Polarization Considerations for CLIC

Ken Moffeit, *SLAC*

2009 Linear Collider Workshop of the Americas
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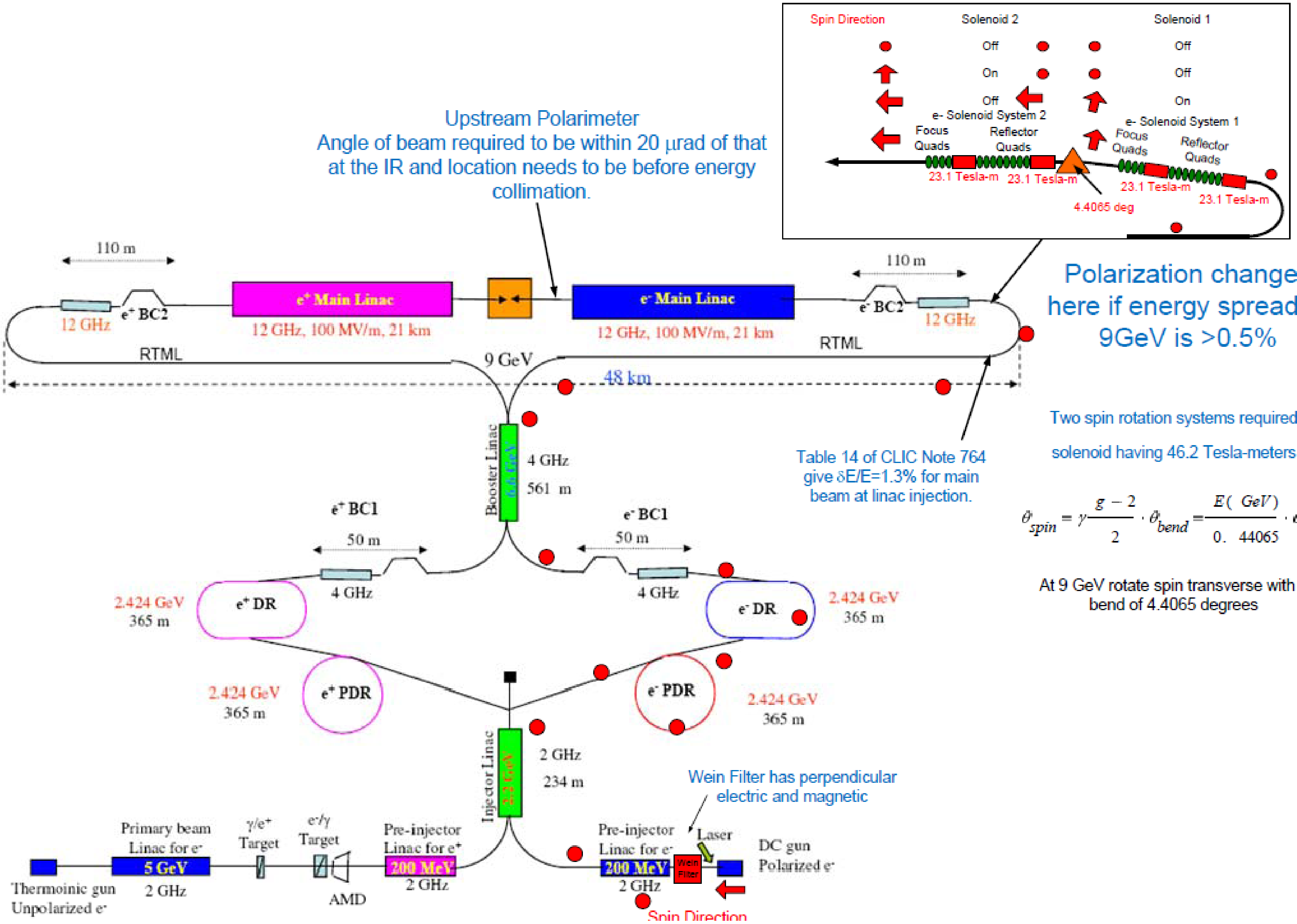
Polarization at CLIC



Upstream Polarimeter
Angle of beam required to be within 20 μrad of that at the IR and location needs to be before energy collimation.

Polarization changes here if energy spread at 9GeV is >0.5%

Table 14 of CLIC Note 764 give δE/E=1.3% for main beam at linac injection.

Two spin rotation systems required

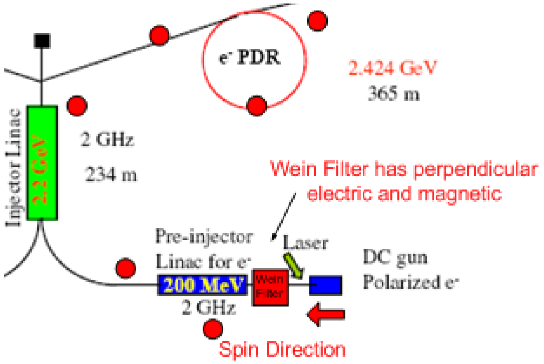
solenoid having 46.2 Tesla-meters

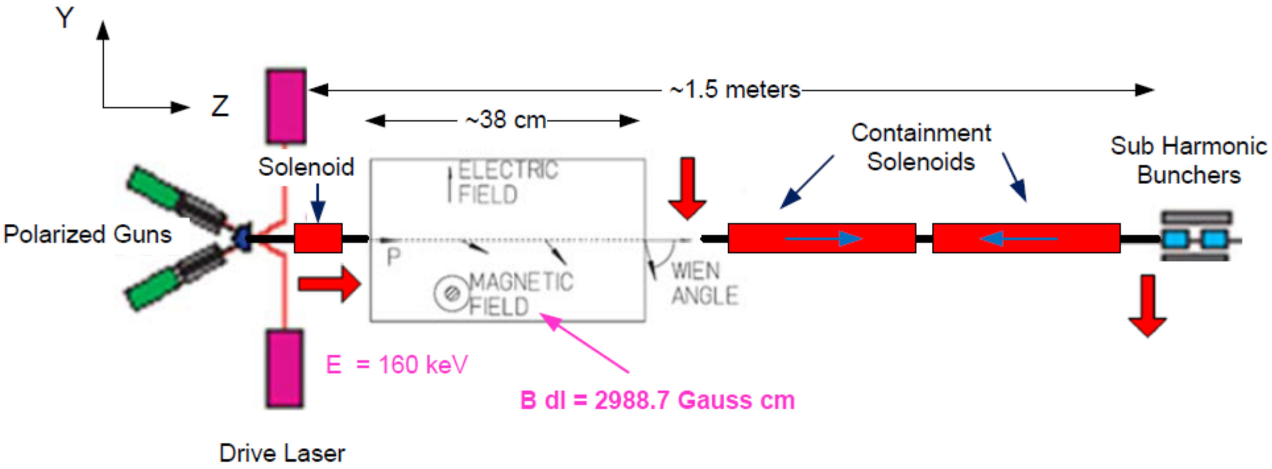
$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(\ GeV)}{0.\ \ 44065} \cdot \theta_{bend}$$

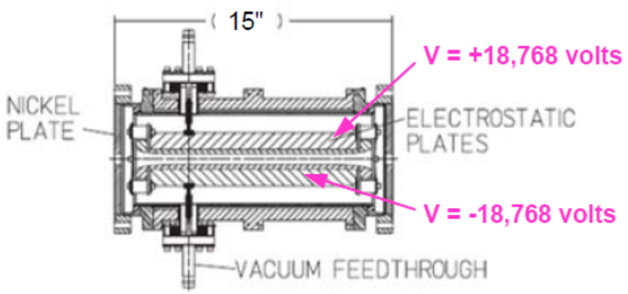
At 9 GeV rotate spin transverse with a bend of 4.4065 degrees

Wein Filter has perpendicular electric and magnetic

Spin Rotation at e^- Source







Wien filter spin manipulator
The magnet is not shown in the cutaway view

ILC source may run above 200 keV to reduce space charge effects.
E=200keV has **B dl ~ 3600 Gauss cm** and **V=+/- 24,253 volts**

C. Y. Prescott, SLAC Engineering Note 71, 8 Feb 1977

Longitudinal depolarization due to energy spread in reverse bend at 9 GeV

$$P = \cos\left(\theta_{spin}\right) = \cos\left(\gamma \frac{g-2}{2} \cdot \theta_{bend}\right) = \cos\left(\frac{E(GeV)}{0.44065} \cdot \theta_{bend}\right)$$

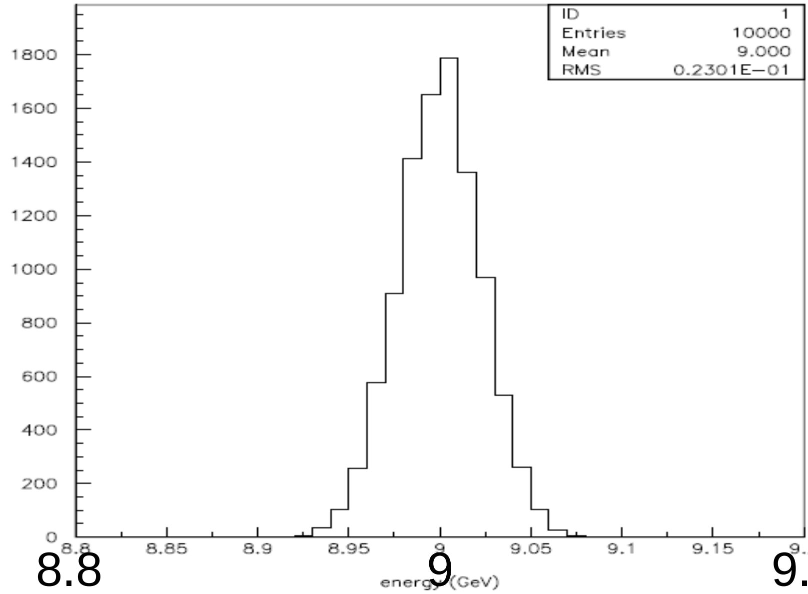
dE/E at 9 GeV	Mean longitudinal or transverse horizontal polarization after 90 deg bend (note: vertical spin component will not be depolarized)
0.25%	99.6%
0.5%	98.6%
1.0%	94.0%
1.3%	90.8%

- Spin diffusion in the 90 degree turnaround at 9 GeV due to an energy spread of less than 0.5% will not be a problem.
- The energy spread at 9 GeV is given as 1.3% in the CLIC-Note-764. Such a large energy spread will destroy the polarization.
- Conclusion: CLIC will have to do the spin rotation after the reverse bend unless energy spread at 9 GeV is less than 0.5%

Beam energy 9 GeV

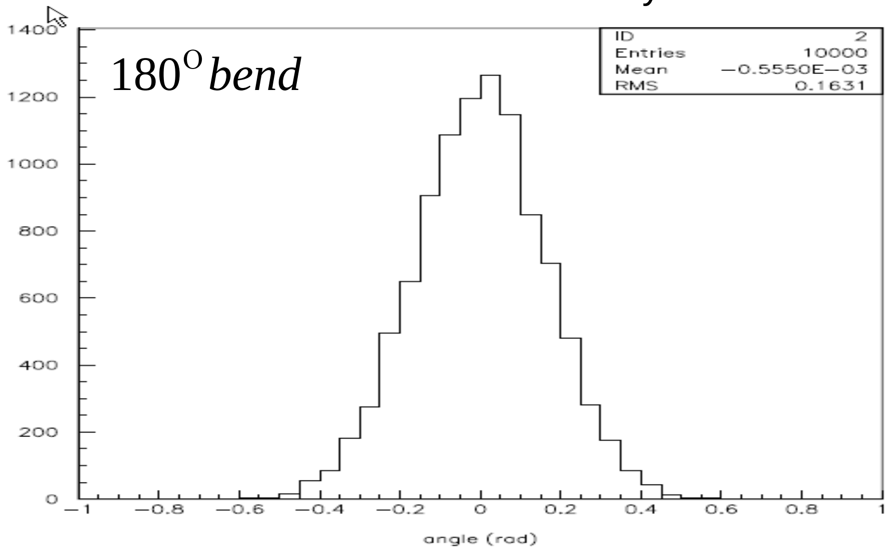
Energy spread 0.25%

Plots from Takashi Maruyama

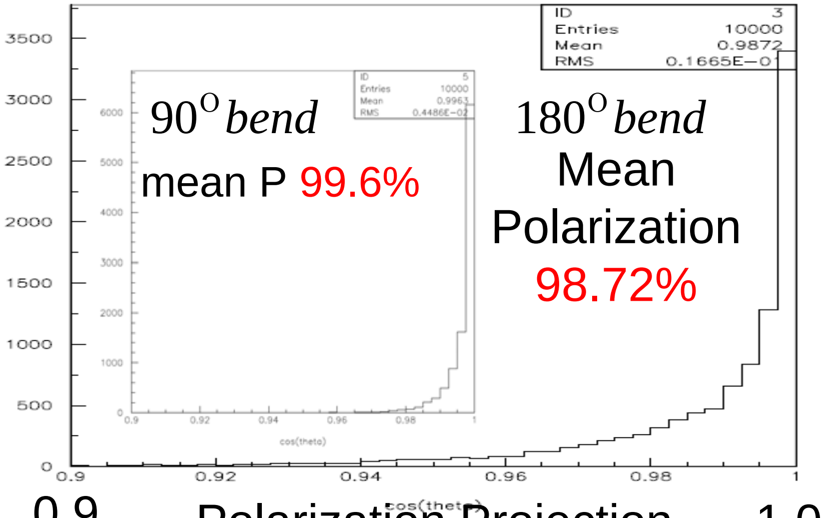


8.8 9 9.2

Energy in GeV



180^{o} *bend*



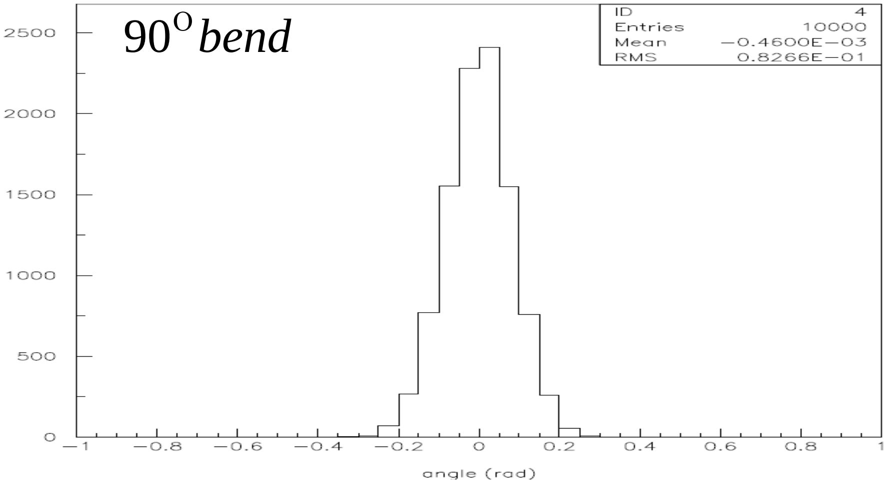
90^{o} *bend*

mean P 99.6%

180^{o} *bend*

Mean Polarization 98.72%

0.9 Polarization Projection 1.0



90^{o} *bend*

Spin direction angle (radians)
after reverse bend

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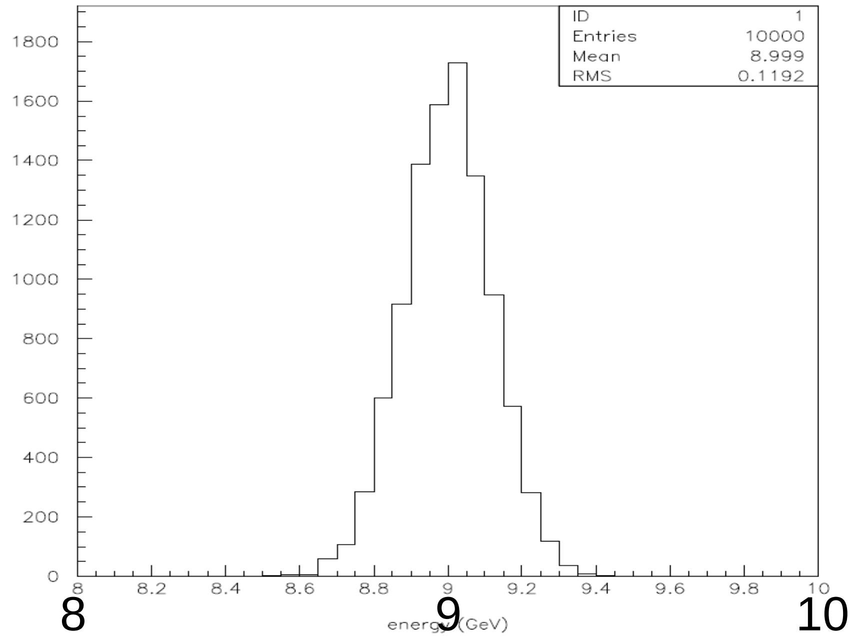
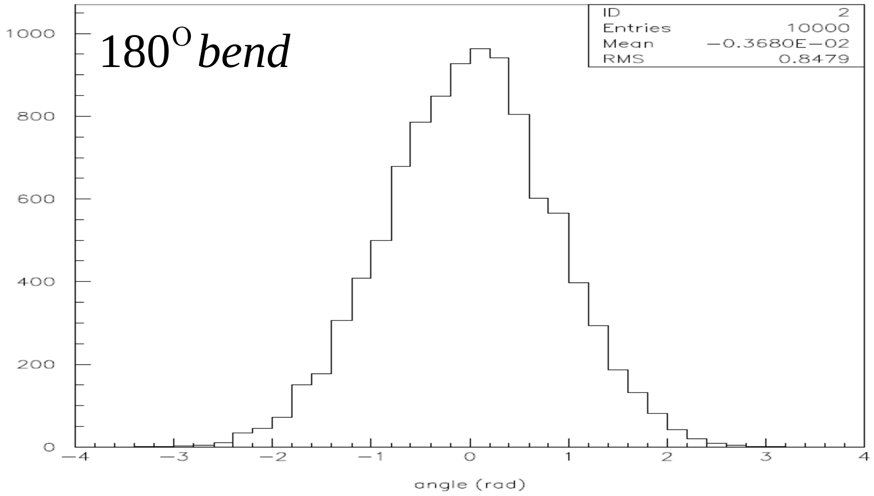
Beam Energy 9 GeV

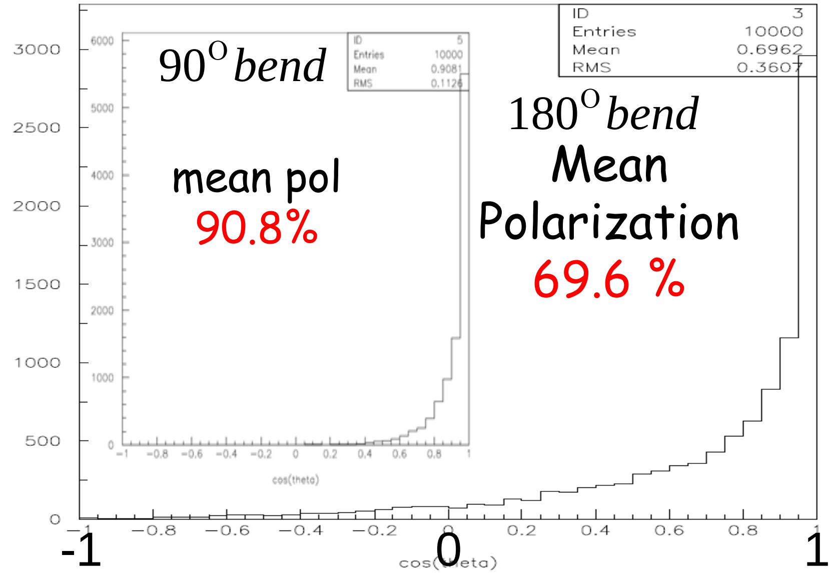
Energy spread 1.3%

Plots from Takashi Maruyama





180^{O} bend

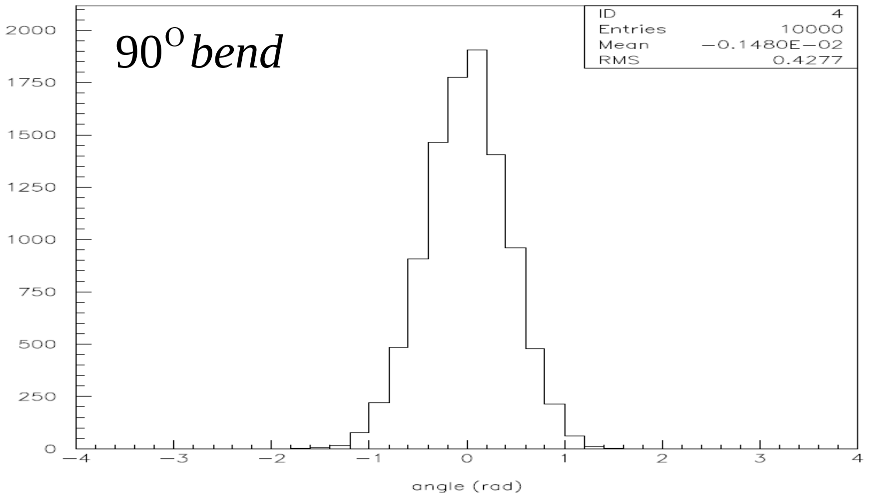


90^{O} bend

mean pol
90.8%

180^{O} bend
Mean
Polarization
69.6 %

Polarization Projection

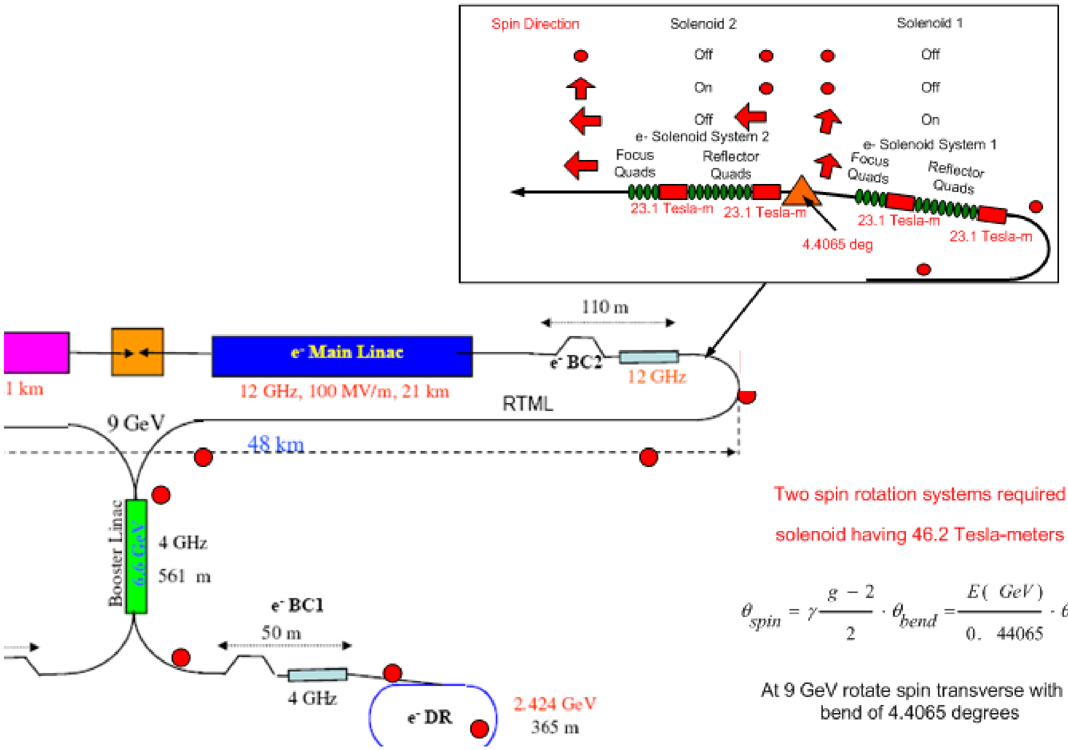


90^{O} bend

Spin direction angle (radians)
after reverse bend

Large spin diffusion !!!

Spin Rotation at 9 GeV



Two spin rotation systems required

solenoid having 46.2 Tesla-meters

$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(\ GeV)}{0.\ 44065} \cdot \theta_{bend}$$

At 9 GeV rotate spin transverse with a bend of 4.4065 degrees

- Difficulty and cost of the 46.2 T-m superconducting spin rotator system.
- Requires a 9 GeV flat-beam spin rotation system proposed by Paul Emma, which, includes half solenoids with a reflector beam line between them to eliminate cross plane coupling and focusing elements to remove the focusing effects of the solenoid (NLC-Note-7 Dec 1994).

The baseline design is to have spin rotation at 9 GeV. But we have no real study of the requirements for the spin rotator. Daniel Schulte

Bottom line: Physics requires $\boxed{\geq 0.99 \times P_{e^-}^{Source}}$ at injection to main linac.

CLIC Polarimeter

Orbit angle tolerances at Compton IP and IR due to spin precession considerations

$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend}$$

$$= 3404.06 \cdot \theta_{bend} \; at\, 1.5 TeV$$

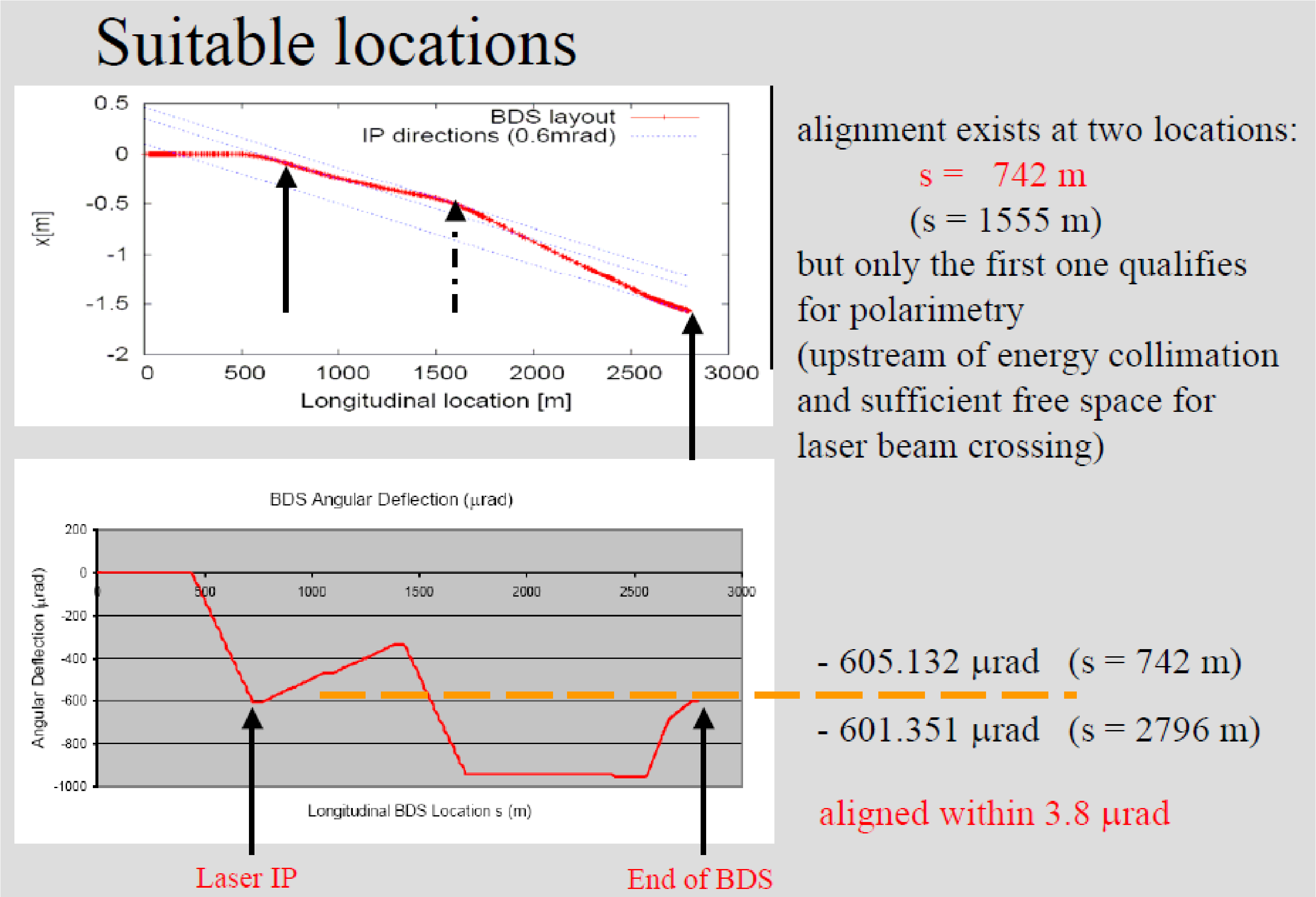
Change in spin direction for various bend angles and the projection
Of the longitudinal polarization. Electron beam energy is 1.5 TeV.

Change in Bend Angle	Change in Spin Direction	Longitudinal Polarization Projection
100 μrad	340.4 mrad (19.5 degrees)	94.26%
50 μrad	170.2 mrad (9.75 degrees)	98.55%
25 μrad	85.1 mrad (4.87 degrees)	99.64%
13 μrad	45 mrad	99.9%

For δP/P = 0.1% implies angle at Compton IP and IR is aligned to better than 13 μrad.
Polarimeter needs to be before energy collimator to clean up Compton electrons.

Upstream Polarimeter

Requirements: $\Delta P/P = 0.25\%$ measurement robust and fast



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

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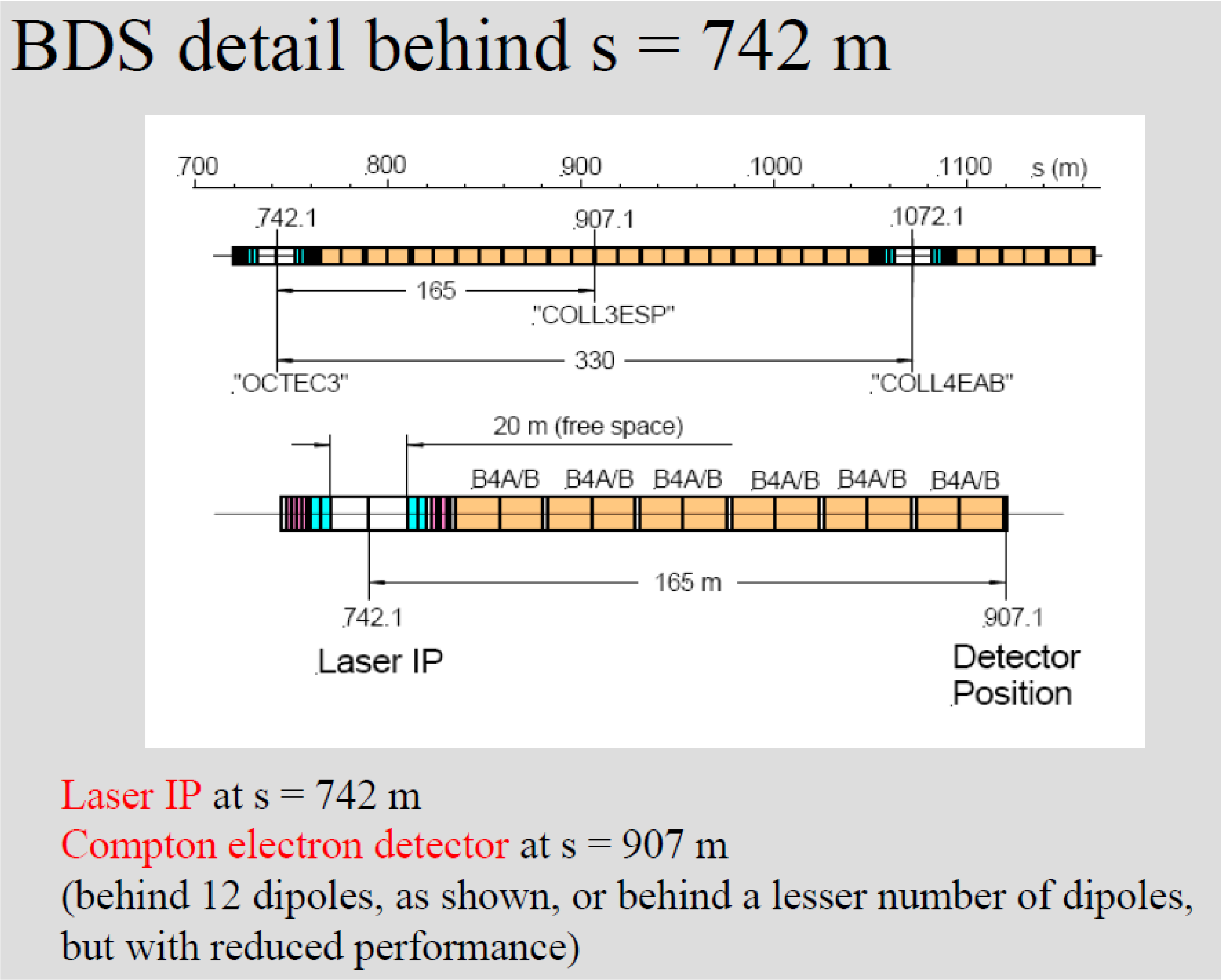

BDS detail behind s = 742 m

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)

No dedicated polarimeter chicane! Use BDS dipole bends. May require a few special bend magnets to allow Compton electrons out.

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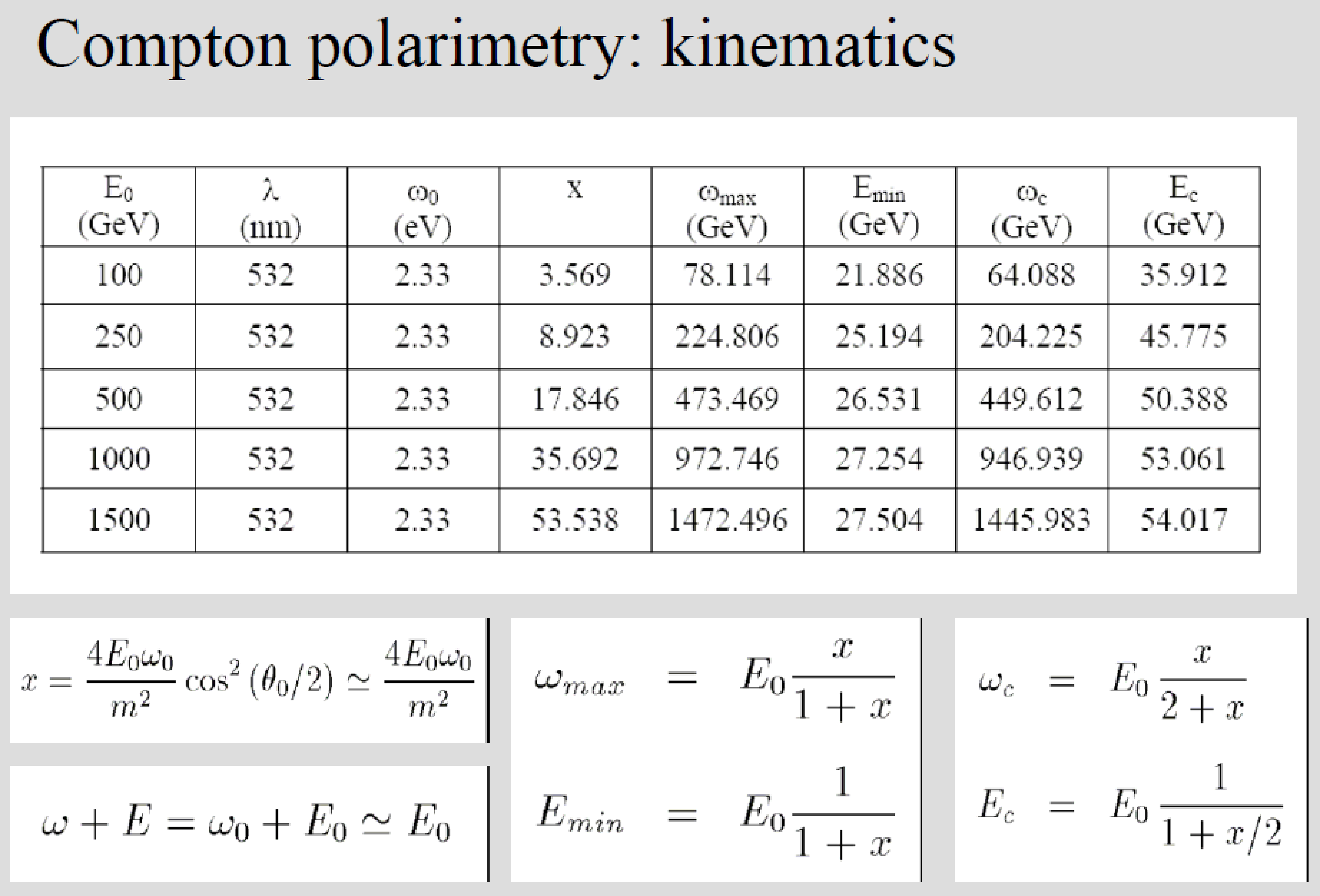

Compton polarimetry: kinematics

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

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

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

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

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

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

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

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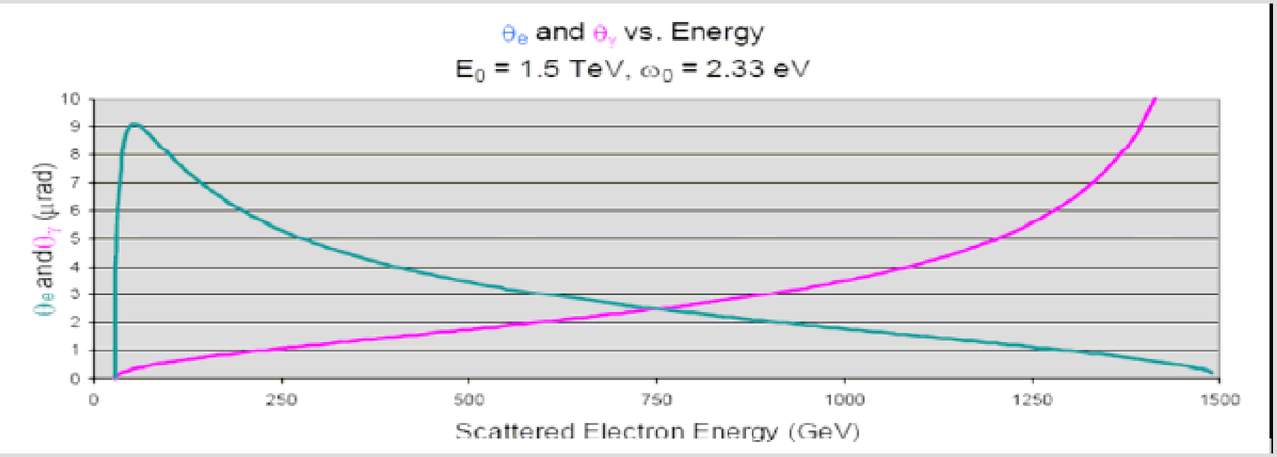
scattering angles, cross sections

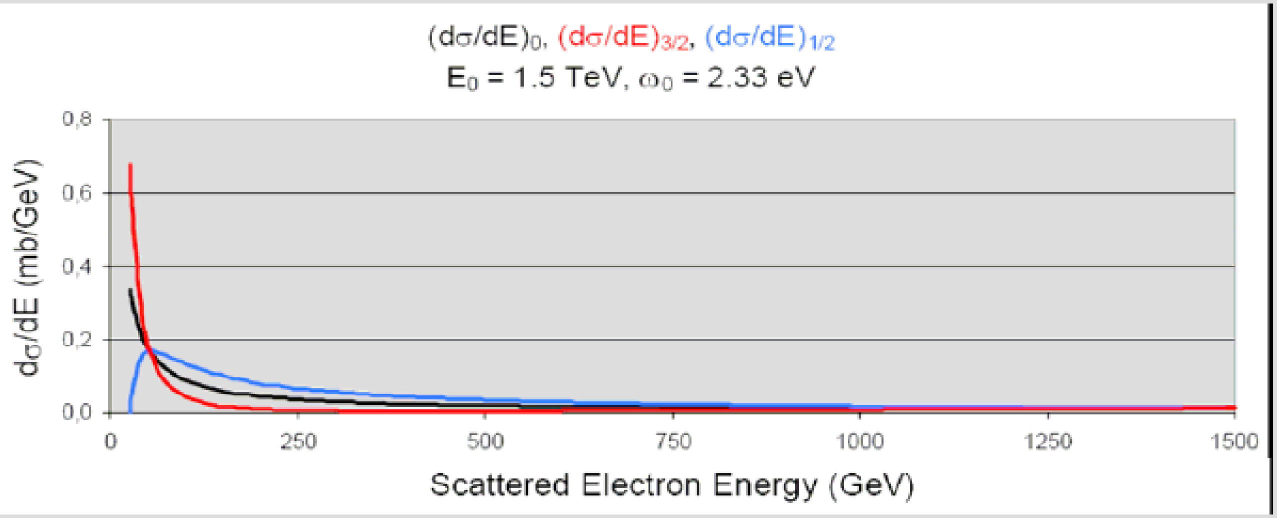
$$\begin{aligned}\theta_\gamma &= \frac{m}{E_0}\sqrt{\frac{x}{y}-(x+1)}\\ \theta_e &= \frac{y}{1-y}\theta_\gamma\end{aligned}$$



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

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

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



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

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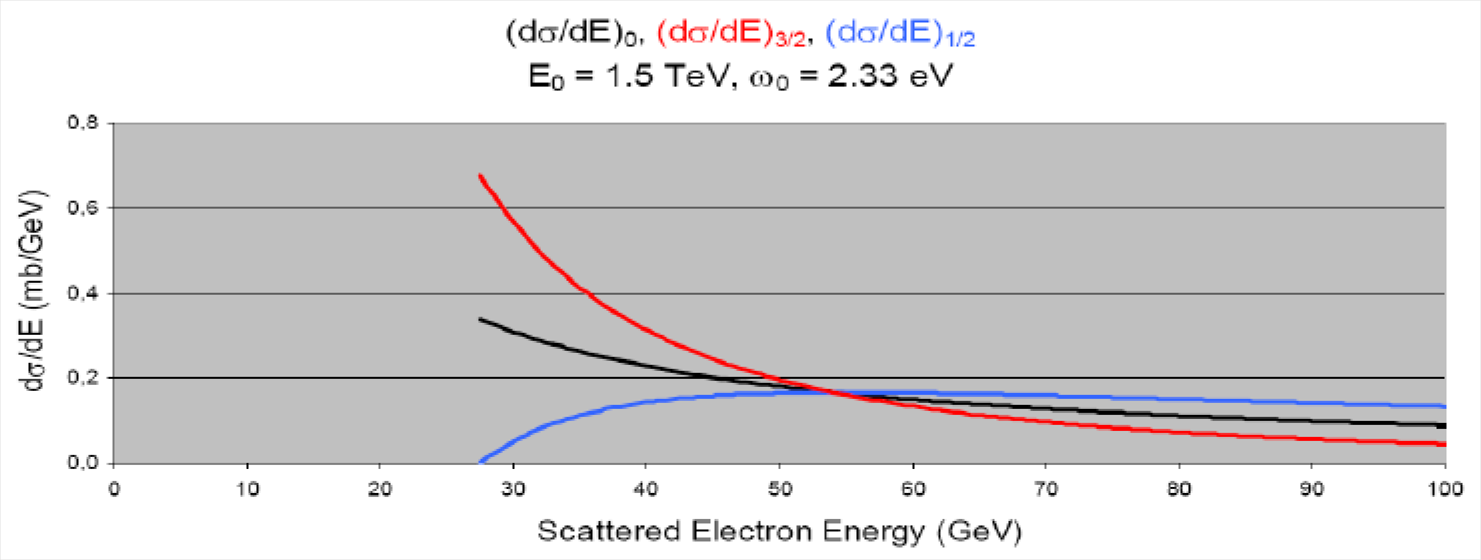
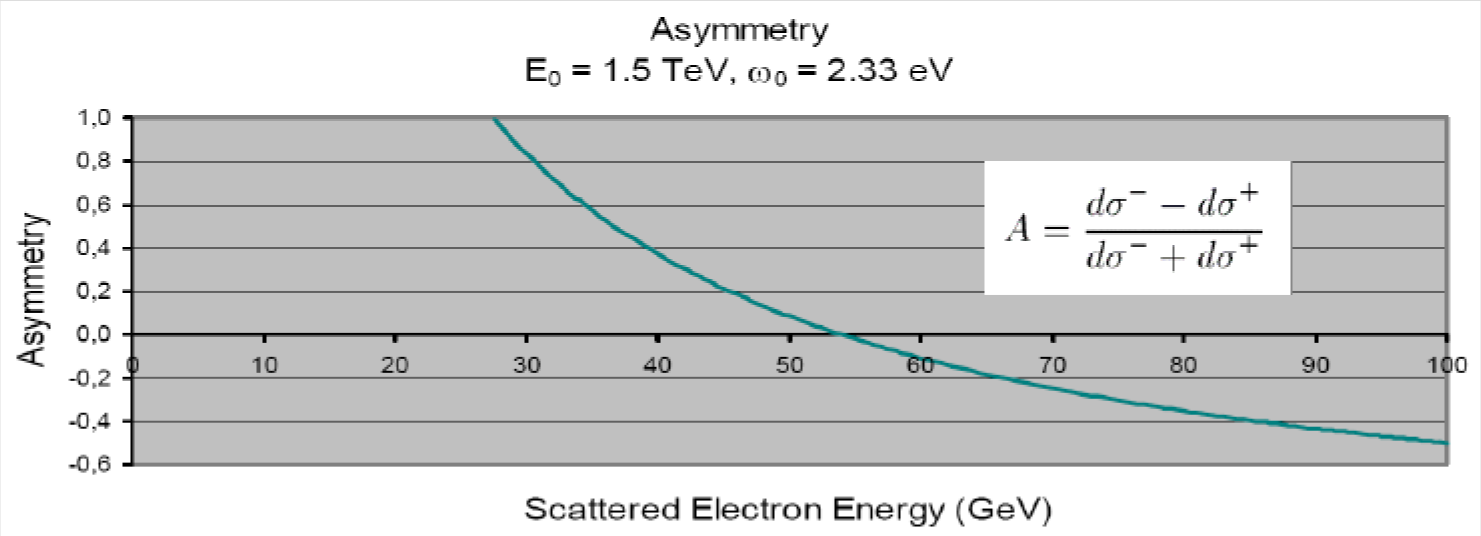
cross sections and spin asymmetry near the Compton edge





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

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Q-switched YAG lasers

-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 ~ 1 ns), will cover ~5 adjacent CLIC bunches
- -laser spot size $\sigma x = \sigma y$ = 50 mm
- -crossing angle of θ_0= 10 mrad

Recent new product from Quantel

New Quantel Pizzicato B

- -30 mJ pulse energy at 532 nm (2.33 eV)
- -20 Hz operation
- -35 picoseconds

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 :

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

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

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

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

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

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

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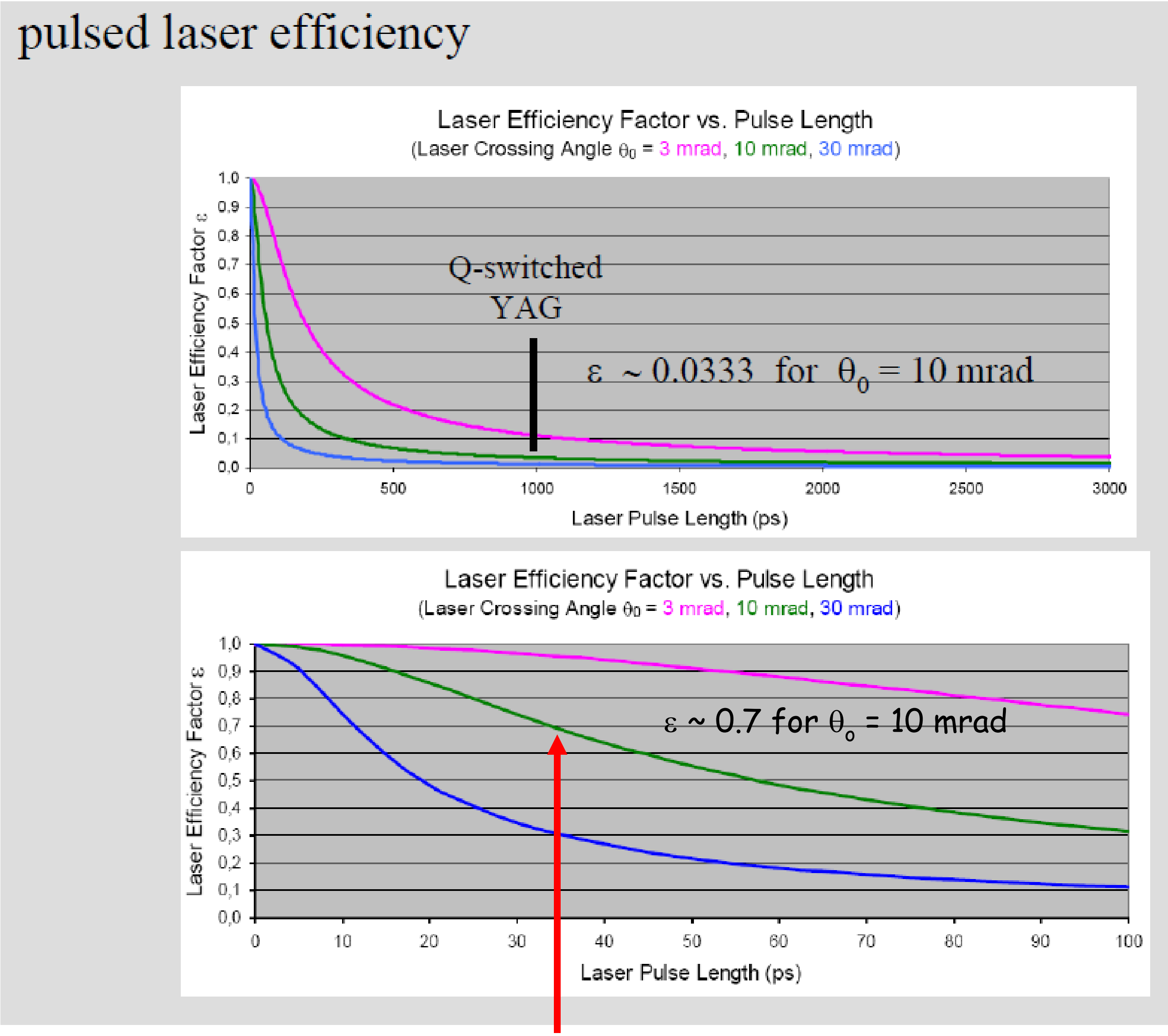

pulsed laser efficiency

Q-switched YAG

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

$\varepsilon \sim 0.7$ for $\theta_o = 10$ mrad

New Quantel Pizzicato B (35 ps)

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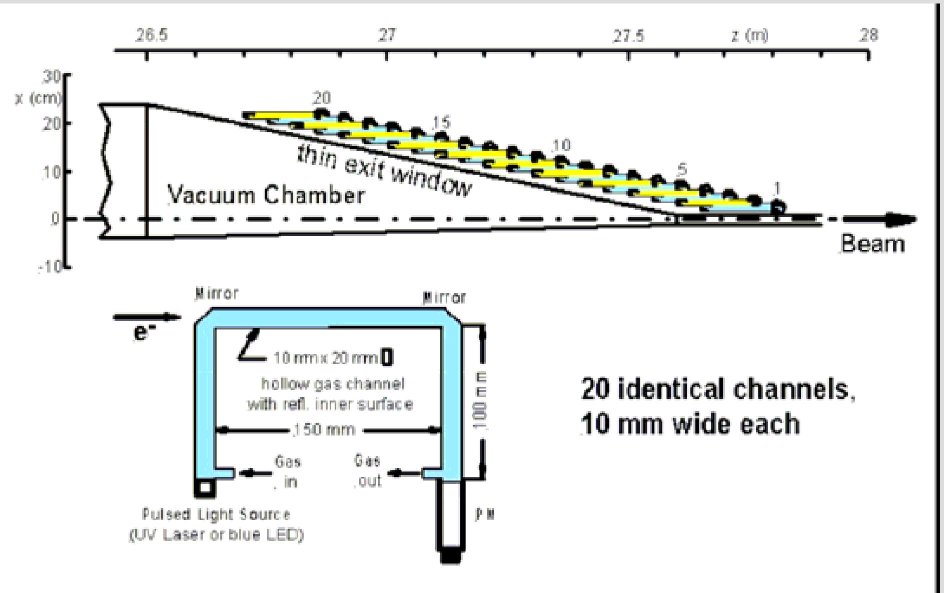
electron detector hodoscope



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.)
- 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

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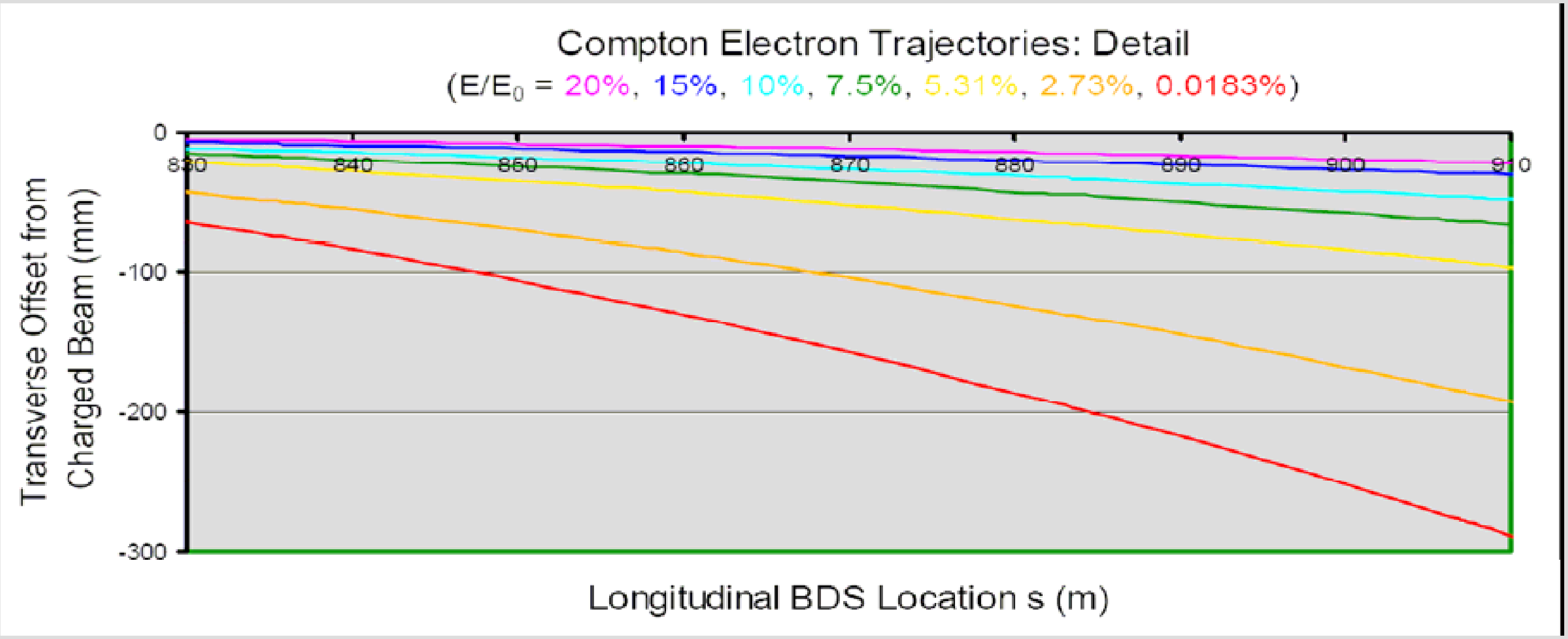
detector hodoscope: where to place it?



- 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.

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expected performance

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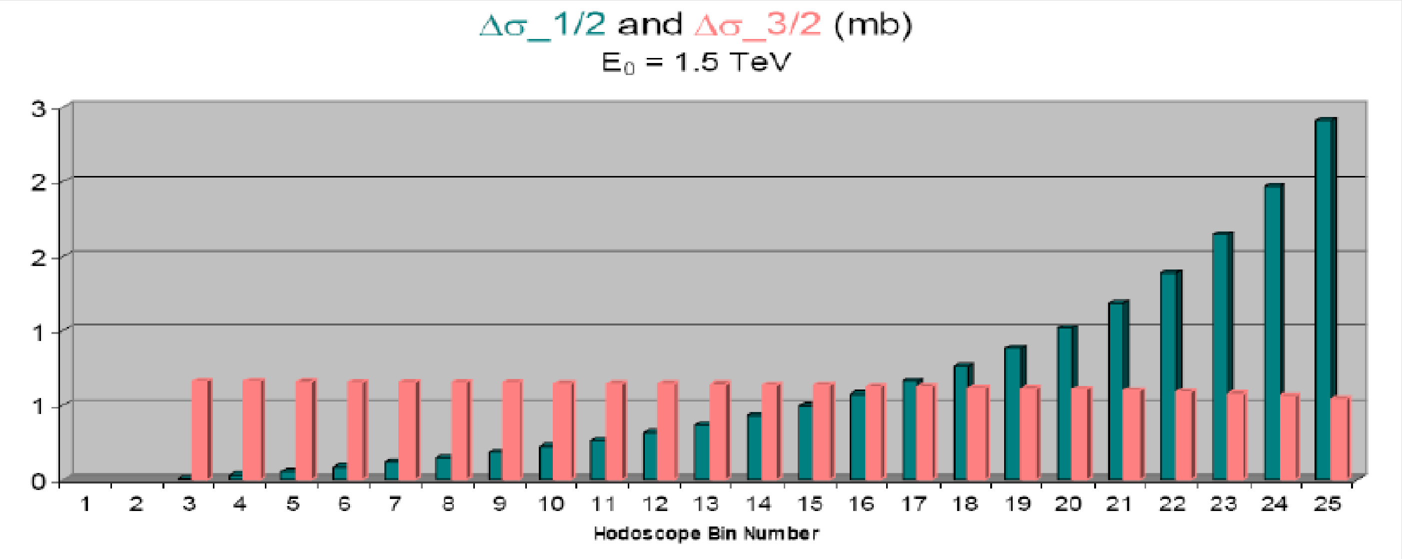
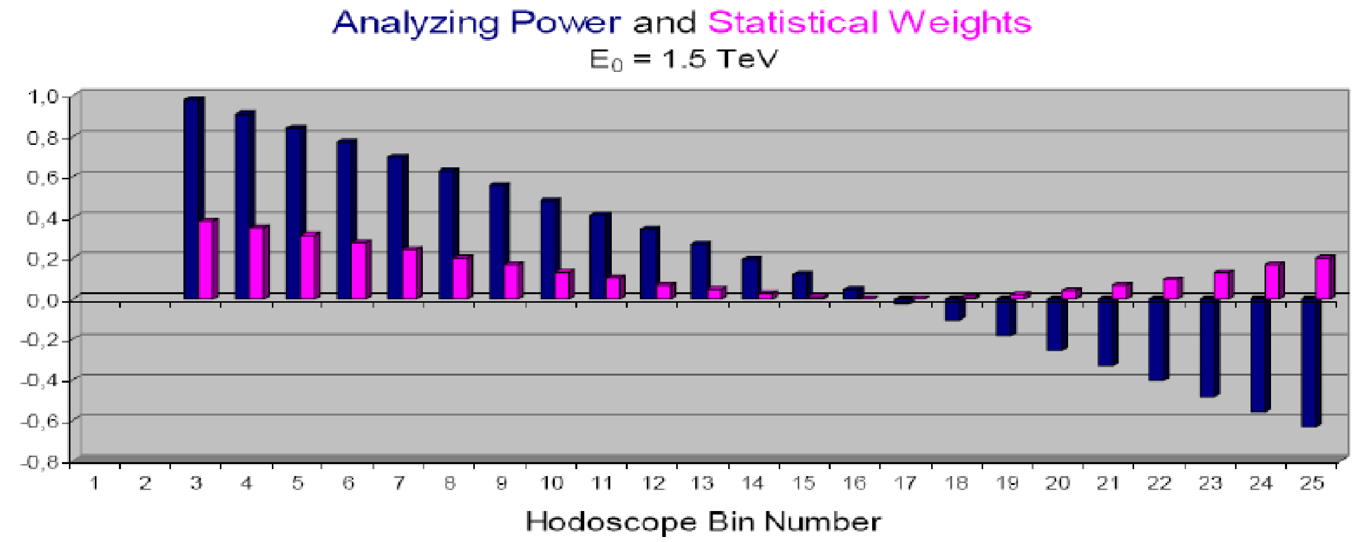
expected performance


$\Delta\sigma$_1/2 and $\Delta\sigma$_3/2 (mb)

E_0 = 1.5 TeV


Analyzing Power and Statistical Weights

E_0 = 1.5 TeV

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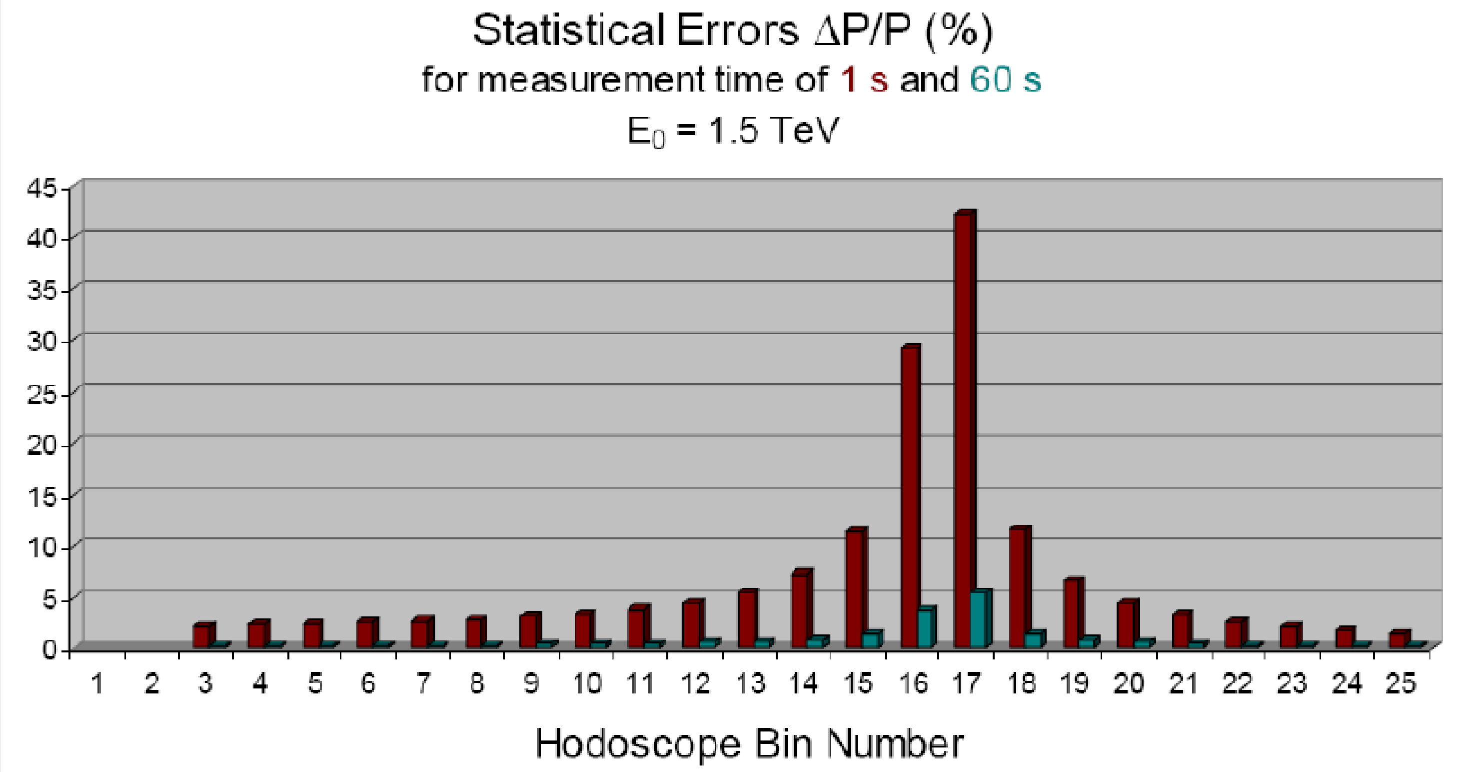
expected performance: statistical errors



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%

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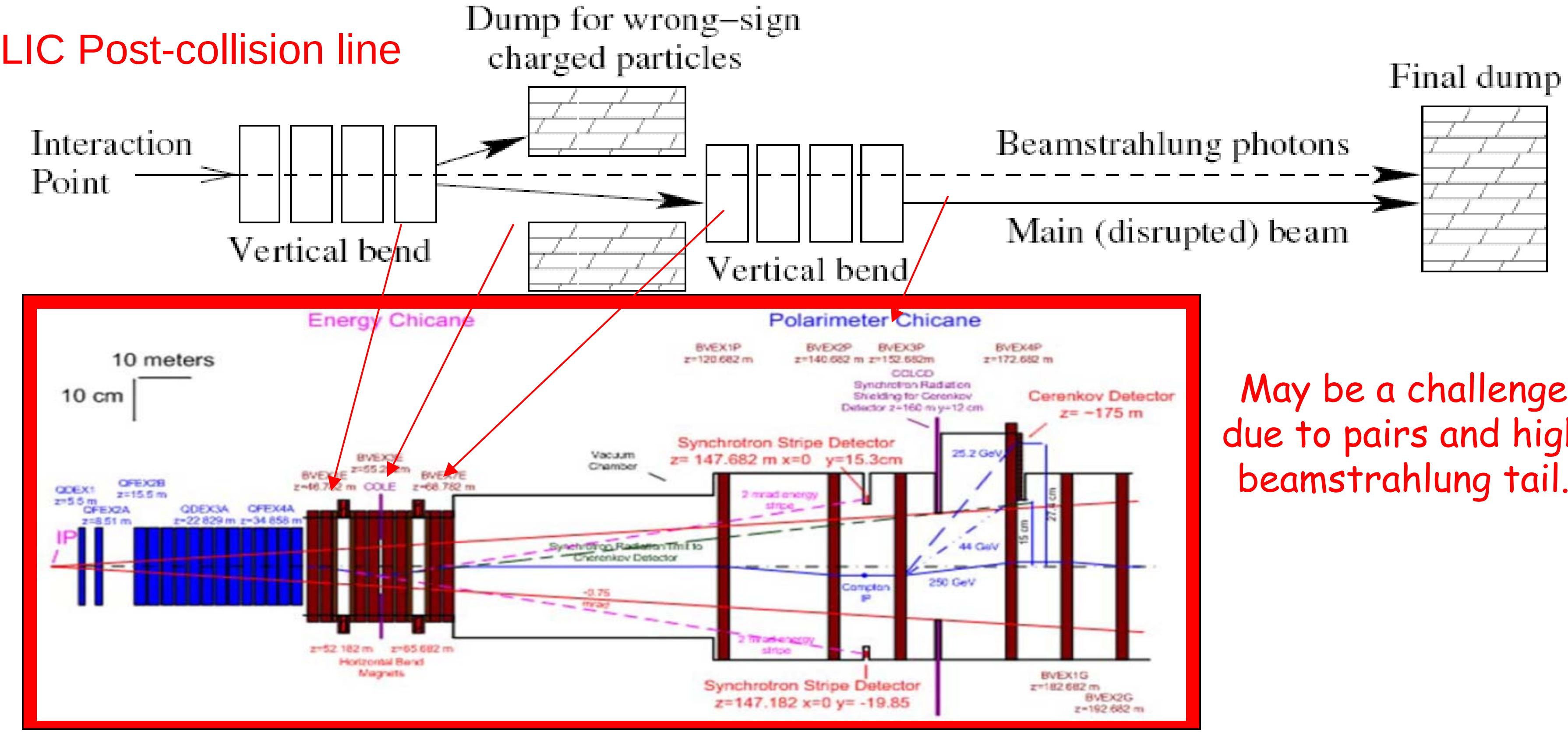
Extraction Line Polarimeter

- Allows ILC type extraction line polarimeter and energy measurement below ~500 GeV beam energy. Important to understand systematic errors of upstream polarimeter.
- At 1.5 TeV polarization and energy can be measured with beams out of collision at low rate of ~1 hertz. Energy measurement may be possible at all energies to 1.5 TeV.
- Magnet apertures may be larger than ILC
- Costs ~$5 million for polarimeter. Add costs for quads and energy chicane.

CLIC Post-collision line



May be a challenge due to pairs and high beamstrahlung tail.

Conclusions

- Spin rotation near electron source to direction perpendicular to damping ring using Wein filter.

- Spin rotation after damping ring will be located after the reverse bend and before injection to main linac at 9 GeV.

  The spin rotation system at 9 GeV requires two spin rotation systems each with two superconducting solenoids of 23.1 tesla-meters.

Physics requires $\boxed{\geq 0.99 \times P_{e^-}^{Source}}$ at injection to main linac.

- CLIC BDS has a suitable upstream polarimeter location at s=742m
- Compton detector placement as s = 907 m (behind 12 dipoles) would allow polarimetry from 1.5 TeV down to 135 GeV, but would require several wide-aperture dipoles.
- A standard Q-scitched YAG laser operated at 50 Hz would give adequate polarimeter performance. New 35 ps laser from Quantel would increase laser efficiency from 3.3% to ~ 70%.

- Upstream polarimeter: Beam direction at upstream Compton IP must be the same as the beam direction at the IR within 13µrad. Compton polarimeter must be upstream of energy collimator.
- Downstream polarimeter in extraction line useful for understanding systematic errors in polarization measurement. May be difficult to operate at full CLIC energy and luminosity due to backgrounds from large beamstrahlung.
- Energy measurement upstream required (needs design). Downstream energy measurement useful for physics.