POLARIMETRY FOR SUPER*B**

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Abstract

We provide an overview description of a Compton polarimeter for measuring electron beam polarization near the IR in the Low Energy Ring of Super*B*. The polarimeter is designed to achieve 1.0% accuracy.

OVERVIEW

The physics program at Super*B*[1] will benefit from precise polarimetry with < 1.0% accuracy. The polarization measurement will be performed using a Compton polarimeter. An accuracy of ($\Delta P_{e^-} / P_{e^-}$) = 1.0% should be achievable. Compton polarimetry is chosen for several reasons: the physics of the scattering process is well understood in QED; detector backgrounds are easy to measure and correct by using laser off pulses; polarimetry data can be taken simultaneously with physics data; Compton scattering rate is high and small statistical errors can be achieved in a short amount of time (sub-1% precision in 30 seconds is feasible); the laser helicity can be selected every ~100msec and the laser polarization is readily determined with 0.1% accuracy.

COMPTON SCATTERING BASICS

One defines E_0 and ω_0 to be the incident energies of the electron and photon, and E and ω to be the scattered energies of the electron and photon. The dimensionless *x*, *y* and *r*–scattering parameters are defined by:

$$x = \frac{4E_0\omega_0}{m^2}\cos^2(\theta_0/2) \approx \frac{4E_0\omega_0}{m^2} \tag{1}$$

$$y = 1 - \frac{E}{E_0} = \frac{\omega}{E_0} \tag{2}$$

$$r = \frac{y}{x(1-y)} \tag{3}$$

where *m* is the mass of the electron and θ_0 is the crossing angle between the electron beam and the laser beam. For polarimeters with small crossing angles at the Compton interaction point, $\cos^2(\theta_0/2)$ is ~1. The spin-dependent differential Compton cross section is given by:

$$\left(\frac{d\sigma}{dy}\right)_{Compton} = \left(\frac{d\sigma}{dy}\right)_{unpol}\left[1 + P\cdot\lambda\cdot A_z(x,y)\right] \tag{4}$$

$$\left(\frac{d\sigma}{dy}\right)_{unpol} = \frac{0.49barn}{x}\left[\frac{1}{1-y} + 1 - y - 4r(1-r)\right] \tag{5}$$

$$A_z(x,y) = rx(1-2r)(2-y) \tag{6}$$

where *P* is the longitudinal polarization of the electron and λ is the circular polarization of the laser photon. The Compton asymmetry analyzing power, $A_z(x,y)$, is maximal at the kinematic endpoint, corresponding to 180° backscattering in the center-of-mass frame, with

$$E_{\min} = E_0\frac{1}{1+x} \tag{7}$$

SPIN ALIGNMENT AT COMPTON IP

The electron beam spin direction is normal to the ring at injection and stays in the vertical direction for most of the orbit in the Super*B* ring. The physics program requires longitudinal polarization of the electron beam at the electron-positron interaction region. The spin is rotated from the vertical to longitudinal in a system of solenoids and dipole magnets on each side of the interaction region. There are 1½ π-spin rotations in the horizontal plane between the solenoid and the interaction region. In groups of 5 the helicity of the 1011 electron bunches in the ring can be randomly selected to be left or right-handed at the polarized electron gun and be topped off in the ring with the correct polarization every few seconds.

The preferred location of the Compton polarimeter is immediately downstream of the IR where the direction of the electron beam is the same as at the IR. However, the space at this location is minimal to locate the Compton IP and severe backgrounds from the e^+e^- collisions are likely to be intolerable in the Compton gamma and electron detectors. As a result the Compton polarimeter will be located upstream of the IR where the spin rotation is close to π-spin rotations from the spin orientation at the IR. An ideal location is where the spin orientation is longitudinal and exactly π-spin rotation from that at the IP. However, that point occurs inside a dipole magnet of the Super*B* lattice. The orbit angle change for π-spin rotation is 0.3312 radians at 4.18GeV. The selected location of the Compton IP in a magnetic field free region has an orbit angle change of 0.3580 radians between the Compton IP and the IR resulting in the spin direction ~14° from longitudinal. This causes the longitudinal spin projection to be 3.2% smaller at the Compton IP than at the collider IP. A systematic error will be introduced in the extrapolation due to uncertainty in the beam direction at the Compton IP with respect to that at the IR. An uncertainty of 1 mrad in the orbit will give an uncertainty in the polarization at the IR of 0.25%. A beam energy uncertainty of 20MeV from 4.18GeV will give a 0.2% error in the polarization at the IR from the measurement at the Compton IP. The layout of the Compton polarimeter is shown in Figure 1.

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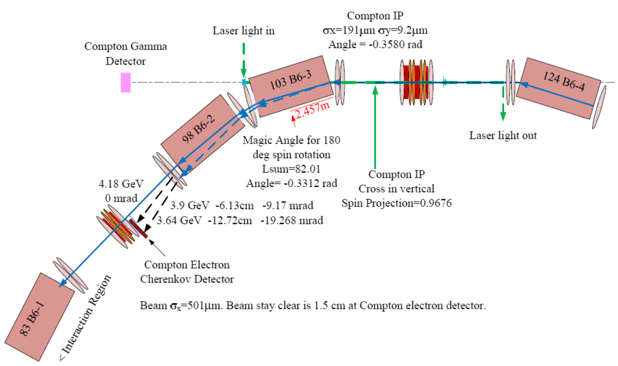

Figure 1: Layout of the Compton polarimeter.

COMPTON POLARIMETER LASER

A 1-watt mode locked Nd:YLF circularly polarized laser at 119megahertz is being considered for the Compton polarimeter. It will provide short pulses 10ps long of 2.3 x 10^{10} photons at 2.33eV. The laser beam enters ~4 cm above the beam line and exits ~12.2 m later with a crossing angle in the vertical of ~5.7mrad. The Compton IP is in a no field region as shown in Figure 1. The small crossing angle allows the laser light to see all electron bunches even as they arrive early or late by ±27psec due to the sawtooth timing effect caused by RF-beam loading after the absence of bunches in the ring for clearing the electron cloud. A crossing angle in the vertical is required to avoid synchrotron radiation damage on the input optics window. The Compton laser is pulsed with a pattern that matches the pulse and bunch structure of the electron bunches in the Super*B* ring. Table 1 gives polarimeter parameters.

Table 1: Compton polarimeter parameters at 4.18 GeV

Beam Parameter	Electron Beam	Laser Beam
σ_x	500 µm	100 µm
σ_y	5 µm	100 µm
σ_z	5 mm	1.3 mm
# particles/bunch	5.7 x 10^{10}	2.3 x 10^{10}

COMPTON RATES AND ASYMMETRIES

For a 4.18GeV electron beam colliding with a 532nm laser, the Compton-scattered electrons have their kinematic endpoint at E_{min} = 3.64GeV. Fig. 2 shows the resulting $J_z = 3/2$ and $J_z = 1/2$ Compton cross sections.

The maximum Compton gamma energy and asymmetries for two different laser energies on 4.18GeV electrons are given in Table 2. The analyzing power at the Compton edge is 0.137 for the present default laser giving green light at the Compton IP. A larger analyzing power occurs for UV light and a laser system giving light in the UV is being evaluated. Flux weighted (energy weighted) asymmetries refer to the asymmetries integrated over the detector acceptance (and weighted by the gamma energy).

The unpolarized Compton cross section for head-on collisions of 4.18GeV electrons with 2.33eV photons is 1.09barns giving a rate = 0.9 scatters/bunch. The small vertical crossing angle, coupled with the electron bunch length, will increase the effective vertical spot size of the colliding beams and decrease the rate. This is parameterized by f_{geom} which for small crossing angles is given by $R_{eff} = R_{Compton} f_{geom}$ where

$$f_{geom} = \frac{\sigma_y}{\sqrt{(\sigma_y)^2 + (\theta_y^{Compton} \cdot \sigma_z)^2}} = \frac{100\mu m}{\sqrt{(100\mu m)^2 + (5.7mrad \cdot 5mm)^2}} = 0.96$$

giving an effective rate for Compton scatters of 0.86 scatters per collision from a 1W laser beam at 119MHz. This rate is high enough to be non-linear in a counting mode for the forward gammas giving a larger systematic error. For this reason it may be desirable to run at lower laser power. The higher rate would not be a problem for the segmented electron detector.

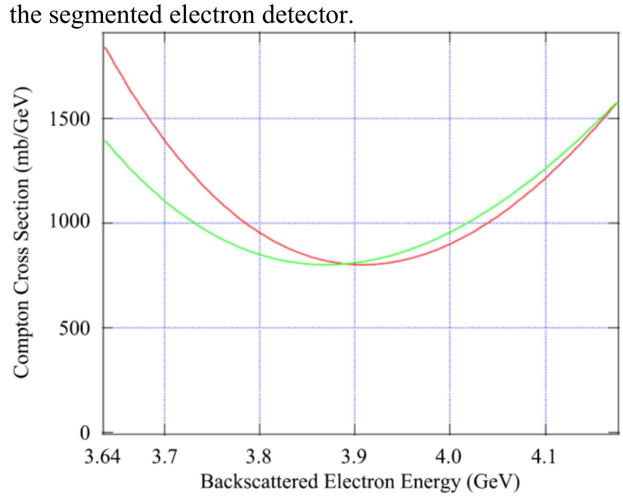

Figure 2: Compton cross section versus backscattered electron energy for 532nm photons on 4.18GeV electron. The $J_z = 3/2$ ($J_z = 1/2$) cross section for electron and photon spins aligned (anti-aligned) is shown in red/darker line (green/lighter line).

Table 2: Compton polarimeter asymmetries (A) and cross section for two laser systems

E_{beam} (GeV)	E_{photon} (eV)	W_{max} (GeV)	$A_{\gamma max}$	$A_{\gamma\ flux\ wt}$	$A_{\gamma\ E\ wt}$	σ_{unpol} (mbarn)
4.18	2.33	0.537	0.137	0.030	0.064	1089
4.18	3.45	0.756	0.197	0.040	0.088	731

COMPTON POLARIMETER DETECTORS

The Compton electron and gamma detector must have time resolution < 4.2nsec. Compton electrons generated at the Compton IP will propagate essentially along the electron beam direction. Two dipole magnets and 3-quadrupole magnets fan out the Compton electron energy spectrum at the location of the Compton detector shown in Figure 1. The segmented electron detector samples the Compton electron flux at energies between 4.06GeV and the Compton kinematic edge at 3.64GeV. The Compton electron detector must discern the Compton edge electrons and must be located outside a 1.5cm beam stay clear. The first cell will start at ~2.5cm from the beam. Compton edge electrons with 3.64GeV occur at 12.7cm from the beam. The detector is a hodoscope with 30 quartz bars on a movable stage so the Compton edge can be determined with high precision. Each quartz bar is 5mm x 5cm by 2.5cm long. Each channel covers ~21MeV of backscattered electrons. The 1mm aluminium beam pipe is flared and angled at ~200mrad. The silica bars are staggered to allow photomultiplier tubes to match the pitch of the counters and will give roughly 12 photoelectrons per track. Fused silica is a good match to the radiation dose in the quartz bars which will absorb ~50megarads per year from the signal itself.

The forward Compton gammas are detected in a 5 by 5 by 2.5cm deep quartz plate. The Compton gammas exit through ~1.5 RL water cooled Al window to remove the heat from absorbed synchrotron radiation. The shower is rejuvenated using a local plate of tungsten of ~2 RL with the fused silica plate behind it. Cherenkov light is taken out through a slanted roof into a light pipe and matched to a fast PMT. The calorimeter will be shielded from backgrounds.

Each of the 1011 electron bunches goes around the 1258.3582m ring 238,241 revolutions per sec giving a rate in the Compton gamma detector of ~214,000 gammas/sec for each of the bunches sampled. Each cell of the Compton electron detector will see ~8360 Compton electrons/second per bunch sampled. The mode locked 119megahertz Compton laser pulses will collide with every other electron bunch in the ring. The timing of the Compton laser pulses can be varied so as to sample the other 506 electron bunches.

TRANSVERSE POLARIZATION MEASUREMENTS

We are evaluating moving the forward Compton gamma detector ~25 meters from the Compton IP and making a hodoscope detector with vertical resolution ~0.25mm. This would allow measurement of the up/down asymmetry from left and right-handed circularly polarized laser light on transversely polarized electrons with spin in the vertical direction. Measurement of the transverse vertical beam polarization with the spin rotation solenoids off will be useful for beam tuning and measurement of the beam energy by locating nearby spin depolarization resonances.

LUMINOSITY-WEIGHTED BEAM POLARIZATION AT THE IR

The luminosity-weighted beam polarization may differ from the measured polarization. With the current location of the Compton IP there is a correction of ~3.2% due to the spin not exactly longitudinal at the Compton IP. There are also effects from energy spread and spin transport. The spin motion of a deflected electron or positron beam in a transverse magnetic field follows from the familiar T-BMT expression

$$\theta^{spin} = \gamma \frac{g-2}{2} \theta^{orbit} = \frac{E_0}{0.44065 GeV} \theta^{orbit} \tag{12}$$

Where θ_{orbit} and θ_{spin} are the orbit deflection and spin precession angles, E_0 is the beam energy, $\gamma = E_o/mc^2$ and (g-2)/2 is the famous g-factor anomaly of the magnetic moment of the electron. The difference between the luminosity-weighted beam polarization and the polarimeter measurement is written as $dP = P_z^{lum-wt} - P_z^{CIP}$. To minimize the uncertainty in dP it is required that the beam direction at the Compton IP be known with the collision axis at the e^+e^- IR to within 1mrad. Orbit misalignments between the Compton IP and the e^+e^- collision IP are expected to be below 1mrad, which would give the uncertainty in $dP < 0.25\%$.

The effect of Sokolov-Ternov spin flips is expected to be small. Effects from the angular divergence of the beam at the Compton IP and at the IR are expected to be negligible as are effects from chromatic aberrations. Systematic errors on the determination of the polarization at the e^+e^- IR from the Compton polarimeter measurement have contributions from the following: error on laser polarization <0.1%; background uncertainty <0.25%; linearity of phototube response <0.25%; luminosity weighted polarization/beam energy/orbit direction <0.4% and analyzing power ~0.5% giving a total systematic error estimated to be $\delta P/P$ ~1% from the Compton electron detector. It may be harder to achieve a 1% measurement from the Compton gamma detector, but, it will give an important cross check in the polarization measurement. Further studies are needed to understand the systematic error on the analyzing power. This will require detector simulations to determine resolution effects, sensitivity to beam and magnet parameters and misalignment. The measurement of polarization at the ~1% systematic error level is expected to be feasible based on experience at SLD[2] and at Jefferson Lab[3].

SUMMARY

A scheme for measuring the electron beam polarization at Super*B* near the IR has been described. The Compton polarimeter has been designed to fit into the existing lattice of the Super*B* ring and results in a Compton IP measuring the polarization located where the beam is almost longitudinal with opposite helicity to that at the IR. The polarization at the IR is expected to be determined with an accuracy of ~1% from the measurement at the Compton IP provided the beam direction at the electron-positron interaction region and the Compton IP are well known and the beam energy is measured to better than 20 MeV. Detailed detector studies are needed to study resolution and acceptance effects on detector analyzing powers, and to determine sensitivity to beam and machine parameters.

REFFERENCES

[1] Super*B* Conceptual Design Report, INFN/AE-07/2, SLAC R 856, LAL 07-15 March 2007

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[3] S. Excoffier, et al., Accurate measurement of the electron beam polarization in JLab Hall A using Compton polarimetry. Nuclear Instruments & Methods in Physics Research Section A 551 (2005) 563