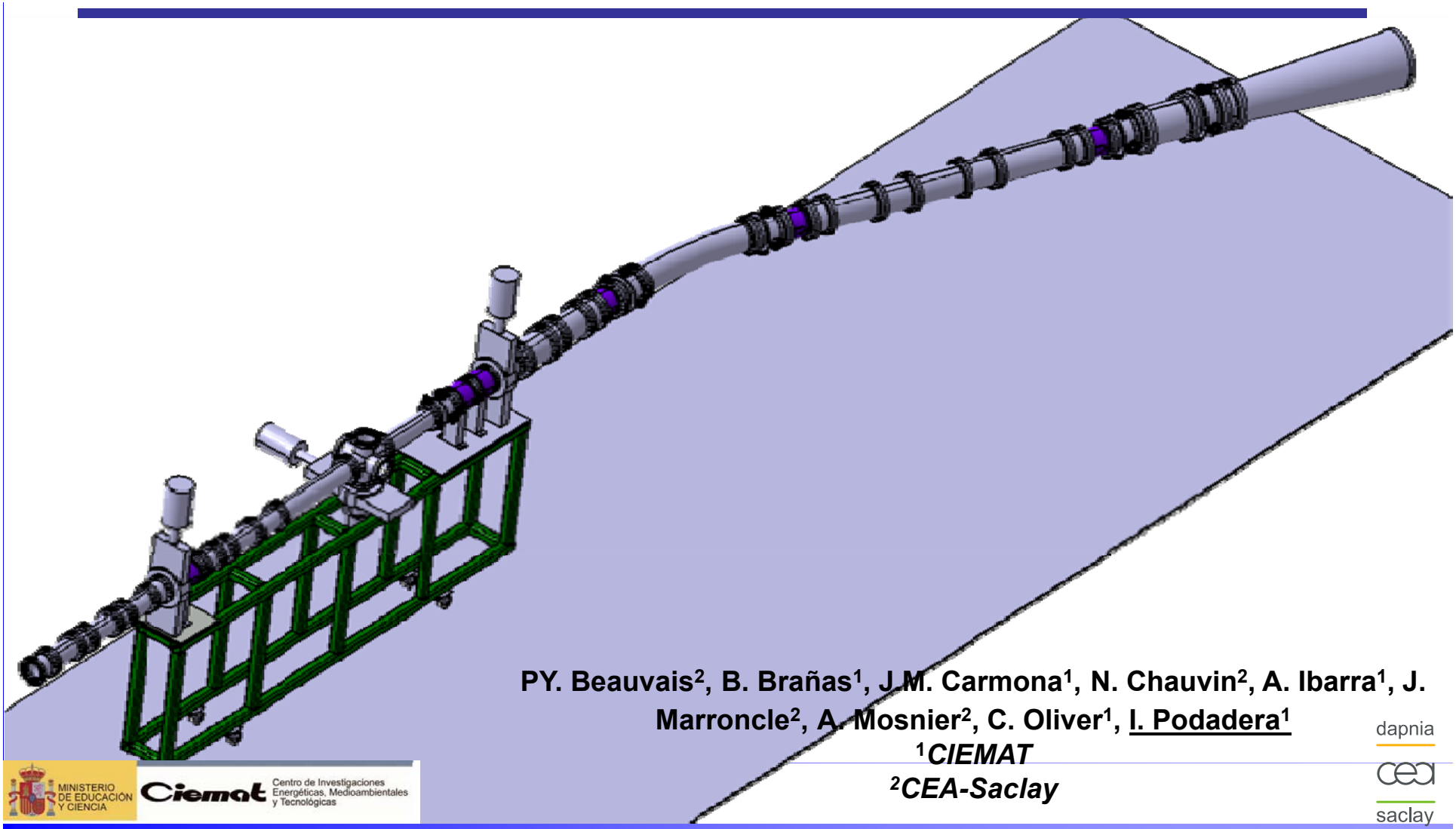
HEBT Diagnostics for Commissioning, Control and Characterization of the IFMIF-EVEDA Accelerator



PY. Beauvais[2], B. Brañas[1], J.M. Carmona[1], N. Chauvin[2], A. Ibarra[1], J. Marroncle[2], A. Mosnier[2], C. Oliver[1], I. Podadera[1]

[1]*CIEMAT*

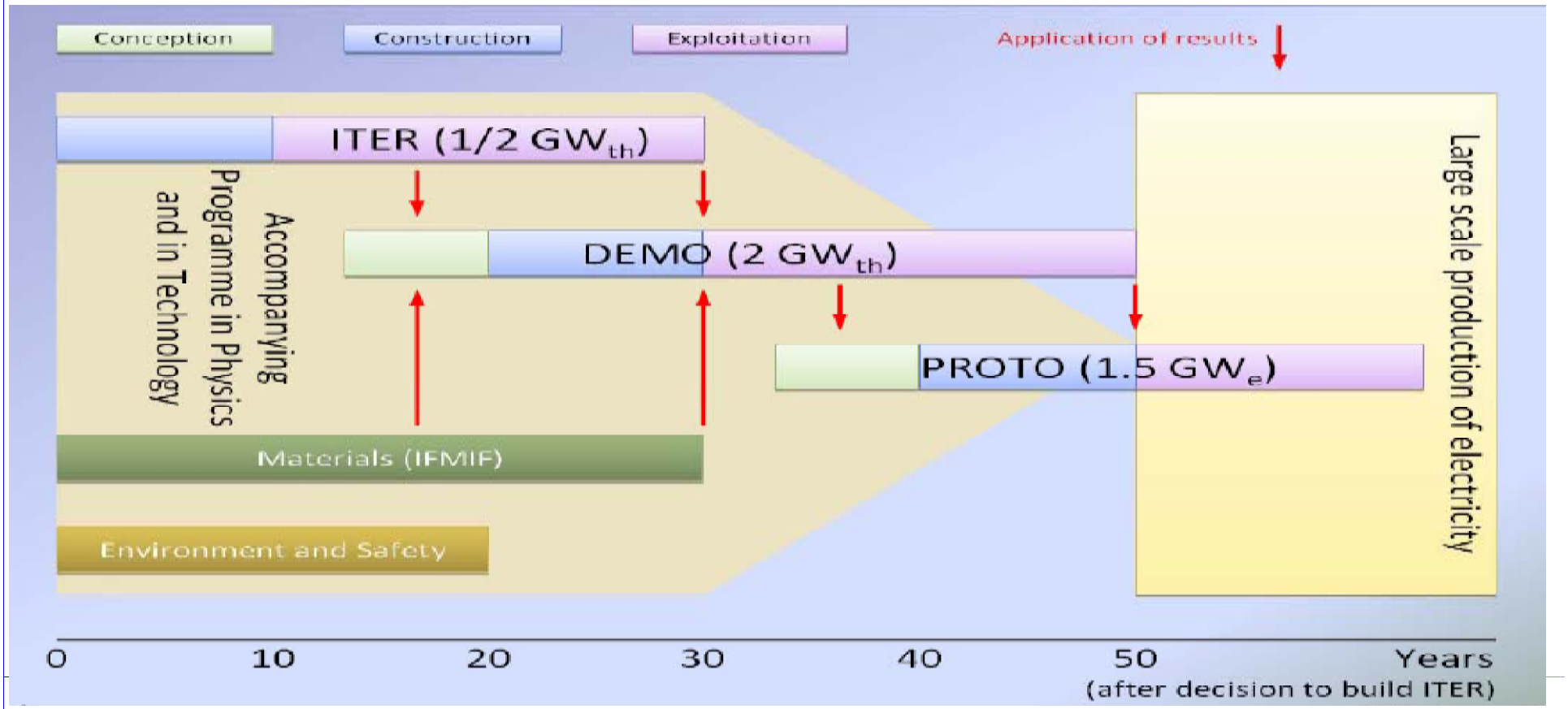
[2]*CEA-Saclay*

IFMIF Goals

International Fusion Materials Irradiation Facility

Characterization of materials envisaged for future fusion reactors.

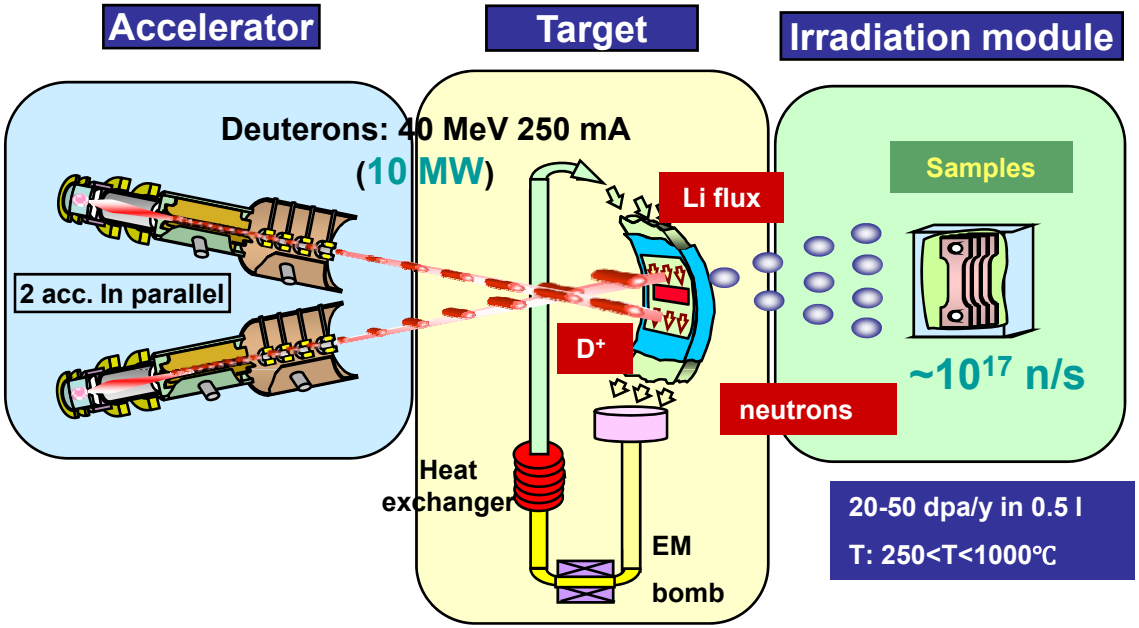
Study and analysis of the behaviour of materials under a high flux of neutrons (10^{18} n/m^2/s).



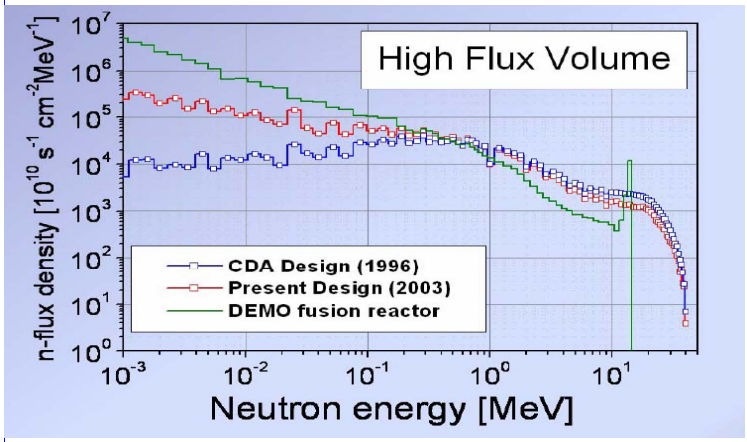
P. Garin, *IFMIF: status and developments*, EPAC08, p. 974 (2008)

IFMIF design

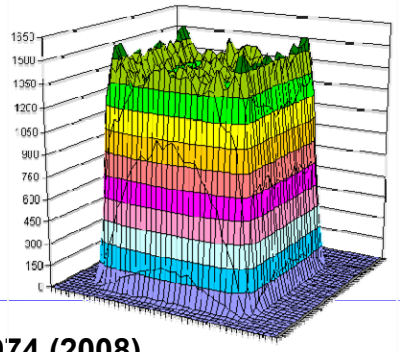
Facility availability >70%

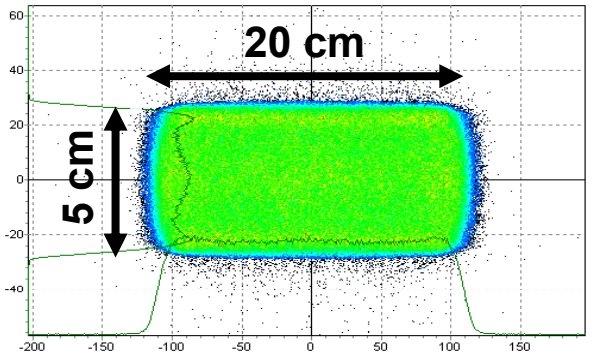


Neutron flux density



Beam footprint at interaction point





P. Garin, *IFMIF: status and developments*, EPAC08, p. 974 (2008)

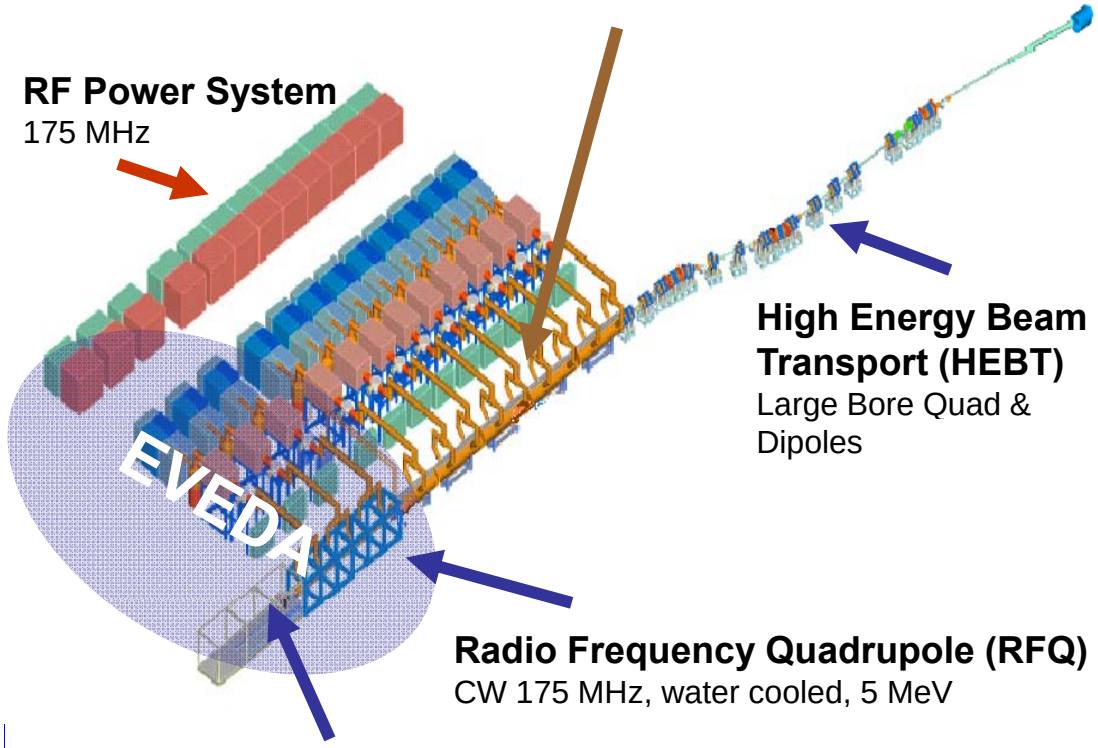
IFMIF Accelerator

Deuterons, 2 x 125 mA, CW, 40 MeV.

Target region: 20 cm horizontal x 5 cm vertical.

Superconducting HWR
CW 175 MHz, HWR, 4 cryomodules, 40MeV

RF Power System
175 MHz



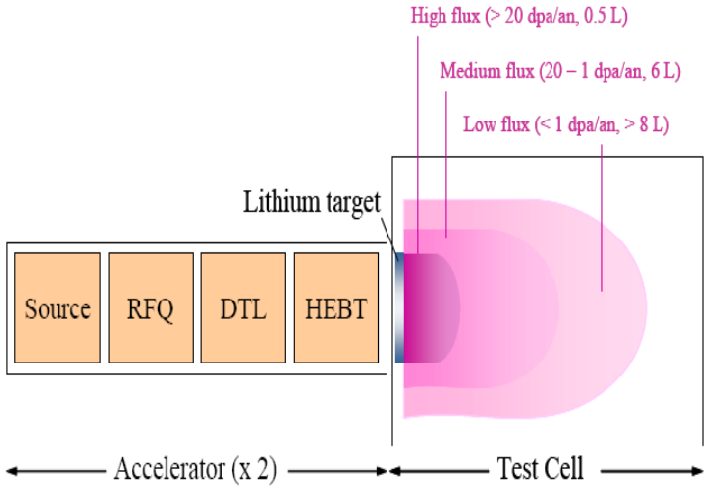
High Energy Beam Transport (HEBT)
Large Bore Quad & Dipoles

Radio Frequency Quadrupole (RFQ)
CW 175 MHz, water cooled, 5 MeV

Ion Injector
CW ECR, Source, 140 mA D^+, 95 keV, Magnetic LEBT to RFQ

Accelerator challenges

- **Space charge.**
- **Beam instabilities.**
- **CW operation.**
- **Beam interception (activation).**
- **Shape of the beam footprint at the target.**



IFMIF-EVEDA Accelerator

EVEDA phase

Engineering Validation and Engineering Design of the IFMIF project

Goals

•to validate the technical options with the construction of a prototype accelerator.

•to produce the detailed integrated design of the future IFMIF accelerator.

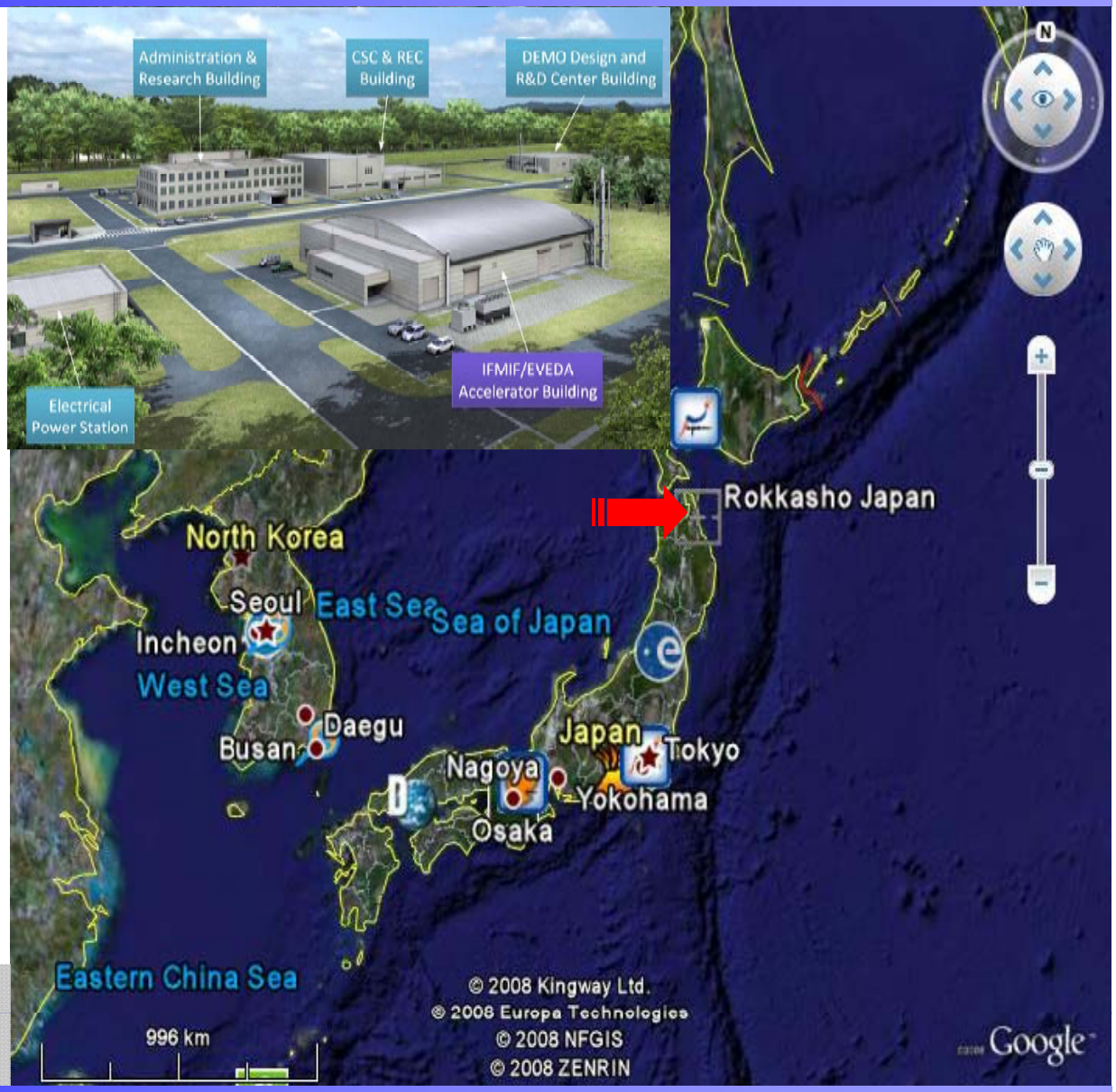
Main specifications

•Installation in Rokkasho-Japan 2012-2013.

•manufacturing and tests of a prototype accelerator (1:1) with 9 MeV final energy.

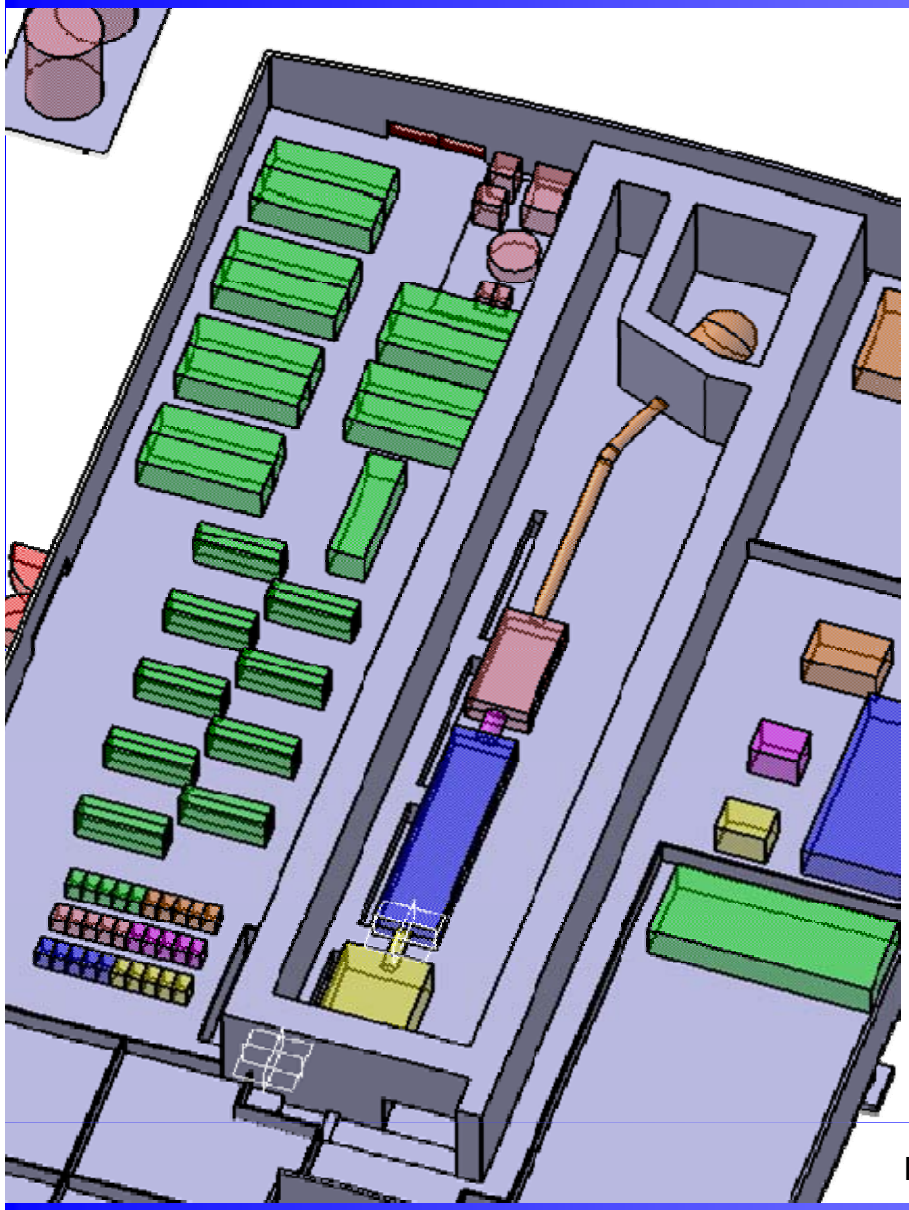
•Deuterons, 125 mA cw, 9 MeV.

•Commissioning phase: 0.5 mA-125 mA, pulsed mode down to 200 ms, 0.1% duty cycle.



A. Mosnier, A. Ibarra, A. Facco, *The IFMIF-EVEDA accelerator activities*, EPAC08, p. 3539 (2008)

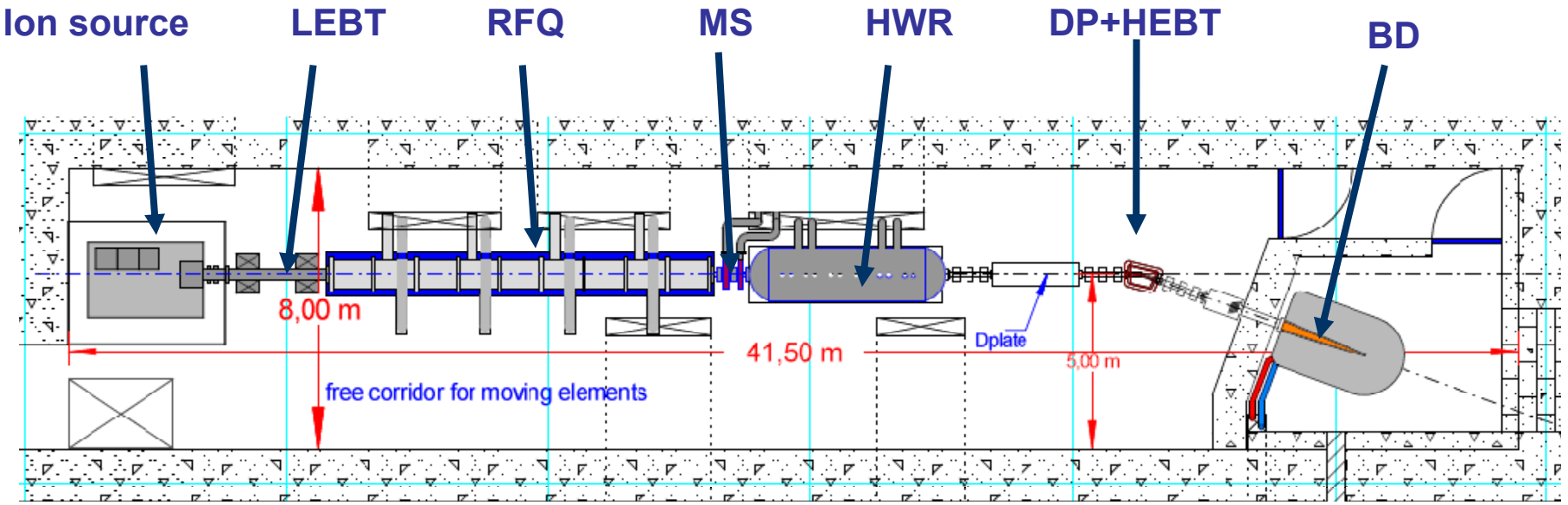
IFMIF-EVEDA Accelerator



Ion especies	D^+ /H_2^+ (tests)
CW current (min/max)	0.5/125 mA
RFQ output energy	5 MeV (β=0.0727)
HWR output energy	9 MeV (β=0.0975)
RF frequency	175 MHz
Bunch width (min/max)	0.1-3 ns
Duty factor (min/max)	0.1%/CW
Pulse length (min/max)	~100 µs/CW
Beam power	1.125 MW

Mockup courtesy of T. Trublet

IFMIF-EVEDA Accelerator

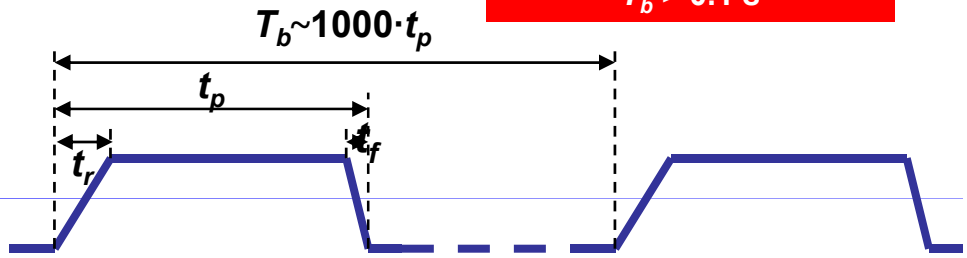


Commissioning

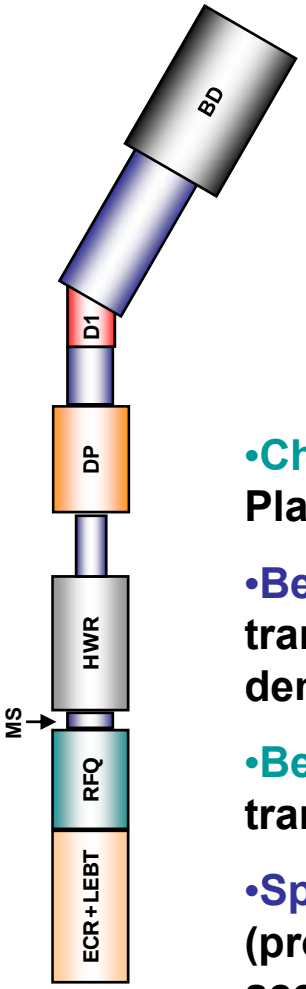
- **5 MeV for RFQ comissioning:**
  - From 0.5 mA to 125 mA.
  - Pulsed and CW operation.
- **9 MeV for HWR commissioning and beam characterization :**
  - From 0.5 to 125 mA.
  - Pulsed and CW operation.

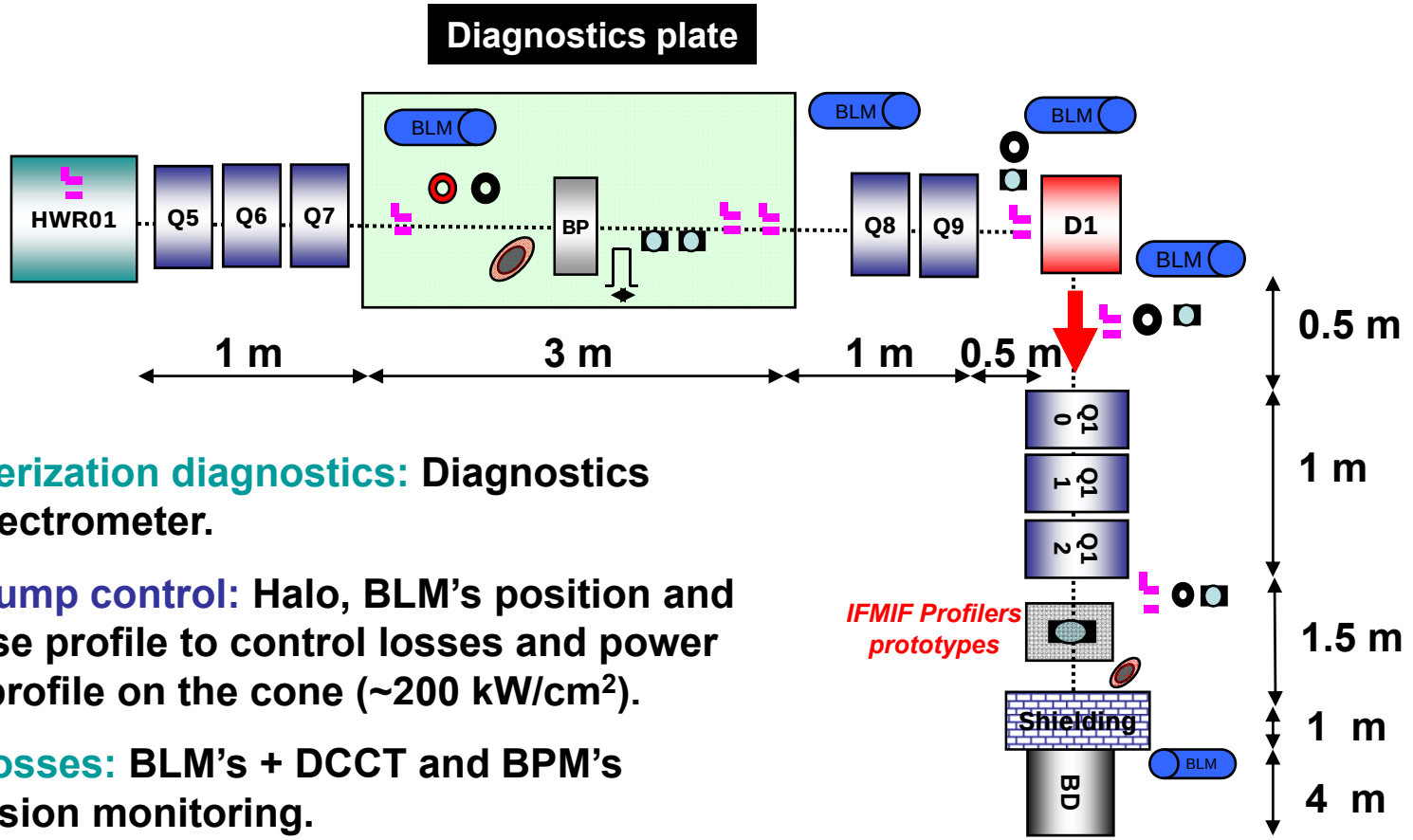
ECRIS Pulse characteristics

t_r >10-20 us
t_f >45 µs
t_p >100 µs
(200 us for stabilization)
DC=0.1%
T_b > 0.1 s



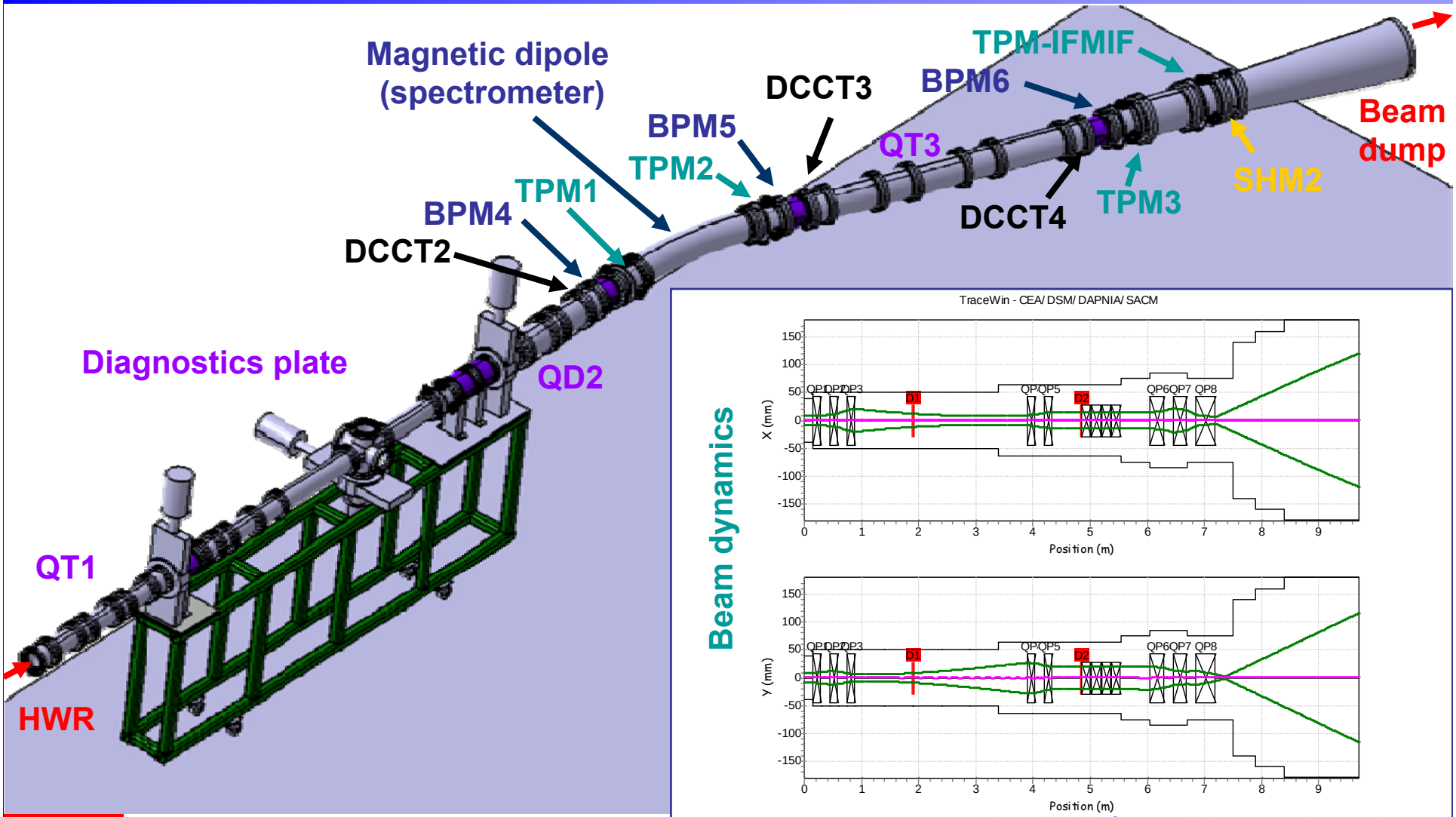
HEBT beam diagnostics





- **Characterization diagnostics:** Diagnostics Plate+spectrometer.
- **Beam Dump control:** Halo, BLM's position and transverse profile to control losses and power density profile on the cone (~200 kW/cm^2).
- **Beam Losses:** BLM's + DCCT and BPM's transmission monitoring.
- **Spectrometer:** beam characterization (profilers), reduction radiation impact on the accelerator, controlled with BPM's, DCCT's transmission and BLM's.

High Energy Beam Transport Line (HEBT)



rms beam envelope along the HEBT (from HWR up to Beam Dump)
C. Oliver et al., *HEBT for the IFMIF-EVEDA accelerator*, EPAC'08, p. 3041 (2008)

draft

HEBT diagnostics

	Parameter	Method	Comments
		EVEDA	
1	AC current	ACCT	
2	DC current	DCCT	
3	Position	Stripline BPM	
4	Transverse Profile	Gas fluorescence (FPM)	
		Gas ionization (BTPM)	

Essential for initial commissioning (HB2006):

Current
Position
Profile

Diagnostics Plate

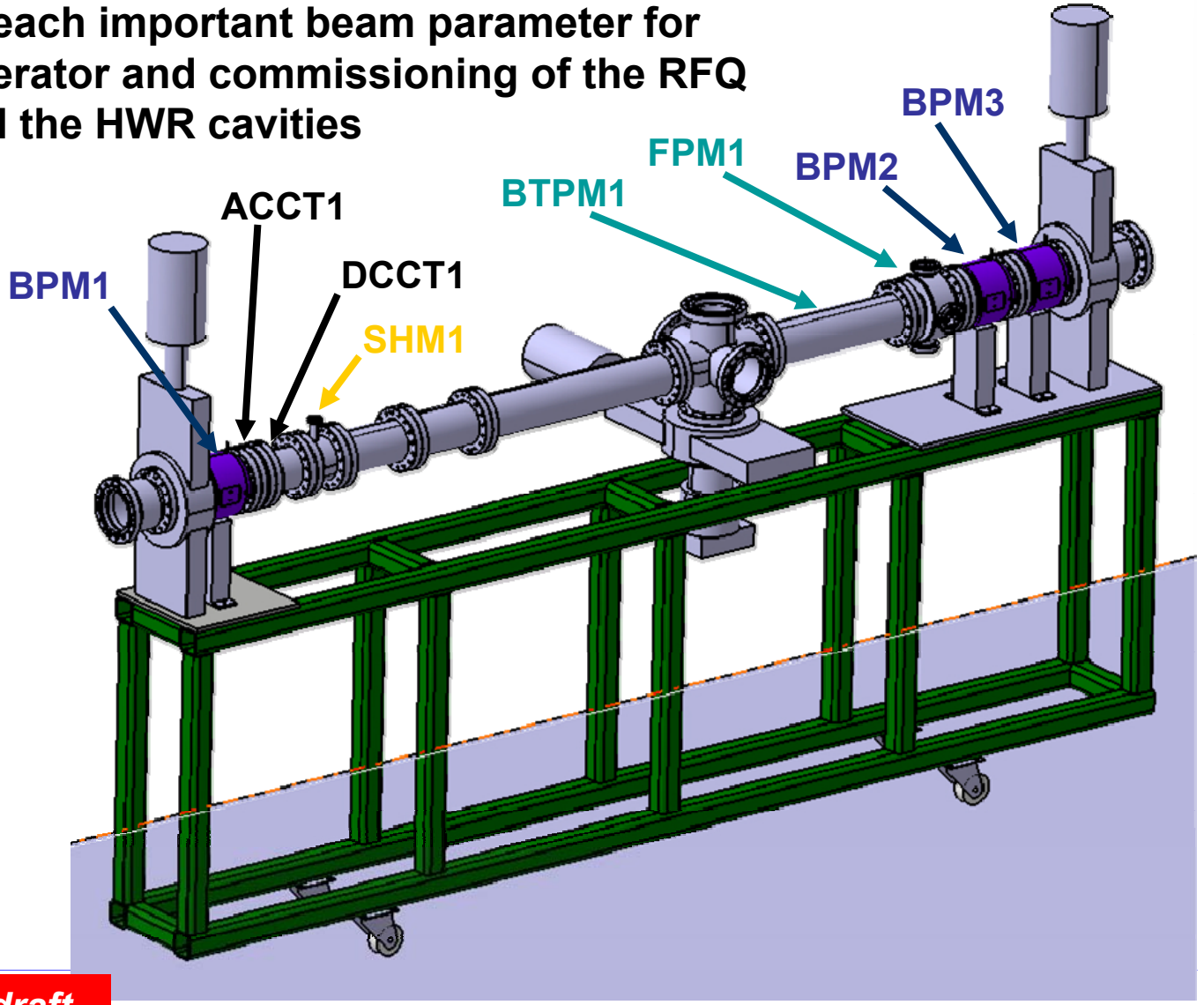
Characterization of each important beam parameter for validation of the accelerator and commissioning of the RFQ and the HWR cavities

Parameters

- DC current
- AC noise
- Centroid jitter
- Transverse profile (size and distribution)
- Halo
- Mean energy
- Bunch width

Challenges

- Low β
- Debunching
- Radiation damage

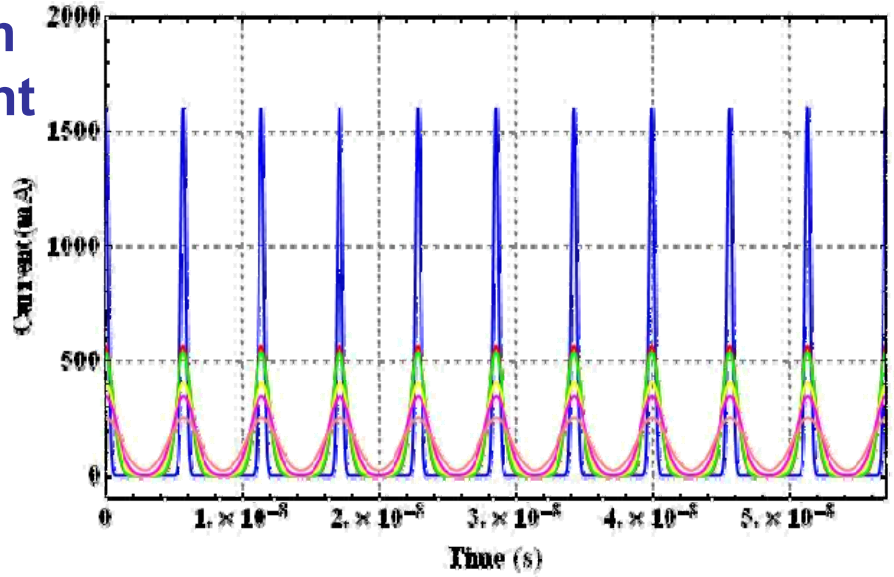


draft

I. Podadera et al., EPAC'08, p. 1248 (2008)

Low-β image current

Beam current



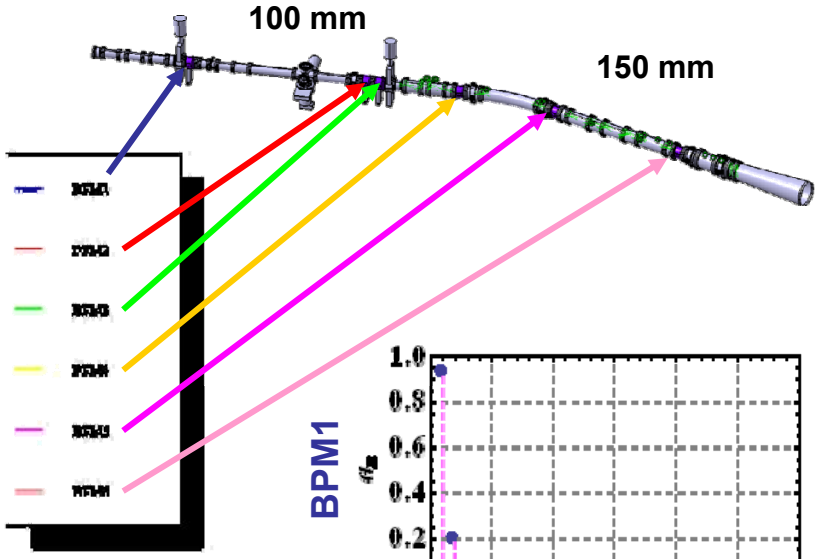
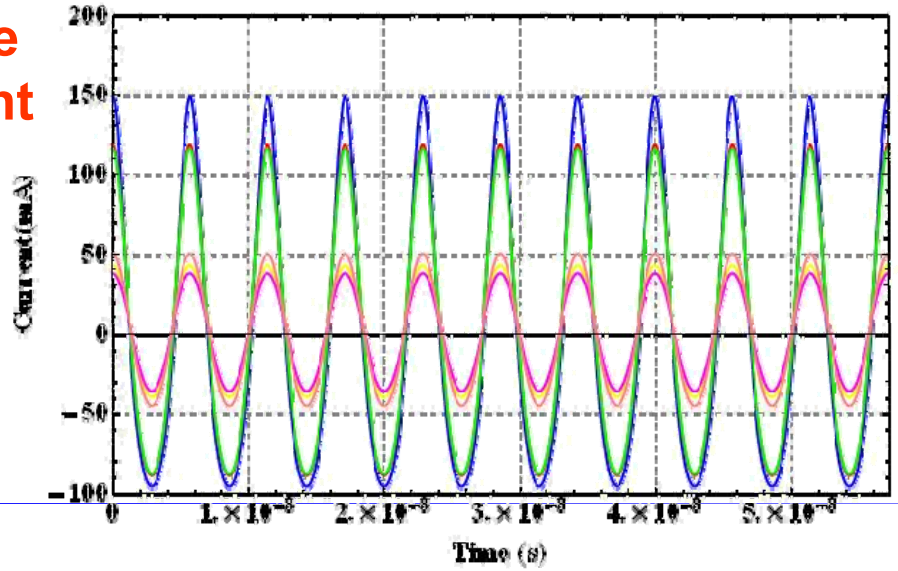
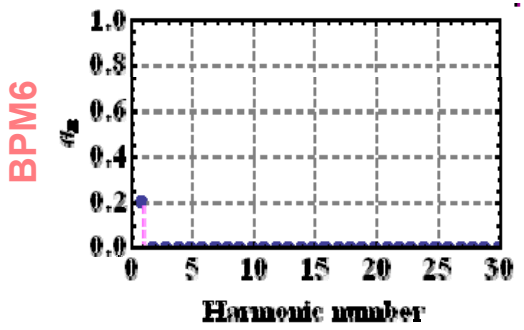


Image current





The fundamental harmonic is reduced almost 5 times from the beginning to the end of the line. The higher harmonics dissapear…

Stripline Beam Position Monitors

- **Shorted stripline Beam Position Monitors along the HEBT (x6).**
- **β=1 approximation not longer valid (Shafer criteria)[1]**
- **Use for beam position measurement (probably at the fundamental harmonic due to the low signal at higher harmonics).**
- **Time of flight measurement (better accuracy than capacitive pick-up for offset beams)[2].**
- **Bunch width measurements at DP using higher harmonics.**

Energy: 5/9 MeV

Position resolution: 10 μm

Absolute precision: 100 μm

Dynamic range: 0.5 mA- 150 mA

Position range: ± 30% aperture.

Linearity error: ±1%.

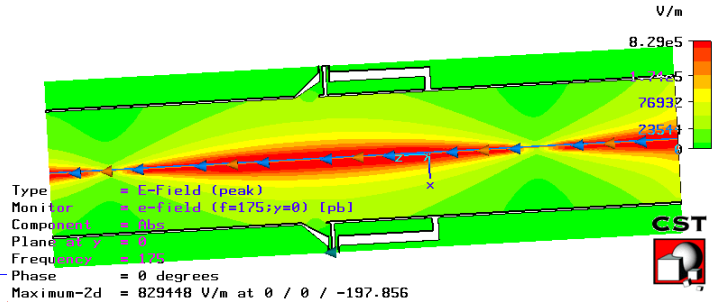
Phase accuracy: 1º-2º.

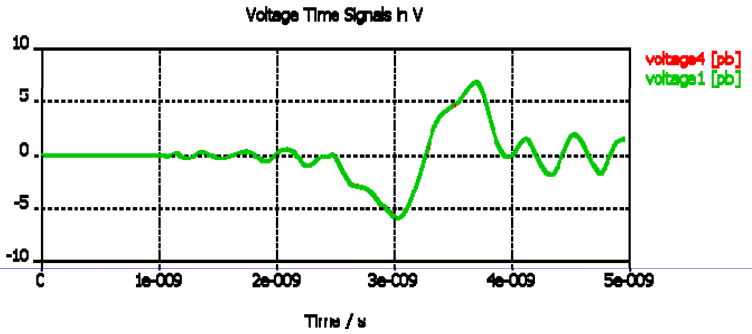
Phase resolution: 0.1º.

[1] R. Shafer, AIP BIW'93,319, p. 303 (1994)
[2] S. Kurennoy, On Beam Phase Detectors for SNS LINAC, SNS 99-65 (1999).

EM simulations

Example for β=0.4





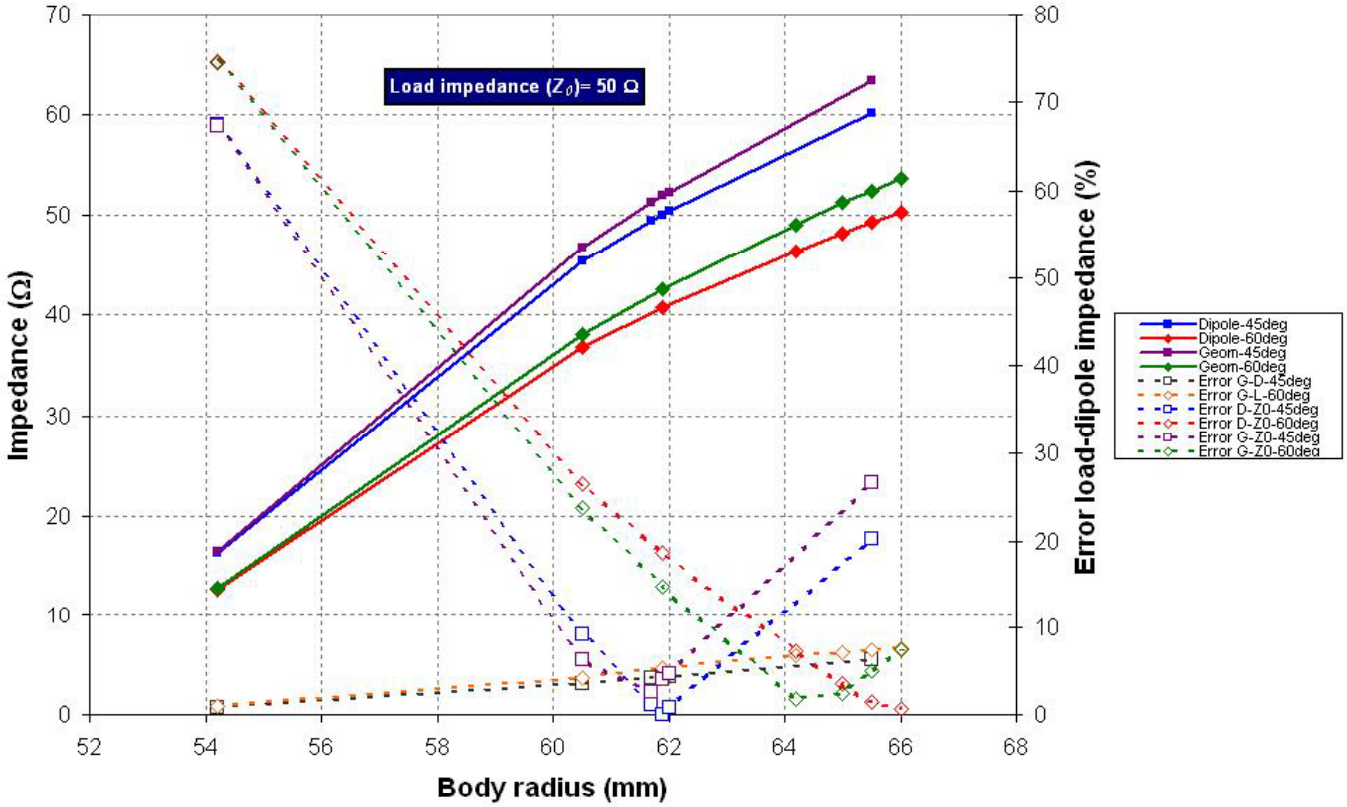
Stripline Beam Position Monitors

Four-strip geometry optimization

Optimization of the geometry parameters using the matching of the four strips with the electronics.

$$Z_{dip} = Z_0 = \sqrt{Z_{sum} Z_{quad}}$$

C. Deibele, Matching BPM stripline electrodes to cables and electronics, PAC'2005, p. 2607 (2005).



Length optimization

Optimum for 175 MHz narrowband measurement

$$l_{opt} = \frac{c}{2f}\left[1/\beta_w + 1/\beta_s\right] \approx$$ **78 mm**

MPS and thermal shock

IFMIF accelerator stop limit (CDR): 10 μs

Maximum time before failure for 90º total beam impact::[1]

$$\Delta t = \frac{2\pi e \sigma_x \sigma_y}{I_0 R_{max}(E_0)} q_{max}$$

Formula for evaluation maximum heat density:[2]

$$q_{max} = \frac{2}{\sqrt{3}} \cdot \frac{c_v}{\alpha E} \sigma_y$$

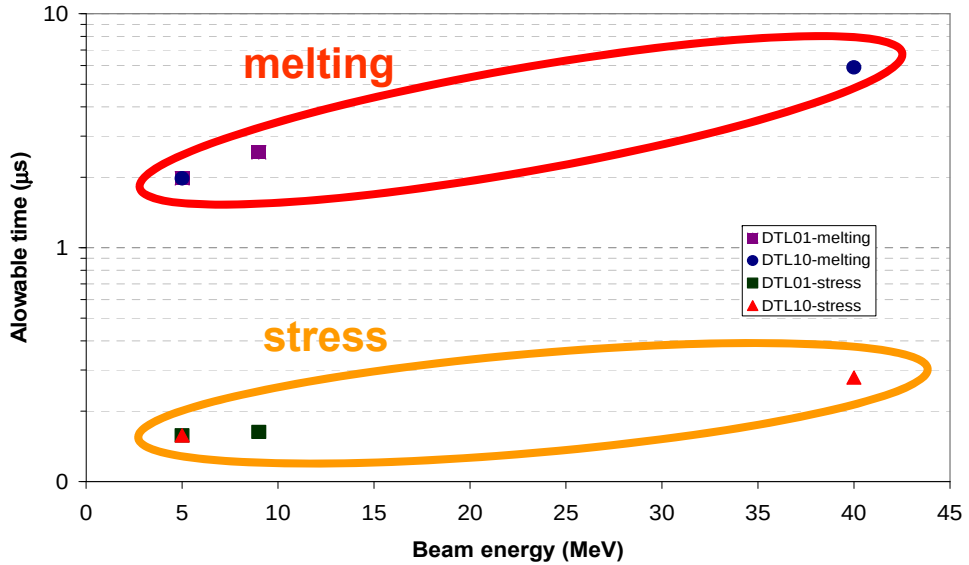
According to the models, at SNS and J-PARC LINACs, the whole pulse injection would not be allowed.[1,2]

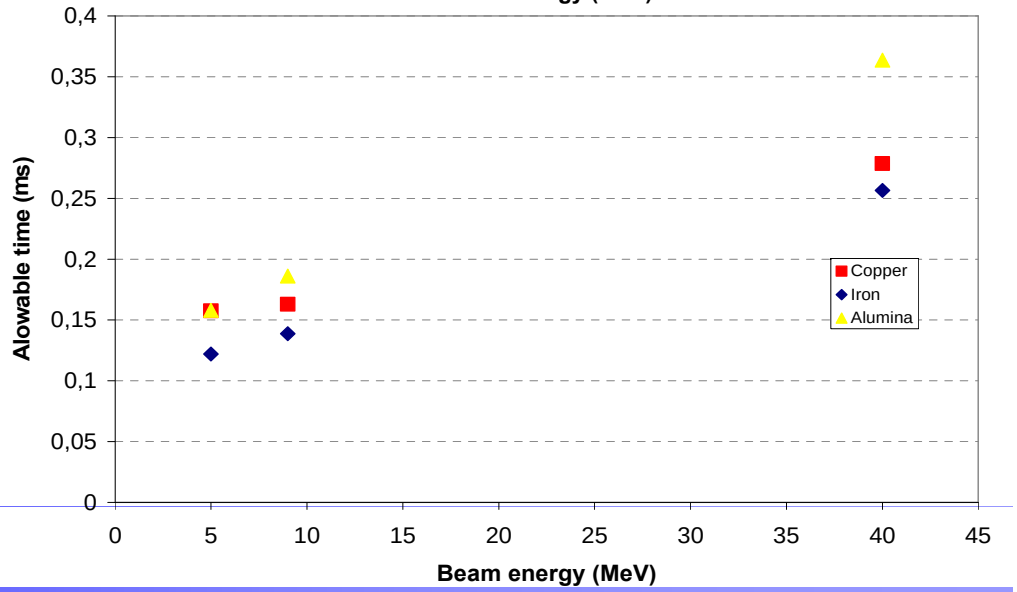
[1] R. E. Shafer, Internal documentation, SNS, 2001.

[2] H. TAKEI and H. KOBAYASHI, J. Nucl. Sci. and Tech., 42, 12, p.1032-1039, 2005.

But a 90º beam impact in the vacuum pipe is not realistic under normal operation conditions…

Time limits for different materials for IFMIF





Transverse Profile

Energy: 5/9 MeV

Aperture: 100/150/200 mm.

Dynamic range: ±3σ.

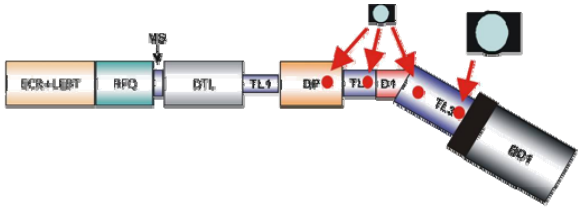
Accuracy: 250 μm, 5 μA.

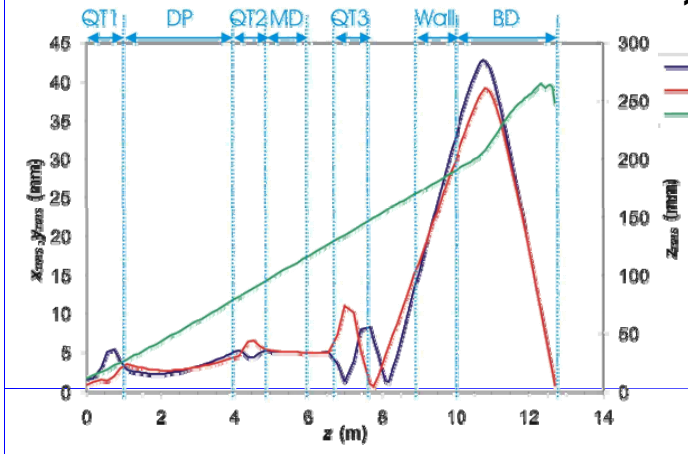
Rms precision: 100 μm, 2 μA.

Frequency bandwidth: 10 Hz.

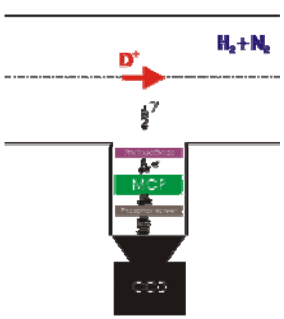
Two non-interceptive methods based on interaction between gas in the chamber and deuteron beam are under design and will be installed at IFMIF-EVEDA.

Fluorescence (FPM)
(CIEMAT development)

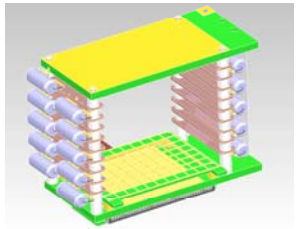




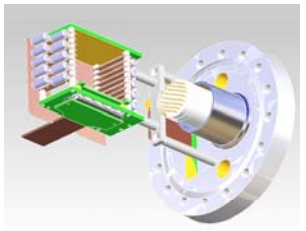
Preliminary calculations:
10^{10} photon/s at 9 MeV, 125 mA



Ionization (BTPM)
(CEA-Saclay development)



Detector : microstrips, grid, resistors for a uniform electric field…



Detector mounted on its flange



Detector assembly in the vacuum pipe

J. Marroncle et al., proceedings BIW'08, 2008

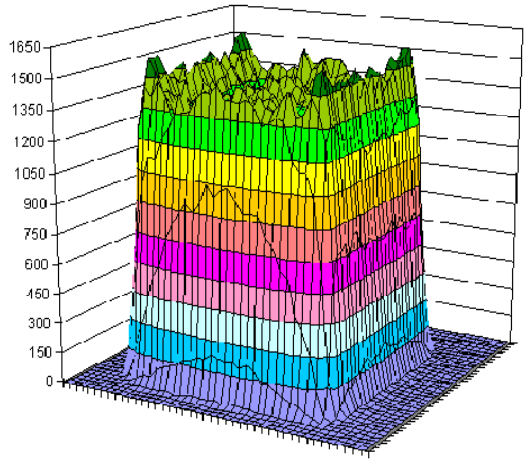
First experiments carried in Saclay with protons at 95 keV, 100 mA

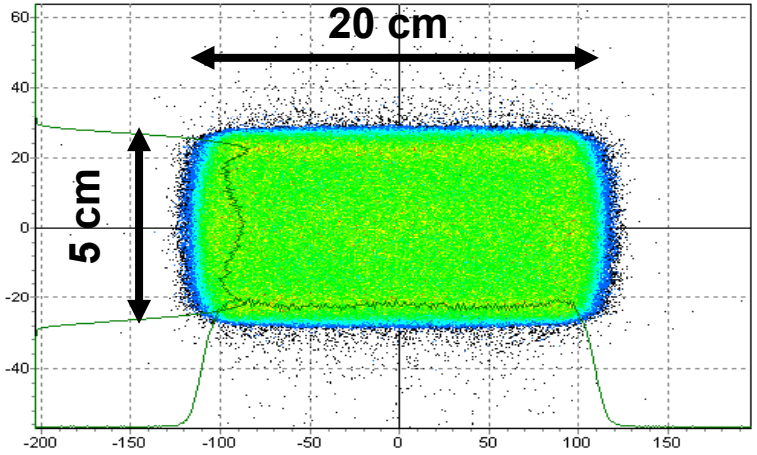
IFMIF profiler

- **Key device for operation of the IFMIF accelerator.**
- **Control the overlap between both accelerators and the flat transverse profile.**
- **Several techniques have been already analyzed.[1]**
- **IFMIF profilers will be tested near the BD region at IFMIF-EVEDA (high neutron flux).**

[1] E. Surrey et al., A beam profile monitor for IFMIF reference, EFDA TW5-TTMI-001 (2006)

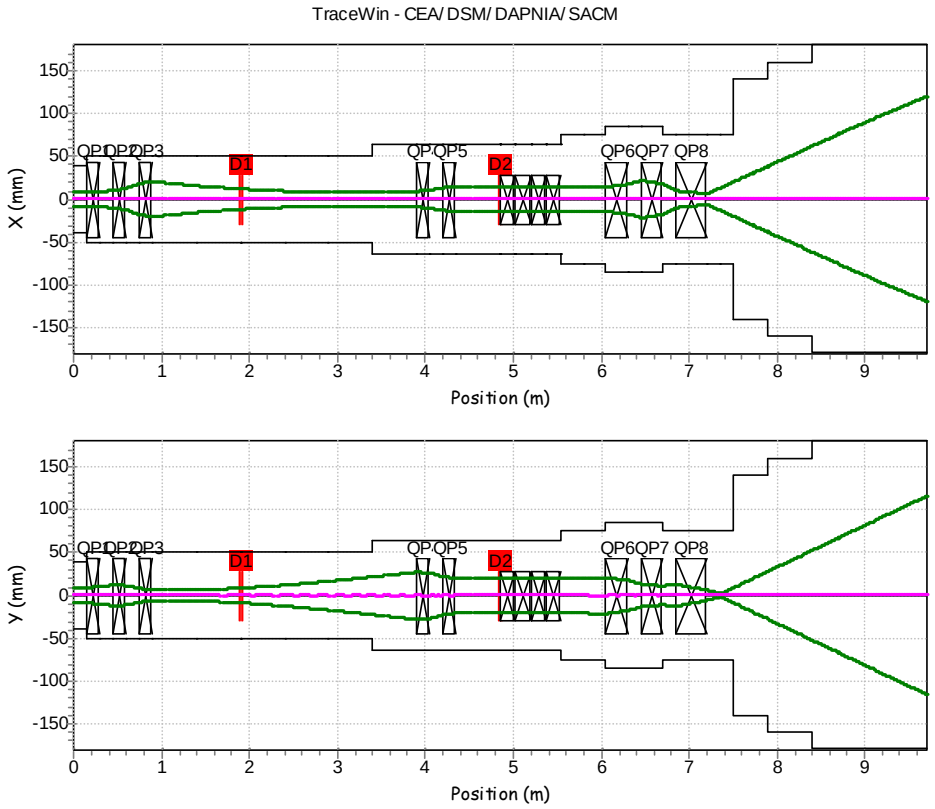
Beam footprint at interaction point

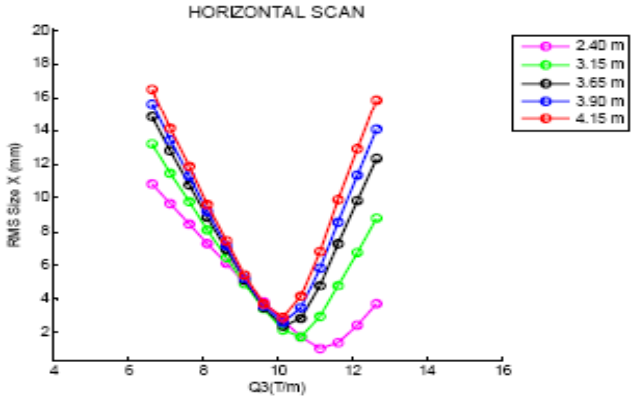


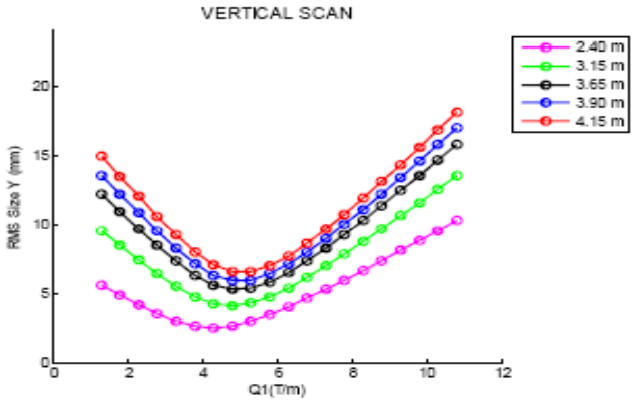


Transverse emittance

- **Quadrupole scan in a free dispersion region (before spectrometer).**
- **Resolution affected by space charge (non-linear optics).**
- **Compromise between maximum size (beam losses) and minimum size (halo creation).**







C. Oliver et al., *HEBT for the IFMIF-EVEDA accelerator*, EPAC'08, p. 3041 (2008)

Conclusions

- **HEBT diagnostics will have to permit the safe transport of the IFMIF-EVEDA high-intensity deuteron beam from the HWR up to the beam dump.**
- **The beam will be fully characterized with a movable diagnostics plate and a spectrometer.**
- **Low beam energy and high intensity precludes the use of any interceptive diagnostics.**
- **The instrumentation placed near the BD will receive high radiation, it will be a good place to test the future IFMIF profiler.**
- **Electromagnetic pick-ups are challenging due to the low beta effect, the debunching process and the relatively high beam pipe diameter.**
- **An intensive R&D programme about the use of non-interceptive gas diagnostics (fluorescence & ionization) to monitor the transverse profile has started and its success is almost mandatory for the accelerator operation.**
- **Due to the high intensity, non-linear space charge forces make difficult the implementation of non-interceptive methods for the measurement of emittances and energy spread.**

We want to thank the support and help of all the ASG

Thanks for your attention!!!