REPORT BY THE RF R&D COORDINATION PANEL

G. BISOFFI
AND
P.MCINTOSH,
NOVEMBER 21,
2022 – CERN

† FAREWELL TO OUR DEAR COLLEGUE AND FRIEND

- Sebastien BOUSSON, director for «Accelerator Physics» at the Irene Joiliot-Curie Lab, Paris; co-chair of the RF Panel in the Accelerator R&D Strategy
- An internationally recognized expert in the field of superconducting accelerators, S. Bousson was the prime contractor and then the manager for several years of the technological platform for research and development on superconducting accelerating cavities **SUPRATech**. He was also responsible for coordinating work packages within European programs, in particular **EURISOL** and **TIARA**. Since 2009, he has been the IPN-IN2P3 coordinator of the French contribution to the construction of the **ESS** (European Spallation Source) project and responsible for the Linac Spoke task package project.
- In addition to his project monitoring activities, Sébastien Bousson has always been involved in communicating research professions to young people, but also to decision-makers and our academic and economic partners, thus joining the community of "CNRS talents".

ACTIVITY SEPTEMBER – DECEMBER 2022

- Aug 29: informal meeting of GB with the RF Panel who wrote the RF strategy
- Sep 27, 2022: proposal of P. McIntosh as deputy-chair
- Sep 27 - Nov 7: preparation of the RF Coordination Panel (RFCP) –only one name tbc
- Nov 10: presentation of the RFCP to the LDG
- Nov 14: kickoff meeting of the RFCP (remote)
- Nov 21: presentation to the LDG on first ideas on the implemetation strategy of the RF pillar
- Dec 16 ?: presentation and report to the Council

DISCLAIMER

- Some of the slides here may serve as a dry-run for the presentation to the Council, others are for internal discussion today, prior to the Council
- As the kickoff meeting is extremely recent, the WG input is still at a preliminary stage AND we need to get full consistent feedback from the WG leader as to some of the points they raised (→ to be fixed by Dec)
- We did not present at the ECFA meeting on November 18, because of the VERY recent input received, and because of the extremely short notice

RF COORDINATION PANEL WORKING GROUPS

Coordination: G. Bisoffi (INFN-I), P. McIntosh (STFC-UK) → Snowmass, Asia, ...

WG1 - Bulk Nb

- M. Baylac (CNRS-F) → *ERL*
- C. Madec (CEA-F)
- L. Monaco (INFN-I)

WG2 - Thin Film SRF

- Claire Antoine (CEA-F)
- Oleg Malyshev (STFC-UK)

WG3 - Couplers (FPC and HOM)

- **Frank Gerick (CERN)**
- E. Montesinos (CERN)
- Axel Neumann (HZB-D) → *ERL*

WG4 - NC Very High Gradient

- **Walter Wuensch (CERN)**
- David Alesini (INFN-I)

WG5 - RF Power Sources and High Efficiency

- Igor Syratchev (CERN-CH)
- **Graeme Burt (U Lancaster-UK)** → MC
- Morten Jensen (ESS-Swe)

WG6 - LLRF, AI and ML

- Wojciech Cichalewski (Uni-Lodz, Po)
- Roger Kalt (PSI) - tbc

Underlined: WG chair; **Bold**: national contact to funding agencies; in dark red: external links

Country	Total
France	3
Germany	1
Italy	3
CERN	4
UK	3
Switerland	1
Sweden	1
Poland	1

Gender	Total
Female	4
Male	13

WGs: we proposed 1 chair and 1 or 2 deputies: any different proposals? Any advice for additional support?
(note: we try not duplicate coordinators from roadmap generation panel and implementation panel).

ON THE SCOPE

- **Each** WG should identify a "scope" (consistent with the approved Roadmap), for substantial steps forward in its field, to be achieved in the **next 5 years**. From the scope, derive an implementation path, by contributions already in place and others. Consider new countries, willing to join Accelerator R&D through RF.
- **Links to the ERL and MC** CPs shall be launched; link to Snowmass, others…
- **Priorities.** We need to push priority items in each WG. We can decide later on, if priorities "across" WGs should be identified or not.
- Our **final deliverable**: another yellow report? to be discussed with the LDG.

From the introduction to the Kickoff meeting, November 14

WORKING METHOD ITEMS, DISCUSSED WITHIN THE RFCP

- The panel should utilize the **RF Roadmap development plan (yellow book) as a basis** for progressing any further consultations with associated R&D communities.
- A **review meeting with the RF Roadmap coordinators** in January 2023, as basis to both appreciate the processes already conducted, and to discuss strategies for taking the roadmap through to its staged implementation (*without Sebastien…*)
- Workshops. I. A **mid-term** (end 2024?) review workshop could be organized with the inclusion of non-European contributors. II. Each WG may set up **subsidiary working groups** when needed, to ensure that decisions are made on a sound technical basis.
- **Who addresses whom?**

– National R&D and projects teams: the WG coordinators (in concert with other areas, in case of overlaps)

– Funding agencies: the national contact points with GB and PM, on the RF strategy as a whole

– LDG and council: GB and PM, representing the RF Coordination Panel

From the introduction to the Kickoff meeting, November 14

FAQ

- Do we have an acknowledged role, when approaching labs and agencies? As in the Roadmap preparation stage, the work of the LDG is communicated top-down to the labs, which should become well-aware of our roles
- RFCP Budget. We are assuming that we all work "without" a specific budget. We assume that each of us finds a national funding source for travelling. Online events should be cheap or no cost. For in-person meetings we shall have to investigate with LDG.
- Shall we hold other specific workshops? Maybe, but let's try not to overlap with all the RF conferences and workshops.
- Research funds. They are national (or CERN) funds. We have no budget nor power on the national spending. However, a consistent LDG action should be able to promote more resources or to steer some towards more productive goals (priorities of RF may clash with priorities of other pillars, LDG and Council may give specific directions if needed). EU funds? Maybe by aligning with the successor of the I.FAST project (around end 2024), others?

From the introduction to the Kickoff meeting, November 14

KO MEETING: PRESENTATION GUIDELINES AND TEMPLATE

1. Starting from the strategy which has been developed in the Accelerator R&D Roadmap (CERN-2022-001), review status of current R&D items in your theme area, versus what is required or wished for the need of future colliders.
2. For each item of the list, with the purpose of defining a staged implementation plan over a 3-5 yr timescale,

- Highlight path and challenges for performance improvements
- Indicate the main labs involved, first ideas for potential collaborations/connections among them
- Timescale and required resources
- Identify any connections to the ERL and Muon Collider theme areas

3. Prioritise all identified items (w/ motivations)
4. Identify any required/desired new technical infrastructures (or upgrades of the existing ones)

To be reported on Nov 21 and Dec 16

	In view of a 3-5 years implementation plan									
Items identified in the Accelerator R&D Roadmap (CERN-2022-001)	**Path**/challenges for performance improvements	**Main labs/groups** involved	Wished/recommended **collaborations/connections**	Approximate **timescale** [y]	Estimation of required **personnel** [FTEy]	Estimation of required **budget** [k€]	**Proirity ranking** among identified items [1, 2, 3, ...]	Short motivation for the ranking	New/upgraded **technology infrastructure** required	Motivation for the new/upgraded technology infrastructure
Item1										
Item2										
Item3										
Item 4										
Item 5										

AGENDA FOR THE KICKOFF MEETING (NOVEMBER 14)

Kickoff meeting of the RF Coordination Panel (Accelerator R&D Roadmap)

Monday 14 Nov 2022, 14:00 → 18:00 Europe/Rome

https://cern.zoom.us/j/9118046813?pwd=TFd1YkRSNDBBNkhja2RLS1RvR2UvQT09

Contact giovanni.bisoffi@lnl.infn.it

14:00 → 14:30 **Introduction** 30m
Speakers: Giovanni Bisoffi (Istituto Nazionale di Fisica Nucleare) , Peter McIntosh (STFC)
20221114-RF Panel ...

14:30 → 15:00 **LLRF, AI and ML** 30m
Speaker: Wojciech Cichalewski (DMCS)
LLRF_AI_1_WCichal...

15:00 → 15:30 **Bulk Nb** 30m
Speakers: Catherine Madec (CEA) , Laura Silvia Monaco (Istituto Nazionale di Fisica Nucleare) , Maud Baylac (CNRS-LPSC)
RFpanel-bulkNb-nov...

15:30 → 16:00 **Thin Film SRF** 30m
Speakers: Claire Antoine (CEA) , Oleg Malyshev (SFTC)
T_2022-11-Thin film...

16:00 → 16:30 **NC Very High Gradient** 30m
Speakers: David Alesini (Istituto Nazionale di Fisica Nucleare) , Walter Wuensch (CERN)
HG RF kickoff meeti...

16:30 → 17:00 **RF Power Sources and High Efficiency** 30m
Speakers: G. Burt (Lancaster) , Igor Syratchev (CERN)
RF Power Sources a... RF_sources_GBIS.xl...

17:00 → 17:30 **Couplers -FPC and HOM** 30m
Speakers: Axel Neumann (Helmholtz Zentrum Berlin) , Eric Montesinos (CERN) , Frank Gerigk (CERN)
Accelerator R&D Ro... Copy of Template fo...

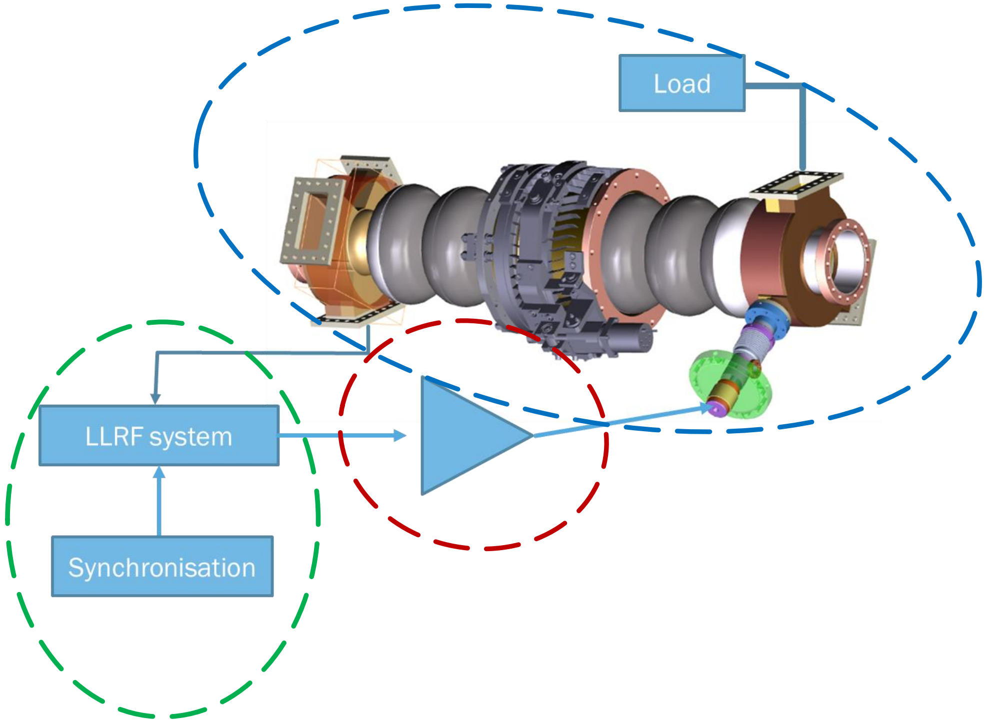
RFCP WORK JUST STARTED

INITIAL APPROACH, still unavoidably a bit **diverse among the WGs** for the following reasons:

- Some report that the scenario should be slightly updated, vs 2021
- New proposed approach, vs analysis of the approved strategy (HGNC, to be better checked)
- Teams with VERY recent appointment (Bulk Nb – 3 days before the kickoff meeting; LLRF, still 1 person before KO, then pending confirmation of a second)

THE TOPICS REVIEWED (RF INSIDE OUT)

- Accelerating units: RF structures and couplers
  - **SRF** Structures in **bulk Nb** (the near term)
  - **Thin film SRF** structure (the long term route to twice Eacc and «half» HEP linacs lnghts, on top of advance Nb/Cu for FCC)
  - CW/pulsed **couplers** for SRF cavities (complex, often much more than an ancillary)
- RF Power Feeders (largest driver of energy efficiency improvement paths)
- Controls of RF amplitude, phase, frequency – also with AI and ML tools



WG1 – BULK NB CAVITIES (M. BAYLAC, C. MADEC, L. MONACO)

- **ASSET** - Bulk niobium technology competitive for years to come, compared to thin-film SC under investigation
- **GLOBAL GOAL** - Driving parameters : Q_0, E_{max}, fabrication and operation cost, reliability, field emission reduction; ensure the best performances on multi-cells, in a cryomodule & in a reproducible way and minimizing cost, environment impact
- **R&D and labs** - Materials: DESY; Heat treatment: IJCLab, INFN, DESY, Uni-Hamburg; Surface polishing: INFN, IJCLab; FE reduction: IJCLab, LPSC, CEA, ESS, DESY (**joint topic with NC-HG?**)
- **ERL/MC joint topics:** better cavity performance, lower cost; operation in H-field (in an ad-hoc infrastructure),…
- Overview of existing **infrastructures**: start from EU-AMICI network of TecHnology Infrastructures (https://amici.ijclab.in2p3.fr/)
- **Communication within community**: check events, website, email list, organize workshops (1 or 2 per year)
- **Develop implementation plan** (HR, €, priorities) considering limiting factors (He, energy, pandemic, war …), try to correlate with future HEP machines

PRELIMINARY THOUGHTS ON BULK NB

- **Material**
  - Fine grain (FG): top performance, PED compliant; high Q_0 and E_{max} yet to be achieved; HT, polishing, FE reduction
  - Large grain (LG) from sliced ingots: very promising, PED qualification required
  - Medium grain (MG): less expensive, performance to be demonstrated
- **Heat Treatment (HT)**
  - Baseline heat : flash chemical etching after the HT, IJCLab
  - N-doping (high Q_0, lower E_{max}) : IJCLab at low-f ; N-infusion (large E_{max}, slight Q_0 increase) : IJCLab at low-f
  - 2 step baking (large E_{max}, slight Q_0 increase)
  - HT at intermediate temperature (200-600°C) : INFN, DESY & Hamburg University
- **Surface polishing**
  - Electropolishing (EP) at low-T: INFN; Vertical EP: CEA (KEK); Electrolytic plasma polishing (EPP) : INFN on samples
  - Mechanical polishing (alternative to chemical or to prepare for thin film deposition): IJCLab
- **Field emission (FE) reduction**
  - Preparation : clean room robotisation/cobotisation : CEA; Diagnostics : CEA, ESS, DESY
  - Mitigation and recovery of low performance cavity : plasma processing (CEA, IJCLab), dry-ice rinsing of cavities
  - FE fundamentals (SEY for several material; surface treatment): IJCLab & LPSC

WG1 – BULK NB CAVITIES (M. BAYLAC, C. MADEC, L. MONACO) (1/2)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort/Cost/Infr	Priority
Qualification of **large/medium grain** Nb cavities	• improve physical performances at reduced cost; • demonstrate **compliance with PED/ASME/HPGS** requirements -> mechanical properties	DESY (LG), CEA (mech measurement?)	KEK/FNAL (MG); Shine, Jlab (mech)	LHeC, FCC, PERLE, ERL, MC (cost reduction for large machines)		
Operational CW **cryomodule at gradient > 20 MV/m**	• improve physical performances at reduced cost (useful for large scale production)	DESY (FG), INFN (FG), LG/MG (R&D needed).	FNAL, Jlab	all SRF projects (CW and cost reduction)		
Develop **new vendors for large/medium grain** Nb	• allow **mass production of cavities at reduced cost**	R&D needed for PED/ASME/HPGS compliance	FG: Ningxia OTIC, Tokyo Denkai, Ulvac, ATI, CBMM, other? FNAL, Jlab, KEK, China labs)	all SRF projects (large scale)	**TBC in comparison with original Roadmap predictions.** **Workshop/ Reviews in early 2023**	TBC and presented to CERN Council in Dec
Optimization of **mid T baking, two-step baking**	• simplify the **cavity preparation process**	Mid-T INFN, DESY, Hamburg Univ., CEA, IJClab; 2-step: CEA, INFN; other?	FNAL, Jlab, other?; RI (D), ZRI (I)	all new SRF projects		
Optimization of **N doping and N infusion** at several frequencies	• improve the cavity preparation process for **high performances and reproducibility**	IJCLab, STFC (PIP-II), DESY; other??	FNAL,KEK, other?; RI (D), ZRI (I)	all SRF projects (CW and cost reduction)		
Optimize electropolishing : at **low temperature, vertical EP**	• improve the cavity preparation process for high performances and reproducibility	Cold EP: INFN (with industry) Vertical/cold EP: CEA (KEK)	ANL FNAL (cold EP), KEK (vertical EP); ZRI (I) (also RI (D)?	all SRF projects (high Q0)		

WG1 – BULK NB CAVITIES (M. BAYLAC, C. MADEC, L. MONACO) (2/2)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort/Cost/Infry	Priority
Investigate **alternative polishing techniques** (mechanical polishing, electrolytic plasma polishing, rotational BCP)	• improve the cavity preparation process for high performances and reproducibility	MP: IJCLab, CERN? EPP: INFN RBCP: INFN (at industry), CEA, CERN	ANL (RBCP), ZRI (I), RI (D)?	all SRF projects	TBC in comparison with original Roadmap predictions. Workshop/ Reviews in early 2023	TBC and presented to CERN Council in Dec
Develop **infrastructures for large cavities** polishing and characterization	• **availability of infrastructures** for cavity preparation	CEA, DESY, STFC, INFN, CERN (R&D only)	FNAL, ANL, Jlab, KEK, other?	all SRF projects		
Develop a new infrastructure with a **versatile cryostat** to test fully equipped cavities of various geometries (or upgrade existing facilities)	• availability of **infrastructures for cavity testing**, bring the community together	DESY AMTF, CEA, INFN, STFC, Uppsala	FNAL, JLAB, KEK, others?	all SRF projects		
Demonstrate **improvment of cleanlines and reproducibility** with robotisation/cobotisation in clean room	• improve **preparation reliability and ease transfer towards industry**	CEA, CERN?, other?	IMP, (HPR, assy, string ass); CEA, FRIB (robot for HPR); other?	all SRF projects (arge Eacc i.e ILC, MC)		
Develop **field emission mitigation** / in-situ recovery techniques : plasma processing, dry-ice rinsing	• **improve preparation reliability**	Plasma: CEA, IJCLab, GANIL Dry-ice: DESY	FNAL, Jlab, ORNL, KEK, others	all SRF projects (existing & future)		
Investigation of **field emission : characterization** (diagnostics) and fundamental studies (SEY, surface treatment)	• improve the **cavity preparation process** (cavity preparation, string assembly, cryomodule assembly and installation) for high performances and reproducibility	CEA, INFN, ESS, IJCLab, DESY, STFC, CERN	FNAL, Jlab, KEK, other?	all SRF projects (existing & future)		

WG2 - THIN FILM SRF (C. ANTOINE, O. MALYSH

1. Continue R&D Nb/Cu (Priority 2)
It took 50 years to get (nearly) there; Nb can be a sublayer for other SC/Structures

2. Intensify R&D of new superconductors on Cu (Priority 4)
Interesting to operate @ 4,2 K instead of 2 K; Precursors for SIS

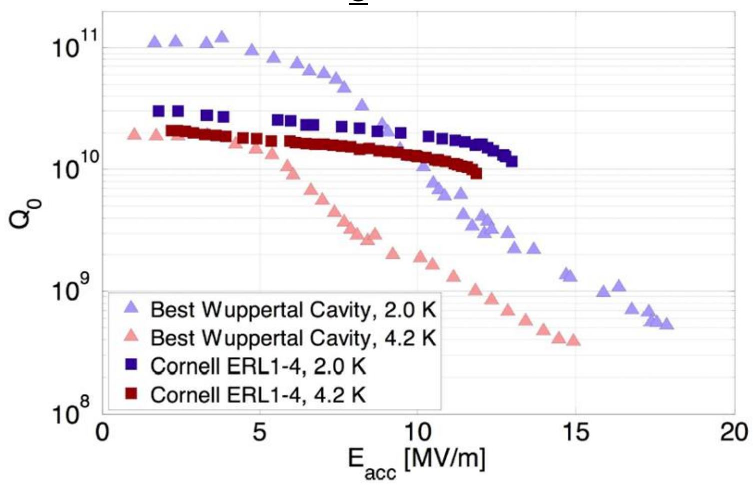
3. Pursue multilayers (SIS structures) (Priority 5)
Probably the only chance to go to high field **AND** high Q_0

4. Intensify Cu cavity production and surface preparation (Priority: 1)
Success of all films depend on it

5. Develop 3D printing and innovative cooling techniques. (Priority 6)
New cooling systems will be needed only if we success in previous points

6. Infrastructures and Manpower (Priority 3)
Reinforcements needed !!! Not novel infrastructures, but more of them and more support from the labs !
Multi-route teams - **INFN**: seamless Cu cavities, Cu surface treatments, Nb/Cu, Nb_3Sn **STFC**: Nb, Nb_3Sn, MgB2 by several different methods, 3 home made characterization tools; **CEA**: SIS, field emission reduction, characterization

Nb_3Sn on Nb



T_C~18K; @ 4,2 K: Q_0 x 20 vs Nb, @ 2K ~ the same

$E_{max\ limited}$, ~25 MV/m

Backbone technologies; perspective routes; IS and HR

HIGHER T_C MATERIAL AND SIS STRUCTURES

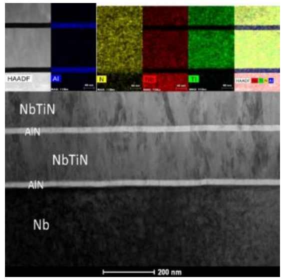
FNAL: Nb_3Sn
SIS in future

Cornell: Nb_3Sn
SIS NbN

DESY, Hambourg: ALD
SIS NbN, NbTiN

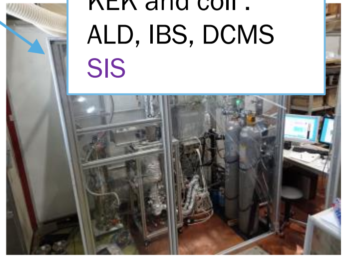
Temple U.+ LANL
MgB_2, hybrid
CVD/PVD SIS

USI: Siegen
HIPIMS
Nb, NbN,
NbTiN
SIS

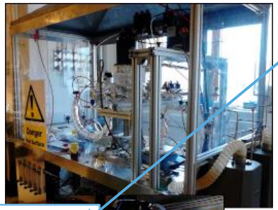


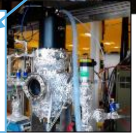
Jlab + ODU +
William &Mary:
ECR: **Nb** NbN,
NbTiN, SIS

Peking U. Beijing, CAS,
Lanzhou:
Nb, Nb_3Sn, MgB_2

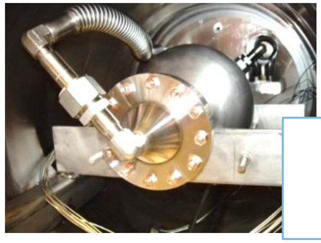


KEK and coll :
ALD, IBS, DCMS
SIS





STFC:PVD: DC, pulsed, HIPIMS,
(PE)CVD, (PE)ALD
Nb, NbN, Nb_3Sn, MgB_2, SIS

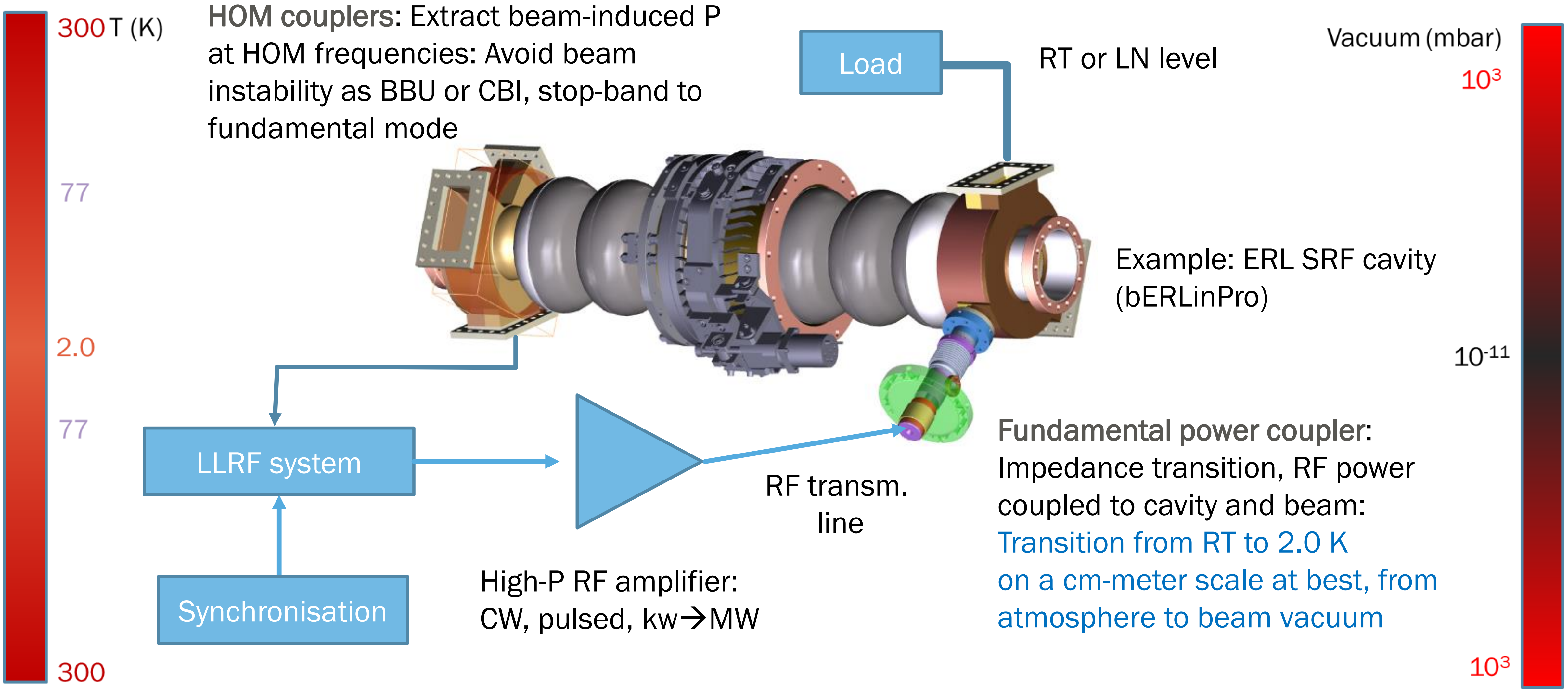


CEA Saclay:
ALD
NbTiN SIS

INFN Legnaro:
HiPIMS
Nb, Nb_3Sn

BARC Mumbai:
Spray coating, MS
Nb
RMS, NbN

WG3 - COUPLERS, FPC AND HOM (E.MONTESINOS, A. NEUMANN, F. GERICK)



WG3 - COUPLERS, FPC AND HOM (E.MONTESINOS, A. NEUMANN, F. GERICK)

- **GLOBAL GOAL**. Future HEP machines require **higher CW/pulsed power** couplers.
- **R&D AND LABS**. High power equivalent testing capabilities, to develop new technologies (window ceramics w/o TiN coating); keep expertise (!) in between projects in labs and industries.
- **Specific topics**: power handling, variable coupler, ceramics, heat load, cryomodule integration, machine integration, multipacting, clean room processes and tooling, test boxes, test benches, RF processing, resonant rings, cost optimization, mass production optimization

WG3 - COUPLERS, FPC AND HOM (E.MONTESINOS, A. NEUMANN, F. GERICK) (2/3)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort /Cost/Infr	Priority
M1bis: Build or upgrade a fully equipped bench for room-temperature high-power RF testing of 1 MW class CW FPCs @ 400 MHz with resonant ring	Single or Double Resonnant rings to reduce the cost of the test bench	CERN	All European labs		3y/4FTEy/2M€	1
M1: Build or upgrade a fully equipped bench for room-temperature high-power RF testing of 1 MW class CW FPCs @ 400 MHz		CERN	All European labs		4y/4FTEy/4M€	2
M3: Demonstrate the feasibility and assess high-power RF performance in a realistic cryogenic environment of a high average power cold window	Cold window at 200 kW average level	DESY	All European labs		3y/4FTEy/0.5 M€	3 (CW)
M4: Conceptual studies of novel FPC architectures and selection of the more promising ones for further prototyping	Variable couplers versus design of the window (disk, coaxial, cylindrical)	CERN	All European labs	All future HEP machines	3y/4FTEy/0.5 M€	3 (Pulsed)
M2: Demonstrate the feasibility of room temperature windows with equivalent power handling as the current state of the art, based on both high-purity and low SEY ceramic	Brazing of high purity (>99%) alumina ceramics	CERN	All European labs & Industry		4y/2FTEy/0.5 M€	5
M5: Demonstrate the performance at room temperature of a power coupler at 1 MW CW @ 400 MHz with current ceramics (up to 97,5 % purity alumina) or with new ceramics (> 99 %) if M2 is demonstrated)	Power levels not yet reached	CERN	All European labs		5y/2FTEy/1M€	6 (CW)

TEST INFRASTRUCTURES

AC, cold windows; CW, novel designs

New RT windows, their overall tests at 400 MHz

WG4 - NC VERY HIGH GRADIENT (W.WUNSCH, D. ALESINI)

- GLOBAL GOAL: **leverage on CLIC developments, for C^3, MC, FCC-ee, FCC-hh, plus multiple stakeholders**, as RFQ, electrostatic separators etc. (in general, smaller, nearer-term projects using overlapping technology)
- R&D, Maintain and apply. **Design – Simulation**: HG limits, control of HOMs, combined optimization with beam dynamics. **Tests**: new designs need validation, at high power and with beam. **Fabrication**: HG and high precision for linacs. **Domains**: Cavities, waveguide networks and components (e.g. pulse compressors) + Photoinjectors.
- R&D, Advance. **High field fundamentals** (breakdown, surface heating damage, FE, and material science, electromagnetism, plasma physics, test infrastructure e.g. for pulsed dc system. **High-gradient design** and field limiting quantities, **higher performance materials** (alloys, dielectrics etc.), **HTS**-based RF cavities and components. **Coolable cavities in strong H-field**: for MC (low-f) and for CLIC, C^3 and Physics Beyond Colliders (3 GHz).

WG4 - NC VERY HIGH GRADIENT (W.WUNSCH, D. ALESINI) (1/2)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort/Cost /Infr	Priority
General NC RF studies covering new geometries, breakdown studies, dark current modelling and simulations	a. Optimize structures for klystron based CLIC RF module. b. Optimize HOM damping with 'rectangular disks'. c. Design RF pulse compressor with correction cavities. d. RF design of accelerating structures for CLIC main linac with distributed coupling. e. Model dark current production and transport, and benchmark it against experimental data.	CERN, INFN	Improve simulation coordination - minimize time for structure optimization	Optimised structure design will fix the baseline of the whole HEP accelerator	5	1
NC RF manufacturing technology	a. Supervise/qualify copper-cell manufacturing companies b. Study/test alternative, brazing-free construction process c. Fabricate prototypes cells with integrated HOM damping loads d. Fabricate structure prototype for klystron based CLIC RF module e. Fabricate RF pulse compression system with correction cavities for klystron based CLIC RF module f. Fabricate 'rectangular disks' cavities based on geometry	CERN, INFN	Improve standardization of mechanical characterization & fabrication procedures	Demo of HOM damped RF cells/structure is key element for R&D of HEP X band accelerators	5	1
NC RF test stands	a. Consolidate the existing X band test stand facilities (CERN X Boxes, INFN TEX) b. Expand the number of X band test stand facilities c. Consolidate the existing test stand facilities in S-C Band (PSI, Valencia, Cockcroft Institute)	CERN, INFN, PSI, Valencia, Lancaster U	Improve standardization of conditioning procedures and BDR characterization	Experimental HP characterization of RF structures - crucial for HEP X band accelerators	5	1

WG4 - NC VERY HIGH GRADIENT (W.WUNSCH, D. ALESINI) (2/2)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort/Cost/Infr	Priority
Test stands for new materials resilient to beam losses and RF breakdown in vacuum	a. Identify materials with better performance than OFE copper re: RF breakdown and beam irradiation. b. Investigate experimentally effects of irradiation H- or other beams. c. Investigate experimentally maximum achievable electric field on surface in a DC test setup and compare it to OFE copper. d. Develop new assembly techniques for the new materials	Lancaster U, CERN, Uppsala U	Improve coordination & share results to standardize conditioning procedures and material characterization	OFHC Cu remains baseline for cavity realization/manufacture/characterization – its exploitation remains the main objective.	5	2
RF design and implementation of low/medium energy high-gradient linacs	a. Operation of CERN facilities (AWAKE, CLEAR, eSPS) b. Realisation of a full RF module prototype for the EuPRAXIA@SPARC_Lab project (INFN); c. Realisation and test of a high-gradient, high-repetition rate C-band RF gun (INFN).	CERN, INFN	Improve coordination, share linac results/strategy - conditioning procedure standardization	Implement/test high gradient X band technology on medium-scale facilities, to fix weak points for HE PP linac facility	5	1
RF test stand and test cavities for R&D on high-gradient NC RF in strong magnetic fields	a. Design/build RF test stand based on the available infrastructure and specific requirements b. Develop test program adapted to test stand, solve limitations in terms of available frequency, power, magnetic field strength and size of a SC solenoid; c. Design, build and test the prototype cavities. d. Synergies with RF guns & positron capture linacs operating in moderate magnetic fields which report increased BDRs	CEA, STFC	Improve coordination and share linac results/strategies for conditioning procedures standardization		5	

WG5 - RF POWER SOURCES AND HIGH EFFICIENCY (I. SYRACHEV, G. BURT, M. JENSEN)

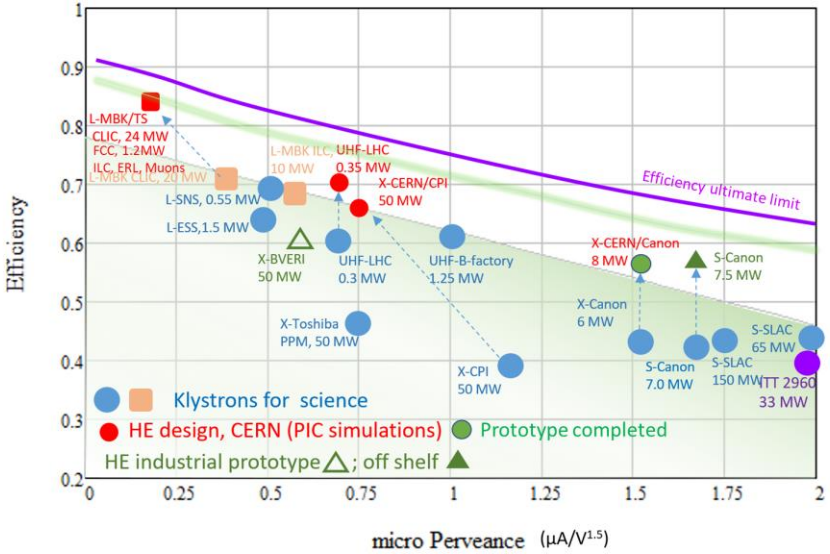
- GLOBAL GOAL. Simulation/design of HE klystrons and SSPA power combiner systems and prototype at High power with industry. Advance simulation tool capabilities, develop efficient solenoids for pulsed X-band klystron, RF power system design for MC. → complete replacement of HL-LHC klystrons.
- R&D AND LABS. Utilise and develop existing test facilities at CERN, Lancaster, Uppsala, INFN, Thales, Canon, CPI.
- On: advance RF simulation tool effectiveness, improve RF source technology efficiency, assess improved material applicability, prototype manufacture with industry, validate at high/low RF powers, develop efficient solenoids for pulsed X-band klystron and complete replacement of HL-LHC klystrons

WG5 - RF POWER SOURCES AND HIGH EFFICIENCY (I. SYRACHEV, G. BURT, M. JENSEN)

- Klystron (CW/pulsed) over broad frequency range (UHF – X-Band) dominate RF power sources for accelerators (>100 kW – 100 MW power range).
- Up to ~1GHz, SSPA becoming more applicable for light sources (synchrotrons/ERLs).
- **Sustainability and energy consumption demands, require strong industry motivation to minimise technology development risks – note that there is only 1 supplier in Europe!**
- **Overall** system efficiency: modulators, magnets, cooling and combiner systems also included.
- Technologies have broad applicability to compact accelerators in health, security and industry.
- Longer term for novel accelerators, enhancements required for very high frequency (100 GHz) RF sources (gyro klystrons) – beyond this implementation phase?.

Technology Development Path:

- Klystron: multi-beam, new bunching schemes, novel prototypes with industry (HE upgrade of LHC klystron by Thales;
- First HE X-Band klystron by Canon
- SSPA: Improved combiner efficiency, isolation of faulty services, cooling and device failure rate improvements.



WG5 – RF POWER SOURCES AND HIGH EFFICIENCY (I. SYRACHEV, G. BURT, M. JENSEN)

Objectives from Accelerator R&D Roadmap (CERN-2022-001)	Path	Labs/Org Involved	New collab's	Project Application	Time/Effort/Cost/Infr	Priority
High Efficiency **LHC klystron replacement** (in progress)	New **CSM techology developped at CERN** and communicated to industry for prototyping	CERN, Lancaster U.	Thales	**Increase of RF power for HL-LHC**, & reduced power consumption	1yr/4FTEy/0.8M €	1
High Efficiency **8MW X-band klystron** (almost completed)	CERN **design communicated to industry**	CERN, Lancaster U.	Canon	RF Efficiency increase from 42% to 56% & reduced power consumption	0yr/3FTEy/0.4M €	2
High Efficiency **50 MW X-band klystron**	CERN **design communicated to industry**	INFN, CERN	CPI	RF Efficiency increase from 40% to 65% & power consumption	2yr/INFN Funded	2
Two Stage (TS) MBK klystron design	New **techology in development** at CERN	CERN, Lancaster U.	None	Very high efficiency (80%) L-band klystron. Technology comaptible with **FCC, CLIC, ILC, ERL and MC**	2yr/4FTEy/0.2M €	1
TS **MBK klystron and modulator** prototype (FCC)	**Collaboration with industry** on the tchnical design and prototyping	CERN, Lancaster U.	Thales		4yr/10FTEy/4M€	1
Prototype of **Permanent Magnet Solenoid** for pulsed X-band klystrons	Novel technology development in **collaboration between CERN/industry**	CERN, Lancaster U.	ELYTT	Significant reduction of RF source power consumption	2yr/2FTEy/0.25 M€	2
High-power prototypes of **various solid state power combining systems.**	**Better transmission losses** = higher efficiency	CERN, Uppsala	Thales, Microwave Amps Ltd, Siemens	Improved efficiency for **light sources**	3yr/6FTEy/0.25 M€	2
Develop RF power sources concept for **Muon cooling complex RF system.**	**High average powers** required	Lancaster U, CERN	Thales	Long term	5yr/7FTEy/0.05 M€	3
Development of **Gyrotron/Gyroklystron prototypes at 36 and 300 GHz**	Increasing **peak powers at high frequency**	Strathclyde U	Thales	Long term	5yr/5FTEy/0.2M €	3
Development of a **36 GHz MBK klystron** prototype.	Small **modular amplifier without oil** or large B field	CERN, Lancaster	Thales	Long term	5yr/4FTEy/0.2M €	3
Design and build prototype **Fast Reactive Tuner (FRT)**	**Reduction in RF power from microphonics or detuning**	CERN, Lancaster, Euclid		Reduced power for **synchrotons and ERLs**	3yr/6FTEy/0.3M €	1

WG6 - LLRF, AI AND ML (W. CICHALEWSKI, +1)

- GLOBAL GOAL. Maximise operational performance and fault-resilience of RF control and synchronisation systems.
- R&D AND LABS. Utilise a variety of RF test facilities to develop suitable solutions for ERLs (PERLE, LHeC), HL-LHC, FCC, CLIC and MCs
- On: **Reduce RF power:** Conceptual technology studies, design/build transient-detuning prototypes and demonstrate fully integrated solution. **LLRF:** uTCA h/w for HL-LHC crab/accelerating cavities, white rabbit link, centralised computing infrastructure for FPGA and System-On-Chip R&D. **AI & ML:** Embed AI/ML in testing/commissioning/operation, algorithm development for early fault detection/mitigation, live data analysis demonstrator, decrease trips on test accelerator and/or operational machine with automatic categorisation of faults, self-calibration, predictive counter-measures.

WG6 - LLRF, AI AND ML (W. CICHALEWSKI, +1)

- **Technologies to reduce RF power: Frequency control for High-Q SRF cavities:**
  - Low beam-loading: For small cavity bandwidth, increased microphonics sensitivity requires over-coupled cavity with substantial increase in RF power. Rapid frequency correction can reduce power demand 10-fold (i.e for ERLs).
  - High beam-loading: Cope with rapidly changing beam currents, minimising peak power, cavity frequency optimised for max. or 50% beam current. Changing cavity tune during transients can significantly reduce peak power (i.e. HL-LHC injector by ~50%).
  - Ferro-Electric – Fast Reactive Tuner (FE-FRT) gives external ability to shift cavity frequency extremely fast, technology is demonstrated and a full-scale validation for LHC is underway, with ERLs and FCC being also directly applicable.
- **Low-level RF:** High performance COTS LLRF systems available, lab focus shifting to high performance software R&D.
  - Challenges: 1) Minimise RF power by advanced beam-loading compensation for high current machines, 2) using very low noise modulators/demodulators, 3) large machines require instantaneous RF transmission to large number of stations (i.e. etc), 4) standardise software and firmware blocks – exchange amongst labs and 5) maintain growing software and firmware libraries.
  - Priority developments: White Rabbit, Update Links for synchronisation, System on a Chip: FPGA/DSP/ADC to significantly reduce development effort/time, new platforms such as uTCA/ATCA to standardise with industry.
- **Artificial intelligence and machine learning (RF conditioning and operation):**
  - Real-time detection to provide advance warning and corrective measures to avoid faults (i.e. field emission, arcs and trips). Requires fundamental shift in taking data to make available for AI/ML. Reactive and pre-emptive fault classification with corrective algorithm developments.

FIRST SEMESTER 2023 –PROPOSAL OF GOALS, MEETINGS (TO BE THEN DISCUSSED WITH LDG ON NOV 21, MAYBE TO CERN COUNCIL ON DEC 16)

- Council meeting (mid December): we aim at a more consistent definition path for each WG
- Proposed meeting with the previous panel: mid January 2023
- From last week of January: 1 meeting/month, plus others if needed
- January-April 2023: work of the RF WGs, to investigate/discuss with R&D groups and projects and funding agencies and setup a proposed implementation plan (coordinated within the RF Coordination Panel as a whole)
- April 2023: presentation of a resource-loaded **RF** implementation plan with milestones, based on the interactions with: I. National groups and projects on one side; II. Funding agencies; III. LDG
- May-end of June 2023: *discussion among the 5 panels (cross-field priorities discussed here?)*
- Supposed goal for end of June 2023: *provide national funding agencies with a coordinated plan and priorities from amongst the 5 pillars (request by INFN to have global priorities defined by mid 2023 – DN said we shoudl query the Council?)*

ISSUES RAISED AT THE K.O. MEETING (FOR TODAY'S DISCUSSION, AHEAD OF THE REVIEW MEETING WITH THE COUNCIL)

- Current focus on RF coordination within Europe; we are considering setting up internatioanal advisoru panels
- Can we have a calendar of presentations (to LDG, CERN Council, ECFA, others…)?
- Which report, which template (to LDG, Council, …)?
- Resource Review Board? (every 2 years, template?)
- Involvement of members of the panel (10% ?) - Mission letter? By LDG or by national FAs?
- How are the different labs notified of this initiative ? (we understand that in some cases the information did not reach the working groups/projects)
- Funding for travels from National FAs
- Any fundings for workshops ?
- LDG Secretariat, document repository, recording of actions from these meetings…?

BACKUP

MAIN ITEMS FROM THE ACCELERATOR R&D STRATEGY

- **BULK NIOBIUM**
- LG-MG materials, development and validation
- Vacuum heat treatment and doping
- Surface polishing and characterisation techniques

- **FE REDUCTION**
- Robotisation/cobotisation for surface processing/cleaning
- Particle counting in clean room and X-ray diagnostics
- FE mitigation, in-situ recovery

- **THIN FILMS**
- Nb/Cu improvements
- New superconductors at 4.2K
- Multilayers (*2 in Q, *30-50% Ea increase)
- Cu cavity production and surface preparation
- 3D printing and innovative cooling
- High-throughput testing, infastructure and personpower
- **COUPLERS (CERN, ...)**
- High performace ceramics
- Architecture and components of FPCs
- Test stands

- **NC HIGH GRADIENT STRUCTURES**
- NC RF studies, geometries, breakdown, dark currents…
- NC RF manufacturing technologies
- mm-wave and high frequency structures
- **HIGH RF POWER (CERN, …), LLRF (CERN, STFC, DESY)**
- High-efficiency klystrons and SS amplifiers
- mm-wave and gyro devices
- Technologies to reduce RF power needs (for LHC, FCC, MC, ERLs…)
- uTCA based LLRF and CS for SRF, LHC ellipticals, etc.
- AI AND ML, to detect cavity quenches, classify anomalies, apply to demonstrator or existing facilities

- TEST STANDS

- NC RF test stands: for structures/components of various types, push breakdown limits, qualify materials/designs
- Materials (resilient to beam loss and RF breakdown in vacuum) – synergy with MC; cryogenic DC tests of Cu (to 30K and maybe below 10K); tests of irradiated materials, RF conditioning, DC testing
- LOW-MID ENERGY HIGH GRADIENT ELECRON LINACS: design of full RF modules, test as facility backbone (EuPRAXIA, AWAKE)
- High-gradient NC RF in strong H-fields
- TI FOR DRESSED SC CAVITY TESTING: from bare cavities/ancillaries to fully-dressed cavity test to cryomodule engineering, to high-P test. For fully-dressed cavity improve existing test stand or build new more flexible ones.