Polarimeter

- requirements and goals
- directional alignment tolerance
- suitable locations
- Compton polarimetry basics
- a possible configuration
- expected performance
- conclusions

requirements and goals

(insprired by earlier work for ILC at SLAC and DESY and elsewhere)

- $\Delta P/P = 0.25\%$ or better (systematics limited)
  from physics requirments
- polarimetry should be robust and fast
  for instant tuneup of spin-dependent machine parameters
  (see spin rotator issues covered by Ken Moffeit)

directional alignment tolerance

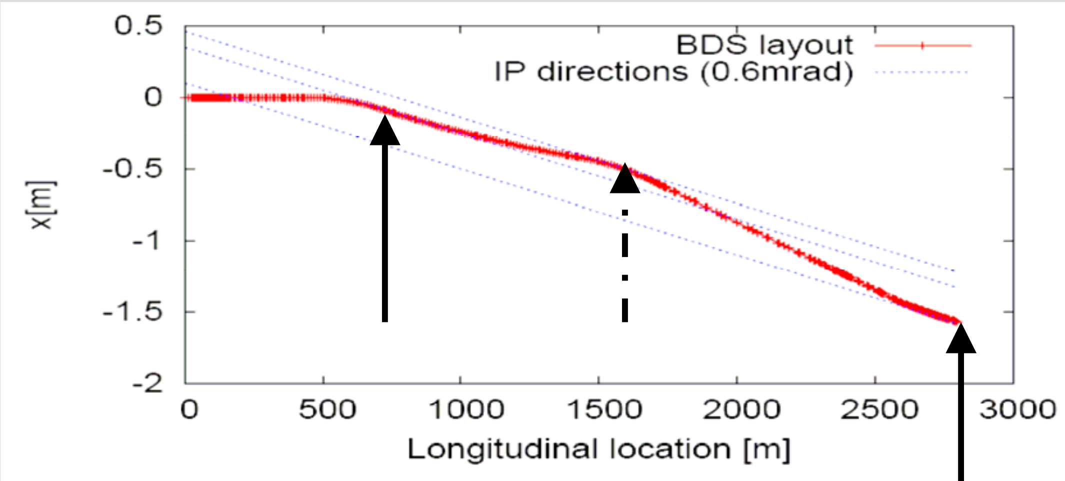
$$\theta^{spin} = \gamma \frac{g-2}{2} \theta^{orbit} = \frac{E_0}{0.44065\ GeV} \theta^{orbit}$$

$$\theta^{spin} = 3404\ \theta^{orbit} \quad for\ E_0 = 1.5\,TeV$$

$$\Delta P/P \leq 0.1\% \longrightarrow \Delta\theta^{spin} \leq 45\,mrad$$

$$\rightarrow \quad \Delta\theta^{orbit} \leq 13\,\mu rad$$

Suitable locations

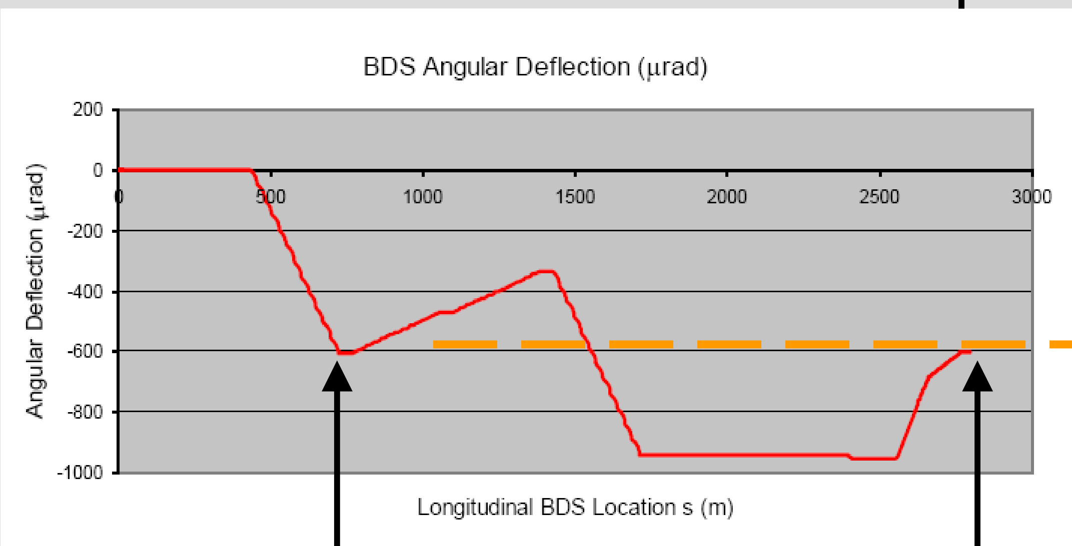


alignment exists at two locations:

s = 742 m

(s = 1555 m)

but only the first one qualifies for polarimetry (upstream of energy collimation and sufficient free space for laser beam crossing)



- 605.132 µrad (s = 742 m)

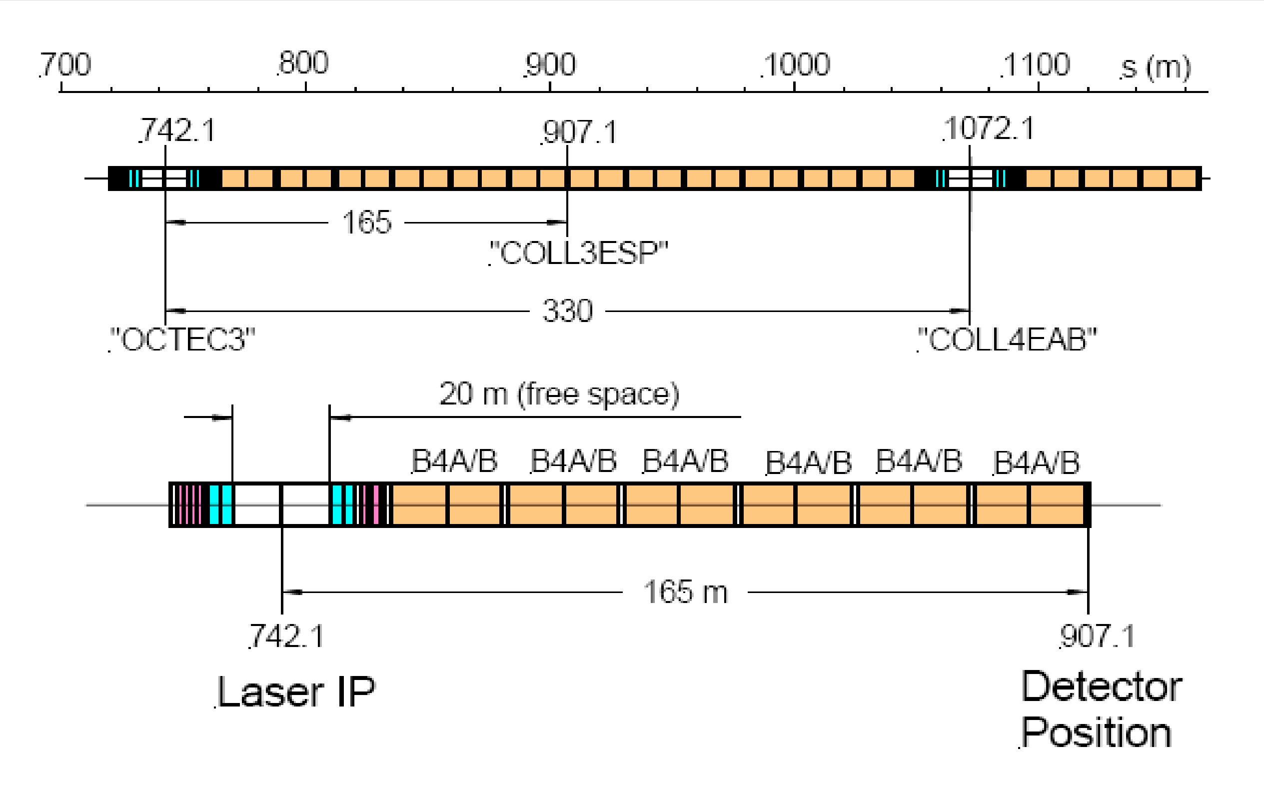
- 601.351 µrad (s = 2796 m)

aligned within 3.8 µrad

Laser IP

End of BDS

BDS detail behind s = 742 m



Laser IP at s = 742 m

Compton electron detector at s = 907 m

(behind 12 dipoles, as shown, or behind a lesser number of dipoles, but with reduced performance)

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

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

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

$$\omega_{max} = E_0\frac{x}{1+x}$$

$$E_{min} = E_0\frac{1}{1+x}$$

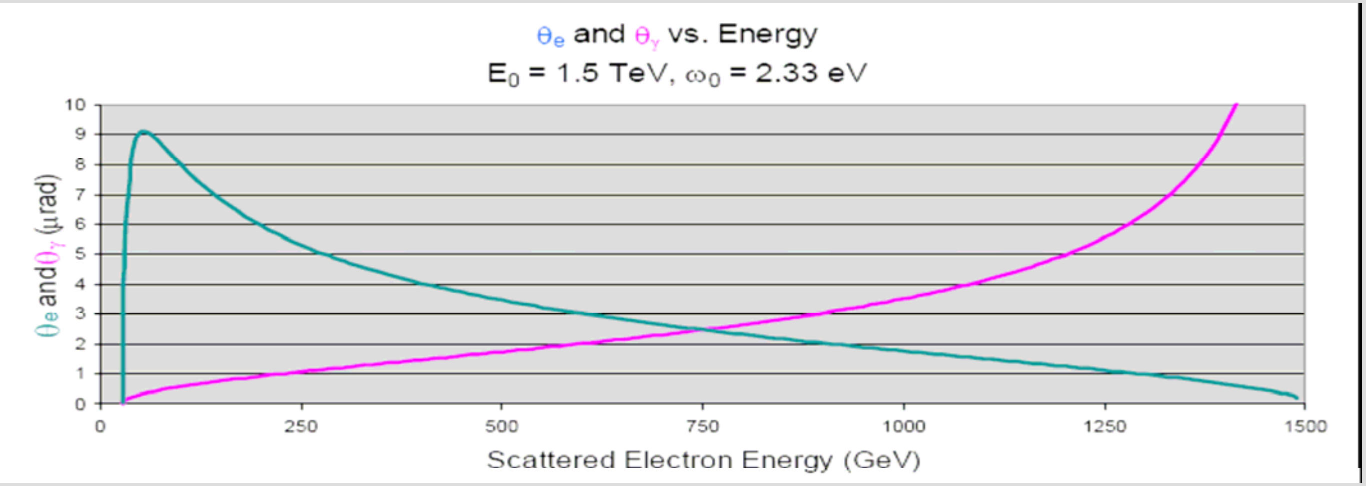
$$\omega_c = E_0\frac{x}{2+x}$$

$$E_c = E_0\frac{1}{1+x/2}$$

scattering angles, cross sections

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

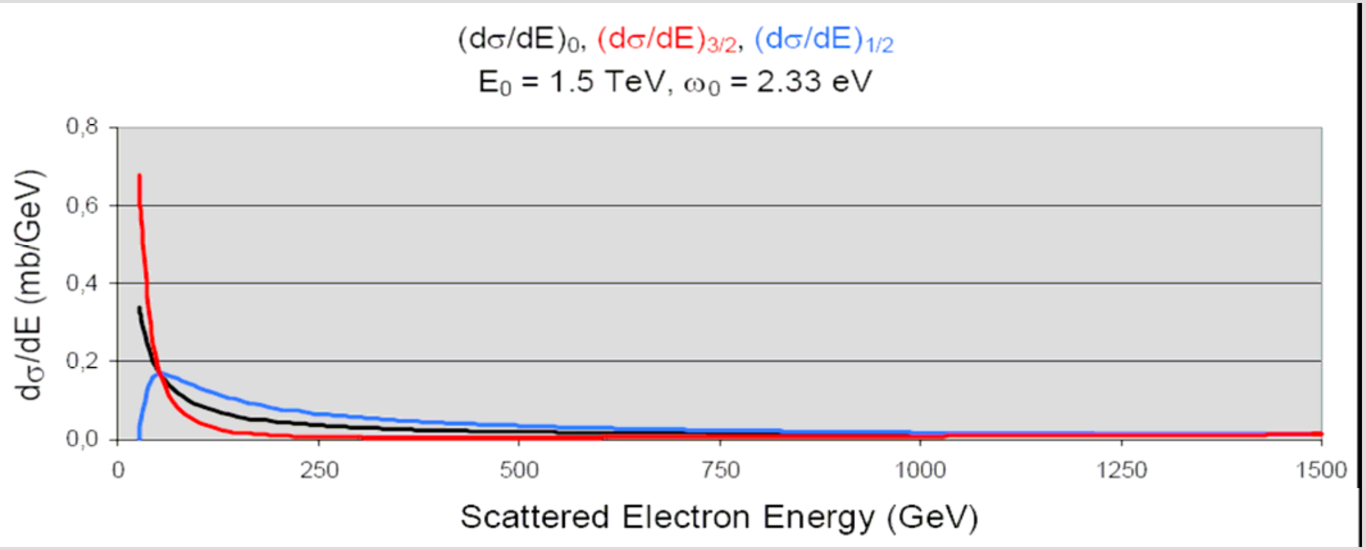
$$\theta_e = \frac{y}{1-y}\theta_\gamma$$



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

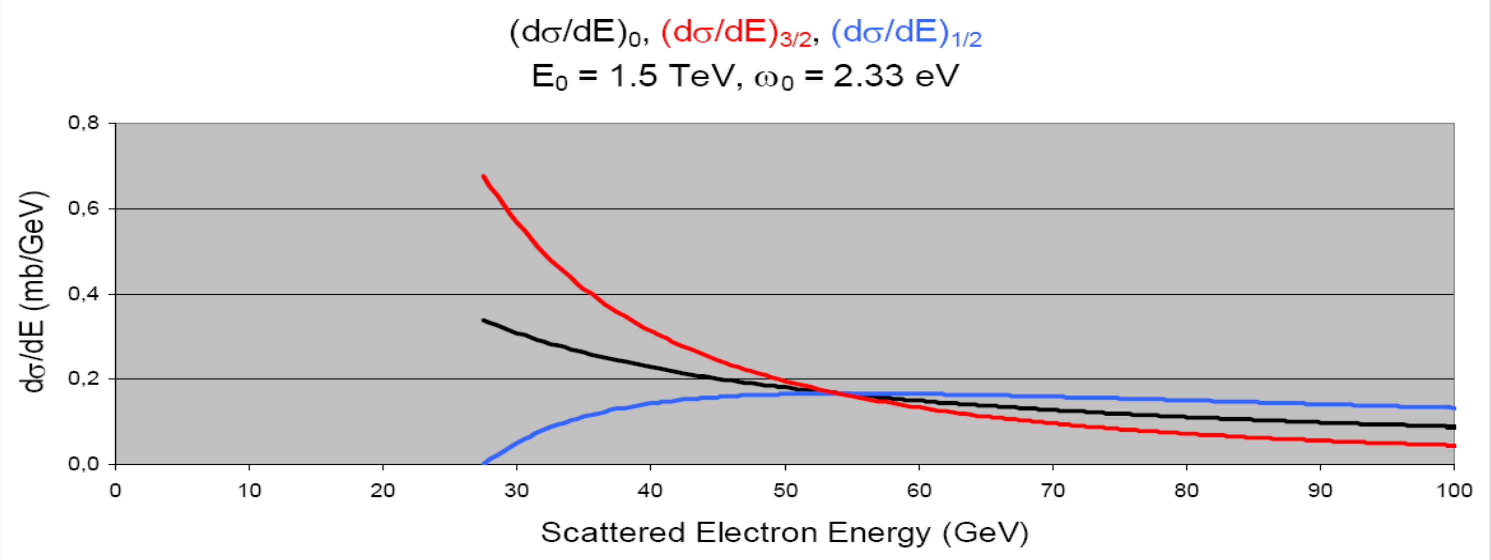
$$r = \frac{y}{x(1-y)}$$

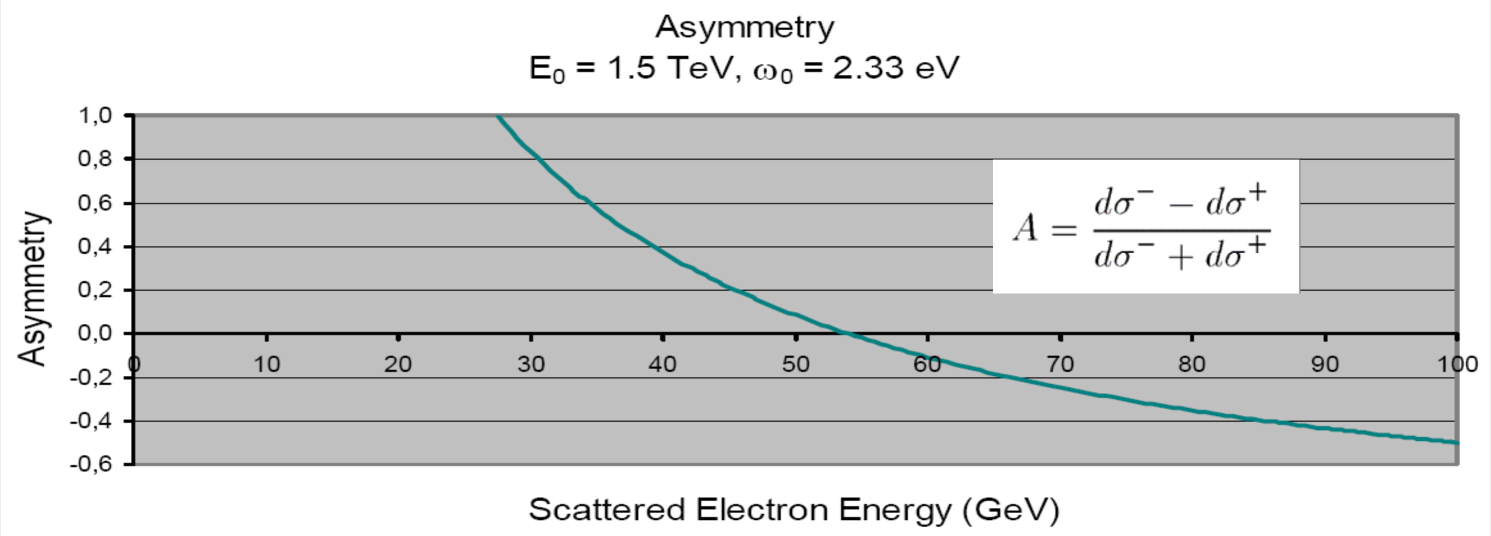
$$\sigma_0 = \pi r_0^2 = 0.2495\ barn$$



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

cross sections and spin asymmetry near the Compton edge





$$A = \frac{d\sigma^- - d\sigma^+}{d\sigma^- + d\sigma^+}$$

Laser

will consider here only standard

- **Q-switched YAG lasers**
  with the following parameters:
  - 100 mJ pulse energy at 532 nm (2.33 eV)
  - 50 Hz operation (one laser pulse per CLIC bunch train)
  - ~3 ns pulse width (σ_t ~ 1 ns), will cover ~5 adjacent CLIC bunches
  - laser spot size $\sigma_x = \sigma_y = 50$ mm
  - crossing angle of $\theta_0 = 10$ mrad
  - overlap efficiency with the ultra-short CLIC bunches will be poor, but sufficient for decent polarimetry

- **other lasers**
  with pulse length and repetition rate better matched
  to the peculiar bunch and pulse structure of the CLIC machine
  - can and should of course be considered
  - this will require in-depth examination with consultation of laser experts

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_γ = number of photons in laser puls
g = geometry factor

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

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

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

$$f_b = 5 \cdot 50 = 250 \, Hz$$

$$N_e = 3.72 \cdot 10^9$$

$$N_\gamma = 0.100 \, J / \left(2.33 \, eV \cdot 1.602 \cdot 10^{-19} \, J / eV\right) = 2.68 \cdot 10^{17}$$

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 :

$$\sigma_{x\gamma} = \sigma_{y\gamma} = 50 \, \mu m = 0.0050 \, cm$$

$$\sigma_{z\gamma} = 30 \, cm \, (1 \, ns)$$

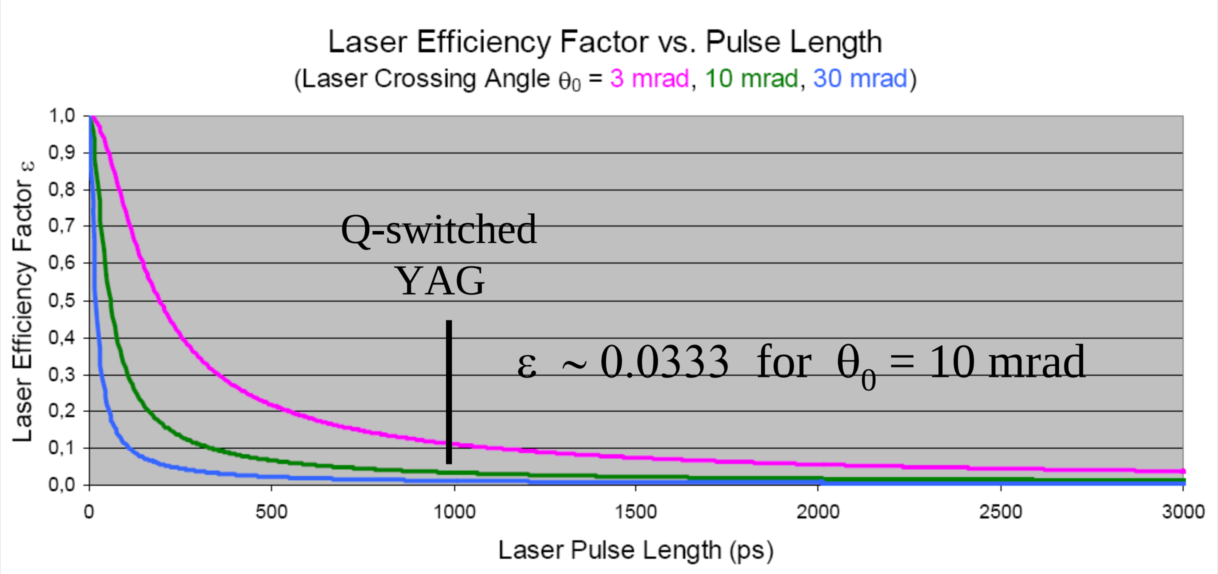
$$\theta_0 = 10 \, mrad = 0.010 \, rad$$

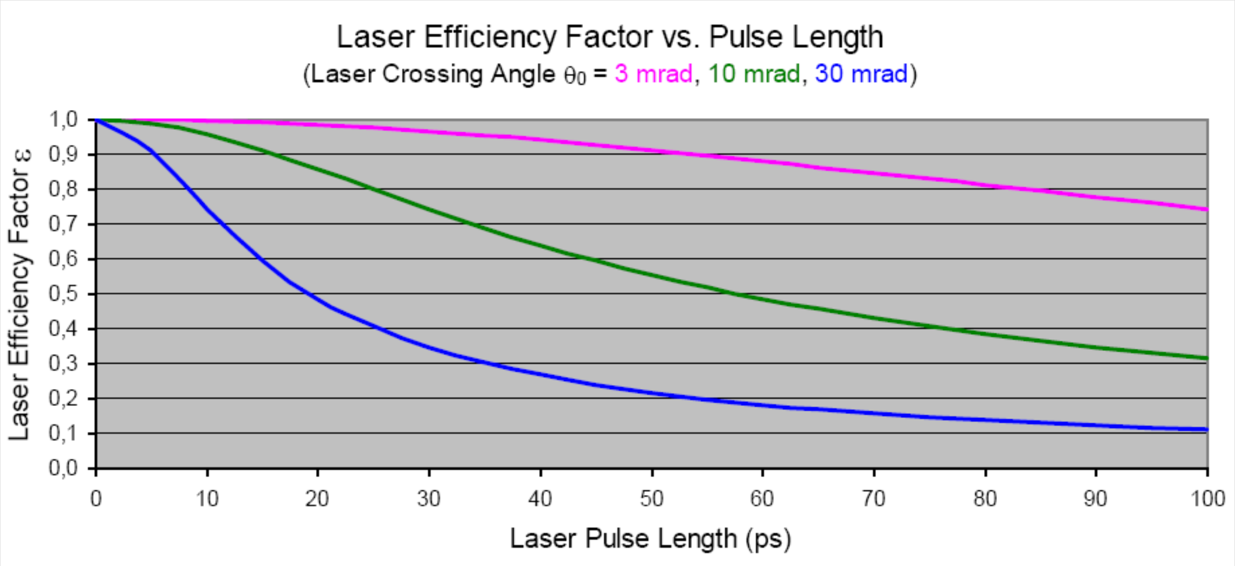
$$g_{max} = 921.2 \, cm^{-2}$$

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

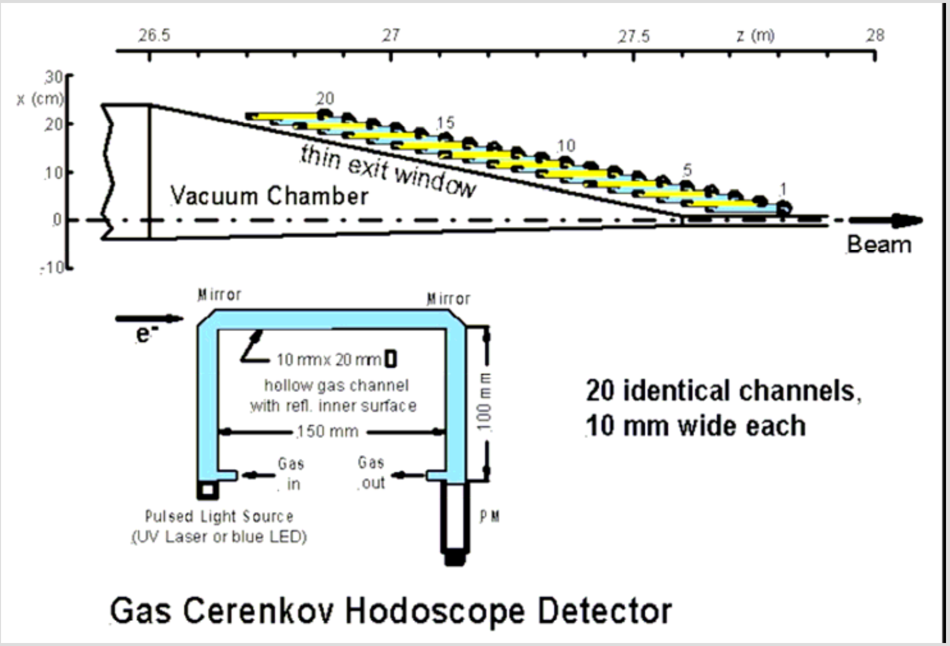
$$L = 7.645 \cdot 10^{30} \, cm^{-2} \, s^{-1}$$

pulsed laser efficiency





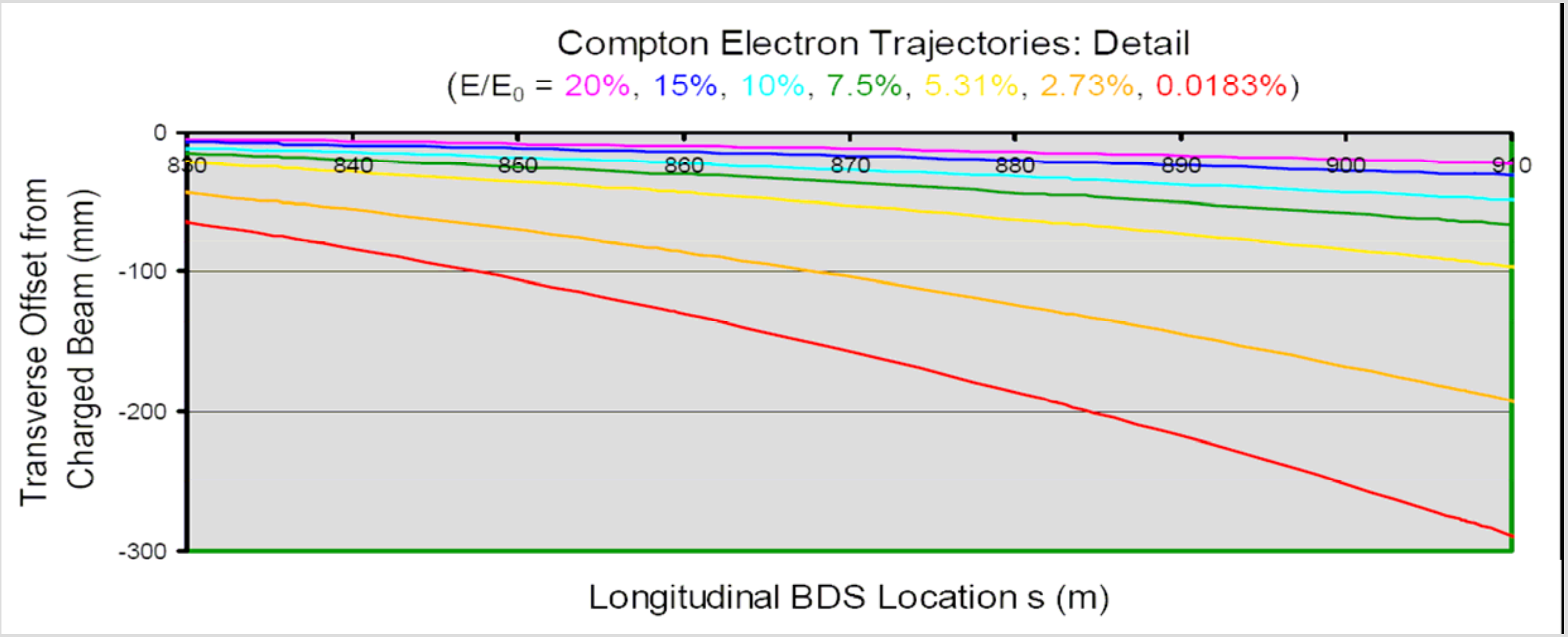
electron detector hodoscope



- 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.)
- could use ~25 channels, 10 mm wide each, to cover a large fraction of the spectrum from the Compton edge to beyond the asymmetry crossing point
- assume minimum distance of 20 mm from the beam axis

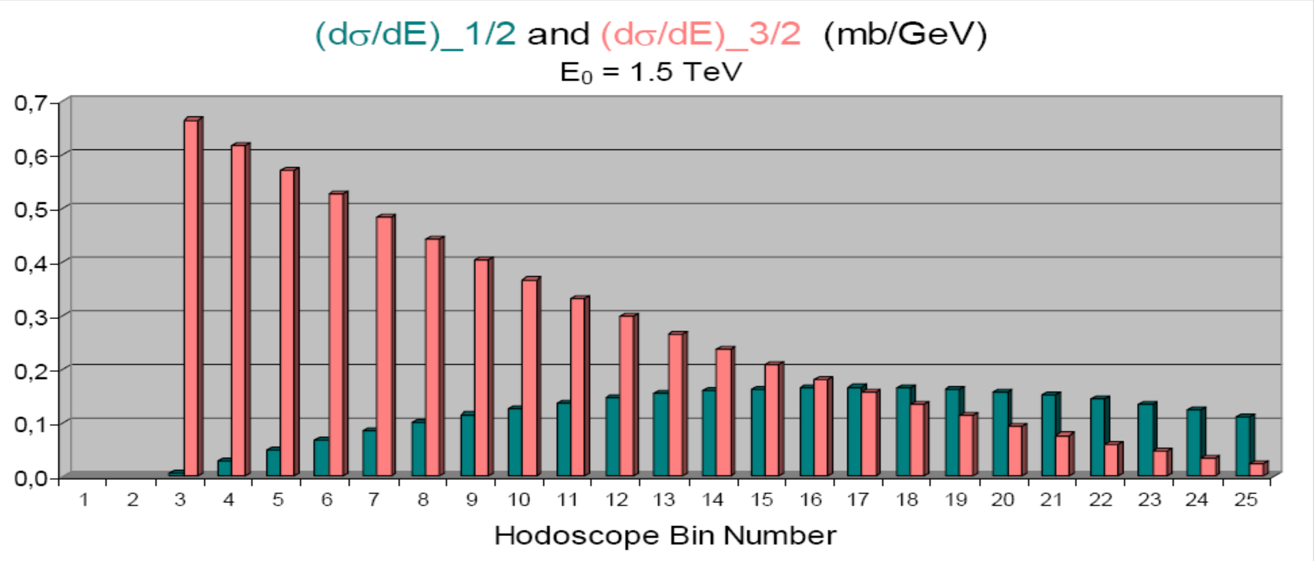
- Compton photon detection is an additional option, but will not be considered here

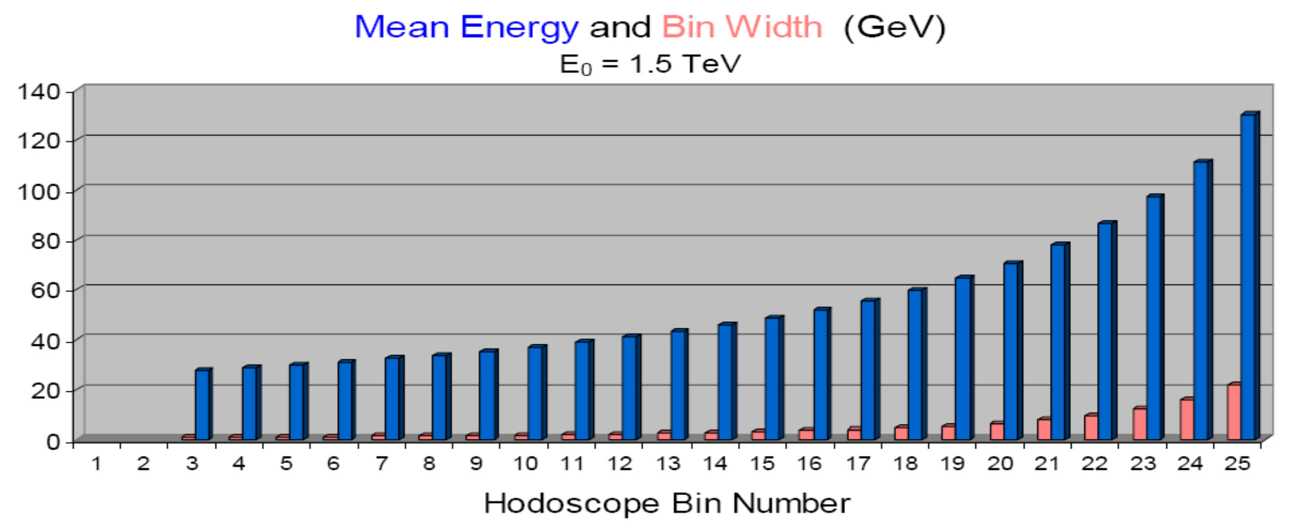
detector hodoscope: where to place it?



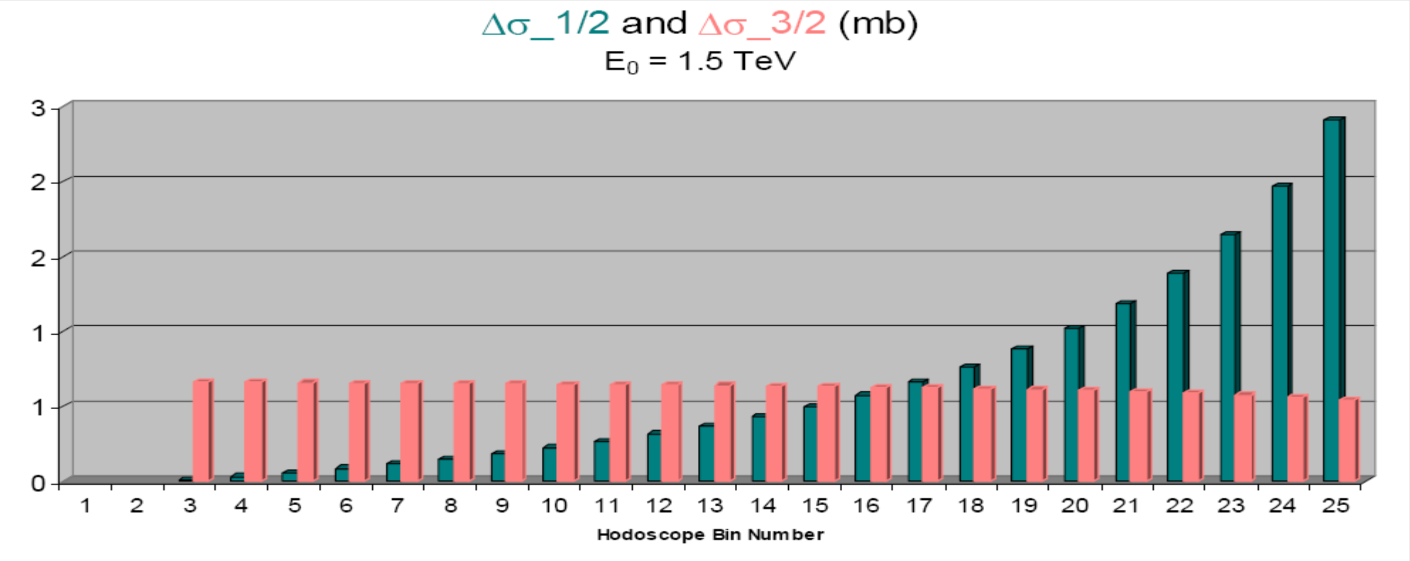
- trajectories shown indicate Compton electrons in the range of interest: red, orange and yellow trajectories correspond to the Compton edge for beam energies of 1.5 TeV, 1.0 TeV and 0.5 TeV.
- a detector position behind 12 dipoles (at s = 907 m) would give excellent coverage for beam energies from 1.5 TeV down to 135 GeV, but would require several wide-aperture dipoles
- a detector position behind 6 dipoles (at s = 835 m) would work only for beam energies down to 511 GeV.

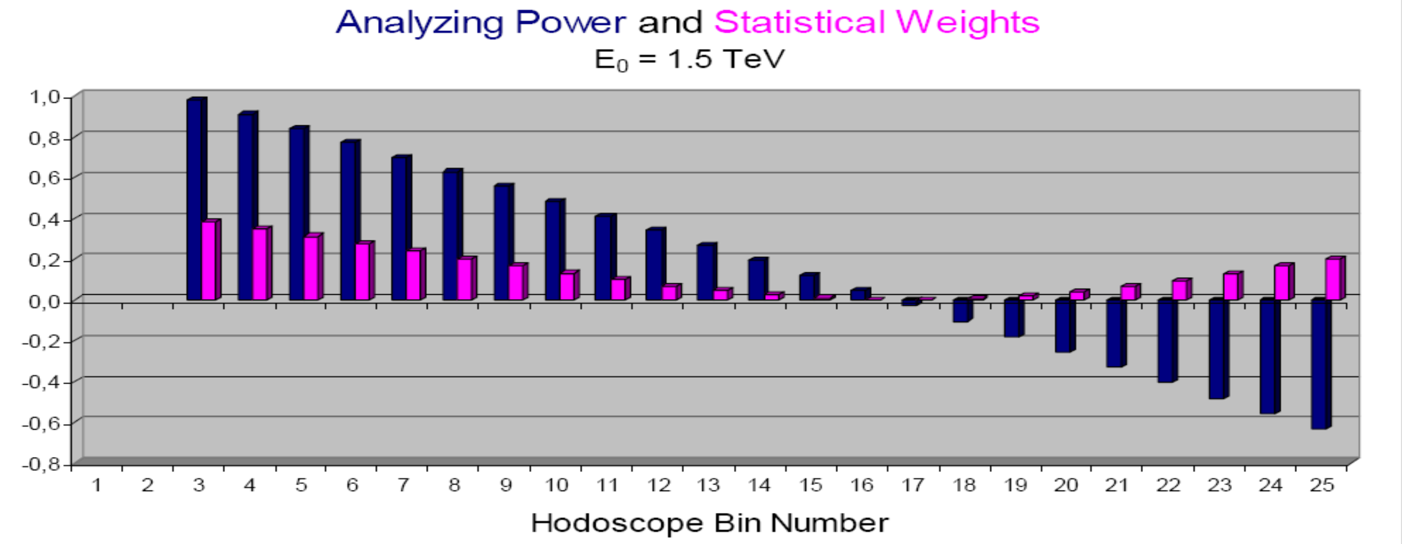
expected performance



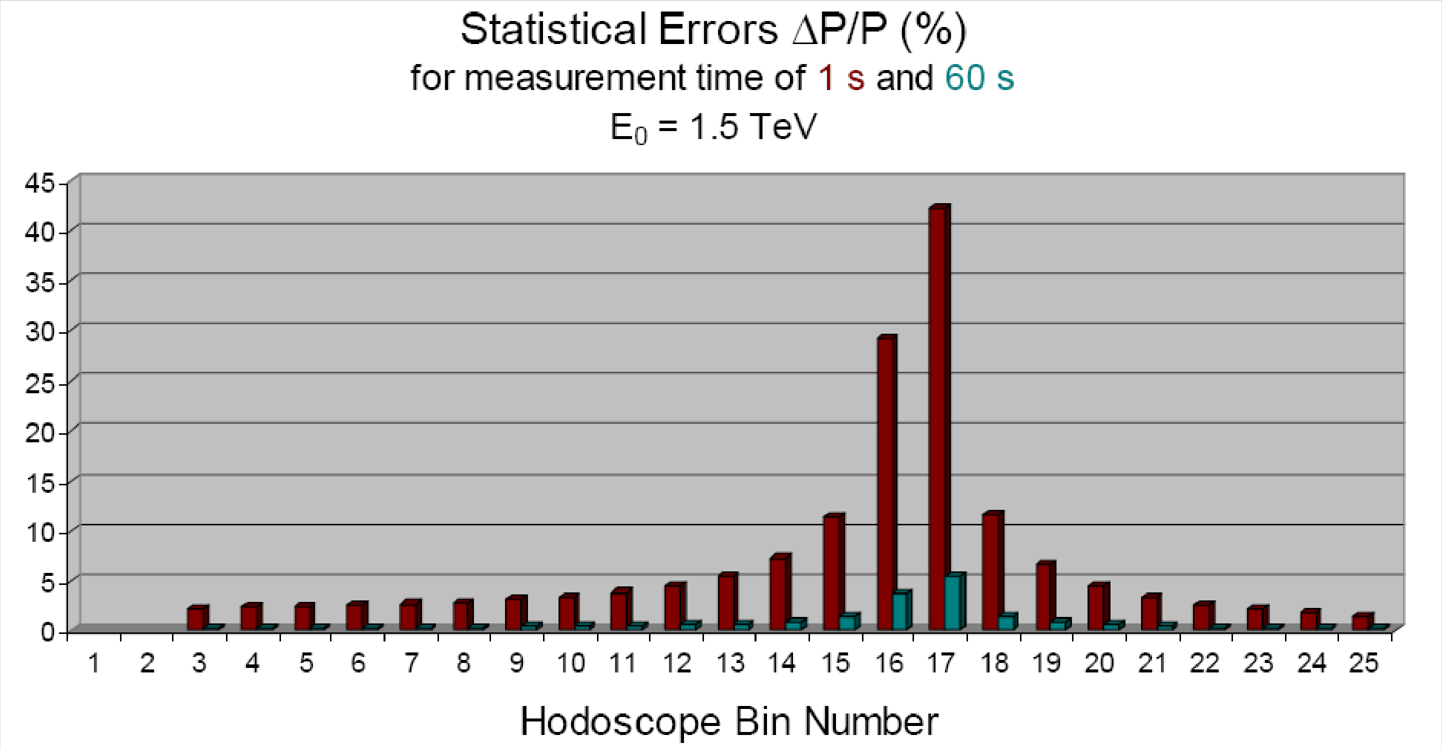


expected performance





expected performance: statistical errors



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%

Conclusions

- the CLIC BDS has a suitable polarimeter location with a laser crossing point at s = 742 m
- detector placement at s = 907 m (behind 12 dipoles) would allow polarimetry from E_0 = 1.5 TeV down to 135 GeV, but would require several wide-aperture dipoles
- detector placement behind a lesser number of dipoles would reduce the aperture requirement, but with diminished low-energy reach, e.g. down to 511 GeV, if placed behind 6 dipoles.
- a standard Q-switched YAG laser operated with 100 mJ/pulse at 50 Hz would already give adequate polarimeter performance although is has low efficiency due to pulse length mismatch