Protected aperture in HL-LHC

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Acknowledgement: C. Bracco, R. De Maria, A. Lechner

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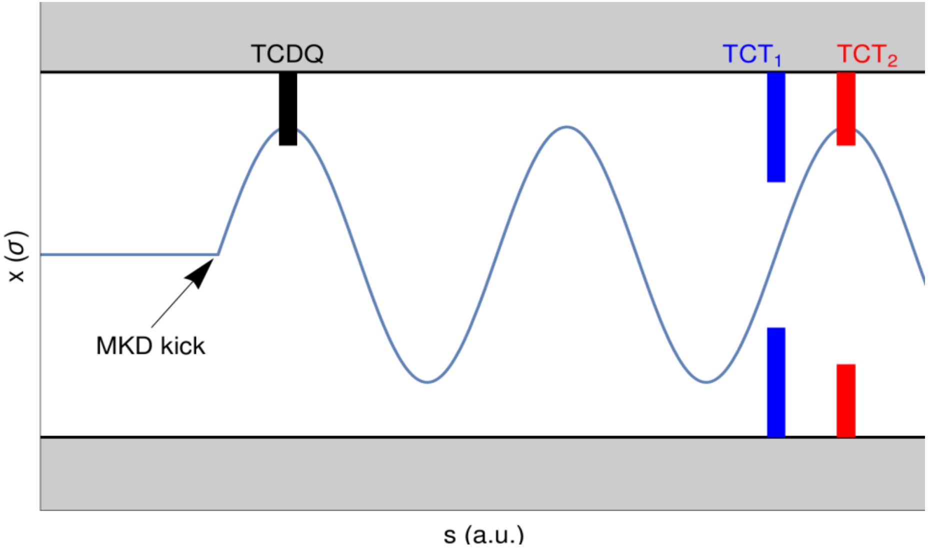
Introduction

- Continuous effort to improve collimation hierarchy and hence reach in β*
  - Tighter collimators => smaller protected normalized aperture => smaller β* 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 β*-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



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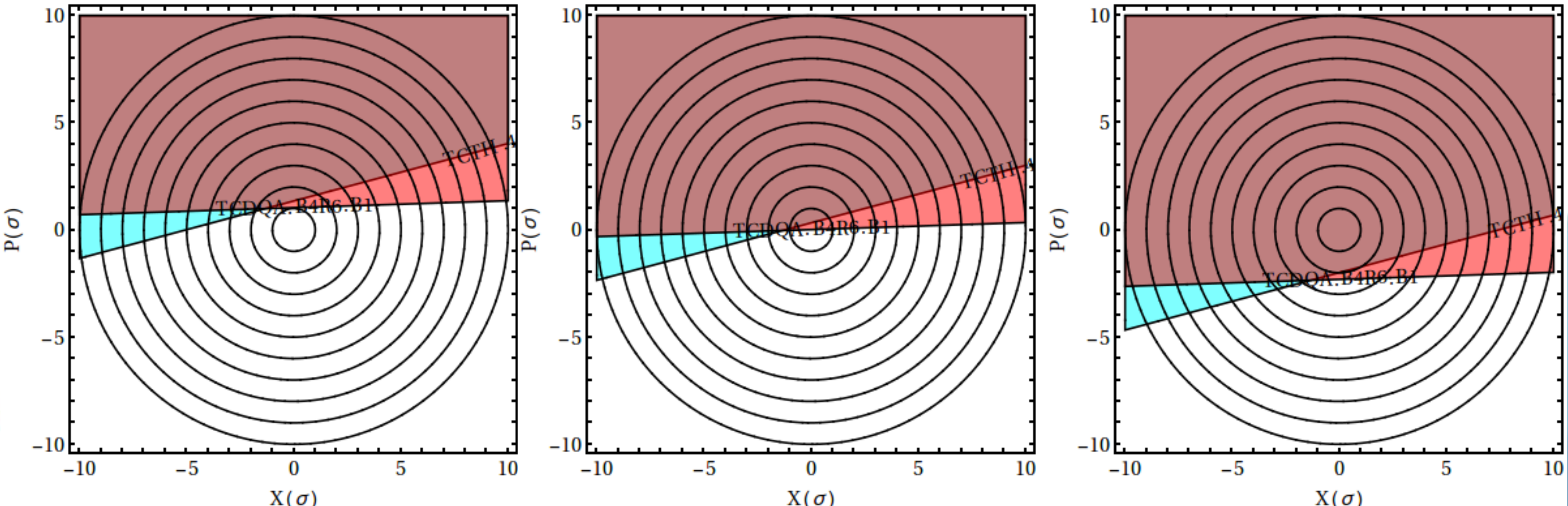
Application to HL-LHC?

- Can we profit of this experience to improve the β*-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.



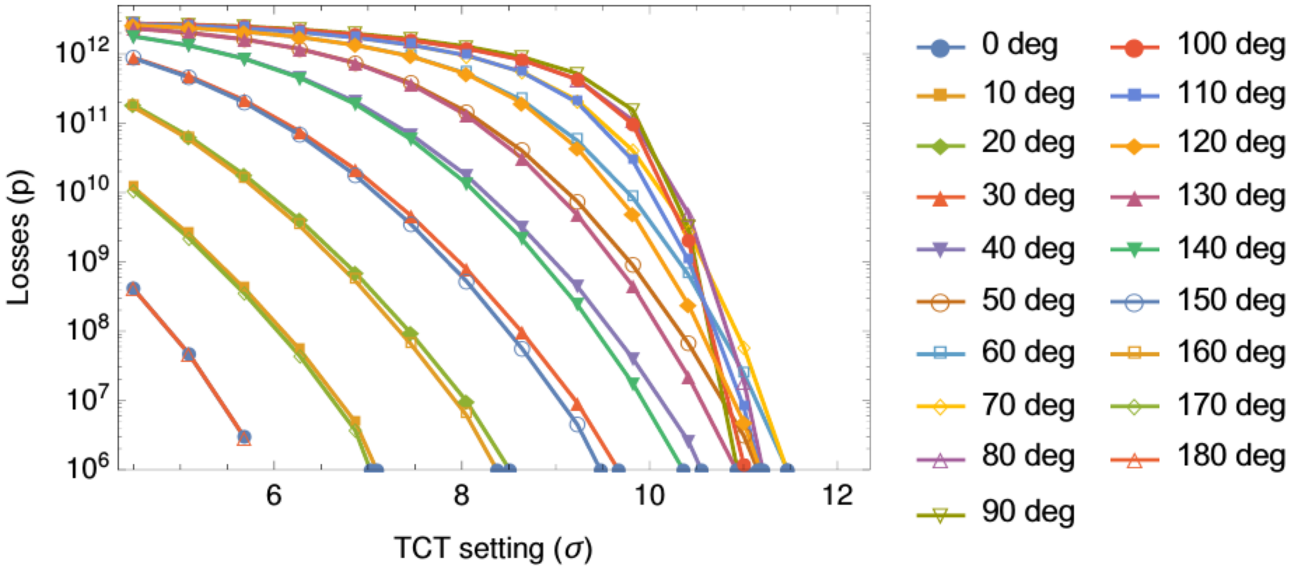
HL-LHC collimator settings, v1.2

	Setting in σ, $\epsilon_n = 3.5\,\mu$m	Setting in σ, $\epsilon_n = 2.5\,\mu$m
TCP7	5.7	**6.7**
TCS7	7.7	**9.1**
TCSP6	8.5	**10.1**
TCDQ6	9.0	**10.6**
TCT	10.9	**12.9**
aperture	12.3	**14.6**

- Present baseline: TCSP is at 10.1 σ, TCDQ at 10.6 σ, but likely that TCDQ can be tightened to 10.1 σ (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

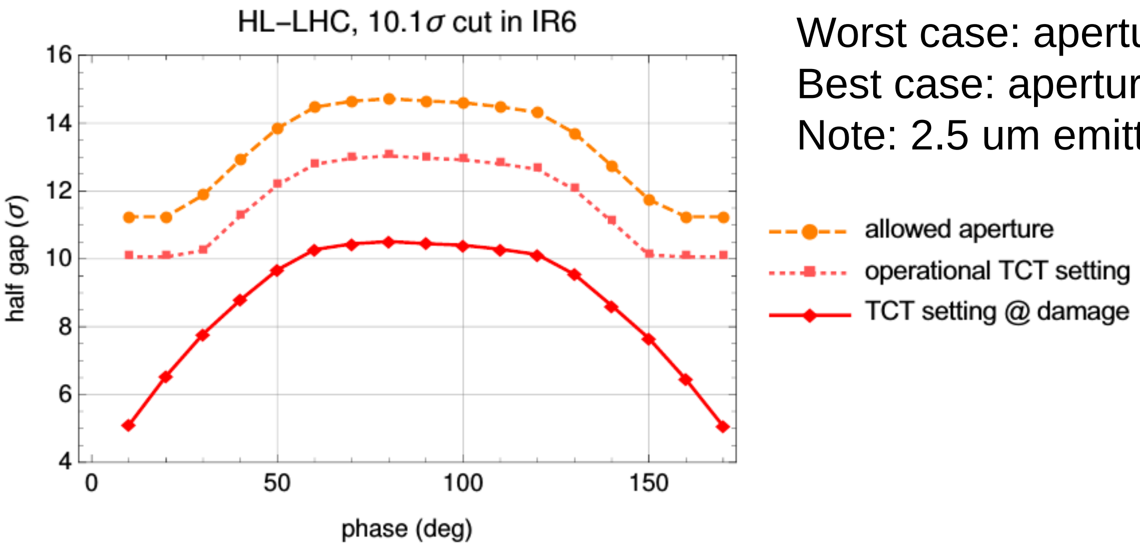
TCT losses vs phase and setting

- Parametric study over phase and TCT opening, keeping the protection device (TCSP/TCDQ) fixed at 10.1 σ, 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 5th 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



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

$\Delta\mu$ MKD-TCT	Protected aperture (σ)	
	LHC, ϵ_n =3.5 μm	**HL-LHC, ϵ_n =2.5 μm**
0°	9.5	**11.2**
10°	9.5	**11.2**
20°	9.5	**11.2**
30°	10.0	**11.9**
40°	10.9	**12.9**
50°	11.7	**13.8**
60°	12.3	**14.5**
70°	12.3	**14.6**
80°	12.3	**14.6**
90°	12.3	**14.6**

Phase advance in HL-LHC v1.3

optics	TCT6 IR1 B1	TCT6 IR5 B1	TCT6 IR1 B2	TCT6 IR5 B2
HL-LHC v1.2 15 cm	106	285	137	101
HL-LHC v1.3 15 cm	180	155	154	152

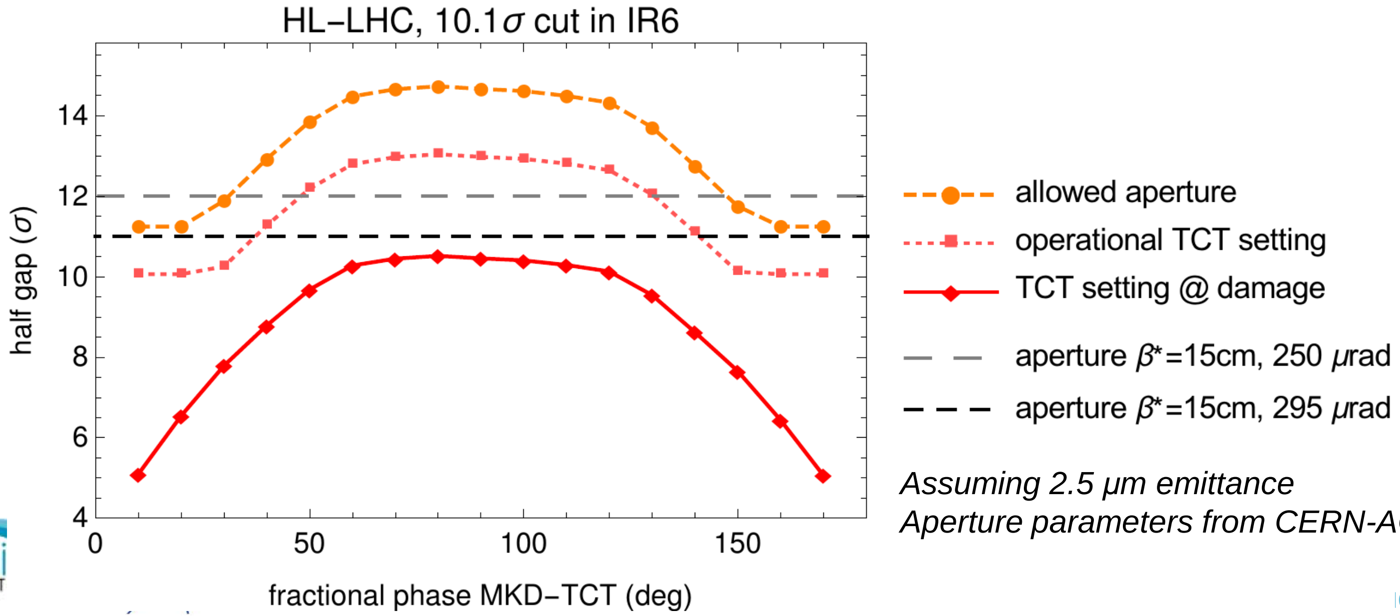
- For **HL-LHC v1.2** optics: aperture should be above **14.6 σ**.
- For **HL-LHC v1.3** optics: aperture should be above **11.9 σ**.

Proposed new collimation hierarchy for v1.3

Collimator	Setting (LHC – 3.5 µm)	Setting (HL – 2.5 µm)
TCP7	5.7	**6.7**
TCS7	7.7	**9.1**
TCSP6	8.5	**10.1**
TCDQ6	8.5	**10.1**
TCT IR1/5	8.8	**10.4**
Aperture IR1/5	10.0	**11.9**

Translate aperture in β*-reach

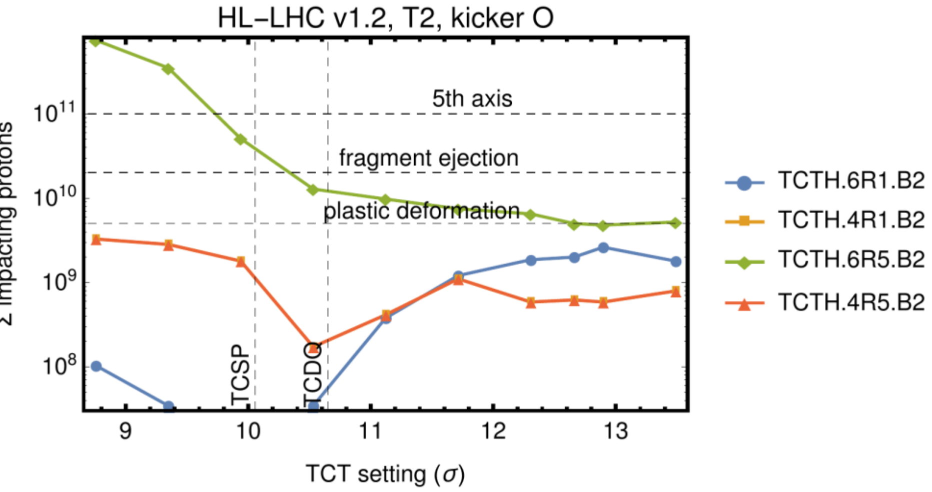
- Below 20 deg phase advance, we can almost recover 15 cm and 295 urad
- For 30 deg phase, reach in β* is between 16 cm and 17 cm
- Need to also decrease crossing angle to recover
- At 30 deg: 250 urad (10.6 σ BB separation) gives enough aperture for β* =15 cm

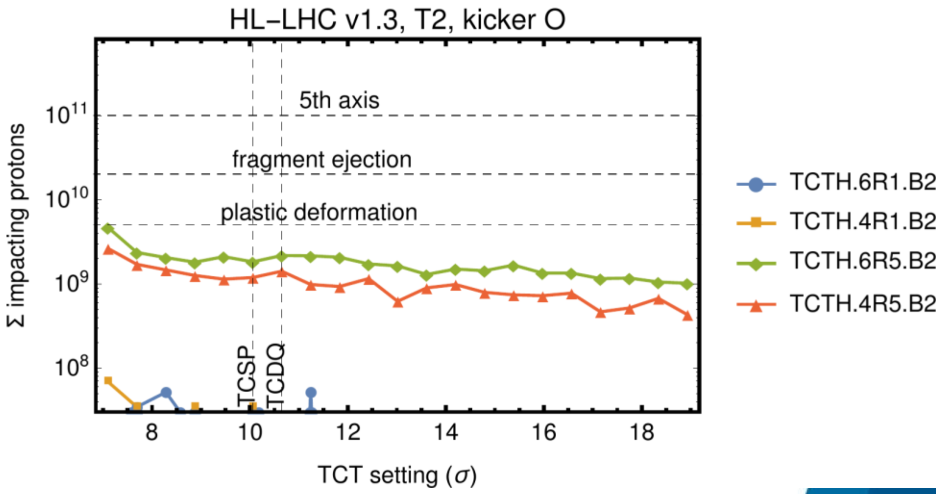


Assuming 2.5 μm emittance
Aperture parameters from CERN-ACC-2017-0051

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 *NIM A 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 β* 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 σ
- β*=15 cm can be recovered in this optics if 250 μrad crossing is used