Summary SRF

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Erk Jensen

FCC Week Berlin 2017 – RF Sessions/presentations

- ***Tue morning:***

J. Zhai: RF system design for the CEPC main ring

S. Belomestnykh: Update on the US decadal roadmap on SRF technology for HEP accelerators

S. Zadeh: Cavity design approaches and HOM damping for FCC-ee

R. Calaga: Crab cavities for FCC

S. Posen: Potential performance of N doping and Nb3Sn

A-M. Valente-Feliciano: ECR: from samples to cavities

K. Ilyina: Alternative materials and coating techniques for cavities

L. Marques Antunes Ferreira: Copper electropolishing studies for the FCC-ee SC-RF cavities

R. Valizadeh: Surface characterization of Nb/Cu 6 GHz seamless cavities

- ***Tue afternoon:***

N. Schwerg: RF scenarios and parameters layout for FCC

A. Butterworth: Cavity design and beam-cavity interaction

I. Karpov: Beam Dynamics studies for FCC-ee

W. Hofle: RF feedback design and performance

S. Aull: Nb/Cu perspectives for FCC

R. A. Rimmer: Innovative cryomodule designs

E. Montesinos: FPC challenges and perspectives for FCC

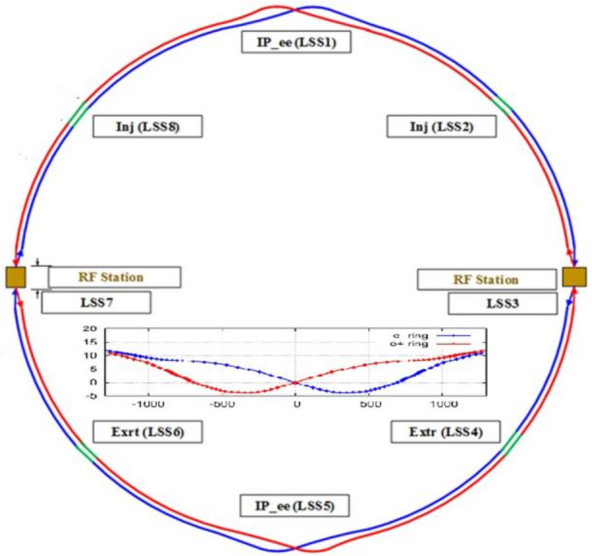
I. Syratchev: High efficiency klystron technology

… and some RF related presentations in other sessions

J Zhai: CEPC concept (here compared to FCC-ee)

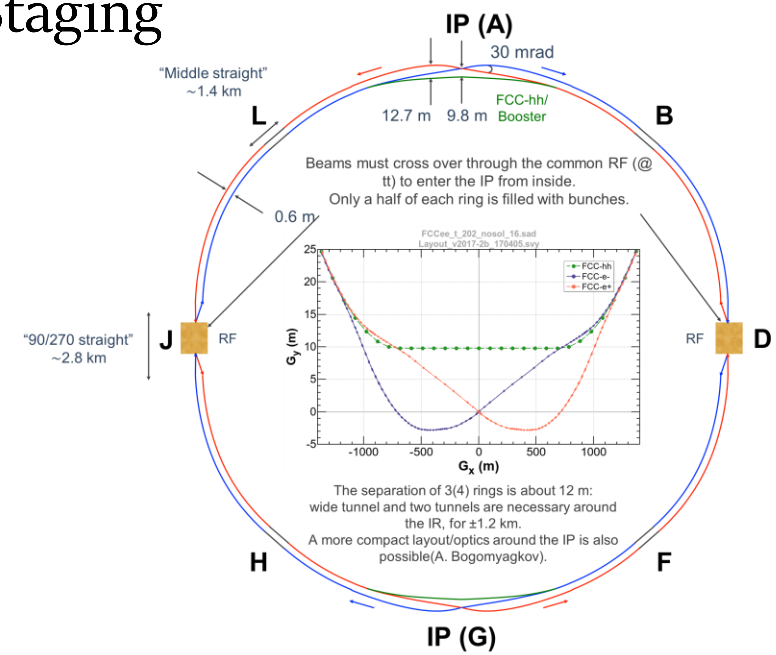
CEPC

- 100 km circumference
- Z, W, Higgs
- Staging not foreseen



FCC-ee

- 100 km circumference
- Z, W, Higgs & $t\bar{t}$
- Staging



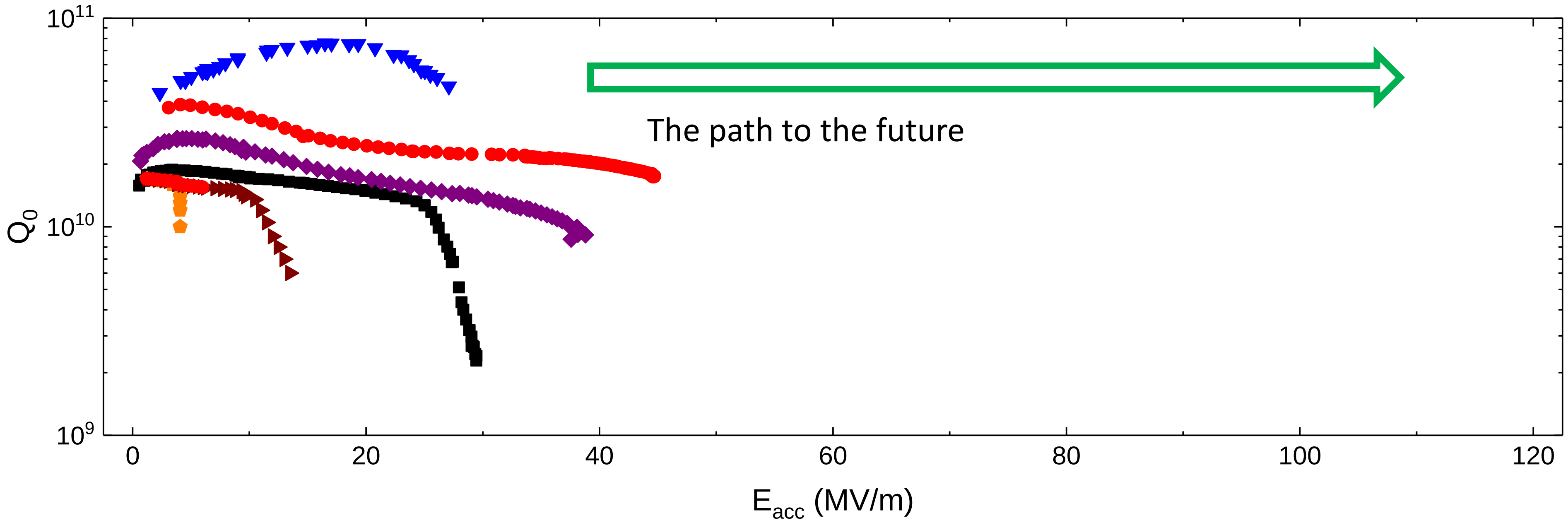
They are very similar: The issues and possibly solutions are similar! We should work together!

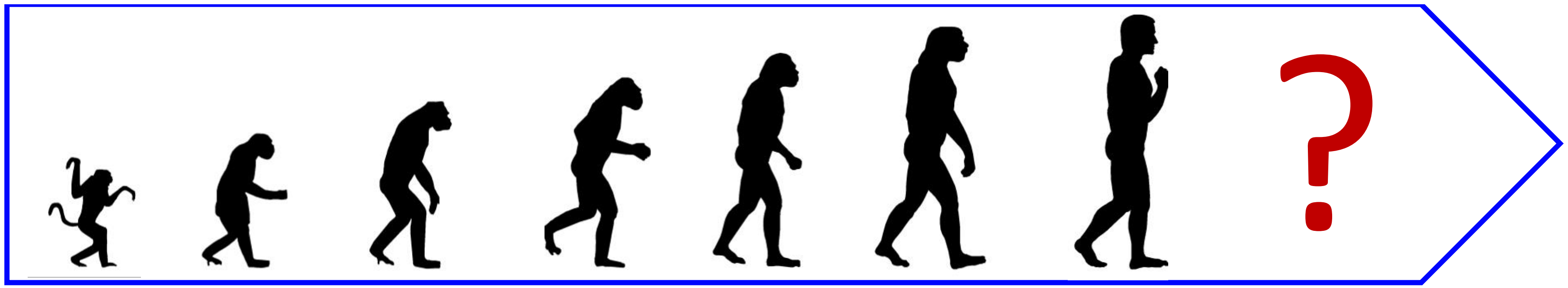
Parameters FCC-ee *vs.* CEPC (moving targets!)

FCC-ee	Z	W	H	tt	
Energy	45.5	80	120	175	GeV
Luminosity	10^{36}	$1.8 \cdot 10^{35}$	$5 \cdot 10^{34}$	10^{34}	$cm^{-2}s^{-1}$
Current	1450	150	30	6.5	mA
Voltage	0.25	0.8	3	10	GV
RF Power	50	50	50	50	MW

CEPC	Z	W	H	tt	
Energy	45.5	80	120		GeV
Luminosity	$1.2 \cdot 10^{35}$	$5 \cdot 10^{34}$	$2 \cdot 10^{34}$		$cm^{-2}s^{-1}$
Current	466	97	19		mA
Voltage	0.14	0.41	2.1		GV
RF Power	16	16	32		MW

S Belomestnykh: SRF Roadmap – “evolution”





S Belomestnykh: High-*Q* roadmap

2018 | 2020 | 2022 | 2024 | 2026 | 2028

Physics of RF Surface Resistance
- Understand the field dependence of BCS surface resistance and effect of different impurities
- Apply gained knowledge and develop new understanding for alternative materials
- Understand origin of residual resistance and its field dependence
- Understand trapped magnetic flux losses and flux trapping

Doping
- Continue exploration with nitrogen in Nb at different temperatures
- Doping for new materials
- Probing the ultimate limits of Nb RF surface resistance by doping with different impurities
- Study Nb doping at different frequencies and temperatures

Potential of Nb material: *Q* (2 K) ~ 1x10[11] @ 1.3 GHz

Nb_3Sn or other new materials
- Pursue current promising path forward for material in bulk form (Nb_3Sn) - explore and optimize coating techniques and treatments for single cell / multi-cell cavities
- Nb_3Sn studies for cryomodule operation
- Explore SIS for Nb_3Sn
- Evaluate alternative materials, bulk or film (NbN, NbTiN, MgB_2) first on samples, then on cavities

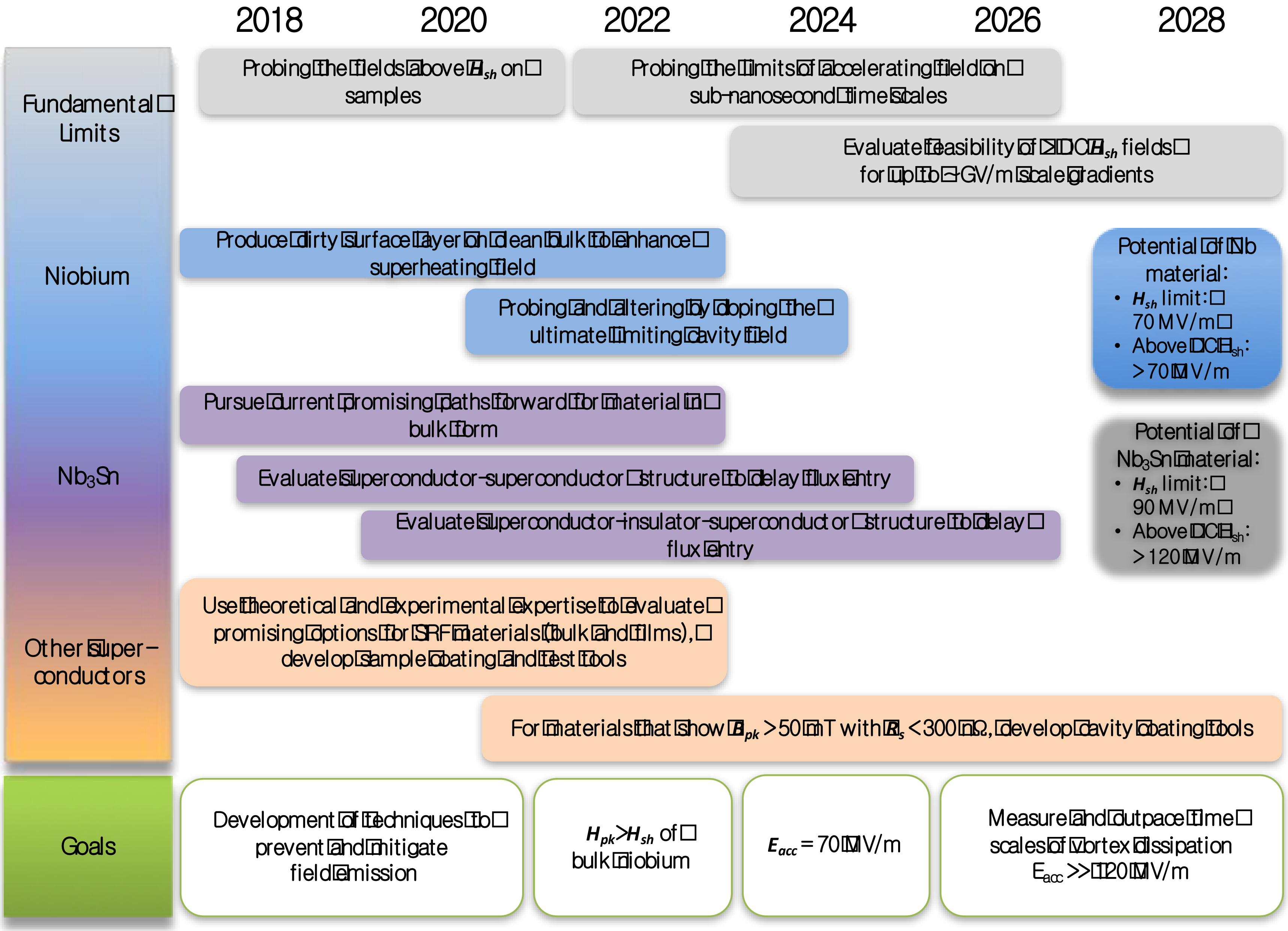
Potential of Nb_3Sn material: *Q* (4 K) ~ 1x10[11] @ 1.3 GHz

Magnetic Flux Losses
- Drastically reduce sensitivity to magnetic flux for Nb and new materials
- In situ removal of trapped magnetic field (in cryomodule)
- Develop Materials Specs to ensure maximum flux detrapping

Impact:
- Retain 1x10[11]
- Sustain very high gradients

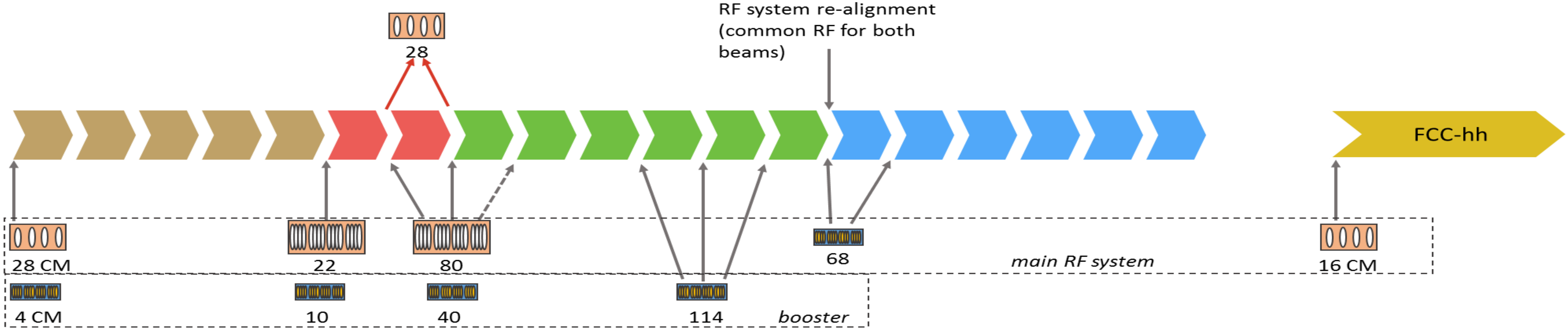
Goals
- Q > 4x10[10] at 2 K, 1.3 GHz and E_{acc} > 35 MV/m
- Nb_3Sn: E_{acc} > 20 MV/m with Q_0 > 1x10[10] at 1.3 GHz, 4.2 K
- *Residual resistance < 1 nΩ in cryomodule*
- *Nb_3Sn cryomodule ready technology*

S Belomestnykh: High-gradient roadmap



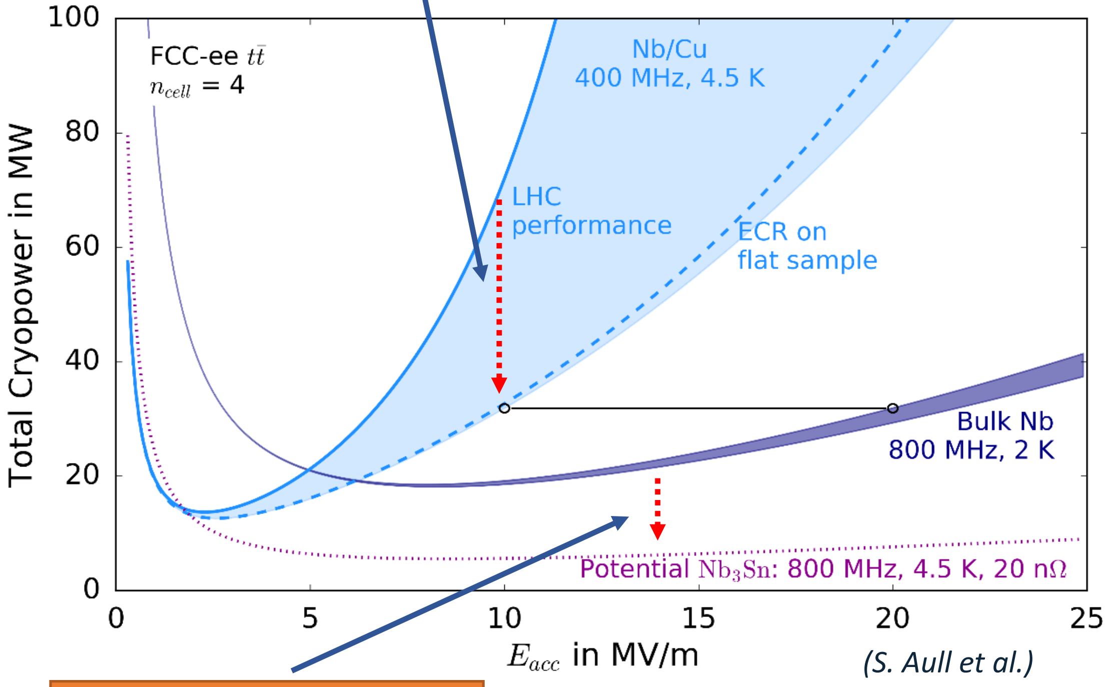
O Brunner, N Schwerg, S Gorgi Zadeh: RF scenarios

- FCC-ee has **baseline plan, fallback options** and a **believable staging scenario**:
  - 5 y @ Z-pole with 36×4 single-cell cavities at 400 MHz, Nb/Cu @ 4.5 K,
  - 2 y W with 28×4 four-cell cavities at 400 MHz, Nb/Cu @ 4.5 K,
  - 6 y Higgs with 102×4 of these same cavities, but run with larger Q_{ext} (P distribution)
  - 6 y $t\bar{t}$ rearranging these cavities,
    and adding about 150×4 four-cell (5-cell?) cavities at 800 MHz, bulk Nb @ 2 K.



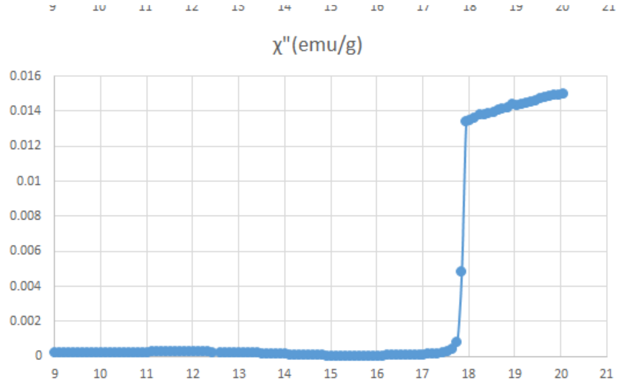
S Aull, K Ilyina, S Posen, R Valizadeh: Optimum SRF Materials – the technology push!

Nb/Cu R&D program

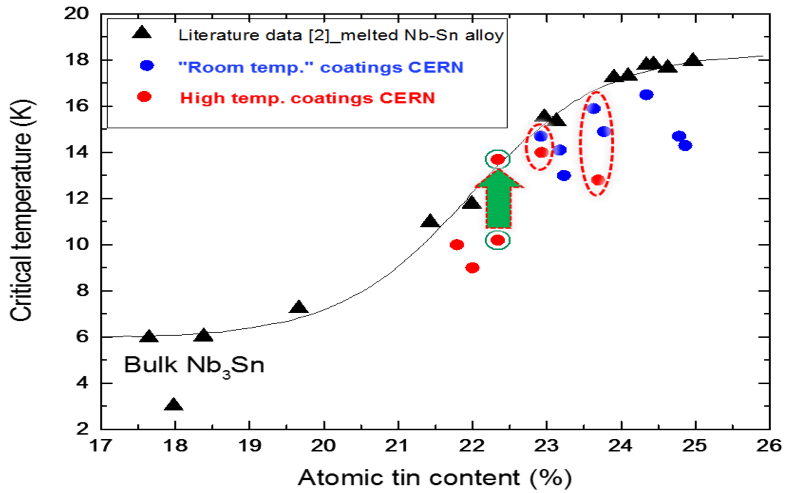


A15 R&D program

Cornell/FNAL: Vapor deposition of Nb_3Sn works well



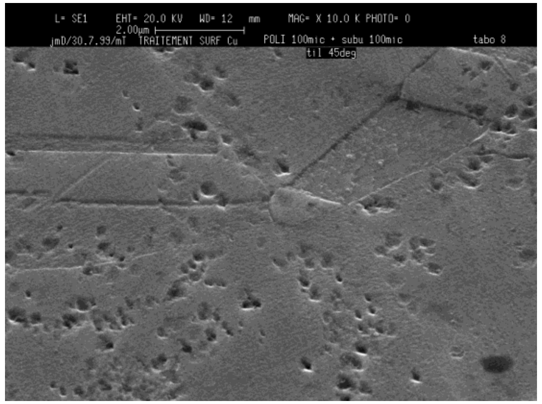
CERN: Coating of Nb&Sn on Cu and annealing to Nb_3Sn



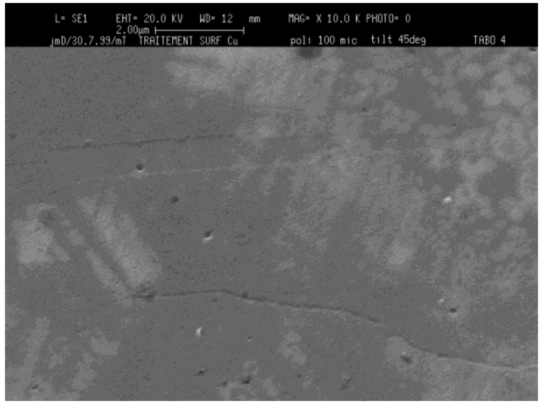
Where does the R&D lead us? What is the most cost effective?

L Ferreira: EP (Electro-chemical polishing)

- The coating techniques require good substrate surfaces
- EP reaches the best surface preparation $R_a = 40$ nm!
- CERN is acquiring/installing a new EP facility compatible with FCC cavities



Chemically polished Cu, $R_a = 0.2$ µm, pinholes



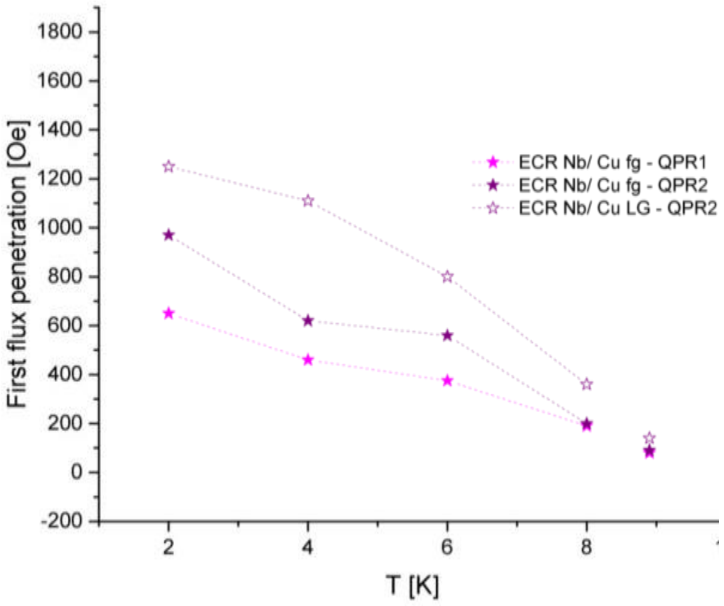
Electropolished Cu, $R_a = 0.02$ µm

	2017				2018			
Task	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q
Concept	■	■						
Supplier survey	■	■						
Design		■	■					
Purchasing			■	■				
Assembly				■				
Commissioning					■			
Preliminary tests					■			

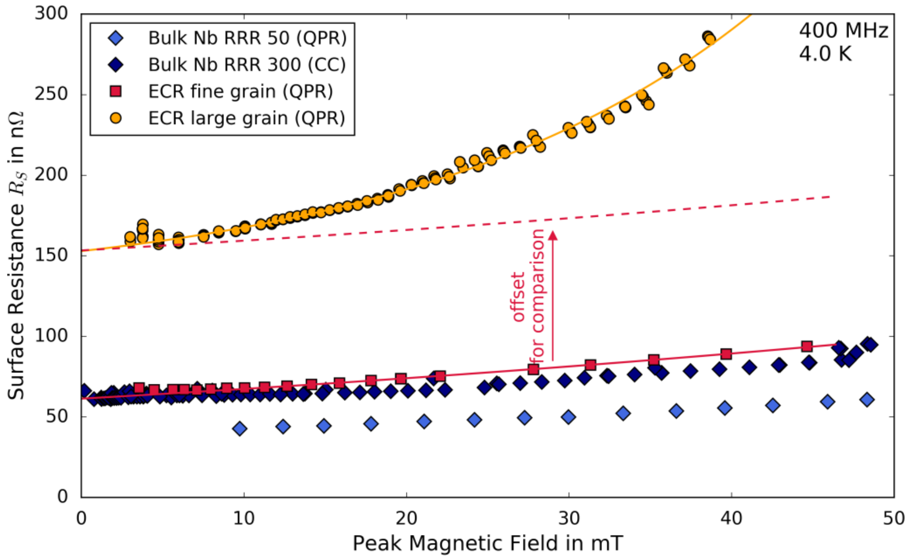
A.-M. Valente Feliciano, S Aull: ECR from samples to cavities

ECR compatible with non-flat surface

Nb/Cu: flux penetration proves very good quality SC layer



Surface resistance ECR on LG Cu has same R_s and Q-slope as Bulk Nb



Cavity technology R&D:
Progress clearly visible – but many things are still in the air!

A Butterworth: beam-cavity interaction challenges

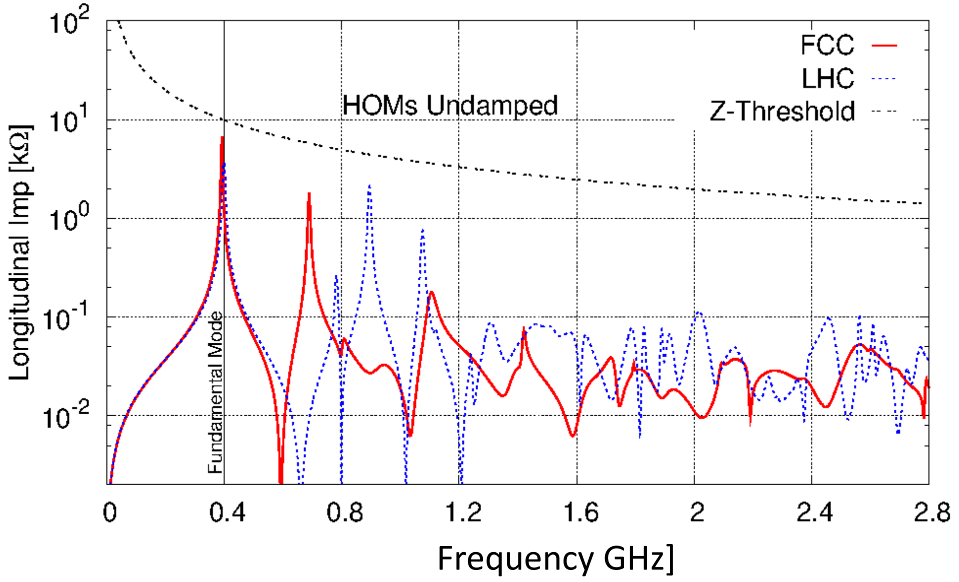
- Macro-particle simulation code BLonD helps predict/solve issues for both FCC-hh and FCC-ee.
- Most challenging: Z machine ($I_b = 1.45$ A)
  - similar to high current super B-factories
- Cavity fundamental-driven coupled-bunch instabilities (CBI)
  - Large number of cavities, large detuning ($> 3 \times f_{rev}$)
  - CBI growth rates much larger than synchrotron radiation damping (~1 ms cf. SR damping time of 440 ms)

→ active damping required:

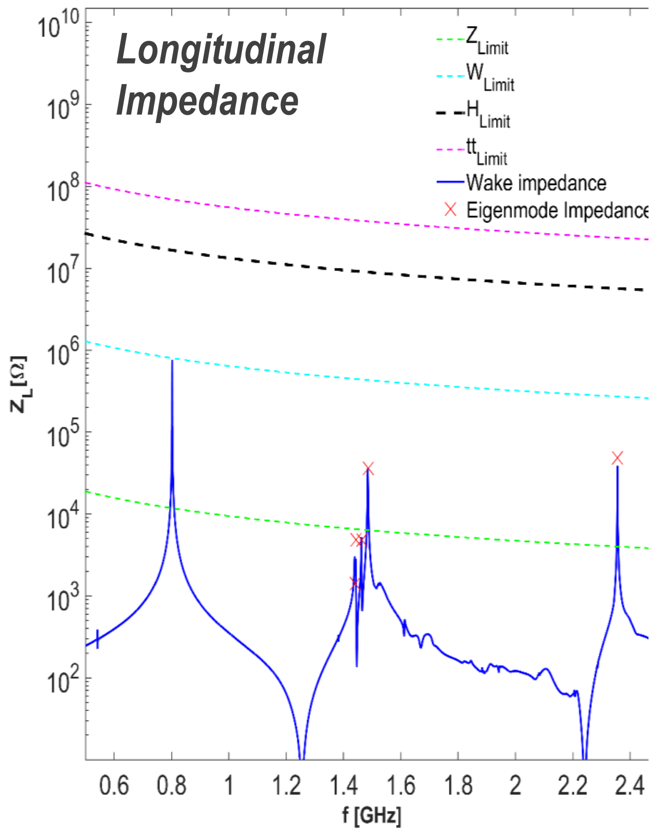
  - Woofer for low order modes
  - Strong bunch-by-bunch longitudinal feedback for higher modes
- Implement beam loading compensation to avoid CBI!
  - full compensation requires very high (peak) power
  - phase modulated RF voltage reduces power transients ("**full detuning**" now baseline in LHC)
- Many LLRF and long. BD issues already addressed/solved in LHC

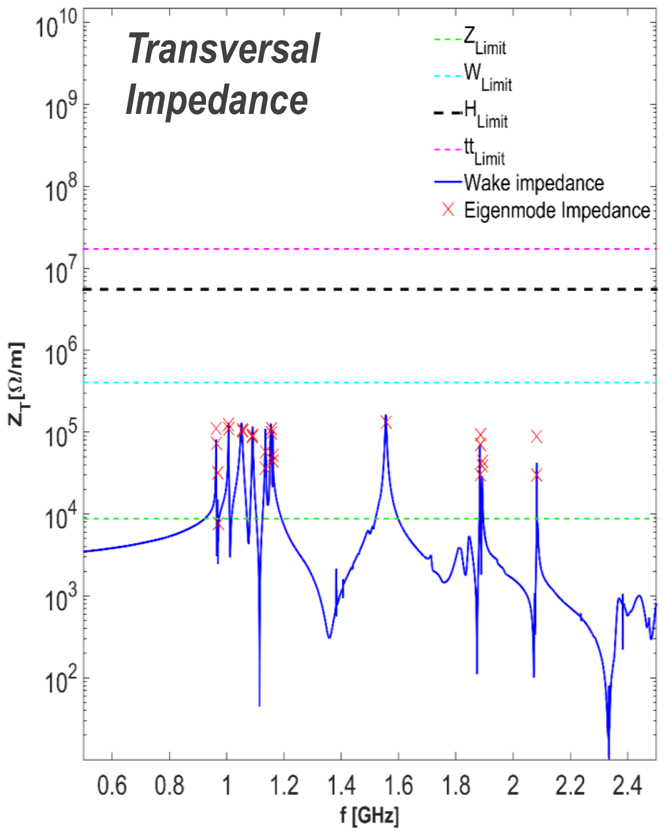
I Karpov, A Butterworth, S Gorgi Zadeh: HOM damping

FCC-ee Z: single-cell 400 MHz cavity meets criteria
HOM's to be damped below 10 kΩ!



FCC-ee (H, $t\bar{t}$): 800 MHz 4-cell (5-cell) cavity OK

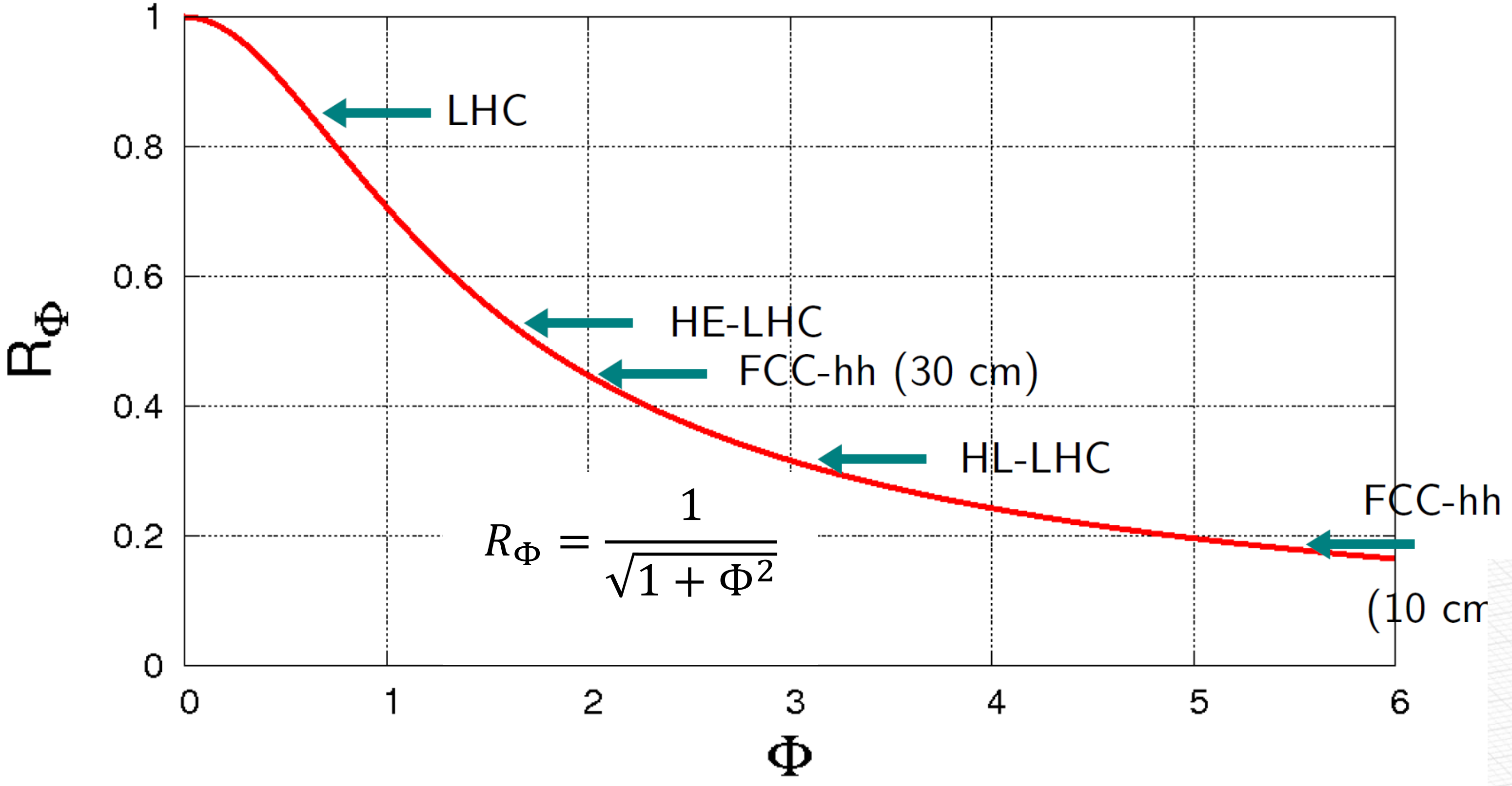




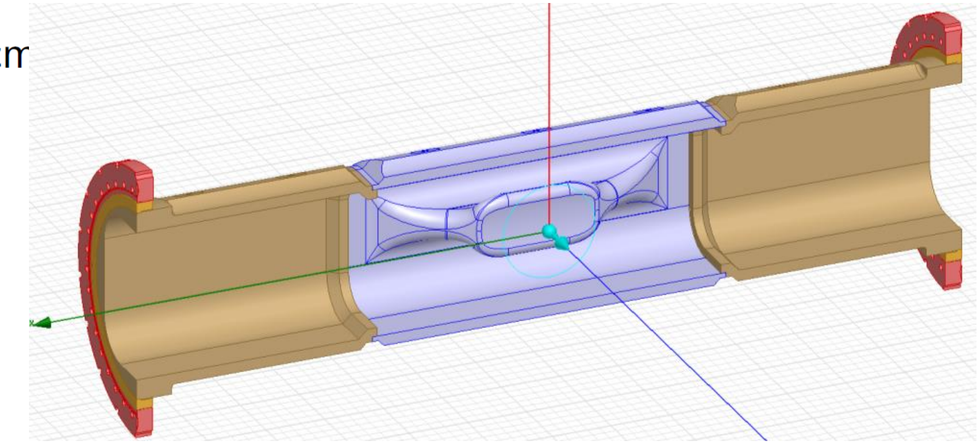
W Höfle: Transverse feedback

- FCC-hh needs a coupled bunch feedback with options for 5 ns and 25 ns bunch spacing (driven by resistive wall instability → fast instability rise times at low frequency)
- **LHC type transverse feedback system proposed** as baseline for 25 ns option, 22 kickers per plane and beam with adaptation of power bandwidth to FCC needs
- 5 ns option requires additional kickers to cover higher frequencies
- GHz feedback can be an option to mitigate slow intra-bunch instabilities, kicker designs being proposed
- Impact of feedback noise, suppression of emittance growth by ground motion and due to crab cavity noise needs consideration
- FCC-ee requires system with distributed kickers to be considered due to very short rise times (< 10 turns)
- Simulation environment developed, integrated with head-tail code to refine in simulation the specifications and evaluate the performance for the CDR treating coupled bunch and intra-bunch instabilities as well as injection errors and filamentation.

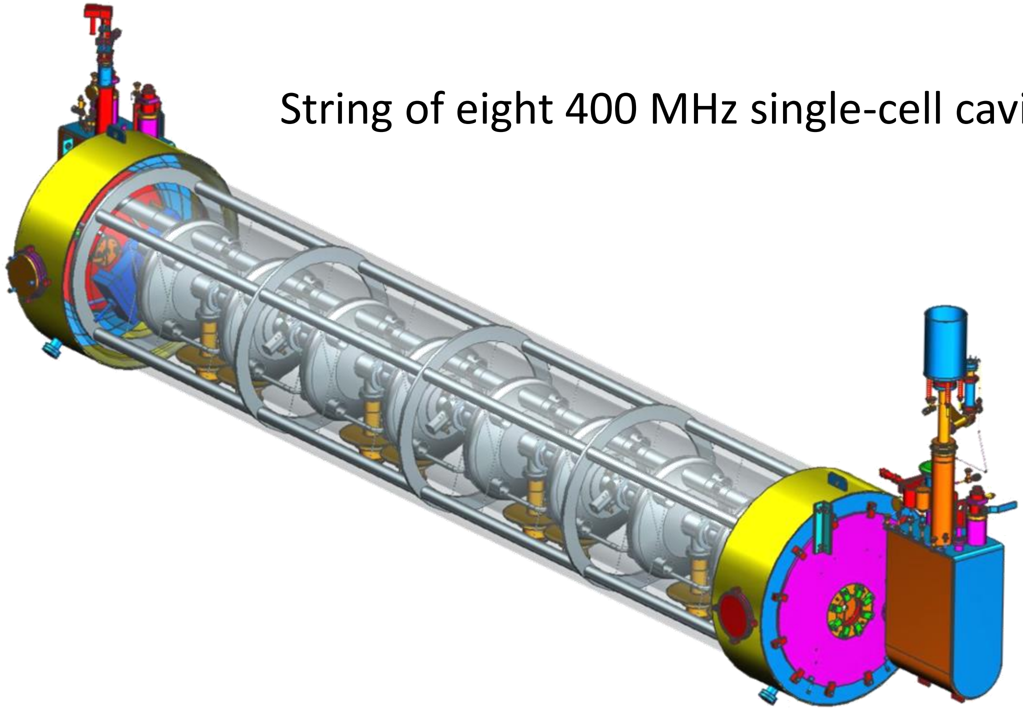
R Calaga: Crab cavities



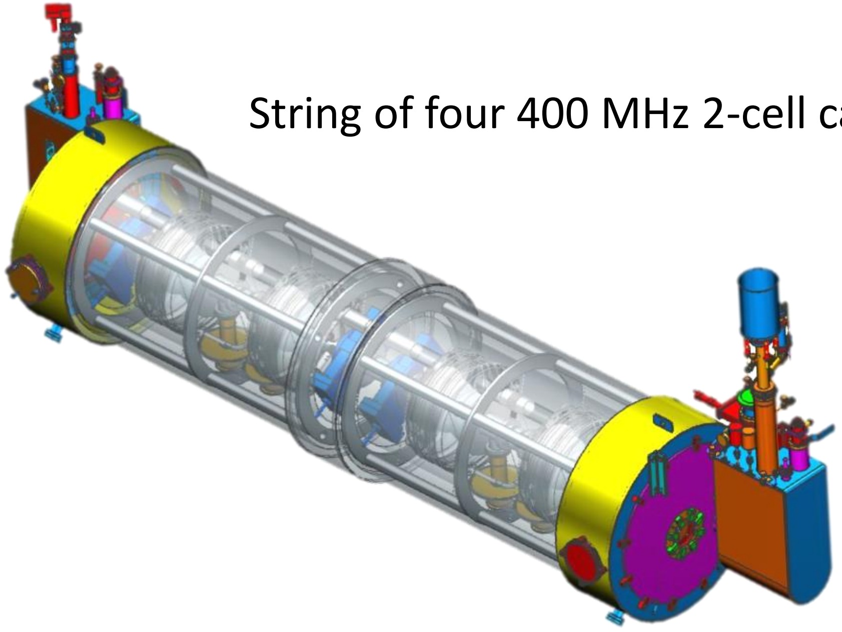
- Crab cavities needed for FCC-hh and HE-LHC
- Large β functions at CC location require low impedance
- A new, low-impedance CC is being prototyped.



R A Rimmer: JLAB Modular CM fits FCC needs

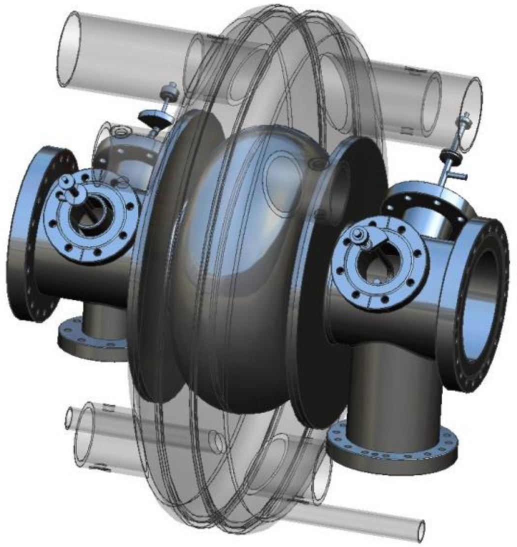


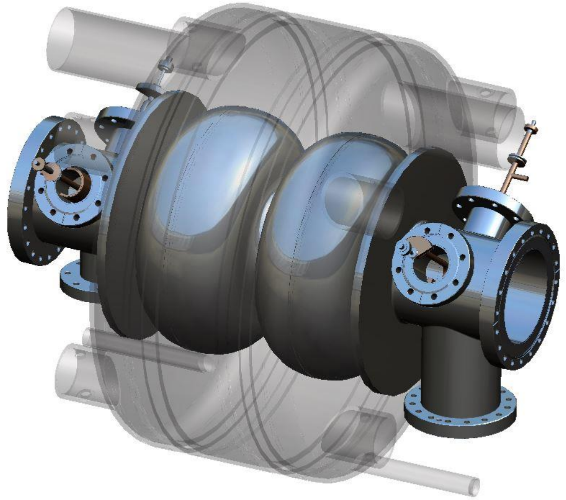
String of eight 400 MHz single-cell cavities

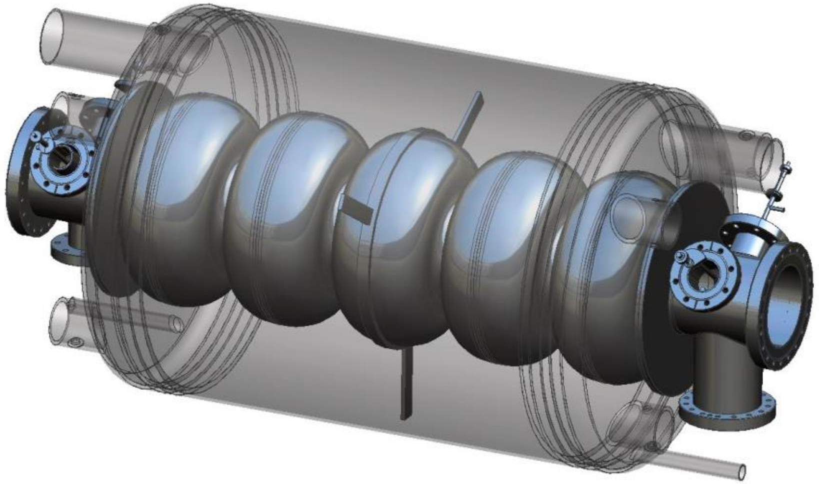


String of four 400 MHz 2-cell cavities

R A Rimmer: A proposed solution for 800 MHz

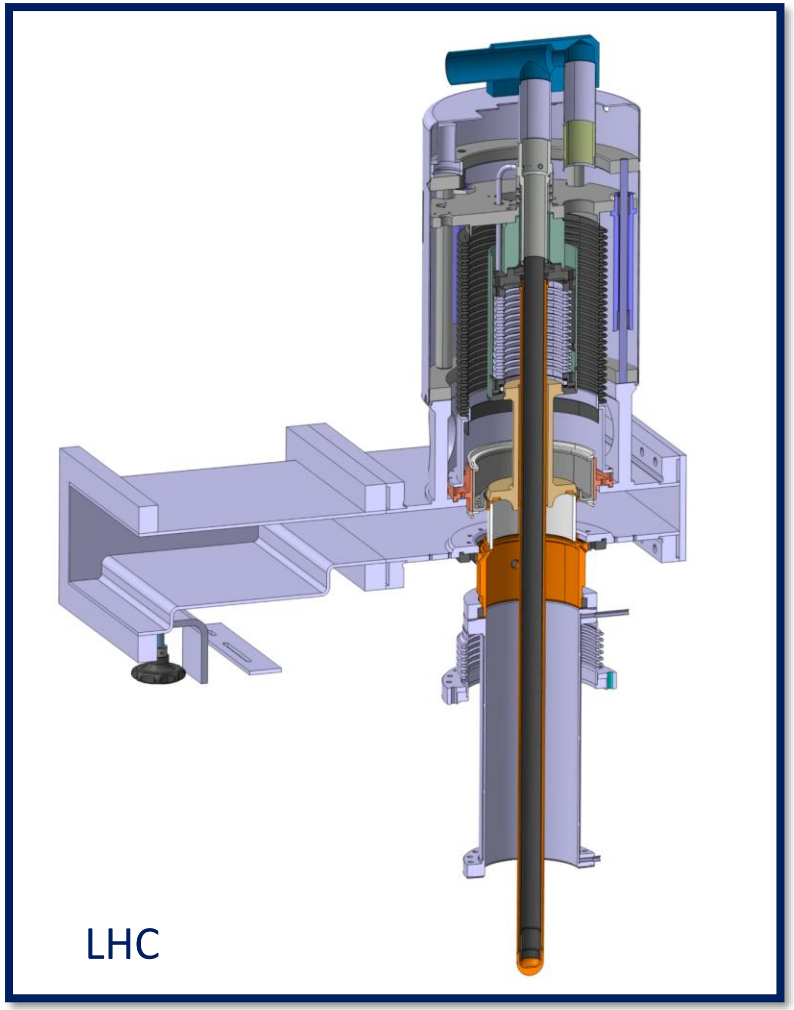






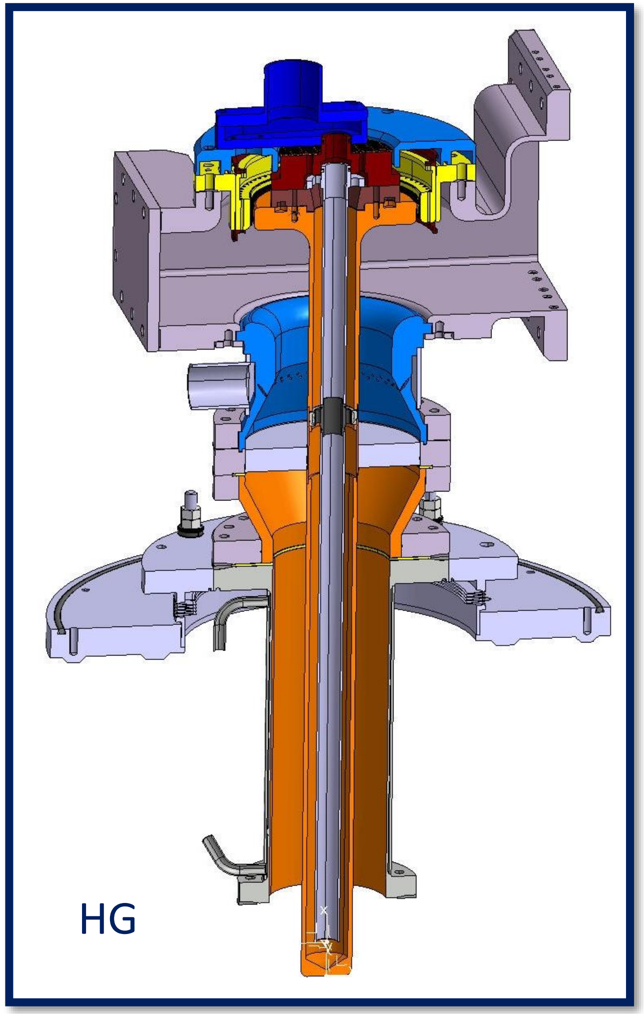
Large He-vessel could fit also 800 MHz cavities and the same, modular CM

E Montesinos: FPC challenges



Present LHC FPC, starting point to develop FPC for 400 MHz, up to 500 kW CW

Present high-gradient FPC (704 MHz), starting point to develop FPC for 800 MHz, up to 100 kW CW



E Montesinos: FPC R&D topics

	FCC ee (Z)	FCC ee (W)	FCC ee (h)	FCC ee (t)	FCC ee (h)	FCC ee (t)	FCC hh
Freq	400 MHz				800 MHz		400 MHz
MV/m	5	10			20		5
kW	1000	500	250	80	300	100	1000
Qty	150	250	500	1500	350	1200	100
Coupling	Fixed	Fixed	Two fixed positions no venting				Mobile

High Power FPC
Variable and Adjustable FPC
Cleanliness
Large series production

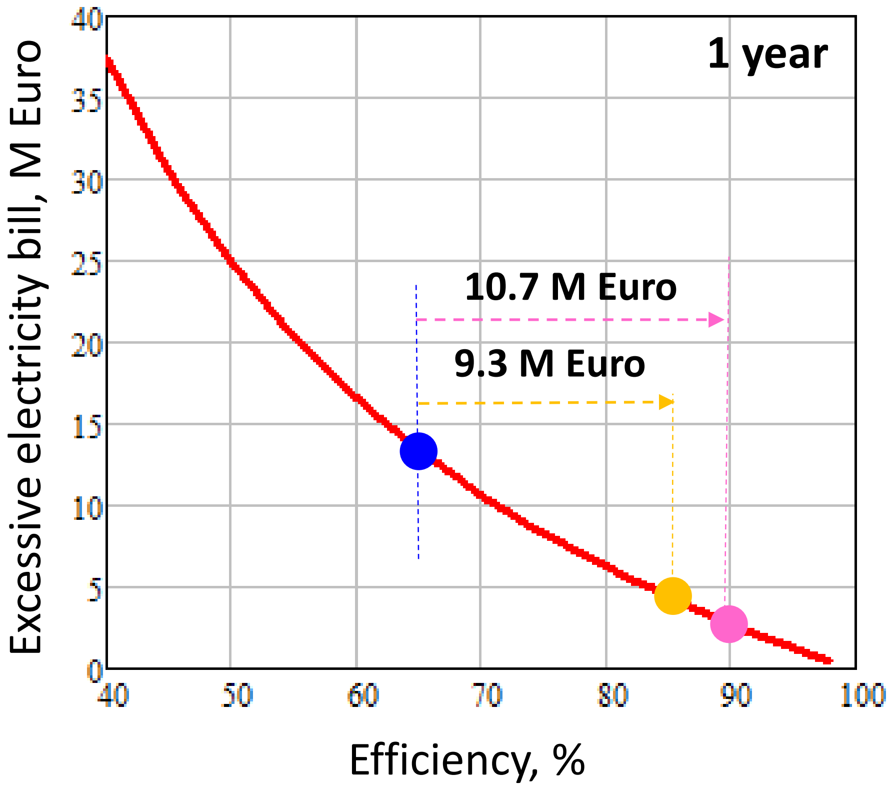
Evaluate robots!

Cost of FPC, and cost impact to the others

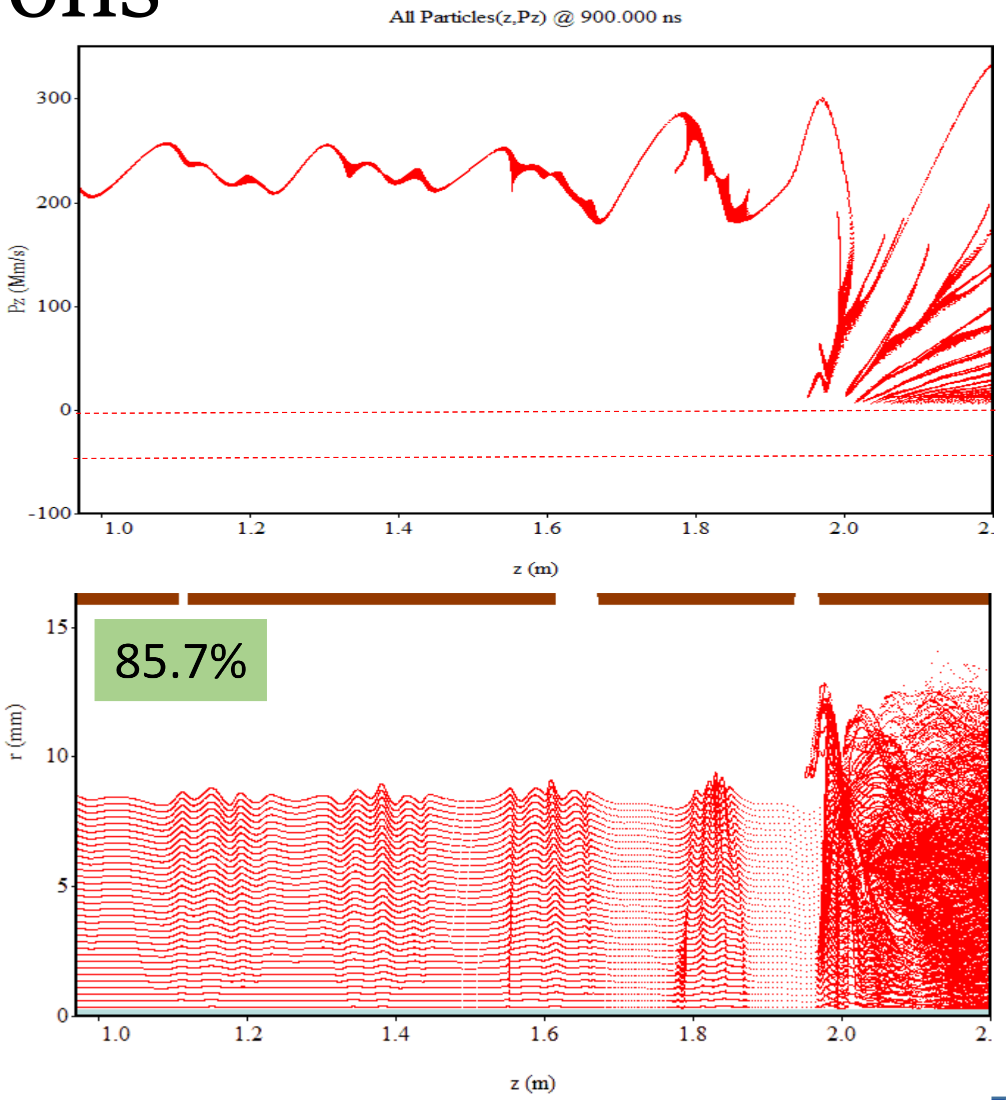
Some of the sub-topics that will have to be addressed as well (non exhaustive list)

Ceramic material
Multipacting
Brazing
Coating
Cryomodule integration
Assembly in clean room
Specific tooling
RF power source for FPC
Resonant rings
Test boxes
Diagnostics
Conditioning processes
Transportation
Constraints for operation
Statistics

I Syratchev: High Efficiency klystrons



- R&D that "pays for itself" Important societal impact!
- Fantastic progress – we firmly believe that we can reach 85% efficiency.
- Example on the right: FCC 800 MHz, 1.4 MW CW



Summary of the summary

- The RF R&D subjects are fascinating – the large international collaboration I see at work now is very motivating and vibrant! The spirit is great!
- The progress is clearly visible, even if the hard experimental evidence is still not complete.
- Concerning FCC-ee, we today have a believable concept for a baseline, fall-back options and a staging scenario
- We have identified R&D topics and are making tremendous progress on them

Thank you very much!