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WP13 General context

- The **European Technology Infrastructure (TI) for accelerators and magnets** is the ensemble of Technological Facilities (TFs), encompassing large-scale Technical Platforms (TPs) for development, fabrication, assembly, integration and performance verification of accelerator and magnets components, together with large concentrations of dedicated, highly-skilled personnel.
- Follow-up of the **H2020 AMICI project** (01/2017-10/2019), which has established the distributed AMICI TI and investigated how it could be reinforced, harmonized and made more efficient, and industry could benefit more from the possibilities offered by the TPs (see http://eu-amici.eu/).

The AMICI collaboration

- Available Technical Platforms (TPs) in the different TFs have been inventoried and are presented on the AMICI website
    - https://amici.ijclab.in2p3.fr/technology_infrastructure

CIEMAT has now joined AMICI and PSI left

WP13 general objectives

- Propose a strategic approach ensuring the long-term sustainability of the TI and the development of its capabilities in view of the construction of future accelerator-based RIs.
- Extend and strengthen the cooperation with industry to exploit opportunities of fostering innovation in related technologies.
- Develop and promote services, within a common approach, for the benefit of RIs, future scientific projects and high-tech industry.

Task 13.1: Strategy for the development of the AMICI TI

- Analysis of the landscape of the different scientific fields that could need the AMICI TPs
- Adoption of a classification of the TPs according to pre-defined categories and sub-categories.
- Status and future plans for each category taking into account the needs for the different domains
  - ↪ **To be presented during this workshop and discussed with the stakeholders and potential users, in particular industry, before establishing the roadmap**

The landscape analysis

- Analysis of the landscape of the different scientific fields based as much as possible on roadmaps or reports from the concerned communities
  - Particle physics
  - Nuclear physics
  - Energy
  - Material and biological science
  - Medicine and other applications

Particle physics needs for TIs

The European Strategy for Particle Physics Update (ESPPU) proposes a vision for the near-term and long-term future of particle physics.

All large-scale particle accelerator facilities are currently based on radio frequency (RF) acceleration with cavities and use of superconducting (SC) magnets, but **advanced R&D programs are needed and are being developed to push the limits of RF technology and SC magnets.**

Infrastructure and facilities for superconductor and magnet activities

High field magnets (HFMs) are among the key technologies that will enable the search for new physics at the energy frontier, and Nb3Sn and high critical temperature (HTS) superconductors are being developed to produce higher magnetic fields than those achieved in the LHC.

Manufacturing infrastructure needs includes machinery for the production of Nb3Sn and HTS cables, insulation and braiding machines, winding machines, reaction furnaces, vacuum pressure chambers, presses, and tooling.

Test infrastructure includes test stations for the electro-mechanical qualification of HTS and LTS wires and tapes, test stations for HTS and LTS cables, high-field magnets for measuring HTS coils, vertical test stations for the test of LTS and HTS R&D and demonstrator magnets, equipment for standard electrical and mechanical tests and measurements, and magnetic measurement benches.

Infrastructure and facilities for SRF and NC RF technology

Required infrastructure for developing and testing superconducting RF (SRF) technology, from bulk Niobium and thin-film coating efforts. **Testing infrastructure includes small test cryostats, vacuum furnaces, and facilities for Atomic Layer Deposition.**

To improve RF performance of normal conducting cavities (NC RF), **novel developments in cryogenically cooled copper alloys, higher frequency structures** are needed. For muon colliders, R&D is required to address the decreased RF performance in high magnetic fields.

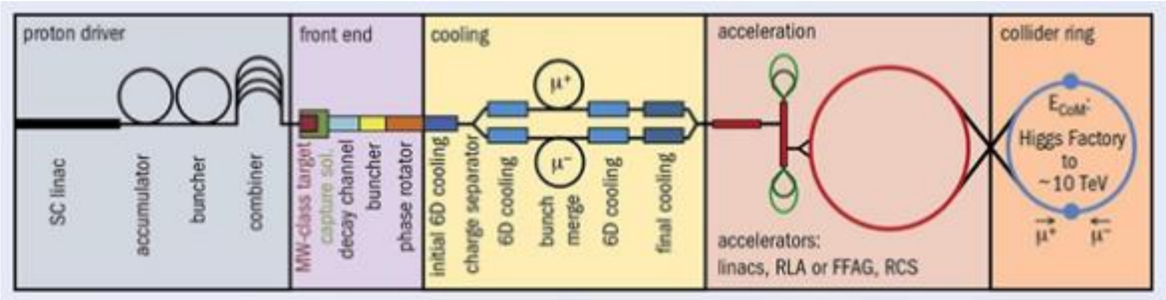
Efforts are also underway to **design high-efficiency klystrons and fast ferroelectric tuners** to reduce the required RF power. AI has shown potential for optimizing RF performance, and LLRF systems require standardization and simplification to decrease costs.

The R&D program on RF accelerating structures relies on a network of existing partners who share test infrastructures, and the **new R&D goals require sustainable operation of these facilities and an increase in capacity**.

The infrastructure can be shared among AMICI partners, but with an increased number of projects and throughput, **more elaborate test facilities may be required.**

Bright muon beams and muon colliders needs for TIs

- A design study for a **Muon Collider complex at 10 TeV center of mass, MuCol,** has been funded by the EU to deliver a conceptual design report in 2027.



- Challenges that need to be addressed to develop a muon collider :
  - The **RF system of the muon ionization cooling** is unique and requires dedicated developments and tests to validate the theoretical models and study the behavior of the cavity prototype under high magnetic fields.
  - The **normal-conducting cavities** of the muon cooling system need to be filled with short high-power RF pulses to avoid excessive power losses in the walls.
  - The **magnets** required for a muon collider span a very broad range of technologies, from ultra-high field superconducting solenoids to very fast resistive pulsed dipoles and quadrupoles.
  - The **ionization cooling cells** are unique to the muon collider and pose specific challenges not only for the components but also for the integration.

Infrastructure and facilities for muon colliders

Test infrastructures are needed for a muon collider, specifically for the period of 5-10 years (2023-2033) and 10-15 years (2033-2038).

In the first period,

- a **high-field magnet test station** is needed to measure RF breakdowns in normal conducting cavities in the frequency range 600-800 MHz ,
- a **test facility for a complete ionization cooling cell** is required to validate the 3D model and ensure performance is reached,
- and a **beam test facility** is necessary to test the behavior of a production target within the solenoidal field magnet and subsequent capture system.

In the second period,

- a new test facility is needed to host a **mock-up cell of the collider to test the wobbling**, which is necessary to increase the average emission angle of neutrinos and mitigate the neutrino hazard for a 10 TeV collider. The aim of this test facility is to verify that all the elements can be moved by a reproducible way to wobble the beam trajectory.

Overall, **recent developments in RF, magnet, and target system technology programs will benefit a muon collider**.

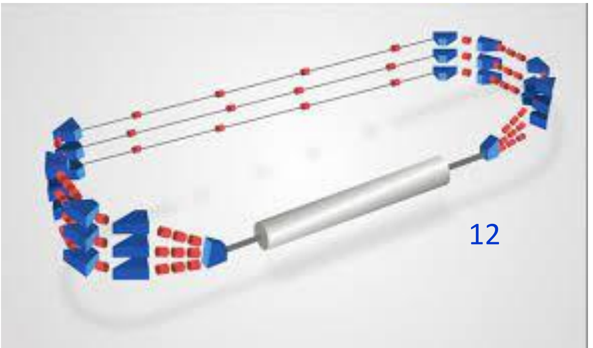
Energy Recovery Linac needs for TIs

- **ERLs (Energy-Recovery Linacs)** combine the high current-carrying capability of storage rings with the efficiency of energy recovery process, making them **a game changer in accelerator technology**

- They have been successfully demonstrated in SRF facilities and are used in various applications in photon science, nuclear and high-energy physics. The 2020 European Strategy for Particle Physics highlights ERLs as an innovative accelerator technology deserving of R&D efforts.

- However, **challenges such as CW operation, high beam current handling, low beam energy spread, and low beam emittance** delivery must be addressed through technical developments and infrastructure.

- Key technical developments include **high cavity quality factors,** multi-pass recirculation, and compact footprint machines.



Infrastructure and facilities for ERL

Two main topics are related to future Energy Recovery Linacs (ERLs):

high-current electron sources and SRF technology.

The quality of the photocathodes is crucial for the performance of the photoinjector of high-current electron sources in terms of emittance and current. Ongoing research focuses on understanding the electronic properties of the materials, the photoemission process, and the intrinsic emittance. **This requires a specific infrastructure for thin layers development and characterization**.

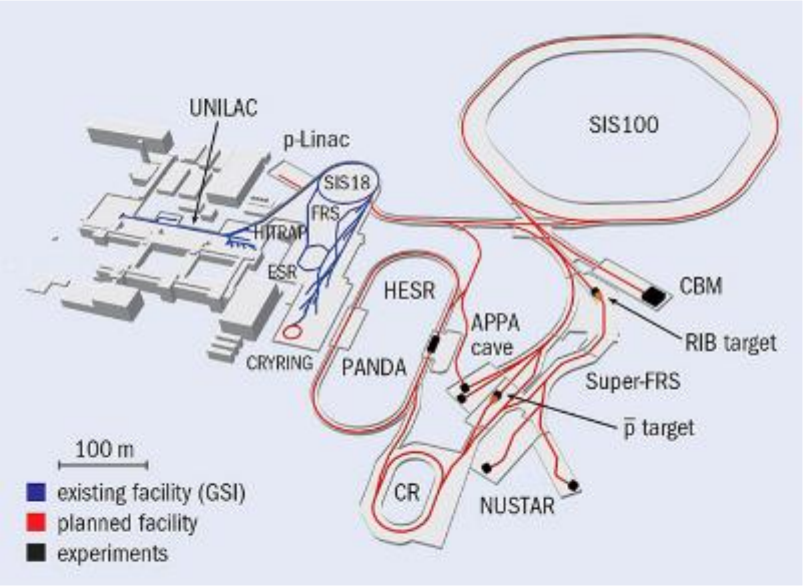
SRF technology will emphasize the importance of developing SRF cavities for near-term 2K developments and the 4K perspective to reduce the RF power dissipation in CW operation. For this purpose, **cavity surface preparation and cryogenic testing in appropriate technical facilities are required** to validate the RF design of the bare cavity, followed by qualification of the dressed cavity.

Technical infrastructures needed for ERLs include testbed machines, prototype qualification, and series tests

Nuclear Physics needs for TIs

- The **technical challenges for accelerators in Nuclear Physics** (NP) are diverse and include improvements in high-power target applications and beam instrumentation.
- These challenges are not limited to NP and are **shared with other applications such as spallation neutron sources, neutrino facilities, and fusion energy reactor materials**.
- Technical advancements in **high current ion sources and low-beta superconducting cavities** are also important for improving accelerator performance and compactness.
- Automation and artificial intelligence tools like Reinforcement Learning and Bayesian optimisation are being developed to reduce accelerator preparation time and improve operational reliability.
- Improvements in radiation-resistant electronics, robotics, energy optimization, digital mock-ups, and automatism in survey and alignment will impact the precision, reliability, user-friendliness, and environmental and radioprotection acceptance of NP machines

Infrastructure and facilities for Nuclear Physics



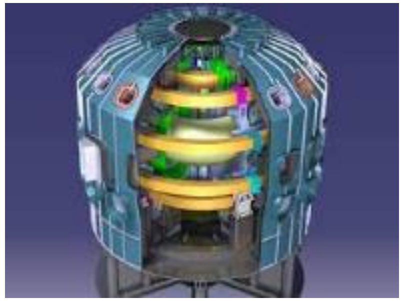
Technological developments on most of the aspects described are quite project-specific and carried out in the laboratories.

New shared platforms, which the NP accelerators (and other fields) would benefit from :

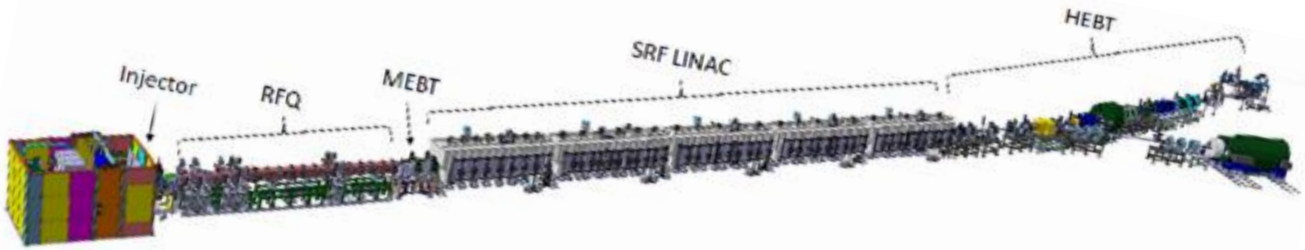
- **Development and tests of high current ion sources**
- **Development and tests of high-power targets** from the largest possible variety of beam species, currents, and energies
- A larger number of **test stations for testing high-power RF amplifiers (of higher energy efficiency) and RF couplers**

On the other hand, there are several Technology Platforms which have already been declared available in the framework of the AMICI project. They refer mostly to the developments, treatments (e.g. thermal and chemical) and tests of superconducting cavities and their ancillaries, such as power amplifiers, couplers, cryomodules (CEA, INFN, DESY, CIEMAT and FREIA).

Energy Applications needs for TIs



- Fusion is using Technological Infrastructures especially for accelerator and superconducting magnet developments (ITER, JT60SA, DTT, IFMIF-DONES).
- Potential breakthroughs in the use of high-temperature superconducting materials for fusion could lead to a significant reduction in size and capital cost of future compact machine. Making this vision a reality requires a wide range of advances and the **development of new dedicated TIs especially for testing large HTS magnet components**
- Accelerator Driven Systems (ADS) is a possible next-generation concept for safe nuclear energy, where the nuclear reaction is sustained by the particle accelerator only. MYRRHA is the world's first large-scale ADS project led by SCK·CEN in Belgium. **Reliability will be the main challenge.**
- Technological developments in Energy applications rely on existing TIs but will require the development of new ones to be defined.



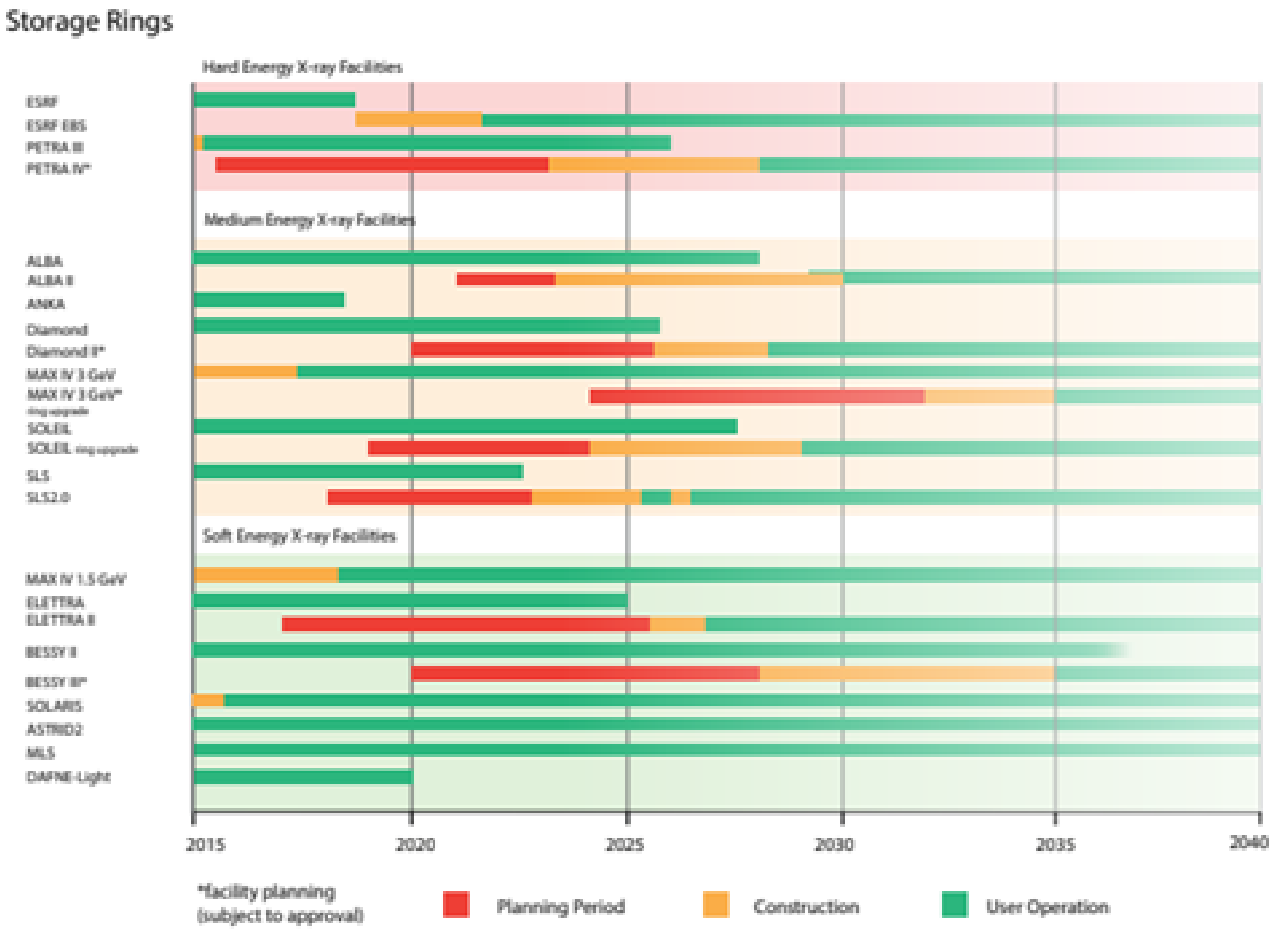
Material and biological science needs for TIs

- **The field of material science increasingly relies on large-scale accelerator-based research infrastructures that produce powerful X-ray or neutron beams**.

- These facilities, such **as light sources, synchrotron radiation, free electron lasers (FELs), and neutron sources**, provide complementary probes for understanding the structure and behavior of materials at the atomic and molecular level.
- They play a crucial role in the design and characterization of advanced materials, chemistry, and biotechnologies.
- In Europe, **light sources have formed the LEAPS consortium**, while **neutron sources, including reactor-based ones, are gathered in the LENS consortium**. Both organizations have recently released scientific roadmaps for their respective domains.

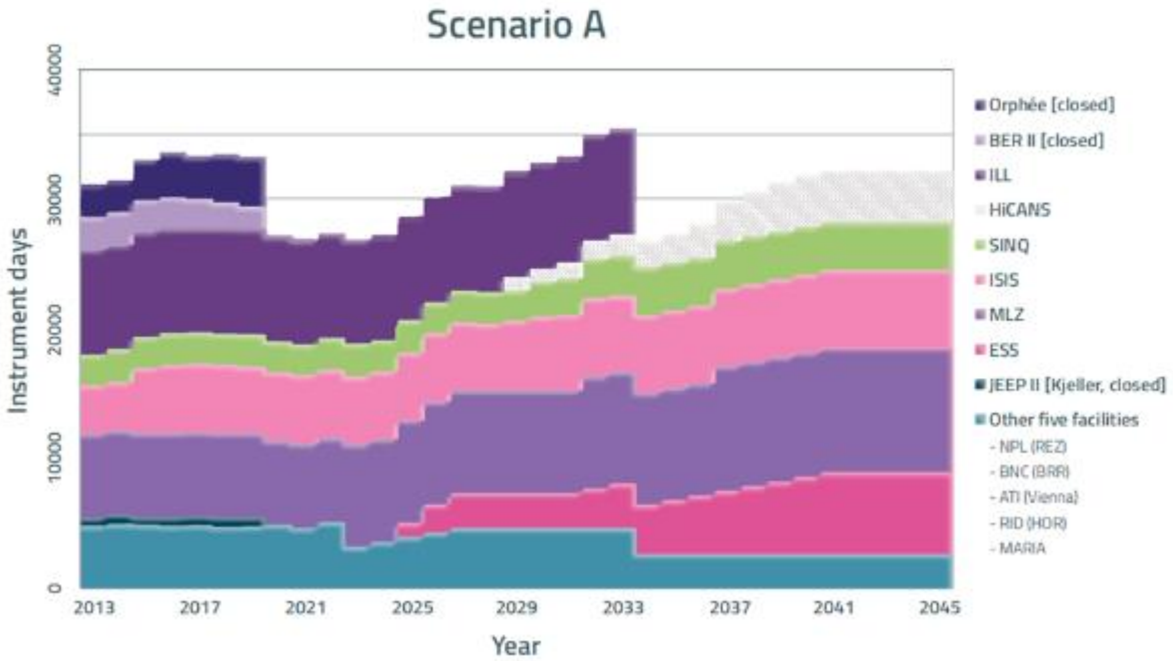
Infrastructure and facilities for Material and Biological Science – Light sources

- The LEAPS consortium has published the European Strategy for Accelerator-based Photon-Science (ESAPS) 2022, presenting a timeline of existing and planned upgrades for storage rings and FEL facilities in Europe.
- **The I.FAST AMICI Technology Infrastructure can benefit all large-scale accelerators, with shared infrastructures being especially useful for long linac based facilities. Pre-testing of certain components can also benefit from shared TPs within AMICI.**



Infrastructure and facilities for Material and Biological Science – Neutron sources

- The landscape of neutron sources for material science in Europe is undergoing major changes with the **construction of the European Spallation Source (ESS)** which will be the world's most powerful neutron spallation source when it reaches its full design performance.
- **Need for new investments in the development and upgrade of existing neutron sources, as well as the development of smaller Accelerator-driven Neutron Sources (HiCANS)** as reported in "Neutron Science in Europe" published by the BrightnESS H2020 project and the League of advanced European Neutron Sources (LENS) highlights.
- **The existing AMICI ETIAM Technology Infrastructure is expected to play a significant role** in the development and upgrades of ESS, ISIS, and HiCANS.



ACCELERATORS FOR MEDICINE needs for TIs

- **X-ray machines** are the most common type of accelerator system used in cancer treatment, with most research and development focused on improved patient planning and imaging techniques. **Proton therapy is gaining popularity** due to its precise energy deposition profile, but it requires larger and more complex machines. **Commercial vendors are developing proton linacs to reduce the overall cost and size of facilities**. Heavy ions such as carbon may provide even greater radiobiological benefits than protons. Very high energy electrons (VHEE) have also been identified as a potential area of development.
- **Compact, reliable, and low-cost accelerators** (such as cyclotrons, linacs, FFAG, and electrostatic machines) are preferred to produce a variety of medical isotopes, with higher beam energies and currents being key. Fixed-Field Alternating Gradient (FFAG) accelerators and plasma-based acceleration are also being investigated.
- **Private companies typically dominate the market** due to their ability to offer complete equipment and faster development times.
- However, public institutions still play a significant role in developing specific accelerator technologies through non-profit and high-risk R&D. **Private companies may also collaborate with public laboratories to access radiation-shielded areas for beam-target tests**. The EU technology infrastructure network is available to both public researchers and private companies for accelerator development.

Categories of TPs

Categories	Sub-categories	Partners
A. Facilities for beam tests of accelerator components		UKRI (A. Gleeson) + IFJ-PAN (**D. Bocian** + J. Swakon) + INFN-LNF (A. Liedl)
B. Test stations for magnets	B.1 - Test stations for superconducting magnets B.2 - Test stations for normal conducting magnets B.3 - Magnetic measurement facilities	INFN (L. Sabbatini + G. Bisoffi) + CEA (**R. Vallcorba Carbonell**) + CIEMAT (L. Garcia Tabares) + UU (T. Ekelof + T. Bagni)
C. Test stations for RF equipment	C.1 - Test stations for superconducting cavities C.2 - Test stations for normal conducting cavities	DESY (**H. Weise**) + UU (A. Miyazaki) + INFN (D. Alesini) + CEA (H. Jenhani) + CNRS (W. Kaabi)
D. Test stations for High Power RF components	D.1 - RF wave guides D.2 - RF power sources D.3 - Power transistors D.4 - High power amplifiers D.5 - Solid State Power Amplifiers with their combiners and control system	**UU (D. Dancila)** + KIT (C. Widmann) + CIEMAT (Daniel Gavela)
E. Test stations for mechanical manufacturing and tests (at cryogenic temperatures)		CEA (**R. Vallcorba Carbonell**) + KIT (C. Widmann) + UKRI (A. Gleeson) + IFJ-PAN (Blazej Skoczen)
F. Platform for characterization, treatments and test of materials	F.1 - Thermal treatment platforms F.2 - Chemical treatment platforms F.3 - Facilities for surface analyses F.4 - Electromagnetic, mechanical, thermal and associated material characterization Platforms	CEA (F. Eozenou) + CIEMAT + **CNRS (W. Kaabi)** + INFN-LNL (G. Bisoffi) + IFJ-PAN (Jaromir Ludwin)
G. Platforms for clean assembly, alignment and tests of accelerator components	G.1 - Complete accelerator modules G.2 - RF power couplers	CEA (H. Jenhani) + CNRS (W. Kaabi) + DESY (**H. Weise**, R. Wichmann) + UU (A. Miyazaki)+ UKRI (A. Gleeson)
H. Platforms for Manufacturing, treatments and test of Magnet components for accelerator		**CEA (S. Roux)** + IFJ-PAN (Jacek Swierblewski)

Categories	Sub-categories	CEA	CERN	CIEMAT	CNRS	DESY	IFJ-PAN	INFN	KIT	UKRI	UU
A. Facilities for beam tests of accelerator components		-IPHI -BETSI		-IST (Ion Source Test bench for cyclotrons) -Electron Van de Graaff Accelerator facility			CCB, AIC-144	Electron BTF (Frascati)	- KARA - FLUTE	- Compact Linac - Front End Test Stand - Versatile Electron Linear Accelerator	
B. Test stations for magnets	***B.1 - Test stations for superconducting magnets***	-STAARQ, -JT-60SA Station	SM18 SC magnets test facility	CIEMAT Superconducting Magnet Lab		Small SC quadrupoles		-MARISA (Genova) -SOLEMI (LASA) -NAFASSY (Salerno)	-CASPER I -CASPER II		Vertical cryostat + istrumentation
	B.2 - Test stations for normal conducting magnets		SM18 SC magnets test facility						LASMagLab		
	B.3 - Magnetic measurement facilities		Magnetic Measurement Laboratory	CIEMAT Superconducting Magnet Lab	BML-Magnetic Measurement Bench				-Magnetic Field Lab	Magnet Test Laboratory	Anti-cryostat probe in development
C. Test stations for RF equipment	***C.1 - Test stations for superconducting cavities***	-Vertical cryostats for cavity tests -Horizontal cryostats for cavity tests -Cryomodule test station	SM18 SC cavities test area		Cryogenic test facilities and tests stands	Vertical cavity test stands		Test station (LASA)			Horizontal and vertiucal cryostat
	C.2 - Test stations for normal conducting cavities							-Test stations (LNL) -Test station (LNF)			
D. Test stations for High Power RF components	***D.1 - RF wave guides***										352 MHz
	D.2 - RF power sources	704 MHZ RF Platform		CIEMAT High Power RF lab (175 MHz 200 kW)					- High power millimeter wave gyrotron test stand - Low power millimeter wave quasi-optical measurements		3252 MHz 400 kW pulsed
	D.3 - Power transistors										352 MHz
	D.4 - High power amplifiers										352 MHz
	D.5 - Solid State Power Amplifiers with their combiners and control system			-200 kW 175 MHz CW SSPA + Cavity combiner (under development) - 400 kW 750 MHz 0.2% d.c. SSPA (under development)							352 MHz in development
E. Platform for characterization, treatments and test of materials	***E.1 - Thermal treatment platforms***	-Chemical treatment cabinets -Vertical electropolishing cabinet -DIVA	Vacuum furnaces	-High T furnaces (1700 C) Vacuum furnace -Tubular furnaces for heat treatments under controlled atmosphere	Oven for cavity heat treatment			-Vacuum furnace (LNF) -High Vacuum Treatments (LNL)			
	E.2 - Chemical treatment platforms	-Surface characterization laboratory (LABCAS) -Thin film deposition	Chemistry laboratory B.10	-Electropolishing, sputtering -Chemistry laboratory : Analytical techniques (spectroscopy, thermal analysis, elemental analysis, chromatography)	SUPRATECH facility: Cavity preparation	Cavity preparation incl. chemistry, bake, CO2 cleaning etc		-Chemistry lab and clean rooms (LNL) -Chemical treatments Lab (LASA)			
	E.3 - Facilities for surface analyses	-DIVA	Surface analysis laboratory	Surface characterization lab: SEM, SIMS, confocal microscope and profiler, XPS and Auger Spectroscopy	Vacuum and surface characterization lab	-Surface examination of Nb sheets -Matallurgical lab				Vaccum and Surface Science Laboratory	
	E.4 - Electromagnetic, mechanical, thermal and associated material characterization Platforms	-CETACES -H0 -Mechanical test laboratory -Insulation laboratory -LABCAF		MECHANICAL TEST LABORATORY: high T, fracture, fatigue, Charpy, tensile, fracture …			-Test-stand for characterization of superconductors -Two vacuum chambers for termal fatigue tests		Cryogenic Materialtests Karlsruhe (CryoMaK)		
	E.5 -Test stations for mechanical manufacturing and tests (at cryogenic temperatures)	-Pressurized superfluid helium cryostat -MECTIX		CIEMAT Superconducting Magnet Lab			-Test-stand for characterization of superconductors -Two vacuum chambers for termal fatigue tests		-COOLSORP -TRANSFLOW - Cryogenic High Voltage Lab -Cryogenic Materialtests Karlsruhe (CryoMaK)	Cryogenic Test Laboratory	
F. Platforms for clean assembly, alignment and tests of accelerator components	***F.1 - Complete accelerator modules***	-Cryomodule assembly platform -ISO4 Clean room -ISO5 Clean room	Magnet Laboratory B.927		SUPRATECH facility: Cryomodule assembly and test	-Cryomodule assembly and disassembly platform -Horizontal cryomodule test stand -Preparation and assembly of partical free vac. components			-Accelerator Technology Platform	Engineering Technology Centre	
	F.2 - RF power couplers	RF Coupler test platform			Power Couplers infrastructure						
G. Platforms for Manufacturing, treatments and test of Magnet components for accelerator		Magnet winding workshop	Large Magnets Assembly facility B.180 and B.181	CIEMAT Superconducting Magnet Lab			Test-stand for characterization of superconductors		- Robotic magnet workshop - VPI facility - Karlsruhe-CERN Collaboration on Coated Conductor (KC4) - KARA (test of wigglers /undulators up to 2.5 GeV e-beam) - FLUTE (magnet systems low energy 40-90 MeV e-beam)		

Goals of the workshop

- Presentation of (some of) the TPs in the different categories with their characteristics and their plans for the future
- Taking into account the needs for the different fields, tentative recommendations for possible upgrades of existing TPs, building of new ones
- Listening to suggestions / requests from potential users in order to establish the roadmap for the different categories

Agenda

Time	Presentation	Speakers
8h30 – 8h50	« Introduction »	S. Leray
8h50 – 9h10	« Implications on the necessary developments/upgrades of the different categories of TPs » - Facilities for beam tests of accelerator components	D. Bocian
9h10-9h15	Platforms for Manufacturing, treatments and test of Magnet components for accelerator	S. Roux (zoom)
9h15-09h35	Test stations for High Power RF components	D. Dancila
09h35-09h55	Test stations for mechanical manufacturing and tests (at cryogenic temperatures)	R. . Vallcorba Carbonell
09h55-10h10	Pause	
10h10-10h30	Platform for characterization, treatments and test of materials	W. Kaabi
10h30-10h50	Test stations for RF equipment	A. Miyazaki (zoom)
10h50-11h10	Platforms for clean assembly, alignment and tests of accelerator components	A. Miyazaki (zoom)
11h10-11h30	Discussion	

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Thank you for your attention!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.