SPIRAL 2

RESONATORS
SPIRAL 2 Linac

- Superconducting quarter wave resonators
  - \( \beta = 0.07 \) 88MHz QWRs CEA/SACLAY
  - \( \beta = 0.12 \) 88MHz QWRs IPN/ORSAY
- options: warm quadrupoles instead of SC solenoids / short cryostats

- RF optimization, RF coupling
- mechanics / RF
- 4K tests
- cryomodule overview
Quarter-wave resonators ($\lambda/4$)

Requirements for SPIRAL 2:

- bulk niobium technology
- 4K operation
- 88 MHz frequency
- minimum beam pipe diameter 30 mm
- separation of cavity vacuum and isolation vacuum
- RF losses < 7 W @ 6.5 MV/m
- specifications on maximum surface field:
  - $E_p < 40$ MV/m
  - $B_p < 80$ mT (at 8 MV/m)
- accelerating field definition adopted for the project

$$E_{\text{acc}} = \frac{V_{\text{acc}}}{\beta \lambda}$$
Quarter-wave resonators (\(\lambda/4\)) optimization

Cavity RF design:

- basic starting geometry: coaxial guide of length \(\approx \lambda/4\) of the TEM mode
  - one Open end (electric region),
  - one Short-circuit (magnetic region)
- transverse electric field: the beam has to travel across the cavity on a radial path, through the stem 2 accelerating gaps
- optimal \(\beta\) mainly dependant on the distance between gap centers: \(\beta_{\text{opt}}\) varies with cavity diameter and drift tube lengths

- The main objectives of the design were
  - to achieve high accelerating voltages
  - to reduce \(E_p/E_{\text{acc}}\) and \(B_p/E_{\text{acc}}\)
  - to ease chemistry and HPR

Gap to gap distance \(\approx \beta \lambda / 2\)
\( \beta = 0.07 \) cavity RF parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (MHz)</td>
<td>88</td>
</tr>
<tr>
<td>Optimal ( \beta )</td>
<td>0.07</td>
</tr>
<tr>
<td>( r/Q (\Omega) ) @ optimal ( \beta )</td>
<td>632</td>
</tr>
<tr>
<td>( E_p/E_{acc} )</td>
<td>5.0</td>
</tr>
<tr>
<td>( B_p/E_{acc} ) (mT/MV/m)</td>
<td>8.75</td>
</tr>
<tr>
<td>( Q_0 @ R_s = 10 ) nOhms)</td>
<td>( 2.2 \times 10^9 )</td>
</tr>
</tbody>
</table>
\[ \beta = 0.07 \text{ cavity RF coupling} \]

- nominal \( Q_{\text{ext}} = 6.6 \times 10^5 \)
- \( \Omega \) 36 mm 50 \( \Omega \) coaxial line
- coupler designed by LPSC Grenoble

- antenna in a low \( H \) area
- no extra opening in He tank

SPIRAL2 resonators
\[ \beta = 0.07 \text{ cavity tuning} \]

- transverse CTS
- saves longitudinal space
- low stress on drift tube welds
- computed tuning range ±24 kHz at 4 K

Mesh for mechanical/RF coupled calculations
CASTEM + i-DEAS + SOPRANO

Von Mises stress
$\beta = 0.07$ cavity frequency stability

He bath pressure variations

- Expected $\Delta P \sim 10$ mbar
- Cavity BW = 132 Hz:
  - $\Delta f_{\text{pressure}} < \text{BW}/10$ $|\Delta f/\Delta P| = 1$ Hz/mbar
- 80% of $\Delta f_{\text{pressure}}$ due to vertical stem displacement
- With 4 mm thickness $\Delta f/\Delta P = -2.5$ Hz/mbar
- Adding a stiffener $\Delta f/\Delta P = -1$ Hz/mbar

Mechanical modes

- Mode 1 @ 43 Hz with stiffener
  - High sensitivity:
    - Transverse: 500 kHz/mm
    - Longitudinal: 650 kHz/mm

- Mode 2 @ 126 Hz with stiffener

If needed, room is provided to include a Legnaro type damper
$\beta = 0.07$ cavity bottom plate

- Large opening for High Pressure Rinsing
- Nb sputtered copper plate
- H field very low in the cavity low end region: the plate can be cooled by conduction due to high thermal conductivity of copper
- Stainless steel He vessel $\rightarrow$ 316LN flange brazed on the cavity
- Copper RF gasket position should be as low as possible
- S-shape:
  - mechanical compliance (differential shrinkage)
  - reduced coupler antenna penetration for required $Q_{\text{ext}}$
  - passes pressure qualification tests at 2.5 bars (vertical cryostat test)
$\beta = 0.07$ cavity Prototype cavity

- Manufactured by ACCEL
- Differs from the final cavity:
  - NbTi end-plate and flange
  - Vacuum tightness: copper ring + indium seal
  - 3 mm Niobium
Cavity preparation at Saclay

Chemical polishing

High pressure rinsing
β = 0.07 cavity vertical cryostat test

- Limited by partial quench at 9.5 MV/m
- Tests at 4.2 K and 1.8 K with same overall behavior. Extra test done in June with a SC Nb/Cu gasket with the same behavior at high field
- Quench attributed to thermal runaway in NbTi bottom plate (λ_{NbTi} ≈ 0.3 W/m.K + defect ?). The stem region is not thermally affected
- Q0 = 10^9 @ 6.5 MV/m Pwall = 3.8 W < Maximum specified losses of 7 W
$\beta = 0.12$ QWR Mechanical Design

- Welded bottom plate
- Nb thickness: 4 mm (except the stem: 3 mm)
- Beam tubes aperture: $\varnothing 36$ mm
- RF coupling by $\varnothing 36$ mm port
- Stiffening plate on top-torus
- 6 ports for HPR
- $\varnothing 418$ mm SS flange brazed on cavity bottom allows to weld the He tank
$\beta = 0.12$ cavity RF parameters

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<td>Frequency (MHz)</td>
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</tr>
<tr>
<td>Optimal $\beta$</td>
<td>0.12</td>
</tr>
<tr>
<td>$r/Q$ (Ω) @ optimal $\beta$</td>
<td>518</td>
</tr>
<tr>
<td>$E_p/E_{acc}$</td>
<td>5.6</td>
</tr>
<tr>
<td>$B_p/E_{acc}$ (mT/MV/m)</td>
<td>10.2</td>
</tr>
<tr>
<td>$Q_0 @ R_s = 12.5$ nOhms</td>
<td>$3.0 \times 10^9$</td>
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</table>
$\beta = 0.12$ cavity tuning

2 systems are studied

**Tuning by pulling the beam tubes**

<table>
<thead>
<tr>
<th>COSMOS &amp; MICAV calculations</th>
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<tbody>
<tr>
<td>Maximum stress for 1 bar [MPa]</td>
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<tr>
<td>Stiffness [kN/mm]</td>
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<tr>
<td>Tuning sens. using beam tubes [kHz/mm]</td>
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<tr>
<td>Tuning sens. using one $\varnothing 30$ plunger [kHz/mm]</td>
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</tbody>
</table>

Tuning using SC plungers

Titanium membrane

Movable plunger

Static plunger
\( \beta = 0.12 \) prototype

- Manufactured by Zanon
- Includes the stainless steel flange needed to attach the He tank

Stiffening on top torus
\( \beta = 0.12 \) Vertical cryostat test

- Limited by power source at 11 MV/m.
- Limited by quench with SC plunger (\( \Delta f \approx 65 \) kHz)
- \( Q_0 = 1.5 \times 10^9 @ 6.5 \) MV/m \( P_{\text{wall}} = 4 \) W < Maximum specified losses of 10 W

SPIRAL2 resonators
Construction of a fully equipped cryostat for each $\beta$ starting in 2005