SRF Summary

O. Brunner, on behalf of the FCC SRF R&D team

CERN
A busy FCC SRF program (+ Easytrain)

SRF Programme (A.M. Valente Feliciano – JLAB)
- Baseline & Cavity options for FCC-ee (Franck Peauger, CERN)
- The SWELL cavity development (Igor Syratchev, CERN)
- Beam-cavity interaction challenges for the FCC_ee (I. Karpov, CERN)
- Overview of the EIC RF system and synergies with FCC-ee (B. Rimmer, JLab)

SRF Technologies 01 (G. Burt - Lancaster U.)
- Hydroforming Elliptical SRF Cavities : Studies on 1.3 GHz and Beyond (M. Garlasche, CERN)
- Cavity Engineering & Fabrication (Said Atieh, CERN)
- TS HE klystron for FCC_ee (J. Cai, CERN/ Lancaster U.)
- FPC challenges and perspectives for FCC_ee (E. Montesinos, CERN)

SRF Technologies 02 (O. Brunner - CERN)
- Overview of Multilayer Developments at JLab (A. M. Feliciano-Valente, JLab)
- SRF characterization of multilayers (S. Keckert, HZB)
- Superconducting Thin Films Studies at CERN (G. Rosaz, CERN)
- RF characterisation techniques, 1.3 GHz cavities (P. Vidal Garcia, CIEMAT/CERN)
- Prototyping the Nb coating of the copper Wide Open Waveguide Crab Cavity for FCC-hh (F. Manke, CERN)

Many thanks to everyone + Julie!!!!!
A ‘solid’ baseline

- 400 MHz 1-cell cavities
- 400 MHz 4-cell cavities
- 800 MHz 5-cell cavities

- 400 MHz -> “natural choice” for FCC_hh
- Very tight timeline
- Focused at optimum re-usage & installation of hardware (RF power, LLRF, controls..)
Z machine: the bar is high

Complex integration with consequences:
- Z, W: require **very compact high RF power systems**
- Very high power fundamental RF couplers

Challenging High Order Modes in the cavities:
- Requires complex damping systems, dedicated beam configurations

Large amount of HOM power propagating through beam pipes:
- Requires absorbers, dedicated beam configurations
Notable R&D challenges

**Z machine**

Minimize the # of cavities for impedance considerations

-> complex LLRF systems

Demonstrate the two-Stage Multi Beam Klystron technology developed at CERN

-> compact + η>80%

Dynamic R&D program on FPC

---

**WW & ZH machine**

Keep the pace - Re-use existing HW.

-> produce HE acceleration system (4-cells cav.)
  - improve Nb coating (~6 m²/cavity!)
  - seamless cavities / internal welds

-> develop large infrastructures

---

**ttbar machine (& booster)**

High efficiency acceleration cavities & CM

-> bulk Nb technology is mature

-> profit from existing expertise (ESS, PERLE, LCLS2, ILC)

---

“Solid baseline” - big technical challenges

- 400 MHz limits the synergies with other projects
Two-Stage Multi Beam Klystron technology

- Tremendous effort to develop home made code for HE klystron design -> now a reference code worldwide
- Consists of several modules: beam-interaction, gun, magneto-static, coupled cavities,
- Unique options: optimizer, scaling generator
- TS MKB features:
  - Bunching at a low voltage -> very compact RF bunching circuit
  - Bunched beam acceleration and cooling in the DC post-accelerating gap
  - Final power extraction from high voltage beam -> Compact + High efficiency
- FCC TS 400MHz, 1.2MW conceptual design finished -> built it!
Challenging the baseline

Alternative cavity design study initiated in Nov. 2020

- CLIC expertise applied to SRF -> **Slotted Waveguide Elliptical (SWELL) cavity operating at ~ 600 MHz** ¹
- Beam dynamics studies - > ~ 600 MHz conceivable for Z machine 1-cell UROS1 and 2-cell SWELL cavity types

¹ The SWELL cavity concept was published in 2010 by Z.Liu and A. Nassiri (Beijing U., ANL)

<table>
<thead>
<tr>
<th>UROS, 400 MHz</th>
<th>SWELL 600 MHz</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient beam loading (Collision point shift due to ±5% charge asymmetry)</td>
<td>2.4 mm</td>
<td>~12 mm (abort gap length need to be checked)</td>
</tr>
<tr>
<td>Longitudinal CBI due to fundamental mode can be suppressed by means of</td>
<td>Direct RF feedback</td>
<td>Direct RF + One turn delay feedback</td>
</tr>
<tr>
<td>Longitudinal CBI due to HOMs can be suppressed by means of</td>
<td>Synchrotron radiation damping</td>
<td>Synchrotron radiation damping</td>
</tr>
<tr>
<td>Transverse CBI due to HOMs suppressed by means of</td>
<td>Bunch-by-bunch transverse feedback system (damping time ~100 turns)</td>
<td>Bunch-by-bunch transverse feedback system (damping time ~100 turns)</td>
</tr>
<tr>
<td>HOM power losses</td>
<td>About 9 kW per cavity</td>
<td>About 9 kW per cavity</td>
</tr>
</tbody>
</table>

I. Karpov
‘SWELL’: a single cavity for all operating points

- A simplified installation schedule
- Optimized slot geometries and HOM power extraction (Z)
- A considerable potential for ampere class accelerators
- Promising even without extraction system

F. Peauger
I. Karpov

I. Syratchev
The SWELL beauties...

- Special cavity shape with optimized/reduced surface E/H fields & HOM damping
- Showcase for CERN’s expertise (CLIC)

- Innovative 4 quadrants technology
  - no welds in critical areas
  - simplified coating

- A challenging concept that must be demonstrated (1.3 GHz)
Synergies with dynamic partners/programs

**EIC RF system:**
- A complex machine, with comparable challenges
- Asymmetric single cell 591 MHz optimized for high current -> FCC_ee?

**Notable challenges**
- High currents
- HOM power, BBU, RF stability, resonant heating
- High bunch charge
  - Single bunch instabilities, wakefields, CSR, resistive wall heating
  - High beam power
    - RF power, couplers, collimators
    - Gap transients
  - Crabbing
    - High voltage, HOMs, linearity, synchronization, noise

**PERLE, JLAB:**
- 5-cell bulk Nb cavity was built and tested by JLAB
- PERLE will use the CERN/ORSAY developed SPL CM concept and complete the module with 800 MHz cavities
Rich SRF R&D programs at CERN (LHC, HL, FCC,..)

The substrate is the key
Fabrication:
- Half cells by electro-hydroforming
- Development of EBW internal welding
- Development of seamless bulk 1.3 GHz cavities

Advanced surface treatment
- New electro-polishing system for copper commissioning

High quality coatings:
- Nb/Cu: very good quality films! ~ bulk Nb properties
- HIPIMS applied to special geometries: FCC WOW cavity
  - Simulations, multi cathodes
- A15/Cu material R&D

Improved RF diagnostic/analysis capabilities
- Quadrupole resonator, RF, temperature mapping
SRF application beyond Nb: SIS multilayers

**Material choice**
- NbN, NbTiN, ...
- Dielectric choice: AlN, Al₂O₃

**Encouraging results:**
- Tc enhancement demonstrated, enhancement of critical fields observed (NbTiN/AlN multilayers) -> encouraging results
- Structure & interfaces are critical

Possibility to move operation from 2K to 4.2K
Summary

- Solid baseline with well defined R&D topics
- Promising challengers
  - Single-cell and multi-cells elliptical cavities @ ~ 600 MHz -> Beam dynamics studies must be completed
  - The potential of the SWELL cavity must be demonstrated -> Long, ambitious but exciting validation process
- Rich ‘ongoing’ core & specific R&D programs
  - Cavity design, beam dynamics, LLRF
  - Cavity fabrication, preparation, cryostating
    - ELL: pursue ongoing R&D -> recent outstanding performances of Nb coatings & substrates
    - SWELL: 1.3 GHz simplified demonstrator -> 600 MHz full cavity
  - High efficiency klystrons: demonstrate the two-Stage Multi Beam Klystron technology
  - FPC: push for very high CW RF power levels
- Favors enthusiastic collaborations and synergies with other projects (EIC, PERLE, …)
  - Ease the topic selection and prioritization (limited resources)
  - Strategically & economically important
Thank you for your attention.