

FROM RESEARCH TO INDUSTRY



# HIGH INTENSITY ACCELERATORS FOR NEUTRON PRODUCTION AT CEA SACLAY

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1. Who are we ?
2. SACM competences
3. Projects for neutron production

# 1. Who are we ?

- CEA
- IRFU
- SACM
- SACM missions

CEA is the French Alternative Energies and Atomic Energy Commission

- 16000 employees, 3900 M€
- 10 centers in France

We are located in Saclay, 20 km South-West from Paris, in the new Paris-Saclay campus

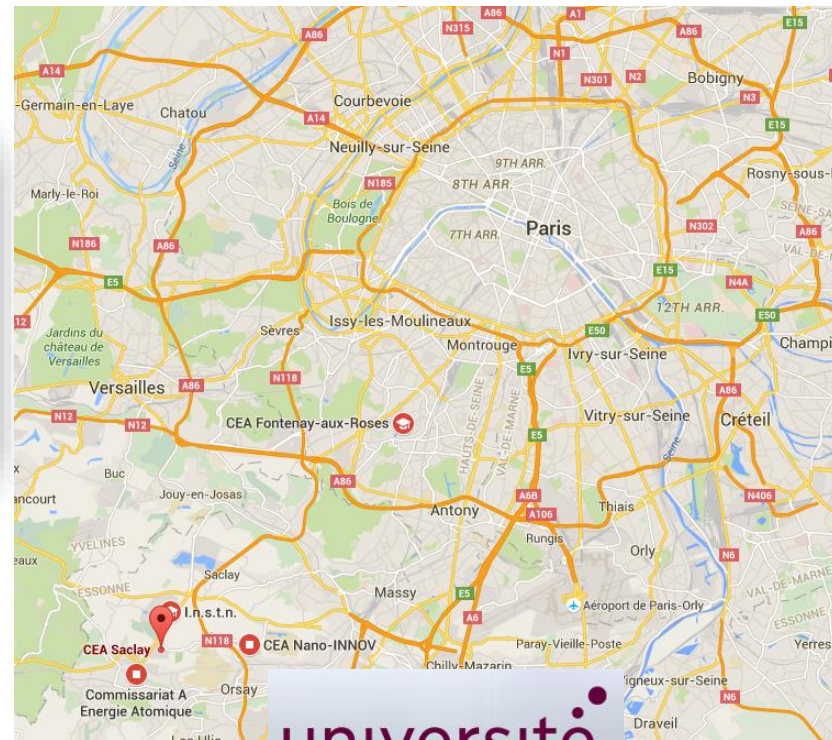
## CEA

### Alternative Energies & Atomic Energy Commission

Commission



## Basic Research





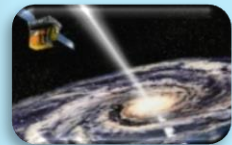
IRFU:

- ~ 800 FTE
- 3 physics divisions, 3 technological divisions



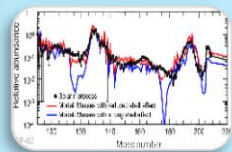
Building a (compact) neutron source requires a large number of competences

## Institute of Research into the Fundamental laws of Universe



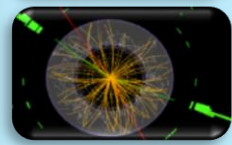
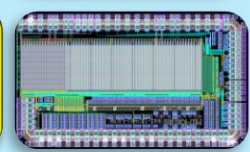
**SAp: Astrophysics**  
Space technologies

**SACM: Accelerators,**  
Cryogenics, Magnets



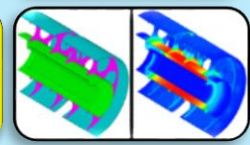
**SPhN: Nuclear Physics**

**SEDI: Detectors,**  
electronic, computing



**SPP: Particle Physics**

**SIS: Systems engineering**



# SACM is organized in 5 laboratories



**Direction : P. Védrine**  
**Deputies : P. Brédy, O. Napoly**



**CSTS :**  
**Président**  
**A. Chancé**



**LEAS**  
**JM. Rifflet, A. Payn**

Superconducting Magnets

**LEDA**  
**J. Schwindling, R. Gobin**

Particle Accelerators

**LCSE**  
**C. Mayri, R. Vallcorba**

Cryogenics & Test Facilities

**LISAH**  
**C. Marchand, G. Devanz**

Accelerating & Radiofrequency  
Systems

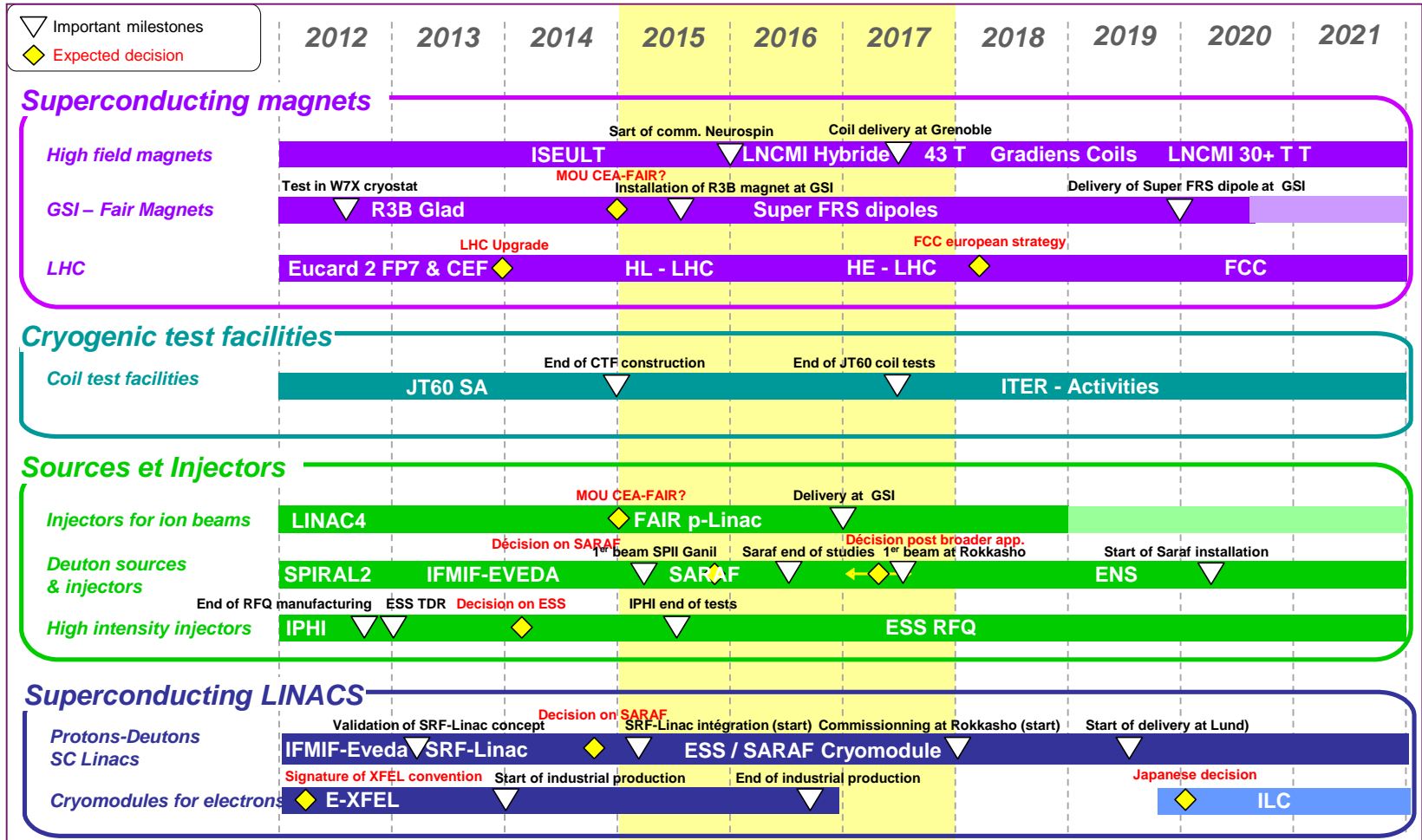
**LIDC2**  
**C. Madec, J.P. Charrier**

Superconducting cavities &  
Cryomodules

- Irfu/SACM is developing and realizing particle accelerators, cryogenic systems and superconducting magnets for the scientific programs of Irfu and more widely of CEA.
- Irfu/SACM is also involved in large scale projects in Europe and Japan
- These projects are managed within the Irfu project organisation
- They rely on the skills and activities of SACM, SIS, SEDI and SPhN.
- Iru/SACM develops R&D activities to support theses programs
- In December 2014 , **81 engineers and 44 technicians**, CEA staff, belong to the Irfu/SACM division.



# SACM ROADMAP FOR 2020



## 2. SACM competences

- High Intensity Light Ion Sources
- Beam Transport Lines
- Beam Diagnostics
- Radio-Frequency Quadrupoles
- Superconducting RF Cavities and Cryomodules
- Superconducting Magnets
- Beam Dynamics



# HIGH INTENSITY LIGHT ION SOURCES

We are specialists of high intensity (5 – 100 mA) light ion ( $H^+$ ,  $D^+$ ) sources for accelerators

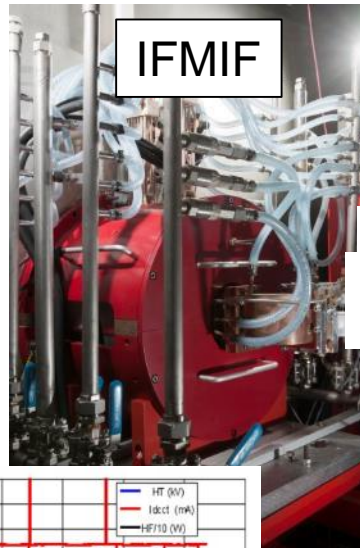
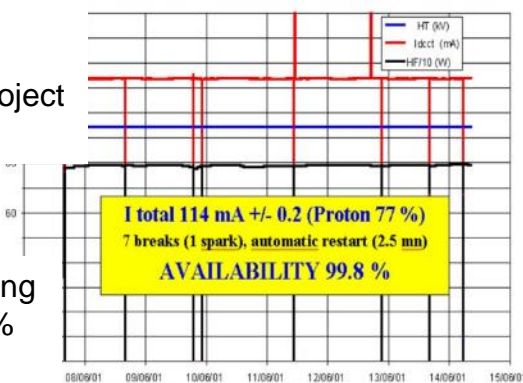
- Current, emittance, species proportions, stability, reliability
- Pulsed or continuous modes



**SILHI**

- Since 1996
- 95 kV, 100 mA
- Fraction  $H^+ > 80\%$
- Source of the IPHI project
- Licence Pantechnik

SILHI reliability tests during 7 days, 114 mA : 99,8 %  
**8 trips > 3s**

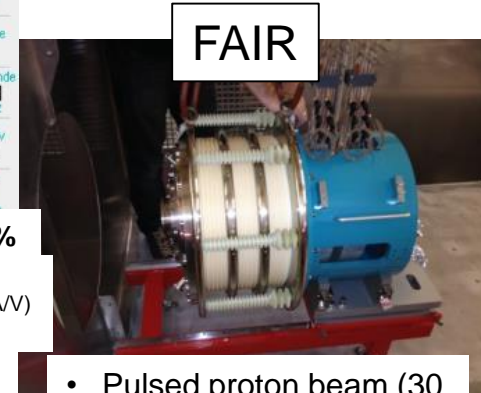


**IFMIF**



**Pulsed mode: duty cycle 20%**

- Vert: courant sortie source (25 mA/V)
- Magenta: courant en fin de ligne (20 mA/V)
- Orange: cadencement



**FAIR**

- Pulsed proton beam (30 ms - 300 ms @ 4Hz).
- 95 keV, 100 mA



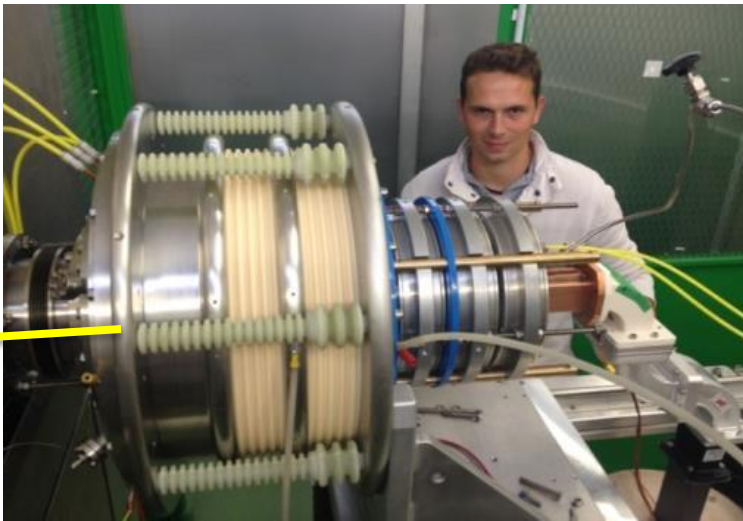
**SPIRAL2**

- 40 kV, 10 mA
- Permanent magnets
- Cost, size

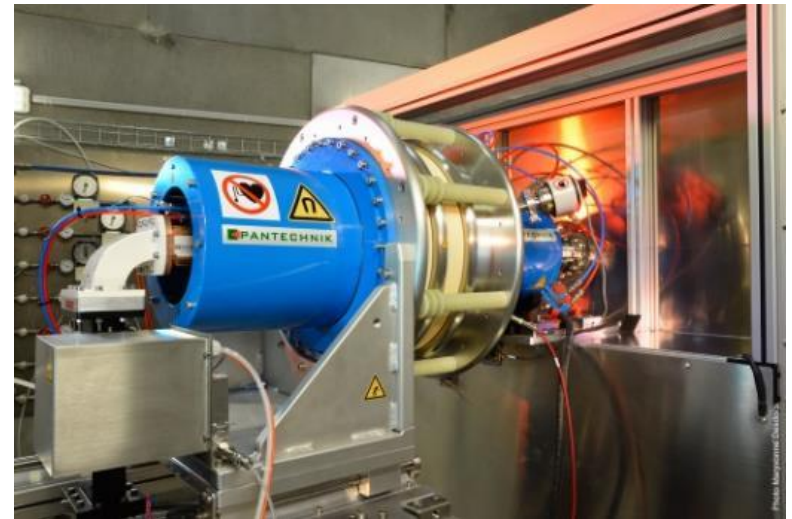
Since beginning 2013, contract with the Pantechnik company (Bayeux, France) for building and selling a commercial version of the SILHI source (50 mA, 50 keV)

Pantechnik is a world-wide known company for medical sources (Carbon ion sources for CNAO and MedAustron for example)

SILHI2 sources sold in China and India



*SILHI2 installed on the BETSI test bench  
by M. Xavier Donzel (Pantechnik)*

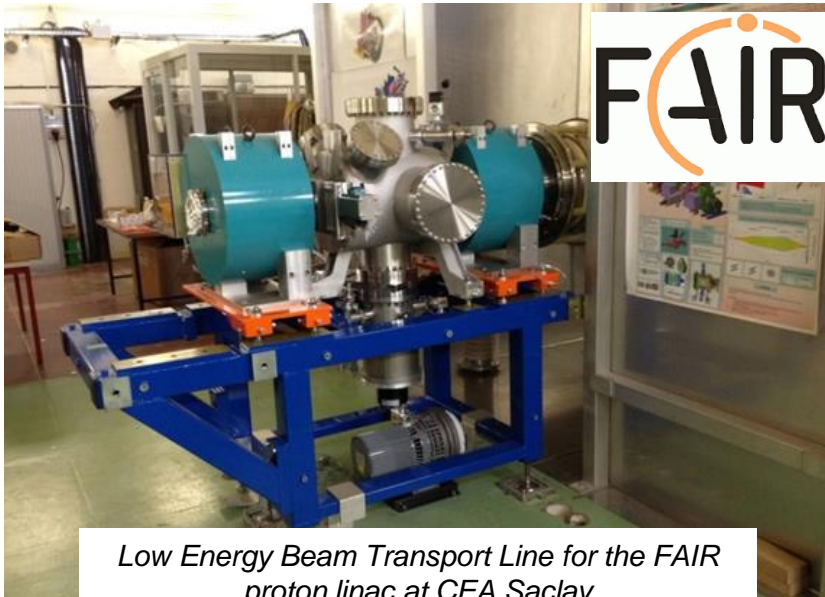


*A SILHI2 source at Pantechnik*

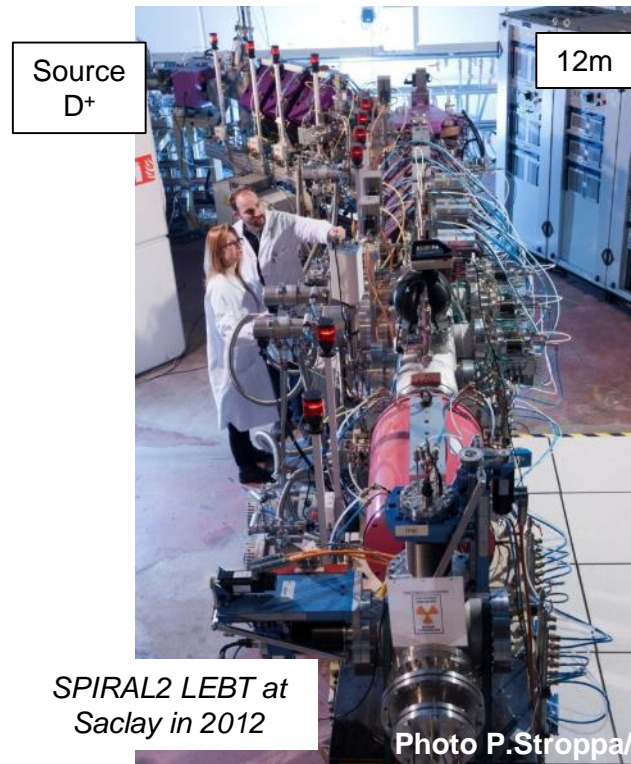
# LOW ENERGY BEAM TRANSPORT LINES (LEBT)

Purpose of the LEBT:

- House beam diagnostics
- Focus the beam at the entrance of the acceleration stage
- « Chop » the pulses
- Challenge = keep the beam emittance small (in particular space charge effects at high intensity)



Low Energy Beam Transport Line for the FAIR proton linac at CEA Saclay



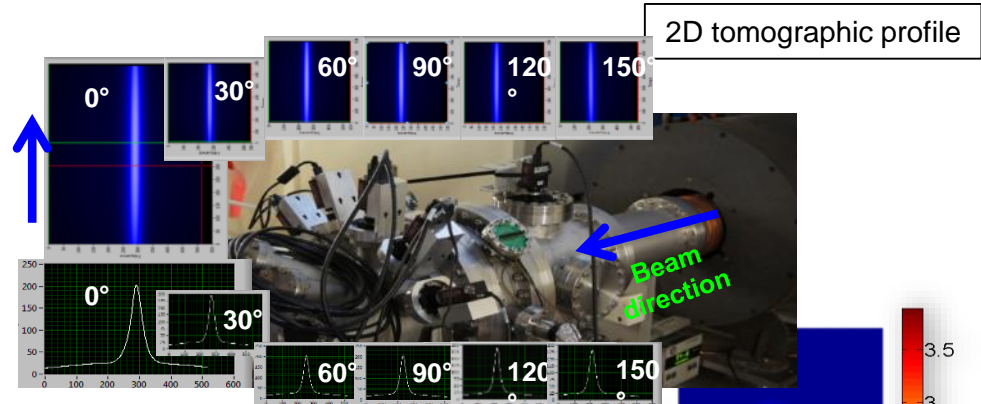
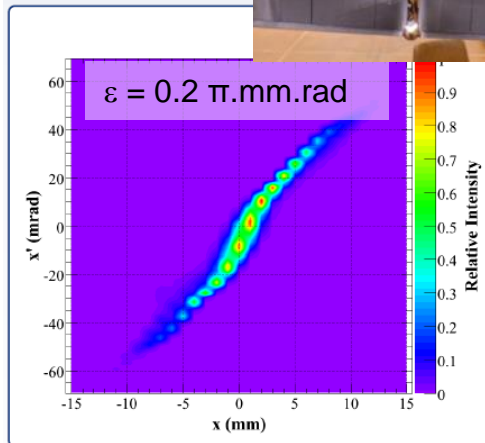
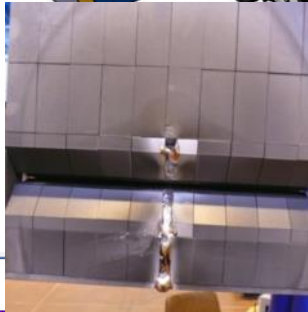
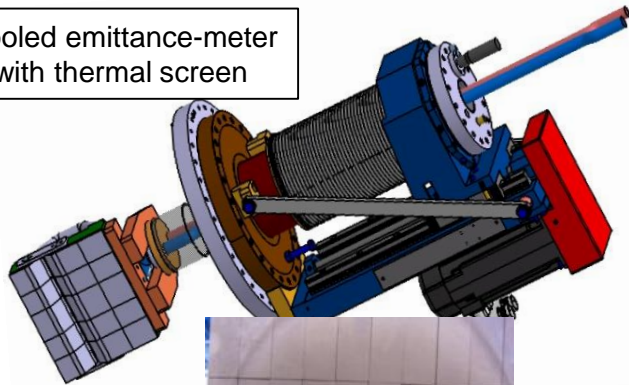
SPIRAL2 LEBT at Saclay in 2012

Photo P. Stroppa/C

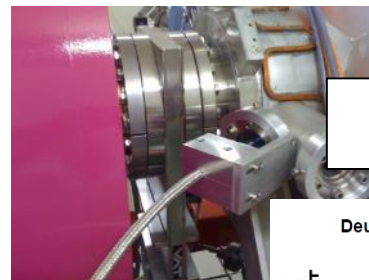


- Needed to characterize the beam: current, proportions, position, profile, emittance
- High intensity = high power → non interceptive beam diagnostics

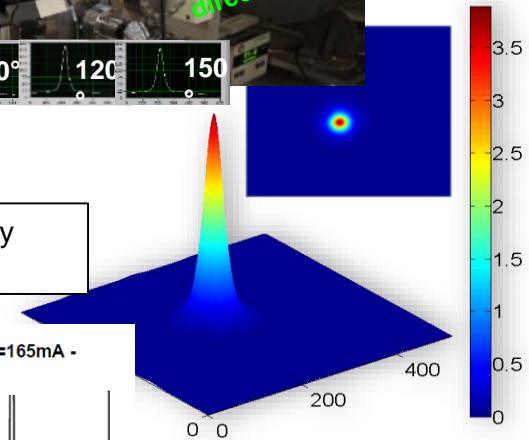
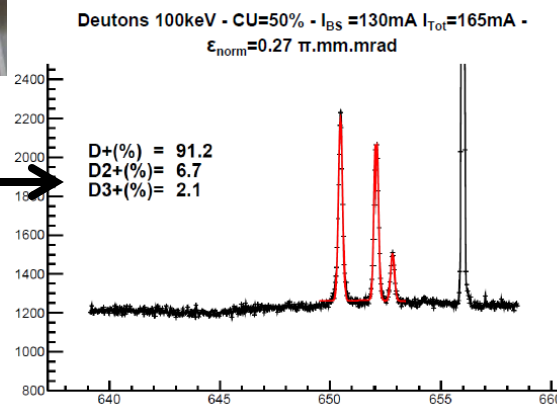
Cooled emittance-meter with thermal screen



2D tomographic profile



Proportions measured by Doppler shift method



# RADIO-FREQUENCY QUADRUPOLES (RFQ)

High intensity = high space charge → beam tends to blow up  
→ Need for continuous focusing

An RFQ has a quadrupolar structure required for the focusing. It also bunches the beam and accelerates it up to a few MeV

SACM has the following competences:

- Beam dynamics simulations
- RF design
- Thermomechanical studies
- Cooling
- Mechanical design
- Ancillary equipment
- Realization with industries
- Assembly
- Tuning
- Conditioning



# RADIO-FREQUENCY QUADRUPOLES (RFQ)

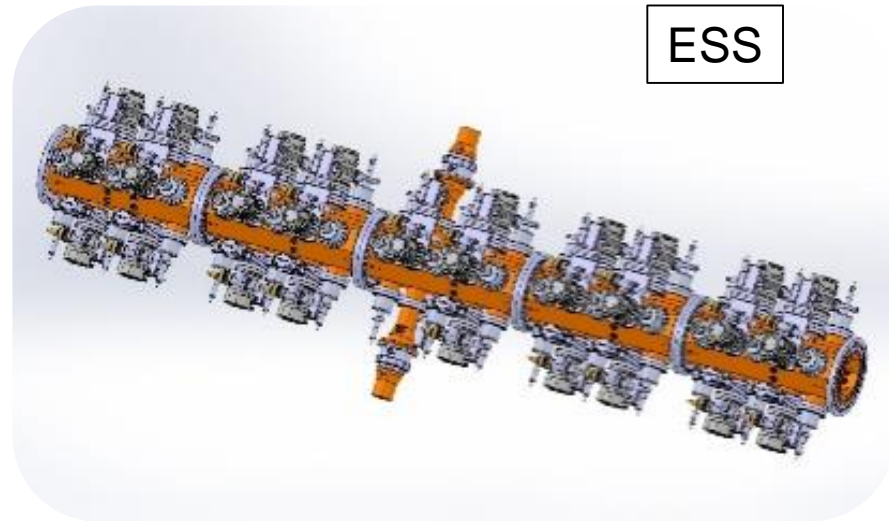
- Design and/or fabrication and/or tuning of the RFQs for LINAC4 and SPIRAL2
- In the coming years, RFQ for ESS: design and realization of the RFQ, tuning, RF conditioning
- IPHI is a local R&D project to accelerate a 100 mA cw beam to 3 MeV.

## LINAC4

First beam tests at CERN in Spring 2013



## ESS

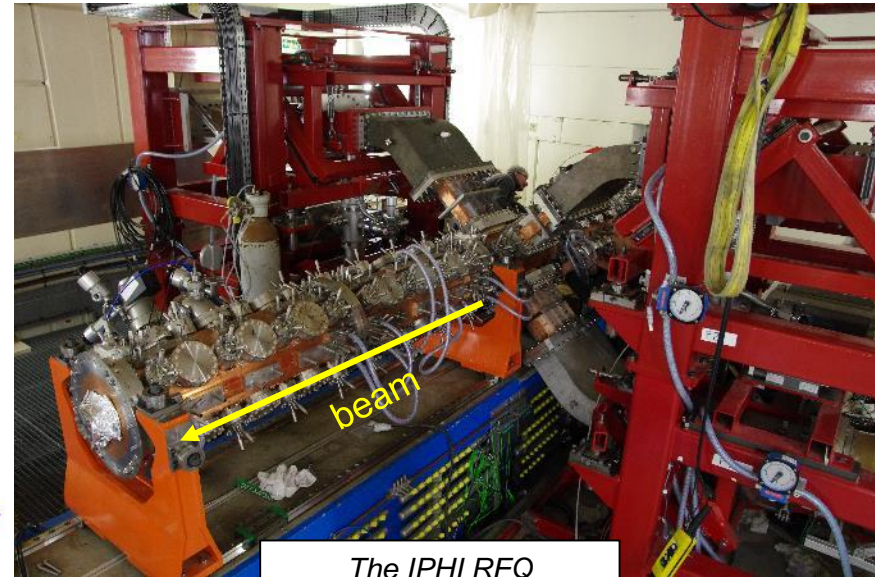
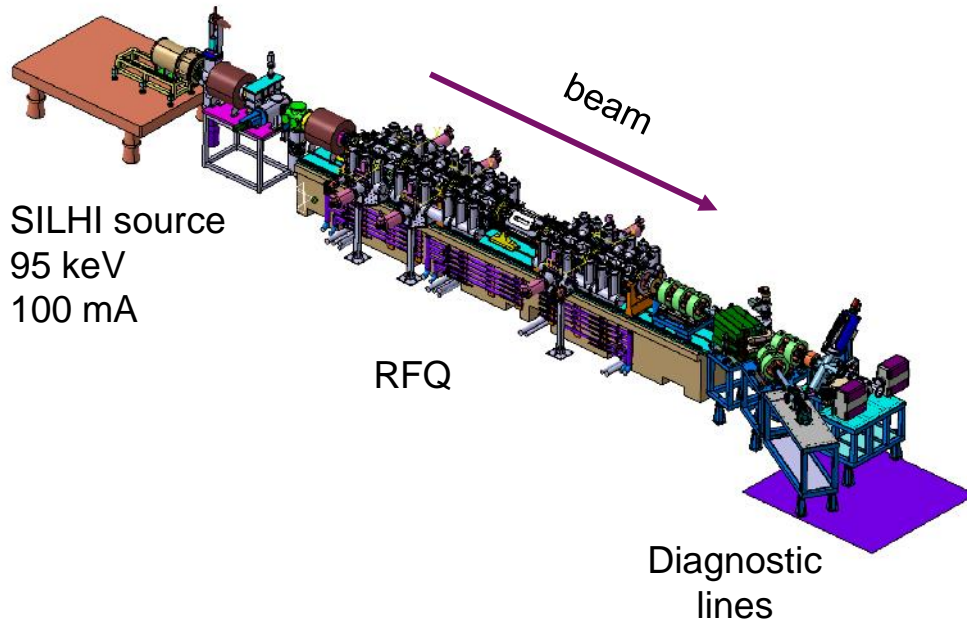




# THE IPHI PROJECT @ SACLAY

## HIGH INTENSITY PROTON INJECTOR

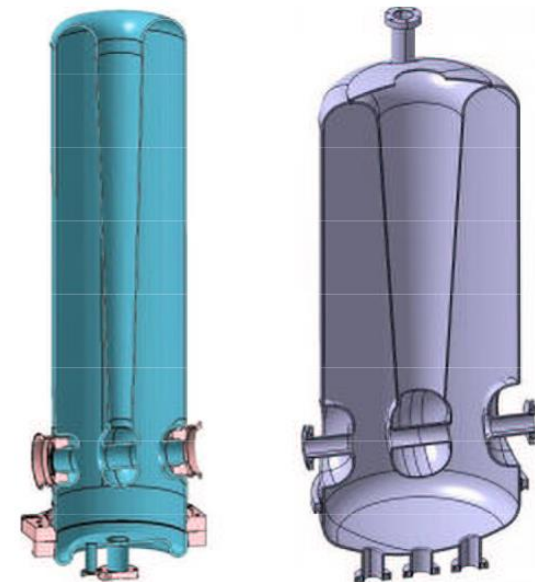
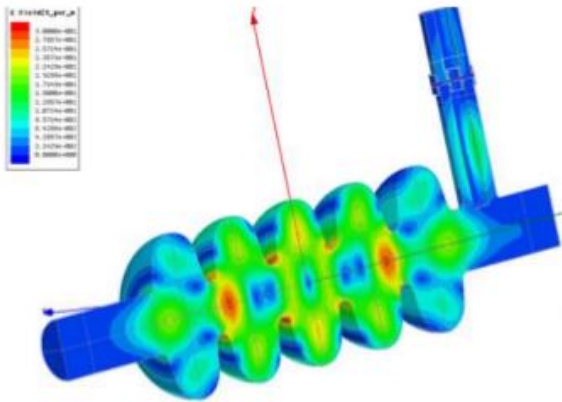
- CEA / CERN / CNRS collaboration to build a **3 MeV, 100 mA, continuous mode** proton accelerator
- RF conditioning of the RFQ has started
- We expect to test with beam (pulsed, cw) in 1<sup>st</sup> semester 2016
- IPHI will then be available at Saclay for R&D (beam diagnostics, neutron source ...)



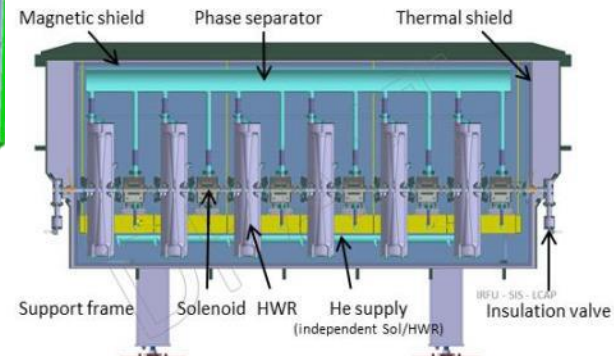
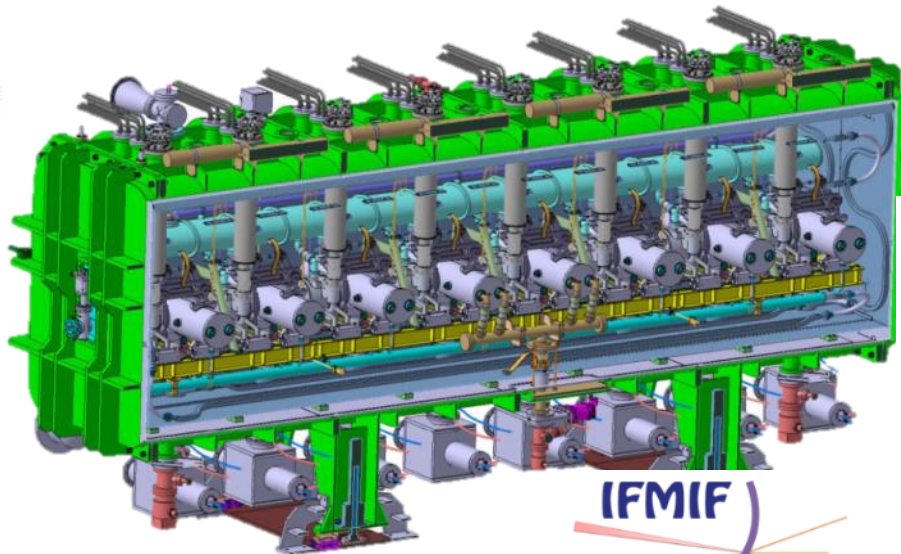
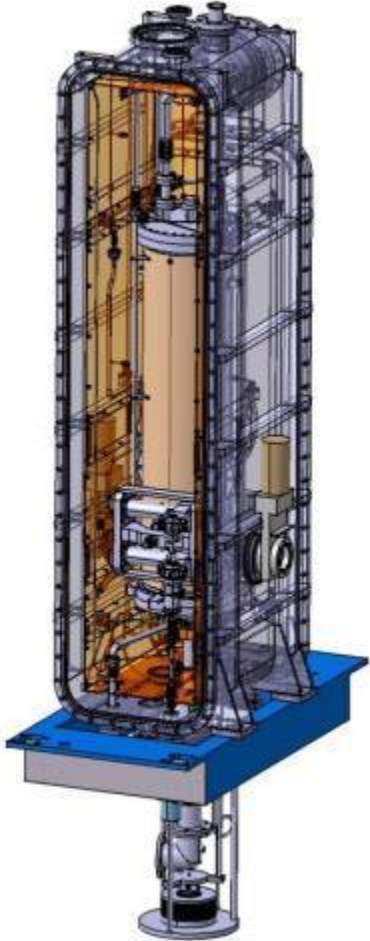
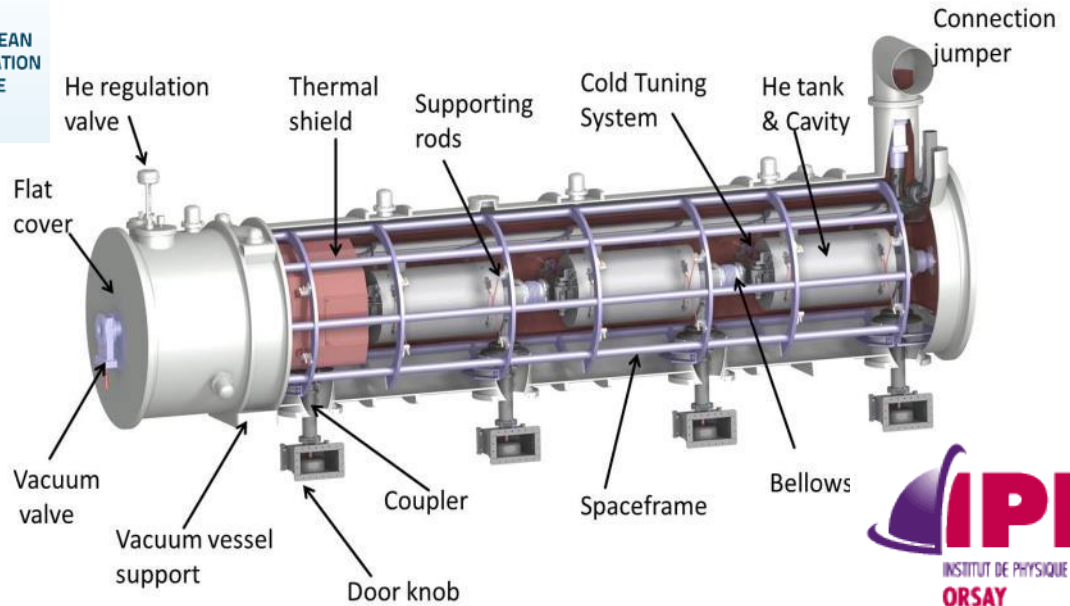
The IPHI RFQ



- Based on bulk Niobium, SRF technology is used for most of the linear accelerators since 2000: EU-CARE (SRF, HIPPI), XFEL, ESS, IFMIF, SPIRAL2, SARAF...
- Simulation, design & realization of all the critical components: cavities, couplers, tuners.
- All types of cavities: multi-cells, HWR, QWR – Low  $\beta$ , High  $\beta$ .
- R&D programs for high gradient cavities: mechanical and chemical processing, multilayer...



# EXAMPLE OF CRYOMODULE DESIGNS FOR SPIRAL2, ESS, IFMIF AND SARAF



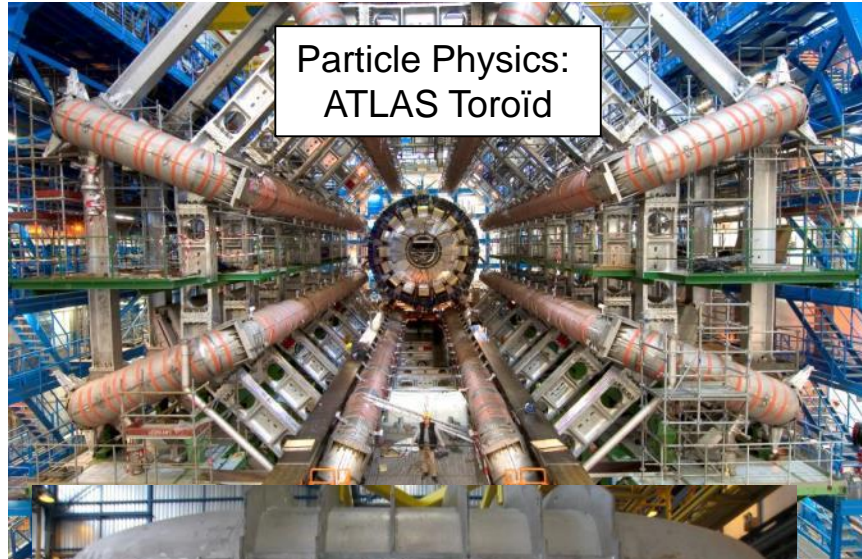
# CRYOMODULES INTEGRATION



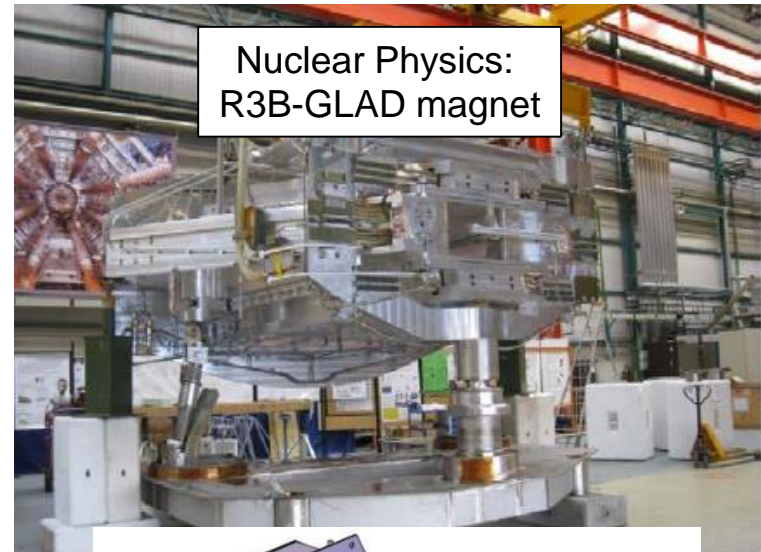


# SUPERCONDUCTING MAGNETS

- Design, fabrication, integration, test of SC magnets (NbTi) for various projects
- R&D on other superconductors (Nb<sub>3</sub>Sn, MgB<sub>2</sub>, YBACUO)



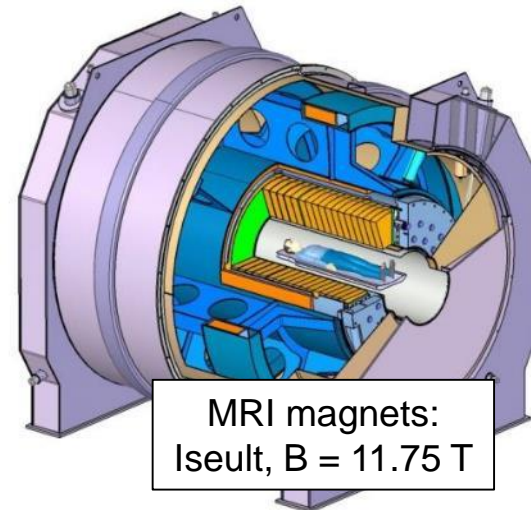
Particle Physics:  
ATLAS Toroid



Nuclear Physics:  
R3B-GLAD magnet



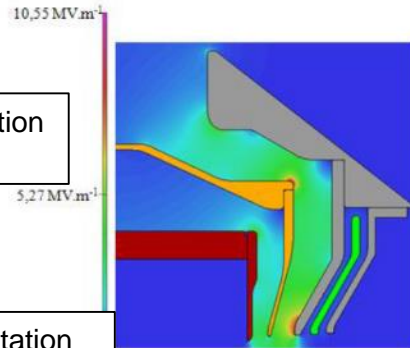
Fusion reactors:  
Test station for the JT60SA coils



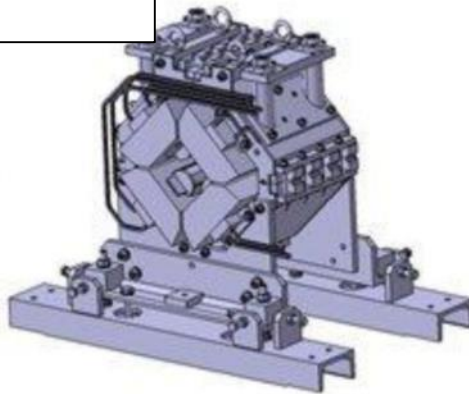
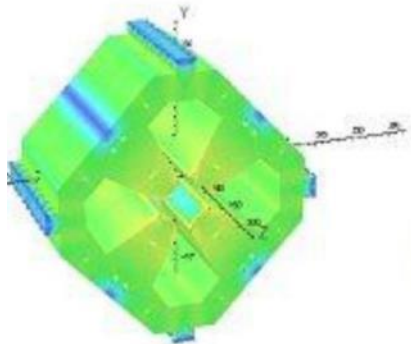
MRI magnets:  
Iseult, B = 11.75 T

Understanding of physics processes, help for design and operation

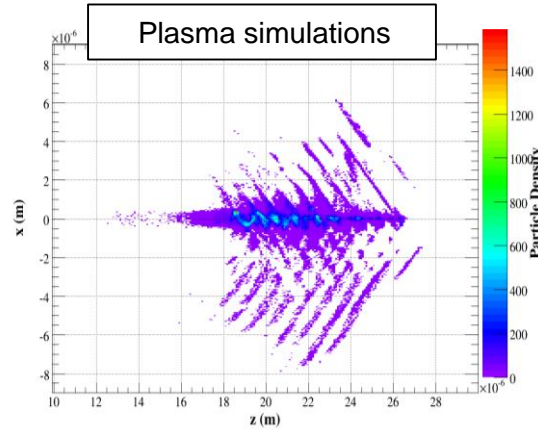
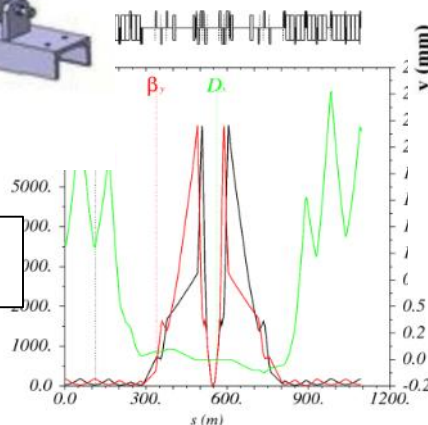
Sources and extraction systems



Electromagnetic computation  
Realistic field maps

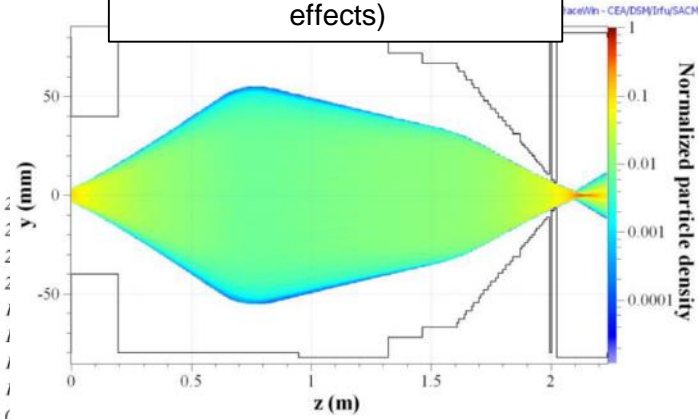


High energy colliders design



- Modeling of ion sources
- Space charge effects
- Laser – plasma acceleration

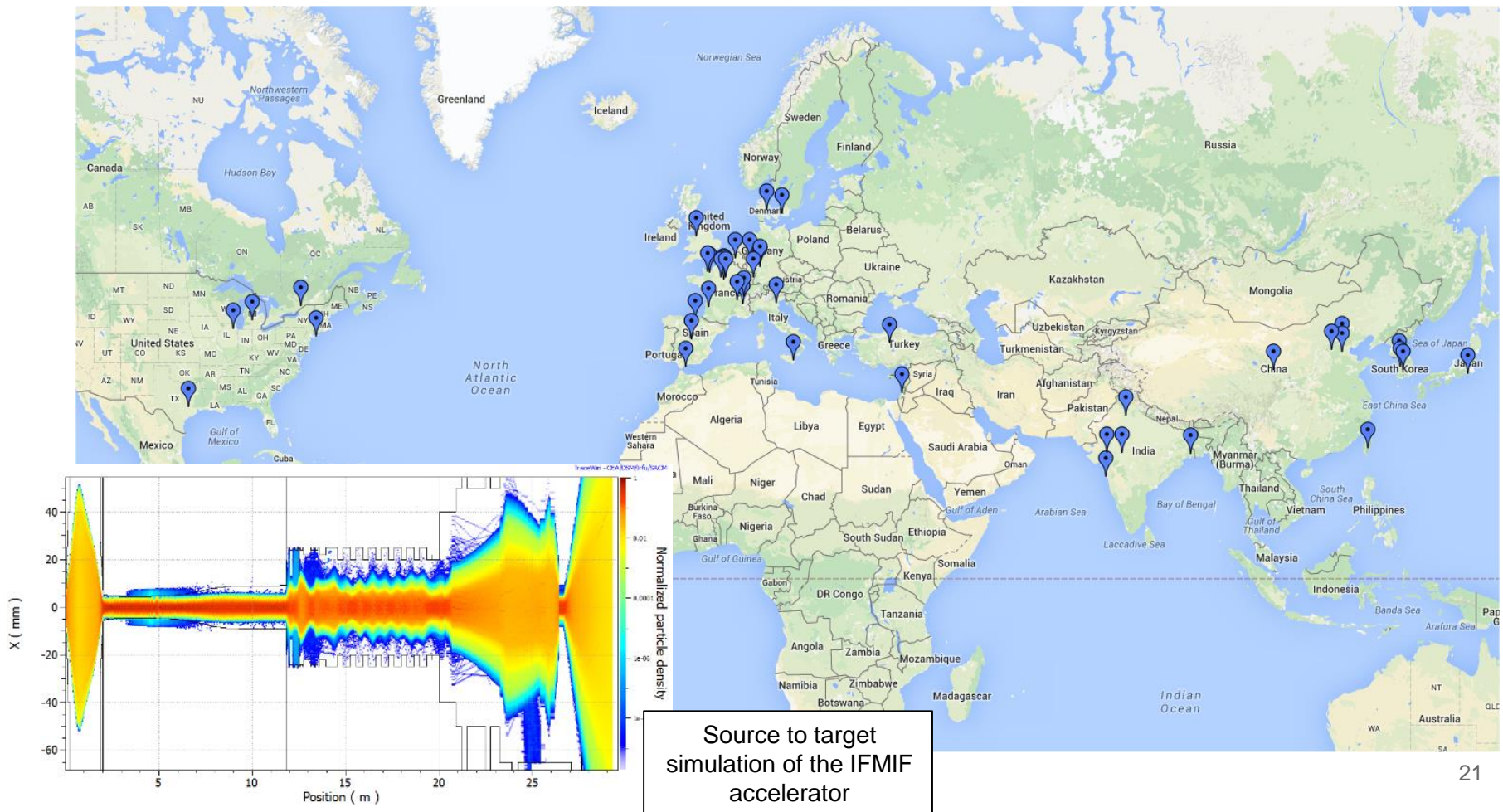
Beam transport (non linear effects)



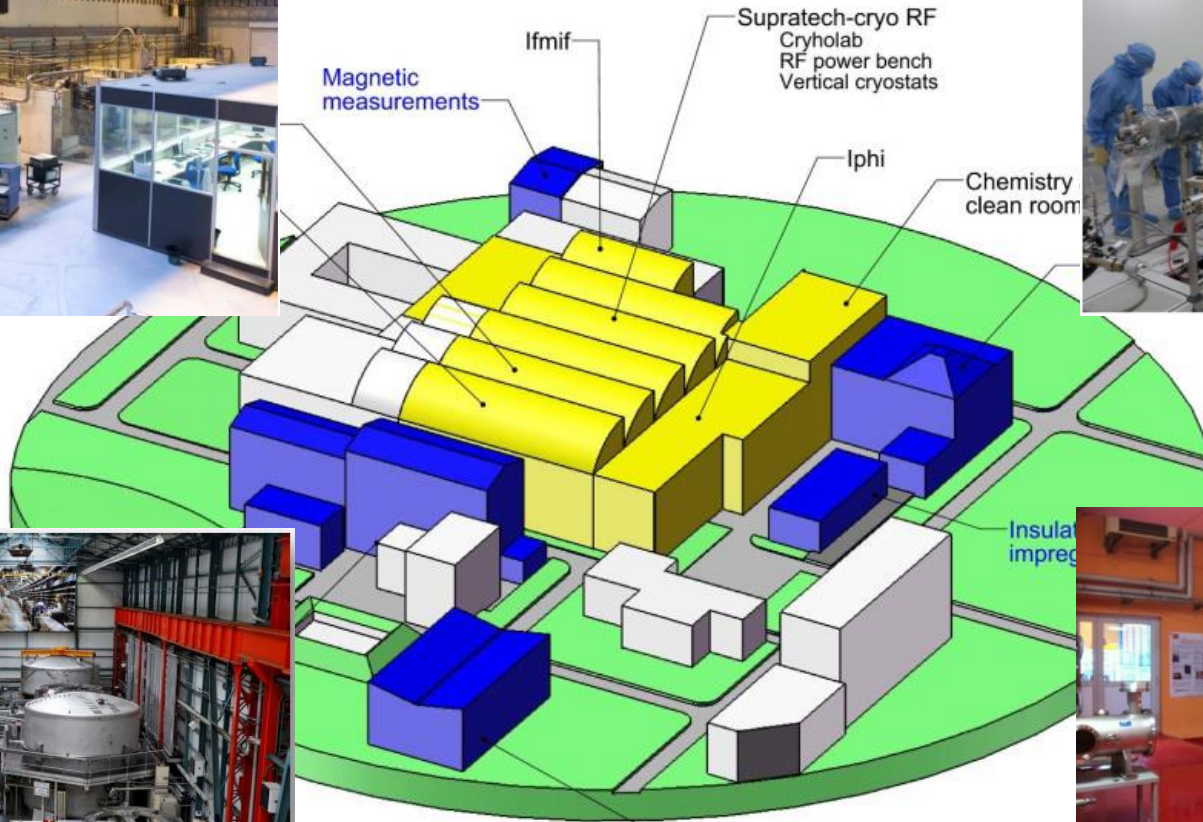


# BEAM DYNAMICS CODES

- SACM is developing codes since 90's. TRACEWIN is commercially distributed.
- 160 users, 47 laboratories, 3 companies, 18 countries



Source to target  
simulation of the IFMIF  
accelerator



Magnetic measurements

Ifmif

Supratech-cryo RF  
Cryohlab  
RF power bench  
Vertical cryostats

Iphi

Chemistry clean room

Insulation impreg

Superconducting magnet test facilities  
W7-X facilities  
Schema  
Vertical cryostat  
Seht

Characterization facilities  
Cetace  
Christiane  
Sejos  
Mecti  
Thermosiphon  
Mechanical tests



# INDUSTRIAL RELATIONSHIPS

- Subcontracting the realization or integration of accelerator parts
- But also common R&D, co-financing of PhD students...



PMB  
ALCEN



Iba



PANTECHNIK



SDMS  
la chaudronnerie blanche®



BRUKER



ALSTOM



Columbus  
Superconductors



SIEMENS



Ateliers  
de la  
Meuse



AIR LIQUIDE



SIGMAPHI  
MAGNETS AND BEAM TRANSPORT



WEKA®



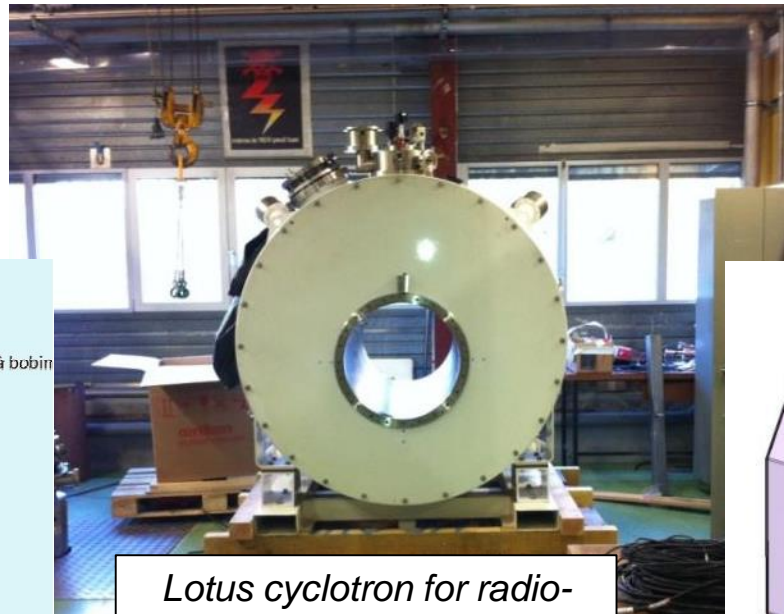
THALES



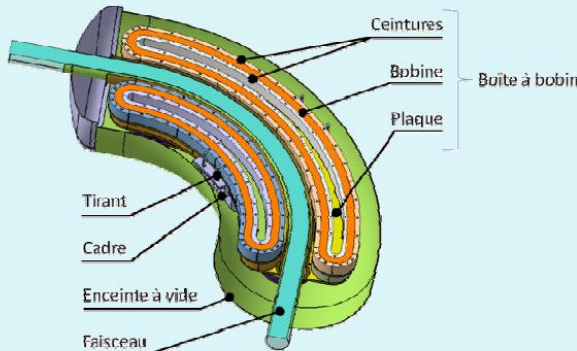
MECACHROME

# MEDICAL APPLICATIONS

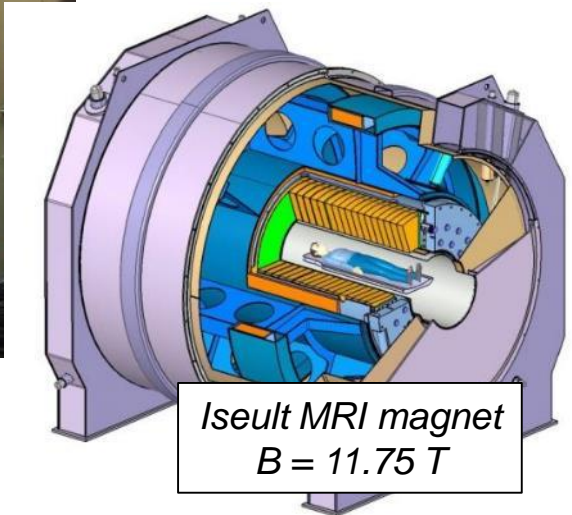
- SACM is involved in some medical applications: superconducting magnet for MRI, improvement of a cyclotron for radio-isotope production, design of a superconducting gantry for proton-therapy
- In relation with industry (PMB, IBA, Thales) and / or with life science division at CEA (DSV)



*Lotus cyclotron for radio-isotopes production*



*Design of a 90° SC magnet for gantries*



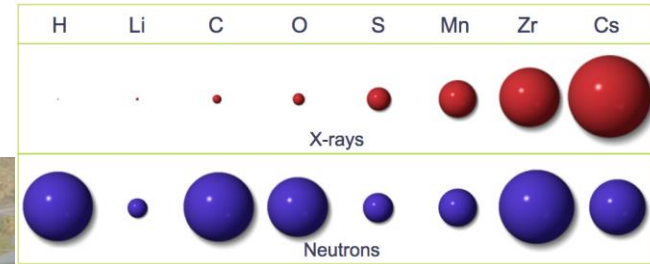
*Iseult MRI magnet  
B = 11.75 T*

# 3. Projects for neutron production

# THE ESS PROJECT @ LUND, SWEDEN

## EUROPEAN SPALLATION SOURCE

- 2 GeV protons, 60 mA, 2.86 ms / 14 Hz pulses, W target
- Neutrons as a probe for matter studies
- First neutrons in 2019





- SARAF is an Israeli project of an accelerator based neutron source to replace a nuclear reactor → 40 MeV, 5 mA, CW deuteron beam
- Will be used for nuclear physics, neutron science but also for medical applications: BNCT and radio-isotope production
- Are / will produce neutrons with Be or liquid Lithium target (LiLit)
- Commissioning in 2022

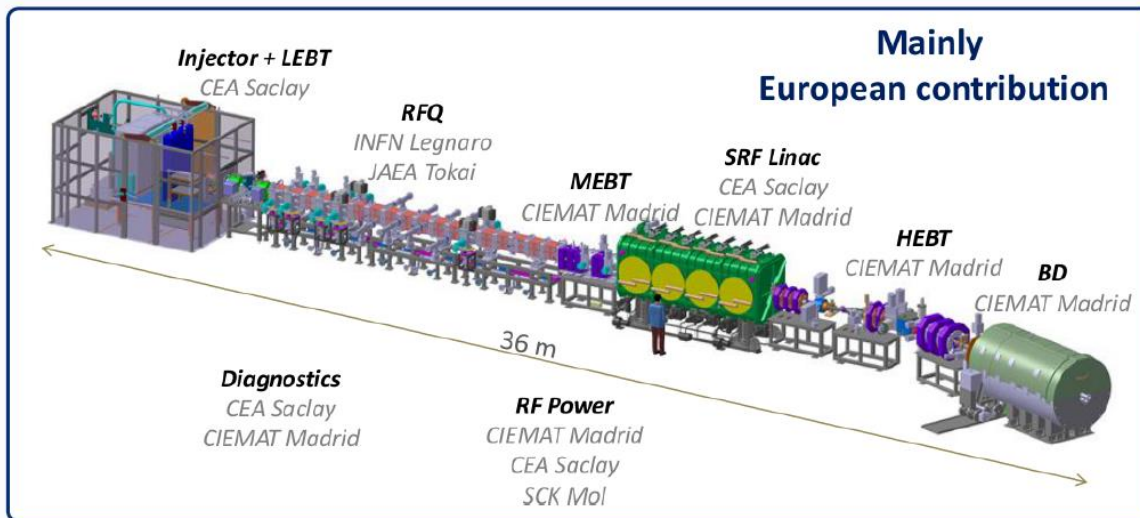


*Current SARAF accelerator*

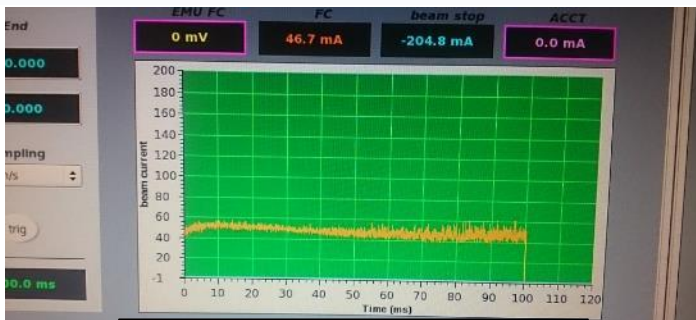
# THE IFMIF – LIPAC PROJECT @ ROKKASHO, JAPAN

## LINEAR IFMIF PROTOTYPE ACCELERATOR

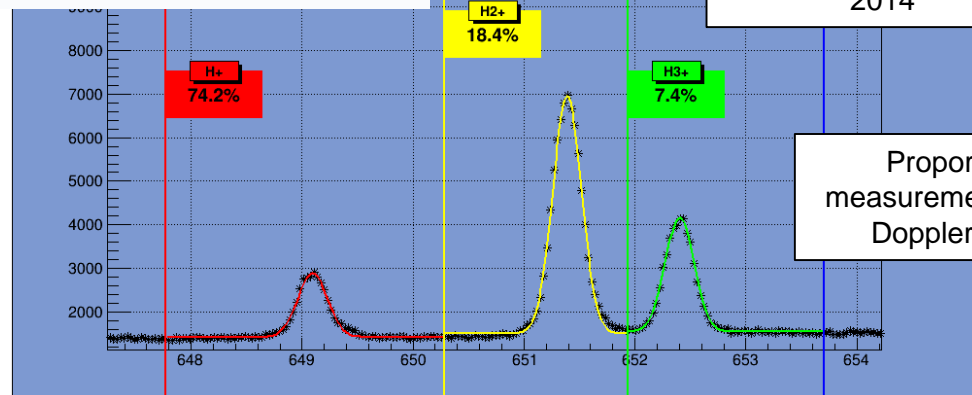
- IFMIF LIPAc is a **9 MeV** prototype for the future IFMIF 40 MeV accelerators (material studies for fusion reactors)
- 125 mA deuterons, cw  $\rightarrow$  ~ 1 MW of beam power
- Source and LEBT are installed in Japan and is being commissioned.



Local paper on Nov 5th, 2014



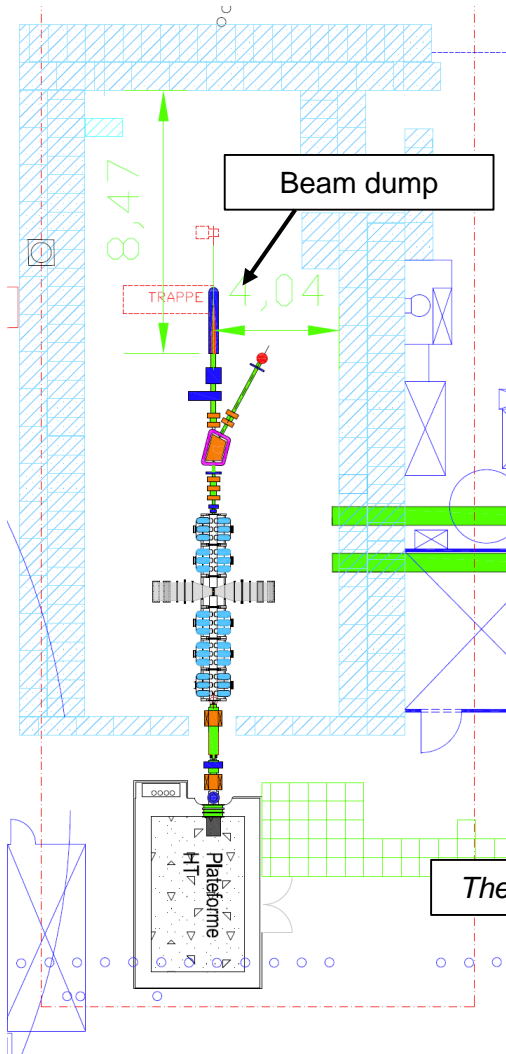
First beam (p) from the source at Rokkasho on Nov 4th, 2014



Proportion measurement using Doppler shift

# IPHI AS A NEUTRON SOURCE

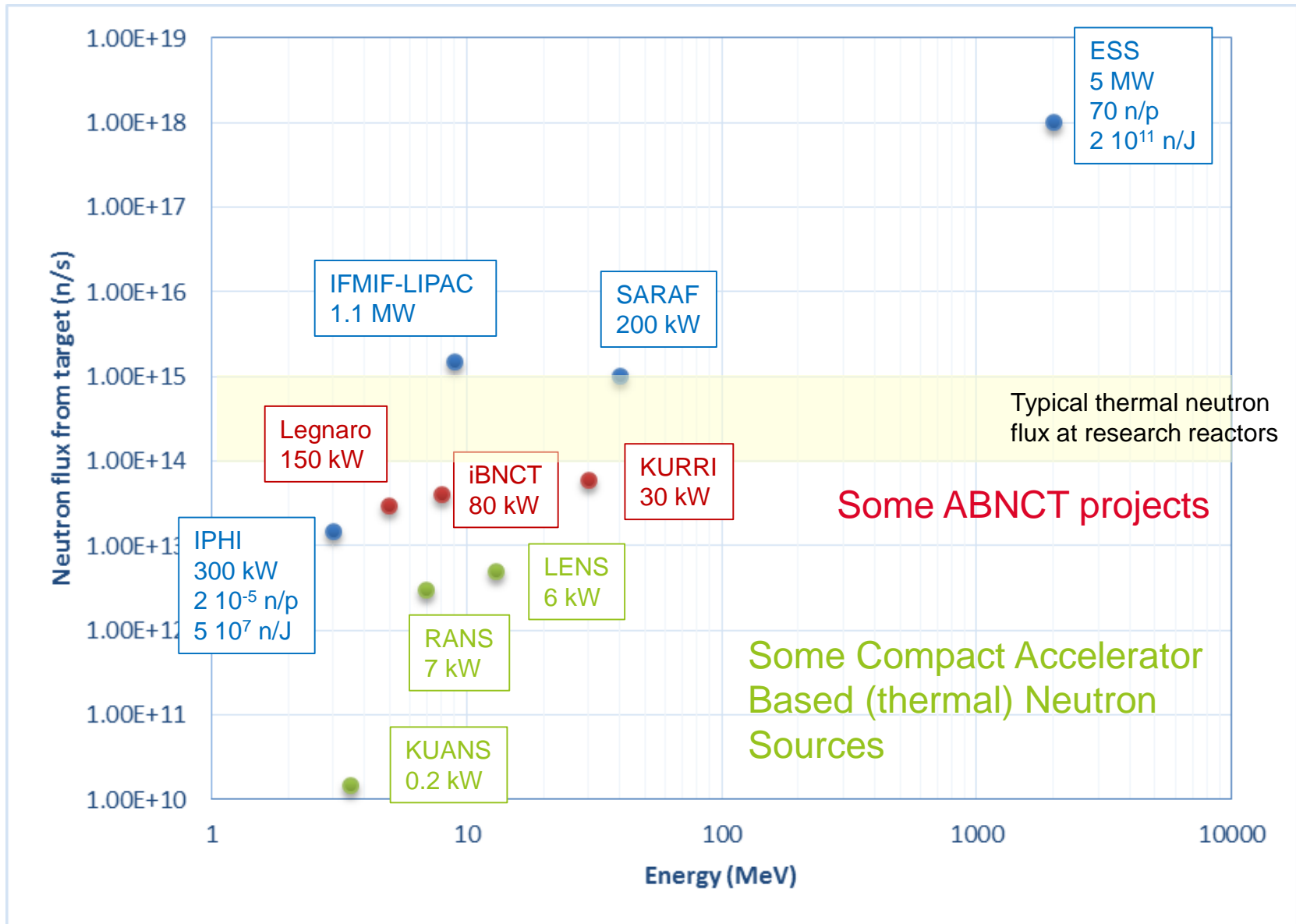
- With the current beam dump (Nickel),  $10^9$  n/s are produced @ 100 mA CW, 3 MeV
- If replaced with a Be target,  $10^{13}$  n/s,  $\langle E_n \rangle = 600$  keV



The IPHI Vault @ Saclay

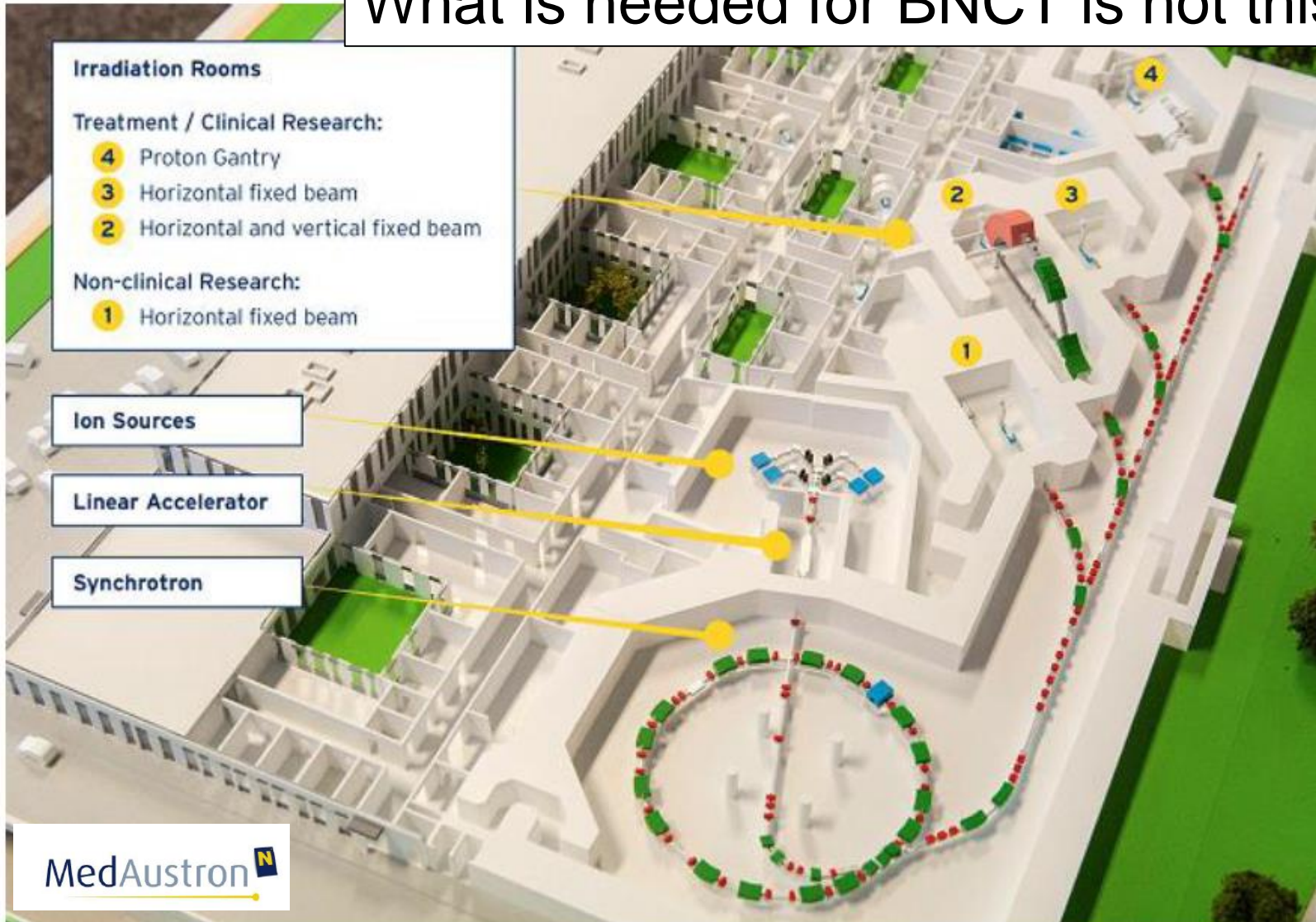


# WHICH MACHINE FOR BNCT ?



- Irfu, and in particular SACM, is working on various **national and international accelerator projects**  
In particular on several accelerator based neutron sources
- This is done in **collaboration** with other French or European labs, and in collaboration with industry
- SACM has large competences on **high intensity proton / deuteron beams**: production, transport, acceleration, characterization, simulation  
In addition, competences at Irfu on thermomechanical studies, neutron simulation, neutron detection
- We are willing to participate to an ABNCT project in France or in Europe

What is needed for BNCT is not this...





...but rather something like this...  
(with more intensity)

Ion Sources

Linear Accelerator

Synchrotron

Irradiation Rooms

Treatment / Clinical Research:

4 Proton Gantry

3 Horizontal fixed beam

2 Horizontal

Non-clinical Rese:

1 Horizontal

**THANK YOU**



# NEUTRON PRODUCTION

- Large gain in n/p, n/W, n/€ with increasing energy but...

