BDS Polarimeter Discussion

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Upstream Polarimeter Overview

- general requirements (as we see them)
- Compton polarimetry basics
- laser performance
- chicane issues (lots of them)
- rates & errors
- conclusions

general requirements

energy range

- baseline: 200-500 GeV CM
- beyond baseline: 1 TeV and GigaZ
- baseline should at least be upgrade compatible

precision

- dP/P ~ 0.25% systematics limited
- 50 μrad directional alignment
- measure each bunch, if possible, to dP/P ~ 3%
  for fast feedback and detection of variations within the train
- d $(P_L - P_R) < 10^{-4}$ relativ for GigaZ (req's excellent statistics)
- backgrounds must be low to very low

other aspects

- measurements should be robust and redundant (many independent channels) and very reliable

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

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

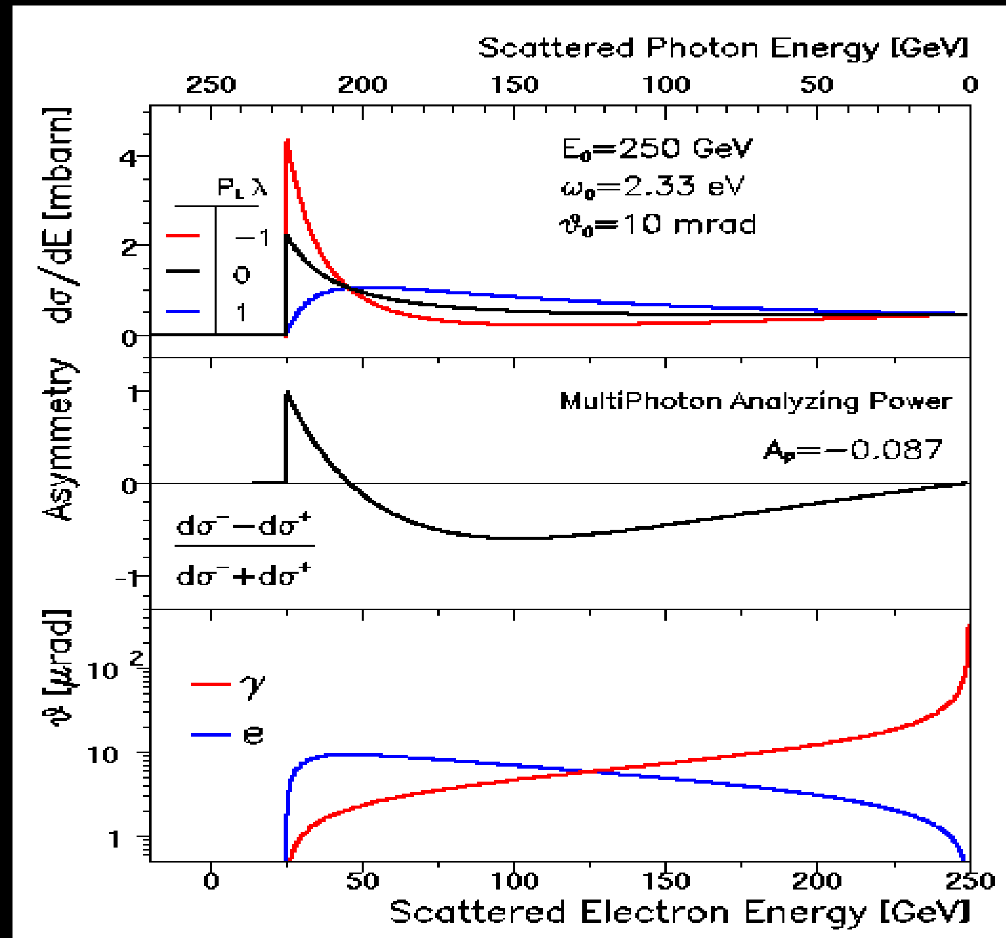
$$\theta_e = \frac{y}{1-y}\theta_\gamma$$

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

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

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

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

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

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

Laser for TTF/Flash injector gun

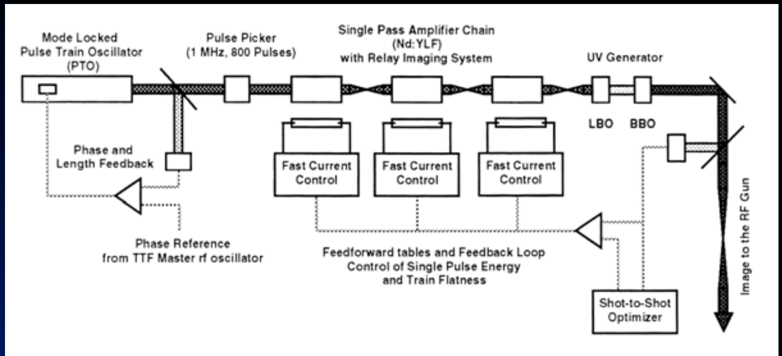
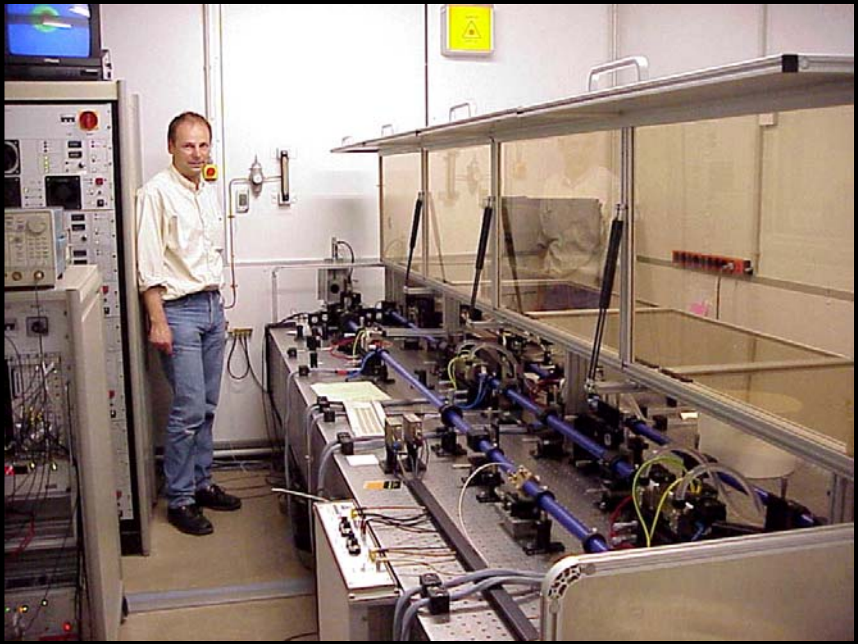
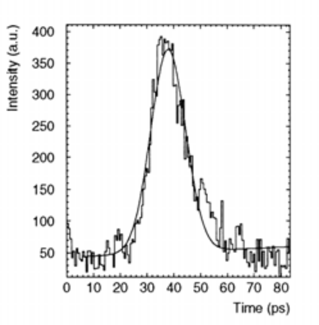


Fig. 1. Schematic overview of the TTF photoinjector laser system.



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



$\sigma_t = 8$ ps

Laser parameters

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

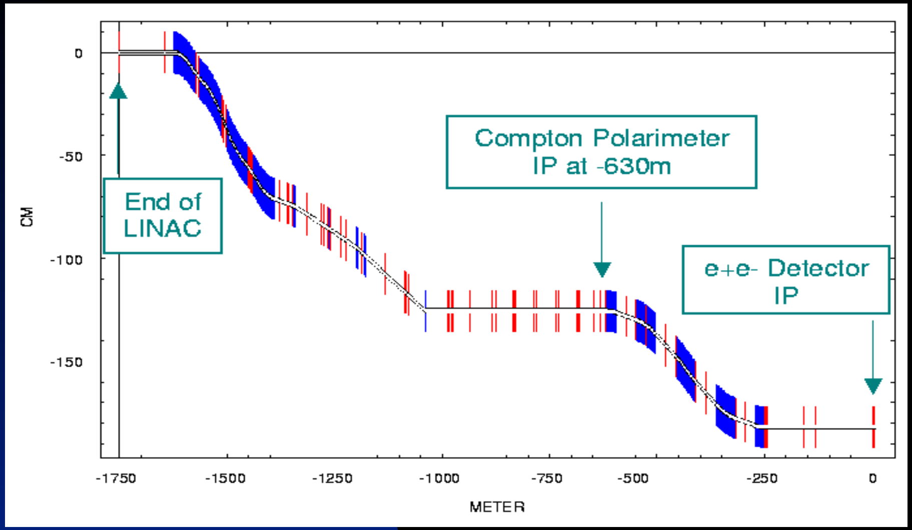
configuration	E_0 (GeV)	$< I_e >$ (μA)	λ (nm)	ϵ_γ (eV)	$< P_L >$ (W)	j_γ (μJ)	$\mathcal{L}$ $(10^{32} cm^{-2} s^{-1})$	
TESLA-500	250	45	532	2.33	0.5	35	1.5	← **green**
TESLA-800	400	45	1064	1.165	1.0	71	6.0	← **IR**
Giga-Z	45.6	45	266	4.66	0.2	14	0.2	← **UV**

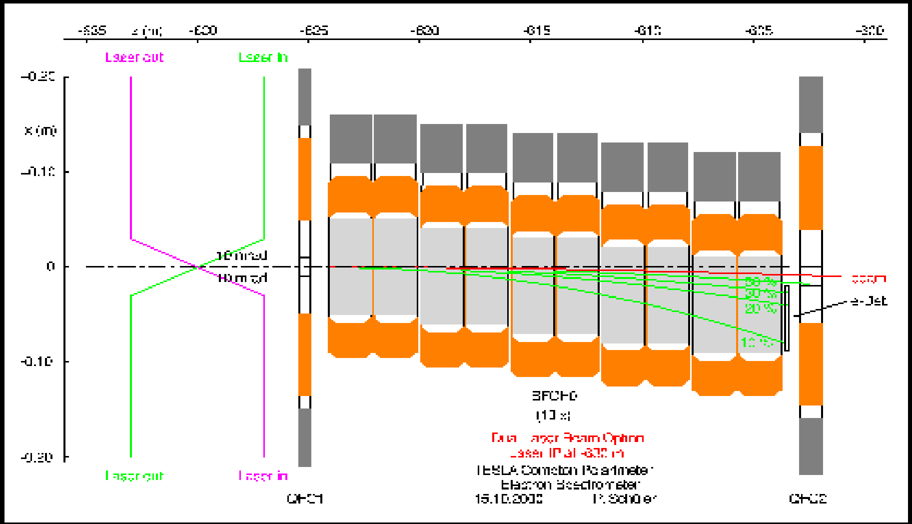
Table 9: Reference parameters for statistical tables.

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

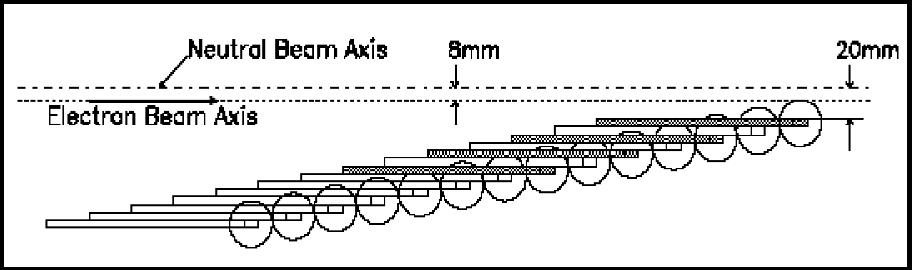
Tesla design

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



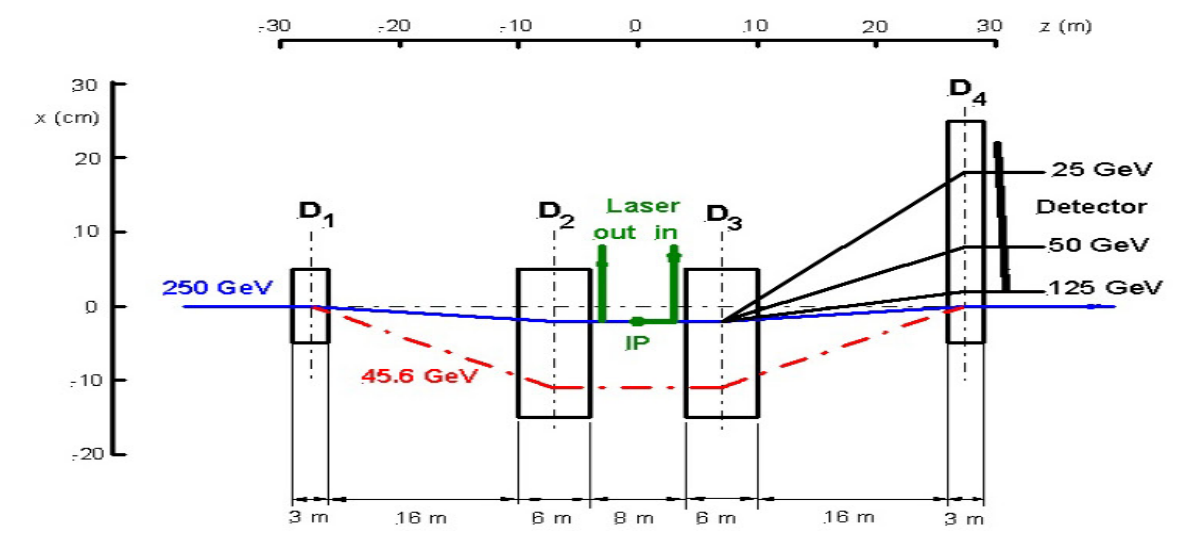


	e^+/e^- beam	laser beam
energy	250 GeV	2.3 eV
charge or energy/bunch	$2 \cdot 10^{10}$	35 μJ
bunches/sec	14100	14100
bunch length σ_t	1.3 ps	10 ps
average current(power)	45 μA	0.5 W
$\sigma_x \cdot \sigma_y$ (μm)	$10 \cdot 1$	$50 \cdot 50$
beam crossing angle	10 mrad	
luminosity	$1.5 \cdot 10^{32} cm^{-2}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



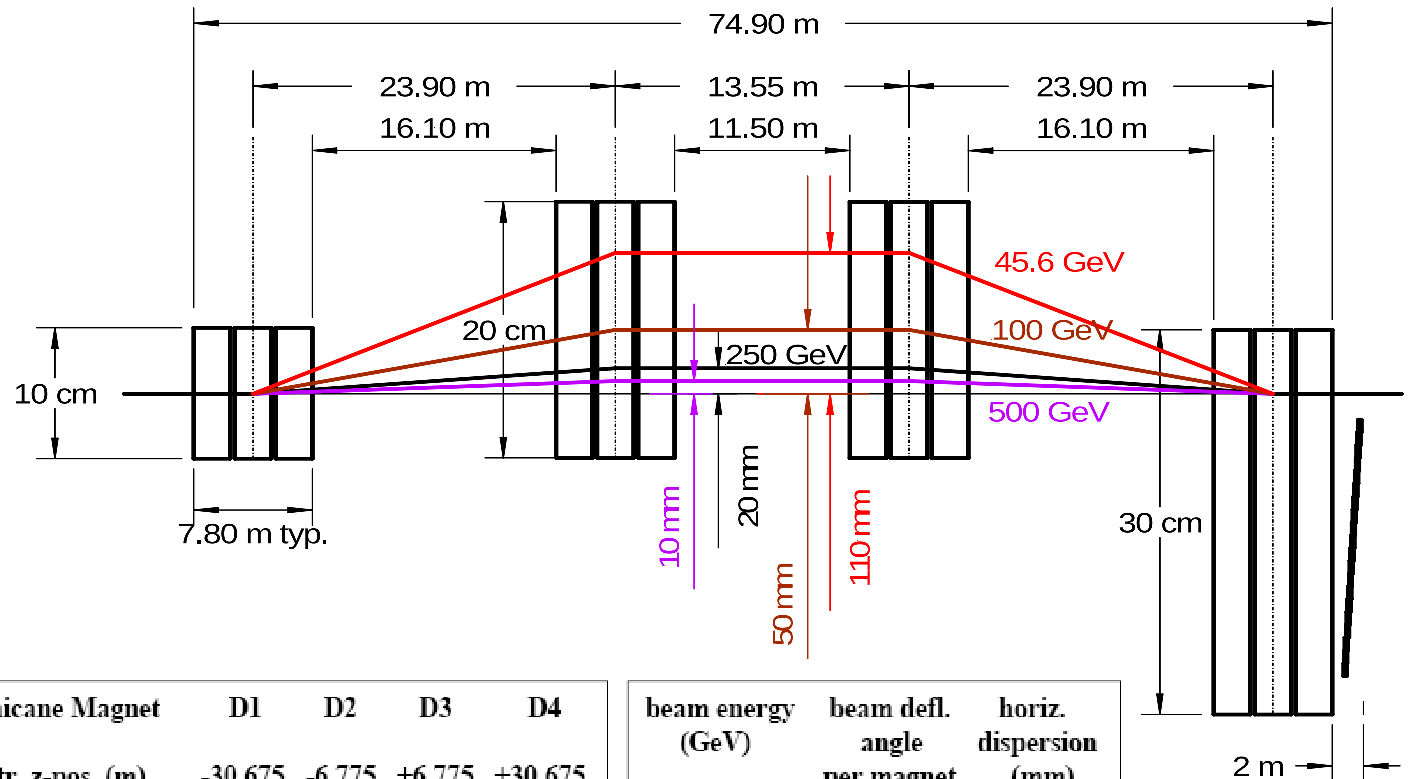
- **minimal space & no special magnets**
- **need to change laser wavelength to UV for z-pole running**

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

fixed-field chicane: general layout

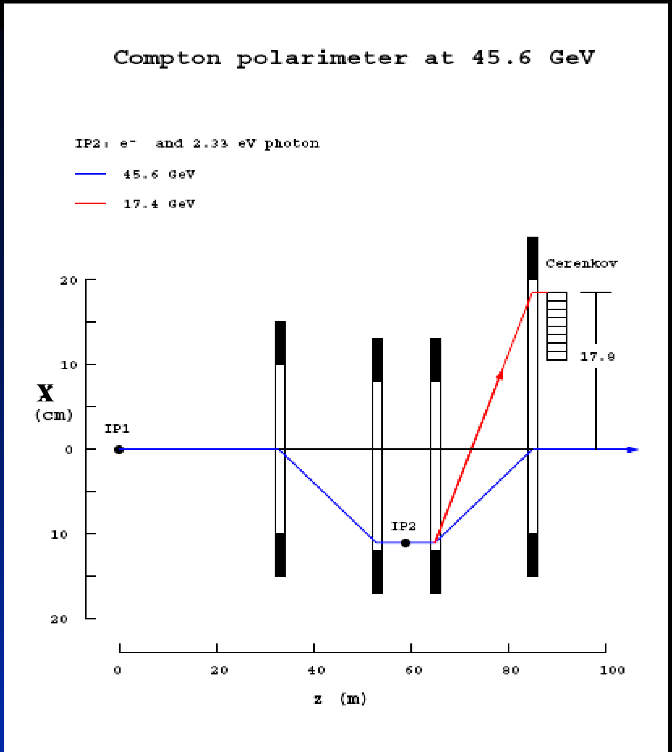


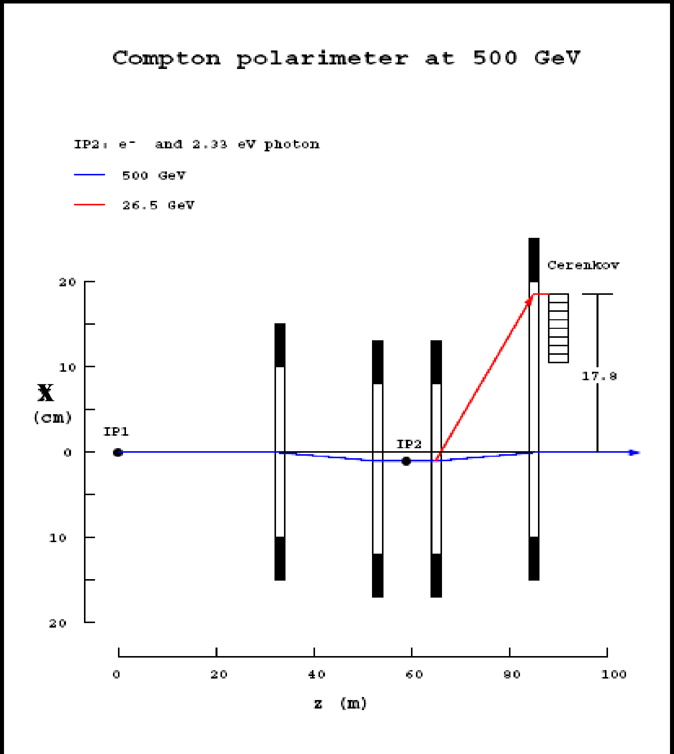
Chicane Magnet	D1	D2	D3	D4
cntr. z-pos. (m)	-30.675	-6.775	+6.775	+30.675
full length (m)	7.80	7.80	7.80	7.80
field length (m)	7.20	7.20	7.20	7.20
hor. width (cm)	10	20	20	30
B (T)	0.0982	0.0982	0.0982	0.0982
<B> (T)	0.0894	0.0894	0.0894	0.0894
<BL> (Tm)	0.6973	0.6973	0.6973	0.6973
P_T (GeV/c)	0.2092	0.2092	0.2092	0.2092

beam energy (GeV)	beam defl. angle per magnet (mrad)	horiz. dispersion (mm)
45.6	4.603	110
100	2.092	50
250	0.837	20
500	0.418	10

Chicane properties

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

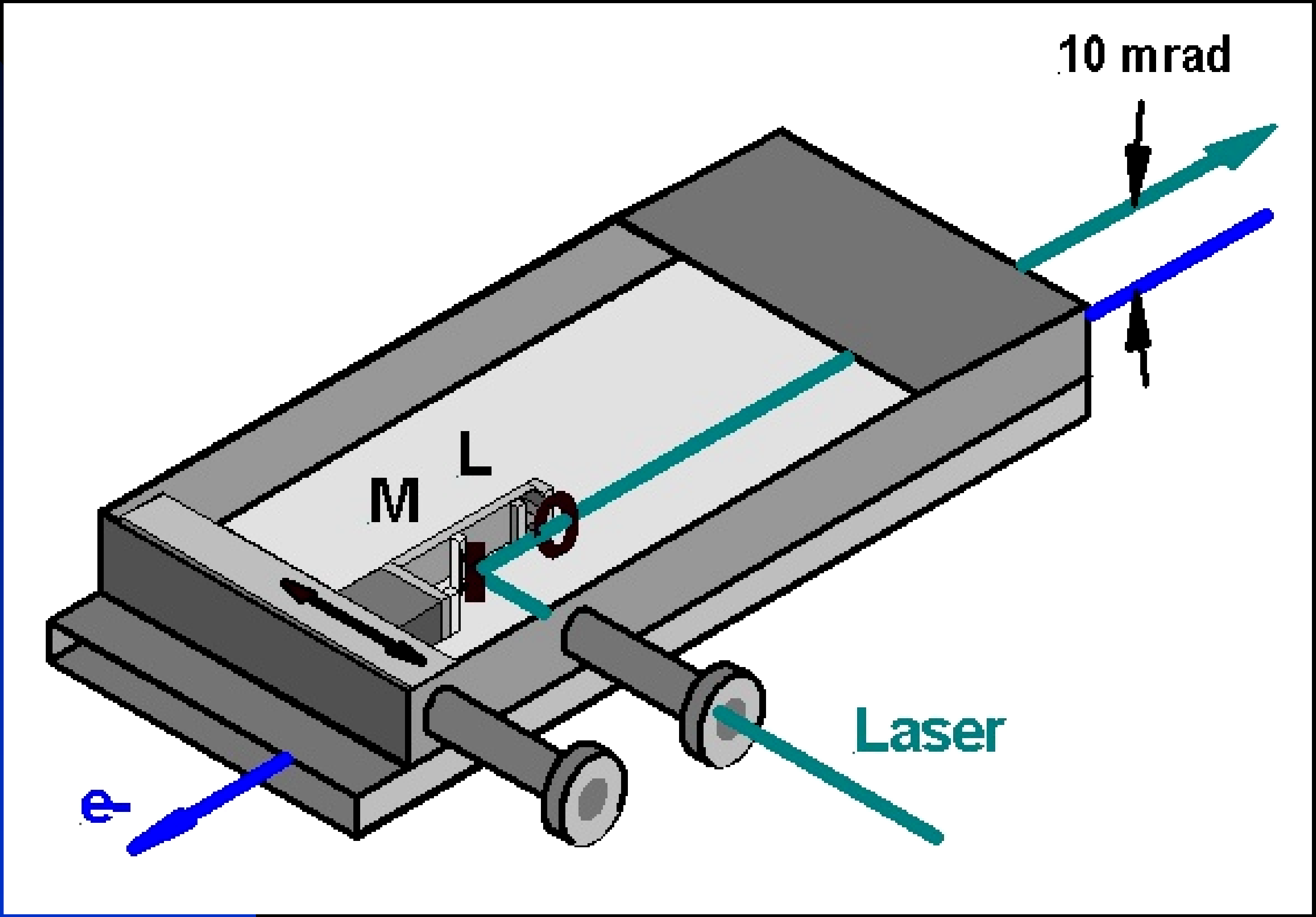




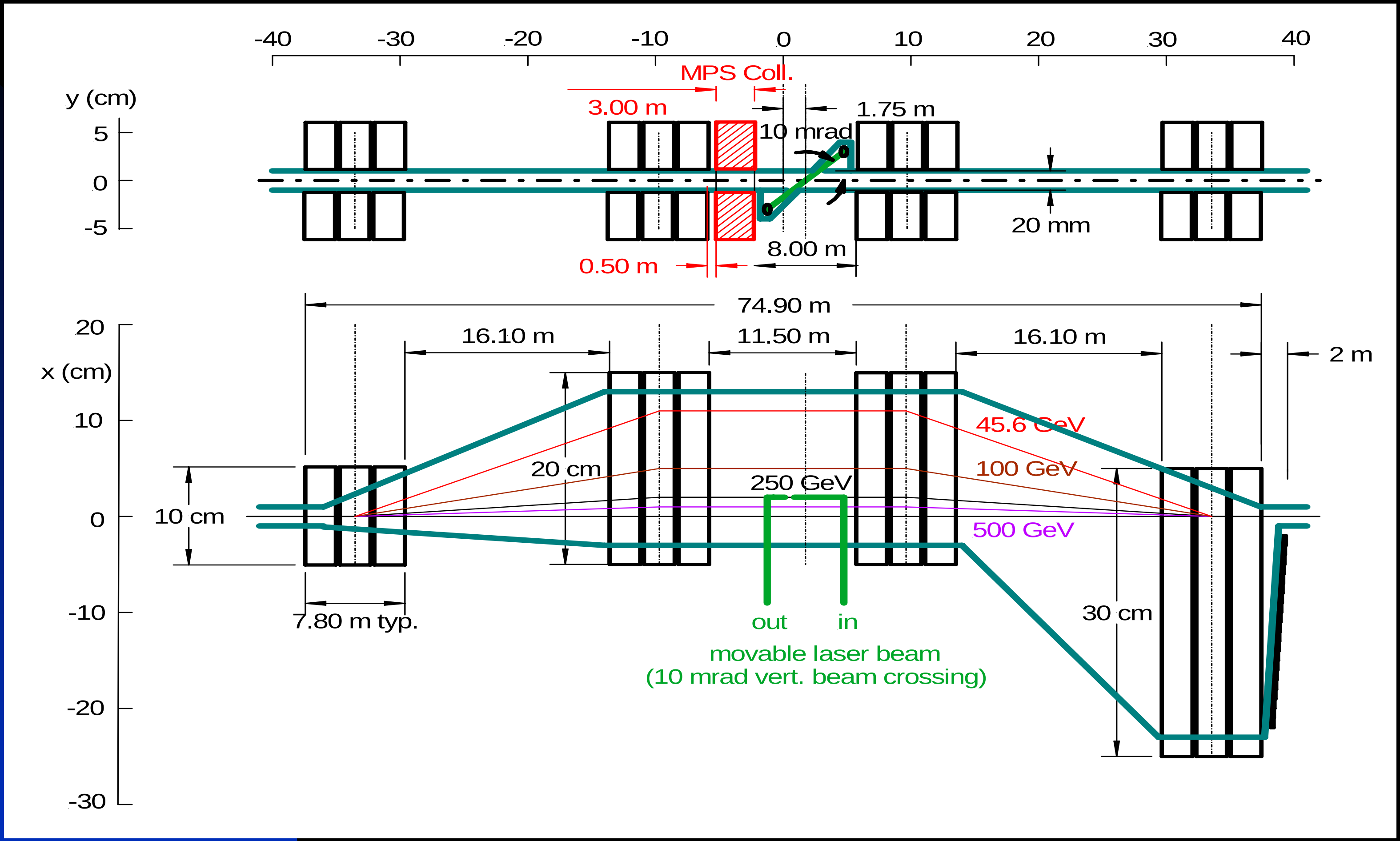
$X_{max} = 4\,\omega_0\, p_T\, L / m^2$ ← position of Compton edge is independent of beam energy

$X_{max} = 17.8$ cm for $\omega_0 = 2.33$ eV, $P_T = 0.2092$ GeV/c, L = 23.90 m

movable laser beam



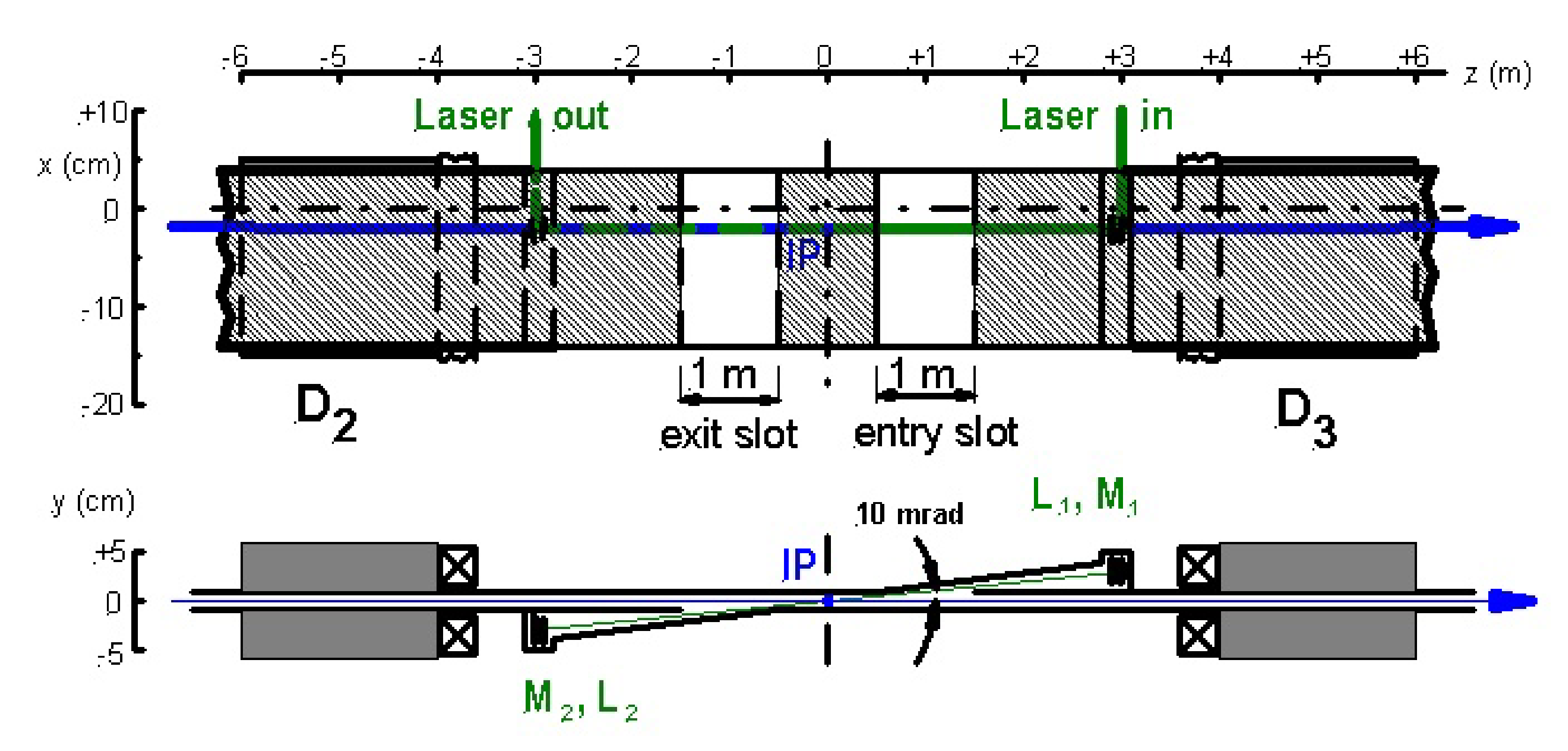
Vacuum Chamber Overview



chambers are tapered to minimize wake fields

… that was our design until the MPS collimator arrived – now what?!

Vacuum Chamber Detail

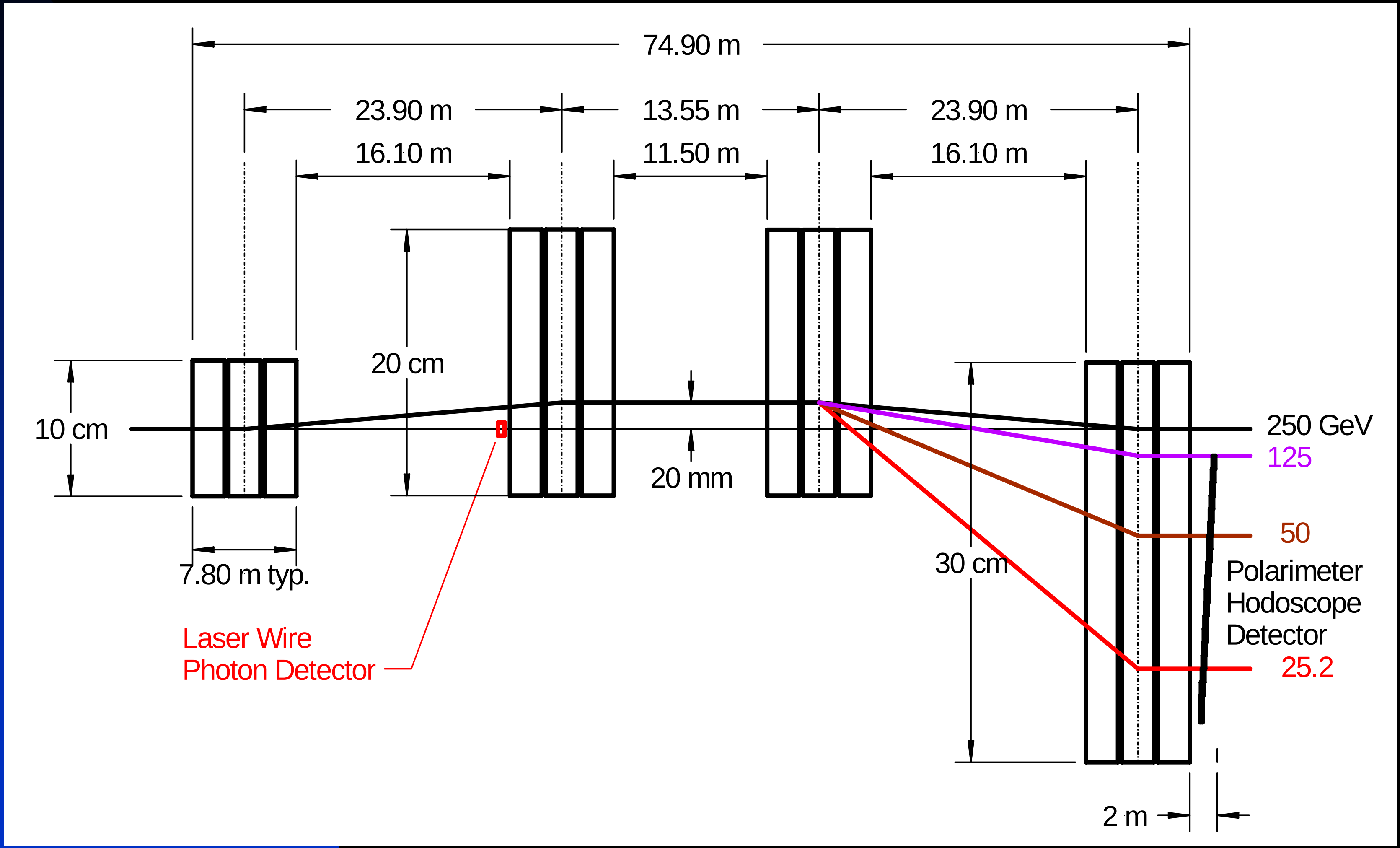


laser beam crossing requires ~ 1 m long insertion/exit slots along z

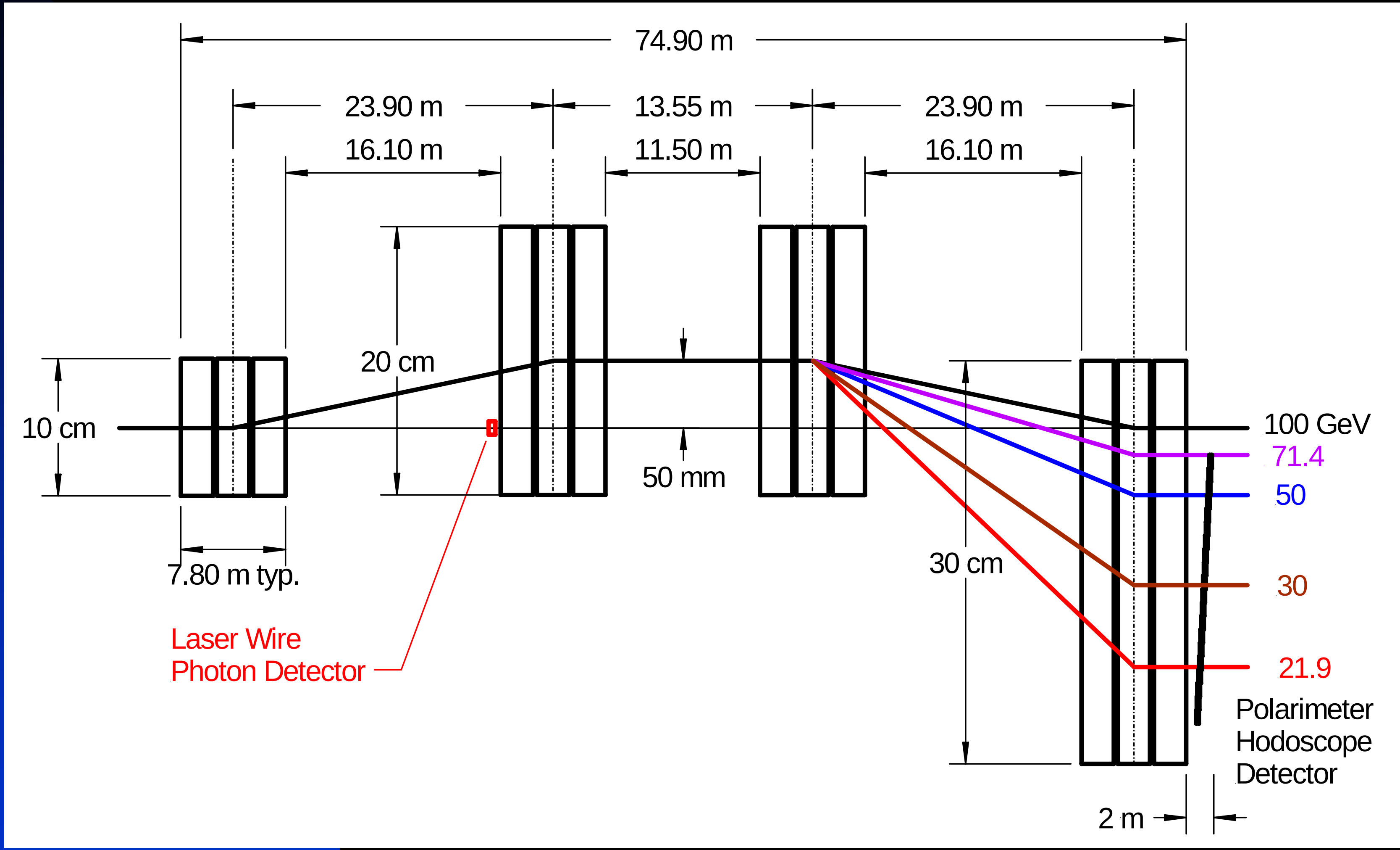
→ wake field effects: have been studied and were found to be harmless (Igor Zagorodnov)

… however, the MPS collimtor has now reshuffled the deck!

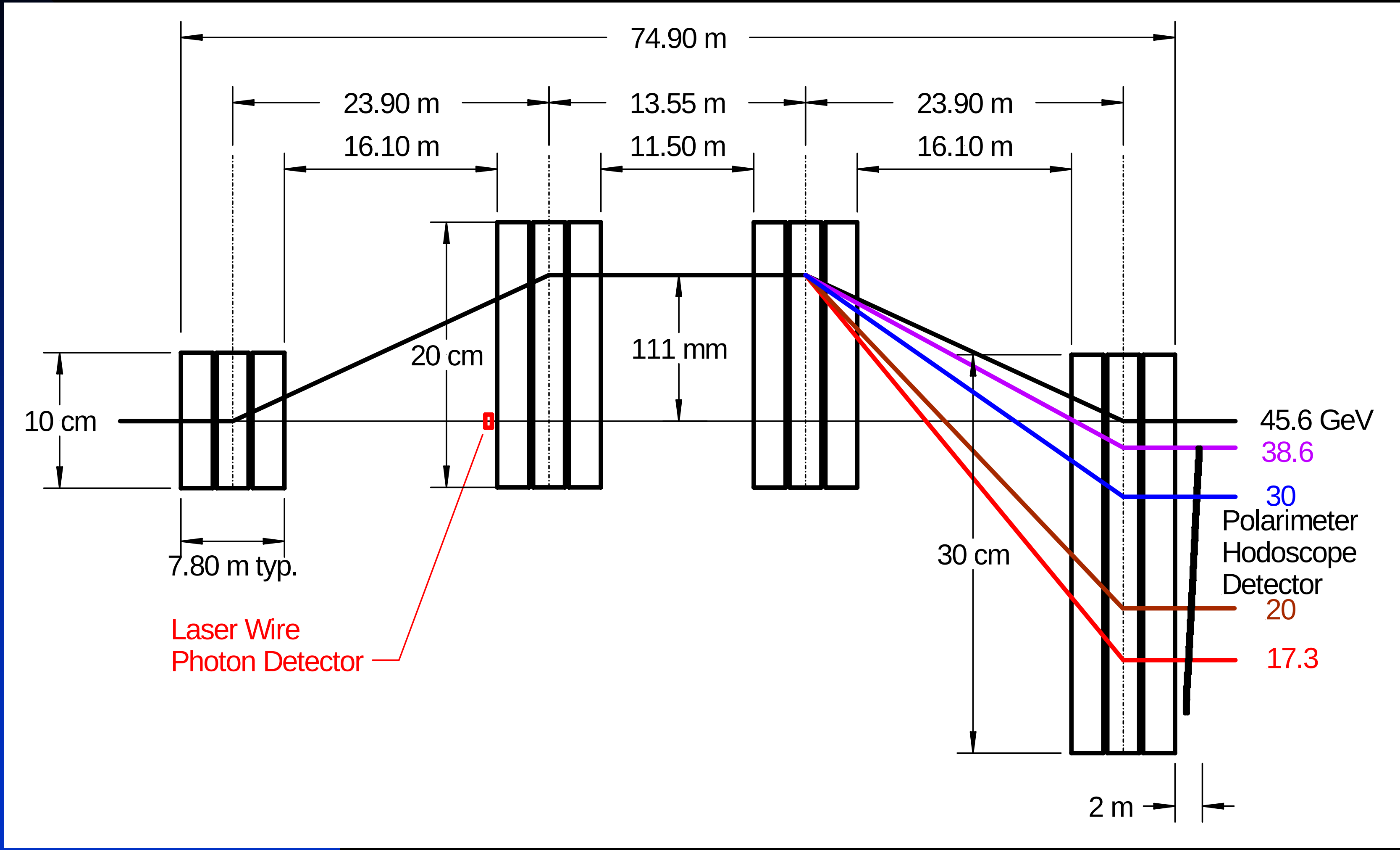
standard fixed-field configuration: 250 GeV



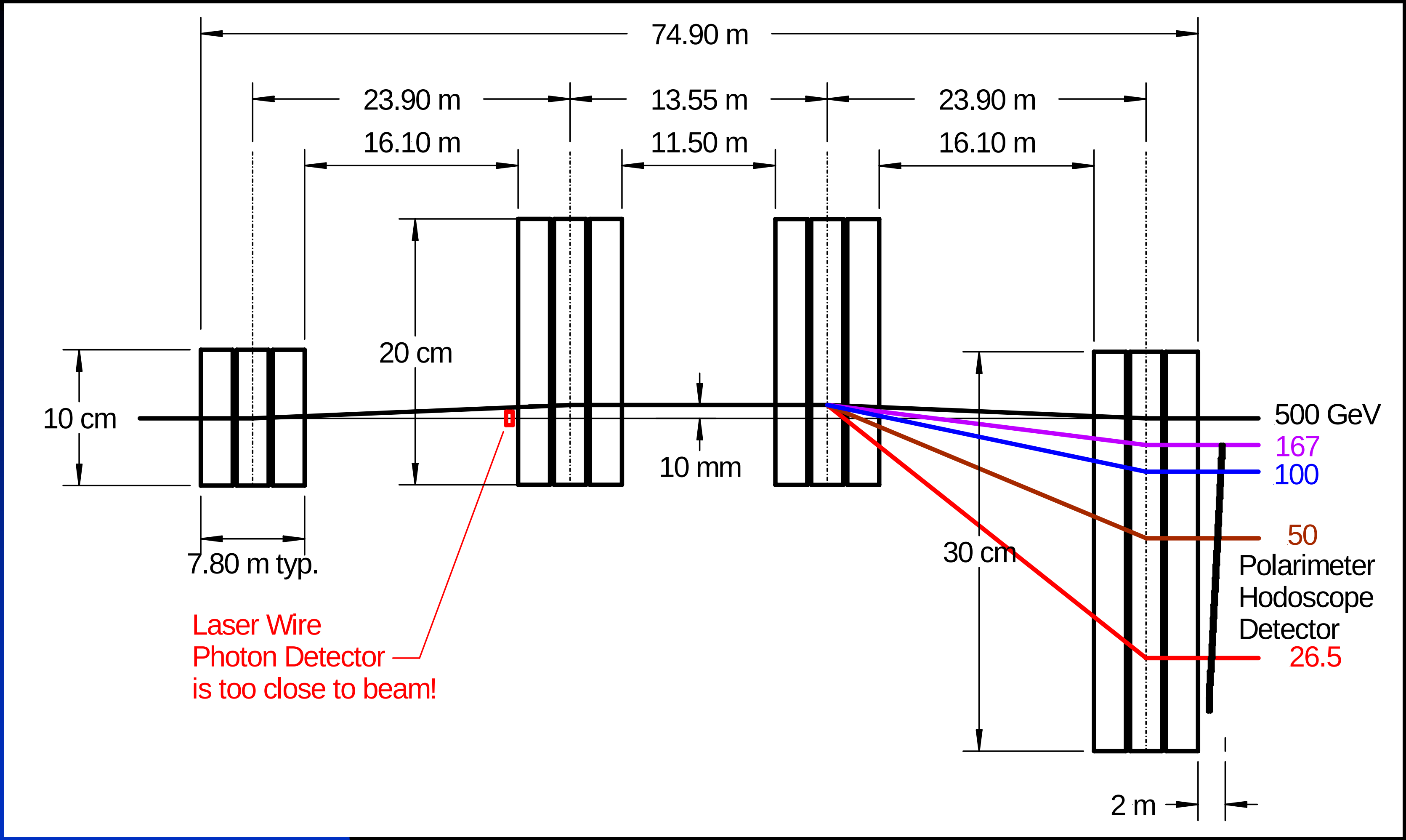
fixed-field configuration: 100 GeV



standard fixed-field configuration: 45.6 GeV

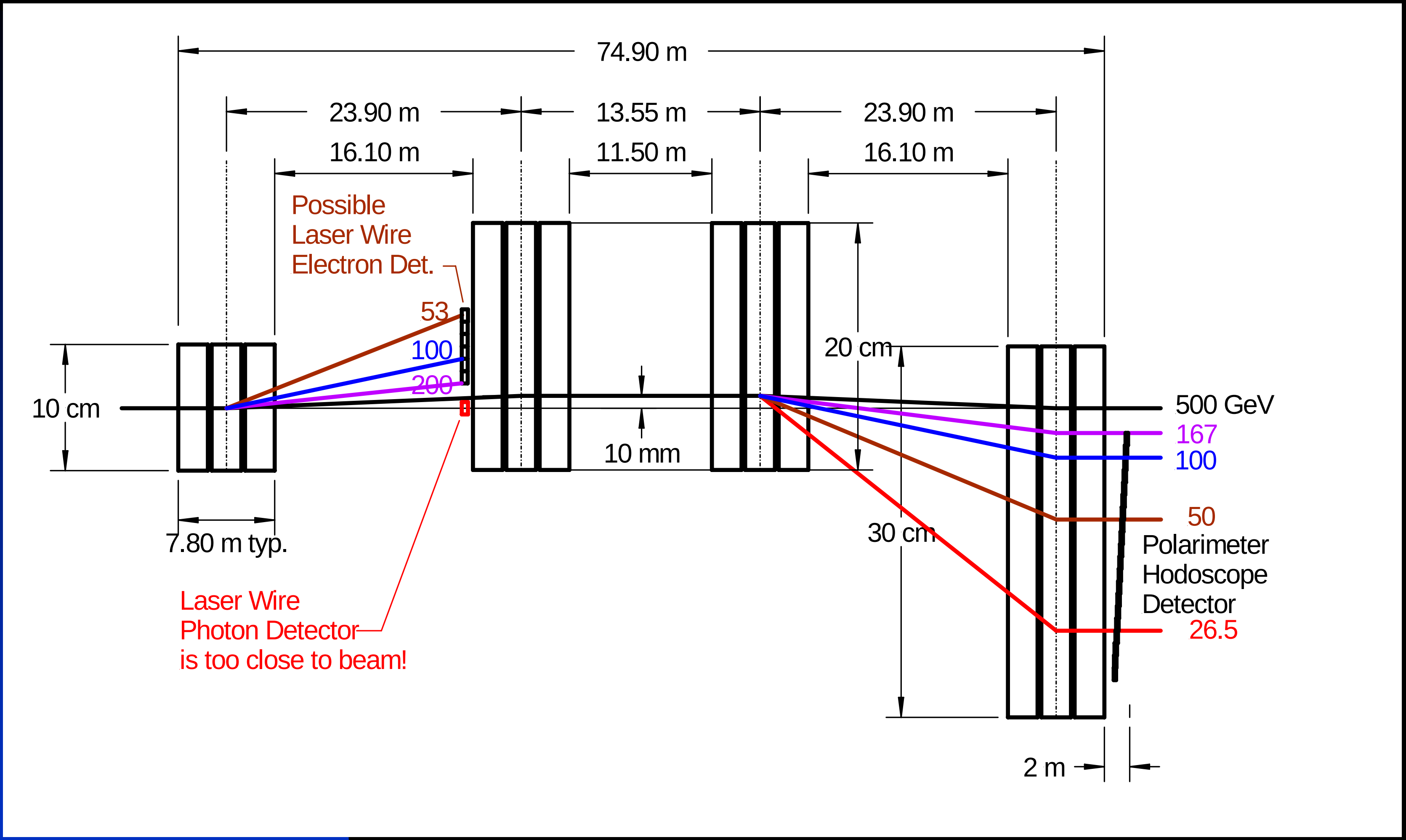


fixed-field configuration: 500 GeV



Problem with insufficient beam clearence of laser wire photon detector!

fixed-field configuration: 500 GeV



Possible alternative: electron detection (but requires modified vacuum ch.)

Now, what about scaled-field operation?

- motivation comes from MPS energy collimator (+-10%) which could then operate with fixed offset and fixed jaw positions
- but what offset (=dispersion) do we scale and over what range in energy?

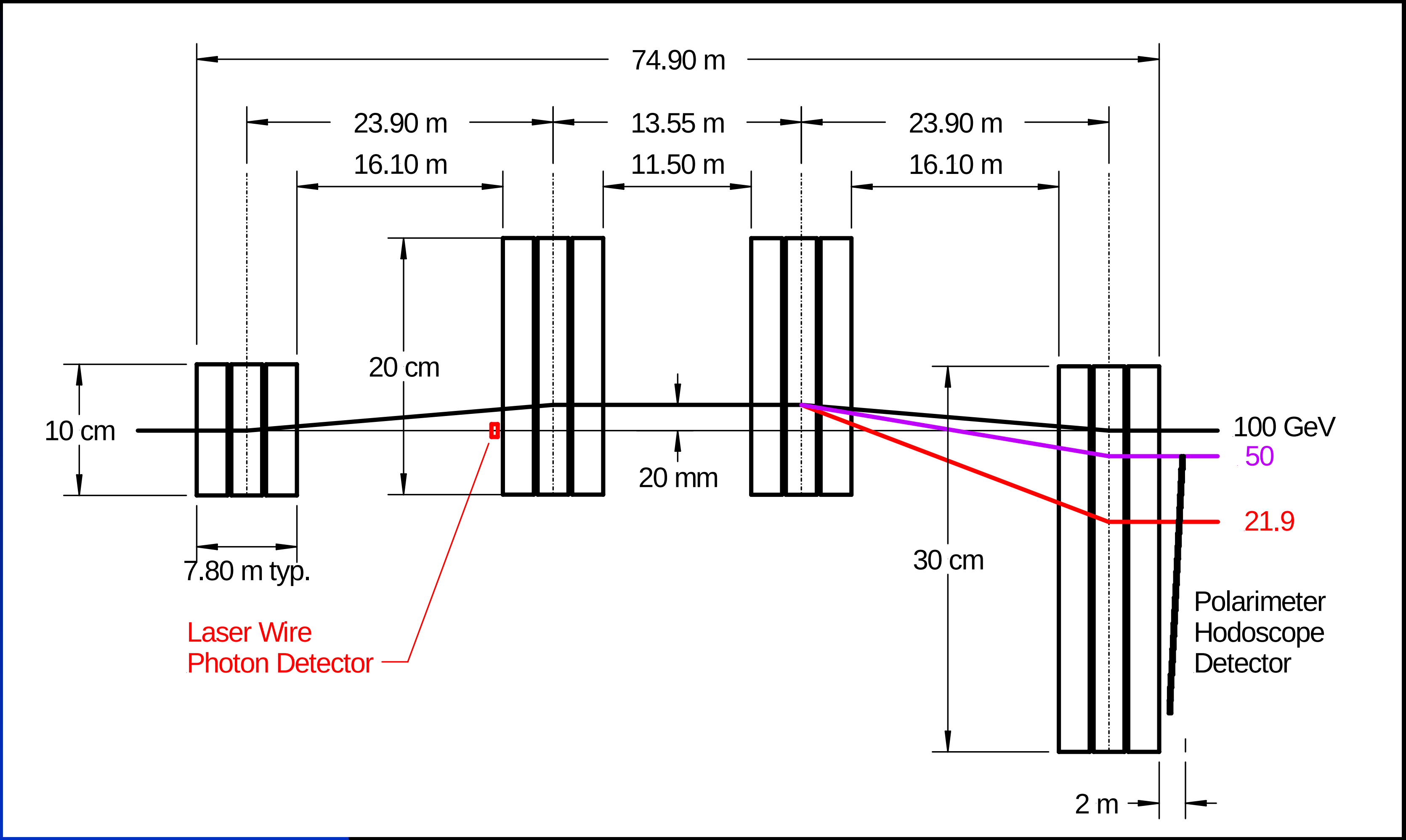
Emittance Growth:

simulation results from Mark Woodley

E_0 (GeV)	dispersion (mm)	$d\varepsilon_x/\varepsilon_x$
250	20	0.1%
500	20	10.3%
250	10	0%
500	10	0.2%

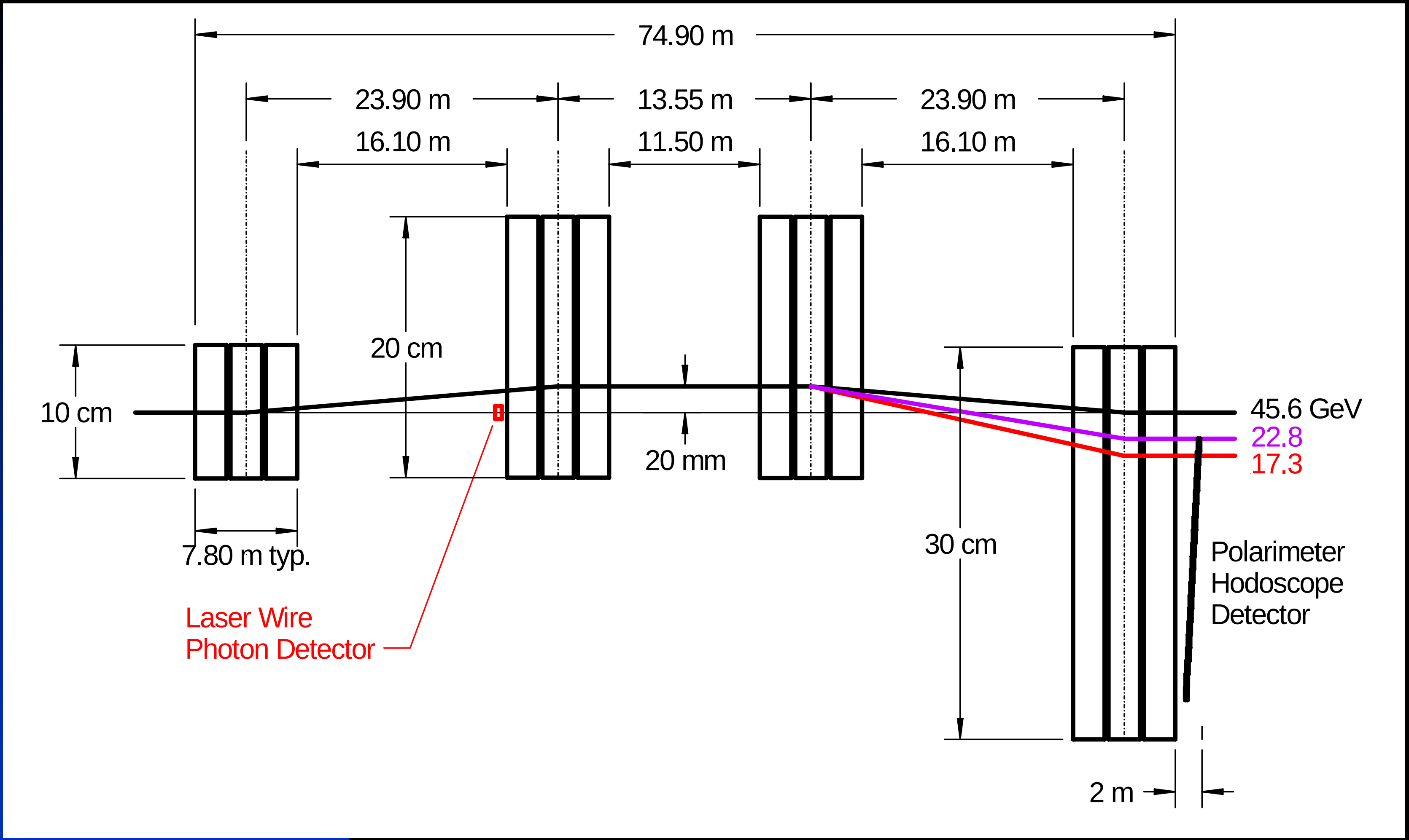
20 mm dispersion at 500 GeV leads to unacceptable emittance growth. Therefore, if scaled operation for all energies is the goal, one has to settle for 10 mm. Or one operates with 20mm up to 250 GeV, and at 10 mm for higher energies!

scaled-field configuration: 100 GeV @ 20 mm



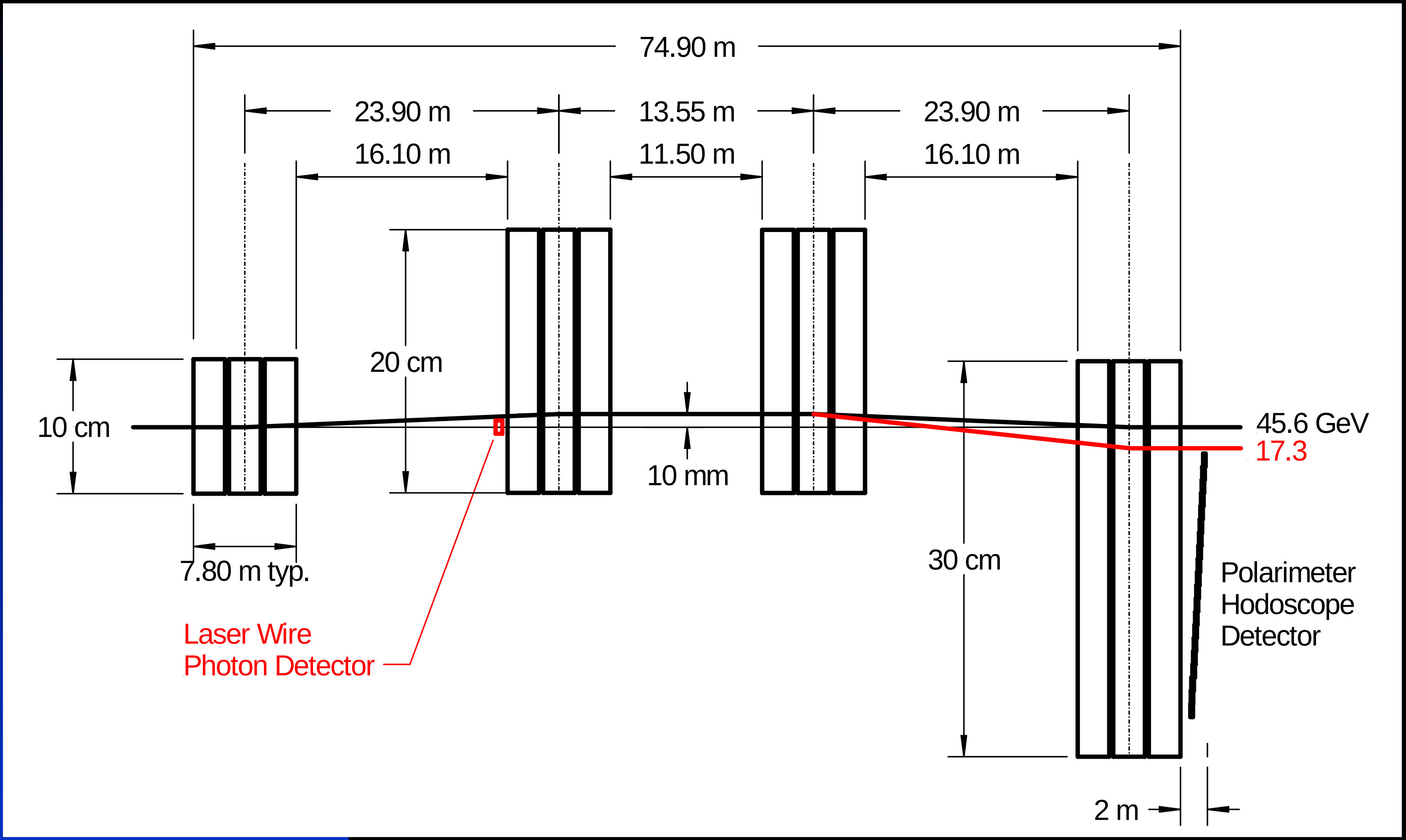
Scaled field operation: reduced hodoscope coverage at lower beam energy

scaled-field configuration: 46.5 GeV @ 20 mm



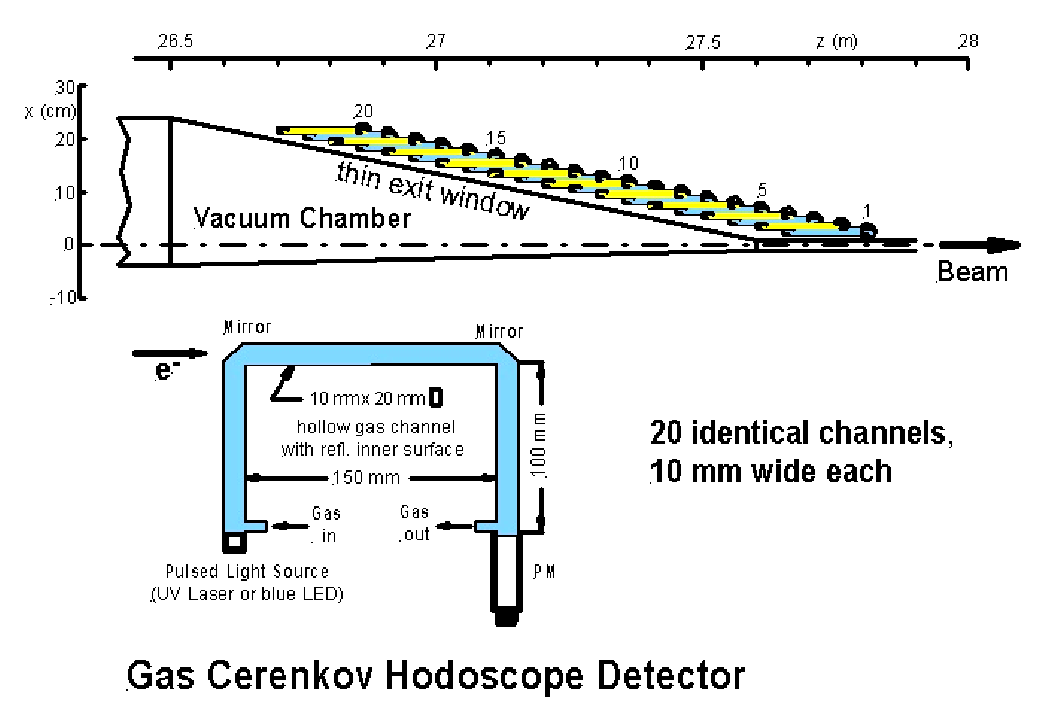
Scaled field operation: really bad for GigaZ !!!

scaled-field configuration: 45.6 GeV @ 10 mm



Scaled field operation: nothing at all at GigaZ !!!

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

100 GeV
fixed field
50 mm disp.

100 GeV (fixed field – 50 mm dispersion – one bunch train)

Ch. 0	AP:-0.2952	L=1426388	R= 882283	Asy:-0.2357	Pol: 79.83 +- 0.22
Ch. 1	AP:-0.3765	L=1122752	R= 601506	Asy:-0.3023	Pol: 80.29 +- 0.19
Ch. 2	AP:-0.4106	L= 902941	R= 455864	Asy:-0.3290	Pol: 80.14 +- 0.20
Ch. 3	AP:-0.3990	L= 739629	R= 382845	Asy:-0.3179	Pol: 79.67 +- 0.22
Ch. 4	AP:-0.3482	L= 617266	R= 347194	Asy:-0.2800	Pol: 80.41 +- 0.28
Ch. 5	AP:-0.2671	L= 514942	R= 336571	Asy:-0.2095	Pol: 78.43 +- 0.39
Ch. 6	AP:-0.1649	L= 436966	R= 337163	Asy:-0.1289	Pol: 78.20 +- 0.67
Ch. 7	AP:-0.0502	L= 372459	R= 344890	Asy:-0.0384	Pol: 76.57 +- 2.25
Ch. 8	AP: 0.0699	L= 317991	R= 359028	Asy: 0.0606	Pol: 86.76 +- 1.88
Ch. 9	AP: 0.1899	L= 275052	R= 371174	Asy: 0.1487	Pol: 78.32 +- 0.63
Ch.10	AP: 0.3063	L= 235858	R= 389621	Asy: 0.2458	Pol: 80.27 +- 0.40
Ch.11	AP: 0.4165	L= 204183	R= 407517	Asy: 0.3324	Pol: 79.81 +- 0.29
Ch.12	AP: 0.5194	L= 173862	R= 423456	Asy: 0.4179	Pol: 80.45 +- 0.23
Ch.13	AP: 0.6144	L= 150563	R= 441713	Asy: 0.4916	Pol: 80.00 +- 0.18
Ch.14	AP: 0.7016	L= 127753	R= 458134	Asy: 0.5639	Pol: 80.37 +- 0.15
Ch.15	AP: 0.7810	L= 109274	R= 473433	Asy: 0.6249	Pol: 80.01 +- 0.13
Ch.16	AP: 0.8532	L= 92894	R= 486831	Asy: 0.6795	Pol: 79.64 +- 0.11
Ch.17	AP: 0.8979	L= 27739	R= 166659	Asy: 0.7146	Pol: 79.59 +- 0.17

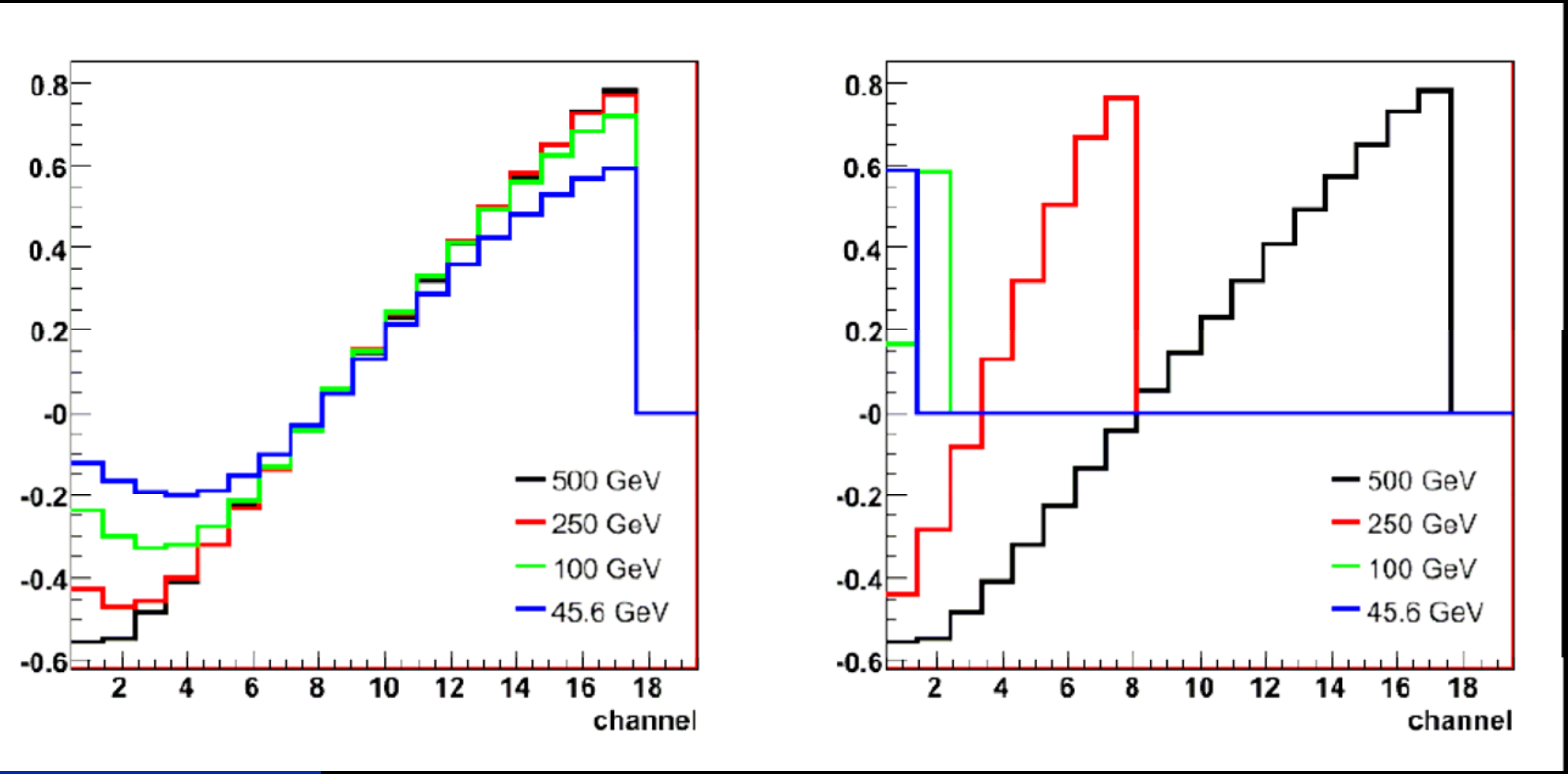
100 GeV
scaled field
10 mm disp.

100 GeV (scaled field – 10 mm dispersion – one bunch train)

Ch. 0	AP: 0.2211	L=1528175	R=2142627	Asy: 0.1674	Pol: 75.70 +- 0.22
Ch. 1	AP: 0.7324	L= 570937	R=2188908	Asy: 0.5863	Pol: 80.05 +- 0.07

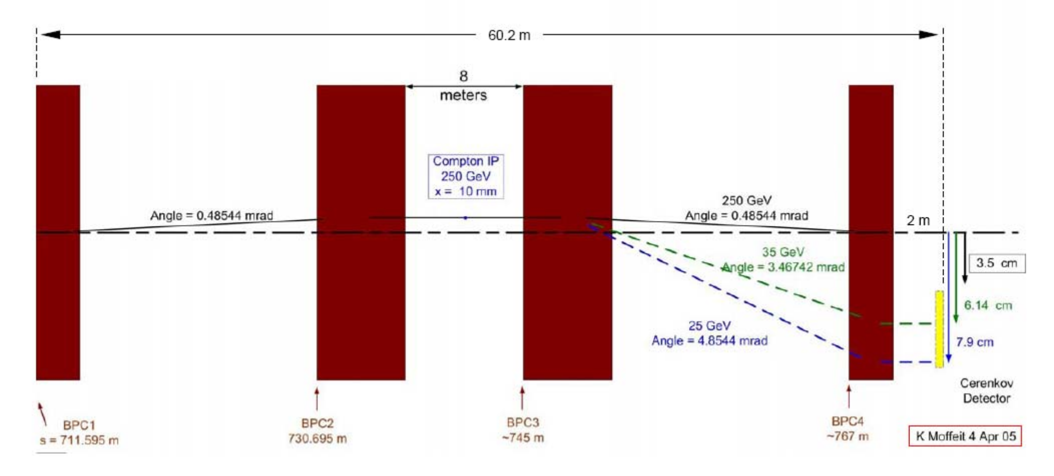
Statistics for one bunch train

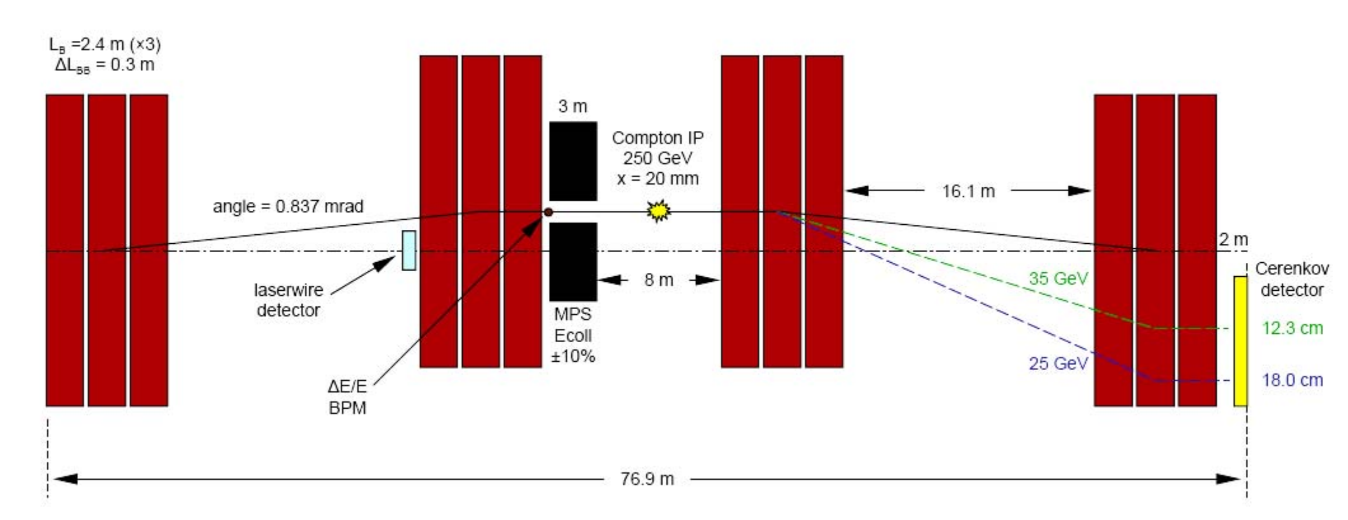
some simulation results



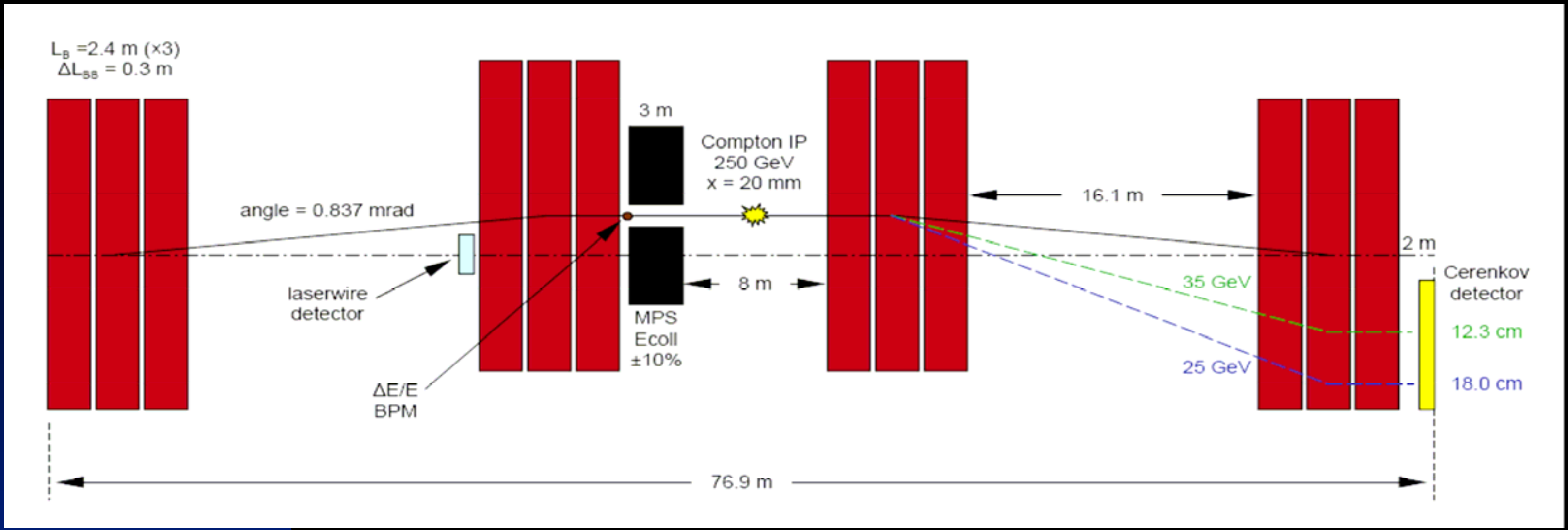
asymmetry vs. hodoscope channel no.
comparison of fixed-field vs. scaled-field

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 (→ only 10 mm @ 500 GeV)**
- **combination of polarimetry with laser wire emittance diagnostic & MPS E-collimator saves ~100 m of beam line space, but creates several nasty issues:**
- **insufficient beam clearance for laser wire photon detector: < 5 mm @ 500 GeV**
  (this problem disappears, if the laser wire folks can switch to electron detection!!!)
- **wake field effects from inserted structures**
- **serious vacuum chamber engineering issues:**
  - collimator destroys tapered vacuum chamber concept
  - collimator position & aperture depend on beam energy

summary & conclusion

- combination of chicanes for polarimetry, laser wire emittance diagnostics & MPS energy collimation saves ~100 m of beam line, but creates serious problems, which have not yet been resolved
- compared fixed vs scaled field operation: we find scaled field operation very inferior at low beam energies (100 GeV) and totally useless at 45.6 GeV
- laser wire photon detector may work, except at 500 GeV, where it lacks sufficient beam clearence; also background issues need further study
- electron detection may be a viable alternative for laser wire diagnostics at 500 GeV, but would require vacuum chamber modifications
- there are serious and unresolved vacuum and engineering problems associated with the MPS energy collimator