Possible layout for arc cells of HE-LHC

Demin Zhou and Yuri Nosochkov

Acknowledgements:

18th HE-LHC design meeting, CERN, Aug. 22, 2017
1. Possible layouts for the arcs of HE-LHC

➤ Arcs designed by Y. Nosochkov
  • 18x 60-deg (helhc_v102)
  • 20x 90-deg (helhc_v201) [Almost given up because of poor geometry fit to LHC layout]
  • 18x 80-deg (helhc_v300) [Preserve resonance cancelation condition: $4\times2\pi$]

➤ Possible modifications using the same layout of helhc_v102
  • 18x 90-deg [Preserve resonance cancelation condition if considering DS as a 90-deg cell: $4\times2\pi \Rightarrow$ Add sextuples to DSs, similar as LHC]
1. Possible layouts for the arcs of HE-LHC

Integration of various arcs with IRs of SLHC3.1a by Thys

- Official directory: /afs/cern.ch/eng/lhc/opRcs/HELHC
1. Possible layouts for the arcs of HE-LHC

» 18x 60-deg (helhc_v102 by Y.N.)

- LB=14.18m, LQ=3.1m, LS=0.369m
- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m
1. Possible layouts for the arcs of HE-LHC

➤ 18x 80-deg (helhc_v300 by Y.N.)

- LB=14.18m, LQ=3.1m, LS=0.369m
- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m
- Same geometry of helhc_v102
1. Possible layouts for the arcs of HE-LHC

➢ 18x 90-deg

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- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m
- Same geometry of helhc_v102
1. Possible layouts for the arcs of HE-LHC

- **20x 90-deg**
  - LB = 12.625 m, LQ = 3.1 m, LS = 0.369 m
  - LBQ = 2.36 m, LSB = 1.831 m, LQS = 0.16 m, LBB = 1.36 m
# 1. Possible layouts for the arcs of HE-LHC

- **FCC tech**: 16 T@B, 400 T/m@Q, 7800 T/m²@S

<table>
<thead>
<tr>
<th></th>
<th>LHC-like</th>
<th>18x60°</th>
<th>18x80°</th>
<th>18x90°</th>
<th>20x90°</th>
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</thead>
<tbody>
<tr>
<td>Arc cell phase</td>
<td>90/90</td>
<td>60/60</td>
<td>80/80</td>
<td>90/90</td>
<td>90/90</td>
</tr>
<tr>
<td>advance [deg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arc cell length [m]</td>
<td>106.958</td>
<td></td>
<td>137.233</td>
<td></td>
<td>124.8</td>
</tr>
<tr>
<td>K1 [m⁻¹]</td>
<td>0.027</td>
<td>0.0148</td>
<td>0.019</td>
<td>0.021</td>
<td>0.023</td>
</tr>
<tr>
<td>β_{max/min} [m]</td>
<td>181.3/31.5</td>
<td>236.7/79.5</td>
<td>227.7/50.0</td>
<td>233.0/40.4</td>
<td>211.7/36.8</td>
</tr>
<tr>
<td>η_{max/min} [m]</td>
<td>2.2/1.1</td>
<td>6.7/4.1</td>
<td>4.3/2.2</td>
<td>3.6/1.8</td>
<td>3.0/1.5</td>
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<tr>
<td>Dipole length [m]</td>
<td>14.3 [x6]</td>
<td></td>
<td>14.18 [x8]</td>
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<td>12.625 [x8]</td>
</tr>
<tr>
<td>Dipole field [T]</td>
<td>16.06</td>
<td></td>
<td>15.59</td>
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<td>15.92</td>
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<tr>
<td>@13.5TeV</td>
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<tr>
<td>Quad. gradient</td>
<td>391.7</td>
<td>214.8</td>
<td>276.2</td>
<td>303.9</td>
<td>334.7</td>
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<tr>
<td>[T/m] @13.5TeV</td>
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</tr>
<tr>
<td>Sext. gradient</td>
<td>4883</td>
<td>866</td>
<td>1824</td>
<td>?</td>
<td>2940</td>
</tr>
<tr>
<td>[T/m²] @13.5TeV</td>
<td></td>
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</tr>
<tr>
<td>Filling factor</td>
<td>0.802</td>
<td></td>
<td>0.827</td>
<td></td>
<td>0.809</td>
</tr>
</tbody>
</table>
1. Possible layouts for the arcs of HE-LHC

General scaling laws

- Assume ideal FODO cell [thin-lens, 100% filling factor]

\[
\sin\left(\frac{\Phi}{2}\right) = \frac{1}{4} K_1 L_{\text{cell}}
\]

\[
\beta_{\pm} = \frac{2 \left(1 \pm K_1 L_{\text{cell}}/4\right)}{K_1 \sqrt{1 - \left(K_1 L_{\text{cell}}/4\right)^2}}
\]

\[
\eta_{\pm} = \frac{4}{\rho K_1^2} \left(1 \pm K_1 L_{\text{cell}}/8\right)
\]

\[
K_{2\pm} = \frac{K_1}{\eta_{\pm}}
\]

Note:
Sextupole strength for chromaticity correction ONLY in arc cells.
IRs and DSs require higher \( K_2 \)
1. Possible layouts for the arcs of HE-LHC

- General scaling laws
  - Assume ideal FODO cell [thin-lens, 100% filling factor]
  - Use 18x60 layout:
    \[ \begin{align*}
    L_{\text{cell}} &= 137.233 \text{ m}, \\
    L_Q &= 3.1 \text{ m}, \\
    L_B &= L_{\text{cell}} / 2, \\
    L_S &= 0.369 \text{ m}, \\
    E &= 13.5 \text{ TeV}
    \end{align*} \]

![Field gradient of arc quadrupole vs. phase advance per cell](chart.png)
1. Possible layouts for the arcs of HE-LHC

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  - Use 18x60 layout:
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1. Possible layouts for the arcs of HE-LHC

➤ Check n1

- **“1-D” aperture** [Ref. J.B. Jeanneret and T. Risselada, LHC Project Note 66, 1996]
- **Parameters** [Ref. F. Zimmermann, 12th HE-LHC meeting, Apr.16, 2017]:
  - $L_x = 15$ mm, $t_x = (2+1)$ mm, $f_{arc} = 0.14$, $\delta_p = 8.6 \times 10^{-4}$, $\varepsilon_x = 2.5$ μm, $k_\beta = 1.05$

\[
n_{1x} = \frac{L_x - t_x - (1 + f_{arc})D_x \delta_p}{k_\beta \sigma_x}
\]

\[
\sigma_x = \sqrt{\beta_x \varepsilon_x}
\]
1. Possible layouts for the arcs of HE-LHC

➤ Check n1 at QF

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1. Possible layouts for the arcs of HE-LHC

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\[ E_{\text{inj}} = 0.45 \text{ TeV} \]
2. Summary

➤ “1-D” aperture n1

- In arcs, the limit in $n_1$ is at QF [Maximum $\beta_x$ and $\eta_x$]
- Very sensitive to dispersion function in arcs
- Inversely proportional to $[\varepsilon_x/E_{\text{inj}}]^{1/2}$
- Using nominal parameters of HE-LHC, $n_1=4.6/6.8/7.3$ for 60/80/90 deg per cell with the 18-cell arc layout
- Open question: What is the minimum $n_1$ for HE-LHC arcs, if we trust the simple “1-D” formula?
3. Strategy for HE-LHC design

➤ Task distribution

- Arc cells and DSs
- IR1 and IR5: Main experiment IRs
- IR3 and IR7: collimation
- IR4 and IR6: RF and beam dump
- Full lattice: Global matching&optimization/chromaticity correction/toolkits
- Beam-beam issues
- Collective effects
- ... ...
3. Strategy for HE-LHC design

➤ Iterative design process

● Step 1: Create arc cells, adjust DSs, matching to SLHC IRs [respect to LHC geometry]
● Step 2: IR design/update, repeat Step 1
● Step 3: Global matching&optimization/chromaticity correction
● Step 4: DA calculations with errors
● Step 5: Check challenges (technical and beam physics), if hit show-stopper, restart from Step 1
● Step 6: Collimation and other sub-system design/update (electron lens, crab cavity, etc.)
3. Strategy for HE-LHC design

➤ Two series of meetings

➤ Design meeting: roughly every two weeks
  ● Overview of optics design
  ● Infrastructure
  ● Hardware, technologies, etc.
  ● Acc. physics-hardware “interfaces”
  ● …

➤ Optics meeting: tentatively weekly
  ● Focus on accelerator physics
  ● Optics design of arcs and IRs
  ● Optics matching/tuning/optimization
  ● Acc. physics simulations
  ● … …