Upstream Polarimetry with 4-Magnet Chicane

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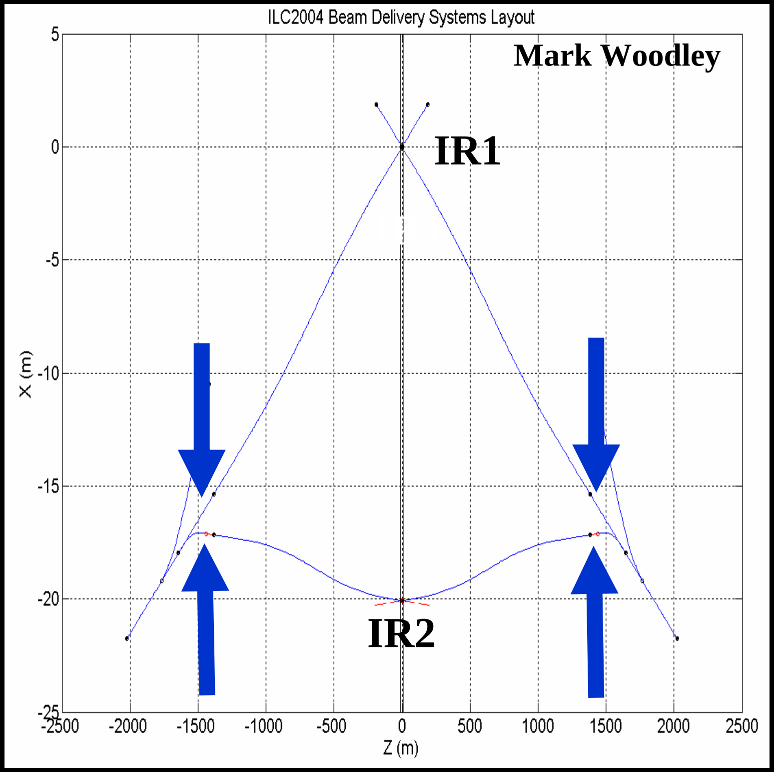
Introduction & Overview

- Compton polarimetry basics I, II, III
- laser parameters
- Tesla design & chicane design

4-Magnet Chicane

- general layout & properties
- movable laser beam
- vacuum chambers
- electron detector
- some simulation results
- synchr. radiation & emittance growth
- remaining issues & homework

Summary & Conclusion



Compton polarimetry basics I : Kinematics

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

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

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

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

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

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

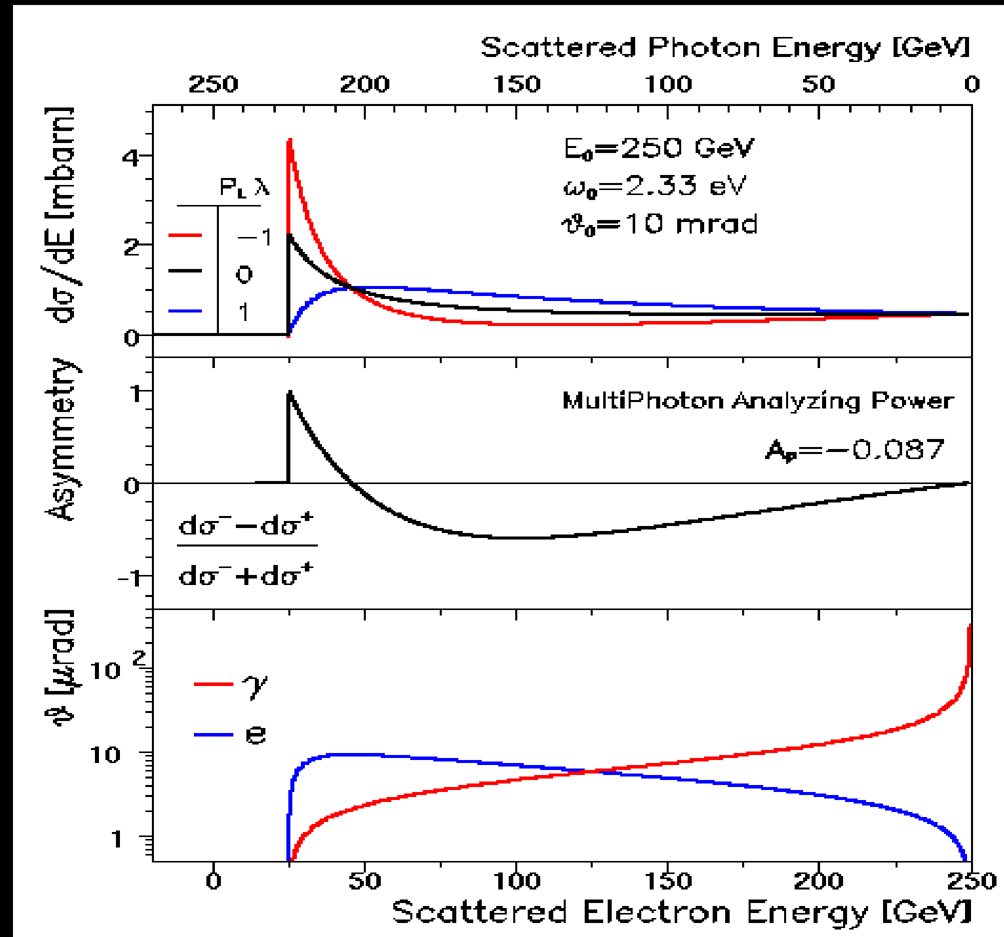
$$\theta_e = \frac{y}{1-y}\theta_\gamma$$

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

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

Compton polarimetry basics II :

cross sections,
spin asymmetry,
scattering angles



$-1 < P < +1$

$-1 < \lambda < +1$

$\vartheta_e^{max} = 2\,\omega_o / m$

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

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

Compton polarimetry basics III: luminosity for pulsed lasers

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

$$g = \frac{1}{2\pi \, \sigma_{x\gamma} \, \sigma_{y\gamma} \sqrt{1 + (0.5 \, \theta_0 \, \sigma_{z\gamma} / \sigma_{y\gamma})^2}}$$

f_b = bunch crossings per sec
N_e, N_γ = no. of e, γ per bunch
g = geometry factor
$\sigma_{x\gamma}$, $\sigma_{y\gamma}$ = transverse laser beam size
$\sigma_{z\gamma}$ = c $\sigma_{t\gamma}$ = laser pulse length
θ_o = laser crossing angle

$$\mathcal{L} = \frac{\mathcal{L}_{max}}{\sqrt{1 + (0.5 \, \theta_0 \, \sigma_{z\gamma} / \sigma_{y\gamma})^2}}$$

$$\mathcal{L}_{max} = \frac{f_b \, N_e \, N_\gamma}{2\pi \, \sigma_{x\gamma} \, \sigma_{y\gamma}}$$

$\sigma_{t\gamma}$	$\sigma_{z\gamma}$	$\mathcal{L}/\mathcal{L}_{max}$		
(ps)	(mm)	$3\ mrad$	$10 mrad$	$30 mrad$
0	0	1.000	1.000	1.000
5	1.5	0.999	0.989	0.912
10	3.0	0.996	0.958	0.743
15	4.5	0.991	0.912	0.505
20	6	0.984	0.857	0.486
30	9	0.965	0.743	0.347
40	12	0.941	0.640	0.268
50	15	0.912	0.555	0.217
100	30	0.743	0.316	0.110
1000	300	0.110	0.033	0.011
10000	3000	0.011	0.003	0.001

$\Rightarrow$ effectiveness of laser degrades with increasing pulse length & crossing angle

Laser for TTF injector gun

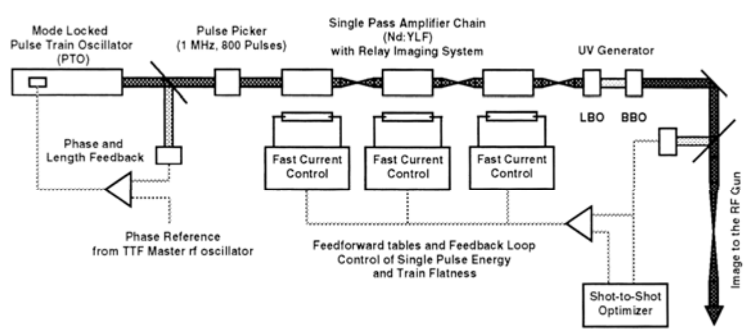
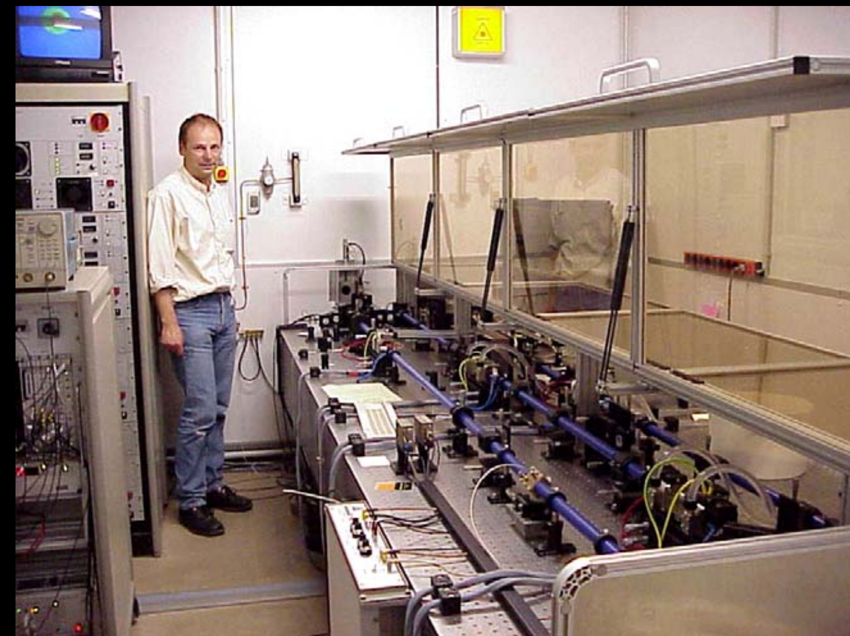
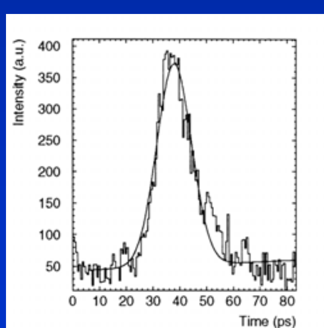


Fig. 1. Schematic overview of the TTF photoinjector laser system.



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

S. Schreiber et al.
NIM A 445 (2000) 427



$$\sigma_t = 8 \text{ ps}$$

Laser parameters

for TESLA TDR (2001), we assumed TTF-style laser of variable wavelength:

configuration	E_0 (GeV)	$< I_e >$ (μA)	λ (nm)	ϵ_γ (eV)	$< P_L >$ (W)	j_γ (μJ)	$\mathcal{L}$ $(10^{32} cm^{-2} s^{-1})$	
TESLA-500	250	45	532	2.33	0.5	35	1.5	← **green**
TESLA-800	400	45	1064	1.165	1.0	71	6.0	← **IR**
Giga-Z	45.6	45	266	4.66	0.2	14	0.2	← **UV**

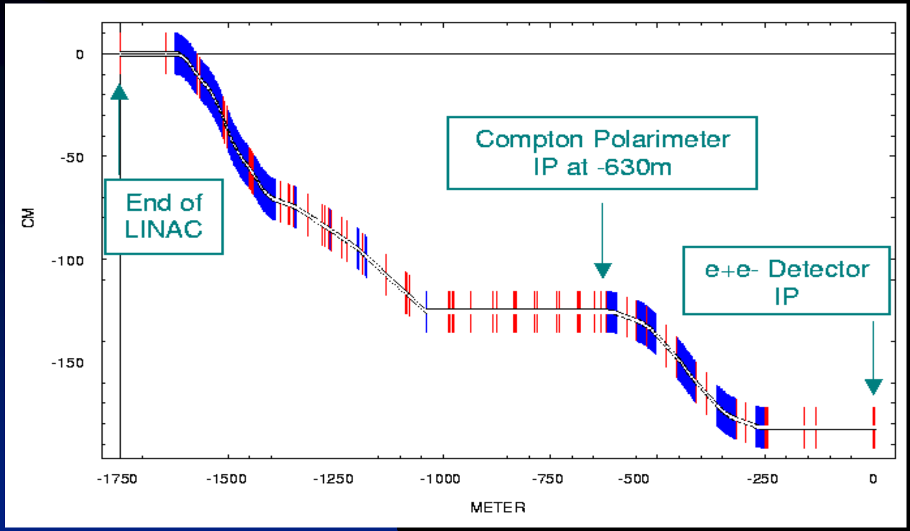
Table 9: Reference parameters for statistical tables.

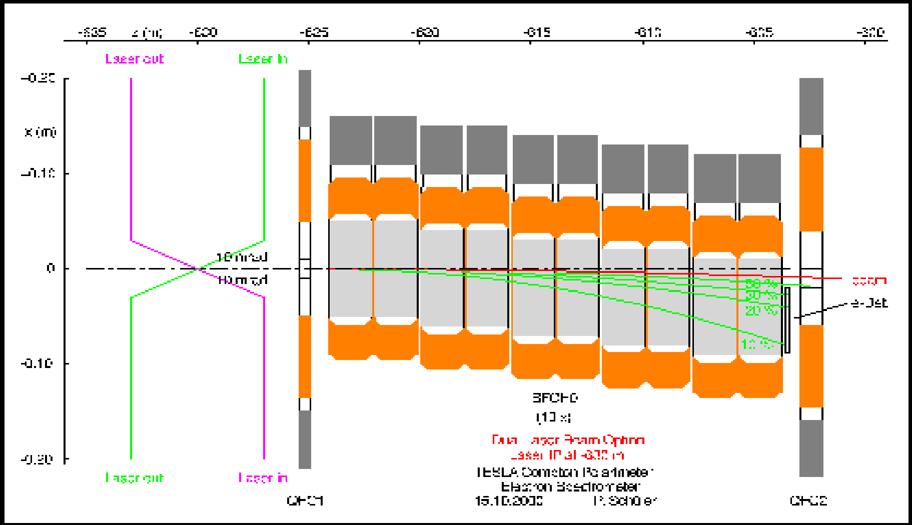
will employ same laser for ILC chicane polarimeter,

but can operate with green line at all ILC beam energies

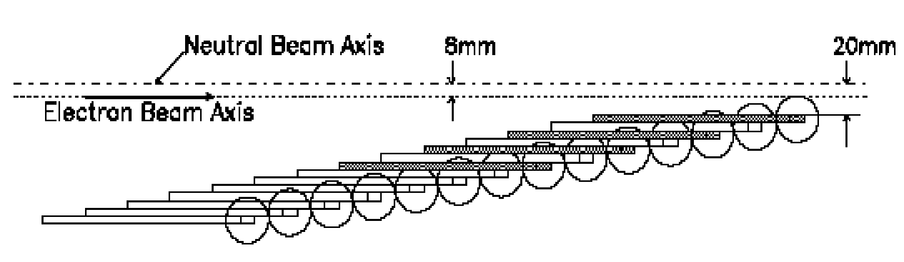
Tesla design

V. Gharibyan, N. Meyners, K.P. Schüler,
www.desy.de/~lcnotes/notes.html, LC-DET-2001-047





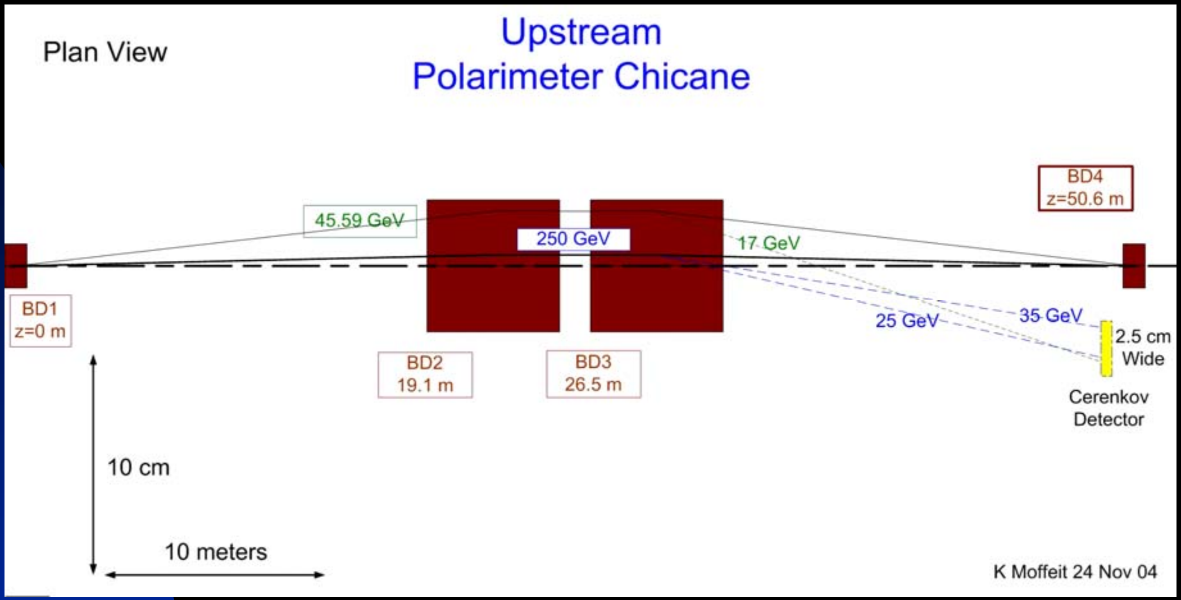
	e^+/e^- beam	laser beam
energy	250 GeV	2.3 eV
charge or energy/bunch	$2 \cdot 10^{10}$	35 μJ
bunches/sec	14100	14100
bunch length σ_t	1.3 ps	10 ps
average current(power)	45 μA	0.5 W
$\sigma_x \cdot \sigma_y$ (μm)	$10 \cdot 1$	$50 \cdot 50$
beam crossing angle	10 mrad	
luminosity	$1.5 \cdot 10^{32} cm^{-2} s^{-1}$	
cross section	$0.136 \cdot 10^{-24} cm^2$	
detected events/sec	$1.0 \cdot 10^7$	
detected events/bunch	$0.7 \cdot 10^3$	
$\Delta P/P$ stat. error/sec	negligible	
$\Delta P/P$ syst. error	$\sim 0.5\%$	



- **minimal space & no special magnets**
- **need to change laser wavelength to UV for z-pole running**

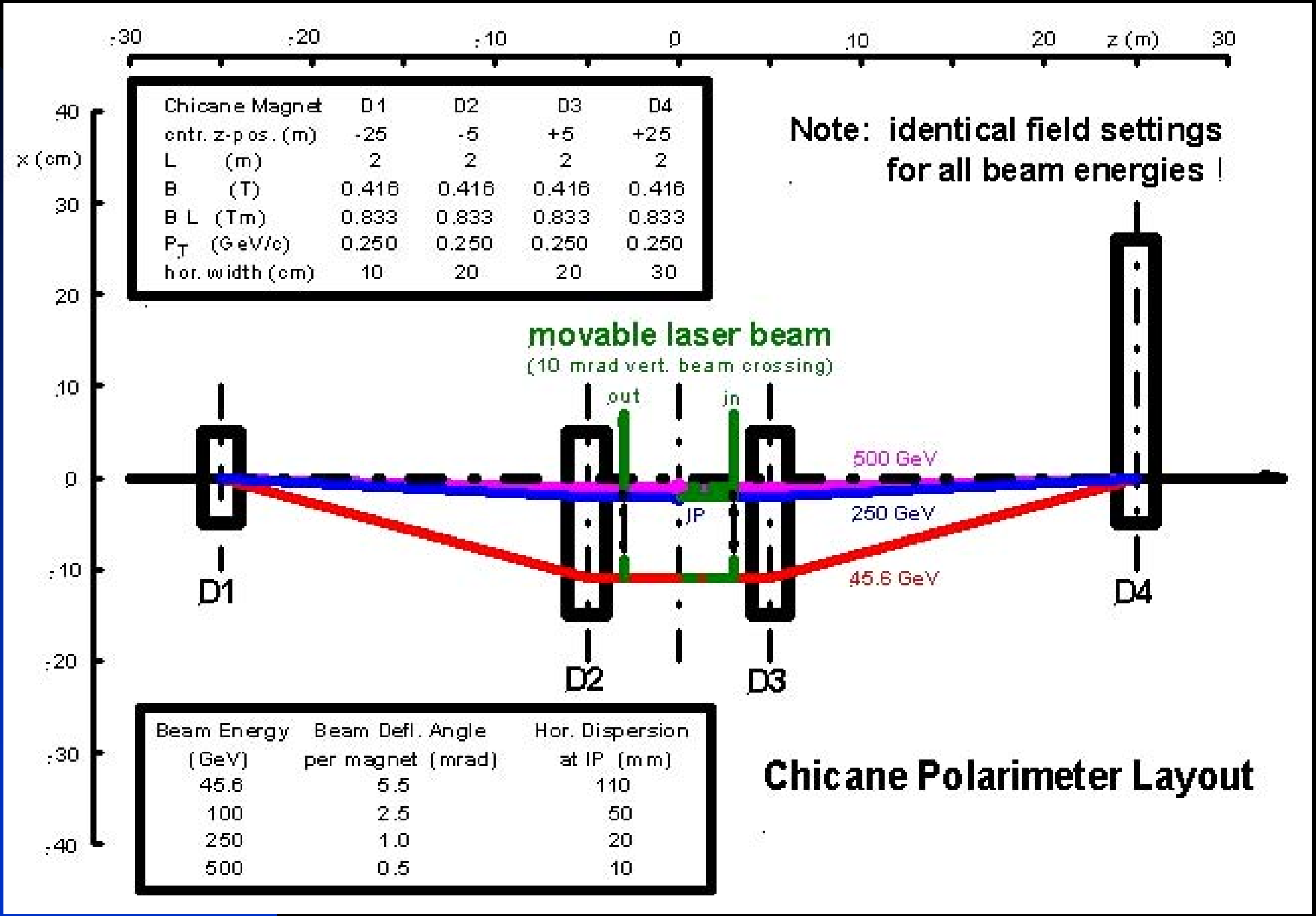
Chicane Design

K. Moffeit, M. Woods, W. Oliver
(see ILC MDI workshop at SLAC, Jan. 2005)



- **essential for downstream polarimetry (separates Compton electrons from low-energy disrupted beam background), but adventageous also for upstream polarimetry**
- **requires ~ 50 meters length**
- **same B-field at Z-pole, 250 GeV and 500 GeV running**
- **good acceptance of Compton spectrum at all energies without changing laser wavelength**
- **laser crossing (Compton IP) at mid-chicane**

4-Magnet Chicane: general layout

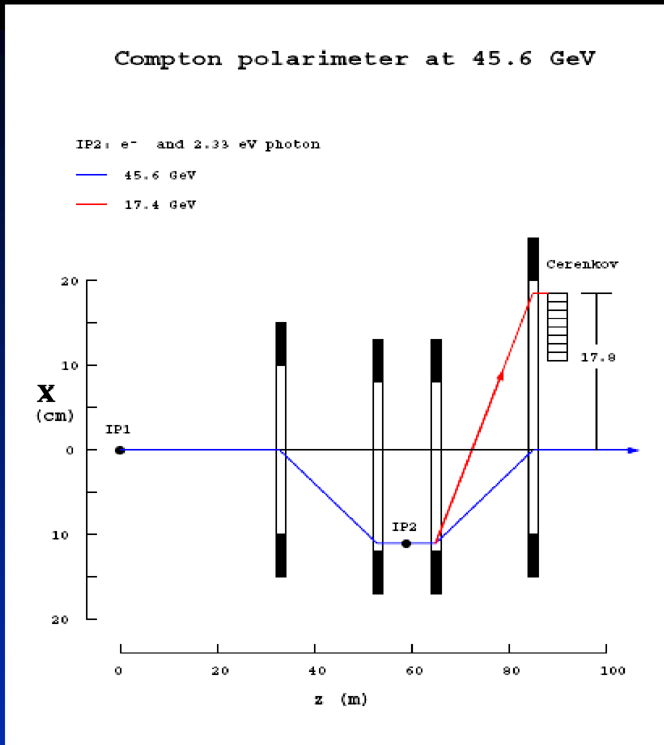


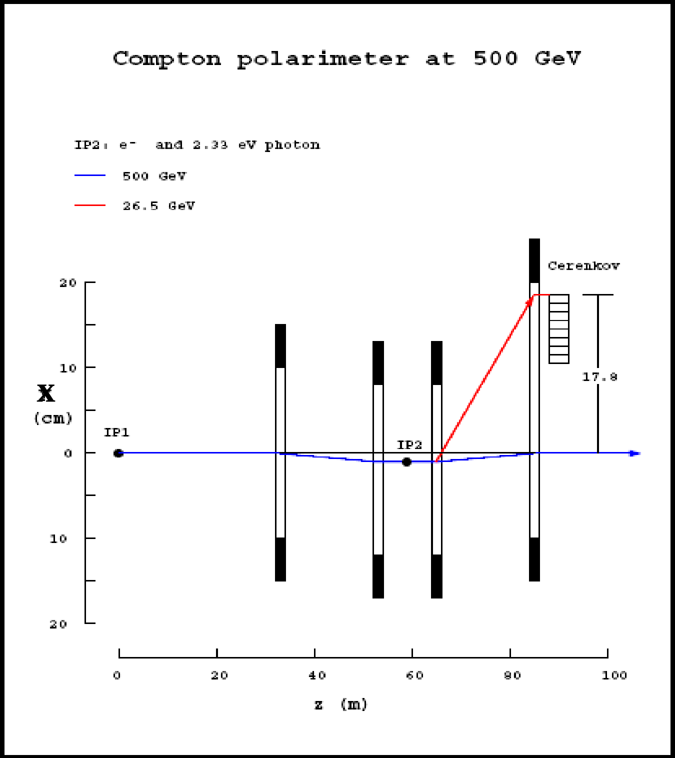
Chicane Magnet	D1	D2	D3	D4
cntr. z-pos. (m)	-25	-5	+5	+25
L (m)	2	2	2	2
B (T)	0.416	0.416	0.416	0.416
B L (Tm)	0.833	0.833	0.833	0.833
P_T (GeV/c)	0.250	0.250	0.250	0.250
hor. width (cm)	10	20	20	30

Beam Energy (GeV)	Beam Defl. Angle per magnet (mrad)	Hor. Dispersion at IP (mm)
45.6	5.5	110
100	2.5	50
250	1.0	20
500	0.5	10

Chicane properties

(see talk of W. Oliver, MDI workshop, SLAC, Jan. 2005)

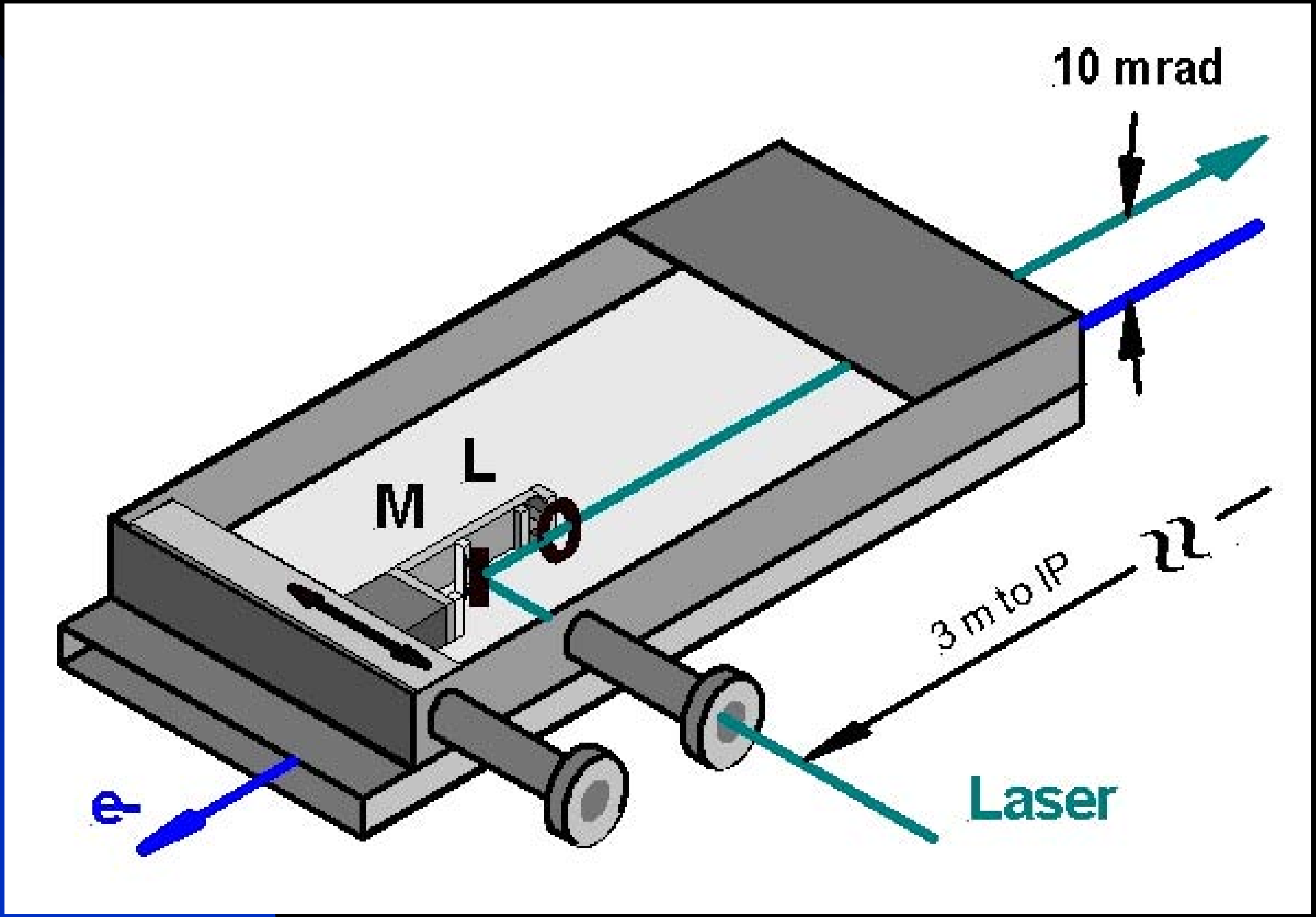




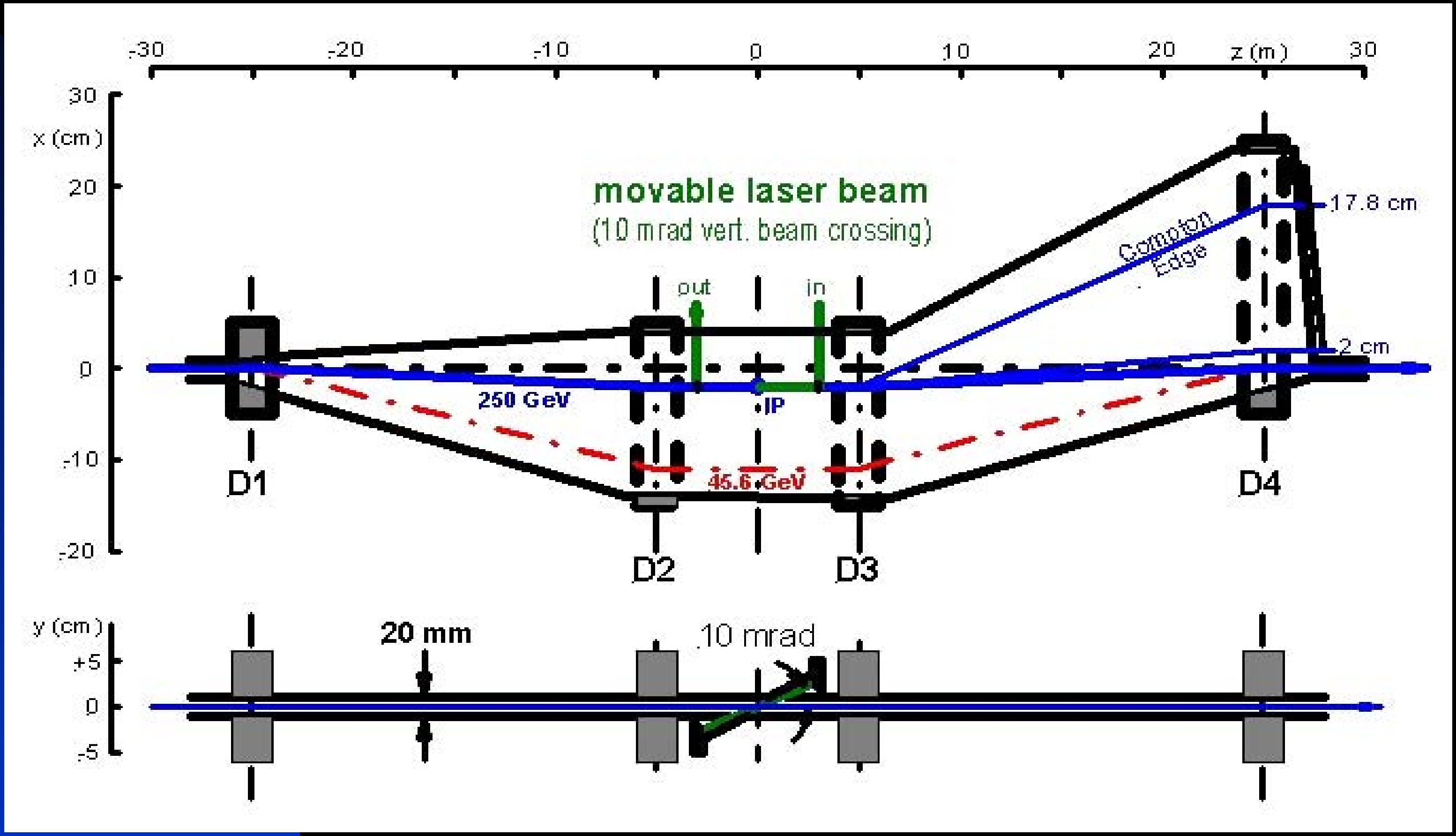
$X_{max} = 4\,\omega_0\, p_T\, L / m^2$ ← position of Compton edge is independent of beam energy

e.g. $X_{max} = 17.8$ cm for $\omega_0 = 2.33$ eV, $P_T = 0.25$ GeV/c, L = 20 m

movable laser beam

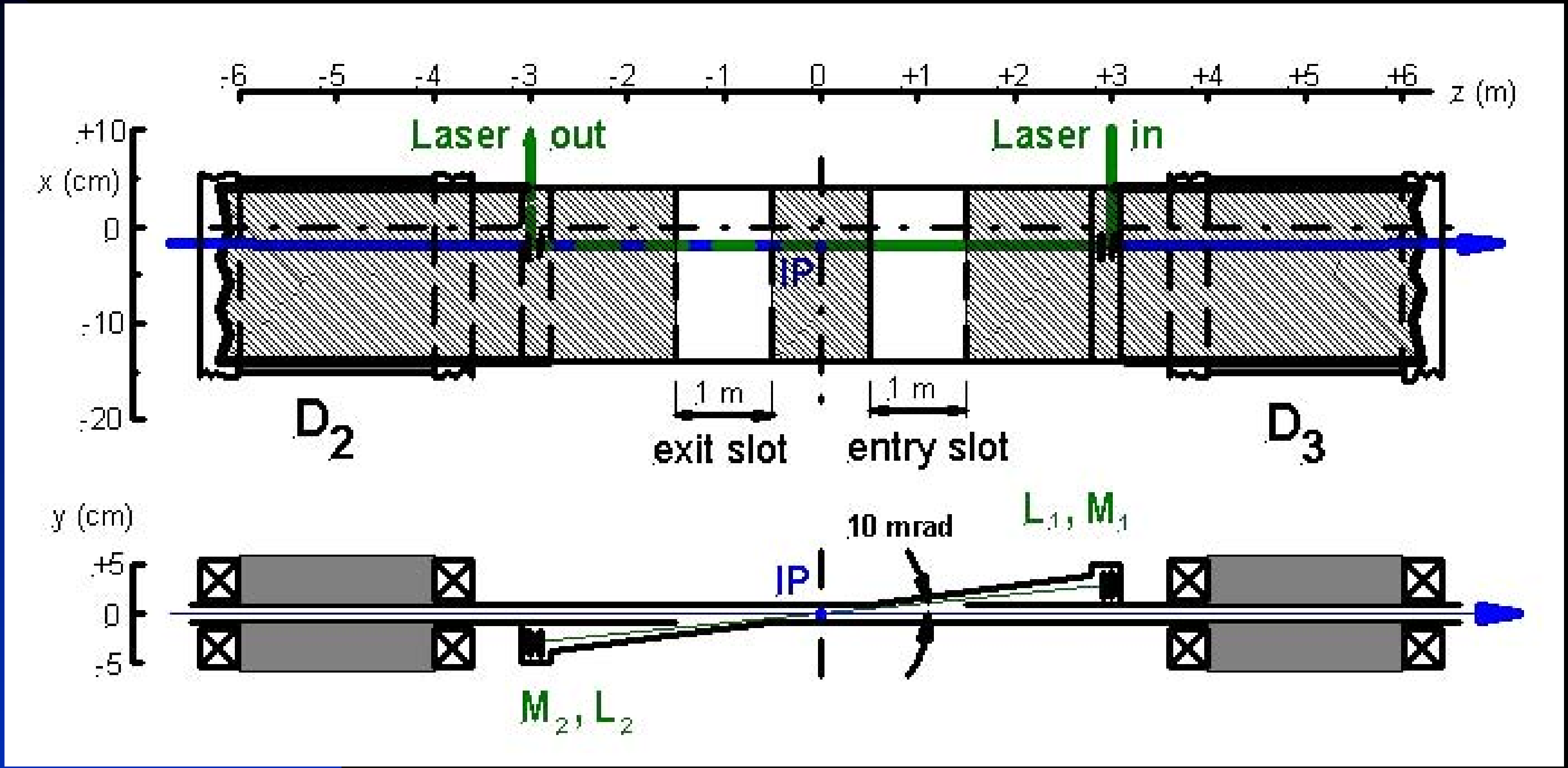


Vacuum Chamber Overview



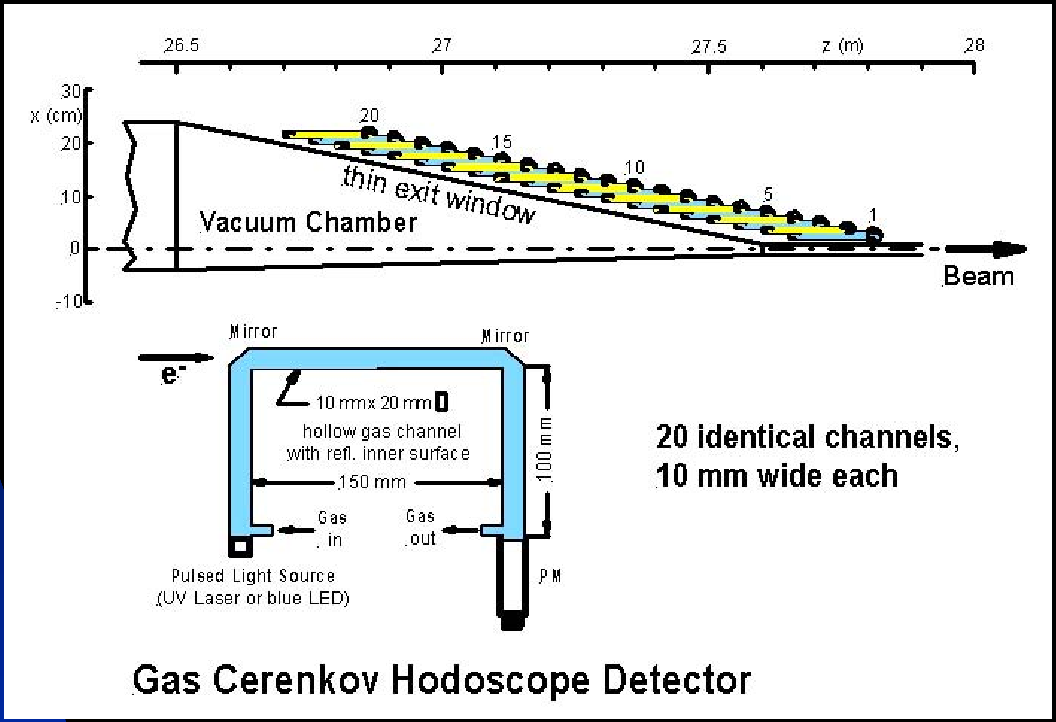
chambers are tapered to minimize wake fields

Vacuum Chamber Detail



laser beam crossing requires ~ 1 m long insertion/exit slots along z
→ will need detailed calculations with Mafia to determine wake fields

Electron 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 (syn. rad.)**
- **do not need explicit preradiator, due to high intrinsic event flux (less cross talk)**
- **20 channels, 10 mm wide each, will cover a large fraction of the Compton spctr.**
- **E_{max} / E_0 = 85%; 50%; 33% at E_0 = 45.6; 250; 500 GeV (with x_{min} = 20 mm)**

some simulation results I

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

ω_0 = 2.33 eV (green laser)

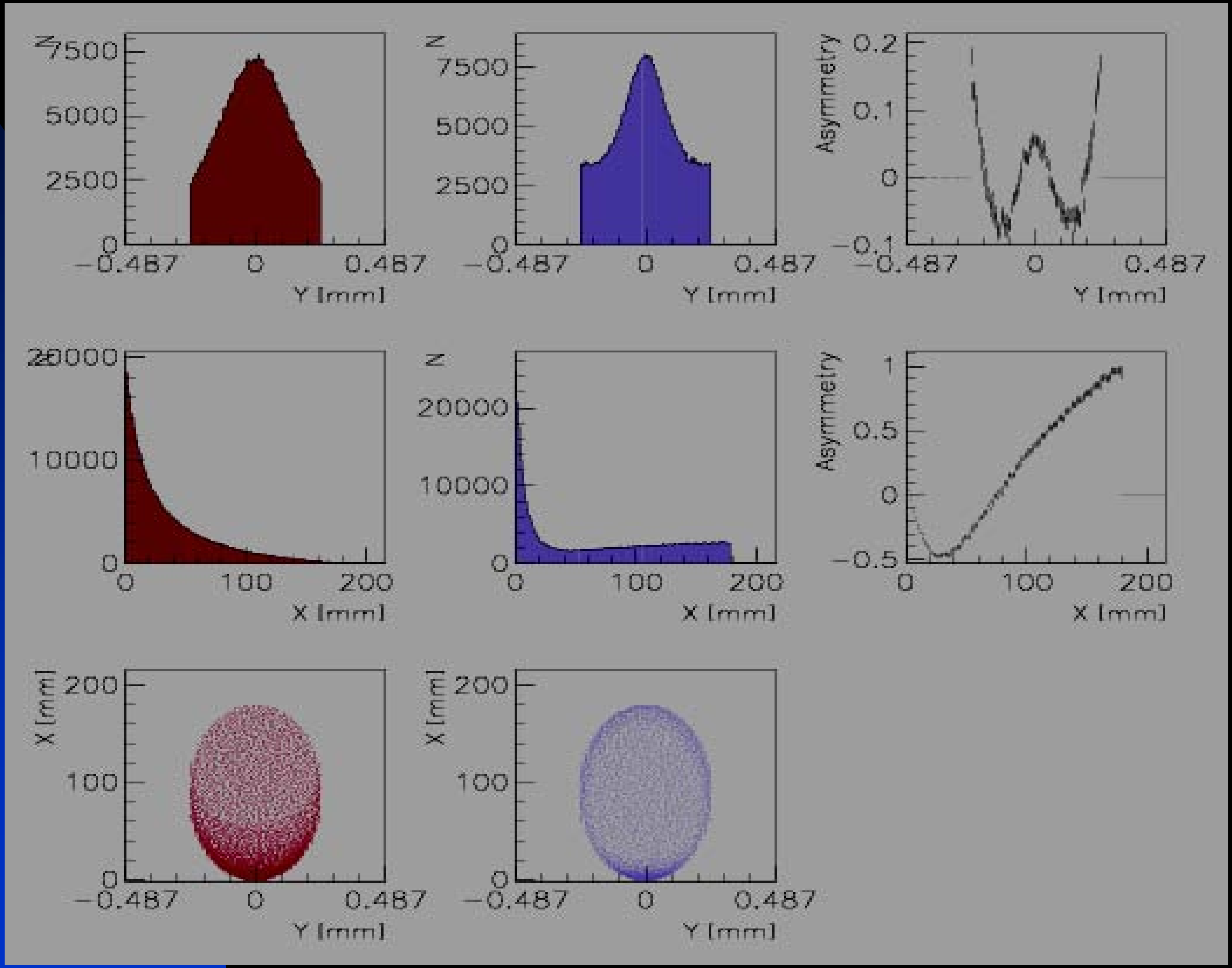
L = 1.5 x 10^{32}/cm²/sec

results

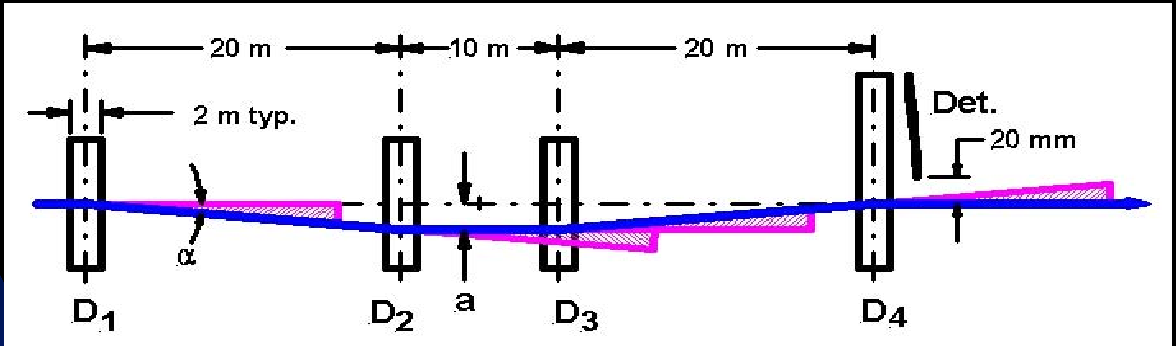
Ch. #	x [mm]	N+	N-	A	Rate*A²	Rate [MHz]	dP/P [%]
1	25	60,682	23,368	-0.444	0.337	1.710	0.228
2	35	45,868	17,348	-0.451	0.262	1.287	0.260
3	45	35,673	16,012	-0.380	0.152	1.052	0.335
4	55	28,337	16,029	-0.277	0.069	0.903	0.486
5	65	22,996	16,956	-0.151	0.019	0.813	0.924
6	75	18,333	17,876	-0.013	0.000	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: dP/P = 0.082%
for dT = 1 sec

some simulation results II



synchrotron radiation



Chicane Polarimeter: Synchrotron Radiation Geometry

E [GeV]	α [mrad]	a [mm]	ΔE / el. [MeV]	ΔE / bunch per magnet [mJ] (*)	ΔE / sec [kJ] (**)	total power (4 magnets) [kW]
45.6	5.5	110	0.9	3	0.04	0.16
100	2.5	50	4.4	14	0.20	0.80
250	1.0	20	27.5	88	1.24	4.96
500	0.5	10	110.0	352	4.96	19.85

(*) 2×10^{10} el./bunch

(**) 5 x 2,820 = 14,100 bunches/sec

emittance growth

from synchrotron radiation

E_{beam} [GeV]	E_{cm} [GeV]	$\Delta\varepsilon_x/\varepsilon_x$ [%]	
45.6	**90.2**	**0.002**	
100	**200**	**0.02**	
250	**500**	**0.3**	
500	**1,000**	**2.5**	**← acceptable**

- scaled from figures obtained by N. Walker for energy measurement chicane
- by comparison, polarimeter chicane generates only 2/3 of synchr. rad. power at E_{cm} = 1 TeV and 1/3 of emittance growth
- for polarimeter chicane, **$\Delta\varepsilon/\varepsilon$ scales as E^3**

remaining issues & homework

- **wake field calculations with Mafia**
- **chicane bunch (de)compression effects**
- **alignment issues: BPM's, surveying techniques**
- **engineering of magnets, vacuum chambers, optics, etc**
- **what else?**

summary & conclusion

- **we have extended our upstream polarimeter study to the chicane spectrometer design**
- **the chicane has several important advantages**
- **so far, we have not found any serious problems with it, but our work is not yet finished**

- **it looks very much like „We should go for the chicane!“**