# CEPC collider ring orbit corrections

Bin Wang (on the behalf of the CEPC error correction team)
Institute of High Energy Physics

11.08
2021

THE 2021 INTERNATIONAL WORKSHOP ON THE HIGH ENERGY CIRCULAR ELECTRON-POSITRON COLLIDER (CEPC)

# Content

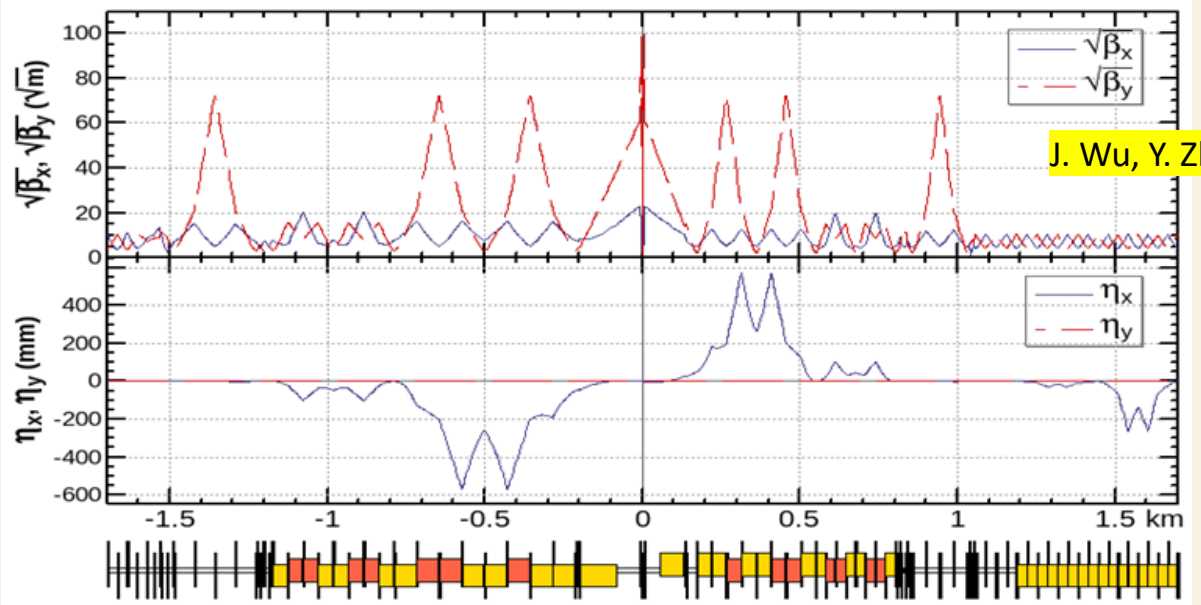
- Introduction of the high luminosity
- The correction scheme
- The correction results
- Summary and to do list

# Beam parameters

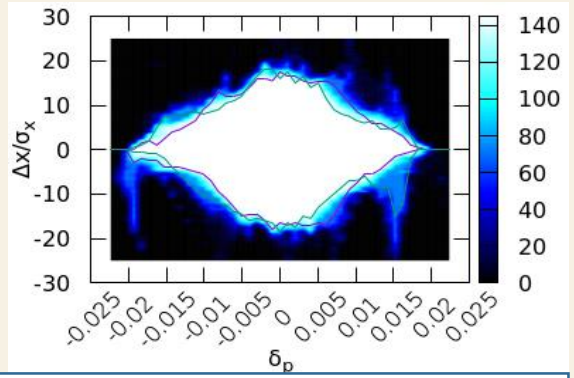
Y. W. Wang, D. Wang, Y. Zhang, J. Y. zhai et al

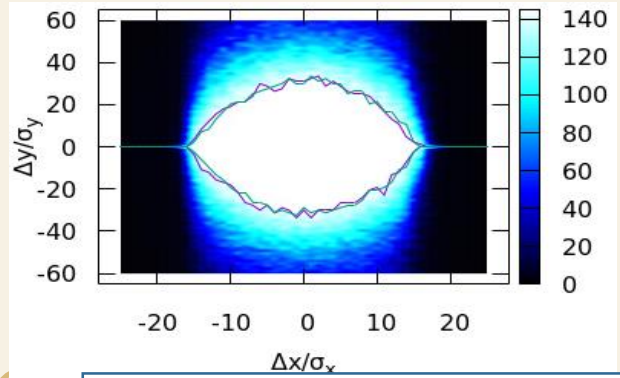
| | ttbar | Higgs | W | Z |
|---|---|---|---|---|
| Number of IPs | 2 | | | |
| Circumference [km] | 100.0 | | | |
| SR power per beam [MW] | 30 | | | |
| Half crossing angle at IP [mrad] | 16.5 | | | |
| Bending radius [km] | 10.7 | | | |
| Energy [GeV] | 180 | **120** | 80 | 45.5 |
| Energy loss per 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




J. Wu, Y. Zhang, Y. W. Wang




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



Goal (w/ error): $7\sigma_x \times 15\sigma_y \times 1.7\%$

# The correction scheme

- Software: SAD and AT
- COD correction with **sextupoles off**
- **Turn on the sextupoles** and perform COD correction again.
- Dispersion correction (DFS)
- Beta beating correction (LOCO)
- Coupling and vertical dispersion correction (Local coupling parameter correction）

# 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 | |

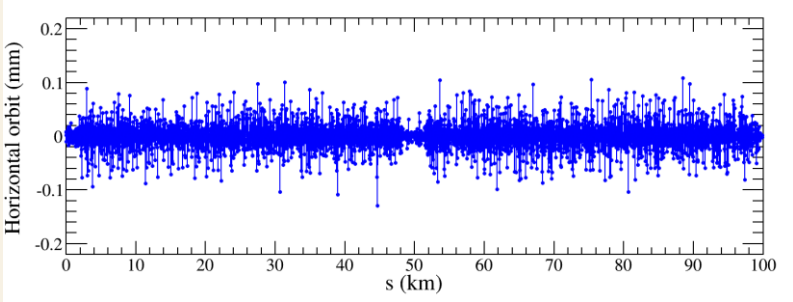
| Component | Δx (mm) | Δy (mm) | $\Delta\theta_z$ (mrad) | Field error |
|---|---|---|---|---|
| Dipole | 0.10 | 0.10 | 0.1 | 0.01% |
| Arc Quadrupole | 0.10 | 0.10 | 0.1 | 0.02% |
| **IR Quadrupole** | **0.10** | **0.10** | **0.10** | |
| Sextupole | 0.10 | 0.10 | 0.1 | |

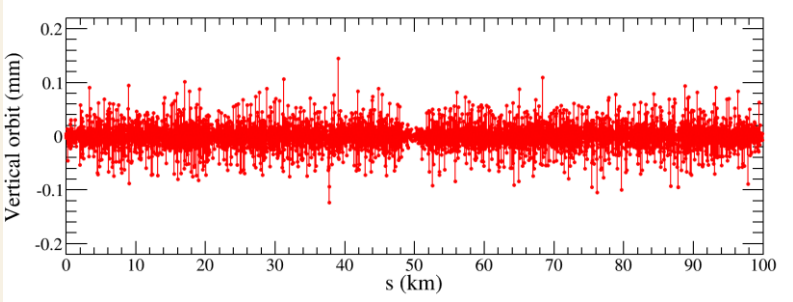
- The high luminosity lattice is much more sensitive to imperfections, the optics correction is very challenging.
- 1000 lattice seeds are generated for further correction.
- We study the error corrections for these two error cases.

# 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.

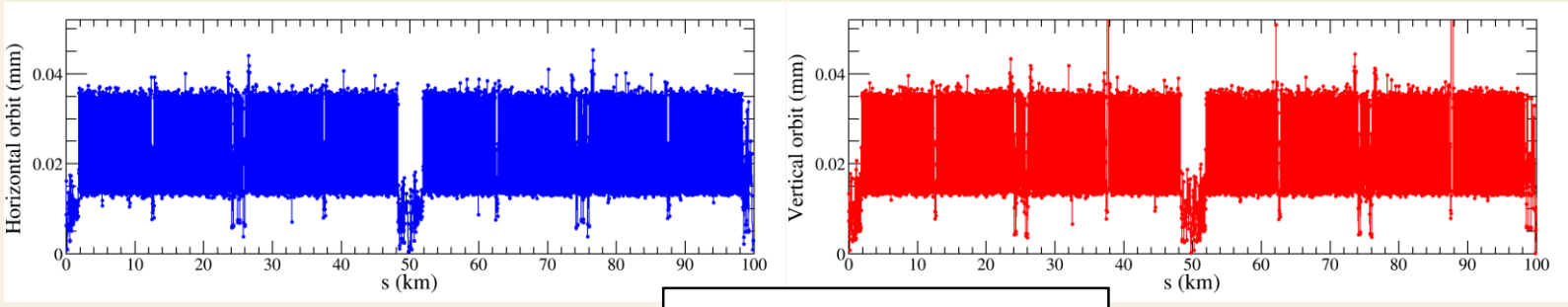
Result of one seed



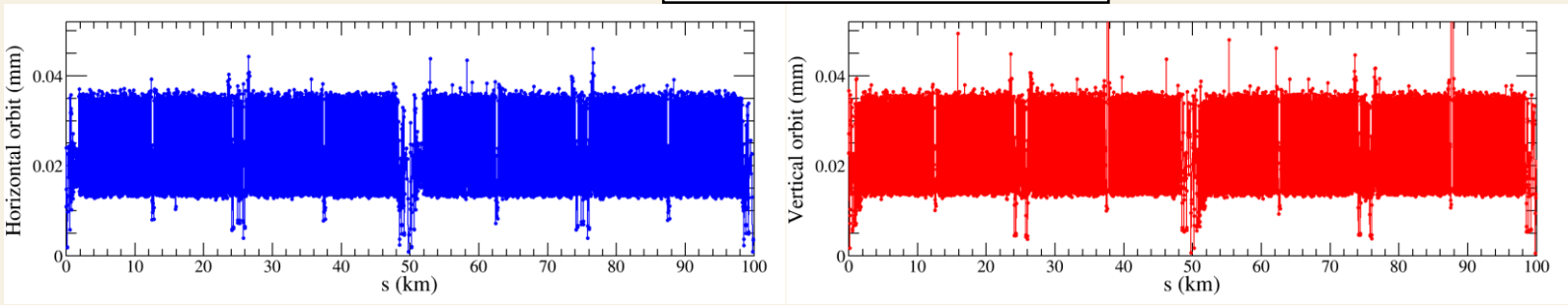
# COD correction

IR=50μm **843 seeds converged**




$RMS_{COD} < 0.05\ mm$

IR=100μm **678 seeds converged**




- The COD correction is performed for all selected seeds;
- The correction effect for this two cases are comparable with those of CDR lattice.

# Dispersion correction

**Dispersion free steering principle (DFS): $\theta_c$**

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

$\vec{u}$: Orbit vector

$\vec{D}_u$ : Dispersion vector

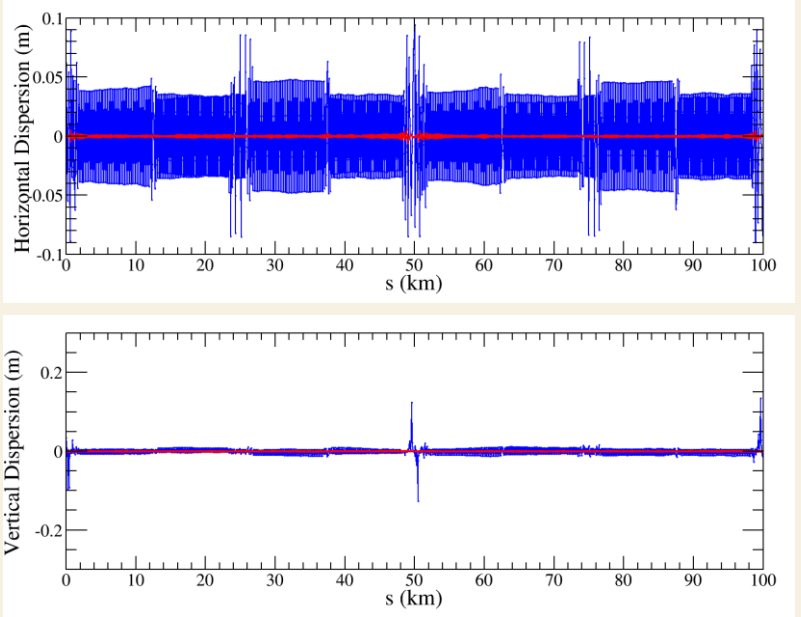
$\vec{\theta}$: Corrector strengths vector

$\alpha$: Weight factor

$A$: Orbit response matrix

$B$: Dispersion response matrix

Result of one seed

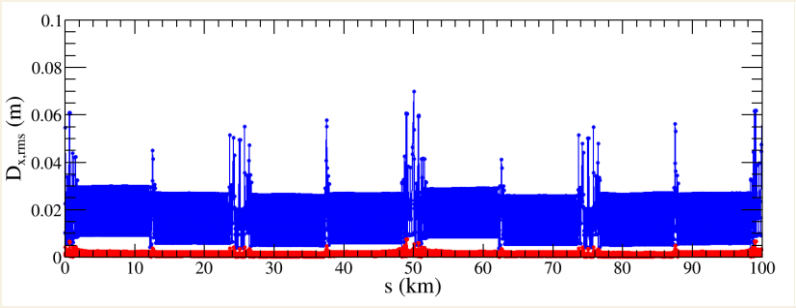



Before DISP correction

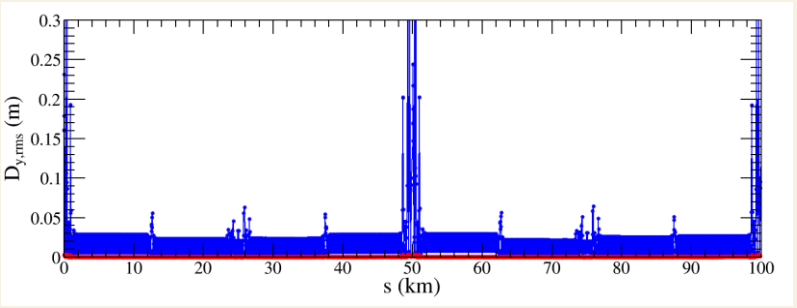
After DISP correction

# Dispersion correction

IR=50μm 674 seeds converged




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

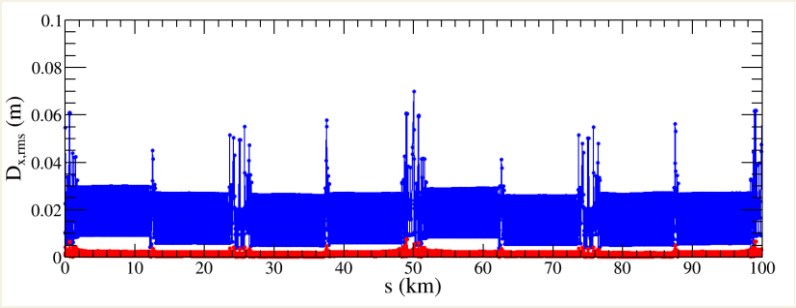



$\Delta D_{x,rms}$ decreased from 21.9mm to 0.6mm
Factor 36 improvement

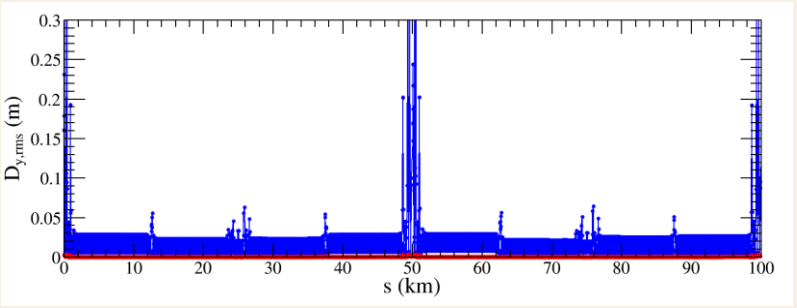
- The dispersion correction is performed for all selected seeds, 753 seeds are converged.
- The correction effect is better than that of CDR lattice.

# Dispersion correction

IR=50μm 674 seeds converged

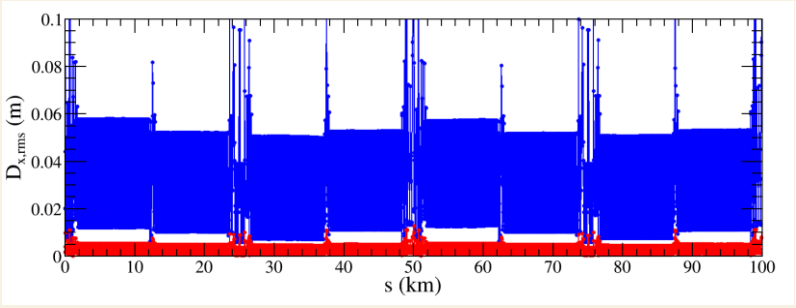



$\Delta D_{x,rms}$ decreased from 15.6mm to 1.3mm
Factor 12 improvement

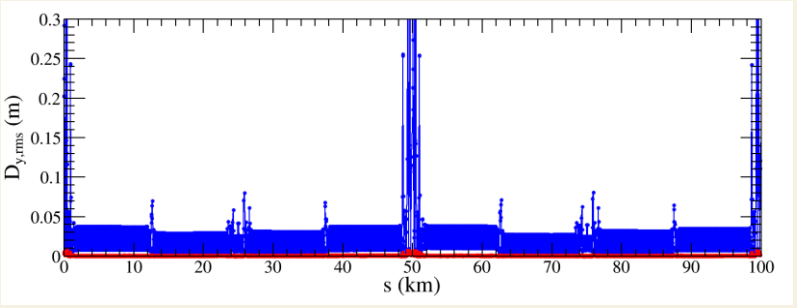



$\Delta D_{x,rms}$ decreased from 21.9mm to 0.6mm
Factor 36 improvement

IR=100μm 541 seeds converged




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

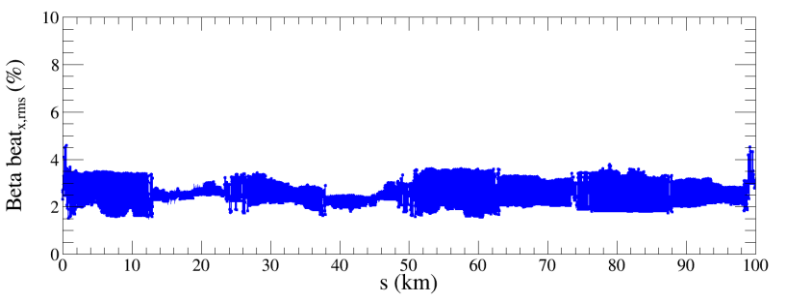


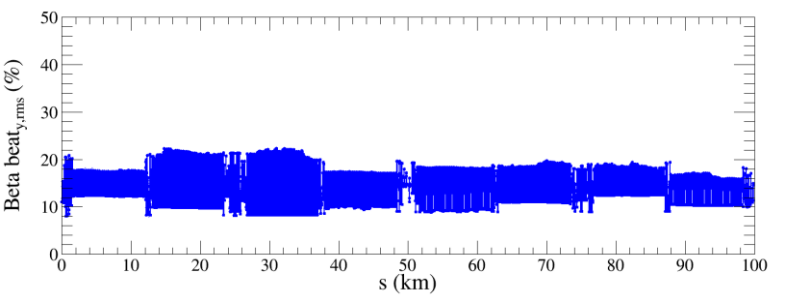

$\Delta D_{x,rms}$ decreased from 23.5mm to 0.6mm
Factor 39 improvement

# Beta-beating distribution

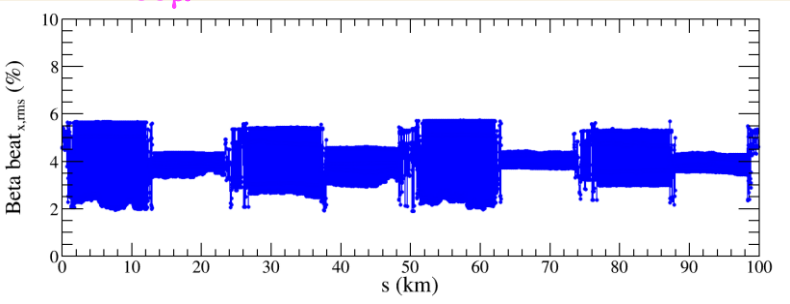
IR=50μm

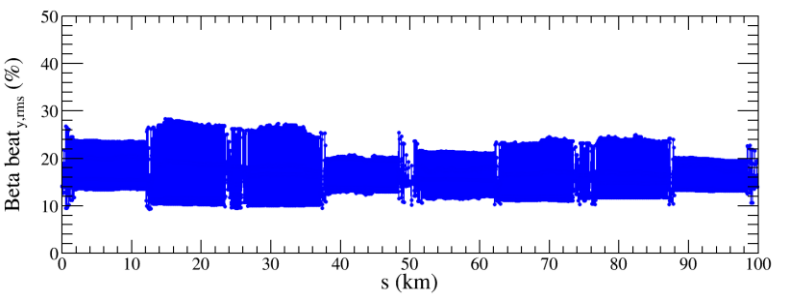
Before correction




IR=100μm

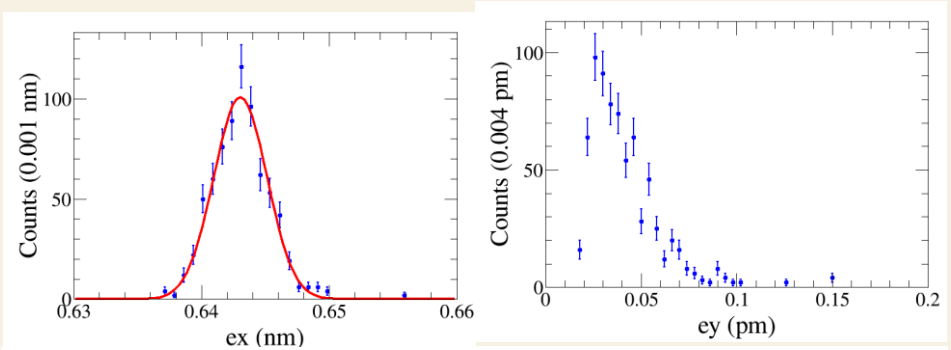



- The beta beating before LOCO correction is comparable with results based on CDR lattice.
- Beta beating correction is ongoing.

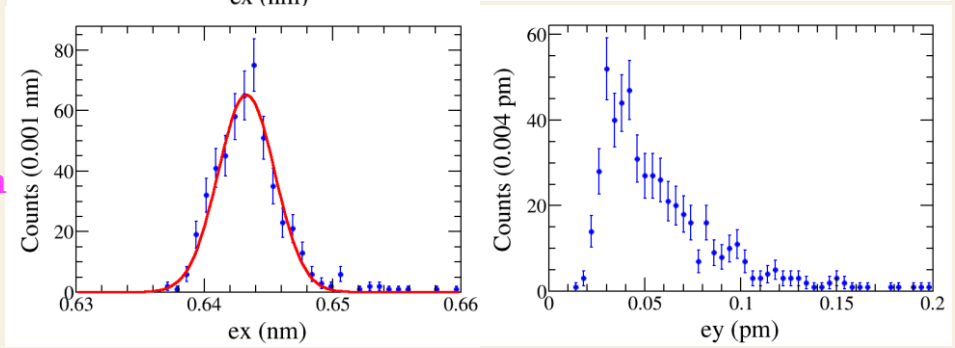
# Results of emittance tuning

IR=50μm




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

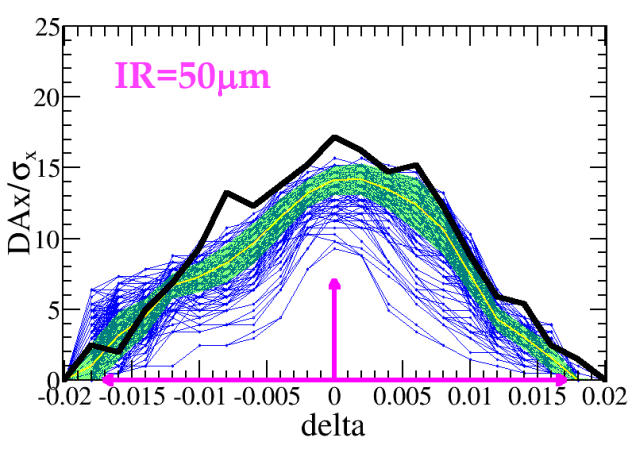
IR=100μm

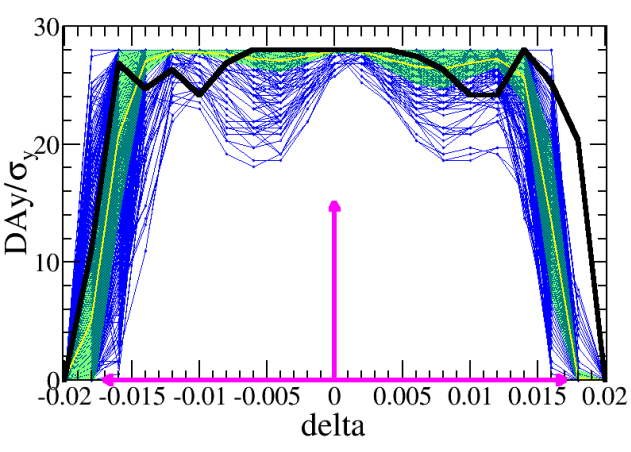



ex = 0.6436±0.0026 nm,
ey = 0.0579± 0.0010 pm
ey/ex = (0.0090± 0.0001)%

Emittance tuning results are comparable with those based on CDR lattice.

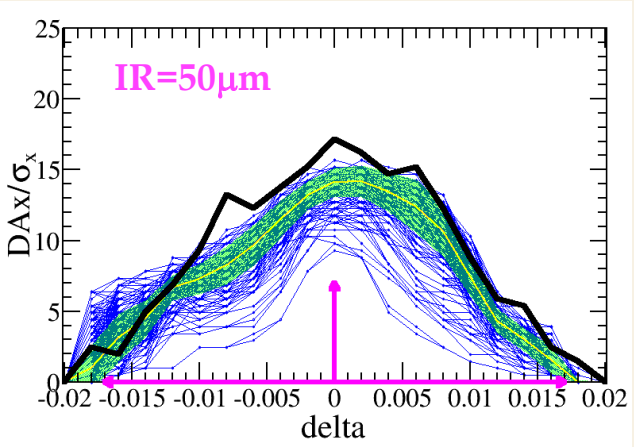
# DA results

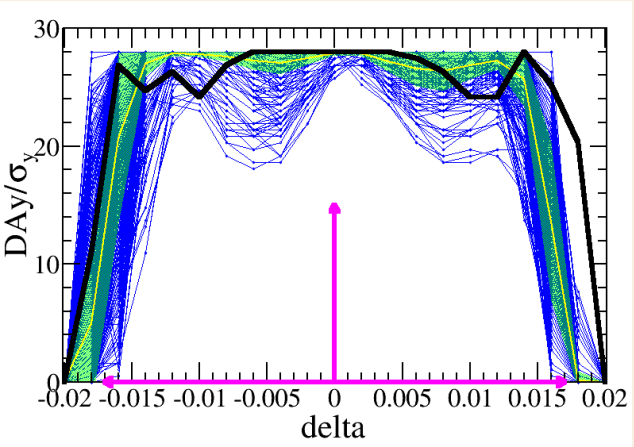


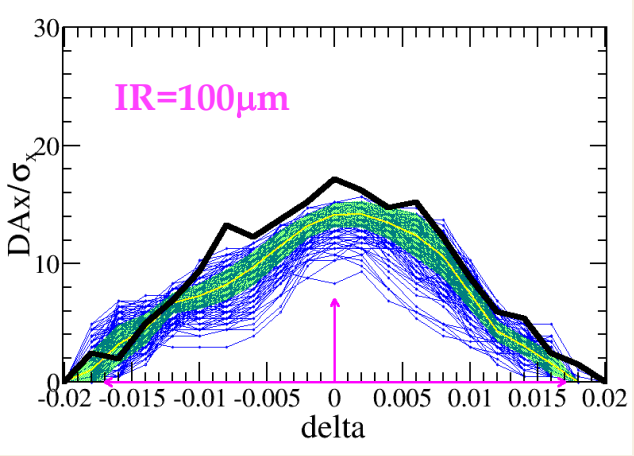



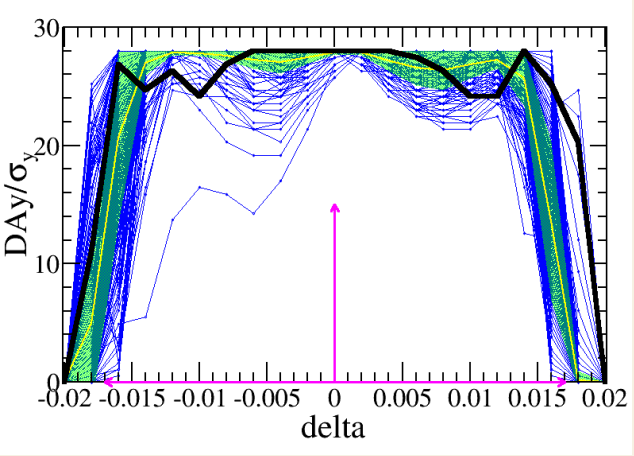

- ✓ The blue lines are the DA of each seed, the yellow lines and green bands are the mean value and its corresponding statistics errors, the black line is the DA of bare lattice, and the pink arrows show the DA requirement for on-axis injection, which is $7\sigma_x \times 15\sigma_y$ & 0.017.
- ✓ The DA of 418 error seeds with errors satisfy the on-axis injection requirements.

# DA results




✓ The DA of 270 error seeds with errors (IR=100μm) satisfy the on-axis injection requirements.

# Summary and to do list

- The imperfection correction for the high luminosity lattice is on going.
- The DA of 418 lattice seeds with **IR=50μm** and 270 lattice seeds with **IR=100μm** satisfy the on-axis injection requirements.

- Optimize the correction strategy to achieve finer tuning of optics.
- Include more types of imperfections.

# Thank you for your attention

E-mail:
wangbin@ihep.ac.cn