Polarization at SuperB

- Overview of scheme to measure polarization near the IR
- Influence of recent Optics changes in LER
- Solution to sawtooth timing problem of varying electron bunch arrival time at Compton IP
- Comments on measurement of luminosity of Left and Right-handed electrons
- New information on availability of mode-locked lasers

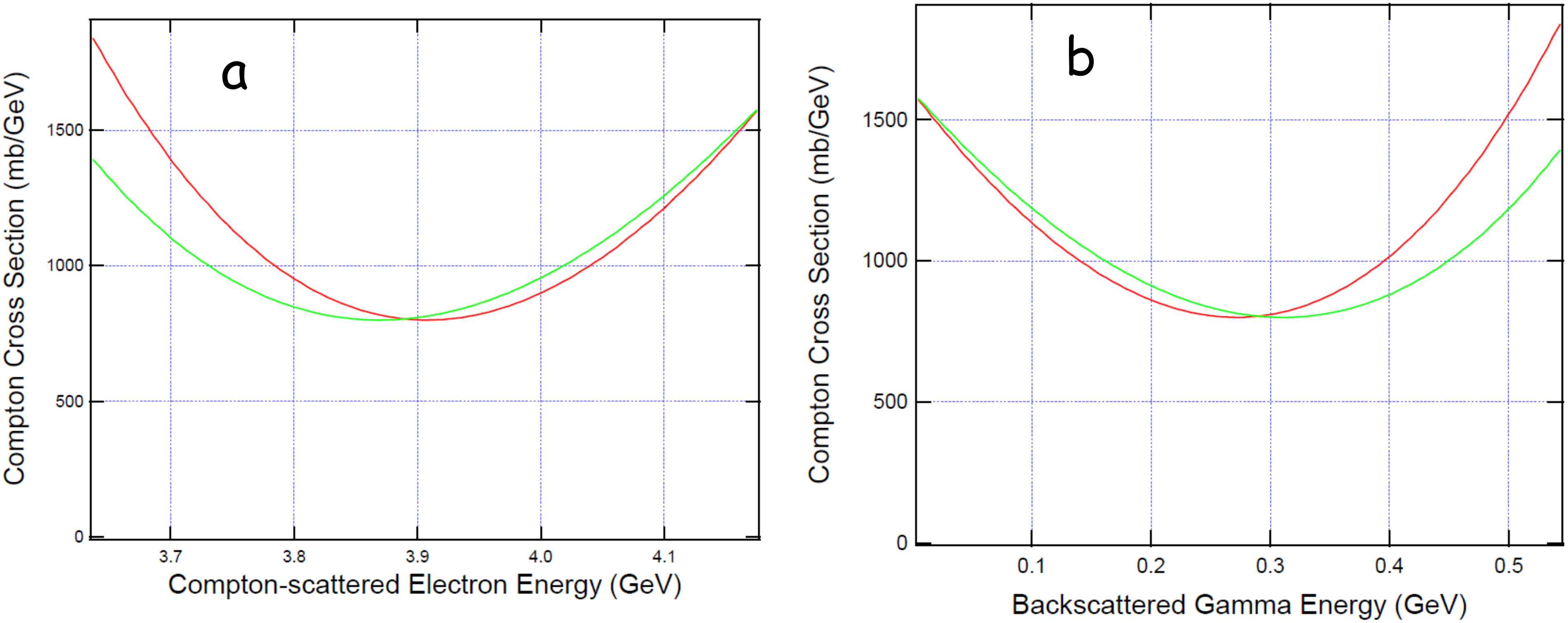
Annecy Workshop
March 16 to 19, 2010
Ken Moffeit, SLAC

Physics with longitudinally polarized electrons at SuperB:

1) Tau asymmetry parameter requires precision measurement of polarization.
2) Alr and measurement of the electroweak parameter $\sin^2(\theta_\omega)$ at 10.85 GeV through γ Z interference. Requires precision measurement of polarization.
3) Measurement of Tau anomalous magnetic moment.
4) Measurement of the Tau electric dipole moment (or upper limit).

Physics measurements require high precision polarimetry.
Goal for polarimeter is
$\delta P/P \sim 1\%$

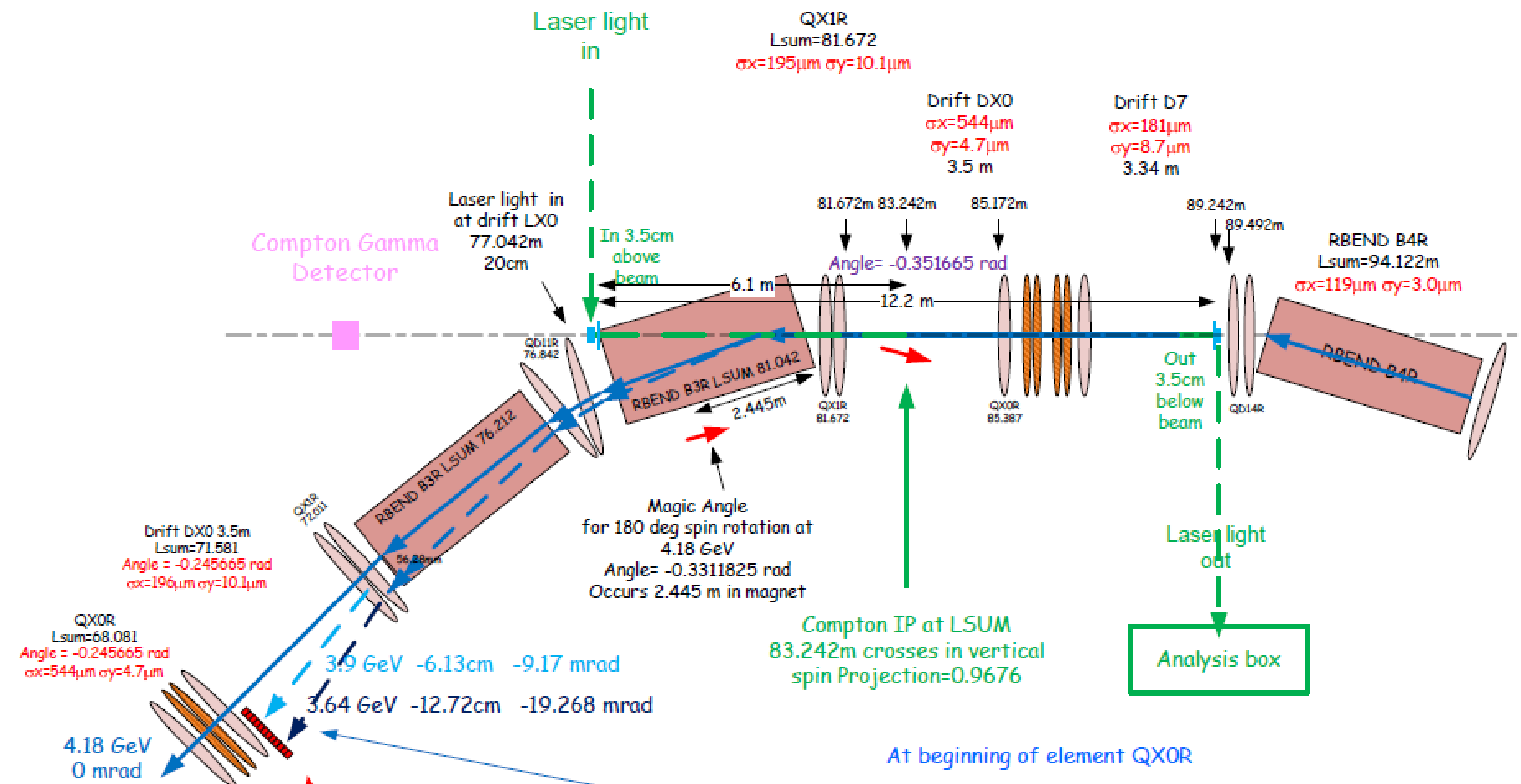
Scattering polarized laser light on longitudinally polarized electrons
Compton Differential Cross Section



Endpoint asymmetry is ~0.15 at 4.18 GeV

Compton differential cross section versus scattered
(a) electron energy (b) Gamma energy
for same (red curve) and opposite (green curve) helicity configuration of laser photon (2.33 eV) and beam electron (4.18 GeV).

Compton IP near 180° spin rotation from spin direction at IR (orbit -0.358019 mrad from orbit at IR)

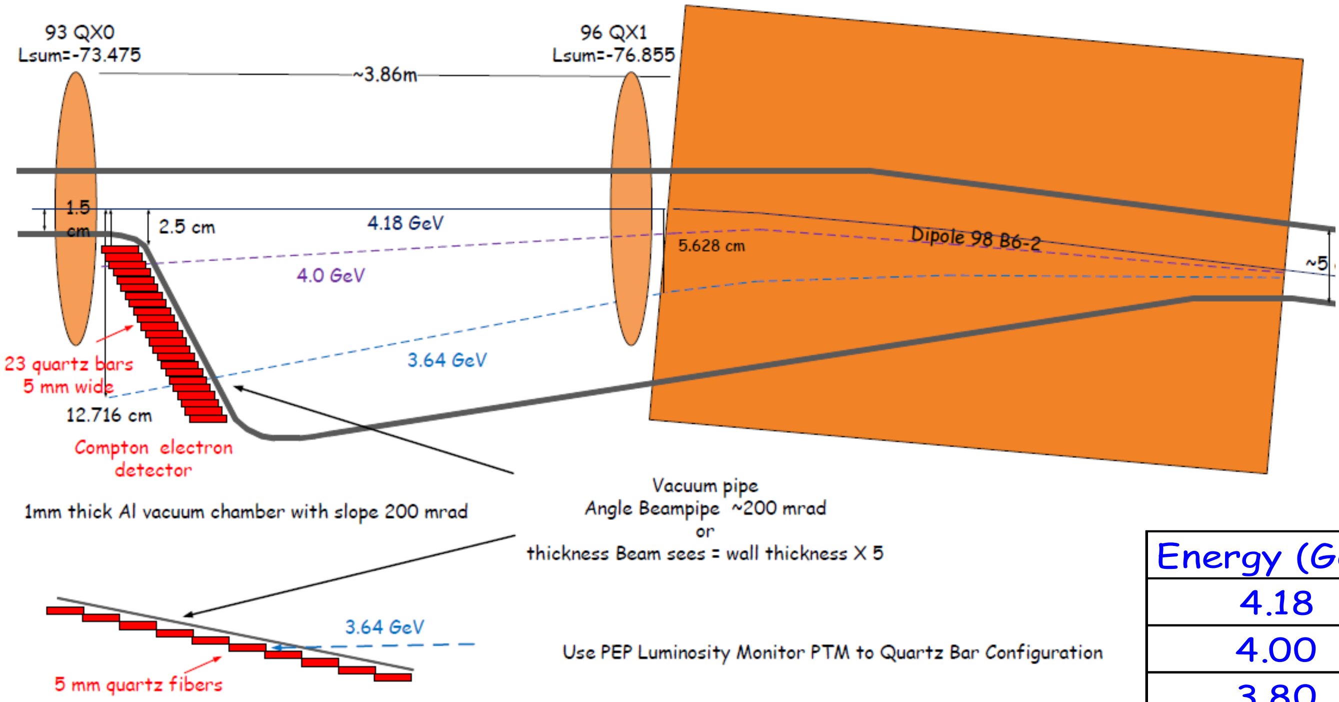


At beginning of element QX0R

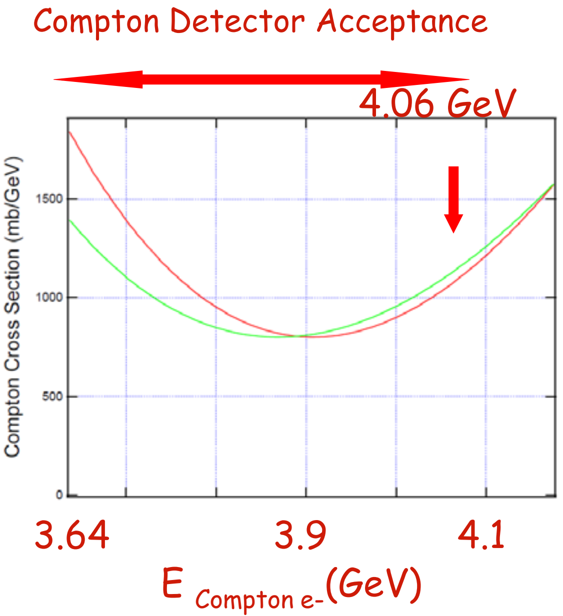
Energy (GeV)	x_{offset} (mm)	x_{angle} (mrad)	Diff (mm)	Diff (mrad)
4.18	-788.86	-92.448	0	0.000
4.10	-805.47	-94.910	-16.61	-2.462
4.00	-827.21	-98.158	-38.35	-5.710
3.90	-850.14	-101.615	-61.28	-9.167
3.80	-874.35	-105.297	-85.49	-12.849
3.70	-899.95	-109.228	-111.09	-16.780
3.64	-916.02	-111.716	-127.16	-19.268

Latest SuperB machine optics do not change spin direction at the Compton IP. Future iterations of SuperB machine optics may give longitudinal spin direction closer to 180° at the Compton IP from the spin direction at the IR.

Compton Electron Detector



Use PEP Luminosity Monitor PTM to Quartz Bar Configuration



Energy (GeV)	Diff (cm)	Diff (mrad)
4.18	0	0.000
4.00	-3.84	-5.710
3.80	-8.55	-12.849
3.64	-12.72	-19.268

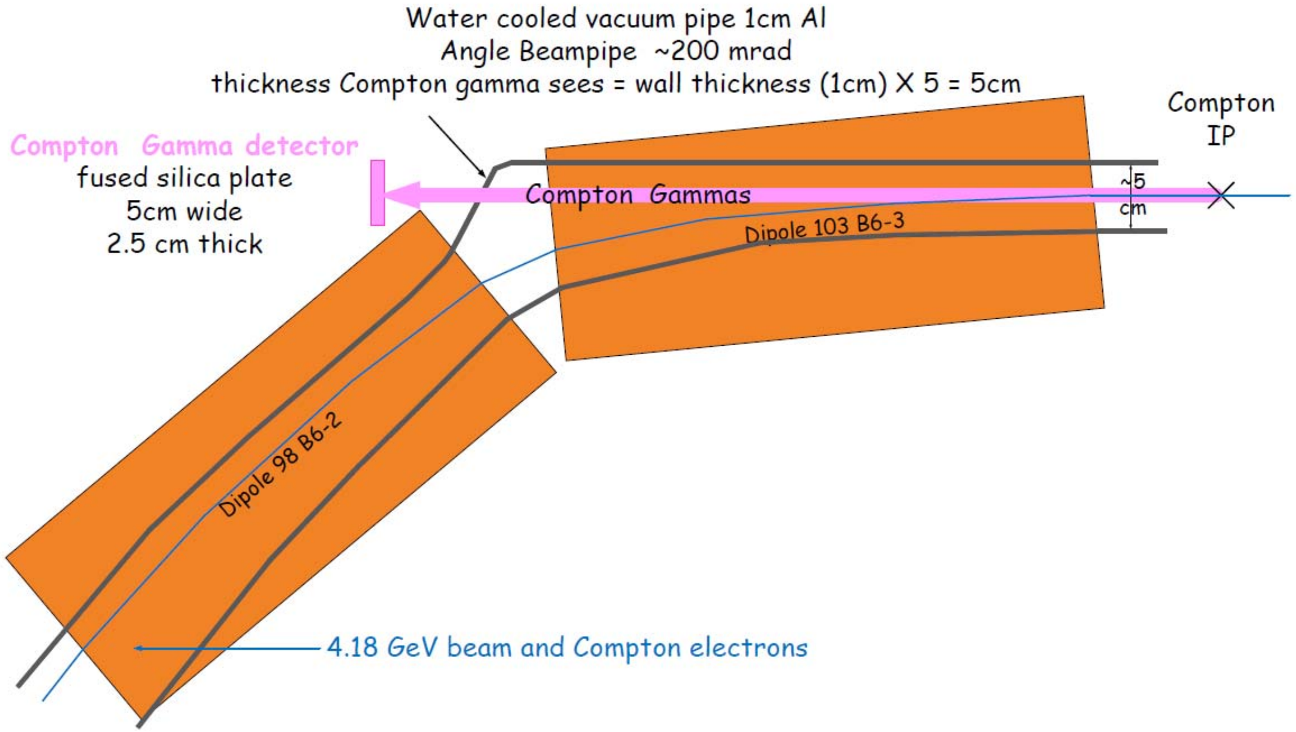
- Detect electrons with 2.5cm thick silica bar mated to a bi-alkali PMT. The silica bar is 5mm wide accepting ~21 MeV of backscattered electrons. Starting the 1st cell of the Quartz Cherenkov Detector at 2.5 cm from the beam gives acceptance from 3.64 to 4.06 GeV for Compton electrons .

- The 200 mrad angled 1mm think aluminum vacuum pipe upstream gives roughly 12 photoelectrons per track. Higher Compton scattered electron rate is preferred, but, Compton gamma detector prefers low rate of ~0.2 per laser electron bunch collision.

- Silica bars staggered enough to allow the PMTs (which would likely be 16 mm diameter using present-day technology) to match the pitch of the counters. As a guide, following the design of the PEPII luminosity counters, the Cherenkov light would be taken out upwards or downwards to the PMT, possibly through an air lightpipe.

- Radiation dose in these counters will absorb ~50 Megarads per year from the signal itself. Fused silica is a good match for this radiation dose.

Compton Gamma Detector



Compton gammas exit beam pipe through ~1.5 RL (water cooling + Al window). Window is water cooled to remove heat from synchrotron radiation which is all absorbed.

Compton gamma detector close to beam pipe.

Shower rejuvenated using local plate of tungsten or lead of ~2 RL covering. Remote insertion of different thickness radiators will allow systematic studies as was done at SLC and PEPII.

Close to radiator is a fused silica plate 5 cm square by 2.5 cm thick which will cover the active region.

Cherenkov light is taken out through a slanted roof into a light pipe, and converted in one or more 8 mm cathode fast PMTs. Fused silica may be extended a few cm to best match the PMT.

Shielding the calorimeter from background will be necessary.

Subjects needing attention after the Dec 09 meeting at Frascati:

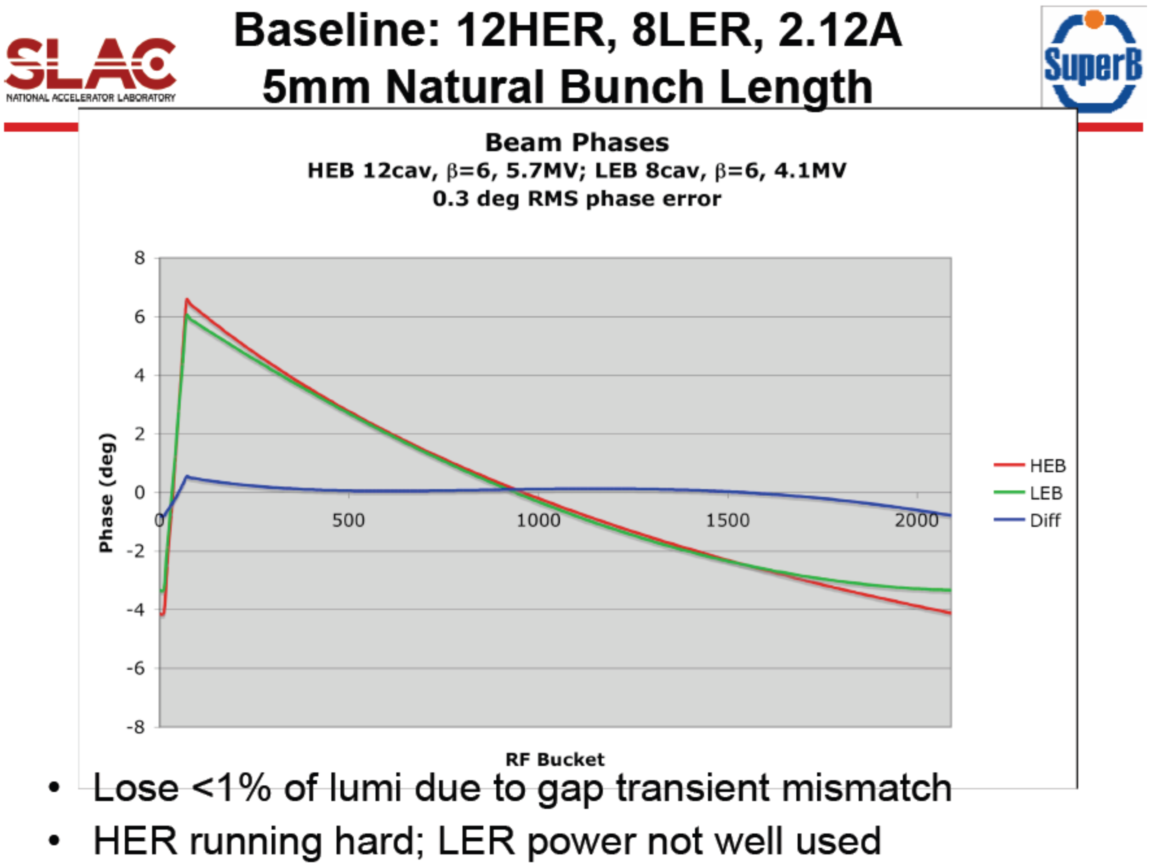
1) **Saw tooth timing** of arrival of electron bunches at Compton IP due to beam loading after gap for electron cloud clearing. This causes the timing of the bunches at the Compton IP to arrive late or early depending on where they are relative to the 1st bunch after the gap. The mode locked laser has uniform spacing of the bunches of laser photons.
2) **Luminosity asymmetry:** Measurement of Alr at the Upsilon 4S will require knowing the luminosity for right handed relative to left-handed electrons to the 10^{-6} level.
3) **New optics for SuperB**: Is the location of the Compton IP more favorable, i.e. is is closer to pi rotation from the spin direction at the IR? **New optics do not change spin direction at Compton IP.**
4) We need to understand the **systematics between the measurement of the polarization at the Compton IP and that at the IR**. Can the spin dynamic programs produce a scatter plot of the longitudinal projection of the spin at the Compton IP and that at the e+e- IR. **Effort by Uli Wienands, Cecile Rimbault and Nicolas Monseu in progress, see talks at this Workshop.**
5) Can we be assured that the **positron polarization is zero**? Does the machine polarize the positrons? Positron could build up to as much at 10% polarization normal to the HER ring. Is there any appreciable longitudinal positron polarization occuring at the e+e- IR ca. What level of longitudinal positron polarization will give significant systematic errors to the measurement of sin2(thetaW)? **Uli Wienands is looking a positron polarization buildup in the HER and if longitudinal component can occur at IR.**
6) Choice of **laser frequency**: Higher frequency laser light is preferred since the backscattered Compton electrons are further from the electron beam and the polarization asymmetry is larger. We are considering lasers with wavelengths in the range 340 to 532 nm using one of the following materials: Ti:sapphire, Nd:YAG and Nd:glass; mode-locked frequency of 68MHz or 119MHz to be externally locked to machine 476MHz.
7) **Detector efficiencies for mu+mu- pairs (other leptons also)**: Systematics need to be understood at the level of 10-6 needed for the Alr measurements.
8) **Theoretical prediction for A_{lr}** at the Upsilon 4S and the theoretical systematic errors.

Sawtooth timing of electron bunch arrival at Compton IP

- SuperB will have a gap for electron cloud clearing. When the beam bunch occur again the beam will have to be off crest to gain the correct energy in the RF.
- Laser bunch timing from mode locked laser fixed at 68 MHz or 119 megahertz.
- Therefore, the electron beam will arrive before or after the laser photon arrives at Compton IP.

Gap Transient and Parameter Options

- Plots for phase transients from Kirk Bertsche http://www.slac.stanford.edu/~bertsche/superb/. The plots give the phases of the bunches in HER and LER, measured with respect to a fixed reference at the RF frequency (476 MHz).
- The total swing is roughly 10 degrees in a quasi-saw-tooth. This would be about 2-3 degrees wrt a 119 MHz signal.
- At 476 MHz there is 2.1 ns per cycle (360 deg), so 10 deg at 476 is about 60 ps. You'll see a slow drift in phase of 60 ps over a turn, then the beam goes away, then comes back with a 60 ps offset from where it went away.



Baseline: 12HER, 8LER, 2.12A
5mm Natural Bunch Length

Beam Phases
HEB 12cav, β=6, 5.7MV; LEB 8cav, β=6, 4.1MV
0.3 deg RMS phase error

- Lose <1% of lumi due to gap transient mismatch
- HER running hard; LER power not well used

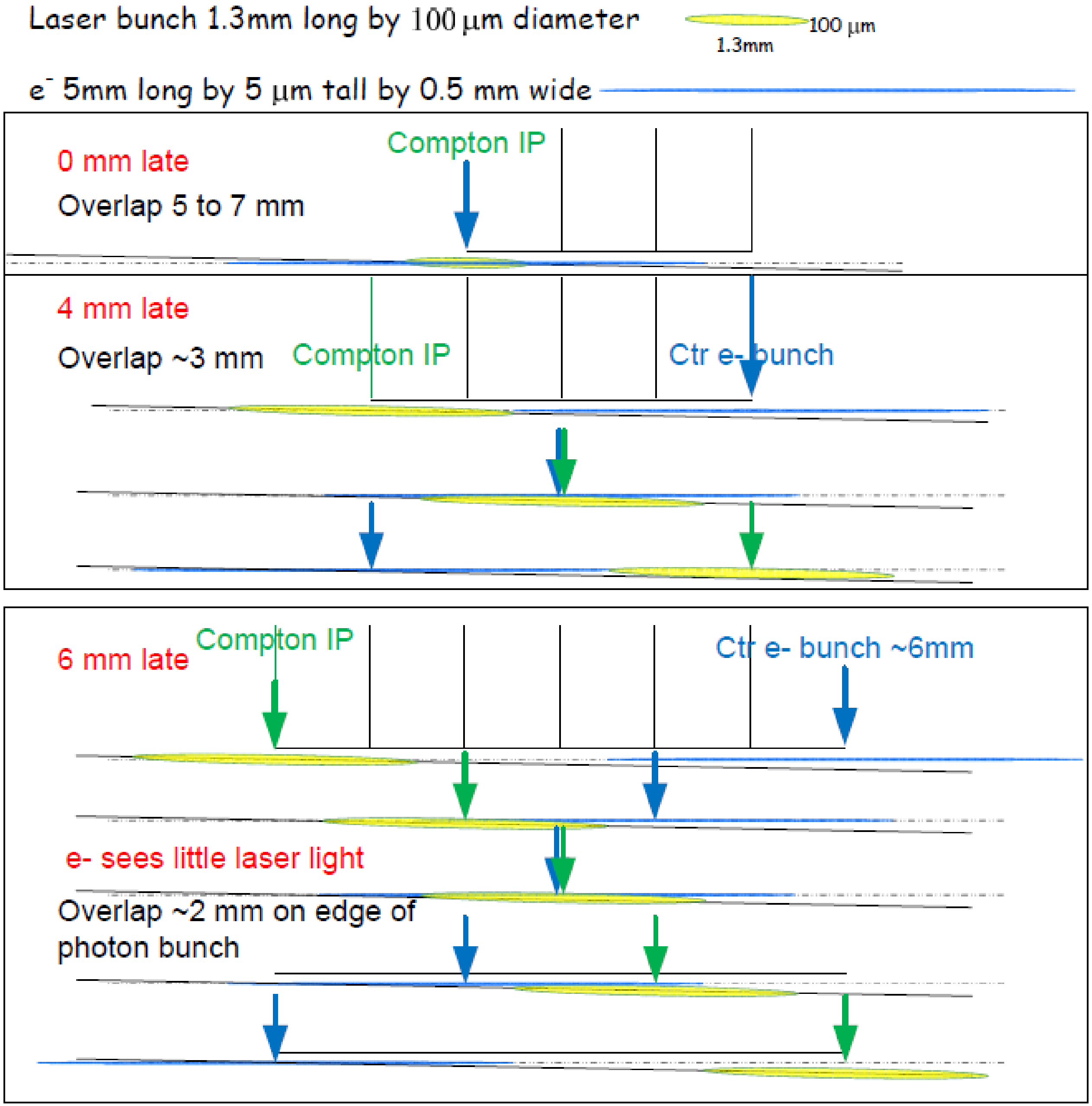
Sawtooth Problem with 18.5 mrad crossing angle

Electron pulse can move 60 psec (18 mm) during pulse train

Laser crossing angle is 18.5 mrad

Laser bunch 1.3mm long by 100 µm diameter

e^- 5mm long by 5 µm tall by 0.5 mm wide



0 mm late

Overlap 5 to 7 mm

4 mm late

Overlap ~3 mm

6 mm late

e- sees little laser light

Overlap ~2 mm on edge of photon bunch

Overlap for about +-4 mm

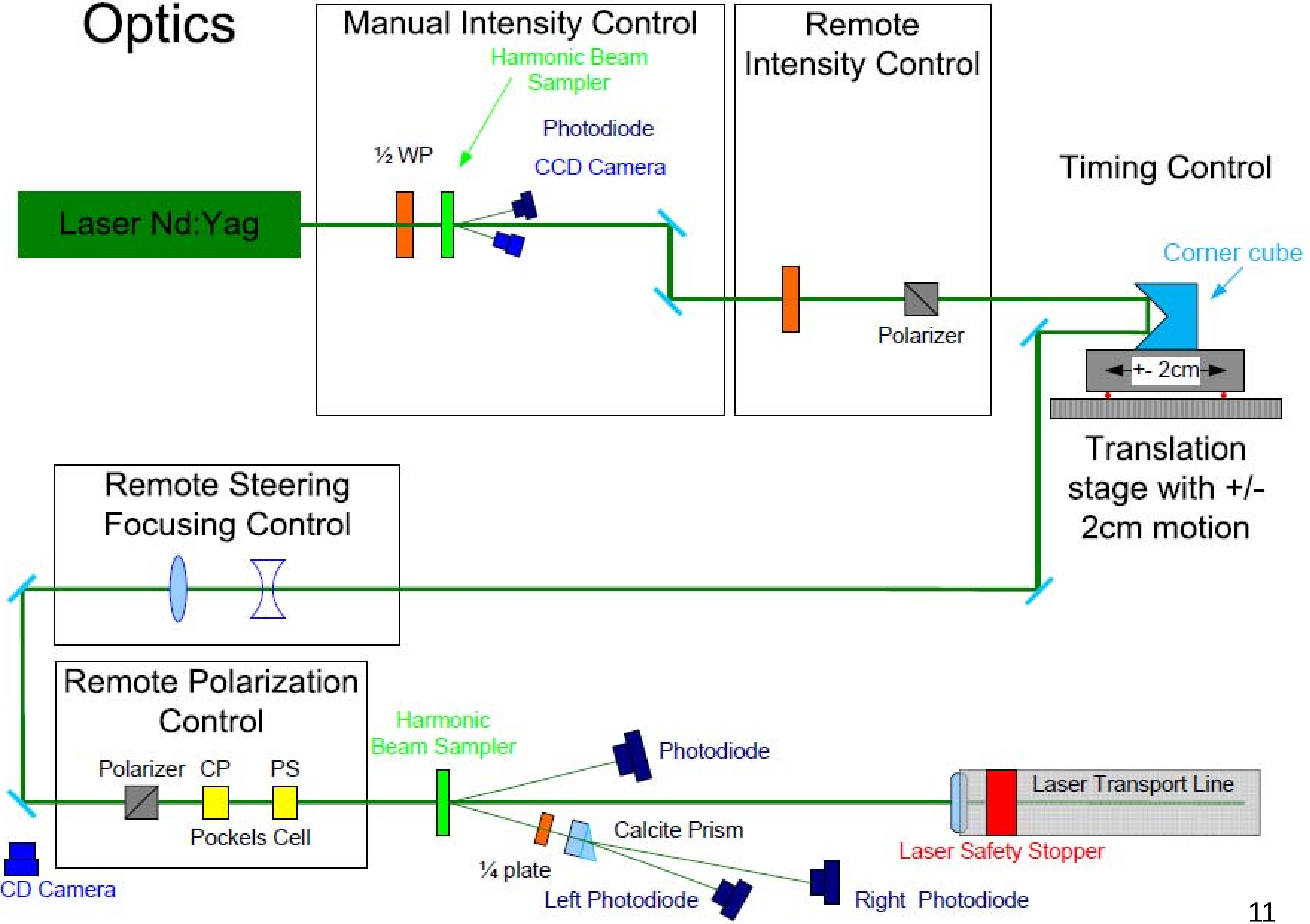
Laser bunches would give Compton luminosity on about ½ the electron bunches

A solution:

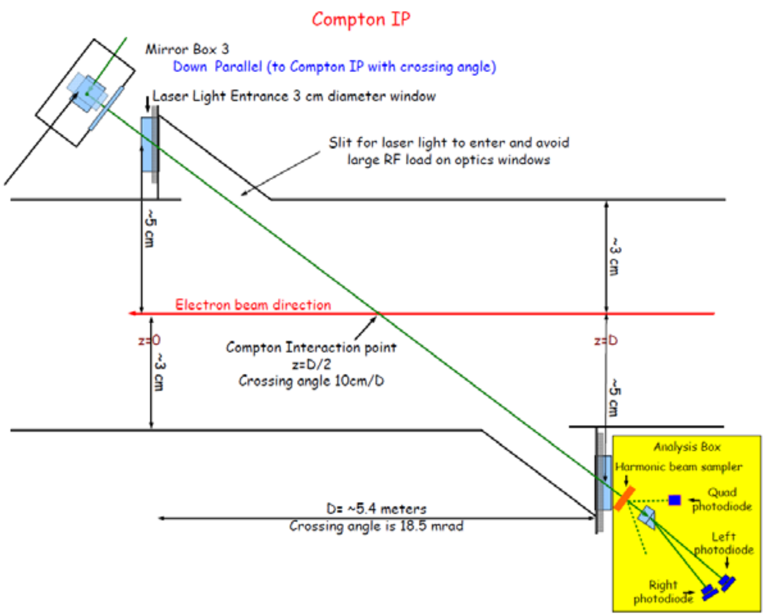
Manually delaying/advancing the time the laser bunches arrive at the Compton IP using a corner cube on a translation stage will allow measurement of electron beam polarization

a) 1st part of bunches
b) Middle part of bunches
c) Last part of bunches

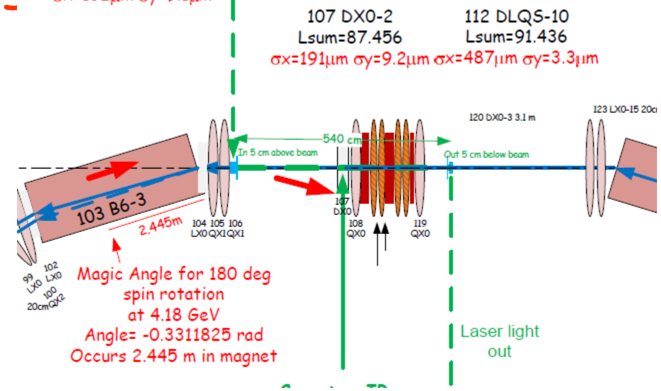
Optics


Manual Intensity Control
Harmonic Beam Sampler
Photodiode
½ WP
CCD Camera
Laser Nd:Yag
Remote Intensity Control
Polarizer
Timing Control
Corner cube
+- 2cm
Translation stage with +/- 2cm motion
Remote Steering Focusing Control
Remote Polarization Control
Polarizer
CP
PS
Pockels Cell
CCD Camera
Harmonic Beam Sampler
Photodiode
Calcite Prism
¼ plate
Left Photodiode
Right Photodiode
Laser Transport Line
Laser Safety Stopper

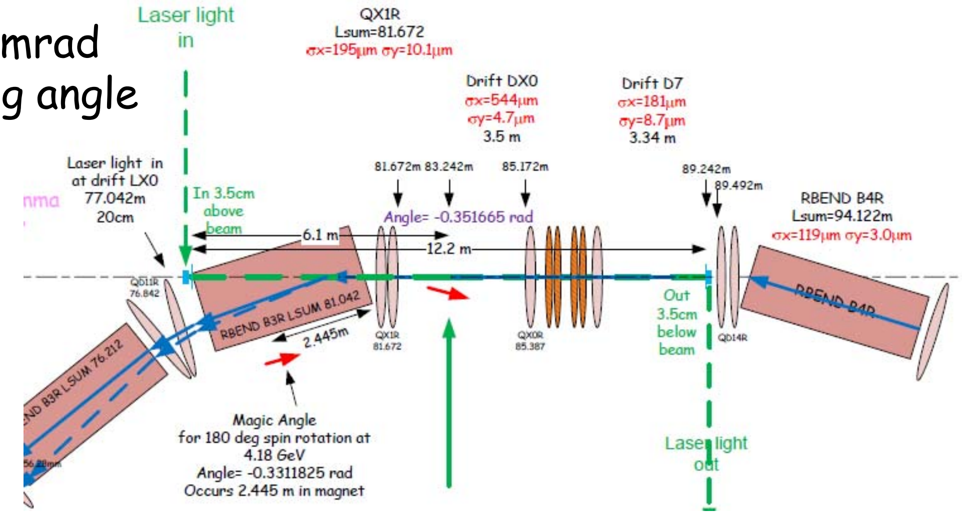
Decrease crossing angle of Laser light with electron beam



18.5 mrad
crossing angle

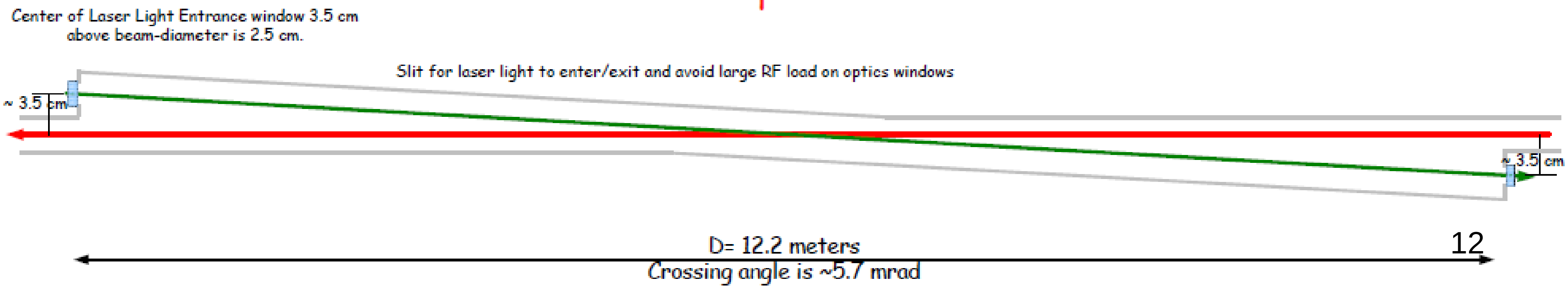


~5.7 mrad
crossing angle

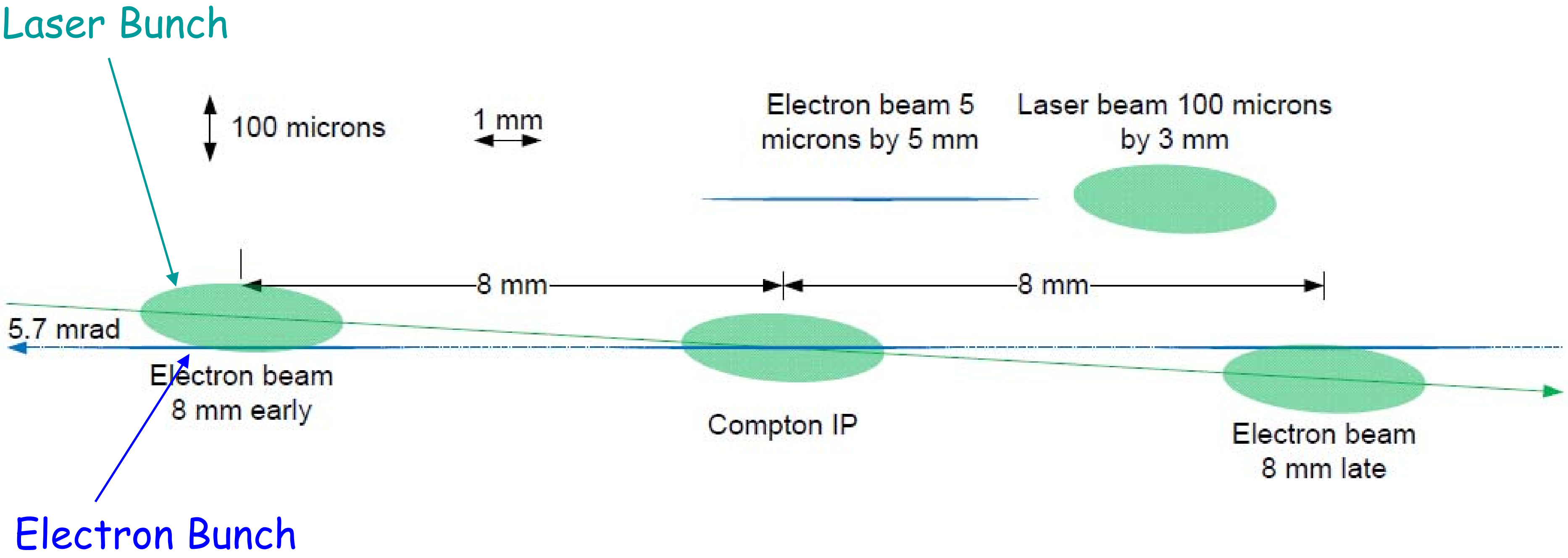


Increase D to ~12 m and decrease entrance window to ~3.5 cm above the beam. Crossing angle is reduced to ~5.7 mrad.

Compton IP

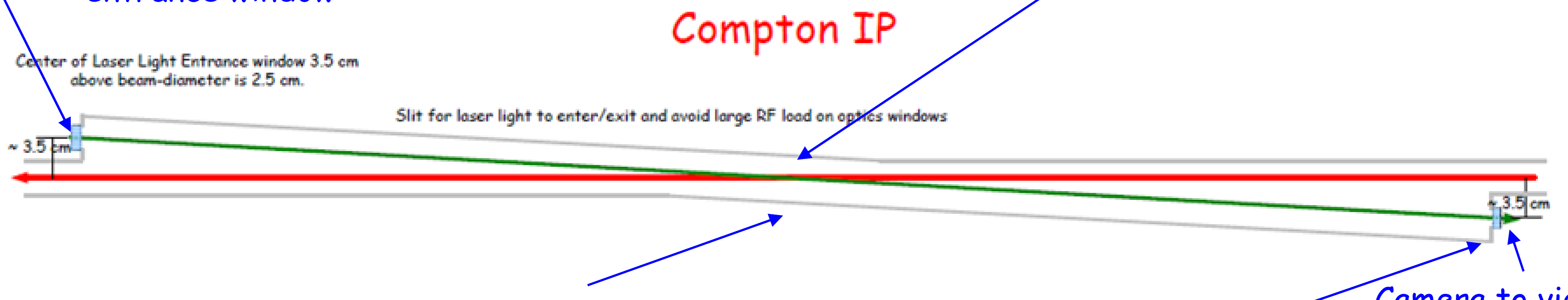


Electron bunches arriving early or late at the Compton IP relative to laser bunches at a fixed 119 megahertz (or 68MHz).



Important to assure electron bunches and Laser bunches collide in field free region of 3.5m drift space between quads QX0R and QX1R.

Steer and time laser light and electron beam at Compton IP for collisions.



Camera to view laser light on entrance window

Compton IP

BPM at Compton IP

Fast beam pickup signal of single bunch arrive at Compton IP for timing of laser bunch and electron bunch with resolution ~50 picosec

Fast diode to measure timing of single laser bunch arrival with resolution ~50 psec.

Camera to view laser light on exit window

Compton collisions require 3-d scan. Timing of laser bunch arrival at Compton IP is needed because of the short bunch and effective collision time.

- Relative timing diagnostic is needed to measure arrival time of beam and laser bunches at Compton IP.
- 2-d transverse scan: Start with laser and e_{beam} trajectories that should get the collisions close:
  Center on BPM.
  Center the laser trajectory on entrance and exit windows with cameras viewing windows. Laser spotsize at the collision point increased to find beam initially.
- Scan timing of Laser bunch to find/optimize collisions with corner cube on laser optics bench (+- 2cm or ~ +- 67 picosec).

Counting Rate for E= 4.18 GeV
Scattered electron rate for each laser/electron bucket crossing

Compton cross section (unpolarized) for head-on collisions of 4.18 GeV electrons with 2.3 eV photons is 1.09 barns

$$R^{0}_{Compton} = \sigma_{Compton} \cdot \frac{N_{electrons} \cdot N_{photons}}{\pi \sigma_x \sigma_y}$$

$$R^{0}_{Compton} = 0.9 / bunch$$

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	5.7×10^{10}	2.3×10^{10}

The small vertical crossing angle, coupled with the electron bunch length, will increase the effective vertical spotsize of the colliding beams. This is parameterized by f_{geom}, which for small crossing angles is given below.

$$R^{eff} = R^{0}_{Compton} \cdot f_{geom}$$

$$f_{geom} = \frac{\sigma_y}{\sqrt{(\sigma_y)^2 + (\theta_y^{Compton} \cdot \sigma_z)^2}}$$

$$f_{geom} = \frac{100\mu m}{\sqrt{(100\mu m)^2 + (18.5 mrad \cdot 5mm)^2}} = 0.73$$

Decreasing the crossing angle will give a larger gamma electron distance at the IR and a larger Compton rate (the geometry factor becomes 0.96).

Hence, the effective rate for Compton scatters (total number of Compton gammas per collision) will be 0.66 scatters/collision for a 1W laser beam w/ parameters: 532nm, 119MHz, 10ps bunch length.

Luminosity asymmetry for left and right handed longitudinally polarized electrons

Requires O(10^12) luminosity Bhabha events. For Radiative Bhabhas in the luminosity monitor, that's not a problem. But no thought has been given to monitoring it independently for the two polarizations. At PEP, and as considered so far for SuperB, the measurements with the best precision and stability would integrate over milliseconds. Pulse by pulse measurements at PEP were subject to several difficulties, were not required to be all that accurate, and monitored every pulse only 1-2 percent of the time. As you've noted, the pulses after the abort gap can be tricky.

Use a wave-form digitizer, synchronized to the machine, and with a sampling rate of ~1GHz. It would take data for several turns, until exhausted, then dump the integers to a fast processor. Then start over again. This will require a moderate R&D effort, to work out how to extract the pulse heights without bias, but it would allow the two polarizations to be handled separately, and post-facto analysis. I don't know what the live-time fraction would be, but a few percent might be possible.

The fast technique used at PEP (and which Clive lobbys for in the polarimeter) imposed a threshold and became a counting experiment. However, with the many gammas per collision of the radiative Bhabhas that's not a linear signal, and pushing it to the part in a million range would require some serious study.

In short, the signal is there, but the devil is in the micro-details. It's been done at pulsed machines, but it's a bit beyond experience at a 4.2 nsec spaced collider.

-Clive Field, SLAC National Accelerator Laboratory

Laser Developments

A. Spectra Vanguard laser we discussed that was 355nm. This is an OEM system that they are not willing to modify for a special application. It does not have a mechanism for locking to an external rf reference and could not be modified to run at 68MHz or 119MHz.

B. Coherent has a 2 picosecond 800nm laser that can be externally mode-locked and they thought it could be adapted to lock at 68MHz and possibly 119MHz. The Coherent system would be the Mira-HP-P -- see attachment and http://www.coherent.com.au/files/products/Coherent/Mira%20HP%20Jan%2007.pdf. It is possible to double this to 400nm with conversion efficiency of 15%. Average powers would be 3W at 800nm and 450mW at 400nm.

Info on 68MHz and 119MHz lasers at SLAC that are locked to rf:

1. NEH lab:
   - i) 800nm, 68MHz 20fs, 520mW (Femtolasers);
   - ii) 1050nm, 119MHz, 100fs, 2.5W (Menlo lasers)

2. NEH Laser Hall: 800nm, 68MHz, 20fs, 520 mW (Femtolasers)

3. LCLS Injector: 755nm, 119 MHz, 20 fs, 400 mW (Manufactured by Femtolasers)

4. SPEAR Gun Test Facility: 1054nm, 119 MHz, 300 fs, 115 mW (Time-Bandwidth/Lightwave)

We used a 1 watt laser beam w/ parameters: 532nm, 119MHz, 10ps bunch length in estimating Compton rate.

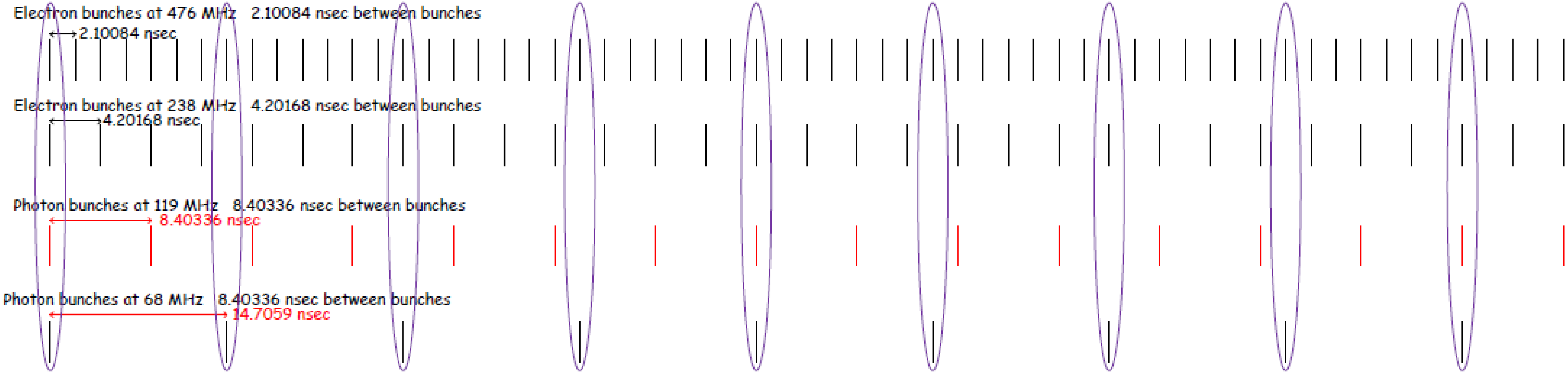
Laser Continued

Additional info:

-changing the nominal frequencies of ~80MHz to 68MHz would involve a longer cavity length whereas going to 119MHz would shorten the cavity length. Expect easier to go to 68MHz since closer to the nominal frequency and easier to lengthen cavity than shorten it. Either change involves changes to the mode size in the cavity and so re-optimization needs to be done.

-SLAC laser group for LCLS has expertise to do that as well as some of the industry when they are willing, but it usually involves it becoming more of a custom laser and adds to cost. Recent SLAC oscillators have been delivered by Femtolasers (Austrian company) with both 68MHz and 119 MHz locki

Electron bunches and laser bunches from mode locked laser

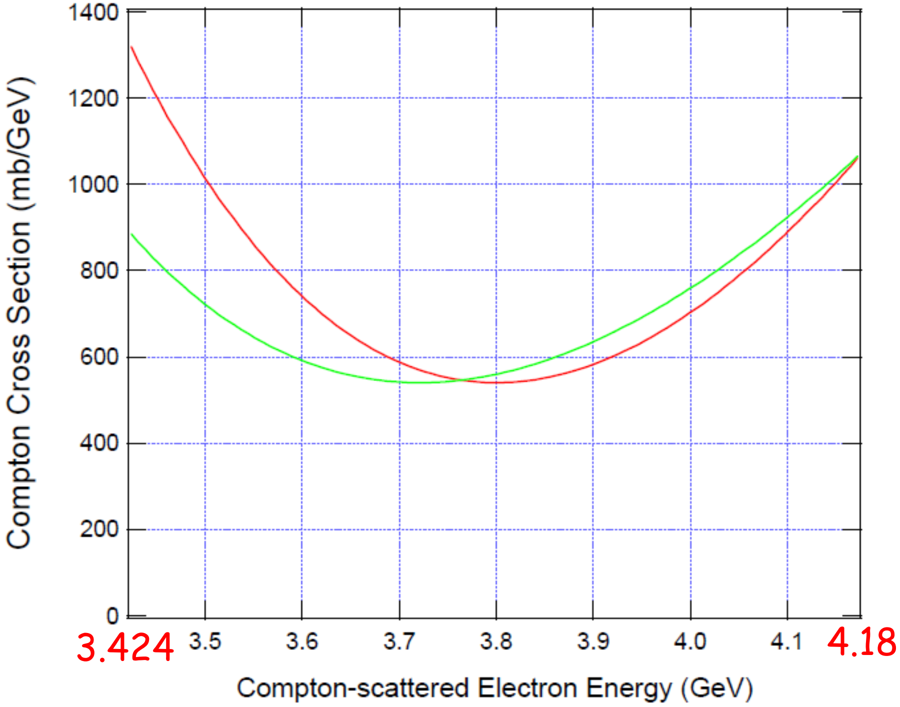


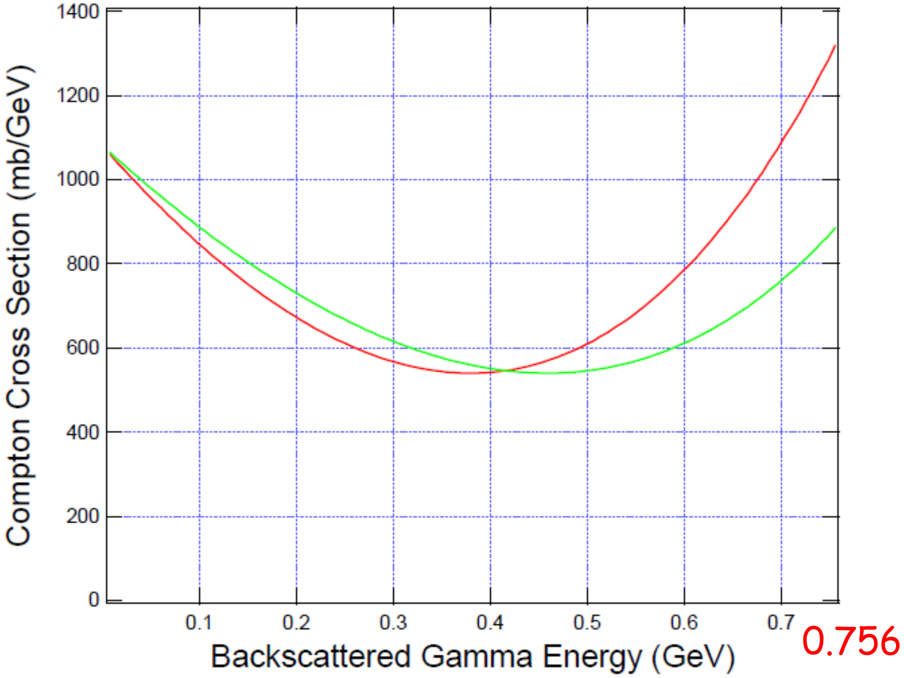
Initial operation with 4.20168 nsec between electron bunches in LER
119 MHz mode locked laser will see every other bunch
68 MHz mode locked laser will see every 7th electron bucket.

Operation with 2.10084 nsec between electron bunches in LER
119 MHz mode locked laser will see every 4th bunch
68 MHz mode locked laser will see every 7th electron bucket.

Laser con't

UV laser light at 3.45 eV





E_{beam} (GeV)	E_{photon} (eV)	Wmax (GeV)	$A\gamma_{max}$	$A\gamma_{flux\ wt}$	$A\gamma_{E\ wt}$	σ_{unpol} (mbarn)
4.18	2.3 green	0.537	0.137	0.030	0.064	1089
4.18	3.45 UV	0.756	0.197	0.040	0.088	731

Conclusions

Progress since Frascati Dec 09 Workshop:

1) Sawtooth timing problem.
2) Some ideas on luminosity measurement for left and right-handed electrons.
3) More information on mode-locked laser with output at different frequencies.

More work needed:

1) Systematics between the measurement of the polarization at the Compton IP and that at the IR. See also talks by Uli Wienands, Cecile Rimbault and Nicolas Monseau at this Workshop.

2) Positron polarization is zero? If it's established that there can be significant e+ polarization then likely need an e+ polarimeter. After estimating how much transverse polarization might be generated, need to see what machine errors and misalignments might do to rotating any generated vertical polarization in the ring into horizontal.

3) Detector efficiencies for mu+mu- pairs (other leptons also): Systematics need to be understood at the level of 10-6 needed for the Alr measurements.

4) Theoretical prediction for A_{lr} at the Upsilon 4S and the theoretical systematic errors.

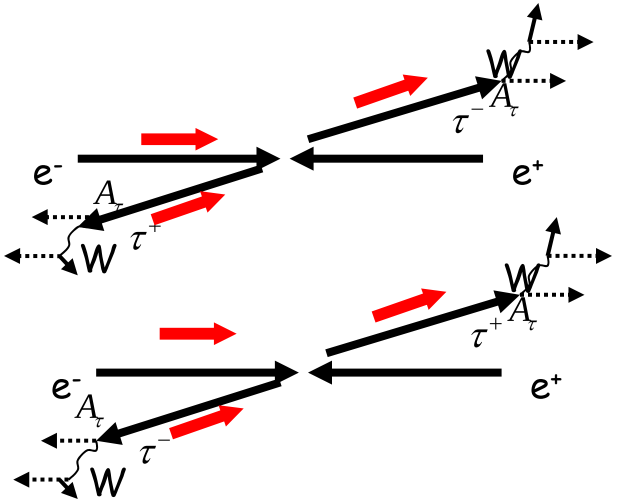
Prefer improved optics with spin direction at Compton IP to be closer to 180 degrees from that at IR.

Polarization at SuperB meetings on the 1st and 3rd Wednesdays of each month from 7:30 am to 8:30 am SLAC time.

Talks distributed by email with call in for voice to a U.S. conference phone number.
Send me an email to be put on list for announcements of agenda and phone number.
moffeit@slac.stanford.edu

Extra Material

Physics with polarized electron at SuperB:



Talks at this meeting:

- "Search for tau LFV with polarized beams" by Alberto Cervelli, INFN & Universita' di Pisa, Monday Physics I
- "Discusion on CP violation in Hadronic tau decays", Oscar Vives, Tuesday Physics V
- "Non-LFV Tau Physics with polarized beams" Michael Roney, Tuesday Physics V

Tau Lepton Flavor Violation: Polarized SuperB extends reach for LFV searches e.g. tau > $\mu\gamma$ and tau > $\mu\mu\mu$ by factor ~1.5 to 2. If tau LFV found then a polarized SuperB can better determine the features of the LFV interaction.

Tau asymmetry parameter:

Present asymmetry parameter measurements from PDG

$$A_e = 0.1515 \pm 0.0019$$

$$A_\mu = 0.142 \pm 0.015$$

$$A_\tau = 0.143 \pm 0.004$$

With polarized electrons SuperB can measure A_τ with the same precision as A_e

There is a 3-sigma discrepancy in weak mixing angle determined from lepton asymmetry measurements versus heavy quark asymmetry measurements at LEP-SLC; tau asymmetry measurements at SuperB will allow a 2nd precise lepton asymmetry measurements.

Physics with polarized electron at SuperB: A_{LR} for $\mu^+\mu^-$, …

A_τ , A_μ , A_b

From $|\gamma + Z|$ interference

and measurement of A_{LR} for muon pairs

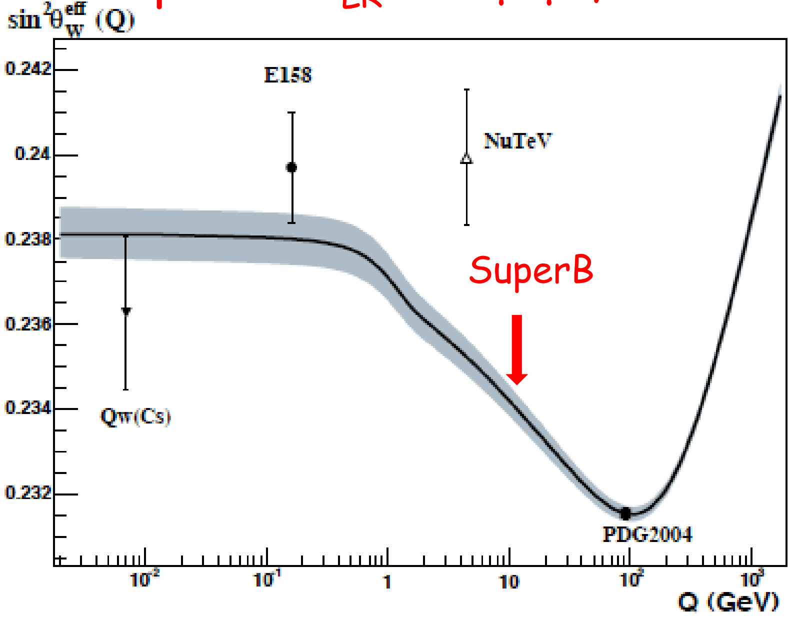


FIG. 2: Predicted variation [18] of $\sin^2\theta_W^{eff}$ as a function of momentum transfer Q (solid line) and its estimated theoretical uncertainty (shaded area). Results of prior low energy experiments [6, 16] (closed triangle, shown at an arbitrarily higher Q) and [7] (open triangle) are overlaid together with the Z^0 pole value [16] (square) and this measurement (circle).

$e^+e^- > \mu^+\mu^-$ at $\sqrt{s}=10.58$GeV

Diagram: $|Z+\gamma|^2$

Cross Section = 1.01 (nb)
A_{FB} = 0.0028
A_{LR}(Pol = 100%) = -0.00051

expected stat. error on A_{LR} = 4.6x10-6

- relative stat. error of 1.1% (pol=80%)
- So require <0.5% systematic error on beam polarization

Error on A_{LR} =5×10^{-6} gives error on ($\sin^2\theta_{eff}$) =0.00018
SLC A_{LR} error on ($\sin^2\theta_{eff}$) =0.00026

Similar measurement with tau-pairs –

see Michael Roney, “SuperB Neutral Current Polarisation Physics: Studies with Z_{Fitter} &tc”

Physics with polarized electron at SuperB: Tau anomalous magnetic moment

(J.Bernabeu, G. A. Gonzalez-Sprinberg, J. Papavassiliou, J. Vidal, Nuclear Physics B 790 (2008) 160 and
See Proceedings of SuperB Workshop VI arXiv:0810.1312v2 [hep-ph] 10 Oct 2008.

Electron anomalous magnetic moment is measured with the highest precision.

$$a_e = \mu_e / \mu_B - 1 = \frac{g_e - 2}{2} = \left(1159.6521810 \pm 0.0000007\right) \times 10^{-6}$$

$$a_\mu = \mu_\mu /(eh/2m_\mu) - 1 = \frac{g_\mu - 2}{2} = \left(1165.92080 \pm 0.00054 \pm 0.00033\right) \times 10^{-6}$$

Present knowledge of Tau anomalous magnetic moment is rather poor.

$$-0.052 < a_\tau < 0.013(95\% C.L.)$$

Standard model predicts: $a_\tau^{SM} = \mu_\mu /(eh/2m_\tau) - 1 = \frac{g_\tau - 2}{2} = 1177.21(5) \times 10^{-6}$

Electron polarization gives the tau polarization and the transverse and longitudinal asymmetries of the tau decays determine the tau anomalous magnetic moment.

Tau anomalous magnetic moment can be measured with a statictical error of ~2.4X10^{-6} with electron polarization in SuperB.

$$a_\tau^{SuperB} = \frac{g_\tau - 2}{2} \approx (11?? \pm 2.4) \times 10^{-6}$$

Physics with polarized electron at SuperB: Tau EDM

The electric dipole moment of the tau (CP violation) can be determined from the transverse asymmetries in the tau decays.

Present Knowledge: Search for the tau EDM with unpolarized beam has been reported by Belle (K. Inami et al.Phys. Lett. B551, 16 (2003)) with sensitivity

$$tau_{EDM} = [0.9 - 1.7] \times 10^{-17} e \cdot cm$$

SuperB with unpolarized electrons sensitivity tau_{EDM} ~ [17-34] X 10^{-20} e cm

SuperB with Polarized electrons: Sensitivity for the real part of the tau electric dipole moment from 75ab^{-1} and 80% polarization, 80% geometric acceptance and 97.5% track reconstruction efficiency. See Proceedings of SuperB Workshop VI arXiv:0810.1312v2 [hep-ph] 10 Oct 2008.

SuperB with P_e~ 80%

$$tau_{EDM} \approx 10 \times 10^{-20} e \cdot cm$$

All the hadronic tau channels can be used to improve the measurement.

A polarized SuperB gives a factor of 1.7 to 3.4 improved sensitivity to an tau electric dipole moment over an unpolarized SuperB.