Challenges for the IR BPMs

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Beam Position Monitors for the Interaction Region (IR BPMs)

- **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?

**3D view of IR**

Assembly updated with the last design of the chamber and the last version of the components

courtesy Manuela Boscolo
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?!

IP (0 mm)

LumiCal BPM
(\sim - 1150 \text{ mm})

QC1LR1 BPM
(\sim - 2180 \text{ mm})

QC1LR1-2 BPM
(\sim - 2930 \text{ mm})

QC1LR2-3 BPM
(\sim - 4260 \text{ mm})
A few Remarks to FCC-ee BPMs

• Large scale beam instrumentation system
  o ~2000 BPMs per MR, ~7000 BPMs total for 2xMR+booster (LHC: ~1100 BPMs total)
  o 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
  o (sub-)\(\mu\)m resolution, (relative) accuracy, alignment, (long-term) stability, etc.
  o Signal source for the fast orbit feedback system (low noise, low latency!)
  o Low beam-coupling impedance, high signal transfer impedance
    ▪ Which is a contradiction in itself...
  o High synchrotron radiation levels, no space (even in a 90 km ring!), low costs
  o 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!
  o But may also play additional roles, e.g., luminosity optimization, IP luminosity feedback, BS-dump interlock, Van-der-Meer scans, etc.

see also BI talk of Thibaut
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 × 28 mm ID**
  - At least ±50 mm longitudinal
- **BPM with four skewed buttons, ~10 mm diameter**
  - Integrated shape memory alloy (SMA) button assembly (no flange-mount UHV feedthroughs)
  - Requires optimization, RF & impedance studies, etc.
- **Needs real-estate!**
  - ~15 mm length for the buttons, more space in radial directions
  - Also, space for the as-short-as-possible(!) 50 Ω semi-rigid SiO₂ RF signal cables
  - If located at ~ ± 1150 mm ⇒ ~7.67 ns e⁺-e⁻ bunch signal separation
What about BPMs near QC1LR1?

• 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:
  \[ Z_{\text{button}}(\omega) = \frac{V_{\text{button}}(\omega)}{I_{\text{beam}}(\omega)} = \phi R_{\text{load}} \frac{\omega_1}{\omega_2} \frac{j\omega/\omega_1}{1 + \omega/\omega_1} \]

- Button size \( d_{\text{button}} \) and coverage factor \( \phi \)
  \[ \phi = \frac{\int J_{\text{wall}} \, dA_{\text{elec}}}{\int J_{\text{wall}} \, dA_{\text{BPM}}} \approx \frac{A_{\text{elec}}}{A_{\text{BPM}}} = \frac{d_{\text{button}}}{4 \, D_{\text{pipe}}} \]
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 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!
Summary

• Please, don’t forget the Beam Instrumentation!
  o 90 km ring, and no space for beam instruments?!
  o You may need beam instruments
to observe, characterize and improve machine and beam quality...

• IR BPMs need to be reliable!!!
  o After final assembly, no access for maintenance or mods!
  o Avoid cable connectors between button electrodes and cables
  o All IR BPM hardware needs to be radiation hard!

• Need for IR layout compromises
  o Requires will and several iterations
    in the mechanical integration of the BPMs in the IR