Meeting opening:
Objectives, Milestones and Deliverables

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WP9 coordinators

WP9 objectives

- Define a strategy for innovative superconducting RF (SRF) cavities coated with a superconducting film.
  - Deposition techniques: PVD and ALD
  - Superconducting films: Nb, NbN, Nb_3Sn, V_3Si (and others) and SIS
  - Optimization of flat SRF thin films production procedure
- Optimise and industrialise the production
  - of seamless copper cavities and
  - of the deposition techniques.
- Produce and test prototypes of SRF (single-cell elliptical) cavities:
  - Initially with pre-prototypes with f = 6 and 3 GHz
  - Scaling up for f = 1.3 GHz.
- Test a new laser treatment of Nb coated cavity.

➢ **Main goal**:

- Improving the performance and reducing the cost of acceleration systems
  - both production and operation

- **Task 9.1**: **Coordination** and strategy for innovative superconducting accelerating cavities
  - *CEA, INFN, HZB, HZDR, LancU, UKRI, USI, JLab…*
    - *Task Leaders: C. Antoine (CEA), O. Malyshev (UKRI)*

Coordination

IFAST WP9 Milestones		IFAST WP9 Deliverables	
MS37 International thin film workshop organization (web site + Report) Report by Claire, Cristian and Oliver? Ask for changing to M29	M28	**D9.1:** Thin-Film SRF roadmap report. *Summaries of the results obtained within the workpackage and prospective inspired from WP advances as well as discussions at TF-SRF 2022.* Report by Claire and Oleg with contribution from all partners by Jan. 2024	M35
MS38 First seamless copper 1.3 GHz cavity produced as substrate for the coating of the SC film (Report - done)	M12	**D9.2:** RF test on coated resonant cavity. *Resonant cavity coated and tested with an alternative material to Niobium with a $Q_0 > 10^9$ at 4.2 K and 1.3 GHz.*	M46
M39 Coating facility built and tested at STFC, USI and INFN (Report - done)	M12	**D9.3:** First 6 GHz cavity coated and characterised. *Results from the morphological and SC characterisation of first coated cavity with an alternative material to Niobium.* Report by Cristian and Reza by end of Feb. 2024	M36
MS40 Construction and operation of the cavity dedicated ALD system (Report - done)	M24	**D9.4:** Deposition of superconducting multilayers on cavities. *1.3 and 3 GHz Nb and Cu cavities coated and tested with multilayers.*	M46
MS41 A facility for laser operation for complex 3D treatment is tested on 1.3 GHz cavity (Report) Report by Artur, Cristian and Reza by mid-March 2024	M36	**D9.5:** 1.3 GHz Nb-coated cavity irradiated by laser in Ar atmosphere and RF tested. *Increasing of the field of magnetic flux entry in Nb coated 1.3 GHz cavity irradiated by laser in argon atmosphere. Standard RF testing.*	M45
MS42 ARIES samples prepared for renewed SC film deposition (Report)	M6	**D9.6:** Test of thin-film samples. *Four thin film samples reprocessed by 4 different techniques and tested with QPR.*	M46

- **Task 9.1**: Coordination and **Strategy** for innovative superconducting accelerating cavities
  - *CEA, INFN, HZB, HZDR, LancU, UKRI, USI, JLab…*
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- This tool is now used for participation in **Accelerator R&D Panel for implementation of the Accelerator R&D Roadmap of the European Strategy for Particle Physics (ESPP)**
  - The Large Particle Physics Laboratory Directors Group (LDG) was mandated by the CERN Council in 2020 to develop an Accelerator Research and Development roadmap.
    - This Roadmap (Annex 1, https://cds.cern.ch/record/2800190?ln=it) was presented to the Council at its meeting in December 2021 and the Council invited LDG to elaborate a detailed implementation plan.
  - C. Antoine and O. Malyshev are co-chairs in WP2: SC TF cavities

First task from Accelerator R&D Panel

To study:

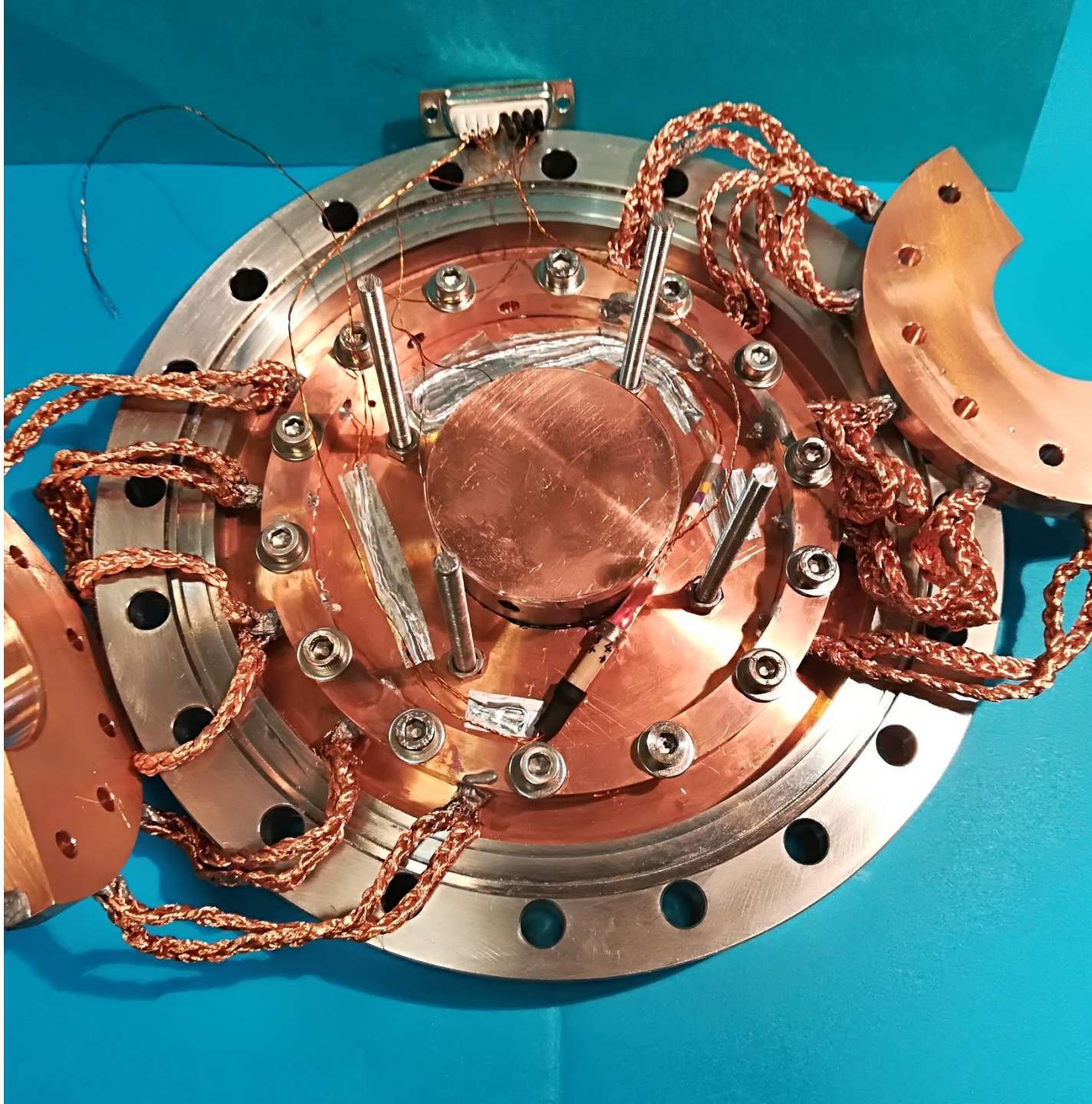
- How big or small is the thin film SRF community in Europe,
- What are we going,
- What is an annual budget,
- How well we are integrated,
- Is there any duplication,
- If we have a larger budget would it give a greater impact on deliverables.

- In June 2023, we invited 1 or 2 leaders from each partner in Europe (including CERN and DESY) to fill an EXCELL table
- The results were analysed and reported to Giovanni Bisoffi (INFN) and Peter McIntosh (STFC), the coordinators of LDG RF Implementation Panel
- They reported a summary of this at Community Report on Accelerators Roadmap on 12–13 Jul 2023 at INFN-FNL

A survey summary what we reported

Roadmap HE ESPP
Accelerator R&D strategy

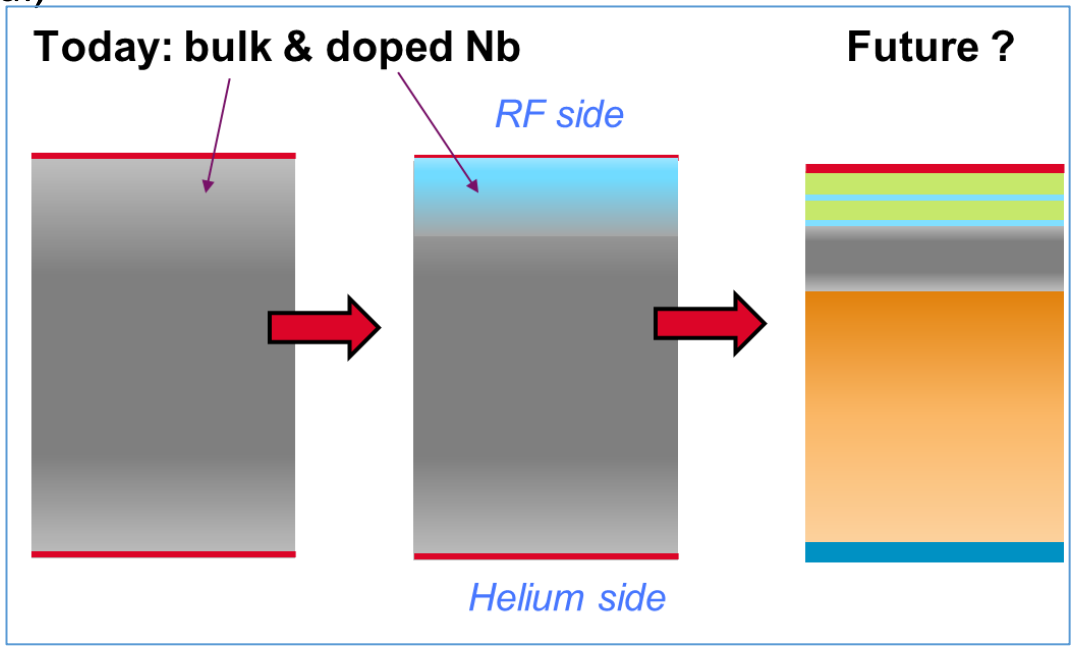
15-06-2023



Thin films for SRF cavities: only route to higher performances

- High accelerating gradients for colliders … *and also compact small machines for medical/industrial applications*:
  - => shorter machines (linear), less cavities (circular)
  - => investment savings in building, superconducting material, RF installations….
- High Quality factor for colliders … *and EVERY other types of accelerators!!!*:
  - => possibility of operation at 4K or even higher
  - => investment and operation cost savings in cryogenic installations
  - => lower plug power (greener operation)
  - => opens the way to new cooling processes (He issues)

Cryogenics @ 4.5 K instead of 2K:
- ***Investment decreased by~35-40 %***
- ***Operation cost decreased by ~60%***

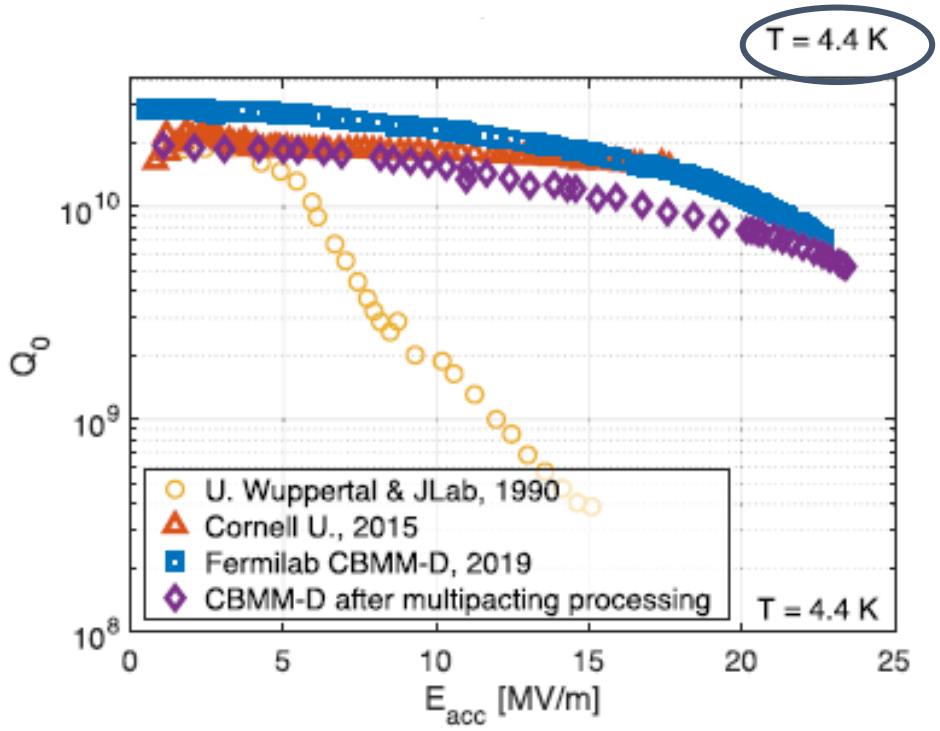


Future : totally functionalized material, each layer its own role (thermal conductivity, high superconducting performance, multipacting mitigation….)

Driving motivation - A15 materials

- A15 materials are very promising, but…
  - Only achieved on bulk Nb cavities (USA, Sn diffusion)
  - A15 on copper: several methods of deposition are studied in EU labs (results on samples mainly)
  - Tunability, field trapping must be assessed
- Other materials:
  - A15 family (to avoid synthesis complication)
  - NbN or NbTiN (less performance in field but easier synthesis)
  - MgB_2 (higher temperature operation, Tc not too sensitive to composition)
  - SIS: higher performance, less sensitivity to defects

Posen, S., et al. (2021). Superconductor Science and Technology **34**(2): 025007.



- *Nb_3Sn cavities exhibit a Q0 @ 4.5 K comparable to bulk Nb@ 2 K, but….*
  - *Accelerating gradient is limited (~25 MV/m)*
  - *They are more sensitive to trap flux*
  - *Nb_3Sn is brittle (tunability)*
  - *Achieving the right composition is tricky*
- ***More R&D required!!!!***

Strategic topic	1) Continue R&D niobium on copper	2) Intensify R&D of new superconductors on Cu	3) Pursue multilayers (SIS structures)
Achieved	Nb/Cu behaving like bulk Nb @ CERN (for $\leq$ 10 MeV/m) and Jlab	Nb_3Sn in Nb cavities (high Q_0), others SC (NbN, NbTiN, V_3Si…) on samples (in many labs)	Higher transition field, lower RBCS on samples, @DESY, HZB, HZDR, STFC, USI First SIS 1.3 GHz cavity tested @ CEA
Expected soon (1 to 4 years)	Reproducible series Improvement of cavity performance by laser and FLA annealing	Nb_3Sn in Cu cavities Prototype - IFAST delivery (2025) Possible laser annealing for A15 phase tuning (on samples)	More cavities deposited and tested @ CEA, INFN, STFC, USI Lower R_s than Nb @4.5 K
Future (5 to 10 years)	Also, thick Nb/Cu as under-layer for higher T_c material	Alternate superconductors w. less production risks, operation at 4.2 K instead of 2 K.	Combined with material developed in 1) and 2) : less sensitive to defects => less production risks.
Comments	Short term: moderate performance improvement: Average $Q_0 = 1\times10^{10}$ at 20 MV/m at 2K on 1.3 GHz cavities. Then push to 25 MV/m, Long term: multicell coating	Medium term: Q_0 improvement, moderate E_{acc} Long term: multicell coating	Medium/longer term: E_{acc}, Q_0 improvement Less sensitive to defects Long term: multicell coating
Challenges/ issues	Going from a few prototypes to reproducible production, LHe availability, **Lack of staff**. Cu cavity manufacturing	Achieving correct chemistry Deposition targets Tunability of brittle material, **Lack of staff**.	Going from samples to cavity: deposition techniques adaptation, larger deposition set-ups. **Lack of staff**.

Strategic topic	4) Intensify Cu cavity production and surface preparation	5) Develop 3D printing and innovative cooling techniques	6) Characterization (Bottleneck 1)	7) RF testing prototypes (Bottleneck 2)
Achieved	Several routes explored An emphasis on seamless (CERN, INFN)	Just starting, promising results. Compatible with LHe and/or cryocooling	Current surface/ material characterization in most labs… … + specific SC tools	QPR: CERN, HZB and DESY Chocked cavity (STFC) and 6 GHz split cavity (STFC and INFN). 6 GHz cavity (INFN). Limited access to clean room, cavity RF testing
Expected soon (1 to 4 years)	Larger scale production, Optimising seamless spinning production	Double walled Cu cavities	More tests in new facilities	Research RF 1.3 GHz facility (end of 2023) at STFC Refurbishment of the INFN set-up
Future (5 to 10 years)	Look for industry partners	Need to optimize surface treatments before deposition	Need for high quality characterization: funding for development and/or subcontracting needed	STFC: potential for full power RF test in SuRF lab facility for serial produced cavities
Comments	Short term, but necessary step for all over topics	Medium term Necessary in view of LHe market evolution	Current surface/ material characterization in most labs, cross-testing the sample within IFAST WP9 – **needs extension** …	Limited access to (1) clean room, (2) RF testing
Challenges/ issues	Lack of industry interest, funding. Need to optimize surface treatments before deposition. Compliance with dimensional tolerances for spinning.	Surface roughness. No funding after 2023	Subcontracting or common equipment? Budget +collaboration agreement needs to be considered	Can labs re-equilibrate the balance between R&D needs and projects? Or building specific shared equipment for EU labs?

Finance and staff

	Staff	PhD students	Finance per year	
Present	30	9	871 k€	
Ideal	60	18	2100 k€	

Additional resources will allow:

- To intensify R&D and accelerate the progress in a field
  - With more staff, postdocs, PhD students
  - More SC materials to explore
  - More tests of TF coated RF cavity, as well as QPR, choke cavity and split cavity
    - To operate existing facilities, which can be used in present due to lack of staff
    - To cover LHe, consumables and electricity costs
  - To intensity laser and FLA annealing of TF on copper samples and cavities
- Scale up of 3D printed cavities, surface state improvement on cavities, explore new 3D processes
- Procure new essential equipment or services
  - For newly built or upgraded existing facilities
  - More copper cavities and their polishing
  - More deposition targets
  - More surface/material characterisation and SC property measurements
  - To enable clean room access
  - New furnace + new ALD coating set-up (to progress to larger cavities and multicell cavities)
  - Quicker progress to multicell coating and testing

Roadmap for future R&D

- Road map has already been clearly identified by the present European actors
  - Collaboration within Europe is active
  - International Collaborations are also active
- Worldwide the landscape is the same:
  - Small teams with limited budget, limited technical support, limited access to RF tests
  - Project always come first, hence R&D is very slow
- Bulk Nb technology has reached its theoretical limits in terms of performance
- Difficult to build ambitious/ advanced machine with the same Nb technology: costs increase with:
  - Increased technological demand (higher energy, higher power machines…)
  - Increasing energy costs
  - Increasing He costs
- Thin films:
  - No European program after 2025 (except ISAS, w. limited participation)
  - Most lab have limited R&D resources (sometimes, individual countries too ☹)

We need to change paradigm !!!

Next steps

Roadmap HE ESPP
Accelerator R&D strategy

20-10-2023

What we should report to LDG and CERN Council

- It is now time to follow up the consultation of the European R&D communities by each WG, through surveys, workshops, or any other ways you may have adopted. All this process must be summarised to LDG and CERN Council, in a report which we should start writing around 20th October 2023.
  - A meeting with at least a representative per each WG.
  - Each WG will be allocated 15', 5' presentation (max 3 slides), 10' discussion.
  - The specific aim of the meeting is to have an update on how far each WG is, in **the consultation of its community**
    - (no scientific details in the presentation, these will come later on).

Memorandum on the Info to collect from the European Teams

- Each WG to report on the progress (timeline) on the survey of each national team in their European reference community on the following content:
  - Areas of specific expertise/strength/weakness (within the WG theme)
  - Table of main devices, their specs (new)
  - Current R&D activities in HEP, and outside HEP (improving the RF field on performance, reliability, energy efficiency, cost) (partially new)
  - Current FTEs involved (partially new)
  - Current budget (which source of funds) (partially new)
  - Interest in future HEP activities (partially new)
  - Which activity would they expand on, in case of extra-funds/additional personnel (partially new)
  - Overlaps/Affinity with R&D carried out in others labs (partially new)
  - Current collaborations with other Institutions (partially new)
  - Available infrastructures, needed infrastructures, insufficient infrastructures (partially new).
- We will send a new survey soon to 1-2 leaders from each partner institution.

NEXT WP11 meeting

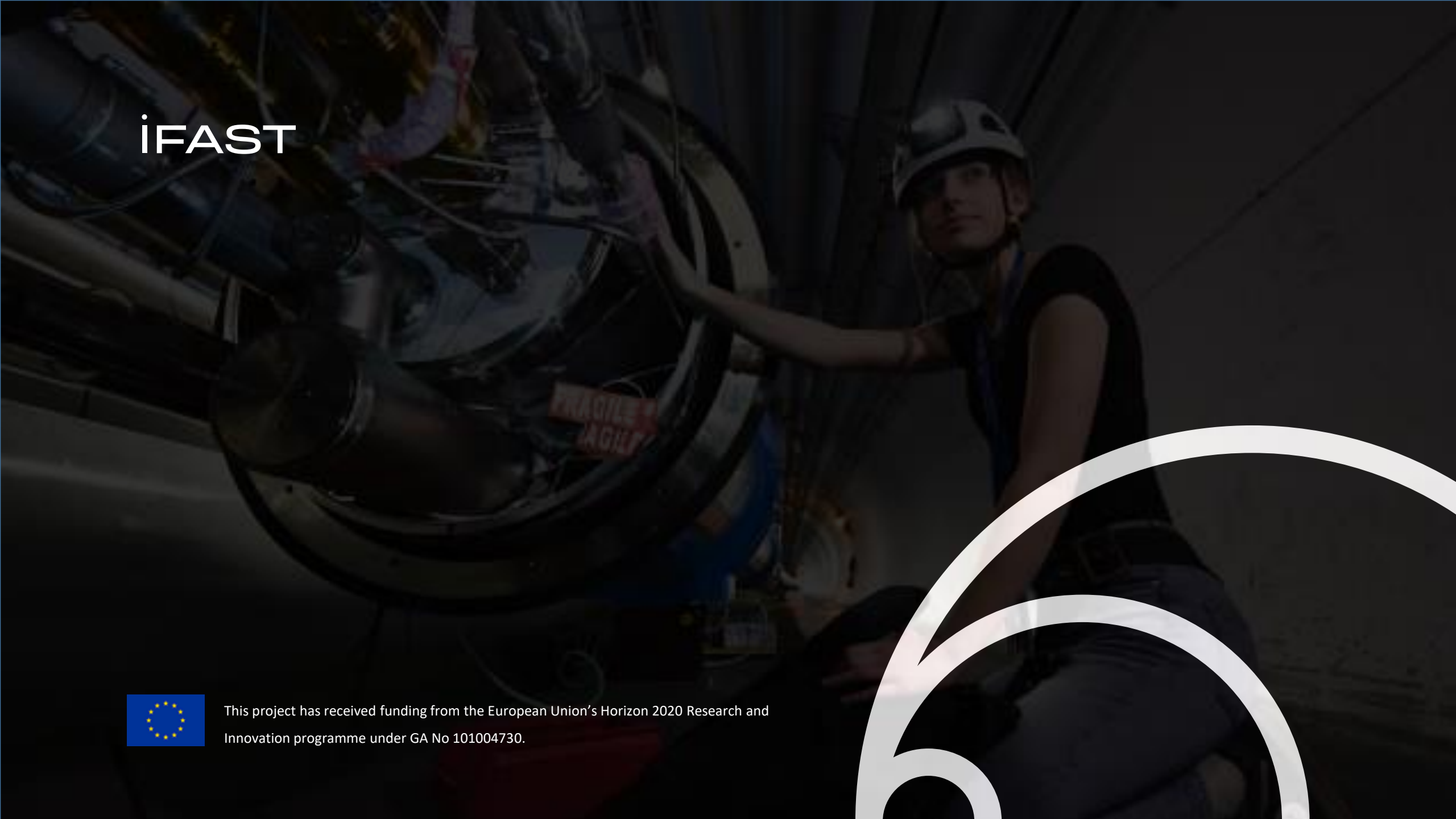
- In-Person meeting
  - In Daresbury Laboratory
  - on 18-19 January 2024
  - Starting at 14:00 CET on 18th Jan
  - Finishing not later than 16:00 on 19th Jan
  - Hybrid (in person and zoom)

2024 IFAST Annual Meeting

- In-Person meeting
  - on 15 to 19 April 2024
  - Near Paris – TBC

HiPIMS supply

- https://energypulsesystems.pt/eps/



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