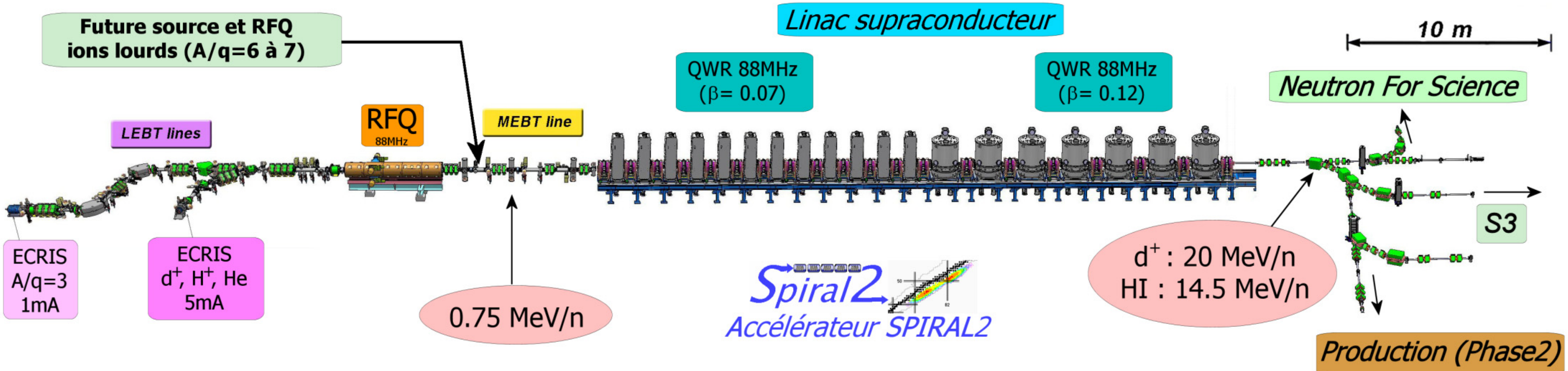
COMMISSIONING OF SPIRAL2 CW RFQ AND LINAC

- Project status
- Commissioning strategy
- Injector results
- LINAC partial cool down
- Next phases

Robin FERDINAND for the GANIL teams

SPIRAL2 accelerator

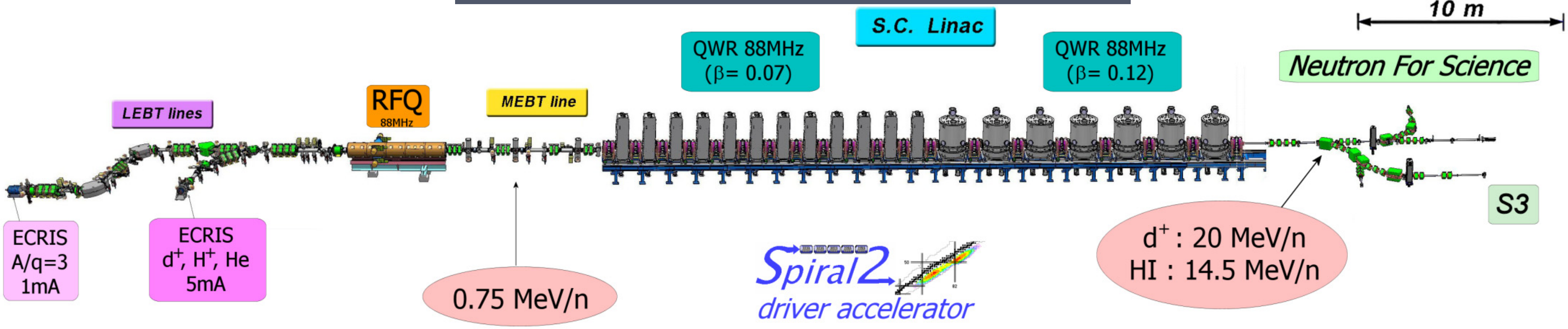


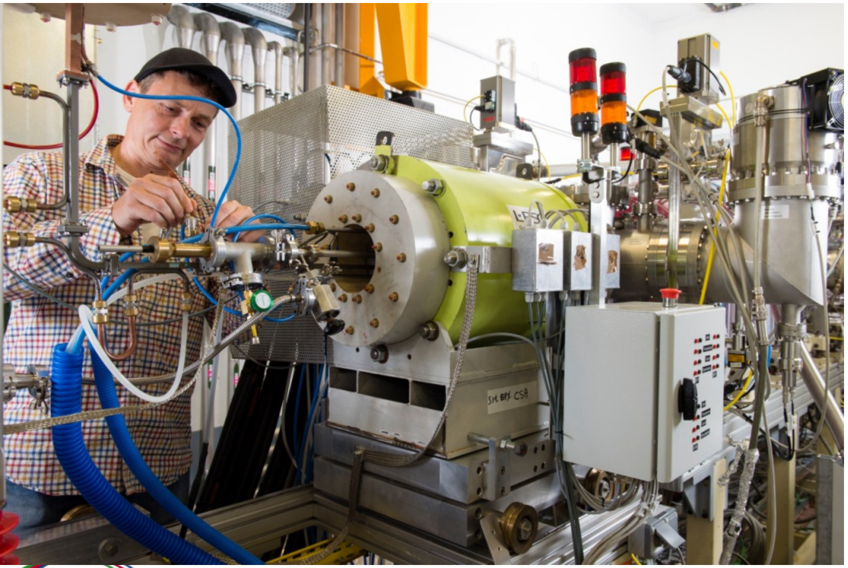
Started

Cool down started. RF when safety authorization

Particles	H+	D+	ions	option
A/Q	1	2	3	6
Max I (mA)	5	5	1	1
Max energy (MeV/A)	33	20	15	8.5
Max beam power (kW)	165	200	45	51

Installation status



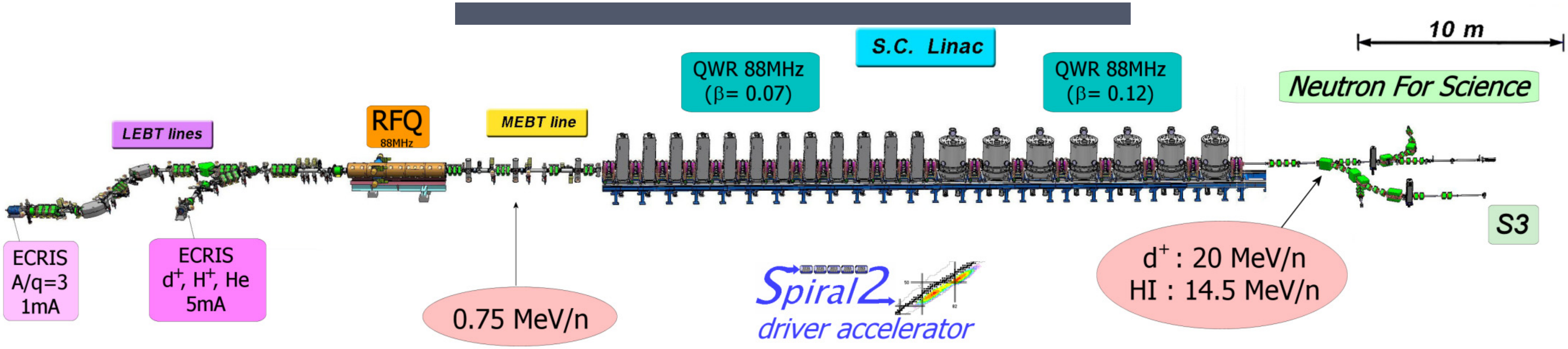


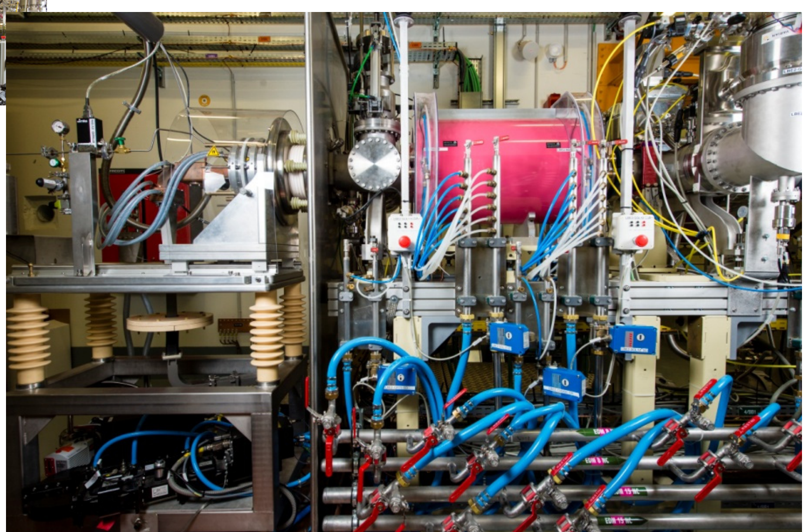
First beam (230 μA Ar^{9+}) July 10, 2015

First RFQ acceleration (230 μA $^4He^{2+}$)

February 12, 2016

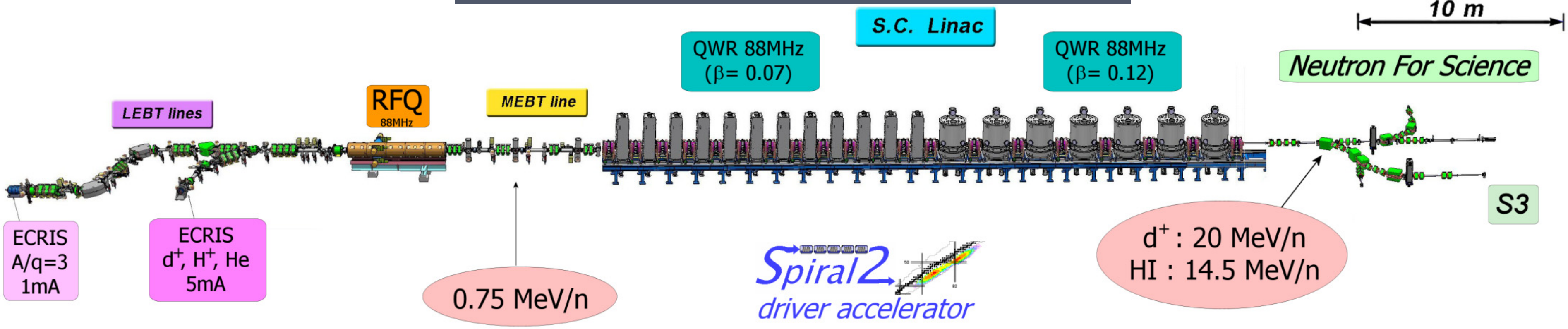
Installation status

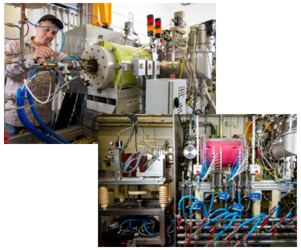




First beam (2mA H^+) Dec. 19th, 2014

Installation status

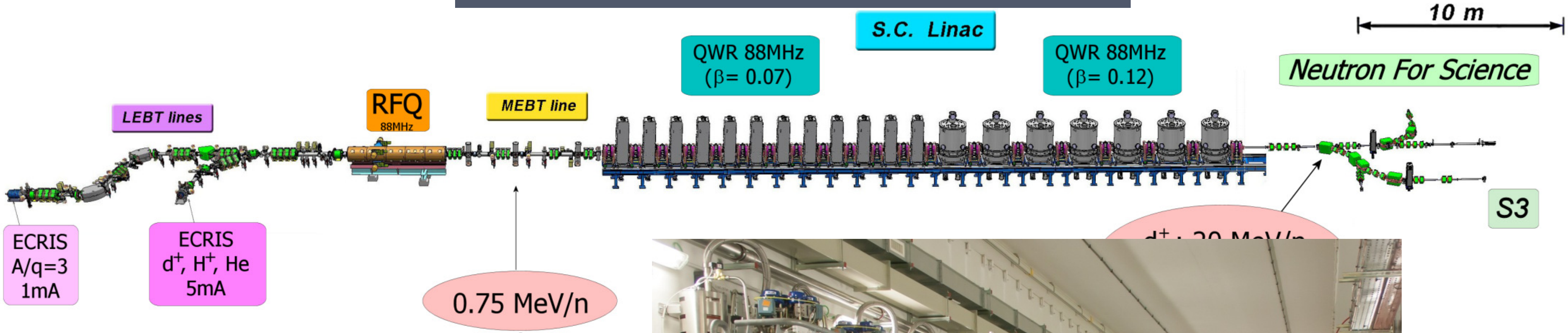




First beam (H+)

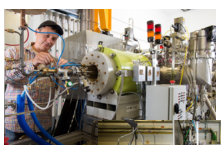
Dec 3rd, 2015

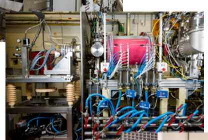
Installation status

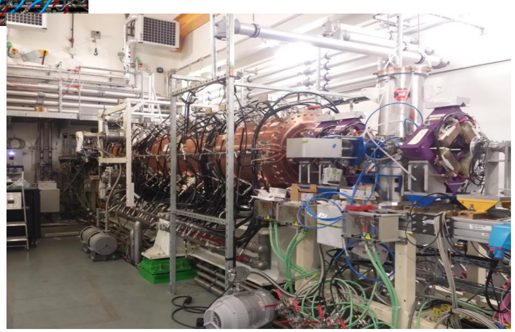


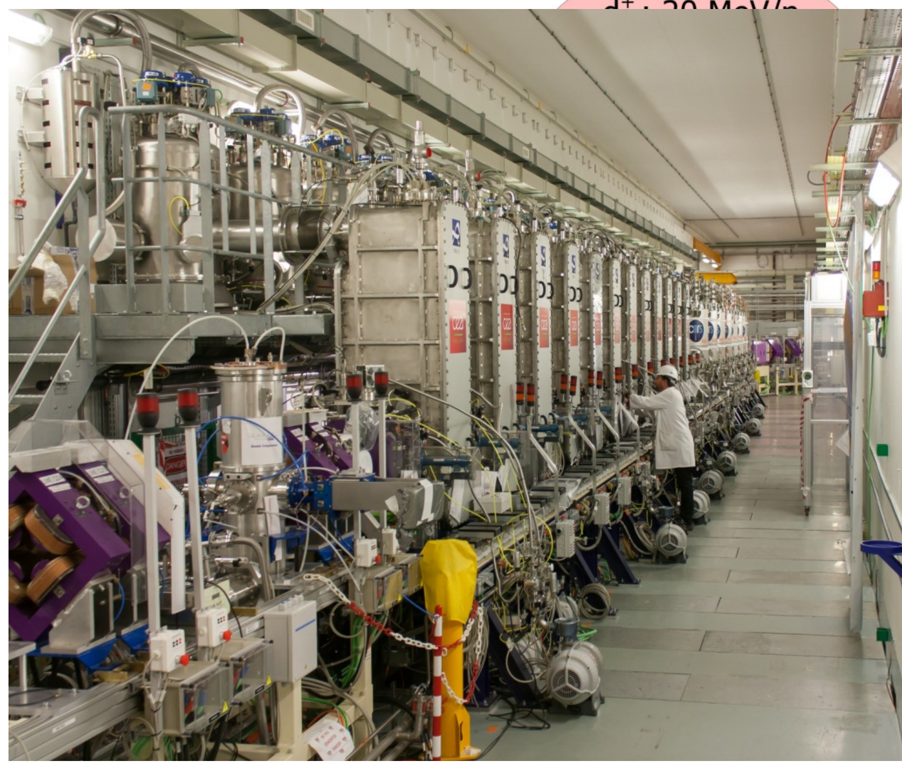
LINAC ready for RF

Partial cooled down









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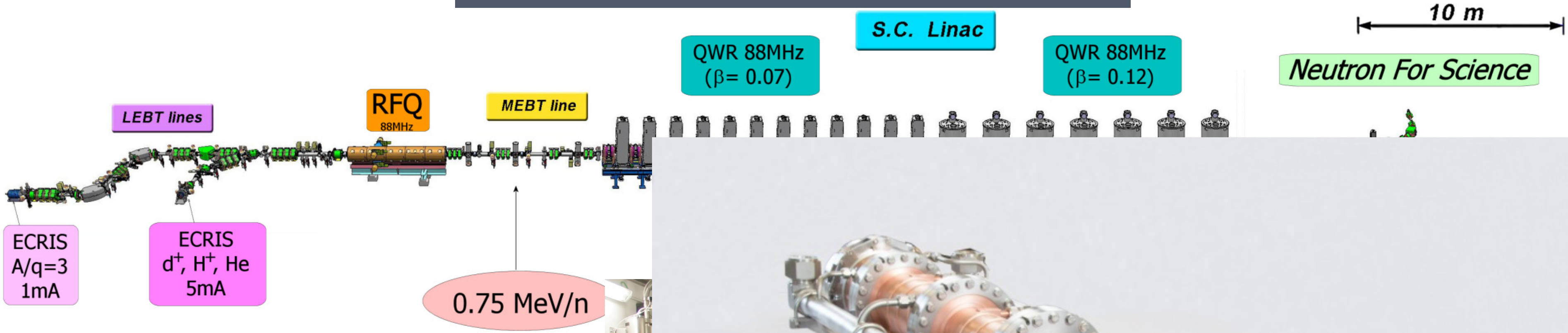
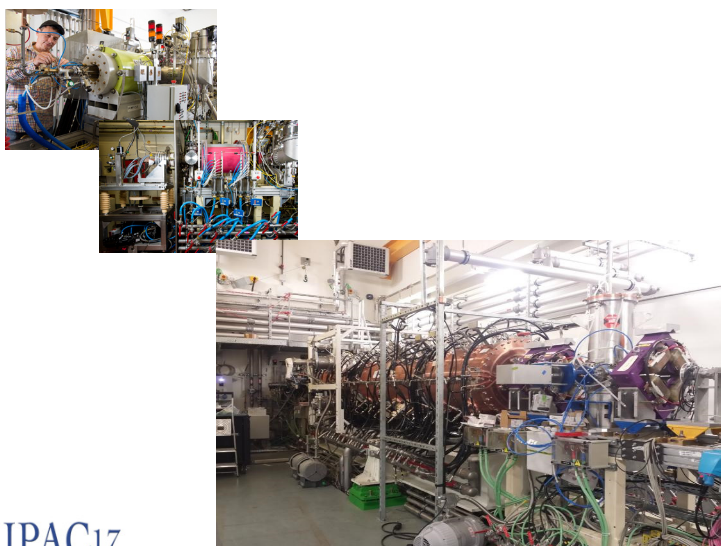
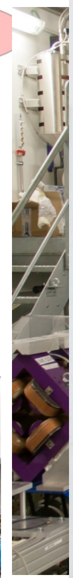
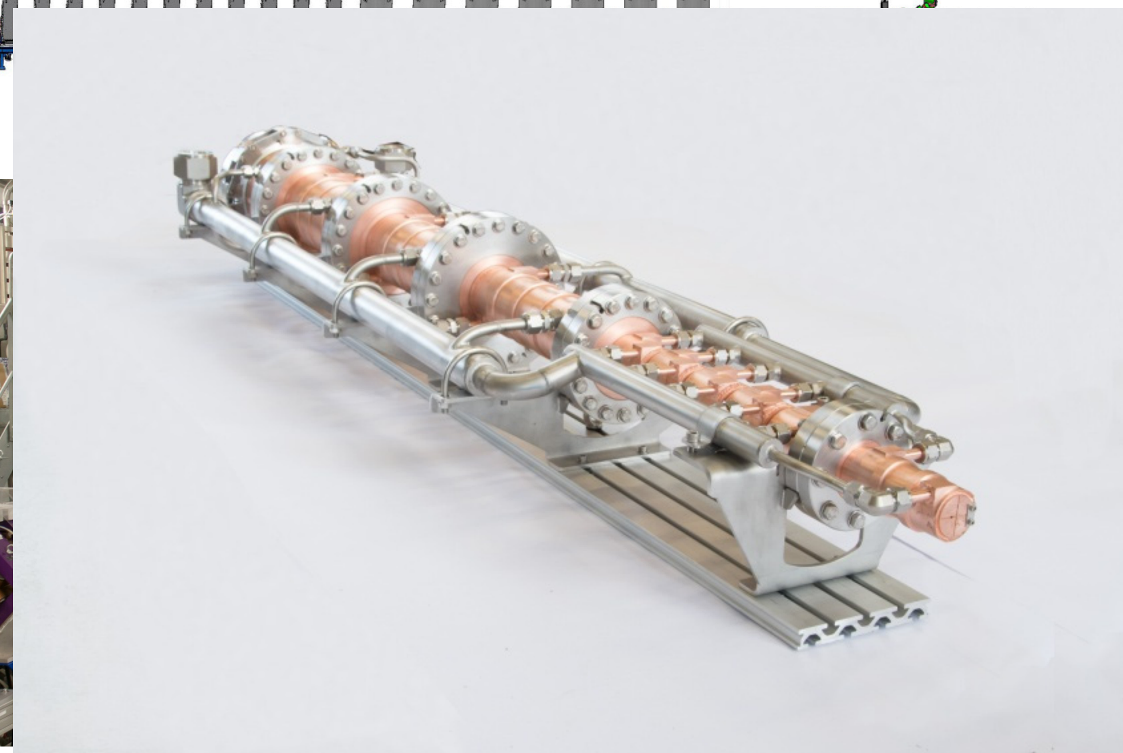
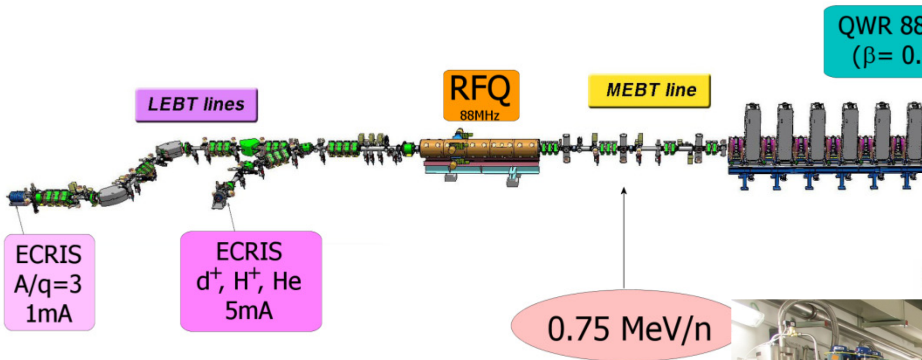


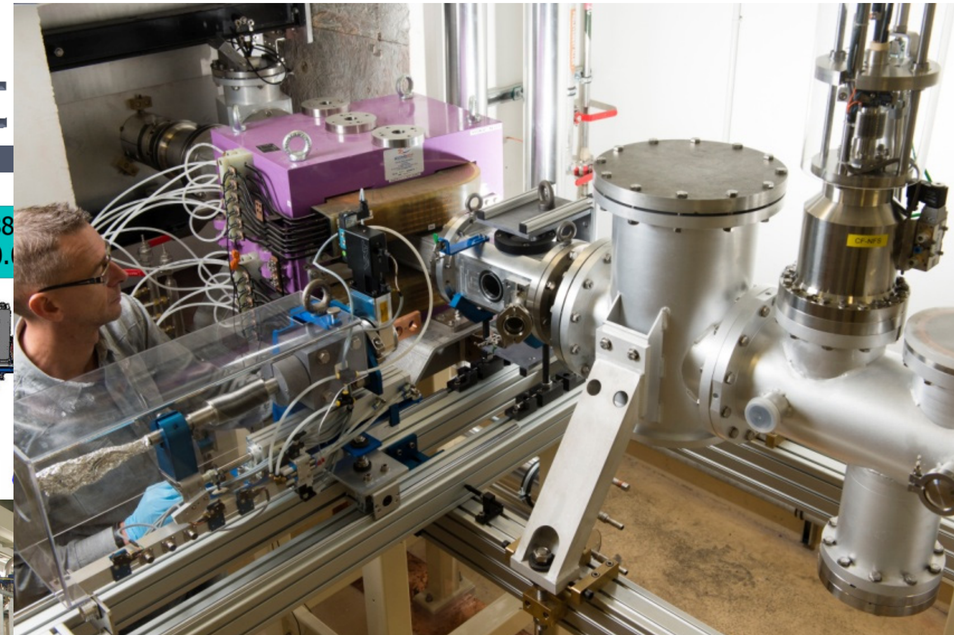


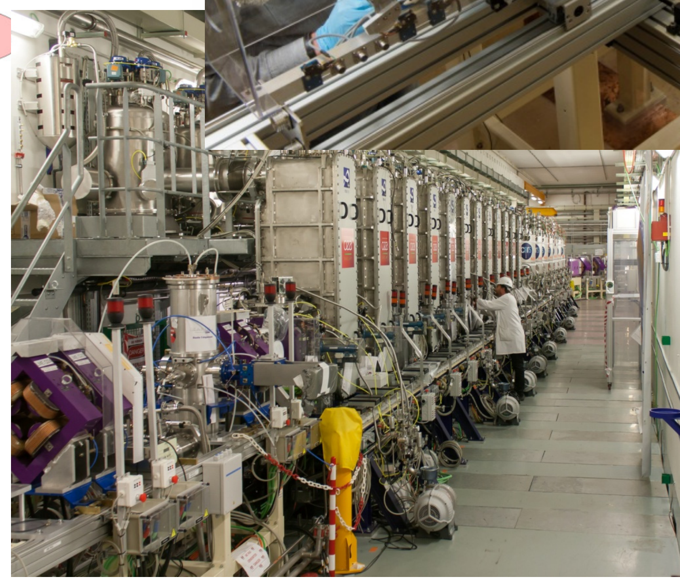


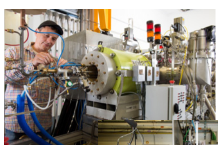


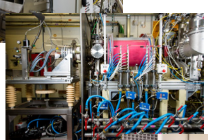
Installat

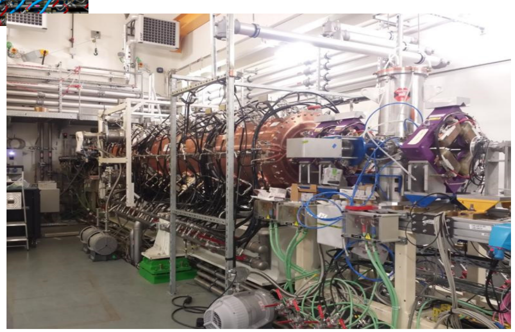

LEBT lines
RFQ
88MHz
MEBT line
QWR 88
(β= 0.
ECRIS
A/q=3
1mA
ECRIS
d^+, H^+, He
5mA
0.75 MeV/n











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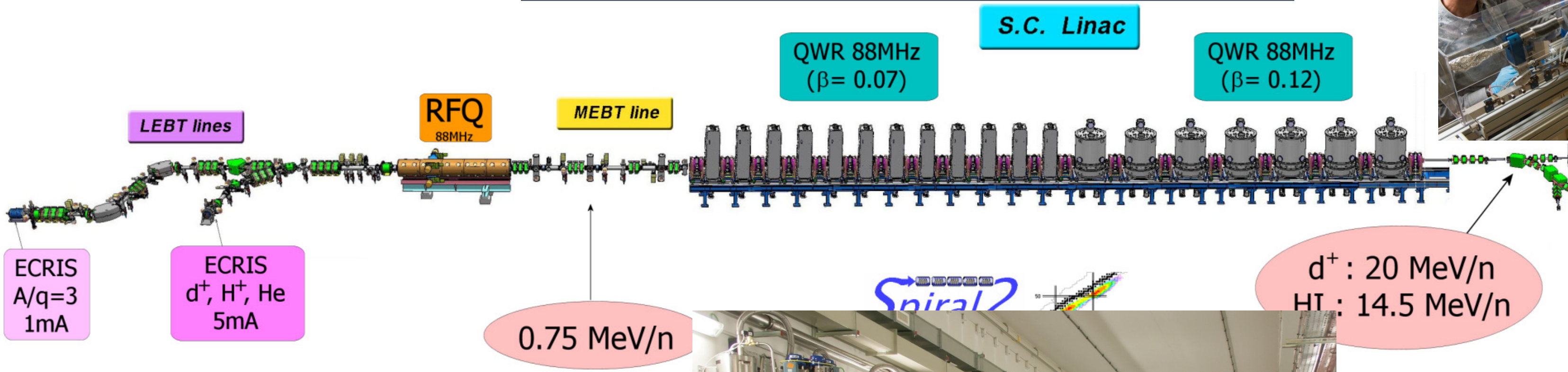

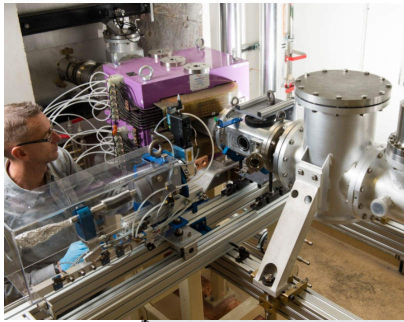

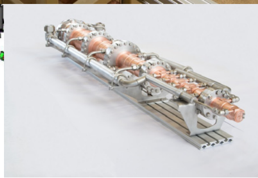

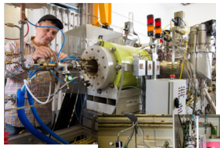

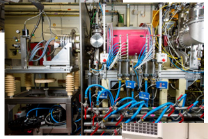

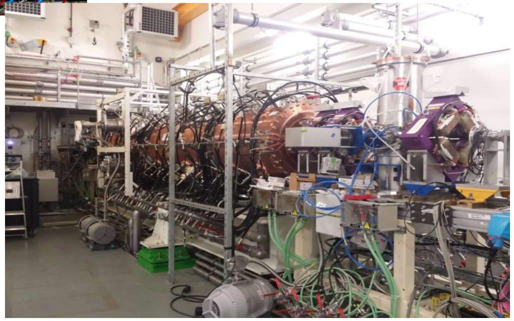

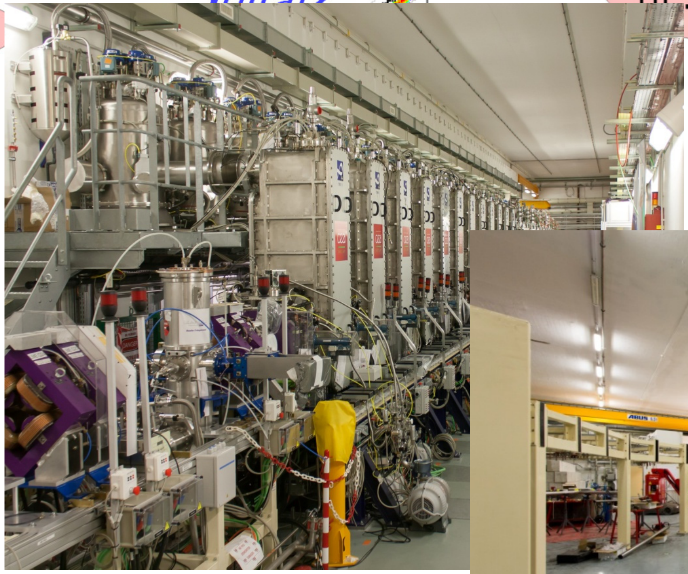

Commissioning
Strategy

SPIRAL2 four commissioning phases

- Qualification of the ion sources and LEBT in the laboratories in charge of the development (LPSC-Grenoble and CEA-Saclay)
  - 2009-2012
- Qualification of the injector on a test bench (GANIL)
  - Reproduce the results from the pre-commissioning
  - Validate the RFQ performances
  - Provide a development platform for various diagnostics
  - Measure the beam characteristics at the RFQ exit.
- SC linac beam commissioning up to the main beam dump
  - Progressive cool down
  - RF validation of all cavities
  - Beam commissioning
- “day-1” experiments to NFS and S3 experimental halls, including commissioning.

Strategy for a multi beam commissioning

- Increasing stress for the RFQ cavity and later for the linac
  - ❶ : H^+ beam, Light ion source and LEBT, 50kV on RFQ vanes, up to 5mA
  - ❷ : $^4He^{2+}$ beam, heavy ion source and LEBT, 80kV, up to 2mA, mimic the D^+
  - ❸ : ultimate injector performances, A/Q=3, 114kV, up to 1mA ➔ $^{18}O^{6+}$
  - ❹ : 20 µA Ni ion beam to facilitate the future tuning of the accelerator

Strategy for a multi beam commissioning

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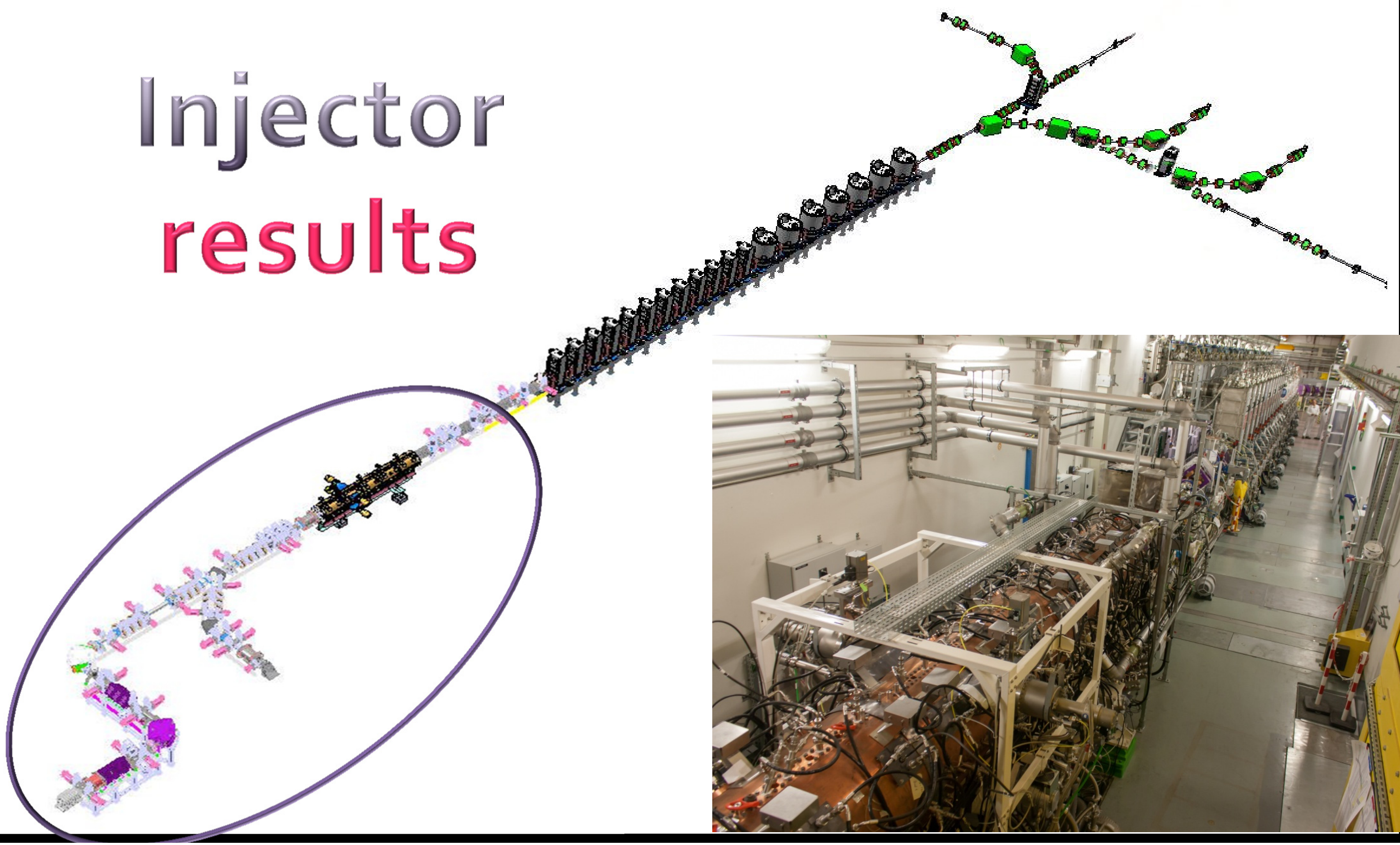
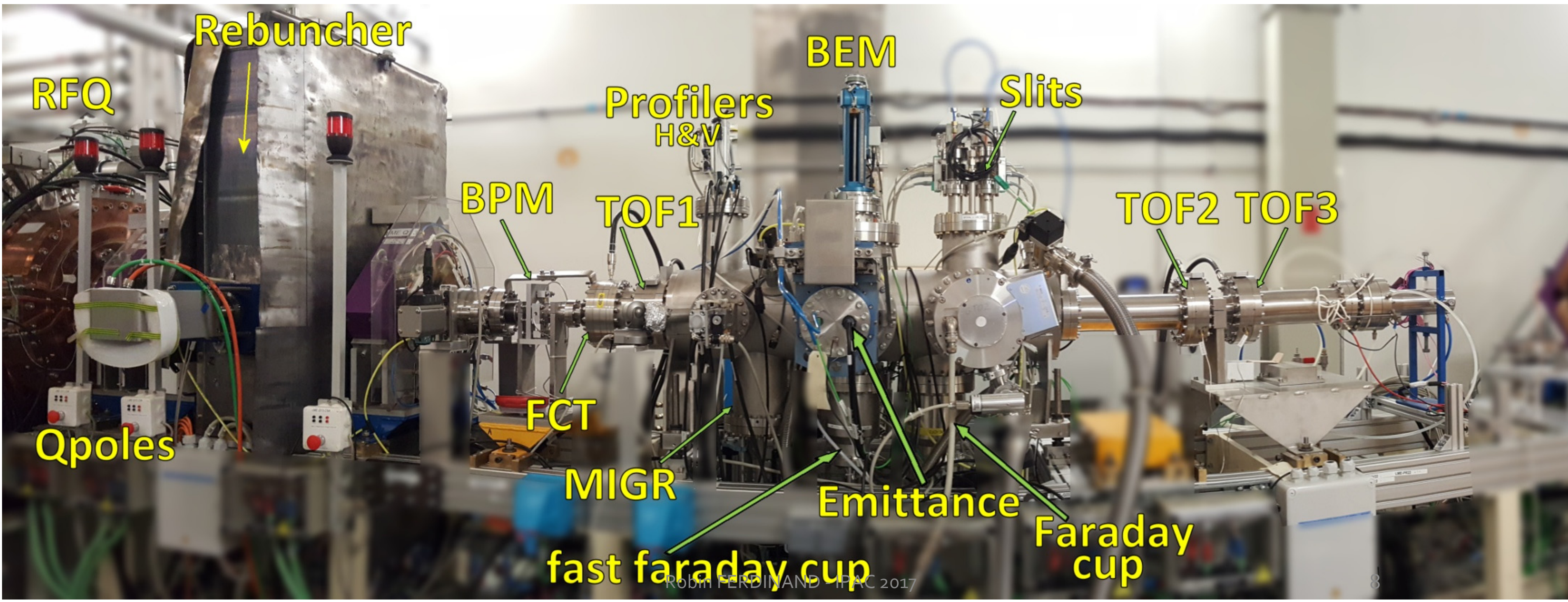
  - ❺ : D^+ beam, up to 5mA
    - requires the final licence from the Safety Authority Offices
    - Activation
    - May become ❸ to respect the Application Decree

Injector results



Test bench configuration

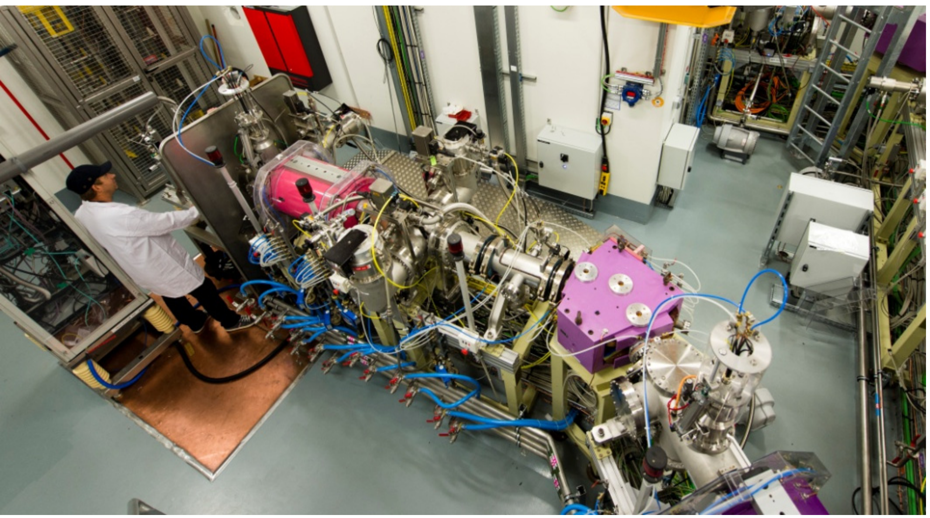


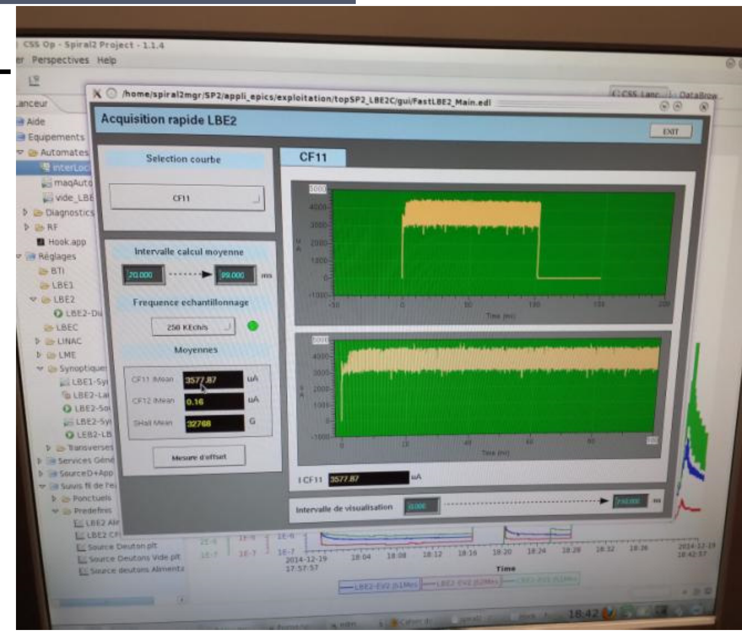
source commissioning

Source deuton (SD)

First beam (proton) at GANIL

December 19, 2014





Ability to extract 11 mA CW from source => up to 6 mA proton beam at the RFQ entrance

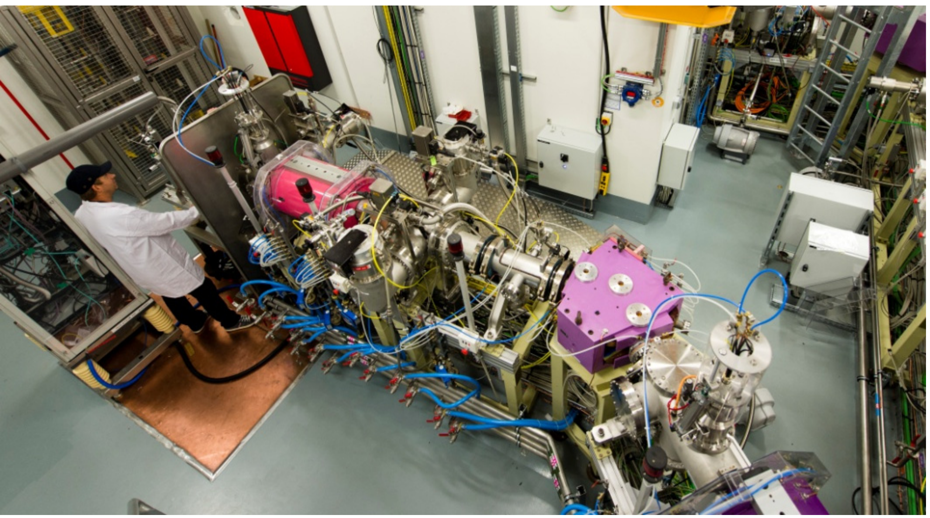
Beam intensity and emittance control using 6 H and 6 V slit systems

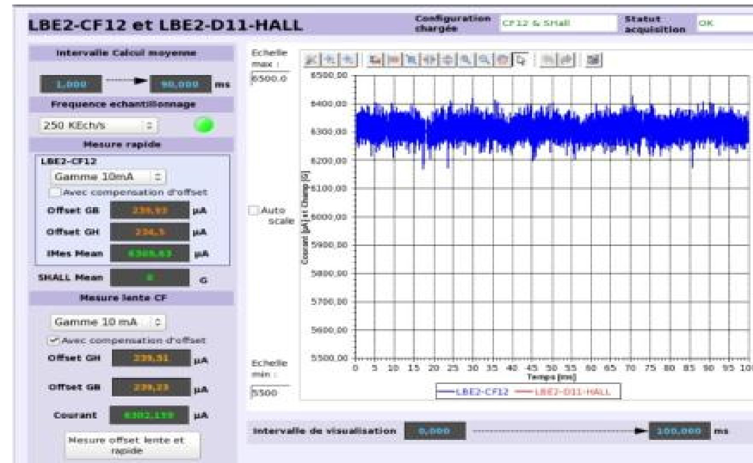
source commissioning

Source deuton (SD)

First beam (proton) at GANIL

December 19, 2014





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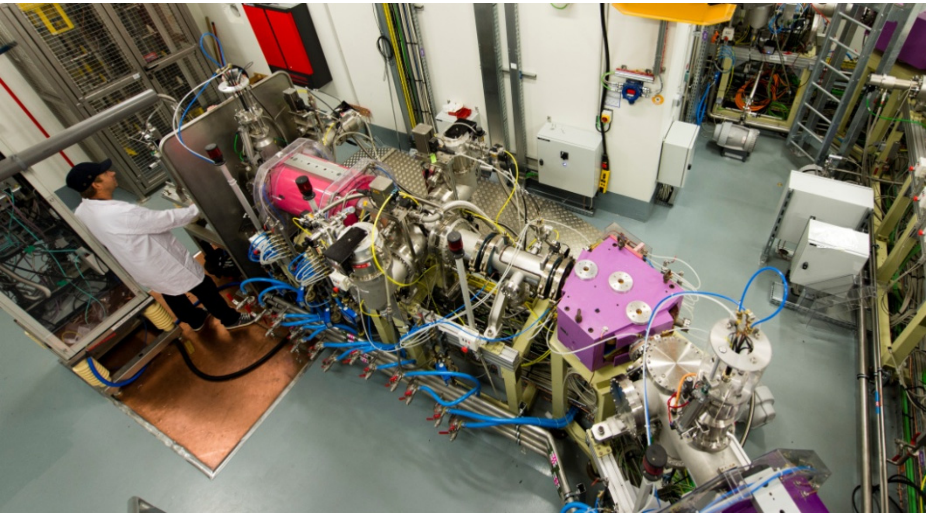
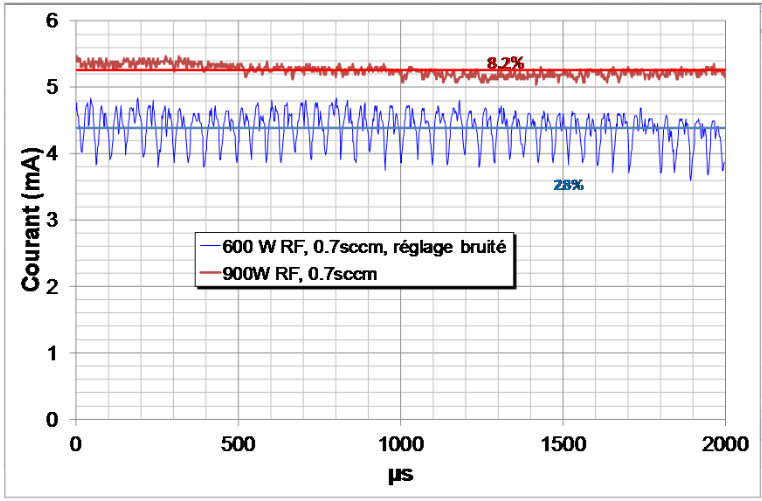




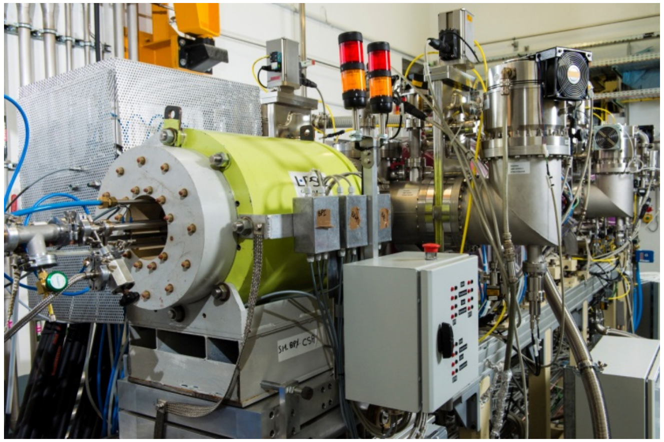
Ability to extract 11 mA CW from source => up to 6 mA proton beam at the RFQ entrance

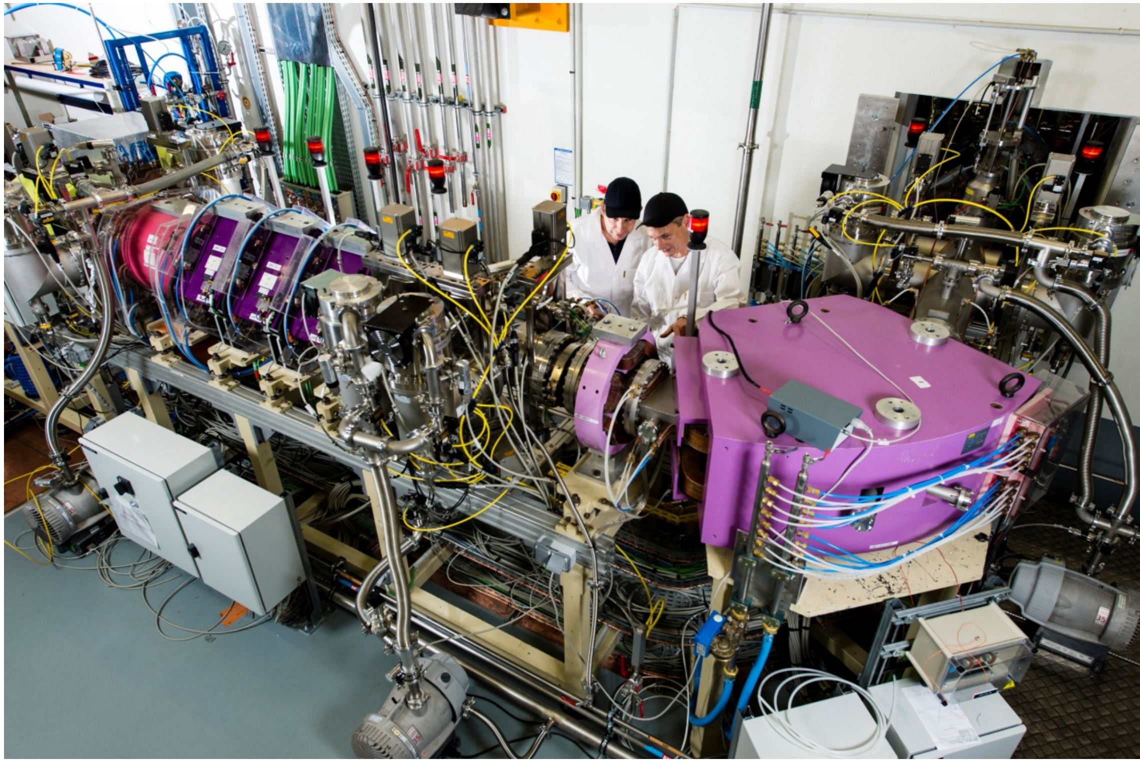
Beam intensity and emittance control using 6 H and 6 V slit systems

source commissioning

HI source (Q/A=1/3)

First beam (230 µA Argon 9+) July 10, 2015





Already tested :

$^{4}He^{2+}$ A/Q = 2, 3mA, 1.5 mA after RFQ

$^{40}Ar^{14+}$: 45µA

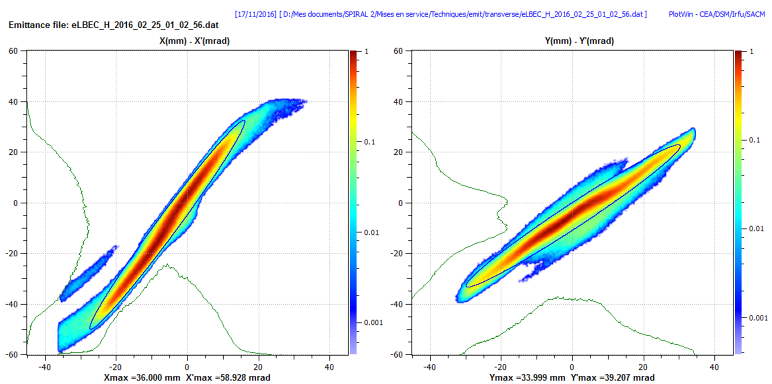
$^{18}O^{6+}$: 1.2 mA

Metallic not showing up… :-(

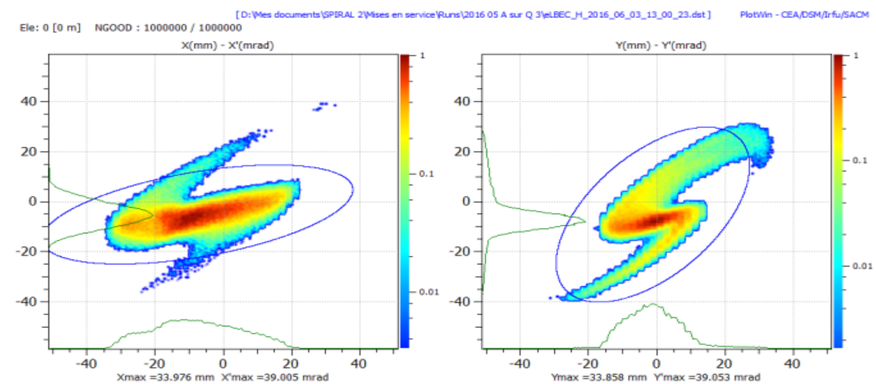
Emittance at the end of the LEBT

Particle	Beam current (mA)	Emit X (π.mm.mrad)	Emit Y (π.mm.mrad)
H^+	5.2	0.18	0.2
$^{4}He^{2+}$	1.35	0.54	0.43
$^{18}O^{6+}$	0.75	0.36	0.42

Expected:
P or D : 5mA, 0.2 π.mm.mrad
HI : 1mA, 0.4 π.mm.mrad



5.2mA H^+, 0.2 π mm mrd rms norm.



750μA $^{18}O^{6+}$, ε=0.36/0.42 π.mm.mrad

RFQ high Power commissioning

- 4 x 60 kW rf amplifiers (tubes / 3 kW solid state preamplifier)

- Voltage law measured by means of 16 pick-ups, in RF operation
- Relative errors are less than ±0.8% as the vane voltage is varied from 10 kV to 95 kV, rise to 3.4% at 113.6kV (might be related to a bad cable)
- Conditionned up to 121kV above the nominal voltage (113.6kV)
  - No sparks at 80kV (D^+ value)
  - @nominal : Spark every 45min (mean), record 1.5h
  - 121kV (one spark every 2min, record 8min)
- RF shows instabilities at high voltage
  - Investigation of cooling circuits/LLRF/RF amplifiers
- 38kW more than expected (200kW instead of 170kW)

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See THPIK005
RF
CONDITIONNING

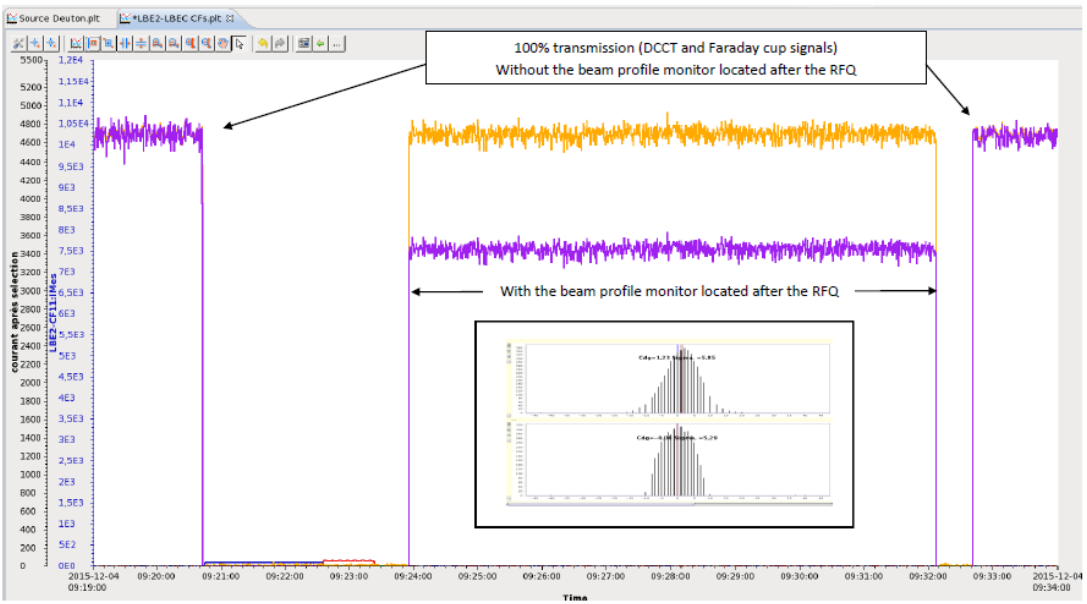
RFQ beam commissioning

- 2015, December 03, 9h26 : First RFQ beams (*Protons*)
- 4.8 mA with 100% transmission at the end of the same working day (SPIRAL 2 nominal beam current)

4.8 mA proton beam   100% SPIRAL 2 RFQ transmission   December 04, 2015

Yellow = beam current, DCCT RFQ entrance

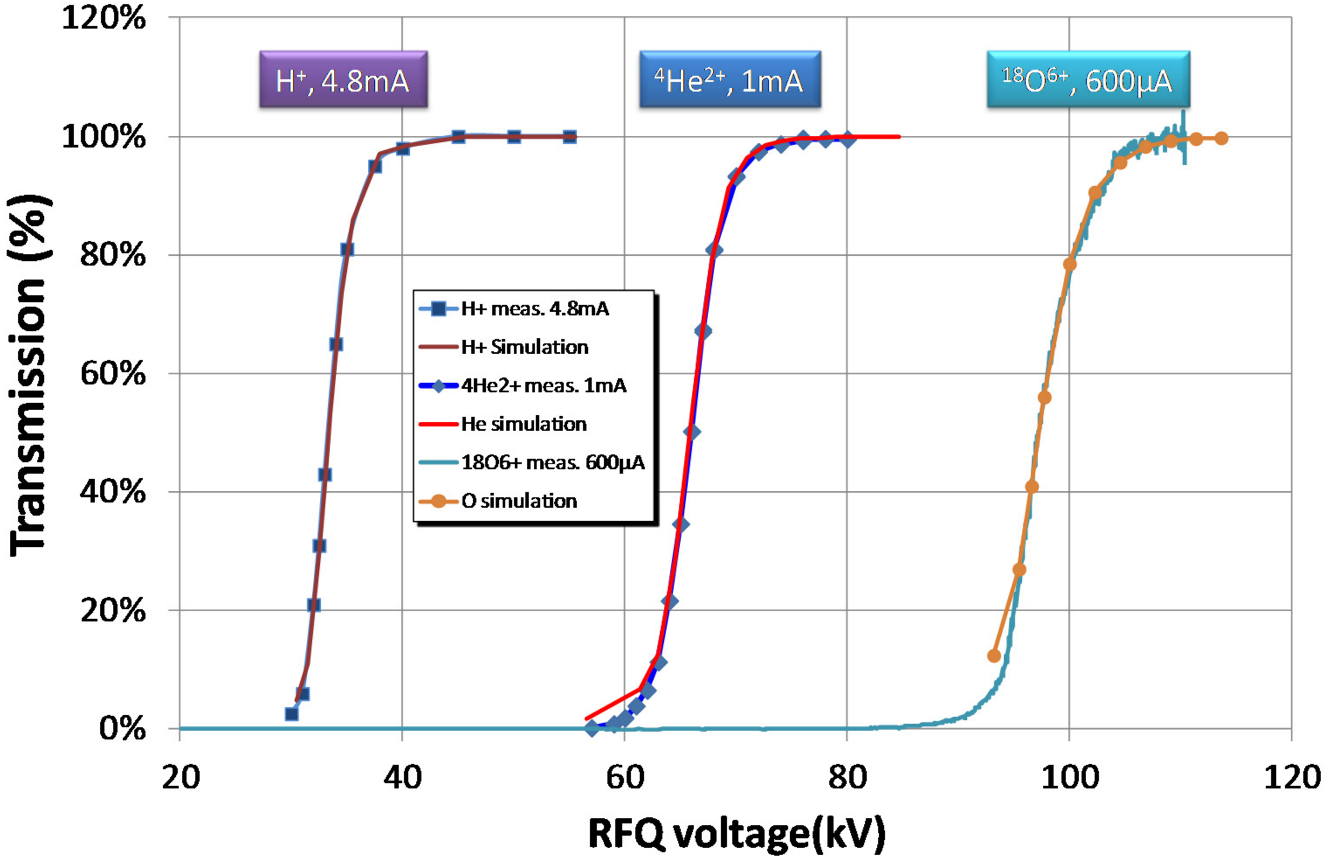
Violet = beam current, Faraday cup RFQ exit



First CW proton beam :
2.3 mA on December 18

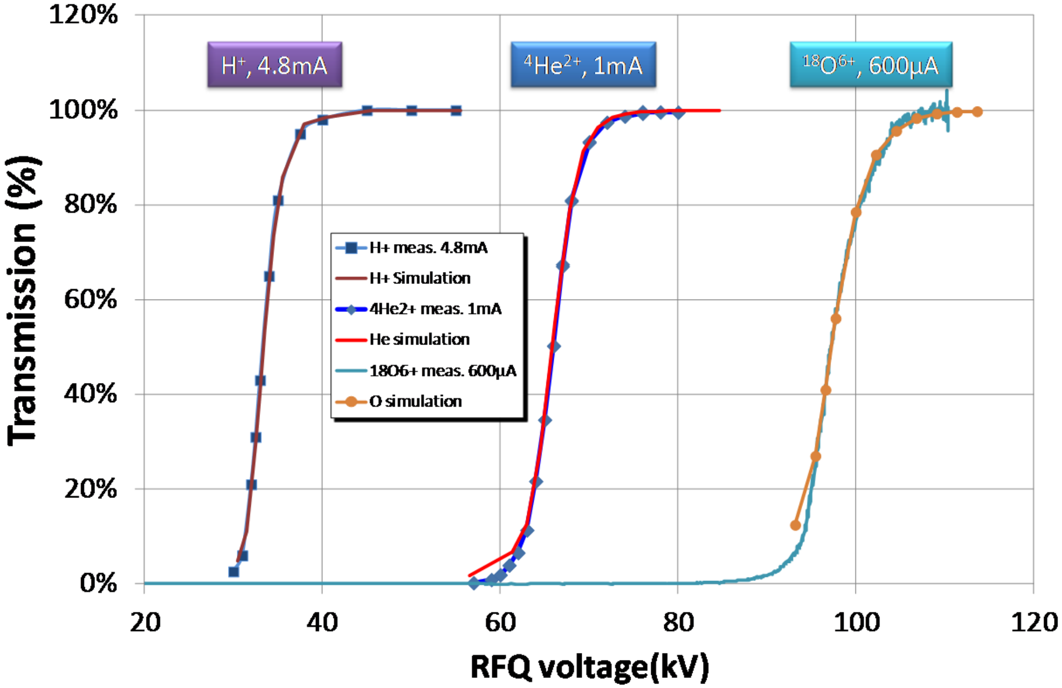
Now routine operation

Transmission comparison with calculation



RFQ always operated CW from the rf point of view, rf operation stable and reliable for Proton/Hélium

Transmission comparison with calculation



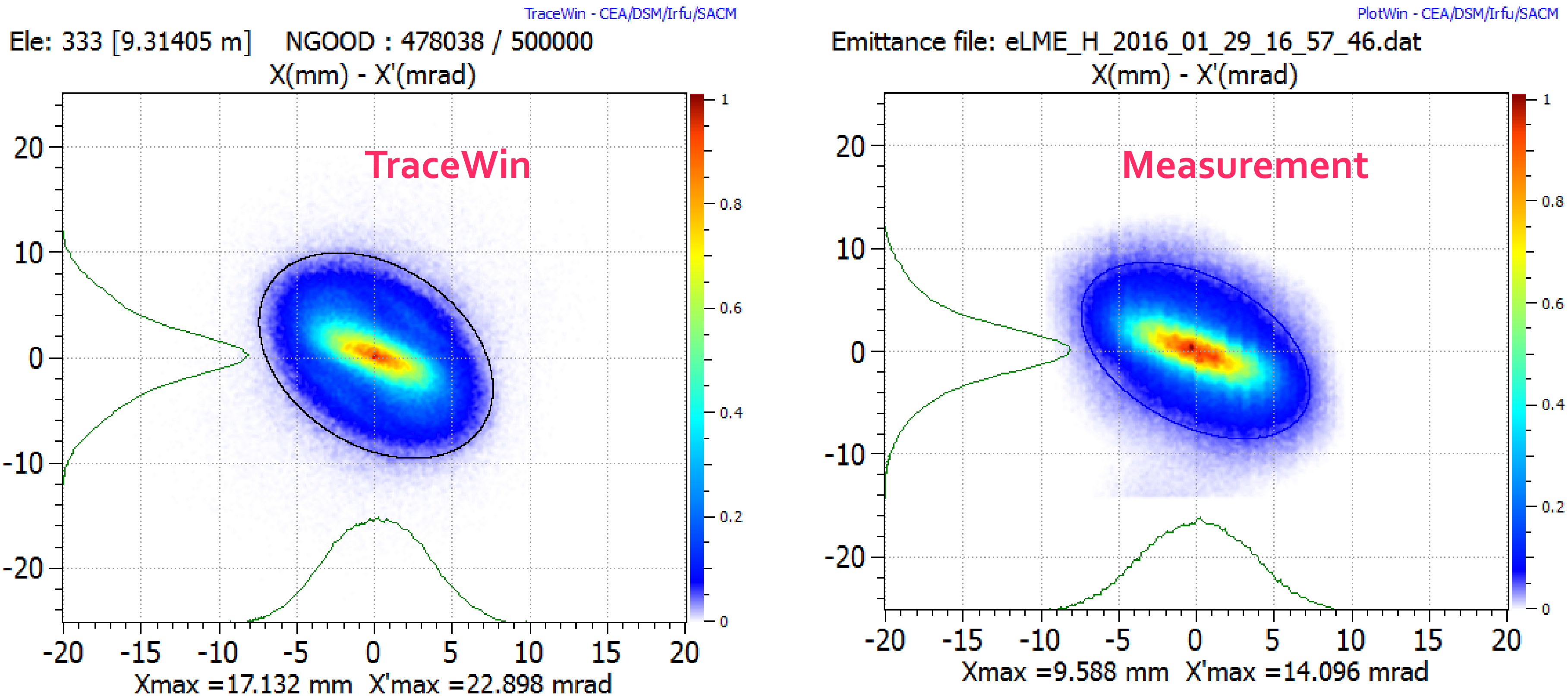
Proton : December 23, 2015
Helium : June 04, 2016
Oxygen : December 9, 2016
trans. OK, but not fully tested

RFQ specifications reached (transm., energy, emittances… In CW operation) for H^+, $^4He^{2+}$

RFQ always operated CW from the rf point of view, rf operation stable and reliable for Proton/Hélium

RFQ beam commissioning

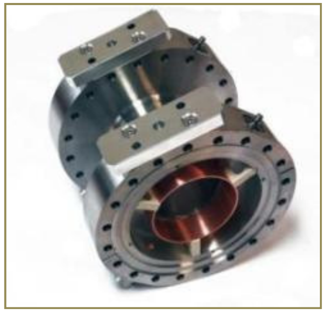
- Emittance measurement and comparison with the code



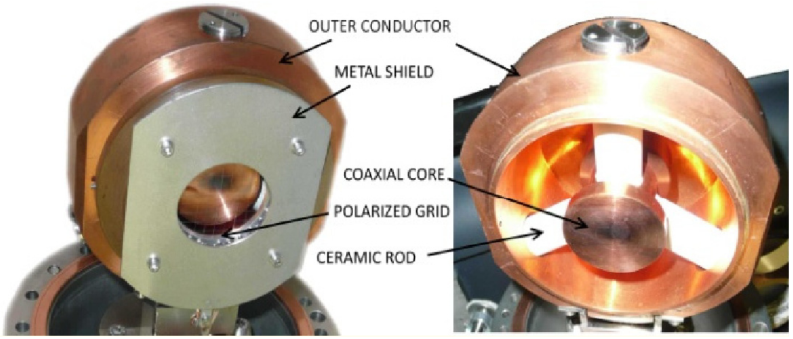
Longitudinal measurements

- TOF measurements (IBIC – W. LeCoz – WEPF32)

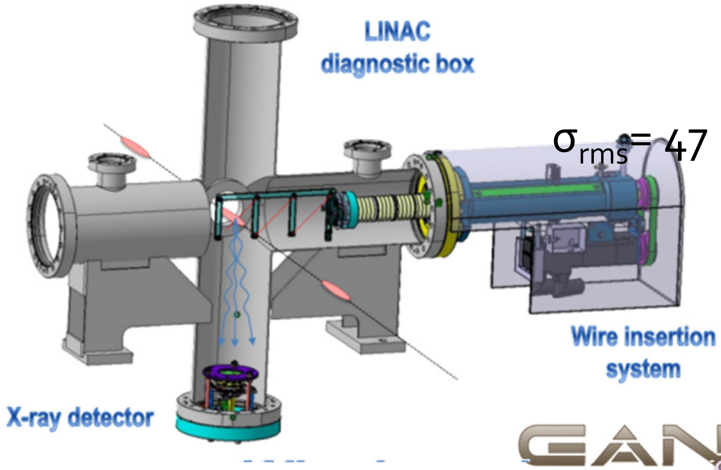
Energy (keV/nucleus)	Toutatis simulations	TOF measurement
Proton	730	729.3
Helium	727.2	728.1



- Fast Faraday Cup (IBIC – C. Jamet - WEPG42) and Beam Extension Measurement (IBIC – R. Revenko - TUPG59)



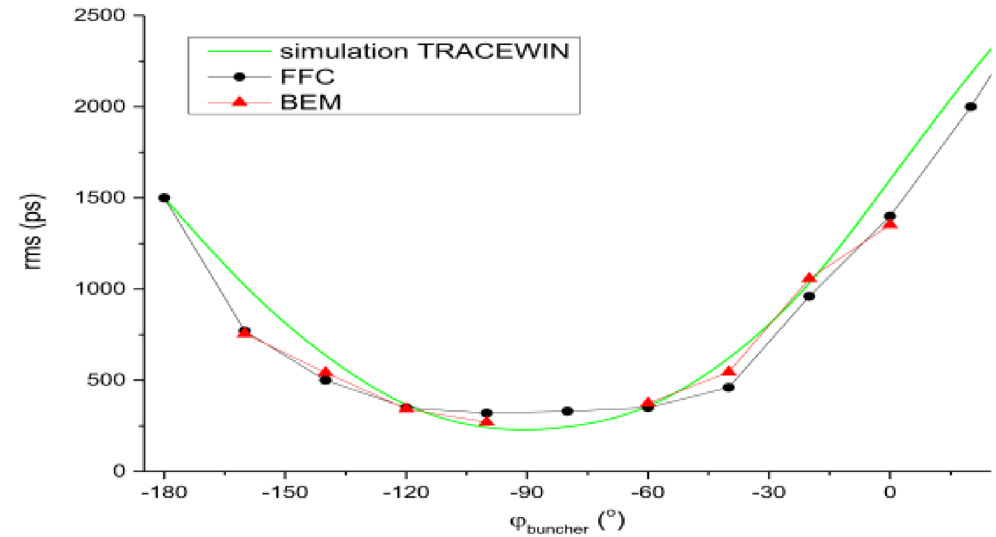
400W max, and σ_{rms}= 320–330 ps



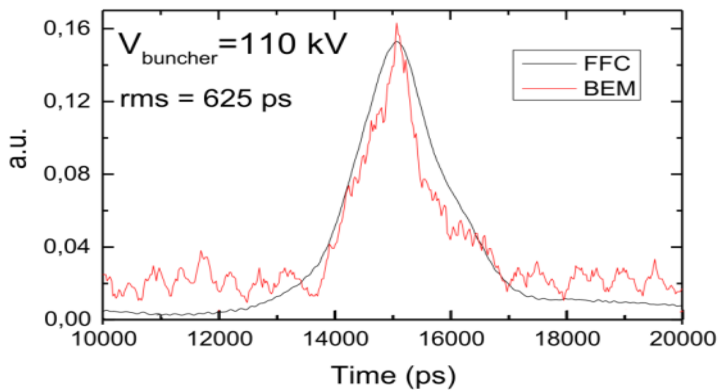
σ_{rms}= 47 ps

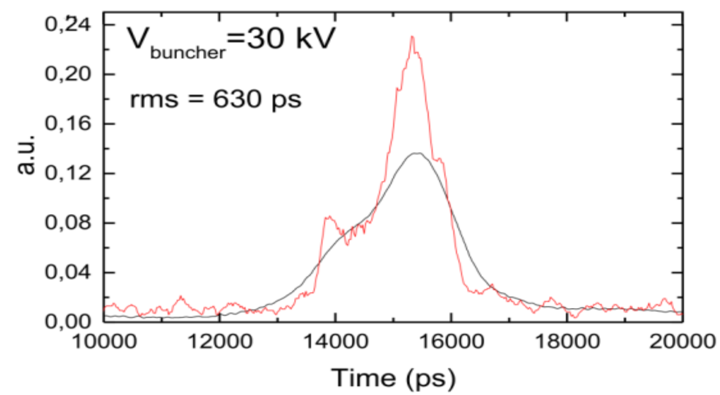
Bunch length measurement comparison

- Good agreement between the two measurements and the TraceWin simulations
- Buncher variation in phase or voltage
- 0.27 π.deg.MeV (Helium, 0.19 expected)



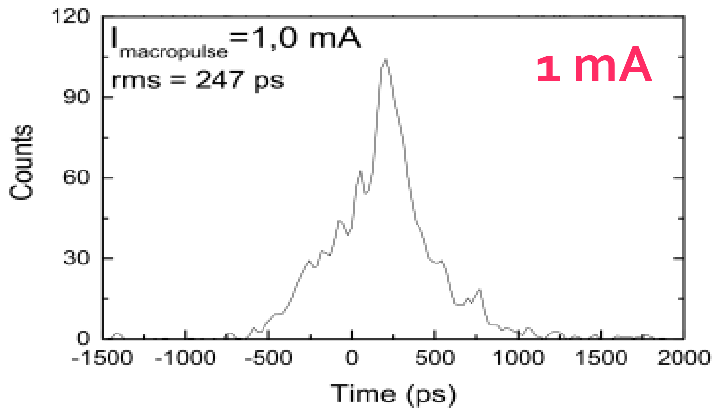
Comparison FFC with BEM, 0.6mA, 1%dC

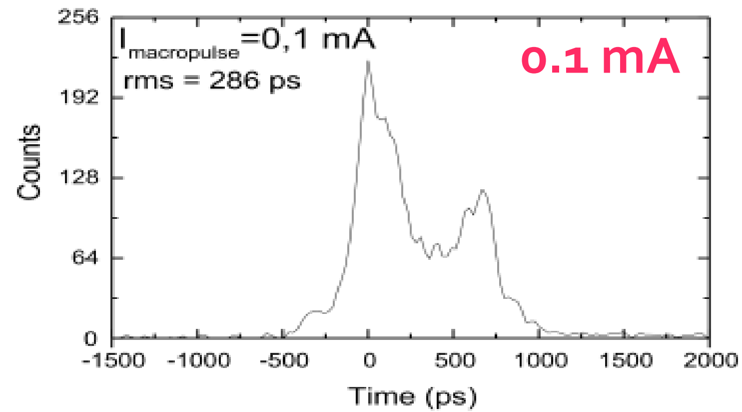


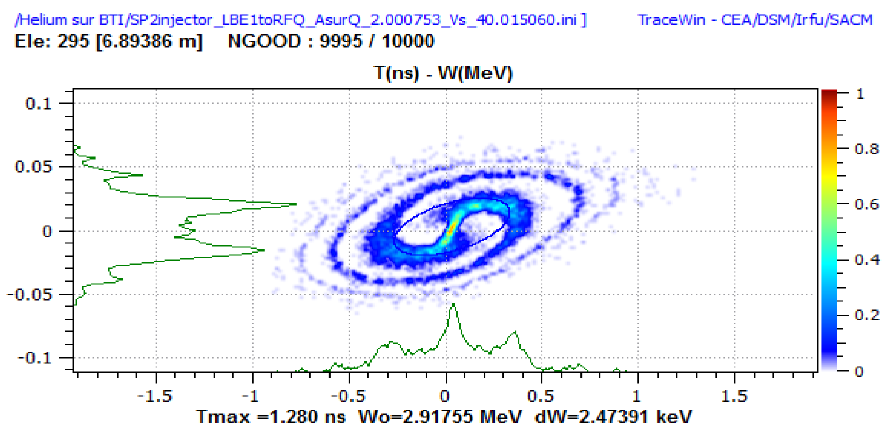


Longitudinal results

- Very different shapes for 1 mA and < 150μA beams

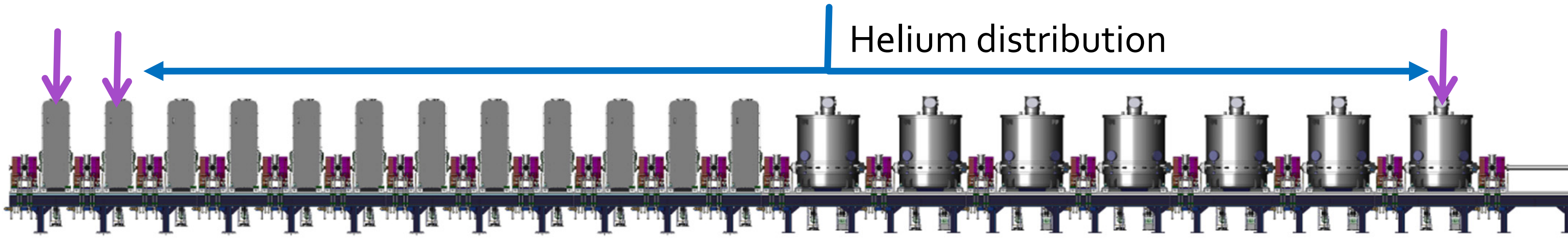




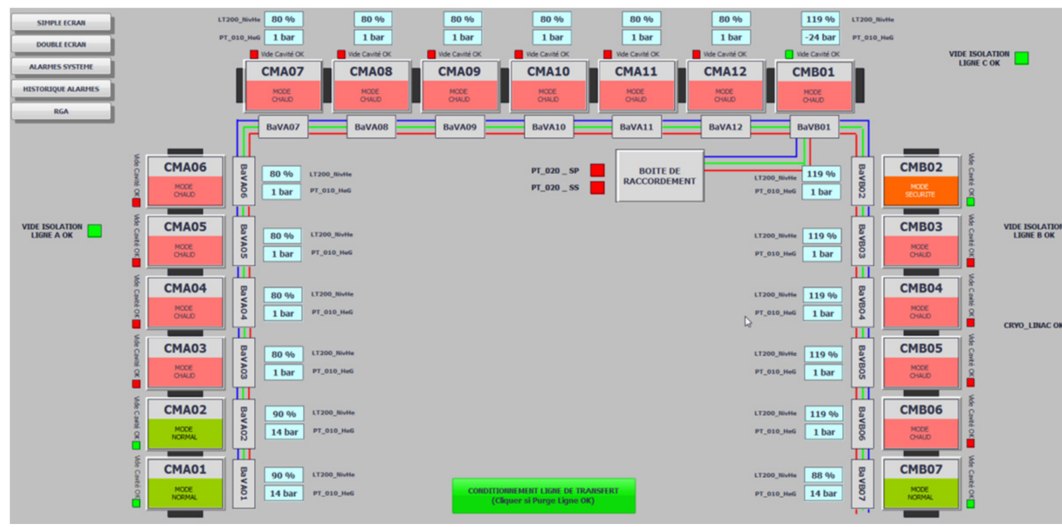


Linac
results

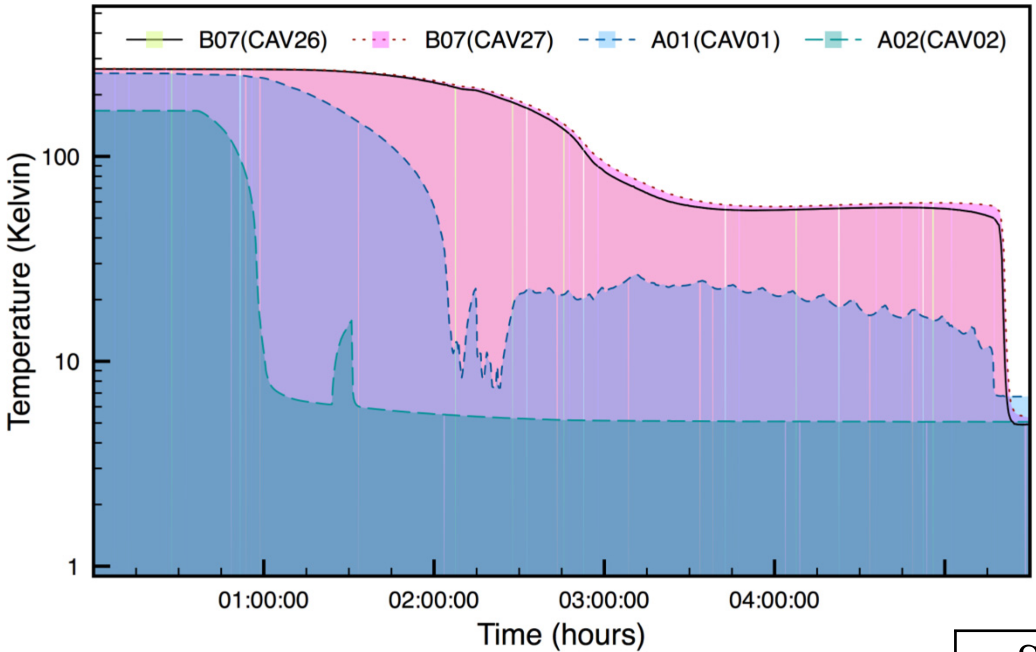
Linac partial cool downs



- First partial cool down on July, 2016
  - test a major part of the cryogenic installation
    - thermal acoustic oscillations (TAO)
  - PLCs and C/C
- Second in march 2017
  - validate the helium pressure stability requirements of ± 3mbar

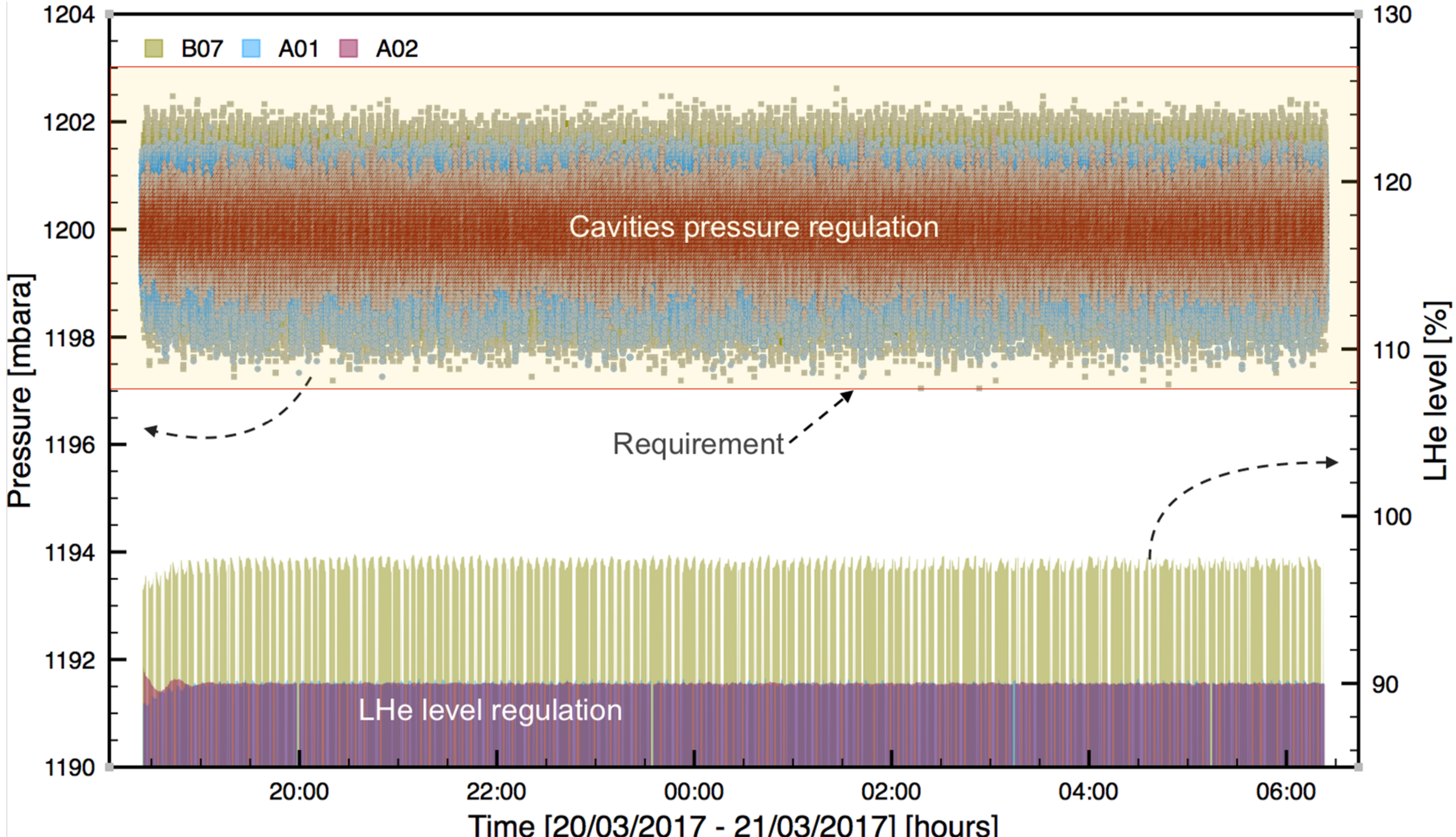


Cryogenic results



Static @4K	*CMA01*	*CMA02*	*CMB07*
Saclay/Orsay meas.	5.73 W	3.98 W	19 W
GANIL meas.	4.95 W	2.99 W	12.33 W

Pressure stability (11h)



What's next ?

- RFQ RF commissioning to be finished
- Deuteron RFQ beam measurement
  - Waiting for the safety authorization
- RFQ validation with beam ($^{18}O^{6+}$)
  - depend on D-plate removing and the Linac commissioning
- RF in linac cavities
  - Waiting for the safety authorization
- Linac first beam (H^{+})
  - Next year

Partner labs for GANIL/SPIRAL2 phase 1

- CEA-Irfu (SACM, SIS, LENAC) : P/D source, RFQ, LEBT, A-type cryomodule, C/C, LLRF, Activation simulation, commissioning
- CEA/DAM/ DP2I : safety
- CNRS-IN2P3 (IPNO, IPNL, IPHC, LPSC, LAL, LPC) : HI source, B-type cryomodules, power couplers, diagnostics, final main beam bump, timing, commissioning
- BARC : BPM electronic
- INFN : Slow Choper, bunch selector (fast chopper), test stand
- IFJPAN: Valves boxes installation
- SOREQ : diagnostic beam test stand
- IFIN-HH : Beam loss monitor
- INRNE-BAS : linac supports
- Argonne : design of A/Q=1/6 injector
- CIEMAT : beam dump

Summary

- Good advances of the SPIRAL2 project !!!
  - Both light and heavy ion sources working very well
  - RFQ working well
    - RFQ with about 100% transmission
    - Very good comparisons with TraceWin simulations
- RFQ partly conditioned up to maximum voltage (114 kV, CW)
- RFQ improvements
  - rf amplifiers (reliability) LLRF (variable freq. loop) Tuning system (faster and stable)
- Superconducting linac :
  - Stable cryogenic operation with 3 cryomodules

Thank you for your attention

Thank all the GANIL and partner labs staff

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