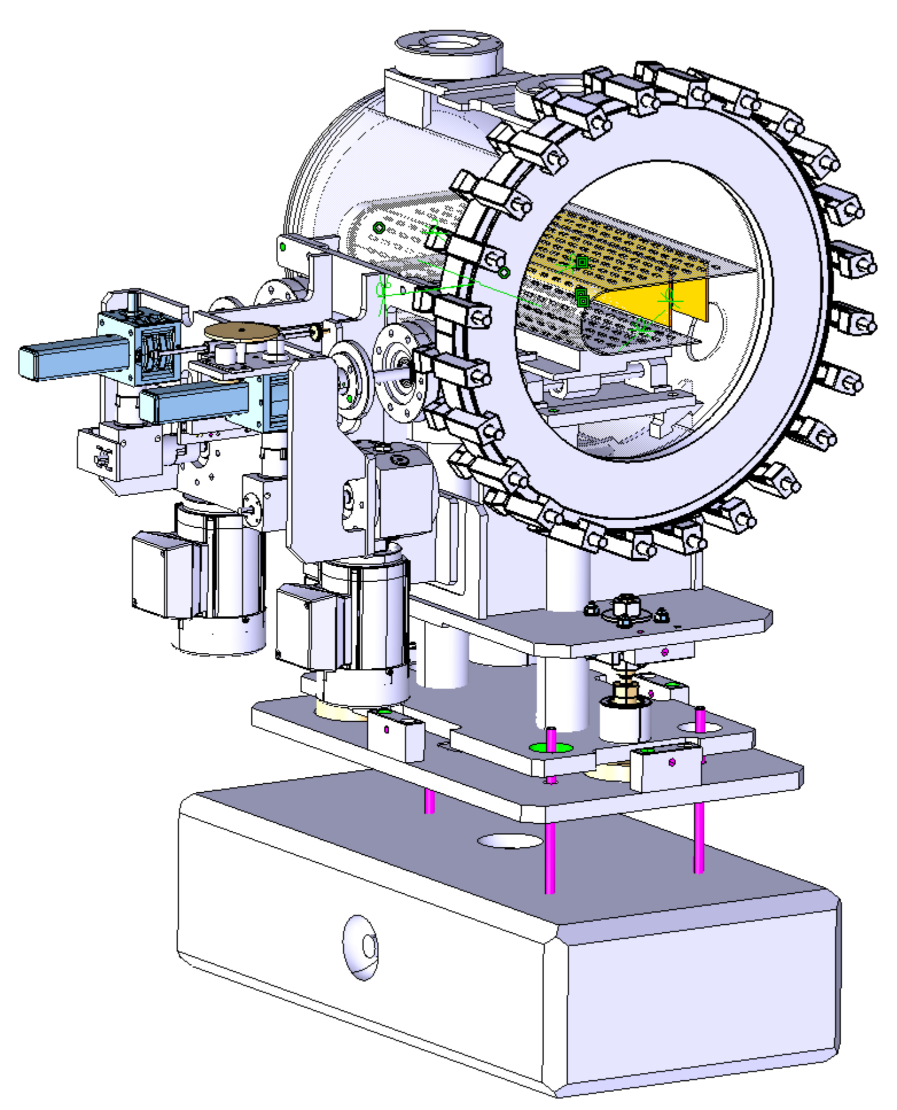
Dummy septum impedance studies



Serena Persichelli

Dummy septum meeting
19-10-2012

Acknowledgements

Jan Borburg
Heiko Damerau
Cedric Hernalsteens
Michael Hourican
Simone Gilardoni
Massimo Giovannozzi
Vincent Maire
Elias Metral
Mauro Migliorati
Benoit Salvant

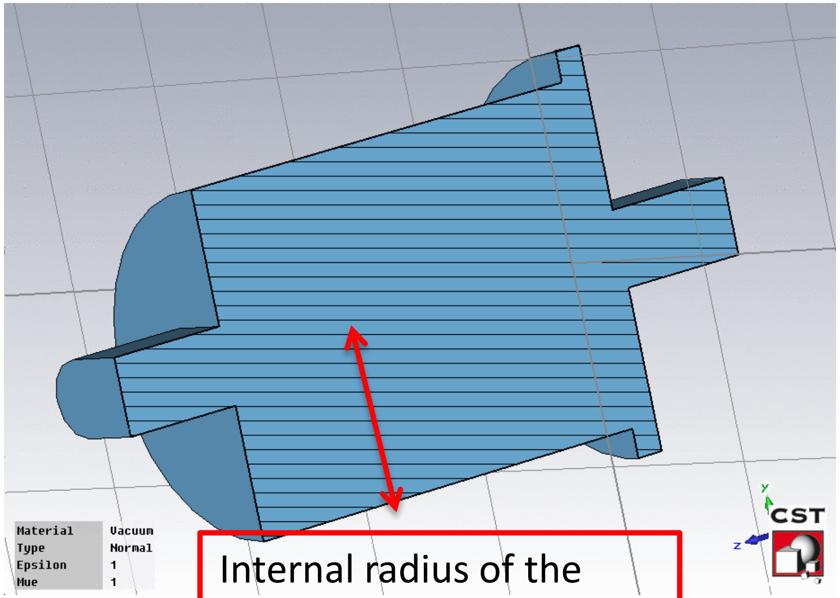
Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

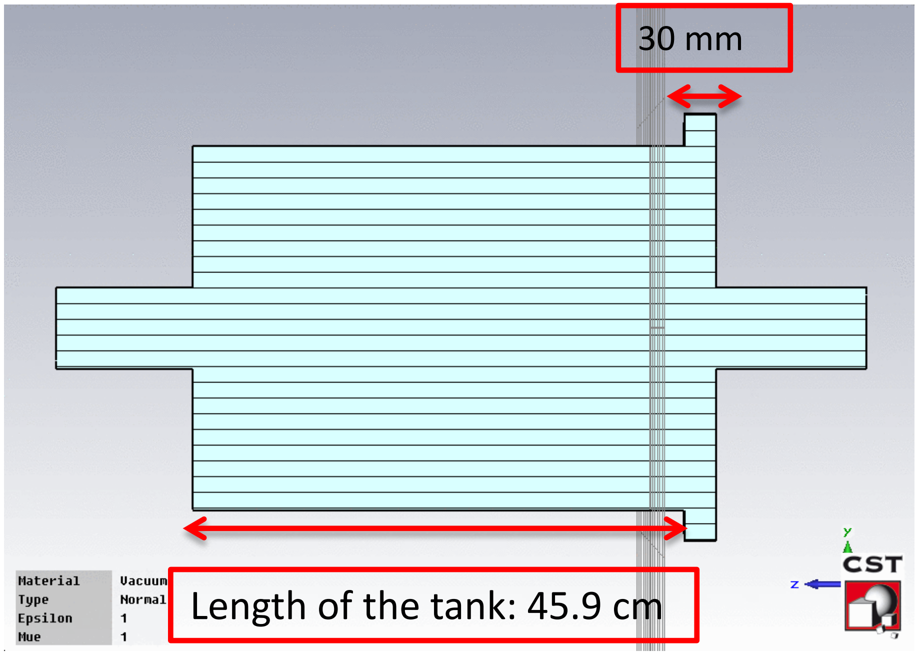
Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Dummy septum tank design

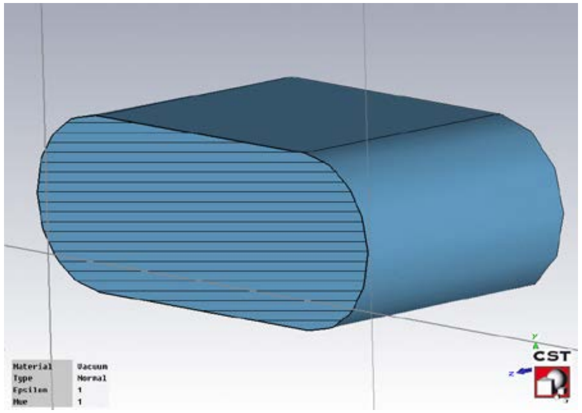


Internal radius of the tank: 17.3 cm



Length of the tank: 45.9 cm

Cut-off frequency of circular pipe of length 46 cm and radius 17.3cm → $\mathbf{f_c^{TE111} = 0.6\ GHz}$



PS elliptical pipe characteristics:

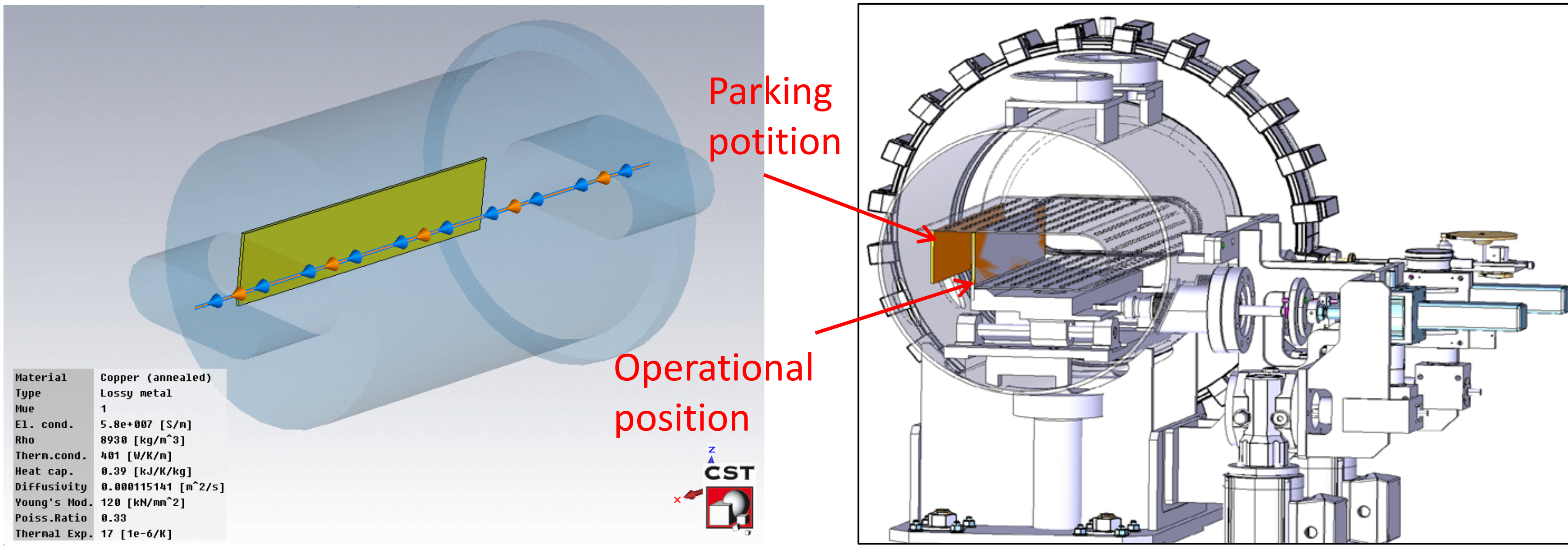
a/2=7.3 cm

b/2=3.5 cm

$\mathbf{f_c^{TM010} = 2.75\ GHz}$

Dummy septum internal design: blade

There are two positions available for the blade, thanks to presence of the displacement system



Dummy septum blade characteristics:

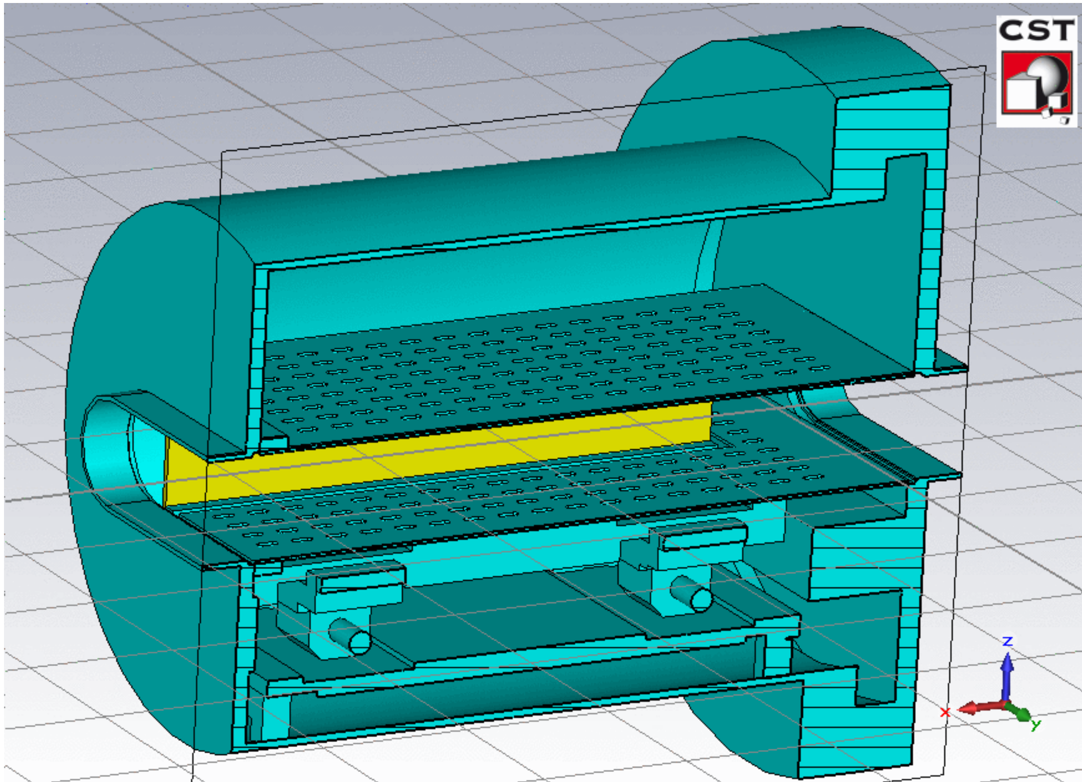
- Material: copper
- Length: 40 cm
- High: 7 cm
- Thickness: 4.2 mm

What should we expect from such geometry?

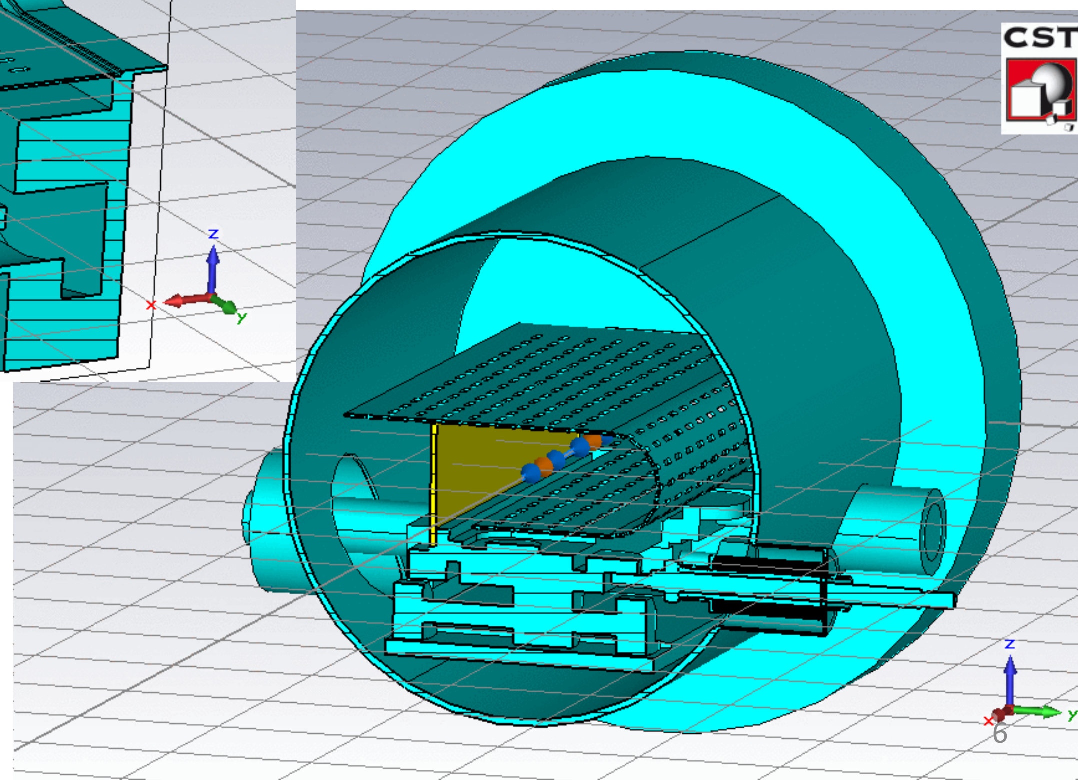
The presence of the blade modifies the arrangement of the mode of the pillbox cavity (high order modes)

- ➢ Parasitic modes of the blade
- ➢ Degeneration of the intrinsic modes of the cavity
- ➢ Trapped modes

Dummy septum design for CST MWS simulations



The internal design considered for CST simulations has been simplify from the original mechanical model!



- For simulations the holes of the screen have been eliminated
- Elliptical pipe have to be extended to avoid negative impedance effects

Few observations on performed simulations

- ✓ The dummy septum has been simulated starting from a simple pillbox cavity and then inserting one at a time the elements (blade, screen and displacement system), to control how they are able to change the modal configuration.

- ✓ Time domain simulations on CST PS show that resonances could be excited by bunches of 10-26 cm passing in the center of the septum or close to the copper blade.

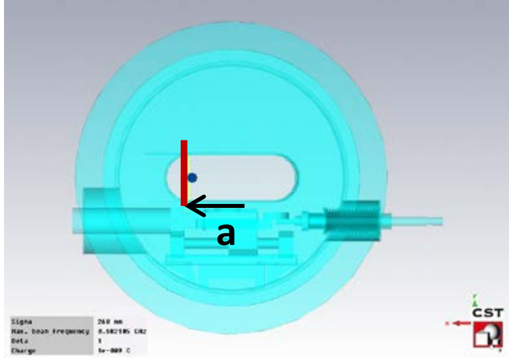
- ✓ Simulating the complete structure (with the displacement system and the electrical connection between the tank and the blade), some parasitic modes after 220 MHz are excited by a bunch of 26 cm circulating in the center of the cavity.

- ✓ Result obtained with CST MWS and HFSS (frequency domain) and CST PS (time domain) agree well for the estimation of the frequencies and the modal configuration in the structure .

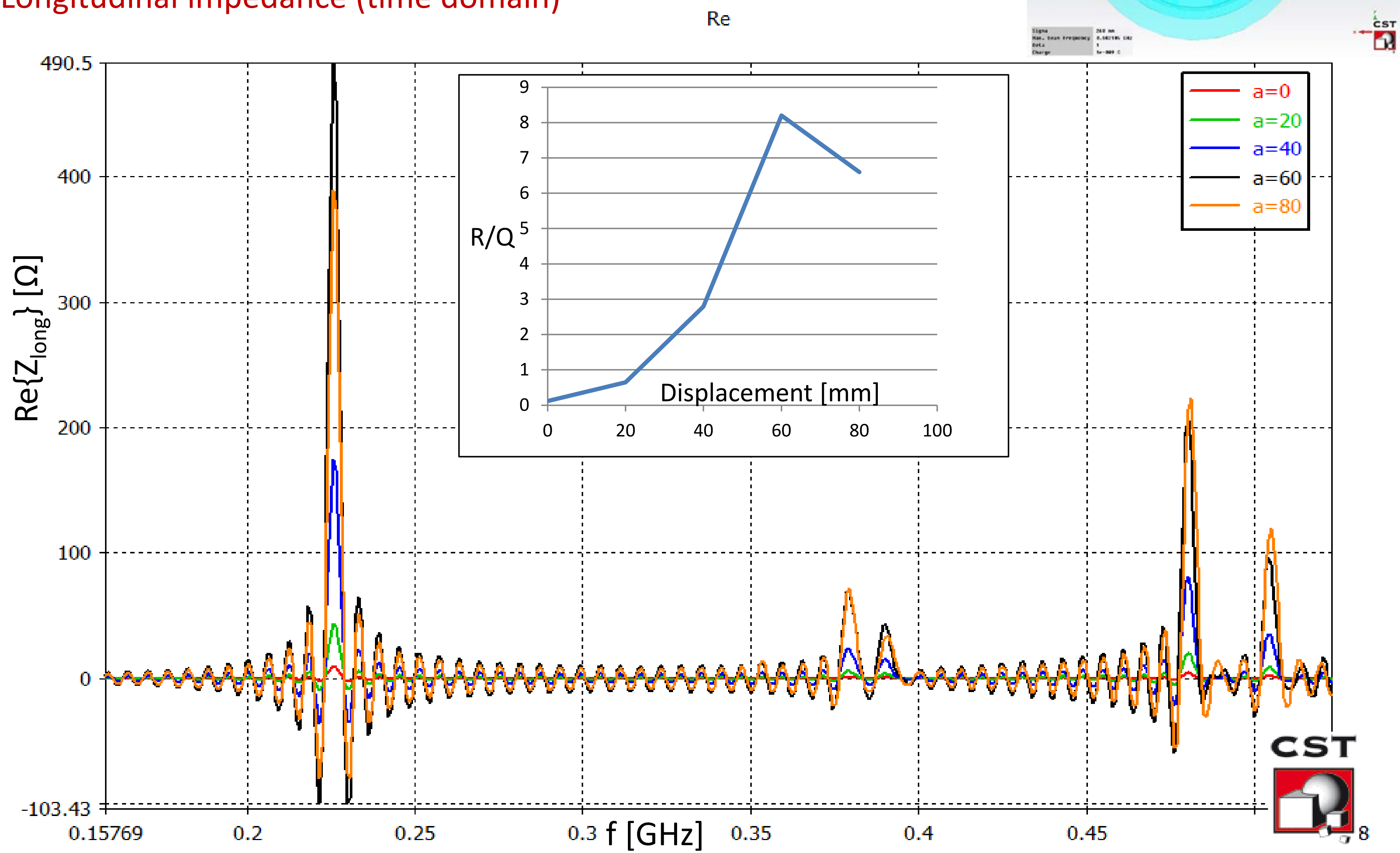
Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Impedance scan varying the position of the beam (1/2)

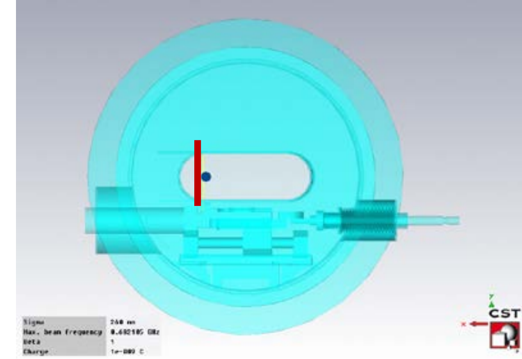


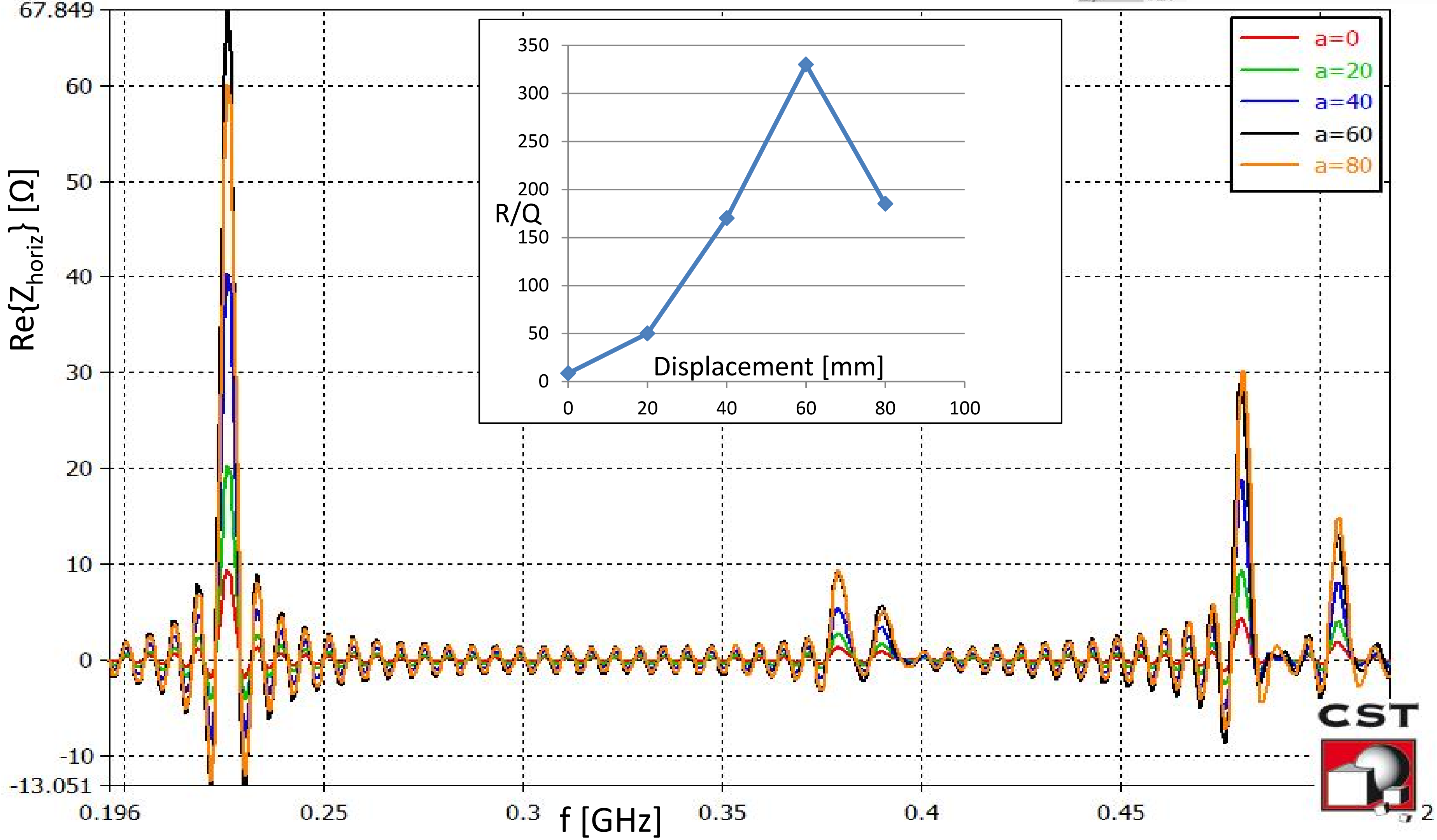
Longitudinal impedance (time domain)



Impedance scan varying the position of the beam (2/2)

Transverse dipolar impedance (time domain)





Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Eigenmode estimation (CST MWS)

Without the screen

	Freq [GHz]	Q	R/Q	R_s [Ω]
1	0.243	1709	60.2	1.04 E05
2	0.268	2116	18.8	39.31 E03
3	0.386	1547	0.03	45.74
4	0.440	4171	1.2	4.94 E03
5	0.517	2440	1.1	2.70 E03
6	0.544	2643	0.5	1.16 E03
7	0.593	3368	2.4	8.10 E03
8	0.602	2691	2.9	7.99 E03
9	0.635	3111	0.08	256.7
10	0.693	2344	0.8	2.01 E03

With the screen

	Freq [GHz]	Q	R/Q	R_s [Ω]
1	0.151	3934	-	-
2	0.225	2025	0.12	249
3	0.229	6113	-	-
4	0.269	9180	-	-
5	0.292	9262	-	-
6	0.351	1721	-	-
7	0.376	2296	0.007	18
8	0.387	1826	0.006	12
9	0.391	8100	-	-
10	0.455	9721	-	-

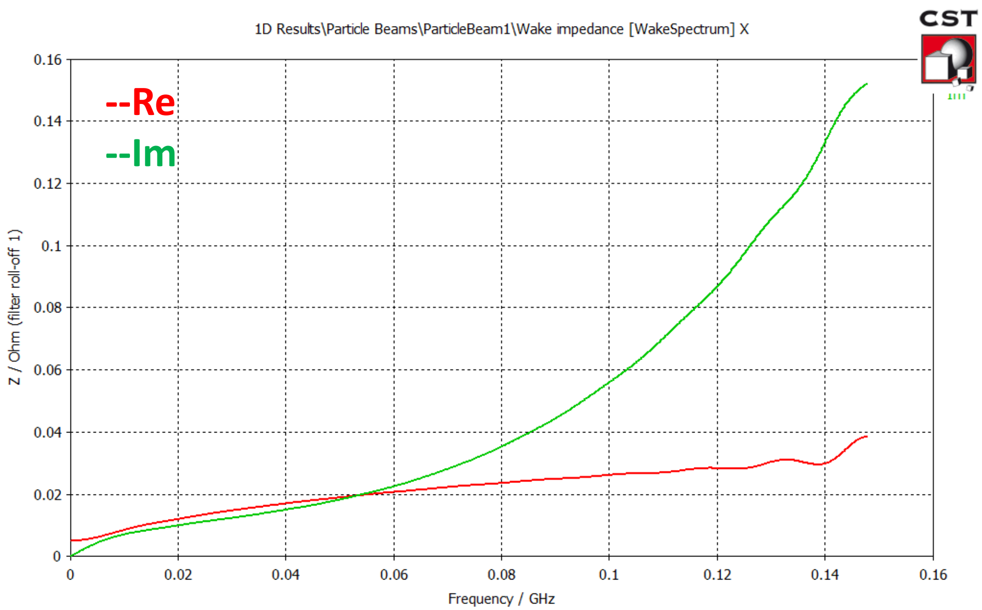
$R=U^2/Pd$
U=1 Joule (CST)
(Linac convention)

Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Contribution of the dummy septum to PS impedance budget (1/2)

Longitudinal impedance



A bunch of 1.2 m length circulating in the center of the septum excite an imaginary part of the longitudinal impedance that is inductive with a small resistive part:

$$\frac{Z}{n}=0.00017\ \Omega$$

Estimated total longitudinal impedance in the PS:

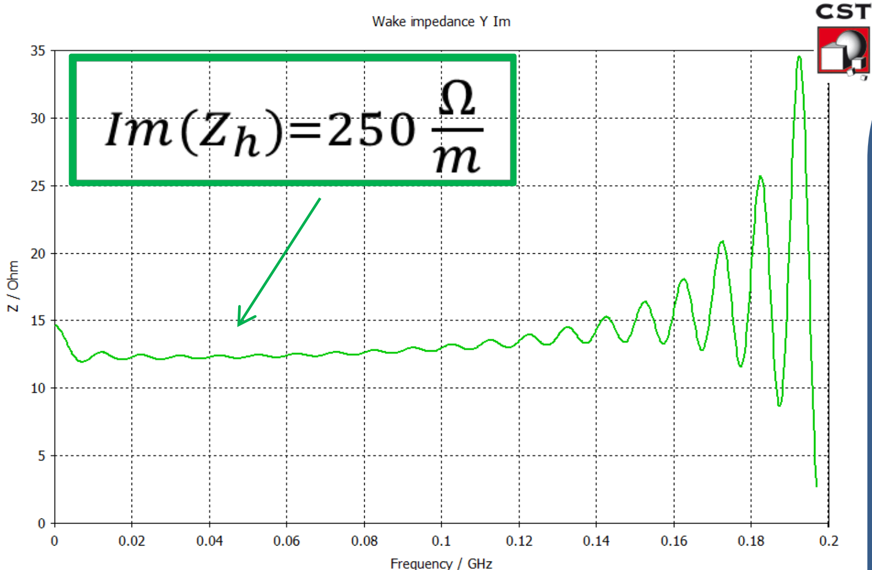
$$\frac{Z(p)}{p}=(18.4\pm2.2)\Omega$$

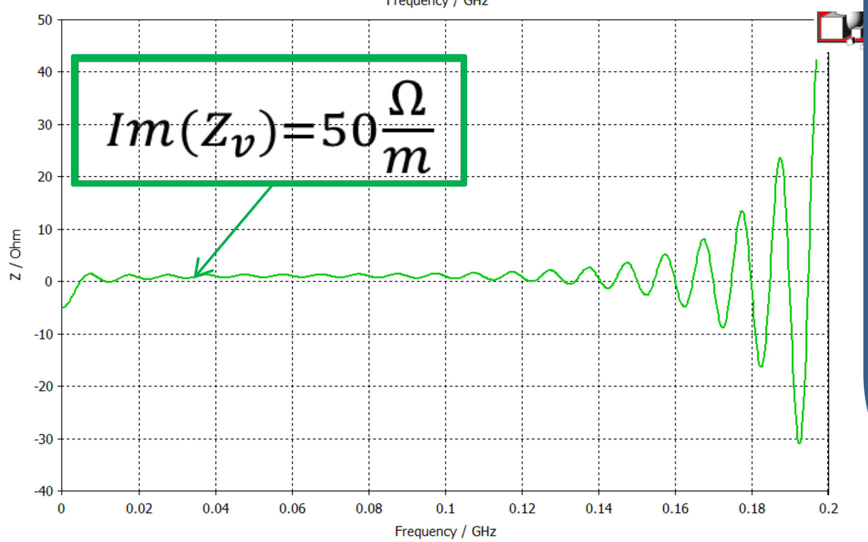
The contribution of the dummy septum to the total imaginary part of longitudinal impedance of the PS is predicted to be negligible

M. Migliorati et al., ***Evaluation of the broadband longitudinal impedance of the CERN PS****, CERN-ATS-Note-2012-064 MD. - 2012.*

Contribution of the dummy septum to PS impedance budget (2/2)

Transverse dipolar impedance





A bunch of 90 cm length displaced in the transverse planes from the centre excites a an imaginary part of the dipolar impedance that is constant at low frequencies:

Estimated total effective transverse impedance in the PS:

$$Im(Z_h)=1\,\frac{M\Omega}{m} \qquad Im(Z_v)=6.1\frac{M\Omega}{m}$$

The contribution of the septum to the imaginary part of the PS total transverse effective impedance is predicted to be negligible

Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Longitudinal instabilities

- The residual shunt impedance of the dummy septum of 250 Ω is sufficiently small to not expect significant influence on coupled-bunch instabilities.

Example 1 : PS 200 MHz cavity (damped with 3 PIN diodes lines)

Q=130
R/Q= 28.5 Ω
R_s=3.7 kΩ

The shunt impedance of the cavity is well above the residual shunt impedance of **250 Ω** estimated for the dummy septum in the centre at 220 MHz!

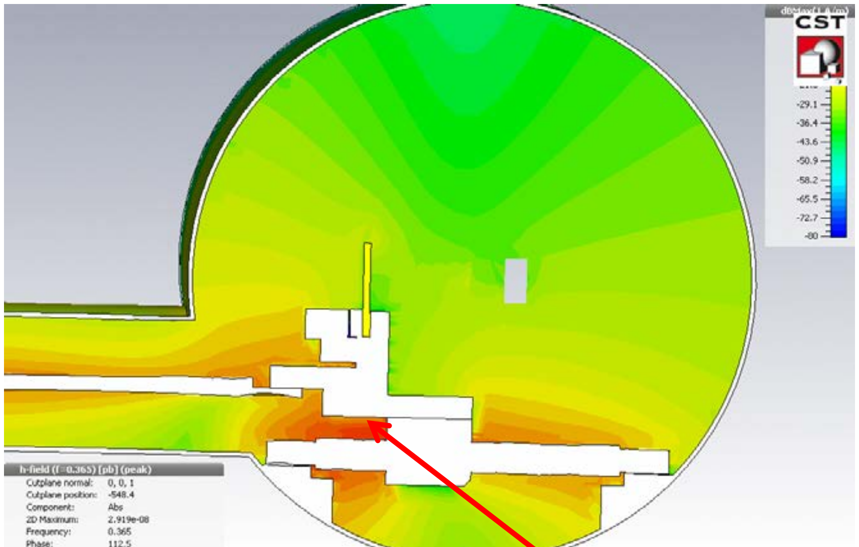
Example 2: PS wire scanner resonant mode at 290 MHz

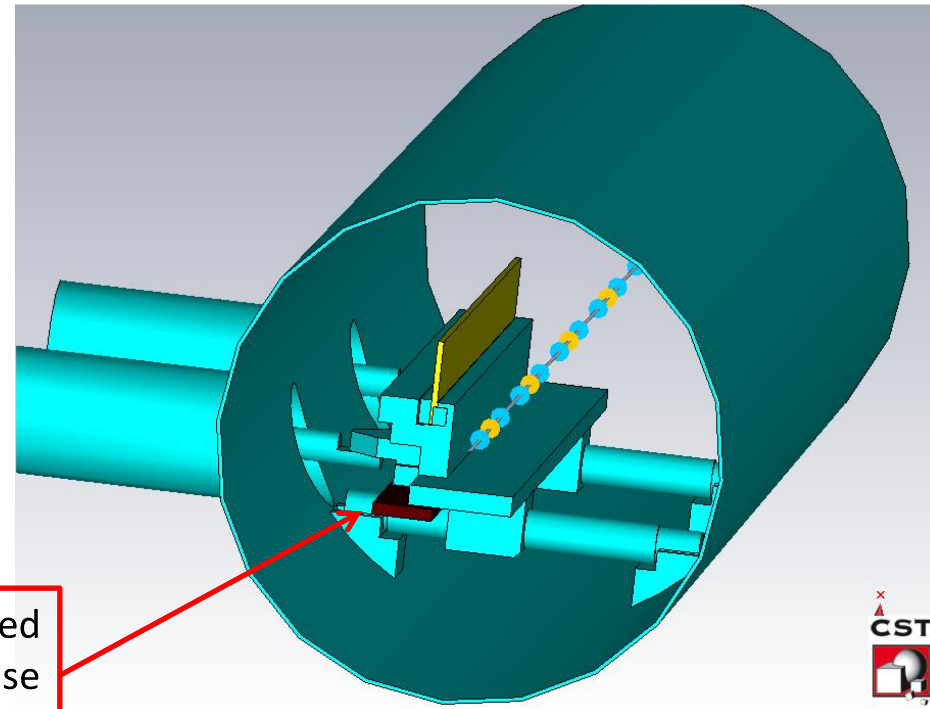
f= 292 MHz
Q=730
R_s=8.7 kΩ

Also the shunt impedance of the wire scanner first mode is well above the residual shunt impedance of **250 Ω** estimated for the dummy septum in the centre at 220 MHz!

Ferrite (1/2)

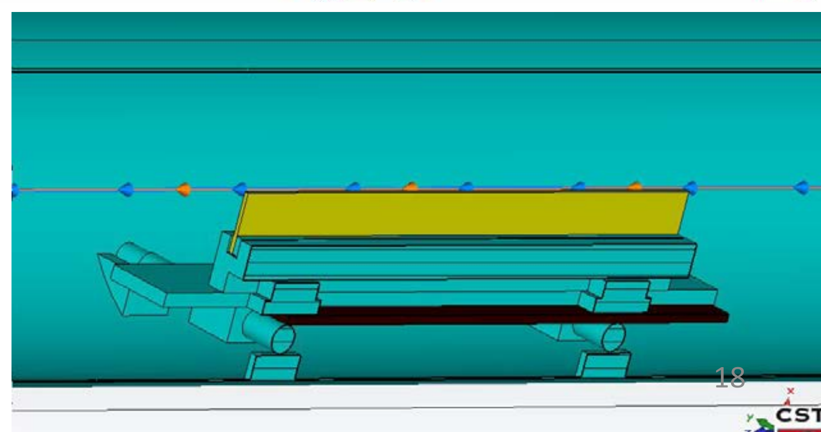
A brief study has been performed for the old design to see the effects of ferrites for the damping of parasitic modes of the blade





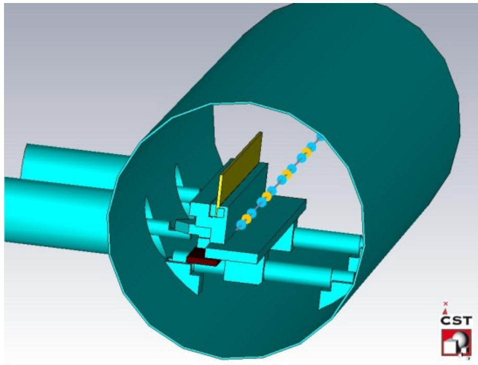
A large brick of ferrite has been located in the area with the more intense magnetic field

400 x 30 mm
Thickness 6 mm

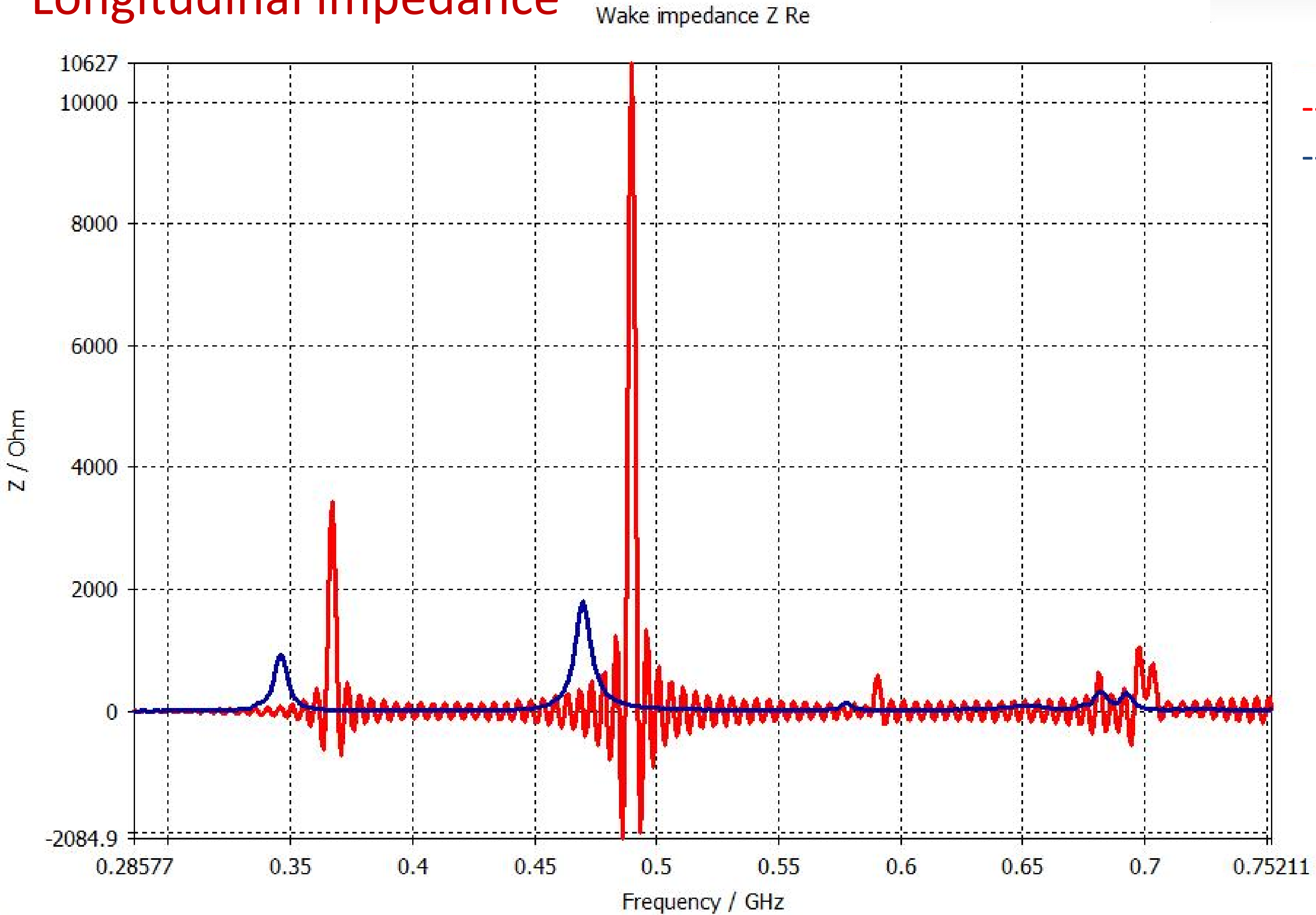


Ferrite (2/2)

With such geometry a damping of the first two resonant modes can be observed in the longitudinal impedance



Longitudinal impedance



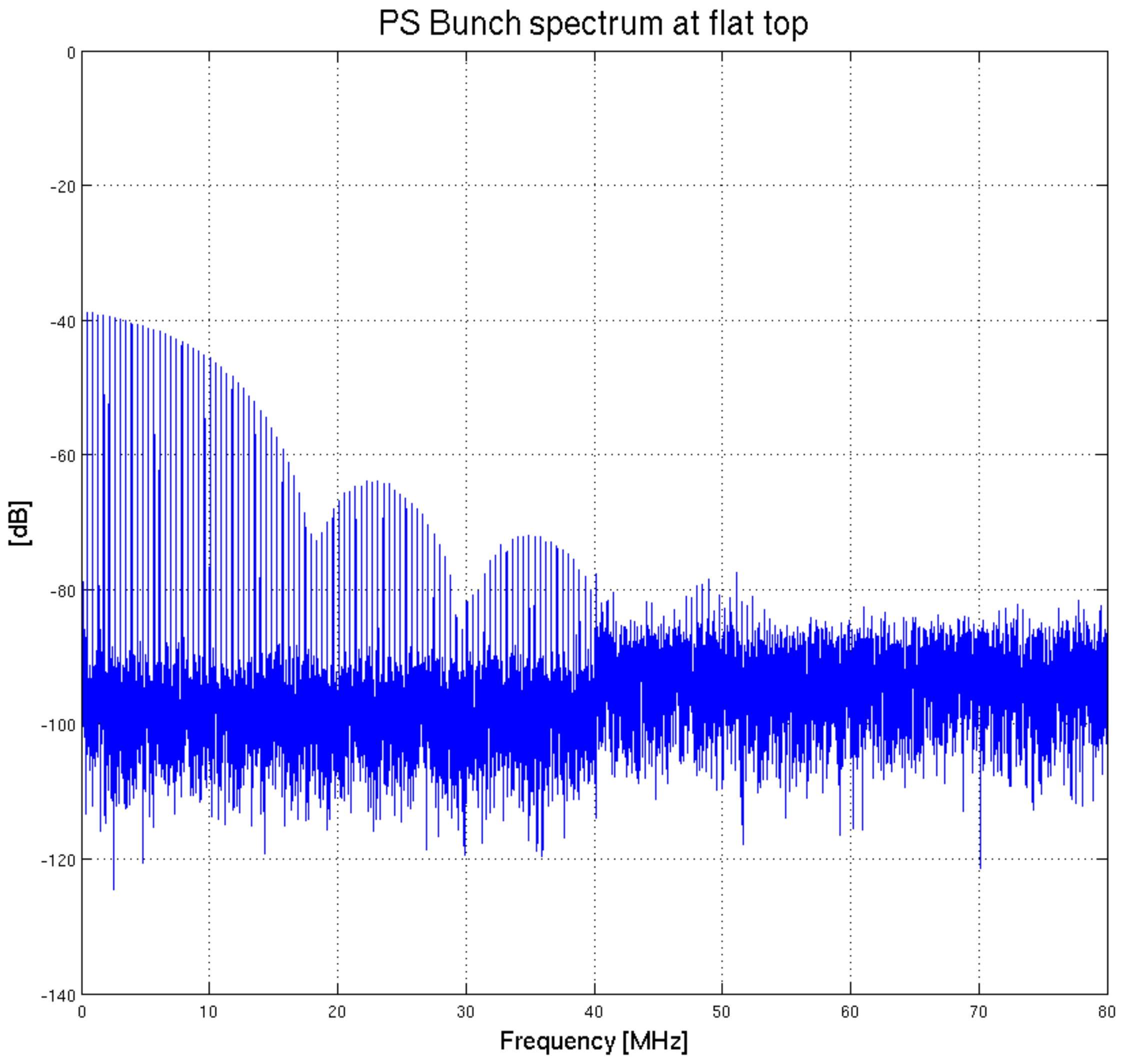
-- Without ferrite
-- With ferrite

Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

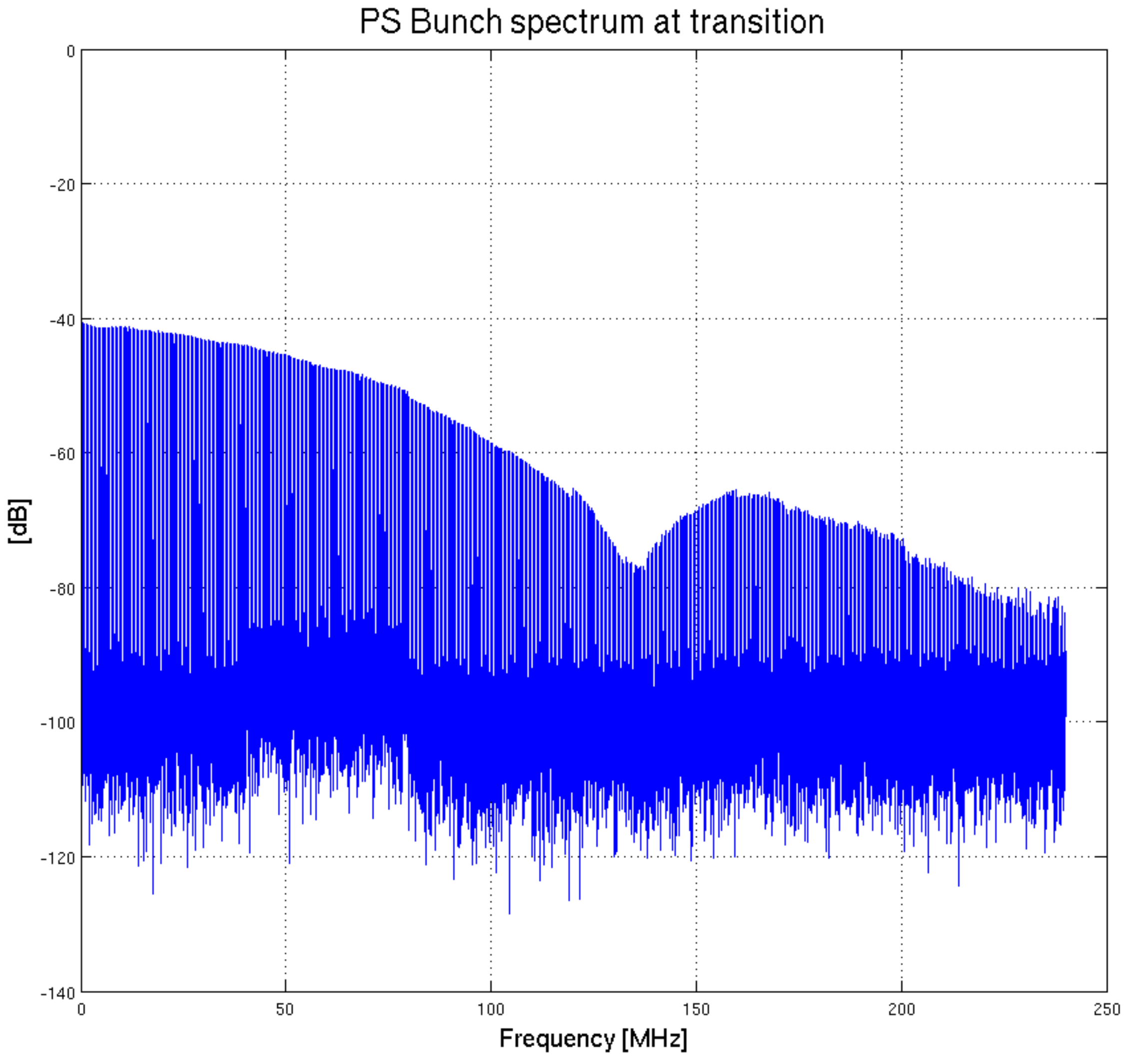
Heating (1/3)

At flat bottom the first mode is far outside the beam spectrum and the power at 220 MHz is less than -40 dB



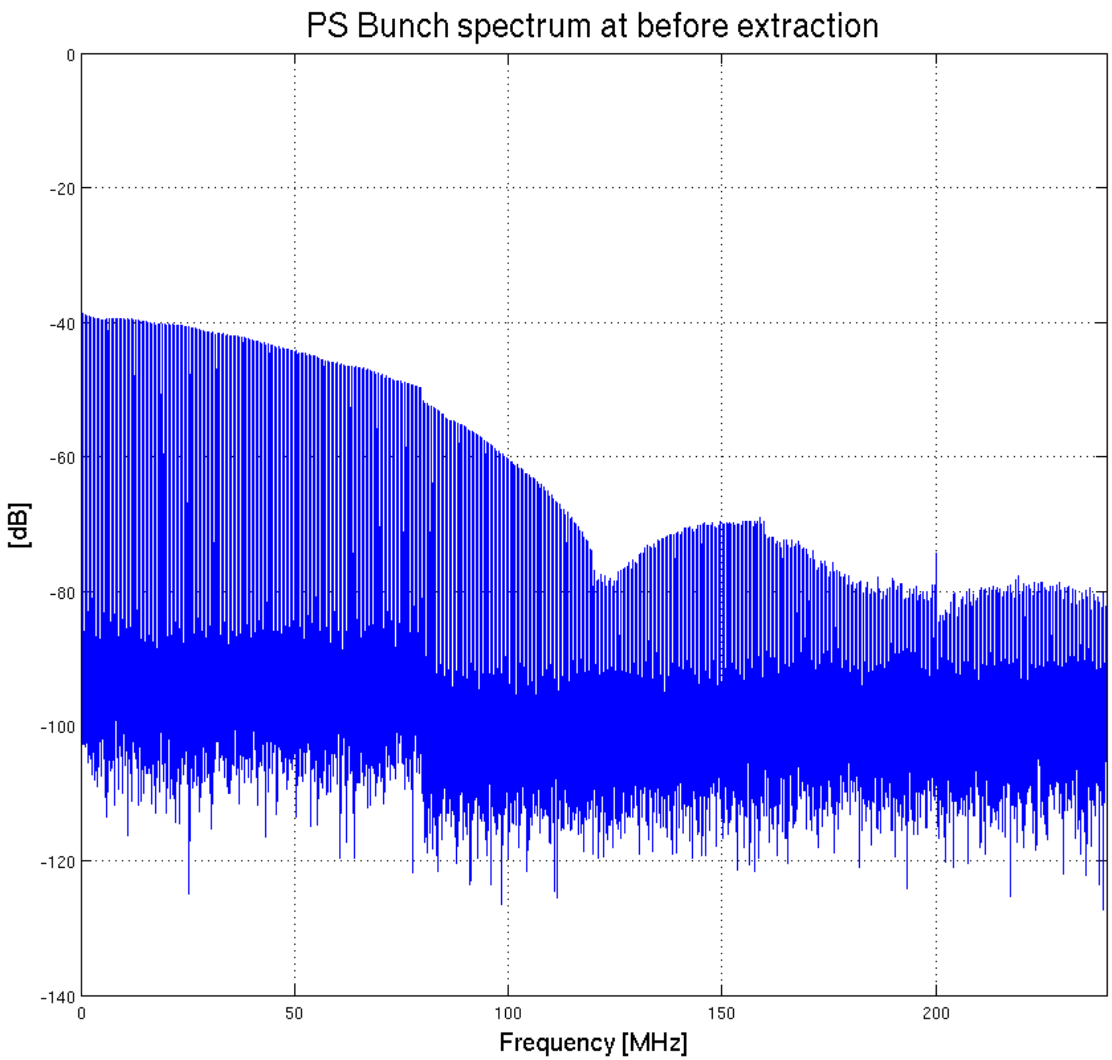
Heating (2/3)

At transition energy (about 5.7 GeV) the first mode is far outside the beam spectrum and the power at 220 MHz is less than -40 dB



Heating (3/3)

At extraction energy the first mode is far outside the beam spectrum and the power at 220 MHz is about -40 dB



Agenda

- Dummy septum impedance simulation with CST
  - *Design for simulations*
  - *General observations*
- Impedance scan varying the position of the beam
  - *Longitudinal impedance*
  - *Transverse impedance*
- RF screen
  - *Eigenmode CST MWS analysis with/without screen*
- Impact of the dummy septum on PS total impedance
  - *Longitudinal imaginary part of effective impedance*
  - *Transverse imaginary part of effective impedance*
- Longitudinal instabilities
  - *Coupled bunch instabilities*
  - *Wakefield CST PS analysis with ferrites*
- Heating and impact on the stability of the beam
  - *Flat bottom*
  - *Transition*
  - *Extraction*
- Recommendations from the impedance team
  - *Impedance and instabilities*
  - *RF screen*
  - *Further measurements and simulations*

Recommendations from the impedance team (1/2)

- **Impedance and instabilities**

  - The imaginary part of the effective longitudinal and transverse impedances are predicted to be negligible compared to the imaginary part of the total impedance measured for the PS

  - For the real part, resonant modes can generate heating and instabilities:

    - *Heating* : the first mode is outside the beam spectrum (except during bunch rotation) and the power at 200 MHz is -40 dB at top energy, so it is not predicted to be an issue

    - *Longitudinal instabilities*: when the beam is in the centre, the shunt impedance of the first mode is 250 Ω, about the 7% of the 200 MHz cavity (for instance), and the impact should be limited. When the beam is few mm far from the blade the shunt impedance is 17 kΩ, but anyway the beam is going to approach the blade only for a limited time. Current coupled bunch instabilities should not be enhanced by this mode. However, more computations (Laclare/Sacherer) and simulations (HEADTAIL) should be performed to be sure that impact on instability growth rates is small.

    - *Transverse instabilities*: when the beam is in the centre the transverse shunt impedance is about 24 kΩ/m, so the same order of magnitude of the 2 kΩ/m transverse shunt impedance evaluated for the PS wire scanner (for instance). When the beam is at few mm far from the blade, the shunt impedance of the first modes is 750 kΩ/m, but anyway the beam is going to approach the blade only for a limited time. More computations (Laclare/Sacherer) and simulations (HEADTAIL) should be performed to be sure that impact on instability growth rates is small.

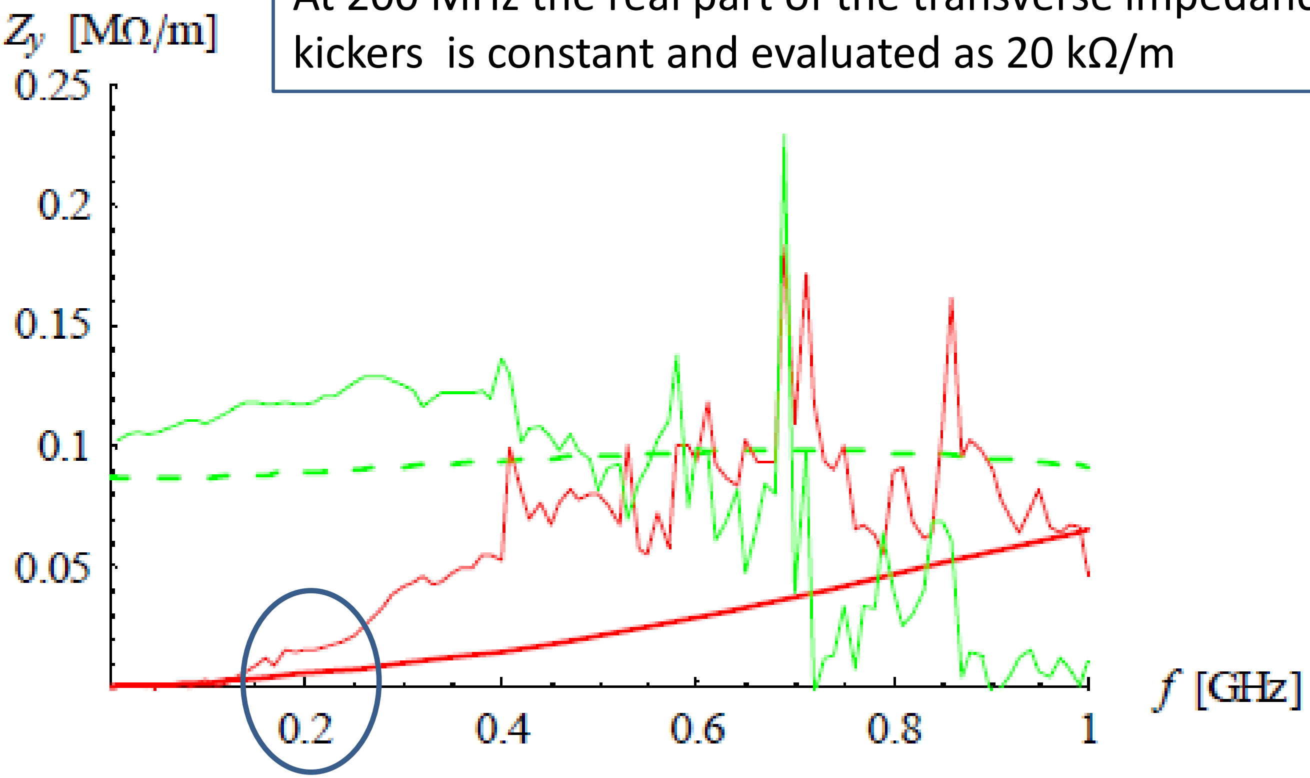
Recommendations from the impedance team (2/2)

- **RF screen**
  - Keep the RF screen in order to avoid parasitic modes with a high loss factor
  - Ensure electrical contact between the tank and the screen on both sides
  - It seem not necessary to put sliding contacts between screen and blade
- **Further simulations/measurements**
  - Perform investigation about the RF screen holes (position, number…) can be done if necessary
  - Since we not expect significant influence from coupled-bunch instabilities, we expect no need to damp high order modes with ferrite
  - We are missing references for resonant modes in PS: other equipment with suspected high impedance should be checked and compared to the 220 MHz impedance (HEADTAIL or analytically)
  - LIU parameters have to be considered for the growth rate estimation, since after installation there won't be any opportunity to operate on the structure
  - Impedance bench measurements should be performed before installation to confirm the results from simulation.
  - Impedance simulations have been performed for the position of the blade given in the 3D model. Other simulations can be performed considering other position for the blade.

Appendix

Transverse impedance of the PS kicker KFA13

At 200 MHz the real part of the transverse impedance for the kickers is constant and evaluated as 20 kΩ/m



E. Metral et al., **KICKER IMPEDANCE MEASUREMENTS FOR THE FUTURE MULTITURN EXTRACTION OF THE CERN PROTON SYNCHROTRON**, CERN-AB-2006-051.

Appendix

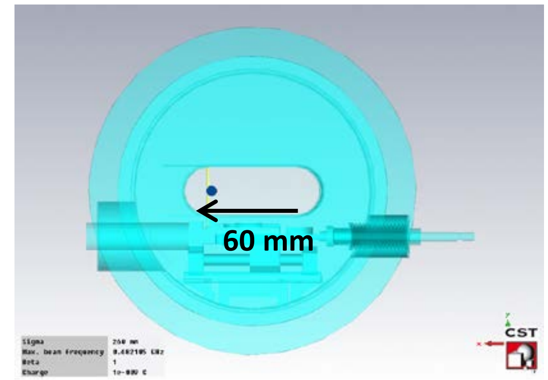
Possible technical solutions to damp high order modes

- Using ferrite
- Using damping resistors
- Connecting the blade to an external load
- Inserting a loop coupled with the magnetic field of the modes

Evaluation of Eigenmodes (CST MWS)

	Freq [GHz]	R/Q	R_s [Ω]	k_{loss} [V/pC]
2	0.225	8.2	16.8 E03	2.91 E-03
6	0.351	0.006	10	3.21 E-06
7	0.376	0.57	1.3 E03	3.37 E-04
8	0.387	0.44	824	2.71 E-04

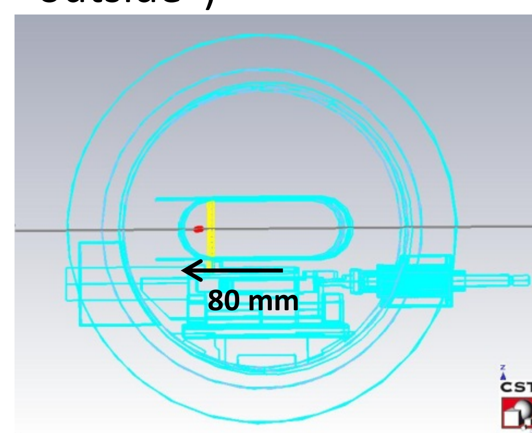
60 mm displacement from the center (beam "inside")



7 ns for the beam to approaching the blade from the centre (3.4 E03 turns)

	Freq [GHz]	R/Q	R_s [Ω]	k_{loss} [V/pC]
2	0.225	6.6	13.5 E03	2.34 E-03
6	0.351	0.07	102	3.39 E-05
7	0.376	0.58	1.3 E03	3.38 E-04
8	0.387	0.37	706	2.32 E-04

80 mm displacement from the center (beam "outside")



Only 4 turns outside (about 8 μs)