Split SRF Thin Film 6 GHz Cavities

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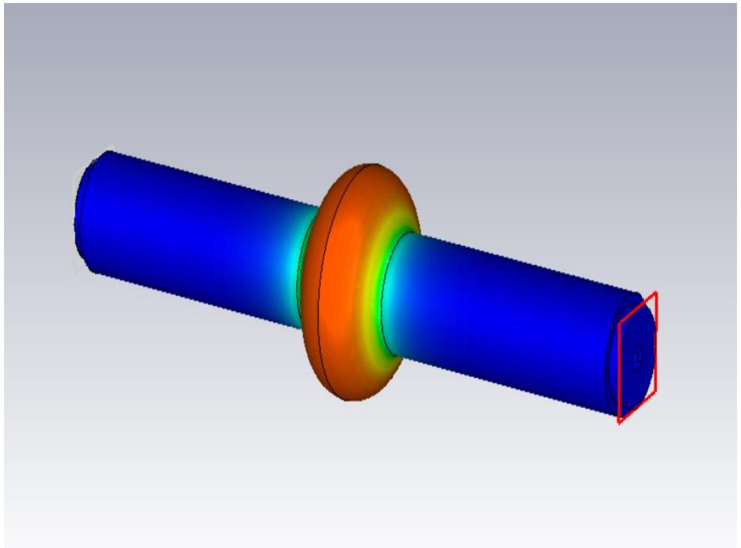
Why Split and Seamless Cavities

- For conventional cavities the weld is along a critical area with the highest surface current.
- The weld is usually where defects occur.
- Defects cause problems with thin films:
  - Increase surface resistance
  - Can be areas of inconsistency or delamination in the film



Contour plot of the surface current of at typical elliptical cavity. (Simulation using CST Microwave Studio)

HIE-ISOLDE Cavities

- HIE-ISOLDE uses Nb coated copper cavities.
- Original design had 2 parts that were welded together.
- Due to micro cracks around the welds they tested seamless cavities.
- These seamless cavities have a higher Q than the welded cavities for the intended accelerating field.

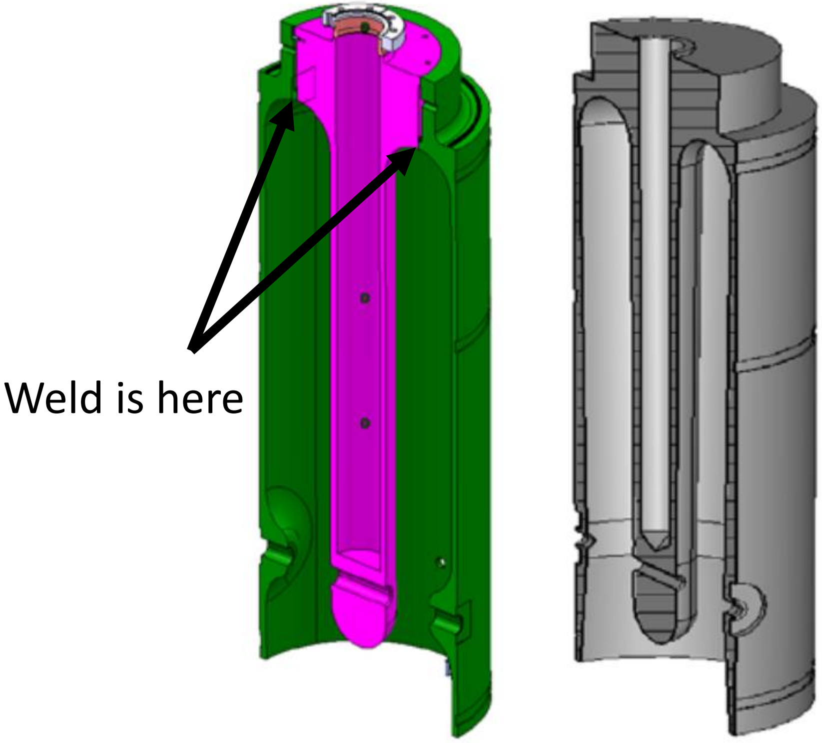
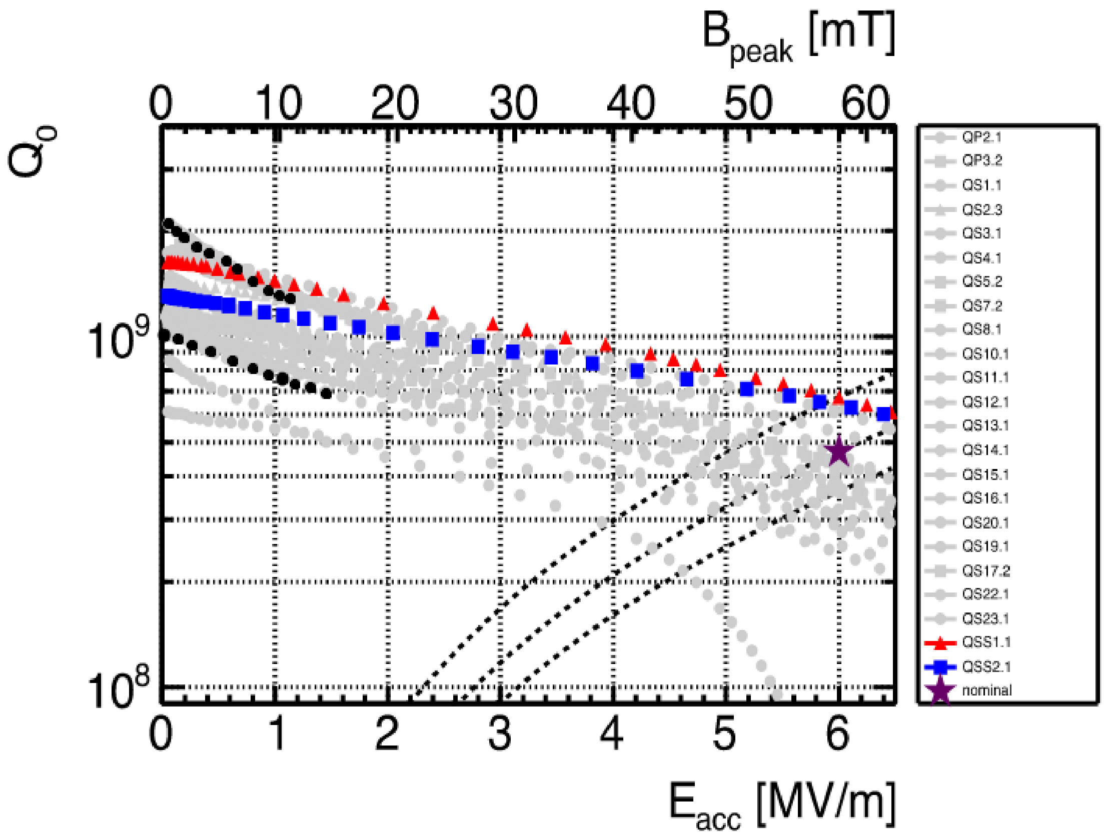


Figure 1: Welded and seamless HIE-ISOLDE QWRs.

Figure from: Delsolaro, W. Venturini, and A. Miyazaki. "Seamless Quarter Wave Resonators for HIE ISOLDE." *29th Linear Accelerator Conference*. 2018.

HIE-ISOLDE Cavities

- Thin film cavities always showed a fast decrease in quality factor
- Conventional cavities show a low field Q-slope (highlighted) not present in the seamless cavities
- Now realise it is due to the weld
- Now want to design cavities without welds



Q vs E plots of the HIE-ISOLDE cavities. The plots in colour represent the seamless cavities
Image from: Delsolaro, W. Venturini, and A. Miyazaki. "Seamless Quarter Wave Resonators for HIE ISOLDE." *29th Linear Accelerator Conference*. 2018.

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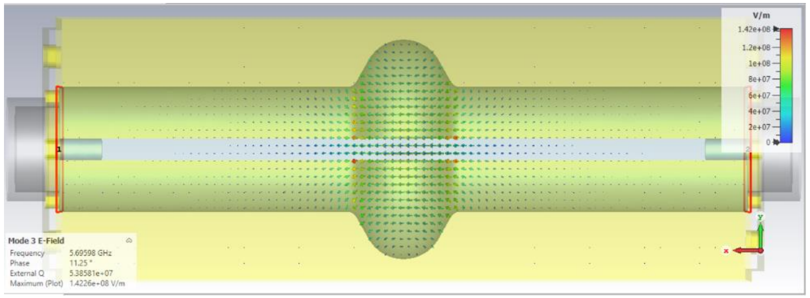
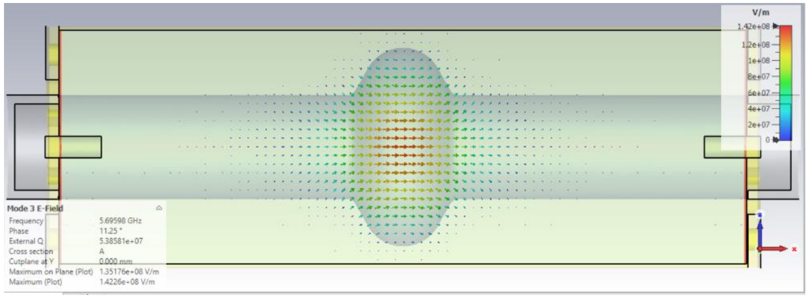
Why Split Cavities

- Longitudinally split cavities do not require welding.
- Split NC cavities have already been used in accelerators.
- Even with a gap, very little RF power is lost or field enhancement as the TM11 mode (shown) doesn't couple to the gap because the gap has a high cut-off frequency as it is small.
- Top image shows the location of the split with a 5 mm gap.
- Bottom image show the top view of the field.





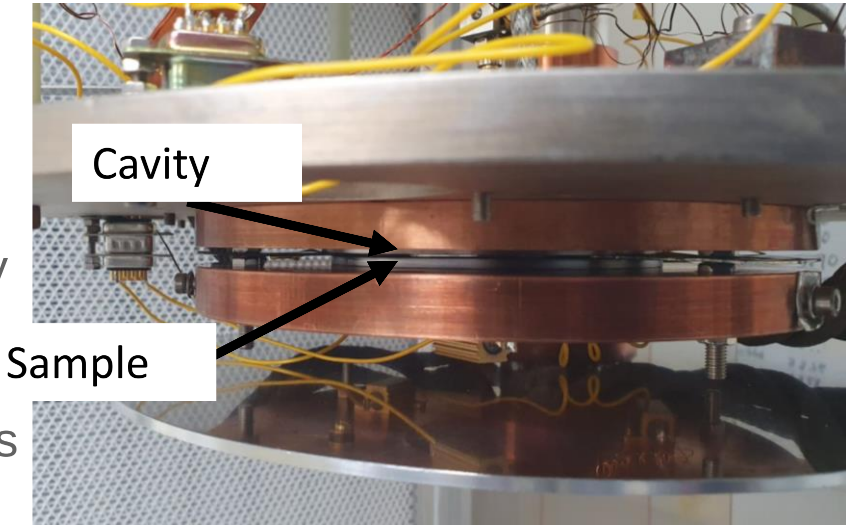
Split cavities for thin film testing

- Flat samples are usually tested first as they are cheaper to manufacture.
- Surface analysis is generally easier as the facilities are generally made to measure flat samples, techniques include:
  - Scanning Electron Microscopy (SEM)
  - X-Ray Diffraction (XRD)
  - Residual Resistance Ratio (RRR)
  - DC field Penetration
- These techniques can provide information about the surface roughness, stoichiometry, structure and critical temperature of the thin film.

Split cavities for thin film testing

- RF testing of flat samples is more difficult.
- QPR requires samples to welded to a sample holder which can damage the sample.
- Choke cavity measurements at DL can be used, however, these are at high frequency (7.8 GHz) and measurements can only be made at low power.
- Flat samples have a simpler geometry than cavities and so deposition parameters have to be changed for cavity deposition.
- See talk by Daniel Seal yesterday for details on the choke cavity measurements

7.8 GHz Choke Cavity



Choke Cavity Measurements

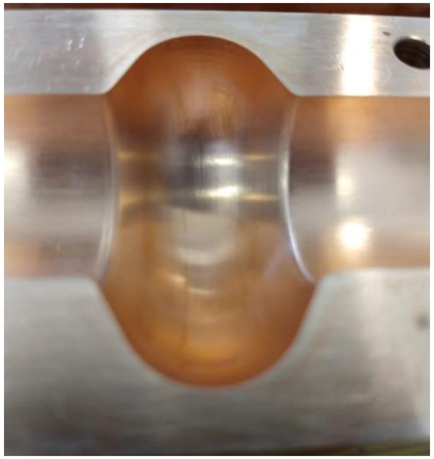
Split cavities for thin film testing

- Can be coated in both closed (for traditional cavity coating) and open (more flexible and better developed) geometries.
- Coating can be inspected for defects/delamination without damaging the cavity.
- RF measurements can be made easily.
- Coating can be removed by machining as well as chemical cleaning (closed cavities can only be chemically cleaned).

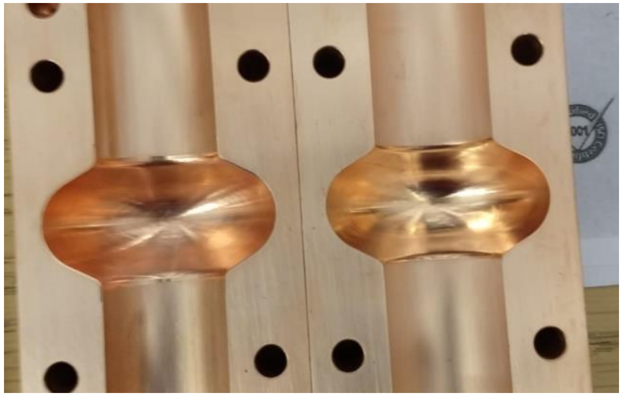
6 GHz cavity in the deposition facility
Before Deposition

Split cavities for thin film testing

- Three 6 GHz cavities designed and manufactured in house at DL.
- Cavities were tested at room temperature and cryogenic temperature then mechanically polished then tested again.
- We tested NC cavities as a rough check of the surface roughness of the cavities
- Cavities B and C were sent to INFN for electro polishing (EP).
- Cavity A was coated with niobium in house by Reza Valizadeh.



Cavity before mechanical polishing at DL



Cavity after mechanical polishing at DL

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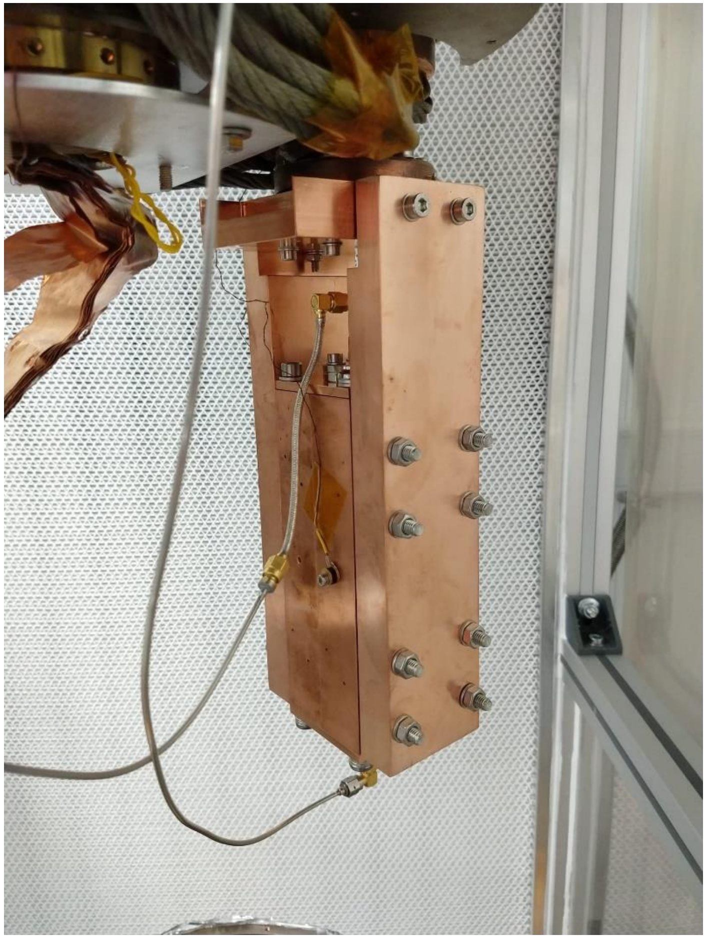
Experimental Facility

- Measurement of surface resistance comes from scattering (S) parameters.
- Uses 2 fixed antennas connected to ConFlat feedthroughs to reduce microphonics.
- Adapter for the cavity bolted to the cold head (helium free) with indium between the joins for good thermal contact.
- Can reach 4 K after 24 hours of cooling.

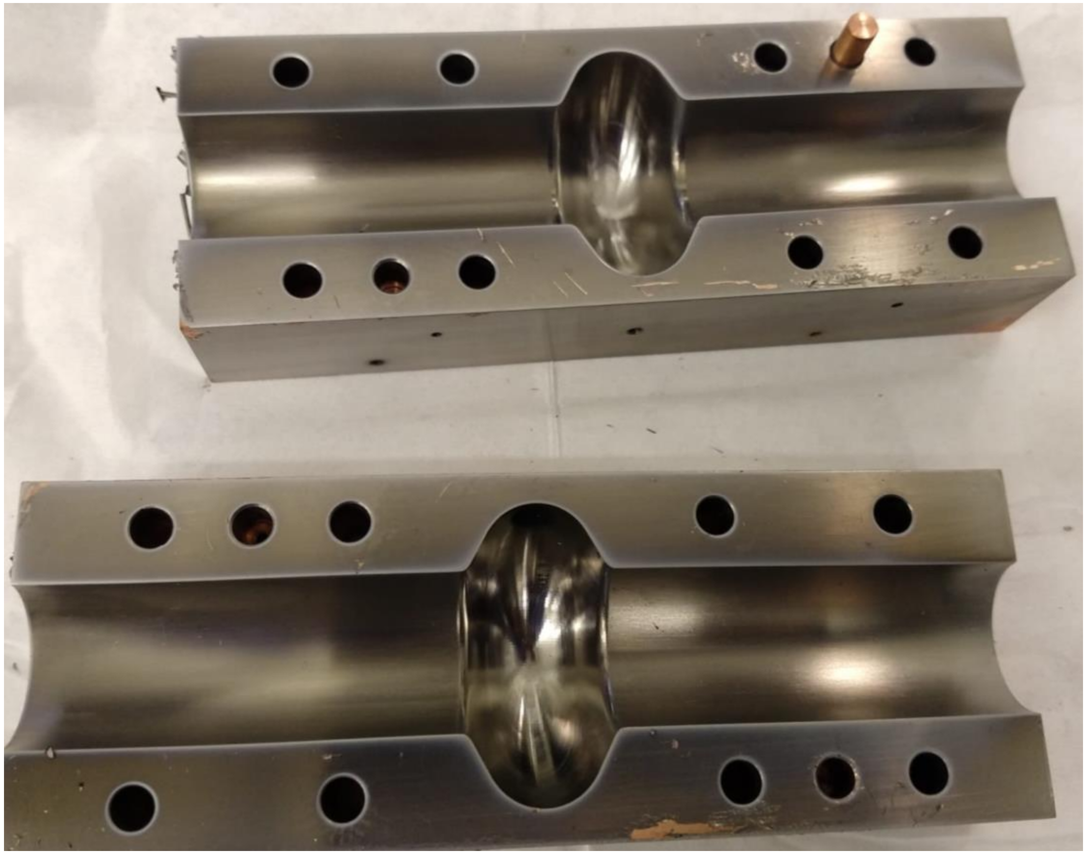


Split Cavity Normal Conducting Results

- Rs of copper cavities from SLAC at 5.7 GHz measured to be 1.6 x 10-2 Ω at room temp.

Cavity	As received R_s (Ω)	After Acetone R_s (Ω)	At ~4K R_s (Ω)
A as received	-	2.6×10^{-2}	1.1×10^{-2}
A Polished	2.3×10^{-2}	2.2×10^{-2}	6.3×10^{-3}
B as received	2.6×10^{-2}	2.4×10^{-2}	6.8×10^{-3}
B Polished	2.2×10^{-2}	2.2×10^{-2}	6.7×10^{-3}
C as received	2.4×10^{-2}	2.5×10^{-2}	9.5×10^{-3}
C Polished	2.2×10^{-2}	2.5×10^{-2}	4.7×10^{-3}

Cavity A Niobium coating



6 GHz cavity A after Nb coating

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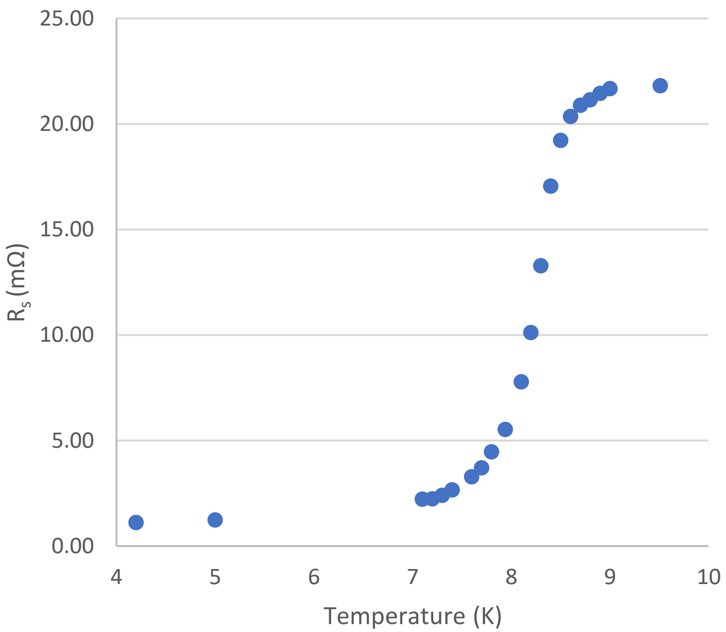
Cavity A Superconducting Preliminary Results

- Clear superconducting transition at the correct transition temperature range.
- Measured Rs =1.13 mΩ at 4.2 K .
- $R_{BCS} = 1.15 \times 10^{-2}$ mΩ.
- 2 orders of magnitude higher than theoretical Rs.
- Maybe due to imperfection of the thin film as it was a trial coating.
- This was the first RF cavity coated with a superconducting thin film at DL and in UK.
- The first RF test of thin film coated SRF cavity at DL.
- First split cavity coated and tested in UK



SWELL Cavities for FCC-ee

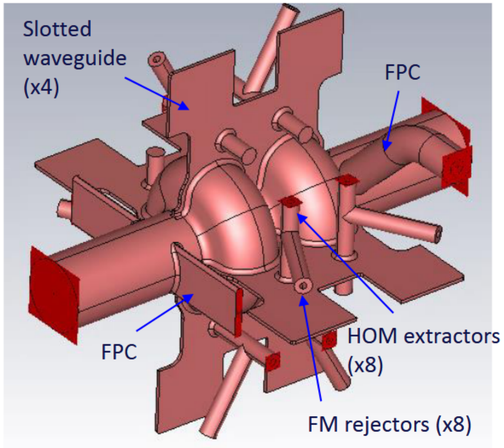
- Slotted Waveguide ELLiptical (SWELL) Cavity.
- Baseline design for FCC-ee RF system even though they have not been tested as they overcome one of the biggest problems in SRF.
- Welds away from the electric field in the HOM dampeners.
- Made as quarter cells.
- Slots reduce HOMs.
- Cavities planned (and simulated to) reach 20 MV/m.
- Bulk Nb or Nb coated Cu.

SWELL Cavities for FCC-ee

FCC SWELL SRF Seminar FCC SWELL Cavity Design, F. Peauger, 23/07/2021 25

SWELL cavity parameters summary

	Z	W	H	ttbar2
Frequency [MHz]	600			
r/Q [Ω] (circuit definition)	96.7			
Transit Time Factor	0.579			
G [Ω]	272.2			
Lacc [m]	0.5			
Epk/Eacc	2.86			
Bpk/Eacc [mT/(MV/m)]	5.72			
Accelerating voltage [MV]	1.2	3	8	10
Accelerating gradient Eacc [MV/m]	2.4	6	16	20
Max. surface electric field Epk [MV/m]	6.9	17.2	45.8	57.2
Max. surface magnetic field Bpk [mT]	13.7	34.3	91.5	114.4
Stored energy [J]	2	12.3	87.8	137.2



Slide from: Franck Peauger. “FCC SWELL Cavity Design”. SRF seminar - 23rd July 2021

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Summary

- The first deposition and tests of an SRF TF cavity at DL have been a success, with better thin film coatings to follow soon.
- The first split cavity designed, produced coated and tested by the CI team
- Slotted SRF cavities are planned to be used in particle accelerators in the future at CERN.
- These cavities are predicted to have better performance than conventional SRF cavities and strong HOM dampening.
- The next steps include testing other thin films for example Nb with more optimised parameters, NbTiN, Nb_3SN etc
- Simulations on how a gap and misalignment affect the cavity's performance

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