THE IFMIF 5 MW LINACS

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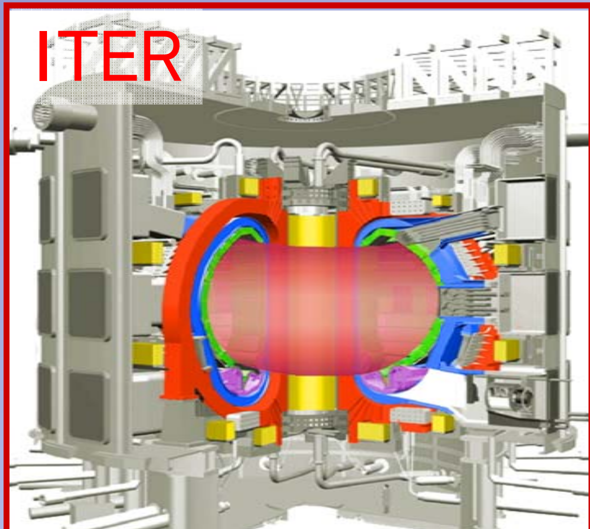
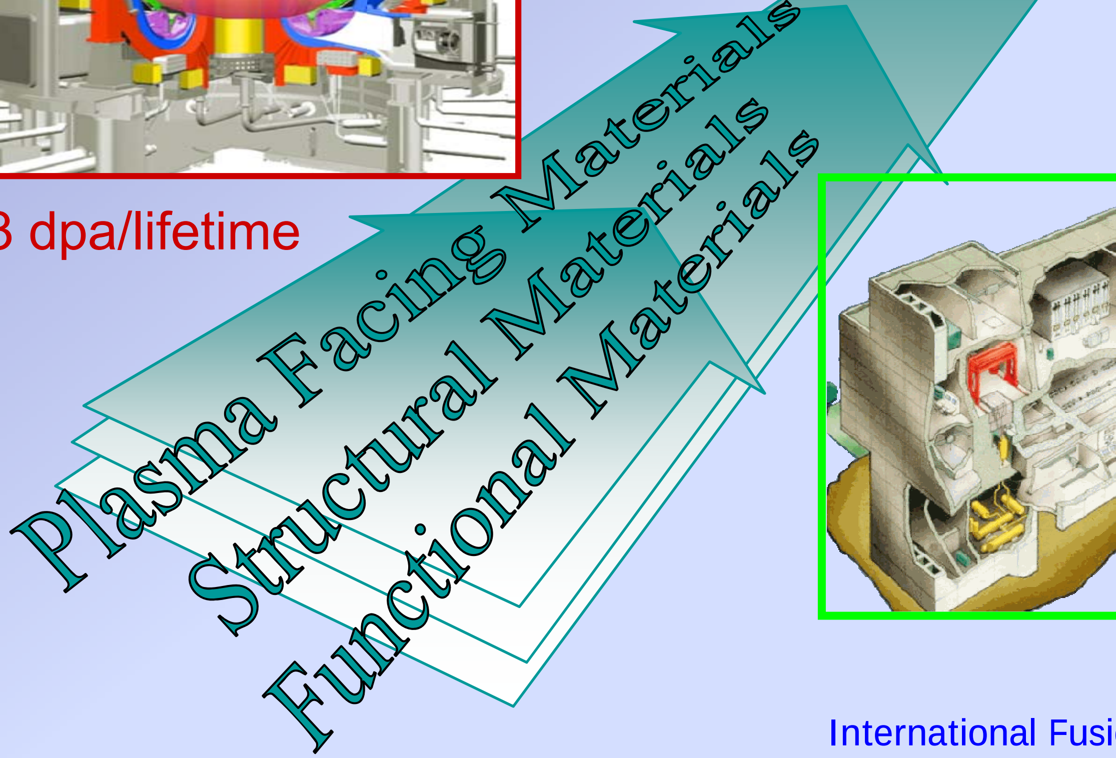
CEA-Saclay, DSM/IRFU

International Road Map

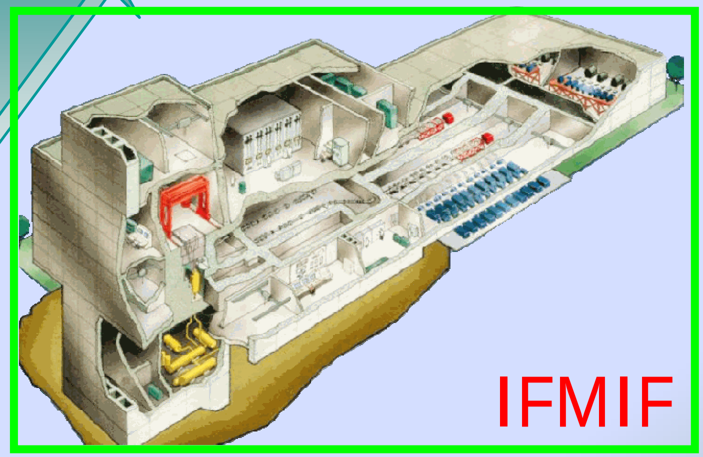
Advanced Materials are at a critical path



1-3 dpa/lifetime



< 150 dpa



20-40 dpa/year

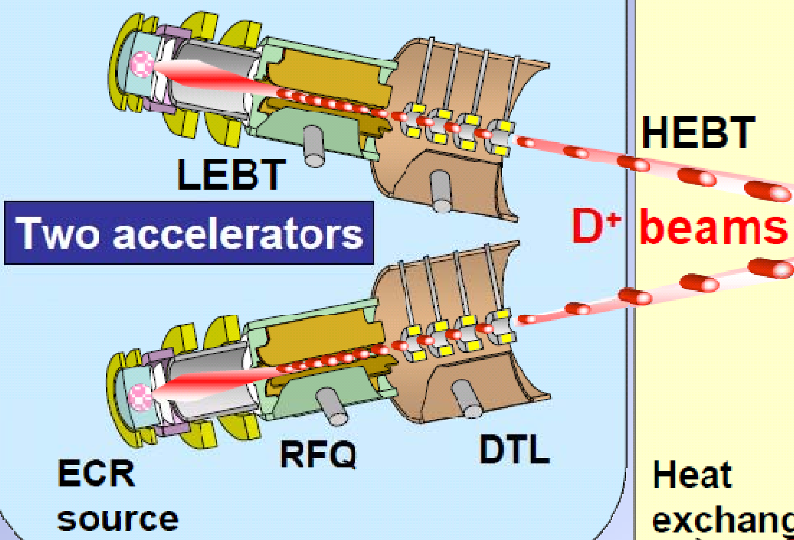
International Fusion Materials Irradiation Facility

IFMIF Principles

Accelerator

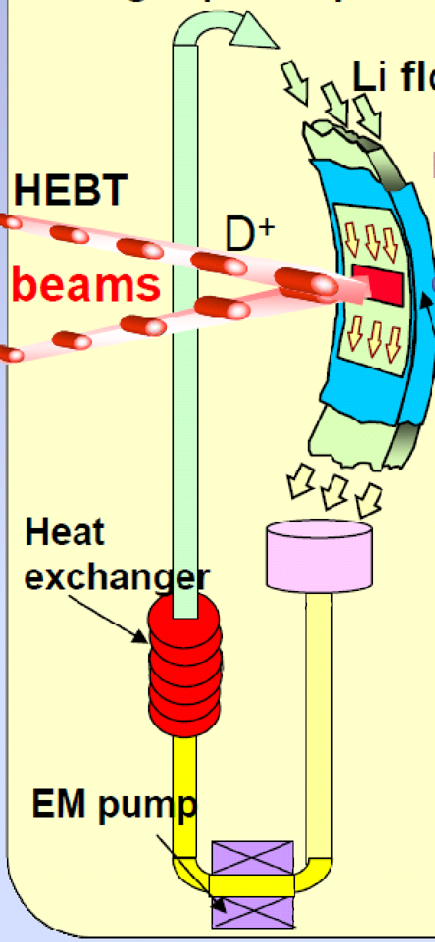
Deuteron accelerators:

2 x 125 mA D^+ CW at 40 MeV



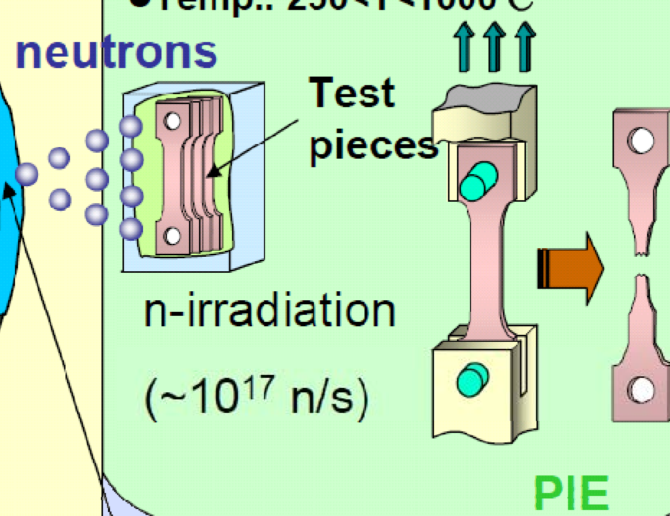
Target

10 MW beam heat removal
with high speed liquid Li flow



Test Modules

- Irrad. Volume > 0.5L
  for 10^{14} n/(s·cm²), (20 dpa/year)
- Temp.: 250<T<1000℃



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

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

Beam footprint on Li target
20cm wide x 5cm high
(1 GW/m²)

the 6-year EVEDA phase has been launched in the middle of 2007

Engineering **V**alidation and **E**ngineering **D**esign **A**ctivities

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

includes 3 systems: **Accelerator, Target and Test Facilities**

The objectives of the accelerator activities are two-fold:

- to validate the technical options with the construction of the **Prototype Accelerator** = full size IFMIF accelerator from source to first DTL to be installed and commissioned at full beam current at Rokkasho (Japan)
- 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 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**

INJECTOR

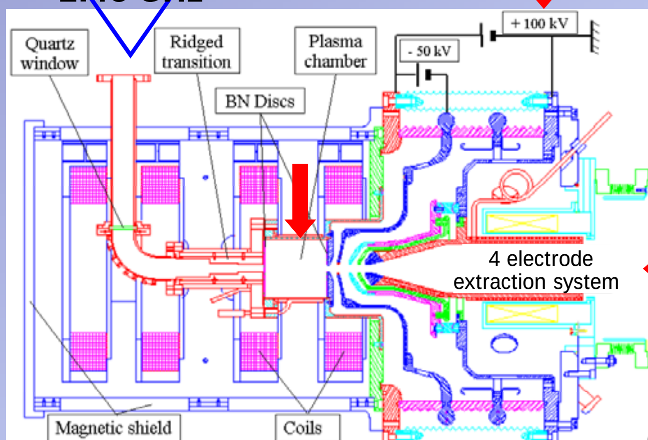
goal • to deliver a 100 keV deuteron beam

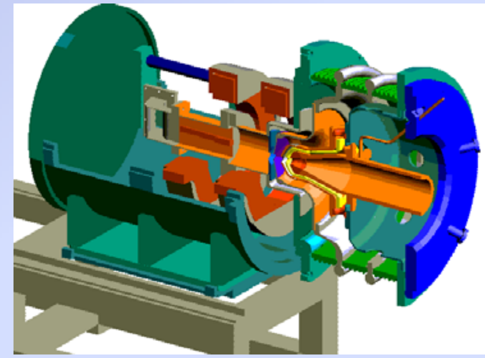
- **high intensity (140 mA)**
- **high quality (0.25 π.mm.mrad)**
- **high reliability**

ECR source selected (Electron Cyclotron Resonance)

- high efficiency, availability and lifetime

magnetron
2.45 GHz





design based on SILHI H^+ source   2.45 GHz, 875 Gauss

(High Intensity Light Ion Source)

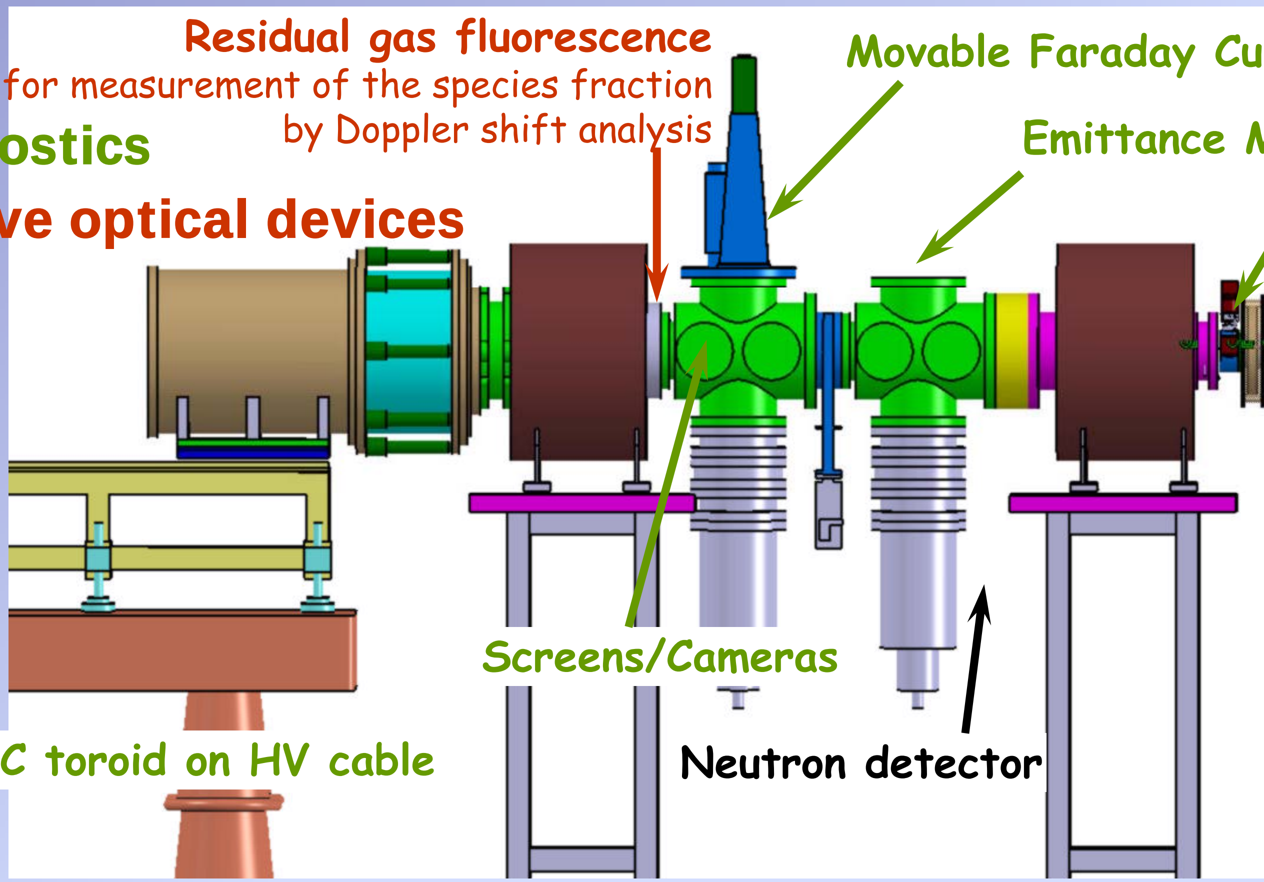
improvements to do ...

- extraction system (better maching for D)
- engineering design (compact HV platform)
- efficient radiation shielding
- required low emittance measurement

Low Energy Beam Transport

Classical diagnostics

Non-interceptive optical devices



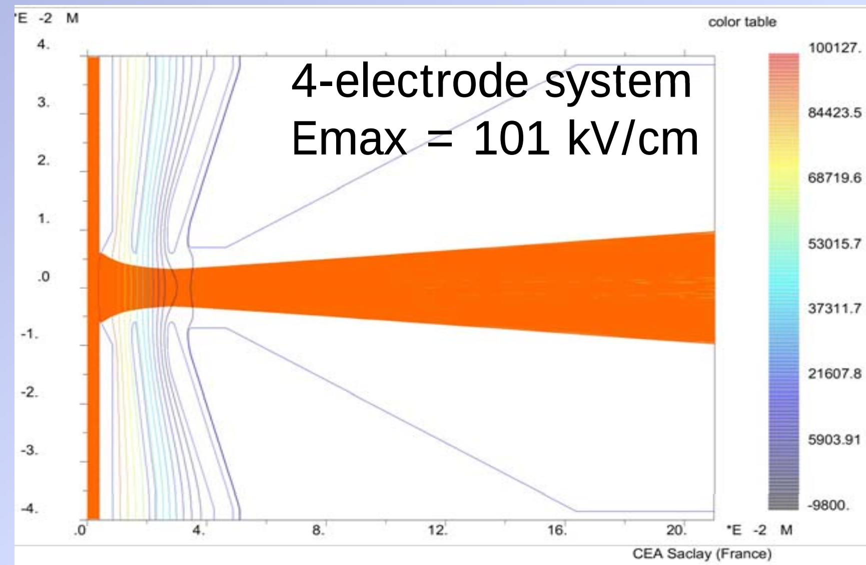
- dual solenoid transport system
- with space charge compensation, small beam aberrations
- small length to minimize the emittance growth
- series of beam diagnostics for source tuning and beam characterization

Ion Source Extraction

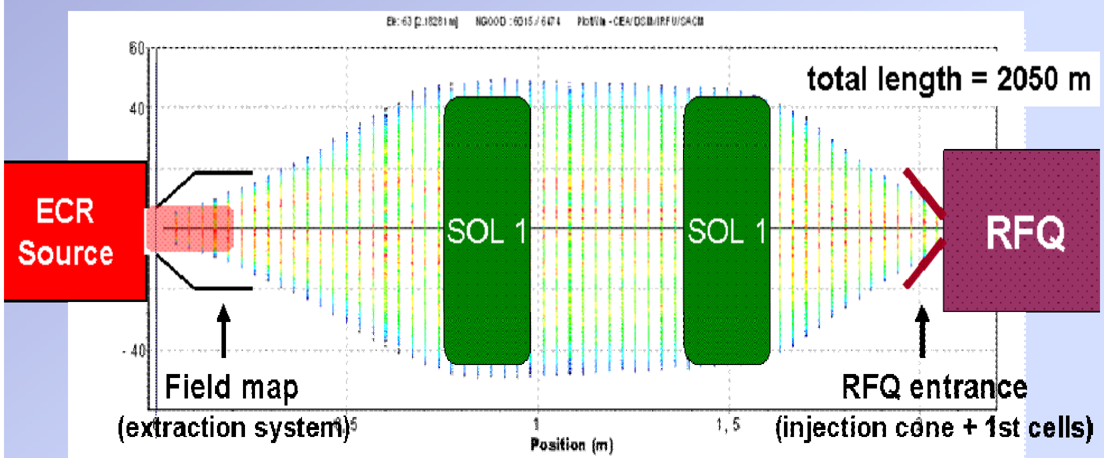
140 mA $D^+ \Rightarrow$ 175 mA total beam
(D^+ 80%, D_2^+ 15%, D_3^+ 5%)

Axcel & Opera2D simulations to optimise

electrode number (3, 4 or 5) electrode shape
aperture diameter (9, 11 or 12 mm)



LEBT simulations



New code developed to calculate the space charge compensation

required emittance at RFQ entrance very challenging (0.25 π.mm.mrad)

could be met, with injection of gas Krypton (P_{Kr} = 4.10^{-5} hPa)
in order to better compensate the space charge forces

N. Chauvin et al (MOP072)
Beam Dynamics Simulations of the LEBT for IFMIF/EVEDA

Radiofrequency Quadrupole

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

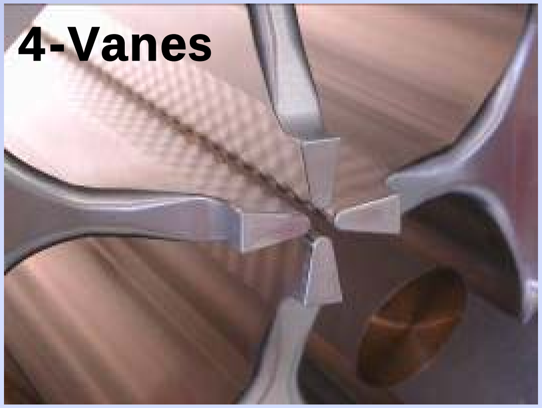
➢ **high transmission (low losses)**

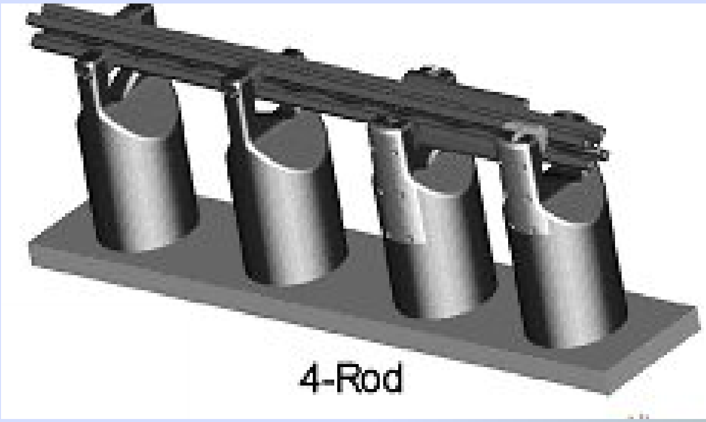
➢ **minimal length with reasonable field**

A. Palmieri et al (MOP037)
RF Design of the IFMIF-EVEDA RFQ

M. Comunian et al (MOP036)
The IFMIF-EVEDA RFQ: Beam Dynamics Design

High current CW operation

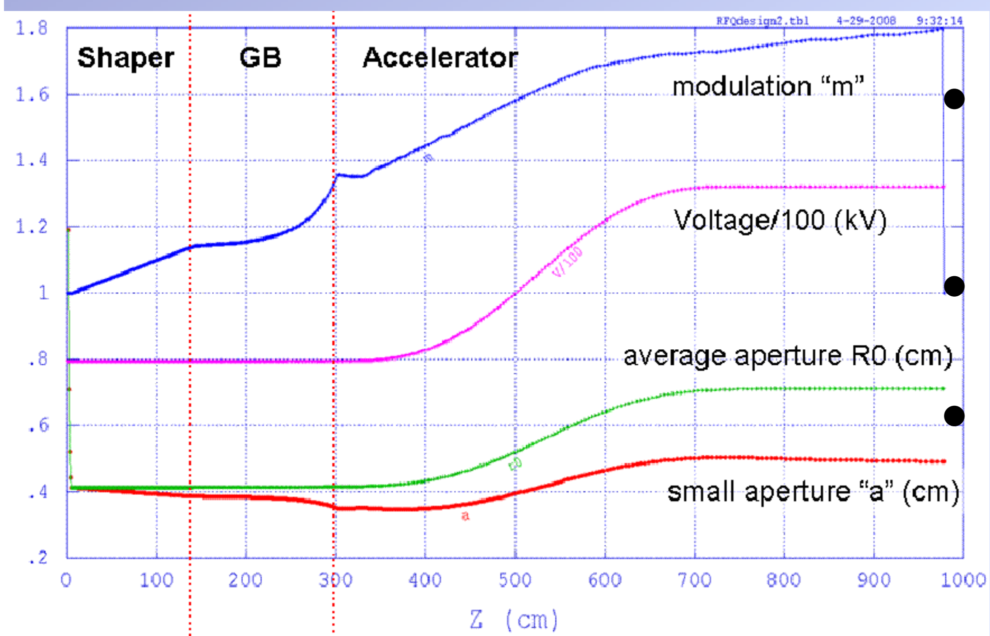




RFQ Beam Dynamics

Design parameters

Input energy	100	keV
Output energy	5	MeV
Input Current	130	mA
Input emittance	0.25 π	mm.mrad
Frequency	175	MHz
Phase adv. trans	220	deg/m
long	90	deg/m



Optimisation of the RFQ

- reduced length (9.8 m) & power consump
- beam loss along the RFQ under control

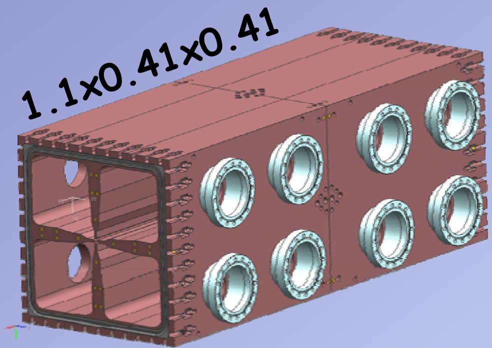
Criteria for the 3 successive sections

- Analytic law for the voltage with a smooth increase in the 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
- High focusing strength *B* to keep the beam in the linear part of the focusing fields
- Peak surface electric field limited to the reasonable value of 1.8 x Kilpatrick

$$B = qV\lambda^2 / mc^2 r_0^2$$

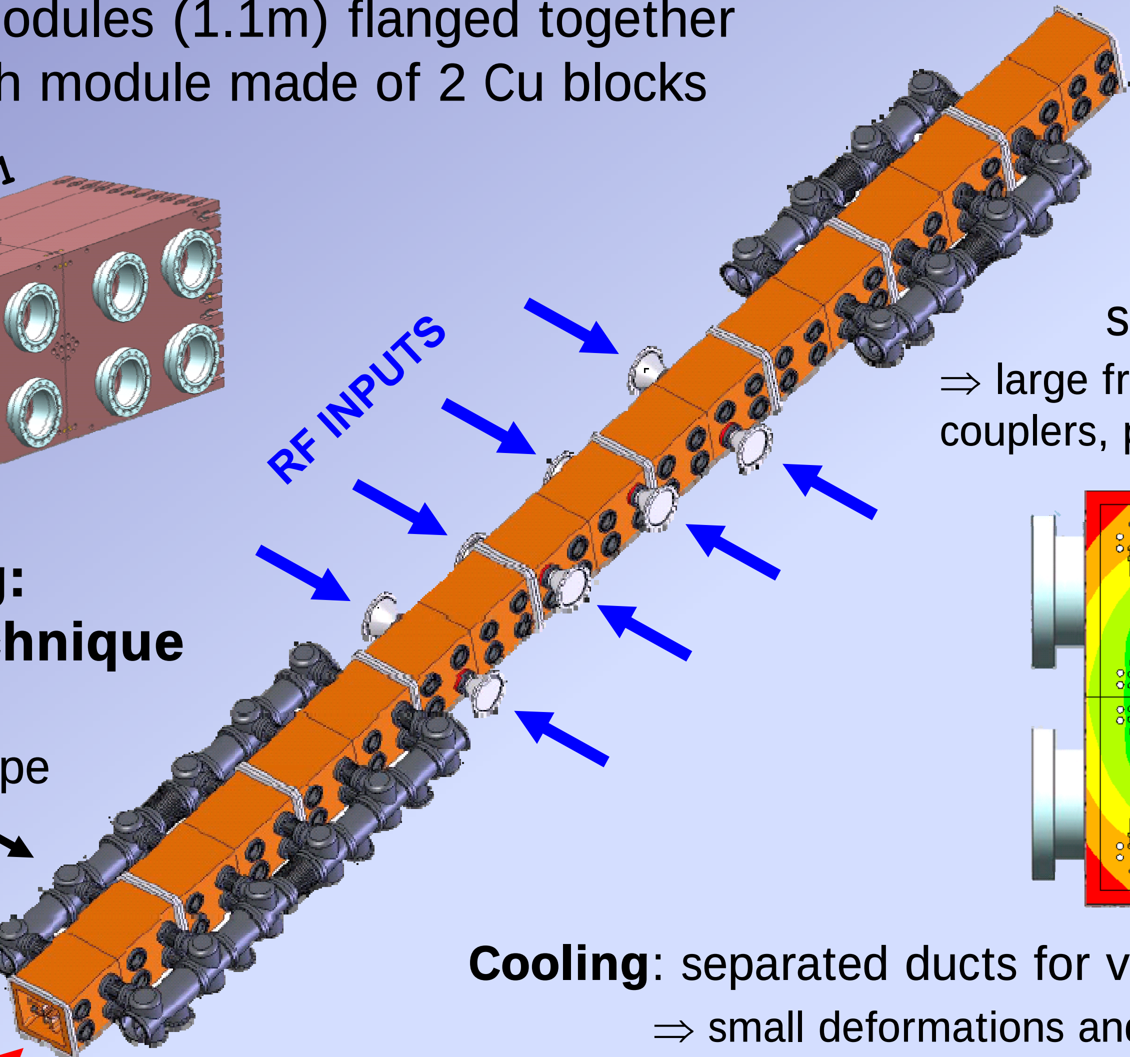
RFQ Mechanical Design

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

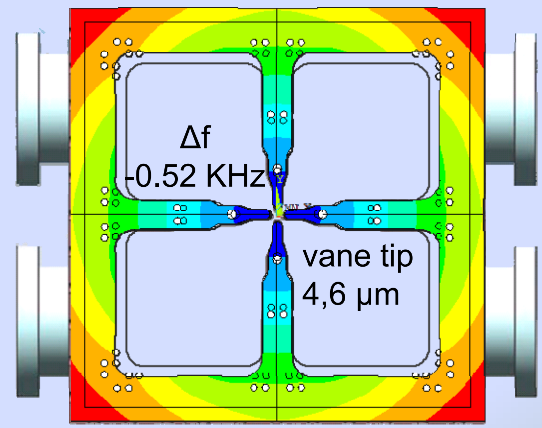


Assembling:
Brazing technique

vacuum pipe



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

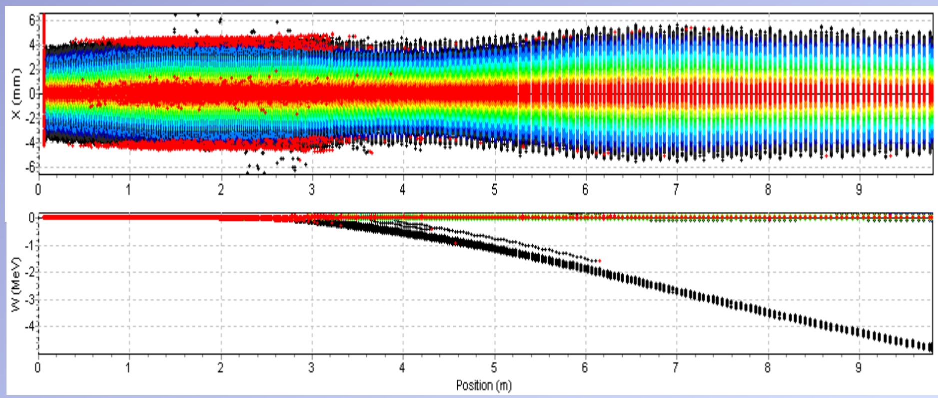


Cooling: separated ducts for vanes & for cavity skin
⇒ small deformations and linked frequency shifts under RF power heating and water cooling

RFQ - beam losses

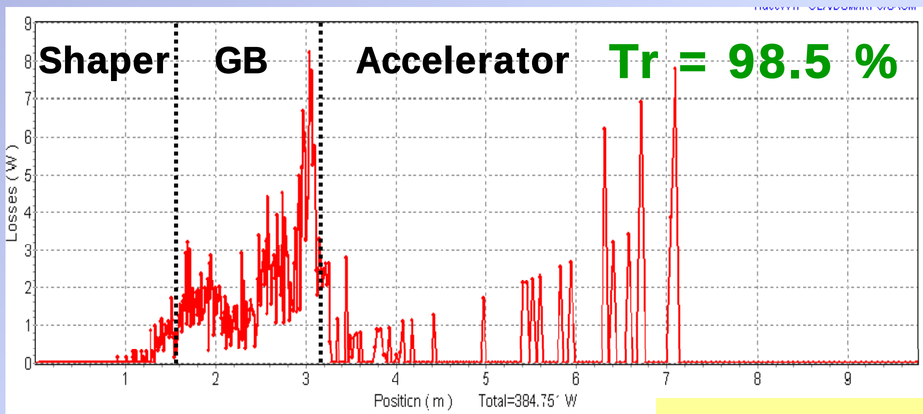
Main concern: activation ⇒ extensive multi-particle simulations

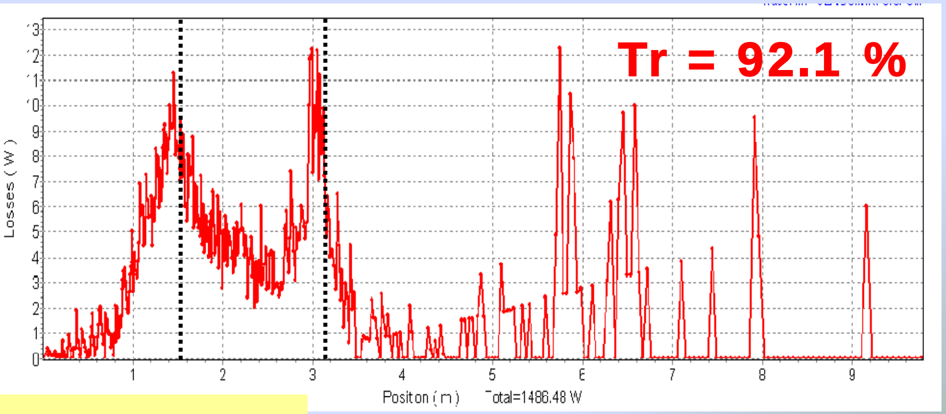
- RFQ transmission ~ 98.5% (input beam: waterbag distribution)
- Losses above 1MeV kept at low level



Sensitivity to input beam

"best case"	"worst case"
waterbag	gaussian
0.25 π mm mrad	0.30 π mm mrad





M. Comunian calculations

Drift Tube Linac

goal:
- **to accelerate the 125 mA CW beam to 40 MeV**
- **while preserving the emittance &**
- **minimizing beam halo, beam loss**

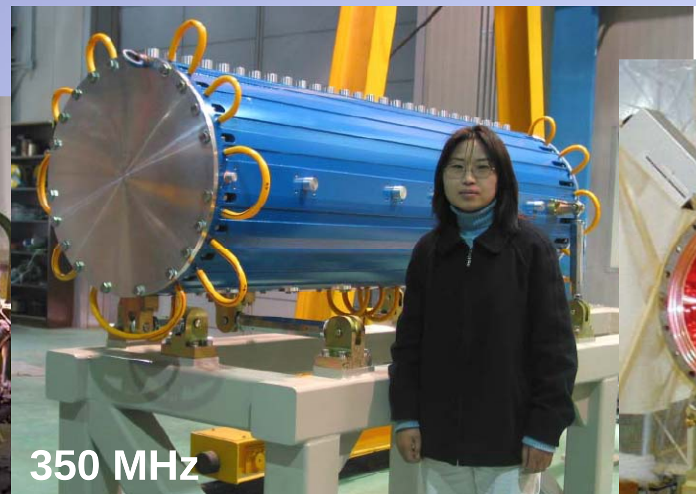
➢ **the n.c. Alvarez DTL**

was the reference but somewhat challenging...

the n.c. Alvarez DTL

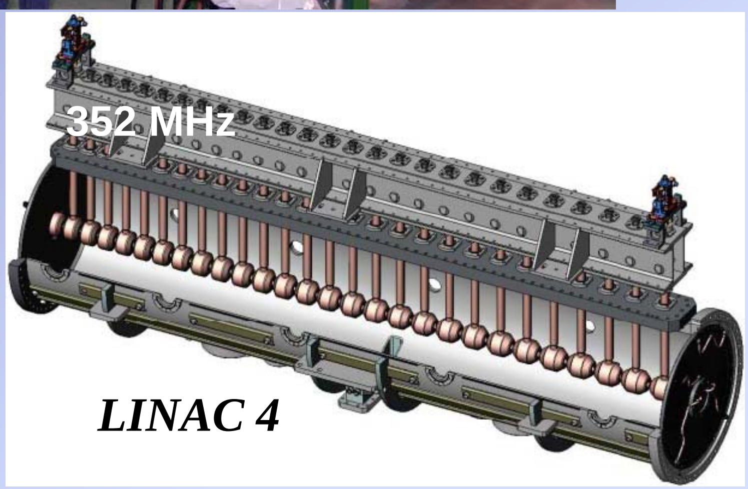
Intense activity on DTLs around the world in the last years !

SNS



PEFP (KAERI)

J-PARC



LINAC 4

BUT: Lower intensity, pulsed linacs !!

	SNS	J-PARC	IFMIF	
peak current (mA)	26	30 (50)	125	
duty cycle	6%	3.25%	CW	
Dissipated Power	4.8	3.4	40	first
(kW/m)	11.8	4.8	80	last

superconducting technology

2 other options, based on *s.c. technology* under investigation:

- **s.c. multi-gap CH-structures**
  proposed by IAP in Frankfurt

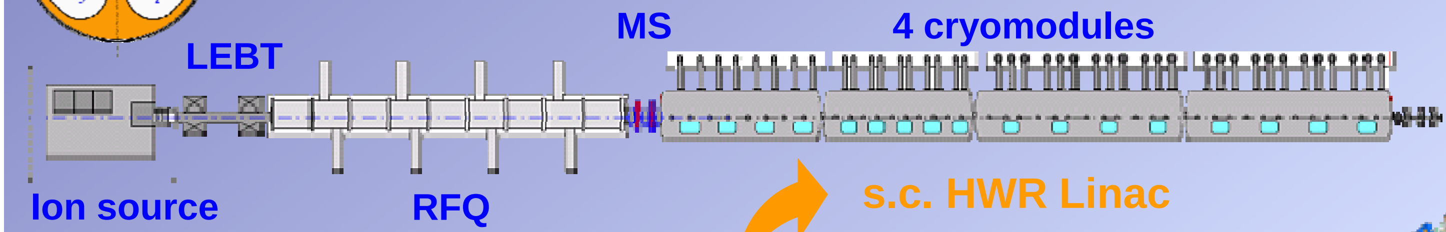
- **s.c. Half-Wave Resonators (HWR)**
  proposed by CEA-Saclay and CIEMAT

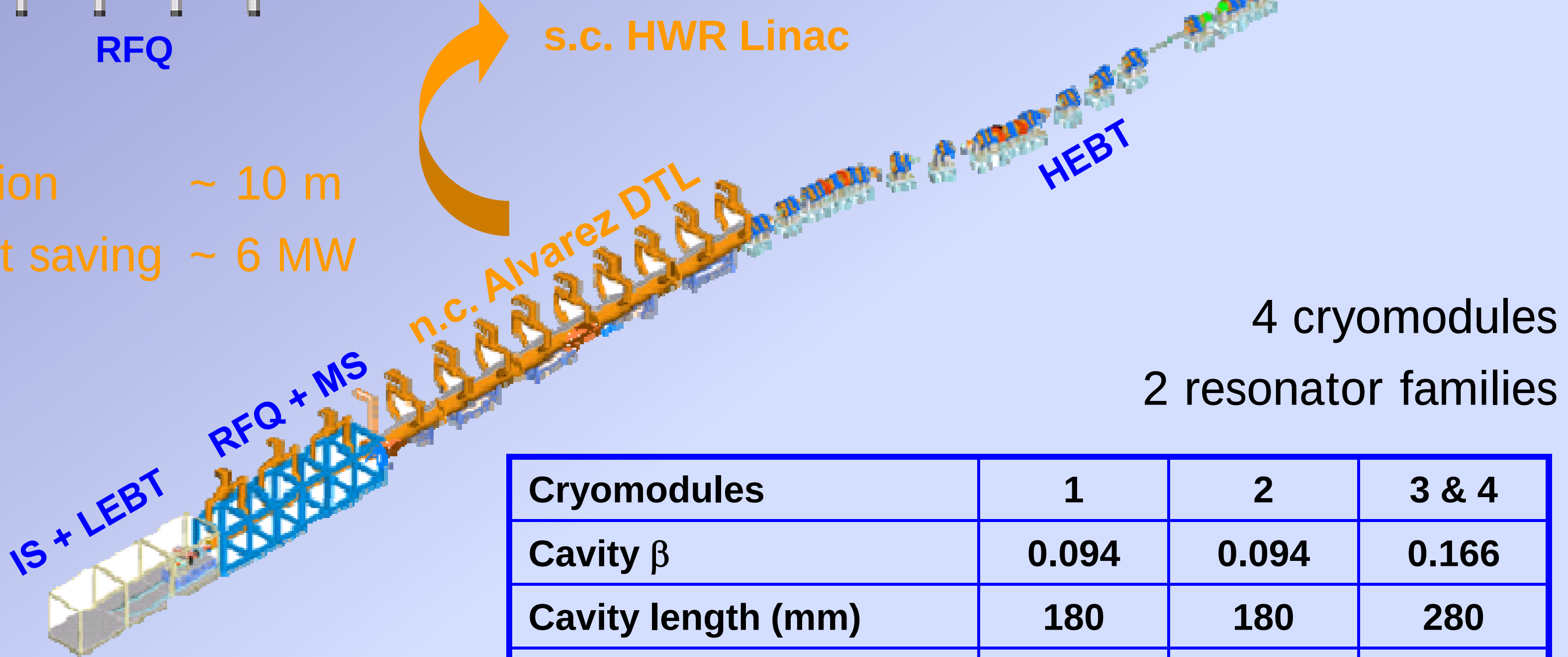
Since they offer some advantages

- **RF power reduction, leading to 6 MW plug power saving**
- **higher flexibility and reliability**
- **mature technology, better suited to existing teams & industries**
- **less sensitive to machining & assembly errors**

The proposal, based on Half Wave Resonators (HWR)
and close to existing & widely used technology was finally selected
ATLAS, ALPI, ISAC-II, SARAF, SPIRAL2, …

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





length reduction ~ 10 m

operation cost saving ~ 6 MW

4 cryomodules

2 resonator families

Cryomodules	1	2	3 & 4
Cavity β	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

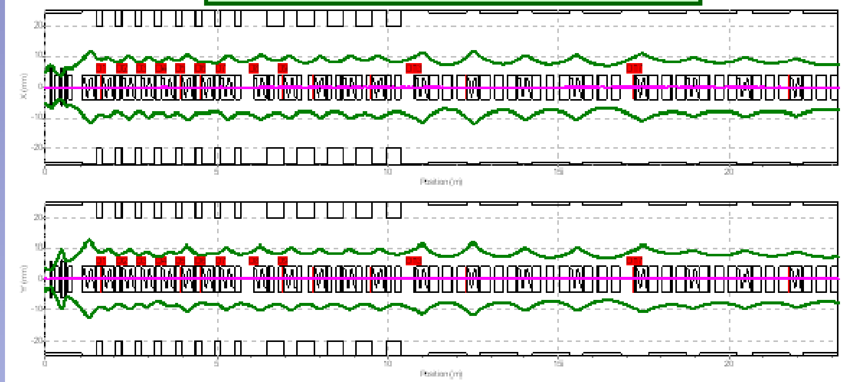
conservative approach

Moderate gradient @ 4.5 MV/m

Large aperture @ 40-50 mm

Beam dynamics (HWR)

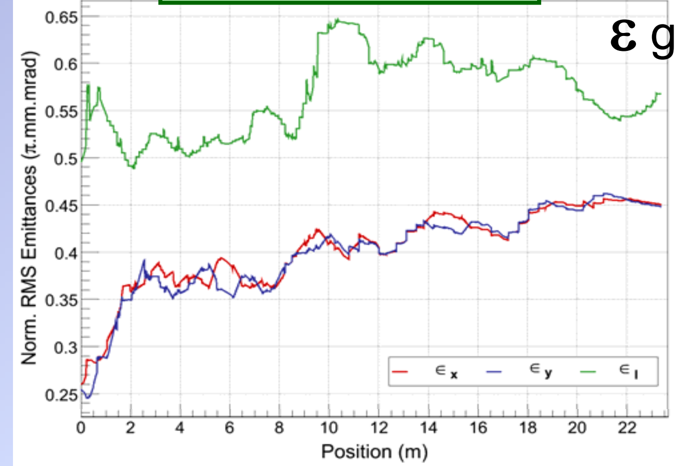
Beam Envelope - 3 RMS



Resonator	
Misalignment [x,y]	1.0 mm
Field amplitude	1 %
Field phase	1 deg
Solenoid	
Misalignment [x,y]	1.0 mm
Magnet tilt	10 mrad
Field amplitude	1 %

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

Emittance Growth

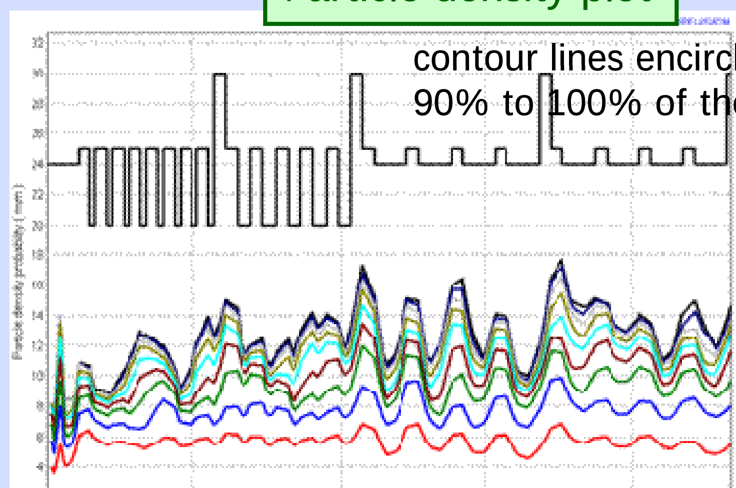


ε growth

14 %

70 %

Particle density plot

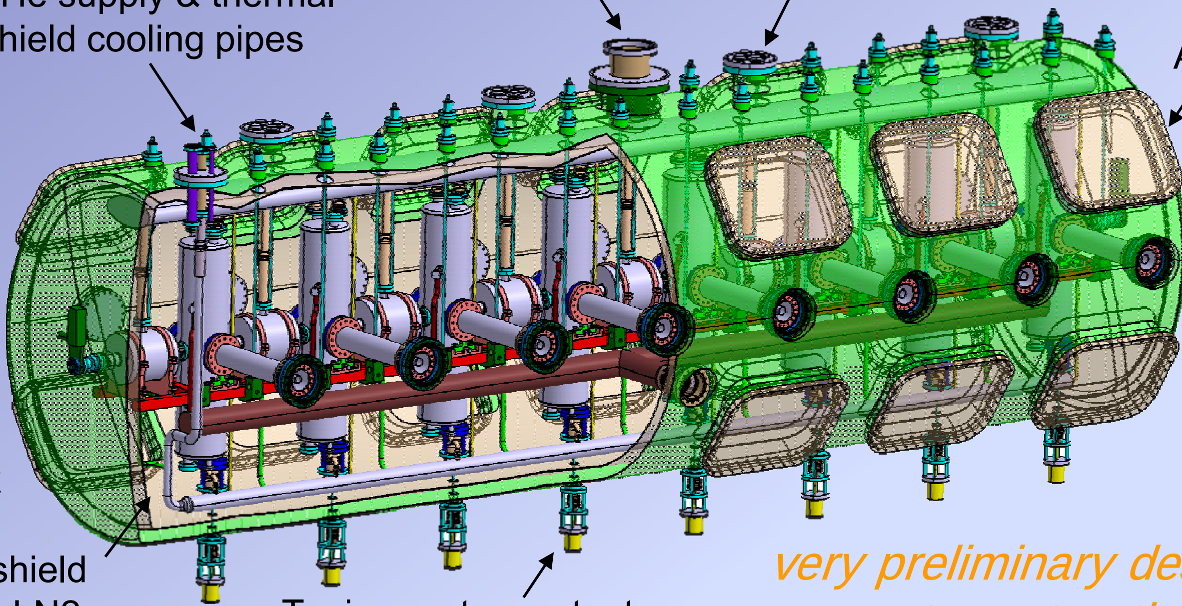


contour lines encircling 90% to 100% of the beam

statistical studies

10^6 particles 200 machines

A possible cryostat (to be optimized)



P. Bosland

very preliminary designs
geometry not optimized !!!

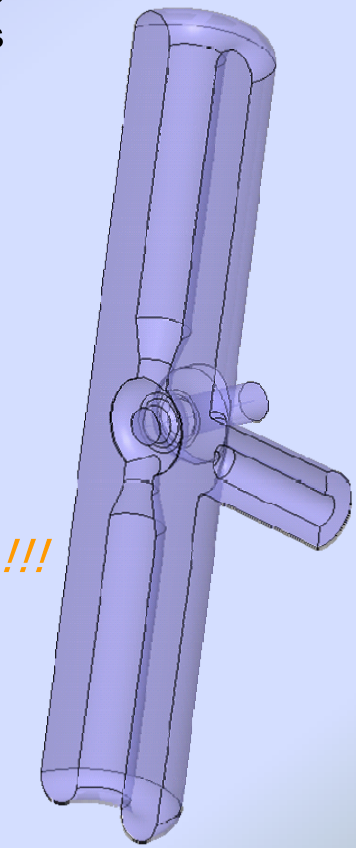
Peak Surface Fields:

much lower than (40 MV/m & 80 mT)

achieved by using well-tried methods developed in the last ten years

high-pressure rinsing, high-purity Nb, clean conditions

Frequency	175 MHz
Optimal beta	0.945
Beam tube Φ	40 mm
Epk *	27.5 MV/m
Bpk *	50 mT
P dis *	4 W
Q_0 for Rs = 20 nΩ	1.4 10^9



G. Devanz

@ 4.5 MV/m

RF Power Systems

responsible Lab: CIEMAT

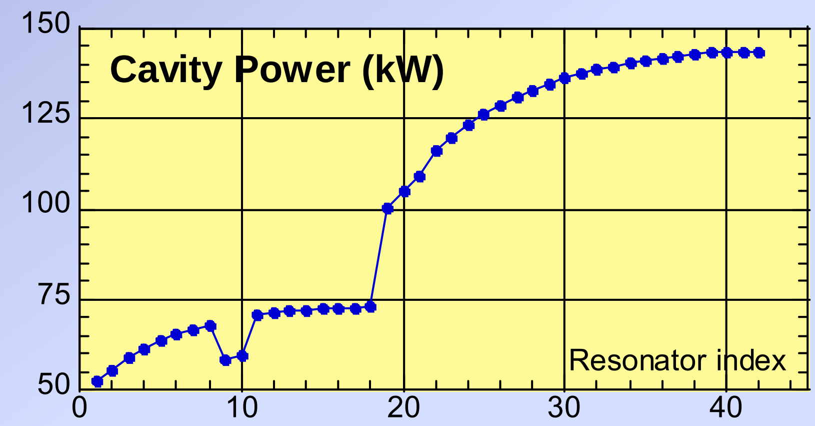
CIEMAT/CEA/SCK•CEN collaboration

RF power needs

RF power to transfer to the beam for each cavity

< 80 kW for 1st module

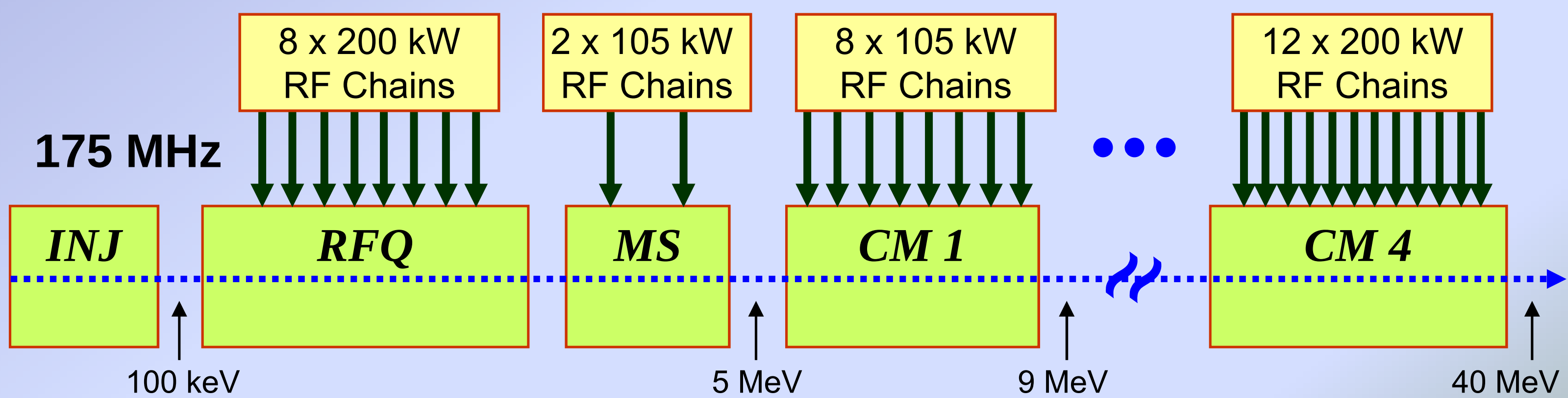
< 150 kW for last module



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)

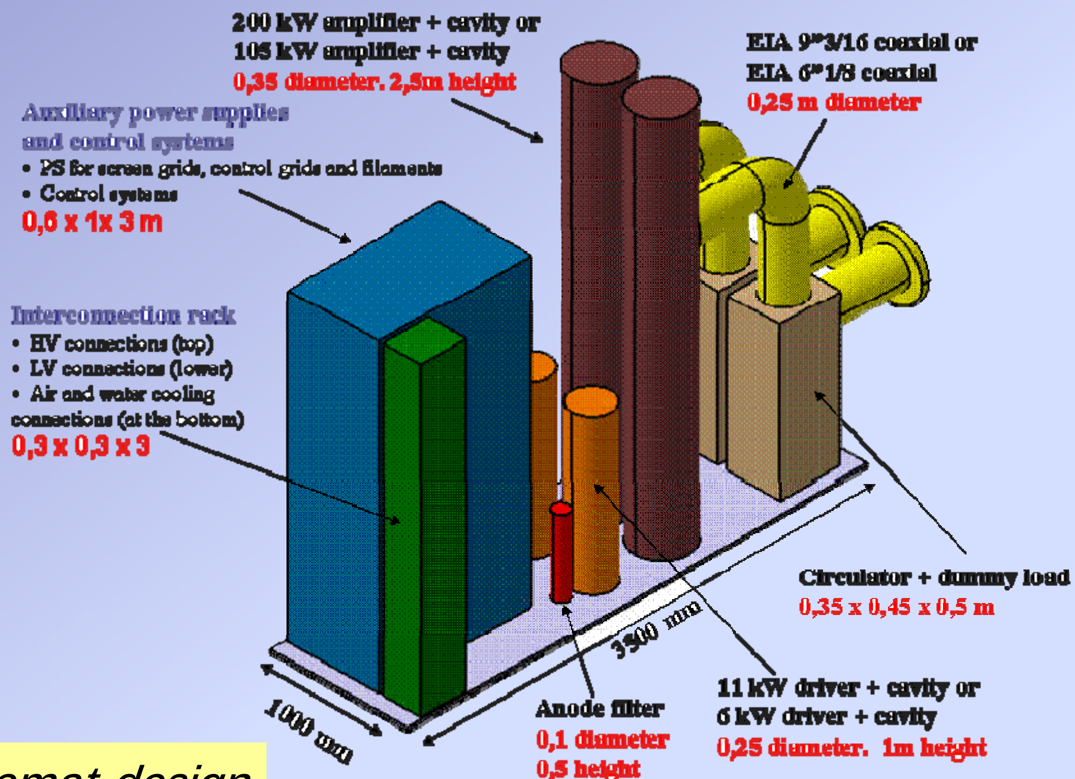


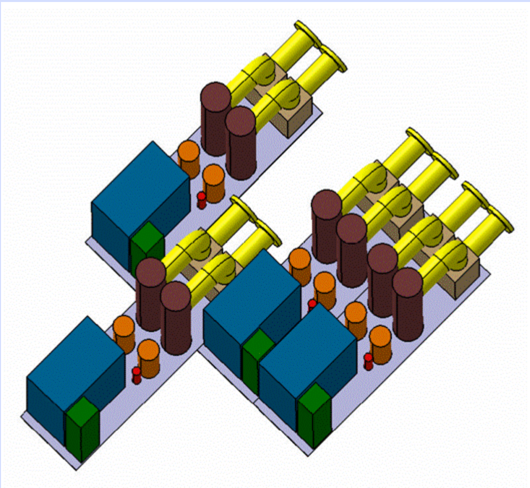
RF System implementation

To optimize space, and improve maintenance and availability

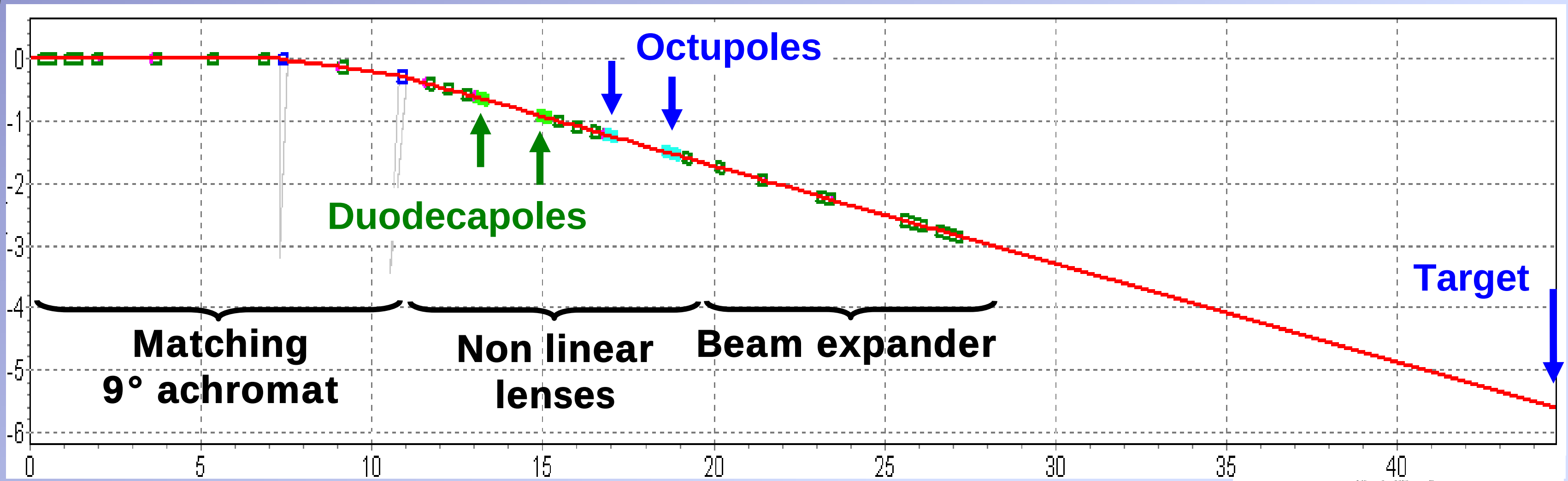
⇒ symmetric modular system composed of removable modules including two complete amplifiers each

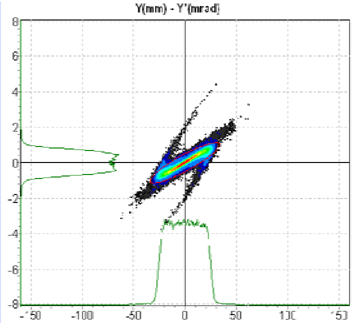
⇒ could allow fast repair in case of failure

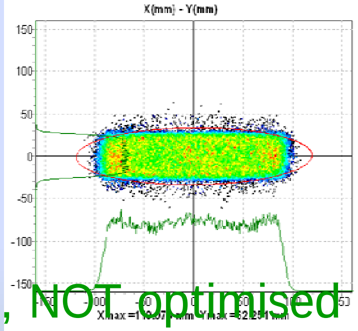




Ciemat design







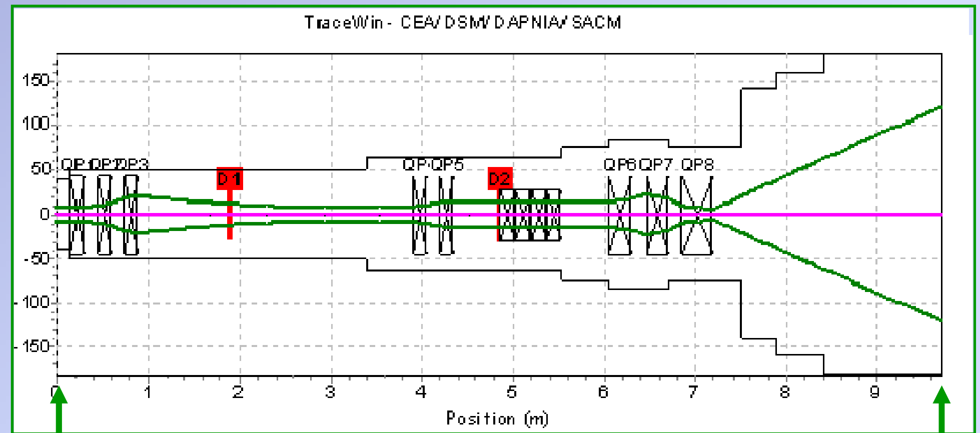
- To transport the 5 MW beam to the Li target
- To tailor the beam distribution coming from the Linac to a rectangular beam (20cm x 5cm) uniform distribution

- 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

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



Linac exit BD entry

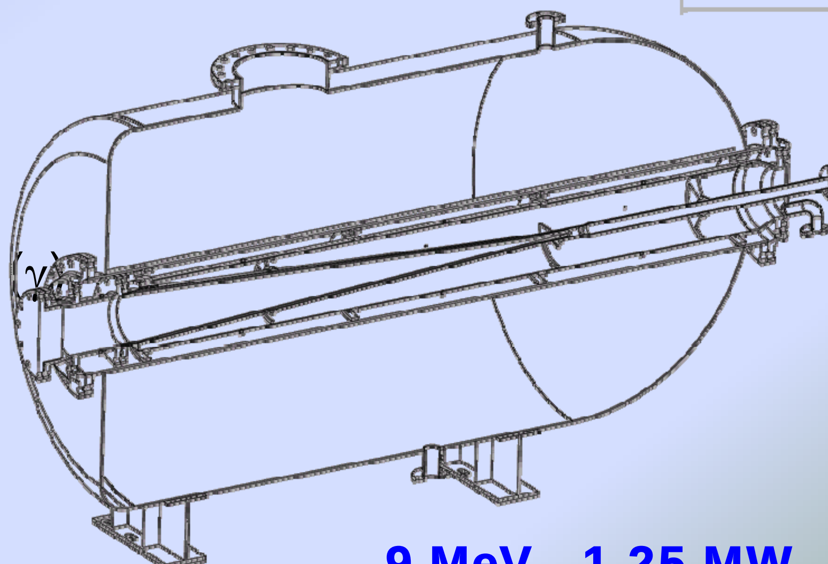
Beam Dump conical shape

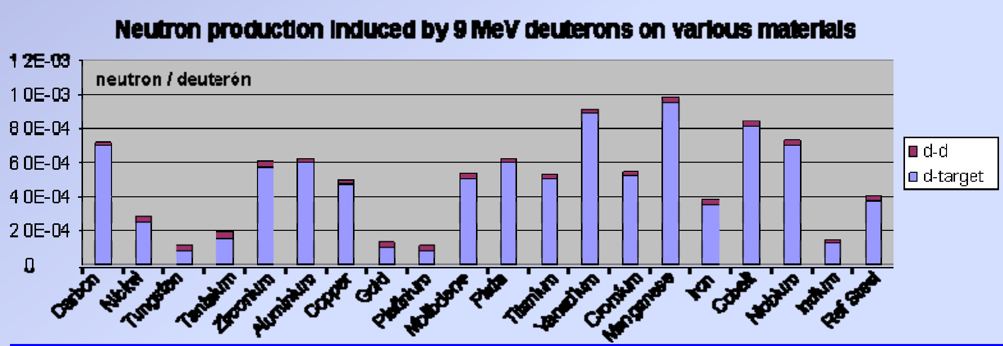
neutron production & activation analysis

thermo-mechanical analysis

⇒ beam facing material : copper
minimum stresses

shielding: water tank (neutron) & concrete (γ)





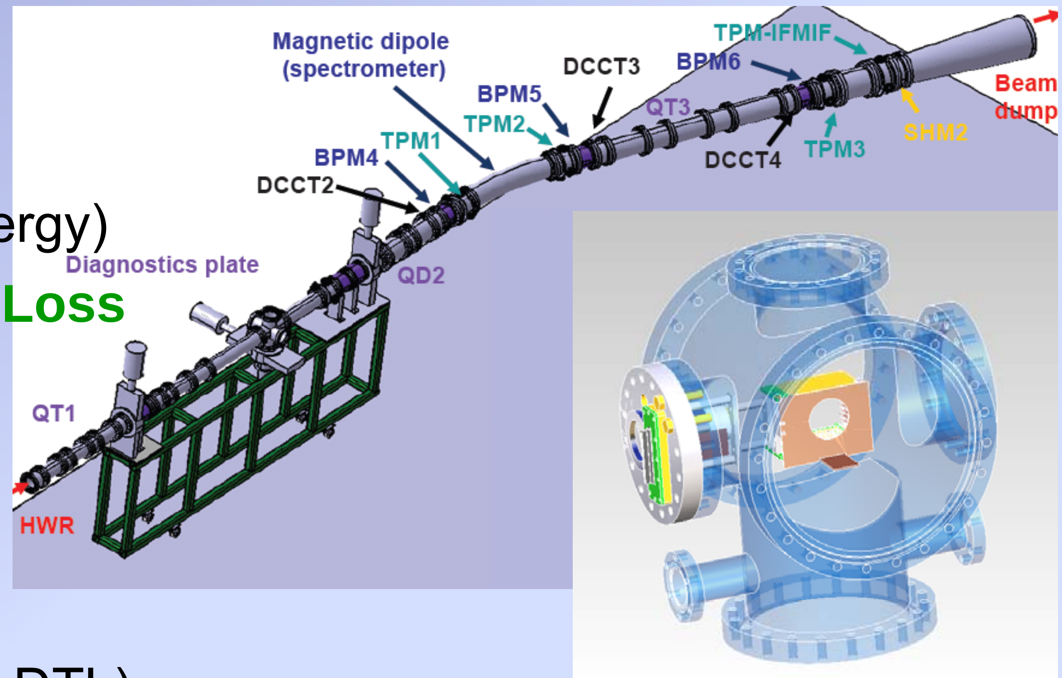
9 MeV - 1.25 MW

Beam Instrumentation

Objectives

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

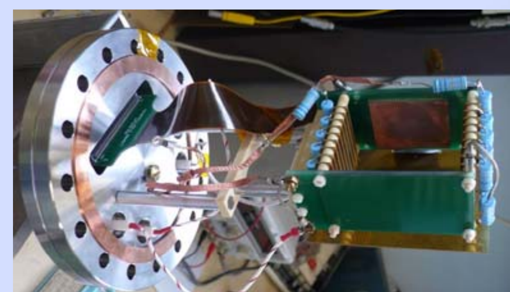
Current, Position, Profile, Beam Loss
+ Halo, bunchlength monitors



Diagnostics Plate

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

Detector : microstrips, grid resistors for uniform electric field

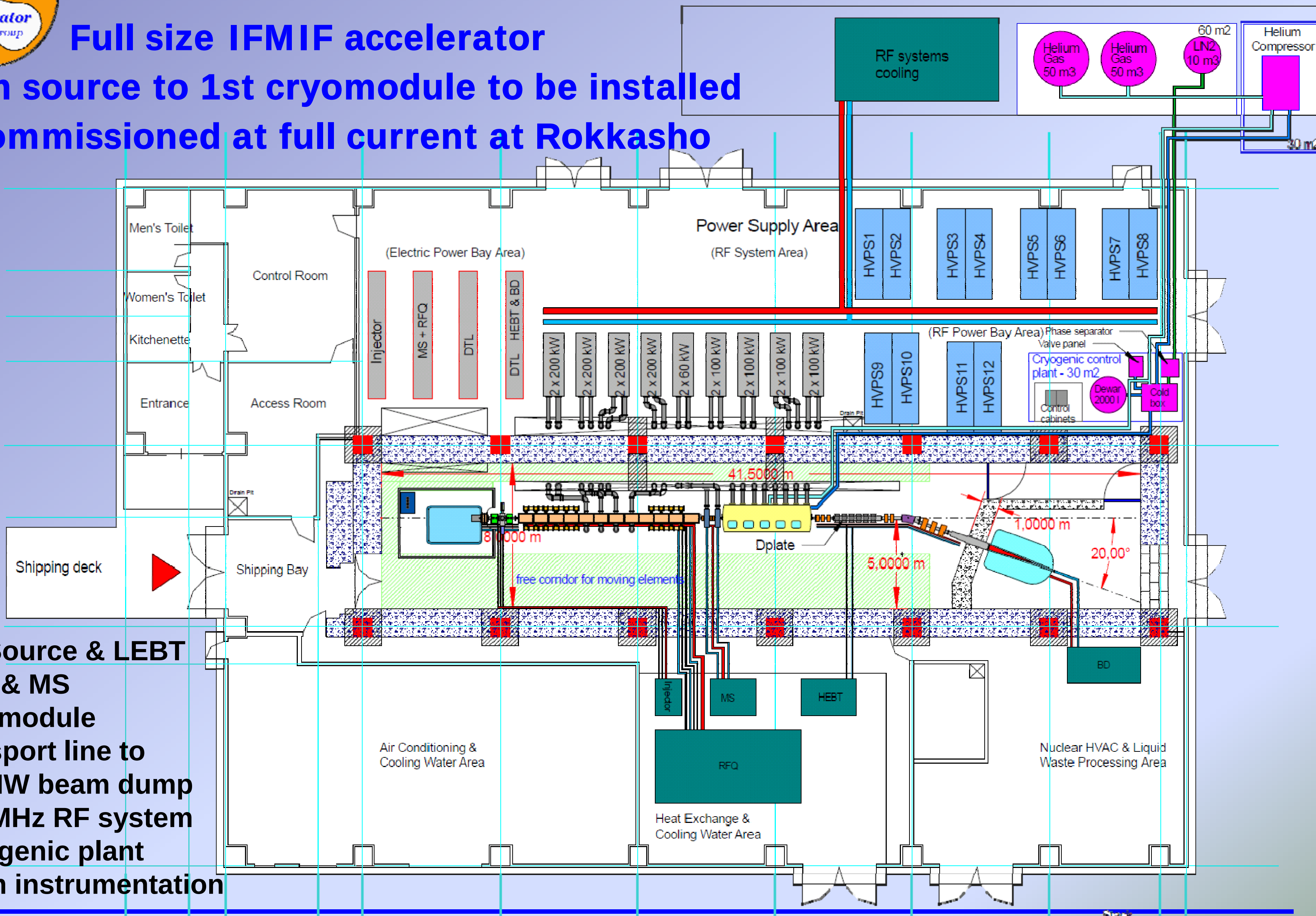


Beam Transverse Profilers

2 types are developed (ionization & fluorescence)
R&D started

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
- 1.2 MW beam dump
- 175 MHz RF system
- Cryogenic plant
- beam instrumentation