Physics at the ILC with an initial Positron Polarization of 30%

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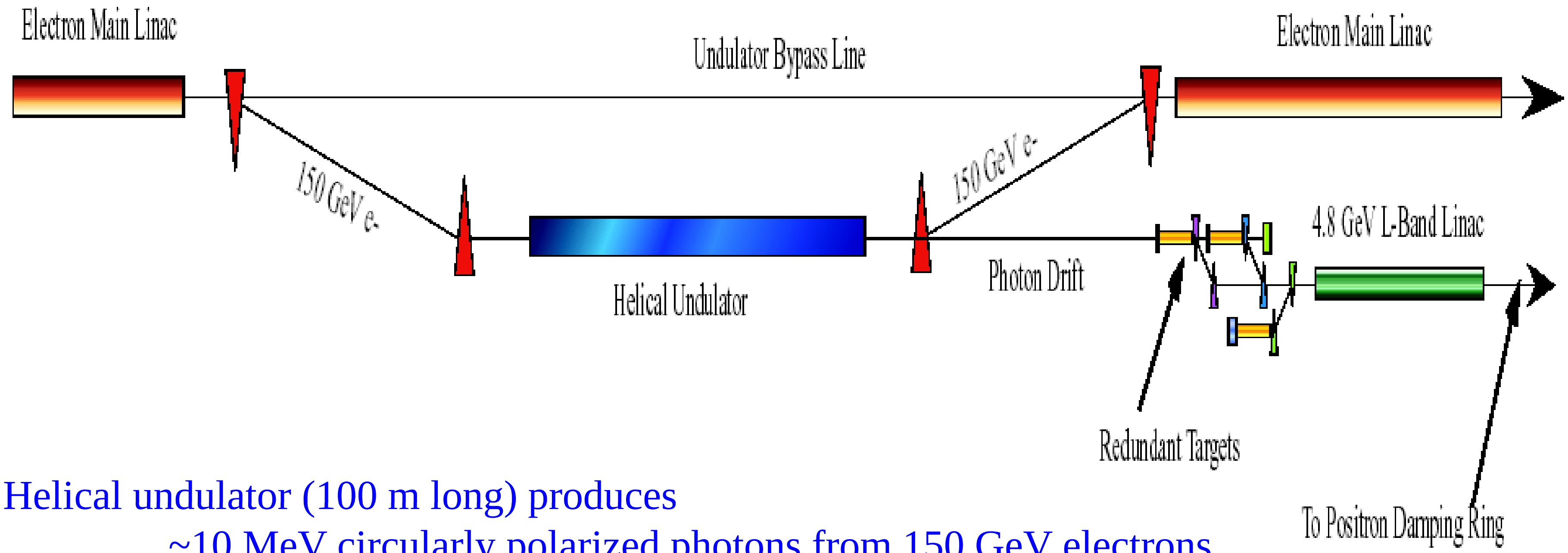
28 June 2007

G. Moortgat-Pick, et. al., *The role of polarized positrons and electrons in revealing fundamental interactions at the Linear Collider*, SLAC-PUB-11087

J. Clarke, K. Flottmann, K. Moffeit, G. Moortgat-Pick, S. Riemann, P. Schuler, M. Woods, et al., *Physics with an initial positron polarization of 30%*, Dec 4, 2006

ILC baseline positron source



Helical undulator (100 m long) produces

~10 MeV circularly polarized photons from 150 GeV electrons

Positrons of collected from a thin target.

Positron polarization depends on:

Photon polarization spectrum (tight collimation increases polarization)

Target material and thickness

Positron capture phase space

Positron longitudinal polarization of ~30% can be expected from the baseline ILC

Fully implemented positron source polarization of 40 – 70% is expected.

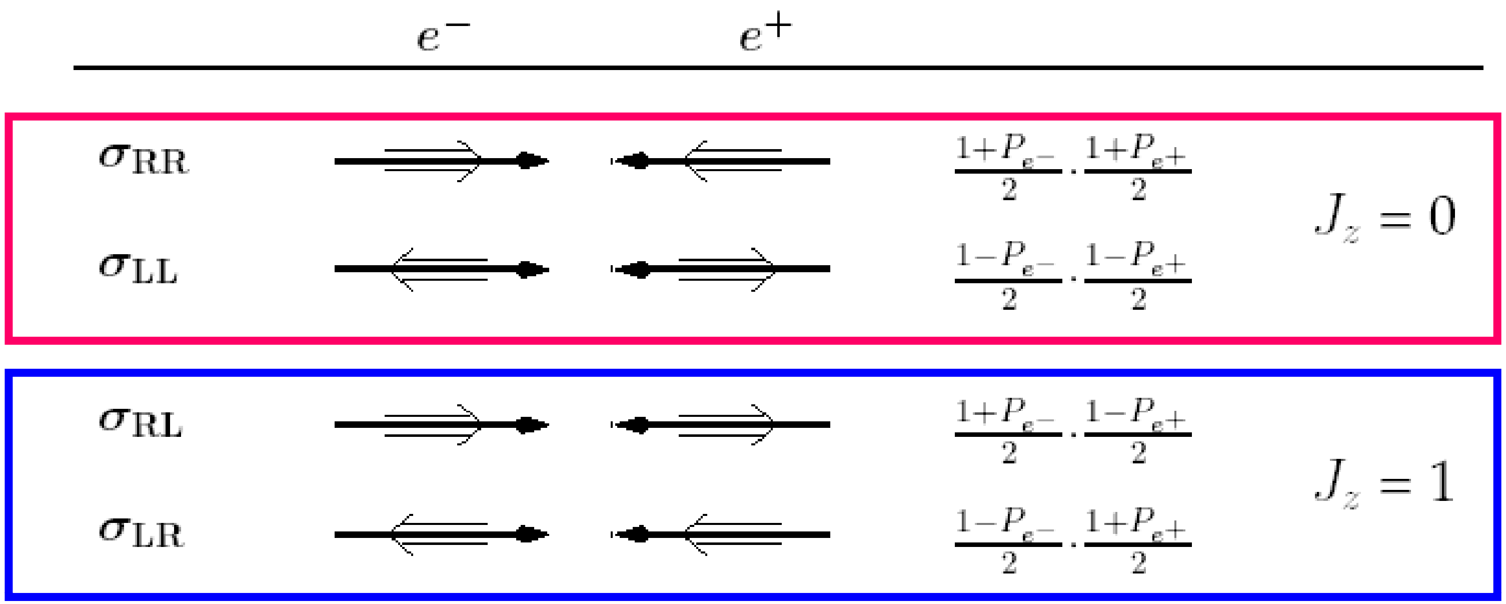
Collimate photons from undulator increases circular polarization of photons hitting target.

Increase length of helical undulator to ~200 m to restore positron beam intensity.

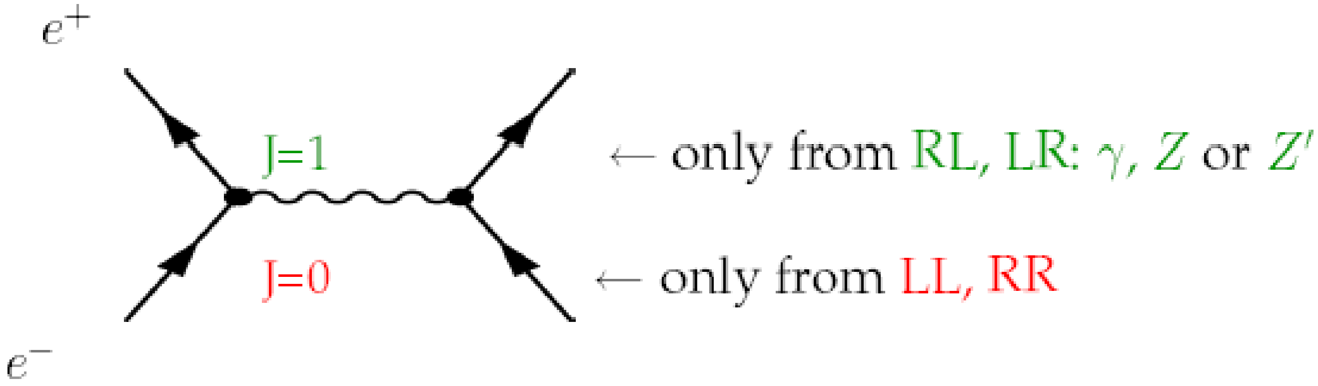
Result is higher positron polarization.

$$\sigma_{P_{e-}P_{e+}} = \frac{1}{4}\{(1+P_{e-})(1+P_{e+})\sigma_{\rm RR} + (1-P_{e-})(1-P_{e+})\sigma_{\rm LL} \\ +(1+P_{e-})(1-P_{e+})\sigma_{\rm RL} + (1-P_{e-})(1+P_{e+})\sigma_{\rm LR}\}$$

σ_{RL} cross section e- beam is completely right-handed polarized ($P_{e-} = +1$)
e+ beam is completely left-handed polarized ($P_{e+} = -1$)



Annihilation diagrams



Standard Model only J = 1 is possible.

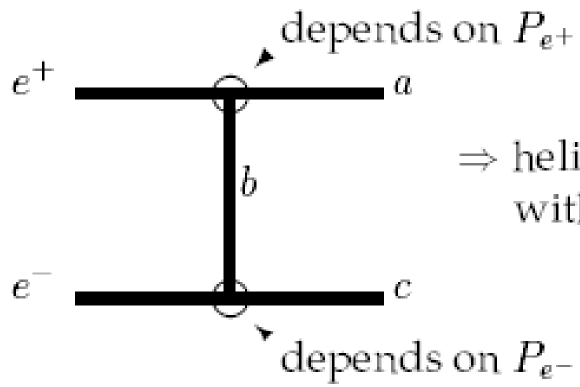
New Physics models:

may contribute to J = 1

may allow the production of scalar particles,

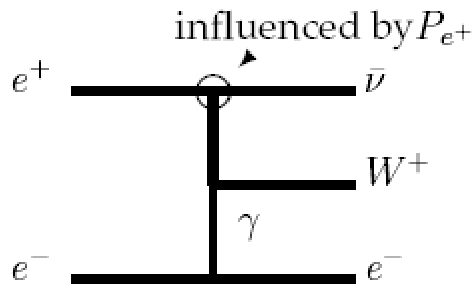
J = 0 would be allowed

Exchange diagrams



$\Rightarrow$ helicity of e^- not coupled with helicity of e^+

T- and u- channel diagrams:
The helicity of the incoming beam is directly coupled to the helicity of the final particle and is completely independent of the helicity of the second incoming particle.



Single W^+ production: the vertex $e^+W^+\bar{\nu}$ depends only on P_{e+}.

(P_{e-}, P_{e+})	unpolarized	$(-80\%, 0)$	$(-80\%, -60\%)$	$(-80\%, +60\%)$
$\sigma(e^+e^- \to e^+e^-)$	4.50 pb	4.63 pb	4.69 pb	4.58 pb

Table 1.2: Bhabha scattering at $\sqrt{s} = 500$ GeV for $45° < \theta < 135°$. Due to the γ, Z exchange in the t-channel all possible helicity configurations are allowed, e.g. the configuration LL leads to higher cross sections than LR.

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.

Uncertainty in zero positron polarization

$$A_{LR} = \frac{A_m}{\langle \mathcal{P}_e \rangle} + \frac{1}{\langle \mathcal{P}_e \rangle}\Big[f_b(A_m - A_b) - A_{\mathcal{L}} + A_m^2 A_{\mathcal{P}} - E_{cm}\frac{\sigma'(E_{cm})}{\sigma(E_{cm})} A_E - A_{\varepsilon} + \langle \mathcal{P}_e \rangle \mathcal{P}_p \Big],$$

$\langle \mathcal{P}_e \rangle$ is the mean luminosity-weighted polarization

f_b is the background fraction

$\sigma(E)$ is the unpolarized Z cross section at energy E;

$\sigma'(E)$ is the derivative of the cross section with respect to E

A_b, $A_{\mathcal{L}}$, $A_{\mathcal{P}}$, A_E, and A_{ε} are the left-right asymmetries [24] of the residual background, the integrated luminosity, the beam polarization, the center-of-mass energy, and the product of detector acceptance and efficiency, respectively

$\mathcal{P}_p$ is any longitudinal positron polarization which is assumed to have constant helicity

(- 0.02 +- 0.07%) at SLC

$$A_{LR}(91.237\ \text{GeV}) = 0.1454 \pm 0.00237(\text{stat.}) \pm 0.00077(\text{syst.})$$

Use of effective polarization and left-right asymmetry

In the case of e^+e^- annihilation into a vector particle (in the SM this would be $e^+e^- \to \gamma/Z^0$) only the two $J = 1$ configurations $\sigma_{\rm RL}$ and $\sigma_{\rm LR}$ contribute, as already mentioned in sect. 1.2.2, and the cross section for arbitrary beam polarizations is given by

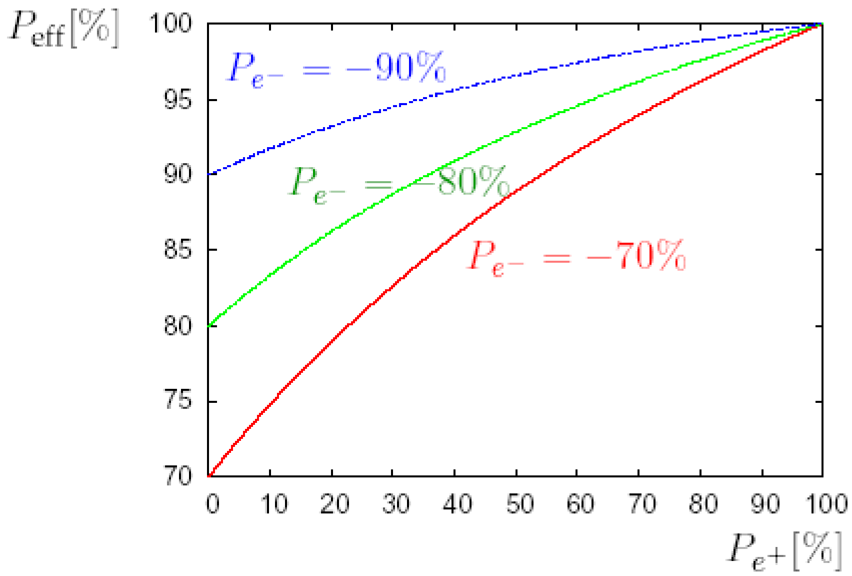
$$\begin{aligned} \sigma_{P_{e^-}P_{e^+}} &= \frac{1+P_{e^-}}{2}\,\frac{1-P_{e^+}}{2}\,\sigma_{\rm RL} + \frac{1-P_{e^-}}{2}\,\frac{1+P_{e^+}}{2}\,\sigma_{\rm LR} \\ &= (1-P_{e^-}P_{e^+})\,\frac{\sigma_{\rm RL}+\sigma_{\rm LR}}{4}\left[1 - \frac{P_{e^-}-P_{e^+}}{1-P_{e^+}P_{e^-}}\,\frac{\sigma_{\rm LR}-\sigma_{\rm RL}}{\sigma_{\rm LR}+\sigma_{\rm RL}}\right] \\ &= (1-P_{e^+}P_{e^-})\;\sigma_0\;[1 - P_{\rm eff}\,A_{\rm LR}] \end{aligned} \qquad (1.16)$$

the unpolarized cross section: $\sigma_0 = \dfrac{\sigma_{\rm RL}+\sigma_{\rm LR}}{4}$

the left-right asymmetry: $A_{\rm LR} = \dfrac{\sigma_{\rm LR}-\sigma_{\rm RL}}{\sigma_{\rm LR}+\sigma_{\rm RL}}$

and the effective polarization: $P_{\rm eff} = \dfrac{P_{e^-}-P_{e^+}}{1-P_{e^+}P_{e^-}}$

Effective polarization



The polarisation will be increased to an effective value $P_{eff} = (P_{e^-} + P_{e^+})/(1 + P_{e^-} P_{e^+})$[1]: for example, 80% electron and 60% (30%) positron polarisation result in an effective polarization of 95% (88%).

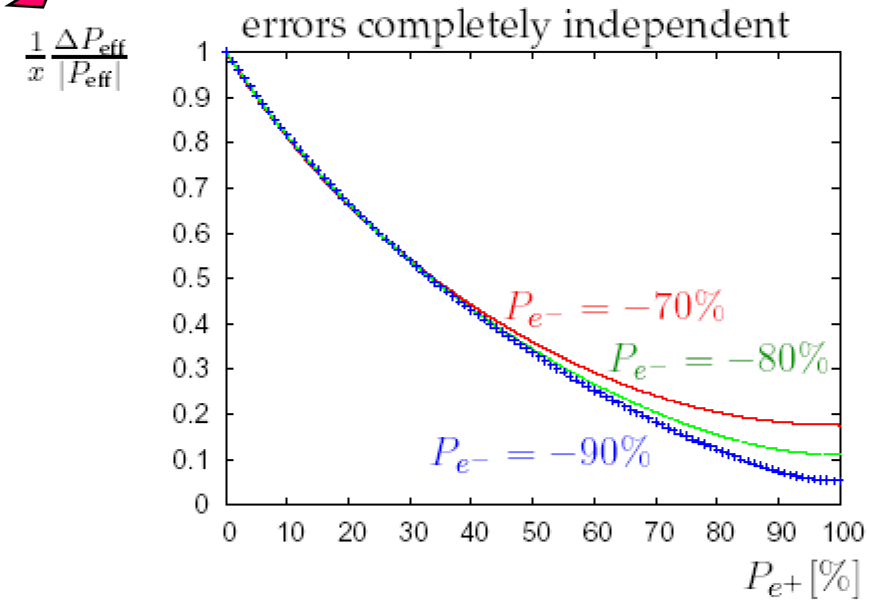
Errors reduced

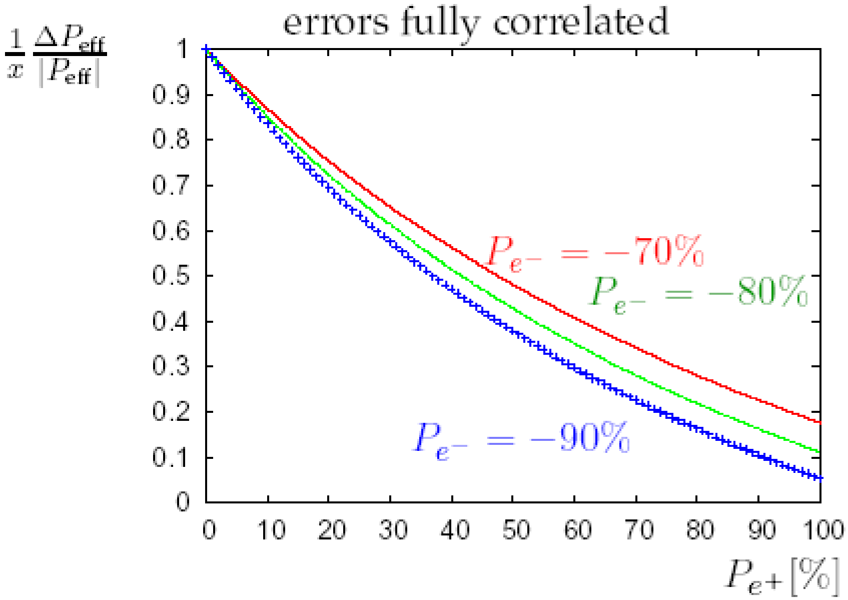
$$A_{\mathrm{LR}} = \frac{1}{P_{\mathrm{eff}}} A^{\mathrm{obs}}_{LR} = \frac{1}{P_{\mathrm{eff}}} \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}}$$

$$\left|\frac{\Delta A_{\mathrm{LR}}}{A_{\mathrm{LR}}}\right| = \left|\frac{\Delta P_{\mathrm{eff}}}{P_{\mathrm{eff}}}\right|$$

$$x \equiv \Delta P_{e^-}/P_{e^-} = \Delta P_{e^+}/P_{e^+}$$

Errors P_{e+} and P_{e-} fully correlated e.g. depolarization effects from Bremsstrahlung



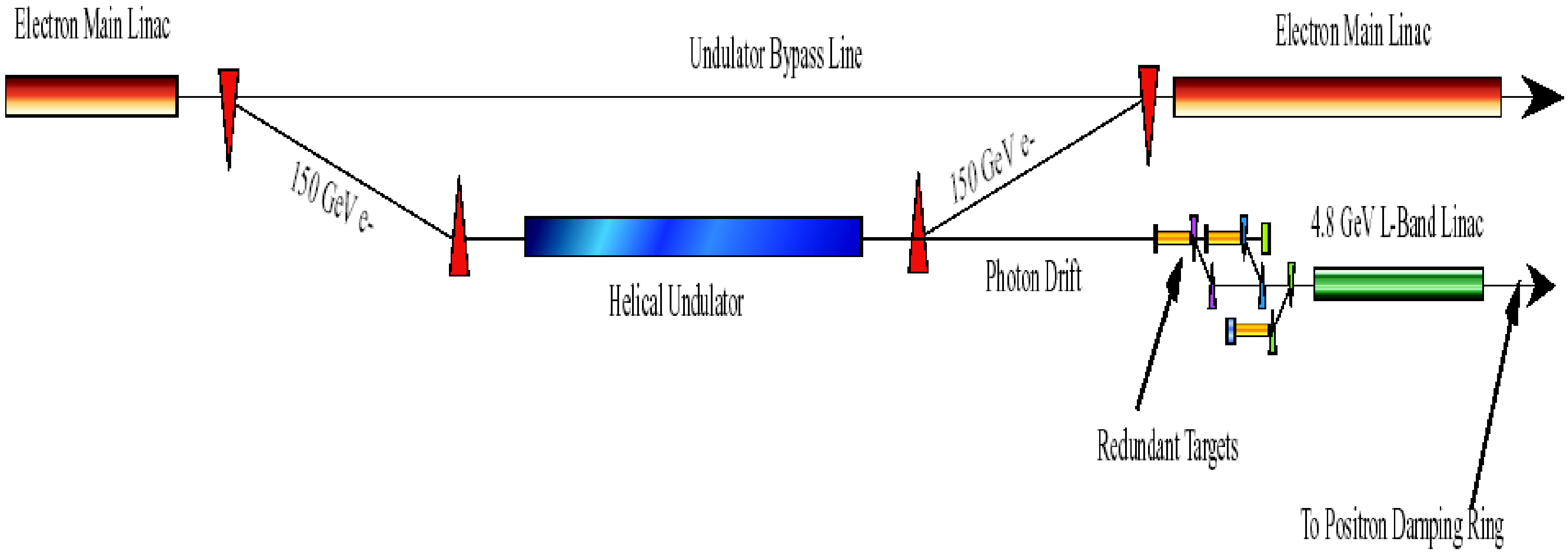


Due to error propagation the polarisation uncertainty is substantially reduced if the positrons are polarized: For the [80%, 60% (30%)] case the error of the effective polarisation is smaller by factor 4 (2) for independent polarization errors ΔP_{e^-}, ΔP_{e^+} and at least by a factor of 3(1.5) for correlated errors.

$(P(e^-), P(e^+))$	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain w.r.t. (80%,0%)& Requirement (80%,60%)	(80%,30%)
Statistics:			
$P_{\rm eff}$	V,A processes	95%	88%
$\Delta A_{LR}/A_{LR}$	due to error propagation	×3	×2
Standard Model:			
top threshold	Electroweak coupling measurement	× 3	× 2
$t\bar{q}$	Limits for FCN top couplings improved	× 1.8	× 1.4
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$ ×0.8
W^+W^-	TGC: error reduction of $\Delta\kappa_\gamma$, $\Delta\lambda_\gamma$, $\Delta\kappa_Z$, $\Delta\lambda_Z$	×1.8	
	Specific TGC $\tilde{h}_+ = {\rm Im}(g_1^{\rm R} + \kappa^{\rm R})/\sqrt{2}$	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	×4	× 2
	Suppression of $B = W^+\ell^-\nu$	×1.7	
$t\bar{t}H$	Top Yukawa coupling at $\sqrt{s} = 500$ GeV	×2.5	×1.6
Supersymmetry:			
$\tilde{e}^+\tilde{e}^-$	Quantum numbers L, R and Yukawa	$P_{e^-} P_{e^+}$	$P_{e^-} P_{e^+}$ ×0.6
HA, $m_A > 500$ GeV	Access to difficult parameter space	×1.6	
RPV in $\tilde{\nu}_\tau \to \ell^+\ell^-$	Test of spin: S/B, $S/\sqrt{B}$	×10	
Extra Dimensions:			
$G\gamma$	Enhancement of S/B, $B = \gamma\nu\bar{\nu}$,	×3	
$e^+e^- \to f\bar{f}$	Unique distinction ADD vs. RS	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$	$P^{\rm T}_{e^-} P^{\rm T}_{e^+}$ ×0.5
New gauge boson Z':			
$e^+e^- \to f\bar{f}$	Measurement of Z' couplings	×1.5	
Contact interactions:			
$e^+e^- \to e\bar{e}$	Model independent bounds	$P_{e^-} P_{e^+}$	$P_{e^-} P_{e^+}$
Precision measurements of the Standard Model at GigaZ:			
Z-pole	Improvement of $\Delta\sin^2\theta_W$	× 10	×5 (?)
	Improvement of Higgs bounds	×10	?

Utilization of 30% positron polarization at the beginning of ILC

Polarized positron source

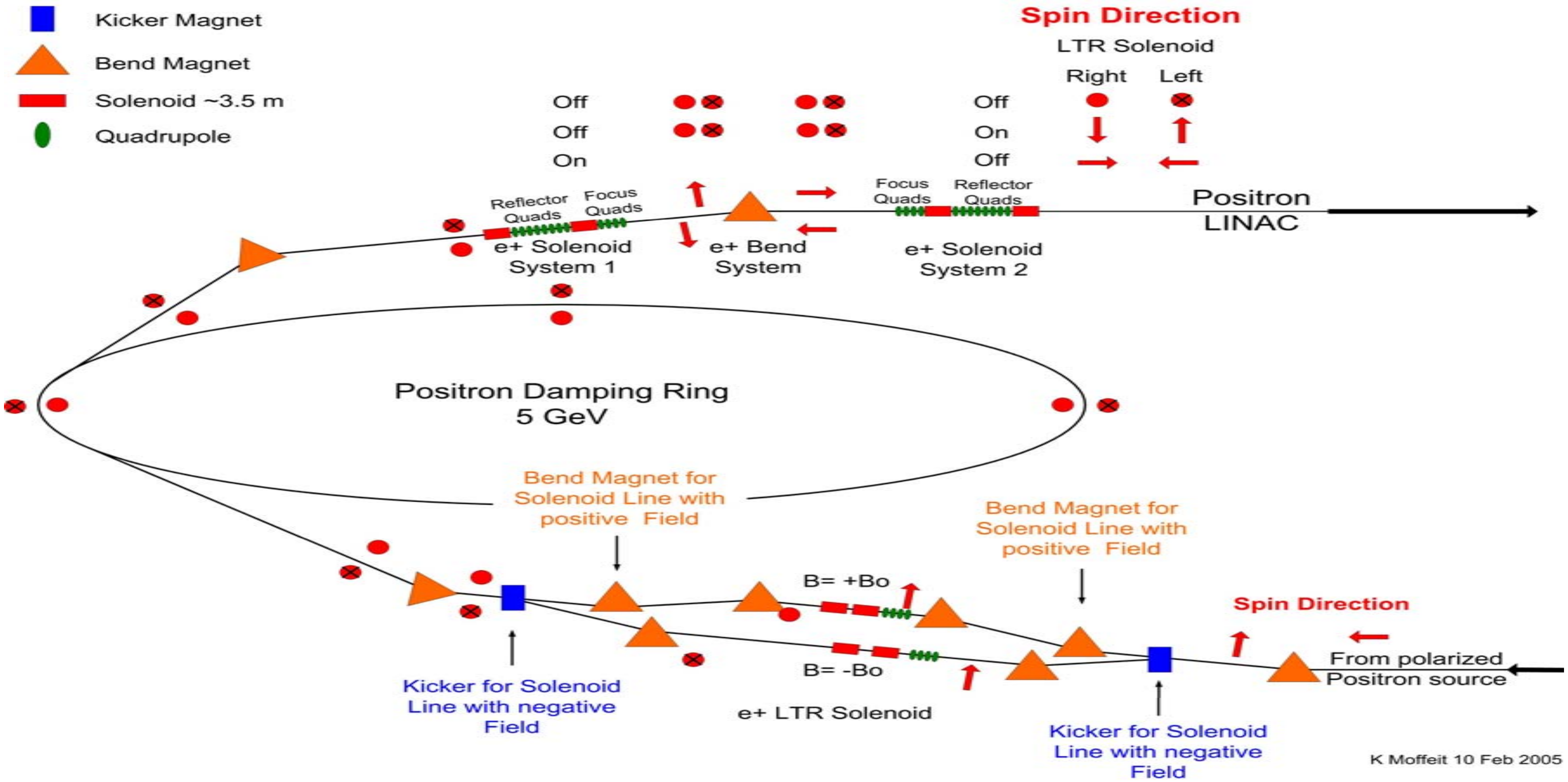


Capture for highest positron polarization with desired positron intensity

Transport polarization efficiently to positron damping ring

Measure positron polarization before positron damping ring with Mott or Moeller polarimeter

Spin transport of positron polarization



Helicity flip on a pulse train to pulse train basis is important:

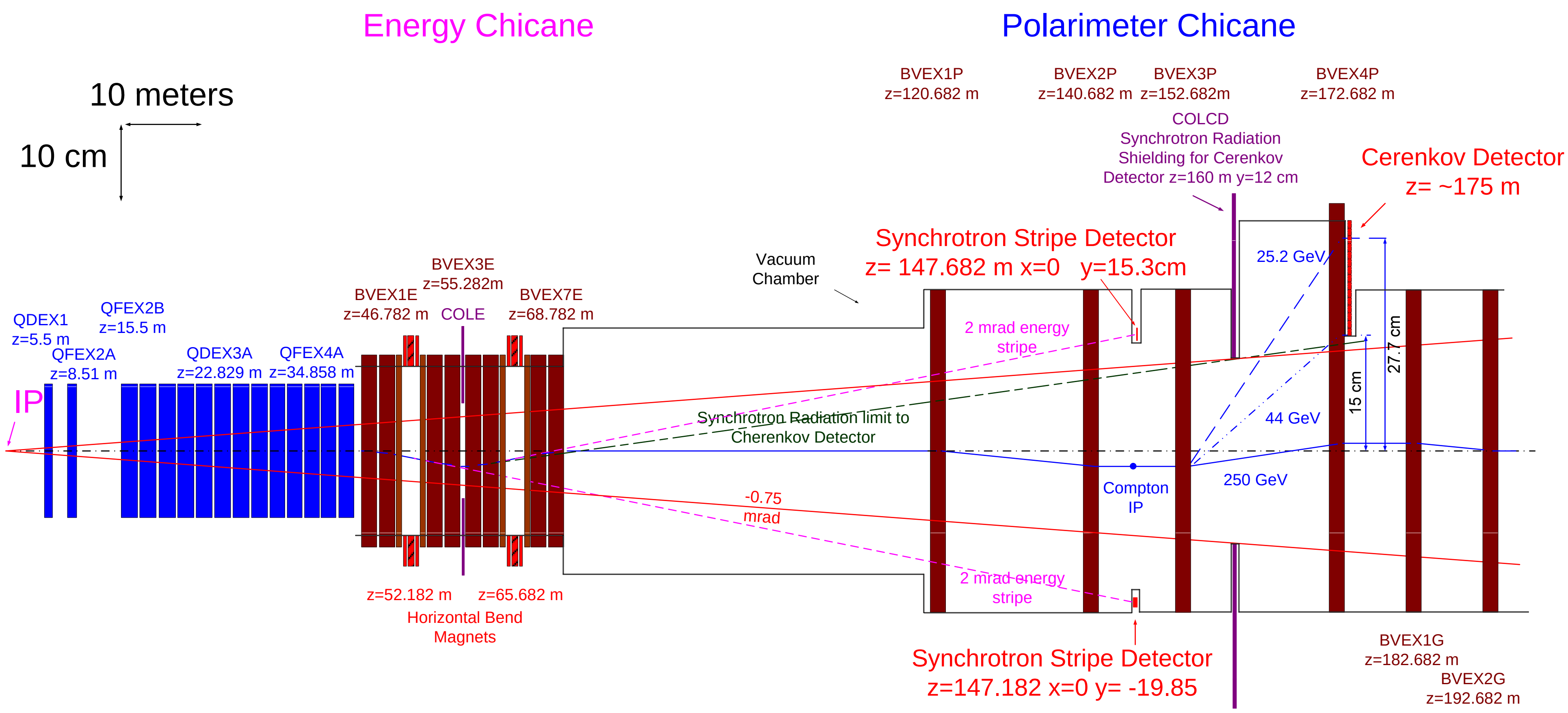
Differences in intensity and polarization between the two positron beam helicity states should stay within a tolerance limit of +-1% after the damping ring.

Fast kickers will be needed to direct the beam to the second linac-to-ring line with the opposite solenoidal B-field.

Inverting helicity periodically (eg weekly) in spin rotation system after damping ring can be used to reduce systematic errors further.

Measure positron polarization

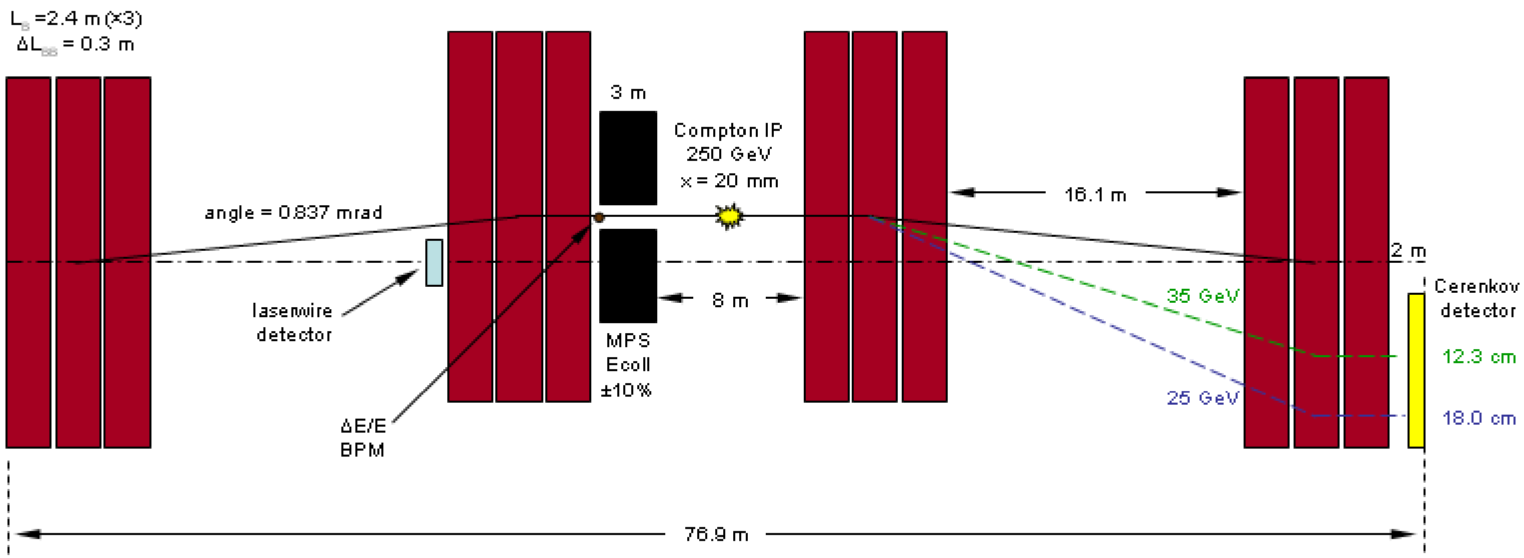
Positron extraction line polarimeter



Positron Beam Delivery System upstream Compton polarimeter

New Upstream Polarimeter Chicane

- constant integrated strength dipoles (B = 0.97 kG)
- dispersion = 20 mm @ 250 GeV, 10 mm @ 500 GeV
- dispersion scales inversely with energy (= 110 mm @ 45 GeV)
- transverse space for laserwire detector @ 500 GeV? (< 5 mm)
- magnet and vacuum chamber engineering issues?



Requirements

Physics measurements will benefit from 30% positron polarization created in a source with a 100m long helical undulator. The following issues are necessary to make use of this polarization. They should be available from the beginning or at least as soon as possible after the start of ILC operation:

• Spin rotators before and after the damping ring.

• Two parallel spin rotation beam lines in the linac-to-ring transfer line before the damping ring.

Helicity Flipping:

Fast kickers will be needed to direct the beam to the second linac-to-ring line with the opposite solenoidal B-field.

• Positron polarimeters in the positron beam delivery system and the positron extraction line are mandatory.

• Positron polarimeter before the positron damping ring may be desired.