HE-LHC injection stability estimates

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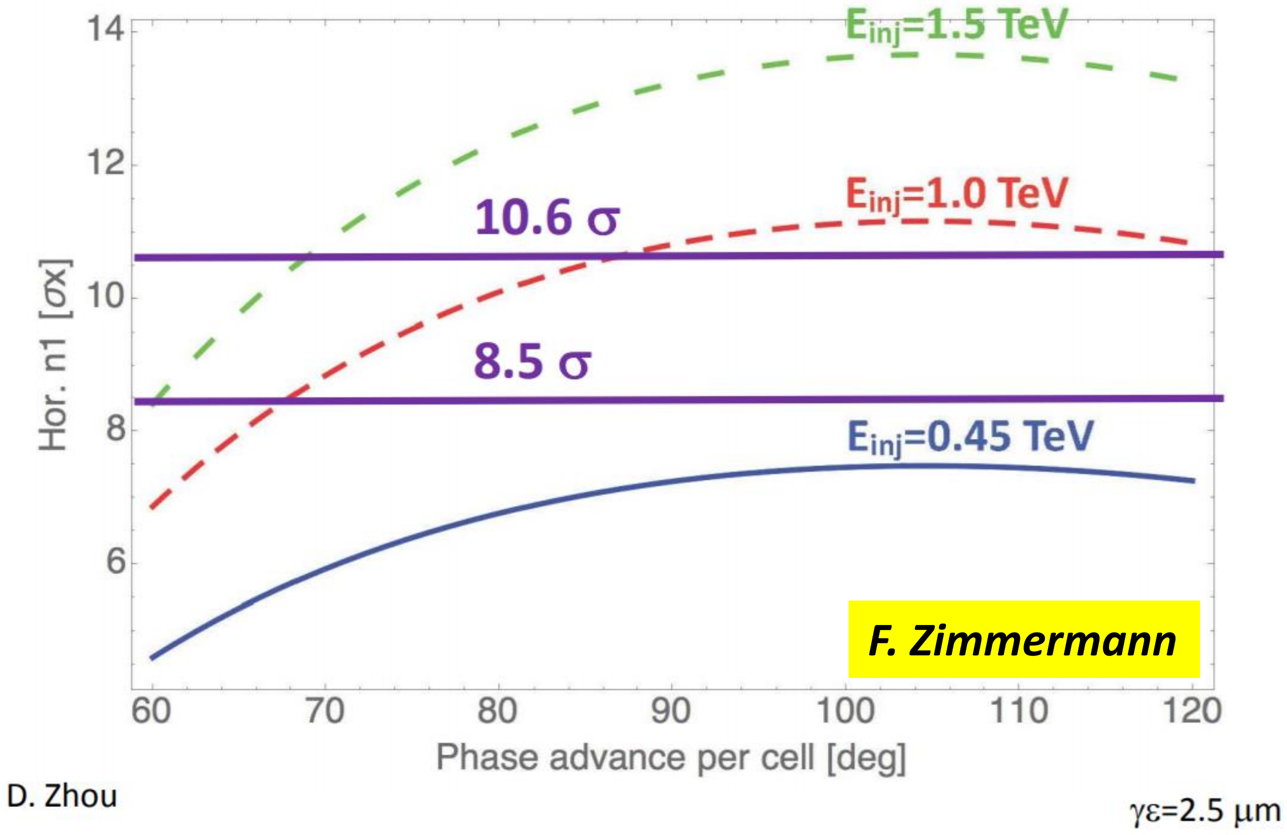
02.10.17

THANKS FOR THE USEFUL DISCUSSIONS TO:

S.ARSENYEV, N.BIANCACCI, R.BRUCE, M.CROUCH, E.MÉTRAL, B.SALVANT, F.ZIMMERMANN,

DA constraints at 450 GeV push to investigate higher energy options for HE-LHC

F. Zimmermann, "A first look at collimator settings for HE-LHC", 21.09.17



Three options are being considered

1) **450 GeV**
   - ✓ OK with the present design of injectors and transfer lines
   - ◦ Might be excluded by DA studies
   - ◦ A test of injection into LHC at lower energy is needed (and foreseen)

2) **900 GeV**
   - ✓ Better DA
   - ◦ 90 deg PA in a cell might be the only option

3) **1300 GeV**
   - ✓ Best DA
   - ◦ Transfer line requires 6 T magnets – feasibility to be checked
   - ◦ Energy per transfer can be a limiting factor: extract only 160 bunches from SPS at a time

Need a new SPS

B. Goddard, "Transfer line / transfer elements considerations", 21.09.17

The choice has to be made within a month from now!
After that the parameters will be frozen

Goal: to give preliminary estimates

1. Is any of the options better from the beam stability point of view?
2. Are there any constraints?

Recommend:

- What Q' and damper gain?
- How much I_{oct}

The cases to study

Tighter gaps than LHC/Hi-Lumi

Scaling from Hi-Lumi

	450 GeV	900 GeV	1.3 TeV
Reference emittance	2.5 um	2.5 um	2.5 um
Primary colls	**5 σ**	5.7 σ	5.7 σ
Secondary colls	6 σ	6.7 σ	6.7 σ
TCDQA	7.3 σ	8.3 σ	8.3 σ
Machine aperture	**~ 8 σ**	> 10.6 σ	> 10.6 σ
Comments	Very tight settings, not compatible with estimated aperture		

Collimators gaps from R.Bruce et al.

Procedure

Collimators:

- Secondary collimators in IR7: Mo coating on MoGr bulk (as in Hi-Lumi)
- Primary collimators in IR7: Mo coating on MoGr bulk (*should be MoGr bulk only*)
- Gaps are scaled with E and ε_n

Beam screen:

- The design choice for HE-LHC has not been finalized
- For impedance estimates: keep LHC/Hi-Lumi beam screen

Optics:

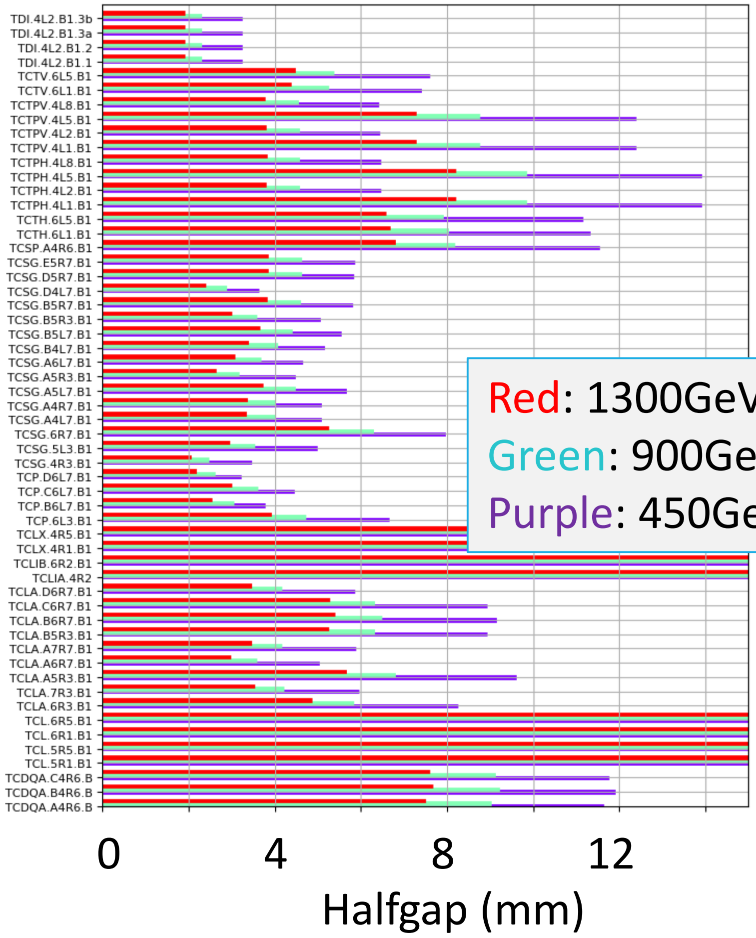
- Hi-Lumi injection optics

Collimator gaps: 1300GeV case is very tight

Red: 1300GeV
Green: 900GeV
Purple: 450GeV

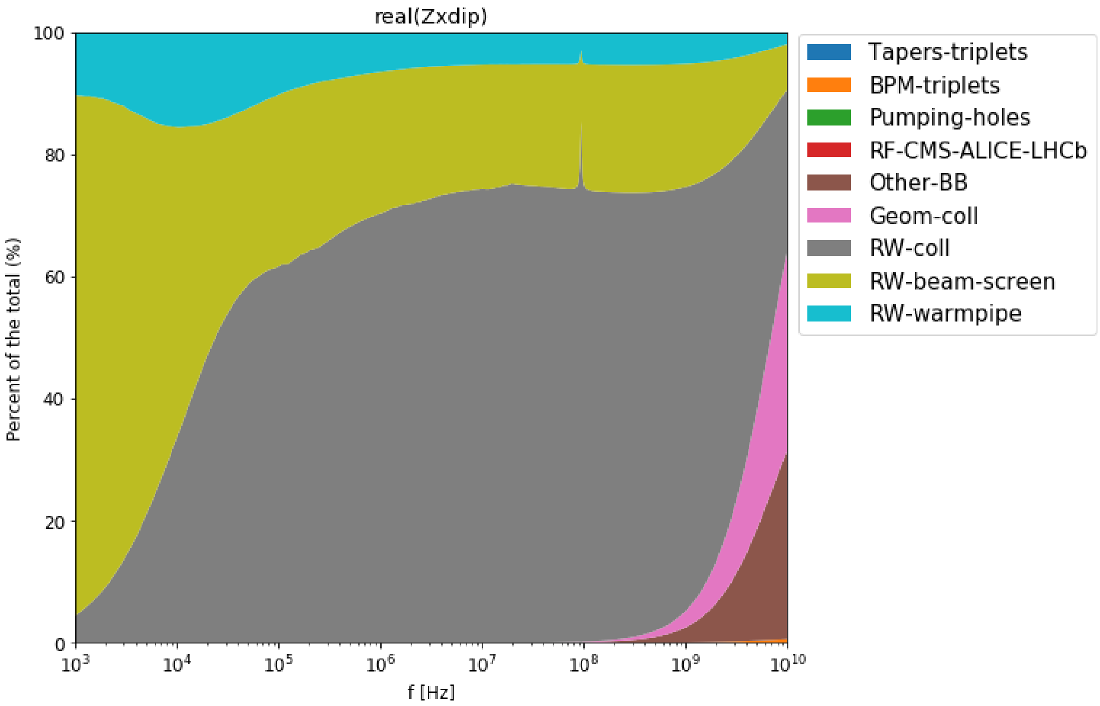
Physical gaps scale as $\sqrt{\frac{\varepsilon_n}{E}}$

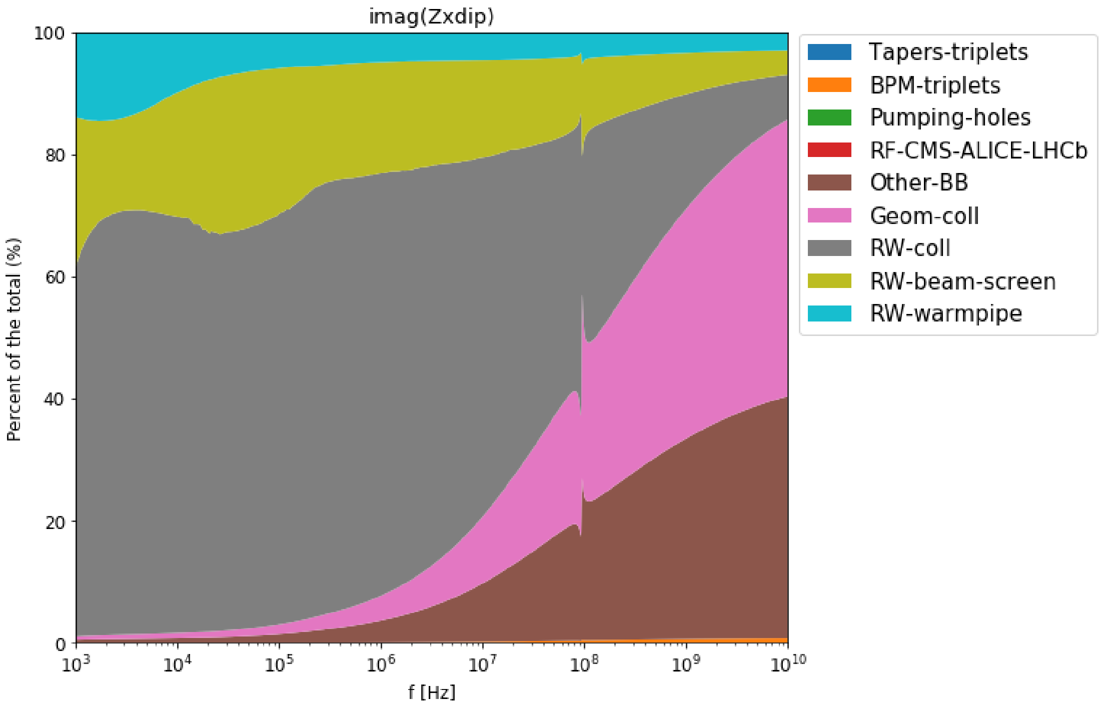
For HL-LHC, $\varepsilon_n = 3.5\mu m$
For HE-LHC, $\varepsilon_n = 2.5\mu m$



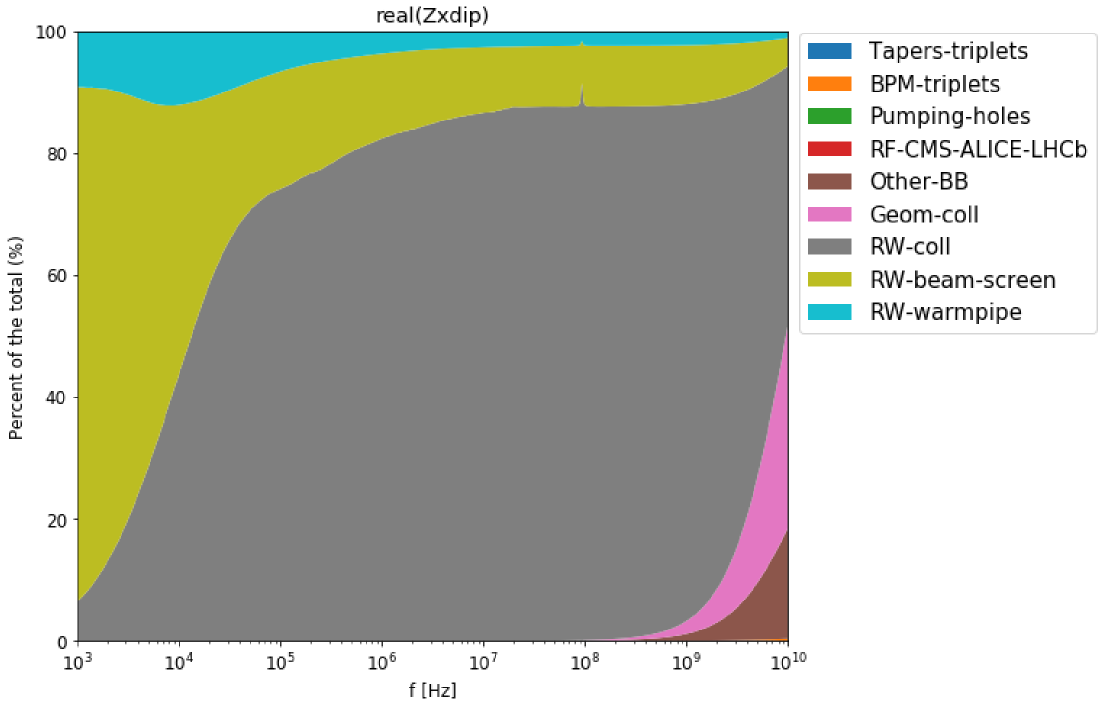
Red: 1300GeV
Green: 900GeV
Purple: 450GeV

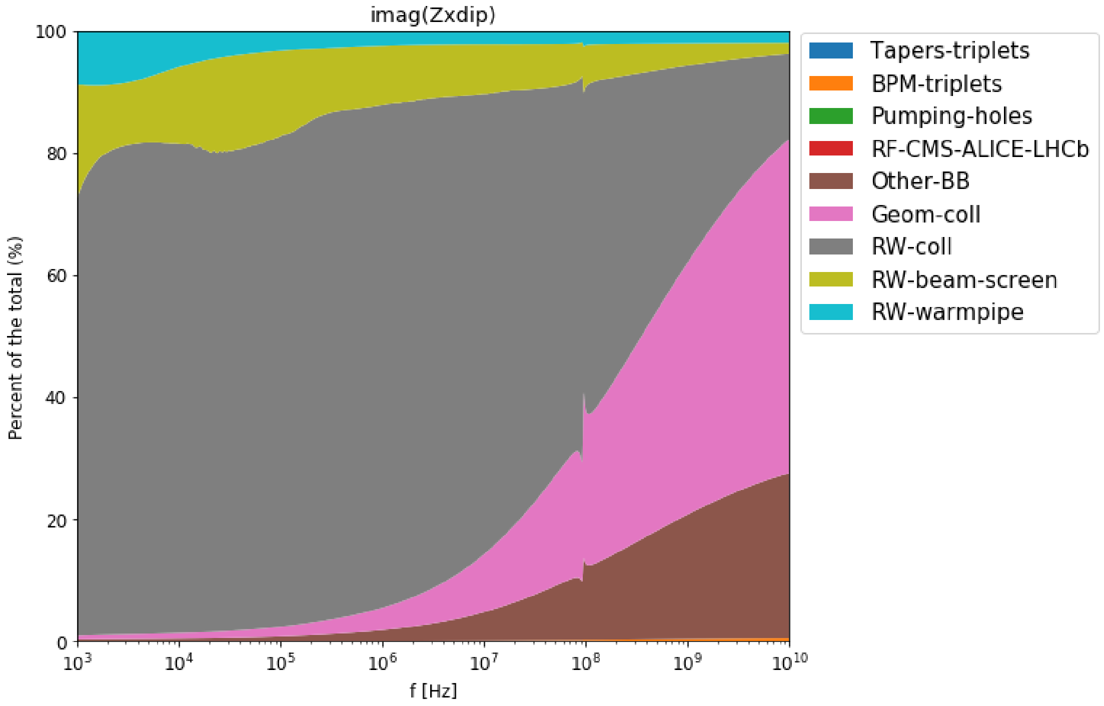
Elements contributions at 450 GeV



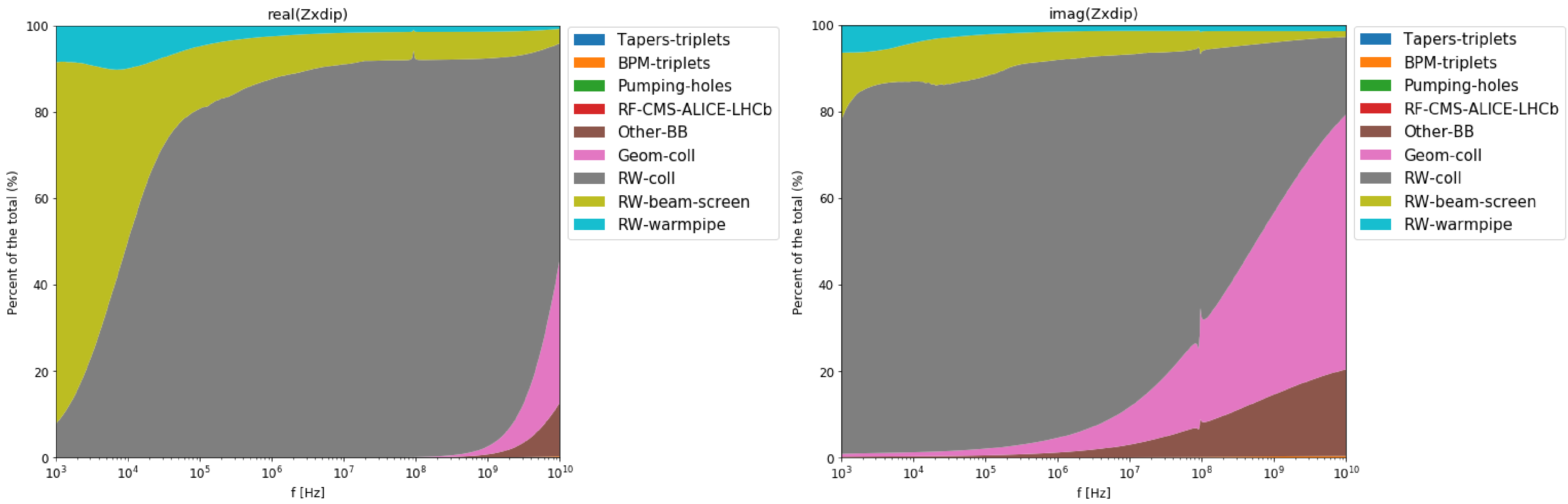


Elements contributions at 900 GeV

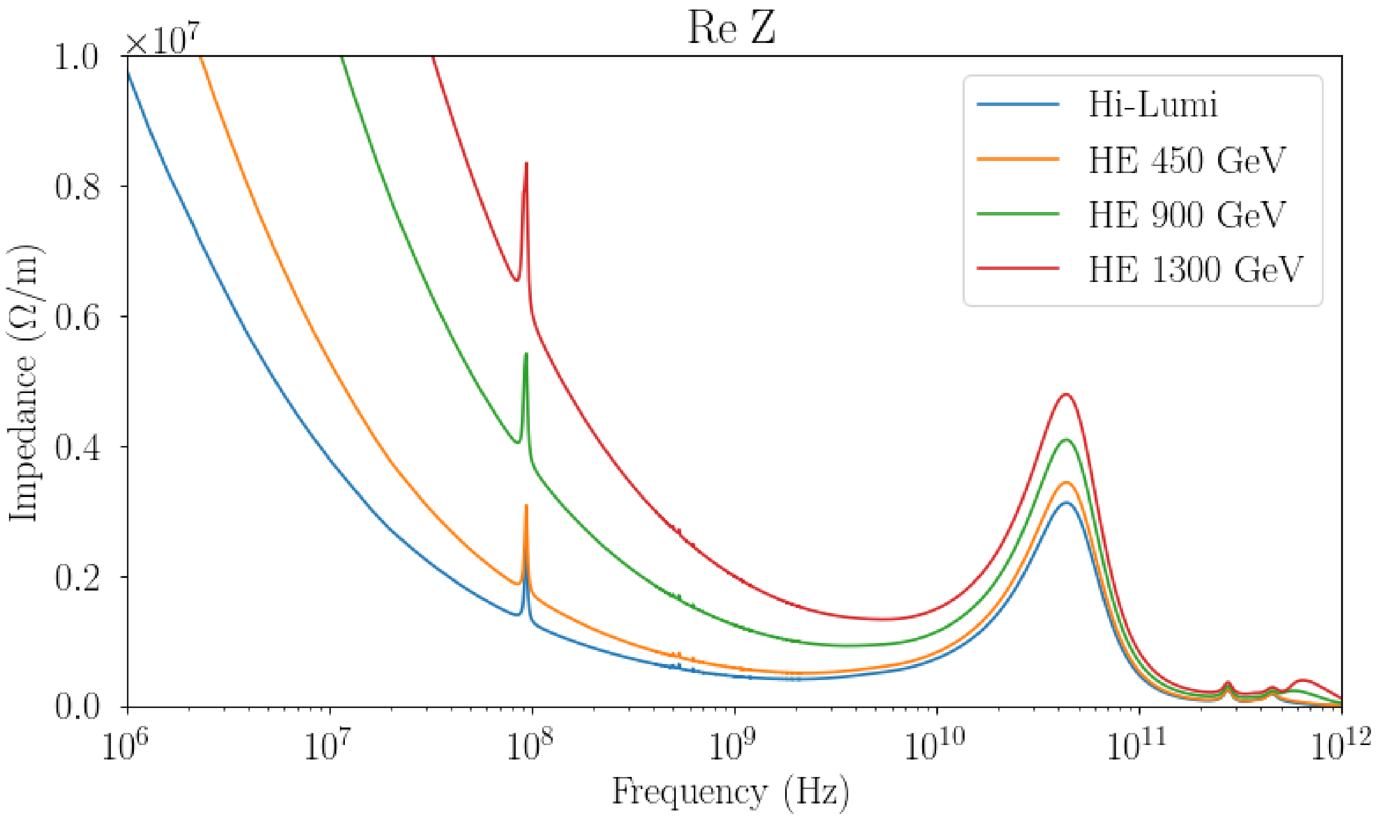




Elements contributions at 1300 GeV



Impedance:
The 1300 GeV option is the most challenging

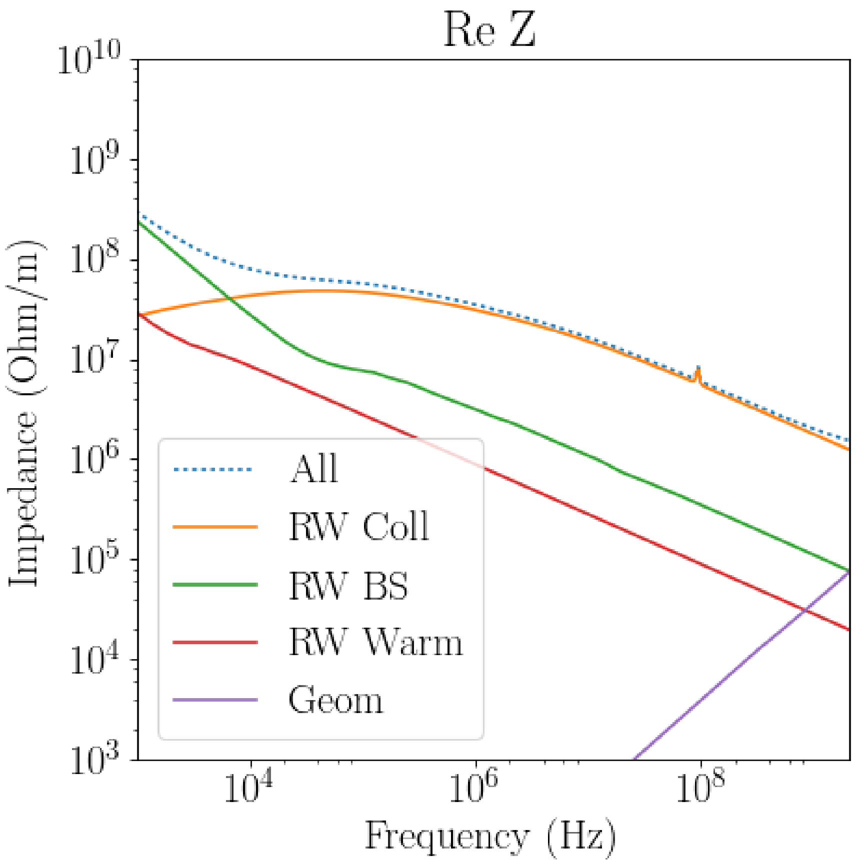


1300 GeV: Resistive wall collimator impedance dominates

At the frequencies relevant for single-bunch collective dynamics the machine's impedance is dominated by the resistive wall contribution of its collimators

FCC beam screen will increase the beam screen contribution at low frequencies by **a factor of 4***

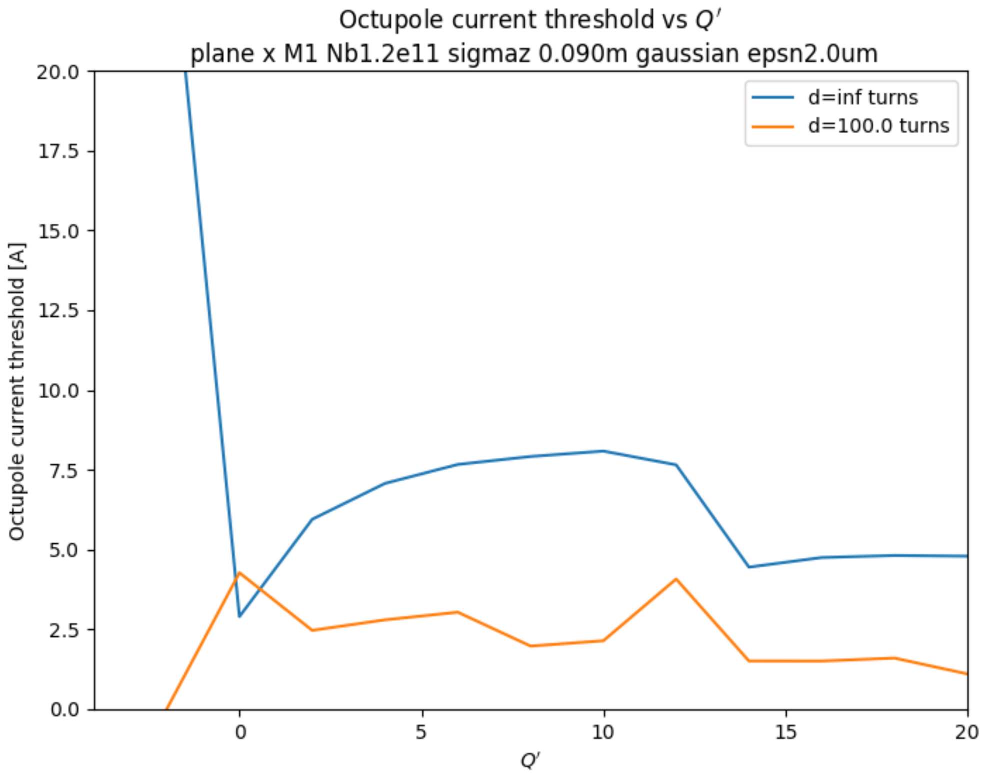
- Overall, leads to an increase of Z below **x2**



* S. Arsenyev, "Impedance/stability/feedback consideration for FCC-hh and HE-LHC", 21.09.17

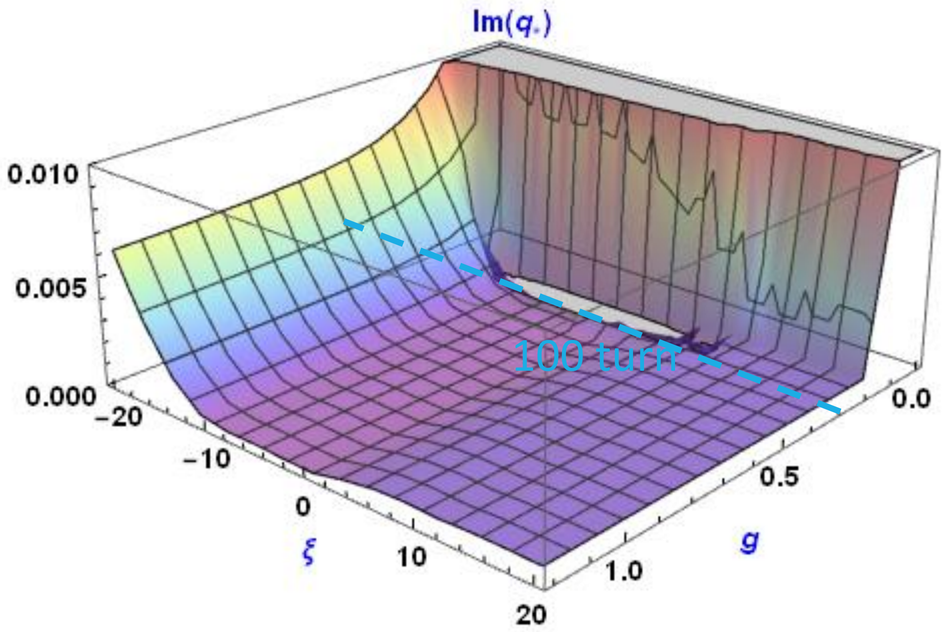
900 GeV: 1.2×10^{11} ppb, **1** bunch, X-plane
ε_n = 2.0 μm, σ_z = 9.0 cm, parabolic, $I_{oct} < 0$

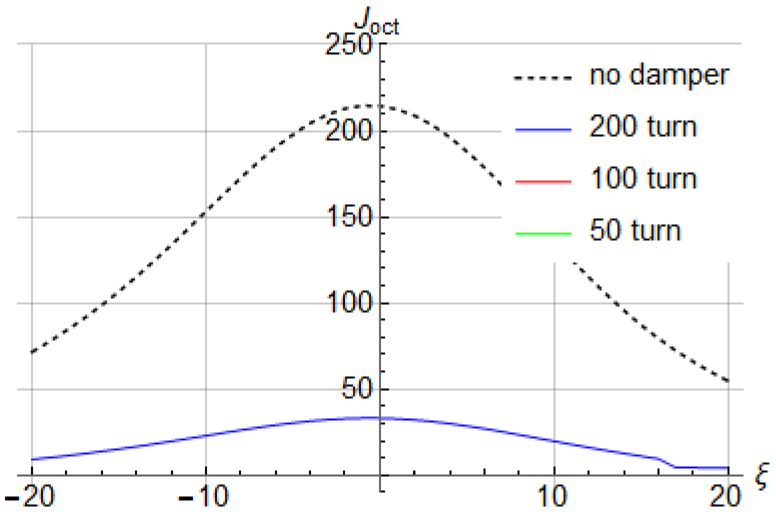
The current required to stabilize is very low



1300 GeV: 1.2x10^{11} ppb, 2748b
ε_n = 2.0 μm, σ_z = 9.0 cm, parabolic, I_{oct} < 0

Damper gain has to be higher than 100 turns – then the octupole current is insignificant





Damper gain: g = damping rate / ω_s
Growth rate: Im q = rate / ω_s

1300 GeV: **x2.5** Impedance, 1.2×10^{11} ppb, 2748b $\varepsilon_n = 2.0\ \mu m$, $\sigma_z = 9.0$ cm, parabolic, $I_{oct} < 0$

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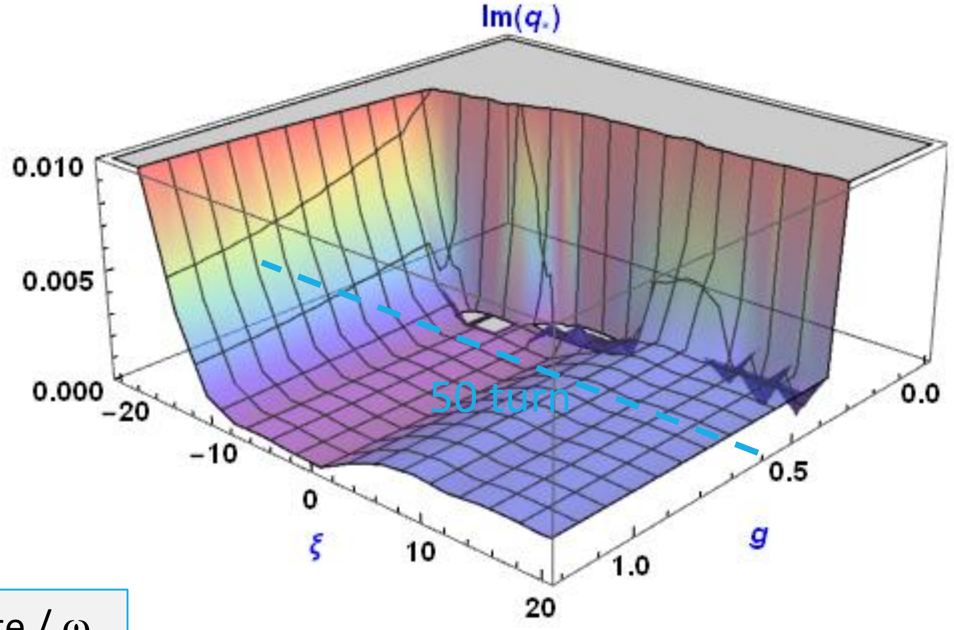

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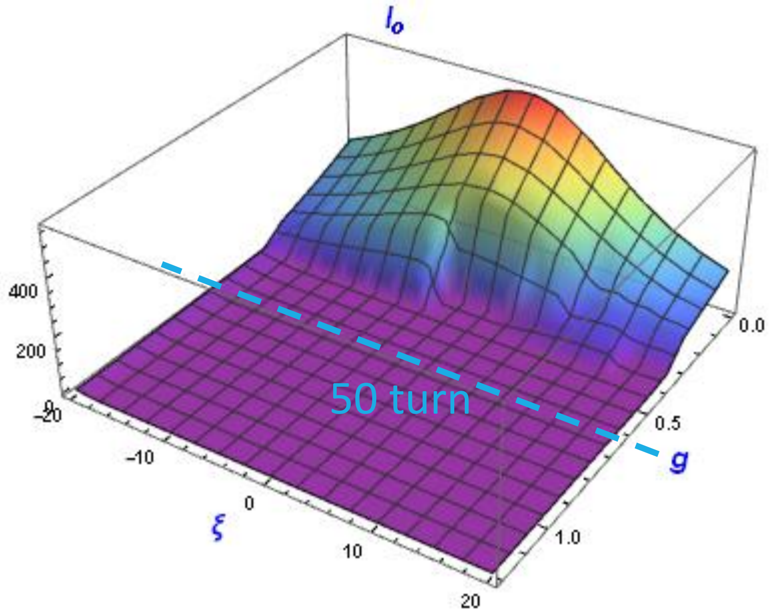
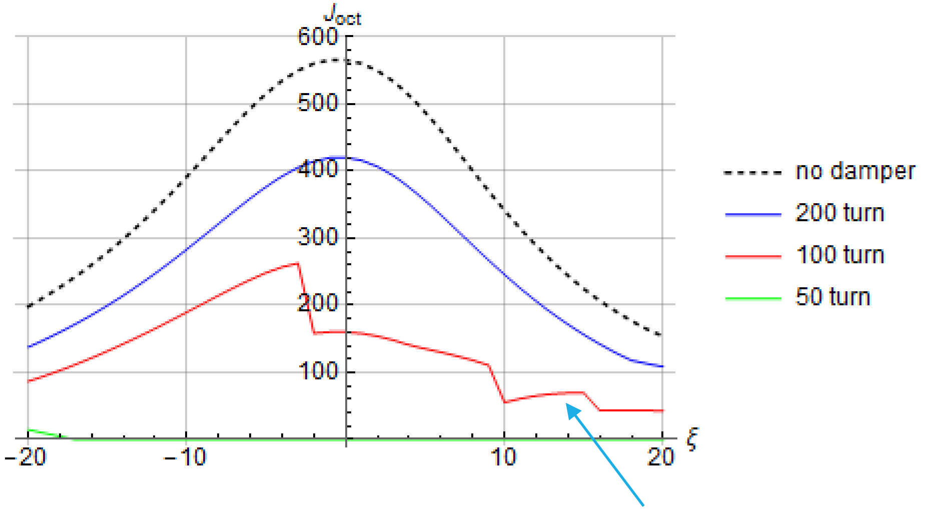
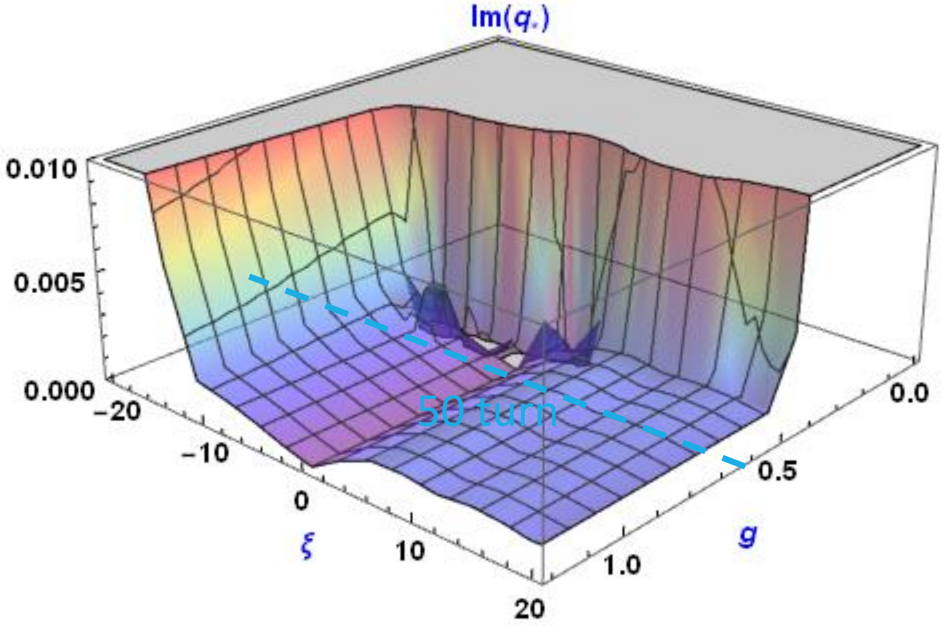


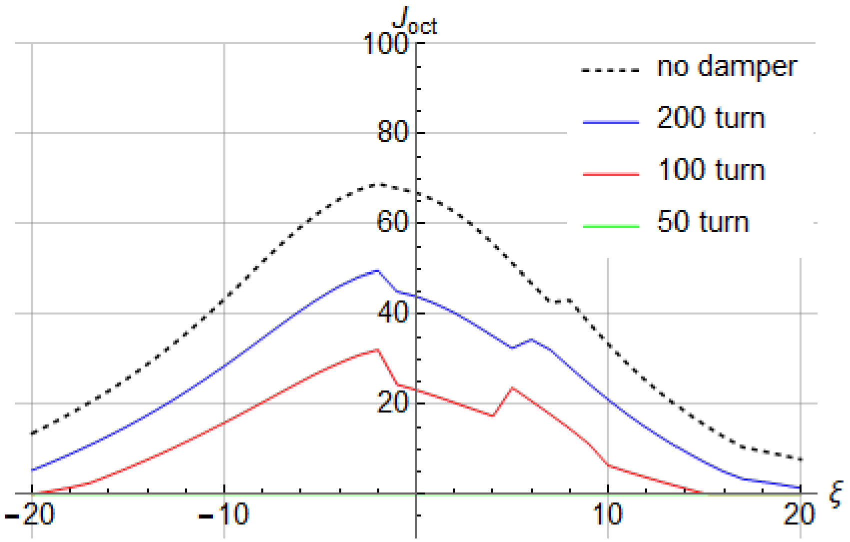


Damper gain: g = damping rate / ω_s

450 GeV: **x2.5** Impedance, 1.2×10^{11} ppb, 2748b, $\varepsilon_n = 2.0\ \mu m$, $\sigma_z = 9.0$ cm, parabolic, $I_{oct} < 0$

Damper gain has to be higher than 100 turns – then the octupole current is insignificant





Conclusion

The stability estimates were made scaling form the present Hi-Lumi model

The 1.3 TeV scenario has smaller margins in terms of octupole current:

- Dominated by collimators impedance due to the tight gaps
- But still low octupole current needed

For all options the beam is stable for a damper gain of 50-100 turns

- Negligible octupole currents needed to stabilize (~10 A or below)
- Even with a higher impedance, accounting for a FCC type beam screen

Top energy is expected to be more challenging for beam stability

Back-up Slides

Assumptions for the impedance model in detail

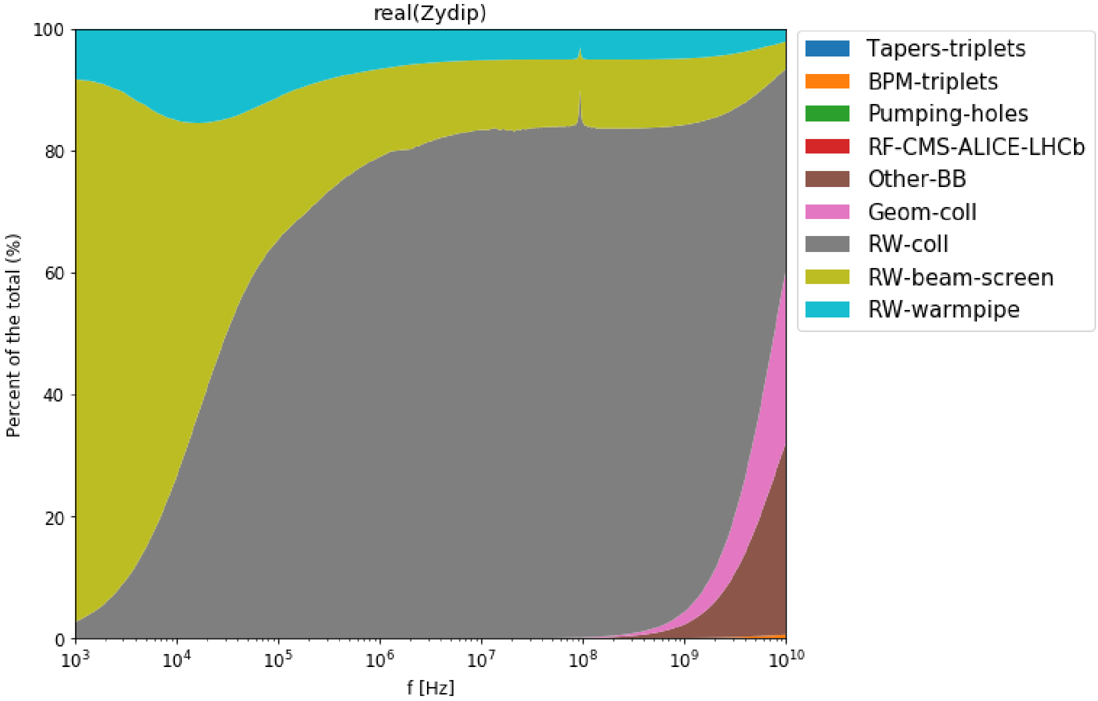
HE-LHC impedance model is derived from the HL-LHC model at injection

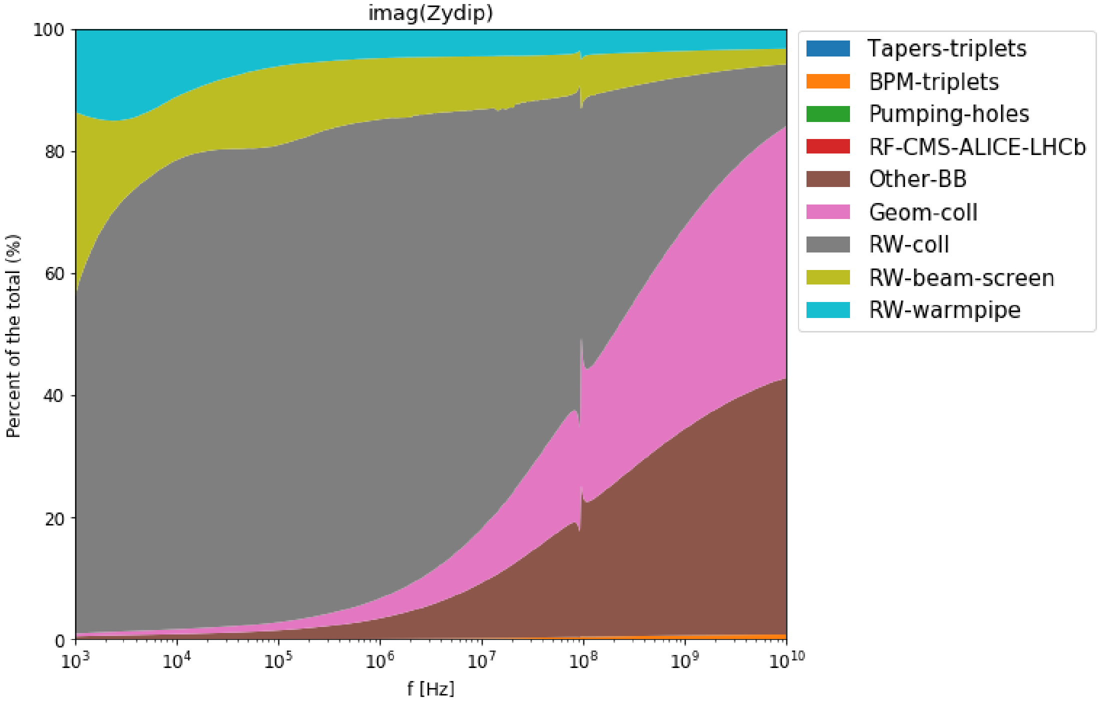
- 450GeV injection
- TDIS (injection protection collimator) in 3D Carbon
- IR7 TCSG (secondary collimators) in Mo coated MoGr
- LHC beam screen
- Scenario reference: HLLHC_inj_450GeV_TDI_in_TDIS-3DC_3.8mm_5umMo+MoC_IP7

Collimators scenarios are adapted for HE-LHC

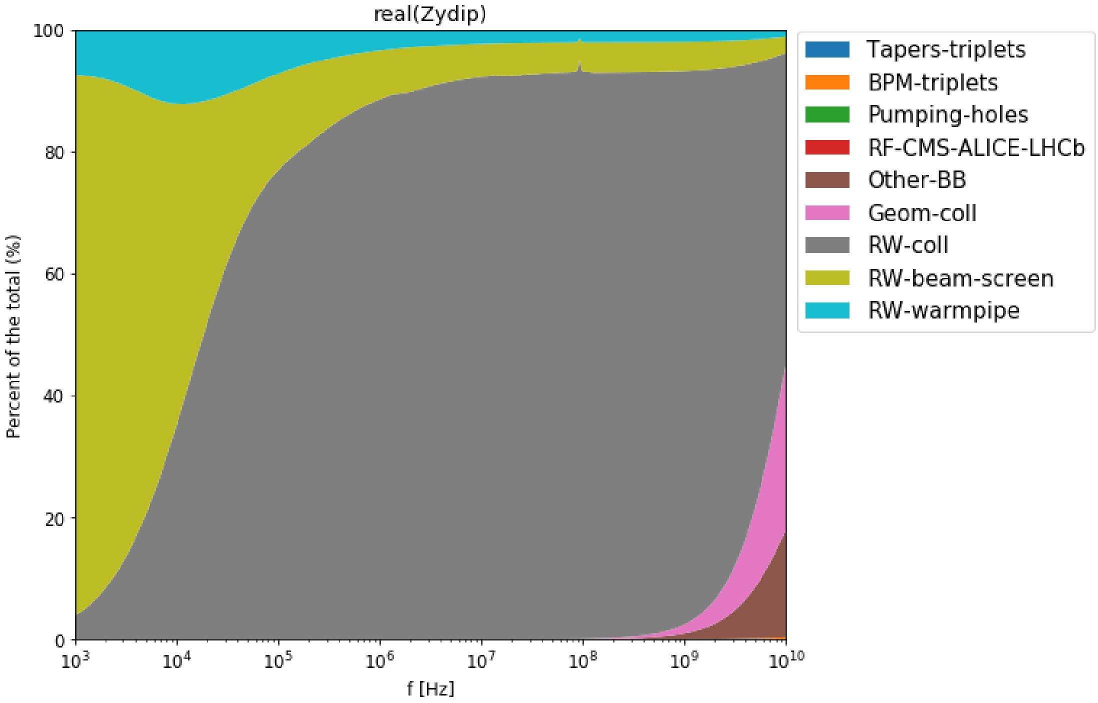
- IR7 TCP (primary collimators) in Mo coated MoGr as well
- At 450GeV: TCP, TCSG and TCDQ (dump protection) collimators gaps are tighter in number of σ_{coll}
- At 900GeV and 1300GeV: gaps in σ_{coll} are kept identical to HL-LHC
- For the three scenarios, the gaps are scaled to the normalized emittance and to the energy

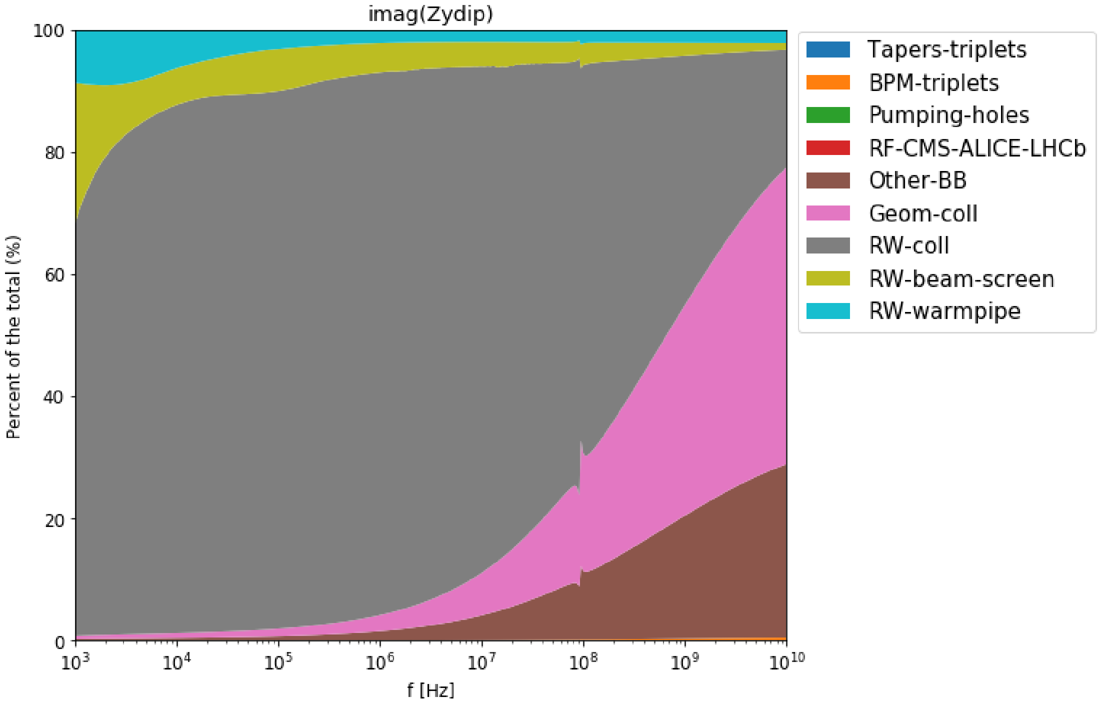
Elements contributions at 450 GeV





Elements contributions at 900 GeV





Elements contributions at 1300 GeV