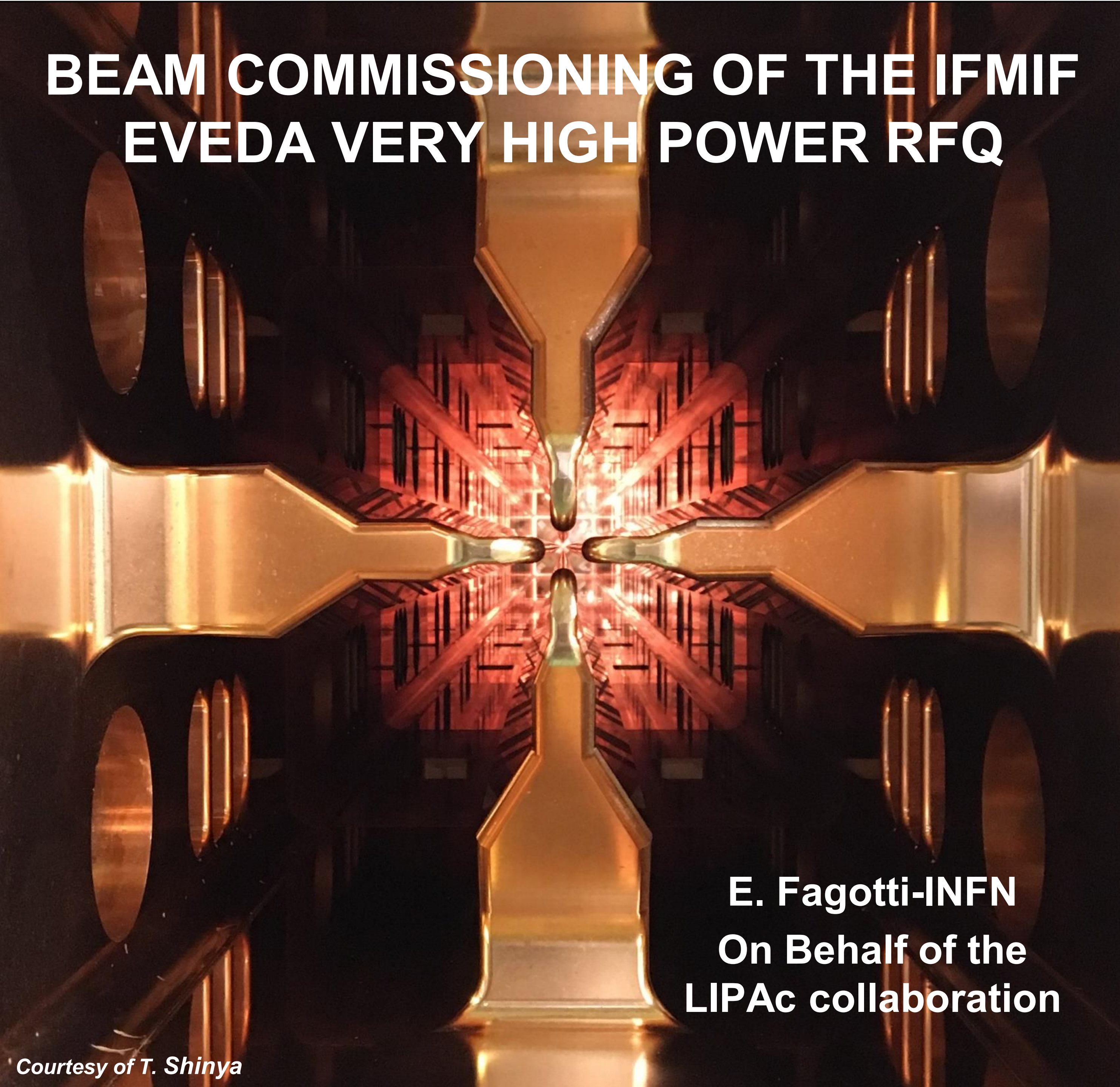
BEAM COMMISSIONING OF THE IFMIF EVEDA VERY HIGH POWER RFQ



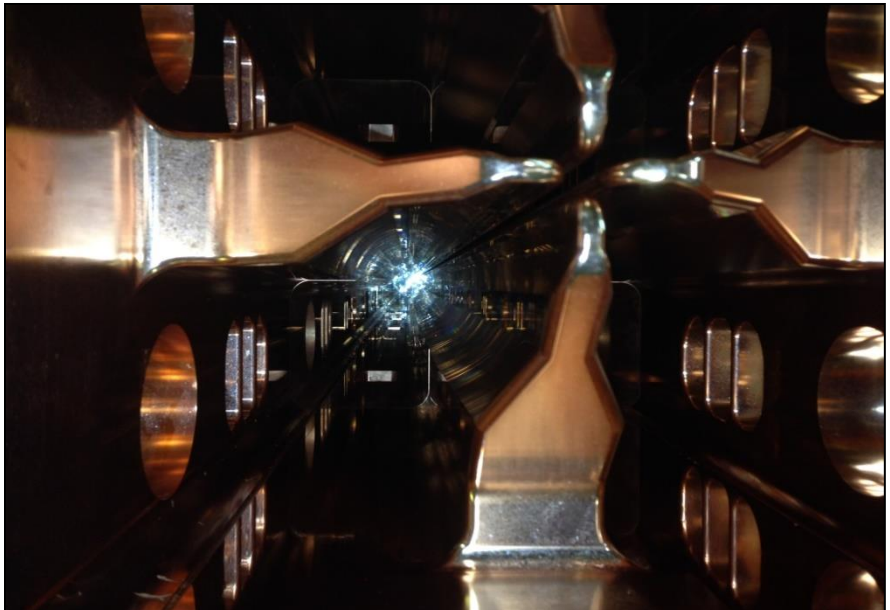
Courtesy of T. Shinya

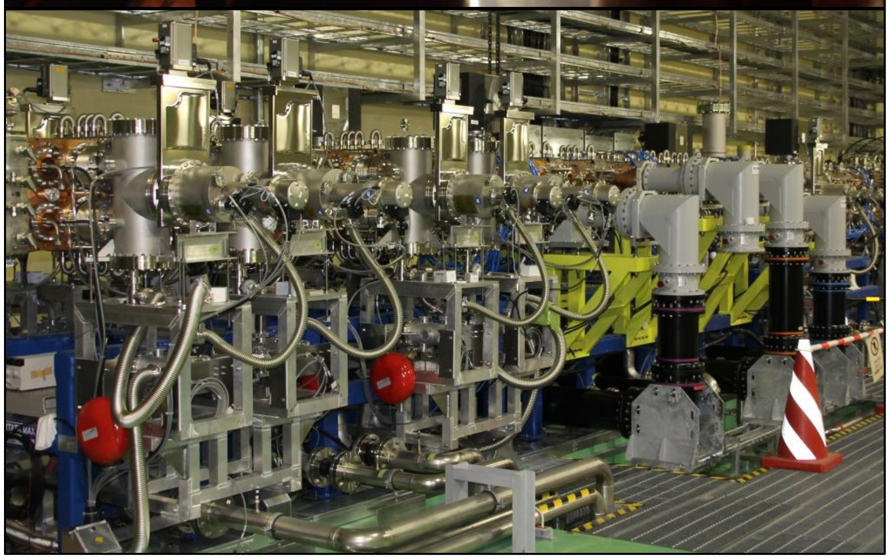
E. Fagotti-INFN

On Behalf of the LIPAc collaboration

Outline:

- ❑ Introduction
- ❑ RFQ characteristics and power test in Europe
- ❑ Installation and hardware commissioning
- ❑ Conclusions

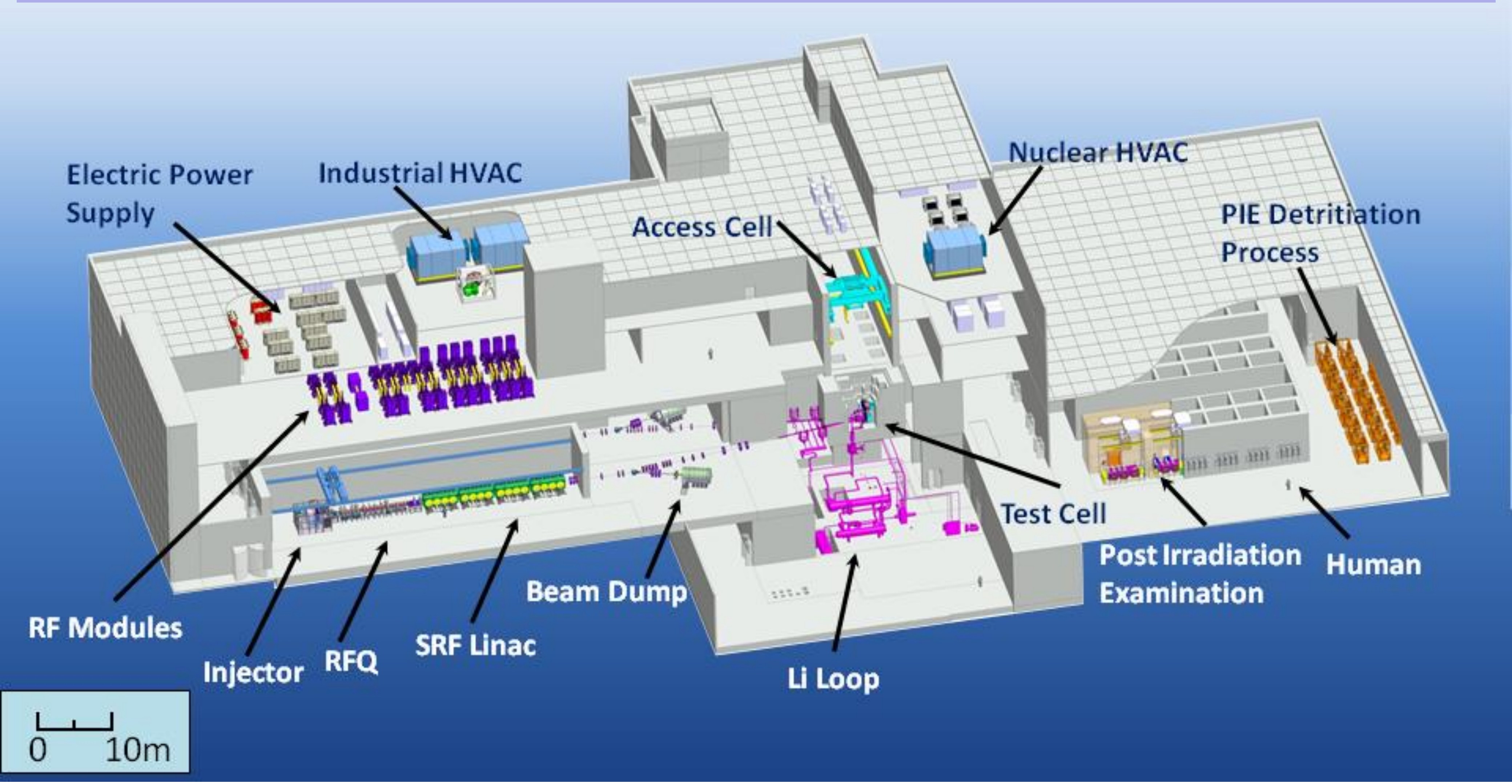




IFMIF-EVEDA RFQ

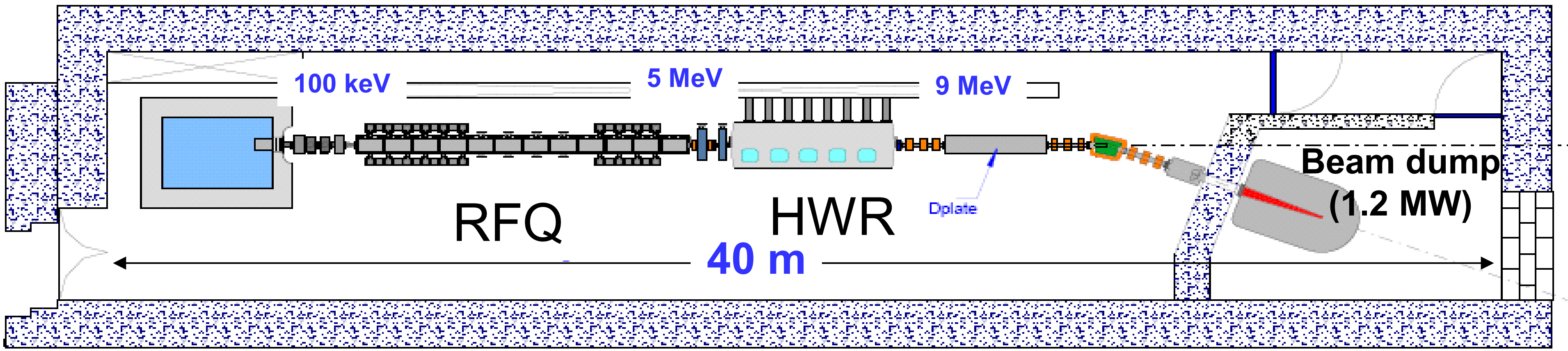
Input/output Energy	0.1-5	MeV
Duty cycle	cw	
Deuteron beam current	125	mA
Operating Frequency	175	MHz
Length (5.7 λ)	9.78	m
Vg (min – max)	79 – 132	kV
R0 (min - max) ρ/R0=.75	0.4135 - 0.7102	cm
Total Stored Energy	6.63	J
Cavity RF power dissipation	550	kW
Maximum dissipated power	86	kW/m
Power density (average-max)	3.5-60	kW/cm^2
Q_0/Q_{sf}=0.82	13200	
Shunt impedance $(\langle V^2 \rangle)L/P_d$	201	kΩ –m
Frequency tuning	Water temp.	

IFMIF facility: two, high power CW drivers, each delivering a 125 mA deuteron beam at 40 MeV (5 MW power) hitting a liquid lithium target in order to yield neutrons ($10^{17} s^{-1}$) via nuclear stripping reactions.



IFMIF - EVEDA

Funded within the Broader Approach to Fusion: construction of **a 9 MeV 125 mA CW deuteron accelerator** (LIPAc, Linear IFMIF Prototype Accelerator) to be built in Rokkasho, (Japan), based on a high power RFQ followed by a Half Wave Resonator superconducting linac



IFMIF - EVEDA

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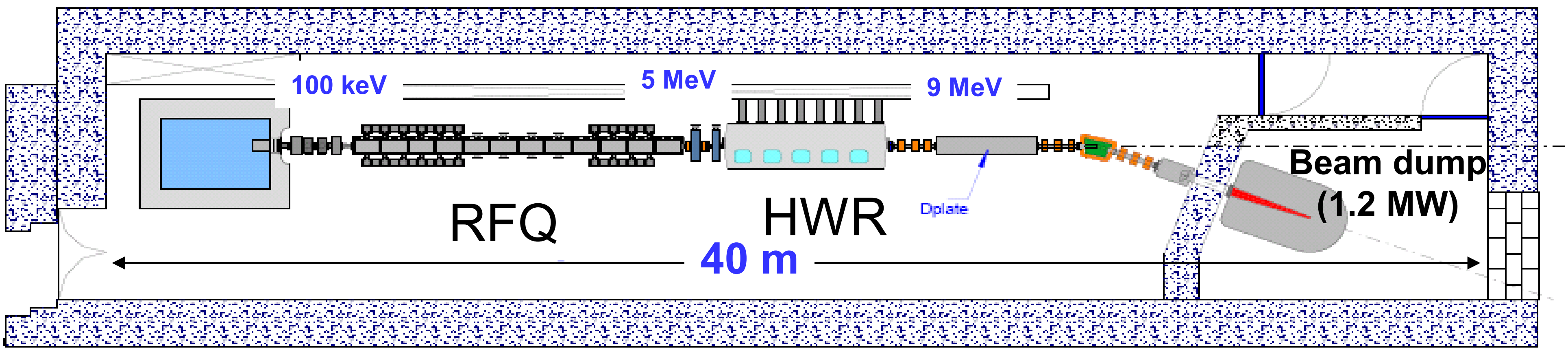
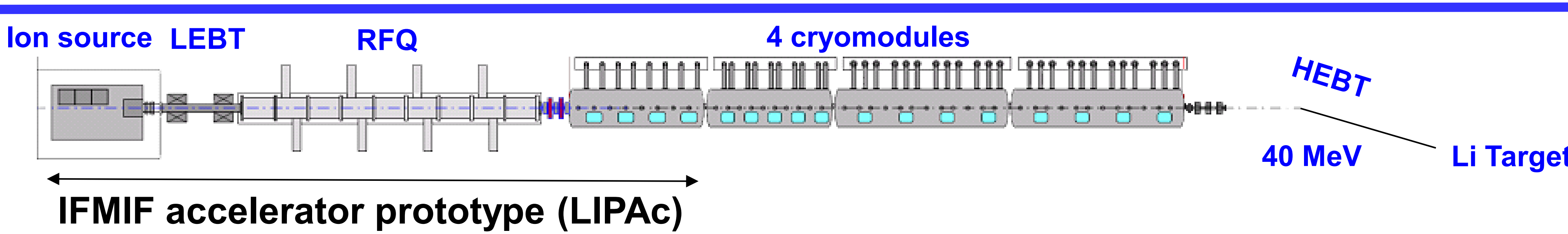




IFMIF EVEDA
Linear IFMIF Prototype Accelerator

Accelerator components from Europe
Beam tests in Japan

100 keV/140 mA D+

Injector + LEBT
CEA Saclay

5 MeV/130 mA D+

RFQ
INFN
QST
F4E

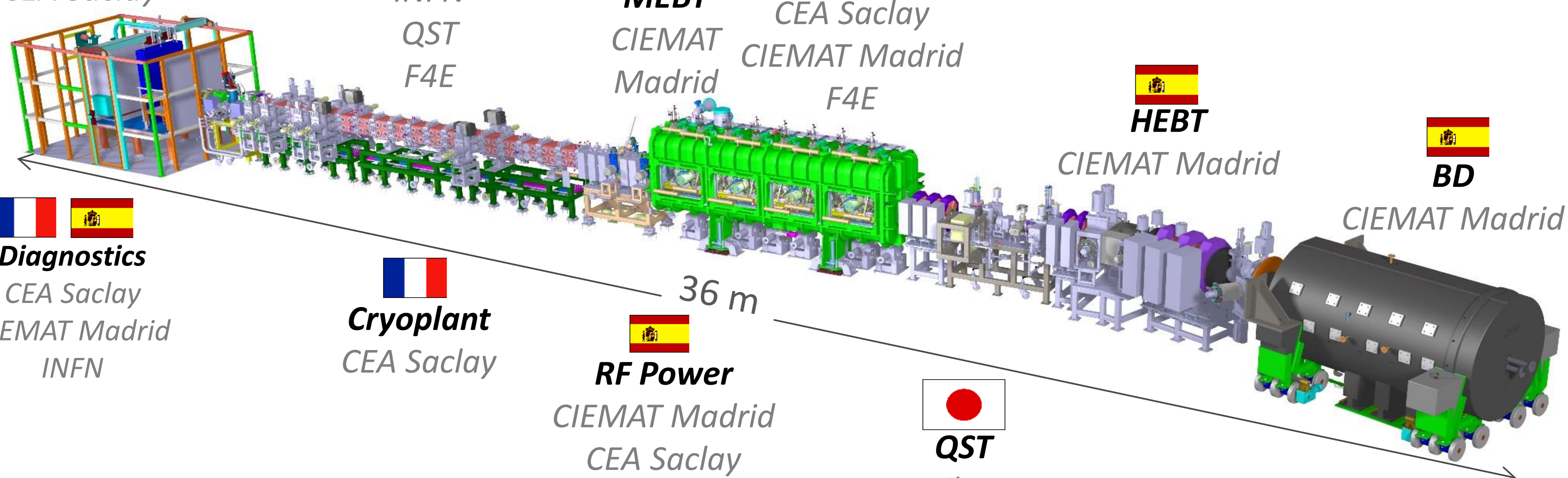
MEBT
CIEMAT
Madrid

9 MeV/125 mA D+

SRF Linac
CEA Saclay
CIEMAT Madrid
F4E

HEBT
CIEMAT Madrid

BD
CIEMAT Madrid



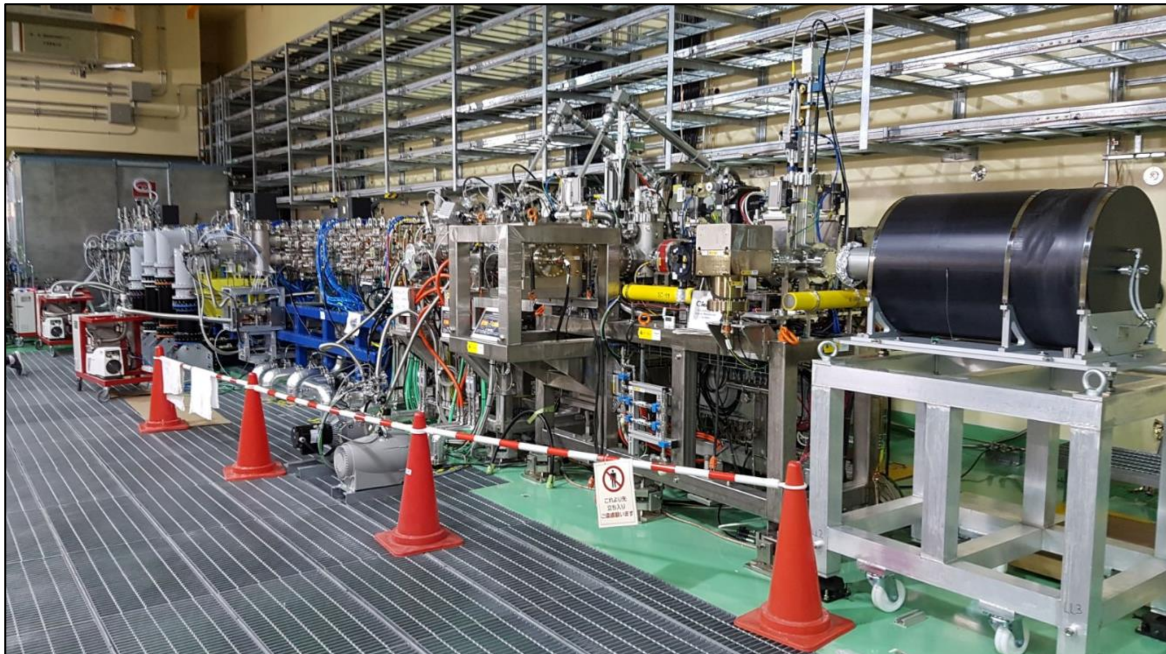
Diagnostics
CEA Saclay
CIEMAT Madrid
INFN

Cryoplant
CEA Saclay

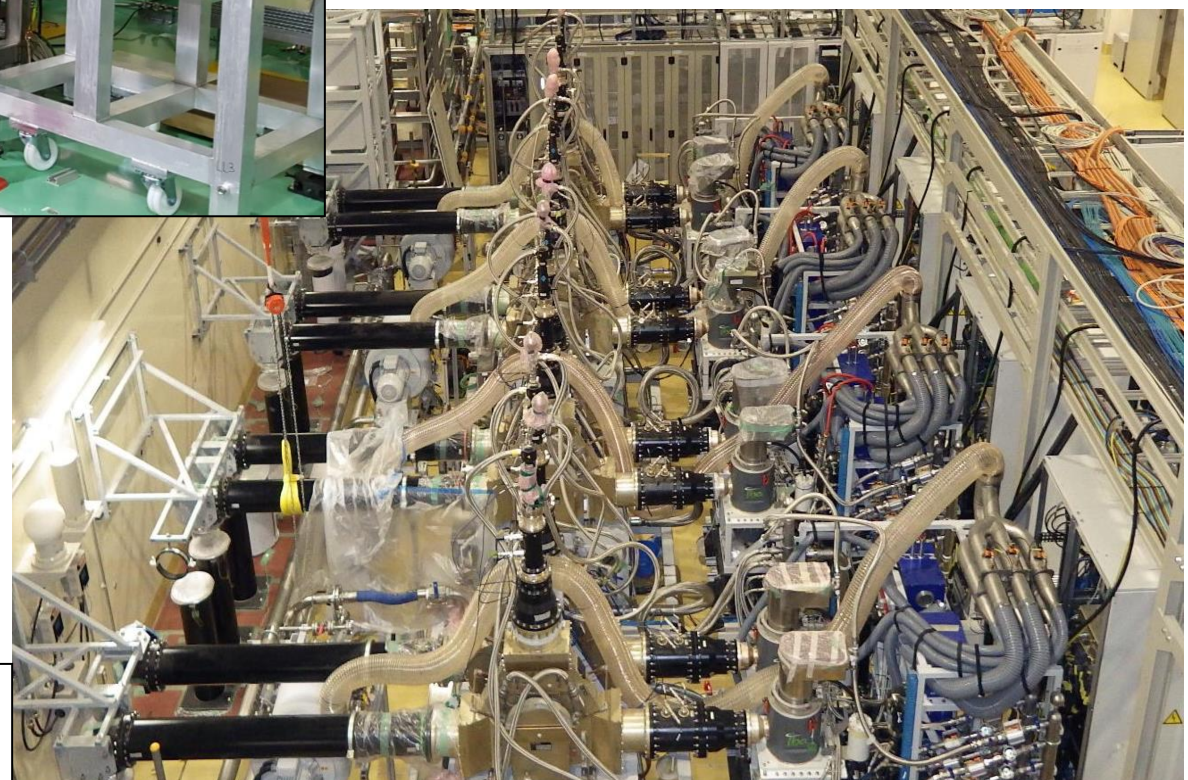
RF Power
CIEMAT Madrid
CEA Saclay
SCK Mol

QST
Builging
Auxiliary System
Control System
Installation

Status of LIPAc (Rokkasho site)



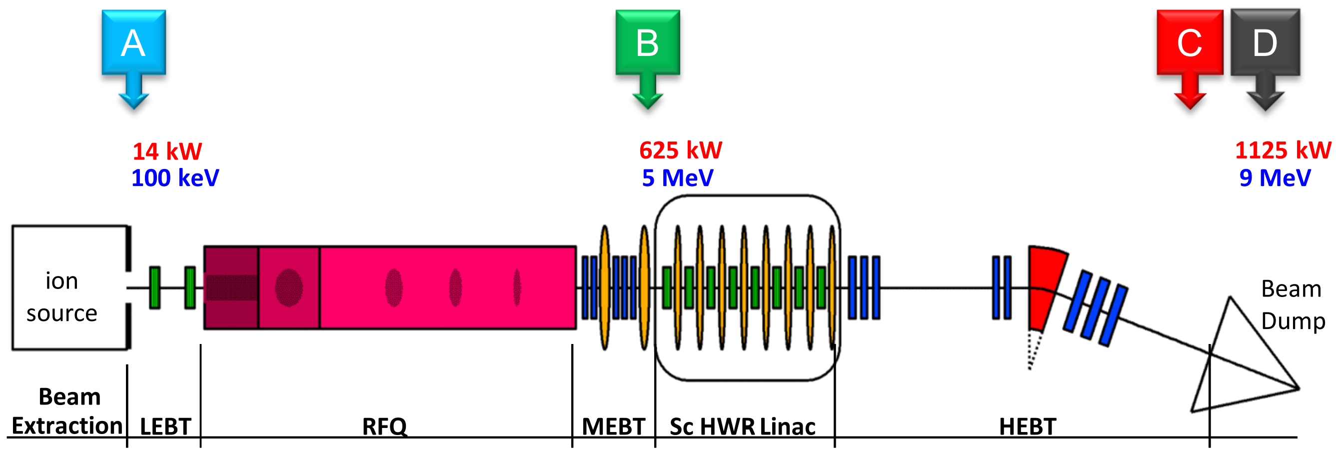
Accelerator installation



RF system installation

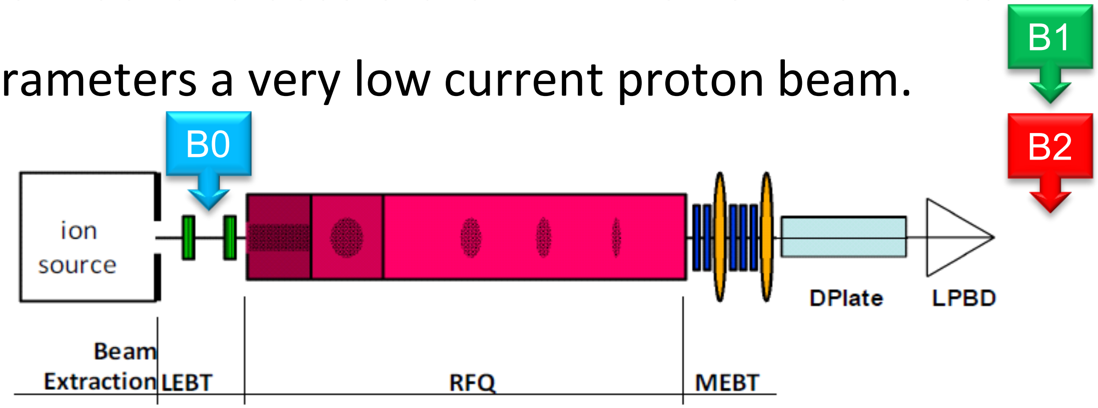
LIPAc Commissioning Plan

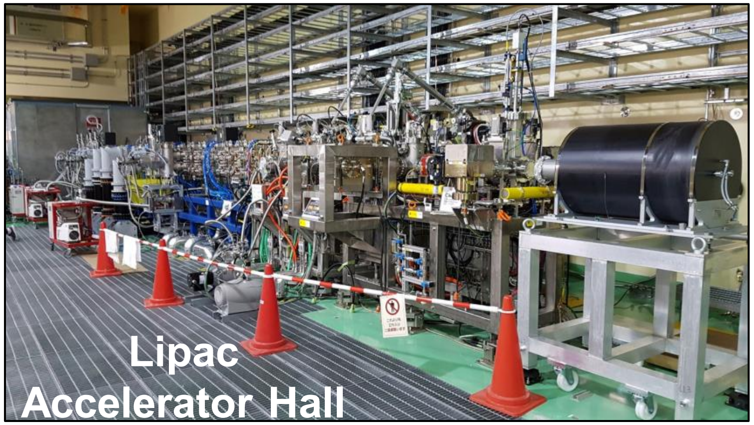
- *Phase A:* 140 mA deuteron current at 100 keV in CW **(DC operation postponed after phase B)**
- *Phase B:* 125 mA deuteron current at 5 MeV at 0.1% duty cycle
- *Phase C:* 125 mA deuteron current at 9 MeV at 0.1% duty cycle
- *Phase D:* Ramp up the duty cycle up to CW



Phase B details

- ***Phase B0:*** Characterization of injector parameters between LEBT solenoids. Verification of the possibility to extract and accelerate with the nominal Twiss parameters a very low current proton beam.



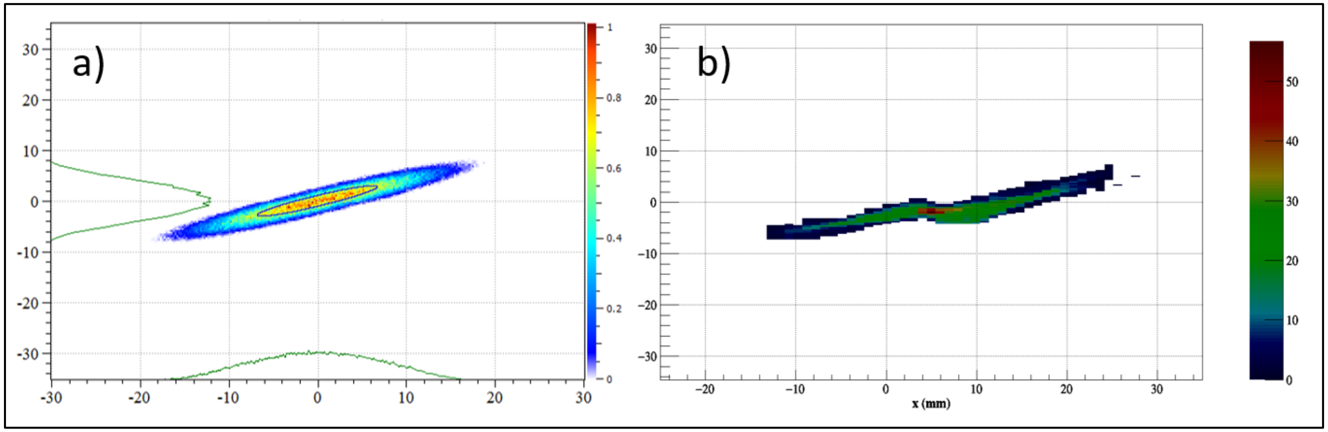


- ***Phase B1:*** Proton beam at 2.5 MeV with increasing current up to 70 mA with 0.1 % dc. Low current injection will be less sensitive to beam mismatch at RFQ entrance. It will be a test beam for calibration purpose in which all diagnostics, even interceptive ones, could be used.

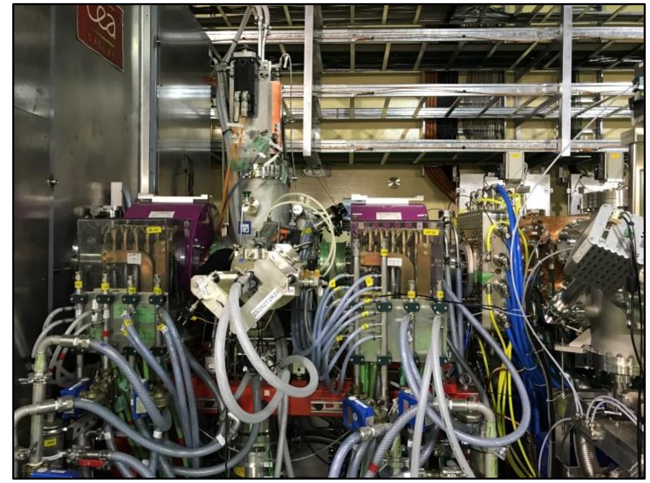
- ***Phase B2:*** Deuteron beam at 5 MeV and 125 mA with 0.1 % dc.

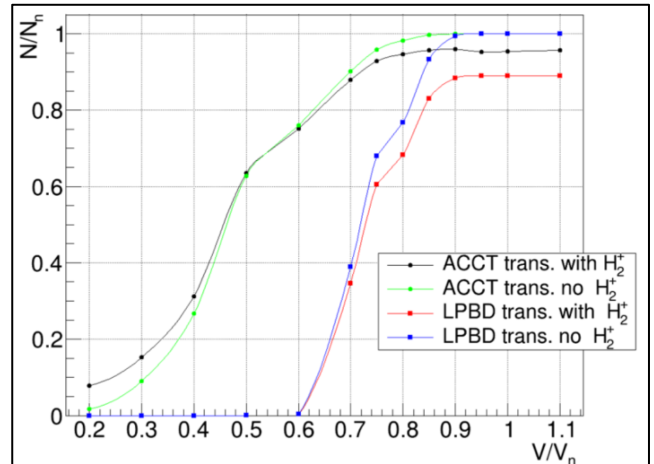
Injector - LEBT Commissioning
Characterization at very low current

Comparison simulation/measurement at EMU position for 7 mA proton beam



a) Simulated distribution $\varepsilon_{n,rms}$ = 0.075 mm-mrad	b) Measured distribution $\varepsilon_{n,rms} = 0.08^{(-0.01+0.004)}$ mm-mrad

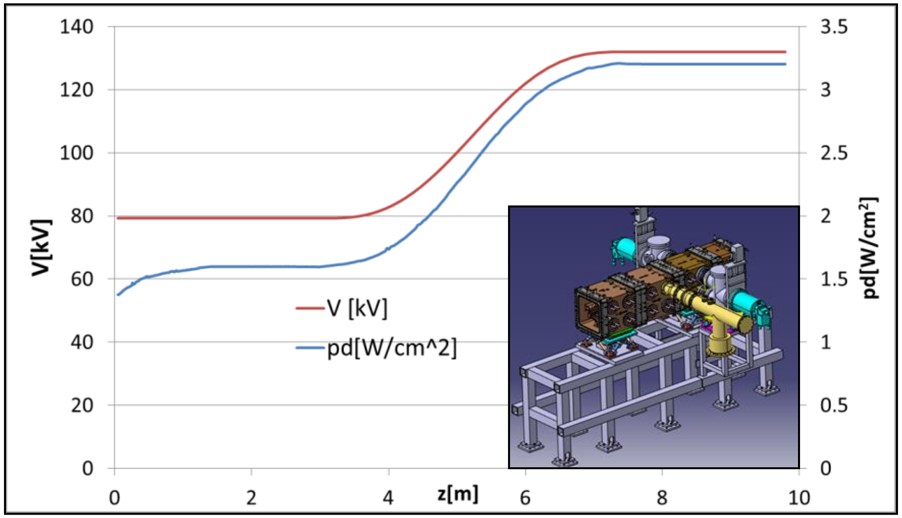


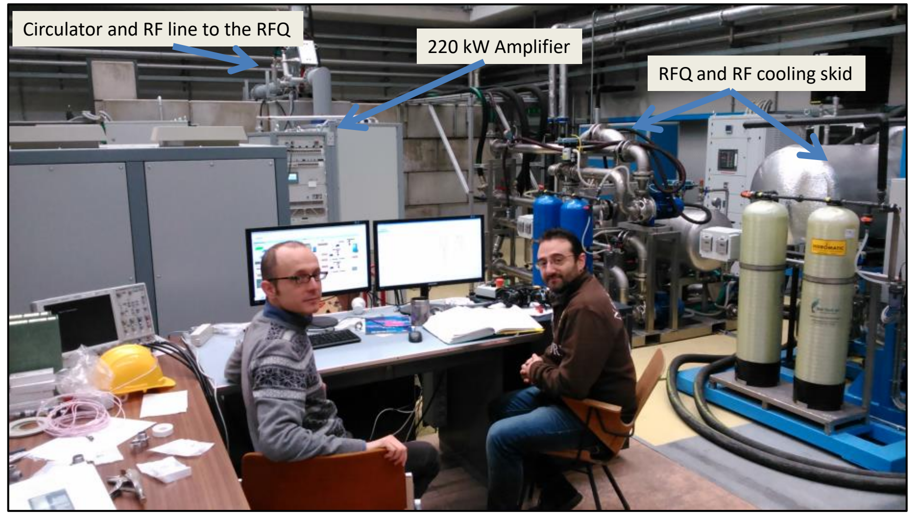


BEAM DYNAMICS OF THE FIRST BEAMS FOR IFMIF-EVEDA RFQ COMMISSIONING
L. Bellan et al THPAK019

According to simulations the beam injected into RFQ will be 100% transmitted even with a mismatch of 220%, confirming the RFQ low sensitivity to solenoid fields setting.

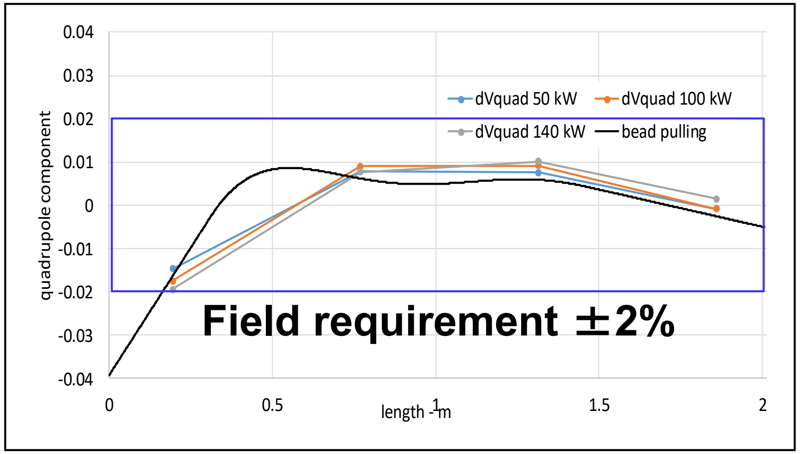
RFQ power tests in Europe



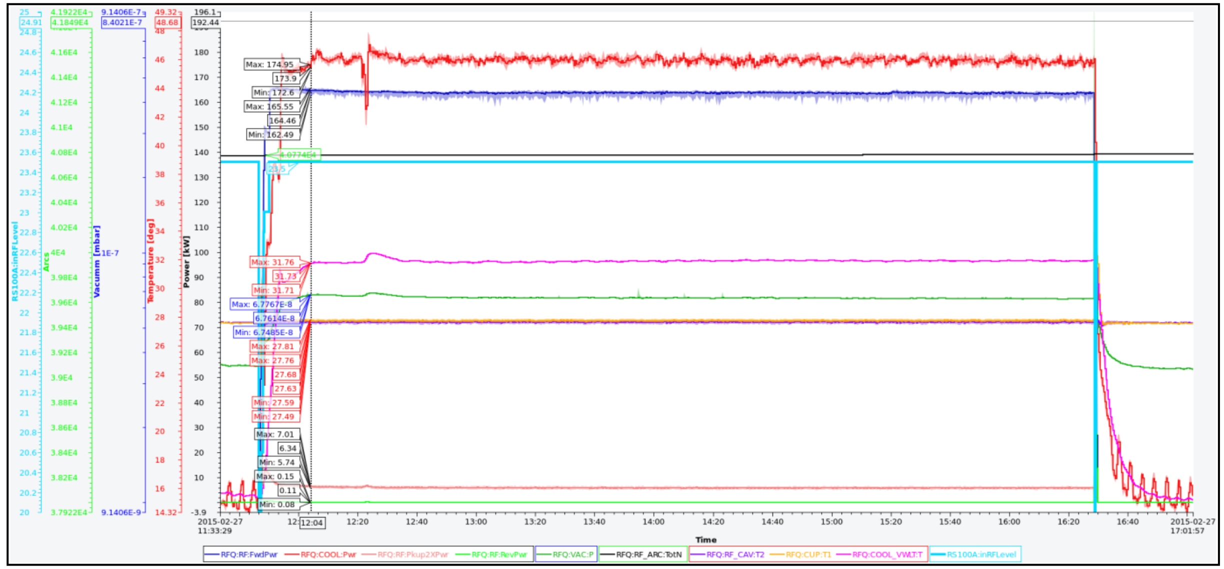


- 500 kW test stand to for 3 RFQ modules up to **200 kW maximum RF power**
- **RFQ design validation**
- Max field limit (**1.8 E_{kp}**) and max power density (**86 kW/m**) **demonstration**

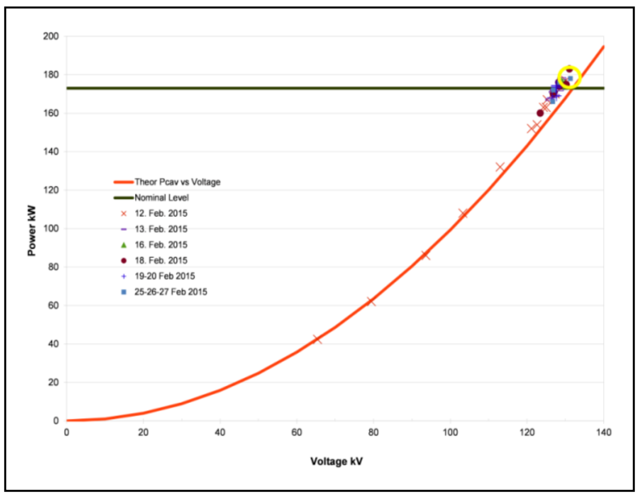
Results: nominal performances demonstrated 173 kW (86 kW/m)



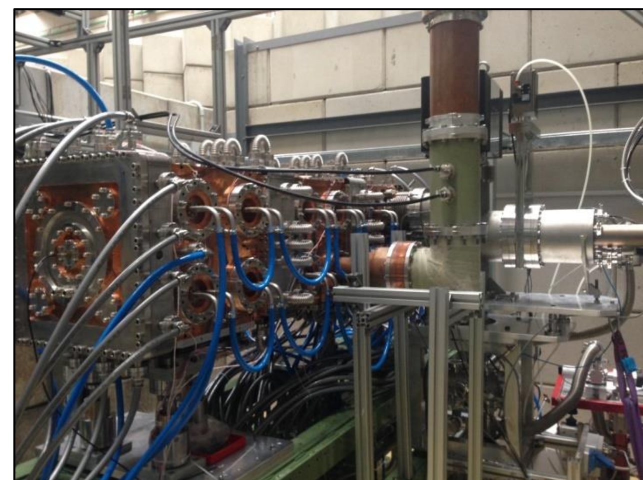
Field configuration (pick up reading) at different RF level



On 27 February '15 the RFQ maintained nominal field level for 5 hours without any stop.

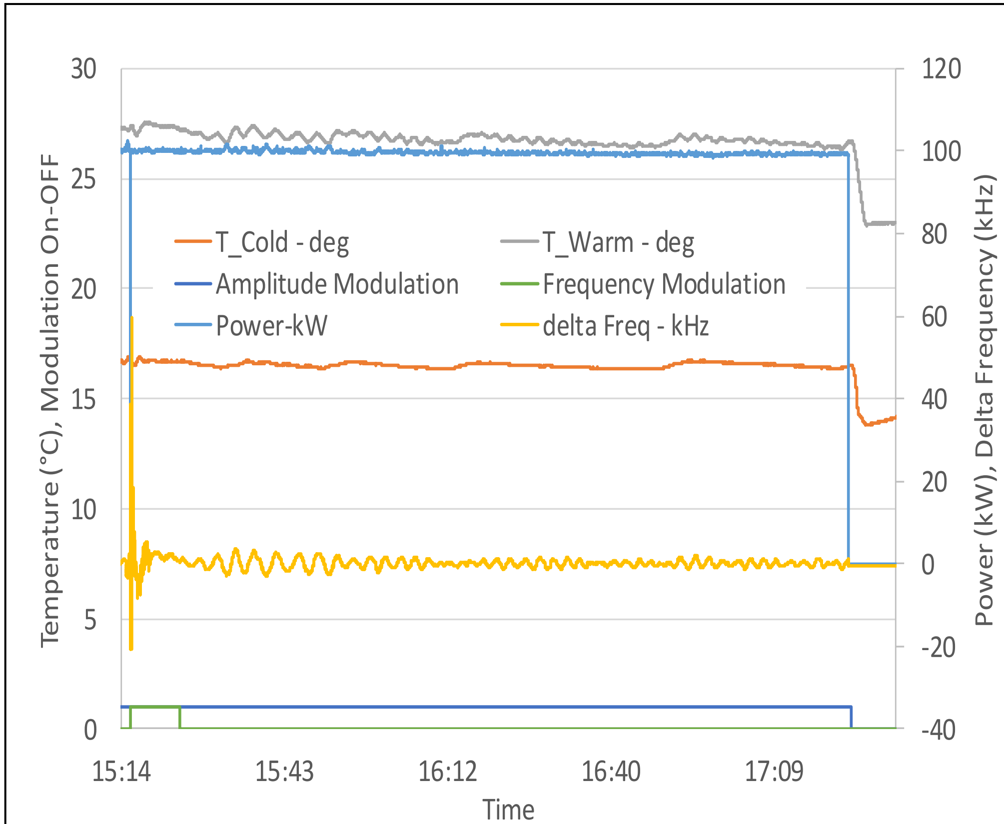


Cavity power (calorimetric measurements) vs. cavity voltage. The yellow circled dot corresponds to the nominal voltage level. Q_0=12500, i.e. 173 kW vs. 132 kV



INFN Istituto Nazionale di Fisica Nucleare

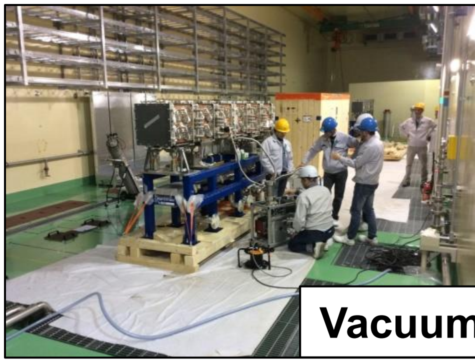
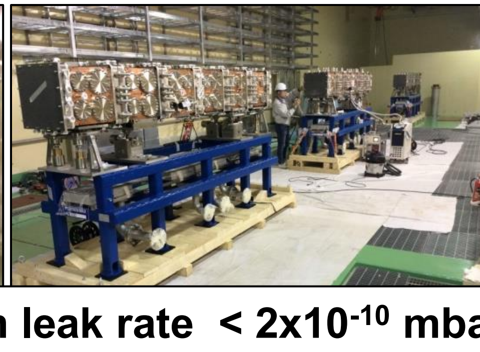
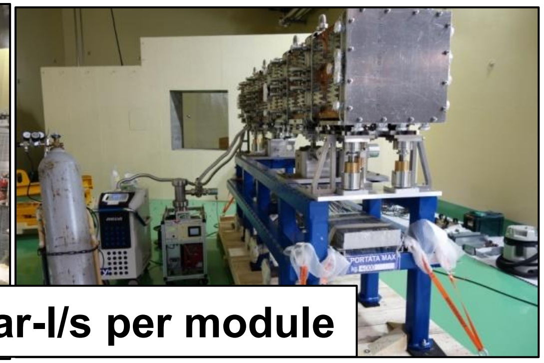
Resonant frequency control demonstrated



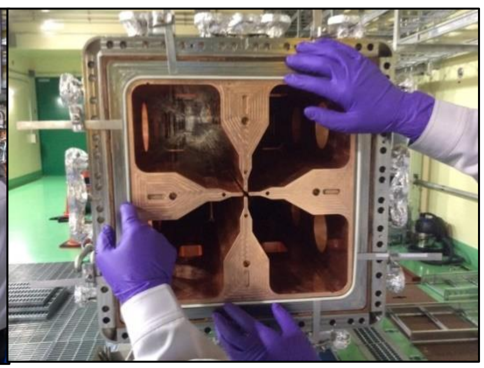
- Resonant Frequency Control (RFC) achieved: cavity nominal frequency maintained using cooling water control loop (16 kHz/^{0}C external channels)
- RFC condition is kept for more than 1.5 hours at 100 kW CW, with frequency oscillation lower than 2 kHz.

RFQ installation

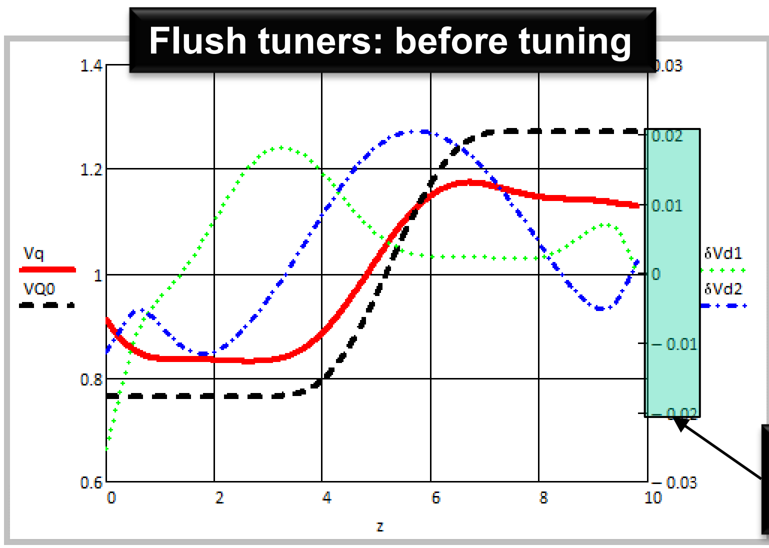
- RFQ arrived in Rokkasho divided into three SuperModules (SMs).
- Each SM was successfully vacuum tested after arrival.
- SMs were installed in provisional position, centred on beam axis but moved 3 m away from the LEBT. Final alignment transversal precision was less that 50 μm.

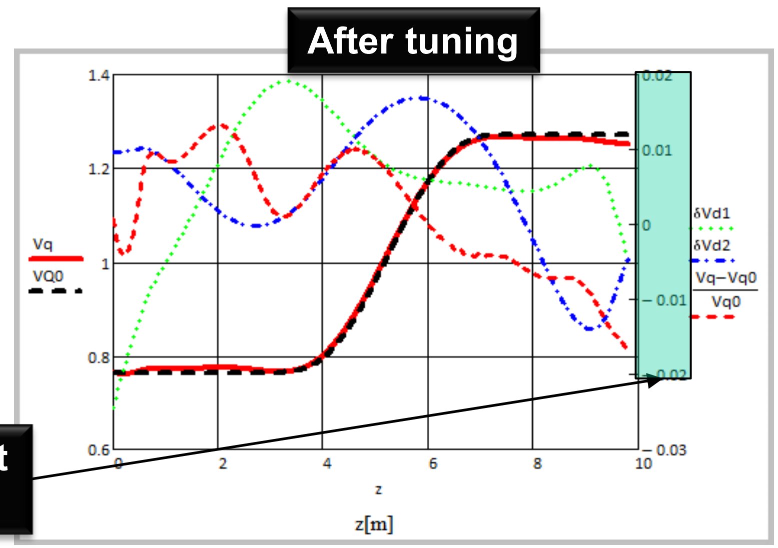




Vacuum leak rate < $2x10^{-10}$ mbar-l/s per module


RFQ tuning

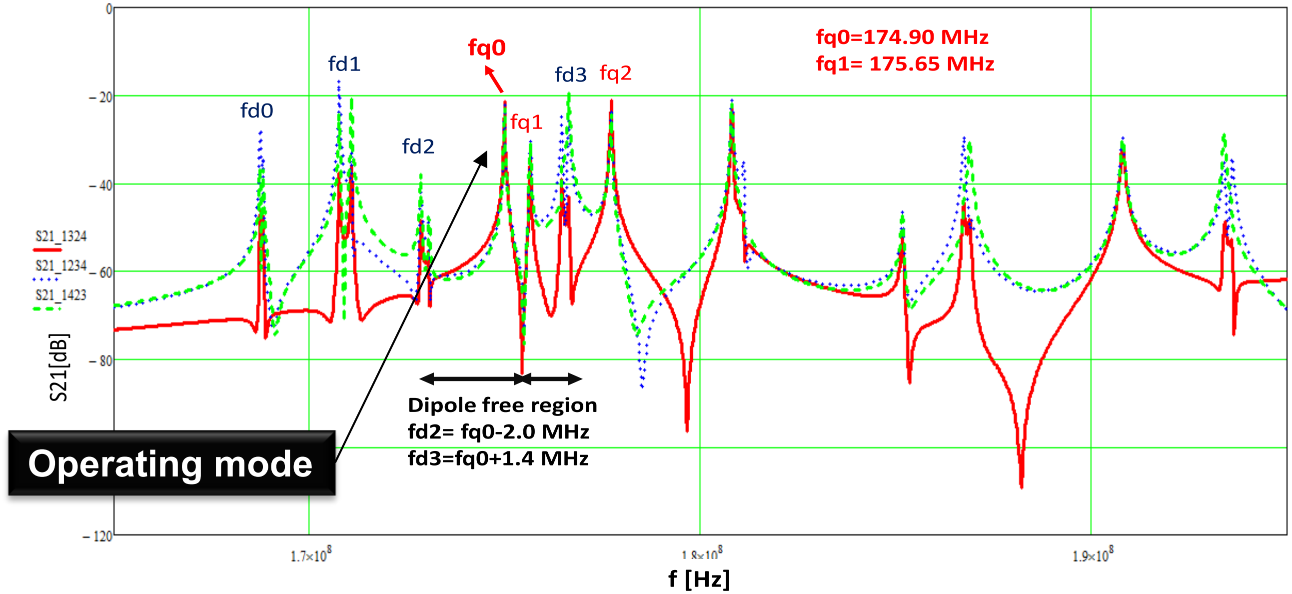


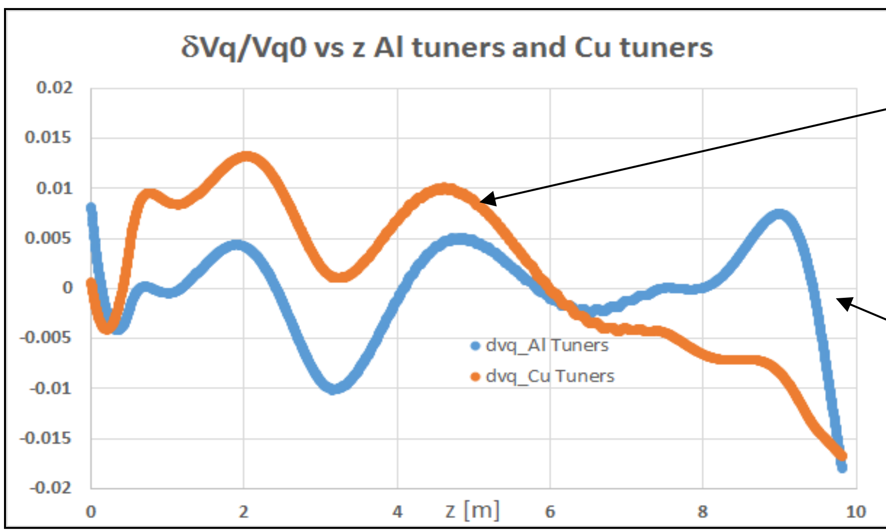


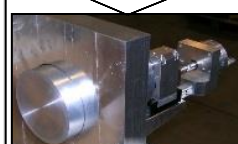
Dipole component tolerances

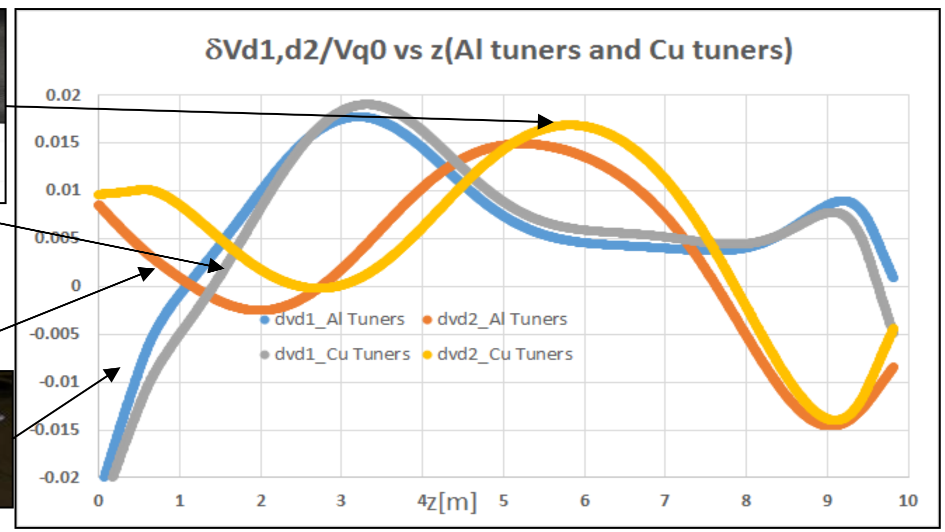
108 Al tuners and 2 dummy end plates

RFQ tuning after final tuners assembly



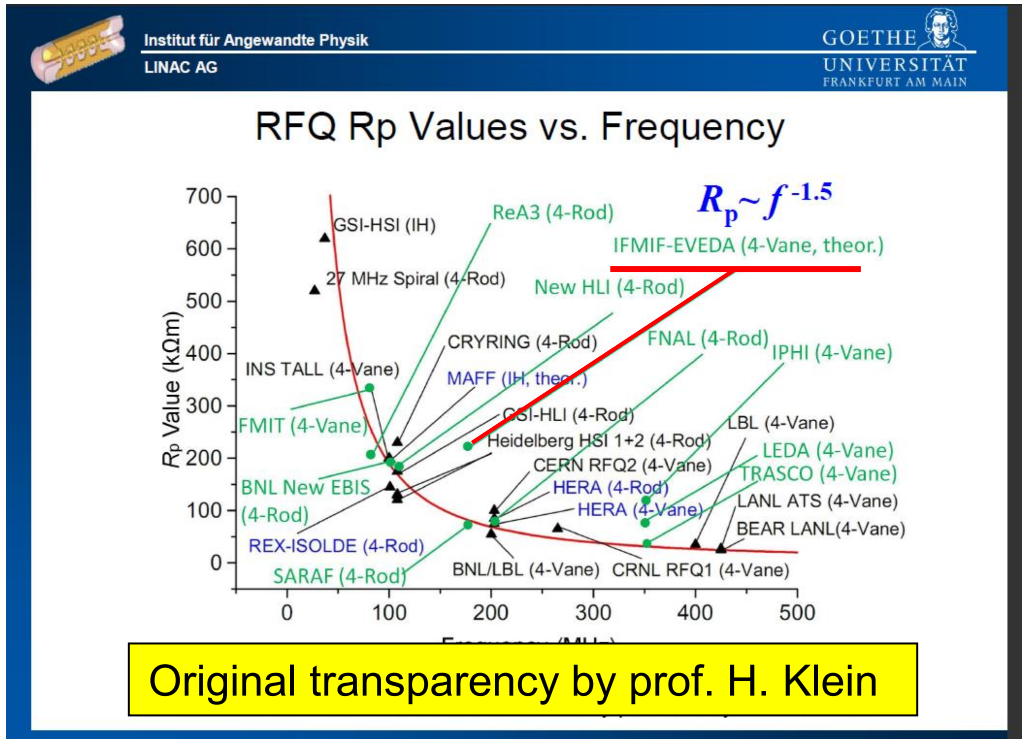






RFQ

- The final measured frequency was equal to 174.989 MHz, equivalent to 175.014 MHz, if one takes into account the rescaling to nominal 20 deg temperature and the effects of vacuum and beam loading (-1 deg water temperature correction necessary).
- Quality factor was measured $\mathbf{Q_0 = 13200 \pm 200}$ that is 82% of SUPERFISH value (low tuner losses).
- The excellent shunt impedance of the design was achieved:
  - $\mathbf{R_{sh}}$**=201 kΩ-m**



Original transparency by prof. H. Klein

RFQ final assembly

RFQ assembly in its final position

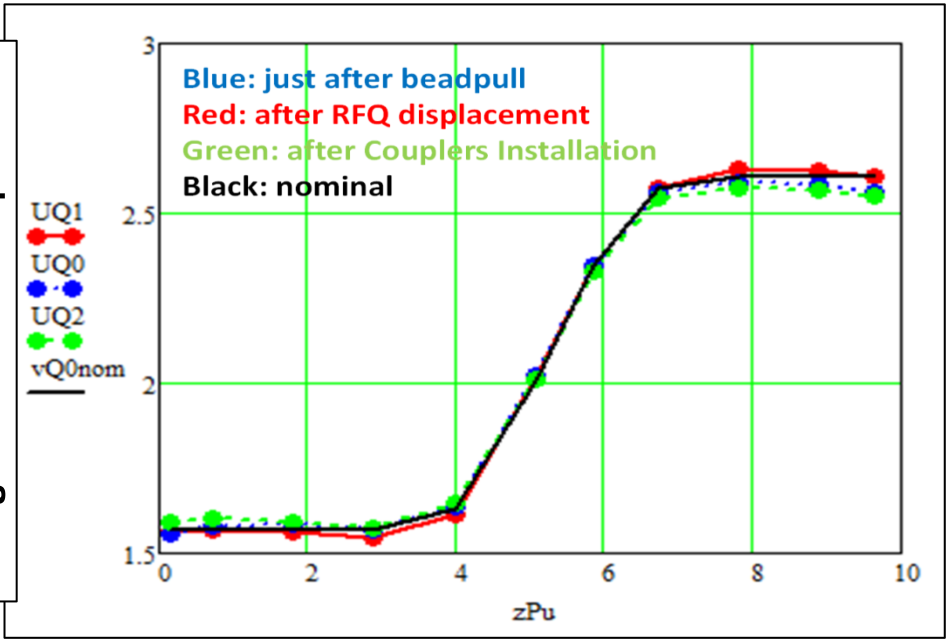
Vacuum system installation

High power couplers installation

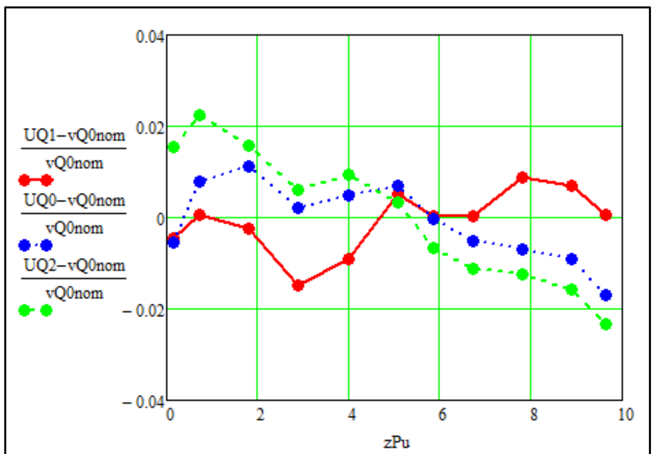
Baking

Final tuning

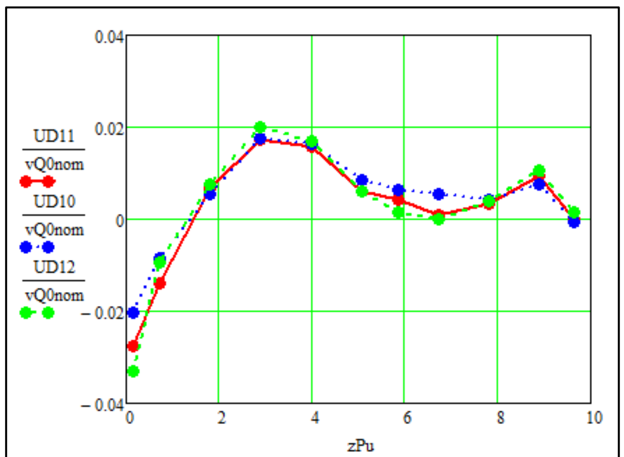
Evolution of the RFQ voltage along the installation phases



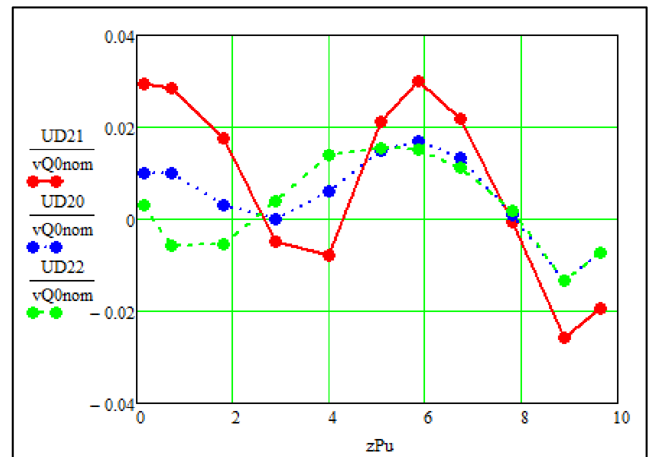
Coup. ID	β(α=0)	α_{opt} [deg]	β_{meas} after rotation	f[MHz]
07142	0.30	18	0.28	175.018
07144	0.29	16	0.26	175.018
09172	0.36	30	0.26	175.018
09174	0.34	27	0.28	175.018
10201	0.45	39	0.25	175.018
10203	0.43	38	0.29	175.018
12232	0.56	46	0.31	175.018
12234	0.52	44	0.23	175.019



Pert Q voltage component



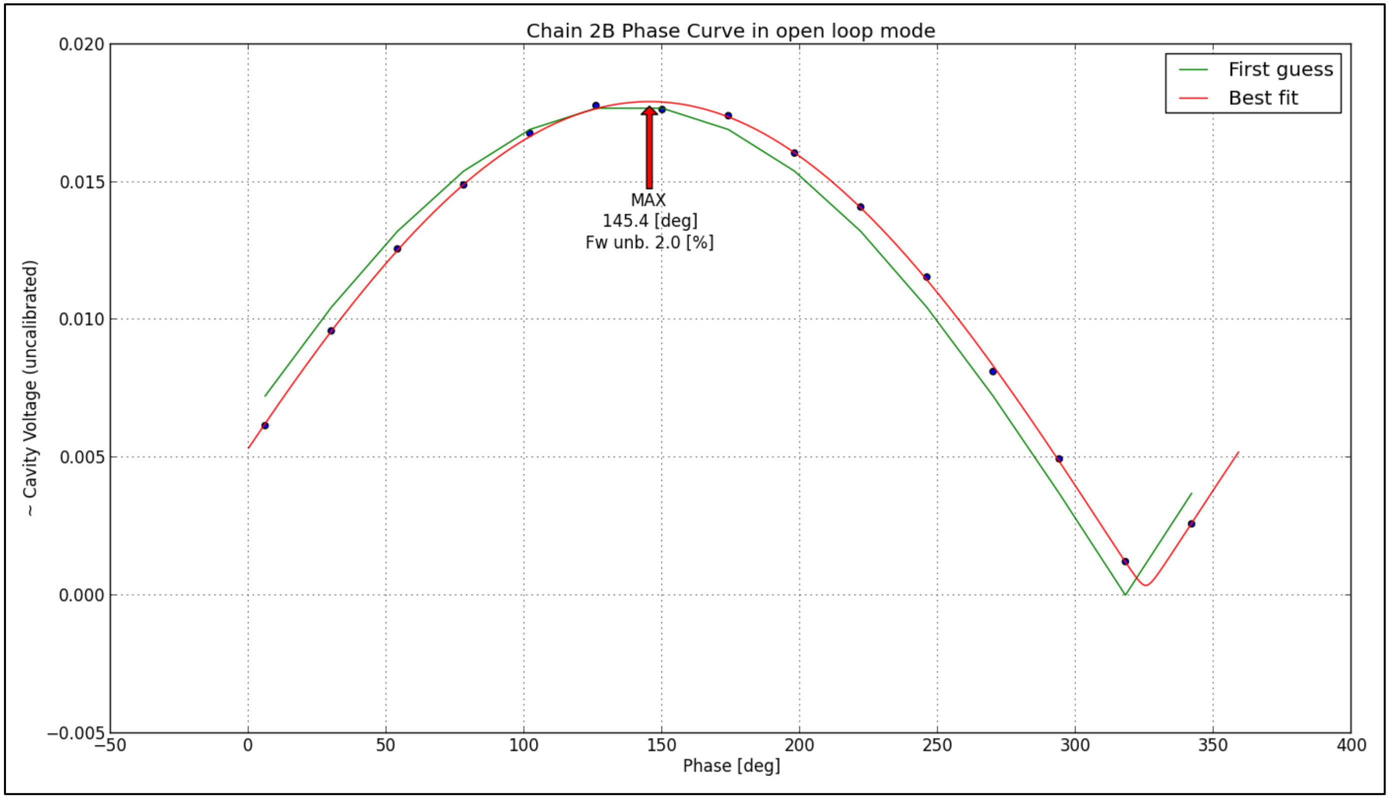
Pert D1 voltage component



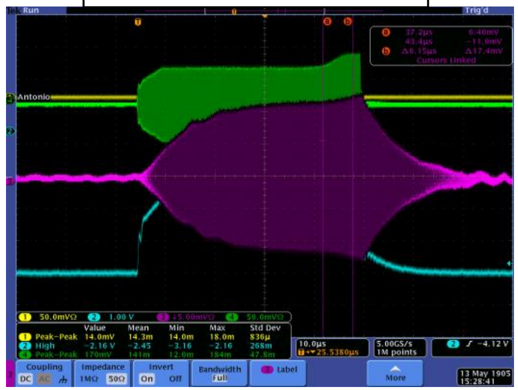
Pert D2 voltage component

Eight power lines phasing

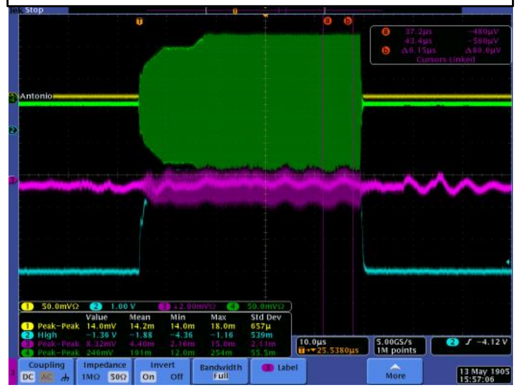
- RFQ power minimization method used to find couplers maximum dephase.
- This method was applied to each of the seven master-slave RF lines couples.
- Final routine took also into account power unbalance.



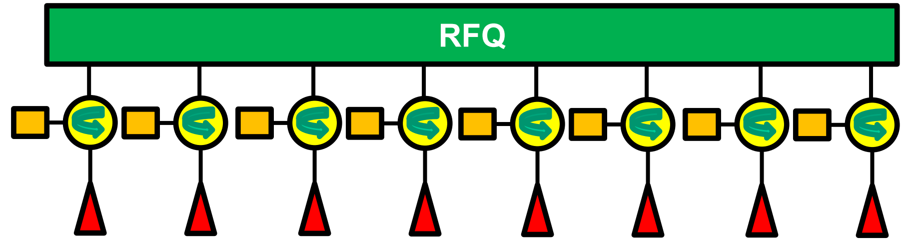
Near right phase



Near maximum dephase

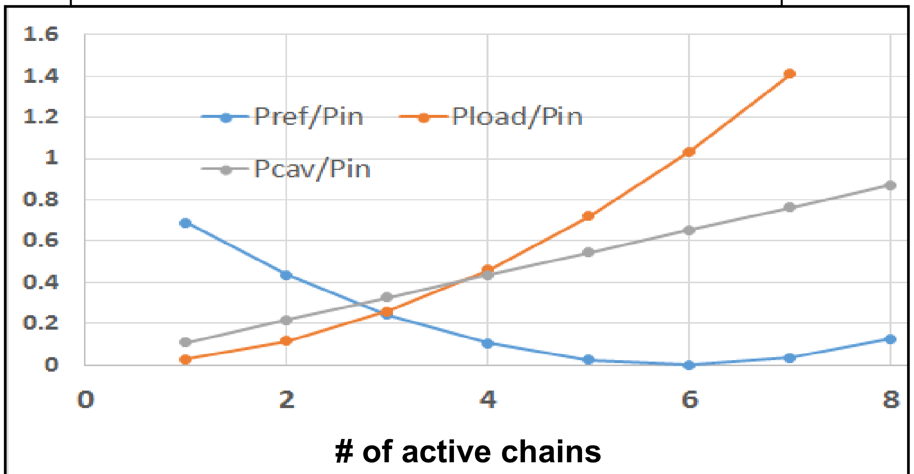


Eight chains coupling challenge



- RF couplers optimized for beam operation
- In conditioning mode without beam, 13% reflected power if foreseen from each chain
- In case of chains amplitude or phase unbalance reflected power amount can increase significantly

Amplitude unbalance (no beam)



- Reflected power decreases with active chains number reaching a minimum with 6 chains.
- Cavity power increases with active chains number
- Reflected power on any inactive chain increases with the number of active chains. It can reach 140% of the single chain input power, with 7 chains active

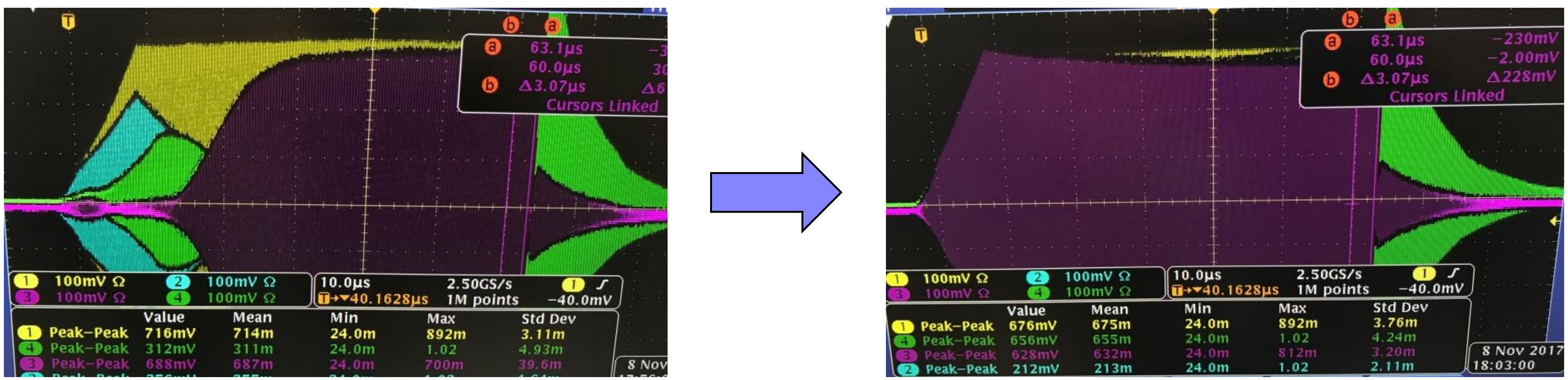
In case of phase unbalance, calculations show that 400% of nominal power can be reached on unbalanced chain reflected power in case of 180 deg phase error.

RF Conditioning Slowdown

- RF interlock system was based on peak reflected power.
  - ➢ **Interlock removed and new intelock system based on average power implemented.**

- Electromagnetic noise frequently caused interlocks enabling.
  - ➢ **Grounding system improved. General e.m. noise reduction under investigation.**

- At the beginning a not perfect chains synchronization prevented to work with pulses shorter than 50 μs.



- ➢ **After chain syncronization 15 μs pulse length was possible**

RF Conditioning Slowdown

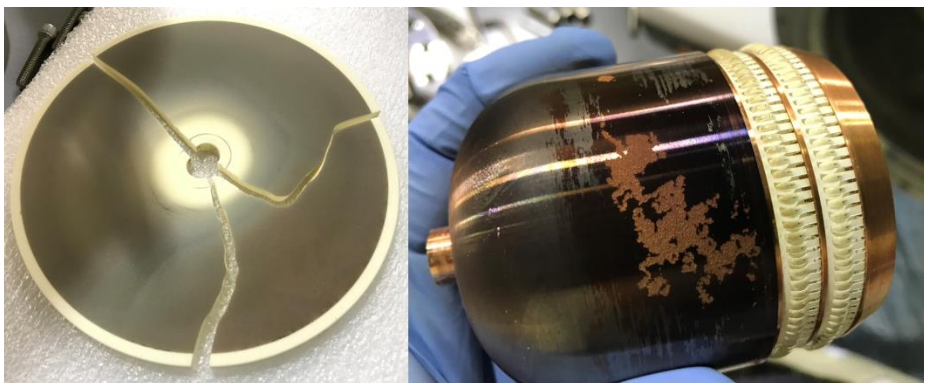
- Circulators dummy loads were dimensioned for 50 kW CW nominal power. In pulsed mode they should resist up to 250 kW peak power for less than 100 ms.

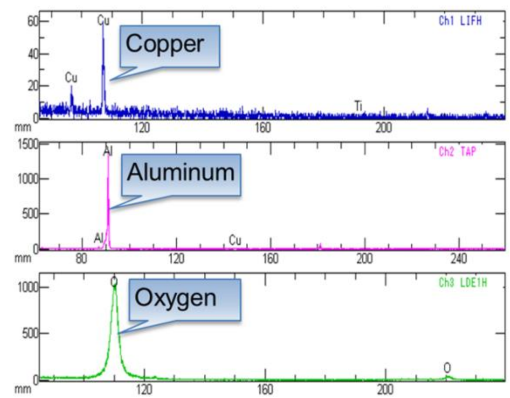
- ➢ **Four circulators dummy loads damaged during conditioning**
- ➢ **Temporary replaced with SC linac ones.**

RF Conditioning Slowdown

- Accident-1: RF power injection with cooling system off and cooling interlock disabled
  - ➢ **Viton® O'ring melting in one RF window without vacuum break**
  - ➢ **RF window disassembled and repaired**

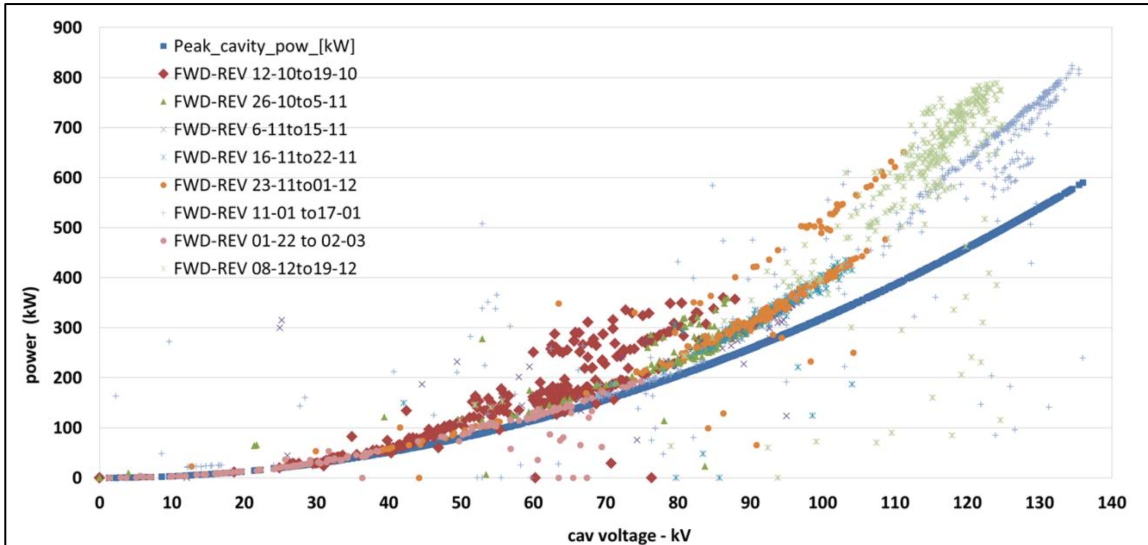
- Accident-2: During a PPS test, involuntary RF power injection into cavity with interlock system disabled
  - ➢ **Uncontrolled arcing in one RF window caused alumina metallization and suqsequent break. Post analysis confirmed copper deposition.**



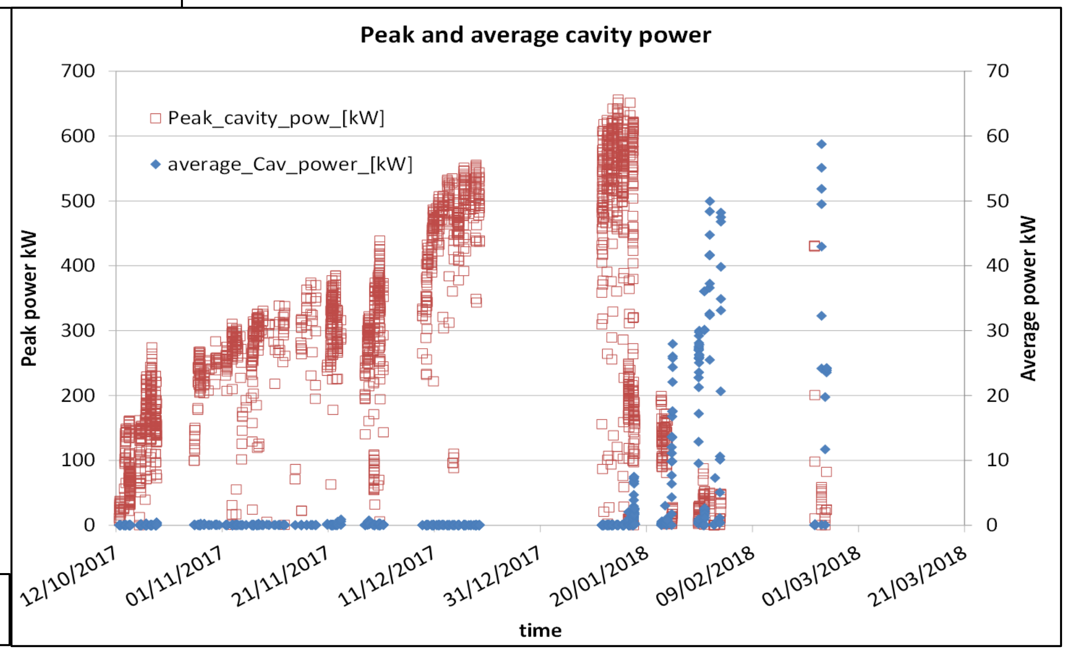


  - ➢ **RF window replacement. Logic change in the control system to prevent interlock disabling**

RF conditioning results



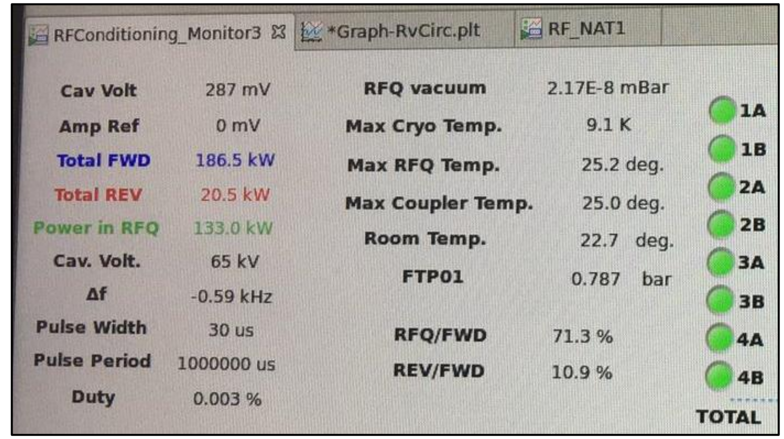
Forward power vs cavity voltage during RFQ conditioning.

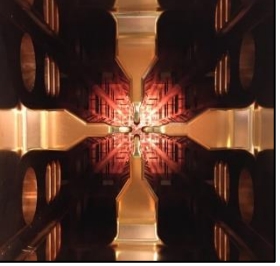


Peak and average cavity power.

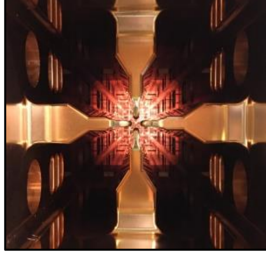
Next weeks plan

- Accident -2 caused a partial cavity deconditioning
- 66 KV RFQ field reached with short pulses (30 μs)
- Pulse increase up to 500 μs reached just this week
- RF system stability in pulsed mode improved
- For H^+ acceleration enough power margin for cavity out of frequency compensation even without water tuning system
- 300 μs pulsed proton beam injection planned end of May with pulsed RF





Conclusions



- LIPAc Phase B accelerator is ready for beam acceleration.
- Hardware fully commissioned. Extensive beam test of the RFQ input conditions were performed in Phase B0.
- RFQ reached nominal field in pulsed mode. RFQ high field section tested in Europe in cw.
- Some problems in the final configuration related to 8 RF chains combination.
- Few accidents with broken components due to RF-RFQ integration.

but

- Problems are being tackled. Almost all solutions implemented.
- **Nominal conditions for the first beam achieved just this week.**

Many thanks to F4E,QST and all the home institutions for their constant support.
Thanks in particular to commissionig team:
L. Antoniazzi, L. Bellan, D. Bortolato, M. Comunian, A. Facco, M. Giacchini, F. Grespan, P. Mereu, M. Montis, A. Palmieri, A. Pisent, F. Scantamburlo, INFN
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T. Ebisawa, A. Kasugai, K. Kondo, K. Sakamoto, T. Shinya, M. Sugimoto, QST
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