Challenges for the IR BPMs

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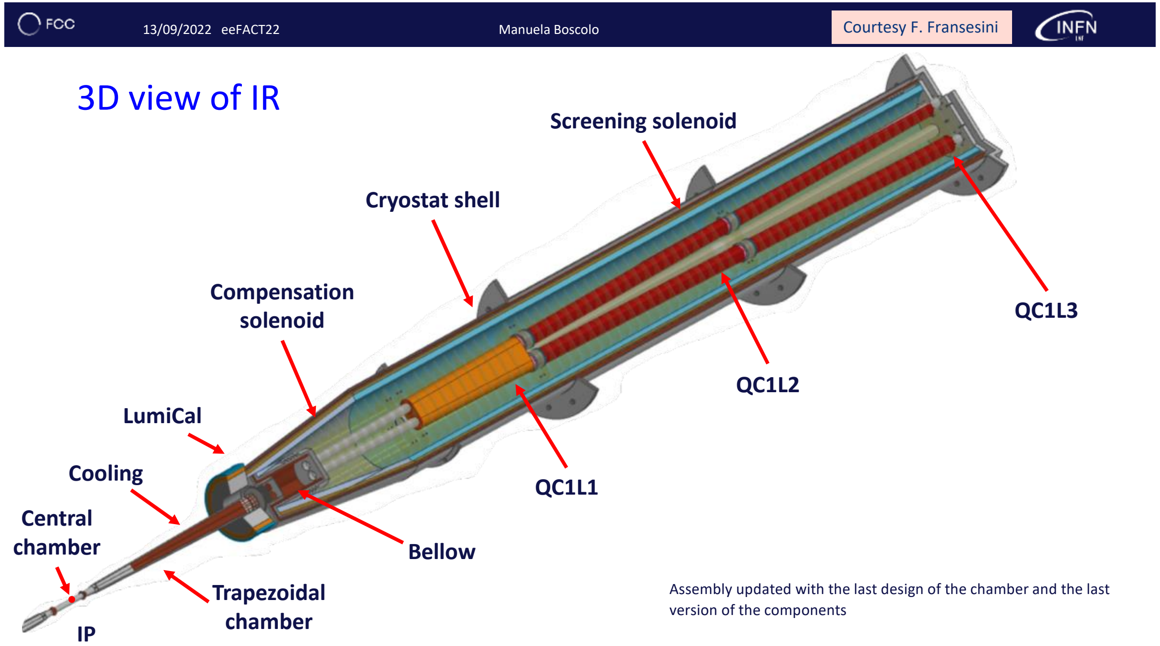
Beam Position Monitors for the Interaction Region (IR BPMs)

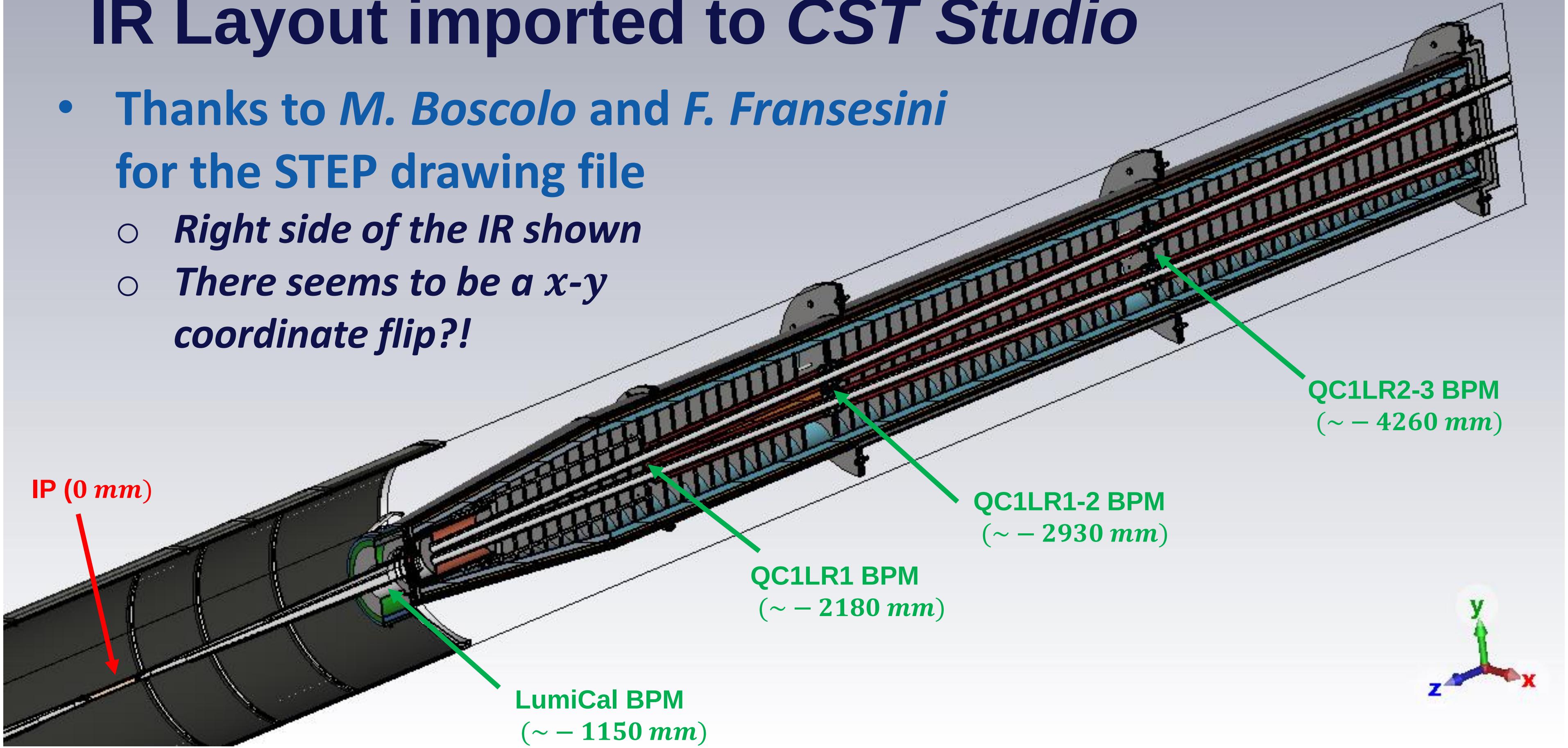


courtesy *Manuela Boscolo*

- **Request: Need BPMs near**
  - ***the LumiCal***
    - in the common vacuum chamber!
  - ***the segmented SC-FF-quad(s) QC1***
    - Located in separated vacuum chambers
    - How many? Between each QC1 segment?

IR Layout imported to *CST Studio*

- Thanks to *M. Boscolo* and *F. Fransesini* for the STEP drawing file
  - *Right side of the IR shown*
  - *There seems to be a x-y coordinate flip?!*

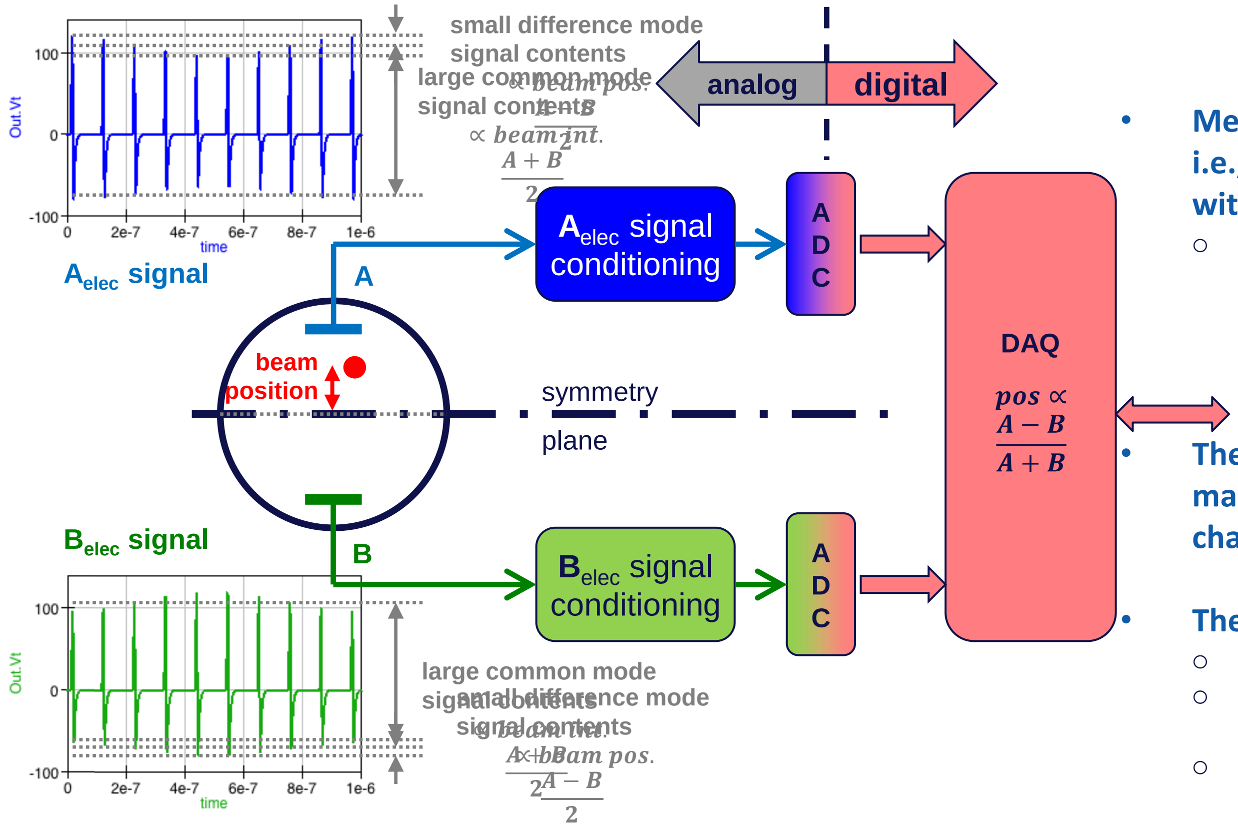


A few Remarks to FCC-ee BPMs

see also BI talk of *Thibaut*

- **Large scale beam instrumentation system**
  - ***~2000 BPMs per MR, ~7000 BPMs total for 2xMR+booster (LHC: ~1100 BPMs total)***
  - ***Only distributed beam diagnostics system with synchronous bunch-by-bunch and turn-by-turn measurement capability***
    - Every BPM measures the center of charge bunch position (optional: bunch intensity, bunch timing)
- **Requirements / conditions alike 4th generation light sources**
  - ***(sub-)μm resolution, (relative) accuracy, alignment, (long-term) stability, etc.***
  - ***Signal source for the fast orbit feedback system (low noise, low latency!)***
  - ***Low beam-coupling impedance, high signal transfer impedance***
    - Which is a contradiction in itself…
  - ***High synchrotron radiation levels, no space (even in a $90\ km$ ring!), low costs***
  - ***ON TOP: large beam pipe aperture! Where can we locate the BPM read-out electronics?!***
- **IR BPMs are a part of the FCC-ee BPM system!**
  - ***But may also play additional roles, e.g., luminosity optimization, IP luminosity feedback, BS-dump interlock, Van-der-Meer scans, etc.***

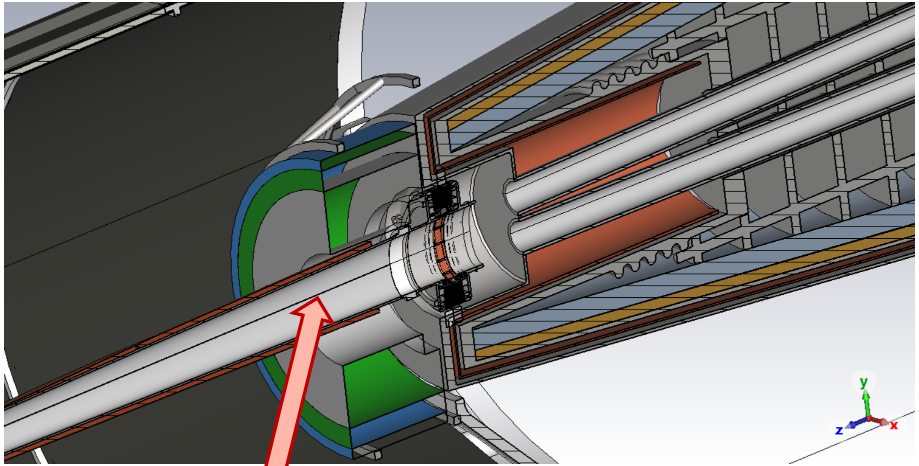
Remember: BPMs are based on Symmetry!

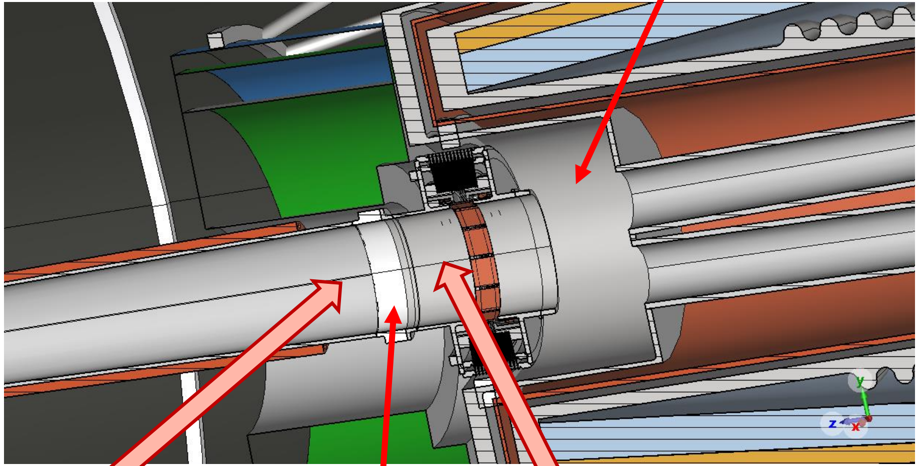


- Measures the bunched-beam displacement, i.e., the transverse beam position asymmetry with a **perfectly symmetric apparatus**
  - *Any small asymmetry in the BPM system causes an offset!*
    - Tolerances, misalignments in the BPM pickup mechanics, signal cables, read-out electronics
    - Aging effects causes a BPM offset drift
- The **relative accuracy** is maintained by mapping (correcting) the non-linear position characteristic of the BPM pickup
- The **resolution** is given by
  - *The BPM pickup transfer impedance (sensitivity)*
  - *The signal-to-noise ratio (SNR) of the BPM read-out system*
  - *The measurement (integration) time*

LumiCal BPM: Where should it go?!

What is THIS?!
A nice cavity?





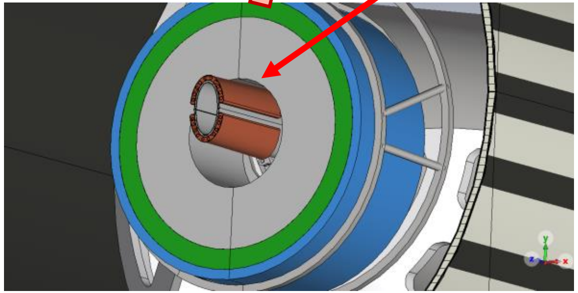
$-1120\ mm$

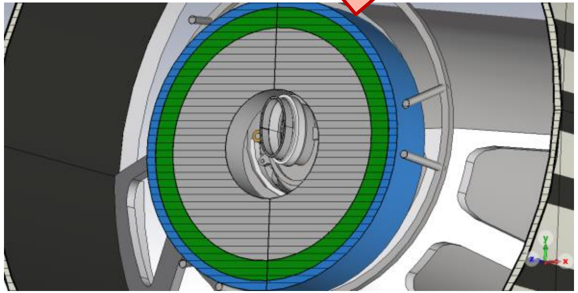
asymmetry on purpose?

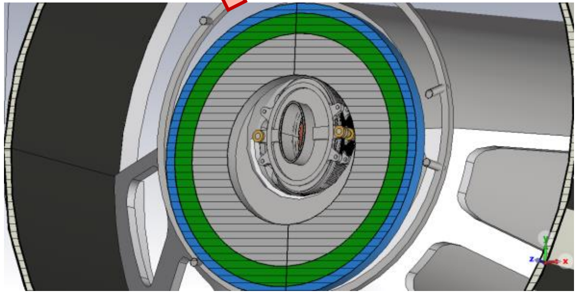
$-1140\ mm$

???

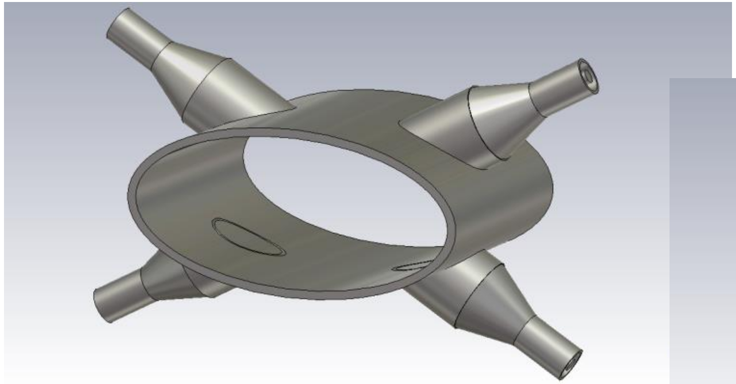
$-1175\ mm$

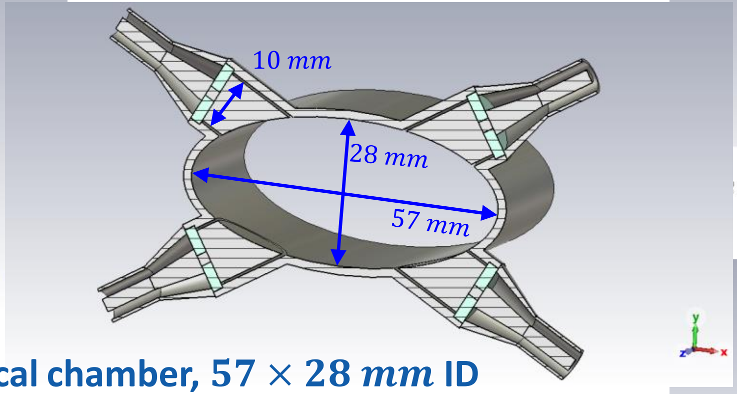


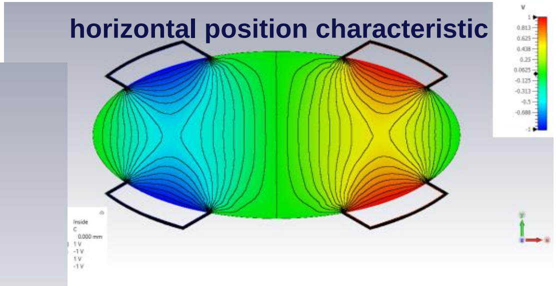


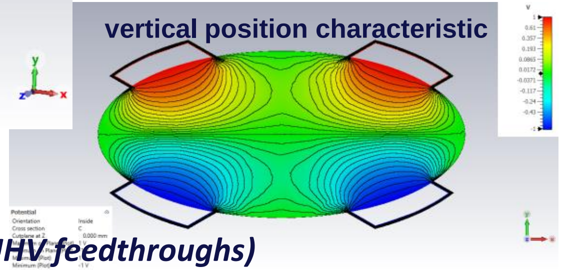


LumiCal BPM Pickup: A Proposal



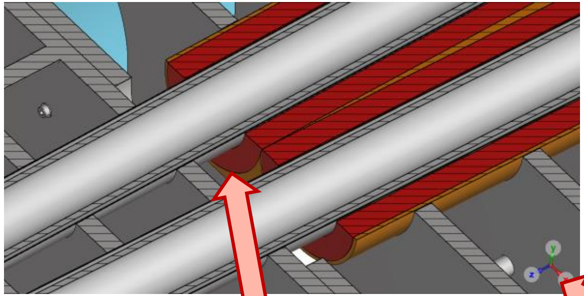


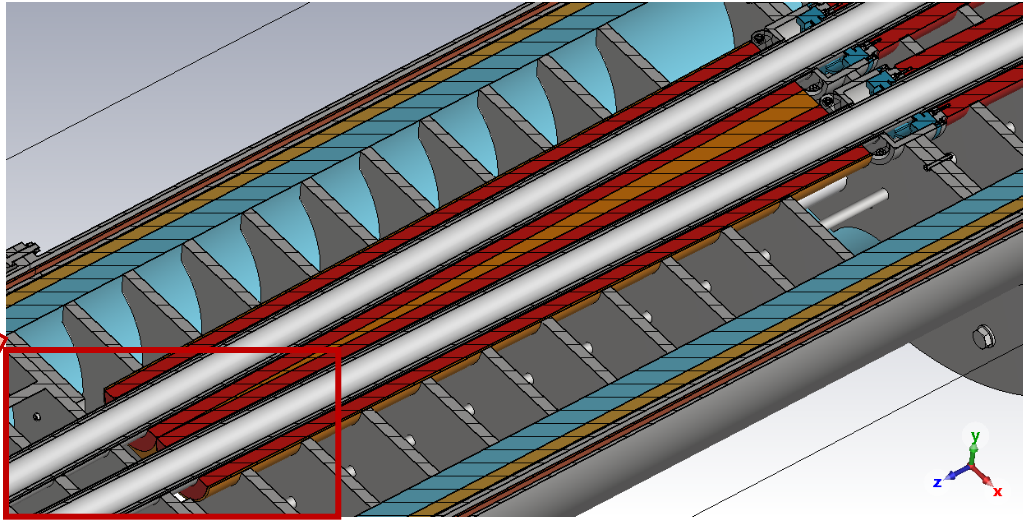




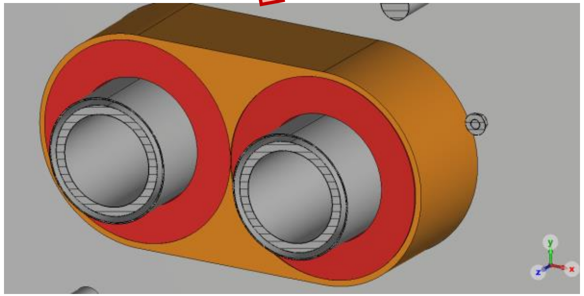
- Straight (non-tapered!) elliptical chamber, $57 \times 28\ mm$ ID
  - *At least $\pm 50\ mm$ longitidinal*
- BPM with four skewed buttons, $\sim 10\ mm$ diameter
  - *Integrated shape memory alloy (SMA) button assembly (no flange-mount UHV feedthroughs)*
  - *Requires optimization, RF & impedance studies, etc.*
- Needs real-estate!
  - *$\sim 15\ mm$ length for the buttons, more space in radial directions*
  - *Also, space for the as-short-as-possible(!) $50\ \Omega$ semi-rigid SiO_2 RF signal cables*
  - *If located at $\sim \pm 1150\ mm \Rightarrow \sim 7.67\ ns\ e^+$-$e^-$ bunch signal separation*

What about BPMs near QC1LR1?



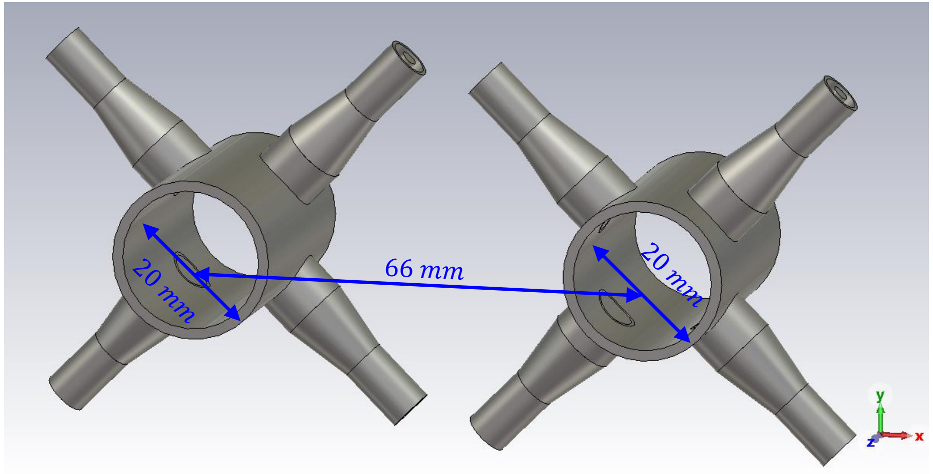


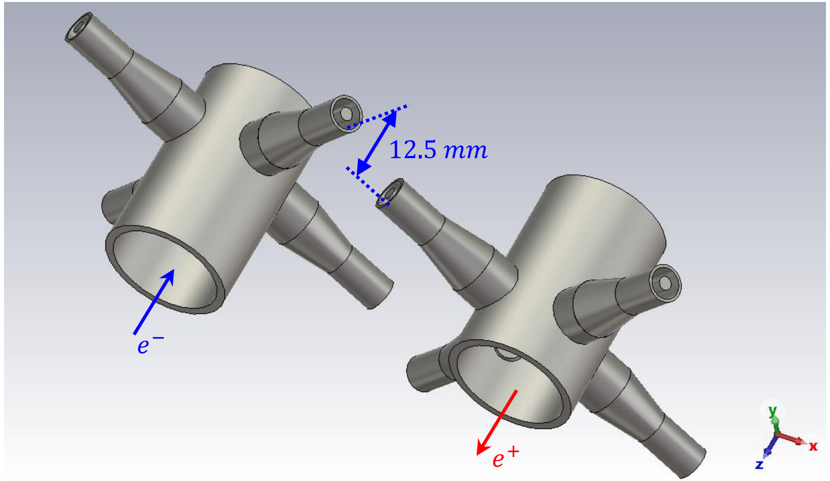
$-2180\ mm$



- **Again: No space for BPMs foreseen**
  - ***Neither for the BPM pickups, nor for the signal cables!***

Proposal for BPM pickups near QC1LR1





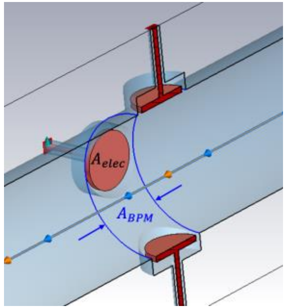
- **Separate chambers with circular cross-section ($20\ mm$ diameter)**
  - *Again: Please no tapering of the beam pipe near the BPM pickup!*
  - *BPM pickups with four skewed buttons ($6\ mm$ diameter)*
    - Staggered by $12.5\ mm$ to accommodate the signal cables

- **Signal transfer impedance:**

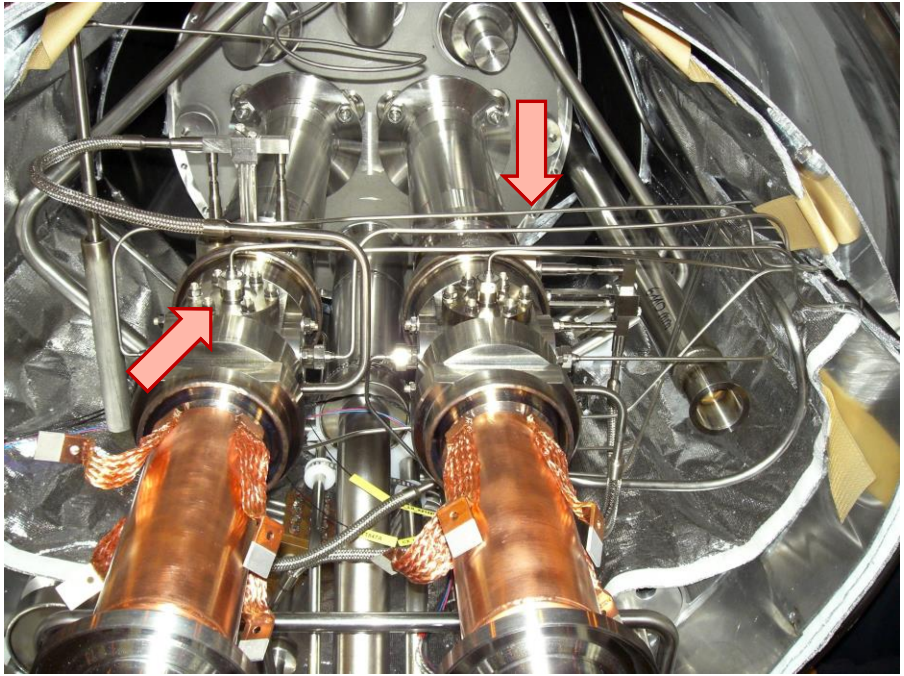
$$Z_{button}(\omega) = \frac{V_{button}(\omega)}{I_{beam}(\omega)} = \phi R_{load} \frac{\omega_1}{\omega_2} \frac{j\omega/\omega_1}{1+\omega/\omega_1}$$

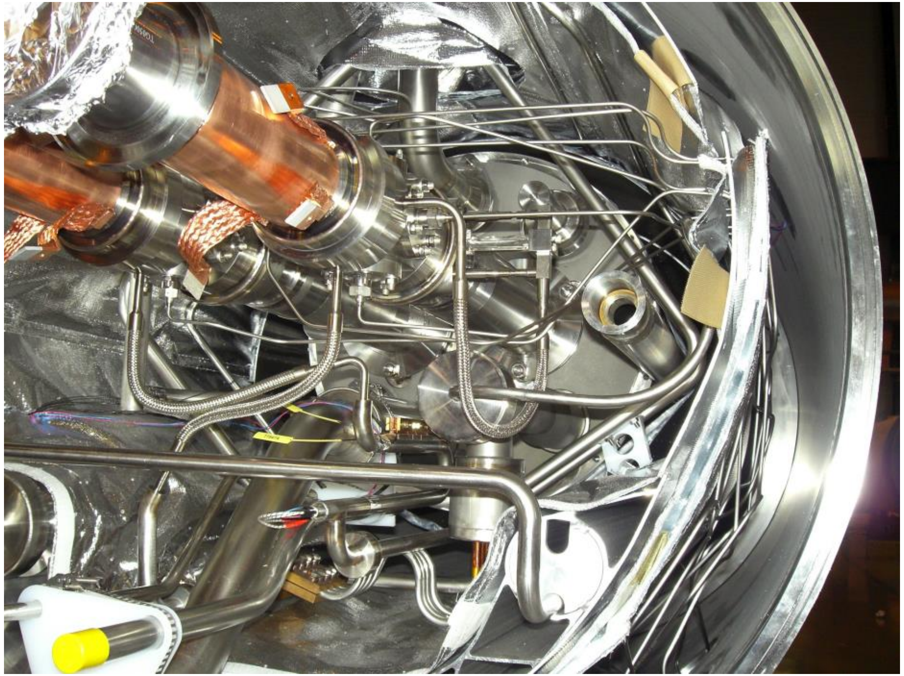
  - *Button size d_{button} and coverage factor ϕ*

$$\phi = \frac{\int J_{wall}\, dA_{elec}}{\int J_{wall}\, dA_{BPM}} \cong \frac{A_{elec}}{A_{BPM}} = \frac{d_{button}}{4\ D_{pipe}}$$

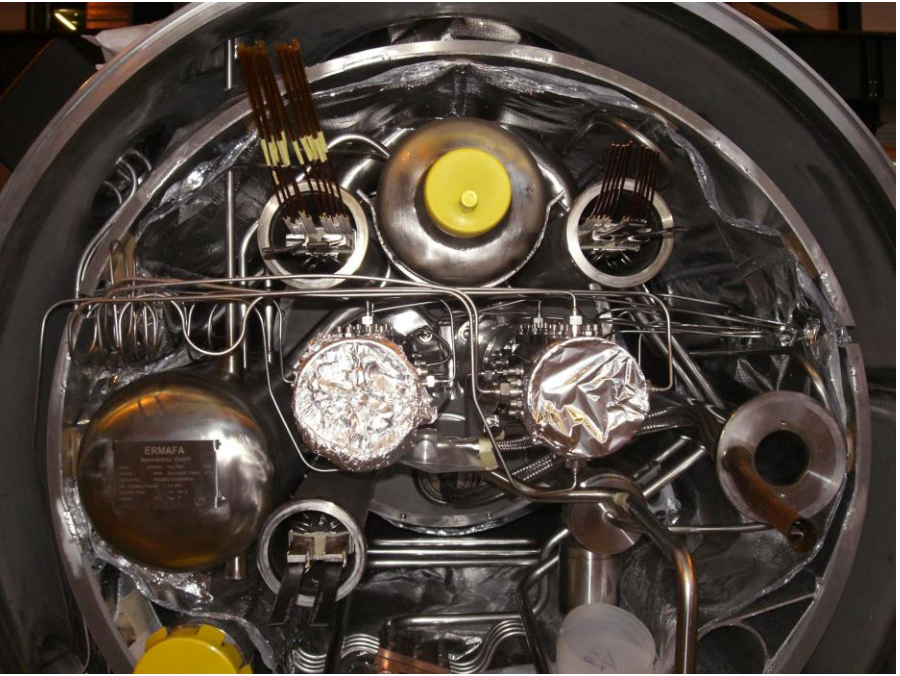


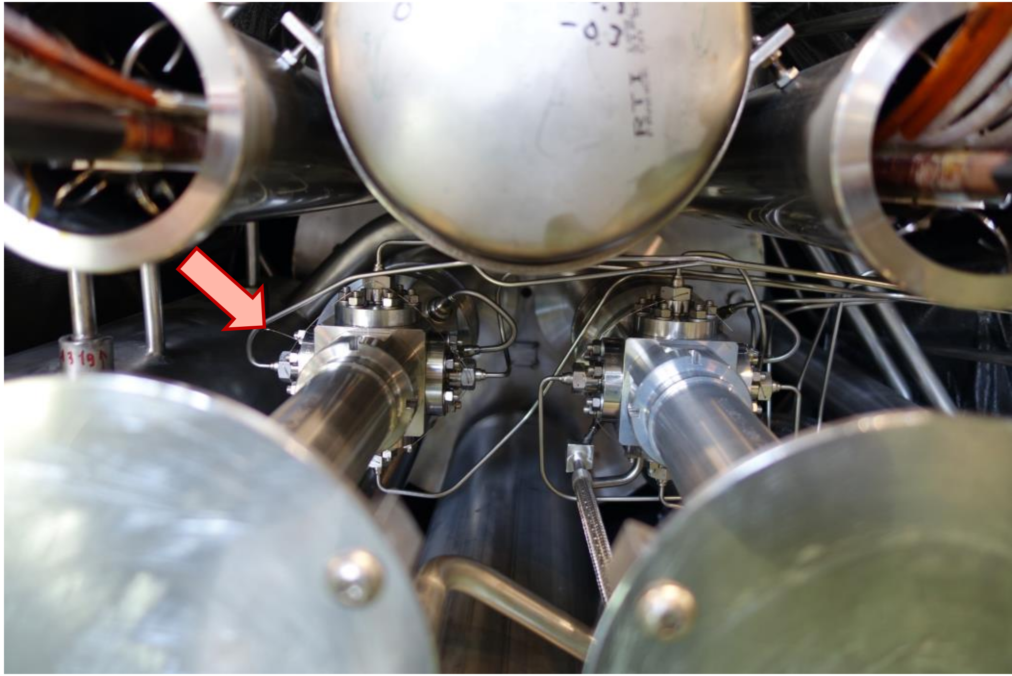
Lessons from LHC Button BPMs (1)





Lessons from LHC Button BPMs (2)



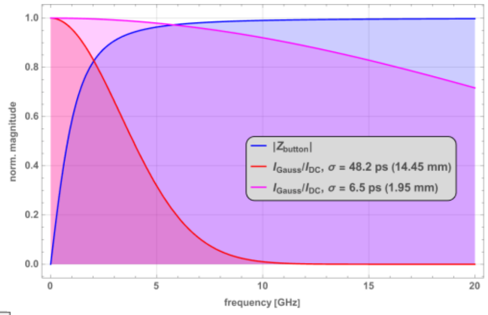


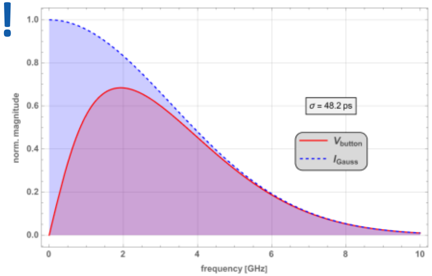
From LHC BPMs to FCC-ee IR BPMs

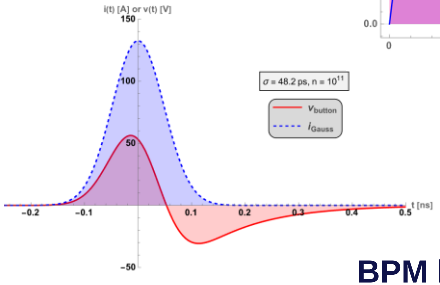
- **The LHC RF button UHV feedthroughs and SiO_2 signal cables are reliable in general, but:**
  - ***Vacuum leaks during warm-up / cool-down periods appear more frequent***
  - ***N-type connector does not always provide a reliable RF signal signal connection***
    - Despite a locking wire
  - ***Typically, 5-of-1000 BPMs in the LHC cryostats have issues***
- **For the FCC-ee IR BPMs**
  - ***The reliability of the IR BPM pickups and signal cables is utmost important!***
    - No access for repairs / maintenance once the IR regions and experiment are fully assembled!
  - ***Consider a connector-less, fixed RF link between the button electrode and the SiO_2 coaxial signal cable***

Question: Bunch length dependence?!

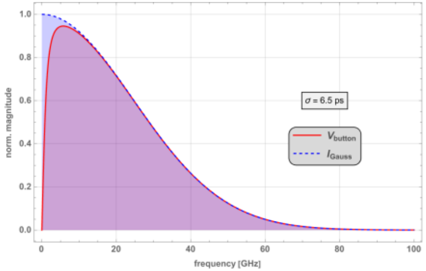
- Yes, the BPM button electrode signals depend on the bunch length
  - ***BUT:*** ***The normalized beam position measurement is bunch length independent!***
- More relevant is the required bunch-to-bunch dynamic range!

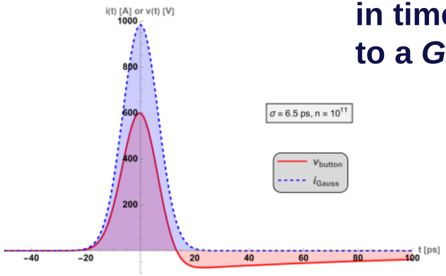






BPM button electrode response in time- and frequency-domain to a *Gaussian* bunch





Summary

- **Please, don't forget the Beam Instrumentation!**
  - ***90 km ring, and no space for beam instruments?!***
  - ***You may need beam instruments***
    to observe, characterize and improve machine and beam quality…
- **IR BPMs need to be reliable!!!**
  - ***After final assembly, no access for maintenance or mods!***
  - ***Avoid cable connectors between button electrodes and cables***
  - ***All IR BPM hardware needs to be radiation hard!***
- **Need for IR layout compromises**
  - ***Requires will and several iterations***
    in the mechanical integration of the BPMs in the IR