Impedance update (other components than Crab Cavities)

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Joint LARP CM26/Hi-Lumi Meeting, SLAC, 19/05/2016

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  - New devices in the triplet region: beam screen; BPMs; RF shielding for bellows; LESS (Laser treated surface to have SEY < 1) in IP2&8
  - Y chambers and TDI re-design
- Summary of new elements: transverse and longitudinal
- Predicted beam stability from HL-LHC impedance model
- Conclusion

Introduction

- Transverse instabilities are a concern based on the experience of the LHC Run 1 (2012 with 50 ns) and beginning of Run 2 (2015 with 25 ns)
- A precise (and well understood) impedance model is needed for the future upgrade
- HL-LHC impedance model was optimized until now mainly focusing on the contributions of
  - Low-impedance collimators
  - Crab Cavities

HiLumi HL-LHC PROJECT

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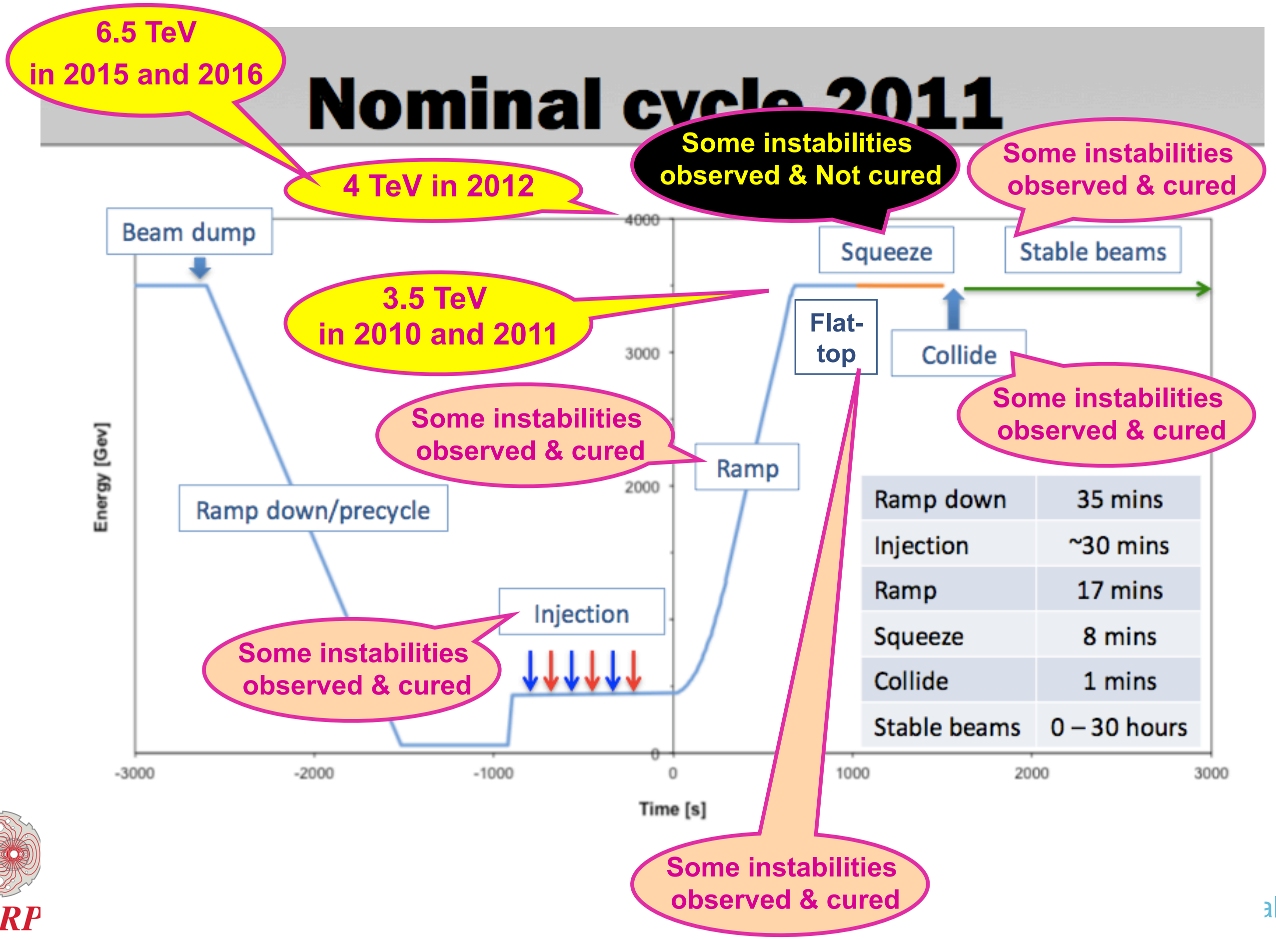
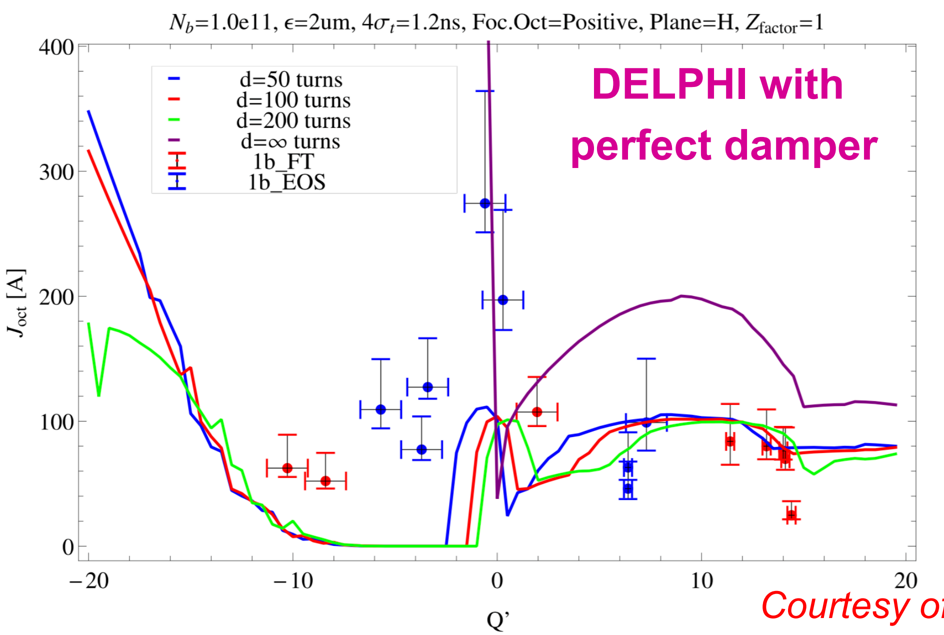
Introduction

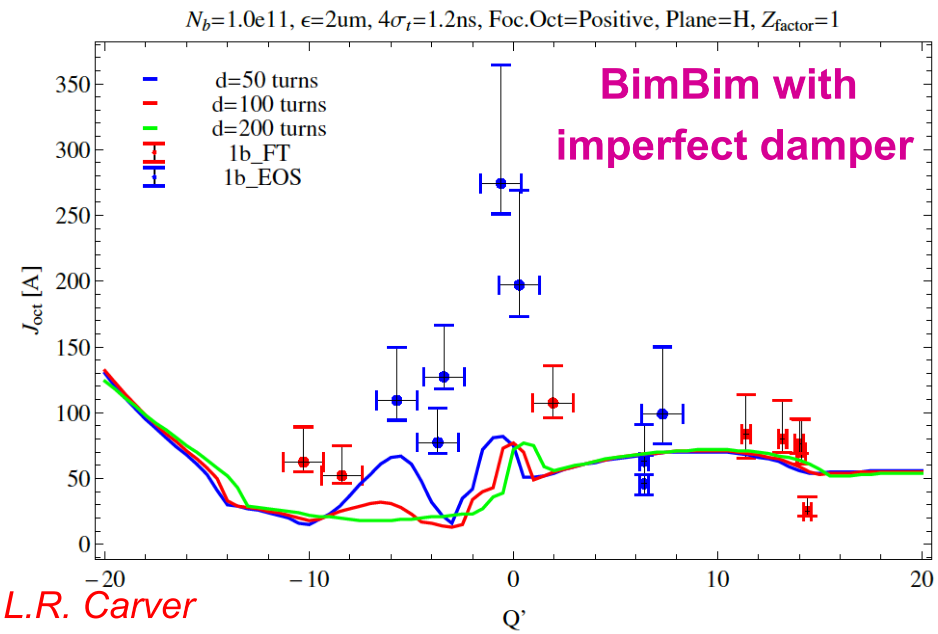


Ramp down	35 mins
Injection	~30 mins
Ramp	17 mins
Squeeze	8 mins
Collide	1 mins
Stable beams	0 – 30 hours

Reminder on beam stability from LHC impedance model

- Transverse impedance and related instabilities: 1 bunch (similar predictions in multi-bunch with ADT)

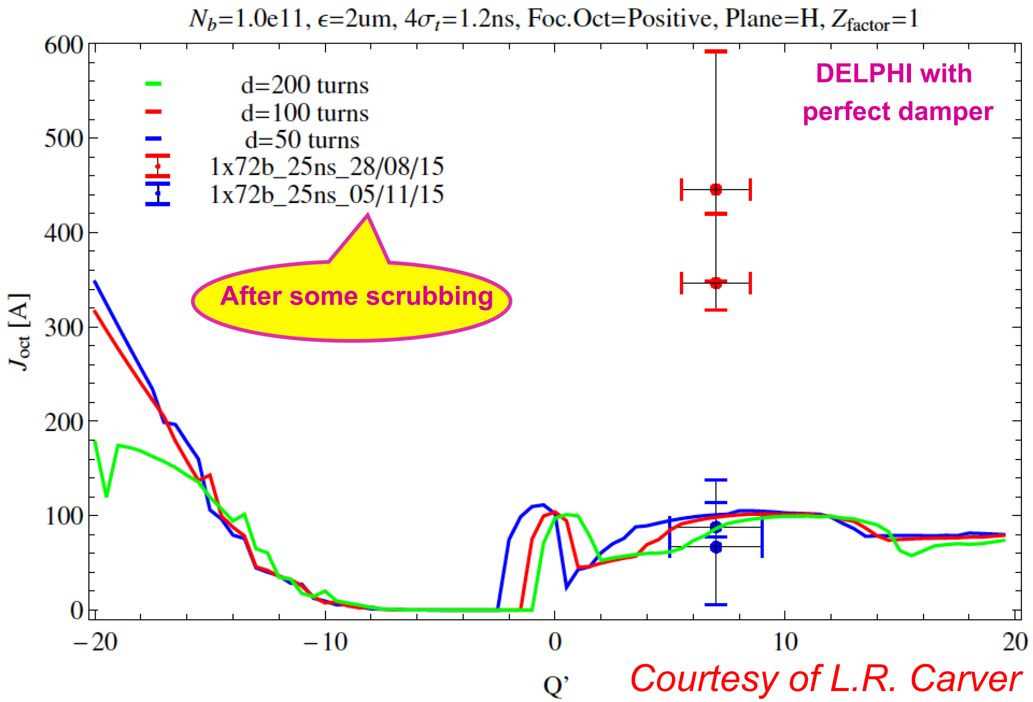




Courtesy of L.R. Carver

Reminder on beam stability from LHC impedance model

- Transverse impedance and related instabilities: 72b



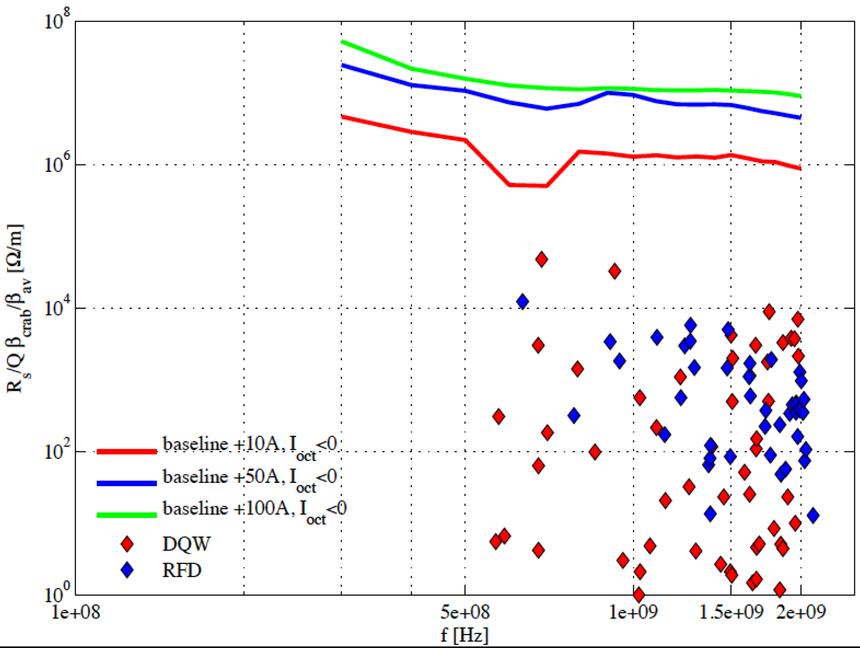
Courtesy of L.R. Carver

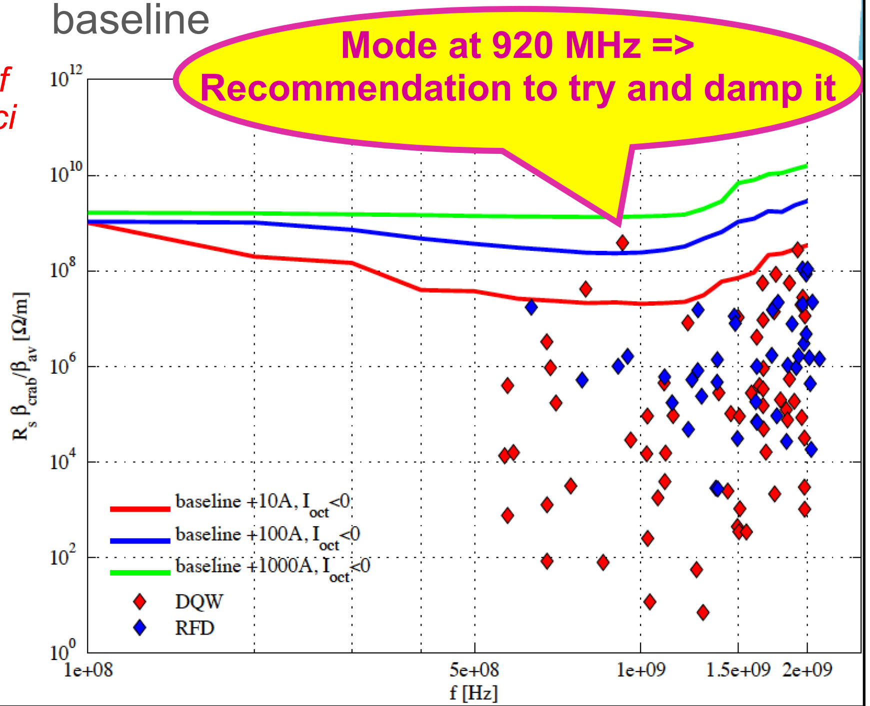
Reminder on the effect of Crab Cavities

- HOM of the DQW and RFD crab cavities and corresponding single bunch thresholds for the increase of octupole current over the machine baseline

- HOM of the DQW and RFD crab cavities and corresponding coupled bunch thresholds for the increase of octupole current over the machine baseline

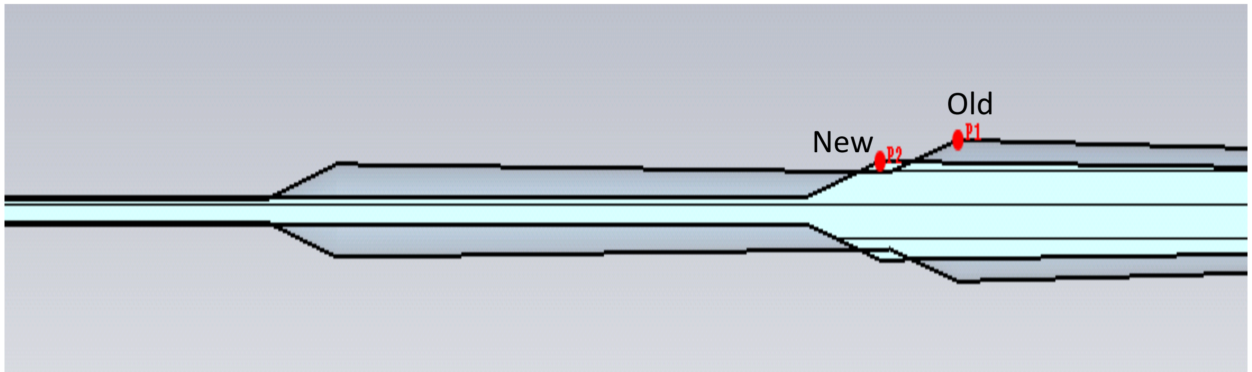
Courtesy of N. Biancacci





New CMS experimental beam pipe

- Main changes with respect Ats_note_2013_018 (from Rainer Wanzenberg) => Change of cone:
  - Reduction of maximum radius (~ 157 mm to ~ 110 mm)
  - Change of material from Stainless Steel to Aluminium



Picked Elements

P1(X,Y,Z)	0, 157.200000, -10528
P2(X,Y,Z)	0, 109.640189, -10854
P2 - P1	0, -47.559811, -326
|P2 - P1|	329.450961

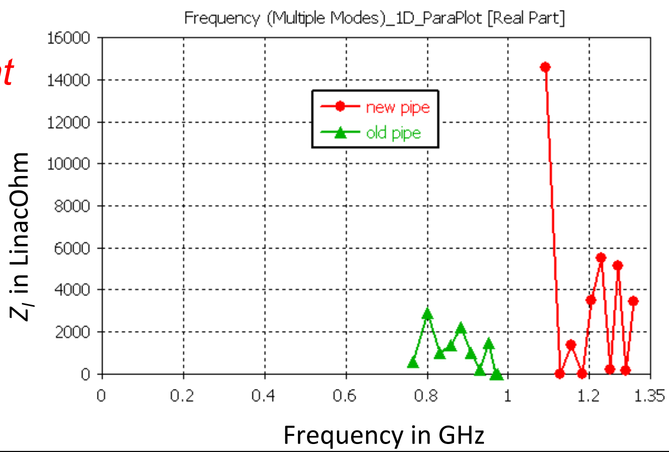
(in mm)

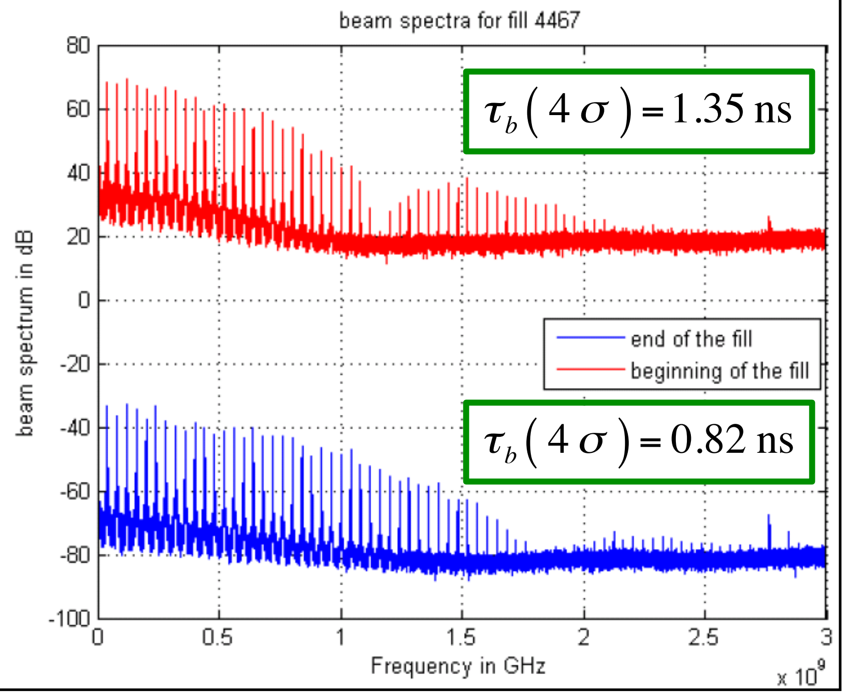
Courtesy of B. Salvant

New CMS experimental beam pipe

- Very significant reduction at the beginning of the fill (where it matters the most)
- The factor 5 increase due to the better conductor should not make things worse
- Impact of NEG coating?
  (skin depth at 1 GHz: 15 μm)

Courtesy of B. Salvant





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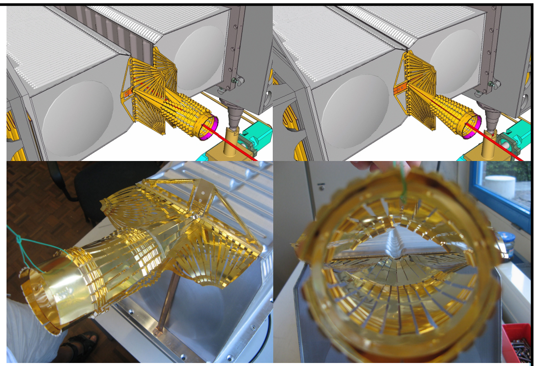
New LHCb VELO

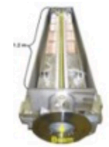


- Several meetings with LHCb
  - Feb 2015 (https://indico.cern.ch/event/367805/)
  - Nov 2015 (https://indico.cern.ch/event/366422/)
- New design and foils closer to the beam (3.5 mm instead of 5 mm in collision)
- Resistive and geometric contributions studied
- Transverse impedance effects reduced thanks to low β at collision point
- Main contribution is the longitudinal geometric impedance (~ 5% of LHC when inserted)
- Power loss of several 10s of W need to be extracted
- Design of RF foil studied, not the wakefield suppressor

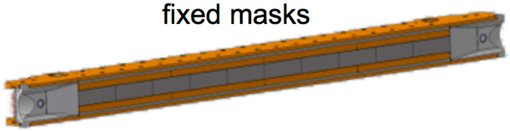
Collimator changes

- New TCLD: collimator inside the 11 T dipole (prototype in production and call for tender for production)
  - 2 H per beam in IR7 with small gaps (1.2 to 1.4 mm) due to small β functions (30 to 45 m in H)
  - Similar jaw design with RF fingers, optimized tapering between BPM and active surface and wider box
- New collimators TCTH6 and TCTV6: 4 per beam
- TCLX would replace TCL4: 2 per beam (exit)
  - Proposed to use design with 2 beams in 1 tank (similar to the MKI, not to the TDI or TCTVB)
  - Large half-gap (17 mm) and high β functions (4 to 6 km)
- TCTPH4 would need more clearance: 2 per beam (exit)
  - Proposed to use design with 2 beams in 1 tank (similar to the MKI, not to the TDI or TCTVB)
  - Large half-gap (12 to 15 mm) and high β functions (4 to 7 km)
- Resistive contribution already included in the computations (they all appear already in our list of collimators - collgaps files)
- 3D simulations of the geometric impedance to be done to confirm the efficient shielding for the wider boxes

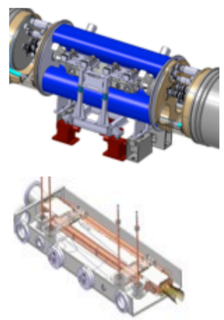
Baseline upgrades



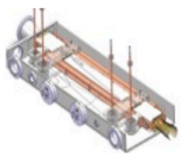
Completely new layouts
Novel materials: TCTs in CuCD
IR1+IR5, per beam:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

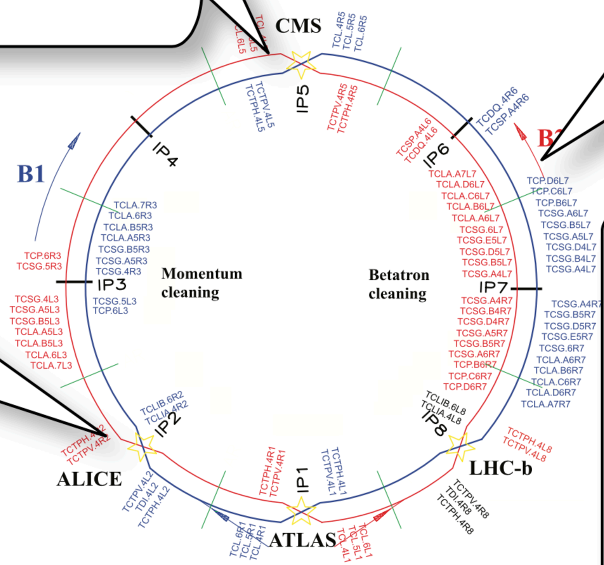


Cleaning: DS coll. + 11T dipoles, 2 units per beam

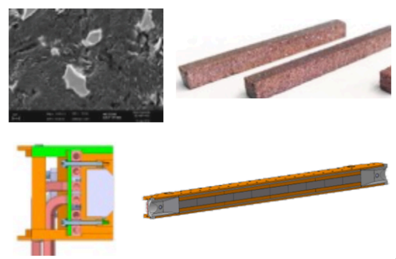


Ion physics debris: DS collimation



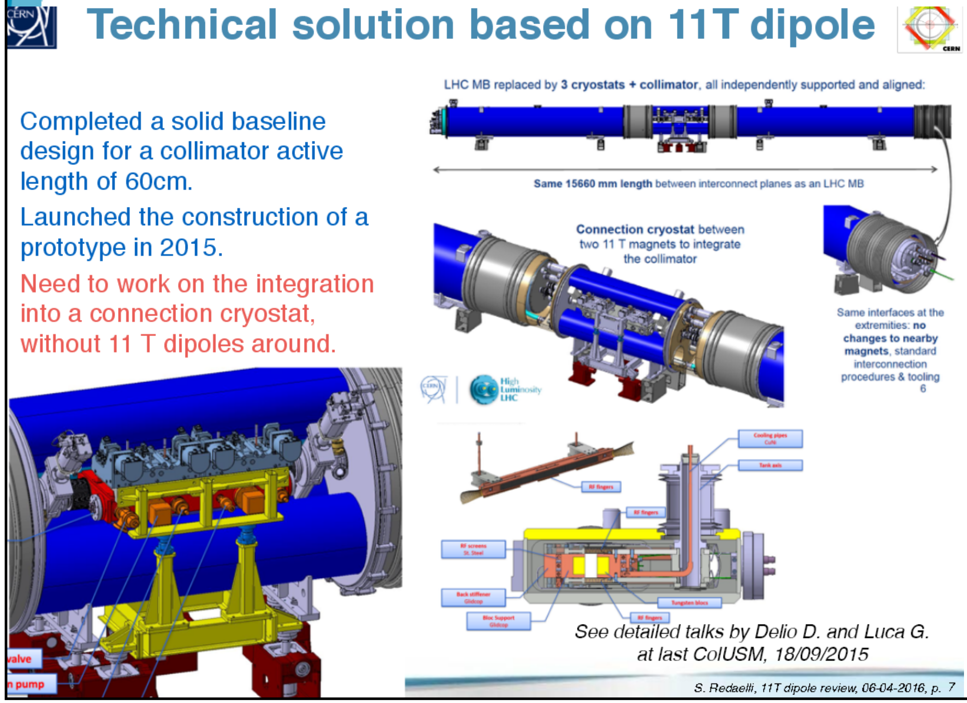


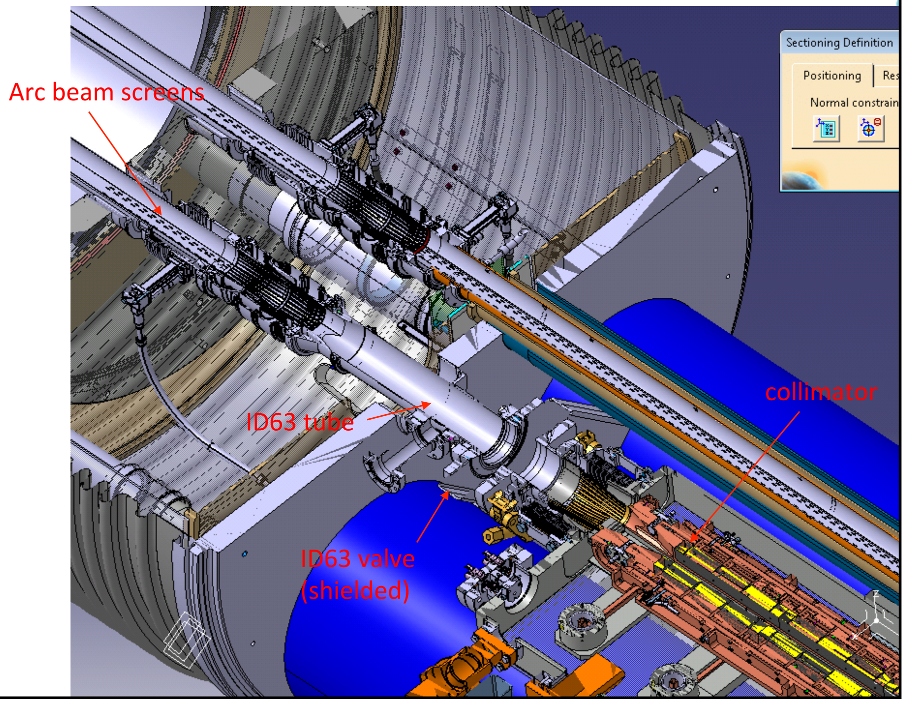
Low-impedance, high robustness secondary collimators: Mo coated MoGr



Collimator changes: 11 T dipole

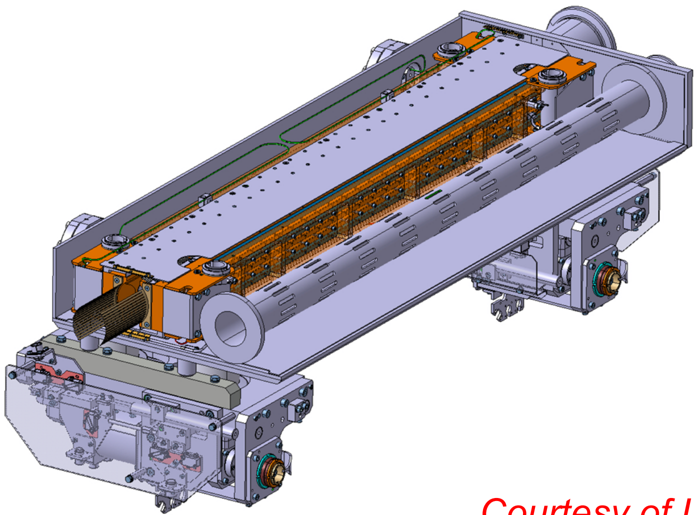
- Several checks on-going (operating length, angle for the RF fingers, heat load could be critical due to the cold transition, etc.) + impedance measurements to verify the shielding, but no critical issues expected

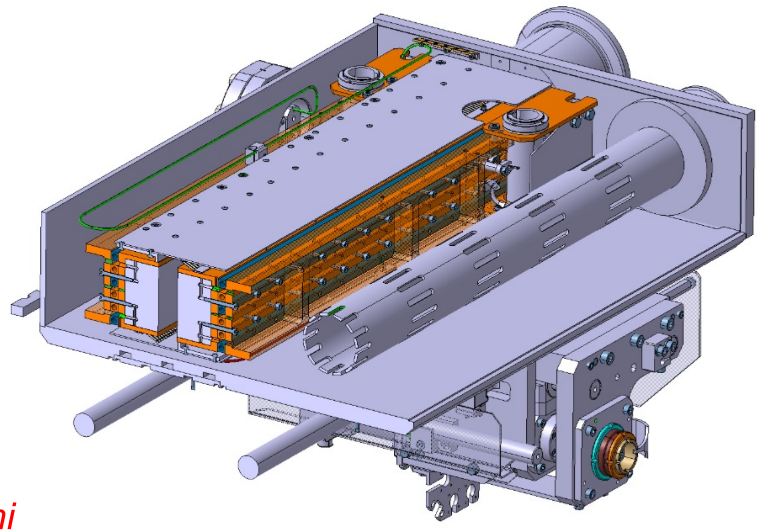




Collimator changes: TCLX and TCTPH4

- Very different from previous 2-in-1 collimator designs (TDI, TCTVB)
- Should optimize the holes’ size and distribution in the beam screen counter rotating beam

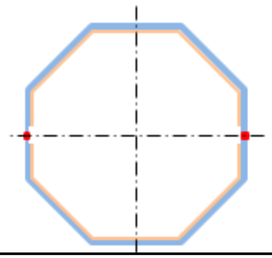


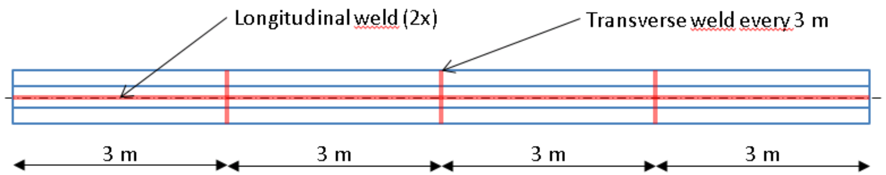


Courtesy of L. Gentini

New devices in the triplet region: Octagonal carbon coated beam screen with 2 welds

- Checked the impacts of
  - Carbon coating in octagonal beam screen of triplets, CP, D1, DFBX, D2 and Q4 in IP1/IP5
  - Carbon coating in current triplets, CP, D1, DFBX, D2 and Q4, Q5 and Q6 in IP2/IP8
  - Transverse weld
  - Longitudinal weld (width, position and number)





New devices in the triplet region: Octagonal carbon coated beam screen with 2 welds

Magnet	Cold bore ID (mm)	Beam screen ID between flats (mm)	Beam screen length (m)
Q1	139	99.7/99.7	11
Q2a	139	119.7/111.7	10.2
Q2b	139	119.7/111.7	10.2
Q3	139	119.7/111.7	11
CP	139	119.7/111.7	7.3
D1	139	119.7/111.7	8.3
DFXJ	139	119.7/111.7	3.7
D2	95	87/78	13.5
Q4	80.8	73.8/63.8	9.5

Info from N. Kos

New devices in the triplet region: Octagonal carbon coated beam screen with 2 welds

- Summary
  - Impact remains small: ~ 0.1% of full LHC impedance per IP in both longitudinal and transverse for the coating (less in transverse for IP8)
  - Negligible effect from transverse weld
  - Longitudinal weld
    - Increase of an order of 50% to a factor 2 of real and imaginary longitudinal impedance (50% to factor 3 for transverse)
    - Increase can be reduced by 30 to 40% if the weld is displaced away from the center

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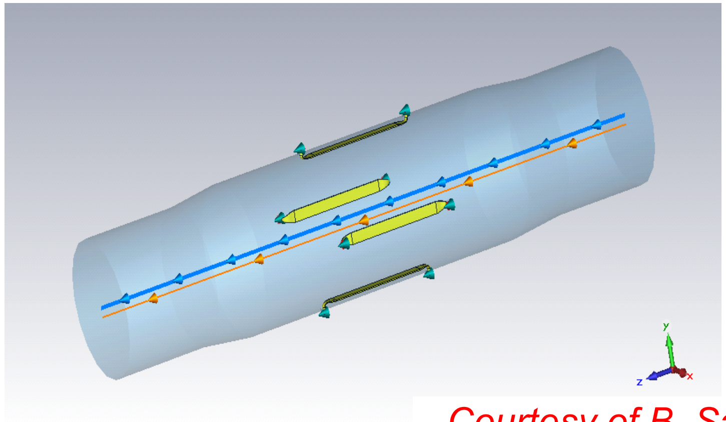
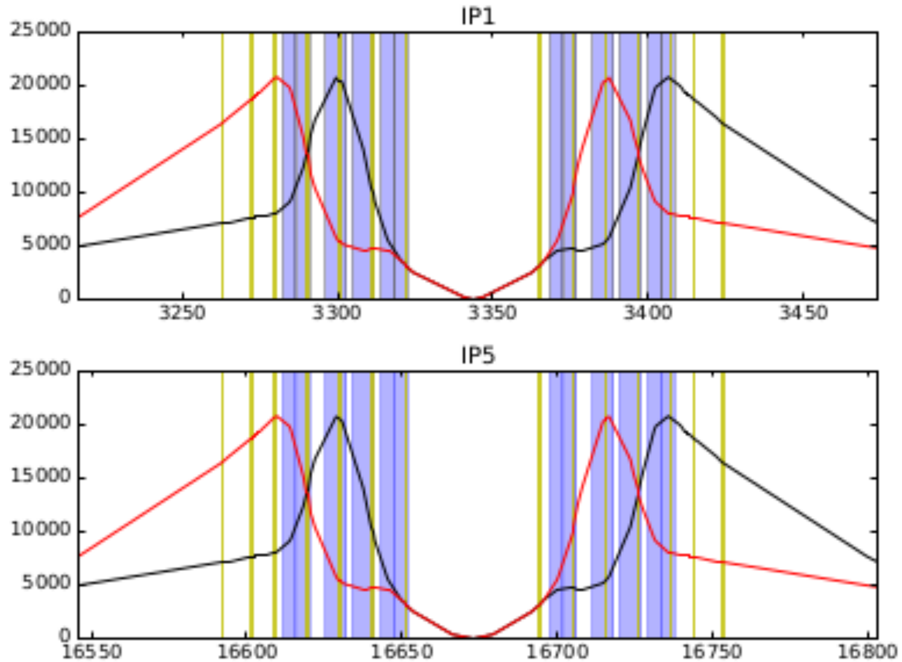
New devices in the triplet region: Stripline BPMs => BPMQS

- Foreseen 28 new stripline BPMs in IP1 and IP5 => < 1% increase in imaginary L and T impedances



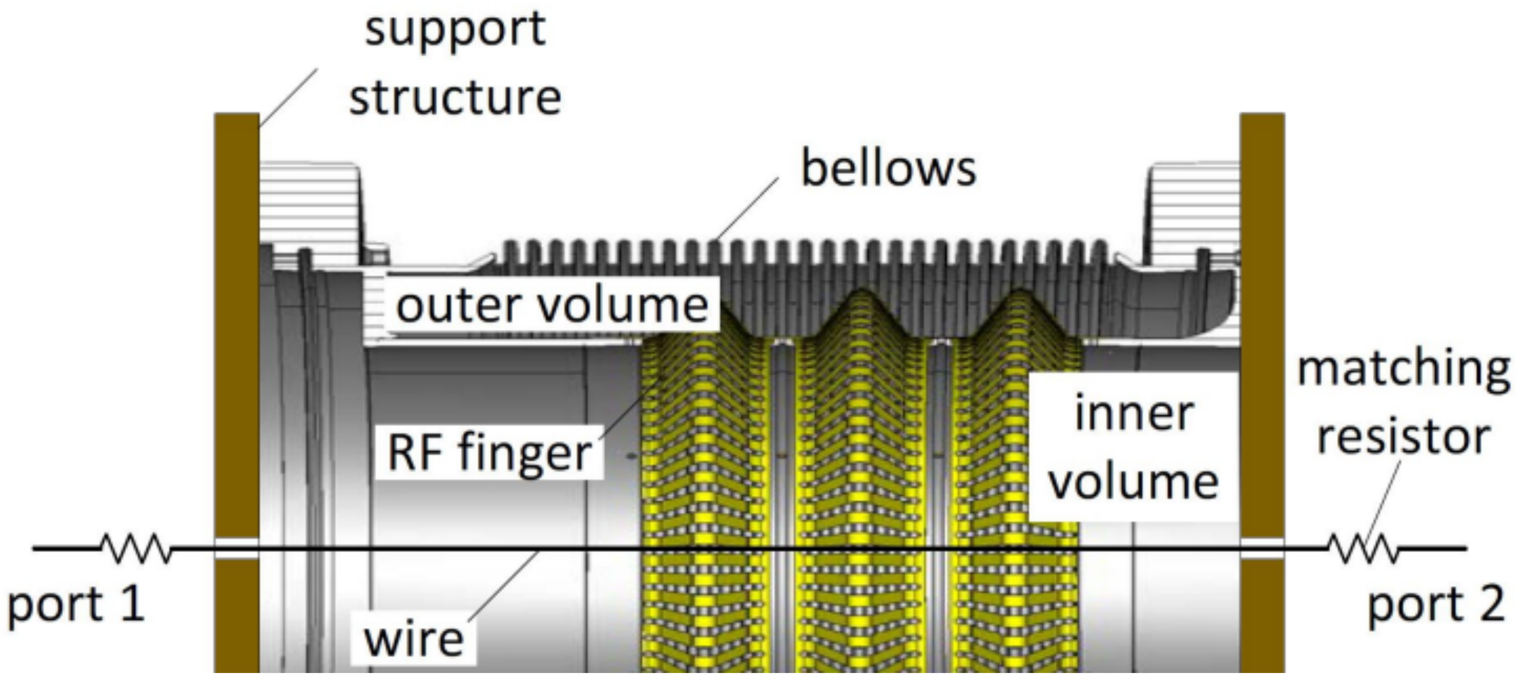
Courtesy of B. Salvant

- L strip =120 mm
- W strip =20 mm
- Radius = 61.9 mm
- No tungsten absorbers anymore



New devices in the triplet region: RF shielding for the bellows

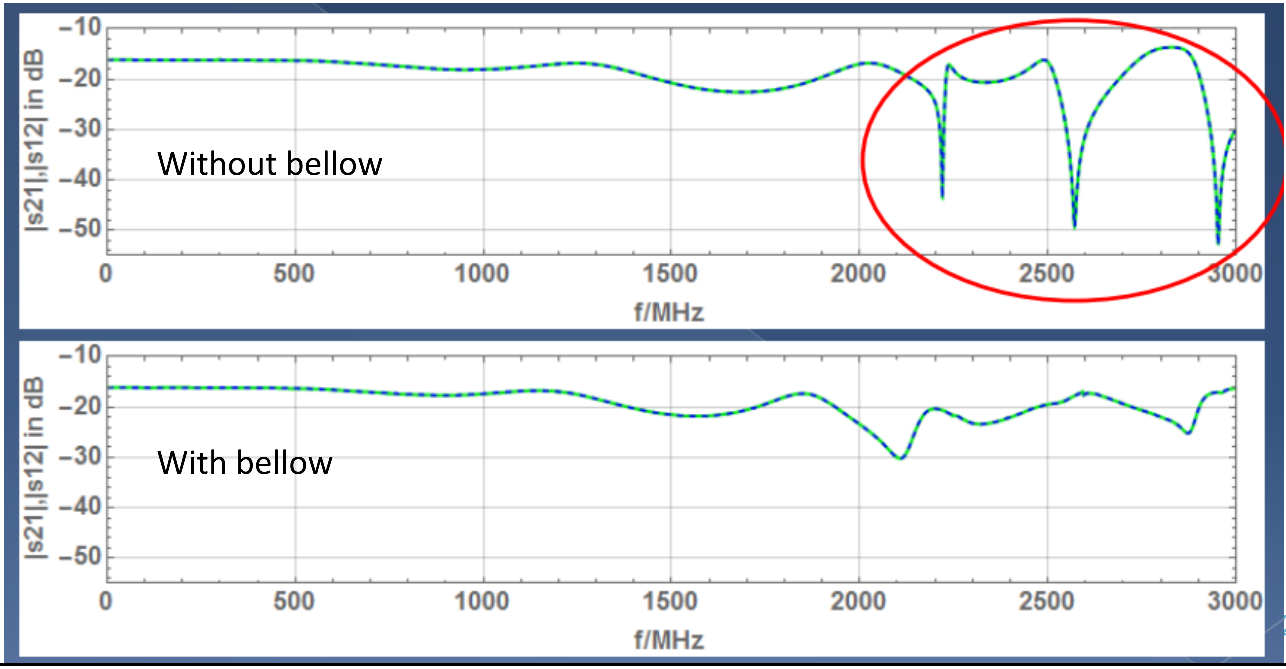
- New design with 3 convolutions (past measurements made with 2)



Christine Vollinger, Fritz Caspers, Thomas Kaltenbacher

New devices in the triplet region: RF shielding for the bellows

- High frequency resonances are gone when closing the structure with the bellow
- Still work on going to study the resonances for different finger positions



Courtesy of C. Vollinger

New devices in the triplet region: RF shielding for the bellows

- Number of shielded bellows => 7 per IP per side:
  - IP – Q1 – Q2a – Q2b – Q3 – Corrector Package – D1 – DFBX
  - 1 with small diameter (100 mm) and 6 with large diameter (120 mm)

- Lateral offset could be 2 mm

- No showstoppers so far, but need to wait for the final results from measurements and simulations (both ongoing)

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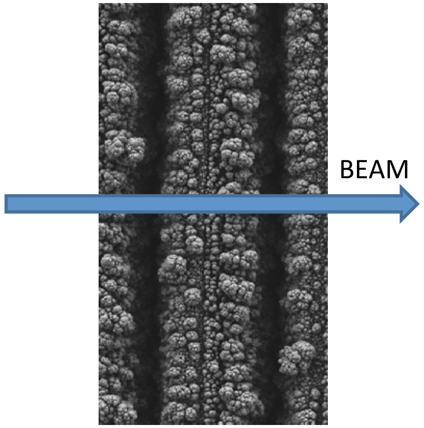
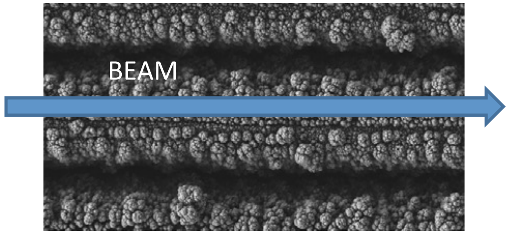
New devices in the triplet region: LESS

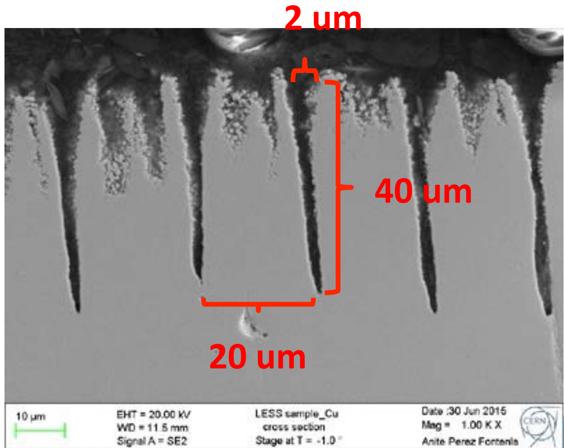
- Plans to produce LESS (Laser Engineered Surface Structures) on the triplets inner surface in IP2 and IP8 (± 45 m) for e-cloud mitigation (SEY < 1)



TRANSVERSE GROOVES

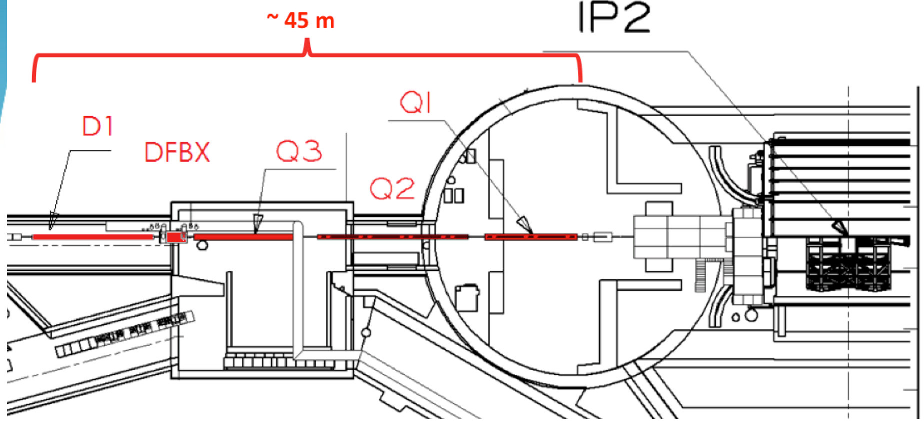


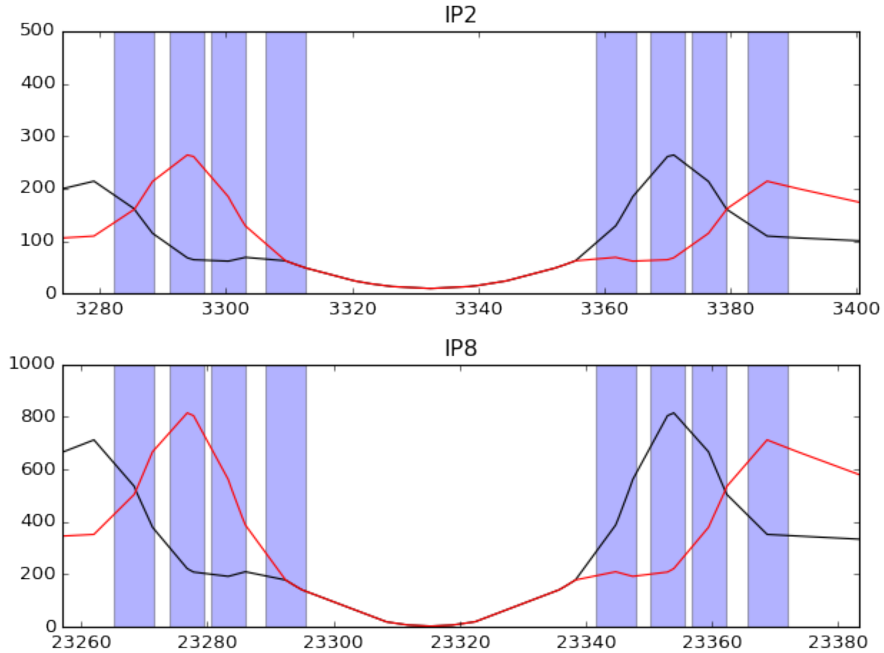
LONGITUDINAL GROOVES



Courtesy of O. Berrig

New devices in the triplet region: LESS





Equipment	Q1	Q2	Q3	DFBX	D1
Length treated [m]	7.9	14.0	9.7	2.6	10.8
Radius HOR [mm] Radius VER [mm]	20.2 25.0	25.2 30.0	25.2 30.0	30.5 35.3	30.5 35.3

Courtesy of O. Berrig

New devices in the triplet region: LESS

- Longitudinal grooves are better than transverse grooves, i.e. less impedance
- Transverse grooves give
  - An increase of ~ 0.8 % in the imaginary part of the longitudinal impedance
  - An increase of ~ 0.4 % in the imaginary part of the transverse impedance
- We assume that the LESS treatment gives a factor 5 increase (F. Caspers) in resistivity (a factor 2 is predicted applying Hammerstad's correction coefficient) => Still to be measured
- The factor 5 increase in resistivity gives a factor ~ 2.2 increase in heat deposition => ~ 1.7 W/m (reminder: 2 – 4 W/m from e-cloud)

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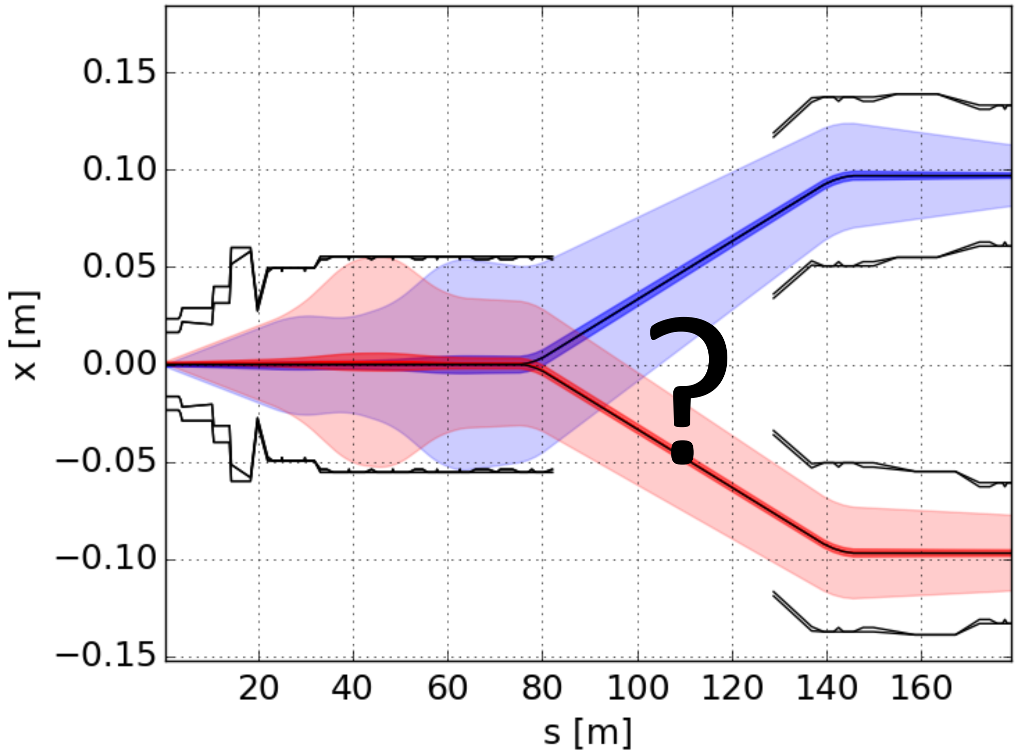
Y chambers

- No design available yet

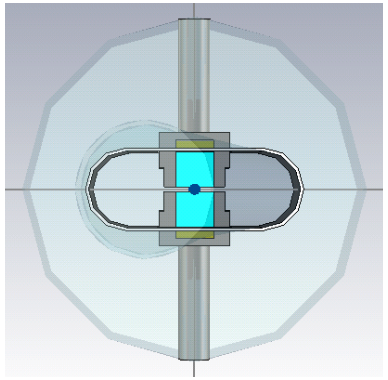


TDI redesign => TDIS

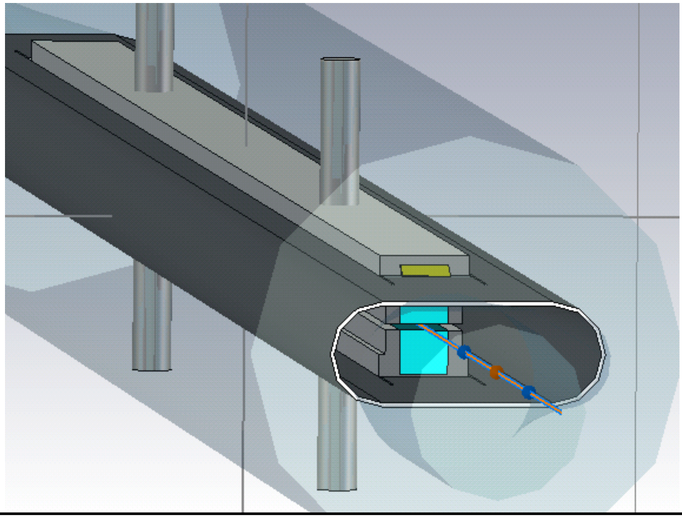
- Design from Nov 27th 2015
- Idea: reduce impedance with high priority (WP14)
- 2 fields of action:
  - Resistive wall contribution: efficiently addressed by the copper coated graphite
  - Modes: gave the guidelines to fill all gaps around the jaws, which are responsible for the low frequency modes (~ 1 kΩ at ~ 100 MHz => Could lead to up to several hundreds of W at injection)

TDI redesign => TDIS

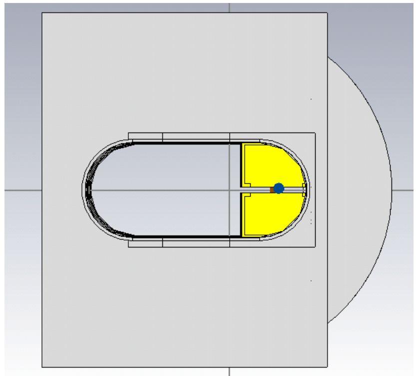
- Current TDI

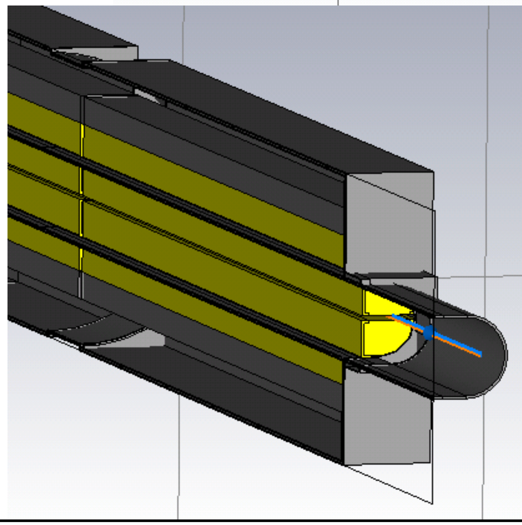


Courtesy of B. Salvant



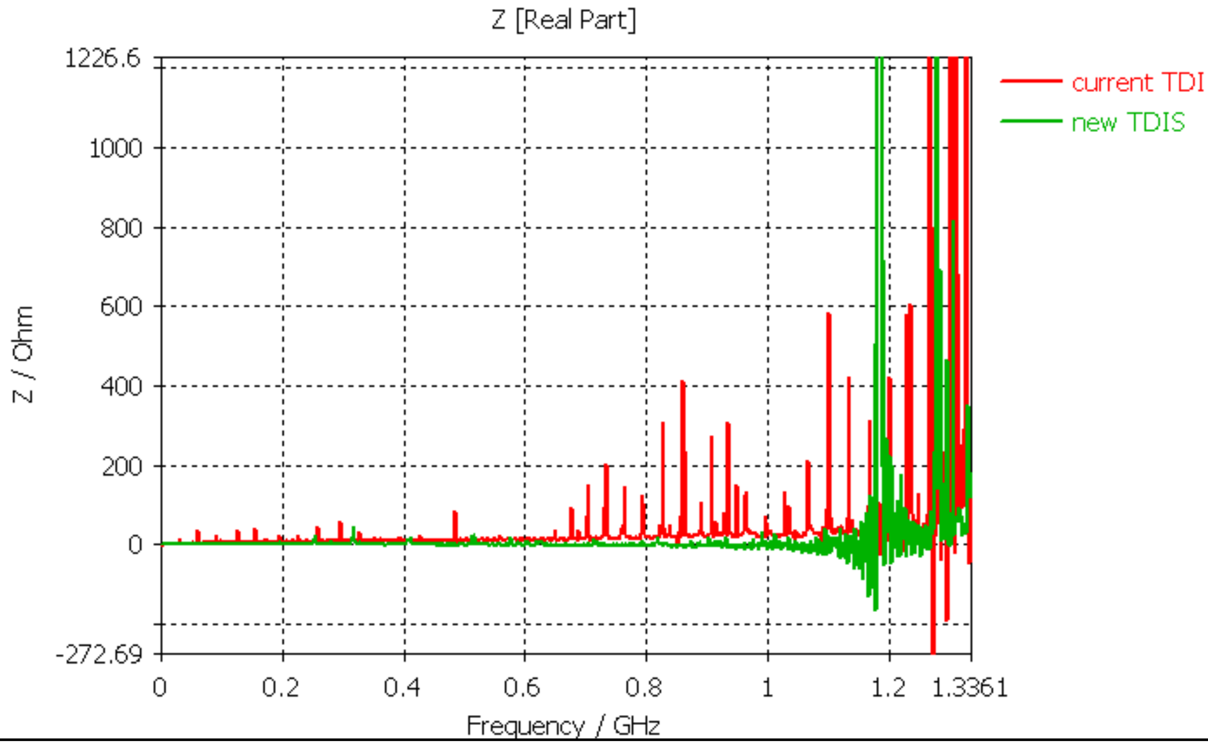
- New TDIS





TDI redesign => TDIS

- Much cleaner from mode point of view thanks to closed gaps



Courtesy of B. Salvant

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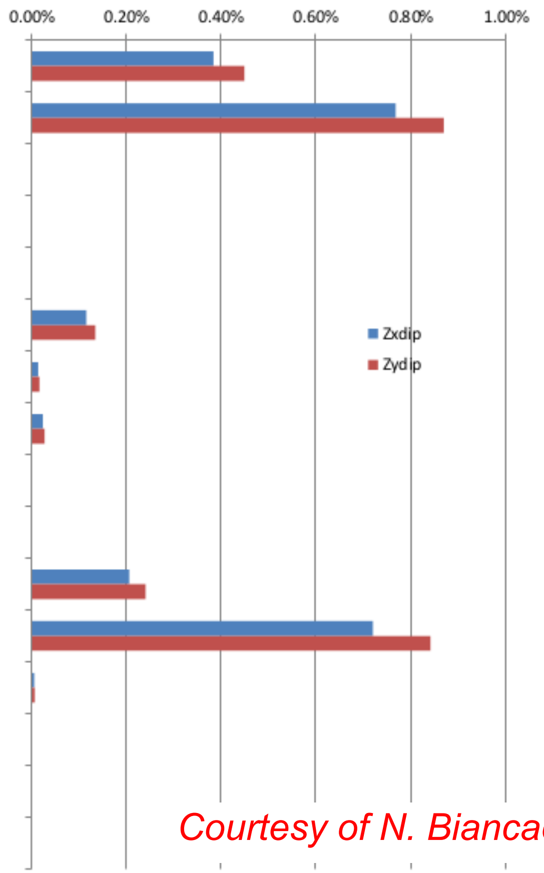
Summary of new elements: transverse

	Zxdip [Ohm/m]	Zydip [Ohm/m]	Comments
HLLHC	2.08E+07	1.78E+07	Total budget without the elements listed below

	Zxdip [% of the total]	Zydip [% of the total]	Comments
LESS	0.38%	0.45%	In IP2 and IP8. Refined studies on going for resistivity estimations
BPMS	0.77%	0.87%	In IP1 and IP5 (14 striplines/IP)
11T dipole	no issues expected	no issues expected	Design close to existing collimators, but larger box
TCLX	large gap: no issues expected	large gap: no issues expected	optimize holes size and distribution
TCTPH4	large gap: no issues expected	large gap: no issues expected	optimize holes size and distribution
Octagonal beam screen IP1/IP5	0.12%	0.13%	
Octagonal beam screen IP2/IP8	0.01%	0.02%	
Transverse weld	0.02%	0.03%	
Longitudinal weld	negligible	negligible	Can reduce of a 40% moving far the weld from the beam
RF fingers in triplet regions	ongoing	ongoing	Measurements analysis ongoing: HOMs canceled by bellow
LHCb velo	0.21%	0.24%	mitigated by low beta* and stabilization in collision.
Triplets NEG coating	0.72%	0.84%	for beam close as 0.5mm to surface
Partially penetrated welds in LSS	0.01%	0.01%	Due to contact rings welding on LSS beam screens
New CMS pipe	negligible	negligible	HOM above 1 GHz
TDIS	ongoing	ongoing	Reduced volume, RF fingers, HOMs with higher frequency
Y chamber	design ongoing	design ongoing	Impedance team waiting for design

% of the total

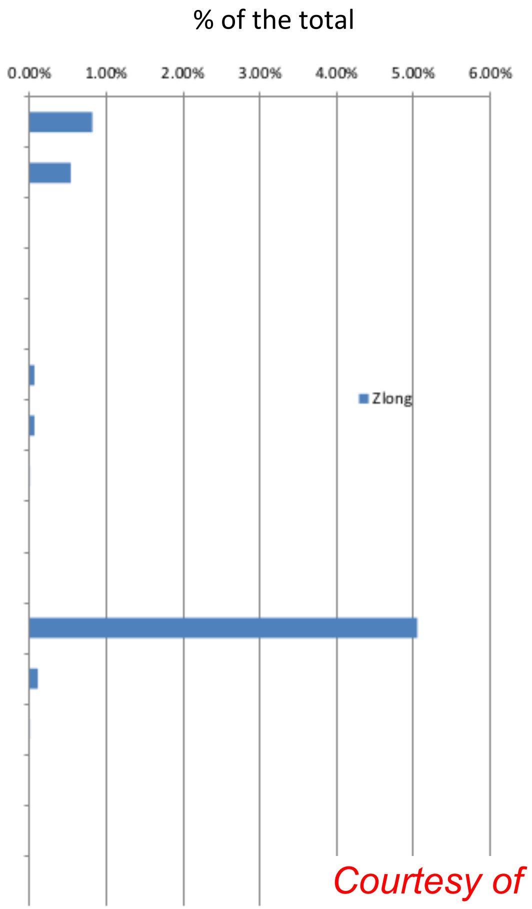


Courtesy of N. Biancacci

Summary of new elements: longitudinal

	Zlong [mOhm]	Comments
HLLHC	93	Total budget without the elements listed below

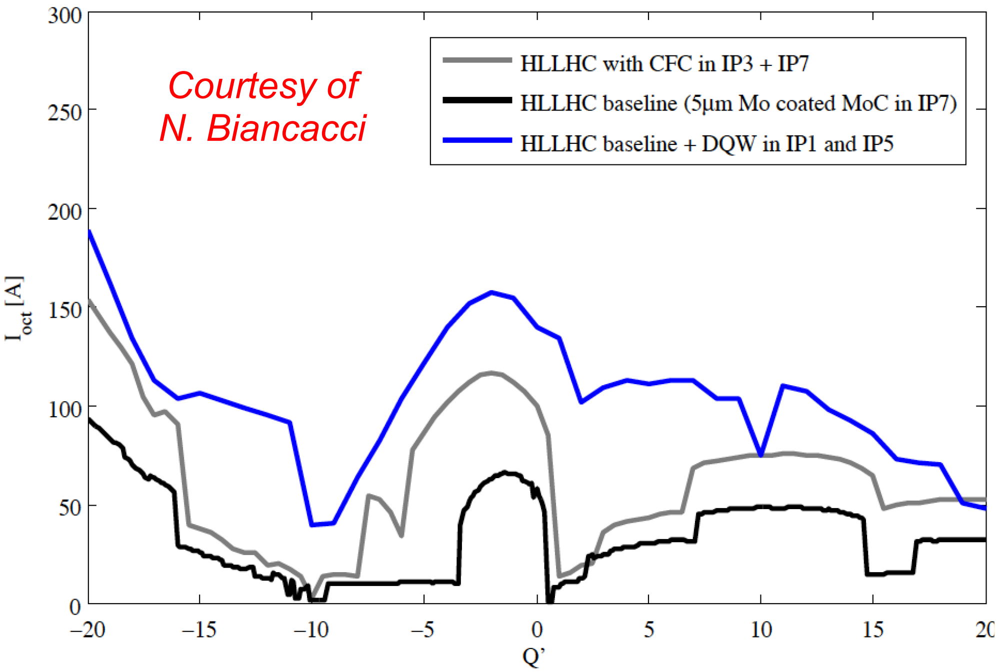
	Zlong [% of the total]	Comments
LESS	0.82%	In IP2 and IP8. Refined studies on going for resistivity estimations
BPMS	0.54%	In IP1 and IP5 (14 striplines/IP)
11T dipole	no issues expected	Design close to existing collimators, but larger box
TCLX	large gap: no issues expected	optimize holes size and distribution
TCTPH4	large gap: no issues expected	optimize holes size and distribution
Octagonal beam screen IP1/IP5	0.06%	
Octagonal beam screen IP2/IP8	0.06%	
Transverse weld	0.001%	
Longitudinal weld	negligible	Can reduce of a 40% moving far the weld from the beam
RF fingers in triplet regions	ongoing	Measurements analysis ongoing: HOMs canceled by bellow
LHCb velo	5.05%	Large impedance due to bellow-like box.
Triplets NEG coating	0.11%	for beam close as 0.5mm to surface
Partially penetrated welds in LSS	0.002%	Due to contact rings welding on LSS beam screens
New CMS pipe	negligible	HOM above 1 GHz
TDIS	ongoing	Reduced volume, RF fingers, HOMs with higher frequency
Y chamber	design ongoing	Impedance team waiting for design



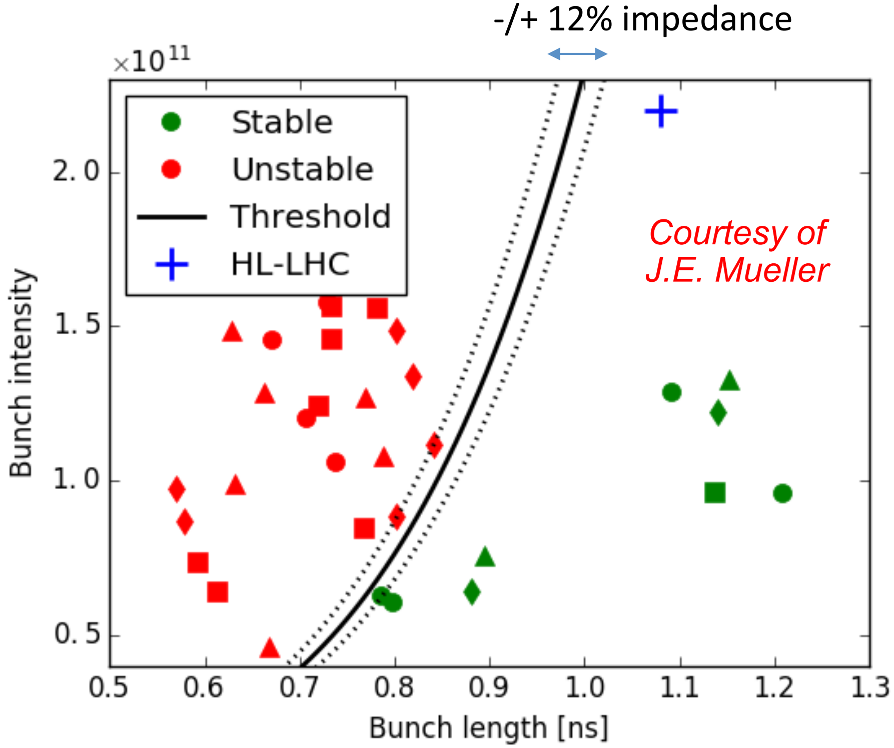
Courtesy of N. Biancacci

Predicted beam stability from HL-LHC impedance model

- Transverse



- Longitudinal



Conclusion

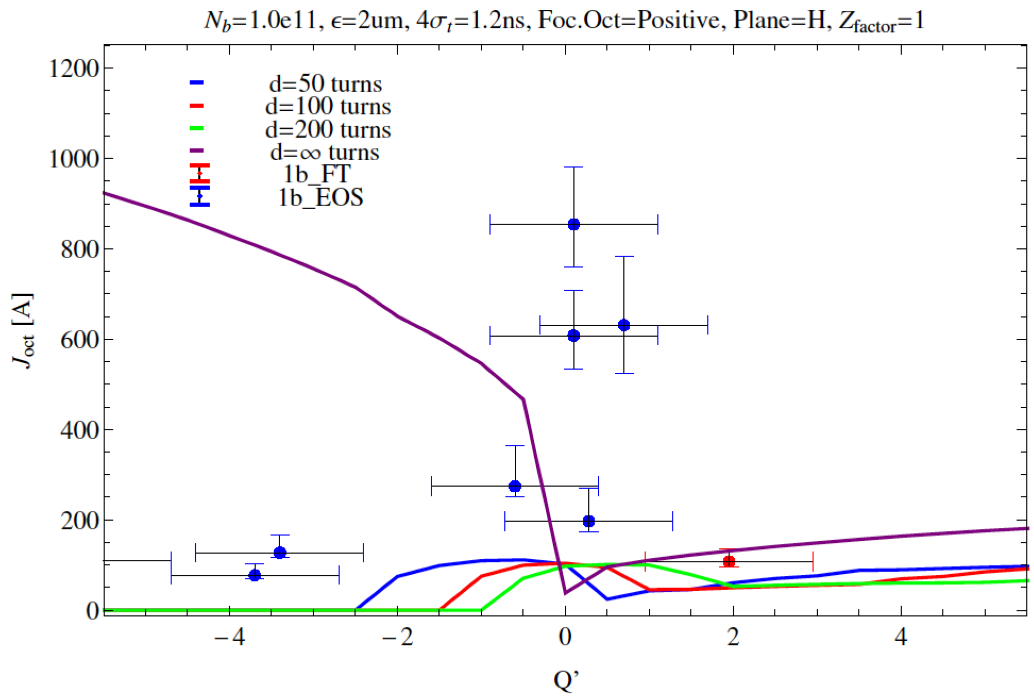
- The HL-LHC impedance model is in relatively good shape and sufficient margins should exist for beam stability in both L and T planes
- Beam stability measurements in the LHC in both L and T planes (for Q' > ~ 2 units) are in good agreement with predictions
- However, the effort to control and minimize the impedance should continue!... As some instabilities are not understood yet (even if other mechanisms are also expected to be involved => See talk on beam stability) and several impedance modifications are foreseen for HL-LHC
  - E.g., more margin could be gained in the T plane by damping the transverse mode at 920 MHz from the DQW Crab Cavity
  - Beam-induced RF heating to be kept under control for all equipment

Conclusion

- Furthermore, some "direct measurements" of the LHC impedance model are still missing (due to other priorities until now)
  - Instability rise-time vs. (negative) chromaticity with 1 bunch (with neither ADT nor Landau octupoles)
    - Started in the past with 48 (12 + 36) bunches at 450 GeV => Good agreement
    - To be done when possible
  - TMCI instability threshold at high energy
    - Should be higher than HL-LHC bunch intensity by a factor slightly more than 2 (see also talk from K. Li) => Need an impedance model better than a factor of 2…

Conclusion

- Higher chromaticity and ADT should help but it is important to understand what happens for Q' ~ 0 (as ideally one would like to operate with the minimum Q'…)



Courtesy of L.R. Carver

Thank you for your attention!