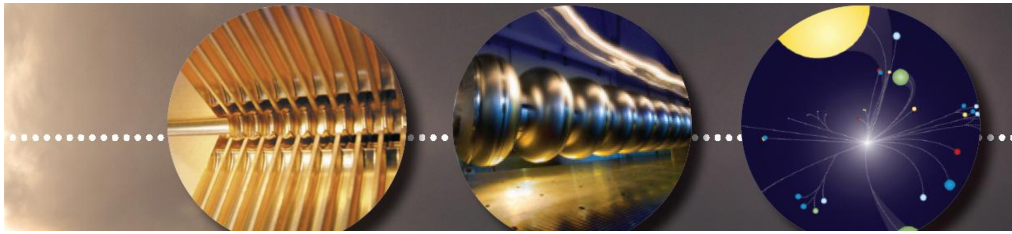


Positron polarization at the ILC: RDR vs. SB2009

Sabine Riemann, DESY Zeuthen

International Workshop on Linear Colliders 2010, Geneva
October 25-29, 2010

Outline

Positron polarisation = upgrade option for ILC, CLIC. Nevertheless, the undulator based ILC design will provide polarized positrons from beginning (~22%…35%).
Up to now no clear strategy has been mediated what to do with this polarized positrons

- Why positron polarization ?
- Positron polarization
  - **in RDR**
  - **in SB2009**
- Physics goal of low positron polarization ?
  What to do with low positron polarization ?
- Summary

FLC – the precision machine

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**

precision

→ Experimental flexibility ⇔ be prepared for the unexpected

The electron beam of a future LC will be polarized.

Lessons from LEP/SLD ⇔ sensitivity to parity violating couplings

- Unpolarized beams (LEP, 17x10^6 Z events) → A_{FB} $\delta\sin^2\theta_{eff}$ = 1.2x10E-3
- Polarized beams (SLC, 5x10^5 Z events) → A_{LR} $\delta\sin^2\theta_{eff}$ = 1.2x10E-3

What about polarized positron?

- **positron polarization is not the Baseline Design of ILC or CLIC**
- **Physics goals are summarized in Moortgat-Pick et al., Phys.Rept.460(2008)131**

ILC Baseline Machine (RDR)

Physics between 200 GeV and 500 GeV
Electrons: P > 80%
Energy stability and precision below 0.1%

Luminosity:

Year 1-4: L_{int} = 500 fb^{-1}:
1. year 10% → L_{int} ≈ 50 fb^{-1}
2. year 30% → L_{int} ≈ 150 fb^{-1}
3. Year 60% → L_{int} ≈ 300 fb^{-1}
4. year 100% → L_{int} ≈ 500 fb^{-1}

➔ expected statistics:

few 10^4	ee → HZ	at 350 GeV (mH≈120 GeV)
10^5	ee → tt	at 350 GeV
$5\cdot10^5$ ($1\cdot10^5$)	ee → qq ($\mu\mu$)	at 500 GeV
10^6	ee → WW	at 500 GeV

➔ statistical cross section uncertainties at per-mille level !!

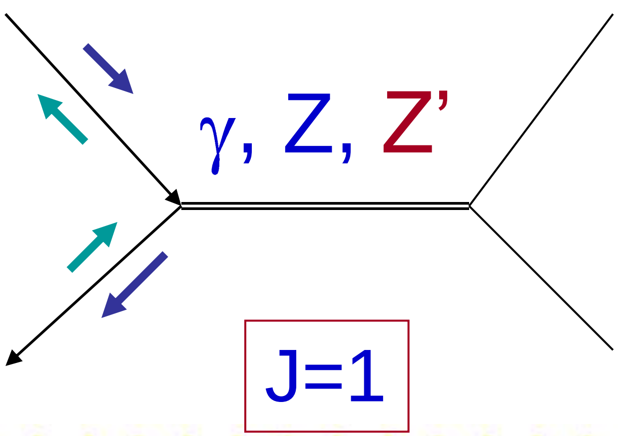
(after 1st year ~ 1% level)

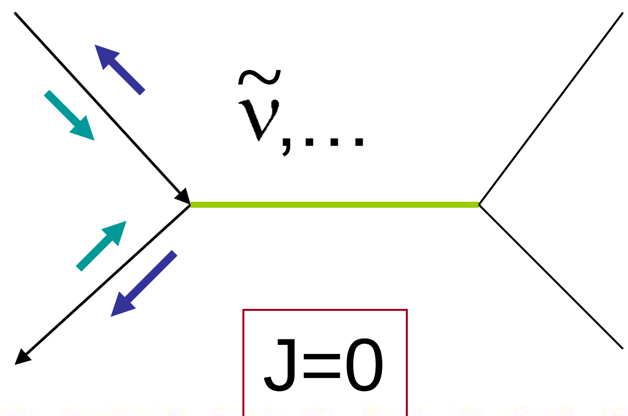
$$\Delta\sigma \propto \frac{1}{\sqrt{N}} \oplus \frac{\Delta L}{L} \oplus \frac{\Delta E}{E} \oplus \frac{\Delta P}{P} \longrightarrow \mathbf{O(10^{-3})}$$

e+e- initial states

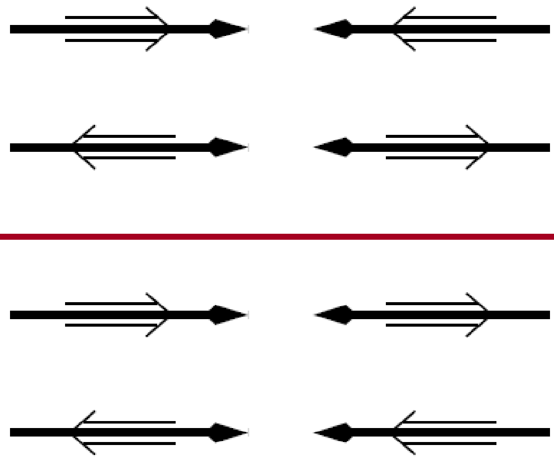
	e^-	e^+		
σ_{RR}	$\Rightarrow$	$\Leftarrow$	$\frac{1+P_{e^-}}{2} \cdot \frac{1+P_{e^+}}{2}$	$J_z = 0$
σ_{LL}	$\Leftarrow$	$\Rightarrow$	$\frac{1-P_{e^-}}{2} \cdot \frac{1-P_{e^+}}{2}$	
σ_{RL}	$\Rightarrow$	$\Rightarrow$	$\frac{1+P_{e^-}}{2} \cdot \frac{1-P_{e^+}}{2}$	$J_z = 1$
σ_{LR}	$\Leftarrow$	$\Leftarrow$	$\frac{1-P_{e^-}}{2} \cdot \frac{1+P_{e^+}}{2}$	

SM





s-channel processes



	e^- e^+		
σ_{RR}		$\frac{1+P_{e^-}}{2}\cdot\frac{1+P_{e^+}}{2}$	$J_z = 0$
σ_{LL}		$\frac{1-P_{e^-}}{2}\cdot\frac{1-P_{e^+}}{2}$	
σ_{RL}		$\frac{1+P_{e^-}}{2}\cdot\frac{1-P_{e^+}}{2}$	$J_z = 1$
σ_{LR}		$\frac{1-P_{e^-}}{2}\cdot\frac{1+P_{e^+}}{2}$	

SM

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

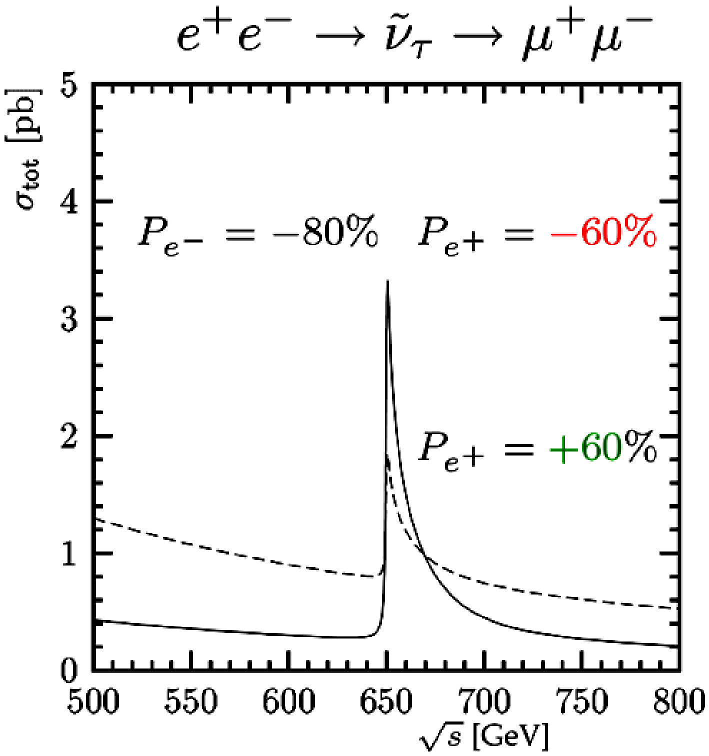
$$P_{\mathrm{eff}} = \frac{P_{e-} - P_{e+}}{1 - P_{e-}P_{e+}}$$

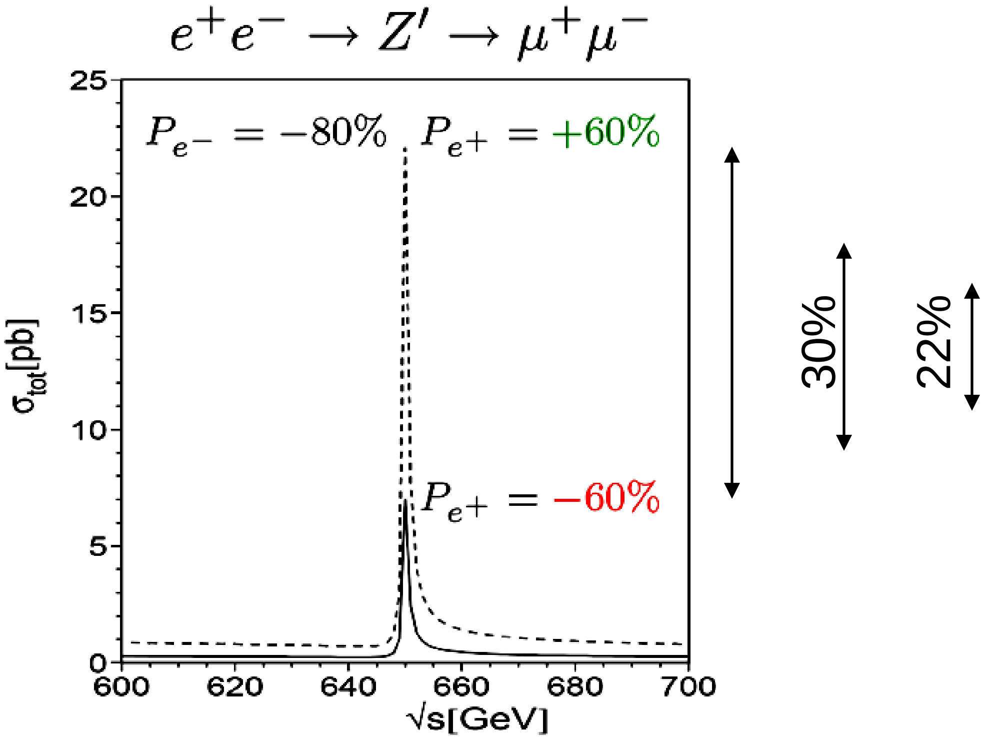
$\Leftrightarrow$

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

Polarized initial states: $e^+e^- \rightarrow \mu^+\mu^-$

R-parity violating SUSY (spin-0) or Z' (spin-1) ?





enhancement for $e^+(L)e^-(L)$

enhancement for $e^+(L)e^-(R)$

(see also POWER report)

➔ e+ polarisation improves sensitivity substantially

s-channel processes

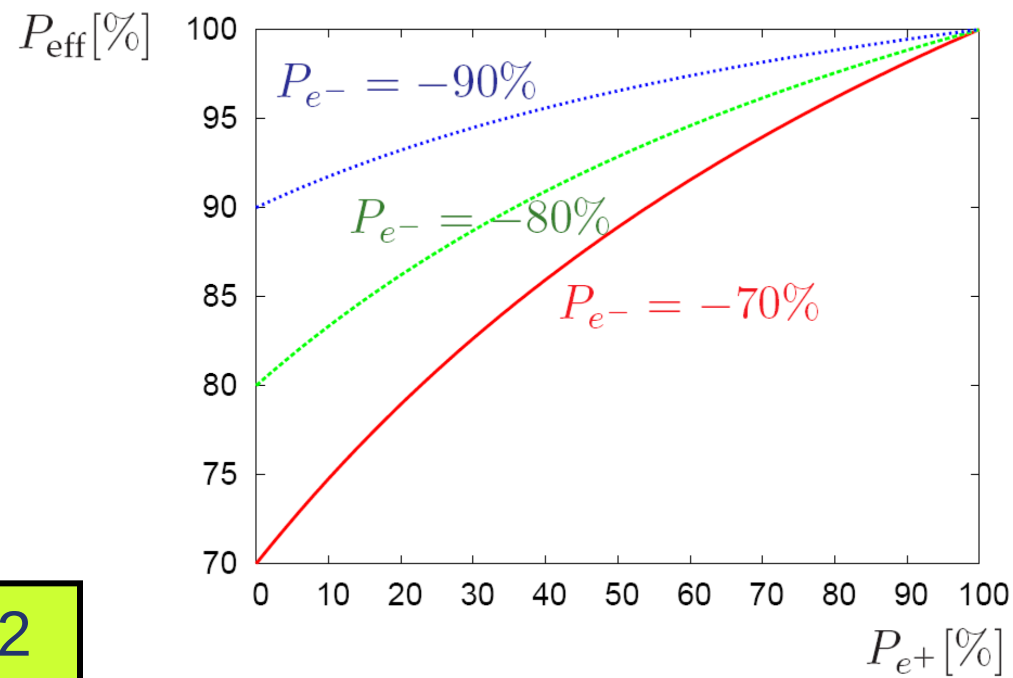
- Cross section measurements: enhancement of SM contributions by factor $1\text{-}P_{e-}P_{e+}$
  - **e.g. LC as Higgs factory (Higgsstrahlung) ⇔ enhancement of effective luminosity**
  - **(±80%,±60%) ⇔ 1.48 → δ_{stat} improved by 22%**
    (±80%,±34%) ⇔ 1.27 → δ_{stat} improved by 13%
    (±80%,±22%) ⇔ 1.18 → δ_{stat} improved by 8%

- Effective polarization P_{eff}
  - **Higher than e- polarization, but this becomes less important for P(e-) >90%**
  - **Uncertainty of effective polarization is substantially smaller, $\delta P_{eff} < \delta P_{e-}$**

P_{eff}

Positron polarization increases effective polarization:

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



P_{e-}/ P_{e+}	0.6	0.34	0.22
0.8	0.95	0.90	0.87
0.9	0.97	0.95	0.93

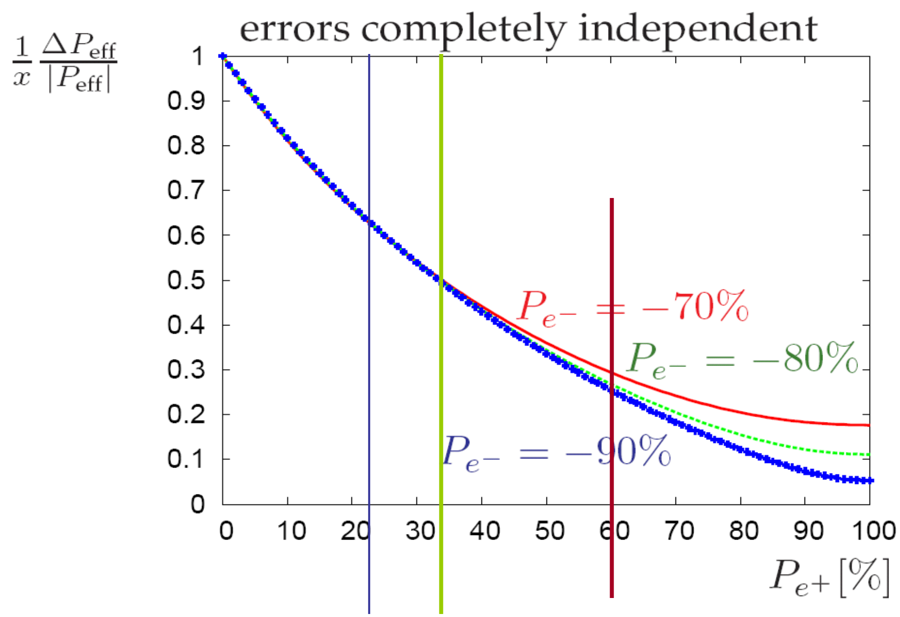
For comparison: first LC studies:
(60%,40%)→ P_{eff} =0.8

Δ P_{eff}

- Decrease of error on P_{eff} (error propagation)

$$\frac{\Delta P_{eff}}{P_{eff}} = x\,\frac{\sqrt{(1-P_{e^+}^2)^2 P_{e^-}^2 + (1-P_{e^-}^2)^2 P_{e^+}^2}}{(P_{e^+}+P_{e^-})(1+P_{e^+}P_{e^-})}$$

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



(80%,60%) ⇔ $\delta P_{eff} = 0.25\ \delta P_{e-}$

(80%,22%) ⇔ $\delta P_{eff} = 0.75\ \delta P_{e-}$

(80%,34%) ⇔ $\delta P_{eff} = 0.50\ \delta P_{e-}$

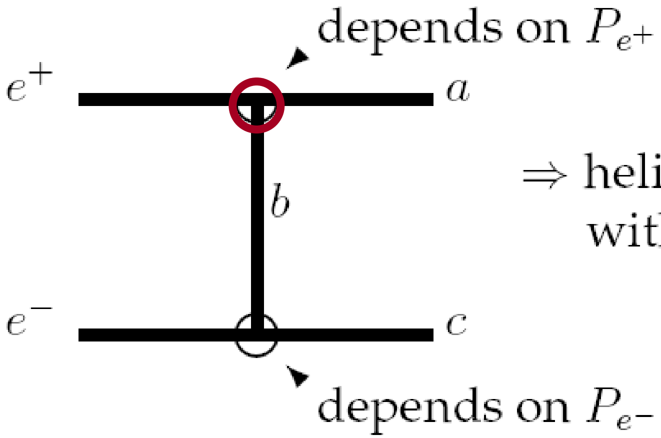
$\delta P_{e-}/P_{e-} = \delta\ P_{e+}/P_{e+} = 0.25\%$

(see ILC-NOTE-2008-047)

➔ $\delta P/P \sim$ **$O(10^{-3})$**

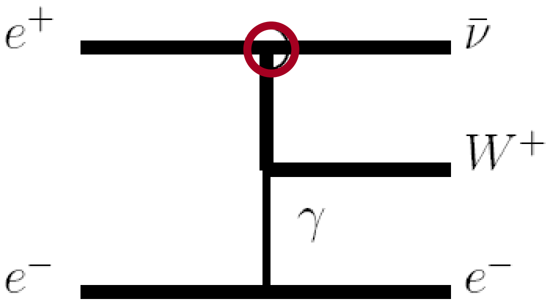
Why positron polarization ? (contd)

- u,t-channel: helicities of initial and final state are directly coupled, but independent of the helicity of the second incoming beam particle



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

- Single W production ⇔ vertex depends only on P(e+)

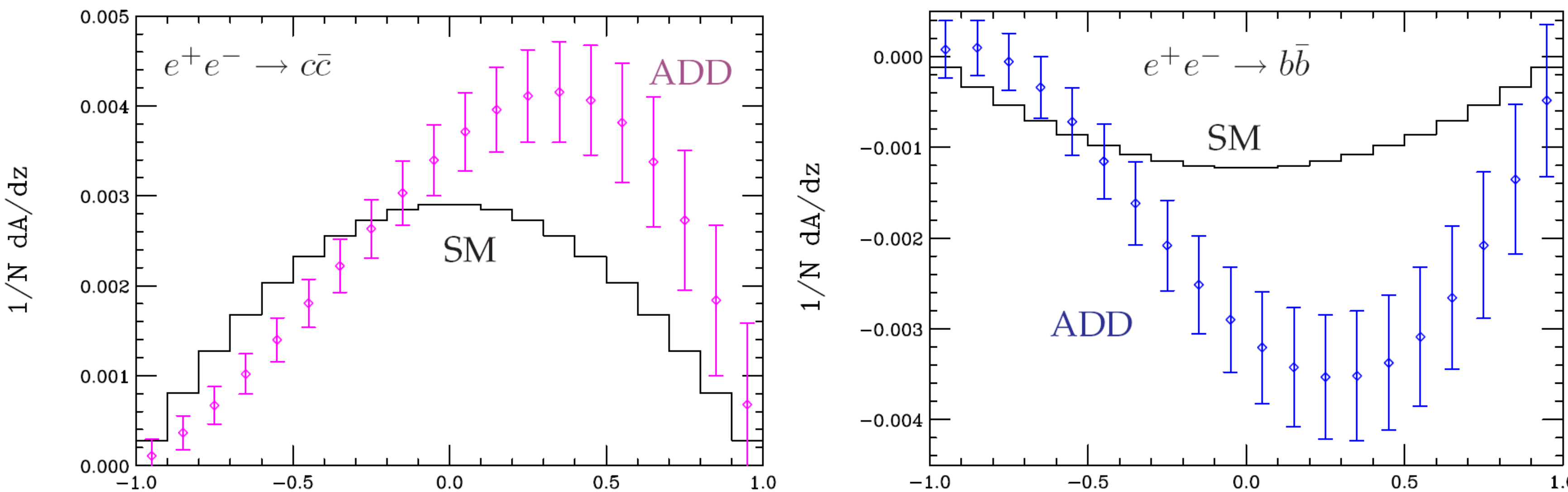


Transverse polarization

$$\frac{d\sigma}{d\Omega} \propto \sigma(longitudinal) + P_\perp^+ P_\perp^- \cos 2\varphi \sin\theta \cdot Q$$

- sensitivity to new physics (CP violation, graviton)
- does NOT work with e- polarization only
- e+ polarization 60% → 22% ⇔ effect is decreased by factor 3

M_H=1.5 TeV, E=500 GeV, L=500 fb^{-1} Rizzo

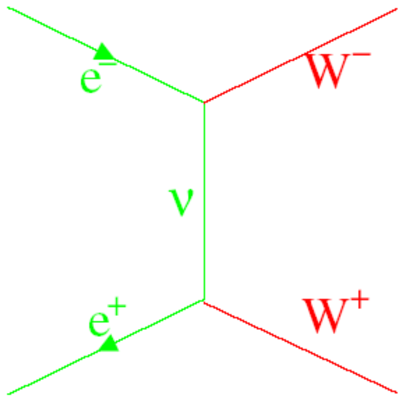


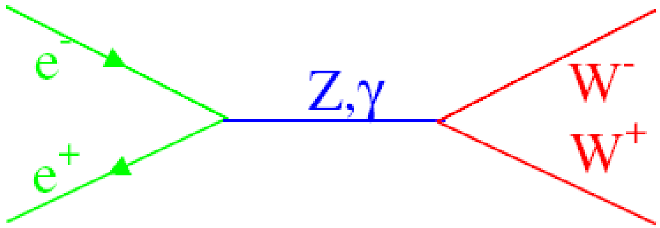
Graviton exchange (ADD model)

More scenarios (KK, Z', spin discrimination) see talk of Tom Rizzo

WW production

suppression of t-channel contribution by chosing the polarization of the initial stat





Simultaneous fitting of TGC's and polarization (e+ and e-) → see talk by Ivan Marchesini

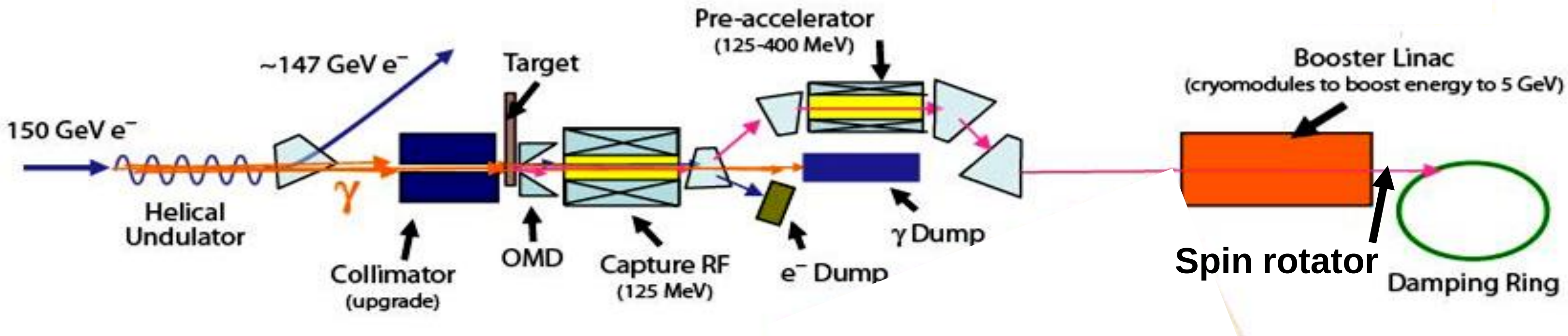
ILC undulator based e+ source is polarized

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**
- **new physics signals are expected at the LHC; they can be interpreted with substantially higher precision if positron polarization is available**
  → distinction of new physics models
- **Z factory "GigaZ" (10^9 Z bosons) is impossible without e+ polarization**

LC Design may not prevent a polarized positron beam

ILC Positron Source Layout



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

RDR (2007)

- Sc. Helical Undulator
  - Located at the 150GeV point in electron linac
  - $\lambda = $ 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 (FC)
- Keep Alive Source (KAS)
  - Independent, conventional
  - 10% intensity

SB2009

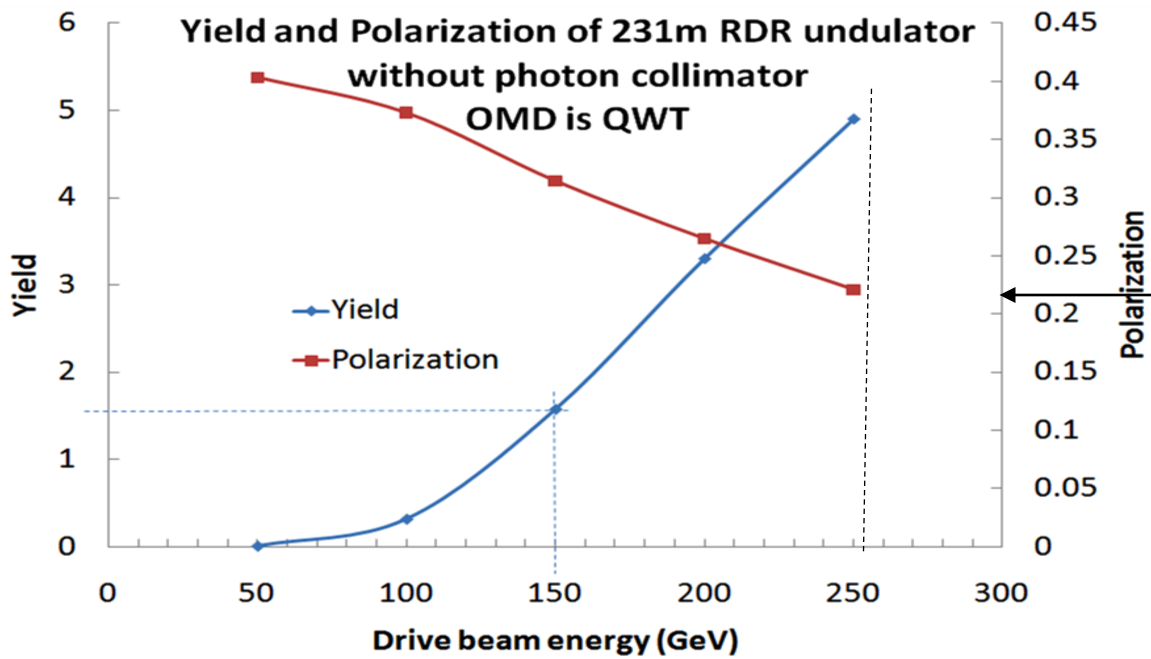
- Sc. Helical Undulator
  - Located at end of electron linac (125…250 GeV)
  - 231 m long, aperture 5.85mm
- Capture
  - Quarter wave transformer (QWT) ➔ lower e+ yield
- Auxiliary Source
  - 3 GeV e- beam to positron target

Yield of Polarized Positrons at ILC

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

SB2009 → e+ polarization ~22%

SB2009 Proposal Document:



distance undulator ⇔ target: 400m

Is P_{e+} = 22 % sufficient or annoying for physics?

Comparison RDR ⇔ SB2009: e+ polarization

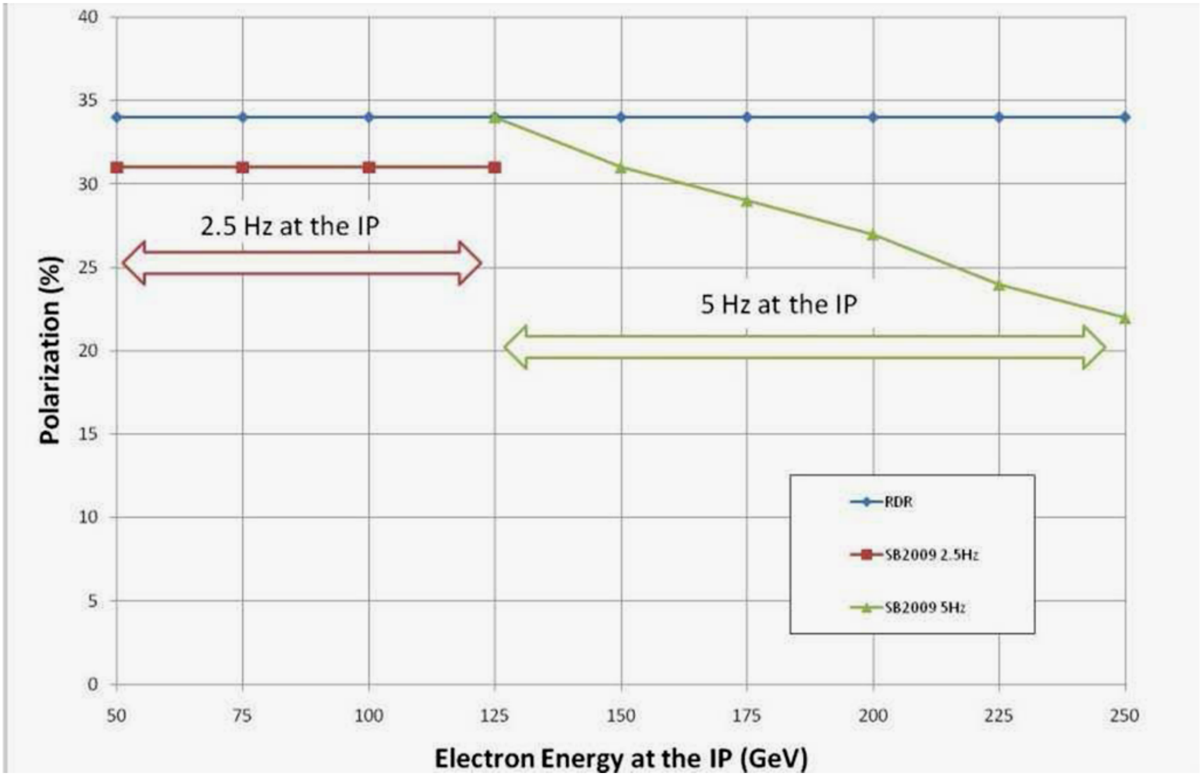


Figure 4.3.6: Positron polarisation vs electron energy for the RDR and SB2009 in the baseline configuration. Much higher polarisation levels are achievable in both layouts following a simple upgrade of the positron source.

SB2009

undulator length ⇔ better positron capture using flux concentrator than quarter wave transformer to achieve high photon yield

ILC positron polarization for physics

Need:

1. Spin rotation upstream e+ damping ring (longit. → vertical), and downstream turnaround (vertical → longit.)
2. Need facility for fast helictity reversal to achieve the desired initial states (+ -, -+)
   - **Undulator source ⇔ '+' or '-' circularly polarization of photons depending on direction of helical windings → Fast kicker with 2 spin rotation lines (**K. Moffeit et al., SLAC TN-05-045)
3. e+ Compton polarimeters at IP (desired up- and downstream)
   - **But also zero positron polarization has to be confirmed**

No ILCpositron polarization ?

1. Destroy the 22%÷34% positron polarization
   - **Need facility to depolarize e+ beam (damping ring is NOT sufficient!)**
   - **Need precision polarimeter to confirm zero polarization at IP**
2. Use planar undulator
   - **Planar instead of helical undulator → transversely polarized photons → unpolarized e+ (e-) beam**
   - **Photon yield of helical undulator is factor 1.5…2 times higher than that of planar undulator**
3. Conventional positron source (unpolarized e- to target)
   - **Intense beam is a huge challenge for positron production target**
     - Several e+ targets – beam stability at the 0.1% level????
   - **Polarization upgrade using helical undulator difficult**
   - **Reduced physics goal of the LC although we can do it much better!!**

- Alternative:

  Compton backscattering (neither at CLIC nor at ILC foreseen as baseline)

  - **ILC time structure ⇔ special effort**
  - **Feasibilty**

Conclusion:

- **Undulators are widely used,**
- **proof-of principle experiment (E166) confirmed method**
- **ILC undulator prototyp is constructed,**
- **➔ Should use low e+ polarization (>30%) for physics**
- **➔ If SB2009 should be baseline, polarization upgrade as soon as possible (desired almost from beginning)**

Summary

- Positron polarization
  - **is important for the physics goal**
  - **will be available from the beginning if the helical undulator is baseline design**

  ➔ **should be used for physics, also if pol upgrade (photon collimator) necessary**
- Milestones:
  - **ILC: Technical Design Report end 2012**
  - **CLIC: CDR in 2011**

  e+ polarization has to be covered in these reports

- Still to do – for ILC and CLIC:
  - **Realistic scenarios with polarization and consequences for physics precision**
  - **Realistic spin tracking from start to end**
  - **Depolarization effects at IP**
  - **Demonstrate target reliability**
  - **Demonstrate that the flux concentrator will work (higher e+ yield)**

… and detection of signals beyond the SM

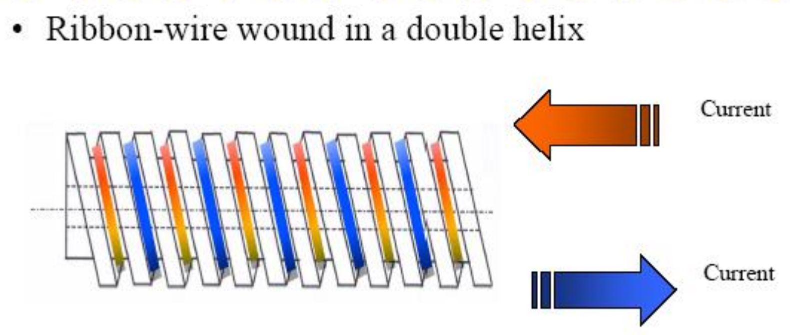
Positron polarization needs more attention from machine and physics groups
→ to be prepared for the unexpected

Thank you !

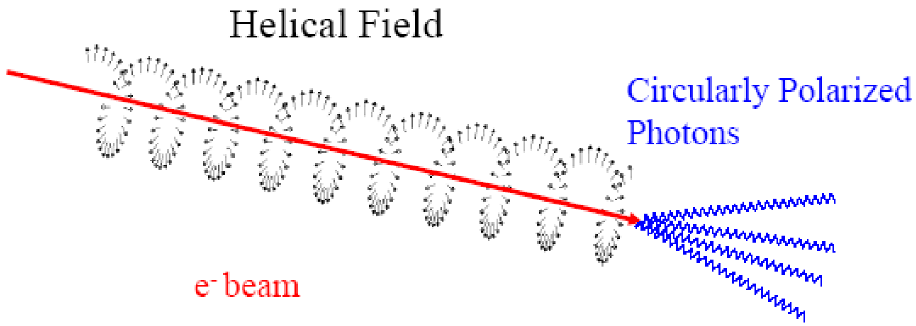
BACKUP

Polarized Positrons from Helical Undulator

- Rotating dipole field in the transverse planes



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



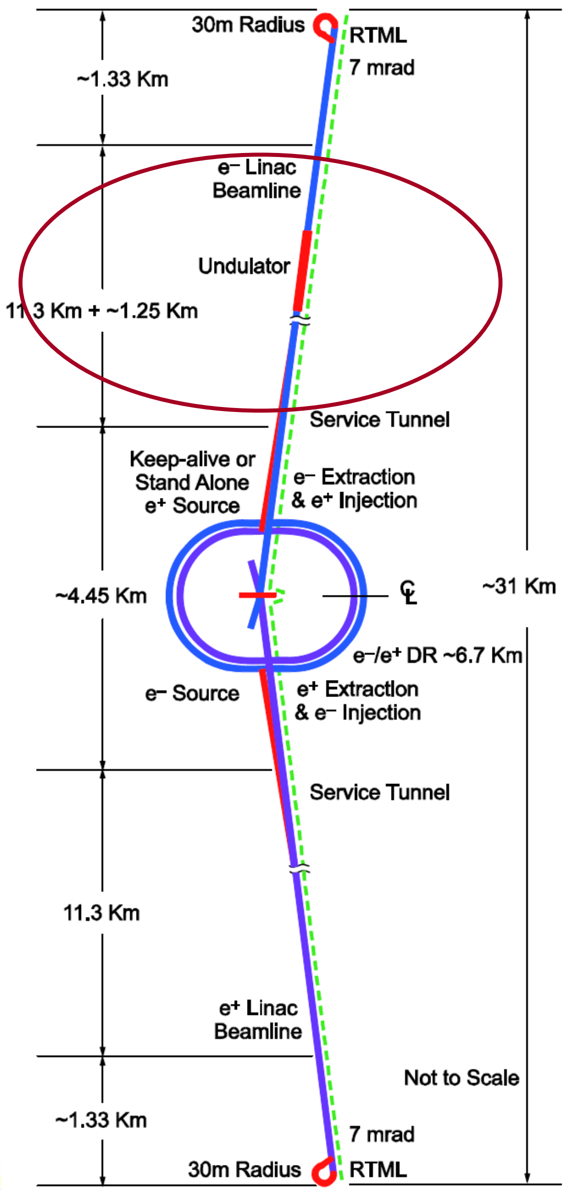
Opening angle
of photon beam ~1/γ
(first harmonic)

- 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)

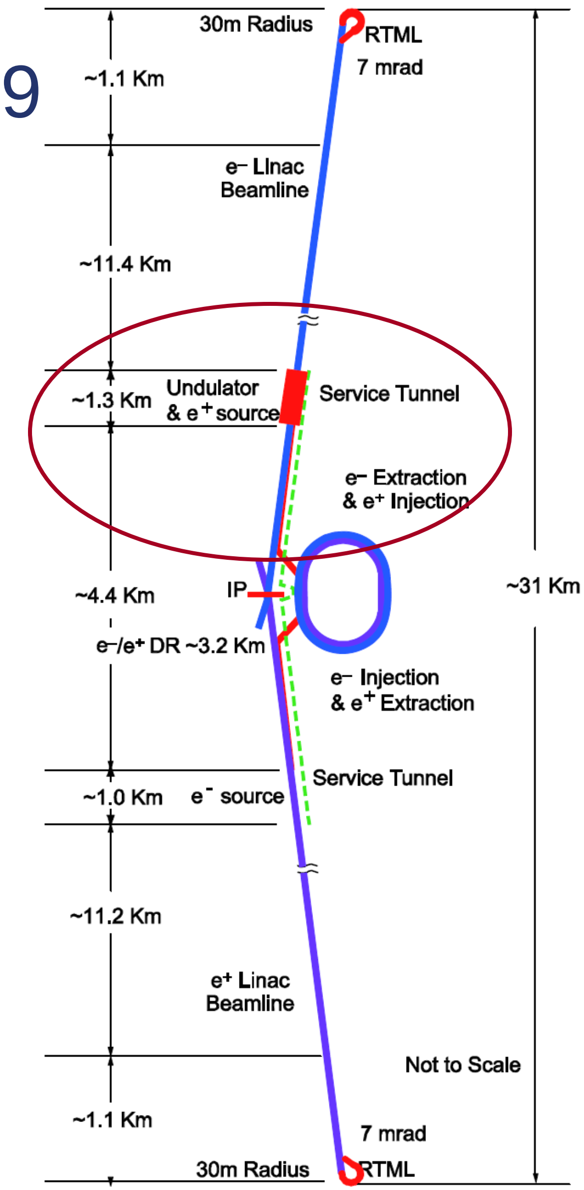
See also Mikhailichenko, CLNS 04/1894

Location of sources at the ILC

RDR:



SB2009

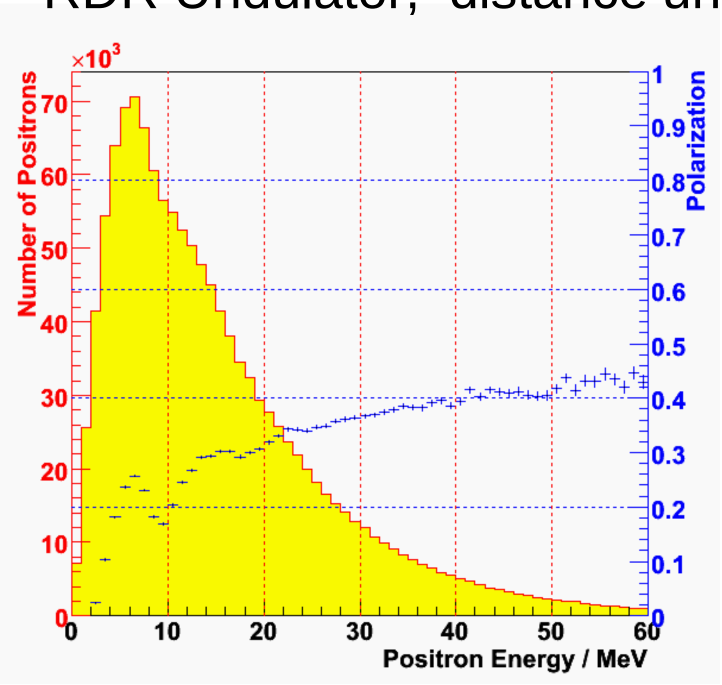


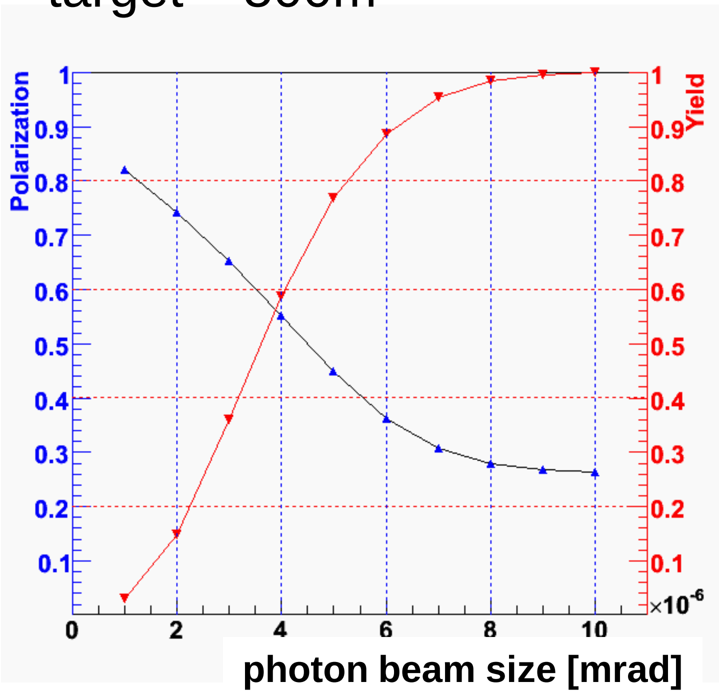
Comparison of RDR and SB2009 e+ source parameters

Parameter	RDR	SB2009	Units
Positrons per bunch at the IP	2 x 10^{10}	1 to 2 x 10^{10} (see Figure 4.3.3 for details)	
Bunches per pulse	2625	1312	
Pulse repetition rate	5	5 (125 to 250GeV) 2.5 (50 to 125GeV)	Hz
Positron energy (DR Injection)	5	5	GeV
DR transverse acceptance	0.09	0.09	m-rad
DR energy acceptance	±0.5	±0.5	%
Electron drive beam energy	150	125 to 250	GeV
Electron energy loss in undulator	3	0.5 to 4.9 (see Figure 4.3.4 for details)	GeV
Required additional electron linac overhead	3	4.1	GeV
Undulator period	11.5	11.5	mm
Undulator strength	0.92	0.92	
Active undulator length	147 (210 after polarisation upgrade)	231 (maximum, not all used when >150GeV)	m
Field on axis	0.86	0.86	T
Beam aperture	5.85	5.85	mm
Photon Energy (1st harmonic)	10	1.1 (50 GeV) to 28 (250 GeV)	MeV
Photon beam power	131	102 at 150 GeV (less at all other energies)	kW
Target material	Ti – 6%Al – 4%V	Ti – 6%Al – 4%V	
Target thickness	14	14	mm
Target power adsorption	8	8	%

Positron spectra

RDR Undulator, distance undulator – target ~500m





→ Average positron polarization (~34% for RDR design)

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

Positron Target

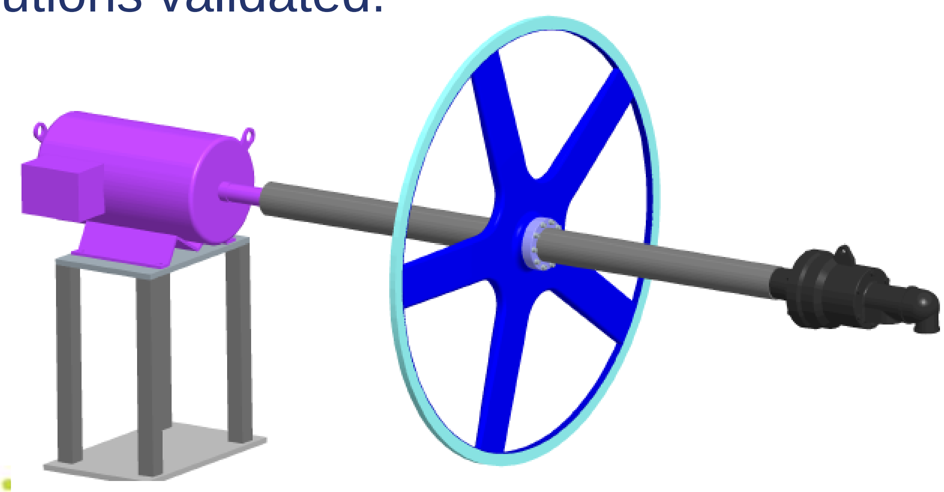
- Material: Titanium alloy

  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

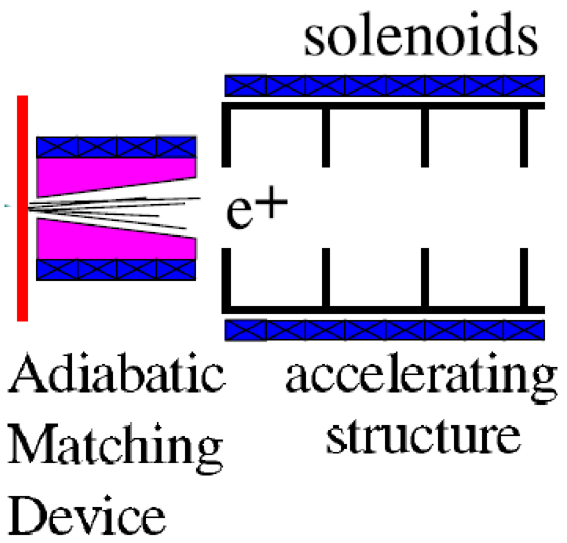
- Issues to be resolved and the solutions validated:
  - **Stress in target material, pressure shock wave impact on target lifetime**
  - **rotating vacuum seals to be confirmed suitable**

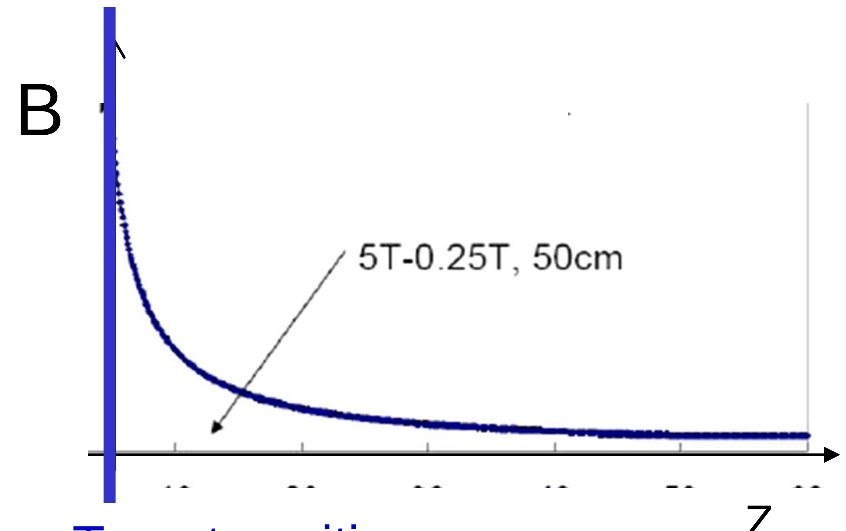


Positron yield ⬄ Optical matching device

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





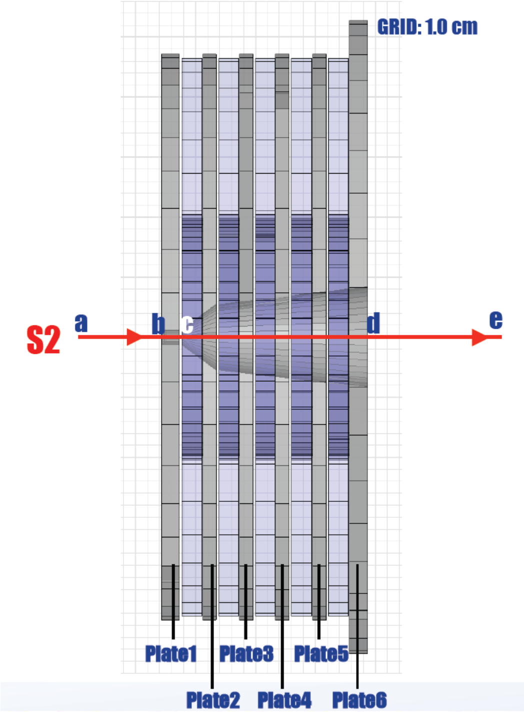
- Capture efficiency >30%
- Rotating target immersed in B field ⬄ eddy currents
- Eddy current experiment @ Cockroft Institute

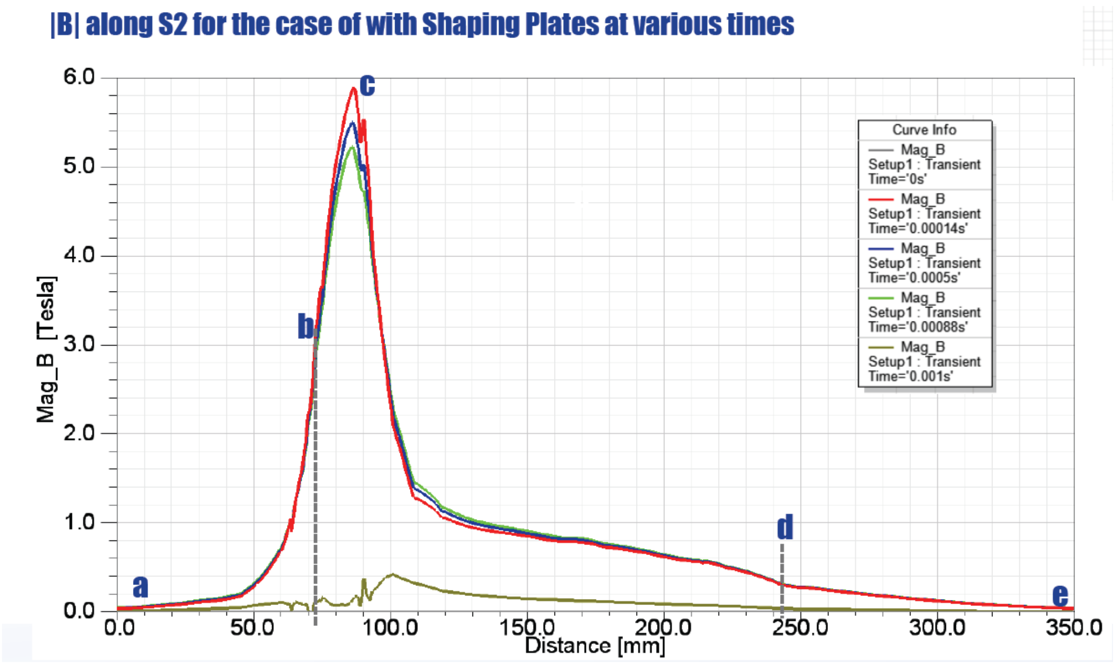
  → expect 8 kW at 2000 rpm

  → heat load on target substantially increased

Optical Matching Device (2)

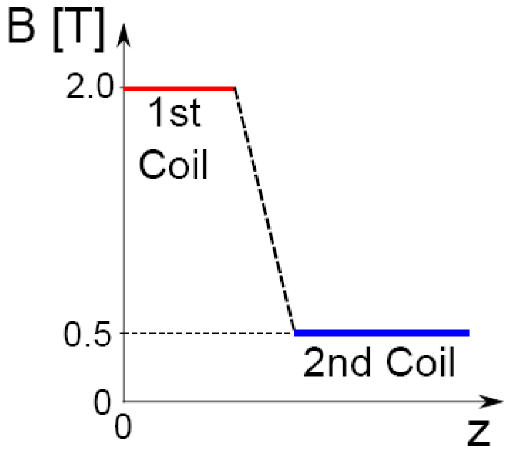
- Flux Concentrator (FC)
  - **Flux concentrator reduces magnetic field on target but lower capture efficiency ~22%**
  - **RDR design with FC**
  - **pulsed flux concentrator (used at SLD):**
    - **ILC** needs ~ 1ms pulse width flat-top
    - LLNL: Design and prototype (budget):

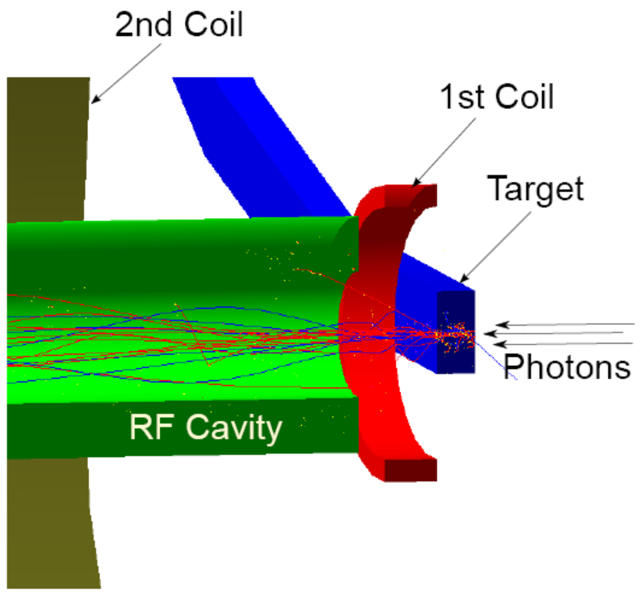




Optical Matching Device (3)

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





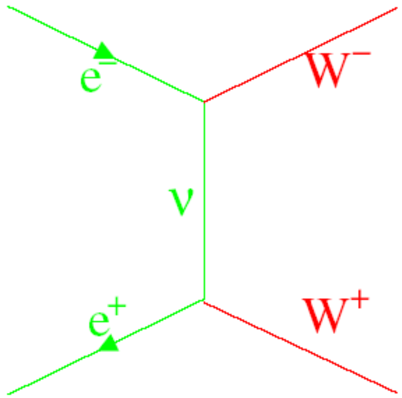
  - **but capture efficiency is ~15 %**
  - **SB2009 design with QWT**

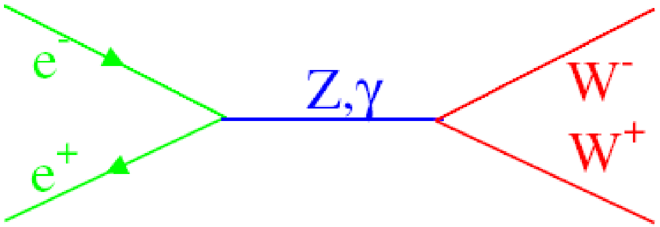
→ Length of helical undulator 231m

- **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**

suppression of t-channel contribution





Suppression factors for t-channel in comparison to unpolarized beams

P_{e-}	P_{e+}	0	-0.6	-0.3	-0.22
0.8		0.2	0.08	0.14	0.16
0.9		0.1	0.04	0.07	0.08