ABP-HSC

Machine impedance and HOM power update

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7TH HL-LHC COLLABORATION MEETING, CIEMAT, MADRID – 15.11.17

MANY THANKS TO OUR COLLEAGUES FROM HSC AS WELL AS RF, OP, AND COLLIMATION
G. ARDUINI, R. BRUCE, R. CALAGA, J. GUARDIA, R. DE MARIA, D. MIRARCHI, J. MITCHELL, AND
D. VALUCH

Goal: review the single-beam stability and heat loads from impedance for the most challenging OP scenario

Structure of this talk:

- First, consider the impedance model focusing on its dominant component – the collimation system
- Then, estimate the impact of the crab cavities on collective stability
- Finally, update the prediction for the crab cavity heat loads

Beam-beam effects:	X. Buffat, WP2/4	Wed. 16:30
Summary of OP scenarios:	E. Metral, WP2/4/5	Wed. 17:00

Beam stability from impedance

Studying the most challenging cases

ULTIMATE

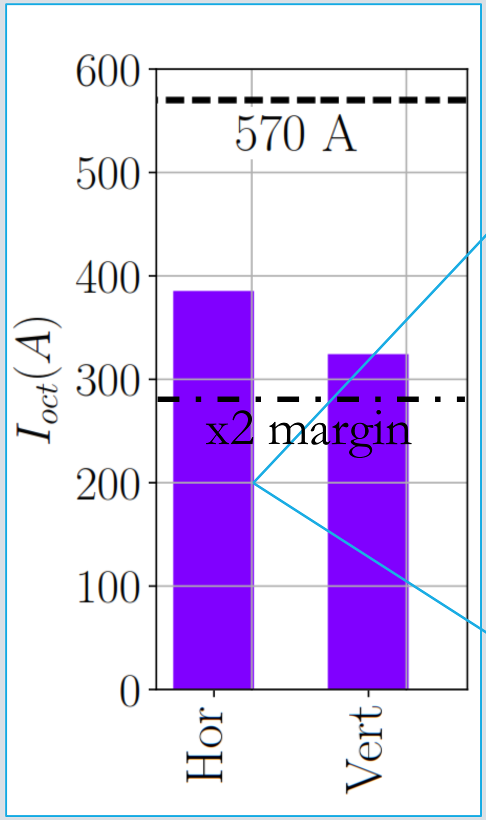
Energy, β^*	E = 7 TeV, β^* = 40 cm
Beam intensity	M = **2760**, N_b = **2.3×10^{11}** p
Beam emittance Bunch length	ε_n = **2.1** μm (injection) σ_z = 9.0 cm, rms, Gaussian
Damper, chroma	d = 100 turns, Q' = 10
Octupole SD	Negative polarity, no ATS Tails cut at 3 rms beam size
Collimator settings	Nominal (2.5 μm ref. ε): TCP – 6.7σ TCSG – 9.1σ

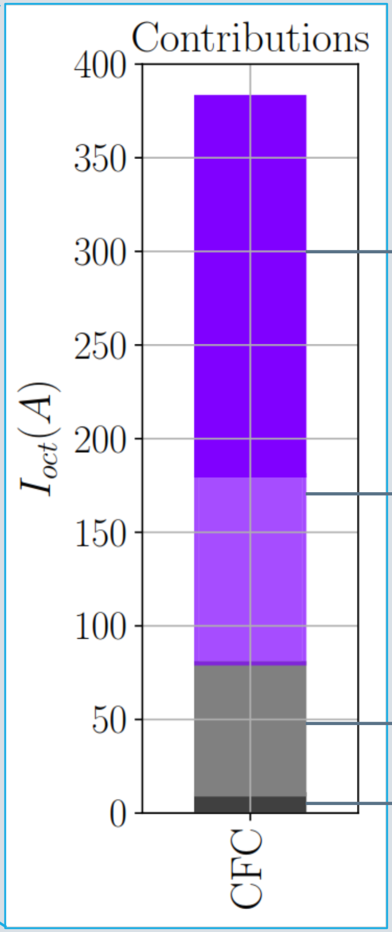
BCMS

Energy, β^*	E = 7 TeV, β^* = 40 cm
Beam intensity	M = **2648**, N_b = **2.3×10^{11}** p
Beam emittance Bunch length	ε_n = **1.7** μm (injection) σ_z = 9.0 cm, rms, Gaussian
Damper, chroma	d = 100 turns, Q' = 10
Octupole SD	Negative polarity, no ATS Tails cut at 3 rms beam size
Collimator settings	Nominal (2.5 μm ref. ε): TCP – 6.7σ TCSG – 9.1σ

Impedance of LHC collimators has to be reduced for the Hi-Lumi upgrade

Octupole current close to threshold





Dominant component is the collimator impedance

11 secondaries in IR-7 - 200 A

- To be upgraded
- 4 to be replaced during LS 2

4 primaries - 100 A

- To be upgraded*
- 2 to be replaced during LS 2

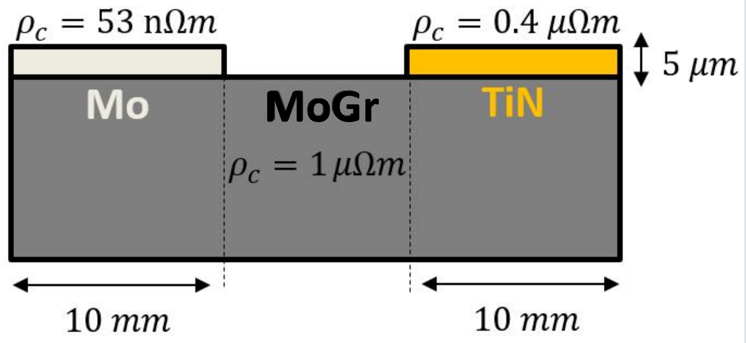
All other collimators - 70 A

Everything else - < 10 A

* 2 approved at the moment

Study of the low impedance collimator in LHC

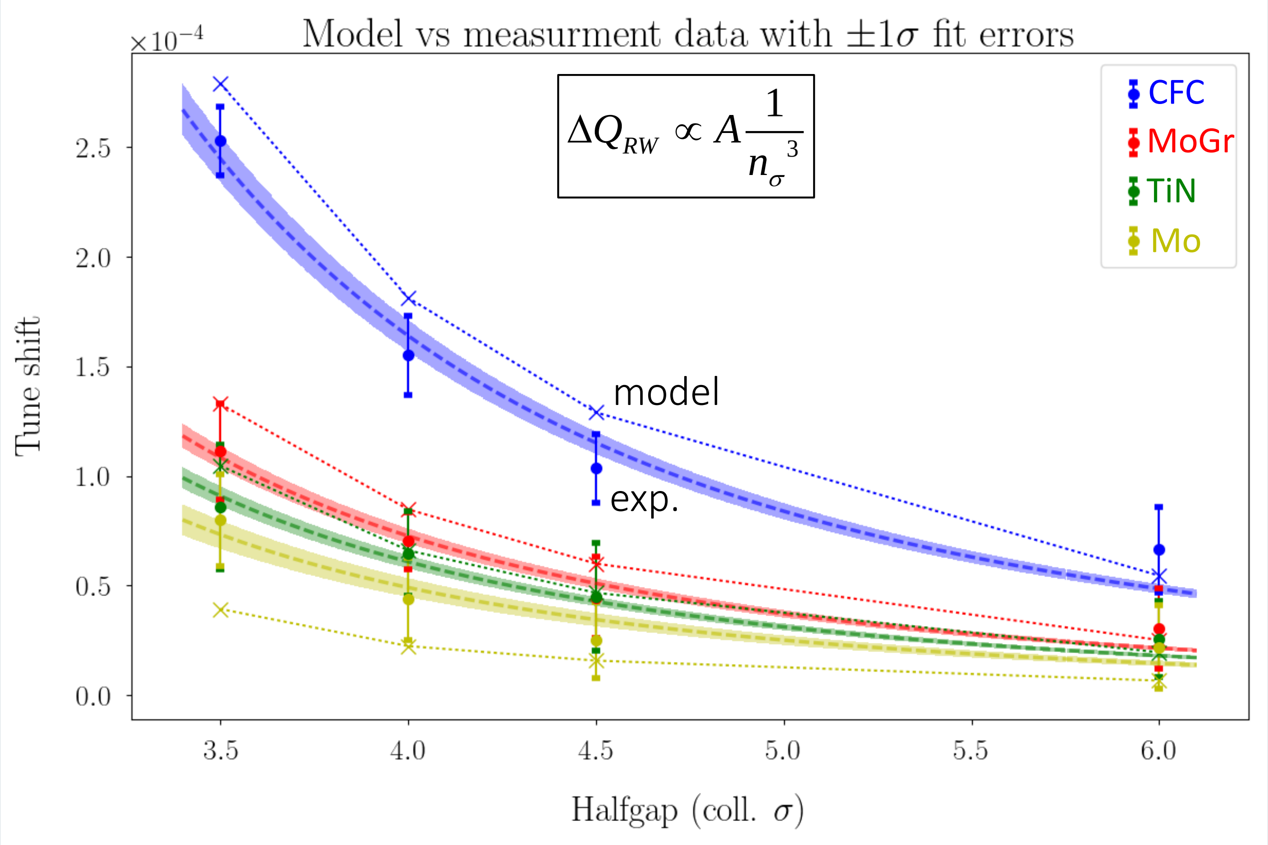
Currently, both primary and secondary collimators have CFC jaws (ρ_c = 5 μΩm)



Primary collimators:
- MoGr to replace CFC

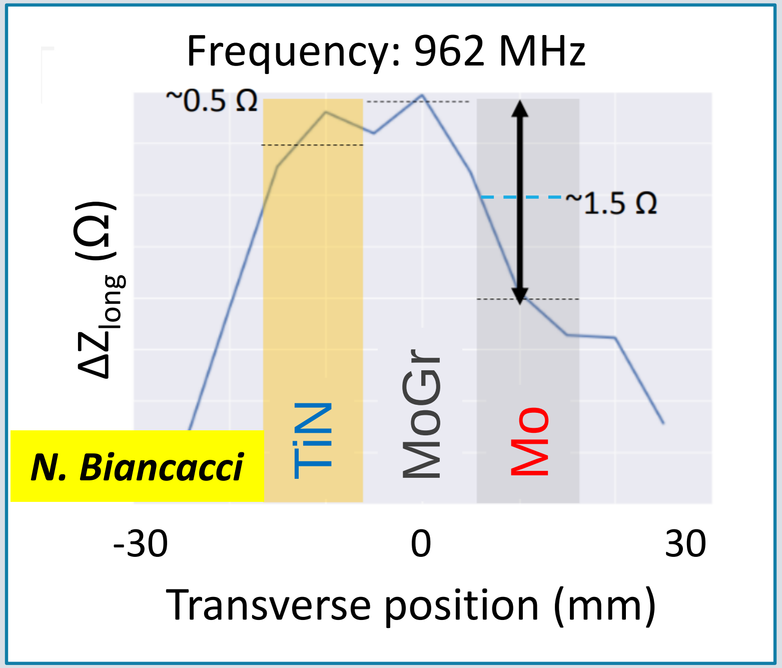
Secondary collimators:
- MoGr jaw
- Low-resistivity coating

The largest reduction of the resistive wall tune shift measured for Mo coating



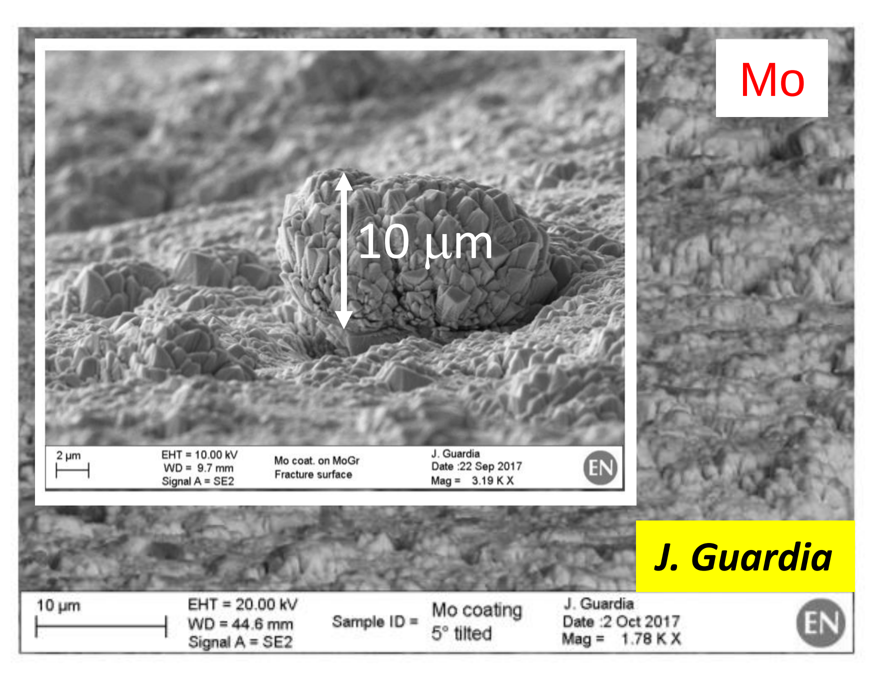
Possible source of discrepancy in Mo resistivity: Roughness of the Mo surface

Wire measurement is in agreement with the expectations



Suggesting the extra impedance is **purely inductive**

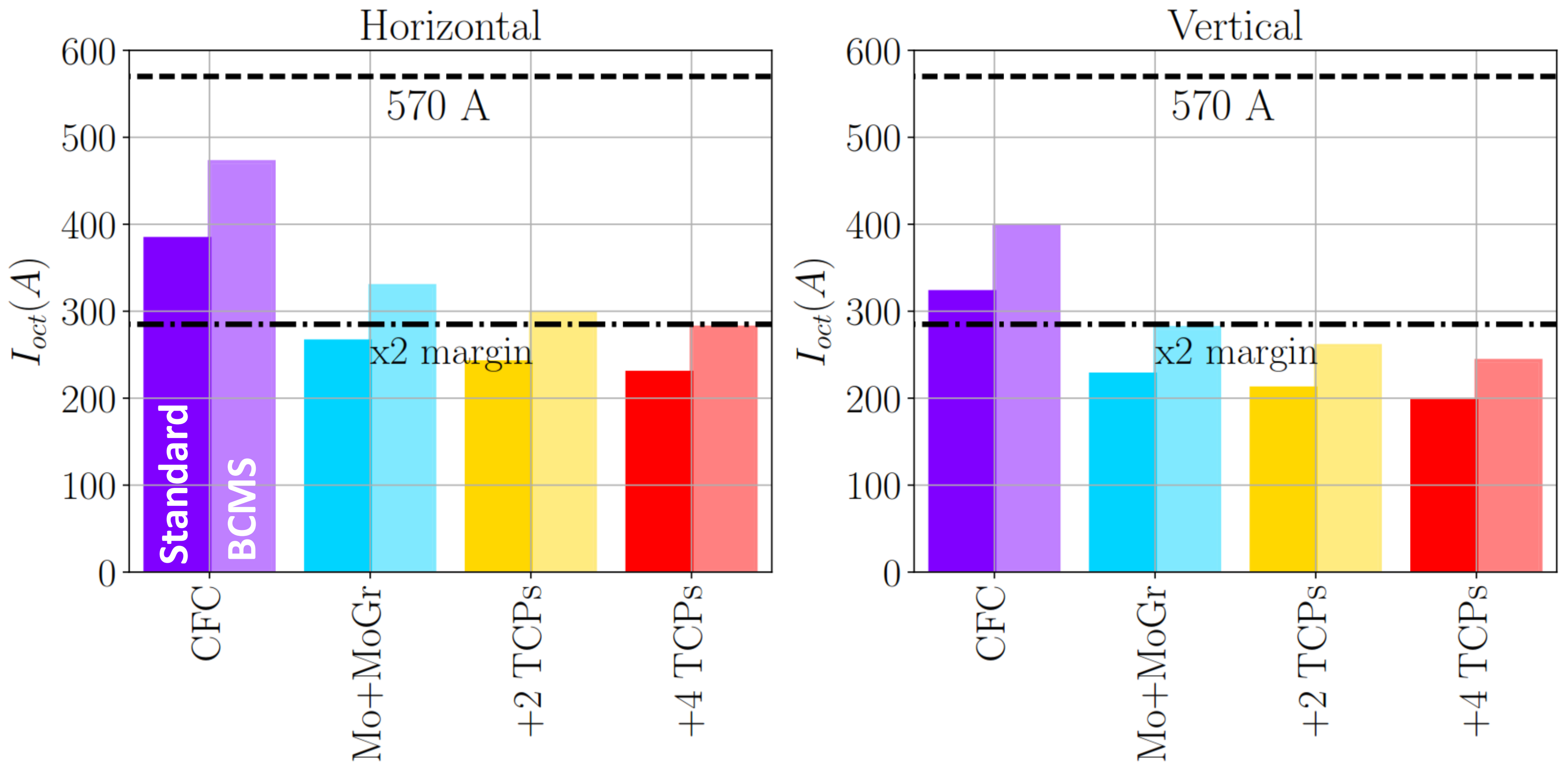
SEM image of the coating



Effect of surface roughness is being investigated:

- G. Mazzacano, N. Biancacci, *et al.*

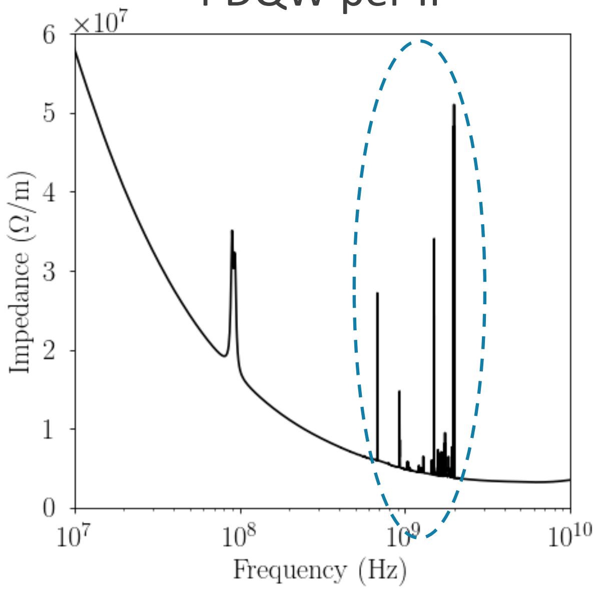
New coating decreases the octupole threshold by up to 150 A for the ultimate scenario



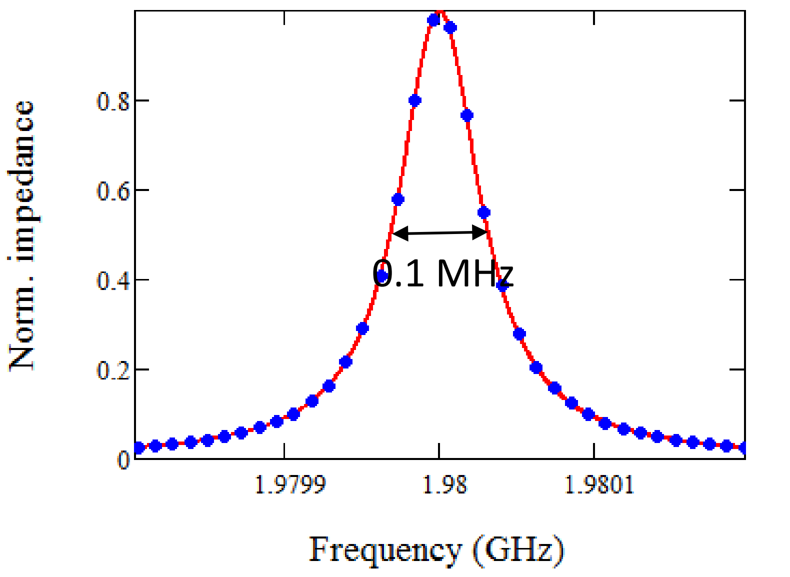
Beam stability: crab cavities

Crab HOMs dominate the impedance at the frequencies around 1 GHz

4 DQW per IP



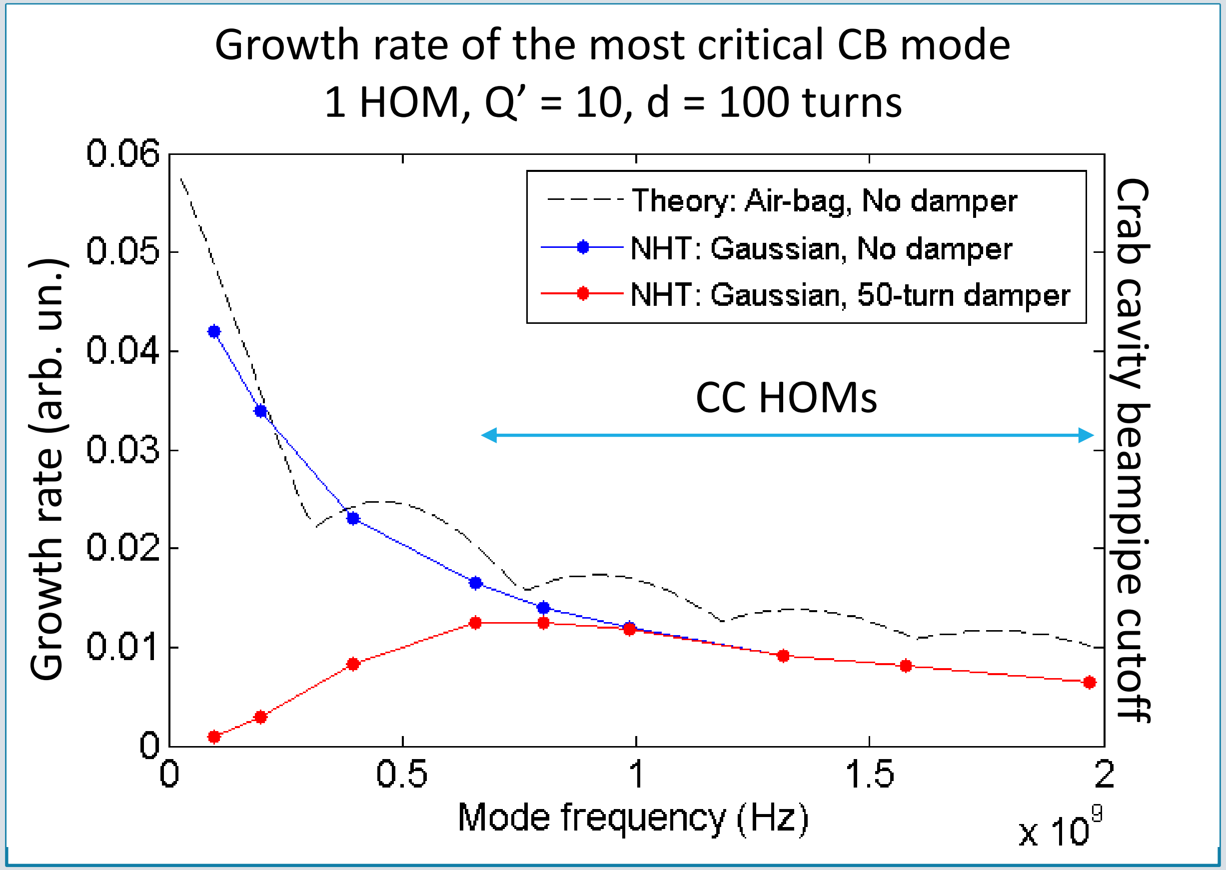
Can drive multiple coupled-bunch modes



It is important to keep the HOMs under control to ensure beam stability

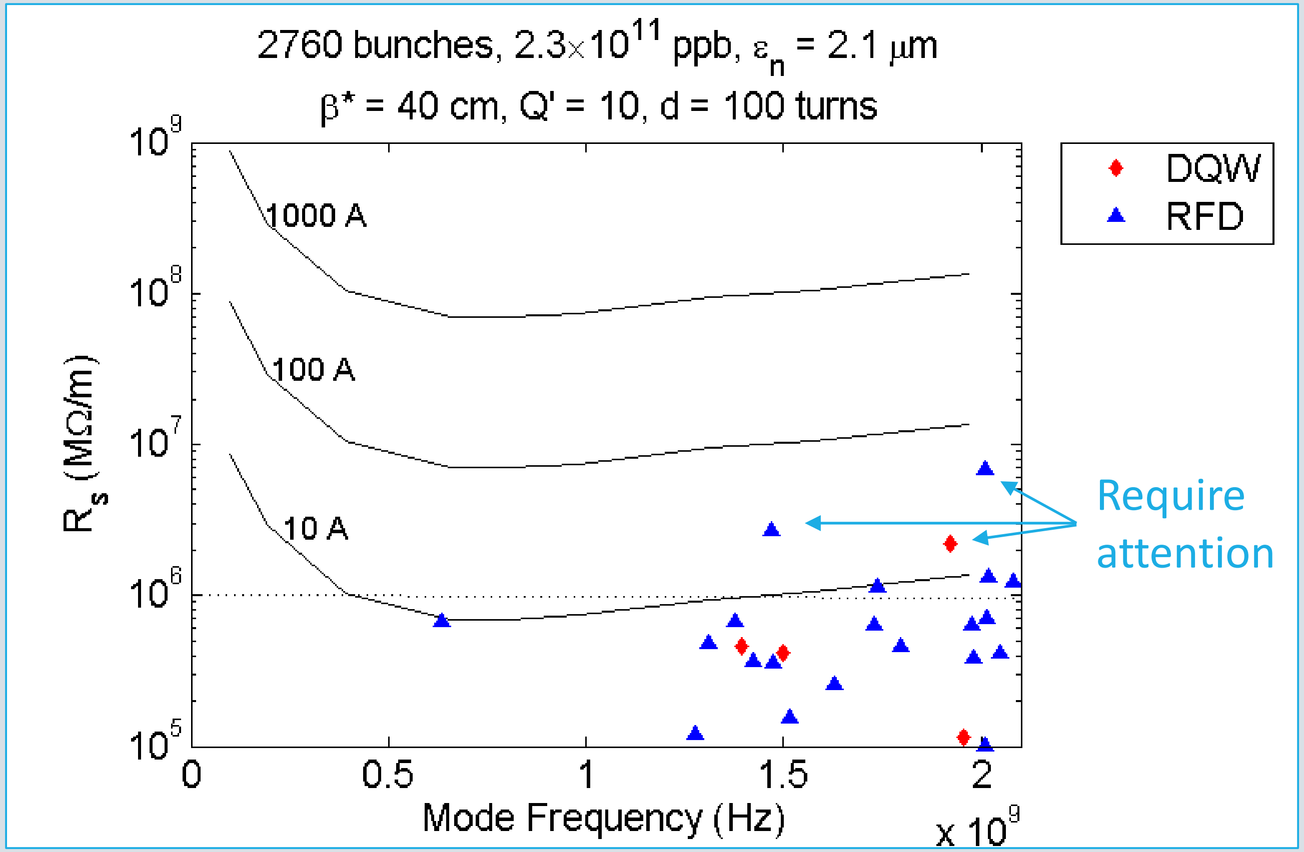
E. Metral, *et al.*, Beam intensity limitations, 4th Joint HiLumi LHC-LARP Annual Meeting, KEK, 2014
N. Biancacci, *et al.*, HL-LHC impedance and stability studies, HiLumi Workshop, FNAL, 2015

Transverse feedback is inefficient above 1 GHz



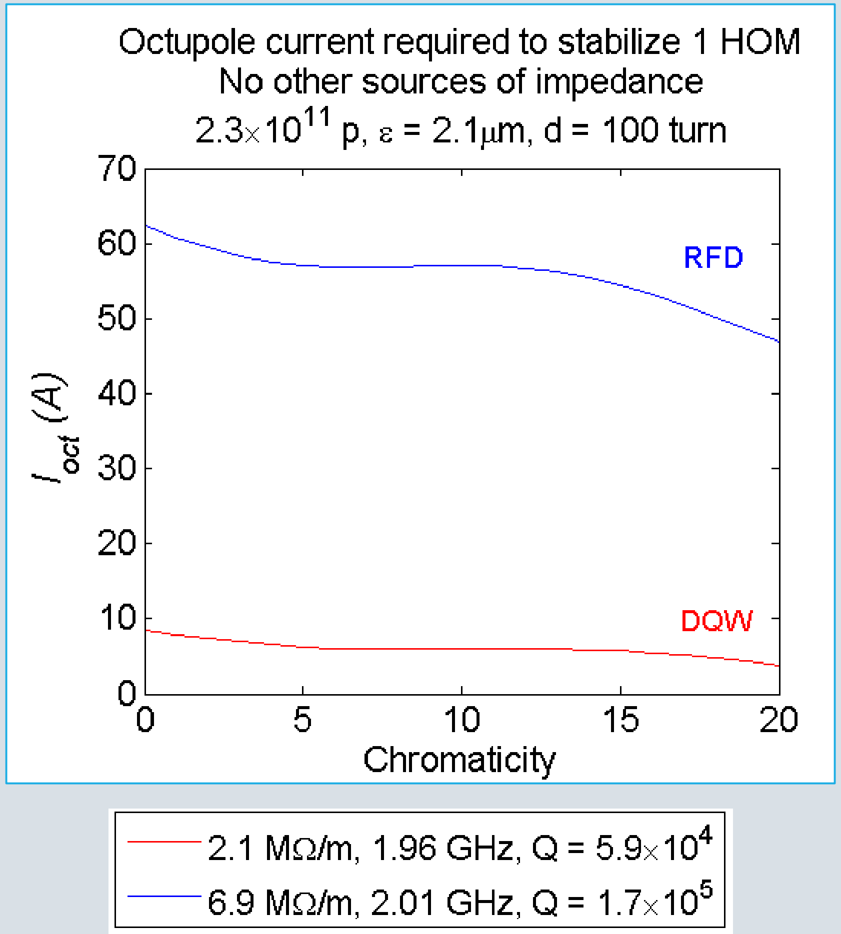
Most HOMs require negligible octupole current, even if they fall on the couple-bunch line

No other sources of impedance

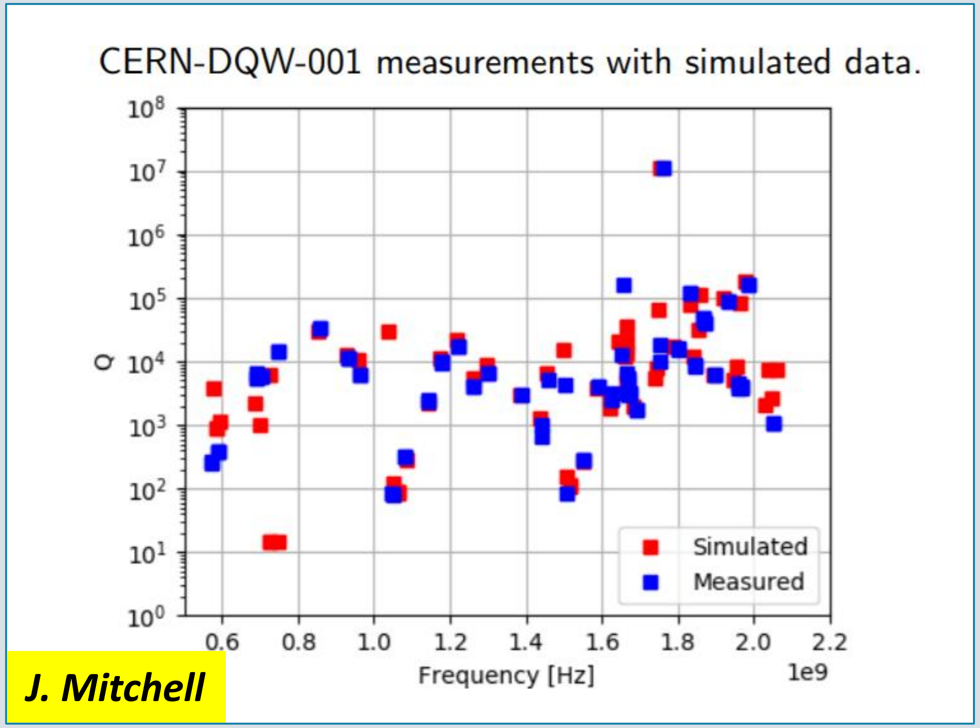


Require attention

10 A or more is needed to stabilize the most critical modes



The HOMs may have different frequencies and shunt impedance due to manufacturing uncertainties



Simulated and real modes might differ

Q can be higher by up to **x3**
- Also means higher R_s

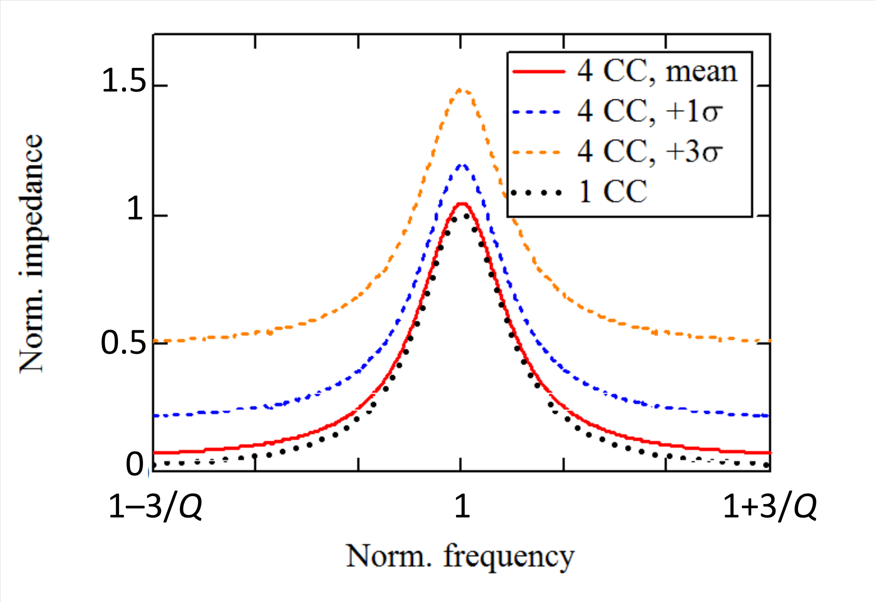
f can vary by up to 0.3%
- That is **±3 MHz** for a 1 GHz HOM

DQW HOM measurements: J. Mitchell, WP2/4 Wed. 14:30

The modes of different cavities are unlikely to overlap

Uncertainties of HOM frequencies are much larger than their width

Assuming an HOM of one cavity hits a couple-bunch line,
the mean expected increase of impedance at that frequency due to 3 other cavities is marginal

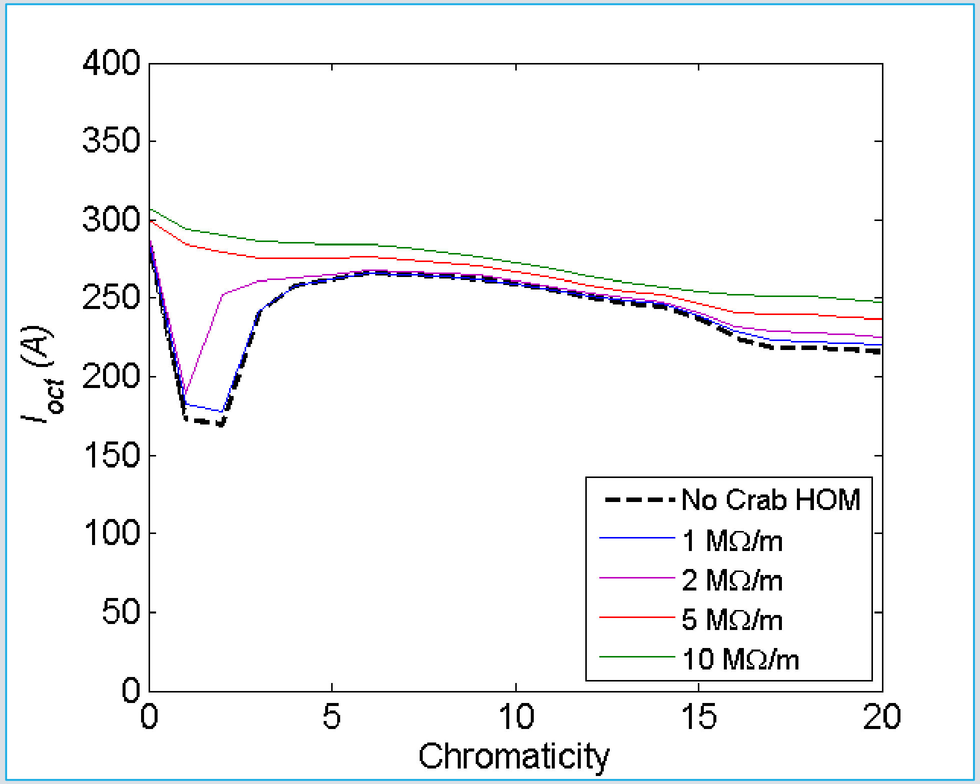


f = 1.92 GHz
Q = 59 000
$3\sigma_f$ = 4 MHz

In order not to affect the operational scenarios we need to keep the CC HOMs below 1 MΩ/m

Ultimate scenario

2760 b, 2.3x10^{11} ppb, β^* = 40 cm, ε_n = 2.1 μm



Crab cavity heat loads

Intersection of the mode line with the peak in beam spectrum leads to kW-scale power losses

The main mode is transverse, not longitudinal

- Many HOMs at low frequencies

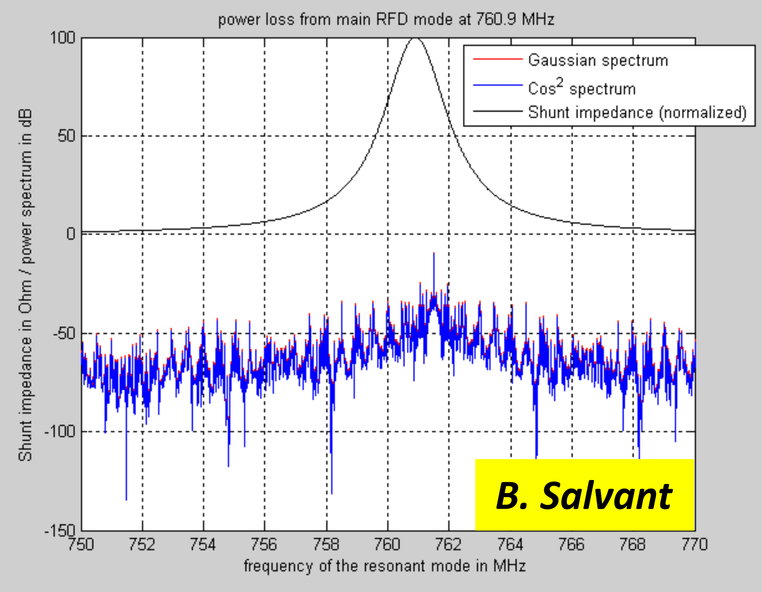
The crab cavities located in the places with high β

- Low Q of the HOMs is needed to ensure transverse stability

It is important to detune the modes from the beam power spectrum lines

- Avoid harmonics of 40.08 MHz for 25 ns beam

'Old' RFD design 761 MHz HOM overlapping with the beam spectrum

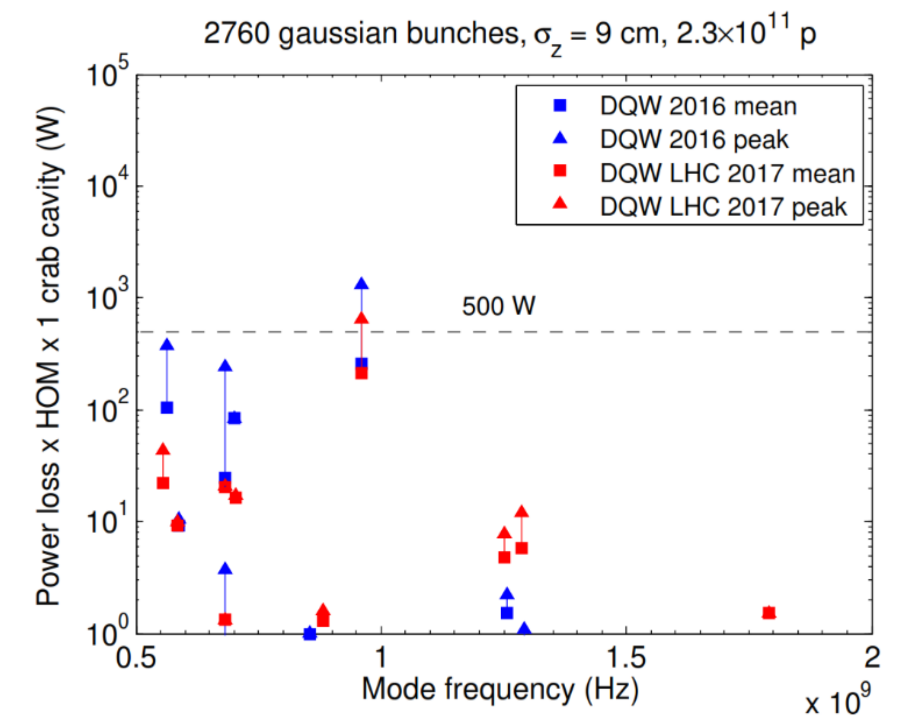


See also:

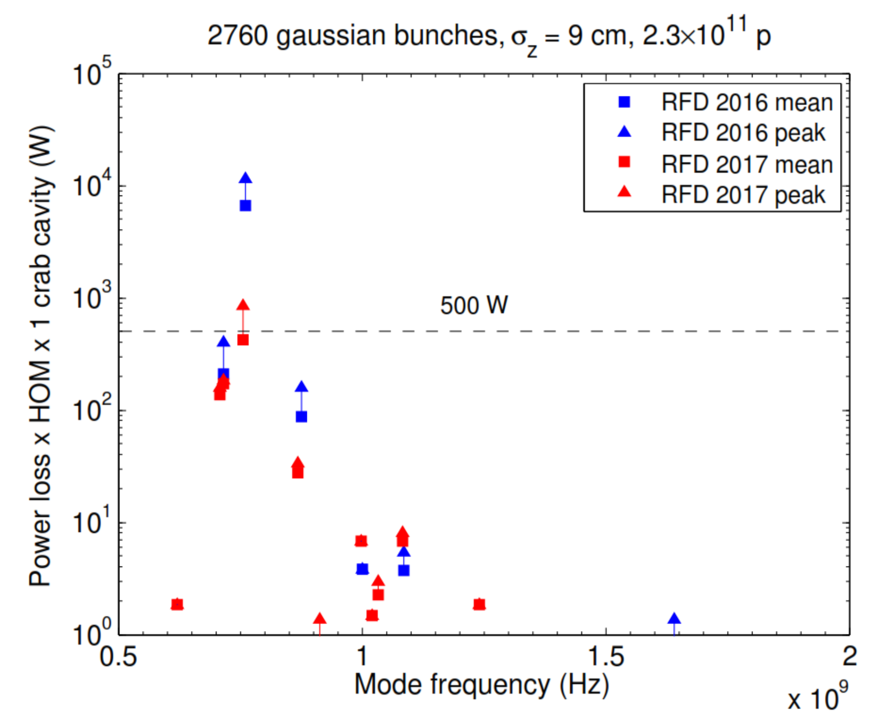
- N. Biancacci et al., Effect of tail cut and tail population on octupole stability threshold in the HL-LHC, CERN, 05.10.15
- E. Metral, Impedance update (other components than Crab Cavities), Joint LARP CM26/Hi-Lumi Meeting, SLAC, 19.05.16
- E. Metral et al., CC: Impedance status, International Review of the Crab Cavity Performance for Hi-Lumi, CERN, 05.04.17

Thanks to HOM optimization the expected power loss decreased for both designs

DQW

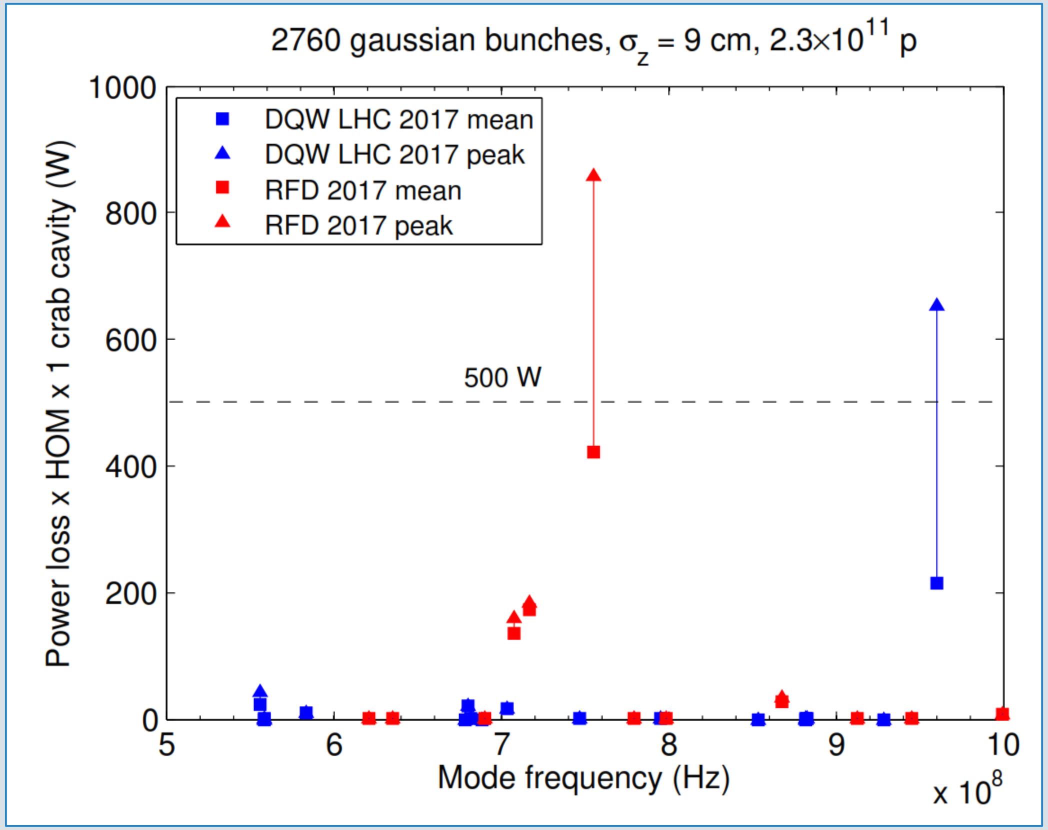


RFD



Peak values calculated assuming ±0.3% frequency uncertainty (based on CERN DQW test)

The most dangerous modes



DQW	RFD
960 MHz, Q = 580, 5.6 kΩ	755 MHz, Q = 420, 41 kΩ

Peak values calculated assuming ±0.3% frequency uncertainty (based on CERN DQW test)

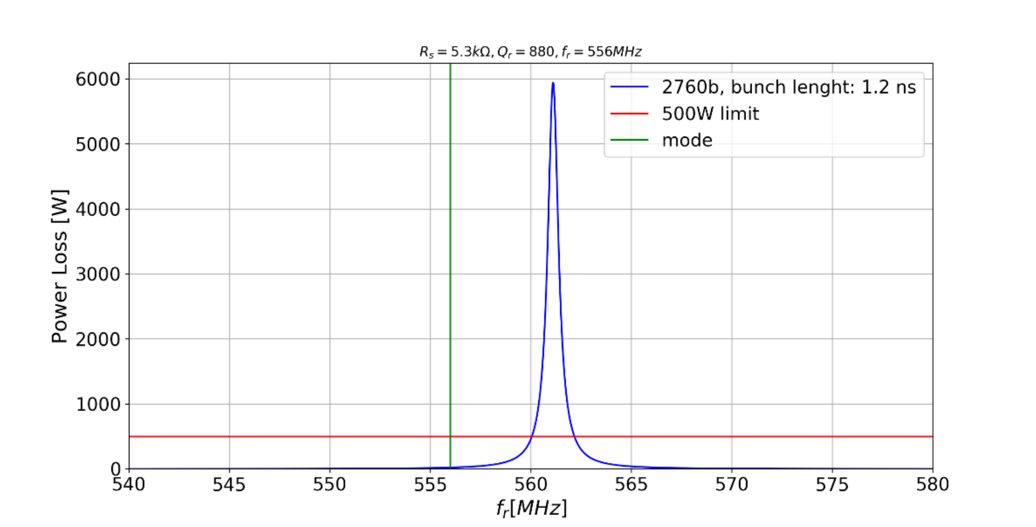
DQW design: the frequency of 960 MHz mode has to be controlled at 1 MHz level

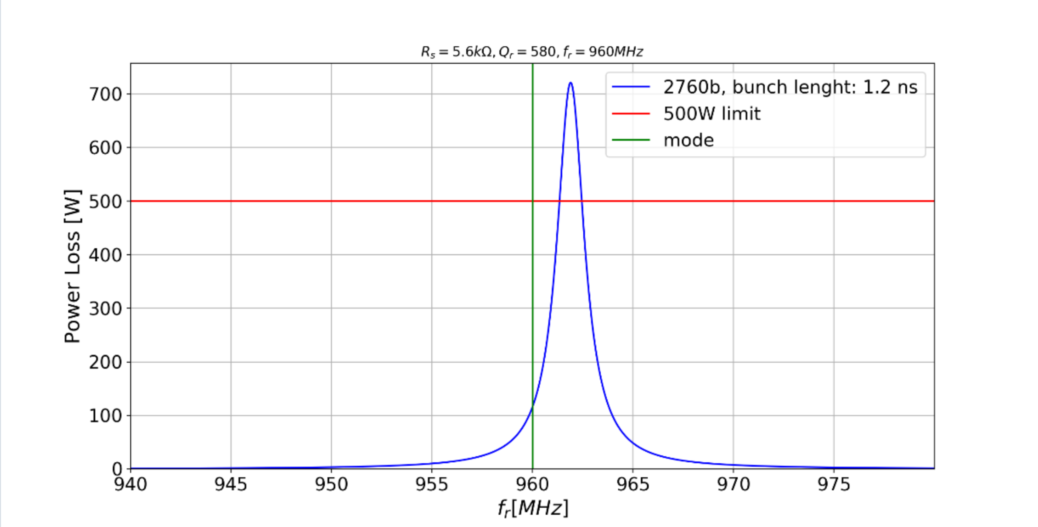
556 MHz mode

Sufficiently far away from the beam line

960 MHz mode

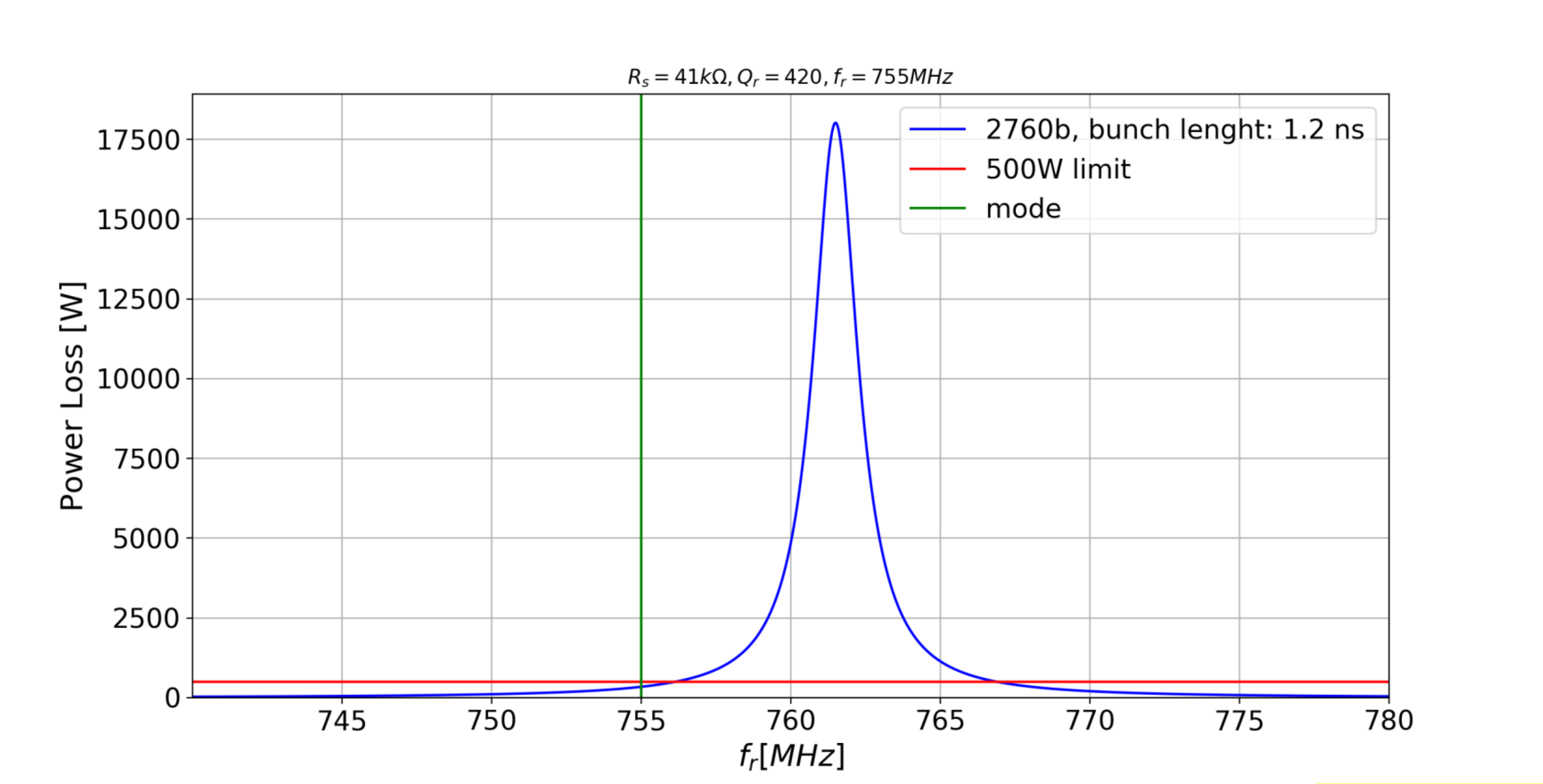
Very close. Need to control precisely





F. Giordano

RFD design: the uncertainty of the 755 MHz mode frequency not to exceed 1 MHz



F. Giordano

Summary

From the past operational experience, a x2 margin in octupole threshold is required

Mo coating on MoGr offers the largest reduction of impedance and octupole current in HL-LHC

- For the ultimate scenario one can gain over 100 A by coating all the secondaries in IR-7
- Additional 50 A can be gained by replacing the 4 primary collimators with MoGr
- Novel coatings provide sufficient stability margin both for standard and BCMS beams

Crab cavity HOMs might affect coupled-bunch stability

- Transverse feedback and chromaticity are inefficient at fighting high-frequency modes
- Transverse shunt impedance below 1 MΩ/m is required for the HOMs not to increase the octupole threshold significantly

If a high-impedance CC HOM is close to a beam spectrum line, it may lead to a high power loss

- Thanks to recent improvement, the nominal power loss is below 500 W threshold for both designs
- Need to control the frequencies of certain modes precisely – at 1 MHz level, or further detune the critical HOMs from the harmonics of 40.08 MHz

Thank you for your attention

BACK UP SLIDES

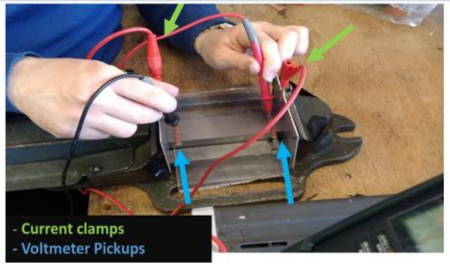
Octupole thresholds for different coating scenarios

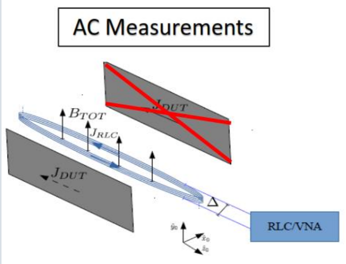
Coating / Op. Scenario		Ultimate Hor (Vert)	BCMS Hor (Vert)	Comment
Secondaries IR-7	Primaries			
CFC	CFC	385 A (320 A)	470 A (400 A)	"As is"
Mo+MoGr	CFC	265 A (230 A)	330 A (280 A)	Based on expected bulk conductivity of Mo
Mo+MoGr (Meas.)	CFC	285 A (240 A)	355 A (295 A)	Worst possible case for Mo coating
Mo+MoGr	2 in MoGr 2 in CFC	240 A (210 A)	300 A (260 A)	Upgrading the 2 TCPs, that are approved at the moment
Mo+MoGr	MoGr	230 A (195 A)	280 A (245 A)	
Partial coating of IR-7: Option 1	CFC	320 A (275 A)	395 A (340 A)	Picking the highest contributors in both planes
Partial coating of IR-7: Option 2	CFC	315 A (295 A)	390 A (365 A)	Avoiding the most exposed to steady losses
Partial coating of IR-7: Option 3	CFC	350 A (280 A)	435 A (350 A)	Avoiding hor. and vert. for protection reasons
Partial coating of IR-7: Option 4	CFC	320 A (275 A)	400 A (340 A)	Optimizing protection at the top energy

Summary of low-impedance collimator resistivity measurements

Material	Beam Meas. [nΩ-m]	Lab Meas. (AC) [nΩ-m]	IW2D Model [nΩ-m]	Lab Meas. (HF)
CFC	4030 ± 380	–	5000	–
MoGr	760 ± 60	800 – 1200	1000	Close to expected
TiN	340 ± 40	Not measurable	400	Close to expected
Mo	250 ± 50	20 – 100	50	Close to expected

A factor **5** higher resistivity than expected!

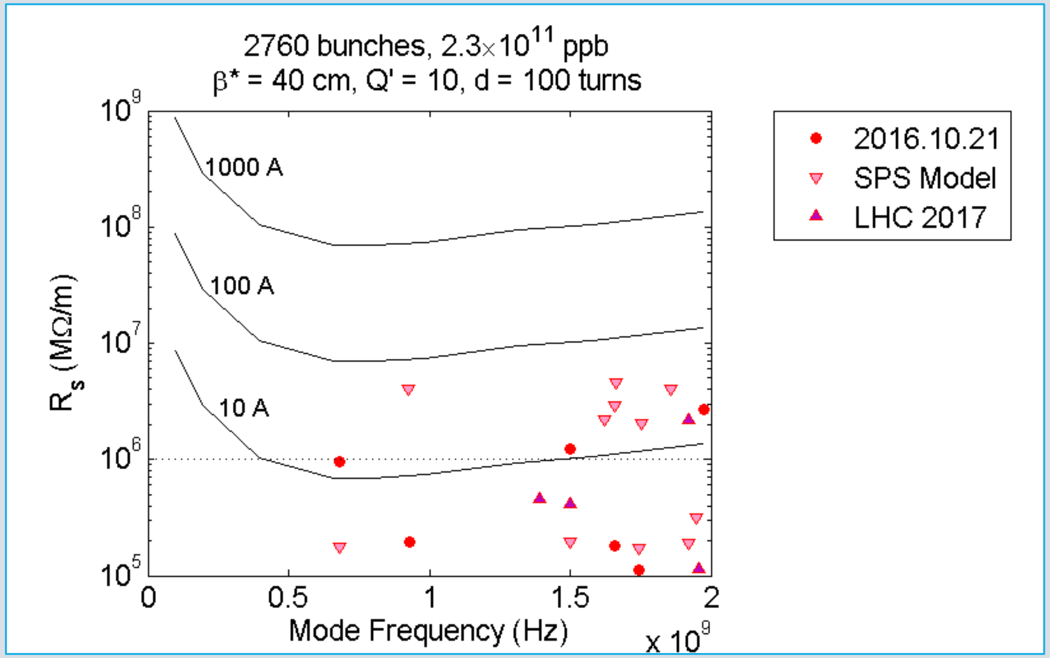




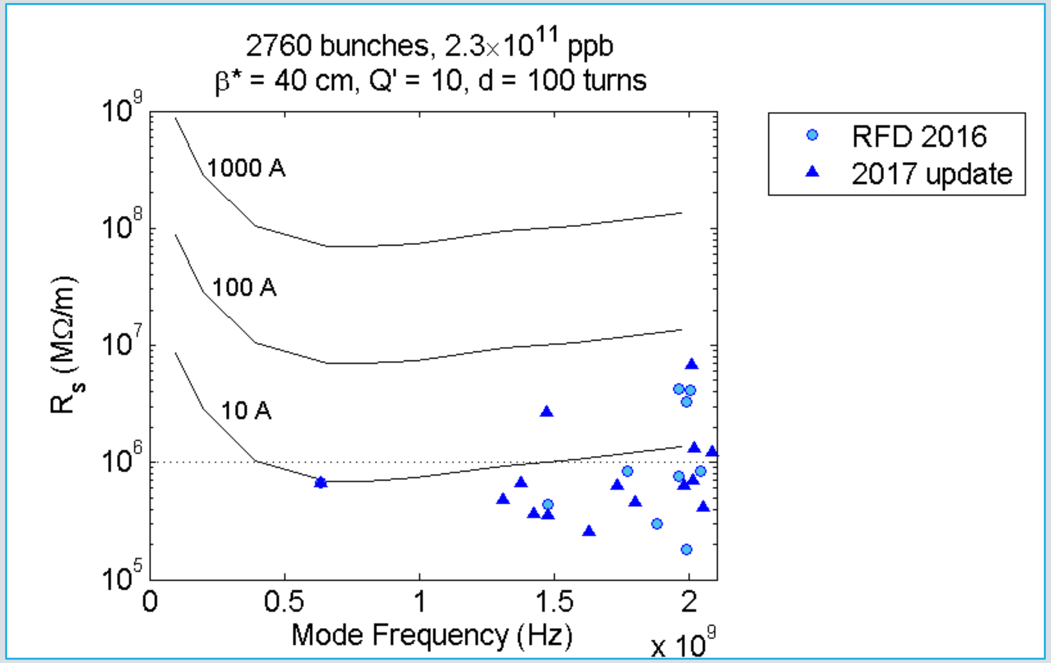
See also: G. Mazzacano's Master Thesis, La Sapienza, Rome, Oct. 2017

Changes in the CC HOMs: Beam stability

DQW

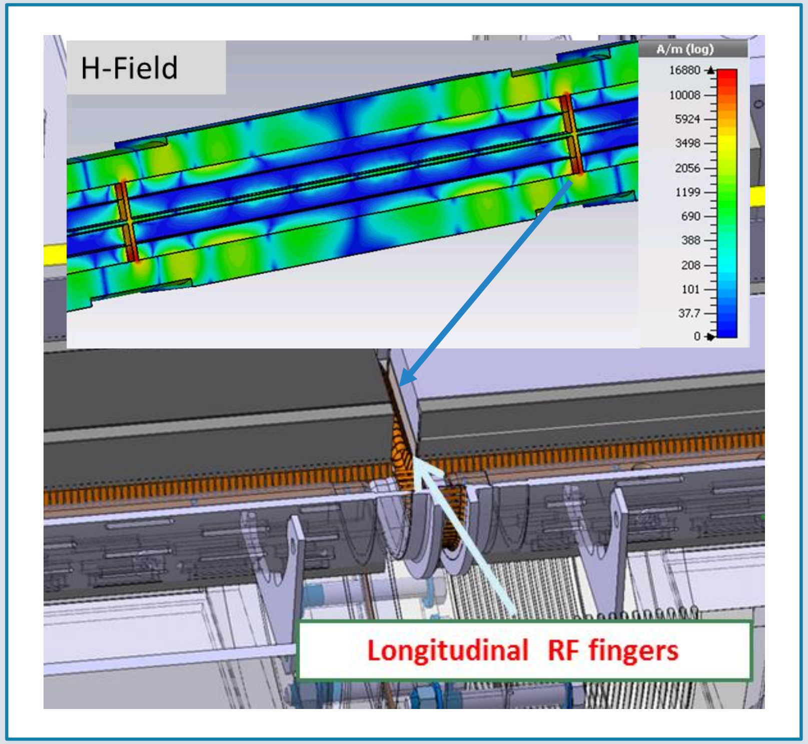


RFD

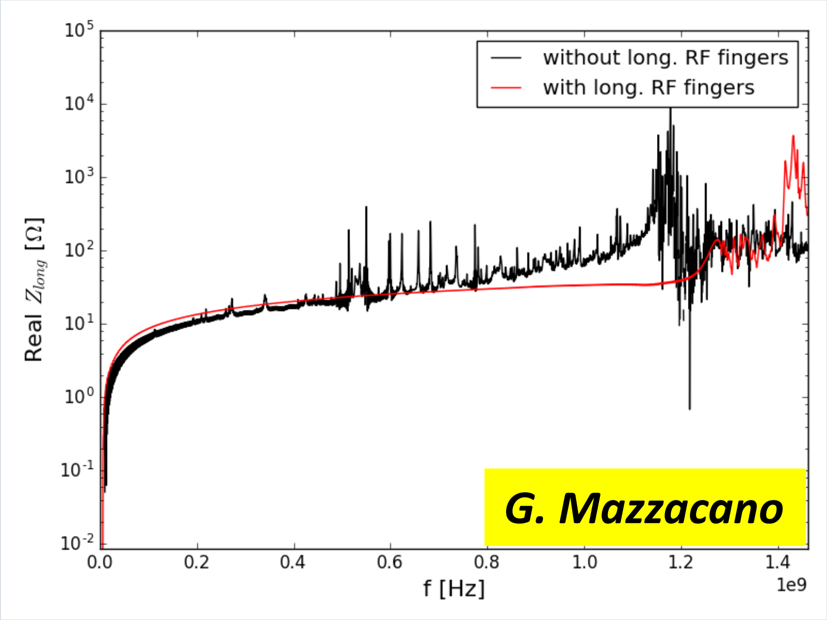


TDIS impedance studies: Removing longitudinal RF fingers may lead to significant power loss

TDI is one of the most important contributors to the LHC machine impedance at injection



Removal of longitudinal fingers produces a 'forest' of HOMs



Power loss up to **250 W** per mode