The RF Coordination Panel

for the ESPP Accelerator R&D

P. McIntosh (STFC), G. Bisoffi (INFN) and I. Syratchev
for the LDG RF Coordination Panel

115th Plenary ECFA Meeting, CERN November 14-15.

Scope: Implementation of an approved R&D strategy

ESPP Accelerator R&D Roadmap. March 2022

- High Field Magnets
- High Gradient RF Structures and Systems
- High Gradient Plasma and Laser Accelerators
- Bright Muon Beams and Muon Colliders
- Energy Recovery Linacs
- R&D Programmes Oriented to Future Facilities
- Sustainability

RF items by: S. Bousson (IJCLab), H. Weise (DESY). G. Burt (ULAN); G. Devanz, T. Proslier (CEA); A. Gallo (INFN); F. Gerigk, A. Grudiev (CERN); D. Longuevergne (IJCLab); R. Ruber (Uppsala), + experts

- ✓ Superconducting RF: bulk niobium cavities, surface preparation, thin films
- ✓ NC structures: fundamental limitations, surface preparation, manufacturing techniques
- ✓ High power RF sources, accelerating structures ancillaries (couplers, tuners…), LLRF and AI

November 2022: RF Coordination Panel nominated, to follow the concrete implementation of the roadmap recommendations”:

FROM:

- ✓ **What** R&D needs to be done, priorities, time/resources, dependencies among activities, scope of demonstrators and intermediate outputs, what is applicable outside the PP scopes

TO:

- ✓ **Coordinate the plan of R&D for HEP accelerator** across national institutes and CERN, *albeit not prescriptive on actions or investments for countries, laboratories, or institutes*
- ✓ **Its implementation** must serve the anticipated update of ESPP on benefits, challenges, feasibility, risk and costs (construction, operation, environment) of each new development, with top priorities to make needed **technology jumps**.

The RF Coordination Panel (RFCP)

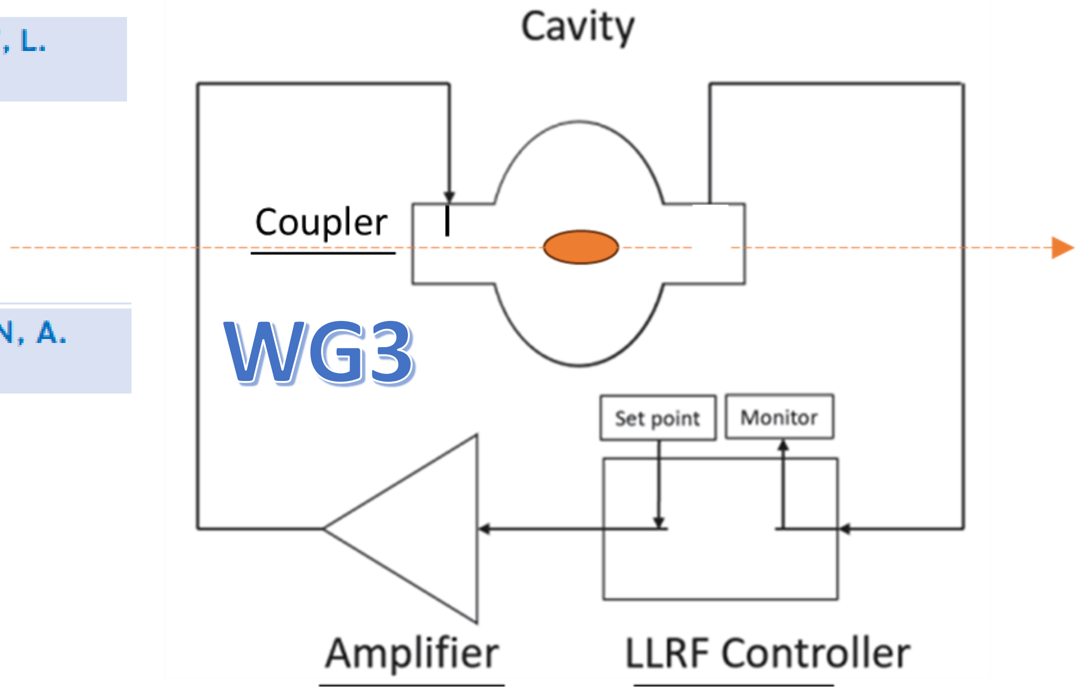
RF Panel coordination	G. Bisoffi INFN-I, P. McIntosh STFC-UK

WG2 C. Antoine CEA-F, O. Malyshev STFC-UK

WG1 M. Baylac CNRS-F, C. Madec CEA-F, L. Monaco INFN-I

SC-Bulk Nb | SC- Thin Film | NC- High gradient

WG4 W. Wünsch CERN, D. Alesini INFN-I



WG3 F. Gerick CERN, E. Montesinos CERN, A. Neumann HZB-D

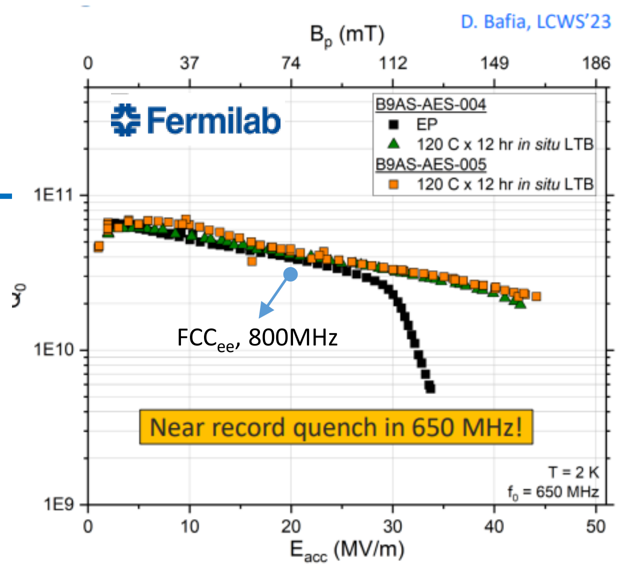
- Efficiency
- Sustainability
- Cost
- Industrialization
- Operation

RFCP is not funded and has no <u>direct</u> coordination responsibility – we drive RF HEP priorities through LDG for Europe!

WG5 I. Syratchev CERN, G. Burt STFC-UK, M. Jensen ESS-S

WG6 Z. Geng PSI-CH, W. Cichalewski U-Lodz-P

WG1: Bulk Niobium



GOALS

1. Further increase Q and E_{acc}
2. Improve reproducibility of high-E_{acc} fields
3. Reduce the cost
4. Reduce risk of losing manufacturing capability?

WHO

CEA, CNRS-IJCLab, CERN, DESY, Uni-Hamburg, HZB, ESS, INFN-LASA, INFN-LNL, STFC

PR. REPORT

- Studies on MG and LG Nb; Eddy Current Scanning;
- FE mitigation R&D with novel infrastructures for CM assembly (candidate: ESS),
- Novel infrastructure for cobotization;
- Novel infrastructure for in-situ plasma processing (candidate: CEA)
- Additional ovens for cavity treatments (high temperature, candidate: CEA; single cell, candidate: INFN-LASA)
- Strategy to keep cavity-manufacturing capabilities in the labs

work in progress

ESPP Acc R&D **fresh funding** from **INFN**, on bulk-Nb preparation recipe; **CEA**: **budget request submitted**, for additional funding; **CERN**: collaborating with FNAL on 800 MHz developments (FCC $_{ee}$)

WG2: Thin-films

GOALS

High Q_0 @ 4.2K; higher E_{acc} (Nb/Cu, Cu base surface preparation; coating techniques; novel materials; Nb_3Sn, multilayers; AM; …)

WHO

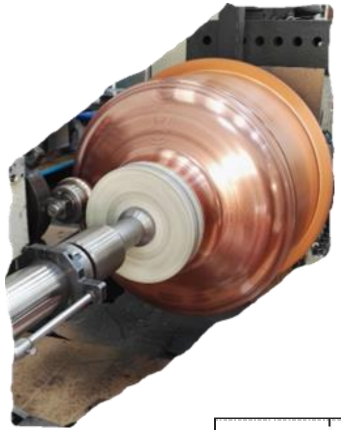
CEA, CERN, DESY, Hamburg U, HZB, HZDR, INFN, IEE, Riga Technical U, STFC/CI and USI, (I.FAST-WP9) Jlab, MEPHI, PTI Minsk, …

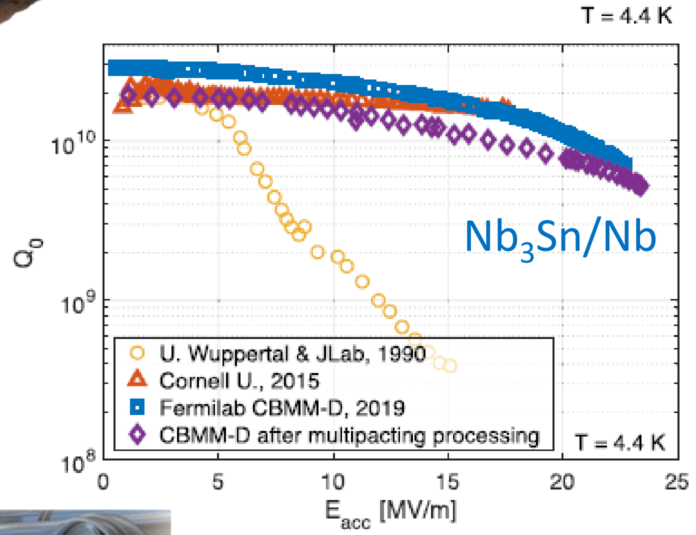
PR. REPORT

- Identify specific initiatives, which might be appealing for FCC (in pilot labs, to be identified, plus collaborators)
- Converge on joint proposals of infrastructures, on specific sites but that may be used by many? (in reference labs, e.g INFN-LASA, …)
- Evolve from EuCard-2, ARIES and IFAST, to Identify priority actions for I.FAST2 (from all existing partners)

work in progress

ESPP Acc R&D **fresh funding** from **INFN**, on Nb3Sn/Cu cavities;
CERN: **investing on R&D** for Nb_3Sn/Cu, Nb/Cu, Nb_3Sn/Nb, multilayers, … for 400 MHz (FCCee);
Room for R&D until 2040-2045 (tt-bar phase) at 800MHz.



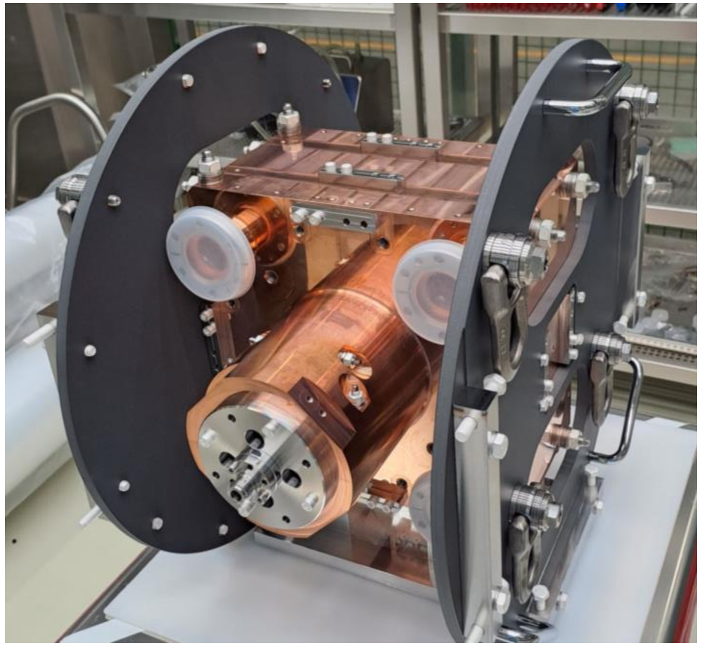


TFSRF24 – 16 – 20 Sept, Université Paris-Saclay.

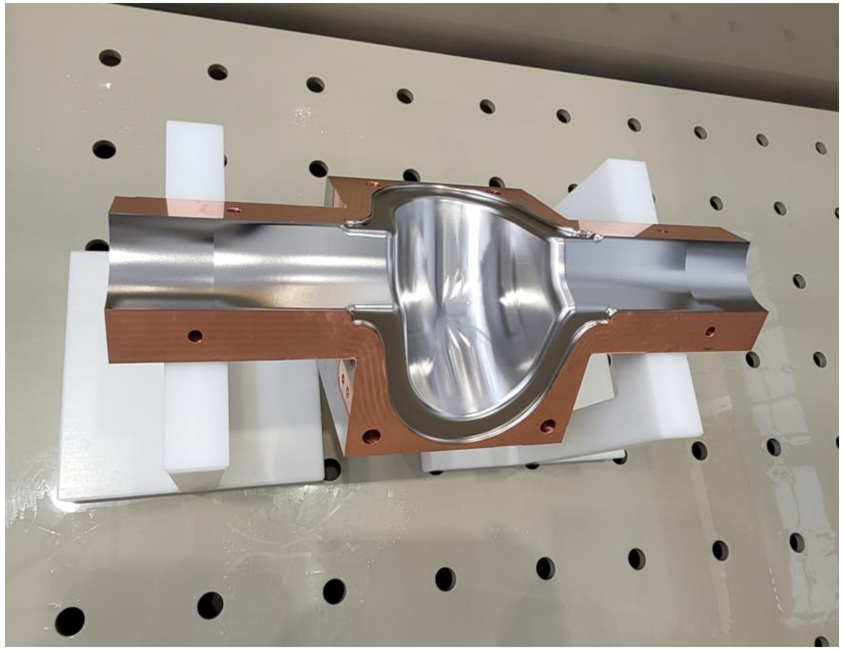
WG2: Thin-films

Slotted **W**aveguide **ELL**iptical (SWELL) cavity - a new SRF cavity concept (FCC_{ee} , EIC…).

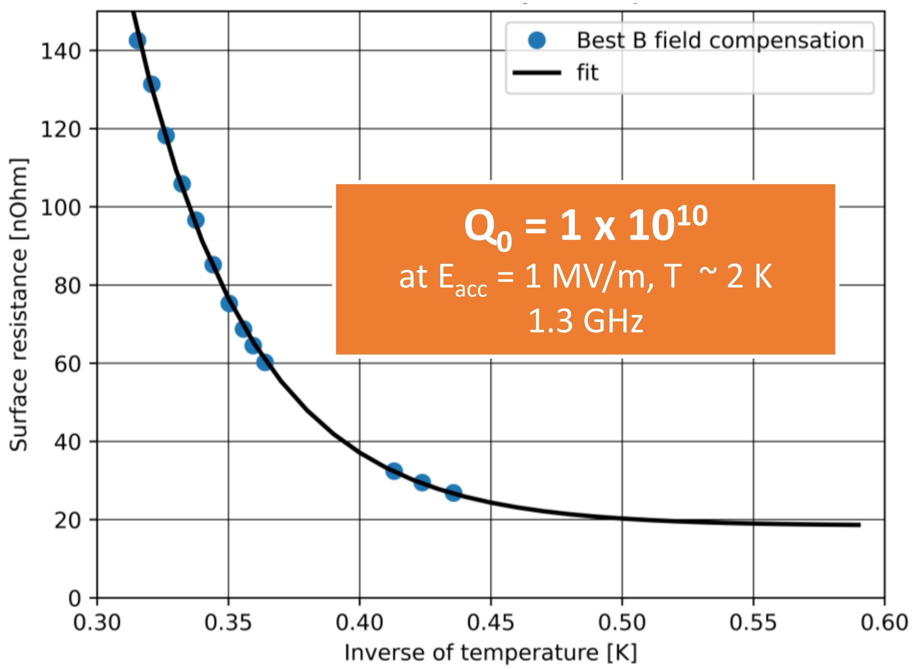
- Powerful approach for high current machines where strong HOM damping is naturally implemented.
- Easy access to the SRF surface for better quality control and processing.
- Niobium (or else?) coating is facilitated thanks to a planar configuration.
- Cryogenic cooldown with reduced volume of liquid helium.



Assembled 1.3 GHz SWELL cavity

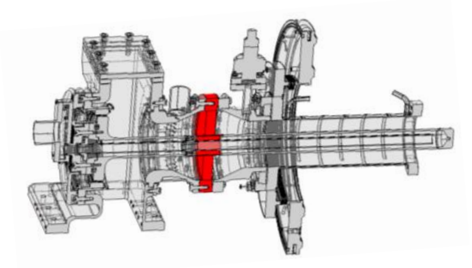


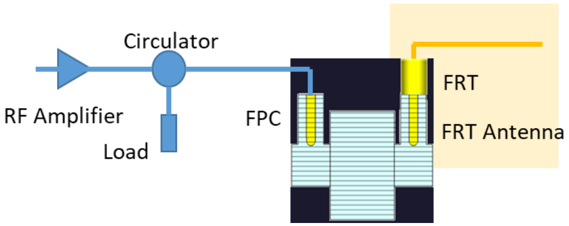
SWELL's individual quadrant

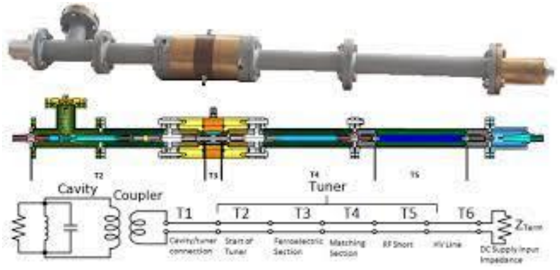


Measured residual resistance is below 20 nΩ

WG3: Fundamental Power Couplers (FPC) and HOM







[GOALS]

FPC couplers - transmitting hundreds of kW (W's in the cold mass) reliably through thin ceramic windows (diameter ~ 5÷ 50 cm) into SRF cavities; **HOMs couplers**: R&D on 800, 1300 MHz multicell; ~ kW RF power out of the cold mass

[WHO]

IJCLab/CNRS-Paris Saclay University, DESY, HZB, CERN

[PR. REPORT]

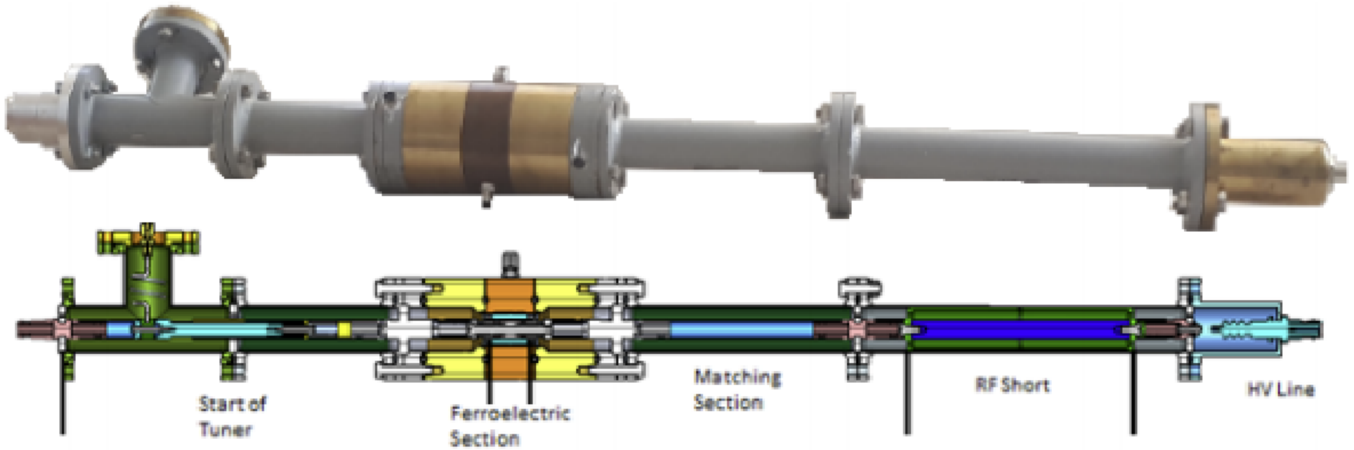
Identify interest for **FCC**, where contributions from other labs or industries can be made to converge (CERN + other labs)
EIC developments: maybe proposal from CERN + other labs, industry…
Any program for investigating on **ceramic windows**, with several institutes involved, to obtain more funding (within or outside an I.FAST2 framework, identify actors)?

[work in progress]

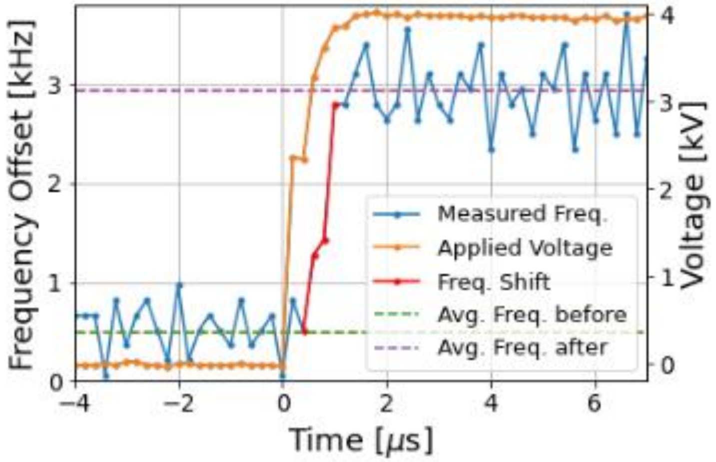
On **FPC**: **CERN** collaboration searched at **PIP2, LCLS-II, iSAS** (but much lower power), INFN and CERN on RF **windows** (lobbying phase)
On **FRT** (compensates u-phonics and transient detuning): **CERN** contacts with **Lancaster, STFC** (their FEL applications), Jlab – iSAS European program kicked off

WG3: Fundamental Power Couplers (FPC) and HOM

Ferro-Electric FAST Reactive Tuner (FRT) for SRF cavities

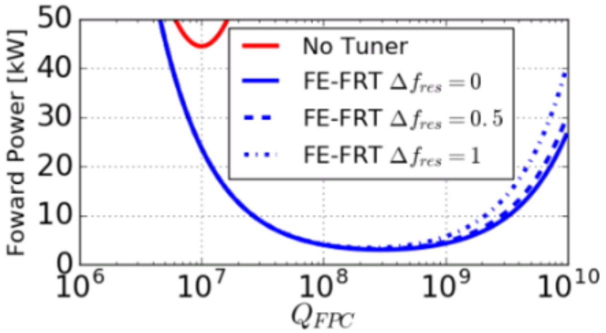


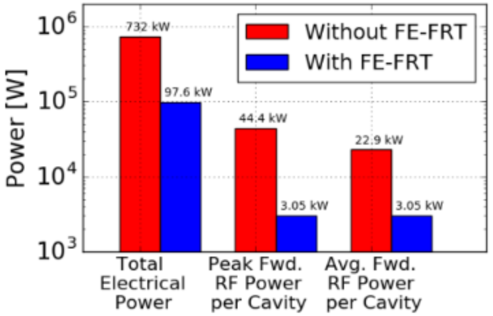
Cavity + FRT time response



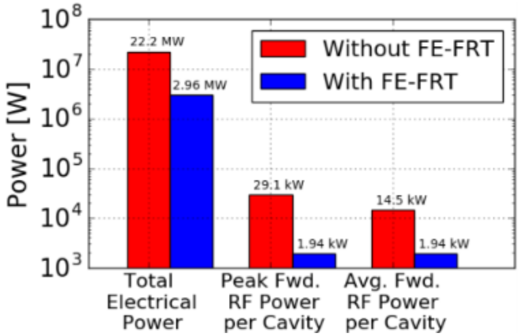
- FRT enables microphonics suppression for low current machines and transient detuning for high current machines. Thus, average RF power consumption could be reduced significantly.

PERLE case study





LHeC case study



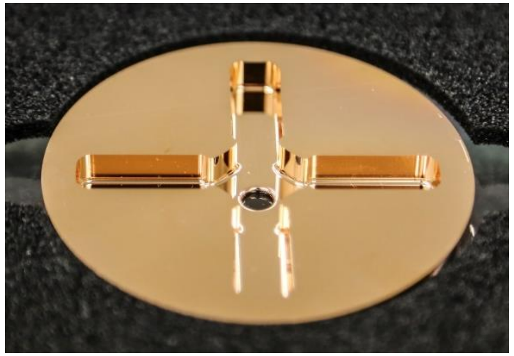
WG4: HG Normal-Conducting RF

GOALS

CLIC - HG (70 to 100 MV/m), X-Band with very low breakdown rate (cost, efficiency). Good alignment, mitigation of HG-beam dynamics interplay (wake-fields).
Muon Collider - Muon capture, L-band, HG cavities within high external magnetic fields.
Synergistic with applications outside HEP, including medical and industrial.

WHO

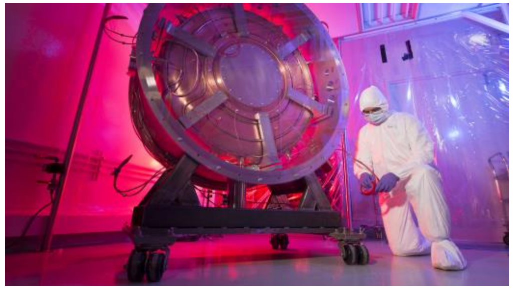
CERN, PSI, DESY, INFN, STFC, ULAN, IFIC, Uni-Uppsala, Uni1-Rome, Elettra, Uni-Tartu, Uni-Helsinki, Hebrew Uni-Jerusalem, TechUni-Eindhoven



PR. REPORT

Joint R&D program on high-gradient and high-average-power capabilities, required by the **FCC**, that require further improvements (CERN + other labs)

The investment plans for the MC test stands: a collaborative effort from the many partners involved (CEA, INFN, CERN, Cockroft, Uppsala, …)



work in progress

CLIC focus: **X-band structures** - also in linacs outside HEP, and high efficiency RF sources, to strengthen industrial base with limited new investments; **MC HG-in-High-B test stand**: community glad to join, very stimulating topic; **FCCee** ~18-20 GeV **electron injector**: they could contribute (but pending as potential Swiss contribution); **C^3** – so far only US project – opportunity.

WG4: HG Normal-Conducting RF

High gradient meets HTS in X-band!

REBCO SAMPLE TESTING FOR A HTS HIGH Q CAVITY

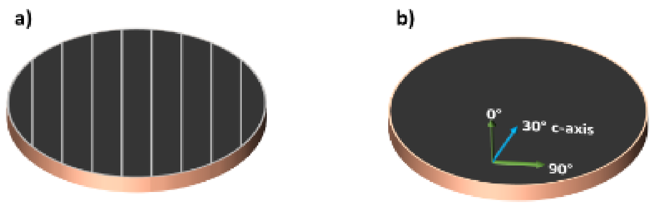


Figure 1: Sketch of the samples: a) soldered REBCO-CCs on copper and b) directly grown REBCO on MgO on copper.

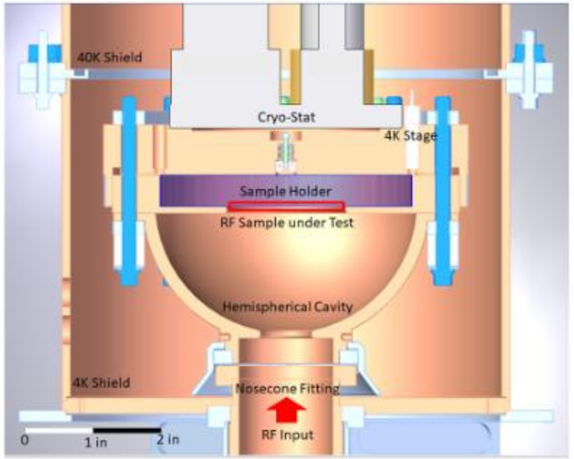


Figure 2: Schematic of Test Stand.

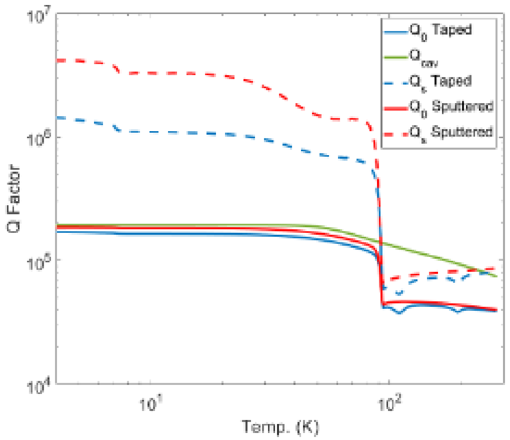
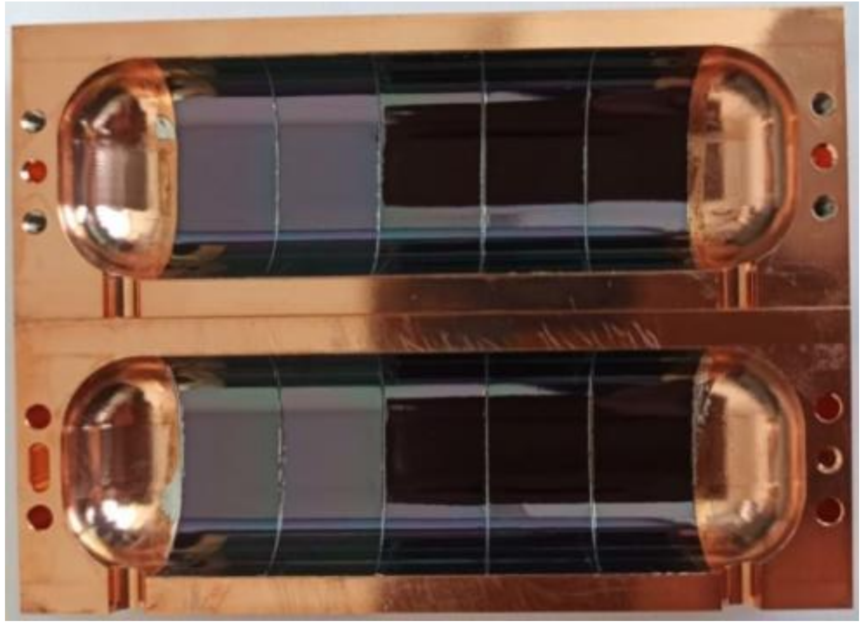


Figure 4: Quality factors of REBCO taped and deposited samples for their Q_0 ,Q_{cav}, Q_s for REBCO sample both had a critical temperature of 88K.

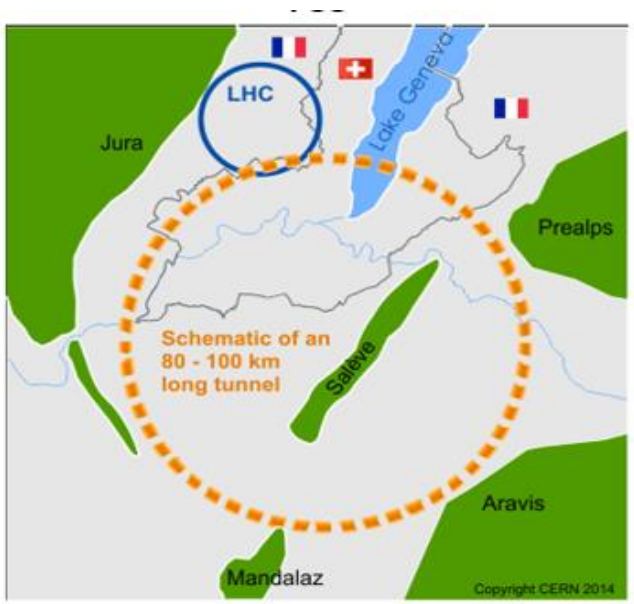
Factor of 20 improvement over copper Q-factor ($88K^0$).

X-band cavity with HTS tapes for Axion CAST project



- Synergy with Mu-Cooler: high impedance (HTS at $88k^0$) in a strong magnetic field.

WG5: High Efficiency Amplifiers



FCC ee: CW, 0.4/0.8 GHz, P_{RF} total= 110 MW

GOALS

- **Novel RF power sources with Efficiency >80% /pulsed (CLIC, ILC, MC…) and >90% /Continues Wave (FCC_{ee}….)**
- **In strong collaboration with industry** to secure and to ensure decades of industrial support.

WHO

On **EVD** CERN, ULAN , with Thales, CPI, Canon; on **SSPA**: Uppsala (L-band (1kW) IFAST2); on **mm-wave sources**: KIT, Strathclyde, INFN, ULAN and CERN

PR. REPORT

Electro-vacuum devices: few projects are at a good pace and involve labs beyond CERN. Strong collaboration with industry.

SSPA: Mostly in industry, GaN (100V) technology with multi-kilowatt transistors and 80%/chip are already commercialized.

2nd High Efficiency RF Workshop 2024, 21 – 23 Sept., Toledo Spain.

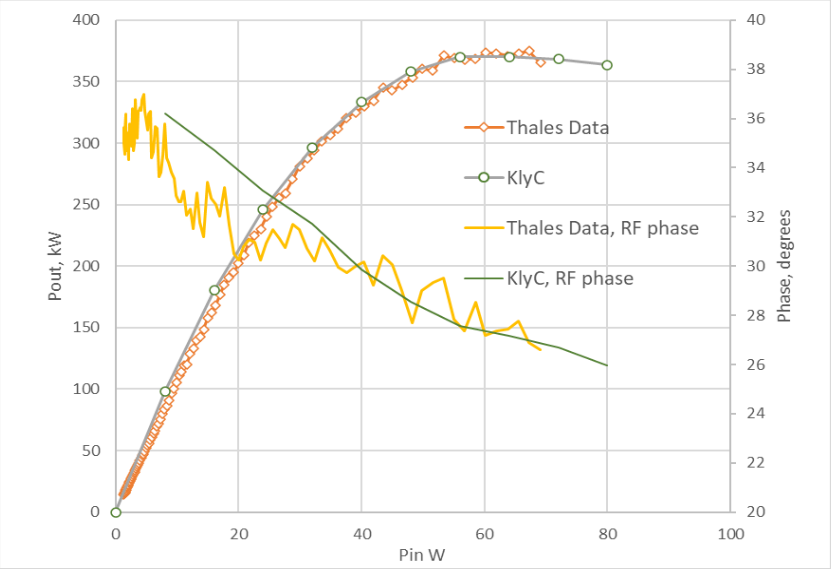
work in progress

FCC: Kly/MB-IOT, 400-800 MHz, prot-2028, series (295) by 2035+, CERN and ULAN. **FCC booster**: IOT/SSPA, 800 MHz, prot-2029/2024, CERN and Uppsala. **MC**: kly 352/704 MHz, prot-2030+, series (100) 2040+, CERN ULAN from 2026

(industrial progress: focus where numbers and/or market situation are potentially high)

WG5: High Efficiency Amplifiers

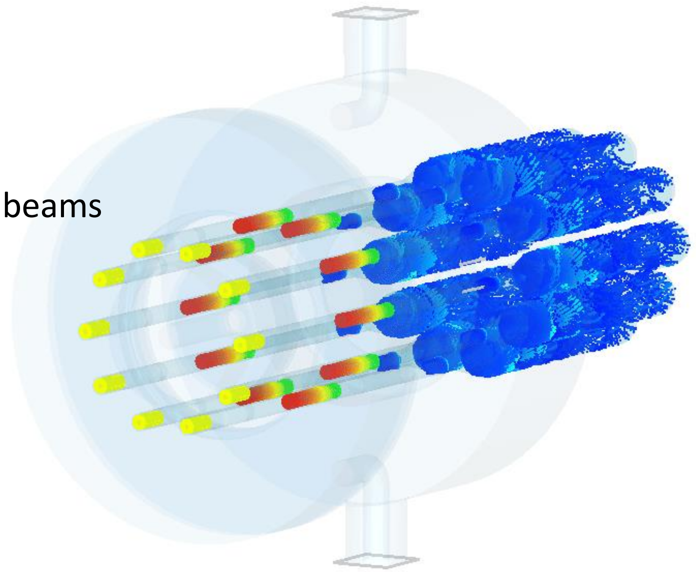
- Retrofit upgrade of existing Thales's tube TH2167 to boost RF production efficiency from **60% to 70%** and provide >350kW CW 400MHz power required by **HL-LHC**.
- Designed at CERN, built by Thales – great example of efficient collaboration between the Lab and Industry.
- **Misson completed, 365 kW (eff.=70.2%) has been demonstrated at factory**. The tube arrived at CERN in **October 2024**.
- Next, Thales will provide series of 24 tubes for HL-LHC in 4-5 years.

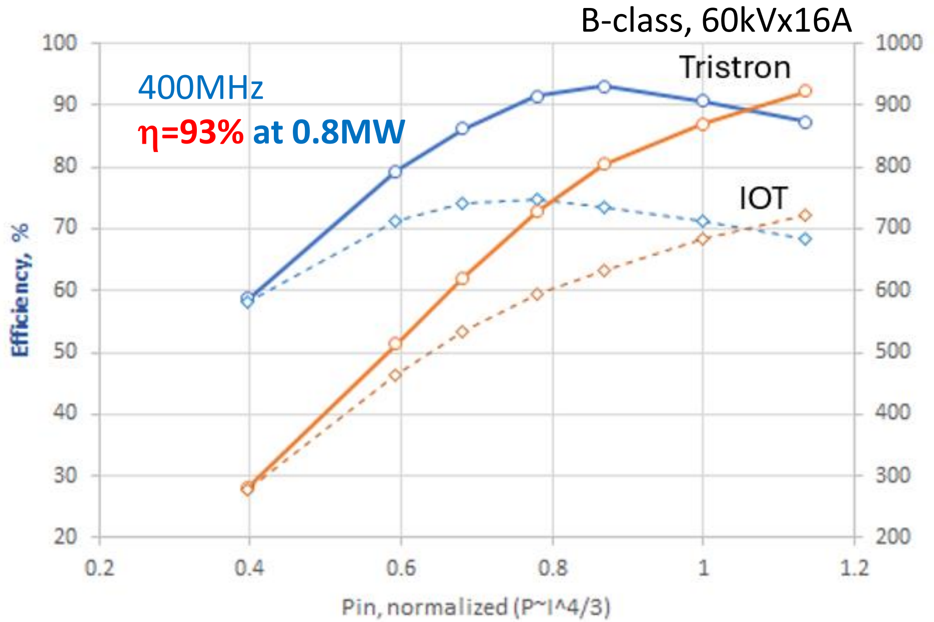


WG5: High Efficiency Amplifiers

MB Tristron – **compact** gridded tube with ultimately high RF efficiency.

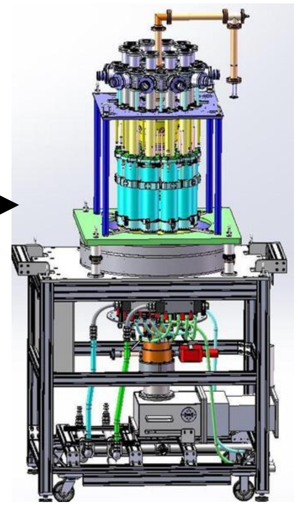
10 beams





MB Triston has a **remarkable potential as an FCC$_{ee}$ RF power source**, in terms of power handling, cost and attainable efficiency above 90%.

Phase#1. Technology demonstrator- low cost at short time (~1.5Y). Retrofit upgrade of existing ESS 0.7GHz, 1.5 MW MB IOT, anticipating efficiency increase from 70% to ~85%. ⟷



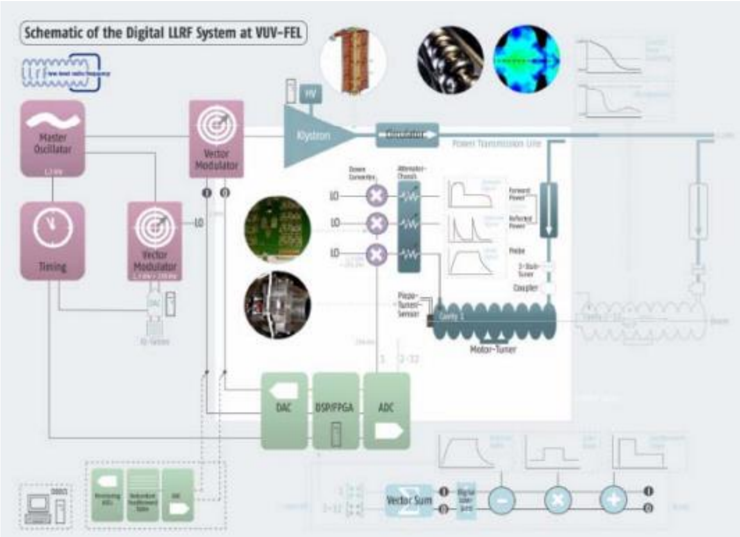
Phase#2. FCC$_{ee}$ 500kW MB Tristron prototype at 400MHz (~3Y). Massive cost optimization. CERN in collaboration with industrial partners.

Phase#3. FCC$_{ee}$ 200kW MB Tristron prototype at 800MHz (3Y+).

WG6: RF Control – LLRF, ML and AI

GOALS

- **Standardized LLRF** system platform, HW, SW firmware
- Advanced **automation** /optimization algorithms for **RF** systems
- **ML** for SC cavity quench detection, RF faults classification
- **LLRF** high-level applications



WHO

Surveyed: Uni-Lodz, Poland National Centre for Nuclear Research, HZB, Freia Lab, Uni-Uppsala, DESY, IJCLab, STFC

PR. REPORT

Standardization of LLRF hardware, firmware and software (PSI, new countries/institutions? plus industry)

LLRF high-level applications (DESY, new countries/institutions? plus industry)

work in progress

***HEP not principal focus** for targetted R&D, as stability/synchronisation performance demands for light sources (**synchrotrons and FELs**) are far more stringent.*

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WG1 – Bulk Niobium

- WG1 – Bulk Niobium
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The main goals driving the development of future accelerators are to lower the power losses (by increasing the quality factor Q_0 – $P_{loss} \propto 1/Q_0$) and increase the accelerating field (E_{acc}) in a reproducible way, to contain both capital and operational costs of future accelerators. Niobium (Nb) is widely recognized as the reference for bulk superconducting material of accelerating cavities, providing extremely high accelerating gradients with small losses (few Watts per cavity at 2 K). To increase Q_0 and E_{acc}, R&D efforts are pursued on Nb material: surface polishing with High Pressure Rinse (HPR), Buffered Chemical Polishing (BCP), ElectroPolishing (EP), surface treatment (Nitrogen doping and infusion) and heat treatments (low/mid/2-step baking, Hydrogen degassing).

In addition to pushing the limits of cavity performances, it is essential to confirm them in large series production by industry and to maintain them over time. Reproducibility is enabled by both reducing contamination during assembly, e.g. via cobots in clean room, and recovering from field emission with in-situ plasma processing.

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RFCP Development Perspectives

- Not always easy to identify a collective «RF HEP-collider community» beyond CERN, as the other European RF teams work for diverse R&D objectives.
- Many RF items are in common to several applications (colliders, smaller-energy science machines, light sources, medical applications, neutron science, …)
- Important to continue nurturing an attitude towards clustering RF communities serving different programs, not only HEP, as it will positively affect all!
- European programs may be used to foster a «network of RF disciplines for multiple goals», following IFAST, iSAS and others
- All driving the next ESPP Update in 2025/26 and future prioritized R&D for HEP.