Overview of scenarios where new materials are needed

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Why new collimator materials?

- LHC collimation is working well
- HL-LHC coming – do we need to change anything in the collimation system?

	Nominal	HL-LHC baseline
Beam energy	7 TeV	7 TeV
Bunch intensity	1.15e11	2.2e11
Number of bunches	2808	2748
Total stored energy	362 MJ	678 MJ
Normalized emittance	3.75 μm	2.5 μm
β*	55 cm	15 cm
Theoretical peak luminosity (without crab cavities)	1.0e34 $cm^2\ s^{-1}$	7.2e34 $cm^2\ s^{-1}$
Leveled luminosity		5e34 $cm^2\ s^{-1}$

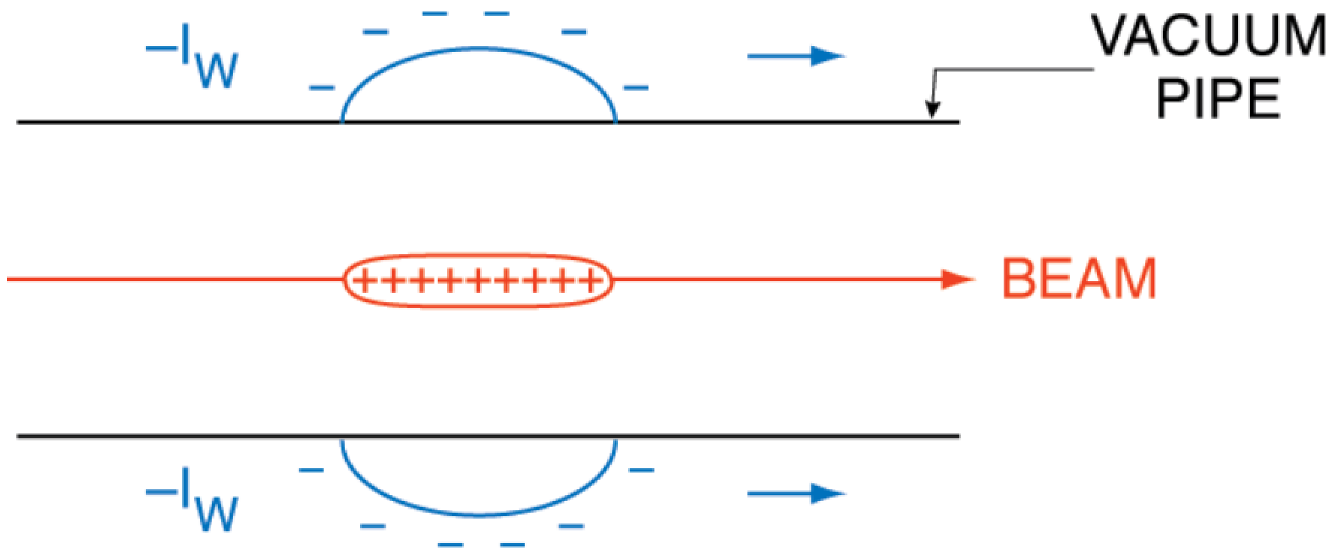
- Several challenges related to collimator materials

Considerations on collimator materials

- Beam instabilities related to collimator impedance could limit beam parameters
    - More important the higher the bunch charge as for HL-LHC
- Robustness of collimators could limit luminosity performance
    - When reducing β^*, non-robust tungsten collimators have to be moved closer to the beam
    - If they are too close, they risk to be hit and damaged during beam failures
    - Potentially more critical in HL-LHC
- If we change any material, need to ensure also that they will work as well as present system in standard operation
    - Beam cleaning, radiation resistance, vacuum behaviour …

Beam instabilities from impedance

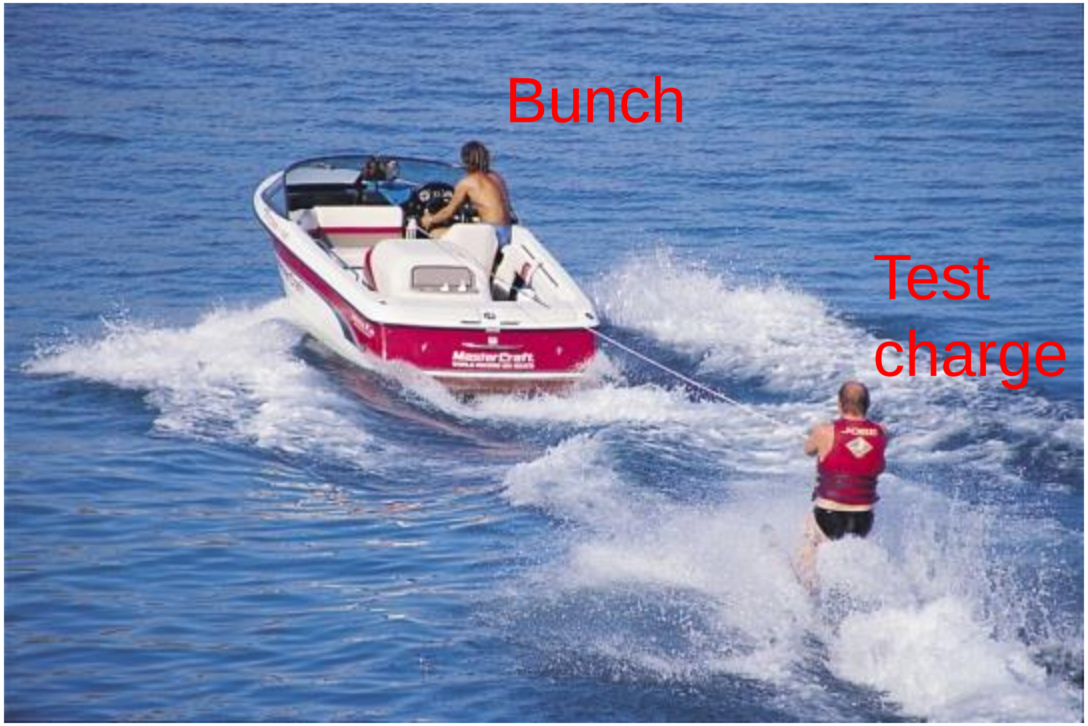
- Passing bunch induces image currents in the surrounding materials (vacuum chambers, collimators …)



- Induced wake fields act back on beam
  - Strength of effect depends on wall impedance and beam current

Induced instabilities

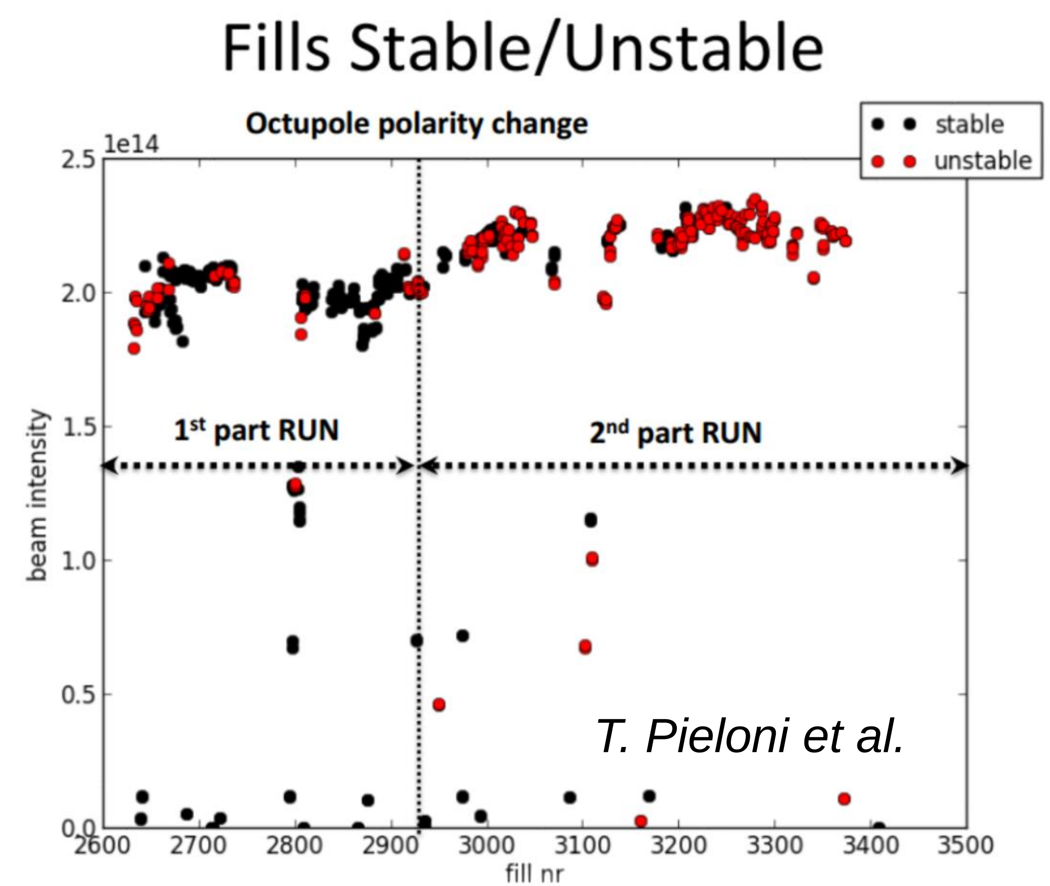
- Wake fields could excite the same bunch, or the following ones, in a self-amplifying manner
  - Beam becomes unstable

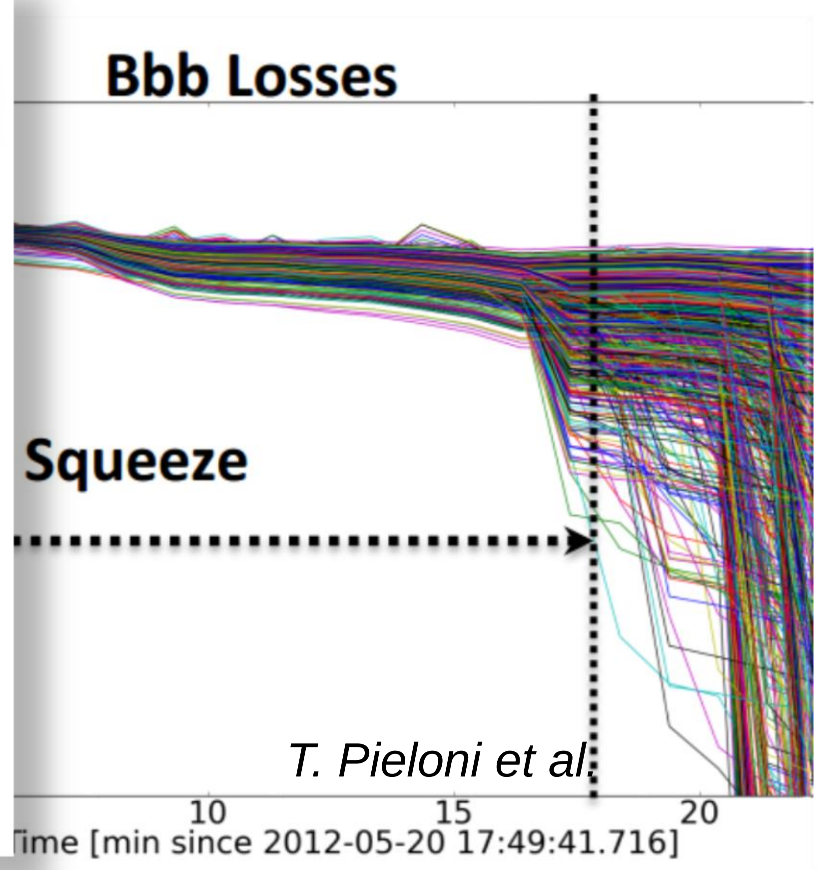


- Mitigations:
  - Lower impedance
  - Lower beam current (not an option for HL-LHC)
  - Damping mechanisms (octupoles, ADT …)

Example observations from the LHC

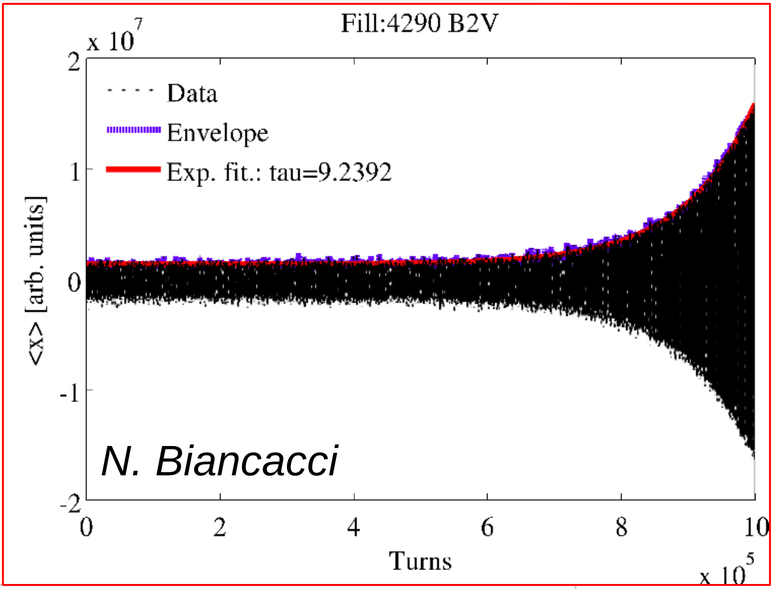
- Examples from 2012 - many LHC fills with observed instabilities
- Not always severe enough to cause beam dump
- Not sure of the exact role of collimator impedance – complex interplay

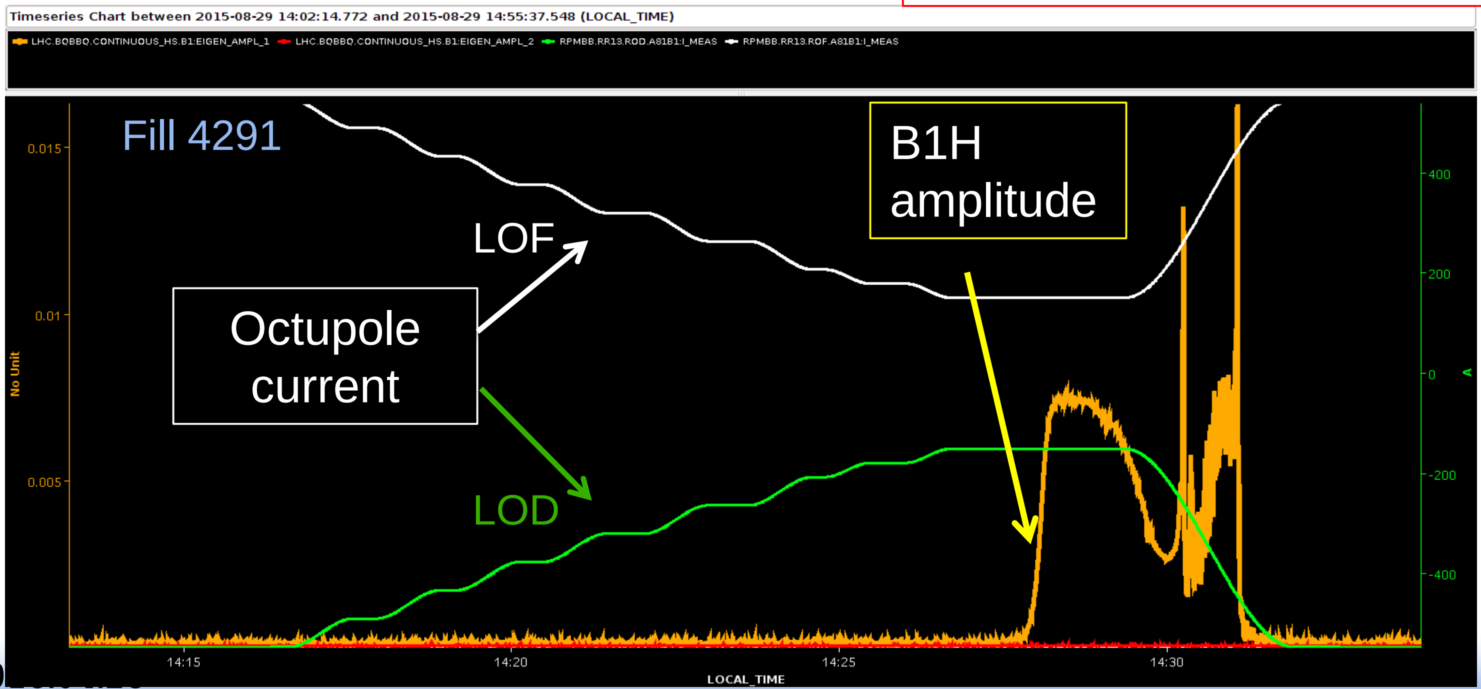




Example observations from the LHC

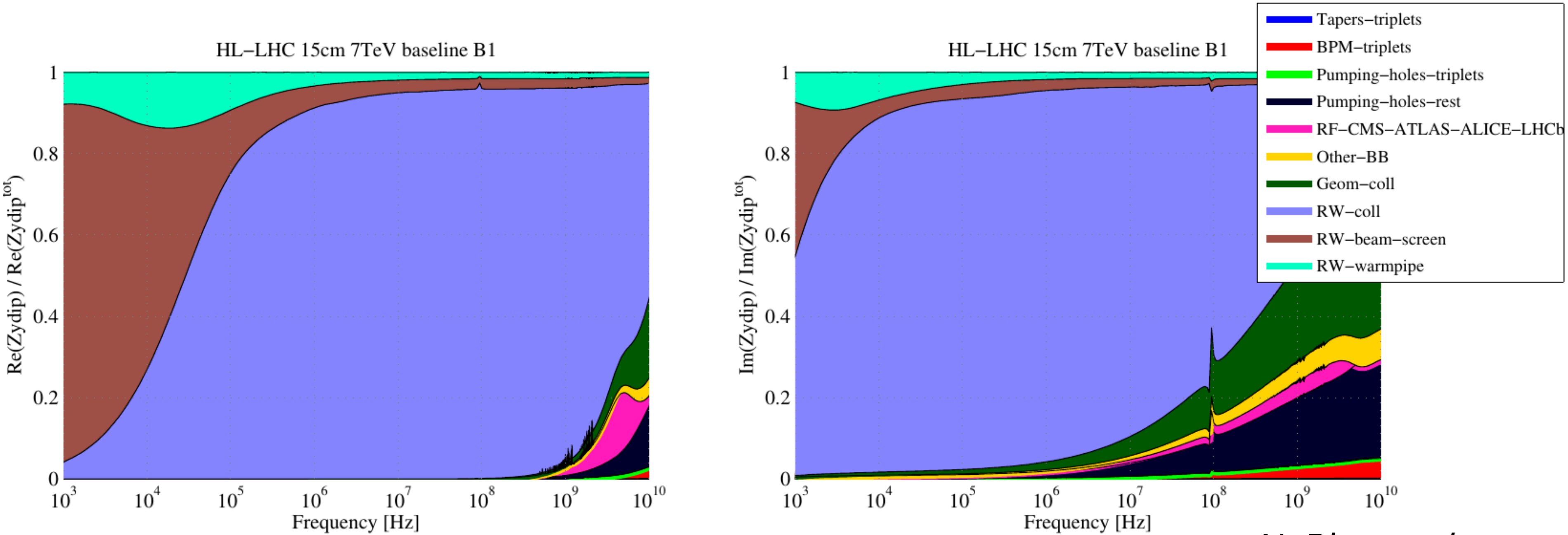
- Examples from 2015 – instability observed when damping effect from octupoles is reduced
- Threshold in octupole current, needed to keep the beam stable, depends on the machine impedance





Impedance from collimators

- Collimators make up for a large part of the HL-LHC total impedance over a large range of frequencies

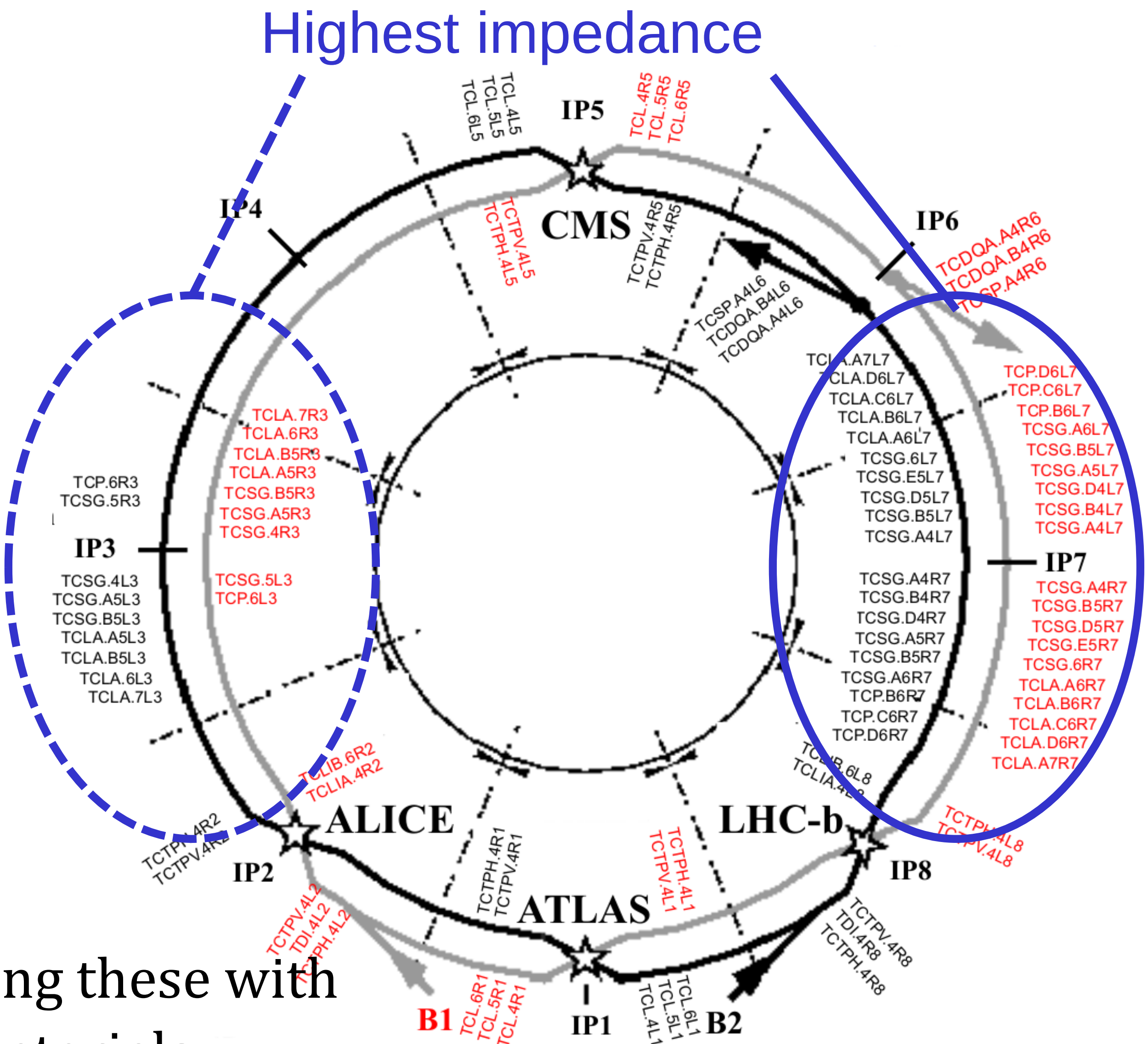


N. Biancacci

- Reducing the collimator impedance could significantly improve the beam stability

Main impedance contributors

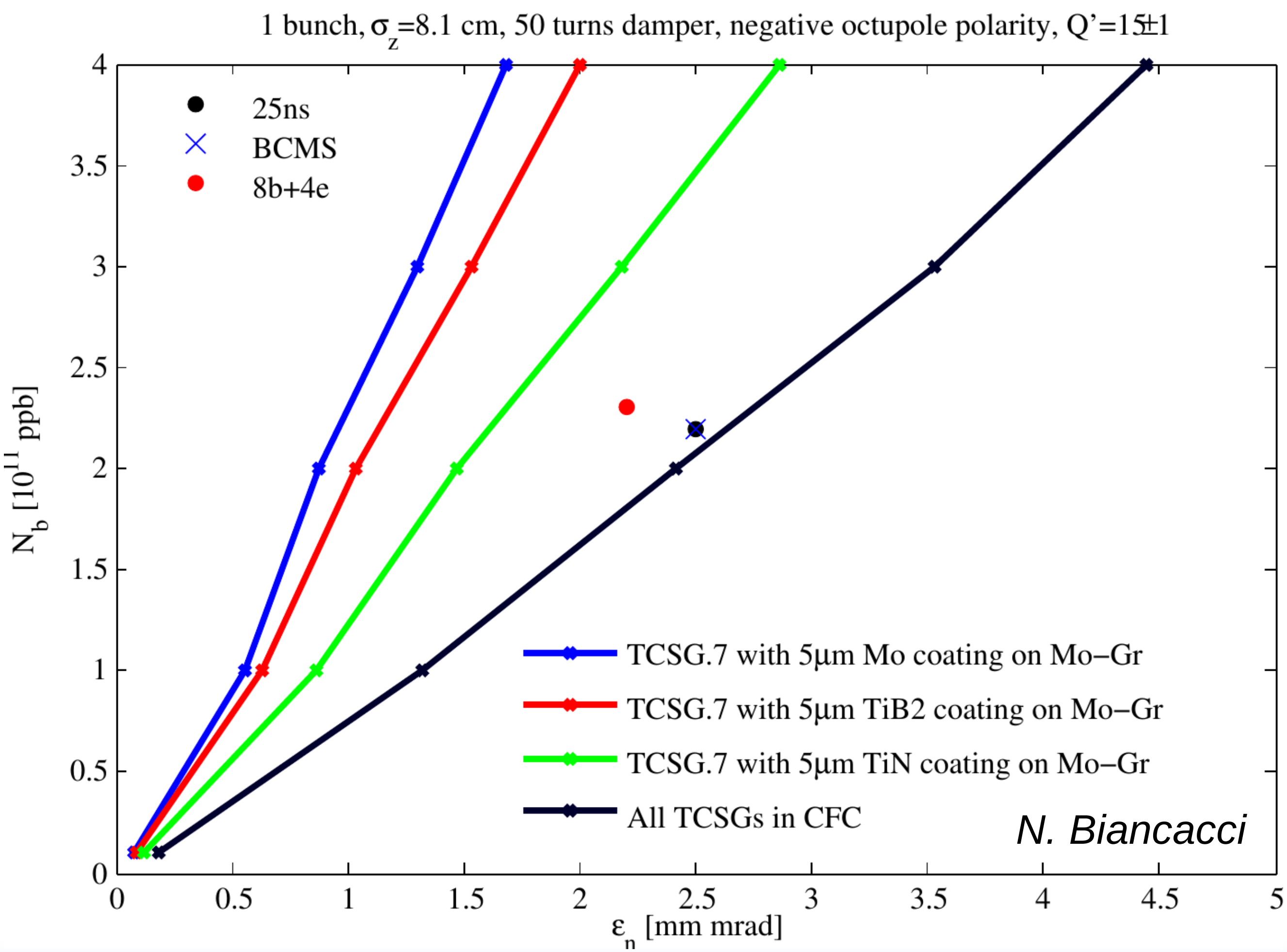
- Graphite (CFC) collimators give main impedance contribution: primaries and secondaries
  - closest to the beam
  - higher resistivity
  - large number of collimators



- Studies on replacing these with low-impedance materials

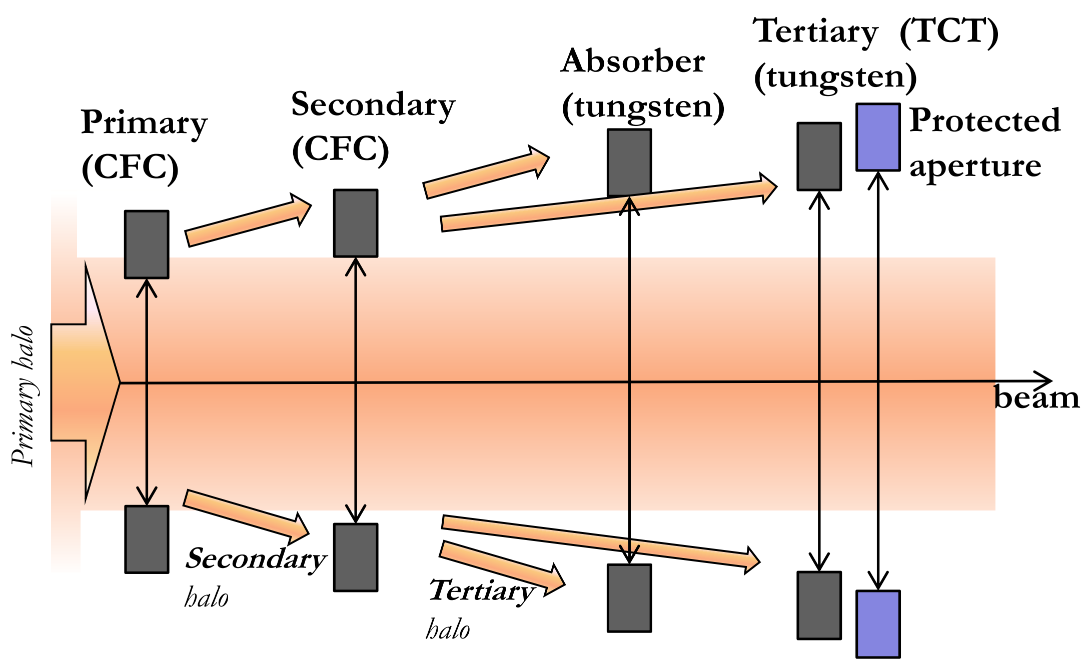
Beam stability with different materials

- New collimator materials predicted to allow bunches with larger intensity and smaller emittance (~transverse beam size)to remain stable



Robustness considerations

- Some collimator materials (e.g. tungsten / inermet180) are less robust than others (e.g. CFC)
- Tungsten collimators are further out from the beam (collimation hierarchy) and should intercept less losses in standard operation
  - During asynchronous dumps, beam could be kicked directly onto tungsten collimators or the aperture, without hitting the primary first



Asynchronous beam dump

- Standard dump: extraction kickers fire when no beam passes

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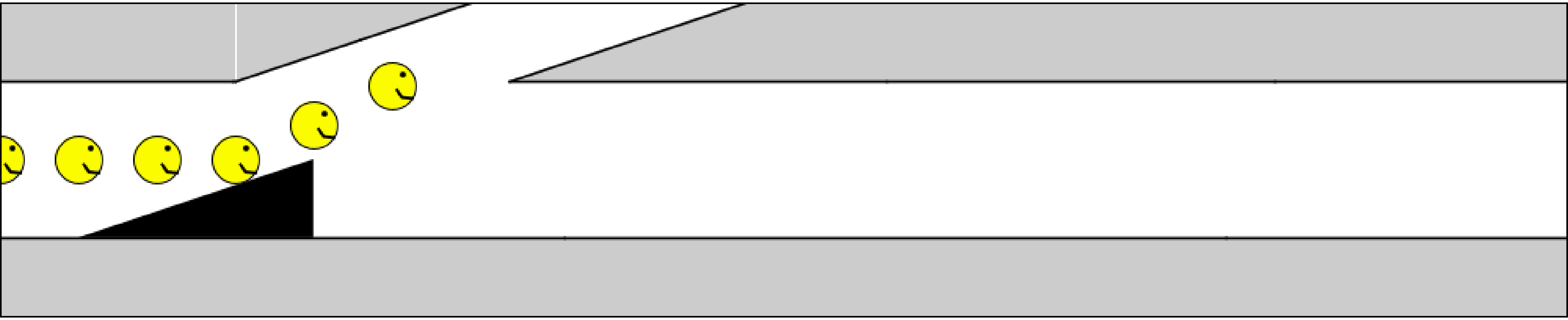

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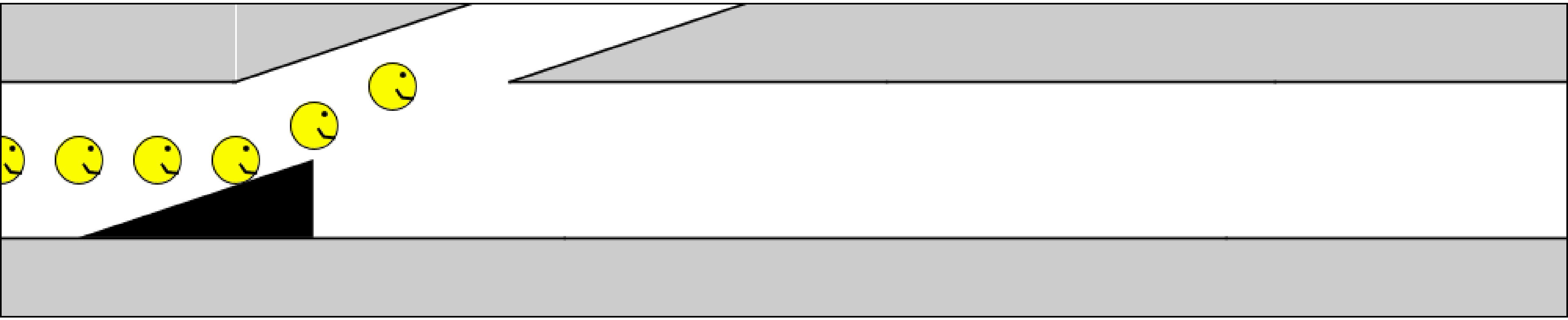

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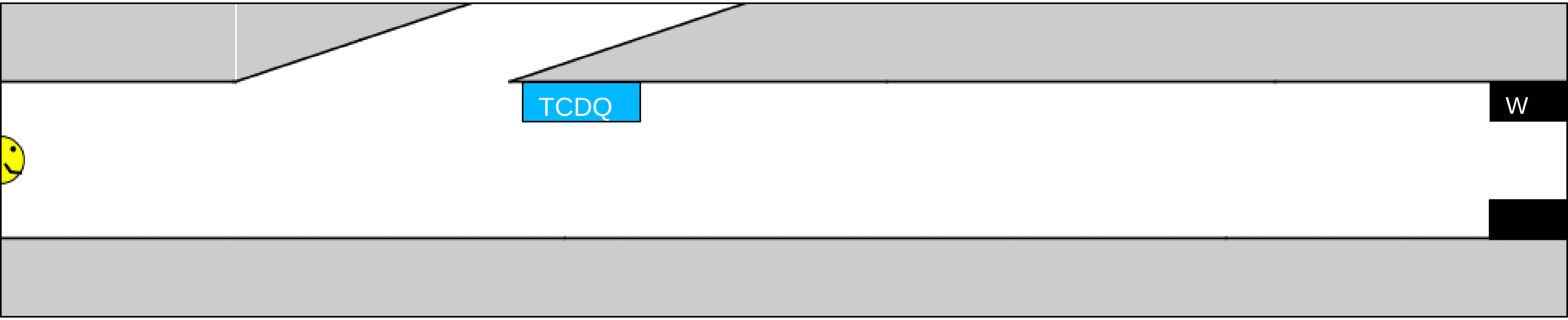
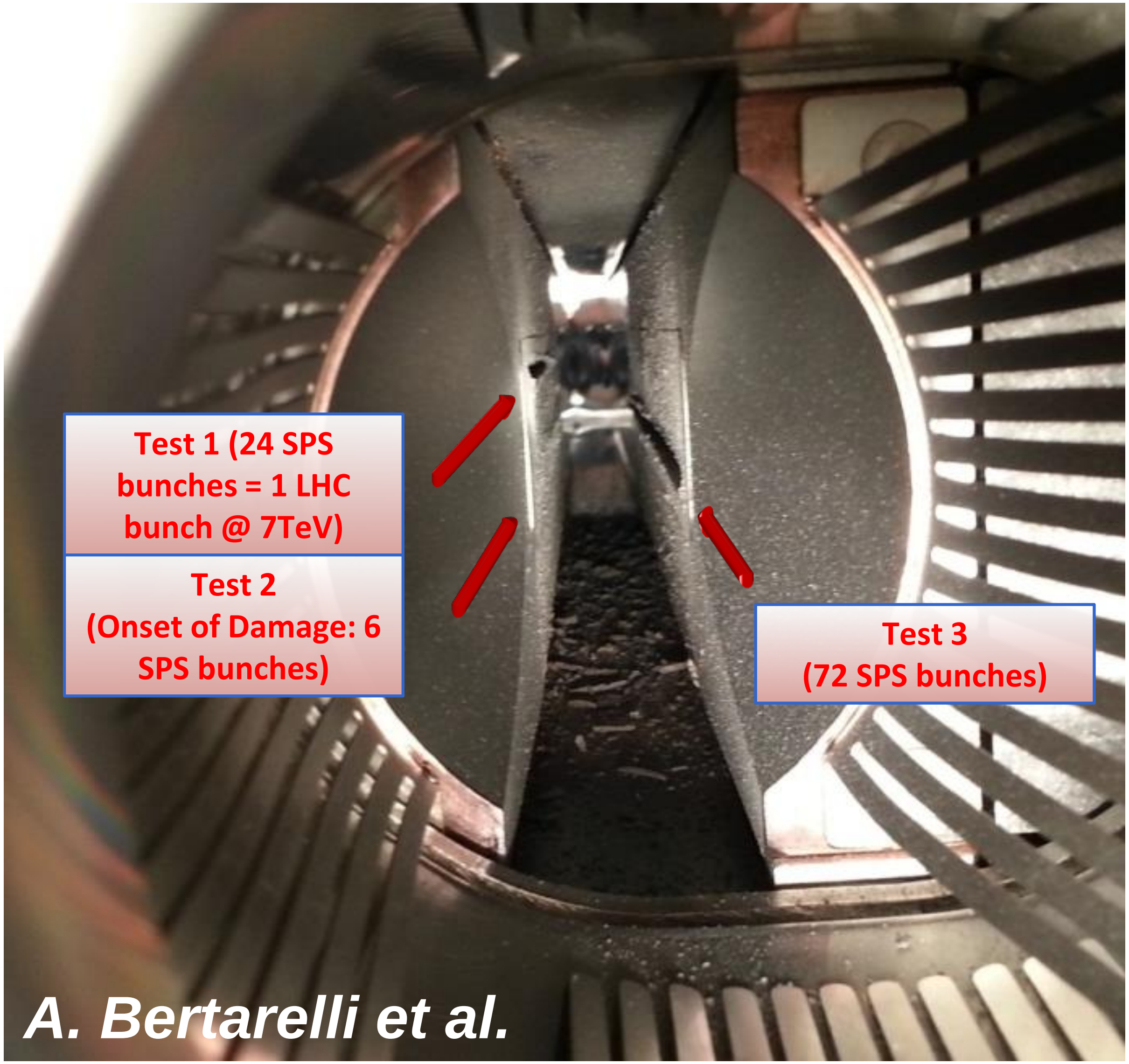


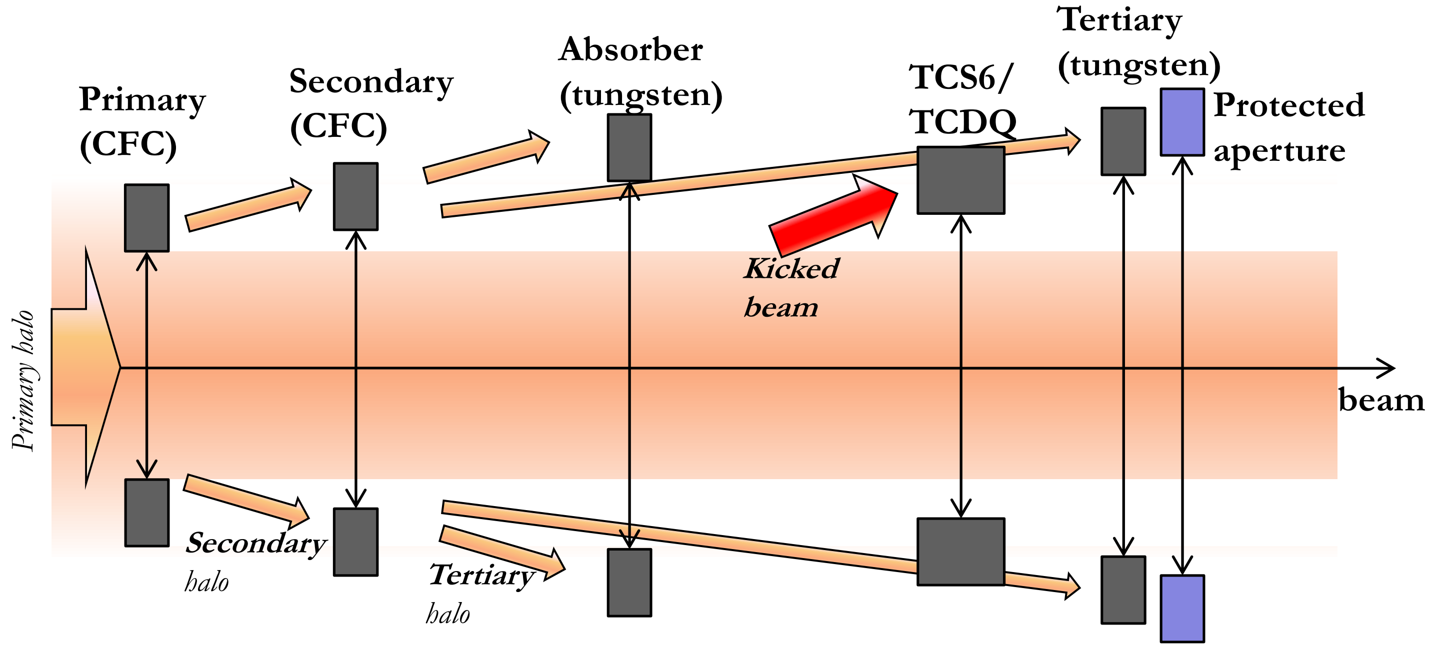
What can happen if a TCT is hit?

- Impacts studied in HiRadMat
- Significant damage observed



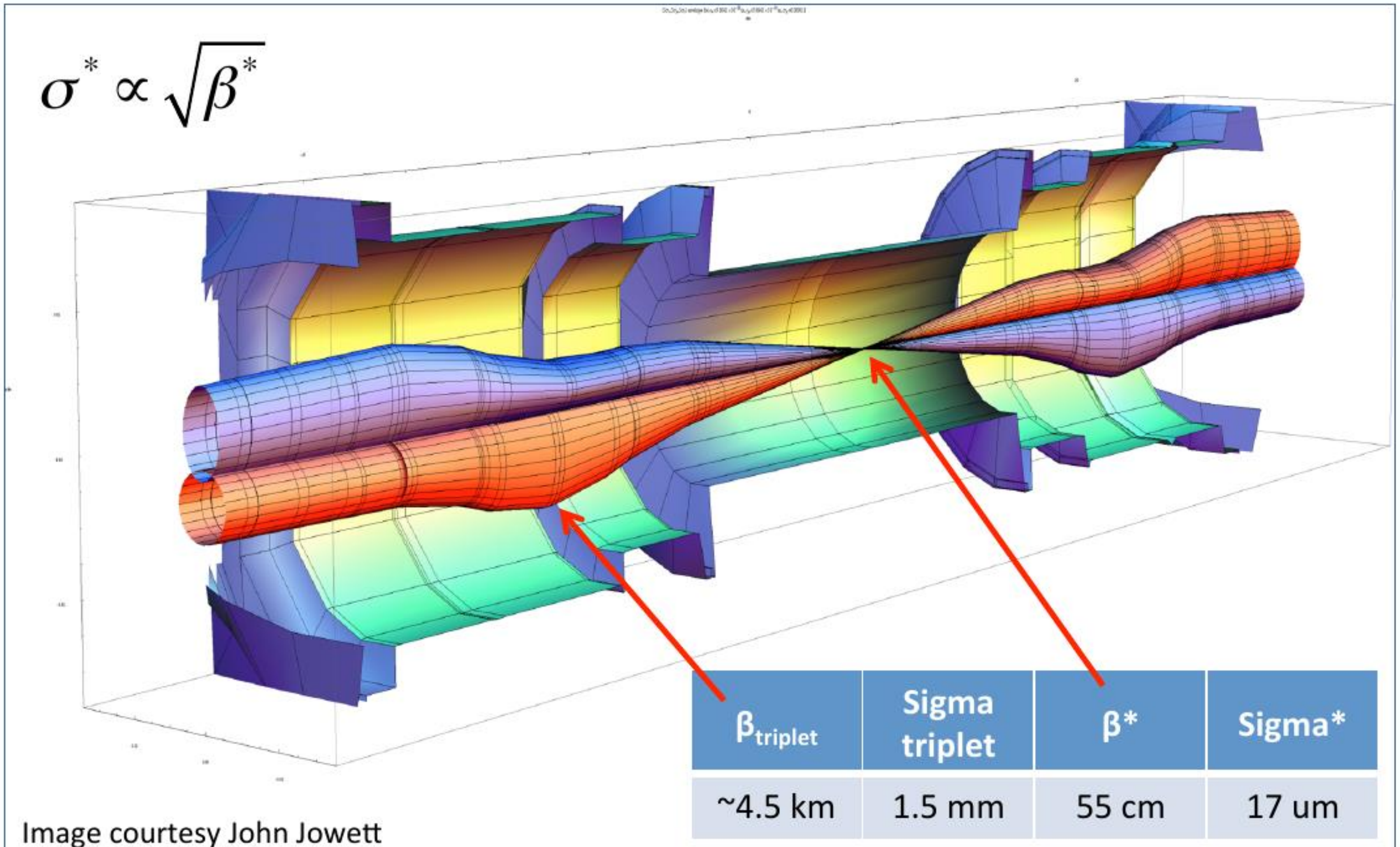
Limits on TCT setting

- Margin to TCDQ needed so that tungsten collimators cannot hit by asynchronous dumps, even if orbit and optics drift
  - Inner limit on how close to the beam the they can be moved
  - At the same time: TCTs must protect aperture => inner limit on (normalized) aperture



Reducing β*

- Normalized aperture depends on beam size in triplet
- When squeezing β*, triplet beam size blows up => limit on β*



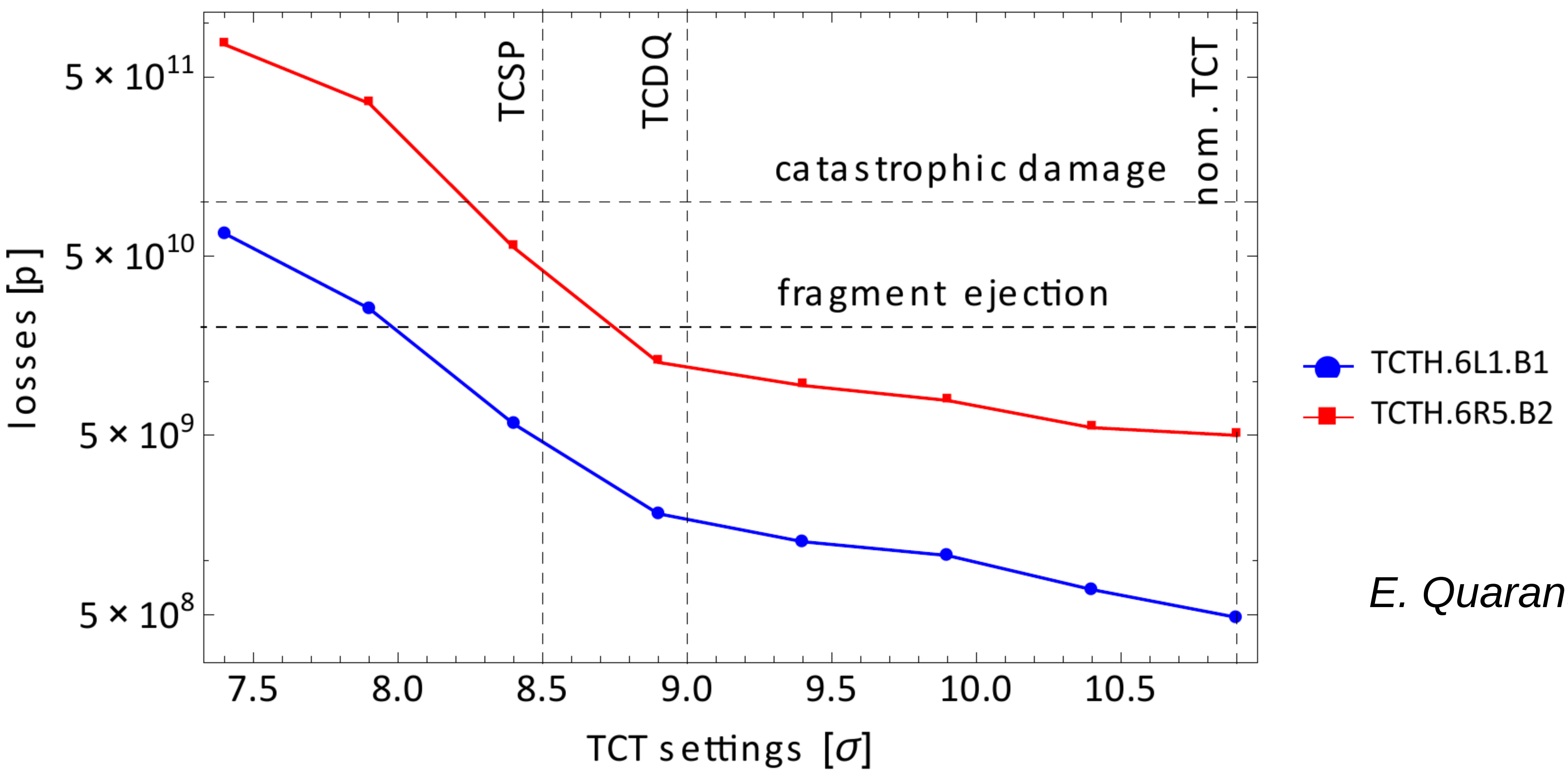
$$\sigma^* \propto \sqrt{\beta^*}$$

$\beta_{triplet}$	Sigma triplet	β*	Sigma*
~4.5 km	1.5 mm	55 cm	17 um

Image courtesy John Jowett

Expected TCT impacts in HL-LHC

- If orbit drifts, so that effective TCT setting goes down by ~2σ, risk of severe damage (see talk E. Quaranta)
- Plastic deformation (possibility to recover with 5th axis) occurs before



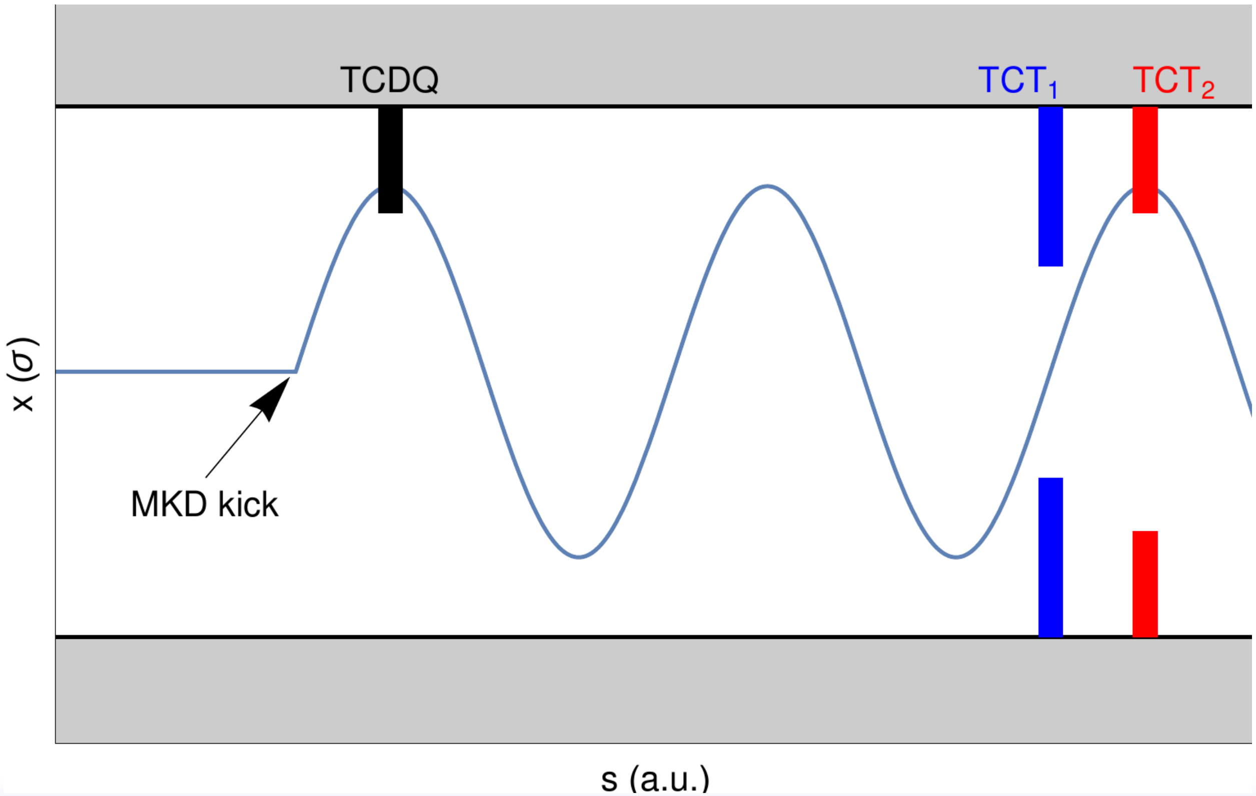
E. Quaranta

Considerations on TCT material

- More robust TCTs could be moved closer to the beam so that
  - Larger drifts of orbit and optics could be tolerated, or
  - We could protect a smaller normalized triplet aperture, allowing a smaller β^* and hence better luminosity performance
- Downsides
  - More robust usually means less dense and less absorbing
  - Larger leakage of shower out of the TCTs to triplets and experiments
  - Under study: impact on experimental background, and impact on damage risks for experiments and triplets
- Similar studies underway also for tungsten absorbers (TCLA) and new DS collimators (TCLD) – see talk E. Quaranta
  - However, their settings are less critical for LHC luminosity performance

Alleviation of losses with phase advance

- Alternative alleviation: Use betatron phase advance from kicker to ensure that tungsten collimators are not hit
  - Implemented in the LHC this year for TCTs => allows sub-nominal β*=40 cm
  - Not sure that this can be done in HL-LHC: strict phase constraints from ATS. Under study (S. Fartoukh et al.)



Conclusions

- The materials of the present LHC collimators impose performance limitations (LHC and HL-LHC)
  - β* and hence luminosity limited by robustness of tertiary collimators (presently in tungsten)
    - Can not go too close to the beam, and protect arbitrary small aperture, to avoid damage during asynchronous beam dumps
  - Bunch intensity and emittance limited by collimator impedance
    - Instabilities risk to occur if too aggressive parameters are used
- New materials under study could alleviate some performance limitations of HL-LHC
  - If one property is improved, e.g. impedance, very important to ensure that all other properties (cleaning, radiation resistance, vacuum behaviour ….) are not degrading