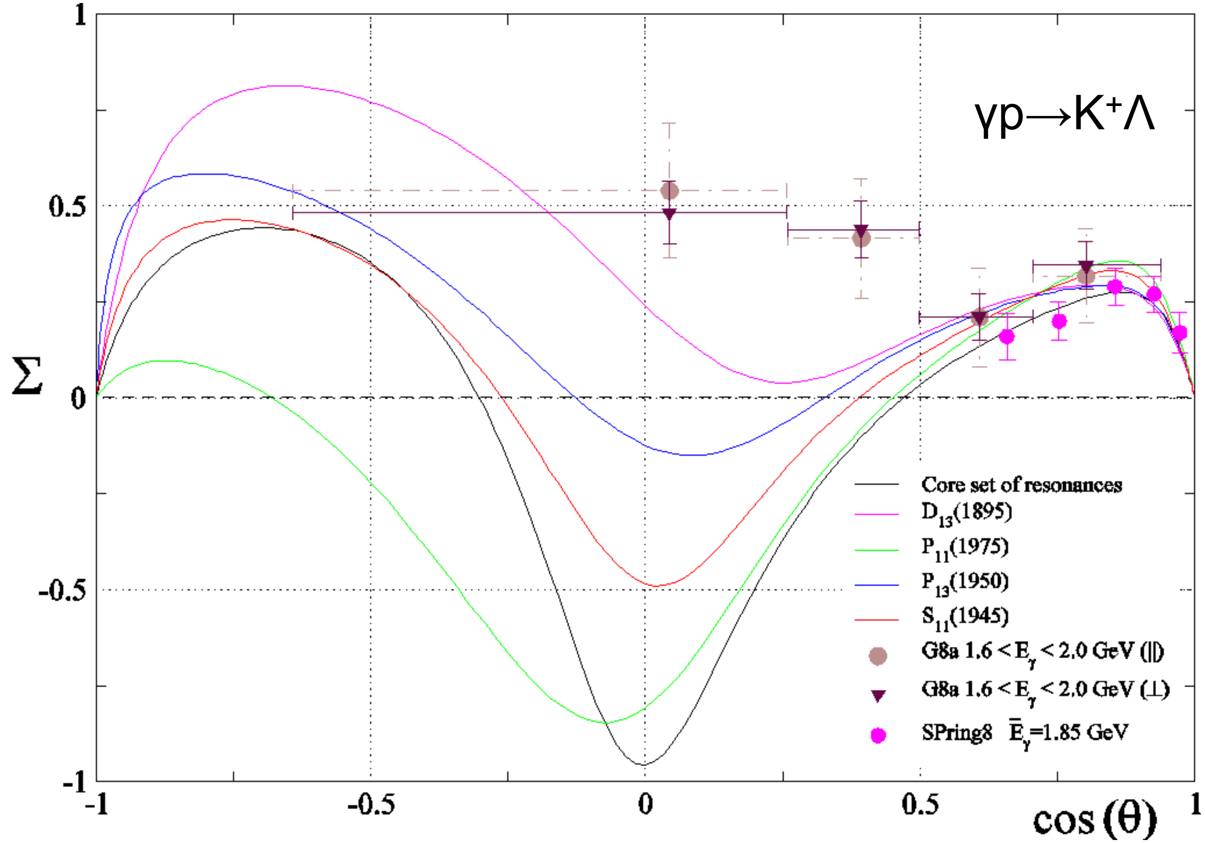


C. Bennhold and A. Waluyo (2006): Full calculation and $D_{13}(1900)$ excluded.

From g13 Presentation to PAC30 (Pawel Nadel-Turonski)

What characteristics should an experiment have to provide the best constraints for coupled-channels calculations?

- Wide kinematic coverage
- Small uncertainties
- Several polarization observables



Beam asymmetry from JLab (*g8a*) and Spring-8
Calculations by Ireland, Janssen, Ryckebusch *et al.*

g13 is currently taking data

- measure
  - $\gamma d \rightarrow N^*(N) \rightarrow KY(N)$ channels
  - using linearly and circularly polarized photons and an LD_2 target
  - with high statistics, good kinematic coverage, and low background.

- main goal is to find evidence for or against the existence of "missing" nucleon resonances. (1.1 < Egam < 2.3 GeV)
- approach is based on coupled-channels analysis, required for reliable *N** extraction.

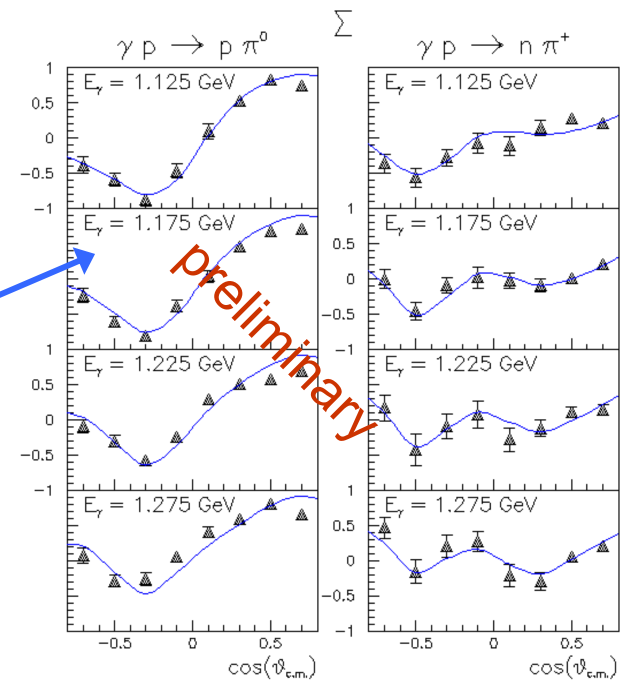
- high-statistics studies of *Y-N, Y*-N,* and *K-N* rescattering will reduce the systematic uncertainties and provide insight into the hyperon – nucleon interaction.

- *g13 (circularly polarized γs) 27 October – 20 Dec 2006 &*
  (linearly polarized γs) 8 March – 25 May 2007

linearly polarized photons

g8b

- ❑ Analysis of many channels will begin soon.
- ❑ High statistics > 10 billion events
- ❑ High photon polarization from 1.3 – 2.1 GeV.
- ❑ Prelim analysis of $\gamma p \rightarrow N\pi$ on a few runs with rough calibration. (M. Dugger ASU)
  - P_γ estimated at 0.8
  - Blue line is SAID prediction
  - Data with statistical errors (no systematics)



Hyperon production on deuterons

- ❑ A-rated at August 2006 PAC. (P. Turonski, E-06-103)
- ❑ Will use circularly and linearly polarized photons.
- ❑ Access to neutron channels.
- ❑ Repeat g8b kaon channels on proton in medium. Look for FSI effects.

The future – polarized photons + polarized targets

FROST (Frozen Spin Polarized Target)

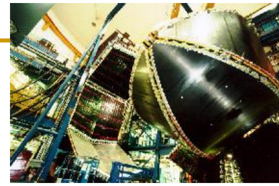
- Longitudinal and transverse target polarization
- Circularly and linearly polarized photons
- Scheduled for Fall 2007
- Double polarization observables
- Several proposals (http://clasweb.jlab.org/frost)

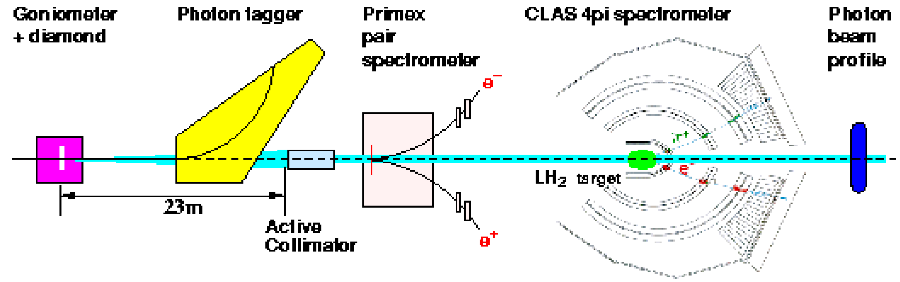
Transverse holding coil

(C,Keith, M. Seely)

Combined HD polarized target (LEGS).

- Target is polarized at LEGS and brought to JLab by truck. (Long relaxation time)
- Simultaneous measurement on polarized p and n
- Combine with circularly and linearly polarized photons
- A-Rated at Aug 2006 PAC (A. Sandorfi and F.J. Klein, E-06-101).
- $0.7 < E\gamma < 2.5$ GeV
- " … and a complete determination of the $\gamma n \rightarrow K^0 \Lambda$ amplitude"
- **Focus is on Hyperon production (for now….)**



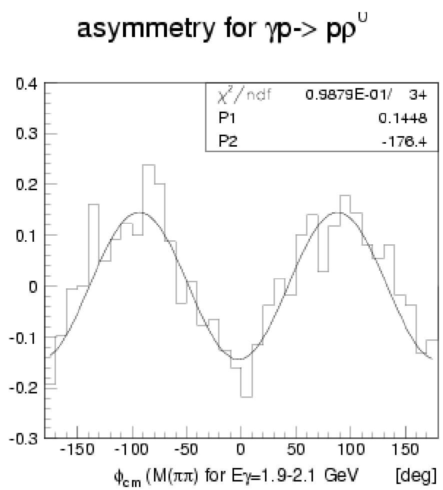


g8b (6/20 – 9/01/05)
[6 times the data of g8a]

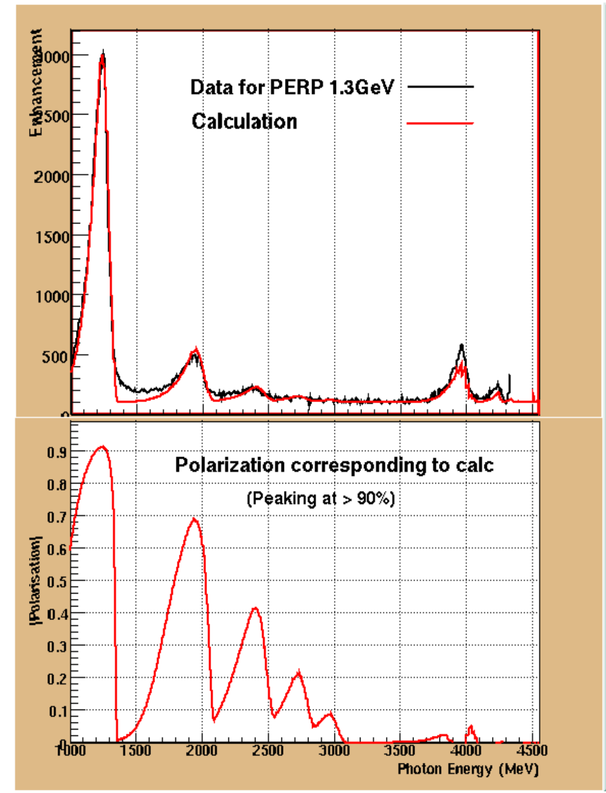
Tagged and Collimated $\vec{\gamma}$ beam in Hall B for beam-asymmetry studies for the reactions:

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

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)

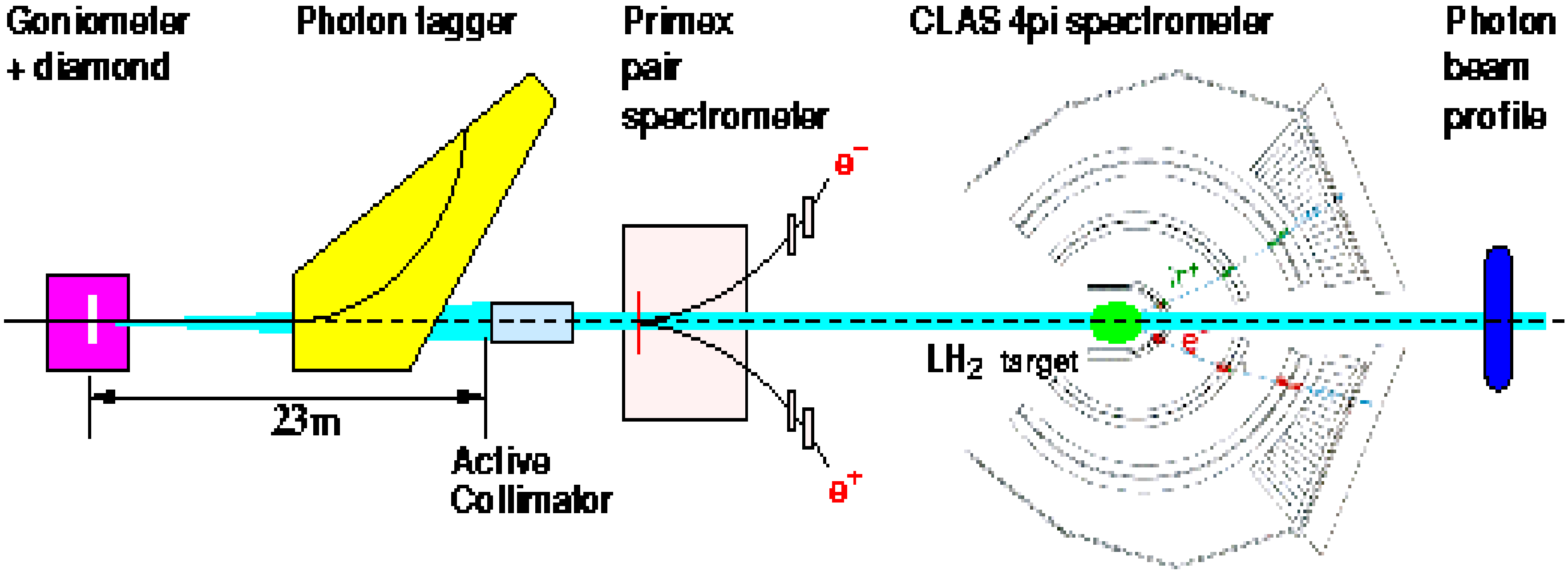


Photon Polarization exceeds 90% in the peak

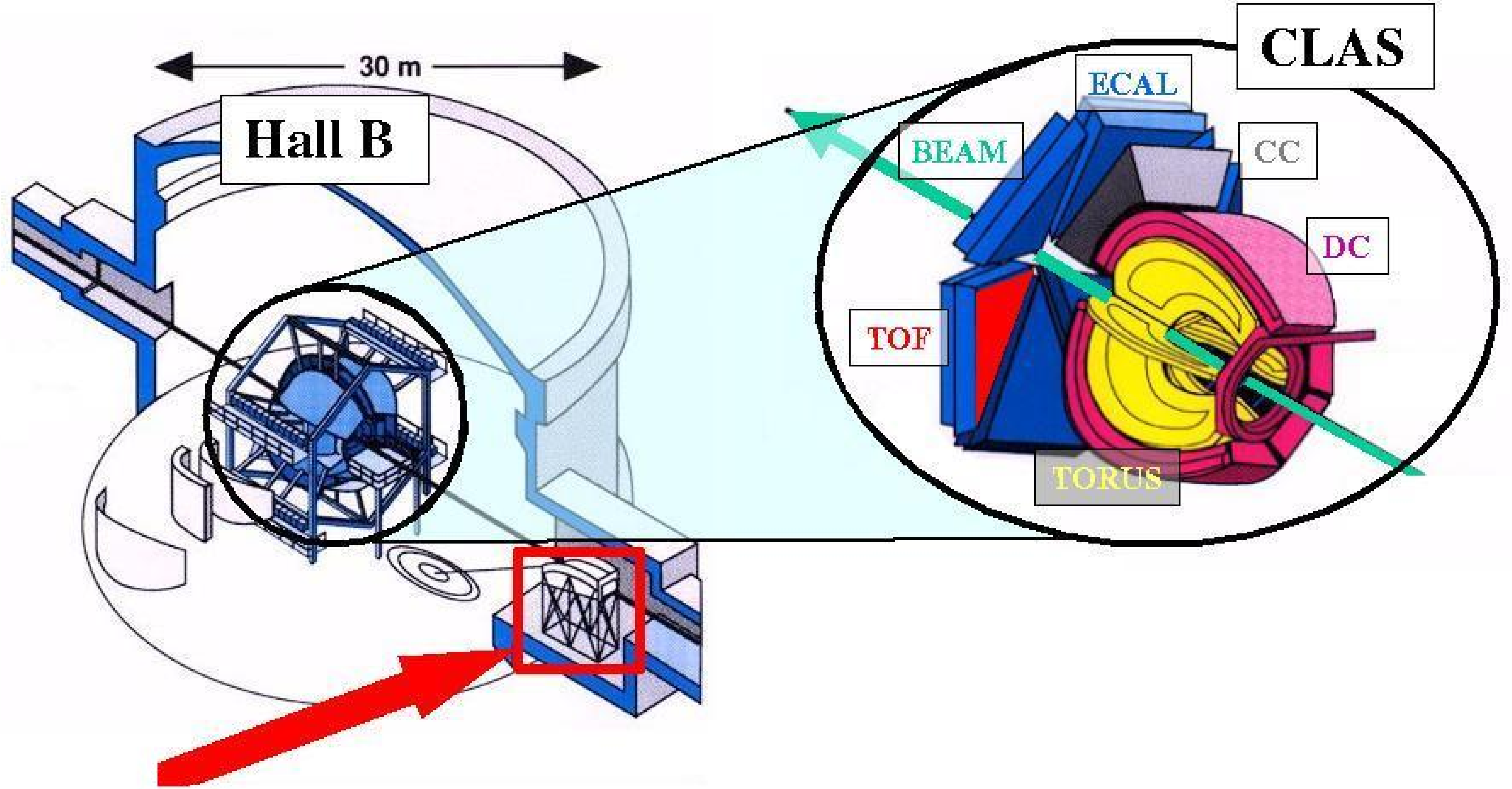
A Few Experimental Details

- Coherent Bremsstrahlung Facility.
  - Commissioned by g8a/g8b
  - To be used by g13, FROST, and HD
- FROST target
- HD target.

Coherent Bremsstrahlung Facility Beamline



The CLAS Detector in Hall B of JLab



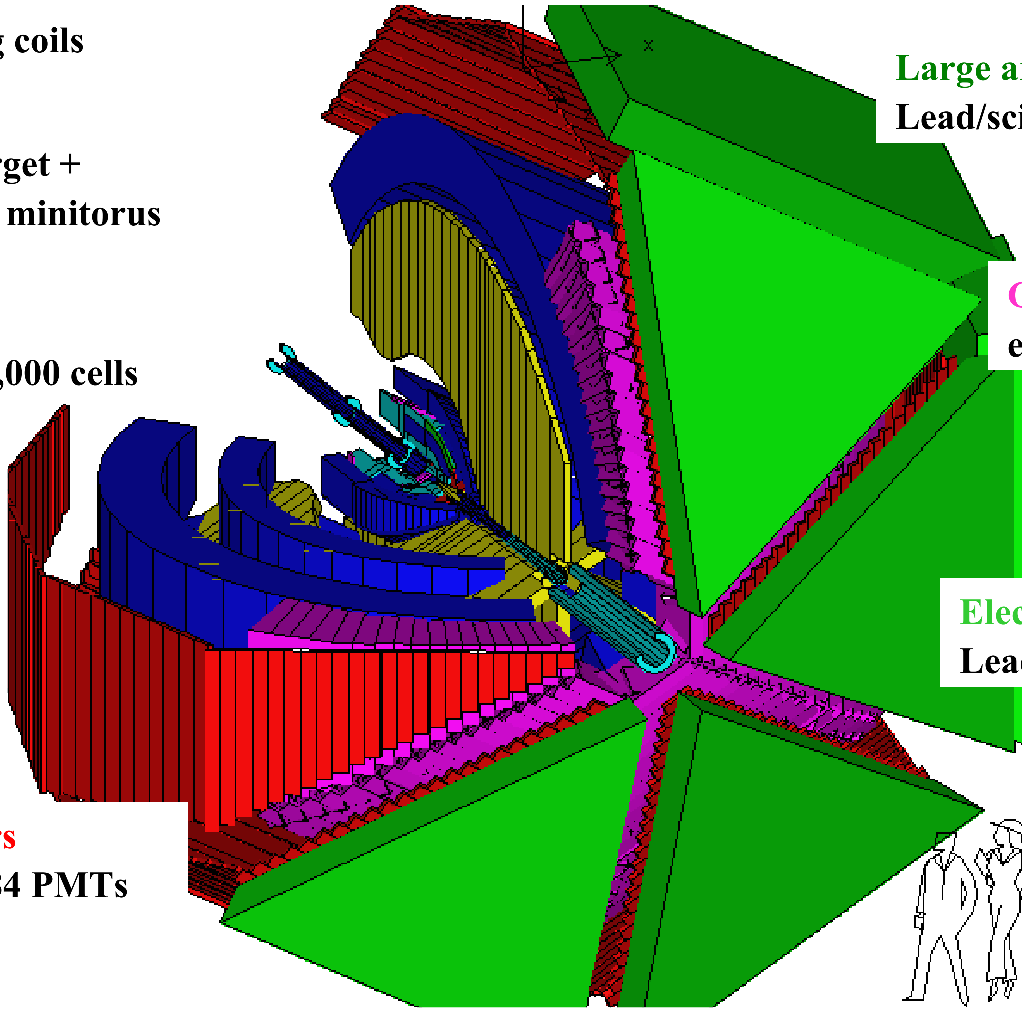
$E_\gamma = 0.90 - 4.28$ GeV (g8b)

CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

Liquid D_2 (H_2)target +
γ start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells



Large angle calorimeters
Lead/scintillator, 512 PMTs

Gas Cherenkov counters
e/π separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

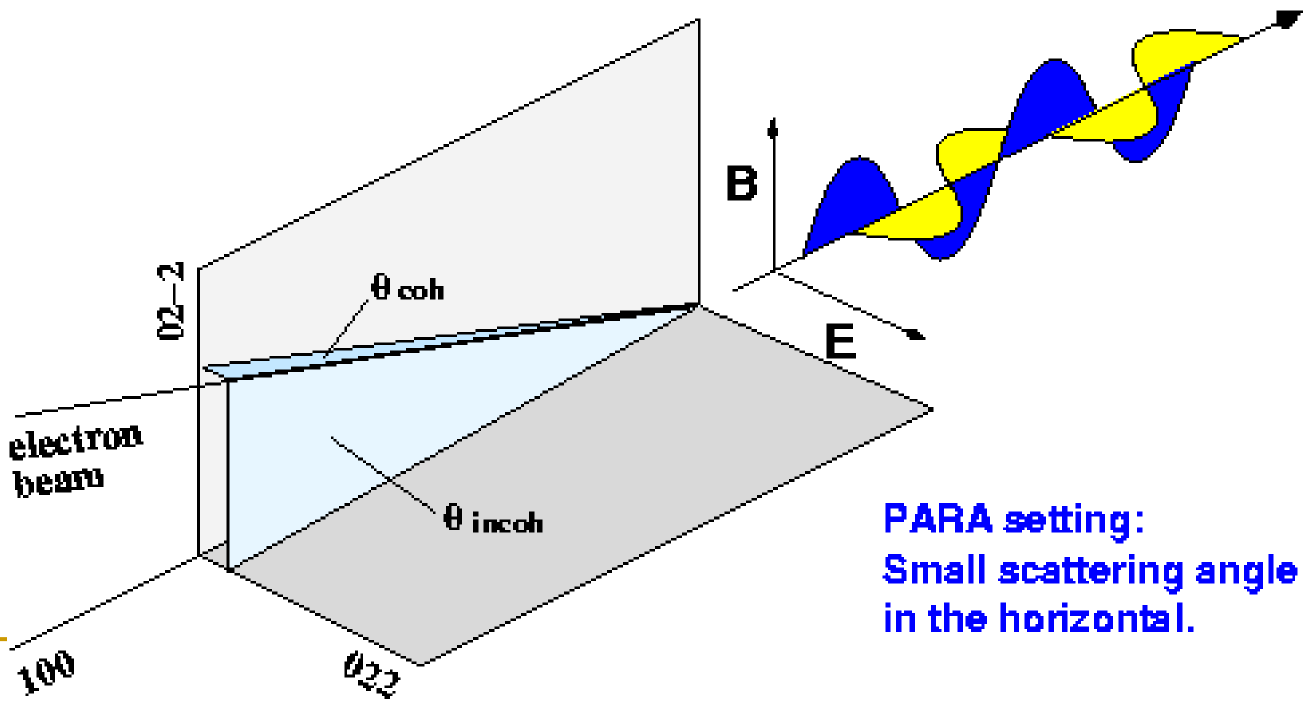
Time-of-flight counters
plastic scintillators, 684 PMTs

How to make polarized photons
First buy a goniometer….

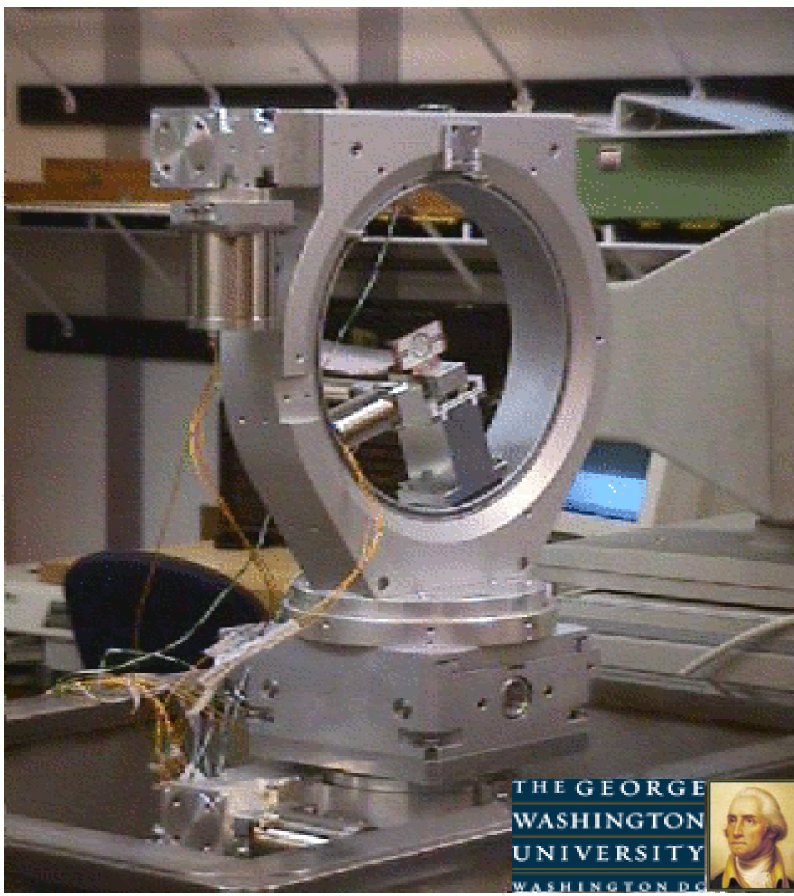
Align crytal in terms of angles between beam and 022, 02–2 planes

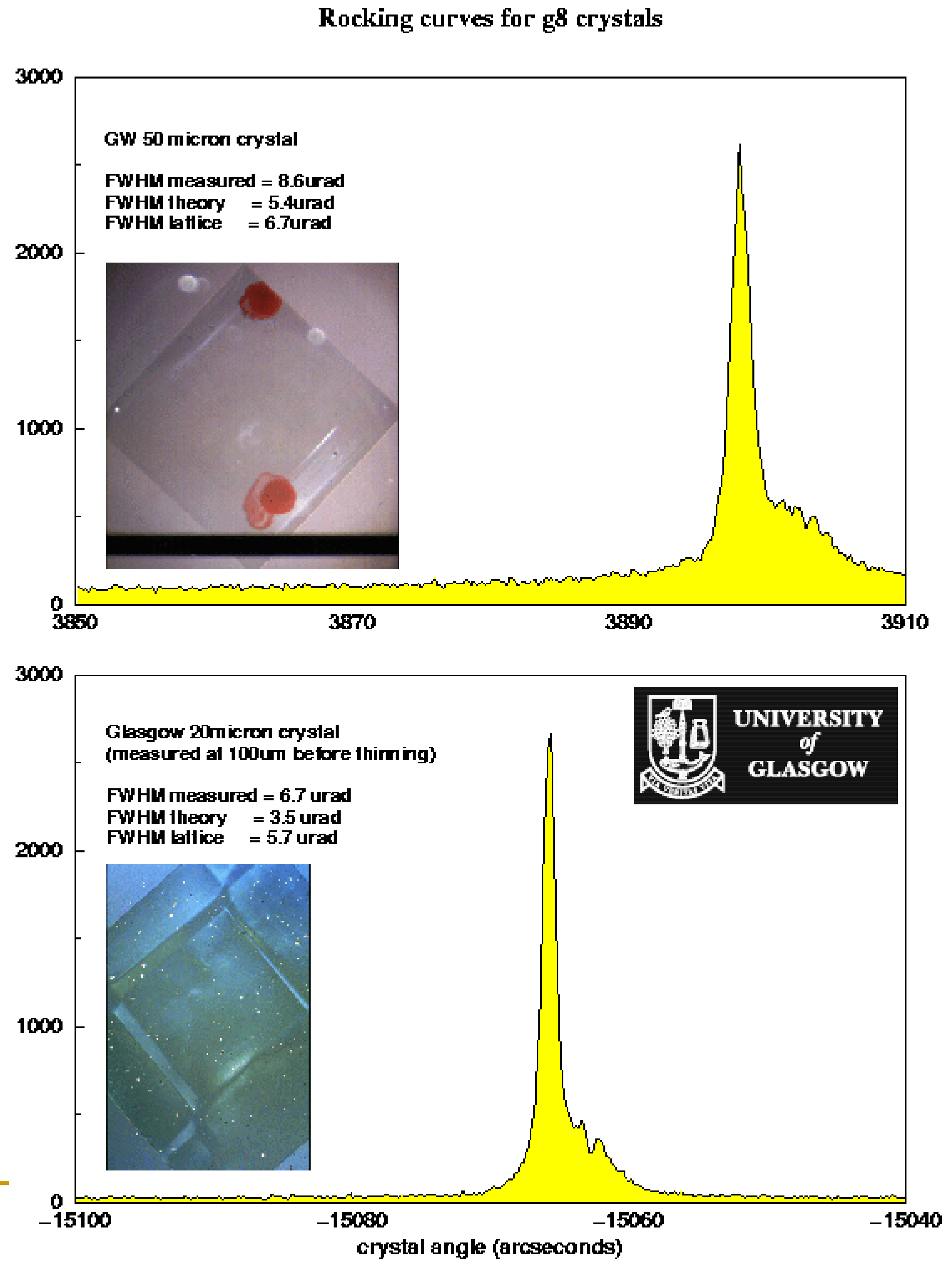
θ_{coh} sets the position of the coherent peak in photon energy spectrum

θ_{incoh} set large to remove coherent components from orthogonal planes

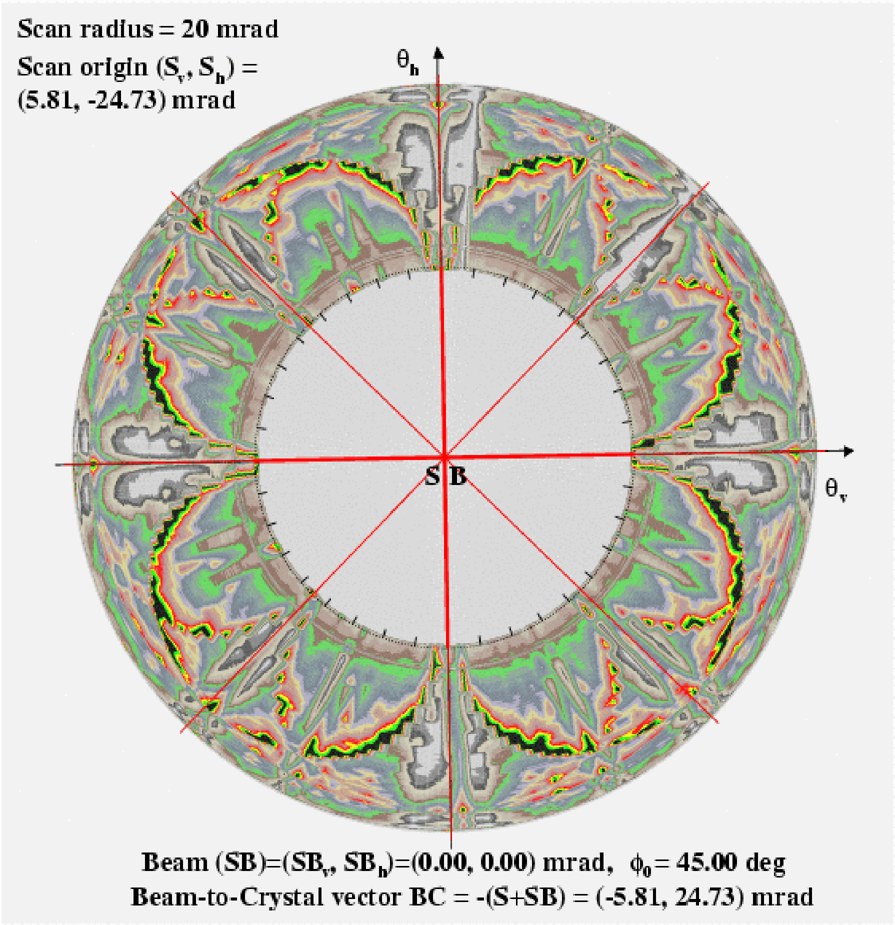


Goniometer and Diamonds

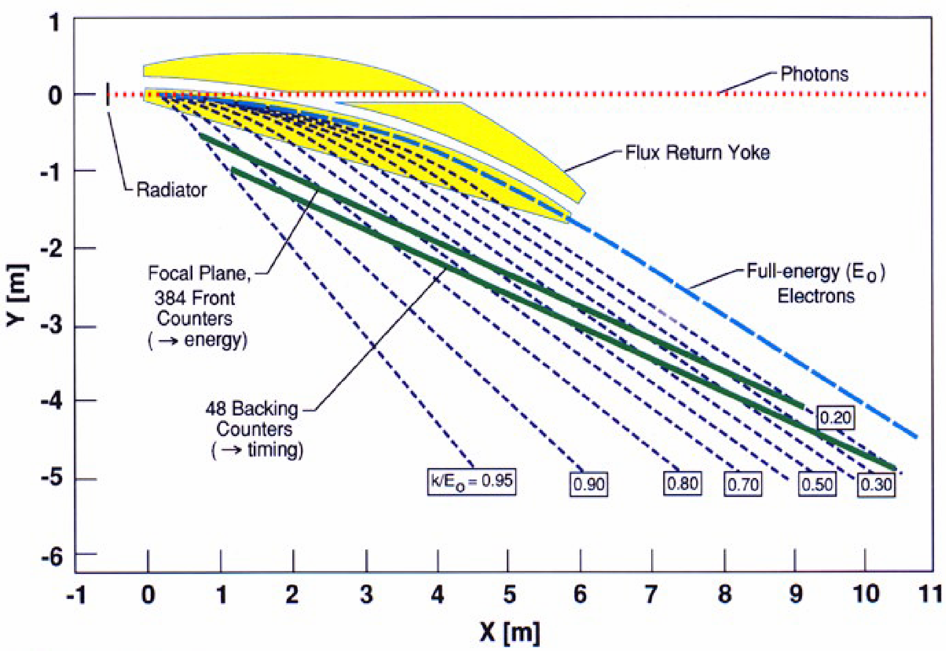




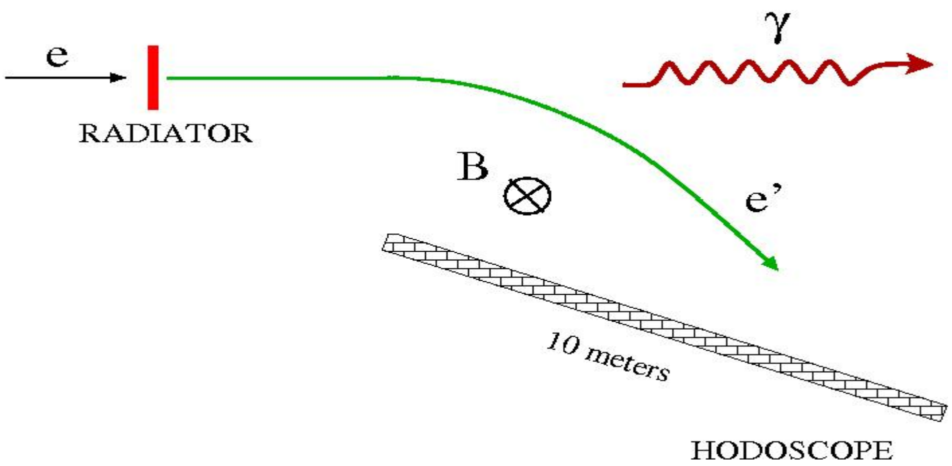
Crystal Calibration



A well-behaved tagger is the **key** for aligning the crystal.



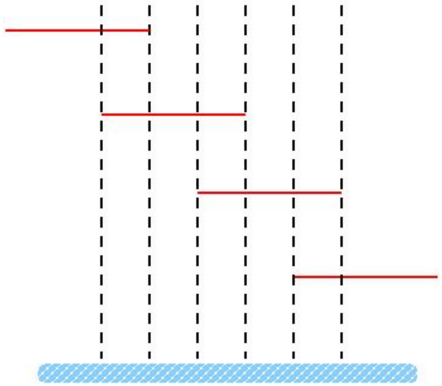
PHOTON TAGGER



- By the conservation of energy:

  $E_\gamma = E_e - E_{e'}$

- *384 energy counters +*
  61 timing counters.
- The energy counters are 1/3 overlapping.



- This means we have effectively doubled the number of channels to ~ ***768 energy bins***

- Because the hodoscope spans the energy region $0.20 \leq E_{e'} \leq 0.95E_0$ this implies that

  Photon energy resolution is 0.1% of the incident electron energy, E_0 !

Tagged and Collimated $\vec{\gamma}$ beam on target

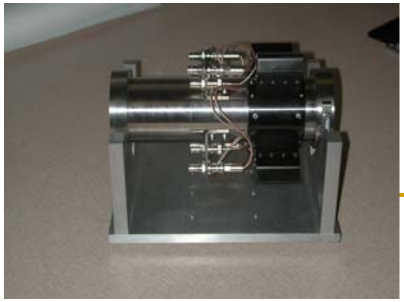
Photon Polarization

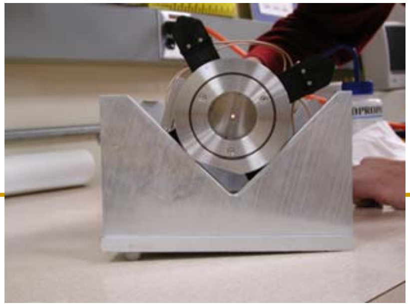
exceeds 90% in the peak

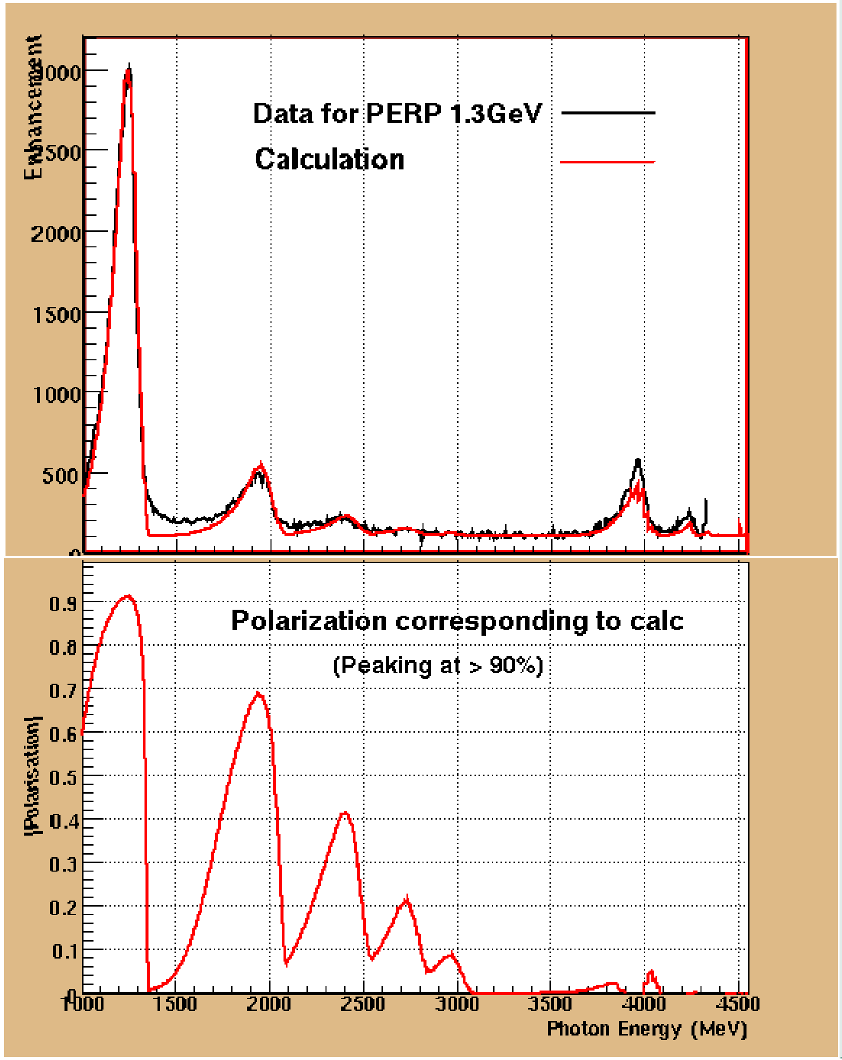
Tightly and Actively Collimated:

~½ of a characteristic angle

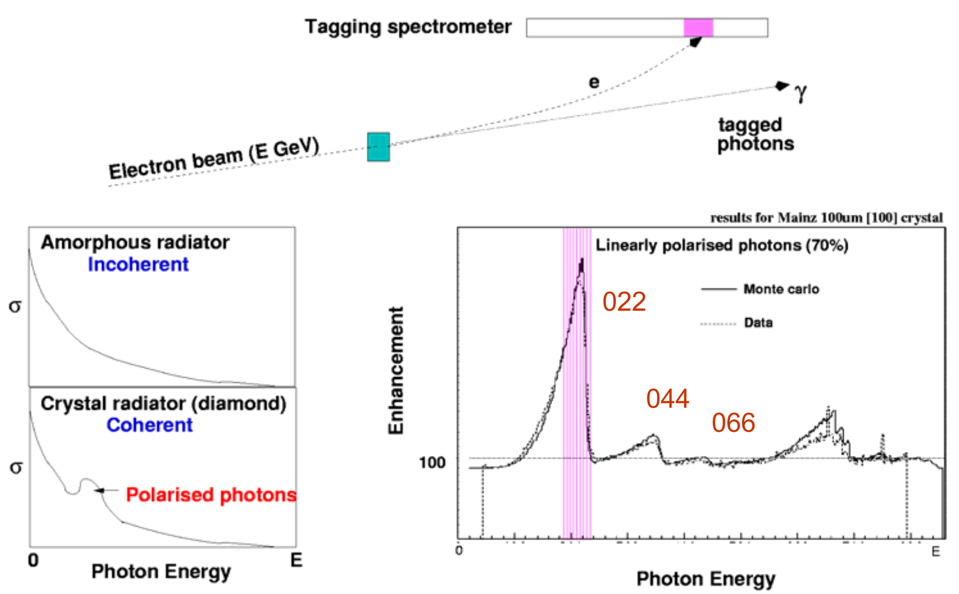
(Collimator subtends 44 μradians)





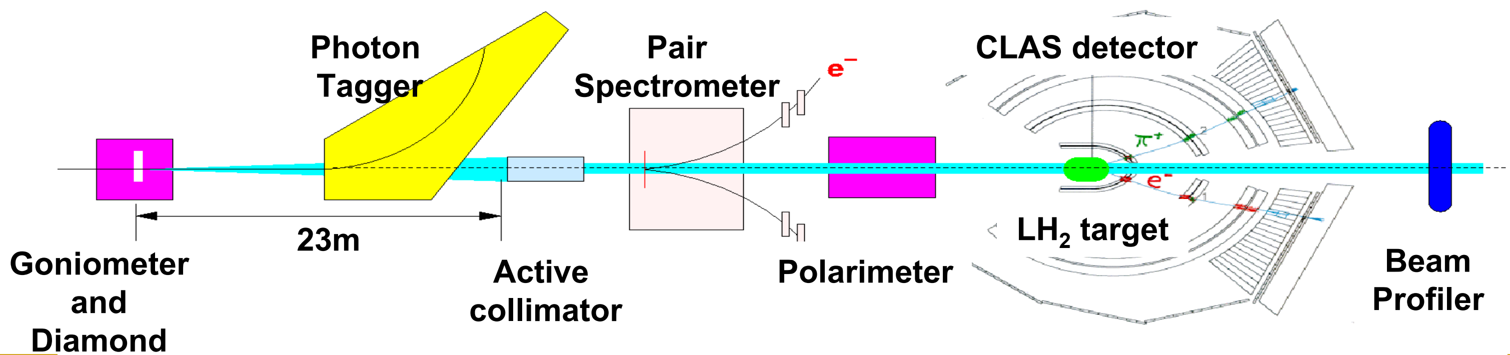


The coherent bremsstrahlung facility at CLAS



Requirements for coherent brem

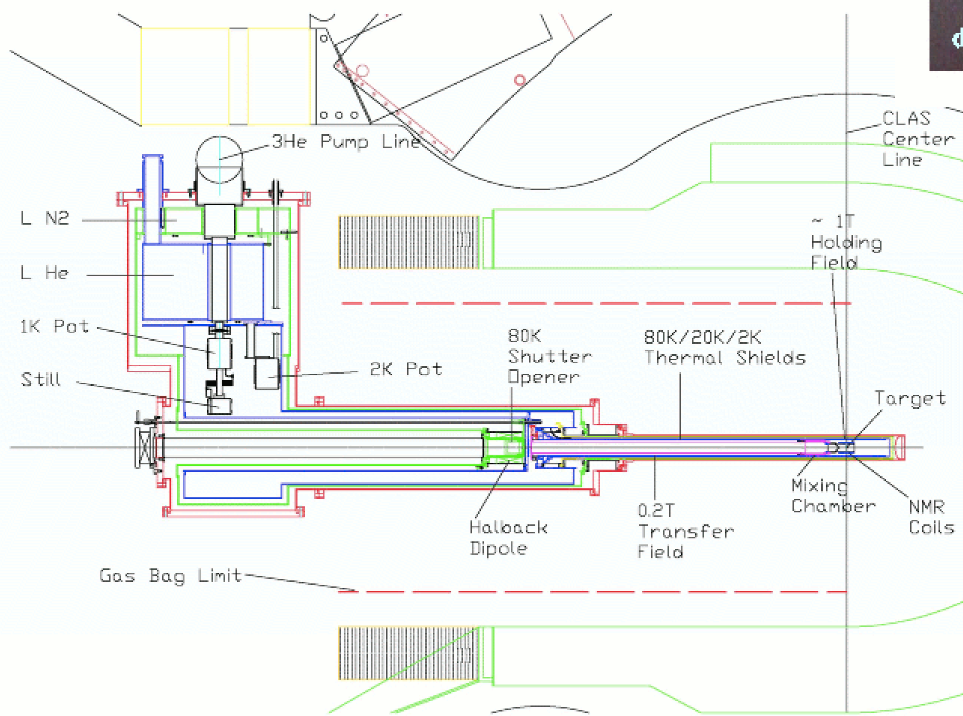
- ❑ Low emittance, stable beam
- ❑ High quality thin crystal
- ❑ Collimation < 0.5 characteristic angle
- ❑ Polarimetry



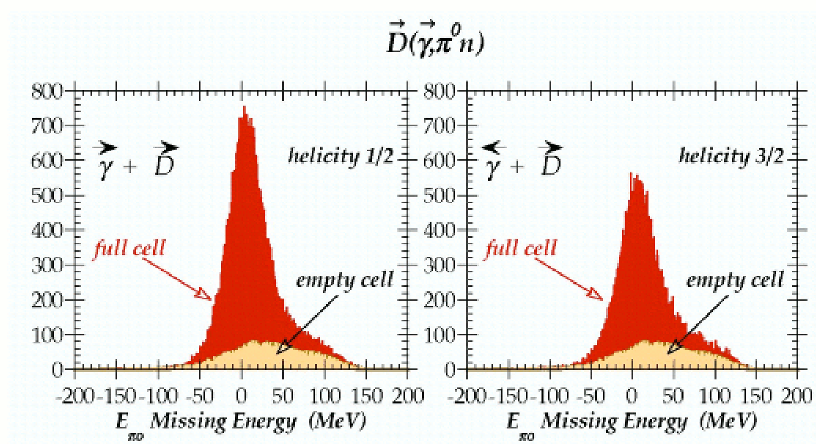
target

target: Ø25mm x 50mm
3g of solid H-D composite
density: 0.147 g/cm^3
2050 cooling wires (Al) Ø50μm
P_V(D)~40%, P(H)~40% or
P_V(D)~0%, P(H)~80%

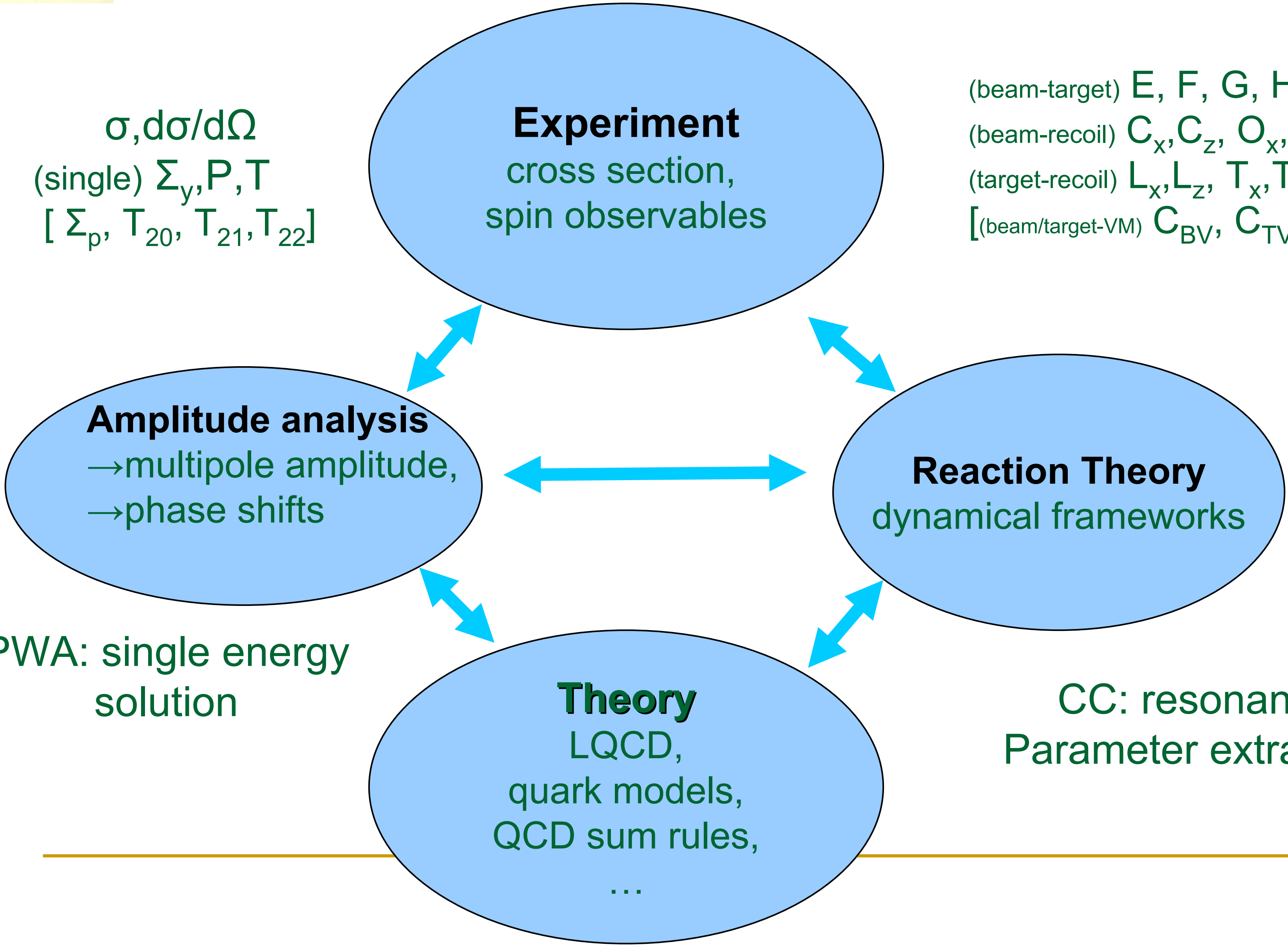
In-Beam-Cryostat for CLAS



additional empty cell downstream:
subtraction of Al background



Experiment and Theory



$\sigma, d\sigma/d\Omega$

(single) Σ_y, P, T

[Σ_p, T_{20}, T_{21}, T_{22}]

(beam-target) E, F, G, H,

(beam-recoil) C_x, C_z, O_x, O_z,

(target-recoil) L_x, L_z, T_x, T_z,

[(beam/target-VM) C_{BV}, C_{TV}, C_{BTV}]

PWA: single energy solution

CC: resonance Parameter extraction

Coupled-channels picture of resonance excitation

$$\gamma N \to N^* \to \begin{cases} \pi N \\ \pi\pi N \\ \eta N \\ K\Lambda \\ K\Sigma \end{cases}$$

The *same* N* resonance must be found in *different* reaction channels in a consistent way!

T=

$T_{\pi N\to\pi N}$	$T_{\eta N\to\pi N}$	$T_{\gamma N\to\pi N}$	$T_{\rho N\to\pi N}$	$T_{\sigma N\to\pi N}$	$T_{K\Lambda\to\pi N}$	$T_{K\Sigma\to\pi N}$
$T_{\pi N\to\eta N}$	$T_{\eta N\to\eta N}$	$T_{\gamma N->\eta N}$	$T_{\rho N\to\eta N}$	$T_{\sigma N\to\eta N}$	$T_{K\Lambda\to\eta N}$	$T_{K\Sigma\to\eta N}$
$T_{\pi N\to\gamma N}$	$T_{\eta N\to\gamma N}$	$T_{\gamma N\to\gamma N}$	$T_{\rho N\to\gamma N}$	$T_{\sigma N\to\gamma N}$	$T_{K\Lambda\to\gamma N}$	$T_{K\Sigma->\gamma N}$
$T_{\pi N\to\rho N}$	$T_{\eta N\to\rho N}$	$T_{\gamma N\to\rho N}$	$T_{\rho N\to\rho N}$	$T_{\sigma N\to\rho N}$	$T_{K\Lambda\to\rho N}$	$T_{K\Sigma\to\rho N}$
$T_{\pi N\to\sigma N}$	$T_{\eta N\to\sigma N}$	$T_{\gamma N\to\sigma N}$	$T_{\rho N\to\sigma N}$	$T_{\sigma N\to\sigma N}$	$T_{K\Lambda\to\sigma N}$	$T_{K\Sigma\to\sigma N}$
$T_{\pi N\to K\Lambda}$	$T_{\eta N\to K\Lambda}$	$T_{\gamma N\to K\Lambda}$	$T_{\rho N\to K\Lambda}$	$T_{\sigma N\to K\Lambda}$	$T_{K\Lambda\to K\Lambda}$	$T_{K\Sigma\to K\Lambda}$
$T_{\pi N\to K\Sigma}$	$T_{\eta N\to K\Sigma}$	$T_{\gamma N\to K\Sigma}$	$T_{\rho N\to K\Sigma}$	$T_{\sigma N\to K\Sigma}$	$T_{K\Lambda\to K\Sigma}$	$T_{K\Sigma\to K\Sigma}$

Outlook

- complete (over-)determination of KΛ amplitude
- almost complete sets for πN, ππN, KΣ, … ηp, ωN

  g8b ran in the summer of 2005

  g13 is running right now

  FROST program to run in late 2007

  HD program ready to run in 2009

Data collected under common conditions

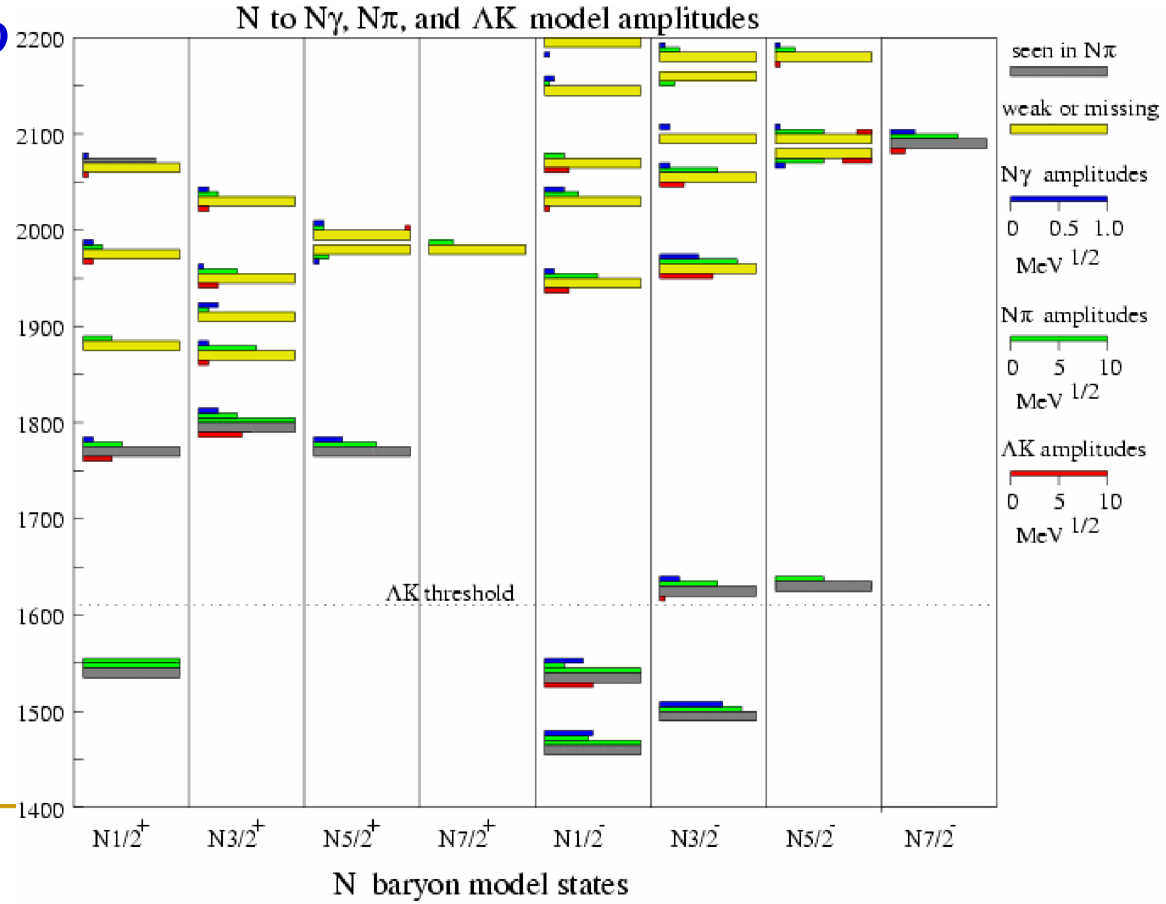
common systematics

consistent analyses (CC):

- extract parameters for "known" resonances
- potential to find any "missing" resonance

↓

reveal a rich new spectroscopy



Extra Slides

Thanks to

- Ken Livingston (g8b)
- Stepan Stepanyan (g10)
- Pawel Nadel-Turonski (g13)
- Franz Klein (FROST + HD)

for providing me their slides