SAPIENZA
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Beam coupling impedance of the main extraction kickers in the CERN PS

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Acknowledgments: C. Antuono, H. Bursali, H. Damerau, S. Joly, M. Migliorati, B. Salvant, L. Sito, M. Stephen Sullivan, M. Valente Dos Santos, Impedance Working Group and all the BR section at CERN.

Motivations

- **Upgrade of LHC injectors** (**LIU** project) in view of HL-LHC, PS goal: bunch intensity up to 2.6×10^{11} p/b, with 72 bunches.
  ➔ important to remain within a **stringent impedance budget.**

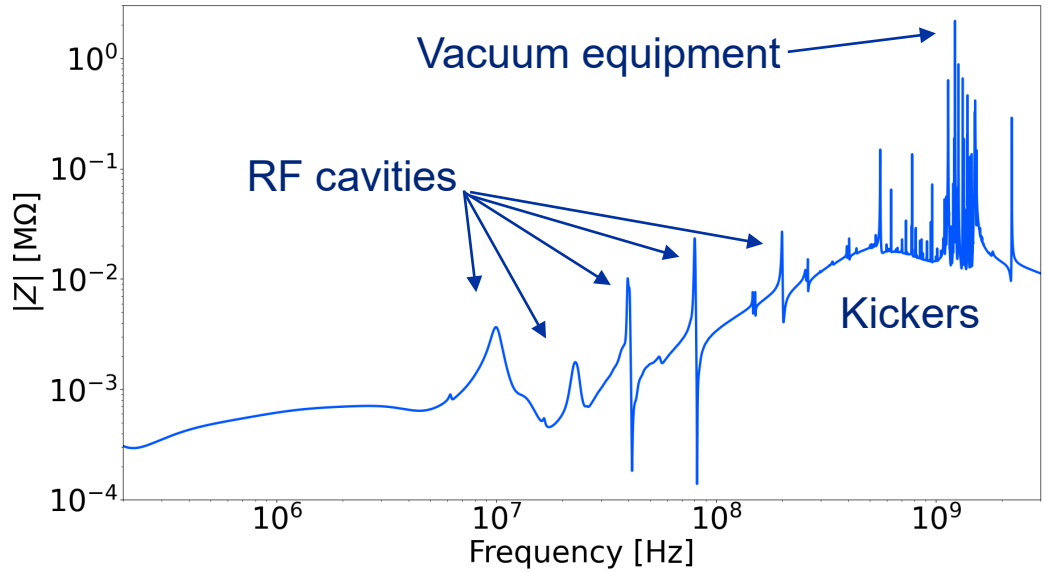
- To keep **PS impedance model up-to-date**, ensure the use of the most recent geometrical model of each component.

- **Kickers** are the main source of **broadband impedance** in the PS, with unwanted effects, e.g. loss of Landau damping.

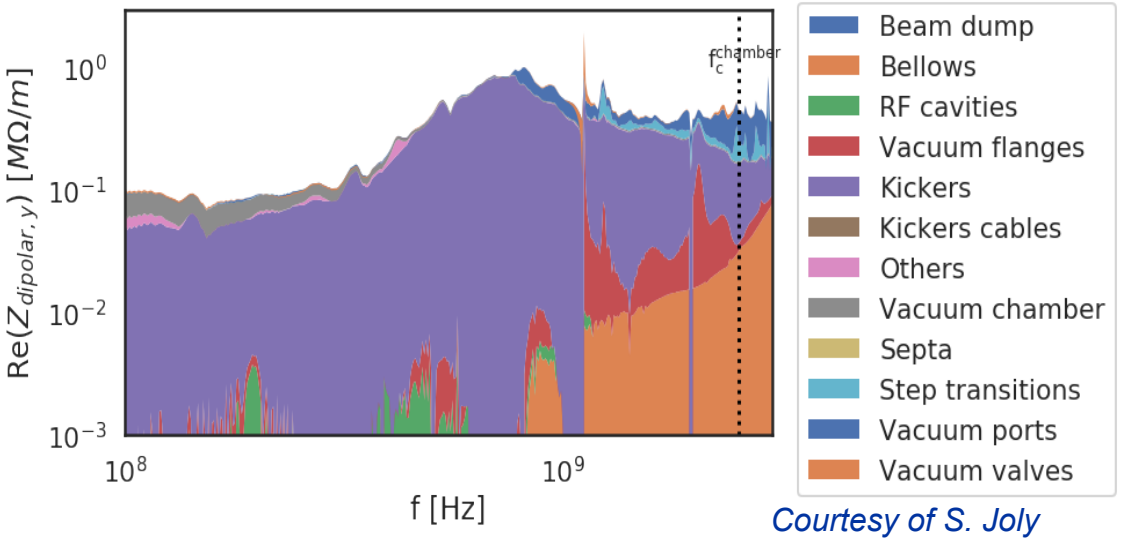
- **Longitudinal coupled-bunch instabilities** were one of the main limitations for reaching higher intensities in the LIU framework**.**

  ➔ While the **LIU target is reached today,** tackling critical impedance sources will provide **additional margin**.

Total PS Longitudinal Impedance



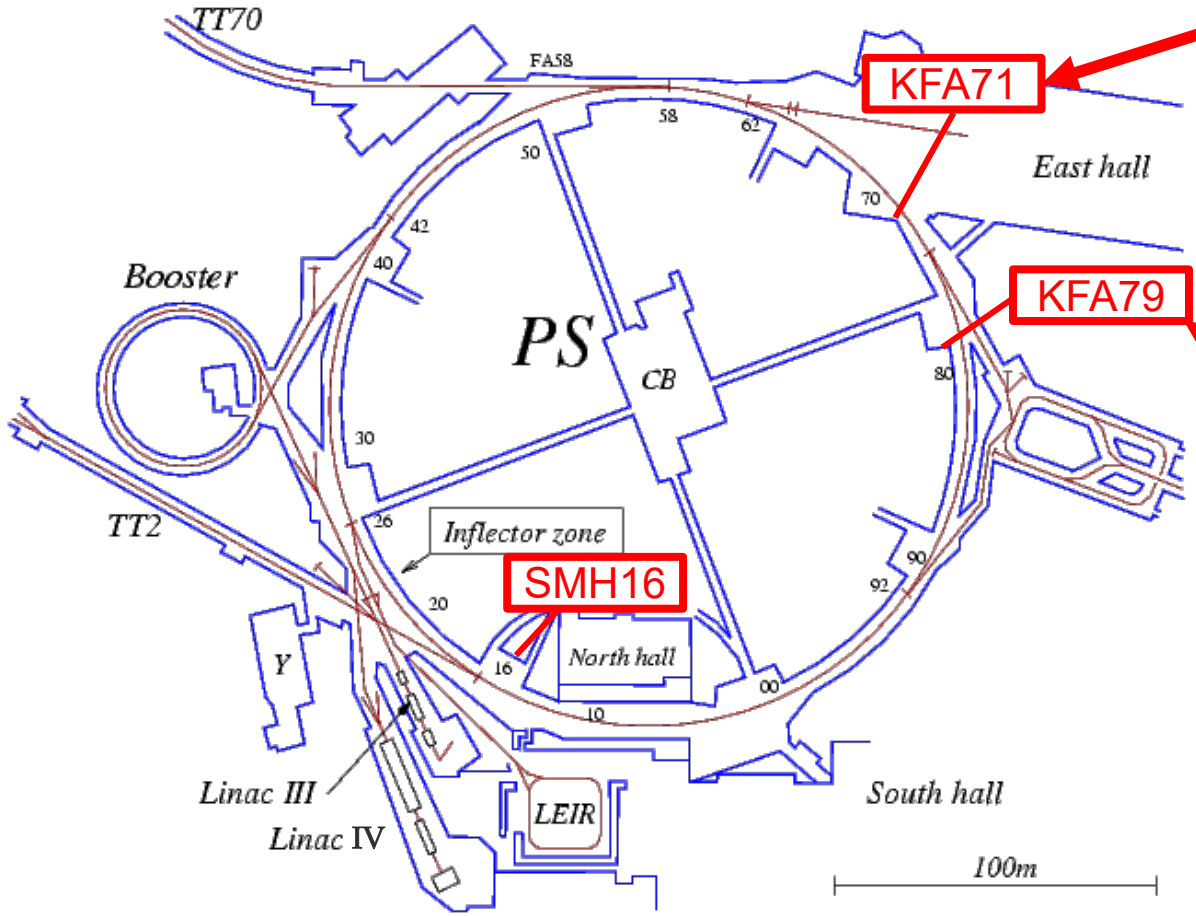
PS Transverse Dipolar vertical impedance

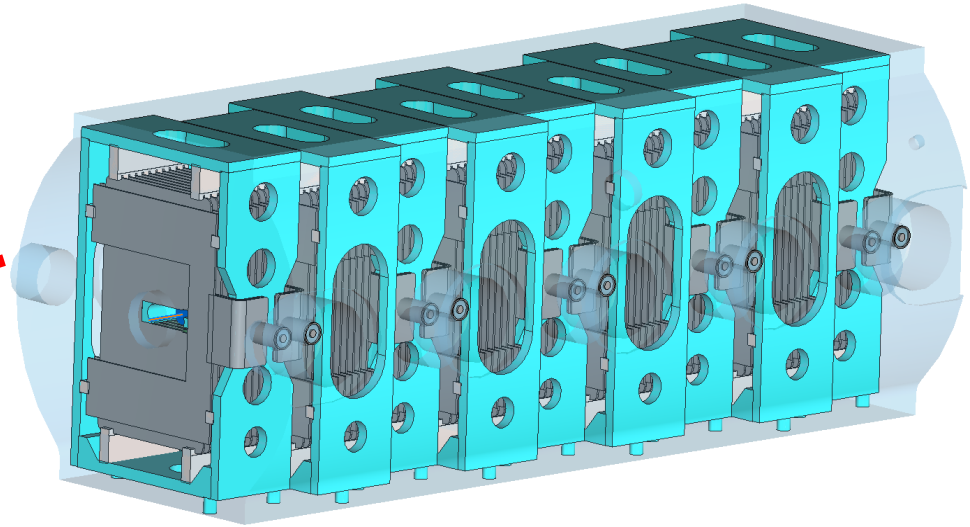


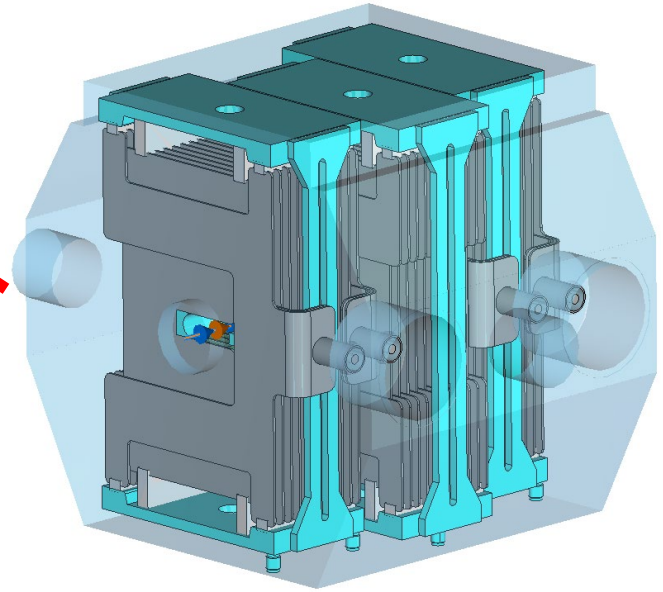
Courtesy of S. Joly

PS fast extraction kickers

KFA71, **KFA79** and **SMH16** involved in the main extraction from PS towards SPS and experimental areas



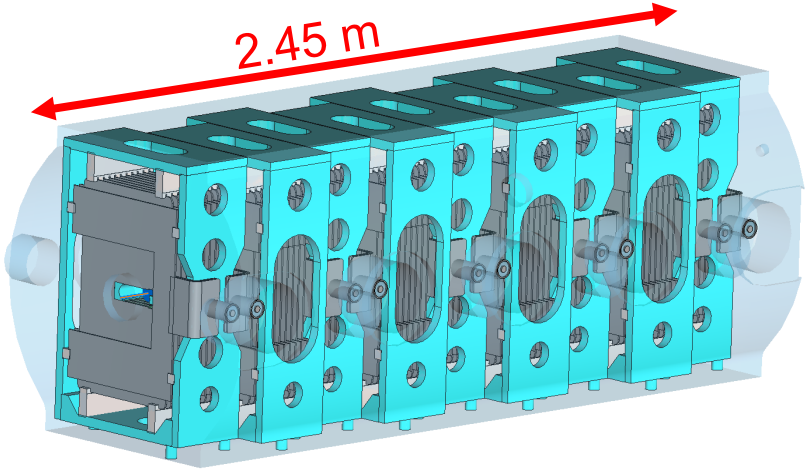


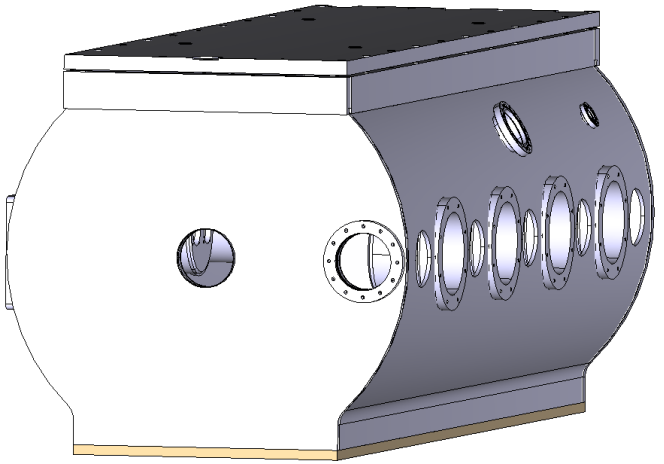


Kickers geometry

- Kickers first installed in the **1970s**
- **Twelve magnet modules** foreseen for extraction, split into **two different devices**

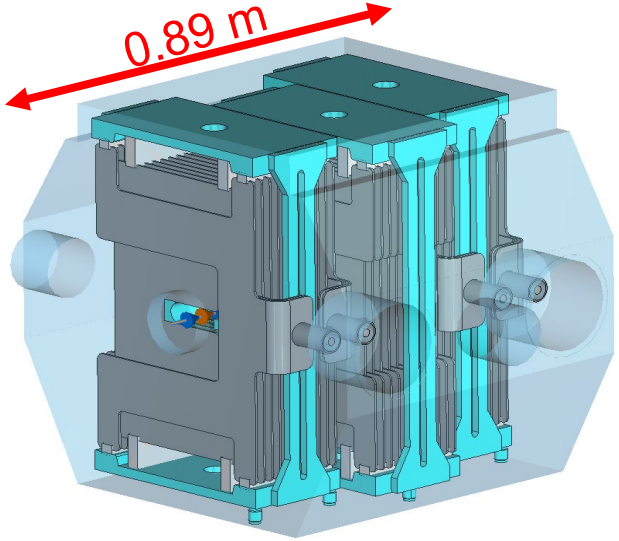
KFA71

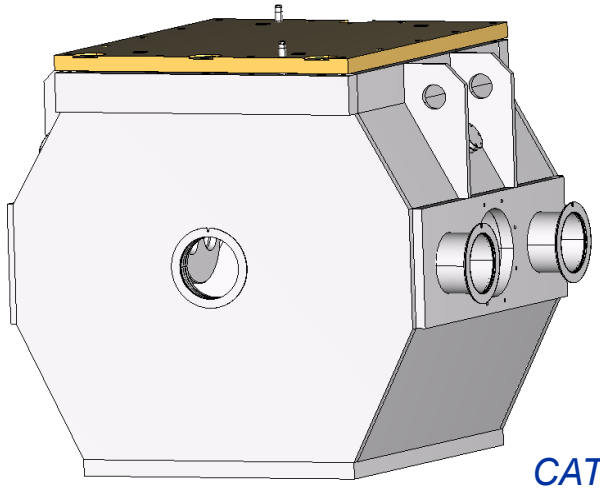




9 modules

KFA79





3 modules

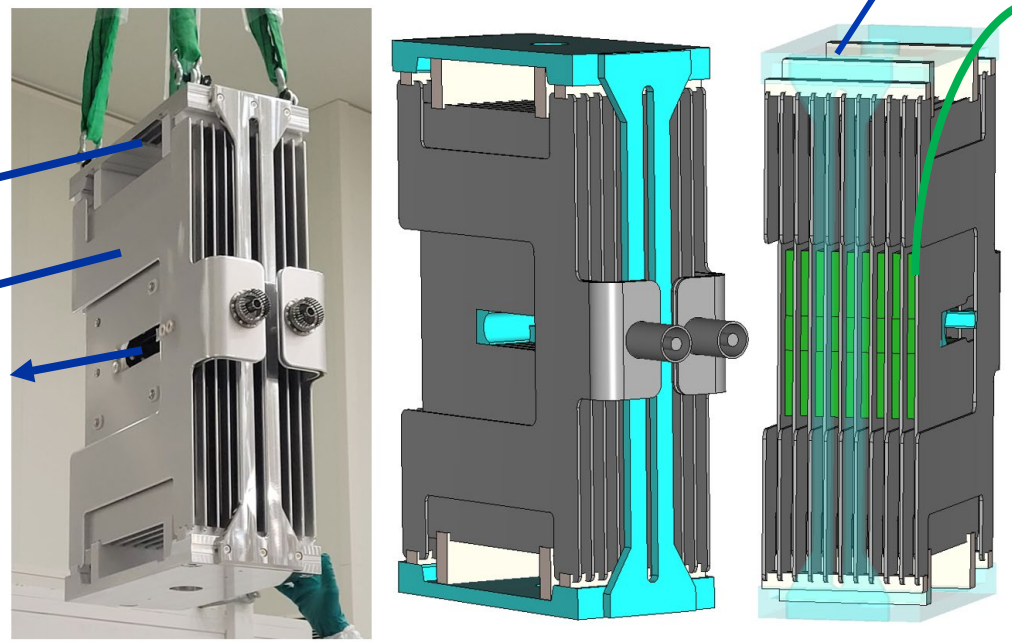
CATIA model by SY-ABT

Model geometry and materials

KFA79 module unit

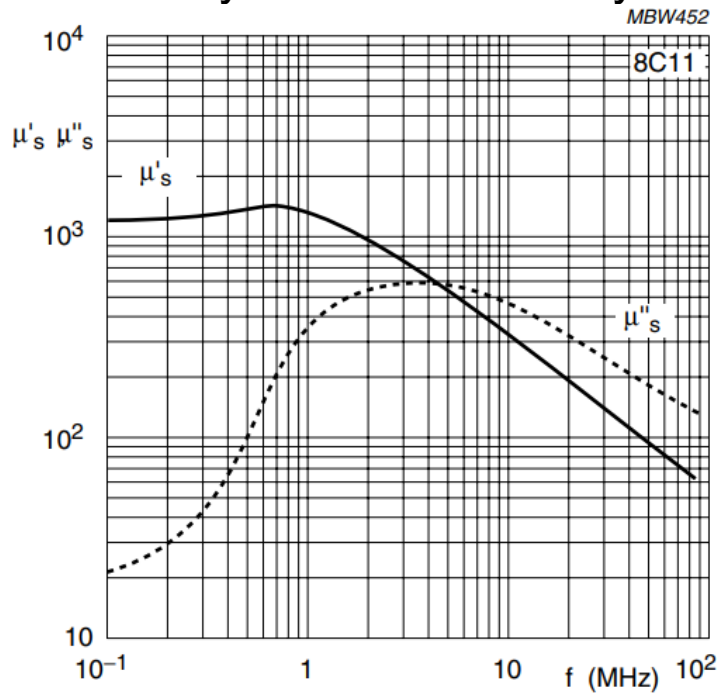
Plates
combs
Alumina

9-cells magnet



Frame
ground/HV plates
ground/HV conductors
Aluminum alloys

Highly dispersive behaviour → magnetic permeability of Ferrite 8C11 by Ferroxcube



High geometrical complexity →
Large computational resources required

Longitudinal impedance

Total voltage induced by the bunch on a charge in a time distance τ

Bunch spectrum

$$V_{ind}(\tau) = -qN_b \int_{-\infty}^{+\infty} S(f)\,Z(f)\,e^{j2\pi f\tau}\,df$$

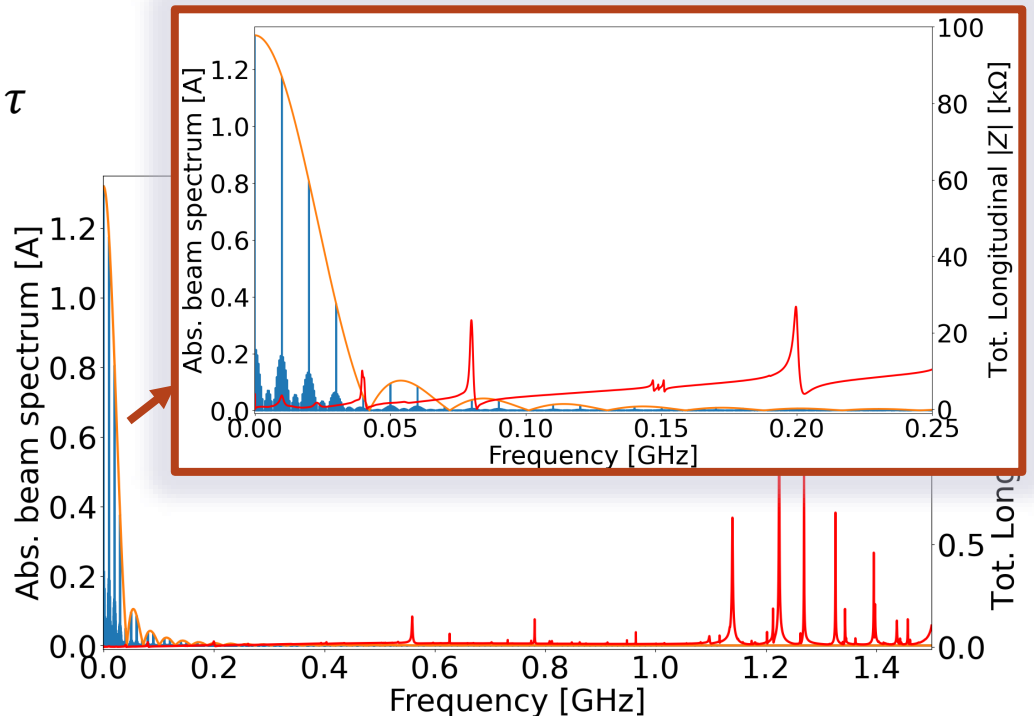
By expanding the exponential to the first order *

$Re\,\{Z(f)\}$ → R_s

$\frac{Im\{Z(f)\}}{f} \leftrightarrow \frac{R}{Q}$

Energy loss
Coupled bunch instabilities

Broadband impedance contribution driven by the **ferrite**
→ Mainly **single bunch instabilities**



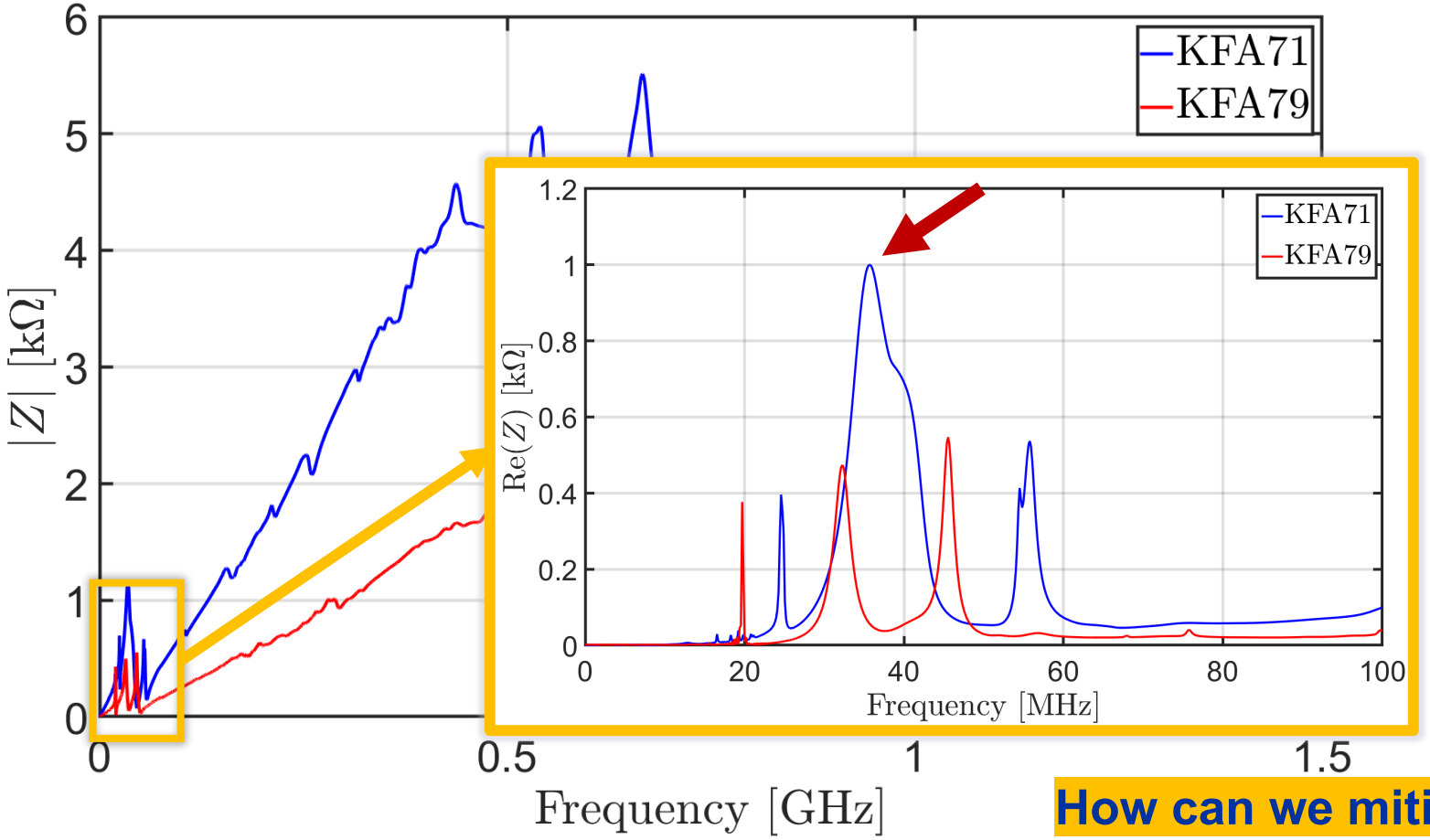
To avoid impedance peaks in the low frequency range, up to 150 MHz

For low frequencies → low **coupled bunch instabilities threshold** $R_s \sim \mathrm{k}\Omega$ (cumulative PS longitudinal shunt impedance) **

* J. L. Laclare, "Bunched beam coherent instabilities," in Proceedings of CAS 1985 Vol. I, pp. 264–326, 1987
** E. Shaposhnikova, "Longitudinal beam parameters during acceleration in the LHC", Tech. Rep. LHC-PROJECT-NOTE-242, CERN, 2000

Longitudinal impedance

Wakefield simulations: compromise between wakelength and number of mesh-cells → Good resolution in the desired range of frequency; Reasonable computational time



Three impedance contributions:

1. **Broadband**
2. **Low frequency**
3. **Higher frequency**

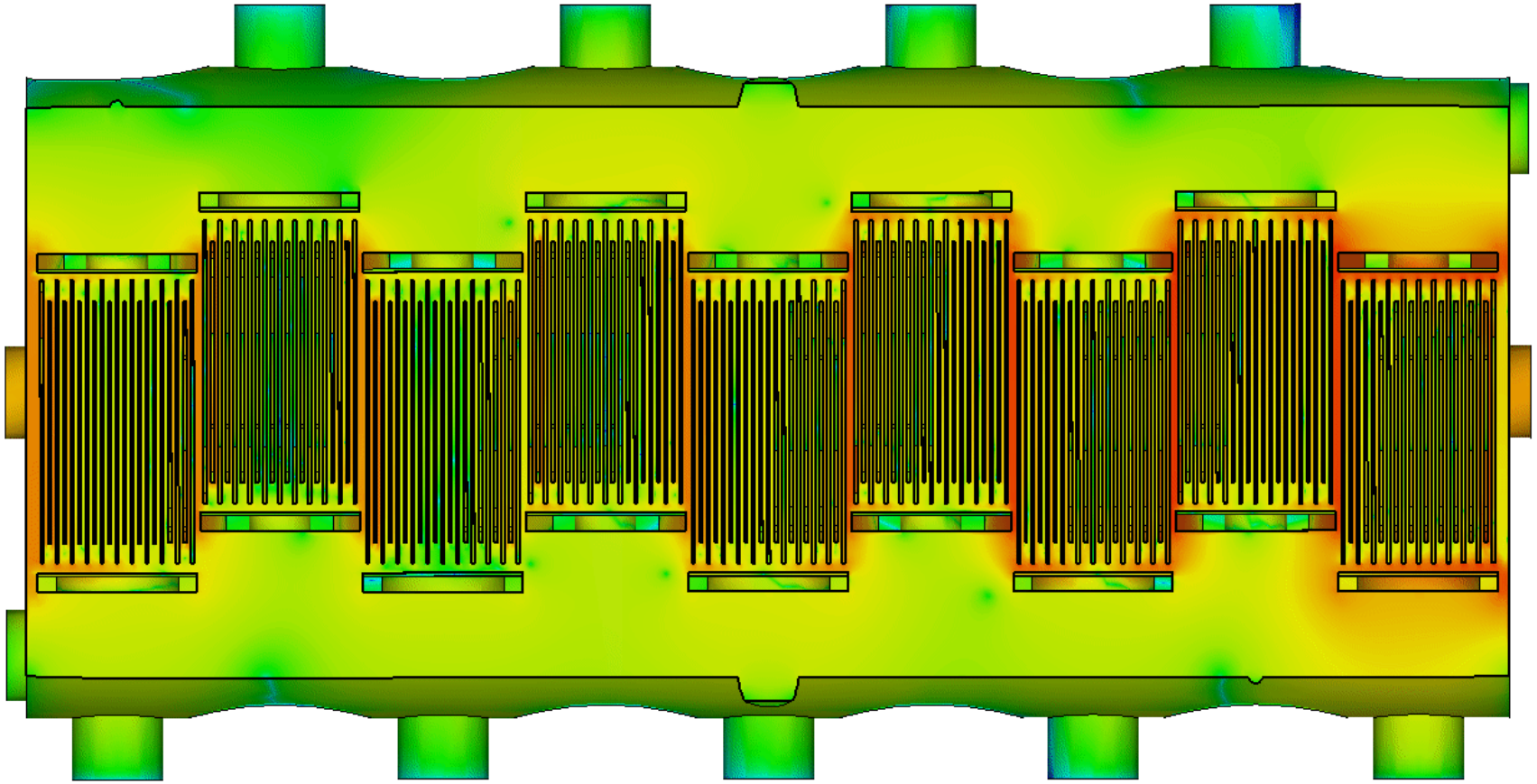
→ Ferrite drives the broadband behavior as expected by Tsutsui model*

How can we mitigate the unwanted contributions?

* H. Tsutsui, "Some simplified models of ferrite kicker magnet for calculation of longitudinal coupling impedance", Tech. Rep. CERN-SL-2000-004-AP, CERN, 2000

Mitigation strategy – resonance location

E-field monitor at 35.7 MHz

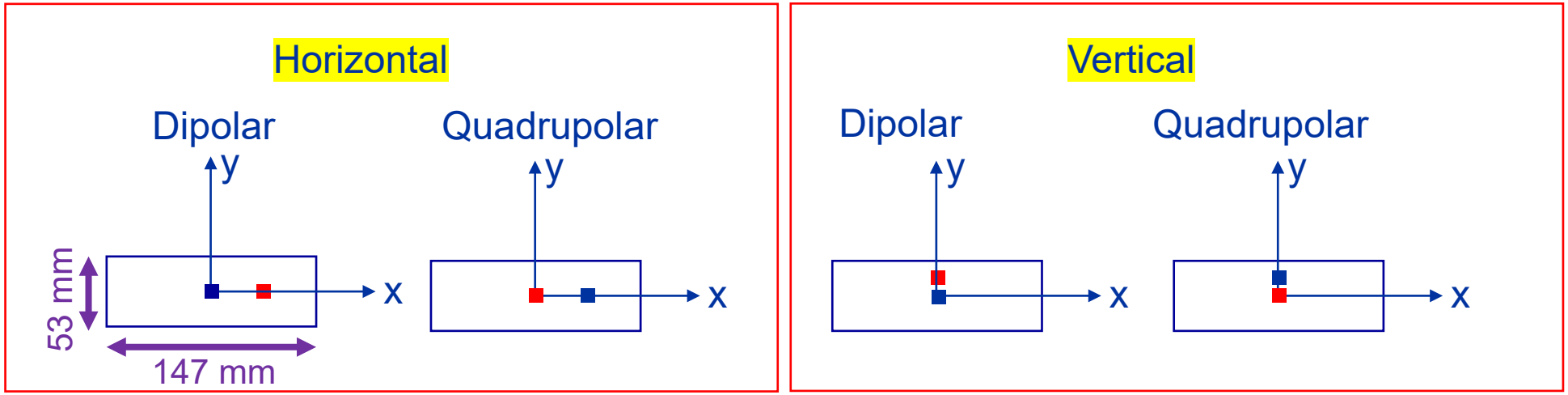


e-field (f=35.7) [pb]	
Component	Abs
Frequency	35.7 MHz
Phase	0 °
Cross section	A
Cutplane at Y	250.000 mm
Maximum on Plane (Plot)	8.80531e-06 V/m
Maximum (Solver)	2.29686e-05 V/m

Created using SIMULIA CST Studio Suite®

Mitigation strategy: M. Neroni et al., "Characterization of the longitudinal beam coupling impedance and mitigation strategy for the fast extraction kicker KFA79 in the CERN PS", in Proc. 14th International Particle Accelerators Conference, 2023

Transverse impedance



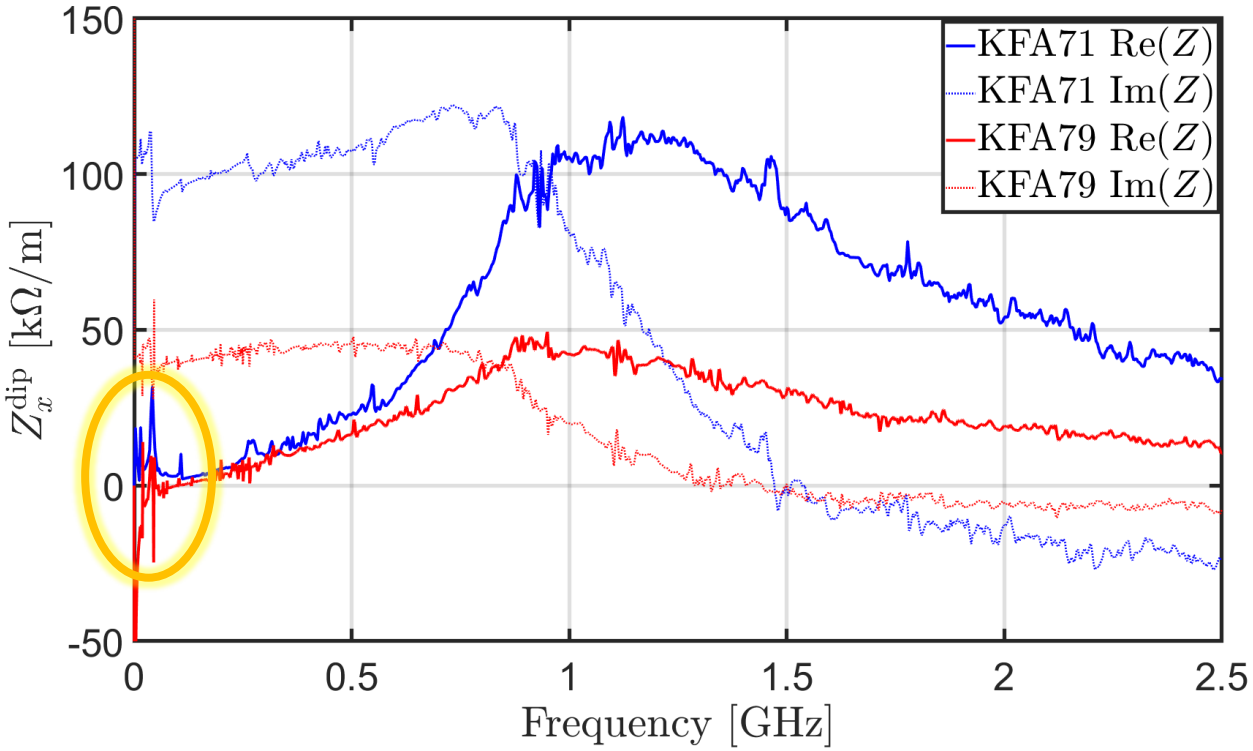
- Mesh density locally increased in the region of beam and integration path
- Calculations carried out for one **offset** case:
  - $x_{\text{off}} = 6.5$ mm
  - $y_{\text{off}} = 2.5$ mm

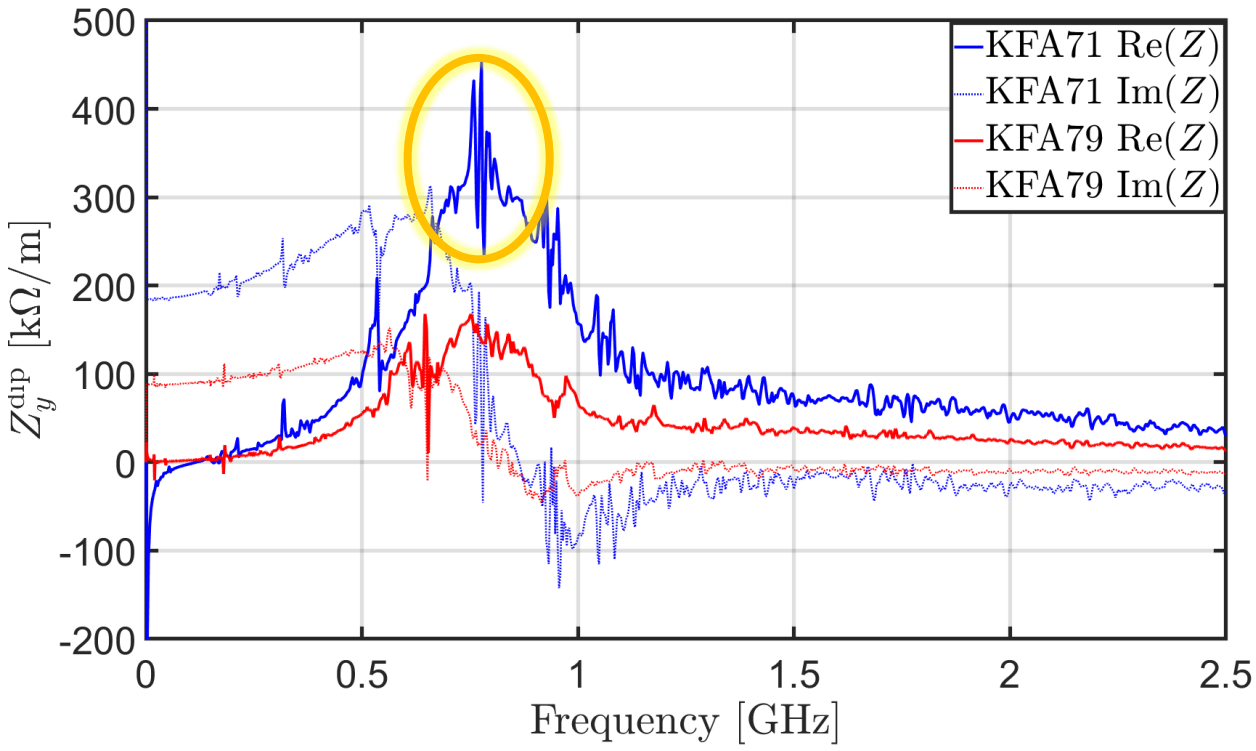
small enough to stay in the region where the linear approximation of the wake functions is valid

$$Z_u^{dip/quad} = -\frac{Z_u(\omega) - Z_u^0(\omega)}{u_{s/t}}$$

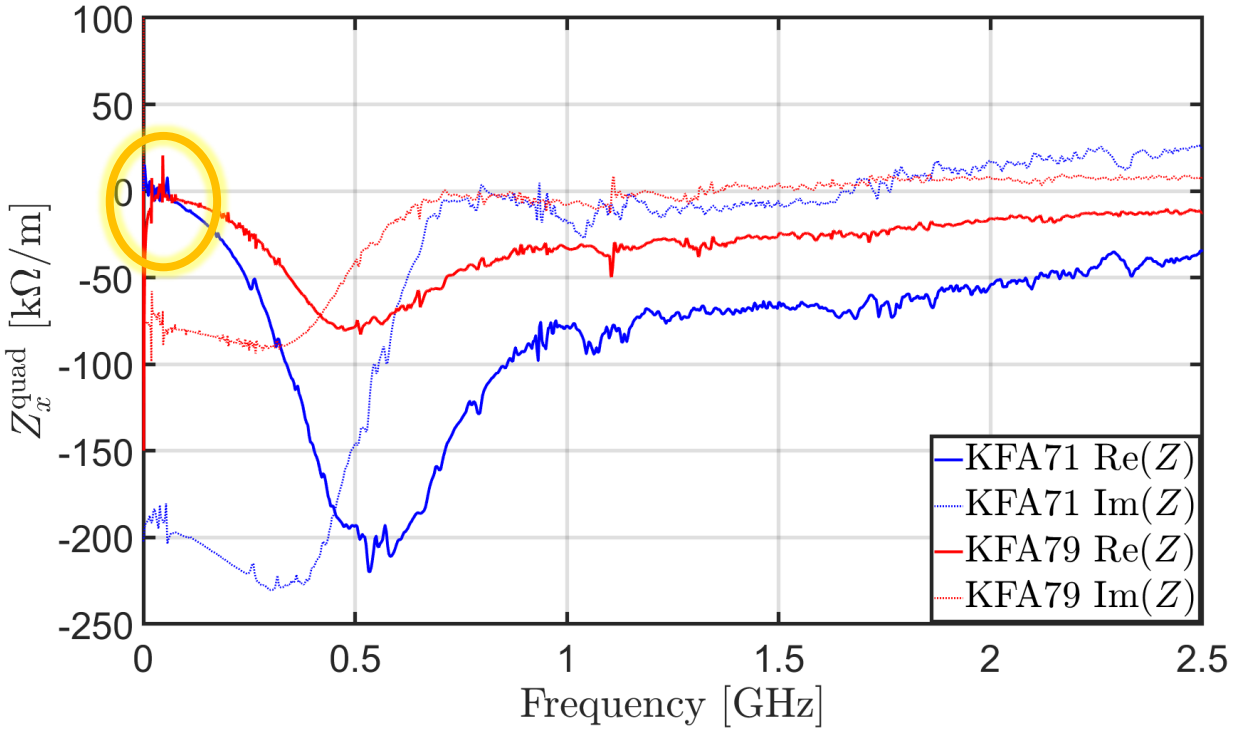
Transverse dipolar impedance

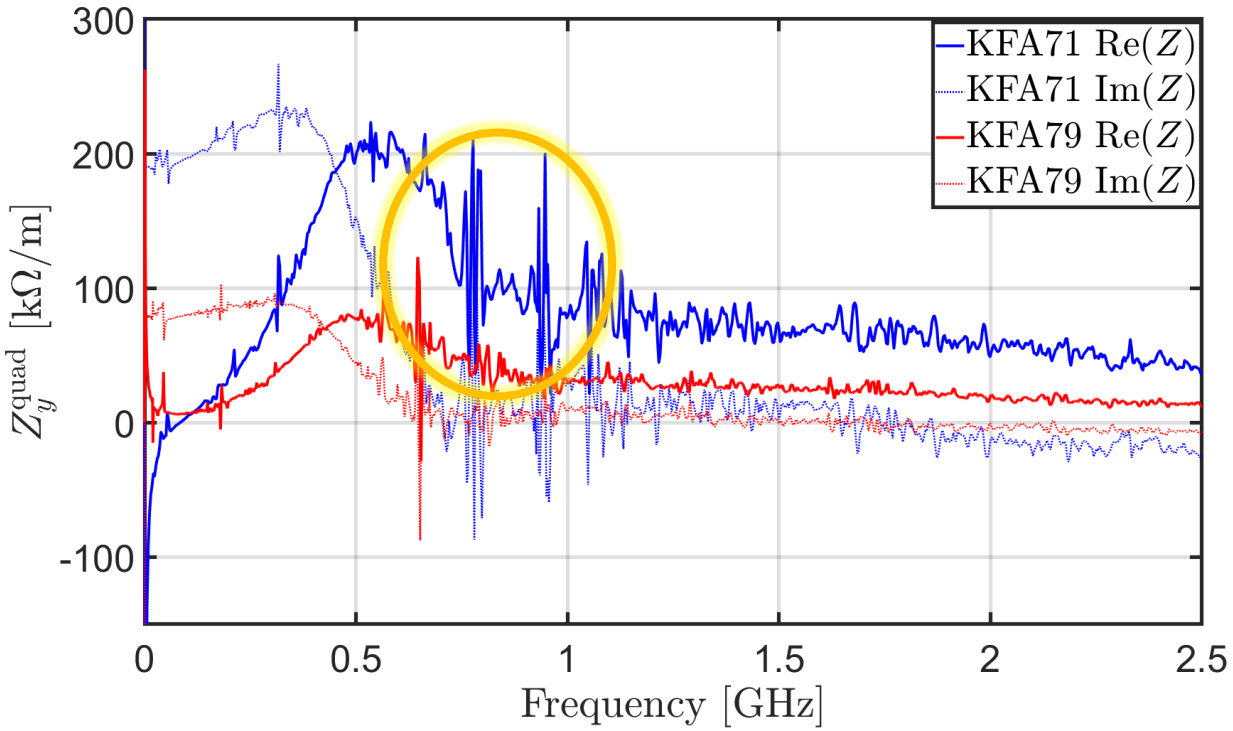
- Simulation up to 2.5 GHz to include broadband behavior tail





Transverse quadrupolar impedance





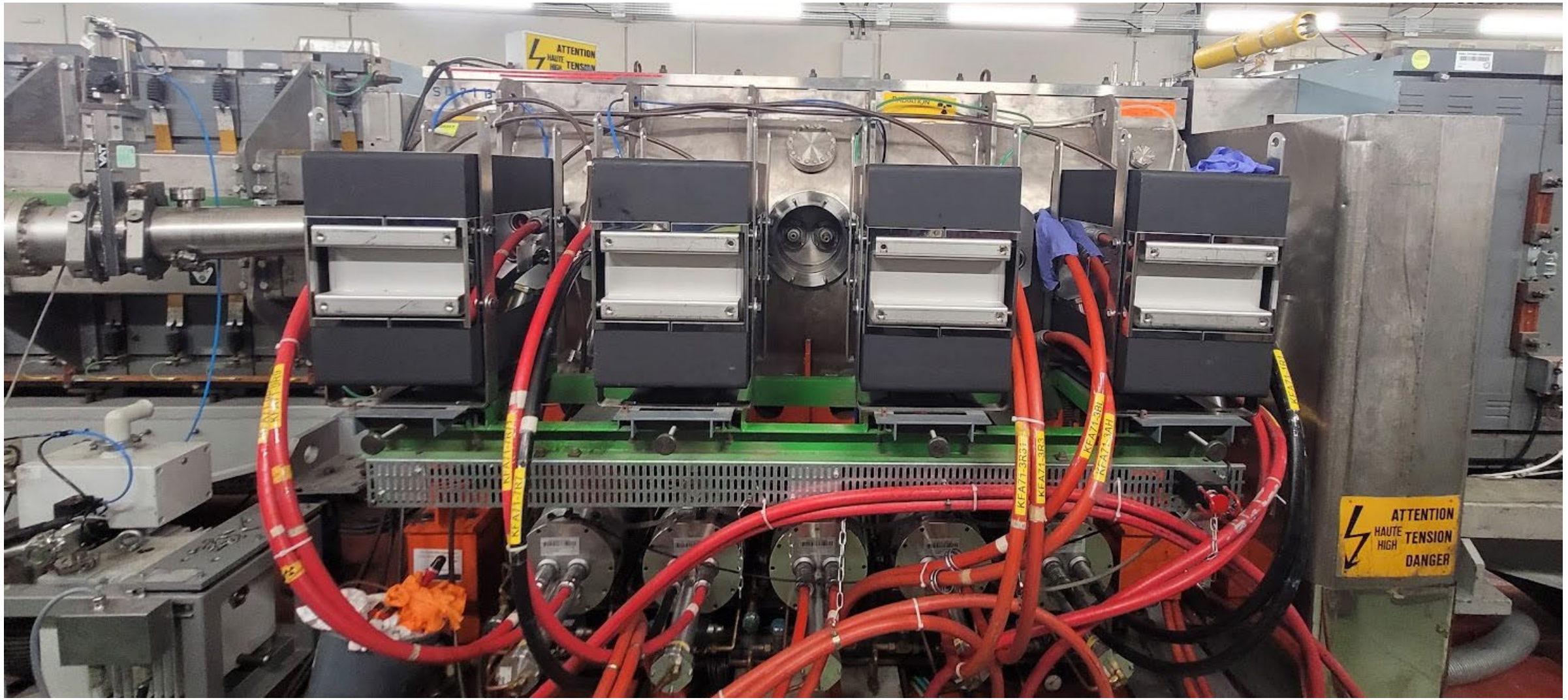
As expected from the theory*, the two quadrupolar components have the same amplitude but opposite sign

Transverse impedance results must be weighted with thee β-functions at the locations of the kickers

*K. Yokoya, “Resistive wall impedance of beam pipes of general cross section” Part. Accel., vol. 41, pp. 221–248, 1993.

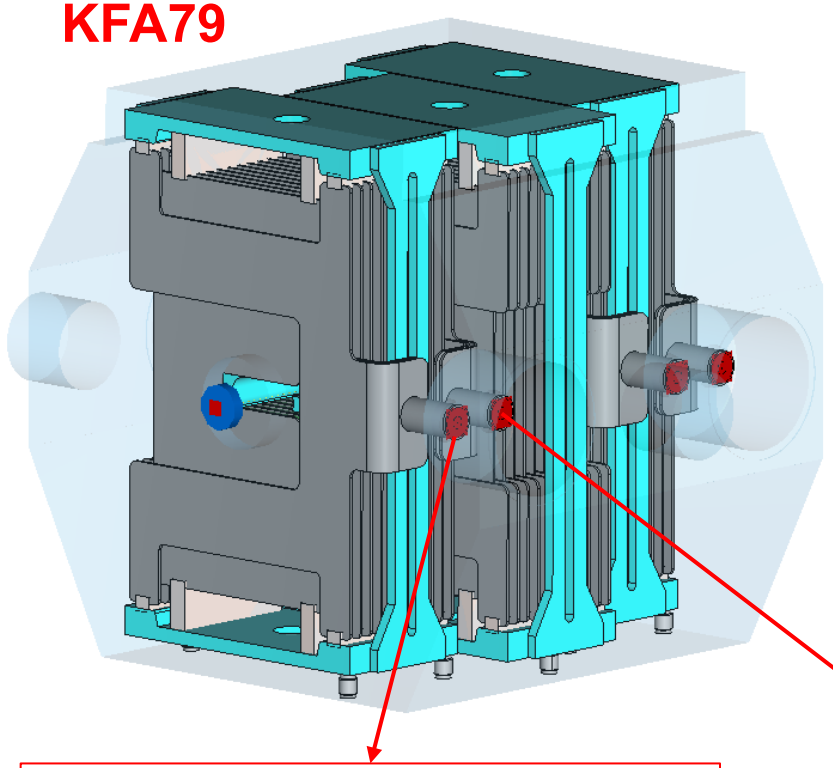
Adding cable terminations

KFA71 in the PS tunnel

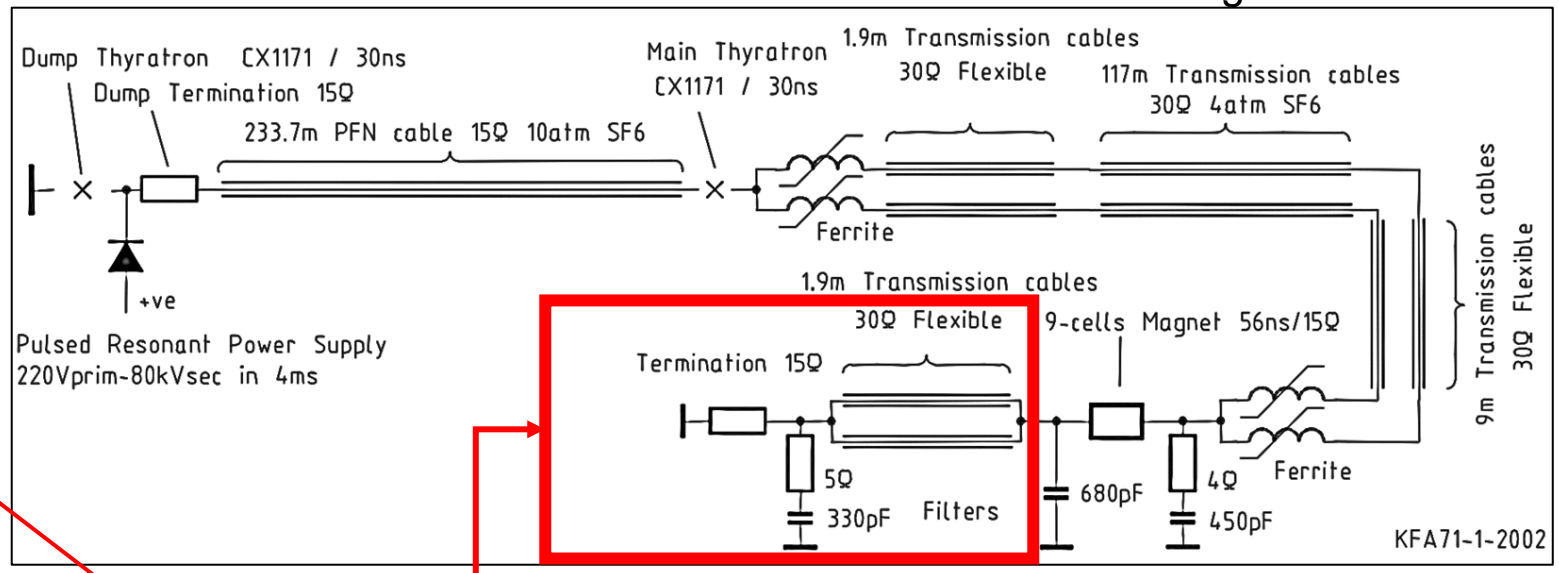


Adding cable terminations

KFA79



Circuit schematic of a magnet module unit*



Input connector → cables terminated on **open circuit** when the main switch in off-state, i.e. when not extracting from the PS

Output connector → Connecting cables terminated on **15 Ω**

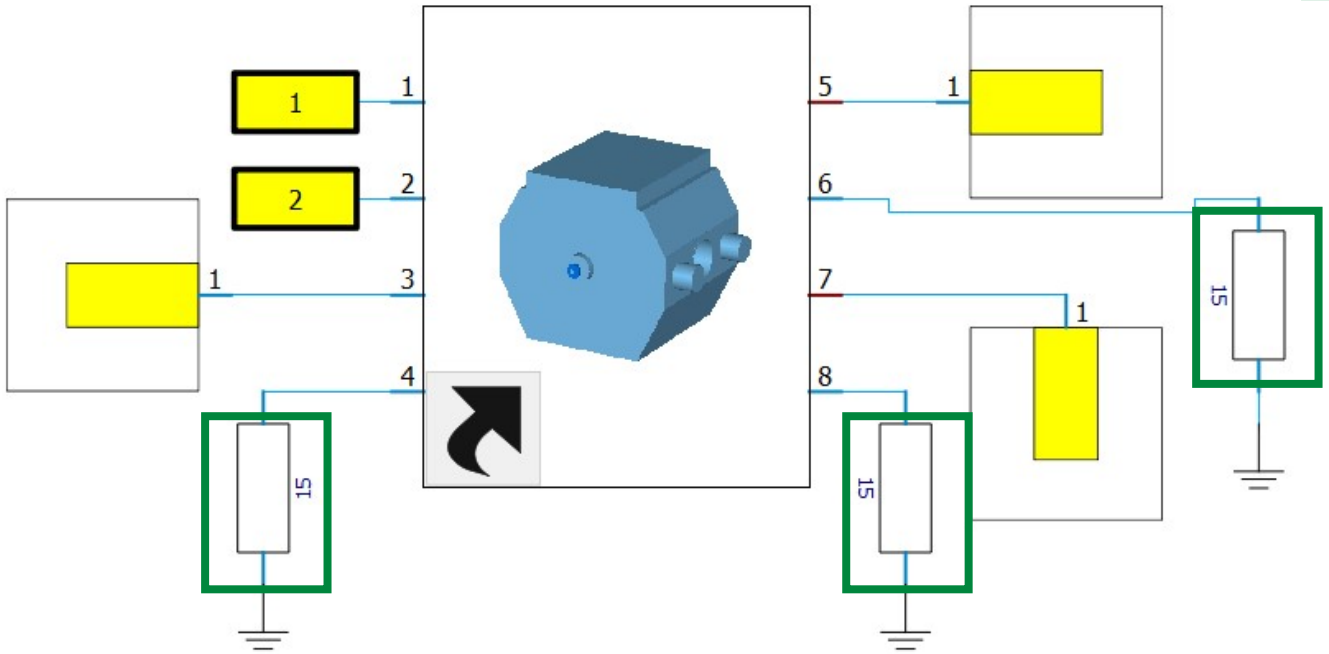
* L. Sermeus et al., "The kicker systems for the PS Multi-turn Extraction", No. CERN-ATS-2010-140, 2010

Simulating wire measurement

1. **Frequency domain simulation (FD)** to mimic single stretched wire measurements setup → including in the 3D model matching resistors and copper wire

   Treating power connectors as **waveguide ports →** 6 + 2 (kicker input/output) ports component

2. **Combined schematic simulation**: lumped element circuit connected to a 3D electromagnetic FD simulation



Three different **configurations** simulated:

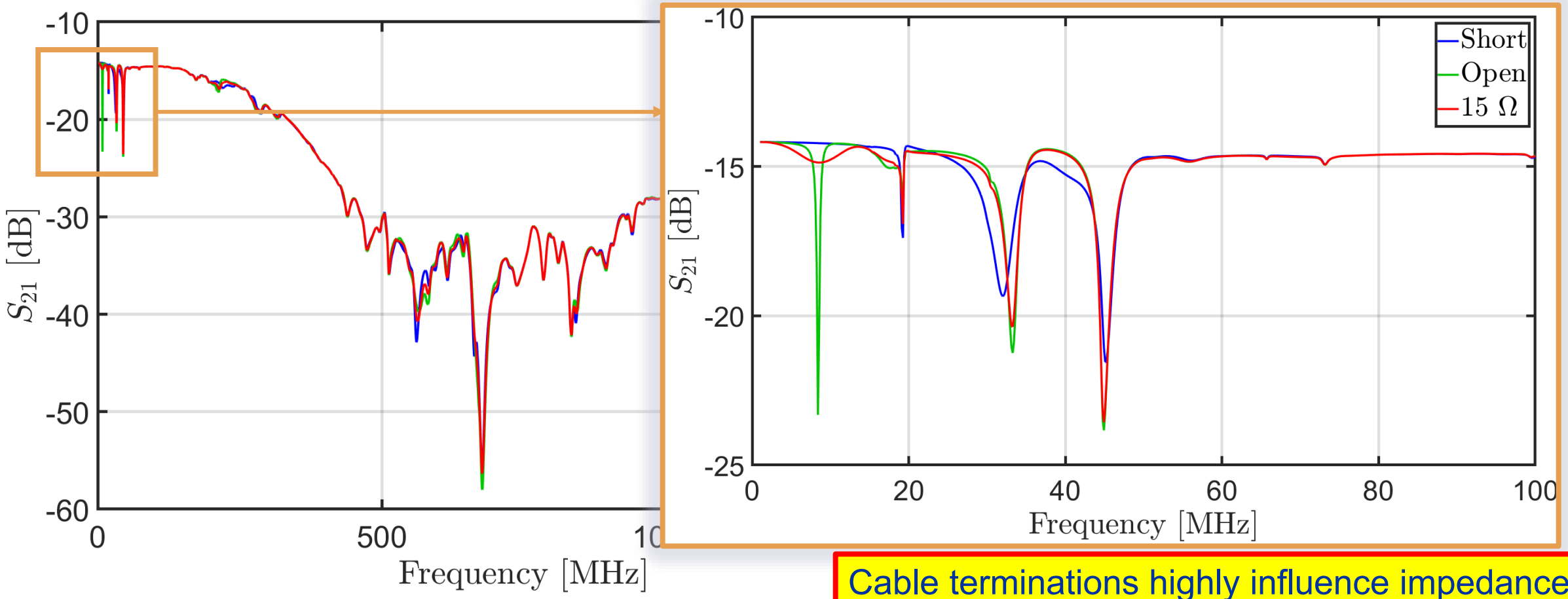
→ **Input** power connectors always terminated on **ideal open transmission line**

→ **Output** power connector terminations considered as:

a) ideal **open** transmission line
b) short circuit
c) 15 Ω resistor (actual situation)

Effect of cable terminations

The transmission parameter, S_{21}, is of interest because it directly gives information on the longitudinal beam coupling impedance



Cable terminations highly influence impedance behaviour in the low frequency range

Conclusions and Outlook

- The **longitudinal** and **transverse beam coupling impedance results** for both **PS extraction kickers** have been presented and **critical resonances** were discussed.

- Work on **mitigation solutions** has started tackling the critical impedance peaks.

- The **transmission cable terminations** highly impacts the beam coupling impedance.

- **Stretched wire measurements** on the KFA79, including proper cable terminations, are currently ongoing for a final confirmation of impedance results.

- The transverse impedance is useful for updating **PS transverse impedance model** and for investigating **transverse instabilities** (see also talk by S. Joly, *"Recent advances in the CERN PS impedance model and instability simulations", HB2023*).

- **Transmission cables** with their proper **terminations** must be included in the **simulations** and be also part of the **measurement setup**.