Single Beam Collective Effects

Impedances and Collective Effects for FCC-hh

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With a lot of input from:
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T. Egenolf, F. Petrov, O. Boine-Frankenheim, TUD

Contents

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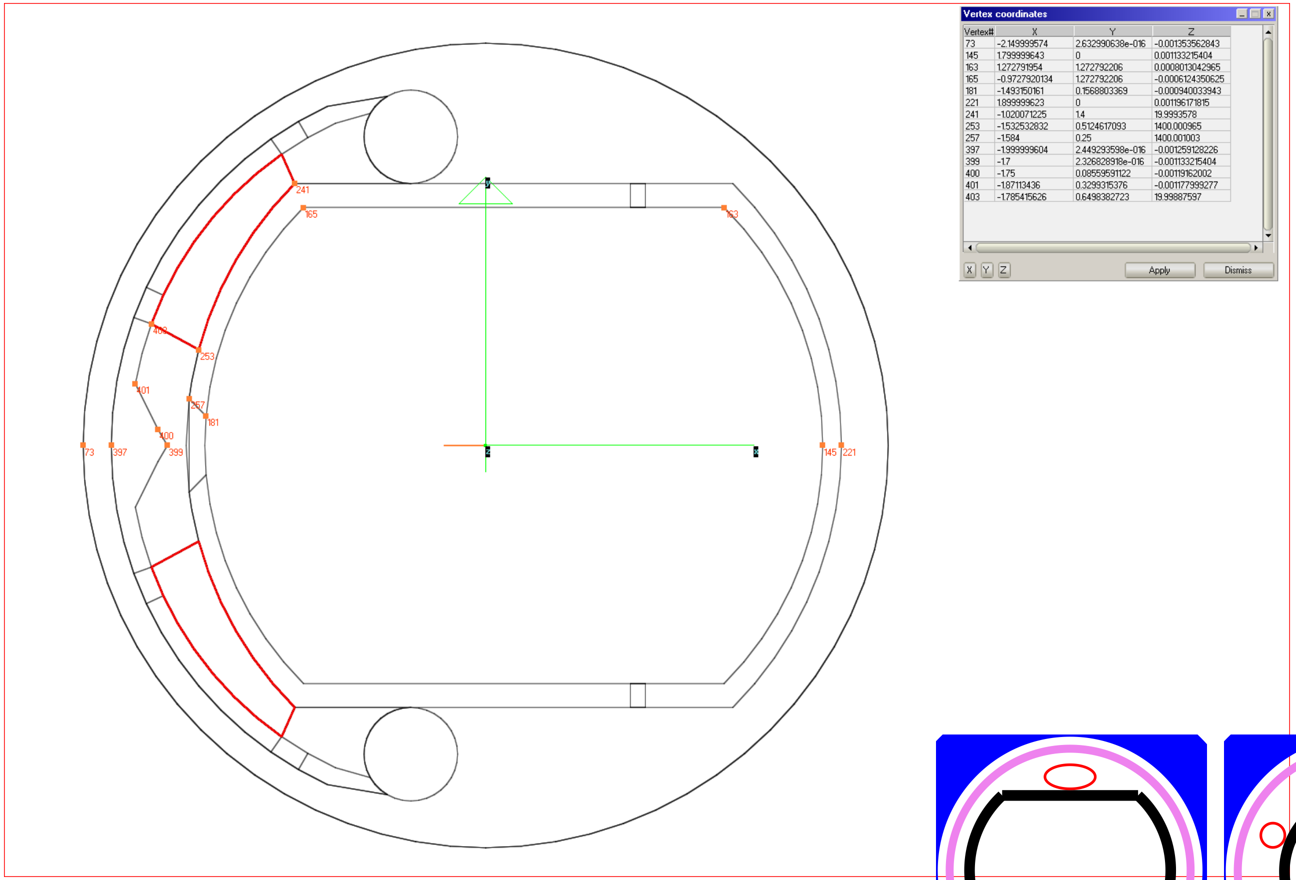
As discussed in Washington:

- Beam pipe impedance
- Other impedance sources
- Coupled bunch instability
- Transverse Mode Coupling Instability (TMCI) threshold

Few new things and issues to be discussed:

- Which components?
- Details on the pipe…
- Plans, codes, outlines, timelines
  →Collimators!!! Pipe aperture!!!

The beam pipe



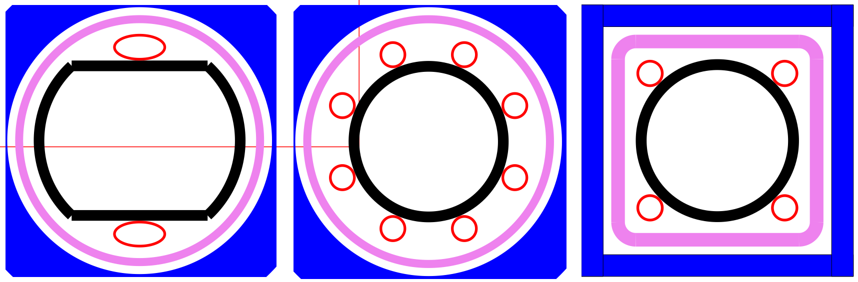
Vertex coordinates

Vertex#	X	Y	Z
73	-2.149999574	2.632990638e-016	-0.001353562843
145	1.799999643	0	0.001133215404
163	1.272791954	1.272792206	0.0008013042965
165	-0.9727920134	1.272792206	-0.0006124350625
181	-1.493150161	0.1568803369	-0.000940033943
221	1.899999623	0	0.001196171815
241	-1.020071225	1.4	19.9993578
253	-1.532532832	0.5124617093	1400.000965
257	-1.584	0.25	1400.001003
397	-1.999999604	2.449293598e-016	-0.001259128226
399	-1.7	2.326828918e-016	-0.001133215404
400	-1.75	0.08559591122	-0.00119162002
401	-1.87113436	0.3299315376	-0.001177999277
403	-1.785415626	0.6498382723	19.99887597

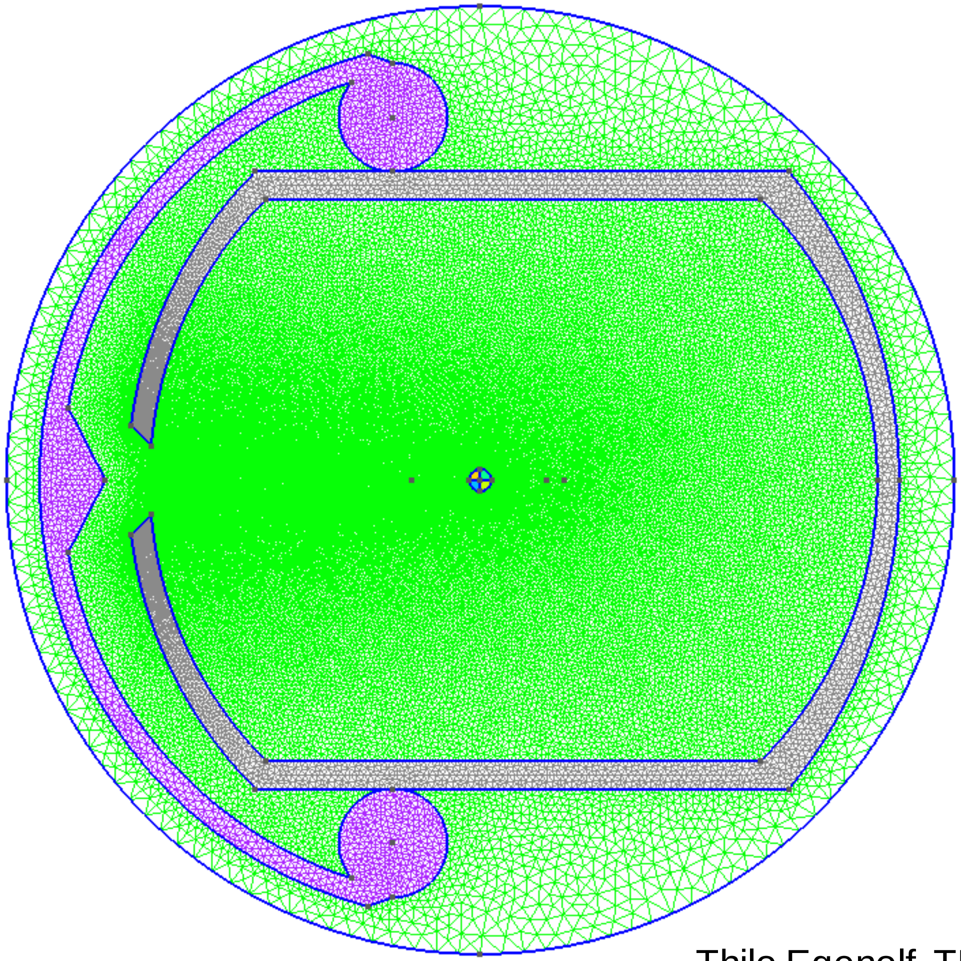
Design by R. Kersevan, CERN

So far only this design considered

D. Schulte



Discretization



GMSH (Geuzaine et al.)
triangular mesh

Meshing the whole structure is required only for extremely low frequency!

Otherwise: **S**urface **I**mpedance **B**oundary **C**ondition (SIBC)

Thilo Egenolf, TU Darmstadt

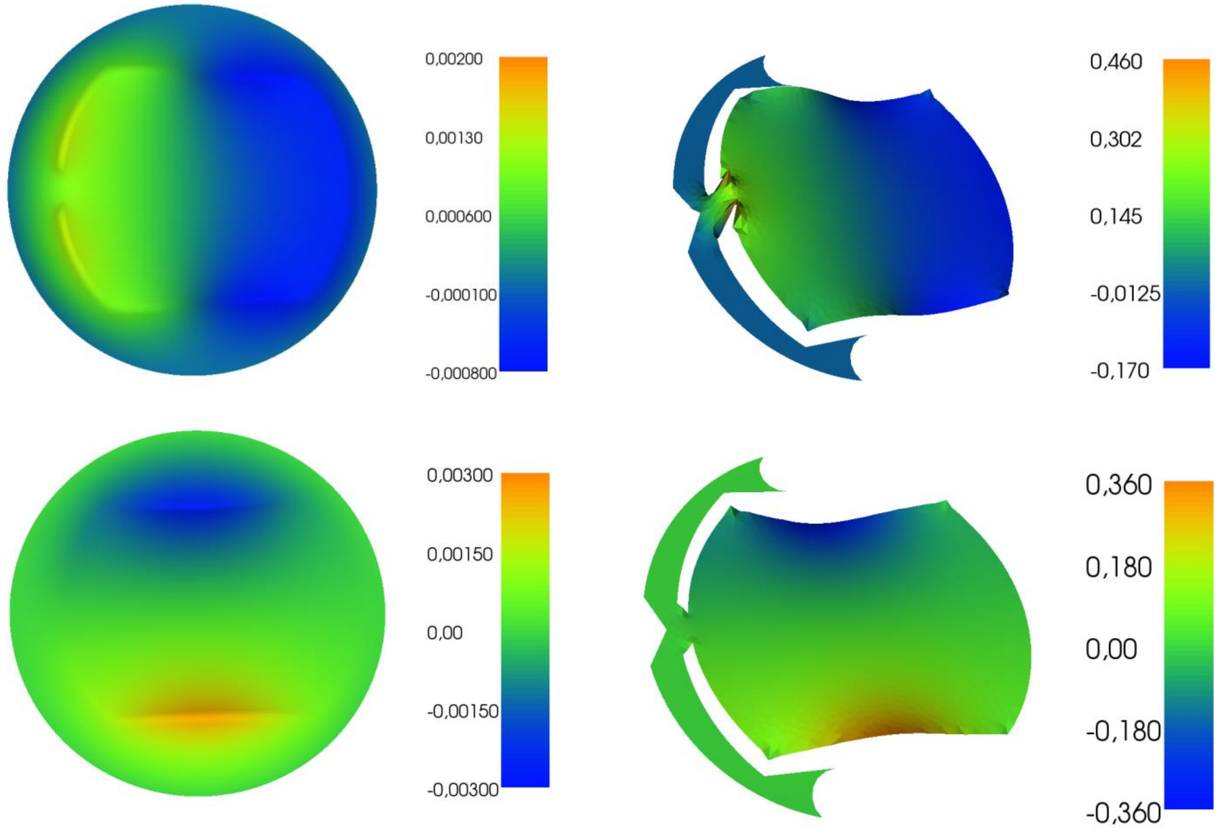
2D Simulations in the Frequency Domain

- BeamImpedance2D, PYTHON code using FEniCS finite element toolbox
  (U. Niedermayer et al., PRSTAB 18 032001, 2015)

$\mathrm{Re}\{E_z\}$

Horizontal

Vertical



f=100Hz

f=1MHz

Materials

- Beam Screen: Titanium
- Coating: Copper (80*u*m or maybe higher)
- Outer pipe, synchr. rad. reflector: Stainless Steel

- Conductivities k at room temperature T=293K

  -Titanium: k_0= 1.8 MS/m

  -Copper: k_0 = 60.0 MS/m

  -Stainless steel: k_0 = 1.4 MS/m

- RRR= k(T=4K)/ k(293K) usually RRR ~ 300
- Temperatures for the FCC pipe:

  -Scenario 1: 40-60 K (roughly… k =100 k_0)

  -Scenario 2: 120-160 K (roughly… k =10 k_0)
- Magnetoresistance at 16T ?

Penetration depth

- Surface impedance for coated surface

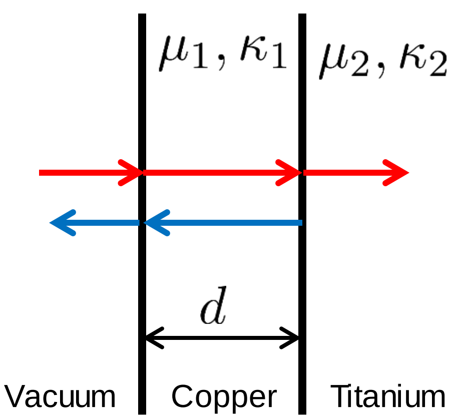
$$\delta = \sqrt{\frac{2}{\mu\kappa\omega}}$$

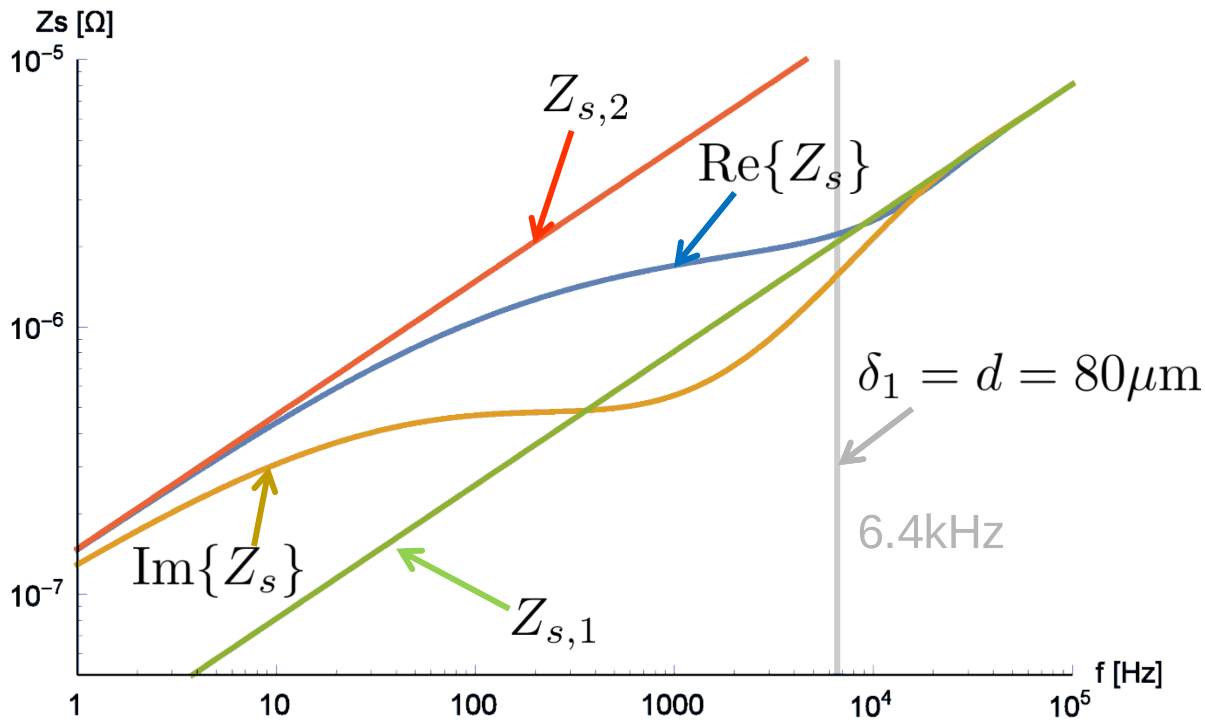
$$Z_s(\omega) = \left.\frac{E_x}{H_y}\right|_{z=0} = \frac{1+i}{\kappa_1\delta_1}\frac{Me^{ik_{z1}d}+Ne^{-ik_{z1}d}}{Me^{ik_{z1}d}-Ne^{-ik_{z1}d}}$$

$$k_z = \frac{1-i}{\delta}$$

$$M = 1 + \sqrt{\frac{\mu_1\kappa_2}{\mu_2\kappa_1}}$$

$$N = 1 - \sqrt{\frac{\mu_1\kappa_2}{\mu_2\kappa_1}}$$

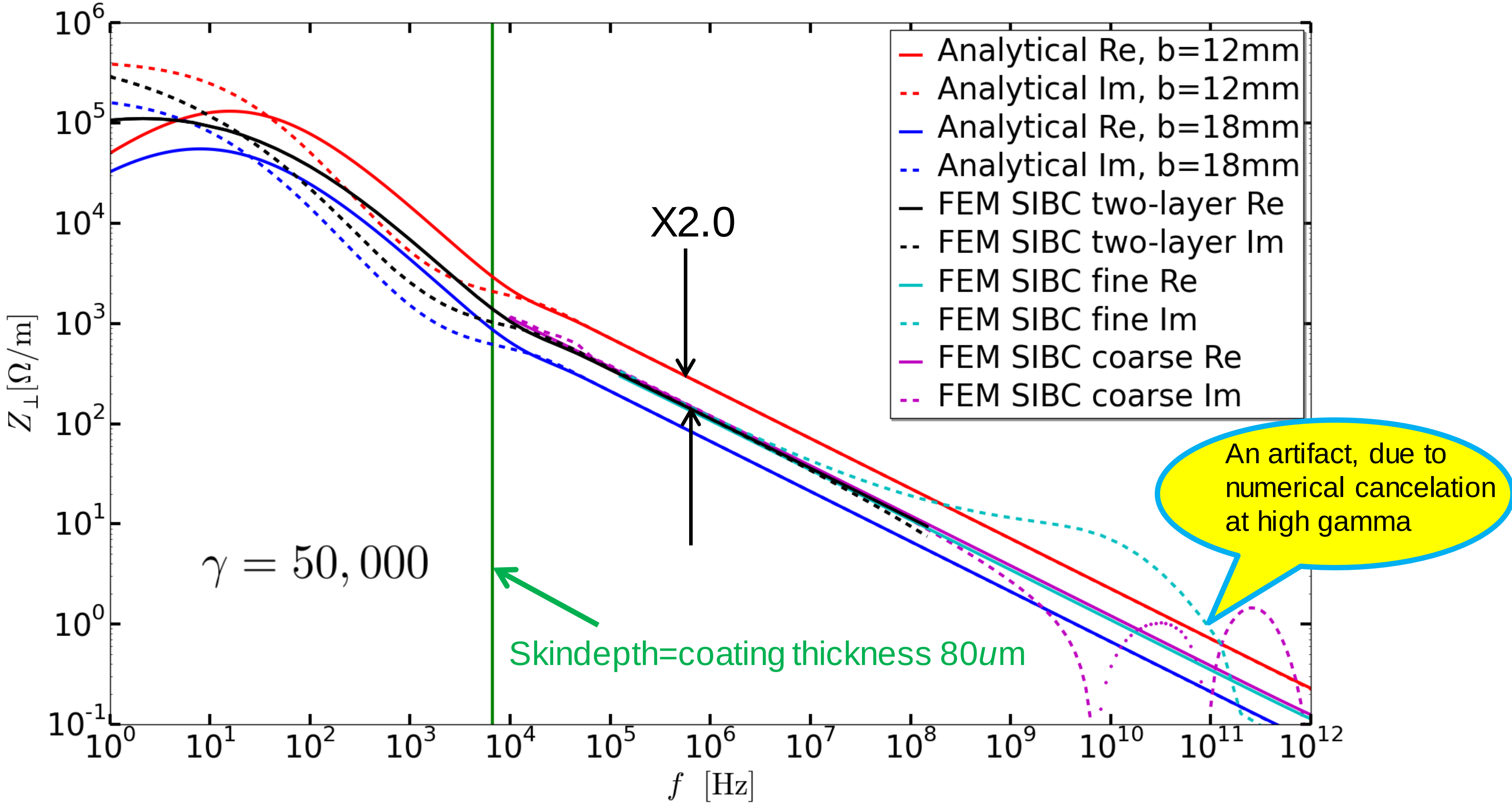




Comparison with round pipe impedance → Horizontal

(1 meter pipe)

Coating with Copper at 50K, *k*=6e9 S/m



Comparison with round pipe impedance → Vertical

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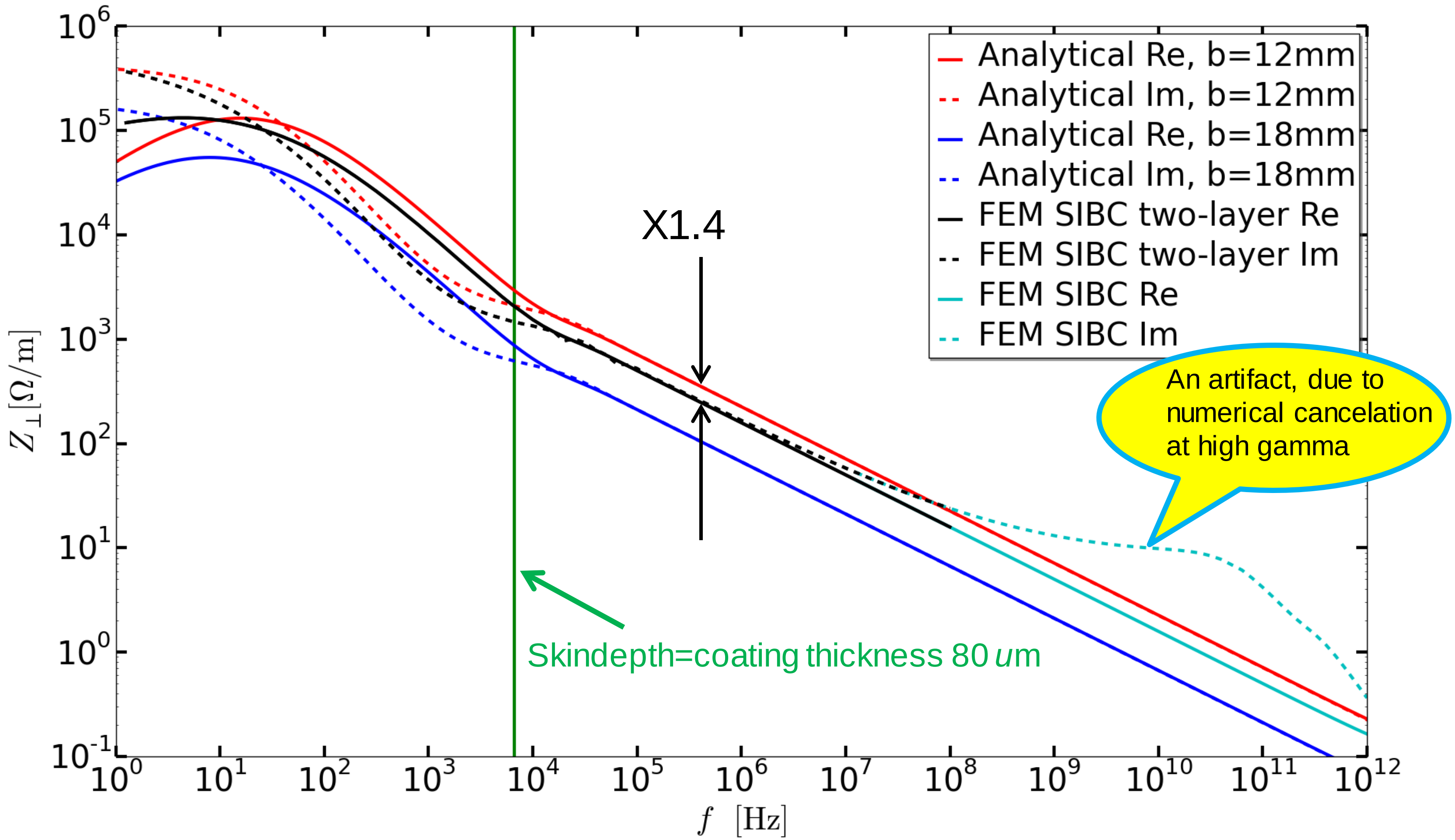
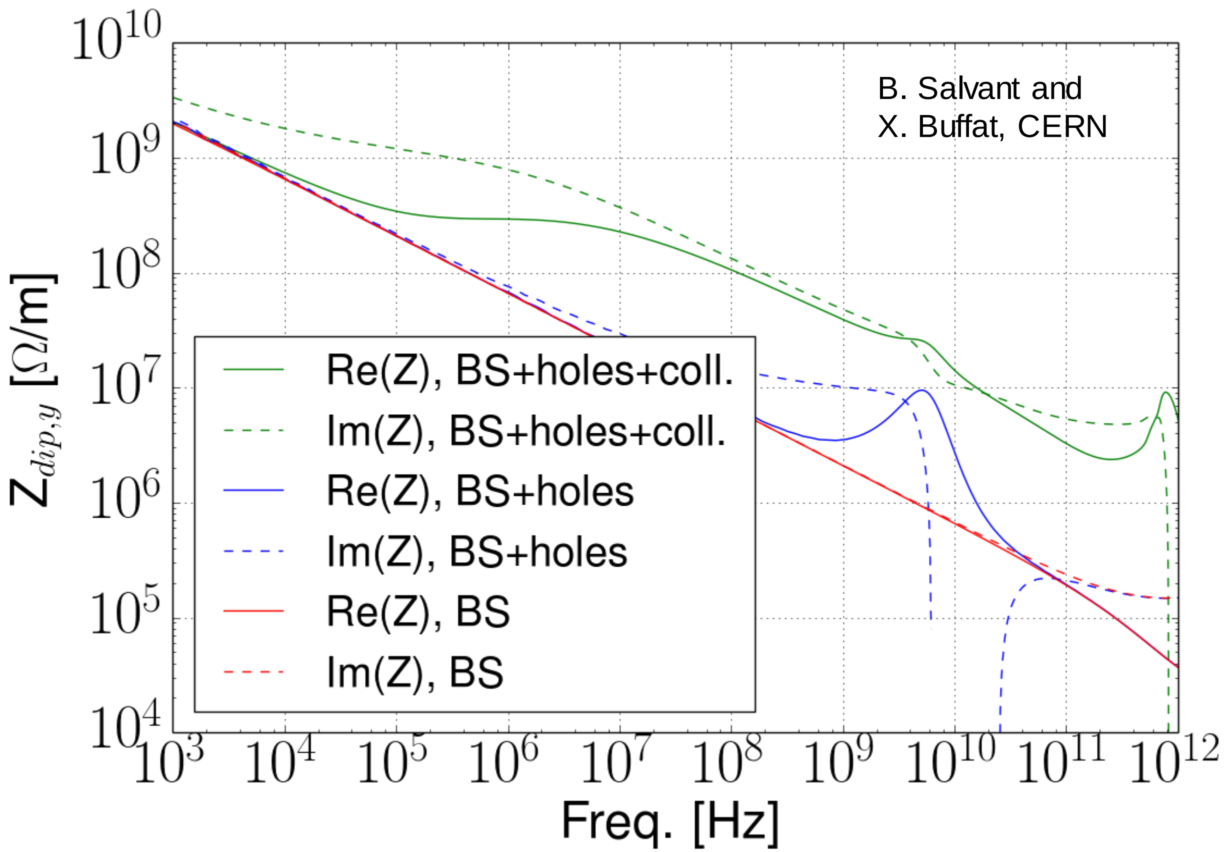
(1 meter pipe)



Pumping Holes, Collimators, …



Pumping holes with resonator model, ...
$f_{res}=f_{cutoff}$ ~6GHz
Q=1 (Broadband)

$$\frac{R}{Q} = 2Z_0\eta\frac{\alpha_e+\alpha_m}{\pi A b^3} \propto \frac{1}{b^4}$$

S. Kurennoy, *Part. Accel.*, 1995, Vol. 50, pp. 167-175

Collimators scaled from LHC, see also talk by M. Fiascaris (this morning)

Collimators closed only at top energy!

Maybe LHC-like carbon collimators are not the best choice…

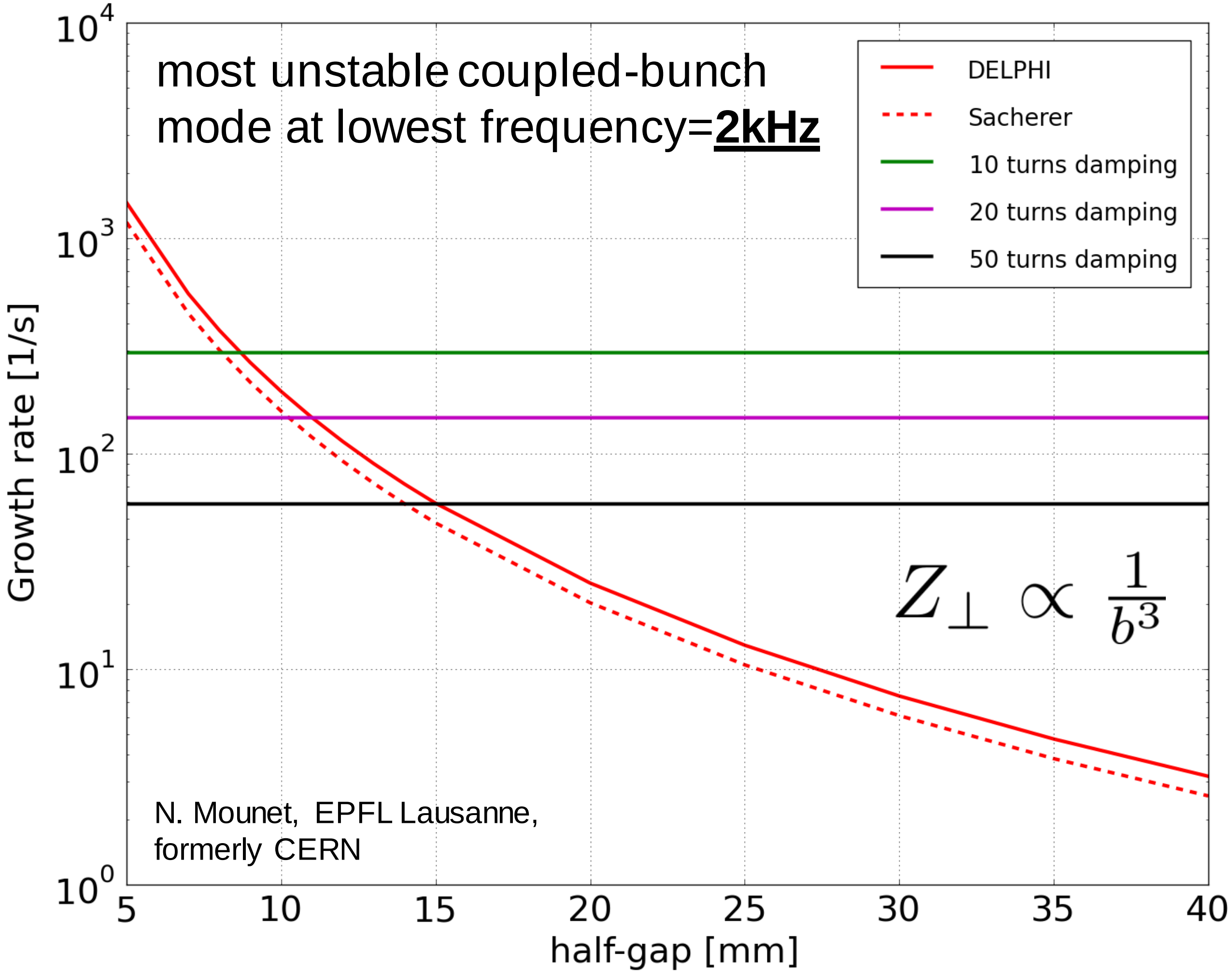
Scenario Data

- M=13344 (25ns)
- rms bunch length 8 cm
- N_b=1.0e11
- Q_x=120.31
- Q_y=120.32
- Chroma=0

- E=3TeV
- Q_s=0.0028

- E=50TeV
- Q_s=0.0078

Coupled bunch resistive instability



Most critical at injection due to less stiff beam!

Pipe only,
solid Cu 50K
E=3TeV

Growth rate by factor 1.6 higher for 80 *u*m coating

Required thickness for “thick wall“
150 *u*m for 50K
450 *u*m for 140K

TMCI intensity threshold 3TeV

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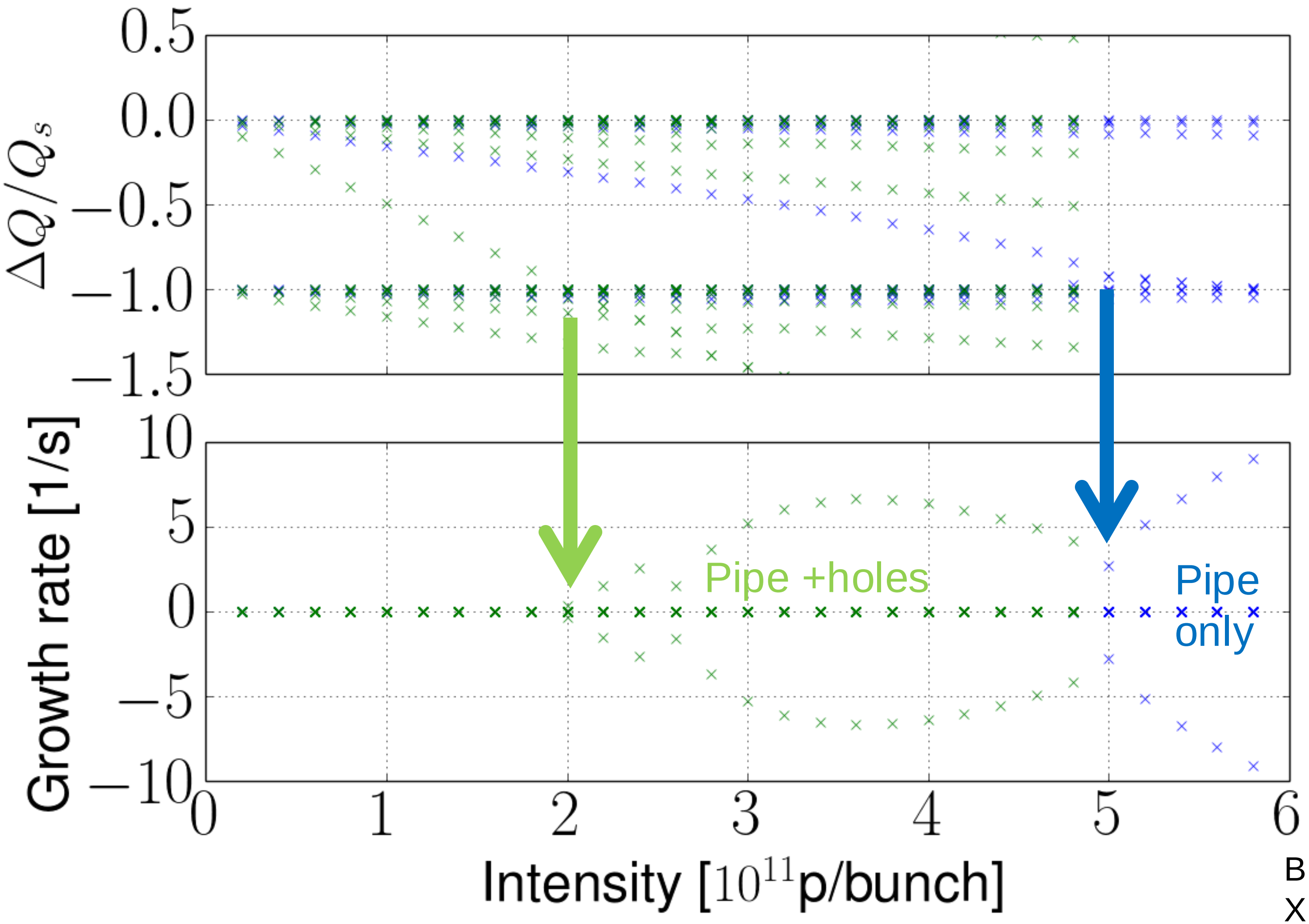

coherent tune shift of the mode

B. Salvant and X. Buffat, CERN

TMCI intensity threshold 50TeV

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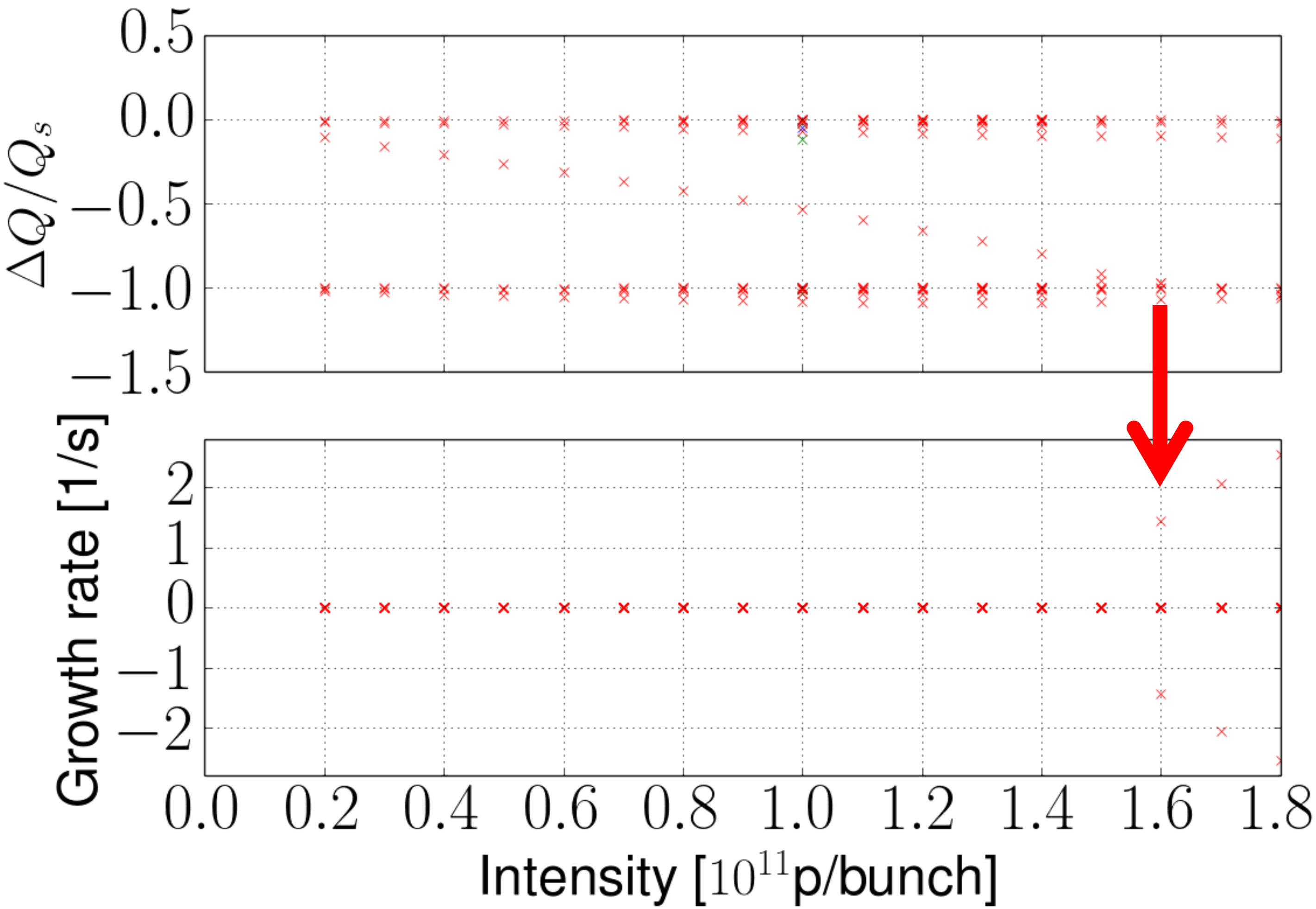


More stiff beam, but higher impedance due to closed collimators

Pipe + holes + collimators

B. Salvant and X. Buffat, CERN

Conclusion

- FCC-hh already on the edge of stability only with resistive pipe

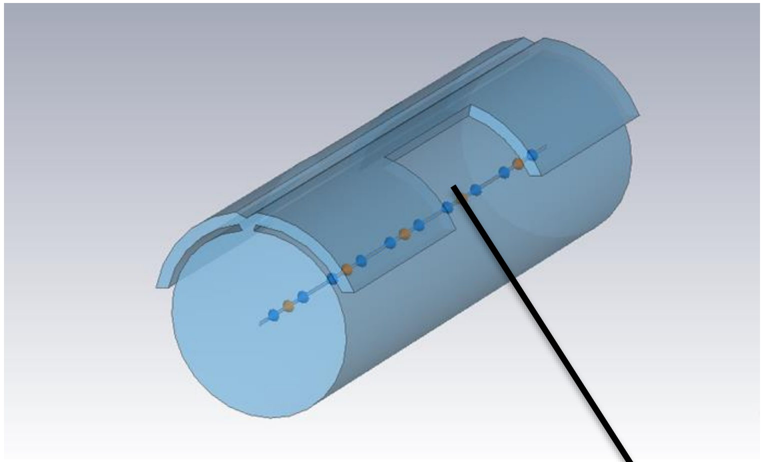
- 50 turns feedback possible but maybe insufficient
- 10 turns feedback possible?

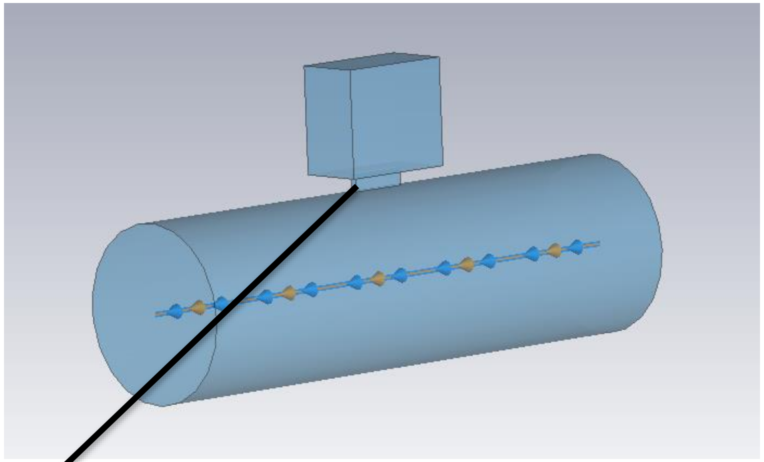
- Kickers not yet considered
- Landau damping and Octupoles not yet considered

- Impedance should play an important role in collimator design

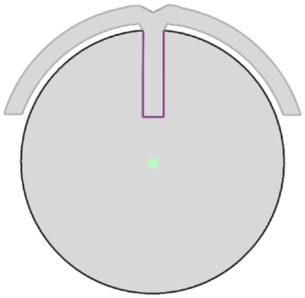
Holes and rips

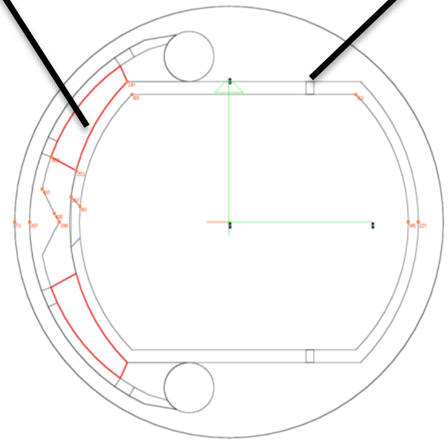
3D simulations in the time domain by CST Particle Studio®





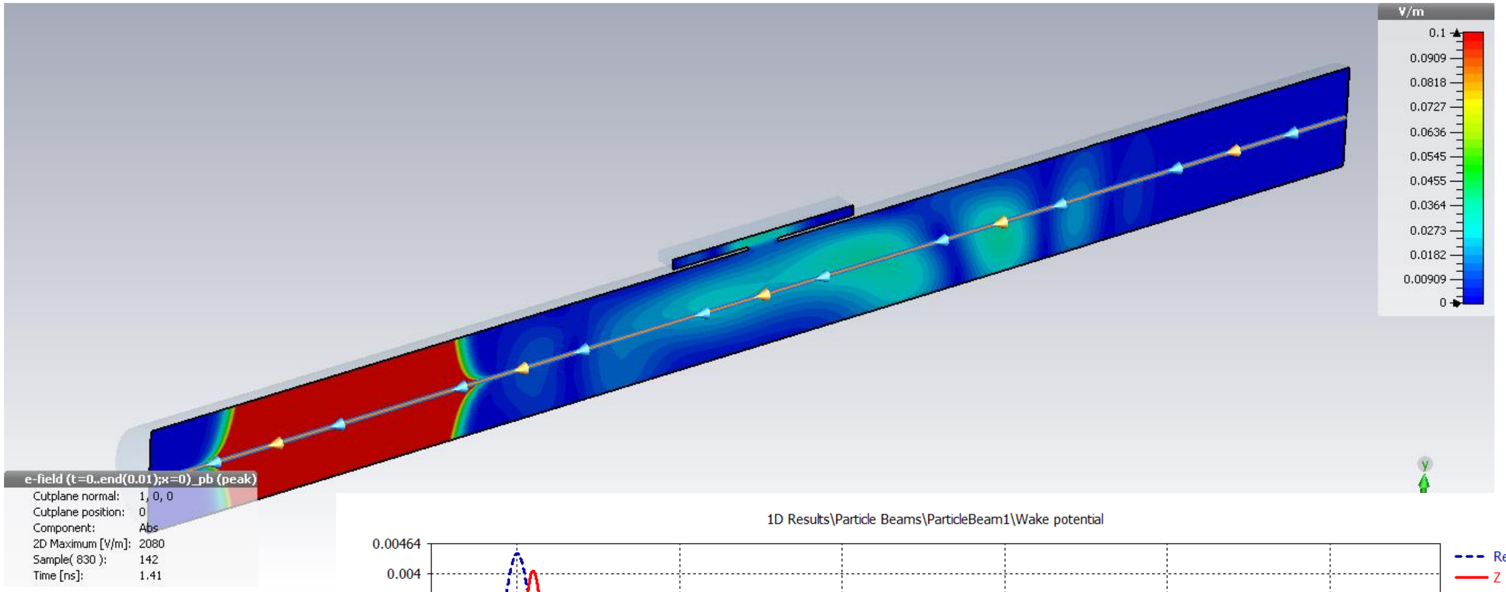
Stabilization fins between beam pipe and reflector

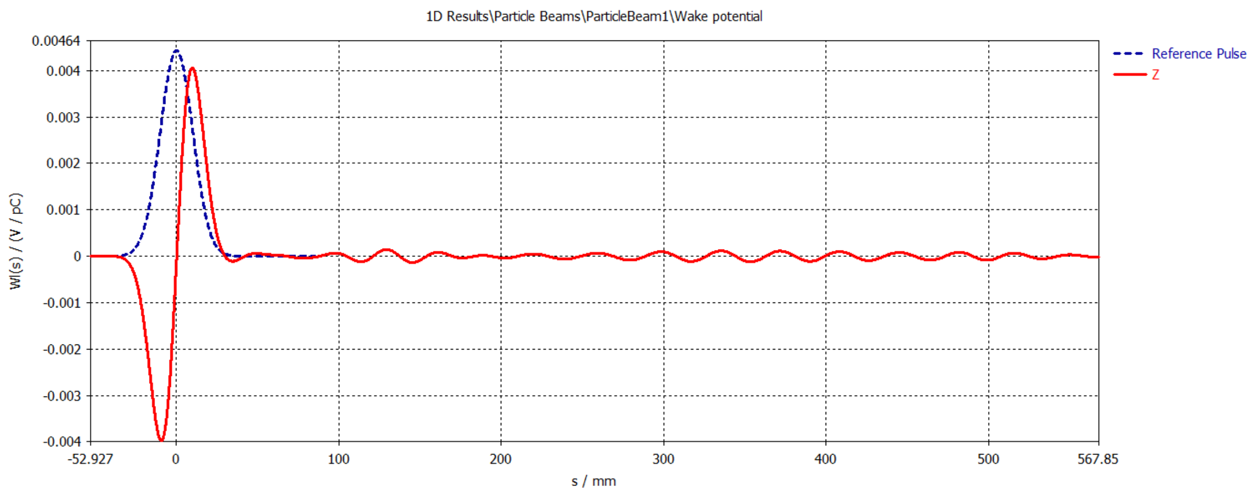




Vacuum pumping holes

Wakefield simulation of hole





Small effect, in the order of the numerical error!

Updates after Washington Meeting

- Holes under investigation: resonator model is justified but probably smaller bandwidth
- First simulations show no effect of stabilizing rips…

- Input from Collimation-Group has to be followed
  → Proper design with few updates required.

- Material data: Vacuum group?

- We should avoid recalculating the impedance model for every screw that has changed!

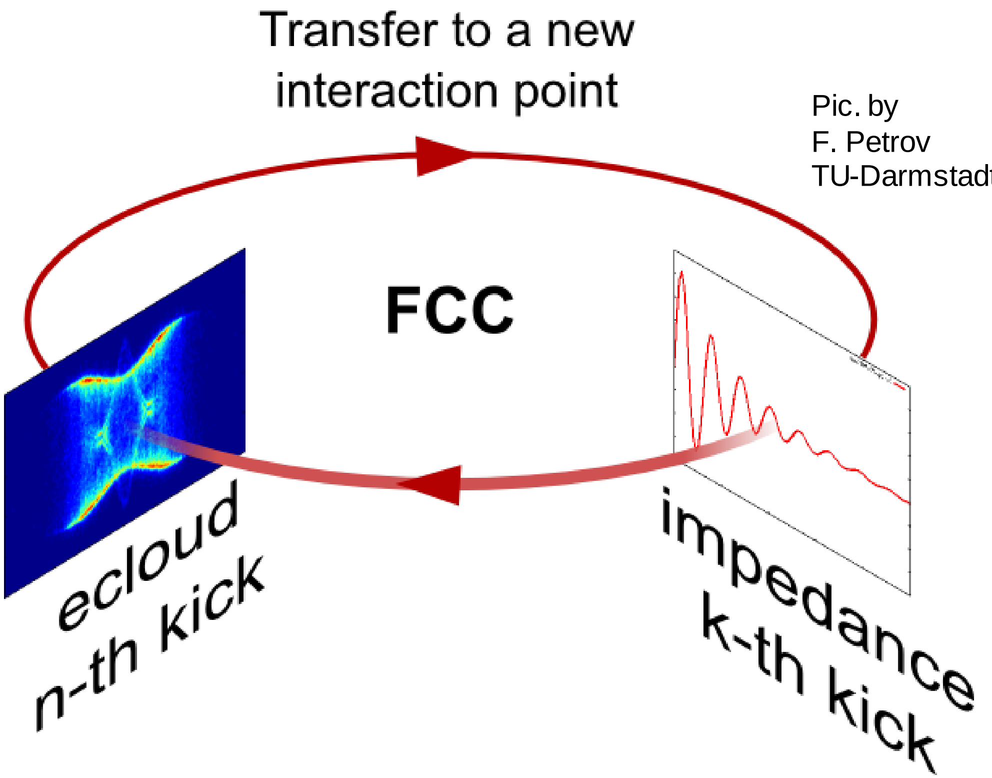
Electron Cloud effects

Electron clouds lead to

- Tune shift / spread
- Synchronous phase shift
- Instabilities

Difference to LHC

- Syncr. Rad.
- Asymmetry
- Small aperture



Pic. by
F. Petrov
TU-Darmstadt

- 3D and 2D particle in cell codes for electron cloud simulations
- community supported beam tracking codes (e.g. PyOrbit)
- working on coupling the electron cloud simulations to the beam tracking including impedances.

Scientific Outlook

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- Asymmetry →Quadrupolar impedance
- Combination of impedance and electron cloud
- Finally impedance check of all components in the ring? Nooo! Rather exclude some devices a priori and make a simplified model.
  → This is a CDR not a TDR!

The End

Thank you for your attention!