Deflecting Section For The European XFEL Polarization Adjustable Beam Line (SASE3)

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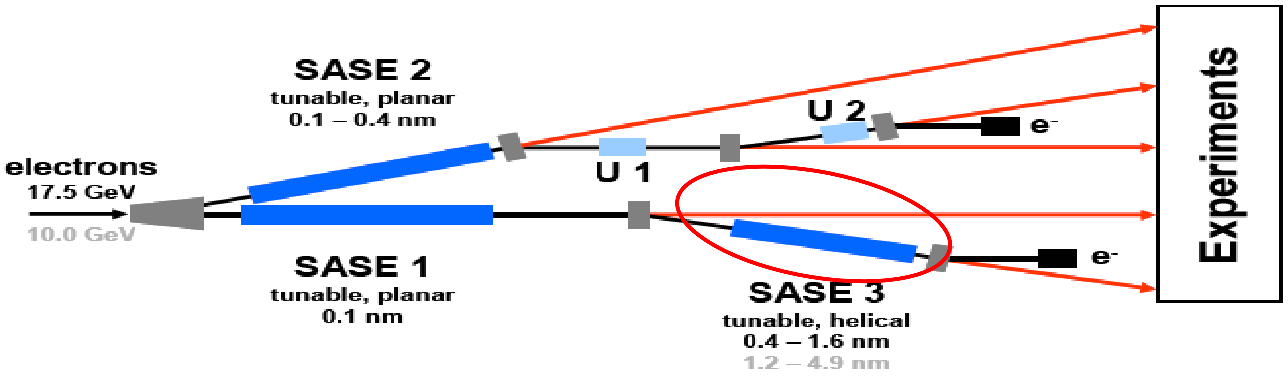
Outline

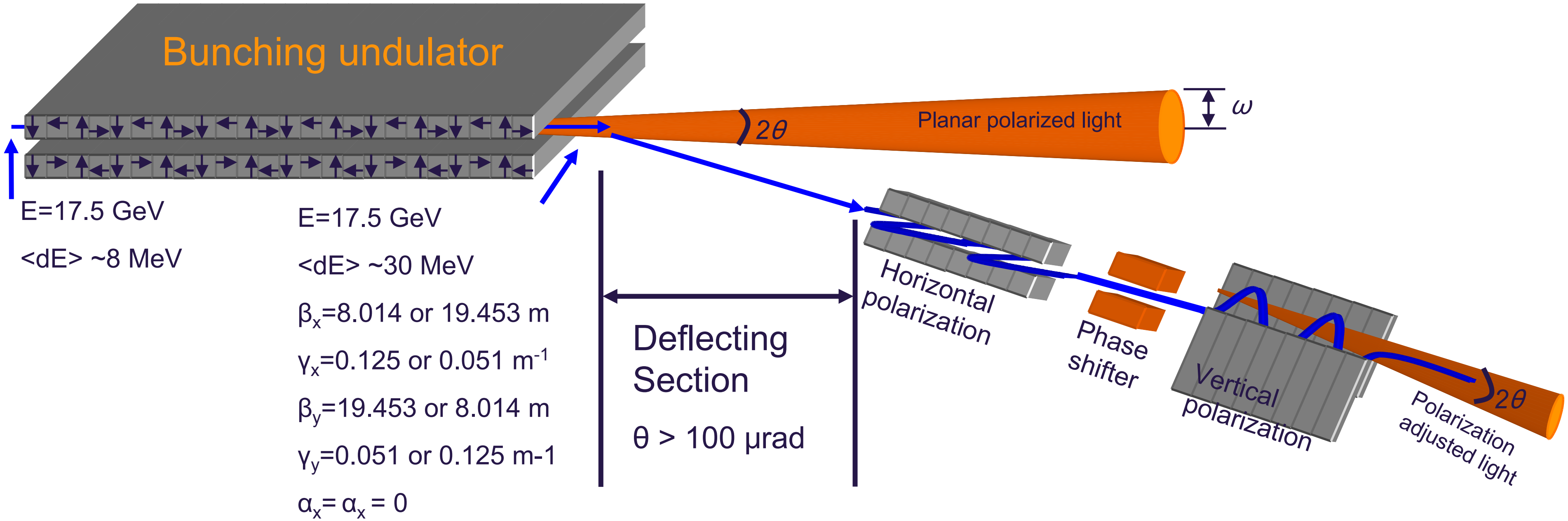
- Brief introductions
- Deflecting section study
  - Single dipole deflecting $R_{5i} \neq 0; T_{5ij} \neq 0$
  - First order isochronous deflecting $R_{5i} = 0; T_{5ij} \neq 0$
  - Second order isochronous deflecting $R_{5i} = 0; T_{5ij} = 0$
  - Questions

Basic Introductions



- Locating after SASE1
- Wavelength range: 0.4~4.8 nm
- Adjustable Polarization

Basic Introductions



For far field Gaussian optical beam, the open angle:

$$\omega \approx \frac{\omega_0 z}{z_R} = \frac{\lambda_s z}{\pi \omega_0} \leftrightarrow \theta \approx \frac{\omega}{z} = \frac{\lambda_s}{\pi \omega_0}$$

$$\omega_0 \sim 30\mu m$$
$$\lambda_s = 4.8nm$$
$$\theta \sim 50\mu rad$$

Numerical calculation for longest and shortest wavelength (4.8 & 0.4nm)

	4.8 nm	0.4 nm
θ (μrad)	24	4
ω_0 (μm)	64	34
Z_R (m)	2.6	10

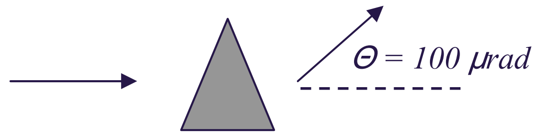
Deflecting section study

All of the deflecting section study concerns the shortest wavelength 0.4 nm

Deflecting section study --- Single dipole

Deflecting angle θ is quite small, if a simple dipole works?

To overcome first order geometry aberrations:



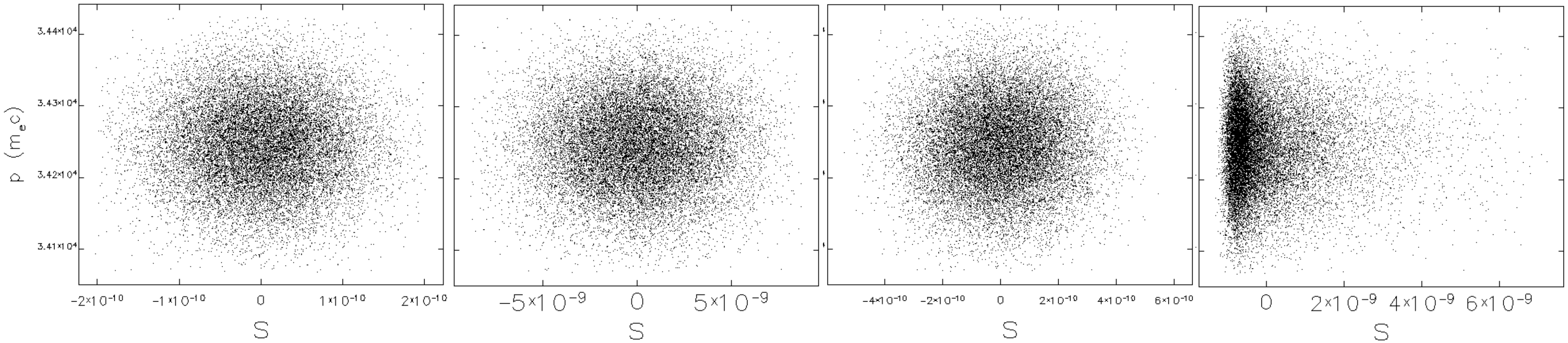
$$\alpha_{x0} = \frac{R_{51}\beta_{x0}}{R_{52}} = \frac{2}{L_{bend}}\beta_{x0} \rightarrow \sigma_{min} = \frac{\sqrt{\varepsilon}\cdot R_{52}}{\sqrt{\beta_{x0}}} = \frac{\sqrt{\varepsilon}\cdot L_{bend}\cdot\theta}{2\sqrt{\beta_{x0}}}$$

Dipole length, the longer, the better

$$\sqrt{\varepsilon}\theta = \sqrt{4.088\times10^{-11}}\times10^{-4} = 6.39\times10^{-10}$$

Standard SASE2 β_x fulfills the initial beta function requirement

Even for a very long dipole, L_{bend} = 2m



Initial Gaussian Bunch

β_{x0} =20 m, α_{x0} = 0
First Order Matrix

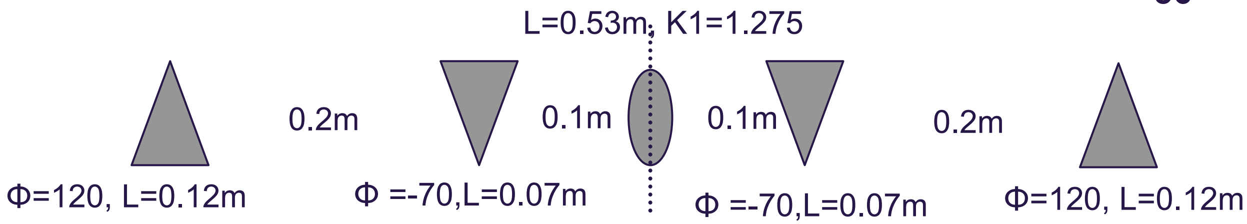
β_{x0} =20 m, α_{x0} = 20
First Order Matrix

β_{x0} =20 m, α_{x0} = 20
Second Order Matrix

- Special initial α_{x0} is required
- How to compensate Second order geometry aberrations ?

Deflecting section study --- first order isochronous

First order isochronous: First order achromate + zero R_{56}



Mirror symmetry system, balance between second order geometry aberrations and R56:

R5: **1.57075e-011 2.78426e-011** 0.00000e+000 0.00000e+000 1.00000e+000 **-1.77057e-008**

T51: **3.40651e-001**

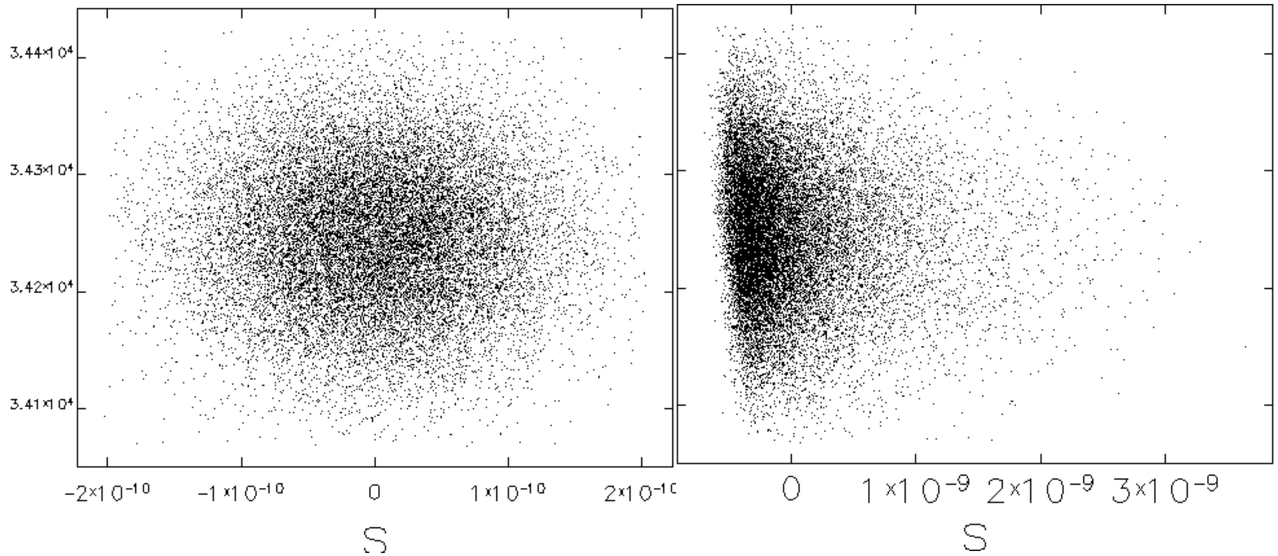
T52: **7.16885e-002 8.39040e-001**

T53: 0.00000e+000 0.00000e+000 **4.28676e-001**

T54: 0.00000e+000 0.00000e+000 **2.74989e+000 5.23755e+000**

T56: 1.88249e-004 3.32063e-004 0.00000e+000 0.00000e+000 0.00000e+000 4.87033e-008

Initial Gaussian Bunch



β_{x0} =20 m, α_{x0} = 0, β_{y0} =20 m, α_{y0} = 0
Second Order Matrix

Deflecting section study --- first order isochronous

For first order order achromate system, the bunch length expansion due to second order geometry aberrations is:

$$\sigma^2 = \varepsilon^2 \begin{bmatrix} 2\left(T_{511}\beta_{x0} - T_{512}\alpha_{x0} + T_{522}\gamma_x\right)^2 + 2\left(T_{533}\beta_{y0} - T_{534}\alpha_{y0} + T_{544}\gamma_x\right)^2 \\ + \left(T_{512}^2 - 4T_{511}T_{522}\right) + \left(T_{534}^2 - 4T_{544}T_{544}\right) \end{bmatrix}$$

if $T_{511} - \frac{T_{521}^2}{4T_{522}} > 0,\ T_{533} - \frac{T_{543}^2}{4T_{544}} > 0$ when

$$\beta_{x0} = \frac{2T_{522}}{\sqrt{4T_{511}T_{522} - T_{521}^2}}; \quad \alpha_{x0} = \frac{T_{521}}{\sqrt{4T_{511}T_{522} - T_{521}^2}}$$

$$\beta_{y0} = \frac{2T_{544}}{\sqrt{4T_{533}T_{544} - T_{543}^2}}; \quad \alpha_{x0} = \frac{T_{543}}{\sqrt{4T_{533}T_{544} - T_{543}^2}}$$

The bunch expansion has smallest value:

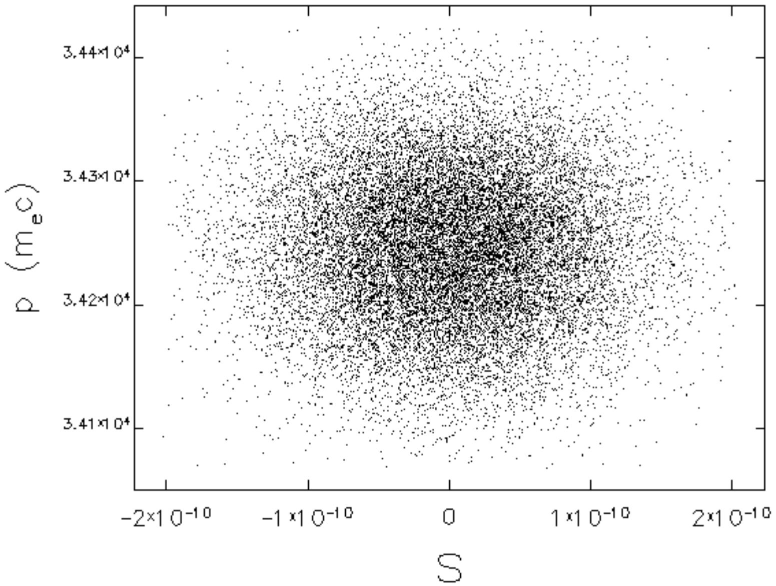
$$\sigma^2 = \varepsilon^2 \left[\left(4T_{511}T_{522} - T_{521}^2\right) + \left(4T_{544}T_{544} - T_{543}^2\right)\right]$$

From the Matrix show above:

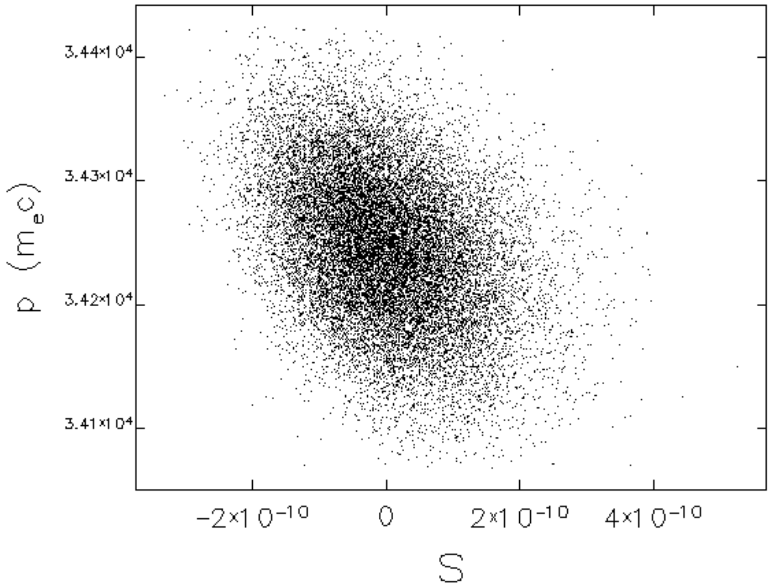
$$\beta_{x0} = 1.573m, \alpha_{x0} = 0.067$$
$$\beta_{y0} = 8.794m, \alpha_{y0} = 2.309$$

Deflecting section study --- first order isochronous

With the required initial TWISS parameters, the beam distribution change is:



Initial Gaussian Bunch

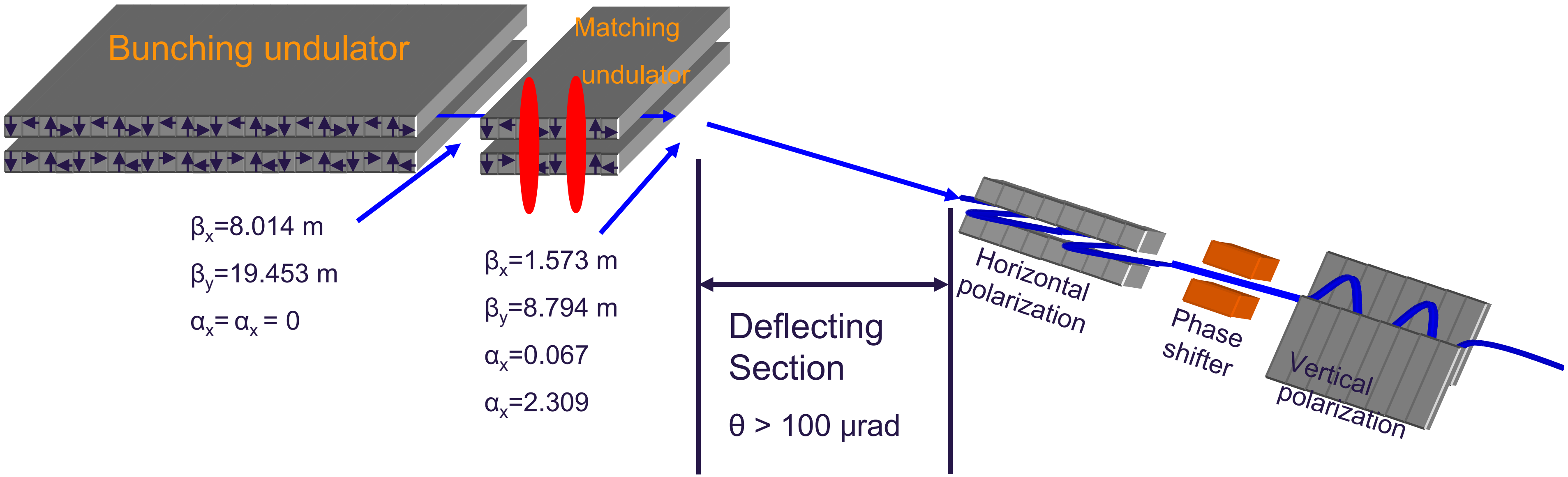


β_{x0} =1.573 m, α_{x0} = 0.067, β_{y0} =8.794 m, α_{y0} = 2.309
Second Order Matrix

- By especially setting the initial TWISS parameters, the 0.4 nm bunch can be well maintained.
- The problem is, how to make the TWISS parameters from SASE3 standard value to the required initial ones?

European XFEL

Deflecting section study --- first order isochronous

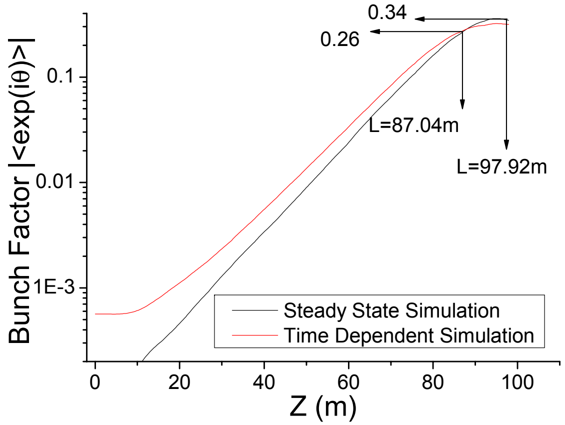


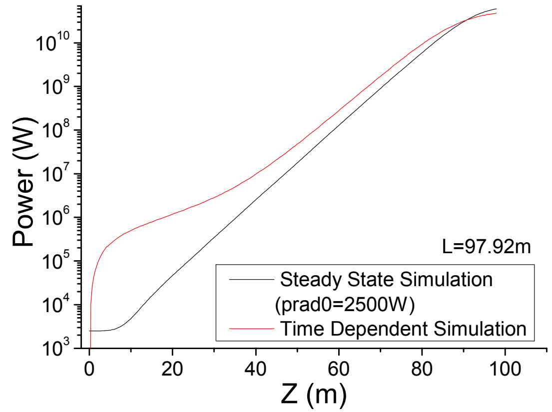
- Add “Matching Undulator” between the Bunching Undulator and deflecting section
- Quadrupoles are set between Matching Undulator segments to adjust TWISS parameters
- Undulator is used to maintain the Bunch during the TWISS parameters matching.

Deflecting section study --- first order isochronous

Matching Undulator Design and Bunching Undulator Length

Bunch factor and FEL power in Bunching Undulator:





- 97.92m long Bunching Undulator can give maximum bunch factor
- Several configurations have been investigated, all of them can match the TWISS parameters. The solutions can be:

  four undulators, 5m, 5m, 5m, 5m

  four undulators, 2m, 2m, 2m, 2m

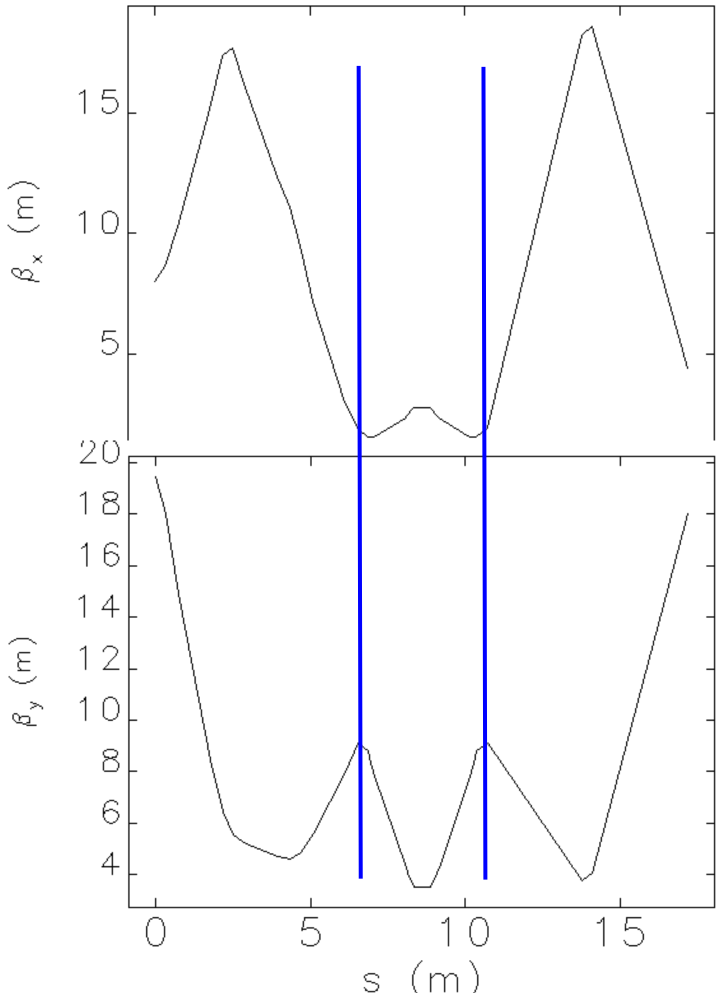
  three undulators, 5m, 1m, 1m

  three undulators, 1m, 1m, 1m
- Different Bunching Undulator length have been studied for each match undulator structure
- the best combination of bunching undulator and matching undulator is :

87.04 m Bunching Undulator + 3*1m Matching Undulator

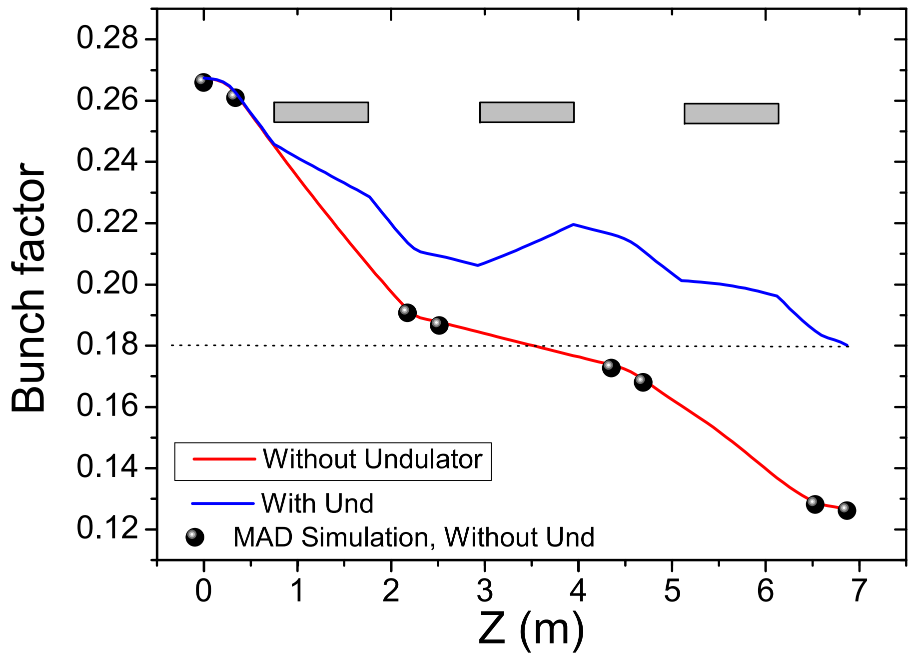
Deflecting section study --- first order isochronous

Beta function of the whole system

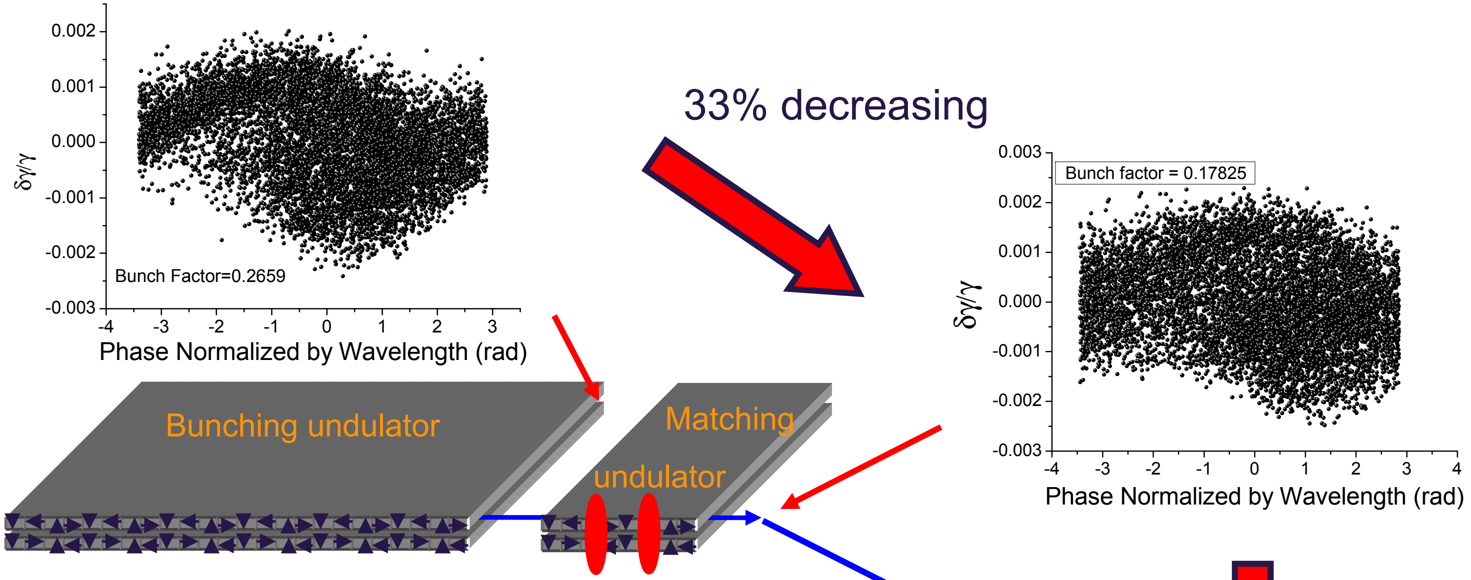


Matching section - Deflecting section – Crossed Und.

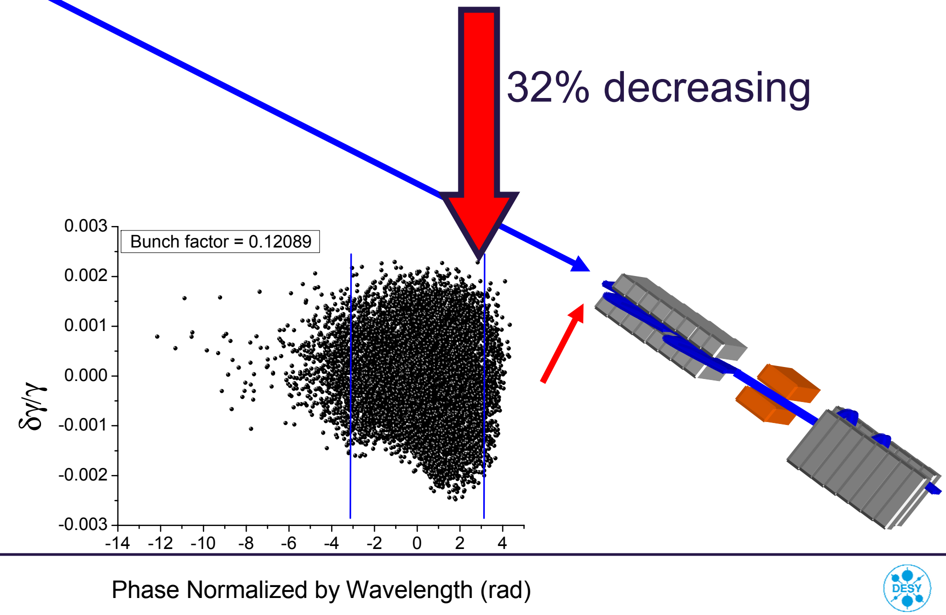
Bunch factor dropping in the undulator matching section



Deflecting section study --- first order isochronous



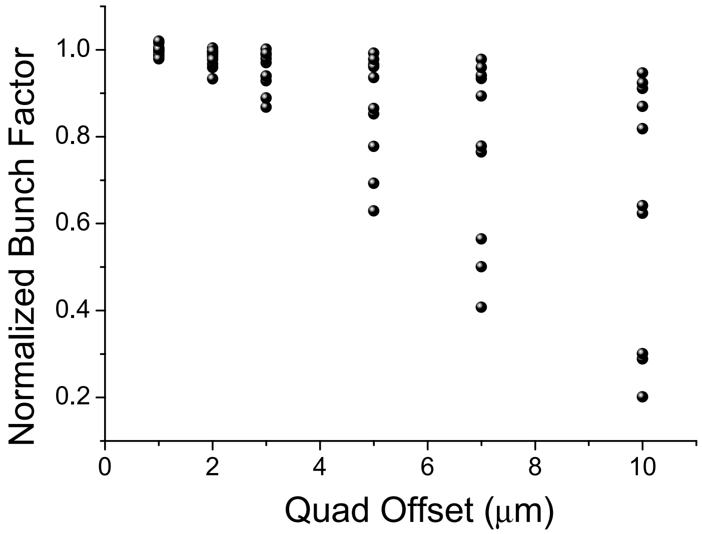
- Due to the abnormal beta function, in the matching section, even there is undulator, bunch factor still drops.
- In the deflecting section, the bunch factor drops to a smaller value.
- At the entrance of crossed undulator, the maximum bunch factor can be 0.12



Deflecting section study --- first order isochronous

Tolerance

Matching Section errors

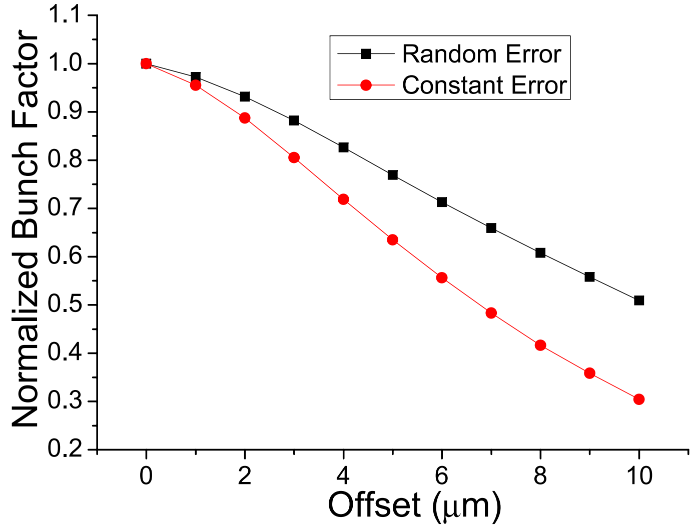


• Random offset of quadrupoles in Matching undulator section

• No error for deflecting section

• Bunch factor measured at exit of deflecting sectiong

Deflecting Section errors



• Random and constant offset of all magnets in the deflecting section

• No error in matching section

Deflecting section study --- first order isochronous

FEL comparison

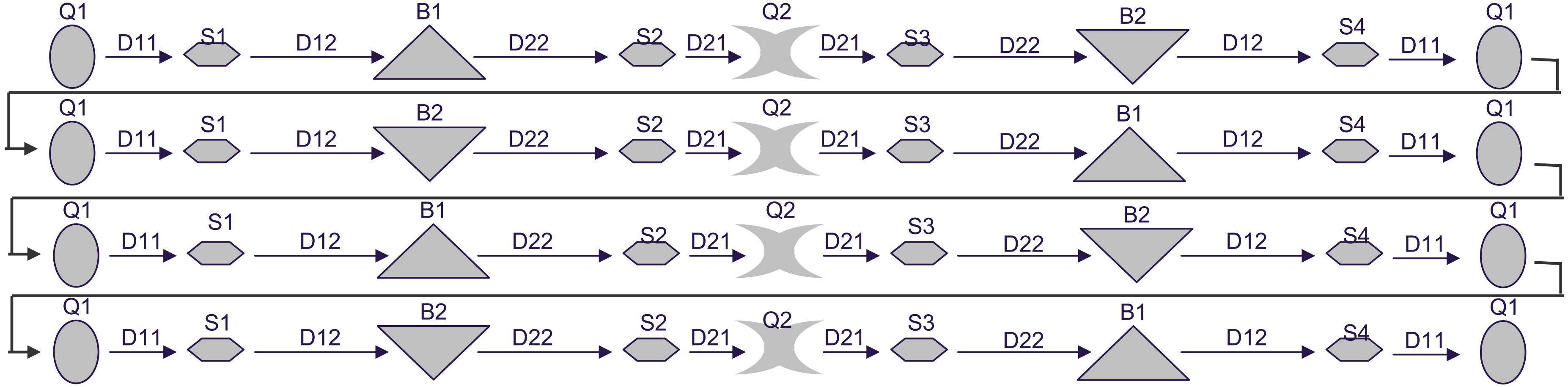
		17.5GeV, 0.4nm, $L_{g,3D} = 8.48$, aperture = 1.474mm			
	Length (m)	P (GW)	P_x/P_y	Polarization %	S_3/S_0 %
Ideal cases	3.06 m	3.69	2.068	93.8~92.4	83.4~79.8
First order isochronous	3.40 m	1.16	3.596	85.5~77.9	74.0~65.0

- Bunch factor drops a lot in the matching undulator section
- The beta function in the crossed undulator is too smaller than the standard values
- Compare to the ideally deflecting, power drops ~68%, total polarization drops ~11%, circle polarization drops ~15%
- The maximum bunch factor in matching undulator can arrive 0.34, with 97.92m, which can not be used

A better solution can be found?

European XFEL

Deflecting section study --- Second order isochronous



Type	B1	B2	Q1	Q2	S1	S2	S3	S4	D11	D12	D21	D22
Stren-gth	**125 μrad**	**-25 μrad**	**-0.106 K1**	**0.289 K1**	**-44.56 K2**	**99.75 K2**	**14.72 K2**	**-100 K2**				
Len-gth (m)	**0.2**	**0.2**	**0.3**	**0.3**	**0.5**	**0.5**	**0.5**	**0.5**	**0.2**	**4.5**	**0.256**	**8.8**

- Four cells system, total deflecting angle is 400 μrad (smaller 100 μrad deflecting hardly gives improvement)
- Total transport matrix is unity

R5: **1.49674e-016 6.50521e-019** 0.00000e+000 0.00000e+000 1.00000e+000 **7.30186e-008**

T51: **-7.46661e-002**

T52: **1.86252e-001 -3.38115e-004**

T53: 0.00000e+000 0.00000e+000 **1.30394e-002**

T54: 0.00000e+000 0.00000e+000 **7.35423e-002 -7.317047e-005**

T56: **1.18833e-004 -1.48212e-004** 0.00000e+000 0.000000e+000 0.00000e+000 **7.37998e-007**

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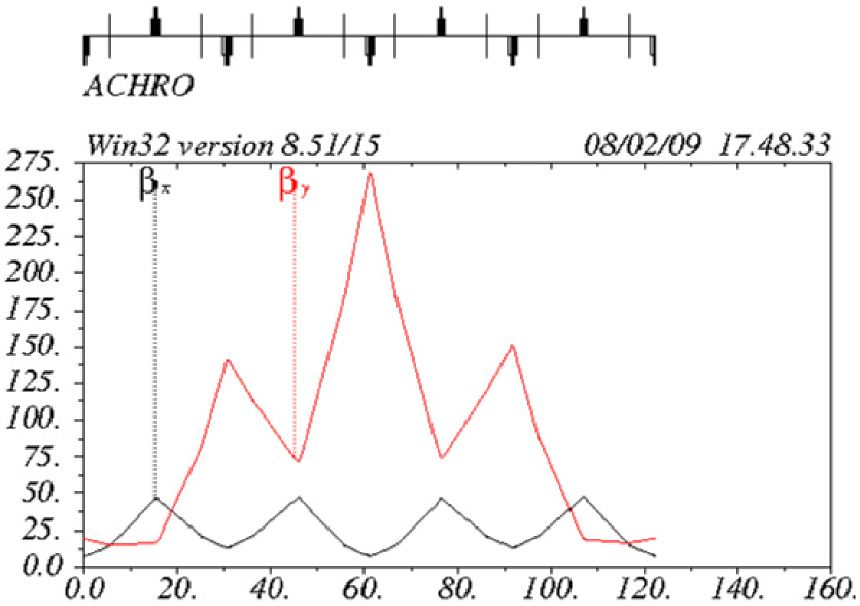
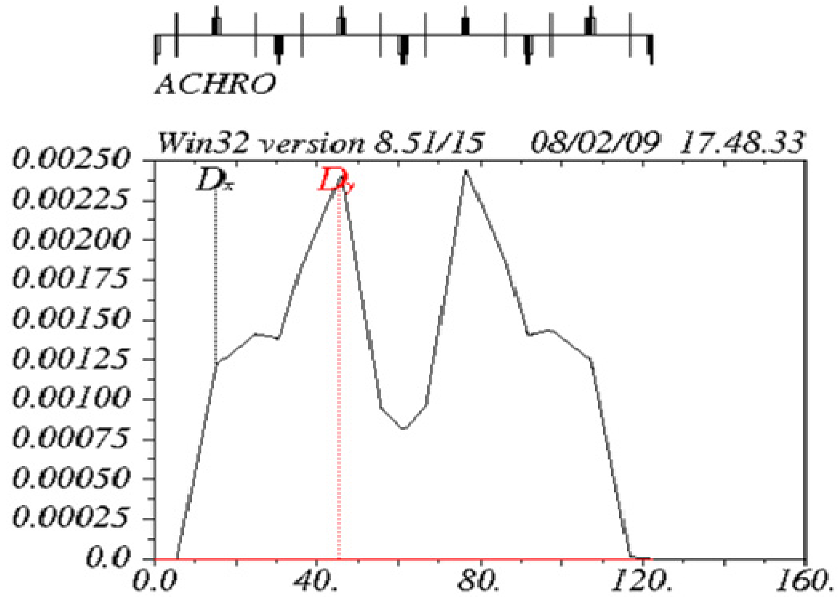
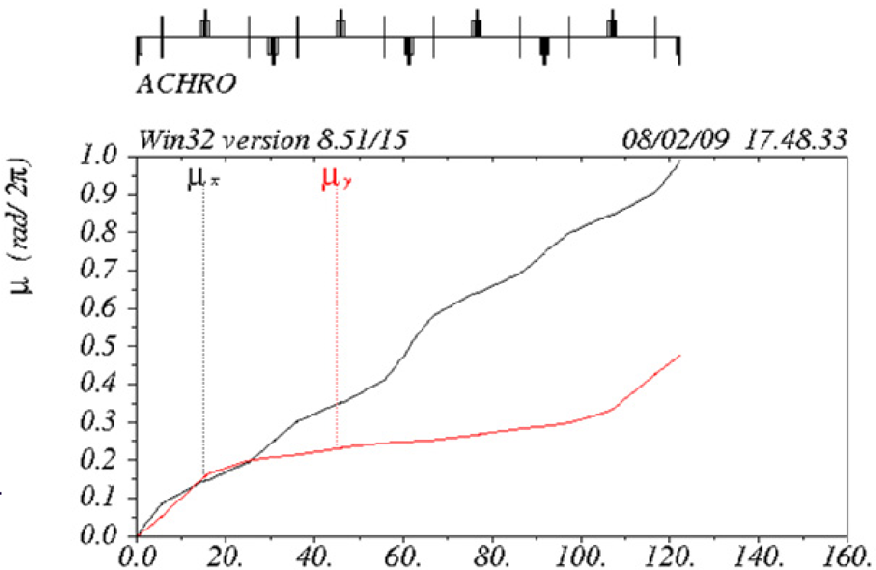
Deflecting section study --- Second order isochronous

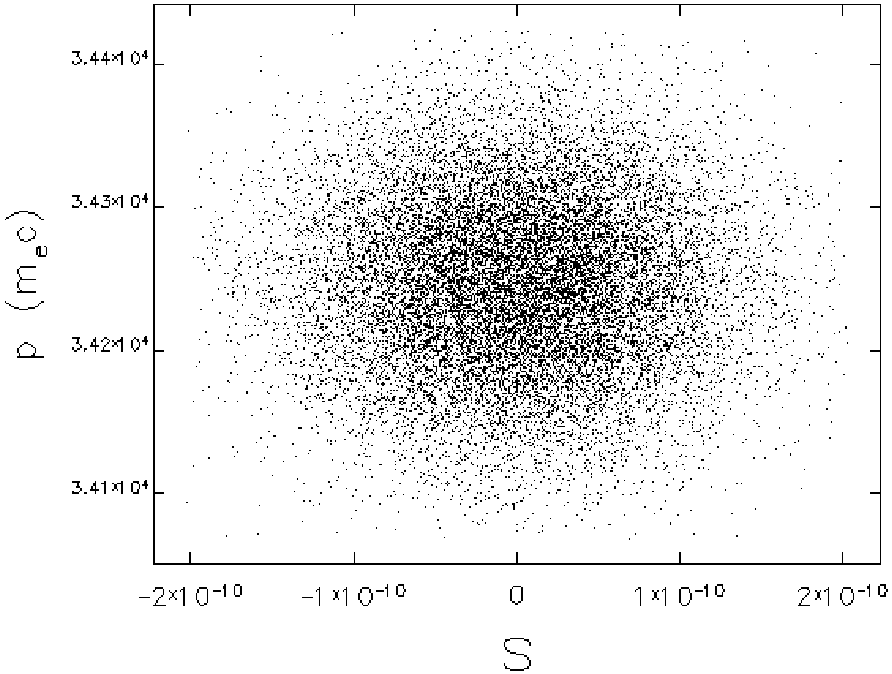




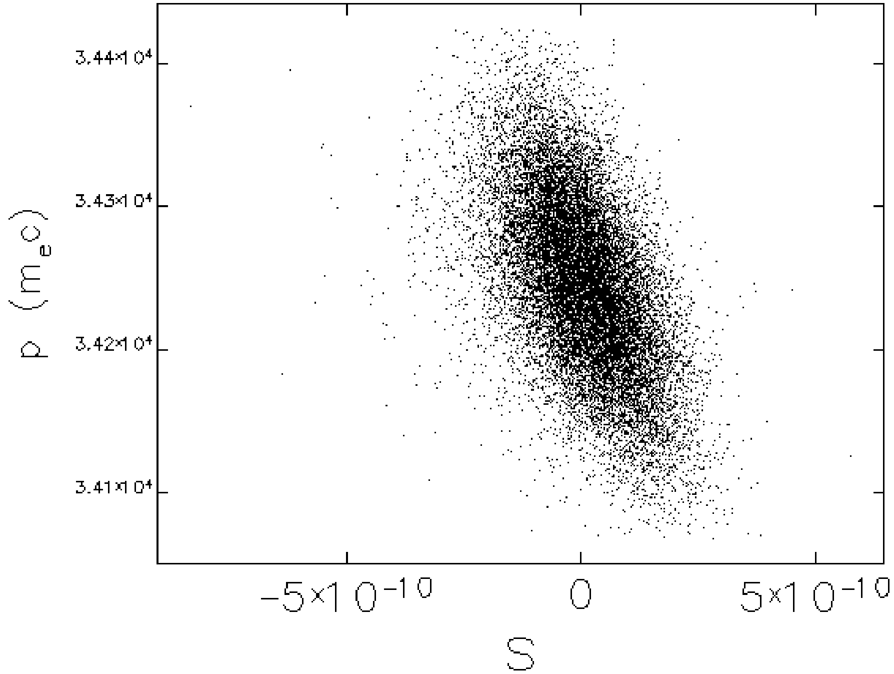
- Long distance is needed to make beta function large
- With large beta function, sextupoles can compensate the second order aberrations



Deflecting section study --- Second order isochronous

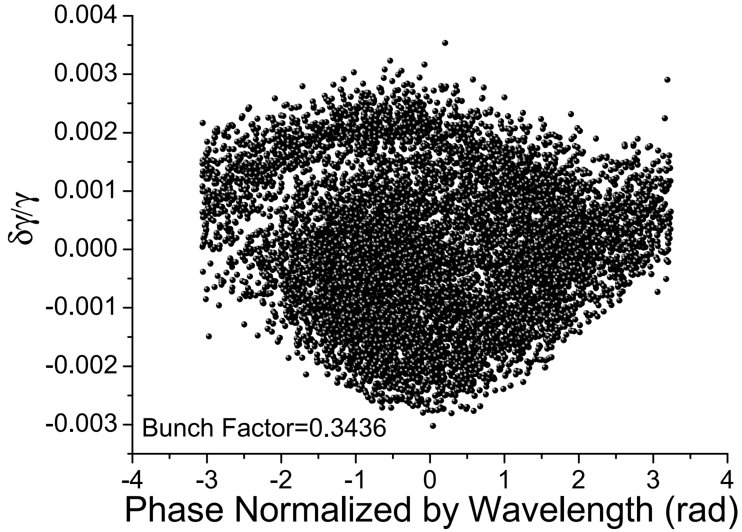


Initial Gaussian Bunch

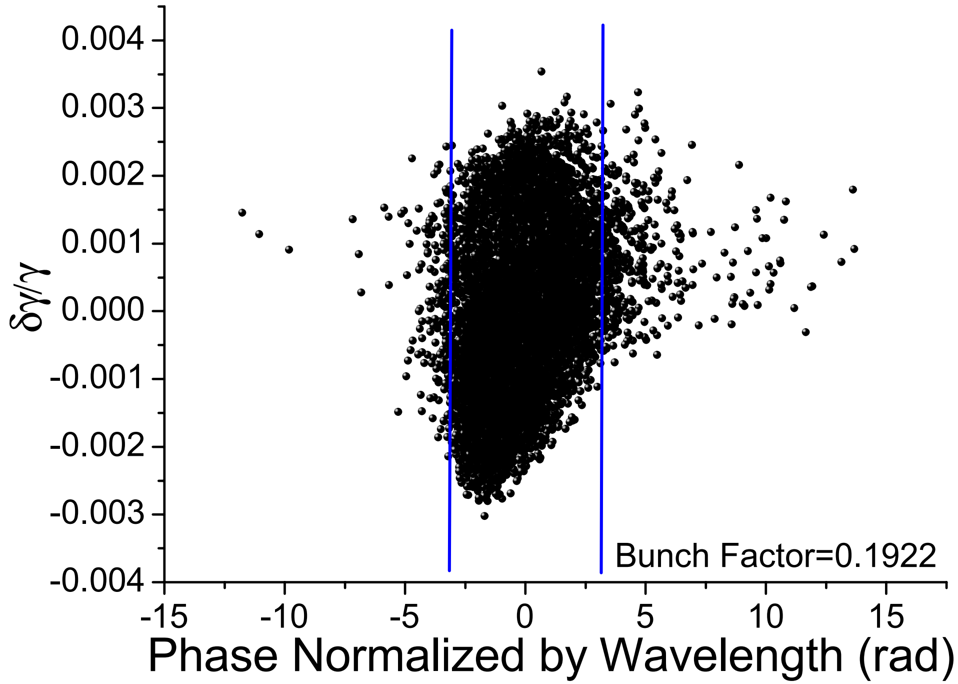


Initial TWISS parameters is Standard SASE3 values
Second Order Matrix

Deflecting section study --- Second order isochronous

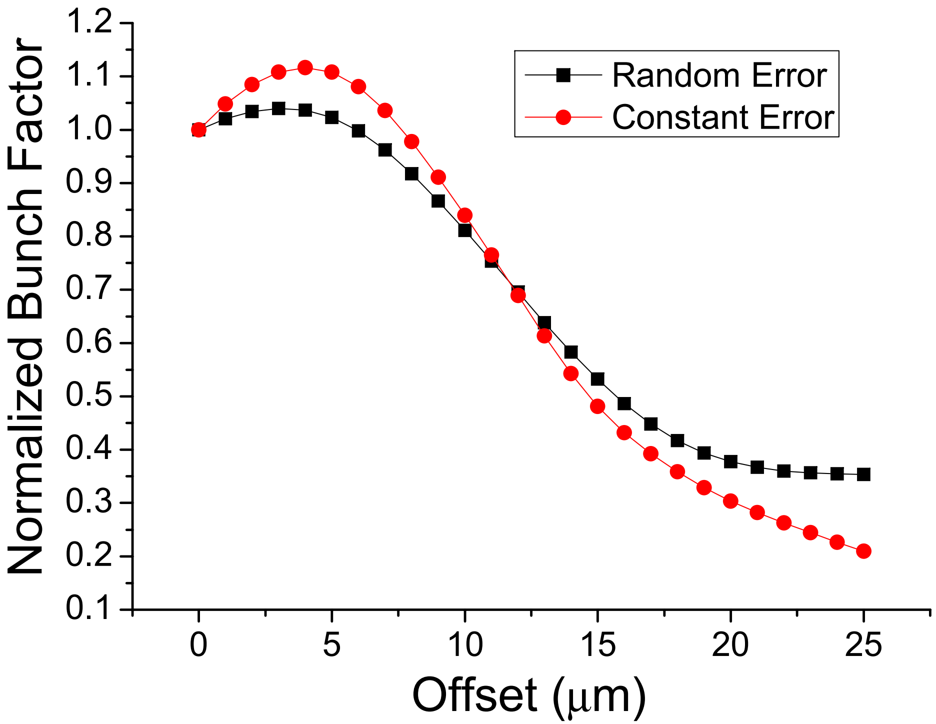


- The Bunching Undulator can be 97.92m long to achieve highest Bunch factor
- Deflecting section drops 44% bunch factor



Deflecting section study --- Second order isochronous

Tolerance



Random and constant offset of all magnets in the deflecting section

Deflecting section study --- Second order isochronous

FEL comparison

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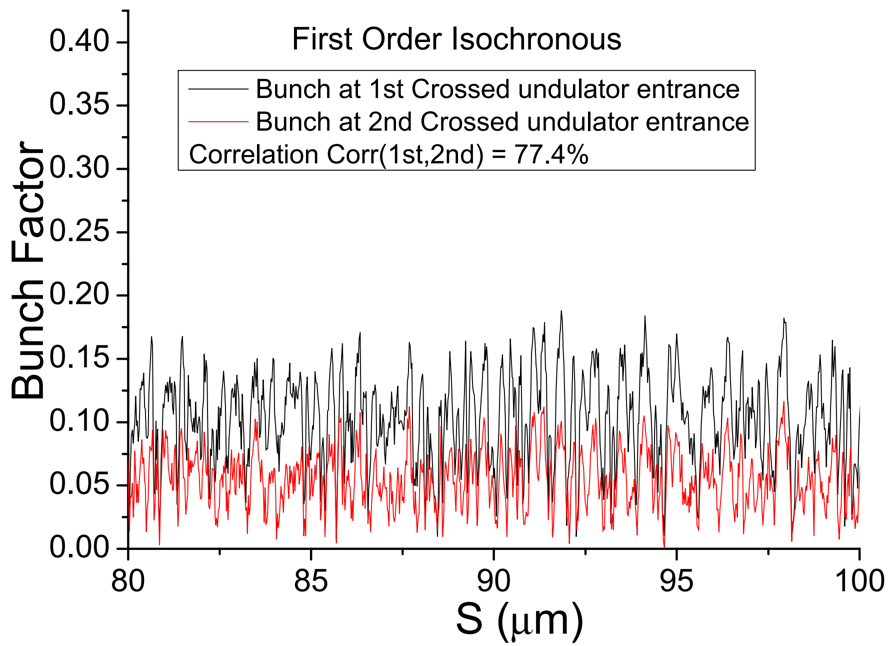
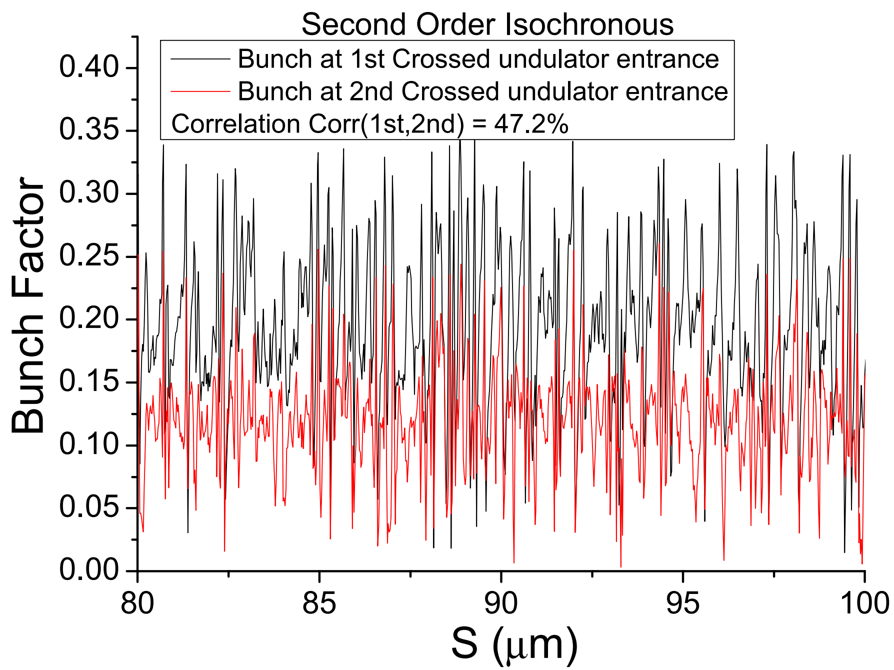
	Length (m)	P (GW)	P_x/P_y	Polarization %	S_3/S_0 %
Ideal cases	3.06 m	3.69	2.068	93.8~92.4	83.4~79.8
First order isochronous	3.40 m	1.16	3.596	85.5~77.9	74.0~65.0
Second order isochronous	3.06 m	1.53	2.297	70.5~62.5	57.6~46.6

- Quite strange that the polarization of Second order isochronous system is worse than the first order isochronous system, Why?

Deflecting section study --- Questions

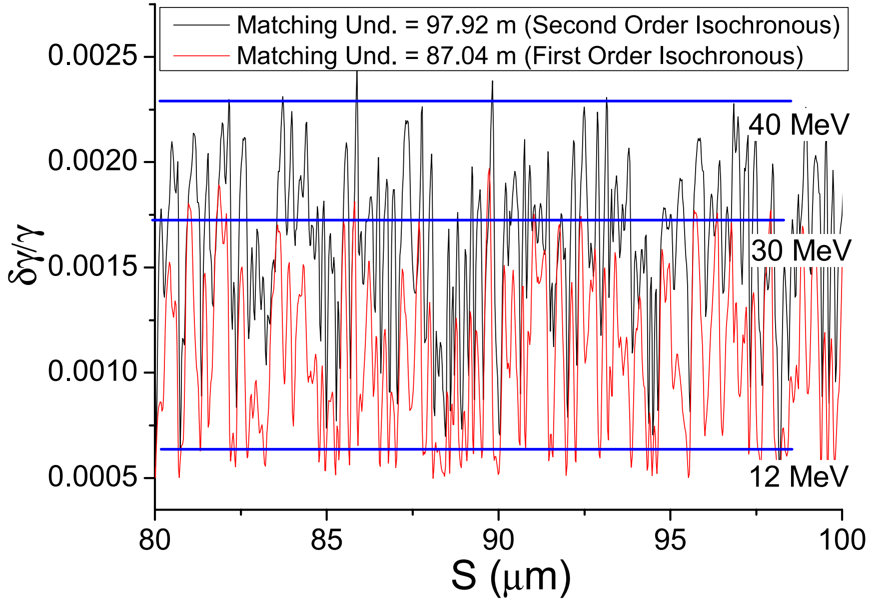




Why the correlation of bunch factor at entrance of 1st and 2nd crossed undulator for 2nd order isochronous deflecting is smaller?

Deflecting section study --- Questions

Bunch slices shape distortion



The Bunch factor difference between the Maximum and Minimum energy spread is:

12.6% --- First Order Isochronous   47.0% --- Second Order Isochronous

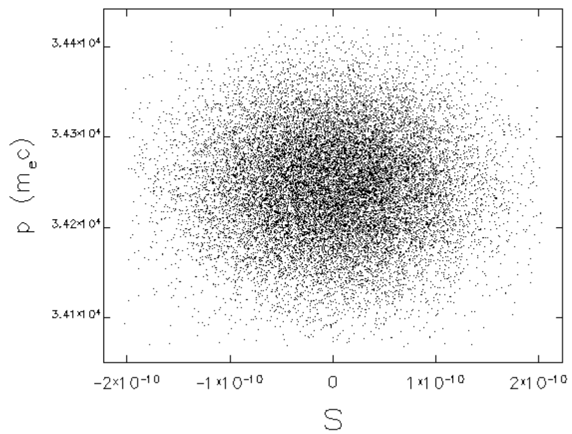
For the Second order isochronous deflecting, distortion is larger

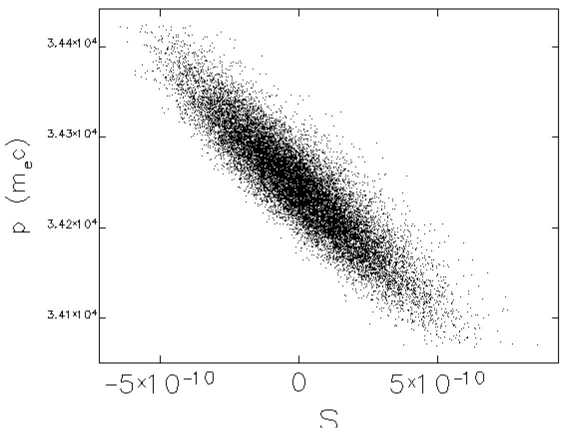
--- Find a smaller R56 for Second order isochronous deflecting

Deflecting section study --- Questions

With the second order isochronous deflecting, the matrix terms R_{5i}, T_{5ij} can be optimized to zero:

R5: -6.13825e-011 6.62404e-015 0.00000e+000 0.00000e+000 1.00000e+000 1.11783e-013
T51: 6.67028e-002
T52: -2.03828e-002 -4.73361e-005
T53: 0.00000e+000 0.00000e+000 3.24998e-002
T54: 0.00000e+000 0.00000e+000 3.45780e-003 1.85512e-005
T55: 0.00000e+000 0.00000e+000 0.00000e+000 0.000000e+000 0.00000e+000
T56: -1.59364e-004 2.43488e-005 0.00000e+000 0.000000e+000 0.00000e+000 1.53949e-006





R_{56} and T_{56j} are very small, why there is still ~1nm expansion?

Sextupoles impact or Elegant does not correctly report the Matrix?

Conclusion

- Second order isochronous deflecting system can best maintain the electron bunching at 0.4nm (higher error tolerance, higher bunch factor, standard beta function in crossed undulators)
- Why the polarization of 2^{nd} isochronous deflecting is worse than the 1^{st} order isochronous?
- Why the elegant reported matrix does not match the simulation result?

Deflecting section study --- Questions

Thanks!