HL-LHC impedance model

with considerations about MKI and triplet beam screens

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Acknowledgements: M. Barnes, R. Bruce, F. Carra, R. de Maria, W. Deng, N. Kos, A. Mereghetti, M. M. Moh'D Al-Esseili.

Outline

- Update of the HL-LHC impedance model.
- Orientation of the longitudinal weld in the triplet beam screens and impact on impedance.
- Impact of the new MKI and various equipment (deformable RF fingers, VAX, Y-chamber) close to the triplets.

HL-LHC impedance model

- Changes w.r.t. the LHC that are **included** in the HL model:
  - ✓ Collimator at almost full upgrade (jaws of 2 TCPs and all but 2 TCSs in IR7 replaced by Mo-graphite ones, Mo-coated for the TCSs); some TCTs in Cu-coated copper-diamond; tungsten TCLD absorber in IR7,
  - ✓ Updated collimator tapers,
  - ✓ Beta functions in the arcs and triplets (optics v1.4),
  - ✓ TDIS (with graphite, Ti_6Al_4V and CuCr1Zr),
  - ✓ New MKI-cool – 4 of them,
  - ✓ New octogonal beam screens in triplets, with up-to-date dimensions, aC-coating, 75K copper, pumping holes and welds (rough estimate for the welds – to be updated by C. Zannini),
  - ✓ Updated experimental chambers (ATLAS & CMS),
  - ✓ Tapers and BPMs in the triplets region,
  - ✓ Crab cavities,
  - ✓ VAX, deformable RF- fingers and Y-chamber (triplet region).

HL-LHC impedance model

- Modifications that are not (yet) in the model:
  - ✗ VELO,
  - ✗ experimental chambers ALICE and LHCb, possibly also CMS,
  - ✗ updated longitudinal weld factor in the triplets beam screens,
  - ✗ new instrumentation,
  - ✗ possible aC-coating in some sectors,
  - ✗ possible additional collimators in IR1 & 5, TCLD in IR2 (in parking for protons) and updated design of all tertiaries and TCLs, old CFC collimators that might stay in parking position,
  - ✗ crab cavities HOMs as measured in real cavities,
  - ✗ electron lens and crystal collimators (recently added to baseline),
  - ✗ new roman pots,
  - ✗ "SMOG3" in LHCb.

HL-LHC – Collimator settings

- Collimator settings (σ computed with $\varepsilon = 2.5\ \mu$m.rad) at top energy:

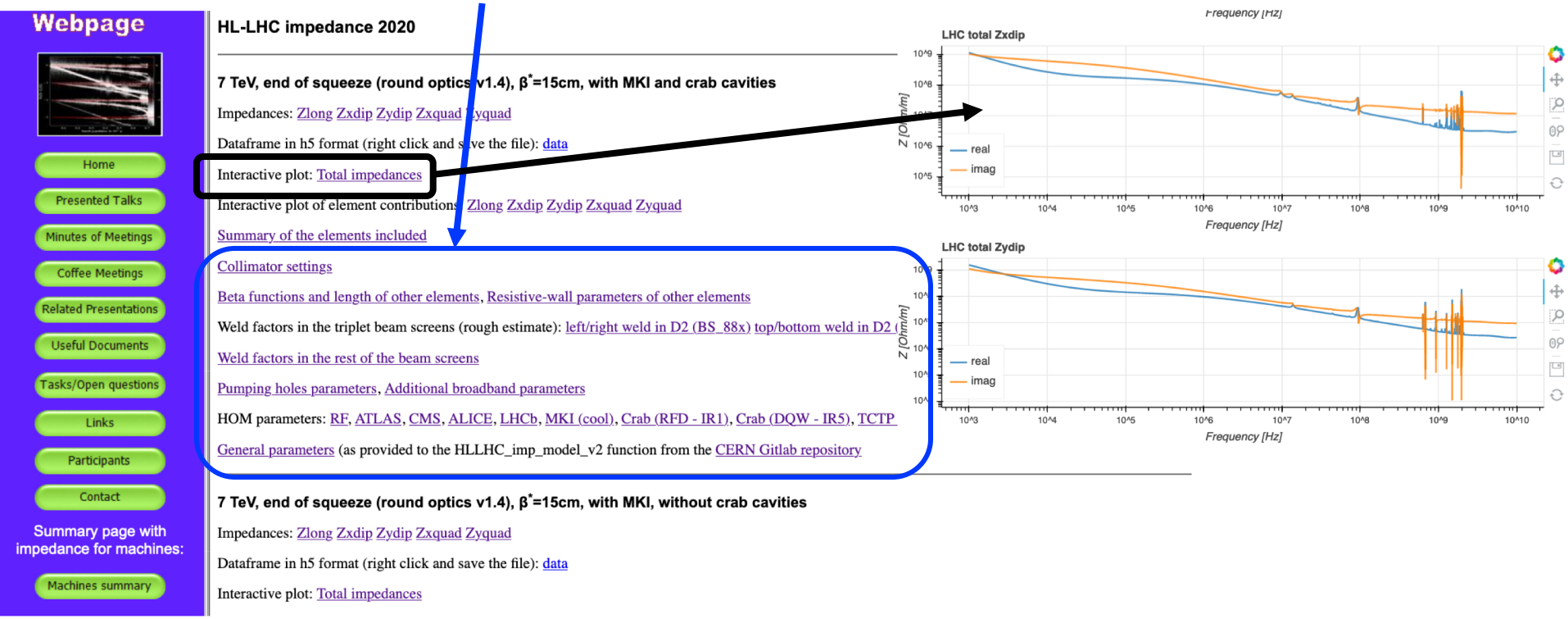
Collimators	Half-gap [#σ]
TCP/TCS/TCLA(D) IR7	6.7 / 9.1 / 12.7 (16.6)
TCP/TCS/TCLA IR3	17.7 / 21.3 / 23.7
TCDQ/TCS IR6	10.1
TCT IR1/5	10.4
TCL (IR1/5) Q4/Q5/Q6	14.2
TCT IR2/8	43.8 / 17.7

Note: injection protection collimators are always considered in parking position at top energy.

HL-LHC impedance model: web page

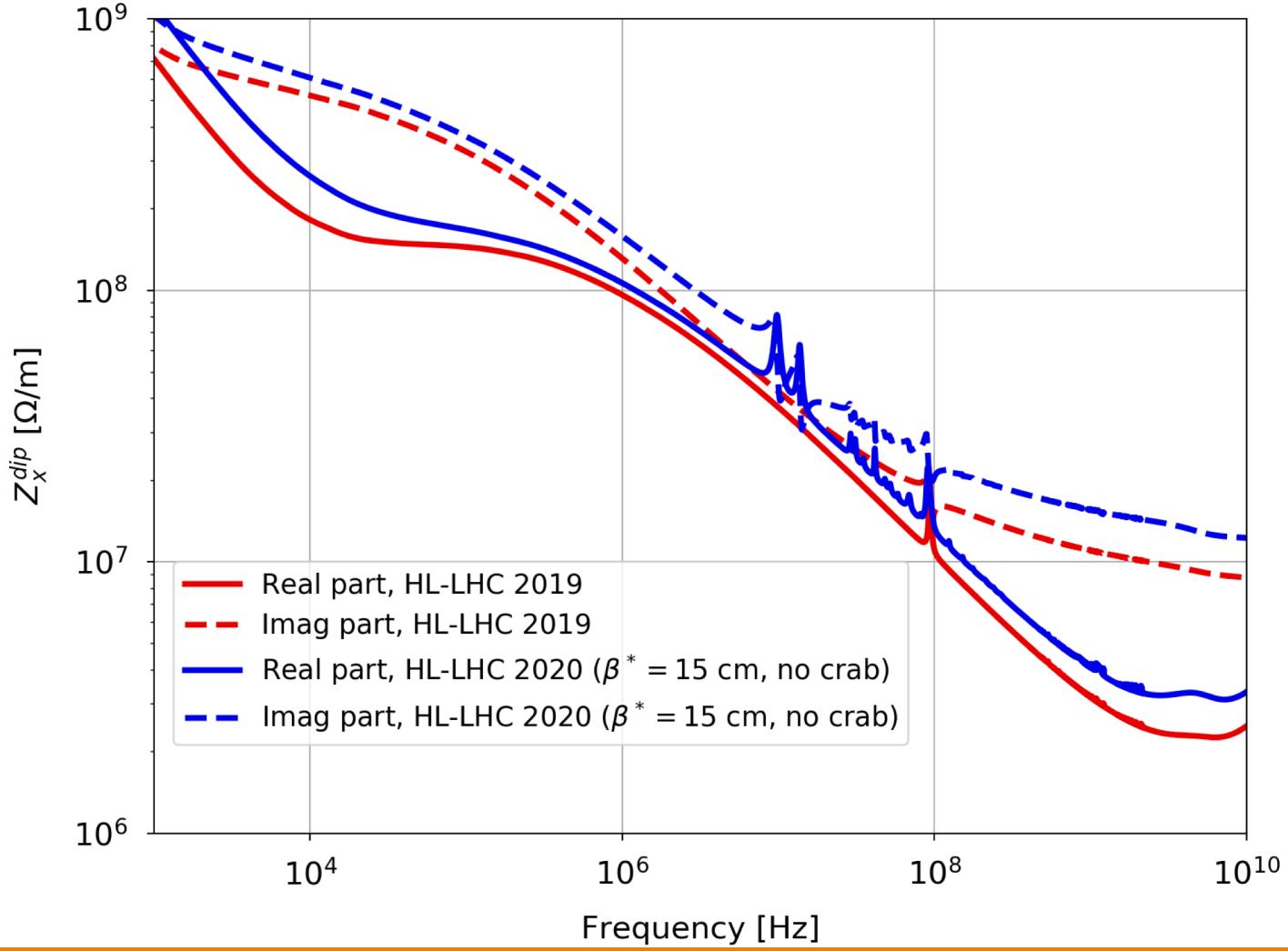
The model is on-line, at https://impedance.web.cern.ch/impedance/ (Machine Summary ⟶ HL-LHC 2020):

- with interactive plots (thanks to **N. Biancacci**),
- several variants (with and without crab cavities – more will come),
- all parameters and settings are provided.



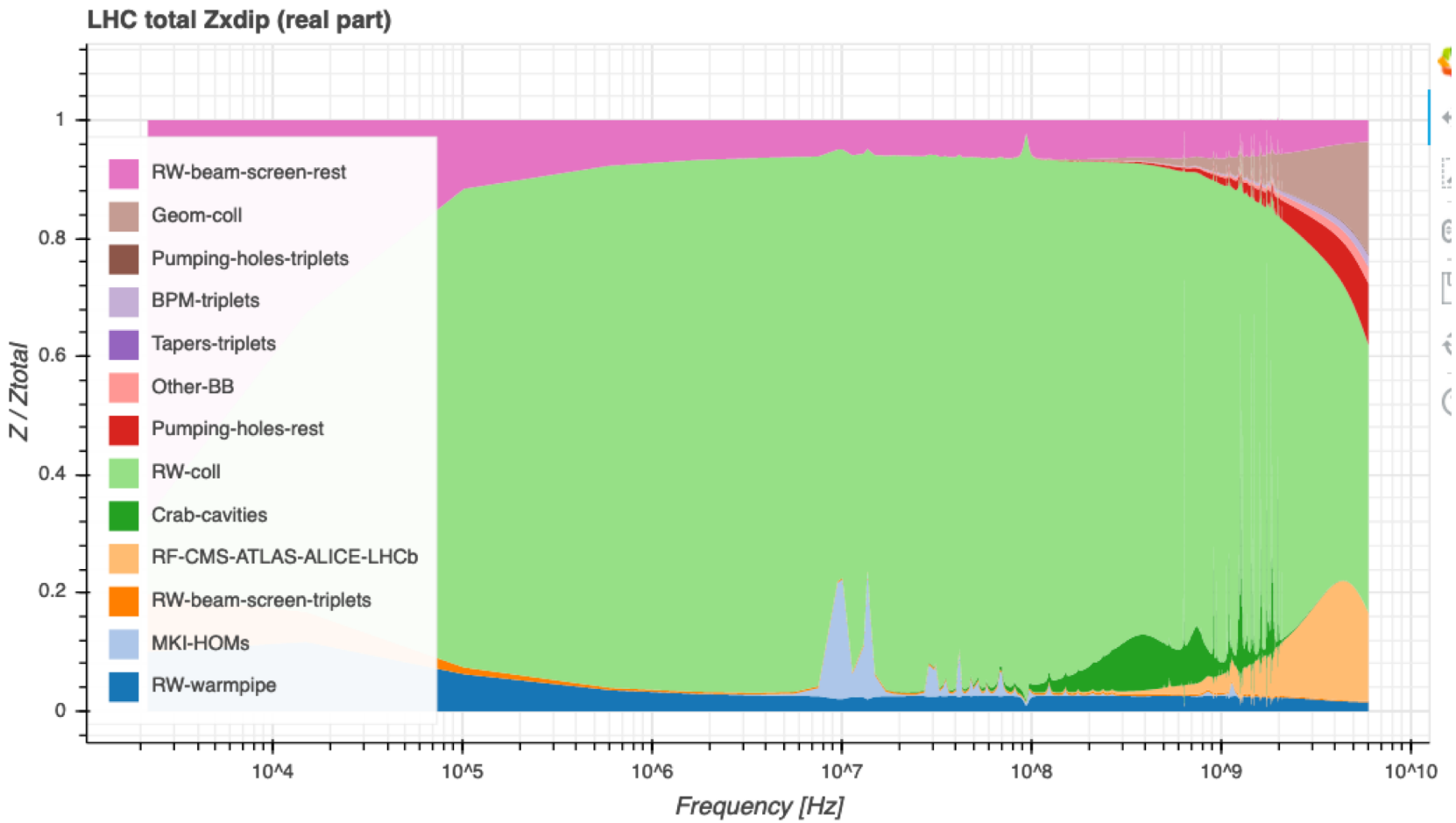
HL-LHC – old vs. updated impedance model

- Frequency dependence of the impedance (dipolar horizontal):



HL-LHC – Impedance contributions (round optics)

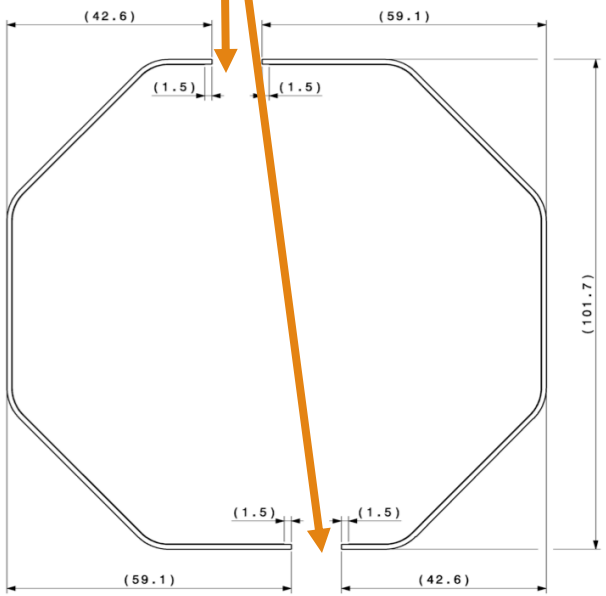
- Frequency dependence of the various contributions to impedance (dipolar horizontal, real part, i.e. the main player for the growth rate):

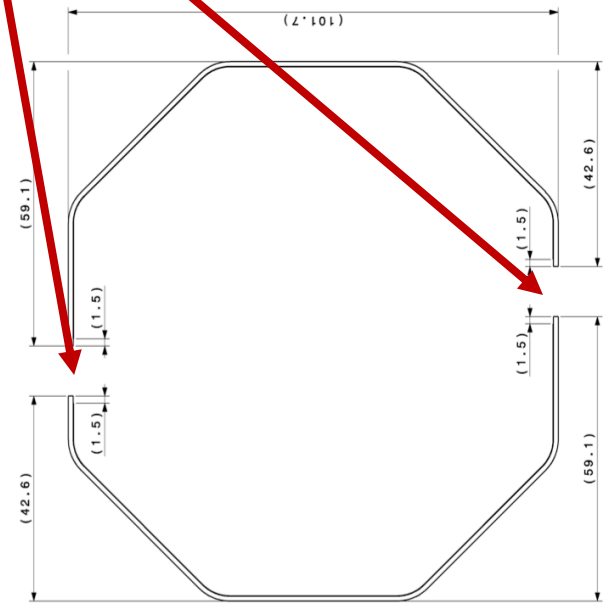


The weld in the triplet beam screen

- The triplet zone is a sensitive region for transverse stability because of the magnitude of the beta functions when squeezed.
- There are two orientation options for the beam screens: with the weld on the top/bottom facets, or on the left/right ones (note that the facets at 45° contain the pumping holes):

Q1 beam screen before assembly





From **N. Kos**

Weld in the beam screens – the question

- The welds are in stainless steel, NOT copper-coated (but with aC coating), and up to 4mm-large.
  → this is seen by the beam and introduce a significant detrimental factor on the resistive-wall impedance (**C. Zannini**, 07/2013 & **B. Salvant** et al, 12/2015).

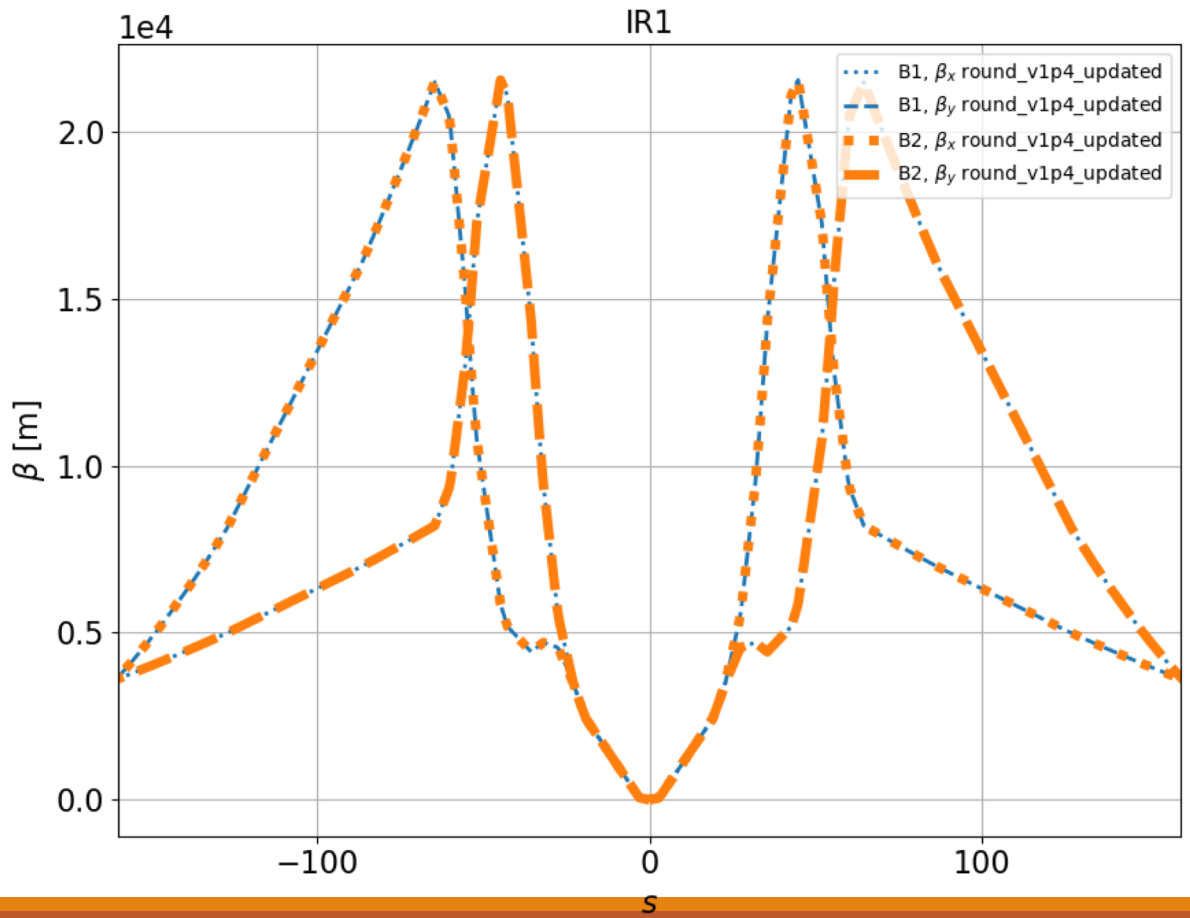
- The plane on which the weld is located can matter, depending on the difference between x and y beta functions

  → an impedance optimization is in principle possible (question by **N. Kos**), by turning some beam screens by 90°.

  → But is it worth the effort?

Optimizing the beam screen orientation - round

- In principle we only have to look at the beta functions (optics v1.4).
- BUT most beam screens contain the two beams (up to D1, i.e. ~80m from IP).
- Only D2 beam screen (from ~140m to ~155m) is single-beam.

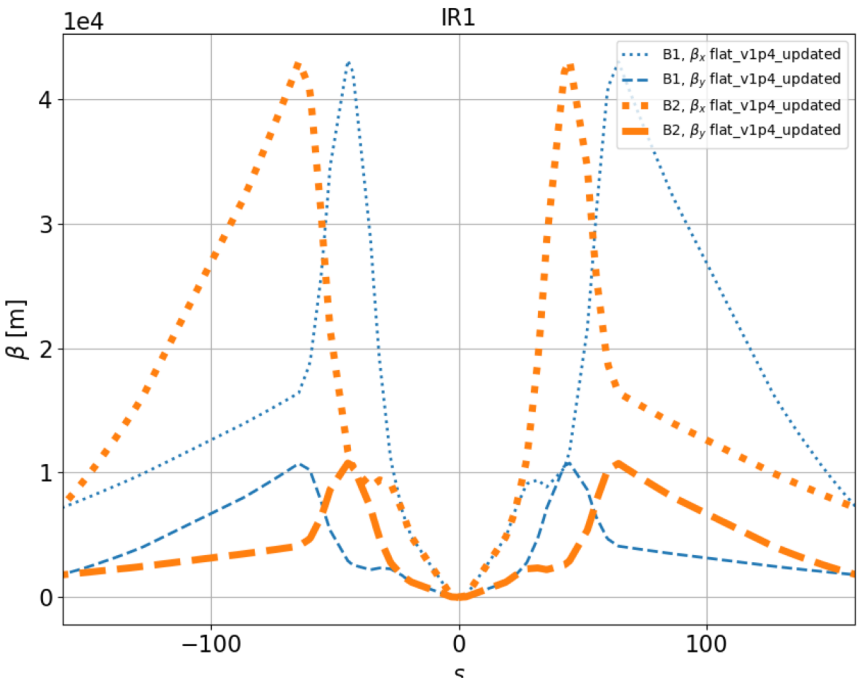


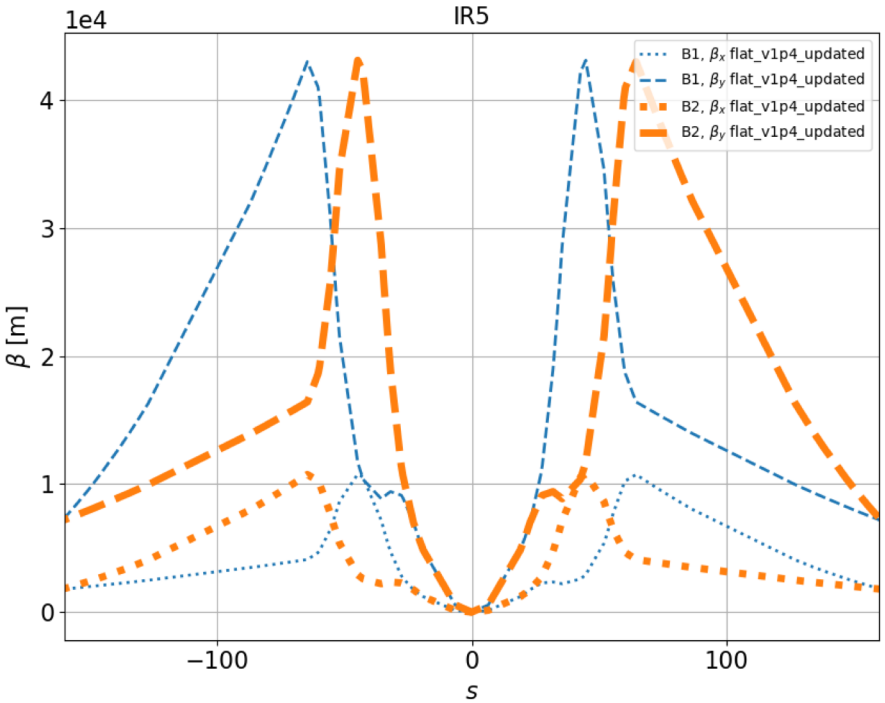
Round optics (IR1 and 5 are similar):

- when e.g. $\beta_x < \beta_y$ for B1, it is the opposite for B2
  → one cannot gain anything in total on the two-beam BS,
- we could gain in D2 only, but the two beta functions are almost the same
  → very small impact.

Optimizing the beam screen orientation - flat

- For flat optics (v1.4) the situation is different: the same plane has a lower beta for both beams .





- We can optimize if we choose the facets where to put the weld as:
  - top/bottom for IR1
  - left/right for IR5

Is it worth the effort?

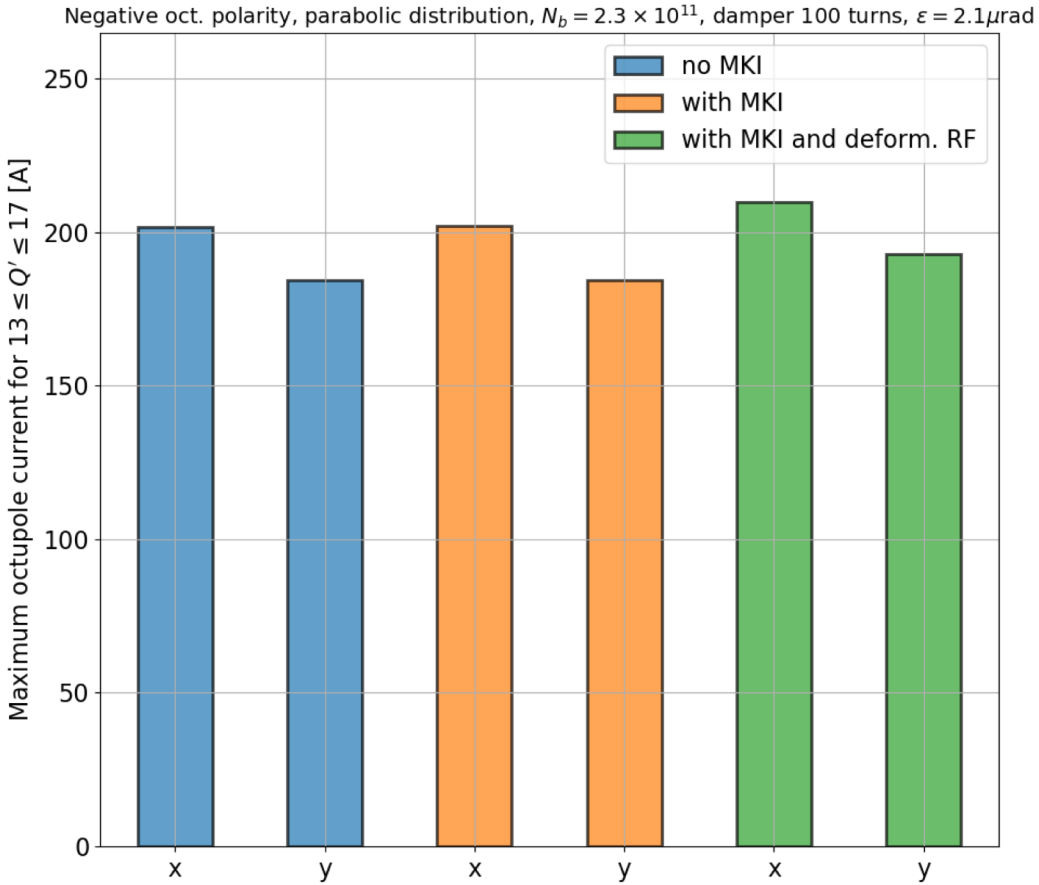
- Octupole thresholds with HL-LHC parameters (N_b=2.3e11 p+/bunch, emittances 2.1μm.rad, with damper at 100 turns, Q'=15, Gaussian distribution), for flat optics:
  - Resistive-wall from collimators only: 55A
  - Resistive-wall from beam screens (including welds): < 0.01 A

→ **The gain from the optimization of the weld orientation is not significant .**

→ It's better to keep the orientation of all beam screens at top/bottom (preferred option from the installation point of view – **N. Kos**).

Impact of MKI & deformable RF fingers (+ VAX + Y-Chamber) on octupole threshold

- We check the octupole thresholds for HL-LHC parameters (N_b=2.3e11 p+/b, ε=2.1μm.rad, damper 100 turns, Q'=15, distributions cut at 3.2σ, negative oct. polarity – positive is very similar), for round optics at β*=15cm:



- MKI "cool" HOMs values from V. Vlachodimitopoulos,
- deform. RF / VAX / Y: broad-band impedance from B. Salvant.

⟶ Impact of MKI is negligible.

⟶ Impact of deformable RF fingers, Y-Chamber and VAX is visible but small (~4%).

⚠️ *This is NOT an octupole current prediction for HL, but only a test of the impact of this equipment (we are not at the most critical point of the cycle).*

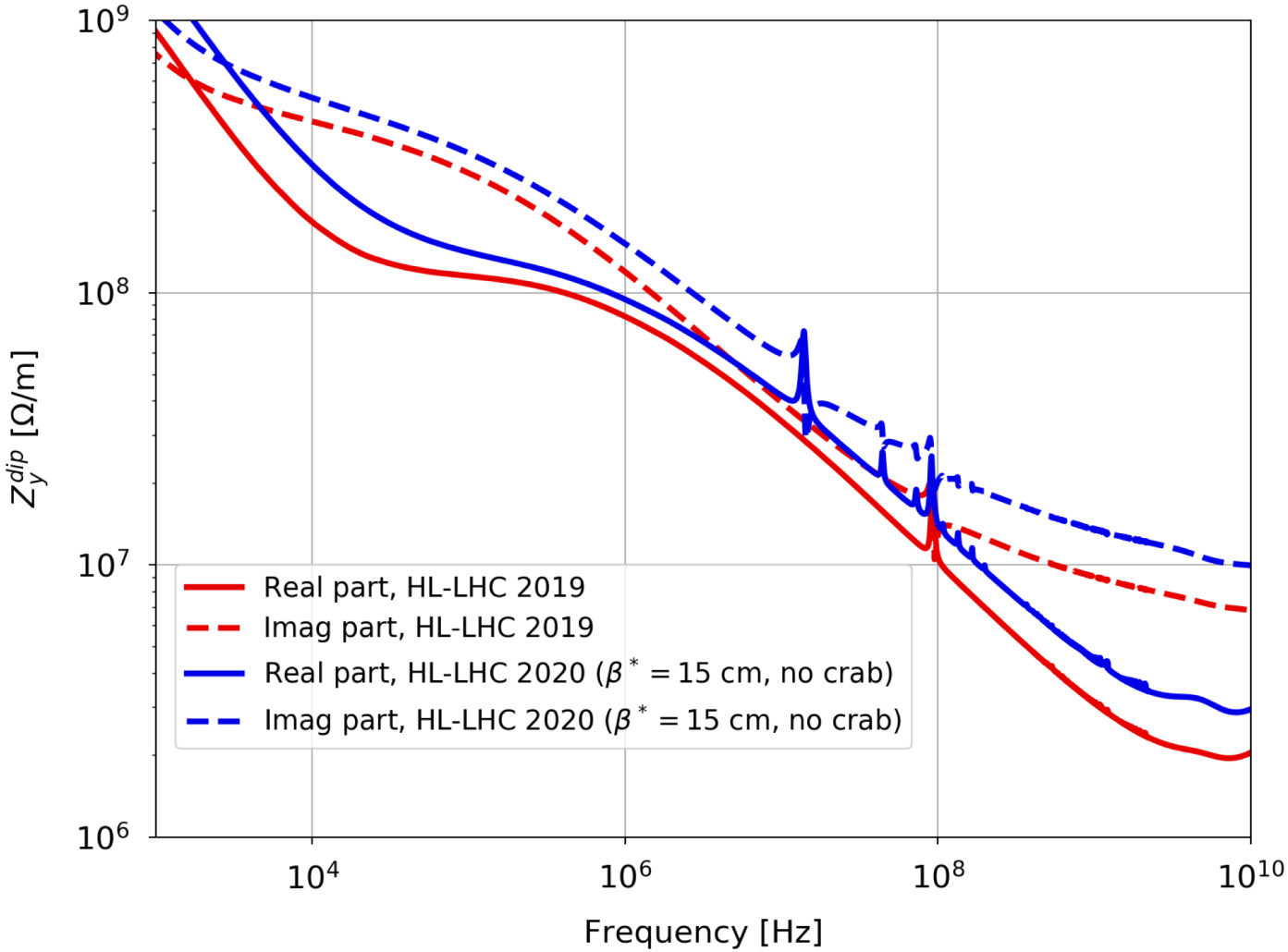
Conclusions

- The HL-LHC impedance model has been updated to take into account the latest developments, and is now available on the impedance web-page.
- The triplet beam screens do not need to be oriented in a particular way to reduce the impedance from the longitudinal weld, as its impact is negligible.
- The MKI does not have a significant impact on stability.
- Deformable RF fingers (mainly) + VAX + Y-chamber (close to triplets) have an overall visible but small impact on stability (~4% for 15cm squeezed round optics).

Backup slides

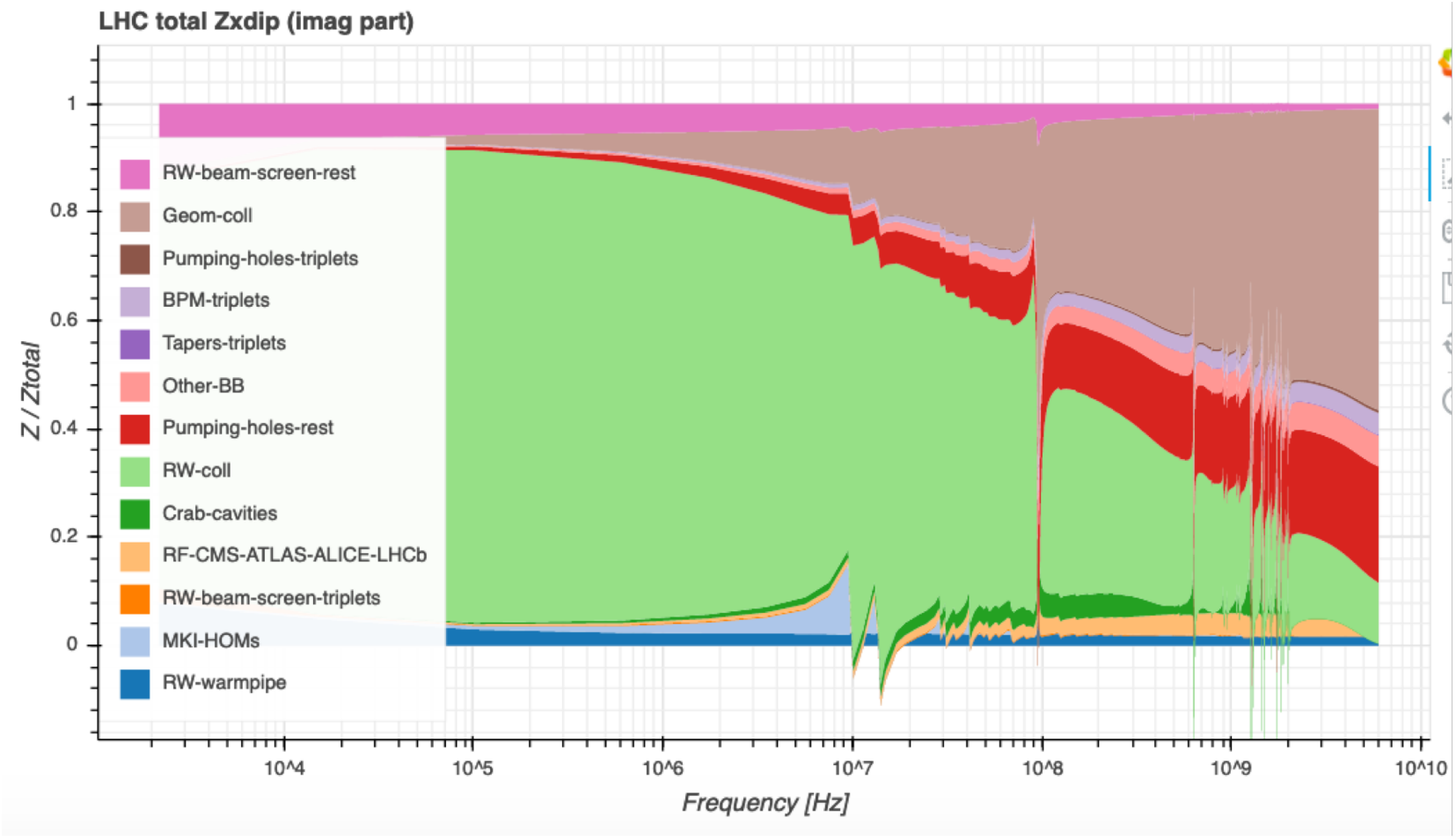
HL-LHC – Old vs. updated impedance model

- Frequency dependence of the impedance (dipolar vertical):



HL-LHC – Impedance contributions (round optics)

- Frequency dependence of the various contributions to impedance (dipolar horizontal, imaginary part, i.e. responsible for tune shift):



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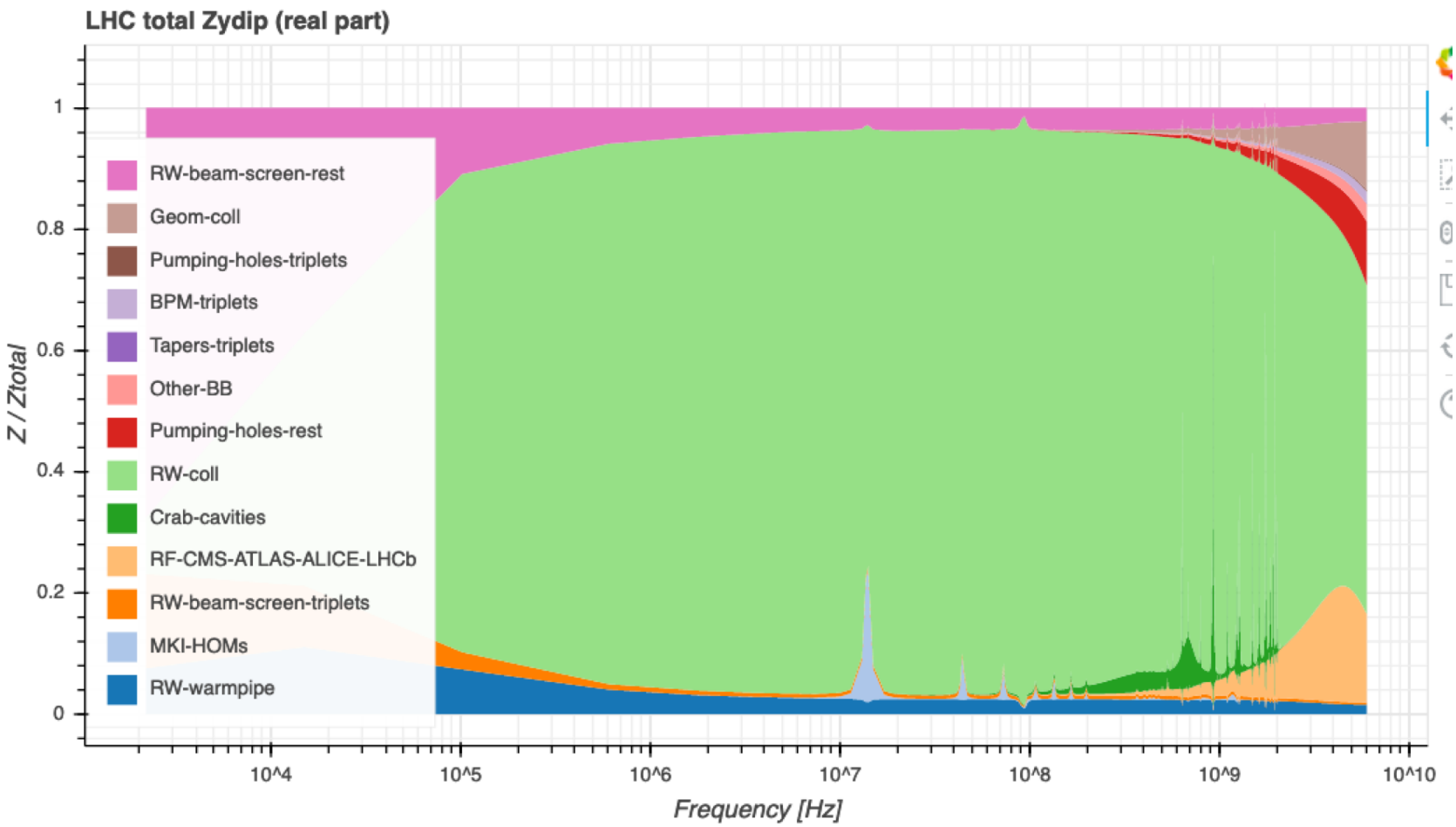

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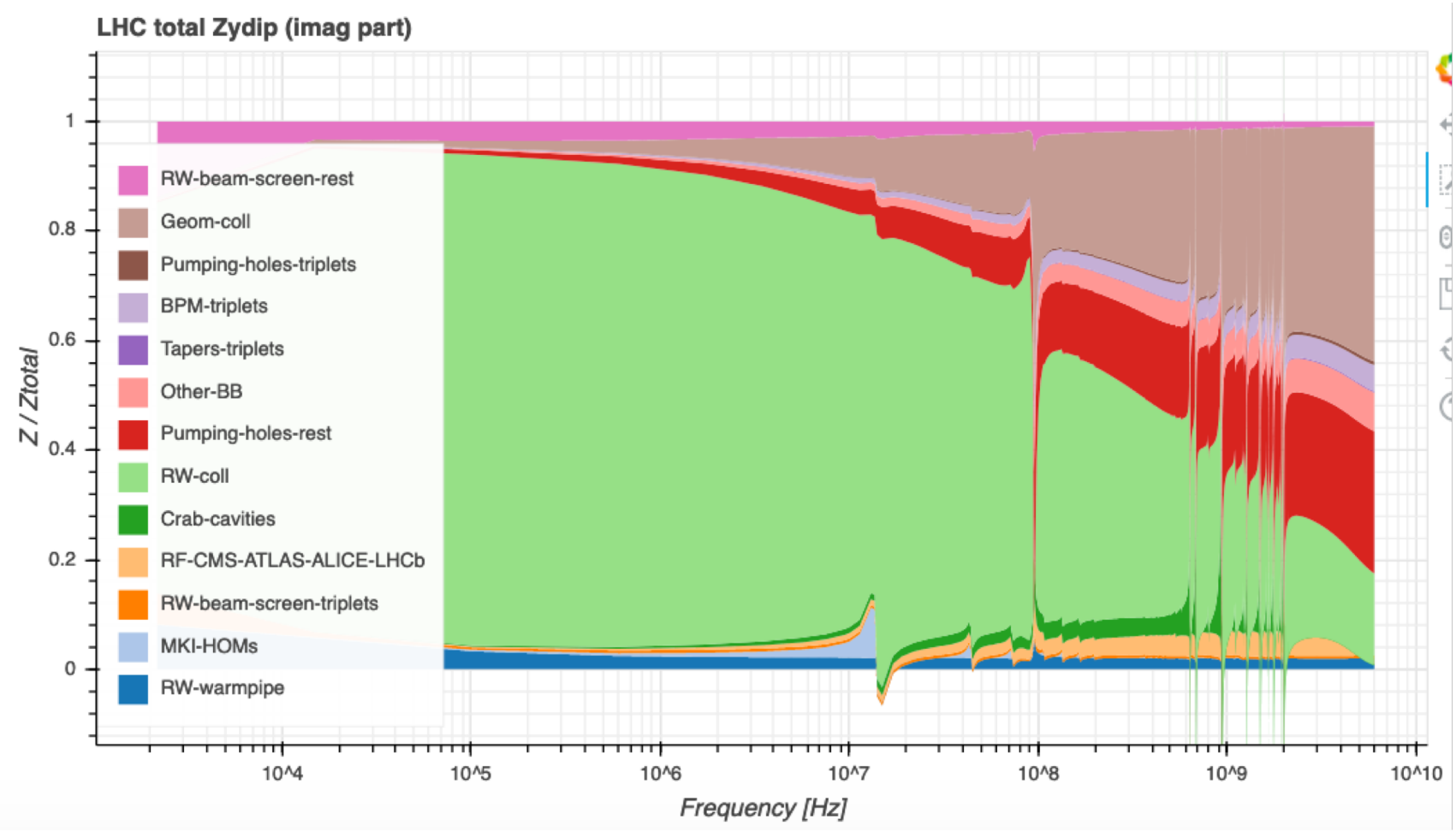
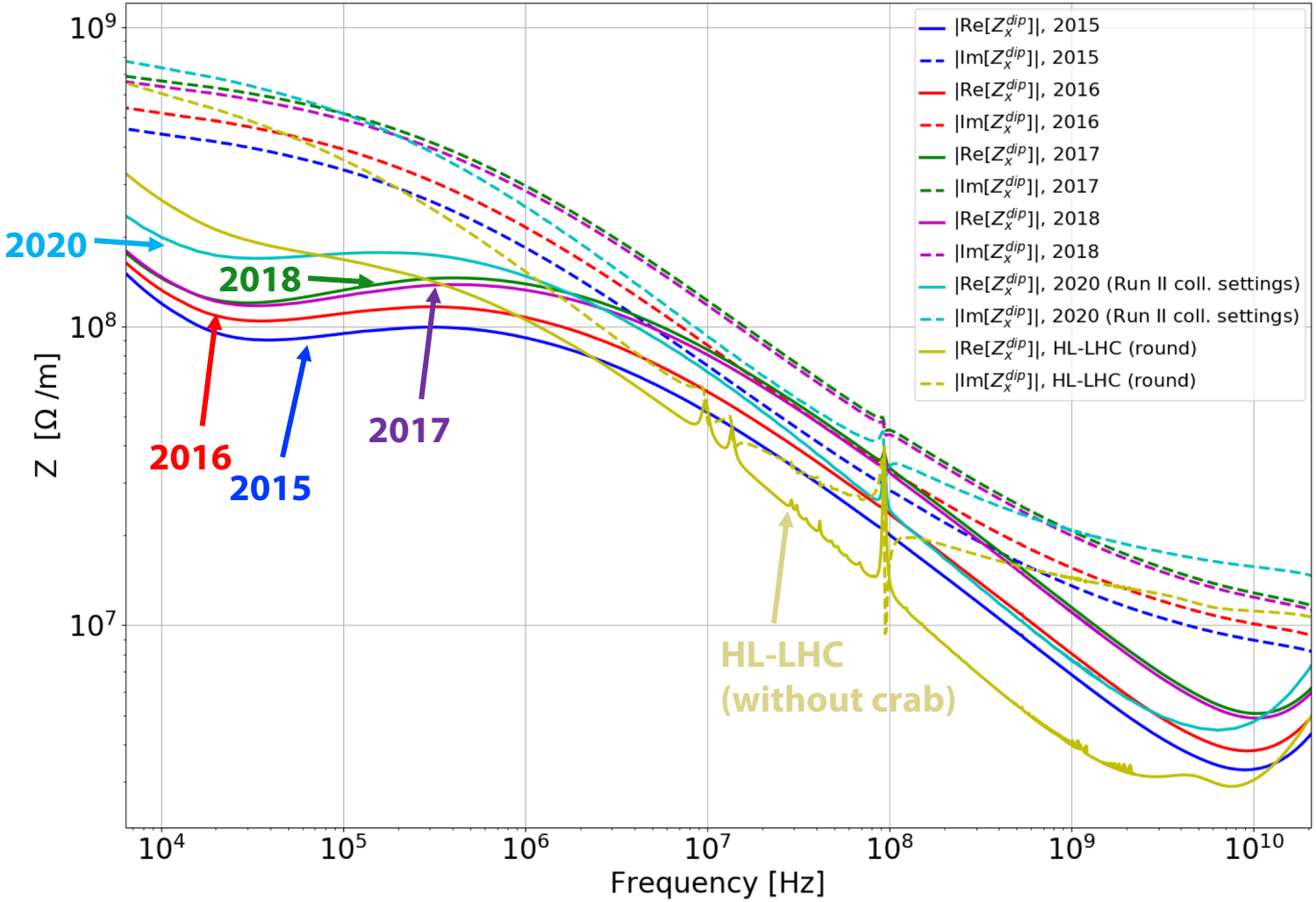


HL-LHC & LHC impedance models: a retrospective

- Putting on the same plot all impedances currently on the web, for LHC & HL-LHC:

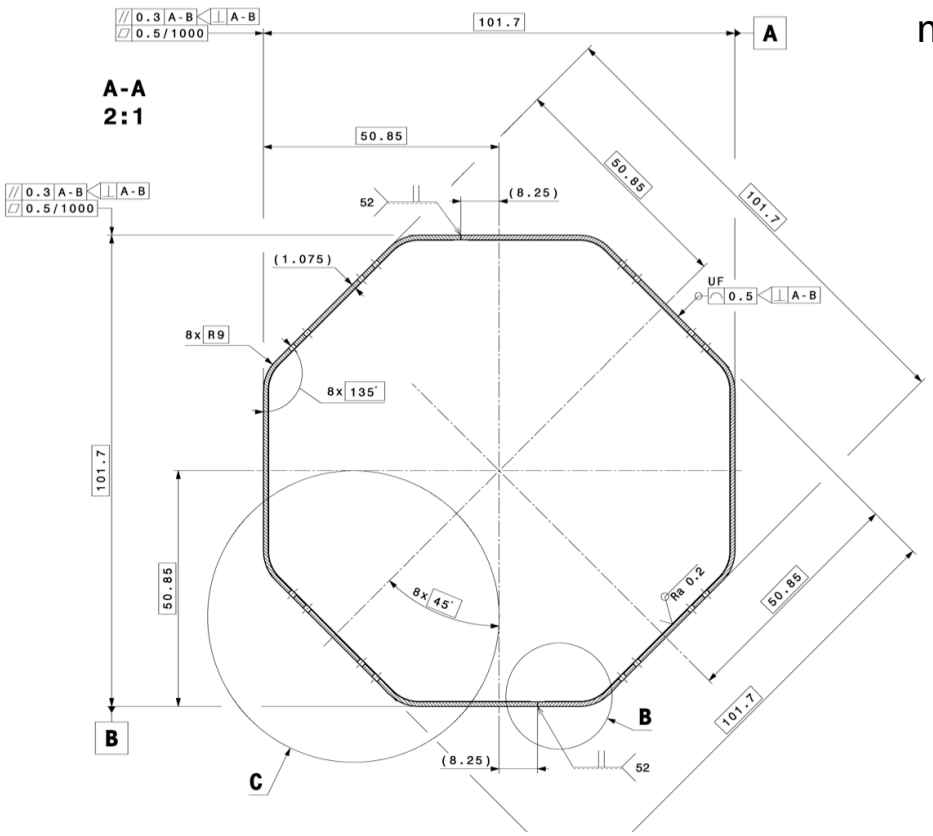


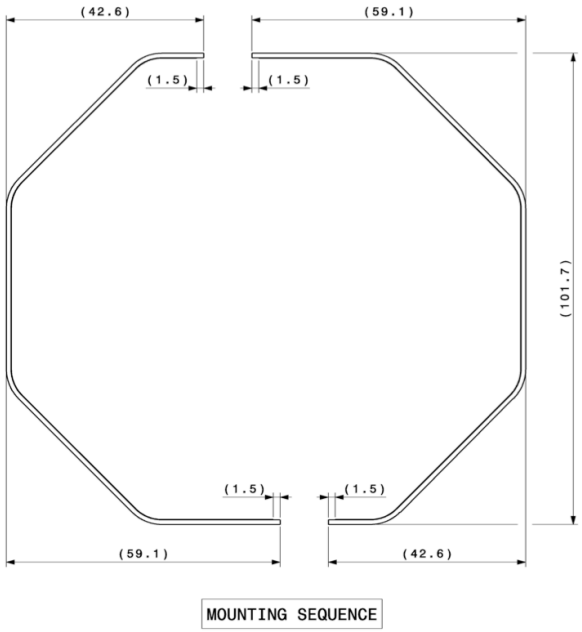
Dipolar horizontal

Octogonal beam screens in HL-LHC triplets (N. Kos)

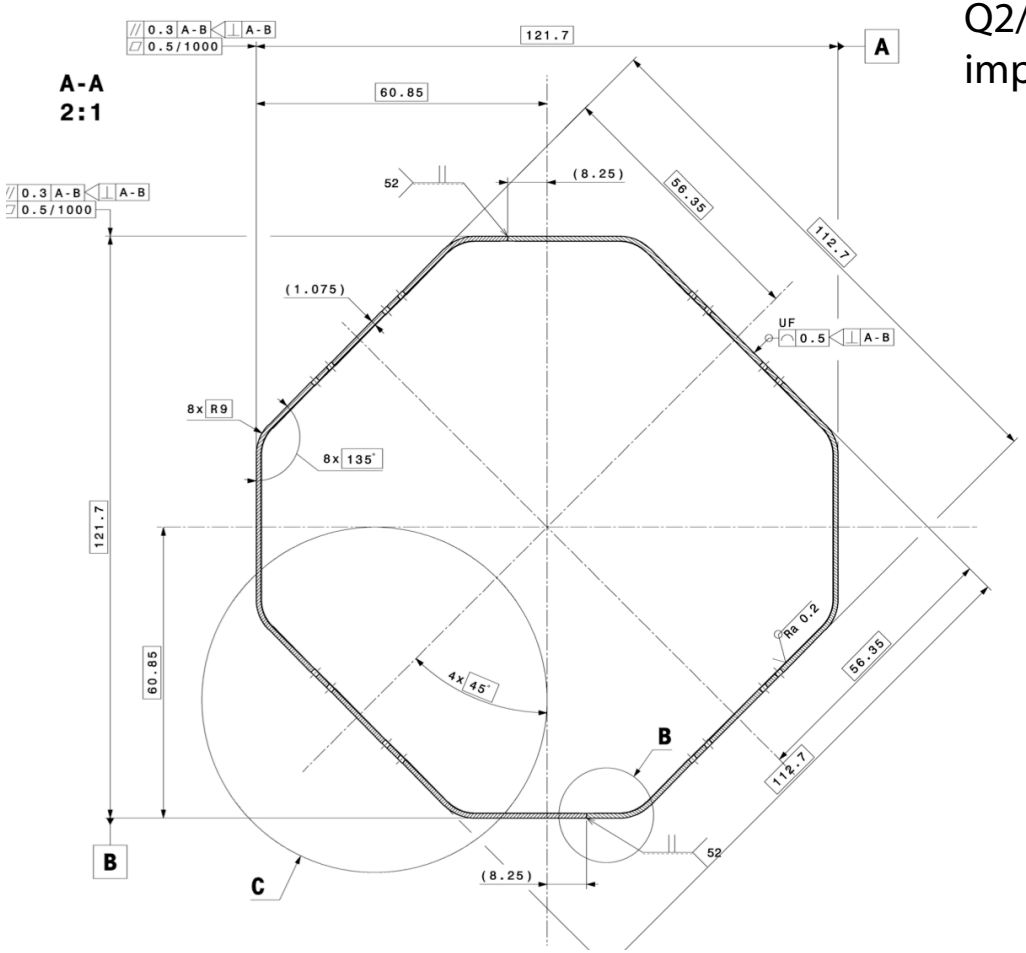
- Three different shapes, depending on the magnet cold bore aperture:

Q1 beam screen ("BS_101" in the impedance model, drawing LHCVSMSH0003)

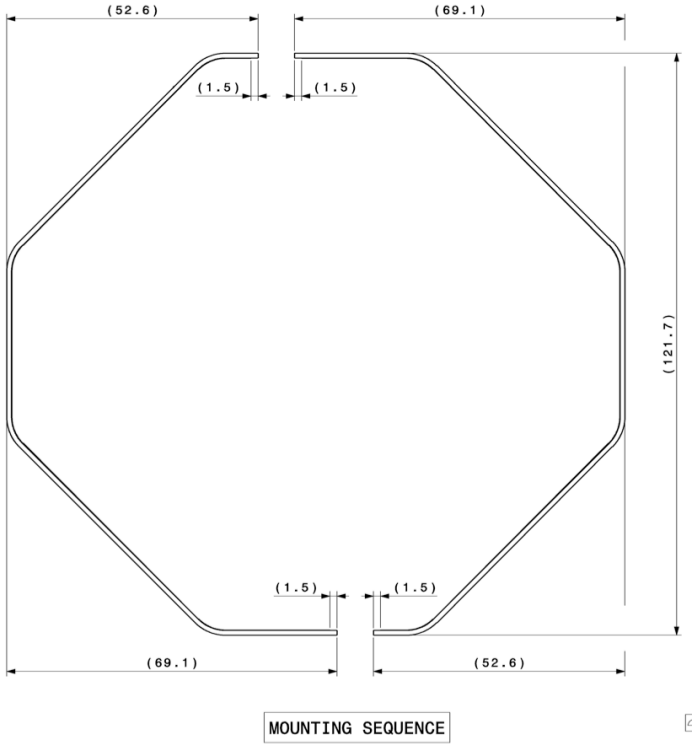




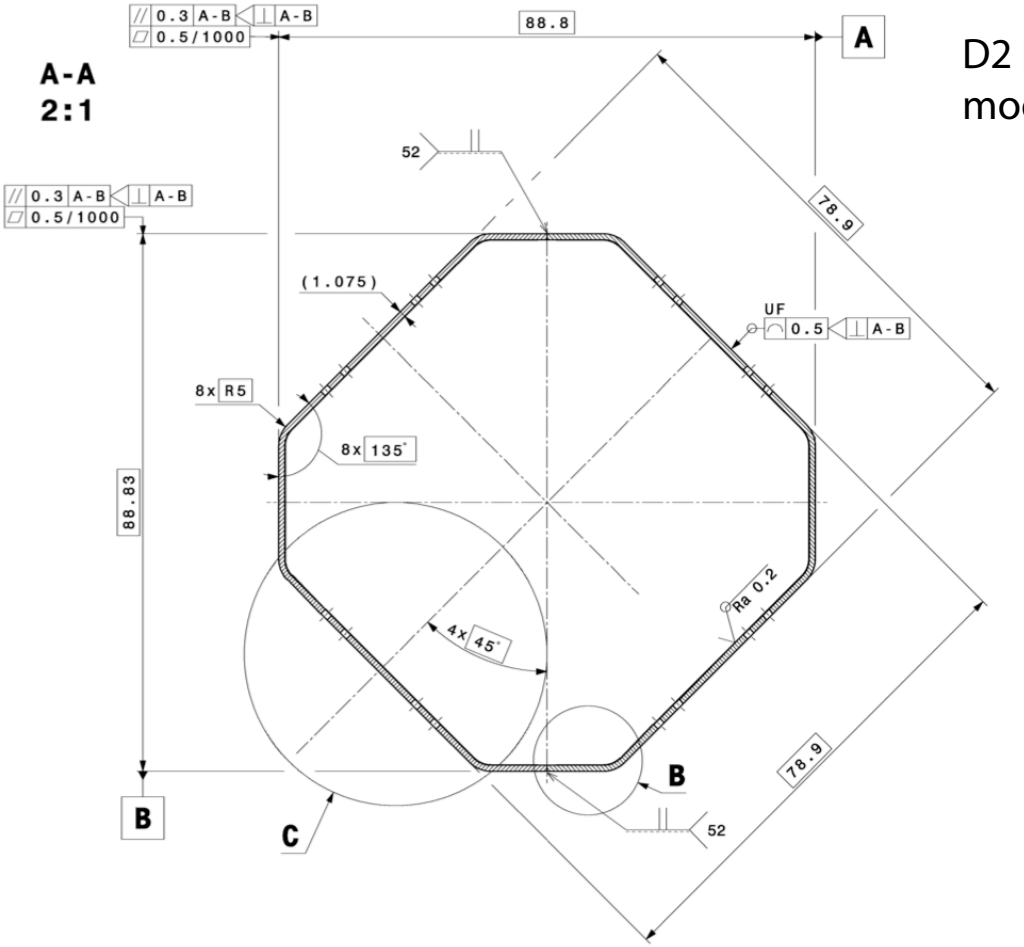
Octogonal beam screens in HL-LHC triplets (N. Kos)



Q2/Q3/CP/D1 beam screen ("BS_121" in the impedance model, drawing LHCVSMSL0001)



Octogonal beam screens in HL-LHC triplets (N. Kos)



D2 beam screen ("BS_88" in the impedance model, drawing LHCVSCS_0001) – single beam