Preliminary considerations on MKD-TCT phase advance for HL-LHC
(work in progress)

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Introduction

- Significant improvement in beta*-reach in the LHC in 2016, thanks to matched phase advance between MKD-TCT
  - Removes risk of TCTs being hit and damaged by primary impacts during asynchronous beam dumps
- Improvements also from tighter collimation hierarchy and smaller beam-beam separation
Experimental validation of phase advance

- Compared several asynchronous dump tests with different TCT settings and optics
- As expected, with the 2016 40 cm optics, TCT losses are flat vs setting (showing most critical LHC case of IR1 B1)
Application to HL-LHC?

- Can we profit of this experience to improve the $\beta^*$-reach in the HL-LHC?
  - Worst phase advance MKD-TCT in optics v 1.2 is around 100 deg. What would be the gain if we could improve?
  - What would be the gain if we could tighten the collimation hierarchy and decrease beam-beam separation?
  - First considerations presented by R. De Maria in WP2 meeting 1/11/2016
TCT setting and phase

- As for LHC, use phase-space integration to estimate losses on TCTs for each bunch during asynch dump.
  - Fast study which does not require full optics for every studied case
  - Disadvantage: does not treat secondary impacts.
  - Recent studies by E. Quaranta et al.: secondary impacts are not always harmless. Further studies needed.
TCT losses vs phase and setting

- Parametric study over phase and TCT opening, keeping the protection device (TCSP/TCDQ) fixed at 8.5 sigma, normalized to 2.2e11 p/bunch
  - Present baseline: TCSP is at 8.5 sigma, TCDQ at 9 sigma. Discussions with LBDS team on whether TCDQ can be tightened
- Next step: find intersection with damage limit for each phase and relate to setting
TCT setting @ damage vs phase

- Using previously calculated limit of plastic deformation (5e9 protons, A. Bertarelli et al. in 2013 MPP workshop) with additional factor 2 safety margin
  - Further margin: Plastic deformation should not require exchange of collimator – can use 5th axis
  - Next damage level, with fragment ejection, is factor 4 higher
  - Under study: further refinement of damage limits (E. Quaranta et al.)

Worst: 8.9 sigma @ 80 deg

TCDQ @ 8.5σ, 2.2×10^{11} p/bunch
Allowed TCT setting and aperture in operation

- TCT must operate sufficiently far outside the setting @ damage
- With standard calculation method for calculating margins from orbit, $\beta$-beat etc.
  - Assume 1 mm orbit and 10% beta-beat.
  - Note: more optimistic than the parameters used for aperture
  - Note: aperture from asynch dump only. Cleaning limits anyway to around 9.5 sigma

Worst case: aperture=12.3 $\sigma$

Note: 3.5 um emittance
Allowed TCT setting – larger tolerances

- Using 2mm orbit and 20% beta-beat
- Assuming 2mm at both TCDQ and TCT, and summing in square, need 3.6 $\sigma$ orbit margin

![Graph showing allowed aperture, operational TCT setting, and minimum TCT setting for HL-LHC, 8.5$\sigma$ cut in IR6, 2mm orbit, 20% $\beta$-beat.]
For $\beta^*$-reach: calculate aperture

- Using apertures from R. De Maria, WP2 meeting 1/11/2016, including all knobs, as “measured” and scale with crossing and $\beta^*$ as for present LHC
  - Scaling agrees with MADX within 0.1 sigma
  - Watch out: With a large separation, aperture bottleneck can move to the 45-deg part of the octagon – method not valid there
Baseline protected aperture

HL aperture vs $\beta^*$ (3.5 um emittance)
Reach in $\beta^*$ vs phase

- For the protected aperture at each phase, use analytic aperture scaling to determine $\beta^*$
- Using 1mm orbit / 10% beta-beat for determining TCT setting
- Including also result with 1σ closer TCDQ – not sure that the TCDQ robustness allows this

![Graph showing $\beta^*(m)$ vs Phase (deg)]
Reach in $\beta^*$ vs phase, 2mm orbit
Conclusions

- Preliminary studies of beta*-reach shown
- With baseline collimation settings, reach is just above 20 cm for 90 deg phase
  - Tolerances TCT setting calculation to be verified – use the same as for aperture calculation?
- We can achieve 15 cm again by using phase advance MKD-TCT, possibly in combination with tighter collimation hierarchy and smaller beam-beam separation
  - If previous tolerances are used, we don’t gain much below 30 deg
  - If we use larger tolerances (2 mm orbit), we could continue to gain below.
  - TCDQ setting to be verified with LBDS
- Any case selected for further study, based on the fast methods, should be checked for aperture and TCT losses using full calculation / simulation