Polarization Issues at CLIC

Polarization is useful for improving the signal-to-noise ratio, for studies of certain interactions, for new-particle searches, etc. SLC has clearly shown its value.

How about polarization for CLIC at 3 TeV?

Issues:

(1) Polarized e^- Source (2) e^+ Source

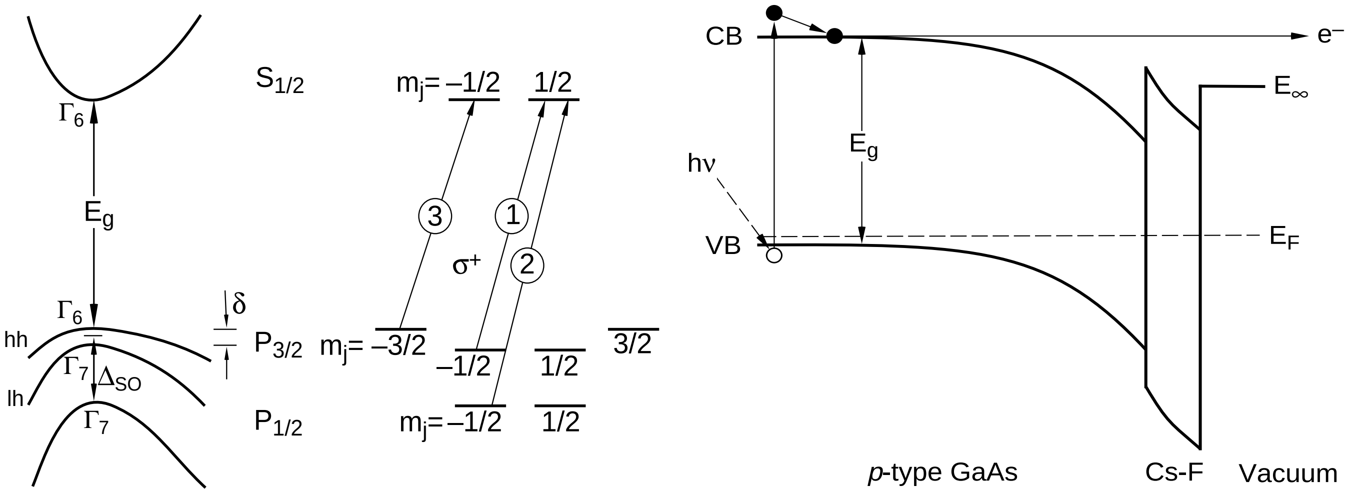
(3) Spin Transport

(4) Depolarization in Collision

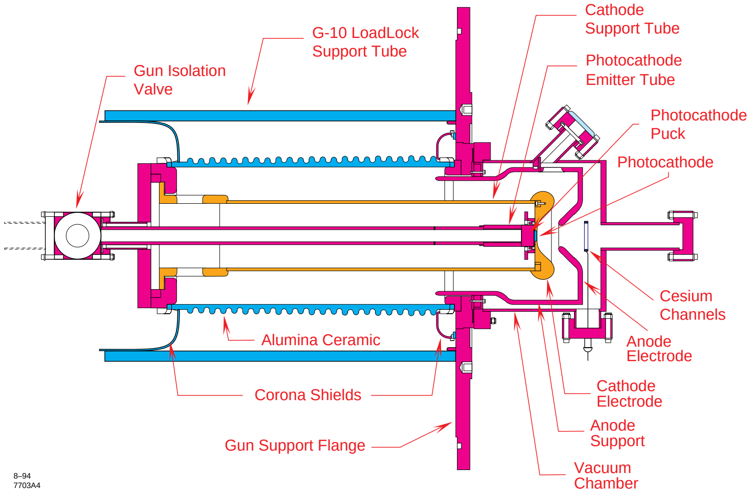
(5) Polarimetry

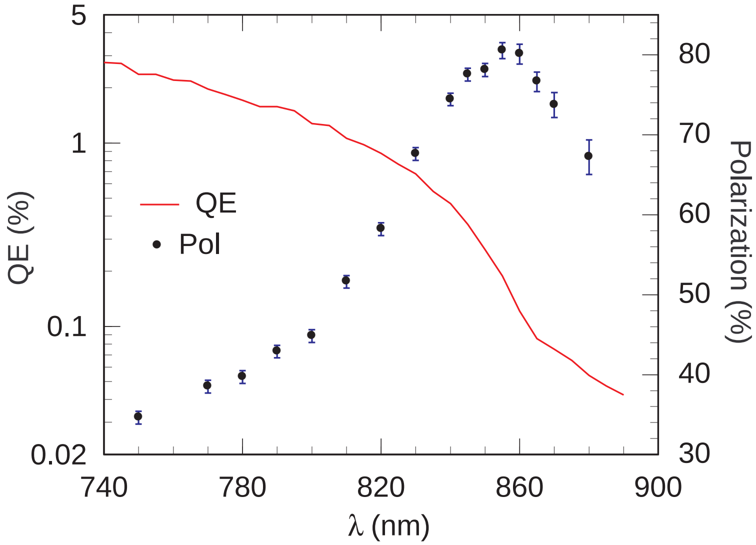
Polarized e^- Source

- DC gun with laser photocathode (SLC type: *p*-type doped strained GaAs semiconductor photocathode)
- Polarized RF gun (research topic)



Left: conduction & valence bands of strained GaAs and relative transition probabilities; right: downward band bending in p-GaAs & Cs-F layer drop vacuum level below cond. b. (H. Tang et al., 1995).





Left: longitudinal cross section of SLC polarized e$^-$ gun; right quantum efficiency and quantum polarization as a function of λ (H. Tang et al., 1995).

concerns: charge limit, current limit, multi-bunch operation

parameter	SLC	NLC-II	CLIC
bunch ch. (10^{10} e$^-$)	7	2.8	0.4
total ch. (10^{10} e$^-$)	14	252	62
av. pulse current (A)	0.4	3.2	1.0
pulse length (ns)	62	126	103
beam polarization	$\sim 80\%$	$\sim 80\%$	$\sim 80\%$

cathode relaxation time for 2×10^{19} cm^{-3} doping:
$\tau_{\rm r} \sim 10$ ns

back-up solutions: modulated doping, As capping, increased cathode surface, multiple guns,...

Polarized e$^+$ Source

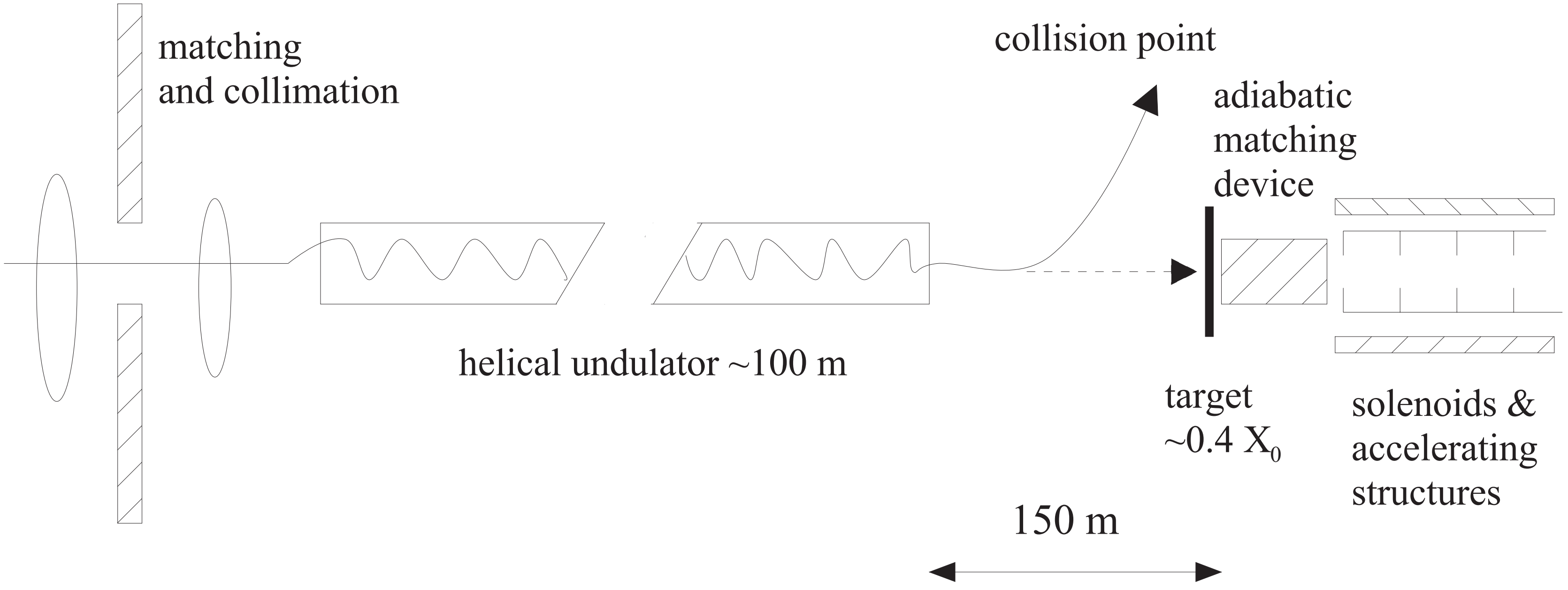
Three schemes:

(1) circularly polarized photons emitted by high-energy electron beam traversing a helical undulator and subsequent e$^+$e$^-$ pair creation on a thin target (VLEPP, Balakin and Mikhailichenko, 1979; TESLA, Floettmann, 1993; CLIC, Kamitani, 2000).

(2) e$^+$e$^-$ pair creation from backward Compton scattered laser photons (JLC, Omori et al., 1996)

(3) collection of high-energetic e$^+$ from thin target hit by polarized e$^-$ beam (NLC, Kotseroglou et al., 1999)

Helical Undulator:

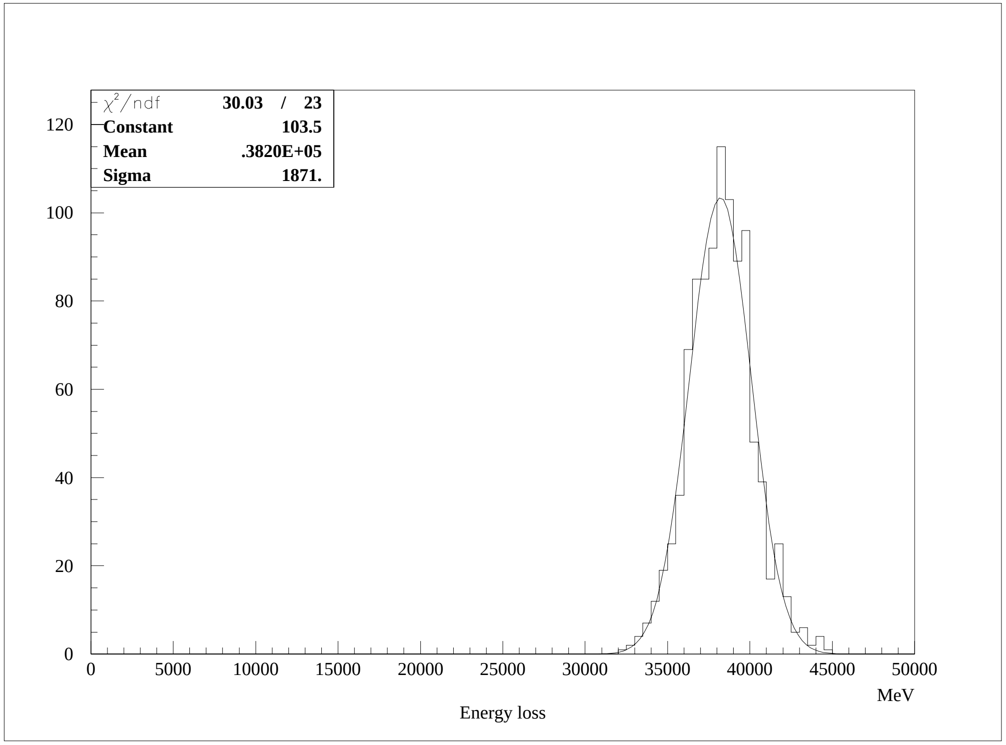


TESLA-style polarized e$^+$ source: helical undulator, a thin low-Z target, and a capture section with adiabatic matching.

$\lambda_\gamma = \frac{3}{4}\frac{\lambda_0}{\gamma^2}$; number of quanta: $N_q \approx \frac{\pi}{8}\ \frac{r_e L}{\lambda_0 \lambda\!\!\!^{-}_e}$. For $\lambda_0 = 1$ cm & $L = 300$ m $E_b = 100$ GeV $\rightarrow E_\gamma = 6.3$ MeV; $E_b = 1.5$ TeV $\rightarrow E_\gamma = 1.4$ GeV. Number of quanta $N_q \approx 170$. Concerns: $\Delta\delta_{\rm rms}$ & $\Delta\epsilon$.

Polarization: 60→40% (TESLA), **85%** (VLEPP).

Helical Undulator at CLIC

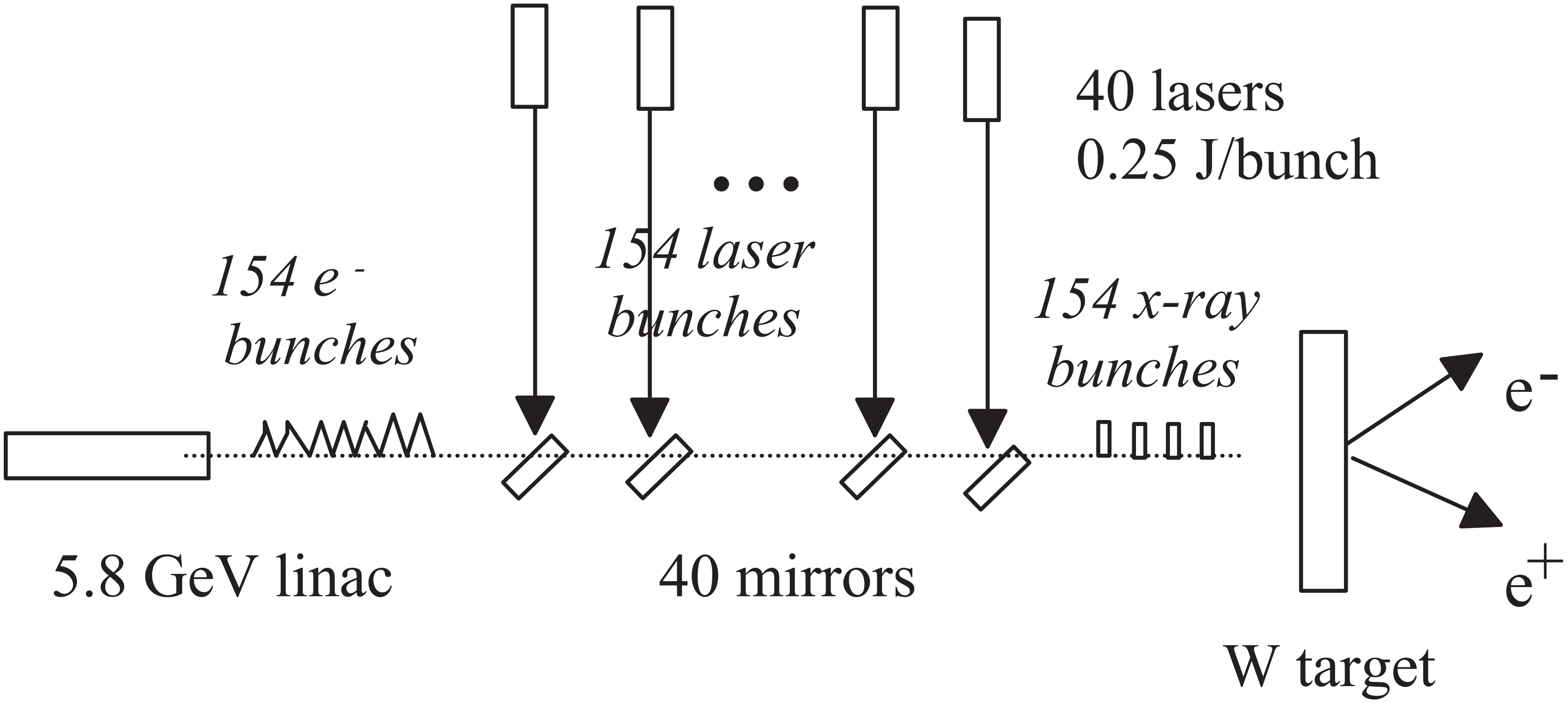


Energy loss for 1.5 TeV beam energy (T. Kamitani, 2000).

Parameters: $L = 150$ m, $B_u = 1.76$ T, $\lambda_u = 3.37$ cm, $K = 5.5$, $E_1 = 20.0$ MeV.

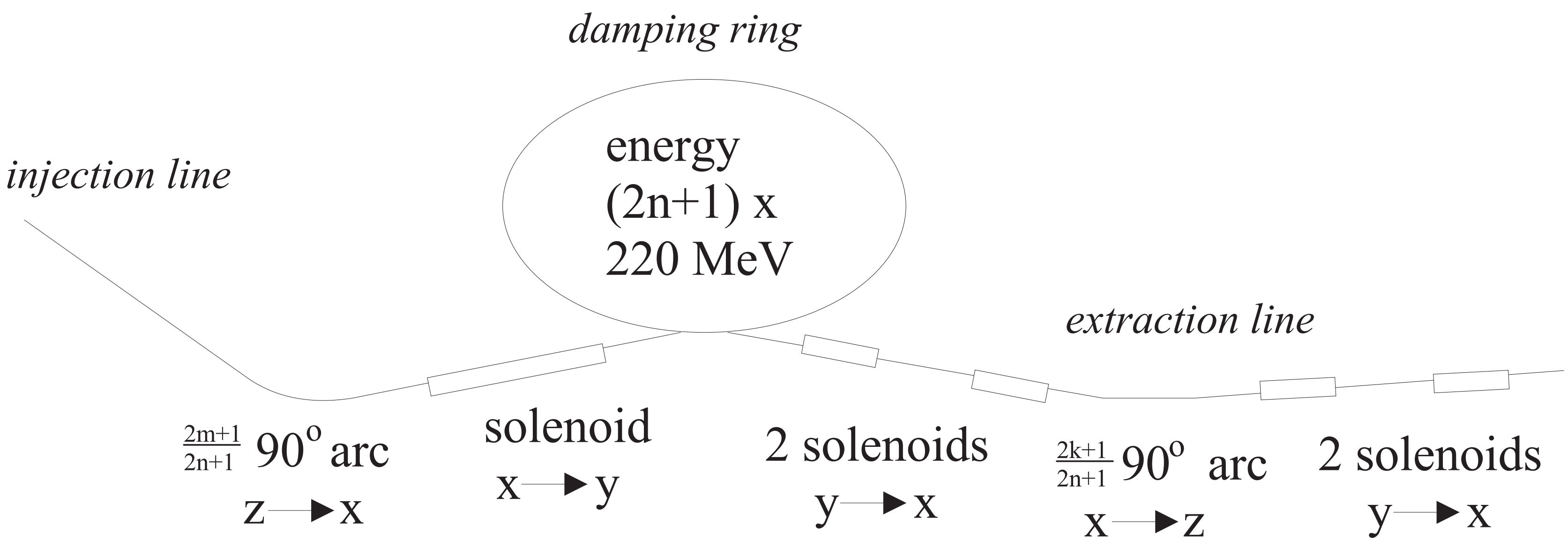
Energy loss $\Delta E = 38.2$ GeV, spread $\sigma_E/E \approx 1.25 \times 10^{-3}$.

Laser Compton Scattering:



JLC-style polarized e^+ source, consisting of 40 CO_2 lasers, each producing 154-bunch pulse, scattering off a 6-GeV beam with 10^{11} e^-/bunch. Projected polarization level is 60–80% (JLC).

Spin Transport



Schematic of spin manipulations around the damping ring à la NLC (P. Emma, M. Minty, T. Raubenheimer et al.).

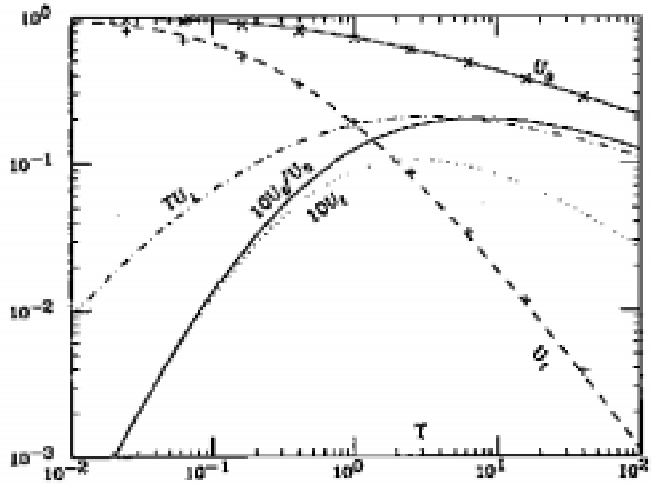
- bending magnet $(x \leftrightarrow z)$, $\psi_s = \alpha\gamma\theta_B$ with $\alpha = (g-2)/2 \approx 1.16 \times 10^{-3}$
- solenoid $(x \leftrightarrow y)$, $\psi_s = \left[1 - \left(\frac{g-2}{2}\right)\right] \frac{B_z L_s}{B\rho} \approx \frac{B_z L_s}{B\rho} \approx 2\psi_b$ where ψ_b is the transverse roll angle
- depolarization $P/P_0 = \exp(-\frac{1}{2}\left(\psi_s\sigma_\delta\right)^2)$ with σ_δ the rms energy spread; $\psi_s \neq 0 \rightarrow \Delta P \neq 0$

E.g., $\sigma_\delta = 0.2\%$ & $\theta_B = \pi$ at 9 GeV: $\Delta P \approx 1\%$, or $\sigma_\delta = 0.28\%$ & $\theta_B = 10$ mr at 1.5 TeV: $\Delta P \approx 0.5\%$.

Strength of Collisions

$$\xi_{x,y}^{\mathrm{eff}} = \frac{\beta_{x,y}^{*}}{\sigma_z} D_{x,y} = \frac{2 N r_e \beta_{x,y}^{*}}{\gamma \sigma_{x,y} (\sigma_x + \sigma_y)}$$

$$\Upsilon = \frac{2}{3} \frac{\hbar \omega_c}{E} \approx \frac{5}{6} \frac{\gamma r_e^2 N}{\alpha \sigma_z (\sigma_x + \sigma_z)}$$



$$N_\gamma \approx \frac{5}{2} \frac{\alpha \sigma_z}{\gamma \lambda_e} \Upsilon \left[\frac{1}{(1+\Upsilon^{2/3})^{1/2}} \right] \approx 2 \frac{\alpha r_e N_b}{\sigma_x + \sigma_y}$$

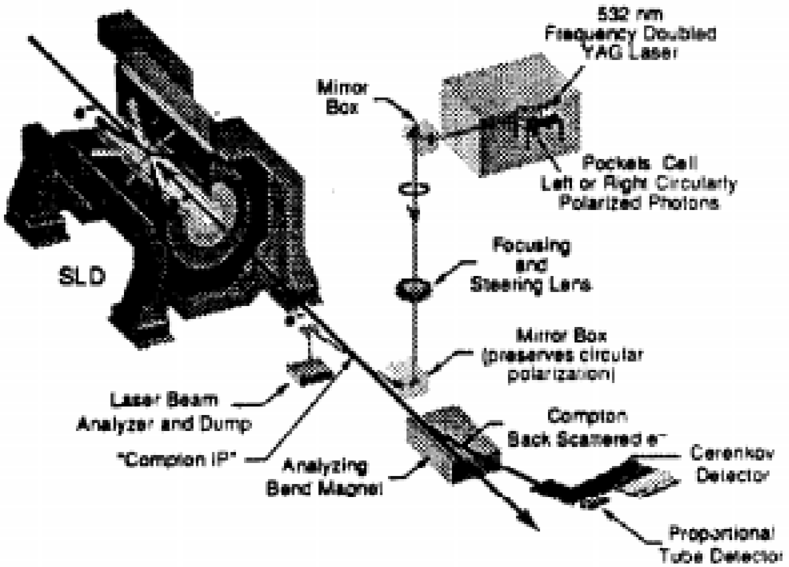
parameter	symbol	SLC	NLC	CLIC
‘collision strength’	$\xi_{x,y}$	1	8	**30**
Upsilon	Υ	2×10^{-3}	0.3	**8.1**
photons per e$^-$ (e$^+$)	N_γ	1	1.4	2.3

Depolarization during Collision

- spin-flip radiation $\Delta P = 2N_\gamma U_{f0}$ (Chen & Yokoya, 1988). With $U_{f0} \approx 0.02$ for $\Upsilon \approx 8$ and $N_\gamma \approx 2.3$: $\Delta P \approx 10\%$ & $[\Delta P] \approx 2.7\%$.
- spin precession in beam magnetic field $\Delta P \approx 0.006(N_\gamma/U_0)^2$ (Chen & Yokoya, 1988). With $N_\gamma \approx 2.3$ and $U_0 \approx 0.5$ one finds $\Delta P \approx 13\%$ & $[\Delta P] \approx 3.5\%$

Note: $N_\gamma \approx \frac{5}{2}\frac{\alpha\sigma_z}{\gamma\lambdabar_e}\Upsilon\left[\frac{1}{(1+\Upsilon^{2/3})^{1/2}}\right] \approx 2\frac{\alpha r_e N_b}{\sigma_x+\sigma_y}$

Polarization Measurement



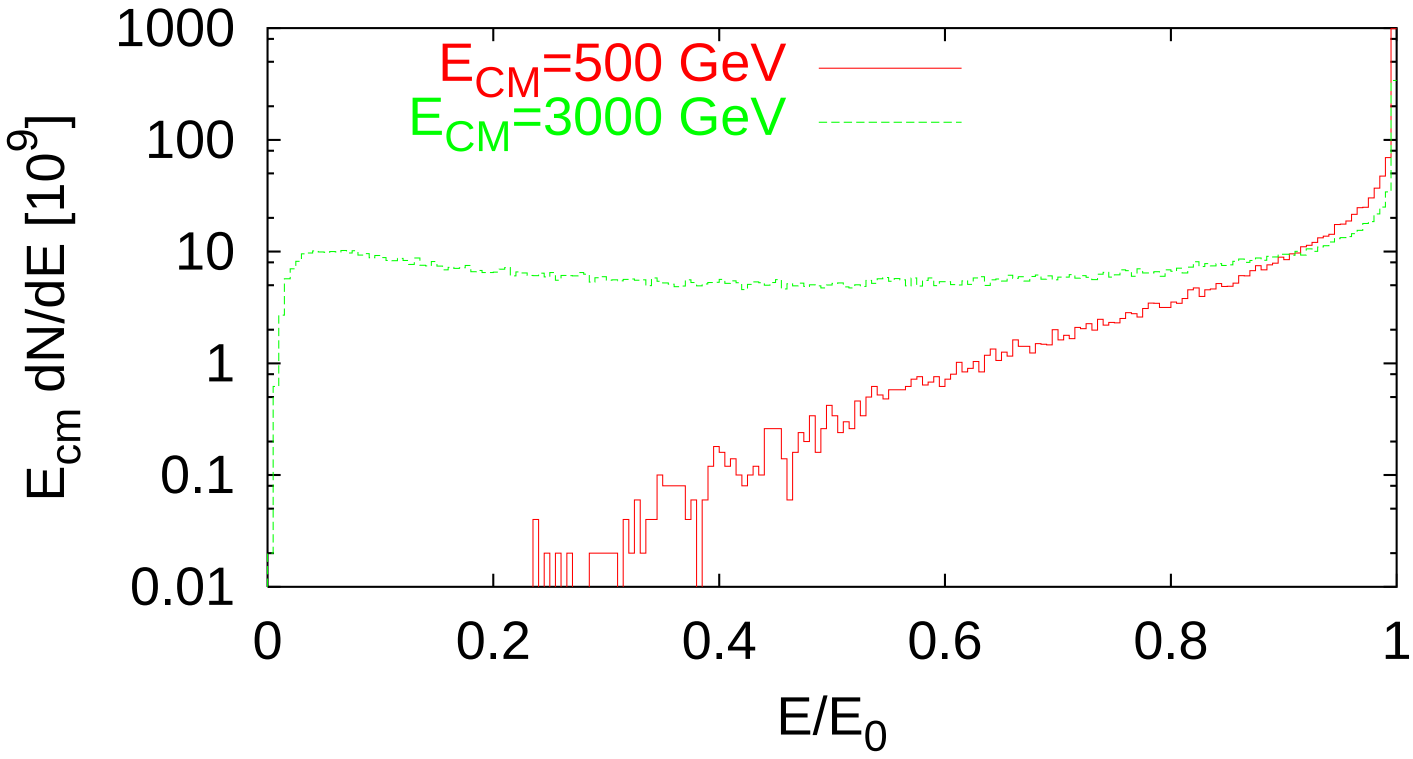
SLC Compton polarimeter (M. Woods et al.).

Asymmetry $A(E) = \frac{R(\rightarrow\rightarrow)-R(\rightarrow\leftarrow)}{R(\rightarrow\rightarrow)+R(\rightarrow\leftarrow)} = P_e P_\gamma A_c(E)$

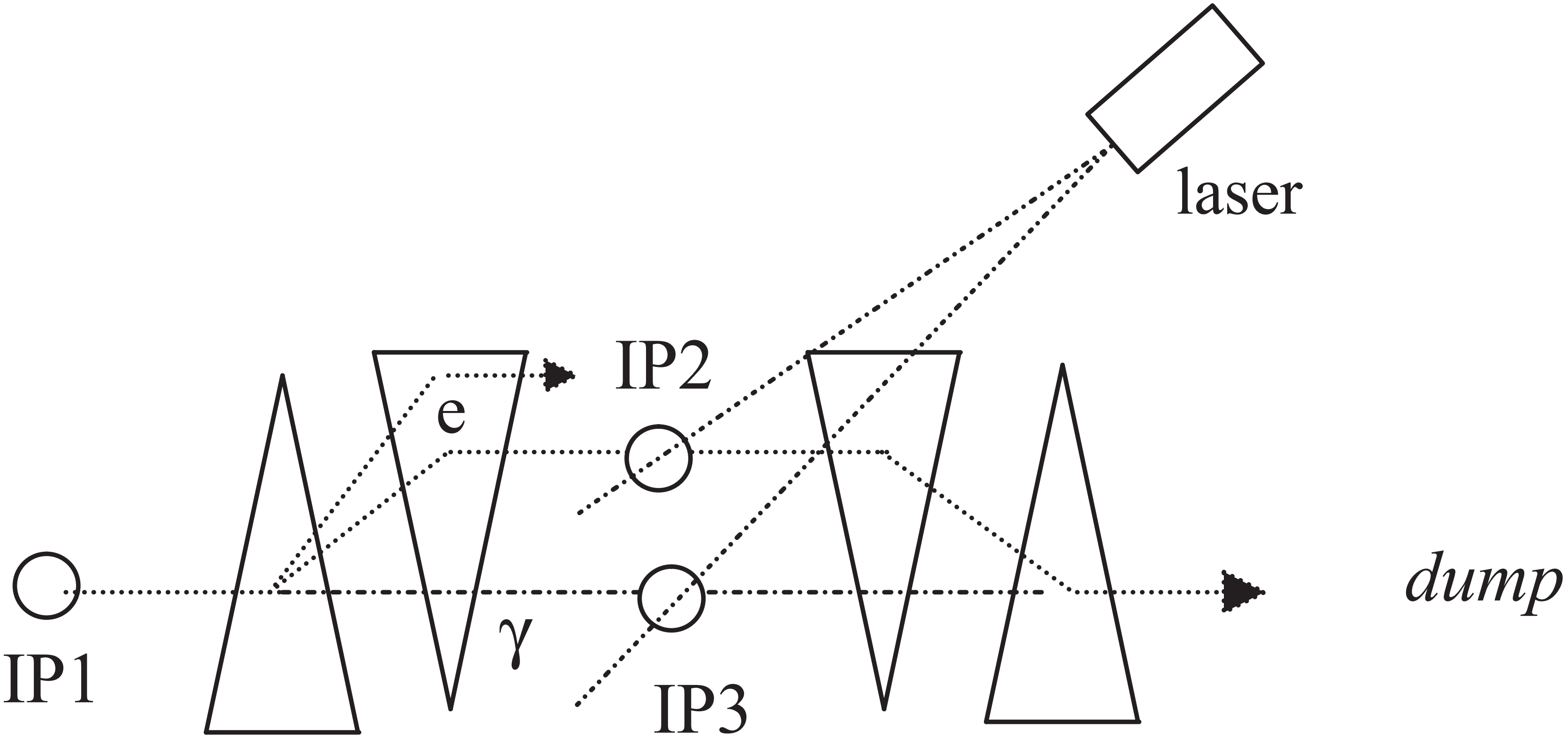
with $A_C(E)$ the Compton asymmetry and E energy of scattered e^-.

Systematic and statistical uncertainties: $\delta P \leq 1\%$.

At 3 TeV, Compton scattered and disrupted e^- may overlap in energy



Energy distribution of spent beam
(Guinea-Pig, D. Schulte).



Schematic of NLC-type spent-beam diagnostics and post-IP laser polarimeter (Spencer, 1996).

Measure effective polarization of disrupted $e^{\pm}$ beam. To avoid background from $e^- \gamma \rightarrow e^- e^+ e^-$: $E_\gamma < 522\mathrm{eV}/E_e[\mathrm{GeV}] \approx 0.3$ eV

Conclusions

- polarized electron beams with $P \approx 80\%$ may be taken for granted
- two techniques could provide a polarized positron beam with $P \approx 60 - 80\%$
- depolarization during the collision will be noticable; at 3 TeV $\Delta P \approx 25\%$ and $[\Delta P] \approx 7\%$; higher polarization is attainable for reduced luminosity