Status of the (polarized) ILC Positron Source

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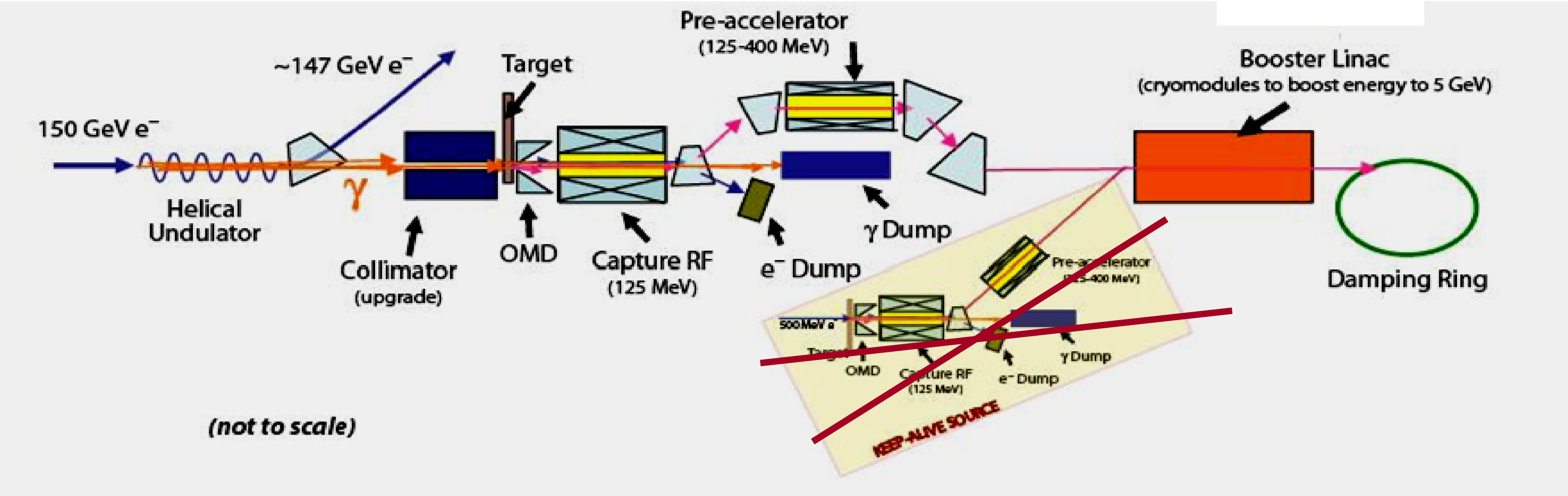
Outline

- Short summary of the Positron Source Collaboration Meeting in April 2008

  (~ positron source status report)
- Focus on polarized positrons
  - **e+ will be polarized (30%)**
    - advantage or annoying?
- Concluding remarks

RDR Source Layout



- helical superconducting undulator at 150 GeV to generate photons
- γ beam transported ~400m beyond undulator, impinges on Ti alloy target ($0.4X_0$)
- e+ captured with optical matching device (OMD) and accelerated with NCRF Linac with solenoidal focussing to 125 MeV
- separation of e- and γ from e+
- e+ further accelerated with NCRF Linac with solenoidal focussing to 400 MeV
- transport at 400 MeV for ~5km
- e+ acceleration to 5GeV in SCRF Linac, injection into DR

The RDR Parameters

Nominal Positron Source parameters († upgrade values).

Beam Parameters	Symbol	Value	Units
Positrons per bunch at IP	n_b	2×10^{10}	number
Bunches per pulse	N_b	2625	number
Pulse repetition rate	f_{rep}	5	Hz
Positron energy (DR injection)	E_0	5	GeV
DR transverse acceptance	$\gamma(A_x+A_y)$	0.09	m-rad
DR energy acceptance	δ	$\pm$ 0.5	%
DR longitudinal acceptance	A_l	$\pm3.4 \times \pm25$	cm-MeV
Electron drive beam energy	E_e	150	GeV
Electron beam energy loss in undulator	ΔE_e	3.01	GeV
Positron polarization †	P	30; $\sim60^{\dagger}$	%

Positron overhead of 50% after the target

→ 3×10^{10} e^+ per bunch at 400 MeV

Positron overhead of 25% at the Damping Ring

→ 2.5×10^{10} e^+ per bunch within the DR acceptance

Positron Source Collaboration

- Groups from Europe, US, Asia working on the design of the ILC PS

  Topics
  - Collimation
  - Undulator
  - Compton Source
  - Target
  - Optical Matching device (OMD)
  - Remote Handling
  - Polarisation
  - Overall Source Modelling

- Last collab. meeting in April 08 after the budget cuts in US and UK

➔ Assess R&D requirements for whole of positron source

→ **Take account of reduced resource level and new timescales**

➔ Assess possible cost reduction measures

(Positron Source Collaboration Meeting:
http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=2639
or http://indico.desy.de/conferenceDisplay.py?confId=586)

Workshop on Polarization and Energy Workshop:
http://indico.desy.de/conferenceDisplay.py?confId=5865

Collimation

- **Low-power photon-collimators** in the undulator lattice
- **High-power photon collimator**
  - **sits directly upstream of the photon production target and is intended to**
    - scrape the beam to protect instrumentation, etc in the target station and
    - Upgrade: adjust the ~60% polarisation of the beam.

      (in that case the power load on the target may be up to 100kW!)

- Initial studies with collimator geometry in FLUKA
- Now: also aspects of the undulator spectra
  - **collimator energy deposition, heat load, activation etc.**
- Report expected for EPAC'08

Undulator

- **42 x 4m cryomodules (42 x 3.5 = 147m active length)**
- Vacuum pumps, photon collimators, quads,
  BPMs installed every 3 cryomodules in room temp sections
- Corrector magnets in every cryomodule

Undulator Parameters	Symbol	Value	Units
Undulator period	λ	1.15	cm
Undulator strength	K	0.92	
Undulator type		helical	
Active undulator length	L_u	147	m
Field on axis	B	0.86	T
Beam aperture		5.85	mm
Photon energy (1st harmonic cutoff)	E_{c10}	10.06	MeV
Photon beam power	P_γ	131	kW

Undulator Session Summary (UK)

UK group (Daresbury and Rutherford):

- Several short prototypes were tested
- STFC are building a full scale 4m undulator module
  - **2 x 1.75m undulators: manufactured and tested**

    → RDR parameters fulfilled !
  - **now focus on design, manufacture and testing of 4m cryomodule**

UK Vac Vessel, Turret, Und II

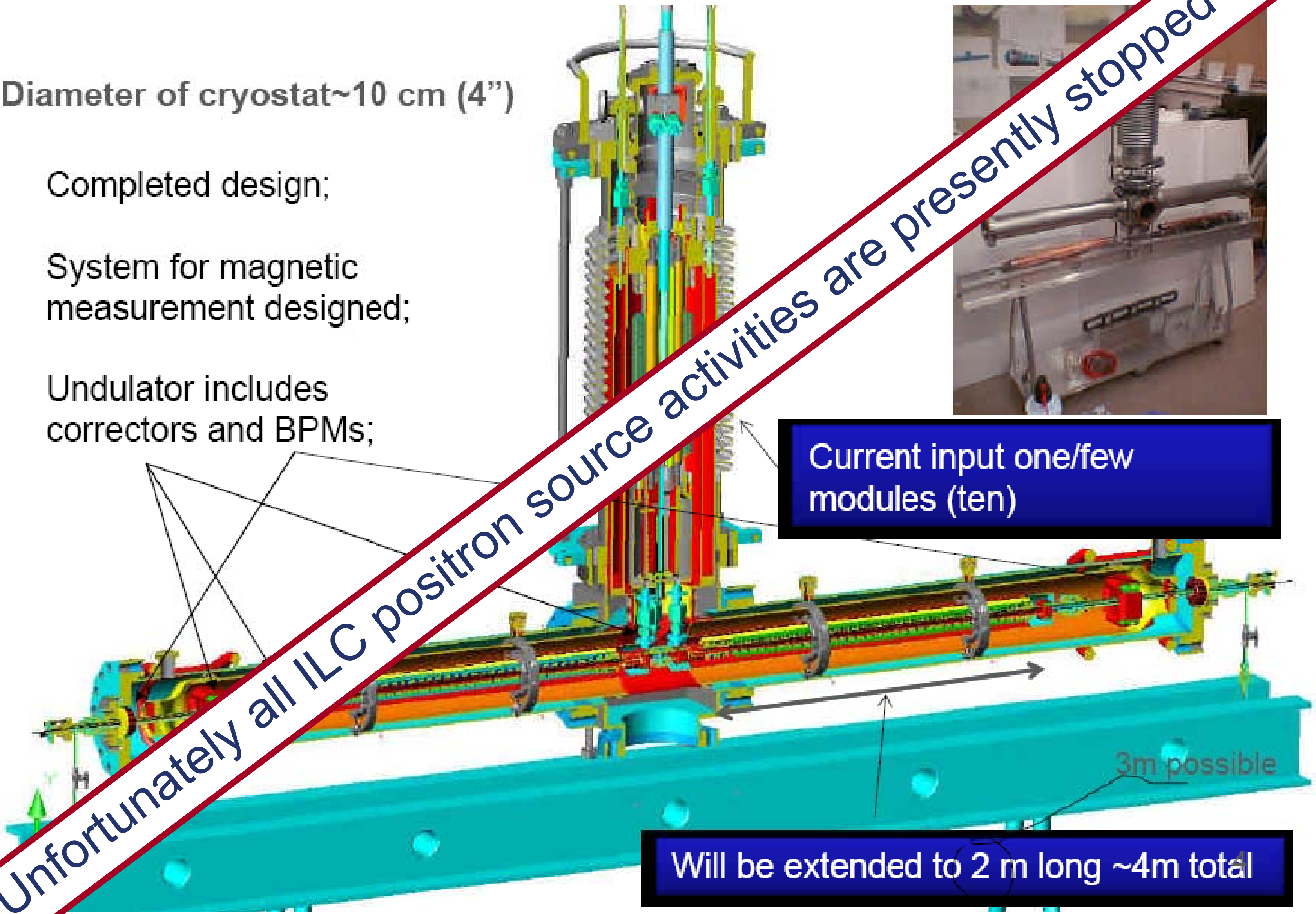
Cornell Undulator

Diameter of cryostat~10 cm (4")

Completed design;

System for magnetic measurement designed;

Undulator includes correctors and BPMs;



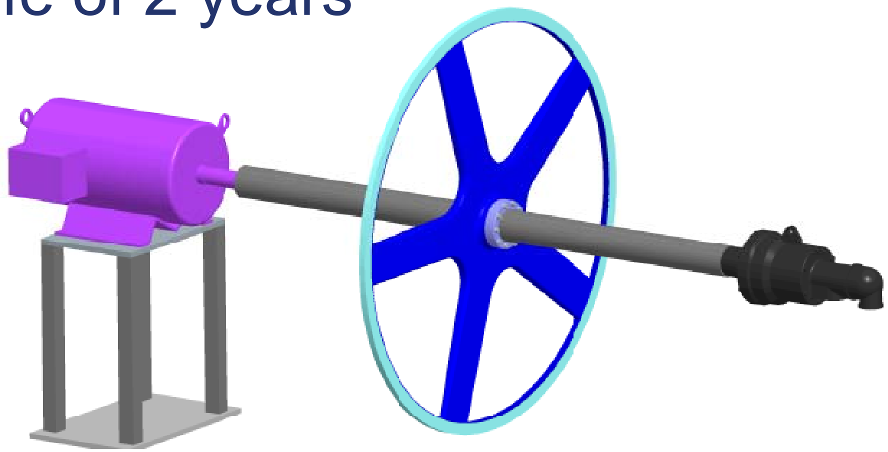
Compton Source

- Compton Source is alternative solution for ILC positron source
- R&D on cavity systems is ongoing
- Continue Damping Ring stacking studies and work with DR group to ensure optimum solution.

Status – see also PosiPol Workshop in Hiroshima next week

Target

- 1m diameter spinning wheel
- Rim & spokes not solid disk to mitigate eddy current effects
- Designed for operational life of 2 years

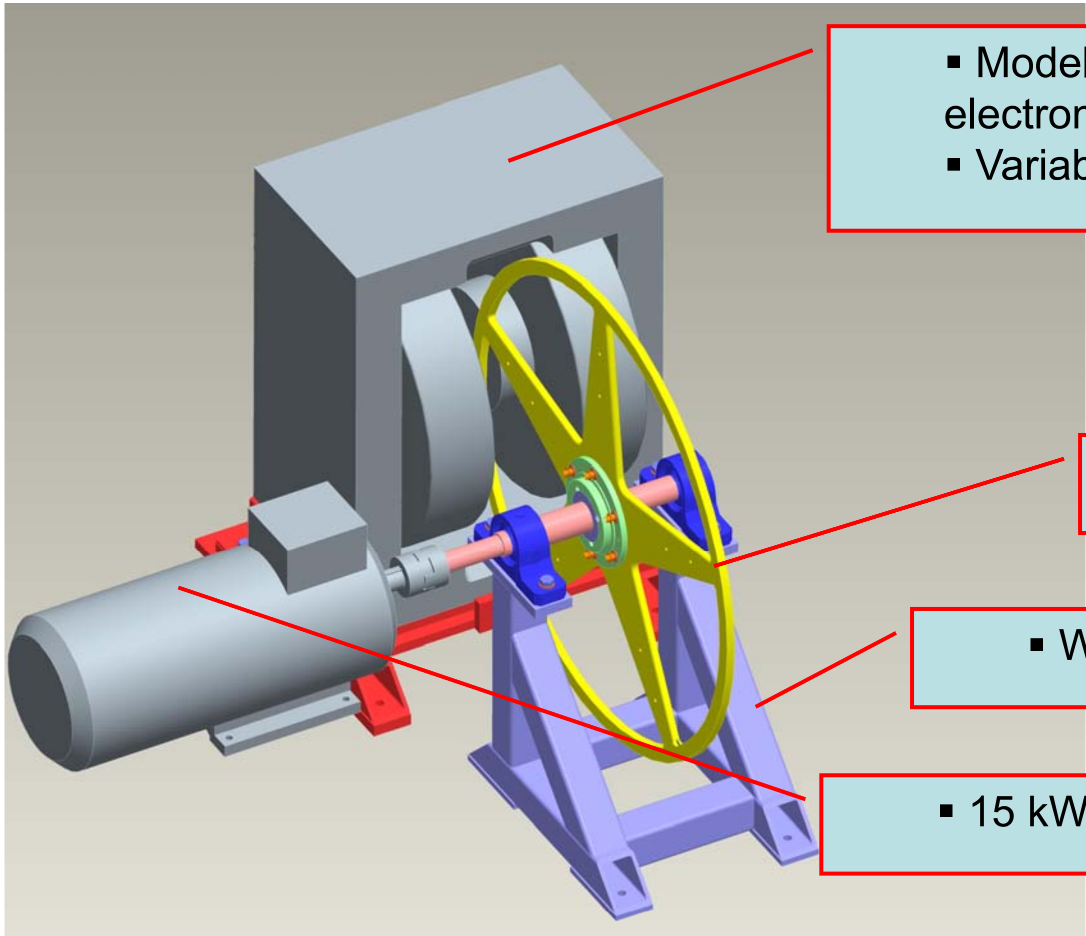


Target Parameters	Symbol	Value	Units
Target material		Ti-6%Al-4%V	
Target thickness	L_t	0.4 / 1.4	r.l. / cm
Target power adsorption		8	%
Incident spot size on target	σ_i	> 1.7	mm, rms

Prototype Design

Prototype I - eddy current and mechanical stability

Ken Davies - Daresbury Laboratory



- Model 3474-140 GMW water-cooled electromagnet
- Variable pole gap (0mm to 160mm)

- Ti alloy wheel.

- Wheel support stand.

- 15 kW drive motor (Control Techniques)

UK Prototype

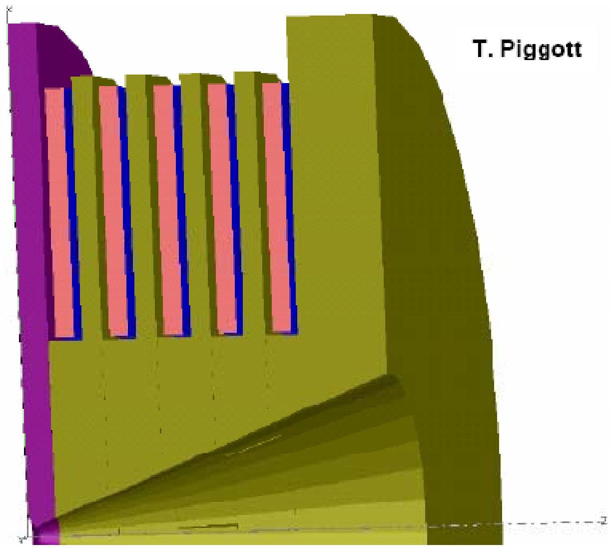
Target

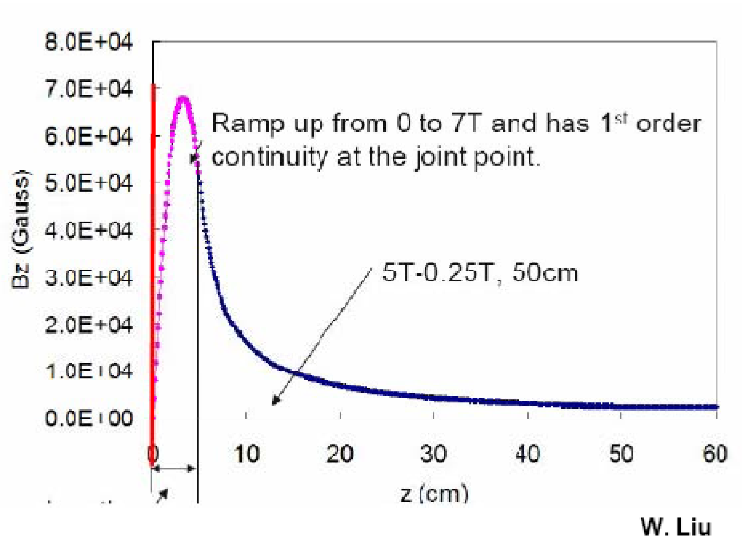
- Complete Eddy current tests at Daresbury, compare with experimental results
- Pressure shock wave analysis and numerical modelling
  - **Simulations of the pressure shock waves using hydrodynamic modelling at Cornell suggests the Ti target would not survive.**
  - **Further simulation will be carried out to verify this.**
  - See also talk by Stefan Hesselbach
- Lifetime studies of target

Goal: Engineered solution, including prototype tests – water, vacuum, …

Optical Matching Device

- Increases capture efficiency from 10% to as high as 40%
  - **Depends on scheme selected (→ target in magnetic field)**
- Flux Concentrator





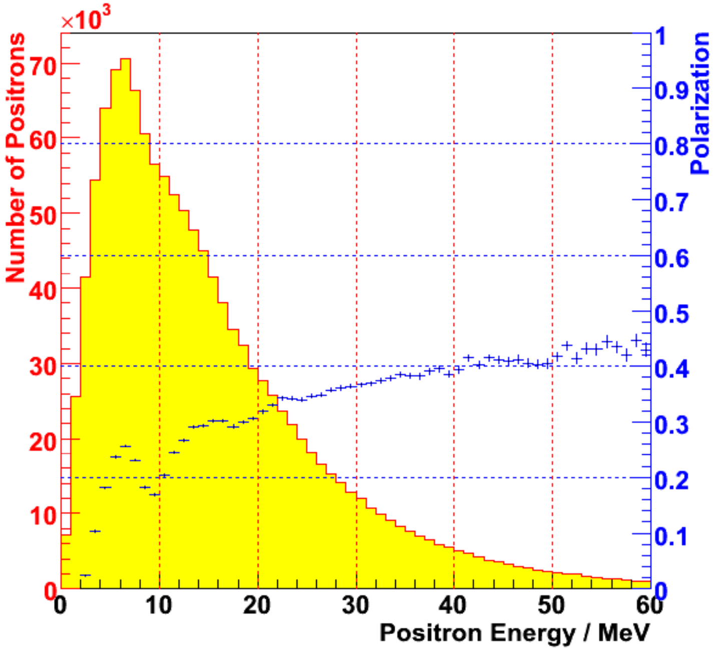
-- Flux concentrator reduces magnetic field on target but lower captur eff.

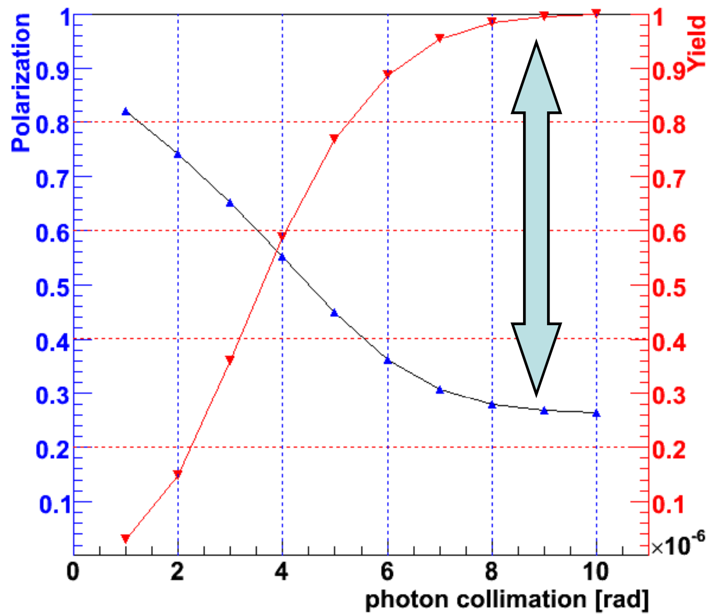
-- pulsed flux concentrator (used at SLD), for ILC only 'extrapolated' design

Alternative solution (suggested by Cornell): Li lens → 40% capture efficiency – but stress, heat and radiation damage in the window?

ILC Baseline design: e+ Polarization

RDR design → helical undulator
→ 30% e+ polarization





photon beam: distance undulator ⇔target ~ 400m

Positron Polarization?!

Physics between 200 GeV and 500 GeV

Luminosity: Year 1-4: L_{int} = 500 fb^{-1}

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

➔ statistical uncertainties at per-mille level !!

Uncertainties: Polarization error could dominate

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

s-channel cross sections with pol e+ beams

Can perform independent measurements (s-channel vector exch.)

$$\sigma_{++} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(+P_{e^+} + P_{e-}\right)\right]$$

$$\sigma_{--} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} - P_{e-}\right)\right]$$

=0 (SM) if both beams 100% polarized

$$\sigma_{-+} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(+P_{e^+} - P_{e-}\right)\right]$$

$$\sigma_{+-} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} + P_{e-}\right)\right]$$

Standard Model s-channel

SLC: $P_{e+,} = 0$

$$\sigma_{-} = \sigma_u \left[1 + A_{LR}\left(-P_{e-}\right)\right]$$

$$\sigma_{+} = \sigma_u \left[1 + A_{LR}\left(+P_{e-}\right)\right]$$

ILC with e+ polarization ➔ Cross section enhancement ~$(1+|P_{e-}P_{e+}|)$
For (80%, ~30%) → 25% gain in luminosity

s-channel asymmetries with pol e+ beams

Can perform 4 independent measurements (s-channel vector exch.)

$$\sigma_{++} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(+P_{e^+} + P_{e-}\right)\right]$$
$$\sigma_{--} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} - P_{e-}\right)\right]$$

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$$\sigma_{+-} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} + P_{e-}\right)\right]$$

Standard Model
s-channel

SLC: σ_{-0} and σ_{+0} used for A_{LR} measurement

$$A_{LR} = \frac{\sigma_{-0} - \sigma_{+0}}{\sigma_{-0} + \sigma_{+0}} \cdot \frac{1}{P_{e^-}}$$

ILC:

$$A_{LR} = \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}} \cdot \frac{1 - P_{e^-} P_{e^+}}{-P_{e^-} + P_{e^+}} = \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}} \frac{1}{P_{eff}}$$

Error propagation:

➔ $$\frac{\Delta P_{eff}}{P_{eff}} < \frac{\Delta P_e}{P_e}$$

Factor 2 (1.5) for P=(80%, 30%)

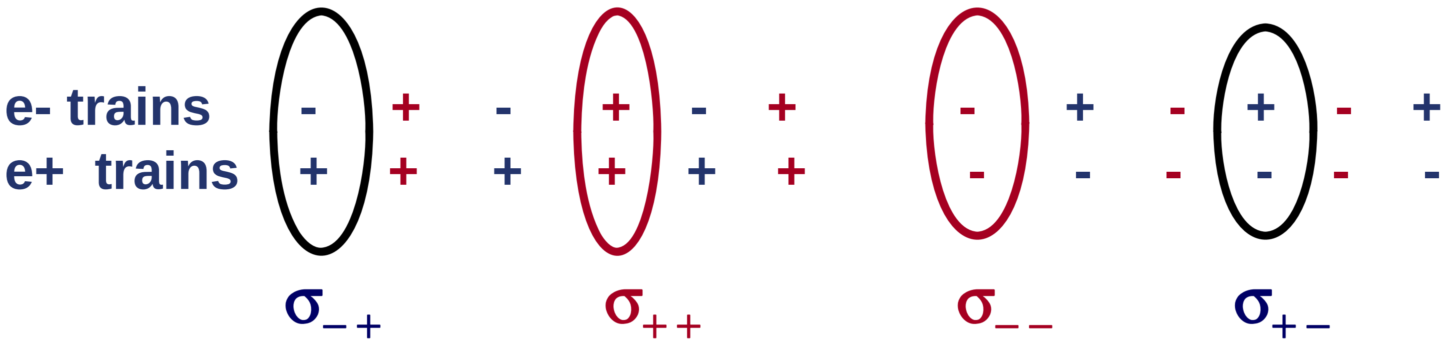
The Problem

- use e+ polarization for measurements → need:
  - **e+ spin rotation before and after the DR**
  - **Reversal of e+ helicity**
  - **polarization measurement at the IP and also near the source**
- RDR:
  - **Spin rotation before and after the DR**
  - **Polarization measurement at the IP**

    (e+ polarization is NOT in the baseline)

e+ Helicity Reversal

e+ helicity flip less frequent than e- helicity reversal ?!



50% spent to 'inefficient' helicity pairing σ_{--} and σ_{++}

➔ gain due to xs enhancement for J=1 processes with e+ pol is lost !!

Improvement of ΔP_{eff} remains

But:
- systematic errors have to be known and small
- time dependent intensity/polarisation tolerances should be small
- $P_{e-} \cdot P_{e+}$ ⇔ need to understand correlations

‘Slow’ vs. ‘fast’ helicity reversal

no reversal → no effective polarization, P_{eff}
→ larger uncertainty of polarization (syst. effects, error propagation)
→ better to destroy e+ polarization
→ Polarimeter needed to verify $P_{e+} = 0$

Fast reversal:

$$A_{LR}^{i} = \frac{\left(N_{-+} - N_{-+}^{Bgr}\right)^{i} - \left(N_{+-} - N_{+-}^{Bgr}\right)^{i}}{\left(N_{-+} - N_{-+}^{Bgr}\right)^{i} + \left(N_{+-} - N_{+-}^{Bgr}\right)^{i}} \cdot \frac{1}{P_{eff}} \qquad \Rightarrow \qquad A_{LR} = \frac{1}{N}\sum A_{LR}^{i}$$

$$\sigma_u^{i} \sim \left(N_{-+} - N_{-+}^{Bgr}\right)^{i} + \left(N_{+-} - N_{+-}^{Bgr}\right)^{i} \cdot \frac{1}{1 - P_{e+} P_{e-}} \qquad \Rightarrow \qquad \sigma_u = \frac{1}{N}\sum \sigma_u^{i}$$

slow reversal:

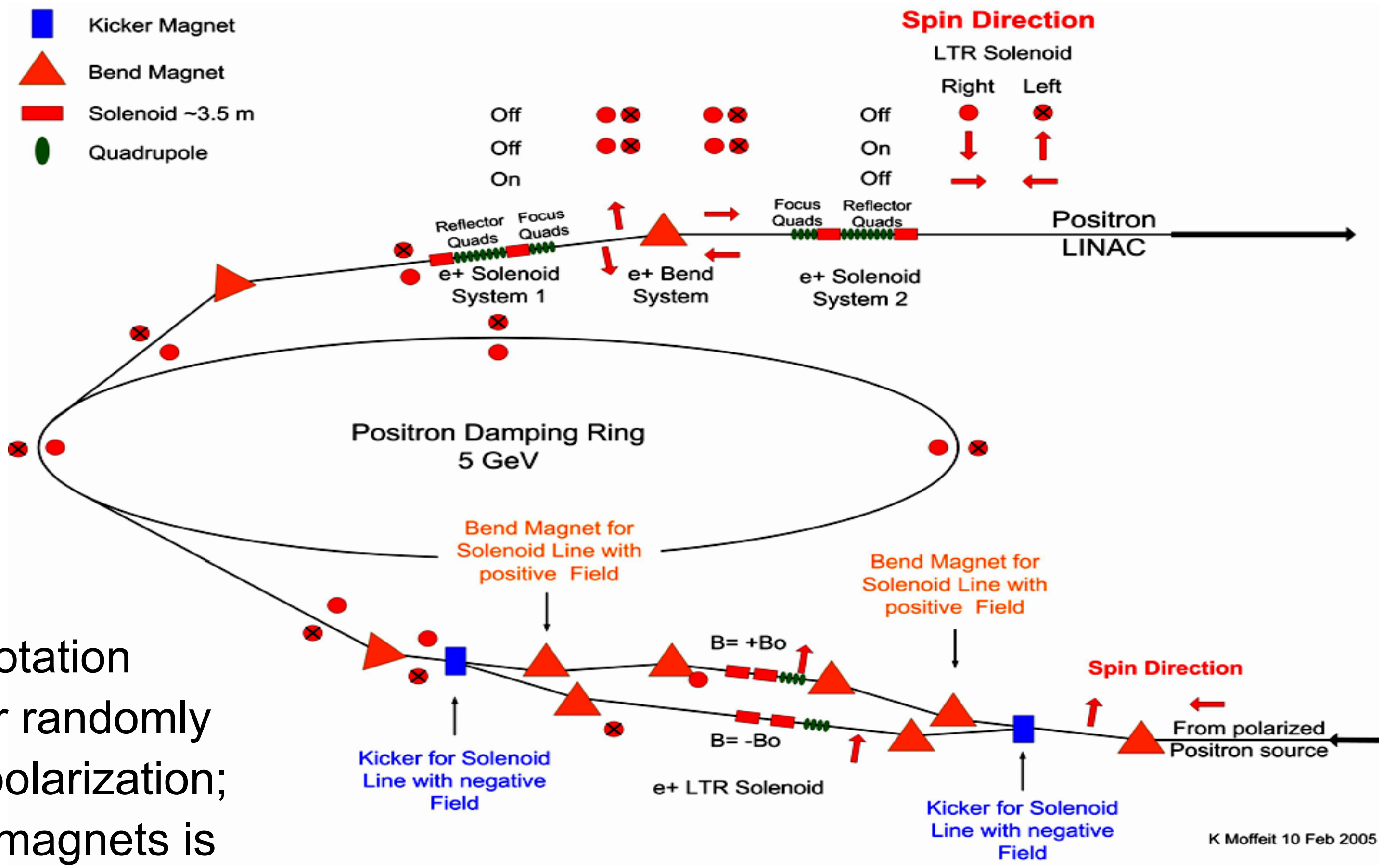
$$N_{-+/+-} \simeq \frac{1}{N}\sum \left(N_{-+/+-} - N_{-+/+-}^{Bgr}\right)^{i} \qquad \Rightarrow \qquad A_{LR} = \frac{1}{\langle P_{eff}\rangle} \cdot \frac{N_{-+} - N_{+-}}{N_{-+} + N_{+-}}$$

$$\sigma_u \sim \frac{1}{1 - \langle P_{e+}\rangle\langle P_{e-}\rangle} \left(N_{-+} + N_{+-}\right)$$

➔ long-term stability at the level of (few) 10^{-3} + small corrections to have agreement between ‘slow’ and ‘fast’

Spin rotation and helicity reversal @ 5GeV

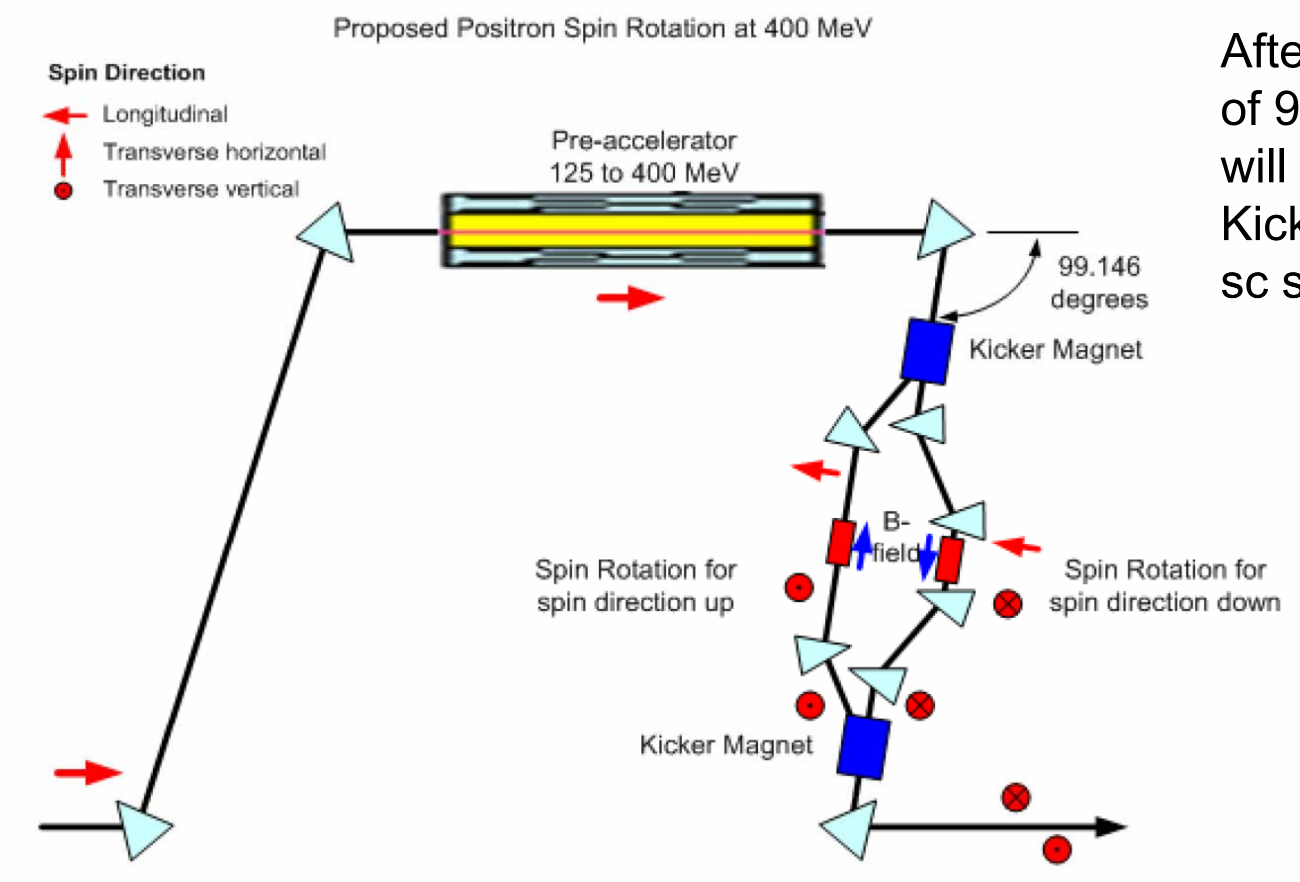
K. Moffeit et al., SLAC-TN-05-045 → fast reversal before DR (5 GeV)



parallel spin rotation beam lines for randomly selecting e+ polarization; pair of kicker magnets is turned on between pulse-trains

Spin rotation and helicity reversal @ 400 MeV

New proposal: K. Moffeit, M. Woods,Walz, ILC-NOTE-2008-040
→ Fast reversal at ~400 MeV



After bend of 99.146 degrees a solenoid will rotate spin to the vertical:
Kicker → 2 parallel lines with sc solenoids for fast rotation

Figure 5: Layout of proposed positron spin rotation systems in the Chicane for the Pre-accelerator. Kicker magnets and parallel spin rotator beamlines allow fast polarization reversals for the positron beam.

Polarimetry; Source Modelling

Polarimetry at low energies

- **Bhabha polarimeter at 400 MeV suggested**
  - Optimization of polarimeter layout
  - Further work for a reliable target design
- **Compton polarimeter after DR, before ML**
  - save costs using the laser of the laser wire system
  - realistic performance study
  - to be done in collaboration with laser wire group

Polarization modelling

- All depolarization effects have to be accurately calculated
- precise spin tracking is required already for the baseline design.
- This work has to be done for the electrons as well as the positrons.

➔ **Theoretical studies to describe spin precession in strong fields.**

➔ **Inclusion of second order depolarization processes**

(see talk of Tony Hartin)

Summary

- e+ polarization has to be taken into account for source modelling and design; realistic physics studies
- Costs !

  → Consider improvements of the RDR layout
  - Change undulator location to end of main linac
  - Change underlying assumption of yield of 1.5 e^+ in DR for every e^- in undulator
  - Reduction of DR acceptance ?
  - Reduce undulator chicane offset from 2.5m to <1m
  - Maximise yield (eg Li lens, energy acceptance)
  - Remove keep alive source, auxiliary source only

  But not destroy the e+ polarization

- LHC ⇔ ILC: ILC could be operated with polarized beams from beginning