Polarized Positrons for Future Linear Colliders

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Thanks to the members of the ILC/CLIC Positron Source Group

High precision measurements of luminosity at future linear colliders and polarization of lepton beams
October 3-5, 2010

Outline

- Why polarized positrons?
- Generation of polarized positrons
- The ILC Positron Source
- Polarized positrons for CLIC
- Polarimetry at the positron source
- Summary

Why polarized positrons ?

Goal of a Future Linear Collider

Observe, determine and precisely reveal the structure of the underlying physics model

Needed:

- **High energy**
- **High luminosity**
- **Polarization ⇔ knowledge of initial state**
- **High precision**

→ Experimental flexibility ⇔ be prepared for the unexpected

The electron beam of a future LC will be polarized.

Physics reasons to have a polarized positron beam are summarized in a review article; see Moortgat-Pick et al., Phys.Rept.**460**(2008)131

But positron polarization is not the Baseline Design of ILC or CLIC

Questions (1)

P(e+) is useful – but is it indispensable for a future linear collider?

- **Up to now we have not yet obtained new signatures that cannot be studied without positron polarization**

- **Signals beyond the Standard Model found at the LHC can be interpreted with substantially higher precision if positron polarization is available**

  → distinction of new physics models

- **Z factory: GigaZ ⇔10^9 Z bosons**
  - extreme precision for weak mixing angle, $\delta \sin^2\theta_W \approx$ 1E-5

  →information about nature of symmetry breaking

GigaZ is impossible without e+ polarization

Questions (2)

What is the minimum P(e+) needed for physics?

- **Desired: ≥60%**
- **Should not be below ~30% (t.b.c.)**
- **Flexible choice of polarization (+-, -+, --, ++),**

  + transversly polarized beams

Polarized e+ as upgrade option??

- **The undulator based source provides polarized e+ from the beginning (~30% ±)**

  → should be used for physics, not destroyed

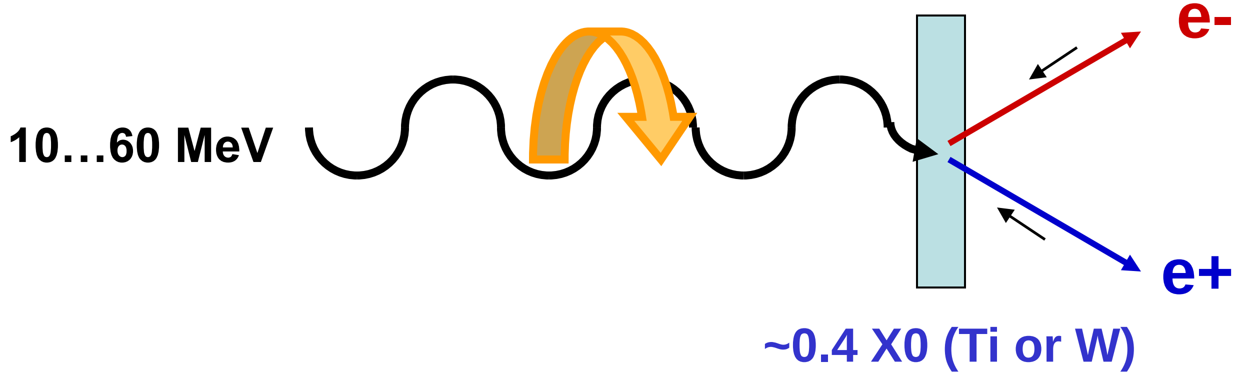
  - if necessary (LHC results!), e+ positron polarization should be available from the beginning

LC Design may not prevent a polarized positron beam

Generation of polarized positrons

Generation of polarized positrons

- Circularly polarized photons produce longitudinally polarized positrons and electrons

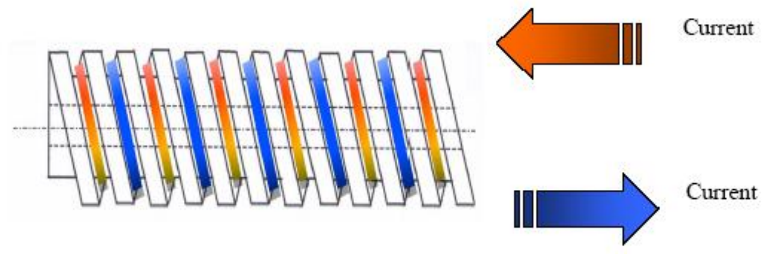


- Methods to produce polarized photons
  - **Radiation from helical undulator** (Balakhin, Mikhailichenko, BINP 79-85 (1979))
  - **Compton backscattering of laser light off an electron beam**

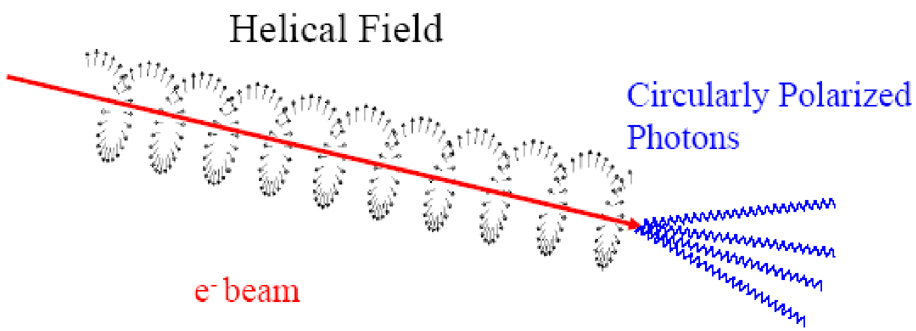
Polarized Positrons from Helical Undulator

- Rotating dipole field in the transverse planes

- Ribbon-wire wound in a double helix



- Electrons follow a helical path
- Emission of circularly polarized radiation



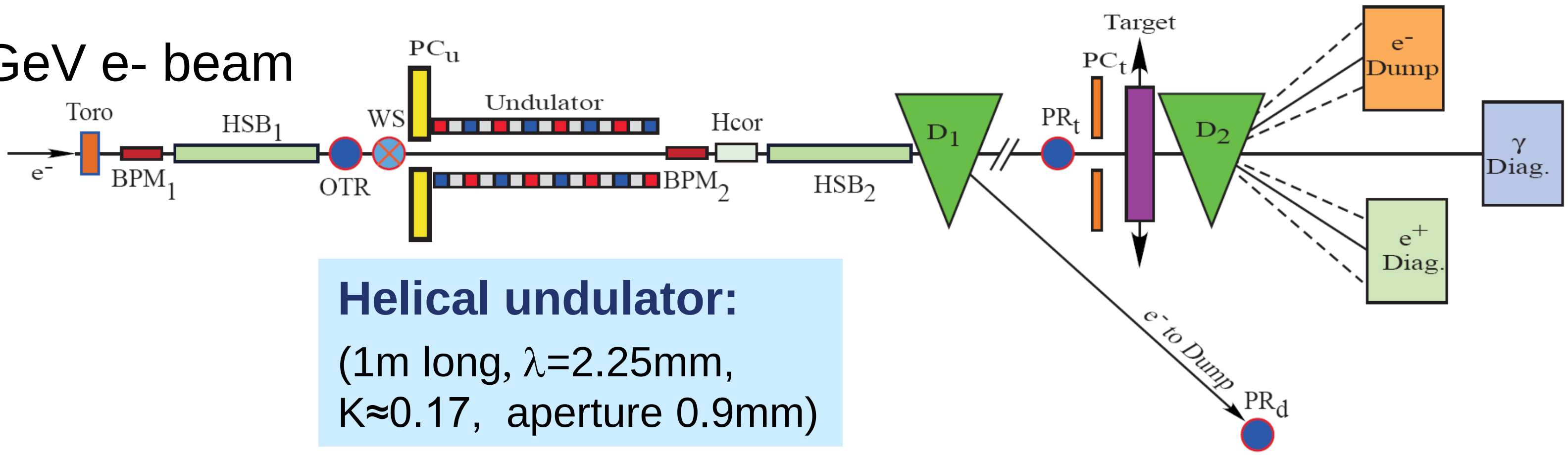
Opening angle of photon beam ~1/γ (first harmonic)

- Polarization sign is determined by undulator (direction of the helical field)
- # photons ~ undulator length
- Photon yield in a helical undulator is about 1.5…2 higher than that in a planar undulator (for the parameters of interest)

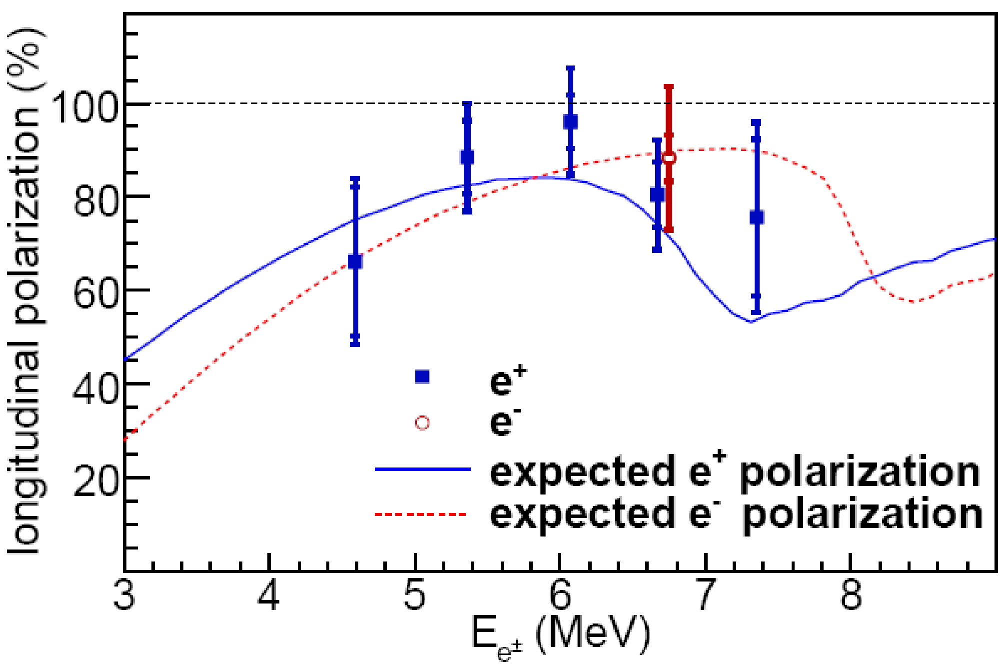
See also Mikhailichenko, CLNS 04/1894

Proof-of-Principle: E166 @ SLAC

46.6 GeV e- beam

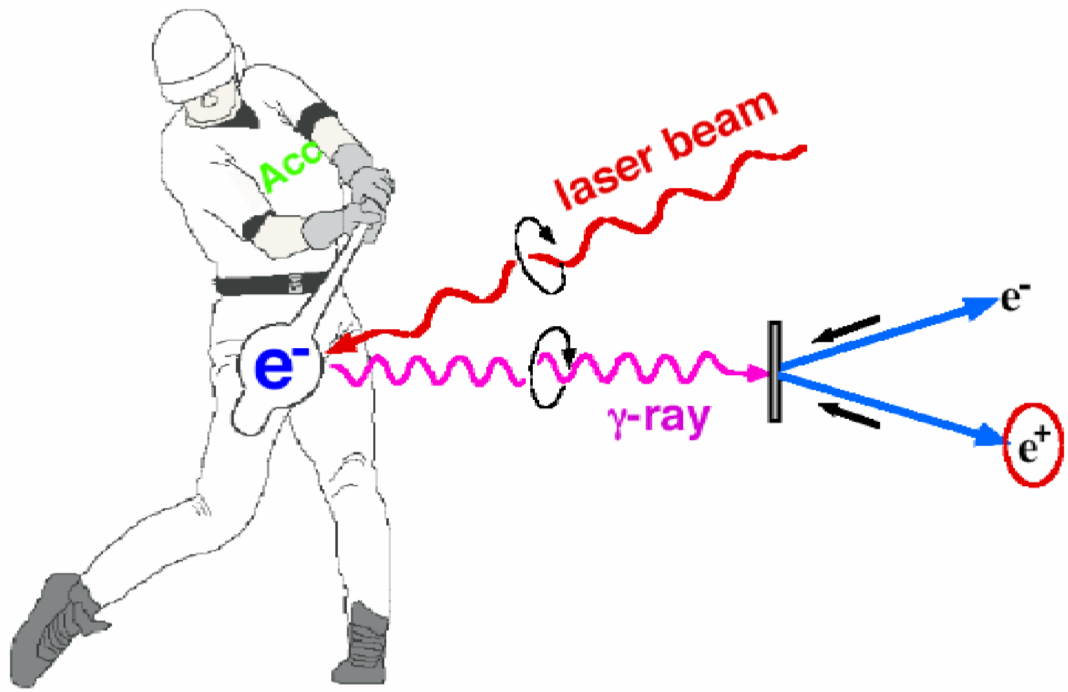


Helical undulator:
(1m long, λ=2.25mm,
K≈0.17, aperture 0.9mm)



Alexander et al., PRL 100:210801,2008,
Alexander et al., NIMA610:451-487,2009,
http://dx.doi.org/10.1016/j.nima.2009.07.091.

The Compton scheme

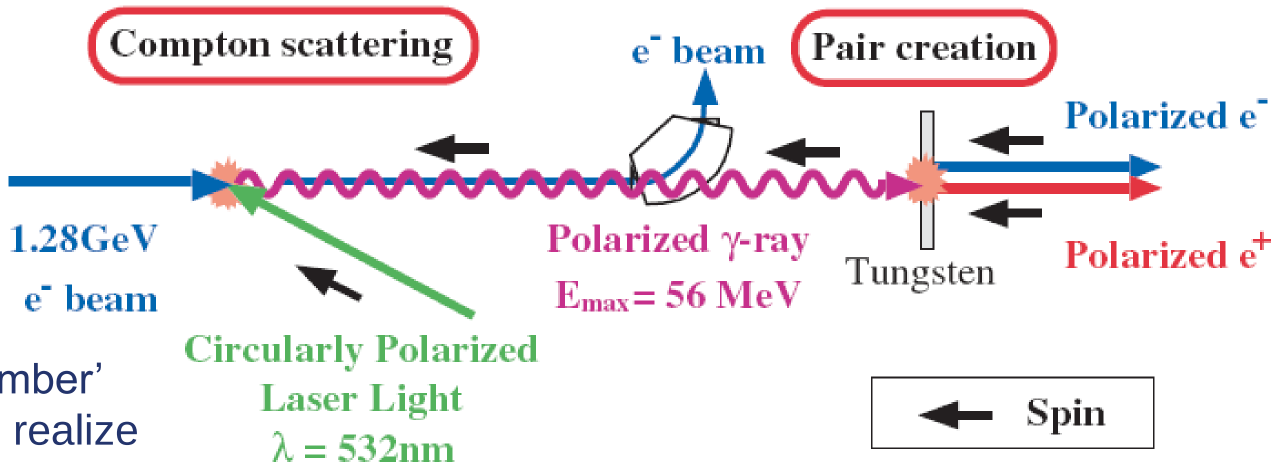


Compton backscattering of laser light off an electron beam

Test experiment at KEK

Omori et al., Phys.Rev.Lett. 96, 114801 (2006)

- KEK-ATF: 1.28 GeV electron beam from ATF and 2nd harmonic of TAG laser used to produce photons with maximum energy of 56 MeV



'Compton chamber' constructed to realize head-on e-γ collisions

$$P_{e^+} = 73 \pm 15\,(stat) \pm 19\,(syst)\ \%$$

Reversing the polarization of laser light ⇔ reversal of positron helicity

Polarized e+ for Future LC

Positron flux at FLC

	SLC	CLIC	ILC (RDR)
e/bunch	3.5×10^{10}	0.64×10^{10}	2×10^{10}
Bunches/pulse	1	312	2685
Pulse rep rate	120	50	5
e+/s	0.042×10^{14}	1×10^{14}	2.7×10^{14}

yield: ~0.02 polarized e+ / photon

→ need high power photon beam

→ huge heat load on target

➔ <u>Rotating</u> positron production target or alternatively liquid metal target

Polarized e+ for Future LC

- **ILC:**
  - **Electron beam is used to produce positrons before brought to IP (yield 1.5e+/e-)**
  - **e+ polarization is upgrade option although ~22% - 35% polarization from beginning**
  - **Undulator + photon collimator → P(e+) = 60%**
  - **Compton backscattering is considered as alternative option to produce polarized e+**

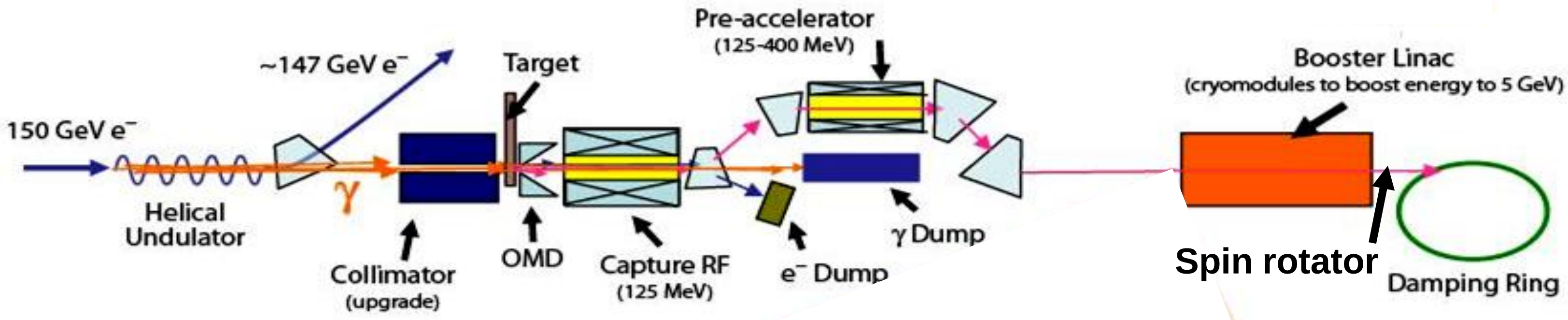
- **CLIC:**
  - **Baseline design with unpolarized e+ source**
  - **e+ polarization is upgrade option, preferred design is Laser-Compton**

- Positron target, collection optics are ‘similar’ for ILC and CLIC

→ Very close collaboration of ILC and CLIC positron source groups

Polarized Positrons for the ILC

ILC Positron Source Layout



Under condsideration:
Strawman Baseline design 2009 **(SB2009)**

RDR (2007)

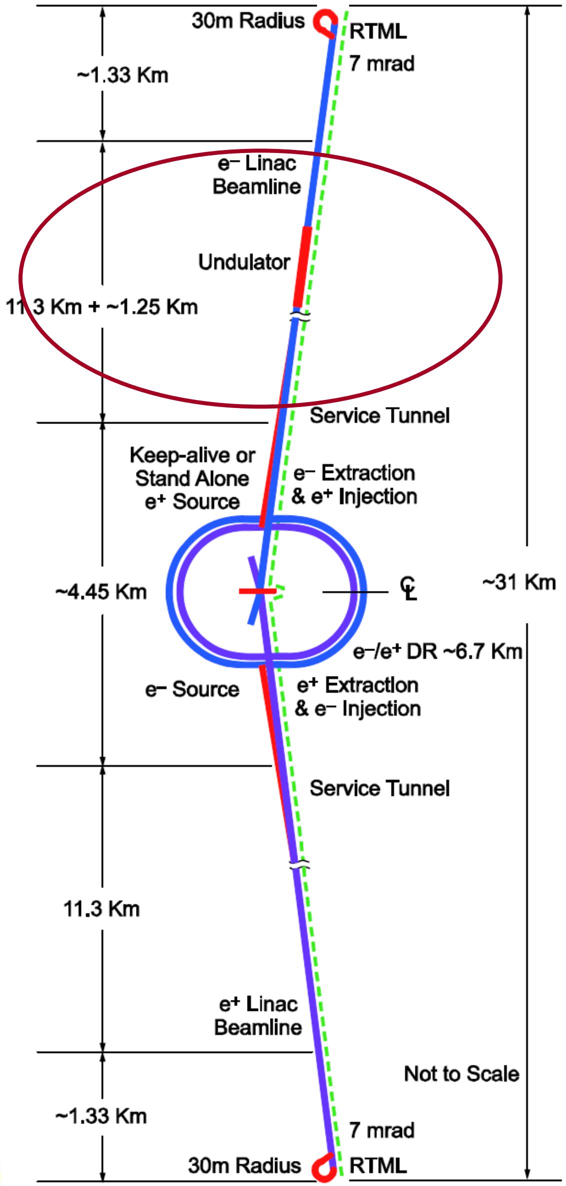
- Sc. Helical Undulator
  - **Located at the 150GeV point in electron linac**
  - **λ = 1.15cm, B=0.86T (K=0.92)**
  - **147m, aperture 5.85mm**
- Target
  - **Ti Alloy wheel**
  - **radius 1m, thickness 1.4cm**
  - **Rotating speed 100m/s (2000rpm)**
- Capture
  - **Flux concentrator**
- Keep Alive Source (KAS)
  - **Independent, conventional**
  - **10% intensity**

SB2009

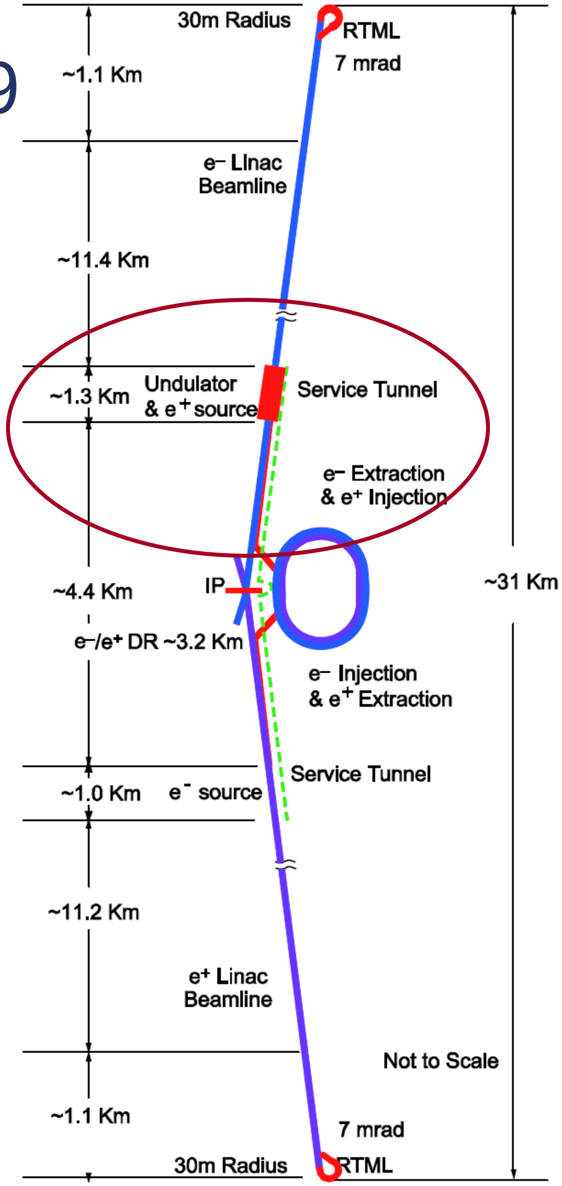
- Sc. Helical Undulator
  - **Located at end of electron linac (125…250 GeV)**
  - **231 m long, aperture 5.85mm**
- Capture
  - **Quarter wave transformer**
- Auxiliary Source
  - **3 GeV e- beam to positron target**

Location of sources at the ILC

RDR:



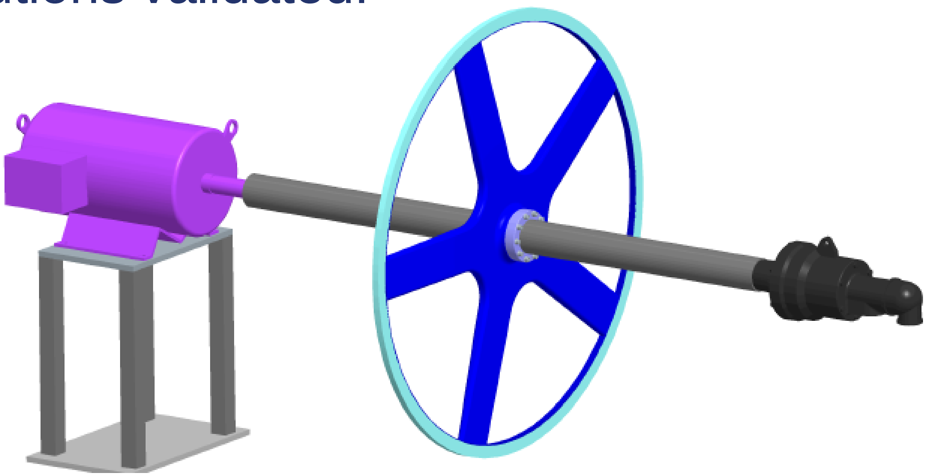
SB2009



Positron Target

- Material: Titanium alloy
  Thickness: 0.4 X_0 (1.4 cm)
- Incident photon spot size on target: $\sigma \sim$ 1.7 mm (rms) (RDR)
  ~ 1.2 mm (SB2009)
- Power deposition in target: 8% → 10.4 kW (RDR); <8 kW (SB2009)
  But peak energy deposition density is higher for SB2009 design
- Rotate target to reduce local thermal effects and radiation damage
  → 2m diameter target wheel, 2000 rpm

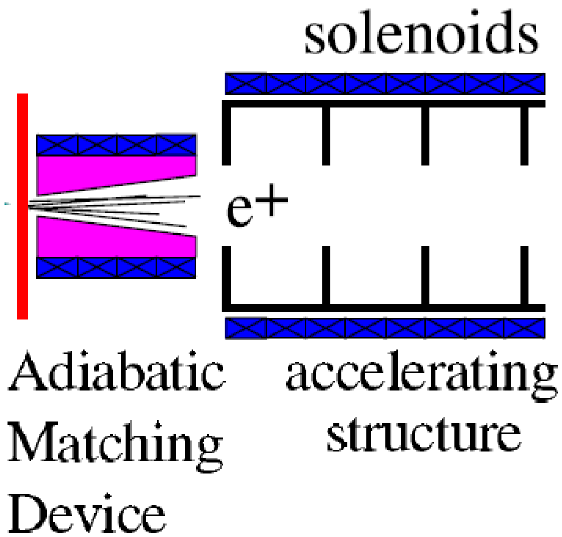
- Issues to be resolved and the solutions validated:
  - **Stress in target material, pressure shock wave impact on target lifetime**
  - **rotating vacuum seals to be confirmed suitable**

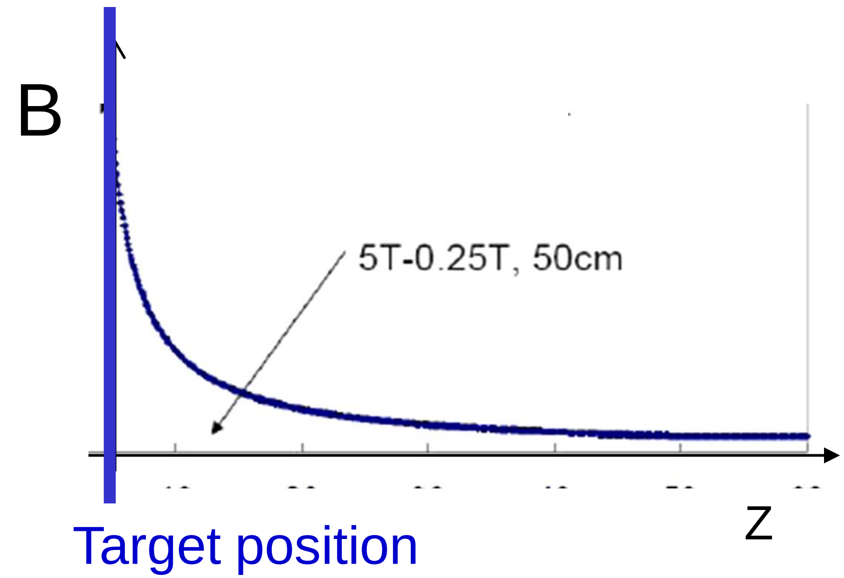


Positron yield ⇔ Optical matching device

OMD: Increases capture efficiency from 10% to as high as 40%

- Adiabatic Matching Device (AMD):
  - Tapered B field from ~5 T at the target to 0.5 T in 50 cm

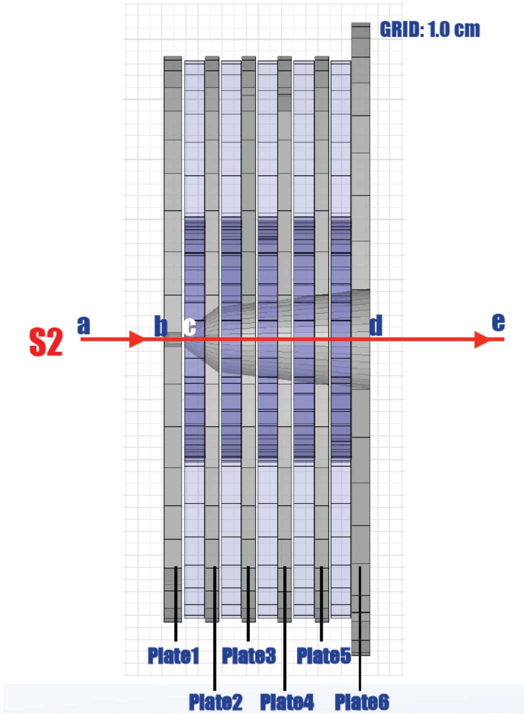


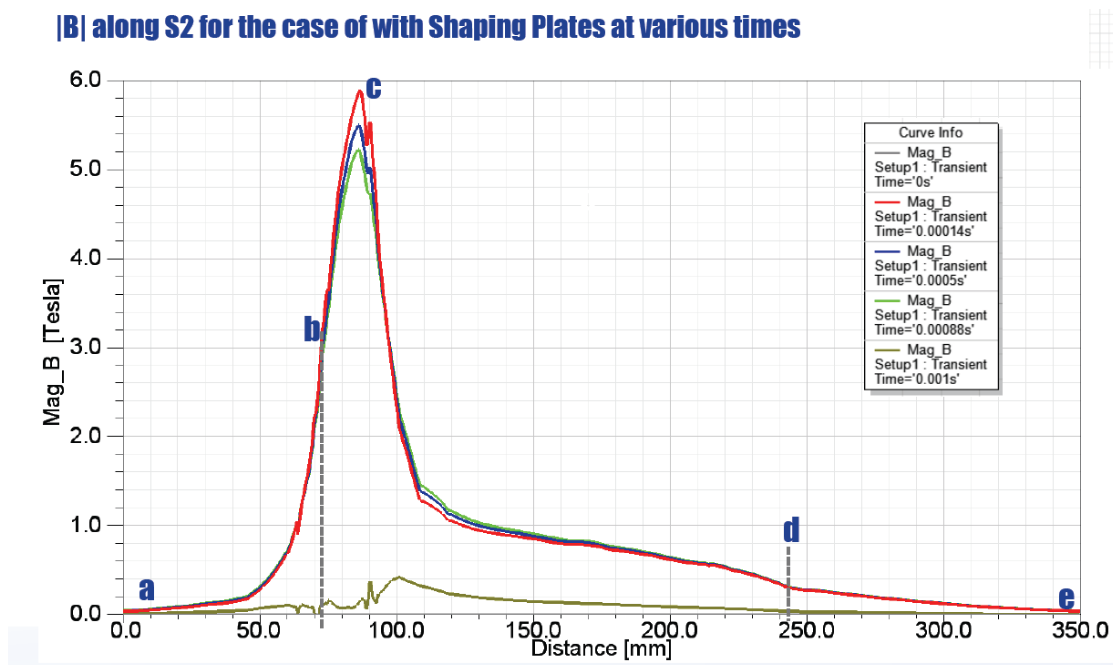


- Capture efficiency >30%
- Rotating target immersed in B field ⇔ eddy currents
- Eddy current experiment @ Cockroft Institute
  → expect 8 kW at 2000 rpm
  → heat load on target substantially increased

Optical Matching Device (2)

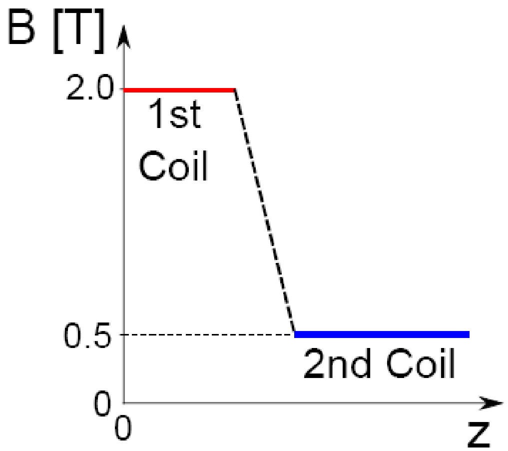
- Flux Concentrator (FC)
  - **Flux concentrator reduces magnetic field on target but lower capture efficiency ~22%**
  - **RDR design with FC**
  - **pulsed flux concentrator (used at SLD):**
    - **ILC** needs ~ 1ms pulse width flat-top
    - LLNL: Design and prototype (budget):

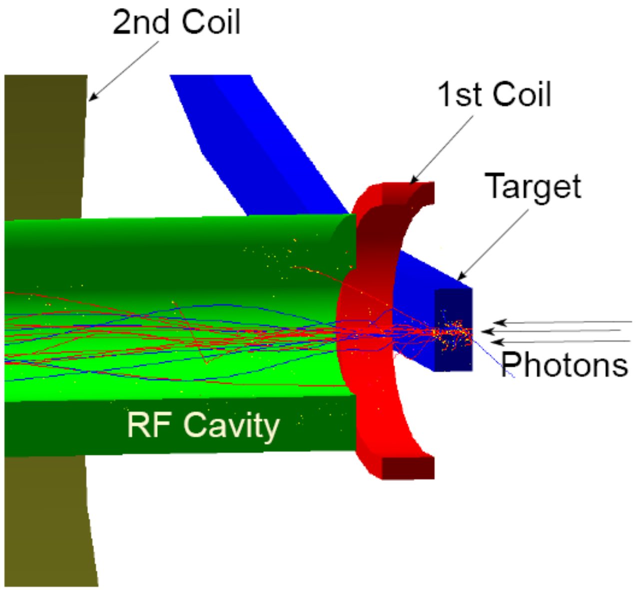




Optical Matching Device (3)

- Quarter Wave Transformer (QWT)
  - **QWT is a save solution**





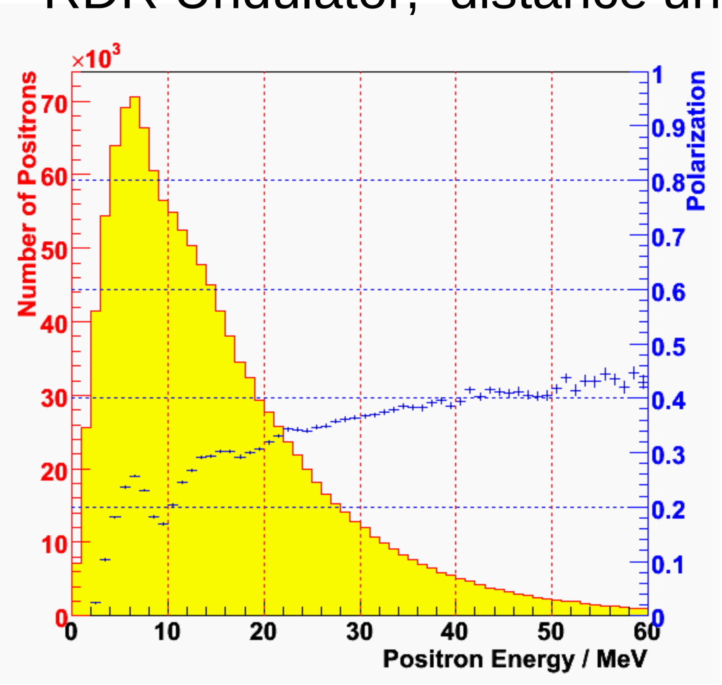
  - **but capture efficiency is ~15 %**
  - **SB2009 design with QWT**

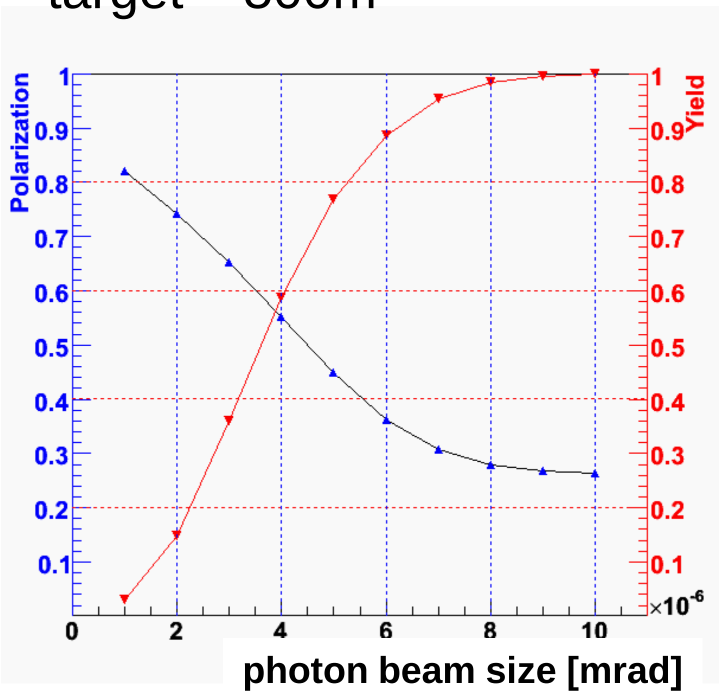
→ Length of helical undulator 231m

Positron polarization

Positron spectra

RDR Undulator, distance undulator – target ~500m



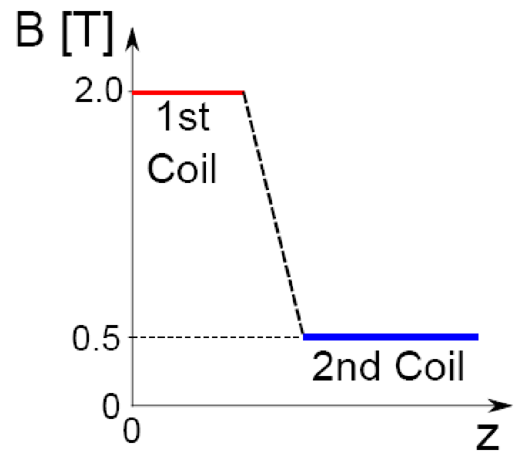


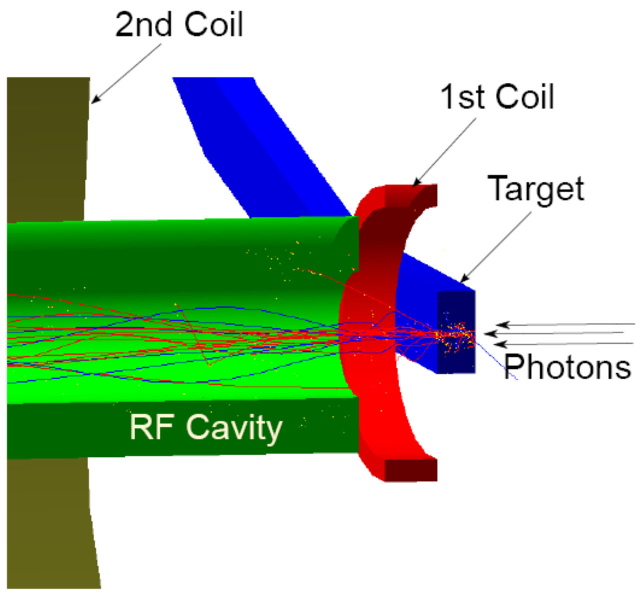
→ Average positron polarization (>30 % RDR design)

- With photon collimator upstream the target:
  - → **increase of polarization**
  - → **decrease of positron yield → longer undulator**

Optical Matching Device (3)

- Quarter Wave Transformer (QWT)
  - **QWT is a save solution**





  - **but capture efficiency is ~15 %**
  - **SB2009 design with QWT**

→ Length of helical undulator 231m

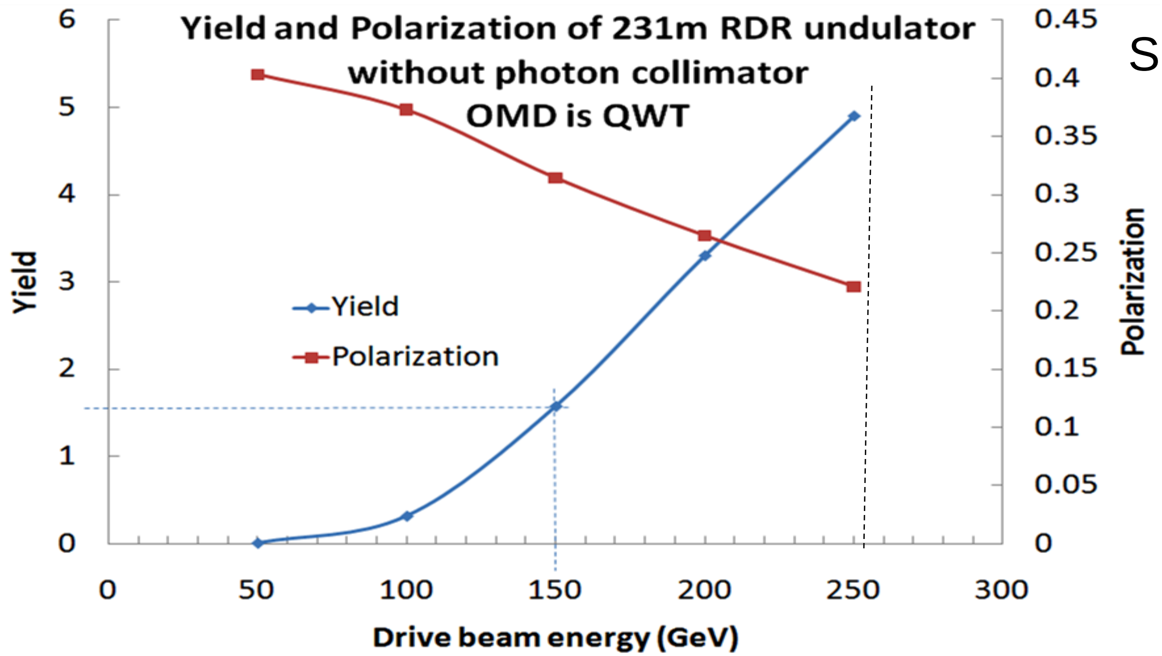
- **upgrade to P(e+) = 60% would make the undulator so long that photon powers become worrying and electron energy loss very high**

→ better to use a flux concentrator

Yield of Polarized Positrons at ILC

Helical undulator, no photon collimator → RDR design → e+ polarization ~30%

SB2009 → e+ polarization ~22%



SB2009 Proposal Document

distance undulator ⇔ target: 400m

- **Use this polarization can be used for physics → facility for fast helicity reversal has to be included in the design**
- **Otherwise one has to destroy the polarization to P≡0**

Polarized Positrons for CLIC

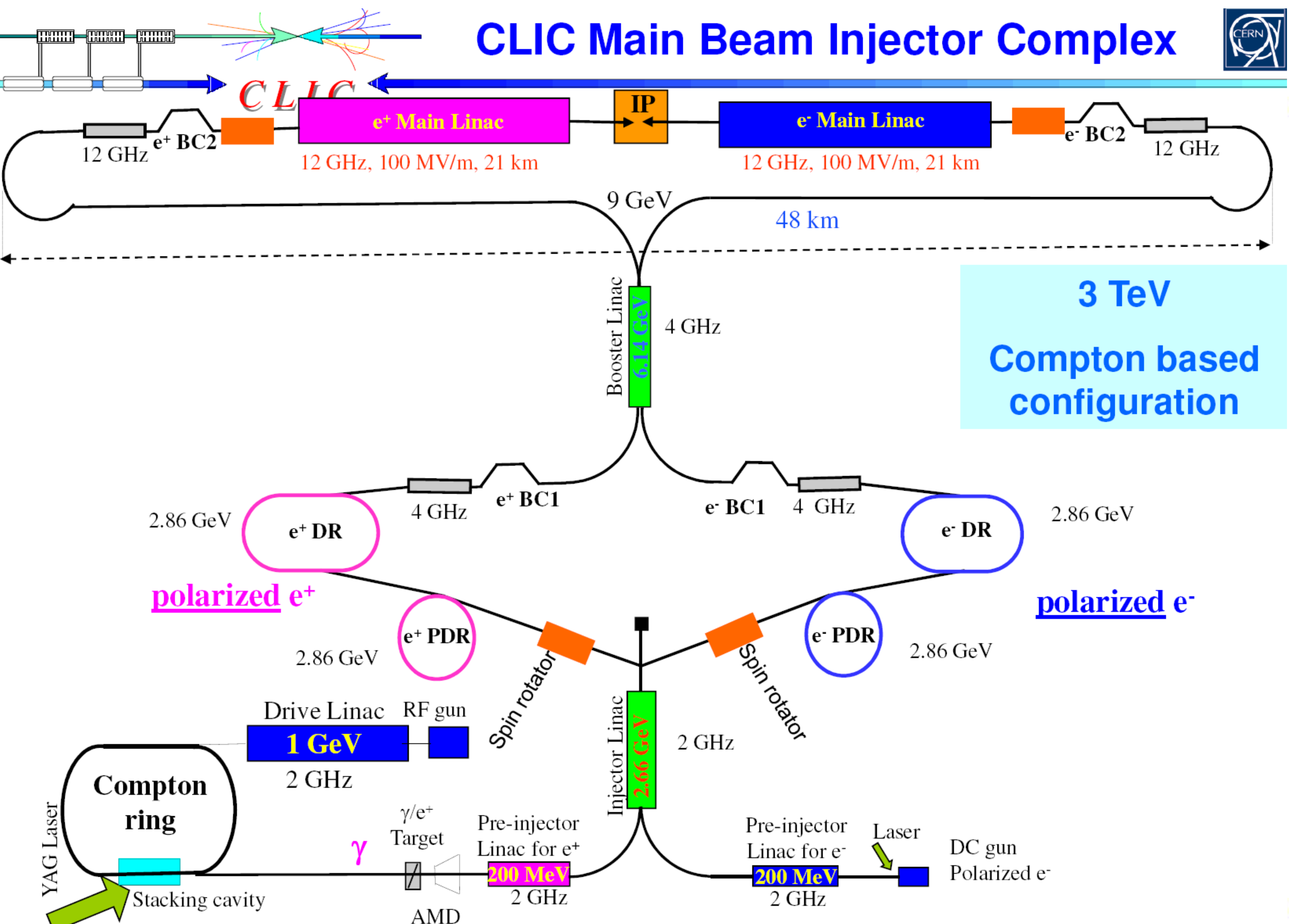
CLIC Polarized Positron Source

- CLIC baseline design has an unpolarized e+ source, e+ polarization is upgrade option (3 TeV)
- Preferred: Compton scheme
  - **e+ beam independent of the main beam linac**
  - **Polarized e+ source can be implemented at any time without modifications of the CLIC complex**
  - **But: Need high intensities for electron and laser beam; at present not available**
    - Requested: 6.7 x 10^9 e+/bunch at PreDampingRing
      → stacking of e+ is necessary

See also Rinolfi et al., PAC09, Vancouver, WE6RFP065

- Proposed designs for electron-photon collisions:
  - **Electron ring and optical laser cavity**
  - **ERL (Energy recovering linac) + laser cavities**
  - **Electron linac and CO_2 laser cavities ⇔ no stacking**
- Undulator: possible, but integration into main linac is more complicated

CLIC Main Beam Injector Complex

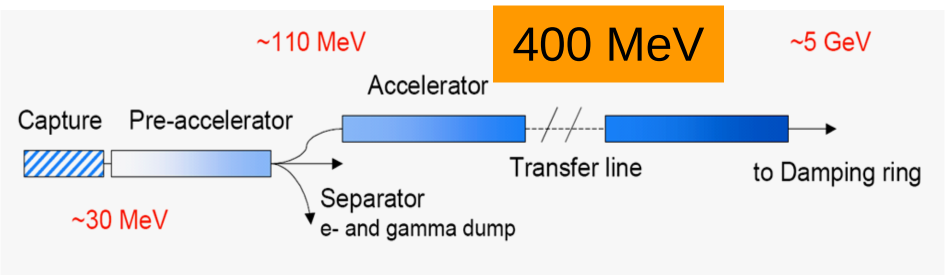


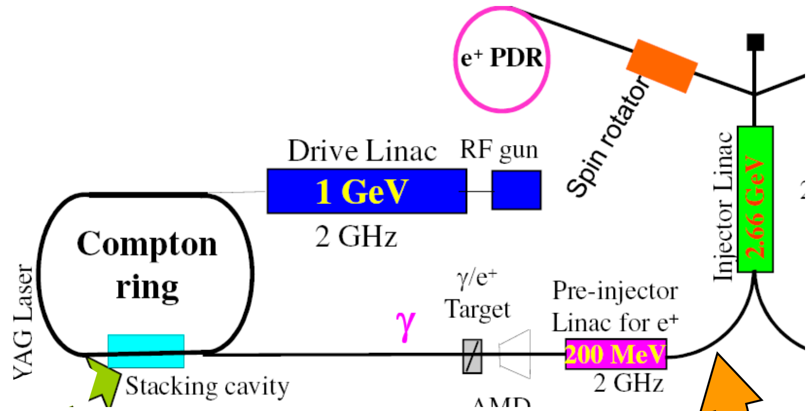
Positron Polarization Measurement

- at the source
- at the IP (see next Talk by Peter Schuler)

Polarimetry at the e+ source

- Polarisation measurement downstream the capture section; E > 125 MeV
  - Large size of positron beam (σ ~ 0.5…1cm)
  - High intensity of positron beam
  - Do not need very precise measurement





Proposal (see LEPOL Group, Alexander et al., EUROTeV-Report-2008-91): use a **Bhabha polarimeter** operated at

- 400 MeV (ILC)
- ~200 MeV (CLIC)
- Downstream the damping rings: Compton polarimeter, but spin orientation is transverse (details: Alexander, Starovoitov, LC-M-2007-014, 2007)

Polarization and Physics Precision

- Precision physics measurements ➔ Luminosity-weighted polarization to be determined with high precision (ΔP_{lw} ~ 0.25%)

- Compton Polarimeters up/downstream the IP
  - **Upstream polarimeter:**
    fast, high precision, clean environment
  - **Downstream polarimeter**
    Slow, high background, access to depolarization at IP

- Beamstrahlung ⬄ depolarization during bunch crossing
  - **CLIC beam sizes @ IP (hor./vert. in nm)**
    - 500 GeV: 248 / 5.7 conservative (202 / 2.3 nominal)
    - 3 TeV: 83 / 2.0 conservative (40 / 1.0 nominal (σ_z=45nm))
  - **ILC beam sizes @ IP (hor./vert. in nm)**
    - 640 / 5.7 (σ_z = 300 nm)

➔ $\Delta P_{lw}^{beamstr}$ ≈ 0.2% (ILC 500), ~5% (CLIC) Bailey et al., EPAC08-MOPP024

Depolarization depends strongly on horizontal beam size variations

Further work on depolarization in strong fields is necessary.
What are the precision requirements for physics at CLIC ?

Summary

- Positron polarization is important and will be available from the beginning if the helical undulator is baseline design
- Milestones:
  - **ILC: Technical Design Report end 2012**
  - **CLIC: CDR in 2011**
- Still to do
  - **Demonstrate target reliability**
  - **Demonstrate that the flux concentrator will work**
  - **Realistic spin tracking from start to end**
  - **Depolarization effects at IP**
- BMBF Joint Research Project 'Spin Management'

Joint Research Project: Spin Management

- Funded by BMBF (Federal Ministry of Education and Research in Germany)
- Participants:
  - **Uni HH (Prof. G. Moortgat-Pick)**
  - **Uni Bonn (Prof. W. Hillert)**
  - **Uni Mainz (Prof. K. Aulenbacher)**
  - **Collaborating groups at DESY (J. List (HH), S. Riemann (Zeuthen))**
- Spin management (FLC related):
  - **Precision polarization measurement at the IP**
  - **Depolarization effects in strong fields**
  - **e+ source modeling, spin rotation + fast helicity reversal**
  - **Spin tracking ⇔ Physics potential of the LC**
  - **Collaboration Uni HH, DESY ⇔ Bonn**
    - simulations and measurements of spin rotation and spin transport through damping ring
- Positron Production Target
  - **Simulation of radiation and thermal load**
  - **Consequences for material aging**
  - **shock waves: modeling (simulations)**
  - **experimental tests currently under discussion**

Summary

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- Still to do
  - **Demonstrate target reliability**
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  - **Realistic spin tracking from start to end**
  - **Depolarization effects at IP**
- BMBF Joint Research Project 'Spin Management'
- Still missing – for ILC and CLIC:
  - **Realistic scenarios with polarization and consequences for physics precision**
    - ⇔ important for physics potential of the LC
    - ⇔ machine/detector design
  - **LHC signals beyond the SM**

Positron polarization needs more attention from machine and physics groups
→ to be prepared for the unexpected


TEL AVIV
Thank you!