

Polarization at Multi-TeV Energies

R. Assmann, CERN-SL/AP

For the AP-CLIC team

**CLIC polarization studies
done by
F. Zimmermann**

Snowmass 2001, July 9th

Outline

- 1) Introduction**
- 2) Generation of polarized beams**
- 3) Depolarization issues**
- 4) Measurement of polarization**
- 5) Conclusion**

Introduction

Characterize particle by:

- 1) Charge
- 2) Mass
- 3) Energy
- 4) Spin

Classical Spin Vector \vec{S}

Polarized particle beam:

$$\vec{P} = \frac{1}{N} \sum_{i=1}^N \vec{S}_i$$

Control **magnitude** and **direction** of polarization.

Use of polarized beams

1) Interactions between particles depend on the particle's spin!

SLC Z-physics with less luminosity than LEP.
However: Polarized electron beam!

More precise measurement of electro-weak mixing angle than in LEP!

+ many more (RHIC, ...)

2) Spin precession rate depends on beam energy

LEP Precise calibration of beam energy (10^{-5})

Accurate mass and width of the Z

LEP prediction of top mass (standard model)

Spin Motion

Thomas-BMT equation:

$$\frac{d\vec{S}}{dt} = \vec{\Omega}_{\text{BMT}} \times \vec{S},$$
$$\vec{\Omega}_{\text{BMT}} = -\frac{e}{\gamma m} \left[(1 + a\gamma) \vec{B}_{\perp} + (1 + a) \vec{B}_{\parallel} - \left(a\gamma + \frac{\gamma}{1 + \gamma} \right) \vec{\beta} \times \frac{\vec{E}}{c} \right]$$

Vertical magnetic fields (rings):

Polarization should point into vertical direction!

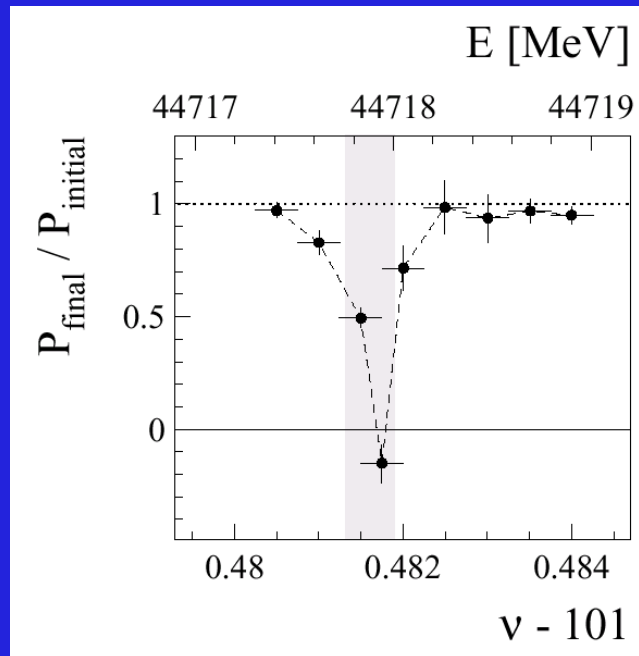
For physics:

Polarization should point in longitudinal direction!

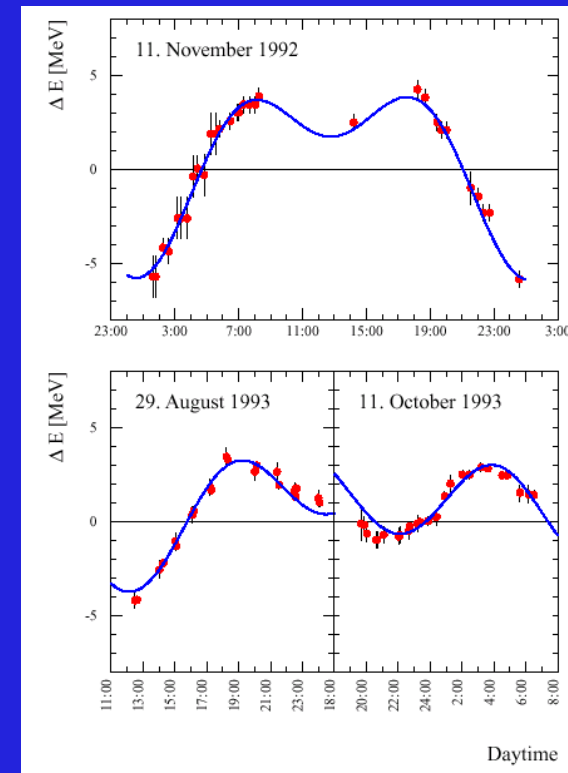
Manipulate the polarization vector!

Energy calibration

LEP
example
(resonant depolarization)



Accuracy:
0.15 MeV or 3.4×10^{-6}

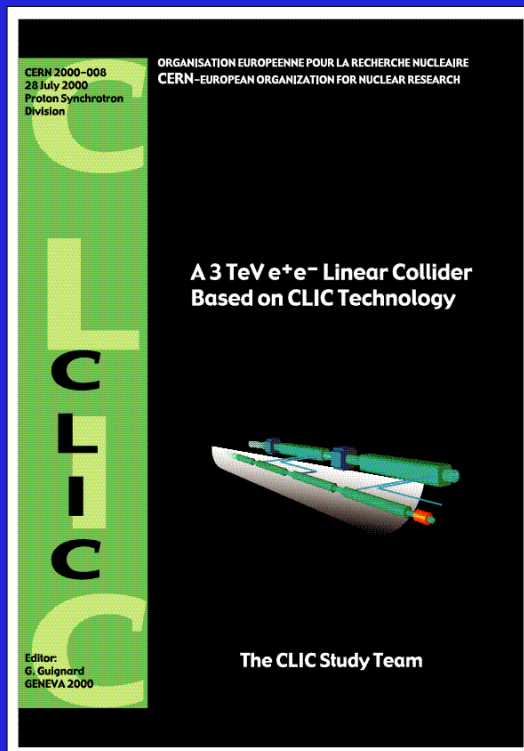


Not possible for linear colliders:

Energy spectrometers (no polarization required)

The Compact Linear Collider (CLIC) study at CERN:

Goal: Study a **3 TeV e⁺e⁻ linear collider** as an option for CERN's long-term future with innovative two beam acceleration scheme (no klystrons for main beam)



Collaborations with:

CEA/CESTA, Le Barp (France) **LAL, Orsay (France)**
IHEP, Protvino (Russia) **LLNL, Livermore**
LBL, Berkeley (USA) **INFN, Frascati (Italy)**
SLAC, San Francisco (USA) **JINR, Dubna (Russia)**
Stockholm University (Sweden) **KEK, Tsukuba**
(Japan)
Technische Universität, Berlin (Germany)

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What are the issues for polarization at multi-TeV?

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Generation of polarized beams

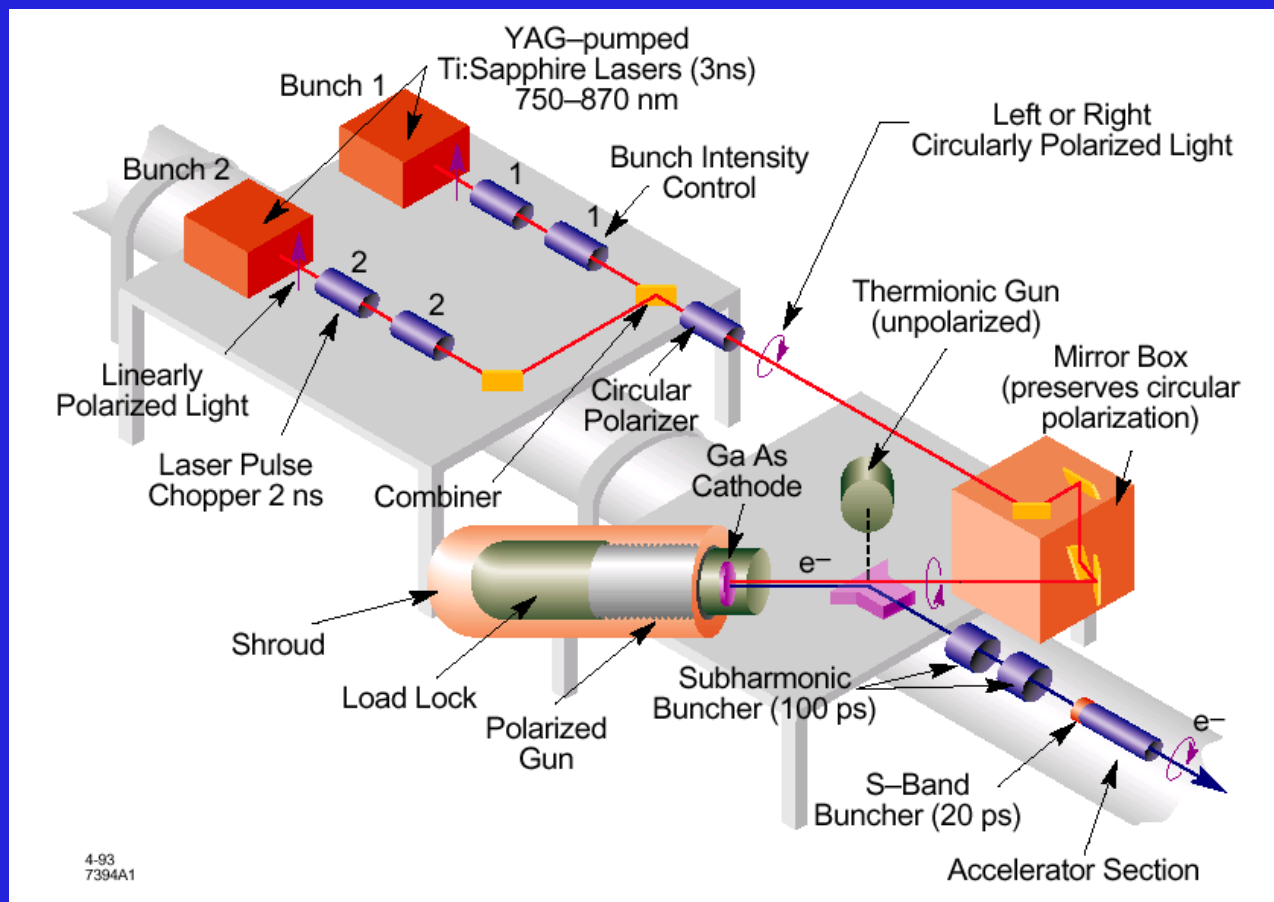
Storage rings: Sokolov-Ternov effect (spin-flip asymmetry from synchrotron radiation)

Cannot be used for linear collider beams (too slow)...

Linear collider approach (all similar):

- 1) Polarized electrons** can be produced directly, using polarized laser light and a photocathode
- 2a) Use high energy electrons to generate ~ 100 MeV photons in a high Z material (bremsstrahlung). Obtain unpolarized positrons** from pair production in same target.
- 2b) Use high energy electrons (unpolarized) to generate circularly polarized photons (helical undulator or Compton scattering). Obtain polarized positrons** from pair production in target.

1) Production of polarized electrons (SLC):



J. Clendenin et al
SLAC-PUB-7619

**SLC used: Strained Ga As photocathode.
Lasers controlled by 10 feed-back and
4 feed-back systems.**

Parameters:

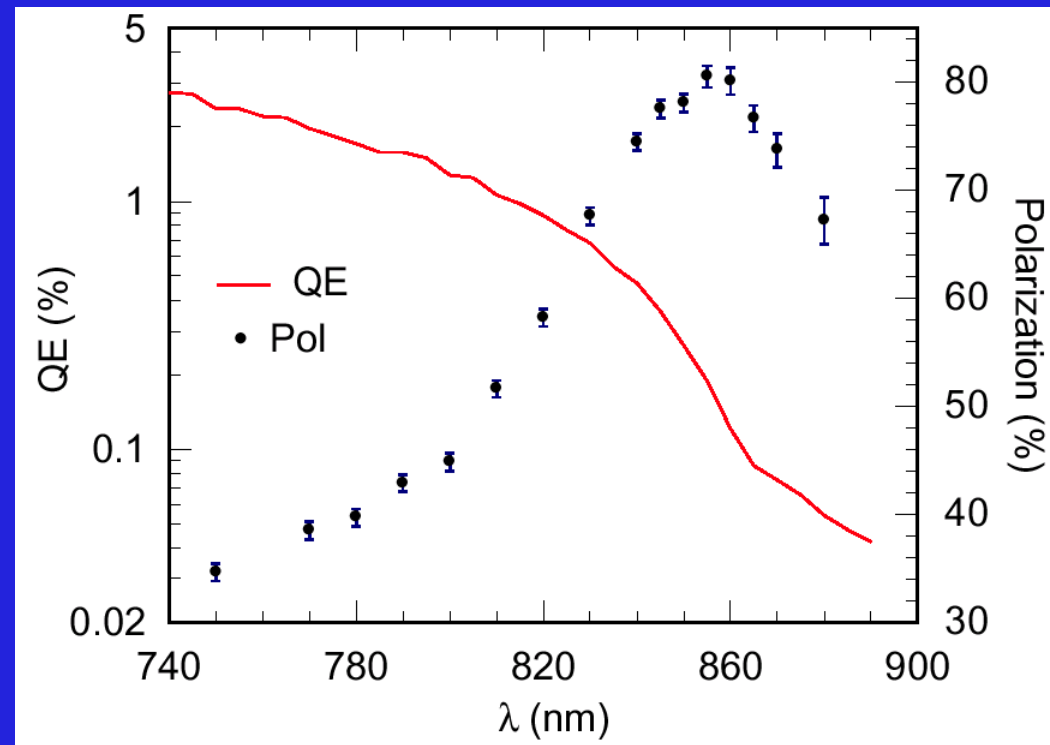
CLIC is OK!

**(rely on SLC
experience,
NLC studies)**

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	$\sim 80\%$	$\sim 80\%$	$\sim 80\%$

F. Zimmermann

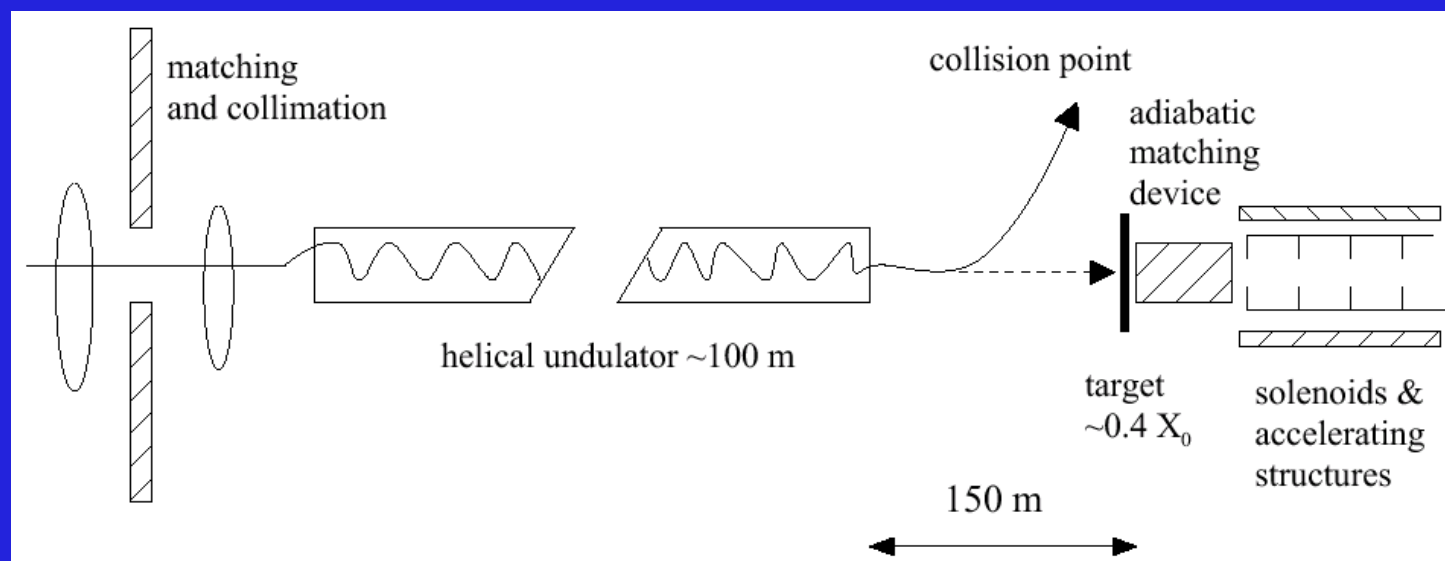
SLC source performance:



2) Production of polarized positrons (TESLA):

K. Floettmann (DESY): "CLIC can just take the TESLA design. It will even work better at higher energy of electron beam (> 250 GeV)"

Principle: Use 250 GeV electron beam and send through helical undulator to produce circularly polarized photons. Pair production in thin target.



Slight emittance / energy spread growth on physics beam.

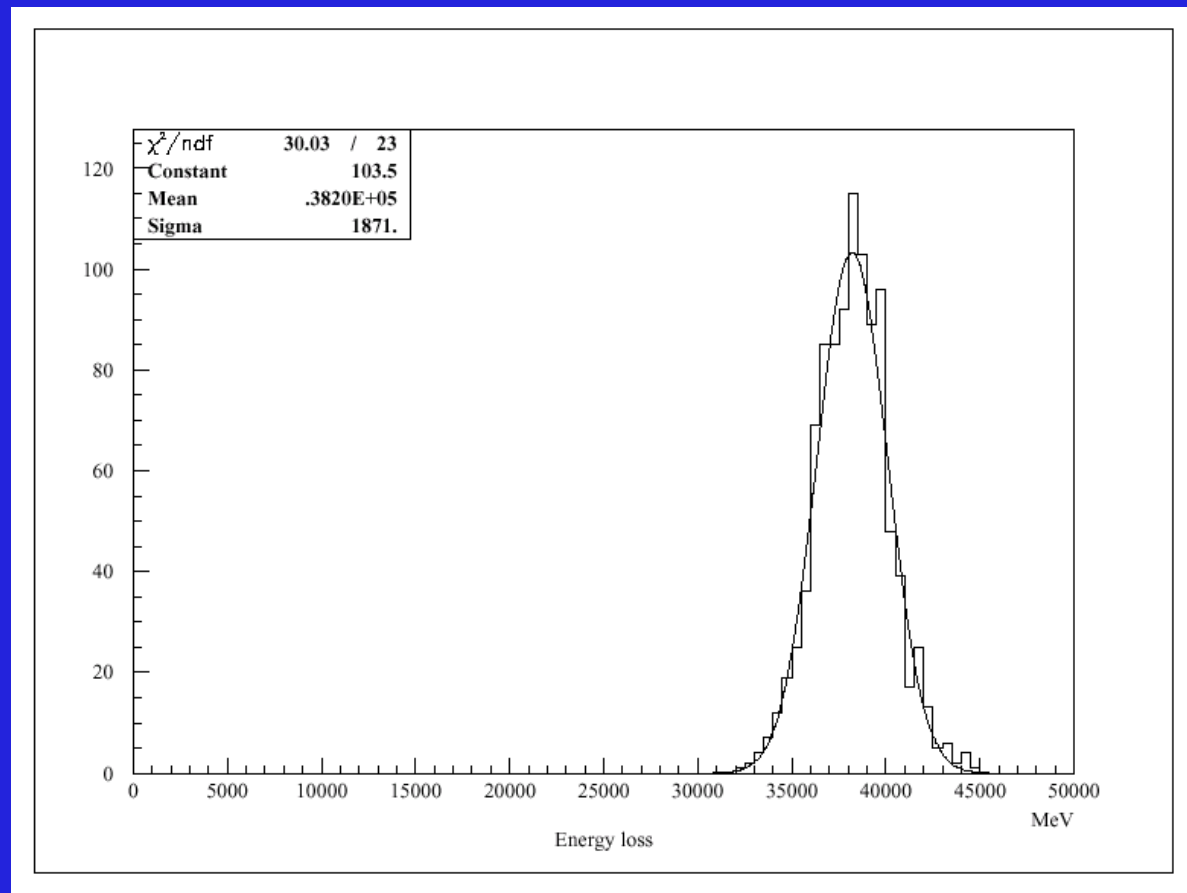
Study for CLIC (T. Kamitani)

Use 1.5 TeV beam

Calculate energy loss in undulator:

Undulator:

Length: 150 m
Field: 1.76 T
Wavelength: 3.37 cm



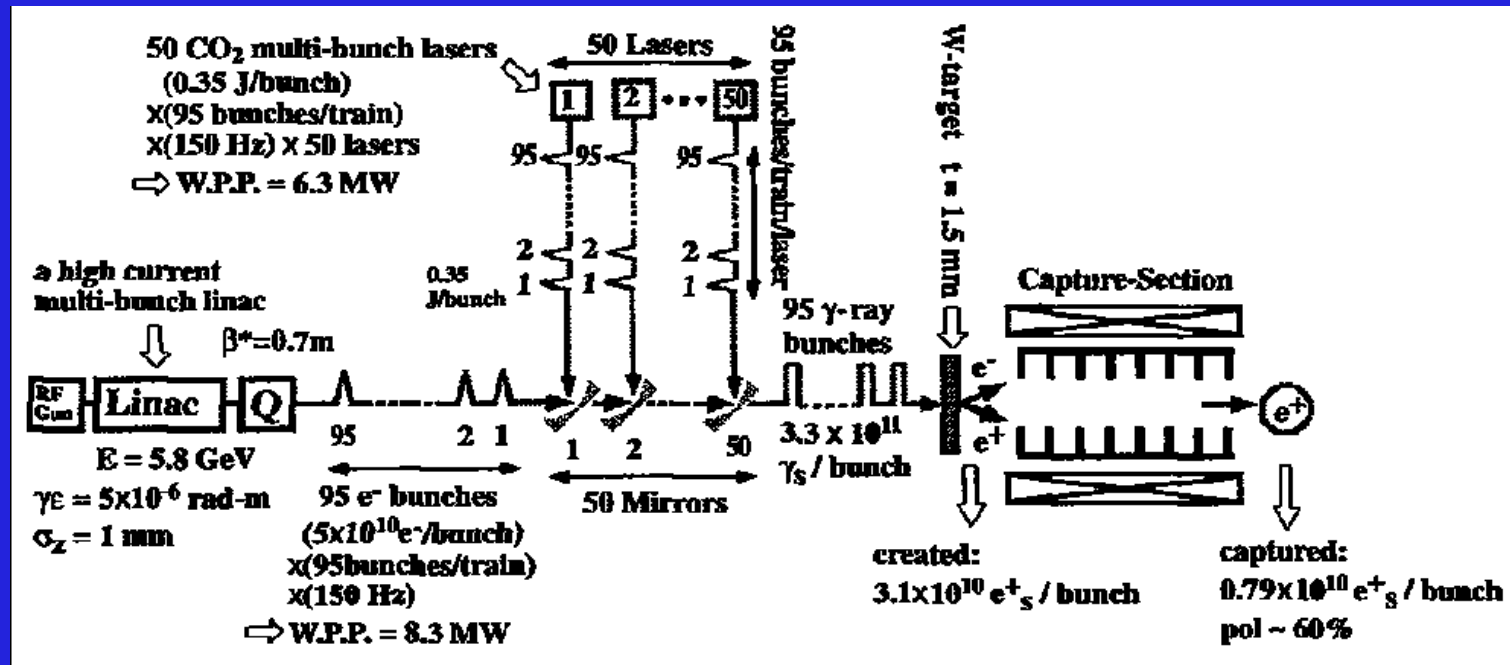
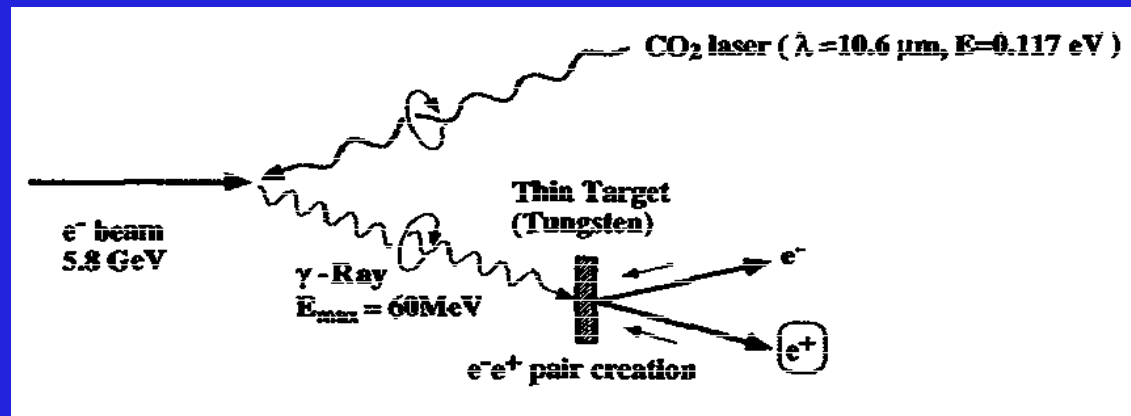
Energy loss: **38.2 GeV**

Energy spread: **1.25e-3** (twice smaller than design)

3) Production of polarized positrons (JLC):

T. Omori

KEK Preprint 99-188
March 2000



0.8e10 e⁺/bunch, 95 bunches/train, 150 Hz, P ~ 60 %

Advantage: Physics beam unperturbed. Disadvantage: Many laser. Additional linac.

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Vertical magnetic fields (rings):

Polarization should point into vertical direction!

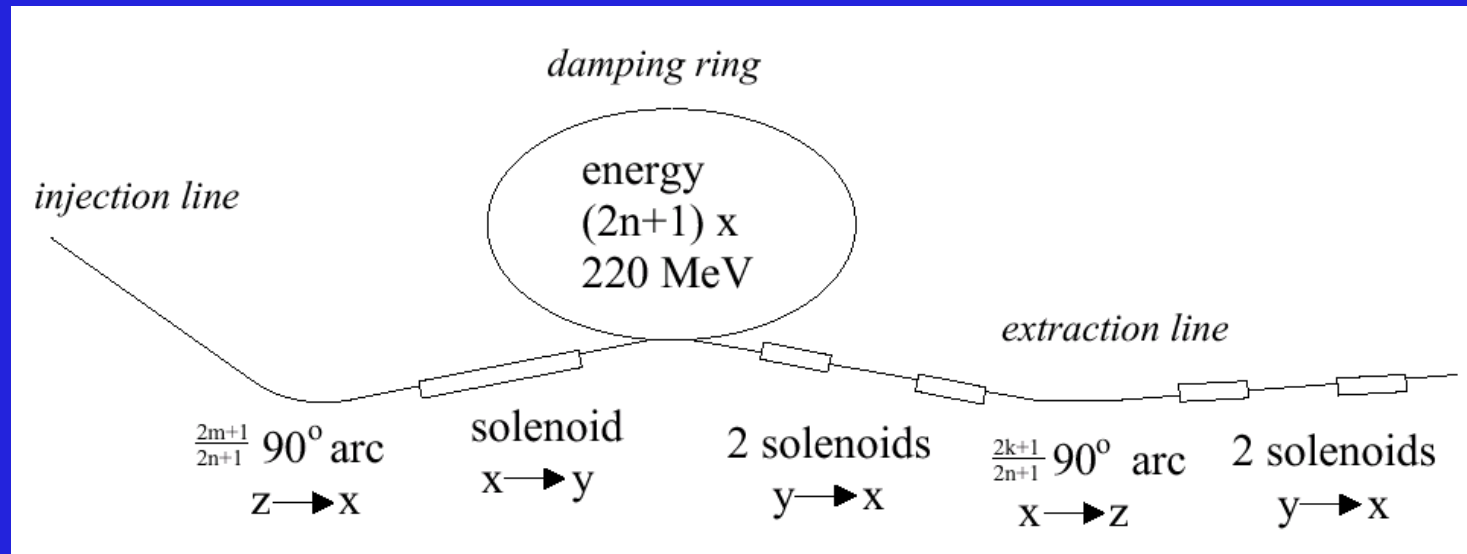
For physics:

Polarization should point in longitudinal direction!

Manipulate the polarization vector!

Design spin manipulations (NLC)

P. Emma
et al



Uncritical. Proven in HERA and SLC!

Estimated depolarization: 0.5 % - 1.0 % (F. Zimmermann)

Much smaller than expected level of polarization (60%-80%)

Depolarization due to beam-beam

Studied by Chen and Yokoya in 1988. Estimated for CLIC by F. Zimmermann.

Two effects:

1) e^+/e^- radiate.

Spin-flip radiation can occur (like Sokolov-Ternov).
Longitudinal polarization is reduced.

Estimate for CLIC: $\Delta P = 10\%$
2.7% (luminosity weighted)

2) **Spin precession** in beam magnetic field:

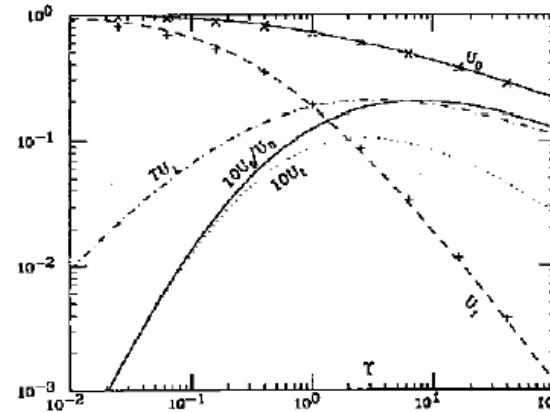
Estimate for CLIC: $\Delta P = 13\%$
3.5% (luminosity weighted)

Only thing really special for CLIC!

Strength of collisions

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

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



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

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

F. Zimmermann

CLIC has larger "tune shift", larger number of photons emitted...

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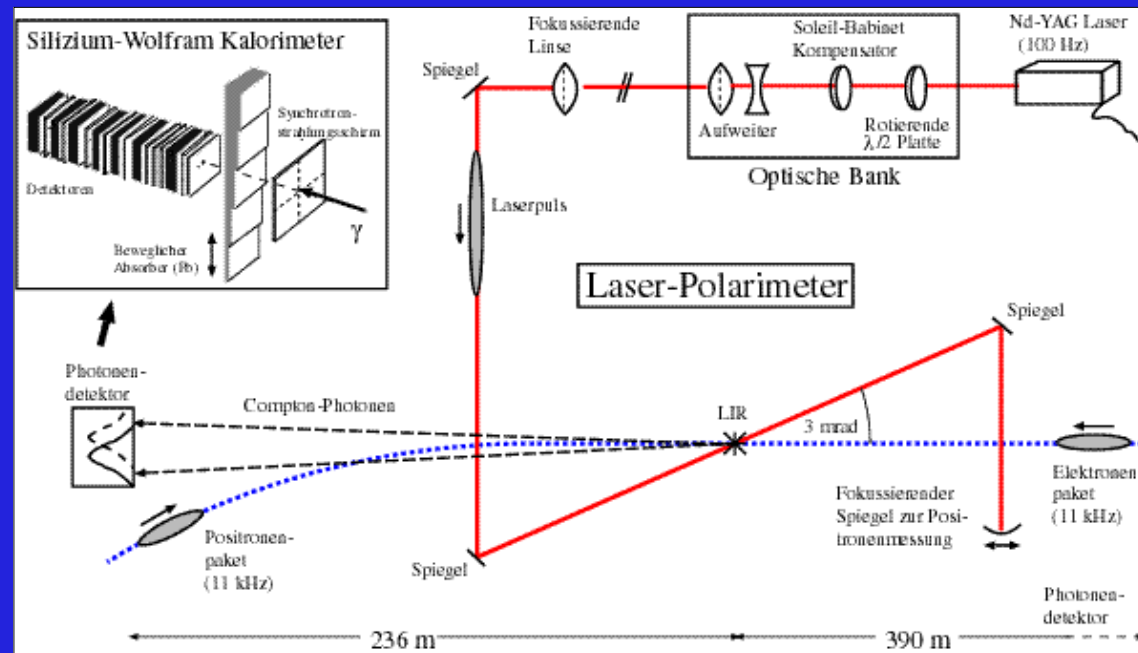
Measuring Polarization

Polarimetry well established at SLC, HERA, LEP, ...

SLC: **Absolute accuracy less than 1%**

Issues at CLIC: **Diagnostics on spent (disrupted) beam including polarimetry. To be designed.**

LEP polarimeter:



Conclusions

Generation of polarized beams (as for other LC):

Electrons: Expect above **80%** polarization for CLIC beam.
Well established experimental basis.

Positrons: Two different schemes promise **60%** polarization for CLIC beam.
No experimental basis.

Spin transport: Uncritical. Well established experience.
Expect \sim **1%** depolarization.

Polarimetry: Well established experience for **1% accuracy**.
Study spent CLIC beam diagnostics.

Beam-beam: **25%** depolarization (**7% luminosity weighted**)
Different compared to other designs.
Trade-off luminosity - polarization.