Polarization at SuperB

- Overview of scheme to measure polarization near the IR
- Transverse polarization measurement with longitudinal polarimeter setup near IR.

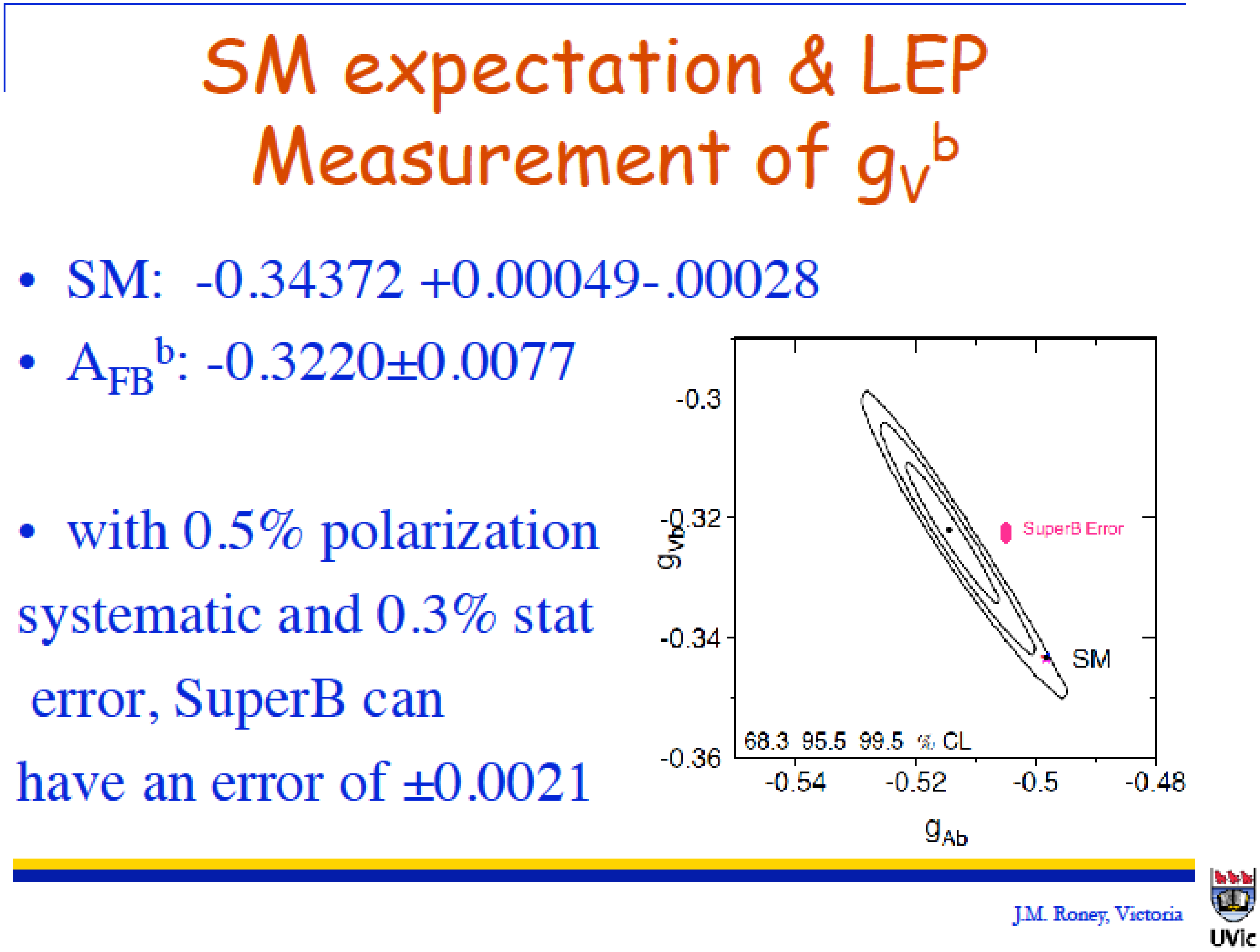
XIV SuperB General Meeting
LNF-INFN
September 27, 2010 to October 1, 2010
Ken Moffeit, SLAC

Physics with longitudinally polarized electrons at SuperB:

1) Tau asymmetry parameter requires precision measurement of polarization.
2) Precision electroweak parameter measurements $\sin^2(q_w)$ at 10.85 GeV through γ Z interference. Requires precision measurement of polarization ~ dP/P 0.5%.
3) Measurement of Tau anomalous magnetic moment.
4) Measurement of the Tau electric dipole moment (or upper limit).
5) Help reduce background for some searches of rare decays.

Physics measurements require high precision polarimetry.
Goal for polarimeter is
dP/P ~1%

Slide from Michael Roney's Alba Talk



SM expectation & LEP Measurement of g_V^b

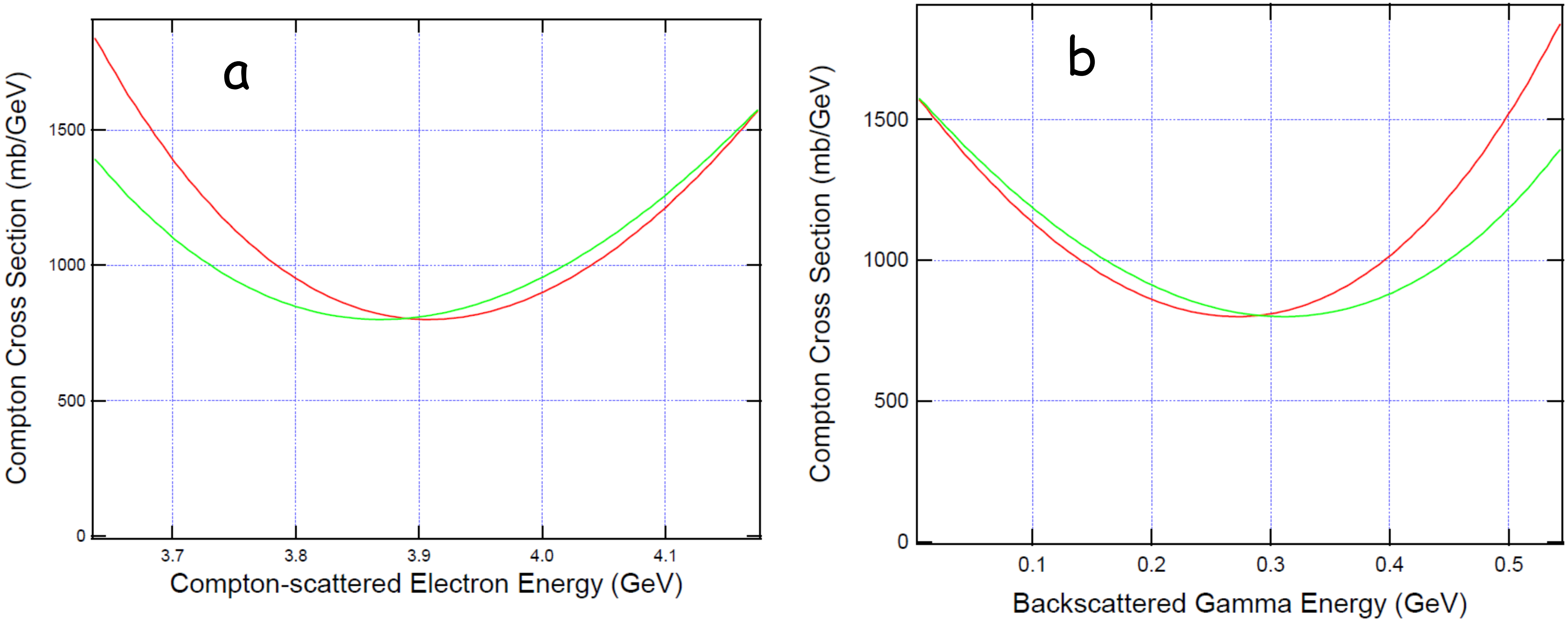
- SM: -0.34372 +0.00049-.00028
- A_{FB}^b: -0.3220±0.0077

- with 0.5% polarization systematic and 0.3% stat error, SuperB can have an error of ±0.0021

J.M. Roney, Victoria

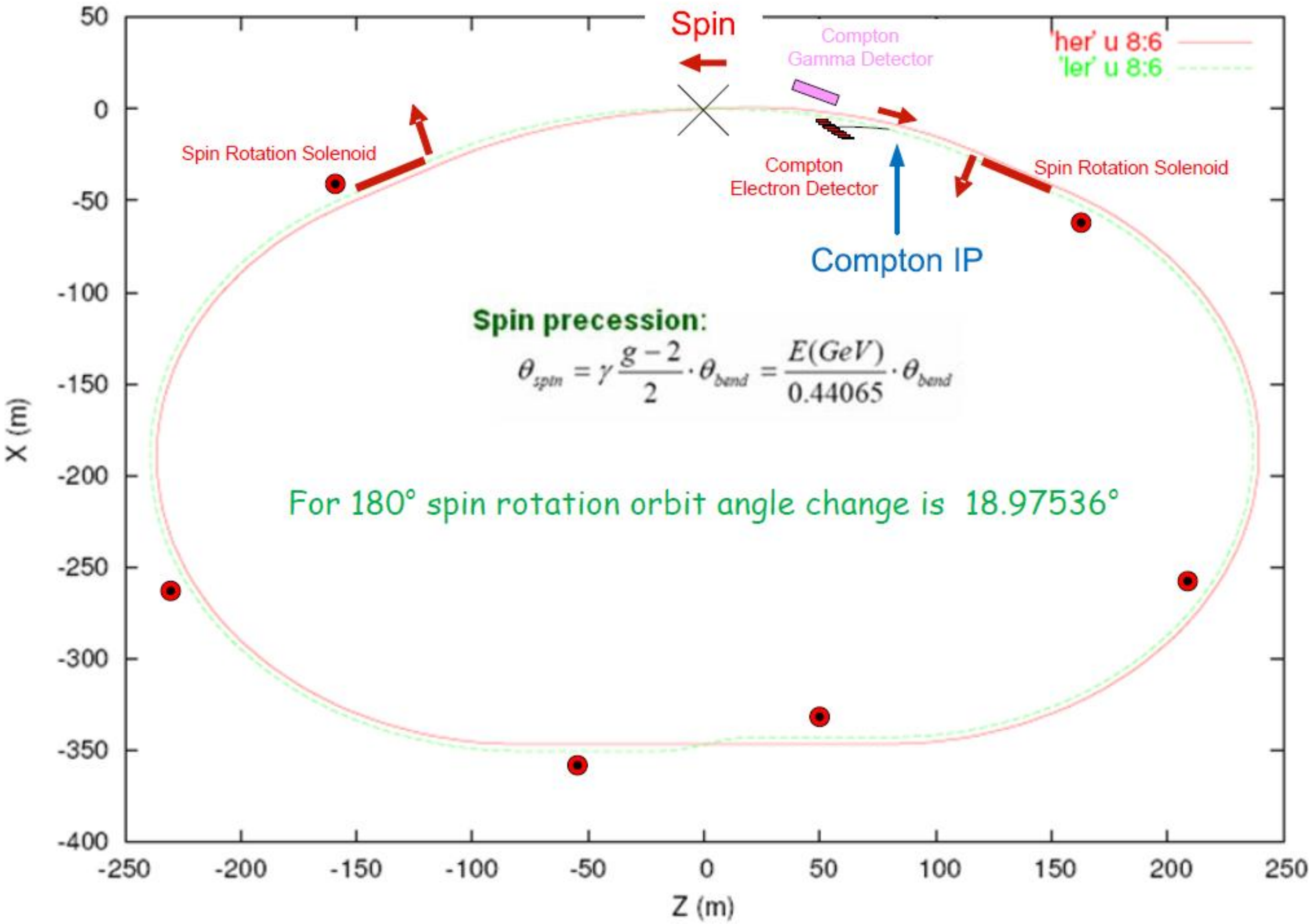
UVic

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).

Interaction Region

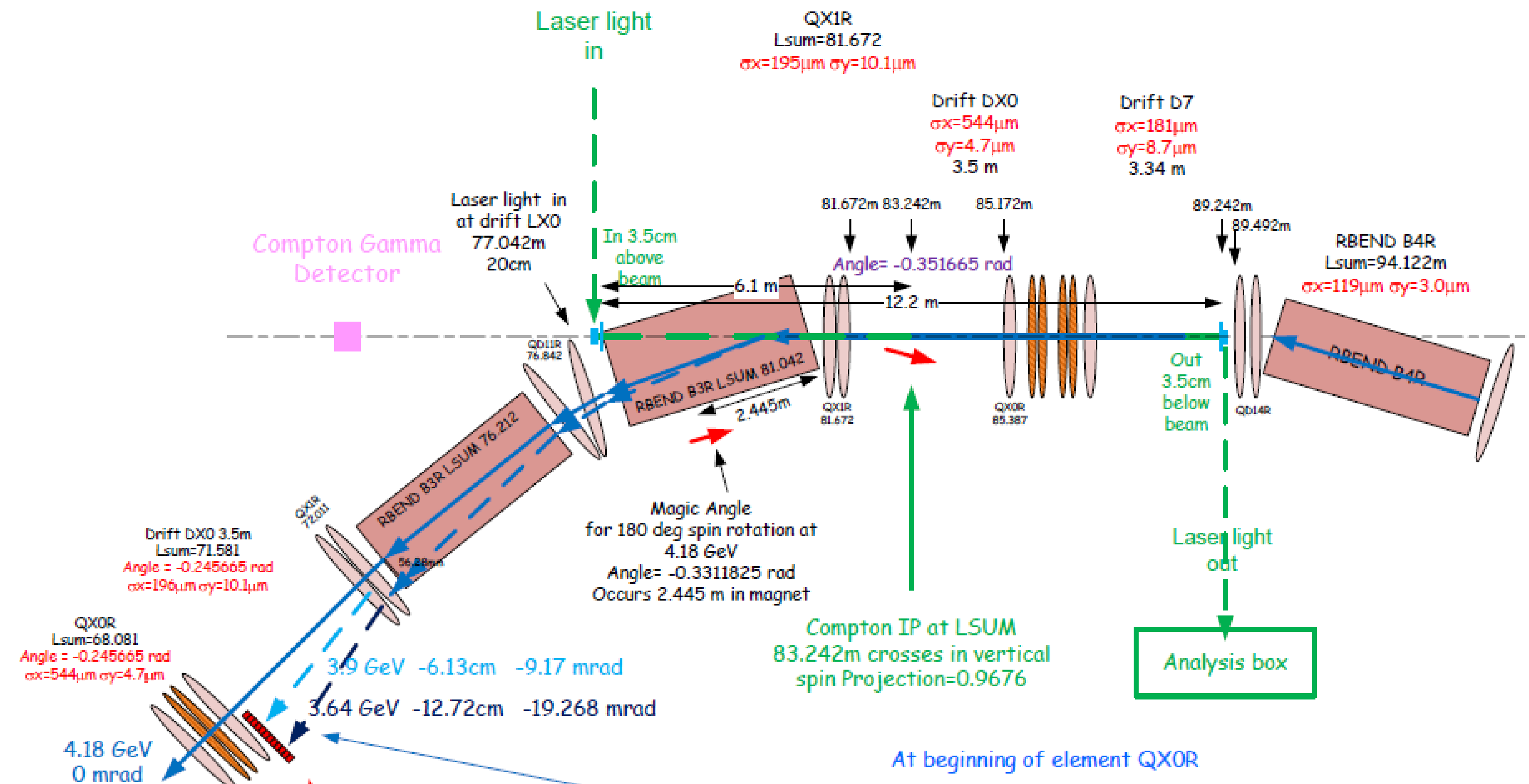


Spin precession:

$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend}$$

For 180° spin rotation orbit angle change is 18.97536°

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

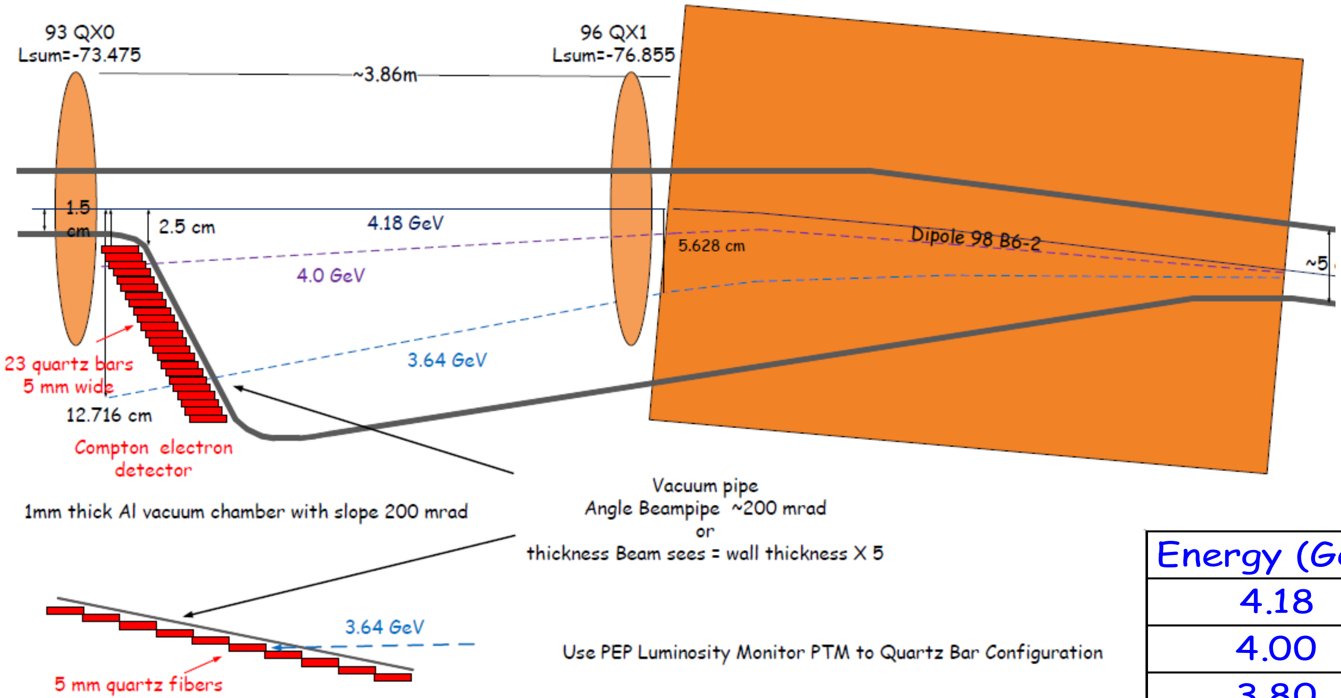


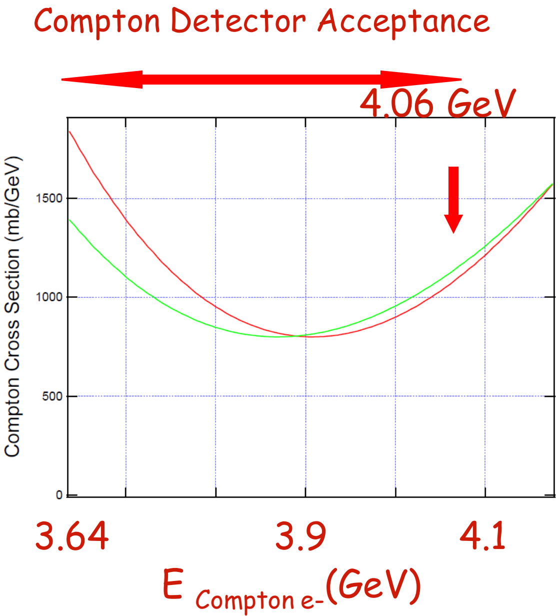
At beginning of element QX0R

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





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 . For electron detector, need to decide whether need an adc on each channel or just a discriminator and register.

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; this assumes have an adc on the detector channel and have some energy resolution to take advantage of large asymmetry for high energy gammas.

- 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.

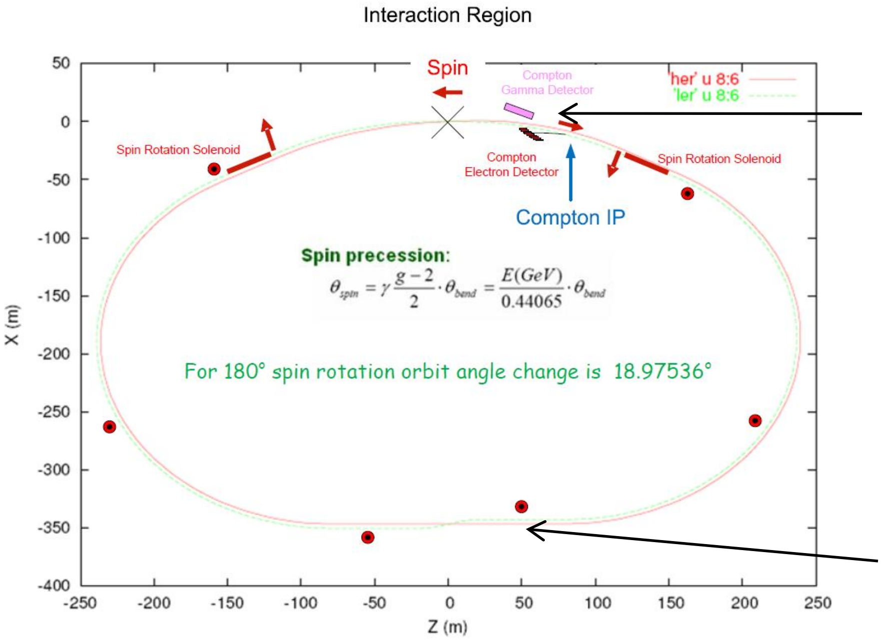
Transverse Polarization Measurement from Forward Gamma Detector

1. Measure all forward gamma for longitudinal polarization measurement.

- Measure longitudinal polarization by summing signals.
- It will be hard to match the 1% precision goal for the electron detector; more study needed.
- During longitudinal polarization running the forward gamma detector will be capable of measuring the transverse vertical polarization and verify that it is small.

2. Measure up/down rate for transverse polarization measurement.

Transverse measurement with **Spin Rotators off** allows machine tuning diagnostics and precision energy measurement of the electron beam from locating spin depolarization resonances.



Option A: Design forward gamma detector to be able to measure transverse polarimeter.

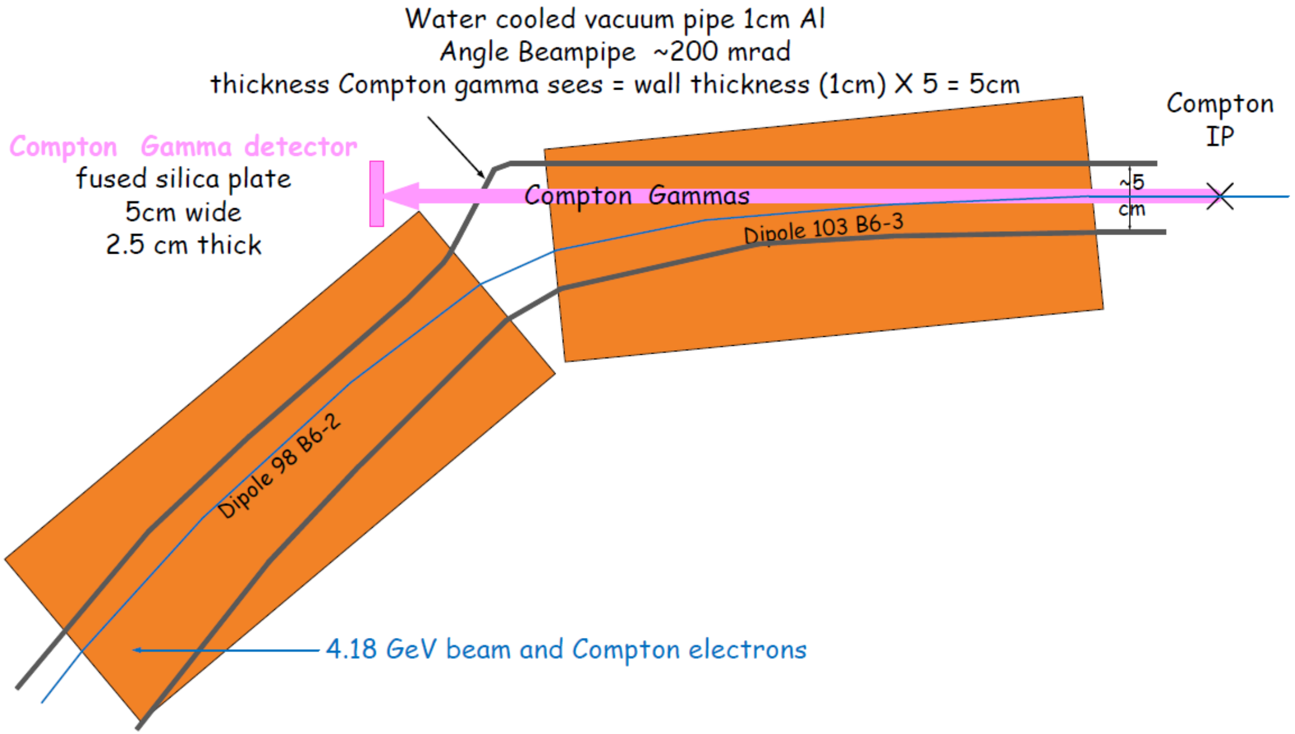
- Spin rotators need to be turned off.
- Only during machine studies.
- Cheap

Option B: Add dedicated transverse polarimeter.

- Continuous transverse polarization measurement.
- Expensive

Compton Gamma Detector

Longitudinal polarization only requires integrated Compton gamma measurement



Fused Silica Plate measures all gamma for longitudinal polarization measurement.

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 (~5cm) to beam pipe.

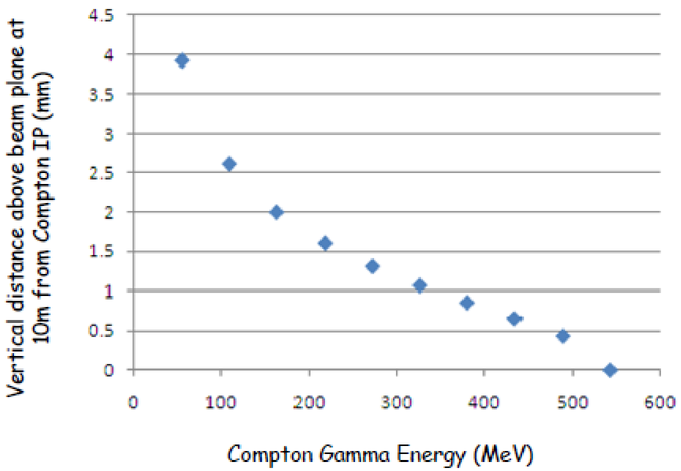
Shower rejuvenated using local plate of tungsten or lead of ~2 RL covering. Remote insertion of different thickness radiators will allow systematic studies as was done at SLC and PEPII.

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

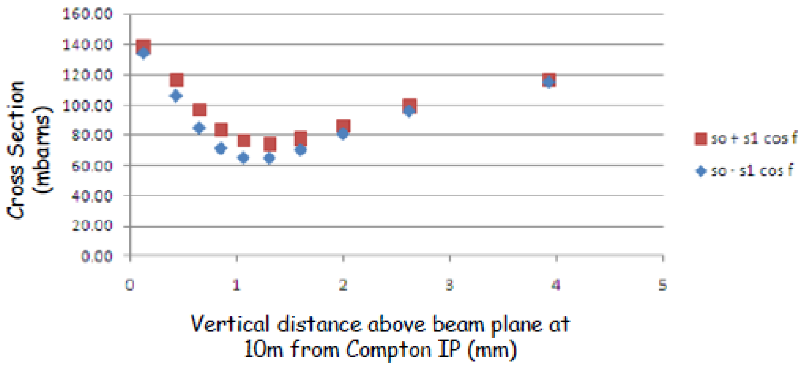
Cherenkov light is taken out through a slanted roof into a light pipe, and converted in one or more 8 mm cathode fast PMTs. Fused silica may be extended a few cm to best match the PMT.

Shielding the calorimeter from background will be necessary.

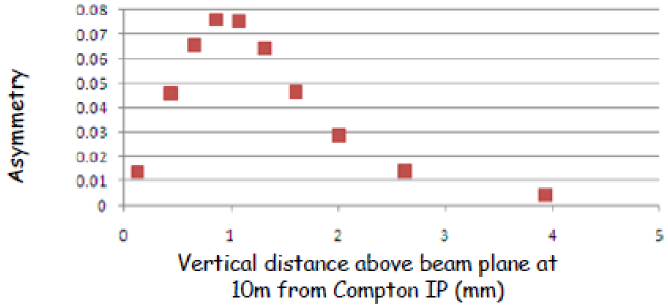
Transverse Polarization Asymmetry with left and right-handed circularly polarized laser light on electrons with spin direction in the vertical.



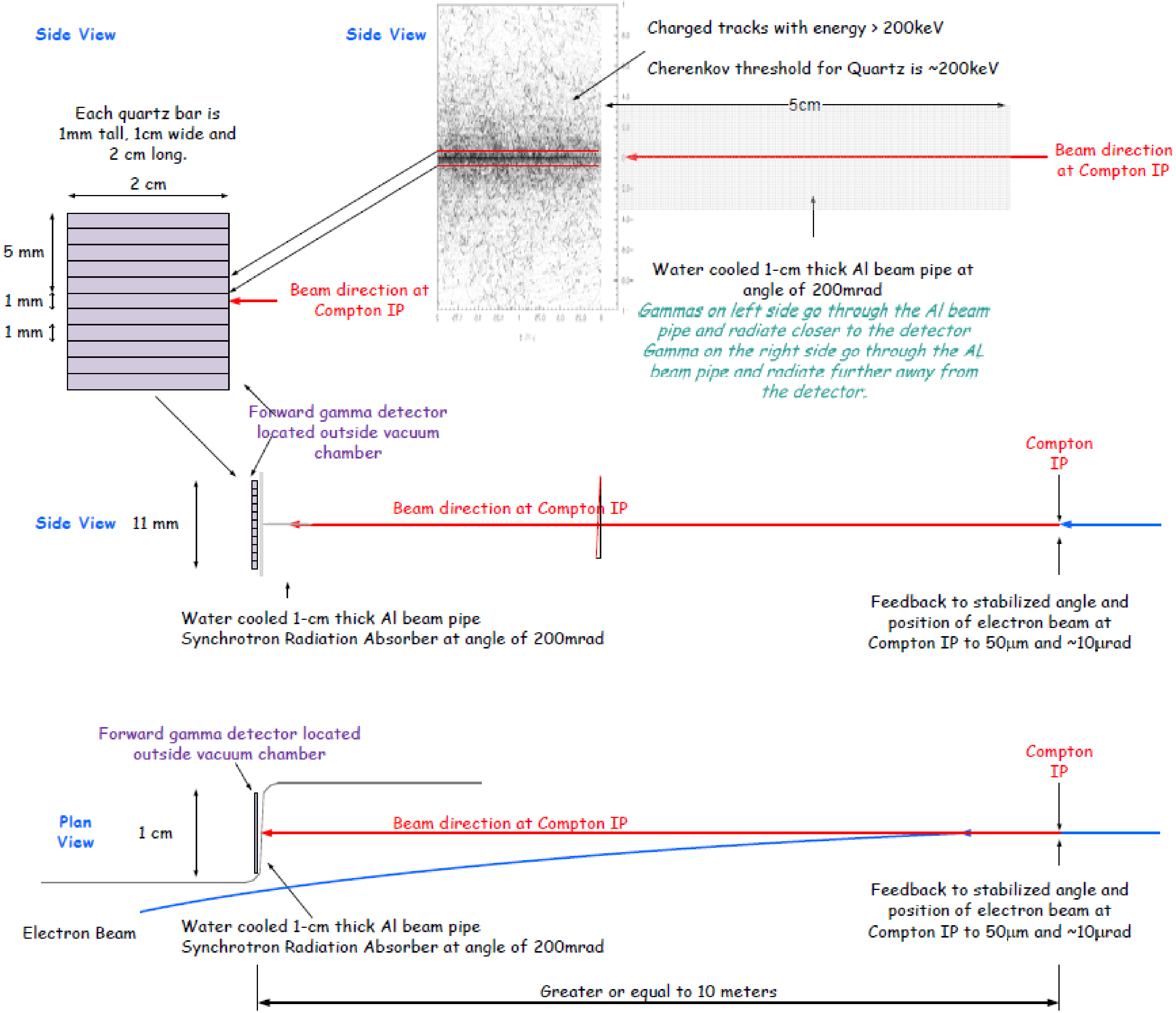
Compton Scattering
$E_{electron}$ = 4,180 MeV
Green Laser Light at 2.33 eV
Distance from Compton IP to Detector = 10m



Asymmetry for left and right handed laser light on polarized electrons with spin direction in the vertical (ϕ = 0)



Gamma Detector for Transverse polarization in Air



Side View

Side View

Charged tracks with energy > 200keV

Cherenkov threshold for Quartz is ~200keV

5cm

Beam direction at Compton IP

Each quartz bar is 1mm tall, 1cm wide and 2 cm long.

2 cm

5 mm

1 mm

1 mm

Beam direction at Compton IP

Water cooled 1-cm thick Al beam pipe at angle of 200mrad

Gammas on left side go through the Al beam pipe and radiate closer to the detector
Gamma on the right side go through the AL beam pipe and radiate further away from the detector.

Forward gamma detector located outside vacuum chamber

Compton IP

Side View 11 mm

Beam direction at Compton IP

Water cooled 1-cm thick Al beam pipe
Synchrotron Radiation Absorber at angle of 200mrad

Feedback to stabilized angle and position of electron beam at Compton IP to 50μm and ~10μrad

Forward gamma detector located outside vacuum chamber

Compton IP

Plan View 1 cm

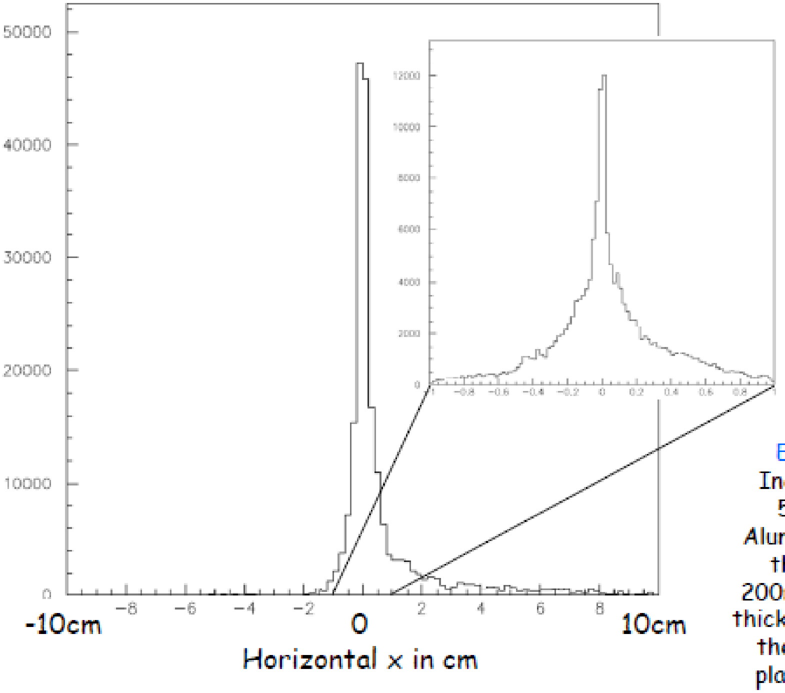
Beam direction at Compton IP

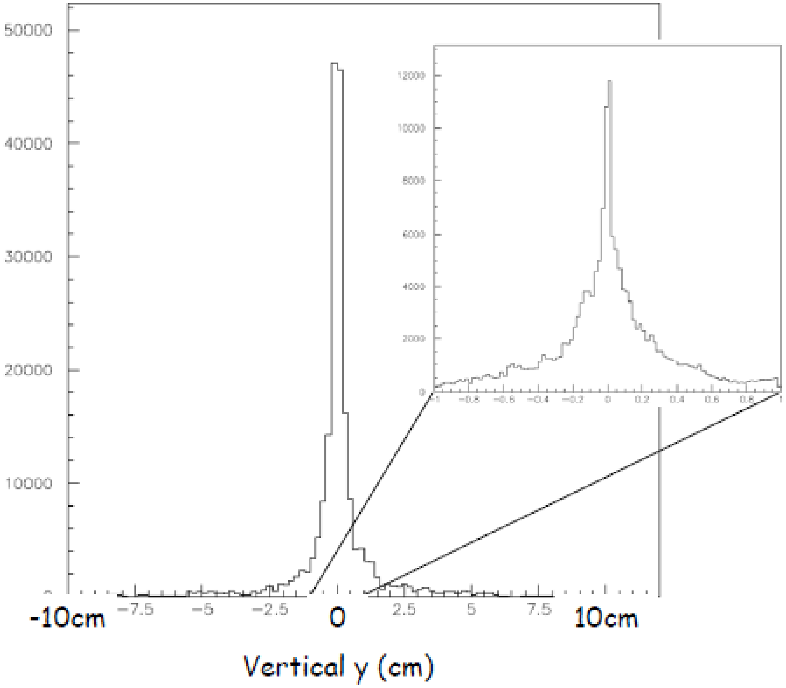
Electron Beam

Water cooled 1-cm thick Al beam pipe
Synchrotron Radiation Absorber at angle of 200mrad

Feedback to stabilized angle and position of electron beam at Compton IP to 50μm and ~10μrad

Greater or equal to 10 meters





EGS simulation results

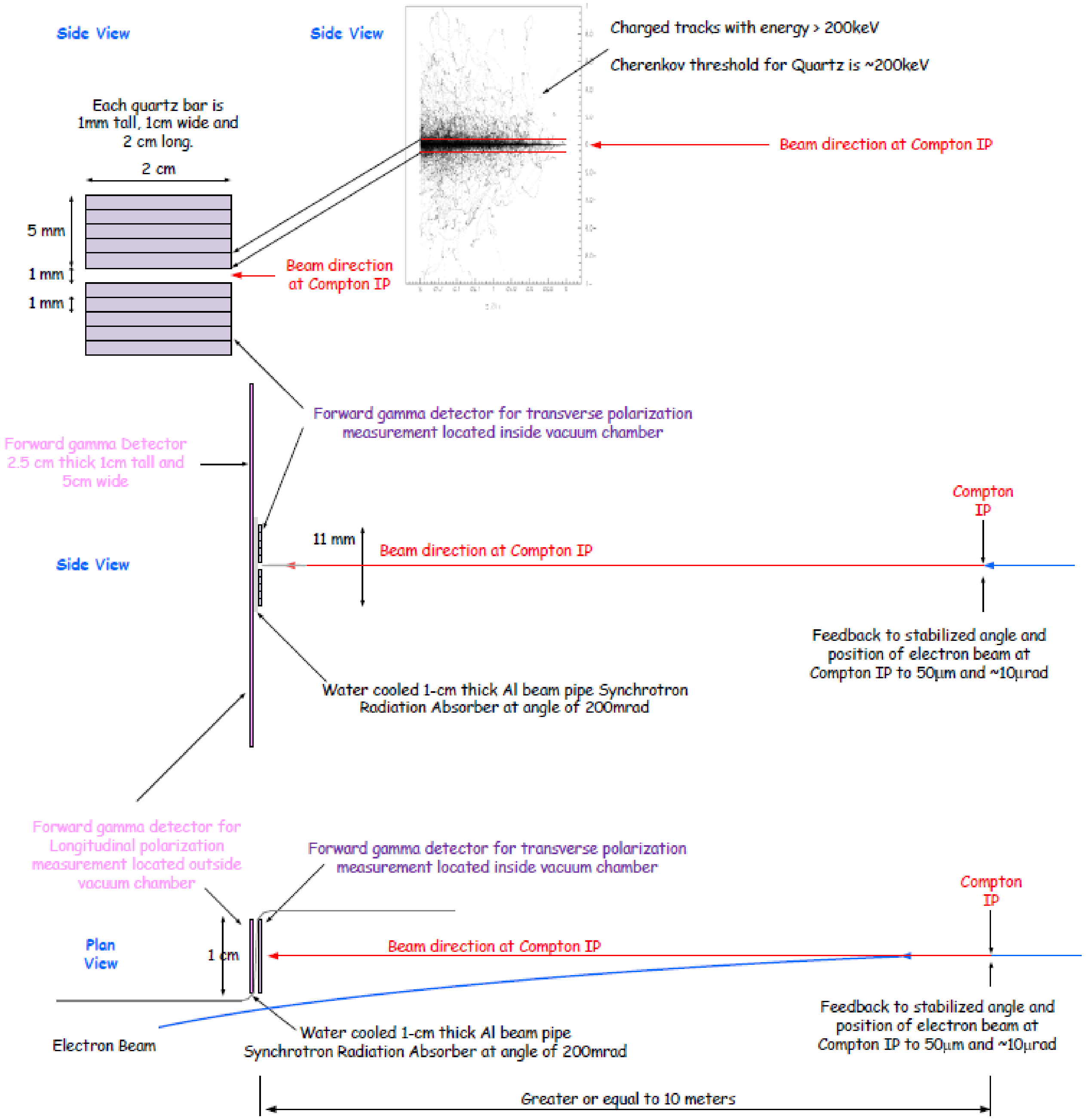
Incident photon energy is 542MeV. A 1-cm thick Aluminum plate is in front of the 2-cm long quartz at 200mrad, ie the effective Al thickness is ~5cm. You can see the asymmetry due to the plate in the x distribution.

Significant smearing of signal, but may be adequate for precision required. If needed, several possibilities for improvement:

a) Use a 0.5 or 1 radiation length converter right in front of the quartz
b) Move the detector back from the cooled vacuum window by a couple of meters or so.
c) The cooled vacuum chamber exit window could be optimized to reduce the "splat" from there. Use Beryllium, boron carbide windows, or your thinned aluminum groove, are conceivable.
d) Absorbing the extra leaking synchrotron radiation heat, externally, would be easy and worth the advantage.

Small R&D effort will be needed before proceeding with a detailed design.

Gamma Detector for Transverse Polarization inside Vacuum Chamber



Side View

Side View

Charged tracks with energy > 200keV

Cherenkov threshold for Quartz is ~200keV

Beam direction at Compton IP

Each quartz bar is
1mm tall, 1cm wide and
2 cm long.

2 cm

5 mm

1 mm

1 mm

Beam direction
at Compton IP

Forward gamma detector for transverse polarization
measurement located inside vacuum chamber

Forward gamma Detector
2.5 cm thick 1cm tall and
5cm wide

Compton
IP

Side View

11 mm

Beam direction at Compton IP

Feedback to stabilized angle and
position of electron beam at
Compton IP to 50μm and ~10μrad

Water cooled 1-cm thick Al beam pipe Synchrotron
Radiation Absorber at angle of 200mrad

Forward gamma detector for
Longitudinal polarization
measurement located outside
vacuum chamber

Forward gamma detector for transverse polarization
measurement located inside vacuum chamber

Compton
IP

**Plan
View**

1 cm

Beam direction at Compton IP

Feedback to stabilized angle and
position of electron beam at
Compton IP to 50μm and ~10μrad

Electron Beam

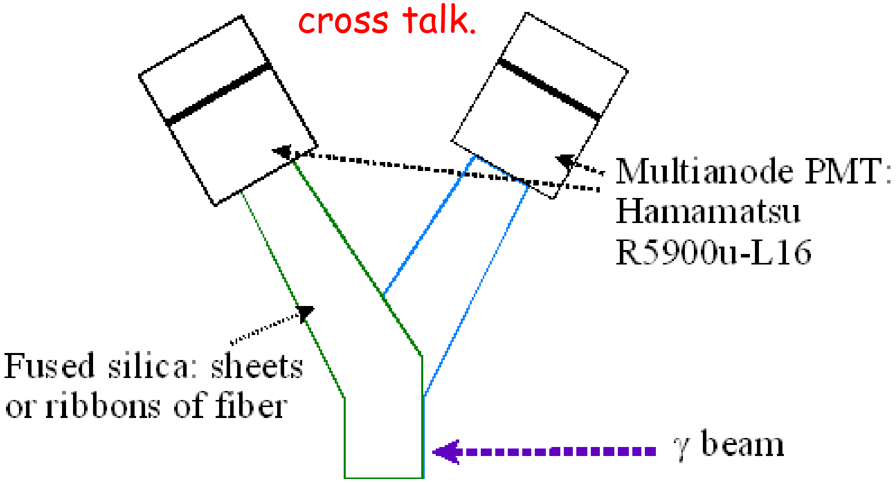
Water cooled 1-cm thick Al beam pipe
Synchrotron Radiation Absorber at angle of 200mrad

Greater or equal to 10 meters

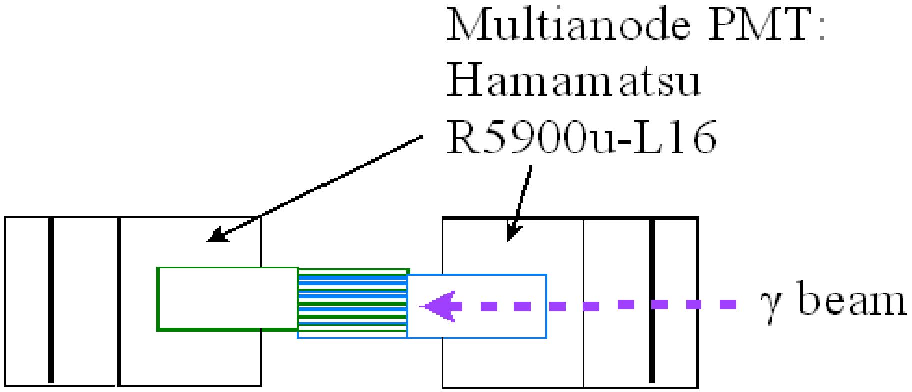
May have significant effect from backsplash on Al beam pipe for the detector response.

Scheme for collecting light from Quartz Bar in forward Gamma Detector

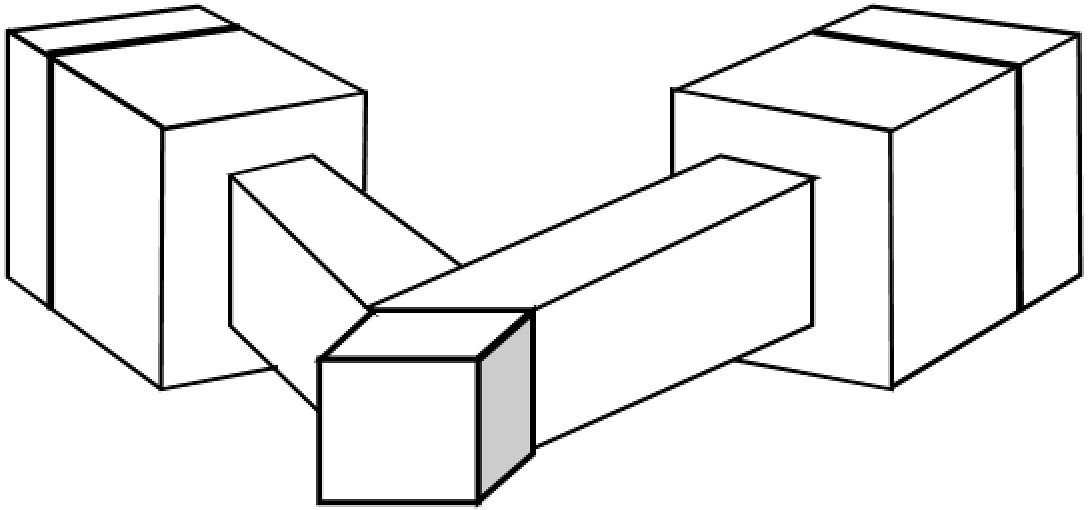
Two PMTs are required to reduce cross talk.



Plan View



Elevation view



The PMT listed on the drawing has 16 independent anodes, each 16 mm wide by ~0.9 mm, all in a single line at 1 mm pitch. The output pulse length claimed is shorter than 4 nsec.

Comments on Forward Gamma Detector

- Requirements: Read out the Compton gamma signals from a single bucket each time it goes around the ring, accumulate data over a few seconds and give polarization. Laser light is randomly flipping right to left-handed circularly polarized.

- Use the 1 mm pitch between samples

- Maintain reasonable light coupling (Careful Monte Carlo of the detector's performance needs to be done.

- Use a sensitive and very fast detector.

- Given the tight geometry and the light levels expected, it seems most natural to do this with a 1 mm pitch multi-anode PMT. However, with light pipes of this kind there would be optical cross-talk at the PMT face ~ 0.5 - 1 mm. To get around this, the light pipes alternate between an upstream and a downstream PMT, with even-numbered PMT anodes reading out cross-talk between the odd-numbered anodes that are directly aligned with the light pipe and read out "signal".

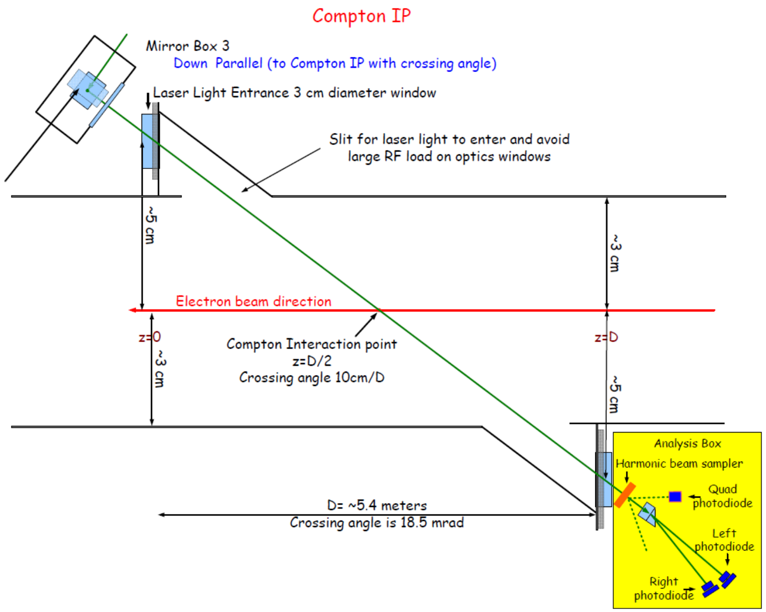
- Technically, there are lots of things to take care of, such as various sources of cross-talk in addition to the optical one noted above, linearity of response, and ~50% variability among the PMT's 16 channels, etc. These would be dealt with as part of the normal technical effort needed to set up and operate the thing.

Scheme for electronics needs to be worked out. This mode requires pulse-height measurements at every laser shot. That may be a bit expensive per channel because of the need for fast digital conversion and deep, fast, data buffering. Maybe only need ADC for the sum signal.

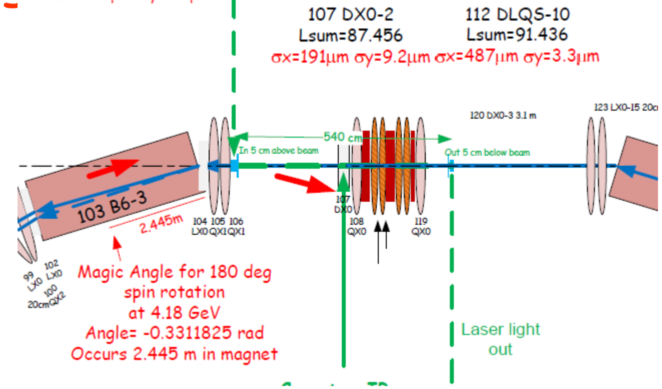
Sawtooth timing of electron bunch arrival at Compton IP

- 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, 79.3MHz or 119MHz.
- Therefore, the electron beam will arrive before or after the laser photon arrives at Compton IP.

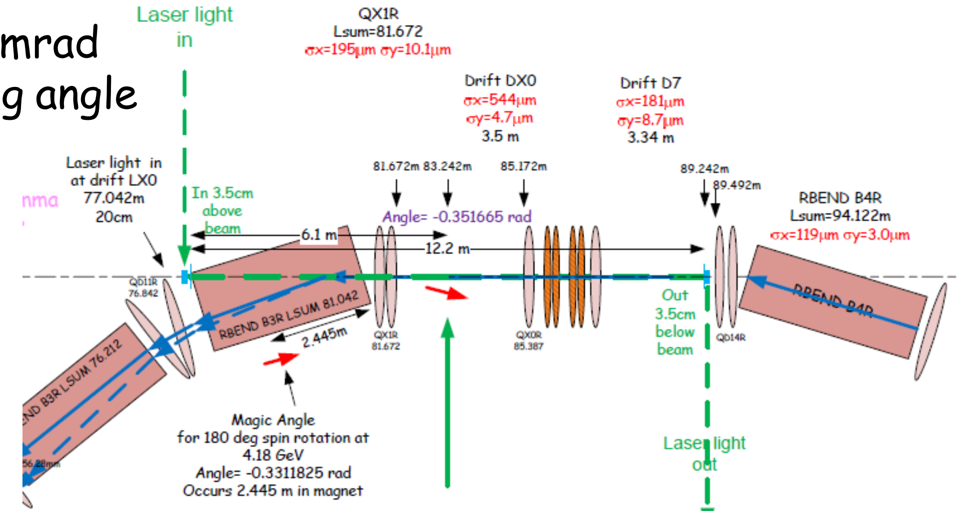
Decrease crossing angle of Laser light with electron beam



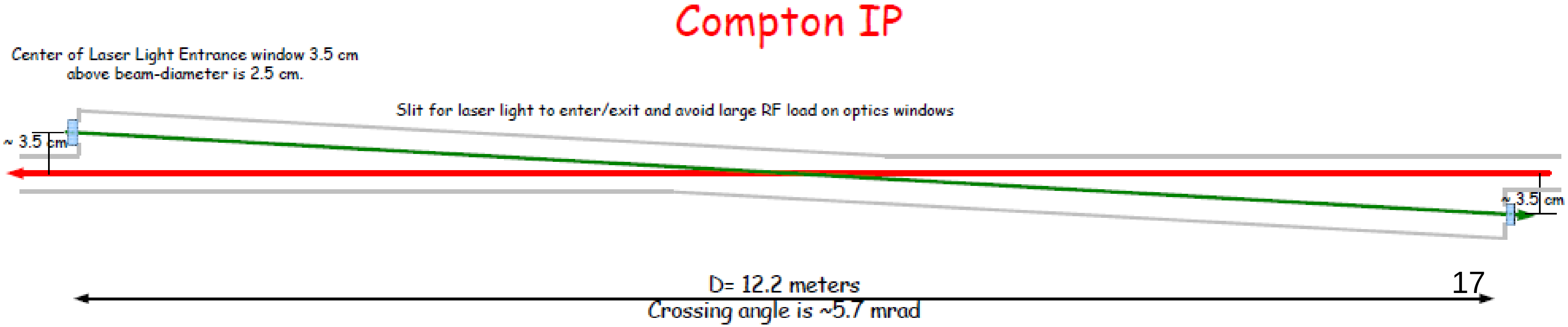
18.5 mrad crossing angle



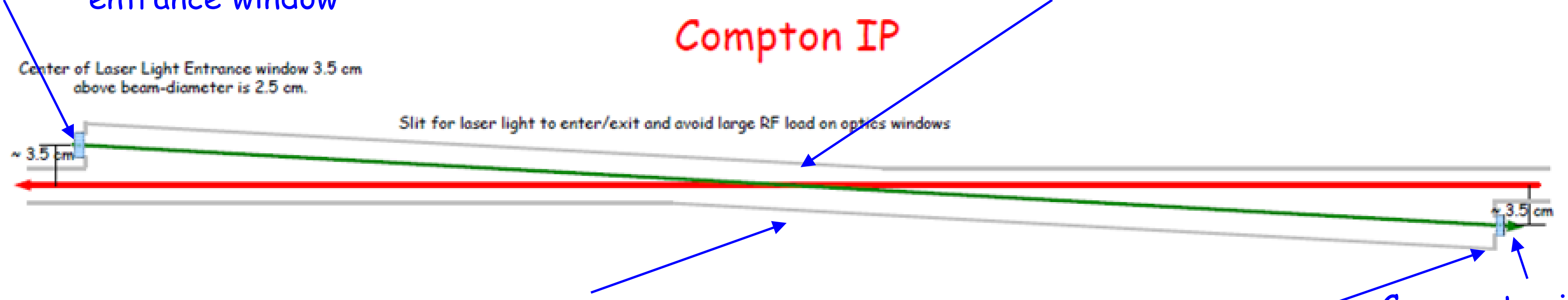
~5.7 mrad crossing angle



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



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



Camera to view laser light on entrance window

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).

Laser Developments

We still need to complete evaluation of options for:

- wavelength (ex. 355, 400, 532, 800nm options)
- frequency (68MHz, 79.3MHz and 119MHz)

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)

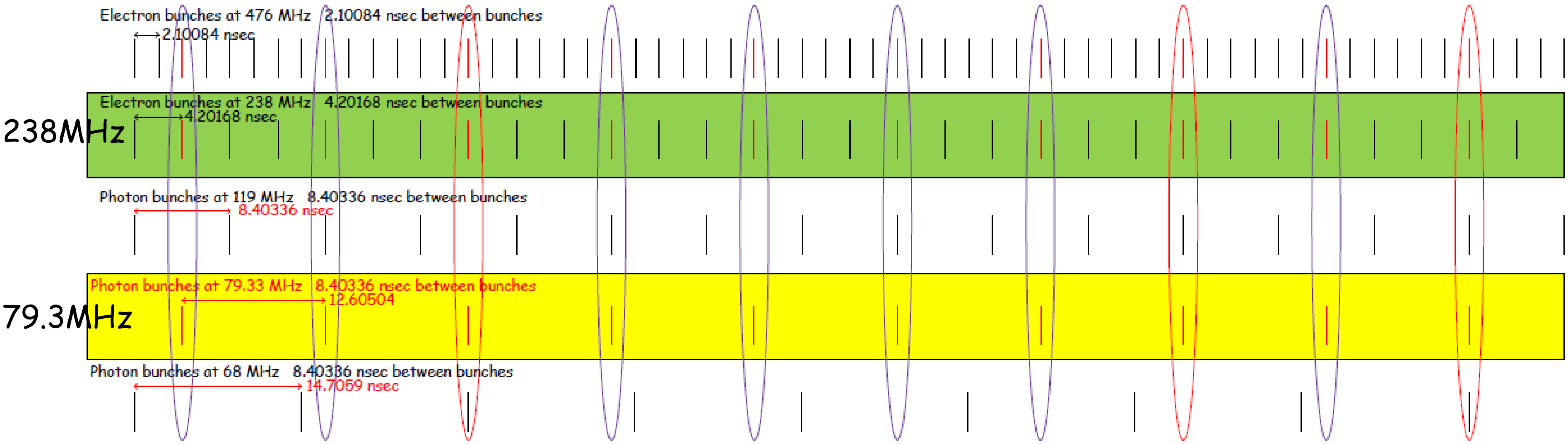
4. SPEAR Gun Test Facility: 1054nm, 119 MHz, 300 fs, 115 mW (Time-Bandwidth/Lightwave)

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

Laser at 3rd harmonic at 79.3MHz

- Recent SLAC oscillators have been delivered by Femtolasers (Austrian company) with both 68MHz and 119 MHz locking.
- Only 68MHz and 119MHz have been considered for SuperB because SLAC has experience with these lasers do.
- A mode locked laser at 79.3MHz should work for the SuperB application with colliding laser pulses at a storage ring.
- Lasers like to run at ~80MHz and so 79.3MHz would be easier to get a good laser.

Electron bunches and laser bunches from mode locked laser



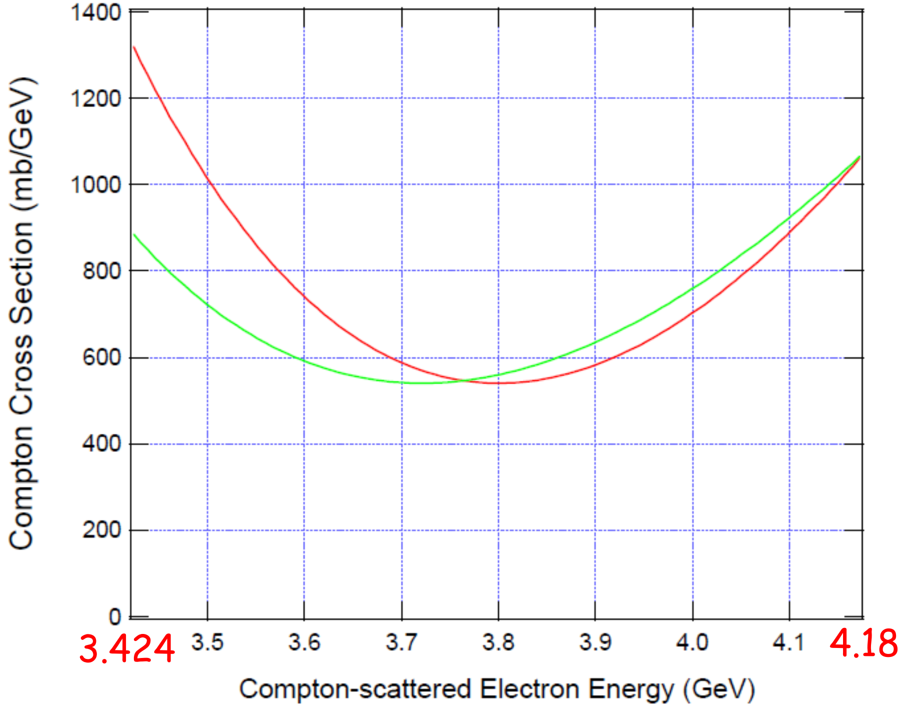
Initial operation with 4.20168 nsec between electron bunches in LER
79.3333 MHz mode locked laser will see every third bunch

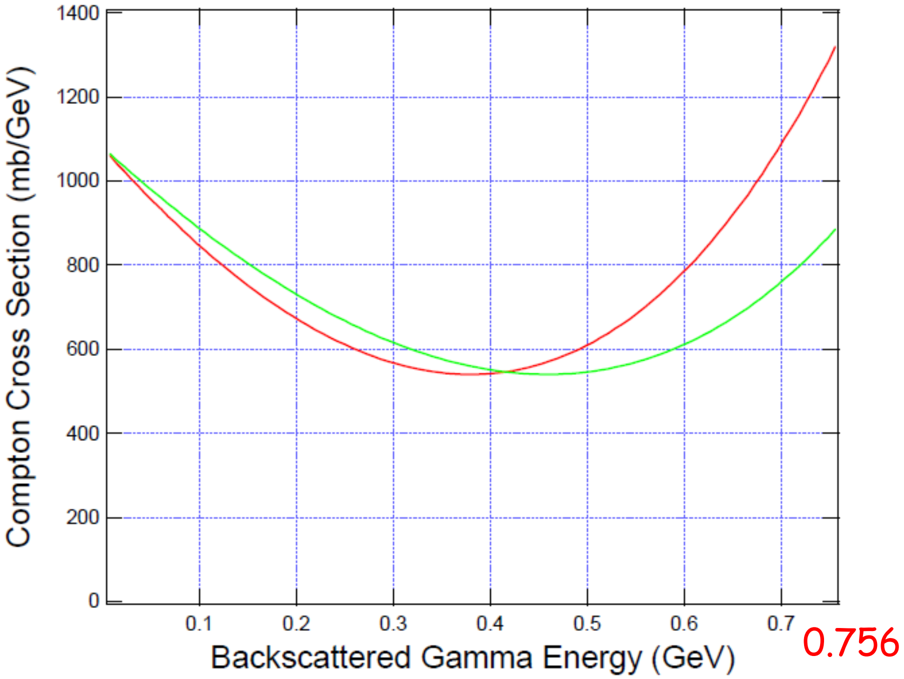
Operation with 2.10084 nsec between electron bunches in LER
79.3333 MHz mode locked laser will see every 6th bunch

- We still need to confirm with accelerator rf experts that 79.3MHz is ok for this application at a storage ring; and for last bullet, state "Commercial mode-locked lasers typically run at ~80MHz, so more options are available at 79.3MHz than for 68MHz or 119MHz."

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

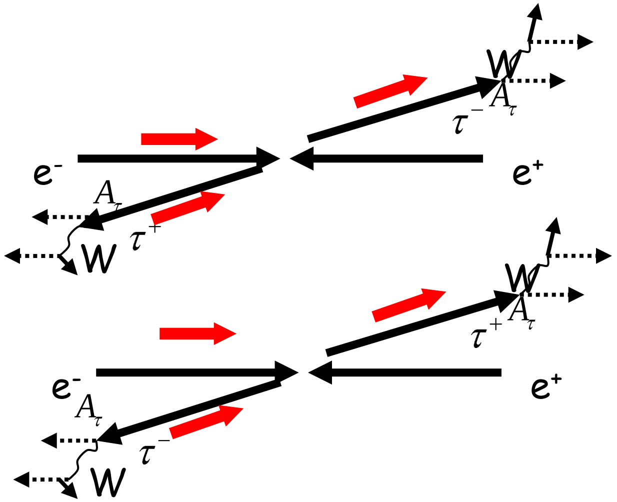
- Need improved optics with spin direction at Compton IP closer to 180 degrees from that at IR.

- Transverse polarization measurement using longitudinal polarimeter with spin rotators off may be possible and would enable measurement of depolarization spin resonances, polarization decay times and other machine studies.

- Precise beam energy measurements for transverse polarization utility.

Extra Slides

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 $\mu^+\mu^-$, …

$$A_\tau, A_\mu, A_b$$

From $|\gamma + Z|$ interference

and measurement of A_{LR} for muon pairs

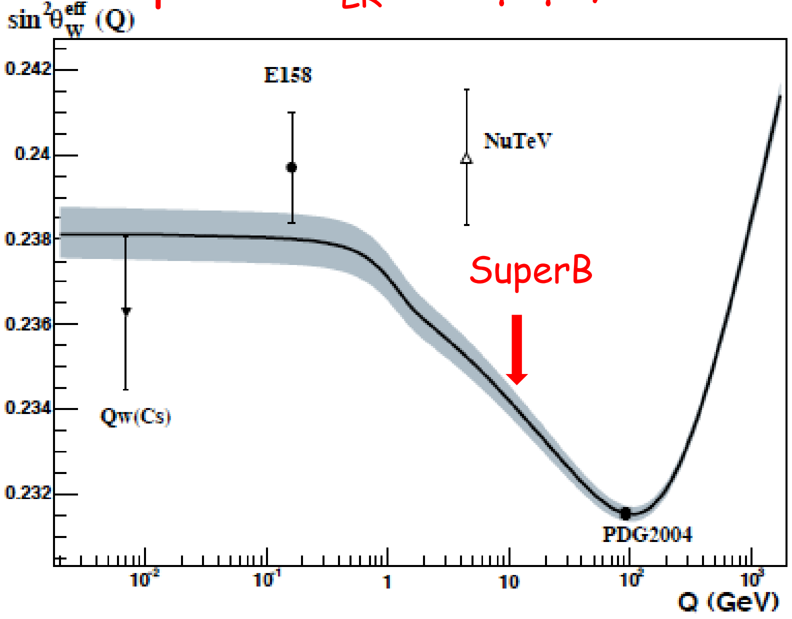


FIG. 2: Predicted variation [18] of $\sin^2\theta_W^{\mathrm{eff}}$ as a function of momentum transfer Q (solid line) and its estimated theoretical uncertainty (shaded area). Results of prior low energy experiments [6, 16] (closed triangle, shown at an arbitrarily higher Q) and [7] (open triangle) are 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** **(Expect ~1%)**

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.

$$a_e = \mu_e / \mu_B - 1 = \frac{g_e - 2}{2} = (159.6521810 \pm 0.0000007) \times 10^{-6}$$

$$a_\mu = \mu_\mu / (eh/2m_\mu) - 1 = \frac{g_\mu - 2}{2} = (165.92080 \pm 0.00054 \pm 0.00033) \times 10^{-6}$$

Present knowledge of Tau anomalous magnetic moment is rather poor.

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

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

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

SuperB with unpolarized electrons sensitivity $\mathrm{tau}_{\mathrm{EDM}}$ ~ [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.

SuperB Neutral Current Polarisation Physics: Precision EW Physics

Michael Roney
University of Victoria

J.Bernabeu, F.J. Botella, M. Nebot, O. Vives
Universitat de Valencia

May 2010

Elba

next three slides courtesy of Oscar Vives

J. Bernabéu , F.J. Botella , M. Nebot , O. Vives

Departament de Física Teòrica, Universitat de València and I.F.I.C.
(Centre Mixte Universitat de València–C.S.I.C.)
E-46100 Burjassot (València, Spain)

BOTTOM LINE: **work confirms conclusion that A_{LR} from BBbar events at the 4S giving access to the Z-b-bbar vector coupling is sound and in fact very robust!**
INDEPENDENT *of whether via Continuum or Resonance !*