

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 $\text{cm}^2 \text{s}^{-1}$	7.2e34 $\text{cm}^2 \text{s}^{-1}$
Leveled luminosity		5e34 $\text{cm}^2 \text{s}^{-1}$

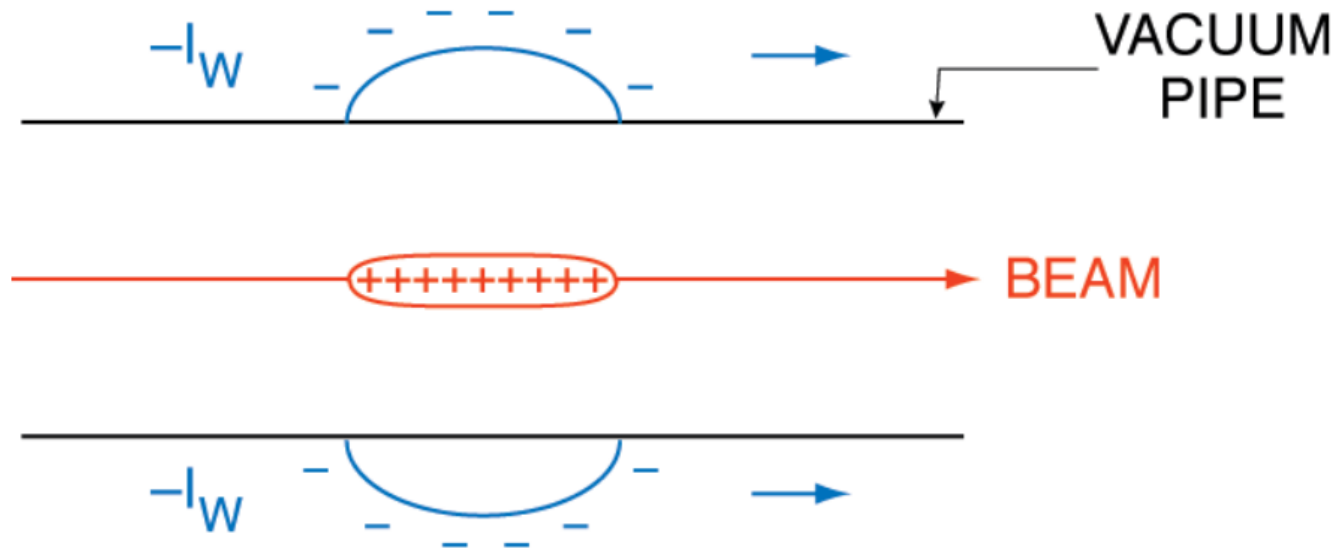
- Several challenges related to collimator materials

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

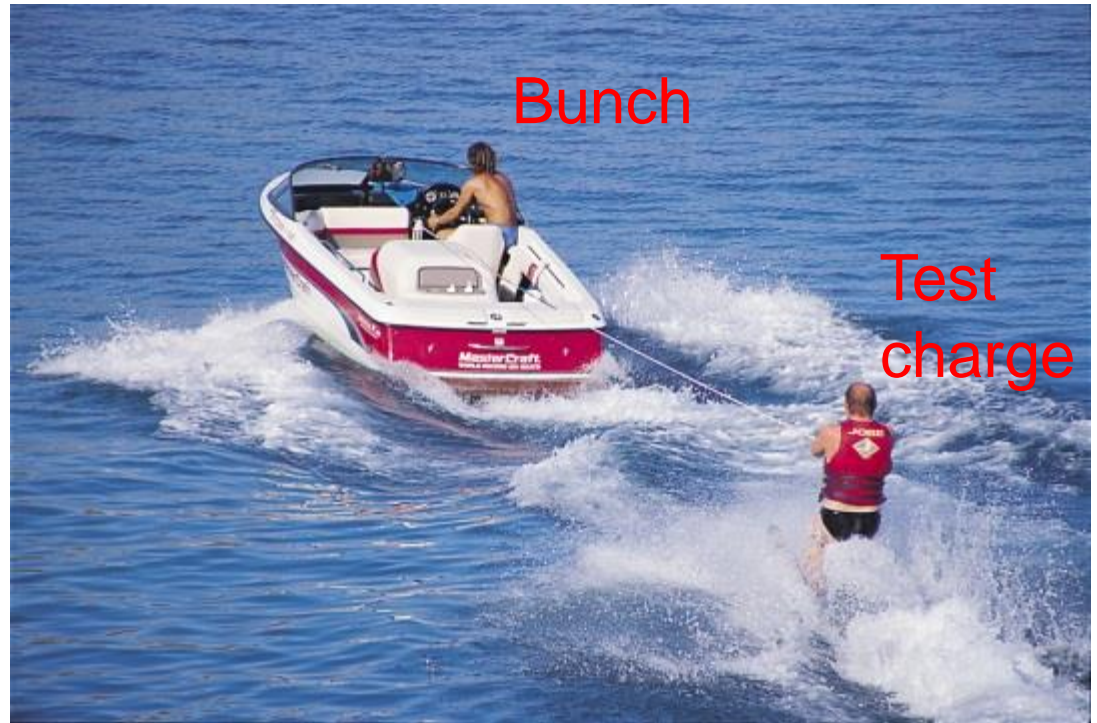
- Passing bunch induces image currents in the surrounding materials (vacuum chambers, collimators ...)



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

Induced instabilities

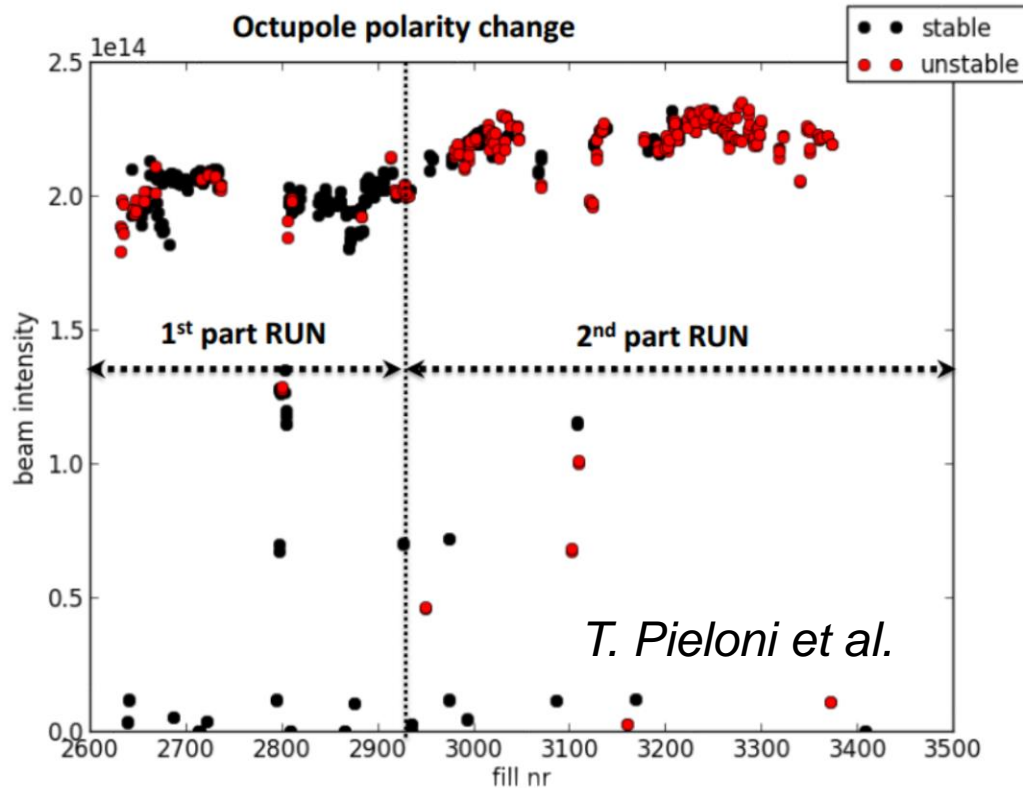
- Wake fields could excite the same bunch, or the following ones, in a self-amplifying manner
 - Beam becomes unstable
- Mitigations:
 - Lower impedance
 - Lower beam current (not an option for HL-LHC)
 - Damping mechanisms (octupoles, ADT ...)



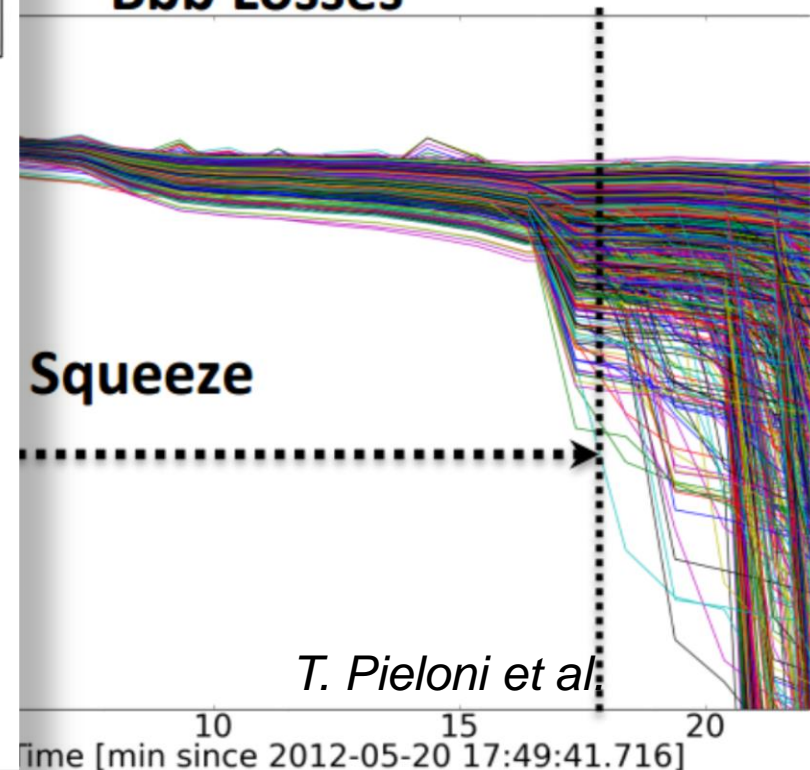
Example observations from the LHC

- 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

Fills Stable/Unstable

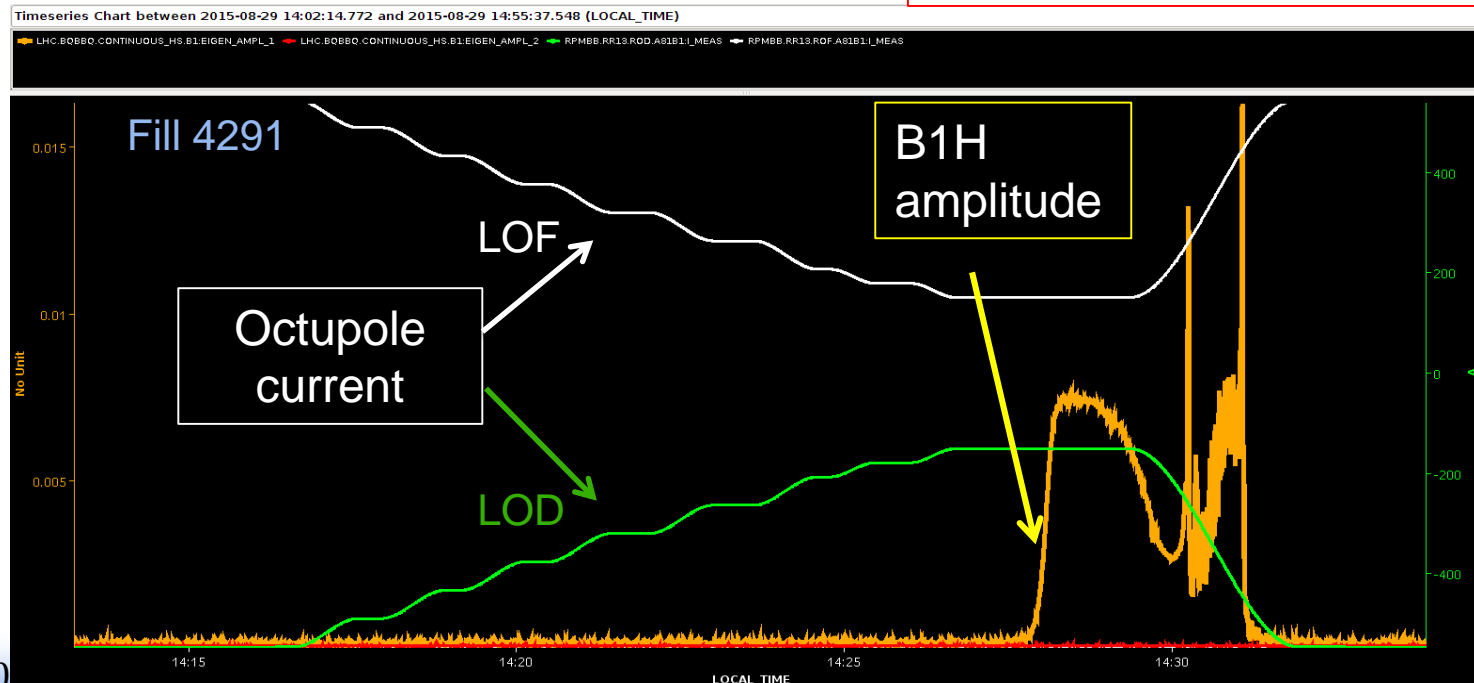
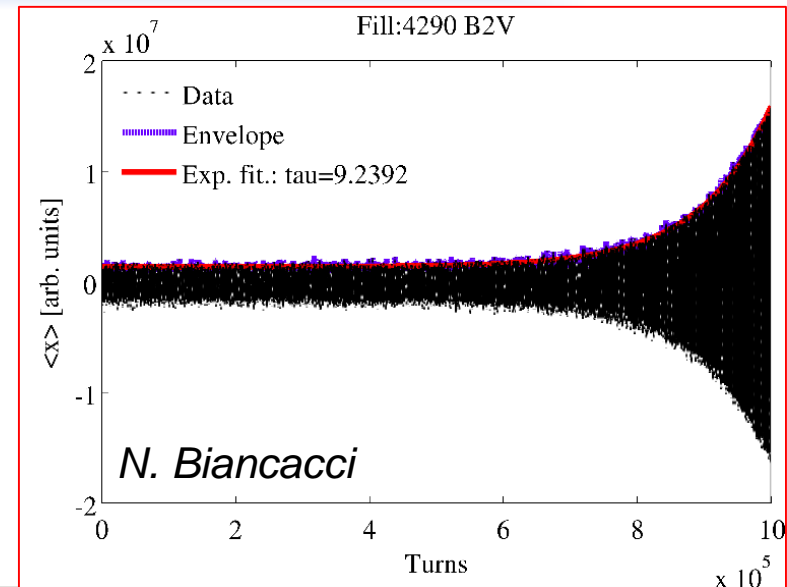


Bbb Losses



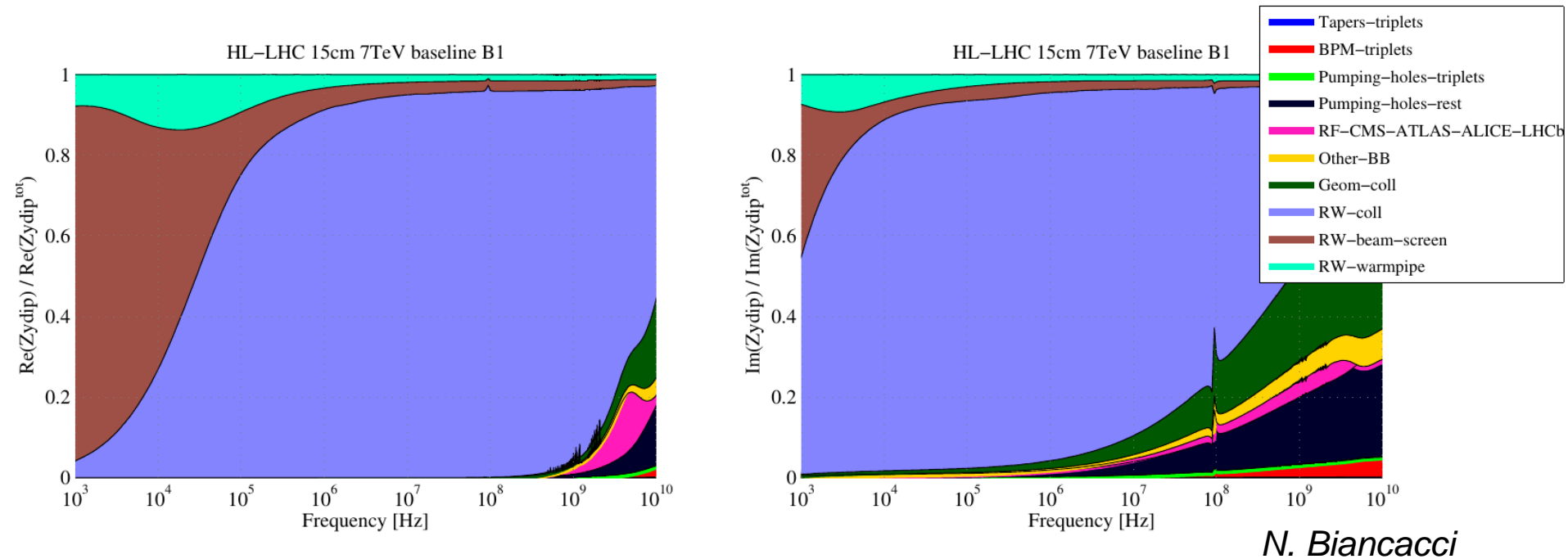
Example observations from the LHC

- 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

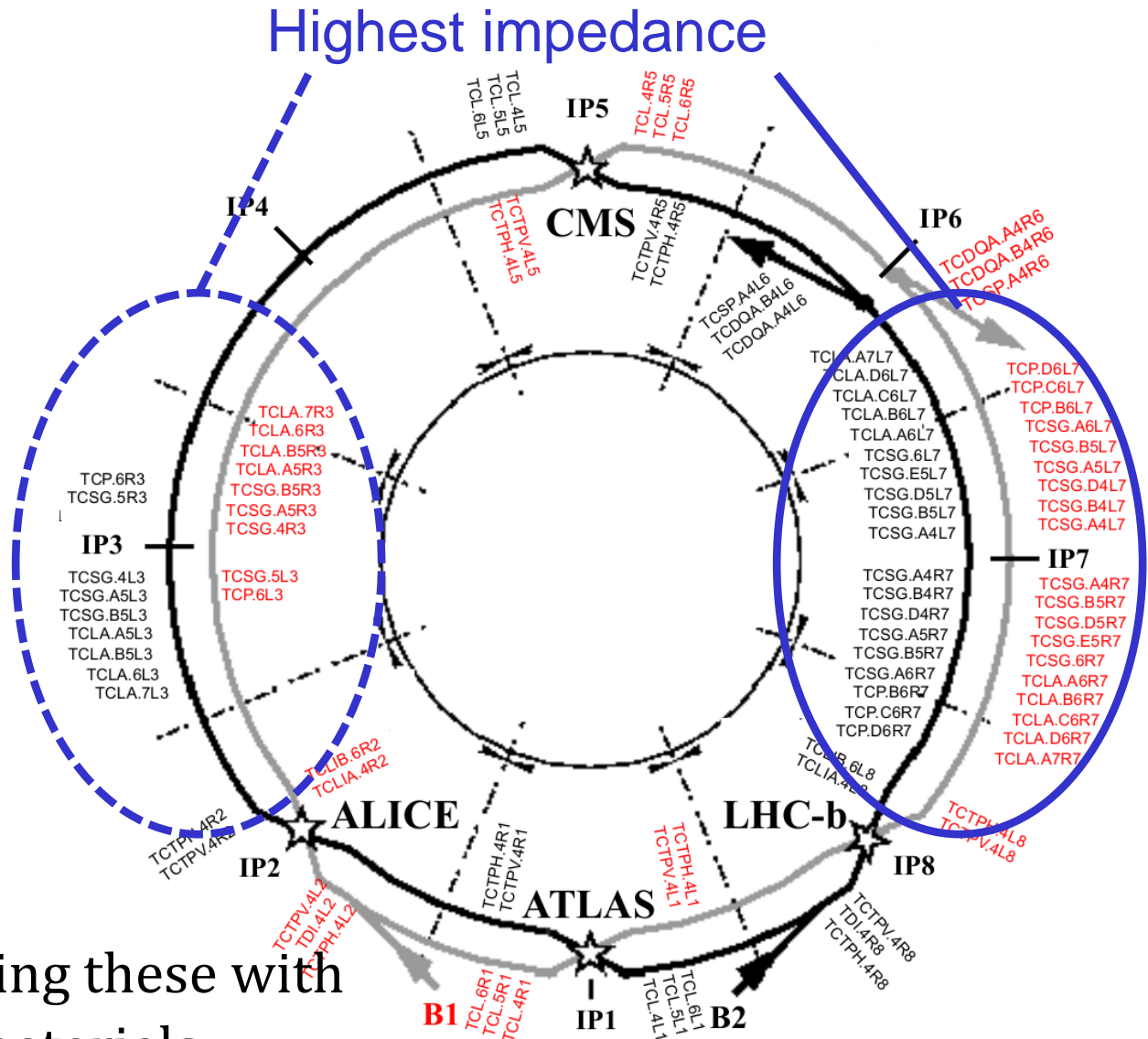
- Collimators make up for a large part of the HL-LHC total impedance over a large range of frequencies



- Reducing the collimator impedance could significantly improve the beam stability

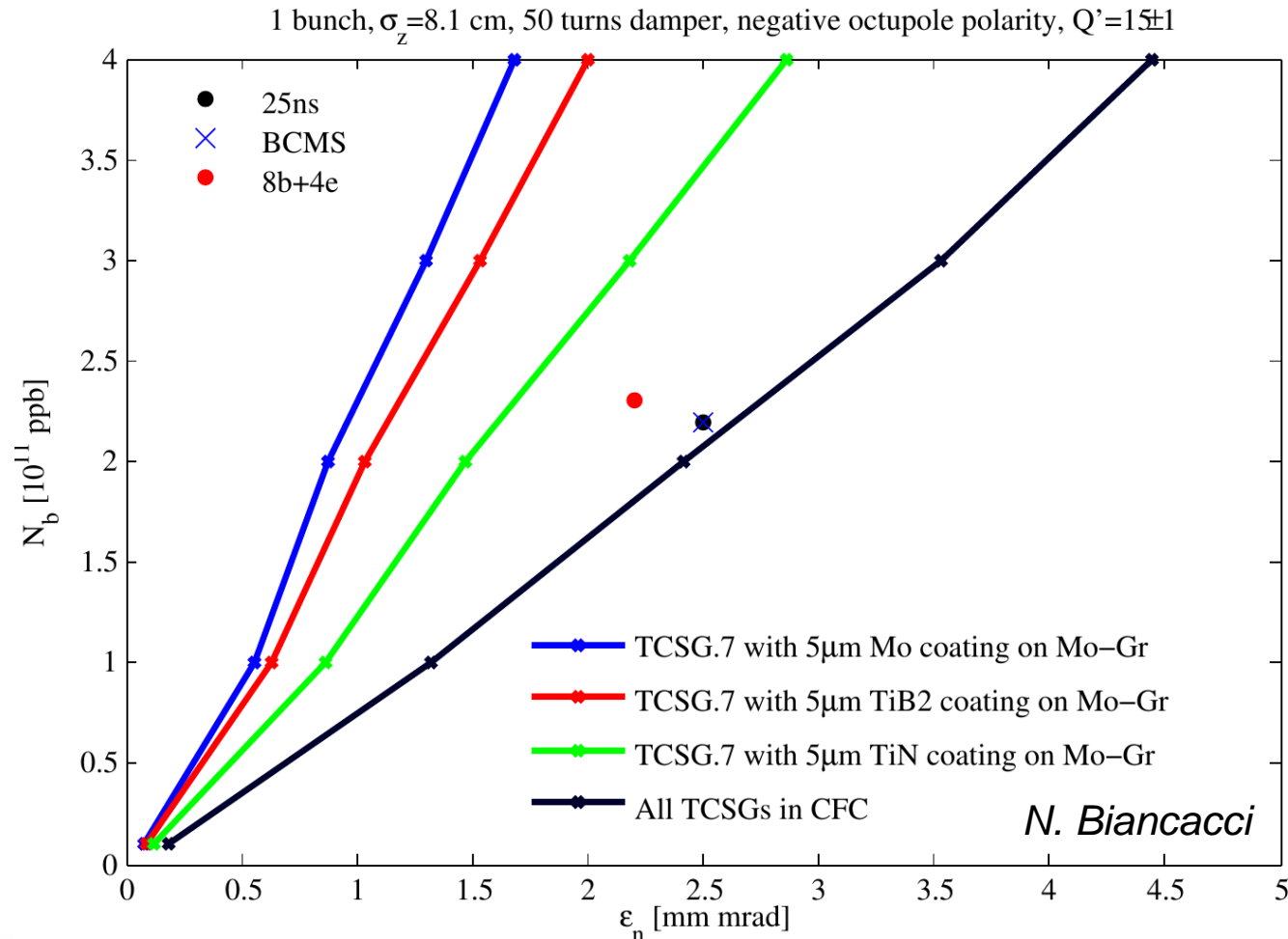
Main impedance contributors

- 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
-
- The diagram illustrates the LHC beam pipe layout, highlighting the locations of collimators and their relative impedance contributions. A dashed blue circle represents the beam pipe, with a solid black line indicating the beam path. Key locations are marked with IP2, IP3, and IP4. Collimators are labeled with codes such as TCPV.4R2, TCPV.4L2, TCPV.4R3, TCPV.4L3, TCPV.5R3, TCPV.5L3, TCPV.6R3, TCPV.6L3, TCPV.7R3, TCPV.7L3, TCPV.8R3, TCPV.8L3, TCPV.9R3, TCPV.9L3, TCPV.10R3, TCPV.10L3, TCPV.11R3, TCPV.11L3, TCPV.12R3, TCPV.12L3, TCPV.13R3, TCPV.13L3, TCPV.14R3, TCPV.14L3, TCPV.15R3, TCPV.15L3, TCPV.16R3, TCPV.16L3, TCPV.17R3, TCPV.17L3, TCPV.18R3, TCPV.18L3, TCPV.19R3, TCPV.19L3, TCPV.20R3, TCPV.20L3, TCPV.21R3, TCPV.21L3, TCPV.22R3, TCPV.22L3, TCPV.23R3, TCPV.23L3, TCPV.24R3, TCPV.24L3, TCPV.25R3, TCPV.25L3, TCPV.26R3, TCPV.26L3, TCPV.27R3, TCPV.27L3, TCPV.28R3, TCPV.28L3, TCPV.29R3, TCPV.29L3, TCPV.30R3, TCPV.30L3, TCPV.31R3, TCPV.31L3, TCPV.32R3, TCPV.32L3, TCPV.33R3, TCPV.33L3, TCPV.34R3, TCPV.34L3, TCPV.35R3, TCPV.35L3, TCPV.36R3, TCPV.36L3, TCPV.37R3, TCPV.37L3, TCPV.38R3, TCPV.38L3, TCPV.39R3, TCPV.39L3, TCPV.40R3, TCPV.40L3, TCPV.41R3, TCPV.41L3, TCPV.42R3, TCPV.42L3, TCPV.43R3, TCPV.43L3, TCPV.44R3, TCPV.44L3, TCPV.45R3, TCPV.45L3, TCPV.46R3, TCPV.46L3, 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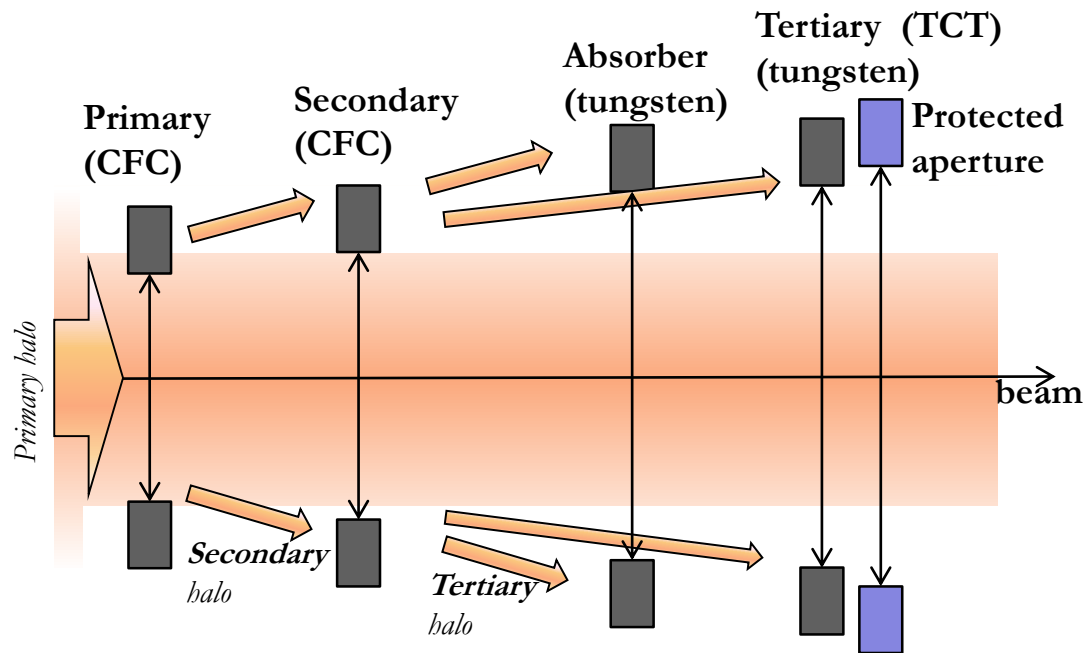
Beam stability with different materials

- New collimator materials predicted to allow bunches with larger intensity and smaller emittance (\sim 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

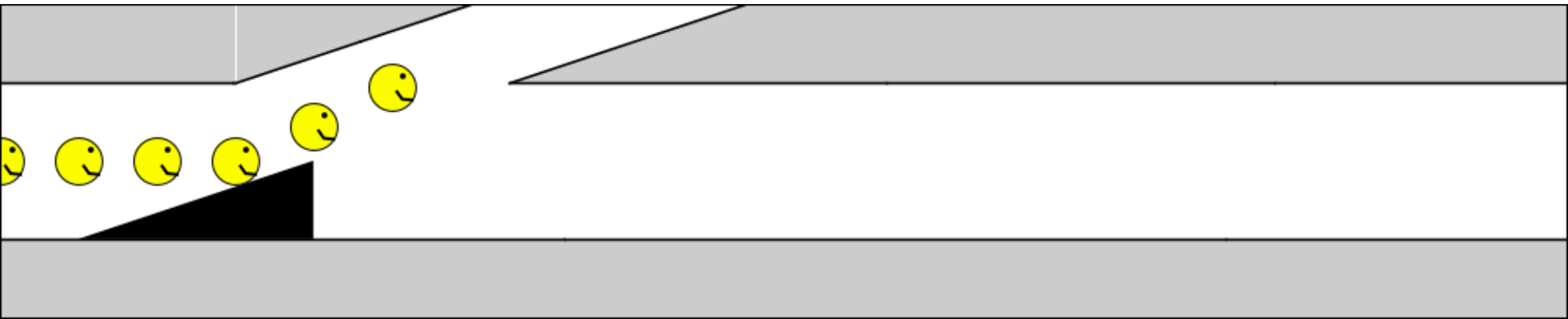


Asynchronous beam dump

- Standard dump: extraction kickers fire when no beam passes

Asynchronous beam dump

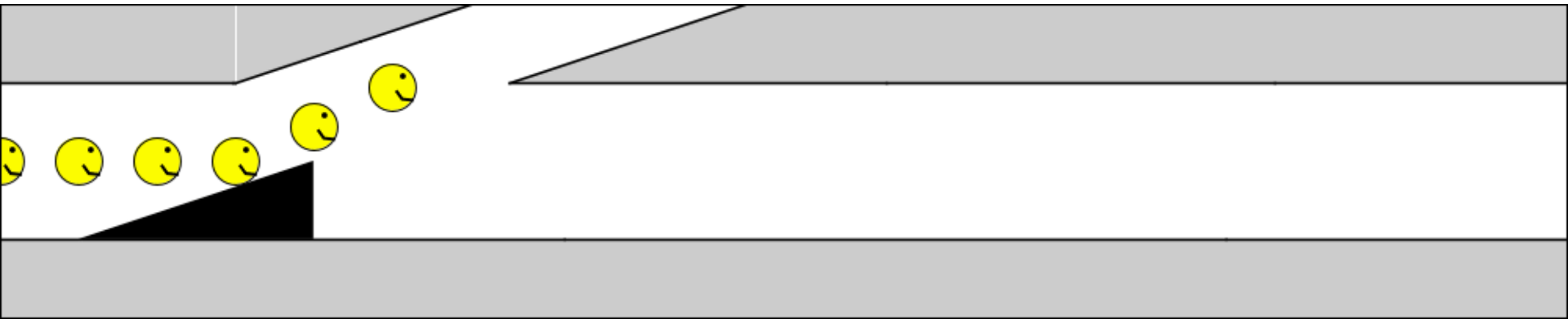
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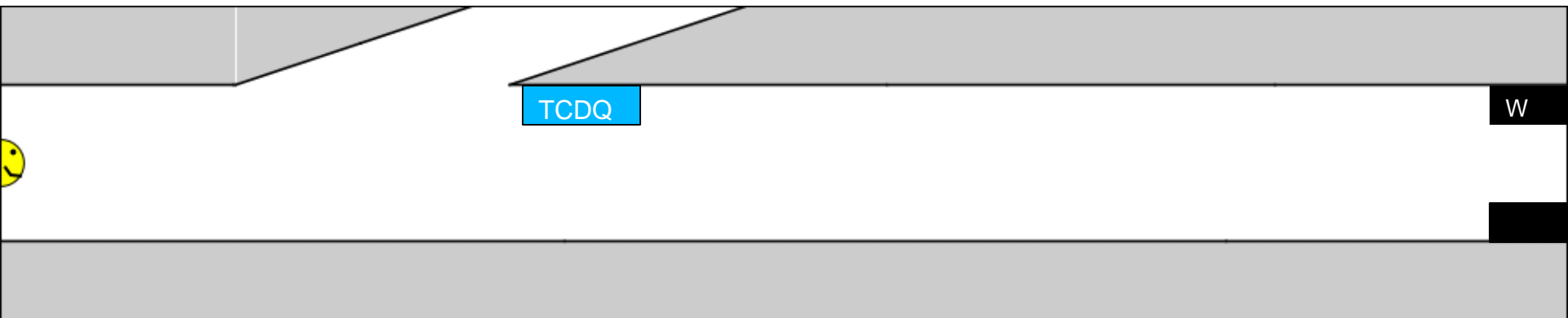
- Asynchronous dump: kicker(s) fire when beam passes – kicked beam damage could tungsten collimators. TCDQ should protect

Asynchronous beam dump

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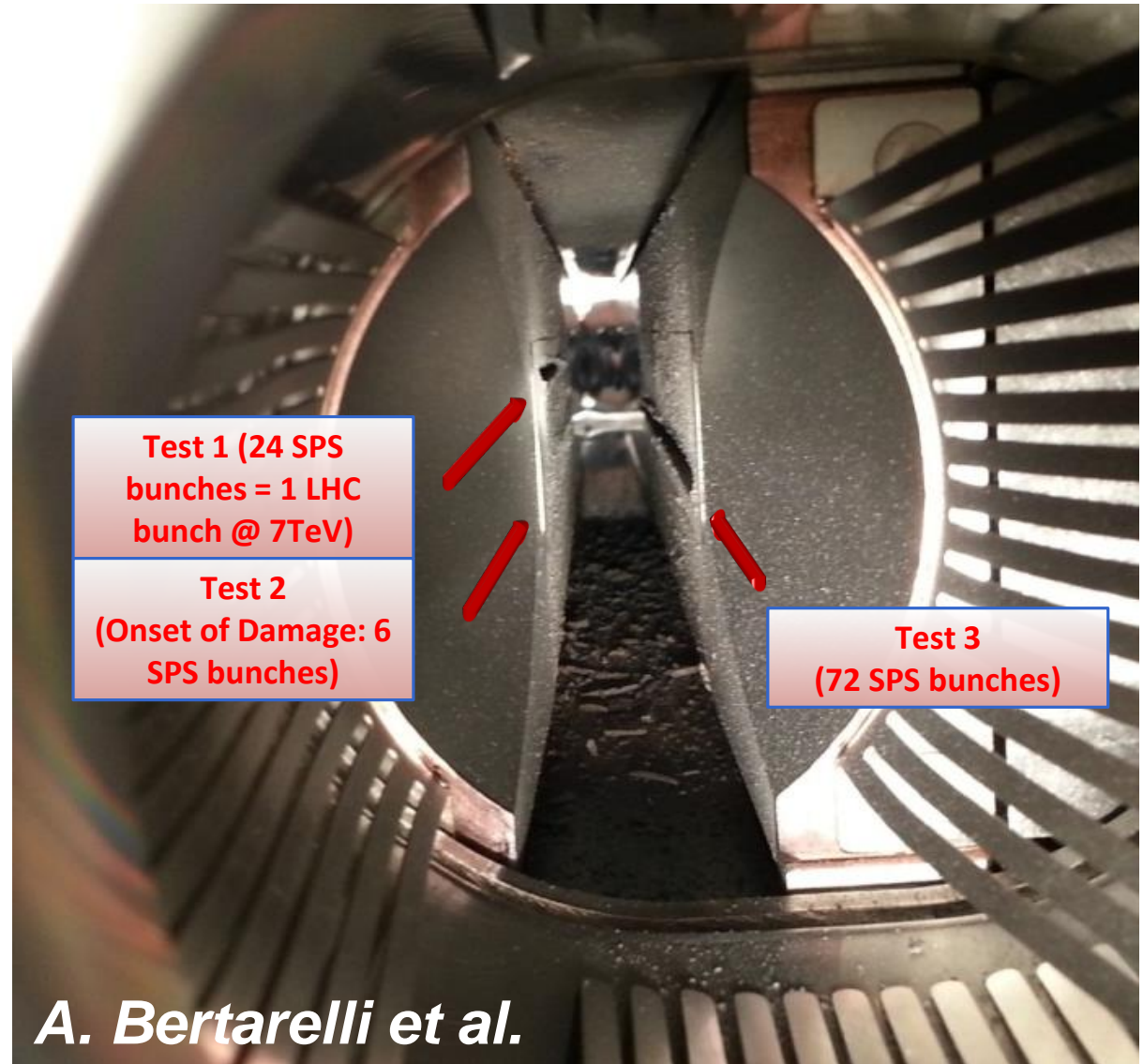


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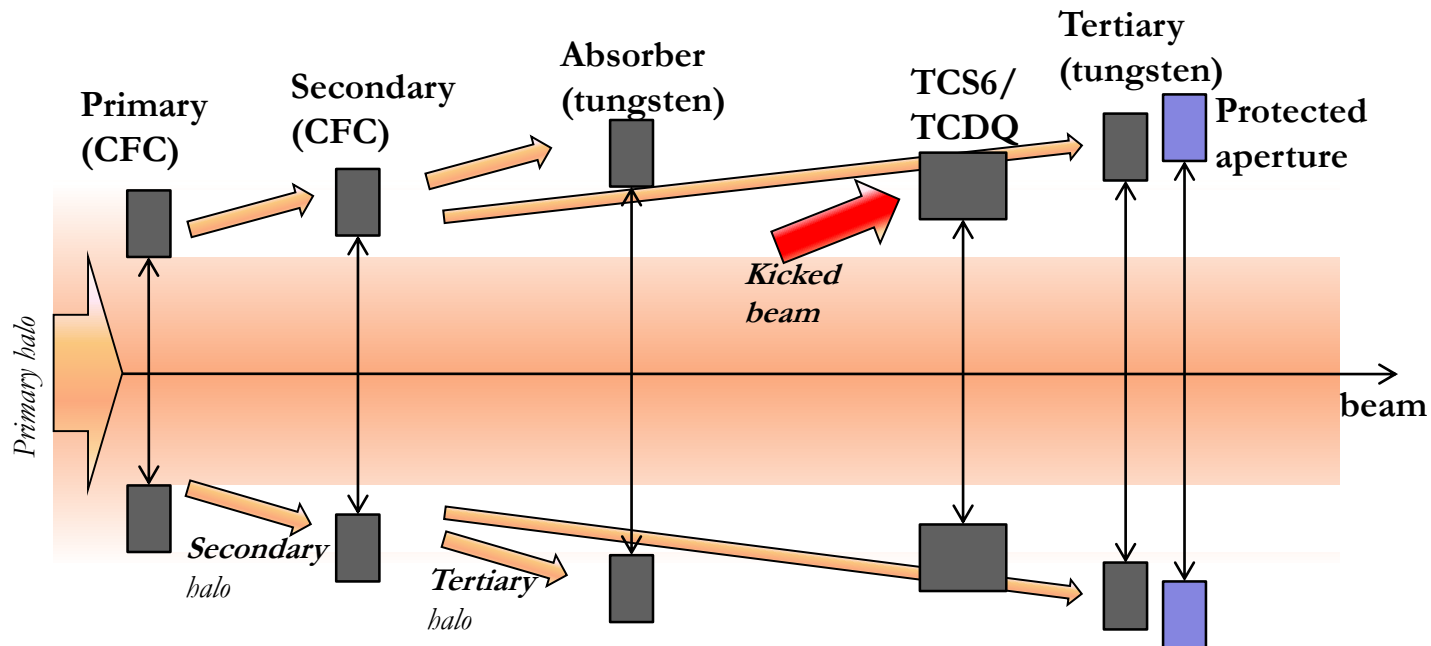
What can happen if a TCT is hit?

- Impacts studied in HiRadMat
- Significant damage observed



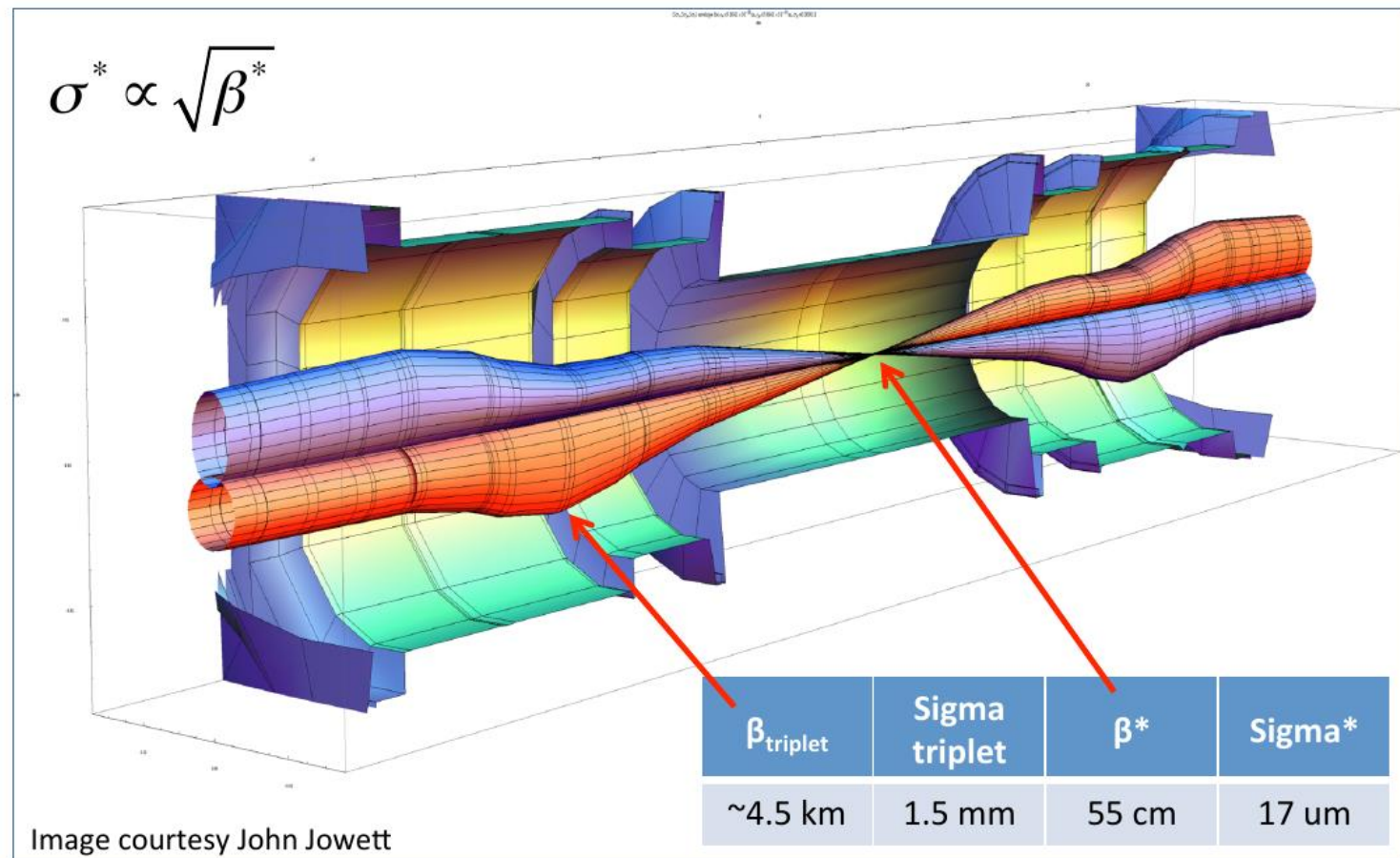
Limits on TCT setting

- 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



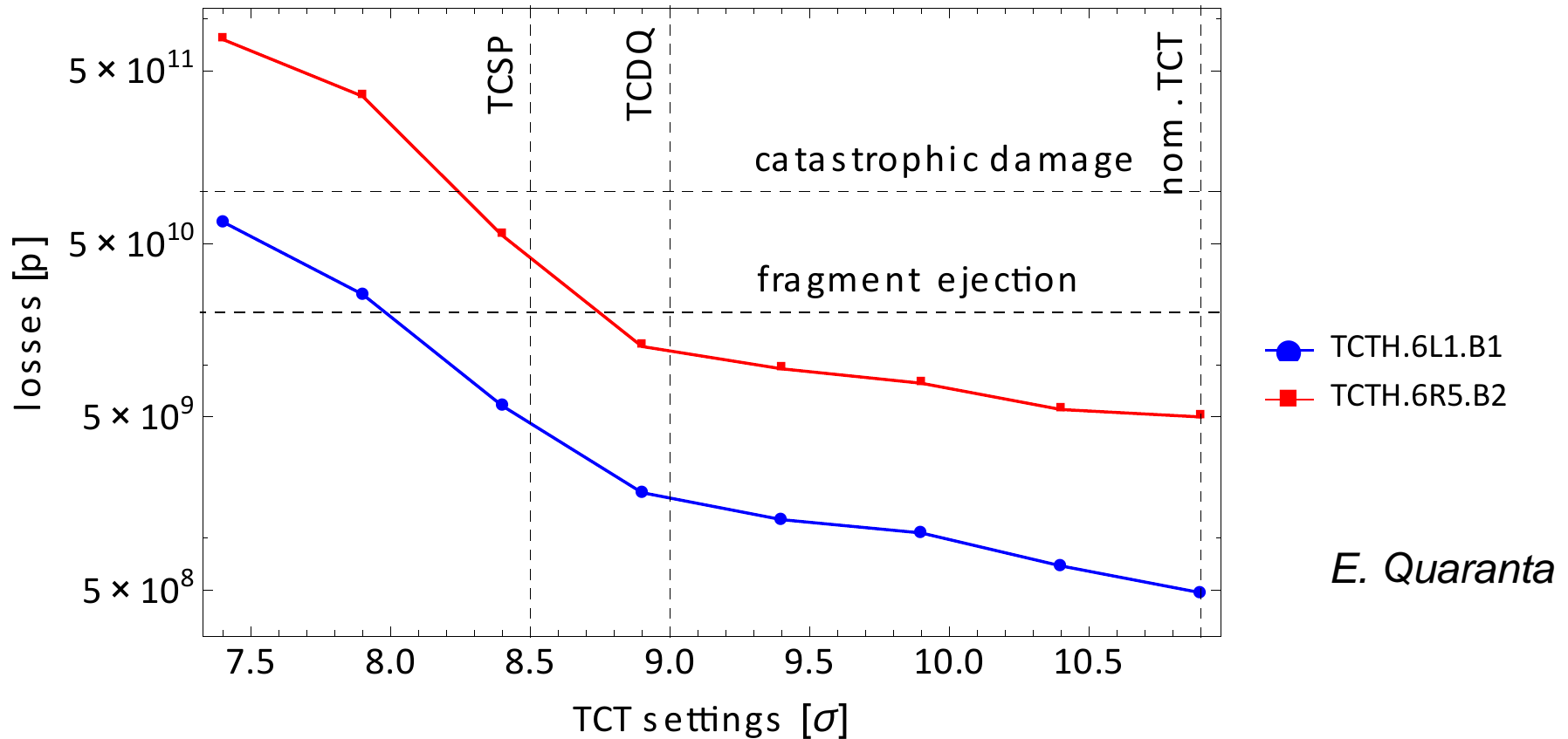
Reducing β^*

- Normalized aperture depends on beam size in triplet
- When squeezing β^* , triplet beam size blows up \Rightarrow limit on β^*



Expected TCT impacts in HL-LHC

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

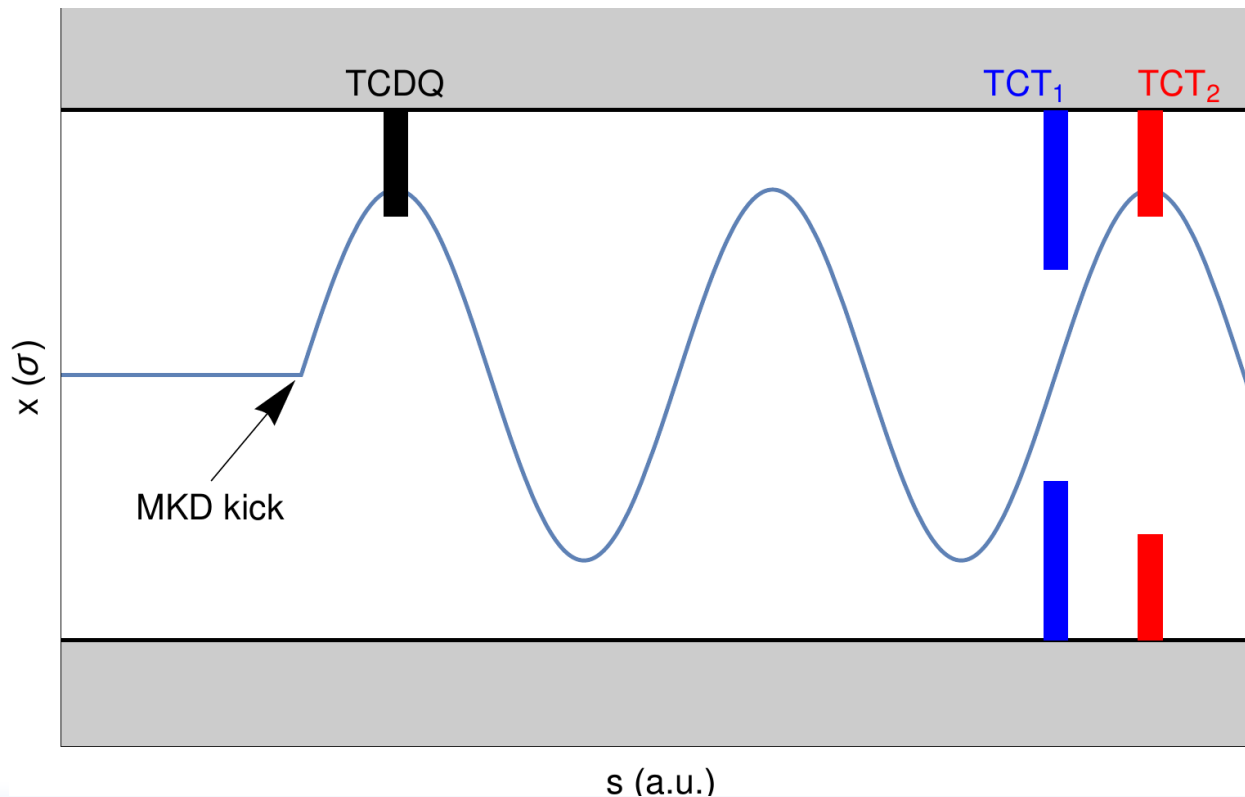


Considerations on TCT material

- 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 $\beta^*=40$ 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