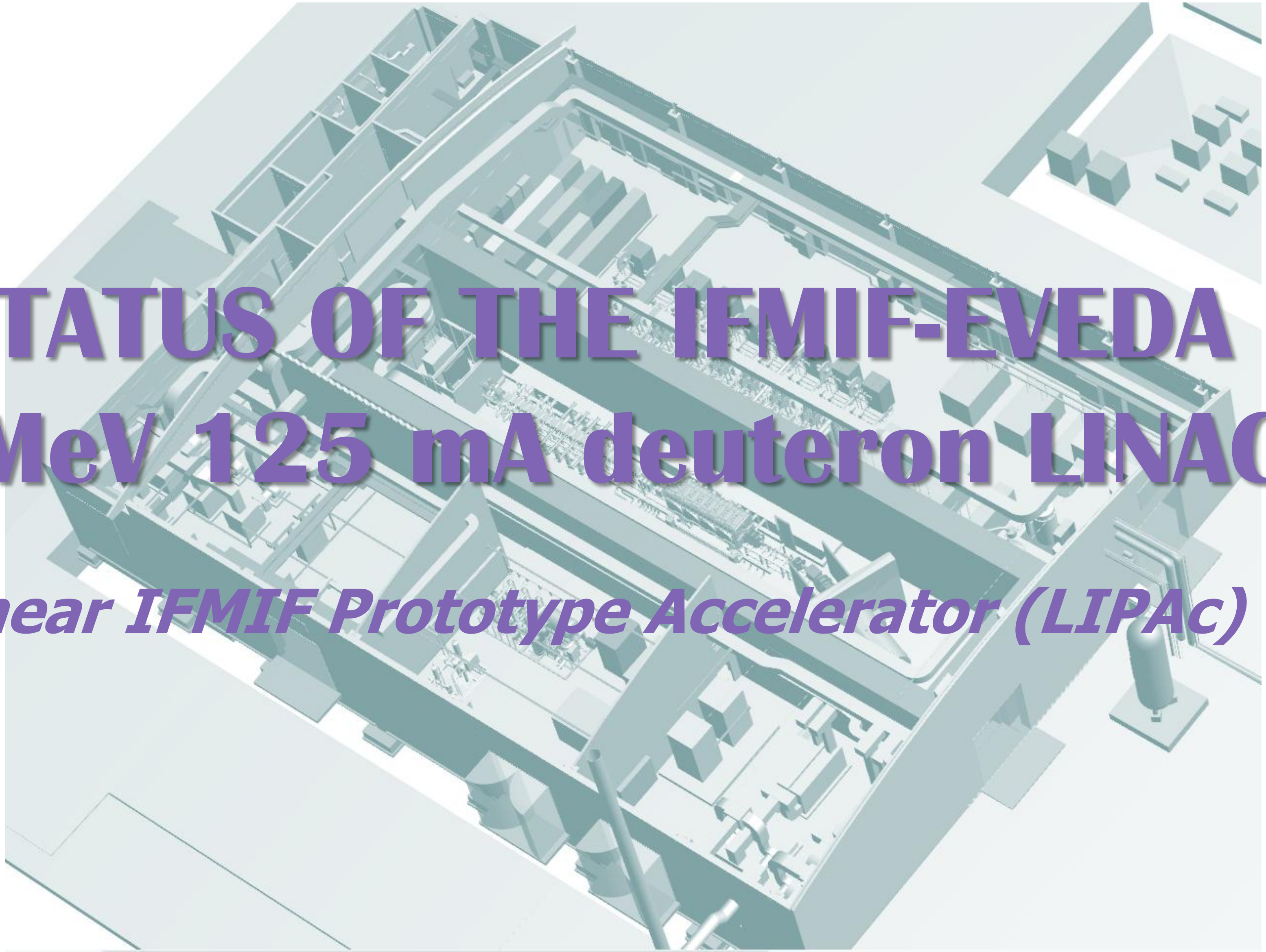


STATUS OF THE IFMIF-EVEDA 9 MeV 125 mA deuteron LINAC

Linear IFMIF Prototype Accelerator (LIPAc)

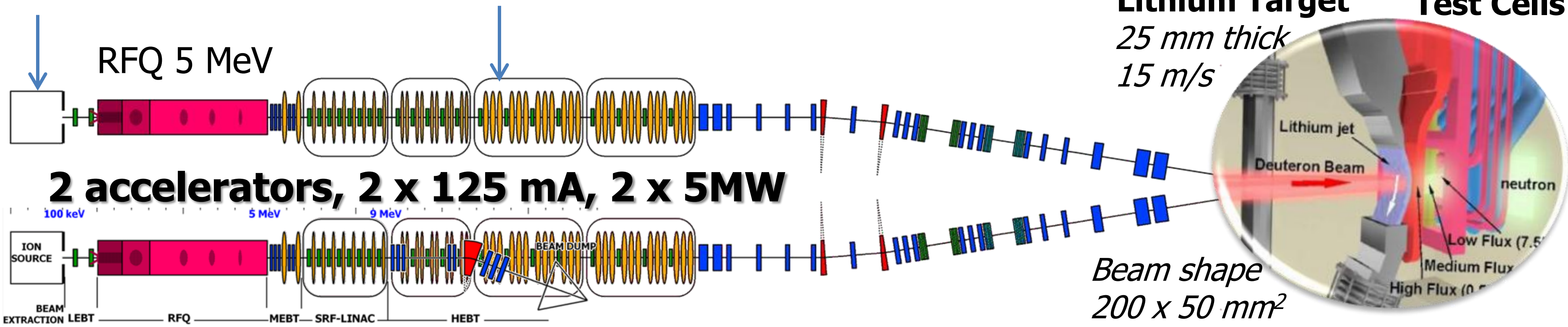
IFMIF objectives

- aims at generating materials irradiation test data for DEMO and future fusion power plants
- based on an accelerator-driven, D-Li neutron source to produce high energy neutrons at sufficient intensity and irradiation volume

High	>20 dpa/an	0.5 L
Medium	> 1 dpa/an	6 L
Low	< 1 dpa/an	8 L

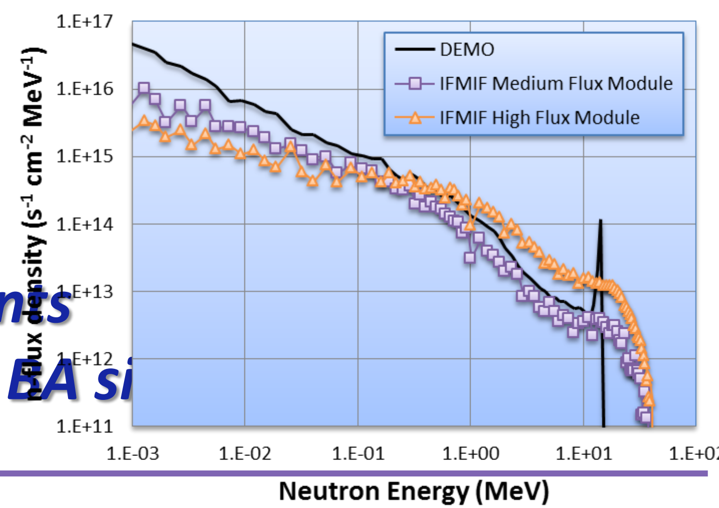
Deuteron source
140 mA, 100 keV

SRF Linac 40 MeV
(Half Wave Resonators)



Total neutron flux ~ 10^{18} n/m²/s
with a broad energy peak near 14 MeV

LIPAc = prototype for IFMIF
includes all critical accelerator components
to be tested at nominal beam current at EA si



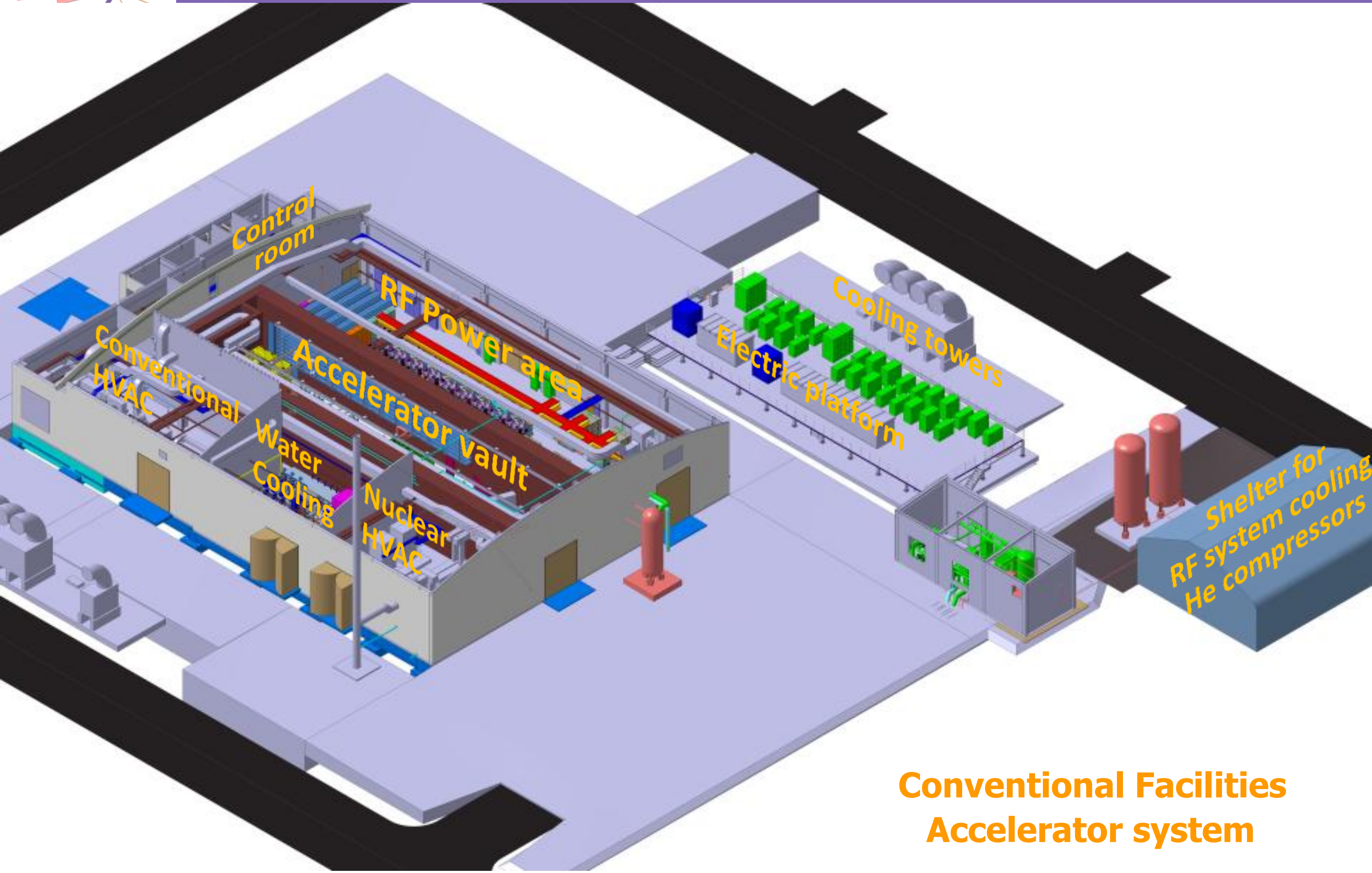
LIPAc objectives and main tasks

- **Objectives**
  - Validate the IFMIF accelerators
    (up to 1st accel module = the most critical portion)
  - Qualify all associated technologies
  - Characterize the beam by means of specific diagnostics
- **Main Tasks**
  - Design and manufacturing of all components
  - Integration of the whole Linac within the building and auxiliaries
  - Commissioning in pulsed mode (H+, D+)
  - Ultimate goal: Operation in CW of a 125 mA D^+ beam at 9 MeV

Engineering validation activities sharing

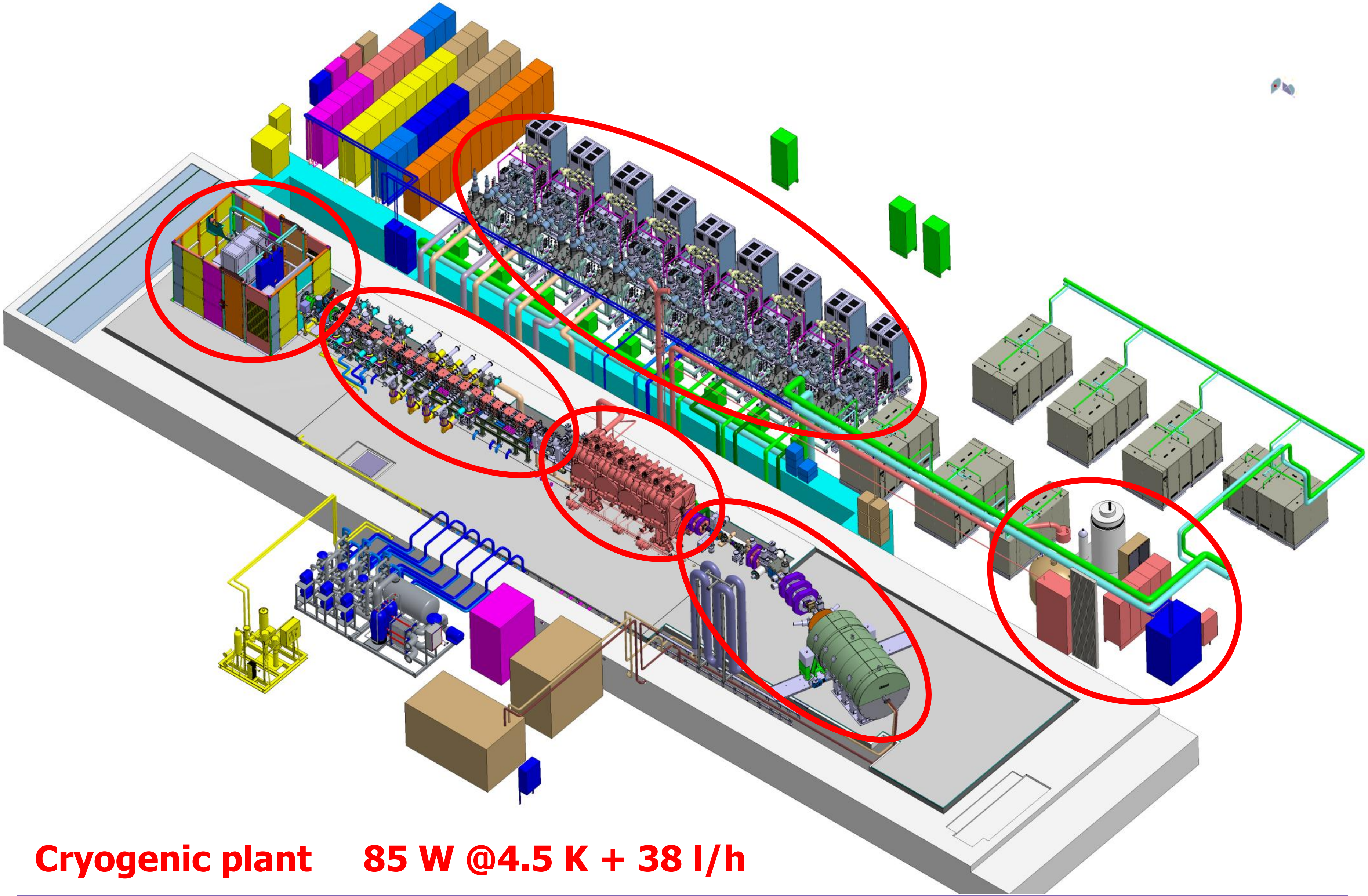
The engineering validation activities conducted since mid-2007 under the framework of the Broader Approach Agreement and shared as follows:

- Accelerator components designed, manufactured and tested by European institutions (CEA, CIEMAT, INFN, SCK-CEN)
  - Injector (CEA)
  - Radio Frequency Quadrupole (INFN)
  - Medium-High Energy Beam Transport lines & Beam Dump (CIEMAT)
  - Superconducting RF Linac (CEA + CIEMAT)
  - 175 MHz RF Systems (CIEMAT)
  - Beam Instrumentation (CEA + CIEMAT)
- Conventional facilities (building and auxiliaries), Central Control System, RFQ couplers provided by Japan (JAEA)
- Design integration & interface management coordinated by F4E
- Coordination & integration on site by the Project Team hosted in Rokkasho



Conventional Facilities
Accelerator system

accelerator components mockup



Cryogenic plant 85 W @4.5 K + 38 l/h

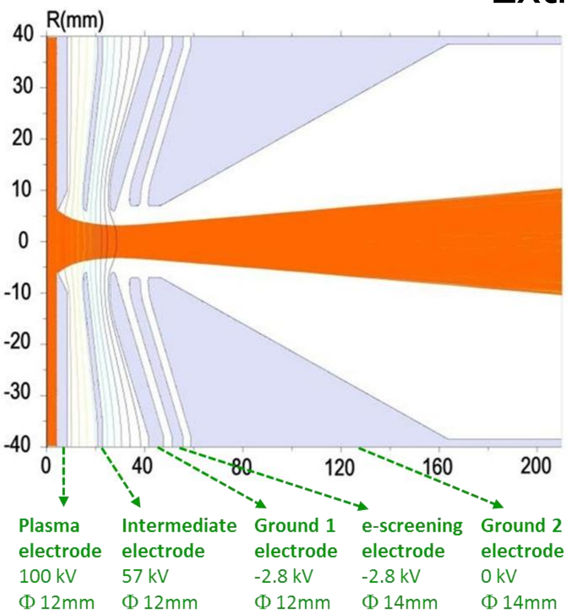
Injector (Ion source, LEBT) beam dynamics

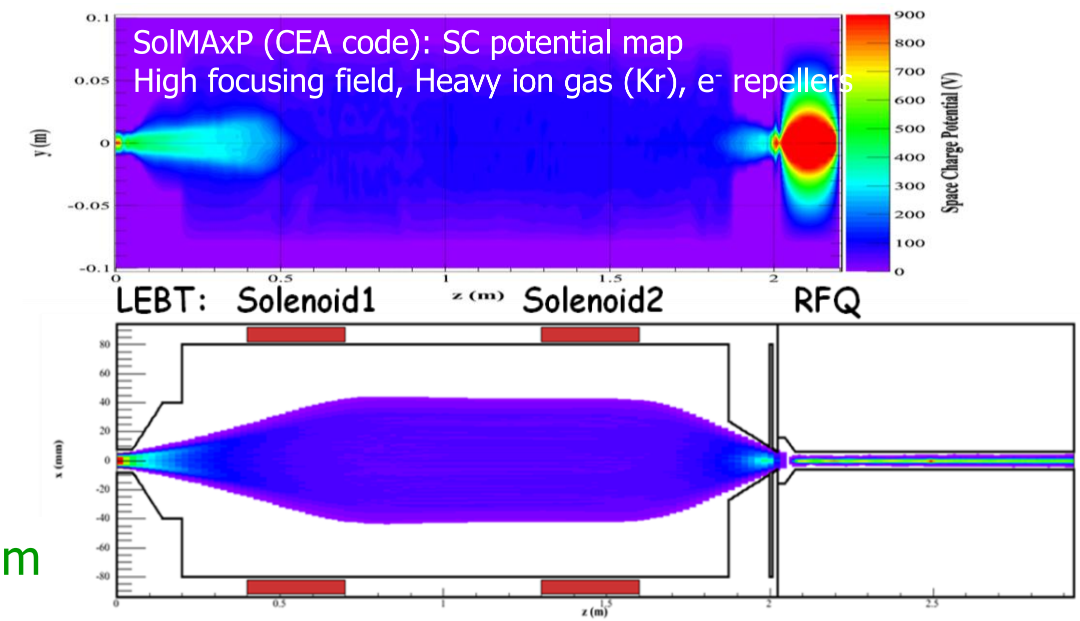
R. Gobin's talk on Friday **CEA**

ECR ion source

Extraction: 175 mA total (140 mA D^+, 26 mA D_2^+, 9 mA D_3^+)

LEBT no beam loss, optimum injection into RFQ





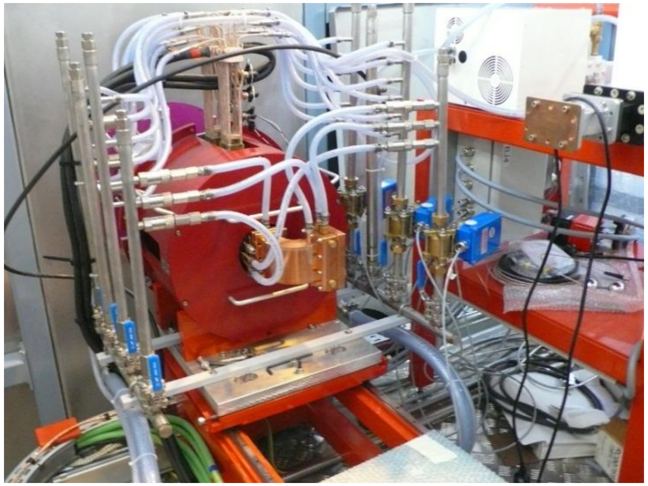
New 5-electrode extraction system after sparking issues at 100 kV

⇒ high level of space charge compensation all along the LEBT line to meet the requirements: emittance (0.25 π mm mrad) + RFQ matching

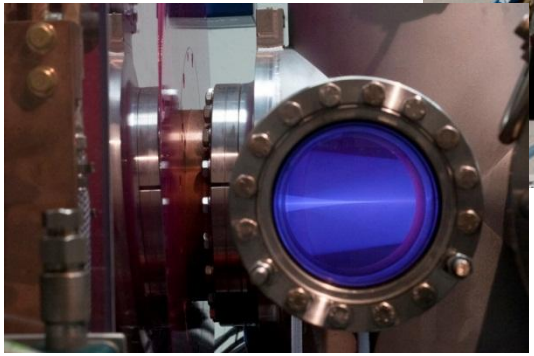
- injection of a specific gas in the line (krypton 4.10^{-5} hPa)
- HV electrode in front of the RFQ to trap the electrons (e-repeller)

Injector at CEA-Saclay

Equipped LEBT



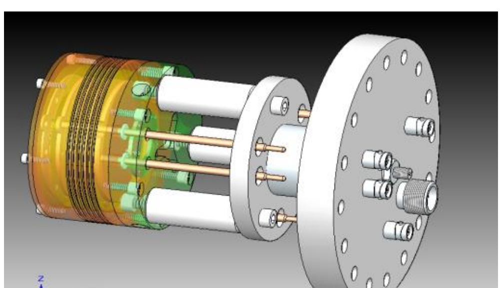
Ion source on HV platform



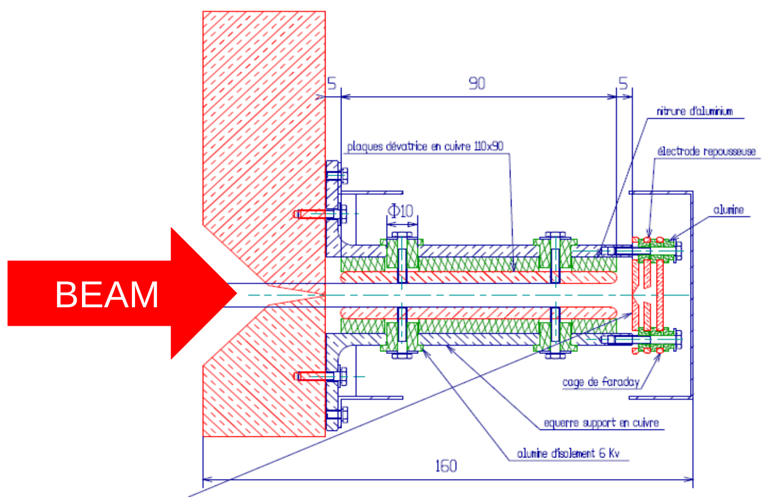
View-port after 1st solenoid

Injector diagnostics

- **Beam Intensity**: Large ACCT (Φ 178 mm) at the RFQ entrance with specific magnetic shielding
- **Beam Profile** and species fraction (Doppler shift method): use of rad-hard CID cameras and CCD camera outside the vault with fiberscope
- **Emittance**: Allison scanner to sustain 17 kW beam power
- **Space charge compensation**: 4 Grid Analyzer to measure the energy of secondary ions or electrons repelled out of the beam



FGA design for IFMIF injector



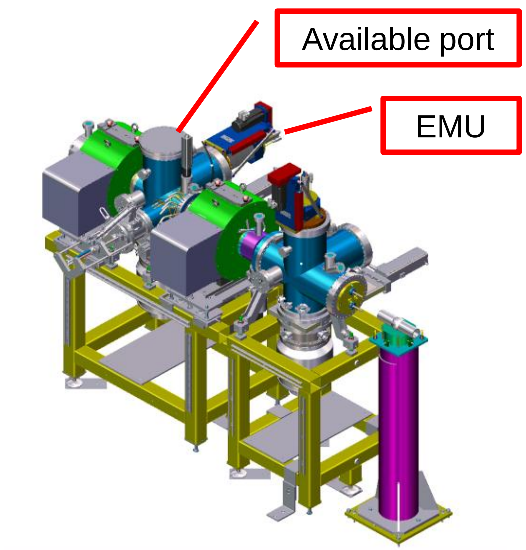
Chopper addition

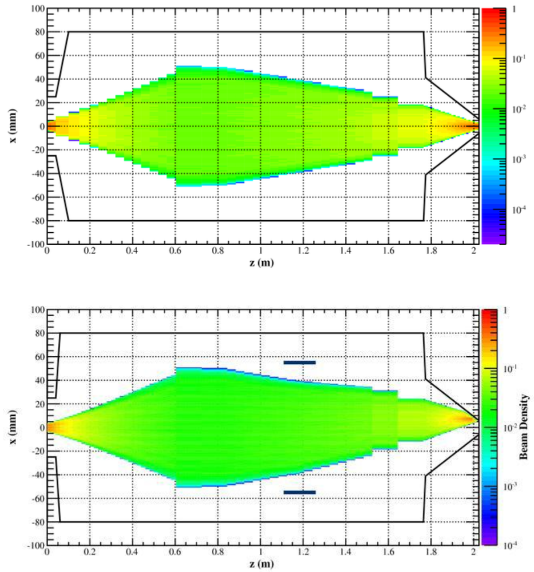
Need of pulsed mode with sharp rise/fall times
(to limit transient current which would be lost downstream)
with beam perfectly matched to the RFQ input conditions all along its duration

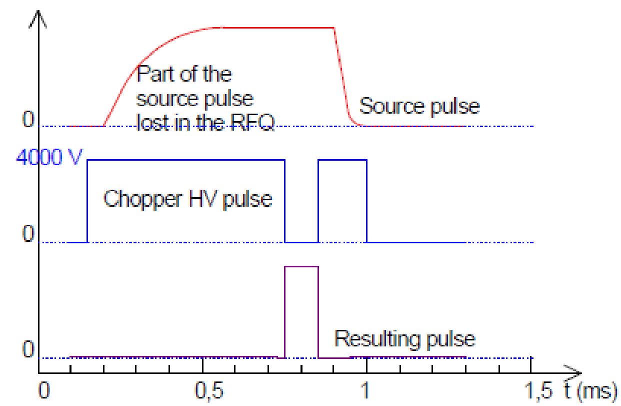
But **ECR ion source**: not able to produce such beam pulses
RF cutting technique in the RFQ: could jeopardize the RFQ operation

⇒ **electrostatic chopper** located in the Injector LEBT
(between the 2 solenoids)

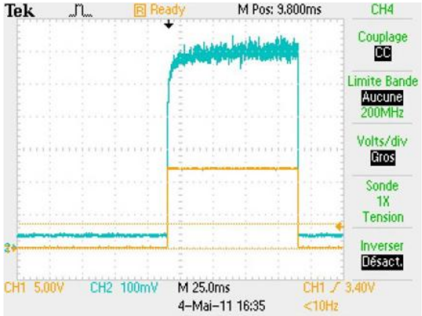
In addition, as a chopper is able to produce short pulses <100 μs
this option enables the use of interceptive diags







Injector beam tests



- First pulsed H+ beam in May 2011
  First test campaign: pulsed beams 150 mA ,100 kV
  or continuous beams 100 mA, 75 kV
- First pulsed D+ beam in May 2012 (125 mA, 100 kV, 1%)
- New 5-electrode extraction system installed in September
  Test campaign starts again at mid-September for completion of the optimization and emittance measurement:
  ion source plasma, krypton pressure, solenoid setting, …
- Electrostatic chopper in-between the two solenoids to enable the LIPAc operation with short pulses of sharp rise/fall times
  Tests of chopper (w/o beam) in September 2012
- Injector delivery at Rokkasho planned in March 2013

RFQ design

Main parameters selected

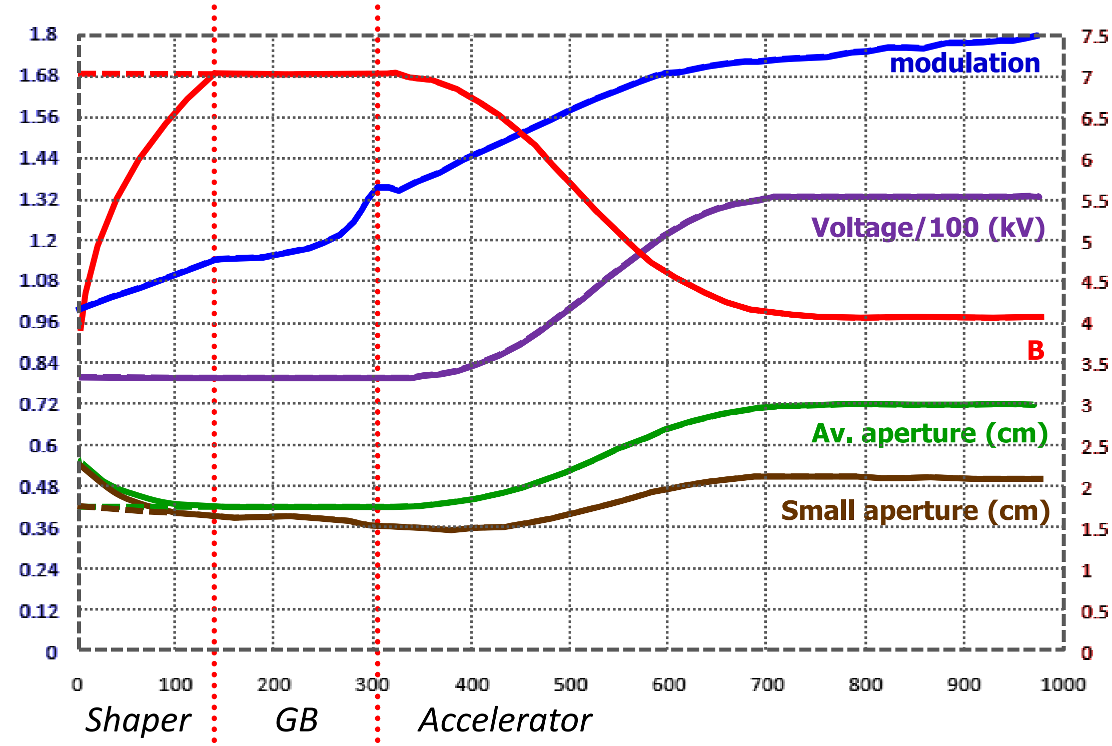
- ✓ Increasing voltage following an analytic law
- ✓ Strong focusing (B=7) to keep the tune depression > 0.4 for better control of space charge
- ✓ Min. beam loss & main resonances avoided in the accelerator section

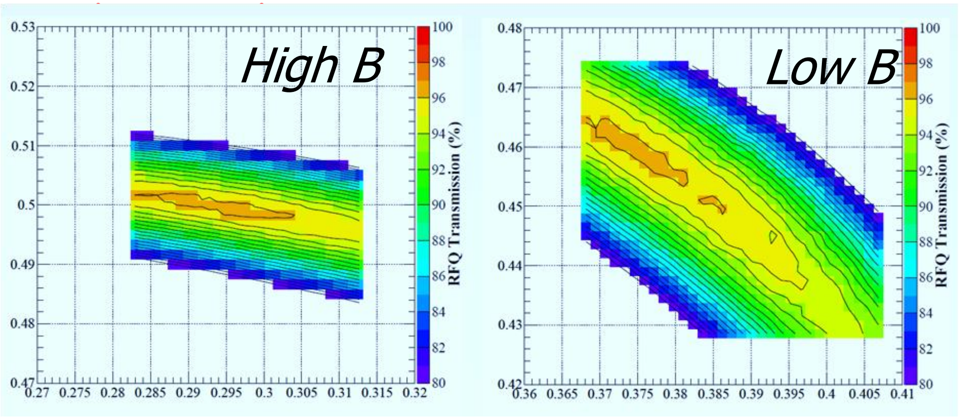
This design allowed to obtain a good transmission with good margin

- ✓ But a lower focusing parameter B at the RFQ entrance will further facilitate beam injection from the LEBT

A low-B RFQ studied and adopted

- ✓ Studies of the transmission of the couple LEBT+RFQ show a more comfortable tunable range





Sensitivity to mismatch: *scan of solenoid fields*

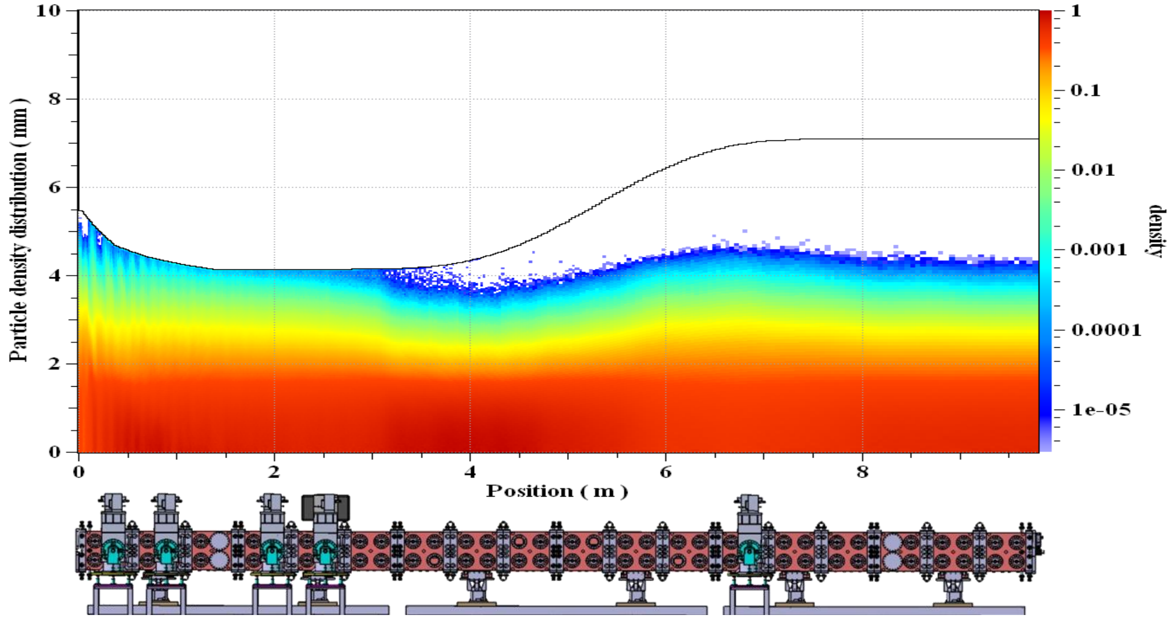
RFQ beam dynamics

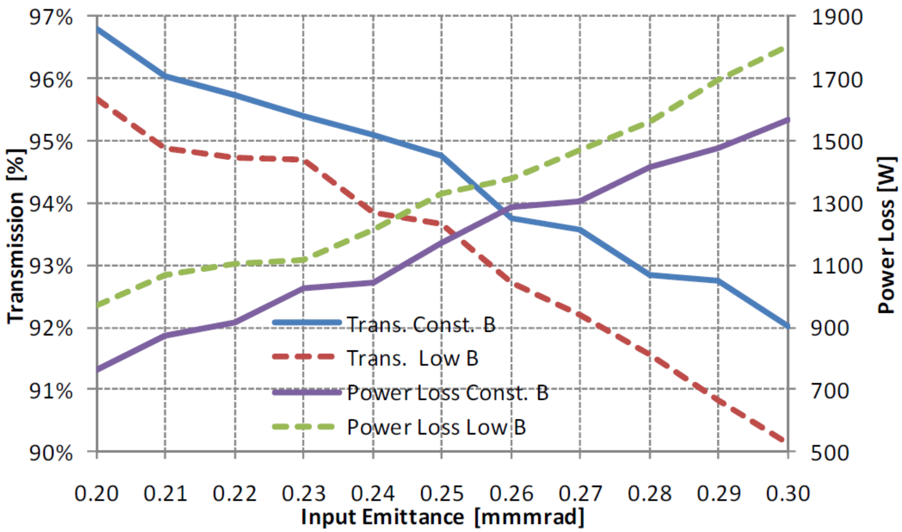
RFQ

96 % transmission (140 mA)

Losses mainly in the first part, at low energy

Input emittance < 0.2 π mm mrad



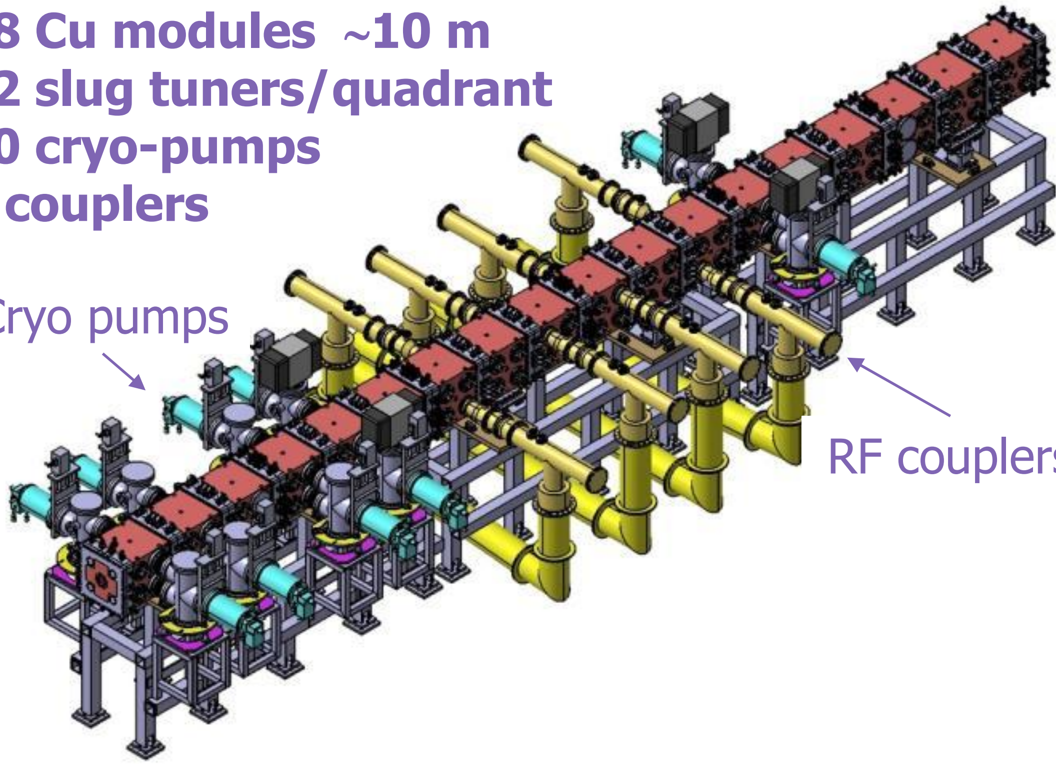


However, emittance at the LEBT exit must be kept low << 0.3 π mm mrad

RFQ technology

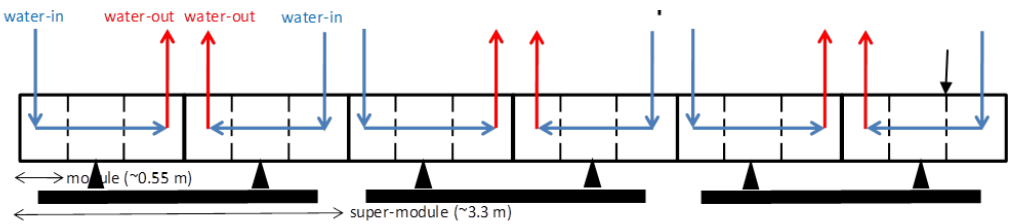
INFN

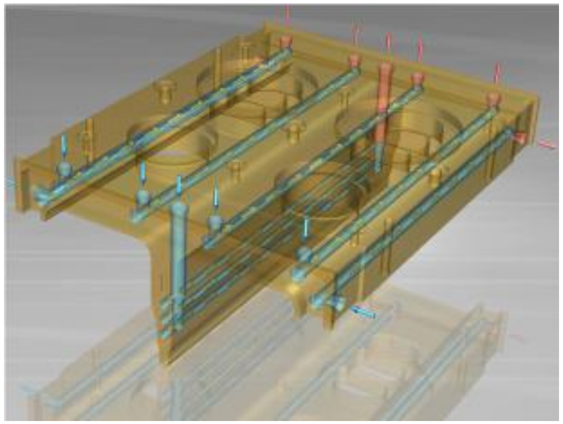
- **18 Cu modules ~10 m**
- **22 slug tuners/quadrant**
- **10 cryo-pumps**
- **8 couplers**



Cooling: ~ 600 kW RF power removed by means of 28 channels longitudinally drilled along the RFQ modules (water velocity ~3 m/s)

Cooling system (4 independent circuits) used for frequency tuning (± 100kHz) and field profile control

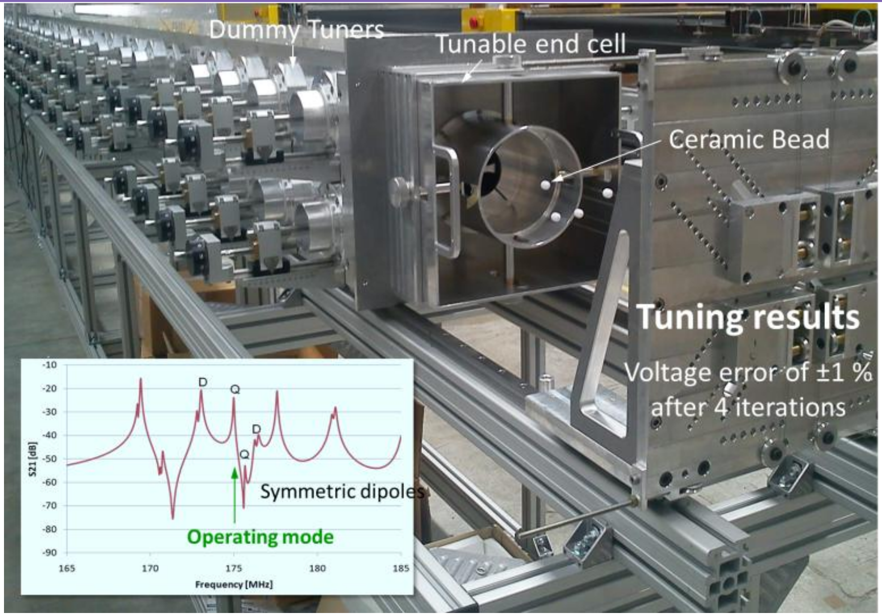


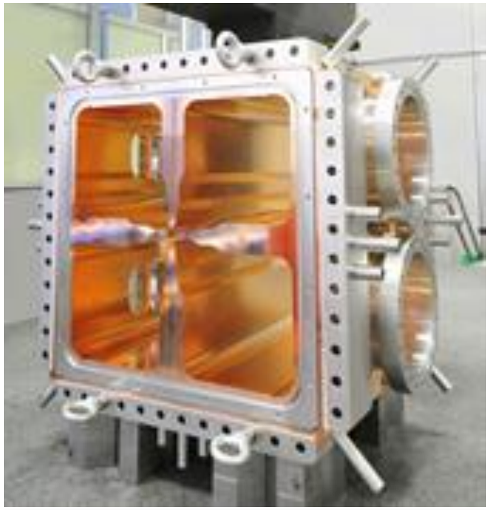


Cooling water channels

RFQ technology

Full scale Al mockup to validate tuning procedure & mode stabilization by means of beadpull measurements





technological prototype machined at INFN and local industries, brazed at CERN

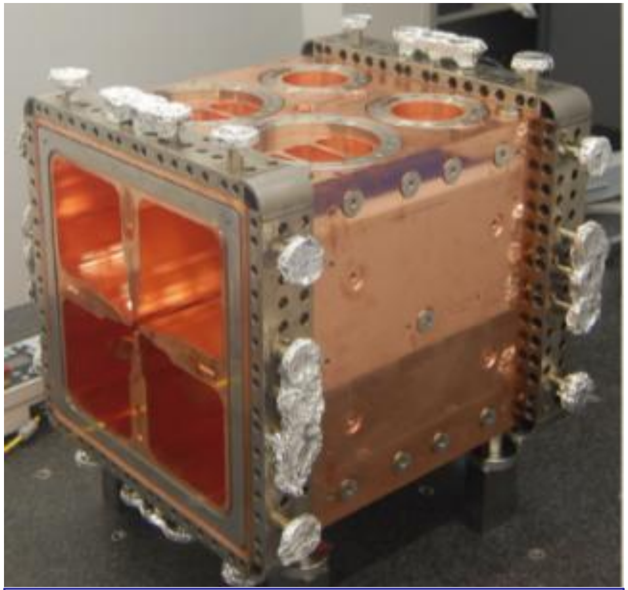
2 prototypes scale ½ brazed in 1 single step

Vacuum ports

Vanes

RFQ fabrication and tests

- **High Energy super module** (6 modules homogenous aperture)
  rough-machining by INFN (electric discharge machining)
  final machining and brazing by Indusry
- **Intermediate Energy super module** (6 modules z-dependent aperture)
  fully machined and brazed by INFN
- **Low Energy super module**
  same procedure as High Energy modules



module #16 (High Energy SM) machined & brazed

First module: 100 μm max deformation measured still acceptable but at the limit of the specification might be corrected for the next modules by using

- appropriate annealing cycle
- improved fixation tooling

3 modules (plus RF plug) completed in Nov 2012 for high power tests, planned at the beginning of 2013 at INFN-Legnaro.

RF coupler

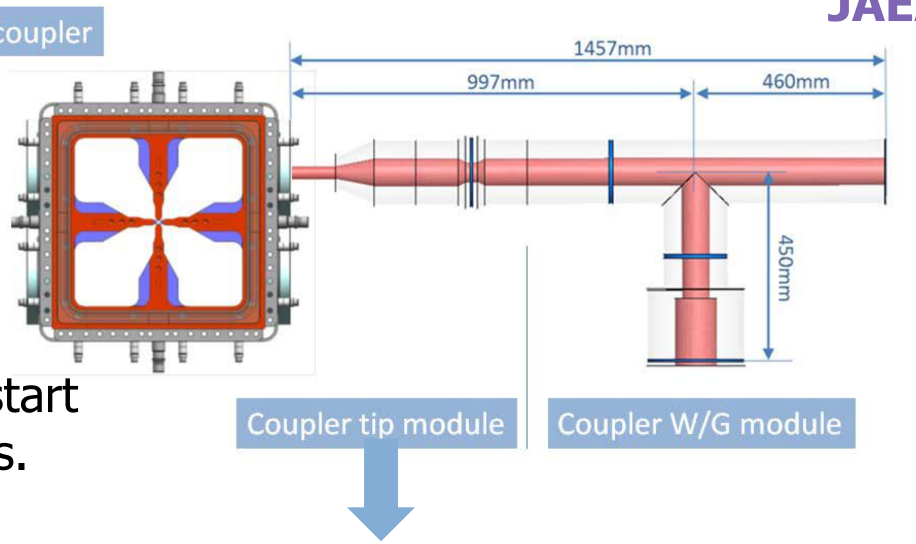
JAEA

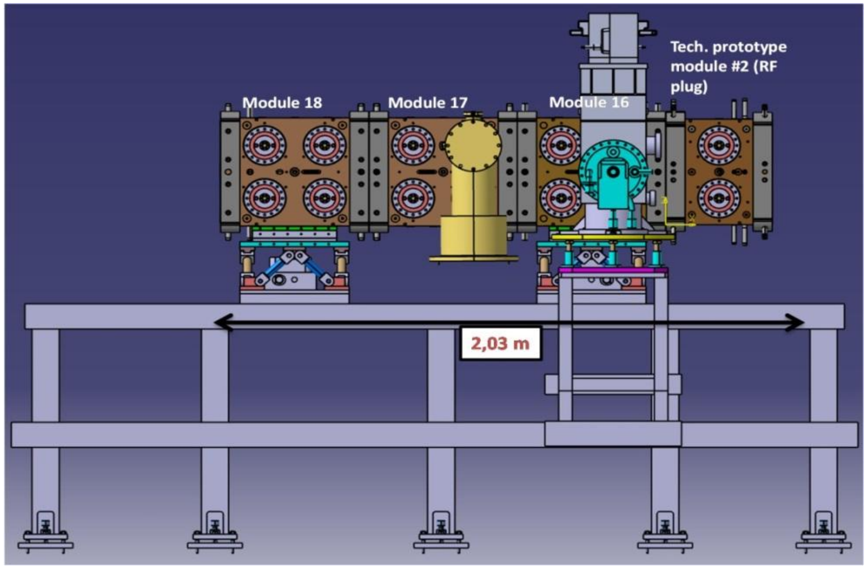
2 RF couplers manufactured delivered at INFN-Legnaro at beginning 2013 for power tests

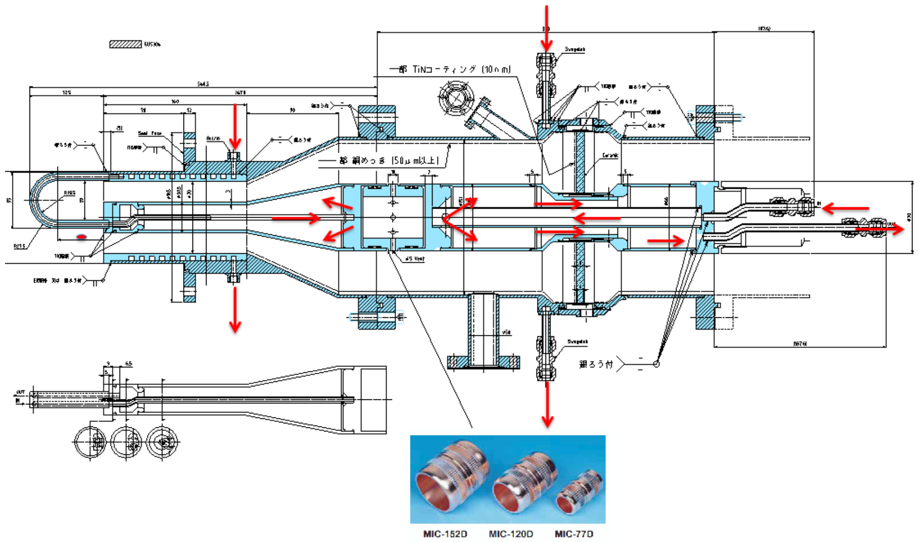
(1) couplers only

(2) Couplers + RFQ modules

manufacturing of the other couplers will start just after approval of the acceptance tests.





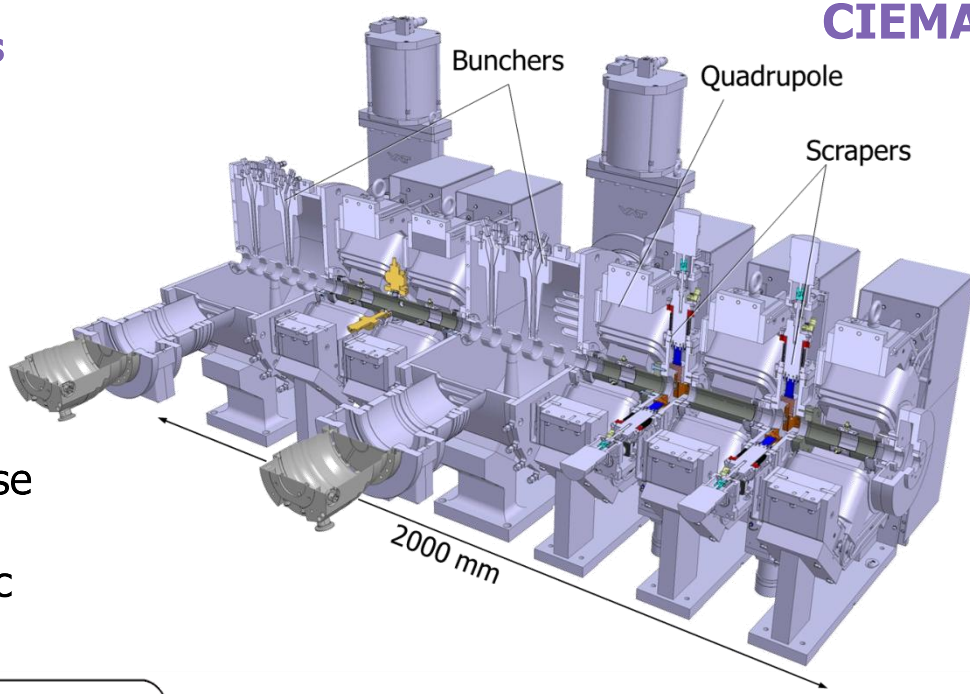


MEBT design & beam dynamics

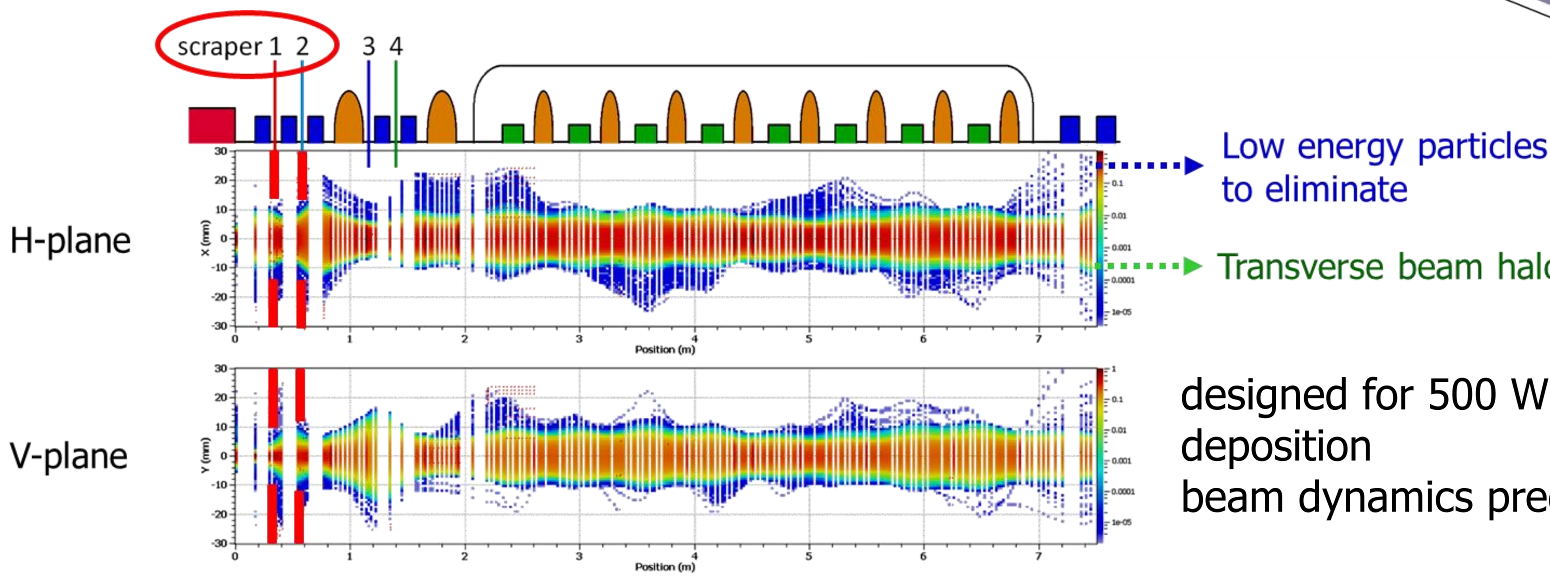
CIEMAT

very compact ~ 2 m, many components

- 5 quadrupoles & steering coils
- 2 bunchers, 2 movable scrapers
- BPMs (in the center of quads)
- turbomolecular pumps on bunchers (1300l/s /buncher)



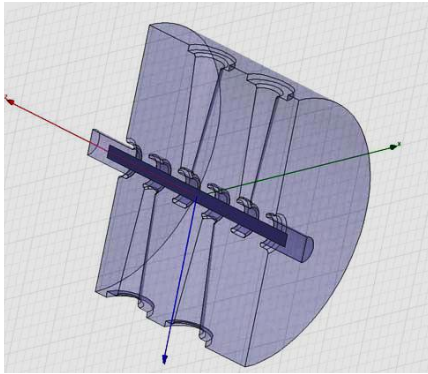
Scrapers: to clean the beam from transverse halo and off-momentum particles (non-accelerated in the RFQ) before the SRF Linac

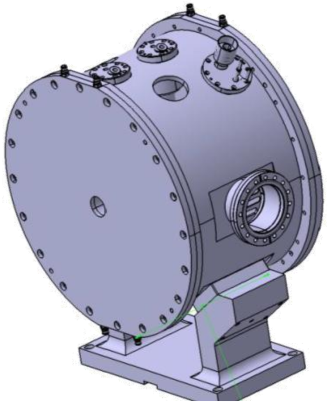


designed for 500 W beam power deposition
beam dynamics prediction < 10 W

Bunchers: 5-gap IH structure

- Voltage EoLT = 350 kV
- Cavity length < 350 mm
- CW & pulsed mode operation

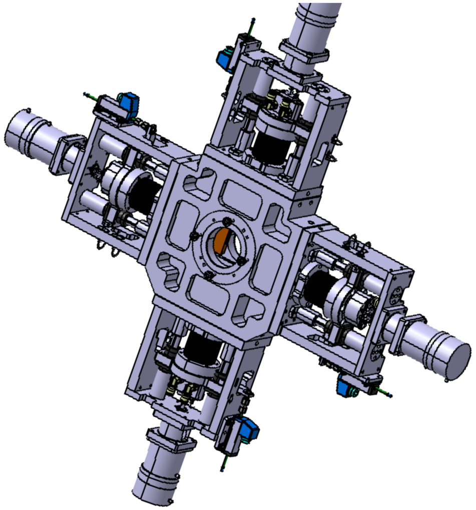




Buncher: prototype under fabrication, power tests planned at mid-2013

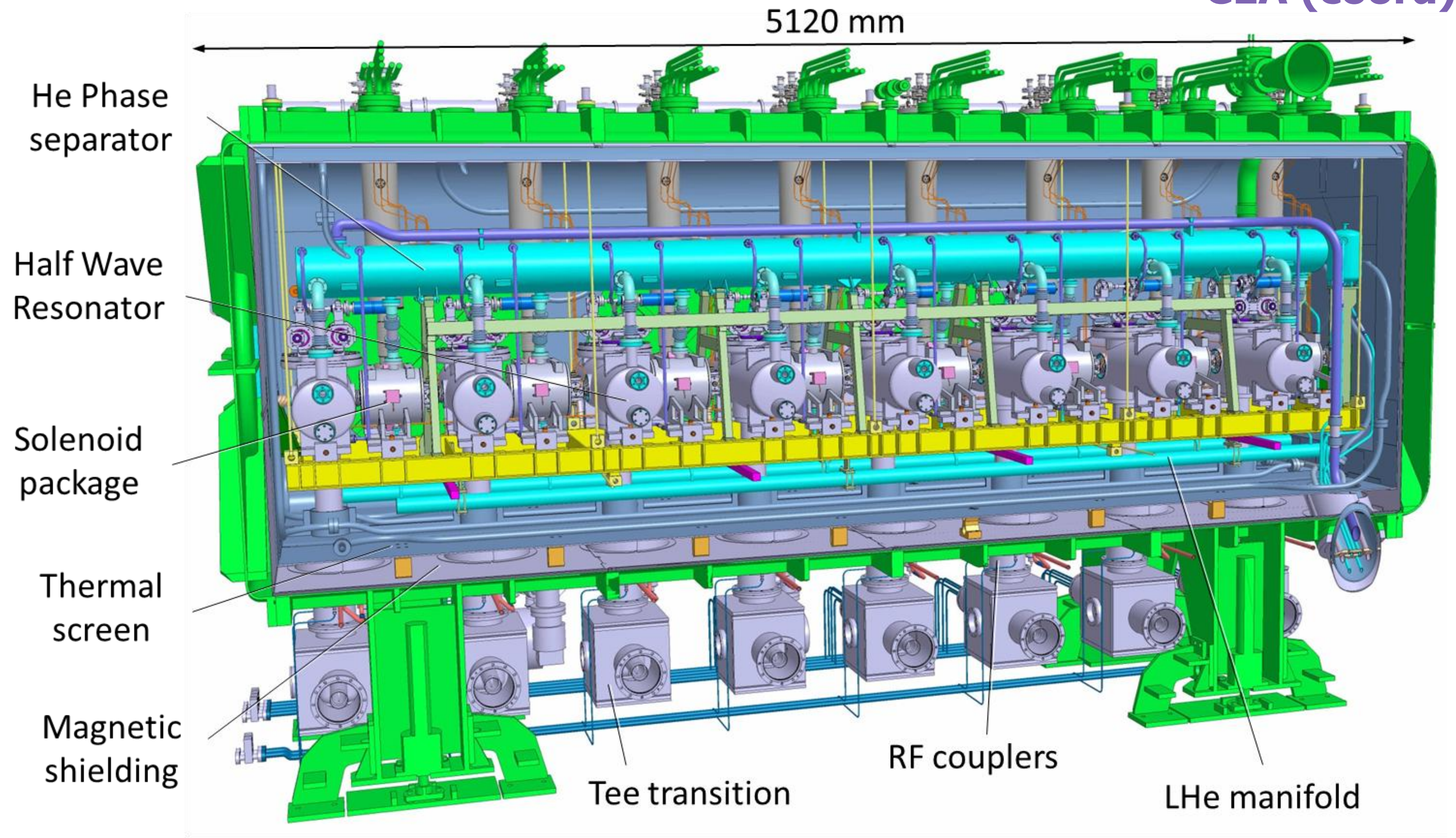
Quadrupole: prototype completed and validated on a magnetic test bench

Scraper: manufacturing completed



Cryomodule

CEA (coord) CIEMAT



8 resonators (β=0.094)
Tuning system
Coaxial coupler

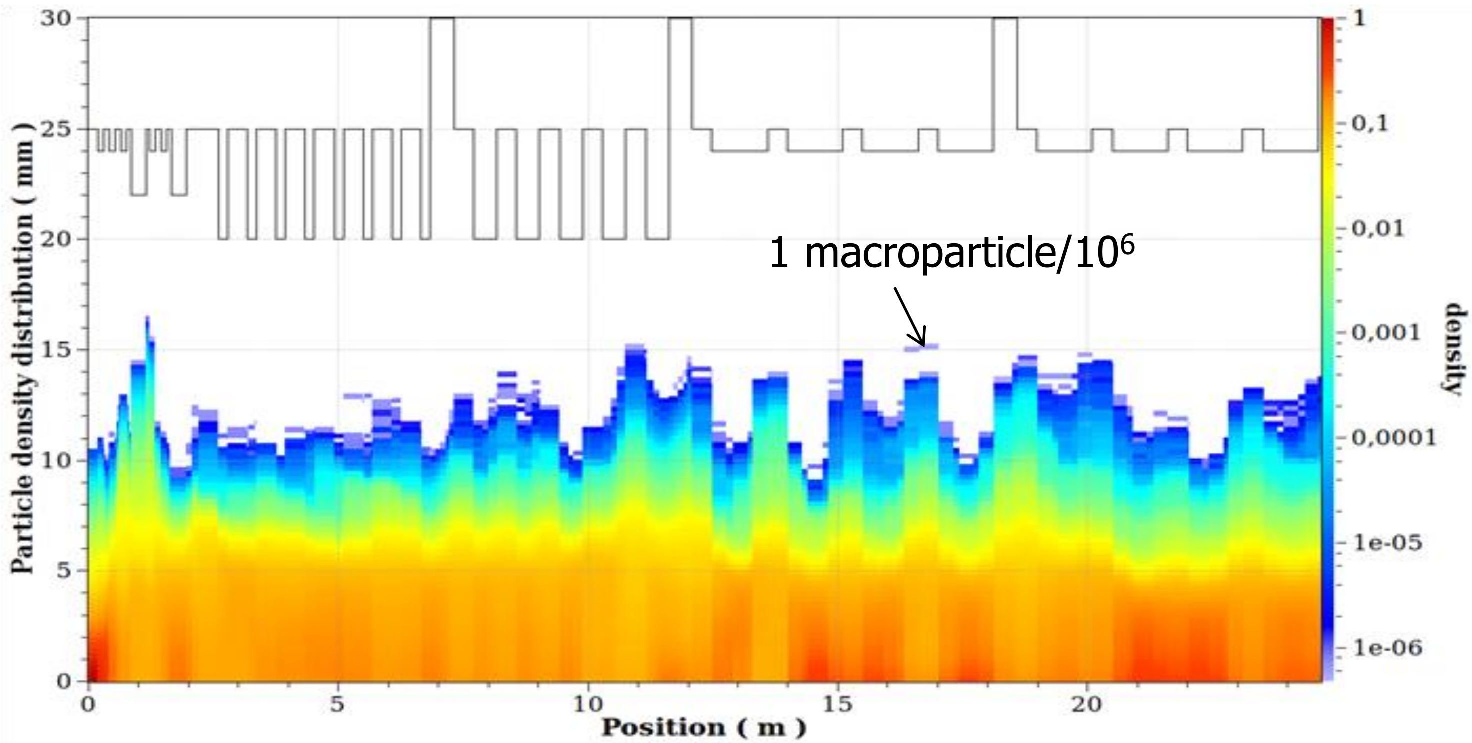
8 solenoid packages
SC magnet (6 T)
Steerers and BPM

SRF Linac beam dynamics

Uncommon procedure:

1. Match beam rms envelope, then
2. Minimise radial beam extension

→ **"Halo matching" instead of "Envelope matching"**

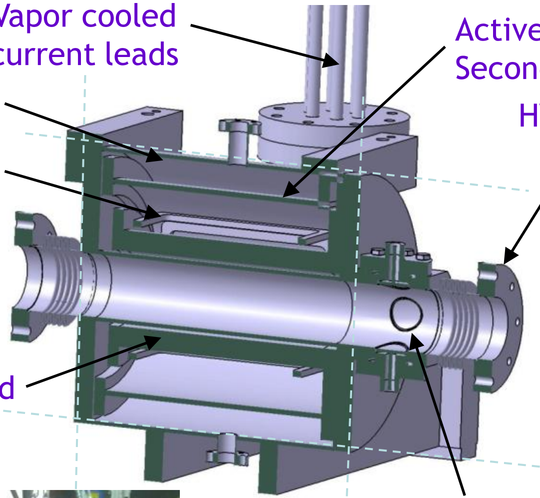


Specifications

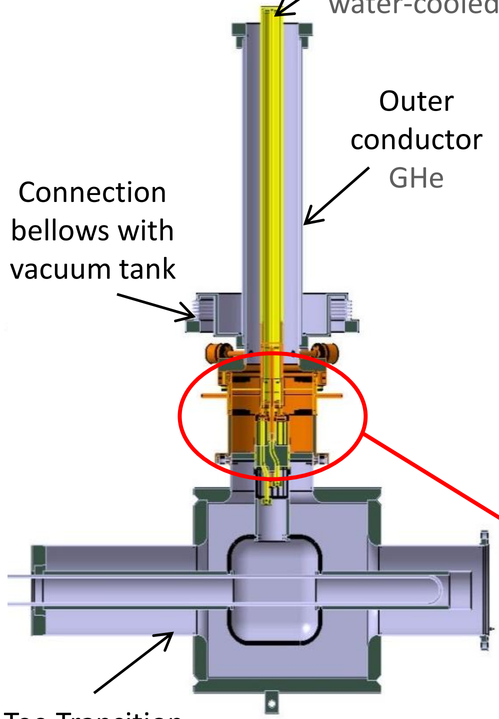
- **8 s.c. Half Wave Resonators**
  - low-β HWRs = 0.094
  - working temperature 4.4 K
  - Accelerating field ~ 4.5 MV/m
- **8 RF power couplers**
  - operating mode CW,
  - RF power: 200 kW (70 kW LIPAc)
- **8 Superconducting Solenoid Packages**
  - focusing solenoid
  - H&V steerers
  - cryogenic BPM
- **Cryostat** with all necessary equipment (supports, cryogenic distribution, alignment, vacuum, magnetic & thermal shields, instrumentations, etc)

Parameters	Target Value	Units
Frequency	175	MHz
β value of the HWR	0.094	
Accelerating field E_a	**4.5**	**MV/m**
Quality factor Q_0 for R_s=20 nΩ	**$1.4\ 10^9$**	
Beam aperture HWR / Solenoid Package	**40 / 50**	**mm**
Freq. range of HWR tuning system	**± 50**	**kHz**
Max. transmitted RF power / coupler	**200**	**kW**
External quality factor Q_{ex}	$6.3\ 10^4$	
Transmission Lines for HWR	coax 6” 1/8	
Magnetic field B_z on axis max.	**6**	**T**
∫ B.dl on axis	≥ 1	T.m
Field at cavity flange	≤ 20	mT
BPM position accuracy	0.25	mm
BPM phase accuracy	2	deg
Total Static/Dynamic Heat losses	18 / 120	W

Solenoid and Coupler



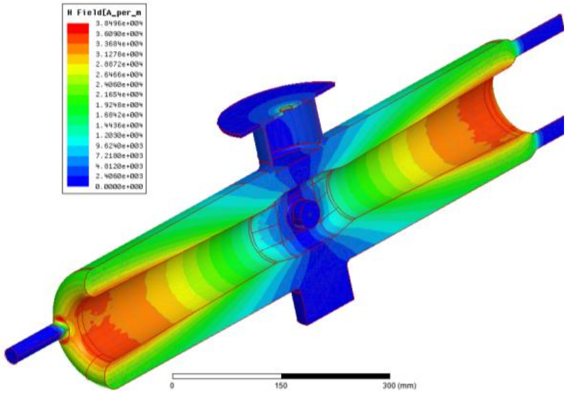
Cold tests at 4.2 K
Quench at ~ 260 A
(210 A nominal)



2 prototypes completed, tested when RF power sources will be available, end of 2012

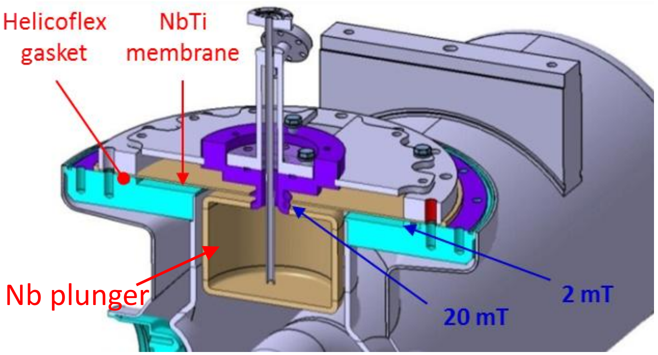
Superconducting Cavities

- **Two cavity prototypes** completed in Summer 2010, delivered in Sept'10



- **Original tuner design**: relied on a capacitive plunger with a large membrane to allow an elastic deformation of ±1 mm
- **First troubles** during cryogenic tests reported in May 2011

A0 plunger design

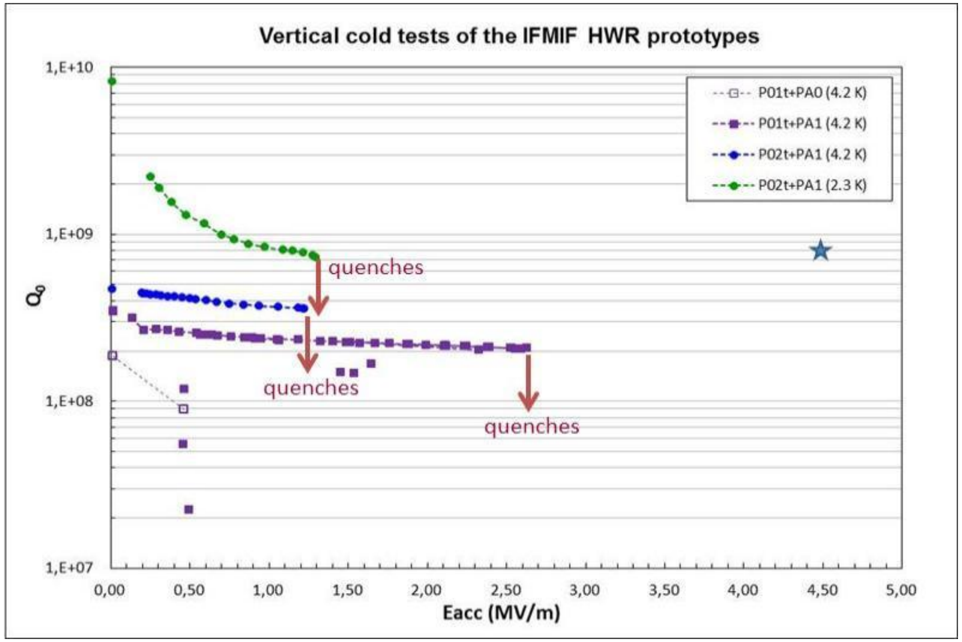


Potential risks

- high peak magnetic field at membrane center
- Helicoflex gasket in region of significant field
- NbTi flange: poor thermal conductivity
- Fabrication issue: neck region contains two NbTi/Nb welds in a recessed area

Results of HWR vertical tests with plunger

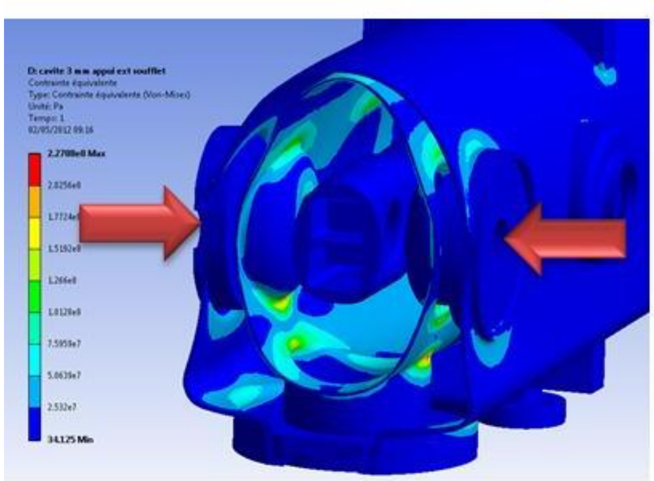
Last cold tests of HWR prototypes with modified plunger (March & April 2012)
Nb membrane, In gasket, suppression of high field at the membrane center

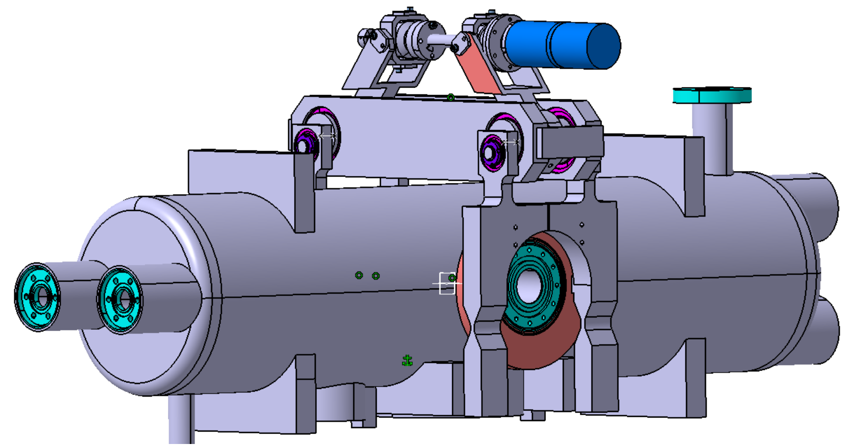


- Systematic thermal quenches at low field and drop of Qo
- Results point to a suspect plunger
- potential problems occurring in the main cavity body cannot be also ruled out

→ Following up the recommendations of a Review Panel, a new design based on **a conventional compression tuner** principle is under development

Compression plunger





- Tuner only acts in one direction (compression)
- 800 kg on each side
- Lever ratio of ~30

Given the rigidity of the present resonator design, this solution implies a lengthening of the cryomodule lattice ~ 10 cm to ease the integration of the tuner between HWR tank & solenoid

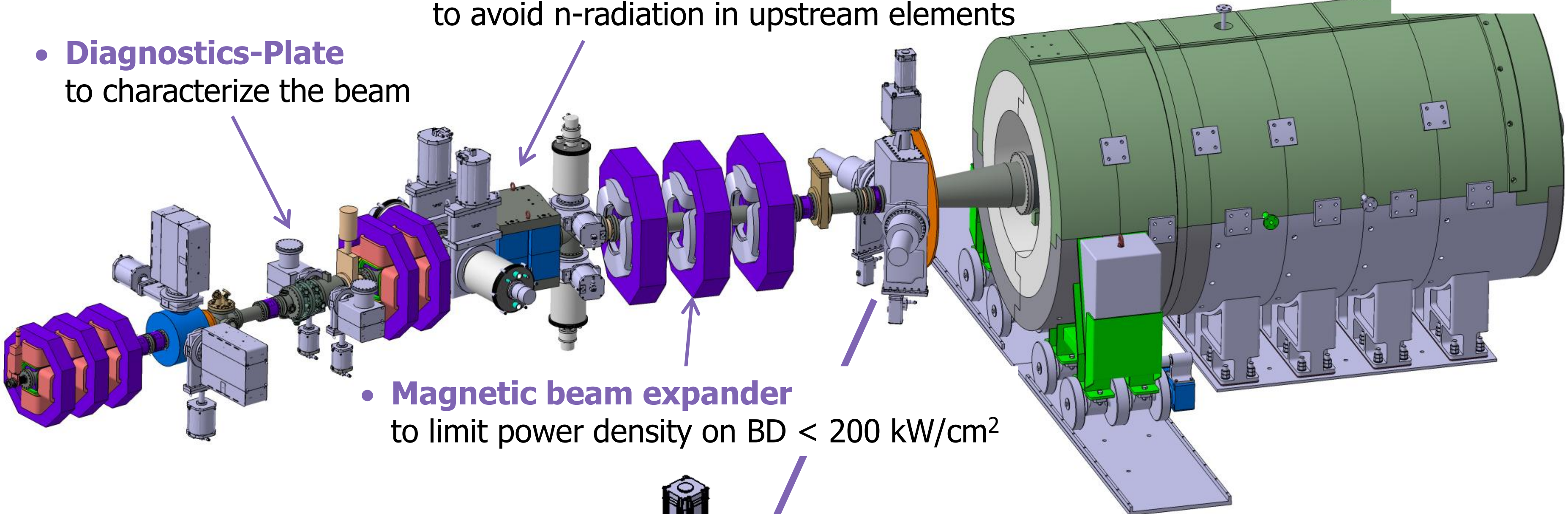
⇒ modification of the tank and cavity and has to be compliant with JA regulations (mechanical stress)

Total cryomodule extra-length ~ 80 cm

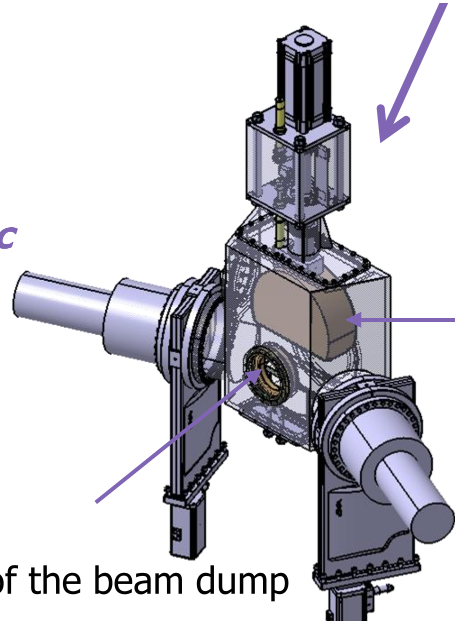
HEBT Line & Beam Dump

CIEMAT

- **Bending magnet(20°)**
  to avoid n-radiation in upstream elements
- **Diagnostics-Plate**
  to characterize the beam



- **Magnetic beam expander**
  to limit power density on BD < 200 kW/cm^2



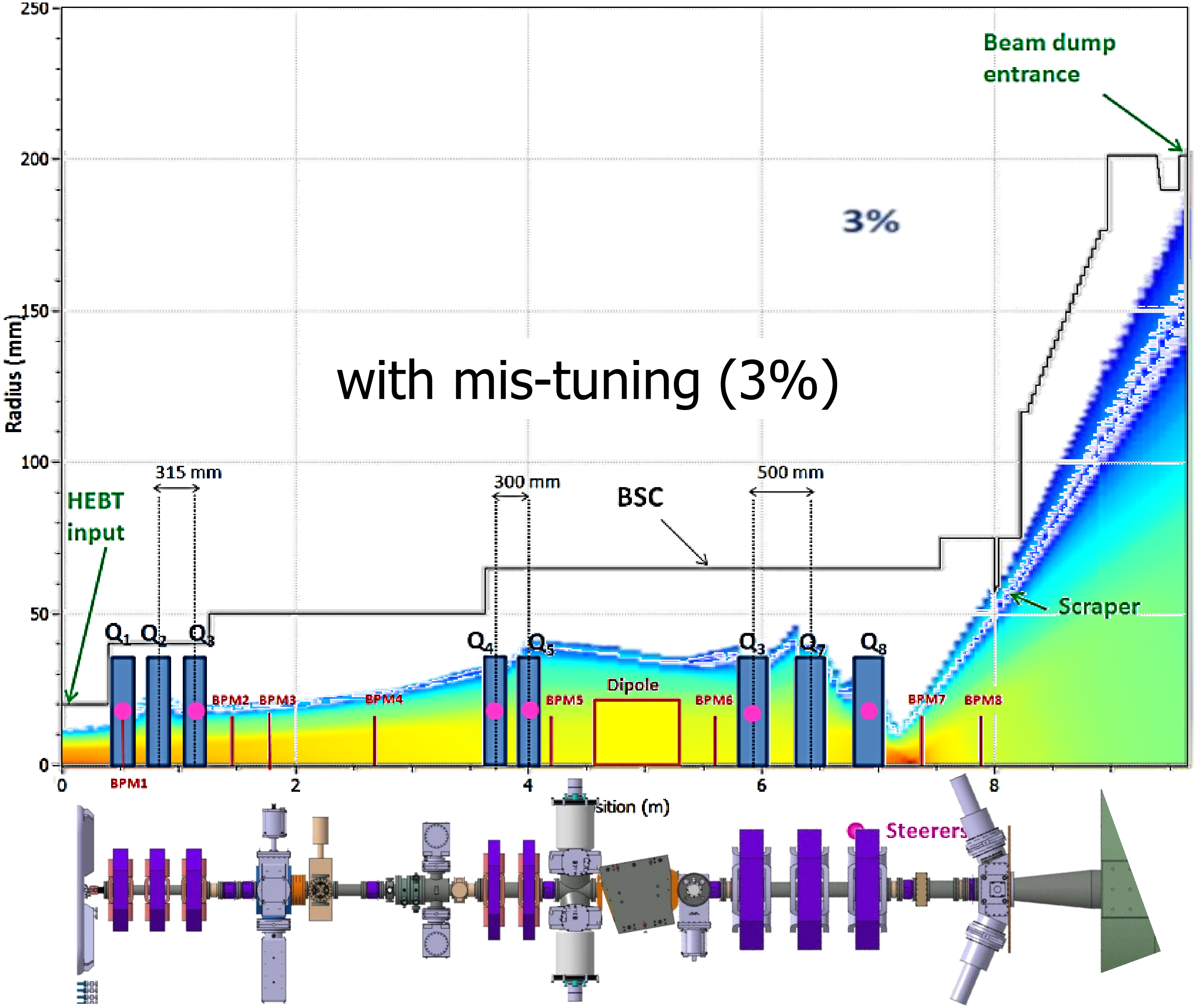
Cryogenic pump

- **Lead shutter**
  closed during beam shutdown to shield residual gamma rays from activated beam dump

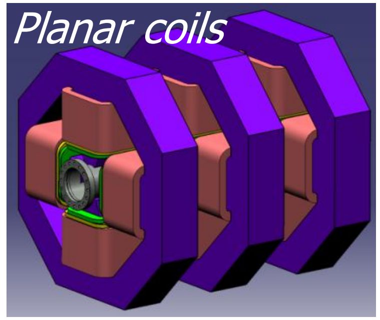
Cryogenic pump

- **Scraper**
  to protect the last portion
  of the vacuum pipe in front of the beam dump

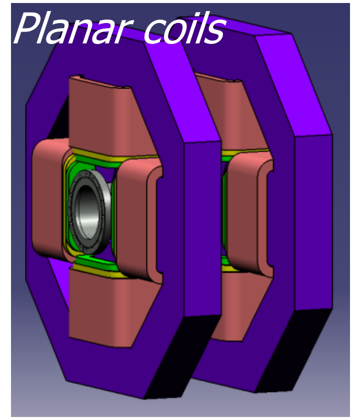
HEBT beam dynamics



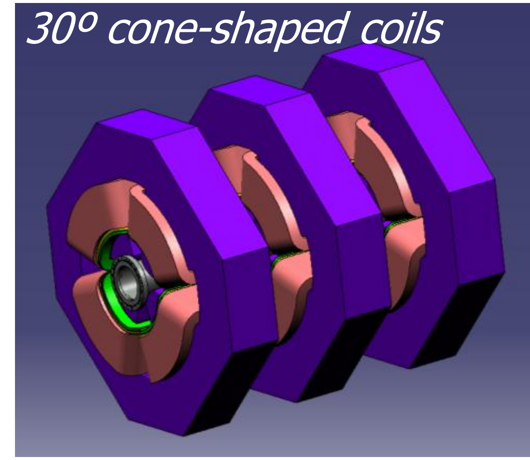
Focusing Magnets



First quadrupole Triplet

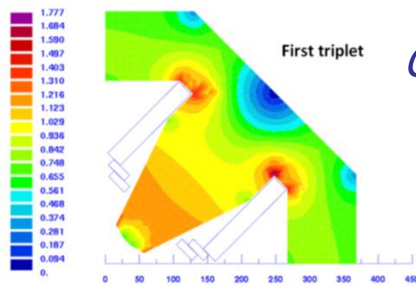


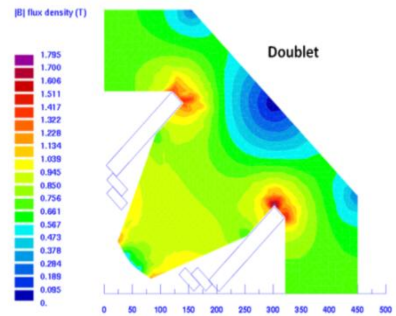
Quadruple Doublet

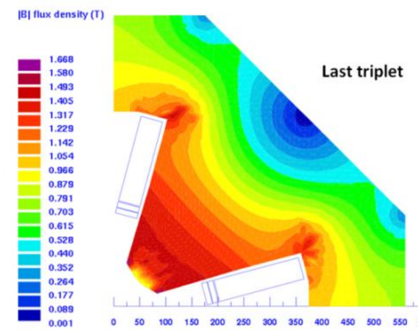


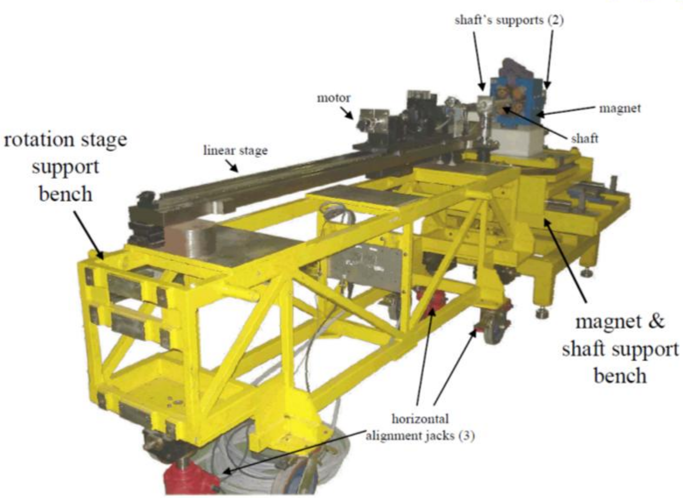
Last quadrupole Triplet

Maximum field
Inside the yoke ~1.8 T







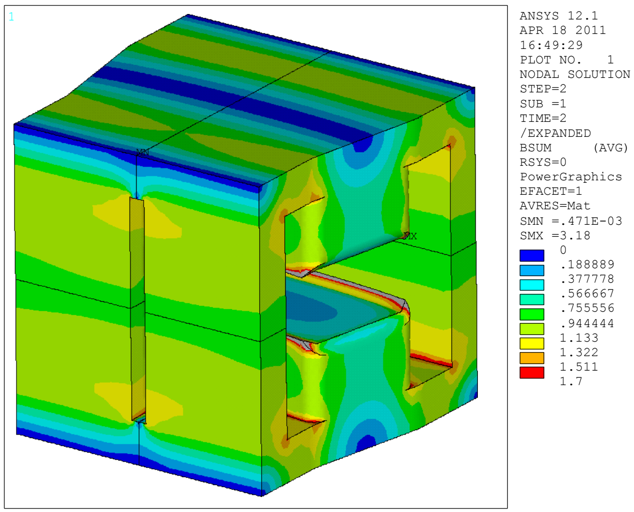


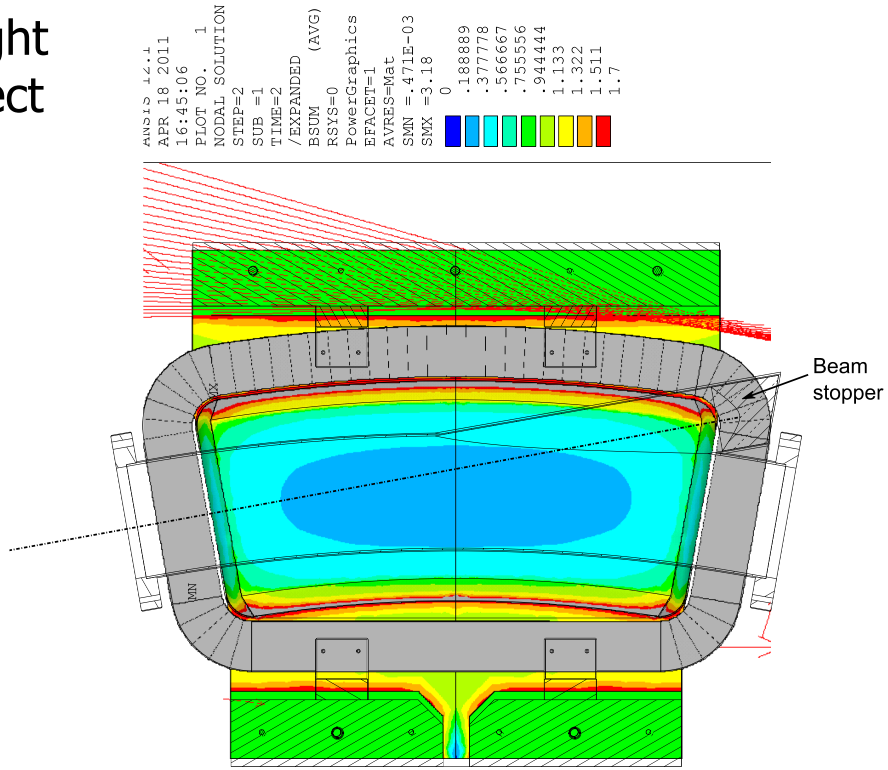
Magnetic measurements on specific test bench at ALBA /CELLS (rotation coil and Hall probe) & Elytt installation (Hall probe)

Dipole Magnet

Reasonable magnetic field in the magnet (~ 1 T in legs)
Only sturation in the shims on the pole edges
Non-linearity error < 0.1%.

Beam stopper at the end of the straight beamline: ~ 350 ms max time to detect and stop the beam

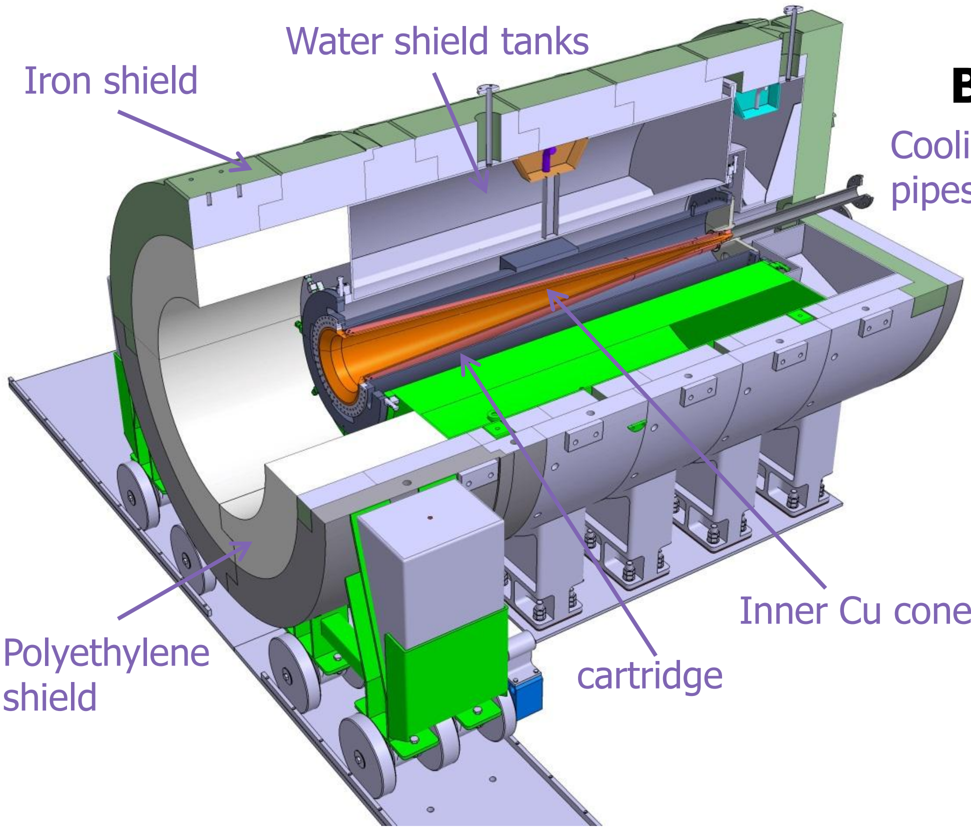


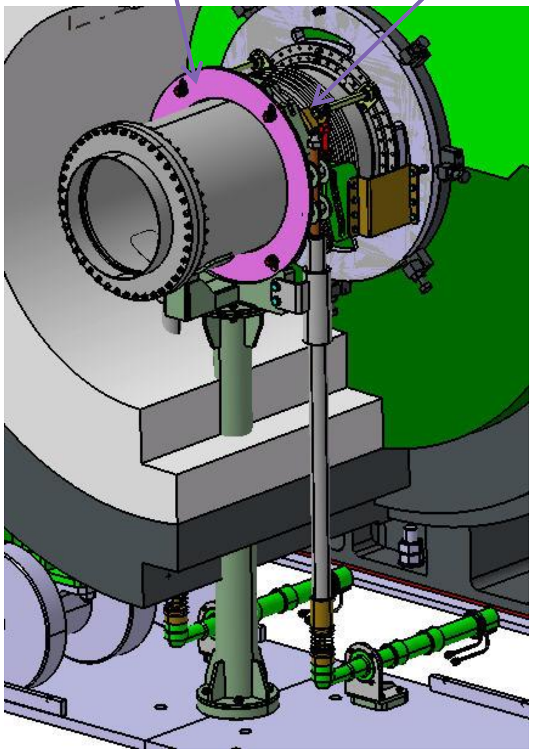


Beam Dump

CIEMAT

Beam dump with its local shielding
water + polyethylene (neutron)
iron (gamma)





Remote disconnection system

Cartridge
Inner & outer cones = Cu (edp)
Cooled by liquid water (high v, 3 bar)
T ~100 ºC not too far from boiling

Beam Dump prototypes and tests

- HEBT & Beam Dump in final stage of detailed design
- Cone prototypes built: electron beam welding and electro-deposition
- Hydraulic test cooling circuit

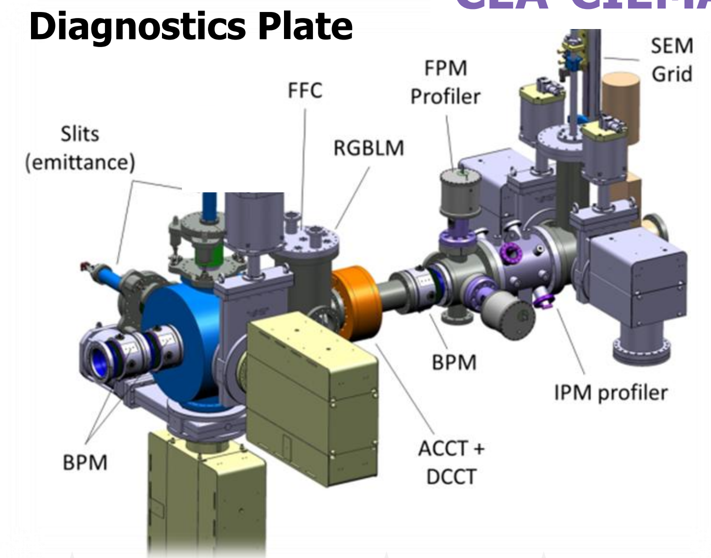
Hydraulic circuit: to study the fluid-dynamics aspects of the beam dump cooling (flow and pressure measurements, vibrations,heat transfer coef estimation,…)

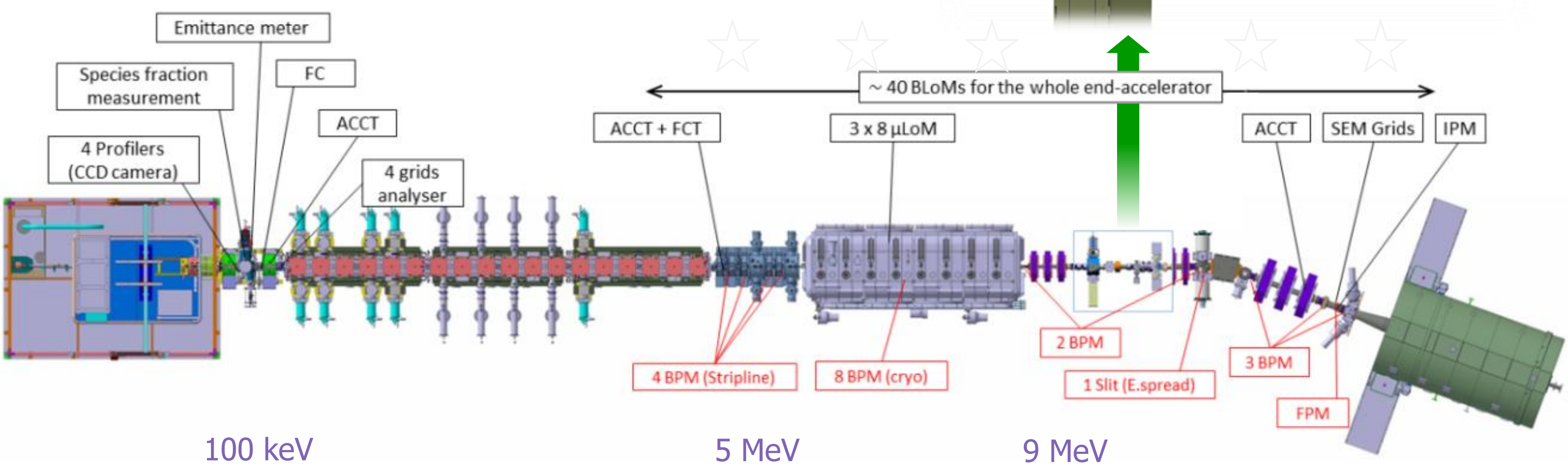
Beam Instrumentation

CEA-CIEMAT

- Current monitors (ACCT, DCCT, FCT)
- Beam Position monitors x 20
- Beam Profile monitors (ionization & fluorescence)
- Beam Loss monitors (ion chambers)
- Micro-Loss monitors (diamond)
- Bunch length monitor (Residual gas, GSI-like)
- Interceptive: SEM grid + slits (E_{spread}, Emit)

Diagnostics Plate

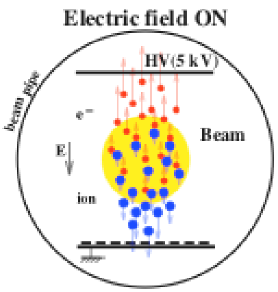


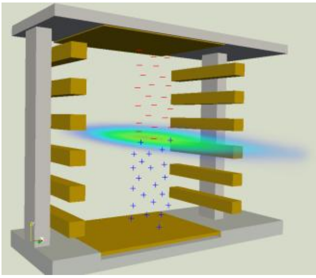


Beam Profilers development

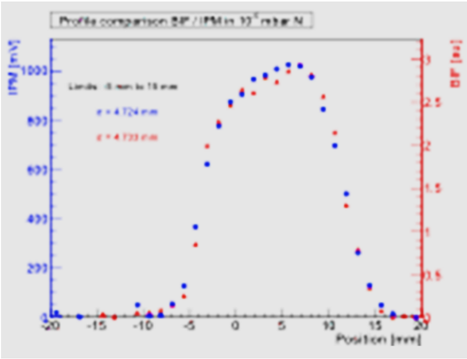
IPM

Principle: ionization of the residual gas
Residual gas pressure: few 10^{-8} to 10^{-5} mbar
Resolution ~ 1 mm   Profile rate ~ few Hz
Apertures >10 cm for DP   >15 cm for HEBT





Test at GSI (5 MeV.A, mA)



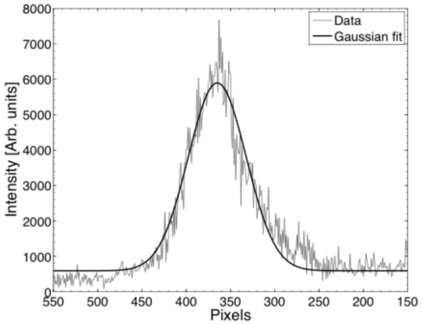
IPM in front of BD

Challenges: Large aperture (15× 15 cm²)
- Radiation hardness ~ 7 kSv/h (neutrons)
- ceramic (HV + strip plates) field uniformity

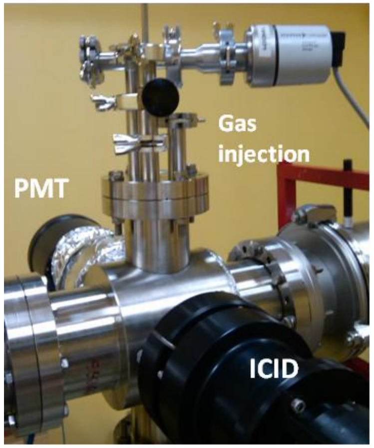
FPM

Principle: fluorescence by interaction of the beam with the residual gas
2 read-out prototypes tested
- ICID (Intensified Charge Injection Device) camera (MCP + CID)
- PMT: multi anode 32 channels linear array

Campaign tests at CNA cyclotron Sevilla:
D^+: 9 MeV and H^+: 18 MeV

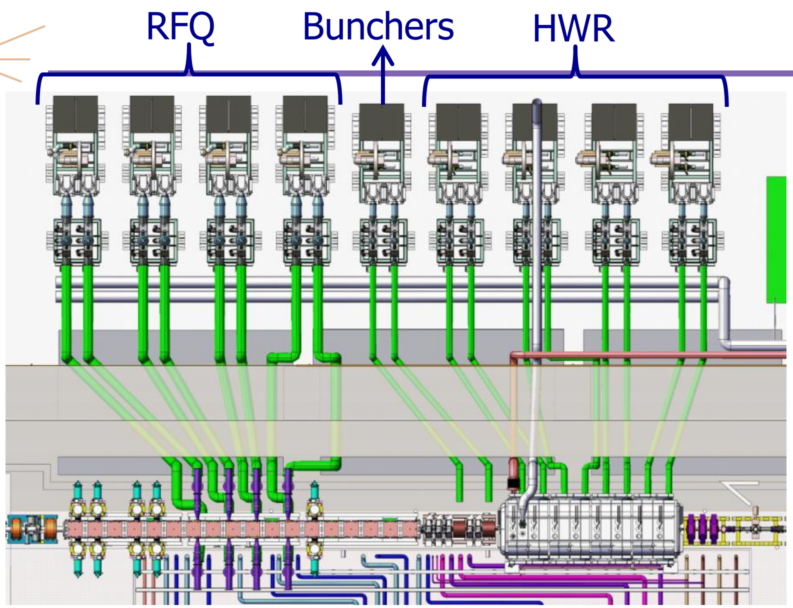


ICID camera



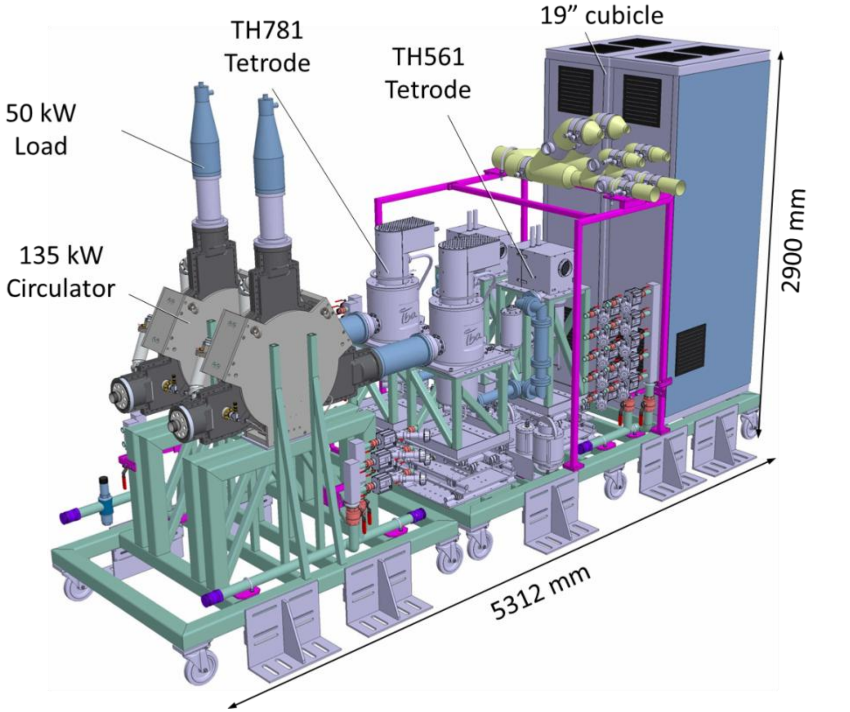
Extrapolation to LIPAc (125 mA) OK
new tests done at Sevilla (Oct 2011)
…improved profile measurements

RF Power system



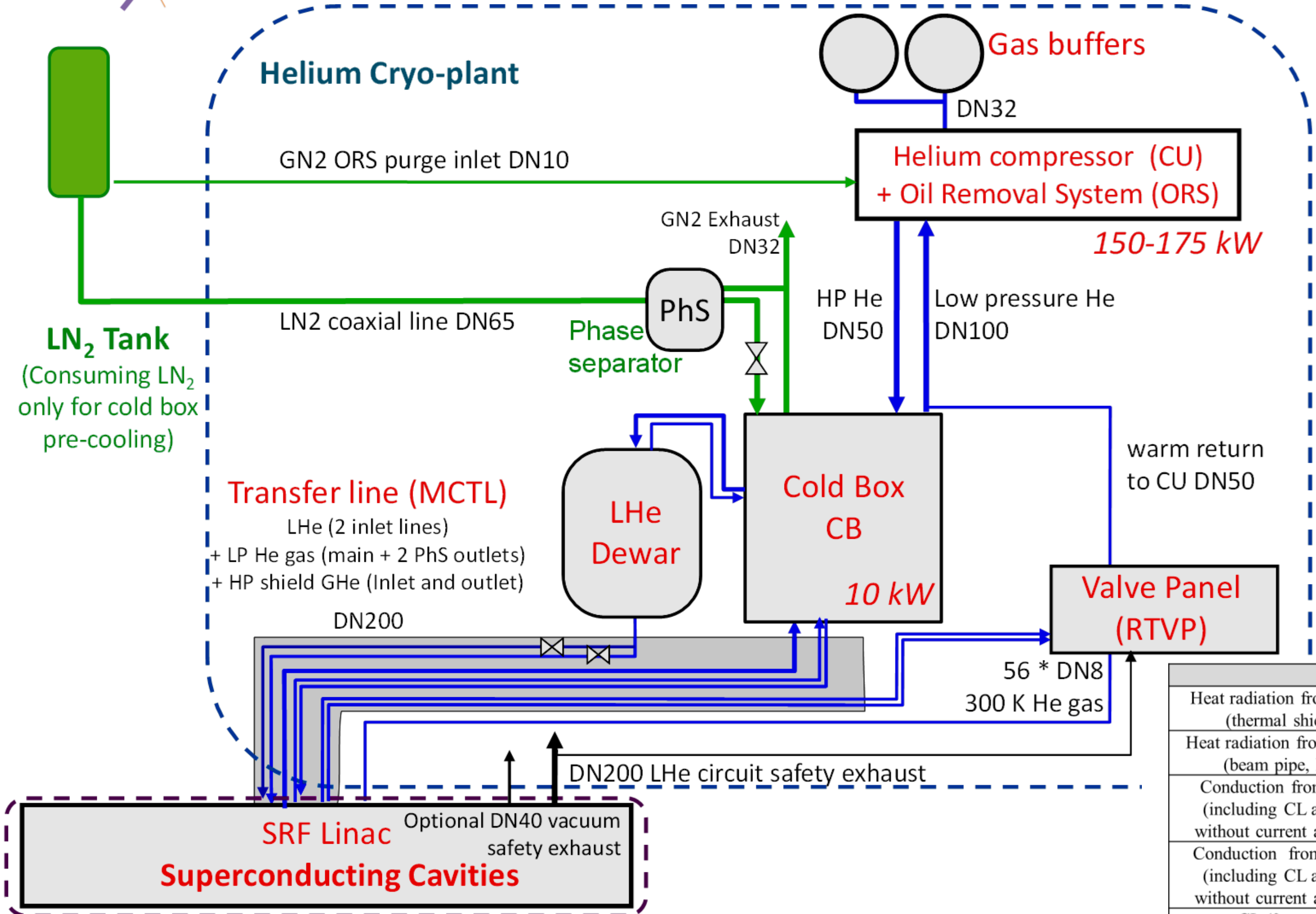
- Prototype RF module (1 x 200kW) ready end of 2012
- First RF module (2 x 100kW) ready beginning of 2013
- 16 kW solid-state amplifier (buncher) ready at mid-2013

Parameter	Value
Operating Frequency	175 MHz
Bandwidth	± 250 kHz @ -1 dB
Phase Stability	± 1º
Amplitude Stability	± 1%
Power Linearity	1%
Full Output RF Power	200kW
Operating Modes	CW or pulsed mode
20kW CW Reflected Power	2 hours
RF Power Emergency Stop	<10 μs
200kW Reflected Power	10 μs



Cryoplant

Market survey done
Call for tender soon



Process Flow Diagram

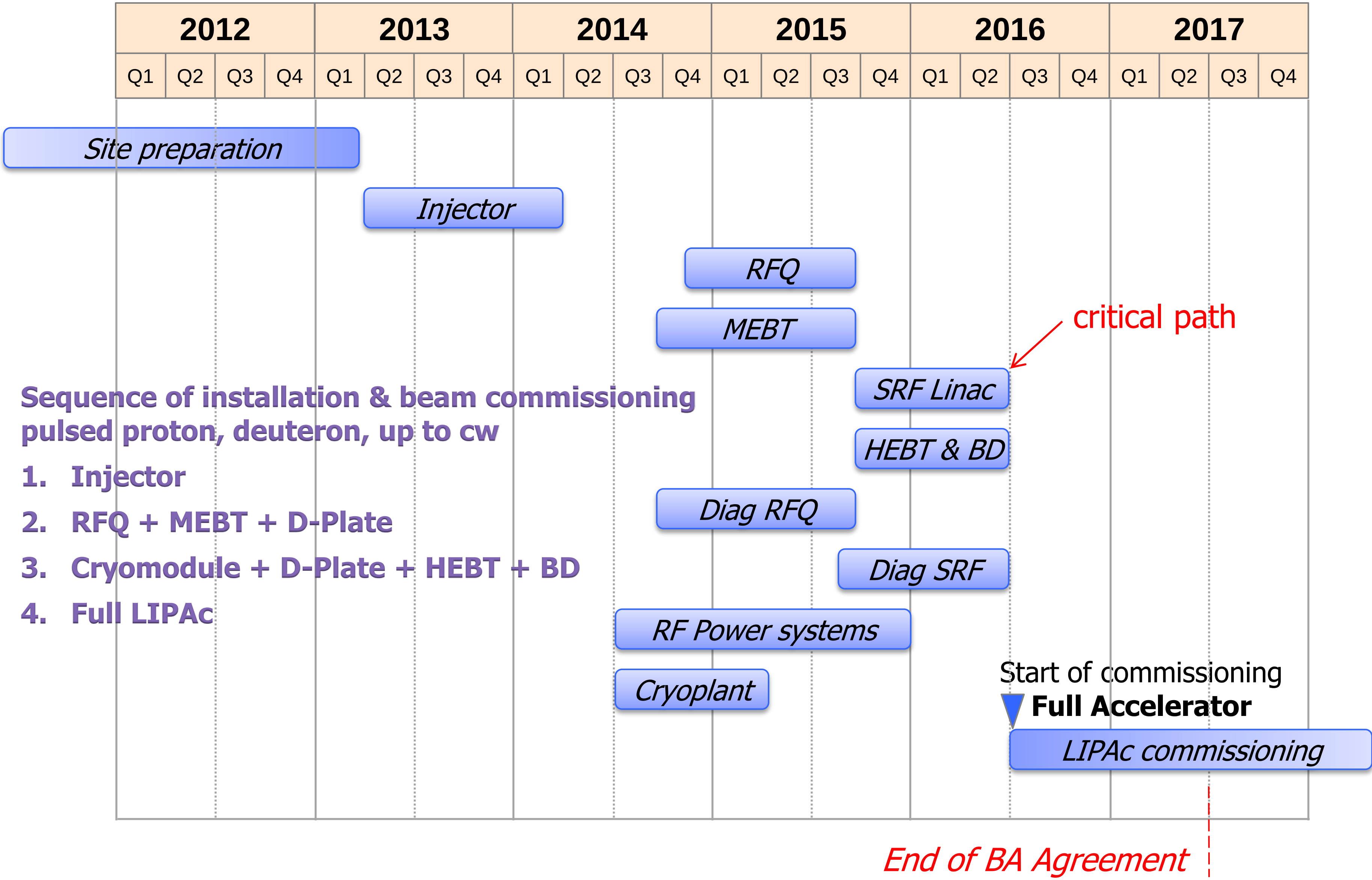
PC (Power Coupler for cavity)
CL (Curent Leads for solenoid)

	Cryomodule	Transfer line MCTL
Static heat loads at 4.4 K		
Heat radiation from 55 K (thermal shield)	3.75 W	8.3 W + 19.8 l/h
Heat radiation from 300 K (beam pipe, PC)	5.8 W	
Conduction from 55 K (including CL and PC without current and RF)	6.7 W	
Conduction from 300 K (including CL and PC without current and RF)	5.4 W	
CL (0 amps)	5.25 l/h	
PC (no RF)	5.53 l/h	
Static total	**30 W + 30 l/h**	
Dynamic heat loads at 4.4 K		
RF	54.4 W	
CL (I nominal)	3.5 l/h add.	
PC (with RF)	3.7 l/h add.	
Dynamic total	**54.4 W + 7.2 l/h**	
TOTAL at 4.4 K	**84.8 W + 37.2 l/h**	

Heat loads estimation

Conventional Facilities

Installation & Commissioning



Sequence of installation & beam commissioning pulsed proton, deuteron, up to cw

1. **Injector**
2. **RFQ + MEBT + D-Plate**
3. **Cryomodule + D-Plate + HEBT + BD**
4. **Full LIPAc**

END