CERN plans for thin films R&D

W. Venturini Delsolaro, CERN
Contributions by F. Gerigk, F. Peauger,
V. Parma, G. Rosaz, D Smekens,
On behalf of CERN SRF Teams

TFSRF24 Workshop,
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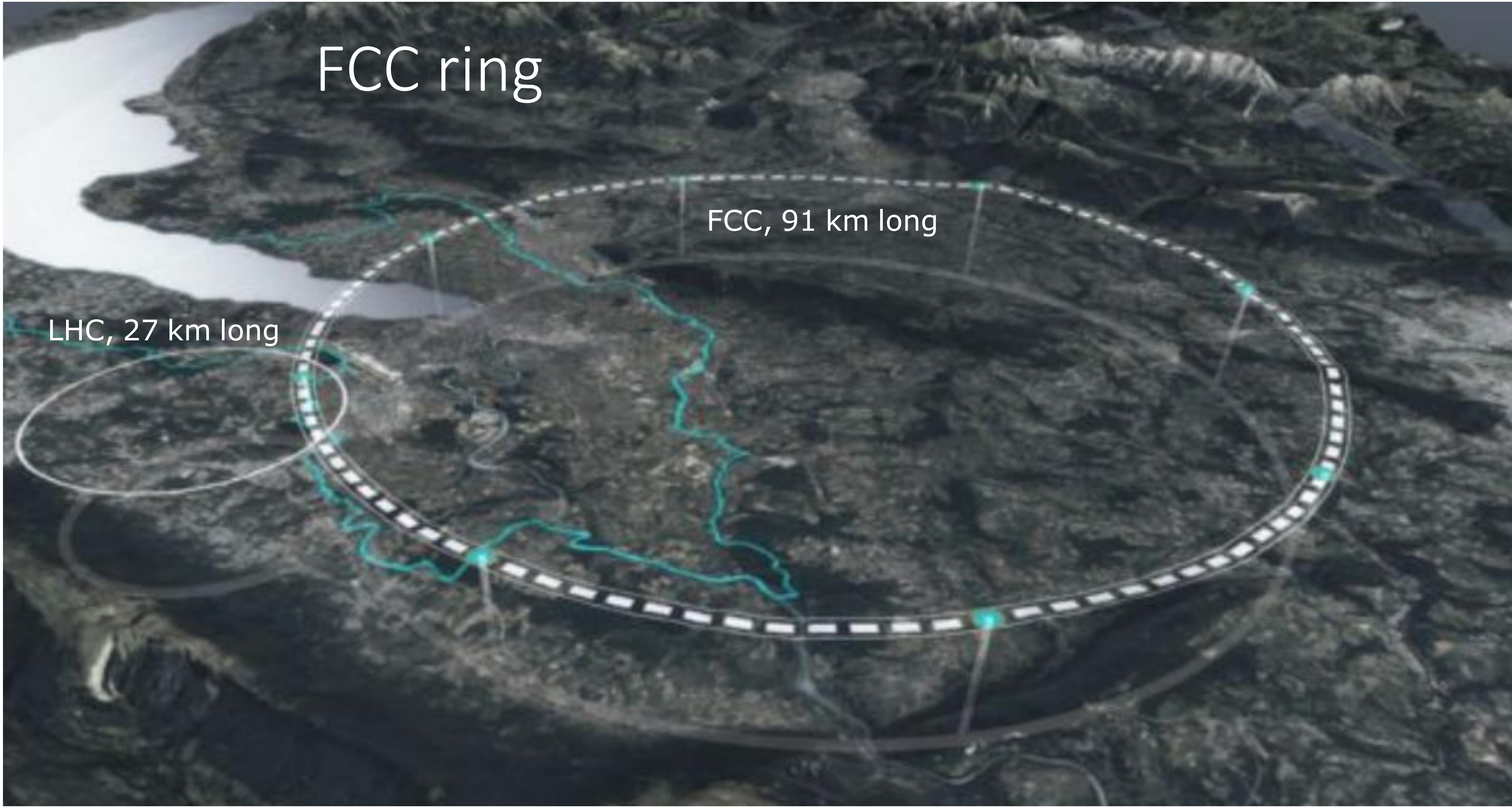
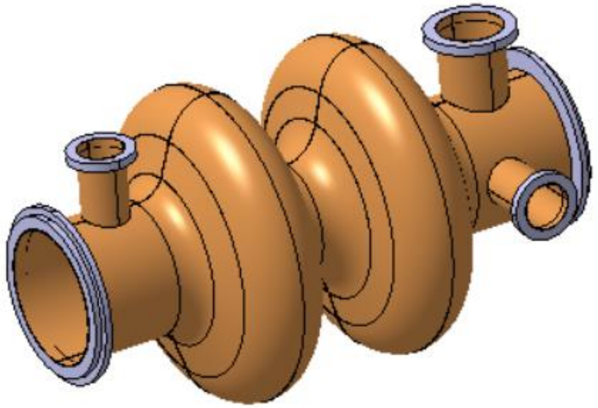
Overview

- Motivation
- FCC planning
- Required SRF performance for FCC-ee
- SRF Challenges
- R&D package towards FCC-ee: milestones & deliverables
- Summary


FCC ring
FCC, 91 km long
LHC, 27 km long

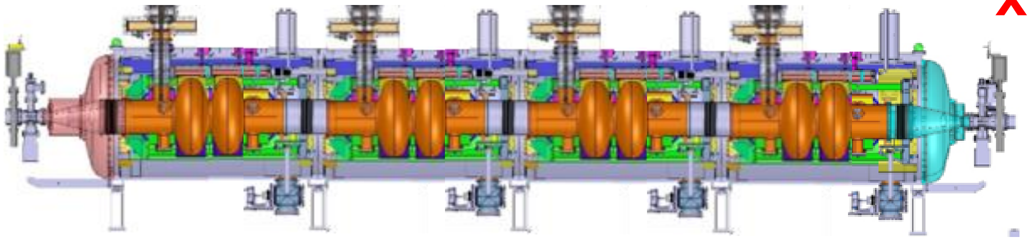
Two design of superconducting RF cavities

Z, W, H



X 264

400 MHz 2-cell cavity
Niobium thin film on Copper,
Operation at 4.5 Kelvin
Max. Accelerating gradient E_{acc} = 13 MV/m
Quality factor $Q_0 = 3.3 \times 10^9$



X 66

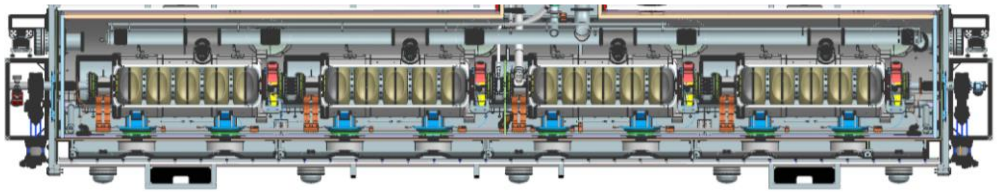
400 MHz cryomodule, ~12 m. long

ttb, booster

X 856 (=88+320+448)

800 MHz 6-cell cavity
Bulk Niobium
Operation at 2 Kelvin
Max. Accelerating gradient E_{acc} = 24.8 MV/m
Quality factor $Q_0 = 3.8 \times 10^{10}$

X 214 (=22+80+112)



800 MHz cryomodule, ~10 m. long

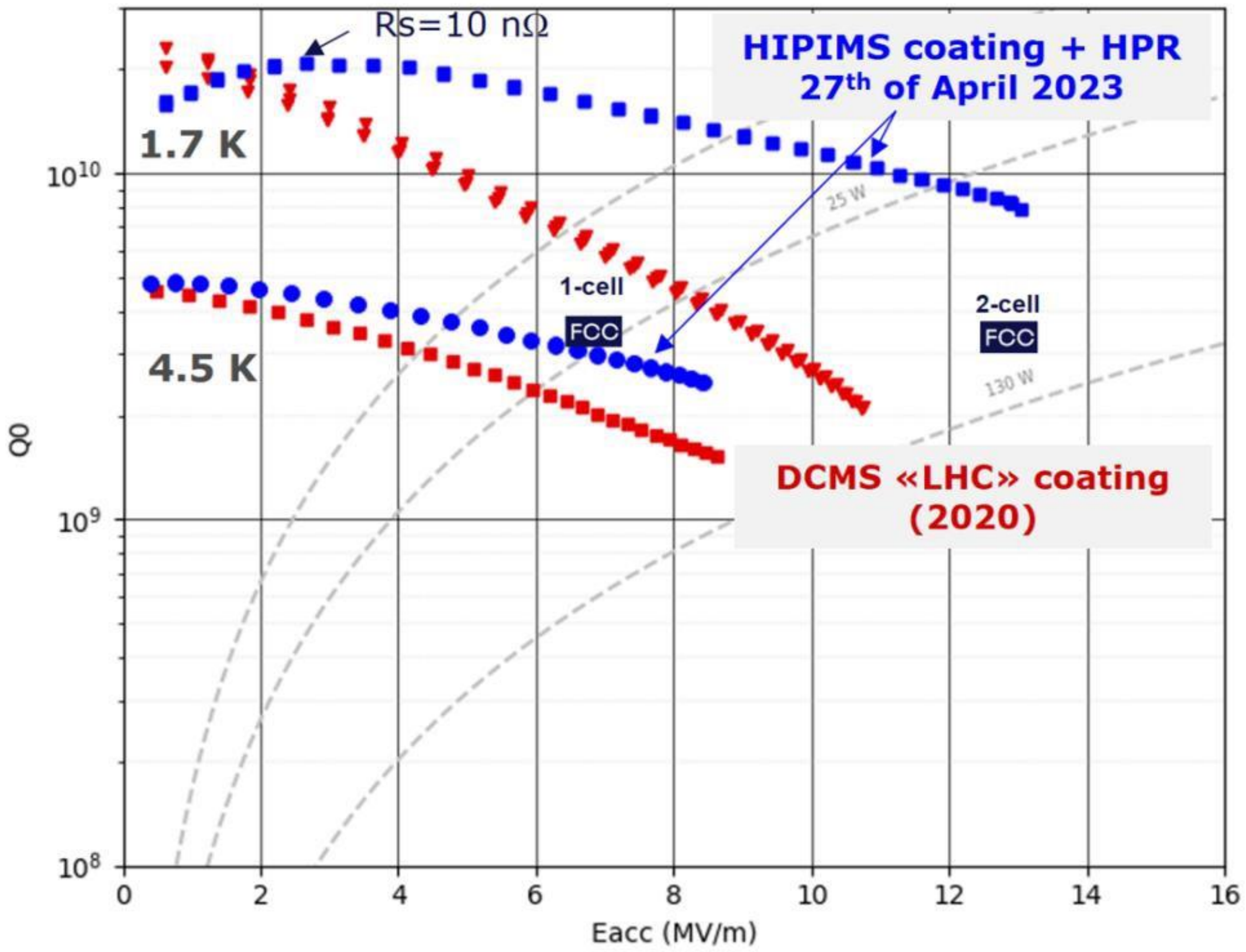
FCC machine specs (surface resistance and peak fields)

Quantity	Booster (800 MHz)	Z (400 MHz, 4K)	W(400 MHz, 4K)	H(400 MHz, 4K)	ttb (800 MHz, 2K)
Q_o	$3\ 10^{10}$	$2.7\ 10^9$	$2.7\ 10^9$	$2.7\ 10^9$	$3\ 10^{10}$
E_a(MV/m)	6.2→ 20.1	3.8	10.6	10.6	20.1
R_s (av n*Ω*)	9.1	89	87	87	9.1
B_{peak}(mT)	87.2	20.4	56.6	56.6	87.2
E_{peak}(MV/m)	41.2	8.4	21.2	21.2	41.2

NB: 4K and 2K are indicative

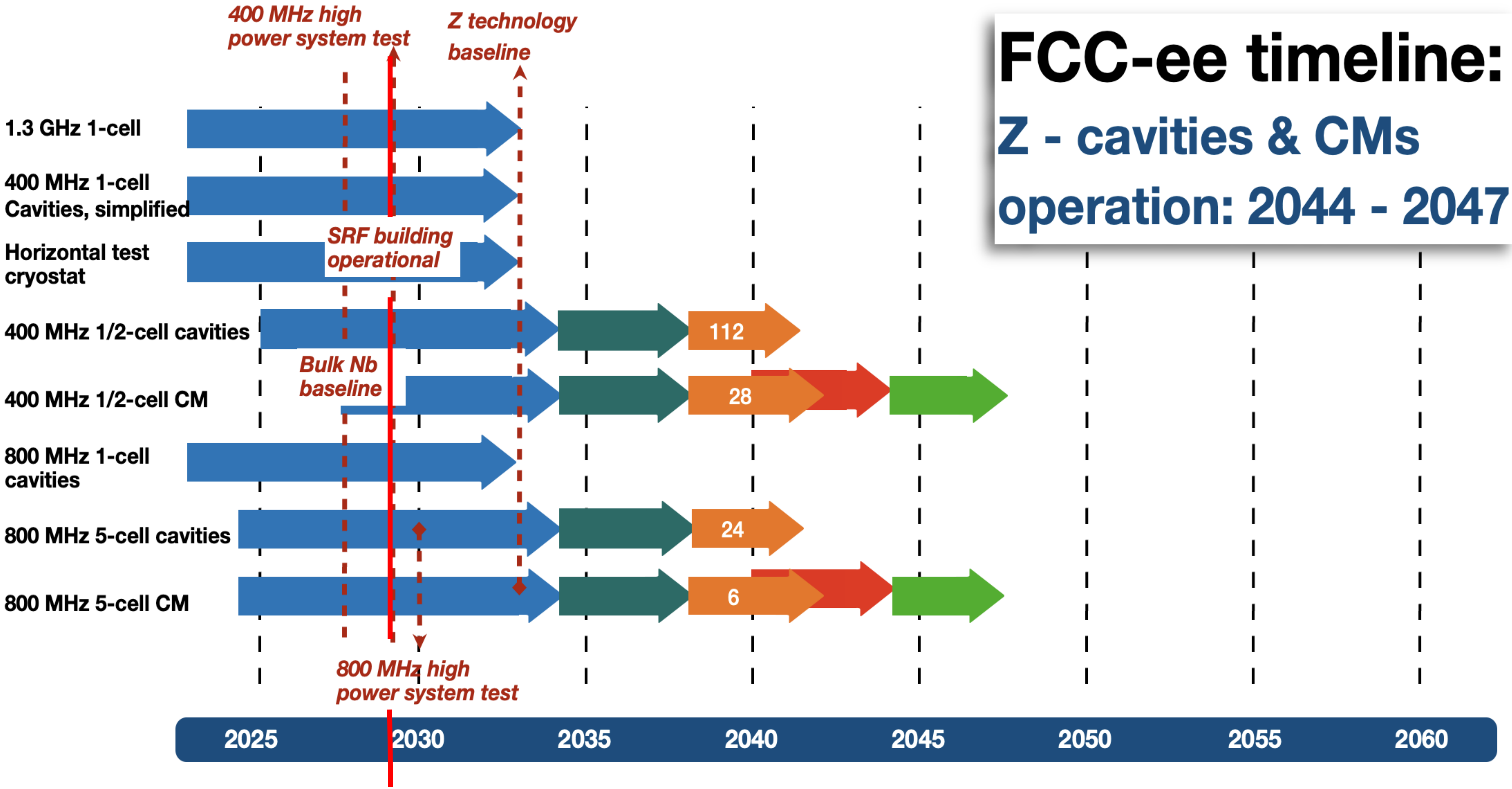
- Compared with state of the art for bulk Nb and Nb/Cu,
  - B_{peak} < 100 mT (no HFQS) in all cases (120 mT demonstrated in Nb/Cu)
  - E_{peak} is quite relaxed
- Fields are limited by RF power: we don't need ultra high fields (x 2 margin to state of the art), except maybe for the booster of the ttb
- But Rs is challenging
- Is 800 MHz with Nb/Cu a possibility? Harder but not so crazy seen the longer time scale
- Challenge staged in time for the collider, booster is pulsed (Q_o may be relaxed?)

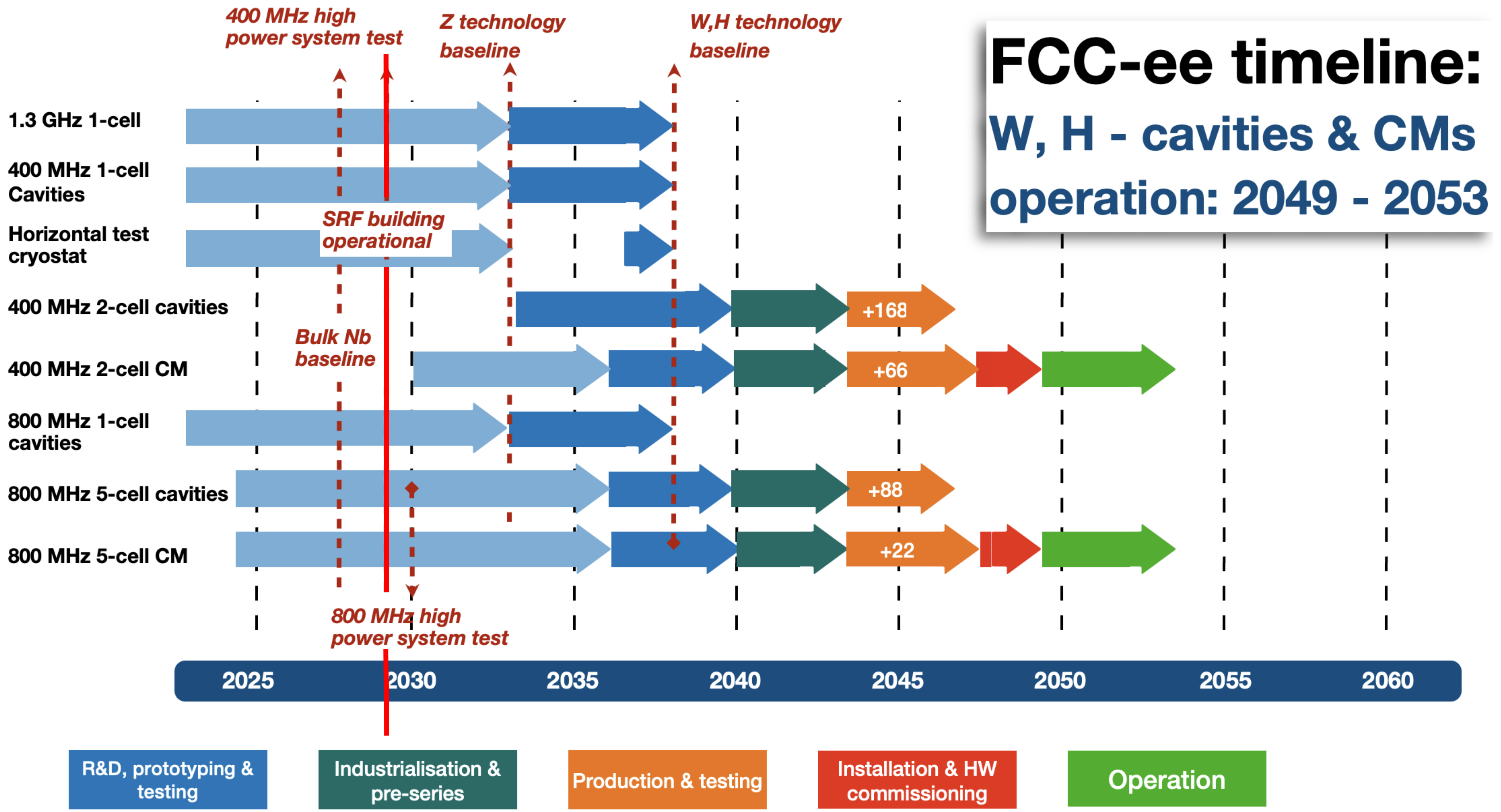
State of the art: 400 MHz



FCC-ee timeline:

Z - cavities & CMs operation: 2044 - 2047





FCC-ee timeline:
W, H - cavities & CMs
operation: 2049 - 2053
400 MHz high power system test
Z technology baseline
W,H technology baseline
1.3 GHz 1-cell
400 MHz 1-cell Cavities
Horizontal test cryostat
SRF building operational
400 MHz 2-cell cavities
+168
Bulk Nb baseline
400 MHz 2-cell CM
+66
800 MHz 1-cell cavities
800 MHz 5-cell cavities
+88
800 MHz 5-cell CM
+22
800 MHz high power system test
2025
2030
2035
2040
2045
2050
2055
2060
R&D, prototyping & testing
Industrialisation & pre-series
Production & testing
Installation & HW commissioning
Operation

Required performance gains in time for series production

Z (2033)

W, H (2038)

ttbar (2041)

400 MHz:
1.2xLHC gradient @ 35% -50% lower surface resistance:
6.6 MV/m @ Q=$2.7x10^9$

2xLHC gradient lower surface resistance

Collaborations with JLAB, INFN, KEK, ….

Collaborations with Cornell, FNAL, JLAB, IJCLAB, …

800 MHz:
6.5 MV/m @ Q=$3x10^{10}$ (2 K)

Bulk Nb

21 MV/m @ Q=$3x10^{10}$ (2 K)

Bulk Nb

Nb/Cu?

21 MV/m @ Q=$3x10^{10}$ (2 K)

Bulk Nb
Nb/Cu?
A15?

Challenges for CERN SRF teams

Maintain LHC ACS

Recover HIE ISOLDE full energy

Deliver crab systems for HL LHC

New SRF facility: optimise design, organise migration

Achieve FCC specs with Nb/Cu for all poles

Achieve FCC specs with Nb_3/Sn at 4 K

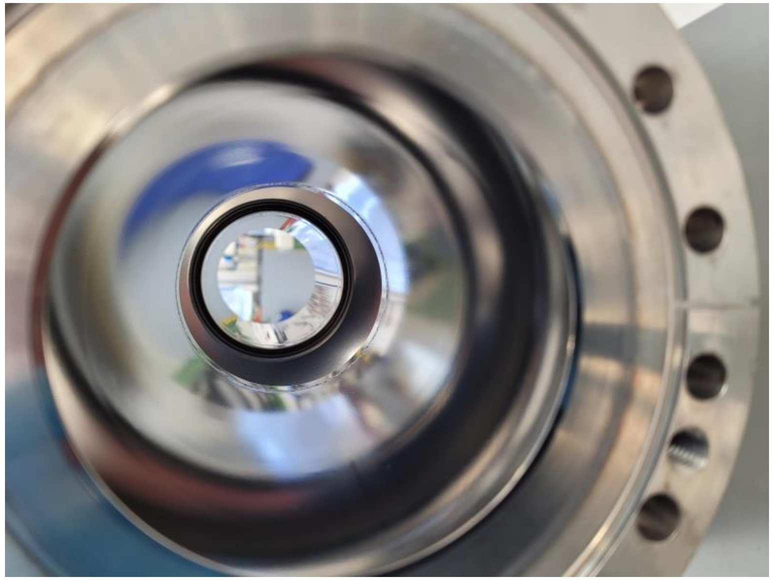
Technology transfer, enable industry for large scale production

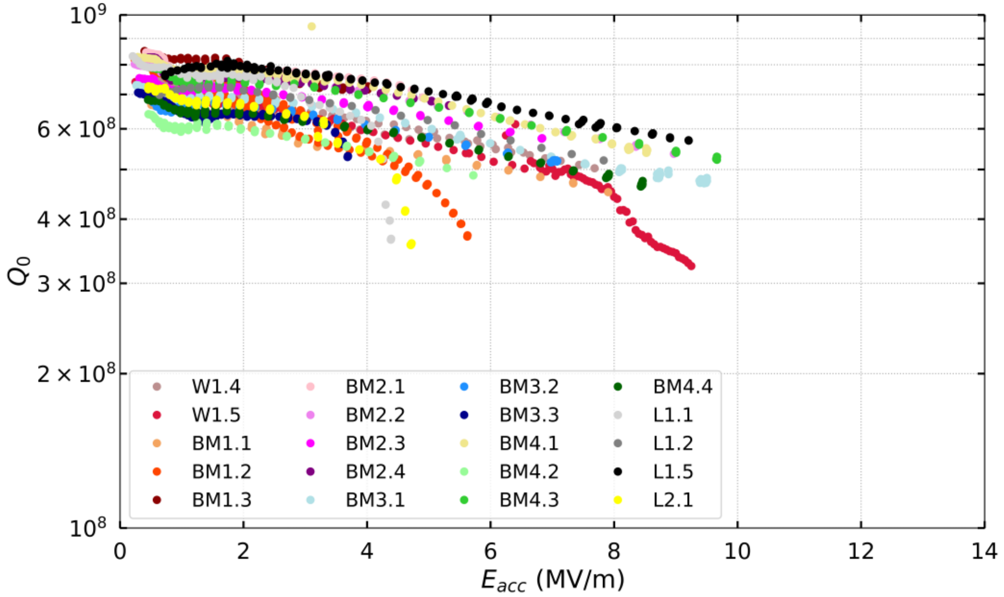
Develop and maintain a coherent set of collaborations with other labs

Our first challenge:
understand and control $R_s(H)$: Nb thin films

No predictive theory to date for the shape of $R_s(B)$

- Degree of "disorder" in thin films still higher than the most aggressive recipes for bulk Nb
- Anti Q slope was never observed in thin films, only LFQS
- "cleaner " films may enter in the anti Q slope regime?
- Role of hydrogen?
- Established role of thermal currents
- Thermal mapping → localized losses
  Optical inspection → features
- Substrate under control, some residual doubts on raw material
- The main problem is the erratic R_{res} (what are the hidden variables?)
- Nb/Cu BCS parameters well under control and reproducible, but "classical" MFQS





Nb_3Sn

See: G. Rosaz, this conference

- Nb_3Sn on copper would be game changer for next generation of CW accelerators. For FCC:
  - Operation at 4 K saves capital cost
  - 3 10^{10} at 2 K corresponds to 7.5 10^{9} at 4 K in plug power: we don't need to equate bulk Nb at 2 K
  - In a second stage, potential to drastically reduce plug power
- Good progress with flat samples, huge challenge: scale the process to a real cavity!
- Decision to focus on 800 MHz
  - Issues: high temperature (700°C) coating system avoiding cavity collapse, multiple cathodes, etc
  - Start from the mechanical design of the cavity
  - Tuning system (FRT?)
  - Conduction cooling for 4.5 K operation?

Technology transfer to industry

A necessity for a large scale production, it must be prepared well in advance

Can we start with a survey of potential actors?

Can KT be involved at this stage?

Market survey for Nb and Cu raw material, how frequently updated?

Only two companies offer Nb cavities?

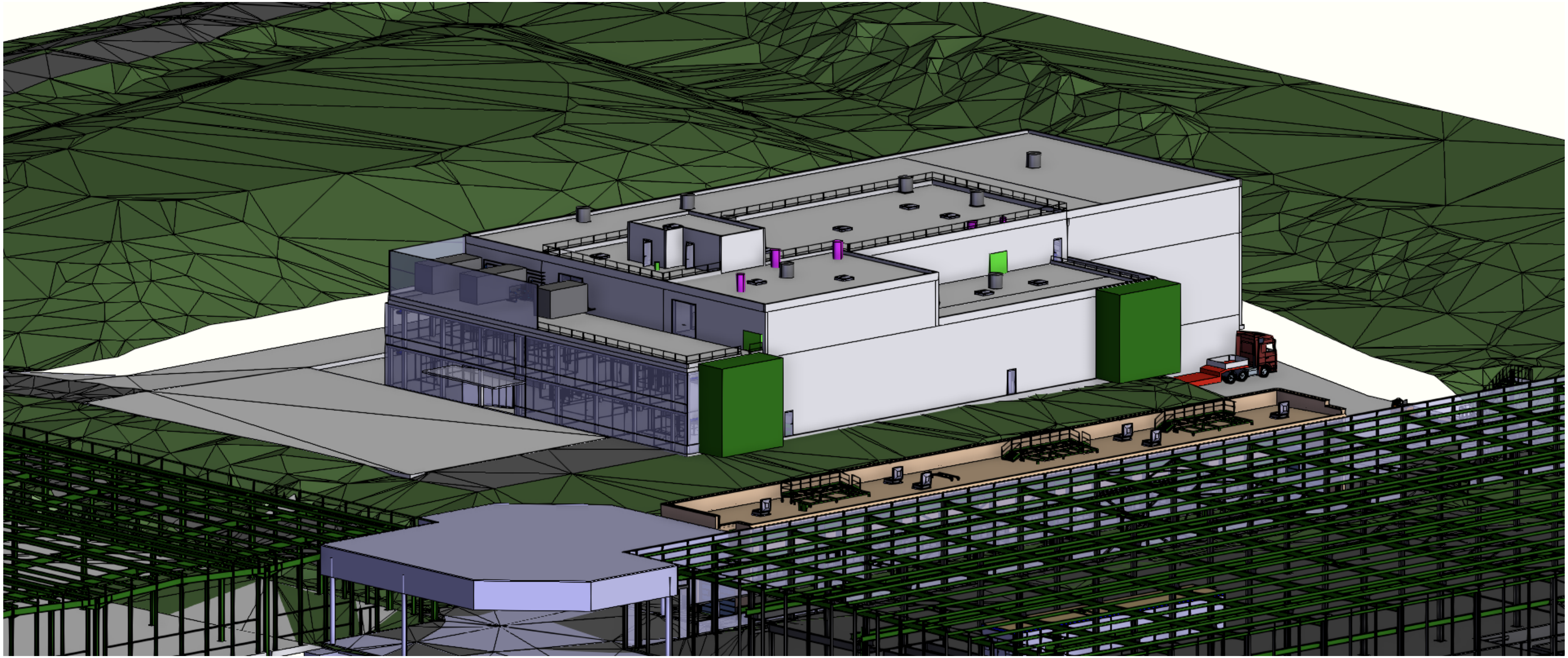
Copper cavity production can be stimulated with some small pilot projects

Integrating more steps of the Nb/Cu process seems more difficult, but it was done at the time of LEP

SA18 goal: establish reproducible recipes

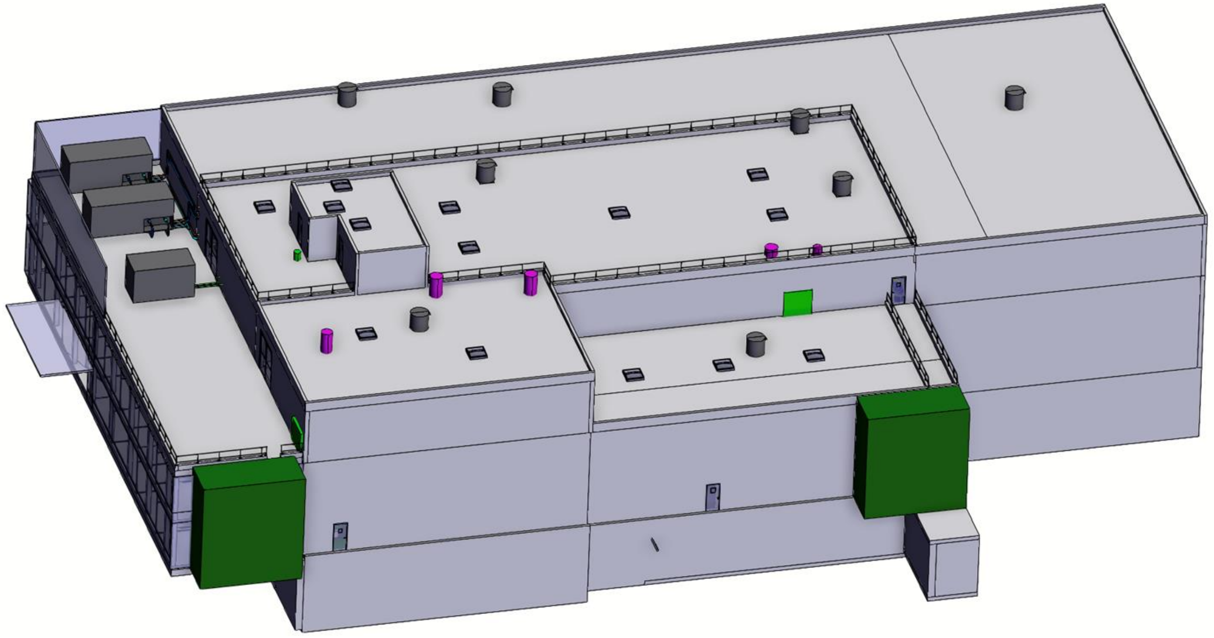
Is a reproducible recipe and a potential for order a large quantity the only possibility to start contacts with industry?

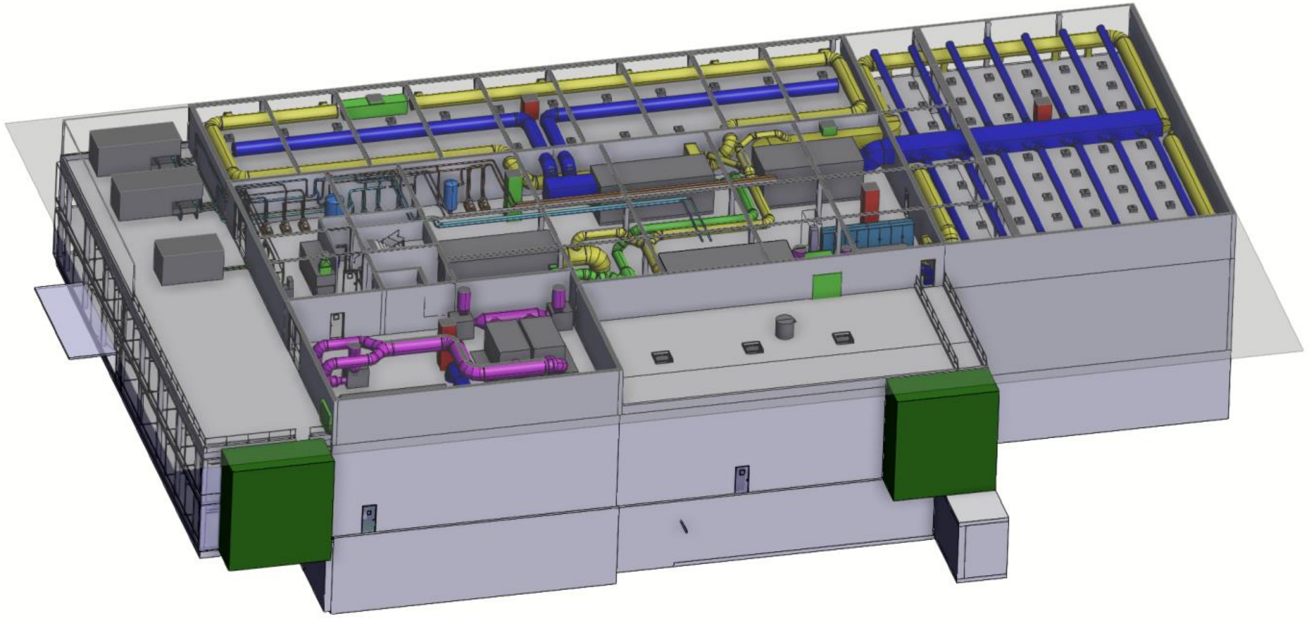
The New SRF Facility: a hub for SRF thin films R&D



Project Schedule

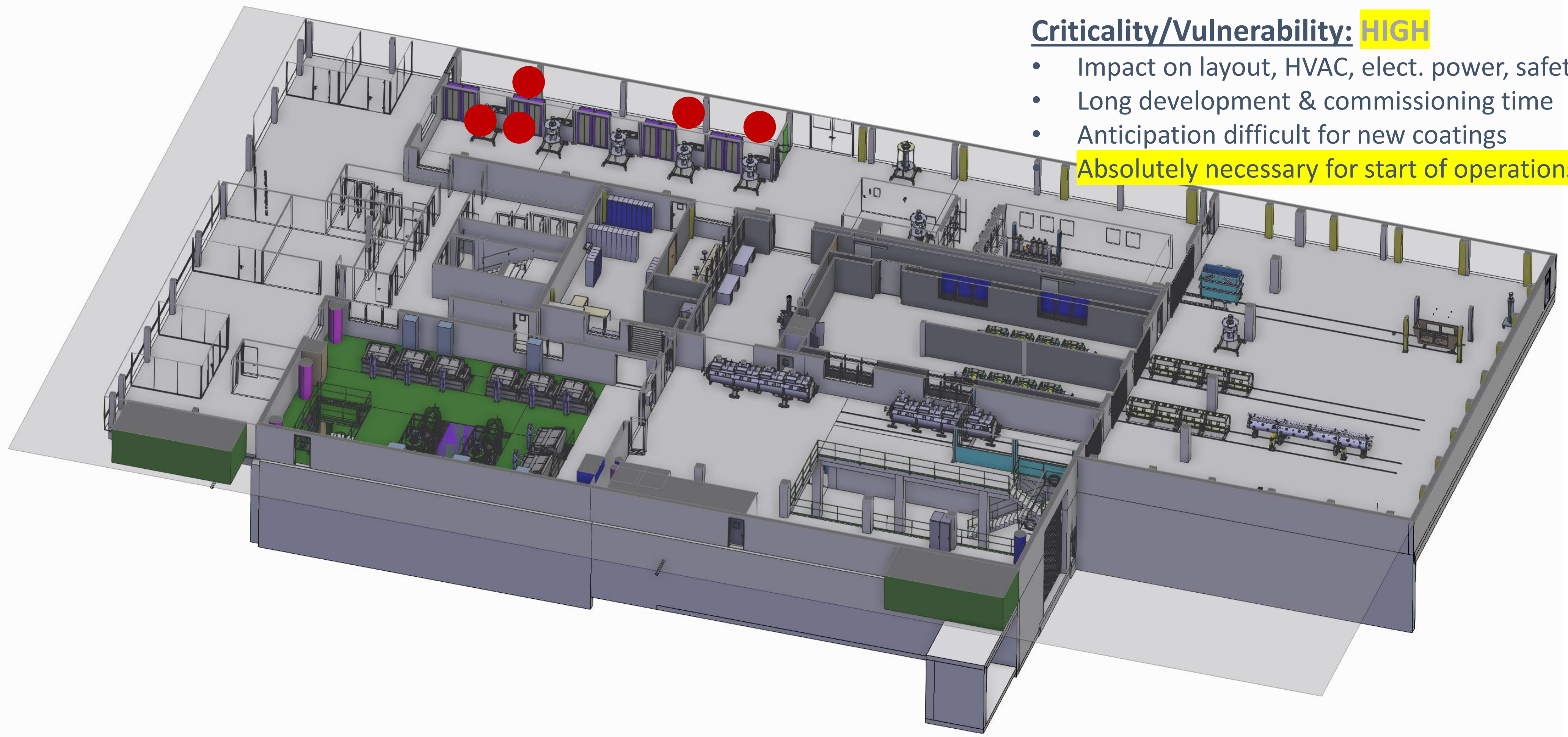
- New facility will be delivered in Q3-2028
- At that stage it will be equipped with:
- A 2MVA main supply
- A 500 kW CV plant to provide:
  - ventilation for the cleanrooms and surface treatment workshop
  - fume extraction and scrubbers for the chemical processes
  - production of chilled water
- All cleanrooms and cleanroom cranes
- Process not yet installed:
  - Electro / chemical polishing stations
  - High pressure rinsing systems
  - Sputtering stations, vacuum oven
  - Waste water treatment plant





Thin film coating systems

- Still some work to do on the future coating systems:
  - Existing sputtering systems need to be re-designed a.s.a.p. (+ addressing the pros & cons of a mobile cathode system)
  - A15 coating station needs to be addressed urgently to study possible integration
  - Use case of a vacuum oven needs to be identified (processes for bulk Nb, Nb sputtering, A15 coating, ALD require different ovens)

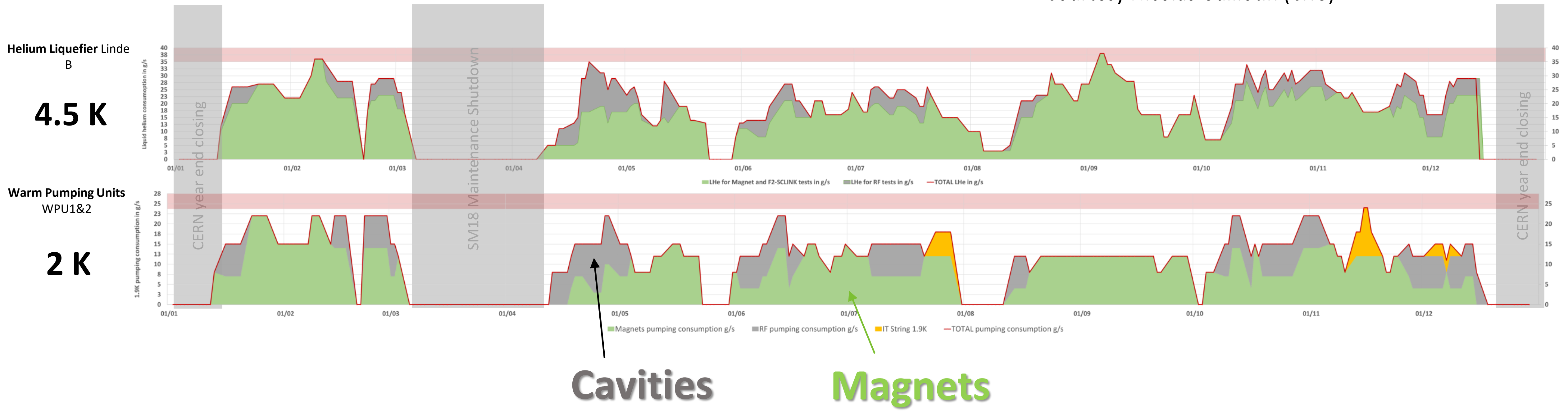


Criticality/Vulnerability: HIGH

- Impact on layout, HVAC, elect. power, safety
- Long development & commissioning time
- Anticipation difficult for new coatings
- Absolutely necessary for start of operations

SM18 Cryogenic capabilities – situation in 2023

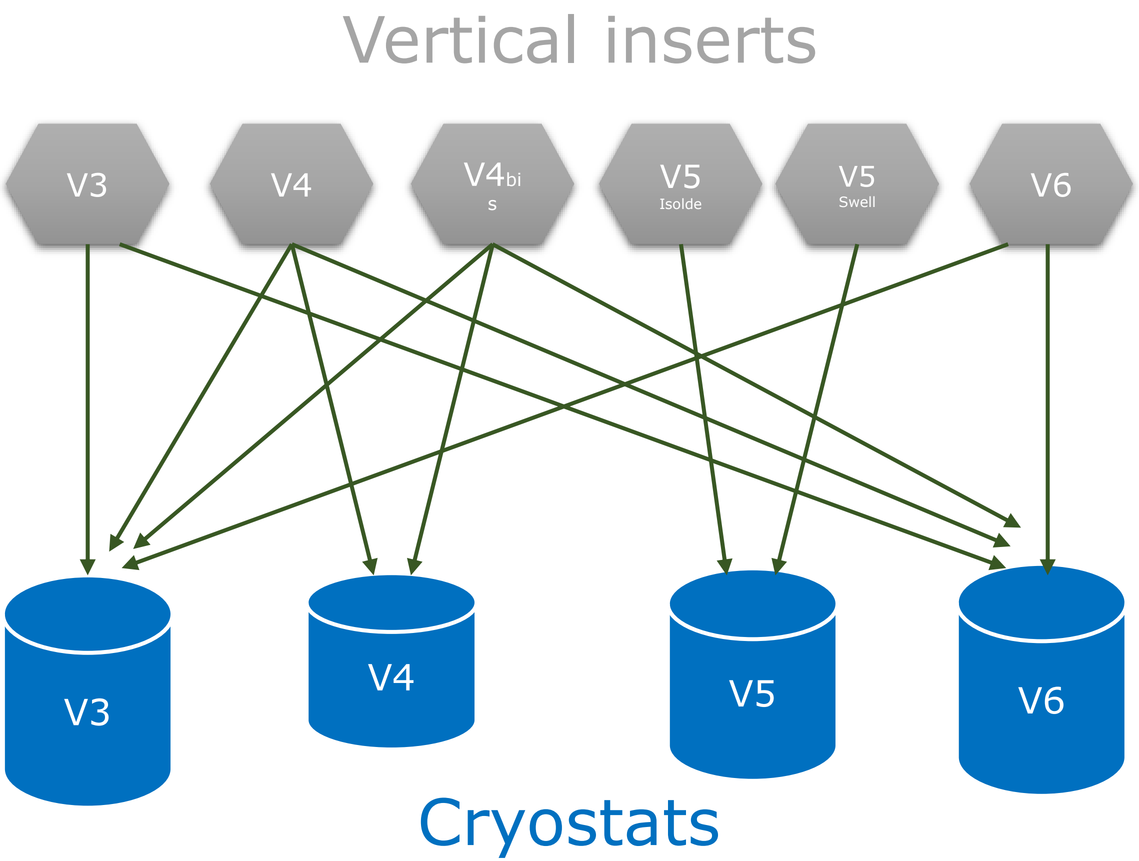
Courtesy Nicolas Guillotin (CRG)



How can we optimize the cryogenic consumption and benefit from available helium in transitory periods ?

Upgrades of RF cold testing facility

V3 / V6 insert with RFD crab bare cavity



$\Rightarrow$ This will allow to have a stock of prepared cavities “ready to be tested”

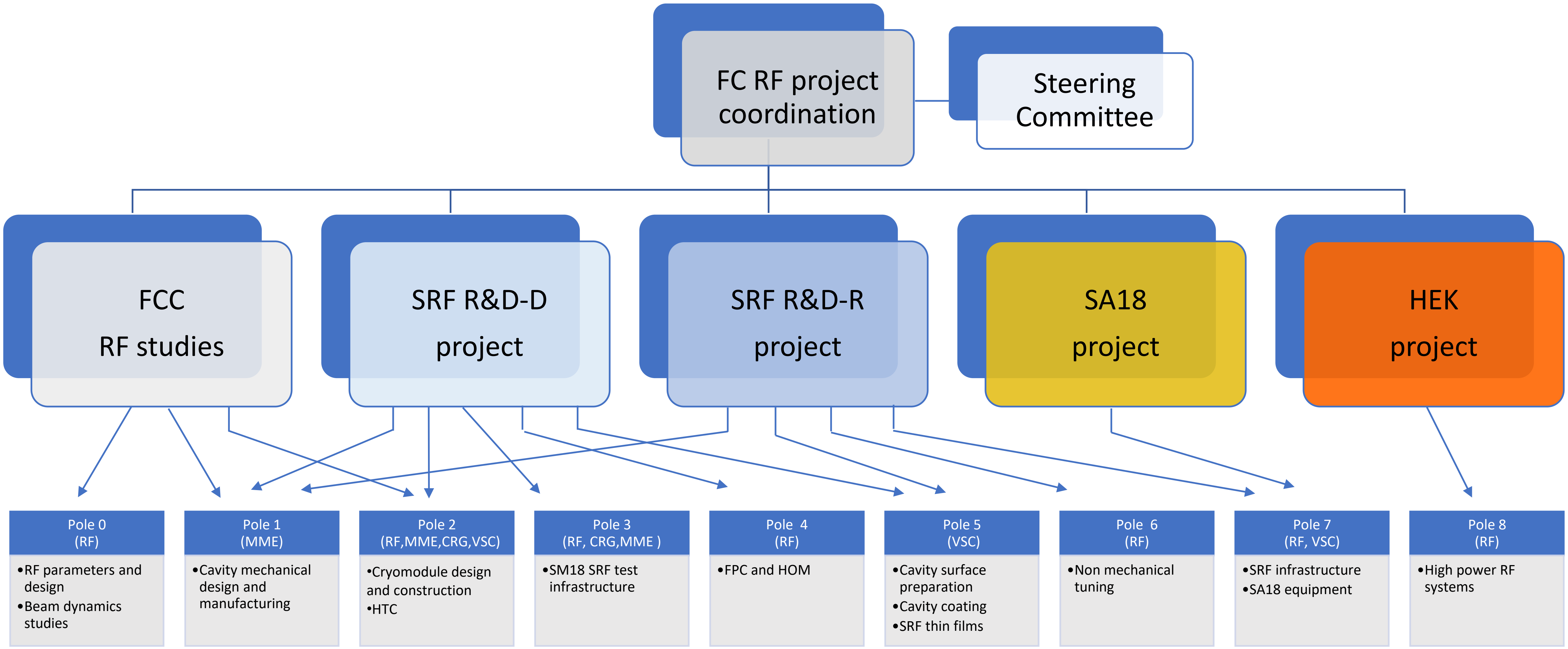
New V4bis insert and preparation area

MTP bid for a dedicated resourse package for (S)RF R&D

- Today resources and infrastructure are booked to keep existing machines running and to secure HL-LHC deliverables
- Additional resources are needed to speed up R/D, and to build hardware (FCC prototypes)
- Proposal prepared at end of 2023 (25 MCHF + 22 new staff)
- Management approved, albeit with 20% cut and smearing over more years
- First posts openings in 2025, in RF, Vacuum, mechanical engineering, cryogenics

Count of Sta	Column			
Row Labe	**2025**	**2026**	**2027**	**Grand Total**
EN	1	2	2	5
SY	2	2	4	8
TE	1	1	2	4
Grand Total	**4**	**5**	**8**	**17**

- New structure and governance being implemented



FC RF project coordination and steering committee (GL team), sets goals, defines priorities, monitors progress, reports to ATS
Projects manage budgets and follow up activities
Each project/study keeps its internal WBS: this is the list of deliverables, activity plan, spending profile, etc
Poles are centres of activity according to different subjects
One link person per participating Group in each pole, participates to enlarged coordination meetings (few/year)
Project meetings on focused, technical topics, with attendance depending on agenda

New SRF-R&D-D project

- Focused on the Development of prototypes (demostrators)
- Not direclty linked to FCC, but under the umbrella of Future Colliders
- WBS and milestones being elaborated

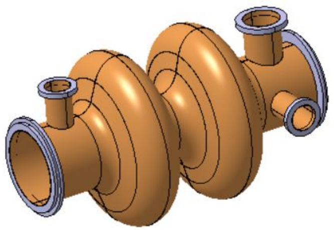
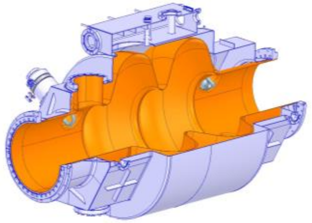
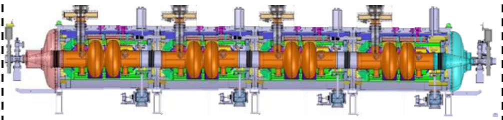
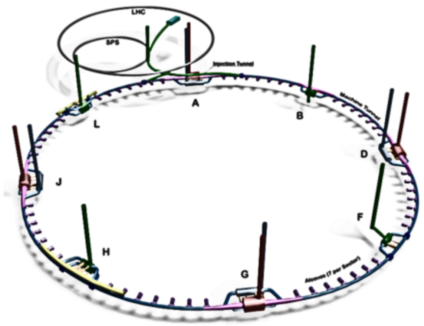
Task/milestone	2024	2025	2026	2027	2028	2029	2030	2031	2032
SA18 facility operational									
HTC operational in SM18 (TBD)									
400 MHz CM Demo (2-cell) ready for testing (TBD)									
Horizontal Test Cryostat (HTC) in M9	Design	Construction	inst.+test						
400 MHz CM Demo (2-cell)									
Cryomodule Design	Conceptual Design		Detailed Design						
Cryomodule manufacture					Construction				
Assembly (in SA18)							Assembly		
2-cell cavities (x4) tested									
RF design									
Mech. Design									
Manufacture									
Coating									
Bare vertical testing									
FPC (x4) & HOMs (x12) tested									
RF design									
Mech. Design									
Manufacture									
Conditioning & warm testing									
Helium tanks/tuning system (x4) ready									
Mech. Design									
Manufacture									
Dressed cavities/FPC/HOM assemblies (x4) ready									
Assembly									
Vertical testing of dressed cavity with HOMs									
HTC testing with FPC and tuning system									

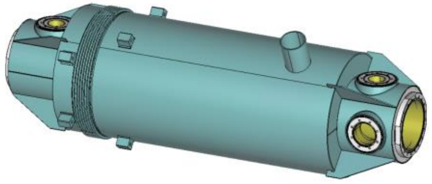
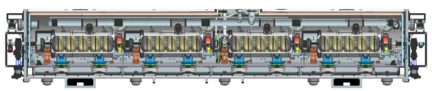
Summary: CERN strategy for SRF thin films

- Ramping up respources and infrastructure for SRF
- Pursue fundamental R&D on Nb/Cu with 1.3 GHz program (see K. Brunner, this confernece)
  - Low field BCS parameters optimized and reproducible
  - Tackling erratic R_{res}
  - Control T gradient at T_c, stabilize cool down protocol
  - This will allow investigate what hides behind (at least one second hidden var)
  - Develop technology for mass scale production of copper substrates
  - Potential spin off: Nb/Cu at 800 MHz
- Immediate focus on Nb/Cu 400 MHz to reach FCC specs
  - Finalise surface preparatiion method (EP is baseline)
  - Improve cleanliness chain (especially surface prep before coating)→ New SRF building
  - Dedicated cold test cryostat, mutuate cooling protocol from 1.3 GHz
- New SRF R&D D project to deliver key facilities (HTC) and cryomodule demonstrators
- In parallel, develop Nb_3Sn/Cu at 800 MHz as longer term, further step
- We are open and actively pursuing collaborations with other labs on **these** topics

SPARE SLIDES

22-Aug-24	Bare cavity in vertical test		Equipped cavity (with HOM couplers) in vertical test		Cryomodule (with FPC) in horizontal test		Operation in the machine	
	Eacc (MV/m)	**Q0**	**Eacc (MV/m)**	**Q0**	**Eacc (MV/m)**	**Q0**	**Eacc (MV/m)**	**Q0**
2-cell 400 MHz	**13.0**	**3.3E+09**	**12.4**	**3.15E+09**	**11.8**	**3.0E+09**	**10.6**	**2.7E+09**
6-cell 800 MHz	**24.8**	**3.8E+10**	**23.6**	**3.65E+10**	**22.5**	**3.5E+10**	**20.25**	**3.0E+10**

+5%

+5%

-10%