Positron Source for ILC TeV Upgrade

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Constrains

- End of linac, => Drive beam energy =~500GeV
- Has to be compatible with the TDR site layout
  - No change to be made on the target station and there after

Challenges

- Radiated Photo parameters from beam passing through a helical undulator:

$$\frac{dNph}{dE}[\frac{1}{mMeV}] = \frac{10^6 e^2}{4\pi\varepsilon_0 c^2 h^2}\frac{K^2}{\gamma^2}\sum_1^\infty (J_n^{'}(x)^2 + [\frac{\alpha_n}{K} - \frac{n}{x}]^2 J_n(x)^2)$$

$$\alpha_n^{\ 2} = [n\frac{\omega_1(1+K^2)}{\omega} - 1 - K^2] \geq 0$$

$$x = 2K\frac{\omega}{\omega_1(1+K^2)}\alpha_n$$

$$J_n = Bessel\ functions$$

$$K = 0.934 * B[T] * \lambda_u[cm]$$

$$E_1 = \hbar\omega_1 = \hbar\frac{4\pi\gamma^2 c}{(1+K^2)\lambda_u}$$

$$\theta \propto \frac{K}{\gamma}$$

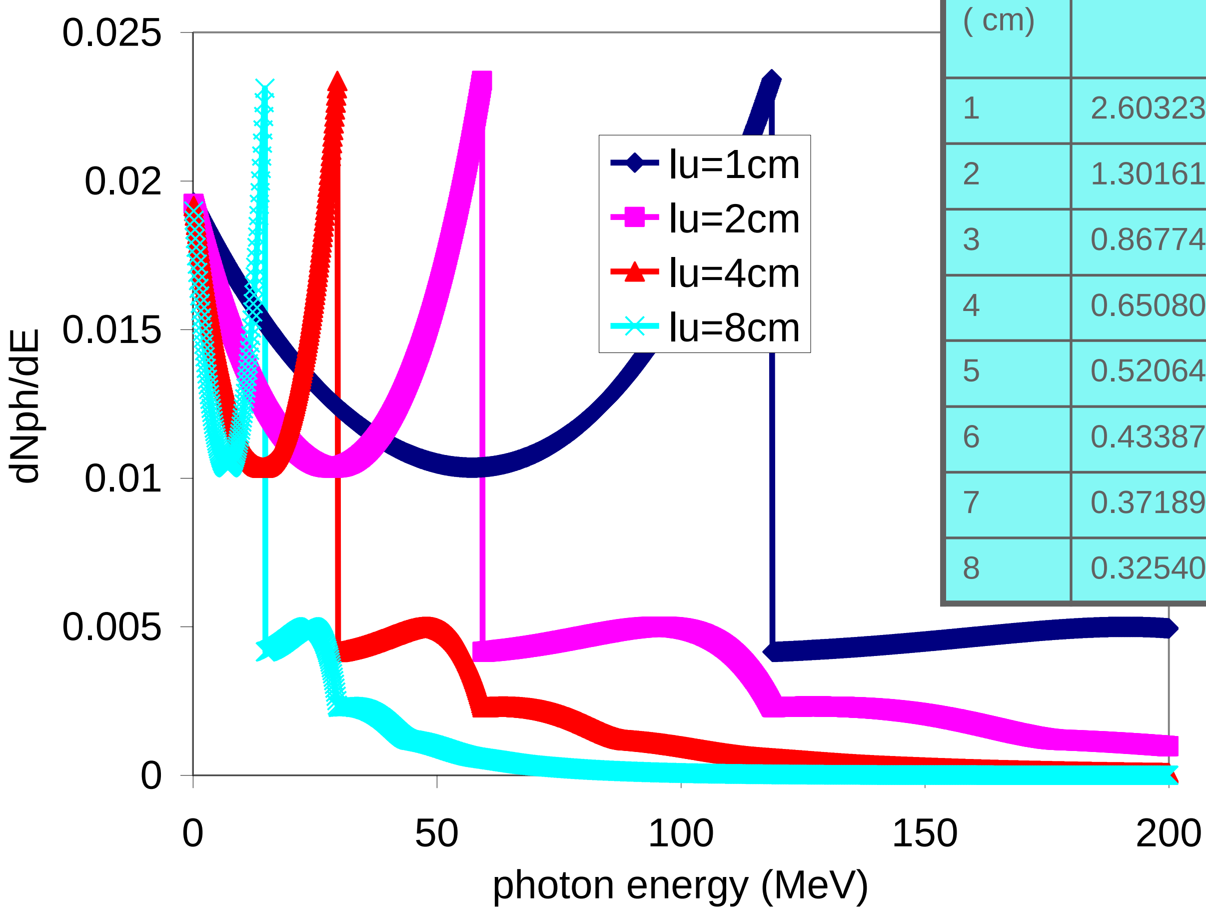
$$\delta\theta \propto \frac{1}{\gamma}$$

- The 1st Harmonic critical energy is proportional γ^2
- $\delta\theta$ is inverse to γ

Goals and Assumptions

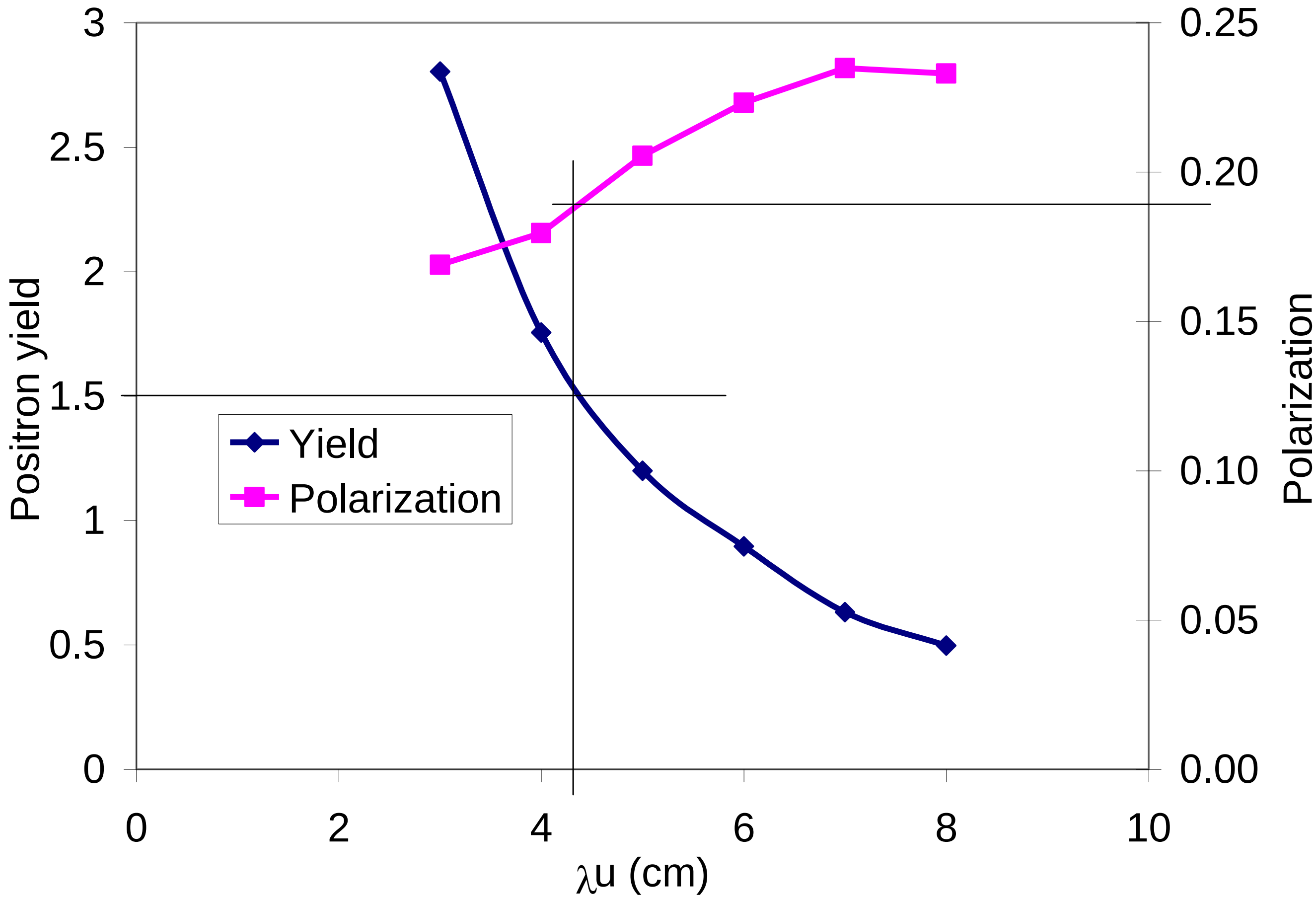
- Goal
  - A reasonable scheme for the 1 TeV option without major impact on the ILC TDR configuration.
- Assumptions
  - Drive beam energy: 500 GeV
  - Target: 0.4 X0 Ti
  - Drift from end of undulator to target: 400m
  - OMD: QWT and FC

Photon number spectrum for K=1 and different undulator period



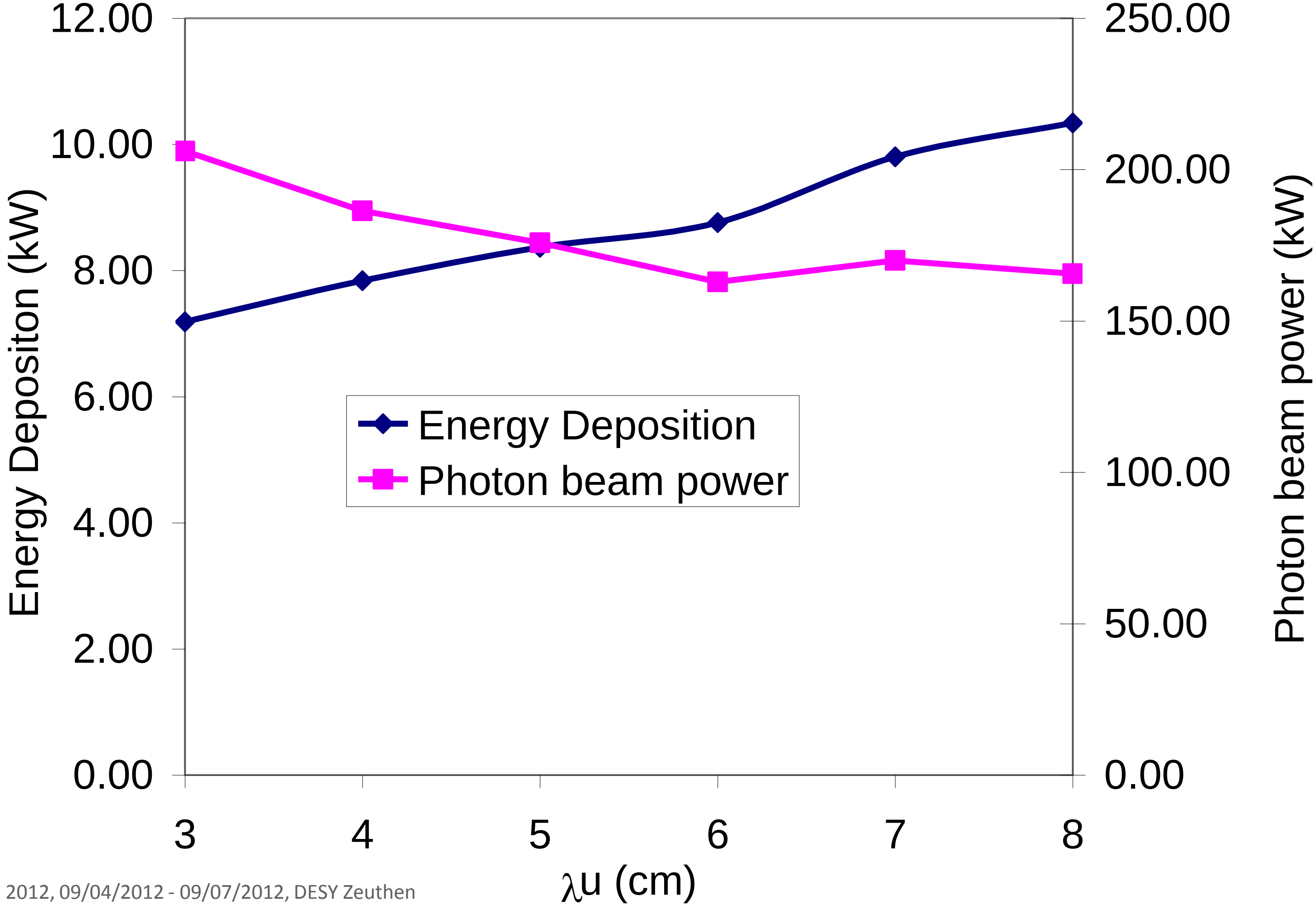
λu (cm)	Nph/m	E average (MeV)	Total photon energy per meter (MeV)
1	2.60323	139.381398	362.841814
2	1.301615	69.690699	90.710454
3	0.867743	46.460466	40.315757
4	0.650807	34.84535	22.677613
5	0.520646	27.87628	14.513673
6	0.433872	23.230233	10.078939
7	0.37189	19.911628	7.404935
8	0.325404	17.422675	5.669403

With Fixed K=1 and different undulator period length



Based on the above plot, λu=4.3cm is used for a more detail simulation to evaluate the energy deposition and impact on drive beam

Photon beam power and energy deposition for generating 3e10 captured positrons



Parameters for 1.5 of positron yield using fixed K=1 with different undulator period

λu (cm)	Photon beam power (kW)	Power deposition (kW)	Drive beam energy lost (GeV)	Undulator length required (m)
3	206	7.19	4.91	124
4	186	7.84	4.44	198
4.3	181	7.94	4.3	221
5	176	8.37	4.19	289
6	166	8.76	3.88	387
7	170	9.80	4.05	549
8	166	10.34	3.94	697

Using FC as OMD

- When FC is used as OMD instead of QWT, the yield increased up to about 2.62 for 231m long undulator with K=1 and lu=4.3m and thus the undulator length is reduced to 132m

				Centre-of-mass energy E_{cm} (GeV)					L upgrade	E_{cm} upgrade
aria	Parameter			200	230	250	350	500	500	1000
	Positron pulse production rate		Hz	5	5	5	5	5	5	4
	Electron beam energy (e+ prod.)		GeV	150	150	150	178	252	252	503
	Number of electron bunches	n_b		1312	1312	1312	1312	1312	2625	2450
	Electron bunch population	N_+	$\times 10^{10}$	2	2	2	2	2	2	1.74
	Photon energy (first harmonic)		MeV	10.1	10.1	10.1	16.2	42.8	42.8	27.6
	Photon openning angle (=1/γ)		μr	3.4	3.4	3.4	2.9	2.0	2.0	1.02
Flux Concentrator capture device										
	Fixed undulator length scenario									
	Undulator length	L_{und}	m	147	147	147	147	147	147	132
	Required undulator field	B	T	0.86	0.86	0.86	0.698	0.42	0.42	0.25
	undulator period length	λu	cm	1.15	1.15	1.15	1.15	1.15	1.15	4.3
	undulator K	K					0.75	0.45	0.45	1.0
	Average photon power on target		kW	91	100	107	55	42	84	65.46
	Incident photon energy per bunch		J	9.6	9.6	9.6	8.1	6.0	6.0	6.67
	Energy deposition per bunch (e+ prod.)		J	0.72	0.72	0.72	0.59	0.31	0.31	0.29
	Relative energy deposition		%	7%	7%	7%	7.20%	5%	5%	4.40%
	Photon rms spot size on target		mm	1.4	1.4	1.4	1.2	0.8	0.8	0.7
	Peak energy density in target		J/cm^3	232.5	232.5	232.5	295.3	304.3	456.4	475
			J/g	51.7	51.7	51.7	65.6	67.5	101.3	105.4

The impact on 500GeV drive beam from the chosen undulator parameters

- Code used: elegant
- Lattice:
  - Quads:
    - Effective length 1m
    - Strenth:0.09717 and -0.1109 alternating.
    - Separation: 12m with space of quad excluded.
  - Undulator:
    - λu=4.3cm, K=1
    - Sections with effective length of ~11.0m between quads
- Initial beam parameters:

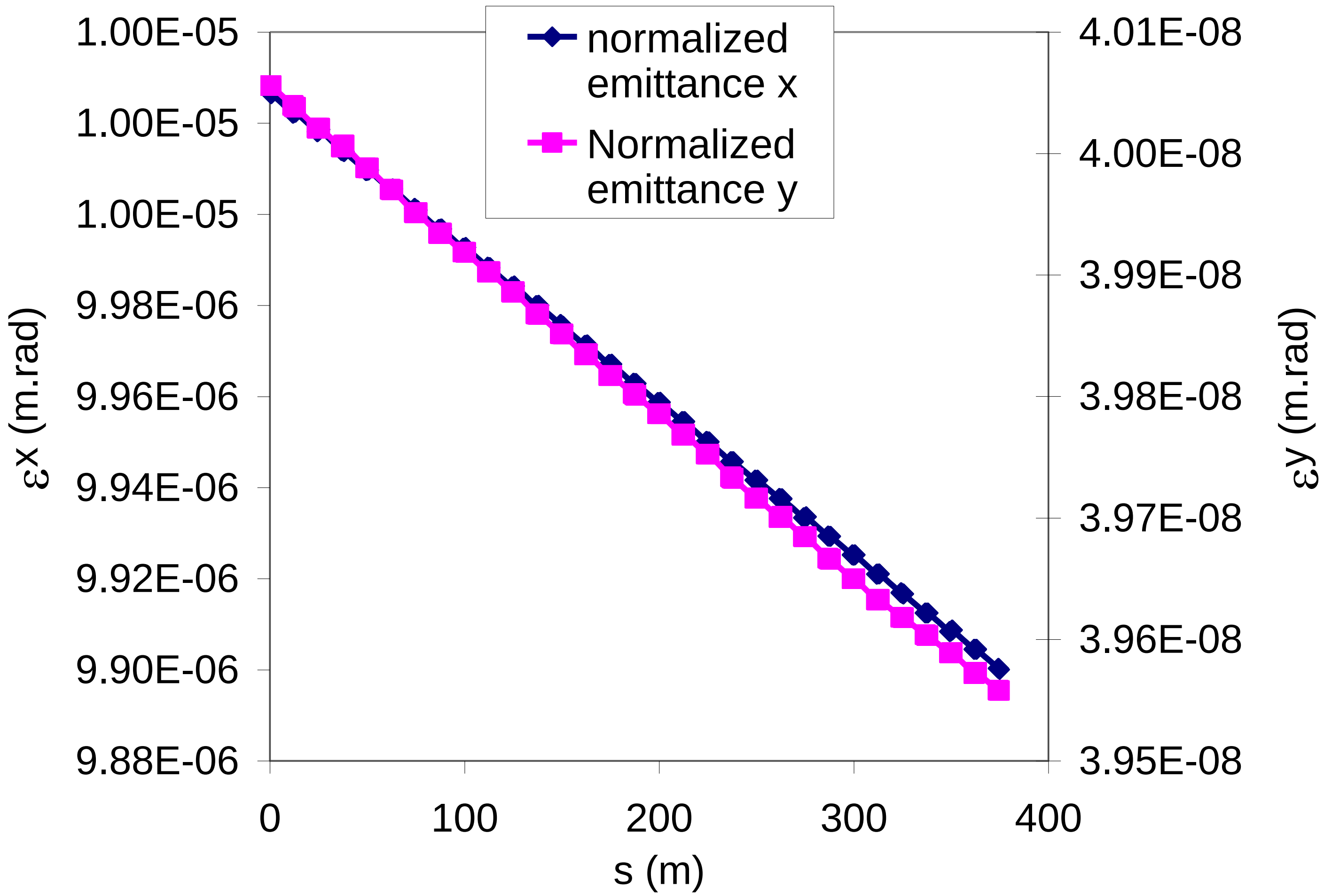
  ε_{nx}=10e-6 m.rad, ε_{ny}=0.04e-6 m.rad

  βx=46m, βy=9m

  Energy spread: 1GeV or 0.2%

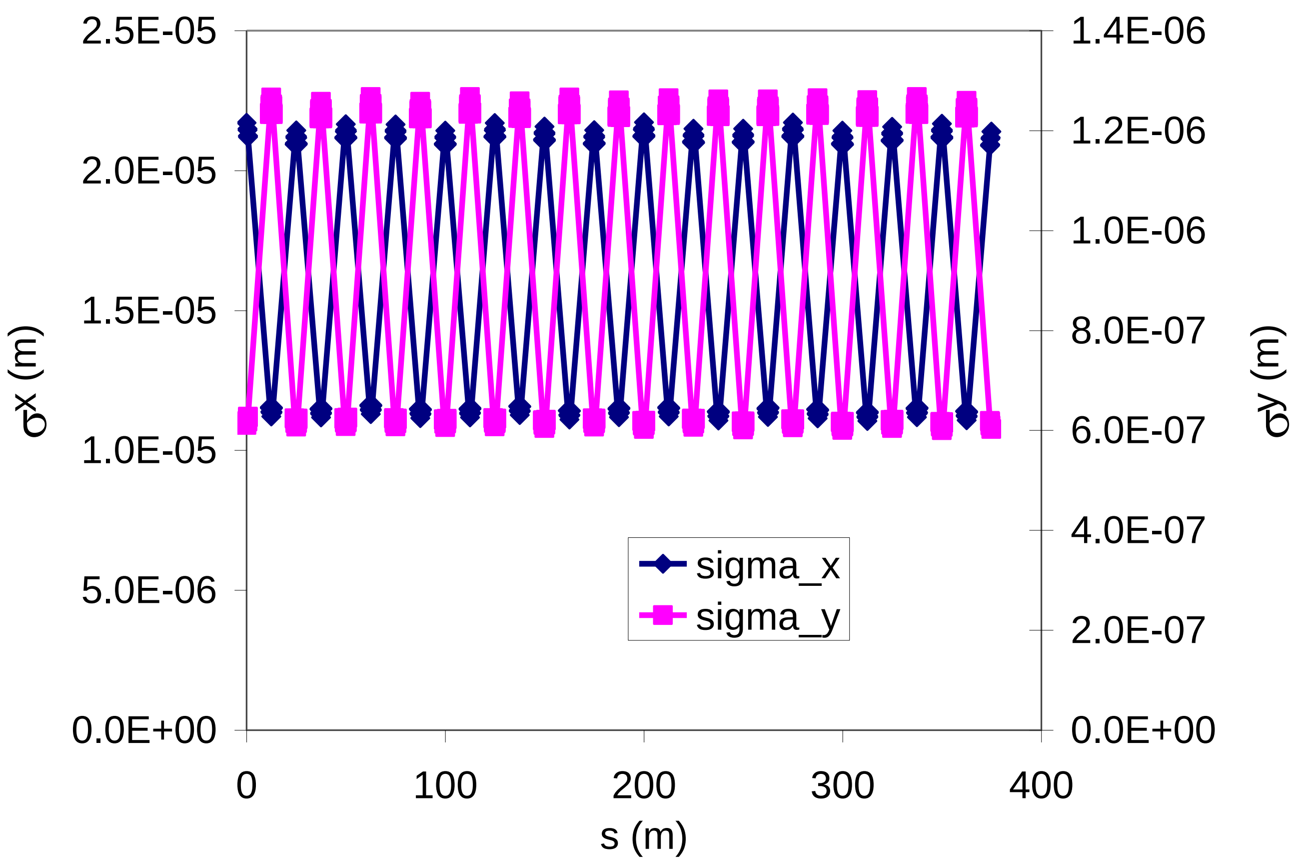
  Average energy: 500GeV

Drive beam emittance



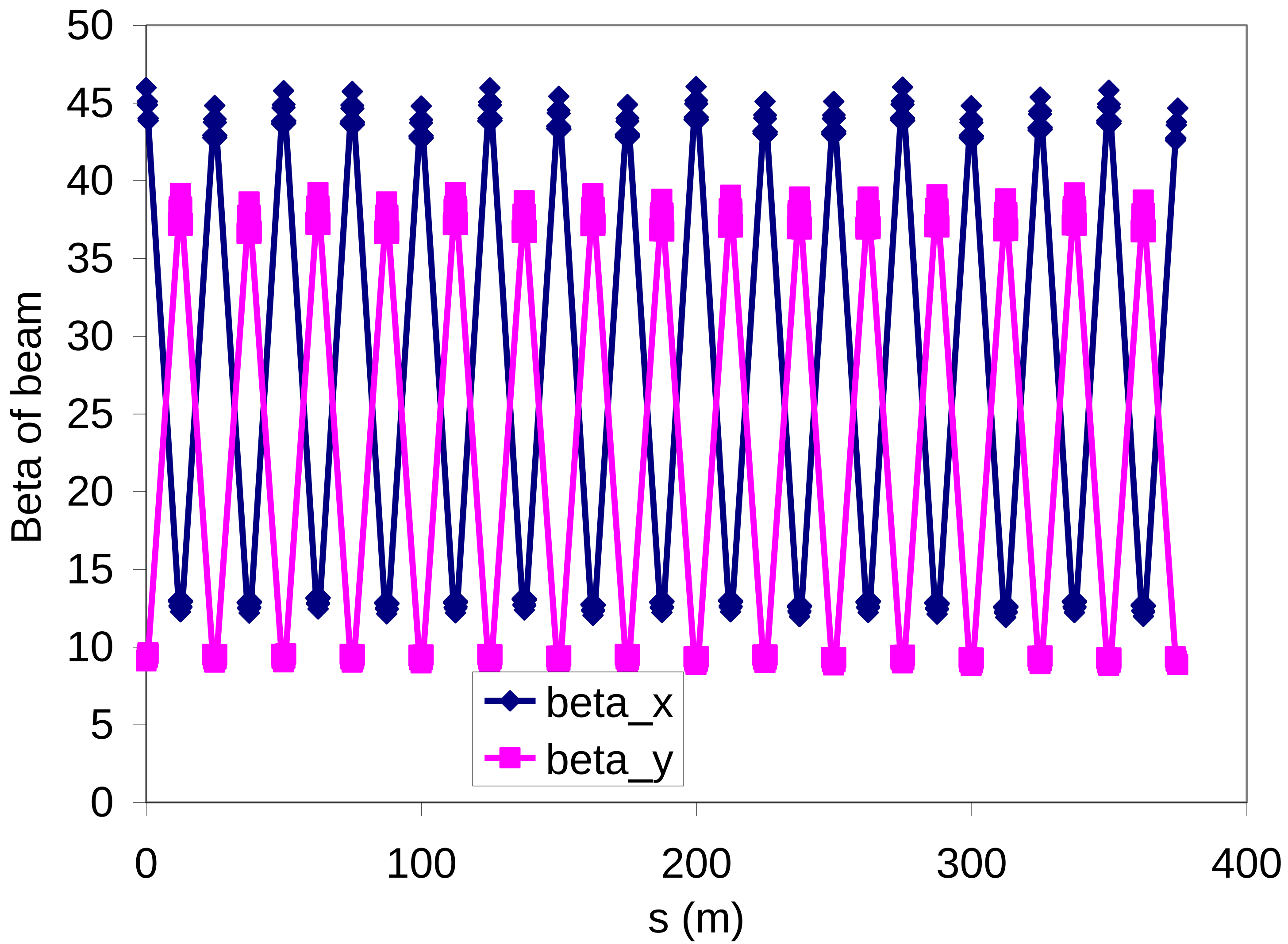
With no quad-bpm error included, the beam emittance is damping.

Size of beam as it passing through the lattice



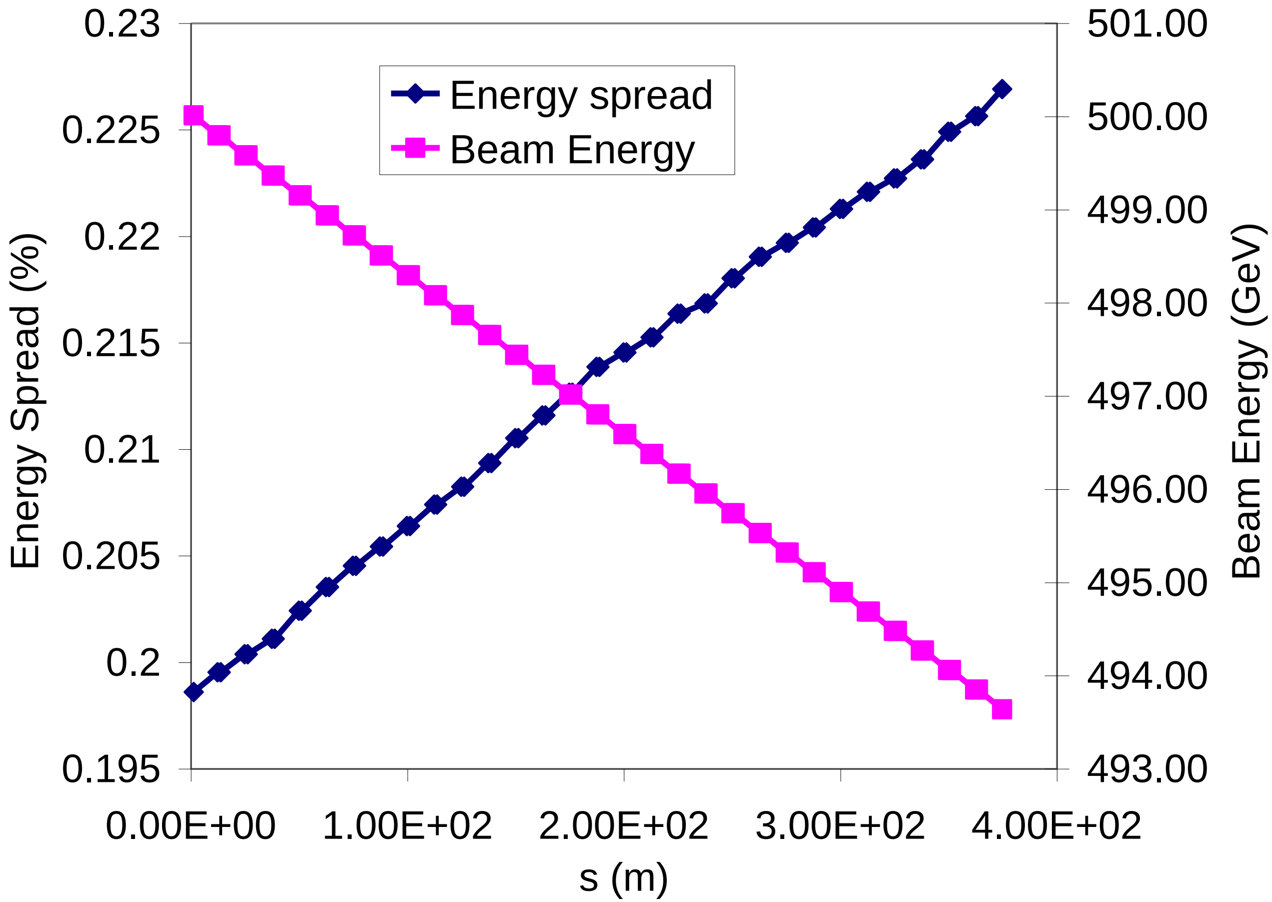
The beam is well matched to the lattice

Beta of beam



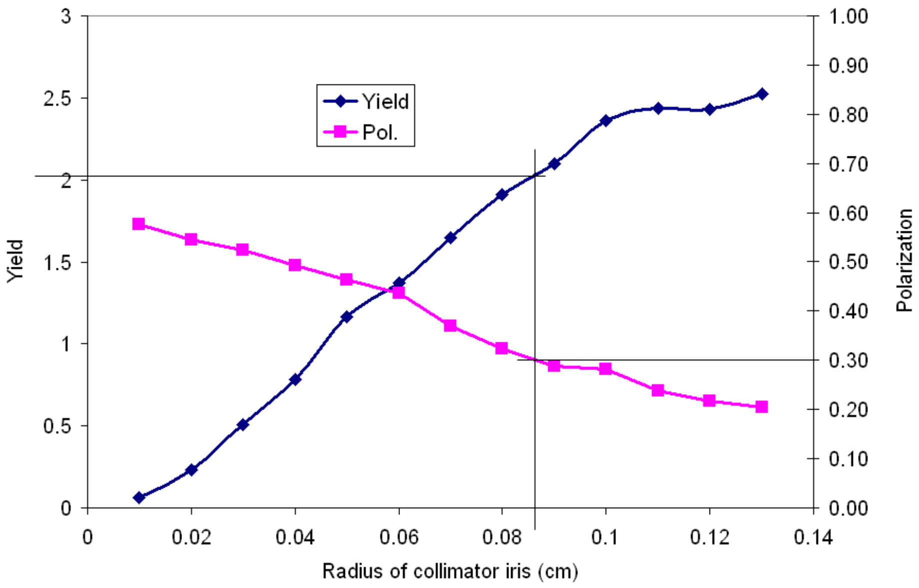
50
45
40
35
30
25
20
15
10
5
0
Beta of beam
0
100
200
300
400
s (m)
beta_x
beta_y

Drive beam energy and energy spread

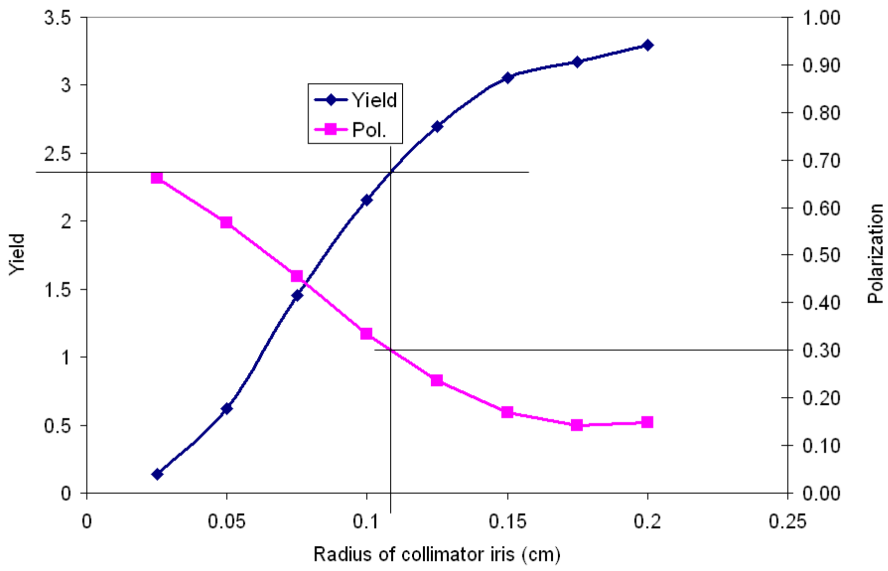


Drive beam energy spread increased from about 0.2% up to about 0.23% with about 400m long undulator beam line.

Preliminary results about polarization



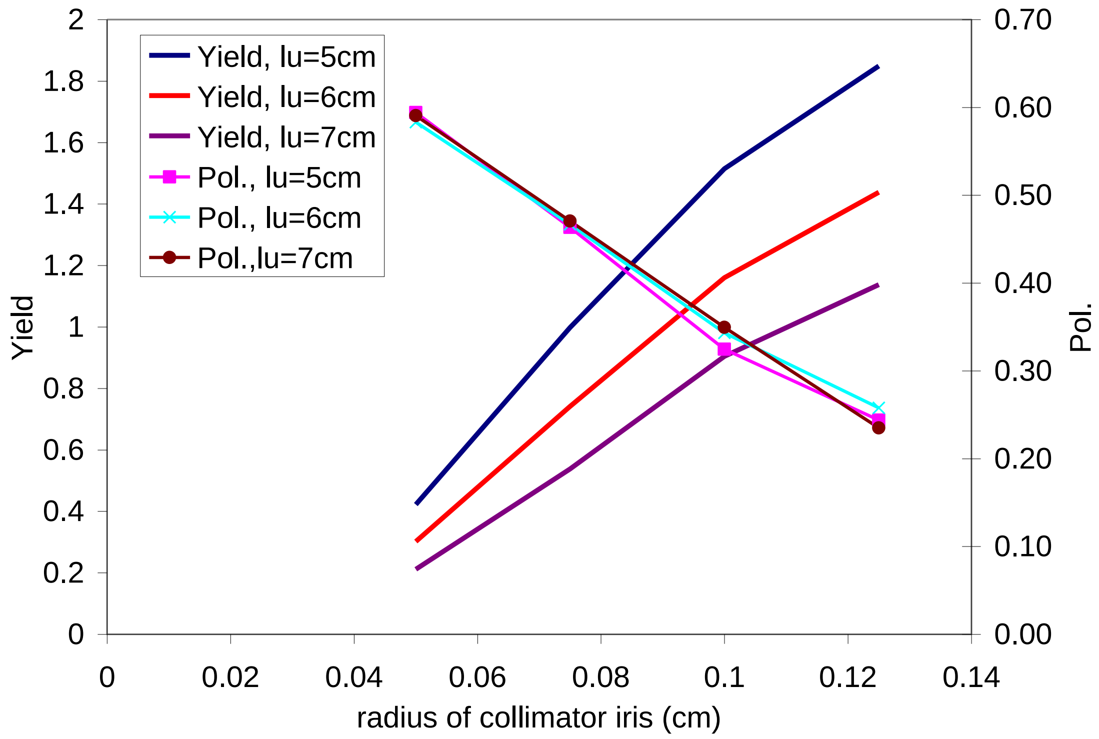
K=1, λu=3cm



K=1.5, λu=4cm

30% polarization can be achieved by using a photon collimator with iris of about 0.9mm with K=1 and λu=3cm or about 1.1 with K=1.5 and λu=4cm

Preliminary results about polarization -Fixed K=1.5, different length of period



Results are showing that the polarization doesn't change much with the undulator period length. The criteria for choosing undulator period length will be depends on other parameters like energy deposition and the impact on the drive beam.

Summary

- To upgrade to TeV ILC, the ILC undulator based positron source can be upgraded to take the ~500GeV drive beam by using an undulator having K=1 with λu=4.3m period without changing other part of positron source. There is no technical difficulty to build a longer period undulator with K=1.
- To upgrade to TeV ILC with polarized positron source (>50% polarization), more studies and optimizations are needed.