VHE-LHC: first study of the effect of beam screens resistive-wall impedance

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Outline

- Beam screens resistive-wall impedance
- Parameters used
- Study of VHE-LHC coupled-bunch effects and TMCI at top energy and injection
- Conclusion

Beam screens resistive-wall impedance

- Assumptions:
  - Round & in copper, maintained below 20K (as LHC beam screens)
    Note: conductivity gain from 20K to 5K neglected, anyway at this temperature conductivity dominated by purity level.
  - Resistivity depends on B field (magnetoresistance – see also E. Métral, HE-LHC10, 15/10/2010). We use the formula (C. Rathjen, CERN EDMS 329882)

$$\rho(B)=\rho(B=0)(1.0048+0.0038\cdot B\cdot RRR)$$

with (F. Caspers et al, EPAC'00, p. 376)

$$\rho(B=0)=2.4\ 10^{-10}\ \Omega.\mathrm{m} \text{ and } RRR = 70$$

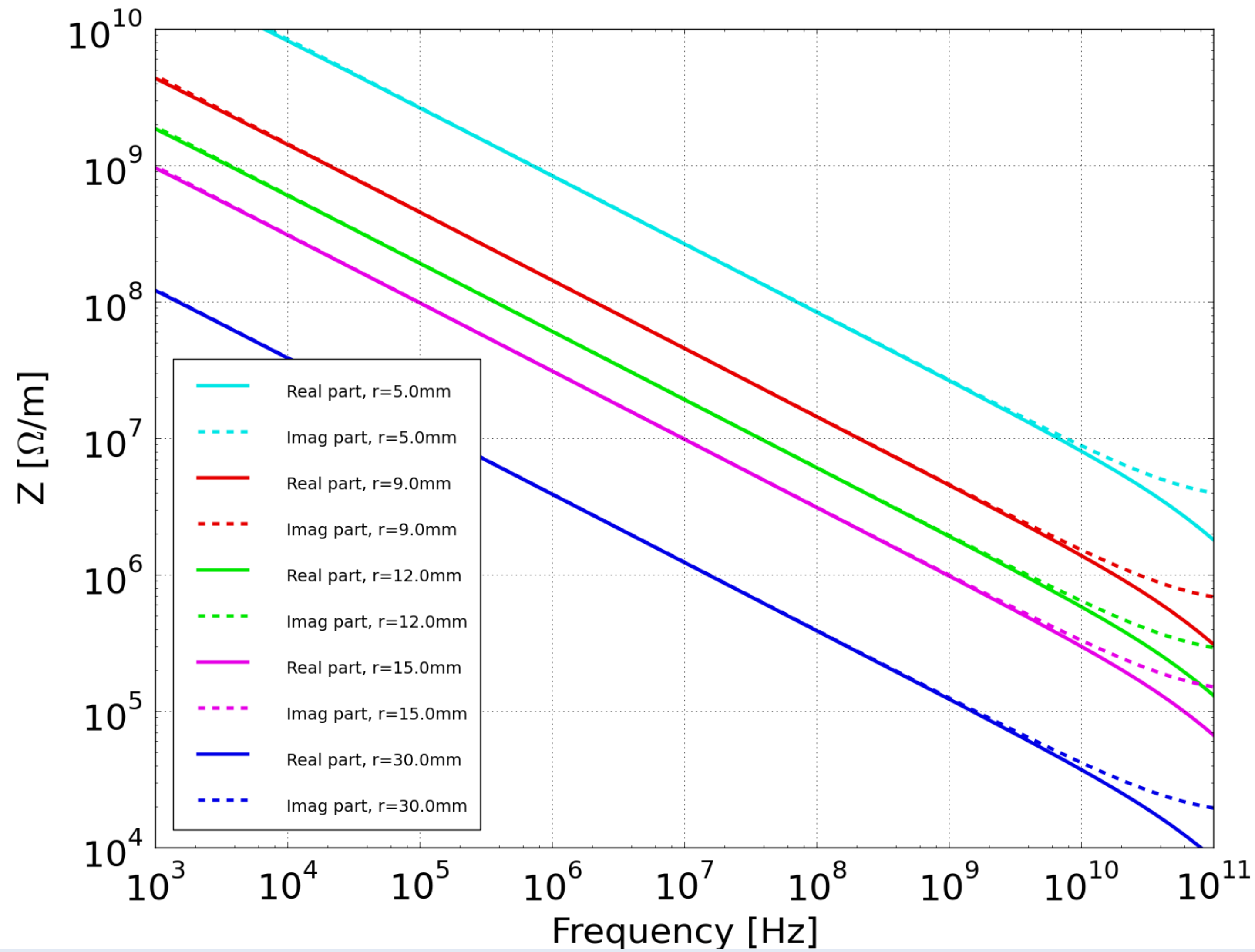
  - We obtain, for 100km circumference (including 12*1440m straight section and only 78% of arcs filled by dipoles):

$\rightarrow$ at 50 TeV, B=16.2 T & $\rho=12.7\ 10^{-10}\ \Omega.\mathrm{m}$

$\rightarrow$ at 3 TeV, B=1 T & $\rho=3\ 10^{-10}\ \Omega.\mathrm{m}$

Beam screens resistive-wall impedance

- Total dipolar impedances of beam screens of various radii (computed with ImpedanceWake2D analytical code – round geometry):



Effect of beam screens RW impedance

- Parameters used (from D. Schulte + simple scaling from LHC for optics & RF parameters → very preliminary):

	Injection	Top energy
Energy	3 TeV	50 TeV
RF voltage	12 MV	64 MV
Q_s	$2.43\ 10^{-3}$	$1.37\ 10^{-3}$
Bunch length (RMS)	8 cm	8 cm
Q_x	120.9	
Q_y	120.9	
Circumference	100 km	
α_p	$6.9\ 10^{-5}$	

Energy and RF voltage → 400 MHz cavity (LHC)

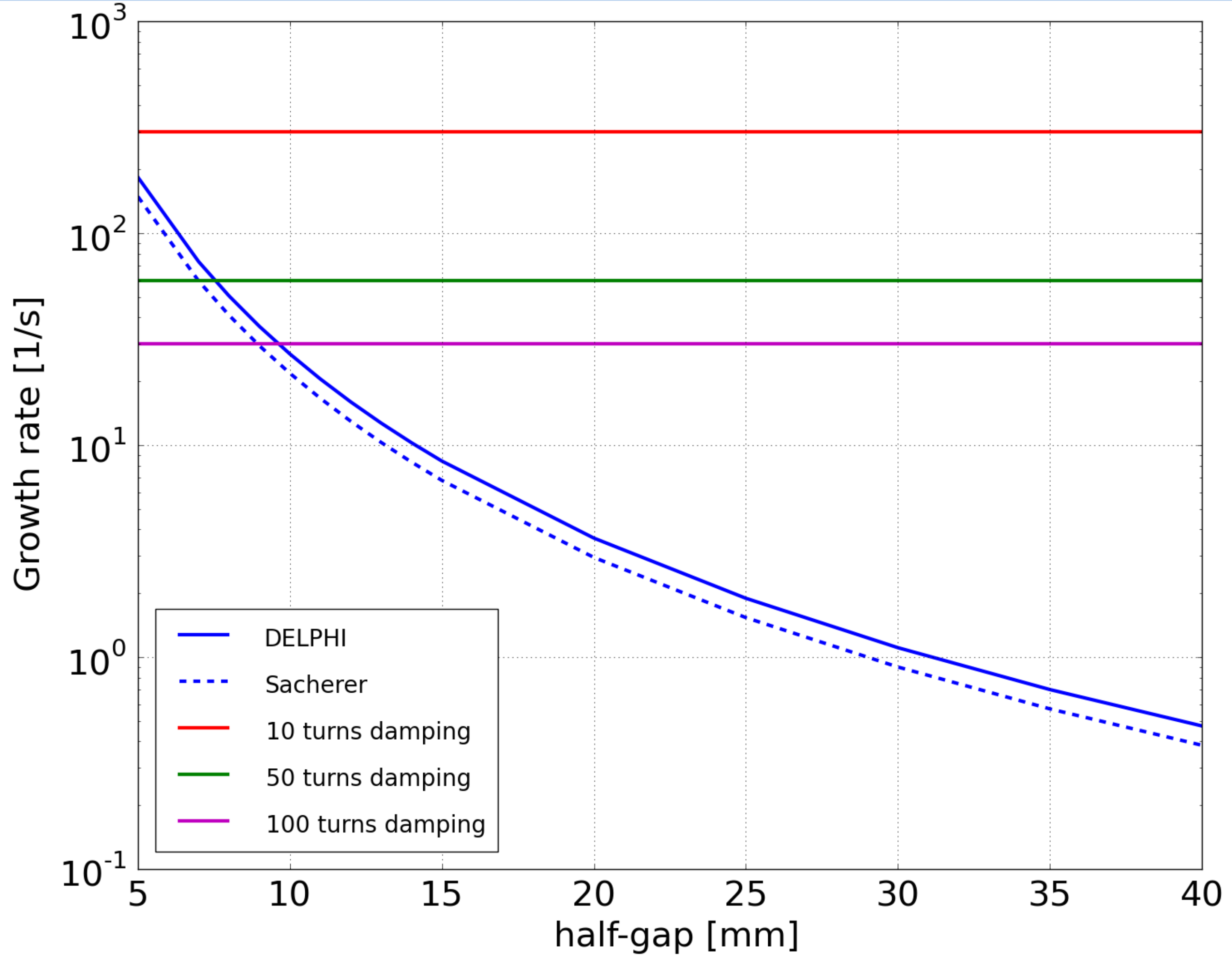
Q_x and Q_y → From $\beta \propto E^{1/3}$ and $\beta \sim R/Q$ (fractional part 0.9 → pessimistic for coupled-bunch effects).

α_p → From $\gamma_t \sim Q$

- Beam dynamics with impedance studied thanks to Sacherer formula (sinusoidal modes) and / or semi-analytical Vlasov solver DELPHI.

Effect of beam screens RW impedance: top energy

- 50 TeV, 13344 bunches (25ns), 10^{11} p+/b, Q'=0: growth rate of most unstable coupled-bunch mode vs radius:

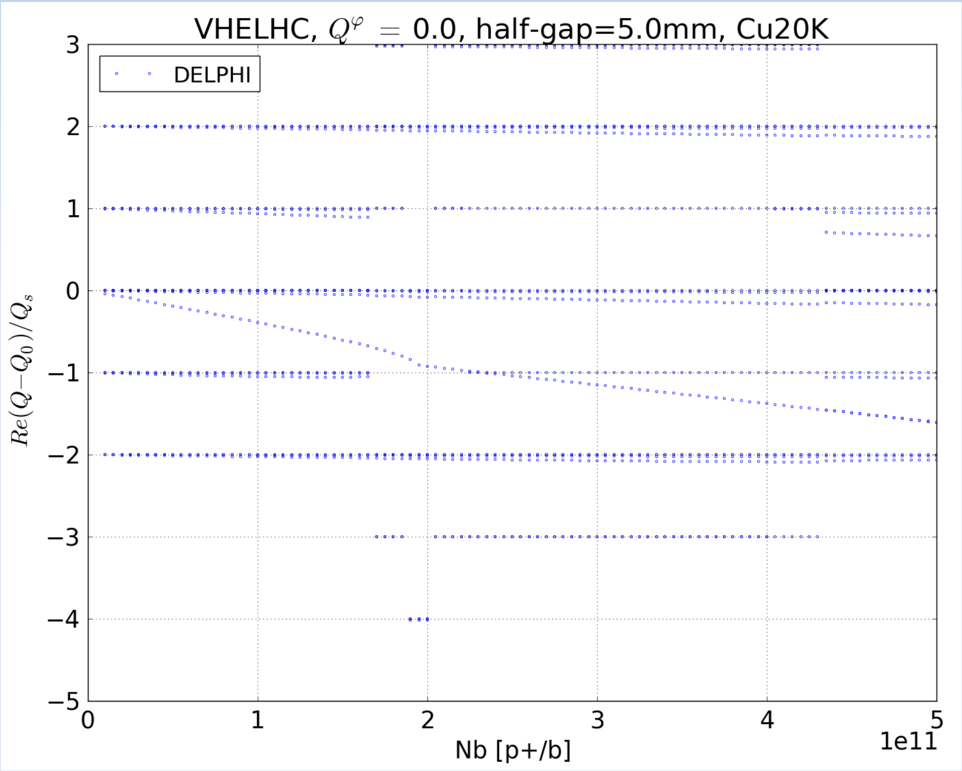


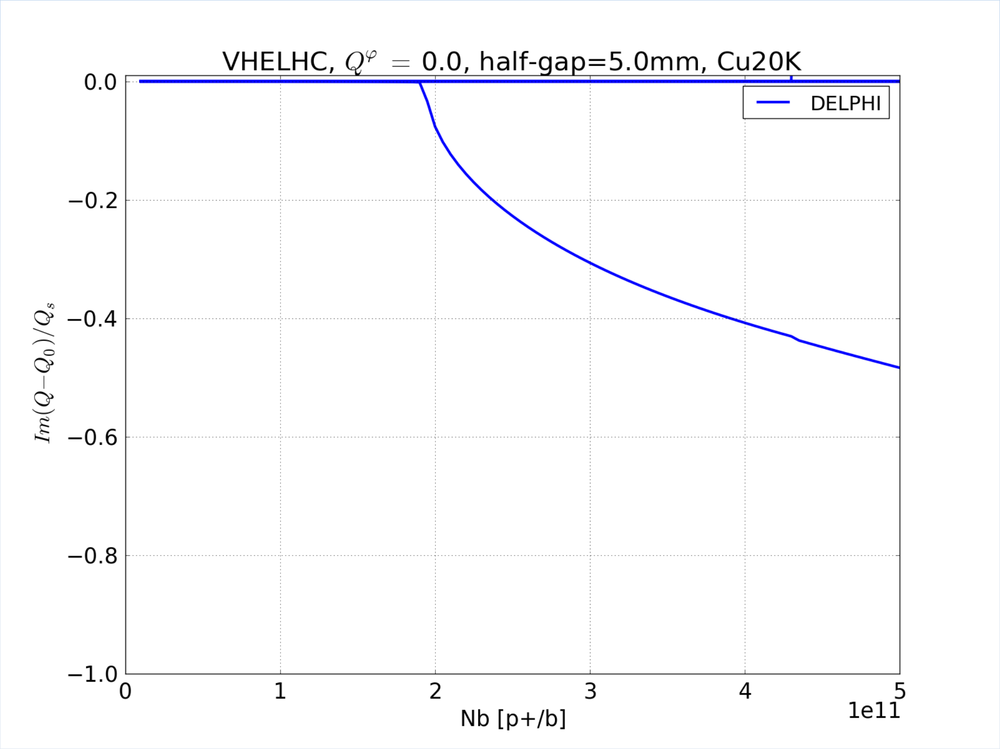
→ 100 turns bunch-by-bunch damper should be enough for radius > 1cm

→ this depends on total beam intensity only, so 5ns and 50ns with resp. 2.10^{10} and 2.10^{11} p+/b, give the same result.

Effect of beam screens RW impedance: top energy

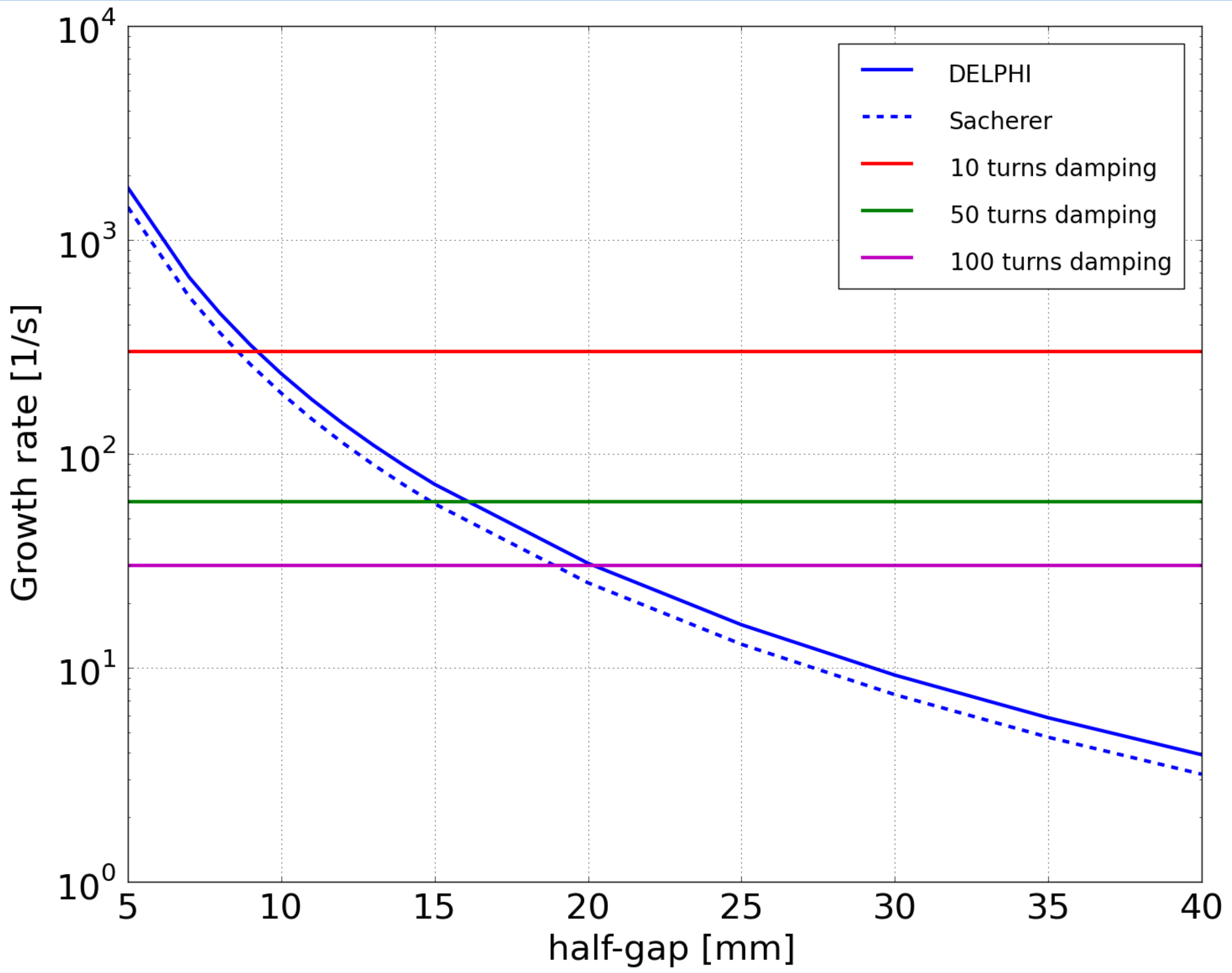
- 50 TeV, single bunch (Q'=0) TMCI threshold below 2 10^{11} p+/b only for very small radius (<5mm):





Effect of beam screens RW impedance: injection energy

- 3 TeV, 13344 bunches (25ns), 10^{11} p+/b, Q'=0: growth rate of most unstable coupled-bunch mode vs radius:

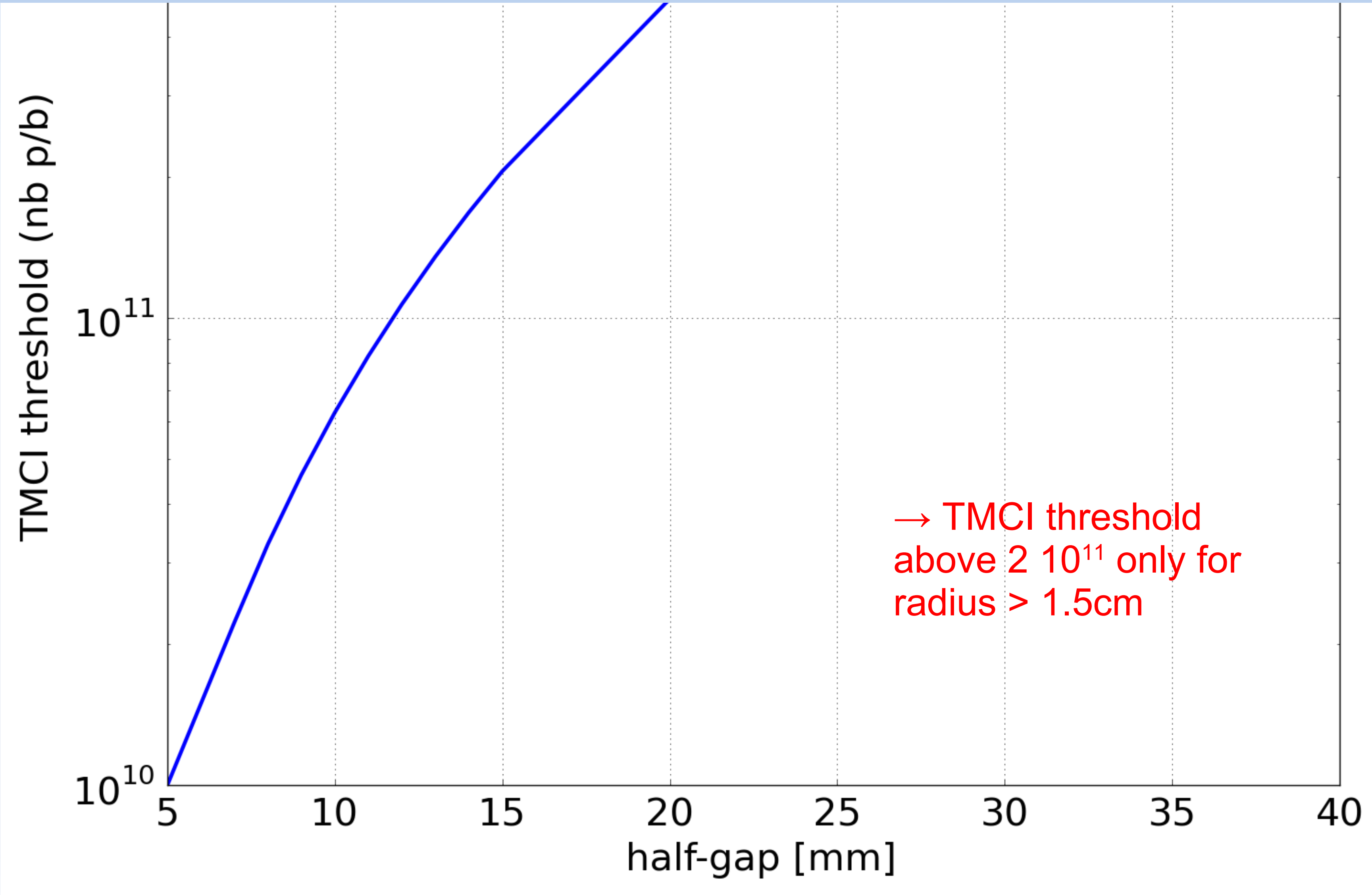


→ 100 turns bunch-by-bunch damper should be enough for radius > 2cm

→ this depends on total beam intensity only, so 5ns and 50ns with resp. 2.10^{10} and 2.10^{11} p+/b, give the same result.

Effect of beam screens RW impedance: injection energy

- 3 TeV, single bunch (Q'=0) TMCI threshold vs. radius:



Summary

- *Parameters chosen (in particular Q_s) still preliminary.*
- Effect of resistive-wall impedance of a round beam pipe in cold copper (including magnetoresistance) studied:
  - TMCI threshold: limitation at injection if radius<1.5cm,
  - Coupled-bunch (rigid bunch) modes for Q'=0: bunch-by-bunch 100 turns damper should be able to take care of them if radius > 2cm (less if higher damping rate).
- Effect of beam screens pumping holes on the total impedance not taken into account yet. In the LHC, it is a significant contribution (in particular for TMCI threshold).

Additional considerations

- Concerning the beam screens temperature:
  - If the beam screens are maintainted at 100K (instead of 20K): From Kohler's law (see in E. Métral, HE-LHC10, 15/10/2010)

$$\rho(B,T)=\rho(B=0,T)\left(1+10^{-2.69}B\cdot\left(\frac{\rho(B=0,T=273\mathrm{K})}{\rho(B=0,T)}\right)^{1.055}\right)$$

assuming (CRC Handbook of Chemistry and Physics – pure copper)

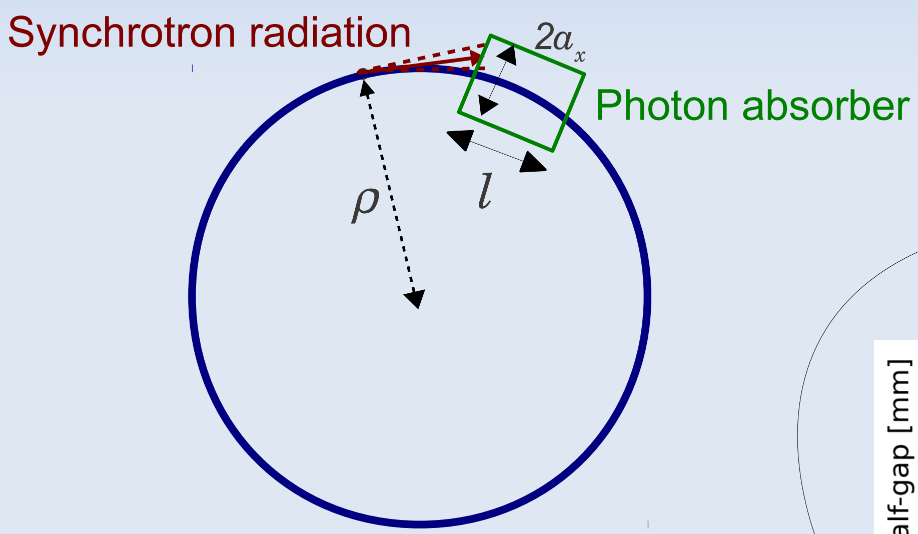
$$\rho(B=0,T=100K)=0.35\ 10^{-8}\ \Omega.\mathrm{m}$$

$$\rho(B=0,T=273K)=1.5\ 10^{-8}\ \Omega.\mathrm{m}$$

  - The effect of magnetoresistance becomes much smaller (relatively) but overall the resistivity is significantly higher: $\rho \sim 35\ 10^{-10}\ \Omega.\mathrm{m}$.
  - Then, from simple scaling laws ($Z \propto \rho^{1/2}/b^3$), the minimum acceptable radius (from the TMCI limitation at injection) would become 2.3cm (instead of 1.5cm).

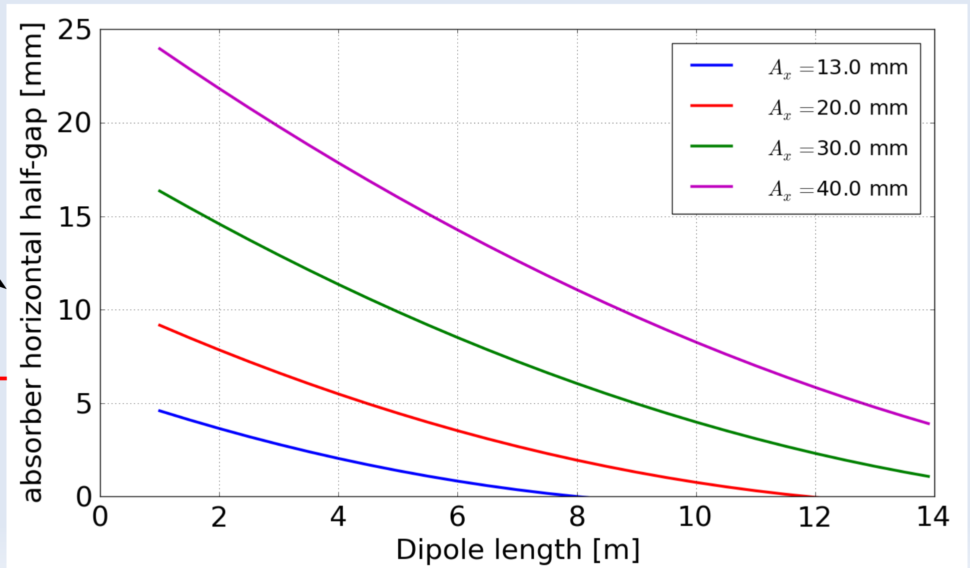
Additional considerations

- Concerning the possible use of photon absorbers to intercept synchrotron radiation (instead of beam screens):
  - using a very simple model (neglecting any straight sections) we can compute the absorber aperture to intercept all (primary) photons from the dipoles:



Abs. hor. aperture a_x depends on dipole length l_d and on hor. aperture A_x of the main pipe:

$$a_x = \rho\left(\frac{\cos\left(\frac{1}{\gamma}\right)}{\cos\left[\arccos\left(\frac{\rho\cos\left(\frac{1}{\gamma}\right)}{\rho+A_x}\right)+\frac{l-l_d}{\rho}-\frac{2}{\gamma}\right]}-1\right).$$



→ Can be very close to the beam, depending on dipole length and pipe hoizontal aperture.
→ Impedance could be high (one photon absorber / dipole, made of a potentially bad conductor ...).