

# Upstream Polarimetry with 4-Magnet Chicane

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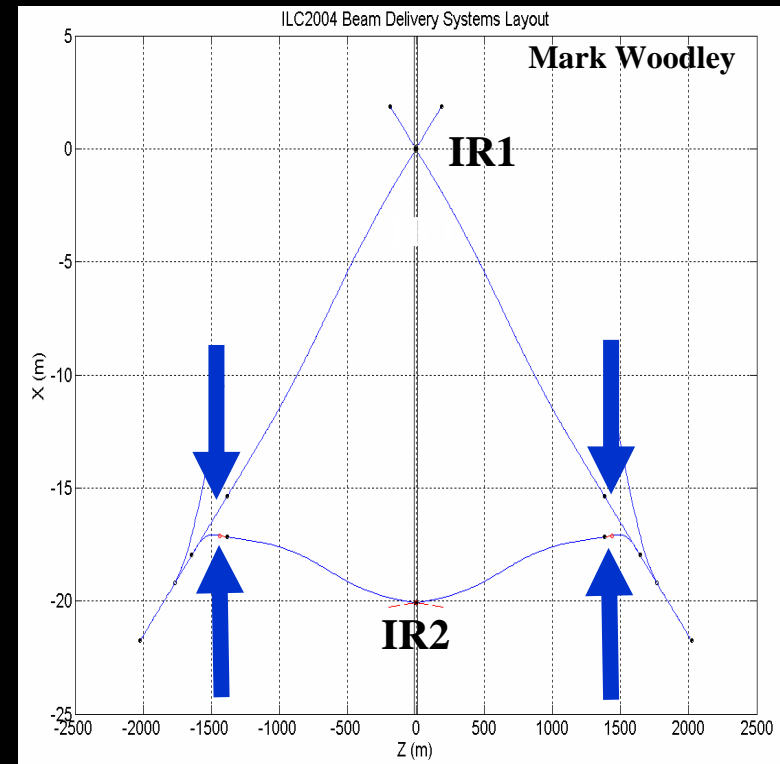
## Introduction & Overview

- 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

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

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

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

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

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

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

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

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

$E_0$ (GeV)	$\lambda$ (nm)	$\omega_0$ (eV)	$\mathfrak{x}$	$\omega_{max}$ (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

# Compton polarimetry basics II :

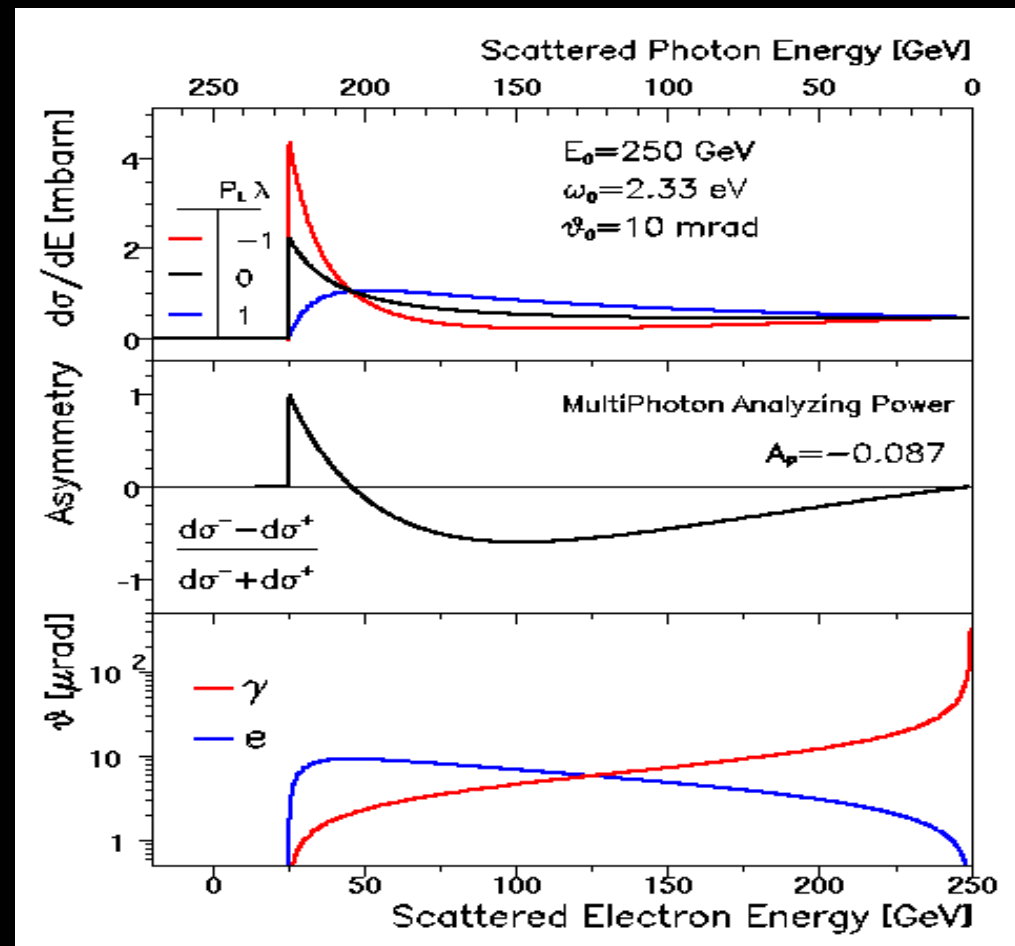
cross sections,  
spin asymmetry,  
scattering angles

$$-1 < P < +1$$

$$-1 < \lambda < +1$$

$$\vartheta_e^{\max} = 2 \omega_0 / m$$

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



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

# Compton polarimetry basics III: luminosity for pulsed lasers

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

$f_b$  = bunch crossings per sec

$N_e, N_\gamma$  = no. of e,  $\gamma$  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

$\theta_0$  = laser crossing angle

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

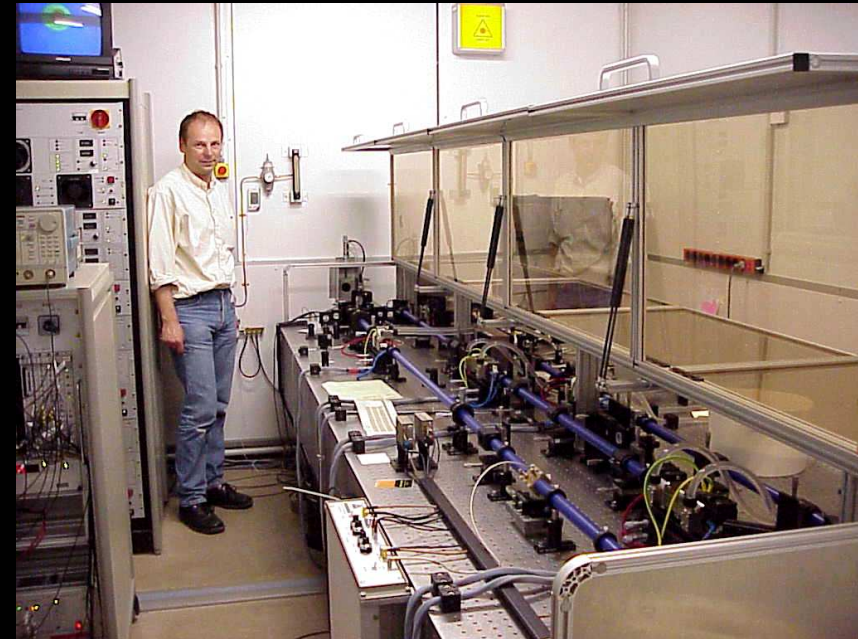
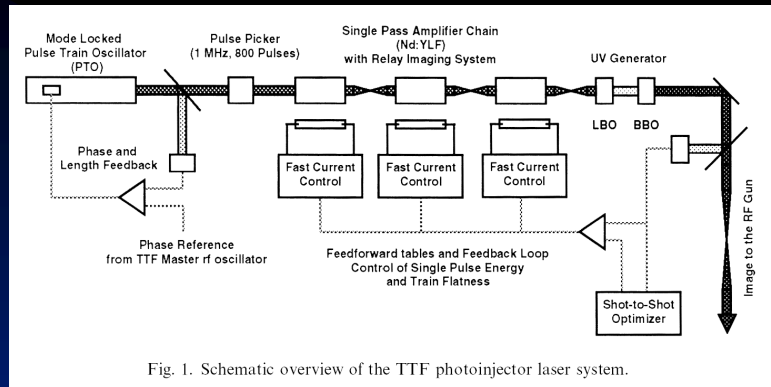
$$\mathcal{L}_{max} = \frac{f_b N_e N_\gamma}{2\pi \sigma_{x\gamma} \sigma_{y\gamma}}$$

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

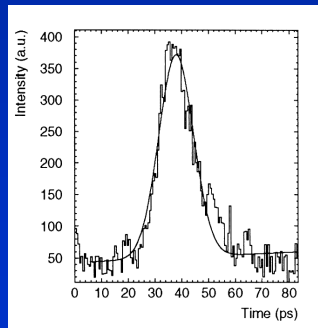
$\sigma_{t\gamma}$	$\sigma_{z\gamma}$	$\mathcal{L}/\mathcal{L}_{max}$		
(ps)	(mm)	3 mrad	10mrad	30mrad
0	0	1.000	1.000	1.000
5	1.5	0.999	0.989	0.912
10	3.0	0.996	0.958	0.743
15	4.5	0.991	0.912	0.505
20	6	0.984	0.857	0.486
30	9	0.965	0.743	0.347
40	12	0.941	0.640	0.268
50	15	0.912	0.555	0.217
100	30	0.743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

⇒ effectiveness of laser degrades with increasing pulse length & crossing angle

# Laser for TTF injector gun



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



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

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

# Laser parameters

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

configuration	$E_0$ (GeV)	$\langle I_e \rangle$ ( $\mu A$ )	$\lambda$ (nm)	$\epsilon_\gamma$ (eV)	$\langle P_L \rangle$ (W)	$j_\gamma$ ( $\mu J$ )	$\mathcal{L}$ ( $10^{32} cm^{-2} s^{-1}$ )
TESLA-500	250	45	532	2.33	0.5	35	1.5
TESLA-800	400	45	1064	1.165	1.0	71	6.0
Giga-Z	45.6	45	266	4.66	0.2	14	0.2

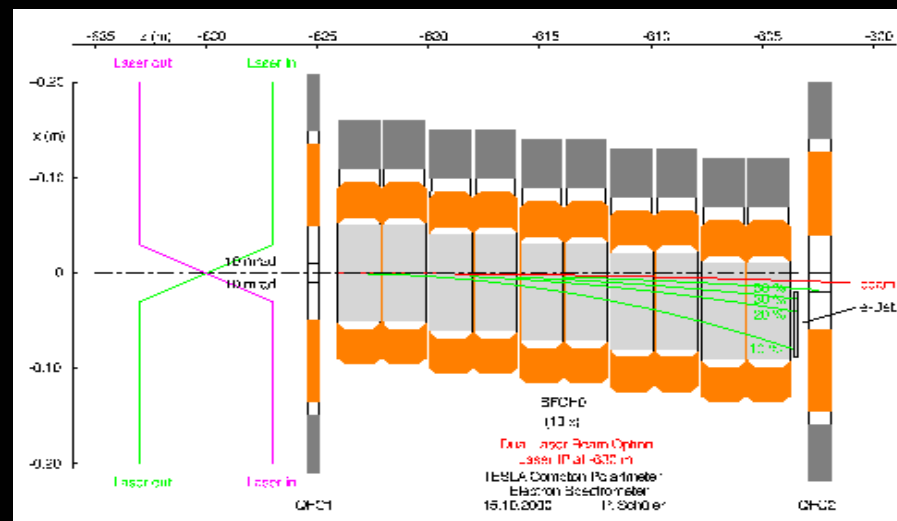
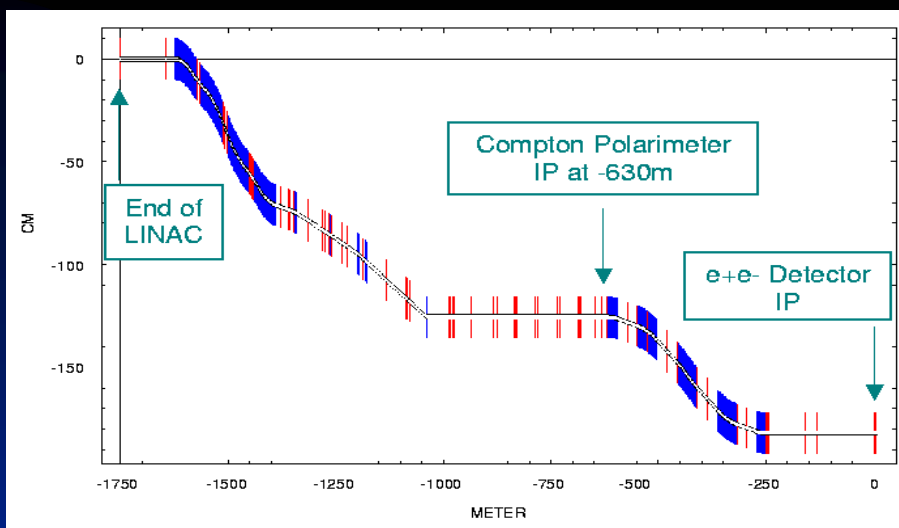
$\beta$  green  
 $\beta$  IR  
 $\beta$  UV

Table 9: Reference parameters for statistical tables.

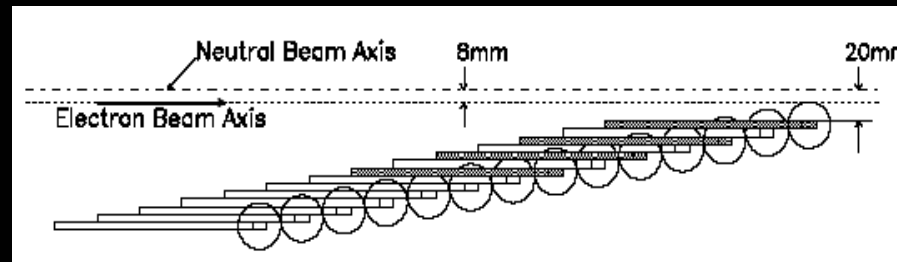
will employ same laser for ILC chicane polarimeter,  
but can operate with green line at all ILC beam energies

# Tesla design

V. Gharibyan, N. Meyners, K.P. Schüler,  
[www.desy.de/~lcnotes/notes.html](http://www.desy.de/~lcnotes/notes.html), LC-DET-2001-047



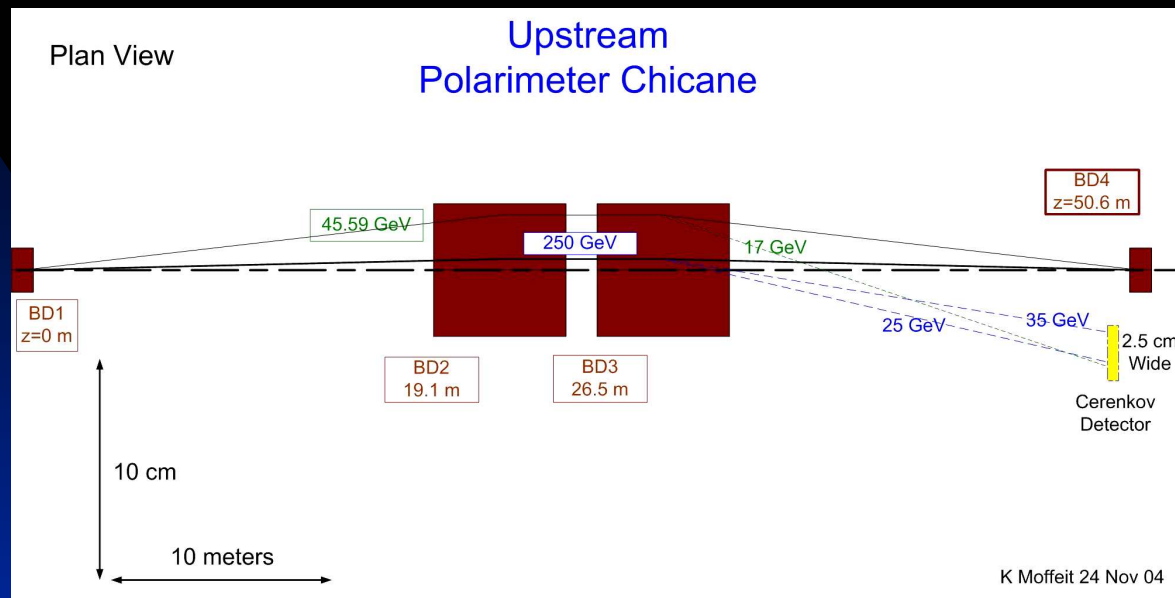
	$e^+/e^-$ beam	laser beam
energy	250 GeV	2.3 eV
charge or energy/bunch	$2 \cdot 10^{10}$	$35 \mu\text{J}$
bunches/sec	14100	14100
bunch length $\sigma_t$	1.3 ps	10 ps
average current(power)	$45 \mu\text{A}$	0.5 W
$\sigma_x \cdot \sigma_y$ ( $\mu\text{m}$ )	10 · 1	50 · 50
beam crossing angle	10 mrad	
luminosity	$1.5 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1}$	
cross section	$0.136 \cdot 10^{-24} \text{cm}^2$	
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

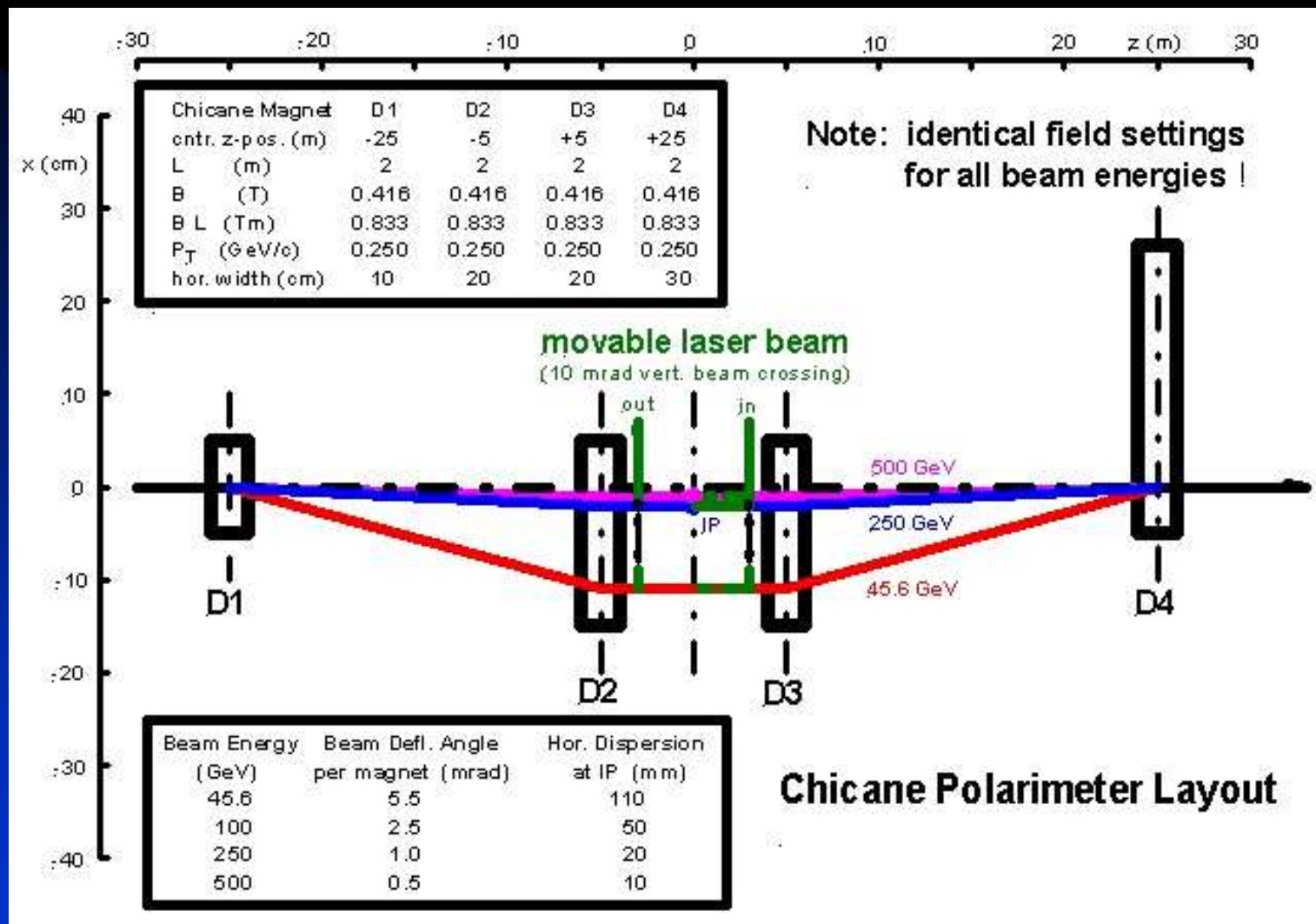
K. Moffeit, M. Woods, W. Oliver  
(see ILC MDI workshop at SLAC, Jan. 2005)



- essential for downstream polarimetry (separates Compton electrons from low-energy disrupted beam background), but advantageous 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

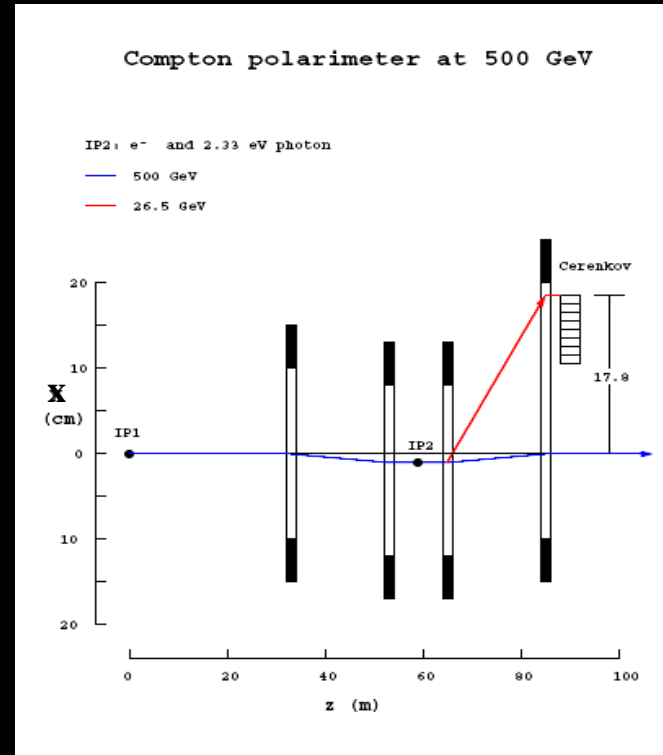
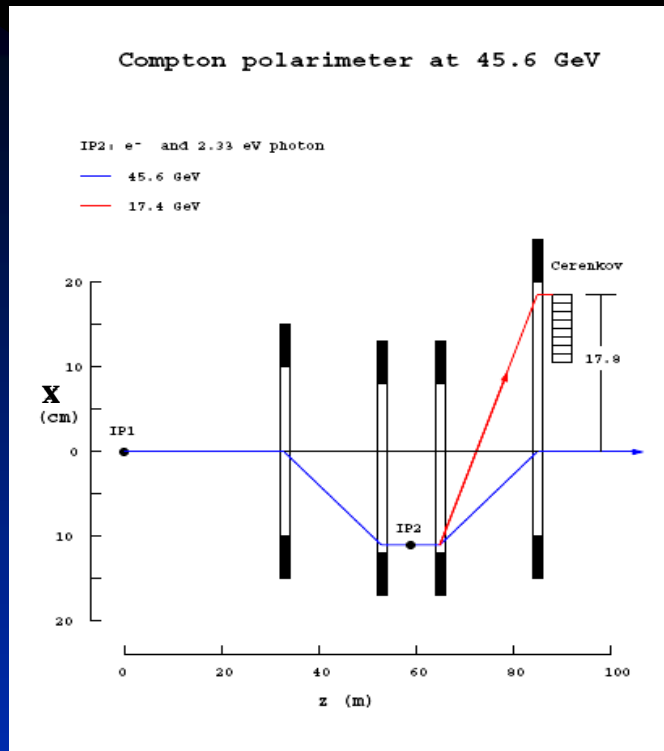


# 4-Magnet Chicane: general layout



# Chicane properties

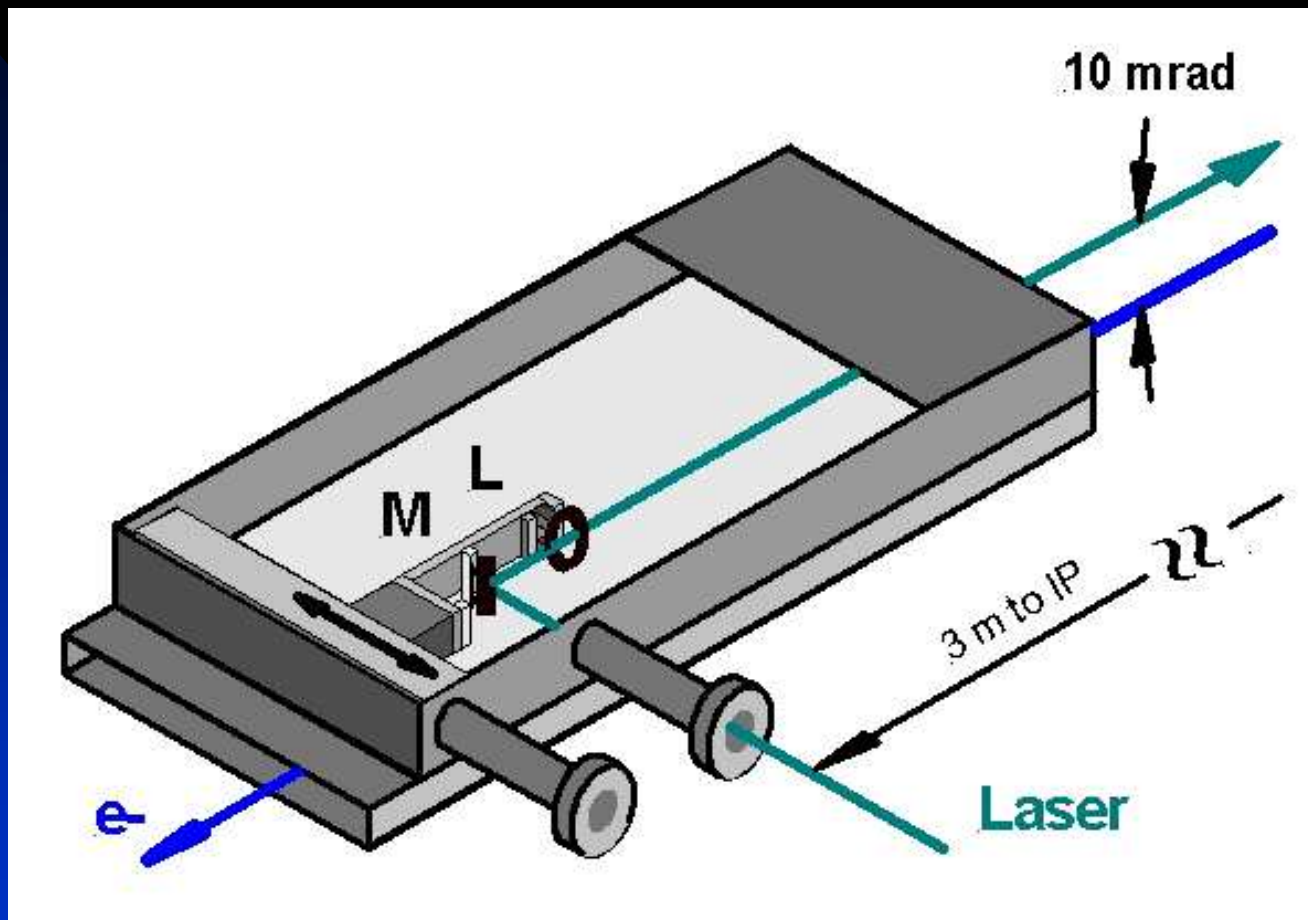
(see talk of W. Oliver,  
MDI workshop, SLAC, Jan. 2005)



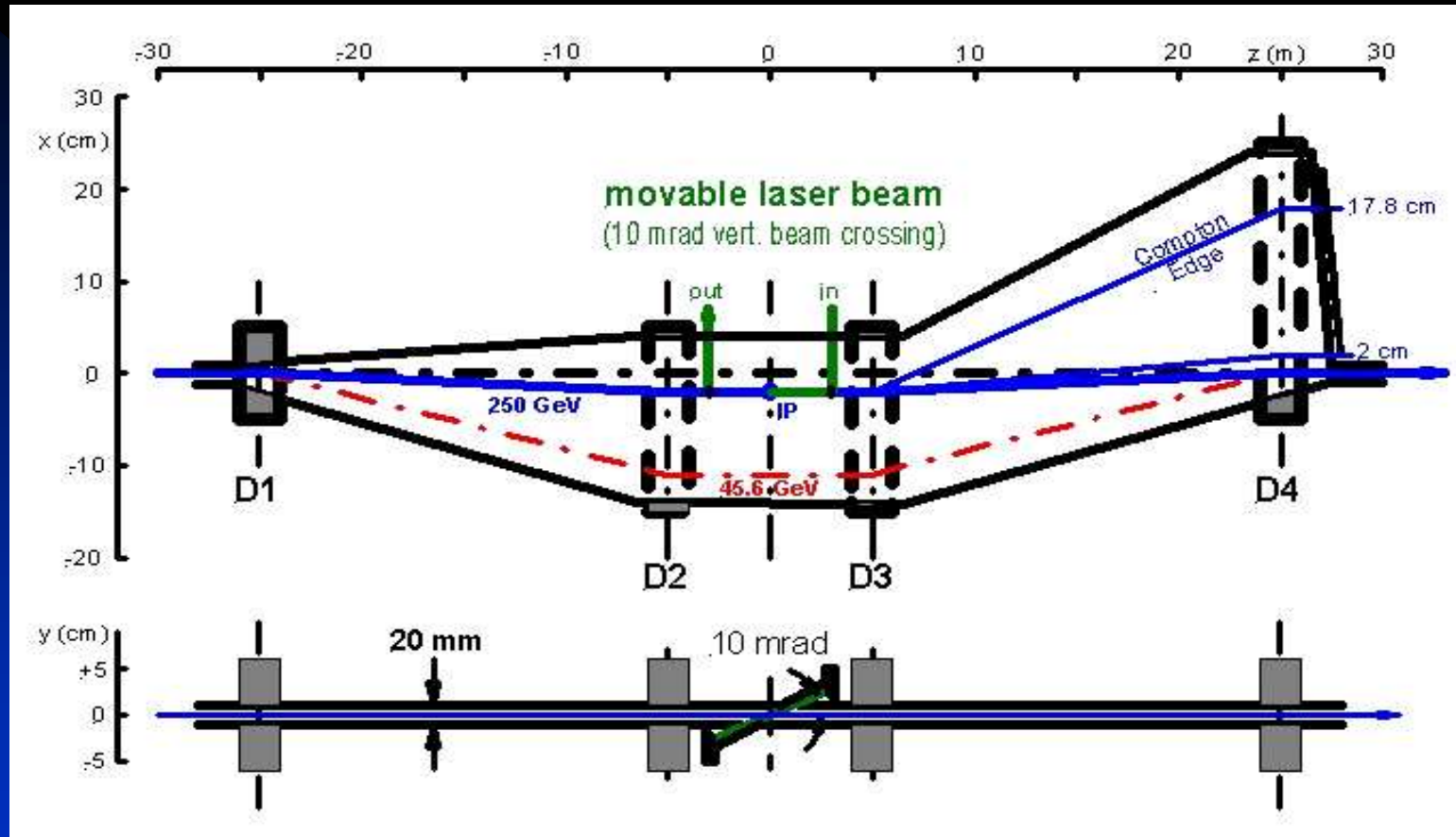
$X_{\max} = 4 \omega_0 p_T L / m^2$      $\beta$  position of Compton edge is independent of beam energy

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

# movable laser beam

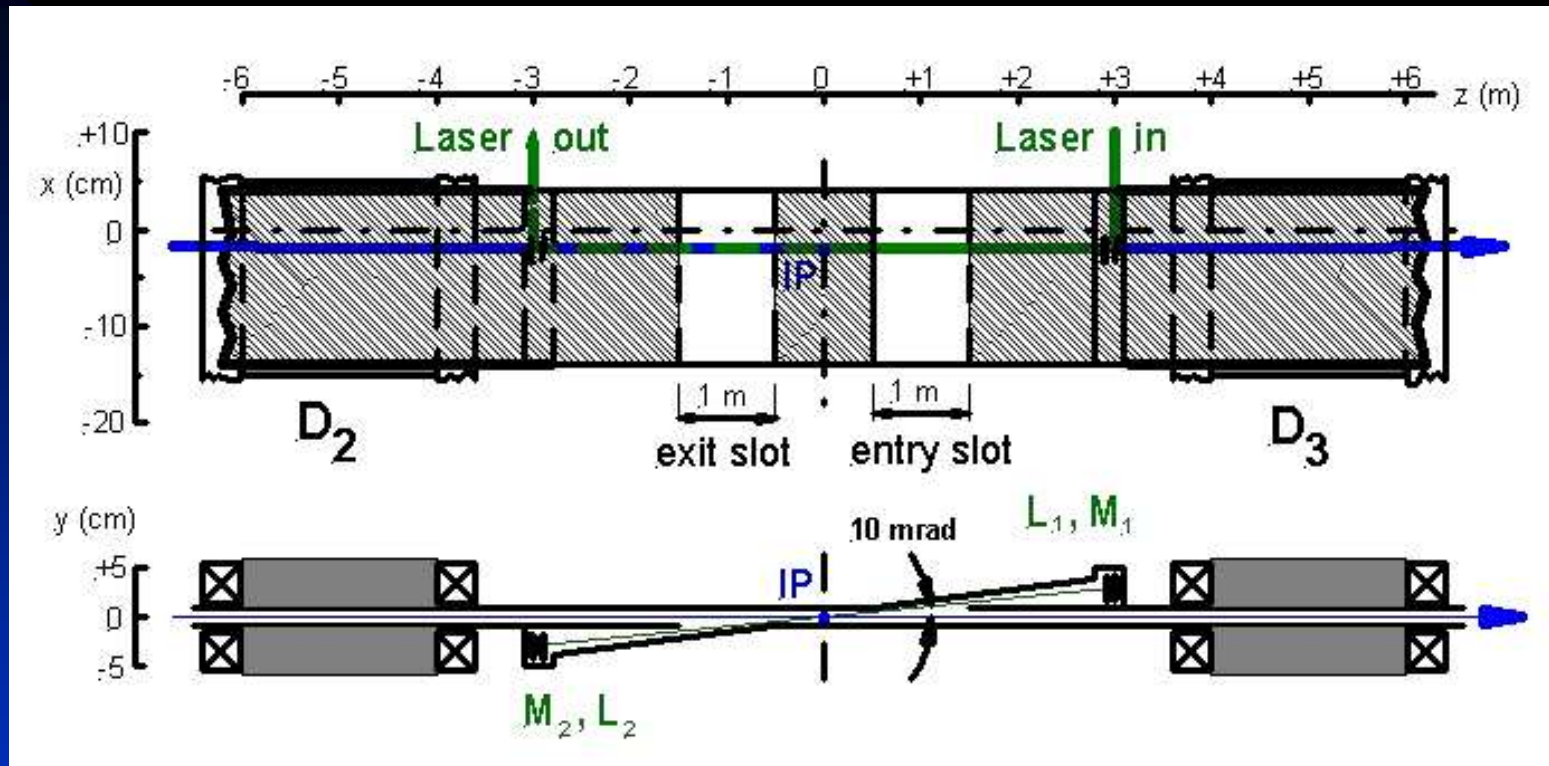


# Vacuum Chamber Overview



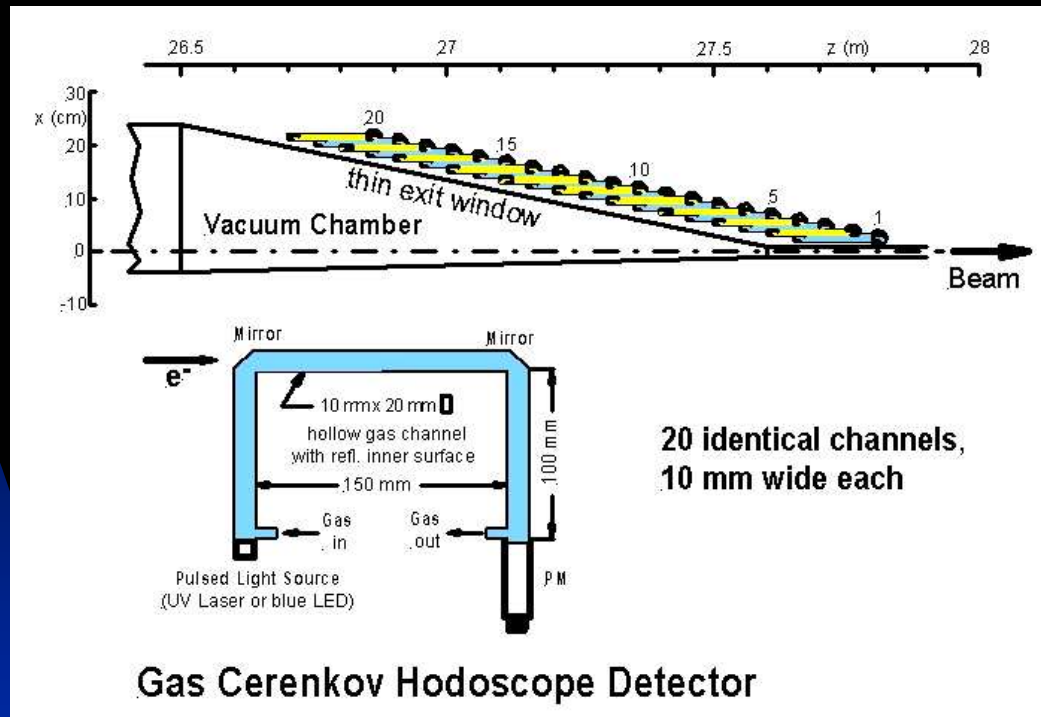
**chambers are tapered to minimize wake fields**

# Vacuum Chamber Detail



laser beam crossing requires ~ 1 m long insertion/exit slots along z  
à 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 ( $\sim 10$  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 spectr.
- $E_{\max} / E_0 = 85\%; 50\%; 33\%$  at  $E_0 = 45.6; 250; 500$  GeV (with  $x_{\min} = 20$  mm)

# some simulation results I

## input parameters

0.5 x 10 <sup>6</sup>	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 <sup>32</sup> / cm <sup>2</sup> / 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

$$E_0 = 250 \text{ GeV}$$

$$\omega_0 = 2.33 \text{ eV (green laser)}$$

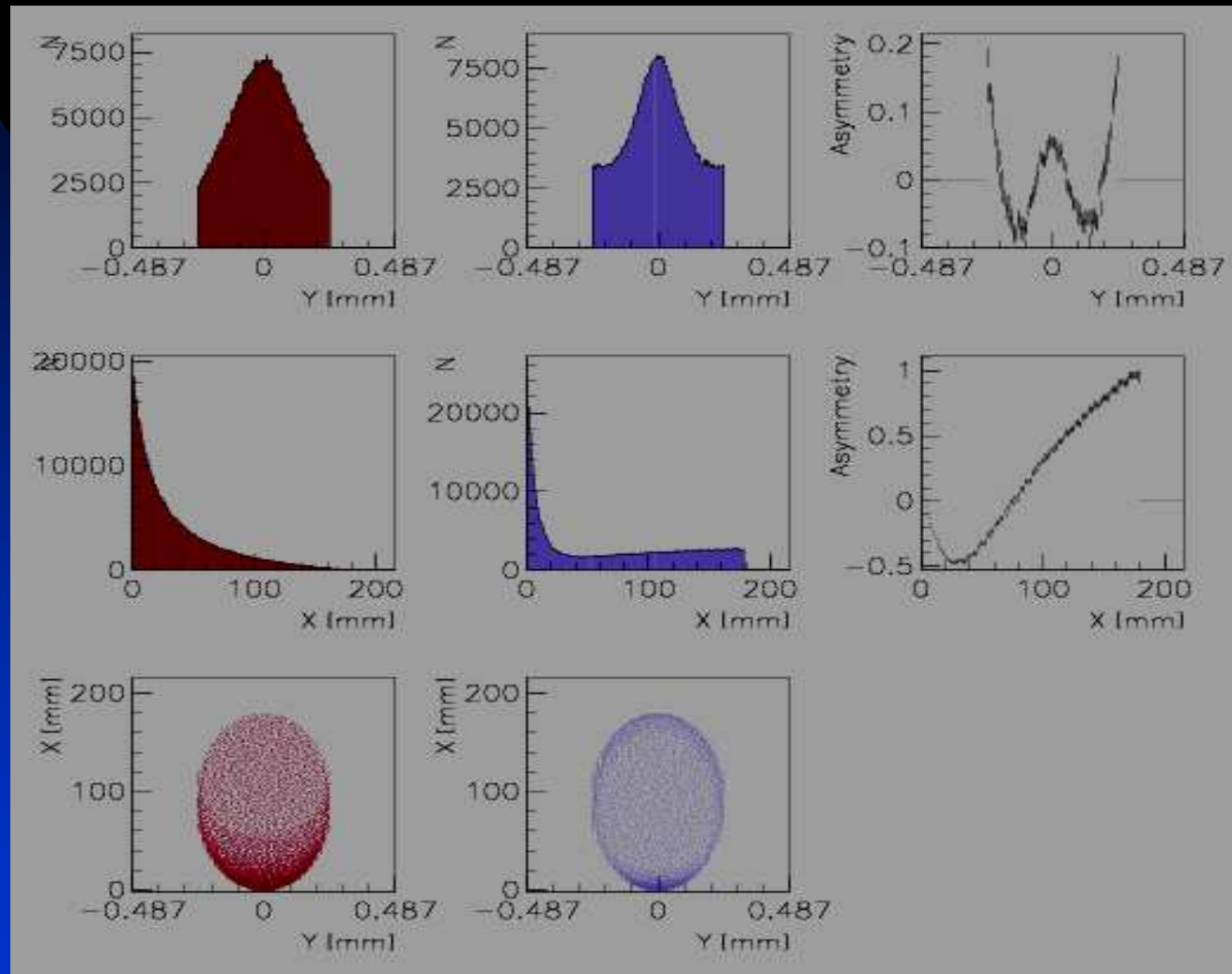
$$\mathcal{L} = 1.5 \times 10^{32} / \text{cm}^2 / \text{sec}$$

## results

Ch. #	x [mm]	N+	N-	A	Rate*A <sup>2</sup>	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				

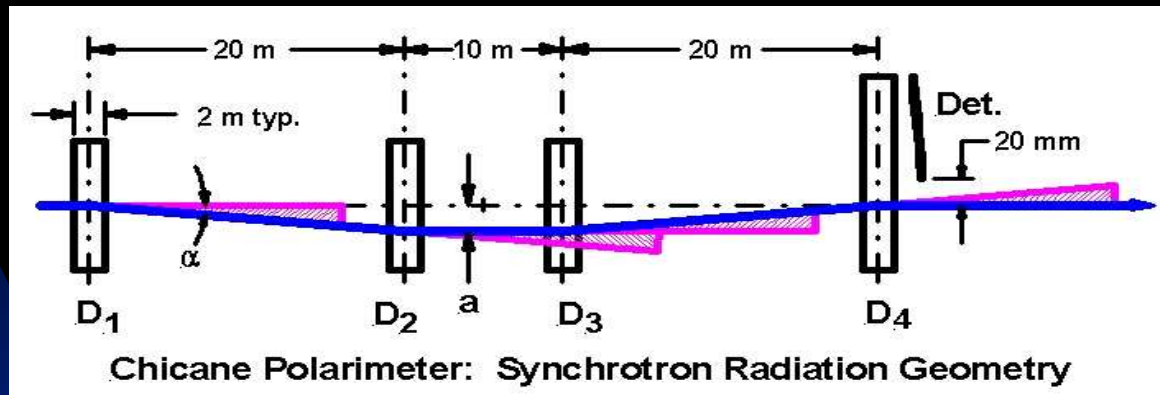
**overall stat. error: dP/P = 0.082%**  
**for dT = 1 sec**

# some simulation results II





# synchrotron radiation



E	$\alpha$	a	$\Delta E / \text{el.}$	$\Delta E / \text{bunch}$	$\Delta E / \text{sec}$	total power
[GeV]	[mrad]	[mm]	[MeV]	per magnet	-----	(4 magnets)
				[mJ]	[kJ]	[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

(\*)  $2 \times 10^{10}$  el./bunch

(\*\*)  $5 \times 2,820 = 14,100$  bunches/sec

# emittance growth

## from synchrotron radiation

$E_{\text{beam}}$ [GeV]	$E_{\text{cm}}$ [GeV]	$\Delta\epsilon_x/\epsilon_x$ [%]		
45.6	90.2	0.002		
100	200	0.02		
250	500	0.3		
500	1,000	2.5	$\beta$	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  $E_{\text{cm}} = 1$  TeV and 1/3 of emittance growth
- for polarimeter chicane,  $\Delta\epsilon/\epsilon$  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!“**