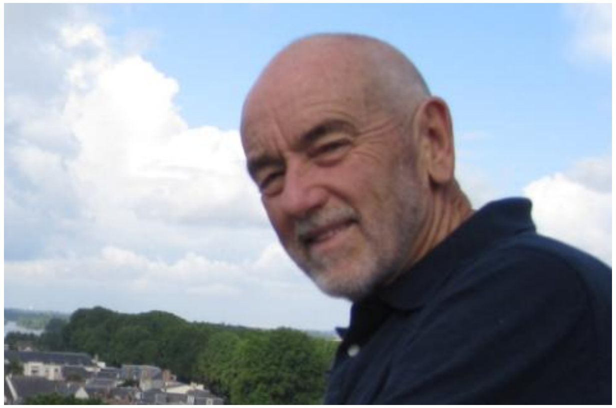
Luminosity Weighted Polarization

International Workshop on Linear Colliders 2010
October 18-22, 2010

Outline of Talk
Polarized Physics
Polarization at ILC and CLIC
Upstream Polarimeter
Downstream Polarimeter
Orbit angle concerns



Ken Moffeit, *SLAC*

Physics with polarized beams

Cross section enhanced or reduced

The cross sections can be enhanced or reduced by an appropriate choice of the polarization states. This allows to suppress the background: For instance, a ratio of 'undesired' to 'desired' polarization states, $[(1 - P_{e^-})(1 - P_{+})]/[(1 + P_{e^-})(1 + P_{e^+})]$, yields a background reduction by a factor 4 having (80%, 60%) polarization instead of (80%, 0%). A positron polarisation of 30% reduces this undesired background by a factor 2.

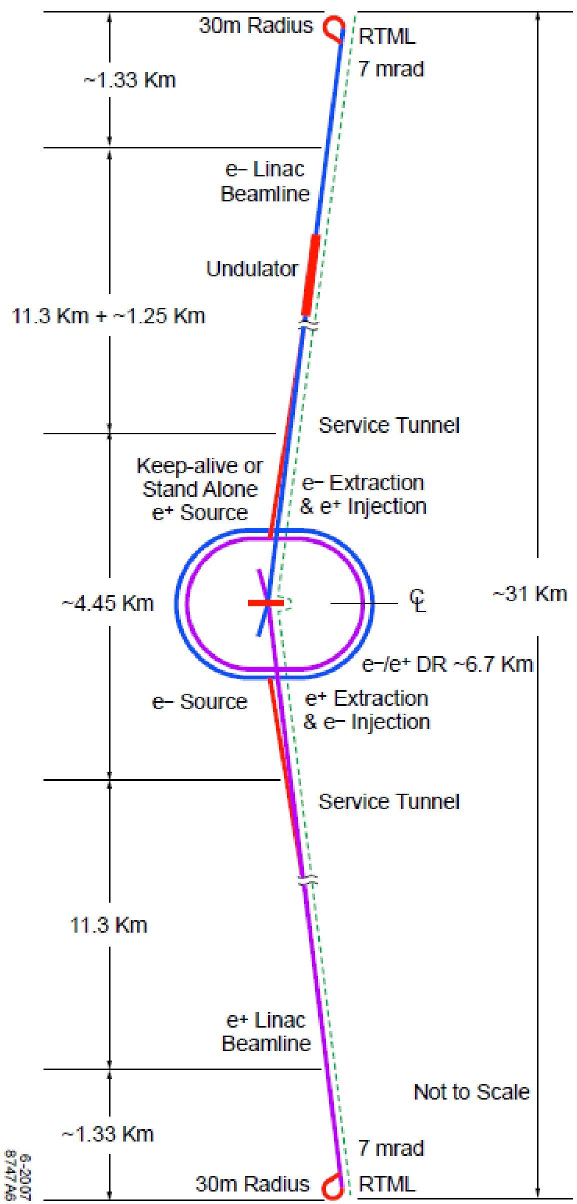
Positron Polarization important

Comparison with (Pe- =80%, Pe+ =0) estimated gain factor when (Pe$^-$=80%, Pe$^+$=60%) (Pe-=80%, Pe$^+$ =30%)

Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement	
Standard Model:			$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required
top threshold	Electroweak coupling measurement	factor 3	gain factor 2
$t\bar{q}$	Limits for FCN top couplings improved	factor 1.8	gain factor 1.4
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required	
	access to S- and T-currents up to 10 TeV		$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required
W^+W^-	Enhancement of $\frac{S}{B}$, $\frac{S}{\sqrt{B}}$	up to a factor 2	
	TGC: error reduction of $\Delta\kappa_\gamma$, $\Delta\lambda_\gamma$, $\Delta\kappa_Z$, $\Delta\lambda_Z$	factor 1.8	
	Specific TGC $\tilde{h}_+ = \mathrm{Im}(g_1^{\mathrm{R}} + \kappa^{\mathrm{R}})/\sqrt{2}$	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required	
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required	
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4	gain factor 2
	Suppression of $B = W^+\ell^-\nu$	factor 1.7	
$t\bar{t}H$	Top Yukawa coupling measurement at $\sqrt{s} = 500$ GeV	factor 2.5	gain factor 1.6

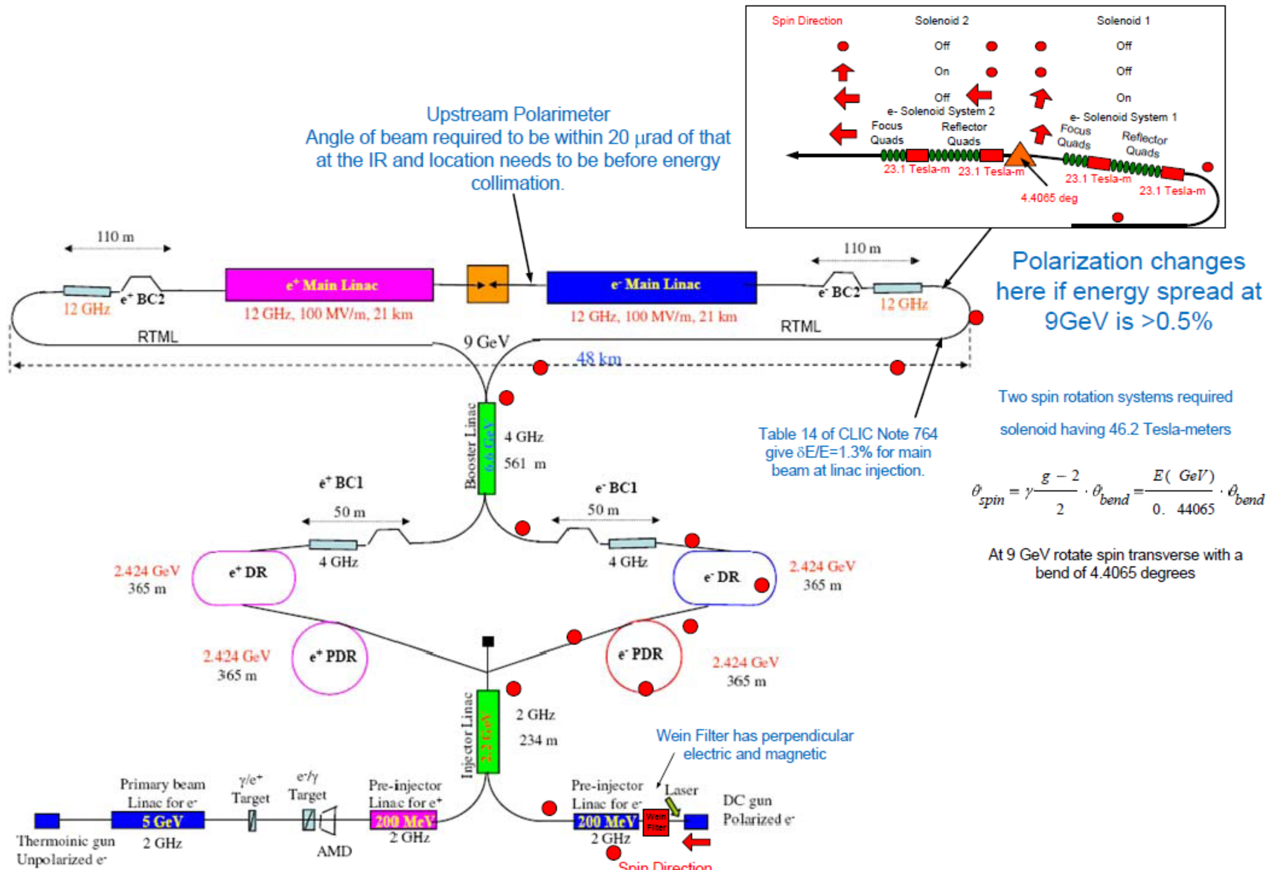
ILC at E_{cm} = 500 GeV

P_{e+} = ~30%



CLIC at E_{cm} = 3000 GeV

Conventional positron source planned with P_{e+} = 0



Machine-Detector Interface Issues

BDS and Polarimeter Alignment

Accelerator Alignment Tolerances (from RDR Volume 3, Table 4.7-1)

Area	Type	Tolerance
Sources, Damping Rings and RTML	Offset	150 μm (horizontal and vertical), over a distance of 100 m.
	Roll	100 μrad
Main Linac (cryomodules)	Offset	200 μm (horizontal and vertical), over a distance of 200 m.
	Pitch	20 μrad
	Roll	
BDS	Offset	150 μm (horizontal and vertical), over a distance of 150 m around the IR.

- locally, achieve 1 μrad over distances up to 200m
- can probably extrapolate this to achieving 10 μrad over 2000m; will be complicated by the 1.5m offset of the upstream polarimeter IP
  → need to flesh out procedure

Spin precession:

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

at E = 250 GeV,

θ_{bend}	θ_{spin}	$\cos(\theta_{spin})$
50 μrad	28.3 mrad	0.9996
100 μrad	56.7 mrad	0.9984

Goal for Spin Alignment: <50μrad between beam direction at polarimeters and IP

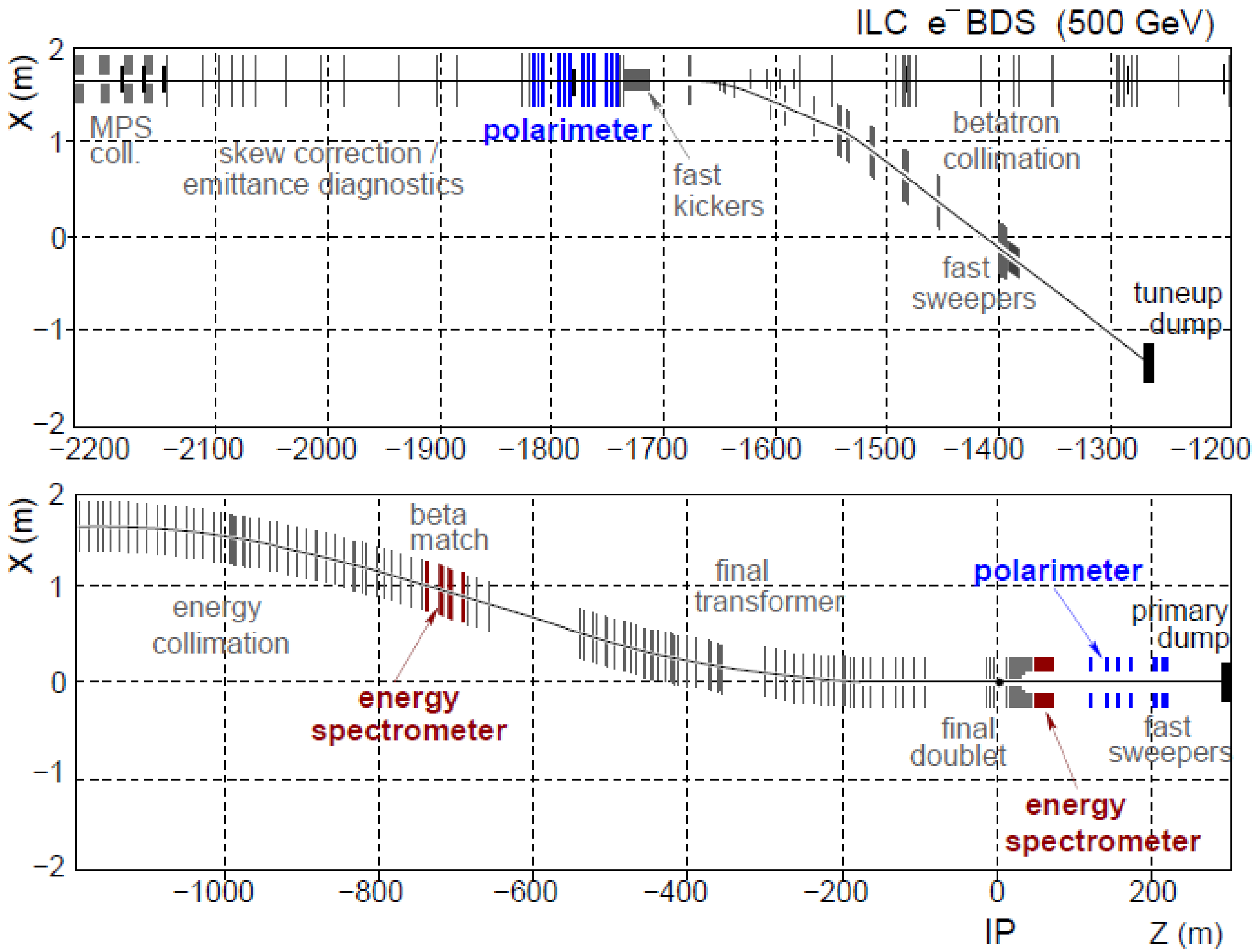
→ spin rotator optimization should be identical for upstream & downstream polarimeters

→ monitor correlations of polarimeter measurements with local BPM trajectories;

+ downstream polarimeter can monitor correlations with IP BPM trajectories5

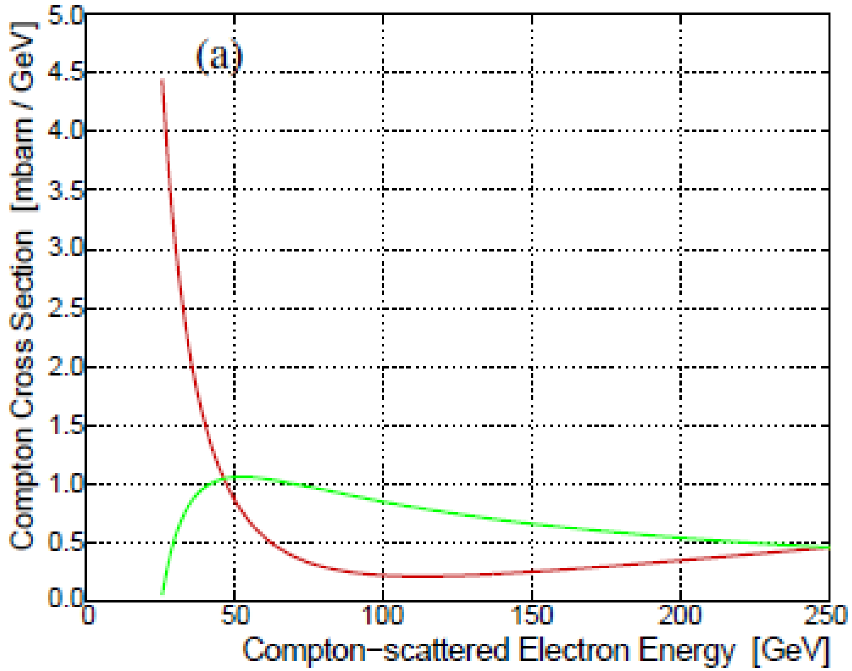
CLIC: For $\delta P/P = 0.1\%$ implies angle at Compton IP and IR is aligned to better than 13 μrad

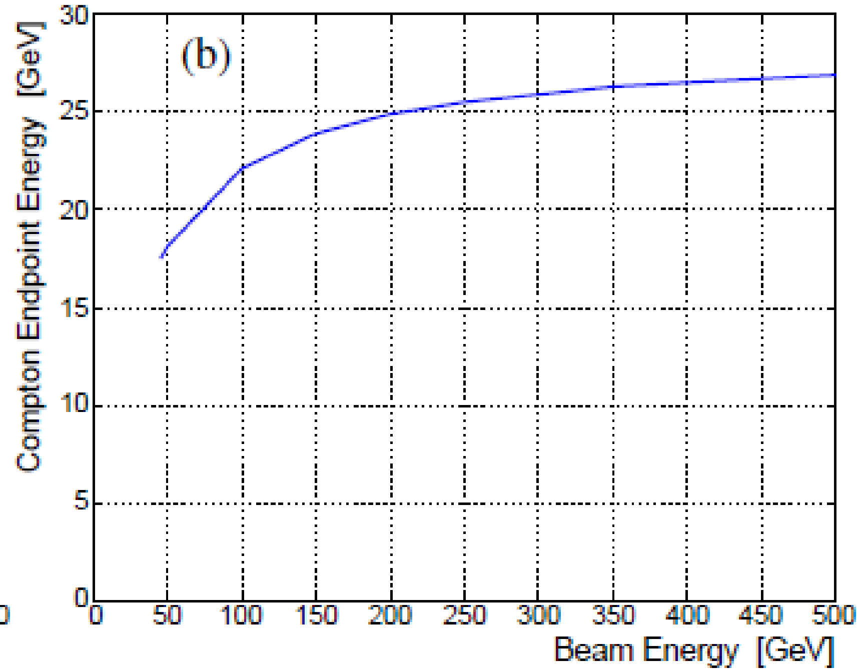
Polarimetry in the BDS of the ILC



Beam Delivery System (BDS) as described in the RDR. The upper part shows the region from 2200 m to 1200 m upstream of the e^+e^- IP, including the polarimeter chicane at 1800 m. The lower part shows the region from 1200 m upstream to 400 m downstream of the IP, including the upstream energy spectrometer at 700 m as well as the extraction line energy spectrometer and polarimeter around 100 m downstream of the IP located at z = 0 m.

Compton Cross Section and Compton Endpoint Energy



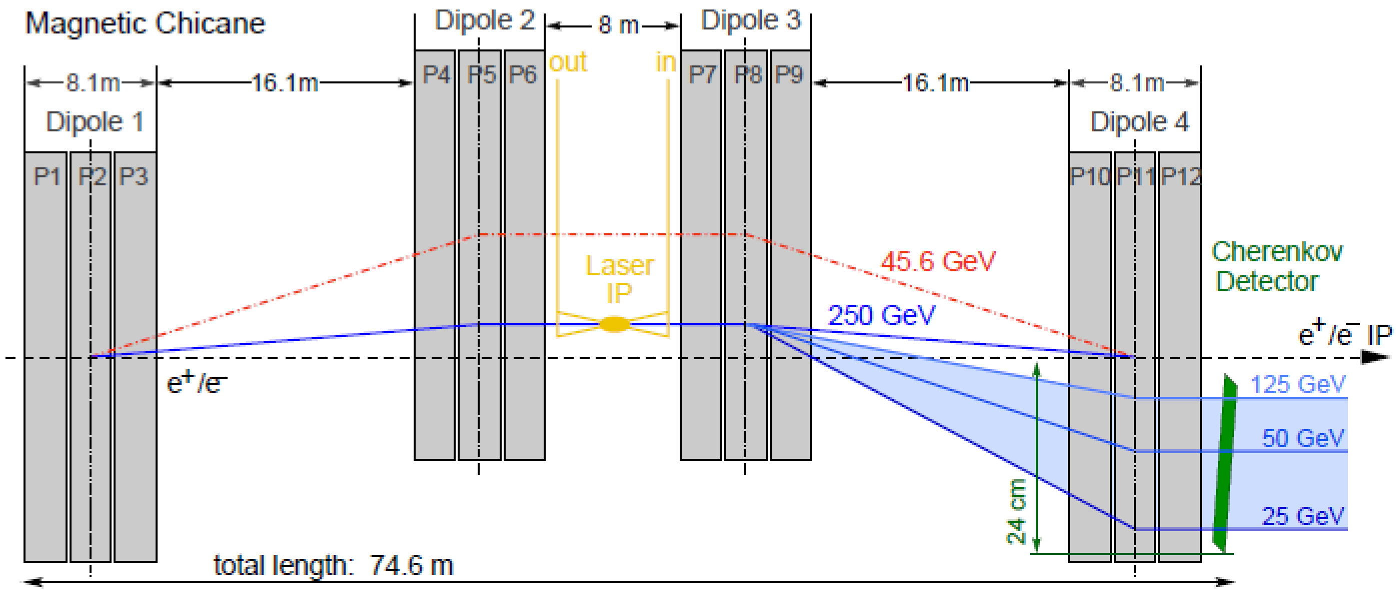


(a) Compton differential cross section versus scattered electron energy for same (red curve) and opposite (green curve) helicity configuration of laser photon and beam electron.

(b) Compton edge energy dependence on beam energy.

The beam energy is 250 GeV and the laser photon energy is 2.3 eV.

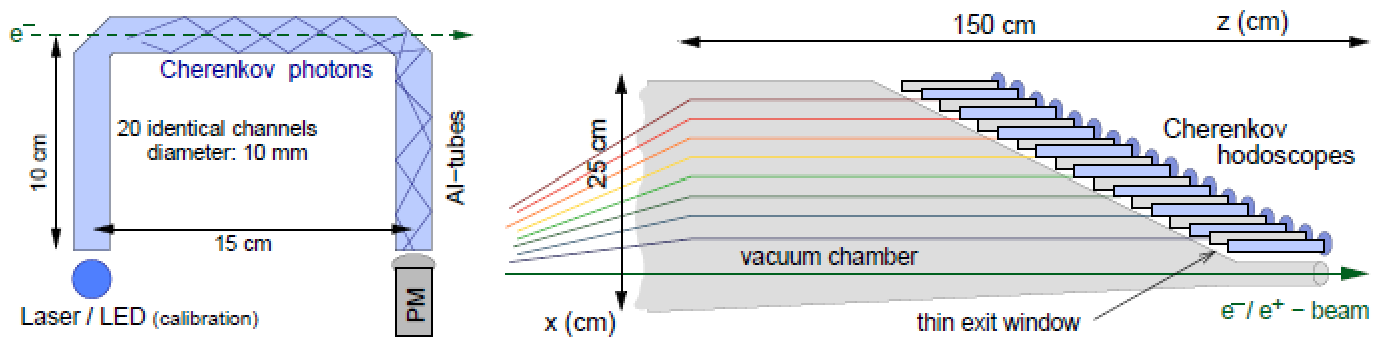
Upstream Polarimeter: Chicane



Schematic of the upstream polarimeter chicane.

- Constant B-field: Compton edge position independent of E_b
- same laser frequency for all E_b
- laser IP moves horizontally with E_b by ~ 10 cm

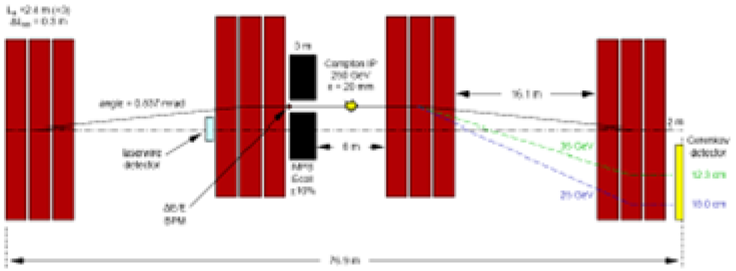
  => vacuum chamber and laser optics have been designed accordingly



Schematic of a single gas tube (left) and the complete hodoscope array covering the tapered exit window (right) as foreseen for the Cherekov detectors of both polarimeters.

Upstream Polarimeter: Issues

- Can the chicane host other instrumentation?
  - laser wire emmittance diagnostics?
  - MPS collimator?

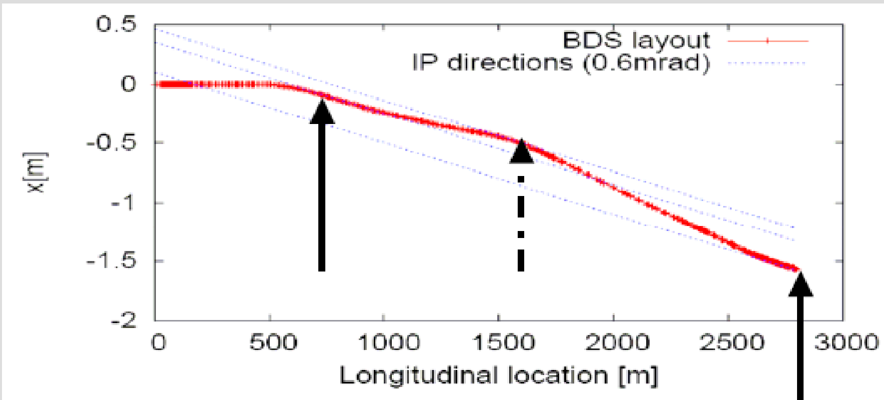


The plan is to separate them.

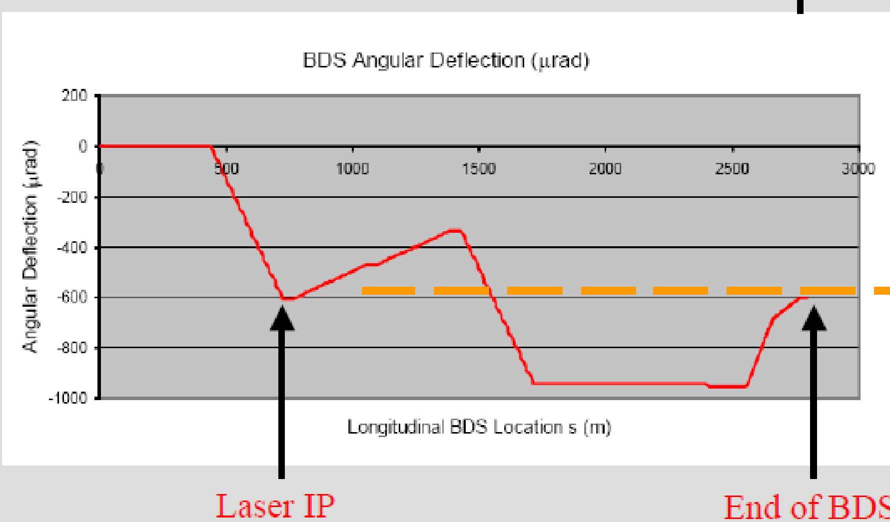
CLIC Upstream Polarimeter

Requirements: $\delta P/P = 0.25\%$ measurement robust and fast

Suitable locations



alignment exists at two locations:
s = 742 m
(s = 1555 m)
but only the first one qualifies for polarimetry
(upstream of energy collimation and sufficient free space for laser beam crossing)



- 605.132 μrad (s = 742 m)
- 601.351 μrad (s = 2796 m)

aligned within 3.8 μrad

Slide from Peter Schuler's talk at CLIC08 Workshop

CLIC Polarimeter

Orbit angle tolerances at Compton IP and IR due to spin precession considerations

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

$$= 3404.06 \cdot \theta_{bend} at 1.5 TeV$$

Change in spin direction for various bend angles and the projection
Of the longitudinal polarization. Electron beam energy is 1.5 TeV.

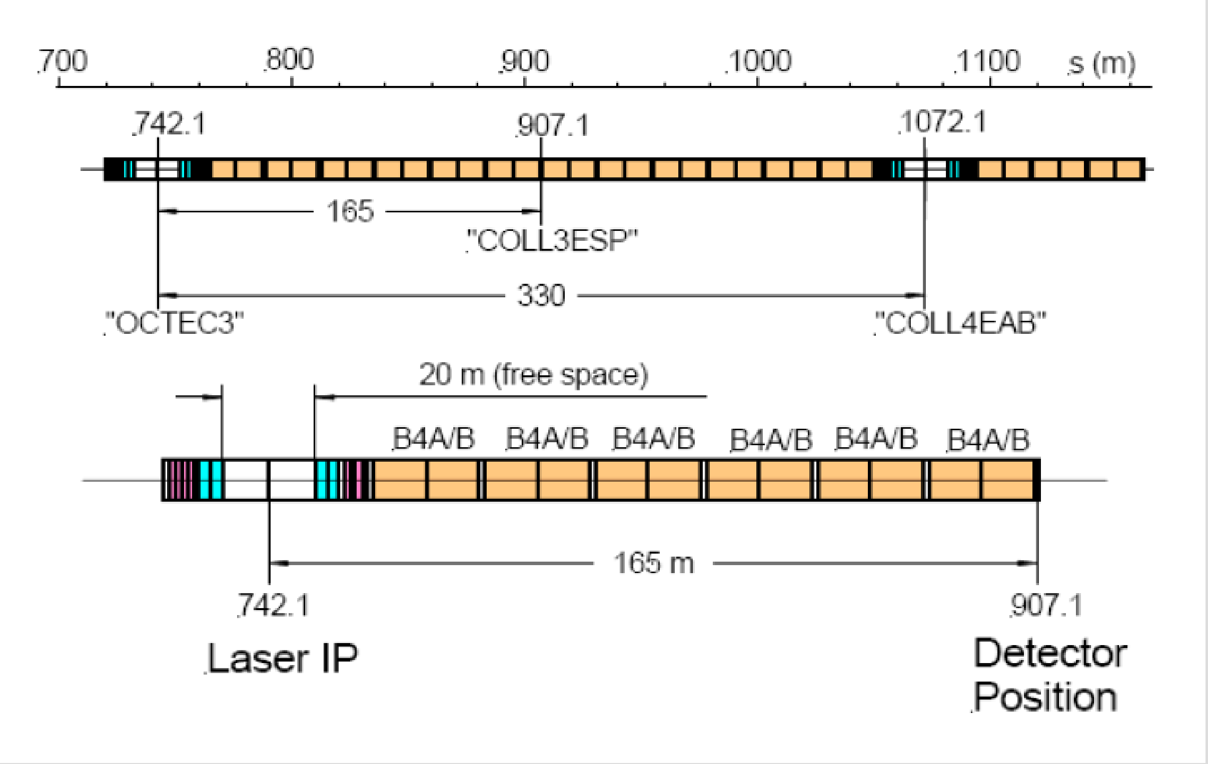
Change in Bend Angle	Change in Spin Direction	Longitudinal Polarization Projection
100 μrad	340.4 mrad (19.5 degrees)	94.26%
50 μrad	170.2 mrad (9.75 degrees)	98.55%
25 μrad	85.1 mrad (4.87 degrees)	99.64%
13 μrad	45 mrad	99.9%

For δP/P = 0.1% implies angle at Compton IP and IR is aligned to better than 13 μrad.

Polarimeter needs to be before energy collimator to clean up Compton electrons.

CLIC Upstream Polarimeter

BDS detail behind s = 742 m



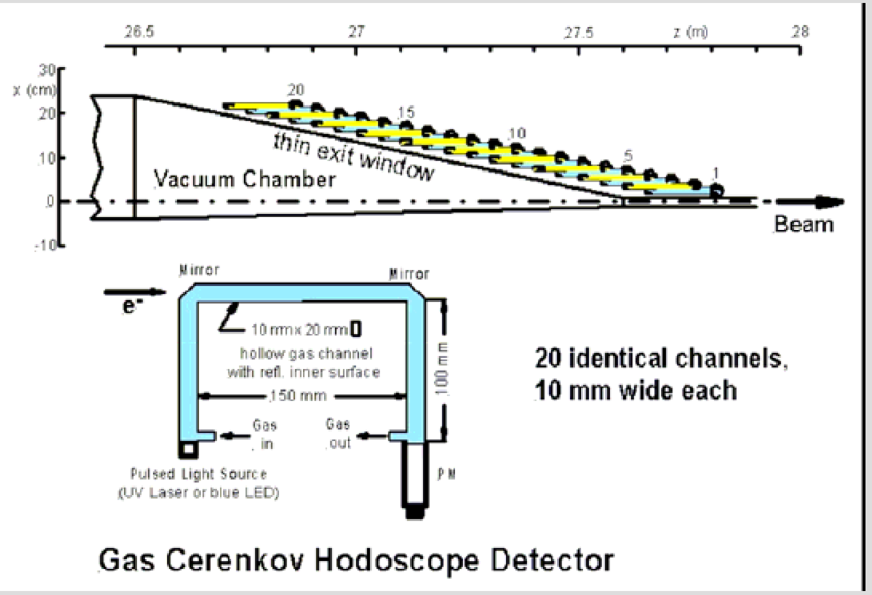
Laser IP at s = 742 m

Compton electron detector at s = 907 m
(behind 12 dipoles, as shown, or behind a lesser number of dipoles, but with reduced performance)

Slide from Peter Schuler's talk at CLIC08 Workshop

CLIC Upstream Polarimeter

electron detector hodoscope

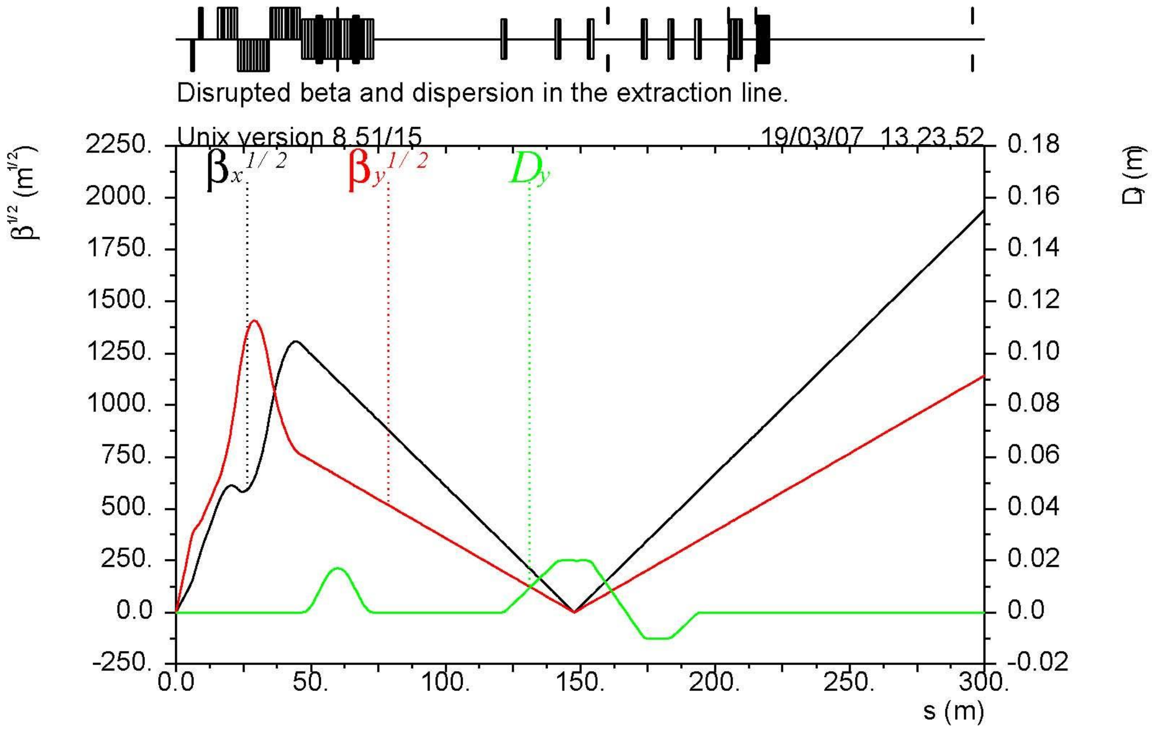


- Design similar to gas Cerenkov employed in SLD Compton polarimeter
- C_4F_{10} gas (~10 MeV threshold)
- detector will be immune against low-energy and diffuse background (synchr. rad.)
- could use ~25 channels, 10 mm wide each, to cover a large fraction of the spectrum from the Compton edge to beyond the asymmetry crossing point
- assume minimum distance of 20 mm from the beam axis

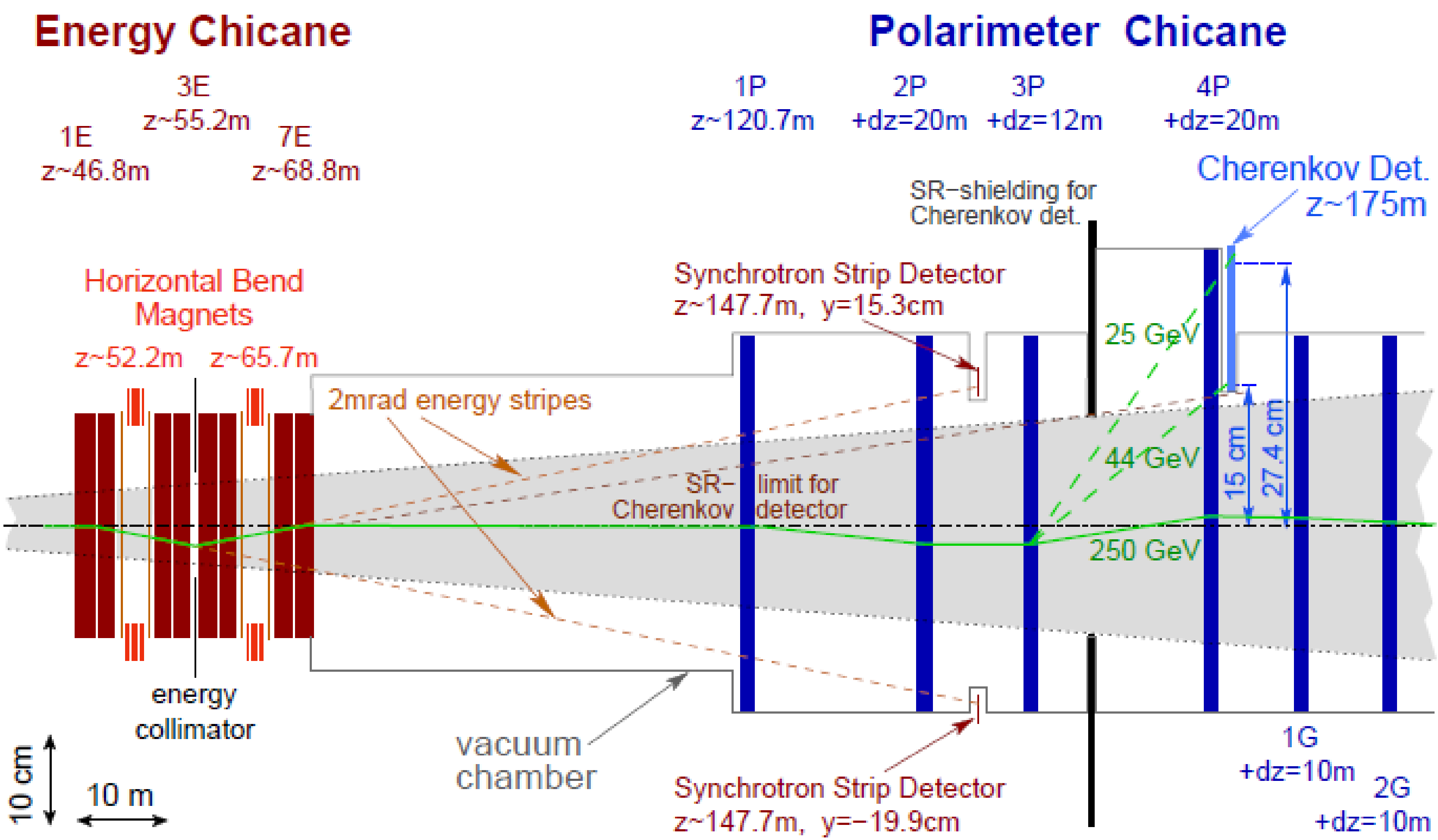
- Compton photon detection is an additional option, but will not be considered here

Downstream extraction line Polarimeter

Goal for Polarimeter Accuracy is <0.25%



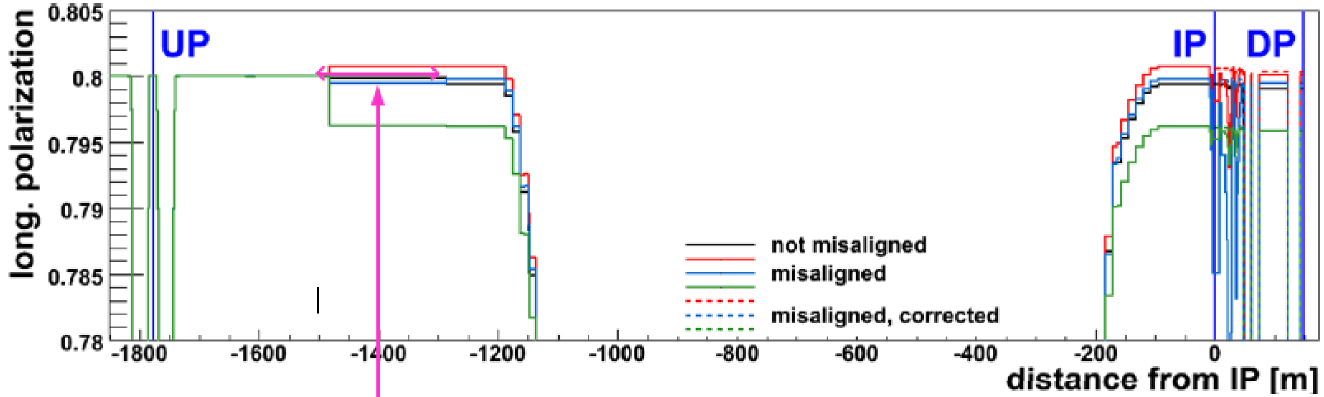
Optical β functions and vertical momentum dispersion Dy in the 14 mrad extraction line from IP to the dump, shown for the 250 GeV nominal disrupted beam.



Schematic of the ILC extraction line diagnostics for the energy spectrometer and the Compton polarimeter.

No scheme for downstream CLIC polarimeter at luminosity.

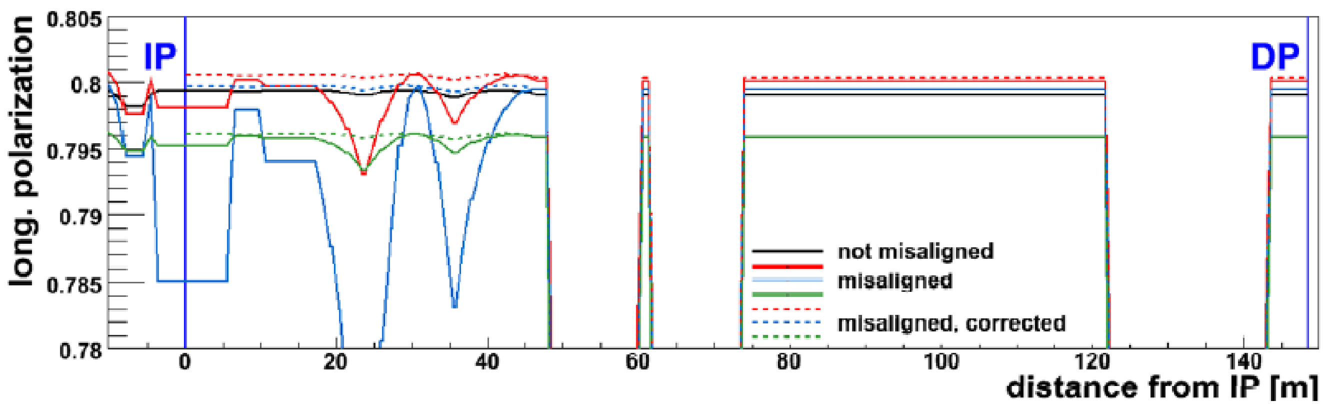
Preliminary Spin Tracking: See following talk by Moritz Beckmann for details and explanations.



Location of Upstream Polarimeter Compton IP

The changes in polarization at -1500m and -1300m are caused by particle losses in collimators
black:99, red:1047, blue:379, green:1140
The loss problem on collimators needs attention.

Location of electron positron IP



Location of electron positron IP

Location of Downstream Polarimeter Compton IP

Lost Beam:
The dipole section begins at z=-1200m; the 'steps' at roughly -1500m and -1300m are collimators absorbing some particles from the beam. As the polarization is calculated from non-absorbed particles, absorption can change the polarization. The changes in polarization in the plot do not exceed two times the calculated standard deviations, so they might be just statistical effects (to be investigated).

Conclusion: There is a need for position and angle measurements at the upstream and downstream Compton IP as well as at the e^+e^- IP. Active feedback needs to maintain the position and beam orbit angle to with tolerance (At CLIC Δ orbit angle < 13 µrad and Δ position < 25 µm. Tolerance relaxed at ILC.).

Compton Polarimetry Overview

- The physics of the Compton scattering process is well understood in QED, with radiative corrections less than 0.1%
- Detector backgrounds are easy to measure and correct for by using laser off pulses;
- Polarimetry data can be taken simultaneously with physics data;
- The Compton scattering rate is high and small statistical errors can be achieved in a short amount of time (sub-1% precision in one minute is feasible);
- The laser helicity can be selected on a pulse-by-pulse basis;
- The laser polarization is readily determined with 0.1% accuracy.
- Extrapolation from upstream and downstream polarimeters to IR (Orbit differences and lost beam)

Expected Polarimeter Systematic Errors

Uncertainty	$\delta P/P$
Detector Analyzing Power	0.2%
Detector Linearity	0.1%
Laser Polarization	0.1%
Electronic Noise and Background Subtraction	0.05%
TOTAL	0.25%

Orbit difference between IR and Compton IPs < 50 μm at ILC and 13μm at CLIC for $\delta P/P$ = 0.1%

Measurement of the beam polarization using the W^+W^- production [1]

Ivan Marchesini [1]

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

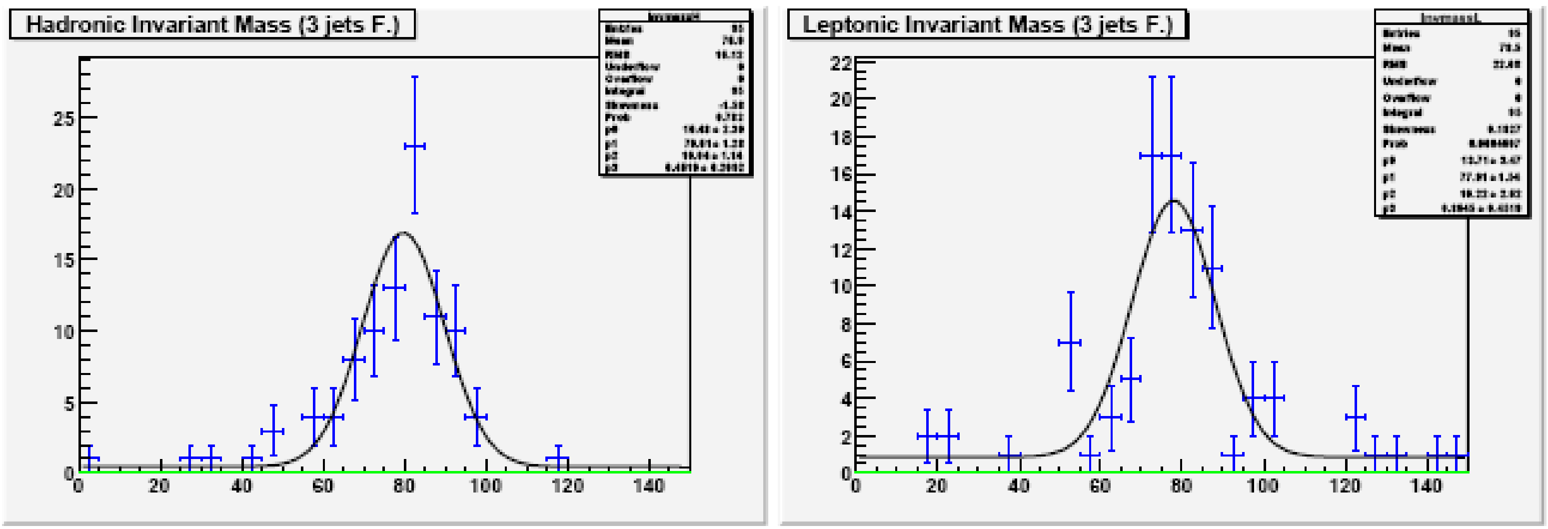


Figure 2: The W invariant mass measured from the hadronic decay (left) and from the leptonic decay (right).

The Blondel scheme

$$| P_{e\pm} | = \sqrt{\frac{(\sigma_{-+} + \sigma_{+-} - \sigma_{--} - \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} + \sigma_{--} - \sigma_{++})}{(\sigma_{-+} + \sigma_{+-} + \sigma_{--} + \sigma_{++})(\pm\sigma_{-+} \mp \sigma_{+-} - \sigma_{--} + \sigma_{++})}},$$

With 860 fb-1 of luminosity, the error on P_{e^-} ~ 0.1% and the error on P_{e^+} ~ 0.2%.

Conclusions

Upstream Polarimeter

- Decision to have a Dedicated Chicane has been reached by ILC management.
- Energy collimator and laser wire system will be moved upstream of polarimeter chicane

Downstream Polarimeter

- The extraction line with six magnets improves the acceptance of the Compton scattered electrons. This allows detection over a larger part of the Compton electron energy spectra. The backscattered electrons are further away from the beam pipe by ~10 cm.

- No scheme for CLIC downstream polarimeter at highest energy and luminosity.

Orbit angle at Compton IPs and IP

- Orbit through Compton IP and e^+e^- IP needs active feedback to maintain orbit angle to
  - 50 μrad for ILC
  - 13 μrad for CLIC

Extra Slides

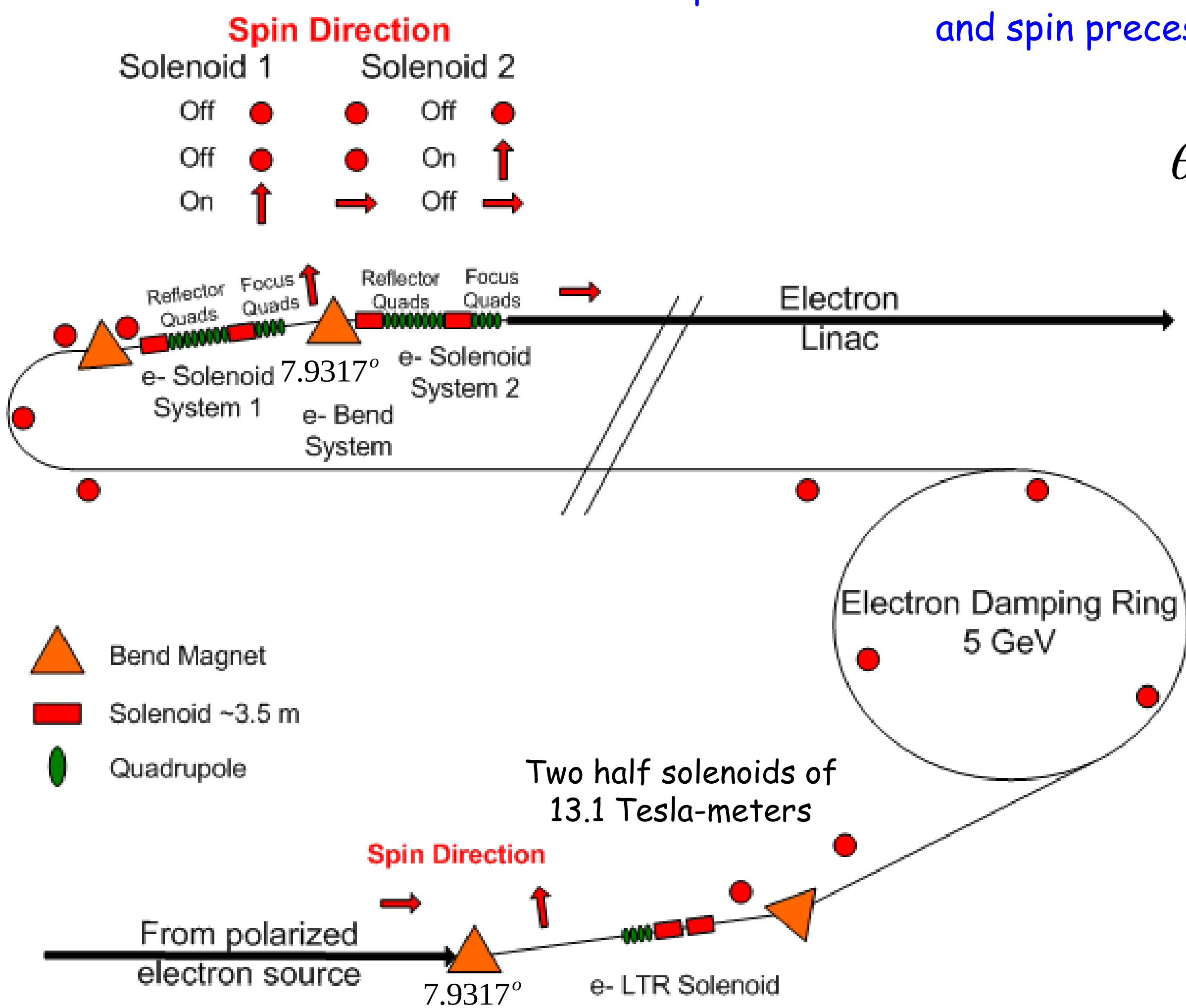
Reference Design Report Damping Ring and Spin Rotation Systems

Requirements:

•Rotate spin to the vertical before damping ring so polarization is not destroyed during damping.

•Rotate spin after the damping ring to have the desired polarization at the e^+e^- IP, e.g. longitudinal polarization at IP. To avoids spin diffusion depolarization effects locate RTL spin rotation system after transport to beginning of main linac.

Spin rotation is done with a combination of spin rotation solenoids and spin precession in dipole bends



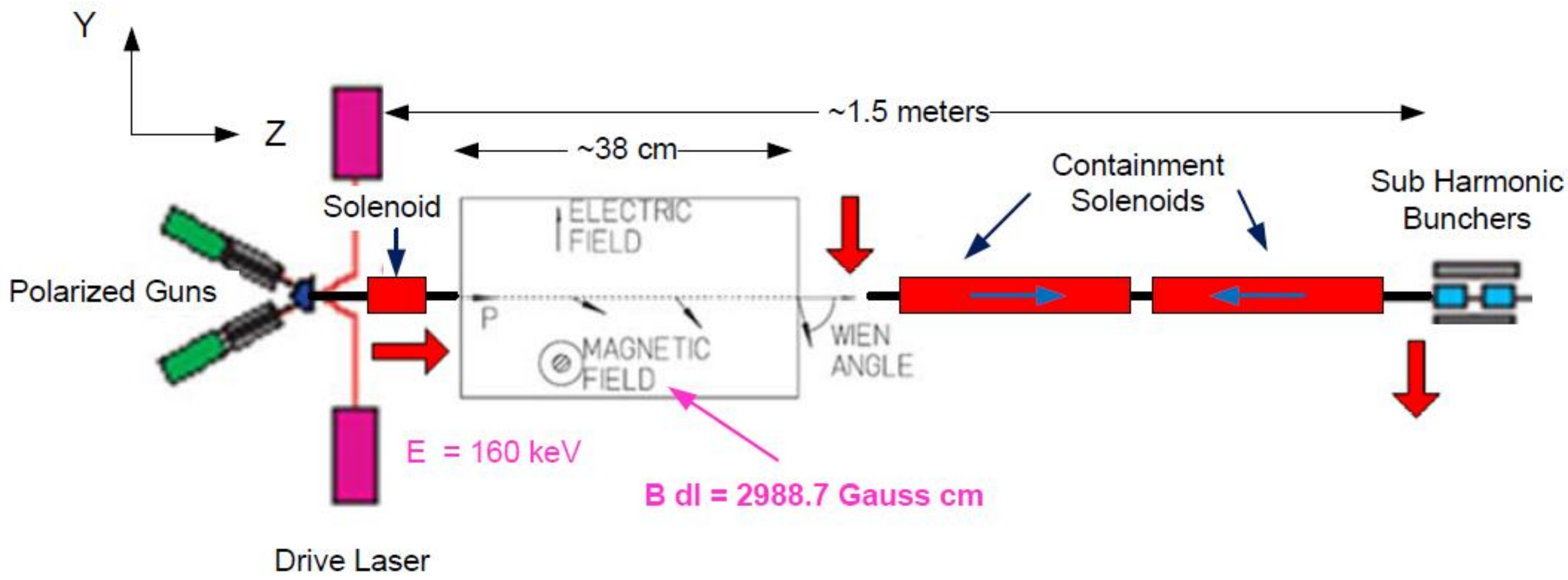
θ_{spin} Is rotated 90° in a solenoid field of 26.2 Tesla-meters at 5 GeV

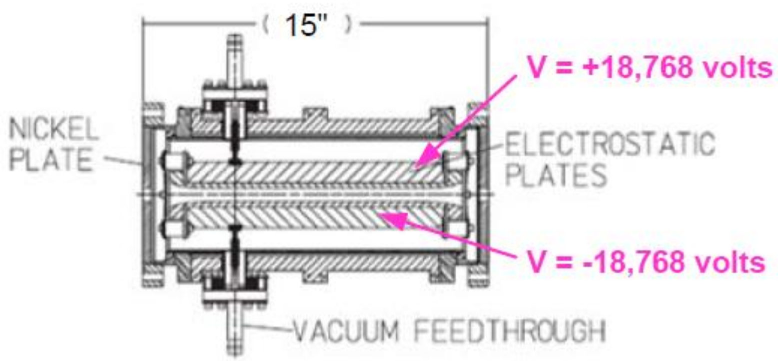
Spin Precession ahead of momentum direction change

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

$$\theta_{spin} = 90^o = \frac{5.0}{0.44065} \cdot 7.9317^o$$

Proposal to rotate spin direction to the vertical near polarized electron source



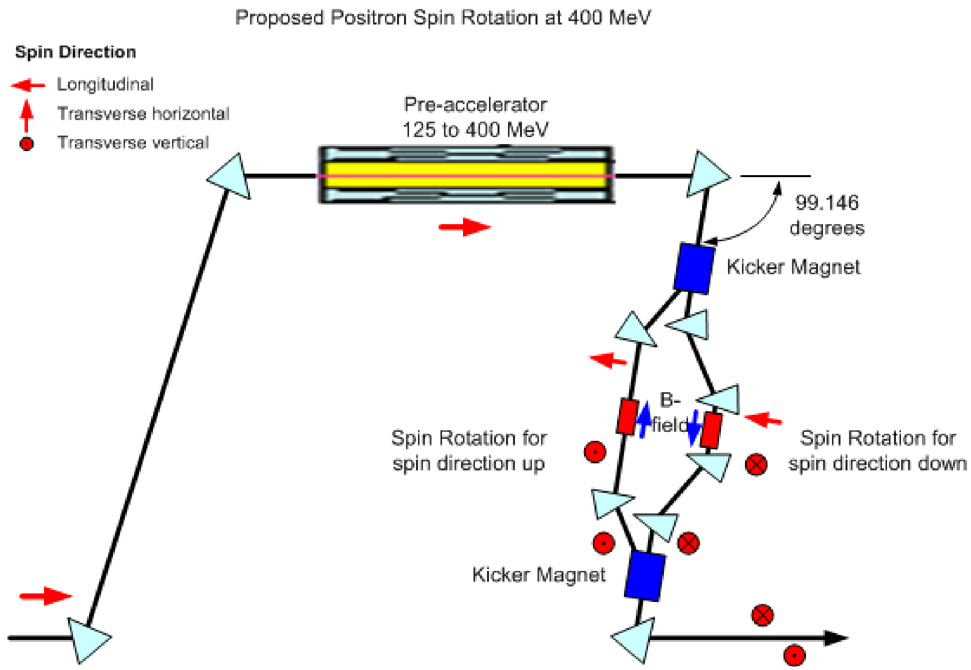


Wien filter spin manipulator
The magnet is not shown in the cutaway view

ILC source may run above **200 keV** to reduce space charge effects.
E=200keV has **B dl ~ 3600 Gauss cm** and **V=+/- 24,253 volts**

C. Y. Prescott, SLAC Engineering Note 71, 8 Feb 1977

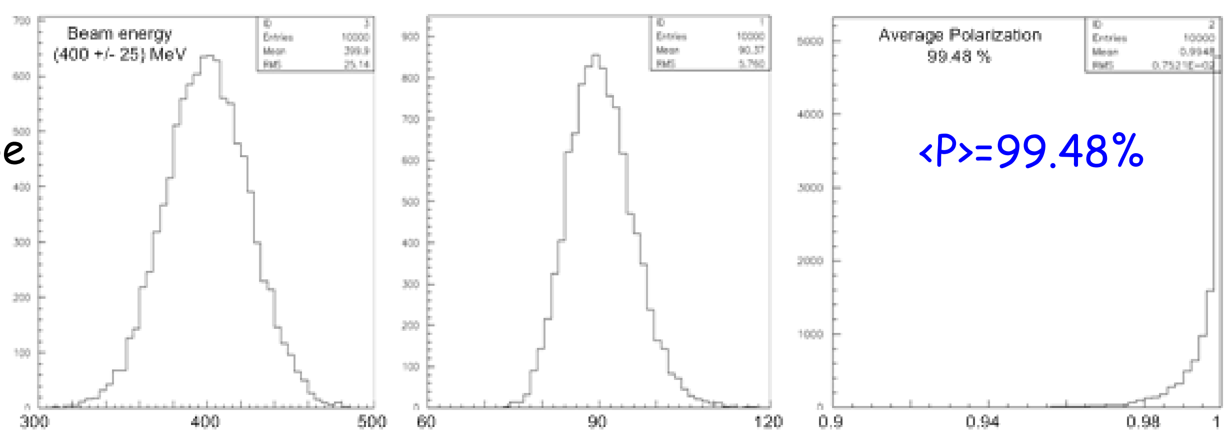
Spin Rotation for positrons directly following Pre-accelerator when beam energy is 400 MeV



After a bend of 99.146 degrees a copper wound solenoid of 2.096 Tesla meters 2.2 meters long with an axial field of 9.53 Kilogauss will rotate the spin from the transverse horizontal direction to the vertical. Criteria for the kicker magnets for spin flip and tunnel space is much less demanding at 400 MeV than at 5 GeV.

Concerns:
Energy Spread at 400MeV may be as large as +/- 25MeV

- Depolarization: only 0.52%
- Positron beam loss in 99.146 deg bends and parallel spin rotation lines needs study



Energy Spin Rotation Angle Polarization

IPBI_TN-2008-1. ***Spin Rotation at lower energy than the damping ring,*** K. Moffeit, D. Walz and M. Woods, ILC-NOTE-2008-040 February 2008.

Conclusions on Spin Rotation Before Damping Ring

The costs and performance requirements for the spin rotation systems before the damping ring will be less demanding at lower energy than at the damping ring energy of 5 GeV.

Positron Beam Spin Rotation and Fast Helicity Selection

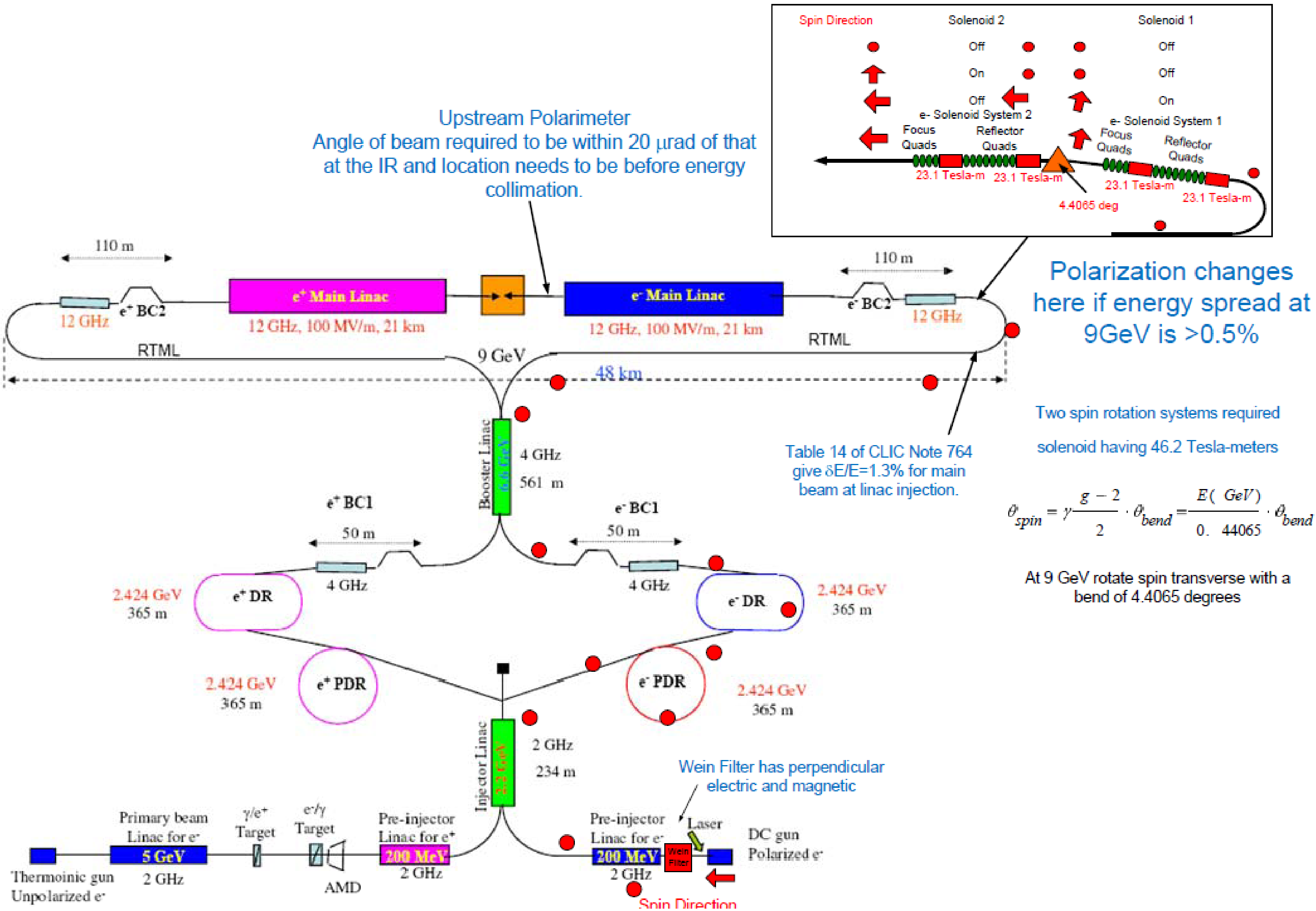
- Copper-wound solenoids for the spin rotation solenoids 2.2 meters long with a bore of 2" can be used for the positron beam at 400 MeV.
- The angle the beam leaves the spin rotation system is required to be in the plane of the damping ring. The tolerance on the angle alignments is ~ 3 degrees resulting in a depolarization of 0.1%.
- A system to randomly select the helicity of the positrons at the e+e- IR is given. Such a scheme is important to minimize systematic errors in the measurement of polarization asymmetries. At 400 MeV the parallel beam lines and kicker magnets will be much simpler than at 5 GeV.

Electron Beam Spin Rotation

Rotate the spin vector to the vertical at very low energy (~150 keV) for the electrons near the polarized gun using a Wien filter.

- The spin rotations systems presented here are conceptual designs. A more detailed optics design, including simulating performance and overall operation, will be needed.

Polarization at CLIC



Longitudinal depolarization due to energy spread in reverse bend at 9 GeV

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

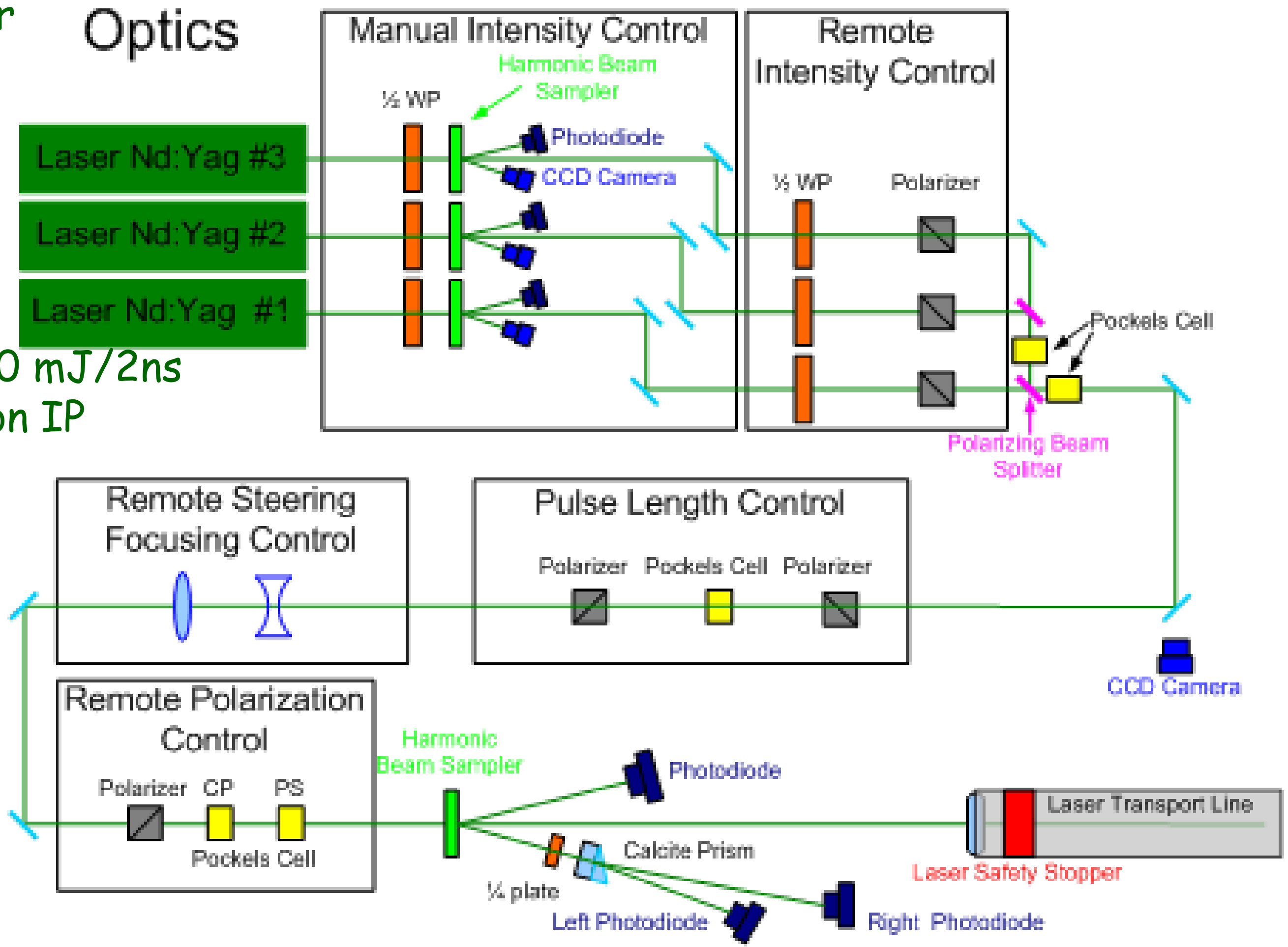
dE/E at 9 GeV	Mean longitudinal or transverse horizontal polarization after 90 deg bend (note: vertical spin component will not be depolarized)
0.25%	99.6%
0.5%	98.6%
1.0%	94.0%
1.3%	90.8%

- Spin diffusion in the 90 degree turnaround at 9 GeV due to an energy spread of less than 0.5% will not be a problem.
- The energy spread at 9 GeV is given as 1.3% in the CLIC-Note-764. Such a large energy spread will destroy the polarization.
- Conclusion: CLIC will have to do the spin rotation after the reverse bend unless energy spread at 9 GeV is less than 0.5%

Laser Optics Bench

Continuum Powerlite 8000
YAG Laser
10 Hz
6ns wide
532 nm
600 mJ

Need ~100 mJ/2ns
at Compton IP



1% measurement every minute
3 bunches per train

1% measurement every hour
180 bunches per train

1% measurement every day
all bunches of train

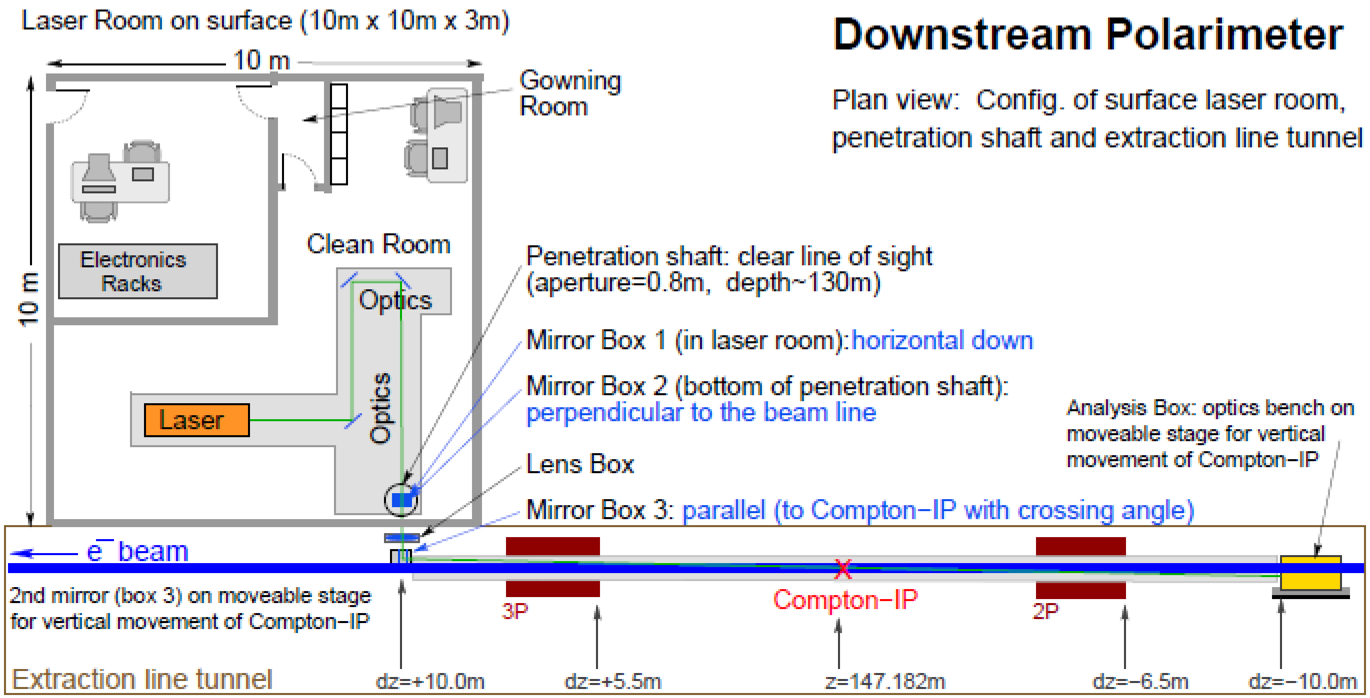
Will investigate availability of a mode-locked laser with ~35 picosec wide pulse width.

Recent new product from Quantel Pizzicato B

- -30 mJ pulse energy at 532 nm (2.33 eV)
- -20 Hz operation
- -35 picoseconds

Downstream Polarimeter

Plan view: Config. of surface laser room, penetration shaft and extraction line tunnel



Laser Transport