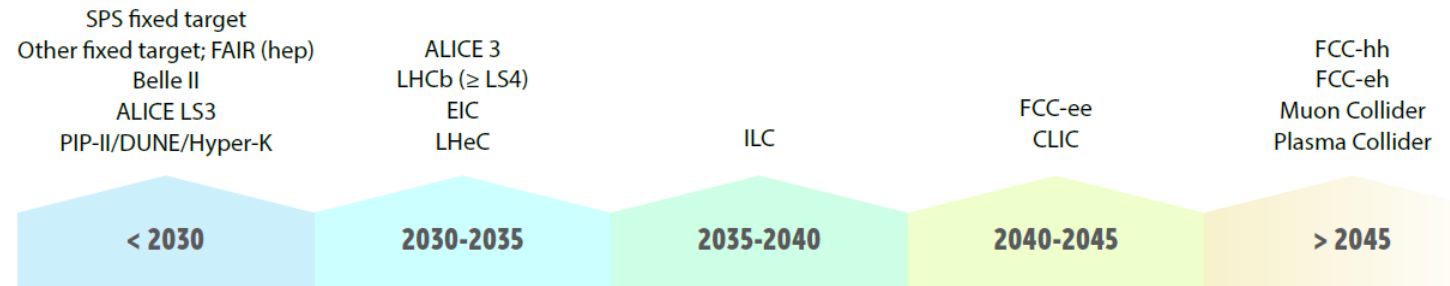


# Progress report from the RF coordination panel in the ESPP Accelerator R&D

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

# Scope: Implementation of an **approved** R&D strategy



2020-2022: ESPP **Accelerator R&D Roadmap**, presented to CERN-SPC in **March 2022**

**RF items** by: S. Bousson (IJCLab), H. Weise (DESY), G. Burt (ULAN); G. Devanz, T. Proslie (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**



# RF = **increase** beam energy **efficiently** and **reliably**

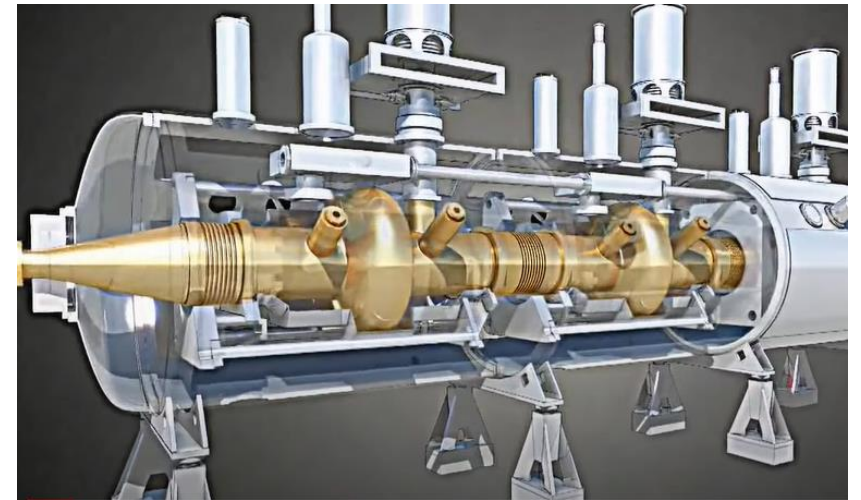
November 2022: RF Coordination Panel nominated, to follow the **concrete implementation of the roadmap recommendations**”:

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**.



RF Panel coordination		G. Bisoffi INFN-I, P. McIntosh STFC-UK
WG1	Bulk Nb	M. Baylac CNRS-F, C. Madec CEA-F, L. Monaco INFN-I
WG2	Thin films	C. Antoine CEA-F, O. Malyshev STFC-UK
WG3	Couplers	F. Gerick CERN, E. Montesinos CERN, A. Neumann HZB-D
WG4	NC High gradient	W. Wünsch CERN, D. Alesini INFN-I
WG5	RF Power sources	I. Syratchev CERN, G. Burt STFC-UK, M. Jensen ESS-S
WG6	LLRF, AI, ML	Z. Geng PSI-CH, W. Cichalewski U-Lodz-P



# Activity in the last 12 months

---

- November 2023 status report (progress status, milestone status, challenges), free access on <https://ldg-rfcp.com/>  
(its short version then submitted to LDG and CERN)
- Building upon list and institutes given in the status report, **elaborate on proposals for additional resources** from the national funding agencies.
- April 2024: progress report update, prepare material for the RFCP **web page**
- June-December 2024: the progress report will serve as basis for Europe-coordinated approach to the next ESPP and next EU-funded R&D activities)



# Survey of the teams/Follow up of the roadmap

The RF Coordination Panel has surveyed all European teams in the 6 Working Group (WG) theme areas.

Progress Report with:

1. **RF needs** of proposed future colliders;
2. **Activities/resources/collab./infrastr. of the teams** across Europe; main labs worldwide;
3. Main progress achieved since the Roadmap (2022), critical areas, needed infrastructures.

Light update **April 2024**, next one: Nov 2024)

Report to the LDG and the CERN Council  
by the RF Coordination Panel  
November 2023

<https://ldg-rfcp.com/>

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1. Bulk Nb, 2. Thin films, 3. Couplers, 4. NC RF, 5. HPRF, 6. Controls





# RF Coordination Panel

UKRI Science and Technology Facilities Council

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## WG1 - Bulk Niobium


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### Introduction

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.



<https://ldg-rfcp.com/>

# WG1: Niobium Cavities



## GOALS

1. Further increase Q and  $E_{acc}$
2. Improve reproducibility of high- $E_{acc}$  fields
3. Reduce the cost
4. 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**: interested in collaborating with FNAL on 800 MHz developments (FCc)ee)

# WG2: Thin-film Cavities

## GOALS

High  $Q_0$  @ 4.2K; much higher  $E_{acc}$  (Nb/Cu, Cu base surface preparation; novel materials; multilayers; AM; ...)

## WHO

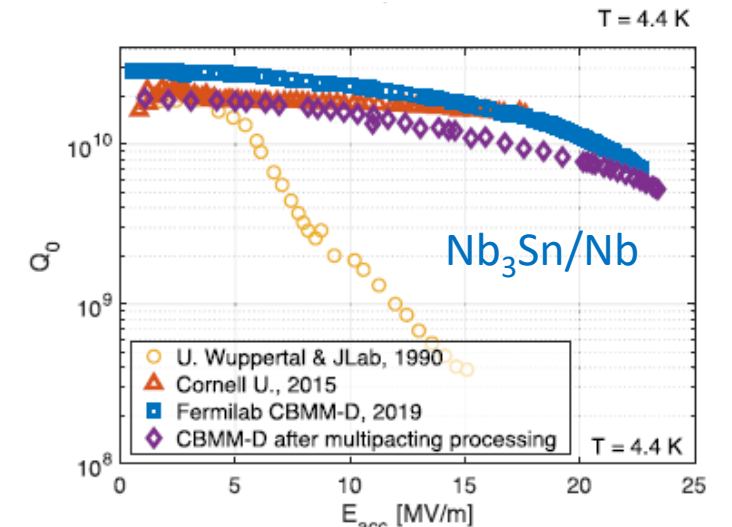
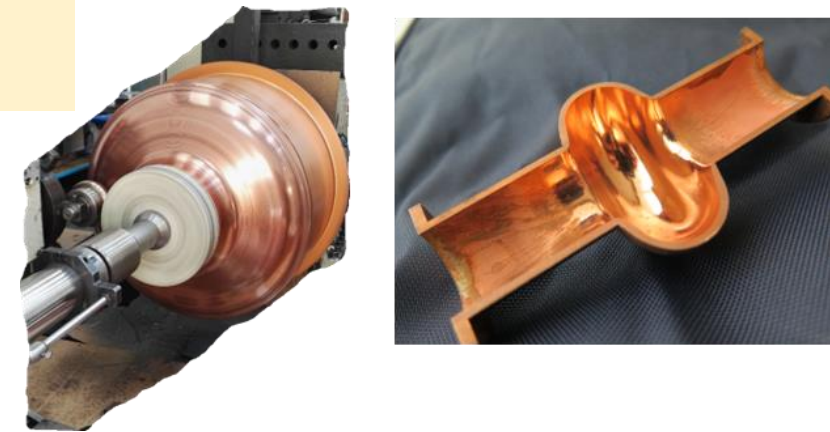
CEA, CERN, DESY, Hamburg U, HZB, HZDR, INFN, IEE, Riga Technical U, STFC/CI and USI, (I.FAST-WP) Jlab, MEPHI, PTI Minsk, ...

## PR. REPORT

- Identify priority actions for I.FAST2 (from all I.FAST partners and more)
- 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, ...)

## work in progress

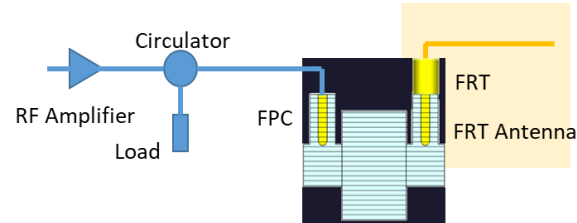
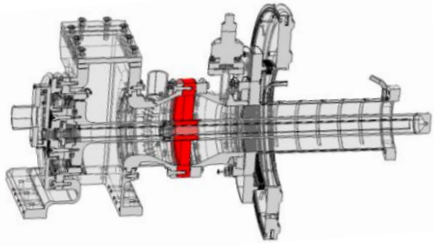
On top of IFAST2: ESPP Acc R&D fresh funding from INFN, on Nb<sub>3</sub>Sn/Cu cavities; CERN: investing on R&D for Nb<sub>3</sub>Sn/Cu, Nb/Cu, Nb<sub>3</sub>Sn/Nb, multilayers, ... for 400 MHz, 800 MHz (FCCee): room for R&D until 2040-2045 (t-tbar phase).







# 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  $\sim 5 \div 50$  cm) into SRF cavities; **HOMs couplers** (see iSAS proposal): R&D on 800, 1300 MHz multicell;  $\sim$  kW RF power out of the cold mass

## WHO

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

## PR. REPORT

Identify sections of 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 programme 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 programme** kicked off

## 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 (wakefields).

Muon Collider - Muon capture, **HG with high external magnetic field**.

Synergistic with applications outside HEP

## WHO

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

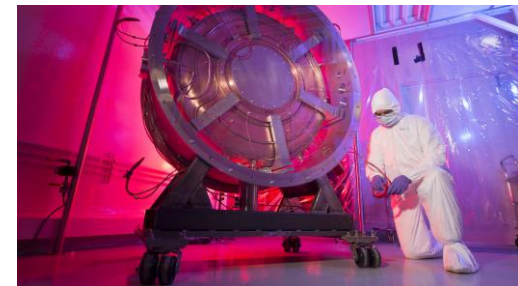
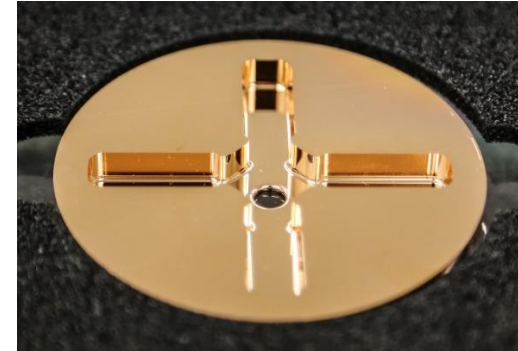
## PR. REPORT

Joint R&D programme 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

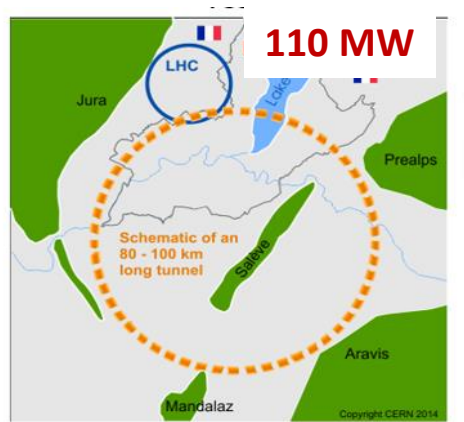
**CLIC** focus: **X-band structures** - also in linacs outside HEP, and high efficiency RF sources, to strengthen industrial base with limited new investments; **MC HG-in-High-B test stand**: community glad to join, very stimulating topic; **FCCee** ~18-20 GeV **electron injector**: they could contribute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



# WG5: High Efficiency Amplifiers

FCCee

380 kly  
600 SSPAs



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

- **High efficiency RF power sources** for future large-scale particle accelerators (LHC and FCC<sub>ee</sub> first)
- **In collaboration with industry to secure** to ensure decades of industry support.

GOALS

WHO

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

PR. REPORT

**Klystrons**: a “real” project could involve labs beyond CERN for realisation/tests, more funding, in coll. with industry

**SSPA**: will they evolve under next European projects, on other frequencies? (beyond Uppsala, w/industry)

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: where numbers are potentially high)

## GOALS

- **Standardised 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

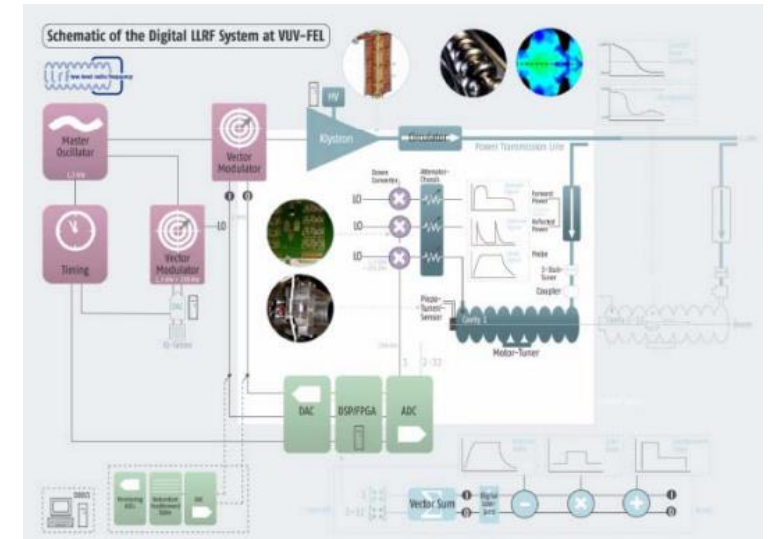
## PR. REPORT

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

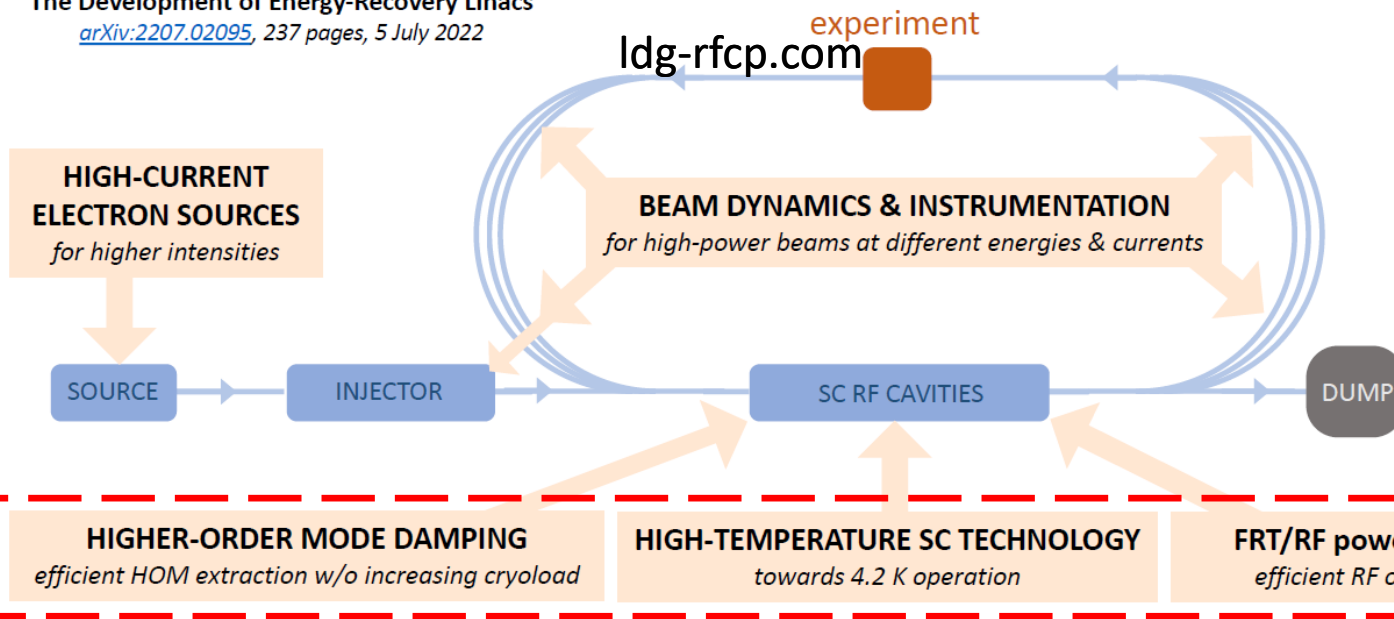
**Only one WG coordinator: PSI stepped down, DESY did not join**



## ERL/RF Panel collaboration: iSAS project (kickoff meeting April 15-16, 2024):

Identified the key aspects for an Energy Recovery accelerator  
towards high-energy & high-intensity beams to be used at particle colliders

The Development of Energy-Recovery Linacs  
[arXiv:2207.02095](https://arxiv.org/abs/2207.02095), 237 pages, 5 July 2022



		Integration Activities			
		WP5 Design new CM	WP6 Existing RIs	WP7 Industry	
Technology Areas	WP1 FE-FRT				Axel Neumann (HZB)
	WP2 LLRF				Holger Scharb (DESY)
	WP3 4K Cavity				Cristian Pira (INFN)
	WP4 HOM & FPC				Yolanda Gomez-Martinez (CNRS)
		Nuno Elias (ESS)	Guillaume Olry (CNRS)	Industry Board Giorgio Keppel (INFN)	

CNRS, CERN, ESS, DESY, VUB, CEA, HZB, INFN

(WG2-Thin films, WG3-Couplers, WG5-Power Sources, WG6-LLRF, ML and AI)



## Regarding next generation of scientific instrumentation, tools, methods and advanced digital solutions for RIs

- Support a preparatory action for common technology development in ASc&T, with the aim of transitioning to a more integrated, long-term planning implementation of joint technology research.
- During the WP 2025-27, ready to advance on the **development of the technology roadmap**.
- **Willing to promote the coordination with other consolidated communities and application fields** to foster synergies.  
(clarification: each technological cluster will develop its own strategic roadmap)
- **In favor of a program based on long-range JRA** (Joint Research Action) projects, **complemented with smaller dimension, targeted actions** to reply to specific technological RIs needs.
- For the selection of these long-range projects, open calls for the technology clusters to present **proposals under competitive basis** is foreseen as a viable mechanism.
- We consider **cascade funding ('internal projects')** as a **suitable internal instrument** to promote specific research and co-innovation sub-programs.

**Integrated, long-term** technology,  
**common** to several communities:  
consider whether to include in a common AS&T project or propose an independent one



# Running and proposed EU projects with RF content

## FCC-IS

Future Circular Collider  
Innovation Study



H2020-INFRADEV-2019-3. Nov  
2020 - Nov 2024; 7.4 (3) M€

## HITRI+

Heavy Ion Therapy  
Research Integration *plus*



H2020-INFRAIA-2020-1. April  
2021 - Sept 2025; 5 (5) M€

## MuCol

A Design Study for a  
Muon Collider complex  
at 10+ TeV center of mass



HORIZON-INFRA-2022-DEV-01.  
March 2023 - Feb 2027, 7 (2.2) M€

## RITIFI

Research  
Infrastructure and  
Technology  
Infrastructure For  
Impact

HORIZON-INFRA-2022-DEV-01.  
April 2023 - Sept 2025, 1.5 (1.5)  
M€

## iFAST

Innovation Fostering in  
Accelerator Science and  
Technology



H2020-INFRAINNOV-2020-2.  
May 2021 - April 2025; 10.6  
(10.0) M€

## EUROLABS

EUROpean Laboratories for  
Accelerator Based Science



HORIZON-INFRA-2021-SERV-01.  
Sept 2022 - Aug. 2026; 1.2 (0.9)  
M€

## ESSnuSB+

Study of the use of the ESS  
facility to accurately measure  
the neutrino cross-sections for  
ESSnuSB leptonic CP violation  
measurements and to perform  
sterile neutrino searches and  
astroparticle physics

HORIZON-INFRA-2022-DEV-01.  
March 2023 - Feb 2027, 5 (2.2) M€

## iSAS

Innovate for  
Sustainable  
Accelerating  
Systems



HORIZON-INFRA-2023-  
TECH-01-01. March 2024 -  
Feb 2028, 12.6 (5) M€

**IFIGENIA:** linear accelerators  
for novel methods/tools for RI  
production for medical  
applications

**ARTIFACT:** ARTificial  
Intelligence For Accelerators,  
user Communities and  
associated Technologies

Including RF items



# Lessons learned (**RFCP**): stay global!

---

- 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
- Very 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 programmes, not only HEP**, as it will positively affect all
- **European programmes** may be used to foster a «**network of RF disciplines for multiple goals**»
  - Some RF programmes are included in **I.FAST**
  - The specific collider goals may be better addressed through such a multi-disciplinary programme (~IFAST2, 2025)
  - The next «programme» (**strategic plan 2025-2027** within Horizon Europe) is a challenge and an opportunity





# Lessons learned (RFCP-to-LDG, bottom-up):

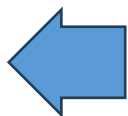
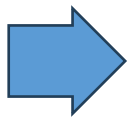
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As a **structured follow-up** of the accelerator R&D strategy is a novelty of the present ESPP exercise (with a **commitment to pull additional funds**), the RFCP wishes to contribute to a broader «lessons-learned» effort:

- RFCP has no strong enough voice to **address the funding agencies** on its specific priorities, and the funding agencies will hardly interact with the 5 Accelerator R&D panels independently (magnets, rf, ERL, MC, PLA)

→ A global **LDG-coordinated effort** is necessary (accelerator experts in the 5 Accelerator R&D panels can help in listing priorities)

- Structured **feedback from LDG and Council** to the Accelerator R&D panels  
→ it will be ensured through a review exercise with independent experts



# Session on RF

---

Progress report from the RF panel of the ESPP Accelerator R&D

*Giovanni Bisoffi*

*Building 1005S 3rd floor, Brookhaven National Laboratory*

10:55 - 11:10

EU R&D lines for all collider options

RF priorities for the FCC

*Frank Gerigk*

*Building 1005S 3rd floor, Brookhaven National Laboratory*

11:15 - 11:30

Focus on the higher priority FCC

RF frontiers for particle physics, the US view

*Sergey Belomestnykh*



*Building 1005S 3rd floor, Brookhaven National Laboratory*

11:35 - 11:50

RF from Snowmass/P5 and the MC

Progress on SRF accelerating cavities for future colliders

*Anne-Marie Valente-Feliciano*

*Building 1005S 3rd floor, Brookhaven National Laboratory*

11:55 - 12:10

R&D on cavities