Polarimeter Studies for TESLA

General Considerations

Spin Motion in BDS; Suitable Pol. Locations; Alignment Tolerances; Beam-Beam Effects; Compton vs. Møller/Bhabha.

Compton Polarimeter

Basics; X-Sections; Asymmetries; Ang. Dist's; Potential Background Processes; Laser System; Laser Location; Pulsed Laser Luminosity; Som Numbers; more Numbers; Dipole Design; Electron Spectrometer; Electron Detector; Syst. Errors; Conclusions.

Møller Scattering

A study by Gideon Alexander & Iuliana Cohen of Tel-Aviv University.

General Considerations

Spin Motion in BDS

$$\vartheta_{spin} = \frac{E}{0.44\,\text{GeV}}\,\vartheta_{orbit}$$

typical BDS bend angles: $\vartheta_{orbit} \approx \pm 3$ mrad

250 GeV: $\vartheta_{spin} = 568 \times \vartheta_{orbit} = \pm 100°$

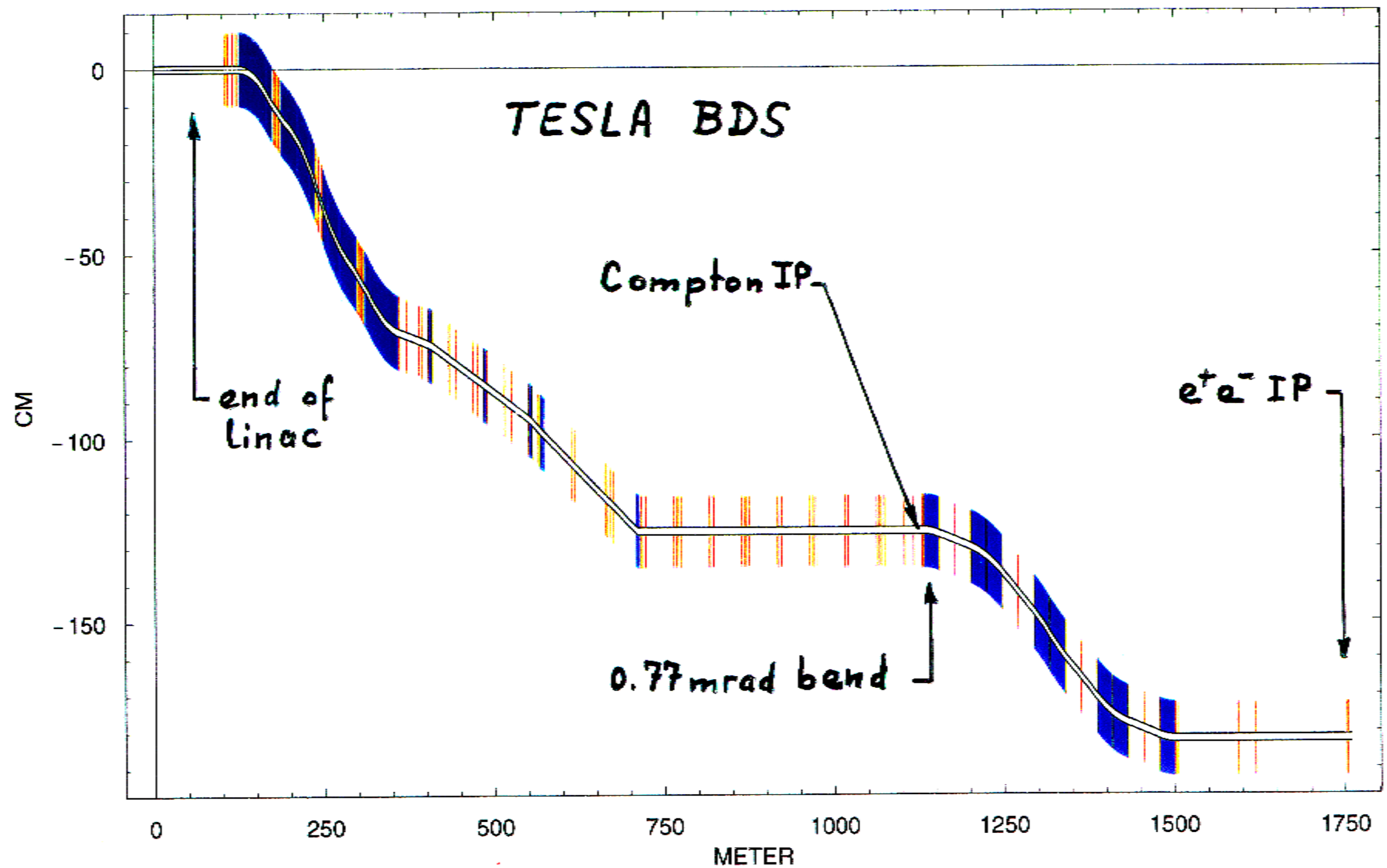
(400) (909) ($\pm 160°$)

Suitable Polarimeter Locations

→ Straight Sections precisely aligned ($\vartheta_{orbit} = 0$) with e^+e^- collision axis

⇒ "Tuning Region" has been selected ($z = -630$ m)

→ no practical "Downstream" Location was found


TESLA BDS
0
-50
-100
-150
CM
0
250
500
750
1000
1250
1500
1750
METER
end of linac
Compton IP
0.77 mrad bend
e+e- IP

General Considerations

Alignment Tolerances

$\frac{\Delta P}{P} \leq 0.1\%$ $\longrightarrow$ $\Delta \vartheta_{spin} \leq 45$ mrad

250 GeV: $\Delta \vartheta_{orbit} \leq 80$ μrad
(400) (50)

$\Rightarrow$ easy to achieve,
actually should be much better

Beam - Beam Effects

(a) at 250 GeV

ϑ_x^{orbit} (rms) = 245 μrad
ϑ_y^{orbit} (rms) = 27 μrad
} disrupted beam spread (from O. Napoly)

$\Rightarrow$ { ϑ_x^{spin} (rms) = 139 mrad, ϑ_y^{spin} (rms) = 15 mrad } $\Rightarrow$ $\frac{\Delta P}{P} \approx 0.5\%$

(b) at 400 GeV $\frac{\Delta P}{P} \approx 0.5\%$

$\Rightarrow$ upstream polarimeter
location should be ok

General Considerations

Compton vs. Møller/Bhabha

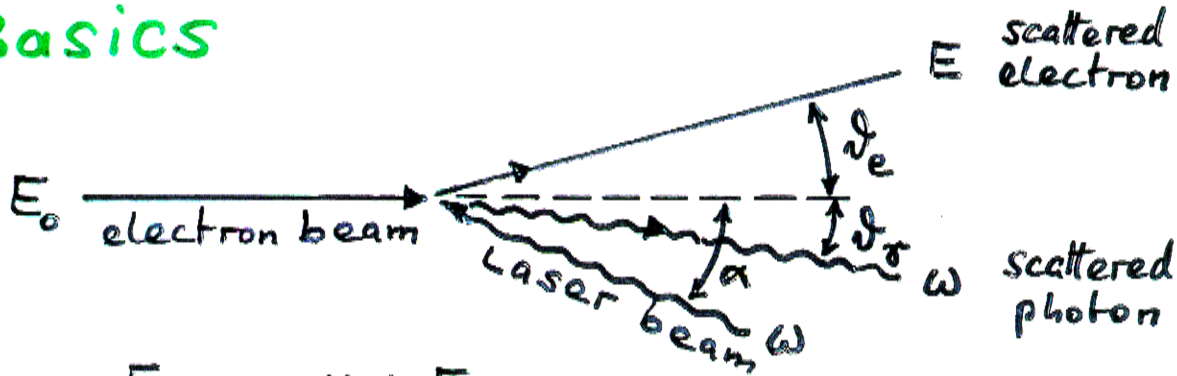
	Compton	Møller Bhabha
basic QED process	✓	✓
higher order terms known	✓	✓
well-established technique	✓	✓
$\Delta P/P \sim 0.5\%$ is possible	✓	✓
works with e^- and e^+	✓	✓
non-destructive to e^+e^- physics data taking	✓	No

→ the Møller technique would work, if a suitable downstream location could be found

→ for upstream locations, it could only be used for machine studies

Compton Polarimeter

Basics

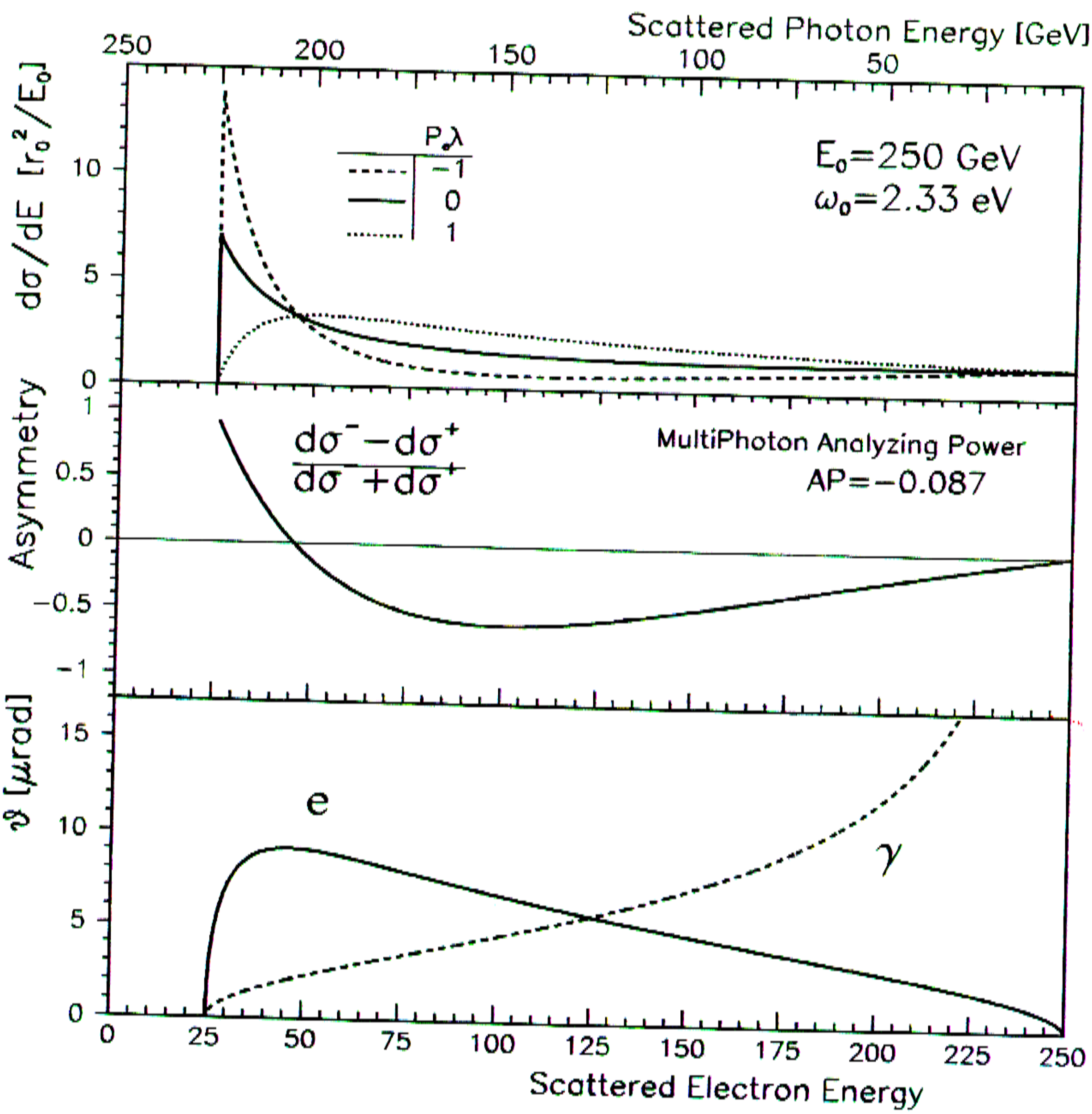


$$E_0 = \omega + E$$

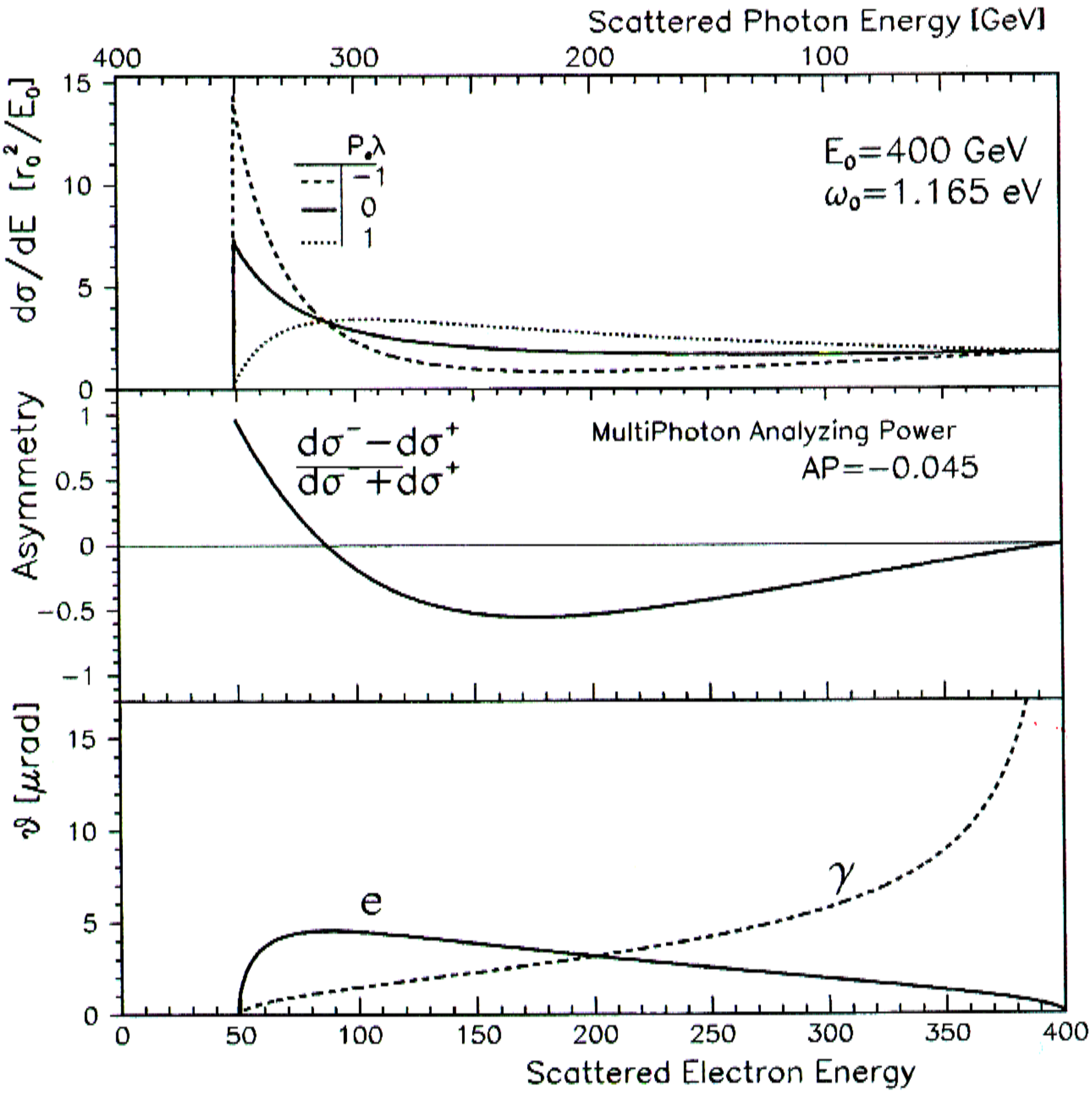
$$x = \frac{4\omega_0 E_0}{m^2}\cos^2\frac{\alpha}{2} \approx \frac{4\omega_0 E_0}{m^2}$$

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

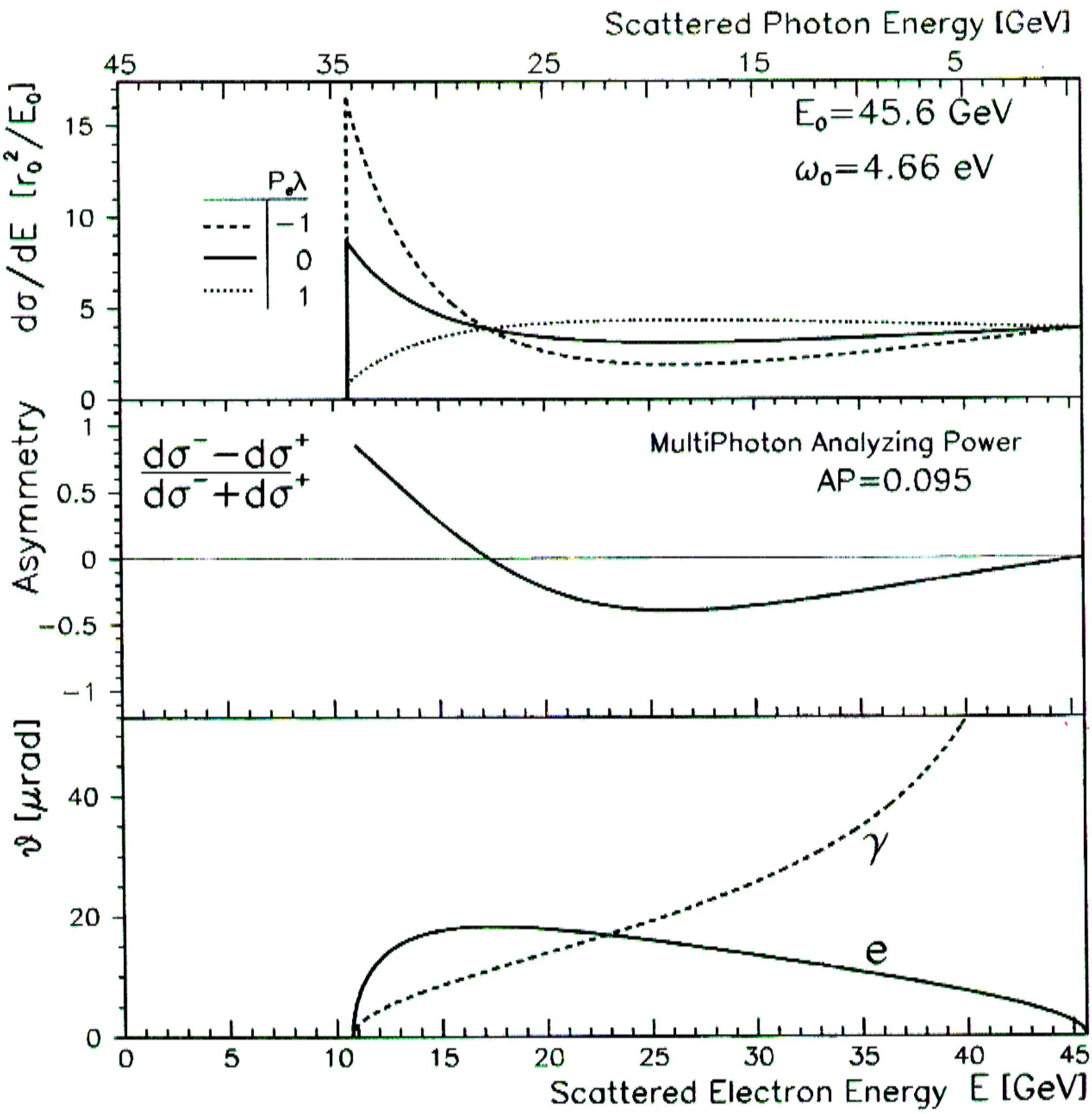
E_0 (GeV)	λ (nm)	ω_0 (eV)	x	ω_{max} (GeV)	E_{min} (GeV)
45.6	1064	1.165	0.813	20.4	25.2
	532	2.33	1.63	28.3	17.3
	266	4.66	3.25	34.9	10.7
250	1064	1.165	4.46	204	46
	532	2.33	8.92	225	25
	266	4.66	17.8	237	13
400	1064	1.165	7.14	351	49
	532	2.33	14.3	374	26
	266	4.66	28.6	386	14



Scattered Photon Energy [GeV]
250
200
150
100
50
dσ/dE [r₀²/E₀]
Pλ
−1
0
1
E₀=250 GeV
ω₀=2.33 eV
Asymmetry
dσ⁻−dσ⁺ / dσ⁻+dσ⁺
MultiPhoton Analyzing Power
AP=−0.087
ϑ [μrad]
e
γ
0
25
50
75
100
125
150
175
200
225
250
Scattered Electron Energy



Scattered Photon Energy [GeV]
400
300
200
100
$d\sigma/dE\ [r_0^2/E_0]$
$P_e\lambda$
−1
0
1
E_0=400 GeV
ω_0=1.165 eV
Asymmetry
$\frac{d\sigma^- - d\sigma^+}{d\sigma^- + d\sigma^+}$
MultiPhoton Analyzing Power
AP=−0.045
ϑ [μrad]
e
γ
Scattered Electron Energy



Scattered Photon Energy [GeV]
45
35
25
15
5
$d\sigma/dE\ [r_0^2/E_0]$
E_0=45.6 GeV
ω_0=4.66 eV
$P_e\lambda$
−1
0
1
Asymmetry
$\frac{d\sigma^- - d\sigma^+}{d\sigma^- + d\sigma^+}$
MultiPhoton Analyzing Power
AP=0.095
ϑ [μrad]
γ
e
Scattered Electron Energy E [GeV]

Potential Background Processes

(1) $\gamma\gamma \rightarrow e^+e^-$

"Laser photon hits backscattered photon"

threshold: $x \geq 4.83$

2-step process, only important for high conversion efficiency ($\gamma\gamma$ collider)

$\Longrightarrow$ negligible for polarimeter situation

(2) $\gamma e^{\pm} \rightarrow e^+e^-e^{\pm}$ (direct pair prod.)

"Laser photon hits beam electron"

threshold: $x \geq 8$

higher order QED process,
suppressed by 1/137,
spin effects have been calculated
and are small (few ‰)

$\Longrightarrow$ may use lasers with short wavelength

Compton Polarimeter

Laser System

⟹ similar to pulsed laser system for RF photoinjector gun (TTF FEL) developed by Max-Borne-Institute (Berlin)

	wavelength (nm)		
	1047	524	262
pulse energy (μJ)	≤ 250		≤ 50
pulse length (ps)	16		8
average power (W)	≤ 2		≤ 0.4

⟹ matched to TESLA pulse pattern

⟹ can change wavelength to match TESLA beam energy

Location

⟹ special surface building (one each for e^- and e^+) at ~ 600 m from e^+e^- IP

⟹ ~ 50 m laser beam transport to Compton IP

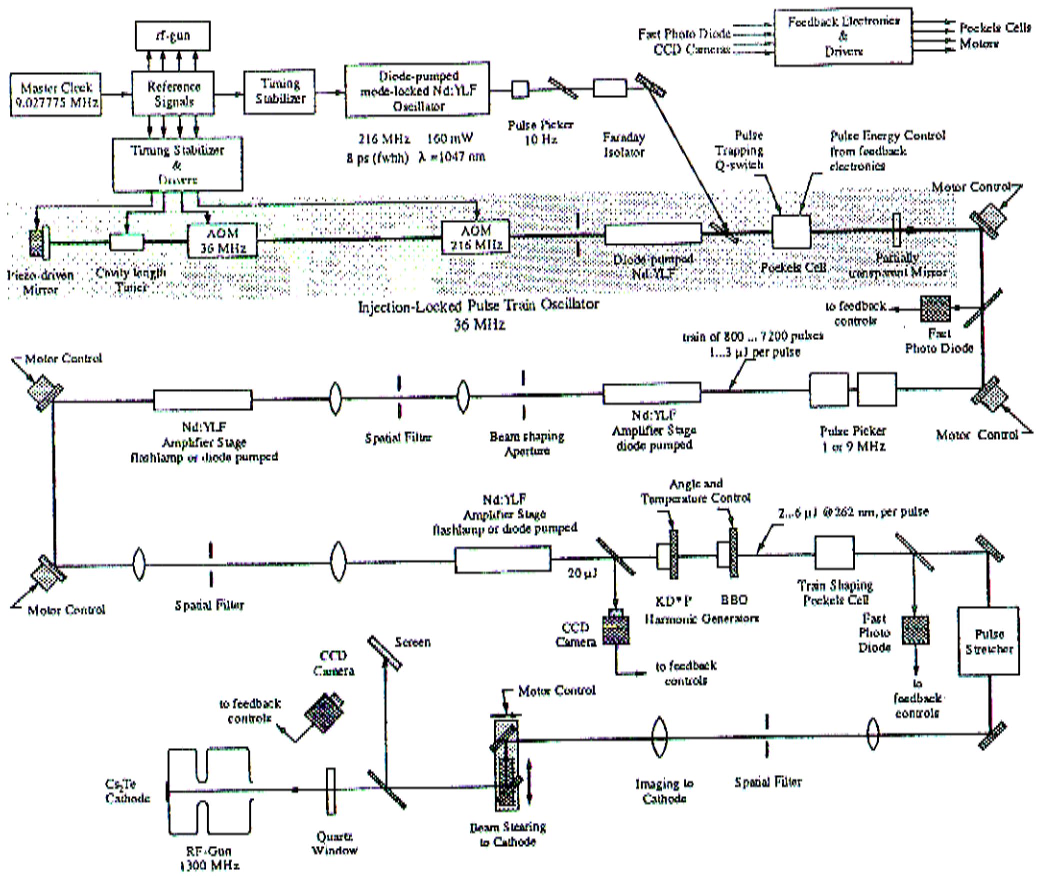
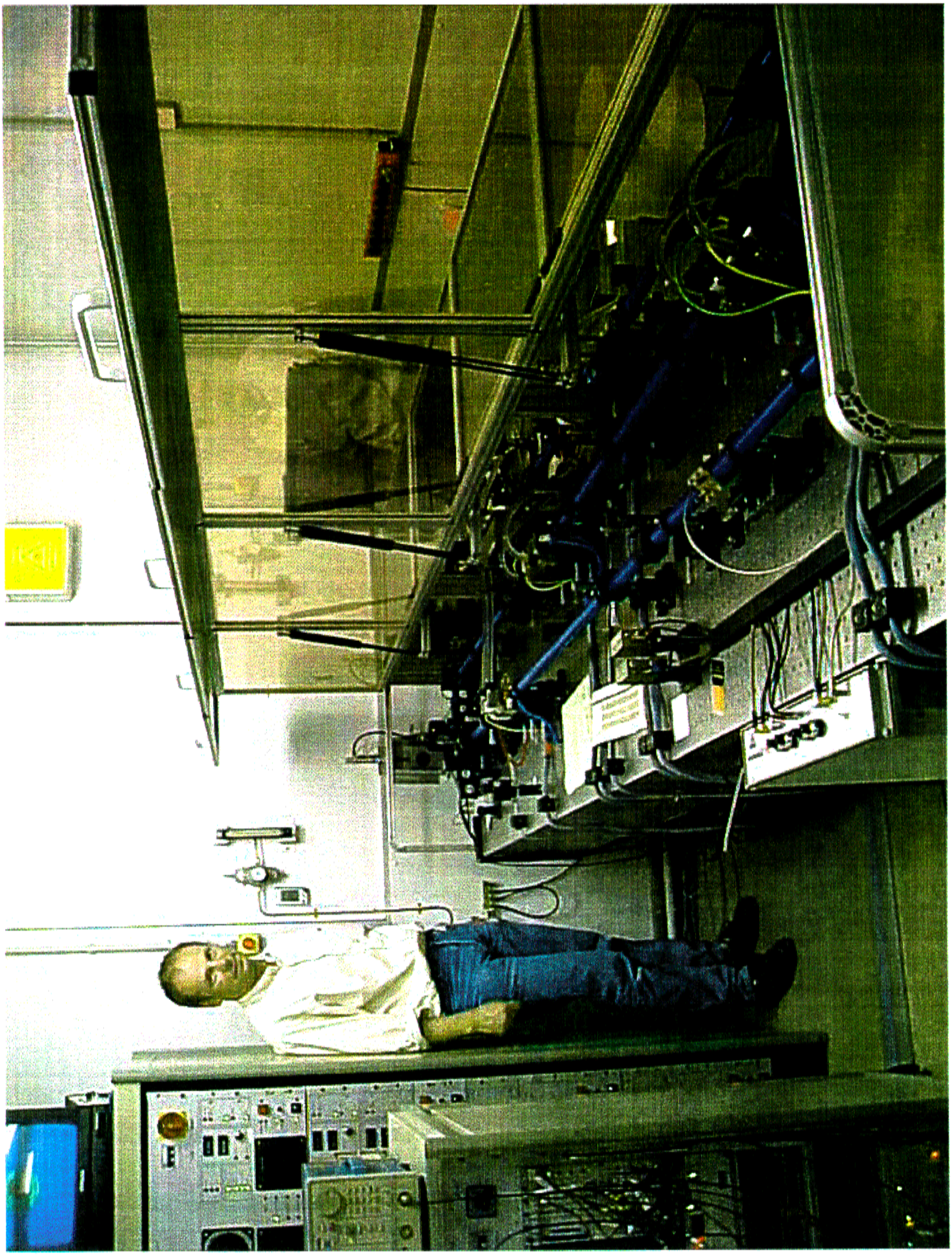


Figure 5.3.7: *Bloc diagram of the laser driving the RF gun of the TTF FEL (from ref.[20]).*



Pulsed Laser Luminosity

$$\mathcal{L} = \frac{1}{2\pi} f N_e N_\gamma g$$

$\frac{1}{2\pi} = 0.159$

$f = 14100 \, s^{-1}$ (bunches per second)

$N_e = 2.0 \times 10^{10}$ (electrons per bunch)

$N_\gamma =$	3.8×10^{14}	(IR laser photons per bunch)	(1.0 W)
	0.95	visible	(0.5)
	0.24	UV	(0.25)

g = geometry factor

for small crossing angle $\alpha = 2\varphi$ and negligible electron beam width:

$$g = \frac{1}{\sigma_x \sigma_y \sqrt{1 + (\sigma_z \varphi / \sigma_y)^2}}$$

Laser focus: $\sigma_x = \sigma_y = 50 \mu m$; $\alpha = 2\varphi = 10$ mrad

$\sigma_z = 5$ mm (16 ps)

$\mathcal{L} =$	6.0×10^{32}	$cm^{-2} s^{-1}$	(IR)
	1.5		(V)
	0.4		(UV)

Compton Polarimeter

Some Numbers

e^+/e^- beam		Laser beam (IR)	
energy	250 GeV	energy	1.2 eV
charge/bunch	2×10^{10}	energy/bunch	70 μJ
bunches/sec	14100	bunches/sec	14100
bunch length	1.3 ps	bunch length	16 ps
average current	45 μA	average power	1 W
$\sigma_x \times \sigma_y$	~10μm × 1μm	$\sigma_x \times \sigma_y$	50μm × 50μm

beam crossing angle	10 mrad
Luminosity	$6.0 \times 10^{32}\ cm^{-2}s^{-1}$
cross section	$0.198 \times 10^{-24}\ cm^2$
Comptons produced/sec	1.2×10^8 (*)
Comptons produced/bunch	8.5×10^3 (*)

* cannot be counted,
must process analog signals
(so-called "Multi-Compton" method)

very good statistics ⇒ only syst. errors !

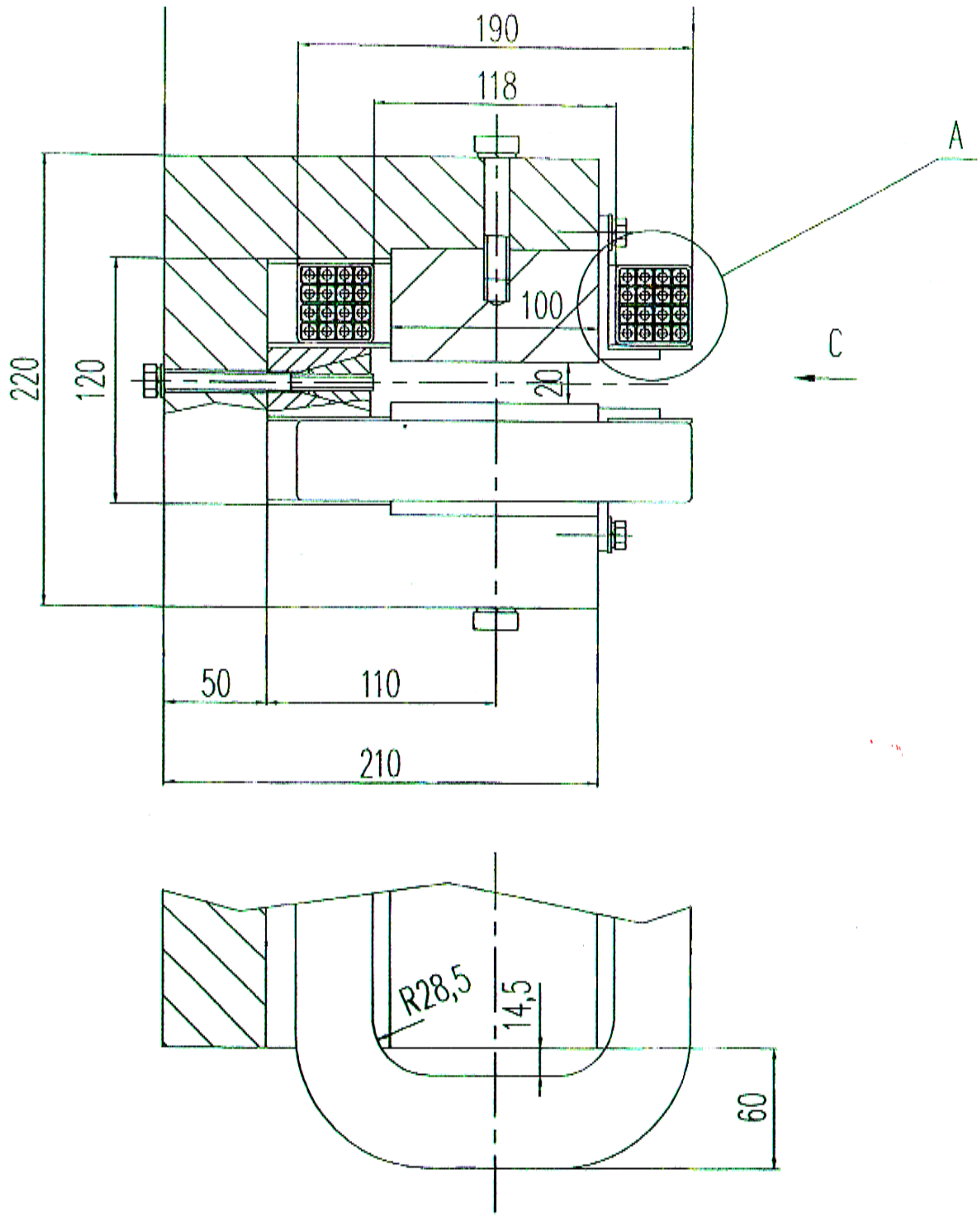
More Numbers

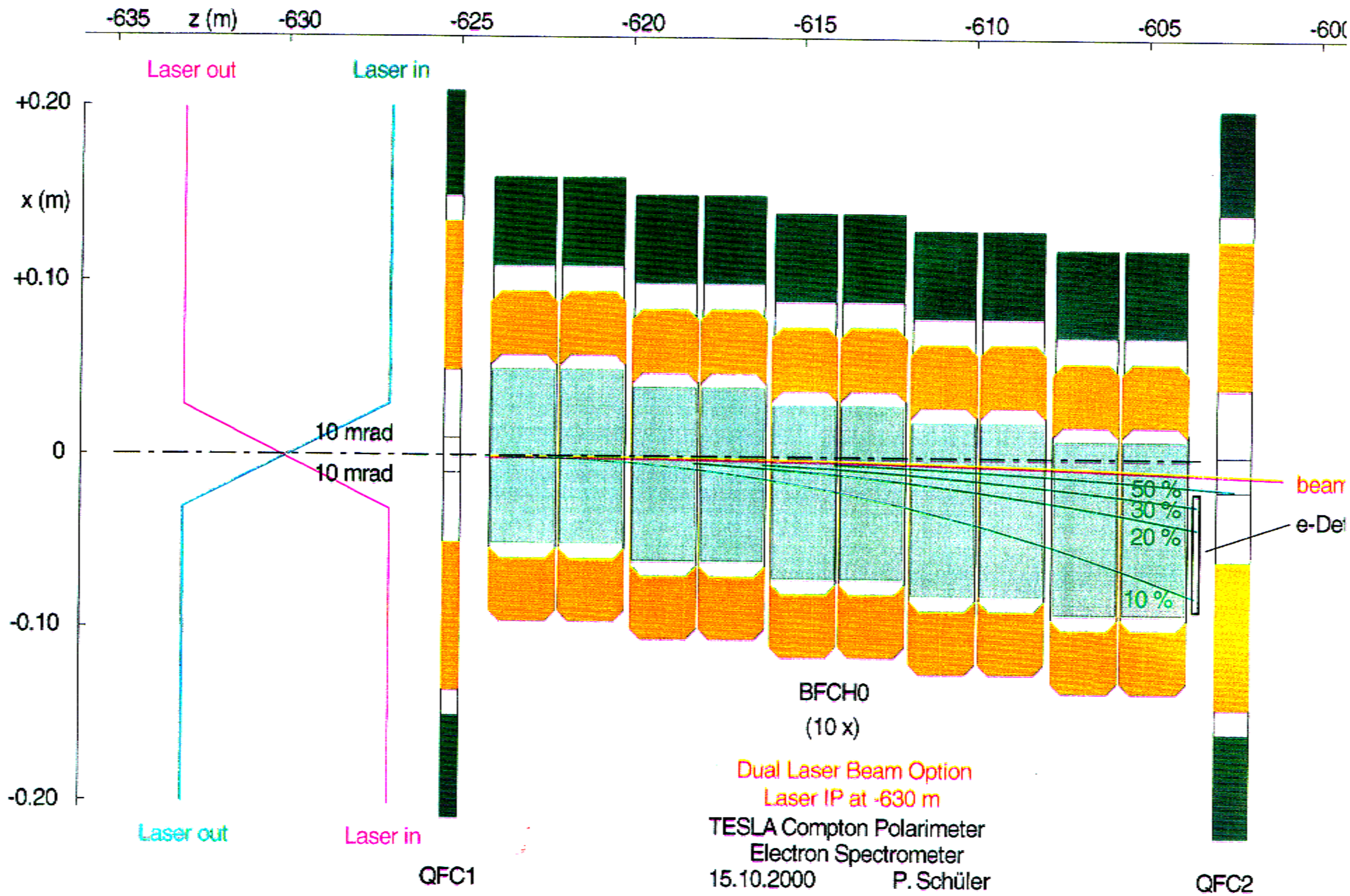
e^+/e^- beam		Laser beam (γ)	
energy	250 GeV	energy	2.3 eV
charge/bunch	2×10^{10}	energy/bunch	35 μJ
bunches/sec	14100	bunches/sec	14100
bunch length	1.3 ps	bunch length	16 ps
average current	45 μA	average power	0.5 W
$\sigma_x \times \sigma_y$	$\approx 10\mu m \times 1\mu m$	$\sigma_x \times \sigma_y$	$50\mu m \times 50\mu m$

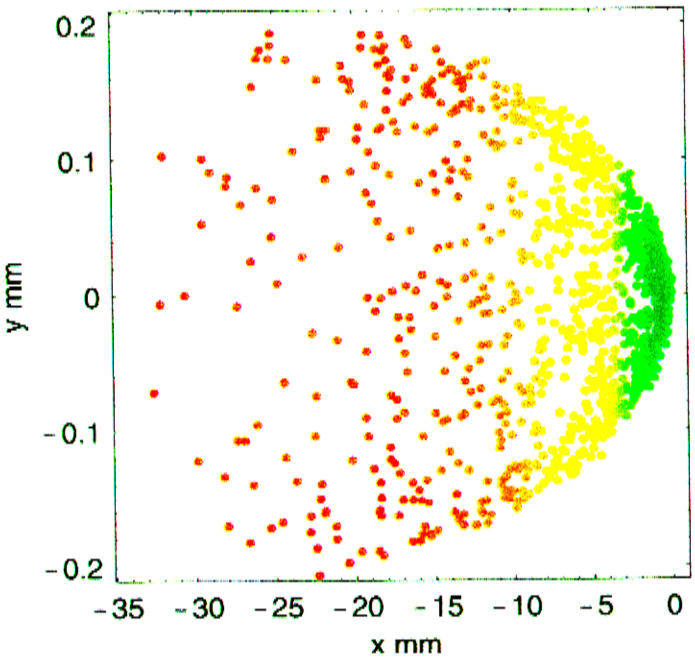
beam crossing angle	10 mrad
Luminosity	$1.5 \times 10^{32}\ cm^{-2} s^{-1}$
cross section	$0.136 \times 10^{-24}\ cm^2$
Comptons produced/sec	0.2×10^8 (*)
Comptons produced/bunch	1.4×10^3 (*)

* multi-Compton signals

Dipole Design

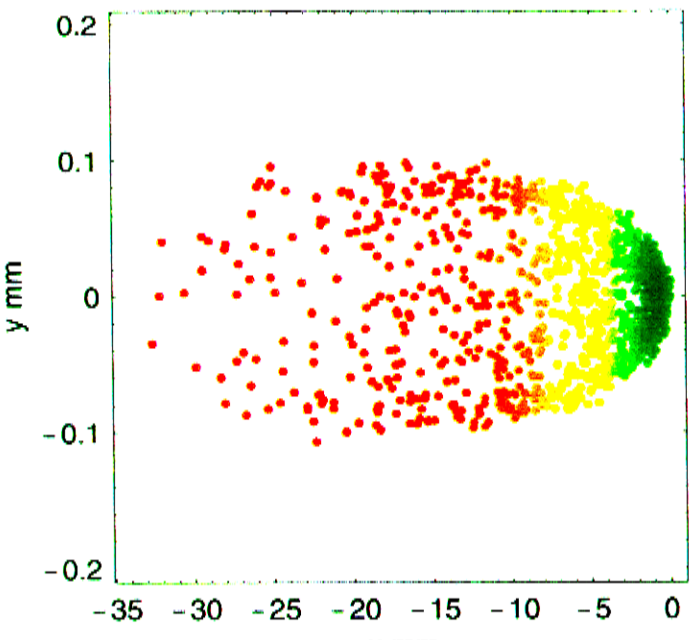



-635
z (m)
-630
-625
-620
-615
-610
-605
-600
Laser out
Laser in
+0.20
x (m)
+0.10
0
-0.10
-0.20
10 mrad
10 mrad
beam
e-Det
50 %
30 %
20 %
10 %
BFCH0
(10 x)
Dual Laser Beam Option
Laser IP at -630 m
TESLA Compton Polarimeter
Electron Spectrometer
15.10.2000
P. Schüler
Laser out
Laser in
QFC1
QFC2



Laser IP at -632.5 m upstream of QFC1

Scatter Plot at Electron Detector



Laser IP at -624.5 m behind QFC1

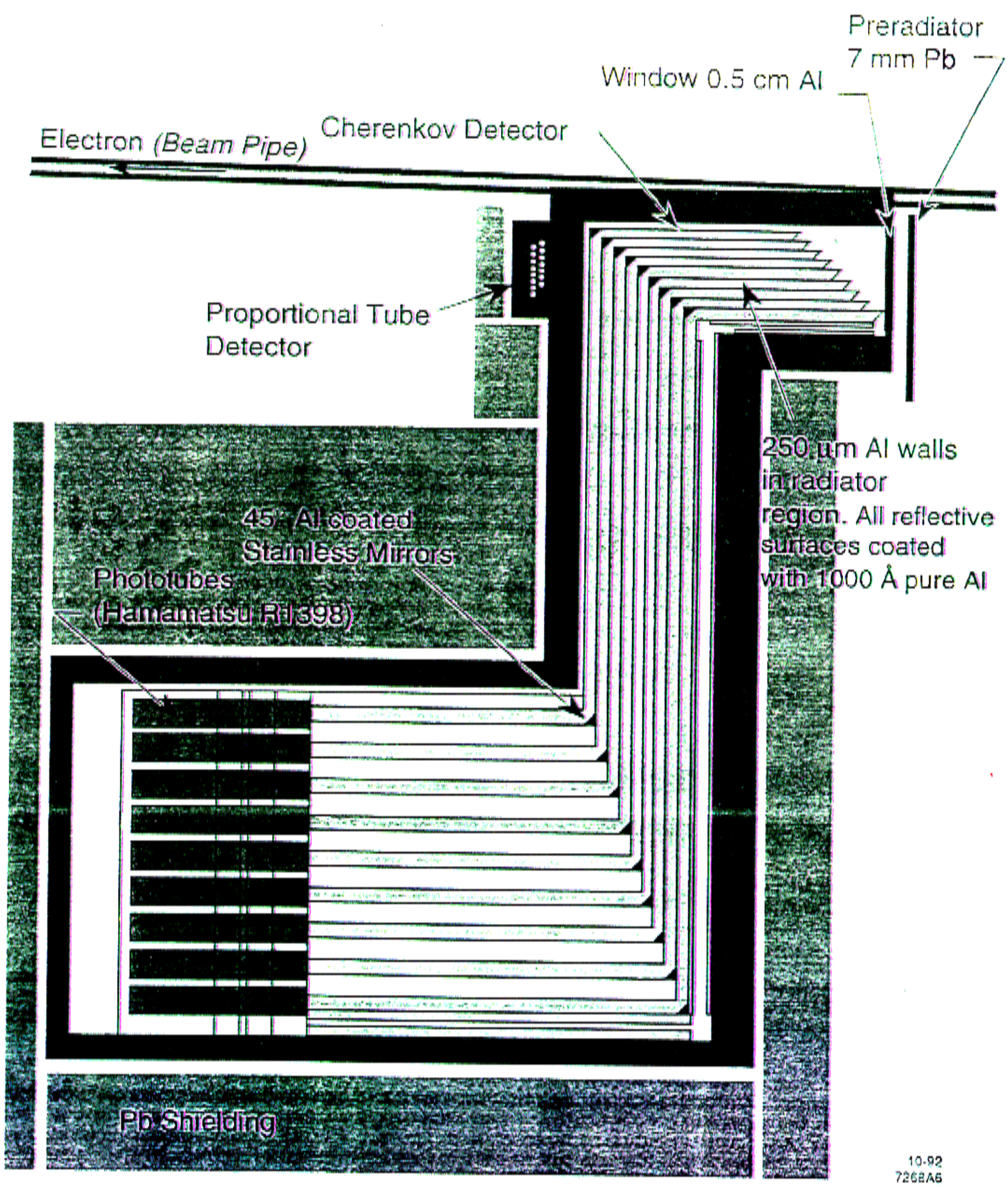


Figure 2-9: The layout of the multi-channel Cherenkov detector for the Compton Polarimeter is shown.

SLAC Compton Polarimeter
Detector Design

Compton Polarimeter

Systematic Errors

→ SLAC SLD attained $\Delta P/P = 0.67\%$
(originates mostly from detector linearity and calibration)

→ for the TESLA polarimeter, we will try to improve this to the level of 0.5%, maybe better

Conclusion

→ we have a reasonable design concept

→ a suitable location for the spectrometer and the laser

→ very high statistical power due to the chosen laser type

→ systematic errors of $\Delta P/P \sim 0.5\%$ or better should be possible

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Møller Scattering Polarimetry for High Energy e^+e^- Linear Colliders

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Abstract

The general features of the Møller scattering and its use as an electron polarimeter are described and studied in view of the planned future high energy e^+e^- linear colliders. In particular the study concentrates on the TESLA collider which may operate with longitudinal polarised beams at a centre of mass energy of the order of 0.5 TeV with a luminosity of about $\mathcal{L} = 10^{33}$ cm^{-2}sec^{-1}.

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