Impedance WG status report

Carlo, Christine, Thomas and Patrick (in 2017), Leo, Elena, Niky, Alice, Rama, Giulia, Giovanni, Benoit

Many thanks

to our colleagues from BI for the teamwork (William, Federico, Jonathan, Manfred)
and to the IWG members for the help and advice

IPP – 5 May 2023

Context

- Systematic SPS wire scanner failure in parking position
- Talk of Carlo at last IPP:
  https://indico.cern.ch/event/1276147/contributions/5360049/attachments/2633054/4554377/Moving%20towards%20HL-LHC%20intensities.pptx
- Talk of Federico at last IEFC:
  https://indico.cern.ch/event/1272497/contributions/5380889/attachments/2637711/4563923/2023-04-28-SPS_BWS@IEFC.pptx
- Talk at last IWG:
  https://indico.cern.ch/event/1281453/contributions/5383477/attachments/2639673/4568381/SPS%20wire%20scanner%20breakage.pptx

→ Evidence points to excessive beam induced heating in parking position
→ Emergency work by many colleagues in BI, RF and ABP to understand the issue and try to find solutions

Agenda

- Simulations
- Possible mitigations
- Bench measurements
- Beam measurements

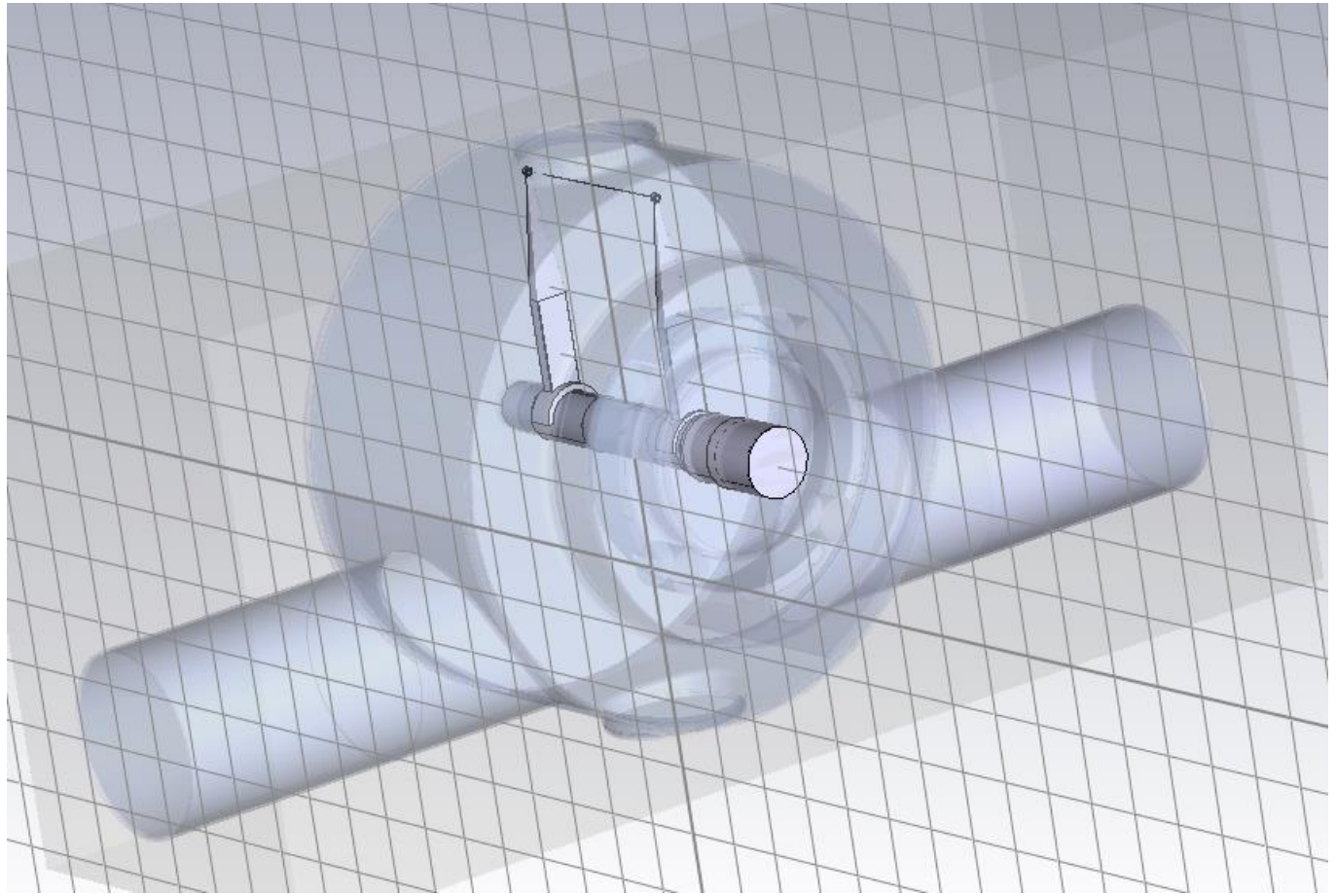
Model of Thomas from 2017

PS/SPS WS:

Eigenmode simulation
(most significant modes)

f [GHz]	Z_s [Ω]	Q_0	R/Q [Ω]
0.149	360.5	1119	0.3
0.781	29711.9	2198	13.5
0.808	3082.6	1827	1.7
1.016	1090.9	1731	0.6
1.116	8880.7	5712	1.6
1.202	14040.5	6425	2.2
1.263	1805.6	4859	0.4

https://indico.cern.ch/event/616762/

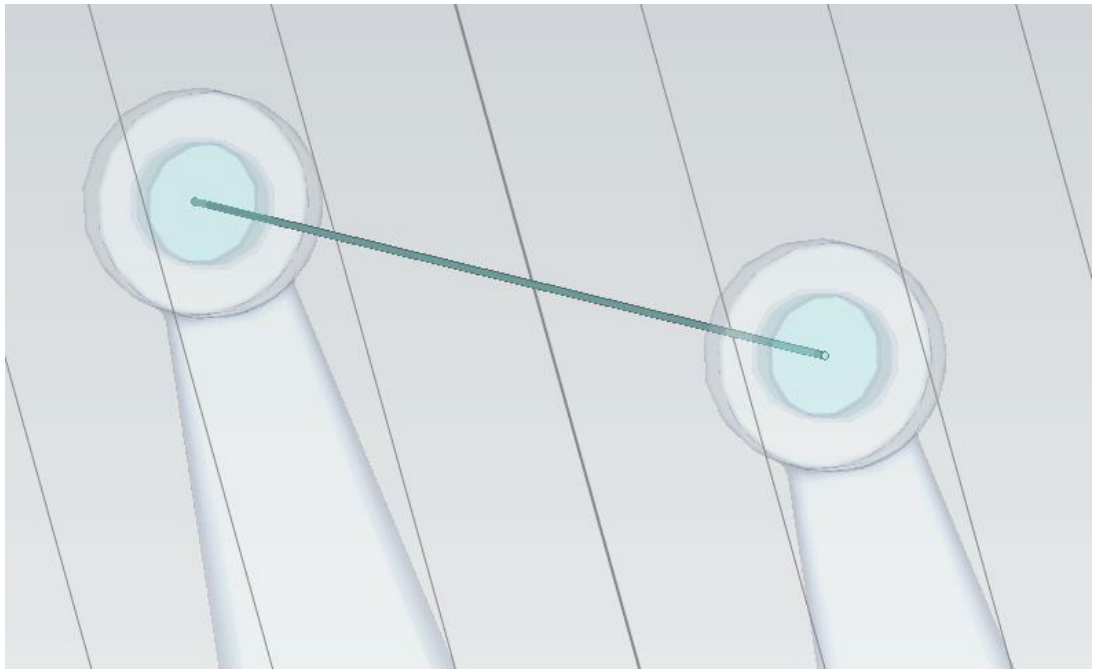


→ First mode power loss is hardly on the wire, and does not change as much with bunch length
→ With such high Q (>2000), hard to explain that mode for all scanners hits the beam spectrum lines at the same time (Deltaf~300 kHz)

Model from Thomas from 2017

- Reduced wire conductivity (9000 S/m)
- Added Macor between wire and fork
- Left the wire with no connection

→Mode much broader



Eigenmode :

- f=786 MHz
- Q=250
- Rsh=3.2 kOhm

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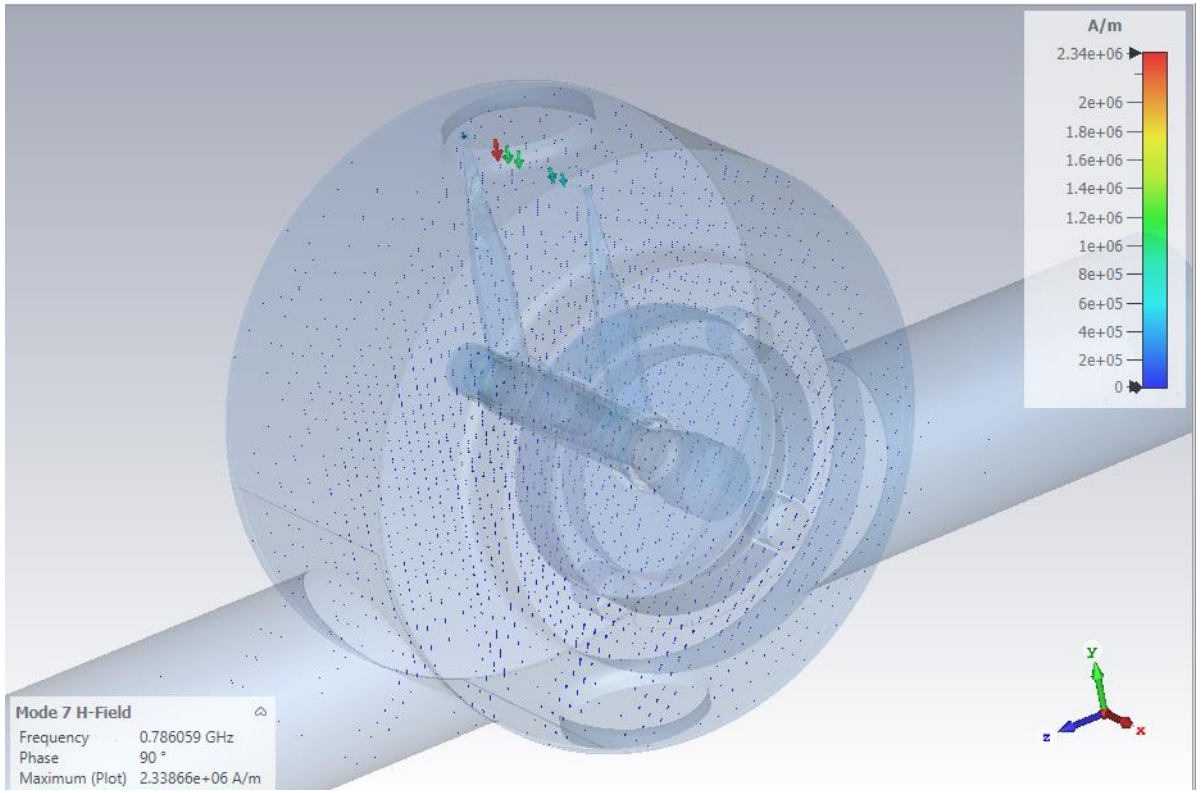


Eigenmode :

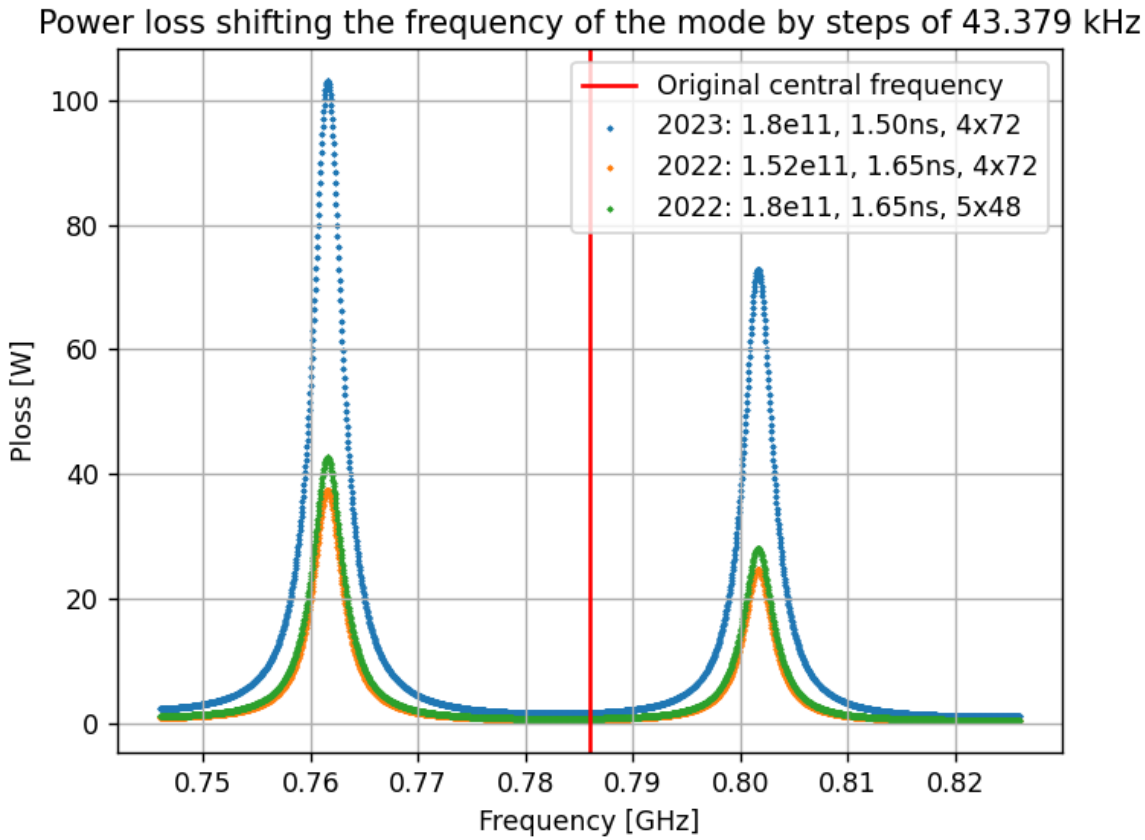
- f=786 MHz
- Q=250
- Rsh=3.2 kOhm

(89% dissipated on the wire)

Power loss expected from mode at ~780 MHz

Power dissipated in the device
at exact frequency:

- 2023: 1.62 W (1.44 W on the carbon wire)
- 2022: 0.59 W (0.52 W on the carbon wire)
- 2022: 0.71 W (0.63 W on the carbon wire)

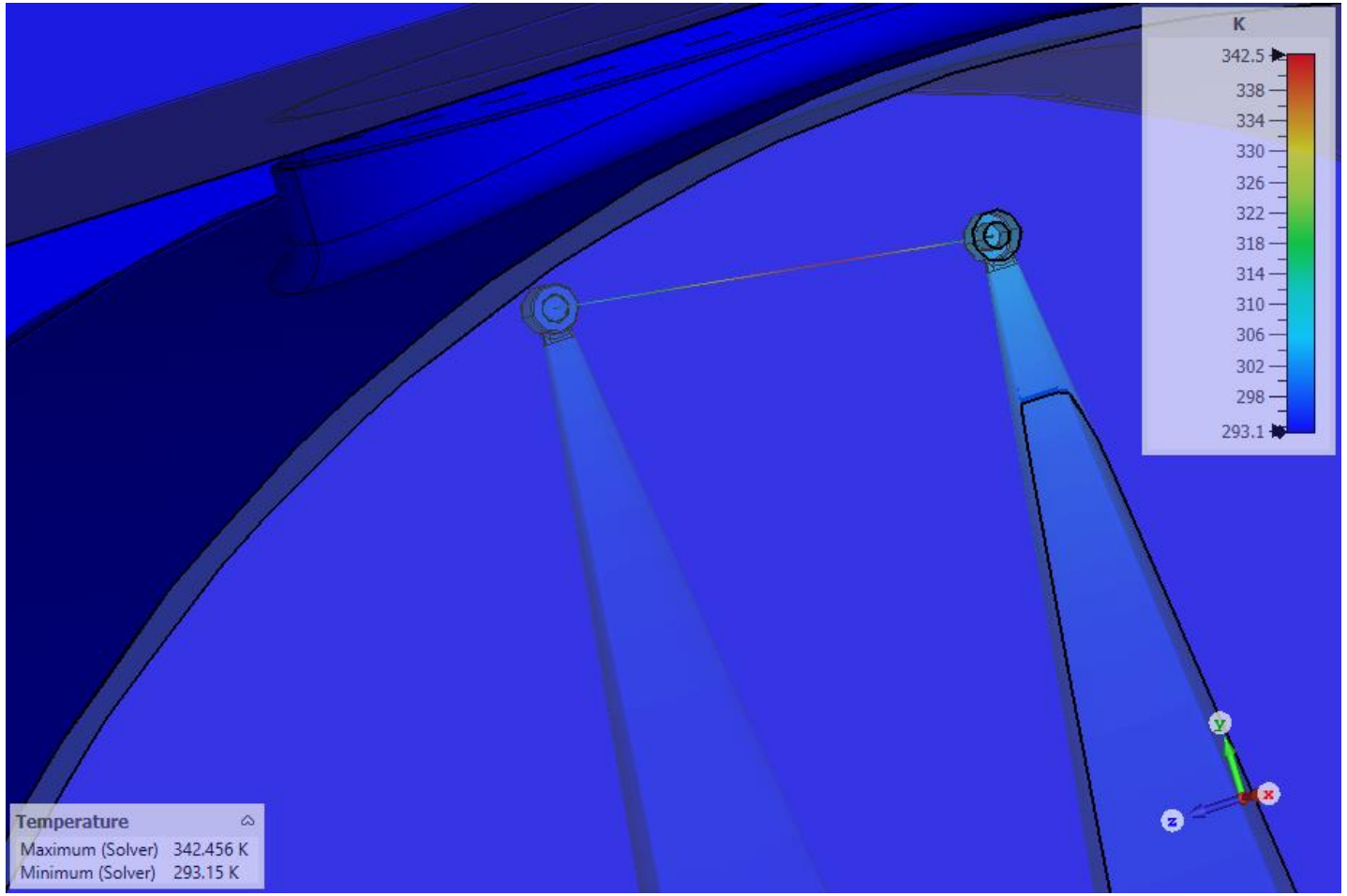


→ Power dissipated increased by more than a factor 2 in 2023 compared to 2022
→ Depending on frequency of the mode w.r.t. beam spectrum line, can increase from ~2W to more than 100W

Thermal simulation with CST

- Steady state
- Assumed 1W dissipated

→ 50C increase on the wire



Modes without ferrite

Frequency	Rsh	Q	On the wire	Power loss at freq	Power loss at freq on the wire	Max power loss	Max power loss on the wire
149 MHz	0.275 kΩ	894	[21%]	0.27 W	0.06W	184 W	38 W
542 MHz	0.250 kΩ	423	[20%]	0.32 W	0.06 W	44.1 W	9 W
786 MHz	3.2 kΩ	250	[89%]	1.61 W	1.43 W	44.1 W	39 W

→ 3 modes are able to generate significant losses on the wire

Modes without ferrite

Frequency	Rsh	Q	On the wire	Power loss at freq	Power loss at freq on the wire	Max power loss	Max power loss on the wire	Injection at freq	Injection max
149 MHz	0.275 kΩ	894	[21%]	0.27 W	0.06W	184 W	38 W	0.02 W	108 W
542 MHz	0.250 kΩ	423	[20%]	0.32 W	0.06 W	44.1 W	9 W	0.001 W	0.20 W
786 MHz	3.2 kΩ	250	[89%]	1.61 W	1.43 W	44.1 W	39 W	0.0077 W	0.012 W

→ 3 modes are able to generate significant losses
→ 1st mode would likely have been too strong at injection energy for 2.3E11 p/b (that we had in 2022)
→ 2nd mode could also be responsible
→ 3rd mode seems the worst

Agenda

- Simulations
- Possible mitigations
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- Beam measurements

Possible solutions to reduce power loss to the wire

$$\Delta W = (f_0 e N_{\text{beam}})^2 \sum_{p=-\infty}^{p=\infty} \left(\left| \bar{\Lambda}(p\omega_0) \right|^2 \text{Re}\left[Z_{||}(p\omega_0) \right] \right)$$

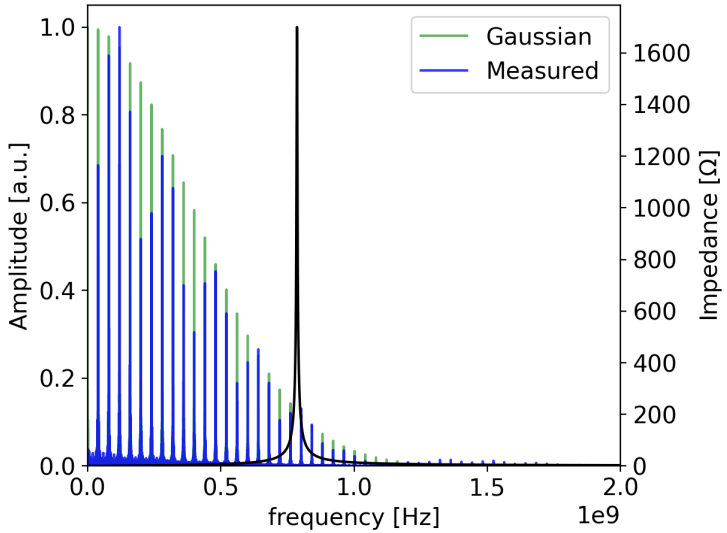
power dissipated on the wire ~ [normalized beam spectrum] * [real longitudinal impedance] * [% on the wire]

[Assuming bunch length, bunch intensity and number of bunches constrained by performance reach]

1. Reduce beam spectrum at mode frequency
   a. Change longitudinal profile
   b. Push impedance to higher frequency (change geometry)
   c. Put impedance in-between 40 MHz spectral lines (adapt geometry, need measurement)

2. Reduce shunt impedance of mode
   a. Change geometry
   b. Change materials

3. Relocate losses elsewhere than wire
   a. Add damping material
   b. Add coupler



Possible solutions to reduce power loss to ferrite

Reduce beam spectrum at mode frequency

- Can the bunch profile be shaped to reduce components beyond 500 MHz? Flattened bunches?
- Can try to reduce the critical duration when bunch length is minimal?

→ not clear if feasible

Reduce impedance

- Geometry already very constrained → not clear anything can be done
- Mode present without wire and with forks in dielectric → not clear anything can be done
- Wire in tungsten?

Relocate losses elsewhere

- Ferrite → see next slides
- Mode coupler → to be checked in measurements (could see if PSB wire scanner fork can be used)
- Add another wire → from 80% to 60% on the wire
- Shielding plate → not very promising

With ferrite

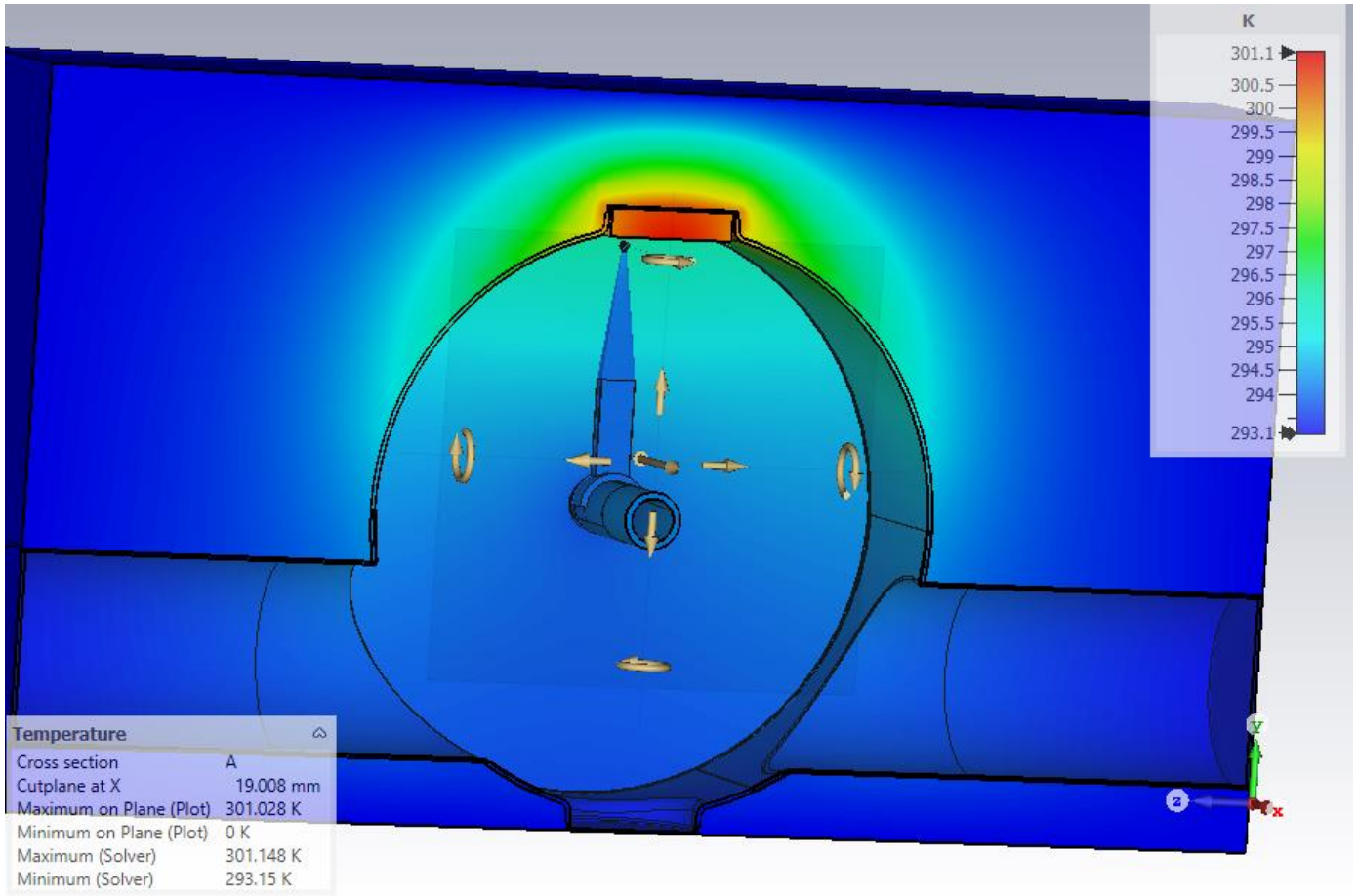
→ TT2-111-R facing parking position
→ For 1 W dissipated

Eigenmode with ferrite:
- f=783 MHz
- Q=218
- Rsh=2.6 kOhm

17% on the wire, the rest on the ferrite

But power relocated mostly to the ferrite (wire at 298K)

→ Need to cool the ferrite, or check that it does not heat too much

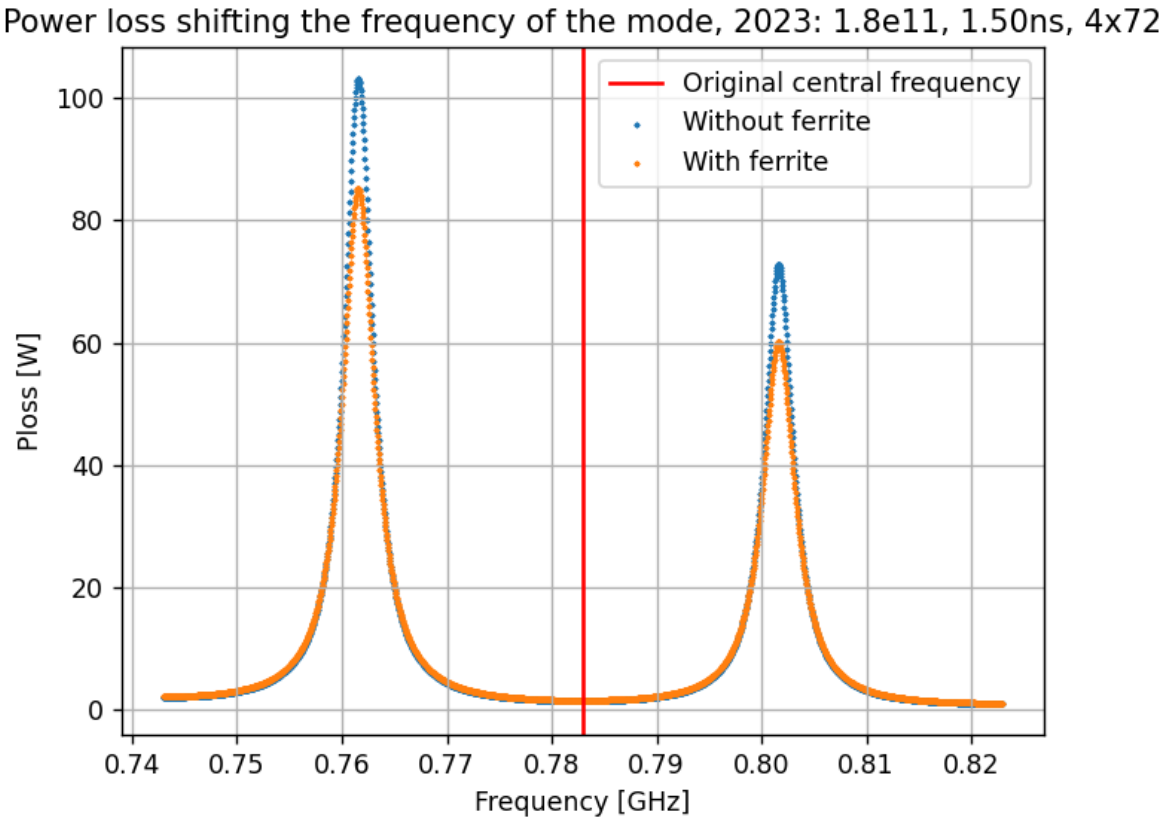


Power loss expected from mode at ~780 MHz

Power dissipated in the device at exact frequency:
- With ferrite: 1.61 W (0.28 W on the wire)
- Without ferrite: 1.62 W (1.44 W on the wire)

→ Maximum power to the device: more than 80W
  → 14 W on the wire
  → 70 W on the ferrite

→ Important to check that the mode is far from spectral lines in measurements!
→ Need to study options for ferrite cooling



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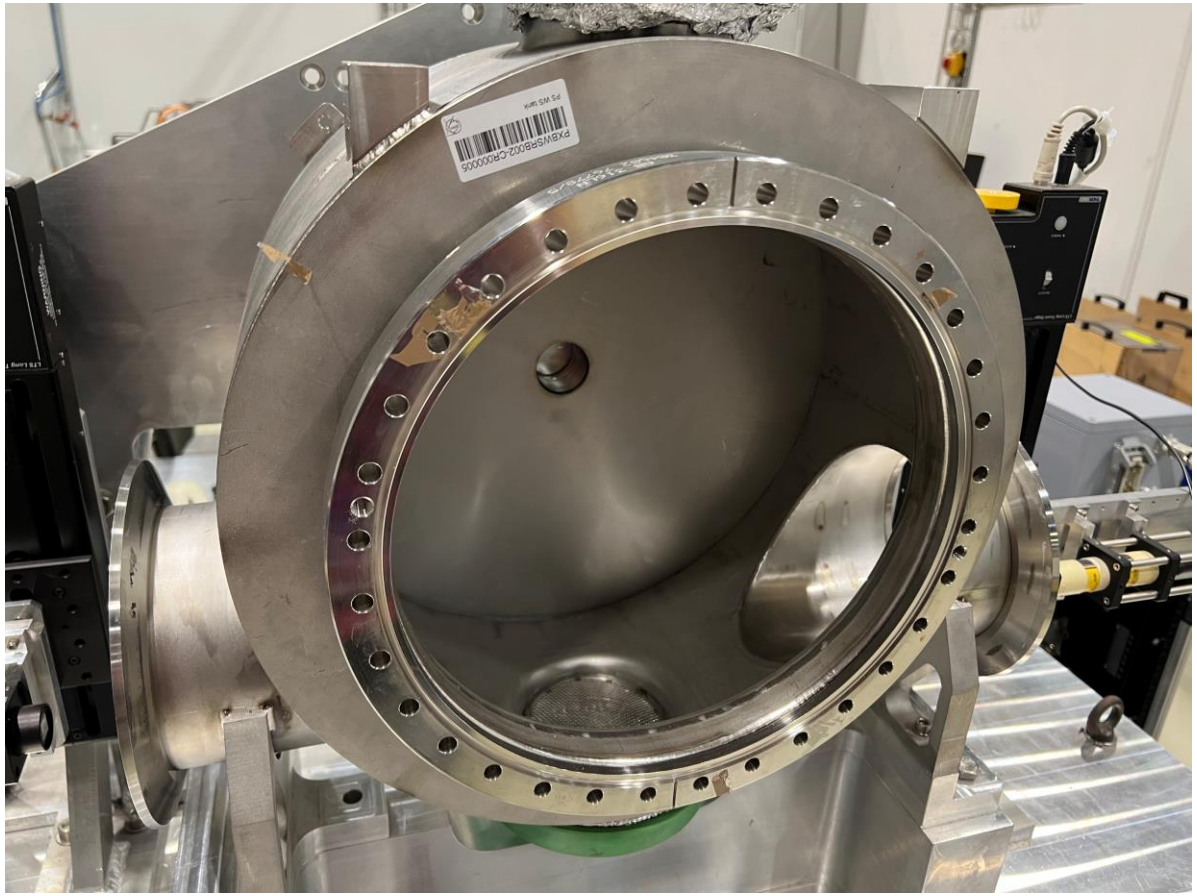
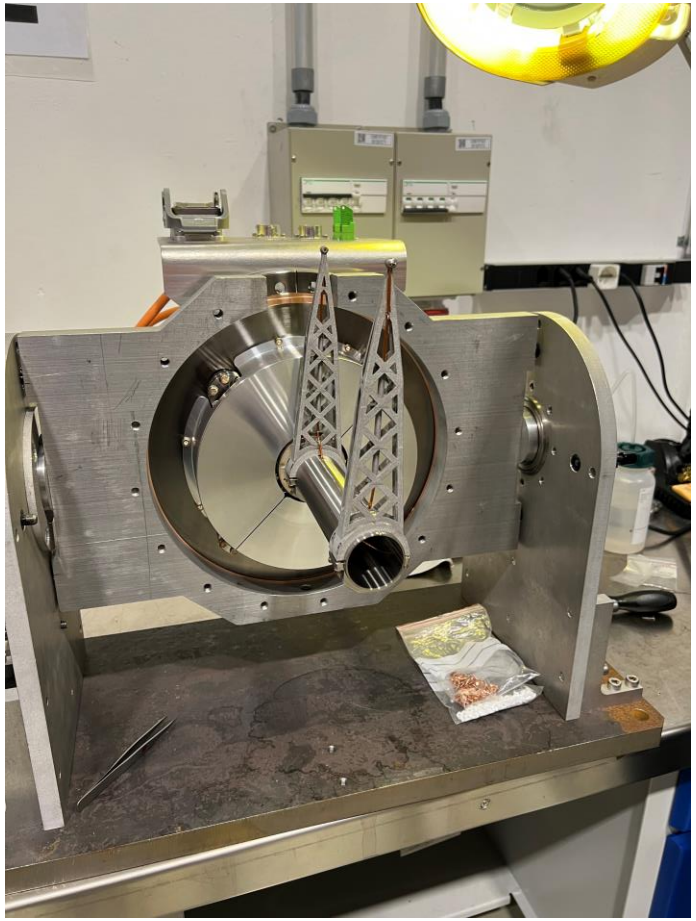
Bench measurements





→ Set up by William and ready for measurements

Goals for bench measurements

- Check frequencies of resonant modes
- Identify those with large coupling
- Test mitigation measures

→ Planned for the coming days (Christine, Michael and Carlo)

Agenda

- Simulations
- Possible mitigations
- Bench measurements
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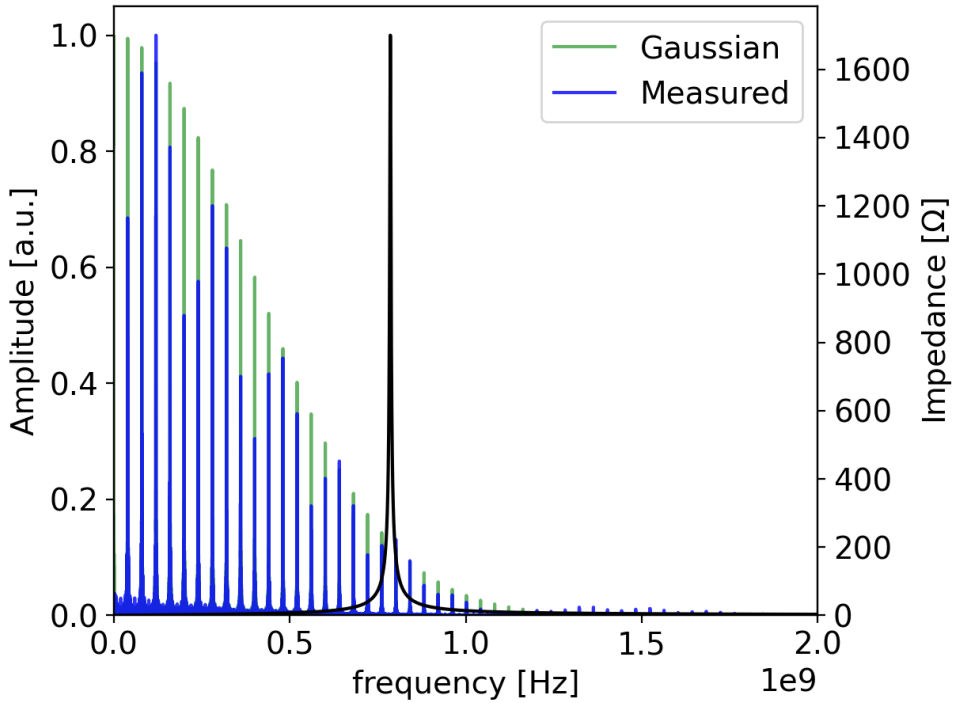
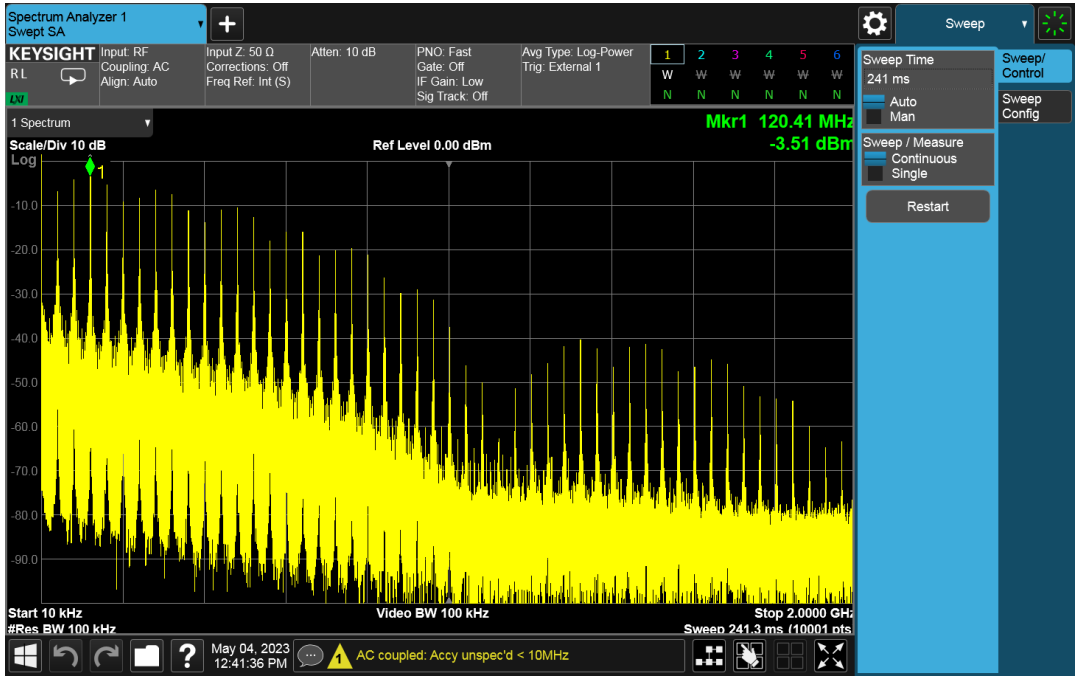
Beam measurements
(by Alice and Niky with the help of Giulia and Rama and SPS OP crew)

- Measured beam spectrum, bunch length and bunch profiles along the cycle with same conditions as for the last wire breakage (except bunch intensity at 1.5E11 p/b)

  → evolution along the cycle can be correlated with voltage induced signal on the carbon wire

  → check measured power spectrum at resonant frequencies and compare to prediction





→ Some aspects to be clarified (e.g. transfer function, undersampling)

→ Comforted us in the use of the Gaussian bunch shape to estimate power loss at the mode frequency → to be continued

Action plan (from Wednesday IWG)

- Impedance measurement of a spare SPS wire scanner with carbon wire to
  - Confirm frequency, quality factor and coupling from beam to the carbon wire of the resonant modes [planned with William to start this week] → instrument received, measurements to start
  - See if mitigation measures could reduce the impedance and/or divert the heat load from the carbon wire to somewhere else (other wires, ferrites, couplers), and whether another parking position could reduce the heat load to the wire → measurements to start

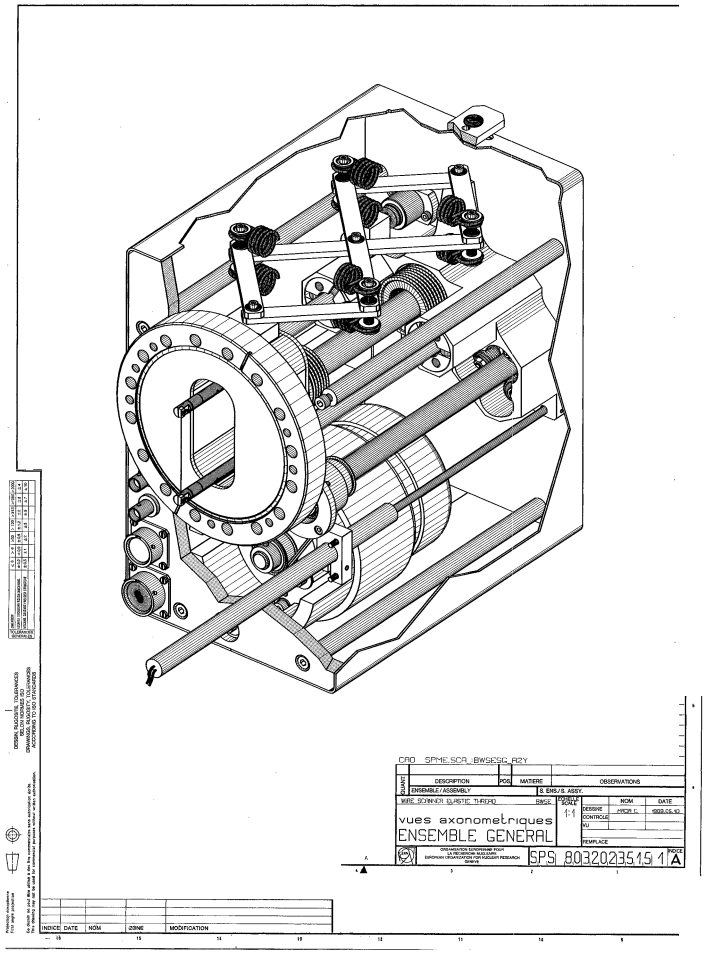
- Check the beam spectrum along the cycle [planned with Giulia for Thursday] → Done!
- and see if we could reduce the high frequency spectrum component with RF settings → to be done

- Continue impedance simulation campaign at parking position with potential mitigation measures [started right after the first breakage]. → ongoing
  - Still a lot of assumptions in there (fork in stainless steel, no connection of the carbon wire and no measurement wire)
  - Need to consolidate and benchmark results

- Note: If we consider ferrite a viable option,
  - need to identify quickly which ferrite type (magnetic losses and vacuum compatibility)
  - start checking procurement possibilities
  - Check how it could be positioned in H and V scanners (clamping? Left laying on the bottom?)
    → to be followed up by task force

SPS linear wirescanners

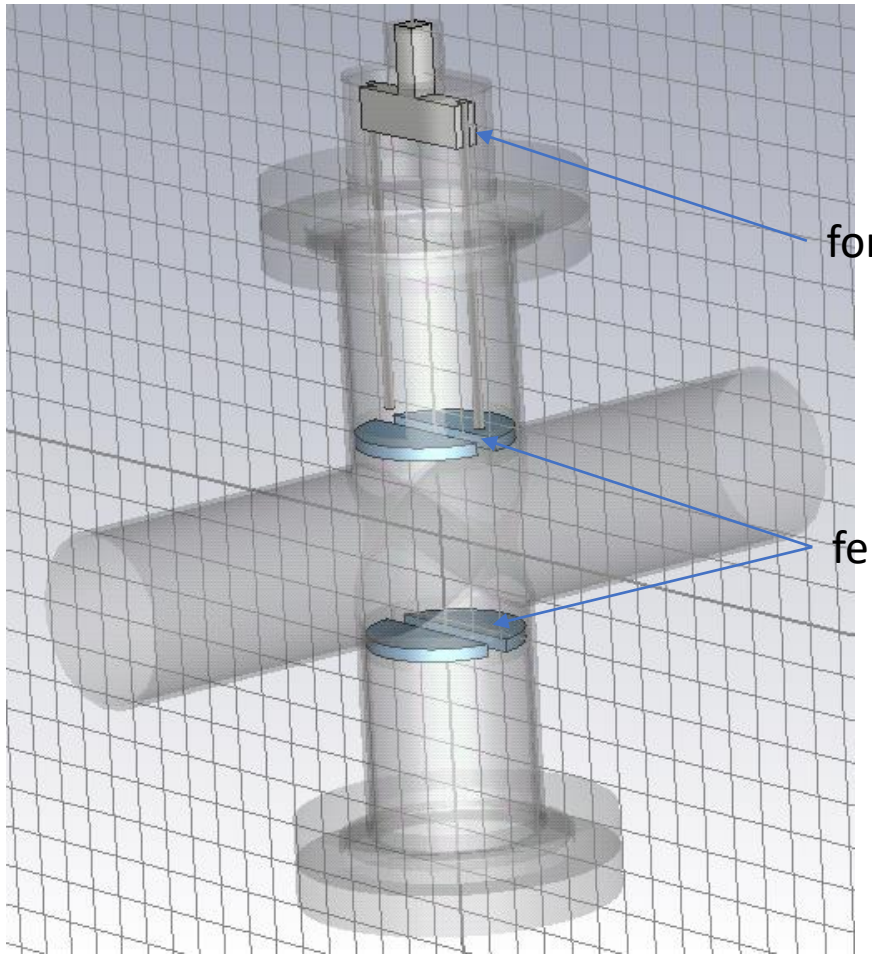
- Thanks Jonathan!



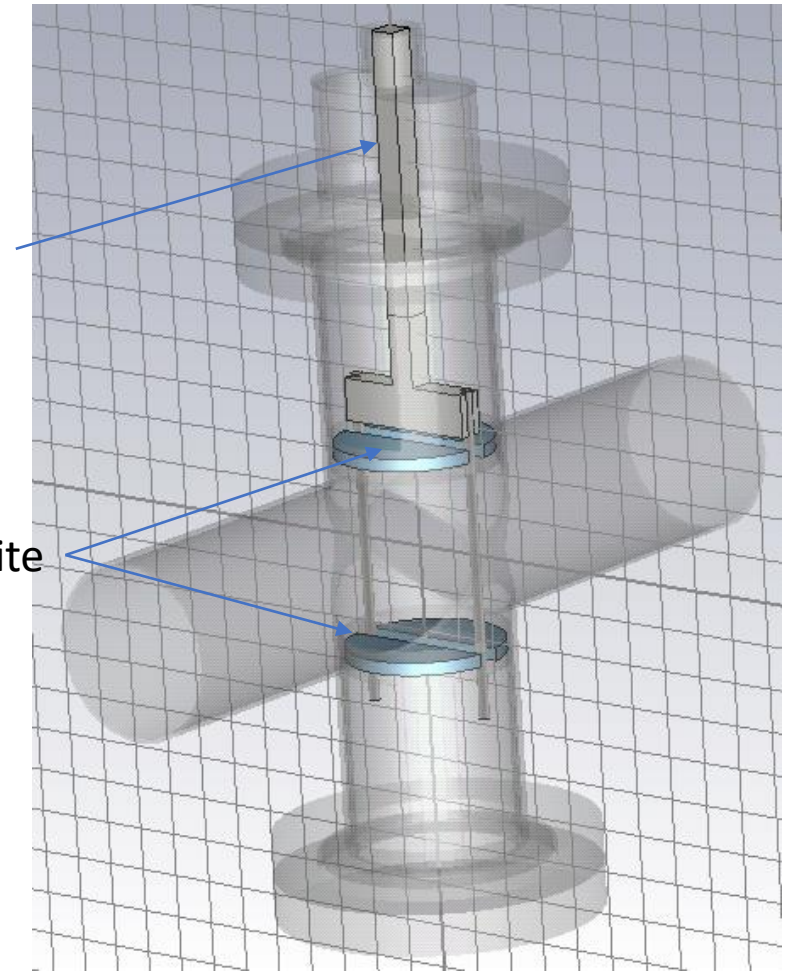
→ Hidden behind a slit (no ferrite)
→ Very different situation in parking position

LHC wire scanner

Model for wire OUT



Model for wire IN



→ Hidden behind a slit (no ferrite)

→ Very different situation

Difficult to fit spectrum with binomial distribution → to be followed up