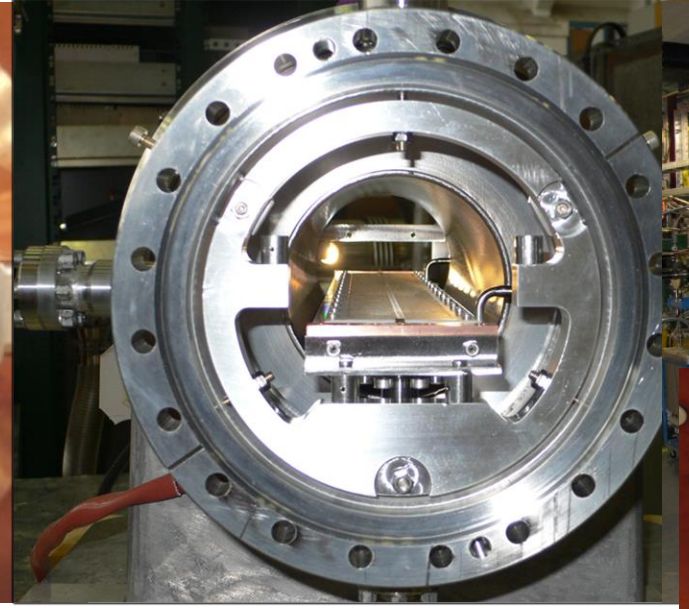
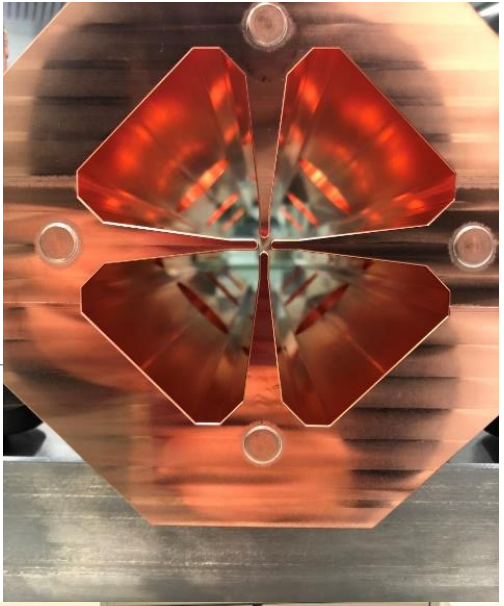
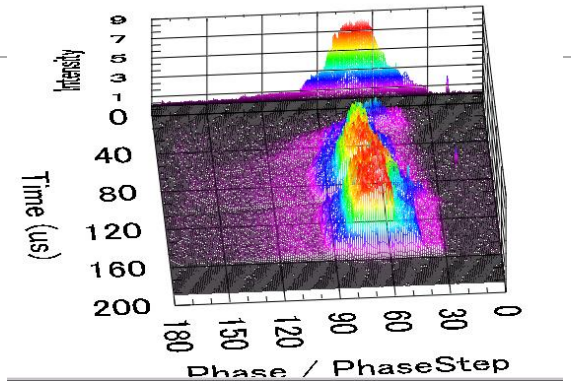
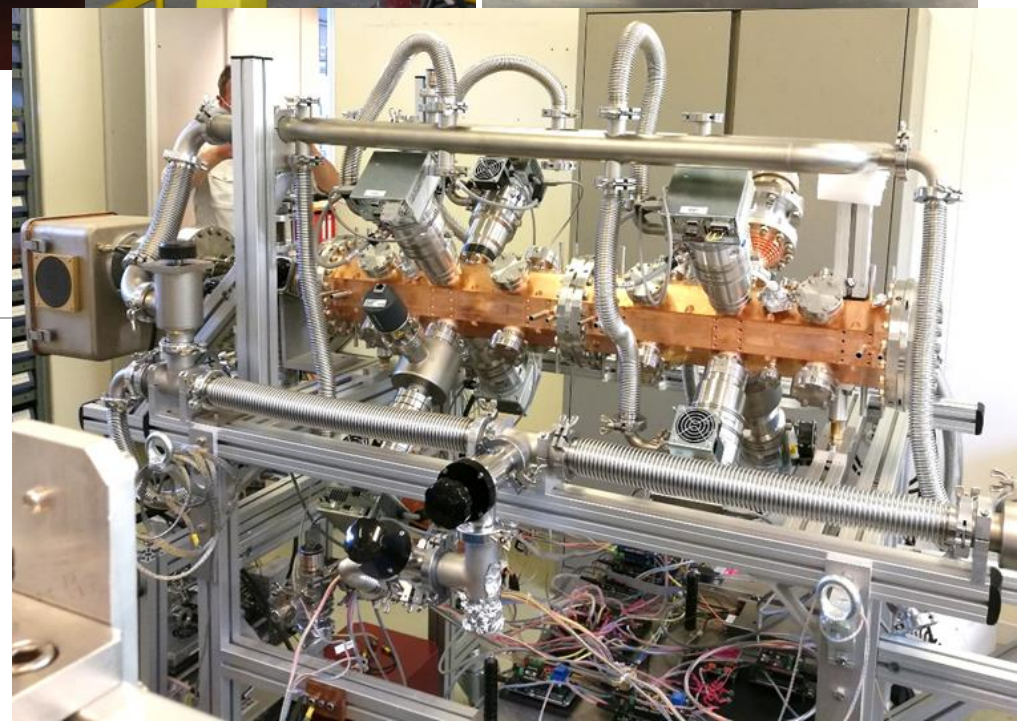



High-frequency RFQ for societal and medical applications

Alessandra M Lombardi (BE-ABP-HSL)



Outline

Highlight of Linac 4 (2006-2020)

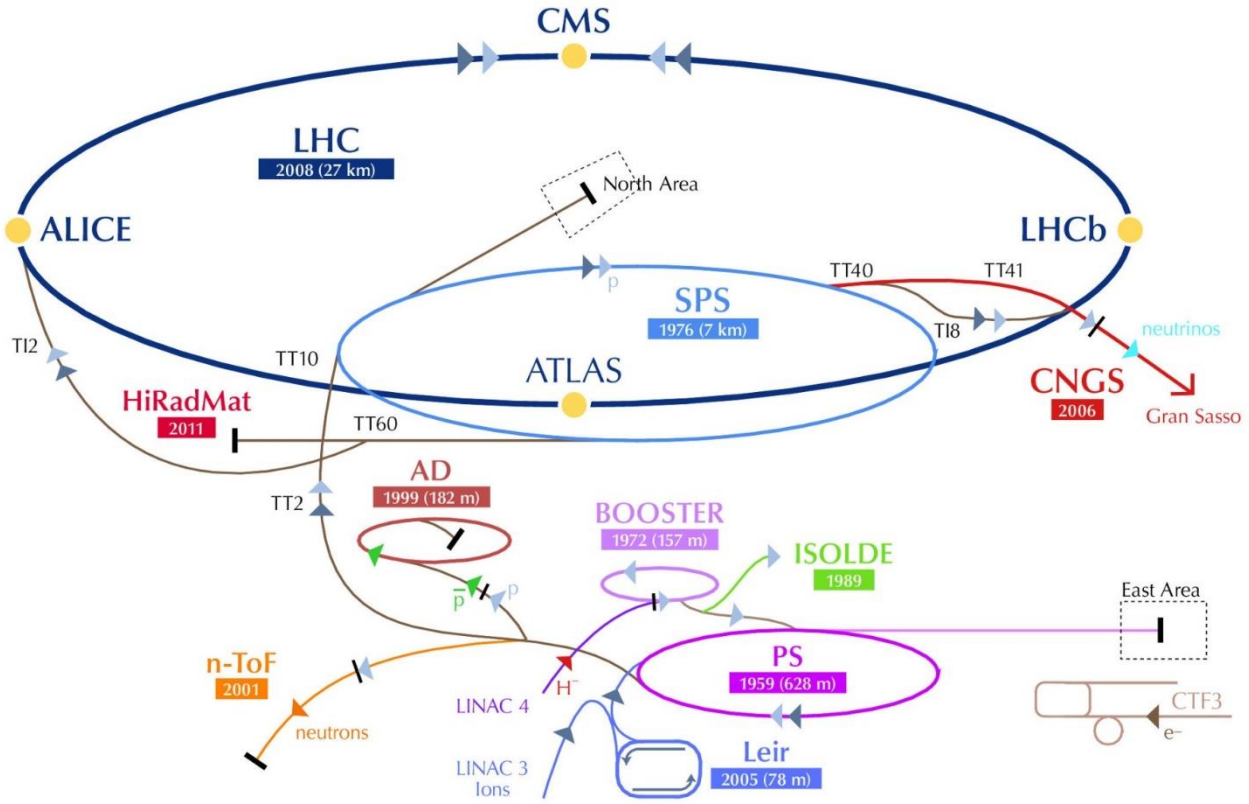
R&D on LINAC4 was applied in medical and societal projects

LIGHT : 750MHz RFQ for medical protons (2015-2017)

ELISA-MACHINA : 750 MHZ RFQ for societal use (2017-2022)

HELIUM and Fully stripped Carbon: 750 MHZ RFQ for carbon ion (about to be tested)

CERN ACCELERATOR COMPLEX



The big picture : LHC Luminosity

$$\mathcal{L} = \frac{\gamma}{4\pi} \times f_r \times \frac{F}{\beta^*} \times n_b \times N_b \frac{N_b}{\varepsilon_n}$$

From optics at Interaction point

From machine design and limitations (e cloud)

Brightness from Injectors : defined at low energy

N_b	number of particles per bunch
n_b	number of bunches
f_r	revolution frequency
ε_n	normalised emittance
β^*	beta value at Ip
F	reduction factor due to crossing angle

LHC INJECTOR CHAIN :

Linac2 (50 MeV) 1978 length 40 m
160mA , 100 µsec , 1 Hz
Max Space Charge Tune Shift reached
↓
PS Booster (1.4 GeV) 1972 – radius 25 m
4 rings stacked
Output energy already upgraded twice
↓
PS (25 GeV) 1959 – radius 100 m

↓
SPS (450 GeV) - 1976 radius 1100 m

PS/RF/Note 96-27
25 October 1996

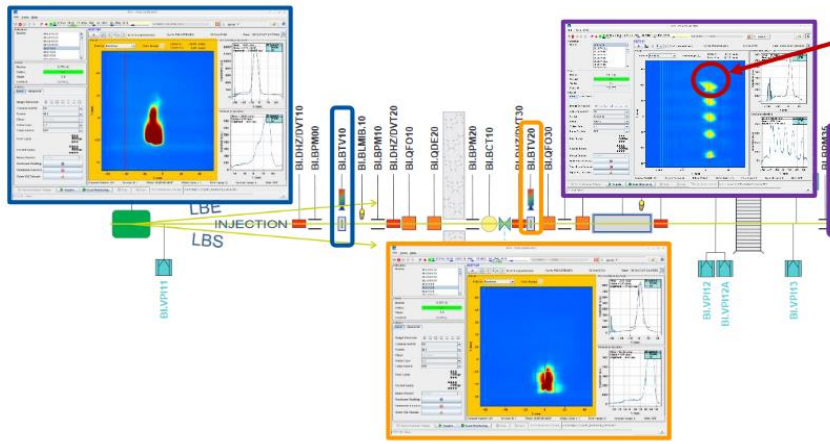
PROPOSAL FOR A 2 GEV LINAC INJECTOR
FOR THE CERN PS

R. Garoby, M. Vretenar

CERN–AB–2006–084 ABP/RF

Linac4 Technical Design Report

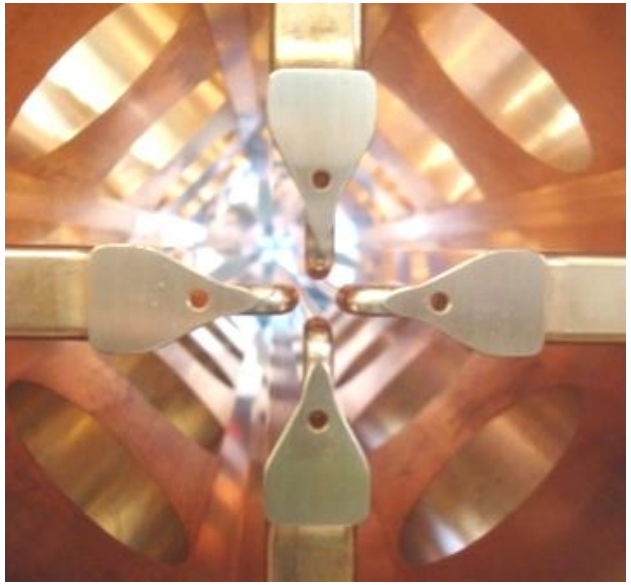
- At 13h00 first beam crossing LTB.BHZ40 and threading to the first BTV, BI.BT



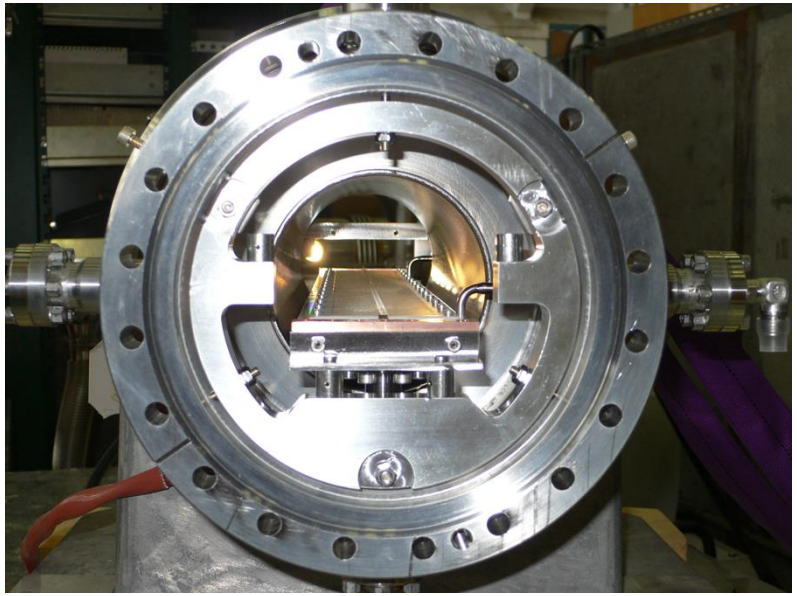
Proposals (1996-2006) → Decision in 2007 R. Aymar director general → Ground Breaking ceremony : 16 October 2008 → Inauguration : 9 May 2017 → Injection in PSB : 7 December2020

In its June 2007 session the CERN Council has approved the White Paper "Scientific Activities and Budget Estimates for 2007 and Provisional Projections for the Years 2008-2010 and Perspectives for Long-Term", which includes construction of a 160 MeV H- linear accelerator called LINAC4, and the study of a 5GeV, high beam power, superconducting proton Linac (SPL).

Innovations in LINAC4



3 MeV/ 352 MHz/ 3 m long RFQ
Commissioned with beam 2013
Experience used for design of equivalent Radio Frequency Quadrupole for medical and societal applications



Fast chopper, validated 2013
Risetime<10nsec/ extinguish factor 100%

PMQ for tank2 , 60 mm in diameter and 80 mm in length
Produced in European industry for the first time

LIGHT pre-injector

2014

- *S. Myers : head of office for medical applications*
- Study efficient accelerator in the energy range few keV to 5 MeV for a LINAC-based hadron-therapy facility (3GHz)

2015-16

- 2015 Construction and assembly at CERN
- 2016 installation at SA2 includes a commercial proton source

2017

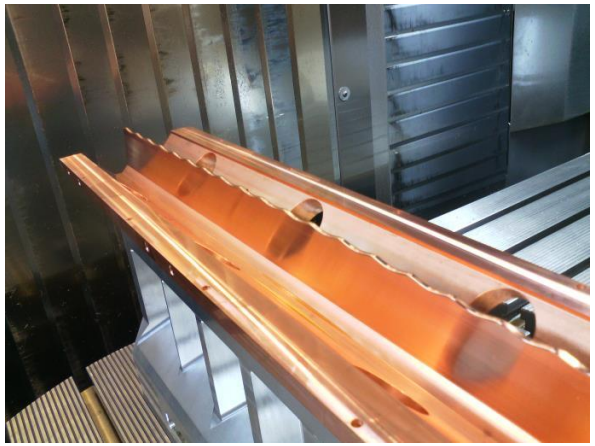
- First beam in February
- Validation of the beam dynamics
- CERN was granted a patent

2017 - 2023

- Used by ADAM/AVO at CERN as a pre-injector for a hadron based facility (tests up to 70MeV)

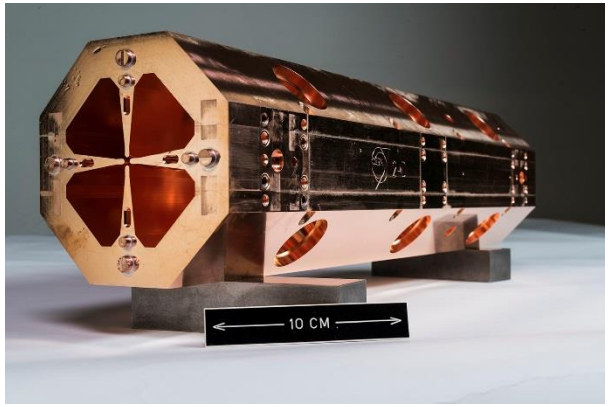
2015 - CONSTRUCTION

Source and RFQ parameters	
RF Frequency	750 MHz
Input	40 keV
Output Energy	5 MeV
Length	2m
Vane voltage	65kV
Peak RF power	400kW
Duty cycle / max	0.4% /(5%max)
Input/Output Pulse Current in 3GHz acceptance	100/30 µA
Transv. emittance 90%	0.1 pi mm mrad
Average aperture (r0)	2mm
Maximum modulation	3

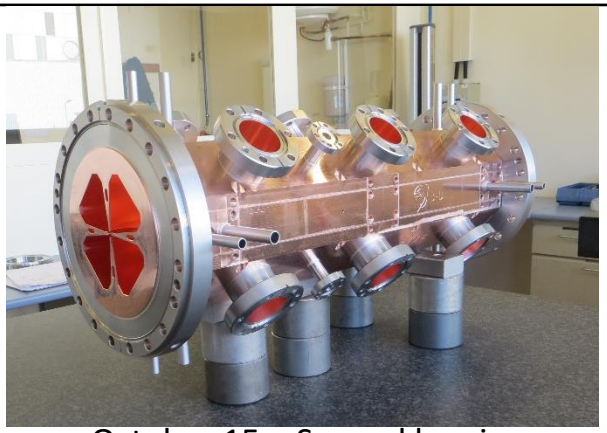


March 15 -Machining (±10 µm)

May 15- Assembling (±15 µm)

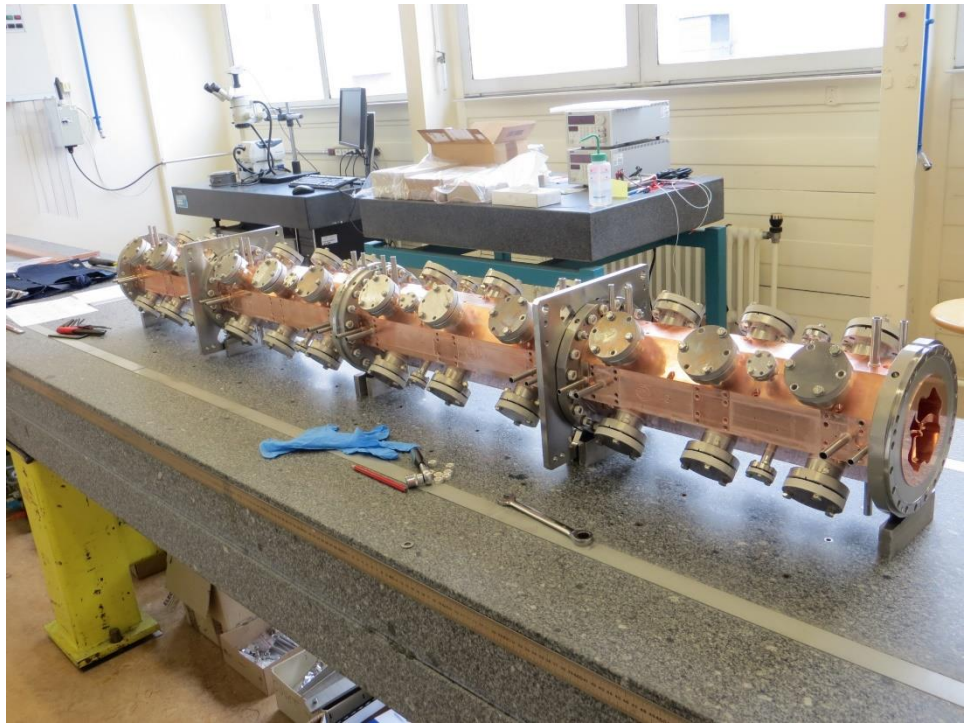


June 15 - First brazing

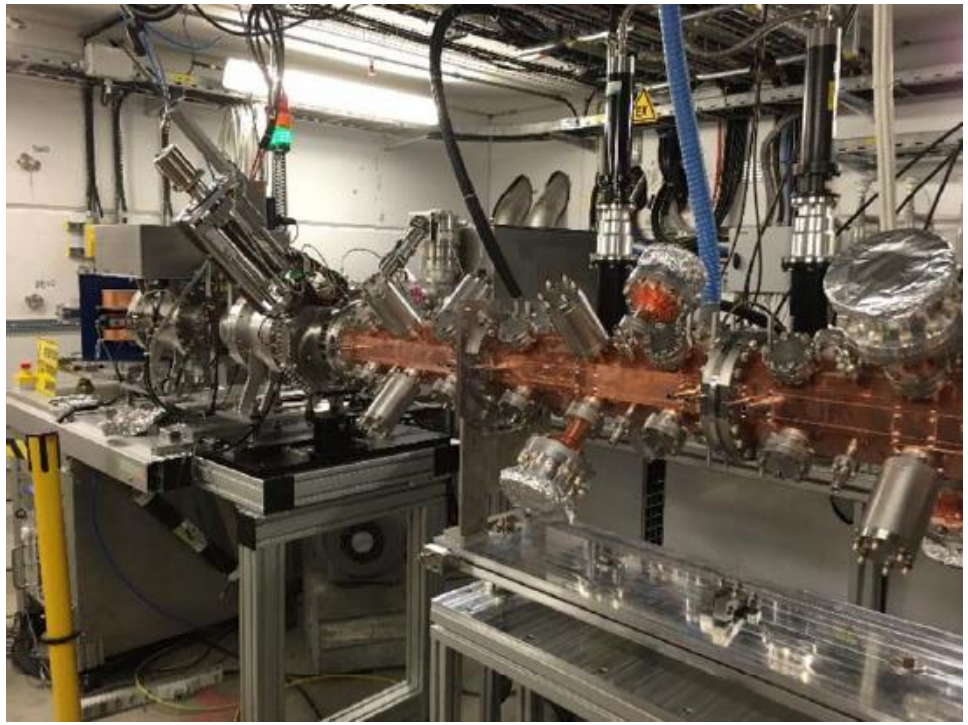


October 15 – Second brazing

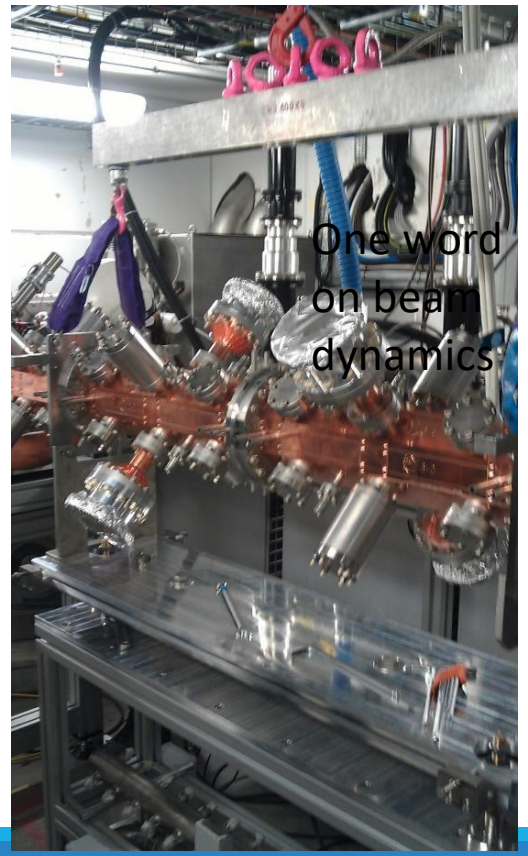
2016 : assembly, tuning and high power RF



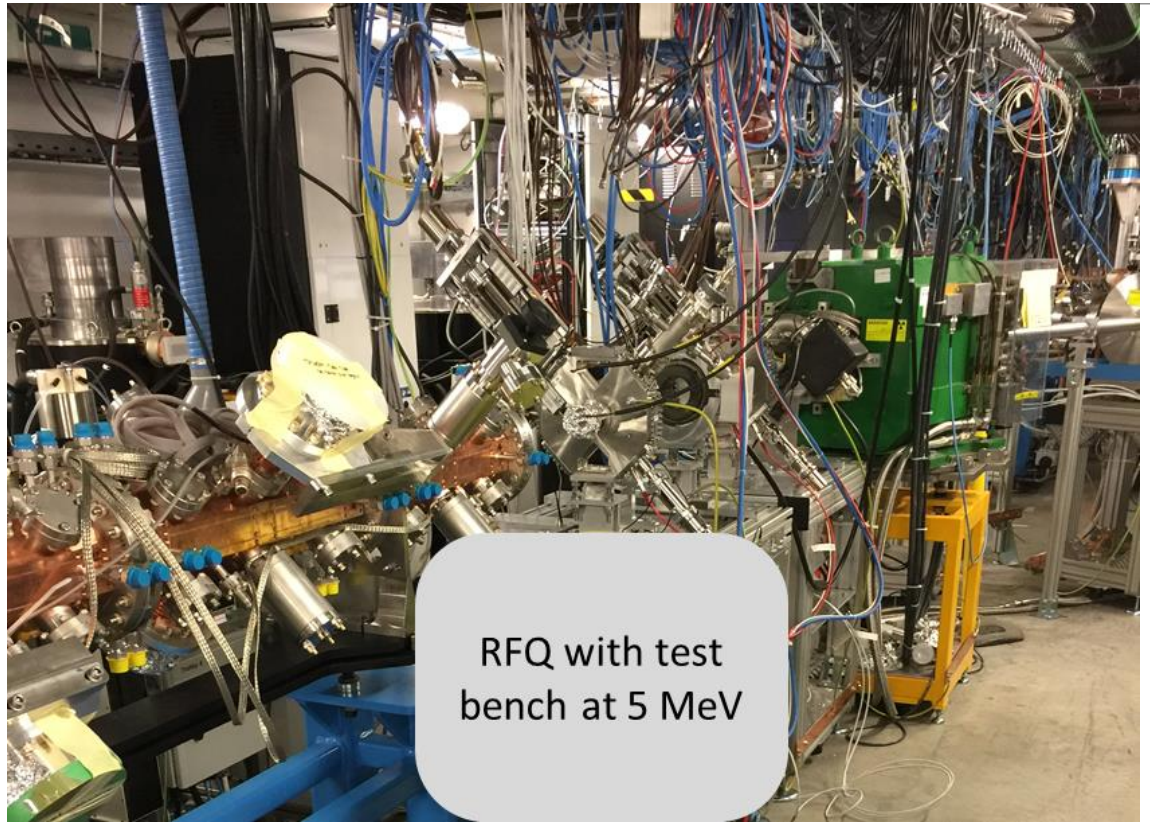
RF measurements

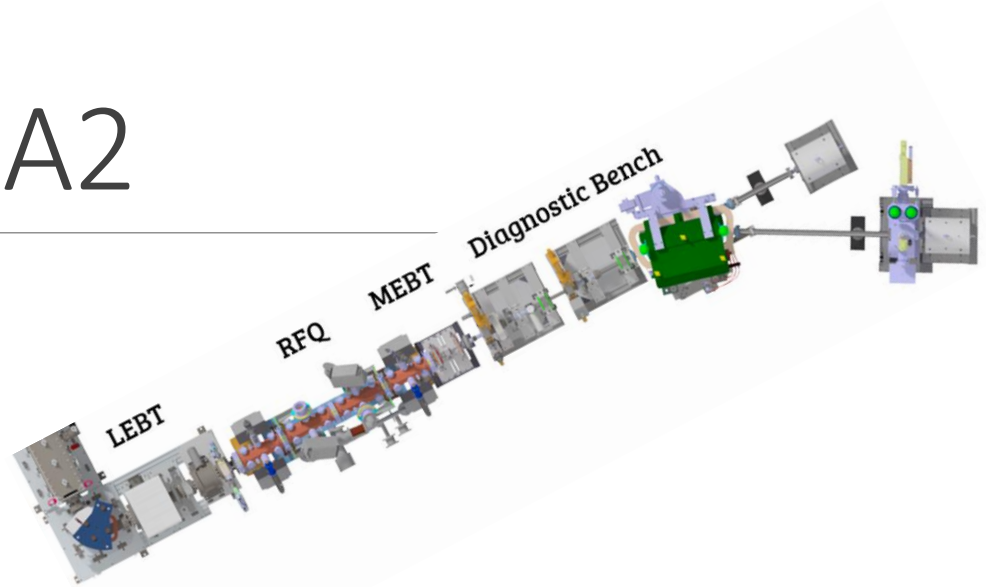


Ready for beam tests



2017 : proton beam at SA2





LOW ENERGY PRE-INJECTOR for ADAM/AVO test facility at SA2

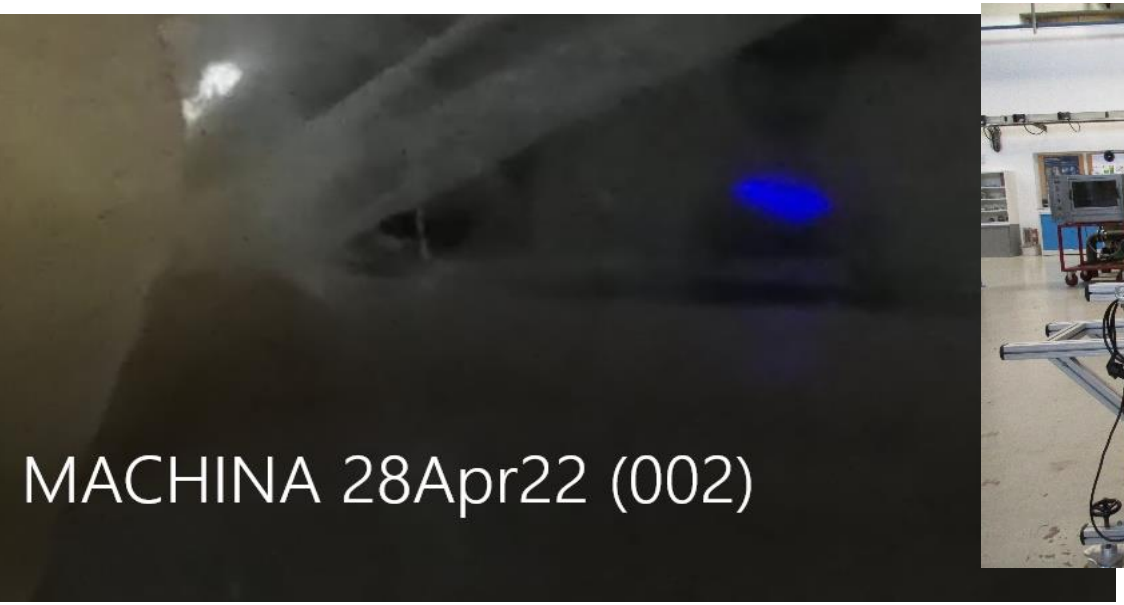
Radically new design from the beam dynamics point of view- validated by beam measurements. It build on the experience of the LINAC4 RFQ for RF design and mechanical design.

Built in the CERN workshop : less than 2 years from start of construction to installation, this included RF tuning.

A copy is built in industry.

MACHINA

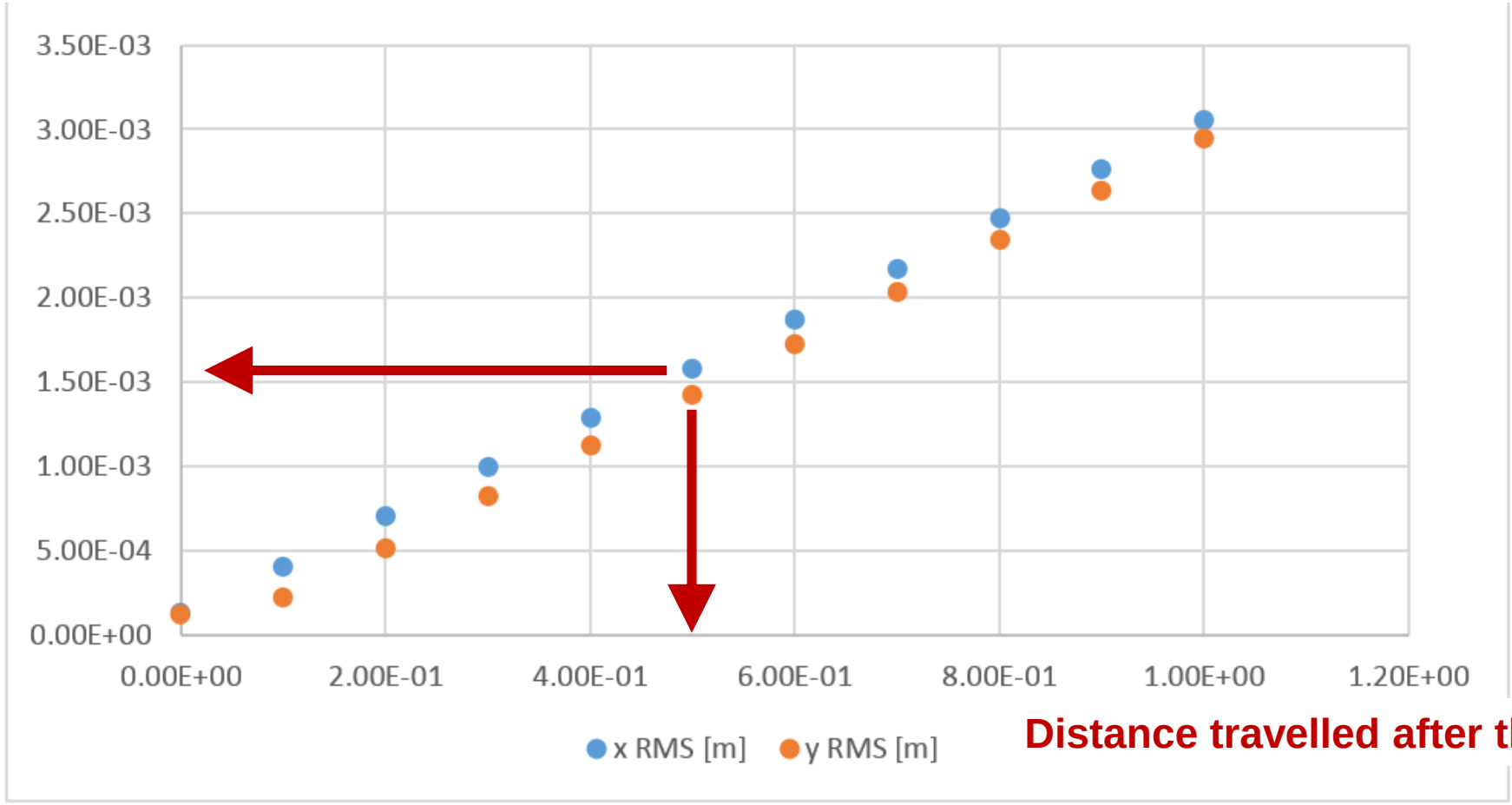
Laboratorio di tecniche nucleari per l'Ambiente e i Beni Culturali
INFN e Dipartimento di Fisica e Astronomia dell'Università di Firenze



Light from the Bragg peak at 2 MeV (measured at CERN).

Source and RFQ parameters	
RF Frequency	750 MHz
Input	20 keV
Output Energy	2 MeV
Length	1m
Vane voltage	35kV
Peak RF power	100kW
Duty cycle / max	0.4% /(5%max)
Input/Output Pulse Current in 3GHz acceptance	100/30 µA
Transv. emittance 90%	0.1 pi mm mrad
Average aperture (r0)	1.4 mm
Maximum modulation	2.8

The 2 MeV proton beam downstream of the RFQ exit port

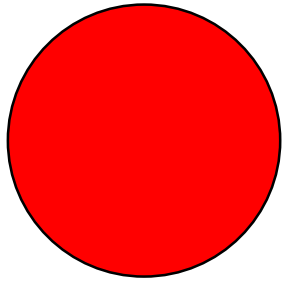


0.5 m Desired HE Beamline lenght

From simulations :

75 cm beamline after the RFQ + 2 PMQ 40 T/m

⇒ Beam spot size on sample ~ 400 μm



40 cm beamline after the RFQ + 2 PMQ 80 T/m

⇒ Beam spot size on sample ~ 400μm

Where can we go?

with 2 PMQ 80 T/m, we could have a

⇒ beam spot size on sample of ~35 μm

with 2 PMQ 90 T/m, we could have a

⇒ beam spot size on sample of ~20 μm

⇒⇒

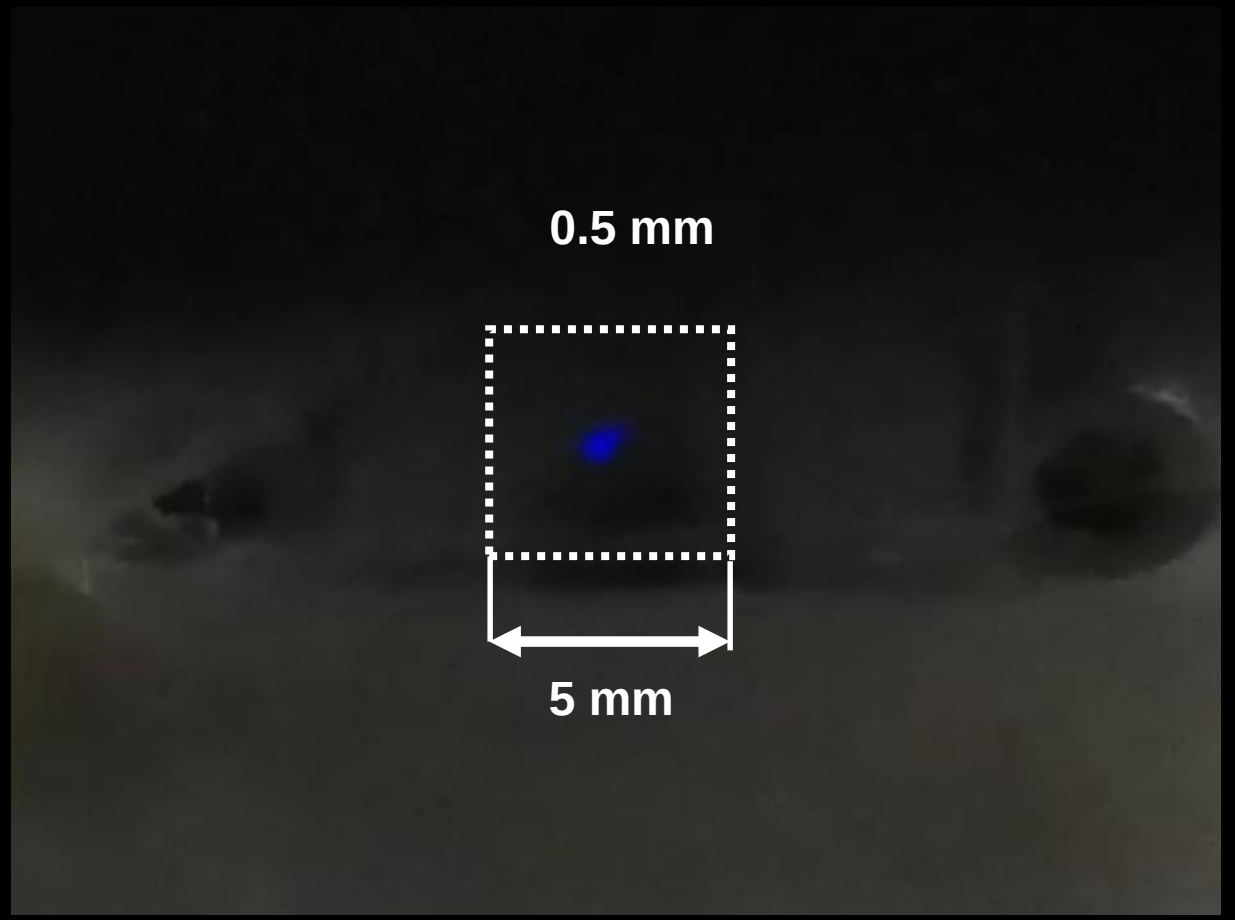
BEAM

First extracted beam

PMQ adjusted

First extracted beam

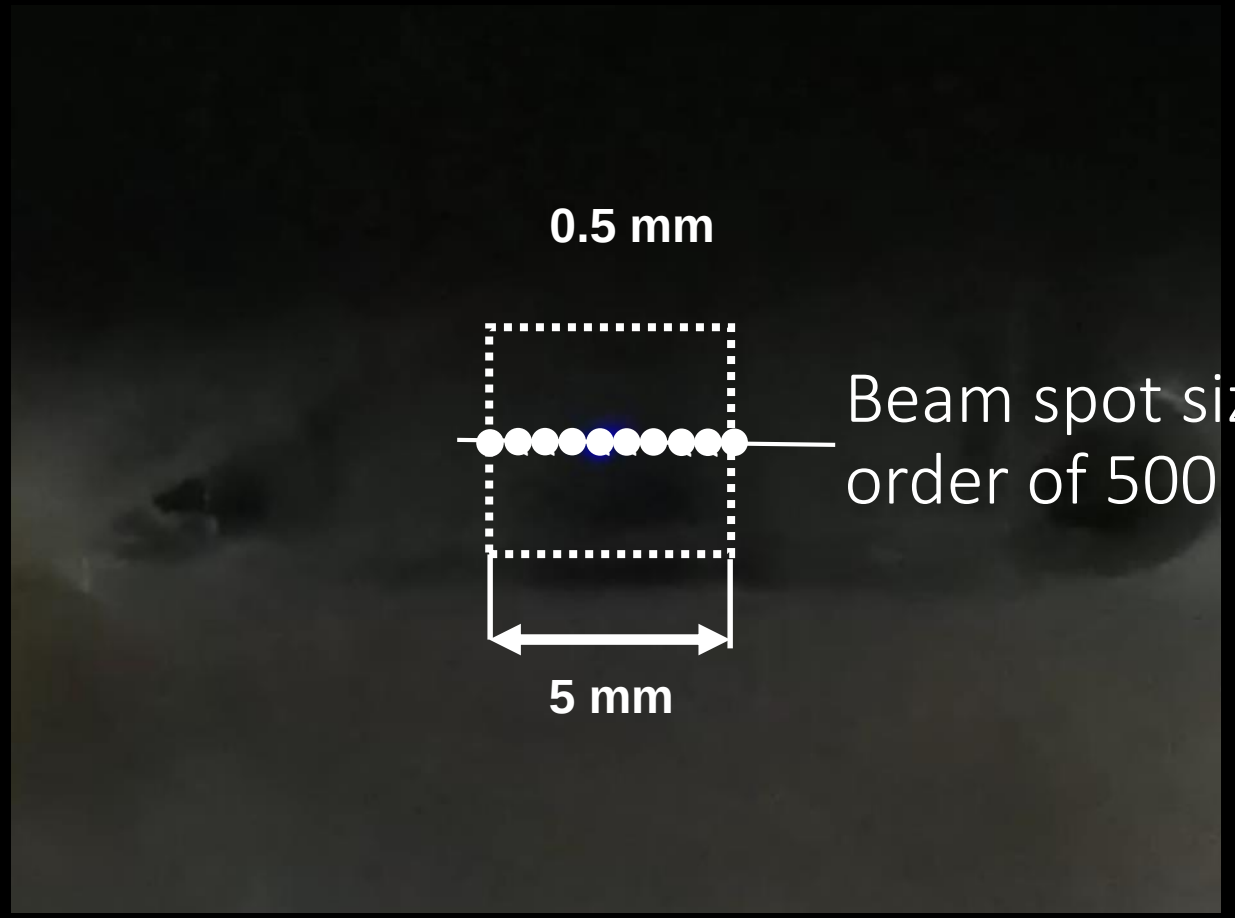
PMQ roughly optimised



BEAM

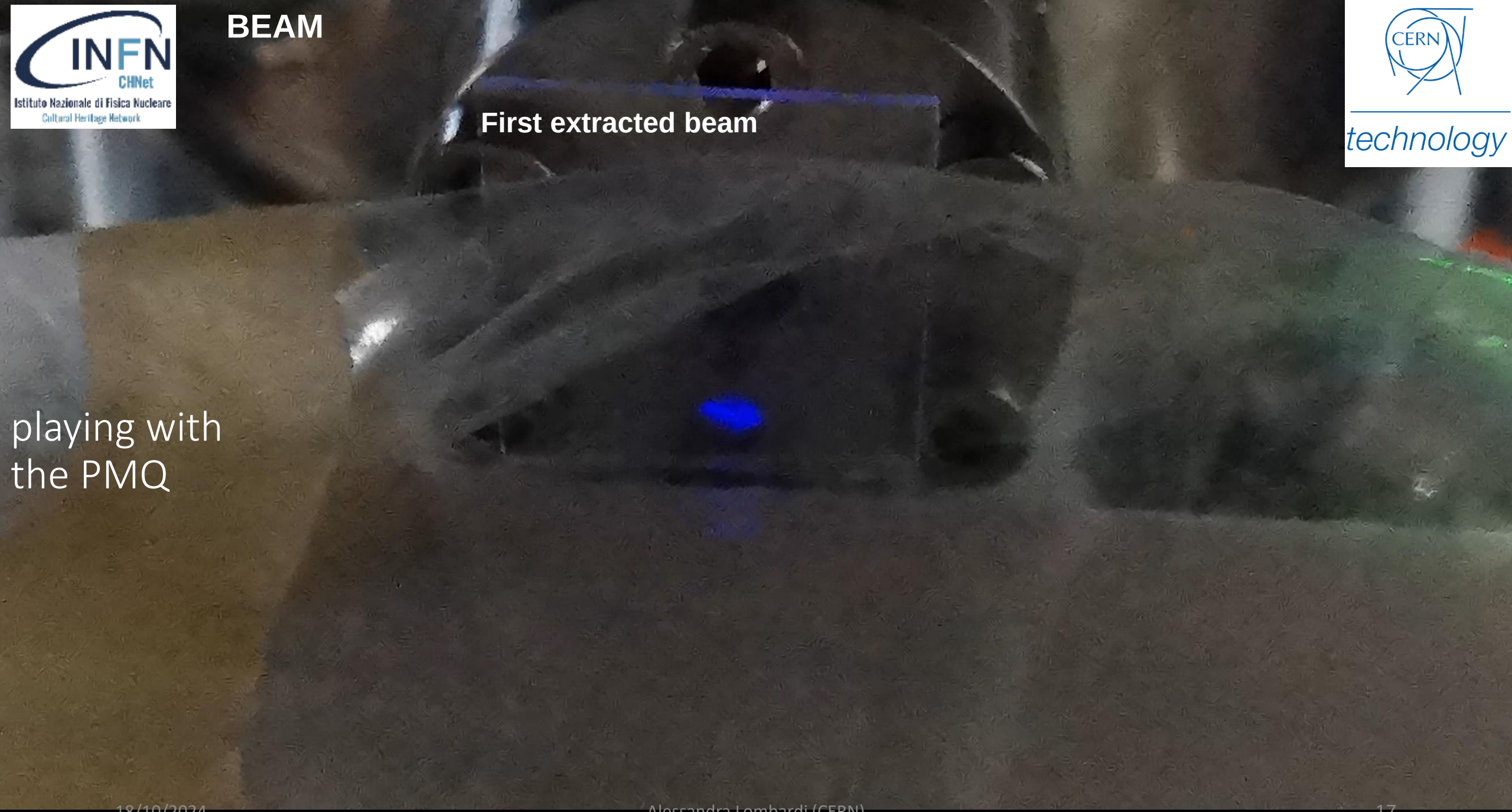
First extracted beam

PMQ roughly optimised



Beam spot size of the order of 500 μm

BEAM

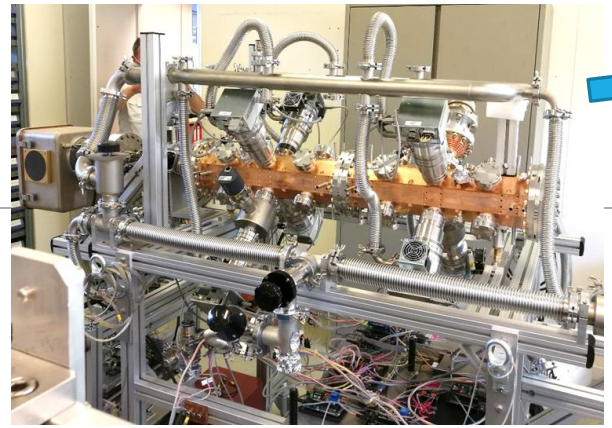


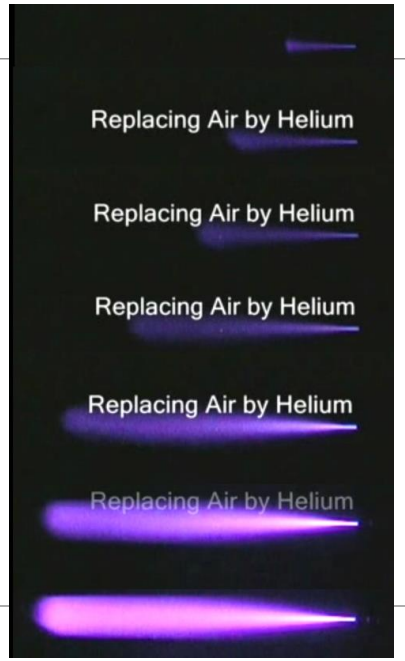
playing with
the PMQ

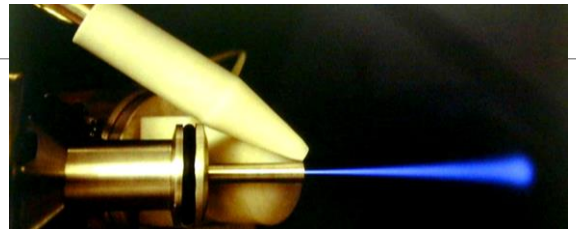
ELISA

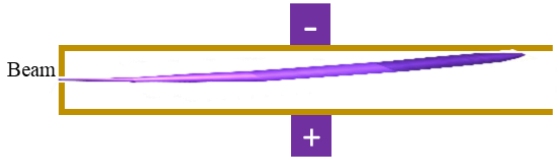
Experimental Linac for Surface Analysis

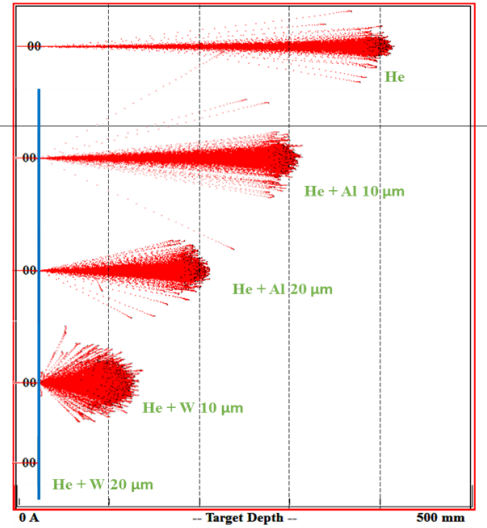
A miniature proton accelerator for Science Gateway







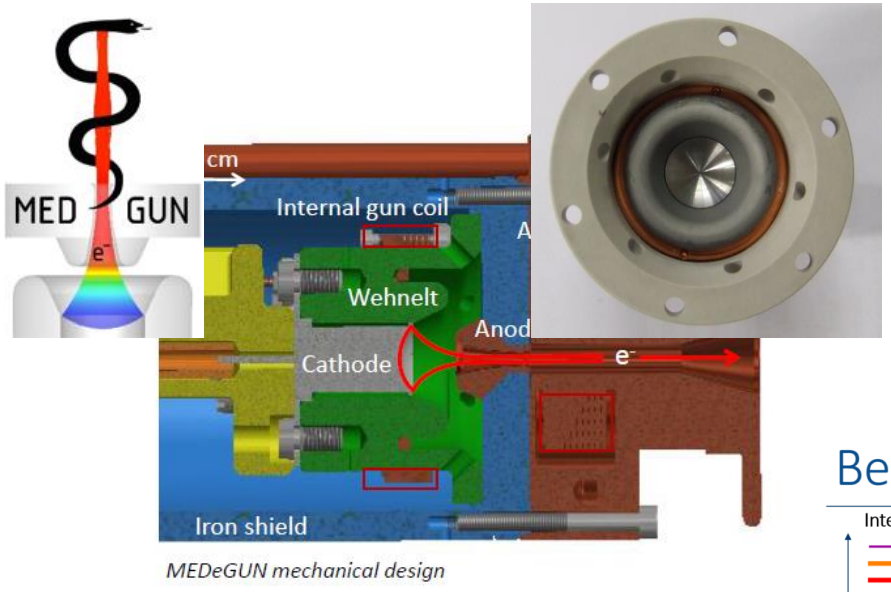




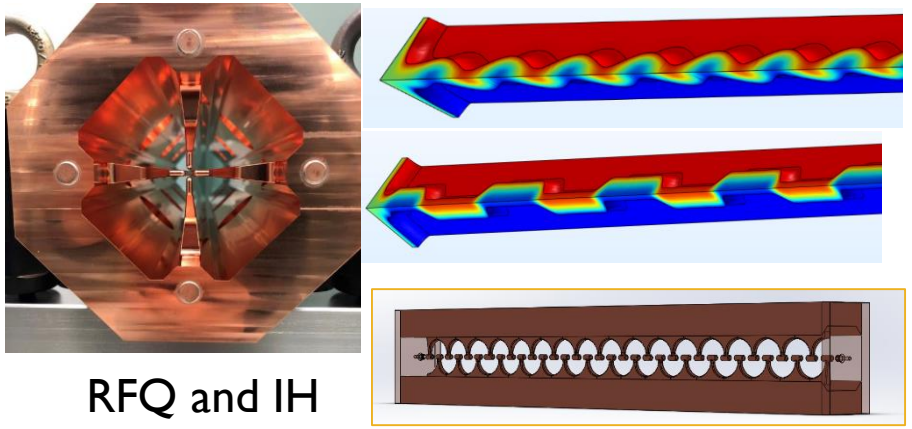
Demonstration / Experience to the public with the beam

NEXT challenge : accelerate Carbon in a LINAC

1- Source of fully stripped carbon ion with sufficient quality for use in a medical facility



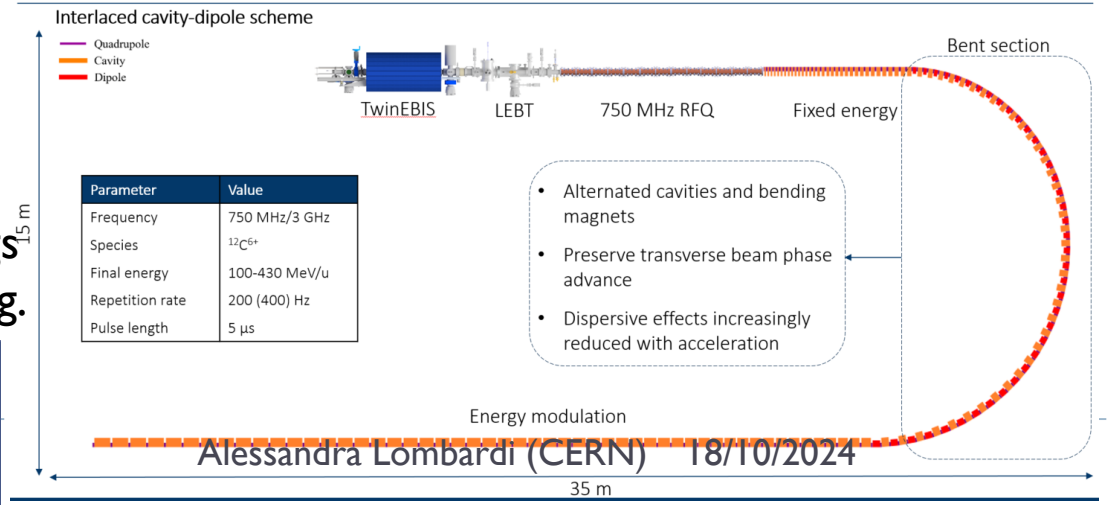
MEDeGUN mechanical design



RFQ and IH

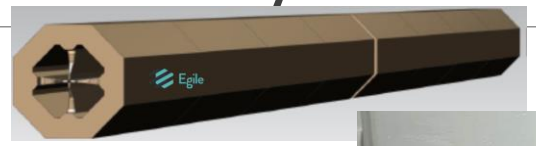
2- An efficient and easy to use pre-injector

Bent linac



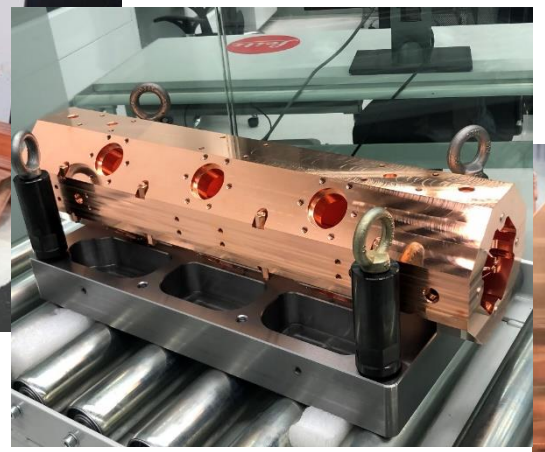
3- LINAC with a "hospital-friendly" footprint , adaptable to existing buildings and allowing intermediate station for e.g. Radioisotope production

Collaboration CERN-CIEMAT-CDTI-Spanish Industry – RadioFrequencyQuadrupole

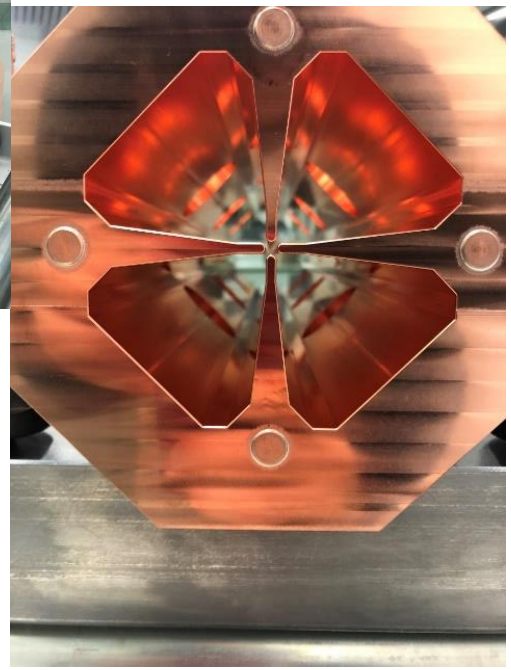


1-Drawings

2-Precision machings



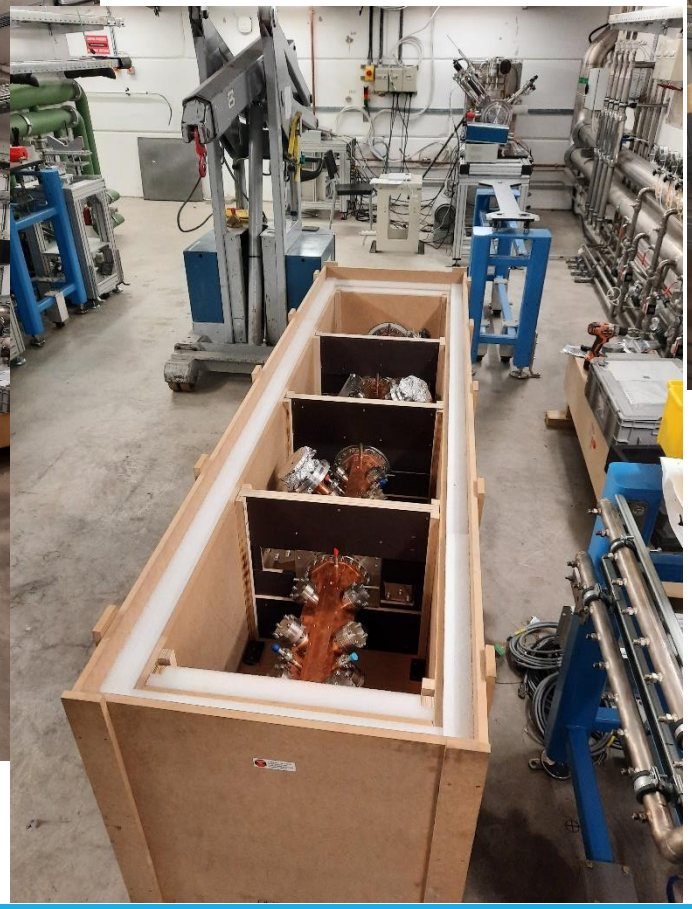
3-Assembly and brazing

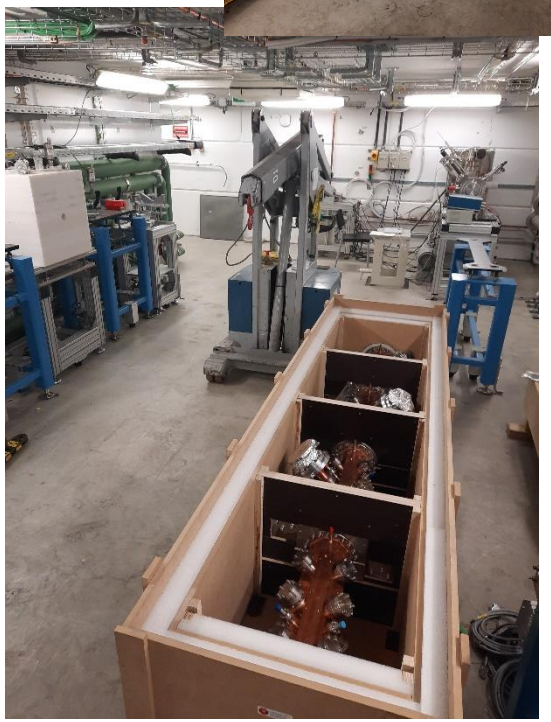


4-First (of 4) section completed

2.5 m long
750 MHz
Will deliver Carbon (or Helium) at 10 MeV (total energy)
Designed at CERN built in Spanish Industry

Hot from test stand





Future plans

We have

- A proton source designed to inject DIRECTLY into the RFQ – see Aris Mamaras contribution in a moment
- A helium source + a Low Energy Beam Transport designed to match a helium beam to the RFQ acceptance – Amer Ajanovic contribution
- A 750 MHz RFQ designed to accelerate from 15keV/ to 2.5 MeV/u particles with q/m =1/2

We will then

Characterize the proton and helium sources for use with the RFQ and accelerate the beam through the Carbon RFQ

Validate (hopefully) the 750 MHz RFQ design and proceed to the construction of the second RFQ to bring the beam to 5MeV/u

Milestones in the development of RFQ at CERN.

1990	2007	2014	2019	2020
RFQ2 200 MHz 0.5 MeV /m Power/m 244kW/m P/MeV 670kW/MeV Weight :1200kg/m Ext. diametre : ~45 cm 200mA proton	LINAC4 RFQ 352 MHz 1MeV/m Power/m 133 kW/m P/MeV 135kW/MeV Weight : 400kg/m Ext. diametre : 29 cm 40 mA H-	HF RFQ 750MHz 2.5MeV/m Power/m 200kW/m P/MeV 80 kW/MeV Weight : 100 kg/m Ext. diametre : 13 cm 0.1 mA proton COMPACT	MACHINA / ELISA 750MHz 2.0MeV/m Power/ m 80kW/m P/MeV 40kW/MeV Weight : 100 kg/m Ext. diametre : 13 cm 0.1 mA proton Portable	Name_to_ be_ found 750MHz 1.0MeV/m (q/m=1/2) Power/ m 100kW/m P/MeV 80 kW/MeV Weight : 100 kg/m Ext. diametre : 13 cm 0.1 mA carbon ions industrialised