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Summary of the considered facilities

Facilities	
CEA Saclay	The CEA-Saclay technical platforms are clustered in a building complex covering an area of 25 000 m^2. Available RF power infrastructure: 704 MHz Radio Frequency (RF) platform is equipped with two pulsed klystrons, with peak powers of 1.1 MW (55 kW average) and 1.5 MW (75 kW average), with pulse durations ranging from 10 to 3600 µs, a repetition rate ranging from 1 to 50 Hz and a duty cycle of 5%.
CERN	The RF Group at CERN is responsible for all cavities, couplers, high-power RF amplifiers, LLRF and RF controls at CERN, ranging from 1 MHz to 30 GHz, pulsed & CW, with power output of up to 50 MW per system. The technologies in use are solid state, IOTs, klystrons & tetrodes.
CIEMAT	Ciemat is a Spanish research institute specializing in the development of RF systems and components oriented to fusion applications. The high-power RF laboratory, and it is complementary to IFMIF-DONES RF laboratory for fusion applications. Available is a clean room, x-ray shielding, etc. Available RF power infrastructure: 200 kW CW @175 MHz RF tetrode-based amplifier with fully digital LLRF.

Summary of the considered facilities

Facilities	
FREIA	The FREIA Laboratory is part of the Department of Physics and Astronomy at Uppsala University, which employs over 30 researchers, engineers, and technicians. The FREIA Laboratory is equipped with a high-capacity Helium liquefier, a large horizontal and vertical cryostat, Available RF power infrastructure: two 400 kW vacuum-tube radiofrequency sources at 352 MHz pulsed power with a 5% duty cycle.
INFN -Legnaro National Laboratory (LNL)	LNL is one of the four of INFN national laboratories. LNL is devoted to nuclear physics, interdisciplinary physics and accelerators science. Target frequencies are 80 MHz, 175 MHz and 352 MHz. To power SPES RFQ cavity foreseen to accelerate Rare Isotope Beams (RIBs) in 2026.
NCBJ	NCBJ is a Polish research institute specializing in the manufacturing of electron linear accelerators for scientific purposes and for medical and industrial applications. Thanks to the existing resources - infrastructure and trained personnel, NCBJ participates to many international accelerator projects, such as: ESS, CERN, XFEL, etc.

CEA Saclay

704 MHZ RF PLATFORM

- two pulsed klystrons, with peak power of 1.1 MW (55 kW average) and 1.5 MW (75 kW average)
- pulsed ranging from 10 to 3600 µs, a repetition rate ranging from 1 to 50 Hz and a duty cycle of 5%.

Current activities: the klystrons are 100% used for ESS. The platform is used for:

- The coupler packages for the ESS elliptical cavities
- Tests of cryomodules for ESS elliptical cavities
- Test of couplers, cavities and LLRF in the framework of the European projects FP6 CARE/HIPPI (CERN INFN) and FP7 SLHC-PP (CERN)
- Packaging of SPL couplers for CERN

CERN RF group

Current activities:

- active development of high-efficiency klystrons together with industry (Thales, CPI, and Canon) for 400 MHz, 800 MHz, and 12 GHz.
- Combining technologies for Solid State Amplifiers.
- µTCA deployment and white rabbit.
- Ferroelectric fast reactive tuners (FEFRT) for the suppression of transient.

Future Plans:

- Future R&D aims at the FCC RF system with a focus on high-efficiency.
- In the next years more of the ageing existing systems may evolve towards µTCA.
- We also see a trend of replacing ageing tetrode systems with solid state solutions.

CERN SPS Thales Solid State Power Amplifiers,

32 towers x 144 kW @ 200 MHz, combined into
2 x 2 MW amplifiers, into operation since 2021

2 kW RF module
50 VDC power supply
Cold plate
RF board with 2 transistors
Output relays

CIEMAT

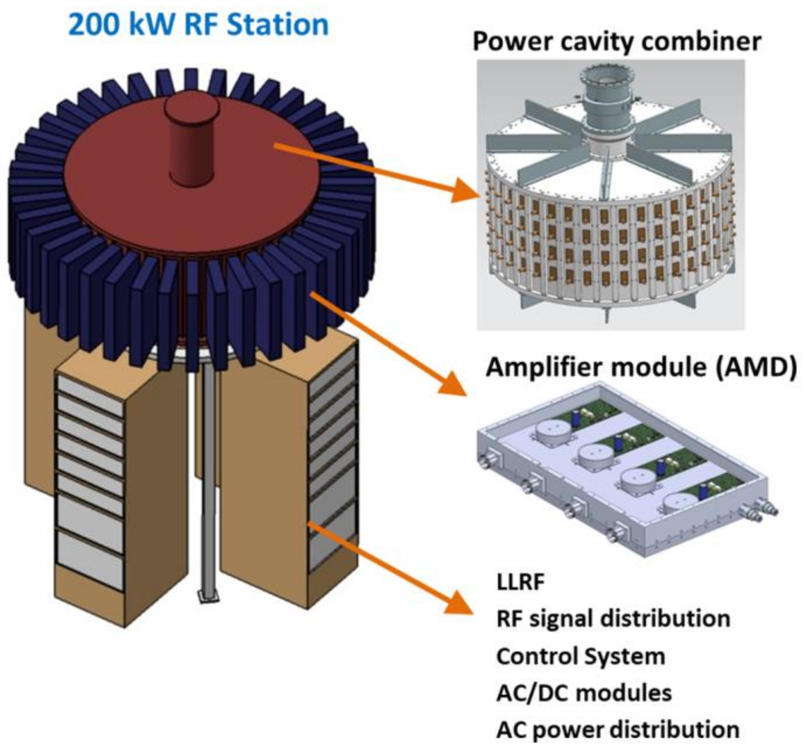
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

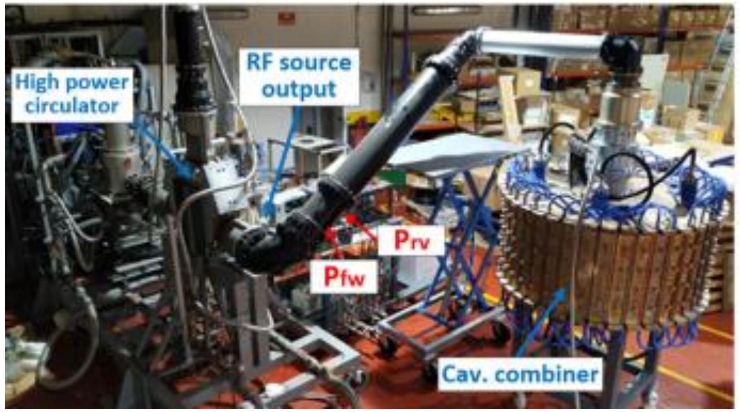
Current activities:

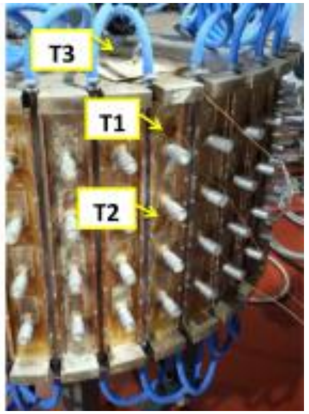
- Development of advanced solutions for the IFMIF-DONES RF power system.
- Development of 750 MHz RFQs for the initial stages of acceleration. Current prototype: two high
- efficiency solid state 200 kW CW @ 175 MHz

Future Plans:

- Ciemat aims to continue developing efficient SSPA solutions and solutions for Ion Cyclotron Resonance Heating (ICRH).
- plasma heating in low frequencies. They also plan to optimize efficiency in all aspects of RF power, including transistor technologies and high efficiency polarization techniques.







FREIA

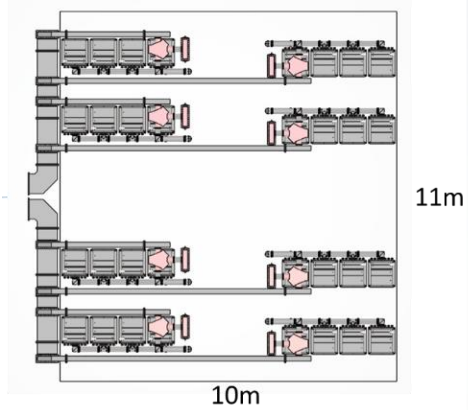
UPPSALA UNIVERSITET

Current activities:

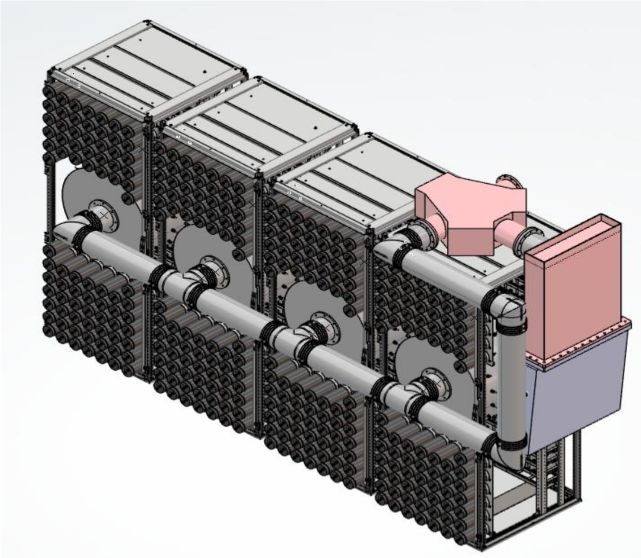
- The FREIA laboratory in close collaboration with ESS and Swedish industrial partners is developing the first pilot RF power station delivering 400 kW at nominal power. The station is composed of 256 high-power solid-state amplifiers, each delivering 1.6 kW.
- The modules are combined in two steps, i.e. using a 4:1 combiner at 400 kW level and four 64:1 100 kW combiners.
- In I.FAST, developing a 1 kW CW SSPA at 750 MHz in GaN technology and a megawatt cross field amplifier based on a magnetron architecture.
- Also in GaN technology, we are developing two amplifiers for the AWAKE project at CERN. The first amplifier operates at 3 GHz and delivers 500 W, while the second at 12 GHz and delivers 1500 W.

Future Plans:

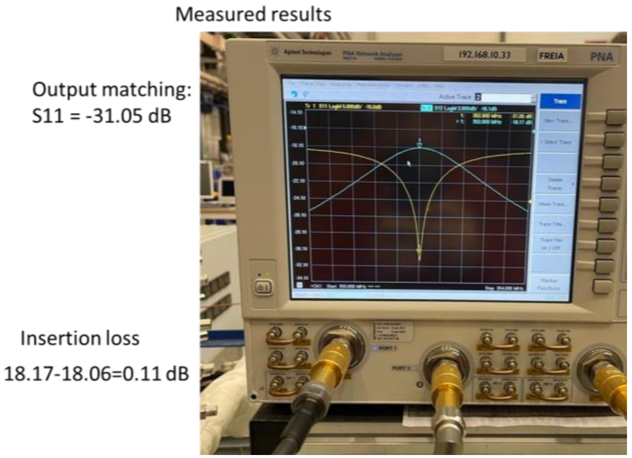
- The collaboration with MYRRHA, the Belgian transmutation project, is started on the development of solid-state power amplifiers at 704 MHz at 10 kW and 20 kW levels in CW.
- The scientific collaboration is also ongoing with the IFMIF-DONES project, in Spain via EUROFUSION, and is related to the development of cavity combiners and efficient amplifier design.



Footprint of 8 stations at ESS for 352 MHz section



400 kW 352 MHz station



measured 64:1 cavity combiner at 352 MHz: IL is only 0.11 dB.

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INFN - Legnaro National Laboratory (LNL)

Istituto Nazionale di Fisica Nucleare

Current activities:

- New 200 kW RF power test-stand in CW is under assembly.
- 200 kW 175 MHz full solid state CW amplifier (test already started)
- 200 kW 80 MHz full solid state CW amplifier (under construction)
- 125 kW 352 MHz full solid state CW amplifiers (5 of 8 are already completed and tested and to be upgraded, 3 of 8 yet to be constructed)

Future Plans:

- high power test of 200 kW 175 MHz solid-state amplifier
- high power test of 200 kW 80 MHz solid-state amplifier
- ANTHEM project high power couplers test (125 kW 352 MHz CW)
- high power test of 3 x 125 kW 352 MHz solid state amplifiers
- high power test of 5 x 125 kW 352 MHz solid state amplifiers

INFN solid-state power amplifier prototype (200 kW CW, 175 MHz)

NCBJ

Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK

Current activities:

- development of an electron accelerator and beam transport system for Hyper-Kamiokande far-detector calibration
- development of FLASH-radiotherapy machines
- construction of several-dozen-MeV machine for neutron-beam based experiments
- production of new radioisotopes, construction of POLFEL (THz-UV FEL light source)
- development of fast energy switching accelerators for cargo scanning
- development of RF power compressors

Future Plans:

- Continuation of current activities

For the Community:

- experience in beam dynamics and beam optics calculations, infrastructure
- expertise in warm cavities production, RF conditioning and beam-based experiments.
- well-equipped test infrastructure for RF components, magnets, radiation-induced material damages, etc.,
- and access to an advanced machine park.

Conclusions

- Some redundant development work was identified and it is recommended to promote cooperation among development efforts. Collaborating and sharing resources can aid in achieving synchronization and fostering collaboration, such as the sharing of testing facilities, research equipment, and expertise development.
- Collaboration can be fostered through various means, including participation in conferences, utilization of platforms like AMICI and IFAST, engagement in training programs, publishing research, and forming closer partnerships. In-kind contributions can also serve as a way to finance collaborative initiatives. Collaboration frameworks can aid in ensuring project progress and stakeholder awareness.
- For instance to develop SSPA, expertise in diverse areas such as cooling solutions, microwave technology, amplifier protection, and interlocks are required, which may not be readily available at every site.
- To ensure a unified development path, involving industrial partners from the definition of specifications to the realization and acceptance tests is crucial. This approach can speed up development, and their participation in upgrades of existing machines can be valuable.
- Power generators for RF/MW developed for accelerator applications have the potential to be useful in other industrial sectors such as high-power microwave technology for mining, geothermal applications, bitumen heating, sewage sterilization, and more. Furthermore, CERN and the UK are leading the development of portable RF power stations required for art analysis and medical applications.

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Thank you for your attention!

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