Triplet and TCT protection during asynchronous dump in HL-LHC

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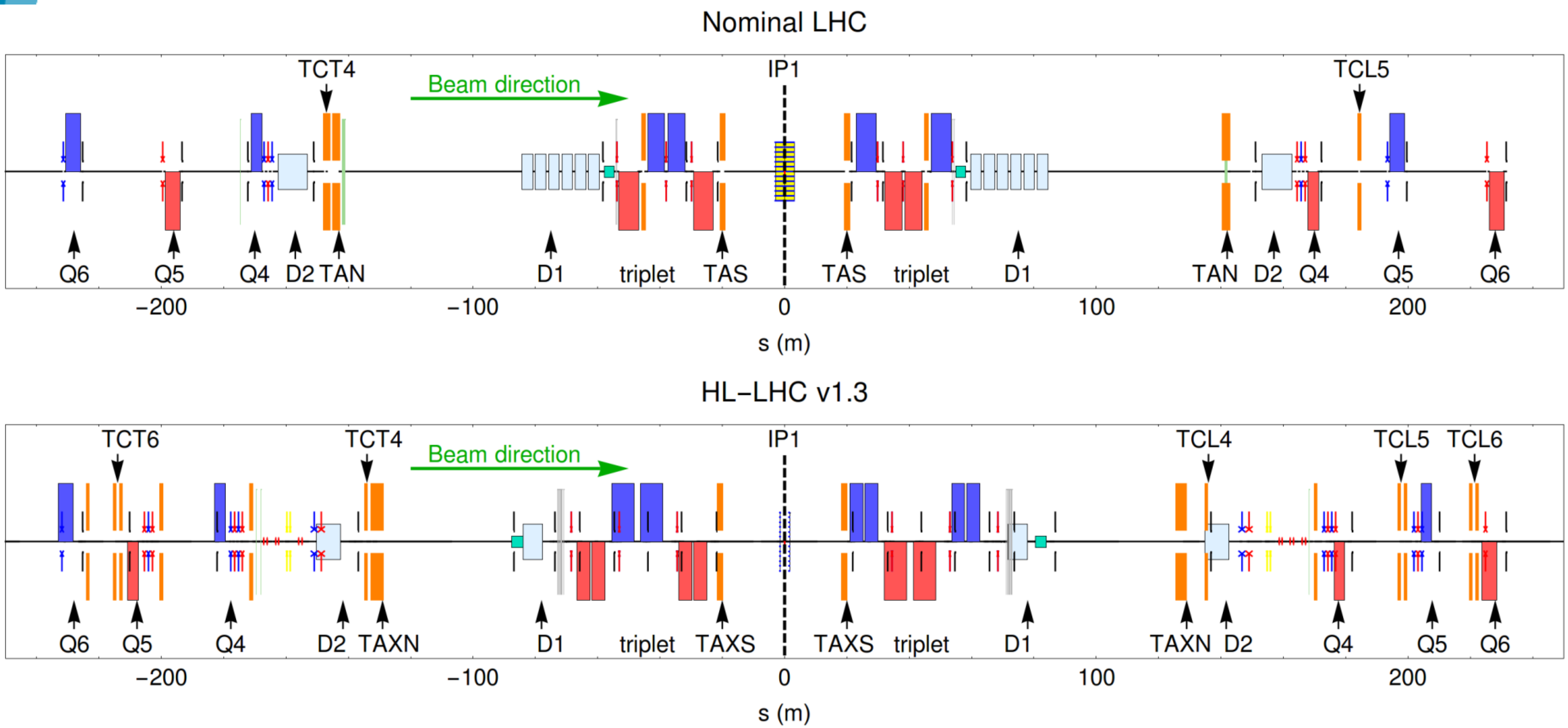
Acknowledgement: C. Bracco, F. Cerutti, S. Mallows, A. Mereghetti, E. Quaranta, A. Sbrizzi, A. Tsinganis

HL-LHC TCC 4/5/2017

Introduction

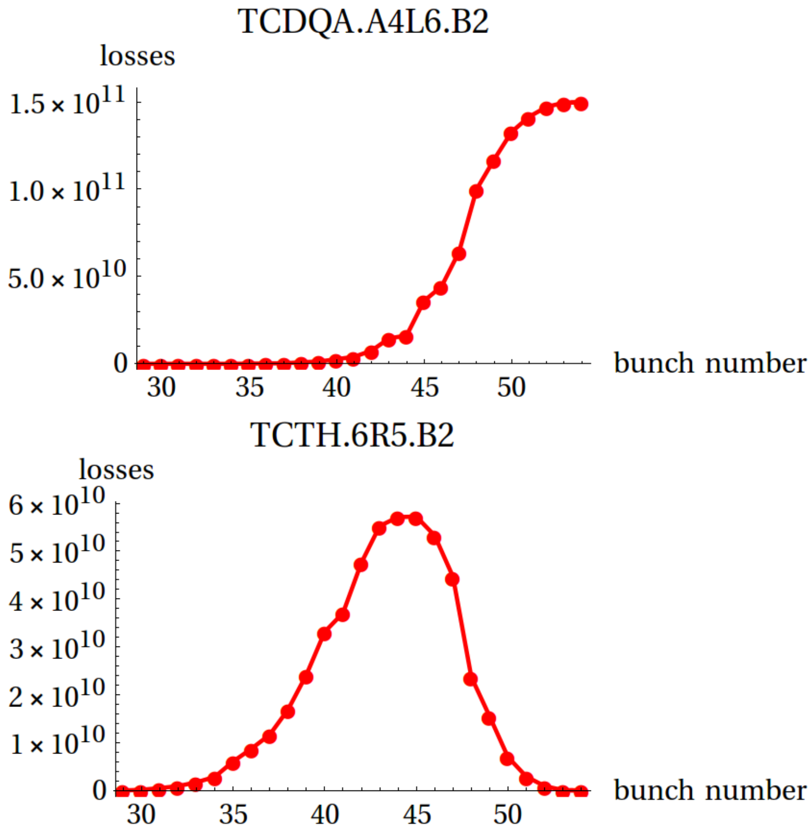
- Risk of hitting and damaging sensitive elements during asynchronous beam dumps
  - TCTs and triplets most exposed, need to stay sufficiently far behind the dump protection
  - Lower limit on normalized triplet aperture => limit on β^* => major performance limitation of the LHC
- Need to study asynchronous beam dumps in detail also for HL-LHC. Limits on performance?

IR layout in HL v1.3



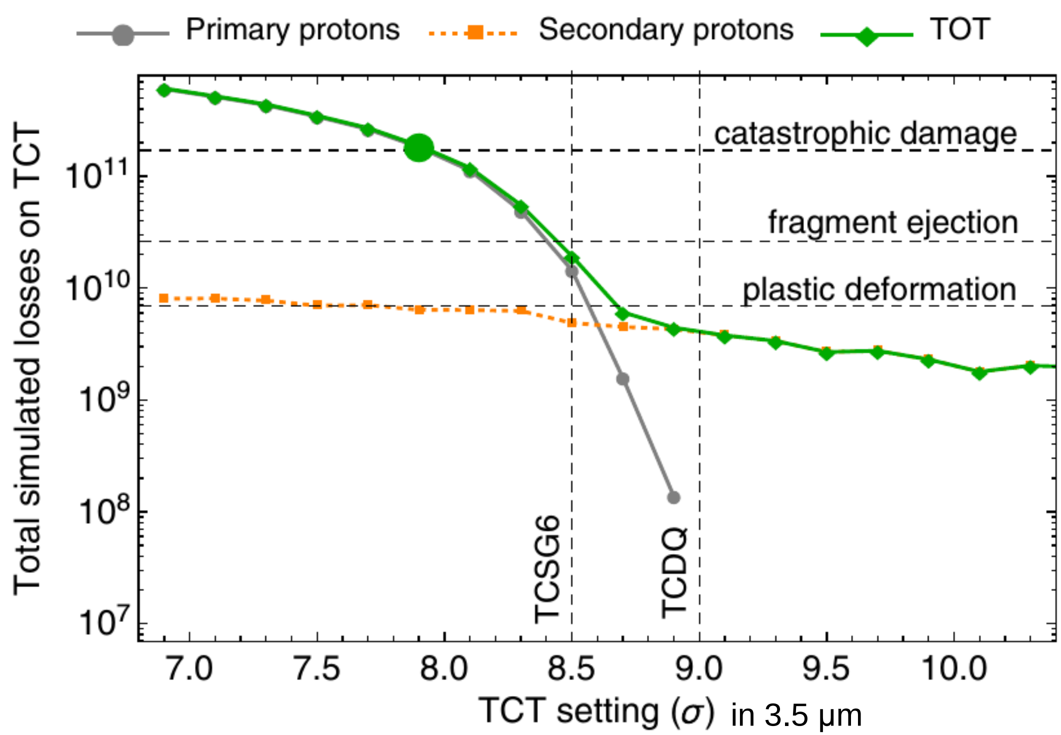
Simulation setup for asynch. dump

- Studies with SixTrack, several bunches receiving different kicks tracked separately, full collimation system in place
- First bunches: small kicks, pass through the whole ring
- Later bunches: large kicks, hit TCDQ, TCDS or are extracted
- Intermediate range of bunches risk to hit TCTs and aperture
- Need to simulate only these bunches



Recap: previous simulations of asynch. dump

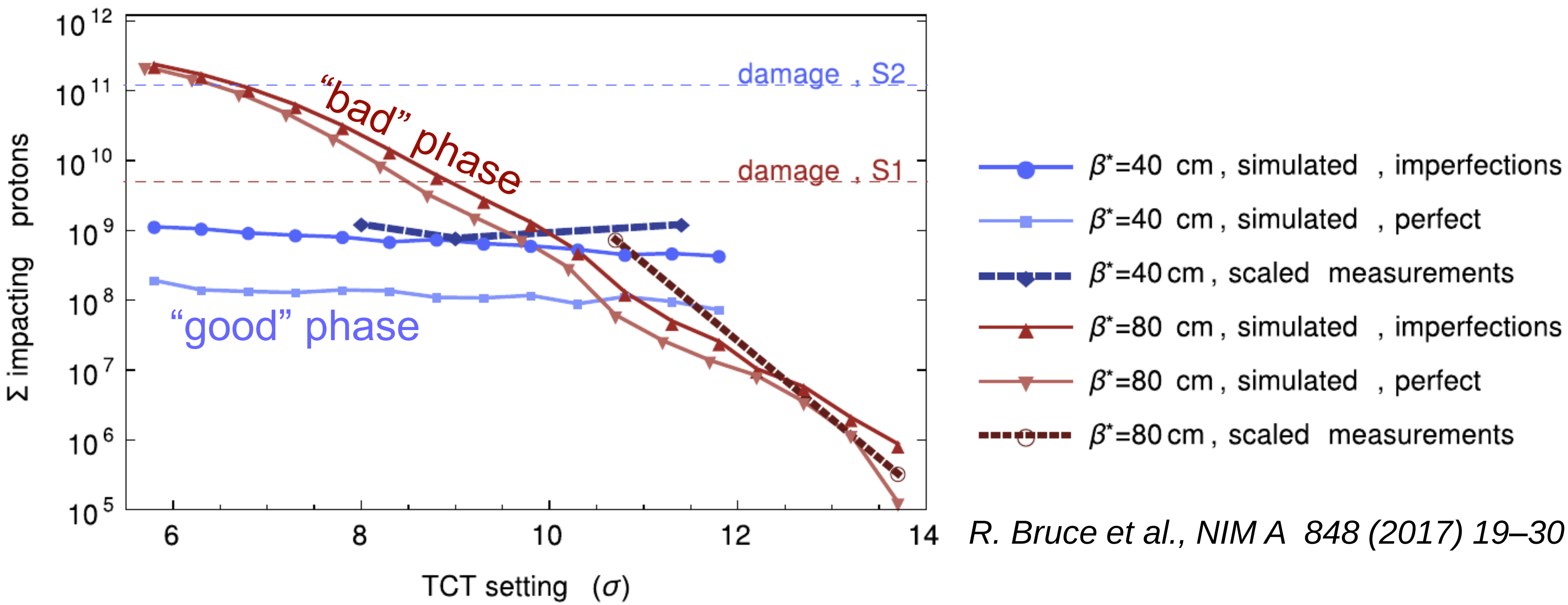
- Sensitivity study: Simulate losses on tungsten TCTs as function of setting
- Up to HL-LHC v1.2, risk for critical losses on TCTs
  - Phase advance between dump kickers and some TCTs close to 90 deg
- Needed significant retraction between TCDQ and TCTs to ensure safety



E. Quaranta et al., PRAB 20, 091002 (2017)
7 Tev, β=15 cm, TCSP/TCDQ at 10.1/10.6 σ*

Possible solutions

- 2 options to mitigate limitation (both being pursued)
  - Upgrade to more robust TCTs. Need to make sure that downstream magnets are still protected
  - Rematch phase advance between dump kickers and TCTs to be close to zero
    - done in the LHC – made it possible to reach β*=40 cm in 2016



R. Bruce et al., NIM A 848 (2017) 19–30

HL-LHC phase advance

- In new optics v1.3, significant improvement of phase advance between dump kickers and TCTs (see talk R. De Maria)

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

Calculation of allowed settings vs phase

- Achieved phase in HL v1.3 allows tighter TCTs and aperture
- Calculation of protected aperture for different MKD-TCT phase advance (see talk R. Bruce later today)

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$\Delta\mu$ 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**

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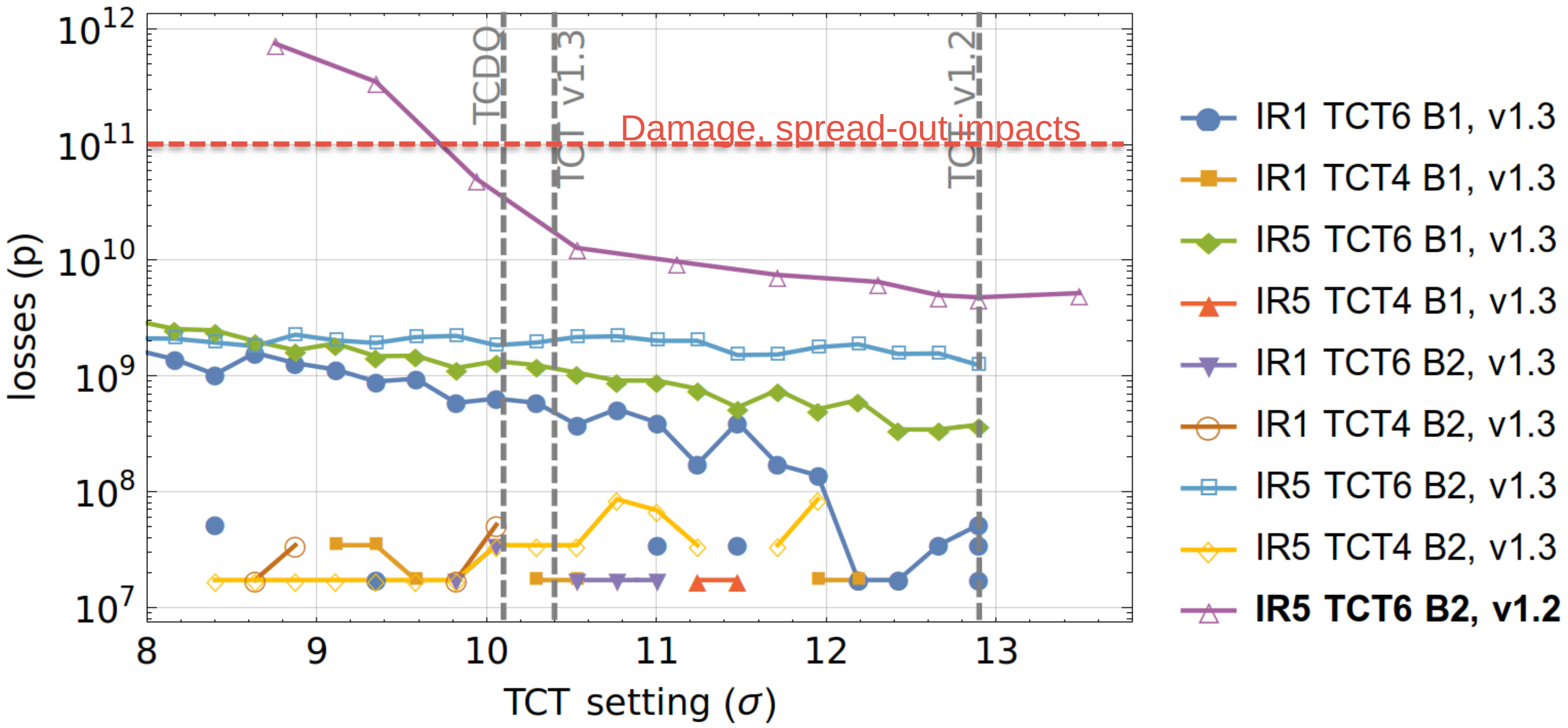
Simulated TCT losses in HL-LHC v1.3

- Conclusion: tungsten TCTs well below damage limit for *secondary impacts*
- New operational setting at 10.4 σ is fine



Additional considerations

- Need to worry not only about damage to the TCTs themselves, but also to the downstream elements
  - Magnets
  - Experiments
- Set up FLUKA study of shower from TCTs during asynch. dump
  - Results in next talk (A. Tsinganis)

Cases studied

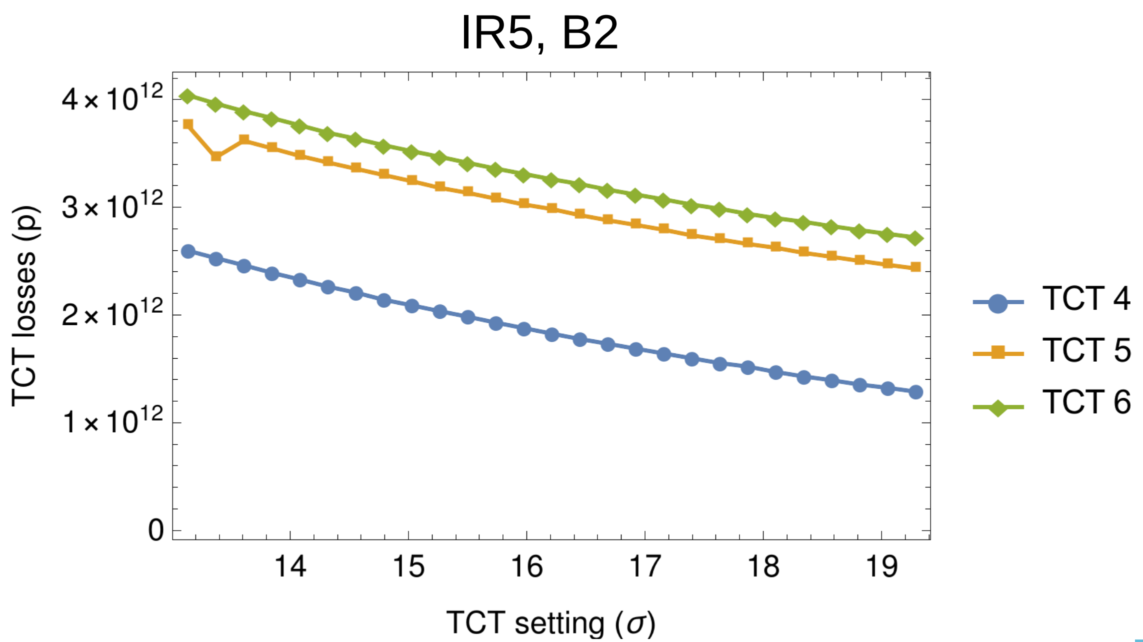
- Several cases considered
  - Old "bad" phase advance in HL-LHC v1.2
  - HL-LHC v1.3, with "good" phase advance
  - Impacts on TCT4 or TCT6
  - Different TCT materials
    - Inermet (tungsten): material of present LHC TCTs
    - CuCD (copper-diamond) : Improve TCT robustness by factor 15-20, but worse protection expetced since lighter material
    - MoGr (Molybdenum graphite): Even lighter and more robust
- In all cases, simulating IR5 (worst case)

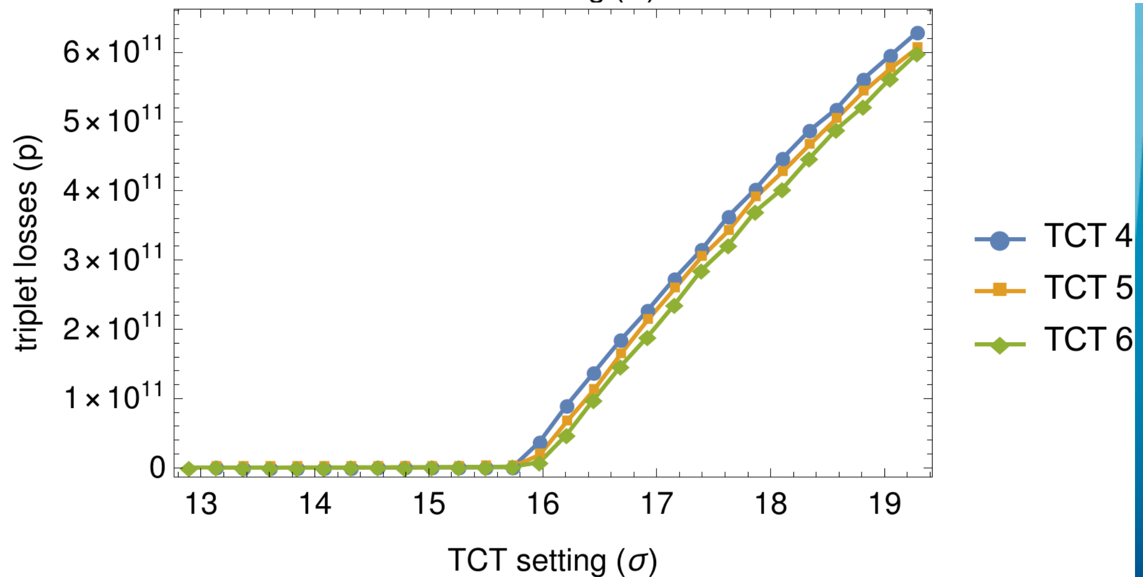
Scenario: bad phase

- Primary beam hit the TCT
- Study case where margin TCT-triplet is exhausted
- Track protons kicked by dump kickers in IR6 (using HL v1.2 phase advance) to TCTs
- Rescale coordinates to fit the opening of the TCT in HL-LHC v1.3
  - can then use same FLUKA geometry for both cases
- Impacts from *single bunch*
  - Pessimistic case in terms of impact distribution and comparable to earlier studies
    - Scaling to other scenario
  - Full bunch, with 2 σ impact parameter
  - Half bunch hitting edge of TCT

Protection of triplet, HL-LHC v1.2, β*=15 cm

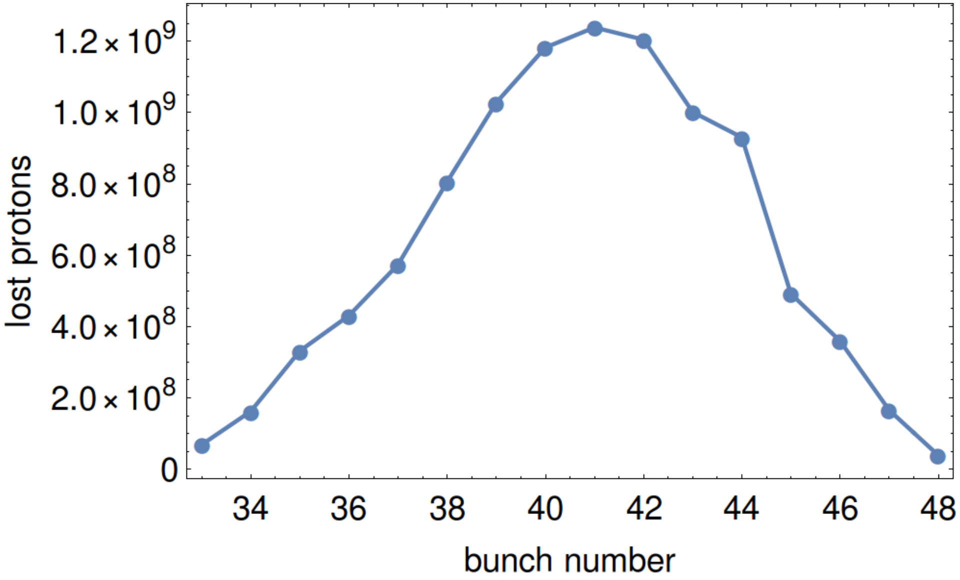
- For pessimistic case with maximum impact on downstream elements:
  - Open TCT until it is on the limit of protecting the triplet aperture
  - Open IR6 TCDQs to allow primary impacts on TCTs
  - Simulates the case of imperfect machine (errors in IR6 and/or IR5)
- For FLUKA study, assuming TCT setting of 15.7 σ (for 2.5 μm emittance)





Scenario: good phase

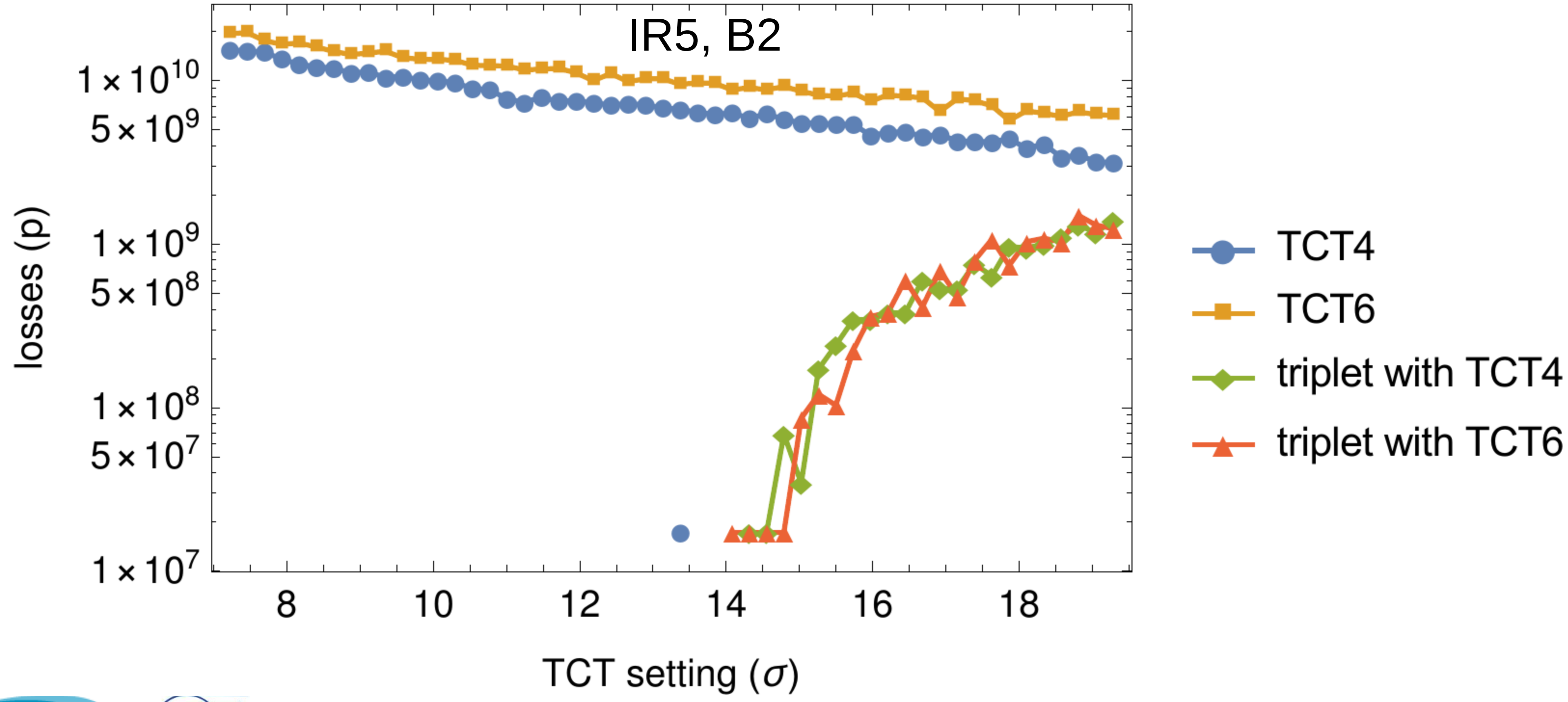
- Dominated by secondary beam outscattered in IR6 collimators
- Keep TCT and IR6 at nominal settings
  - TCTs at 10.9 σ and TCDQ at 10.6 – previous baseline
- Fractions of several 16 bunches hit
- In total, around 1E10 protons hitting TCT



Normalized to 2.2E11 p/bunch

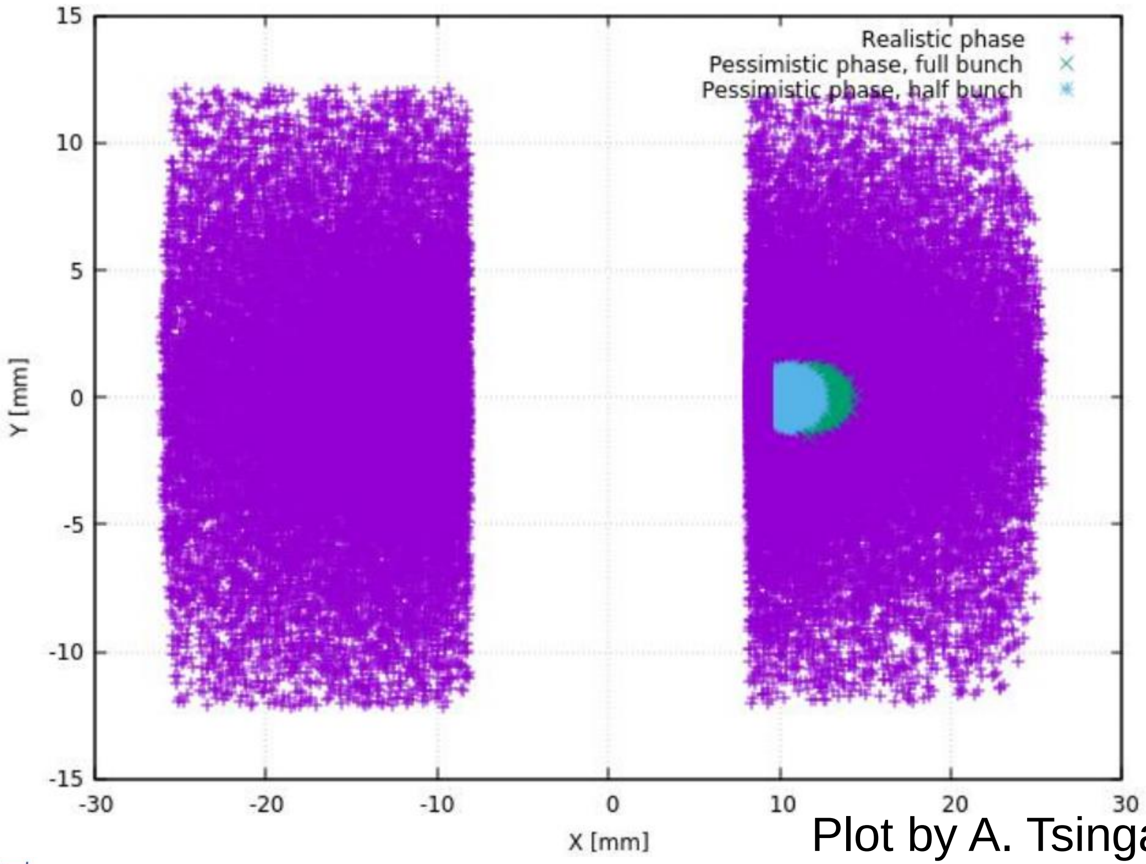
Protection of triplet, HL-LHC v1.3, β*=15 cm

- Variation of losses with TCT setting
- Losses appear in triplet with TCT around 14 σ (2.5 µm emittance)



Comparison of impacts in both scenarios

- Secondary losses distributed over both jaws and much more spread out
- FLUKA results for the different cases: see next talk A. Tsinganis



Plot by A. Tsinganis

Next steps

- Ideally, energy deposition studies in downstream elements and the damage limits could be used to decide on TCT material
- Choose material where the largest number of protons impacting the TCT is tolerated without damage to any element (TCT, magnets detector)
- Damage limit of experiments evolving
  - **ATLAS:** HiRadMat tests indicate that damage limit on current IBL could be significantly higher (at least a factor ~1000) than the lower limit previously measured of 1E10 MIPs / cm^2 (see talk B. Di Girolamo)
  - **CMS:** Previous limit of 1E9 MIPs/cm^2 believed to be too pessimistic – under study. Hope to have an update in a few months
- Additional consideration: experimental background from TCTs. Impact of material choice to be quantified

Conclusions

- Risk of damage to TCTs and triplets could impose major performance limitations
- Two ways of mitigating
  - Improved optics with rematched phase advance between dump kicker and TCT
  - More robust TCTs
- 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 – below estimated tungsten damage limit with good margin
- Study of risk of damage on downstream elements due to shower from TCT
  - Tracking studies for several scenarios – starting conditions at face of TCT passed to FLUKA (see next talk A. Tsinganis)
  - Energy deposition and accurate damage limits to be used for decision on material

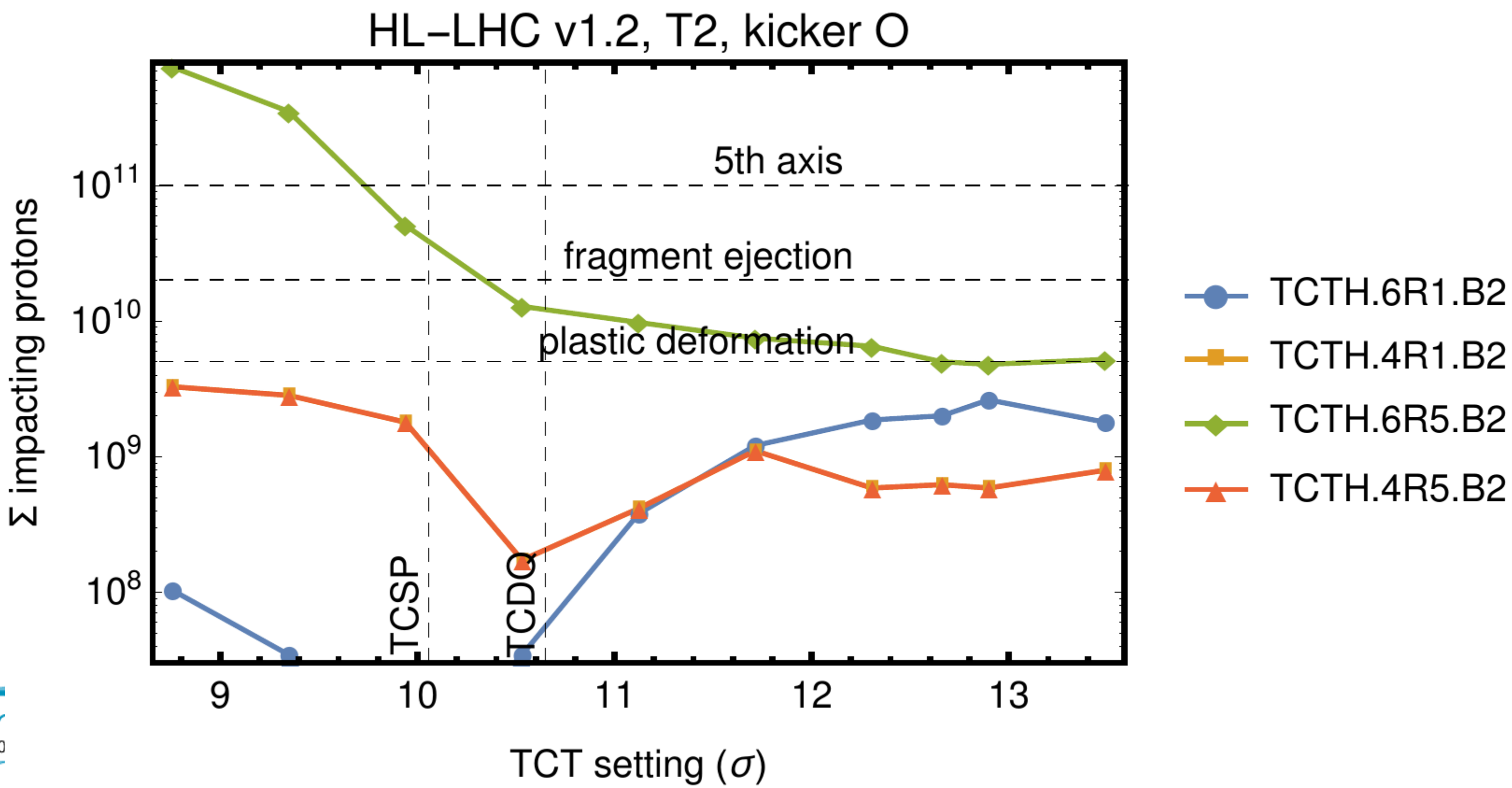
Thanks for your attention!

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, β*=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)



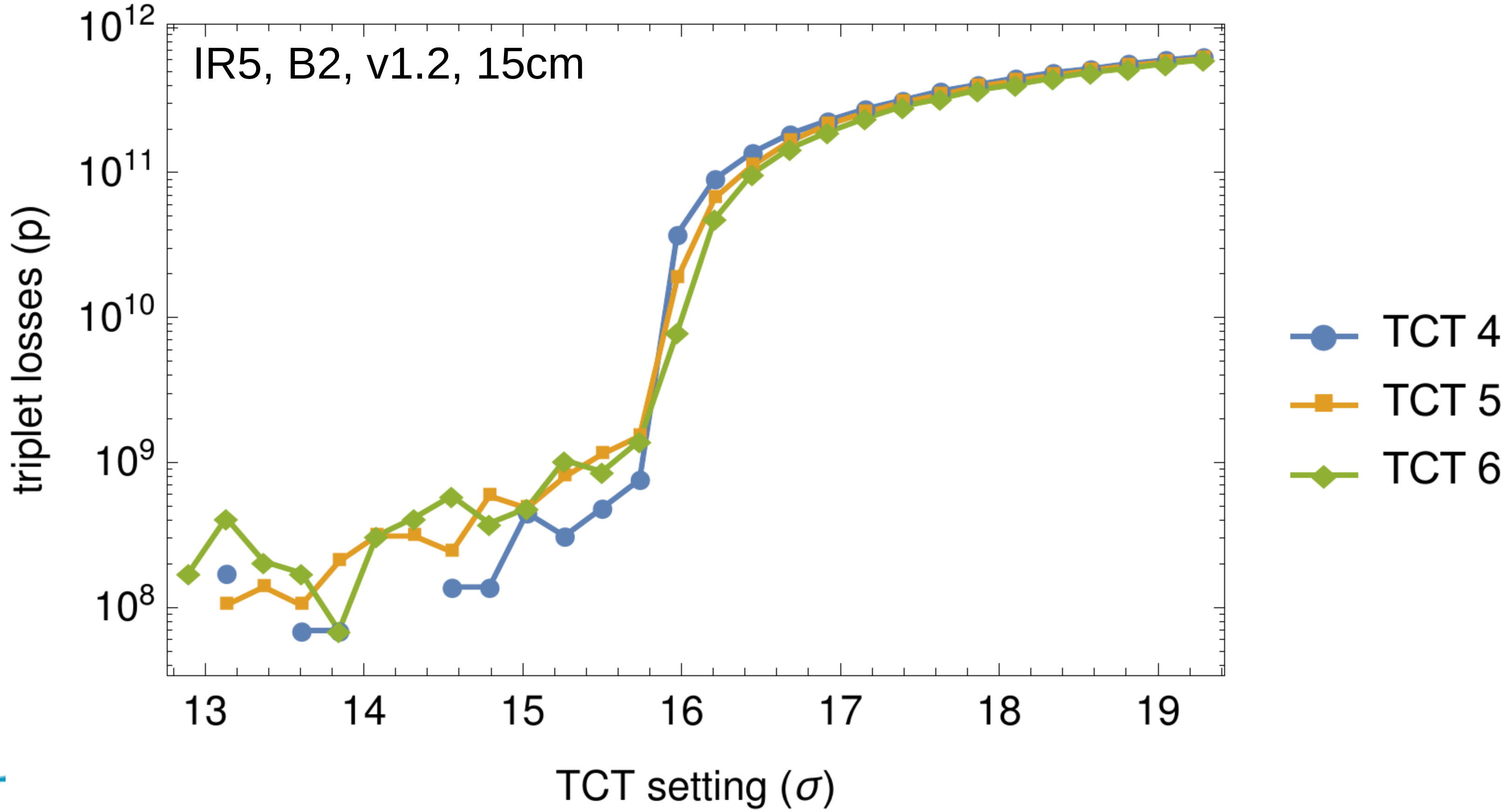
Phases: IR5 B2 TCTs, HL-LHC v1.2, β*=15 cm

- A few degrees of phase advance between TCT6 and triplet

Element	Fractional phase advance from MKD.O
TCTPH.6R5.B2	101.5
TCTPH.5R5.B2	102.7
TCTPH.4R5.B2	103.5
Q3R5	104.1
Q2R5	104.2
Q1R5	104.3

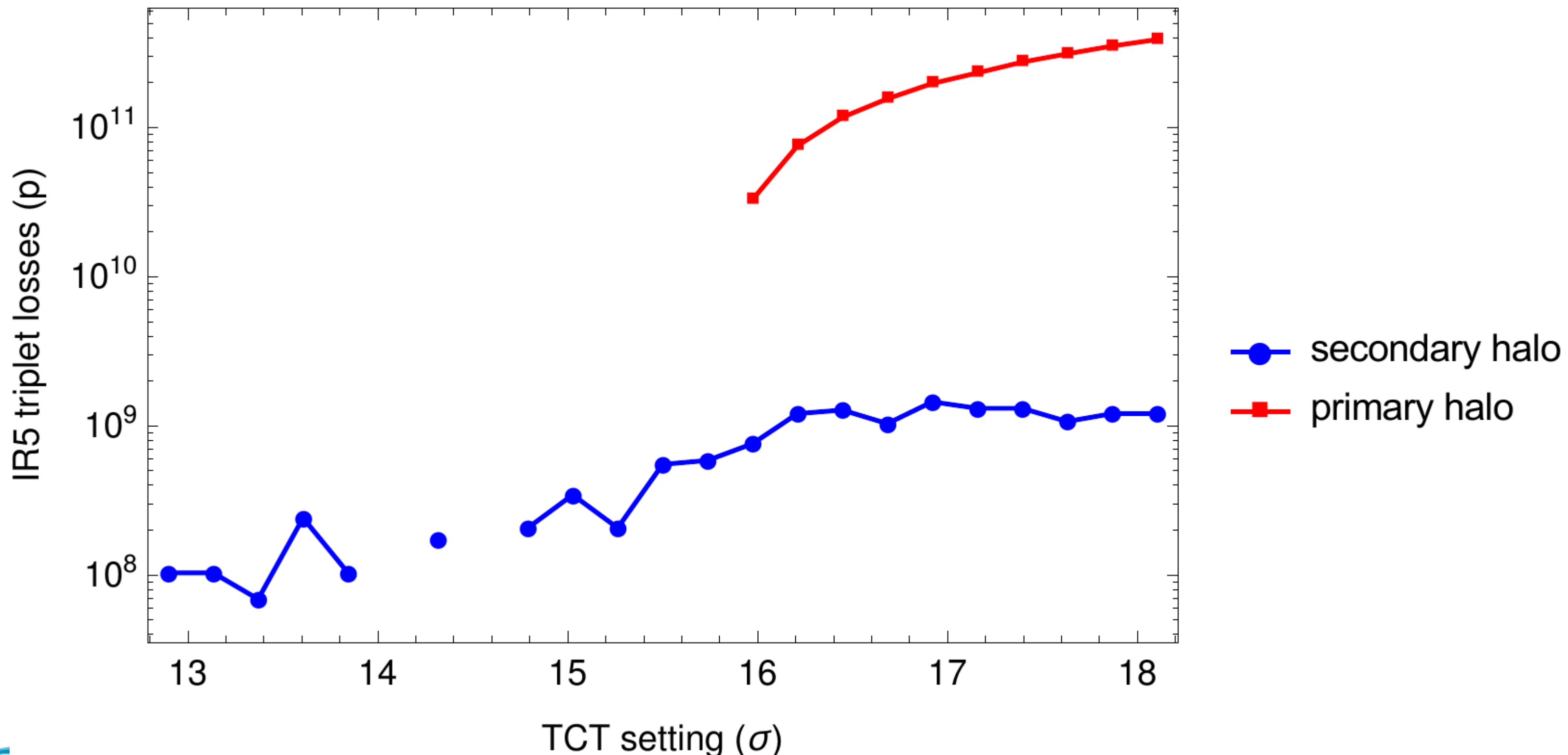
Triplet losses (log scale)

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



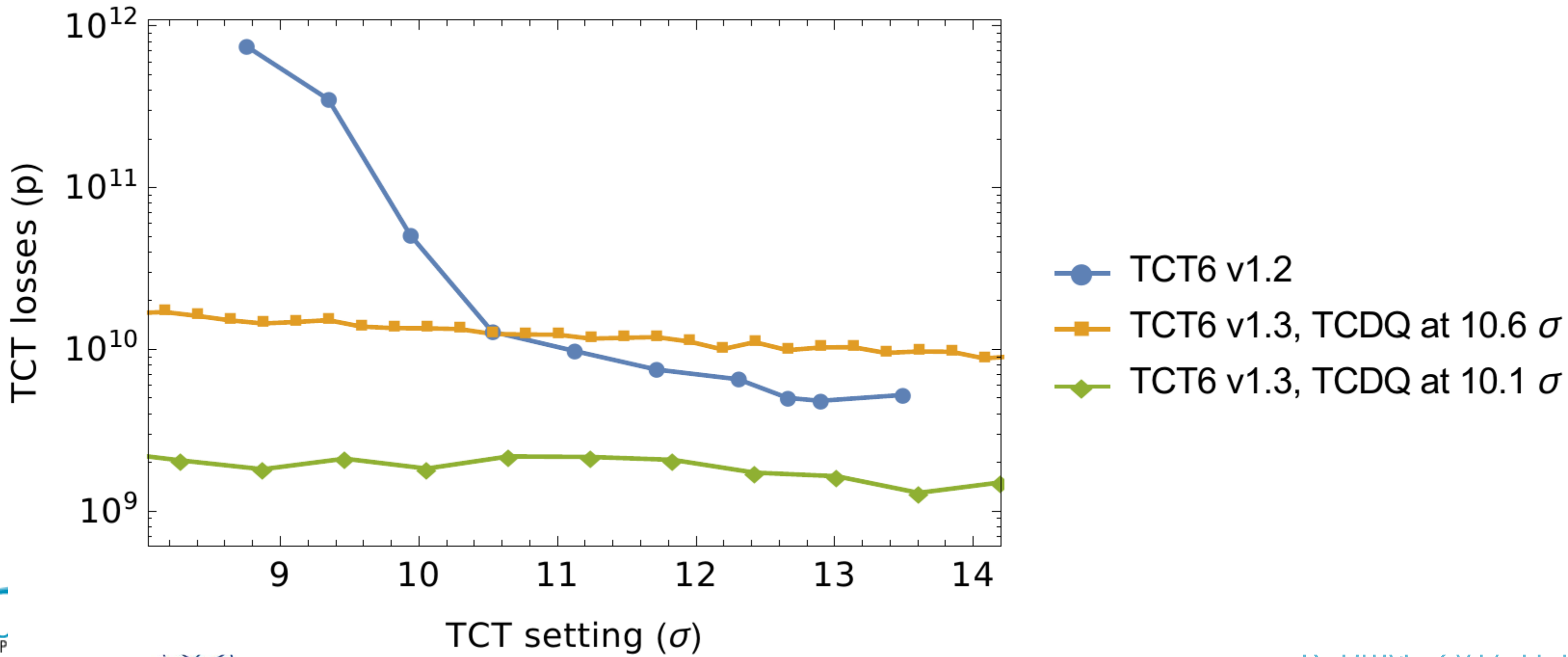
Decomposition of triplet losses

- As triplet is also at bad phase, it starts intercepting primary losses when the TCT is open enough
  - In these simulations, IR6 open



TCDQ at same setting as TCSP?

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



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 σ, TCT6 intercepts slightly more of the core than TCT4
- When TCT is more open than triplet (in σ), TCT6 protects better
- If phase would be between 0 and 90 deg, TCT4 would instead protect better