# Transverse kick factor of HL-LHC crab cavities

S. ANTIPOV, N. BIANCACCI, X. BUFFAT, E. METRAL
MANY THANKS TO R. CALAGA, J. MITCHELL, R. DE MARIA
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# Could the random nature of crab cavity HOMs lead to emittance growth?

Randomness of the modes comes from the construction, once the cavity is built, there are no random component in the resulting wake fields/impedance

There is no reason to treat the impedance of the CC differently from other impedances

Might be an issue

- Alex Lumpkin, "Observations of Higher-Order-Mode Effects in Tesla-Type SCRF Cavities on Electron Beam Quality", IPAC'18, to be followed up

Is the HOM impedance strong enough to amplify an external source of noise?

How does it compare to the other sources of impedance?

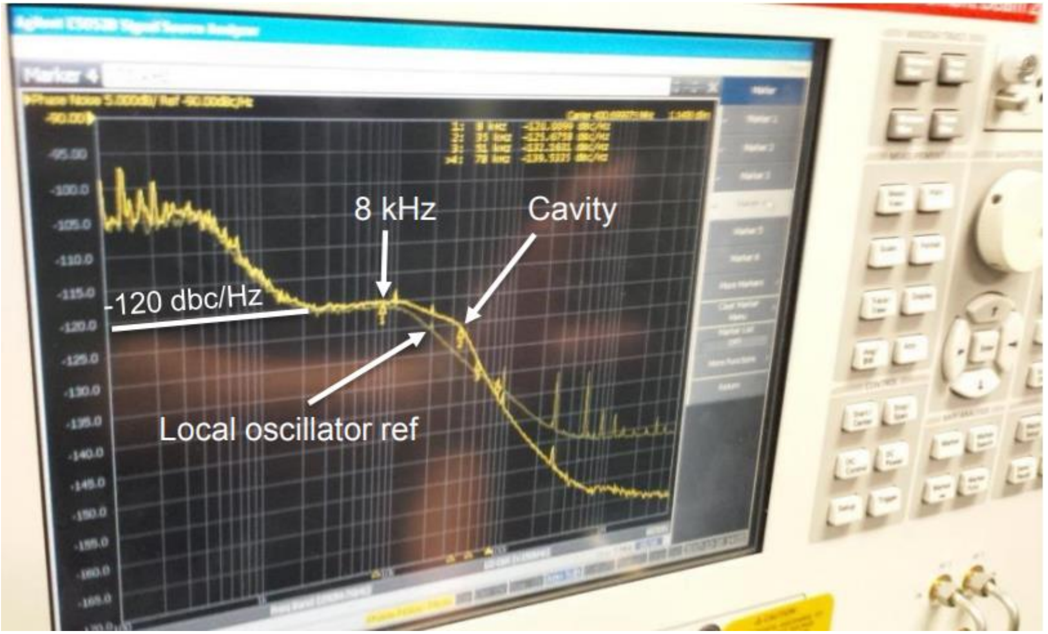
# In RF measurements no noise signal is seen at the HOM frequencies

No dedicated test of RF noise in HOMs has been done, but can be performed if needed

The RF source bandwidth is not enough to excite them

The HOMs have to be excited by the beam

Most of the measured phase noise is at the low frequency end of the spectrum




R. Calaga, SPS Crab Cavity Tests, Chamonix 2018

# Kick factor from Crab Cavities

- We define the transverse kick factor as:

$$k_t = \frac{1}{2\pi} \int_{-\infty}^{+\infty} Z_t(\omega) h(\omega) \mathrm{d}\omega, \quad (1)$$

where $h(\omega) = \lambda(\omega)^2$ is the power spectrum of the current distribution , $Z_t$ the transverse impedance (dipolar + quadrupolar). Given in units $[k_t]$=V/(mm pC).

- For a Gaussian bunch we have:

$$h(\omega) = e^{-\omega^2 \sigma_t^2}. \quad (2)$$

- The kick factor is related to the transverse kick $\Delta y'$ a particle would get due to an impedance:

$$\Delta y' = -\frac{N_b q^2 y_0}{\beta^2 E} k_t. \quad (3)$$

with $N_b$ bunch intensity, $q$, $v$ and $m_p$, proton particle charge, velocity and rest mass, $y_0$ the closed orbit position at the impedance location.

- From the loss factor we can recover the usual tune shift formula (same as Sacherer for single bunch, azimuthal mode $m = 0$):

$$\Delta Q_y^{m=0} = \frac{1}{4\pi} \beta_k \Delta y' = -\frac{I_b q T_0}{4\pi \beta^2 E} \bar{\beta}_y k_t', \quad \text{with} \quad k_t' = \frac{\beta_k}{\bar{\beta}_y} k_t. \quad (4)$$



N. Biancacci, et al., "Follow-up of the impedance of the crab cavities", WP2.4 Meeting, 04.03.15

# Previous studies have estimated the effect to be small

All crab cavities combined:

- $k'_t$ = 1.4 V/mm-pC → ~ $2 \times 10^{-4}$

One primary collimator at a half-gap of 1 mm: → ~ $5 \times 10^{-4}$

- $k'_t$ = 3.1 V/mm-pC

Whole collimation system:

- $k'_t$ = 45.3 V/mm-pC

Amplification:

$$\beta_{imp} \frac{\Delta y'}{y_0} = \frac{N_b q_e^2}{E} \beta_{av} k_t'$$

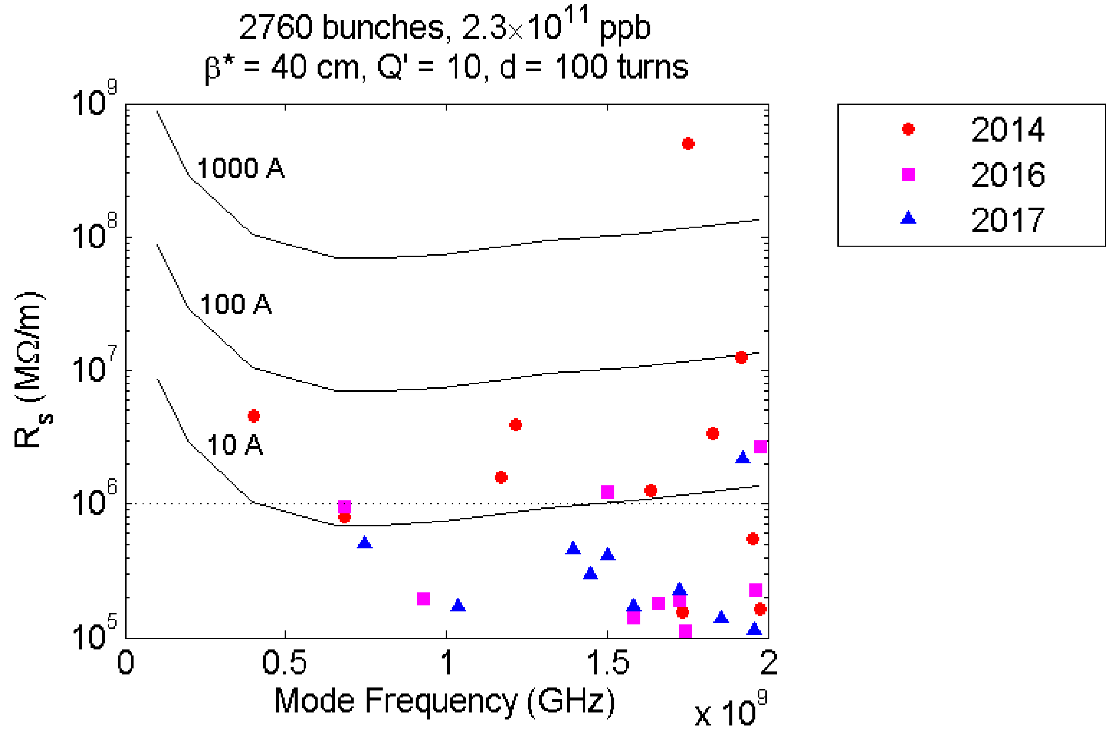
| 8 CC / beam / IP |
| --- |
| $E$ = 7 TeV, $\beta^*$ = 15 cm, $\sigma_z$ = 7.6 cm |
| $N_b$ = $2.2 \times 10^{11}$ ppb |

N. Biancacci, et al., "Follow-up of the impedance of the crab cavities", WP2.4 Meeting, 04.03.15

# CC HOM kicks have reduced dramatically

1) Shunt impedance has decreased
2) 8 CC per IP -> 4 CC per IP
3) Bunch length has decreased, lowering the impact of high frequency modes
   $\sigma_z$: 7.6 cm -> 9.0 cm

Progress of DQW HOM shunt impedance



# The total impact of the HOMs is insignificant

Assuming the max $\beta$-function at the cavities

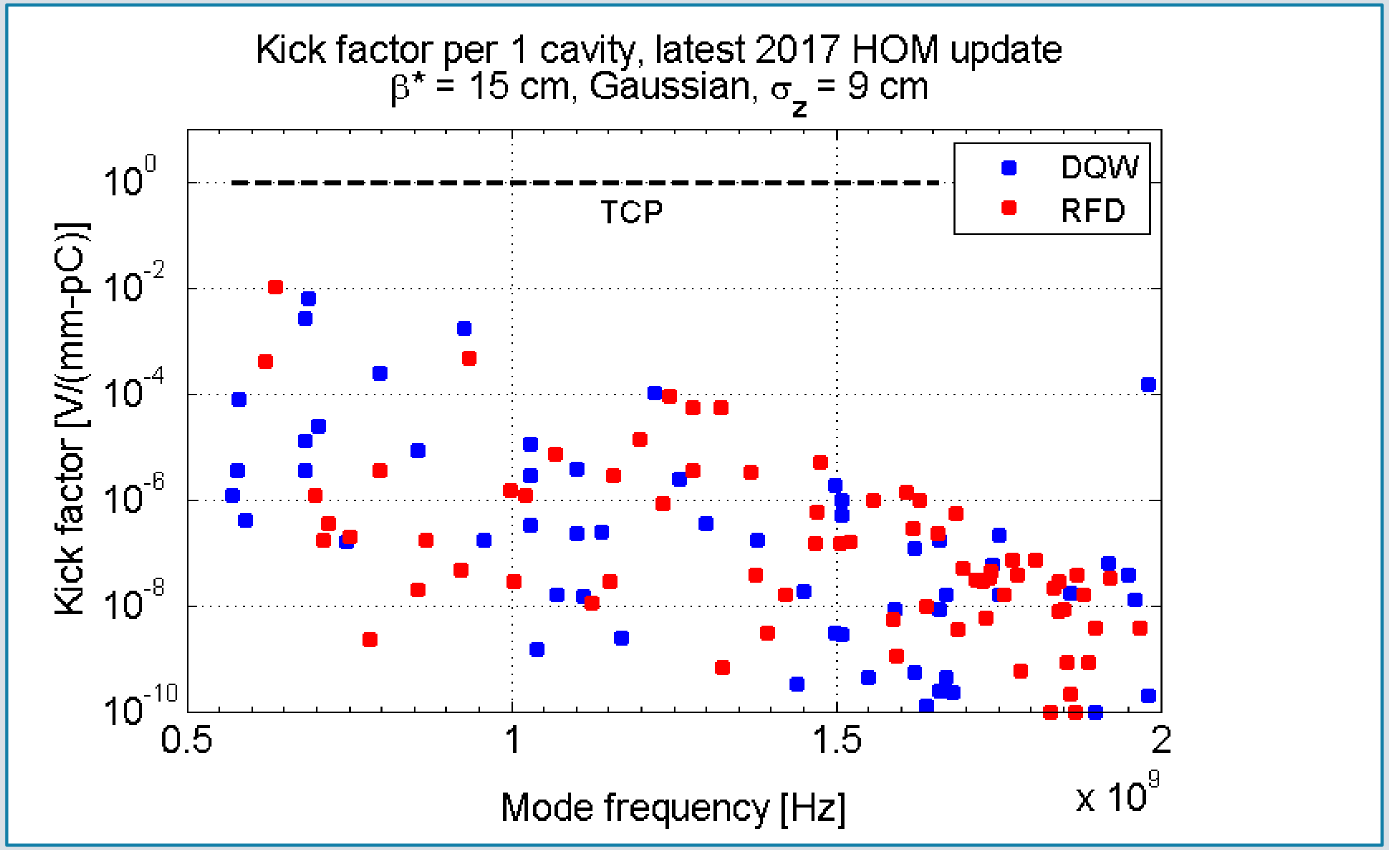
- During collision, $\beta^* = 15$ cm

One crab cavity:

- $k'_t = 1\text{x}10^{-2}$ V/mm-pC

All 4 crab cavities:

- $k'_t \sim 0.04$ V/mm-pC (DQW)
- 2 orders of magnitude lower than the collimator system



# Conclusion

Crab cavity HOMs can lead to an emittance growth, but should be treater as and in comparison to any other source of impedance

- RF source does not create noise at the high HOM frequencies

The impact of the HOMs on the beam emittance is negligible for both DQW and RFD designs

# Back-up slides

# Before the beams are brought into collision

Maximum impact at β* = 41 cm for the Ultimate OP scenario

One crab cavity:

- $k'_t = 4.3 \times 10^{-3}$ V/mm-pC

All 4 crab cavities:

- $k'_t \sim 0.02$ V/mm-pC
- 2 orders of magnitude lower than the collimator system