IMPEDANCE AND TRAPPED MODES FROM COLLIMATORS

E. Métral
for the LHC Collective Effects team

- **Transverse resistive-wall impedance model**
- **Stability diagram and coherent tune shifts for**
  - **The "old" collimator setting of the 2004 LHC Design Report**
  - **The new baseline layout (V6.5, Phase 1)**
- **Trapped modes**
- **Conclusion and outlook**

Transverse resistive-wall impedance model (1/3)

- **First unstable betatron line** $f_\beta^1 \approx 8\ \mathrm{kHz}$
- **Skin depth for graphite (ρ = 14 μΩm)** $\delta\left(8\ \mathrm{kHz}\right) \approx 2\ \mathrm{cm}$
- **Collimator thickness** $d = 2.5\ \mathrm{cm}$

$$\Rightarrow \quad \delta\left(f_\beta\right) = \sqrt{\frac{\rho}{\mu \pi f_\beta}} < d$$

⇒ **One could think that the classical "thick-wall" formula would be about right**

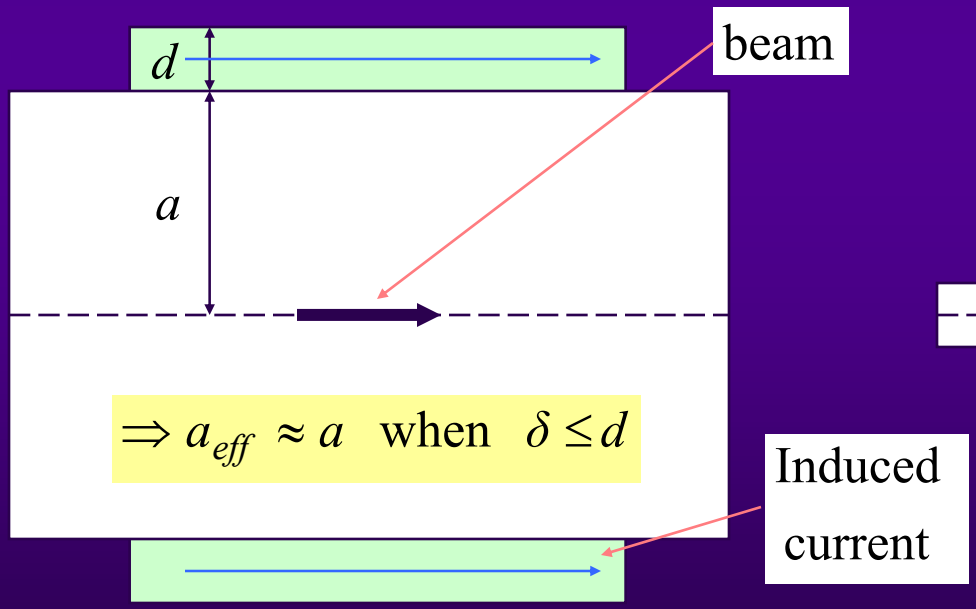
$$Z_\perp^{\mathrm{thick-wall}}\left(f\right) \propto \frac{1}{a^3\sqrt{f}}$$

Transverse resistive-wall impedance model (2/3)

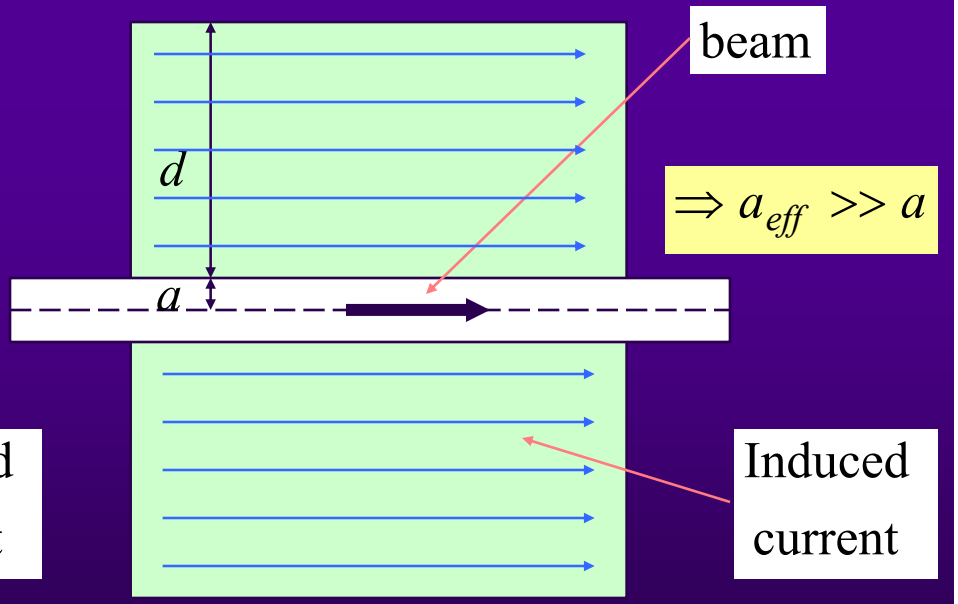
- **In fact it is not $\Rightarrow$ The resistive impedance is ~ 2 orders of magnitude lower at ~ 8 kHz !**

$\Rightarrow$ A new physical regime is revealed by the LHC collimators

Usual regime : $d, \delta < a$



New regime : $d >> a, \delta \leq d$



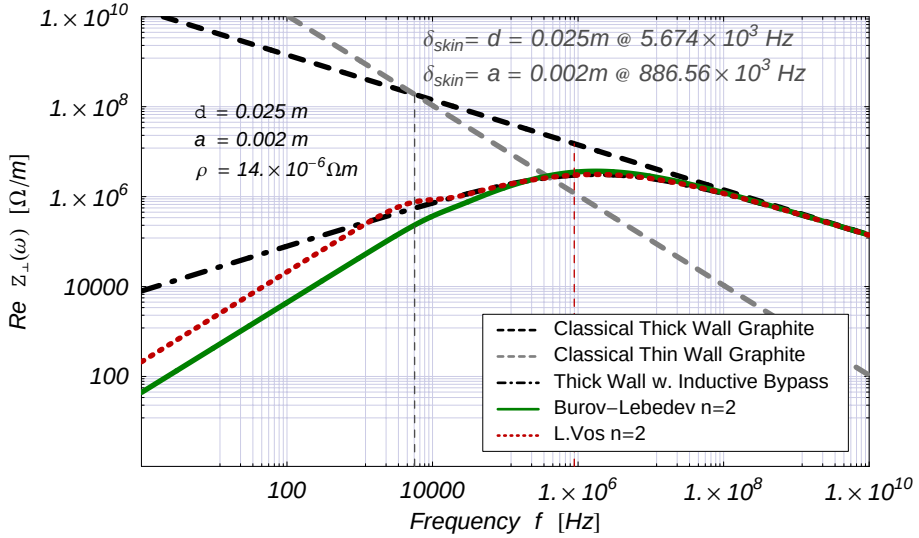
Transverse resistive-wall impedance model (3/3)

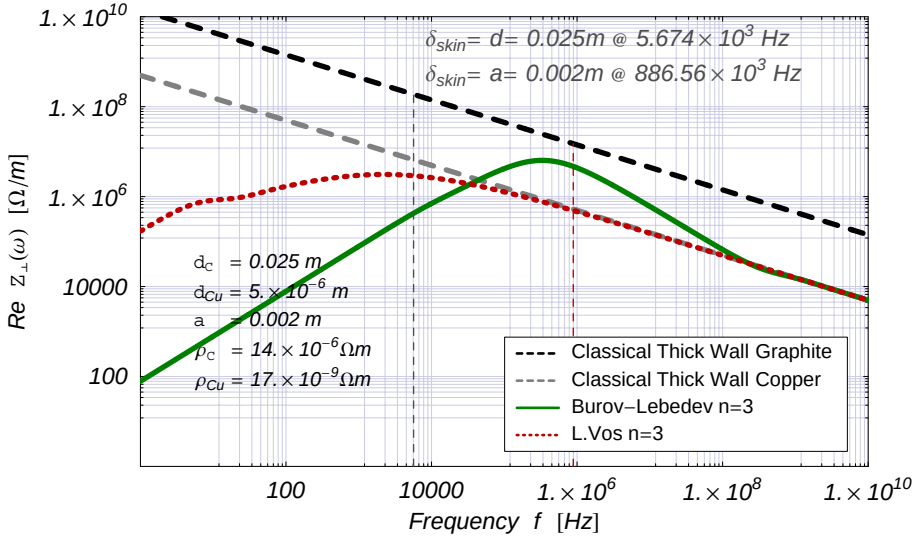
$\Rightarrow$ Good agreement between 2 recently derived general multi-layer formulae

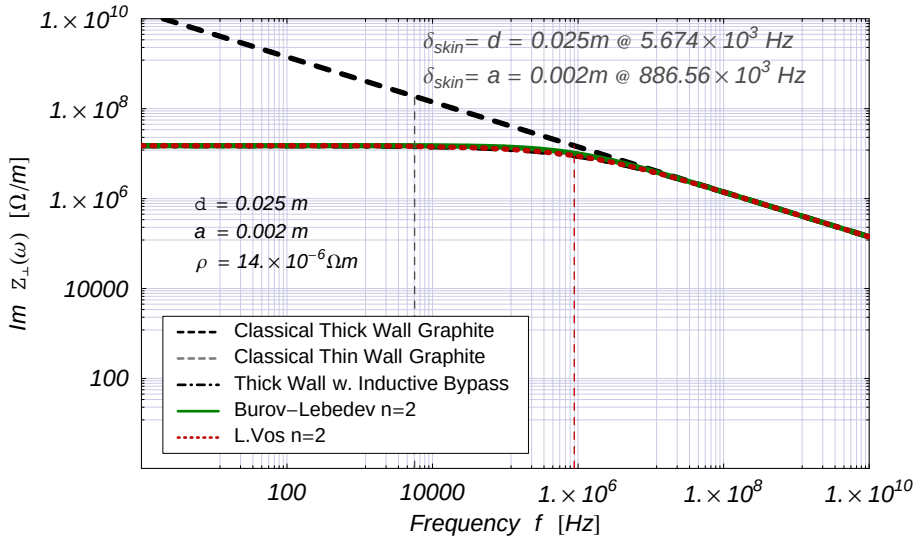
- L. Vos (circuit analysis, using an "inductive bypass")
- A. Burov and V. Lebedev (quasi-static beam model)

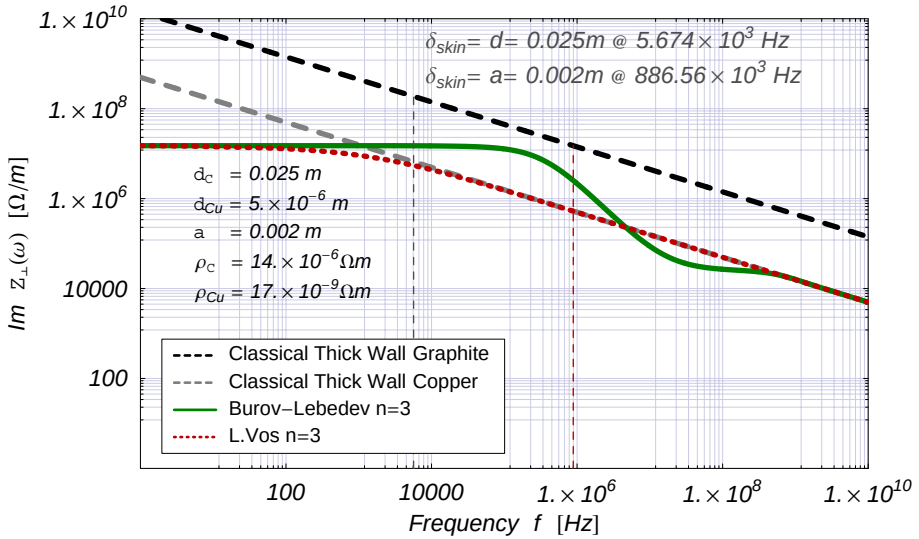
and HFSS simulations by H. Tsutsui

Comparison between Vos and Burov-Lebedev









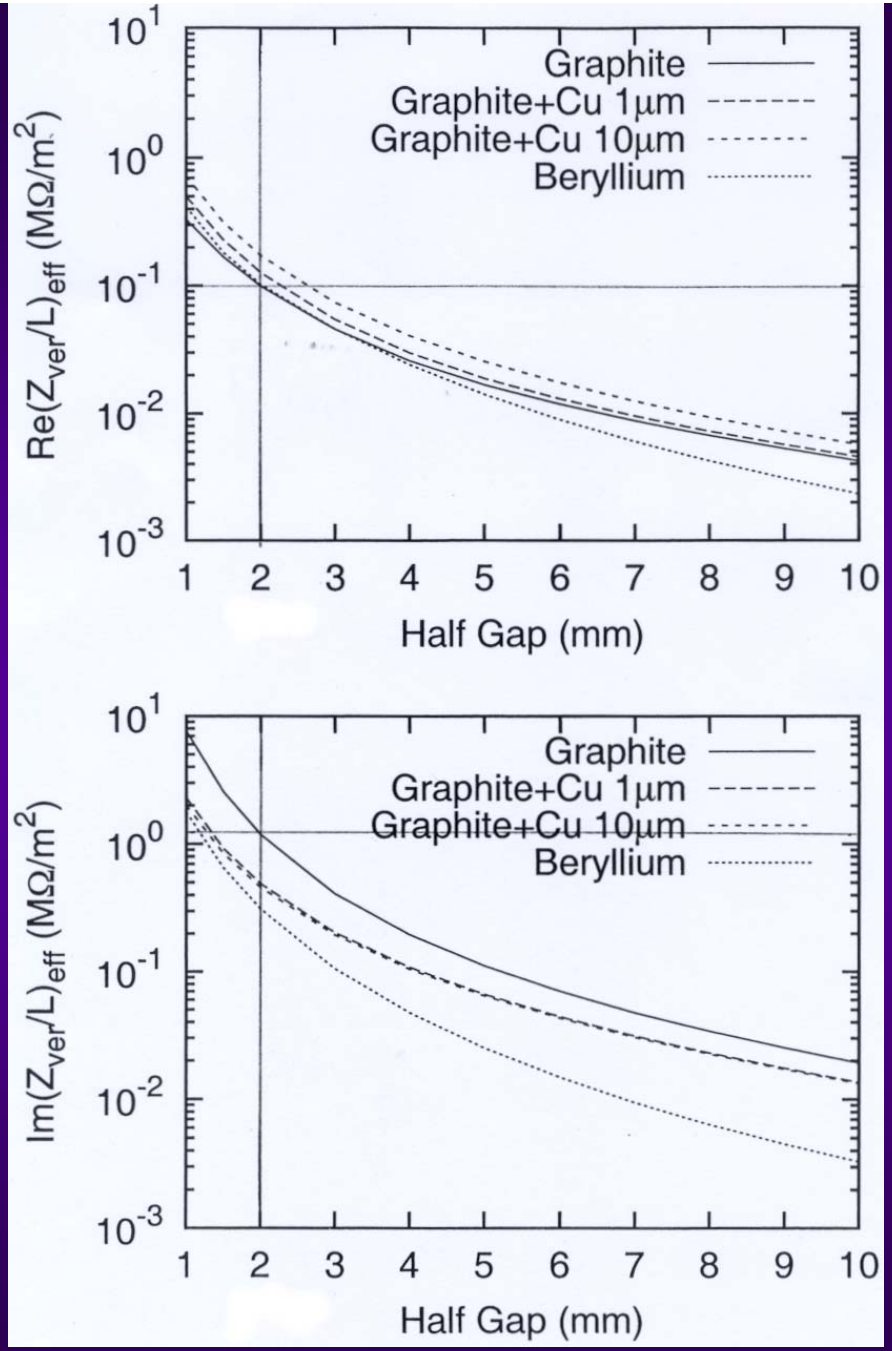
- **HFSS simulation by Tsutsui**

- **Results obtained using Vos formalism**

$$a = 2 \text{ mm}$$

$$\Rightarrow \quad \mathrm{Re}\left(Z_{\mathrm{ver}} / \mathrm{L} \right)_{\mathrm{eff}} \approx 0.09 \ \mathrm{M\Omega / m^2}$$

$$\mathrm{Im}\left(Z_{\mathrm{ver}} / \mathrm{L} \right)_{\mathrm{eff}} \approx 1.2 \ \mathrm{M\Omega / m^2}$$



Stability diagram and coherent tune shifts

- **Old situation (LHC Design Report, CERN-2004-003)**
  - IR7 : 20 collimators
  - IR3 : 7 collimators

  ⇒ 27 collimators in total = 5 P + 22 S

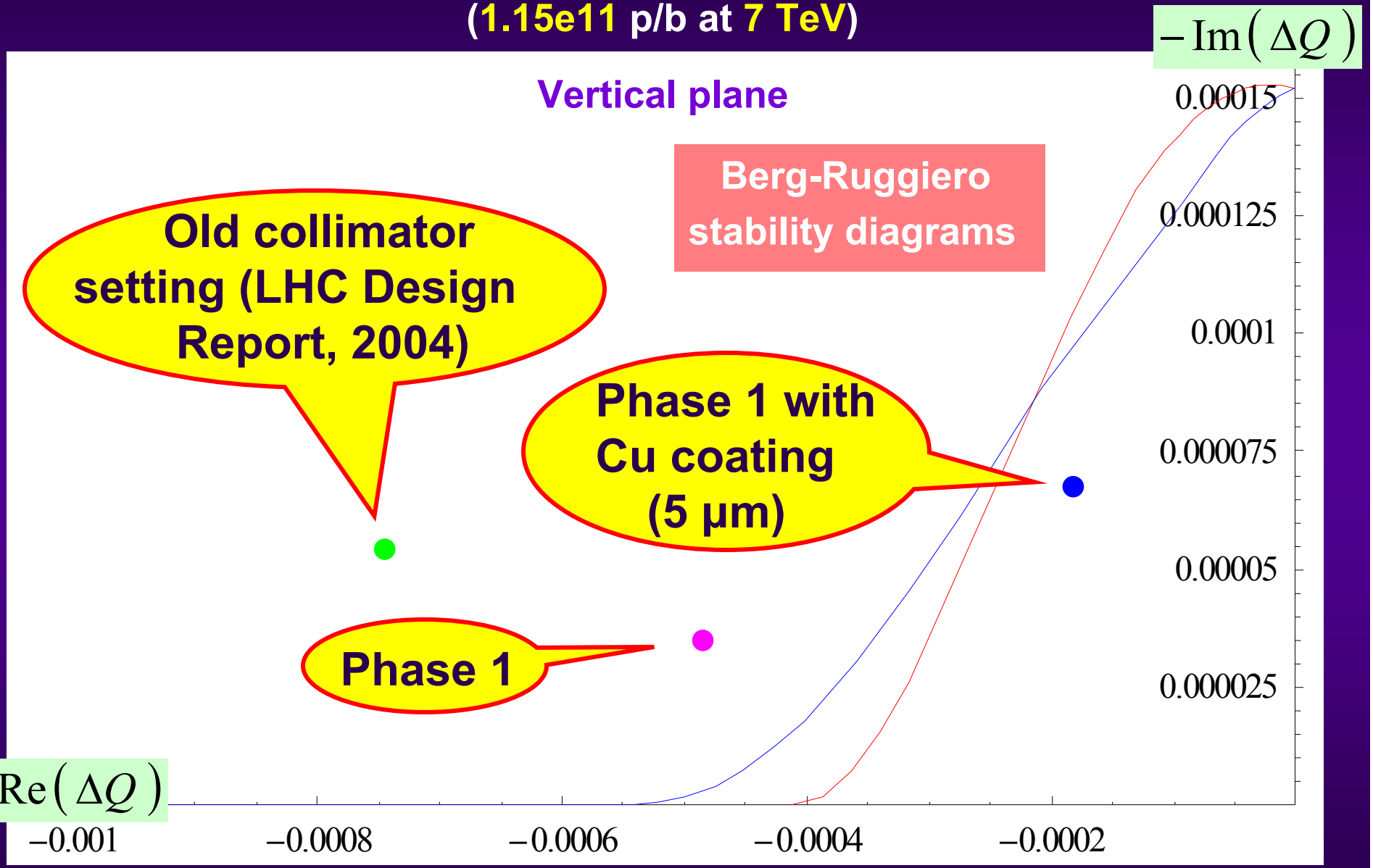
- **New situation = Present baseline for Phase 1**
  - IR7 : 3 P + 11 S = 14 collimators
  - IR3 : 1 P + 4 S = 5 collimators

  ⇒ 19 collimators in total = 4 P + 15 S

~ - 30% in number and length

Primaries contribute ~ 5% of the effective impedance

Stability diagram (maximum octupoles) and collective tune shift for the most unstable coupled-bunch mode and head-tail mode 0 (1.15e11 p/b at 7 TeV)



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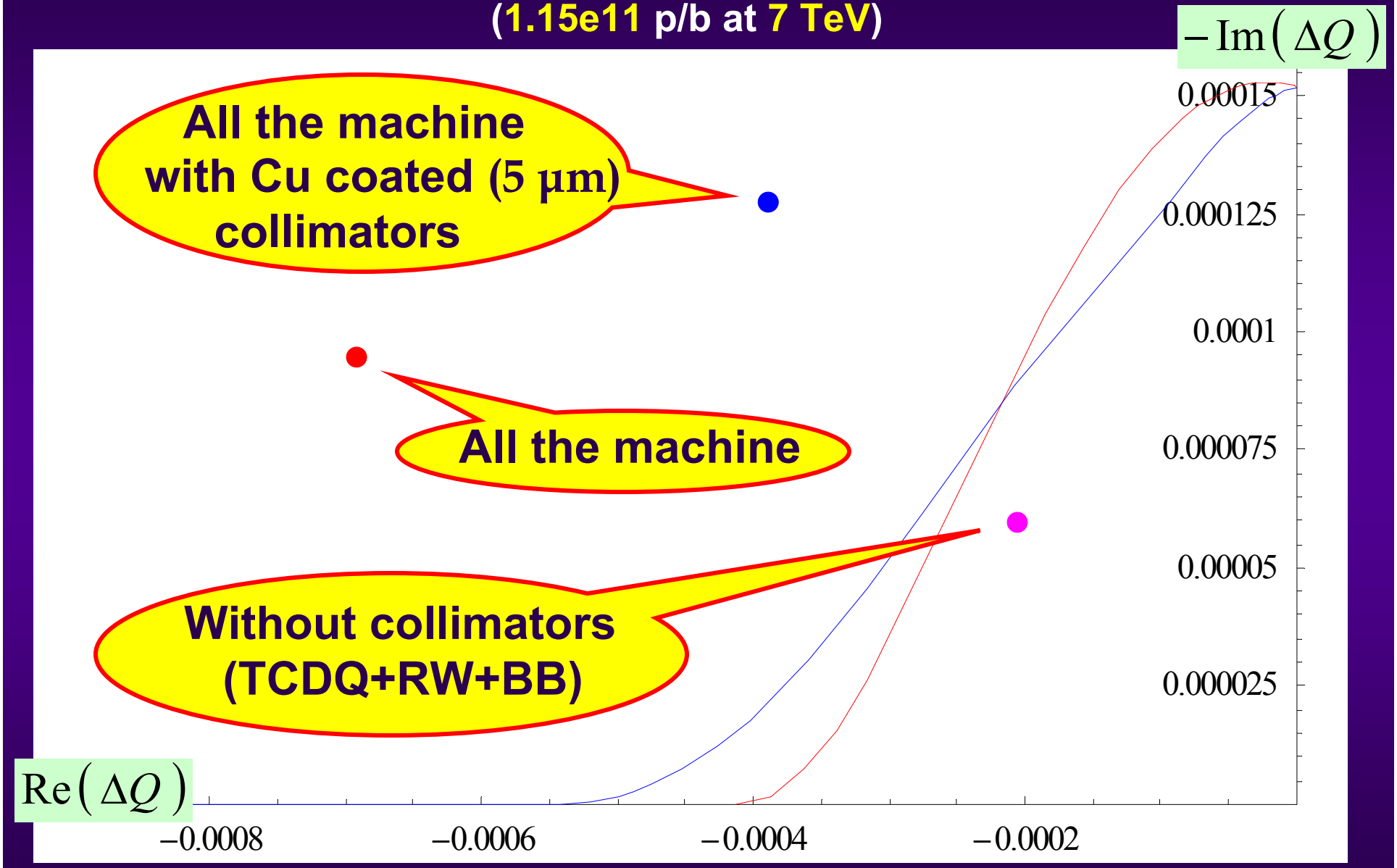
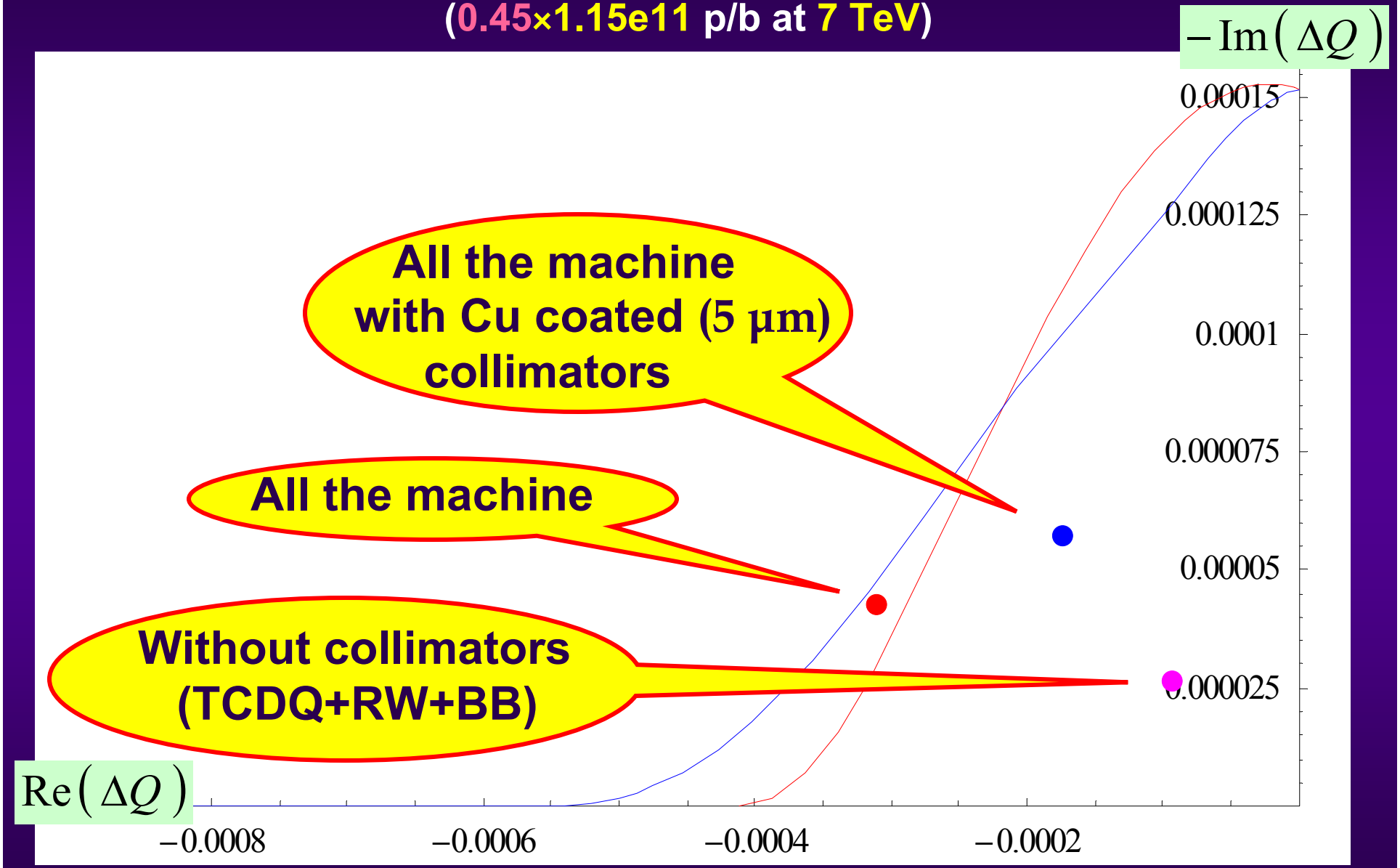
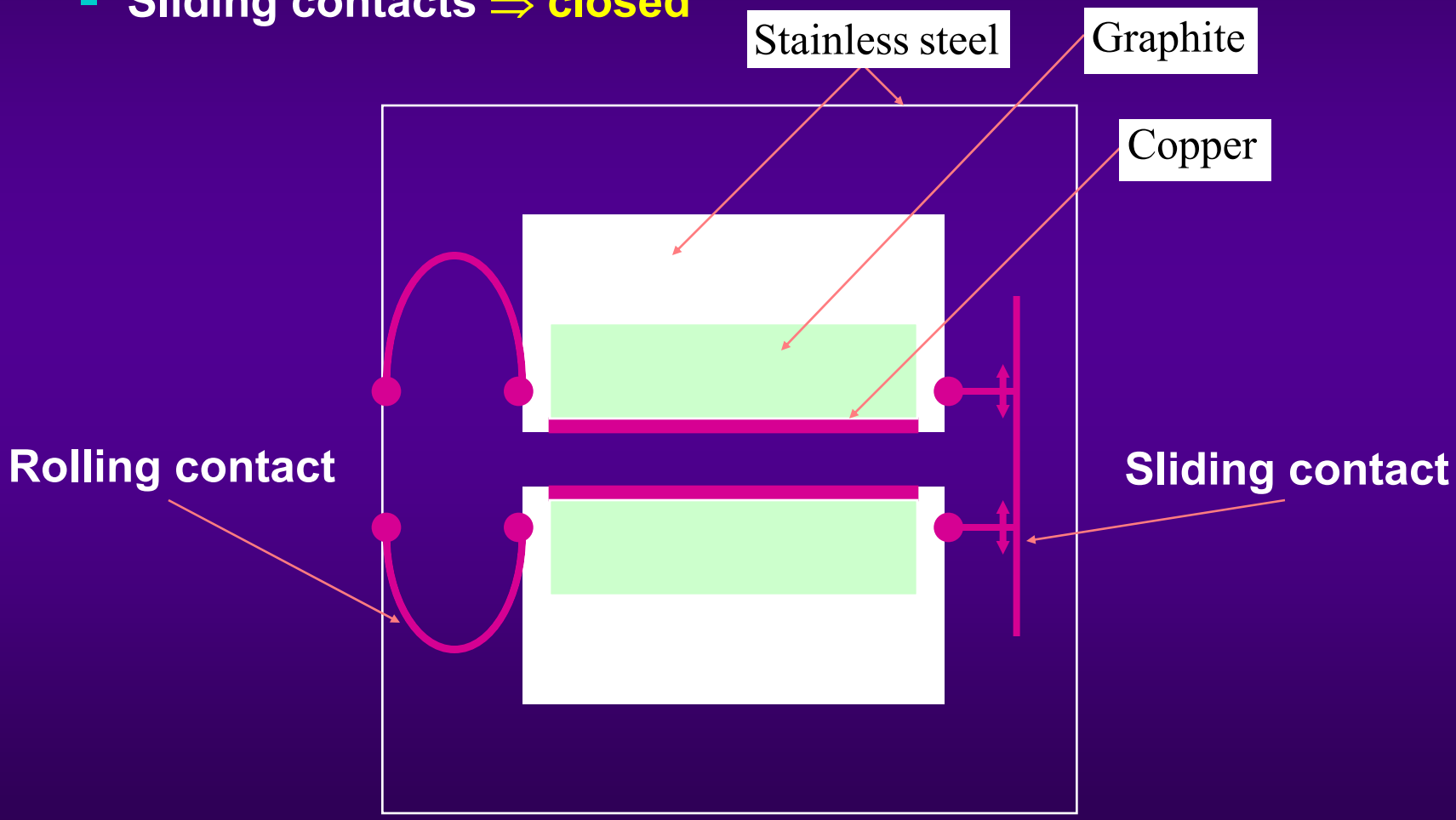


Stability diagram (maximum octupoles) and collective tune shift for the most unstable coupled-bunch mode and head-tail mode 0 (0.45×1.15e11 p/b at 7 TeV)

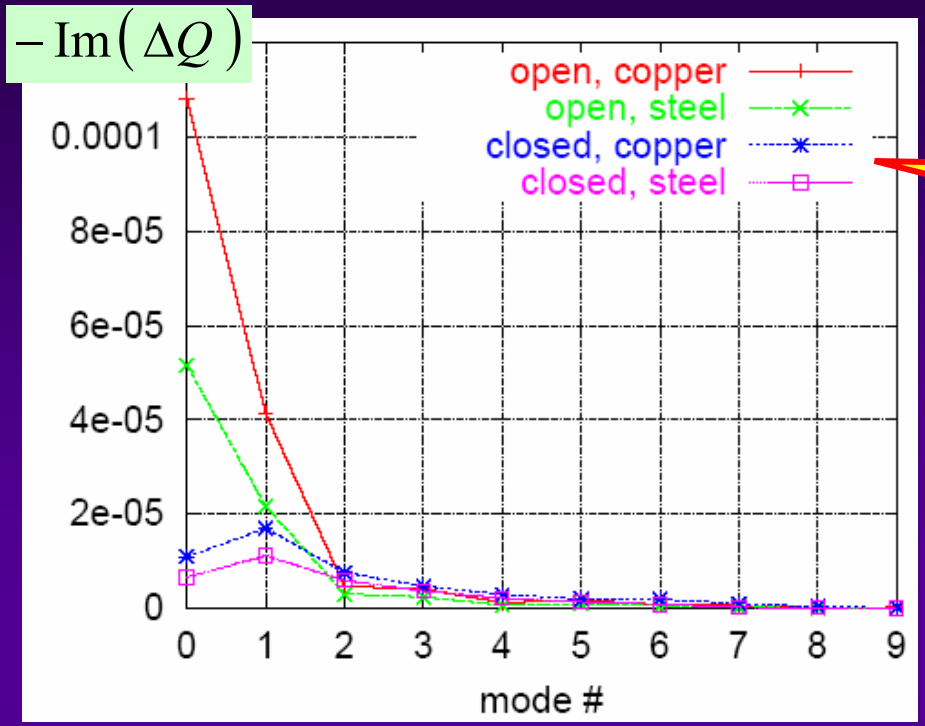


Trapped modes (1/2)

- 2 options to connect the collimator jaws to each other and to the tank have been simulated with GDFIDL
  - Rolling contacts (based on a flexible conductor) ⇒ open
  - Sliding contacts ⇒ closed



Trapped modes (2/2)



Copper ⇔ Everything is in Copper

For 1 collimator with

$a = 1.3$ mm

- **The rolling contact is more stable mechanically, but it gives rise to a cavity, where trapped modes are excited**
- **Inner surface of tank and outer surface of collimator is better if made from stainless steel**
- **Maximum (pessimistic) heat load of 700 W for collimator with sliding contacts and stainless steel (1100 W if copper)**

Conclusion and outlook

- The computations presented here for the resistive-wall impedance were made using Vos formalism, which is in good agreement with Burov-Lebedev theoretical results and Tsutsui simulations with HFSS
- A measurement campaign is planned for this year with an LHC collimator prototype
  - Beam-based measurements in the CERN SPS
  - Bench measurement using a vibrating wire method
- Concerning the trapped modes, stainless steel and sliding contacts should be used
- Only ~40% of the nominal beam intensity is stable with Phase 1 !