IR collimation upgrades -incoming beam-

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ROYAL HOLLOWAY UNIVERSITY OF LONDON

HiLumi HL-LHC PROJECT

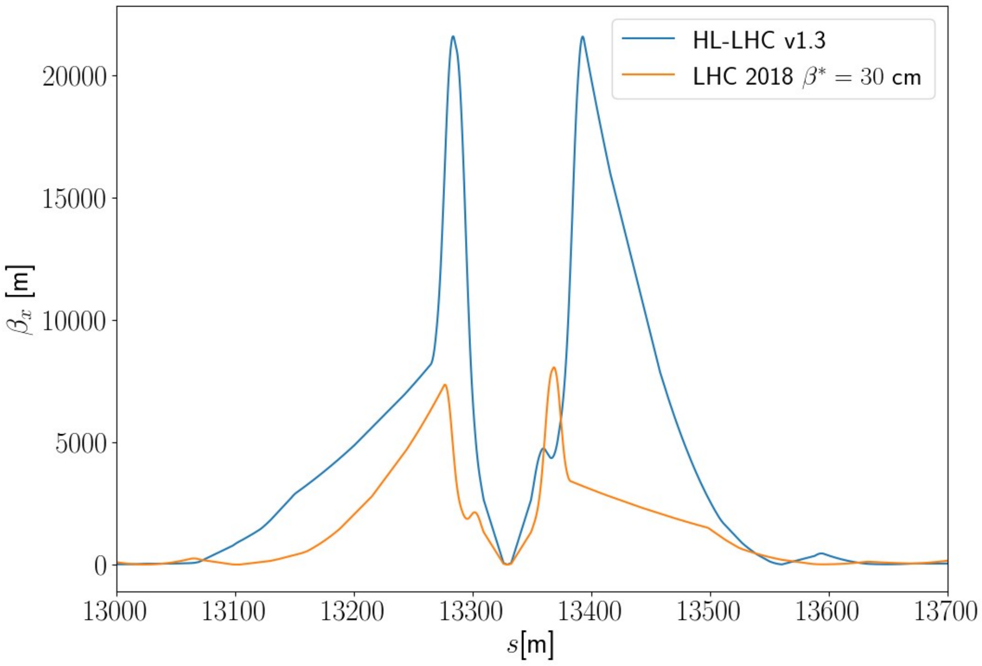
LHC Collimation Project CERN

CERN

IR optics: LHC vs HL-LHC v1.3

- Significant change in IR optics and layout from current LHC to HL-LHC v1.3.

- Need to review the protection of the inner triplet (and upstream magnets) in the new environment.



Motivation for IR layout upgrade

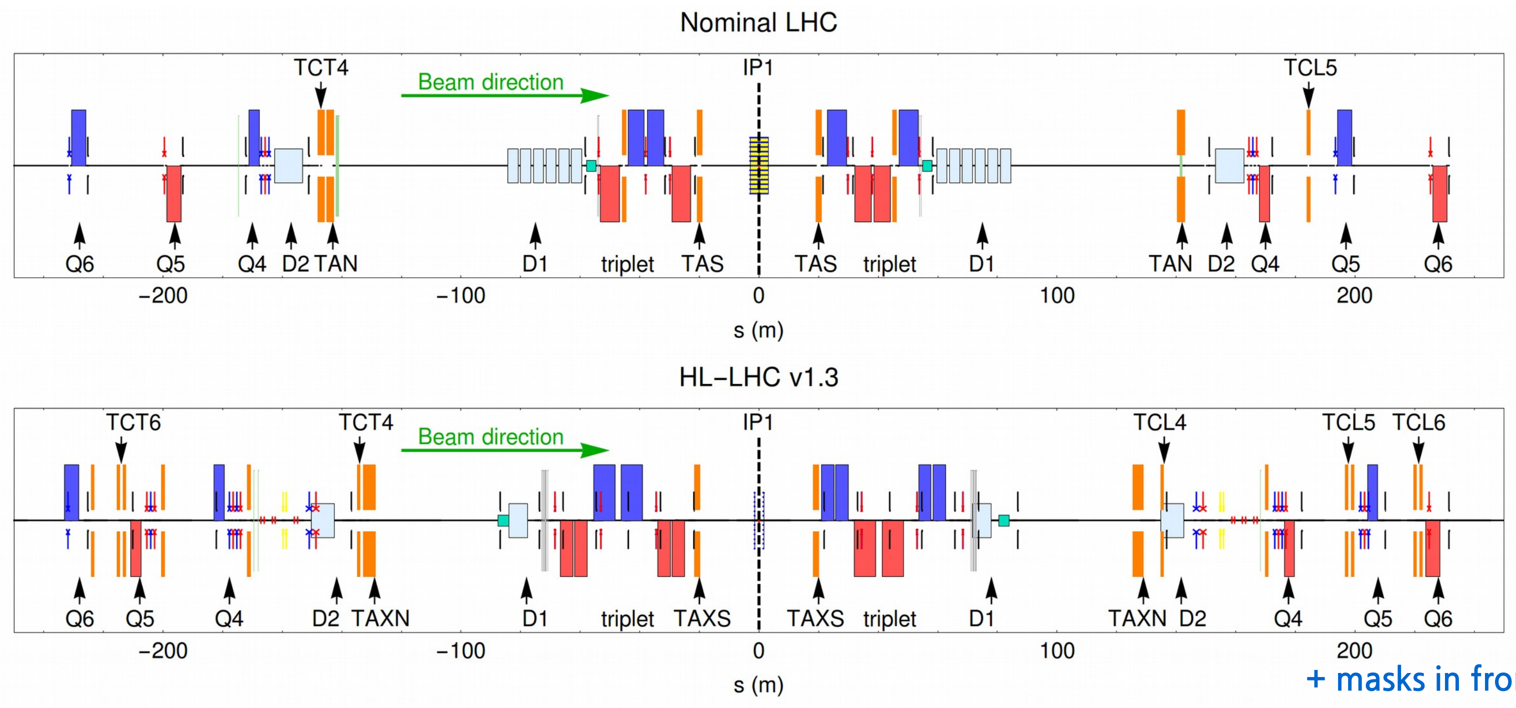
HL challenges for IR cleaning

- Higher luminosity (peak and integral)
- Higher bunch intensity and brightness
- Complexity of operational modes with tight collimation hierarchy (levelling)
- Tighter aperture requested in the matching section magnets in addition to the triplet

Required upgrade of the present layouts

- **Additional bottleneck observed in Q4-Q5 region demands an additional pair of TCT in cell 6 to protect them while keeping TCT in cell 4 for triplet protection.**
- Need for fixed masks on the outgoing beams (in addition to movable TCLs)
- More robust collimator materials to withstand impacts from asynchronous dumps (H)
- In-jaw BPM design for all new IR collimators: flexibility and efficiency (=availability) for considered levelling scenarios with $\beta*$ and crossing

Current IR layout and foreseen upgrade



+ masks in front of Q4, Q5 and Q6

- Tertiary collimators of type "TCTPXH, TCTPXH, TCTP, ..." → TCT
- Physics debris collimators "TCLPX, TCLP, …" → TCL
- Append the cell number. Example: "TCT.4" is the TCT in cell 4

Current IR layout and foreseen upgrade

Copper Diamond
(CuCD)

TCTPH.6
TCTPXH.4

Tungsten alloy
(Innermet 180)

TCTPV.6
TCTPXV.4

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**

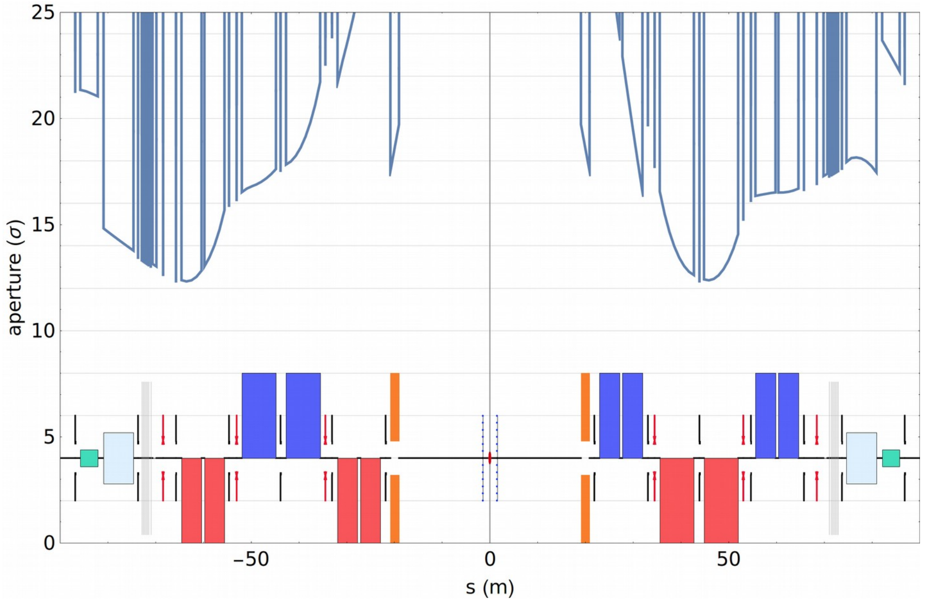
Contents of the presentation

- Verify protection with new collimator layout in cleaning and asynchronous dump scenarios.
- What is the energy deposition in the experimental insertion?
  - What are the effects on downstream magnets?
  - What are the effects on the experiment?

Cleaning efficiency in IR1/5

- **Inner triplet** is the global machine **bottleneck** in collision.
- Additional bottlenecks at **Q4/Q5** also critical for HL-LHC.
- **Reduction of triplet aperture** represents different sources of errors (beta-beating, misalignment…).
- **Betatron cleaning efficiency** evaluated with SixTrack for different triplet, Q4 and Q5 apertures and TCT settings.

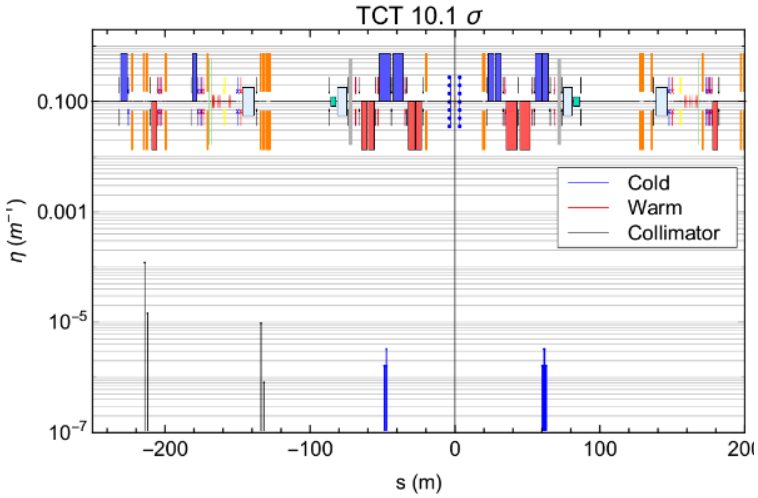
LHC layout in IR1 with aperture that collimation system should protect (emit = 2.5 um, beta*=15cm).

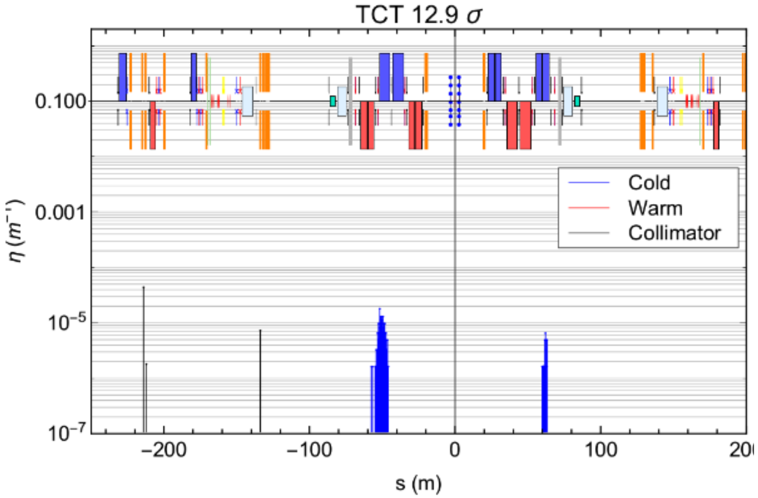


Cleaning efficiency in IR1/5

Aperture reduced to 10.9
(optics V1.3 beta = 15cm)

- Cleaning satisfactory in new layout with nominal TCT setting, even with very pessimistic aperture
- Example shown:
  - margin of ~1 sigma MQX/TCT
  - LHC 2018: ~1.5 sigma (see RB's talk).
- If TCTs are more open than aperture, already for a perfect machine significant losses appear in triplet as expected



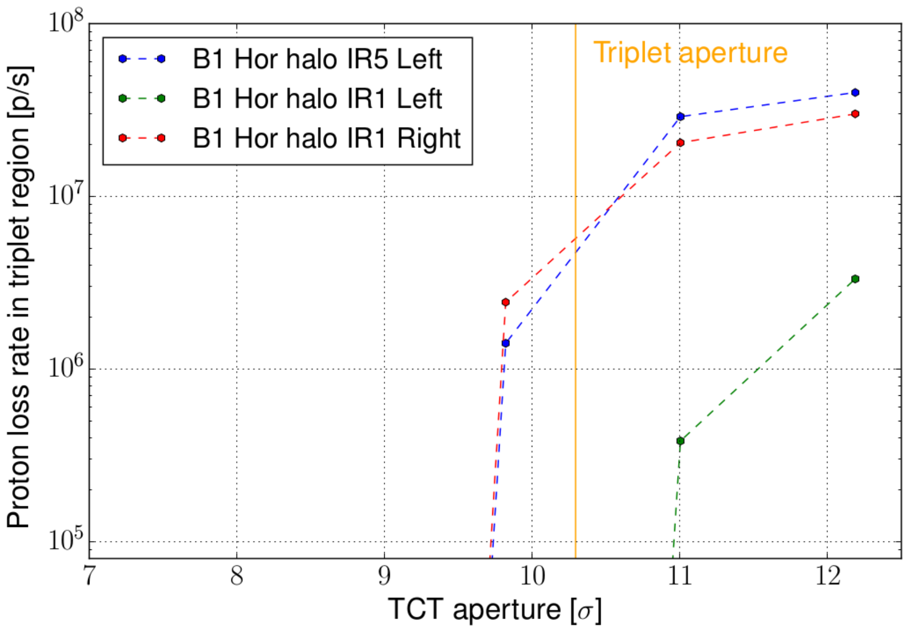


Cleaning efficiency in IR1/5

- Cleaning efficiency as a function of TCT4/6 apertures.
- Aperture reduced to 10.3 sigma

(very pessimistic case).

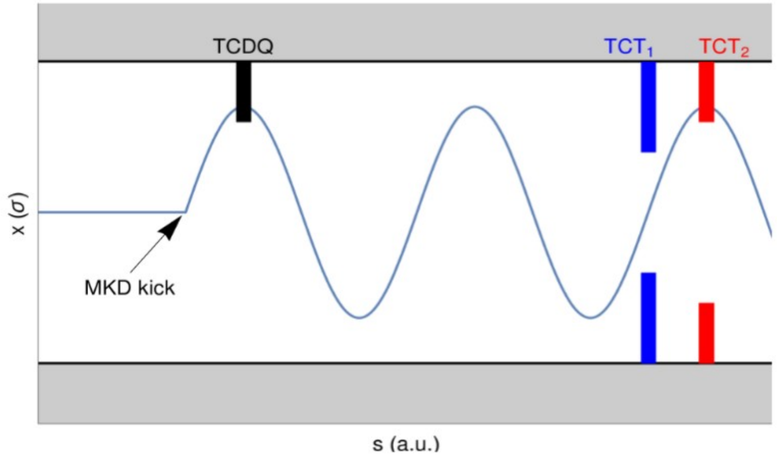
- **No losses observed for TCT settings below 9.8 sigma.**



H.Garcia-Morales: CERN-ACC-NOTE-2017-0023

Recap: Asynchronous dump

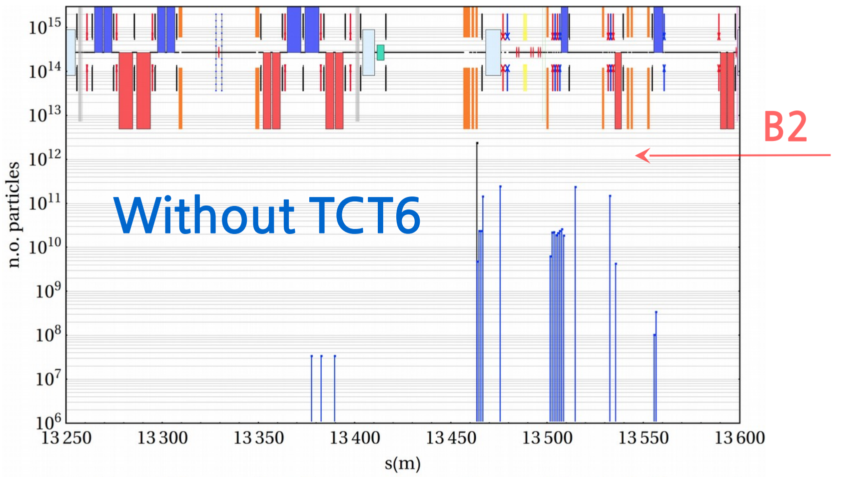
- Asynchronous dump:
  - The MKD fires not synchronized with the abort gap and the beam receives a kick.
- This might have an severe impact if beam oscillations drive the beam towards the TCTs.
- Beta* reach very much determined by a well matched phase advance between the MKD and the TCTs.
  - Also allows tighter collimator hierarchy.

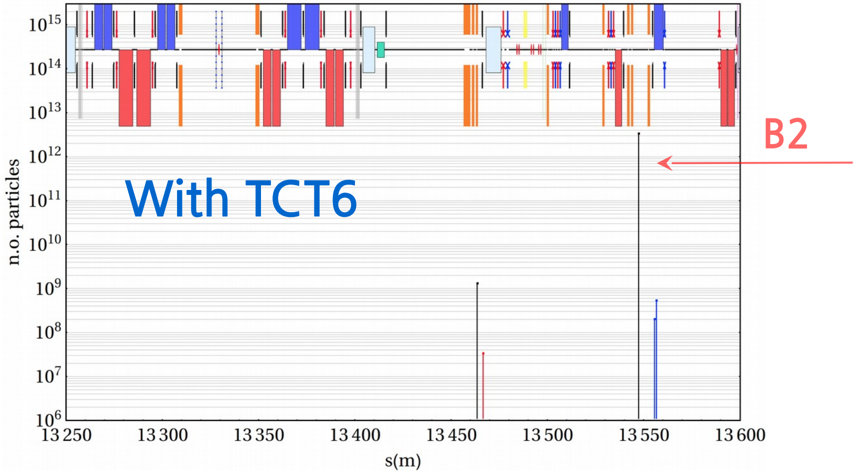


Cleaning efficiency in IR1/5 - Asynchronous dump

- SixTrack simulations for **worst case scenario type-2 single module pre-fire.**
- **Several bunches simulated each receiving different kicks.**
- **Phase advance between MKD and TCT improved** from optics version v1.2 to v1.3.

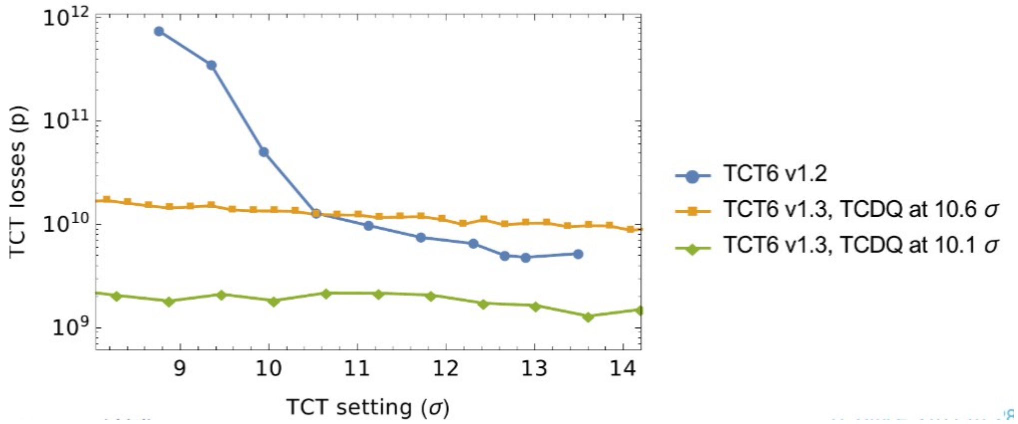
HL-LHC v1.2

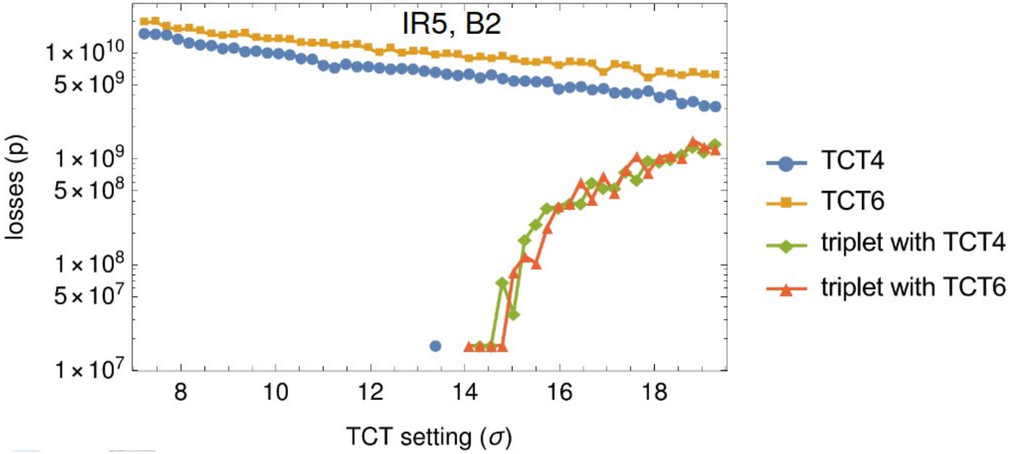




Cleaning efficiency in IR1/5 - Asynchronous dump

- Scans of TCT settings.
- Excellent improvement of v1.3 due to the new phase advance.
- For TCT settings beyond 14 sigma, the triplet starts to be exposed for ideal triplet aperture.
- Only secondary losses reach triplet.
- **Based on tracking simulations using v1.3 both tertiary collimators and triplet are fully safe over a realistic range of TCT settings.**
- Shower studies needed for full assessment of downstream elements.





R.Bruce ColUSM #90 :https://indico.cern.ch/event/656269/

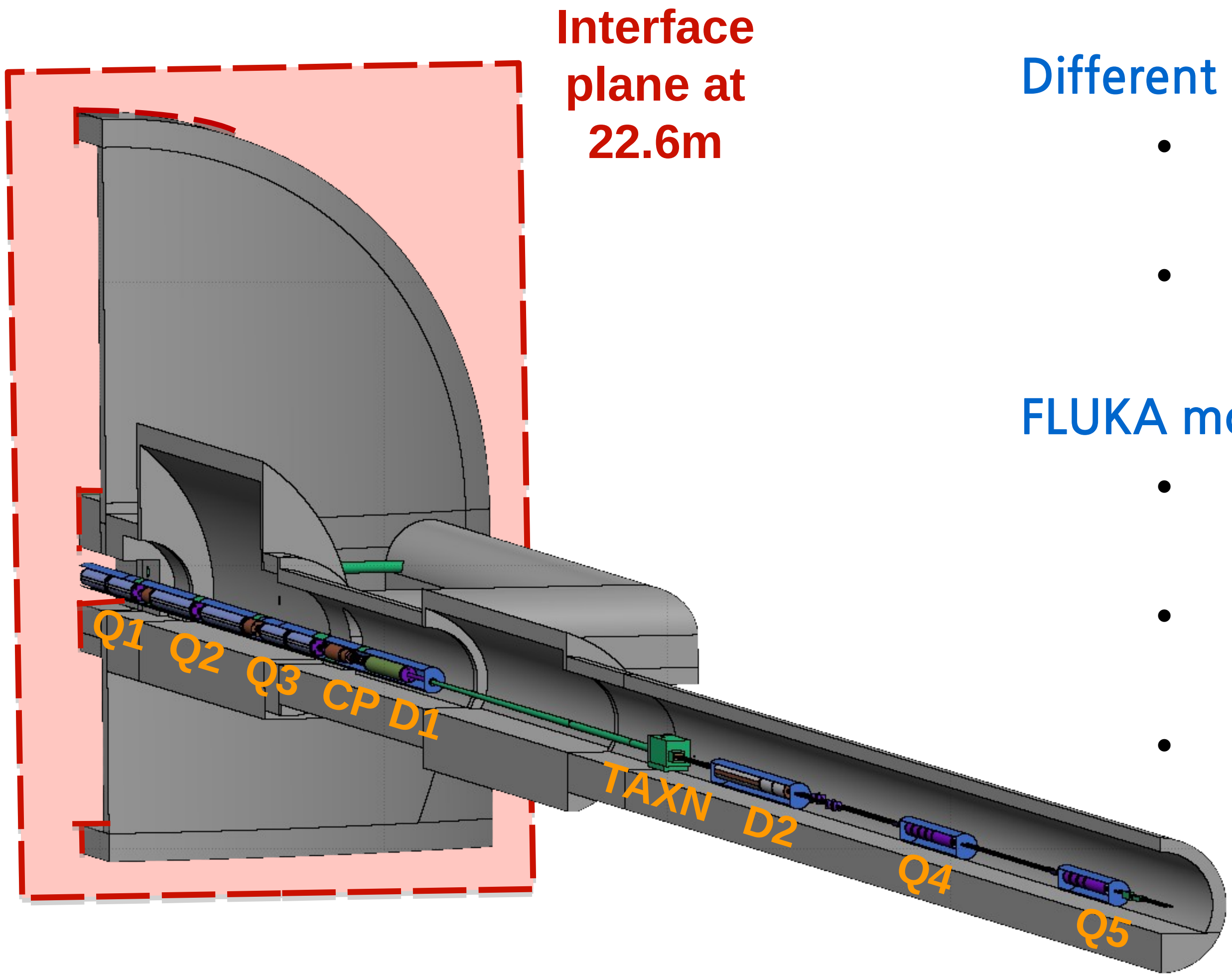
Recap. on failure scenarios

- See also introduction by RB
- Study case of **single bunch** on the TCT as design case for **material choice** and impact on :

  - **Downstream magnets**: quench or even SC coil damage
    - (newer) quench protection
  - **Detectors**

- Dedicated studies for effect on TCT jaw from **diffused halo that escapes IR6**
- Benchmark case against innermet TCT destructive test in HRM
  - Talk by A. Bertarelli in 2012
- Complex tools (Geant4, FLUKA, Autodyne…)

Asynchronous dump - FLUKA simulations



Different scenarios:

- **Pessimistic**: single bunch (half or full) impact on one jaw.
- **Realistic**: fractions of several bunches impact on both jaws.

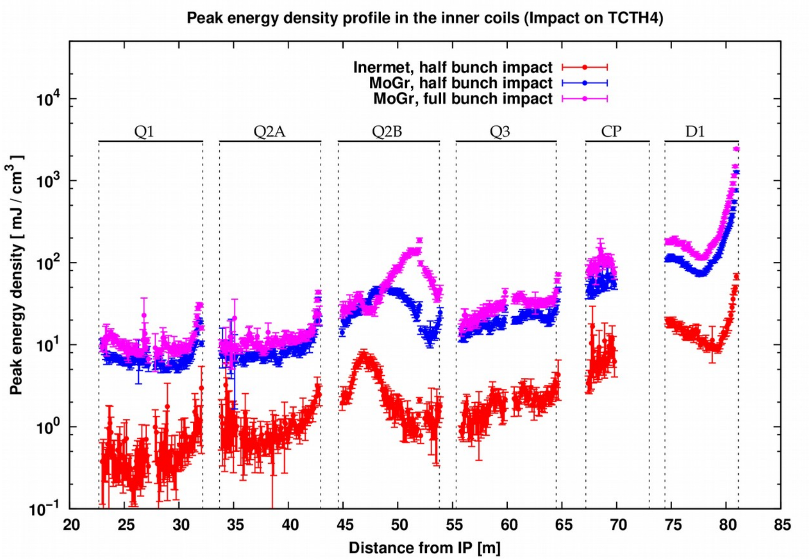
FLUKA model:

- Losses from SixTrack loaded at appropriate location.
- Radiation propagated towards the experiment.
- Different jaw materials considered

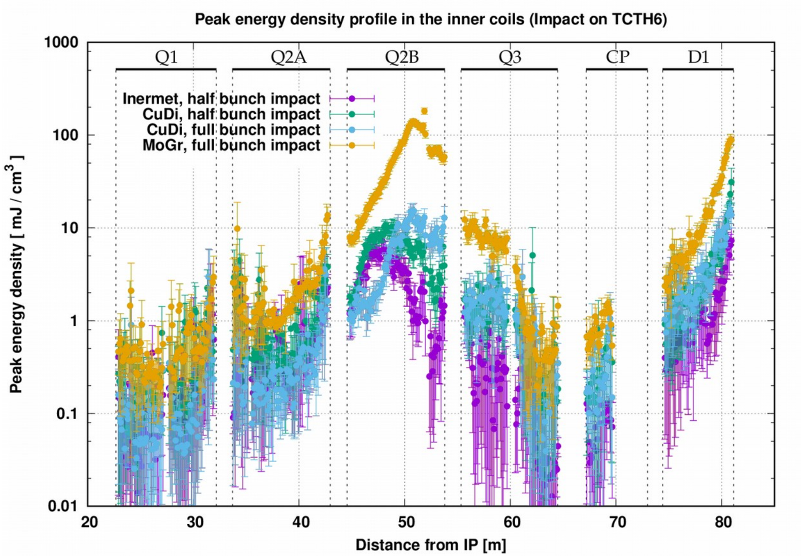
(Innermet, MoGr, CuCD).

Asynchronous dump - FLUKA simulations

Impact on TCT4



Impact on TCT6



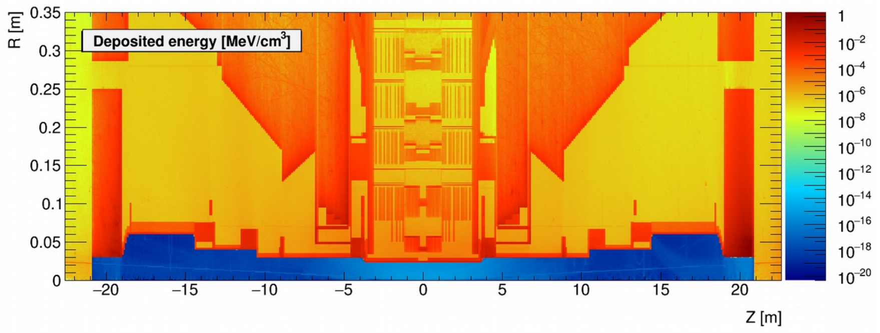
- All values below damage limit (1kJ/cm^3)
- Only D1 would quench with Inermet TCT4.
- **The choice of the material has a significant impact on protection effectiveness.**

- **All values drop with respect to TCT4 case but quenches are not excluded.**
- Baseline with TCT pairs in cell 4 and 6, is safely **below the material damage threshold** (over the Q1 - Q5 region) for all TCT jaw material options

A. Tsinganis et al.:https://indico.cern.ch/event/647714/contributions/2646539/

Damage in the experiments - ATLAS

A.Sbrizzi et al.



Beam impact on TCTs due to asynchronous dump generate secondary showers that reach the experimental area.

HL-LHC configuration:

- 7 TeV, beta* = 15cm
  - HL-LHC v1.2
- TCT4 opened to be on the limit of protecting the triplet (13.3 sigma)
- Assuming dump protection is misaligned and single bunches can directly hit the TCT4. Magnetic tracking from dump kicker of miskicked bunch to the TCT4.
- Cases considered:
  - Full/half bunch impact on TCT4
  - Tungsten alloy or MoGr

TCT4	Scenario	Np[1e11]	dEdep/dEthr [%]	
			TAS D = 60 cm	TAS D= 34 cm
W alloy	Half-bunch	1.167	0.0048	0.0016
MoGr	Half-bunch	1.167	0.17	0.038
MoGr	Full bunch	2.184	**0.30**	0.078

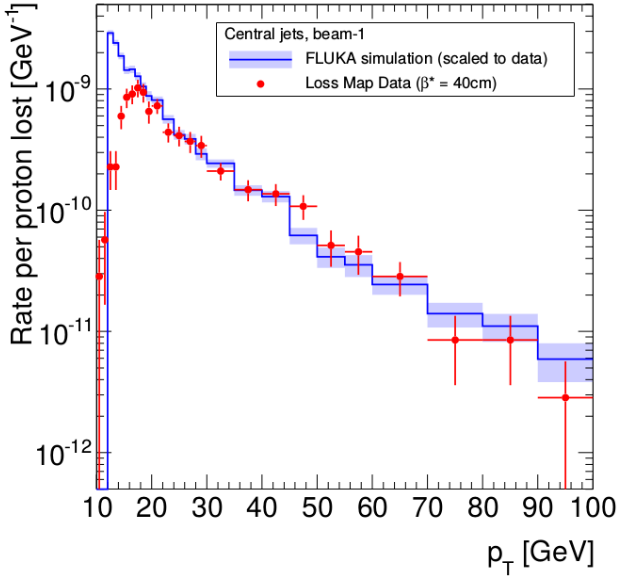
ATLAS damage threshold = 10^{13} MIP/cm^2

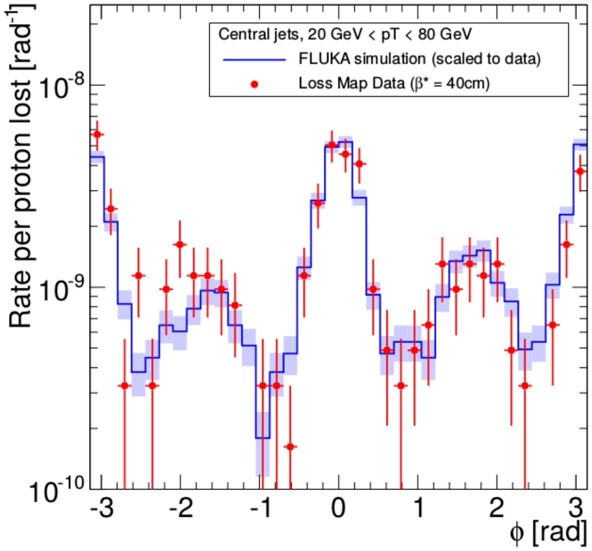
Worst case scenario:
energy deposit = 0.3% of the damage threshold

Experimental background during operation

Dedicated studies of beam **halo background in ATLAS** allowed to quantify the **measured background per lost proton** on TCPs.

- With present beam lifetime and TCT settings **total background in physics is less than 1 %** of beam gas background.
- Beam halo background is **not a strong driver** for TCT material and layout choice.



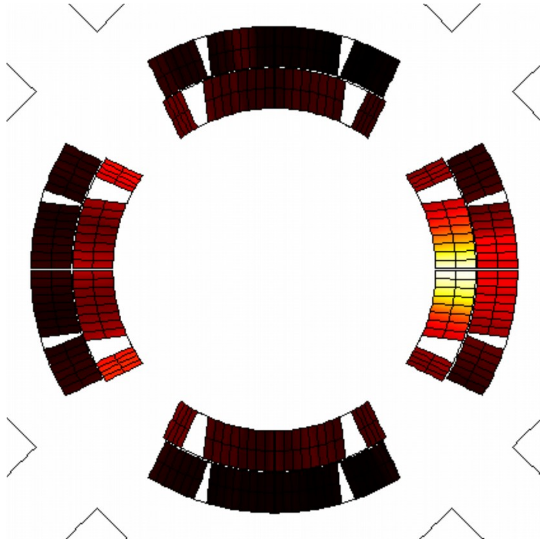


R.Kwee

CERN-ACC-2017-0025

Impact on triplet from asynchronous dump

- In case of magnet quench, due to large inductive currents, there is an increase of voltage-to-ground.
- Circuit protection simulations done to study electric behavior of triplet (M. Mentink)
- Asynchronous beam dump hitting TCT6 in CuCD, 1 full bunch
  - Risk to quench Q2b, but not Q3
- In very pessimistic scenario with simultaneous failure of single quench heater and an inhomogeneous conductor distribution:
  - Voltage to ground is 1876 V. Allowed: 1900 V
- Compare: only single heater failure and inhomogeneous conductor distribution:
  - Voltage to ground is 1647 V
- Conclusion: there is no worry for the triplet for CuCD - extremely pessimistic scenario
  - In reality, **very unlikely** with the simultaneous failures
  - Situation will improve with matched MKD-TCT phase or if TCT is made of tungsten alloy
- Comparison with **MoGr**:
  - risk to quench Q3 and create short to ground
    - Very unlikely, but still not recommended to use MoGr TCTs



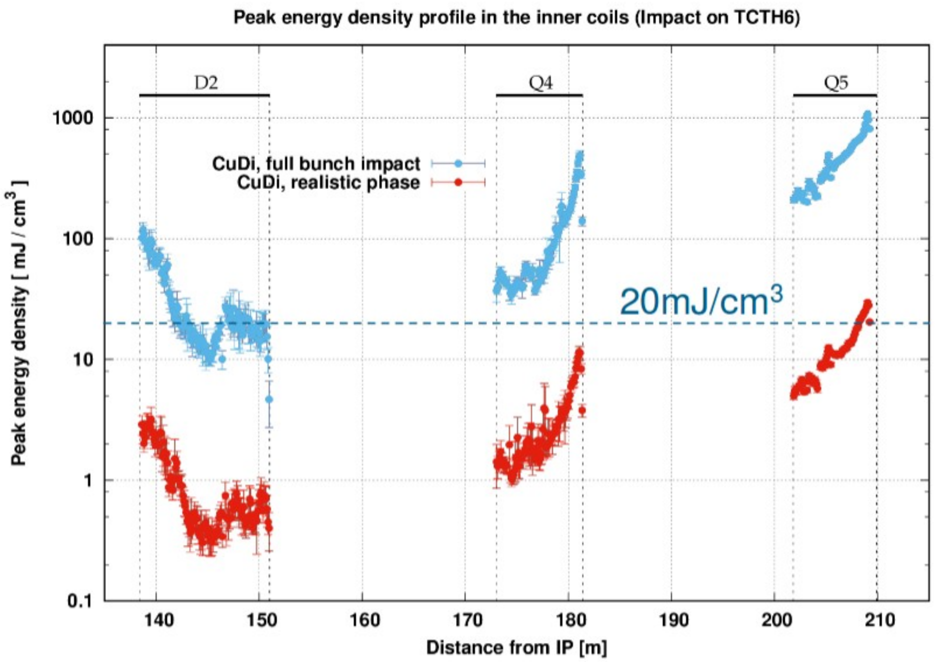
M.Mentink: HL-MCF Meeting #29

Conclusions

- New layouts of high-luminosity experiments interaction region for the incoming beam protection at the HL-LHC.
- The baseline adds a pair of TCTs in cell 6 to protect critically exposed matching section quadrupoles in addition to the triplet
- Very extensive simulation campaigns for regular and abnormal losses show adequate protection levels for all design cases
- New, more robust, materials in the horizontal plane protect adequately for the (pessimistic) design case of single bunch lost in the IR, with sufficient margin to known possible limiting factors:
  - Magnet protection, including voltage to ground.
  - experiment electronics
- Choice of CuCD seems appropriate, while inermet would maximise absorption at the TCT but collimator would not survive.

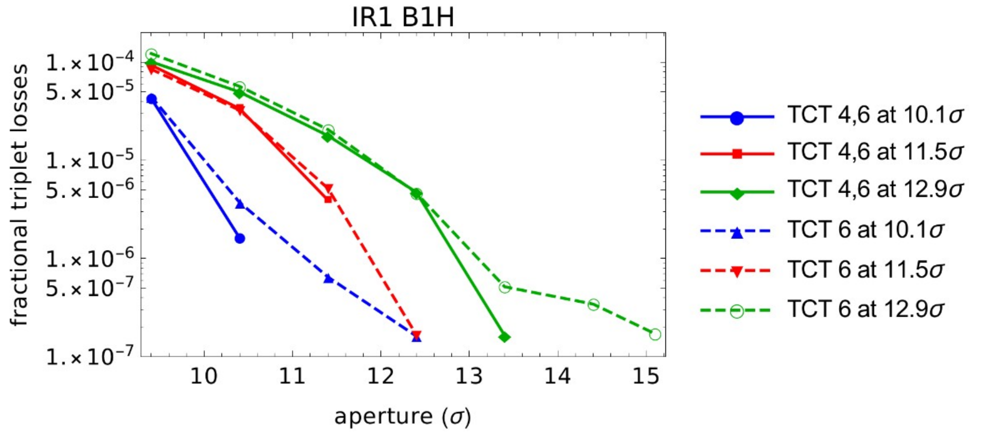
Backup

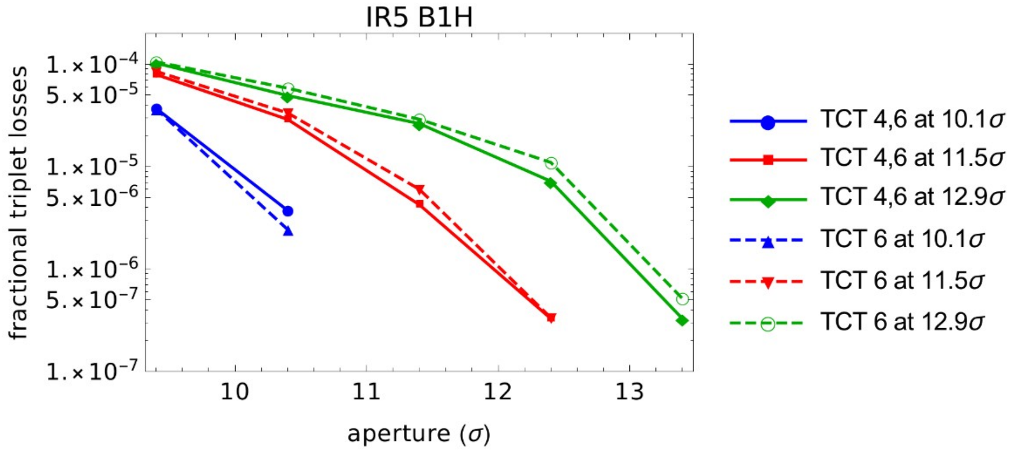
D2 - Q5 exposure: comparison of the two cases



Cleaning efficiency in IR1/5

- Some losses observed for large apertures when only TCT6 is included.
- When both TCT4 and TCT6 are included **slight improvement with respect to TCT6 only**.





Damage limits on tertiary collimators

TABLE IV. Damage limits calculated for the tungsten collimator jaw for the three cases discussed in the paper.

	Thresholds (number of protons)		
Material damage	Case 1	Case 2	Case 3
Plastic deformation	1.2×10^{11}	4.6×10^{9}	6.9×10^{9}
Fragment ejection	7×10^{11}	1.8×10^{10}	2.6×10^{10}
Catastrophic damage	1.1×10^{12}	1.4×10^{11}	1.7×10^{11}