• Part I, Status of CEPC Accelerator (Physics) Study
• Part II, Multi-Objective Optimization with possible application in SuperKEKB
Status of CEPC Accelerator (Physics) Study

Yuan Zhang for CEPC Accelerator Team
zhangy@ihep.ac.cn

Institute of High Energy Physics, Beijing
KEK  Mar, 2016
What is a (CEPC + SppC) (Q. Qin)

• Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel
The CEPC-SPPC Study Group

Armen Apyan, Lifeng Bai (白利锋), Mei Bai (柏梅), Sha Bai (白莎),
Paolo Bartalini 28, Sergey Belomestnykh14, Tianjian Bian1 (边天剑),
Xiaojuan Bian1 (边晓娟), Wenyong Cai8 (蔡文勇), Yunhai Cai15 (蔡云海),
Jiaxin Cao1 (曹佳鑫), Weiping Chai2 (柴伟平), Ningbo Chang28 (畅宁波),
Fuqing Chen1 (陈福庆), Geng Chen4 (陈耿), Jiaxin Chen1 (陈佳鑫),
Fusan Chen1 (陈福三), Shiyong Chen28 (陈时勇), Xiaonian Chen8 (陈晓年),
Xuron Chen1 (陈旭龙), Gang Chen1 (陈刚), Jian Cheng1 (程健),
Yadong Ding1 (丁亚东), Haiyi Dong1 (董海义), Jiajia Dong8 (董甲甲),
Lan Dong1 (董岚), Yuhui Dong5 (董宇辉), Zhe Duan1 (段哲), Jingzhou Fan5 (范荆洲),
Junjie Fan34 (范俊杰), Yoshihiro Funakoshi21 (船越义裕), yonggui Gao46 (高勇贵),
Pingping Gan4 (甘娉娉), Jie Gao1 (高杰), Yuanning Gao5 (高原宁),
Huiping Geng2 (耿会平), Dianjun Gong1 (宫殿军), Li Gong46 (龚丽),
Ramesh Gupta14 (古拉梅),

300 authors from 57 institutions in 9 countries
1. The Committee considers the CEPC-SPPC to be well aligned with the future of China’s HEP program, and in fact the future of the global HEP program.

2. The design goals are well defined and comprehensive. We provided remarks and recommendations to improve the design, but we definitely consider this design to be credible and with sufficiently conservative assumptions.

3. The great majority of the accelerator physics issues are adequately addressed, and after addressing our recommendations, we expect that all the accelerator physics issues would be adequately addressed.

4. The designs of the technical systems and conventional facilities are effective for achieving the performance goals.

5. We find the CEPC design compatible with the future upgrade to the SPPC.

6. Technical risks and their potential impact were presented together with mitigation measures, while in some cases more study and R&D are needed.

7. The R&D program is clearly defined, and while we recommended a few additional R&D items, the program is adequate. We further believe that this R&D program will be highly beneficial to the science and technology infrastructure in China and will contribute to its economy.

8. We made a few suggestions for improvements of the design.
CEPC-SPPC Timeline (preliminary)

**1st Milestone:** Pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China’s 13th Five-Year Plan 2016-2020)

**2nd Milestone:** 13th Five Year Plan R&D

---

**CEPC**

- **Pre-studies (2013-2015)**
- **Engineering Design (2030-2035)**
- **Construction (2035-2042)**
- **Data taking (2042-2055)**

---

**SPPC**

- **2020**
- **2030**
- **2040**
### CEPC Design – Top Level Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>e+, e-</td>
</tr>
<tr>
<td>Center of mass energy</td>
<td>240 GeV</td>
</tr>
<tr>
<td>Integrated luminosity (per IP per year)</td>
<td>250 fb(^{-1})</td>
</tr>
<tr>
<td>No. of IPs</td>
<td>2</td>
</tr>
</tbody>
</table>

⇒ one million Higgs from 2 IPs in 10 years

### CEPC Design – Z-pole Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>e+, e-</td>
</tr>
<tr>
<td>Center of mass energy</td>
<td>45.5 GeV</td>
</tr>
<tr>
<td>Integrated luminosity (peak)</td>
<td>&gt;1(\times)10^{34}/cm^{2}s</td>
</tr>
<tr>
<td>No. of IPs</td>
<td>2</td>
</tr>
</tbody>
</table>
Injectors

Top-up Full-energy Injection

Booster Cycle (0.1 Hz)
CEPC Lattice Layout (September 24, 2014)

One RF station:
• 650 MHz five-cell SRF cavities;
• 4 cavities/module
• 12 modules, 10 m each
• RF length 120 m

4 straights, 849.6 m (944 m) each
8 arcs, 5852.8 m each

4 IPs, 1038.4 m (944 m) each

\( D = 17.3 \text{ km} \)

\( C = 54.374 \text{ km} \)
## CEPC Design – Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy [E]</td>
<td>GeV</td>
<td>120</td>
<td>Circumference [C]</td>
<td>m</td>
<td>54752</td>
</tr>
<tr>
<td>Number of IP [N_IP]</td>
<td></td>
<td></td>
<td>SR loss/turn [U_0]</td>
<td>GeV</td>
<td>3.11</td>
</tr>
<tr>
<td>Bunch number/beam [n_b]</td>
<td></td>
<td>50 (48)</td>
<td>Bunch population [N_e]</td>
<td></td>
<td>3.79E+11</td>
</tr>
<tr>
<td>SR power/beam [P]</td>
<td>MW</td>
<td>51.7</td>
<td>Beam current [I]</td>
<td>mA</td>
<td>16.6</td>
</tr>
<tr>
<td>Bending radius [r]</td>
<td>m</td>
<td>6094</td>
<td>momentum compaction factor [α_p]</td>
<td></td>
<td>3.36E-05</td>
</tr>
<tr>
<td>Revolution period [T_0]</td>
<td>s</td>
<td>1.83E-04</td>
<td>Revolution frequency [f_0]</td>
<td>Hz</td>
<td>5475.46</td>
</tr>
<tr>
<td>emittance (x/y)</td>
<td>nm</td>
<td>6.12/0.018</td>
<td>β_IP(x/y)</td>
<td>mm</td>
<td>800/1.2 (3)</td>
</tr>
<tr>
<td>Transverse size (x/y)</td>
<td>μm</td>
<td>69.97/0.15</td>
<td>ξ_x/y/IP</td>
<td></td>
<td>0.118/0.083</td>
</tr>
<tr>
<td>Bunch length SR [σ_x,SR]</td>
<td>mm</td>
<td>2.14</td>
<td>Bunch length total [σ_x,SR tot]</td>
<td>mm</td>
<td>2.65</td>
</tr>
<tr>
<td>Lifetime due to Beamstrahlung</td>
<td>min</td>
<td>47</td>
<td>lifetime due to radiative Bhabha scattering [t_L]</td>
<td>min</td>
<td>51</td>
</tr>
<tr>
<td>RF voltage [V_rf]</td>
<td>GV</td>
<td>6.87</td>
<td>RF frequency [f_rf]</td>
<td>MHz</td>
<td>650</td>
</tr>
<tr>
<td>Harmonic number [h]</td>
<td></td>
<td>118800</td>
<td>Synchrotron oscillation tune [ν_s]</td>
<td></td>
<td>0.18</td>
</tr>
<tr>
<td>Energy acceptance RF [h]</td>
<td>%</td>
<td>5.99</td>
<td>Damping partition number [J_e]</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Energy spread SR [σ x,SR]</td>
<td>%</td>
<td>0.132</td>
<td>Energy spread BS [σ x,BS]</td>
<td>%</td>
<td>0.096</td>
</tr>
<tr>
<td>Energy spread total [σ x,SR tot]</td>
<td>%</td>
<td>0.163</td>
<td>n_y</td>
<td></td>
<td>0.23</td>
</tr>
<tr>
<td>Transverse damping time [n_x]</td>
<td>turns</td>
<td>78</td>
<td>Longitudinal damping time [n_e]</td>
<td>turns</td>
<td>39</td>
</tr>
<tr>
<td>Hourglass factor</td>
<td>Fh</td>
<td>0.68</td>
<td>Luminosity /IP[L]</td>
<td>cm⁻²s⁻¹</td>
<td>2.04E+34</td>
</tr>
</tbody>
</table>

W. Chou
CEPC-SPPC Meeting, May 17-18, 2015
General Comment:

• Pre-CDR is easy
• CDR is hard
• Why? Because we leave all hard things to CDR!
• But still, the Pre-CDR was a success:
  ➢ made it possible to propose this project to the government in the 13th five-year plan
  ➢ formed a CEPC-SPPC team
  ➢ provided a baseline design
  ➢ gave China the needed credit in the world HEP community that it is capable to carry out this project
5. Dynamic aperture for $L^* = 1.5m$, $\beta_y^* = 3mm$

6. Pretzel scheme:
   
   to complete a consistent design including beam orbit/optics in the arcs and IRs, dynamic aperture, beam-beam, beam injection, etc.

7. Investigating alternative designs:
8. **Saw-tooth orbit**
   - 0.3% energy error within an arc
   - for single-pipe design, there is no way to correct it
   - various effects on the beam

9. **To start machine errors analysis**

10. **To start corrector design**

11. **Arc lattice optimization, e.g.,**
   - working point
   - horizontal emittance
   - phase advance
   - momentum compaction
   - bunch length and RF voltage

12. **IR optics**
   - optimize $\beta_y$ at the sextupoles
   - including fringe field, solenoid and compensation, errors and tolerances
13. Beam-beam effect:

- to study beam-beam from parasitic crossing
- this is especially important in Z operation due to large number of crossings
- compensation method
CDR Worklist (6)

14. To establish an emittance budget
   • from source to linac to Booster to collider
   • including machine imperfection and allowance, optics mismatch and energy errors

15. To establish a geometric aperture model for the collider
   • including the injection region, beam dump region, doublet, maximum beta area

16. Machine-detector interface (MDI)
   • radiation shielding design
   • simulation using Sullivan’s code
   • collimator design
17. Beam instability
   • to establish a realistic impedance model instead of scaling from KEKB or LEP, including separators, collimators, ferrite damper in RF, etc.
   • Banana effect due to transverse wake from off-center orbit
   • to study instabilities at Z-pole, which has lower energy and higher beam current
   • feedback system design
18. Orbit stability
   • not covered in the Pre-CDR but should be in the CDR
19. Polarization
   • not included for Higgs operation
   • but may be needed for Z operation
   • even for Higgs, we may need it for energy calibration
   • to investigate the options (e.g., Gai Wei’s scheme)
20. Source and linac

- a complete simulation for e+ beam: from the e- beam to target to capture to transport line to re-injection into the linac to acceleration to injection into the Booster
- If the requirement of 3 nC, 0.3 mm-mrad cannot be met, then a damping ring is needed in the CDR
- e+ beam return line design
- SLAC has offered us a 15 GeV linac including klystrons as well as two damping rings. We need a decision about whether we will take the offer. If yes, when and how.
- to include the study for Z operation, which needs higher beam current

21. Booster

- to mitigate low field injection problem: earth field shielding, to add SLAC’s linac, to add a pre-Booster
- To study saw-tooth effect, vacuum pipe, eddy current, machine imperfection, correctors, etc.
Pretzel Scheme
After adding pretzel orbit (with correction):

Solution need to be improved....

GENG Huiping
Main output parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design momentum</td>
<td>P0 = 120.00000 GeV</td>
</tr>
<tr>
<td>Energy loss per turn</td>
<td>U0 = 3117.5564 MV</td>
</tr>
<tr>
<td>Equilibrium position</td>
<td>dz = 34.554035 mm</td>
</tr>
<tr>
<td>Orbit dilation</td>
<td>dl = 0.0000000 mm</td>
</tr>
<tr>
<td>Bucket height</td>
<td>dV/P0 = 0.0599503</td>
</tr>
<tr>
<td>Imag. tune</td>
<td>-0.0000000</td>
</tr>
<tr>
<td>Real tune</td>
<td>0.0852147</td>
</tr>
<tr>
<td>Damping per one revolution</td>
<td>X: -2.226889E-02 Y: -1.290562E-02 Z: -1.626322E-02</td>
</tr>
<tr>
<td>Damping time (sec)</td>
<td>X: 8.484064E-03 Y: 1.463941E-02 Z: 1.161705E-02</td>
</tr>
<tr>
<td>Tuning factor</td>
<td>5 Y: -3.278430E-08 Z: 2.805327E-05</td>
</tr>
<tr>
<td>Damping partition number</td>
<td>X: 1.7317 Y: 1.0036 Z: 1.2647</td>
</tr>
<tr>
<td>Emittance X</td>
<td>= 3.77813E-9 m</td>
</tr>
<tr>
<td>Emittance Z</td>
<td>= 4.39763E-6 m</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>= 2.67407981 mm</td>
</tr>
<tr>
<td>Beam size xi</td>
<td>= 0.58021456 mm</td>
</tr>
</tbody>
</table>

GENG Huiping
Number of PC (with lifetrac)

Luminosity

Lifetime reduction due to transverse aperture
Beam Tilt Estimation

\[ \sigma_x = 69.97(\mu m) \approx 0.7 \times 10^{-4}(m) \]

\[ \Delta X_{\text{max}} \approx 1.16 \times 10^{-4}(m) \]

SUN Yuansheng
Interaction Region
Lattice of interaction region

- IR lattice design with local chromaticity correction with
  - $\beta_x^*=0.8\text{m}$, $\beta_y^*=3\text{mm}$, $\epsilon x=6.12\text{nm}$, $\kappa=0.3\%$, $L^*=1.5\text{m}$, 2IPs
  - latest lattice for head-on collision: FFS_3.0mm_v3.0_Nov_2015

![Diagram showing lattice design parameters and fields]
I break down and high order dispersion

- I break down and high order dispersion

additional sext at 1st image point* to control higher order chromaticity

- Many additional sextupoles in IR
- Idea from linear collider final focus*
- Six more sextupoles (3,4,5,8,9,10) to correct break down of –I transformation
- Three more sextupoles (2,6,7) help to correct the second order dispersion and so on

R. Brinkmann, DESY M-90-14, Nov 1990.

+(2,3,4,5,6,7,8,9,10) sextupoles
Weak-Strong Simulation with Lattice (LR\text{sext})
DA with 240 sextupole families in Arc with DAPWIDTH=15
Weak-Strong Simulation with Lattice (240sext)
Partial Double Ring
THE ‘BOWTIE’ DESIGN
by Michael Koratzinos (University of Geneva)

A solution that can accommodate $O(1000)$ bunches while keeping more than 90% of the ring with a single beam pipe.

Figure 1: Schematic of the ‘bowtie’ idea (not to scale).

IPAC’15, MITIGATING PERFORMANCE LIMITATIONS OF SINGLE BEAM-PIPE CIRCULAR e+e- COLLIDERS
## Primary parameter for CEPC double ring

(wangdou20160219)

<table>
<thead>
<tr>
<th></th>
<th>Pre-CDR</th>
<th>H-high lumi.</th>
<th>H-low power</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of IPs</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Energy (GeV)</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>45.5</td>
</tr>
<tr>
<td>Circumference (km)</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>SR loss/turn (GeV)</td>
<td>3.1</td>
<td>2.96</td>
<td>2.96</td>
<td>0.062</td>
</tr>
<tr>
<td>Half crossing angle (mrad)</td>
<td>0</td>
<td>14.5</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Piwinski angle</td>
<td>0</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>$N_e$/bunch (10$^{11}$)</td>
<td>3.79</td>
<td>2.85</td>
<td>2.81</td>
<td>2.67</td>
</tr>
<tr>
<td>Bunch number</td>
<td>50</td>
<td>50</td>
<td>67</td>
<td>40</td>
</tr>
<tr>
<td>Beam current (mA)</td>
<td>16.6</td>
<td>16.9</td>
<td>16.9</td>
<td>10.1</td>
</tr>
<tr>
<td>SR power /beam (MW)</td>
<td>51.7</td>
<td>50</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Bending radius (km)</td>
<td>6.1</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Momentum compaction (10$^{-5}$)</td>
<td>3.4</td>
<td>2.5</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>$\beta_p$ x/y (m)</td>
<td>0.8/0.0012</td>
<td>0.306/0.0012</td>
<td>0.25/0.00136</td>
<td>0.22/0.001</td>
</tr>
<tr>
<td>Emittance x/y (nm)</td>
<td>6.12/0.018</td>
<td>3.34/0.01</td>
<td>2.45/0.0074</td>
<td>2.67/0.008</td>
</tr>
<tr>
<td>Transverse $\sigma_P$ (um)</td>
<td>69.97/0.15</td>
<td>320/0.11</td>
<td>24.8/0.1</td>
<td>24.3/0.09</td>
</tr>
<tr>
<td>$\xi$/IP</td>
<td>0.118</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>$\xi$/IP</td>
<td>0.083</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>$V_{RF}$ (GV)</td>
<td>6.87</td>
<td>3.7</td>
<td>3.62</td>
<td>3.6</td>
</tr>
<tr>
<td>$f_{RF}$ (MHz)</td>
<td>650</td>
<td>650</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Nature $\sigma$ (mm)</td>
<td>2.14</td>
<td>3.3</td>
<td>3.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Total $\sigma$ (mm)</td>
<td>2.65</td>
<td>4.4</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>HOM power/cavity (kw)</td>
<td>3.6</td>
<td>3.3</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Energy spread (%)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Energy acceptance (%)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Energy acceptance by RF (%)</td>
<td>6</td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>$n_g$</td>
<td>0.23</td>
<td>0.49</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Life time due to beamstrahlung_cal (minute)</td>
<td>47</td>
<td>53</td>
<td>36</td>
<td>41</td>
</tr>
<tr>
<td>$F$ (hour glass)</td>
<td>0.68</td>
<td>0.73</td>
<td>0.82</td>
<td>0.69</td>
</tr>
<tr>
<td>$L_{max}$/IP (10$^{32}$cm$^2$s$^{-1}$)</td>
<td>2.04</td>
<td>2.97</td>
<td>2.96</td>
<td>2.07</td>
</tr>
</tbody>
</table>
CEPC Partial Double Ring Layout

IP1_ee/IP3_ee, 3.37Km
IP2_pp/IP4_pp, 892.8m
4 Short Straights, 141.6m?
4 Medium Straights, 466.4m
4 Long Straights, 892.8m
2 Short ARC, 24*FODO, 892.8m
4 Medium ARC, 132*FODO, 4910.4m
4 Long ARC, 144*FODO, 5356.8m

C=56145m

Bypass about 43.89m
Arc redesign-ultra low emittance

- Length of FODO cell: 37.2m
- Phase advance of FODO cells: 90/60 degrees
- Emittance: 2.52nm, $\alpha_p=1.05\times10^{-5}$
- Bunch length: 1.5168mm

Dispersion supressor:
- Angle(BDIS1)=3.5816546264E-3
- Angle(BDIS2)=8.59314326219E-4
- Angle(B0)=2.72235074352E-3
CEPC Local Double Ring Lattice (F. Su et al)

For CEPC 120GeV beam:
- Max. deflection per separator is 66μrad.

Using Septum Dipole after separator to acquire 13 mrad

Version 1.0
sufeng
2015.12.24-new
Orbit (RING3_DR_IP1) Version 1.1 + FFS(test20160115-2-Wangdou)

0.0625*12=0.75mrad
+4.25mrad
+5.49302mrad
=10.49302mrad

4.50608+10.49302=15mrad
0: 13\sigma x 55\sigma y 
0.01: 0 
0.02: 0

-0.8628% and 0.719% has DA, out is 0.

Dp/p=-0.1605%
Dp/p=0
Dp/p=0.1605%
Booster
CEPC booster lattice

- 47.2 meter FODO structure.
- Non-interleaved sextupole scheme.
- 10 FODOs make up a cell to cancel off-momentum particle’s beta beat effect.
- 8 folds symmetry
- 16 families sextupole are used to cancel second order chromaticity.
- DA of on-momentum and off-momentum are good enough for booster.
- 94.4 meter FODO structure is also trying

Tianjian Bian, Xiaohao Cui
Wiggling Bend Scheme

- The inject energy is 6GeV.
- If all the dipoles have the same sign, 33Gs@6GeV may cause problem.
- In wiggling bend scheme, adjoining dipoles have different sign to avoid the low field problem.
- Shorten the Damping times greatly.
- The picture below shows the FODO structure.
Main difference in parameters between Pre-CDR booster (old) and the alternating field booster (new)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Old@6GeV</th>
<th>New@6GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>U₀ [MeV/turn]</td>
<td>0.019</td>
<td>0.70</td>
</tr>
<tr>
<td>Damping times(x/y) [s]</td>
<td>115.61</td>
<td>3.12</td>
</tr>
<tr>
<td>Emittances(x) [πi nm]</td>
<td>0.015</td>
<td>0.11</td>
</tr>
<tr>
<td>Strength of dipole [Gs]</td>
<td>33</td>
<td>-164.3/+229.9</td>
</tr>
<tr>
<td>Beam offset in dipole[cm]</td>
<td>0</td>
<td>2.3</td>
</tr>
<tr>
<td>Length of dipole [m]</td>
<td>19.6*1</td>
<td>4.9*4</td>
</tr>
<tr>
<td>Length of FODO [m]</td>
<td>47.2</td>
<td>47.2</td>
</tr>
</tbody>
</table>
CEPC field error

- The multipole errors in the main ring seem to have a large effect on the 2% off-momentum DA.
- The field errors in the FFS seem to have a large effect on the vertical on-momentum DA.
- With all B,Q,S multipole errors in CEPC whole ring including FFS, the 2% off-momentum DA reduced to about $1/3\sim1/2$.
- With correctors and BPMs adding in the beam line, SAD hash table has no space. SAD can not deal with large ring.

Method 1: Optimization of DA (precondition: best DA without error)
- orbit correction (for misalignment errors)
- tune correction (for quad $B*L$ error)
- FMA analysis, add octupole, decapole, dodecapole…….
  Although could be corrected in simulation, may not the case in real situation……

Method 2: Reduce errors (maybe high level requirement in magnet manufature)
reduce the errors to the DA that we can accept

Sha Bai
MDI
MDI Status

• Develop MDIToolkit – uniform computing platform to establish the environment for MDI study on IHEP computing cluster.

• Background study: SR, Radiative Bhabha scattering, Beamstrahlung.

• With 2cm aperture collimator, lost particles of radiative Bhabha and beamstrahlung in IR after several machine turns can be effectively prevented, but need to be optimized.

• SC magnets are designed preliminarily. Conceptual design and magnetic field calculation.

• Anti-solenoid design is optimizing, set up solenoid model in accelerator software.
Local double ring MDI layout

Detectors (including silicon tracker, vertex detector, TPC etc on...) which are “far” from this region, should be same as in the single ring.
Summary

• We’ve made much progress after pre-CDR.
• Many problems have been “touched”.
• All work should converge to a self-consistent design.
• It is urgent to finish the CDR in the end of 2016.
• This page is blank
Multi-Objective Optimization with possible application in SuperKEKB

Y. Zhang and D. Zhou
Mar. 9th, 2016
Introduction

• This work was firstly excited by Oide’s talk.
  K. Oide, “A design of beam optics for FCC-ee”, 2015-09
  “255 sextupole pairs per half ring”

• Downhill Simplex is a local optimization algorithm

• We use a global optimization algorithm: Differential Evolution
  (Suggested by Ji Qiang@LBNL)

• Other popular algorithm: Genetic Algorithm, Particle Swarm
Differential Evolution

- The “DE community” has been growing since the early DE years of 1994 – 1996 (new)
- DE is a very simple population based, stochastic function minimizer which is very powerful at the same time.
- There are a few strategies, we choose ‘rand-to-best’. Attempts a balance between robustness and fast convergence.
  \[ v(i,j) = \begin{cases} 
  x(i,j) + F \times [x(b,j) - x(i,j)] + F \times [x(r1,j) - x(r2,j)], & \text{If } rand(j) < CR \\
  x(i,j), & \text{Otherwise} 
\end{cases} \]
- Different problems often require different settings for NP, F and CR
- F is usually (0.5,1) but according to our experience, maybe (0.1~0.5) better
Optimization with Algorithm
- Objective function

\[ \frac{x^2}{20^2} + \frac{z^2}{16^2} = 1 \]
- \( z \) for energy deviation in unit of \( \sigma_p \)
- \( x \) for transverse amplitude in unit of \( \sigma \)

- For \( z = \text{Range}[-15,15,3] \),

\[
\text{objective function} = \begin{cases} 
0, & \text{if aperture boundary is outside the ellipse} \\
\text{distance between the boundary and the ellipse}, & \text{otherwise}
\end{cases}
\]
The first test, with 240 sextupoles, 100 turns

V1, 100 turns

da = DynamicApertureSurvey[{{0, 0.25}, {0, 1.369}, Range[{-15, 15}, 3]}, 100, Output -> 6]

DynamicApertureSurvey[{{0, 0.25}, {0, 1.369}, z}, 100, Output -> 6]

Score: 129

Score: 182
CEPC: Dynamic Aperture Optimization with 240 sextupoles in ARC (v1-IR)
Tune
The multiple objective algorithm based on differential evolution is implemented referencing J. Qiang, IPAC’13.
More Objective in CEPC test

- DA with PhaseX->0, PhaseY->0
- DA with PhaseY->Pi/2, PhaseY->Pi/2
- Qx in [0, 0.5]
- Qy in [0, 0.5]
- ChromaticityX in [0, 5]
- ChromaticityY in [0, 5]

- DA: $\frac{x^2}{20^2} + \frac{y^2}{50^2} + \frac{z^2}{16^2} = 1$, for $z = 0$
- DA: $\frac{x^2}{20^2} + \frac{y^2}{50^2} + \frac{z^2}{16^2} = 1$, for $z = -5$
- DA: $\frac{x^2}{20^2} + \frac{y^2}{50^2} + \frac{z^2}{16^2} = 1$, for $z = +5$
A solution (not good enough, just a test)
We have to suppress the skew sextupole resonance, and enlarge the DA in the mean time. This is a multiple objective task.
Objective

- DA: \( \frac{x^2}{50^2} + \frac{z^2}{26^2} = 1 \) with PhaseX->0, PhaseY->0, for z=-26:2:26
- DA: \( \frac{x^2}{50^2} + \frac{z^2}{26^2} = 1 \) with PhaseX->\( \pi/2 \), PhaseY->\( \pi/2 \), for z=-26:2:26
- \( \frac{y}{\sigma_y} \) for a particle with initial coordinate \((5\sigma_x,0,0,0,0,0)\)
- \( \frac{|y-\langle y \rangle|}{\sigma_y} \) for a particle with initial coordinate \((5\sigma_x,0,0,0,0,0)\)
- Coupling Chromaticity: \( \sum |R_1R_4 - R_2R_3| \), for \( \delta = (-0.018, +0.018) \)

To correct the skew sextupole nonlinear terms, the skew sextupole strength symmetry in one pair is broken. Totally we use 24 skew sextupole.
Status of Optimization (1)
Status of Optimization (2)
Status of Optimization (3)
Status of Optimization (4)
It’s evolving
Other way to be tried

• Insert a skew sextupole pair before/after IP, the pair could cancel each other and help compensate the nonlinear resonance at IP. It is like the crab-waist scheme. This may need to change the linear optics. 😞

• If the DA with suppressed skew sextupole resonance is not good enough, we may need to optimize the sextupole strength further.
Summary

• DA optimization is a complicated problem
• DA is not the only objective. Chromaticity, coupling and even nonlinearity should also be well controlled. We have a multiple objective task.
• The multi-objective optimization has been used in light source machine (not only storage ring based) for a few years
• SuperKEKB team has developed powerful optimization tool.
• We wish the Multi-Objective-Differential-Evolution could also help the optimization of SuperKEKB
• The MODE is just a tool, no physics. Physics exist in the definition of objective function.
• The tool could only help us find the ‘ceiling’ of a design. But the ‘ceiling’ is determined by the design itself.