FOLLOW-UP OF SOME ACTIONS

E. Métral, N. Biancacci, K. Li, B. Salvant

- **Review of all the past recommendations for the impedance of the Crab Cavities**
- **Transverse kick factor for the crab cavities**
- **Some comments from Stephane Fartoukh**

Review of all the past recommendations for the impedance of the Crab Cavities (1/3)

summary of 2nd thoughts

$R_{sh,L}$< 100 kΩ/#cavities
(Q < 100-200 OK)

Im(*Z*/*n*) << 0.10 Ω/#cavities

$R_{sh,T}$<< 2 MΩ/m/#cavities

- **F. Zimmermann, 3rd LHC-ILC crab synergy meeting, 2008**

Based on stability diagram

- **E. Métral, PAC09 (https://cds.cern.ch/record/1235159/files/mo4rac02.pdf)**

- The recommendation was given in the PAC'09 paper http://cds.cern.ch/record/1235159/files/mo4rac02.pdf for the maximum allowed HOMs (for nominal LHC beam parameters: 1.15E11 p/b within 3.75 μm and using [illegible] convention")

From all the Crab Cavities

$$\frac{\beta_{CC}}{\beta_{av}} \times R_{HOM} << 1\,\mathrm{G\Omega/m}$$

"A reasonable target would be to have a margin of 2 orders of magnitude" mentioned in the paper

$$\frac{\beta_{CC}}{\beta_{av}} \approx \frac{3600}{70} \approx 51$$

$$N_{CC\,/\,plane} = 8$$

$$\Rightarrow \quad R_{HOM\,/\,CC} << 2.5\,\mathrm{M\Omega/m}$$

Similar to FrankZ et al. (2008)

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- **Updating this to the HL-LHC parameters (2.2E11 p/b within 2.5 μm), yields**

$$R_{HOM\,/\,CC} << 1\,\mathrm{M\Omega/m}$$

Based on stability diagram

Summary: transverse impedance budget

- For nominal intensity at 450 GeV threshold determined by the damping time of 60 ms is 2.5 MOhm/m. With margin for particle distribution - 0.6 MOhm/m
- Approximate frequency dependence
  - 0.6 /(1-f_r/1.6) MOhm/m for f_r [GHz] < 0.8
  - 1.2 (0.5+f_r) MOhm/m for f_r [GHz] > 0.8

→ 0.8 MOhm/m at 0.8 GHz for ultimate intensity and 0.4 MOhm/m for 2 identical cavities

Additional factor proportional to local beta-function β/‹ β ›

- **E. Shaposhnikova, LHC-CC10 (https://indico.cern.ch/event/100672/session/5/contribution/19/material/slides/1.pdf)**

Based on transverse damper (60 ms)

- **A. Burov, LHC-CC11 (https://indico.cern.ch/event/149614/session/6/contribution/27/material/slides/0.pdf)**

- The transverse HOM may not exceed 1.5 Mohm/m per cavity.

Review of all the past recommendations for the impedance of the Crab Cavities (2/3)

- BenoitS and NicolasM used / mentioned in the past the threshold from A. Burov (scaled to the latest parameters) before looking at it in more detail with HEADTAIL and DELPHI. Meanwhile it was mentioned that a transverse damper damping time of 5 ms could/should be considered

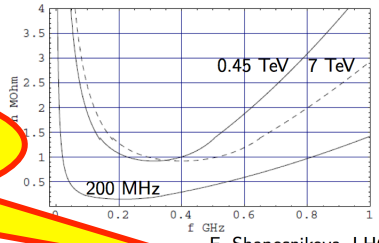
- Introduction talk from Alessandro Ratti at the Crab Cavity HOM Coupler Design & Fabrication Review II, US, 25/02/15 (http://indico.cern.ch/event/371427/session/1/contribution/3/material/slides/0.pdf)

Aspect #2: Impedance — See tomorrow B. Salvant

Longitudinal criteria:

Threshold set at 200 kΩ (E=7TeV, N_b=2.2x10^{11}, 4σ =1ns)

Can be relaxed as $f_r^{5/3}$



E. Shaposnikova, LHC-CC10

Transverse damper with damping time of 5 ms

Transverse criteria:

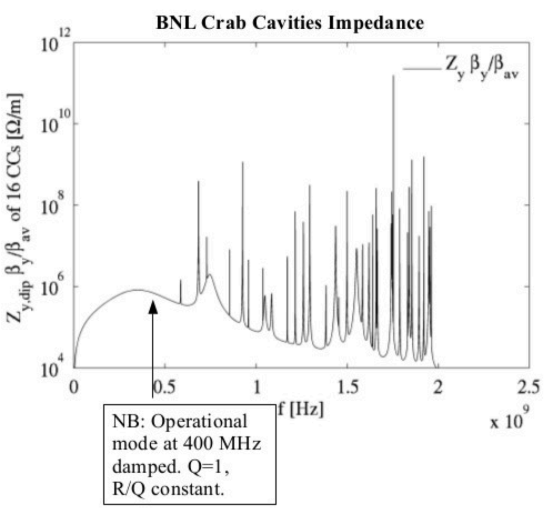
Threshold of < 4.8 MΩ/m (determined by damper time of 5ms)

Spread in HOM freq. best way to increase budget (else 0.3 MΩ/m)

Main RF cavities are damped to Q_{ext} ~ 10^2 - 10^3

Elias Métral, HL-

Reviewed again at last HiLumi Meeting, KEK



As from [1,2] in a single mode test case:

$$\frac{\beta_y}{\beta_{av}} R_\perp^{sh} \ll 1G\Omega/m$$

With $\beta_y \simeq 3600\ m$, $\beta_{av} \simeq 70\ m$, $\ll \rightarrow \frac{1}{50}$

→ *Details on procedure on E.Métral talk after*

Review of all the past recommendations for the impedance of the Crab Cavities (3/3)

- **From the Hilumi KEK meeting (Nov. 2014)**

CRAB CAVITIES (5/6)

- Conclusion: Despite the huge effort to optimize the Crab Cavities design (many thanks!), some HOMs are still too high
- 2 conditions should be satisfied
  - 1) $R^{\max}_{HOM\,/\,CC} \approx 10 - 20\ \mathrm{k\Omega/m}$
  - 2) $\left(\frac{R}{Q}\right)^{\max}_{\text{All CC}} \approx \text{few k}\Omega/\text{m}$

See N. Biancacci (or Appendix)

Could be 8 (N_{CC} / plane) higher if the HOMs of all the cavities are not at the same f_r => ~ 160 kΩ/m

To be confirmed with HEADTAIL simulations

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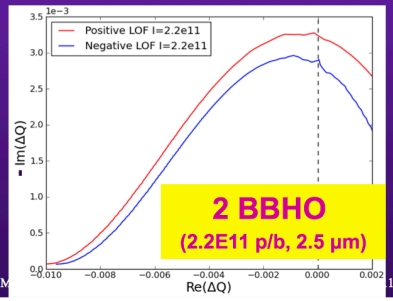
CRAB CAVITIES (6/6)

- HOWEVER, it is true that the beta functions will increase to maximum values only while in collision (with β* leveling)
  - Collisions in IP1 and IP5 should start at β* ≈ 70 cm (instead of 15 cm) for lumi reason => ~ 70 / 15 ≈ 4.7 times smaller beta functions at Crab Cavities
    => Previous limits can be increased by factor ~ 5 (~ 0.8 MΩ/m)
  - Once in collisions in IP1 and IP5, ~ 30 times more Landau damping due to Beam-Beam Head-On (BBHO)



=> Previous limits can be increased by factor ~ 30 => Could therefore help to collide even earlier if impedance of Crab Cavities cannot be reduced sufficiently

However, this does not work for non-colliding bunches!

Elias M … 1/2014

- If we assume that we collide at ~ 45 cm (ultimate performance) AND that all the modes are not at the same frequency, then the limit becomes **~ 0.5 MΩ/m**

Transverse kick factor for the crab cavities (1/3)

- **NicoloB found 1.4 V / pC mm for all the crab cavities (see last Task 2.4 meeting: https://indico.cern.ch/event/377643/contribution/1/material/slides/0.pdf)**

- **Considering the single mode discussed in the past**

$$f_r = 800 \text{ MHz} \qquad Q = 1000 \qquad \frac{3600}{70} \times R = 1.4 \text{ G}\Omega/\text{m}$$

yields:

Transverse kick factor: ~ 1.96 V / pC mm

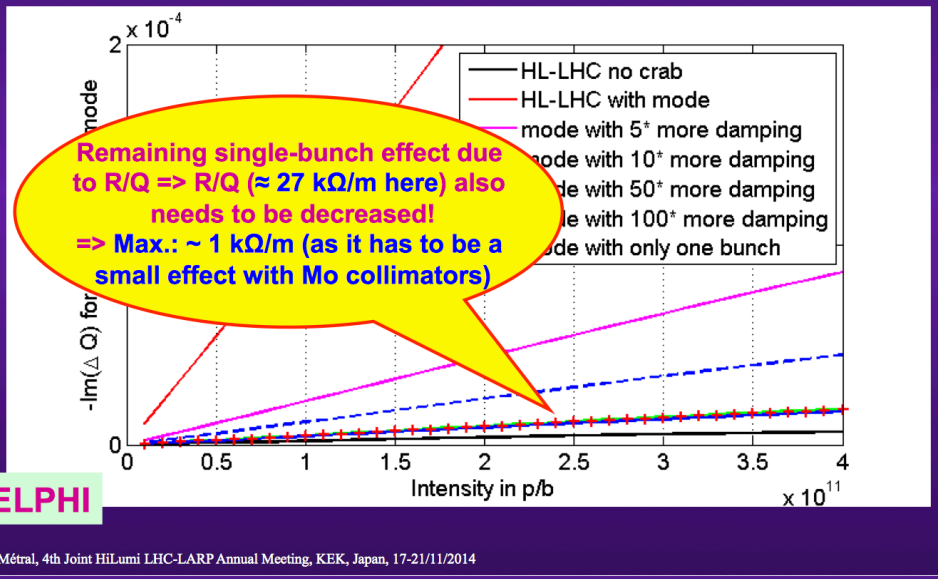
Induced voltage: ~ 69.1 kV by 1 HL-LHC bunch with offset of 1 mm

Induced kick: ~ 9.9 nrad

Effective impedance (imaginary): ~ 1.7 MΩ/m

Transverse kick factor for the crab cavities (2/3)

- **Is an impedance like this dangerous?**



DELPHI

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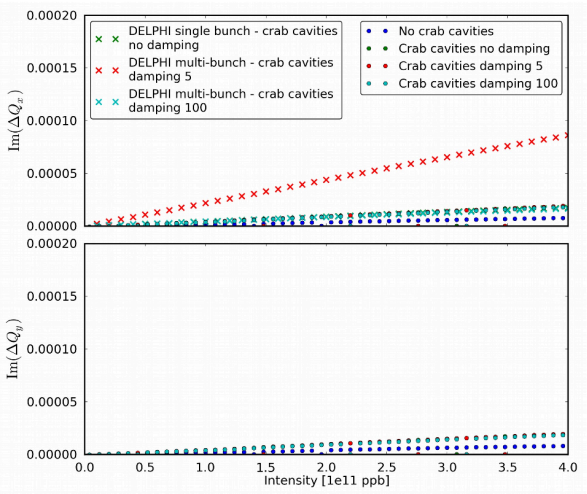
Compare PyHEADTAIL - DELPHI



- Crab cavity impedance leads to a factor ~2 increase in growth rates
- Crab cavity single bunch growth rates reproduced from DELPHI (horizontal)
- HOM damping has marginal effect for single bunch
- HOM damping has significant effect for multi-bunch
- HOM damping of >50 reduces growth rates to single bunch growth rates

BenoitS

KevinL, Task 2.4 meeting, 10/12/14

⇒ **YES, confirmed by 2 independent codes**

⇒ **Furthermore, the comparison has been made here with CFC collimators and we should have Mo coated Mo-Gr in the future…**

Transverse kick factor for the crab cavities (3/3)

- **Assuming the same mode as before but with R / Q = 1 kΩ/m leads to**

  Transverse kick factor: ~ 0.072 V / pC mm

  Induced voltage: ~ 2.5 kV by 1 HL-LHC bunch with offset of 1 mm

  Induced kick: ~ 0.36 nrad

  Effective impedance (imaginary): ~ 0.064 MΩ/m

i.e. everything is divided by ~ 27

In summary: our recommendations for the transverse impedance of the Crab Cavities (assuming collisions at $\beta^* = 45$ cm for ultimate HL-LHC performance)

- **Limit in R per HOM per Crab Cavity** (assuming 16 Crab Cavities in total and that all the resonances of the Crab Cavities are not overlapping - input from Rama Calaga): **~ 0.5 MOhm/m**

- **Limit in R / Q (for all the Crab Cavities): ~ few kOhm/m** (ongoing studies to be more precise and see for instance if 10 kOhm/m would be fine)

Some comments from Stephane Fartoukh (1/2)

- 1) the HL-LHC momentum compaction and slippage factor is 7% less than for the LHC (the H focusing is reduced for ATS optics), i.e. you cannot have simultaneously the nominal LHC voltage (e.g. 16 MV at 7 TeV) the nominal emittance (2.5 eVs at 7 TeV) and the nominal bunch length (7.55 cm at 7 TeV)

- 2) No longer sure if starting the telescope before the end of the pre-squeeze is a good idea, and in fact really needed even if LOF<0 (and a fortiori if leveling is made with parallel sep in IP8). The reason is subtle related to the correction of the spurious dispersion induced by the crossing angle, using the orbit bumps in the arcs as foreseen by the ATS. The later will be huge up to +/- 13 mm e.g. stopping the pre-squeeze at 2 m, reaching the 70 cm with the telescopic

Some comments from Stephane Fartoukh (2/2)

techniques and if one wants to fully correct the spurious dispersion at 70 cm. Of course then we could not completely correct at 70 cm, or we could mitigate by reducing the crossing angle at 70 cm, but then more LR tune spread, more compensation when LOF<0, so in both cases and in general more complexity, more risk, etc. It is worth doing this only if leveling with parallel sep in IR8 will not work… but it should

- 3) Important MD to be done: lumi leveling MD with parallel sep in IR1 and IR5 and LOF>0 (end of fill). Then a nice objective for end of 2015 (too optimistic) or 2016 (more realistic), would be to do the same thing with LOF<0 and a ATS telescopic optics commissioned and validated with a few trains at a reasonable beta*