Upstream Compton Polarimeter Update

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Introduction & Overview

- Compton polarimetry basics
  (nothing new here)

4-Magnet Chicane

- old layout: dedicated polarimeter chicane
- new layout: combined with energy and emittance diagnostics

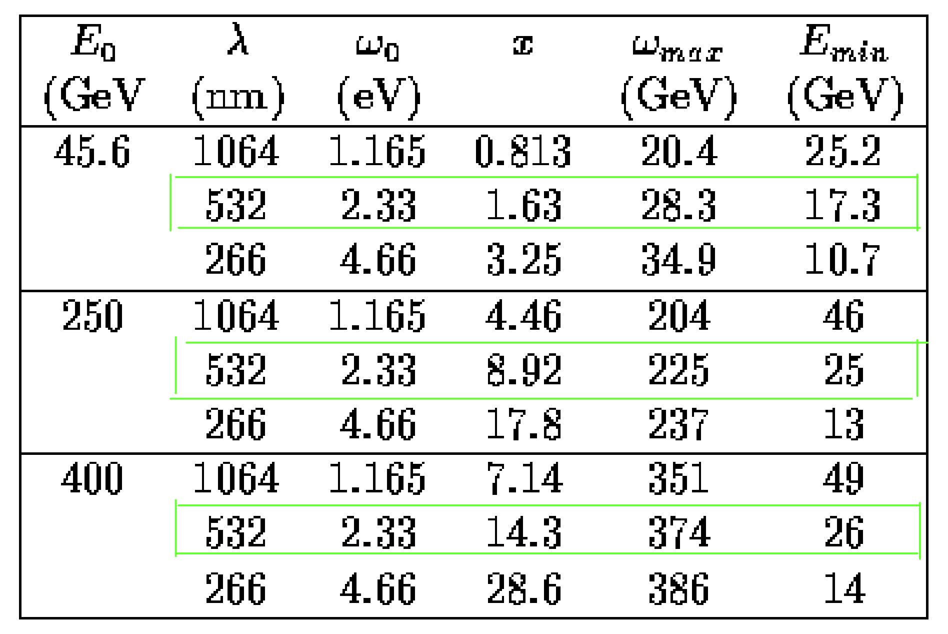
Compton polarimetry basics I : Kinematics

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

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

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

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



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

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

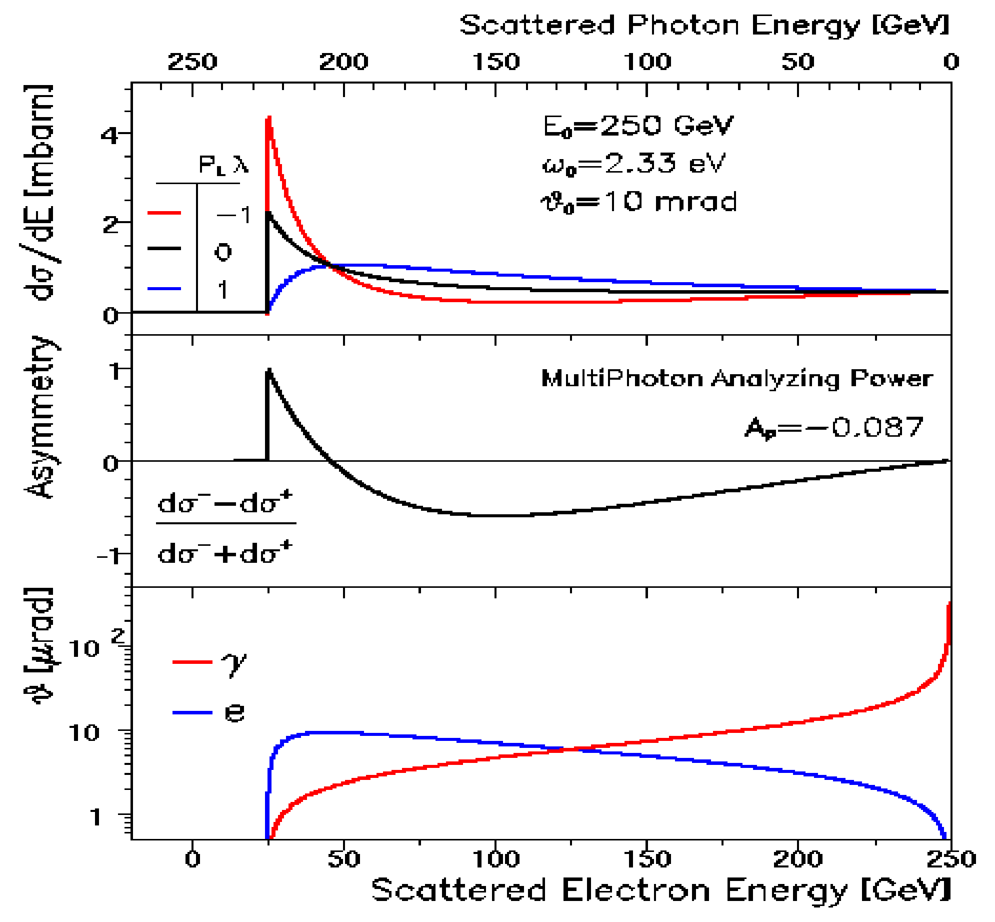
$$\theta_e = \frac{y}{1-y}\theta_\gamma$$

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

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

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

$\sigma_{t\gamma}$	$\sigma_{z\gamma}$	$\mathcal{L}/\mathcal{L}_{max}$		
(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

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

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

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

Laser for TTF injector gun

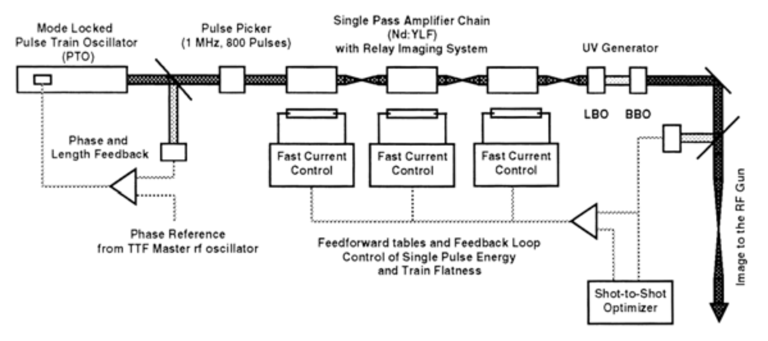
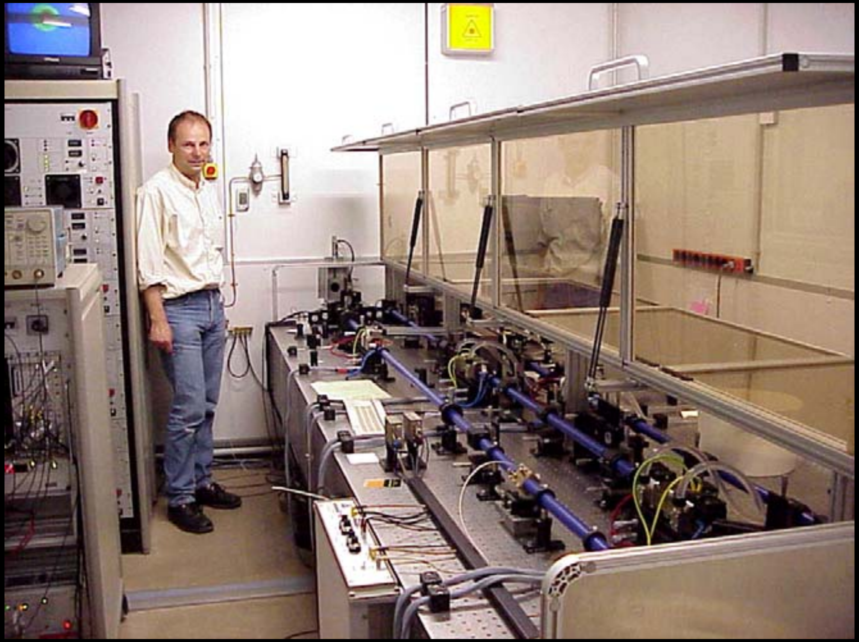
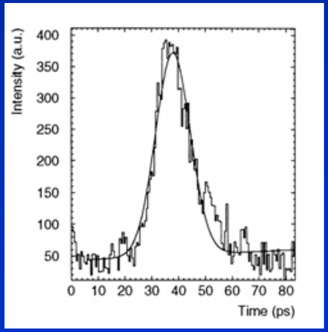


Fig. 1. Schematic overview of the TTF photoinjector laser system.



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

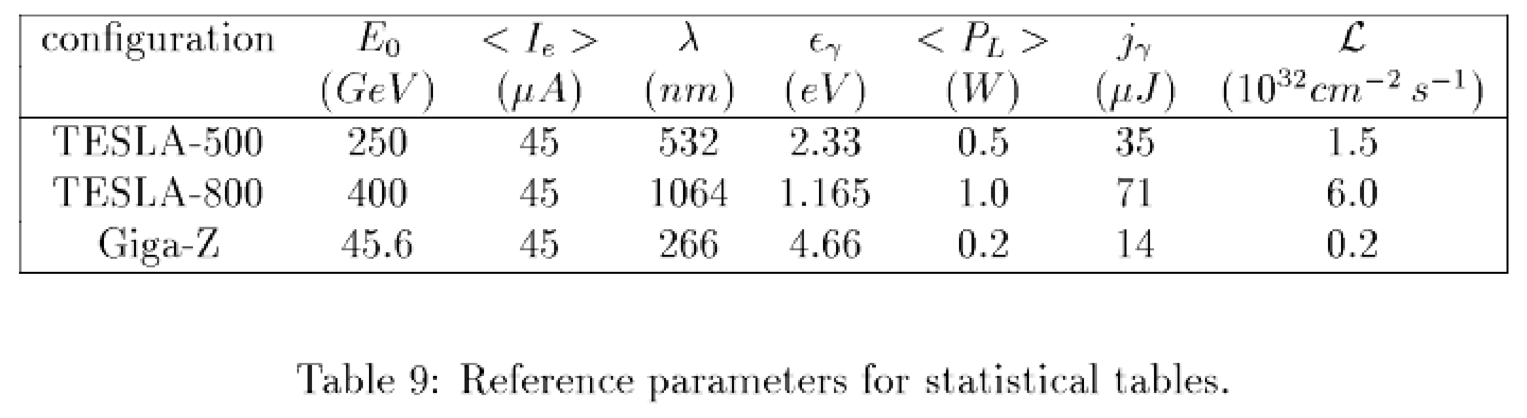
S. Schreiber et al.
NIM A 445 (2000) 427



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

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
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

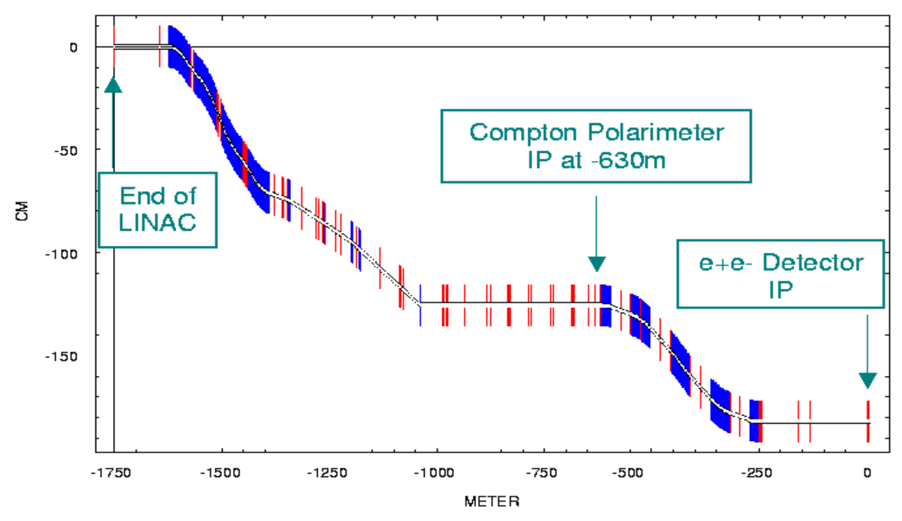
Table 9: Reference parameters for statistical tables.

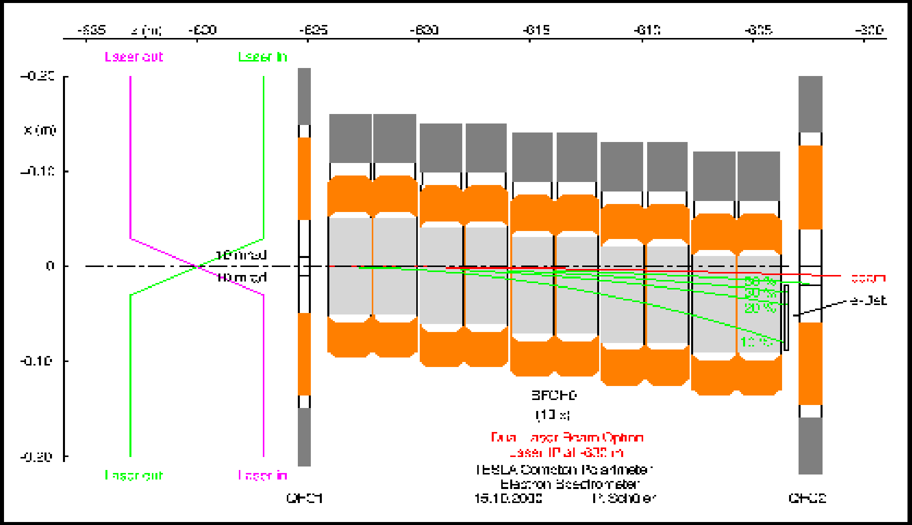
← green
← IR
← UV

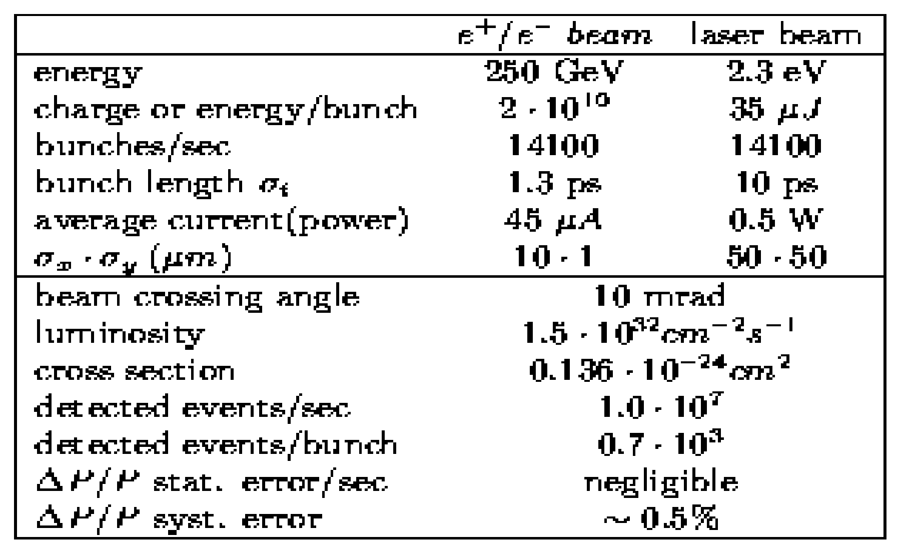
will employ similar laser for ILC chicane polarimeter, but can operate with green line at all ILC beam energies

Tesla design

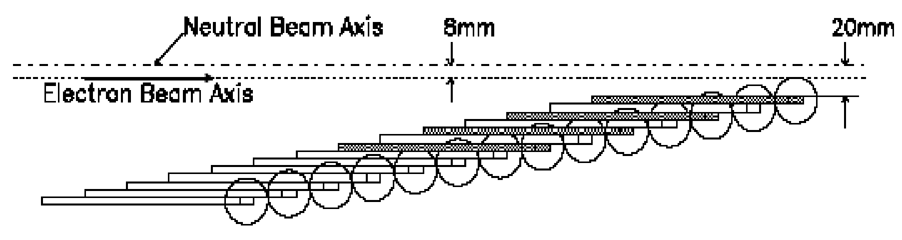
V. Gharibyan, N. Meyners, K.P. Schüler,
www.desy.de/~lcnotes/notes.html, LC-DET-2001-047





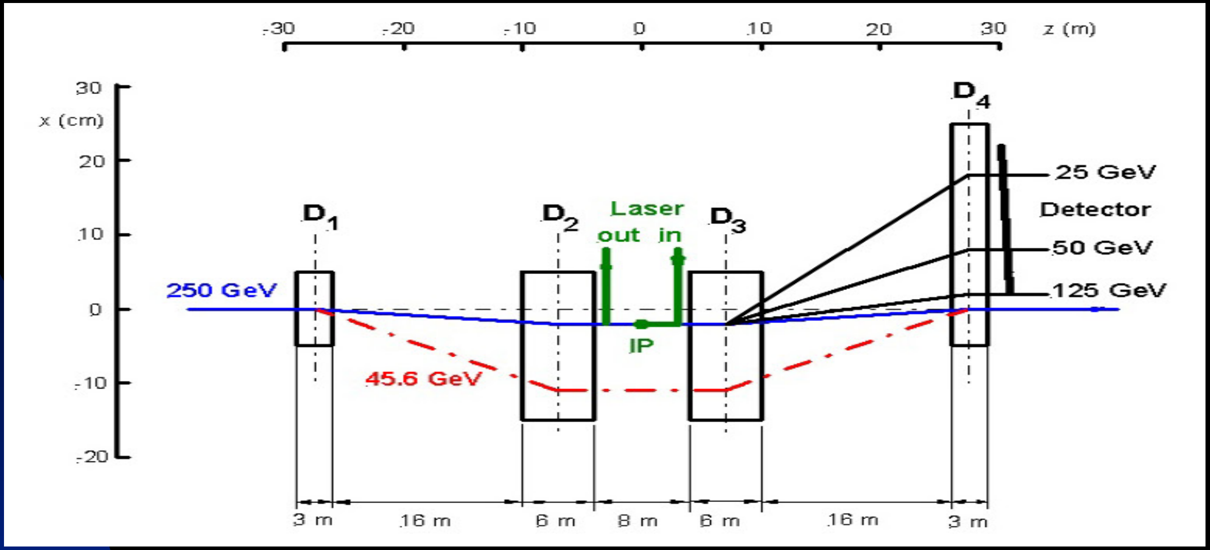


	e^+/e^- beam	laser beam
energy	250 GeV	2.3 eV
charge or energy/bunch	$2 \cdot 10^{10}$	35 μJ
bunches/sec	14100	14100
bunch length σ_t	1.3 ps	10 ps
average current(power)	45 μA	0.5 W
$\sigma_x \cdot \sigma_y$ (μm)	$10 \cdot 1$	$50 \cdot 50$
beam crossing angle	10 mrad	
luminosity	$1.5 \cdot 10^{32} cm^{-2} s^{-1}$	
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	$\sim 0.5\%$	



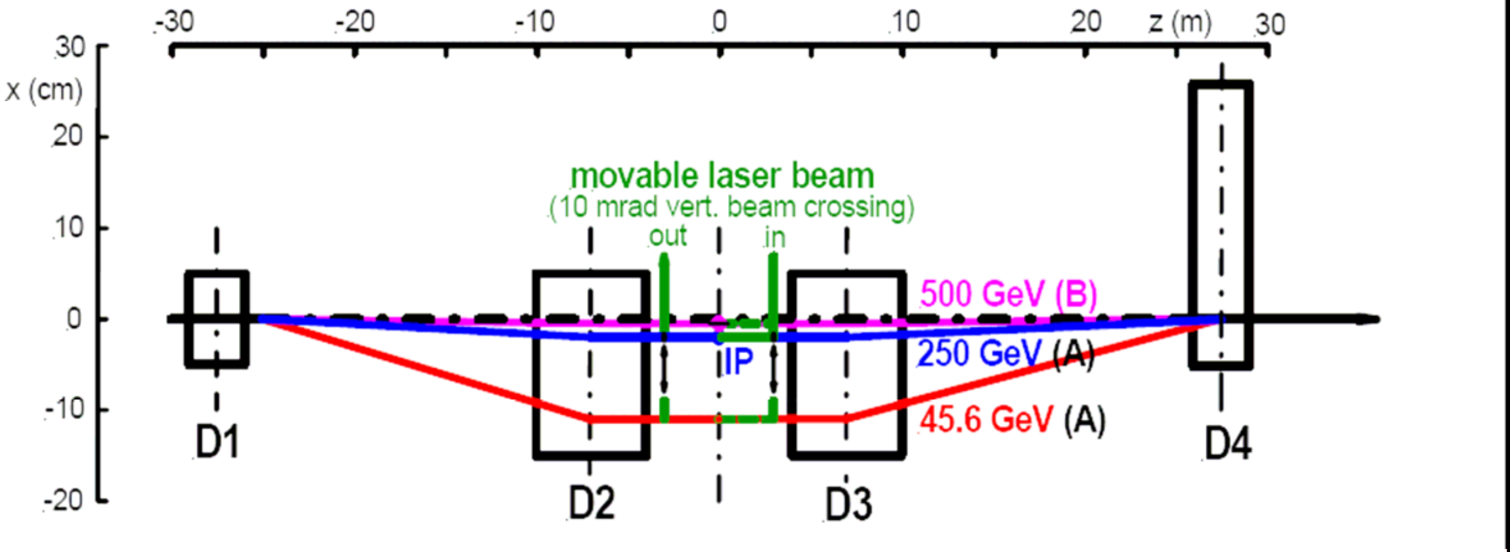
- **minimal space & no special magnets**
- **need to change laser wavelength to UV for z-pole running**

Chicane Design



- **essential for downstream polarimetry (separates Compton electrons from low-energy disrupted beam background), but adventageous also for upstream polarimetry**
- **requires ~ 60 meters length**
- **constant field settings ∫ B dl over wide range of energies**
- **good acceptance of Compton spectrum at all energies without changing laser wavelength**
- **laser crossing (Compton IP) at mid-chicane**

4-Magnet Chicane: general layout

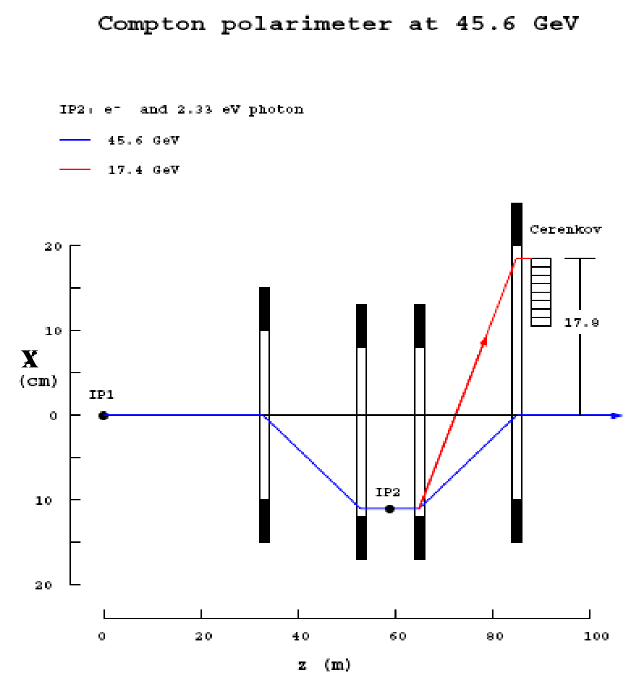


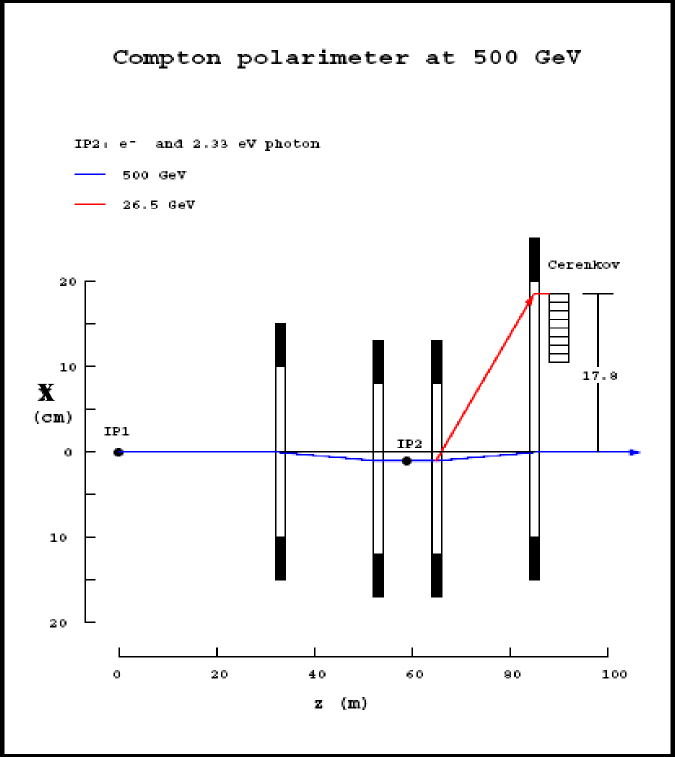
Chicane Magnet	D1	D2	D3	D4
cntr. z-pos. (m)	-27.5	-7	+7	+27.5
L (m)	3	6	6	3
hor. width (cm)	10	20	20	30
B_T (T)	0.272	0.136	0.136	0.272
B L (Tm)	0.815	0.815	0.815	0.815
P (GeV/c)	0.245	0.245	0.245	0.245

Beam Energy (GeV)	Beam Defl. Angle per magnet (mrad)	Hor. Dispersion at IP (mm)
45.6	5.366	110
100	2.447	50
250	0.979	20
500	0.489	10

Chicane properties

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

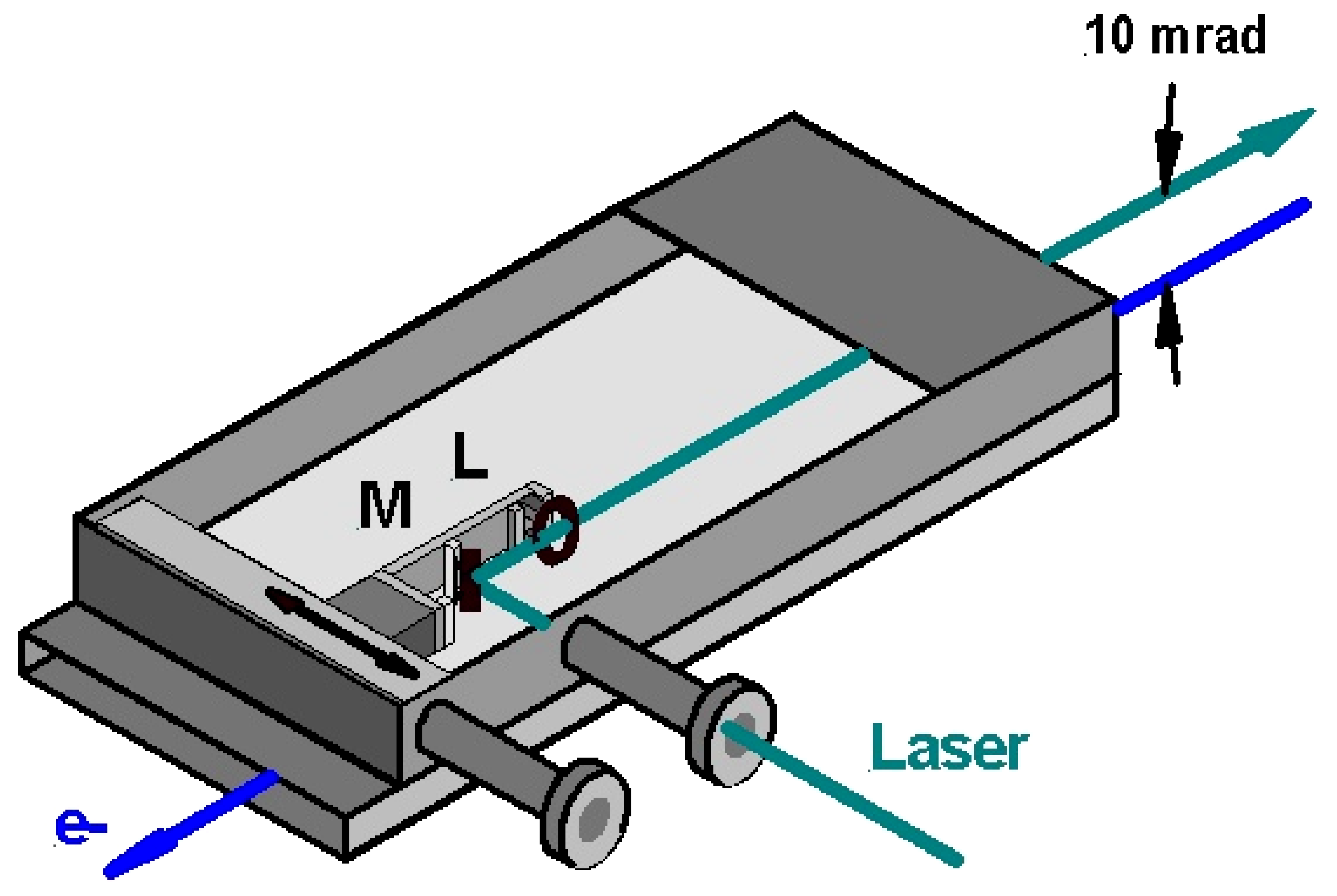




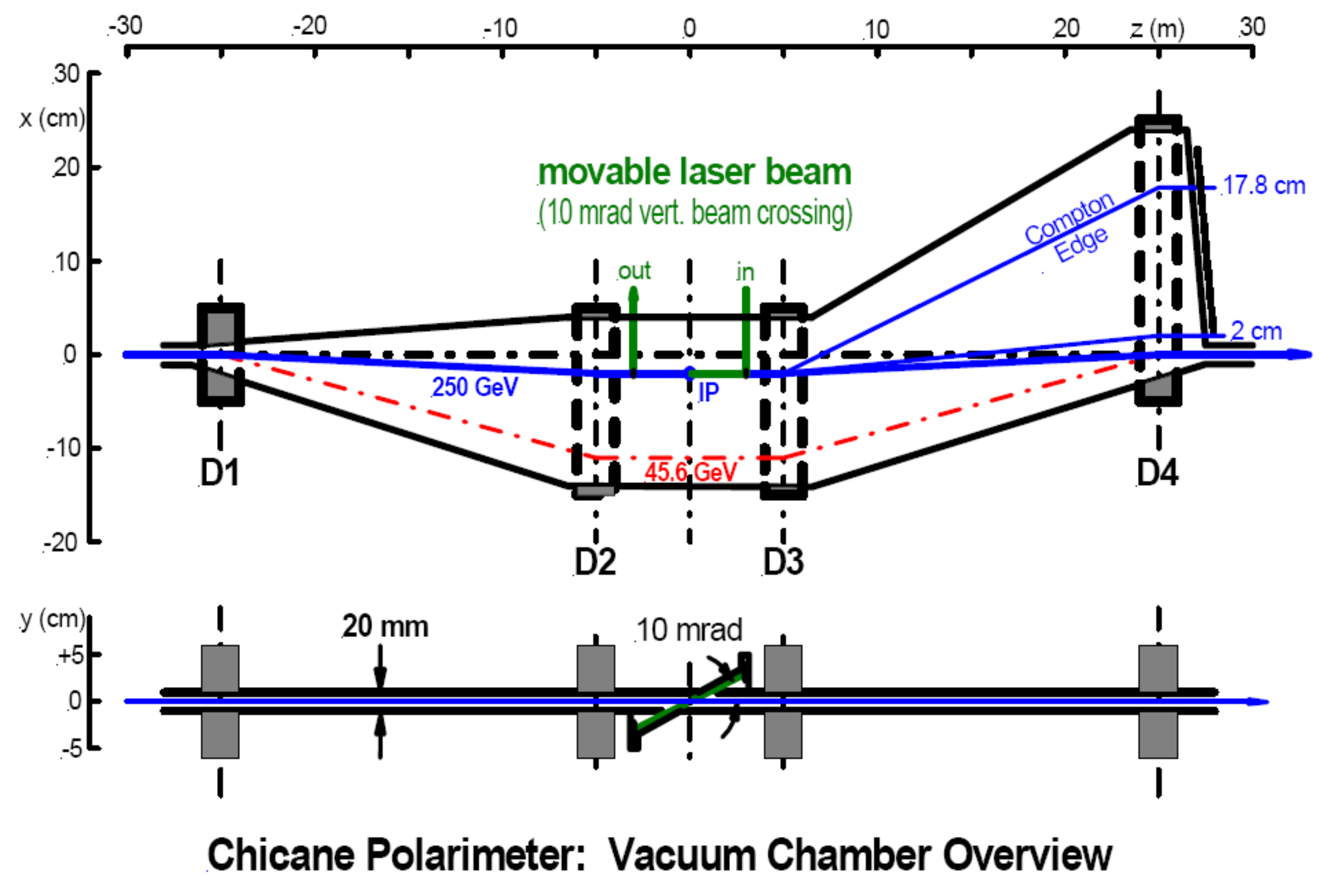
$X_{max} = 4\,\omega_0\, p_T\, L / m^2$ ← position of Compton edge is independent of beam energy

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



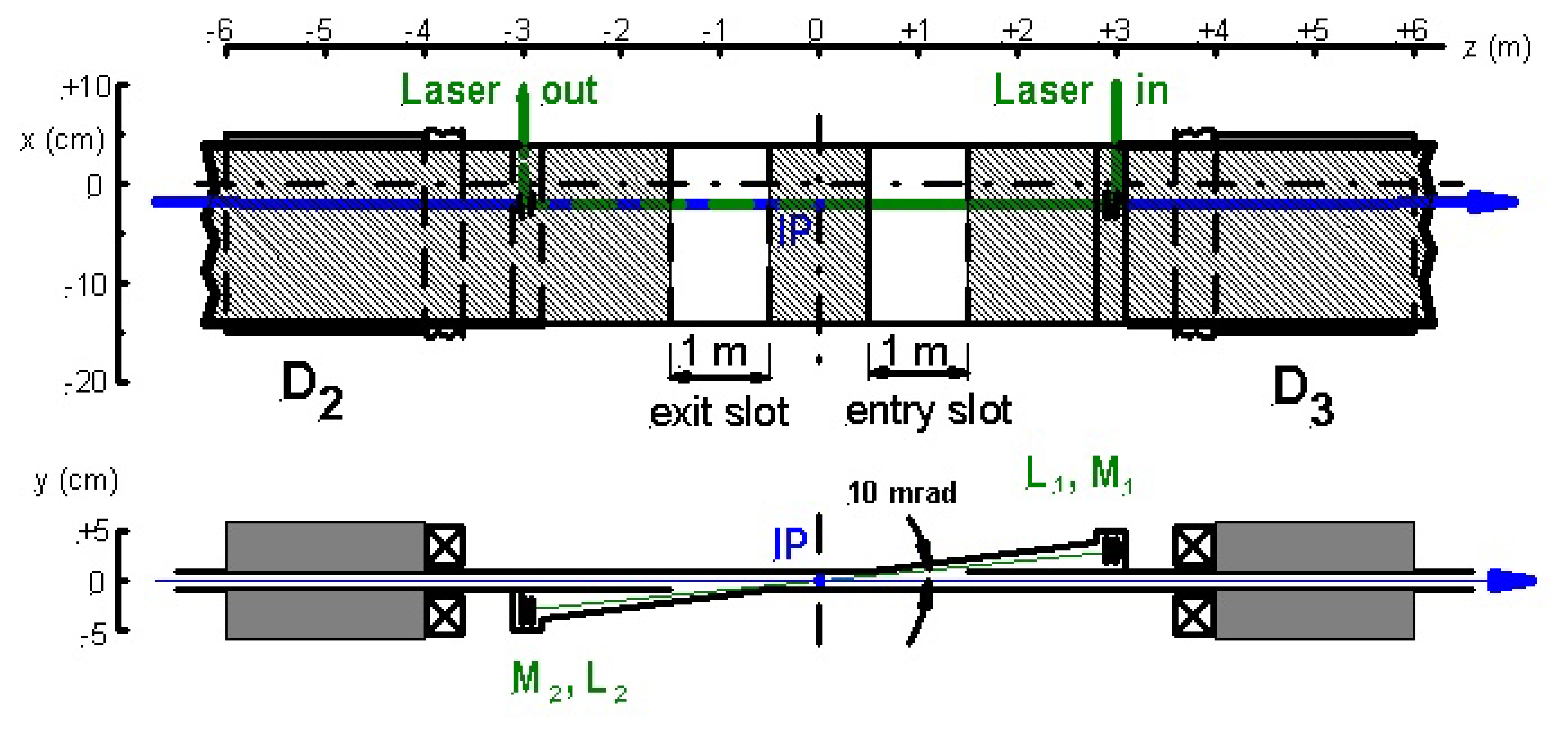
Vacuum Chamber Overview



Chicane Polarimeter: Vacuum Chamber Overview

chambers are tapered to minimize wake fields

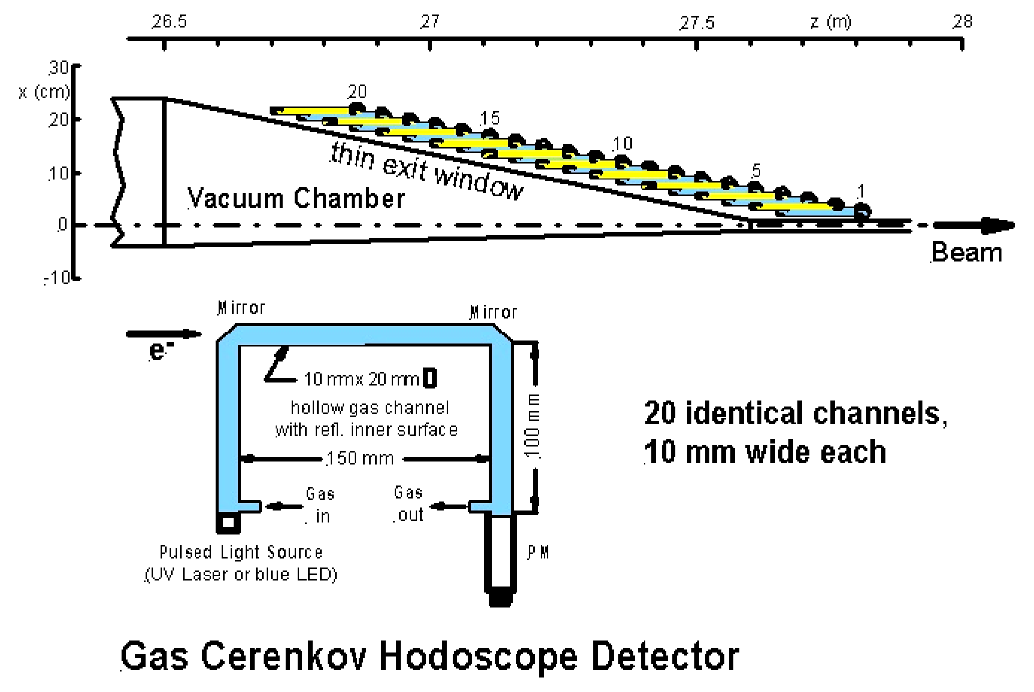
Vacuum Chamber Detail



laser beam crossing requires ~ 1 m long insertion/exit slots along z

→ wake field effects: have been studied and were found to be harmless (Igor Zagorodnov)

Electron Detector



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 (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.**
- **$E_{max} / E_0 = 85\%; 50\%; 25\%$ at $E_0 = 45.6; 250; 500$ GeV (with $x_{min} = 20$ mm)**

some simulation results

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

$\omega_0 = 2.33$ eV (green laser)

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

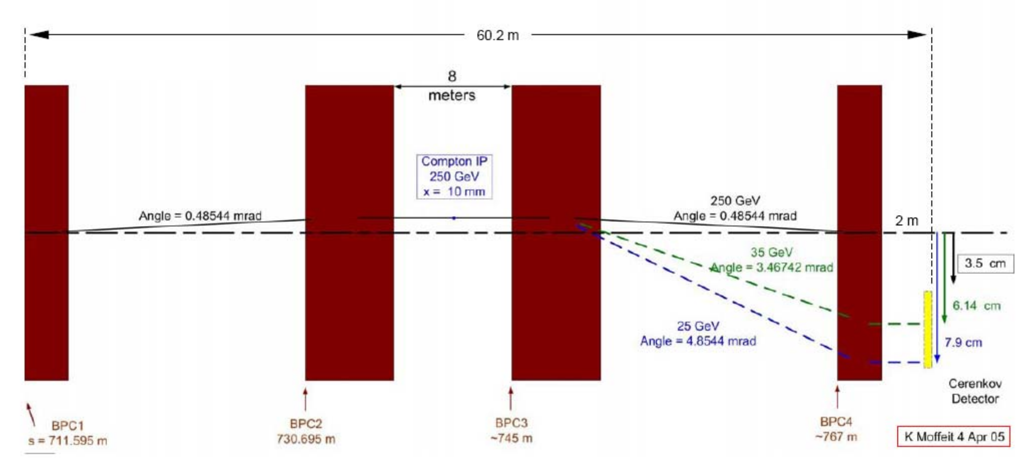
results

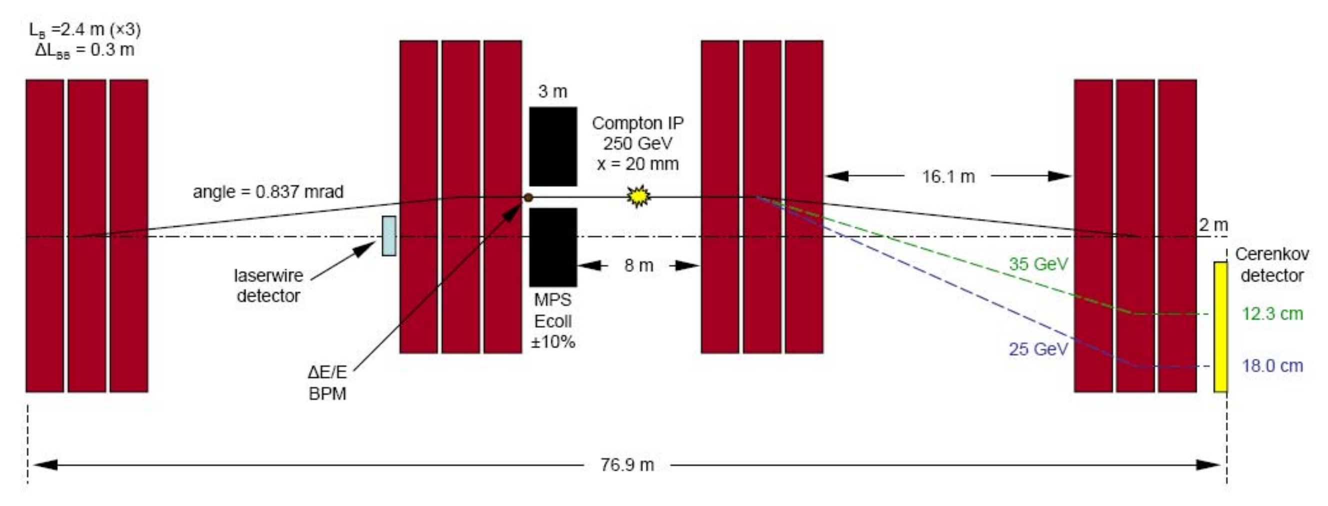
Ch. #	x [mm]	N+	N-	A	Rate*A²	Rate [MHz]	dP/P [%]
1	25	60,682	23,368	-0.444	0.337	1.710	0.228
2	35	45,868	17,348	-0.451	0.262	1.287	0.260
3	45	35,673	16,012	-0.380	0.152	1.052	0.335
4	55	28,337	16,029	-0.277	0.069	0.903	0.486
5	65	22,996	16,956	-0.151	0.019	0.813	0.924
6	75	18,333	17,876	-0.013	0.000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

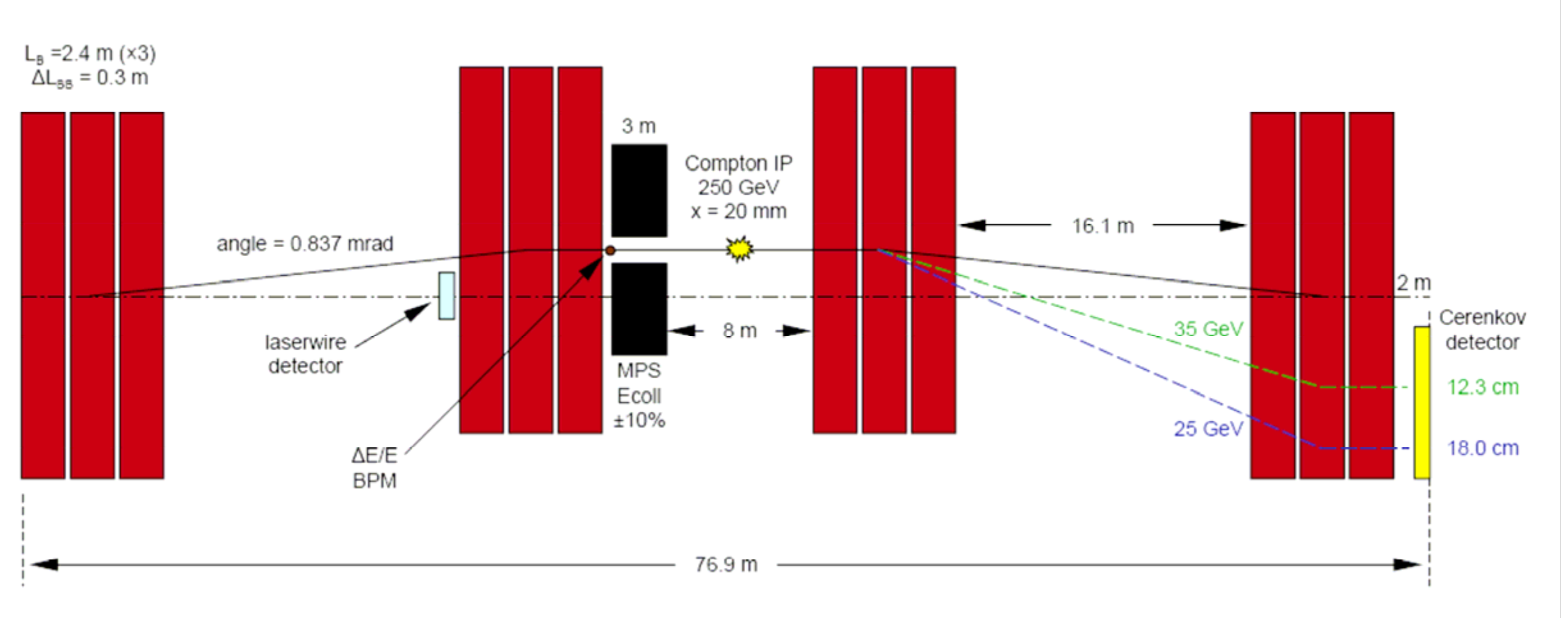
for dT = 1 sec

original vs new chicane layout





new upstream polarimeter chicane



- **constant integrated strength dipoles (0.097 Tesla) for all beam energies**
- **dispersion of 20 mm at 250 GeV (scales inversely with energy)**

combination of polarimetry with ΔE/E and emittance diagnostic saves ~100 m of beam line space, but creates several nasty issues:

- **transverse space for laser wire detector @ 500 GeV? (< 5 mm)**
- **magnet and vacuum chamber engineering issues**
- **wake field effects from inserted structures?**
- **will high-energy Compton electrons (w/o energy collimation) get to the e+e- detector?**

summary & conclusion

- **elimination of dedicated chicanes for polarimetry, ΔE/E and emittance diagnostics saves ~100 m of beam line, but creates problems, which have not yet been resolved**
- **the situation will get even more complicated, if yet another energy measurement (based on Compton scattering) will want to employ the same chicane**