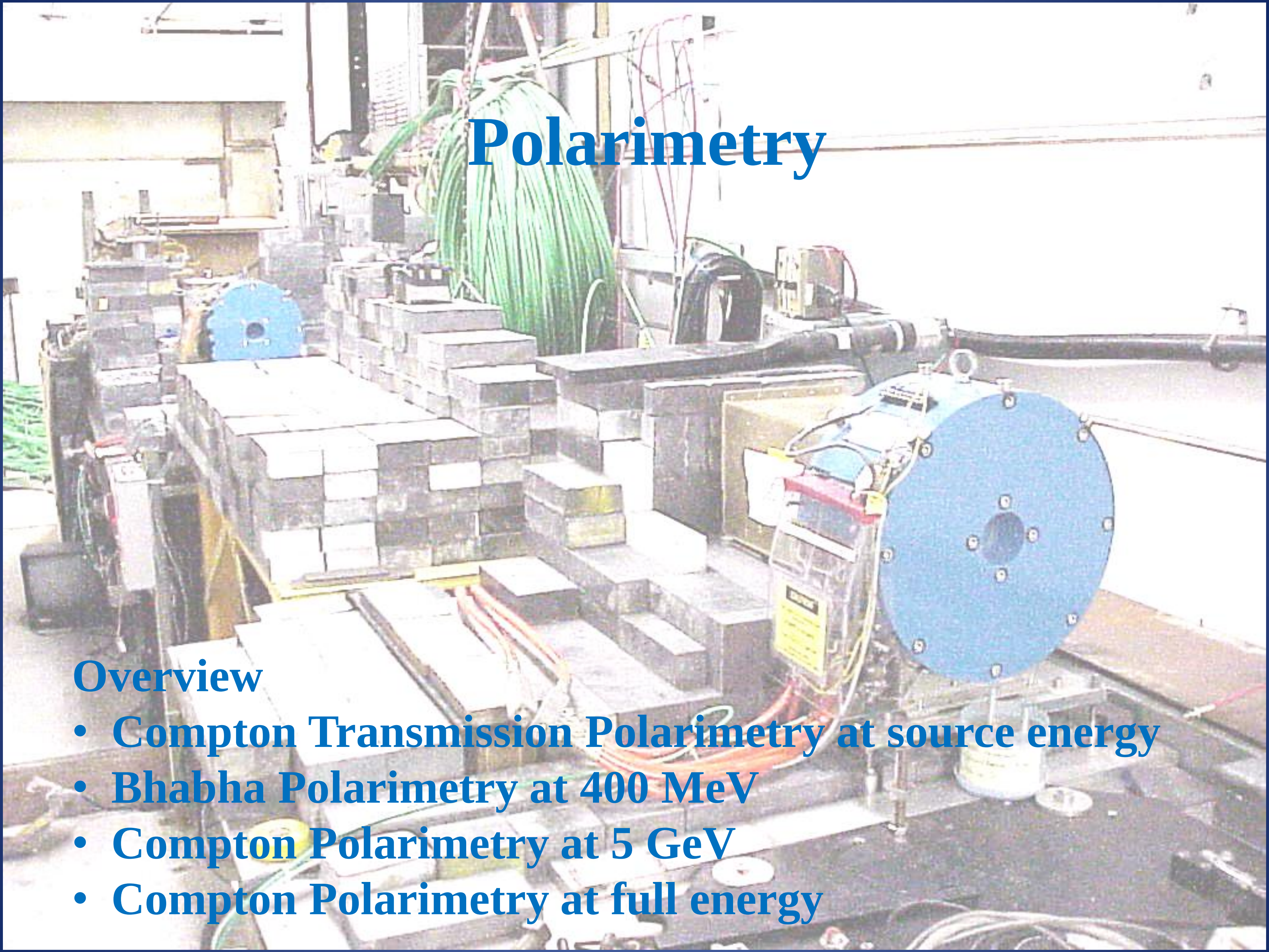
Polarimetry



Overview

- Compton Transmission Polarimetry at source energy
- Bhabha Polarimetry at 400 MeV
- Compton Polarimetry at 5 GeV
- Compton Polarimetry at full energy

Suitable Processes

- **Compton Transmission Polarimetry**
- **Bhabha Scattering**
- **Annihilation in Flight**
- **Compton Polarimetry (laser backscattering)**

Process	**Energy**	**Target**	**Remarks**
Compton Transmission Pol.	< 20 MeV	solid iron	destructive
Bhabha Scattering	> 400 MeV	iron foil	destr. (*)
Annihilation in Flight	> 400 MeV	iron foil	destr. (*)
Compton Pol. (laser backsc.)	> 5 GeV	(laser beam)	non-destr.

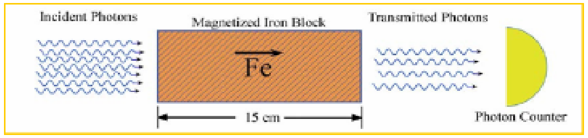
* dependent on target foil thickness and beam emittance,

- laser backscattering Compton polarimetry is method of choice at high-energy
- Compton Transm. pol. is only suitabe for Source R&D
- Bhabha polarimeter is being studied for low-energy LTR beamline at 400 MeV

Compton Transmission Polarimetry

Has been employed successfully in proof-of-principle experiments for Compton- and Undulator-based source developments at ATF and in E166 at SLAC

1. **Compton Transmission Polarimetry for Low-Energy Photons relies on spin dependence of Compton effect in magnetized iron:**



$$\sigma_{tot} = \sigma_{phot} + \sigma_{comp} + \sigma_{pair} \quad \text{with} \quad \sigma_{comp} = \sigma_0 + P_\gamma P_e \sigma_{pol}$$

Transmission

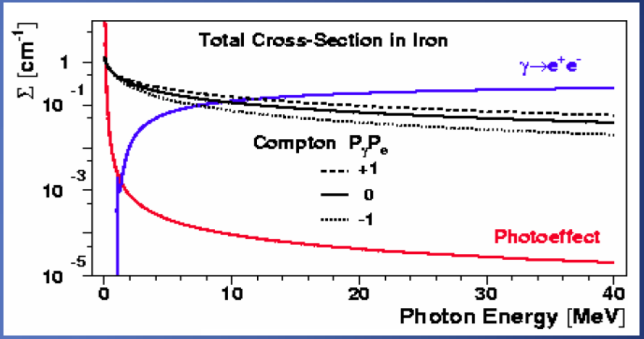
$$T^{\pm}(L) = e^{-nL\sigma} = e^{-nL(\sigma_{phot}+\sigma_{pair}+\sigma_0)} e^{\pm nLP_\gamma P_e \sigma_{pol}}$$

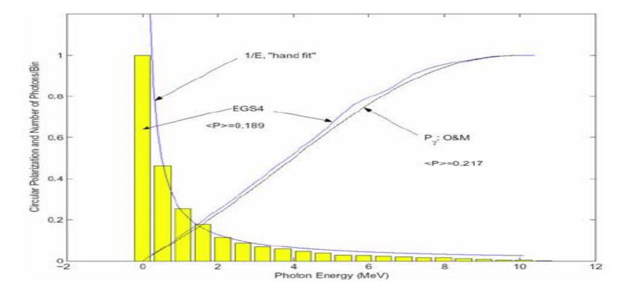
Asymmetry

$$\delta(L) = \frac{T^+ - T^-}{T^+ + T^-} \approx nLP_\gamma P_e \sigma_{pol}$$

Photon Polarization

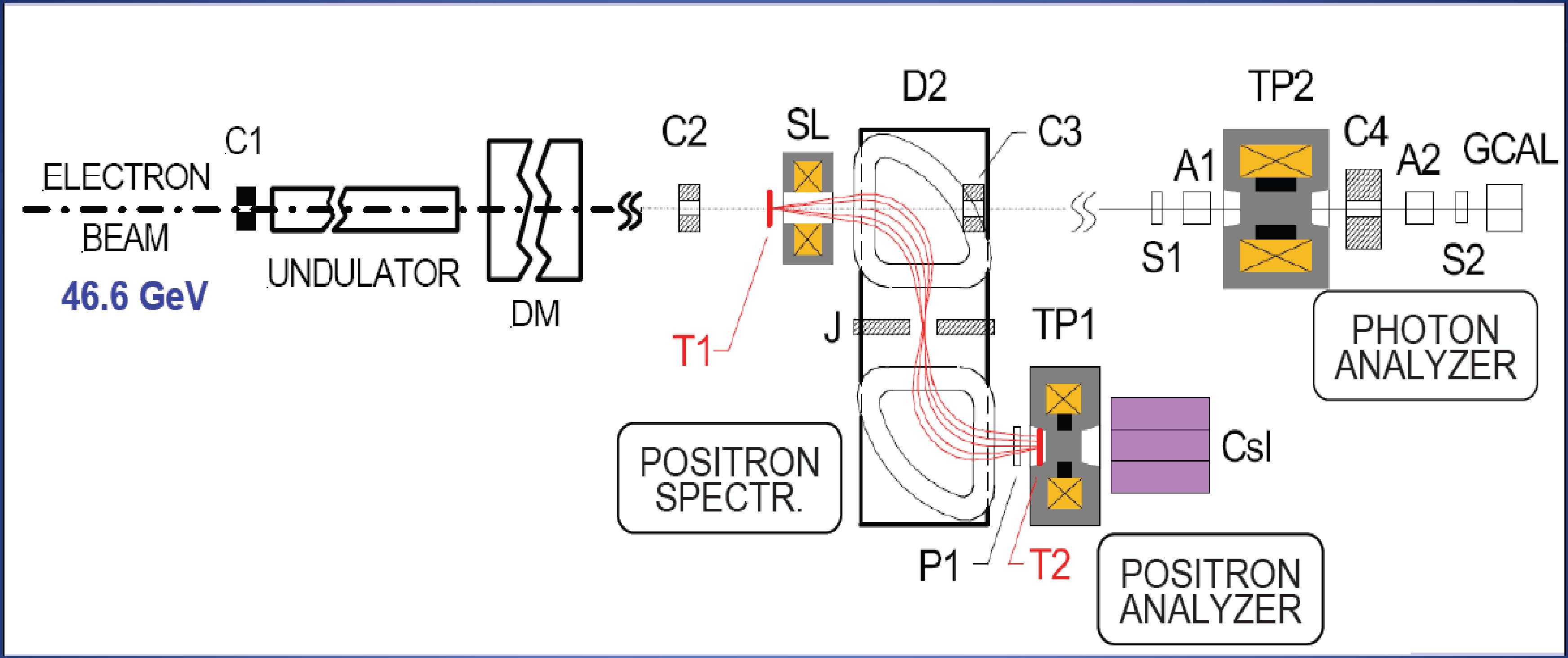
$$P_\gamma = \frac{\delta}{nL\sigma_{pol}P_e} = \frac{\delta}{A_\gamma P_e} \qquad A_\gamma = \text{Analyzing power}$$





2. **Positron Polarimetry:**
   (a) transfer e+ polarization to photon via brems/annihilation process
   (b) then infer e+ polarization from measured photon pol. as in method 1.

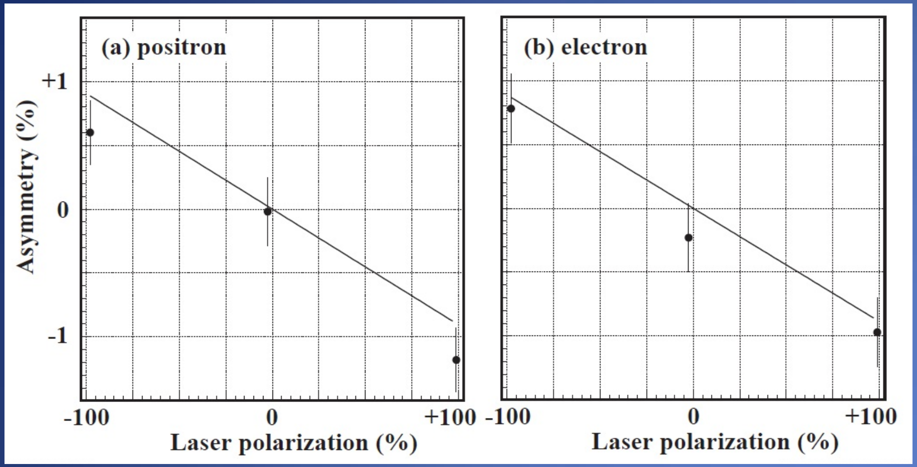
Compton Transmission Polarimetry: E166



DM: electron beam dump magnets
T1: $\gamma \rightarrow$ e+ prod. target (0.2 X_0 W)
T2: e+ $\rightarrow \gamma$ reconv. target (0.5 X_0 W)
P1: e+ flux monitor (Silicon)
CsI: Cesium Iodide calorimeter
SL: solenoid lens
J: movable jaws

C1 – C4: photon collimation
A1, A2: aerogel detectors
S1, S2: silicon detectors
GCAL: Si/W-calorimeter

Transmission Polarimetry: Results

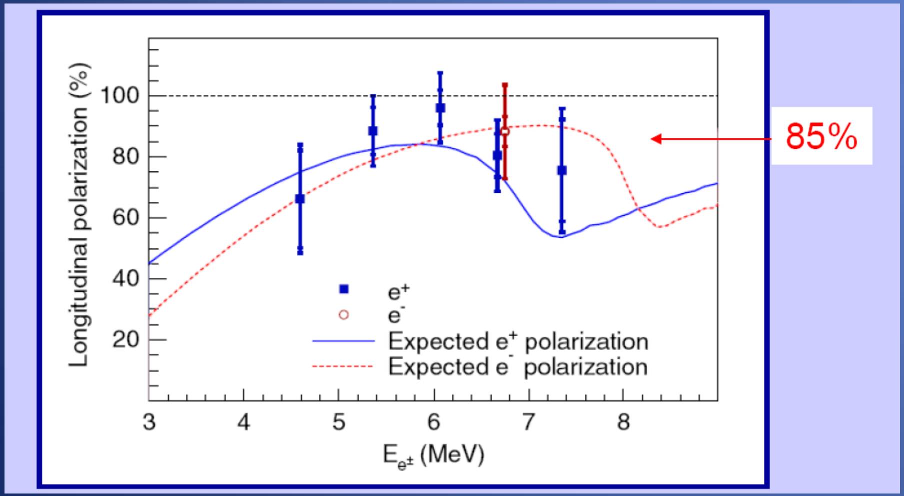


ATF

P(e+) = 73±15(stat)±19(syst)%

M. Fukuda et al., PRL 91(2003)164801

T. Omori et al., PRL 96, 114801 (2006)



E166

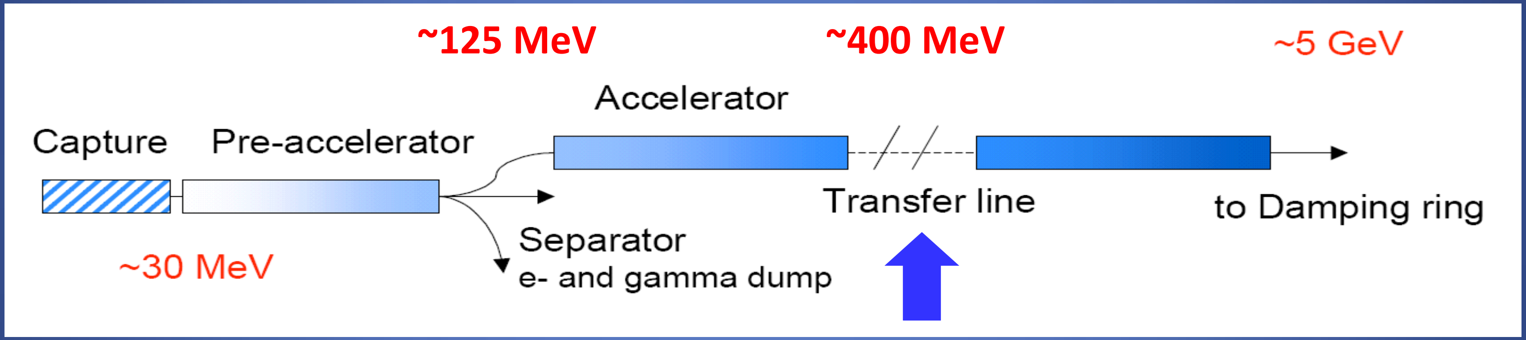
PRL 100, 210801 (2008), G. Alexander et al.

NIM A 610 (2009) 451-487, G. Alexander et al.

Polarimetry at the e+ source

Considered options for the ILC:

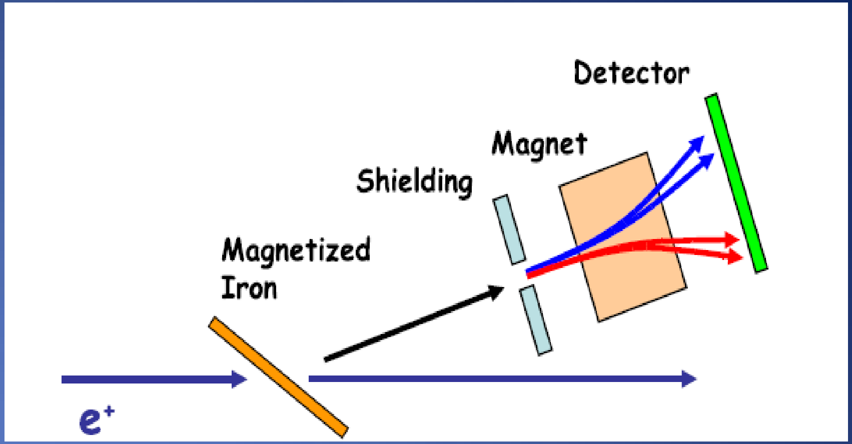
- Bhabha polarimeter in beam transfer line @400 MeV
- Compton polarimeter @5GeV after DR



General Remarks:

- Bhabha pol.: will show here only very preliminary simulation studies from the DESY/Zeuthen group (as reported earlier by S. Riemann)
- Compton @5 GeV: currently only a generic concept in analogy to the high-energy polarimetrs

Bhabha Polarimetry

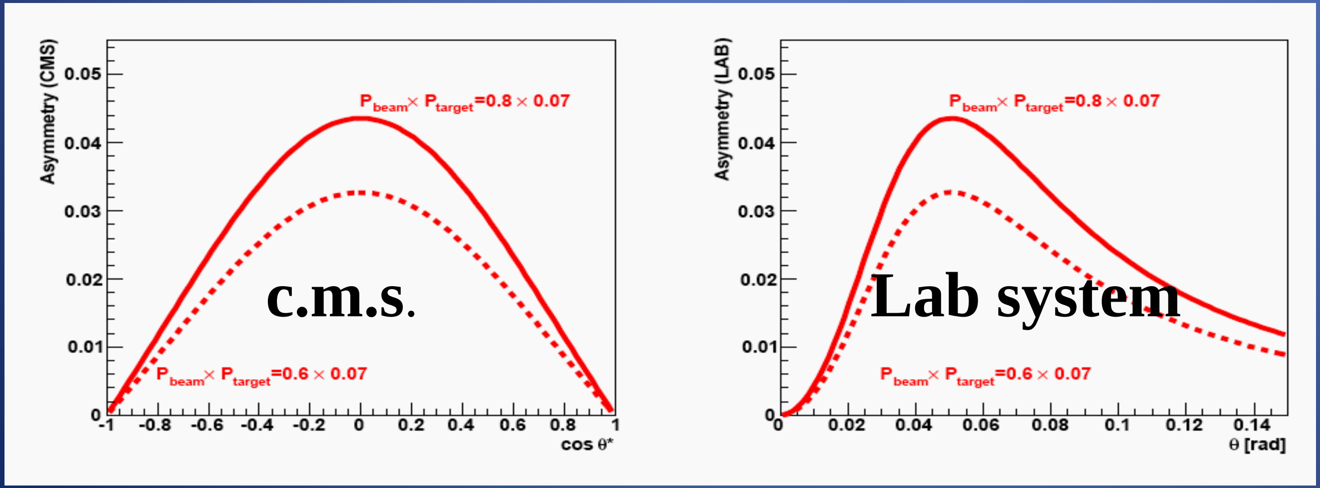


Established method,
used in many experiments

spin-dep. cross section:

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

- e+ beam and e- target (magn. iron foil) must both be polarized
- max. asymmetry at 90°(CMS) ~ 7/9 ≈ 78 %



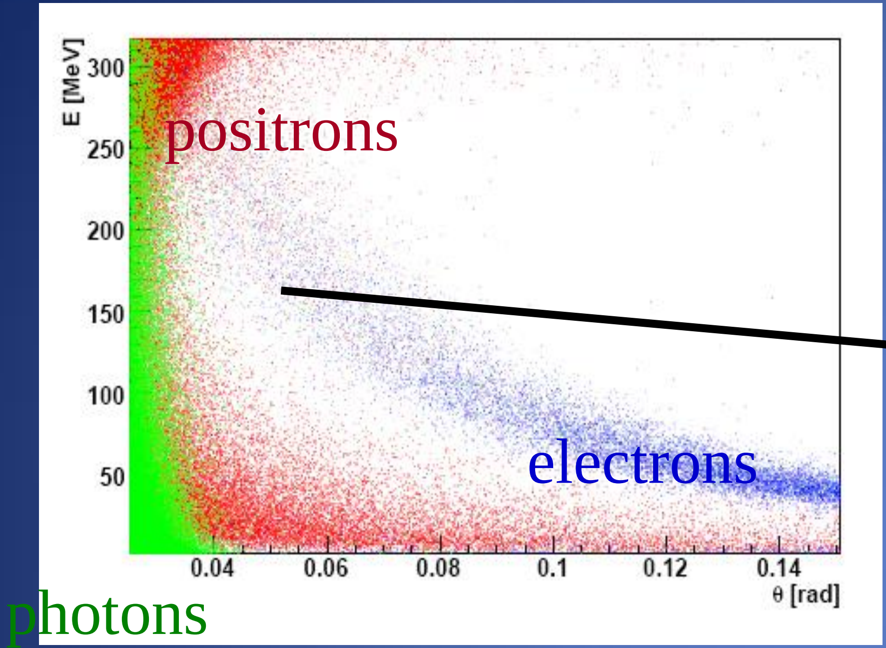
Example:

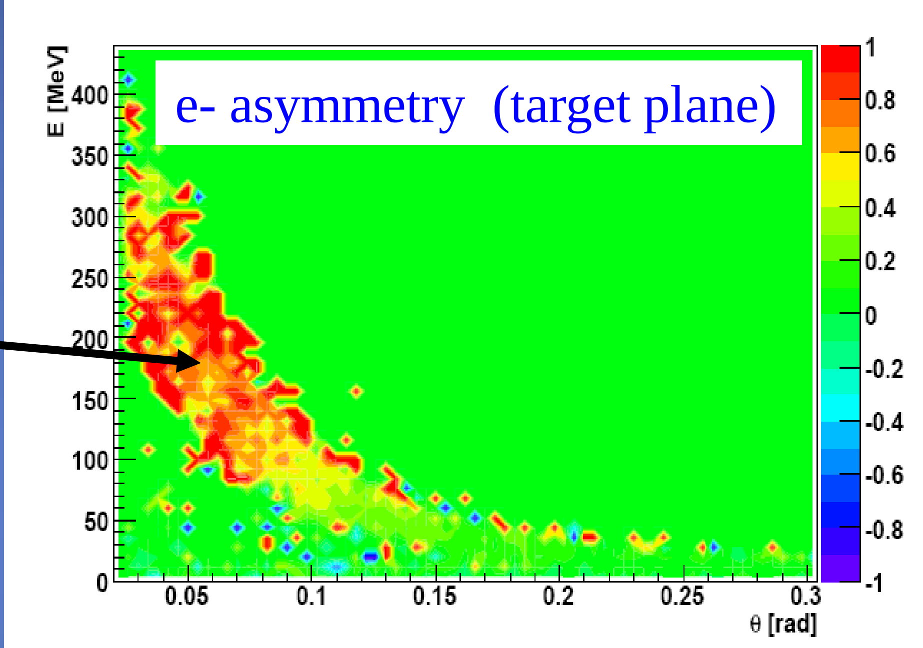
$P_{e+} = 80\%$,

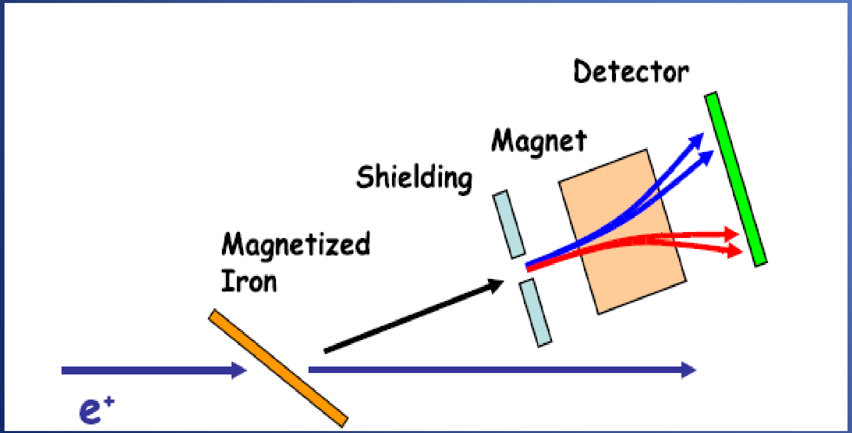
$P_{e-} = 7\%$

$A_{max} \sim 4.4\ \%$

Bhabha Polarimetry @400MeV







Selection of scattered electrons and positrons:

0.05 < θ < 0.09rad (2.9°-5.2°) slit-mask
100 MeV < E < 300 MeV (spectrometer)

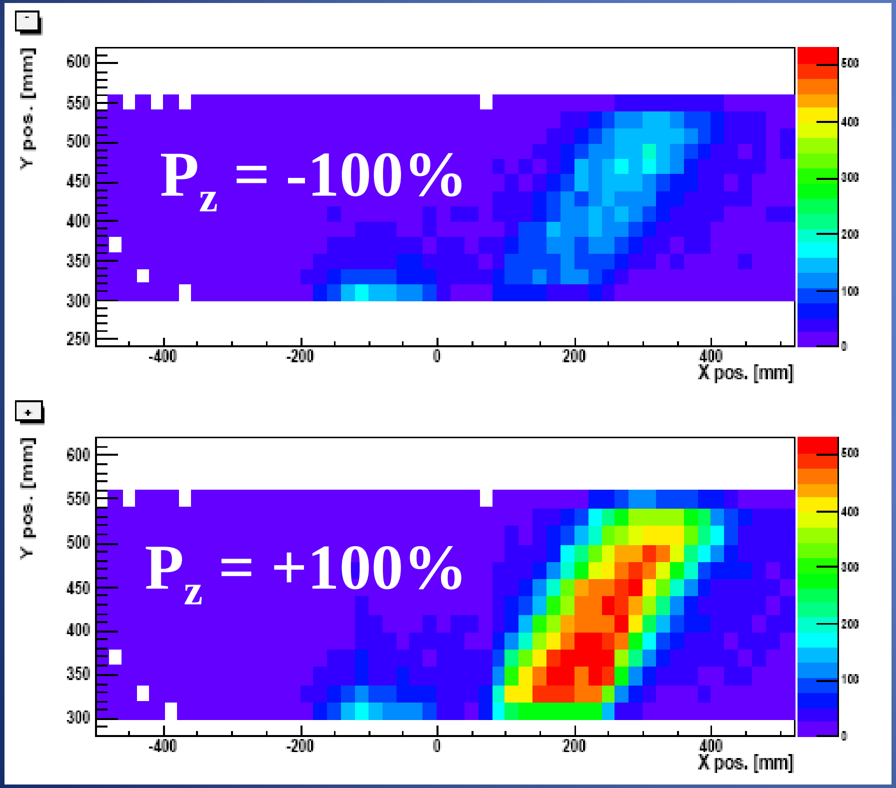
reverse polarization in target foil
→ asymmetry ~ P (e+)

Bhabha Pol.: asymmetry measurement

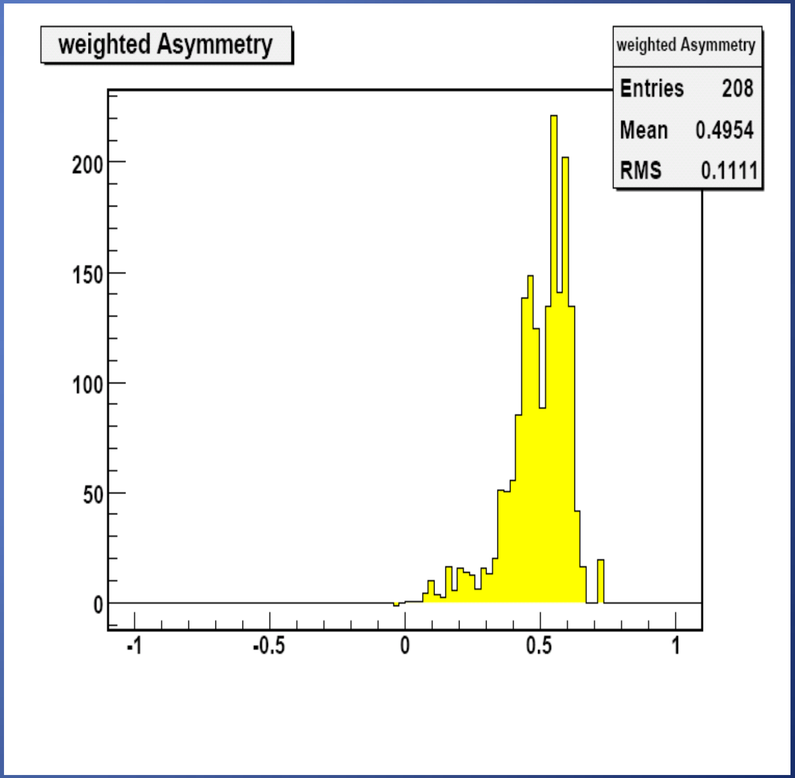
Simulation assumptions:

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

e^- distribution (detector plane)

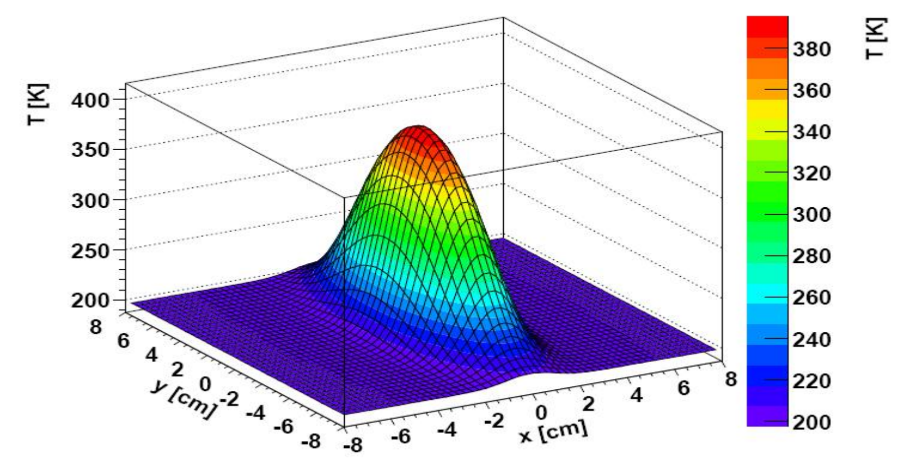


asymmetry ➔ e+ polarization

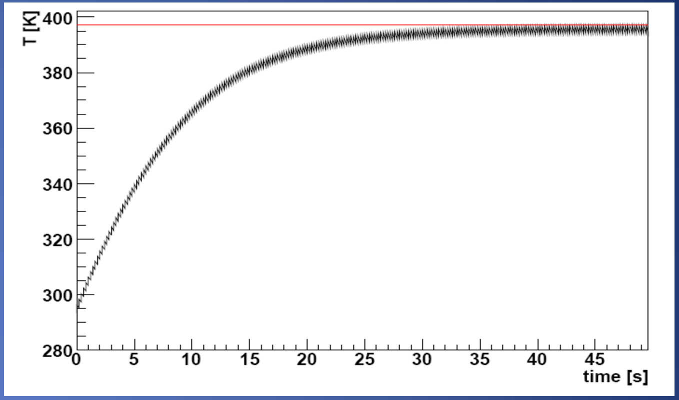


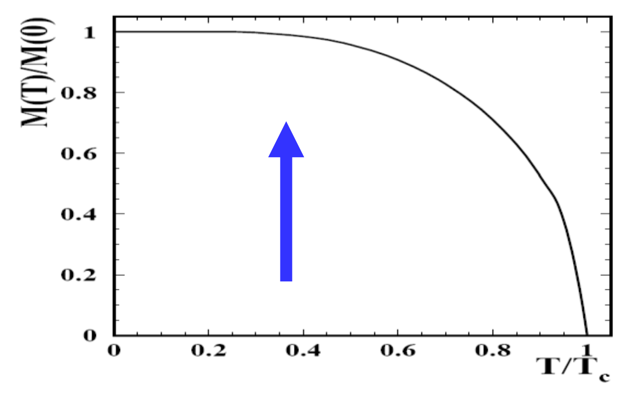
Bhabha target heating

Peak temperature for iron foil (30μm)



Time dependence



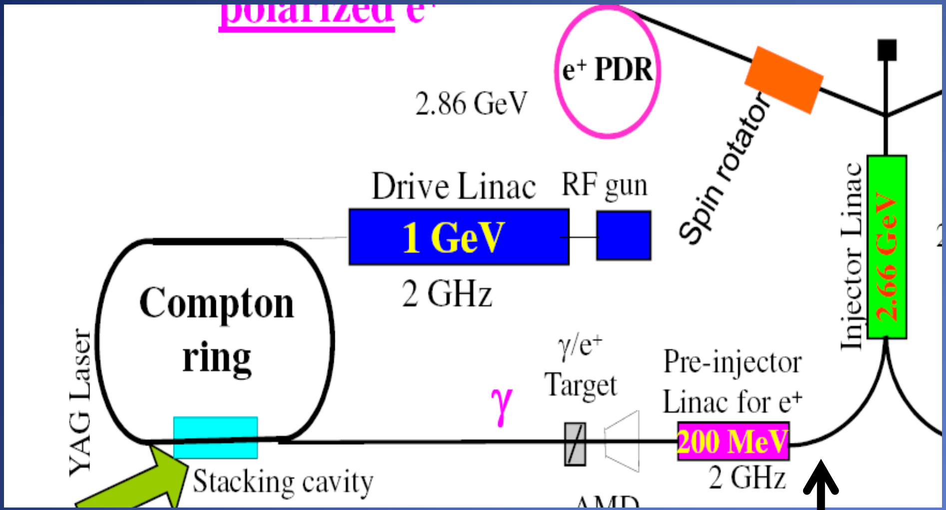


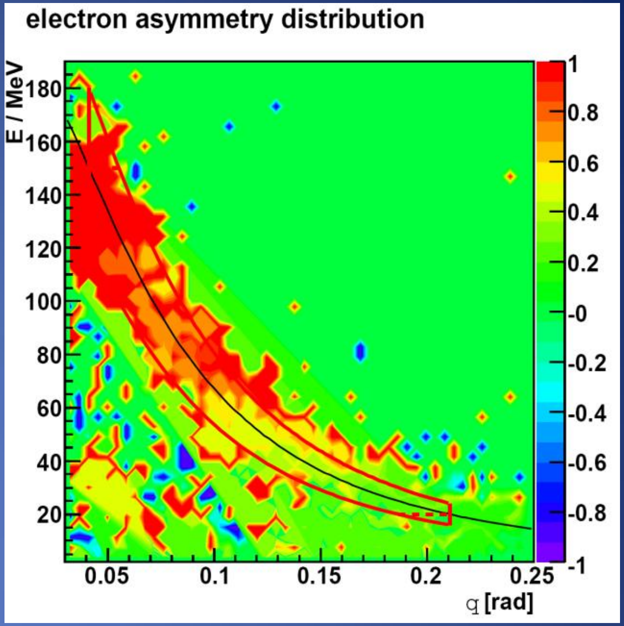
temperature dependence of iron foil magnetization
➔ Only small reduction of $P_{Fe:}$

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

standard strategies against beam heating :
beam rastering & target rotation

Bhabha polarimeter at CLIC





Bhabha polarimeter
at 200 MeV

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

target heating at CLIC less severe than at ILC
assuming same beam size

asymmerty measurement with recoil electrons:
energy range: 30 – 150 MeV
angular range: 0.04 ~ 0.2 rad (2.3° - 11.5°)

„200 MeV Bhabha polarimetry at CLIC seems possible“

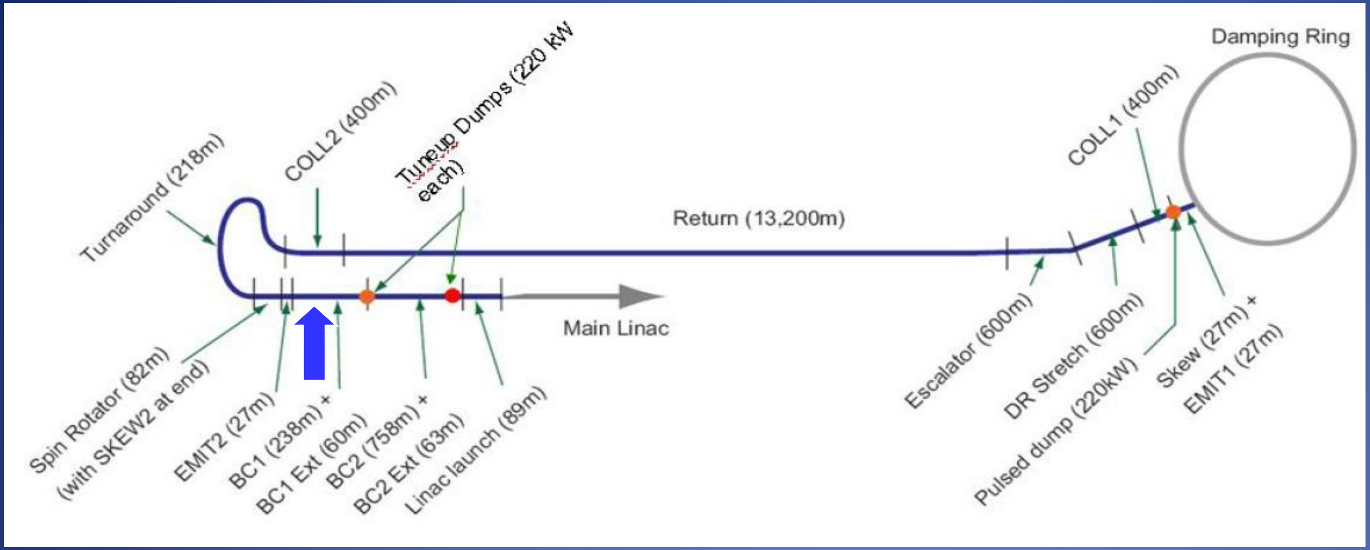
Bhabha **Polarimeter Status**

many open issues remain, in particular

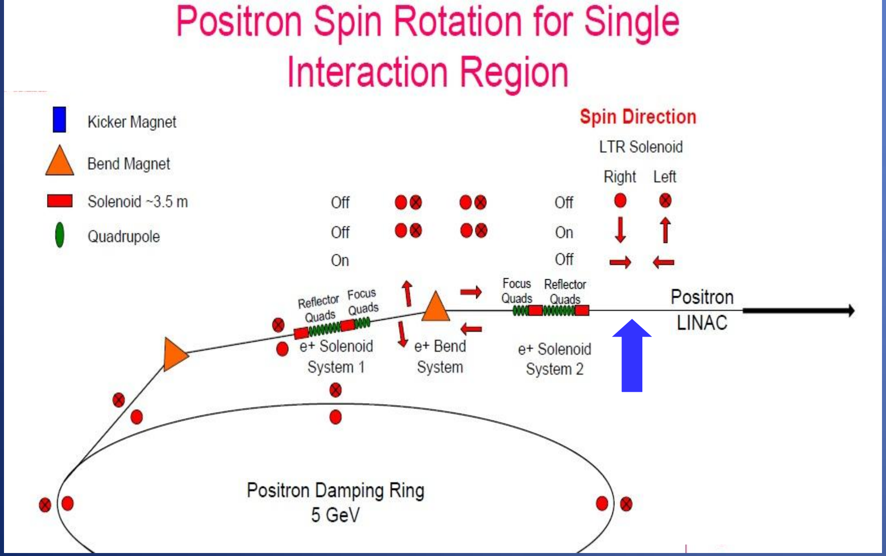
- magnet & beam septum design
- beamline integration & topology layout
- detector & instrumentation concept
- single event vs multiple event detection
- background issues
- impact on accelerator operation
- dedicated vs parasitic operation
- rates, errors, performance, …

Lots of remaining work, this requires numerous additional in-depth studies!

Compton Polarimetry at 5 GeV after DR



RTML schematic
from RDR (Aug. 2007)


Positron Spin Rotation for Single Interaction Region

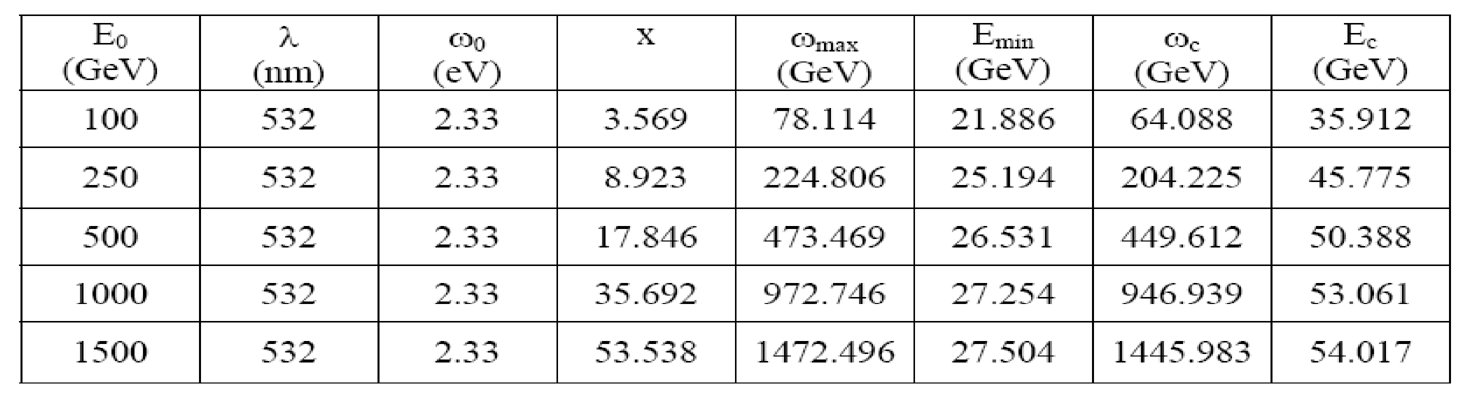
Motivation

- fast feedback for instant tune-up of spin rotator optics
- independent of main linac
- verfication of spin manipulation issues at a critical junction
- Compton polarimetry works equally well on e+ and e- beams

Compton Polarimetry at High-Energy

- will try to model the 5 GeV Compton polarimeter after the well-studied high-energy Compton polarimeters, so review those first

Compton polarimetry: kinematics



E_0 (GeV)	λ (nm)	ω_0 (eV)	x	ω_{max} (GeV)	E_{min} (GeV)	ω_c (GeV)	E_c (GeV)
100	532	2.33	3.569	78.114	21.886	64.088	35.912
250	532	2.33	8.923	224.806	25.194	204.225	45.775
500	532	2.33	17.846	473.469	26.531	449.612	50.388
1000	532	2.33	35.692	972.746	27.254	946.939	53.061
1500	532	2.33	53.538	1472.496	27.504	1445.983	54.017

$$\omega + E = \omega_0 + E_0 \simeq E_0$$

$$x = \frac{4E_0\omega_0}{m^2}\cos^2(\theta_0/2) \simeq \frac{4E_0\omega_0}{m^2}$$

$$\begin{aligned} \omega_{max} &= E_0\frac{x}{1+x} \\ E_{min} &= E_0\frac{1}{1+x} \end{aligned}$$

$$\begin{aligned} \omega_c &= E_0\frac{x}{2+x} \\ E_c &= E_0\frac{1}{1+x/2} \end{aligned}$$

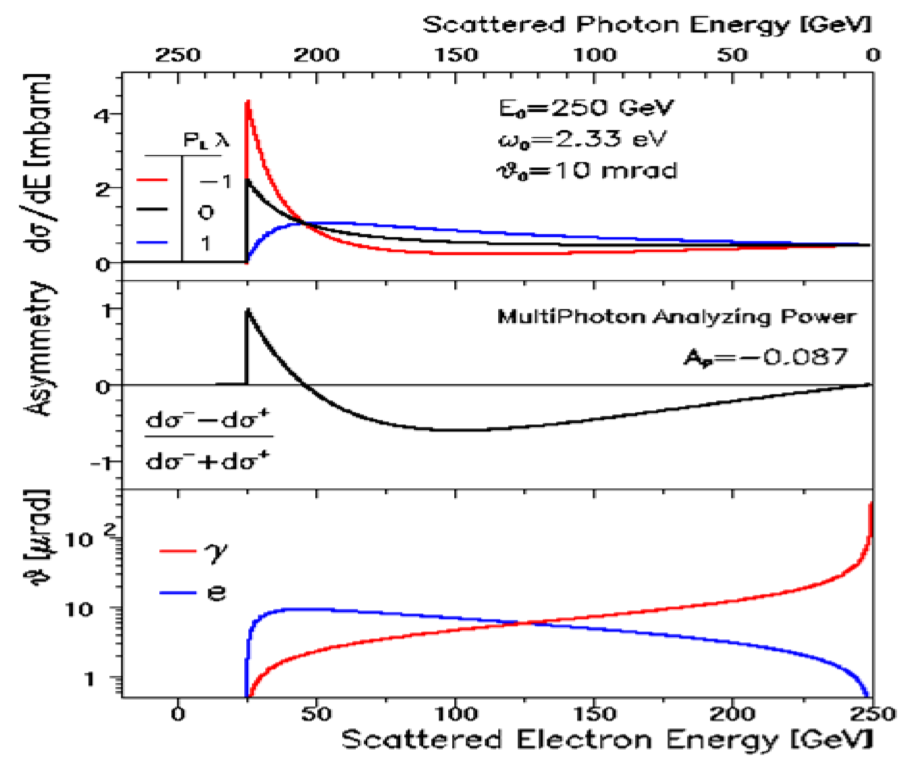
Compton Polarimetry at High-Energy

Spin dependent cross section, asymmetry and angular distribution

$$\frac{d\sigma}{dy} = \frac{2\sigma_0}{x}\left[\frac{1}{1-y} + 1 - y - 4r(1-r) + P\lambda r x(1-2r)(2-y)\right]$$

$-1 < P < +1$

$-1 < \lambda < +1$



$$\sigma_0 = \pi r_0^2 = 0.2495\ barn$$

$$y = 1 - \frac{E}{E_0} = \frac{\omega}{E_0}$$

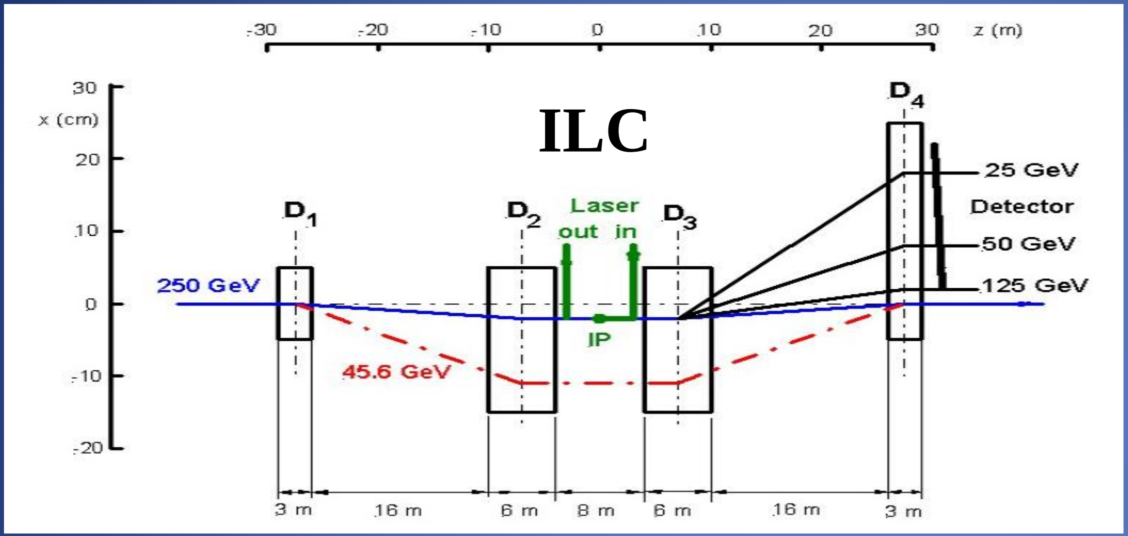
$$r = \frac{y}{x(1-y)}$$

$$\theta_\gamma = \frac{m}{E_0}\sqrt{\frac{x}{y} - (x+1)}$$

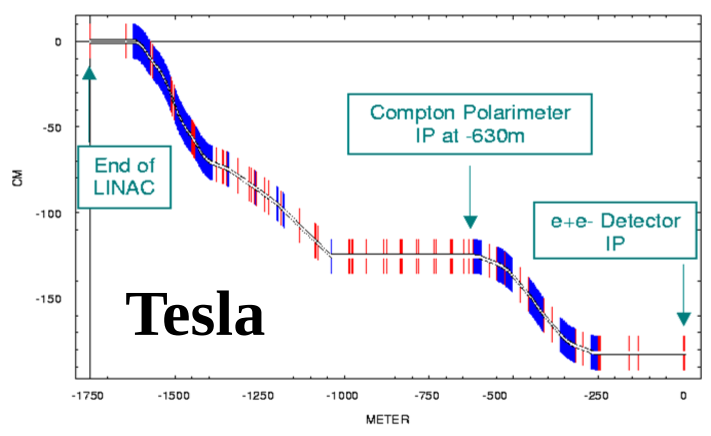
$$\theta_e = \frac{y}{1-y}\theta_\gamma$$

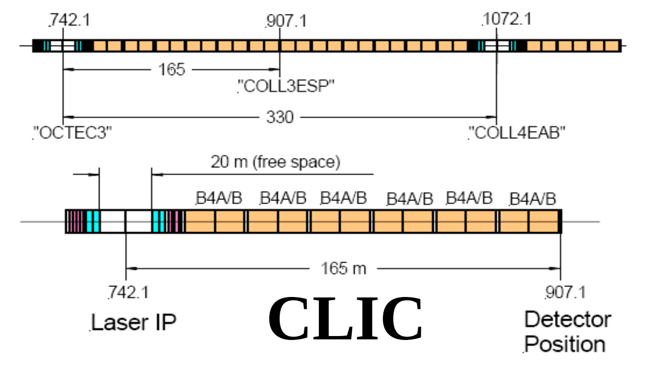
Compton Polarimetry at High-Energy

electron/positron spectroscopy

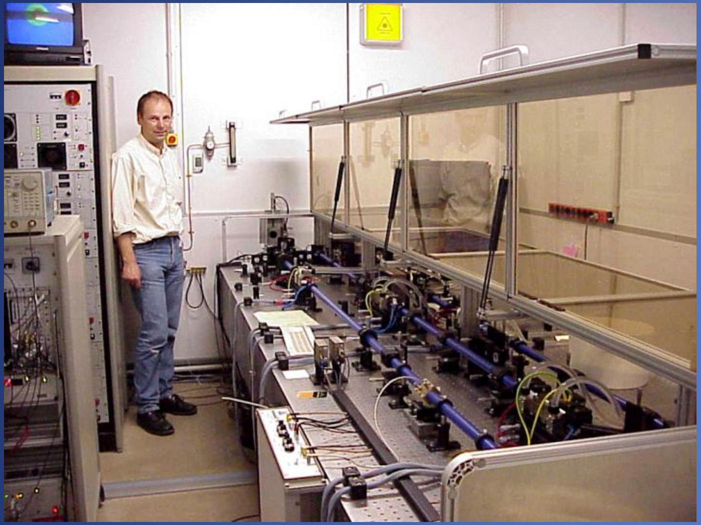


4-Magnet Chicane
or
string of dipoles





Compton Polarimetry at High-Energy



Laser

- can be either special short pulse (σ ~ 8 ps) high-performance type (as shown)
- or simple commercial Q-switched YAG-type

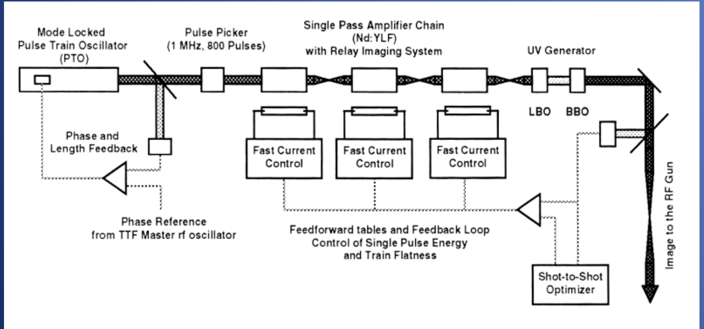
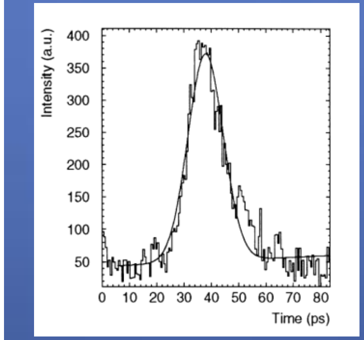


Fig. 1. Schematic overview of the TTF photoinjector laser system.



regen. multi-stage Nd:YLF ampl.
(built by Max-Born-Inst.)
operates at nominal pulse &
bunch pattern of ILC

Compton Polarimetry at High-Energy

luminosity for pulsed lasers:

$$\mathcal{L} = f_b\, N_e\, N_\gamma\, g$$

For small crossing angle θ_0

$$g = \frac{1}{2\pi \sqrt{\sigma_{xe}^2 + \sigma_{x\gamma}^2}\, \sqrt{\sigma_{ye}^2 + \sigma_{y\gamma}^2}\, \sqrt{1 + \frac{\sigma_{ze}^2 + \sigma_{z\gamma}^2}{\sigma_{ye}^2 + \sigma_{y\gamma}^2} (\theta_0 / 2)^2}}$$

f_b = number of bunches per second hit by laser
N_e = number of particles per bunch
N_g = number of photons in laser puls
g = geometry factor

With simple commercial Q-switched YAG-laser (100 mJ @ 30 Hz) at CLIC:

$$g = g_{\max}\, \varepsilon$$

$$g_{\max} = \frac{1}{2\pi \sqrt{\sigma_{xe}^2 + \sigma_{x\gamma}^2}\, \sqrt{\sigma_{ye}^2 + \sigma_{y\gamma}^2}}$$

$$\varepsilon = \frac{1}{\sqrt{1 + \frac{\sigma_{ze}^2 + \sigma_{z\gamma}^2}{\sigma_{ye}^2 + \sigma_{y\gamma}^2} (\theta_0 / 2)^2}}$$

$$f_b = 5 \cdot 50 = 250\ Hz$$
$$N_e = 3.72 \cdot 10^9$$
$$N_\gamma = 0.100\ J / \left(2.33\ eV \cdot 1.602 \cdot 10^{-19}\ J/eV\right) = 2.68 \cdot 10^{17}$$

$CLIC:$
$$\sigma_{xe} = 300\ \mu m = 0.03\ cm$$
$$\sigma_{ye} = 27\ \mu m = 0.0027\ cm$$
$$\sigma_{ze} = 44\ \mu m = 0.0044\ cm$$

$Laser:$
$$\sigma_{x\gamma} = \sigma_{y\gamma} = 50\ \mu m = 0.0050\ cm$$
$$\sigma_{z\gamma} = 30\ cm\ (1\ ns)$$
$$\theta_0 = 10\ mrad = 0.010\ rad$$

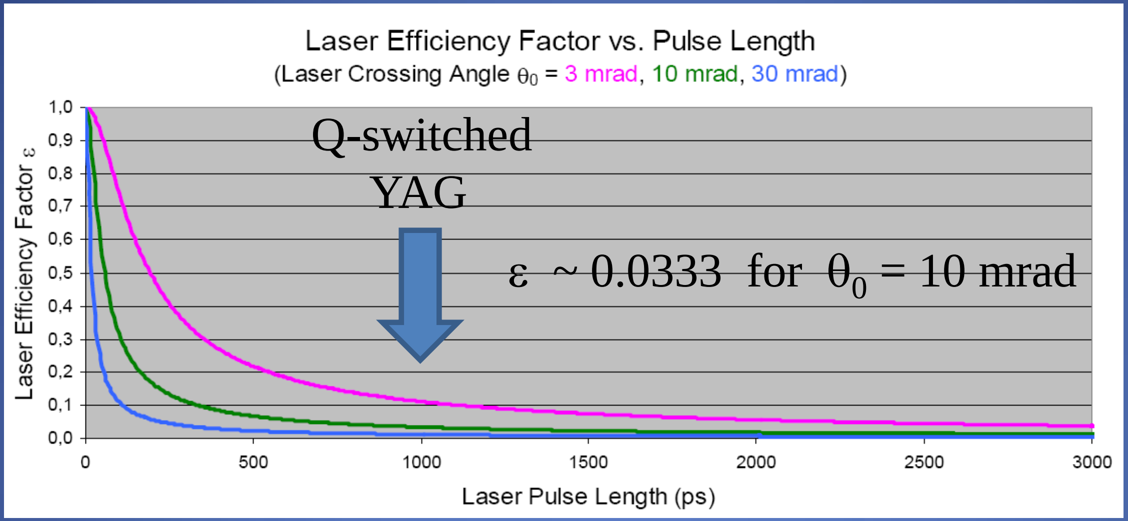
$$g_{\max} = 921.2\ cm^{-2}$$

$$\varepsilon = 0.0333 \quad (for\ Q-switched\ YAG\ laser)$$

$$L = 7.645 \cdot 10^{30}\ cm^{-2}\ s^{-1}$$

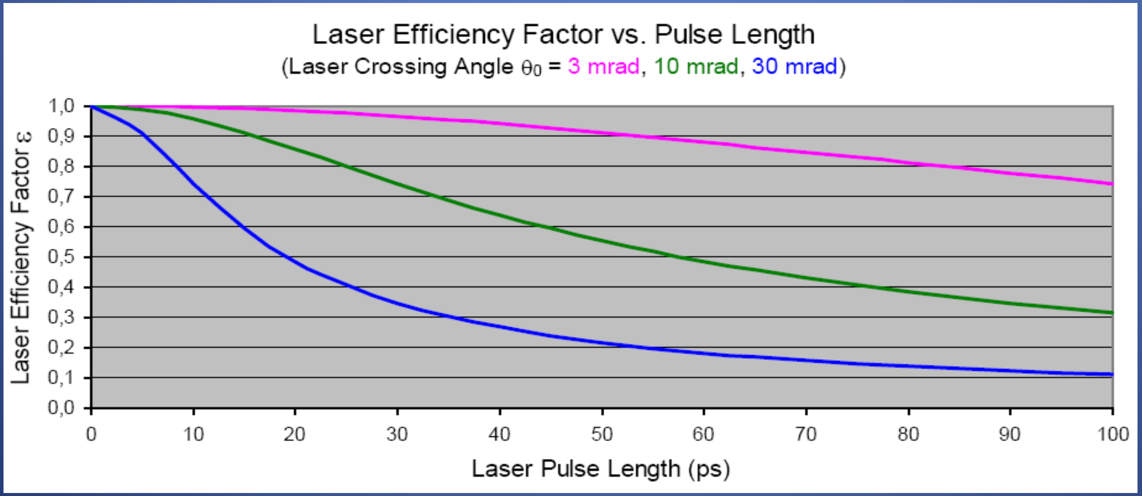
Compton Polarimetry at High-Energy

pulsed laser efficiency



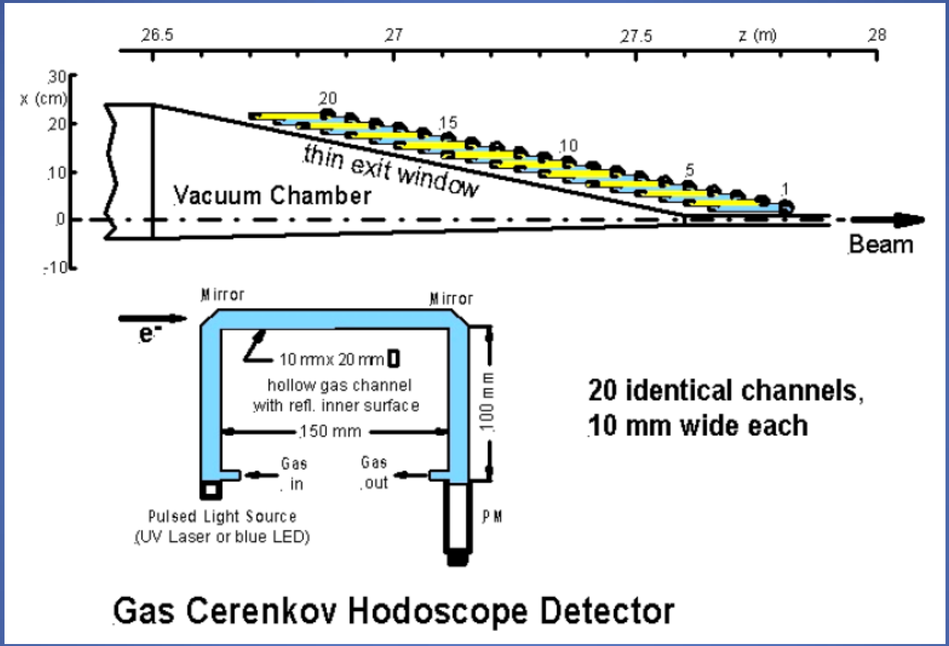
Q-switched YAG

$\varepsilon \sim 0.0333$ for $\theta_0 = 10$ mrad



Compton Polarimetry at High-Energy

electron detector hodoscope



20 identical channels,
10 mm wide each

Gas Cerenkov Hodoscope Detector

- Design similar to gas Cerenkov employed in SLD Compton polarimeter
- C_4F_{10} gas (~10 MeV threshold)
- detector will be immune against low-energy and diffuse background (synchr. rad.)

Compton Polarimetry at High-Energy: ILC Upstream Pol.

input parameters

0.5 x 10^6	no. of Compton evt's per polarity	
676749.	random seed	
2.33	laser photon energy	(eV)
250.	electron energy	(GeV)
10.	crossing angle	(mrad)
1.50	luminosity	(10^32 / cm² / sec)
0.250	chicane transv. mom. kick	(GeV/c)
2.	magnet length	(m)
20.	cntr. dist. magnets 1&2 (3&4)	(m)
10.	cntr. distance magnets 2&3	(m)
0.7	dist. mag. 4 edge to det. ch. n	(m)
20	no. of det. channels (max. 100)	
10.	det. channel x-size (hor.)	(mm)
20.	det. channel y-size (vert.)	(mm)
150.	det. channel length along z	(mm)
20.	distance det. ch. 1 to beam	(mm)
50.	z-dist. btw. det. channels	(mm)
1.	meas. time for stat. error	(sec)
0.80	beam pol. to calculate stat. error	

$E_0 = 250$ GeV

$\omega_0 = 2.33$ eV (green laser)

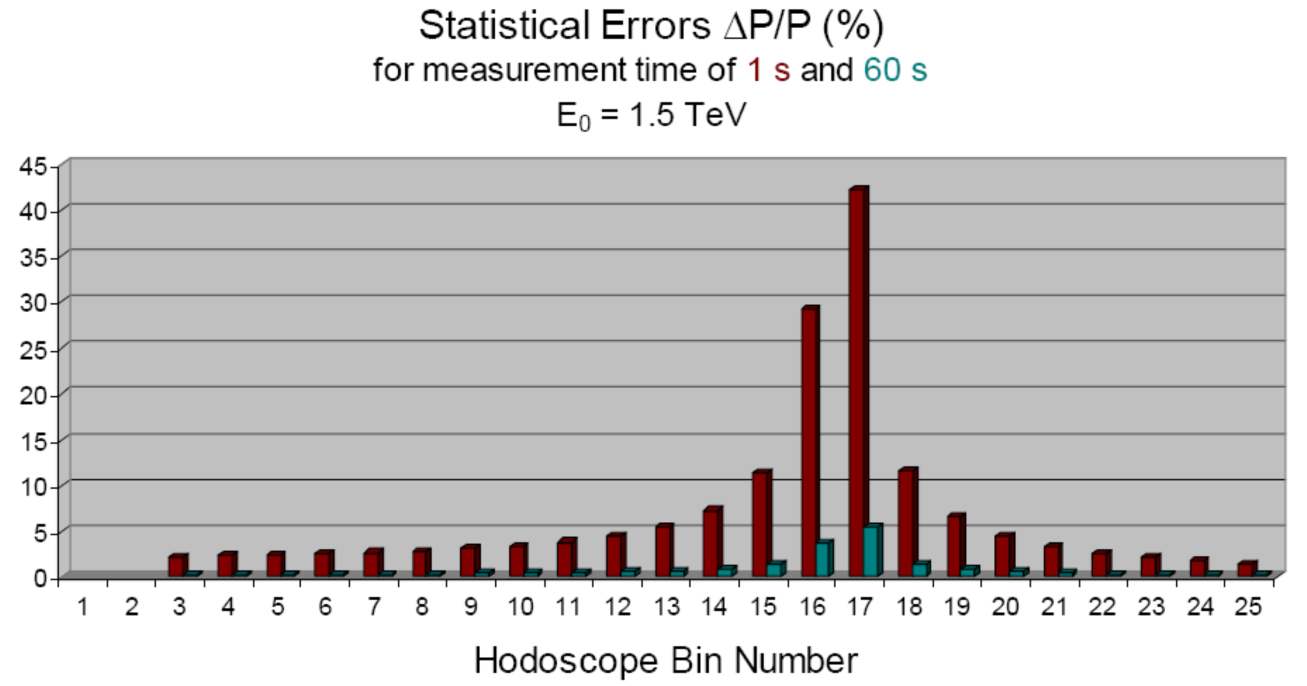
$\mathscr{L} = 1.5 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$

simulation results

Ch. #	x [mm]	N+	N-	A	Rate*A²	Rate [MHz]	dP/P [%]
1	25	60,682	23,368	-0.444	0.337	1.710	0.228
2	35	45,868	17,348	-0.451	0.262	1.287	0.260
3	45	35,673	16,012	-0.380	0.152	1.052	0.335
4	55	28,337	16,029	-0.277	0.069	0.903	0.486
5	65	22,996	16,956	-0.151	0.019	0.813	0.924
6	75	18,333	17,876	-0.013	0.000	0.737	11.521
7	85	15,248	18,744	0.103	0.007	0.692	1.466
8	95	12,025	19.818	0.245	0.039	0.648	0.646
9	105	9,881	20,480	0.349	0.075	0.618	0.473
10	115	7,815	21,525	0.467	0.130	0.597	0.370
11	125	6,246	21,961	0.557	0.178	0.574	0.324
12	135	4,849	22,795	0.649	0.237	0.562	0.289
13	145	3,479	23,315	0.740	0.299	0.545	0.266
14	155	2,385	23,821	0.818	0.357	0.533	0.250
15	165	1,346	24,171	0.895	0.416	0.519	0.238
16	175	457	20,900	0.957	0.398	0.435	0.249
17	185	0	0				
18	195	0	0				
19	205	0	0				
20	215	0	0				

overall stat. error: $\Delta P/P = 0.082\%$
for $\Delta T = 1$ sec

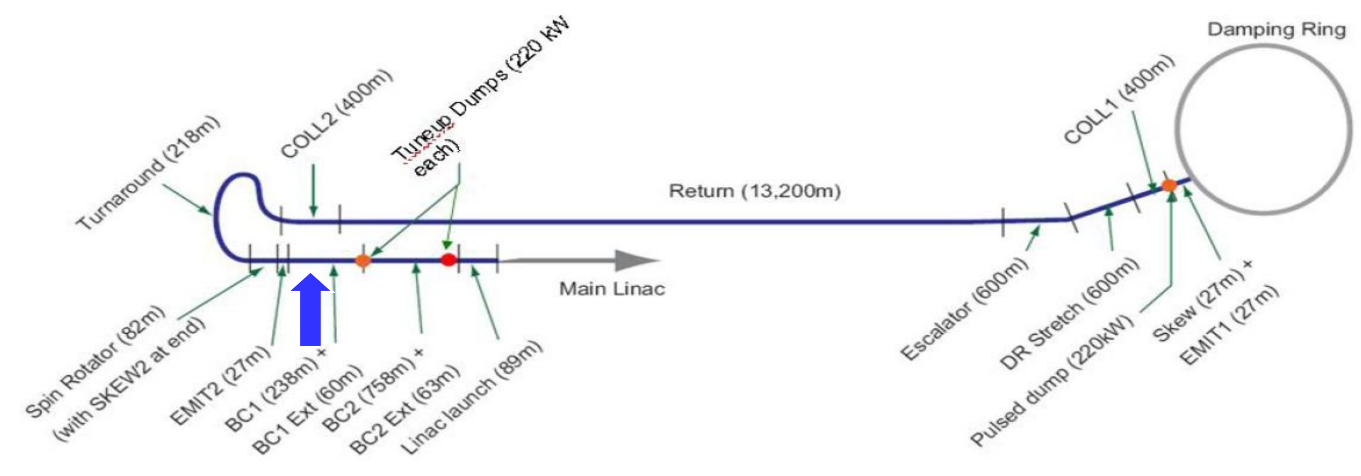
Compton Polarimetry at High-Energy: CLIC



From CLIC08 Workshop

measurement time	1 s	60 s
statistical error	ΔP/P	ΔP/P
bins 1-10 (edge region) combined	0.89%	0,11%
all 25 bins combined	0.61%	0.08%

Compton Polarimetry at 5 GeV after DR



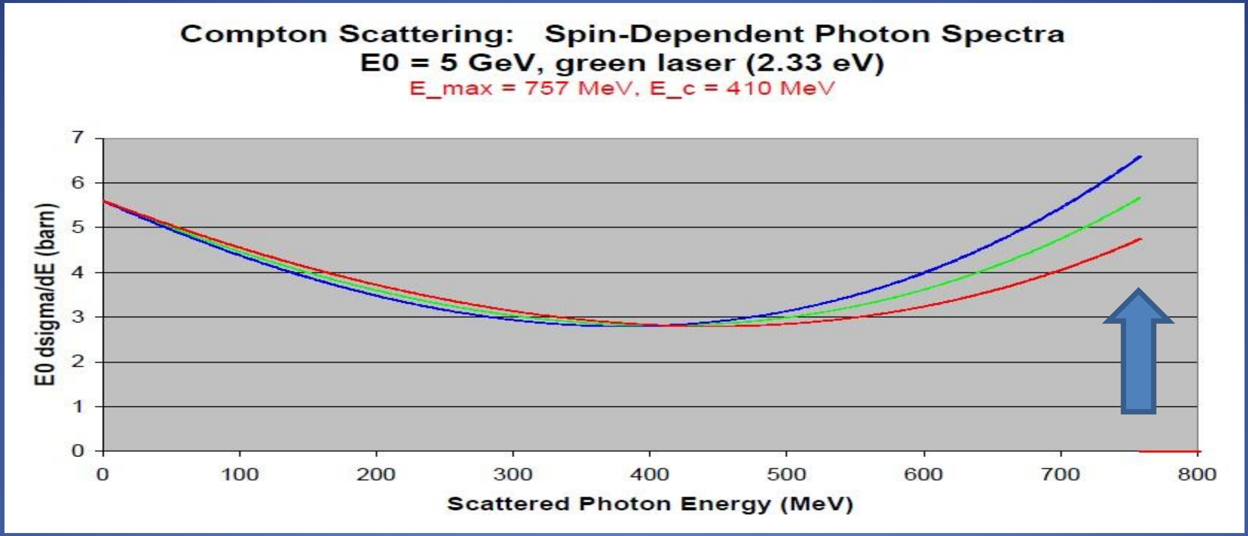
Now let#s return to the original question:

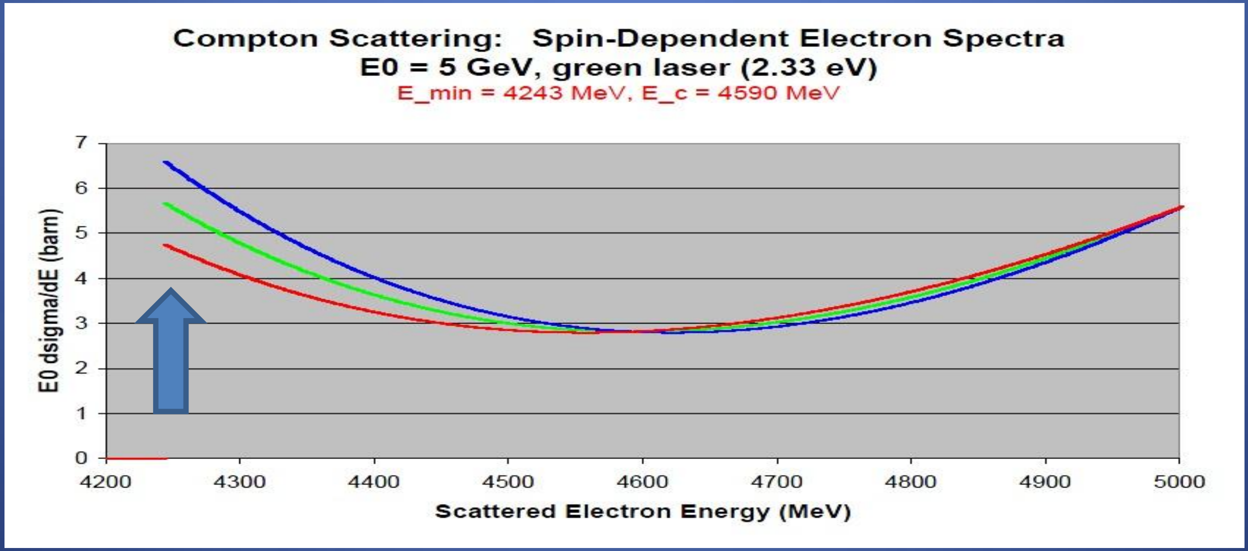
Is it possible to do Compton polarimetry at 5 GeV after the damping ring?

E	λ	ω_0	x	ω_{max}	E_{min}	ω_c	E_c
(GeV)	(nm)	(eV)		(GeV)	(GeV)	(GeV)	(GeV)
5	532	2.33	0.1785	0.757	4.243	0.410	4.590

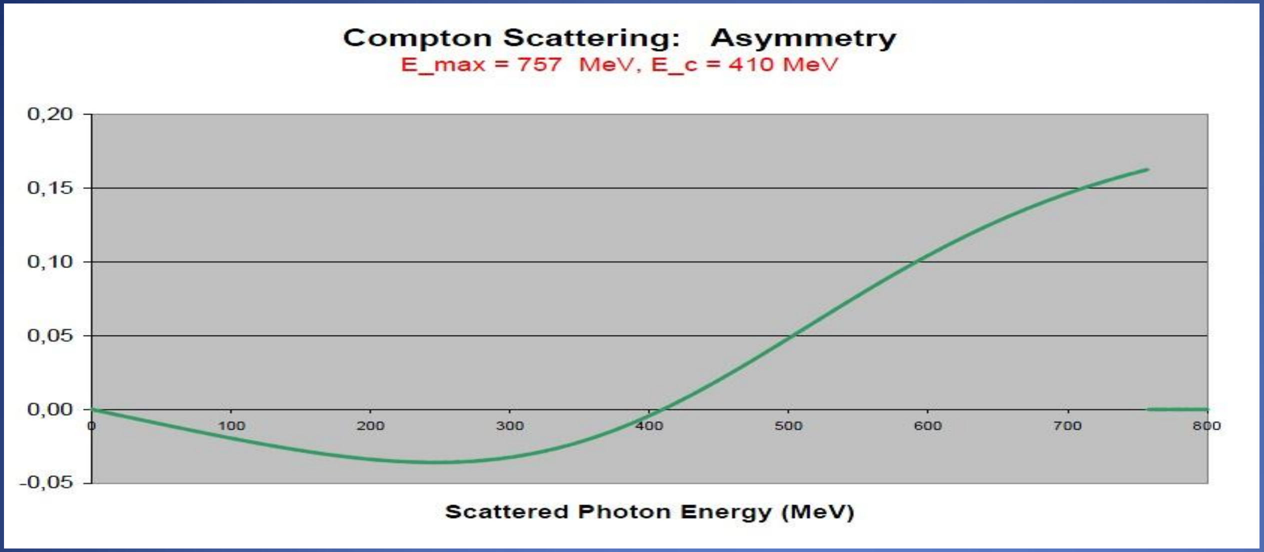
recoil positrons do not vary much in energy from the beam, so it will be easier to do photon detection

Compton Polarimetry at 5 GeV after DR

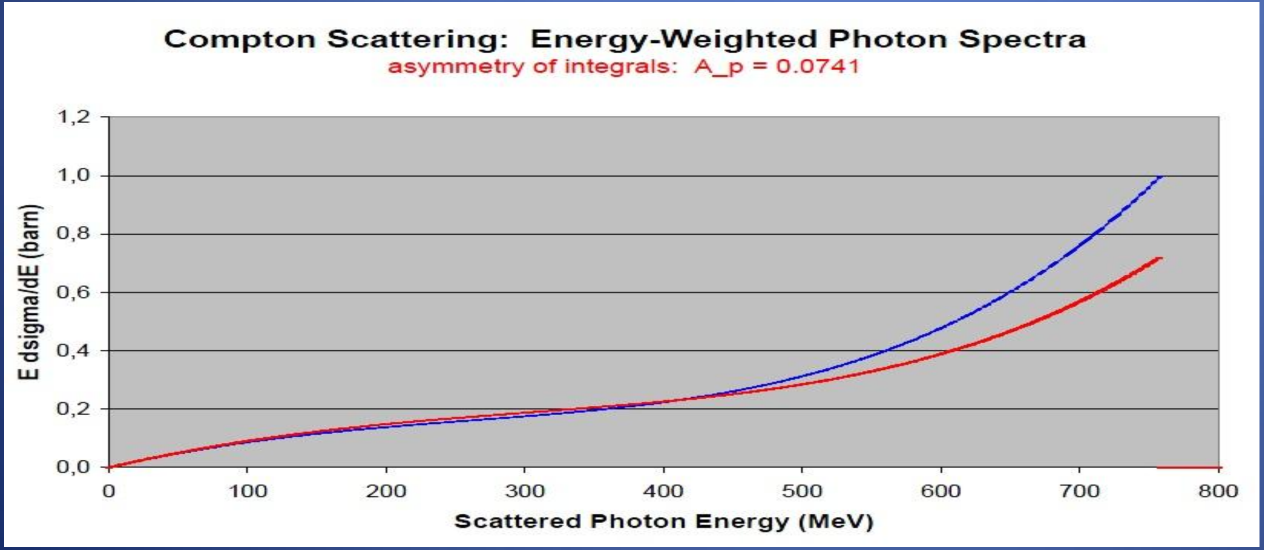

Compton Scattering: Spin-Dependent Photon Spectra
E0 = 5 GeV, green laser (2.33 eV)
E_max = 757 MeV, E_c = 410 MeV


Compton Scattering: Spin-Dependent Electron Spectra
E0 = 5 GeV, green laser (2.33 eV)
E_min = 4243 MeV, E_c = 4590 MeV

Compton Polarimetry at 5 GeV after DR

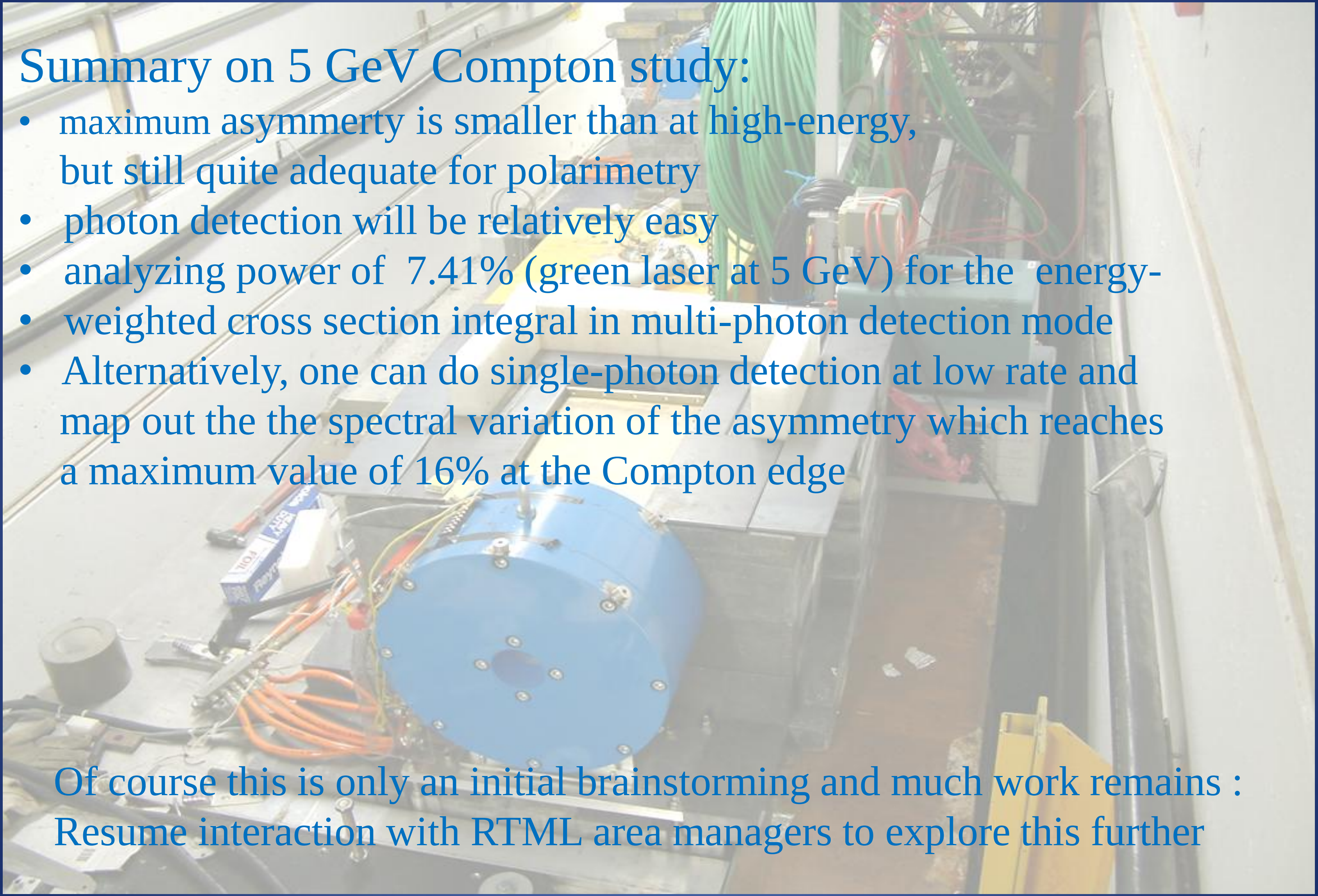


spectral mapping requires single photon detection (low rate)



asymmetry of energy-weighted integral can be measured in multi-photon mode (high rate)

Compton Polarimetry at 5 GeV after DR



Summary on 5 GeV Compton study:

- maximum asymmerty is smaller than at high-energy, but still quite adequate for polarimetry
- photon detection will be relatively easy
- analyzing power of 7.41% (green laser at 5 GeV) for the energy-
- weighted cross section integral in multi-photon detection mode
- Alternatively, one can do single-photon detection at low rate and map out the the spectral variation of the asymmetry which reaches a maximum value of 16% at the Compton edge

Of course this is only an initial brainstorming and much work remains : Resume interaction with RTML area managers to explore this further