DETERMINATION OF THE LINEAR POLARIZATION FOR THE HALL-B PHOTON BEAM AT JLAB

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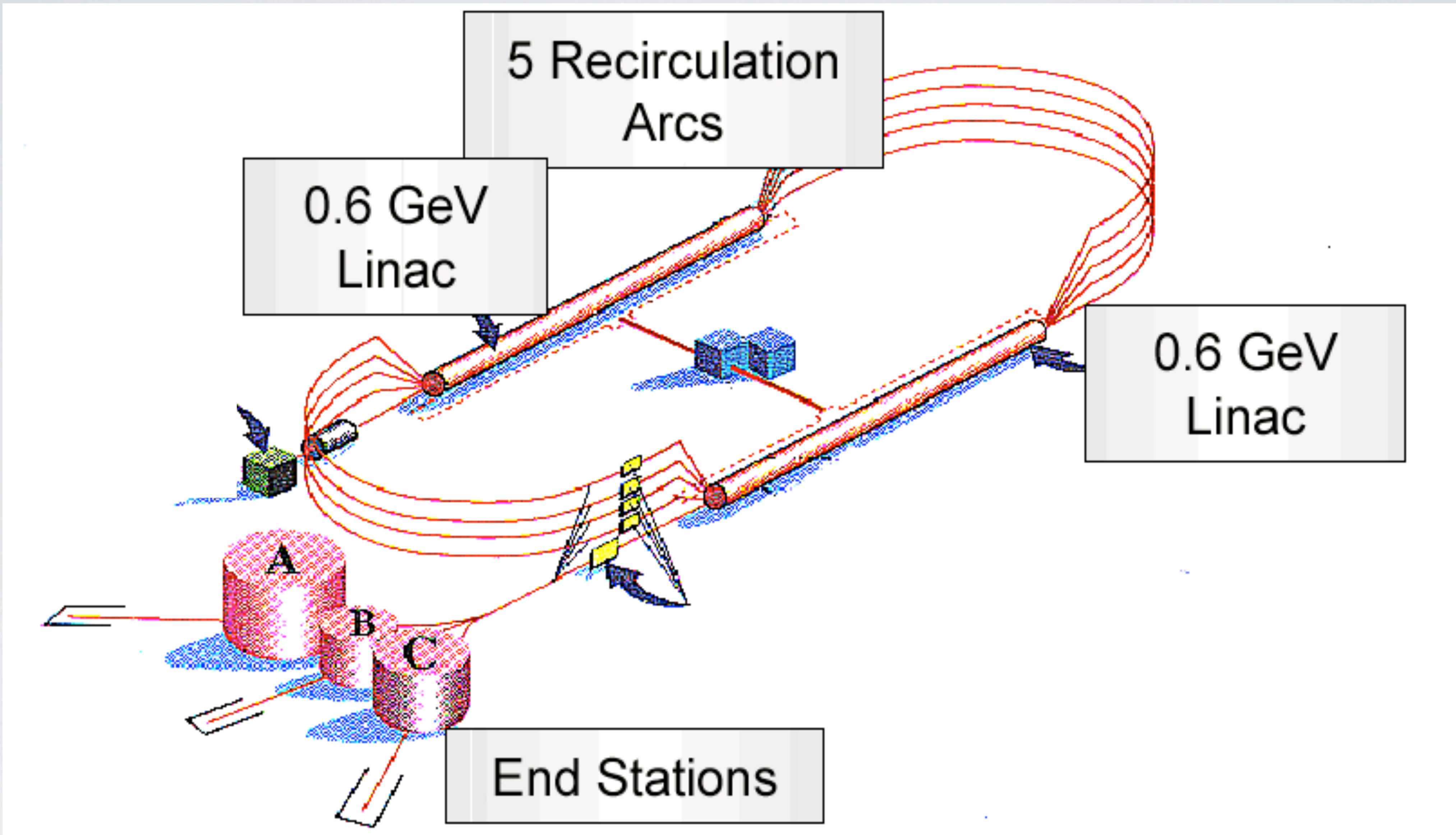
HALL-B AT JEFFERSON LAB

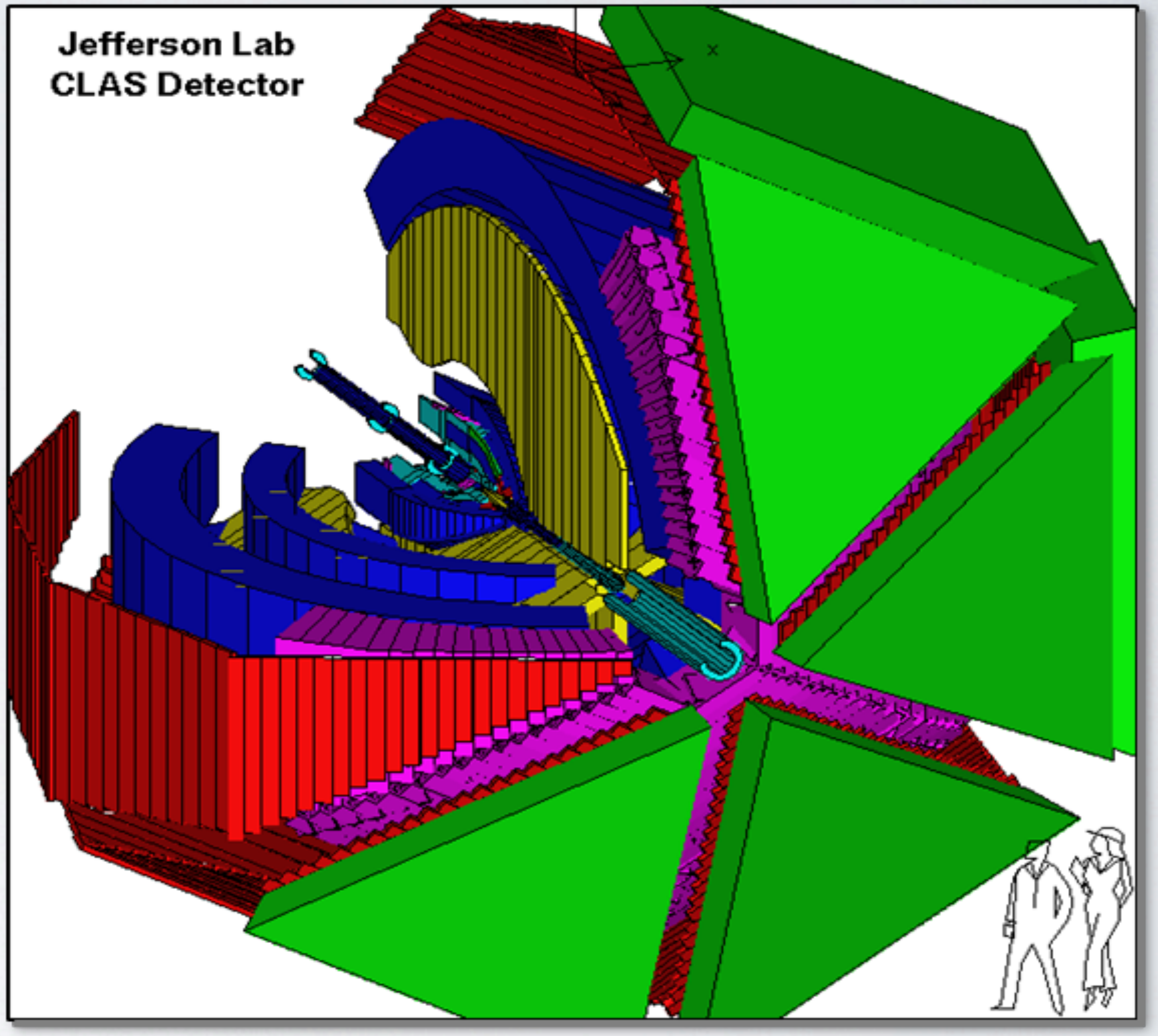


Accelerator Energy = 6 GeV
Maximum Current = 200 μA
Duty Factor ~ 100%
$\sigma E/E = 2.5 \cdot 10^{-5}$

Beam Polarization $\geq$ 80%
Tagged γ Energy = 0.5-5.8 GeV
$E_\gamma = 0.20 E_0$ to $0.95 E_0$

CLAS
CEBAF LARGE ACCEPTANCE SPECTROMETER

- Green = Electromagnetic Calorimeters
  - 1296 PMTs
- Red = Time of Flight Counters
  - Plastic Scintillators
  - 684 PMTs
- Purple = Gas Cherenkov Counters
  - Electron/Pion Separation
  - 256 PMTs
- Blue = Drift Chambers
  - 35,000 cells filled with Argon/CO_2
- Yellow = Torus Magnet
  - 6 Superconducting Coils
- Large aperture for detecting scattered particles (0.75•4π)



Courtesy of Eugene Pasyuk

FROST WITH CLAS

- FROST = **FRO**zen **S**pin **T**arget
  - Polarized scattering experiments w/a nuclear-spin polarized target
    - Designed for tagged photon experiments
    - Circular and linear polarized photon beam: **0.5 - 2.4 GeV**
    - Longitudinally polarized target (g9a)
  - Three targets: **Butanol**, **Carbon (^{12}C)**, & **Polyethylene (CH_2)**
  - **Butanol** target (15mm x 50mm) is frozen at 30 mK
  - Run Time: Nov. 3, 2007 - February 12, 2008

FROST - TOTAL EVENTS

Linearly polarized beam

0.7 GeV	300M triggers
0.9 GeV	500M triggers
1.1 GeV	500M triggers
1.3 GeV	600M triggers
1.5 GeV	600M triggers
1.7 GeV	850M triggers
1.9 GeV	720M triggers
2.1 GeV	800M triggers
2.3 GeV	780M triggers

Circularly polarized beam

E_0=1.645 GeV	1.1B triggers
E_0=2.478 GeV	2.3B triggers

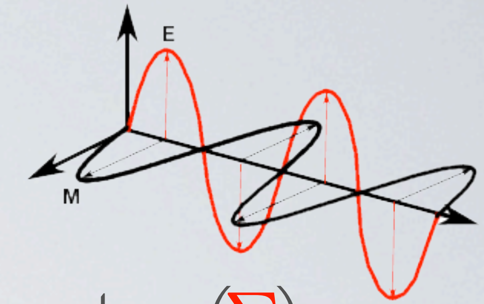
Total

10 Billion Triggers

Trigger

Charged Particle

FROST - LINEAR POLARIZATION



❖FROST uses **Linear** and **Circular** beam polarization.

❖We use the polarization (P) to calculate the photon beam asymmetry (Σ)

❖Differential cross section (for Polarized Beam): $\frac{d\sigma}{d\Omega} = \frac{d\sigma_0(\theta)}{d\Omega}[1 - P\Sigma\cos(2\phi)]$

❖Photon Beam Asymmetry: $\Sigma = \frac{d\sigma_{\parallel} - d\sigma_{\perp}}{d\sigma_{\parallel} + d\sigma_{\perp}}$

$$
\begin{aligned}
\rho_f \frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{unpol} \{ 1 - & P_\gamma^{lin}\Sigma\cos 2\phi + P_x(P_\gamma^{circ}F + P_\gamma^{lin}H\sin 2\phi) \\
& + P_y(T - P_\gamma^{lin}P\cos 2\phi) + P_z(P_\gamma^{circ}E + P_\gamma^{lin}G\sin 2\phi) \\
& + \sigma'_x[P_\gamma^{circ}C_x + P_\gamma^{lin}O_x\sin 2\phi + P_x(T_x - P_\gamma^{lin}L_z\cos 2\phi) \\
& \quad + P_y(P_\gamma^{lin}C_z\sin 2\phi - P_\gamma^{circ}O_z) + P_z(L_x + P_\gamma^{lin}T_z\cos 2\phi] \\
& + \sigma'_y[P + P_\gamma^{lin}T\cos 2\phi + P_x(P_\gamma^{circ}G - P_\gamma^{lin}E\sin 2\phi) \\
& \quad + P_y(\Sigma - P_\gamma^{lin}\cos 2\phi) + P_z(P_\gamma^{lin}F\sin 2\phi + P_\gamma^{circ}H)] \\
& + \sigma'_z[P_\gamma^{circ}C_z + P_\gamma^{lin}O_z\sin 2\phi + P_x(T_z + P_\gamma^{lin}L_x\cos 2\phi) \\
& \quad + P_y(- P_\gamma^{lin}C_x\sin 2\phi - P_\gamma^{circ}O_z) + P_z(L_z + P_\gamma^{lin}T_x\cos 2\phi)]\}
\end{aligned}
$$

[Barker, Donnachie & Storrow. Nuclear Physics B95 (1975)]

16 Observables (in Red)

➡1 Unpolarized Observable
➡3 Single Polarized Observables
➡3 Beam-Target Polarized Observables
➡3 Target-Recoil Polarized Observables
➡3 Beam-Recoil Polarized Observables

Courtesy of Ken Livingston

FROST - THE EXPERIMENTS

- ❖E02-112 $\gamma p \rightarrow KY(K^+\Lambda, K^+\Sigma^0, K^0\Sigma^0)$ P. Euginio, F. J. Klein, L. Todor
- ❖E03-105/E04-102 $\gamma p \rightarrow \pi^0 p, \pi^+ n$ N. Benmouna, W.J. Briscoe, D.G. Crabb, M. Khandaker, G.V. O'Rielly, I. Strakovsky, S. Strauch, D.I. Sober
- ❖E05-012 $\gamma p \rightarrow \eta p, \eta' p$ M. Dugger, E. Pasyuk
- ❖E06-013 $\gamma p \rightarrow \pi^+\pi^- p$ M. Bellis, V. Crede, S. Strauch

Photon	Target			
	–	–	–	–
	–	x	y	z
unpolarized	σ_0	0	T	0
linear pol.	$-\Sigma$	H	(-P)	$-G$
circular pol.	0	F	0	$-E$

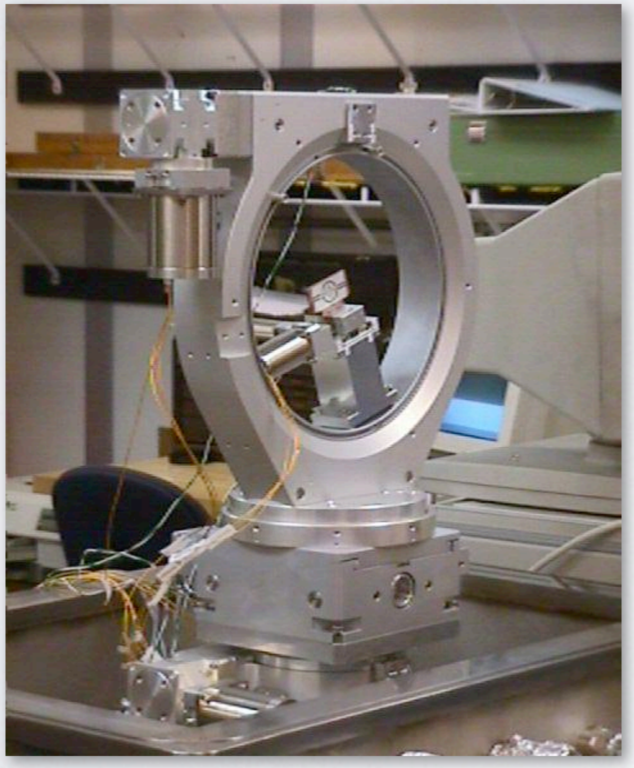
Observables for FROST

COHERENT BREMSSTRAHLUNG

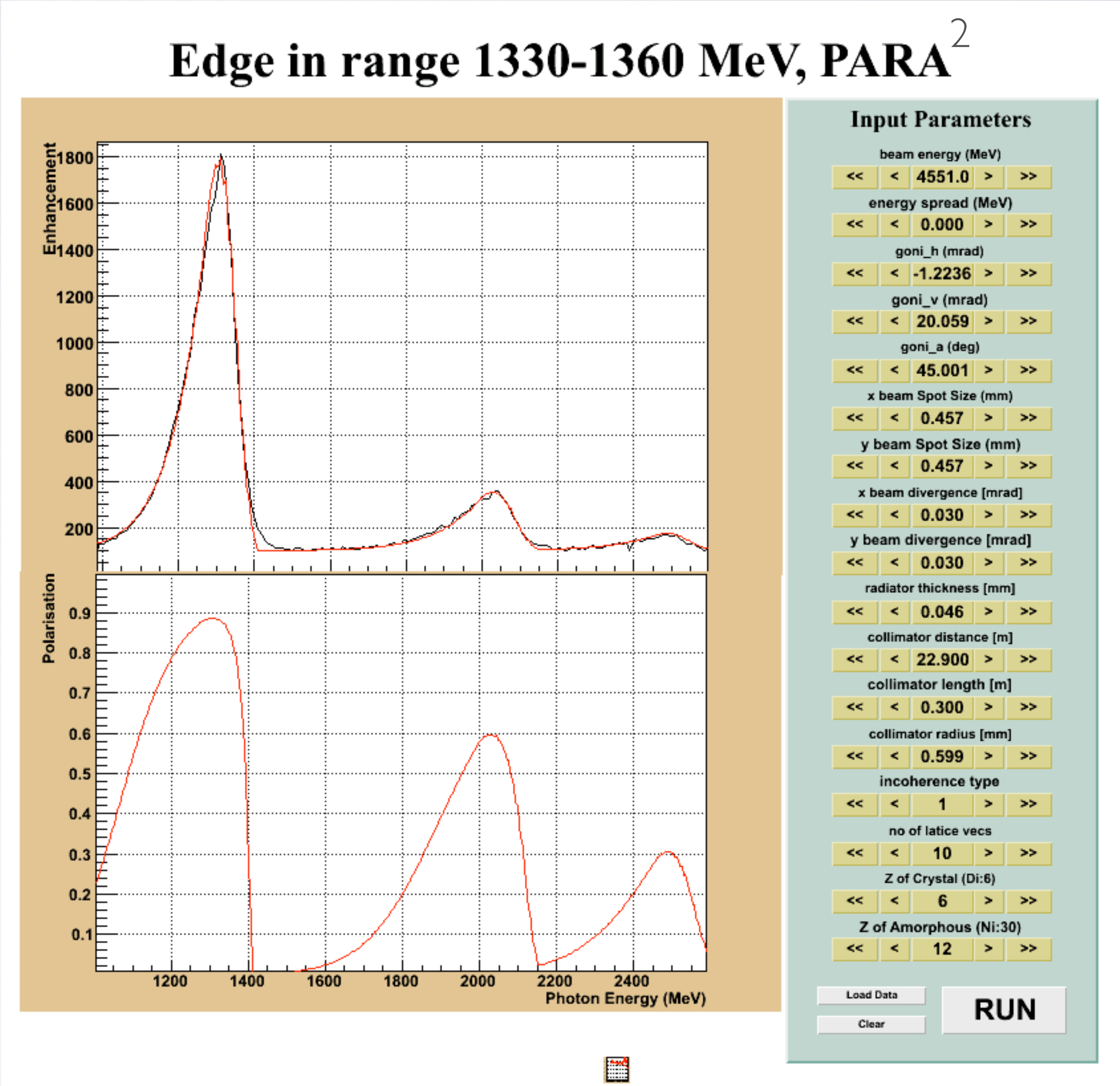
❖**Definition:** Electrons incident on an oriented diamond radiator yield an enhancement in the photon energy spectrum with respect to the amorphous radiator.[1]

❖Position of the peak depends on the angle between the crystal planes of the diamond and the energy of the electron beam bombarding the diamond.

❖Energy flux that is incident on the diamond causes the position of the peak to waver slightly. (see slide 12)



Diamond inside the Goniometer



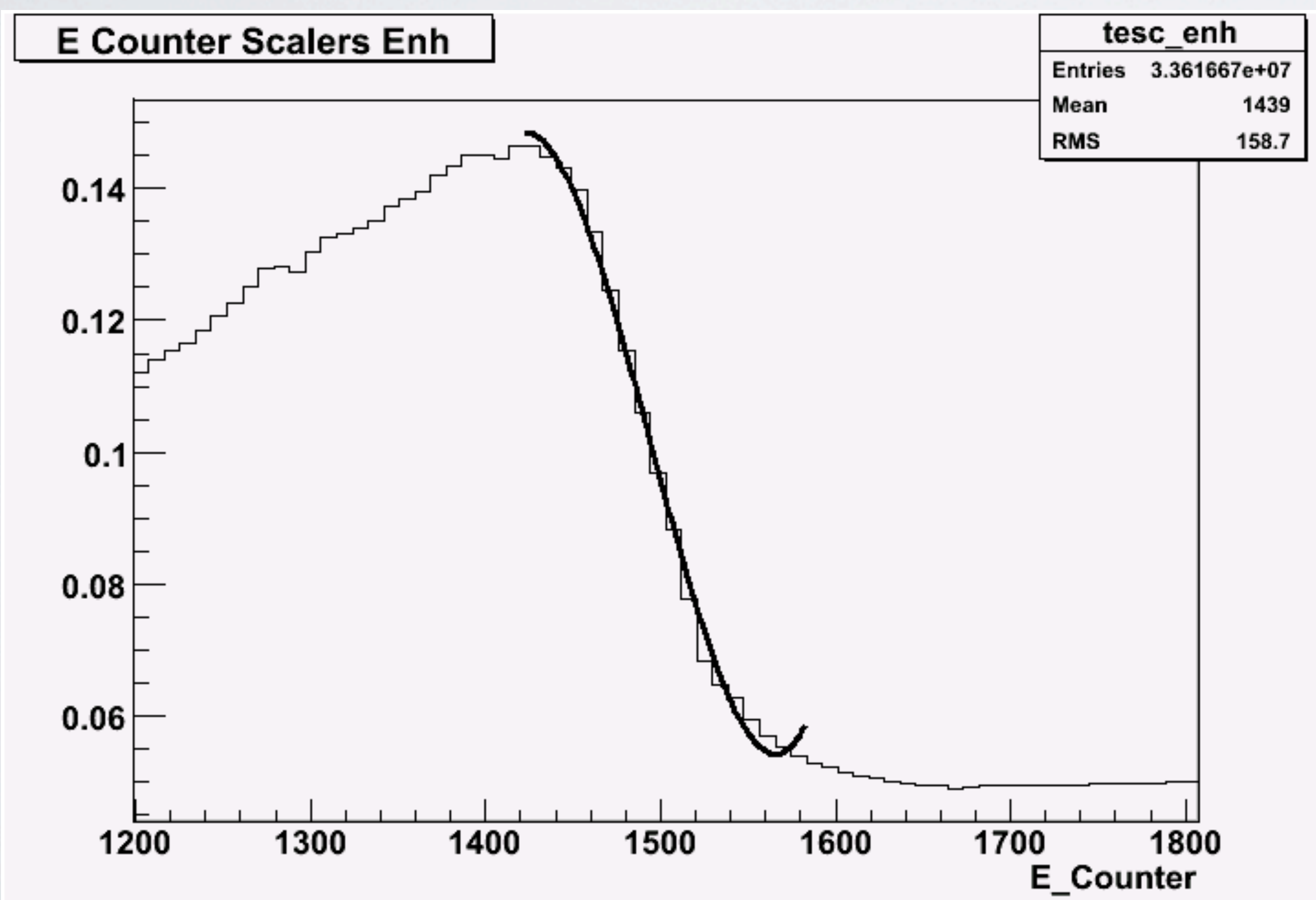
[1] U. Timm, "Coherent Bremsstrahlung of Electrons in Crystals". Fortschritte der Physik **17**, 765 (1969)
[2] A. Natter, *et al.*,"Monte Carlo simulation and analytical calculation of coherent bremsstrahlung and its polarisation". Nuc. Inst Meth B. **211**, 465 (2003)

COHERENT BREMSSTRAHLUNG

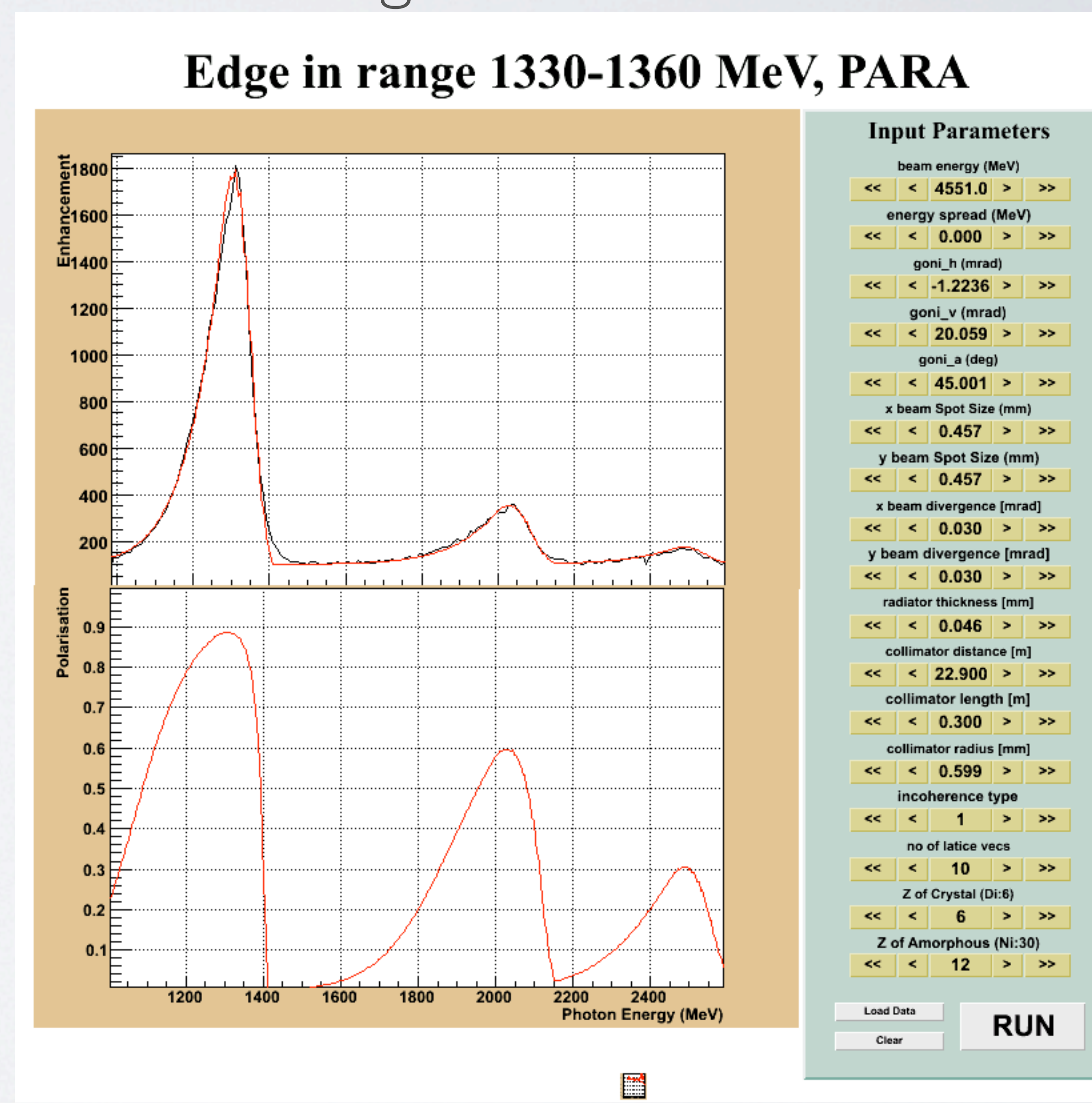
- **Coherent Peak:** Peak with the highest negative gradient. The highest degree of polarization is observed here.

- **Coherent Edge:** Tailing slope of a coherent peak.

- **Tagged photon experiments** allow us to determine the photon energy to the degree of polarization via Coherent Bremsstrahlung.



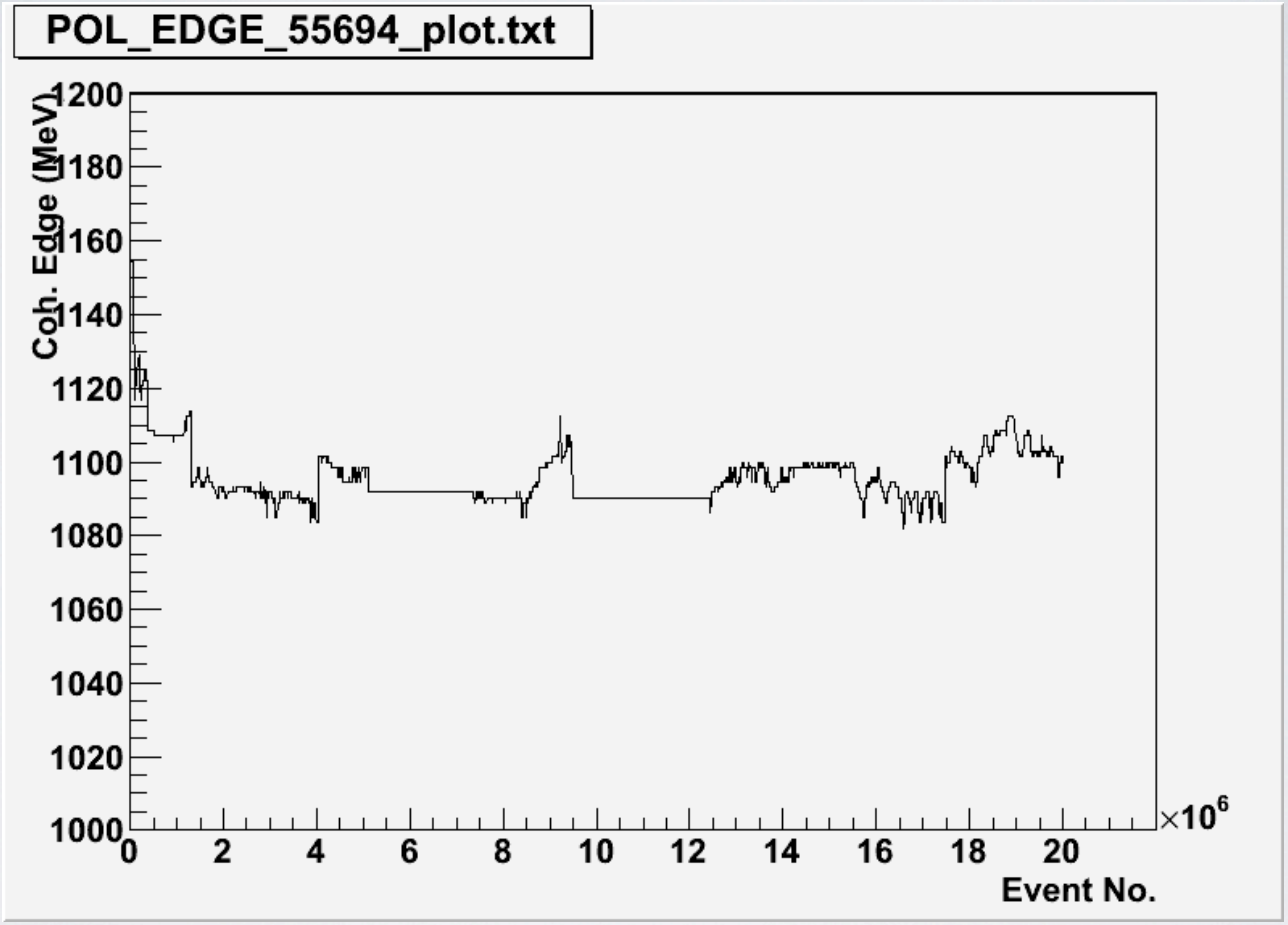
The Coherent Peak & Edge



HOW TO: DETERMINATION OF THE POLARIZATION

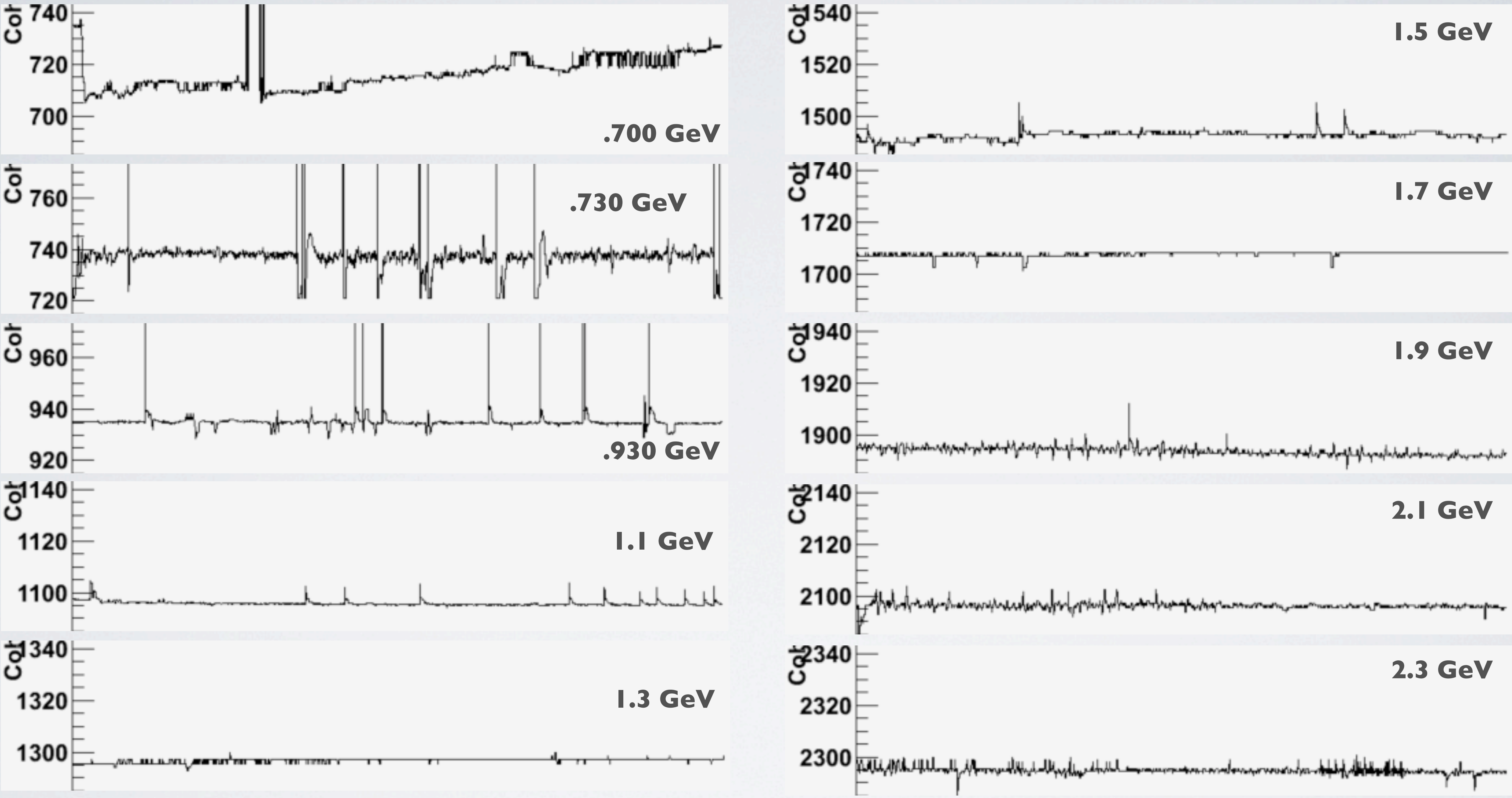
- **Overall Goal**
  - Analyze data from the photon tagger and produce a set of run tables relating the photon energy to the degree of linear polarization (g9a/FROST).
  - Create a software package that is modular; can be used in future JLab experiments performed in Hall-B (e.g. g9b/FROST)
- **Execution**
  - Created a suite of software tools that extract the linear polarization data and produce enhancement plots for the analytic bremsstrahlung calculation.
    - **Enhancement Plots:**
      - Visual delineation of the coherent peak of the linear polarization and its energy fluctuations.
      - Used to produce the photon energy vs. polarization tables via Analytic Bremsstrahlung calculations.

ENERGY vs. TIME (SAMPLE)



Parallel Polarization of Diamond Radiator @ 1.1 GeV

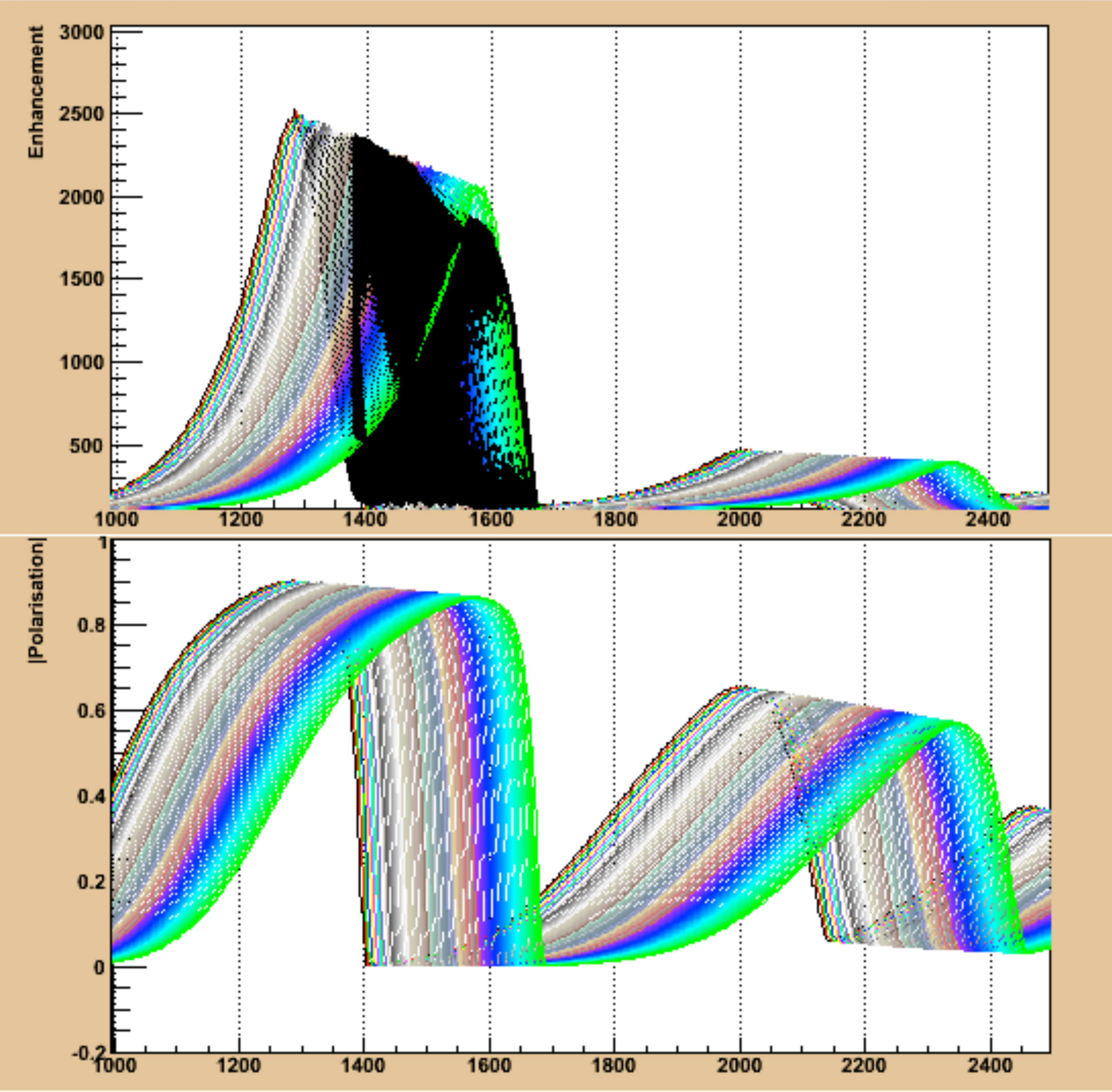
ENERGY vs. TIME - COMPARISON



As we increase the energy, we increase the goniometer angle.
At large angles, the photon beam is less prone to energy fluctuations.

All plots are available at:
http://nuclear.gla.ac.uk/~arthurs/polPlot/

COHERENT EDGE VARIATION

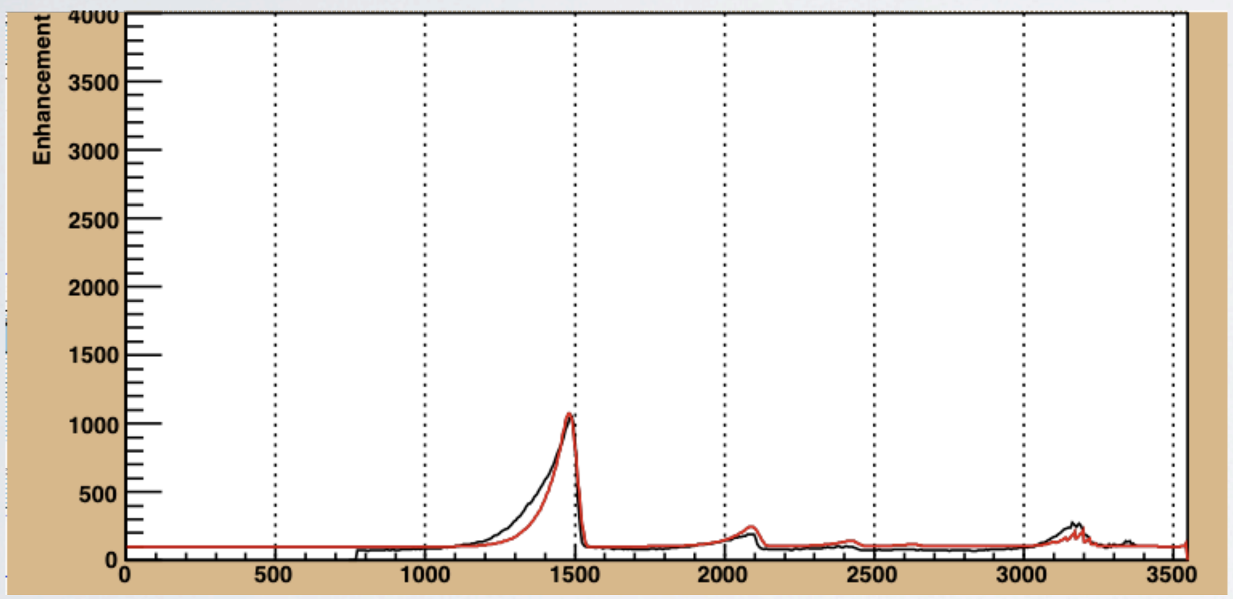


Different photon energy vs. linear polarization tables produced for each energy setting due to the variations of the coherent edge

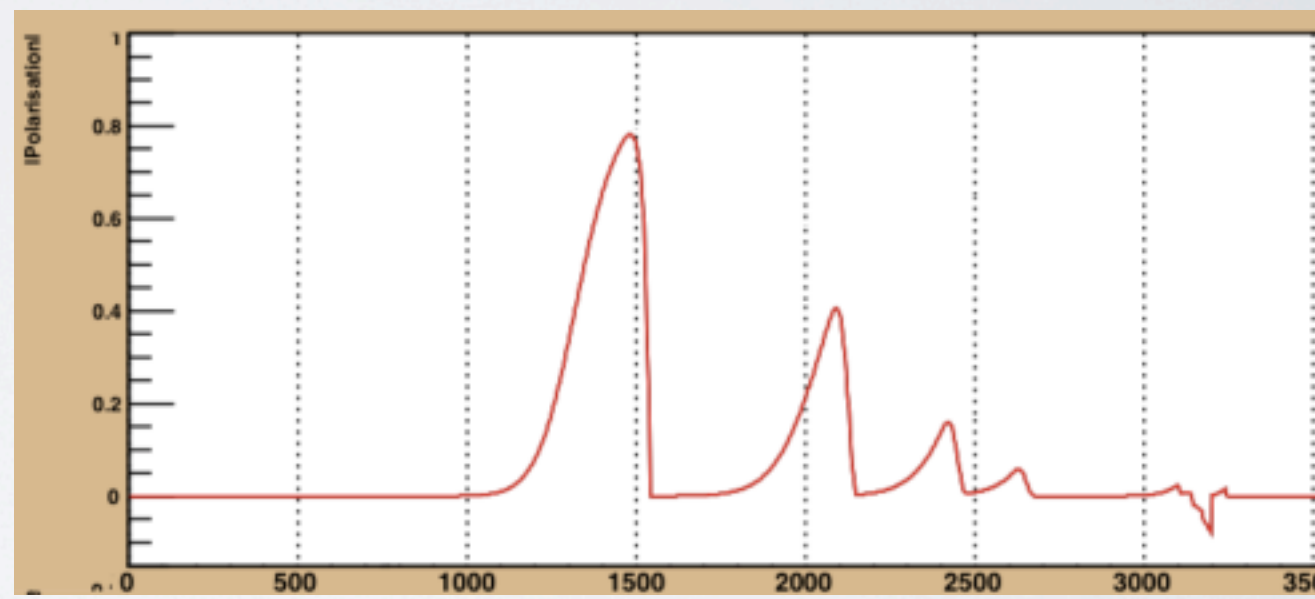
ANB CALCULATION

- **Analytic Bremsstrahlung**[1] is software that compares the enhancement plot that is generated from the run-data to a theoretical bremsstrahlung calculation.

Analytic Bremsstrahlung Calculation for 1.5 GeV



Enhancement vs. Energy



Polarization vs. Energy

Black Line = Experimental Determination
Red Line = Theoretical Calculation Generated By Analytic Bremsstrahlung

[1] A. Natter, *et al.*,"Monte Carlo simulation and analytical calculation of coherent bremsstrahlung and its polarisation". Nuc. Inst Meth B. **211**, 465 (2003)

WHAT'S NEXT?

- ★ Finish the analytic bremsstrahlung calculations
- ★ Produce a software manual for the determination of the linear polarization.
- ★ Submit manual as internal report (JLab CLAS Note)

THANK YOU!

THE GEORGE WASHINGTON UNIVERSITY WASHINGTON DC

CNS Center for Nuclear Studies

Jefferson Lab

University of Glasgow

POLARIZATION OBSERVABLES

- 4 Complex Invariant Amplitudes/Helicities $|b_i|^2$
- Complete measurement from 8 Polarization Observables

Observable	Polarization[a] of γ	Polarization[a] of p	Polarization[a] of Λ	
1. $\{d\sigma/d\Omega\}/\mathcal{N}$				$=\lvert b_1\rvert^2+\lvert b_2\rvert^2+\lvert b_3\rvert^2+\lvert b_4\rvert^2$
Single polarization				
2. $P\cdot\{d\sigma/d\Omega\}/\mathcal{N}$			y'	$=\lvert b_1\rvert^2-\lvert b_2\rvert^2+\lvert b_3\rvert^2-\lvert b_4\rvert^2$
3. $\Sigma\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	p			$=\lvert b_1\rvert^2+\lvert b_2\rvert^2-\lvert b_3\rvert^2-\lvert b_4\rvert^2$
4. $T\cdot\{d\sigma/d\Omega\}/\mathcal{N}$		y		$=\lvert b_1\rvert^2-\lvert b_2\rvert^2-\lvert b_3\rvert^2+\lvert b_4\rvert^2$
Double polarizaton				
Beam-target				
5. $E\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	c	z		$=2\,\mathrm{Re}(b_1b_3^*+b_2b_4^*)$
6. $F\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	c	x		$=2\,\mathrm{Im}(b_1b_3^*-b_2b_4^*)$
7. $G\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	t	z		$=2\,\mathrm{Im}(b_1b_3^*+b_2b_4^*)$
8. $H\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	t	x		$=-2\,\mathrm{Re}(b_1b_3^*+b_2b_4^*)$
Beam-recoil				
9. $C_x\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	c		x'	$=-2\,\mathrm{Im}(b_1b_4^*-b_2b_3^*)$
10. $C_y\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	c		z'	$=2\,\mathrm{Re}(b_1b_4^*+b_2b_3^*)$
11. $O_x\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	t		x'	$=2\,\mathrm{Re}(b_1b_4^*-b_2b_3^*)$
12. $O_z\cdot\{d\sigma/d\Omega\}/\mathcal{N}$	t		z'	$=2\,\mathrm{Im}(b_1b_4^*+b_2b_3^*)$
Target-recoil				
13. $T_x\cdot\{d\sigma/d\Omega\}/\mathcal{N}$		x	x'	$=2\,\mathrm{Re}(b_1b_2^*-b_3b_4^*)$
14. $T_z\cdot\{d\sigma/d\Omega\}/\mathcal{N}$		x	z'	$=2\,\mathrm{Im}(b_1b_2^*-b_3b_4^*)$
15. $L_x\cdot\{d\sigma/d\Omega\}/\mathcal{N}$		z	x'	$=-2\,\mathrm{Im}(b_1b_2^*+b_3b_4^*)$
16. $L_z\cdot\{d\sigma/d\Omega\}/\mathcal{N}$		z	z'	$=2\,\mathrm{Re}(b_1b_2^*+b_3b_4^*)$

[Barker, Donnachie & Storrow. Nuclear Physics B95 (1975)]