FUTURE CIRCULAR COLLIDER

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)

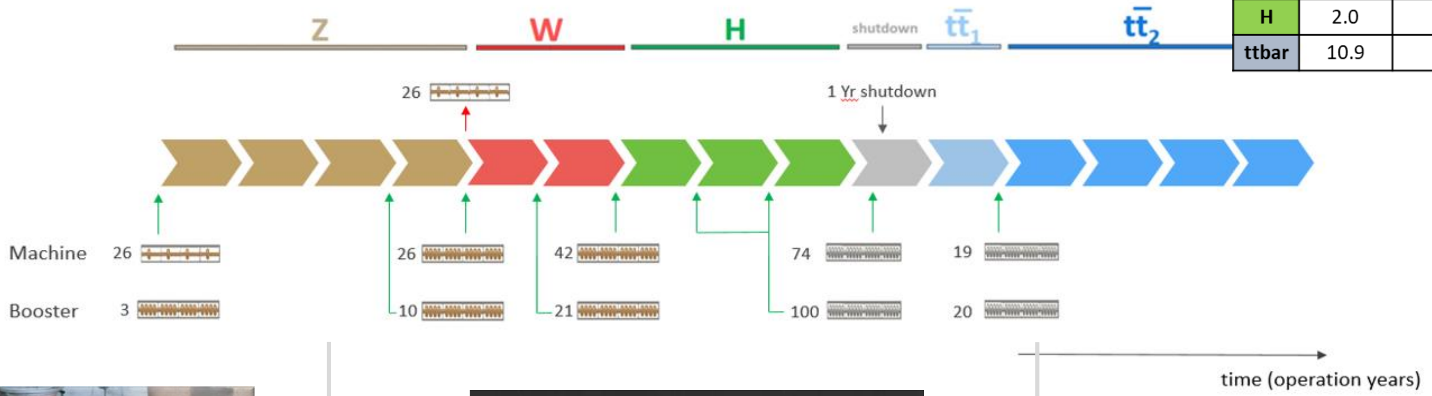
SRF Technologies 02 (O. Brunner - CERN)
- Overview of Multilayer Developments at JLab (A. M. Feliciano-Valente, JLab)
- SRF characterization of multilayers (S. Keckert, HZB)
- Superconducting Thin Films Studies at CERN (G. Rosaz, CERN)
- RF characterisation techniques, 1.3 GHz cavities (P. Vidal Garcia,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

https://indico.cern.ch/event/995850/timetable/

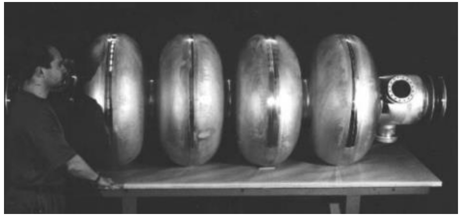
Many thanks to everyone + Julie!!!!!

A ‘solid’ baseline

WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4



400 MHz 1-cell cavities

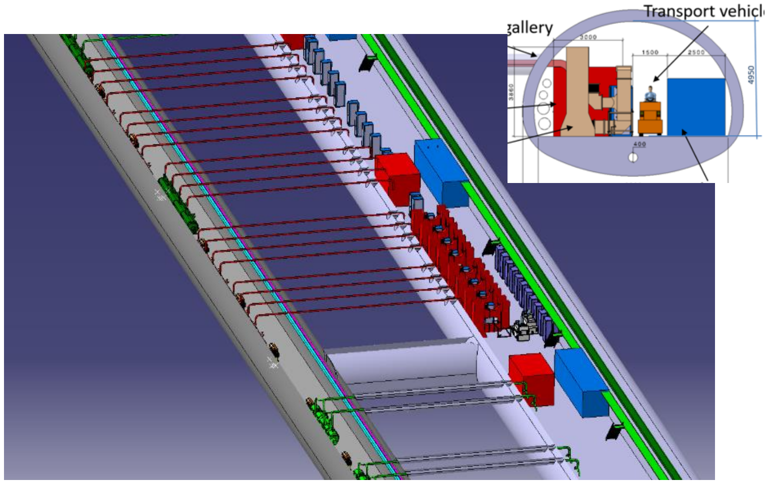


400 MHz 4-cell cavities

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



Fani Valchkova-Georgieva

Complex integration with consequences:

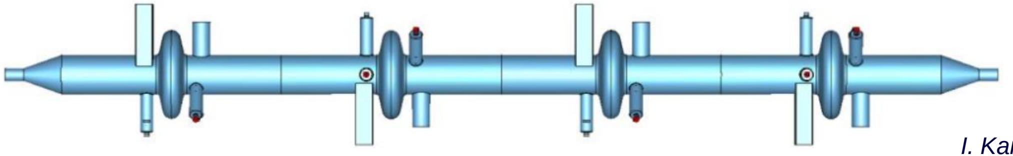
- Z, W: require **very compact high RF power systems**
- **Very high power fundamental RF couplers**

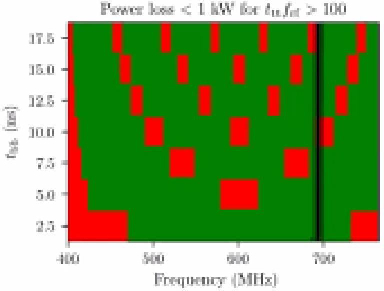
Challenging High Order Modes in the cavities:

- Requires complex damping systems, dedicated beam configurations

Large amount of HOM power propagating through beam pipes:

- Requires absorbers, dedicated beam configurations





I. Karpov

Notable R&D challenges

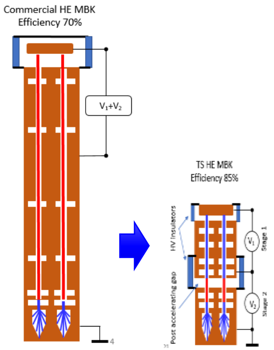
Z machine

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



J. Cai, I. Syratchev

E. Montesinos

WW & ZH machine

Keep the pace - Re-use existing HW.

-> produce HE acceleration system (4-cells cav.)

- improve Nb coating (~6 m^2/cavity!)
- seamless cavities / internal welds

-> develop large infrastructures

ttbar machine (& booster)

High efficiency acceleration cavities & CM

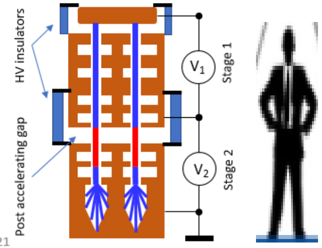
-> bulk Nb technology is mature
-> profit from existing expertise (ESS, PERLE, LCLS2, ILC)

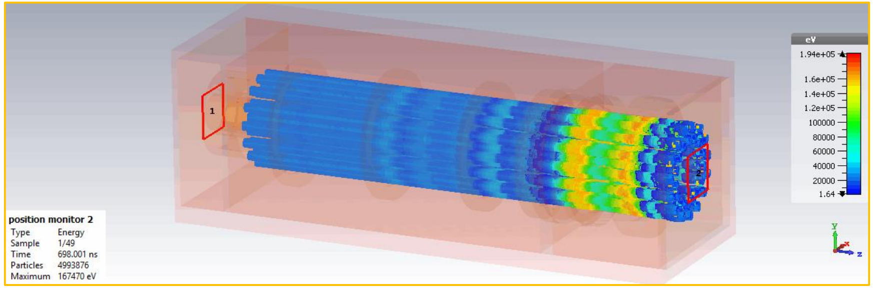
"Solid baseline" - big technical challenges
- 400 MHz limits the synergies with other projects

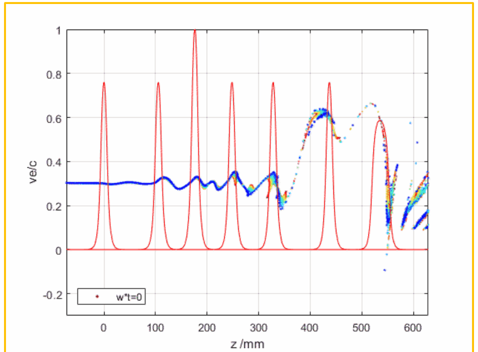
Two-Stage Multi Beam Klystron technology

- 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!

TS HE MBK
Efficiency 85%

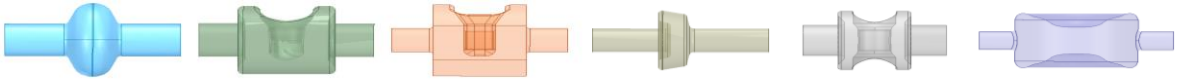






J. Cai, I. Syratchev, G. Burt

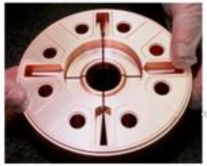
Challenging the baseline

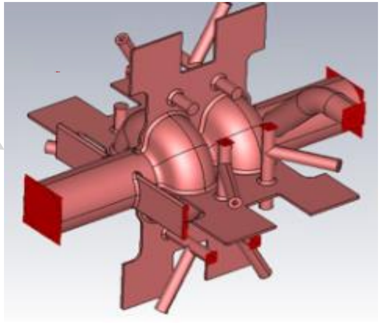


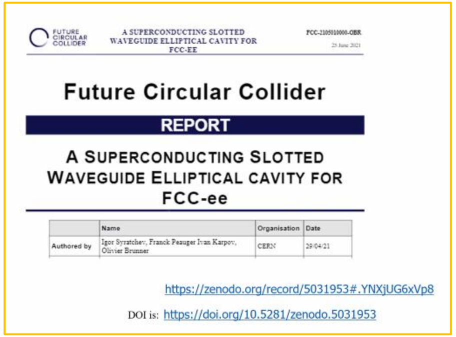
F. Peauger

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







FUTURE CIRCULAR COLLIDER — A SUPERCONDUCTING SLOTTED WAVEGUIDE ELLIPTICAL CAVITY FOR FCC-EE — FCC-2105010000-OBR — 25 June 2021

Future Circular Collider

REPORT

A SUPERCONDUCTING SLOTTED WAVEGUIDE ELLIPTICAL CAVITY FOR FCC-ee

	Name	Organisation	Date
Authored by	Igor Syratchev, Franck Peauger Ivan Karpov, Olivier Brunner	CERN	29/04/21

https://zenodo.org/record/5031953#.YNXjUG6xVp8

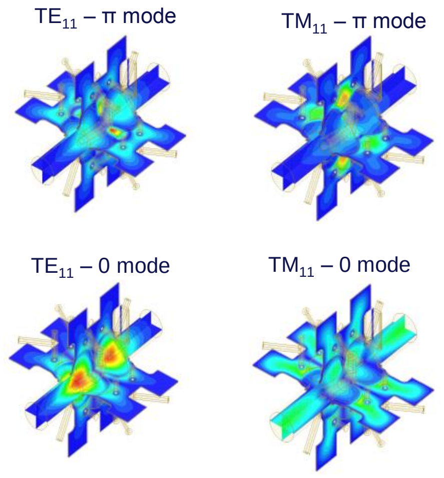
DOI is: https://doi.org/10.5281/zenodo.5031953

	UROS$_1$ 400 MHz	SWELL 600 MHz	Comments
Transient beam loading (Collision point shift due to ± 5% charge asymmetry)	2.4 mm	~12 mm (abort gap length need to be checked)	Luminosity is degraded for shifts above 5 mm; mitigation schemes and abort gap length need to be reconsidered
Longitudinal CBI due to fundamental mode can be suppressed by means of	Direct RF feedback	Direct RF + One turn delay feedback	More complicated RF feedback is required for SWELL cavities
Longitudinal CBI due to HOMs can be suppressed by means of	Synchrotron radiation damping	Synchrotron radiation damping	Well under control
Transverse CBI due to HOMs suppressed by means of	Bunch-by-bunch transverse feedback system (damping time ~100 turns)	Bunch-by-bunch transverse feedback system (damping time ~100 turns)	This system is not yet planed to be used
HOM power losses	About 6 kW per cavity	About 9 kW per cavity	For 600 MHz the impact of beam parameters and multi-cavity configuration needs to be studied

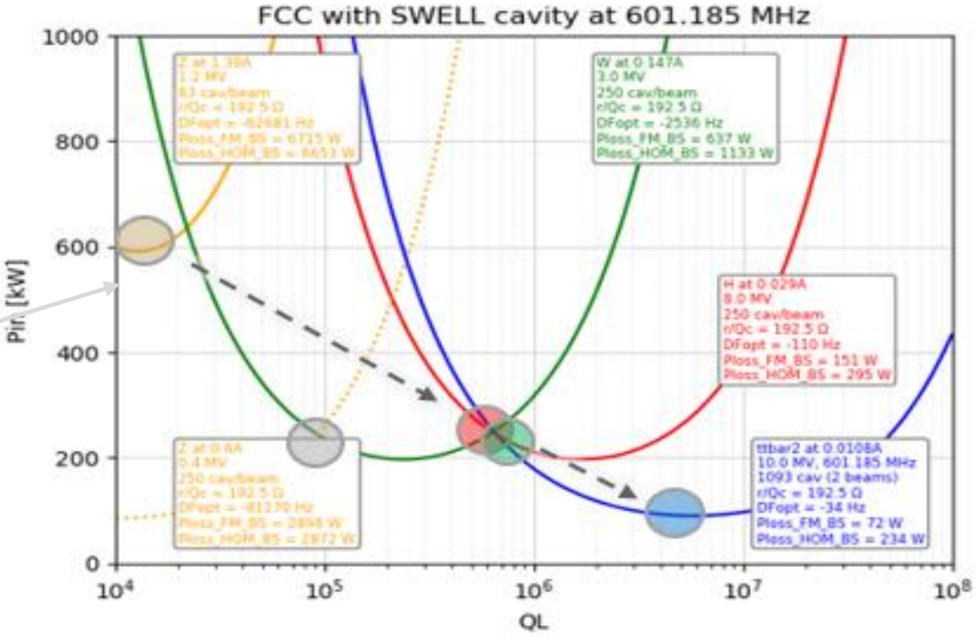
I. Karpov

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

'SWELL': a single cavity for all operating points



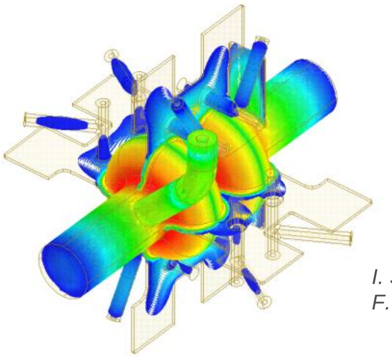
I. Syratchev



F. Peauger
I. Karpov

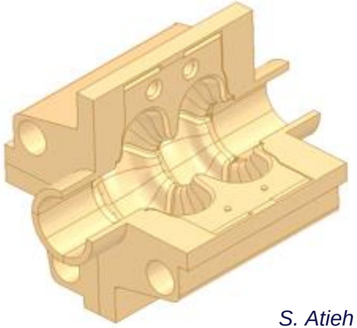
- A simplified installation schedule
- Optimized slot geometries and HOM power extraction (Z)
- A considerable potential for ampere class accelerators
- Promising even without extraction system

The SWELL beauties…



I. Syratchev
F. Peauger

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



S. Atieh
G. Rosaz

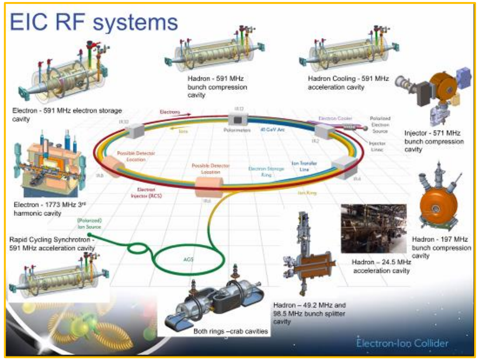
- Innovative 4 quadrants technology
  -> no welds in critical areas
  -> simplified coating

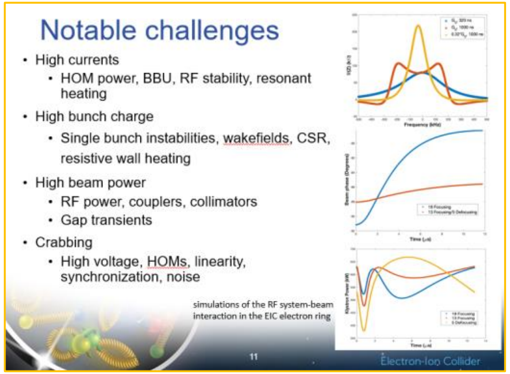
- A challenging concept that must be demonstrated (1.3 GHz)

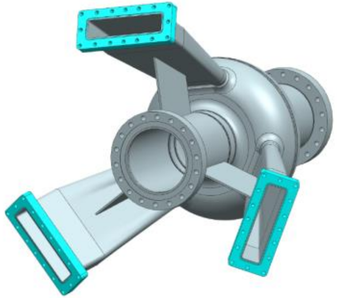
Synergies with dynamic partners/programs

EIC RF system:

- a complex machine, with comparable challenges
- Asymmetric single cell 591 MHz optimized for high current -> FCC_ee?







B. Rimmer

PERLE, JLAB:

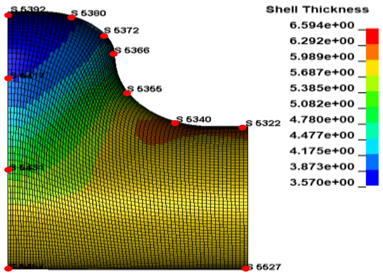
- 5-cell bulk Nb cavity was built and tested by JLAB
- PERLE will use the CERN/ORSAY developed SPL CM concept and complete the module with 800 MHz cavities

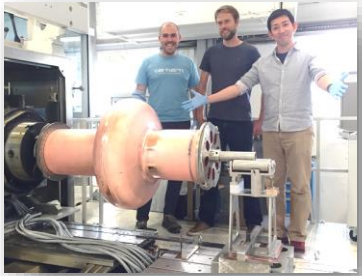
Rich SRF R&D programs at CERN (LHC, HL, FCC,..)

The substrate is the key

Fabrication:

- Half cells by electro-hydroforming
- Development of EBW internal welding
- Development of seamless bulk 1.3 GHz cavities



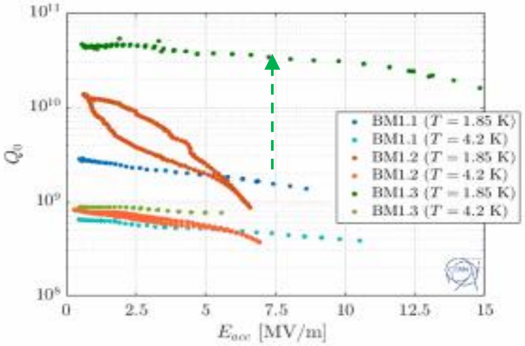


Advanced surface treatment

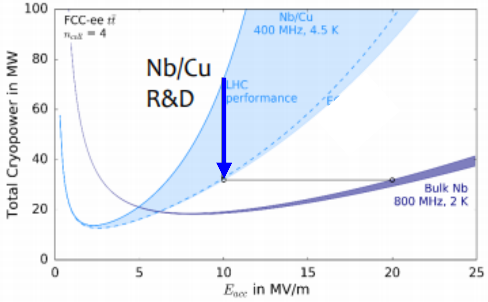
- New electro-polishing system for copper commission

High quality coatings:

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



S. Aull, FCC week 2017



Improved RF diagnostic/analysis capabilities

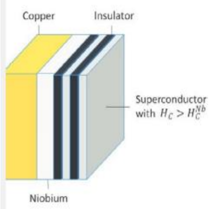
- Quadrupole resonator, RF, temperature mapping

M. Garlasche, S. Atieh, G. Rosaz, JF. Croteaux,P.Vidal-Garcia, F. Manke, L. Ferreira

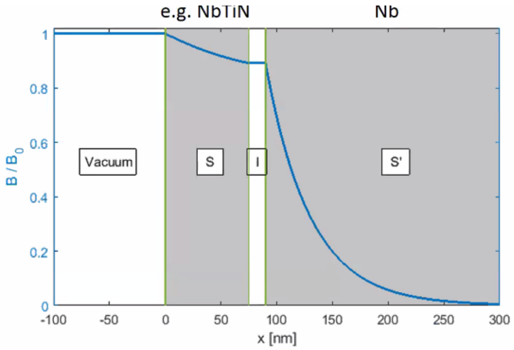
SRF application beyond Nb: SIS multilayers

Material choice

- NbN, NbTiN,..
- Dielectric choice: AlN, Al_2O_3



Higher T_c thin layers provide magnetic screening of the Nb SC cavity (bulk or thick film) without vortex penetration

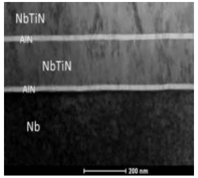


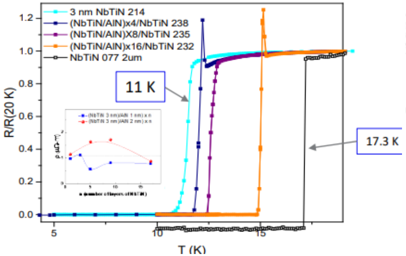
Possibility to move operation from 2K to 4.2K

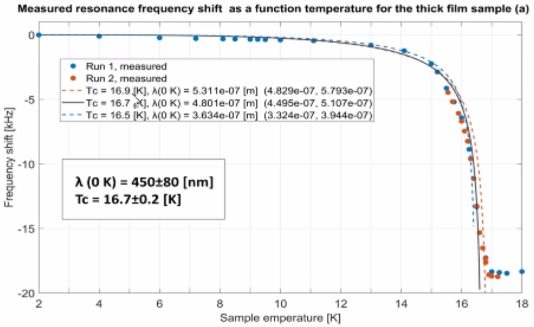
A.M. Valente
S. Keckert

Encouraging results:

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







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.