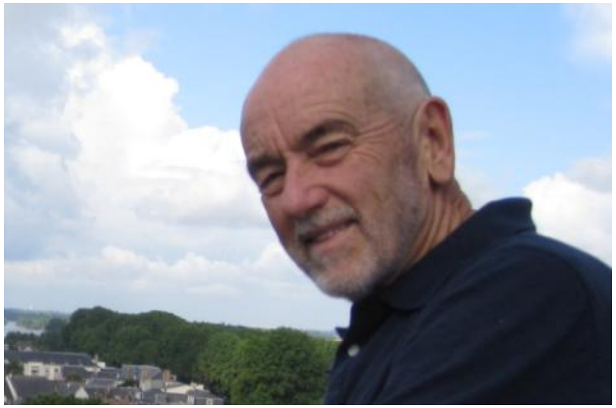
Overview of Polarimetry

ALCPG 2011
March 22, 2011

Outline of Talk
Polarized Physics
Machine-Detector Interface Issues
Upstream Polarimeter
Downstream Polarimeter



Ken Moffeit, *SLAC*

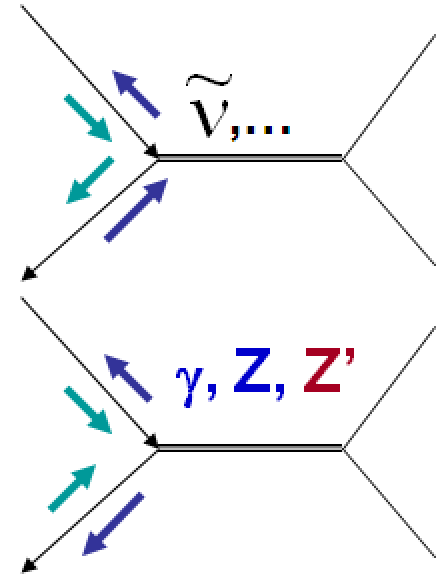
s-channel processes

	e^-	e^+	
σ_{RR}	⇒ →	← ⇐	$\frac{1+P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$
σ_{LL}	⇐ →	← ⇒	$\frac{1-P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$
σ_{RL}	⇒ →	← ⇒	$\frac{1+P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$
σ_{LR}	⇐ →	← ⇐	$\frac{1-P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$

J=0 (σ_{RR}, σ_{LL})

J=1 (σ_{RL}, σ_{LR})

SM



$$\sigma^{\text{meas}} = \sigma_0 \left(1 - P_{e-}P_{e+}\right)\left(1 + A_{LR} P_{\text{eff}}\right)$$

$$P_{\text{eff}} = \frac{-P_{e-} + P_{e+}}{1 - P_{e-}P_{e+}}$$

⟺

$\pm P_{e+}$, $\pm P_{e-}$ → enhancement or suppression of processes related to σ_{ij}

Physics with polarized beams

Cross section enhanced or reduced

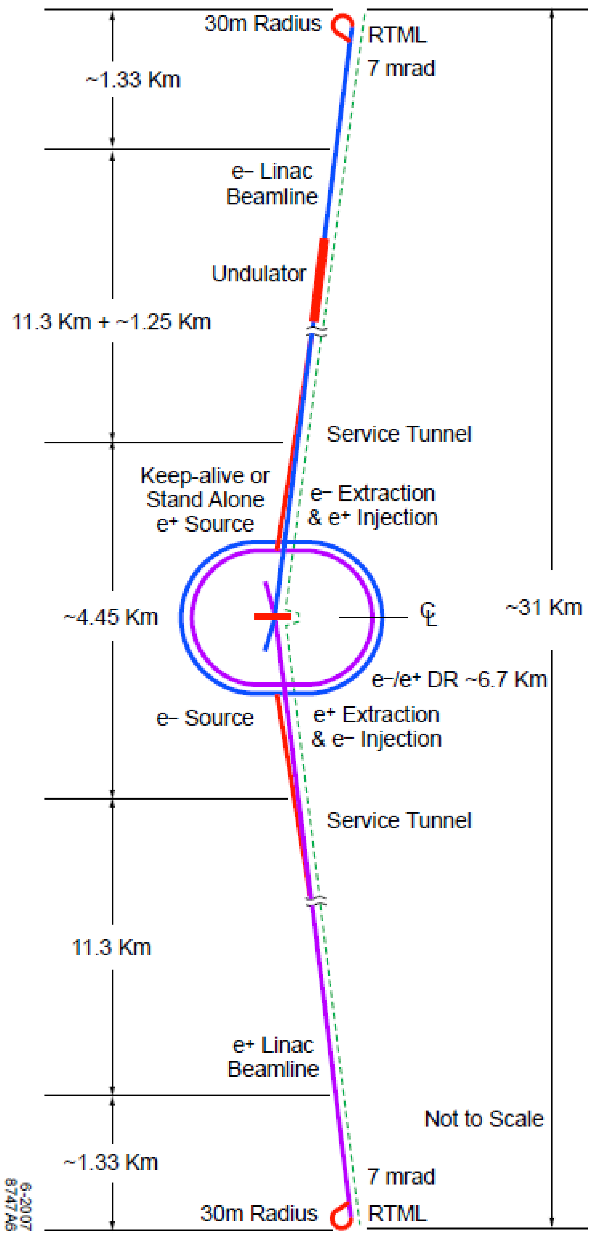
The cross sections can be enhanced or reduced by an appropriate choice of the polarization states. This allows to suppress the background: For instance, a ratio of 'undesired' to 'desired' polarization states, $[(1 - P_{e^-})(1 - P_{+})]/[(1 + P_{e^-})(1 + P_{e^+})]$, yields a background reduction by 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

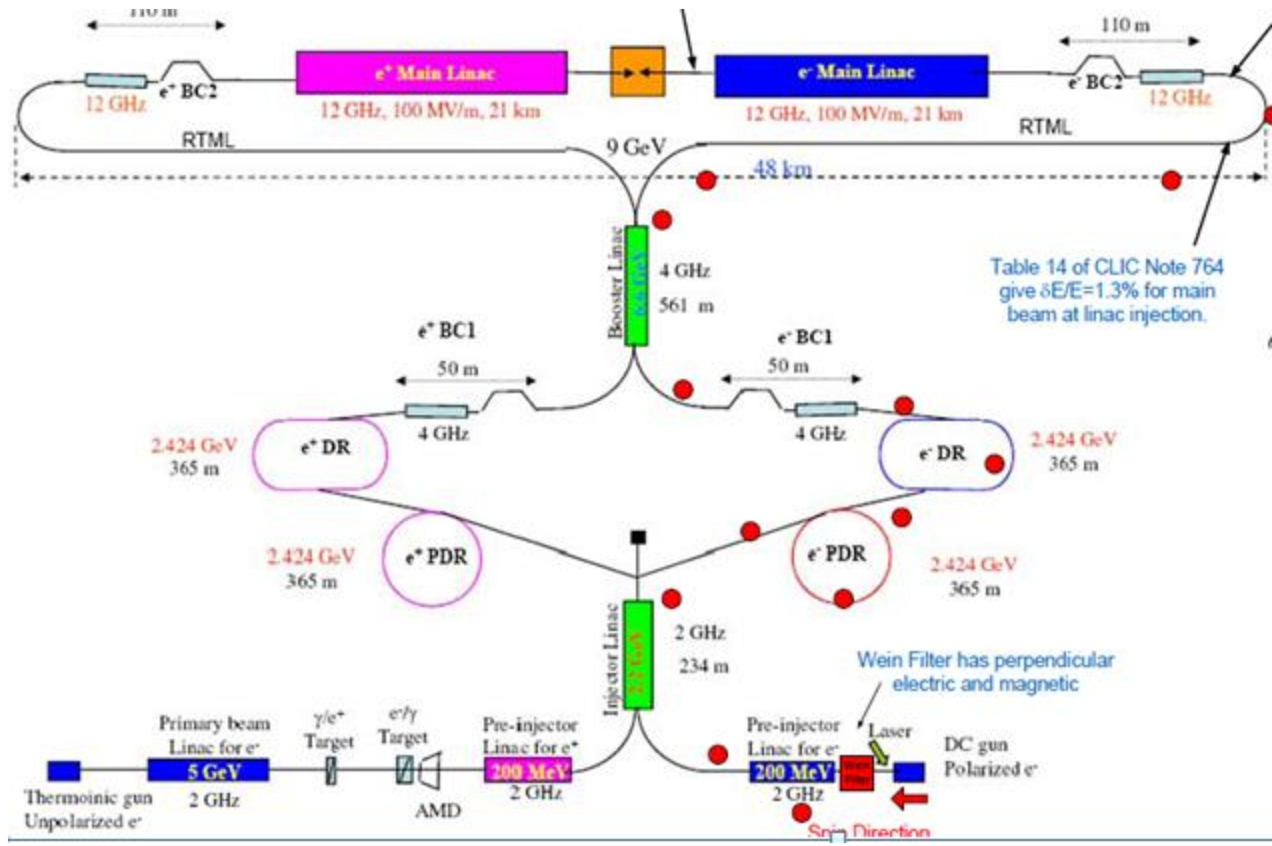
Comparison with (Pe- =80%, Pe+ =0) estimated gain factor when (Pe$^-$=80%, Pe$^+$=60%) (Pe-=80%, Pe$^+$ =30%)

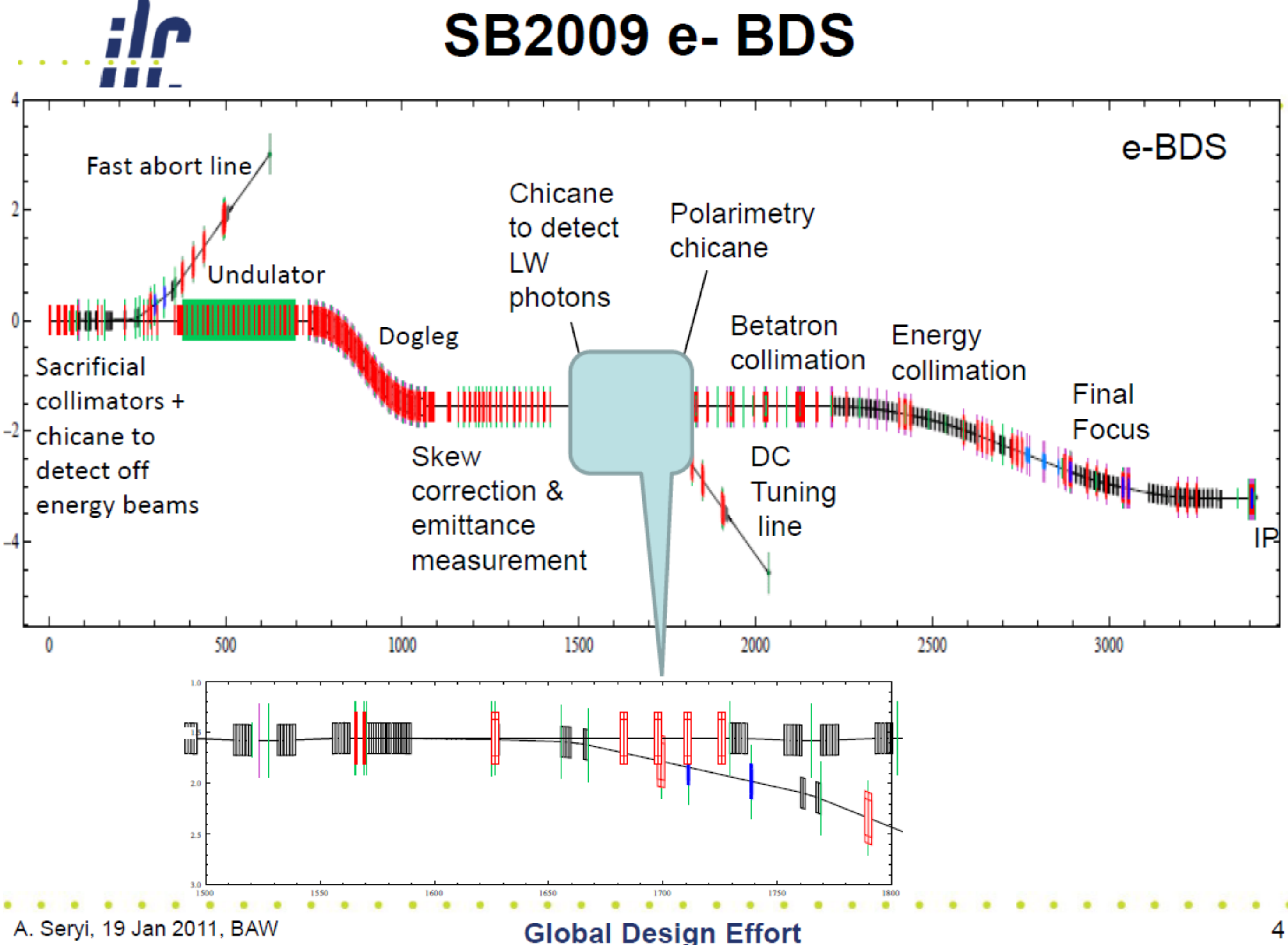
Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement	(Pe-=80%, Pe$^+$ =30%)
Standard Model:			$P^T_{e^-} P^T_{e^+}$ required
top threshold	Electroweak coupling measurement	factor 3	gain factor 2
$t\bar{q}$	Limits for FCN top couplings improved	factor 1.8	gain factor 1.4
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give	$P^T_{e^-} P^T_{e^+}$ required	
	access to S- and T-currents up to 10 TeV		$P^T_{e^-} P^T_{e^+}$ 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 $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P^T_{e^-} P^T_{e^+}$ required	
CPV in γZ	Anomalous TGC $\gamma\gamma Z, \gamma ZZ$	$P^T_{e^-} P^T_{e^+}$ 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 500 GeV



CLIC at 1500 GeV





Two changes effecting polarization:

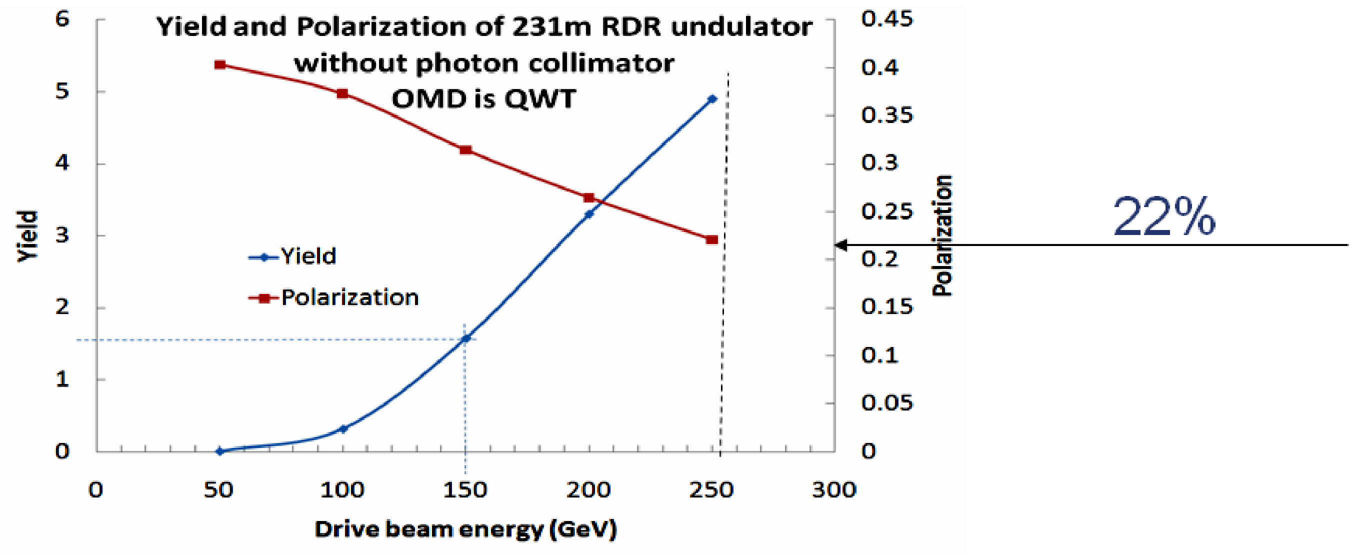
1) Undulator for positron production is at the end of the linac.
2) Location of the upstream polarimeter is now separated from the machine protection collimator, skew correction and emittance measurement.

Yield of Polarized Positrons at ILC

Helical undulator, no photon collimator → RDR design → e+ polarization ~34%

SB2009 → e+ polarization ~22%

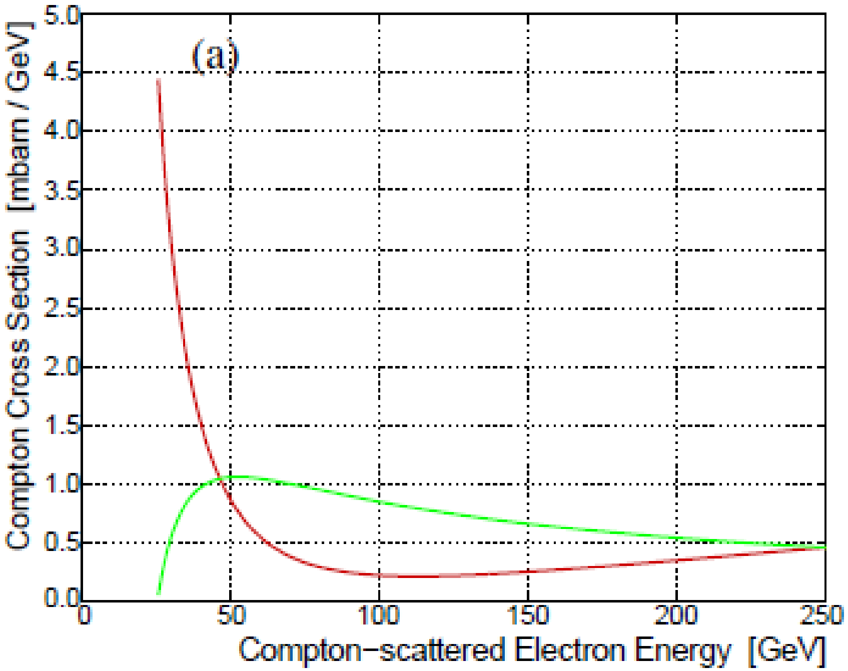
SB2009 Proposal Document:



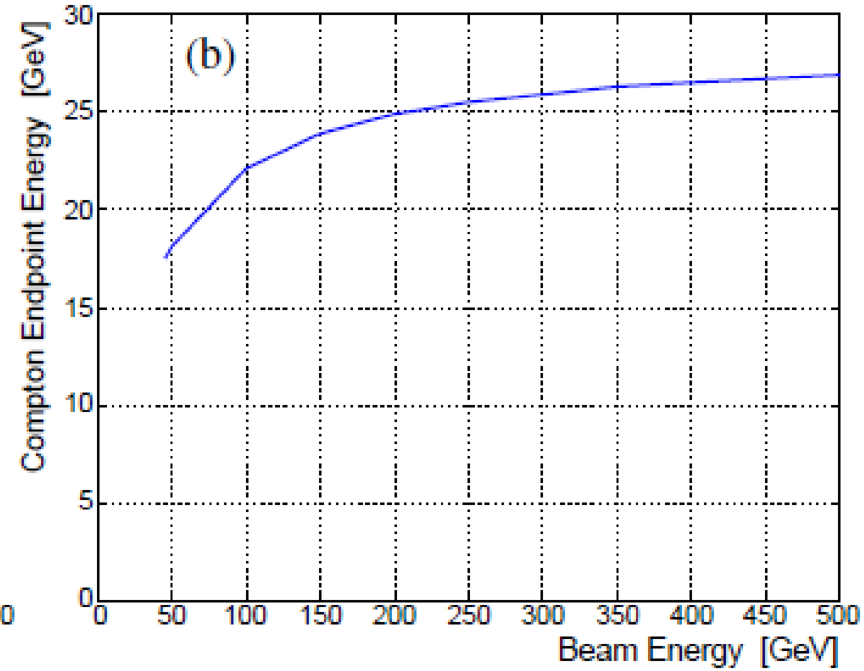
see also talk of Wei Gai

Can polarization at 250GeV be increased above 22% by accepting fewer low energy positrons? Studies needed!

Polarimetry uses Compton differential cross section on Compton edge



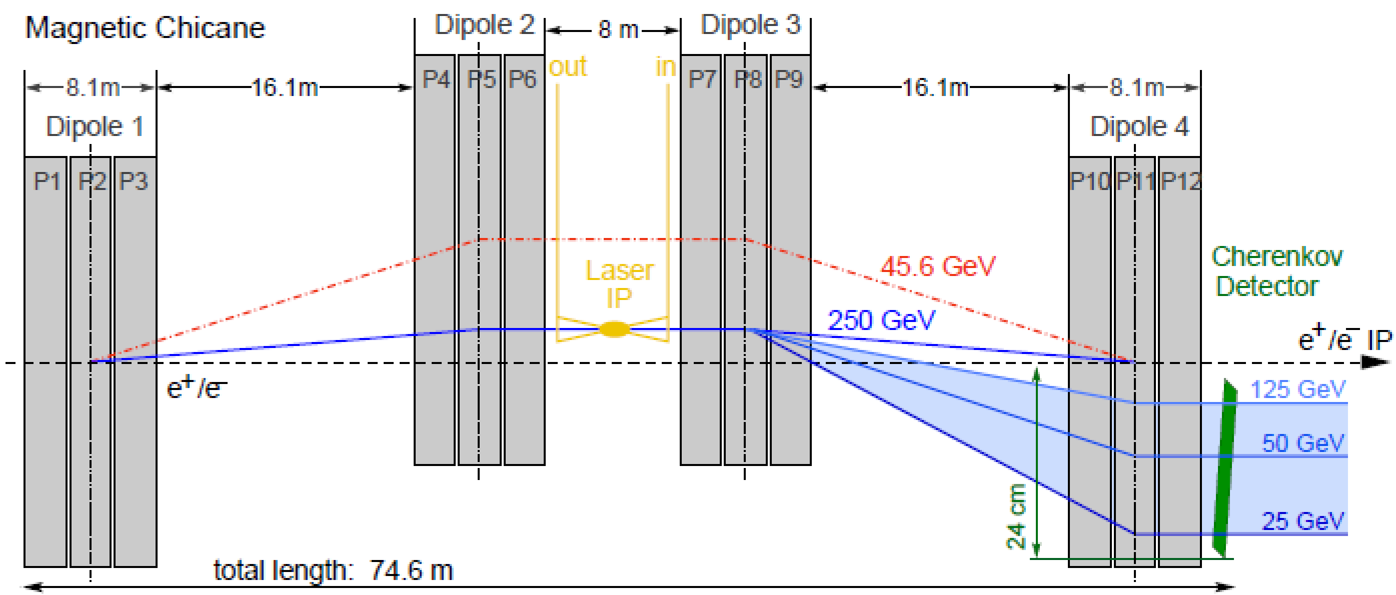
(a) Compton differential cross section versus scattered electron energy for same (red curve) and opposite (green curve) helicity configuration of laser photon and beam electron.



(b) Compton edge energy dependence on beam energy.

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

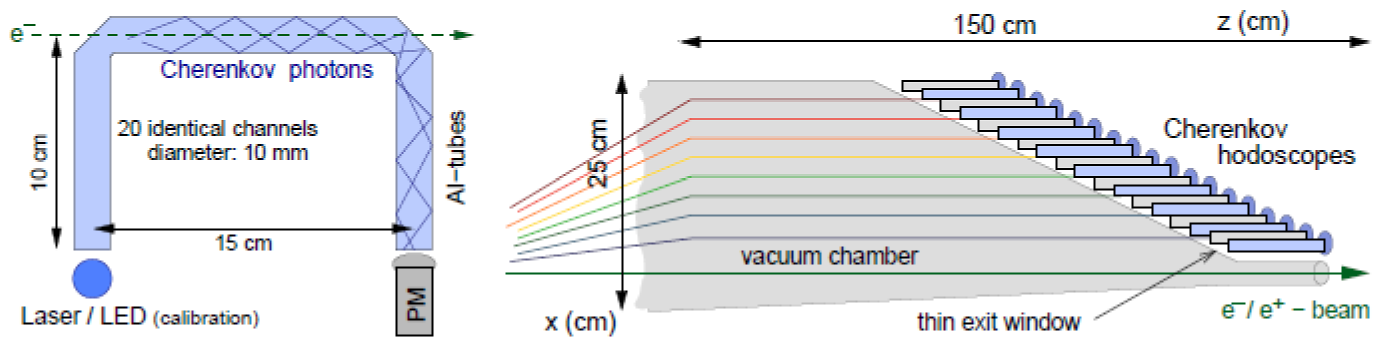
Upstream Polarimeter: Chicane



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

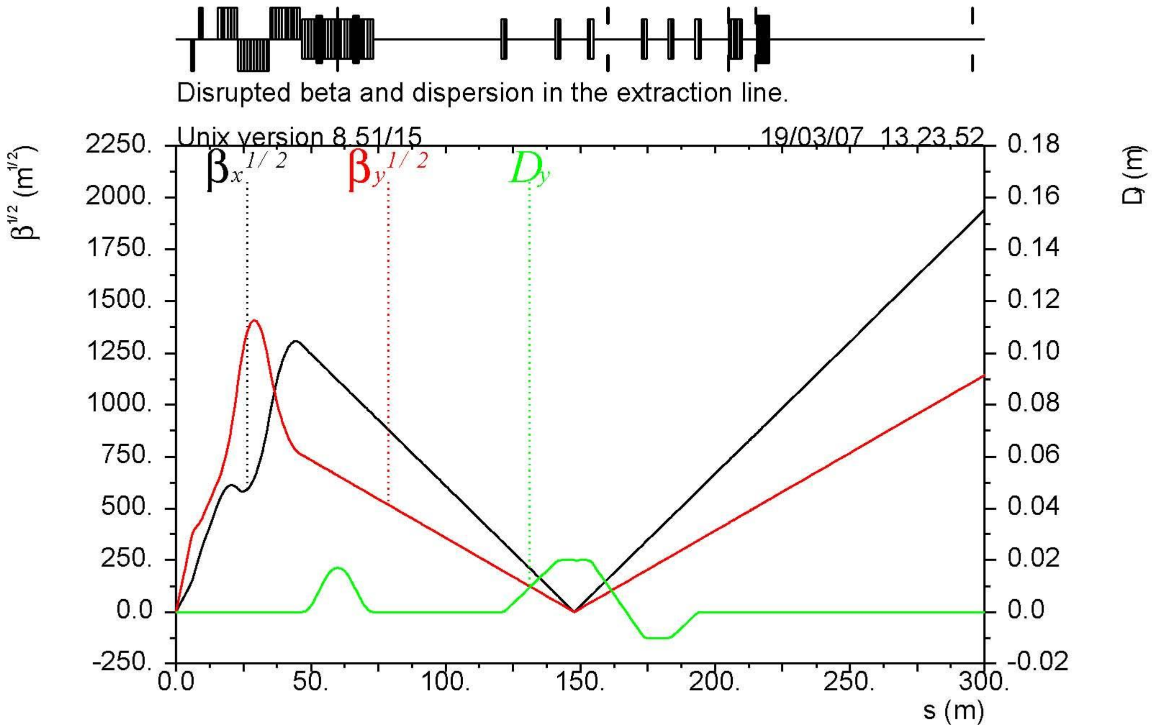
  => vacuum chamber and laser optics have been designed accordingly



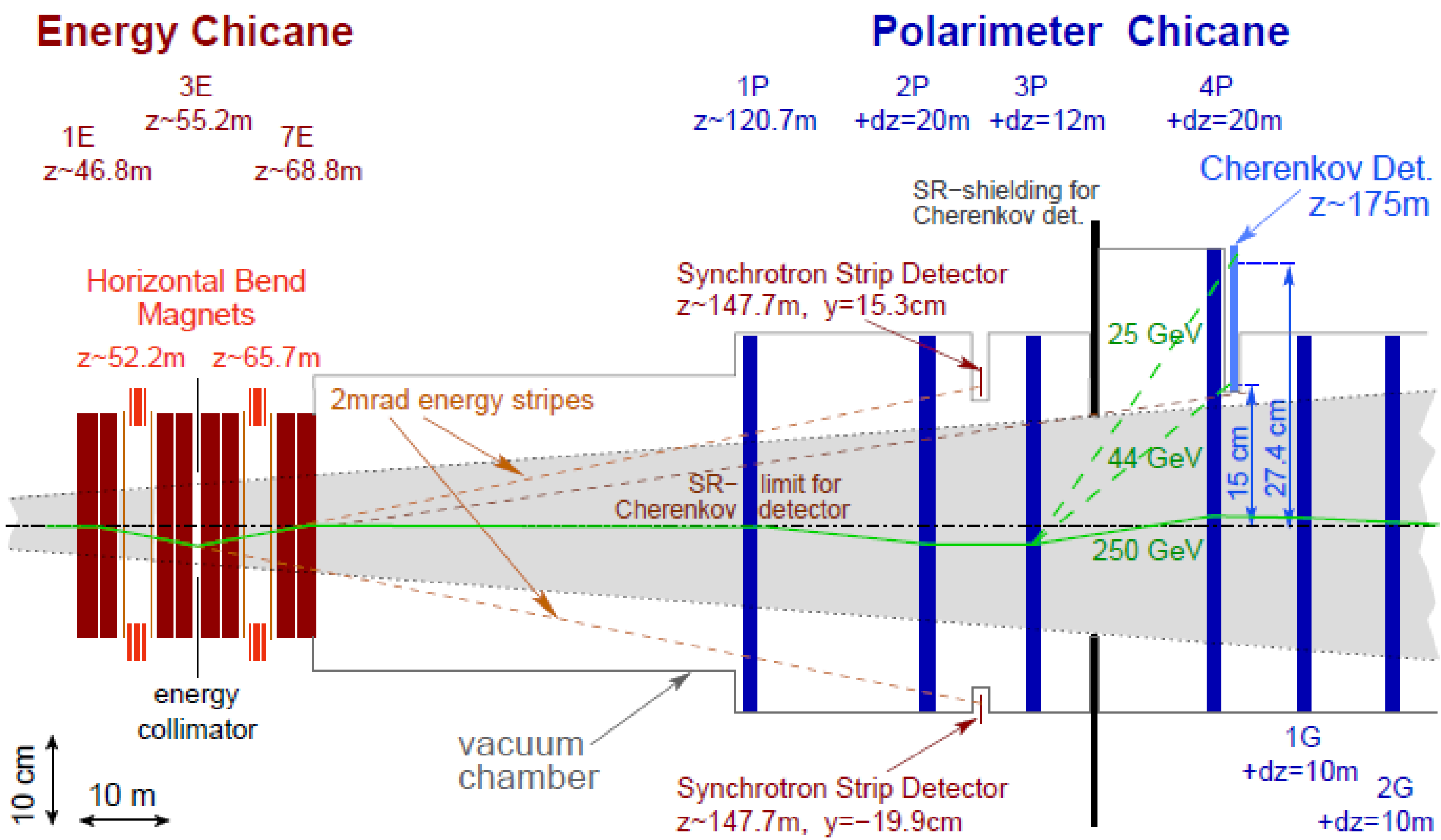
Schematic of a single gas tube (left) and the complete hodoscope array covering the tapered exit window (right) as foreseen for the Cherekov detectors of both polarimeters.

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.

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:

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

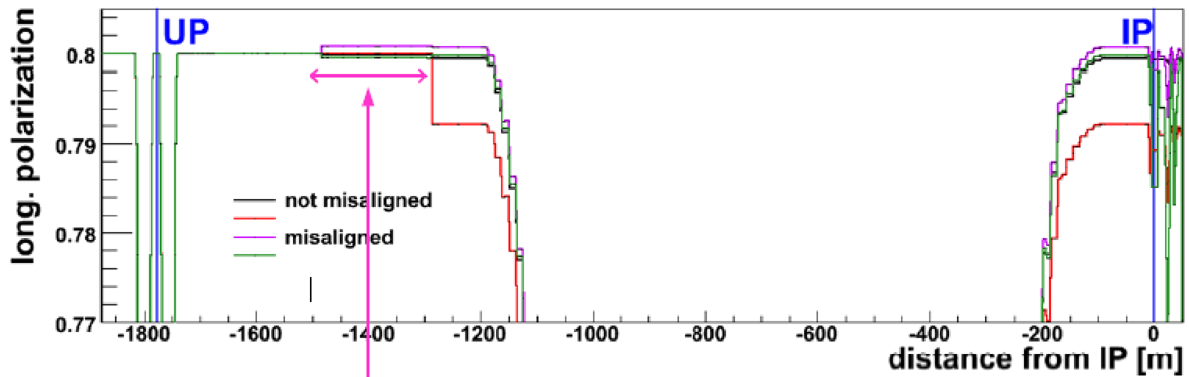
at E = 250 GeV,

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 θ_{bend} = 16.7 μrad gives θ_{spin} = 28.3 mrad and cos (θ_{spin}) =0.9996

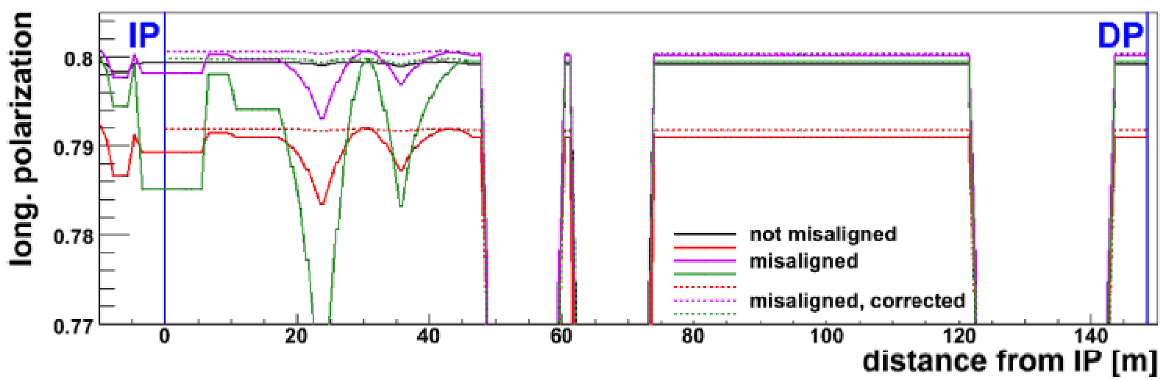
Preliminary Spin Tracking: See following talk by Moritz Beckmann for details and explanations.



Location of Upstream Polarimeter Compton IP

The changes in polarization at -1500m and -1300m are caused by particle losses in collimators
black:99, red:5622, violet:1047, green:379
The loss problem on collimators needs attention.

Location of electron positron IP



Location of electron positron IP

Location of Downstream Polarimeter Compton IP

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 (Δ orbit angle < 25 μrad and Δ position < 100 μm)

Proposal: Add feedback system to keep orbit angle the same at the upstream polarimeter, interaction region and the downstream polarimeter.

Systematic Errors

- 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 simulatanously 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.

Expected Polarimeter Systematic Errors

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

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

Ivan Marchesini [1]

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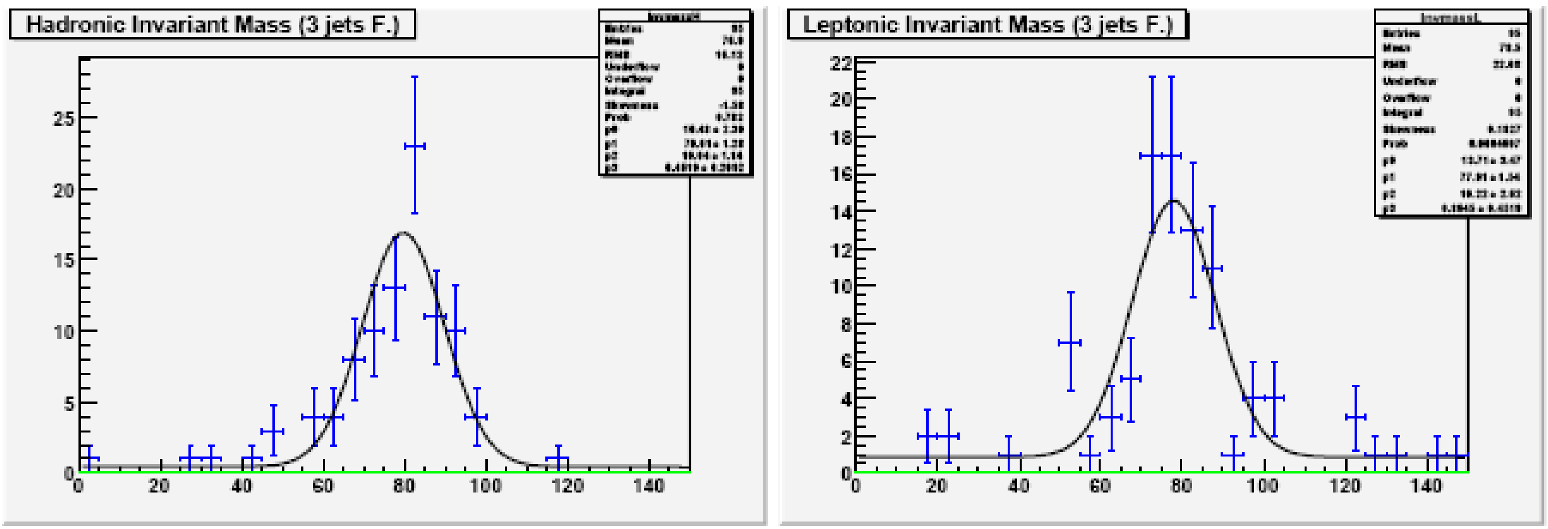

Figure 2: The W invariant mass measured from the hadronic decay (left) and from the leptonic decay (right).

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%.

Requires Positron Polarization

Conclusions

New Baseline:

• Undulator for positron production is at the end of the linac giving 30% polarized positrons at 150GeV and ~22% at 250GeV.

• Spin rotations systems for both electrons and positrons

Does not have positron helicity flip randomly pulse train to pulse train

• Upstream and downstream polarimeters for both electrons and positrons. Both upstream and downstream polarimeters required. Physics benefit of having both polarimeters justifies $(10 to 15) million cost for either.

Positron polarization of 30% improves physics reach (factor 2 in some reactions)
Positron helicity flip important for systematic error reduction.

Upstream Polarimeter

Location of the upstream polarimeter is now separated from the machine protection collimator, skew correction and emittance measurement.

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.

Feedback

Orbit through Compton IPs and e^+e^- IP needs active feedback to maintain orbit angle to ~25 μm.