SWELL progress and status

Franck Peauger, Shahnam Gorgi Zadeh, Marc Timmins, Mathieu Therasse, Torsten Koettig, Igor Syratchev, Guillaume Rosaz

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• Introduction and context

• Mechanical design and challenges of the 1.3 GHz SWELL cavity (reminder)

• Preparation of the 1.3 GHz SWELL for RF measurements

• Intermediate RF measurements

• What’s next?
RF system for FCCee
Alternative scenario at 600 MHz

<table>
<thead>
<tr>
<th></th>
<th>Energy (GeV)</th>
<th>Current (mA)</th>
<th>RF voltage (GV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>45.6</td>
<td>1280</td>
<td>0.120</td>
</tr>
<tr>
<td>W</td>
<td>80</td>
<td>135</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>120</td>
<td>26.7</td>
<td>2.08</td>
</tr>
<tr>
<td>ttb</td>
<td>182.5</td>
<td>5</td>
<td>11.67</td>
</tr>
</tbody>
</table>

A new optimized RF system with a single operating RF frequency and only two cavity types.

600 MHz 2-cell Nb/Cu for Z, W&H

600 MHz 5-cell bulk Nb for ttb and booster
SWELL cavity feasibility study & development plan

**SWELL 1-cell 1.3 GHz**
- RF/mechanical Design: done
- Machining: done
- EP + Nb coating
- Clean assembly: in progress
- RF test at cold (V5 cryostat in SM18)

**SWELL 2-cell 600 MHz with strong damping**
- RF Design and machine parameters: done
- Mechanical & thermal design
- Machining
- EP + Nb coating
- Rinsing & clean assembly

**Horizontal test cryostat for SWELL**
- Design
- Manufacturing
- Installation
- Commissioning

**New coating set-up**
- RF test at cold without beam
- Test with beam?

**Beam studies**
- Beam beam interactions, dynamic apertures, collective effects

OK for FCCee
Mechanical design and challenges of the 1.3GHz SWELL cavity (reminder)

RF shape and volume

Mechanical shape and volume
4 blocks to be machined independently
Mechanical design and challenges of the 1.3GHz SWELL cavity (reminder)

Four Nb coated copper blocks precisely assembled together

Each block is precisely machined on a 5 axis CNC machine.
105 kg

He Cooling channels down to 2°K

400mm

270mm

4 copper quadrants precisely positioned

Transmitted antenna

RF shape Nb coating

Incident antenna
V5 insert

- He reservoir
- He gas collector
- Swell cavity

4 cooling channels
Fabrication and assembly challenges

Each quadrant needs to be precisely machined and positioned.

5 axis machining to 40µm

Quadrant after final machining
1 - Reference surfaces are machined after the cavity has been aligned and tightly assembled with tie rods.

2 – Reference surfaces will be used to find back the position for final assembly after coating using alignment keys.

- Tie rods
- Reference surfaces
- Alignment keys

4 blocks aligned in metrology thanks to fiducial surfaces on the outside of the cavity (5µm)
Machining and alignment completed

Close to perfection in terms of alignment between quadrants

Typical values 10-12µm

Results picture courtesy Bartosz Bulat

Picture courtesy Romain Ninet and Karol Scibor
Outstanding machining precisions

Typical values 10-12µm

Results picture courtesy Bartosz Bulat
Preparation of the 1.3 GHz SWELL measurements.

Collection of all the components (cleaned for clean room assembly)
Blank assembly test of the cavity – following strict assembly process
Rotation of the cavity to installation position for cryostating in V5 insert
Connection of the cavity to V5 insert

- He reservoir
- Cavity connection
- Cooling connection
## SWELL 1.3 GHz warm RF measurements

### Expected frequency sensitivity parameters (calculated with CST)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Calculated values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency at 4.5 K under vacuum of nominal geometry</strong></td>
<td>F1</td>
</tr>
<tr>
<td><strong>Frequency at 20 °C under vacuum of nominal geometry</strong></td>
<td>F2=F1/1.00324</td>
</tr>
<tr>
<td><strong>Frequency shift between 20 °C and 4.5 K</strong></td>
<td>F2 – F1</td>
</tr>
<tr>
<td><strong>Frequency sensitivity to uniform material removal by chemistry</strong></td>
<td>+12.824 kHz/um</td>
</tr>
<tr>
<td><strong>Frequency at 20 °C under vacuum with 50 mm overthickness</strong></td>
<td>F3</td>
</tr>
<tr>
<td><strong>Frequency shift at 20 °C under vacuum between nominal geometry and 50 mm overthickness</strong></td>
<td>F3 – F2</td>
</tr>
<tr>
<td><strong>Frequency with 50 mm overthickness in air at normal conditions 20°C, 50% humidity, 1015 mbar</strong></td>
<td>F4=F3/sqrt(e_{air}) =F3/1.0003229</td>
</tr>
<tr>
<td><strong>Frequency shift between vacuum and air at normal conditions 20°C, 50% humidity, 1015 mbar</strong></td>
<td>F3 – F4</td>
</tr>
</tbody>
</table>
SWELL 1.3 GHz warm RF measurements

Measurement results

with 50 mm overthickness

<table>
<thead>
<tr>
<th>L input antenna [mm]</th>
<th>L transmitted antenna [mm]</th>
<th>f_{meas} [GHz]</th>
<th>f_{meas} normalized at 20°C under vacuum</th>
<th>F_{calculated} at 20°C [GHz] normalized at 20°C under vacuum</th>
<th>ΔF_{meas/calc} [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>17.5</td>
<td>1.2969123</td>
<td>1.2973742</td>
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<td>53.5</td>
<td>17.5</td>
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<td>1.2969091</td>
<td>1.2973710</td>
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<tr>
<td>80</td>
<td>17.5</td>
<td>1.2969090</td>
<td>1.2973709</td>
<td></td>
<td>-79.736</td>
</tr>
</tbody>
</table>

The average frequency deviation \( ΔF_{\text{meas/calc}} \) is about -78 kHz which corresponds to an error of 6e-5 or 0.006 %
SWELL 1.3 GHz warm RF measurements

The Q factor is measured at -3 dB from the maximum of the $S_{21}$ parameter amplitude and is 28481.

At ambient temperature, the total Q factor is dominated by the losses in the cavity given by the $Q_0$ of the resonator. The $Q_0$ factor is defined as $Q_0 = \frac{G}{R_S}$ with:

$$R_S = \frac{1}{\delta \sigma} = \frac{1}{\sqrt{\frac{\pi f}{\mu r} \frac{\sigma}{\mu_0}}} = \sqrt{\frac{\pi f \mu r \mu_0}{\sigma}}.$$

With $\sigma = 59.4 e6 S/m$ for pure OFHC copper, the surface resistance is $R_S = 9.284 \, m\Omega$ at $f=1.29696 \, GHz$. With a geometric factor of $G = 265.5 \, \Omega$, the intrinsic quality factor is $Q_0 = 28600$, which is in agreement with the measurements.

→ no RF leakage occurs in the contact areas of the quadrants. the mechanical alignment of the quadrants is very good.
Next steps

- Blank assembly of toolings for surface treatments of the quadrants
- Degreasing, electropolishing and HiPIMS Niobium coating of the quadrants
- In parallel, cryogenic test of the cryostat insert (without the cavity) in SM18
- HPR, clean room assembly of the cavity and preparation of the insert
- RF test at 4.5 K and 2 K before end of 2023

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Thank you for your attention

Questions?

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