Simulations of losses during asynch dump on TCTs in HL-LHC (work in progress)

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Introduction

- In 2016, decreased $\beta^*$ significantly to 40 cm
  - Prerequisite: improved MKD-TCT phase advance, so that TCTs can be operated at smaller retraction from TCDQ
  - Did series of asynch dump test to verify assumptions
  - Conclusion (measurements and simulations): TCT losses do not depend strongly on TCT setting with good phase, while they do with bad phase

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\begin{align*}
\text{NIM A 848 (2017) 19–30}
\end{align*}
\]
Gain for HL-LHC?

- In ColUSM 11/11/2016, showed potential to use MKD-TCT phase advance to improve reach in $\beta^*$, as in LHC
  - With good phase advance (< 30 deg from 0 or 180), TCTs do not risk damaging losses during asynch dump and can be moved in closer to the beam, gaining aperture margin
- In new optics v1.3, this strategy was implemented (WP2)

<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</td>
<td>106</td>
<td>285</td>
<td>137</td>
<td>101</td>
</tr>
<tr>
<td>15 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HL-LHC v1.3</td>
<td>180</td>
<td>155</td>
<td>154</td>
<td>152</td>
</tr>
<tr>
<td>15 cm</td>
<td></td>
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</tbody>
</table>
Additional considerations

- Question raised whether the 2-TCT layout still needed
  - Integration issues exist in cell 4
  - Special designs needed for TCTPHX.4 (2-in-1: similar to TCLX) and TCTPV (larger stroke)

- This talk: simulations of TCTs and triplet losses during asynch dumps in different HL-LHC optics
  - Comparison of protection between different TCT configurations
  - Investigate if we can profit of better phase advance as in LHC to gain in beta* and recover baseline
Simulation setup

- Using SixTrack with collimation, one simulation per bunch (different kick angles)
- Baseline HL collimator settings (CERN-ACC-2017-0051)
  - Explore different TCT configurations and optics
  - TCT4, TCT6 or TCT5 (installed just upstream of Q4)
- On second turn, bunch receives kicks from each MKD
- Single module pre-fire type 2 assumed (waveforms provided by M. Fraser)
- Post-processing: sum losses over all bunches, normalize to HL bunch intensity at top energy 2.2E11
Results: HL-LHC v1.2, $\beta^*=15$ cm

- Worst case: IR5 B2
- All collimators kept constant, scan in TCT setting, TCT4+6 both in
- Conclusion: risk for damaging losses with imperfect (smaller) TCT setting ("bad" phase)
Results: HL-LHC v1.3, $\beta^*=15$ cm

- All collimators constant but scan in TCT4 and TCT6 one at a time
- As expected: losses now approximately independent of TCT setting ("good" phase)
- Could consider to move in TCTs to level of TCSP/TCDQ to gain aperture, as hoped / expected.
Distinguish primary and secondary losses

- Dominated by less dangerous secondary losses

![Graph showing the number of impacting protons vs TCT setting (\(\sigma\))](image)
Protection of triplet, HL-LHC v1.2, $\beta^* = 15$ cm

- Assume IR6 open – TCT should still protect triplet
- Scan TCTs outwards, one TCT at a time
- As TCTs move out, losses increase in triplet
- TCT6 seems slightly better at protecting the triplet – why?
Phase space of TCTs / triplets

- TCT4 is closer to triplet in phase
- TCT6 is closer to 90 deg (102 deg, phase increasing downstream)
- At the same setting in $\sigma$, TCT6 intercepts slightly more of the core than TCT4
- When TCT is more open than triplet (in $\sigma$), TCT6 protects better
- If phase would be between 0 and 90 deg, TCT4 would instead protect better
Phases: IR5 B2 TCTs, HL-LHC v1.2, $\beta^*=15$ cm

- A few degrees of phase advance between TCT6 and triplet

<table>
<thead>
<tr>
<th>Element</th>
<th>Fractional phase advance from MKD.O</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCTPH.6R5.B2</td>
<td>101.5</td>
</tr>
<tr>
<td>TCTPH.5R5.B2</td>
<td>102.7</td>
</tr>
<tr>
<td>TCTPH.4R5.B2</td>
<td>103.5</td>
</tr>
<tr>
<td>Q3R5</td>
<td>104.1</td>
</tr>
<tr>
<td>Q2R5</td>
<td>104.2</td>
</tr>
<tr>
<td>Q1R5</td>
<td>104.3</td>
</tr>
</tbody>
</table>
Triplet losses (log scale)

- When TCT setting is inside triplet aperture, TCT4 protects better (direct shadowing at almost same phase)
Decomposition of triplet losses

- As triplet is also at bad phase, it starts intercepting primary losses when the TCT is open enough
  - In these simulations, IR6 open
Protection of triplet, HL-LHC v1.3, $\beta^*=15$ cm

- Now doing same study in v1.3. IR6 open
- Worse triplet losses due to smaller triplet aperture (57.65 mm vs 59.5 mm)
Protection of triplet, HL-LHC v1.3, $\beta^*=15$ cm

- Redoing study also with IR6 at nominal setting
- Only secondary losses reach triplet, orders of magnitude below previous case
TCDQ at same setting as TCSP?

- Cases shown so far assume TCDQ at 10.6 $\sigma$ and TCSP at 10.1 $\sigma$
- Recent studies C. Bracco, A. Lechner: maybe we could allow TCDQ also at 10.1 $\sigma$?
- Significantly reduces the secondary protons exiting IR6
- Triplet losses below simulated statistics
Conclusions

- Simulated with SixTrack type 2 single-module pre-fire with several configurations of TCT settings and optics for HL-LHC
- IR5 B2 worst case
- HL-LHC v1.3: Improved phase advance.
  - Very large improvement in losses on TCTs / triplets compared to v1.2 seen
  - Only secondary protons reach TCTs in realistic cases
  - Still B1 to be redone. Have only older optics version with worse phase
- With optics v1.2 and v1.3 (90< MKD phase advance< 180), TCT6 can better protect the triplet than TCT4.
  - Could be the opposite if the optics is changed
- Setting the TCDQ to the same opening as TCSP reduces the secondary losses on TCTs / triplets very significantly