Polarimetry at the CLIC Sources

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LEPOL Group

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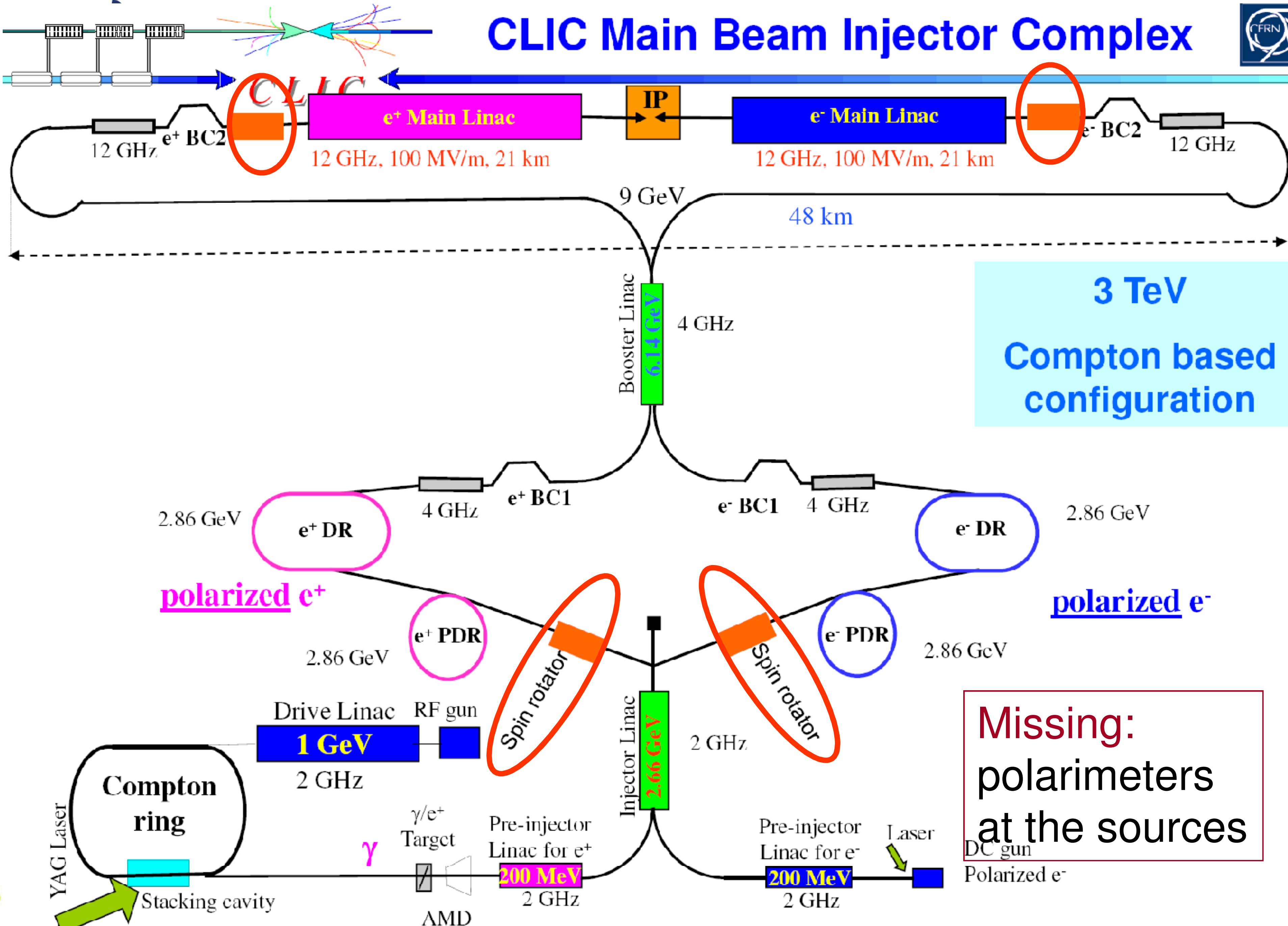
Outline

- Sources (CLIC and ILC)
- e+ polarimetry at low energies (LEPOL)
  - Compton transmission polarimeter
  - Bhabha polarimeter studies
  - Compton polarimetry after DR
- Spin rotation, fast helicity reversal

Low Energy POLarimeter Group:
DESY/HUB: R. Dollan, T. Lohse, S. Riemann, A. Schälicke, P.Schuler, A. Ushakov
Minsk: P. Starovoitov, Tel Aviv U: G. Alexander

CLIC Main Beam Injector Complex



3 TeV

Compton based configuration

Missing: polarimeters at the sources

ILC Electron Source System

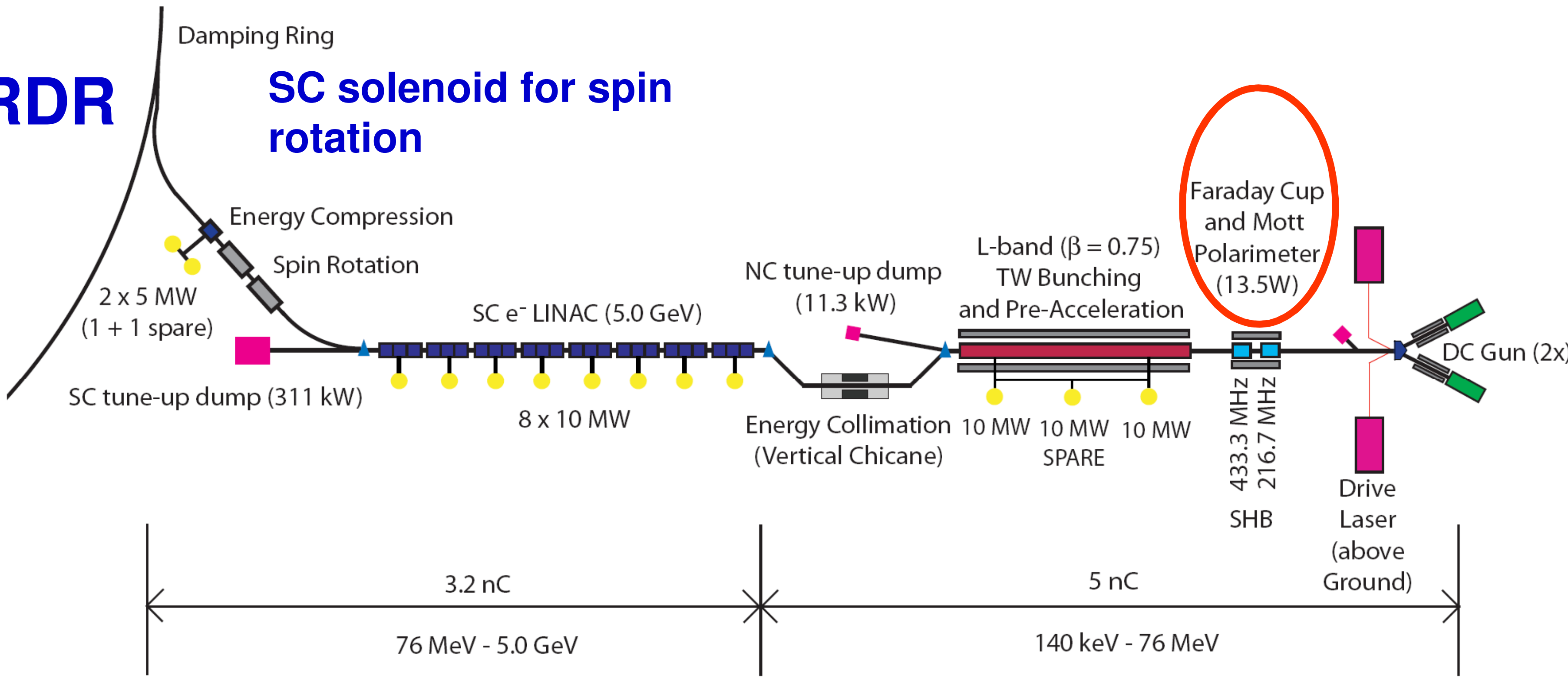
Spin rotation:

- before damping ring: rotate spin to the vertical (alternative: rotation at 1.7 GeV, Moffeit et al., ILC-NOTE-2008-040)
- after damping ring: rotate spin to the desired polarization (e.g. longitudinal polarization) at the IP,

Fast helicity reversal done with laser

RDR

SC solenoid for spin rotation

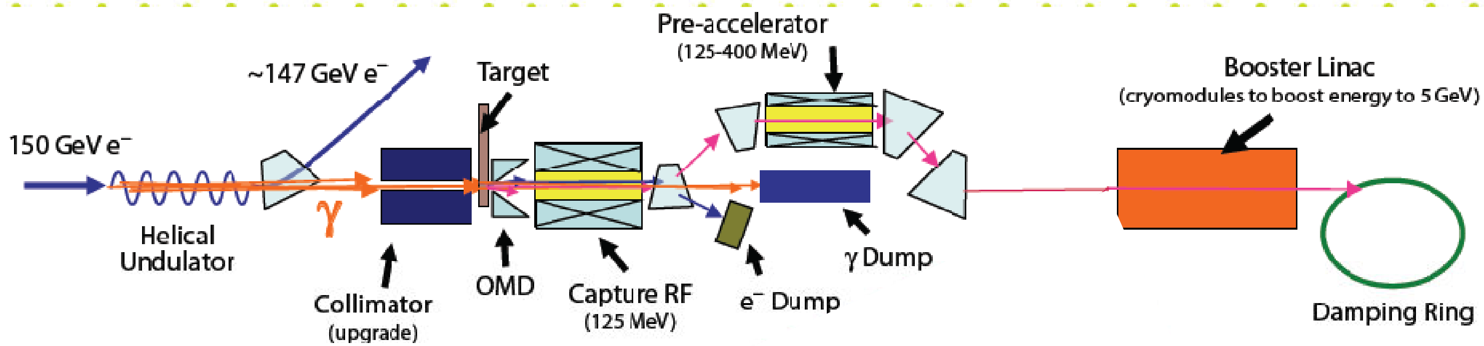


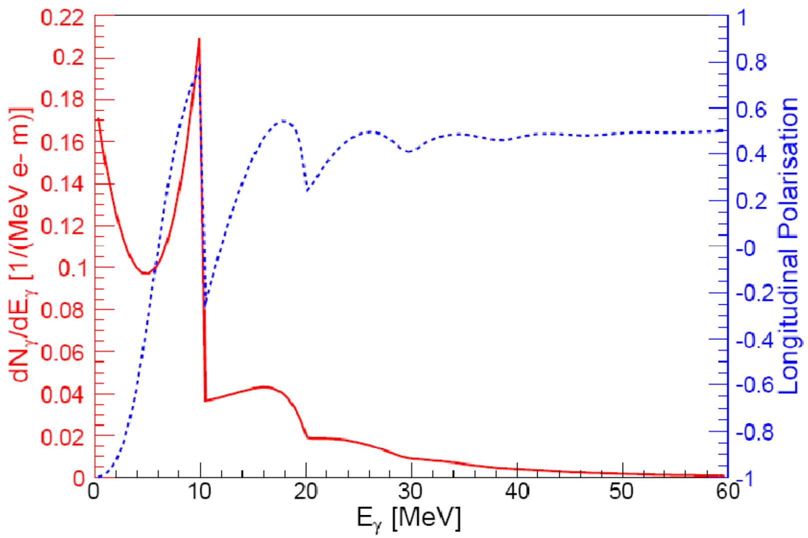
e- polarimeter

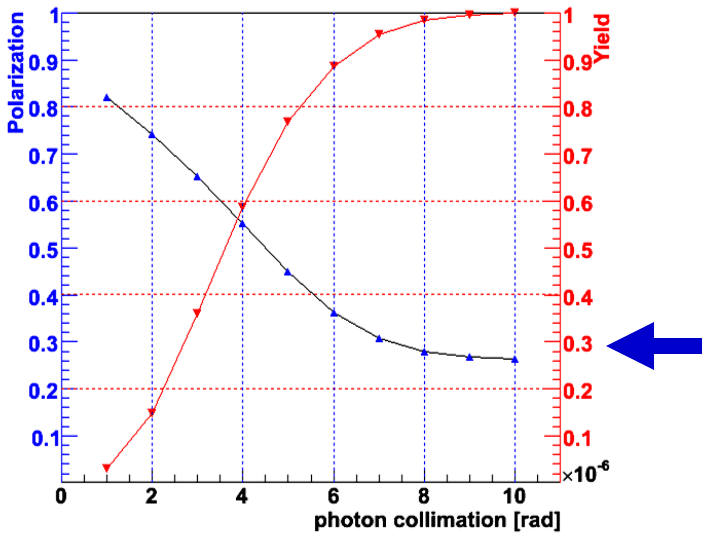
→ **Mott polarimeters to measure e- polarization near the gun at ILC and CLIC**

- Mott polarimetry requires transverse polarization of positrons → spin rotation
- Mott at SLAC: (Clenendin et al.)
  - **The** CTS **(Cathode Test System)** Mott **is a compact low-energy (20 kV) retarding-field polarimeter located in the Cathode Test Lab**
  - **The** GTL **(Gun Test Lab)** Mott **is a medium-energy (120 kV) multiple-foil polarimeter located in the GTL**

ILC positron source (RDR)







Helical undulator ➔ Average positron polarization **~30%**

Polarimeter:

- Optimization of e+ polarization and e+ intensity at the source
- Control of polarization transport

Polarimetry at positron source

Conditions:

- Large beam size
- Energy (ILC): ≥125 MeV

Requirements for the method:

- Suitable for low energy range
- Suitable for large positron beam size
- Suitable for intense beam
- Fast, non-destructive
- Accuracy O(few %)

Laser Compton Scattering

- High intensity Laser on low emittance beam
- High precision
- Only after Damping Rings

Bhabha/Møller scattering

- Thin magnetized target
- Suitable for desired energy range

Compton Transmission

- Beam absorbed in thick target
- energy ~few tens MeV

Mott scattering

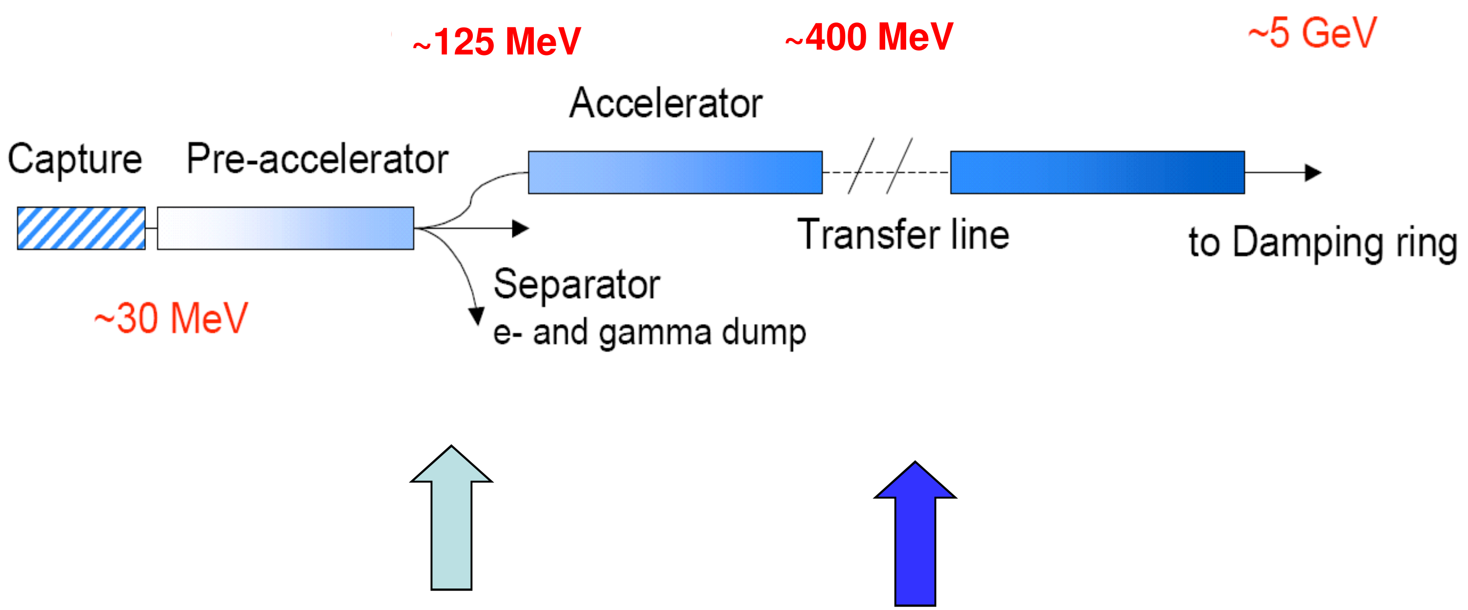
- Transverse polarized positrons

Polarimetry at the e+ source

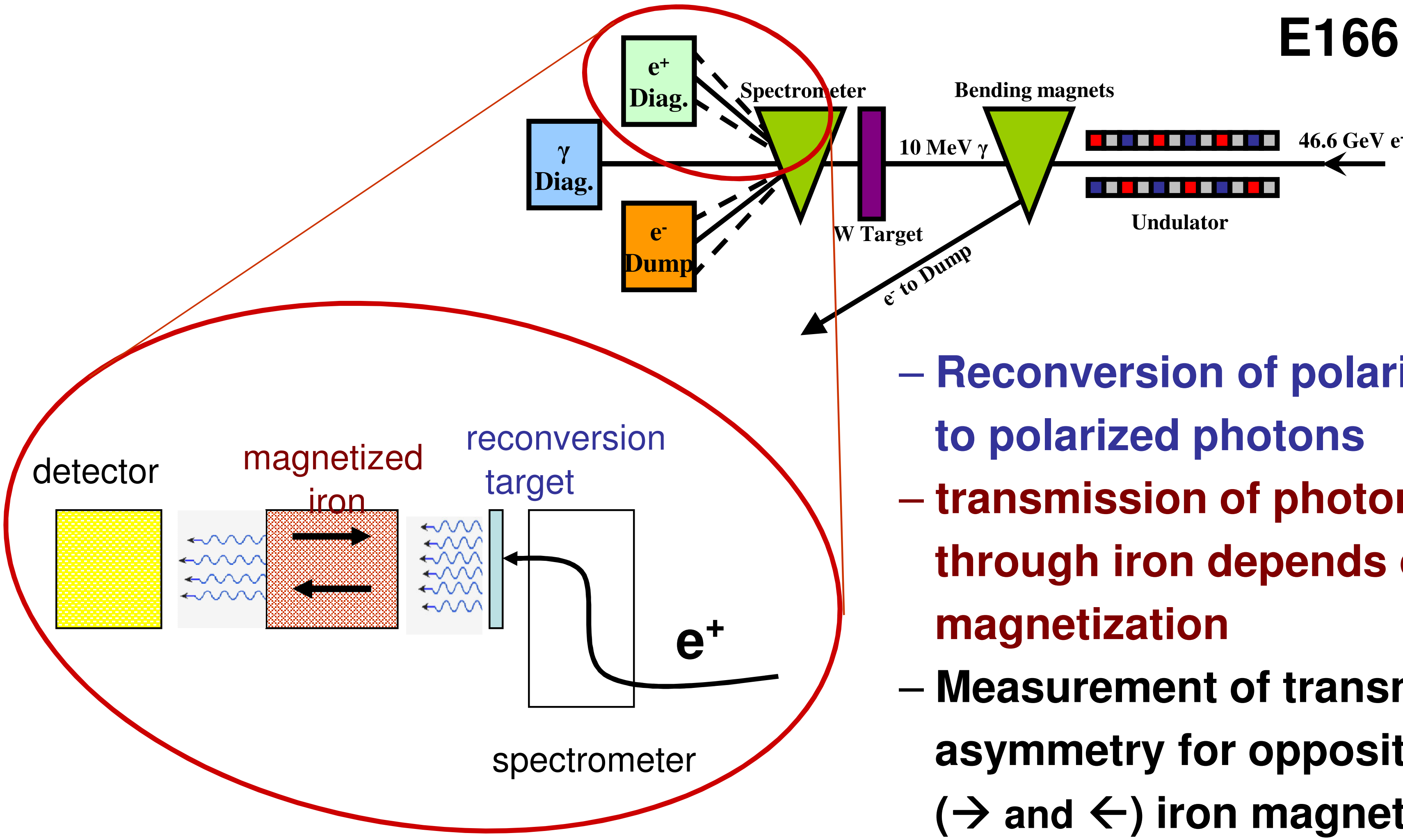
Considered options for the ILC:

- **Compton transmission (125 MeV)**
- **Bhabha polarimeter (400 MeV)**
- **Compton – after DR (beamsize!) (5 GeV**

Simulations using Geant4 with polarized processes



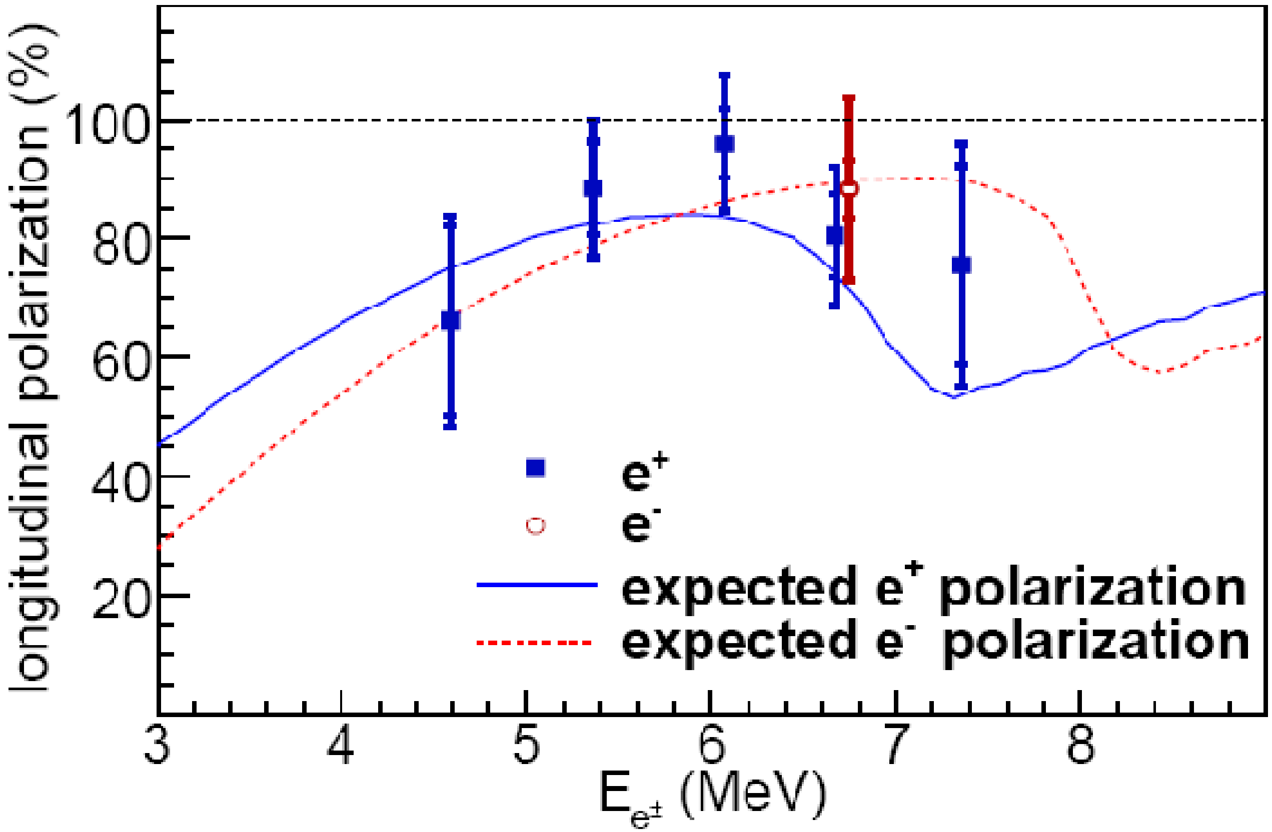
Compton transmission polarimeter



- Reconversion of polarized e+ to polarized photons
- transmission of photons through iron depends on its magnetization
- Measurement of transmission asymmetry for opposite (→ and ←) iron magnetization

Method was used at ATF and E166

E166 results



Good agreement of measurement and prediction

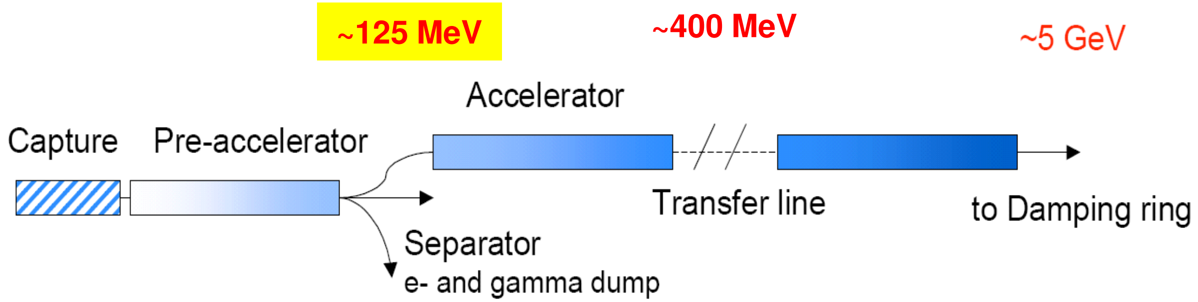
E166 results published in

PRL 100:210801,2008 (arXiv:0905.3066 [physics.ins-det])

NIM: http://dx.doi.org/10.1016/j.nima.2009.07.091

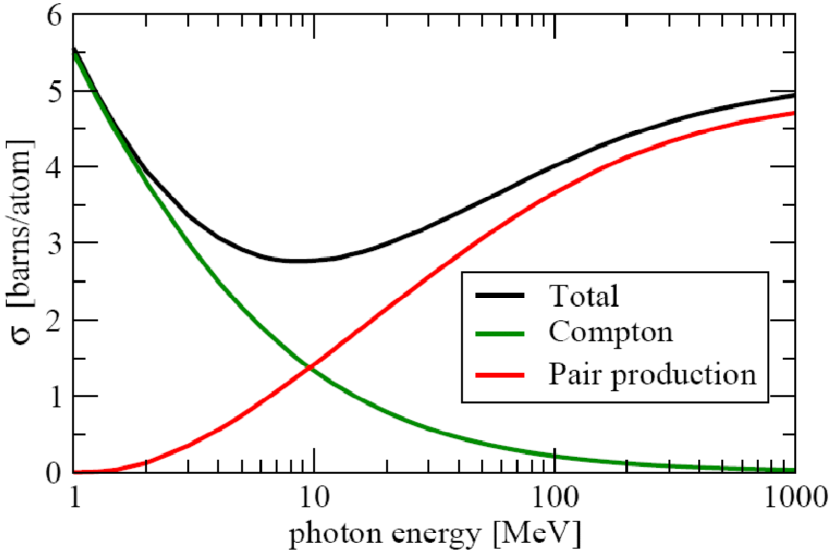
Application of Compton transmission polarimetry at ILC

- E_{e+} = 125 MeV



Disadvantages:

- At 125MeV Compton process is suppressed
- Method is destructive
  → only few bunches/pulse

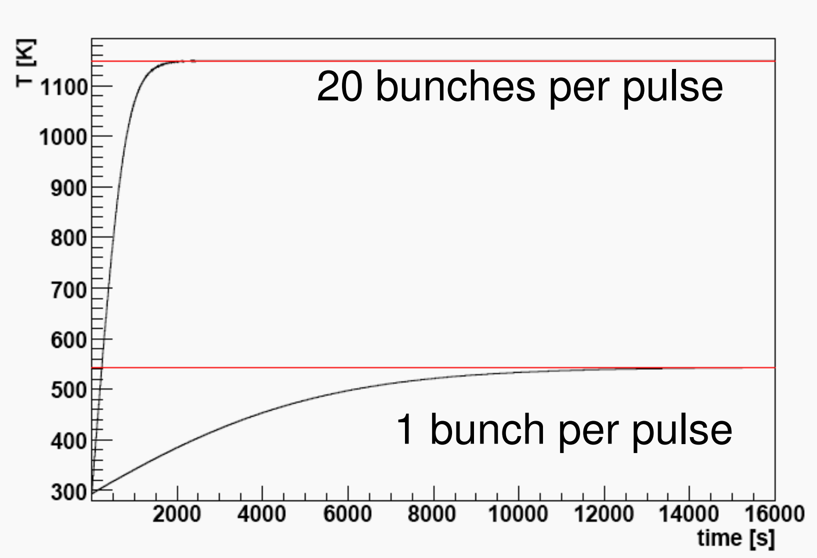


CT polarimetry at ILC

- Reconversion target heating:

  power deposition in target (W, $2X_0$) and iron absorber ➔ only few bunches (1 bunch) for polarization measurement

  → fast kicker needed



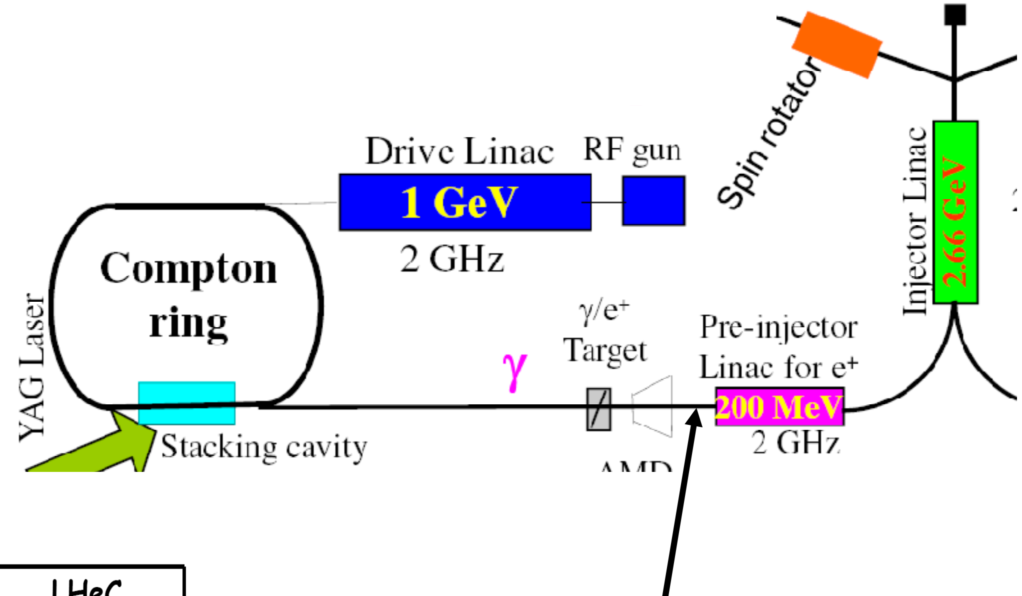
	Positron beam energy [MeV]	material	thickness [X_0 / mm]	E_{dep} per e^+ [MeV/1e^+]
Target	35	W	2.0 / 7.0	22.4
Absorber		Fe	26.7 / 150	6.9
Target	125	W	2.0 / 7.0	38.1
Absorber		Fe	26.7 / 150	61.6

- **Precision:**

  Intense ILC beam → sufficient statistics, precision <10% after few pulses

➔ Compton transmission polarimetry is possible, but not the preferred solution

CT polarimetry at CLIC



e+ flux (Rinolfi)

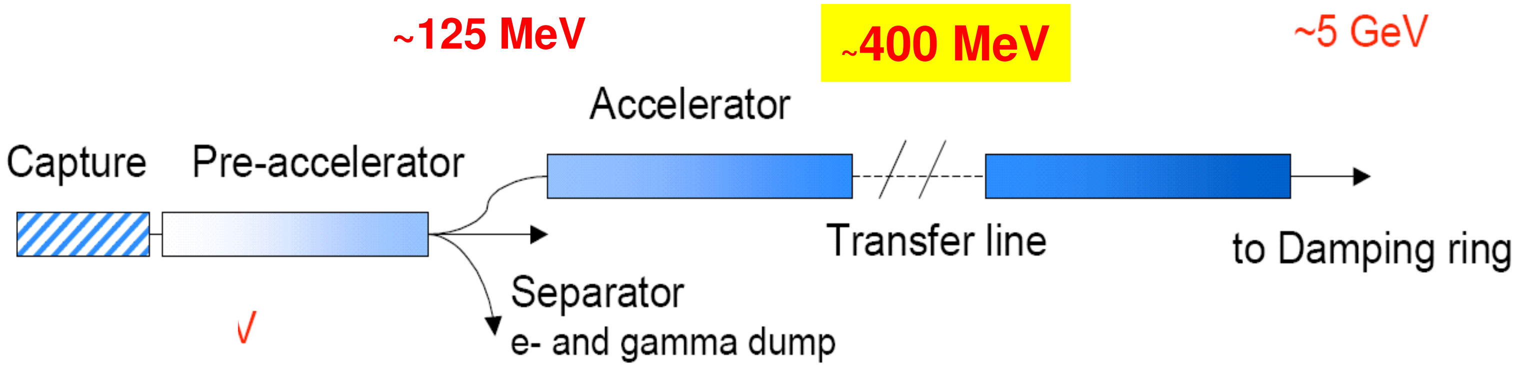
	SLC	CLIC	ILC	LHeC
e^+/ bunch	3.5 x 10^{10}	0.64x10^{10}	2 x 10^{10}	1.5x10^{10}
Bunches / macropulse	1	312	2625	20833
Macropulse Rep. Rate.	120	50	5	10
e^+ / second	0.042 x 10^{14}	1 x 10^{14}	2.6 x 10^{14}	31 x 10^{14}

x 24

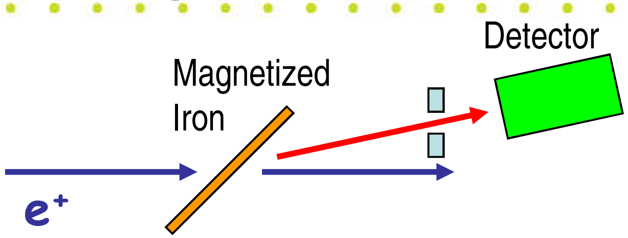
Compton transmission with selected bunches

→ kicker needed

Bhabha Polarimeter



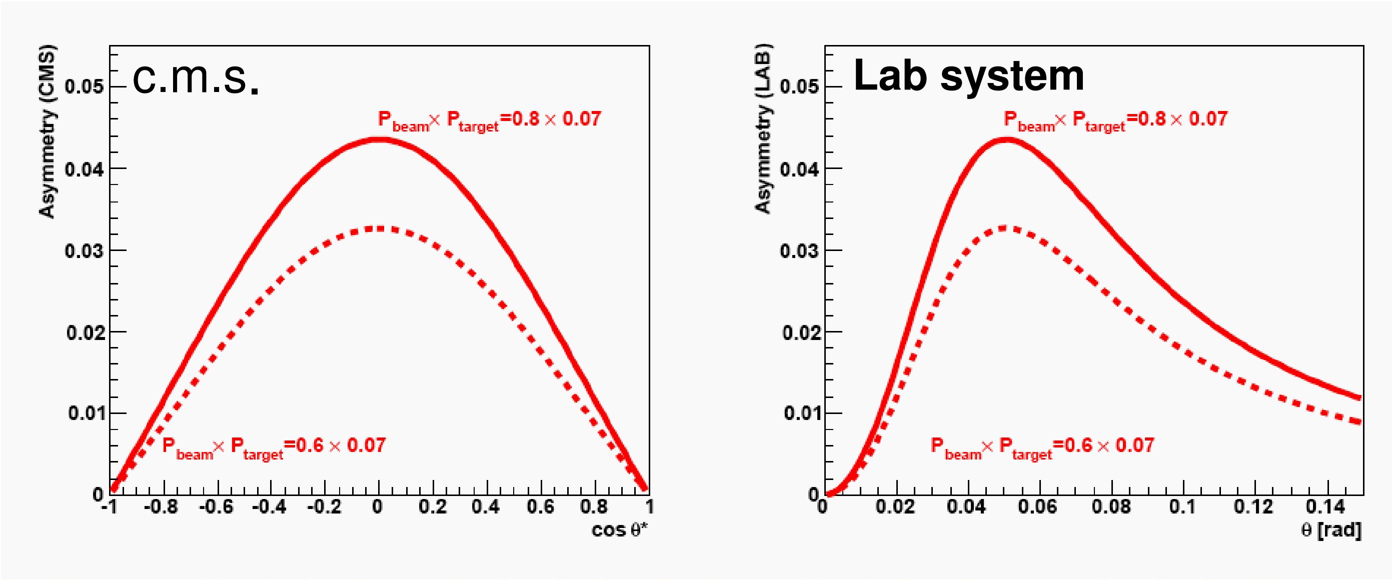
Bhabha Polarimetry



Cross section:

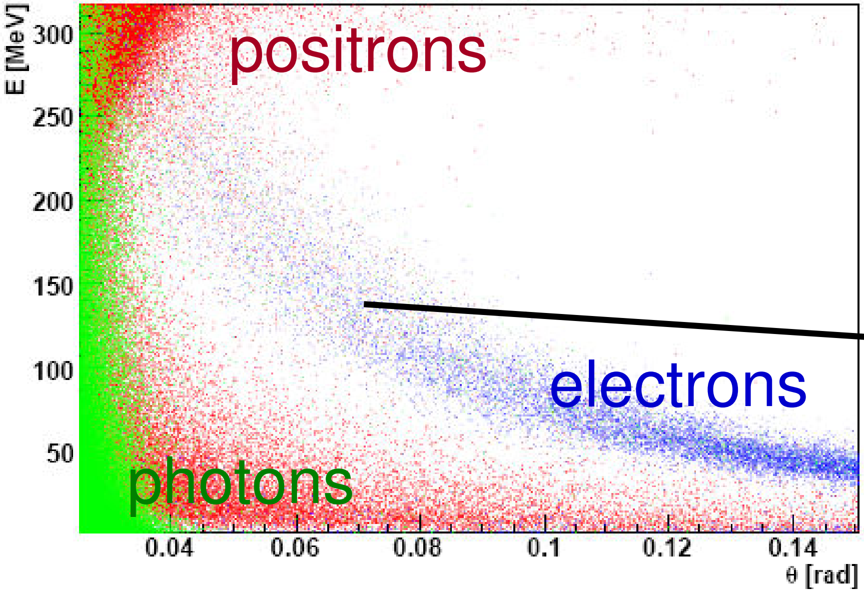
$$\frac{d\sigma}{d\Omega} = r_0^{\,2}\,\frac{(1+\cos\theta)^2}{16\gamma^2\sin^4\theta}\left[\left(9+6\cos^2\theta+\cos^4\theta\right)-P_{e^+}P_{e^-}\left(7-6\cos^2\theta-\cos^4\theta\right)\right]$$

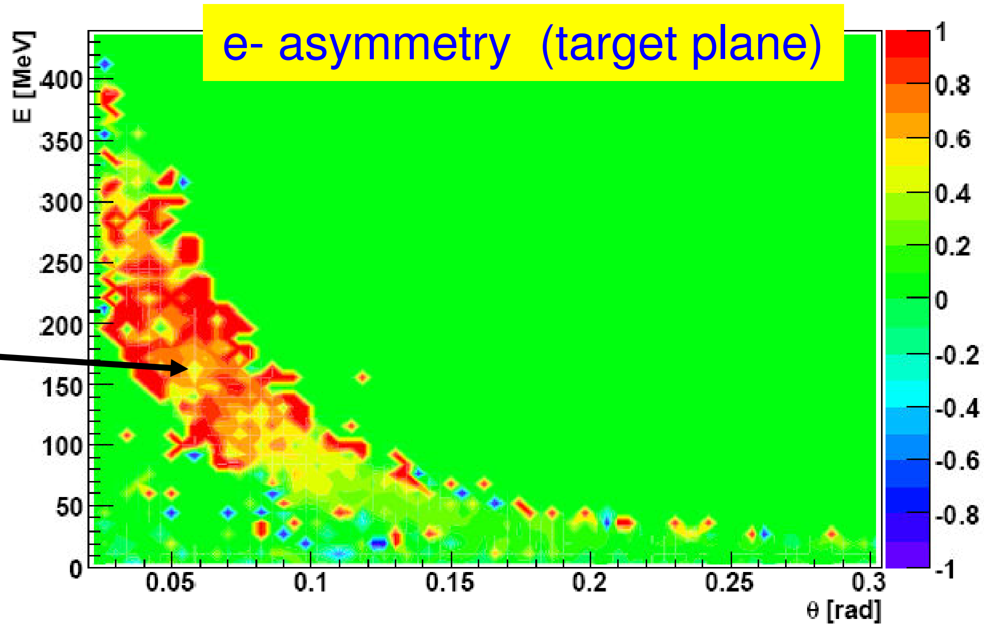
- e+ and e- must be polarized
- maximal asymmetry at 90°(CMS) ~ 7/9 ≈ 78 %



Example:
P_{e+}= 80%,
P_{e-}= 7%

A_{max} ~ 4.4 %



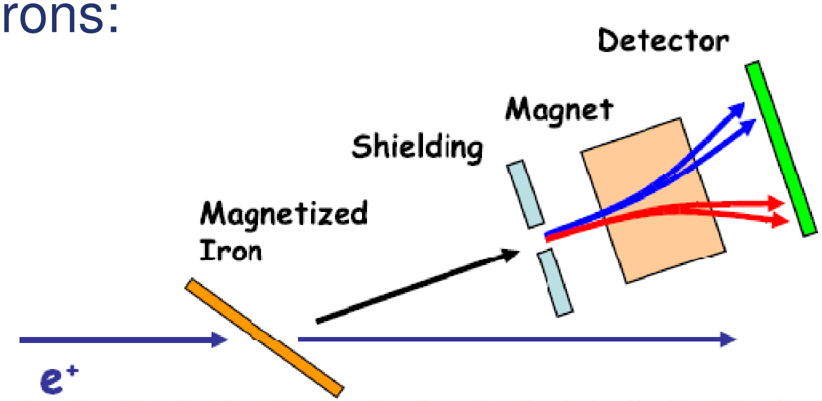


Selection of scattered electrons and positrons:

- **$0.05 < \theta < 0.09$rad (mask)**
- **100MeV < E < 300 MeV (spectrometer)**

Reverse polarization in target foil

→ Asymmetry ~ P(e+)

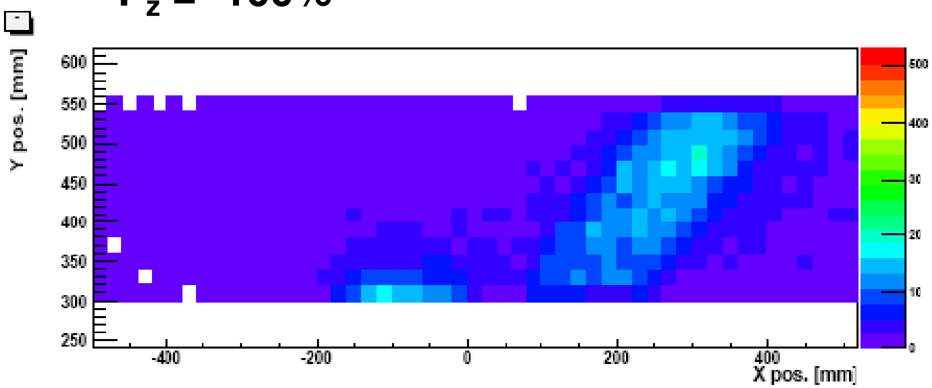


Bhabha Pol.: asymmetry measurement

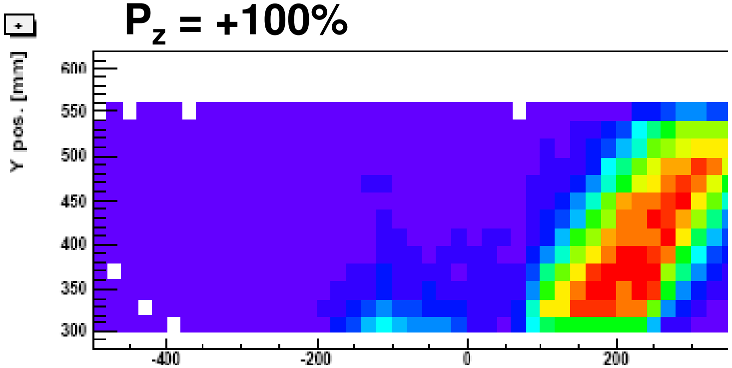
- 30 µm magnetized Fe foil
- E_{beam} = 400 MeV (±3.5%)
- Angular spread: 0.5º
- 100% e+ and e- polarisation

e^- distribution (detector plane)

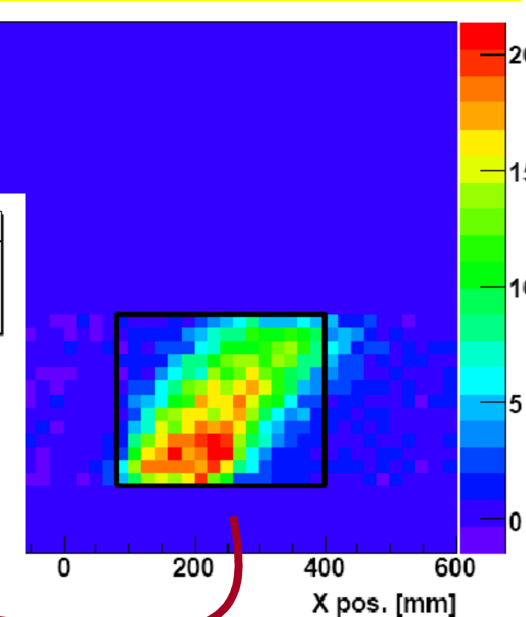
P_z = -100%

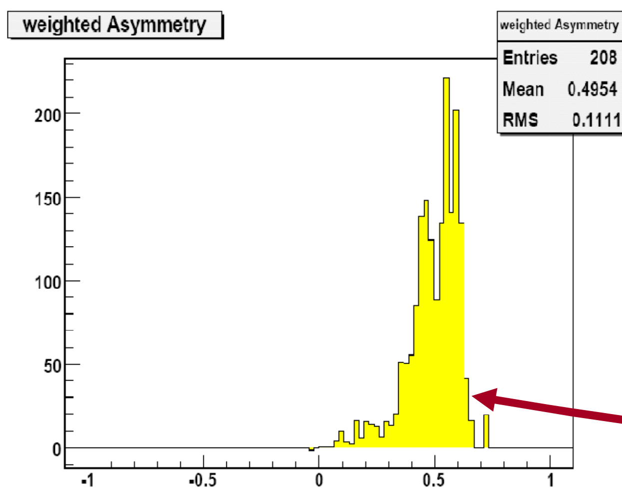


P_z = +100%



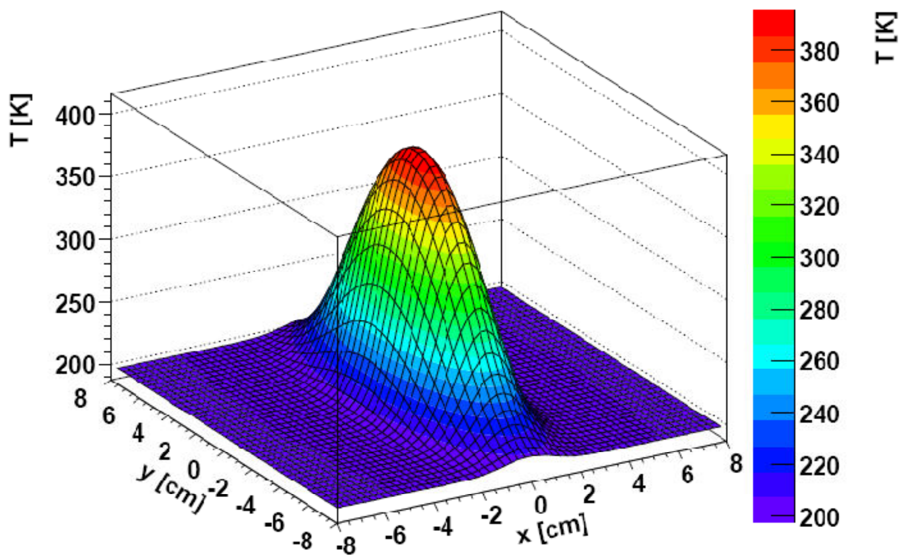
e- asymmetry ➔ e+ polarization



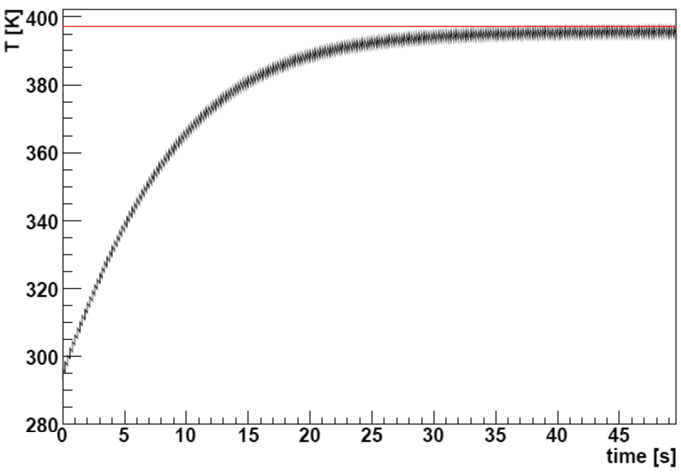


Bhabha target heating

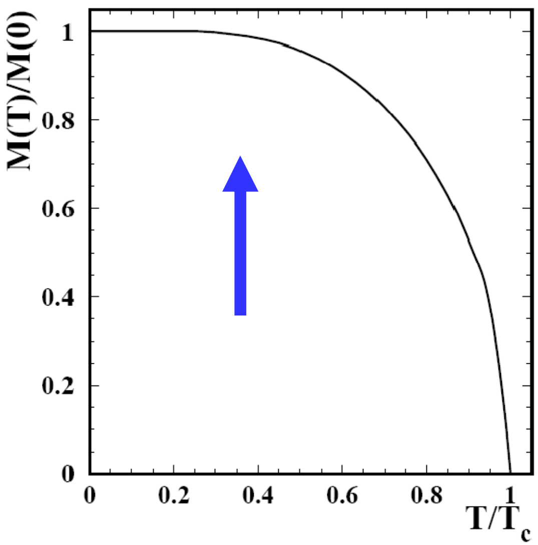
Peak temperature for iron foil (30μm)



time dependence



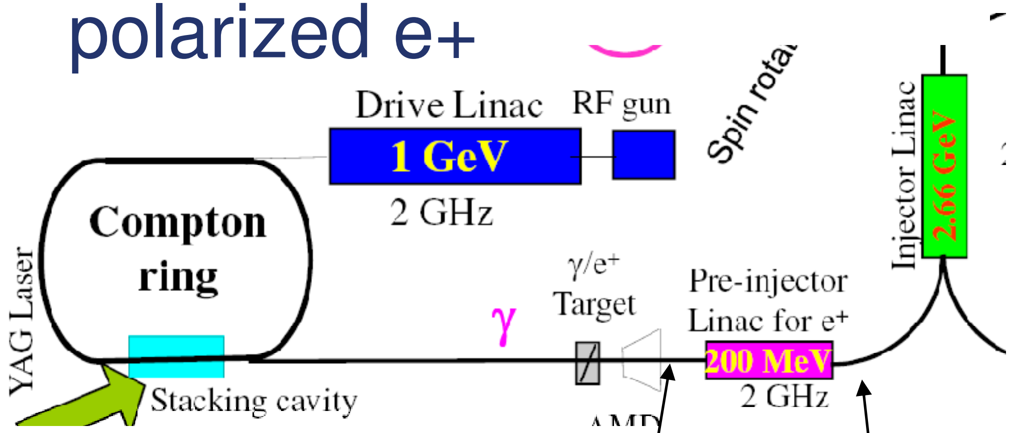
Magnetization of iron foil
depending on temperature
➔ Only small reduction of P_{Fe}



Emittance growth (ILC): 1.3% (σ=1.0cm)
5.2% (σ=0.5cm)

Bhabha polarimeter at CLIC

polarized e+



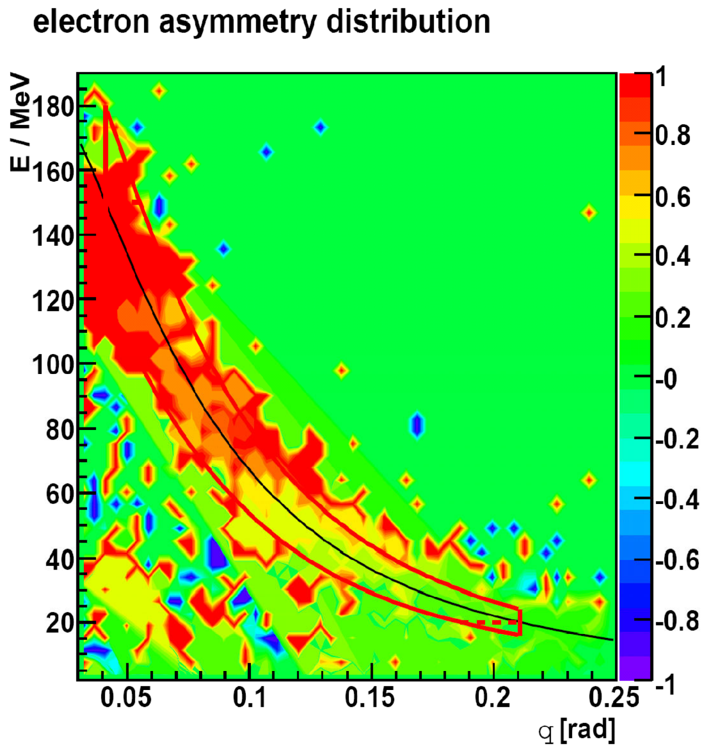
Compton transmission with selected bunches

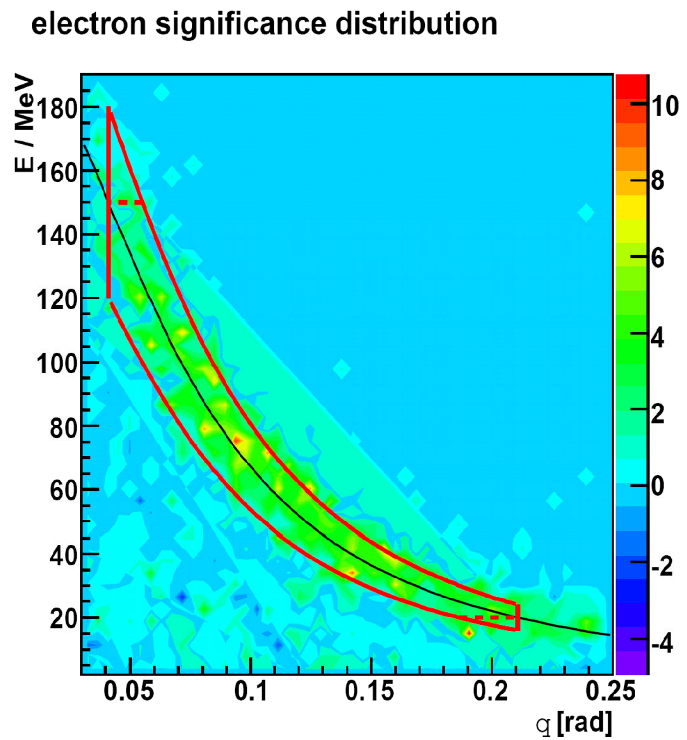
Bhabha polarimeter at 200 MeV

Bhabha Polarimeter @ 200 MeV

- G4 Simulation
  - E_{e+} 200 MeV
  - Target 30 µm Fe

$$S = \frac{A}{\Delta A} \approx \frac{n-p}{2}\sqrt{\frac{n+p}{(n+1)(p+1)}}$$





asymmetry measurement with scattered electrons

Energy range: 30 – 150 MeV

cosθ: 0.04 ~ 0.2 rad

- Target heating at CLIC less than at ILC (assuming beam sizes as at ILC)

	SLC	CLIC	ILC	LHeC
e^+/ bunch	3.5×10^{10}	0.64×10^{10}	2×10^{10}	1.5×10^{10}
Bunches / macropulse	1	312	2625	20833
Macropulse Rep. Rate.	120	50	5	10
e^+ / second	0.042×10^{14}	1×10^{14}	2.6×10^{14}	31×10^{14}

Bhabha polarimetry at CLIC, 200 MeV, is possible

Compton Polarimetry after DR

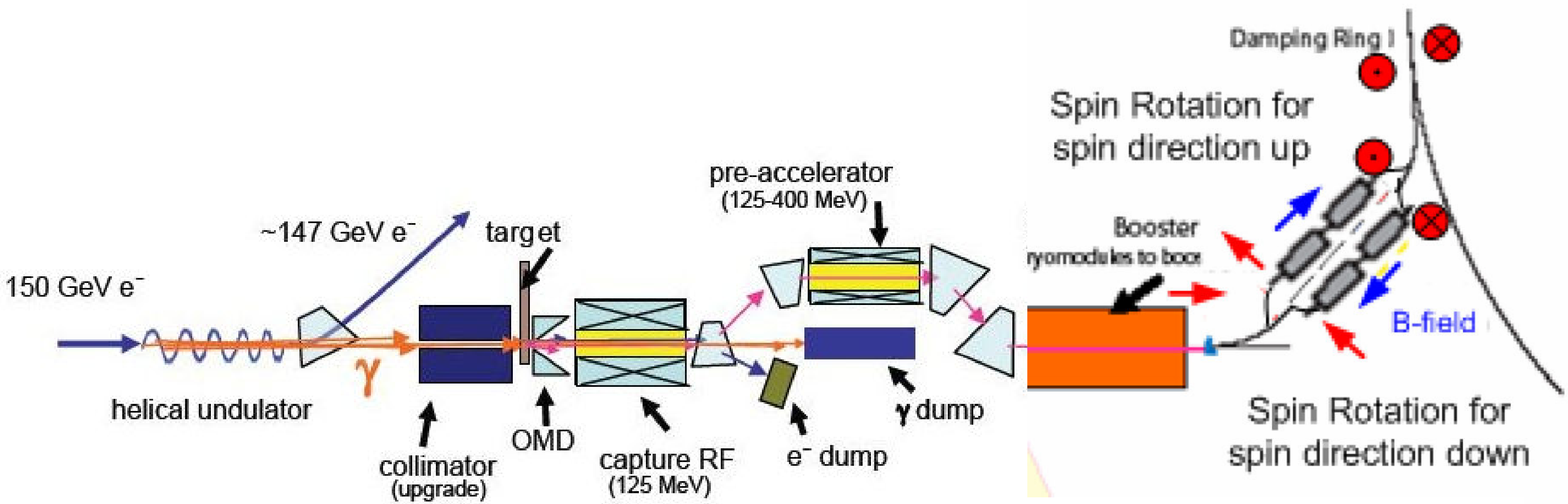
Compton polarimetry is only efficient for small beam sizes → after DR

- Considerations for 5 GeV
  - see G. Alexander, P. Starovoitov, LC-M-2007-014
  - **Fast measurement for ~π crossing angle between e and γ**
  - **Combination with laser wire?**
    - e beam size larger than laser beam waist → not a good solution
    - in principle, $\pi/2$ crossing angle between e and γ ⇔ possible, but larger statistical error, $\Delta(\pi/2) \approx 15 \bullet \Delta(\pi)$

      → needs more time
  - **Transverse polarization after DR !?**
    - Luminosity and cross section are the same as for longitudinal polarization
    - Very small asymmetry ~ 1-2%
    - Detector has to resolve the φ dependence of asymmetry

Spin rotation and fast helicity flip

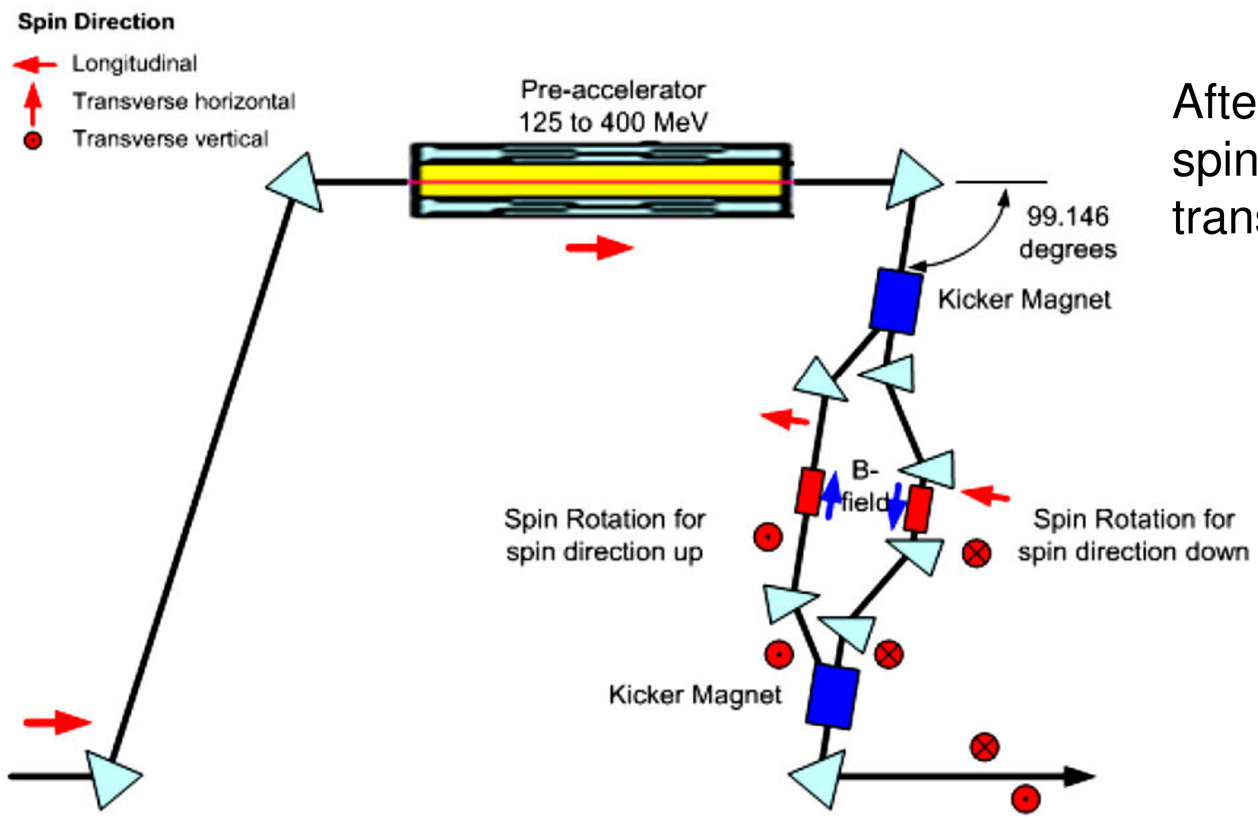
Scheme suggested by K. Moffeit et al., SLAC-TN-05-045



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

“Compton source”:
fast helicity flip by reversing polarization of laser

Proposal: K. Moffeit, M. Woods,Walz, ILC-NOTE-2008-040
→ spin rotation and fast helicity reversal at ~400 MeV



After bend of 99.146 degrees spins are horizontally transverse.

Kicker → 2 parallel lines with solenoids to rotate spin to the vertical

Bhabha polarimeter has to be passed before spin rotation

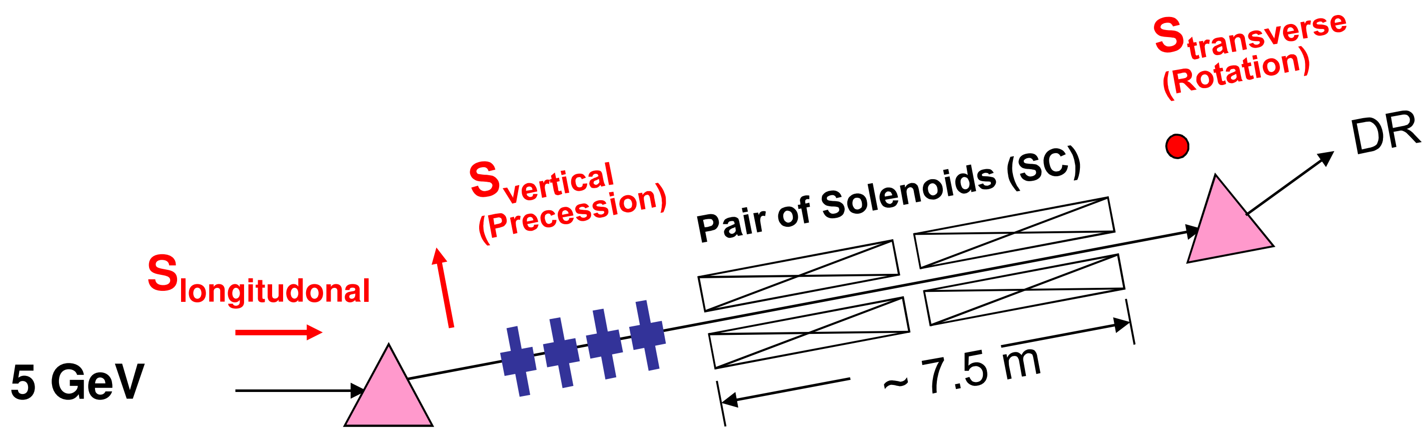
Summary

- Polarimetry at e- source: Mott
- Polarimetry at e+ source:
  - **Undulator based e+ source is polarized**
  - **Low energy e+ polarimetry:**
    - Compton transmission → very few bunches
      - E ≈ 125 MeV for ILC
      - ?? for CLIC
    - Bhabha (~400 MeV at ILC, 200 MeV for CLIC)
    - Compton after DR (5 GeV ILC),
      - Where is it needed ?
      - Longitudinal polarization recommend, transverse possible but more complicated due to lower asymmetry
  - **Details of e+ polarimeter design will depend on LC design**
  - **Fast helicity flip to match the experimental precision for physics is also useful for polarization measurement at the e+ source (control of syst. effects) but studied options require longitudinally polarized positrons**
  - **Tools for design/performance studies: G4 with polarization**
- So far, there is no low energy e+ polarimeter in the ILC design

Backup

Center-of-mass energy	CLIC 500 GeV		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	0.9(0.6)·1034	2.3(1.4)·1034	1.5(0.73)·1034	5.9(2.0)·1034
Repetition rate (Hz)	50			
Loaded accel. gradient (MV/m)	80		100	
Main linac RF frequency (GHz)	12			
Bunch charge (109)	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam (MW)	4.9		14	
Hor./vert. norm. emitt (10-6/10-9)	3/40	2.4/25	2.4/20	0.66/20
Hor/Vert FF focusing (mm)	10/0.4	8 / 0.1	8 / 0.3	4 / 0.07
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 2.0	40 / 1.0
Hadronic events/crossing at IP	0.07	0.19	0.57	2.7
Coherent pairs at IP	10	100	5 107	3.8 108
BDS length (km)	1.87		2.75	
Total site length km	13.0		48.3	
Wall plug to beam transfer eff	7.5%		6.8%	
Total power consumption (MW)	129.4		415	

Baseline Spin Rotation System



Bend of n * 7.9312°

Odd Integer

$$\theta_{spin} = \frac{E[GeV]}{0.44065} \cdot \theta_{bend}$$

$$\theta_{spin} = \frac{\int B_z dl}{B_0 \cdot \rho}$$

Dipole and solenoid strength are set by spin manipulation requirements

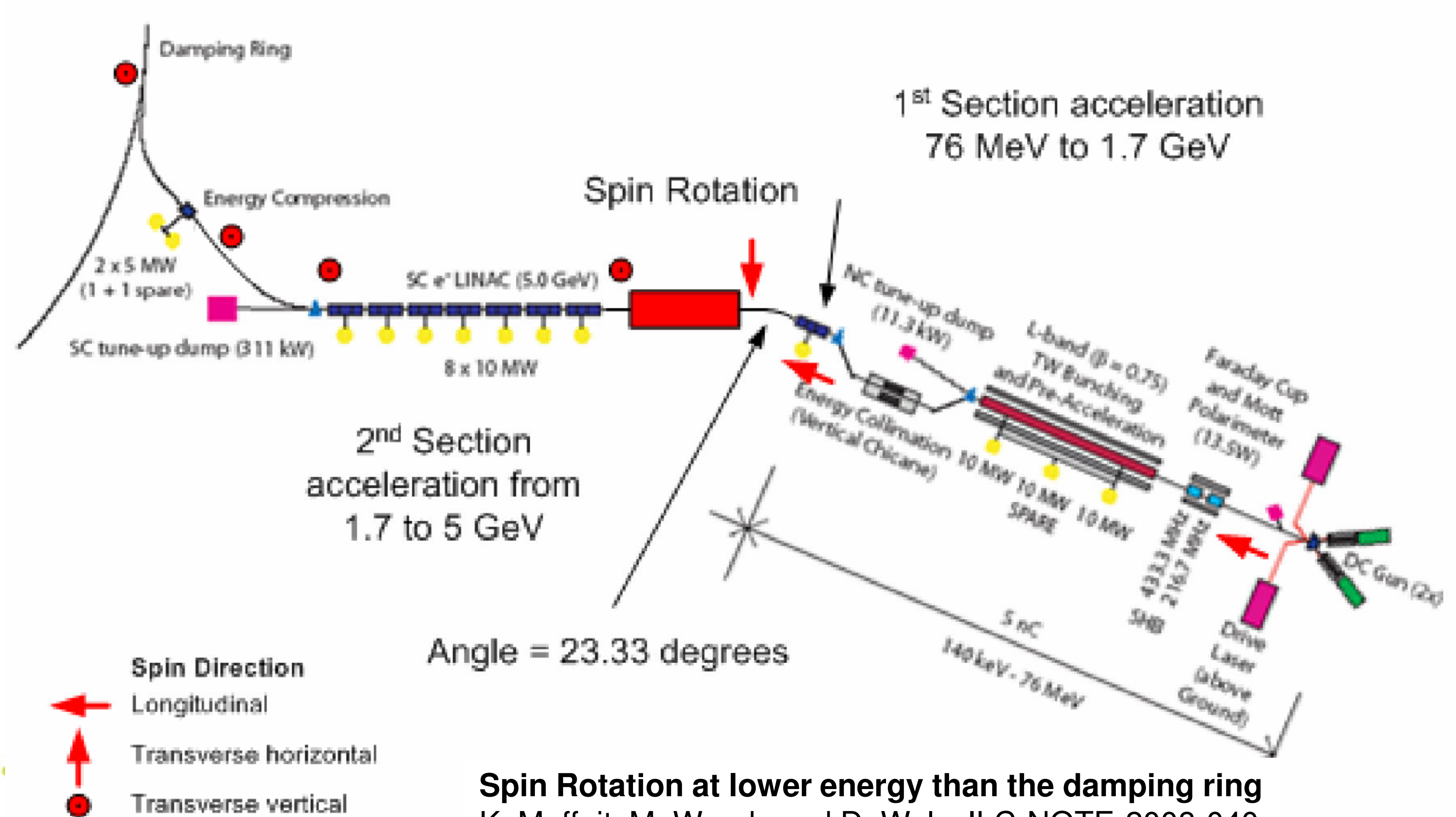
Dipole: 7.9312°
→ ~ 2 kG
Solenoid: 26.2 T
→ 2x3.5 m; 38.5 kG

Design is based on paper by Moffeit, Woods, Schuler, Moenig and Bambade (2005), SLAC-TN-05-045

Spin Rotation – Alternatives

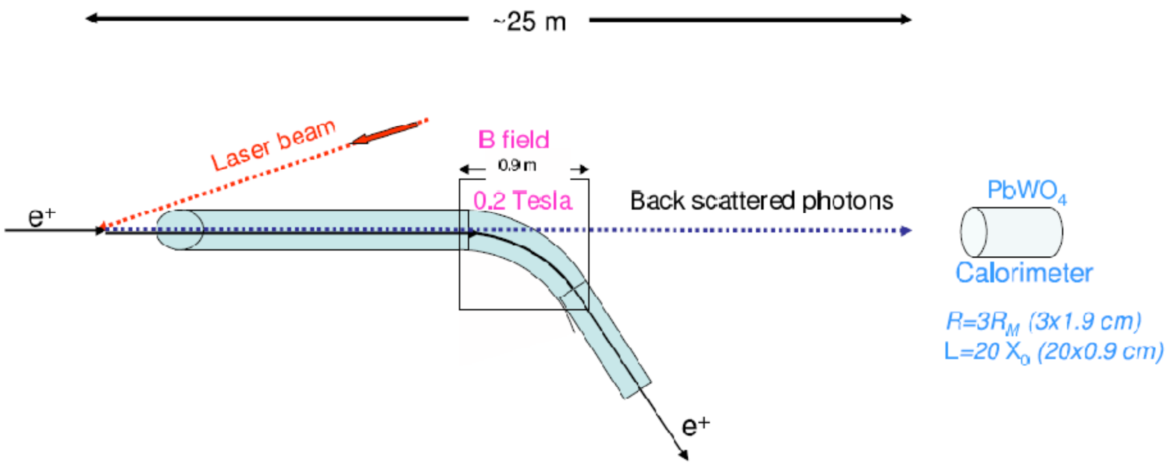
Example: Spin rotation at 1.7 GeV
→ less stringent requirements for solenoid

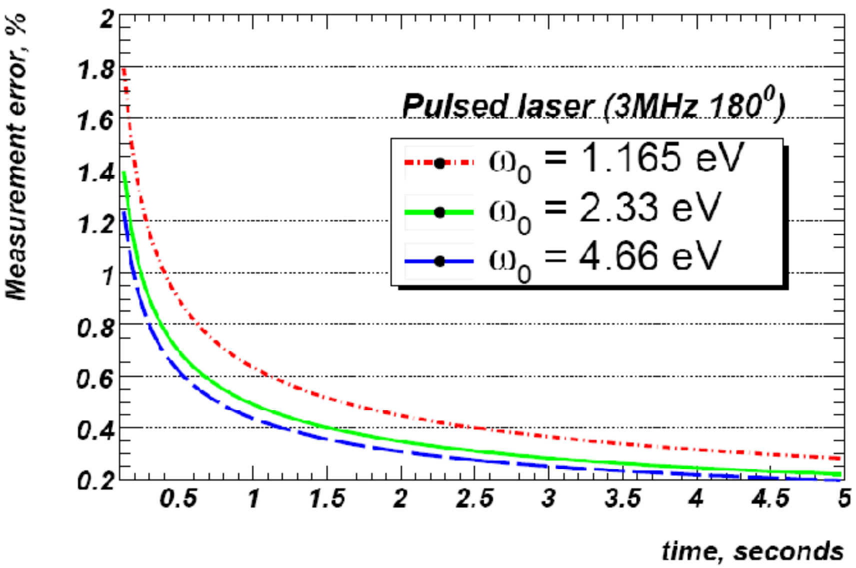
Proposal: spin rotation using Wien filter near gun
→ concern: emittance blow-up (?)

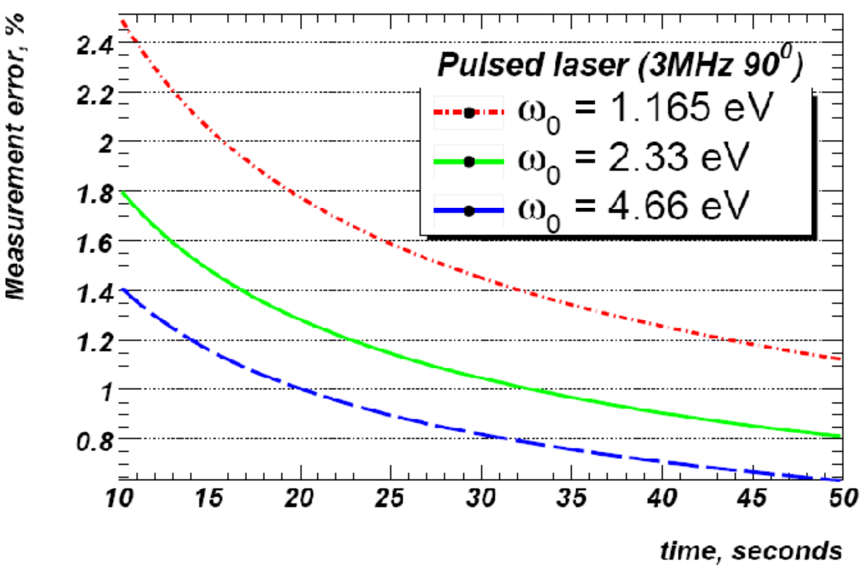


Spin Rotation at lower energy than the damping ring
K. Moffeit, M. Woods and D. Walz, ILC-NOTE-2008-040

Compton polarimeter @ 5 GeV



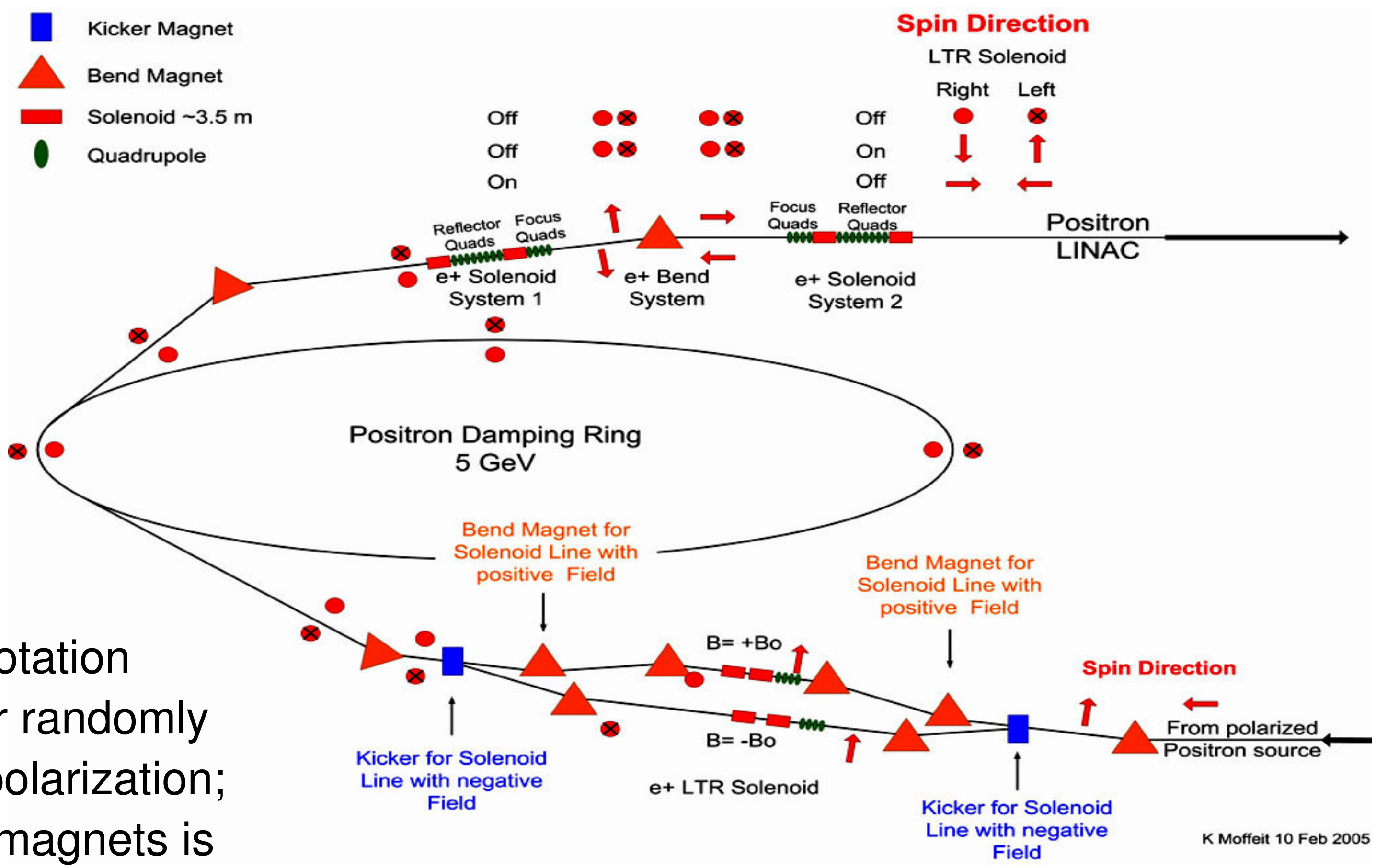




Method	e+ Energy		precision	
Compton transmission	125 MeV	Destructive → use only very few bunches per pulse	Stat: few %; Syst. will dominate	Prototype (E166,) ILC design Simulations
Bhabha	400 MeV	Almost non-destructive	Stat: few %; Syst. will dominate	ILC design Simulations
Compton	5 GeV (after DR)	Non-destructive	Stat: few %; Syst. will dominate	ILC design simulations

e+ 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

s-channel asymmetries with pol e+ beams

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

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

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

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

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

ILC:

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

$$= \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}} \cdot \frac{1}{P_{eff}}$$

Error propagation:

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