Installation and commissioning of the 1.1 MW deuteron prototype Linac of IFMIF

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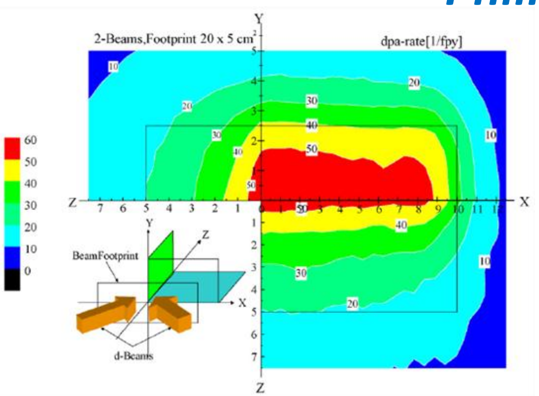
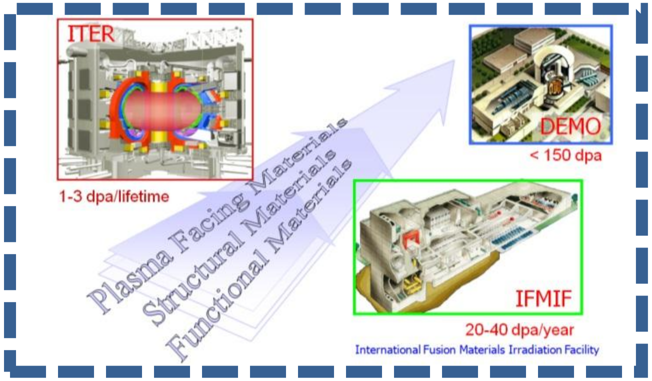
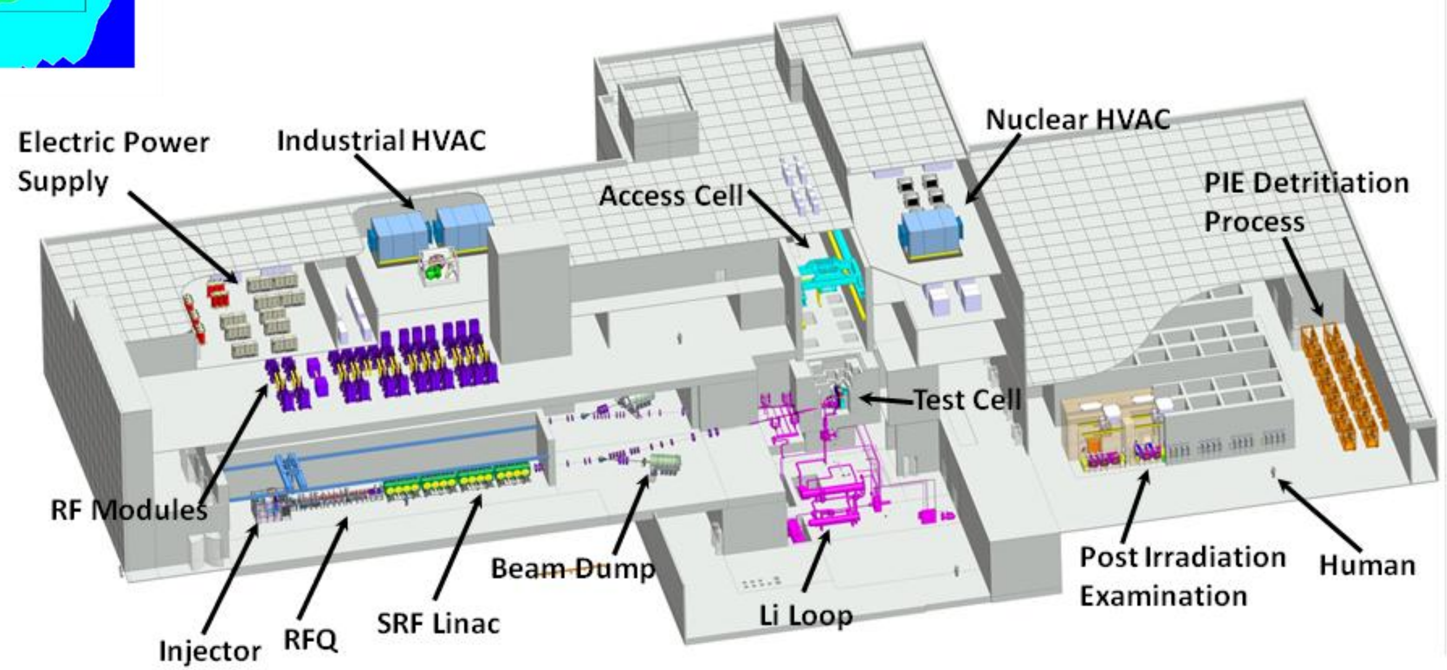
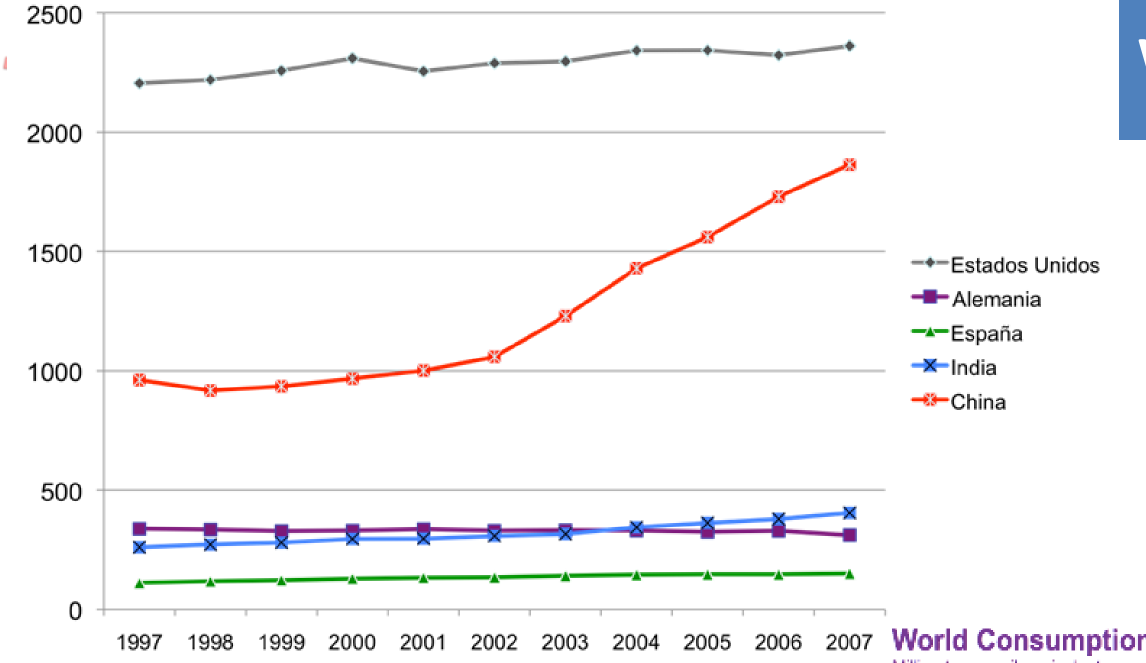
Alberto Facco (INFN)
Joaquín Molla (CIEMAT)
Hiromitsu Suzuki (JAEA)







World energy scenario



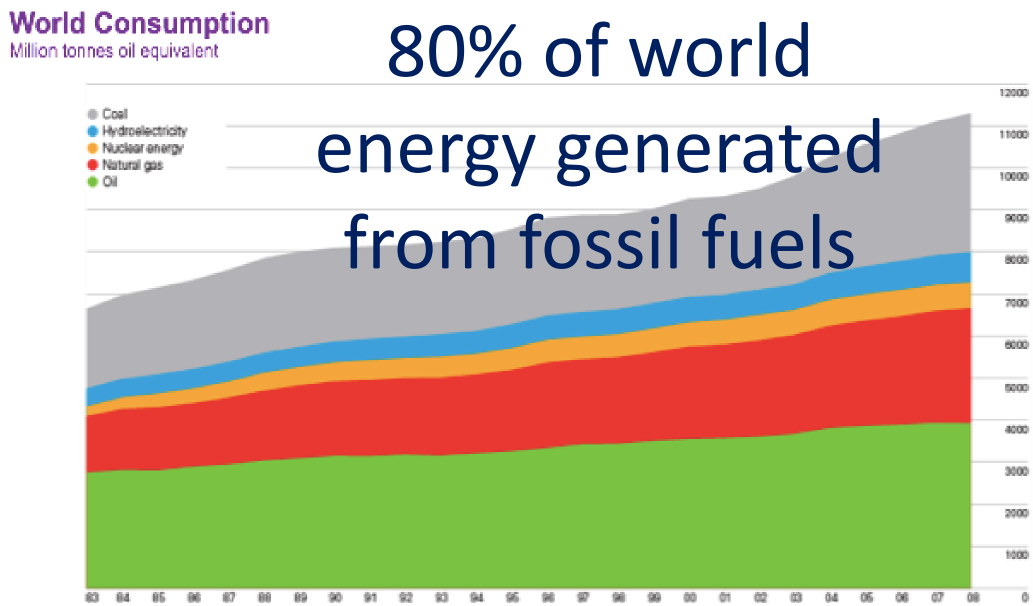
In 2 years,
the growth of energy consumption in China was greater than total consumption in Germany

Medium term Problems

Greenhouse effect

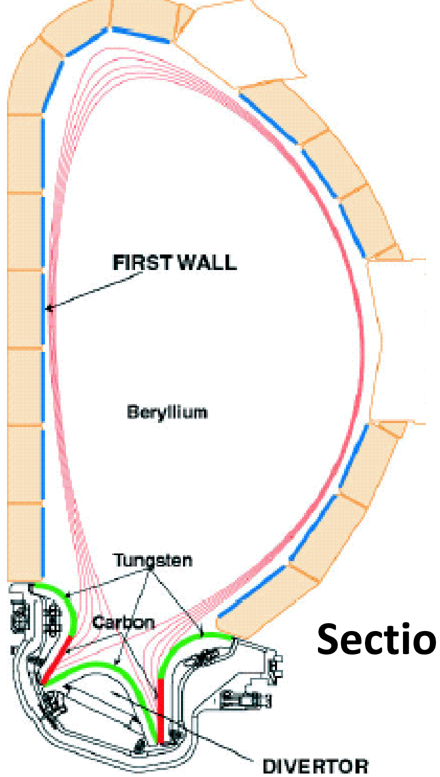
Resources are finite

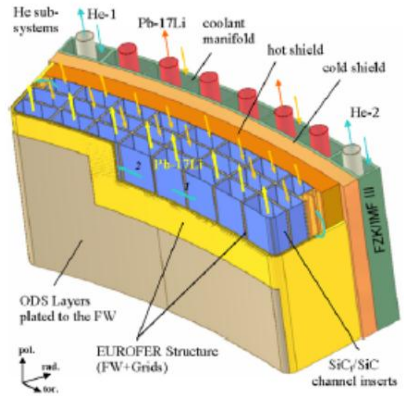
80% of world energy generated from fossil fuels



FUSION ENERGY WILL BECOME A SOLUTION

Neutrons in first wall





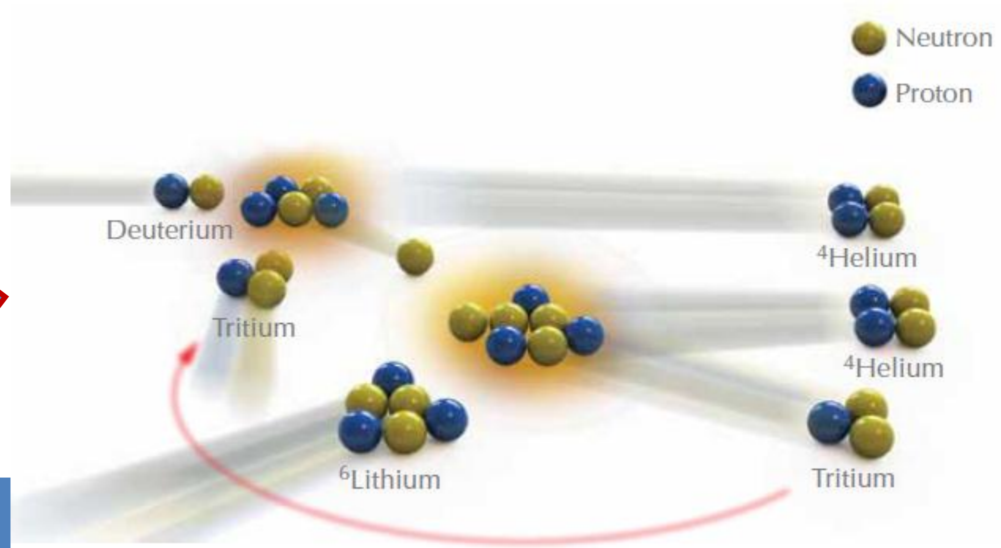
Section of Vacuum Vessel of a Tokamak

ITER first wall will present
<2 dpa at the end of its operational life

In a Fusion power plant
~150 dpa within 5 years are expected

Transmutation energies threshold
of Fe >3 MeV yield α-particles
He induced embrittlement

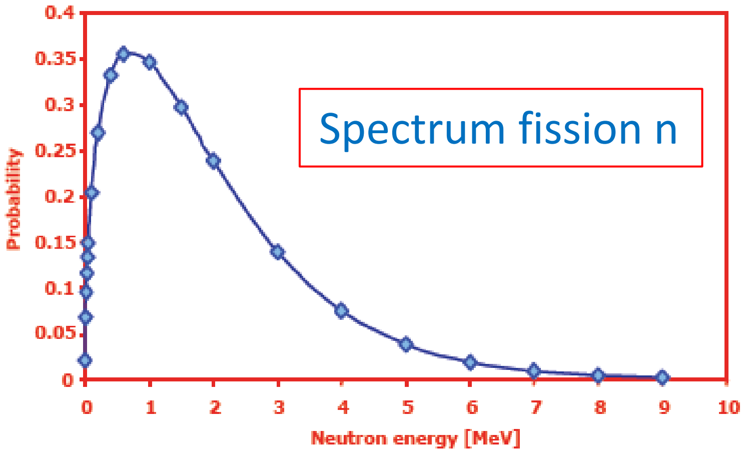
The first wall
of the reactor vessel shall
absorb neutrons energy
and
breed tritium



Existing neutron sources

do not provide the needed answers

Fission reactors n average energy ~2 MeV

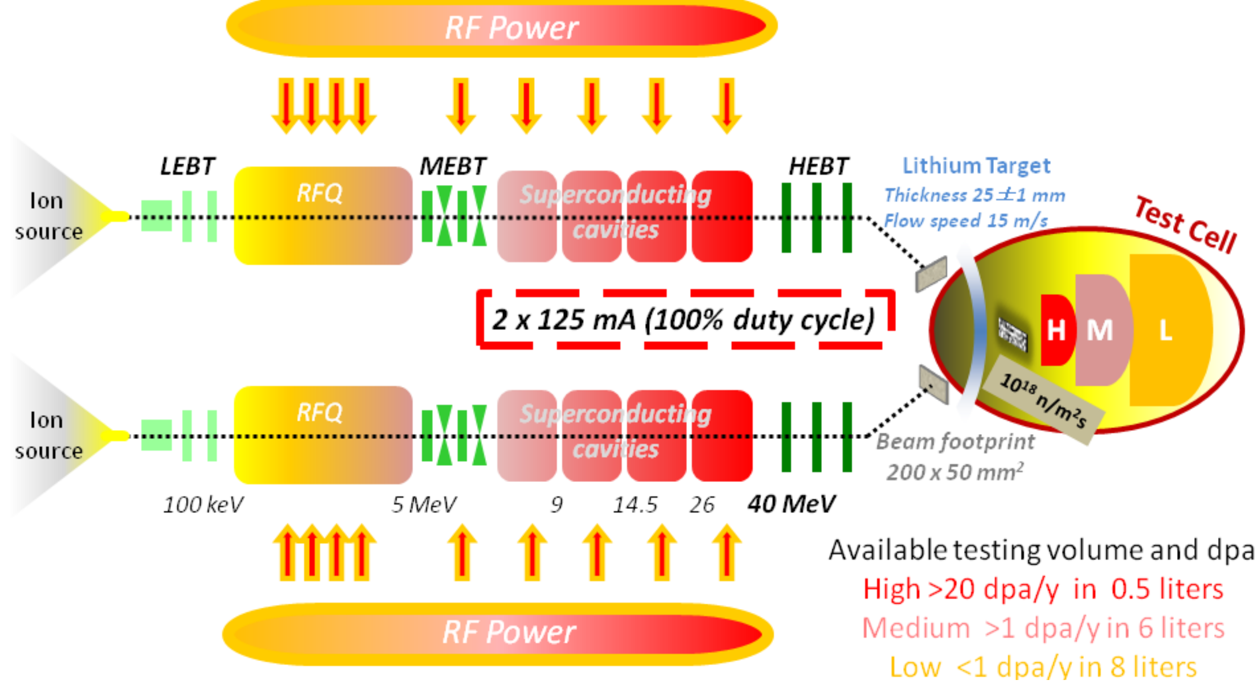


No efficient
p or α-particle generation

Spallation sources present a wide spectrum with tails in the order of hundreds of MeV

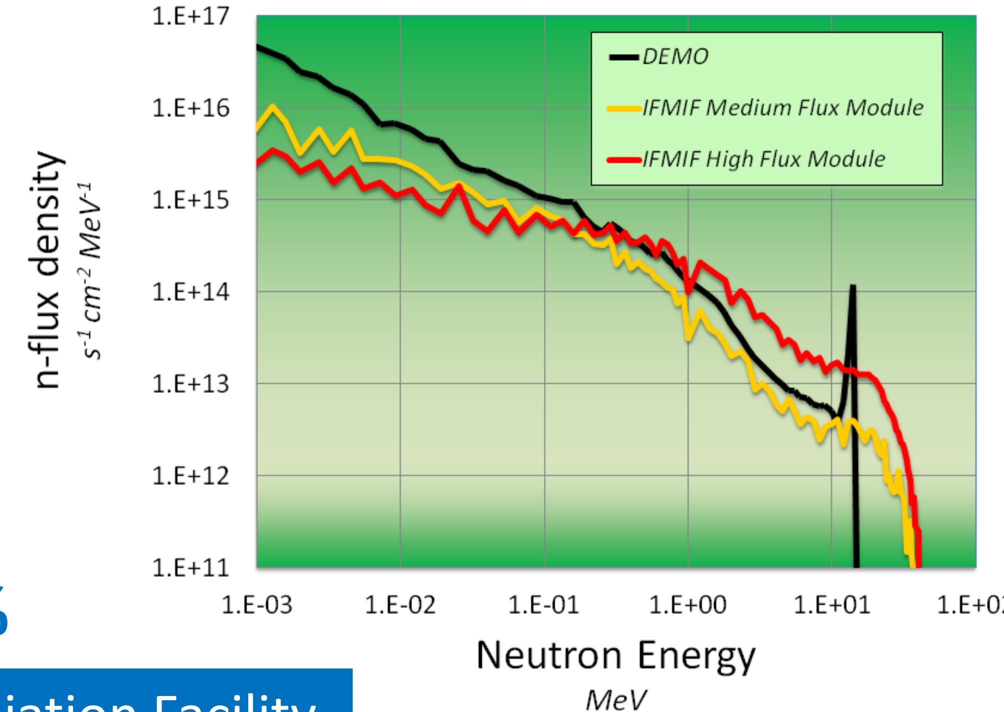
Generation of light isotopes in the order of ppm

IFMIF concept



Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

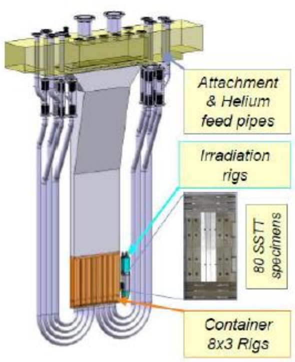
A flux of 10^{18} n·m^{-2}s^{-1} is stripped with a broad peak at 14 MeV



Availability of facility >80%

International Fusion Materials Irradiation Facility

IFMIF/EVEDA

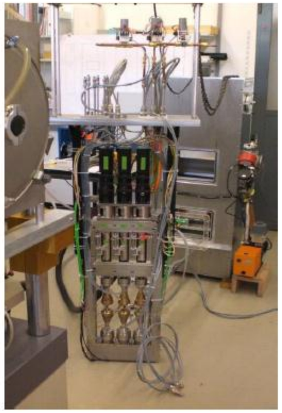


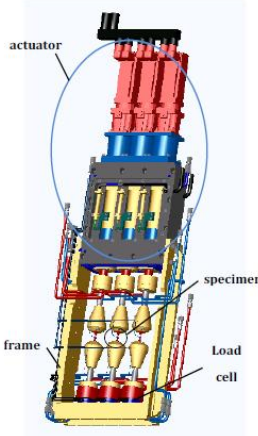
EVEDA

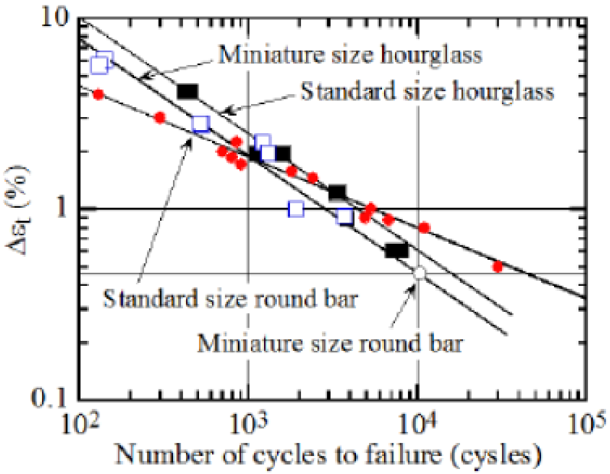
Engineering Validation & Engineering Design Activities

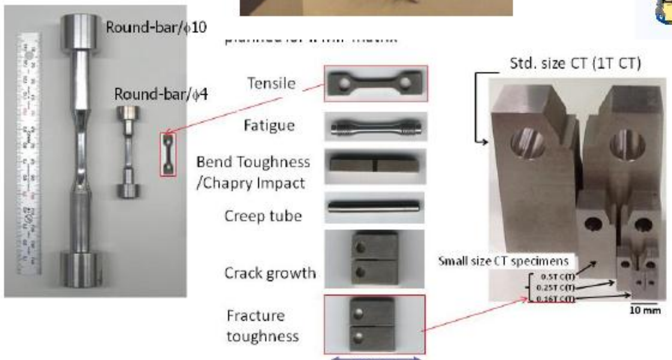
Broader Approach

JAEA-EURATOM Agreement

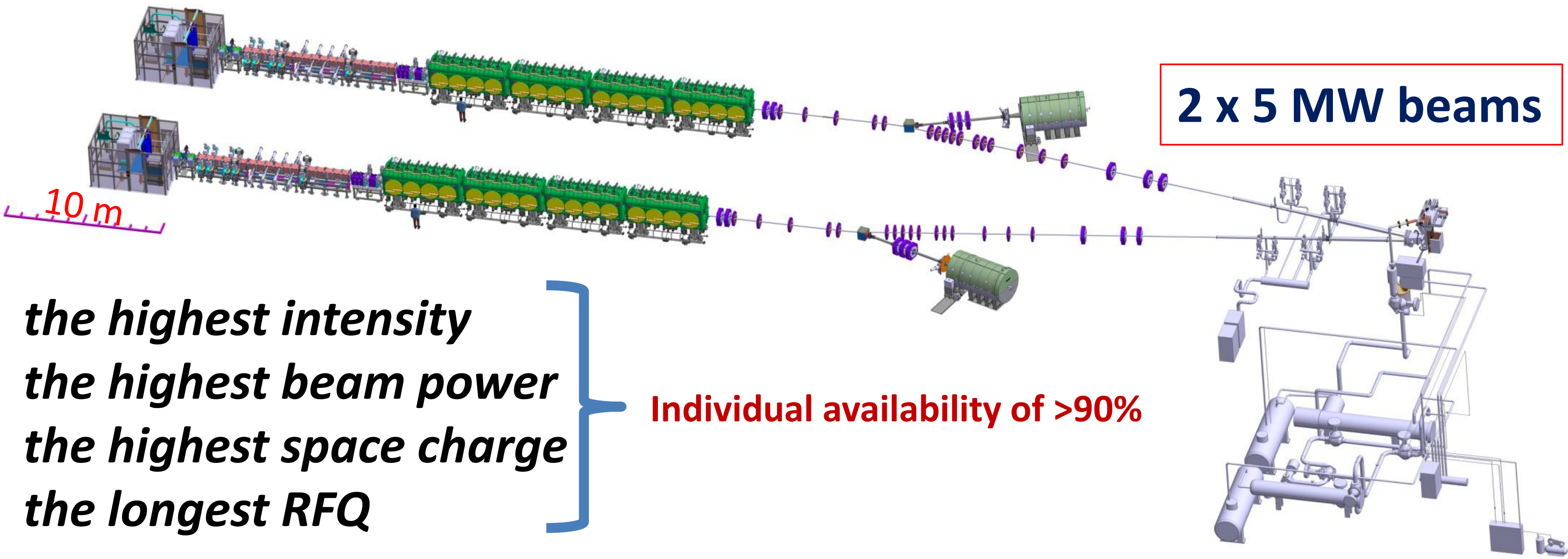








Accelerator facility of IFMIF



2 x 5 MW beams

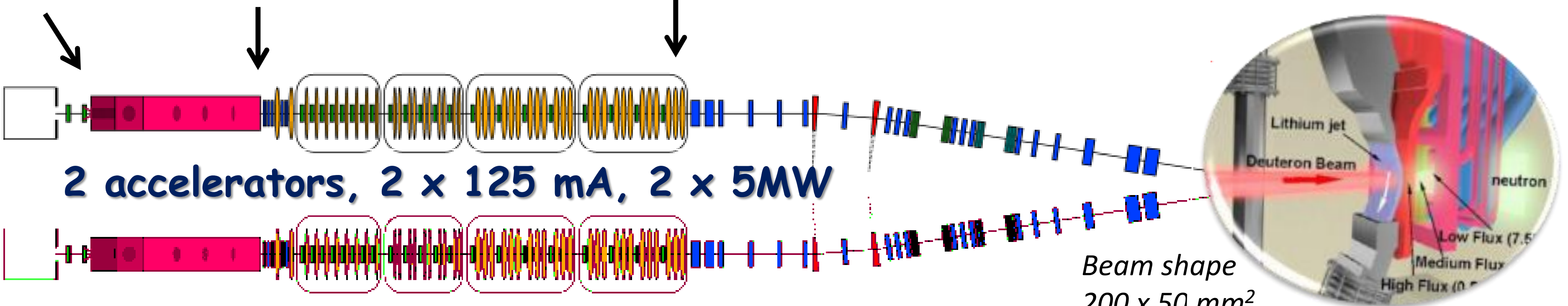
the highest intensity
the highest beam power
the highest space charge
the longest RFQ

Individual availability of >90%

D^+ source
CW 140 mA
100 keV

RFQ
175 MHz
5 MeV

SRF Linac
HWR 175 MHz
40 MeV



2 accelerators, 2 x 125 mA, 2 x 5MW

Beam shape
200 x 50 mm^2

Validation of IFMIF accelerator

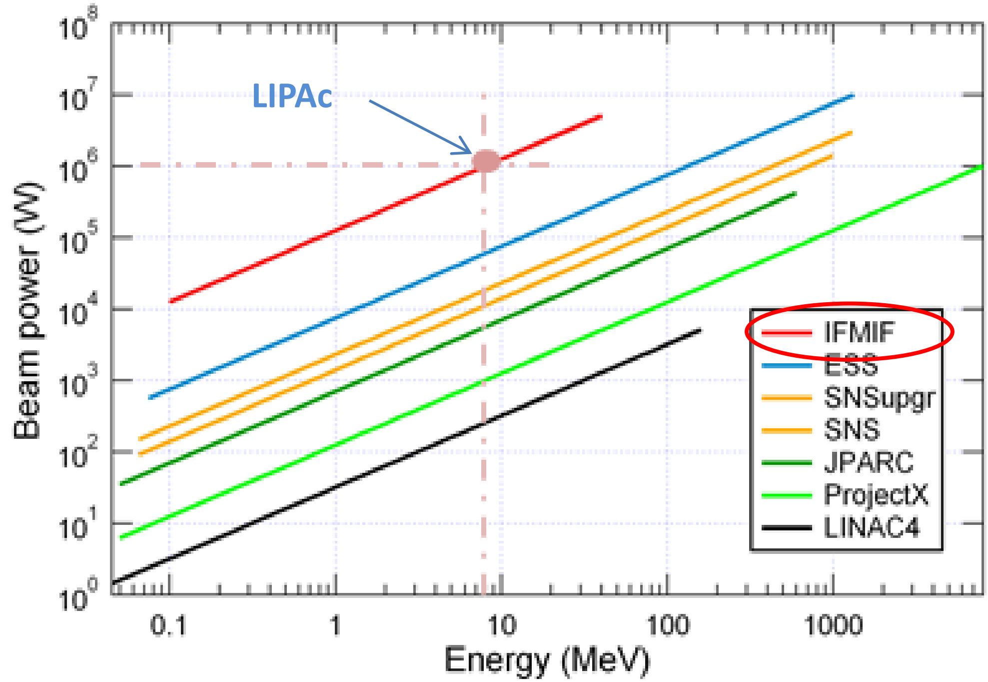
Features of IFMIF vs LIPAc d^+ accelerator

125 mA (100% duty cycle)

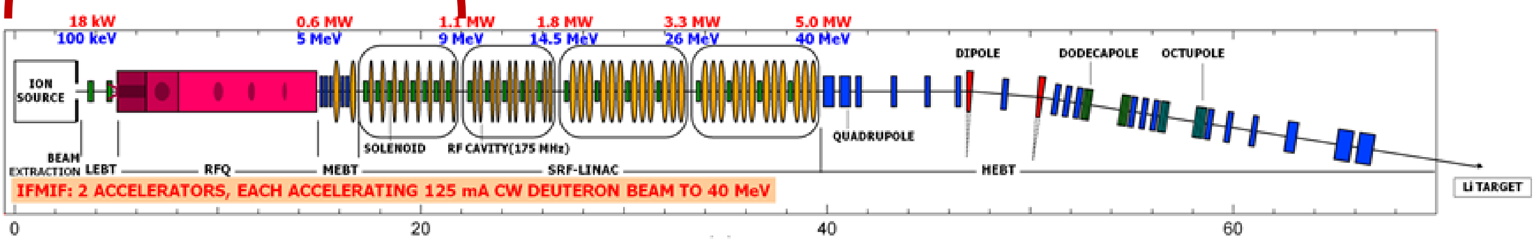
5 MW vs 1.125 MW

Space charge issues

Low energy-high power



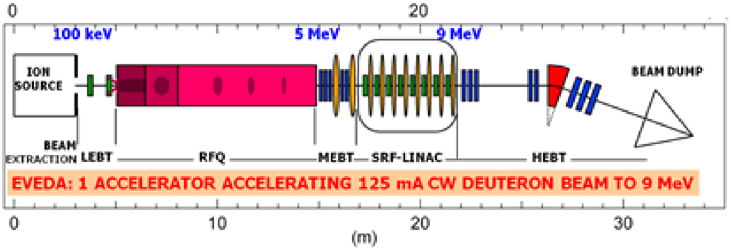
Matched design



40 MeV

125 mA

5 MW



9 MeV

125 mA

1.125 MW

LIPAc

Linear IFMIF Prototype Accelerator

Features of LIPAc

Beam halo is known to be a major cause
of beam loss and activation
in high current hadron Linacs

LEDA reached 100 mA at 6.7 MeV with protons
and demonstrated that beam halo is due to resonances between individual particles and beam core oscillations
through optical mismatches in transition regions

C.K. Allen et al., *Beam Halo Measurements in high current Proton Beams*, Phys. Rev. Lett. 89, 214802

Alignment and commissioning key aspects

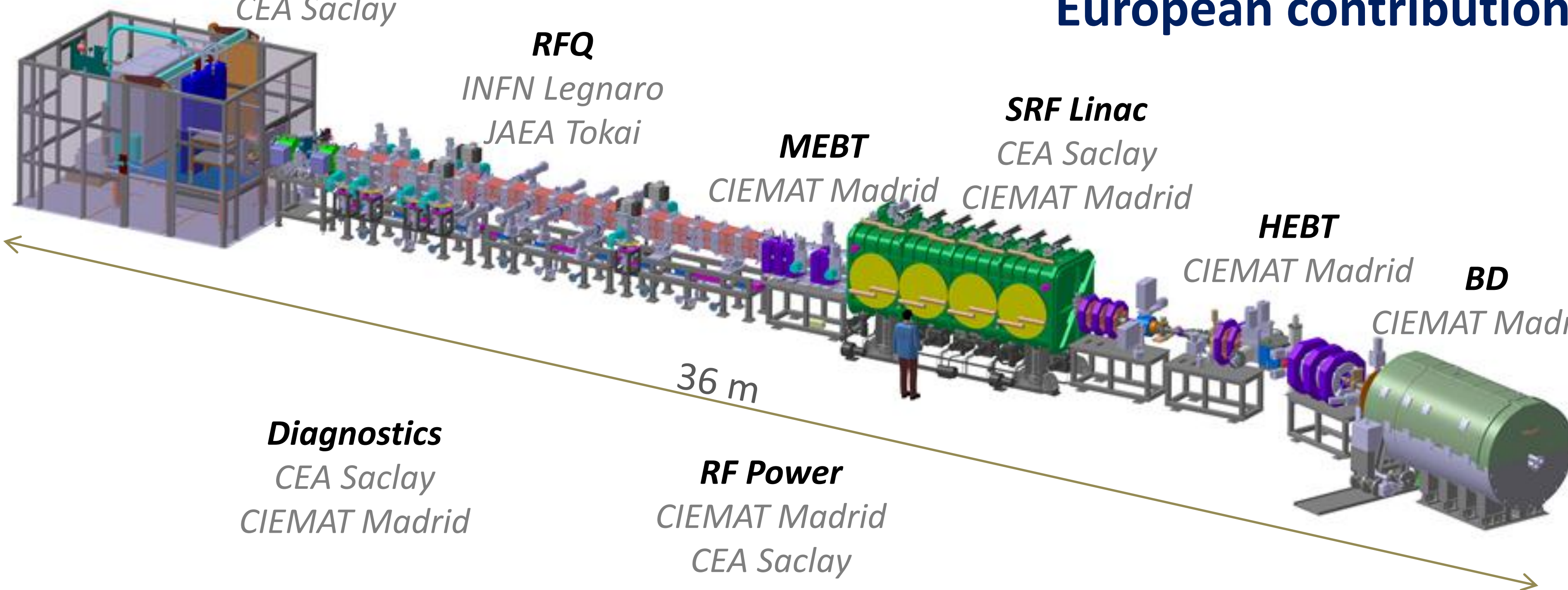
Precise alignment

Halo-matching approach

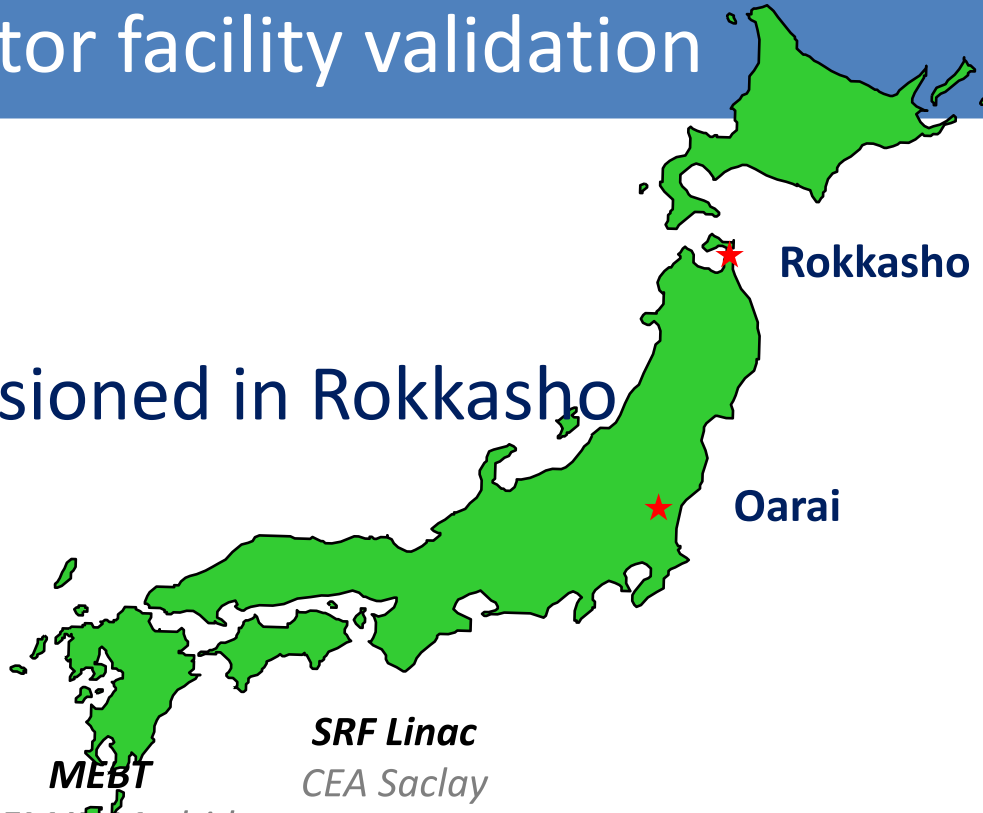
P. Nghiem et al., *The IFMIF-EVEDA Challenges in Beam Dynamics and their Treatment*, Nucl. Inst. Meth. 654 (2011) 63–71

LIPAc contribution

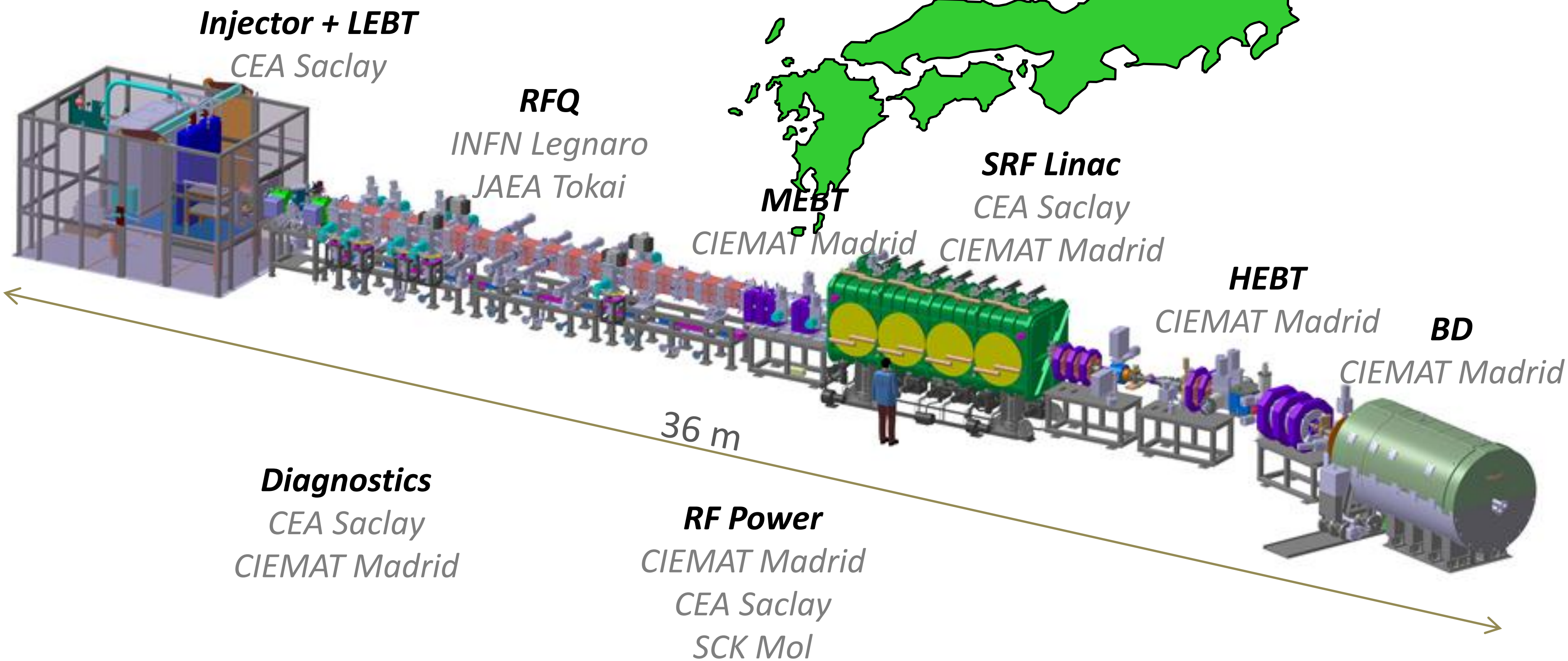
Mainly European contribution



Accelerator facility validation



To be installed and commissioned in Rokkasho



Ion source (CEA Saclay)

D$^+$ (95% species fraction)

ECR (2.5 GHz)

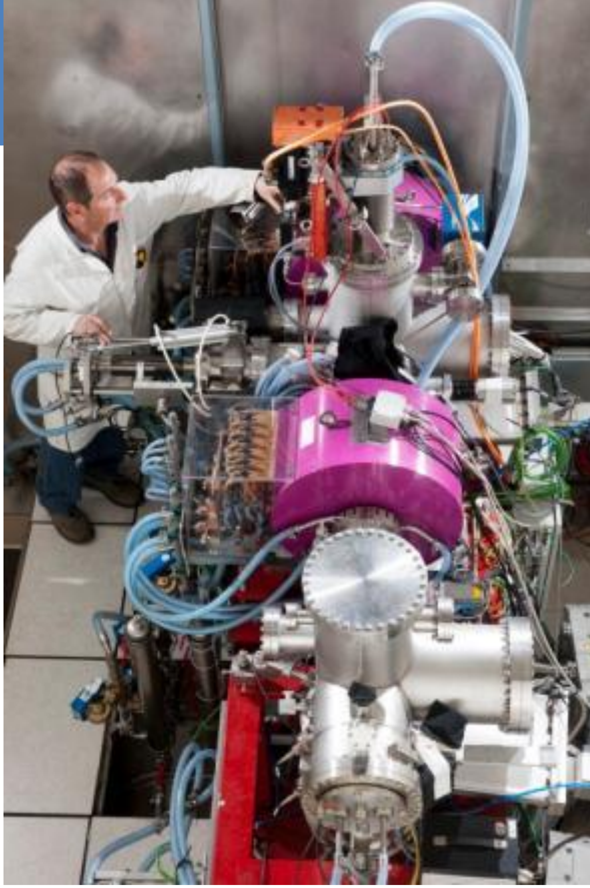
E = 100 keV

I = 140 mA

Duty cycle 100%

ε < 0.3 π mm·mrad

Availability > 95%



Acceptance tests in Saclay successful!!

R. Gobin et al., *Final Design of the IFMIF Injector at CEA/SACLAY*, IPAC 2013, Shanghai

Ion source (CEA Saclay)

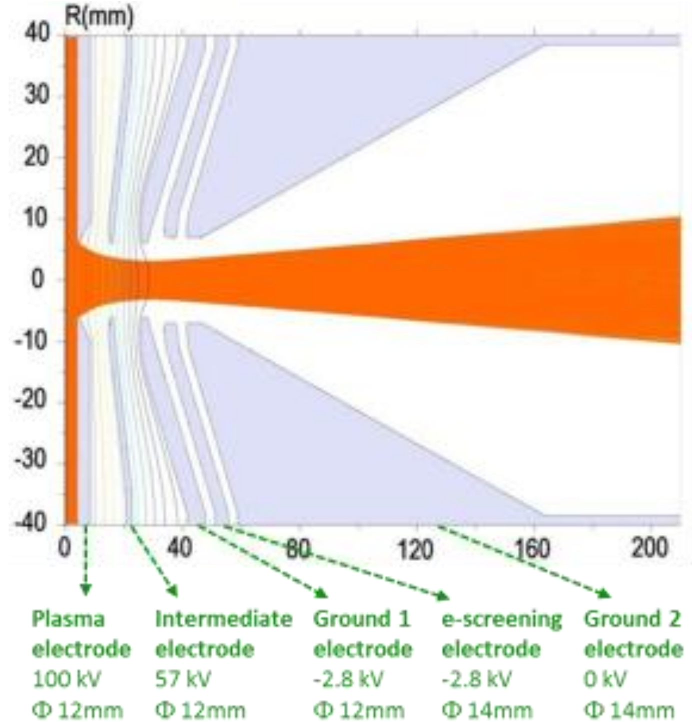
Margin for performance improvement

Emittance growth mitigated
by neutralizing low partial pressure
heavy gas in LEBT

5-electrode beam extraction system
recently installed

1st stage beam extraction system

V increase will reduce further the emittance

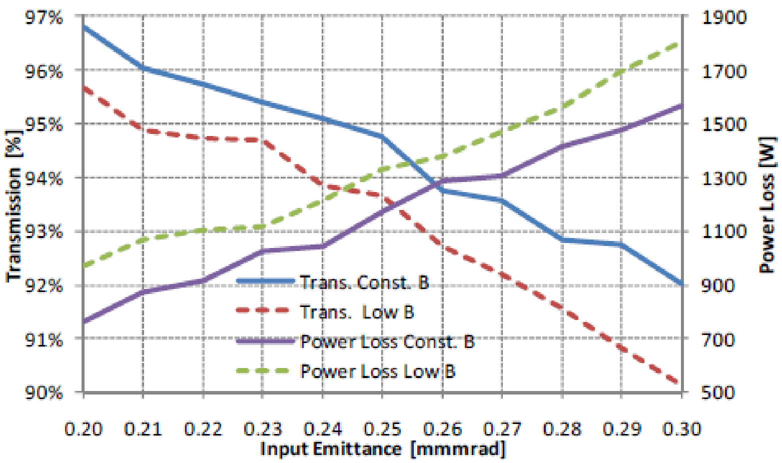


N. Chauvin et al., *Beam commissioning of the Linear IFMIF Prototype Accelerator Injector: measurements and simulations*, IPAC 2013, Shanghai

Injector Installation is starting!!

RFQ (INFN-Legnaro)

175 MHz
I_{input}= 130 mA
E_{output}= 5 MeV
Up to 10mA beam losses allowed
Max surface field 25.2 MV/m (1.8 Kp)



Tuning feasibility demonstrated in an Al full scale prototype

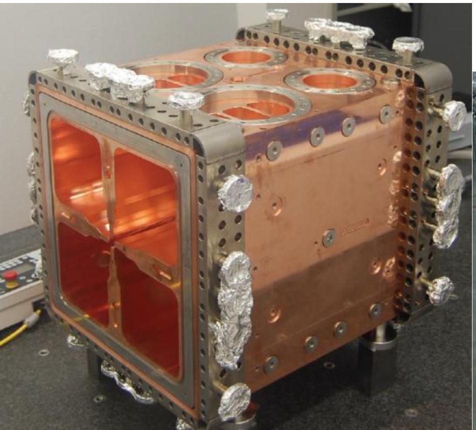
Brazing technology developed at CERN

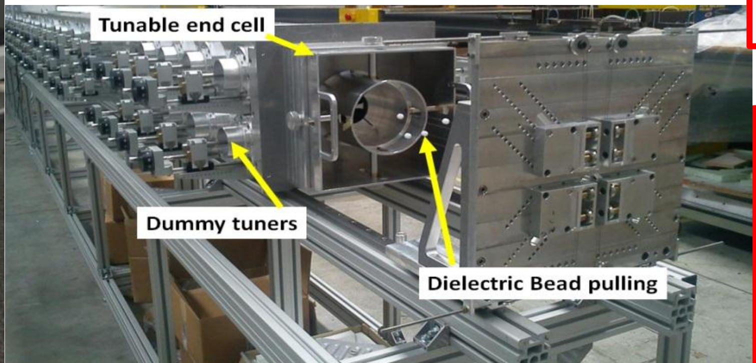
Prototype module leak tight and on tolerances

M. Comunian, A. Pisent , *The Beam dynamics redesign of IFMIF-EVEDA RFQ for a larger input beam acceptance*, IPAC 2011, San Sebastián

18 modules
9.8 m long RFQ

F. Grespan, *Modelization of the beam loading effect in the IFMIF-EVEDA RFQ in pulsed regime*, IPAC 2013, Shanghai



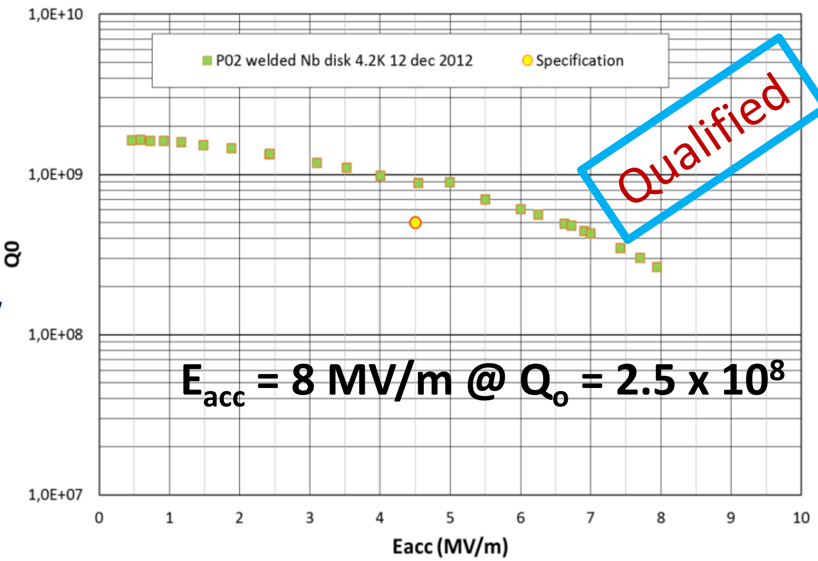


R. Dima et al., *Present status and progress of the RFQ of IFMIF/EVEDA*, IPAC 2013, Shanghai

Superconducting cavities (CEA-Saclay)

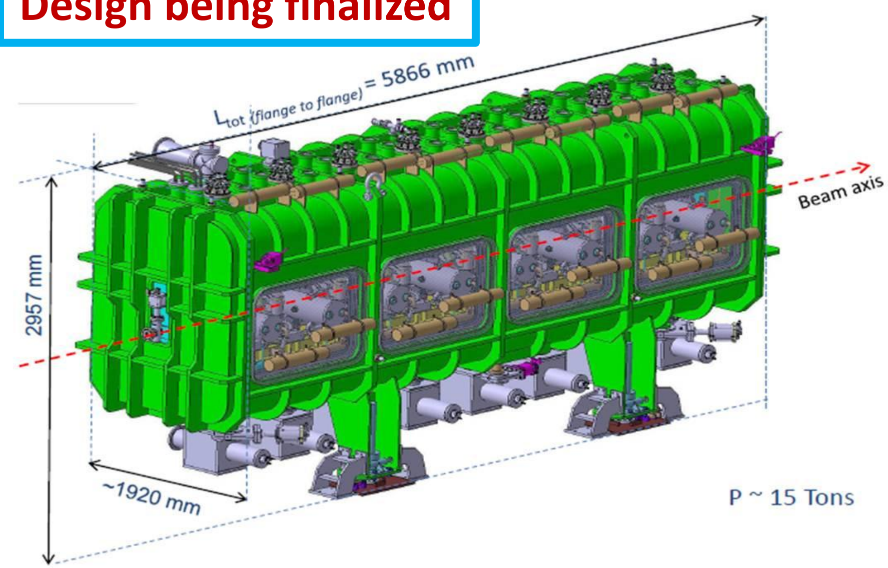
Superconducting HWR resonator at 175 MHz

E_{input}= 5 MeV
E_{output}= 9 MeV
Beam loss < 10W
E_{acc}=4.5 MeV/m
Max transm. RF power = 70 kW



E_{acc} = 8 MV/m @ Q_o = 2.5 x 10^8

Design being finalized

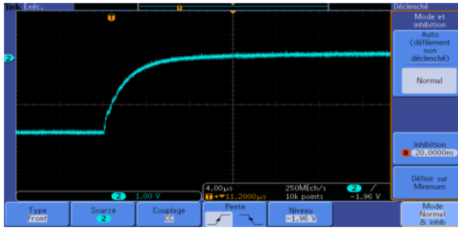


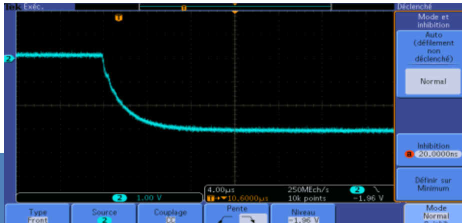
Commissioning phases

D^+ operation time will be limited
to allow hands-on maintenance

Proton beams at half energy and half intensity present
same speed and space charge
than deuteron beams at nominal energy and intensity

Duty cycles will start with 0.1%
Chopper in LEBT qualified
Pulse duration 20 ms to 5 ms
repetition rate of 10 Hz
8 kV rise/fall time of 4 µs





R. Gobin et al., *Final Design of the IFMIF Injector at CEA/SACLAY*, IPAC 2013, Shanghai

Commissioning phases

Four consecutive phases are foreseen

1st Phase

Repetition of Injector + LEBT Individual System Tests in Rokkasho

2nd Phase

RFQ + MEBT at full intensity but with a reduced duty cycle (0.1% is targeted)

D-plate will be an essential element of the commissioning tasks

3rd Phase

Individual System Tests of cryomodule, HEBT and Beam Dump

Commissioning with 0.1% duty cycle

4th Phase

Full current with a slow ramping up of duty cycle to reach 100%

μ-loss monitors will be the essential beam halo diagnostic

H. Shidara et al., Installation status of deuteron injector of IFMIF prototype accelerator in Japan, IPAC 2013, Shanghai

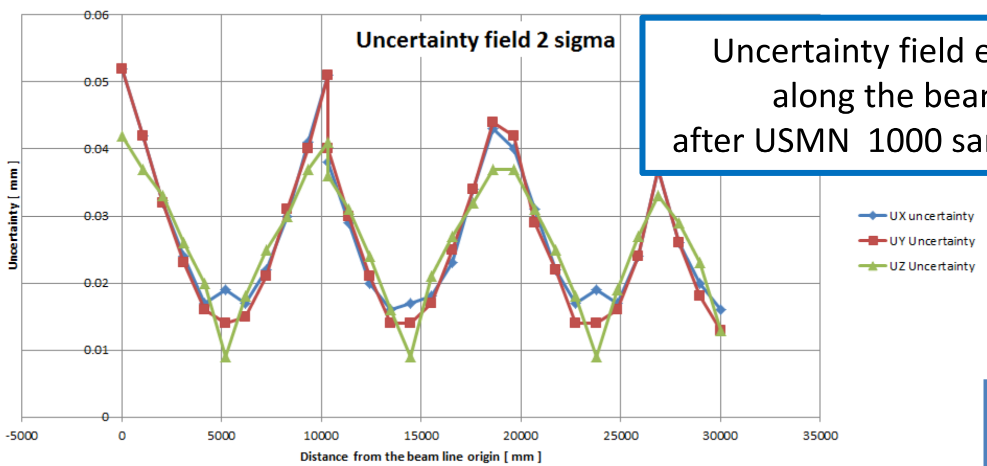
Essential elements I - Alignment

An upgrade of the survey network in the Accelerator has been undertaken

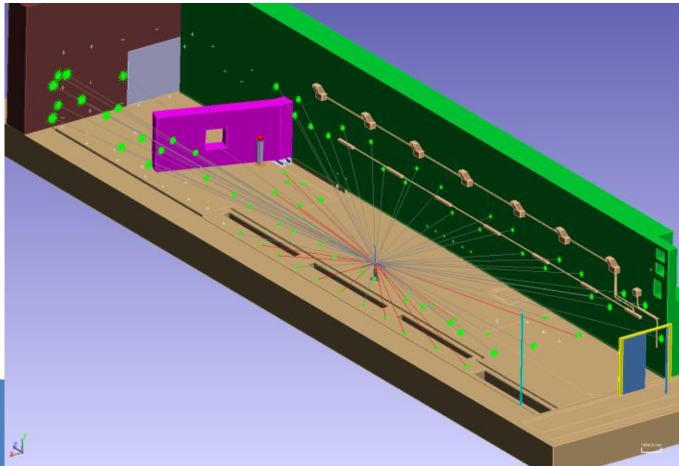
Beam error simulations demands
alignments (or precision of measurements) within 0.1 mm

Simulations carried out by F4E on the existing fiducials in the accelerator hall
with Unified Spatial Metrology Network (USMN) of SpatialAnalyzer® (SA) showed an uncertainty of the measurement of **0.145 mm**

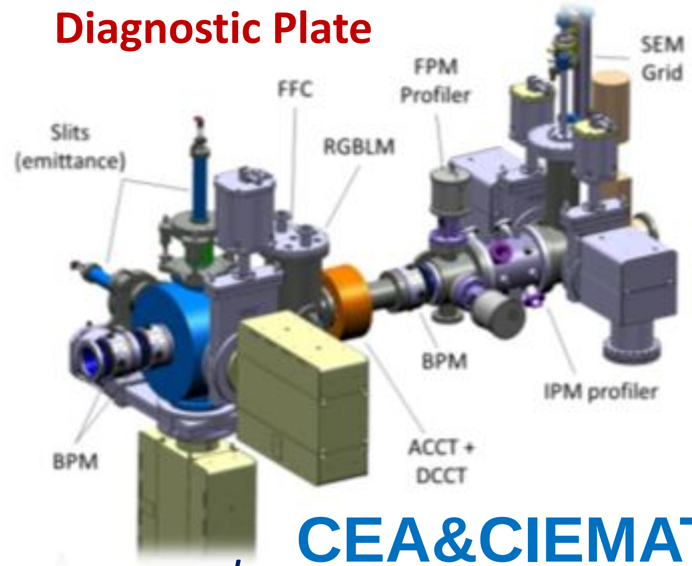
Placement of 120 new fiducials will limit
measurement uncertainties **<0.03 mm** with the laser tracker Leica AT401 suitably located
in the accelerator hall during all future alignment tasks



Uncertainty field evaluation
along the beam line
after USMN 1000 samples @ 2 σ



Essential elements II



CEA&CIEMAT

Diagnostic Plate will be used
for Phase II and part of Phase III
beam current, phase, position,
transverse and longitudinal profiles,
transverse halo, mean energy and energy spread, transverse and longitudinal emittance and beam losses

I. Podadera et al., *A Diagnostic Plate for the IFMIF-EVEDA Accelerator,* IPAC 2008, Genoa

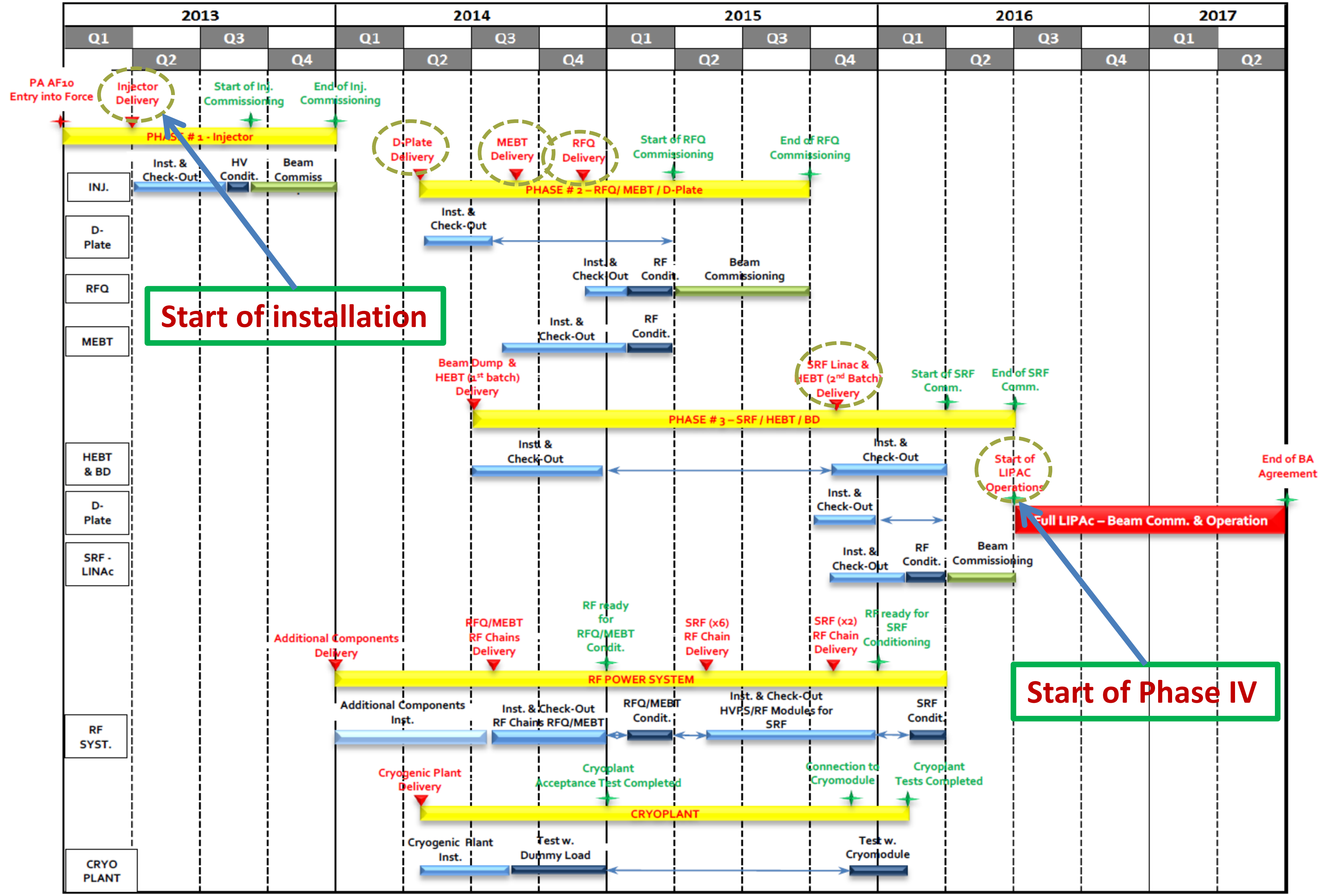
3 μ-loss monitors (CVD diamonds) 4 mm x 4mm
placed azimuthally per solenoid (x8)
in the SRF module will be used in Phase IV
to precisely determine
the beam halo

And learn

from all other world's

high current accelerator experiences!!!

Schedule


2013
2014
2015
2016
2017
Q1
Q2
Q3
Q4
PA AF10 Entry into Force
Injector Delivery
Start of Inj. Commissioning
End of Inj. Commissioning
PHASE # 1 - Injector
Inst. & Check-Out
HV Condit.
Beam Commiss
INJ.
D-Plate
RFQ
MEBT
Start of installation
D-Plate Delivery
MEBT Delivery
RFQ Delivery
Start of RFQ Commissioning
End of RFQ Commissioning
PHASE # 2 – RFQ/ MEBT / D-Plate
Inst. & Check-Out
Inst. & Check Out
RF Condit.
Beam Commissioning
Inst. & Check-Out
RF Condit.
Beam Dump & HEBT (1st batch) Delivery
SRF Linac & HEBT (2nd Batch) Delivery
Start of SRF Comm.
End of SRF Comm.
PHASE # 3 – SRF / HEBT / BD
HEBT & BD
D-Plate
SRF - LINAc
Inst. & Check-Out
Inst. & Check-Out
Start of LIPAC Operations
End of BA Agreement
Inst. & Check-Out
Full LIPAc – Beam Comm. & Operation
Inst. & Check-Out
RF Condit.
Beam Commissioning
Start of Phase IV
Additional Components Delivery
RFQ/MEBT RF Chains Delivery
RF ready for RFQ/MEBT Condit.
SRF (x6) RF Chain Delivery
SRF (x2) RF Chain Delivery
RF ready for SRF Conditioning
RF POWER SYSTEM
Additional Components Inst.
Inst. & Check-Out RF Chains RFQ/MEBT
RFQ/MEBT Condit.
Inst. & Check-Out HVPS/RF Modules for SRF
SRF Condit.
RF SYST.
Cryogenic Plant Delivery
Cryoplant Acceptance Test Completed
Connection to Cryomodule
Cryoplant Tests Completed
CRYOPLANT
Cryogenic Plant Inst.
Test w. Dummy Load
Test w. Cryomodule
CRYO PLANT

Conclusions

IFMIF is an essential facility in the world Fusion programme
It will become a Fusion relevant neutron source

The validation activities not only cover the Accelerator
also
the Target facility (JAEA&ENEA) and Test facility (KIT&JAEA)

IFMIF/EVEDA is an effective risk mitigation phase
that will allow facing the construction of IFMIF
as soon as the Fusion community needs it

LIPAc beam performance (125 mA CW), going beyond present achieved limits,
makes it be an unique tool to learn issues related with high beam powers

LIPAc Installation is starting, time ahead is scientifically exciting.
Phase IV of commissioning is scheduled to start middle 2016