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Preliminary Study on CLIC Undulator Polarized Positron Scheme

Wei Gai, Wanming Liu @ ANL

John C. Sheppard @ SLAC

Louis Rinolfi @ CERN

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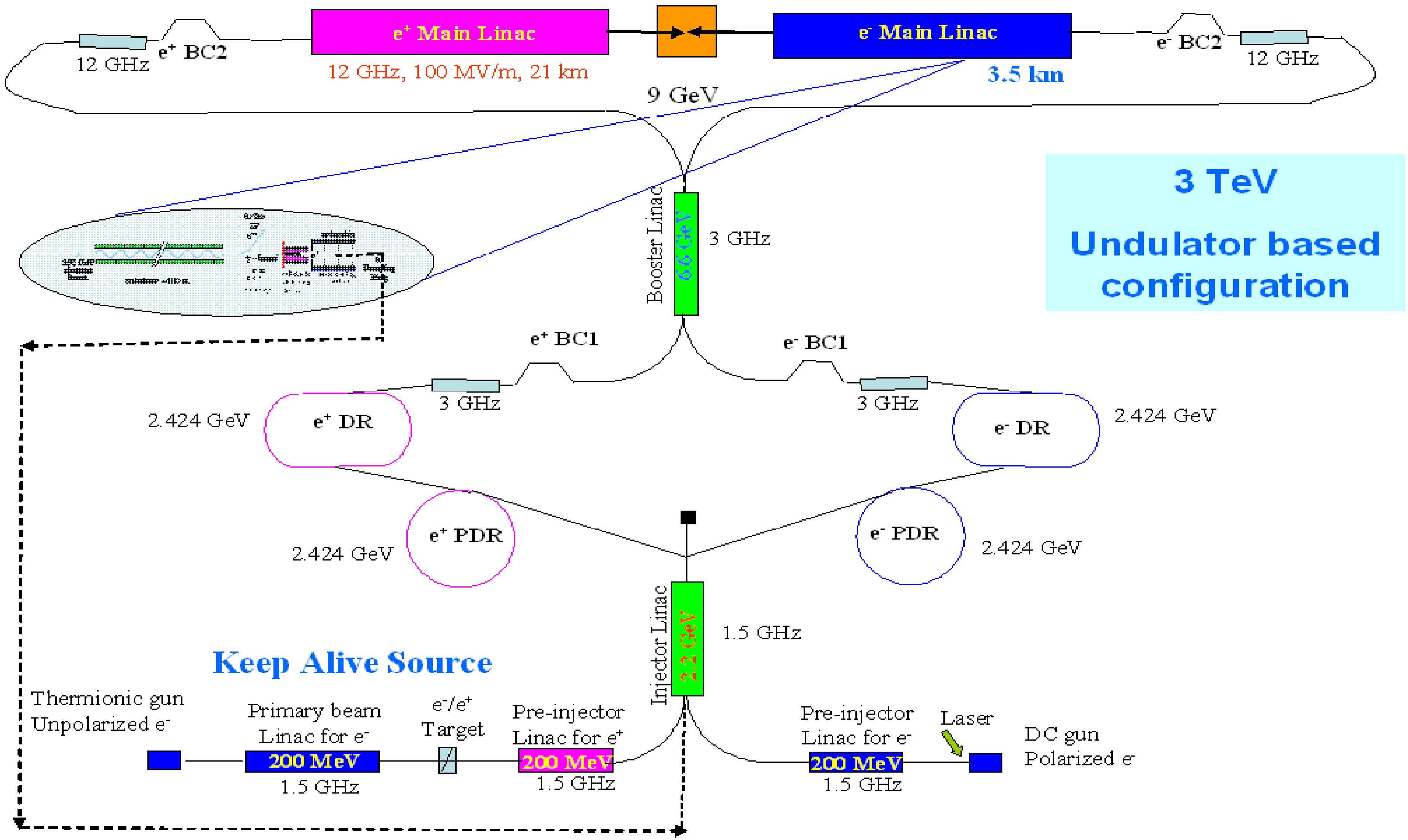
Outline

1. A possible CLIC undulator scheme e+ source
2. Numerical Simulation on the effect of undulator parameter and accelerating gradient
3. Optimizing OMD for yield
4. Emittance evolution of drive electron beam in undulator
5. Summary

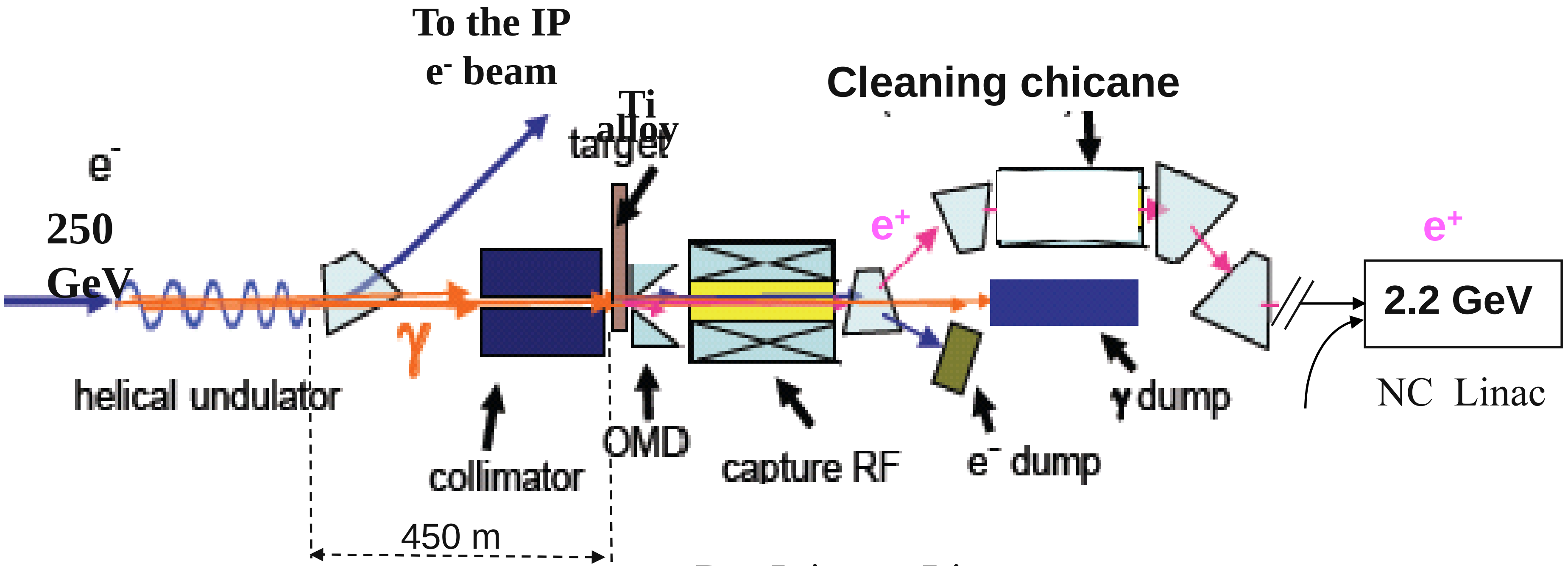
CLIC Injector complex



3 TeV

Undulator based configuration

A possible CLIC scheme for polarized e^+



Undulator

$K = 0.75$

$\lambda u = 1.5$ cm

$L = 100$ m

Pre-Injector Linac

$G = 12$ MV/m

$E = 200$ MeV

$f_{RF} = 1.5$ GHz

$B = 0.5$ T

Injector Linac

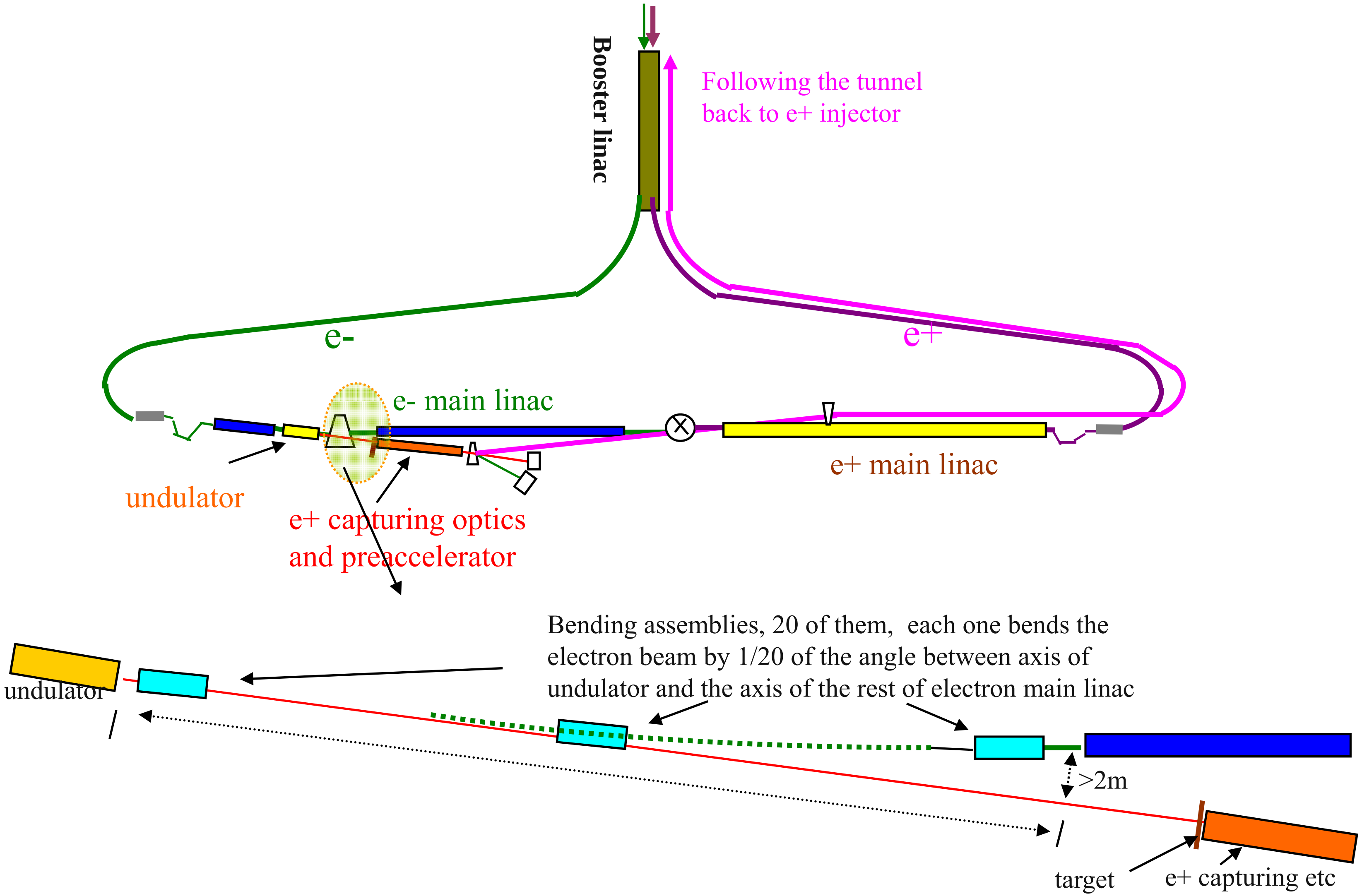
$G = 17$ MV/m

$E = 2.424$ GeV

$f_{RF} = 1.5$ GHz

$f_{rep} = 50$ Hz

A possible CLIC complex layout with undulator based e+ source



Bending assemblies, 20 of them, each one bends the electron beam by 1/20 of the angle between axis of undulator and the axis of the rest of electron main linac

Photon Spectrum and Polarization of ILC baseline undulator

Results of photon number spectrum and polarization characteristic of ILC undulator are given here as examples. The parameter of ILC undulator is K=1, λu=1cm and the energy of electron beam is 150GeV.

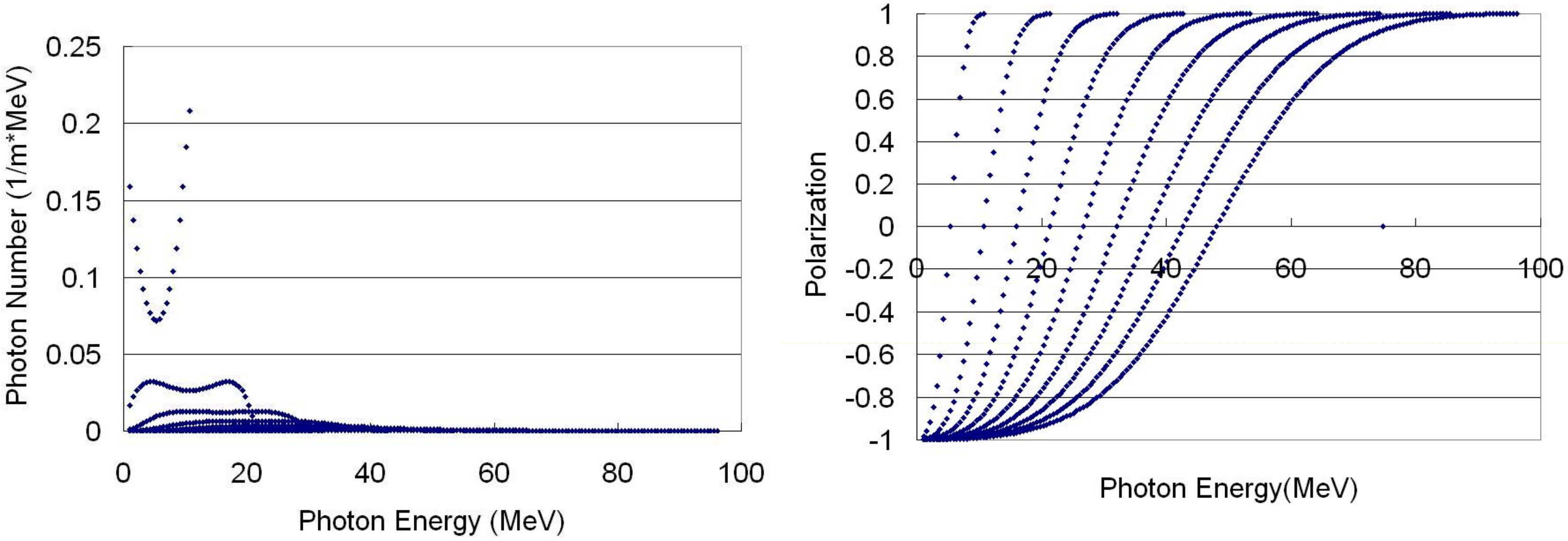
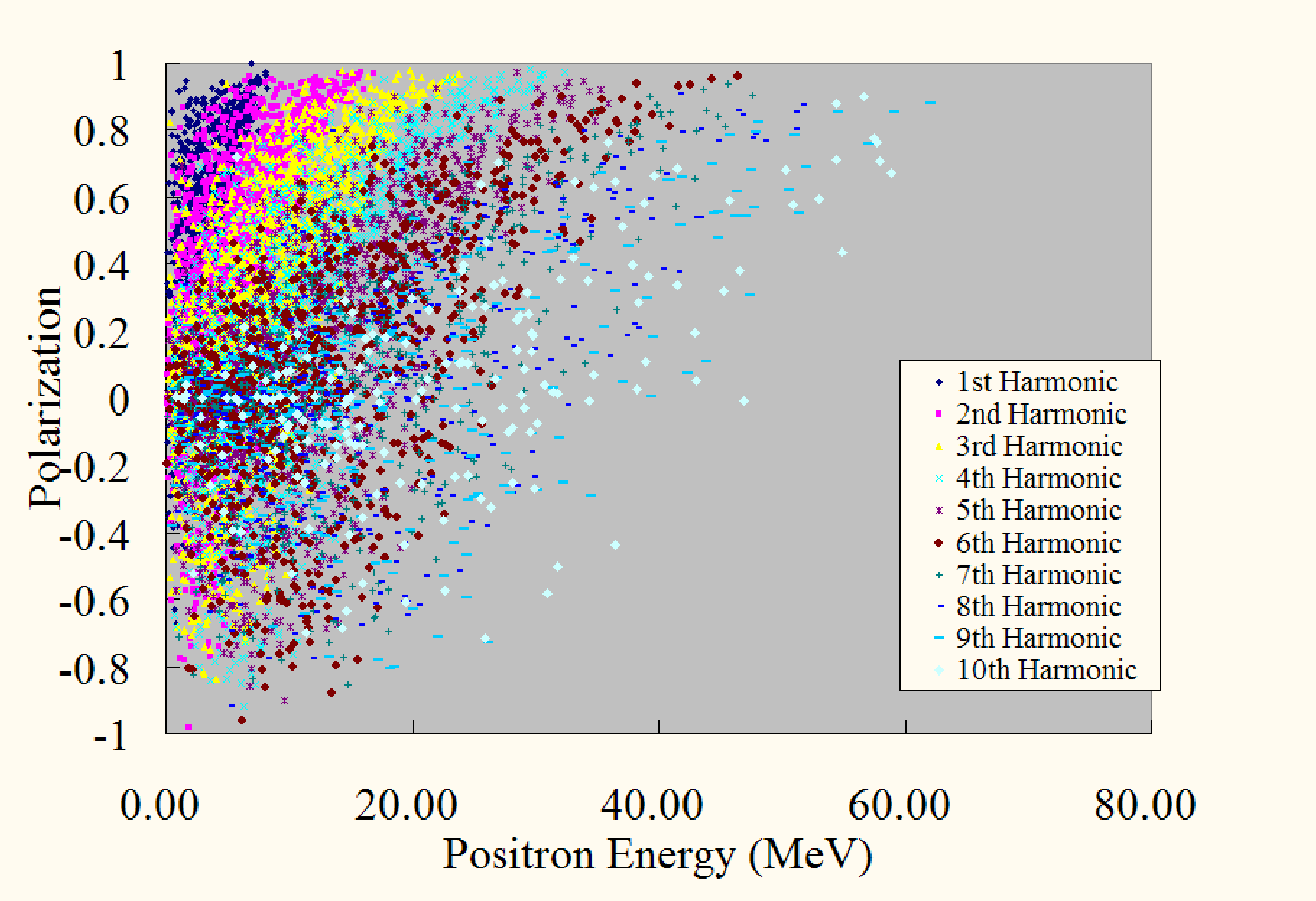


Figure1. Photon Number spectrum and polarization characteristics of ILC undulator up to the 9th harmonic. Only those have energy closed to critical energy of its corresponding harmonics have higher polarization

Initial Polarization of Positron beam at Target exit(K=0.92 λu=1.15) (for ILC)



“Nominal” CLIC positron source parameters

	Symbol	**Value**	Units
Positron per bunch at IP	n_b	3.72×10^9	number
Bunches per pulse	N_b	312	number
Pulse repetition rate	f_{rep}	50	Hz
Positron energy (PDR injection)	E_0	2.424	GeV
Pre-Damping transverse acceptance	$\gamma (A_x + A_y)$	0.09	m - rad
Pre-Damping energy acceptance	δ	± 1	%
Pre-Damping longitudinal acceptance	A_l	4980	eV . m
Electron drive beam energy	E_e	250	GeV
Electron beam energy loss in undulator	ΔE_e	2.27	GeV
Positron polarization	P	~ 60	%

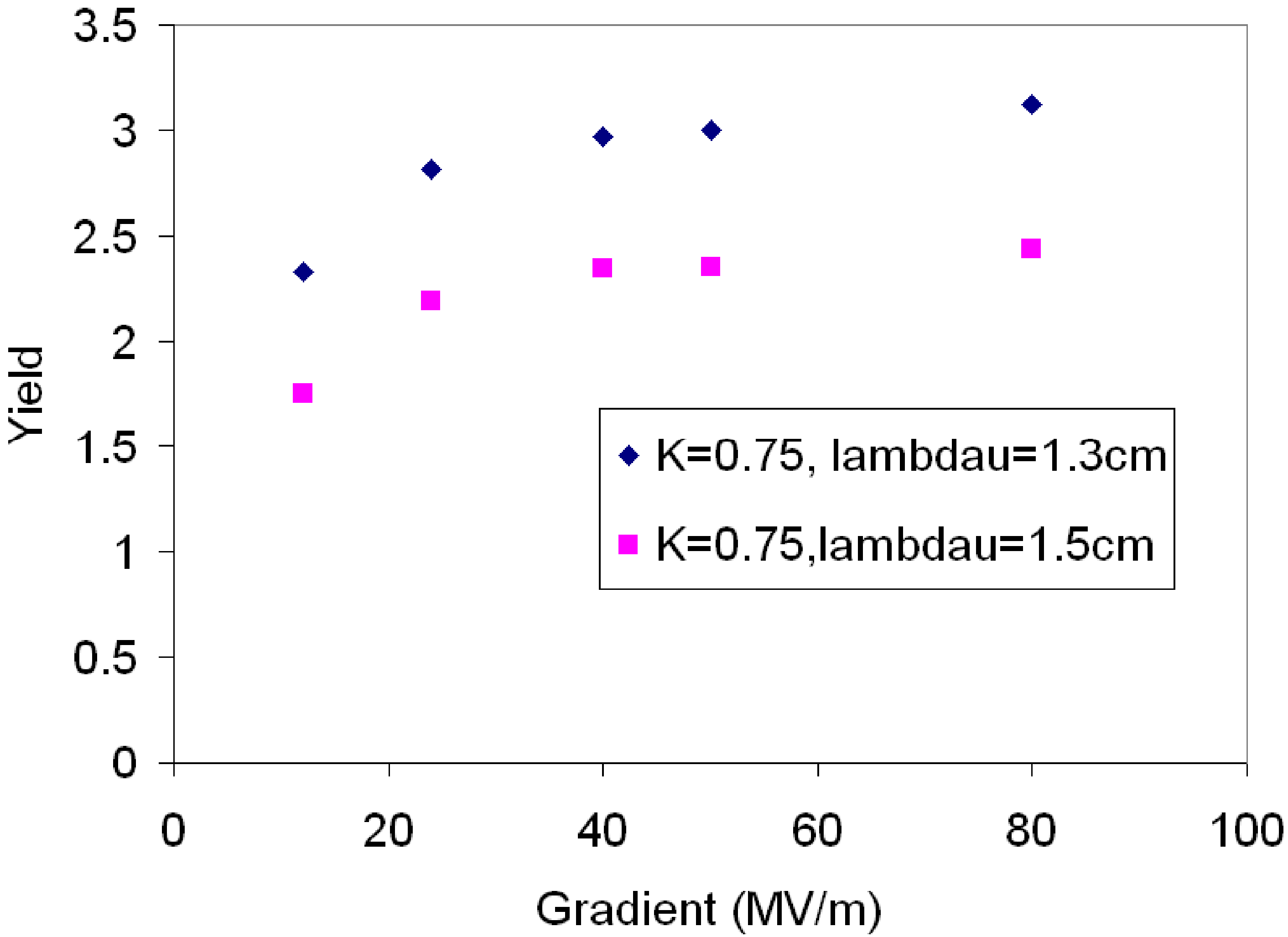
Numerical Simulation on the effect of undulator parameter and accelerating gradient

- Drive e- beam energy: 250GeV
- Undulator K: 0.75 and 0.5
- Undulator period: 1.5cm and 1.3cm
- Length of undulator: 100m
- Drift to target: 450m
- Accelerator gradient and focusing: 12MV/m to 80MV/m for beam energy <250MeV, 0.5T background solenoid field focusing; for 250MeV to 2.4GeV, 25MV/m with discrete FODO set.
- OMD: 7T-0.5T in 20cm (immersed); 10T-0.5T in 20cm (non-immersed).
- Photon collimator: None
- Target material: 0.4 rl Titanium, immersed and non-immersed
- Yield is calculated as Ne+ captured/Ne- in drive beam.
- Positron capture is calculated by numerical cut using damping ring acceptance window: +/-7.5 degrees of RF(1.3GHz), $\varepsilon x+\varepsilon y<0.09\pi$.m.rad,1% energy spread with beam energy ~2.4GeV

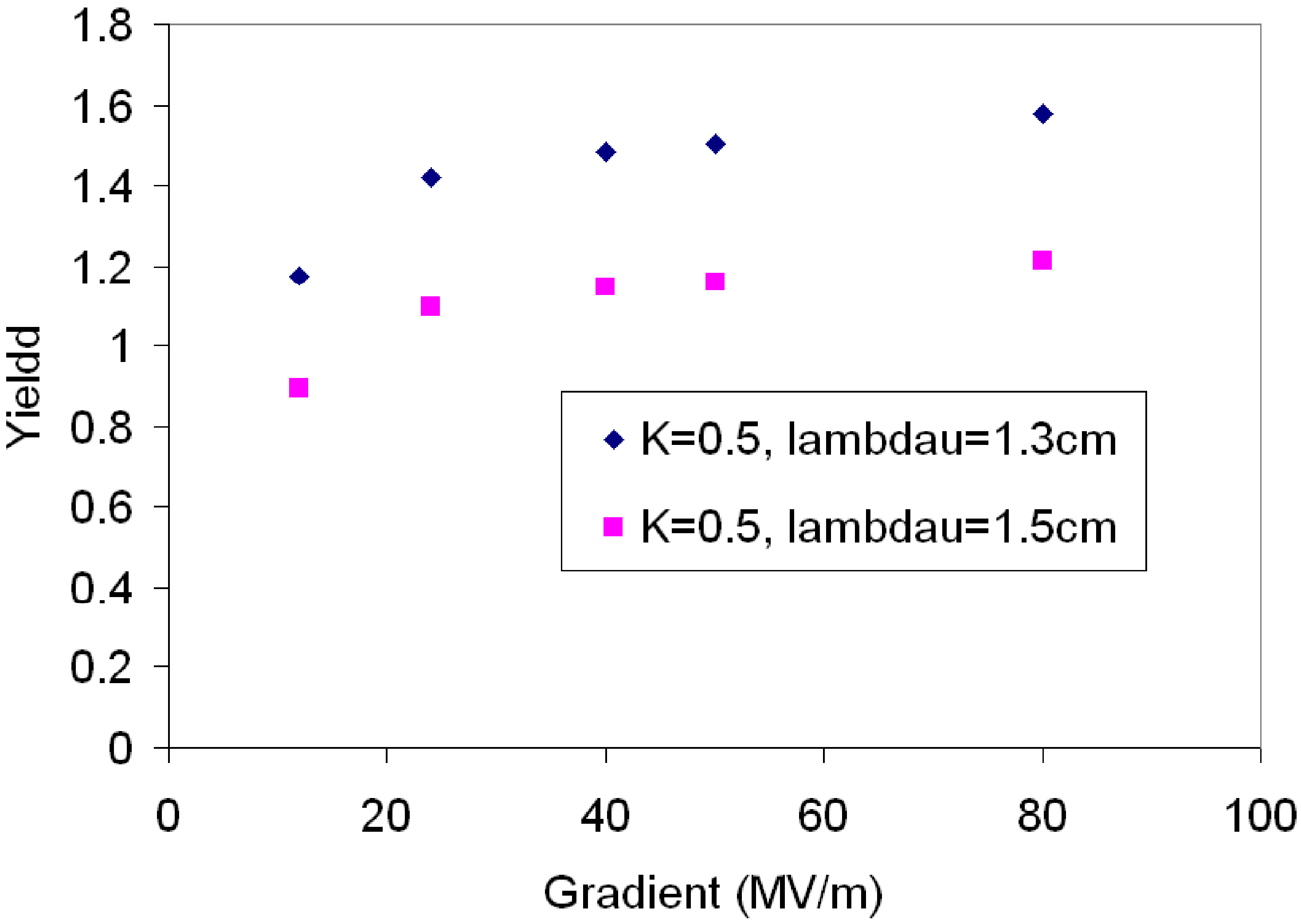
Yield with immersed target

- For immersed case, the OMD field is 7T on the surface of target and decrease adiabatically down to 0.5T in 20cm.
- We consider helical undulators with K=0.75 and 0.5, λu = 1.5cm and 1.3cm.

Immersed target, K=0.75



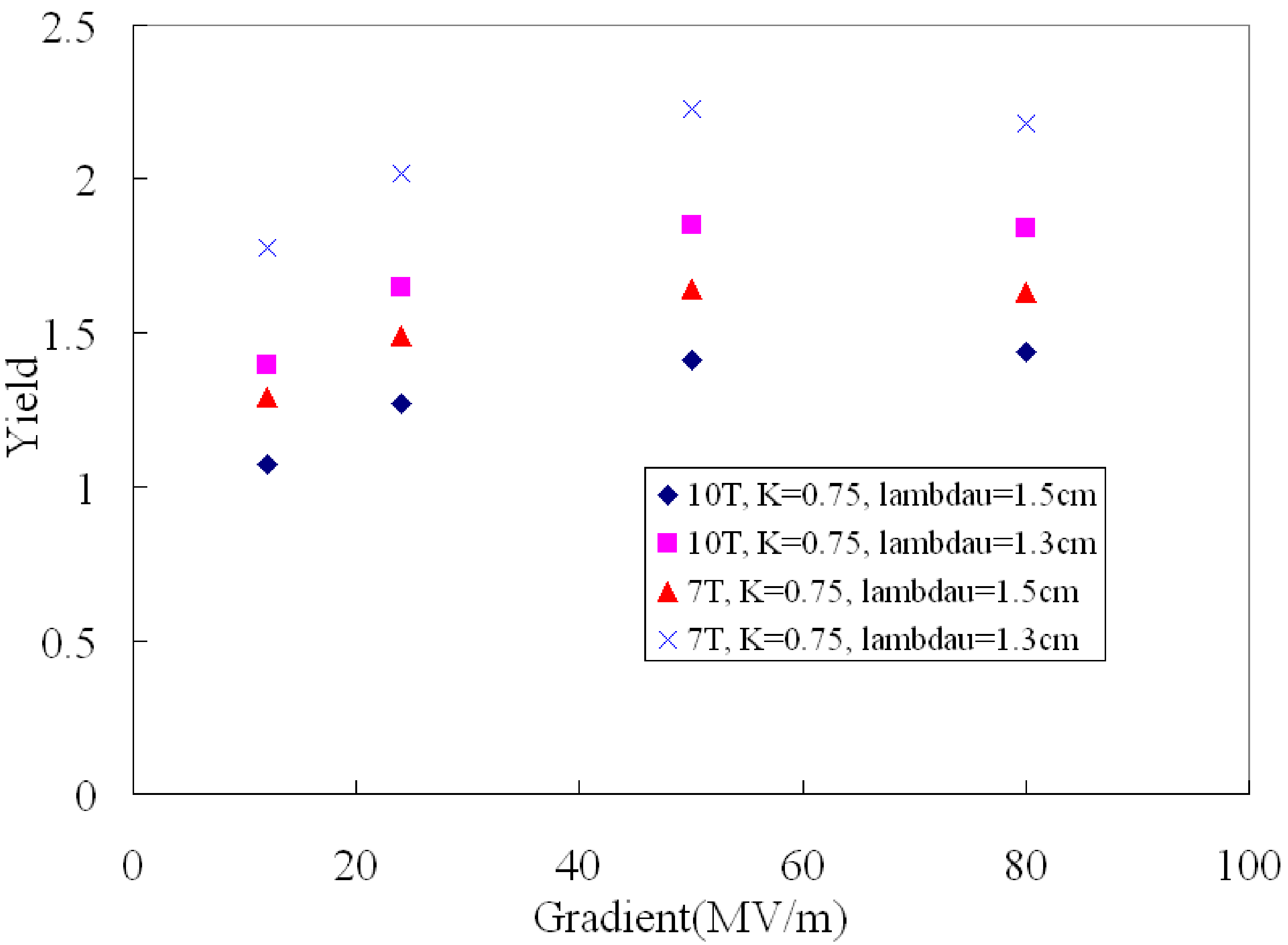
Immersed target, K=0.5



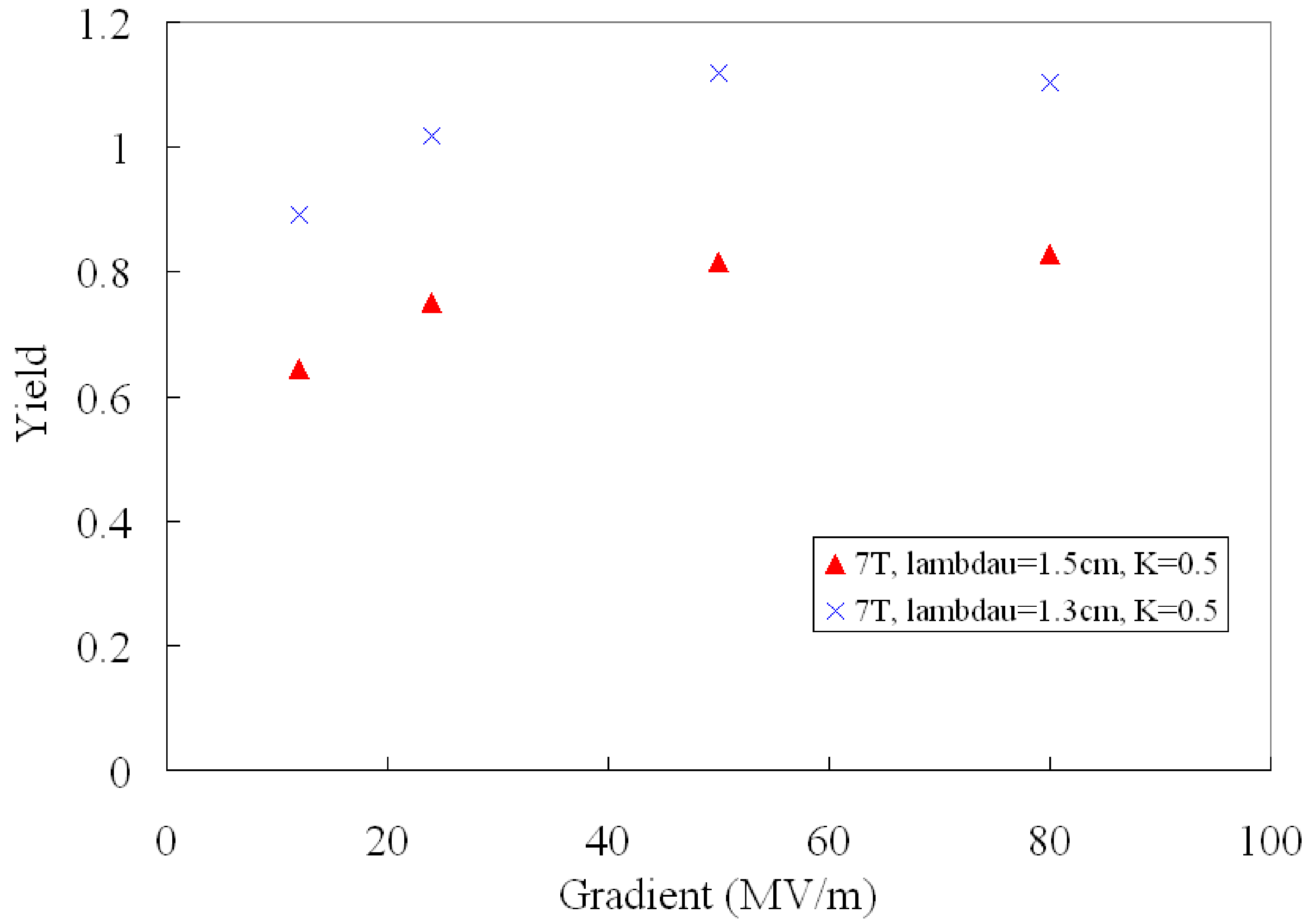
Yield with Non-immersed target

- For non-immersed target, the OMD field is about 0 on the surface of target and ramp up to over 7T or 10T in 2cm and then adiabatically decrease down to 0.5T in 20cm.
- We considered helical undulators with K=0.75 and 0.5, period λu = 1.5cm and 1.3cm.

Non-immersed target, K=0.75



Non-immersed target, K=0.5

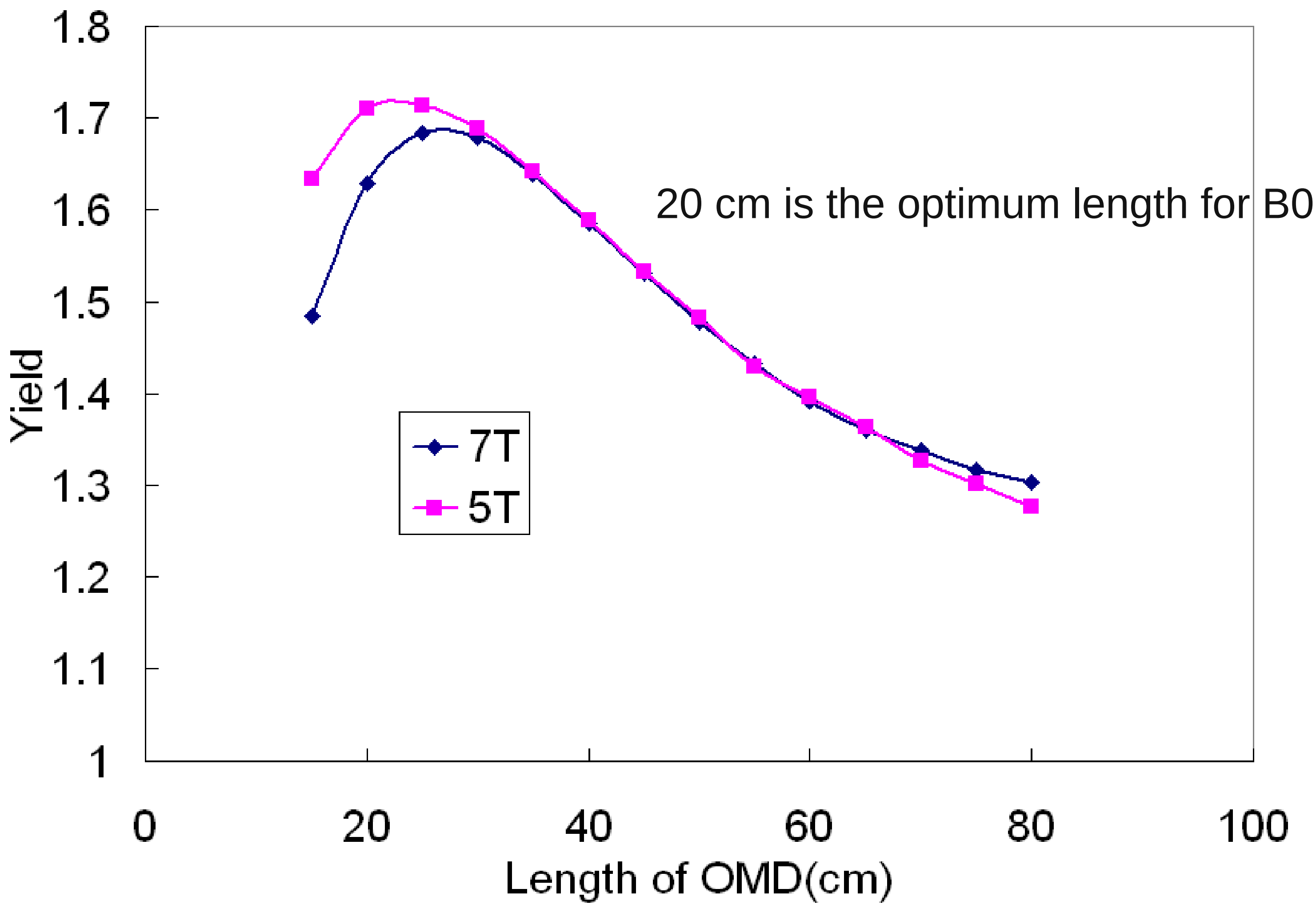


- Using gradient higher than 50MV/m doesn’t help much on the yield for either immersed and non-immersed cases.
- For non-immersed target, increasing the OMD field doesn’t necessarily increase the yield because of the associated higher transverse B field.
- For low polarization e+ source, yield of 1.5 can be achieved by choosing undulator with K=0.75, λu=1.5cm; using non-immersed target and using accelerator gradient >24MV/m.

Optimizing OMD for yield

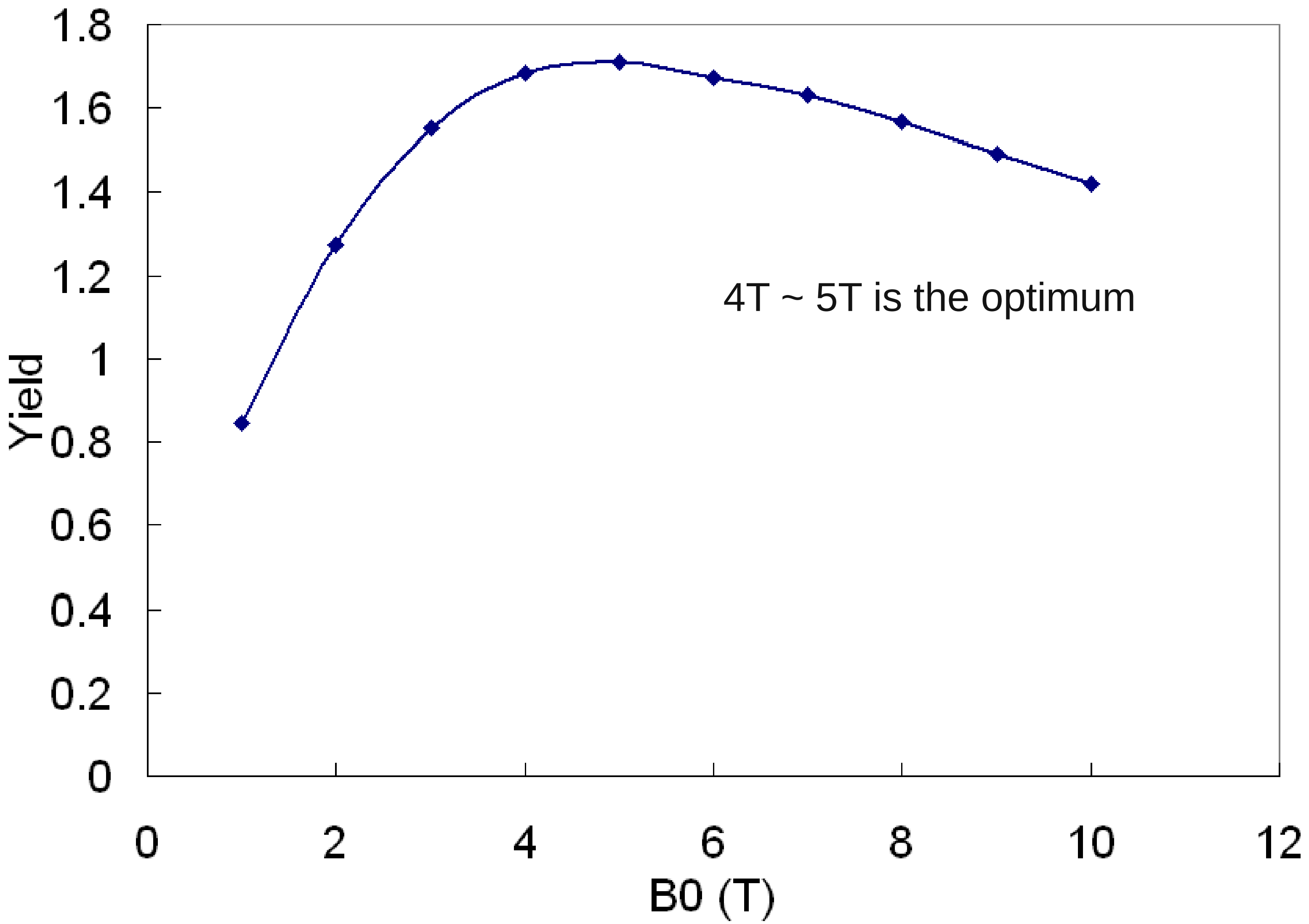
- Drive e- beam energy: 250GeV
- Undulator K: 0.75
- Undulator period: 1.5cm
- Length of undulator: 100m
- Drift to target: 450m
- Accelerator gradient and focusing: 50MV/m for beam energy <250MeV, 0.5T background solenoid field focusing; for 250MeV to 2.4GeV, 25MV/m with discrete FODO set.
- OMD: Non immersed, ramping distance 2cm
  - 1)7T-0.5T and 5T-0.5T, the thickness varies from 15cm to 80cm in 5cm steps;
  - 2) the thickness fixed at 20cm, B0-0.5T, B0 varies from 1 T to 10T
- Photon collimator: None
- Target material: 0.4 rl Titanium, non-immersed
- Yield is calculated as Ne+ captured/Ne- in drive beam.
- Positron capture is calculated by numerical cut using damping ring acceptance window: +/-7.5 degrees of RF(1.3GHz), $\varepsilon x+\varepsilon y<0.09\pi$.m.rad,1% energy spread with beam energy ~2.4GeV

Optimum length of OMD



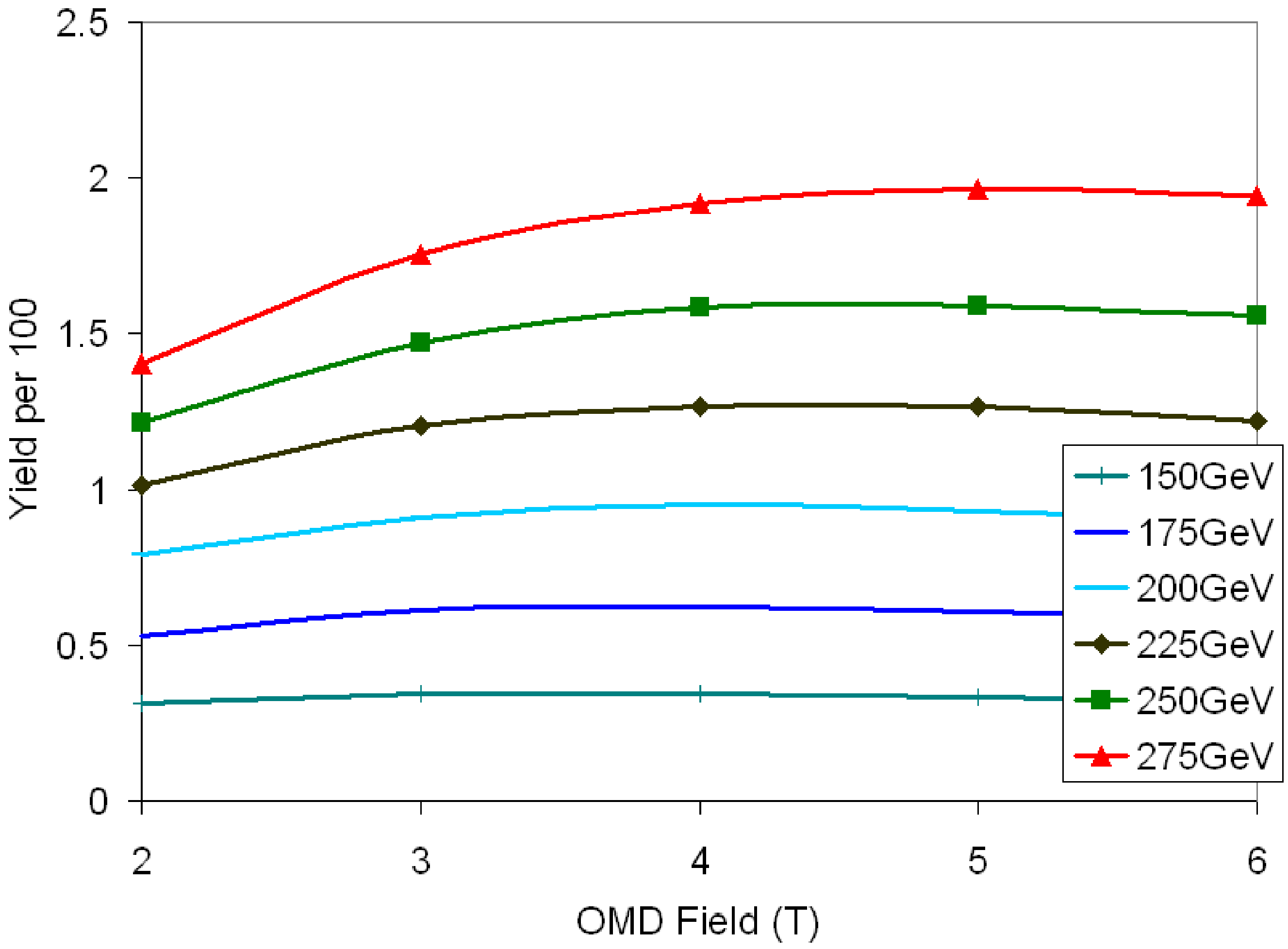
20 cm is the optimum length for B0=5T

Optimum B0 of OMD (non-immersed case)

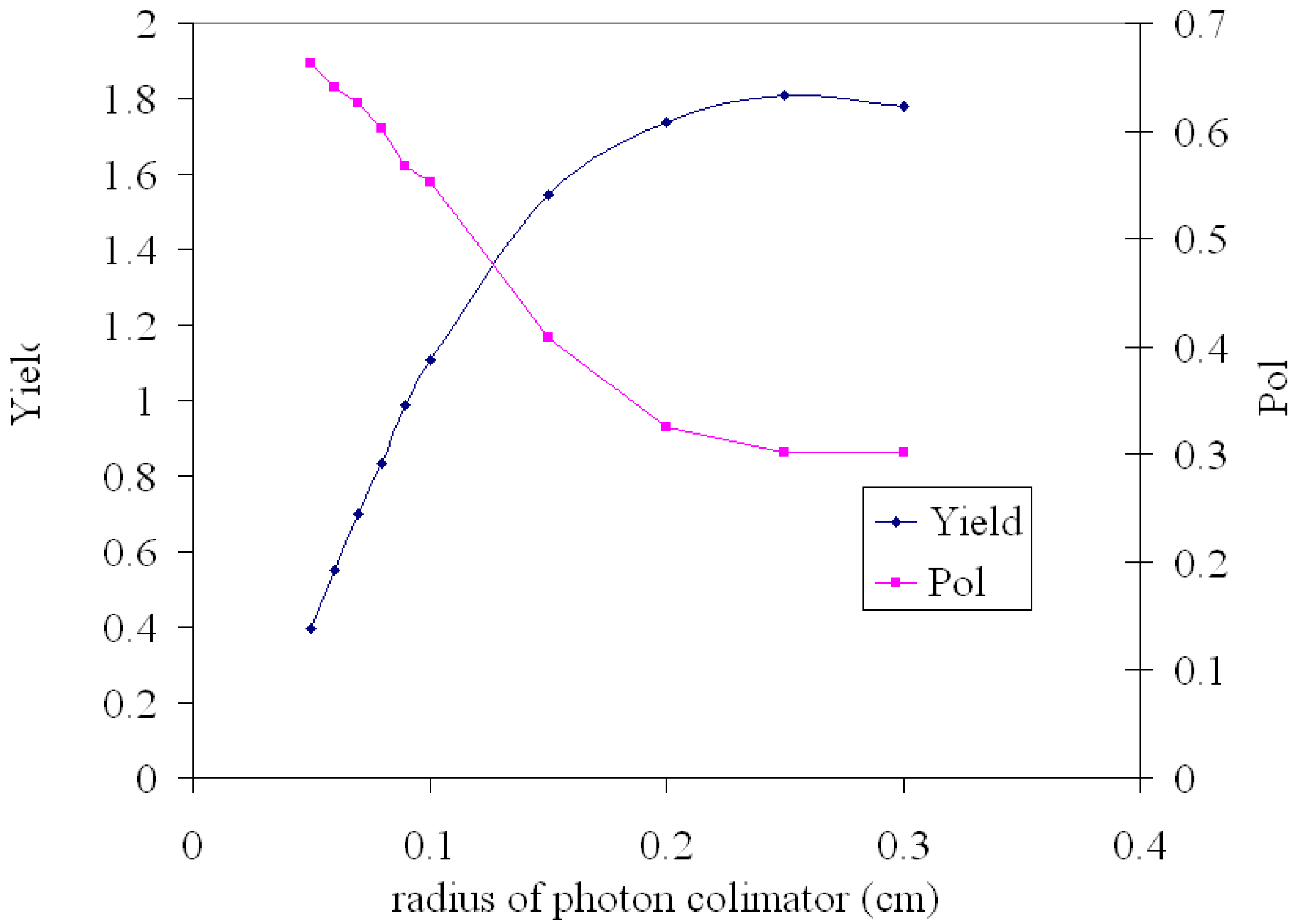


4T ~ 5T is the optimum

Yield as function of drive beam energy and OMD



Yield and polarization

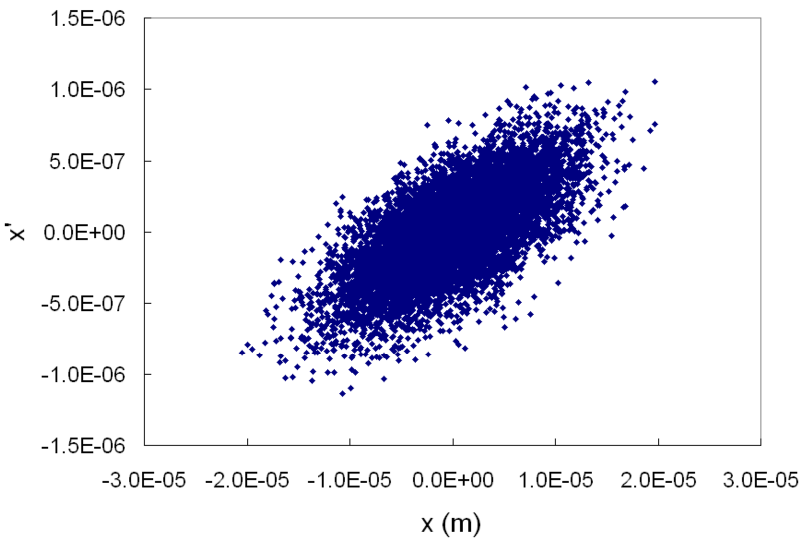


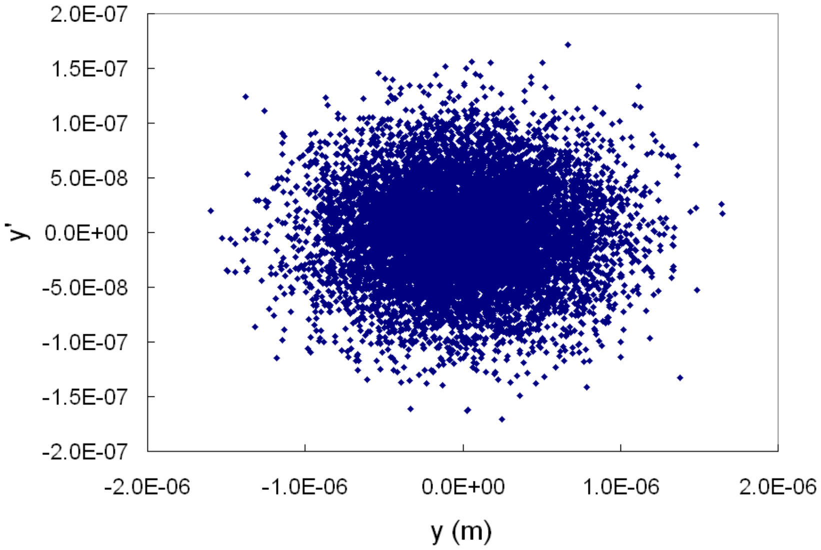
Emittance evolution in CLIC undulator

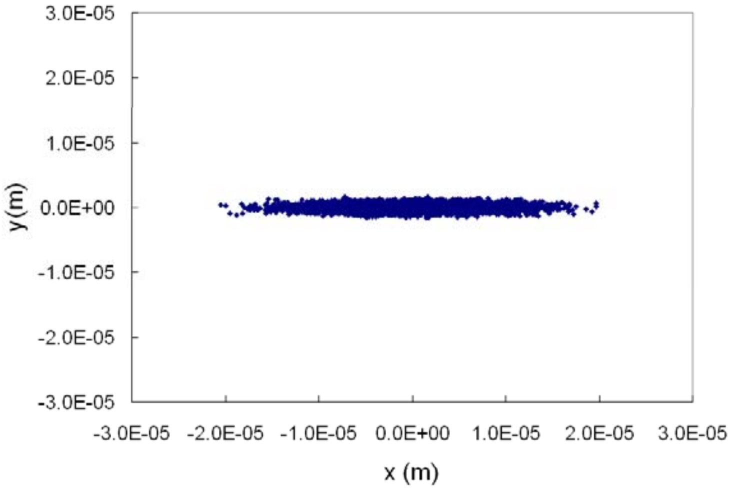
Initial conditions:

- Beam parameters of drive electron beam :
  - Energy: 250GeV
  - Energy spread: $\sigma_{\Delta E/E}$= 0.35%
  - Emittance:
    - $\gamma\varepsilon_x$=0.6 e-6
    - $\gamma\varepsilon_y$=0.01e-6
  - Bunch length: 45μm, or 0.15ps
- Lattice:
  - Assuming FODO lattice of 25m per FODO, total length of beam line is 125m.
  - Assuming 90 degrees per FODO phase advance in vertical and 70 degrees in horizontal
  - 10 pieces of undulators in between Quads. Each one has a length of 12m long with K: 0.75, and λ=1.5cm
- Assume beam is well matched with undulator beam line.

Phase space distribution of input drive electron beam

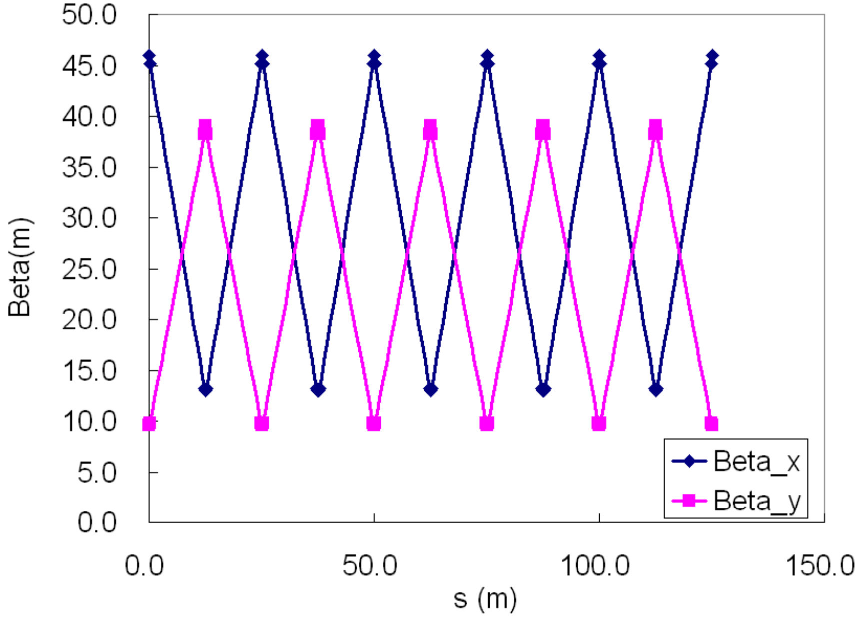


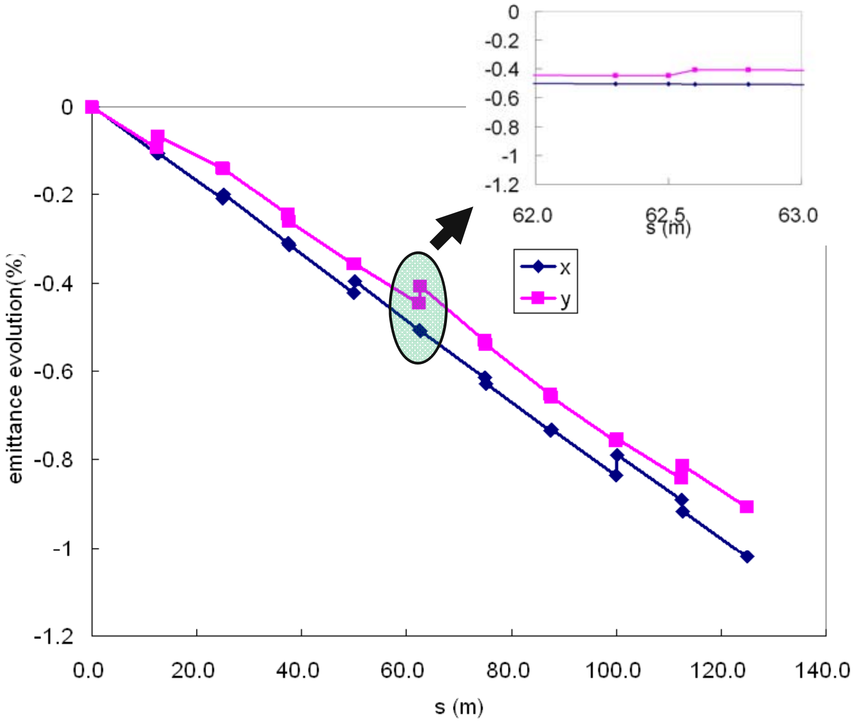




Beam injected at the entrance of the 1st Quad

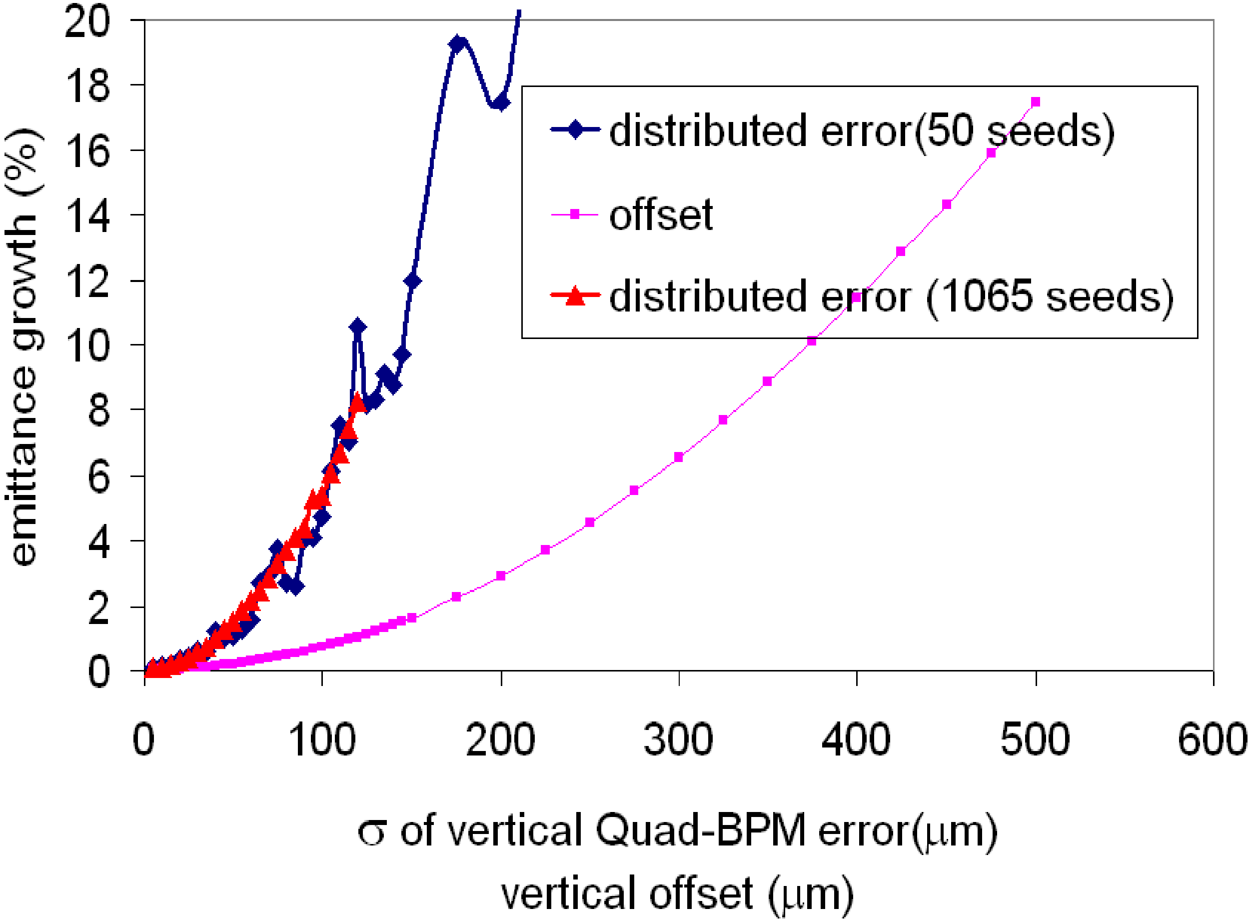
Beta function and emittance evolution





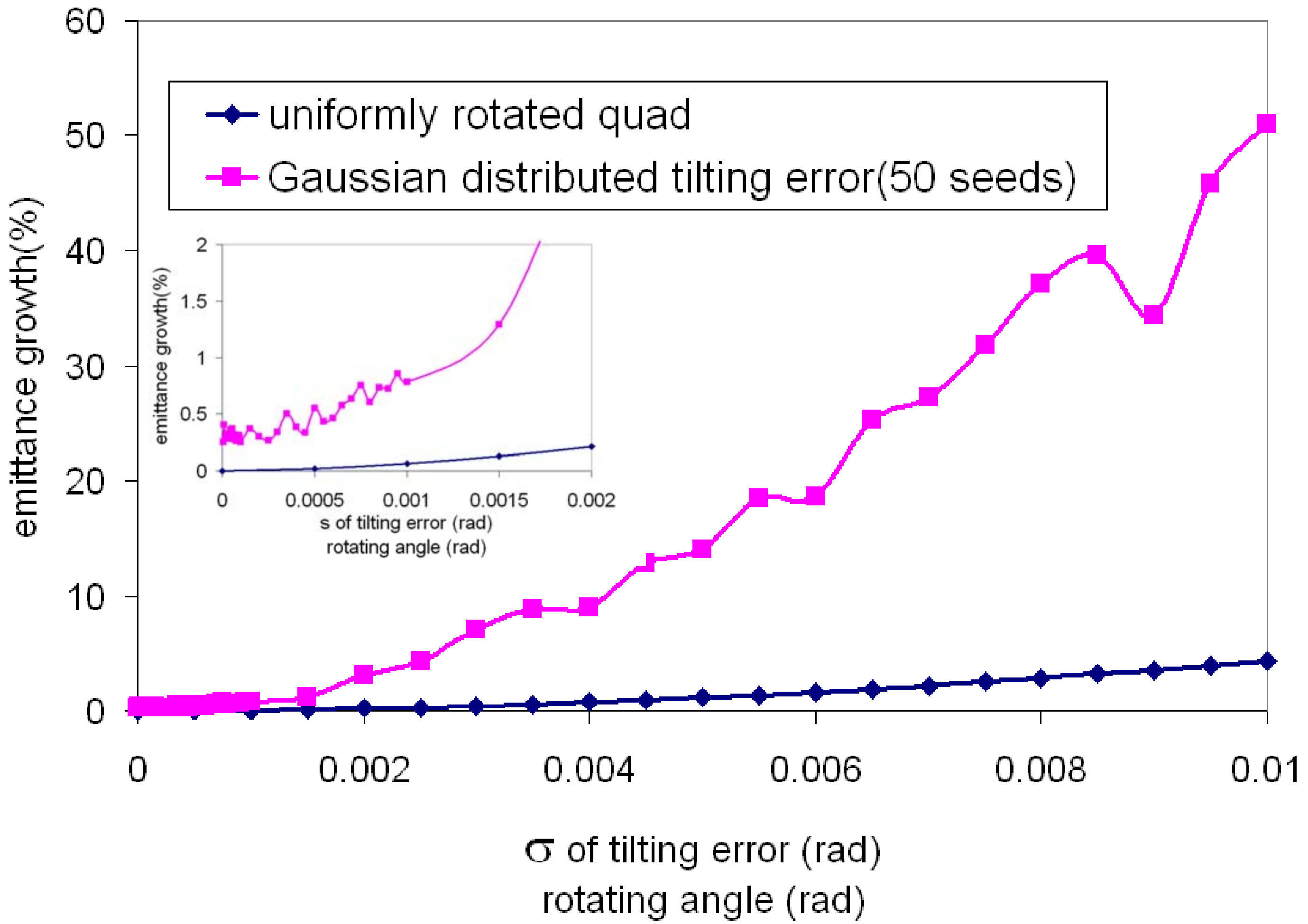
Drive electron beam lost 2.68GeV due to radiation in undulators. Normalized emittance get damped by ~1%.

Emittance growth due to quad BPM error

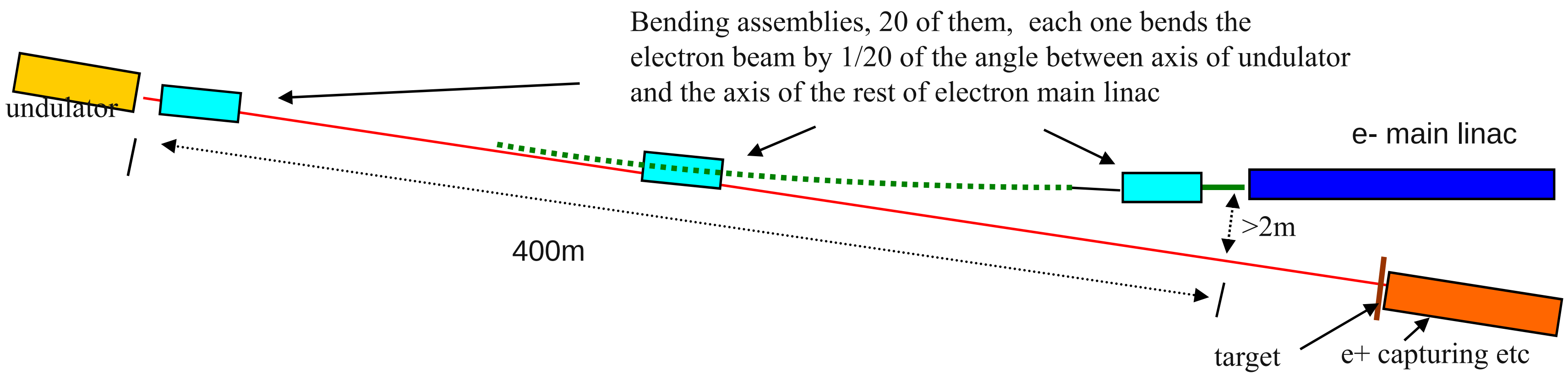


Emittance growth due to quad rotation

20um of quad BPM error is assumed, 50 random seeds were used



Separation of gamma and main e- beam

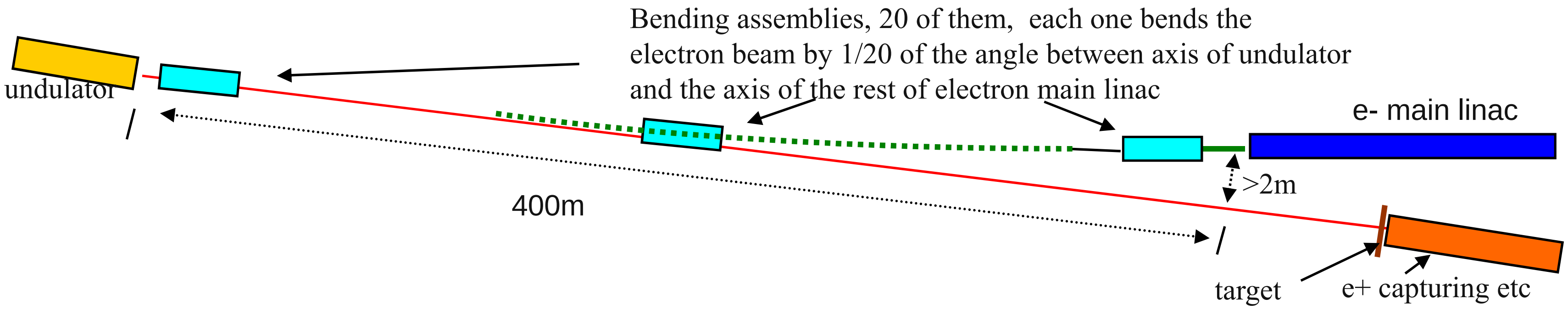


- Because of the possible emittance blowup due to synchrotron radiation, we divided the 400m into 20 sections and bend a very small angle on each section to minimize synchrotron radiation excitation.

Assuming the dispersive contribution can be corrected, simulation shows that it is possible to steer the main e- beam away for > 2m in 400m without introducing significant synchrotron radiation related emittance growth.

Emittance growth for different configurations

Bending angle per section (rad)	Effective length of bending per section (m)	Required B dipole (T)	growth without synchrotron radiation (1 section)		growth with synchrotron radiation (1 section)		Emittance growth without synchrotron radiation % (20 sections)	Emittance growth with synchrotron radiation % (20 sections)
			Emittance (%)	Energy spread(%)	Emittance (%)	Energy Spread(%)		
0.0005	**5**	**~0.083**	**~0.0094**	**0**	**~0.0065**	**~-0.0006**	**~0.18**	**~0.13**
0.00075	**5**	**~0.125**	**~0.021**	**0**	**0.033**	**~0.0005**	**~0.42**	**~0.66**
0.001	**5**	**~0.167**	**~ 0.0382**	**0**	**~ 0.13**	**~0.003**	**~0.77**	**~2.6**
0.002	5	~0.334	~0.14	0	~3.97	~0.039	~1.03	~118
0.003	5	~0.501	~0.28	0	~27.4	~0.138	~1.06	~12588



Bending assemblies, 20 of them, each one bends the electron beam by 1/20 of the angle between axis of undulator and the axis of the rest of electron main linac

Summary

- Based on the our study, an undulator based positron source for CLIC is achievable.
- The undulator will not dilute the emittance of the e- beam.
- Simulation shows it is possible to restore the main e- beam after undulator.
- Further studies are needed to study other undulator options systematically.
- More detailed studies are needed for e+ capturing and transportation within CLIC scheme.
- More detailed studies are needed for realizing the beamline for separating between produced gamma rays and main e- beam.