First assessment of the impact of the beam screen interconnects on the FCC-hh impedance model

D. Amorim

EuroCirCol meeting

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Thanks to:

S.Arsenyev, N.Biancacci, X.Buffat, D.Ferrazza, M.Fiascaris, E.Métral, B.Salvant

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Outline

- Beam screen interconnects impedance
  - Interconnects model used for the simulations
  - Resulting impedance model
- Impact of the interconnects on beam stability
  - Impedance model and parameters used for the simulations
  - Impact of the interconnects on the TMCI threshold

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Beam screen interconnect: objective

- The current FCC-hh impedance model includes the beam screen and the collimators impedance
- Need to assess the impact of other elements on the impedance
- Objective: have a first assessment of the interconnects impedance and their impact on beam stability
- Impedance model of the interconnects studied by Diego Ferrazza during summer 2016 (CERN-THESIS-2016-146)

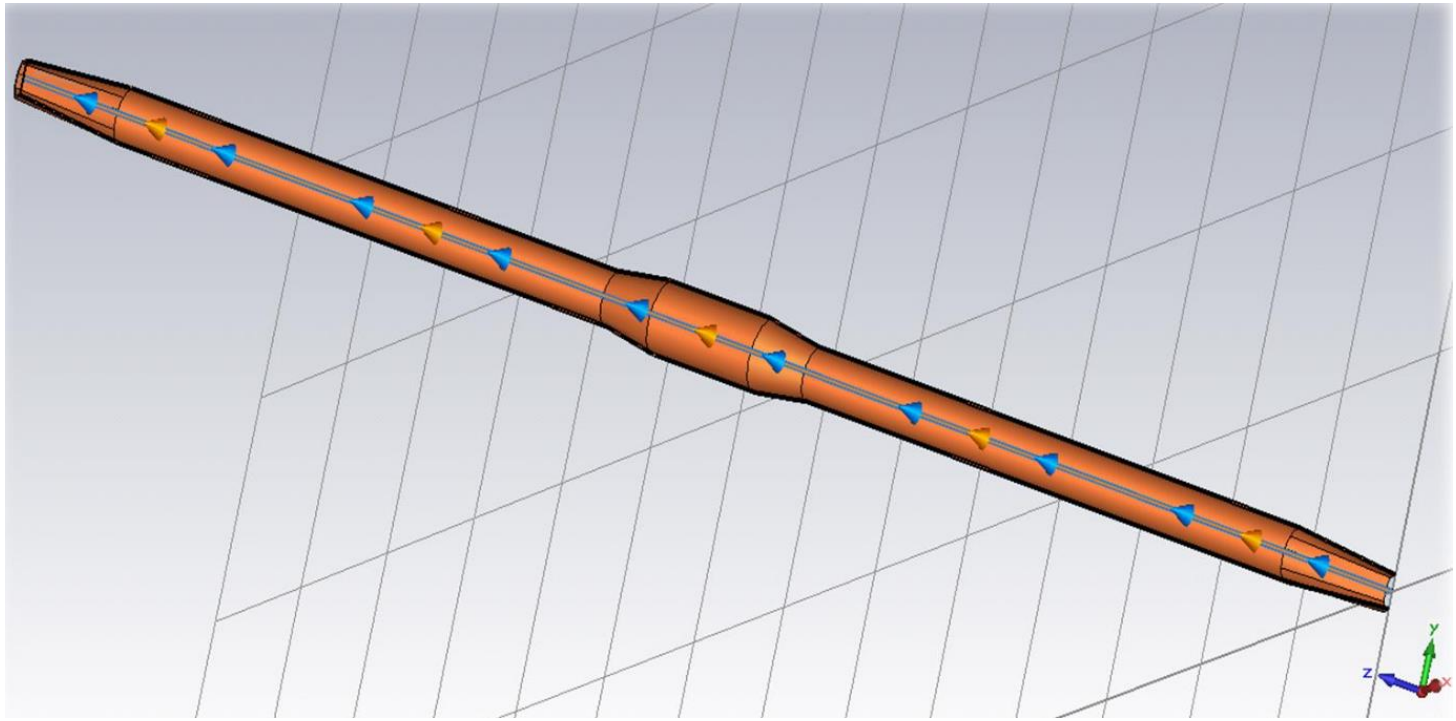
LHC impedance budget

element	Ref.	b	$\mathrm{Im}(Z/n)$	$\mathrm{Im}(Z_\perp)$
		mm	Ω	MΩ/m
Pumping slots	[23]	18	0.017	0.5
BPM's	[24]	25	0.0021	0.3
Unshielded bellows		25	0.0046	0.06
Shielded bellows		20	0.010	0.265
Vacuum valves		40	0.005	0.035
Experimental chambers		-	0.010	-
RF Cavities (400 MHz)		150	0.010	(0.011)
RF Cavities (200 MHz)		50	0.015	(0.155)
Y-chambers (8)	[25]	-	0.001	-
BI (non-BPM instruments)		40	0.001	0.012
space charge @injection	[2]	18	-0.006	0.02
Collimators @injection optics		$4.4 \div 8$	0.0005	0.15
Collimators @squeezed optics		$1.3 \div 3.8$	0.0005	1.5
TOTAL broad-band @injection optics			0.070	1.34
TOTAL broad-band @squeezed optics			0.076	2.67

LHC design report, chapter 5

Beam screen interconnects model

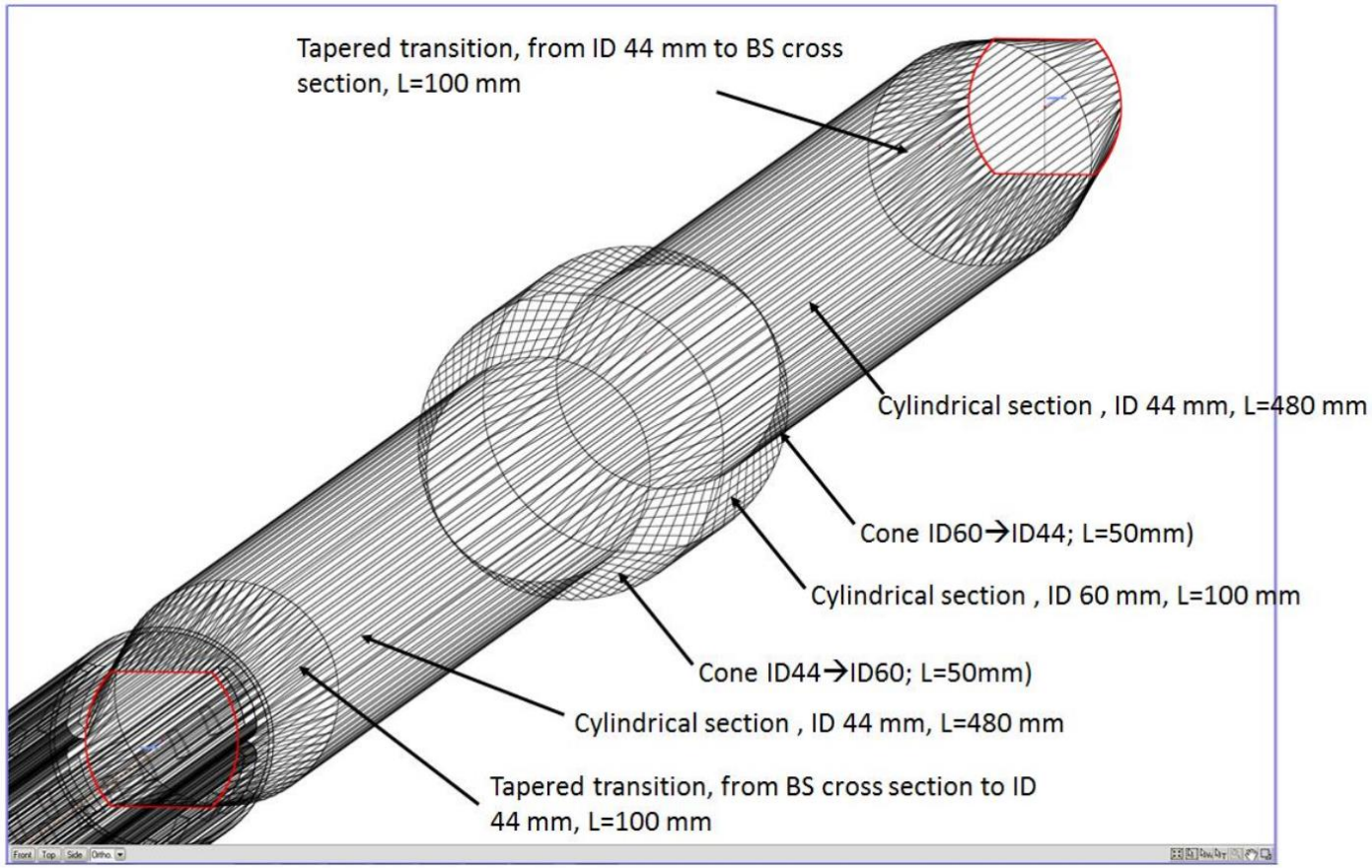
- Single element length: 1.36 m
- Approximately 4000 interconnects in the FCC-hh
- Total length is approximately 5 km



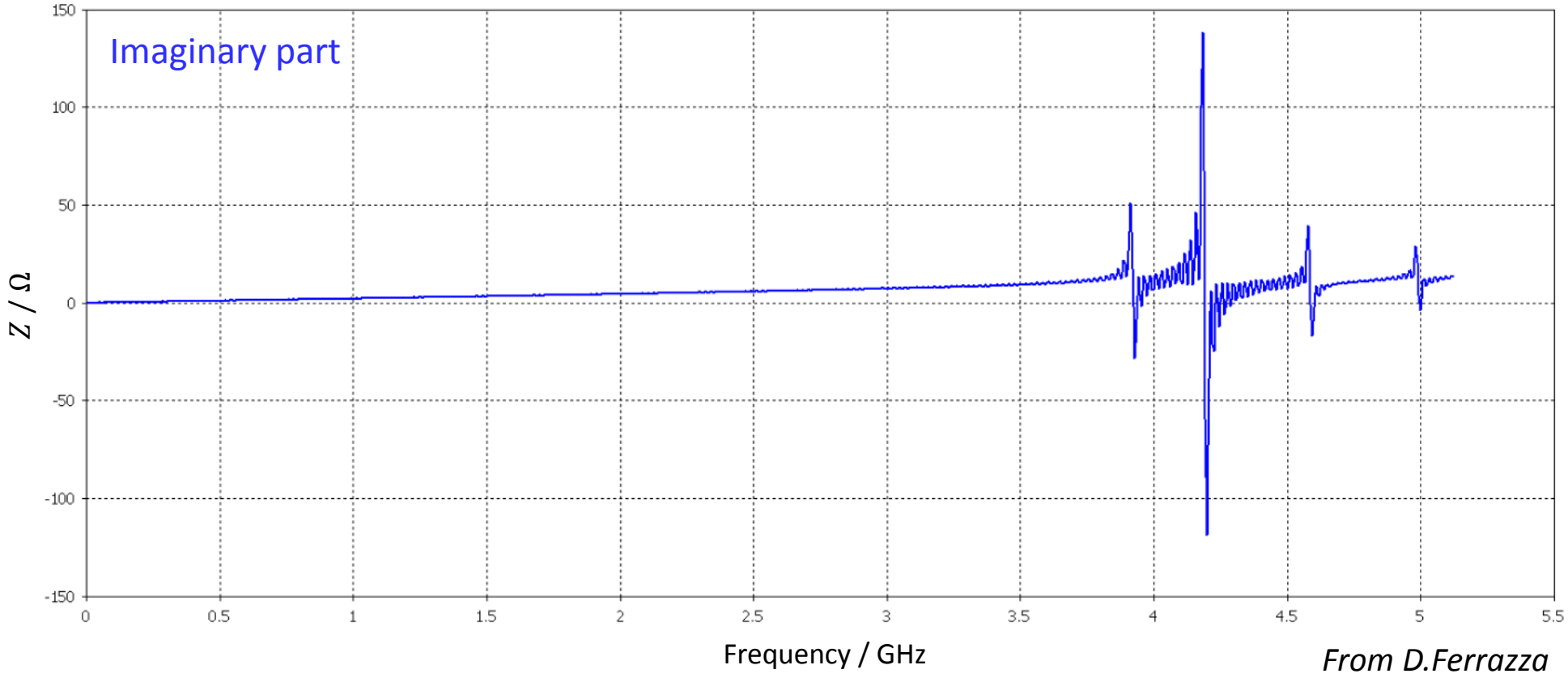
From D.Ferrazza

Beam screen interconnects model

- Single element length: 1.36 m
- Material: copper at 50 K ($\rho_{Cu}\ (50K) = 0.75\ 10^{-9}\Omega m$)
- Three cylindrical sections, conic and tapered transitions



Beam screen interconnects: longitudinal impedance

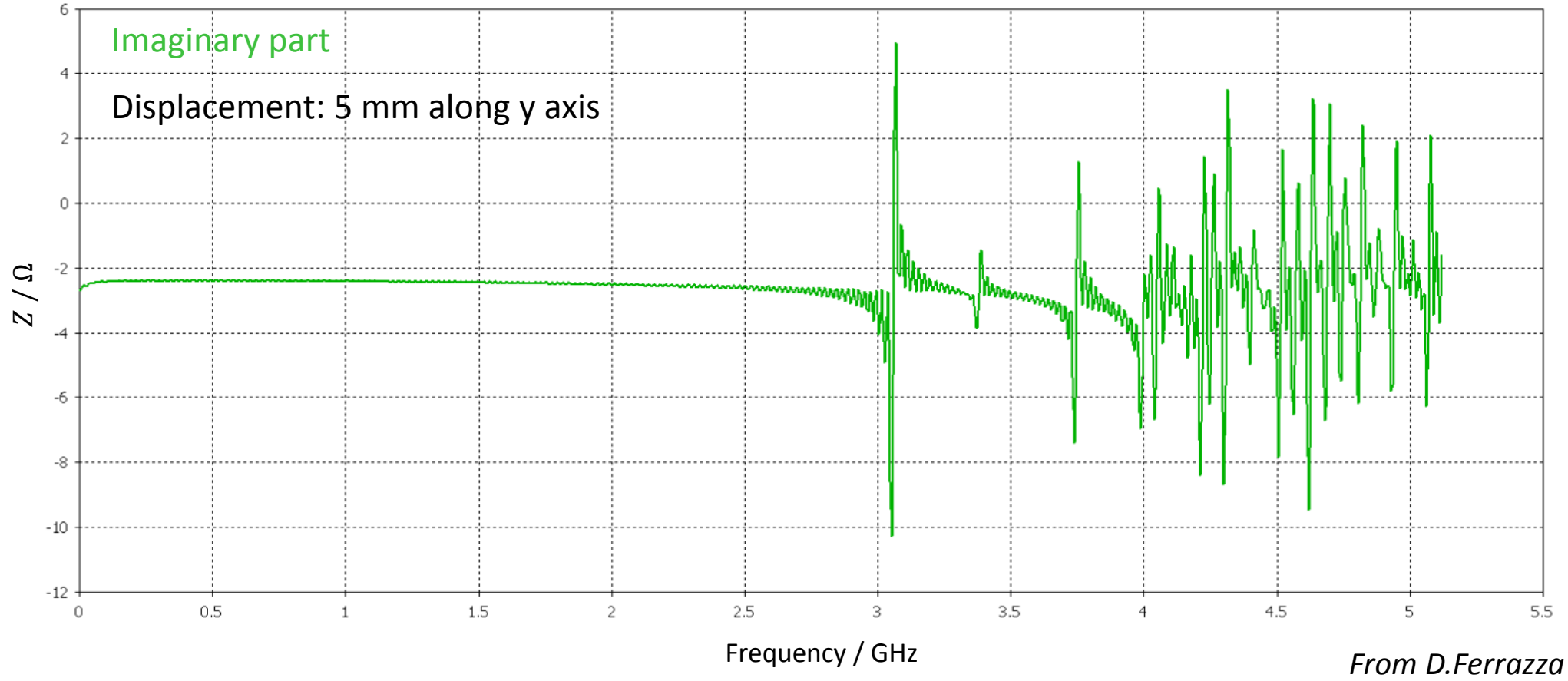


From D.Ferrazza

- Longitudinal impedance for one element: $Im\left(\frac{Z_{\parallel}}{n}\right) = 7\ 10^{-6}\ \Omega$

- **Longitudinal impedance** for 4000 elements: $\boldsymbol{Im\left(\frac{Z_{\parallel}}{n}\right)_{tot} = 28\ m\Omega}$ LHC: $\boldsymbol{10\ m\Omega}$

Beam screen interconnects: transverse impedance



From D.Ferrazza

- Broad-band part: $\boldsymbol{Im(Z_{x\perp}) = 1.52\ M\Omega/m}$ and $\boldsymbol{Im(Z_{y\perp}) = 1.92\ M\Omega/m}$ LHC: $\boldsymbol{0.265\ M\Omega/m}$

- First resonance: $\boldsymbol{f_{res} = 3.058\ GHz, R_s = 1.4\ G\Omega/m, Q = 86802}$

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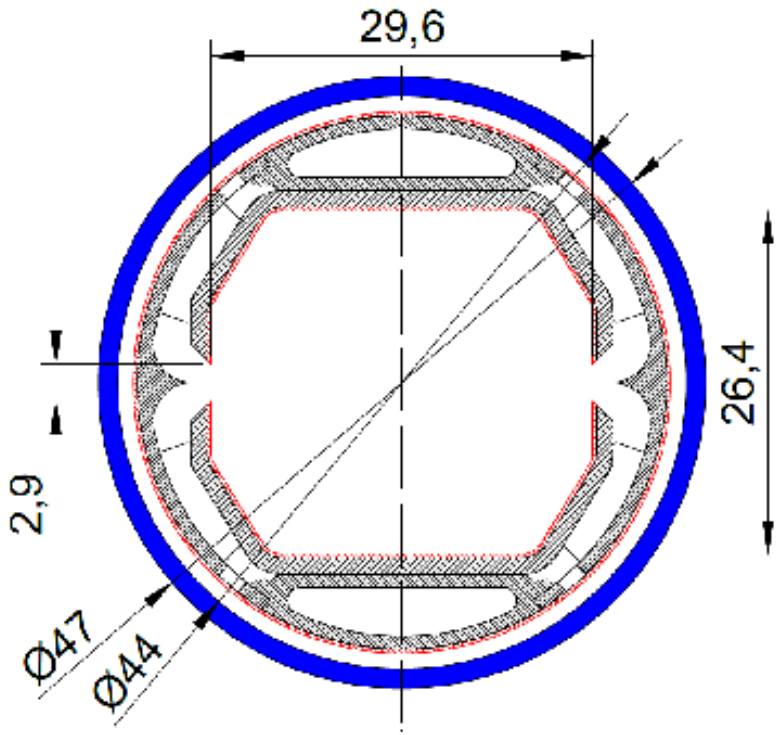
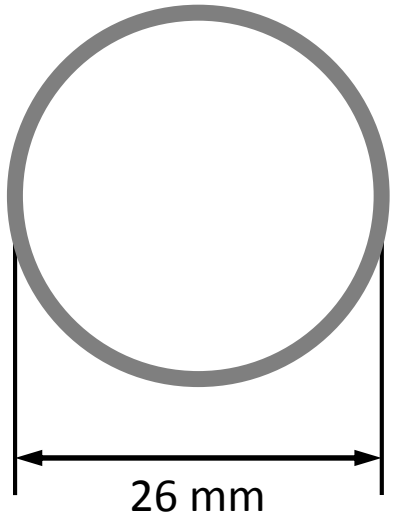
FCC-hh impedance model

- Beam screen impedance model
- Very simple model as the purpose is to study the impact of the interconnects



C. Garion, FCC week 2016

Beam screen model

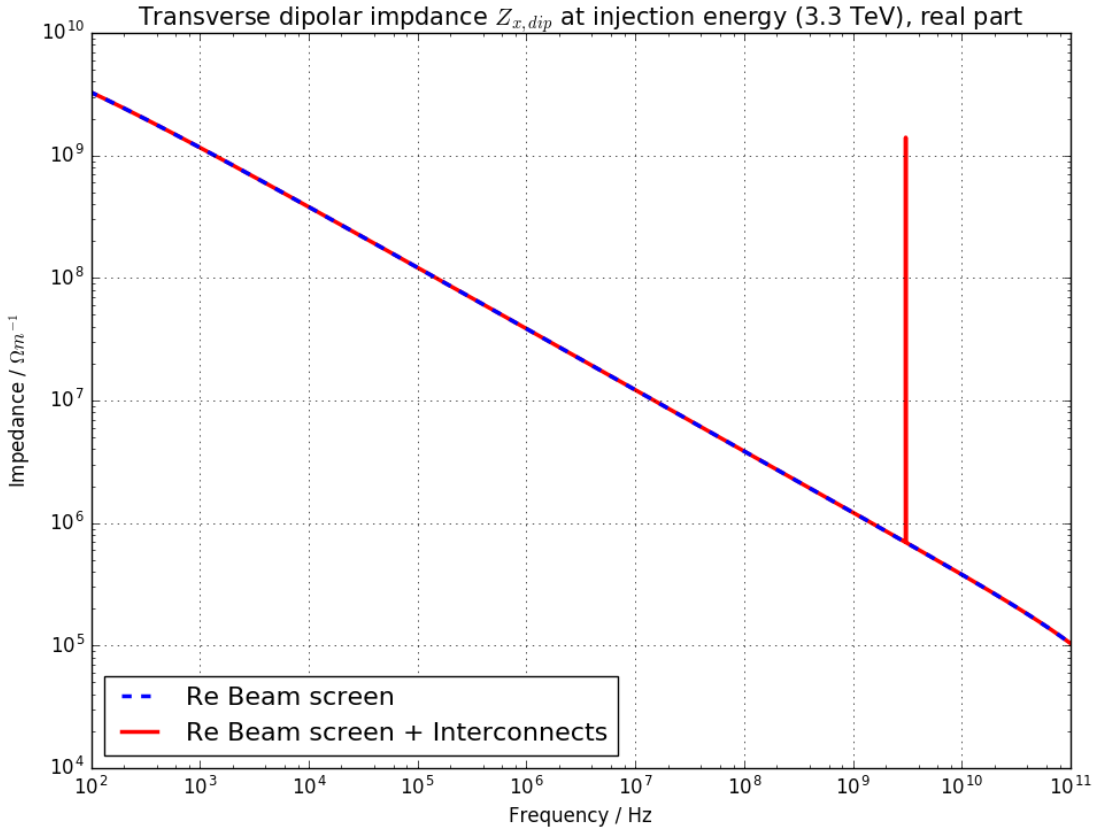


Length	100.2km
Material	Copper at 50K One layer

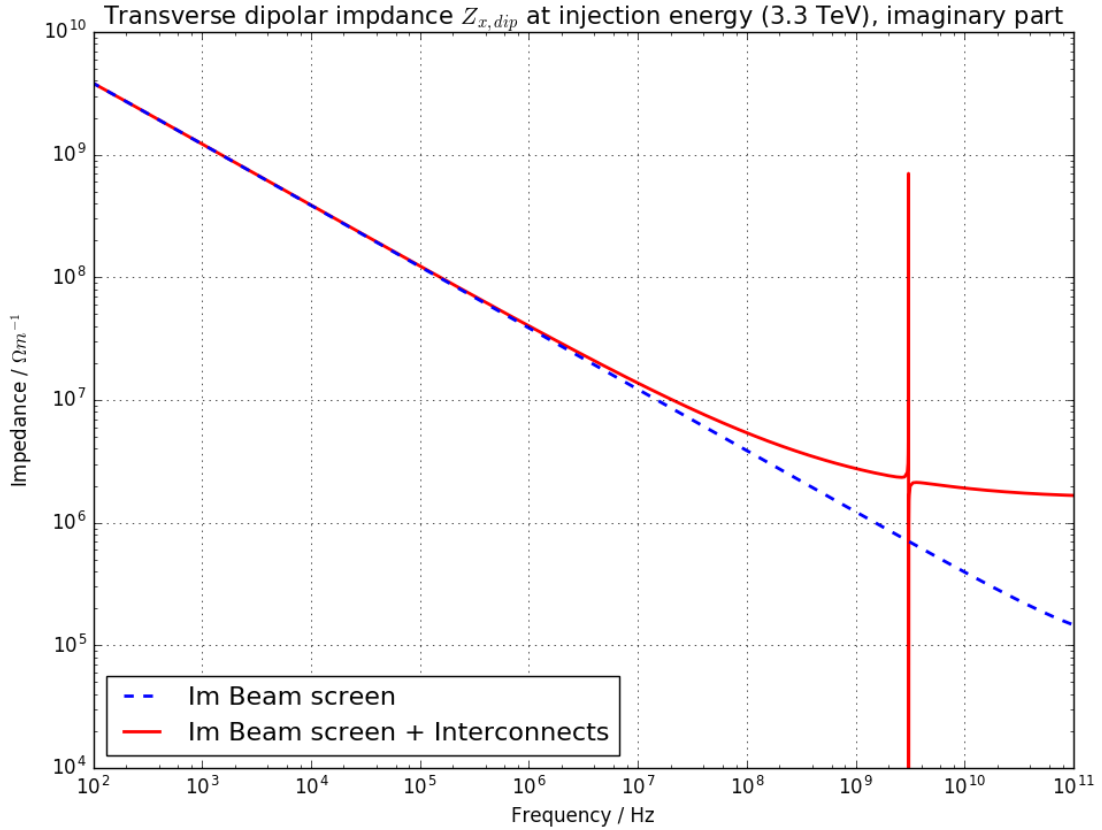
Magnetic field	$\rho_{Cu}\ (50K)$
B = 0 T	$0.75\ 10^{-9}$
B = 1.06 T	$0.788\ 10^{-9}$
B = 16 T	$1.32\ 10^{-9}$

Impedance model at injection energy (3.3 TeV)

- Model includes a circular copper (at 50K) beam pipe and the collimators
- Interconnects treated as a resonator with a broad-band part. Only the first resonance is included
- Impedance model is similar at top energy (50 TeV)



Real part



Imaginary part

Beam stability simulation parameters

	Injection (3.3 Tev)	Top Energy (50 TeV)
Circumference / km	100,2	
Revolution frequency / Hz	2942	
RMS bunch length σ_z / cm	8	
Qx / Qy	120.31 / 120.32	
Momentum compaction factor α_p	$1/110^2$	
Harmonic number	133650	
Slippage factor	8.256e-5	8.264e-5
RF voltage / MV	12	16 or 32
Qs	2.527e-3	7.500e-4 or 1.061e-3

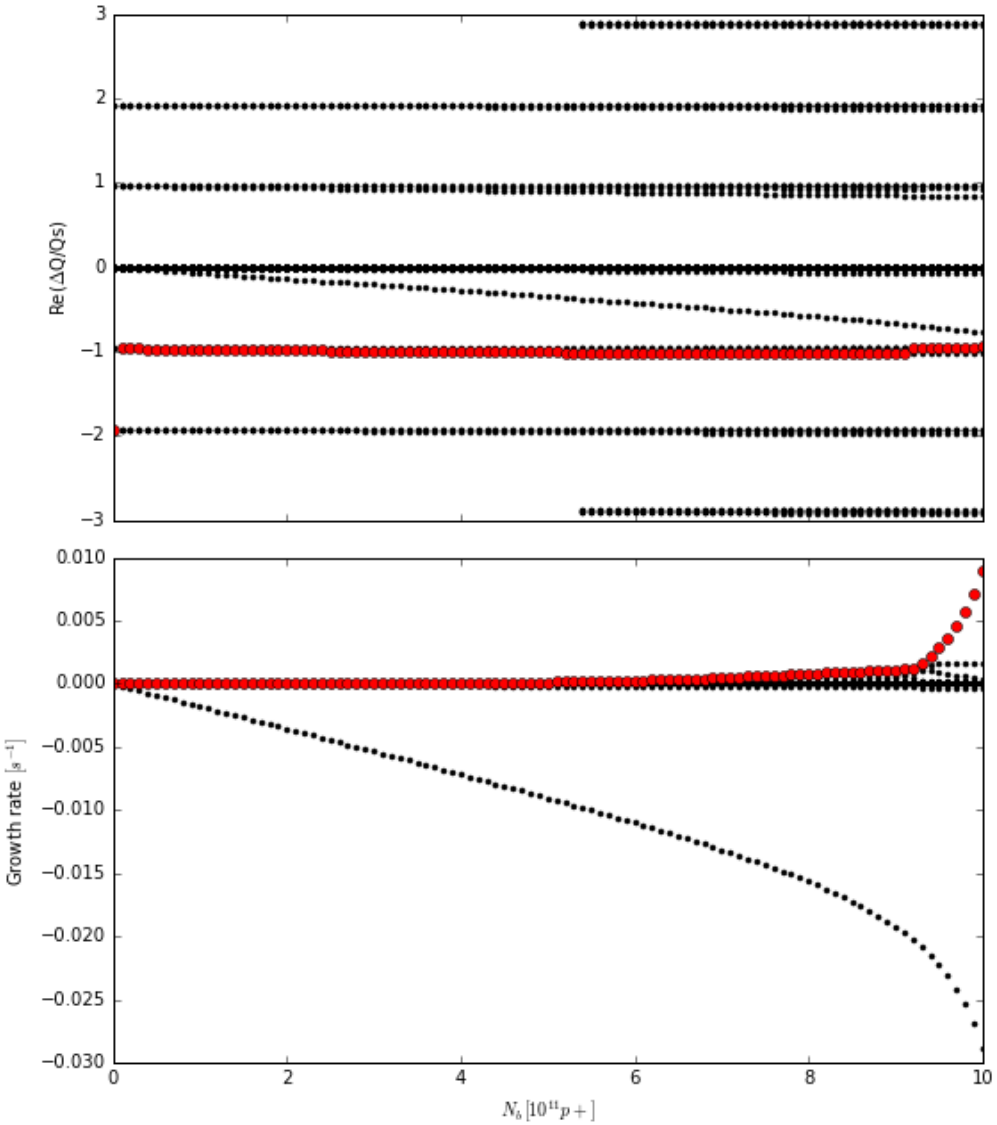
Remark: Some parameters are different from the optics ones

- Harmonic number, circumference, transition gamma, RF voltage at top energy from E.Shaposhnikova presentation at FCC week 2016
- Qx and Qy scaled from the LHC, with $Q \propto \frac{R}{\beta} \propto \frac{R}{E^{1/3}}$

Beam stability simulations scenarios

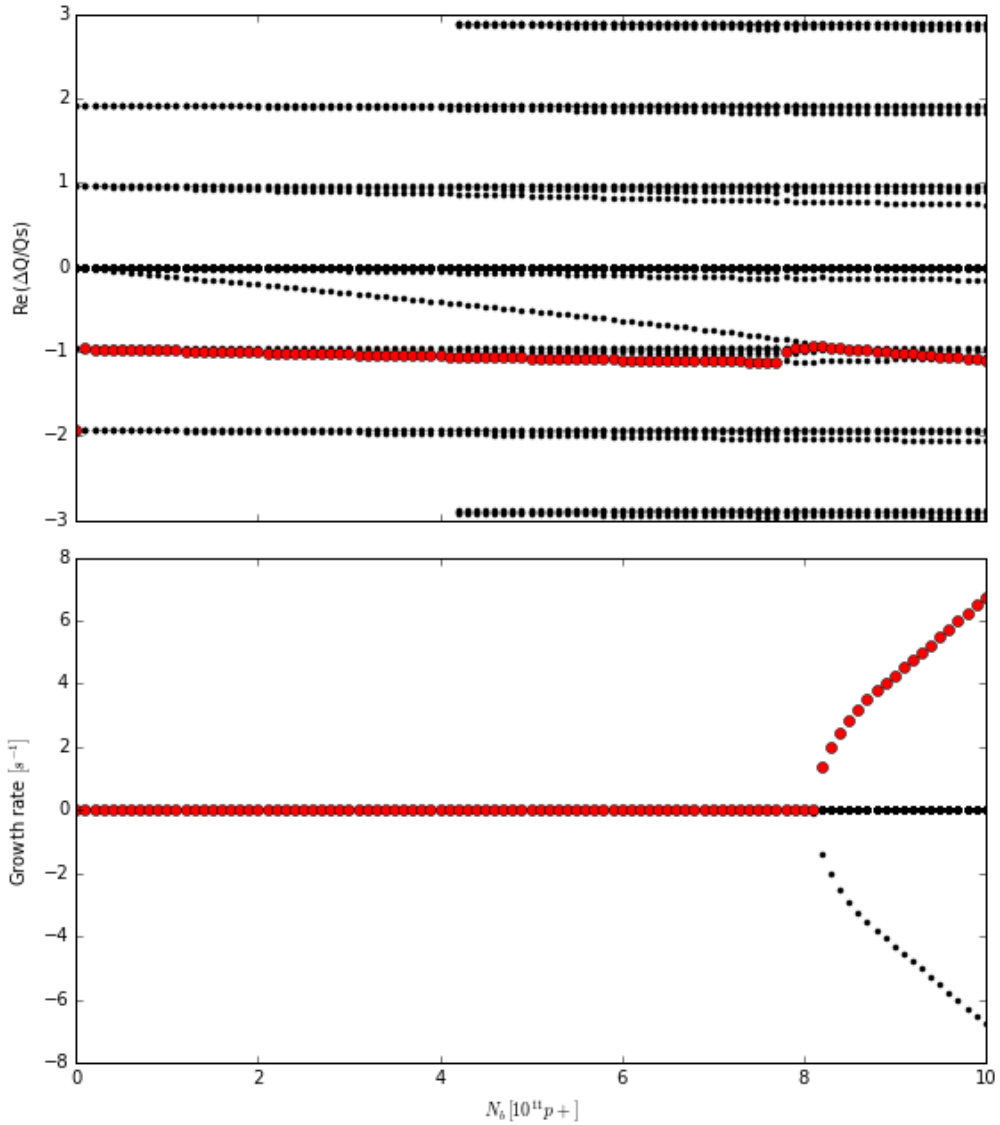
- Simulations performed with DELPHI, an analytic Vlasov solver (available at gitlab.cern.ch/groups/IRIS)
- Impedance model considered:
  - **Beam screen only**
  - **Beam screen + interconnects**
- At top energy, two sets of RF parameters considered: RF voltage of 16 MV and 32 MV
- Simulations with a single bunch, scans in intensity (from 0 to 10^{12} ppb)
- Ongoing simulations with 10600 bunches for the coupled bunch mode stability

Stability simulations at injection: effect of the interconnects



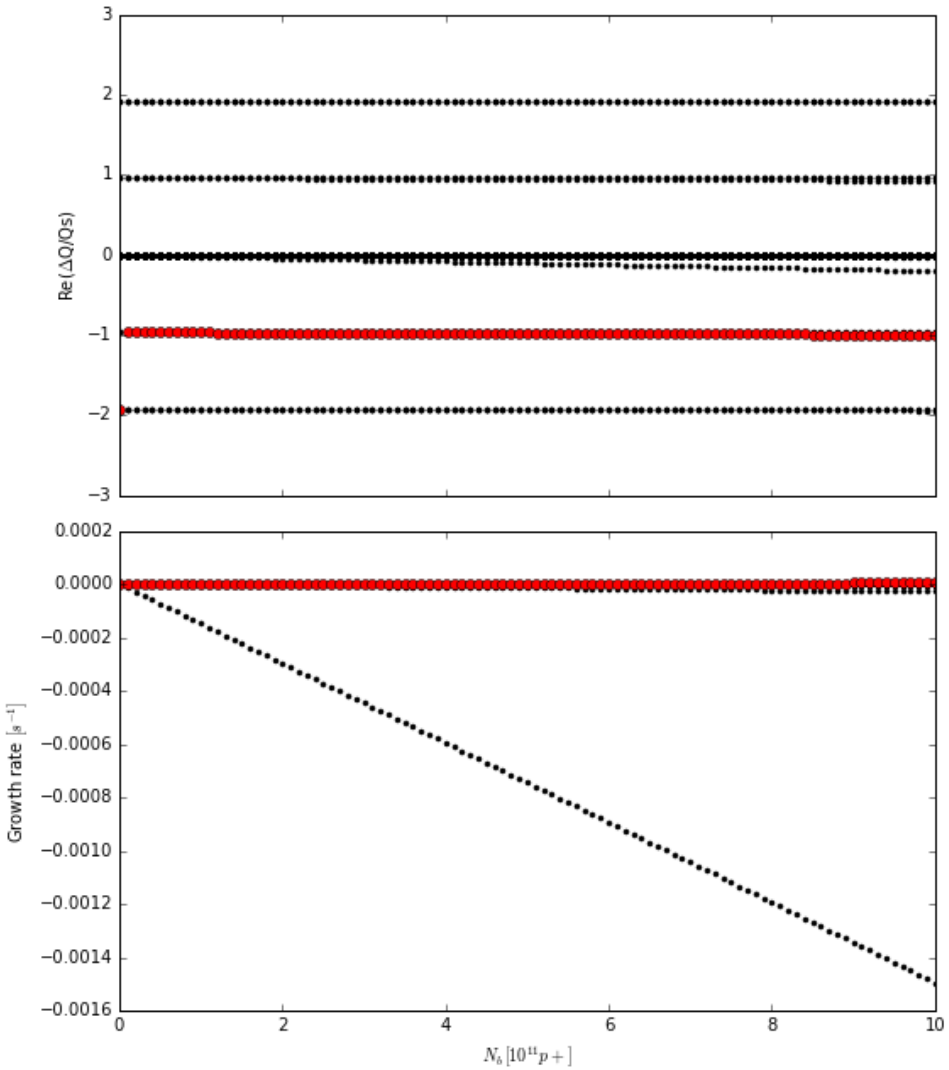
- Case: **Beam screen only** (treated as a cylindrical pipe)
- Tuneshifts and growth rates at **injection (3.3 TeV)**, single bunch, zero chromaticity, no damper
- TMCI threshold at $\sim \mathbf{9\ 10^{11}}\ \boldsymbol{ppb}$

Stability simulations at injection: effect of the interconnects



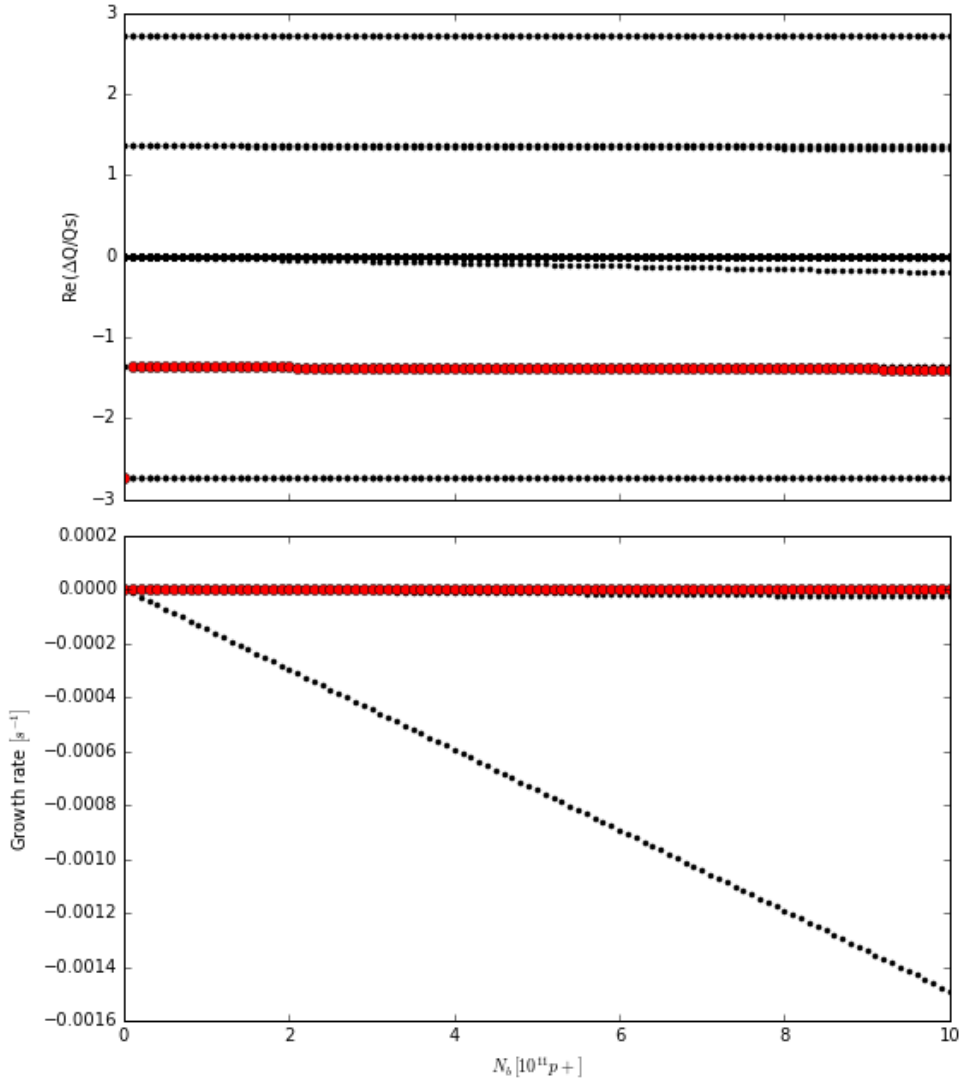
- Case: **Beam screen + interconnects**
- Tuneshifts and growth rates at **injection (3.3 TeV)**, single bunch, zero chromaticity, no damper
- TMCI threshold at $\boldsymbol{8\ 10^{11}\ ppb}$

Stability simulations at top energy: effect of the interconnects



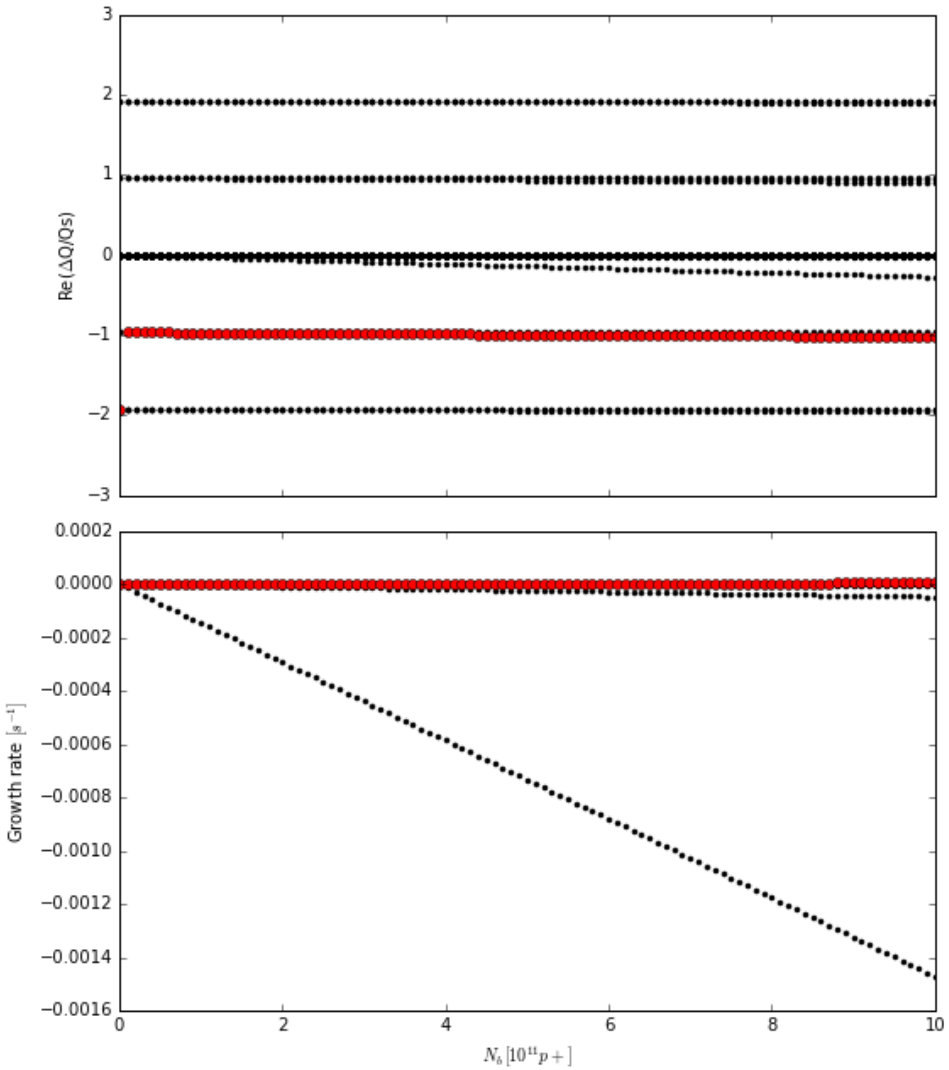
16 MV RF voltage

- Case: **Beam screen only**
- Tuneshifts and growth rates at **top energy (50 TeV)**, single bunch, zero chromaticity, no damper
- For **16 MV** RF voltage: TMCI threshold $> \mathbf{10^{12}}$ $\boldsymbol{ppb}$
- For **32 MV** RF voltage: TMCI threshold at $> \mathbf{10^{12}}$ $\boldsymbol{ppb}$



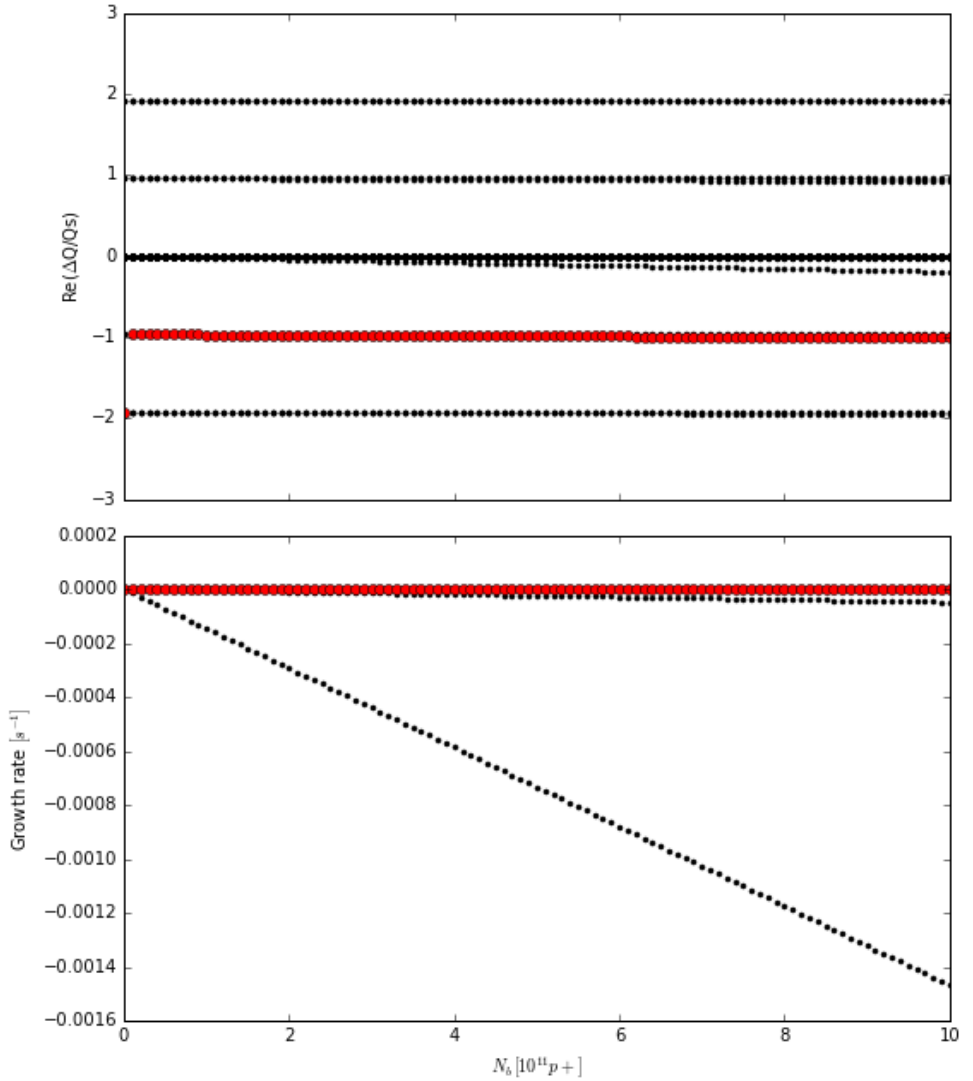
32 MV RF voltage

Stability simulations at top energy: effect of the interconnects



16 MV RF voltage

- Case: **Beam screen + interconnects**
- Tuneshifts and growth rates at **top energy (50 TeV)**, single bunch, zero chromaticity, no damper
- For **16 MV** RF voltage: TMCI threshold $> \mathbf{10^{12}}\ \boldsymbol{ppb}$
- For **32 MV** RF voltage: TMCI threshold at $> \mathbf{10^{12}}\ \boldsymbol{ppb}$



32 MV RF voltage

Conclusion

- A first simple model of the beam screen interconnects impedance was elaborated by D.Ferrazza
- The beam screen interconnects have a visible impact on the stability threshold at injection energy, their impedance model should be further refined
- Their impact is negligible at top energy

- The **design of the beam screen interconnects should be followed-up** and included in the impedance model
- Other elements such as the **collimators** should also be **further investigated (materials, length…)**

Backup

FCC-hh impedance model

- Collimators settings at injection and top energy from M.Fiascaris

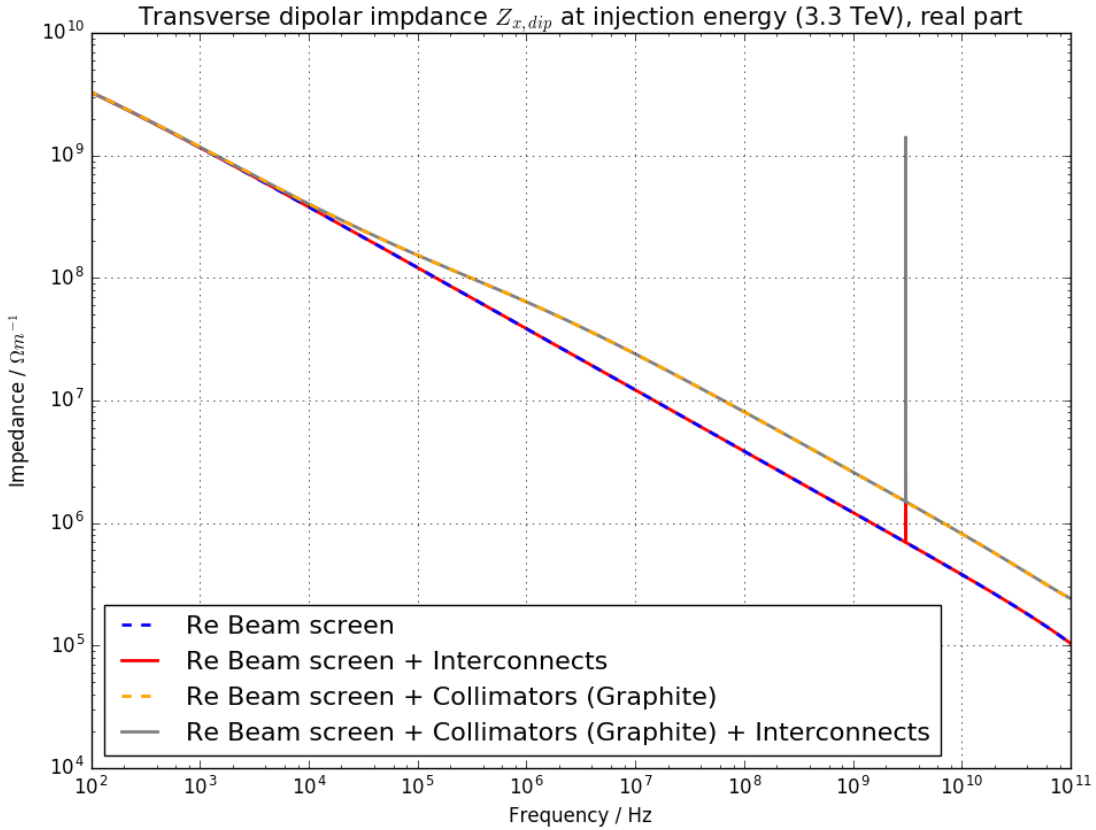
- At injection (3.3TeV), lowest half gap are $\sim 4\ mm$
- At top energy (50TeV), lowest half gap are $\sim 1\ mm$

Type	Total length	Material	Halfgap in σ
Primary (TCP)	1.8m	Graphite	7.2
Secondary (TCSG)	11m	Graphite	9.7
Shower absorbers (TCLA)	9m	Tungsten	12/16

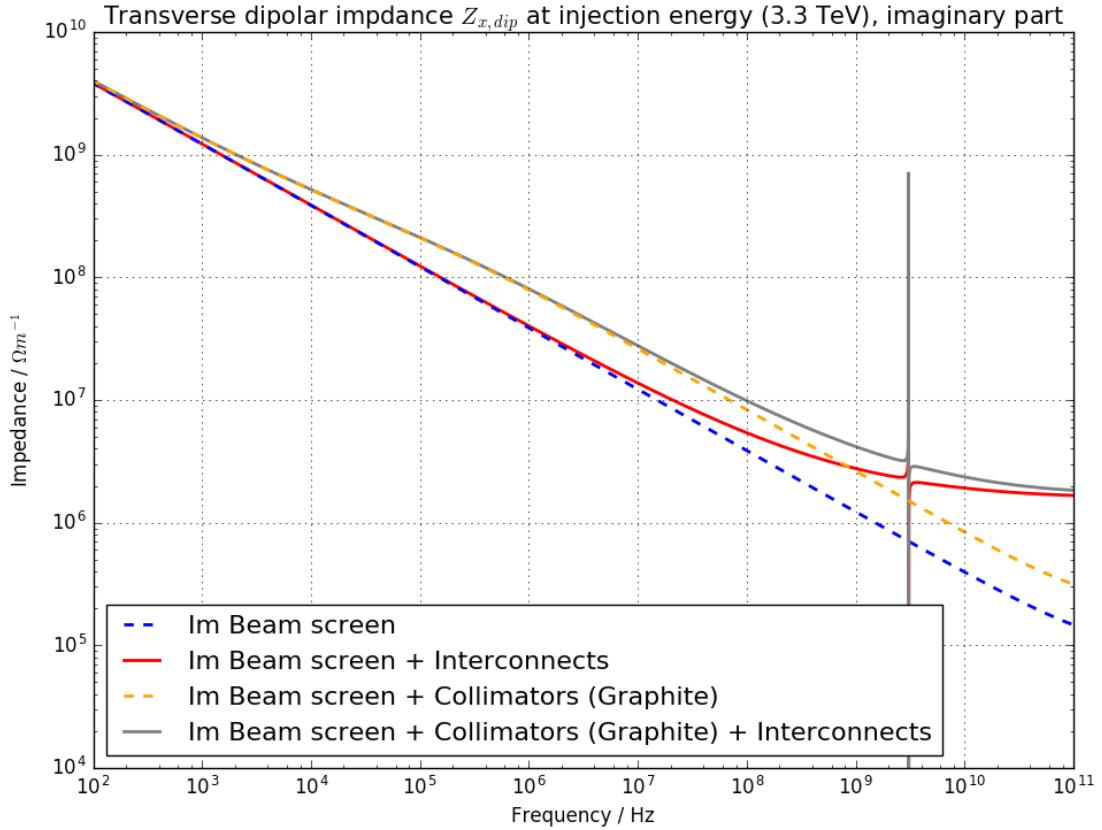
- Impedance database available at impedance.web.cern.ch/impedance/fcchh/

Impedance model at injection energy (3.3 TeV)

- Model includes a circular copper (at 50K) beam pipe and the collimators
- Interconnects treated as a resonator with a broad-band part. Only one resonance mode is treated



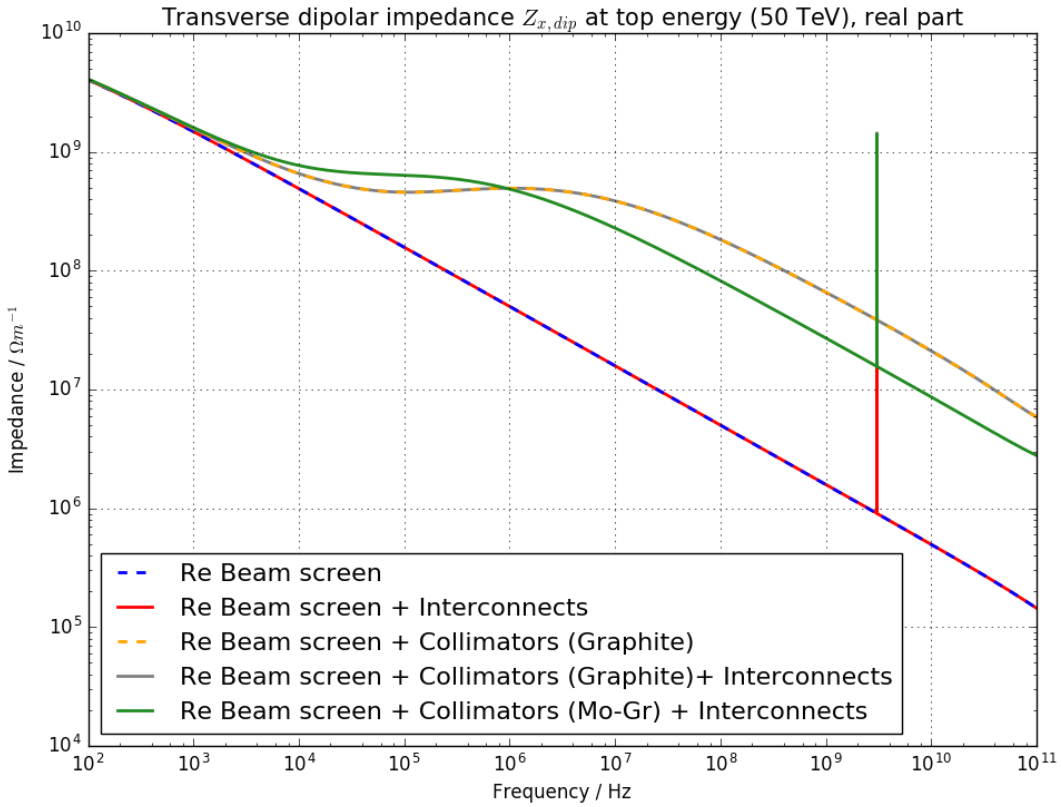
Real part



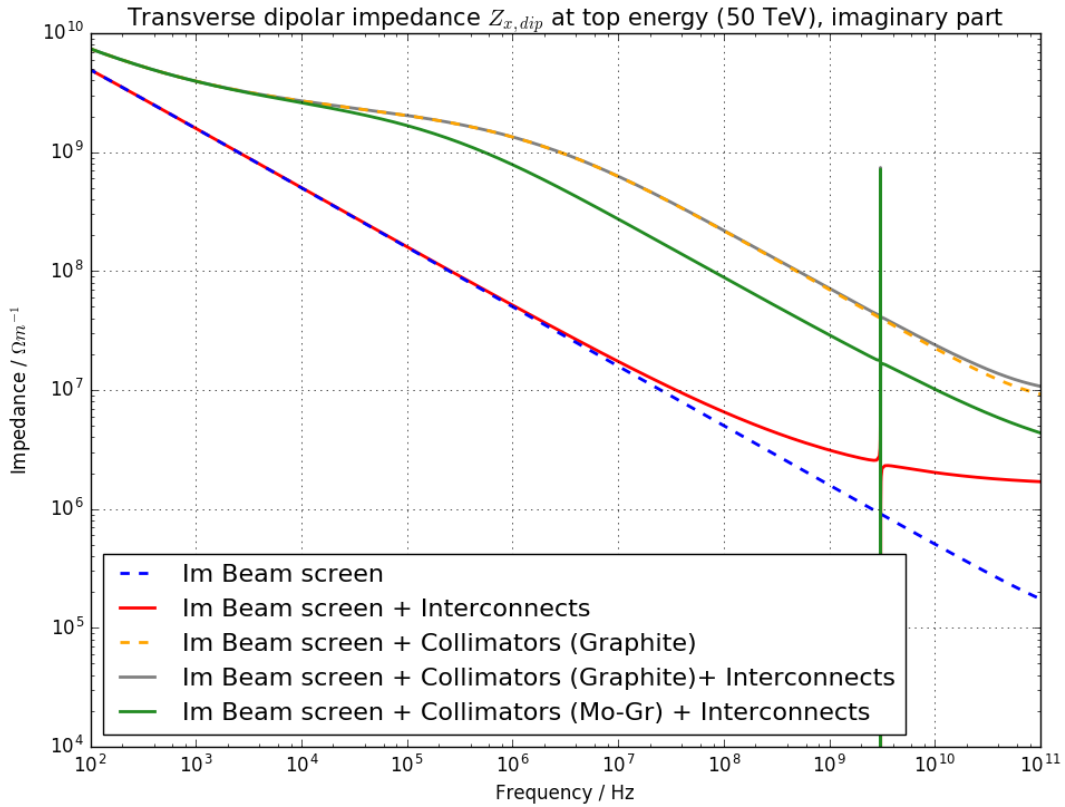
Imaginary part

Impedance model at top energy (50 TeV)

- At top energy, two scenarios for the collimators materials are considered:
  - **Graphite primary and secondary collimators** (LHC type collimators)
  - **Molybdenum-Graphite primary and secondary collimators** (possible HL-LHC collimators)

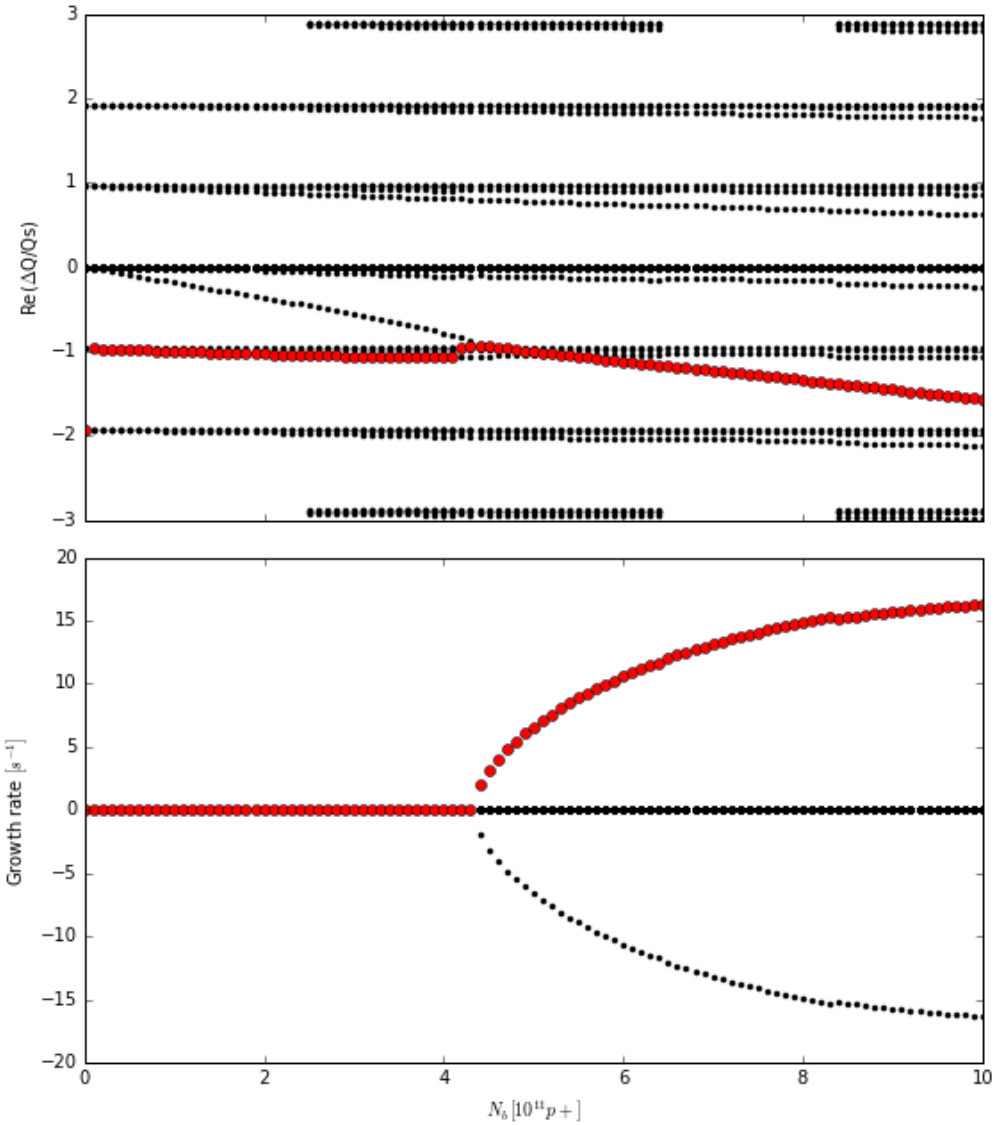


Real part



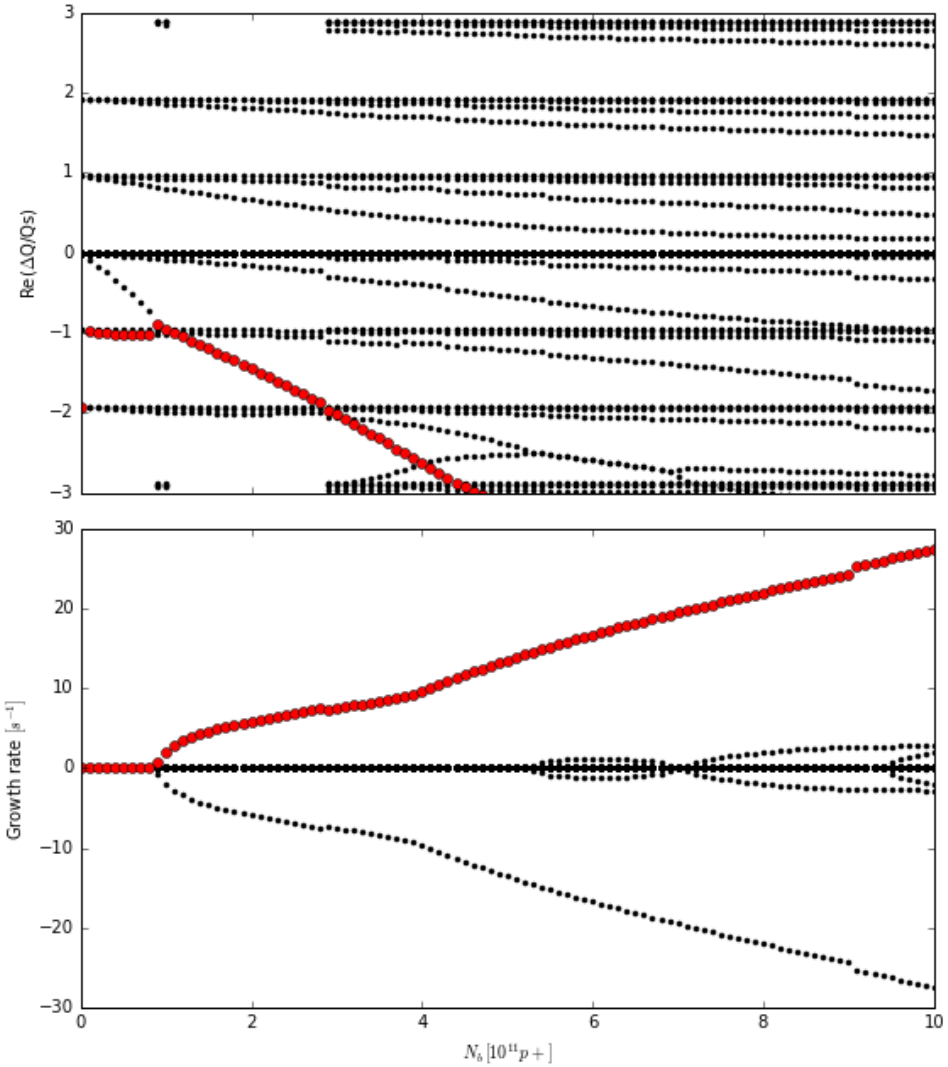
Imaginary part

Stability simulations at injection: effect of the collimators



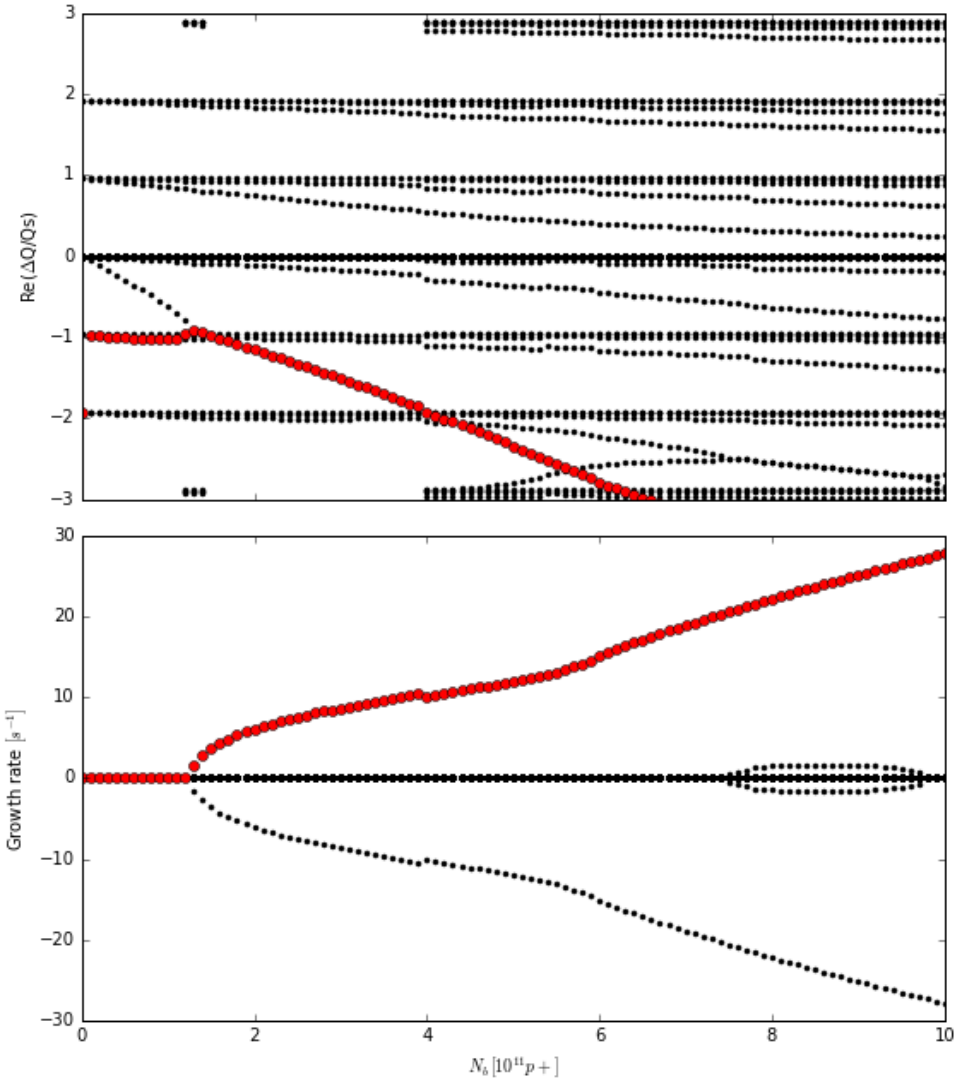
- Case: **Beam screen + graphite collimators + interconnects**
- Tuneshifts and growth rates at **injection (3.3 TeV)**, single bunch, zero chromaticity, no damper
- TMCI threshold at $\boldsymbol{4.3\ 10^{11}\ ppb}$

Stability simulations at top energy: effect of the collimators



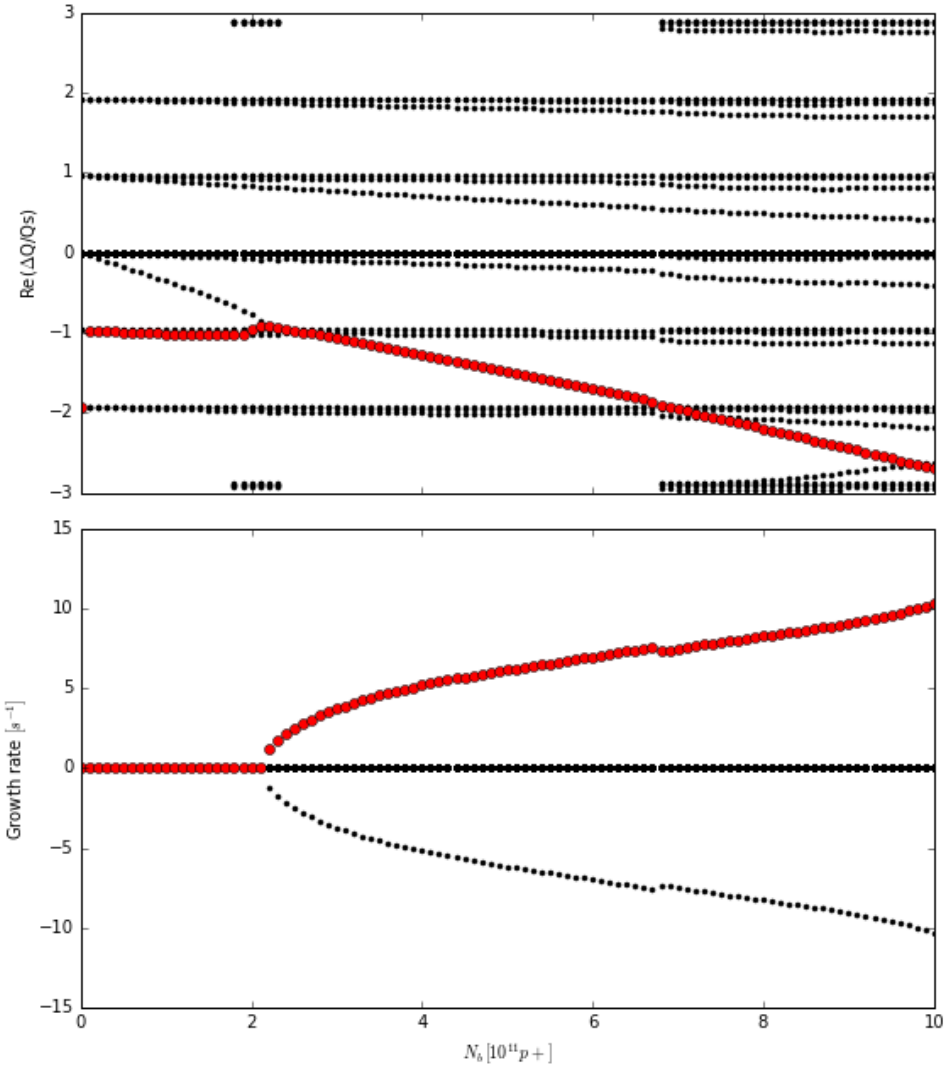
16 MV RF voltage

- Case: **Beam screen + graphite collimators + interconnects**
- Tuneshifts and growth rates at **top energy (50 TeV)**, single bunch, zero chromaticity, no damper
- For **16 MV** RF voltage: TMCI threshold at $\mathbf{0.8\ 10^{11}}\ \boldsymbol{ppb}$
- For **32 MV** RF voltage: TMCI threshold at $\mathbf{1.2\ 10^{11}}\ \boldsymbol{ppb}$



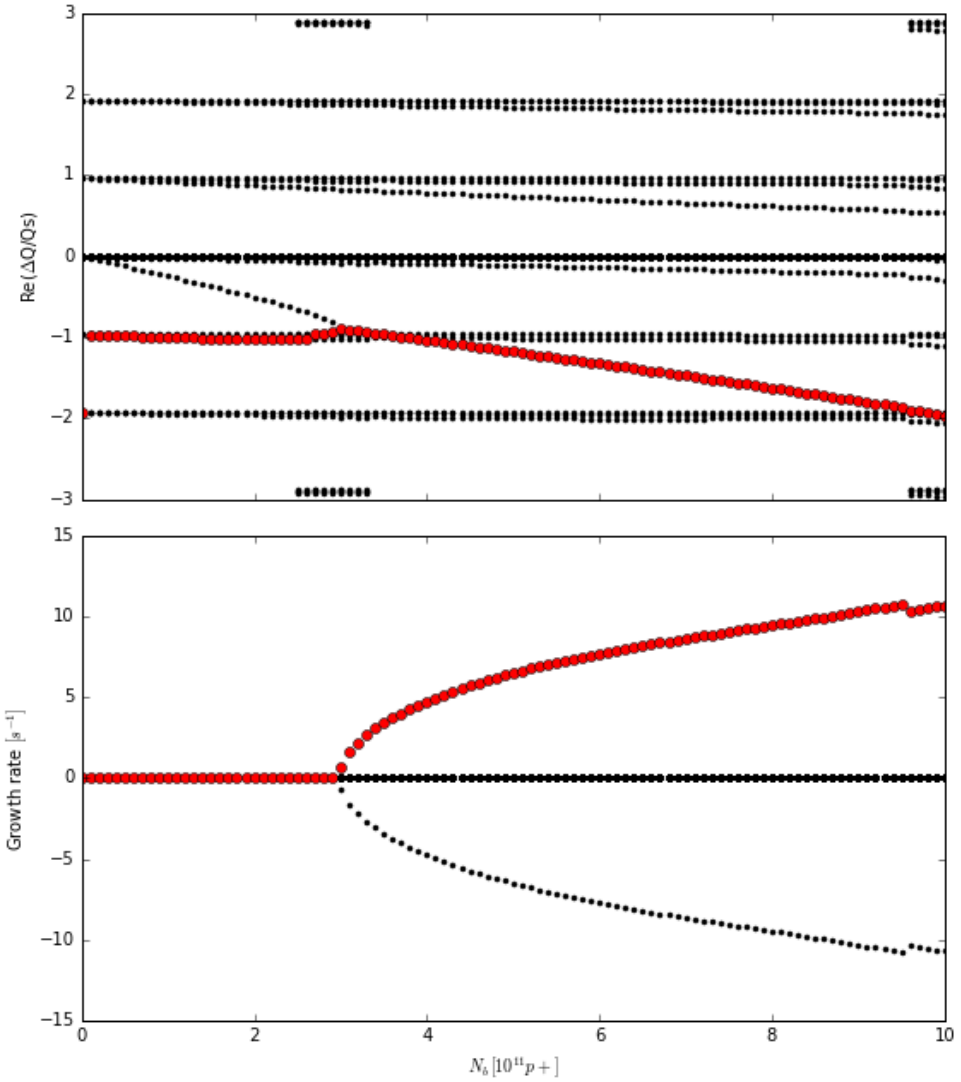
32 MV RF voltage

Stability simulations at top energy: effect of the collimators



16 MV RF voltage

- Case: **Beam screen + molybdenum-graphite collimators + interconnects**
- Tuneshifts and growth rates at top energy, single bunch, zero chromaticity, no damper
- For **16 MV** RF voltage: TMCI threshold at $\mathbf{2.1\ 10^{11}}\ \boldsymbol{ppb}$
- For **32 MV** RF voltage: TMCI threshold at $\mathbf{3.0\ 10^{11}}\ \boldsymbol{ppb}$



32 MV RF voltage