The RF Coordination Panel
for the ESPP Accelerator R&D

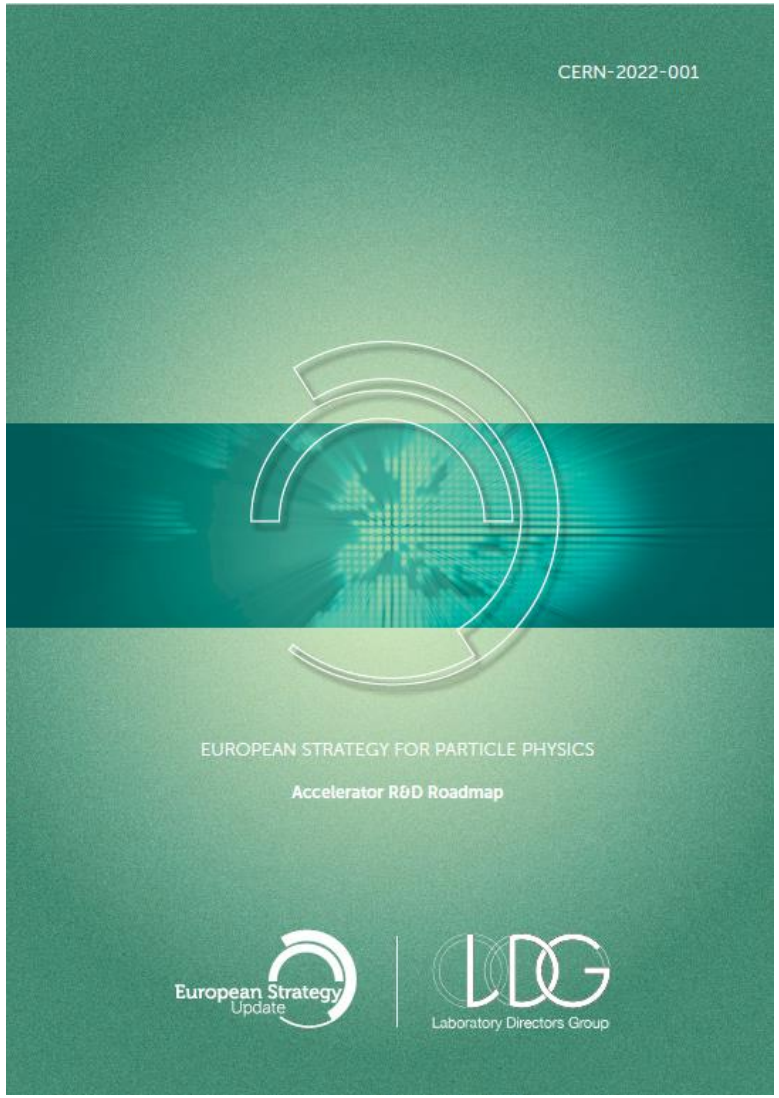
P. McIntosh (STFC), G. Bisoffi (INFN)
for the LDG RF Coordination Panel

2nd Workshop on Efficient RF Sources – Toledo, Spain, 23 – 25 September 2024

Outline

- What is the RFCP
  - RFCP Themes
- HEP R&D Priorities
- RF Implementation Evolution
- Next ESPP Opportunities for RF
- RFCP Development Perspectives

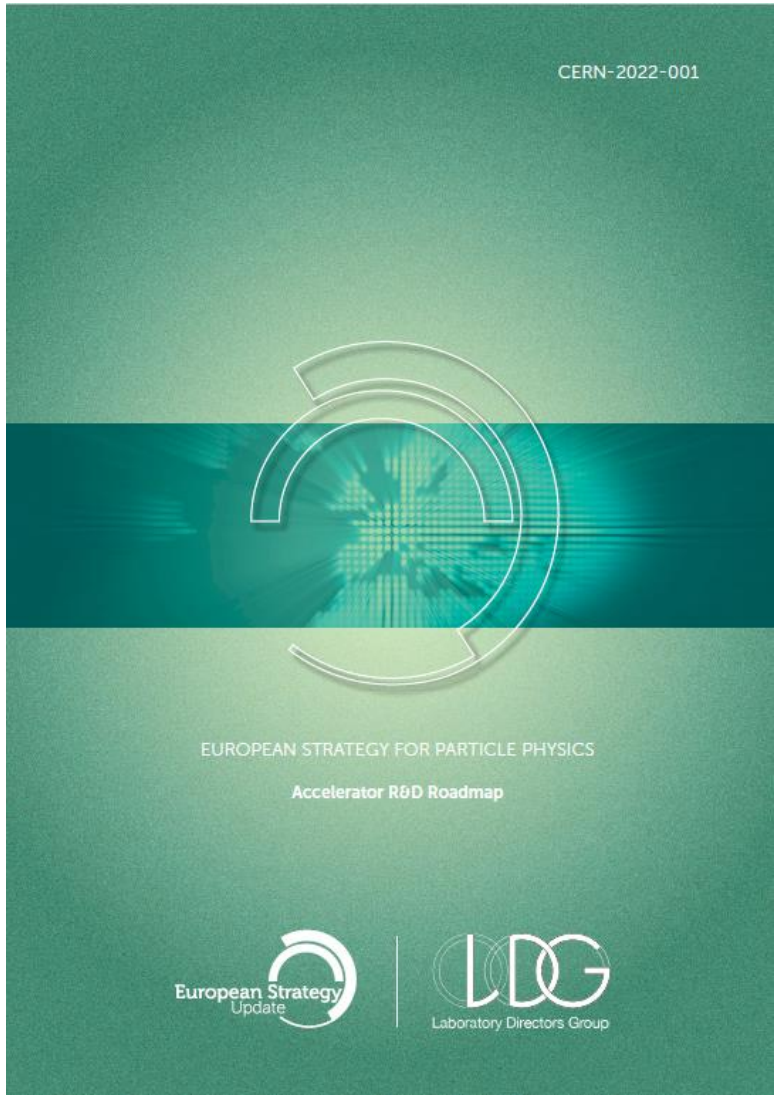
European Strategy for Particle Physics



Accelerator R&D Roadmap (CERN 2022.001)

- 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:
  - FCC-ee
  - ILC
  - CLIC
- Sustainability

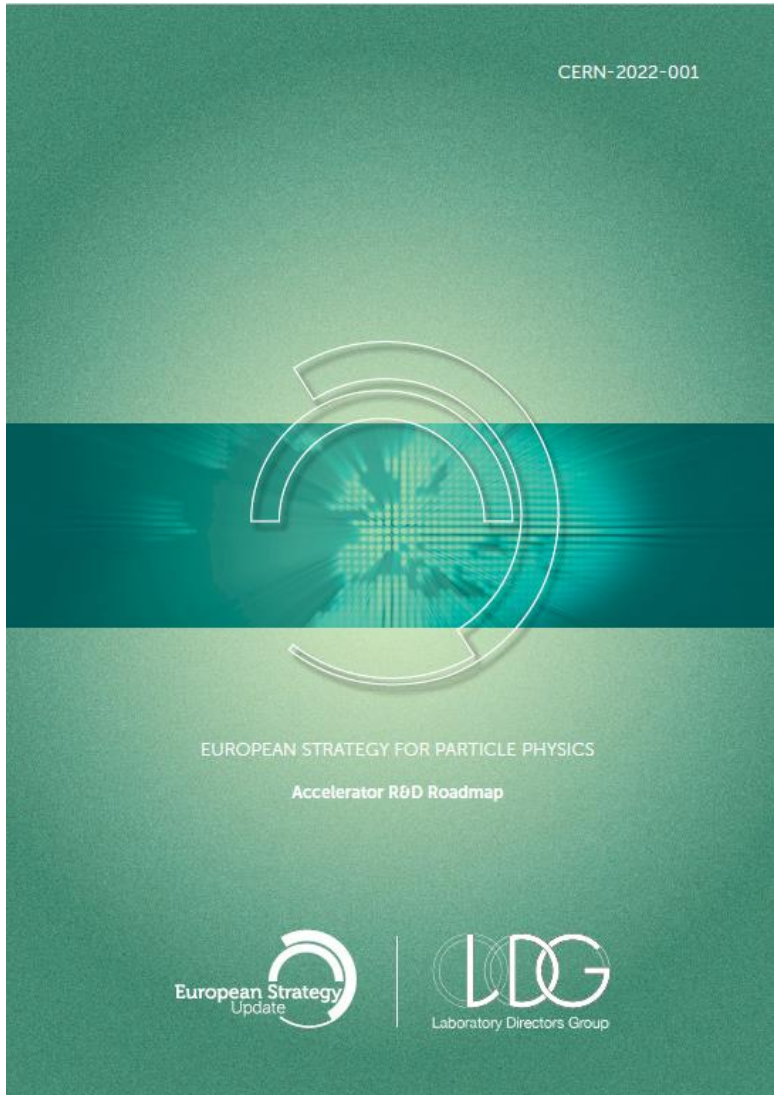
European Strategy for Particle Physics



Accelerator R&D Roadmap (CERN 2022.001)

- 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:
  - FCC-ee
  - ILC
  - CLIC
- Sustainability

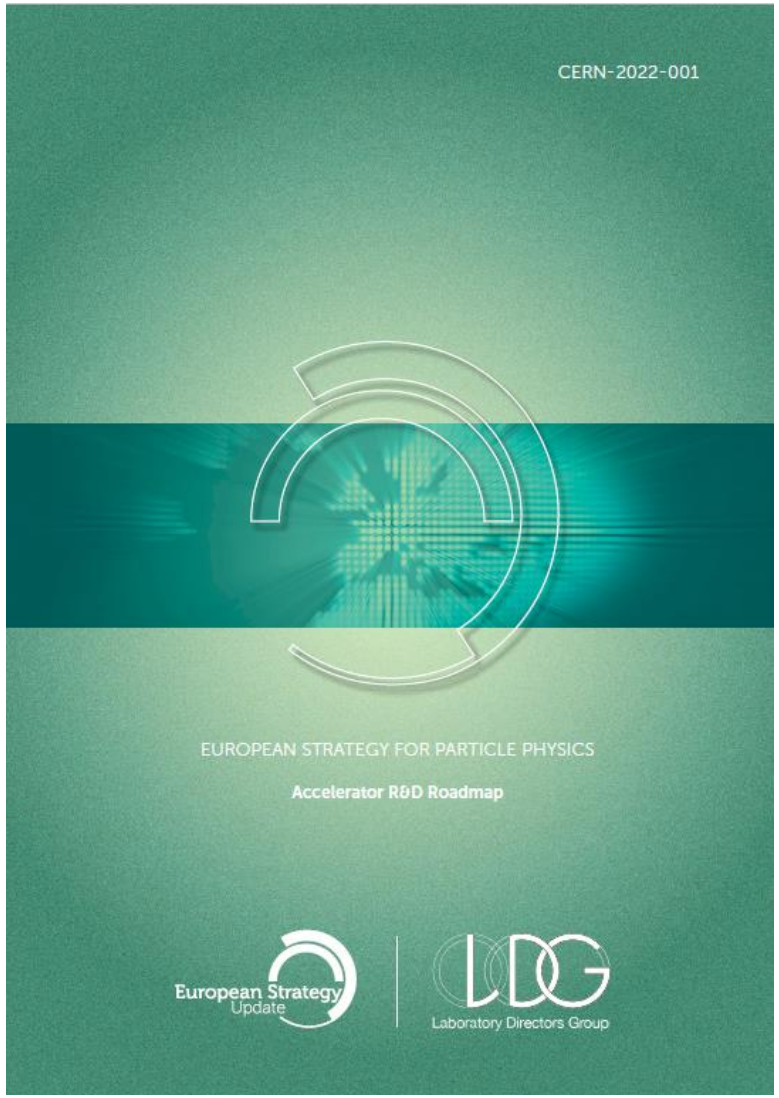
European Strategy for Particle Physics



Accelerator R&D Roadmap (CERN 2022.001)

- 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:
  - FCC-ee
  - ILC
  - CLIC
- Sustainability

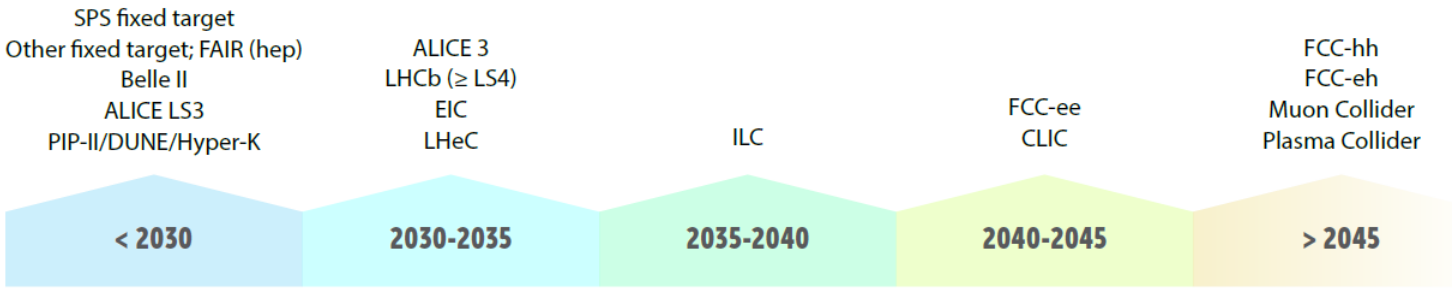
European Strategy for Particle Physics



Accelerator R&D Roadmap (CERN 2022.001)

- 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:
  - FCC-ee
  - ILC
  - CLIC
- **Sustainability**

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. 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

The RF Coordination Panel (RFCP)

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

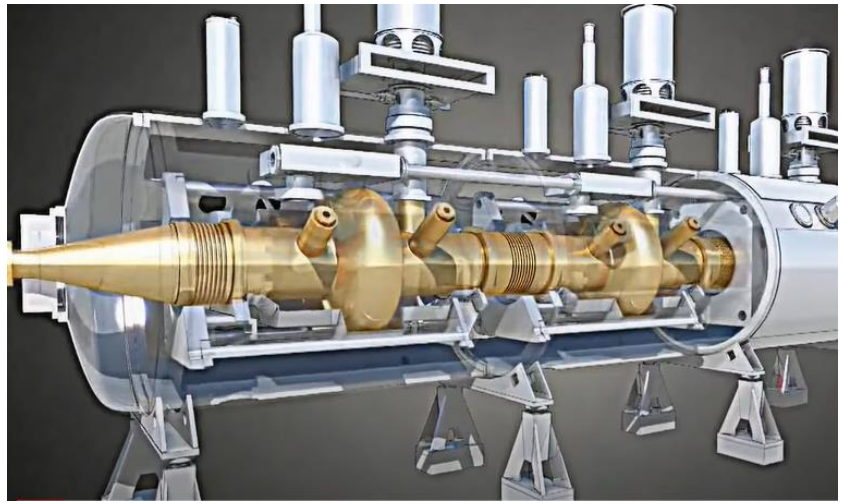
FROM:

- ✓ **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:

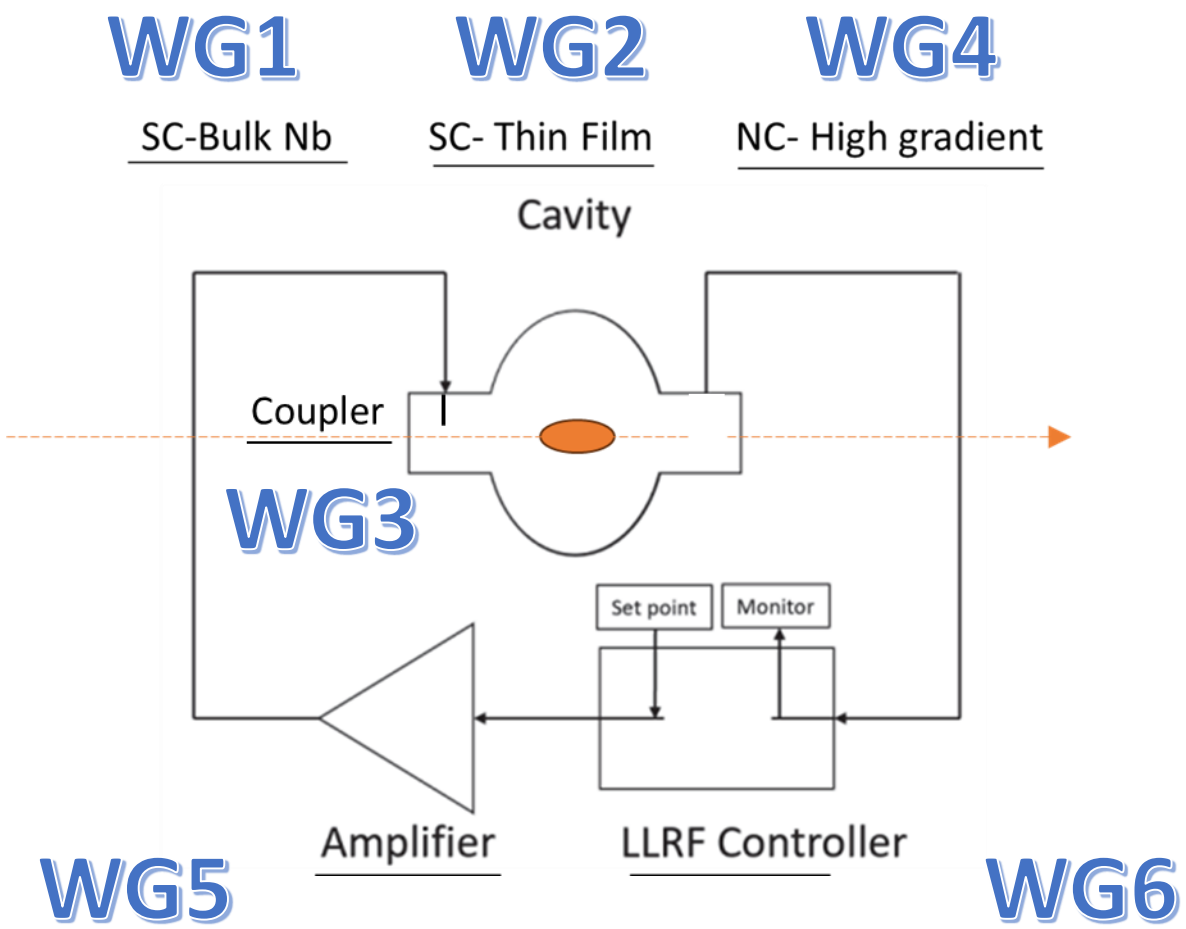
- ✓ **Coordinate the plan of R&D for HEP accelerator** across national institutes and CERN, *albeit not prescriptive on actions or investments for countries, laboratories, or institutes*
- ✓ **Its implementation** must serve the anticipated update of ESPP on benefits, challenges, feasibility, risk and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

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

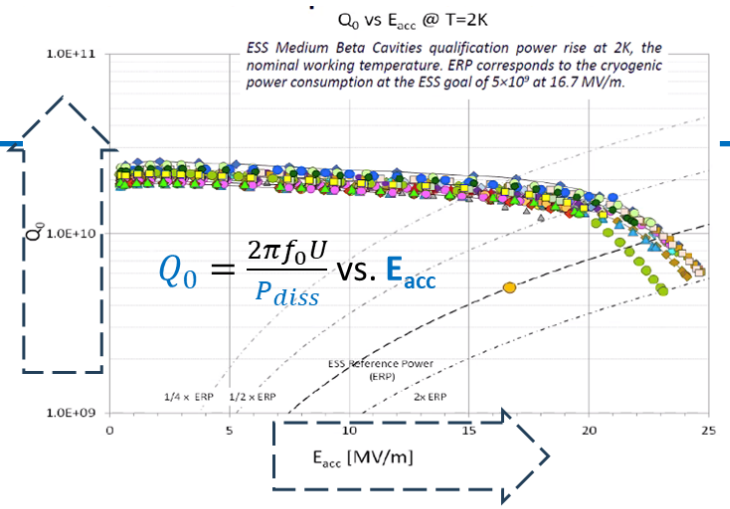


RF Panel coordination		G. Bisoffi INFN-I, P. McIntosh STFC-UK
WG1	Bulk Nb	M. Baylac CNRS-F, C. Madec CEA-F, L. Monaco INFN-I
WG2	Thin films	C. Antoine CEA-F, O. Malyshev STFC-UK
WG3	Couplers	F. Gerick CERN, E. Montesinos CERN, A. Neumann HZB-D
WG4	NC High gradient	W. Wünsch CERN, D. Alesini INFN-I
WG5	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

The RF Coordination Panel (RFCP)



WG1: Bulk Niobium



$P_{diss, ref}$

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

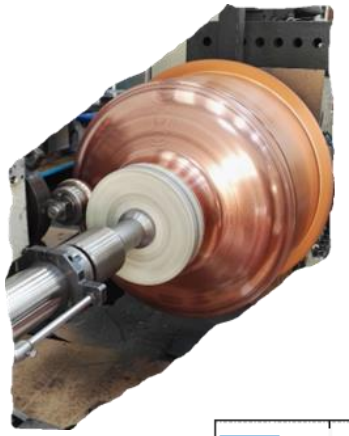
work in progress

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 (FCCee)

WG2: Thin-films

GOALS

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

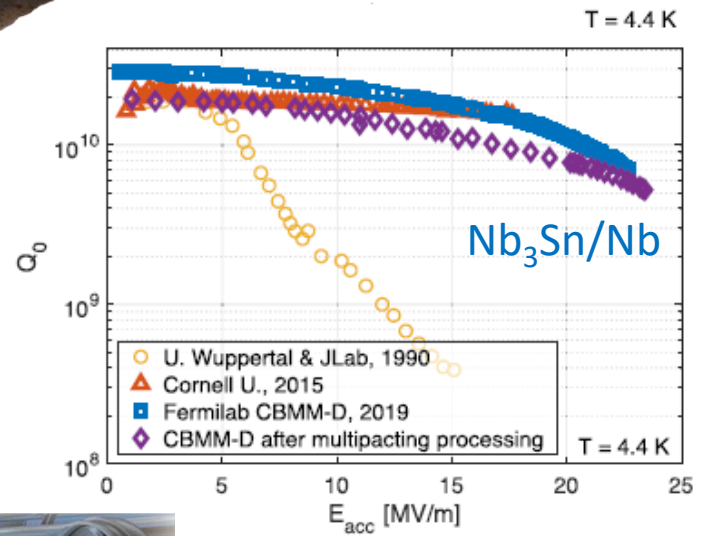


WHO

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)

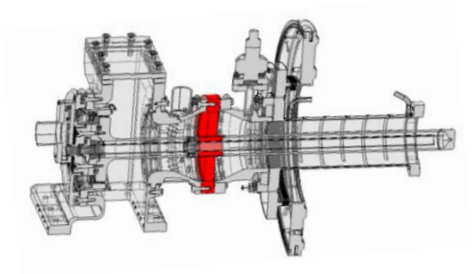


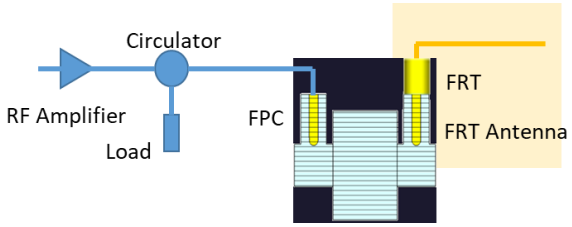
work in progress

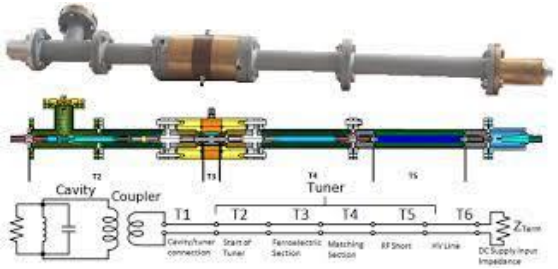
ESPP Acc R&D **fresh funding** from **INFN**, on Nb3Sn/Cu cavities;
CERN: **investing on R&D** for Nb_3Sn/Cu, Nb/Cu, Nb_3Sn/Nb, multilayers, … for 400 MHz, 800 MHz (FCCee);
Room for R&D until 2040-2045 (t-tbar phase).

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

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 programme for investigating on **ceramic windows**, with several institutes involved, to obtain more funding (within or outside an I.FAST2 framework, identify actors)?

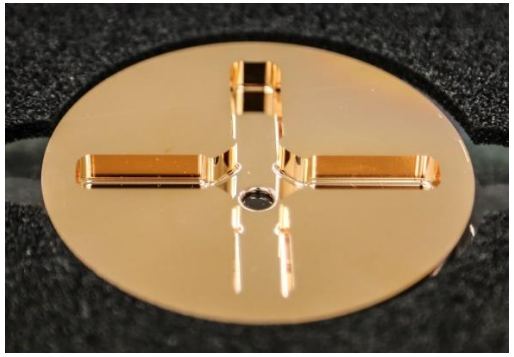
work in progress

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

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 (wakefields).
Muon Collider - Muon capture, HG cavities within high external magnetic fields.
Synergistic with applications outside HEP



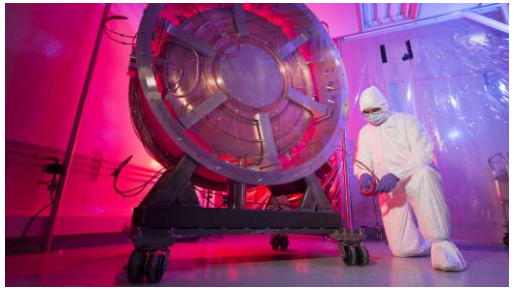
WHO

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, …)



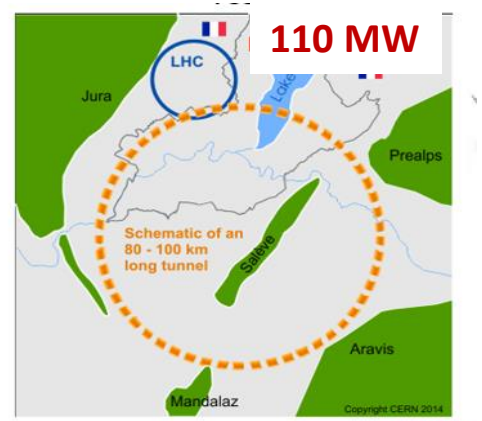
work in progress

CLIC focus: **X-band structures** - also in linacs outside HEP, and high efficiency RF sources, to strenghten 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.

WG5: High Efficiency Amplifiers

FCCee

380 kly
600 SSPAs



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

GOALS

- **High efficiency RF power sources** for future large-scale particle accelerators (**LHC** and **FCC_{ee}** first)
- **In collaboration with industry to secure** to ensure decades of industry support.

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

Canon E37117 – 25% improved efficiency!

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

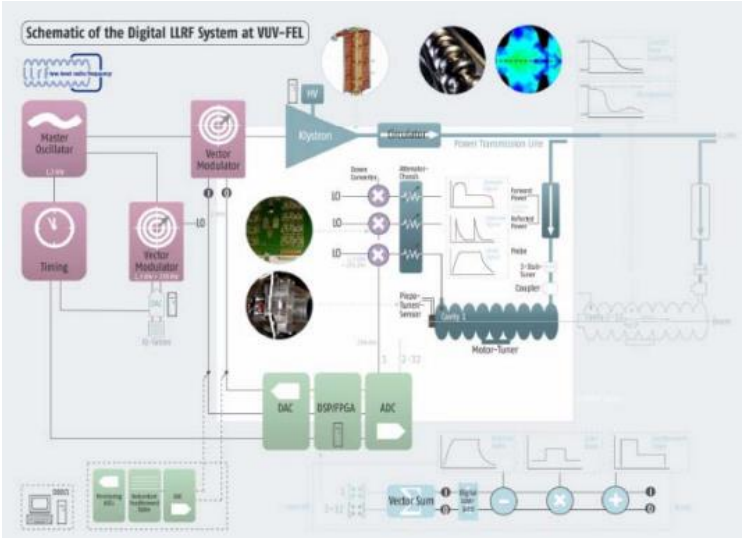
FCC: kly/MB-IOT, 400-800 MHz, prot-2028, series (295) by 2035+, CERN and ULAN. **FCC booster**: IOT/SSPA, 800 MHz, prot-2029/2024, CERN and Uppsala. **MC**: kly 352/704 MHz, prot-2030+, series (100) 2040+, CERN ULAN from 2026

(industrial progress: focus where numbers are potentially high)

WG6: RF Control – LLRF, ML and AI

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

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

Survey of the teams/Follow up of the Roadmap

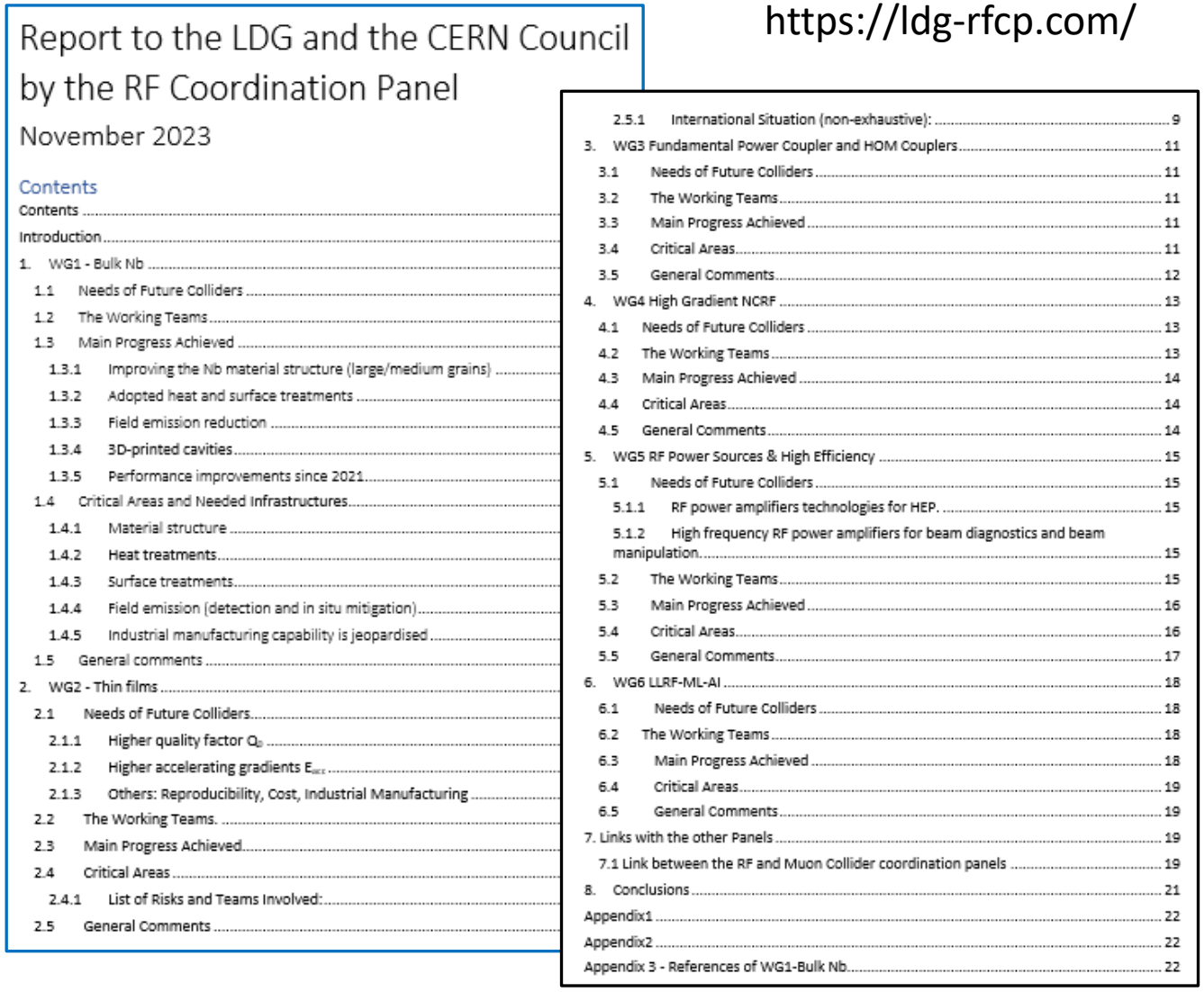
The RF Coordination Panel has **surveyed all European teams** in the 6 Working Group (WG) theme areas.

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)

https://ldg-rfcp.com/



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

Contents

Contents
Introduction
1. WG1 - Bulk Nb
1.1 Needs of Future Colliders
1.2 The Working Teams
1.3 Main Progress Achieved
1.3.1 Improving the Nb material structure (large/medium grains)
1.3.2 Adopted heat and surface treatments
1.3.3 Field emission reduction
1.3.4 3D-printed cavities
1.3.5 Performance improvements since 2021
1.4 Critical Areas and Needed Infrastructures
1.4.1 Material structure
1.4.2 Heat treatments
1.4.3 Surface treatments
1.4.4 Field emission (detection and in situ mitigation)
1.4.5 Industrial manufacturing capability is jeopardised
1.5 General comments
2. WG2 - Thin films
2.1 Needs of Future Colliders
2.1.1 Higher quality factor Q_0
2.1.2 Higher accelerating gradients E_{acc}
2.1.3 Others: Reproducibility, Cost, Industrial Manufacturing
2.2 The Working Teams.
2.3 Main Progress Achieved
2.4 Critical Areas
2.4.1 List of Risks and Teams Involved:
2.5 General Comments
2.5.1 International Situation (non-exhaustive):
3. WG3 Fundamental Power Coupler and HOM Couplers
3.1 Needs of Future Colliders
3.2 The Working Teams
3.3 Main Progress Achieved
3.4 Critical Areas
3.5 General Comments
4. WG4 High Gradient NCRF
4.1 Needs of Future Colliders
4.2 The Working Teams
4.3 Main Progress Achieved
4.4 Critical Areas
4.5 General Comments
5. WG5 RF Power Sources & High Efficiency
5.1 Needs of Future Colliders
5.1.1 RF power amplifiers technologies for HEP.
5.1.2 High frequency RF power amplifiers for beam diagnostics and beam manipulation.
5.2 The Working Teams
5.3 Main Progress Achieved
5.4 Critical Areas
5.5 General Comments
6. WG6 LLRF-ML-AI
6.1 Needs of Future Colliders
6.2 The Working Teams
6.3 Main Progress Achieved
6.4 Critical Areas
6.5 General Comments
7. Links with the other Panels
7.1 Link between the RF and Muon Collider coordination panels
8. Conclusions
Appendix1
Appendix2
Appendix 3 - References of WG1-Bulk Nb

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

https://ldg-rfcp.com

Search Log In

European R&D
Development Programme

Working Groups About Composition and Roles Documents Presentations

European Strategy Update

RF Coordination Panel

https://ldg-rfcp.com/

UKRI Science and Technology Facilities Council

Working Groups About Composition and Roles Documents Presentations

Home / Working Groups

WG0 – RFCP Management

WG1 – Bulk Niobium

WG2 – Thin Films

WG3 – Fundamental Power Coupler and HOM Couplers

WG6 – LLRF-ML-AI

European R&D
Development Programme

Working Groups About Composition and Roles Documents Presentations

WG1 – Bulk Niobium

- WG1 – Bulk Niobium
- Progress
- Priorities
- Slide Deck

Home / Working Groups / WG1 – Bulk Niobium

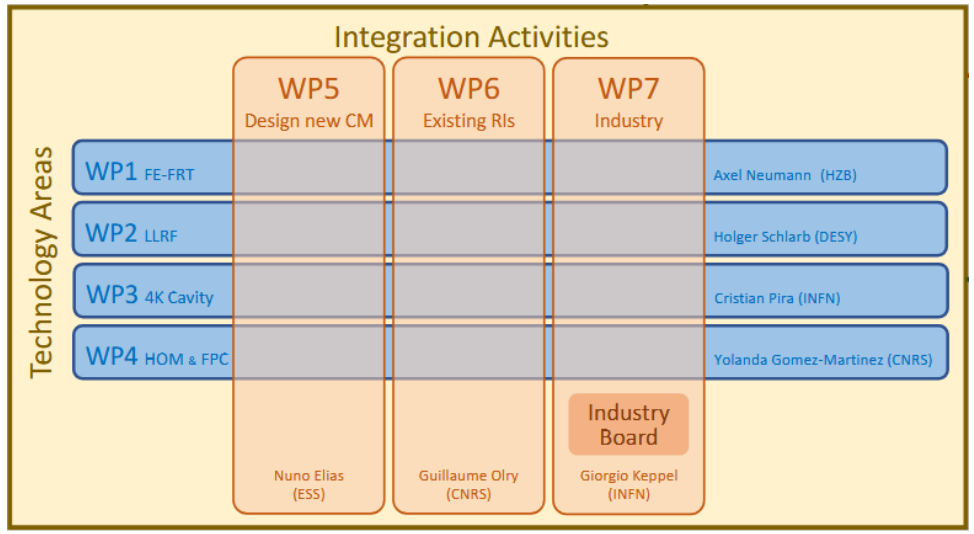
The main goals driving the development of future accelerators are to lower the power losses (by increasing the quality factor Q_0 – $P_{loss} \propto 1/Q_0$) and increase the accelerating field (E_{acc}) in a reproducible way, to contain both capital and operational costs of future accelerators. Niobium (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.

Link to the ERL Panel: RF topics

M. Baylac (CNRS)

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

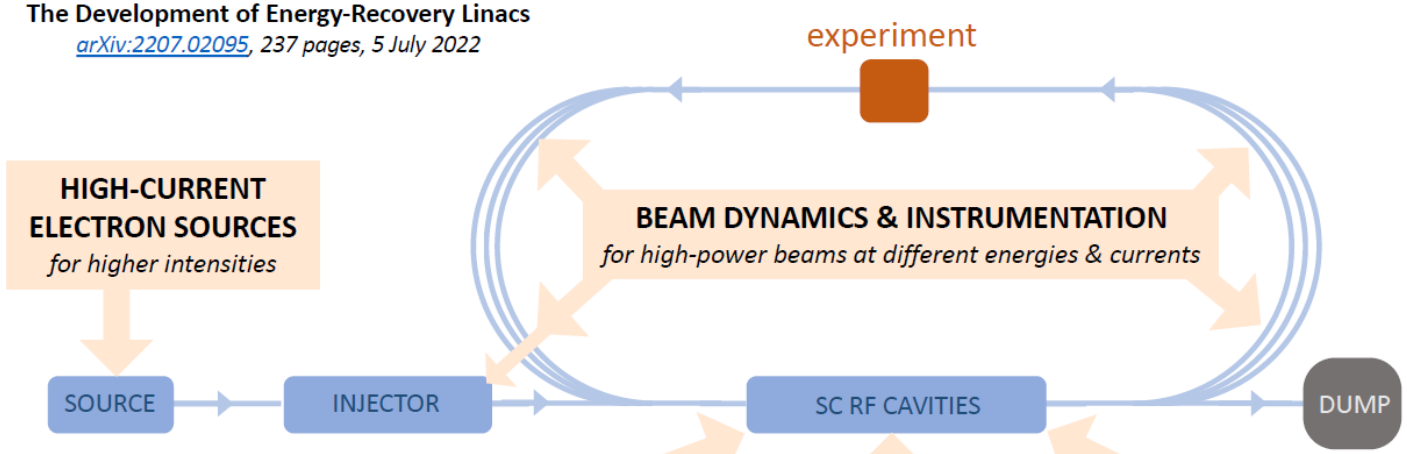


CNRS, CERN, ESS, DESY, VUB, CEA, HZB, INFN, UKRI, ULAN, EPFL

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, 237 pages, 5 July 2022



HIGHER-ORDER MODE DAMPING
efficient HOM extraction w/o increasing cryoload

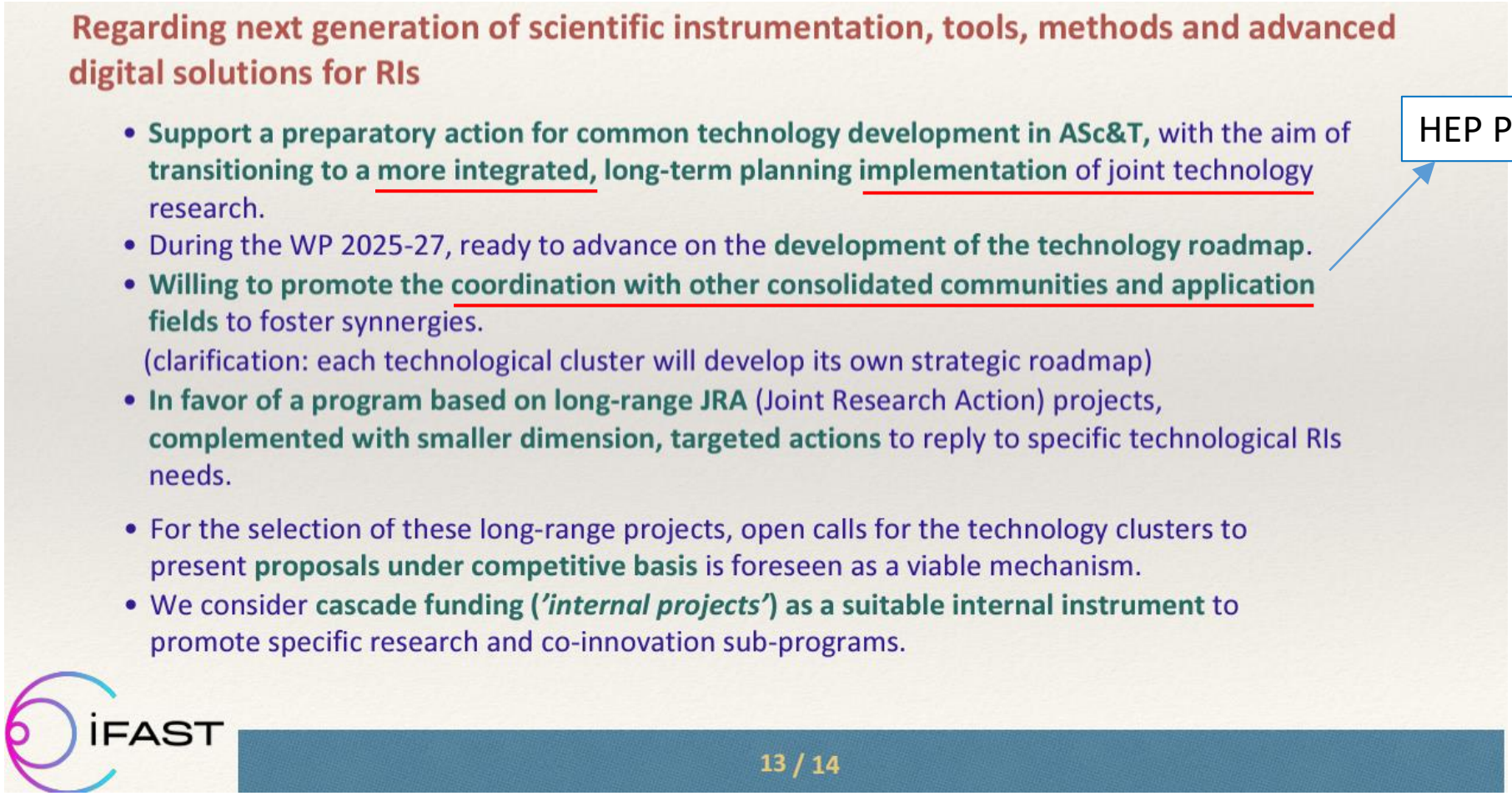
HIGH-TEMPERATURE SC TECHNOLOGY
towards 4.2 K operation

FRT/RF power source
efficient RF operation

Highly Sustainable RF Technology Demonstrator!

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

European Programme Opportunities



HEP Priorities

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

J.M. Perez-TIARA, at IFAST Annual meeting, Paris, April 2024

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 fon novel methods/tools for RI production for medical applications

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

Including RF items

J.M. Perez-TIARA, at IFAST Annual meeting, Paris April 16-19, 2024

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.
- 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.
  - Stronger emphasis introduced for iSAS.
  - 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.
- **All driving the next ESPP Update in 2025/26 and future prioritised R&D for HEP.**


Mercé
ありがとう
Gracias
Rahmat
Matondo
Grazie
Misaotra
Efharisto
Köszönöm
Rahmat
Gracias
Terima Kasih
Köszönöm
Dankjewel
Mahalo
Takk
Mahalo
Efharisto
Terima Kasih
Kiitos
Sagolun
Danke
Merci
Mauruuru
Xièxie
Grazie
Toda
Tak
Köszönöm
Matondo
Takk
Dankie
Takk
Tak
Takk
Mercé
Grazie
Dankie
Falemindert
Kiitos
Obrigado
Hvala
Faleminderit
Sagolun
Misaotra
Danke
Misaotra
Merci
Gracias
Sagolun
Obrigado
Obrigado
Спасибо
Kiitos
Danke
Mercé
Thank You
Obrigado
Mahalo
Kiitos
Tak
Mercé
Xièxie
Thank You
Toda
Toda
Grazie
Hvala
Hvala
Спасибо
Faleminderit
Rahmat
Gracias
Xièxie
Danke
Matondo
Merci
Rahmat
Merci
Thank You
Спасибо
ありがとう
Faleminderit
Sagolun
Tak
Efharisto
Gracias
Efharisto
Sagolun
Merci
Dankie
Dankjewel
Dankjewel
Matondo
Takk
Obrigado
Kiitos
Thank You
Xièxie
Grazie
Спасибо
Tak
Misaotra
ありがとう
Toda
Hvala
Dankie
Danke
Köszönöm
Mahalo
Thank You
Terima Kasih
Terima Kasih
Mauruuru
Mauruuru