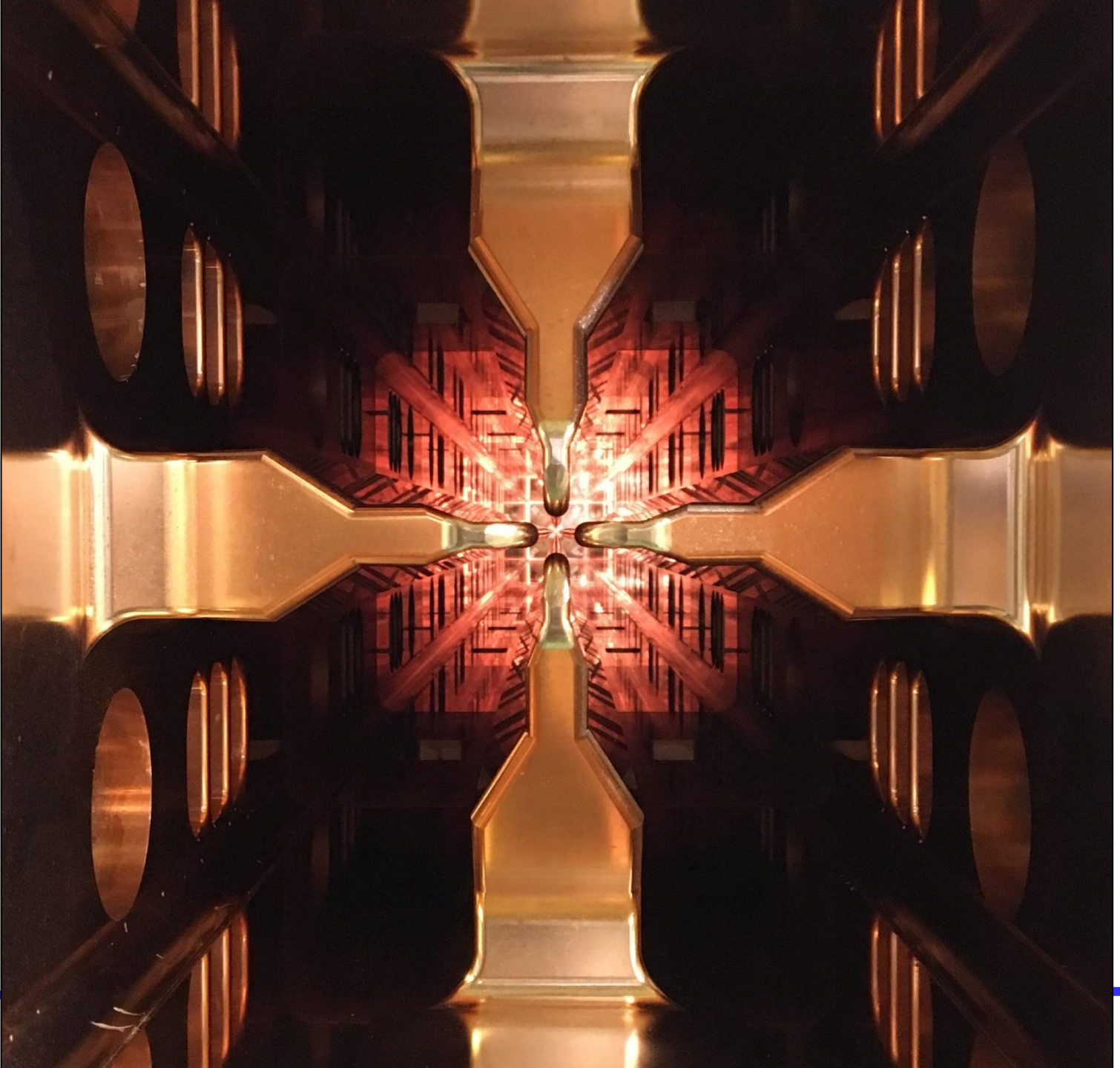
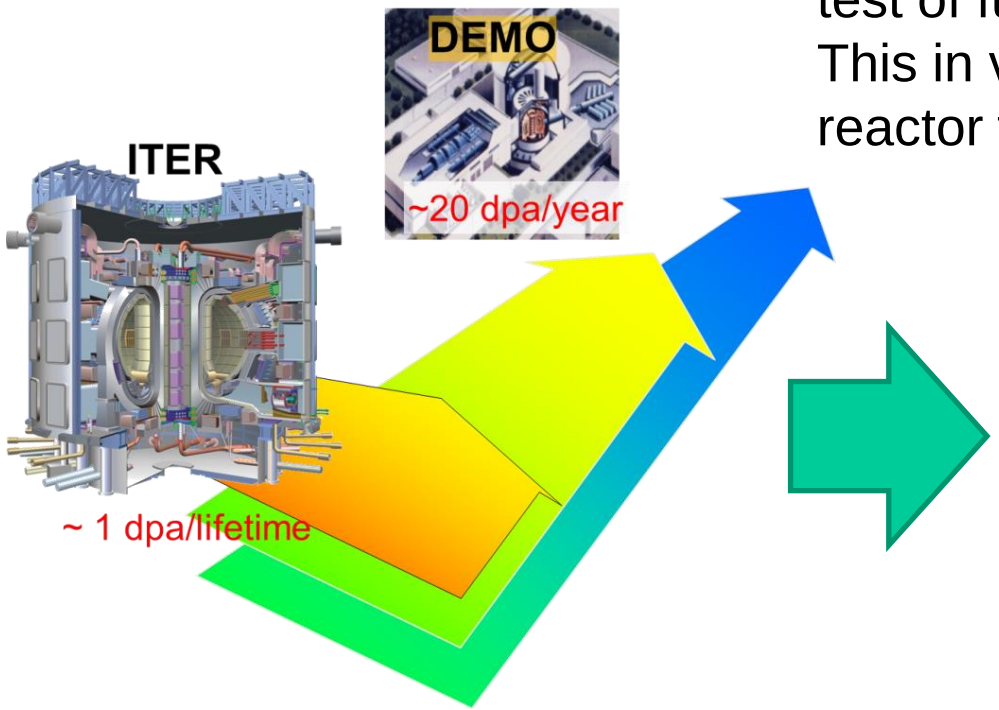


DONES: the development line of high intensity injectors.

A. Pisent- INFN Laboratori Nazionali di Legnaro

DONES

- DONES, Demo Oriented Neutron Source, is the European version of IFMIF, i.e. a facility based on high intensity linear accelerator, for the test of fusion reactor structural materials.
  This in view of DEMO, that will be the first fusion reactor for electrical power production



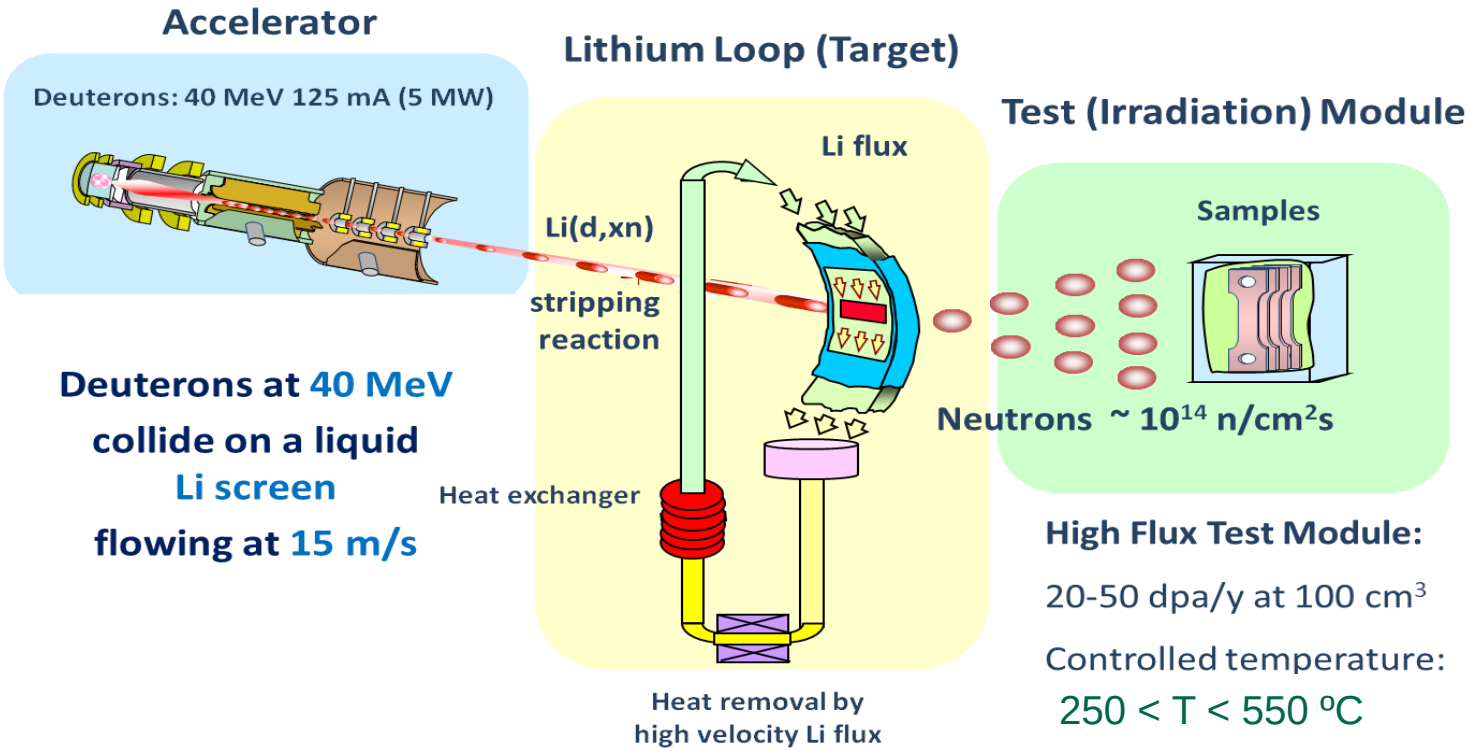
One of the main differences between ITER and DEMO is the radiation dose: at DEMO more that two orders of magnitude higher

DONES: DEMO oriented Neutron Source

A fusion-like neutron source required for the qualification of the materials to be used in the EU DEMO

What is IFMIF-DONES?

A neutron flux of ~ 10^{14} $cm^{-2}s^{-1}$ is generated with neutron spectrum up to 50 MeV energy



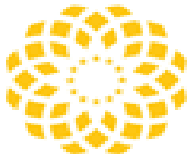
Identified as high priority in the EU Fusion Roadmap
Included in the ESFRI Roadmap as a EU strategic facility

DONES overall framework

The need for a facility of this type was identified long time ago and work has been carried out by using different frameworks

In the last 15 years, some key projects has been contributing. Presently more relevant ones are:

- **IFMIF/EVEDA** (included in the BA)
- **WPENS** –including specific Industry contract- (EUROfusion WP)
- **DONES-PreP** (ESFRI preparatory phase, EURATOM CSA)
- **DONES-PRIME** and **DONES-UGR** (Spanish funded projects)



FUSION FOR ENERGY

IFMIF DONES GRANADA

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

EUROfusion

Junta de Andalucía

Consejería de Transformación Económica, Industria, Conocimiento y Universidades

IFMIF-DONES ESPAÑA

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

Laboratorio Nacional de Fusión

Ciemat

ENEA

AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

KIT

Karlsruher Institut für Technologie

cea

IFPiLM

Institut Ruđer Bošković

TÉCNICO LISBOA

IPP

INFN

Istituto Nazionale di Fisica Nucleare

Jožef Stefan Institute

Swedish Research Council

VTT

DTU

ifa

CCFE

CULHAM CENTRE FOR FUSION ENERGY

Updated Cost Estimate (May 2021)

Last update (2021) based on industrial quotations for conventional systems and BA expertise for high-technology ones

WBS N°	Task Name	*Low Value (M€)	Base Value (M€)	*High Value (M€)
5.0.0.0.0.	Task Name. DONES Construction, Installation, Test and Systems Commissioning	526,77	643,03	819,85
5.1.0.0.0	Design integration	2,99	3,33	3,82
5.2.0.0.0	Plant Level Integrated analysis	7,61	8,45	9,72
5.3.0.0.0	Site, Buildings and Plant Systems manufacturing, installation and checkout	282,94	332,87	416,08
5.4.0.0.0	Test Systems Manufacturing, Installation & Check out	21,80	29,07	39,25
5.5.0.0.0	Lithium Systems Manufacturing, Installation & Check out	27,69	36,92	49,85
5.6.0.0.0	Accelerator Systems Manufacturing, Installation & Check out	113,72	151,62	204,69
5.7.0.0.0	Project Management	56,68	62,98	72,42
5.8.0.0.0	Central Instrumentation and Control Systems Manufacturing, Installation & Check out	13,34	17,79	24,02
6.0.0.0.0	DONES Integrated Commissioning and Start-up	34,74	40,87	51,09
7.0.0.0.0	DONES Operation	960,84	1130,4	1.413
8.0.0.0.0	DONES Decommissioning	158,33	211,11	285,00

(*) Class 3-4 according to AACE Cost Estimate Classification System

The Site

It has been agreed that if it is built in EU, it will be located in the Granada province (Andalusia region – southern Spain), 18 km southwest from Granada city in the Granada


Ayuntamiento de
ESCÚZAR
Parque Metropolitano
industrial y tecnológico
TERRENOS CEDIDOS POR
EL AYUNTAMIENTO DE ESCÚZAR
PARA EL PROYECTO DEL ACELERADOR
DE PARTÍCULAS IFMIF DONES
IFMIF
DONES
SPAIN

IFMIF-DONES in EU: Schedule milestones

DONES Preparatory Phase

Critical path milestones

- Project “start” T0
- Initial team build up +1 y
- Site preparation contract +1 y
- Buildings and Plant Systems contract +2 y
- Building ready +6 y
- Injector contract +4 y
- Injector installation +6 y
- RFQ contract +4 y
- RFQ installation and commissioning +7 y
- SRF linac contract +5 y
- Start of SRF installation and commissioning +8 y
- DONES (integrated) commissioning +10 y
- Start of DONES operation +11 y

Identification of the critical path is very important because it guides the design effort

Hold point linked to LIPAc results

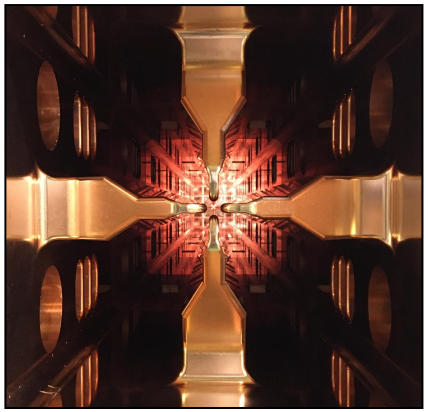
+1-2 years of irradiation and +1-2 years of PIE

First materials data around T0+(13-15)y

International collaboration=> Italian in-kind contribution

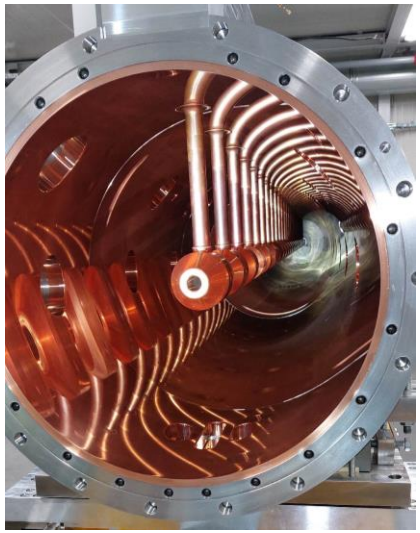
IFMIF EVEDA

International fusion material irradiation facility, engineering validation and engineering design activity



ESS

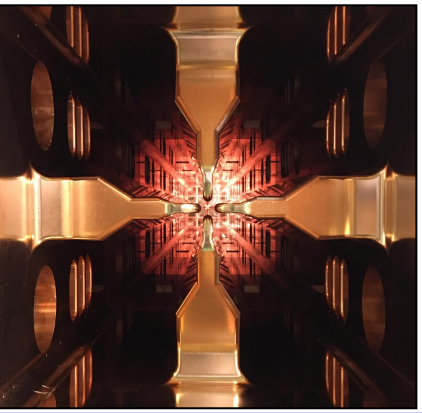
European Spallation Source



- The international project can benefit of very specialized know how from national laboratories (particularly important for green field projects, but also for specific developments in well established labs).
- The national laboratory gain an international challenge to develop new knowledges and know how.
- The in-kind contribution is generally in a sector where the national industry is well developed, in close contact with national labs.
- Two examples are INFN participation to IFMIF-EVEDA (since 2008, beam in 2018) and ESS (since 2015 in construction phase, beam on target in 2024).

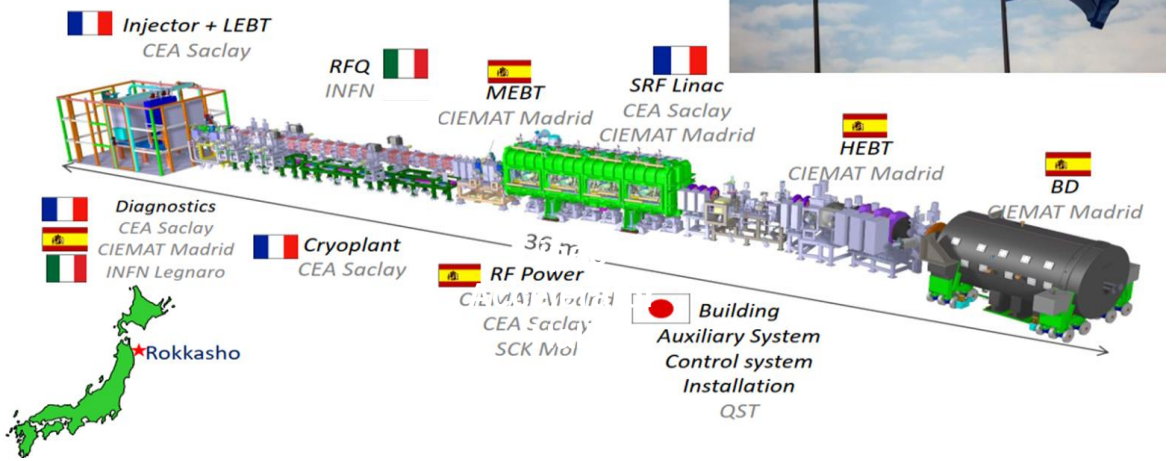
IFMIF EVEDA

International fusion material irradiation facility, engineering validation and engineering design activity

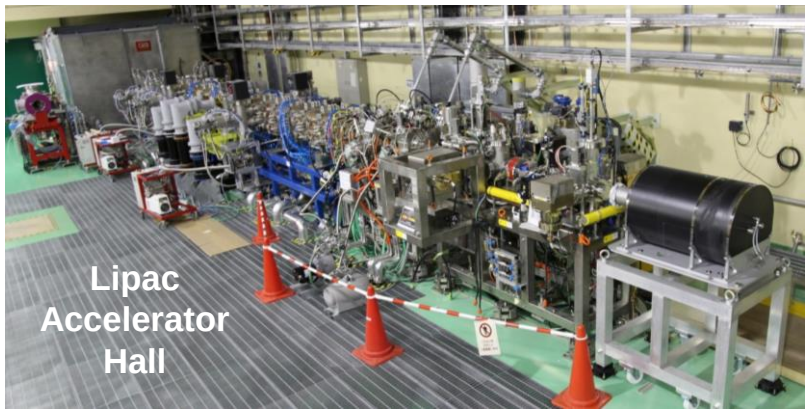


Prototype of DONES linac

LIPAc (9 MeV 125 mA)



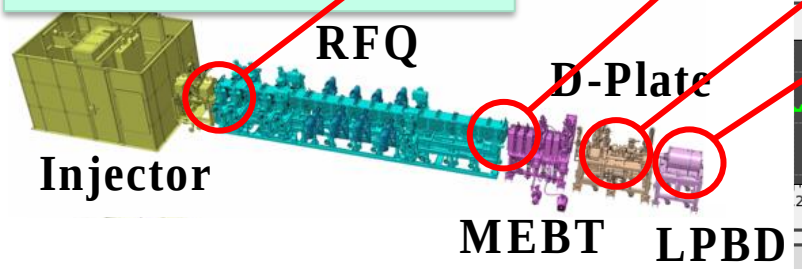
In-kind contribution through INFN 24 M€



First Successful Acceleration of 125mA D+ at LIPAc, 24 July 2019, 19:13

- 166 mA extracted from source (D^+ fraction~85%, $\varepsilon_{n.rms}$~0.2π mm mrad)
- 142 mA injected to RFQ
- RFQ vane voltage ~132 kV (nominal design value)
- RF pulse ~1 ms, 1 Hz
- 127 mA exit from RFQ (Tr~90%)
- 125 mA transported to LPBD
- Beam energy ~5 MeV (under checking with ToF)

➔ **Design of all LIPAc components of the low and medium energy part successfully validated.**



RFQ Status

- Achieved nominal transmission in pulsed mode
- Scientific activity in Rokkasho extended of 4 years thanks to the BA2, funded ba EU and JA
- Participation of INFN in remote due to Covid restrictions
- Conditiong in December 2021 up to 80% of the nominal field in cw (100% duty cycle).
- Main fragility on RF system (Ciemat) and F4E-INFN temporary couplers.
- The beam acceleation from the source and then cw acceleration in the RFQ during 2022 and 2023

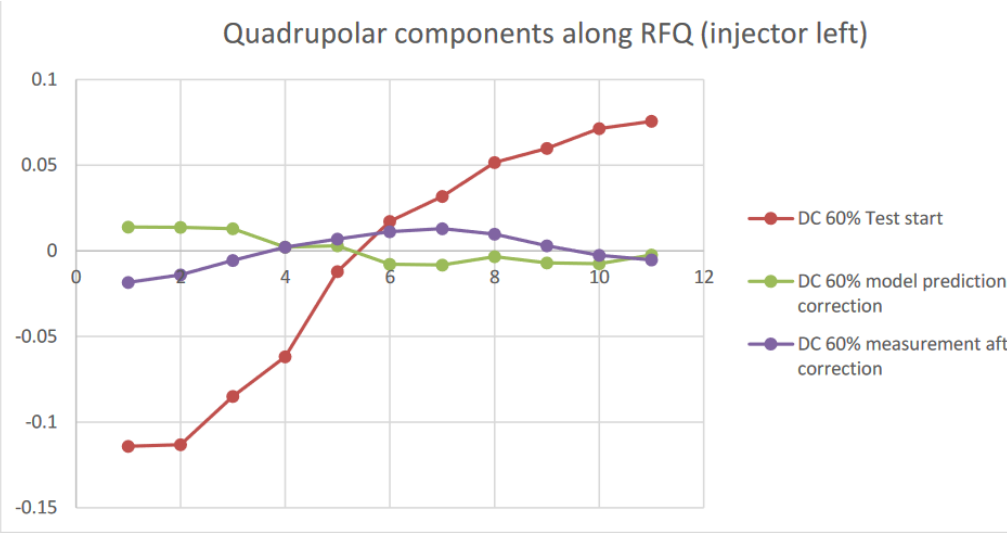


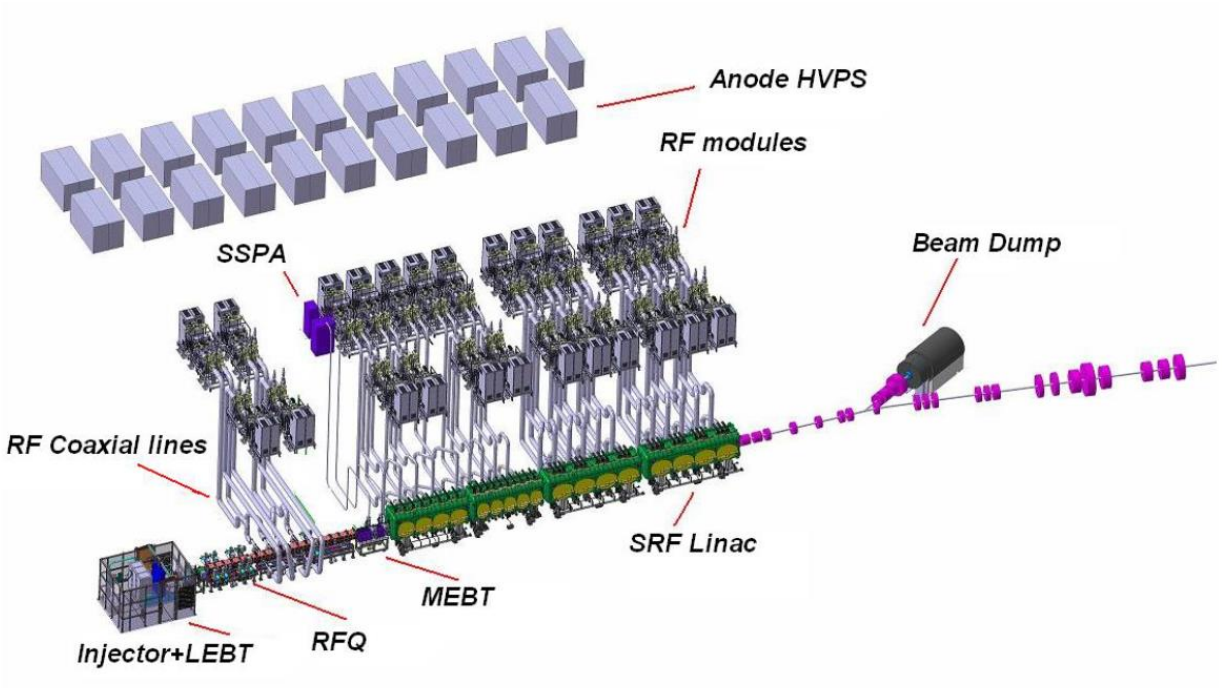
Figure 2-4: Example of quadupolar perturbative components tilts adjustment with differential water cooling temperatures among supermodules. In red components at the test start, in purple data acquired after corrections applied, in green model predictions. Preliminary analysis by A. Palmieri.

Contributi principali

- **General accelerator physics**: A. Pisent (DT),E. Fagotti (1T)
- ***Beam dynamics:*** M. Comunian (R), L. Bellan (TD), C. Baltador (AR)
- ***Diagnostica del fascio***. M. Poggi (1T)
- ***Radio frequenza***: A. Palmieri (T), F. Grespan, (T), A. Baldo (CTER TD)
- ***Progettazione Meccanica e prototipi*** L. Ferrari (TD), P. Bottin T (CTER); F. Scantamburlo (congedo F4E a Rokkasho),
- ***Computer control*** L. Antoniazzi(T), M. Montis(T), M. Giacchini
- ***Inoltre, principalmente impegnato nei progetti IFMIF e ESS***
  - M. Giacchini,, A. Battistello (CTER ESS), A. Colombo (INFN PD), D. Conventi, R. Panizzolo (CTER ESS),
- Sia per ESS che per IFMIF è attiva un'intensa collaborazione con INFN TO, Gruppo guidato da P. Mereu (1T) [*]

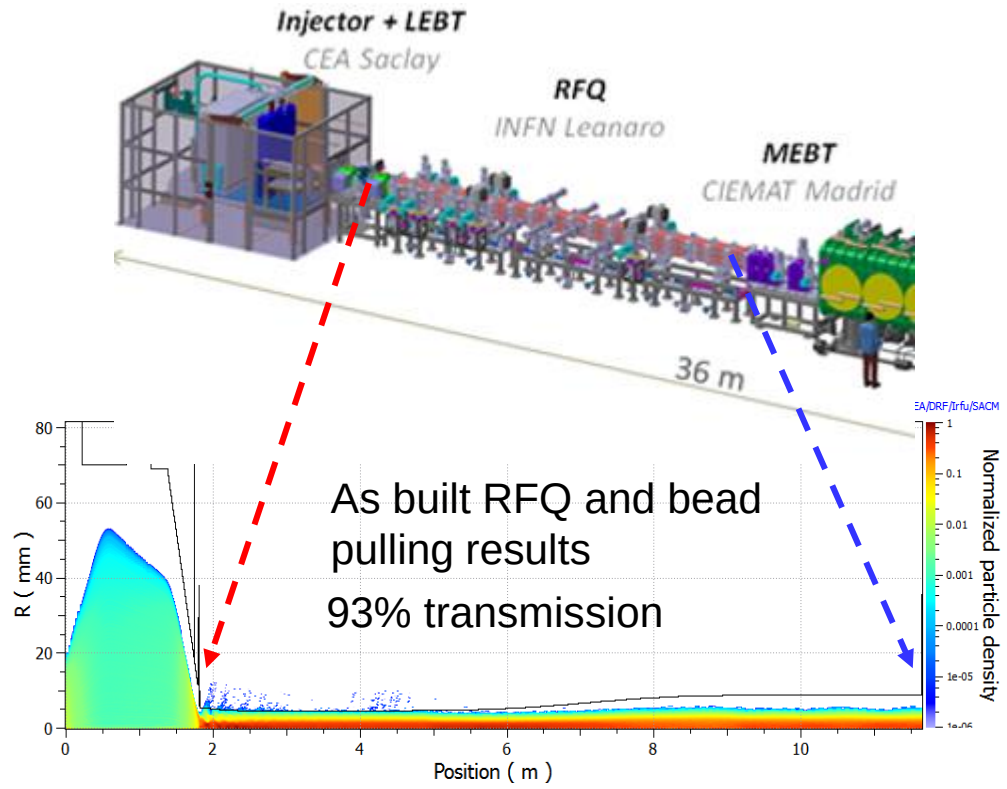
[*] situazione attuale, in passato anche sezione di Padova (A. Pepato et al.) e Bologna (A. Margotti et al.)

INFN and the development of high intensity injectors



- high intensity ion sources (CEA deliv. In IFMIF-EVEDA, INFN expertise)
- LEBT (CEA deliv, INFN expertise)
- RFQ (INFN, mechanics in LNL, Torino, in IFMIF-EVEDA also Padova and Bologna)
- SRF (CIEMAT deliv. in IFMIF-EVEDA, can be solid state with INFN design)

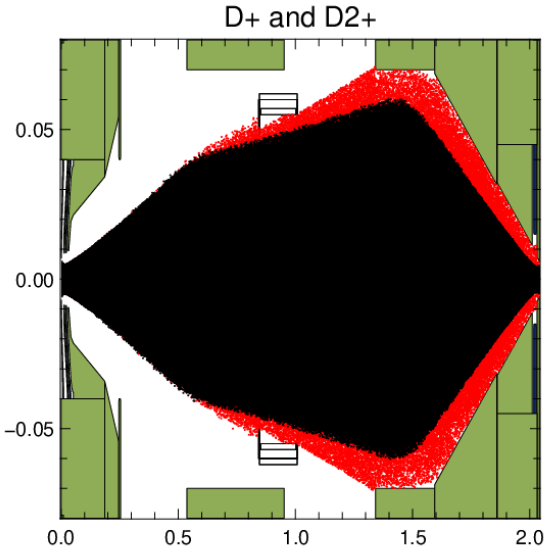
LEBT models development

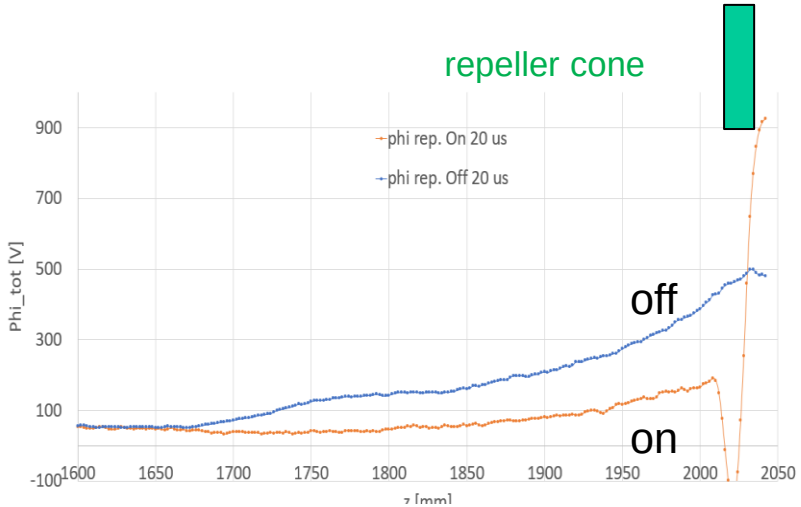


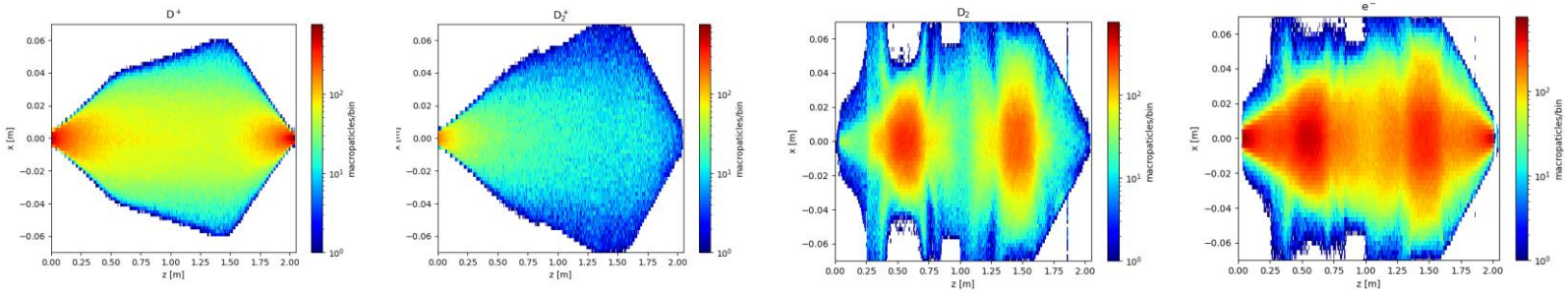
LEBT and RFQ beam profile (transverse particle density)

- **Transport line that matches the IS beam into the RFQ**
- **Physics with space charge, very high neutralization by electrons**
- **, multiple species (D+, D2+, D3+, electrons)**
- **During operation a deep understanding of the beam behavior allowed to correct HW misfunctioning and recuperate performances. both at IFMIF EVEDA and ESS**

High intensity plasma beam simulation capability

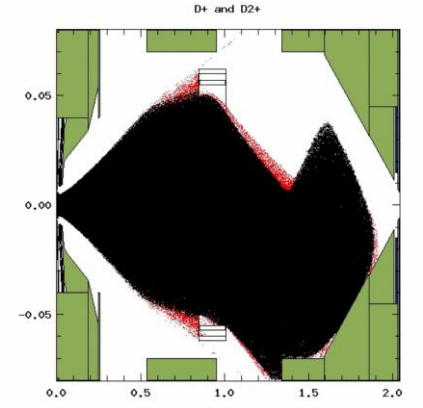




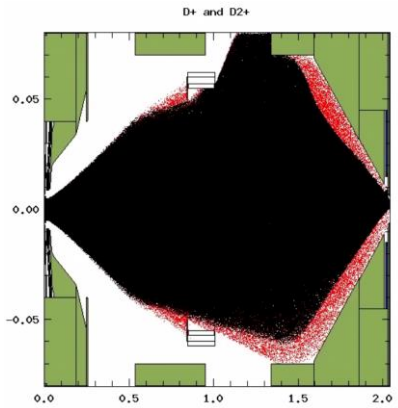


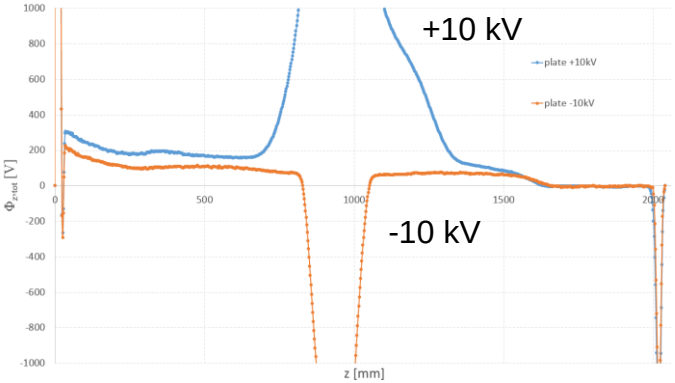
Luca Bellan, PHD thesis and following studies

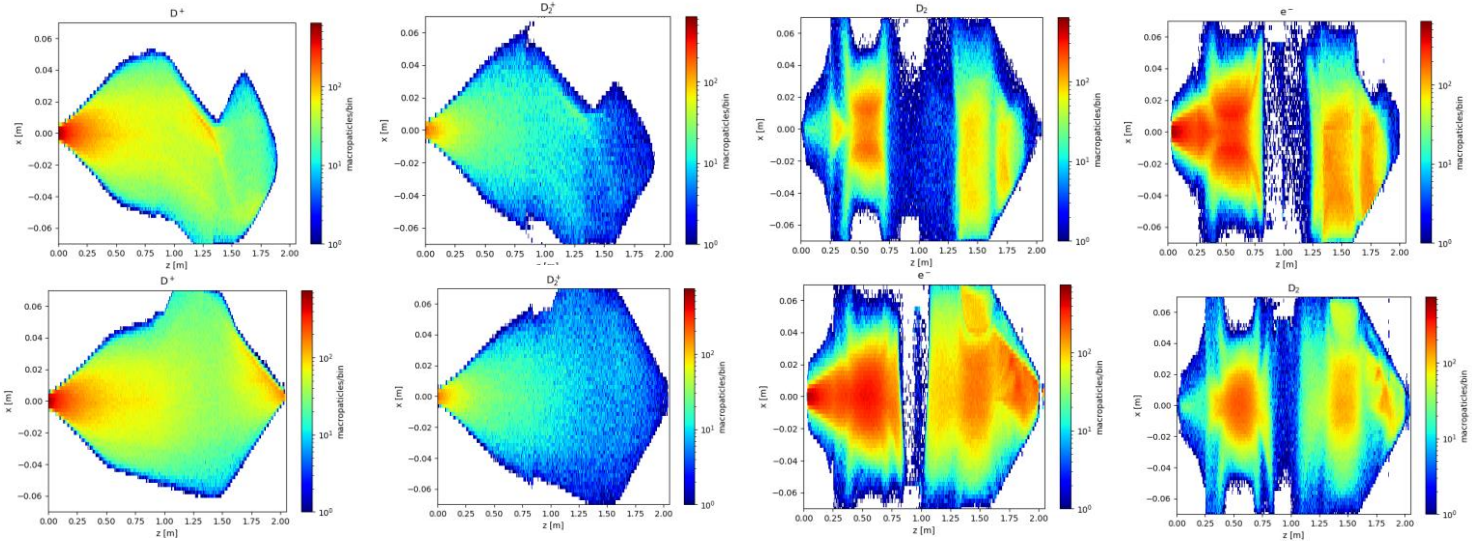
+10 kV



-10 kV



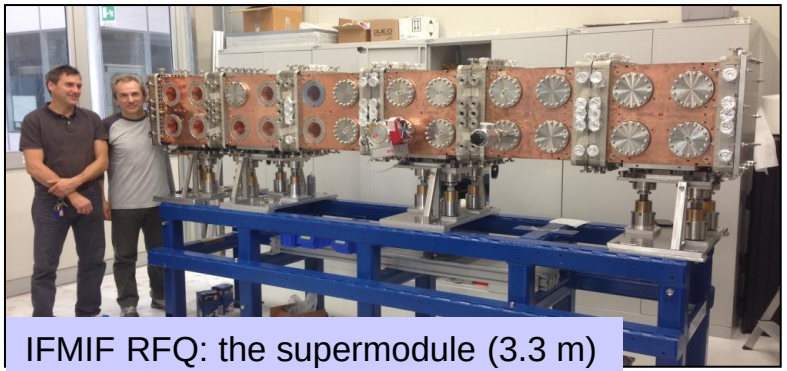




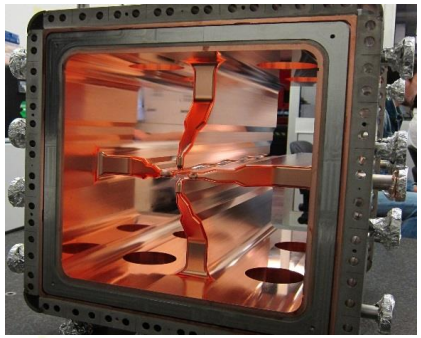
+10 kV

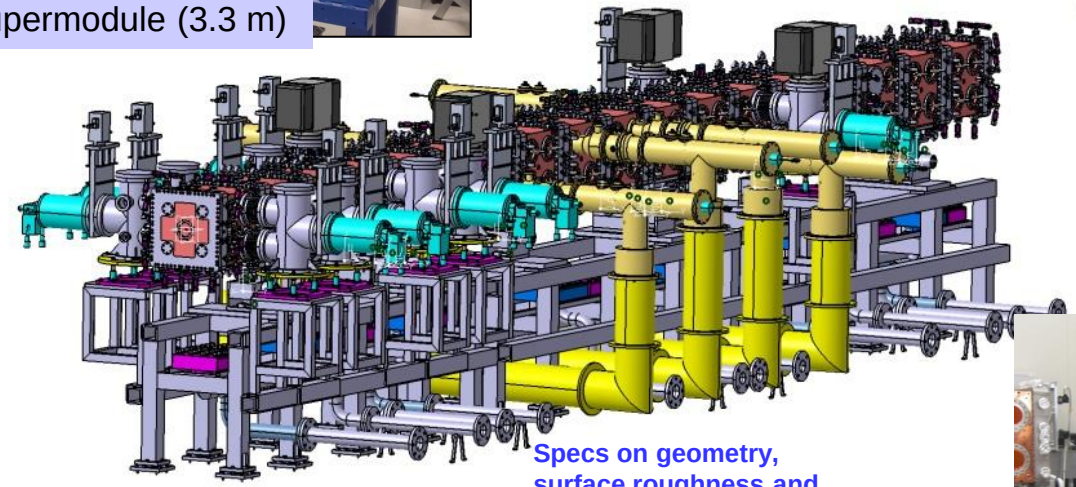
-10 kV

RFQ construction

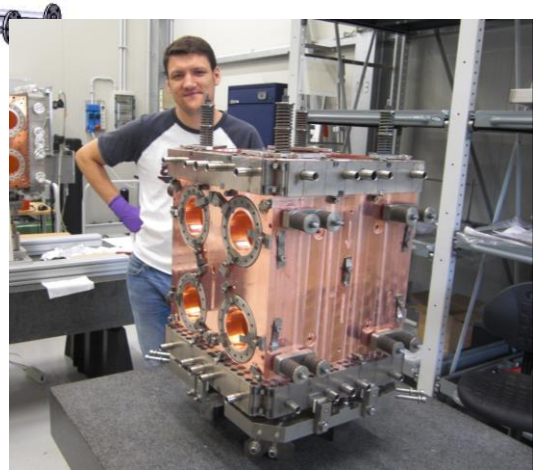


IFMIF RFQ: the supermodule (3.3 m)





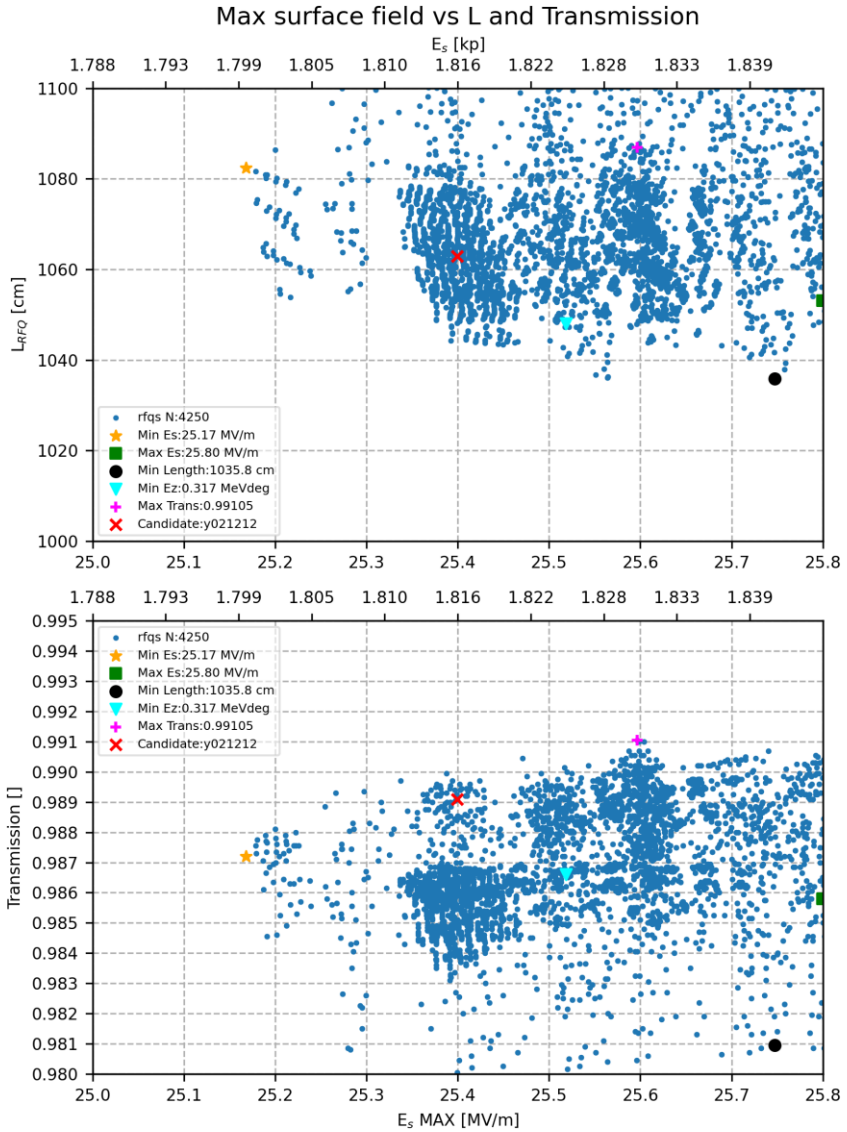
Specs on geometry, surface roughness and quality, vacuum tightness….
Field and beam performances under INFN responsibility

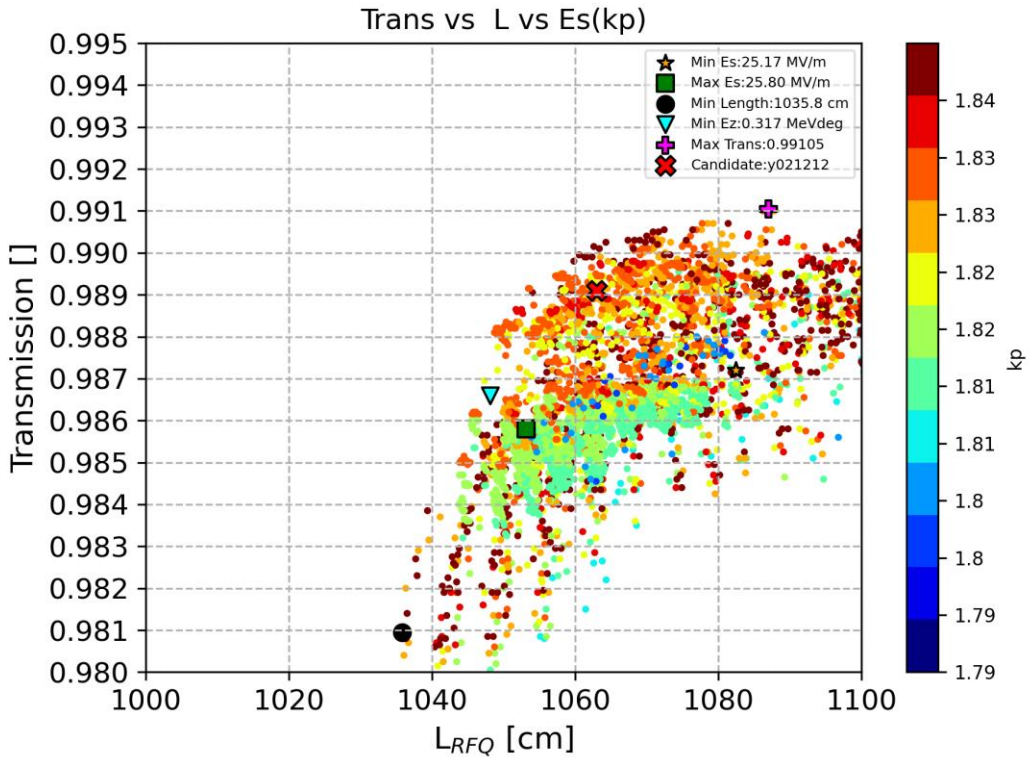


INFN development for Brazing

18 modules in three supemodules

- High energy SM built by Cinel, Padua (Italy),
- Intermediate energy built internally by INFN,
- Low energy attributed to RI Koln (Germany), concluded by INFN

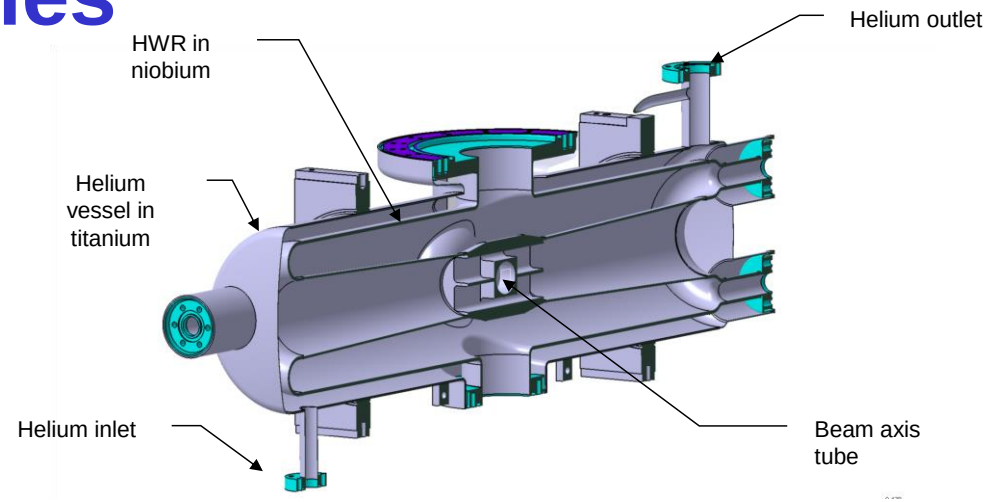




DONES RFQ Design Study for higher current (150 mA)
Each dot is a full multiparticles simulation of a complete RFQ (intense
AI algorithms also used for optimization

Superconducting cavities

- The superconducting linac (cryomodules based on HWR and superconducting solenoids) is developed by CEA
- HWR linac concept is hystorically an evolution of HI superconducting linacs like ALPI
- Cavities for IFMIF EVEDA were fabricated in Italy (Zanon)



LNL low beta (A. Facco et al)

IFMIF EVEDA HWR designed by CEA

High power RF systems

– RF system 175 and 352 MHz narrow band, high efficiency.
– Based on tetrode and solid state technology
– In this case the specs to industry are functional (power, frequency, band, linearity, efficiency, interfaces…..)

INFN solid state amplifier (125 kW cw, 352 MHz), 5 machines built for MUNES project in the national industry (2017).

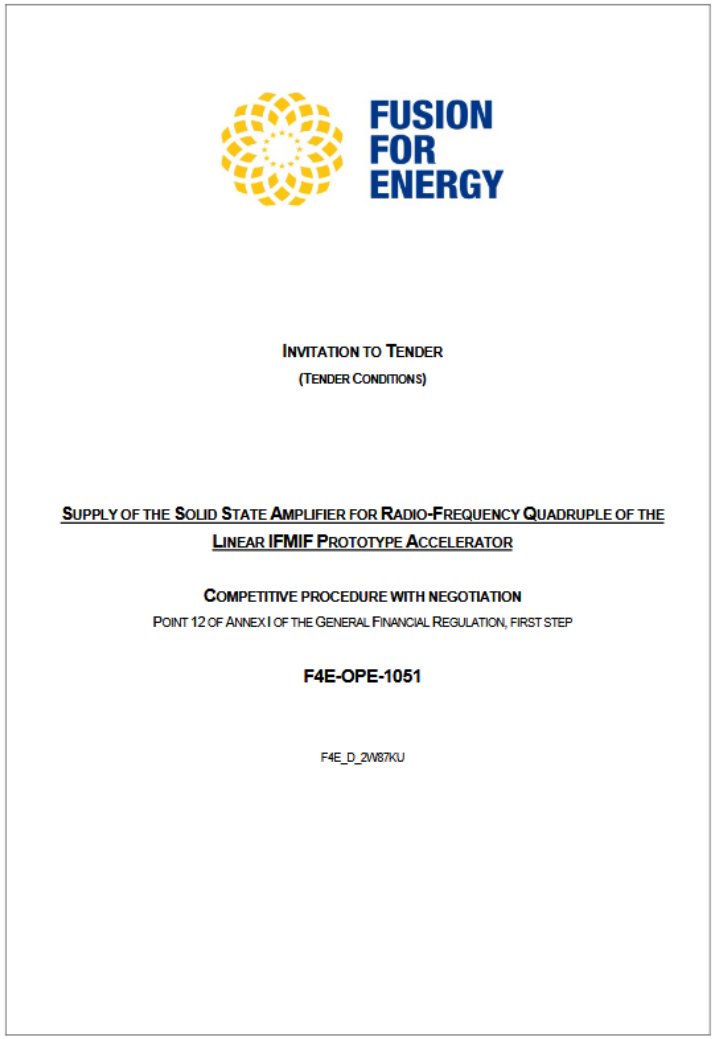
Two stages tetrode based amplifier (200 kW cw, 175 MHz), installed in 2013 used for high power tests of IFMIF RFQ segment, built in national industry

DONES PROTOTYPE

INFN prototype of solid state amplifier (200 kW cw, 175 MHz), under construction in the national industry. To be delivered May 2022

Broader Apprach2 RF system for the RFQ

- F4E tender to which INFN should participate together with Italian industry
- Development of the new RF system for the INFN RFQ in Rokkasho based on solid state amplifiers, prototype, construction of 8 chains, installation in Rokkasho, participation to commissioining
- First administrative step, Submission of Requests to Participate (10/05/2022).
- Estimated value 8.8 M€



FUSION FOR ENERGY

INVITATION TO TENDER

(TENDER CONDITIONS)

SUPPLY OF THE SOLID STATE AMPLIFIER FOR RADIO-FREQUENCY QUADRUPLE OF THE LINEAR IFMIF PROTOTYPE ACCELERATOR

COMPETITIVE PROCEDURE WITH NEGOTIATION

POINT 12 OF ANNEX I OF THE GENERAL FINANCIAL REGULATION, FIRST STEP

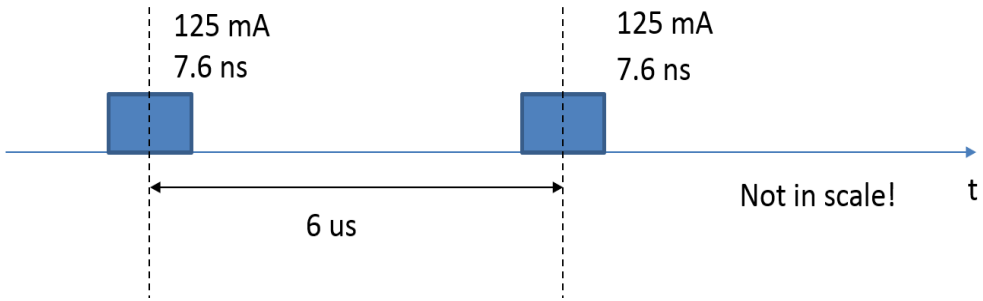
F4E-OPE-1051

F4E_D_2W87KU

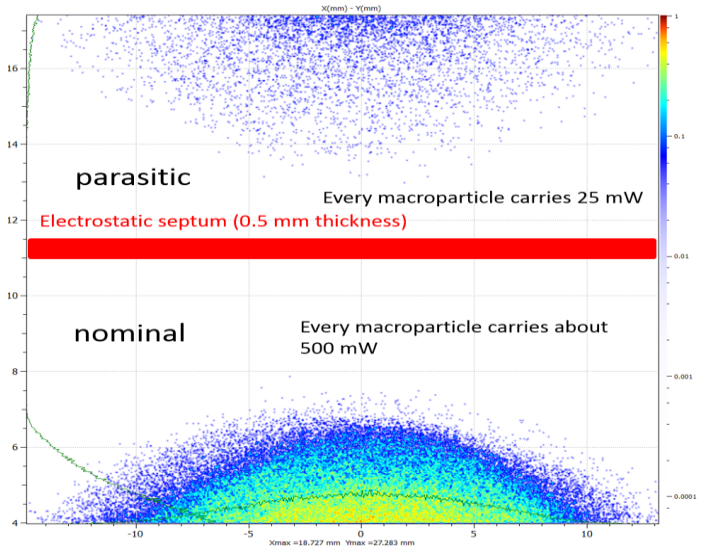
DONES Preparatory Phase

- l'INFN ha partecipato alla preparatory phase di DONES (EU Grant Agreement no. 870186 DONES-PreP) (2019-21)
- responsabilità specifica dello studio applicazioni del fascio di deutoni non legate alla fusione e in particolare allo sviluppo di un fascio parassita (1 – 0.1 %) da estrarre ad alta energia.

DONES-PreP Kick off meeting (Madrid ottobre 2019)



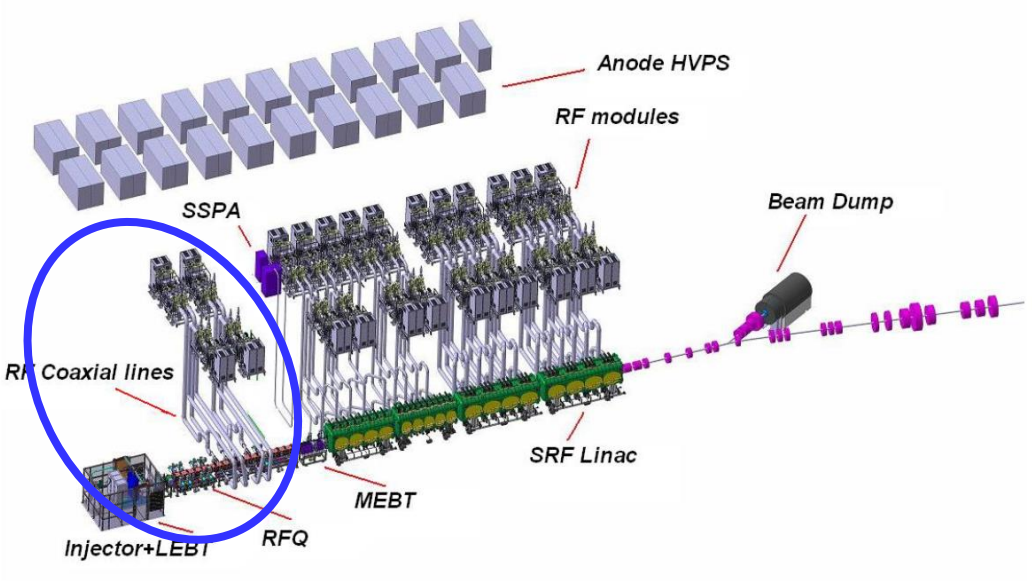
Struttura temporale del fascio per gli esperimenti (TOF)



Simulazione della potenza di fascio (principale e parassita) al setto elettrostatico

Participation in DONES (discussion in progress)

- In the next phase of DONES, the INFN could provide, in addition to the **RFQ**, the entire **injector** (ECR source, LEBT line, chopping system) having all the necessary skills and excellent contacts with highly qualified Italian industries.
- Integrating the **RF system** and **injector** under the INFN responsibility would simplify the management of two interfaces between different components that have proved to be very complex in the LIPAc experience.



conclusions

- Interest letters were collected from Italian industries
- Based on available know how INFN and ENEA, within DONES PrepF, compiled the following EURATOM Survey
- Next step could be a request from Spaing for an inkind contribution

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Date: 13/01/2022 15:01:07

Survey on possible contributions to the DONES Program

Fields marked with * are mandatory.

Answers to the survey should be given by Country Representatives involved in the DONES Working Group. Answers should by no means be seen as commitments from the represented countries, but rather as informative indications. The main objective is to develop an informed overall view on the possible future contributors to the DONES Program.

Accelerator Systems Manufacturing, Installation & Check out

WBS Name	Interested (1)	Priority (2)	Likelihood of commitment (3)	Comments
Accelerator Ancillaries System (excluding cryoplant)	Yes	1	2	
Cryoplant	No			
RF Power	Yes	3	3	
Injector	Yes	2	3	
RFQ	Yes	3	3	
MEBT	No			
SRF Linac	Yes	2	2	Limited to the manufacturing of cavities
HEBT & Beam Dump	No			
Control Systems	Yes	2	3	

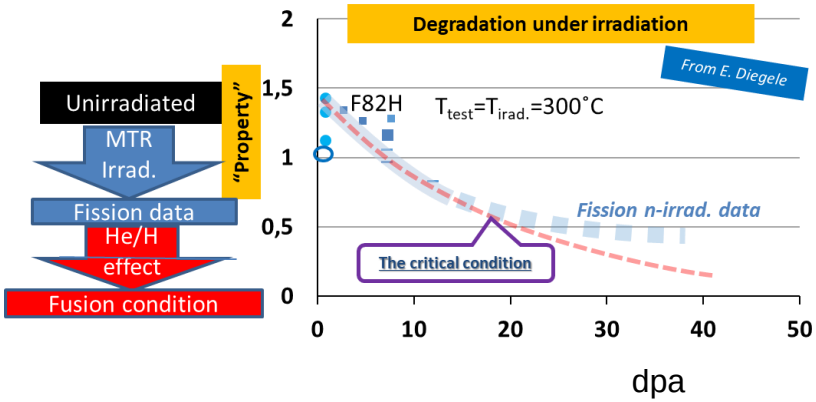
RISERVA

EU Strategy for Material n-Irradiation

Fission irradiations

- **Intensive and broad use of MTR (Material Test Reactors) fission irradiation:** EU plans for 50M€ in the next decade
- **Complementary irradiation modelling and verification (multi-ion beams)**

To establish 1st step "best estimate" to perform engineering design



Fusion-like irradiations

•Mandatory: a dedicated facility for material qualification that best mimics 14Mev neutrons with reasonable irradiation volume, fluence, and optimized homogeneity in T with the objective to (finally) validate in-vessel materials

Based on the assumption that fusion-related effects will appear only at high dose (>10-20 dpa)

Financial overview

- **Spanish committment**:

  As host, Spain is committed to the success of DONES construction and operation and it is ready to provide for:

  - 50% construction costs (main planned contributions: people to the PT, Buildings and Plant Systems)
  - 10% operation costs

- **Croatian committment**:
  - 5% construction costs

- **F4E** (around 20% construction costs -130 M€- **included in the presently planned long-term budget**)

- other possible partners that showed some interest (Italy, France, Germany, Sweden, Belgium, Hungary, Portugal, Poland,…)

+ EUROfusion contribution during the design phase (already committed) and during the future operation phase