Institute of High Energy Physics
Chinese Academy of Sciences

CEPC Circular Electron Positron Collider

# Status of CEPC and SPPC collider ring lattice

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# Outline

- Status of lattice design for CEPC collider ring
  - Lattice design for a higher luminosity
  - Dynamic aperture optimization
  - Correction of magnet errors
- Status of lattice design for SPPC collider ring
- Summary

# Lattice design for a higher luminosity

| | *Higgs (CDR)* | *Higgs (high)* | |
|---|---|---|---|
| Number of IPs | 2 | 2 | |
| Beam energy (GeV) | 120 | 120 | |
| Circumference (km) | 100 | 100 | |
| Synchrotron radiation loss/turn (GeV) | 1.73 | 1.68 | The filling factor of bends should be increased to get a even lower SR with smaller emiitance. |
| Crossing angle at IP (mrad) | 16.5×2 | 16.5×2 | |
| Piwinski angle | 3.48 | 3.78 | |
| Number of particles/bunch $N_e$ ($10^{10}$) | 15.0 | 17.0 | single bunch charge increased thus larger momentum acceptance required |
| Bunch number (bunch spacing) | 242 (0.68μs) | 218 (0.76μs) | |
| Beam current (mA) | 17.4 | 17.8 | |
| Synchrotron radiation power /beam (MW) | 30 | 30 | |
| Bending radius (km) | 10.7 | 10.7 | |
| Momentum compact ($10^{-5}$) | 1.11 | 0.91 | |
| β function at IP $\beta_x^*$ / $\beta_y^*$ (m) | 0.36/0.0015 | 0.33/0.001 | much larger natural chromaticity |
| Emittance $\varepsilon_x/\varepsilon_y$ (nm) | 1.21/0.0024 | 0.89/0.0018 | |
| Beam size at IP $\sigma_x/\sigma_y$ (μm) | 20.9/0.06 | 17.1/0.042 | |
| Beam-beam parameters $\xi_x/\xi_y$ | 0.018/0.109 | 0.024/0.113 | |
| RF voltage $V_{RF}$ (GV) | 2.17 | 2.4 | |
| RF frequency $f_{RF}$ (MHz) (harmonic) | 650 (216816) | 650 (216816) | |
| Natural bunch length $\sigma_z$ (mm) | 2.72 | 2.2 | |
| Bunch length $\sigma_z$ (mm) | 4.4 | 3.93 | |
| HOM power/cavity (2 cell) (kw) | 0.46 | 0.58 | |
| Energy spread (%) | 0.134 | 0.19 | |
| Energy acceptance requirement (%) | 1.35 | 1.7 | larger momentum acceptance required |
| Energy acceptance by RF (%) | 2.06 | 3.0 | |
| Photon number due to beamstrahlung | 0.082 | 0.104 | |
| Beamstruhlung lifetime /quantum lifetime* (min) | 80/80 | 30/50 | |
| Lifetime (hour) | 0.43 | 0.22 | |
| *F* (hour glass) | 0.89 | 0.85 | |
| Luminosity/IP $L$ ($10^{34}cm^{-2}s^{-1}$) | 2.93 | 5.2 | |

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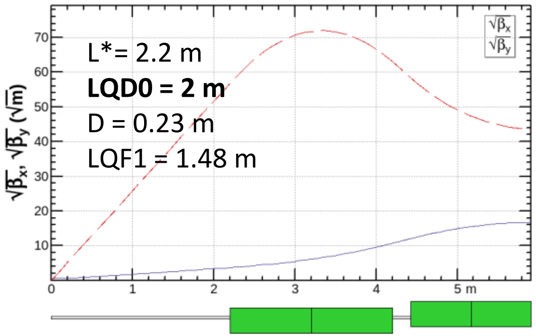
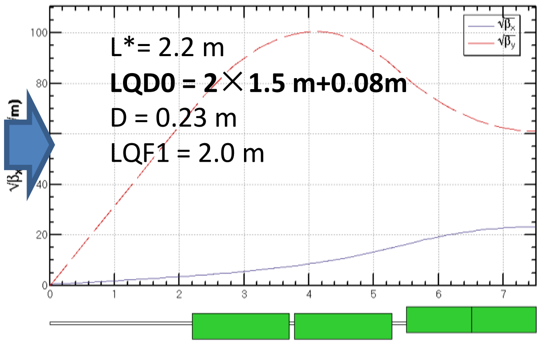
# Lattice design with luminosity of $5.2 \times 10^{34}/\mathrm{cm}^2/s$

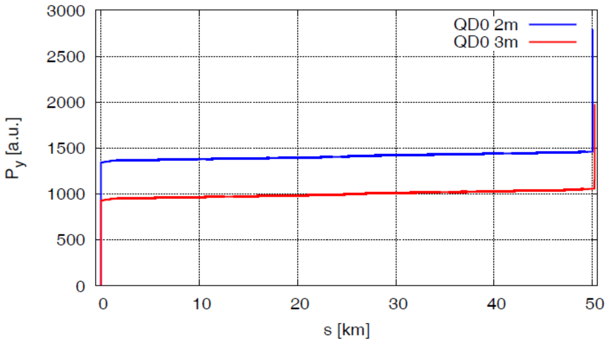
- Fit parameter list with luminosity of $5.2 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
  - Stronger optimization and stricter hardware requirement should be made to get enough dynamic aperture
- Optimization of the quadrupole radiation effect
  - Interaction region: longer QD0/QF1 (2m/1.48m => 3m/2m)
  - ARC region: longer quadrupoles (2m => 3m )
- Reduction of dynamic aperture requirement from injection
  - Straight section region: larger $\beta$x at injection point (600m => 1800m)
- Maximization of bend filling factor to minimize the synchrotron radiation loss per turn
  - ARC region: sextupoles in two rings changed from staggered to parallel; The left drifts are used for longer bend.
  - RF region: shorter phase tuning sections

# Optimization of the quadrupole radiation effect

- The dynamic aperture reduction due to the damping and fluctuation is significant especially on the vertical plane.
- Radiation power due to quadrupoles: $P \propto \int B^2 ds \propto \int K_1^2 \beta ds \cong \sum (K_1 l)^2 \beta / l$
  - contribution of QD0 dominant
  - longer QD0 will significantly decreased the power on vertical plane and thus help to increase the dynamic aperture: QD0/QF1 2m/1.48m => 3m/2m
  - longer ARC quadrupoles: 2m => 3m
  - **With longer QD0, the vertical dynamic aperture increased around 30%**

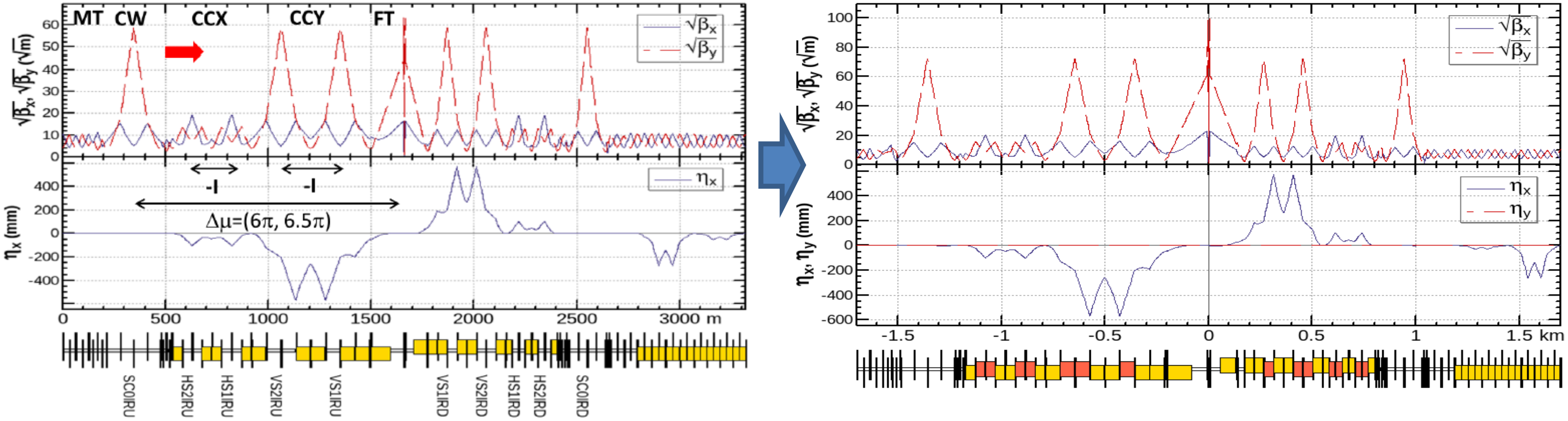


# Optics design of Interaction region

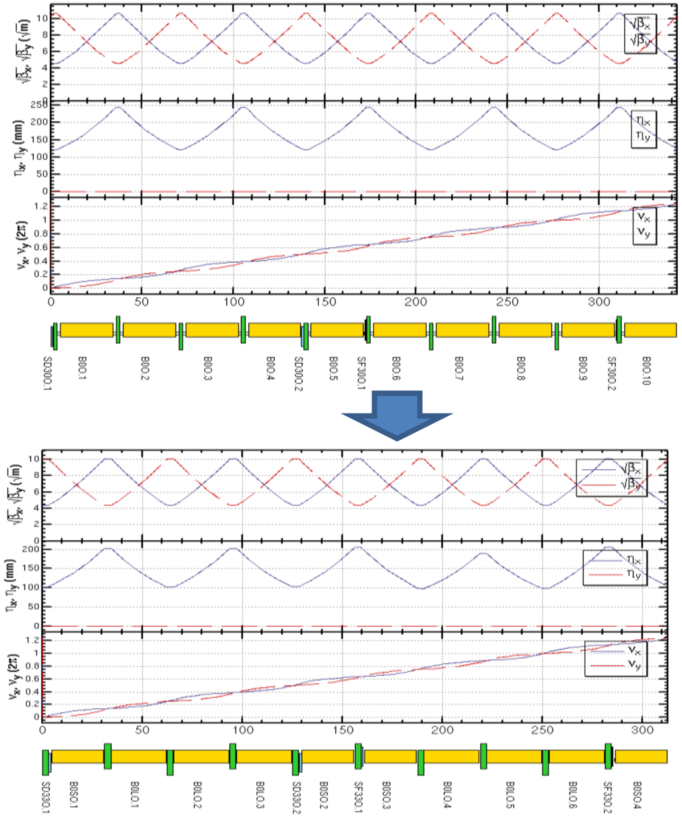
- local chromaticity correction of both plane, asymmetric layout 1), crab-waist collision 2)
- $L^*$=2.2m, $\theta_C$ =33mrad, **$G_{QD0}$ =77 T/m, $G_{QF1}$ =63 T/m, $L_{QD0}$ =3.0m, $L_{QF1}$ =2.0m**
- IP upstream of IR: Ec < 120 keV within 400m, last bend Ec = 25.5keV (45 keV CDR)
- IP downstream of IR: Ec < 300 keV within 250m, last bend Ec = 36.6keV (97 keV CDR)





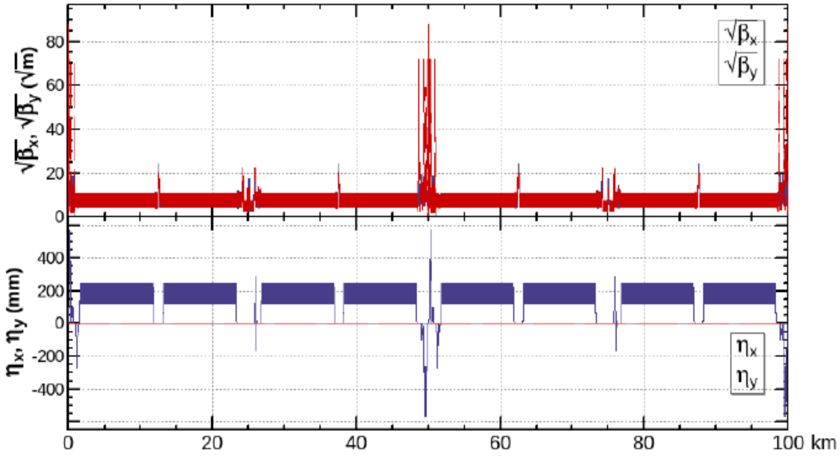
1) K. Oide et al., ICHEP16.
2) M. Zobov et al., Phys. Rev. Lett. 104, 174801(2010).

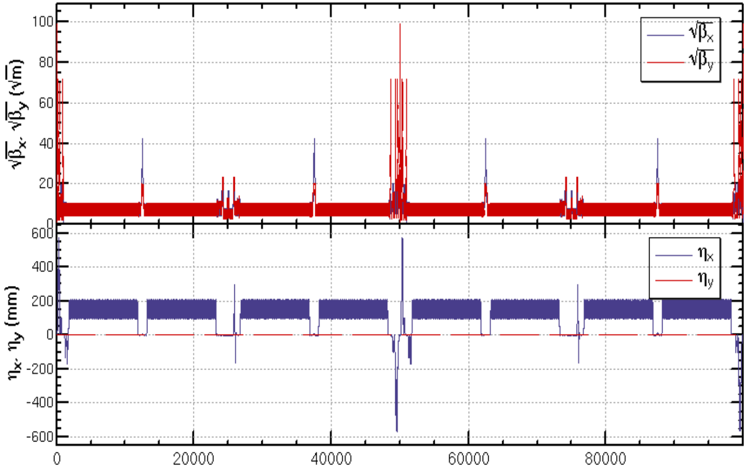
# Maximization of the bend filling factor in the ARC



| | CDR lattice | High lum. lattice |
|---|---|---|
| Emittance [nm] | **1.21** | **0.89** |
| Period length [m] | 342.9 | 312.8 |
| Drift length<br>In one period [m] | 31.8 | 10.2 |
| Dipole length<br>In one period [m] | 286.9 | 268.4 |
| Quadrupole length<br>In one period [m] | 20 | 30 |
| Sextupole length<br>In one period [m] | 4.2 | 4.2 |
| Dipole filling factor [%] | 83.7 | 85.8 |
| Quadrupole filling factor [%] | 5.8 | 9.6 |

# Optics of the whole collider ring



# Dynamic aperture optimization

# Optimization of dynamic aperture

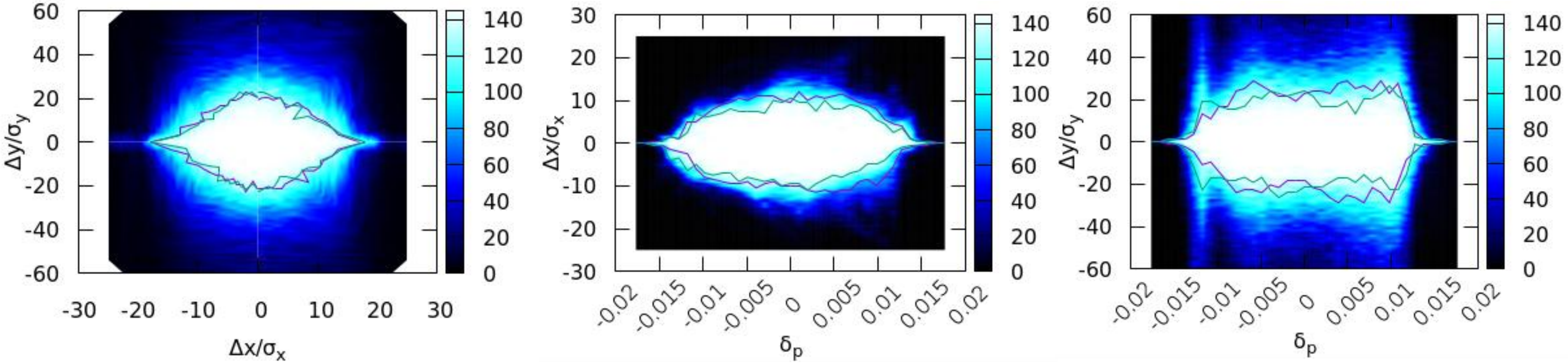
- Start point of the optimization
  - **Nonlinearity optimized term by term** with 10 families of sextupoles in the IR and 4 families of sextupoles in the ARC.
- **Dynamic aperture further optimized with MODE**
  - Higgs dynamic aperture with 90% survival of 100 samples
  - **Including radiation damping, fluctuation, energy sawtooth and tapering, beam-beam effects, w/o error**
  - 145 turns (2 damping times), 4 initial phases

# Different versions of lattice

- To make sure the effect of changement, different versions were studied
  - V1, bx*=0.36m, **by*=0.001m,** ex=1.1nm rad: $15\sigma_x$*$18\sigma_y$*1.5%
  - V2, **bx*=0.33m**, by*=0.001m, **ex=0.89nm rad**: $17\sigma_x$*$22\sigma_y$*1.5% (benefit from smaller nonlinearity in IR and smaller beam size)
  - V3, bx*=0.33m, by*=0.001m, ex=0.89nm rad, **shorten the RF region** (to increase the bend filling faction): $18\sigma_x$*$21\sigma_y$*1.5%
  - V4, bx*=0.33m, by*=0.001m, ex=0.89nm rad, shorten the RF region, **add octupole and decapole for vertical chromaticity correction**: $18\sigma_x$*$21\sigma_y$*1.5%
  - V5, bx*=0.33m, by*=0.001m, ex=0.89nm rad, shorten the RF region, add octupole and decapole for vertical chromaticity correction, **add multipoles for horizontal chromaticity correction** : $11\sigma_x$*$21\sigma_y$*1.3%

# Status of DA optimization

- V4: bx*=0.33m, by*=0.001m, ex=0.89nm rad, shorten the RF region, add octupole and decapole for vertical chromaticity correction
- 145 turns tracked, 100 samples for radiation fluctuation, IR sextupoles + 32 arc sextupoles
- With beam-beam and SR radiation damping and fluctuation, without errors
- The on-momentum DA should be large enough even with errors.
- The momentum acceptance need to be further optimized to fulfill the requirement 1.7 %

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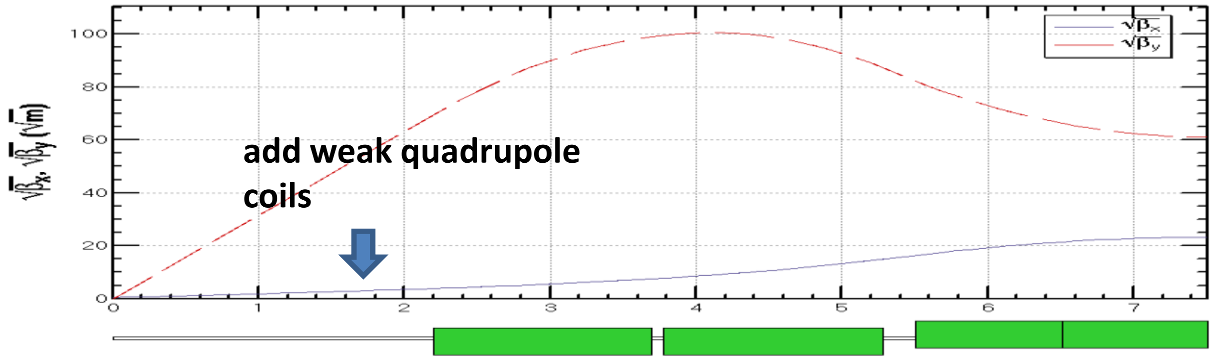
$\mathbf{18\sigma_x \times 21\sigma_y \times 0.015}$ **w/o errors**

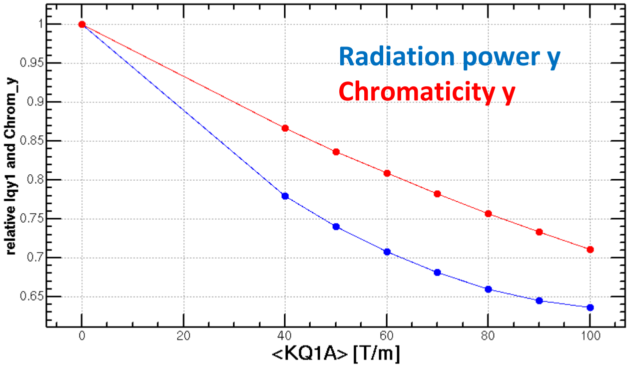
# Optimization of final doublet design

- Goal: lower vertical radiation power from the quadrupoles and chromaticity
  - Add weak quadrupole coils in front of the QD where mainly for anti-solenoid (proposed by Chenghui YU)
    - Sliced into several pieces and installed with rotation defined by coupling angles
    - Turned on only for Higgs mode
  - Different strength ratio of Q1B and Q1C, length ratio of Q1B and Q1C, distance of Q1 and Q2, length of Q1 and Q2

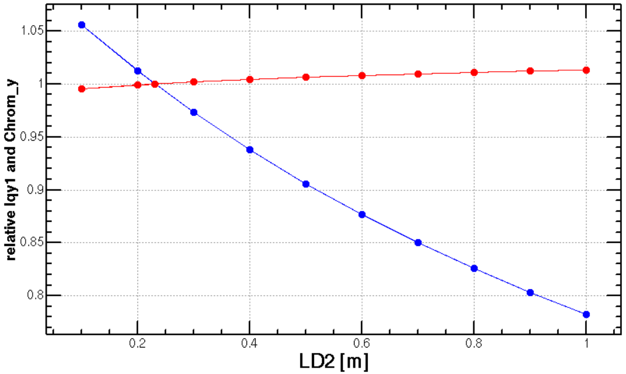


# Optimization of final doublet design

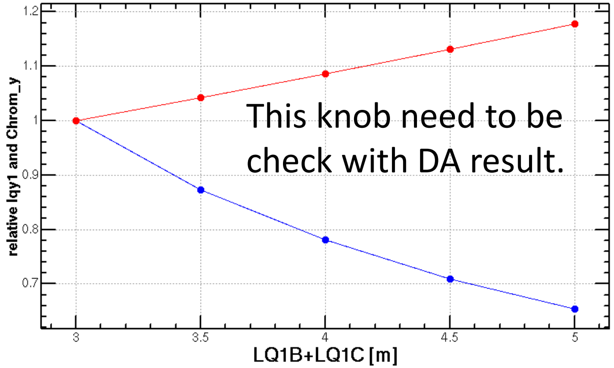
## Add weak quadrupole coils



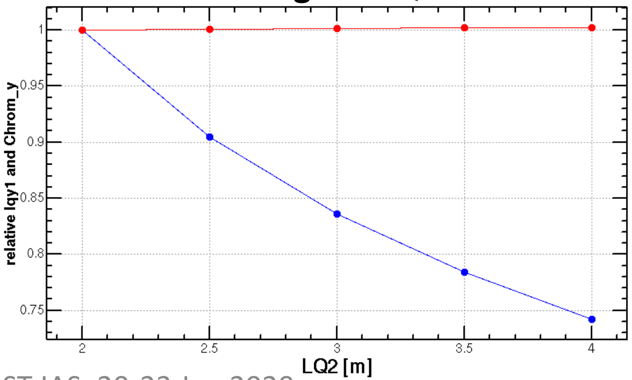

## Distance of Q1 and Q2




## length of Q1

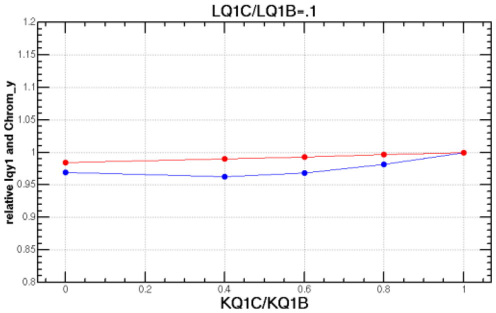


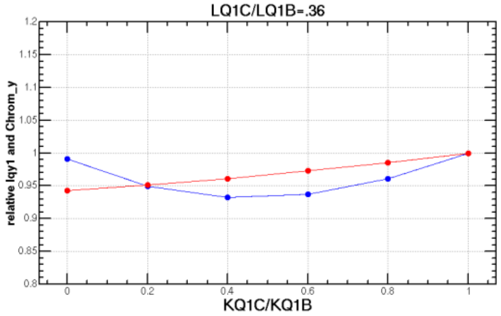

## length of Q2

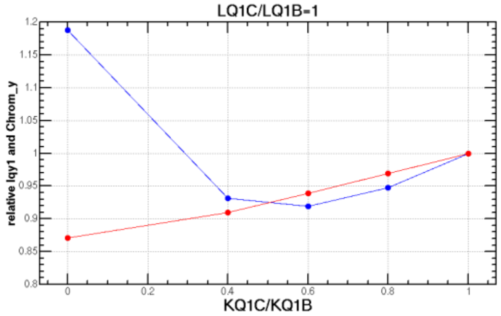


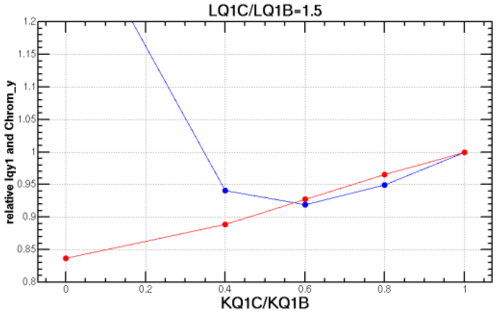
# Optimization of final doublet design

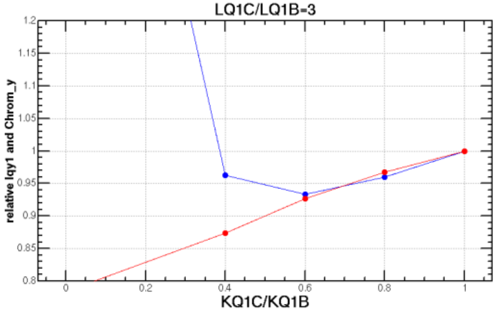
Different **strength ratio of Q1B and Q1C** with **different length ratio of Q1B and Q1C** when keep total length of Q1B+Q1C




- Minimum of radiation power occurs at KQ1C/KQ1B≈0.6
- Different length of Q1B and Q1C doesn't affect much on the minimum of the power and chromaticity.
    - **Provide more freedom of the FD technical design**
- Shorter and stronger Q1B help a bit on the DA.

Iqy1≈Kb^2*βb*Lb+Kc^2*βc*Lc ≥ 2KbKc(βbβcLbLc)^1/2
when Kc/Kb=((βb/βc)/(Lc/Lb))^1/2

# Optimization of final doublet design

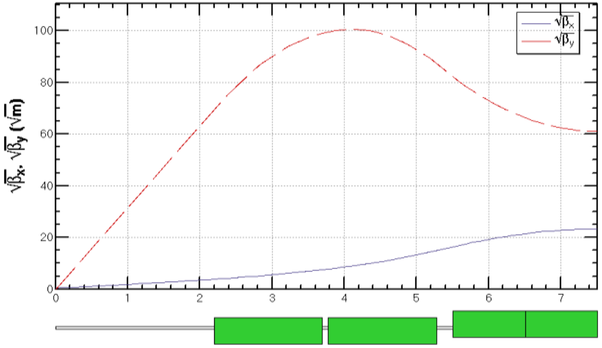
The vertical radiation power and chromaticity decreased significantly.

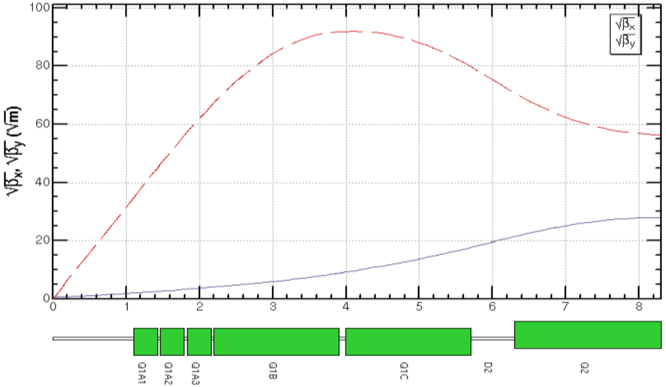
**These optimization will help to further decrease the by* to less than 1mm.**

| Parameters | Before optimization | After optimization | Contribution to Py | Contribution to Chromy |
|---|---|---|---|---|
| **Px [a.u.]** | 30 | 26 | - | - |
| **Py [a.u.]** | 1209 | 674 | 0.56 | - |
| **Chromx [a.u.]** | -90 | -118 | - | - |
| **Chromy [a.u.]** | -3429 | -2909 | - | 0.85 |
| **<KQ1A> [T/m]** | 0 | 40 | 0.78 | 0.87 |
| **KQ1C/KQ1B** | 1 | 0.6 | 0.92 | 0.94 |
| **LD2 [m]** | 0.23 | 0.6 | 0.88 | 1.00 |
| **LQ1B+LQ1C [m]** | 3 | 3.5 | 0.87 | 1.04 |
| **LQ1C/LQ1B** | 1 | 1 | - | - |
| **LQ2 [m]** | 2 | 2 | - | - |

with $\varepsilon x$=0.68nm, cp=1%, $\sigma e$=0.134%, bx*=0.33m, by*=1mm

# Optimization of final doublet design




## Before optimization

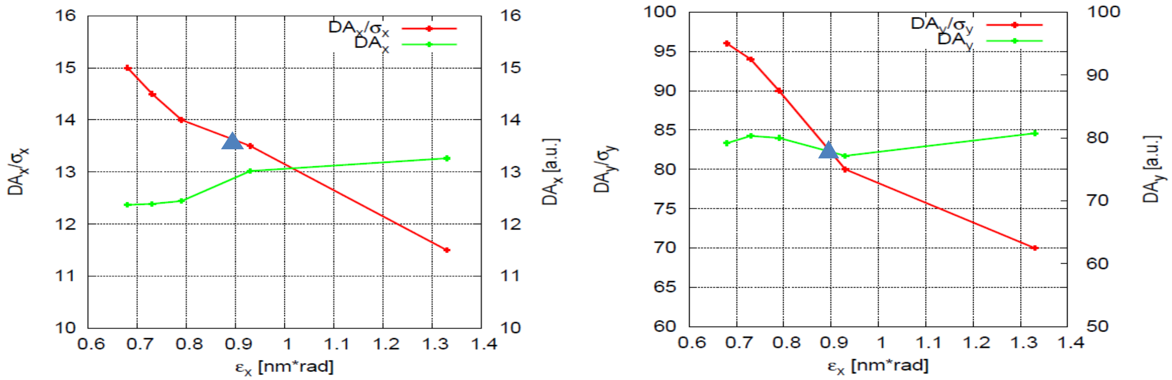
| NAME | L [m] | K1 [T/m] | Mean betay [m] |
|---|---|---|---|
| Q1B | 1.460 | -79.3 | 7611 |
| Q1C | 1.460 | -79.3 | 9280 |
| Q2 | 2.000 | 62.7 | 4814 |

## After optimization

| NAME | L [m] | K1 [T/m] | Mean betay [m] |
|---|---|---|---|
| Q1A1 | 0.327 | -20.0 | 1604 |
| Q1A2 | 0.327 | -40.0 | 2633 |
| Q1A3 | 0.327 | -60.0 | 3839 |
| Q1B | 1.710 | -70.8 | 6935 |
| Q1C | 1.710 | -42.5 | 7747 |
| Q2 | 2.000 | 48.8 | 3797 |

# Dynamic aperture vs. emittance

- **Larger normalized dynamic aperture with smaller emittance ( for ex~1nm )**
  - The nonlinearity in interaction region is much larger than the arc region
  - Better DA with smaller emittance benefits from smaller nonlinearity in the IR and smaller beam size though stronger nonlinearity in ARC thus stronger error correction will need
  - Efficient direction of dynamic aperture optimization
  - Just show the tendency; each dynamic aperture result can be further optimized with directly optimization




DA without fluctuation

# Analytic formula for dynamic aperture

- Jie Gao and Ming Xiao's analytic formula for DA

ELSEVIER Nuclear Instruments and Methods in Physics Research A 451 (2000) 545–557
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.nl/locate/nima

Analytical estimation of the dynamic apertures of circular accelerators

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ANALYTICAL ESTIMATIONS OF THE DYNAMIC APERTURES OF BEAMS WITH MOMENTUM DEVIATION AND APPLICATION IN FFAG*

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$$A_{dyna,sext,x} = \sqrt{2J_{max}\beta_x(s)} = \sqrt{\frac{8\beta_x(s)}{3(B^2+C^2)}}$$

On momentum

$$A_{dyna,sext,\Delta} = \frac{1}{1-\Delta}\sqrt{\frac{8\tilde{\beta}_x(s)}{3(B^2+C^2)}} = \Omega \times A_{dyna,sext}$$

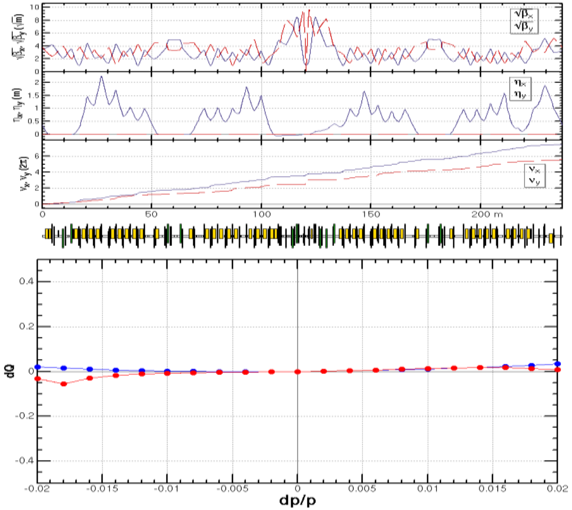
Off momentum

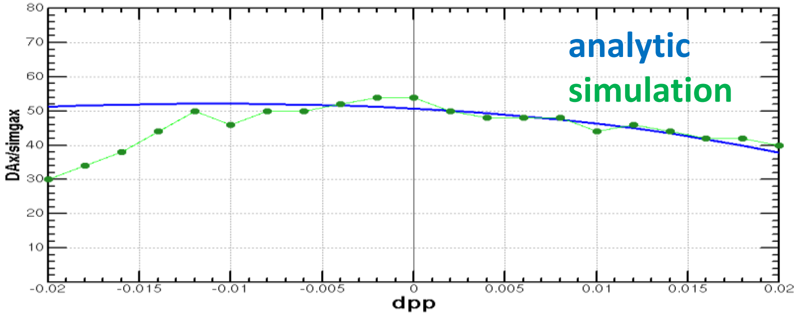
$$A_i = \beta_x(s_i)^{3/2} S_i \qquad B = \sum_i A_i \cos 3\Delta\Psi_i \text{ and } C = \sum_i A_i \sin 3\Delta\Psi_i.$$

$$\tilde{\beta}_x(s) = \beta_x(s)\left(1 + \frac{1}{2\sin(2\pi\nu)} \oint \beta_x(t) k \cos\alpha dt\right)$$

# Comparison of analytic and simulation result

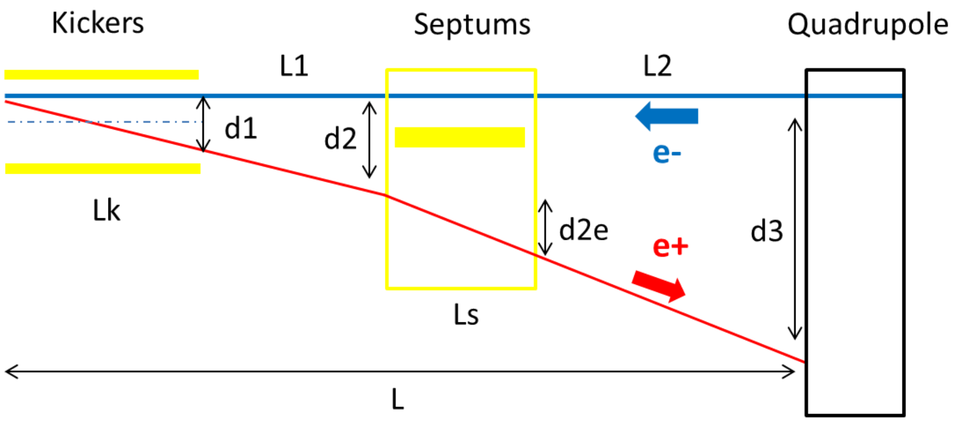
- The analytic and simulation results of dynamic aperture agree well for small energy deviation particles.
  - Jie Gao and Ming Xiao's analytic formula for DA are used.
  - Compared with DA by tracking using lattice of BEPCII positron ring
  - Will be applied to CEPC for DA optimization




bpr.alphap.7k1v23.k2v21.sad, 1000 turns,
no synchrotron motion, Q=7.5050/5.5750, Q'=0

# New separation scheme with kicker and septum




Use kicker to instead of electro-static separator in order to reduce the impedance. (Proposed by Jinhui Chen)

| | Kicker | Septum | |
|---|---|---|---|
| **Integrated strength BL [T*m]** | 0.1624 | 1.4 | |
| **Strength B [Guass]** | 203 | 1000 | Field for up to 182.5GeV. Septum is weak to suppress emittance growth. |
| **Effective length Leff [m]** | 8 | 14 | |
| **Half width of good field region Hgf/Vgf [mm]** | 10.1/3.8 @ 5E-4 | 18.9/3.8 @ 5E-4 | Kicker: 18σx+3mm+d1/2, 18σy+3mm<br>Septum: 18σx+3mm+d2e/2, 18σy+3mm |
| **Half width of beam stay clear Hbsc/Vbsc [mm]** | 9.6/3.6 | 9.2/3.6 | 18σx+3mm, 18σy+3mm |
| **Septum width width [mm]** | - | 5 | |

# Correction of magnet errors

with by*=1.5mm lattice

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# Correction scheme

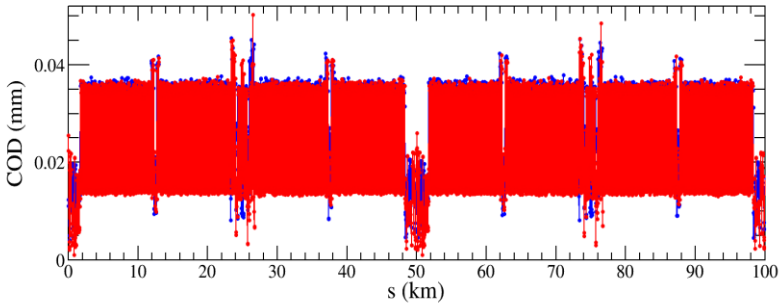
- Closed-orbit-distortion (COD) correction with sextupoles off
  - BPMs placed at quadrupoles (~1500, 4 per betatron wave)
  - Horizontal correctors placed beside focusing quadrupoles（~1500）
  - Vertical correctors placed beside defocusing quadrupoles（~1500）
  - Orbit correction is applied using orbit response matrix and SVD method.
- Turn on the sextupoles and perform COD correction again
- Dispersion correction with dispersion free steering
  - orbit manipulation by knob correctors
- Beta beating correction with LOCO of Accelerator Toolbox
- Coupling and vertical dispersion correction (Local coupling parameter correction)
  - Using the trim coils of the sextupoles (~1000), which providing skew-quadrupole field

# Result of Case1

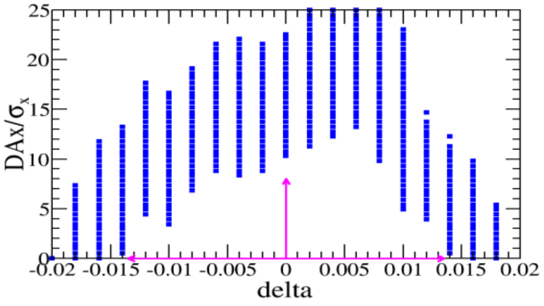
| Component | $\Delta x$ (μm) | Δy (μm) | $\Delta\theta_z$ (μrad) |
|---|---|---|---|
| Arc quadrupole | 100 | 100 | 100 |
| IR Quadrupole | 50<br>(30 for FF) | 50<br>(30 for FF) | 50<br>(30 for FF) |
| Sextupole | 100 | 100 | 100 |

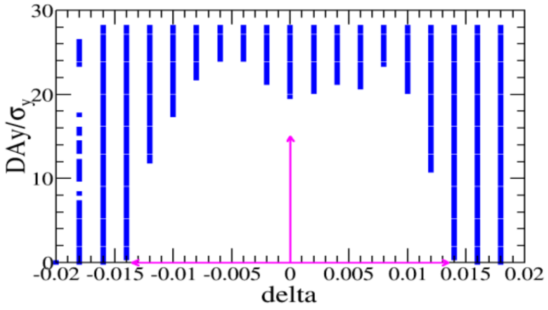
| Component | Field error |
|---|---|
| Dipole | 0.01% |
| Quadrupole | 0.02% |

COD correction: $RMS_{COD} < 0.05\ mm$




| Observable | Before correction | After correction |
|---|---|---|
| Hori. disp. | 29.0 mm | 3.8 mm |
| Vert. disp. | 83.4 mm | 0.6 mm |
| Hori. Beta-beating | 5.7% | 0.8% |
| Vert. Beta-beating | 6.8% | 0.6% |




**Out of 1000 seeds, 831 converged**

ex = 1.217±0.005 nm

ey = 0.043 ± 0.002 pm

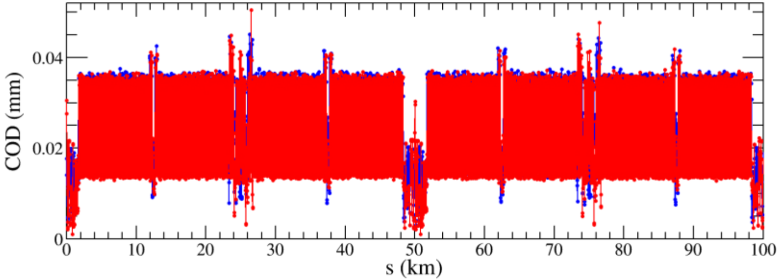
ey/ex = (0.0035 ± 0.0002)%

# Preliminary result of Case2

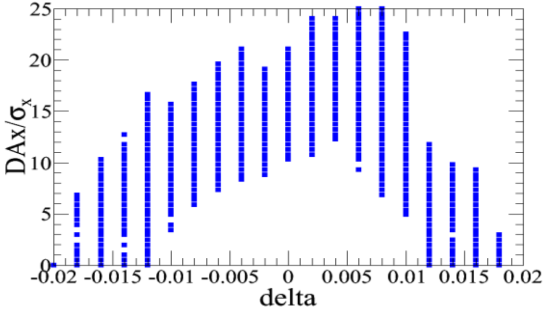
| Component | $\Delta x$ (μm) | $\Delta y$ (μm) | $\Delta\theta_z$ (μrad) |
|---|---|---|---|
| Arc quadrupole | 100 | 100 | 100 |
| IR Quadrupole | 50 | 50 | 50 |
| Sextupole | 100 | 100 | 100 |

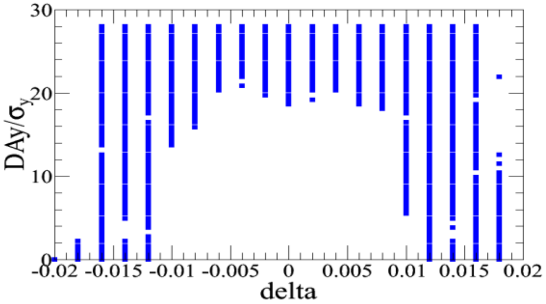
| Component | Field error |
|---|---|
| Dipole | 0.01% |
| Quadrupole | 0.02% |

COD correction: $RMS_{COD} < 0.05\ mm$




| Observable | Before correction | After correction |
|---|---|---|
| Hori. disp. | 33.0 mm | 5.0 mm |
| Vert. disp. | 136.8 mm | 1.0 mm |
| Hori. Beta-beating | 5.5% | 1.2% |
| Vert. Beta-beating | 10.7% | 0.9% |




**Out of 500 seeds, 300 converged**

ex = 1.218$\pm$0.009 nm

ey = 0.059 $\pm$ 0.002 pm

ey/ex = (0.0048 $\pm$ 0.0002)%

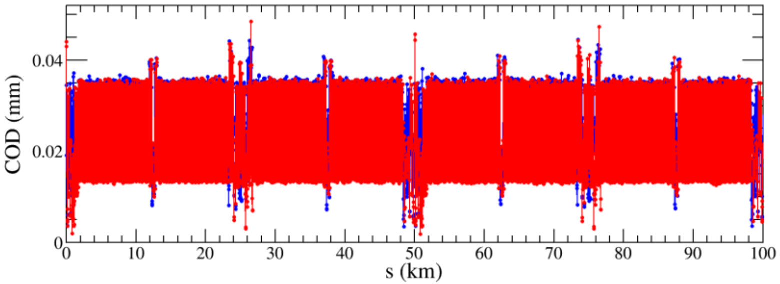
# Preliminary result of Case3

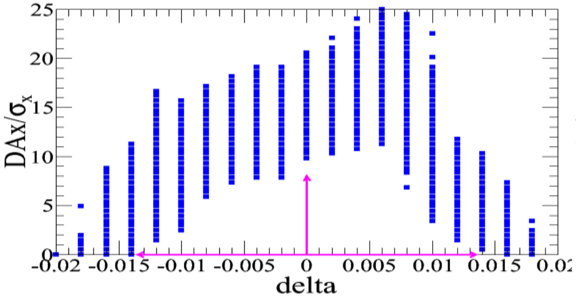
| Component | $\Delta x$ (μm) | $\Delta y$ (μm) | $\Delta\theta_z$ (μrad) |
|---|---|---|---|
| Arc quadrupole | 100 | 100 | 100 |
| IR Quadrupole | 100 | 100 | 100 |
| Sextupole | 100 | 100 | 100 |

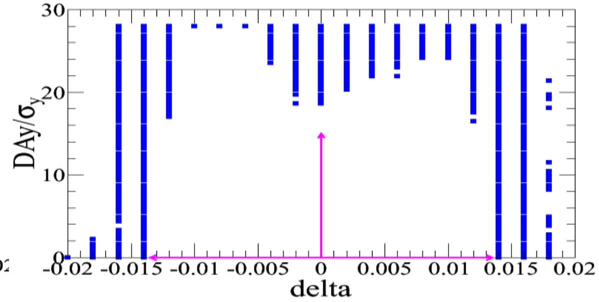
| Component | Field error |
|---|---|
| Dipole | 0.01% |
| Quadrupole | 0.02% |

| Observable | Before correction | After correction |
|---|---|---|
| Hori. disp. | 30.9 mm | 2.2 mm |
| Vert. disp. | 42.7 mm | 5.9 mm |
| Hori. Beta-beating | 4.3% | 1.4% |
| Vert. Beta-beating | 14.3% | 1.5% |

COD correction: $RMS_{COD} < 0.05\ mm$




**Low converged rate of the beta-beating correction (~20%).**

**Further correction is undergoing.**

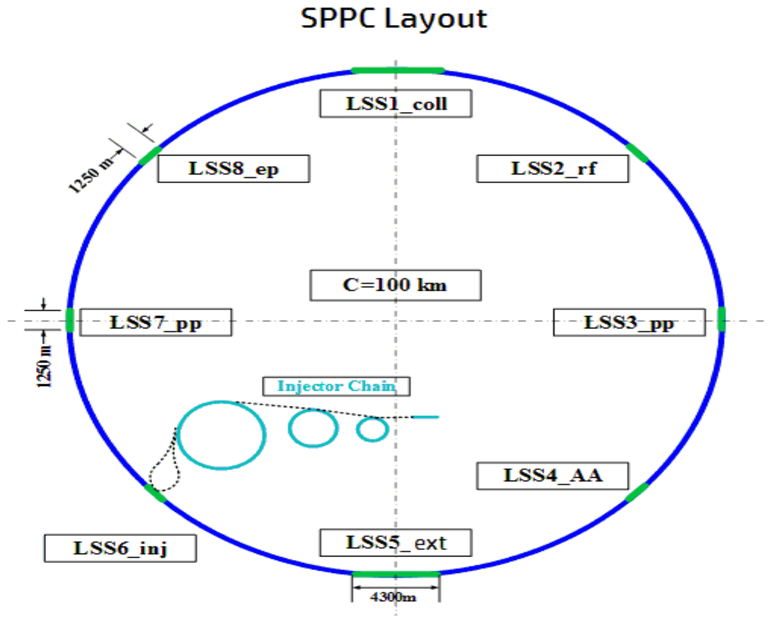
# Status of lattice design for SPPC collider ring

Yukai Chen, Jianquan Yang, Jingyu Tang, Yiwei Wang, Jie Gao, Chenghui Yu

# SPPC main parameters

| Parameter | Unit | Value | | |
|---|---|---|---|---|
| | | PreCDR | CDR | Ultimate |
| Circumference | km | 54.4 | 100 | 100 |
| C.M. energy | TeV | 70.6 | 75 | 125-150 |
| Dipole field | T | 20 | 12 | 20-24 |
| Injection energy | TeV | 2.1 | 2.1 | 4.2 |
| Number of IPs | | 2 | 2 | 2 |
| Nominal luminosity per IP | $cm^{-2}s^{-1}$ | 1.2e35 | 1.0e35 | - |
| Beta function at collision | m | 0.75 | 0.75 | - |
| Circulating beam current | A | 1.0 | 0.7 | - |
| Bunch separation | ns | 25 | 25 | - |
| Bunch population | | 2.0e11 | 1.5e11 | - |
| SR power per beam | MW | 2.1 | 1.1 | - |
| SR heat load per aperture @arc | W/m | 45 | 13 | - |

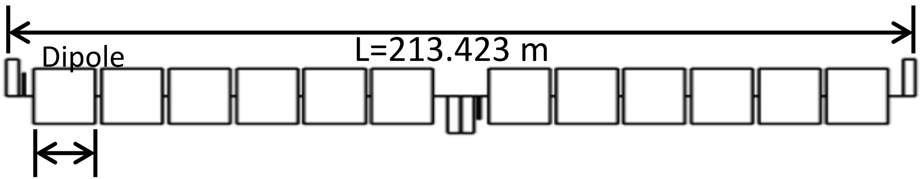
# General layout of SPPC



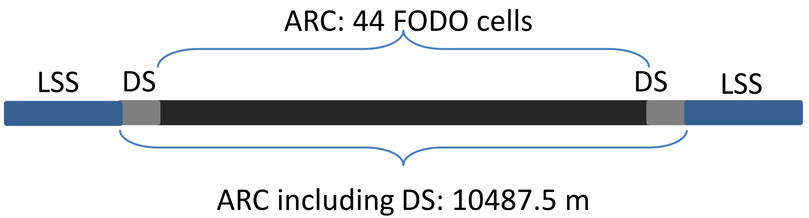

- Use the same CEPC tunnel to build SPPC
- Maximize the beam energy to 37.5 TeV by using ~12T Iron-based SC magnets
- 8 arcs, total length 83900 m
- 2 IPs for pp, 1250 m each
- 2 IRs for injection or RF, 1250 m each
- 2 IRs for ep or AA, 1250 m each
- 2 IRs for collimation( ee for CEPC ）, 4300 m each
- C = 100 km

- Dipole length needed: 65.45 Km (12 T Dipole, Ep=37.5 TeV)
- Dipole filling factor: 0.79
- ARC length( including DS ): 65.45 Km/0.79=83.9 Km, Considering some reserved length, ARC length is chosen as 83.9 Km, left 16.1 Km for long straight section

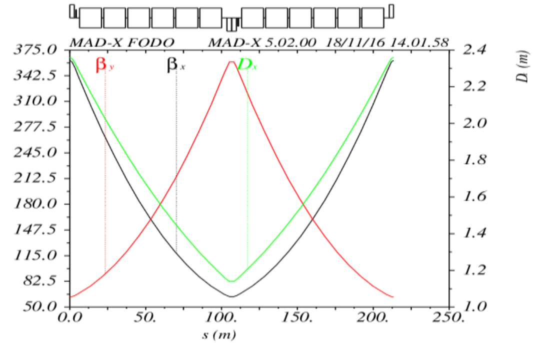
# FODO cell structure and ARC section



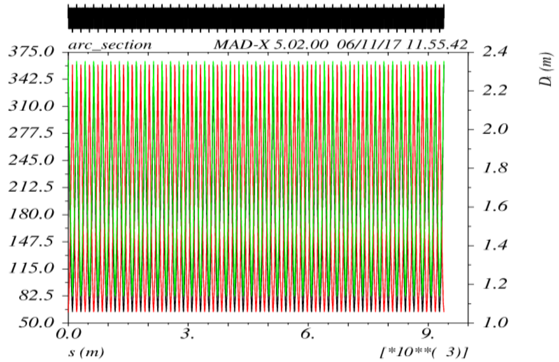

L_dipole: 14.452 m, B_dipole: 11.8 T, ρ=10598.8 m
L_quadrupole: 6 m
Gap of dipole-dipole: 3.5 m – For sextupole, beam diagnostic equipment
Gap of dipole-quadrupole: 1.4 m
Equivalent radius of FODO cell : 13043.3 m
$\beta$_max= 361.9 m, $\beta$_min= 62.9 m
D_max= 2.36 m, D_min= 1.136 m
Phase of advance: 90 deg




Structure of one ARC section

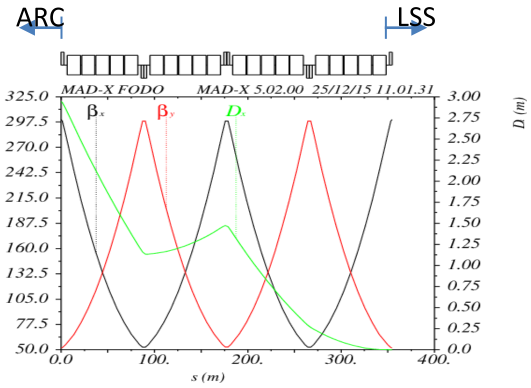



**Optics functions of FODO cell**

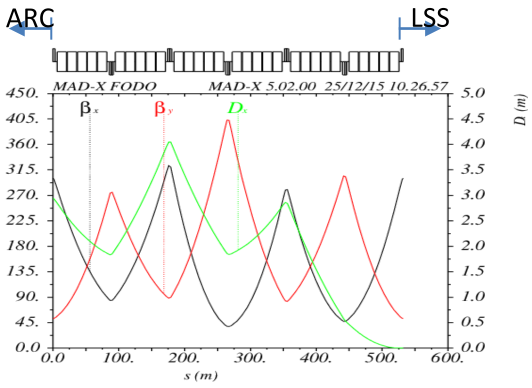



**Optics of one ARC section**

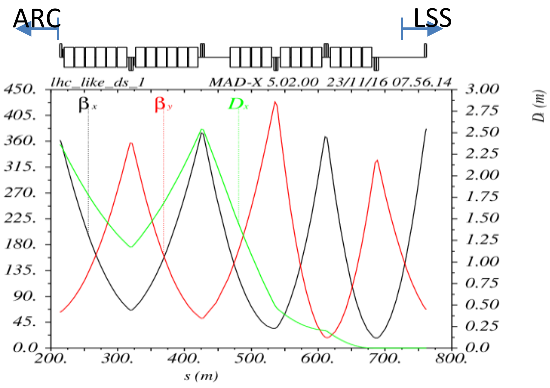
# Dispersion Suppressor design




Half bend DS




Full bend DS




LHC-like DS

**Half bend DS**

- Dipoles strength in DS is half of that in ARC
- Dispersion function can be cancelled perfectly without disturbing the beta functions
- Because of reducing in dipoles strength, more space is needed for ARC section, which will reduce the dipoles filling factor.

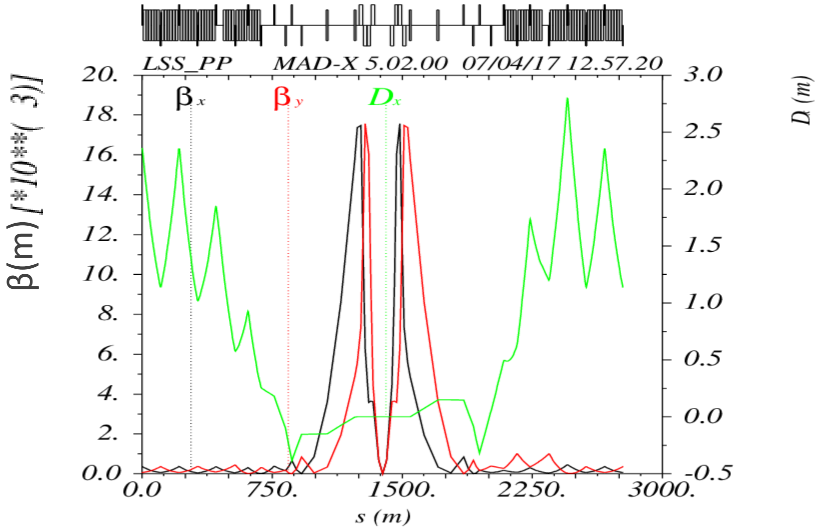
**Full bend DS**

- FODO cell in DS is the same as ARC section.
- Dipoles strength in DS is equal to that in ARC
- Adjust the last 6-7 quadrupoles to match the optics functions.
- Dispersion function and beta functions increase obviously.

**LHC-like DS**

- Irregular shorter FODO cells than that of ARC section.
- Dipoles strength in DS is equal to that in ARC
- Adjust the last 6-7 quadrupoles to match the optics functions.
- Dispersion function and beta functions increase slightly.
- Used in present SPPC lattice

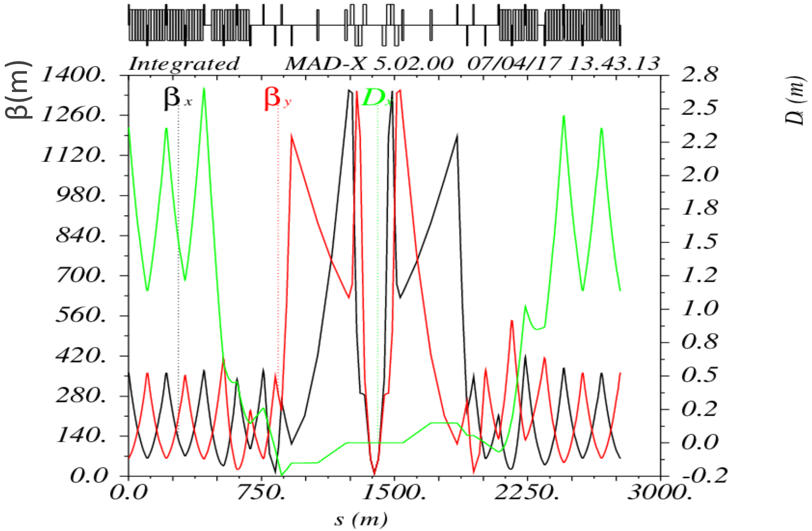
# Lattice of collision section




**LSS_PP at collision ( beta*=0.75 m )**

$\varepsilon_n$=2.4 μm
$\beta_{max}$=18 km
Ep=37.5 TeV

$$\sigma_{max} = \sqrt{\frac{\varepsilon_n}{\gamma} \cdot \beta_{max}} = 1.04 \text{ mm}$$




**LSS_PP at injection ( beta*=10 m )**

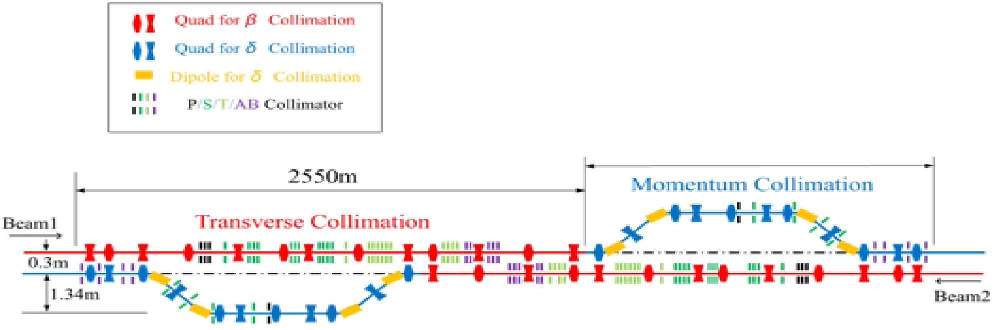
$\varepsilon_n$=2.4 μm
$\beta_{max}$=1.3 km
Ep=2.1 TeV

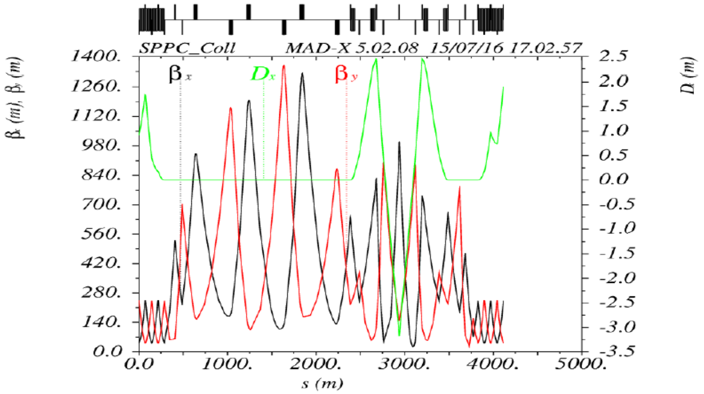
$$\sigma_{max} = \sqrt{\frac{\varepsilon_n}{\gamma} \cdot \beta_{max}} = 1.18 \text{ mm}$$

# SPPC collimation section

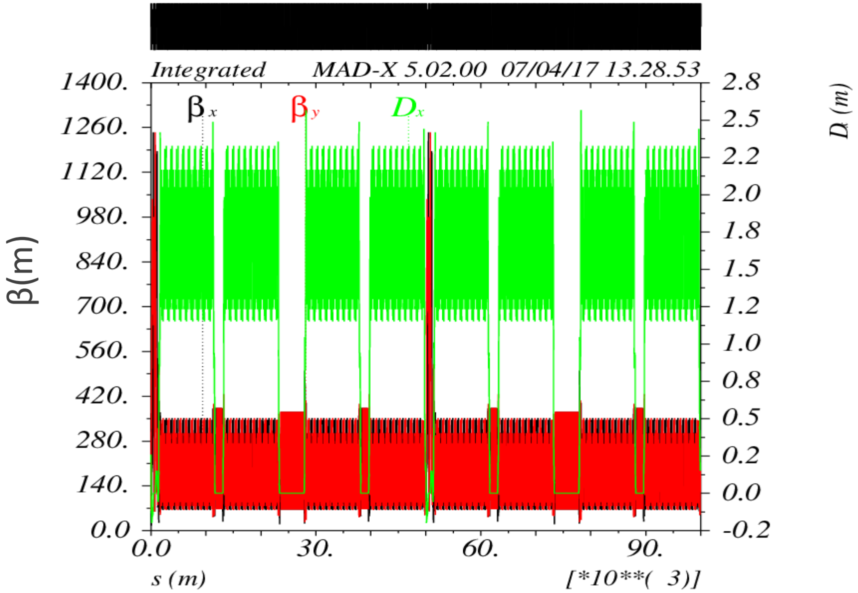
- Combining the transverse and momentum collimation in the same section

- The particles experiencing single diffractive interactions in the primary collimators will loss in the cold magnets of DS
- In order to deal with these particle losses, we can arrange the transverse and momentum collimation in the same cleaning insertion

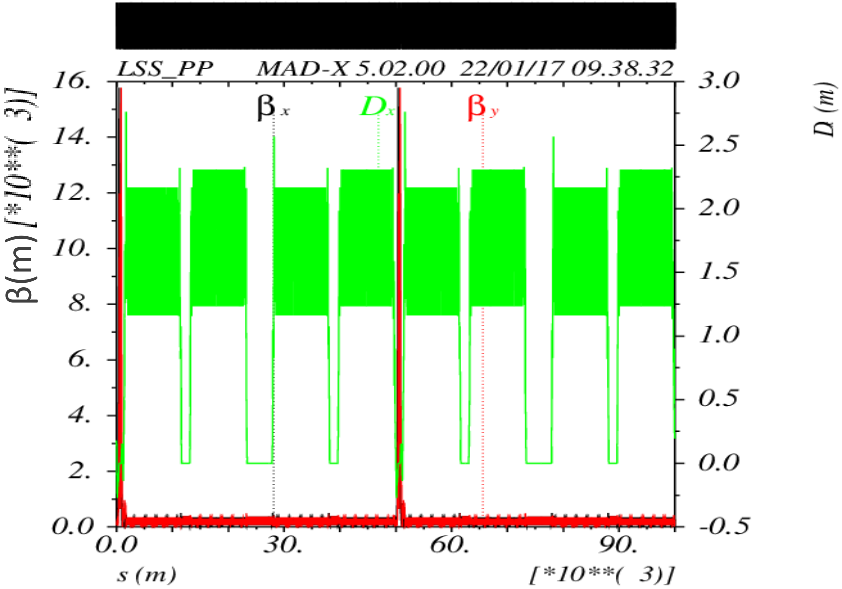


# Integrated lattice




**Integrated Lattice at injection**
**(beta*=10 m Qx =119.28, Qy=118.31)**

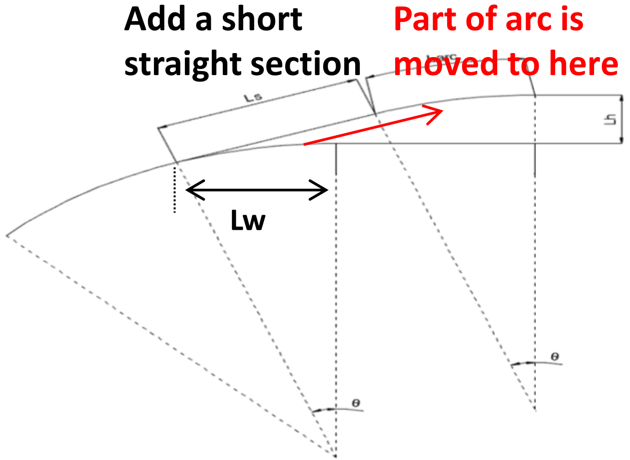



**Integrated Lattice at collision**
**(beta*=0.75m Qx =121.28, Qy=118.31)**

# Geometry compatibility at IP2 and IP4

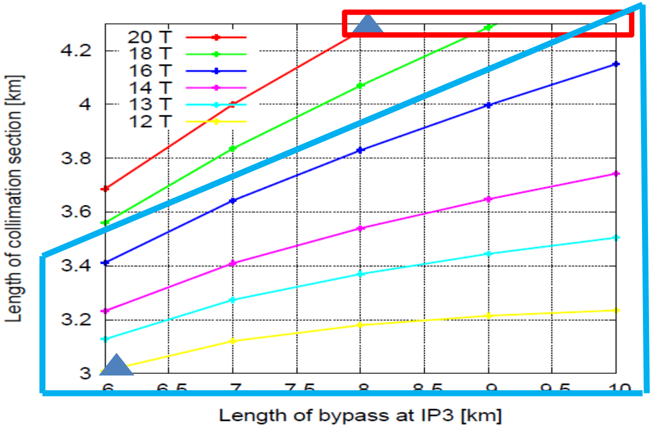
- For IP2 and IP4, the SPPC interaction regions are much shorter than the CEPC RF regions. SPPC can bypass CEPC within a reasonable length using baseline bend (12T).
- Bypass Scheme
  - add a short straight section at the end of ARC
  - Lw is the additional length for bypass which is 0.28km for distance of 23m
  - Total length of bypass at IP2 or IP4 is 4 km

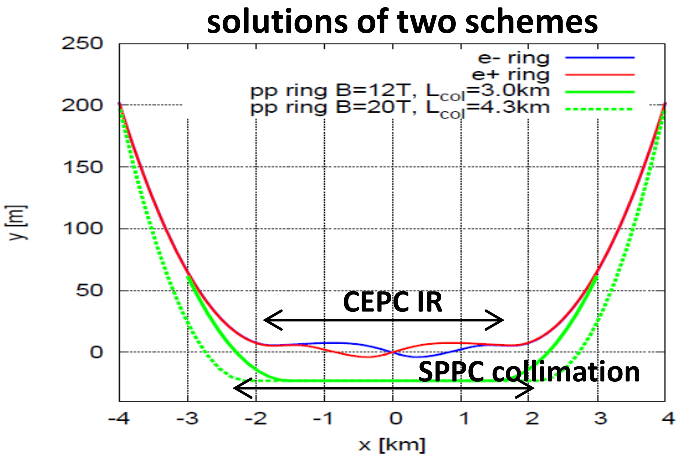
| | IP2 & IP4 |
|---|---|
| SPPC | 1.25 km |
| CEPC | 3.42 m |



# Geometry compatibility at IP1 and IP3

- Possible bypass Schemes
  - bypass within a reasonable length using much stronger bend
    - Lcol = 4.3 km, 17 T ≤ B ≤ 20 T, 8km ≤ length of bypass ≤ 10 km
  - bypass within a reasonable length using a bit stronger bend which need to shorten the length of SPPC collimation length thus a different design of SPPC collimation section
    - 3 km ≤ Lcol < 4.3 km, 12T ≤ B < 17 T, 6km ≤ length of bypass ≤ 10 km



# Summary

- Lattices for a higher luminosity has been designed whose by*=1mm.
- Stronger optimization had be made in order to get enough dynamic aperture.
- Dynamic aperture optimization
  - The on-momentum DA should be large enough even with errors.
  - The further optimization of momentum acceptance is under going to achieve 1.7%.
  - Some new attempts made for further optimization of dynamic aperture including final doublet optimization, decreasing emittance and application of analytic DA formula.
- With by*=1.5mm lattice, error correction made with 1000 random seeds and the pre-alignment requirements has been loosed.
- SPPC lattice designed based on the 12T bend. Geometry compatibility of CEPC and SPPC was studied.