Protected aperture in HL-LHC

R. Bruce, S. Redaelli
Acknowledgement: C. Bracco, R. De Maria, A. Lechner

2017.09.26
Introduction

- Continuous effort to improve collimation hierarchy and hence reach in $\beta^*$
  - Tighter collimators => smaller protected normalized aperture => smaller $\beta^*$ allowed
  - Main limitation in the LHC was in Run I and 2015 the risk of damaging tertiary collimators / triplets during asynchronous beam dumps
Introduction

- Significant improvement in $\beta^*$-reach in the LHC in 2016 / 2017
  - matched phase advance between MKD-TCT
  - Removes risk of TCTs being hit and damaged by primary impacts during asynchronous beam dumps

Application to HL-LHC?

- Can we profit of this experience to improve the $\beta^*$-reach in the HL-LHC?
- Possibilities discussed previously: R. De Maria in WP2 meeting 1/11/2016, R. Bruce in ColUSM 11/11/2016, R. Bruce at Chamonix 26/1/2017
- Published CERN report CERN-ACC-2017-0051
- In new version optics HL-LHC v1.3: MKD-TCT phase significantly improved
- Today: status of protected aperture in HL-LHC for different phase advance
Studies of TCT losses during asynch dump

- As for LHC, use phase-space integration to estimate losses on TCTs for each bunch during dump failure (type 2 single-module pre-fire – worst case).
  - Integrate beam distribution over phase space area caught by studies bottleneck
  - Fast study which does not require full optics for every studied case
  - Disadvantage: does not treat secondary impacts.
Present baseline: TCSP is at 10.1 $\sigma$, TCDQ at 10.6 $\sigma$, but likely that TCDQ can be tightened to 10.1 $\sigma$ (2.5 um emittance)

- We don’t think we can move in TCDQ further due to robustness constraints (C. Bracco, A. Lechner)
  - Decreasing margin TCP-TCSG doesn’t bring a gain at the moment
  - As function of MKD-TCT phase, study how TCT and aperture can be tightened
TCT losses vs phase and setting

- Parametric study over phase and TCT opening, keeping the protection device (TCSP/TCDQ) fixed at $10.1 \sigma$, normalized to $2.2e11$ p/bunch

- Next step: find intersection with damage limit for each phase and relate to setting

- Using previously calculated limit of plastic deformation ($5e9$ protons, E. Quaranta et al. PRSTAB 20, 091002 2017) with additional factor 2 safety margin
  - Further margin: Plastic deformation should not require exchange of collimator – can use $5^{th}$ axis
Allowed TCT setting and aperture in operation

- TCT must operate sufficiently far outside the setting @ damage
- Calculate operational setting and allowed aperture with methods used for LHC (PRSTAB 18, 061001 (2015)) accounting for orbit, β-beat, setup error etc.
- **Note**: aperture from asynch dump only. Cleaning limits anyway to around 10.1 sigma

![Graph of HL-LHC, 10.1σ cut in IR6](image)

Worst case: aperture=14.6 σ
Best case: aperture=11.2 σ below 20 deg.
Note: 2.5 um emittance
# Protected aperture vs MKD-TCT phase

<table>
<thead>
<tr>
<th>$\Delta \mu$ MKD-TCT</th>
<th>Protected aperture ($\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LHC, $\epsilon_n$ = 3.5 $\mu$m</td>
</tr>
<tr>
<td>0°</td>
<td>9.5</td>
</tr>
<tr>
<td>10°</td>
<td>9.5</td>
</tr>
<tr>
<td>20°</td>
<td>9.5</td>
</tr>
<tr>
<td>30°</td>
<td>10.0</td>
</tr>
<tr>
<td>40°</td>
<td>10.9</td>
</tr>
<tr>
<td>50°</td>
<td>11.7</td>
</tr>
<tr>
<td>60°</td>
<td>12.3</td>
</tr>
<tr>
<td>70°</td>
<td>12.3</td>
</tr>
<tr>
<td>80°</td>
<td>12.3</td>
</tr>
<tr>
<td>90°</td>
<td>12.3</td>
</tr>
</tbody>
</table>
### Phase advance in HL-LHC v1.3

<table>
<thead>
<tr>
<th>optics</th>
<th>TCT6 IR1 B1</th>
<th>TCT6 IR5 B1</th>
<th>TCT6 IR1 B2</th>
<th>TCT6 IR5 B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-LHC v1.2 15 cm</td>
<td>106</td>
<td>285</td>
<td>137</td>
<td>101</td>
</tr>
<tr>
<td>HL-LHC v1.3 15 cm</td>
<td>180</td>
<td>155</td>
<td>154</td>
<td>152</td>
</tr>
</tbody>
</table>

- For **HL-LHC v1.2** optics: aperture should be above $14.6\,\sigma$.
- For **HL-LHC v1.3** optics: aperture should be above $11.9\,\sigma$. 

R. Bruce, 2017.09.26
Proposed new collimation hierarchy for v1.3

<table>
<thead>
<tr>
<th>Collimator</th>
<th>Setting (LHC – 3.5 μm)</th>
<th>Setting (HL – 2.5 μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP7</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>TCS7</td>
<td>7.7</td>
<td>9.1</td>
</tr>
<tr>
<td>TCSP6</td>
<td>8.5</td>
<td>10.1</td>
</tr>
<tr>
<td>TCDQ6</td>
<td>8.5</td>
<td>10.1</td>
</tr>
<tr>
<td>TCT IR1/5</td>
<td>8.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Aperture IR1/5</td>
<td>10.0</td>
<td>11.9</td>
</tr>
</tbody>
</table>
Translate aperture in $\beta^*$-reach

- Below 20 deg phase advance, we can almost recover 15 cm and 295 urad
- For 30 deg phase, reach in $\beta^*$ is between 16 cm and 17 cm
- Need to also decrease crossing angle to recover
- At 30 deg: 250 urad (10.6 $\sigma$ BB separation) gives enough aperture for $\beta^*$ =15 cm
TCT asynch dump losses from SixTrack

- Simulating type 2 single-module pre-fire with SixTrack
  - Full magnetic tracking with collimation system in place
  - Method described in *NIMA 848 (2017) 19–30*
- As expected, only secondary impacts on TCTs over studied range of settings in HL-LHC v1.3
Conclusions

- One main limitation for protected aperture and $\beta^*$ has been risk of damage on TCTs and triplets during asynch dumps
- Studied how limitation varies as function of MKD-TCT phase
- In HL-LHC v1.3, mitigated with good phase advance MKD-TCT as in LHC
- Protected aperture for HL-LHC v1.3 is estimated at 11.9 $\sigma$
- $\beta^*$=15 cm can be recovered in this optics if 250 $\mu$rad crossing is used