A Compton Polarimeter for Hall C

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Overview

Compton polarimetry:

Scatter circularly-polarized laser photons off longitudinally-polarized electrons.

Differential Cross Section:

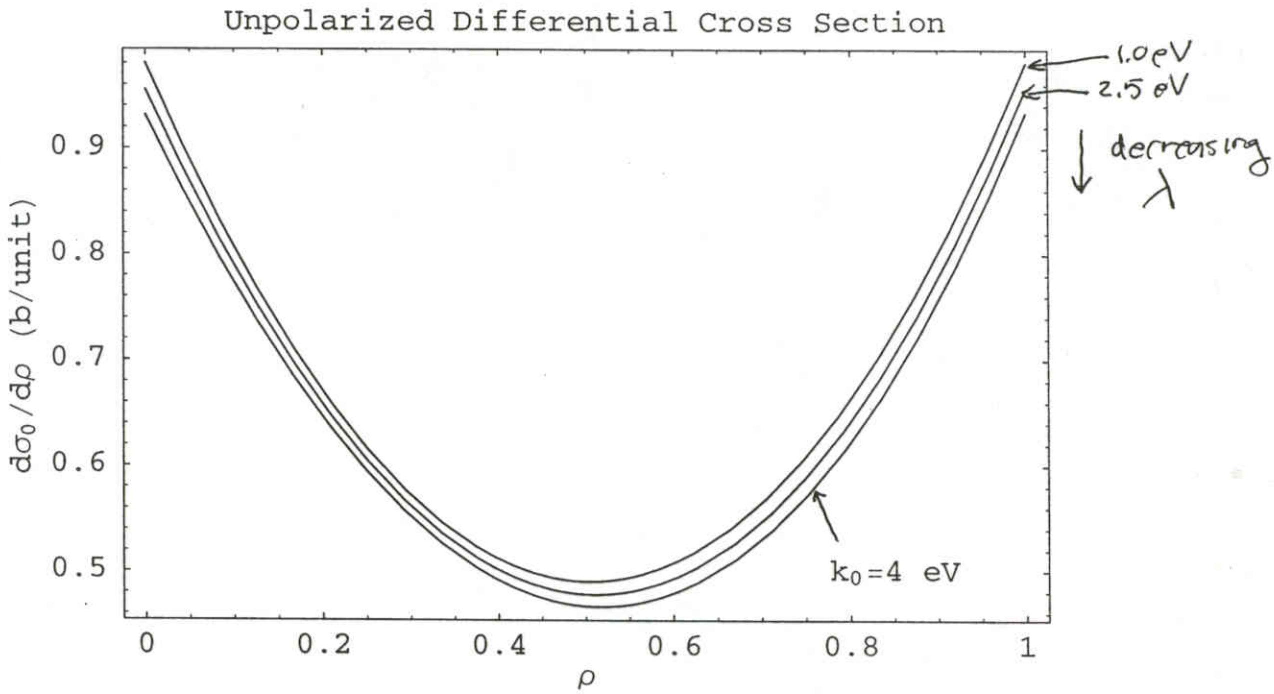
$$\frac{d\sigma}{dk} = \frac{d\sigma_0}{dk}\left(1 + P_\gamma P_e A_l(k)\right)$$

- k= backscattered photon energy
- P_γ = laser light polarization,
- P_e = electron beam polarization.

Asymmetry:

$$A_l = \frac{2\pi r_e^2 a}{k_{max}\frac{d\sigma_0}{dk}}\left(1 - \rho(1+a)\right)\left[1 - \frac{1}{(1-\rho(1-a))^2}\right]$$

- k_{max}= maximum backscattered photon energy
- $\rho = k/k_{max}$
- r_e = classical radius of electron
- a depends on laser photon and electron beam energies.



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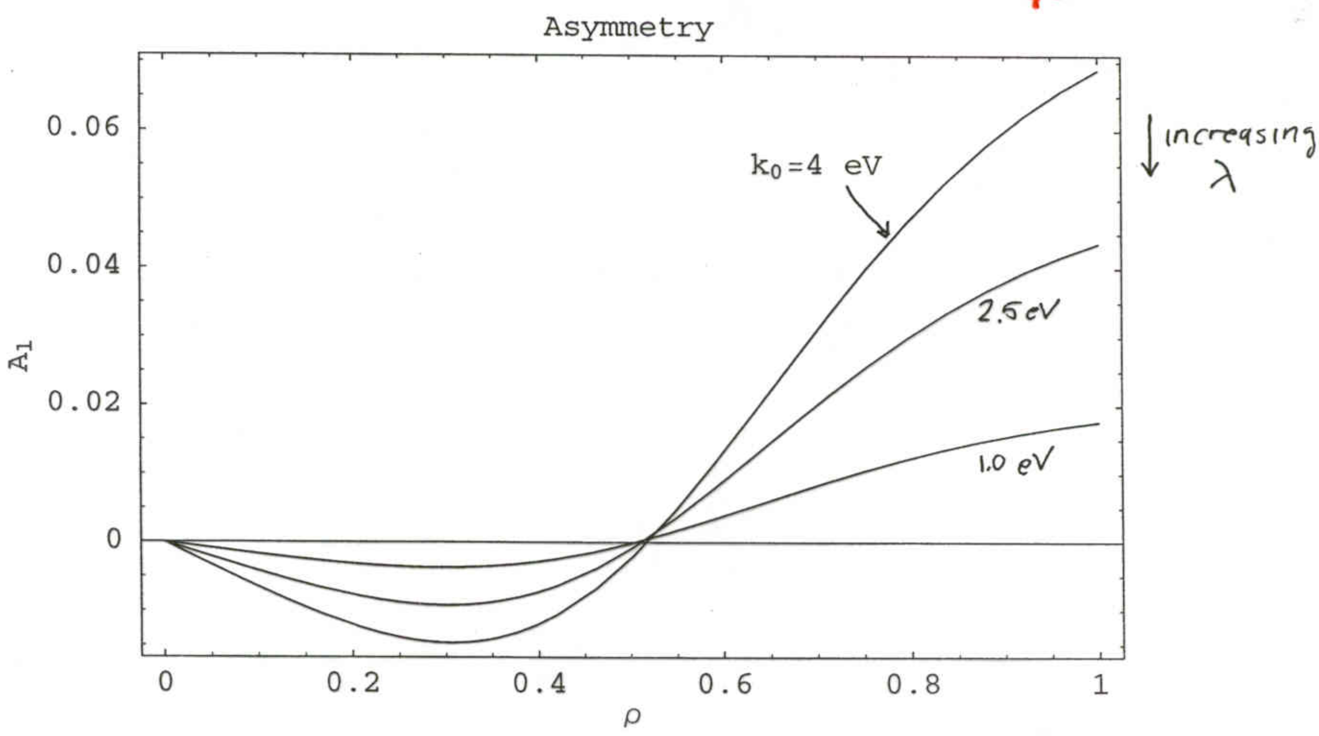
$E_e = 1.165$ GeV



Overview (cont.)

Maximum Luminosity:

$$\mathcal{L}_{max} = \frac{I_e P_\gamma}{e k_0 c} \frac{1}{\varepsilon_e + \varepsilon_\gamma}$$

- I_e= electron beam current
- P_γ = laser power
- k_0 = laser photon energy
- ε_e= electron beam emittance $\approx 1 \times 10^{-9}$ meter-radian
- ε_γ= laser beam emittance $\geq \lambda/4\pi$.

Non-zero crossing angle α:

$$\mathcal{L} \approx \frac{1 + \cos\alpha}{\sqrt{2\pi}} \frac{I_e P_\gamma}{e k_0 c} \frac{1}{\sqrt{\sigma_e^2 + \sigma_\gamma^2}} \frac{1}{\sin\alpha}$$

- $\sigma_{e,\gamma}$ Gaussian width at beam waist.

Time required for δP_e statistical uncertainty:

$$\Delta t = \frac{1}{\langle A_l \rangle^2 \delta P_e^2 \sigma_{TOT} \mathcal{L}}$$

Design Goals/Constraints

Fit Compton apparatus within Hall C tunnel

- Preserve polarized target capability
- Preserve Møller apparatus

Track electron polarization over time frame of several hours, not several days

- Need high luminosity, large asymmetry

Keep systematic errors to minimum:

- Would like 1%
- At least aim for a few percent a la Hall A
  Cross-calibrate to Hall C Møller polarimeter

Design polarimeter usable for range of electron energies

The Chicane

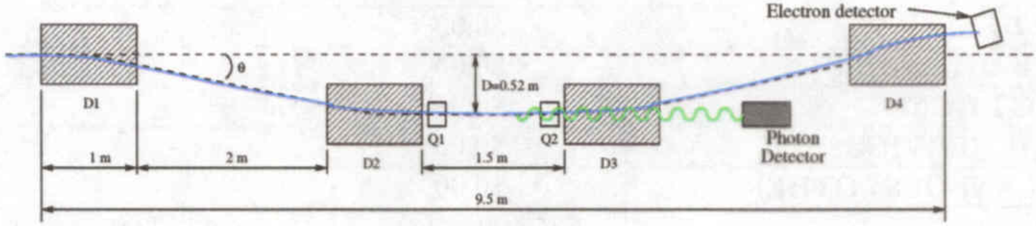
Four dipole design allows detection of backscattered photons.

- Dipole length=1.0 m with 25.4 mm gap
- D1 to D2 (D3 to D4) separation=2 m
- Deflection angle $\theta = 10^\circ$ up to $E_e \approx 2.5$ GeV

  Reduce θ to 2.5° for higher energy – reconfiguration needed!
- laser photon/electron beam interaction region between D2 and D3

Positioned in tunnel downstream of Møller.

- Need about 9.5 m of space...



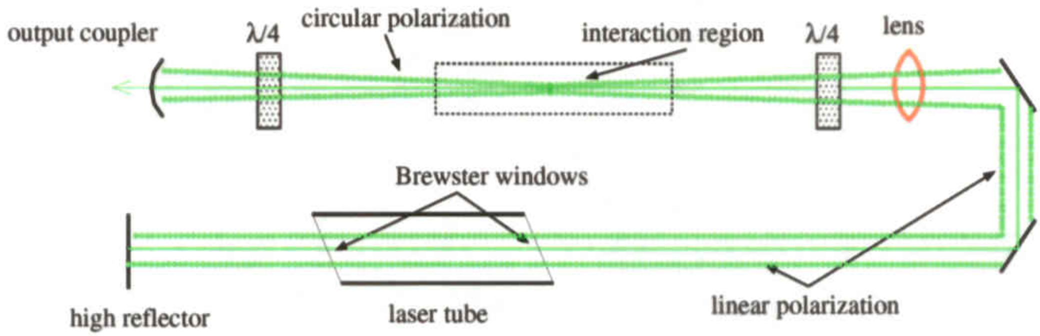
Laser Options

$\langle A_l \rangle$ and k_{max} increase with shorter wavelengths.

- We are considering green (e.g. Argon-Ion) or ultraviolet (e.g. excimer) lasers.

Maximize luminosity:

- Fabry-Perot cavity a la Hall A
- Intra-cavity design a la Mainz ← we currently favor this approach



Method	λ (nm)	Power (Watts)	E_γ^{max} (MeV)	$\int dE\sigma$ (mb)	Rate (KHz)	$\langle A \rangle$ (%)	t (1%) (min)
Hall A	1064	2100	23.7	514	350.4	0.68	16
Ar–Ion	514	10	48.1	501	0.8	1.37	1762
–intra–cavity		200			15.7		225
UV ArF	193	32	119.8	463	0.9	3.36	262
–intra–cavity		640			17.5		13
UV KrF	248	60	95.4	476	2.2	2.69	165
–intra–cavity		640			43.2		8

Table 2: Figure–of–merit comparison of proposed laser options for the Hall C Compton polarimeter, for comparison, the Hall A configuration is also shown. The figure–of–merit is simply the time needed for a 1% (statistical) measurement of the electron beam polarization assuming an 80% polarized beam at 180 μA. Further assumptions include $\sigma_e = \sigma_\gamma = 100\ \mu$m, $E_{e,beam} =$ 1.165 GeV and a crossing angle of 2 degrees between the electron and laser beams.

Photon Detector

Requirements:

- High density, high Z material
- Fast time response
- Good energy resolution
- Radiation-hardness

Some candidates:

Material	τ(ns)	$\rho(g/cm^3)$	N_γ/MeV	X_0(cm)	R_M(cm)
NaI(Tl)	230	3.67	38000	2.6	4.5
CsI(undoped)	16,35?	4.51	2300	1.9	3.8
$Bi_4Ge_3O_{12}$ (BGO)	300	7.13	8200	1.1	2.4
$PbWO_4$	$\sim$5,$\sim$20, $\sim$100,$\sim$1000	8.28	$\sim$500	0.9	2.2

Currently favor $PbWO_4$

- Highest density, smallest radiation length, fast time response, high radiation hardness
- Caveat: low light output

Electron Detector

Scattered electrons are defected more by dipole magnets D3 and D4 than primary beam.

Detector Options:

- Scintillating fibers

  Prototype being built for Mainz Compton Polarimeter

  Concern: radiation-hardness of fibers

- Silicon micro-strips

  Hall A already has such detectors: can we learn from their experience?

Outlook

Design is still in planning stage

- Ideas taking shape
- Exploring manageable number of options

Learn from Mainz experience

- Use their intra-cavity design for laser?

Learn from Hall A experience

- Use their photon/electron detector designs as starting point?

Compton Polarimeter working group

- JLAB, MIT, UConn, Yerevan,...