Error correction for the collider Ring

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Content

- Error correction for the high luminosity lattice
- Response and plan for the IARC comments
- Summary and to do list

Beam parameters

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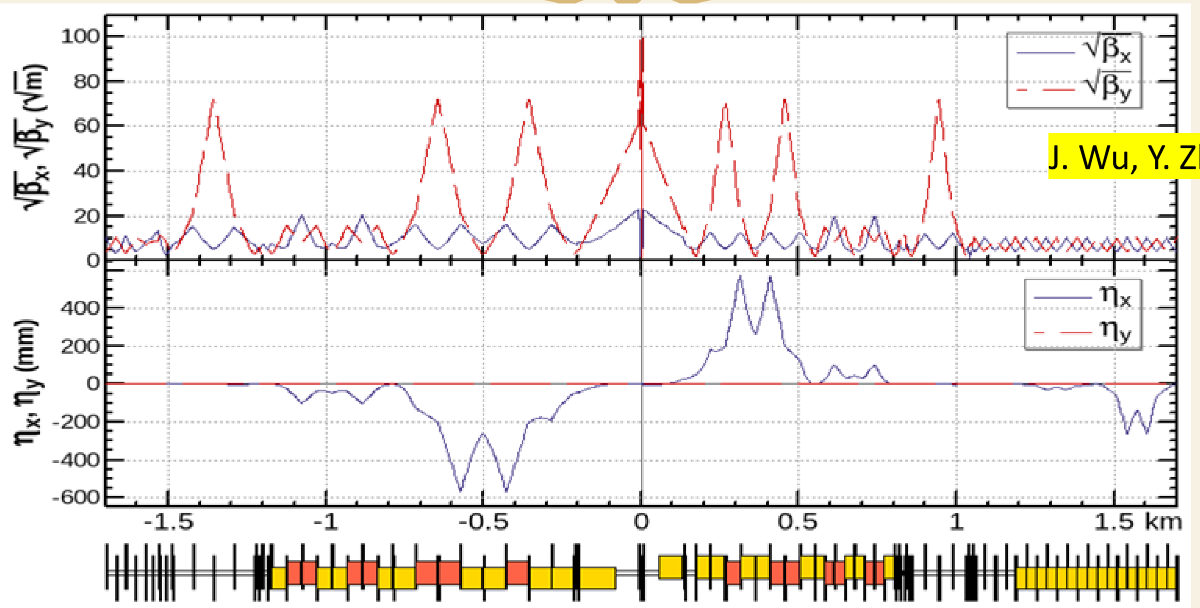
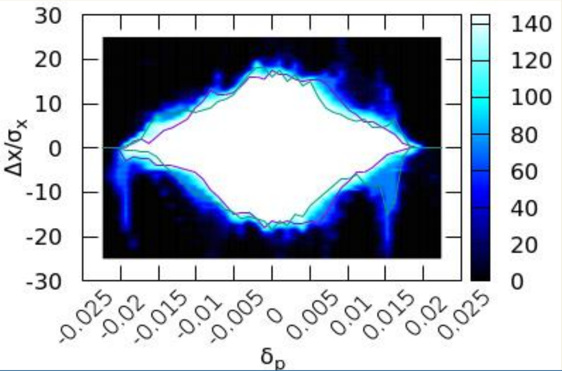
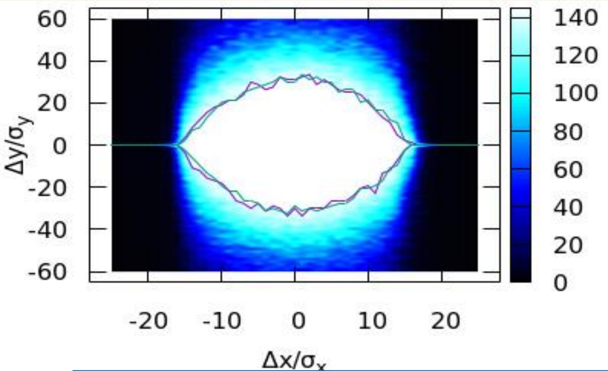
	ttbar	Higgs	W	Z
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	**120**	80	45.5
Energy loss per turn [GeV]	9.1	**1.8**	0.357	0.037
Piwinski angle	1.21	**5.94**	6.08	24.68
Bunch number	35	**249**	1297	11951
Bunch population [10^10]	20	**14**	13.5	14
Beam current [mA]	3.3	**16.7**	84.1	803.5
Momentum compaction [10^-5]	0.71	**0.71**	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	**0.33/1**	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	**0.64/1.3**	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	**15/36**	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	**2.3/3.9**	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	**0.10/0.17**	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	**1.6/2.2**	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	**0.015/0.11**	0.012/0.113	0.004/0.127
RF voltage [GV]	10	**2.2**	0.7	0.12
RF frequency [MHz]	650	**650**	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	**1/0.4/0.2**	-/1.8/0.9	-/-/5.8
Longitudinal tune Qs	0.078	**0.049**	0.062	0.035
Beam lifetime (bhabha/beamstrahlung)[min]	81/23	**39/18**	60/717	80/182202
Beam lifetime [min]	18	**12.3**	55	80
Hour glass Factor	0.89	**0.9**	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	**5.0**	16	115

Lattice and requirements







Achieved (w/o error): $16\sigma_x \times 32\sigma_y \times 1.9\%$

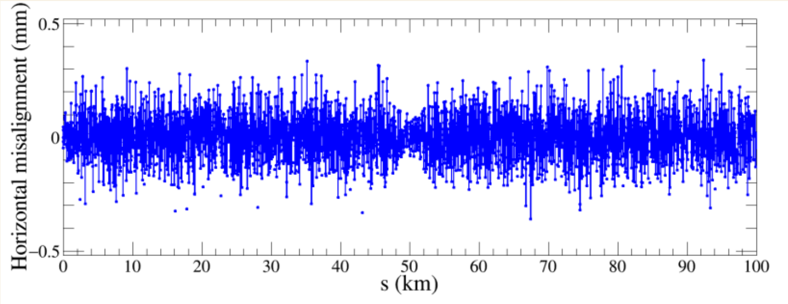
Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.7\%$

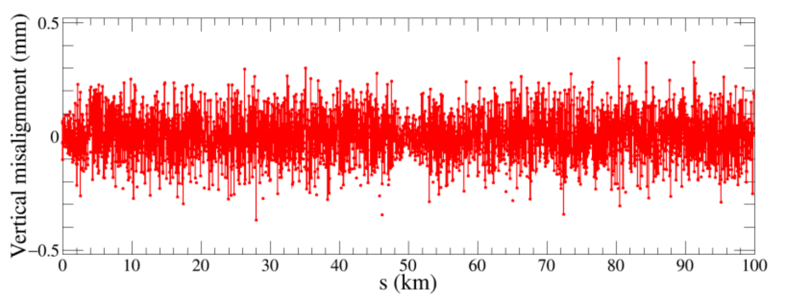
The correction scheme

- Correction steps:
  - Optimize the correction scheme step by step;
  - Optimize the correction scheme by using few lattice seeds (20 ~ 100 seeds);
  - Perform the correction for all 1000 seeds and calculate the passing rate;
  - Repeat above steps for increasing the passing rate.

Errors definition and challenges

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	

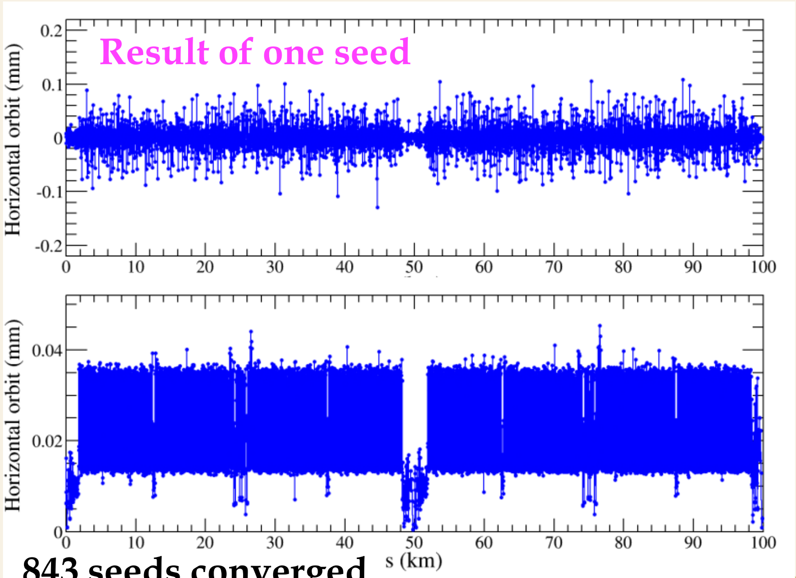




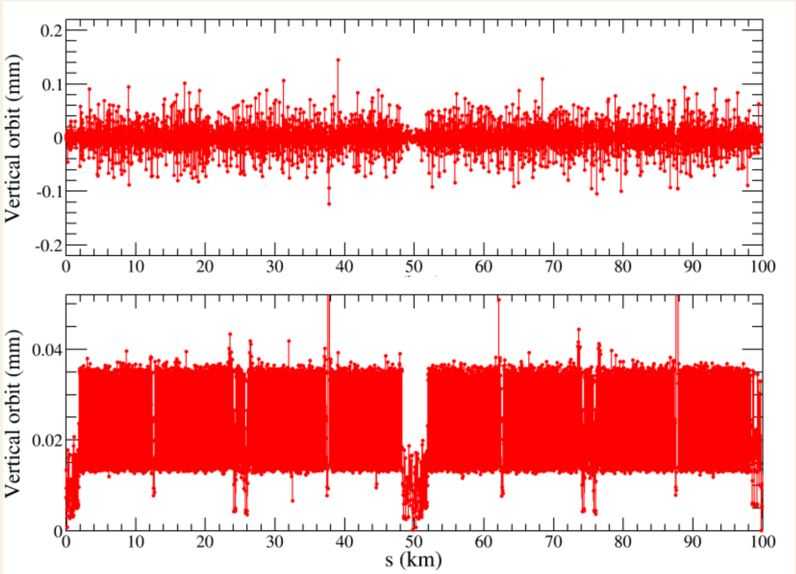
- The high luminosity lattice is much more sensitive to imperfections, the optics correction is very challenging.
- 1000 lattice seeds are generated for further correction.

COD correction

- A new corrector setting is necessary for the more limited lattice.
- BPMs placed at quadrupoles (~1800, 4 per betatron wave) Horizontal correctors placed beside focusing quadrupoles（~1800）
- Vertical correctors placed beside defocusing quadrupoles（~1800）
- Orbit correction is applied using orbit response matrix and SVD method.



843 seeds converged



$RMS_{COD} < 0.05\ mm$

Dispersion correction

Dispersion free steering principle (DFS): $\boldsymbol{\theta}_c$

$$\vec{d} = \begin{pmatrix} (1-\alpha)\vec{u} \\ \alpha\vec{D}_u \end{pmatrix} \quad M = \begin{pmatrix} (1-\alpha)A \\ \alpha B \end{pmatrix} \quad \vec{d} + M\vec{\theta} = 0$$

$\vec{u}$: Orbit vector

$\vec{D}_u$: Dispersion vector

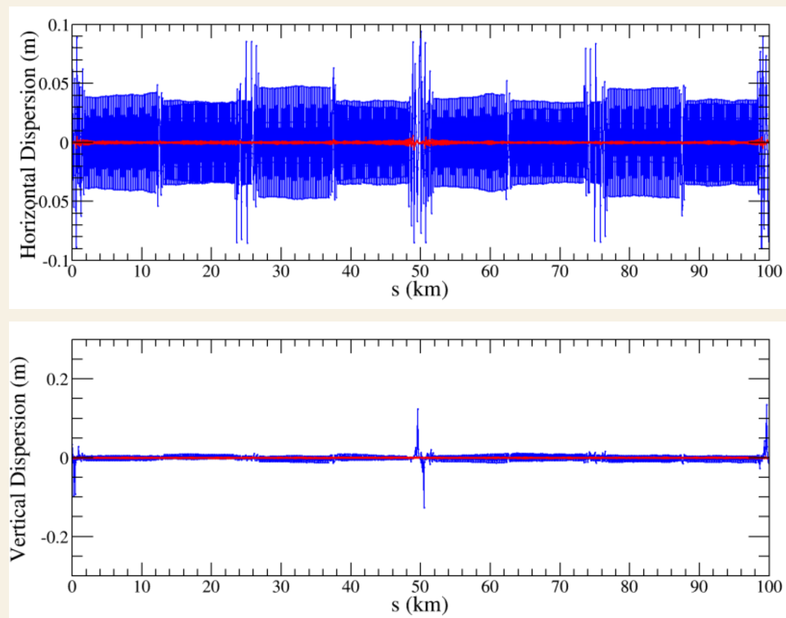
$\vec{\theta}$: Corrector strengths vector

α: Weight factor

A: Orbit response matrix

B: Dispersion response matrix

Result of one seed

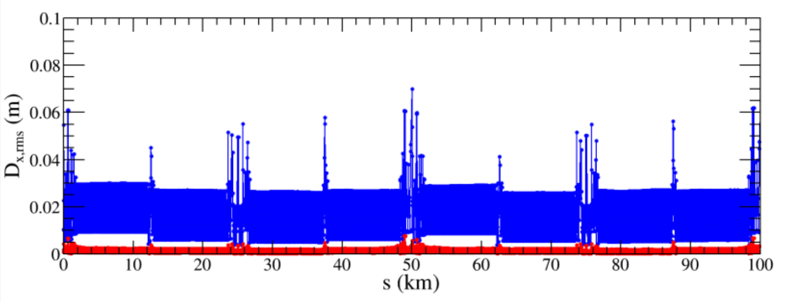


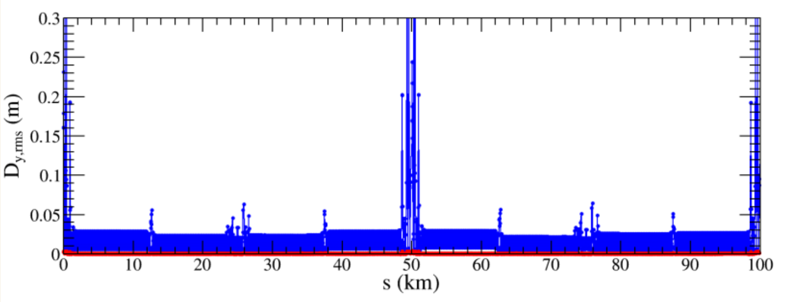
Before DISP correction

After DISP correction

Dispersion correction

674 seeds converged





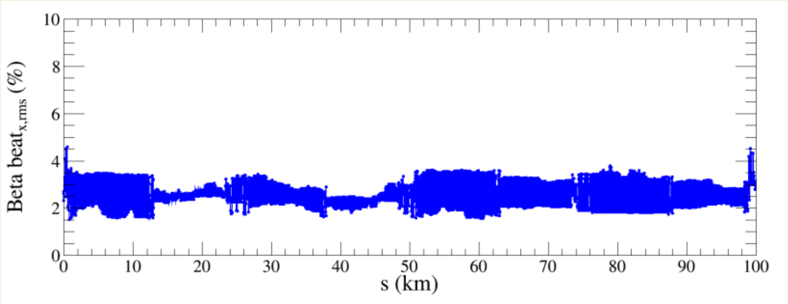
$\Delta D_{x,rms}$ decreased from 15.6mm to 1.3mm
Factor 12 improvement

$\Delta D_{x,rms}$ decreased from 21.9mm to 0.6mm
Factor 36 improvement

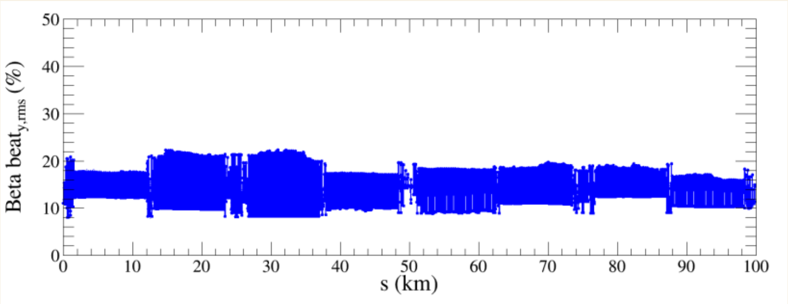
- The dispersion correction is performed for all selected seeds, 753 seeds are converged.
- The correction effect is better than that of CDR lattice.

Beta-beating distribution

Before correction



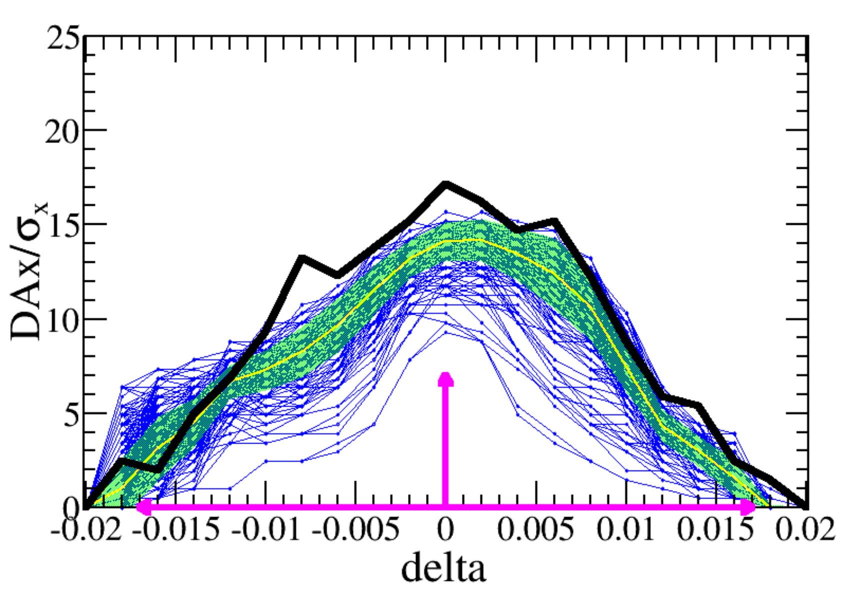
$\Delta\beta/\beta_{x,rms}$ is 2.6% compared with

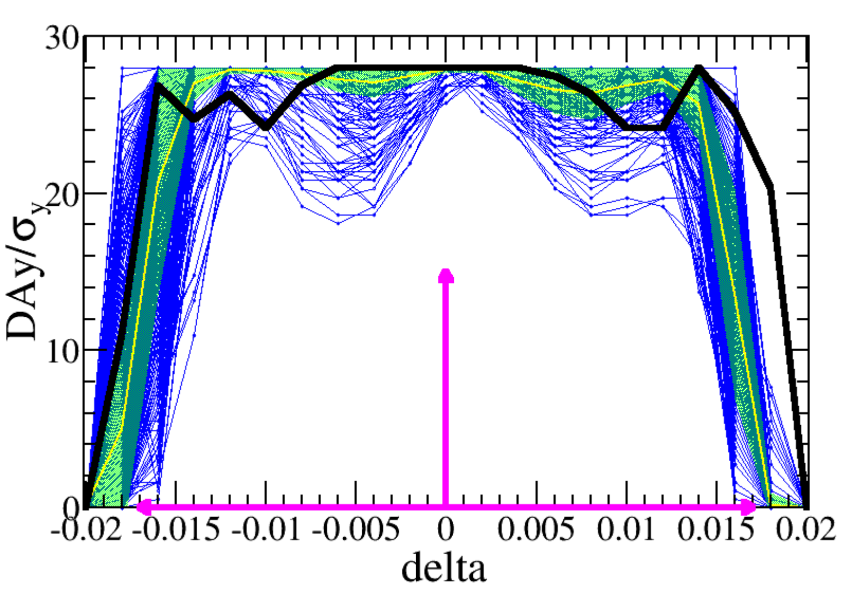


$\Delta\beta/\beta_{x,rms}$ decreased from 11.7% to 5.1%
Factor 2 improvement

- The beta beating before LOCO correction is comparable with results based on CDR lattice.
- Beta beating correction is ongoing.

DA results





- ✓ The blue lines are the DA of each seed, the yellow lines and green bands are the mean value and its corresponding statistics errors, the black line is the DA of bare lattice, and the pink arrows show the DA requirement for on-axis injection, which is $8\sigma_x \times 15\sigma_y$ & 0.017.
- ✓ The DA of 418 error seeds with errors satisfy the on-axis injection requirements.

IARC Comments

- 1. The error-correction procedure could benefit from other tools developed for the vertical emittance correction in synchrotron-light sources, as for example the Machine Learning technique or other iterative methods as done for ESRF. Contact with the SLS community could be beneficial;

[Status and plan] The error correction for each lattice seed takes about 8 hours, the machine learning would obviously speed up this procedure. However, we have thousands of variables which need large training data. Due to the limited computing resource, we have not enough training data. Actually, we also want to add the machine learning in our scheme and have accumulated about four thousand seeds of lattice. Much more data will be generated and corrected for machine learning study.

IARC Comments

- 2. Verify that the stability of the correction procedure complies with the 100-micron misalignment resolution in the IR quadrupoles set by the mechanical-engineering team;

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.10**	**0.10**	**0.10**	
Sextupole	0.10	0.10	0.1	

- 1000 lattice seeds are generated for further correction.

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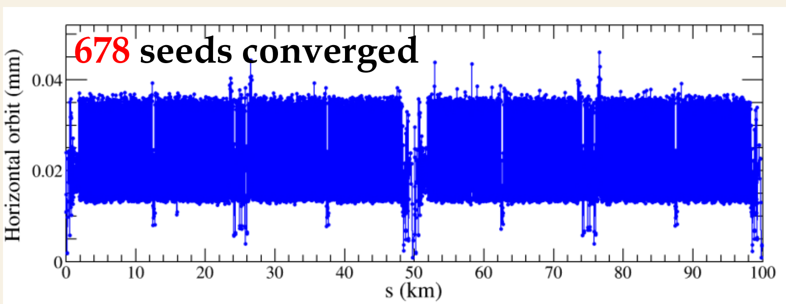
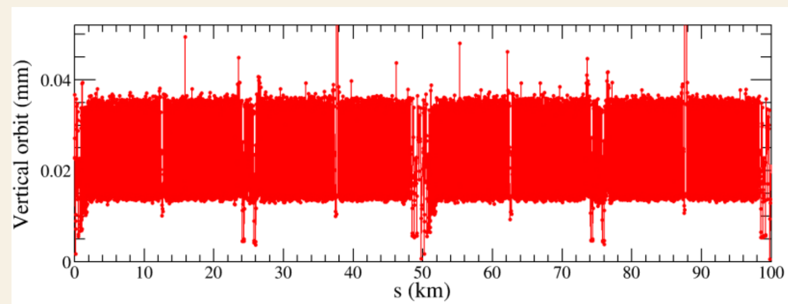
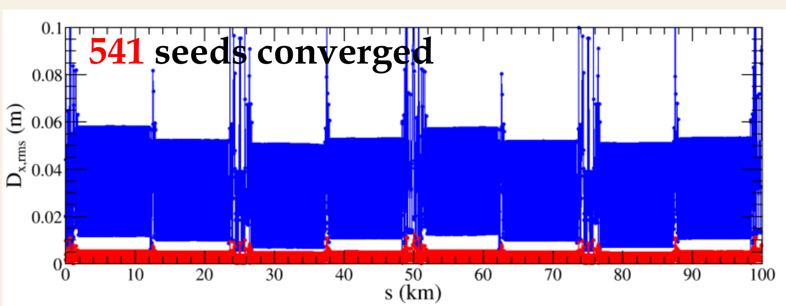
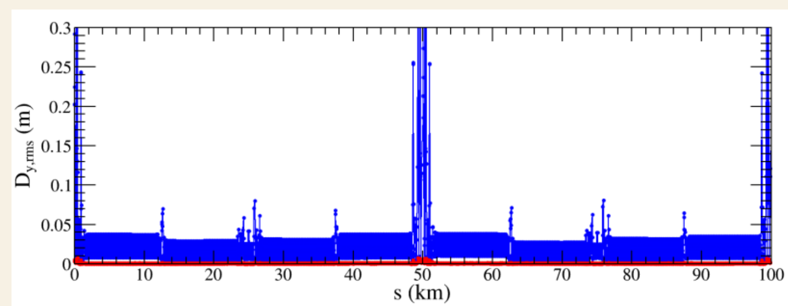






$\Delta D_{x,rms}$ decreased from 28.8mm to 2.7mm
Factor 11 improvement



$\Delta D_{x,rms}$ decreased from 23.5mm to 0.6mm
Factor 39 improvement

IARC Comments

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
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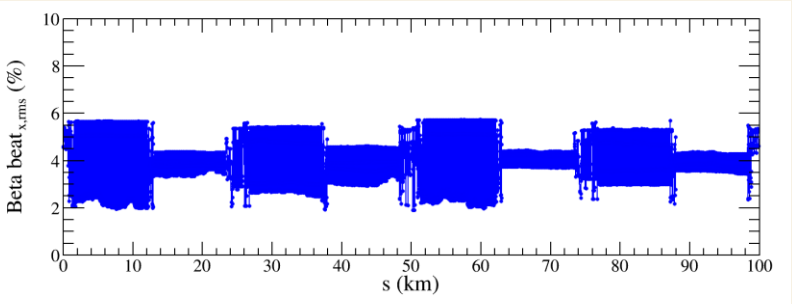
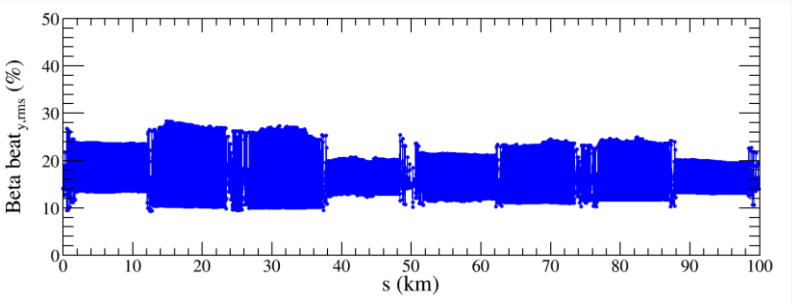
IR Quadrupole	**0.10**	**0.10**	**0.10**	
Sextupole	0.10	0.10	0.1	





- The beta beating before LOCO correction is comparable with results based on CDR lattice.
- DA tracking is ongoing.

IARC Comments

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Arc Quadrupole	0.10	0.10	0.1	0.02%
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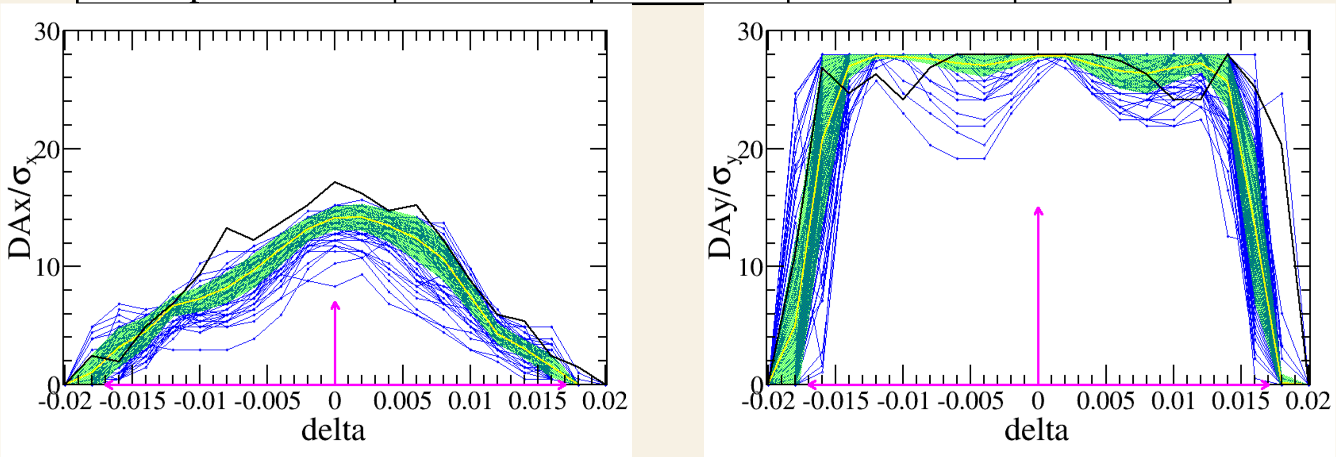
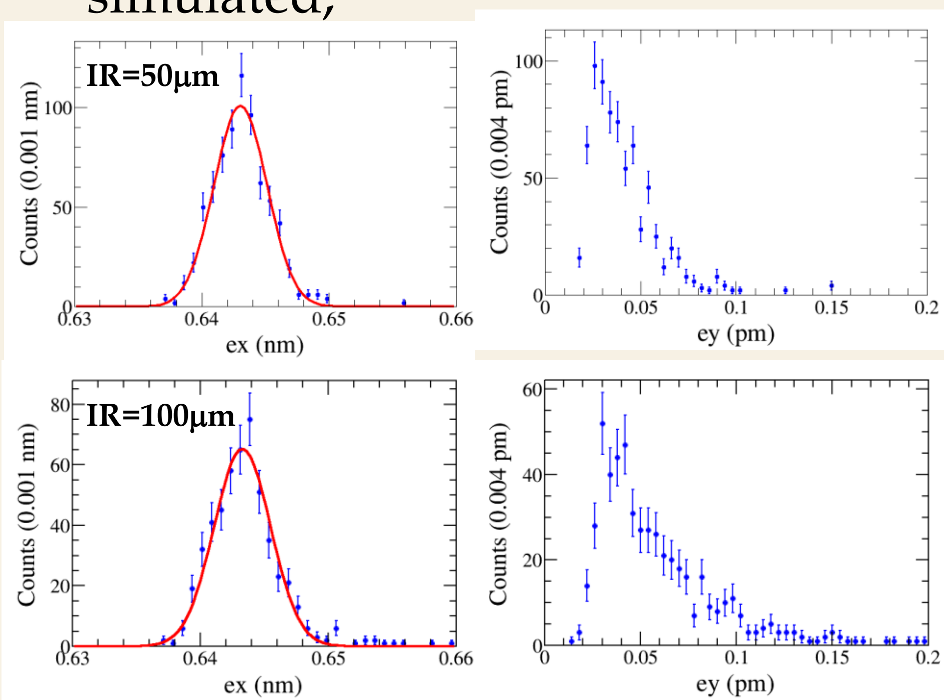
Sextupole	0.10	0.10	0.1	



- We perform the DA tracking for 167 lattice seeds (~1/3 of all seeds after dispersion correction).
- Half of seeds satisfy the on-axis injection requirements.

IARC Comments

- 3. The influence of the errors on the emittance, especially for the vertical one, which is important for the luminosity, should be simulated;



ex = 0.6430±0.0021 nm,
ey = 0.0413± 0.0005 pm
ey/ex = (0.0064± 0.0001)%

ex = 0.6436±0.0026 nm,
ey = 0.0579± 0.0010 pm
ey/ex = (0.0090± 0.0001)%

- The emittance is tuning. The emittance ratios satisfy the injection requirement.

IARC Comments

- 4. Since on-axis injection at all energies would be preferable, further studies on the errors correction, to increase the dynamic aperture at the Higgs, where on-axis injection is preferred, would be needed. A beta-beating correction scheme should be developed and implemented, which will improve the DA.

We are focus on the Beta beating correction.

Summary

- The imperfection correction for the high luminosity lattice is on going.
- The DA of 418 lattice seeds with **IR=50mm** and 84 (~1/3) lattice seeds with **IR=100mm** satisfy the on-axis injection requirements.
- Part of comments from IARC are replied.
- Focusing the beta beating correction to improve the correction results.