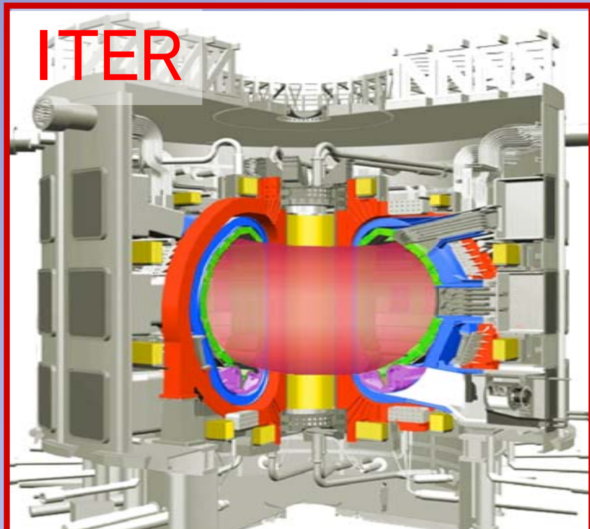
Development of the IFMIF/EVEDA Accelerator

Alban Mosnier

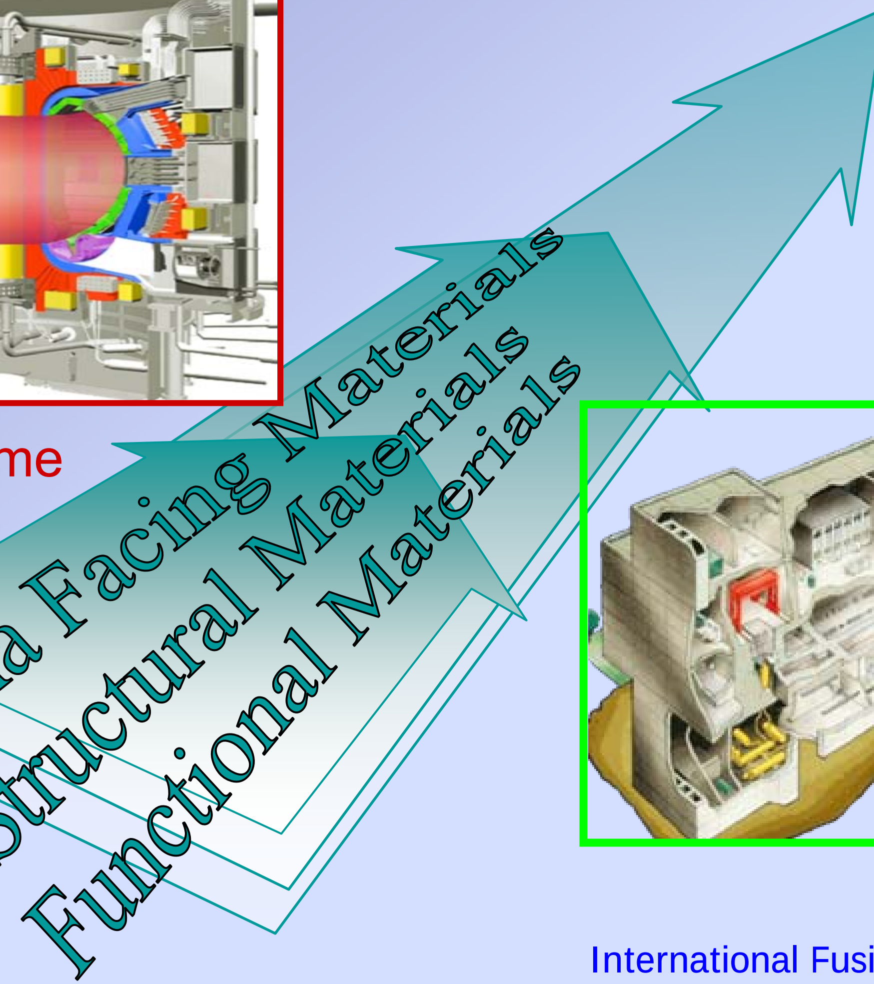
CEA-Saclay, DSM/IRFU

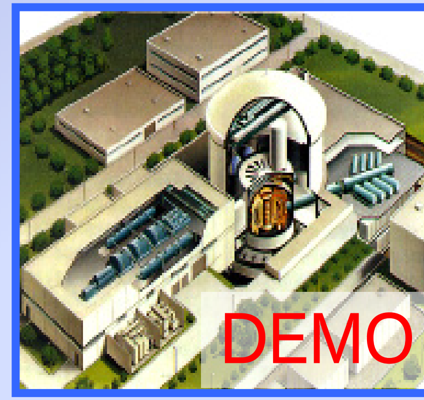
International Road Map

Advanced Materials are at a critical path

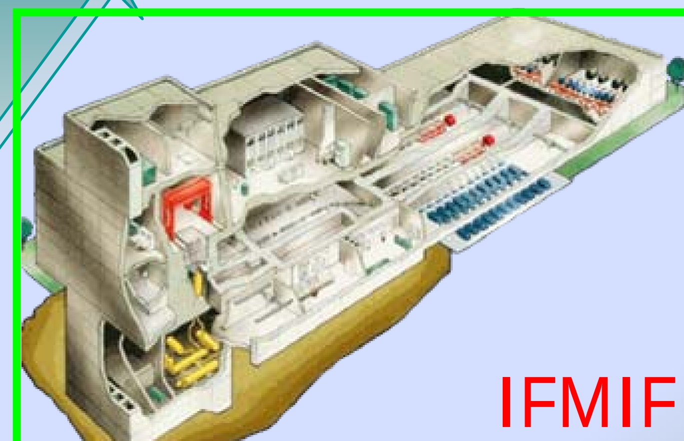


1-3 dpa/lifetime





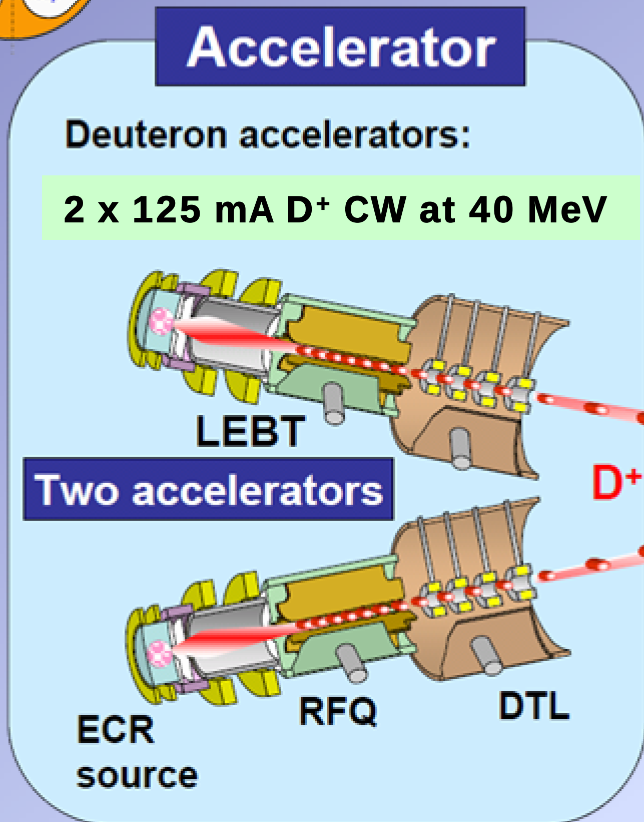
< 150 dpa

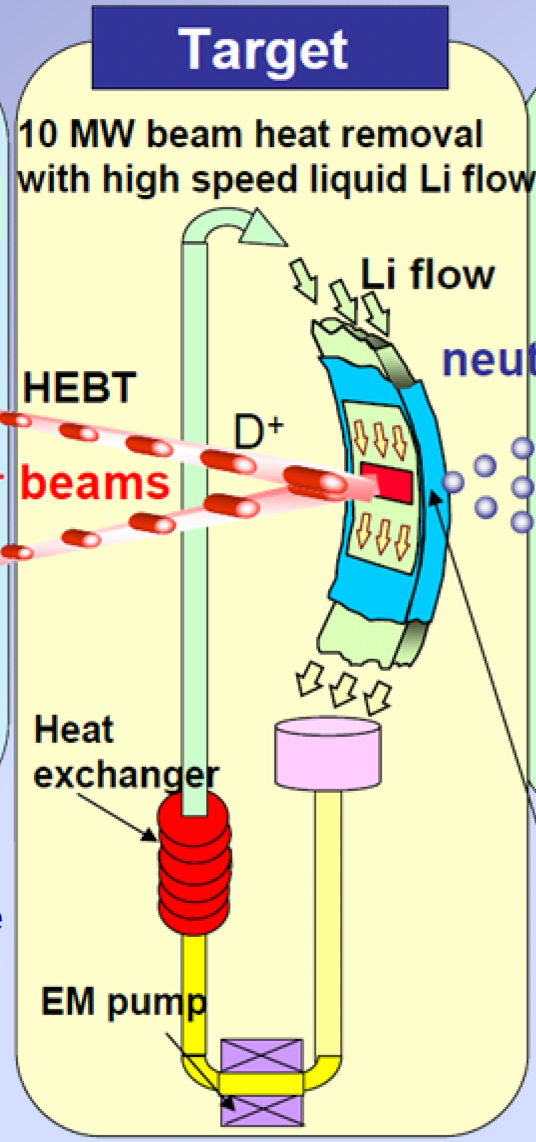


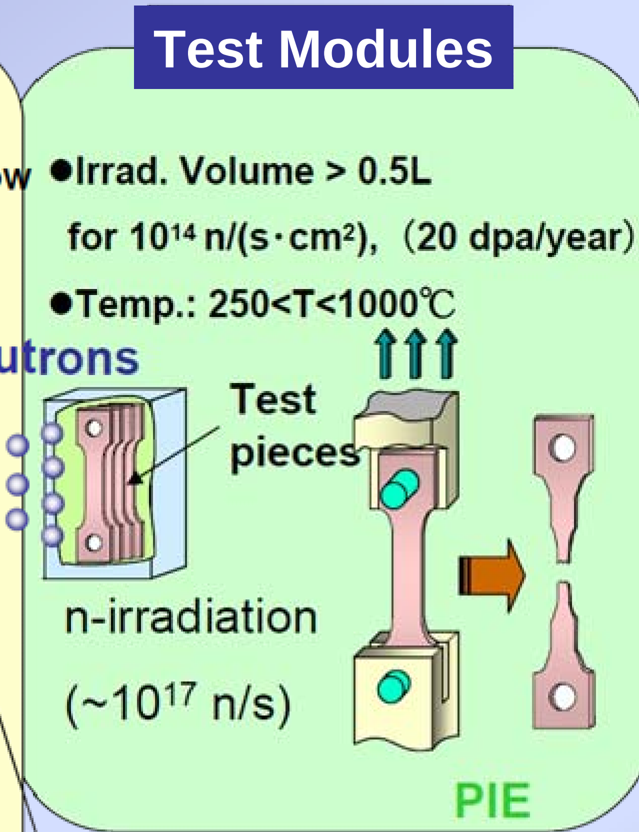
20-40 dpa/year

International Fusion Materials Irradiation Facility

IFMIF Principles







Accelerator based neutron source using the D-Li stripping reaction ⇒ intense neutron flux with the appropriate energy spectrum

Typical reactions:
$^{7}Li(d,2n)^{7}Be$, $^{6}Li(d,n)^{7}Be$, $^{6}Li(n,T)^{4}He$

Beam footprint on Li target
20cm wide x 5cm high
(1 GW/m^2)

IFMIF EVEDA project

in the framework of an agreement between
Euratom & Government of Japan

a 6-year program has been launched in the middle of 2007, called EVEDA
Engineering **V**alidation and **E**ngineering **D**esign **A**ctivities
includes 3 systems: **Accelerator, Target and Test Facilities**

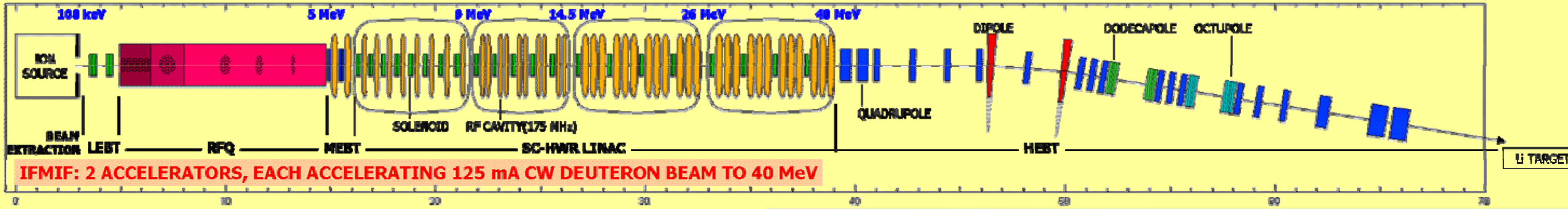
The objectives of the accelerator activities are two-fold:

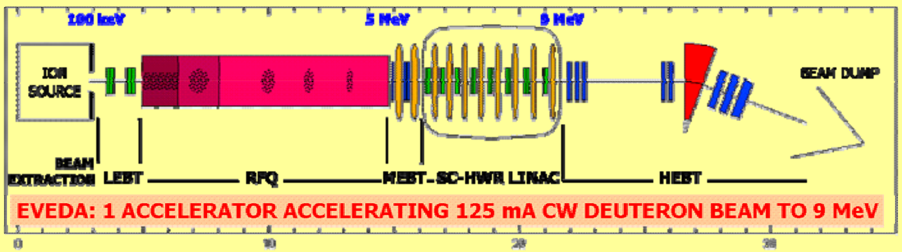
1. to validate the technical options with the construction of the **Prototype Accelerator**: full size IFMIF accelerator from source to 1st DTL to be installed and commissioned at full beam current at Rokkasho (Japan)
2. to produce the detailed integrated design of the future **IFMIF Accelerator** (including complete layout, safety analysis, cost, planning, etc) to be ready to start the IFMIF facility construction

- Components of the prototype accelerator provided by European institutions **CEA, INFN, CIEMAT, SCK-CEN**: Injector, RFQ, DTL, transport line and 1.2 MW beam dump, 175 MHz RF systems, local control systems and beam instrumentation
- Building at Rokkasho BA site, supervision of the control system, RFQ couplers, provided by **JAEA**

IFMIF Accelerators

One Accelerator of IFMIF





Prototype Accelerator of IFMIF/EVEDA

Recipes used to cope with the high beam current

- transport lines as short as possible
- best compensation of beam space charge at low energy
- strong focusing in the RFQ
- focusing in the Linac: multi-part simulations to minimize the beam halo
- non interceptive diagnostics: micro-loss detectors along the vacuum chamber and profile monitors at the end

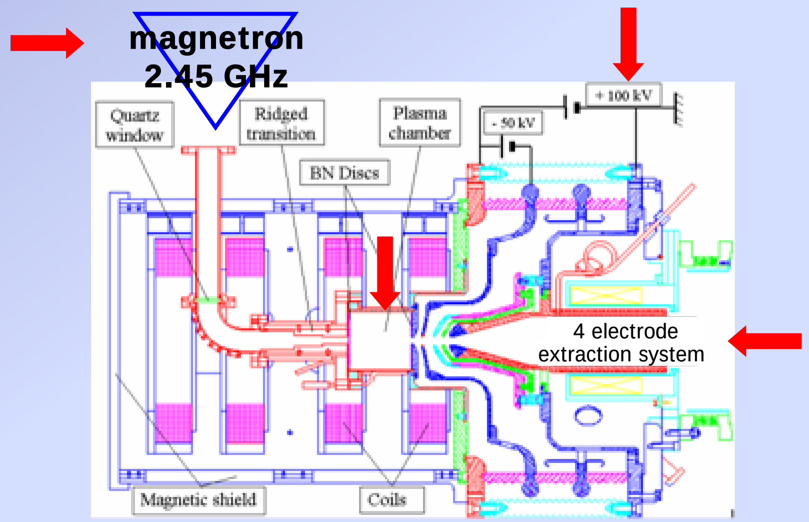
P. Nghiem et al (TH5PFP006) IFMIF-EVEDA Accelerators: Strategies & Choices for Optics & Beam Measur.

INJECTOR

goal • to deliver a 100 keV deuteron beam

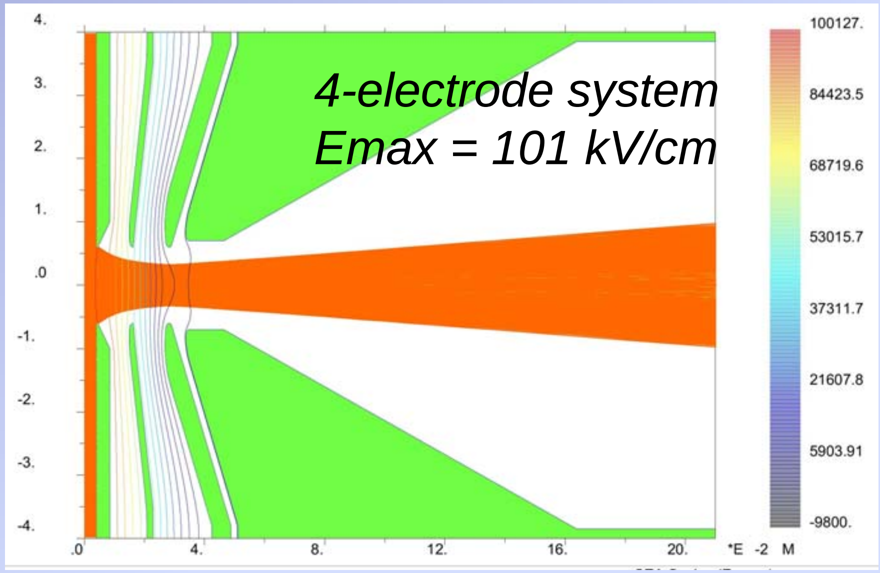
- **high intensity (140 mA)**
- **high quality (0.25 π.mm.mrad)**
- **high reliability**

ECR source selected design based on SILHI H^+ source
(Electron Cyclotron Resonance)



Studies focused on ...

- extraction system (better maching for D)
- engineering design (compact HV platform)
- efficient radiation shielding
- fast beam interlock to implement < 10 µs



Ion Source Extraction ...

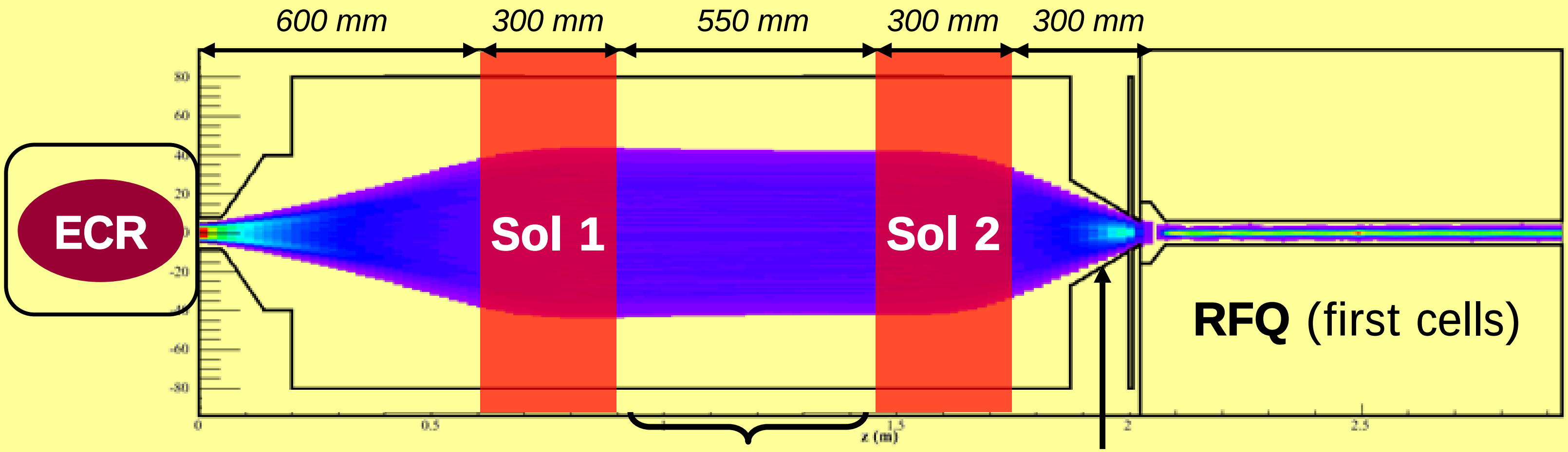
140 mA $D^+ \Rightarrow$ 175 mA total beam
(D^+ 80%, D_2^+ 15%, D_3^+ 5%)

Axcel & Opera2D simulations to optimize
electrodes (4) aperture ø (12 mm)

based on a **dual solenoid focusing system**

total length 2.05 m minimized to restrain the beam emittance growth

LEBT schematic layout & particle density plot



challenging requirements: emittance < 0.25 π mm.mrad + matching conditions to RFQ high focusing strength

⇒ high level of space charge compensation all along the line

- injection of a specific gas in the line (krypton 4.10^{-5} hPa)
- HV electrode in front of the RFQ to trap the electrons (e-repeller)

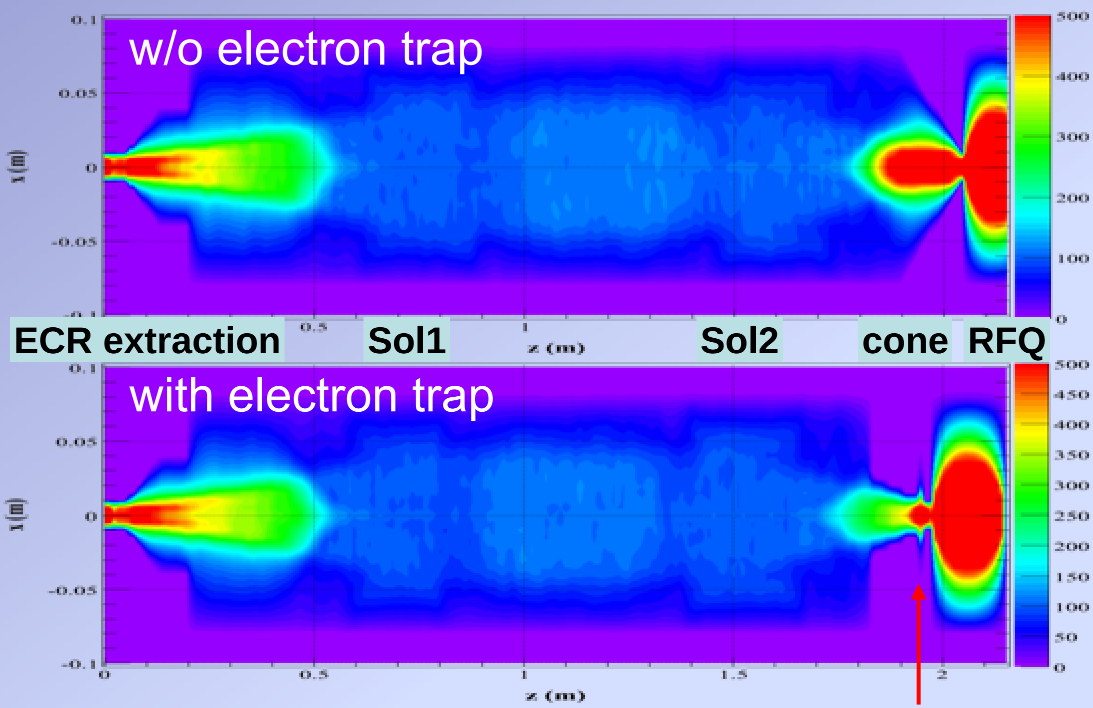
Low Energy Beam Transport 2 / 2

development of a 3D particle-in-cell code (SOLMAXP) to study the space charge compensation induced by the ionization of the residual (additional) gas

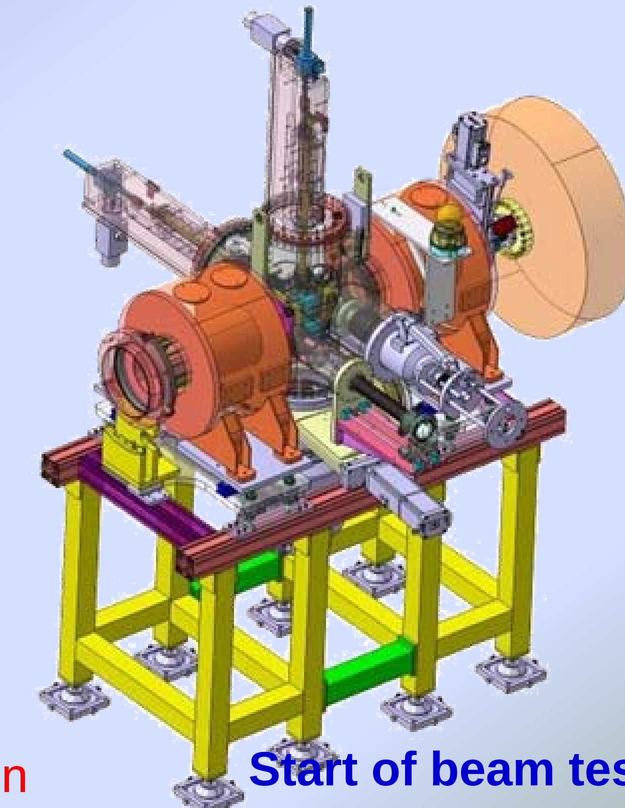
LEBT parameters optimized to maximize the beam transmission through the RFQ
⇔ beam matching to the RFQ entrance

N. Chauvin et al (TH5PFP004)
Final design of the IFMIF/EVEDA LEBT

Space charge potential maps (cut @500 V)



Effect of the e- repeller electrode ⇒ better compensation



Start of beam tests in April 2010

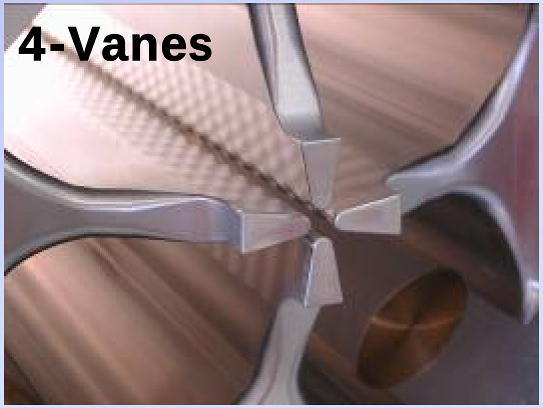
Radiofrequency Quadrupole

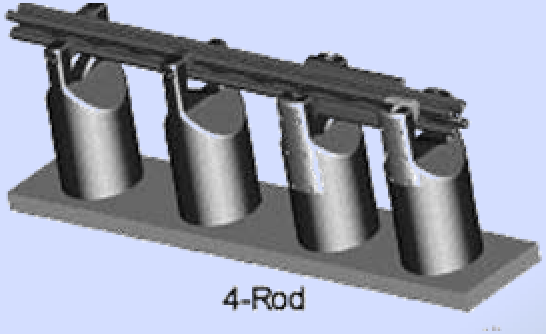
goal
- to bunch the dc beam from the injector
- to accelerate the beam from 0.1 to 5 MeV

➢ high transmission (low losses)

➢ minimal length with reasonable field

High current
CW operation





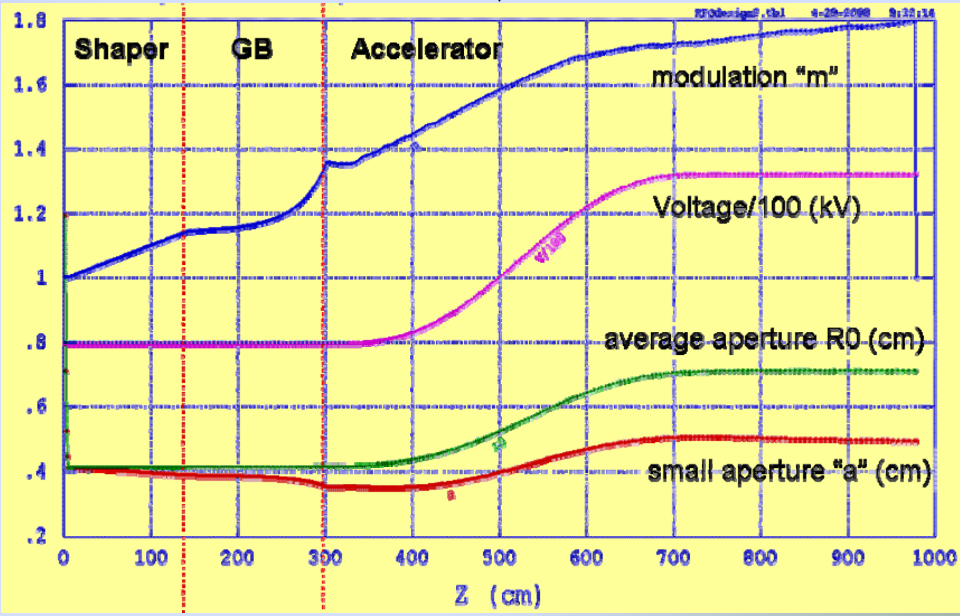
Optimisation of the RFQ

- reduced length (9.8 m)
- reduced power consumption
- minimal beam loss at high energy > 1 MeV

Frequency	175 MHz
Input current	130 mA
Input emittance	0.25 π mm.mrad
Max Surface field	25.6 MV/m
Length	9.78 m
Voltage min/max	79/132 kV
R0 min/max	4.1/7.1 mm
Transmission (Gaus.)	96 %
Cu Power dissipation	< 650 kW

Criteria for the 3 successive sections

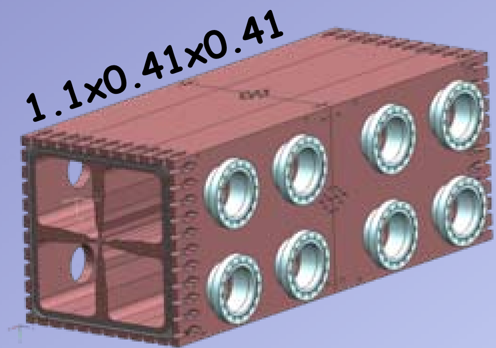
- Analytic law for the voltage V(z) with a smooth increase in accelerator section
- Larger acceptance in accelerator section to reduce losses at high energy
- Physical aperture "a" minimal at GB end playing the role of beam collimation to prevent for beam loss downstream
- Peak surface electric field limited to the reasonable value of 1.8 x Kilpatrick



RFQ Mechanical Design

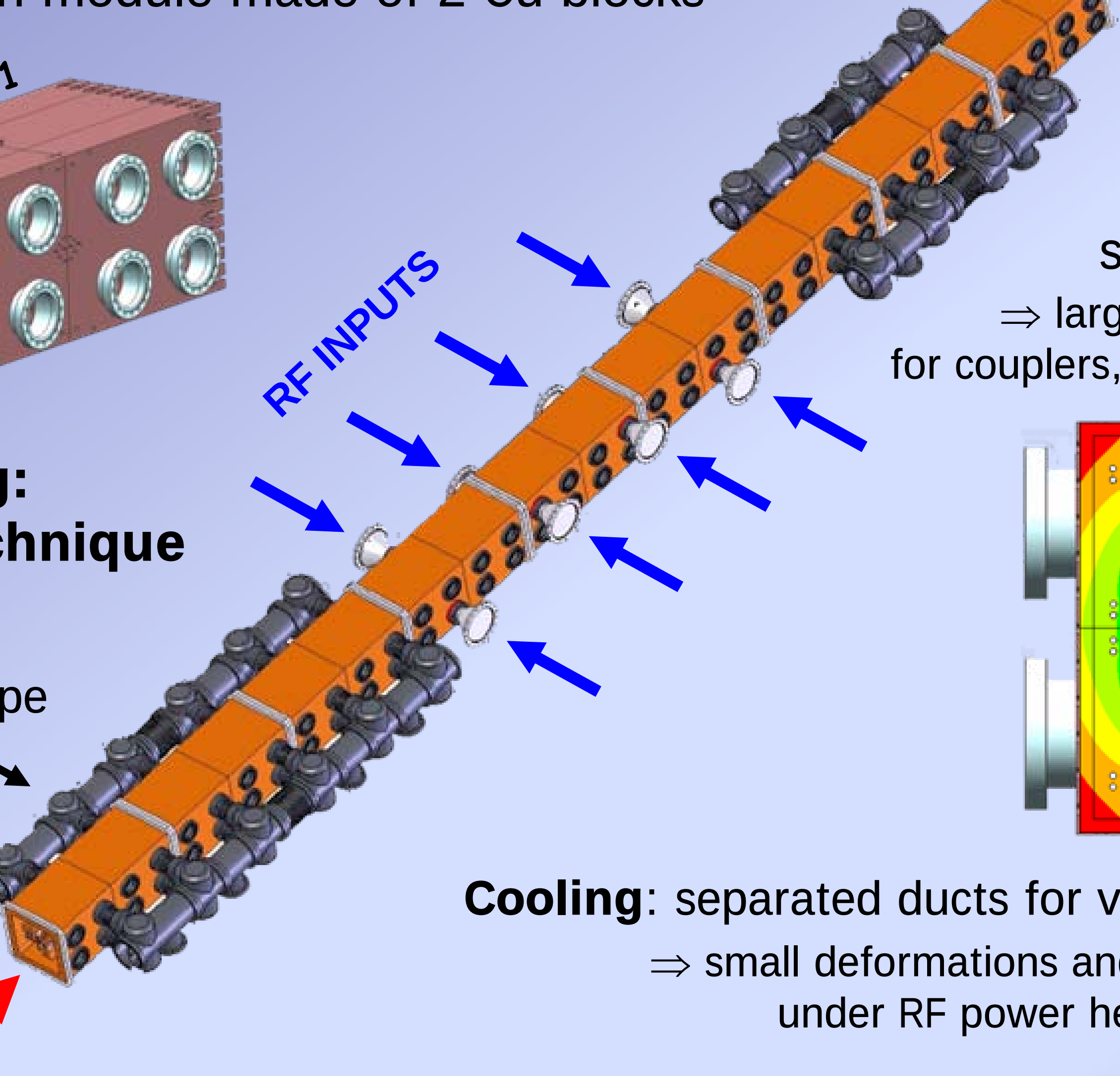
9 modules (1.1m) flanged together
each module made of 2 Cu blocks

A. Pepato et al (FR5REP065)
Mechanical design of the IFMIF/EVEDA RFQ

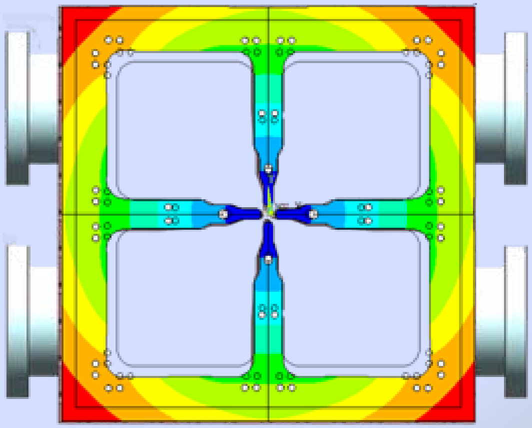


Assembling:
Brazing technique

vacuum pipe



square cross section
⇒ large free surfaces available
for couplers, plungers, vacuum ports



Cooling: separated ducts for vanes & for cavity skin
⇒ small deformations and linked frequency shifts
under RF power heating and water cooling

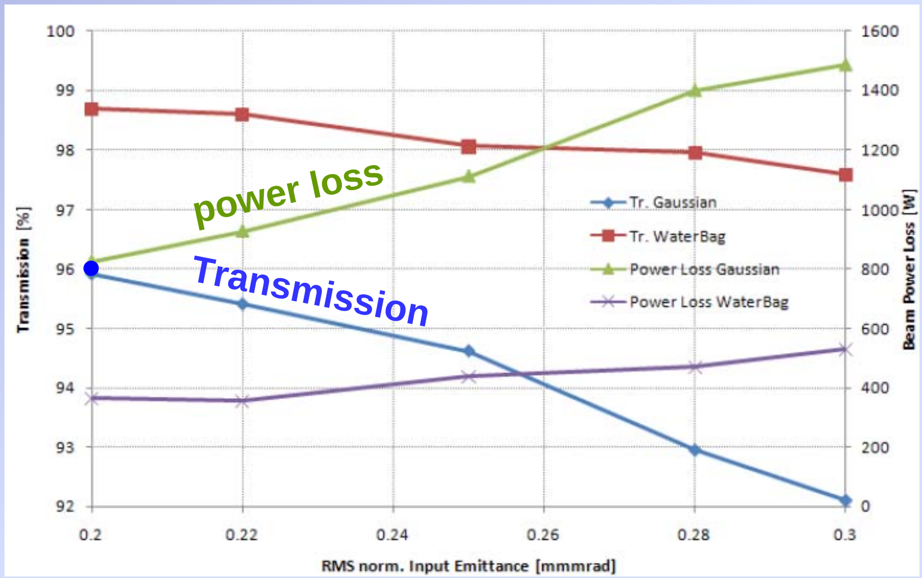
M. Comunian calculations

Main concern: activation

⇒ extensive multi-particle simulations

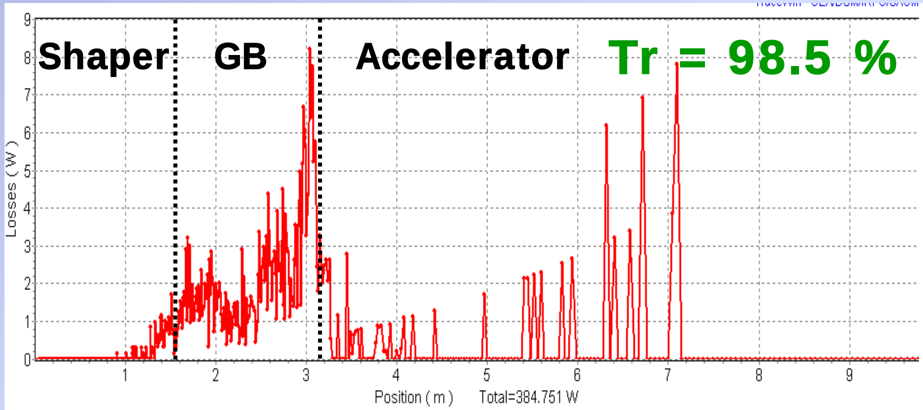
- RFQ transmission ~ 96% for input beam Gaussian 0.2 π mm.mrad
- Losses above 1 MeV kept at low level

Sensitivity to input current

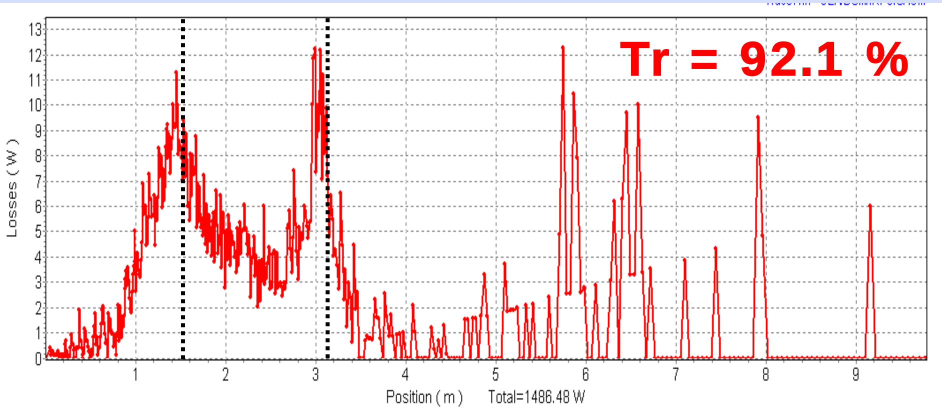


Sensitivity to input beam

best case: waterbag 0.25 π mm mrad



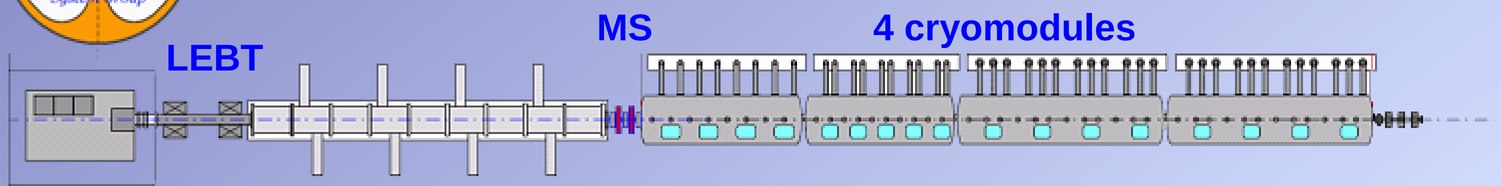
worst case: gaussian 0.30 π mm mrad

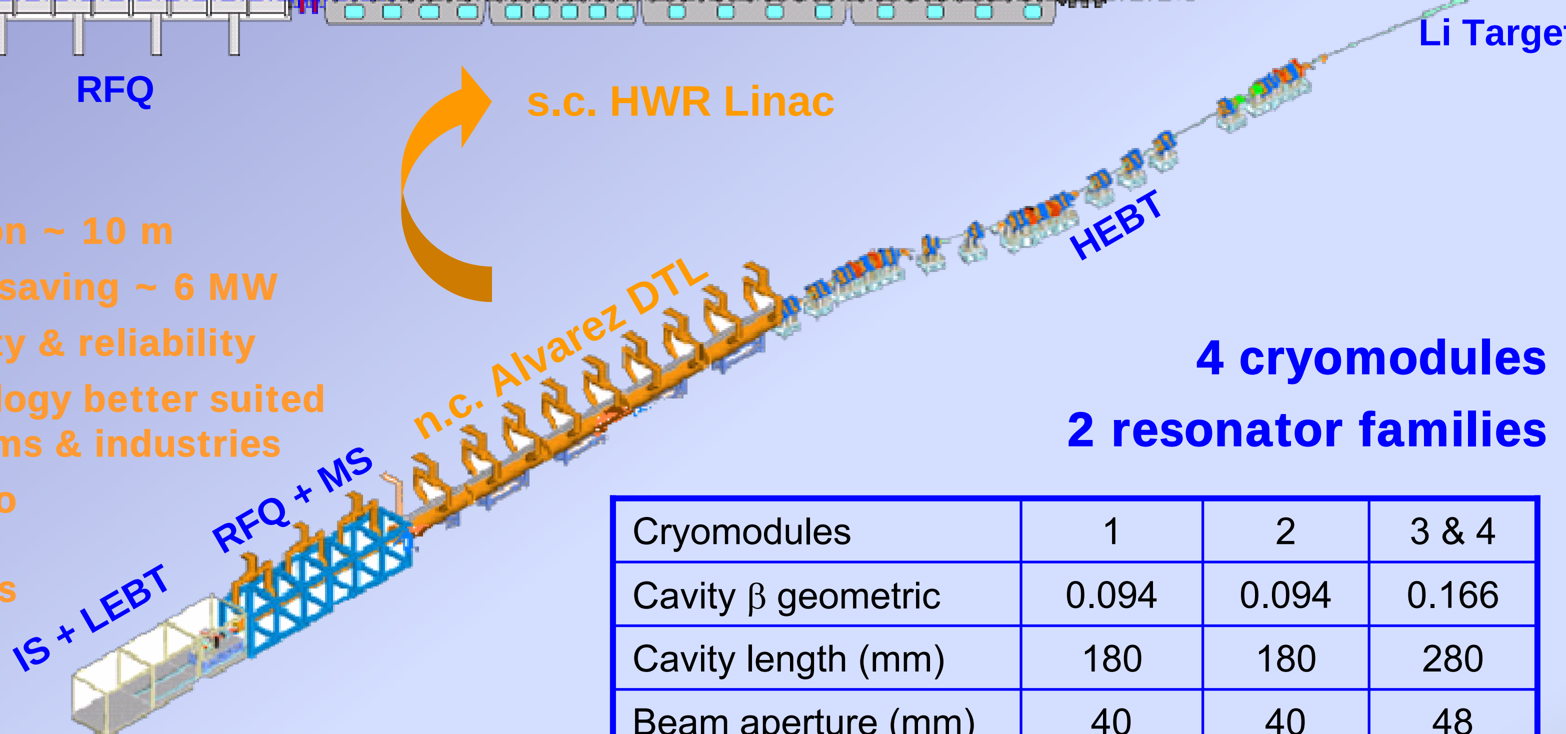


Drift Tube Linac

goal:
- to accelerate the 125 mA CW beam
  - to 40 MeV for IFMIF
  - to 9 MeV for the prototype accelerator
- while preserving the emittance &
- minimizing beam halo, beam loss

n.c. Alvarez DTL replaced by s.c. HWR DTL





Advantages

- length reduction ~ 10 m
- operation cost saving ~ 6 MW
- higher flexibility & reliability
- mature technology better suited to existing teams & industries
- less sensitive to machining & assembly errors

4 cryomodules

2 resonator families

Cryomodules	1	2	3 & 4
Cavity β geometric	0.094	0.094	0.166
Cavity length (mm)	180	180	280
Beam aperture (mm)	40	40	48
Nb cavities / cryostat	1 x 8	2 x 5	3 x 4
Nb solenoids	8	5	4
Cryostat length (m)	4.64	4.30	6.03
Output energy (MeV)	9	14.5	26 / 40

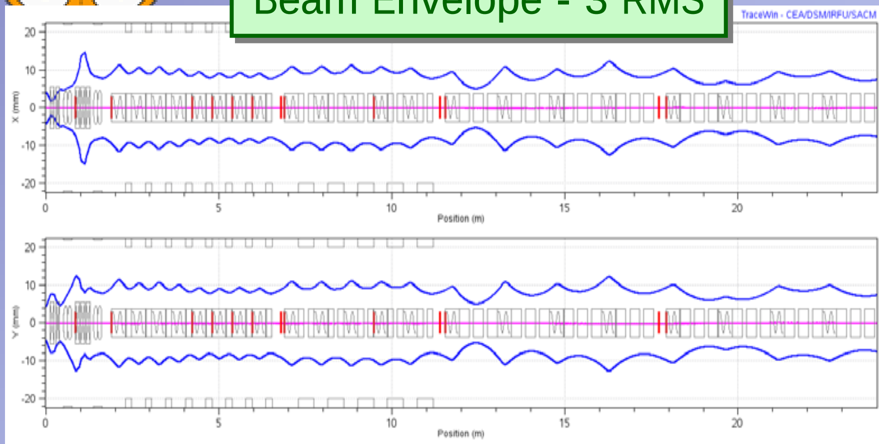
conservative approach

Moderate gradient @ 4.5 MV/m

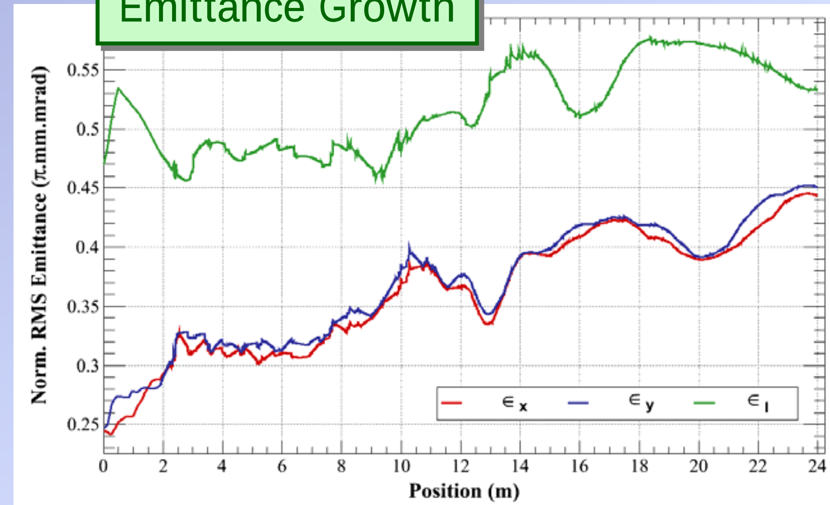
Large aperture @ 40-50 mm

Beam dynamics (HWR)

Beam Envelope - 3 RMS



Emittance Growth

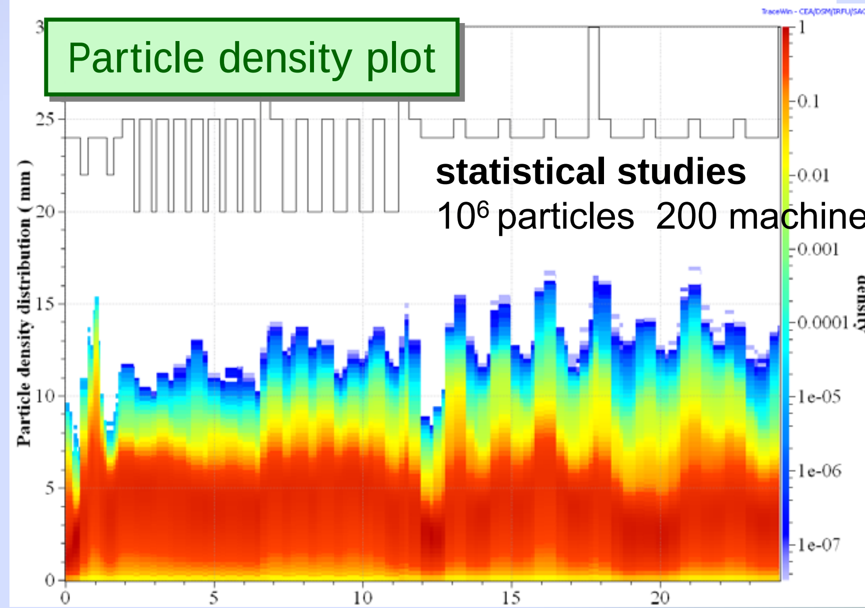


13%

80%

	Resonator	Solenoid
Misalignment	± 2 mm	± 1 mm
Tilt	± 20 mrad	± 10 mrad
Field amplitude	± 1 %	± 1 %
Field phase	± 1 deg	

Particle density plot



statistical studies

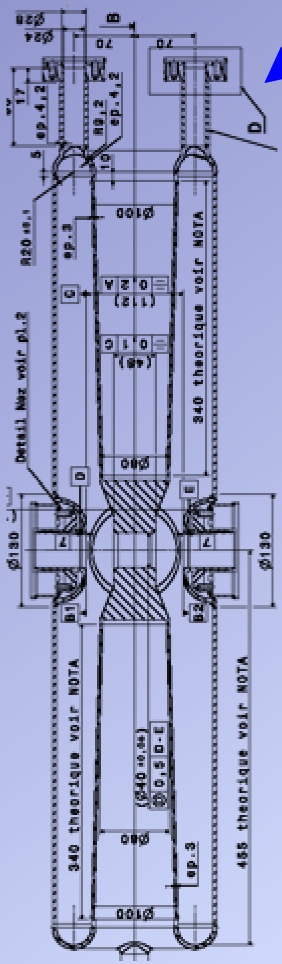
10^6 particles 200 machines

can sustain very **conservative alignment** and **field errors** while keeping a large safety margin between the beam occupancy and the pipe aperture

N. Chauvin et al (TH5PFP005)

Optimization Results of Beam Dynamics Simulations for the Superconducting HWR IFMIF Linac

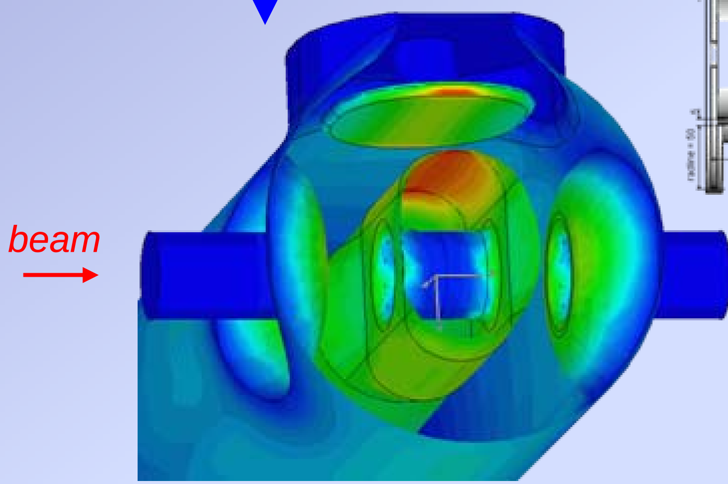
Resonator & Tuner conceptual design

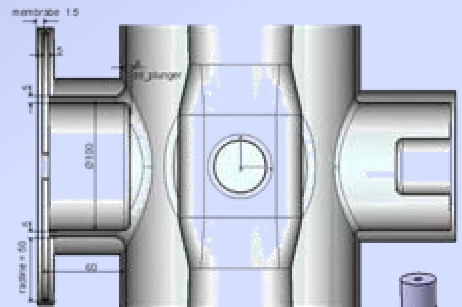


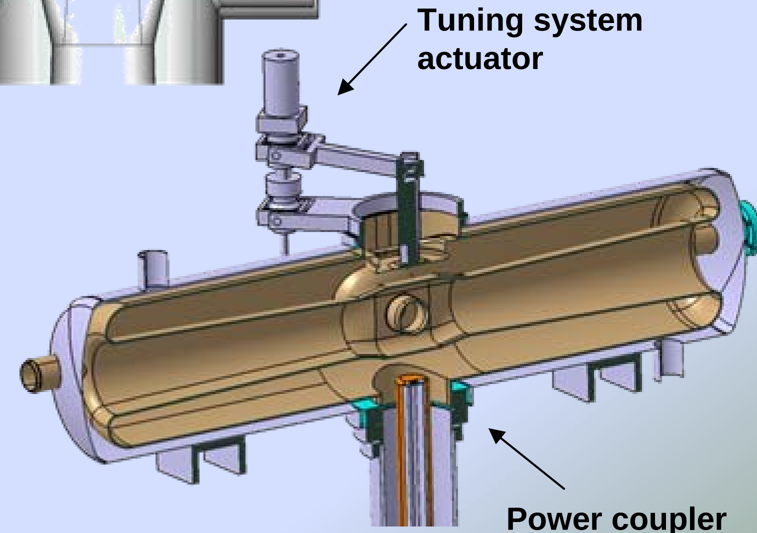
Geometry optimisation ⇒ peak surface fields sufficiently reduced (determine the maximum reachable accelerating field)

$E_p/E_{acc}=4.4$ $B_p/E_{acc}=10.1$

Tuning method : plunger at the opposite of the coupler port in a region of high electric field (tuning range easily achieved)

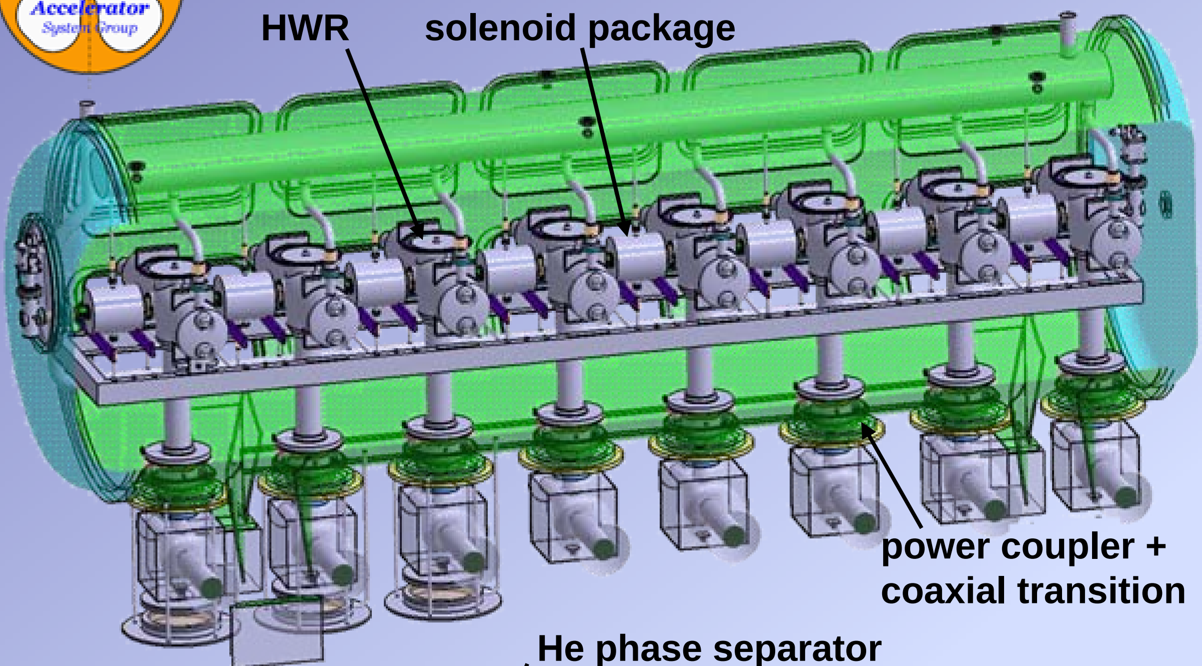




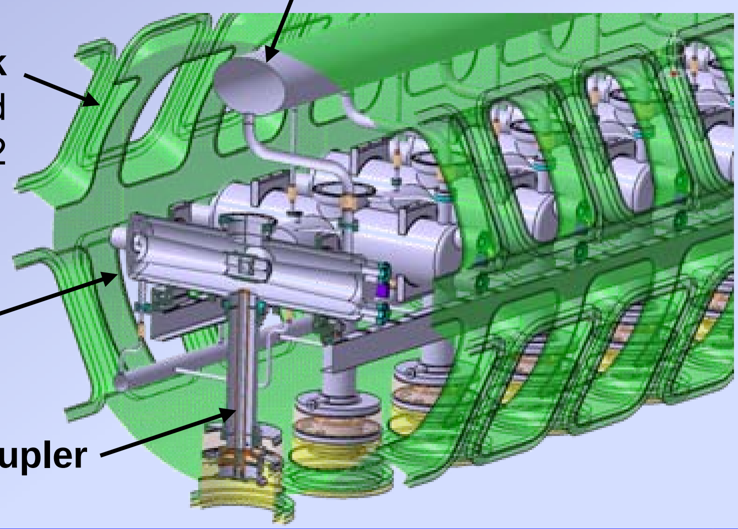


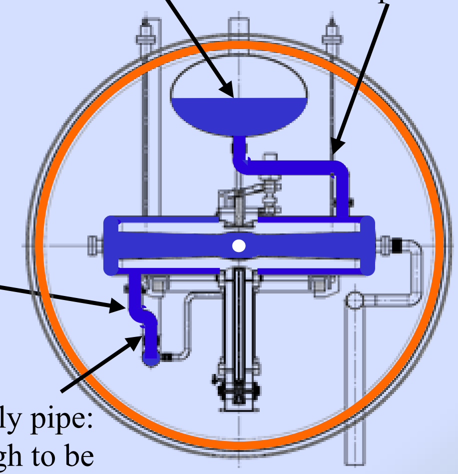
E. Zaplatin et al (TU5PFP066)
IFMIF Superconducting β=0.094 Half-Wave Resonator Design

Cryomodule Conceptual design



- **Conceptual design for:**
  cold mass support, alignment system, cryogenic pipes, vacuum pipes, interfaces, connections with all services





- **Conceptual design for:**
  He cooling (forced flow mode)

RF Power Systems

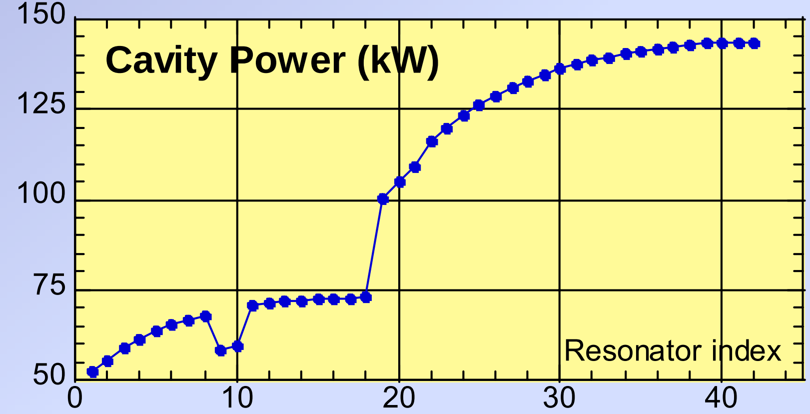
CIEMAT/CEA/SCK•CEN collaboration

RF power needs

RF power to transfer to the beam for each cavity

< 80 kW for 1st module

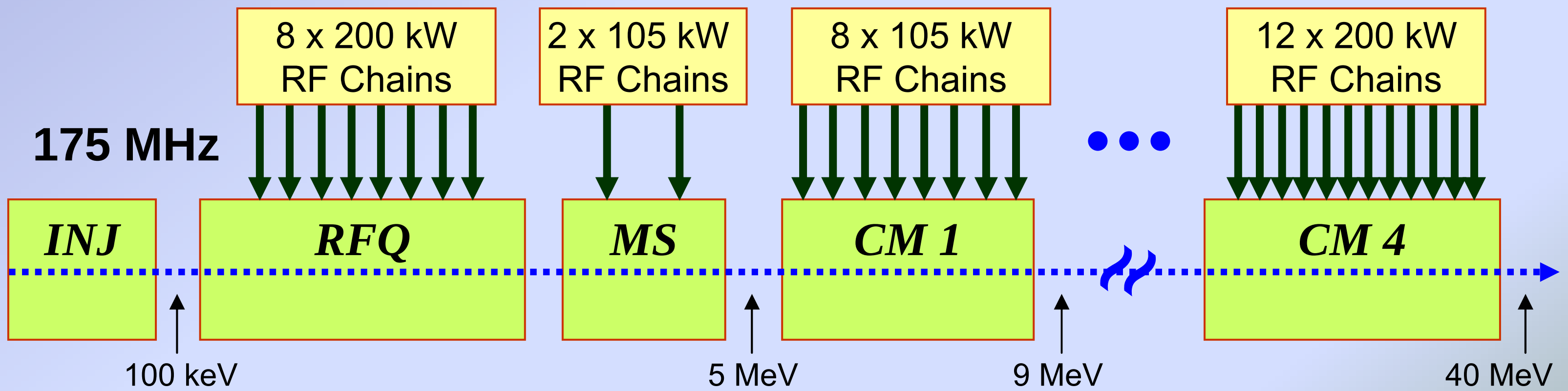
< 150 kW for last module



Standardization: identical RF sources used for all components (RFQ, Bunchers, HWR)

with 2 different RF power ratings : 20 x **105 kW** and 32 x **200 kW**

only 1 type 400 kW HVPS (feeding 1 x 200 kW or 2 x 105 kW RF power units)

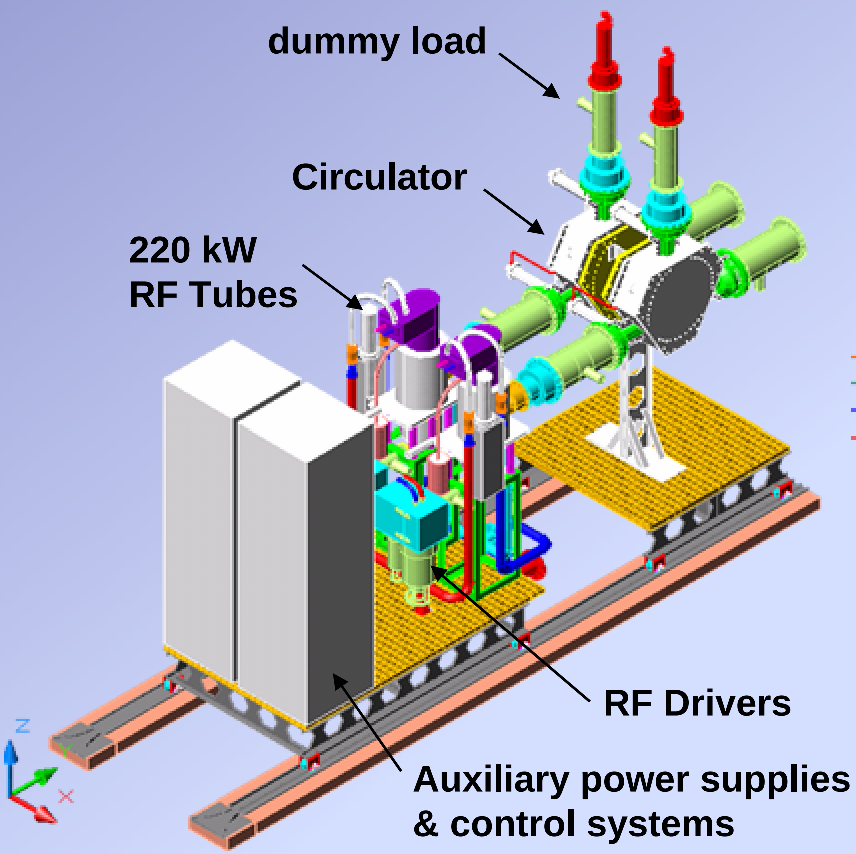


RF System implementation

To optimize space, improve maintenance and availability

symmetric modular system composed of removable modules including two complete amplifiers each

⇒ compact & fast repair in case of failure

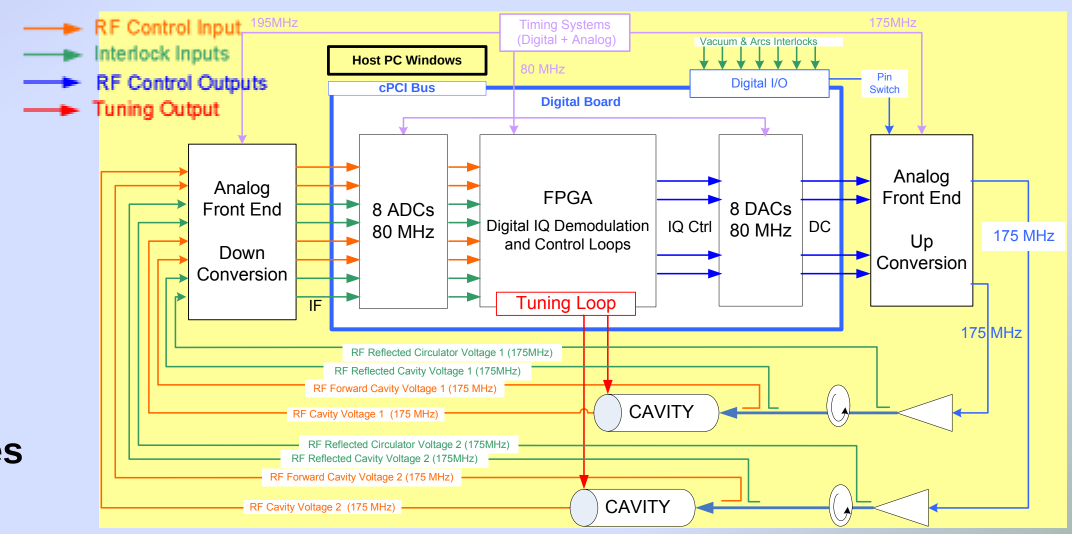


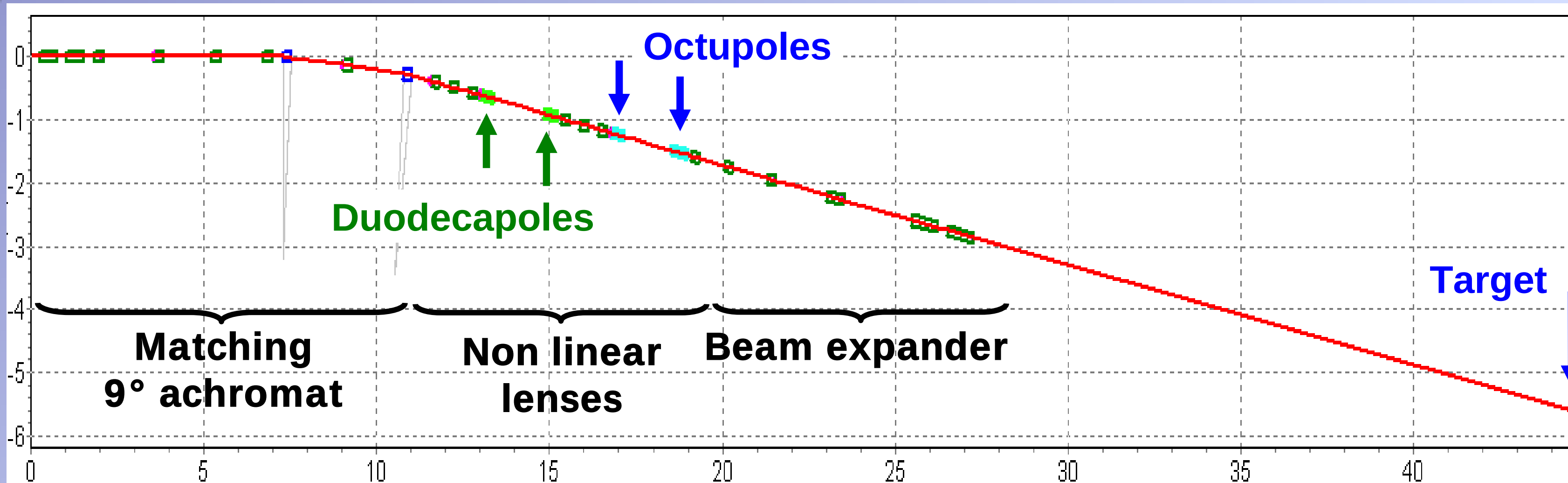
LLRF: Digital Commercial Board

cPCI with 8 ADCs, 8 DACs and FPGA

Analog Front Ends for Downconversion (RF to IF) and Upconversion (DC to RF)

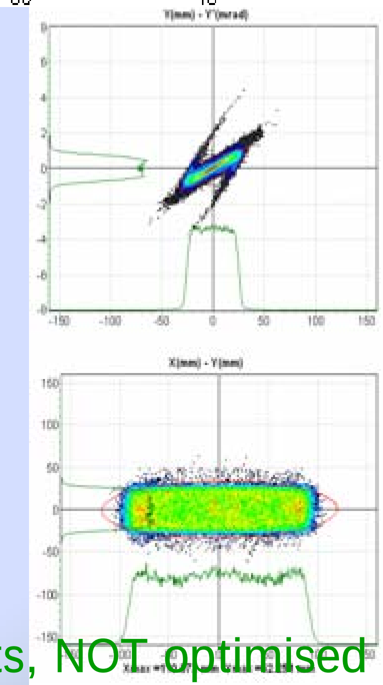
Timing systems: 195 MHz (175 + 20) for downconversion synchronized with digital 80MHz clock for digital acquisition





- To transport the 5 MW beam to the Li target
- To tailor the beam distribution coming from the Linac to a rectangular beam (20cm x 5cm) uniform distribution

- 9° achromat to avoid neutron backstreaming in the linac
- non-linear focusing for beam folding in each plane (to fold back the tails onto the core)
- final beam expander (quadrupoles)

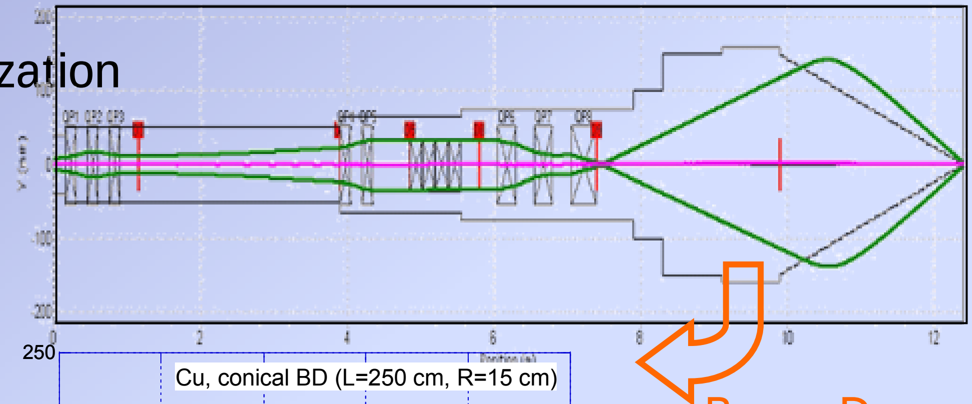


First results, NOT optimised

HEBT & Beam Dump - P. A.

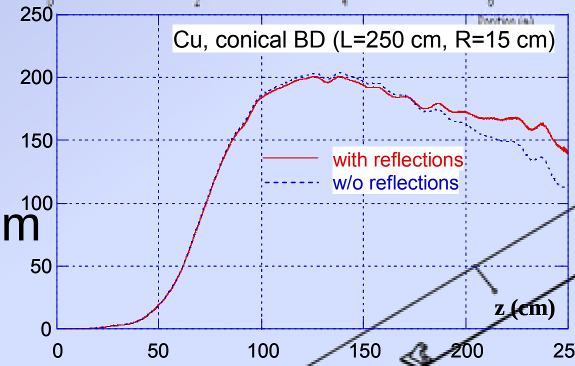
responsible Lab: CIEMAT *coordinator: Beatriz Brañas*

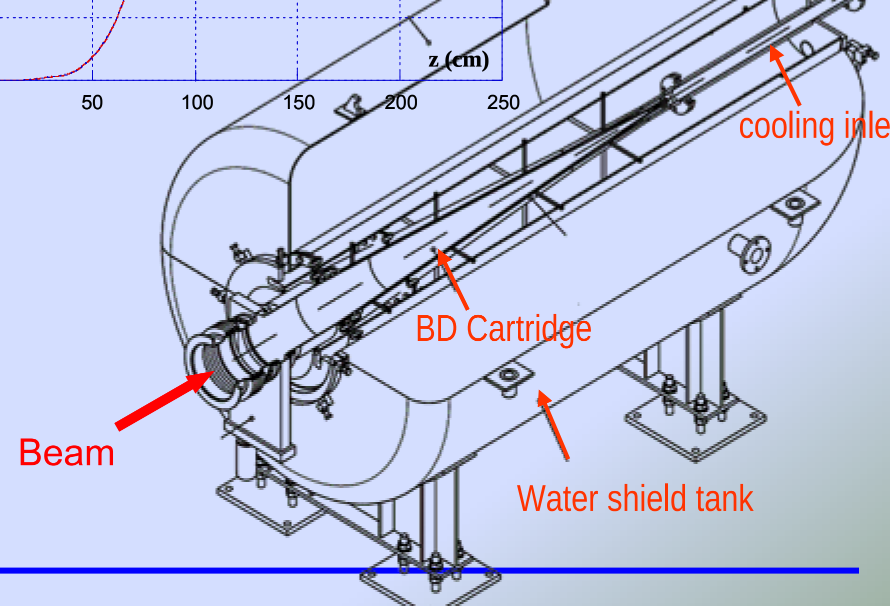
- **Diagnostics-Plate** for beam characterization
- **20° dipole magnet** to avoid neutron backstreaming
- **8 quadrupoles** for beam matching & expanding



Beam Dump 9 MeV - 1.125 MW

- **cartridge** ø=30 cm, L=2.50 m
  conical shape + cyl. input scraper ø=30 cm
- **beam facing material**
  activation & thermo-mechanical analysis
  copper (minimum stresses)
- **cooling system**
  axial flow in counter-beam direction
  through annular channel of varying width
  30 kg/s, Tin=31 ºC, p=3.4 bar
- **shielding**: water tank (n) & concrete (γ)

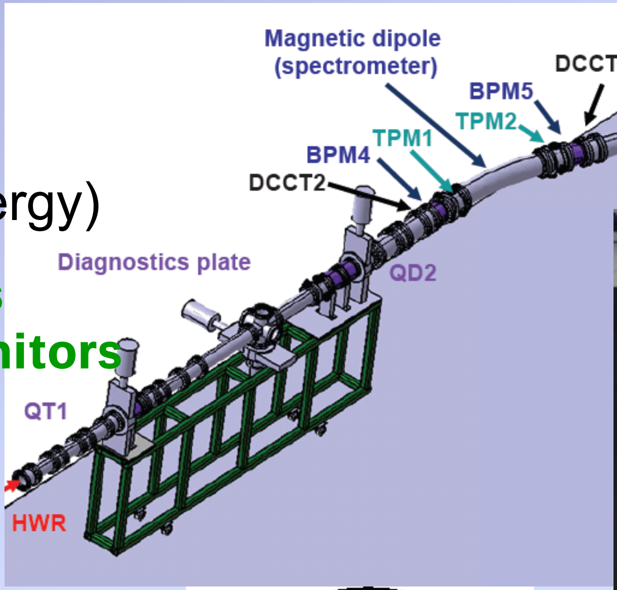


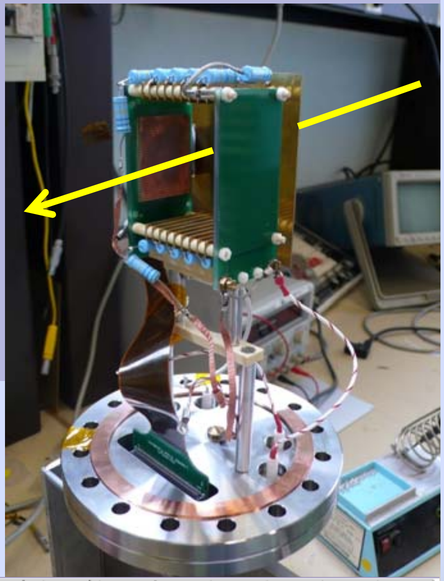


Objectives

- linac tuning & commissioning
- beam loss minimization
- beam characterization (emit, energy)

Current, Position, Profile monitors
Beam loss, Halo, bunchlength monitors



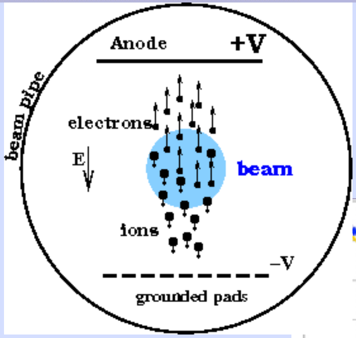


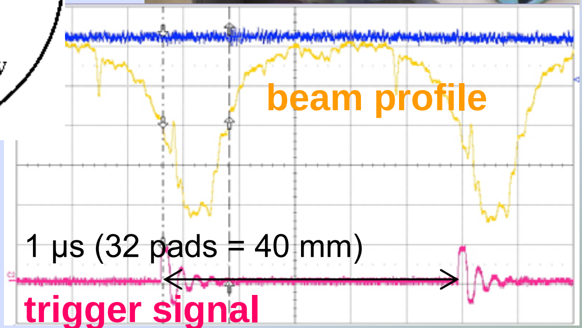
Diagnostics Plate

specific beamline for a set of diags installed at 2 different locations (downstream RFQ and downstream DTL)

Beam Transverse Profilers

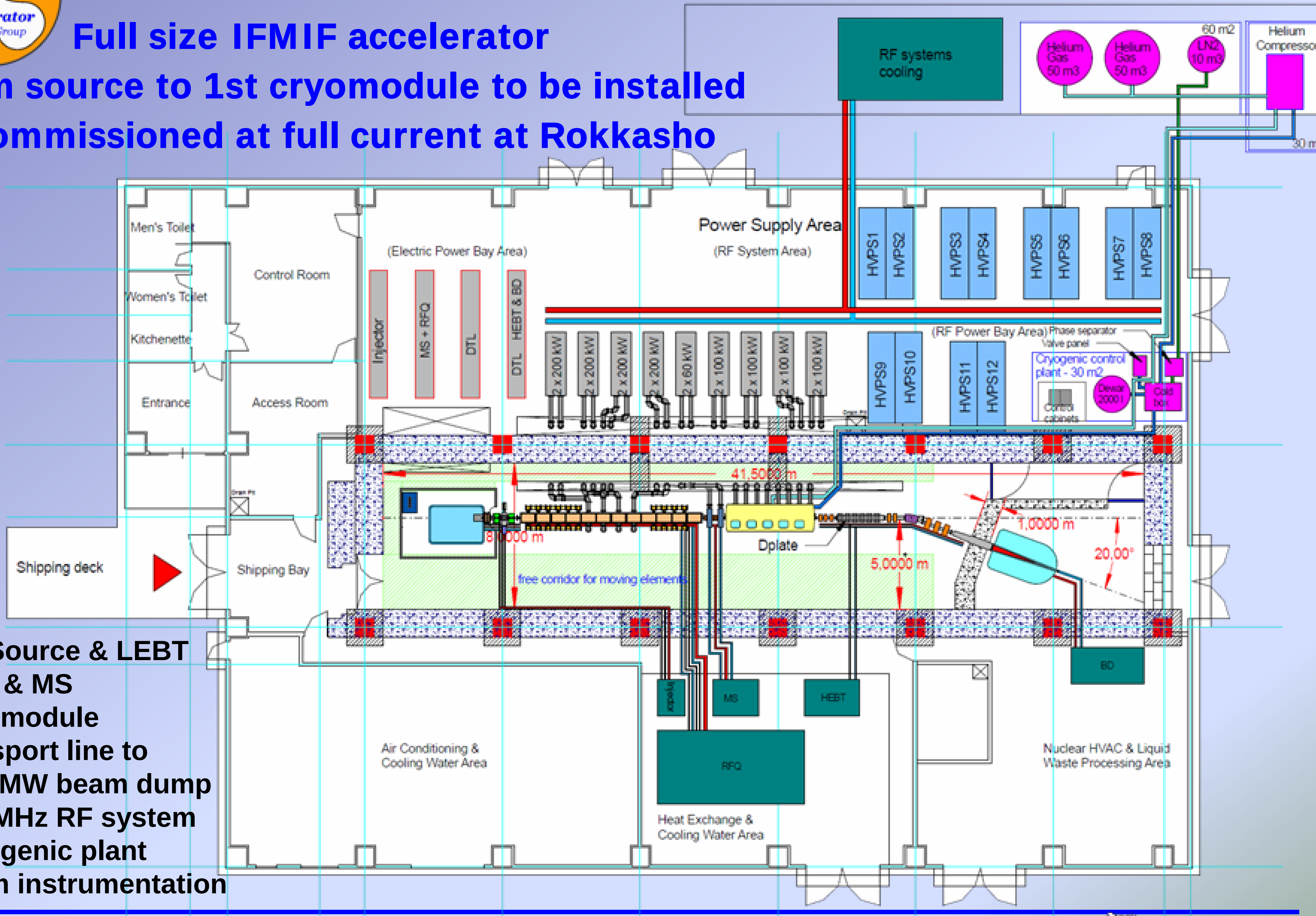
high intensity ⇒ non interceptive !
based on residual gas ionization
2 types developed: fluorescence & ionization
R&D started (test à low energy)





the P.A. of the EVEDA phase

Full size IFMIF accelerator
from source to 1st cryomodule to be installed
& commissioned at full current at Rokkasho



- **Ion Source & LEBT**
- **RFQ & MS**
- **Cryomodule**
- **transport line to**
- **1.12 MW beam dump**
- **175 MHz RF system**
- **Cryogenic plant**
- **beam instrumentation**

Conclusion

1½ year after the start of the project, substantial technical updates have been brought in order to optimise the design of the entire linac:

- RFQ looks now shorter and less prone to beam loss
- switch from the room temperature DTL to superconducting technology for the high energy portion of the linac
- complete redesign of the RF system, based on conventional RF amplifiers

The beam dynamics studies have shown that the acceleration of the full beam looks feasible with reasonable emittance growth and beam loss

The components of the prototype accelerator, starting with the injector, the RFQ and the RF power system, enter now into the manufacturing phase.

Most of them will be tested in Europe before the shipping, installation, check-out, commissioning and operation at Rokkasho

IFMIF/EVEDA building (Rokkasho)

Foundations of the building at Rokkasho…