HB2014

54th ICFA Advanced Beam Dynamics Workshop on High-Intensity, High Brightness and High Power Hadron Beams

East Lansing, MI

10-14 November 2014

Initial commissioning of ion beams at SPIRAL2

Patrick Bertrand

On behalf of the SPIRAL2 accelerator team

Summary

- SPIRAL2/GANIL layout and baseline
- SPIRAL2-NFS-S3 building/infrastructures
- Installation of the SPIRAL2 accelerator
- Beam commissioning strategy
- Conclusion

GANIL/SPIRAL2 Layout and mid term roadmap

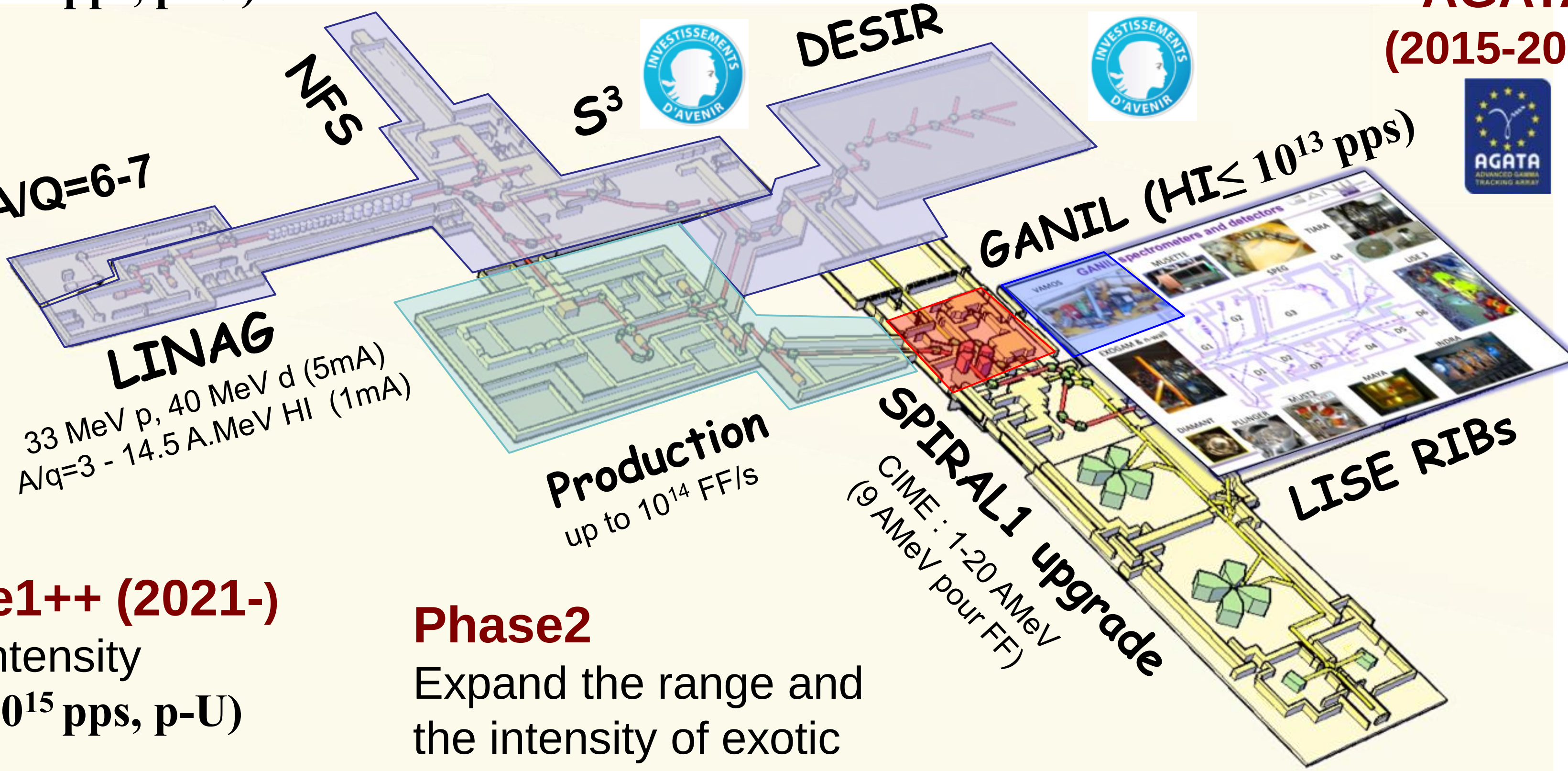
Phase1 (2015-)

Increase the intensity of stable beams
High intense neutron source
(HI≤ 10^{15} pps, p-Ni)

DESIR Phase1+ (2019-)

Low energy facility

AGATA (2015-2016)



Phase1++ (2021-)

High Intensity
(HI≤ 10^{15} pps, p-U)

Phase2

Expand the range and the intensity of exotic nuclei

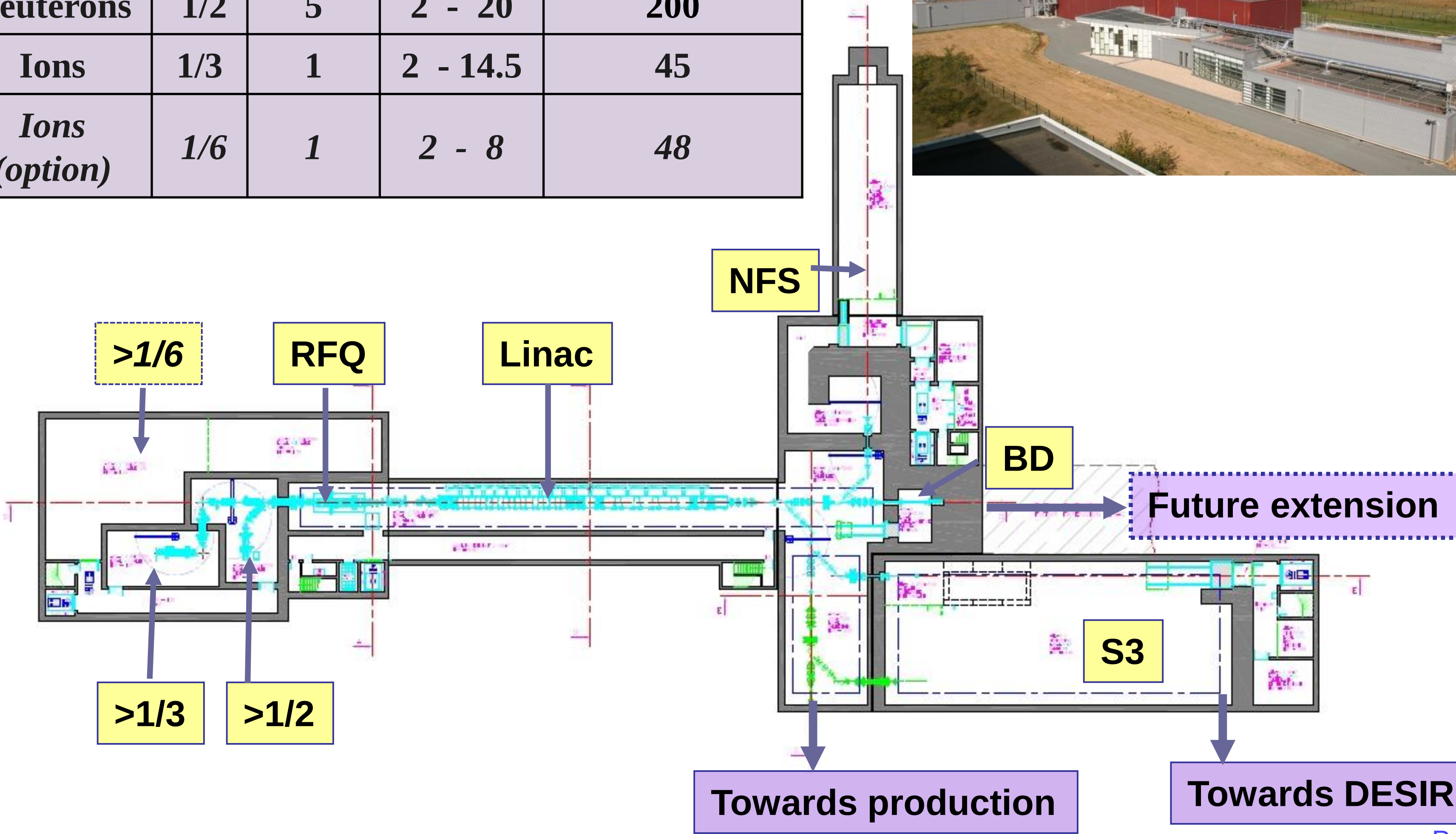
A National & EU priority

SPIRAL1 Upgrade (2016-)

New light RIBs from beam/target fragmentation

SPIRAL2 Accelerator Baseline

	Q/A	I (mA)	Energy (Mev/u)	Max beam Power (KW)
Protons	1/1	5	2 - 33	165
Deuterons	1/2	5	2 - 20	200
Ions	1/3	1	2 - 14.5	45
Ions (option)	*1/6*	*1*	*2 - 8*	*48*



Construction of SPIRAL2 Phase 1 building

Nov. 2010

Feb. 2011

May 2011

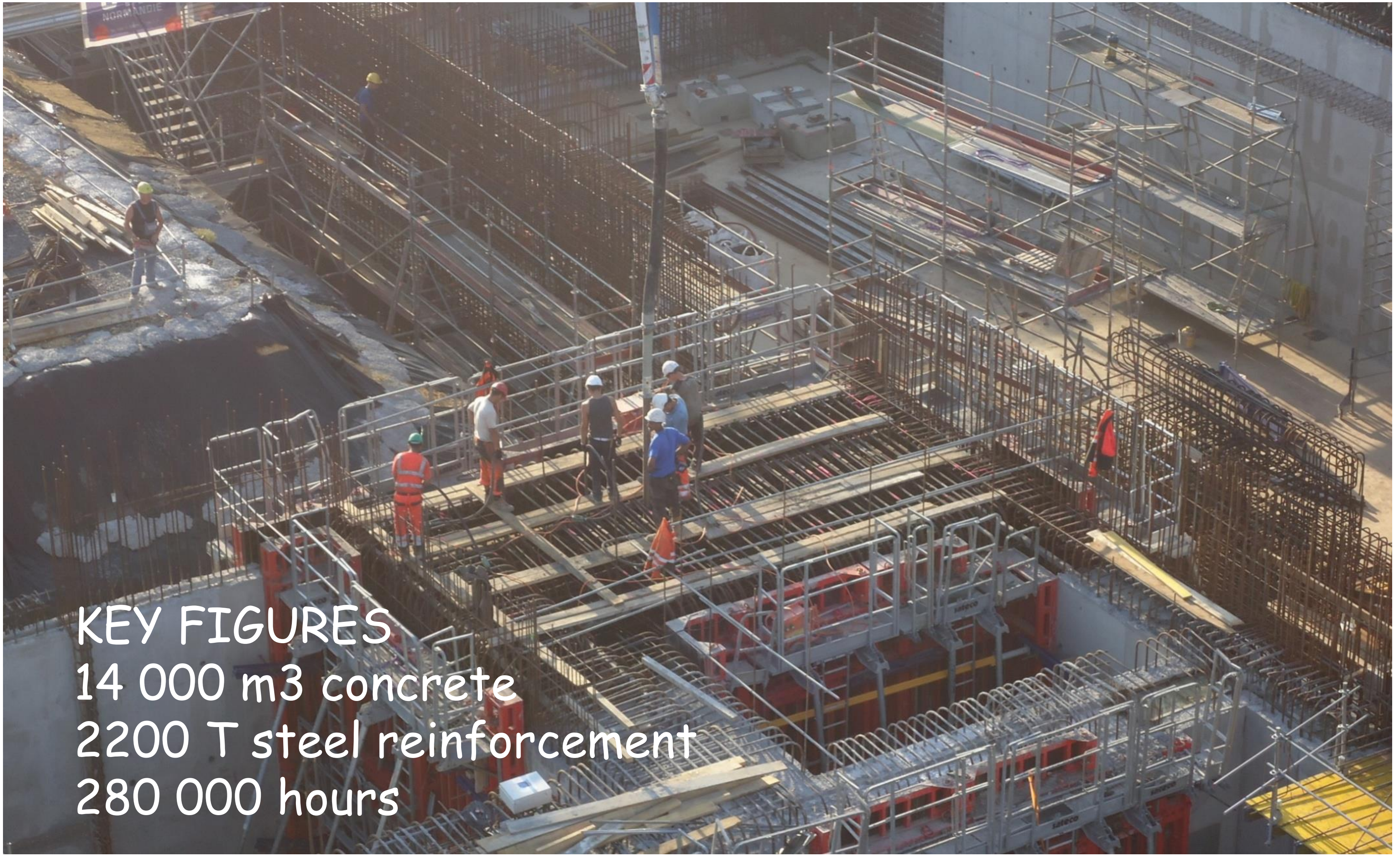
Oct. 2011

May 2012

Oct. 2012

Key figures of SPIRAL2 Building construction...

CIVIL ENGINEERING / 06/2011 TO 07/2013



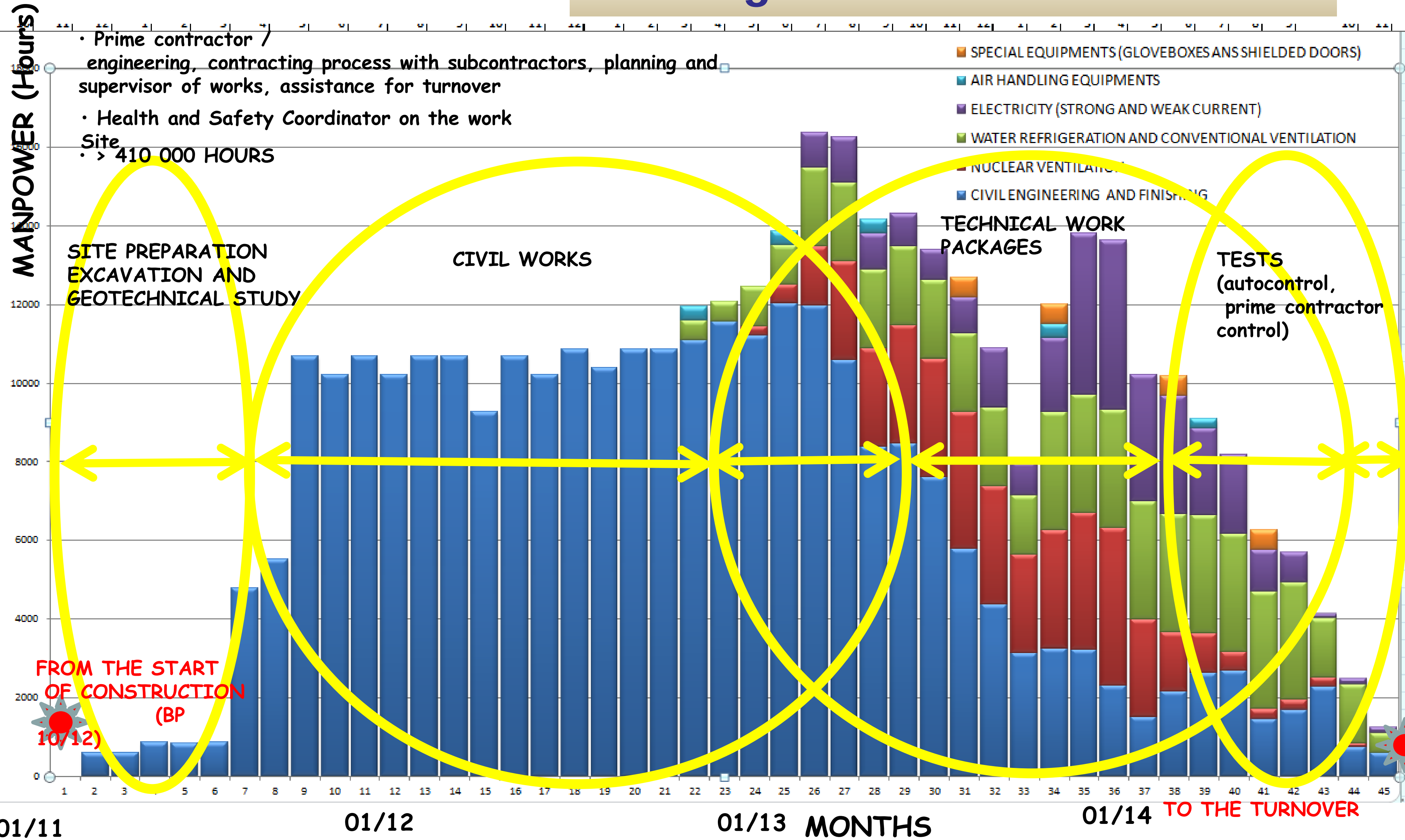
KEY FIGURES
14 000 m3 concrete
2200 T steel reinforcement
280 000 hours

SPIRAL2 Building...

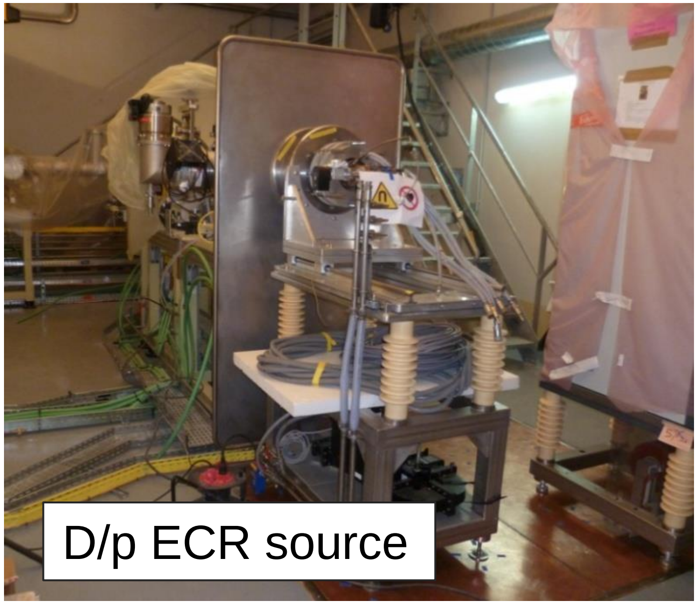
Nuclear ventilation

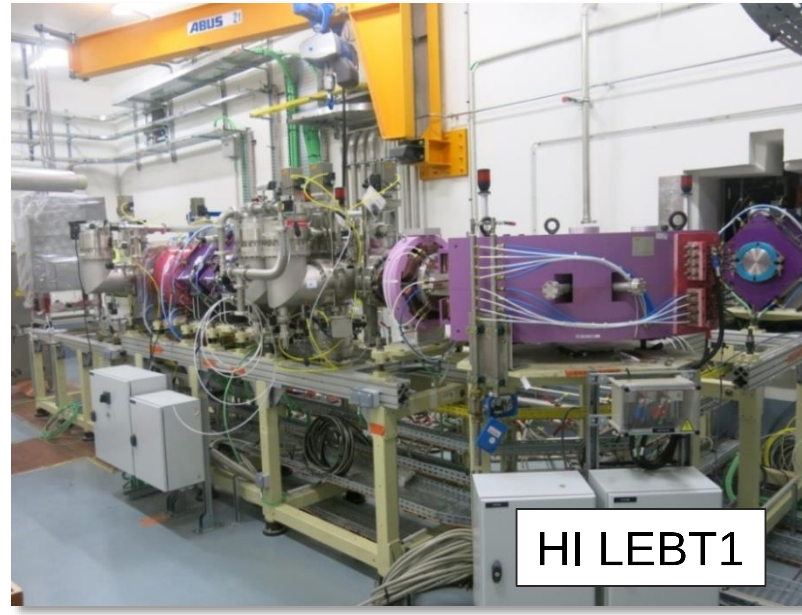
Water cooling system

Simplified planning of SPIRAL2 Building construction...



Installation of SPIRAL2 accelerator

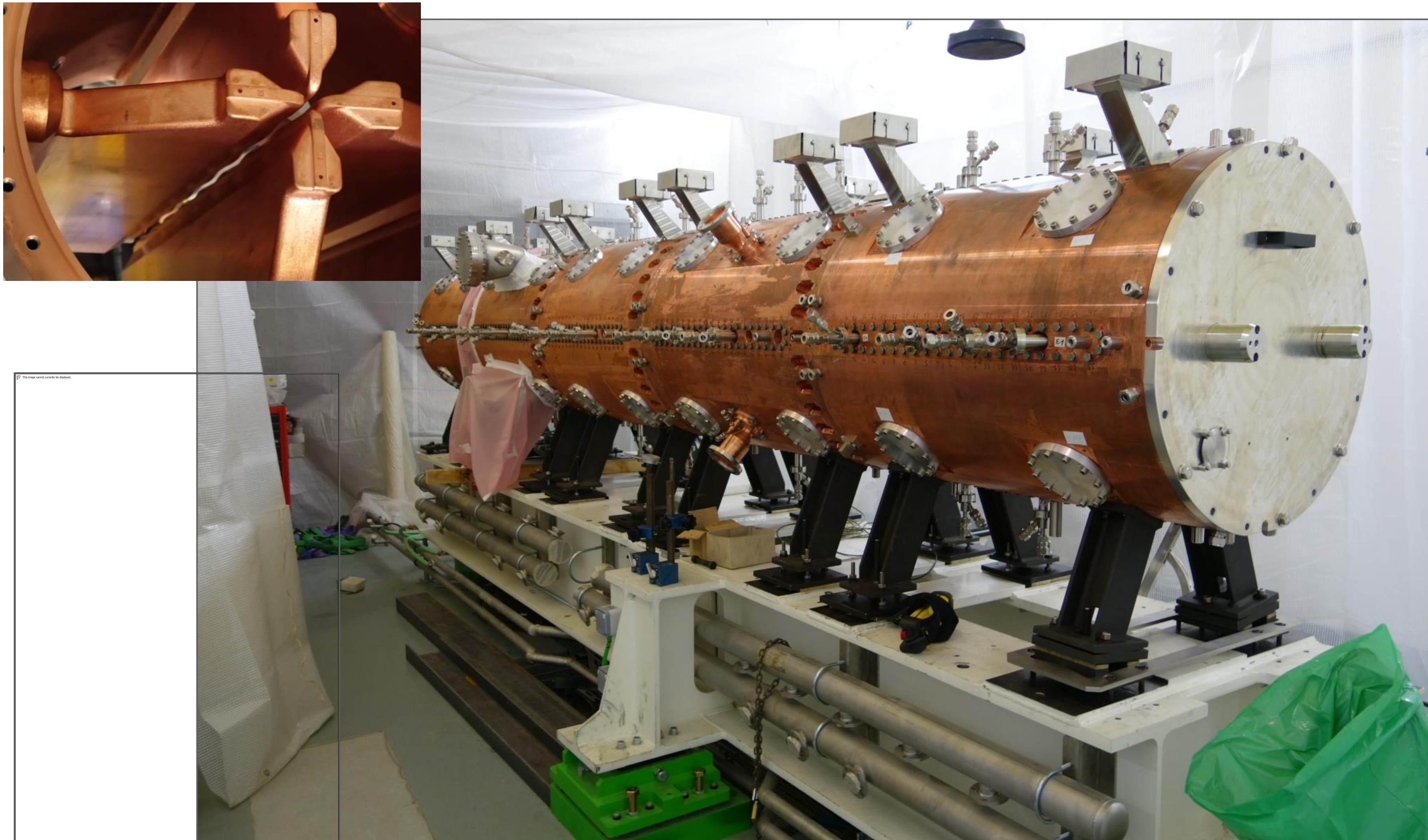

D/p ECR source


HI LEBT1


Power supply…

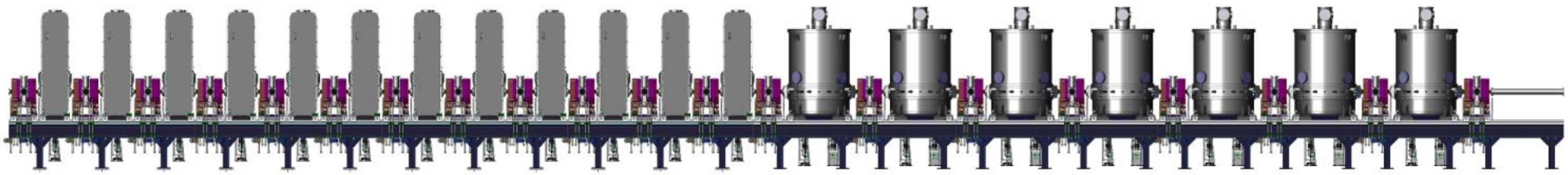

LEBT1 / LEBT2 connection

RFQ: The 5 segments assembled !!!



Bead pull tests began last week ..

SC LINAC: 88 MHz QWR cavities with short cryomodules, and warm focusing sections…



12 low beta cryomodules (0.07) and 7 high beta cryomodules (0.12)
L≈35 m

Assembly test
Cryo A + Warm section

Cryomodule	A	B
Valve-to-valve length [mm]	610	1360
# cavities	12	14
f [MHz]	88.05	88.05
β_{opt}	0.07	0.12
Epk/Ea	5.36	4.76
Bpk/Ea [mT/MV/m]	8.70	9.35
r/Q [Ω]	599	515
Vacc @ 6.5 MV/m & β_{opt}	1.55	2.66
Lacc [m]	0.24	0.41
Beam tube ∅ [mm]	38	44

LINAC cavities, cryomodules and couplers

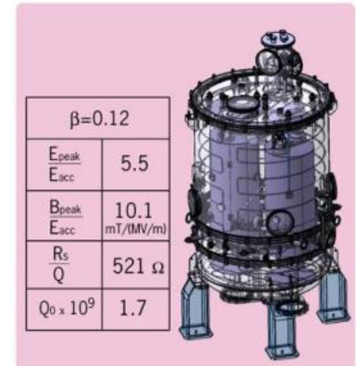
A

IRFU/Saclay

GANIL/Caen (amplifiers)

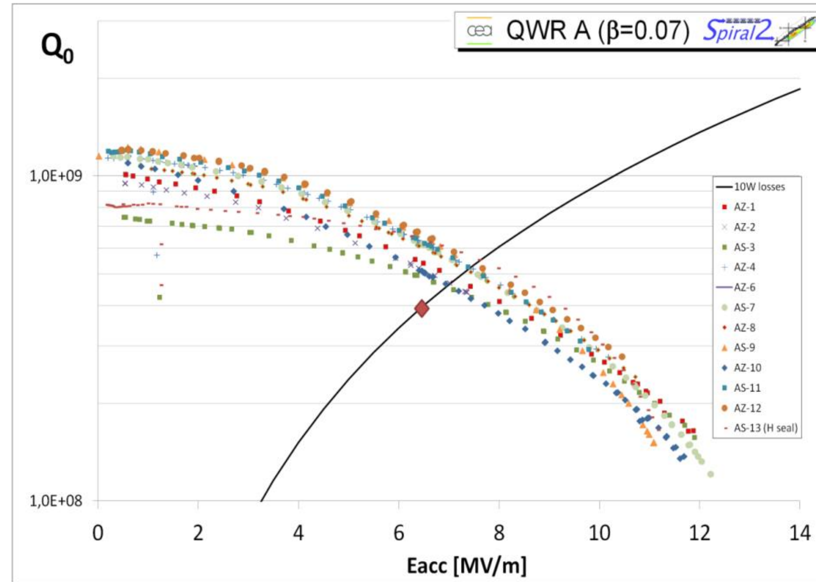
LPSC/Grenoble (couplers)

B



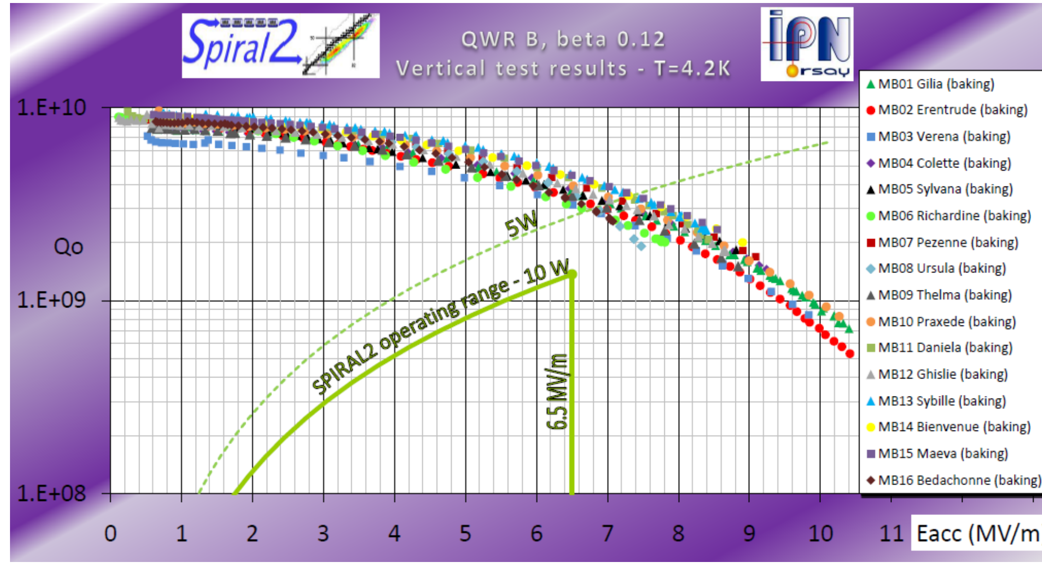
IPNO/Orsay

Status of cryomodules A (IRFU)



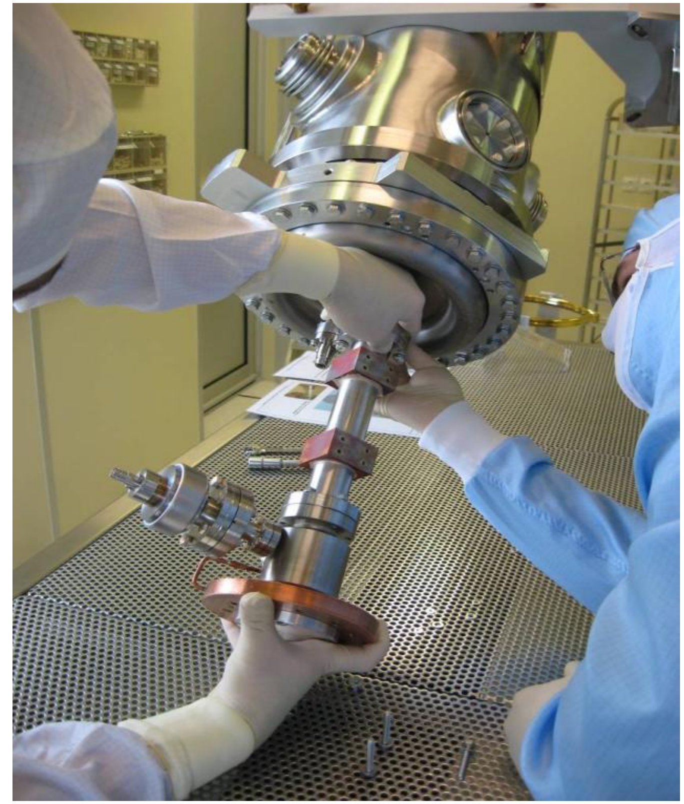
- **Cavities:**
  - All cavities qualified on vertical cryostat
- **Cryostats:**
  - 8 cryomodules assembled and tested
  - 2 cryomodules delivered at GANIL
  - Cryomodule number 9 ready to be tested very soon
  - All **CMA** to be delivered to GANIL before **March 2015**

Status of cryomodules B IPNO



- **Cavities:**
  - All cavities have been qualified without and with plunger
- **Cryostats:**
  - 5 cryomodules qualified
  - These 5 cryomodules delivered at GANIL
  - **Last 2 cryomodules B** to be transported to GANIL before **December 2014**

Status of couplers (LPSC)



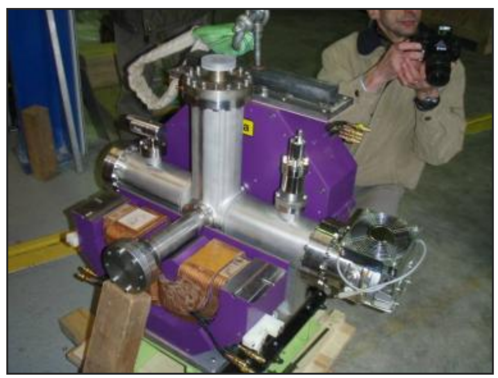
All couplers have been processed and conditionned

And LINAC Warm Sections..

Quadrupole assembly

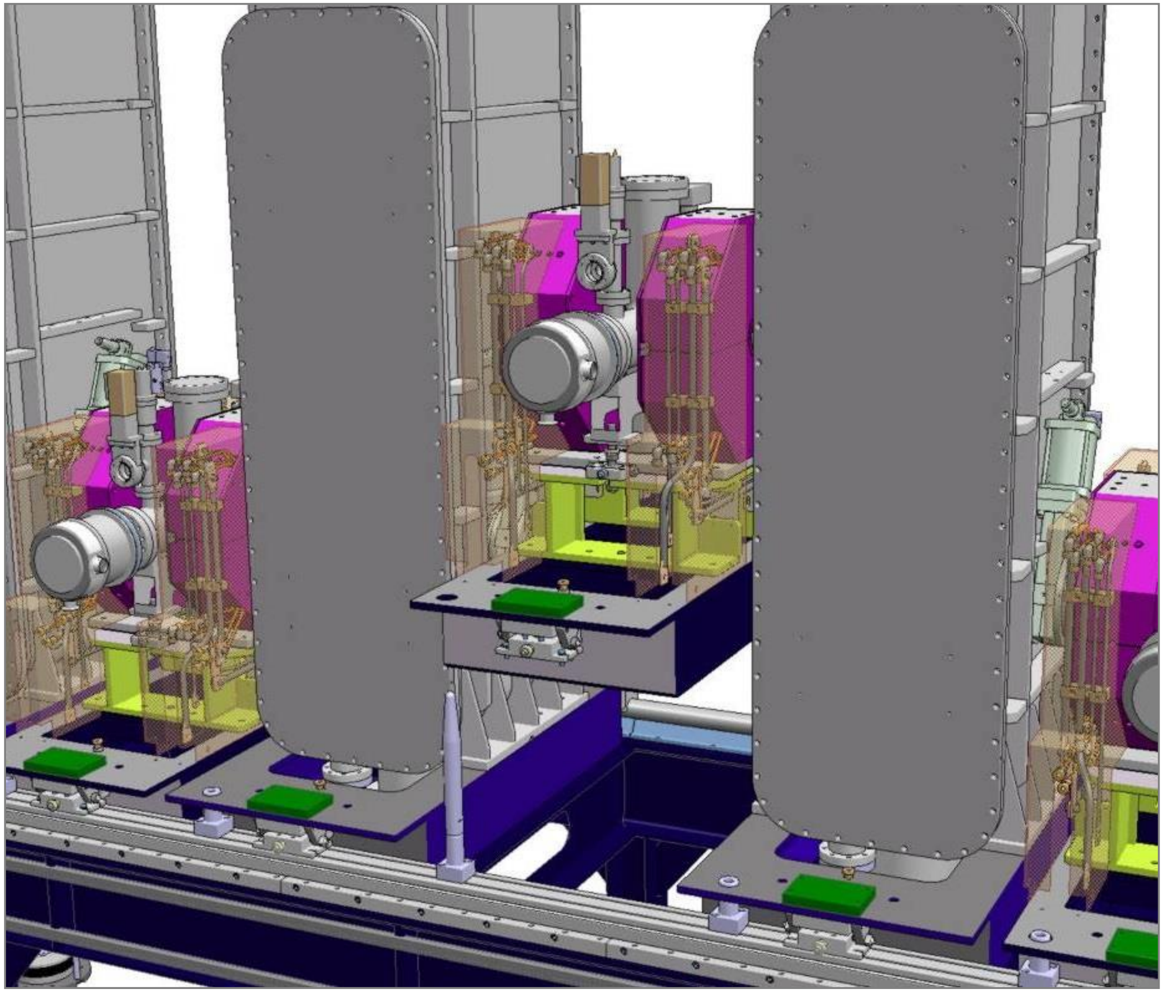
Magnetic measurements

All vacuum boxes ready



Box + qpole assembly…

Insertion of one BPM (BPMs = IPNO & BARC)




tesla

LINAC and HEBT Installation

RF transmission lines and circulators (linac corridor)

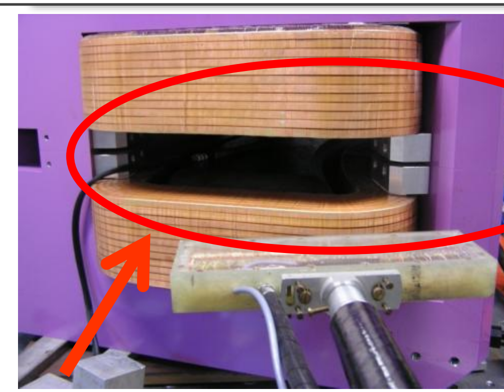
Solid State amplifiers

First cryomodule to be installed **17 November**

HEBT transfer lines

- **All dipoles** at GANIL and measured…
- **All quadrupoles** at GANIL, and all phase1 quads measured
- **All Steerers** at GANIL
- **All Power Supplied** at GANIL
- **RMN &Hall probe system :** under test (on-line monitoring)

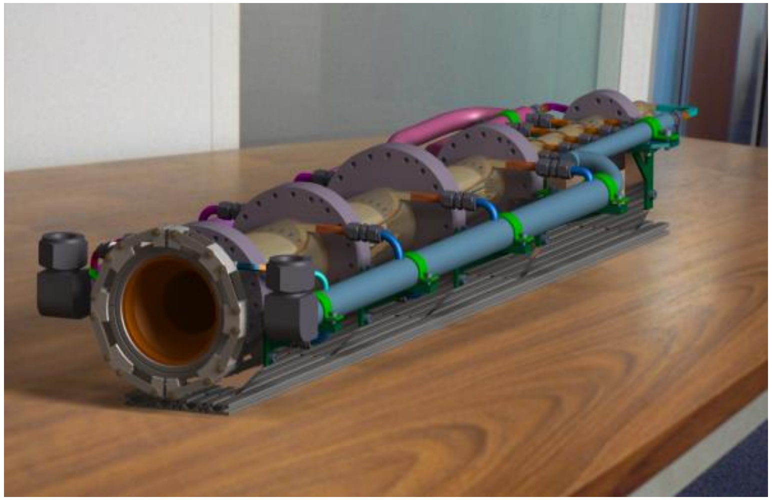
HEBT installation



- 21 Hall probes every cm in a thermostated box (35°)
- Measurement mesh : 5mm

RMN & Hall probe system

200 KW Main Beam Dump (IPN Lyon)



3D Virtual view

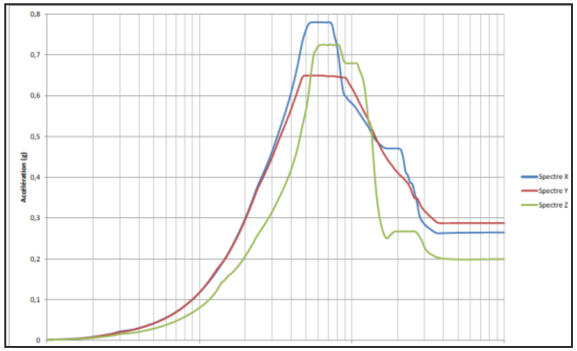
Copper pieces

Beam Dump segments

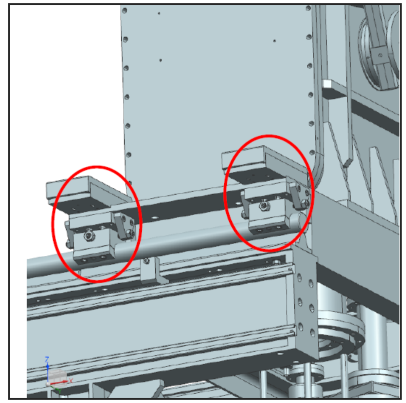
Beam Dump segments

Cooling tubes

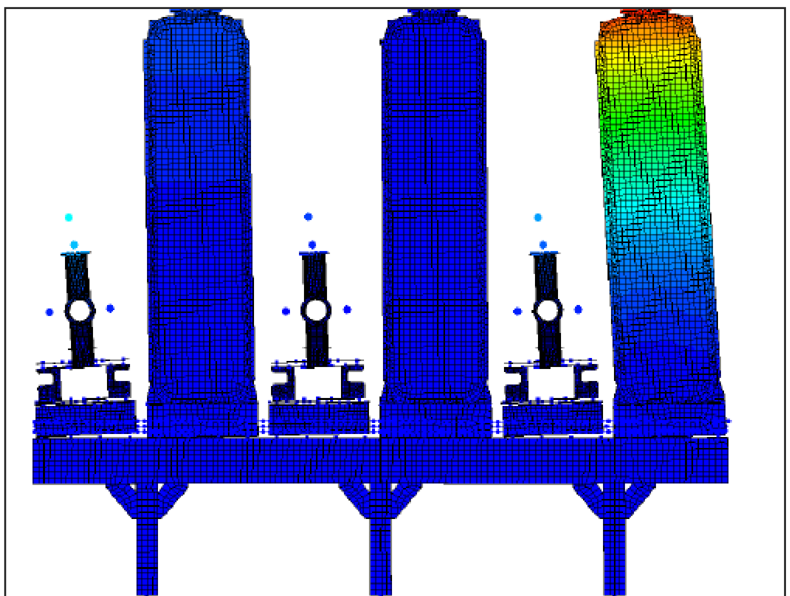
Earthquake Simulations (cryoA)



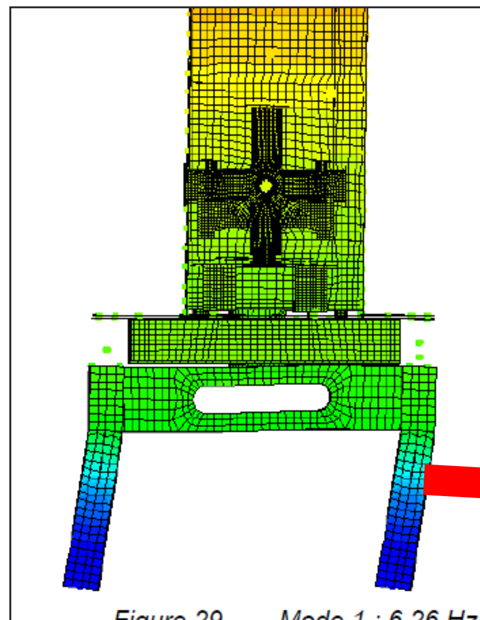
Sismic spectrum



Elcom profile



Exemple of one mode



Earthquake Simulations (RFQ)

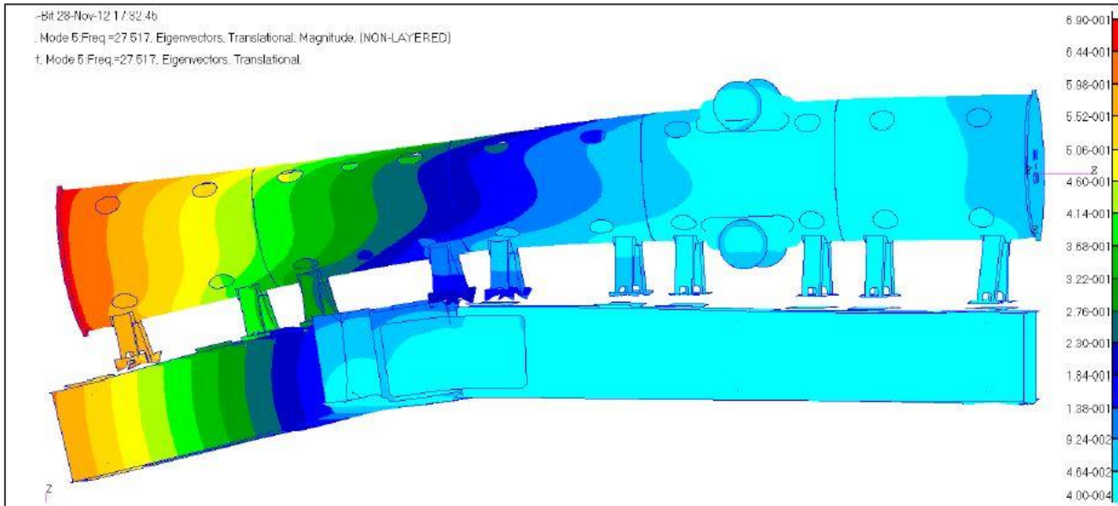


Figure 31 Mode 5 : 27.52 Hz

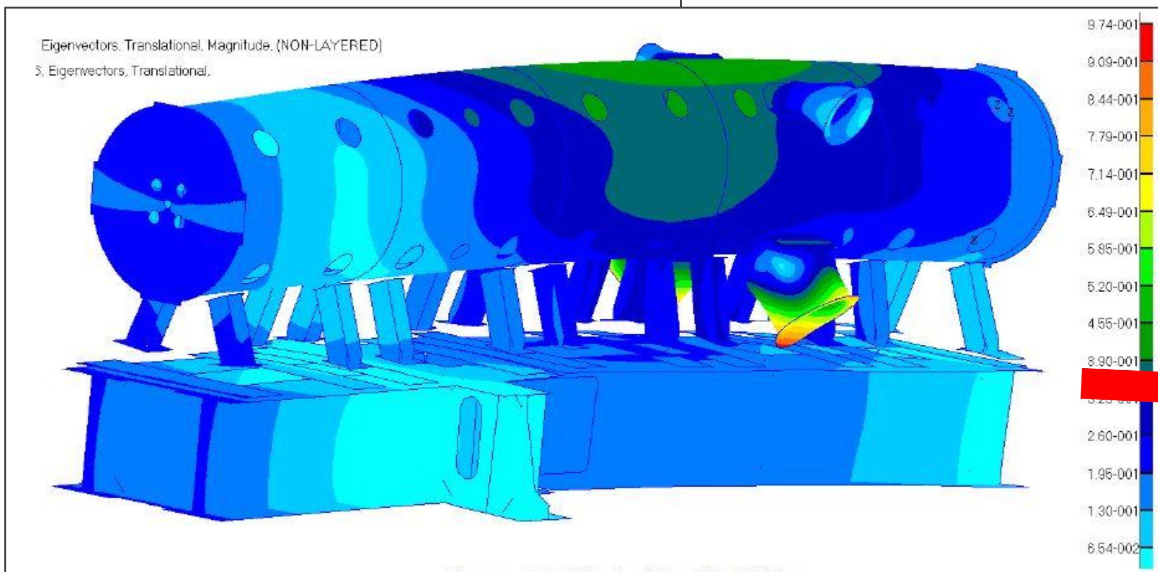
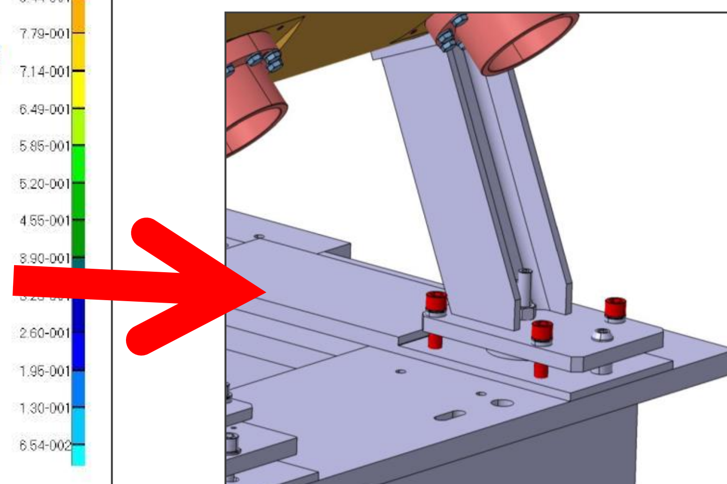


Figure 32 Mode 10 : 40.05 Hz



Beam Commissioning Strategy

- **Step 1**: **beam pre-conditionning of ECR sources and LEBTs** at LPSC/Grenoble and IRFU/Saclay

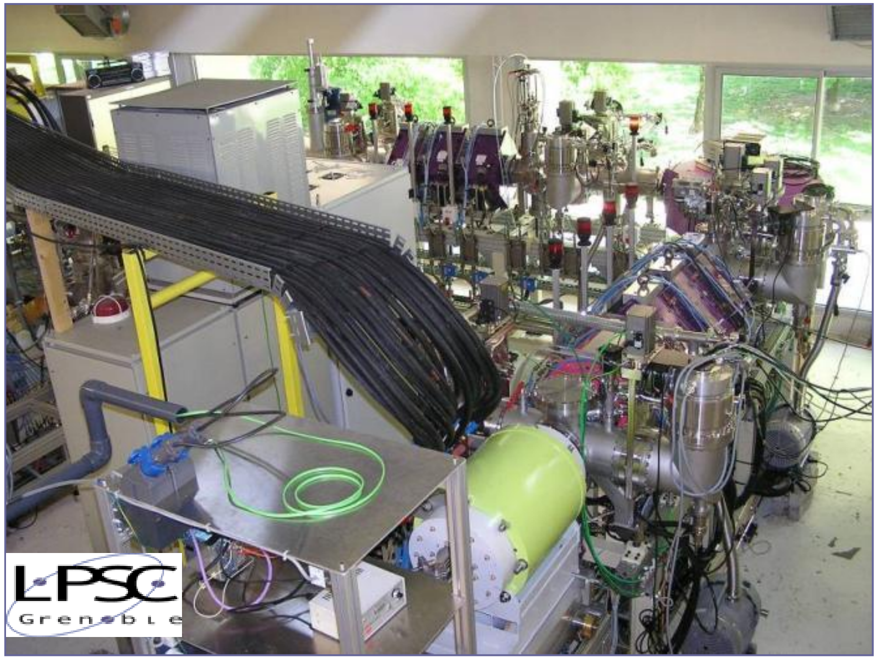
  . **Collaboration** between teams
  . **Validation** of the Design et the beam dynamics
  . Run a maximum of **technical and assembly tests** in laboratories and/or with companies
  . **Gain time** for the installation/tests at GANIL/SPIRAL2 site

- **Step 2**: **complete injector beam commissioning** at SPIRAL2/GANIL

- **Step 3**: Complete MEBT, + **Linac beam commissioning** using the HEBT1 towards the Beam Dump

- **Step 3**: **Day-1 experiment**, with NFS

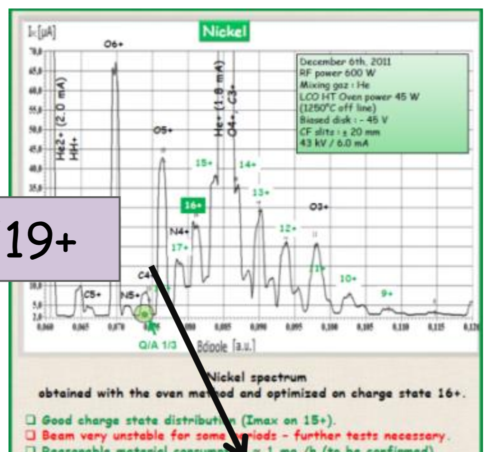
STEP 1: Phoenix-V2+LEBT1 beam tests (at LPSC Grenoble)



RESULTS FOR GASES		
	I max for Q optimum	I max for Q/A 1/3
4He	> 2.4 mA ¦ 2+ non opt.	> 2.4 mA ¦ 2+ non opt.
16O	1.3 mA ¦ 6+	**1.3 mA ¦ 6+**
40Ar	450 µA ¦ 9+ 350 µA ¦ 11+	175 µA ¦ 12+ Isotope 36 --------------- 70 µA ¦ 13+ Isotope 40 --------------- 22 µA ¦ 14+ Isotope 40
86Kr	110 µA ¦ 17+	non measurable

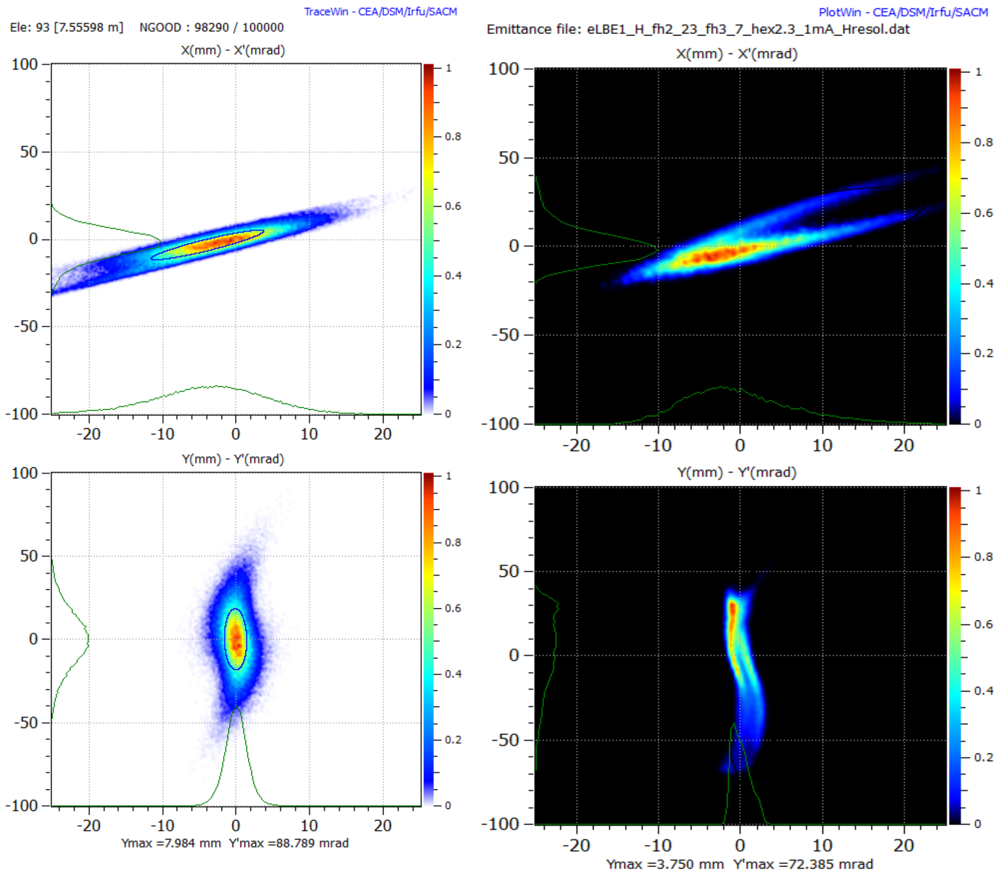
12C3+

58Ni19+



20 µAe Ni 19+ obtained

STEP 1: Phoenix-V2+LEBT1: technical and beam tests (Grenoble)



Simulation

Beam test

$^{16}O^{6+}$ at 53.33.kV

Source Voltage : 53.33 kV

Q/m : 1/2.66

Beam Intensity : 1.3 mA

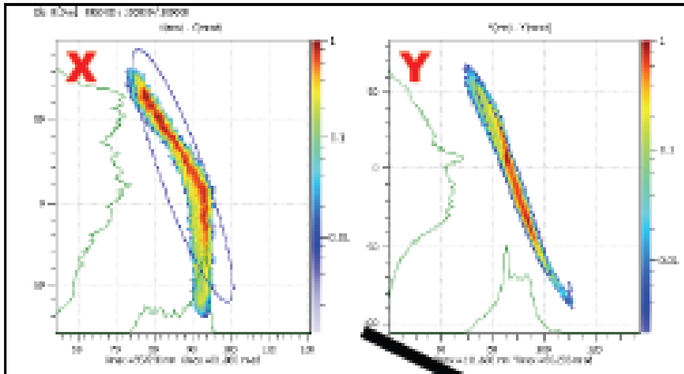
Measured emittances (π.mm.mrad norm.rms)

Horizontal : 0.25

Vertical : 0.14

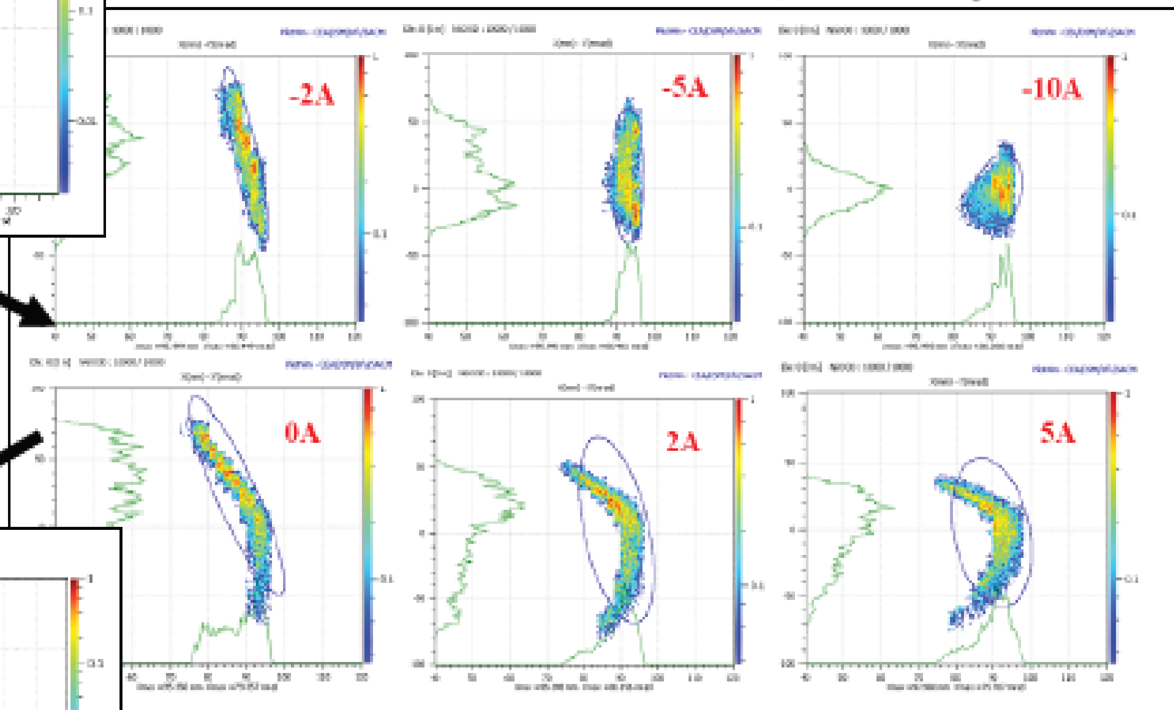
stable 62 kV reached

STEP 1 : Phoenix-V2 + LEBT1:
Optimisation of emittances (Grenoble)

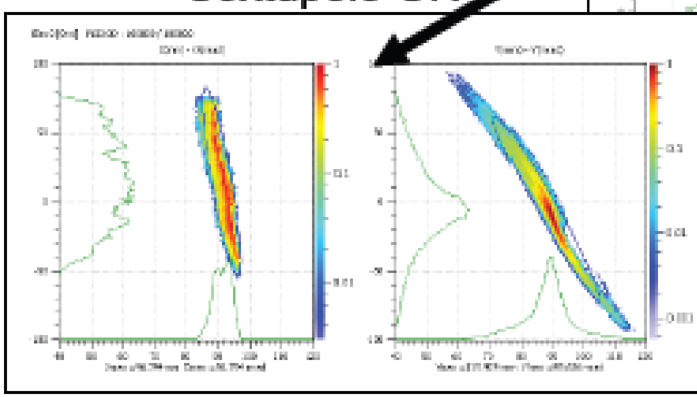


Sextupole OFF

Sextupole tuning



Sextupole ON

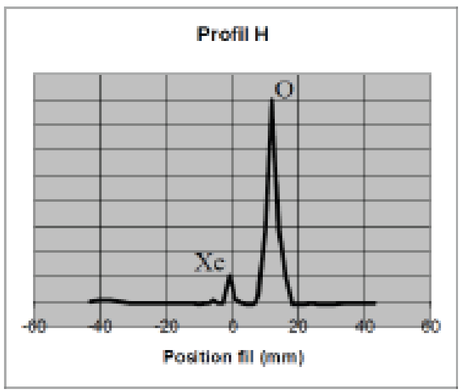


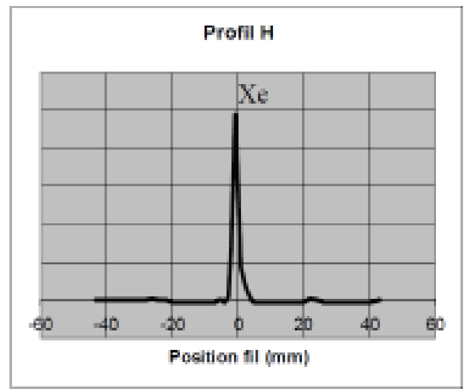
2nd order dipole aberration correction with sextupole

STEP 1: Phoenix-V2 + LEBT1: Purification of the beam (Grenoble)

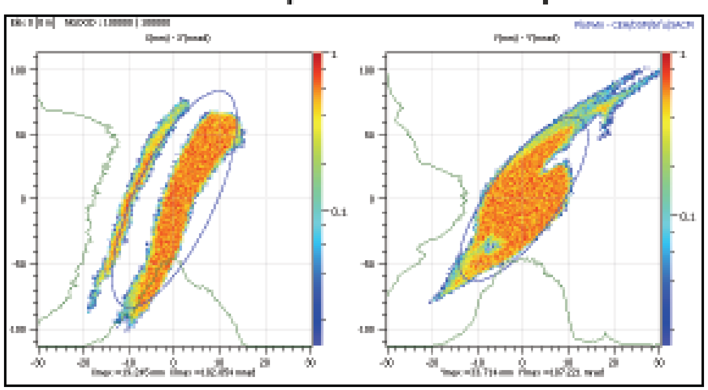
Milestone « Separation 100 » → OK

Experimental validation of the line separation power (> 100 in q/A), using a Xenon beam and **separating $^{132}Xe^{25+}$ (~10uA) from « pollutant » $^{16}O^{3+}$ (~300uA)**

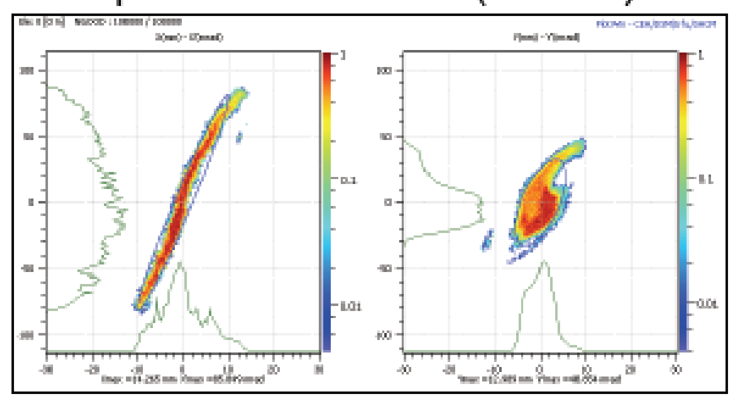




Separation slits opened

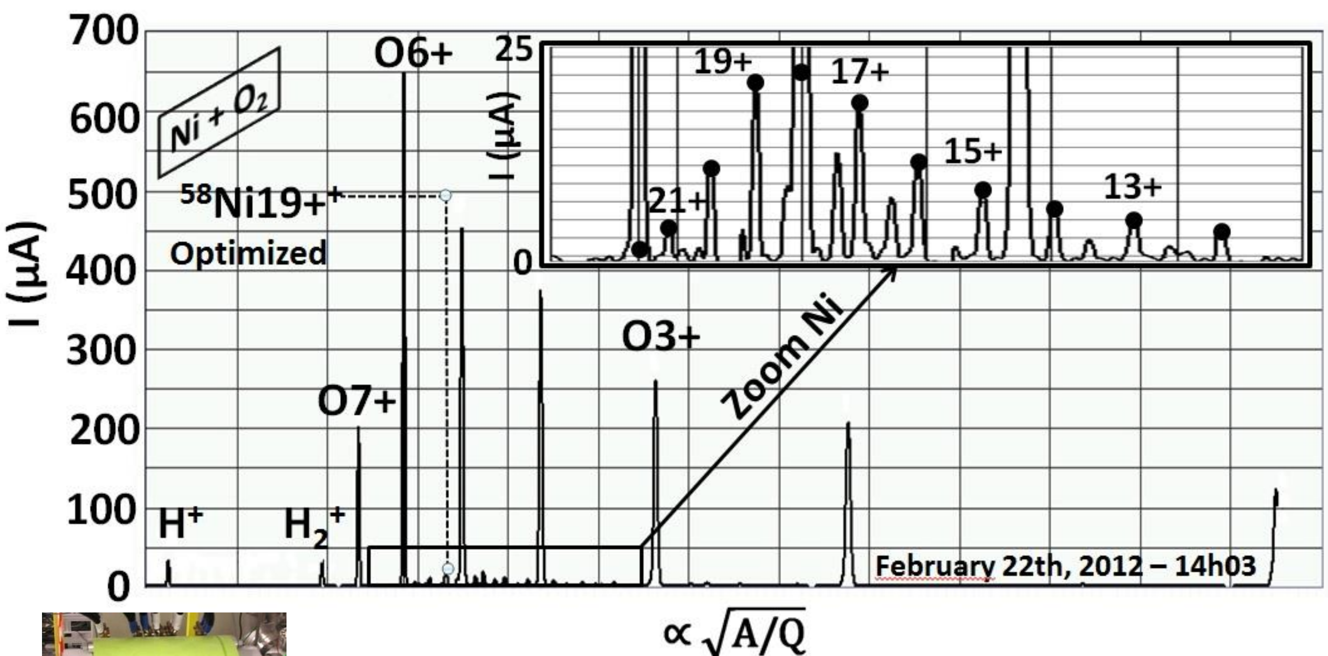


Separation slits closed (+/-5mm)



STEP 1: Phoenix-V2 Nickel Beam production with LCO

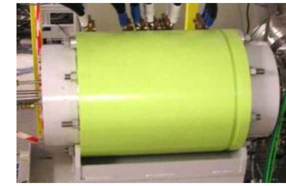
- O_2 buffer gas , 0.9 kW RF injected (1.7 kW emitter)
- Max. oven temperature reached (~1500 °C) => limited evaporation => limited Ni intensity
- 1 pµA Q/A=1/3 produced => suitable for first physics experiments at SPIRAL2
- Result can be enhanced with a larger evaporation rate
- A new higher temperature/higher capacity oven is under study at GANIL (Ø20)



1 pµA $^{58}Ni^{19+}$
Q/A=1/3 beam

Ion	Charge state	Intensity (µA)
^{58}Ni	19+	20
	20+	11
	21+	4

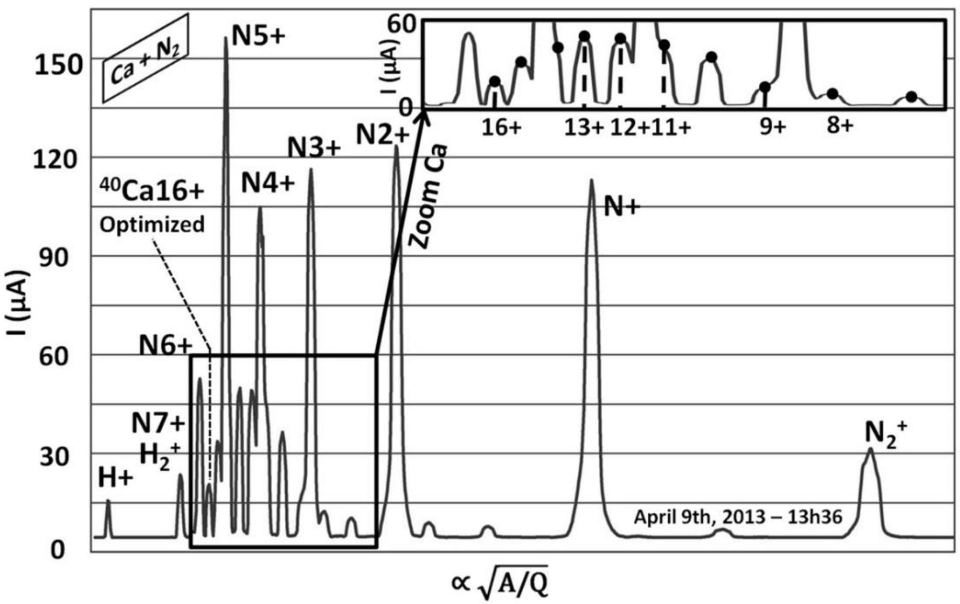
STEP 1: Phoenix-V2 Calcium Beam production with LCO



- N2 buffer gas
- Dominant parasitic plasma/microwave heating of the oven
- RF limited to ~450 W injected (800 W emitter)
- Above this RF value: over-evaporation and charge state distribution degradation
  - **~10 W** of parasitic heating (plasma/microwave)
  - **0.4 W** of normal oven resisitive heating only ($\Delta T \sim 50° C!$)

Very Limited source tuning!

- 1 pμA Ca^{16+} demonstrated => suitable for first SPIRAL2 experiments
- Performance can be improved by using a dedicated low temperature oven (see next slide

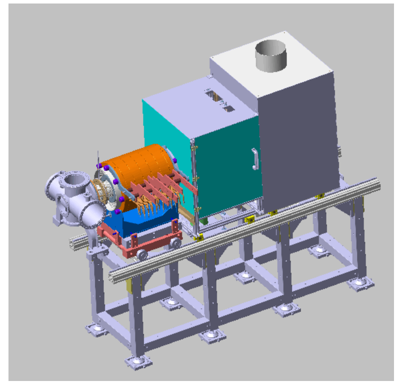


1 pμA $^{48}Ca^{16+}$
Q/A=1/3 beam

Ion	Charge state	Intensity (μA)
^{40}Ca	13+	48
	14+	40
	15+	30
	16+	16

STEP 1: new Phoenix-V3 under development… (Grenoble)

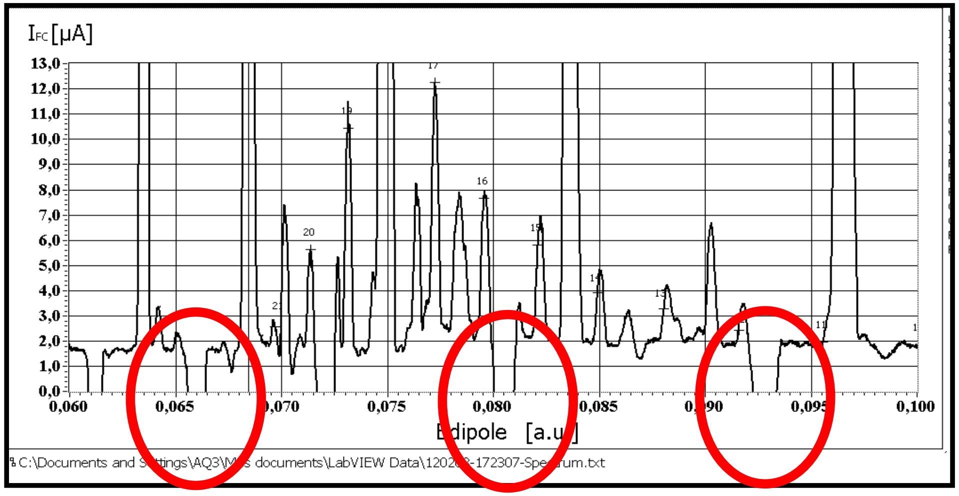
- Conceptual design ✓
- Detailed drawing ✓
- Quote ✓
- Purchase orders ✓
- Parts delivery under progress…
- Source Assembly expected in November 2014
- First beam: January 2015
- Gas commissioning, metal beams : 01→10/2015

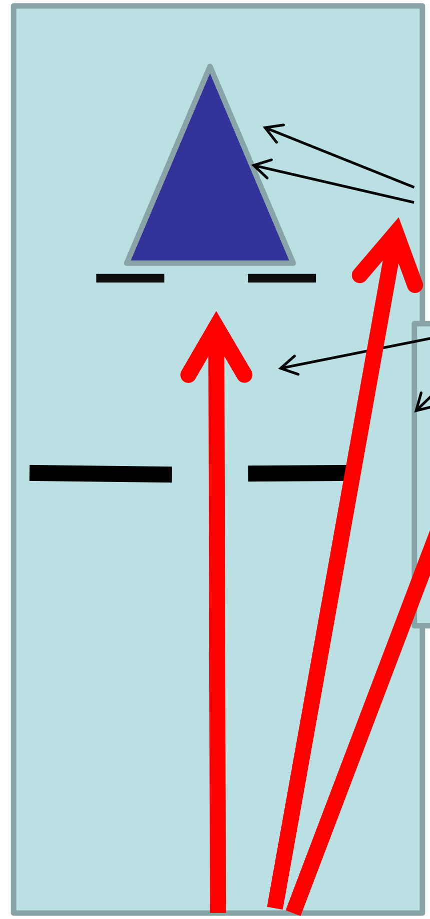


GOAL:

✓ **Increase the Plasma Chamber (0.7 → 1.4 liter)**
✓ **Ø 20 mm oven capability**

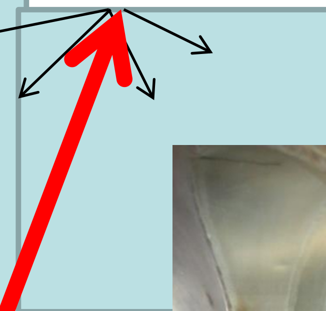
STEP 1: negative peaks observed!



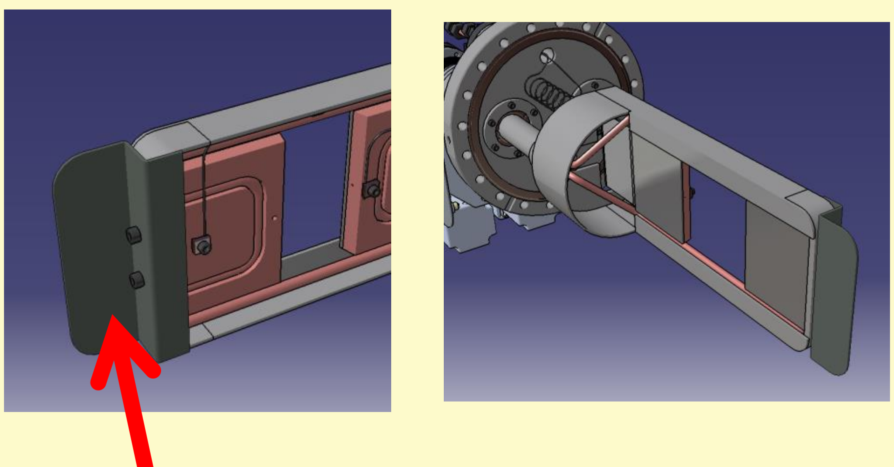


Faraday cup

Induced electrons



Beams with different q/As



Solution: Additional piece of Tantalum at slit extremety

STEP 1: Deuteron/proton Beam tests with 2.45 GHz ECR source + LBE2 + LBEC (at IRFU/Saclay)

- LBEC beam line was added in 2011 with all instrumentation and Interlocks. **(up to RFQ entrance)**

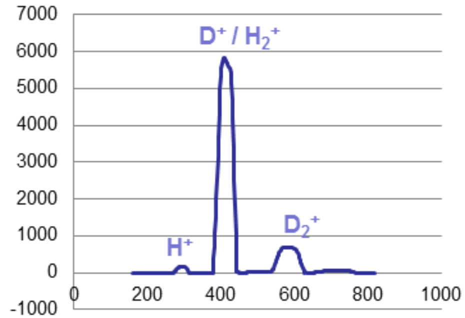
- **More than 5 mA proton or Deuteron**

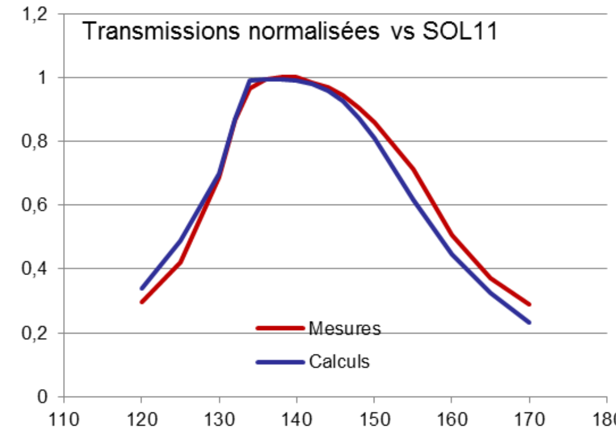
- beam conducted to **end LBEC** in September 2011

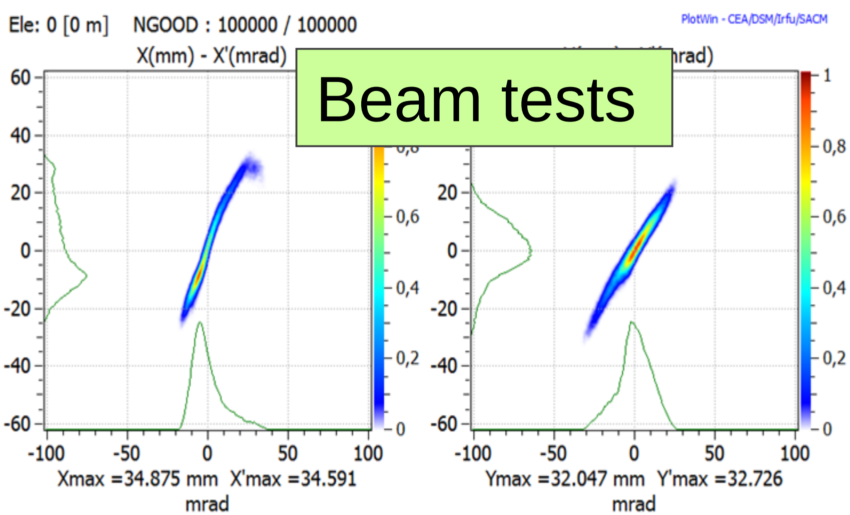
- Slow chopper tested with success .
 (developed by INFN Catania)

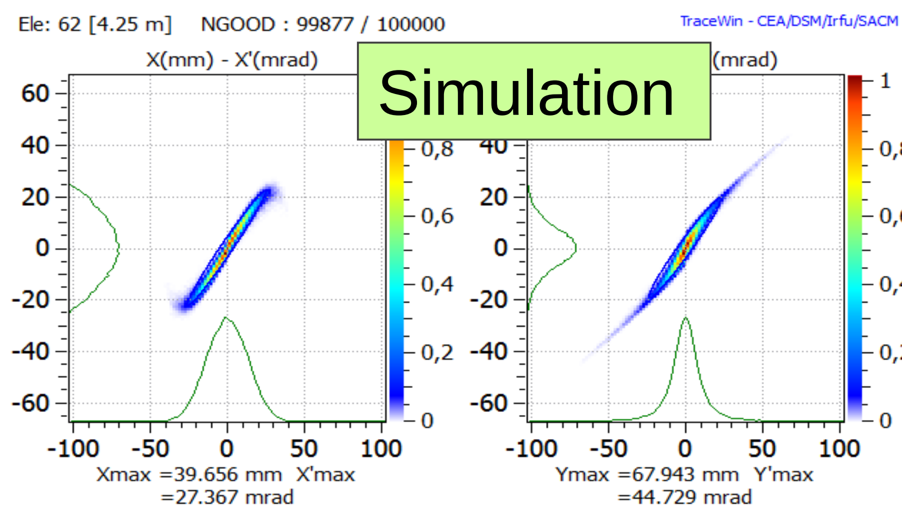
STEP 1: Beam tests results for Deuterons (Saclay)

Ion	Proportion	Courant
Ions	100 %	6.9 mA
H^+	2.1 %	0,15 mA
H_2^+	0,5 %	0.035 mA
D^+	83 %	5.8 mA
D_2^+	9.7 %	0.68 mA
D_3^+	0 %	0 mA
Ions lourds	3.5 %	0.25 mA



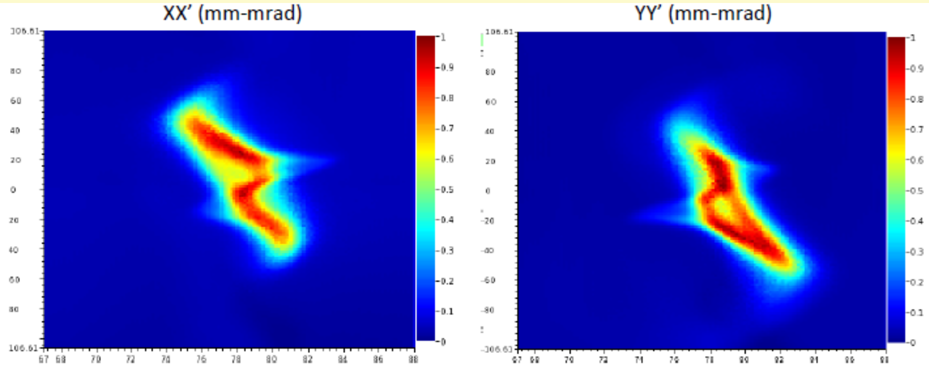






Nominal emittance : ~0.18 π.mm.mrad rms norm
Emittance = key parameter for the Linac !!

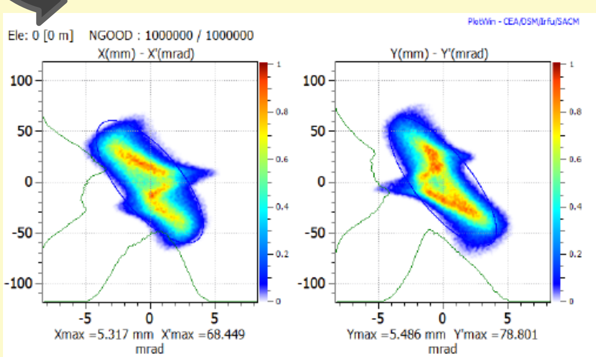
STEP1: Last result with deuterons in 2012



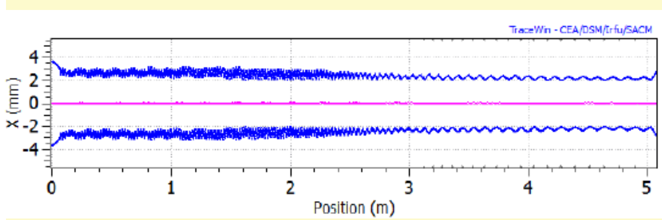
Real beam matched to RFQ and emittance measurement

$\varepsilon_{xx'}$	0.23 π.mm.mrad
$\beta_{xx'}$	0.095 π.mm/mrad
$\alpha_{xx'}$	0.99
$\varepsilon_{yy'}$	0.22 π.mm.mrad
$\beta_{yy'}$	0.10 π.mm/mrad
$\alpha_{yy'}$	1.17

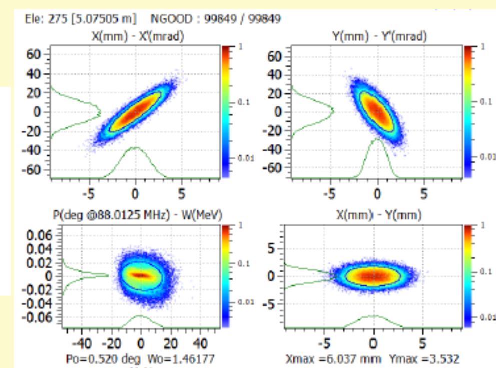
Measured emittance RFQ entrance



Generation of particles using TRACEWIN…

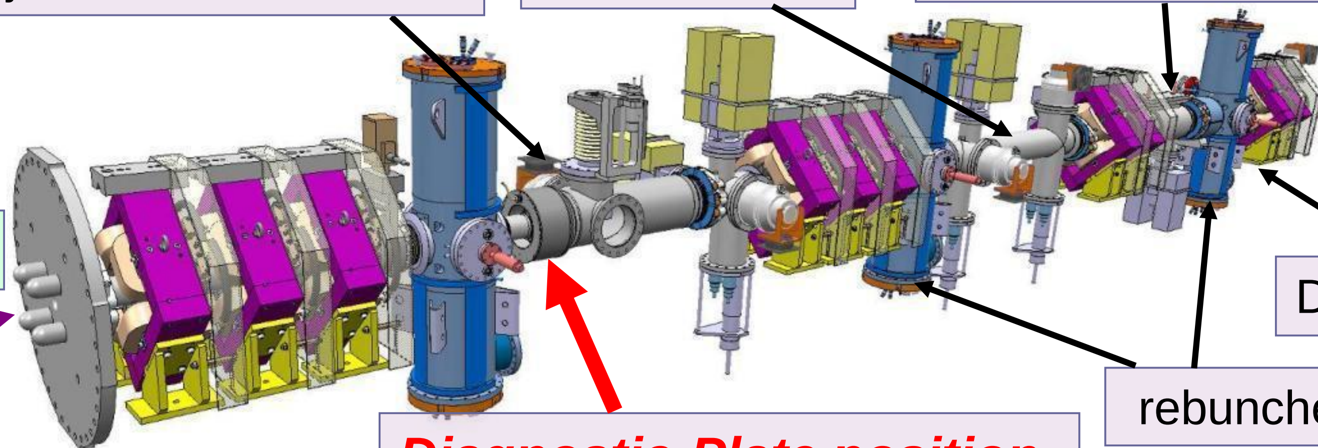


… send to RFQ model… Acceleration + bunching

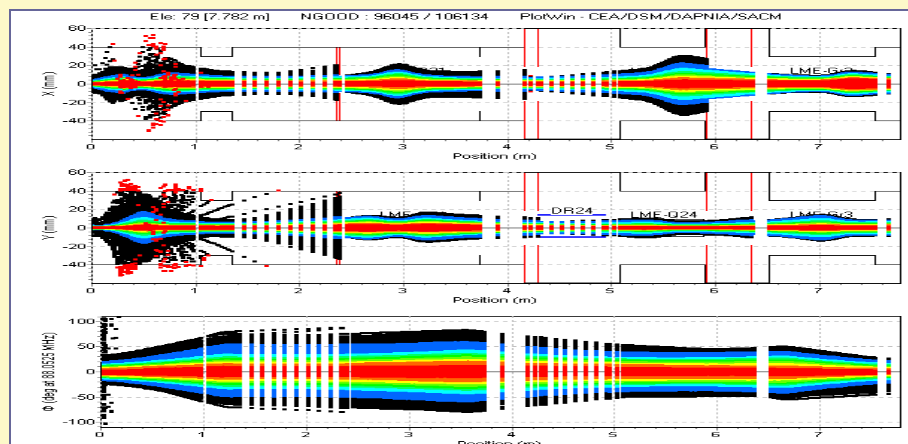


Emittance at RFQ exit

STEP 2: Injector beam commissioning at SPIRAL2 (Dec. 2014 - June 2015)



- Accepts **future 1/6 beams** Injector



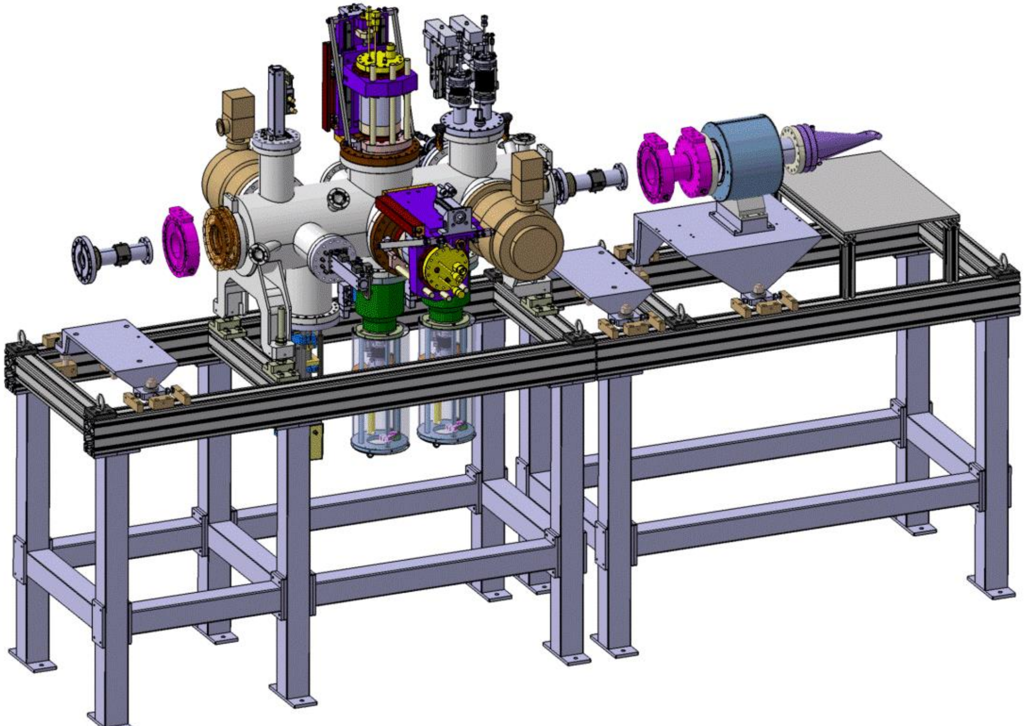
- **Fast chopper** and deviated beam stop.

- Protect the linac against **halo**
  → *3 sets of H-V slits*

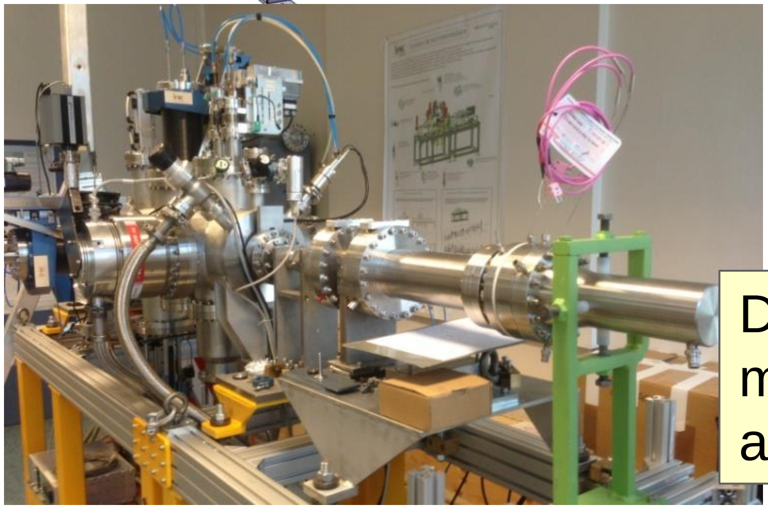
- **Match all types of beams** to linac

- Non interceptive **measurement of beam intensity** at Linac Entrance

STEP 2 : Diagnostic plate (IPHC + IPNO + GANIL)

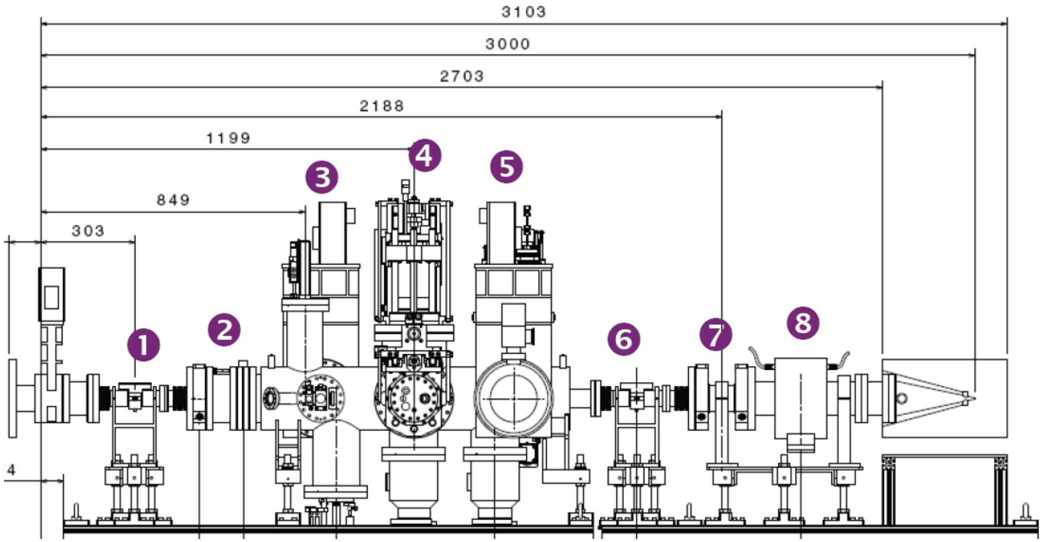


Diag-plate installation at GANIL (last week)



Development and mechanical Integration at IPHC Strasbourg

STEP 2 : Diagnostic plate (IPHC + IPNO + GANIL)



- ❑ **Characterize RFQ beams**
  - ✓ Current (RFQ transmission)
  - ✓ Energy (ToF)
  - ✓ Transverse emittances
  - ✓ Longitudinal emittance (3-gradients method)

❶ : BPM de type LINAC ;
❷ : électrode ToF et mesure de courant par FCT ;
❸ : profileur MIGR (ionisation gaz résiduel) et profileur EMS (à fils) ;
❹ : émittance-mètres H&V, CF rapide et moniteur longueur de paquet ;
❺ : CF lente et fentes H&V de nettoyage ;
❻ : BPM de type LINAC
❼ : 2 électrodes ToF ;
❽ : mesure de courant par DCCT+ ACCT.

- ❑ **Prepare linac commissioning**
  - ✓ Characterize the operation of the <u>beam diagnostics</u> tb used in the SC linac with (low-energy) beams. In particular: Beam Position Monitors (position, phase, ellipticity…), Bunch Extension Monitors…
  - ✓ Practice the cavity (V,φ) tuning procedure (buncher)

Planned beams:

Protons (A/Q=1)

- 150μA peak, 200μs pulsed@5Hz (0.1% duty cycle),
- Increase the peak current from 150μA to **5mA**, with duty cycle from 0.1% to 100%

Helium $^{4}He^{2+}$ (A/Q=2)

- 150μA peak, 500μs pulsed @2Hz (0.1% duty cycle),
- Increase the peak current from 150μA to **2.4mA**, with duty cycle from 0.1% to 100%

Oxygen $^{18}O^{6+}$ (A/Q=3)

- *Pencil beam* 150μA peak, 500μs pulsed @2Hz (0.1% duty cycle),
- Increase the peak current from 150μA to **1mA**, with duty cycle from 0.1% to 100%

If enough time:

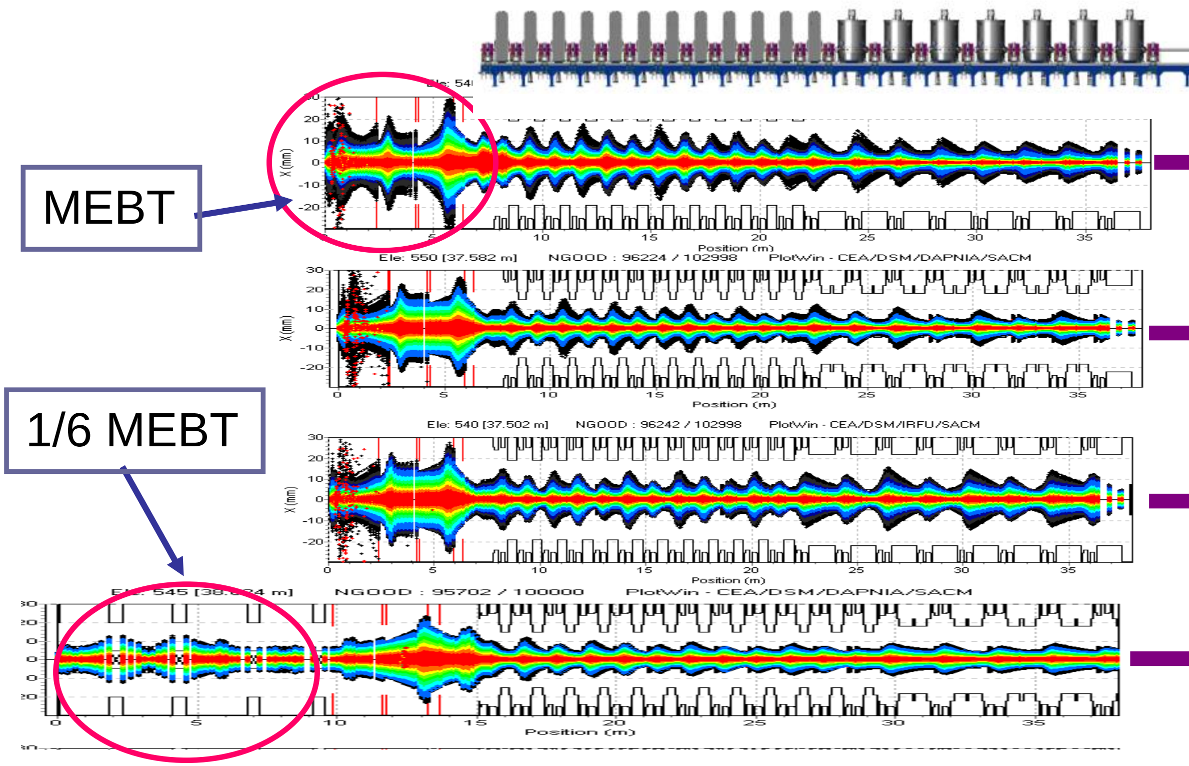
- ***Argon, Carbon, Xenon***
- **Nickel** $^{58}Ni^{19+}$ up to 20μA

… and finally Deuteron beam when full authorization obtained !!!

STEP 3: LINAC + HEBT1 beam commissioning (>2015)

MEBT

1/6 MEBT



Deuterons 5 mA , 40 MeV

q/A=1/3,1 mA , 14.5 MeV/A

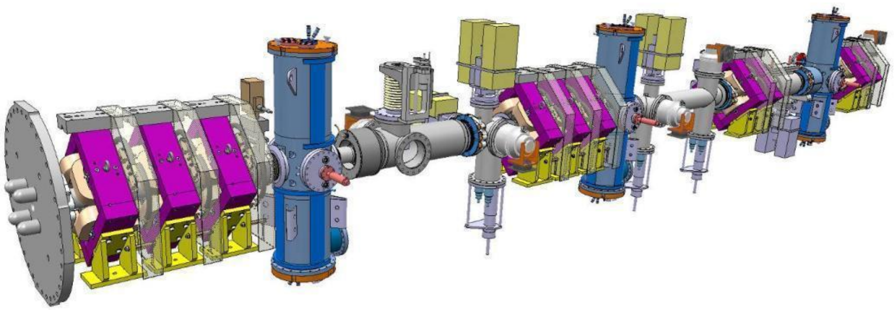
q/A=1/3 1 mA , 2 MeV/A

q/A=1/6 1 mA , 7 MeV/A
(In the future ..

- Knowledge acquired before…
- Efficiency of TRACEWIN code
- 3D calculated and/or measured cavity and quadrupole maps
- 19 BPMs, 6 BEM, many BLMs along the Linac
- ToF, ACCT/DCCT, profilers, loss rings BLMs along the HEBT…

STEP 3: LINAC + HEBT1 beam commissioning (>2015)

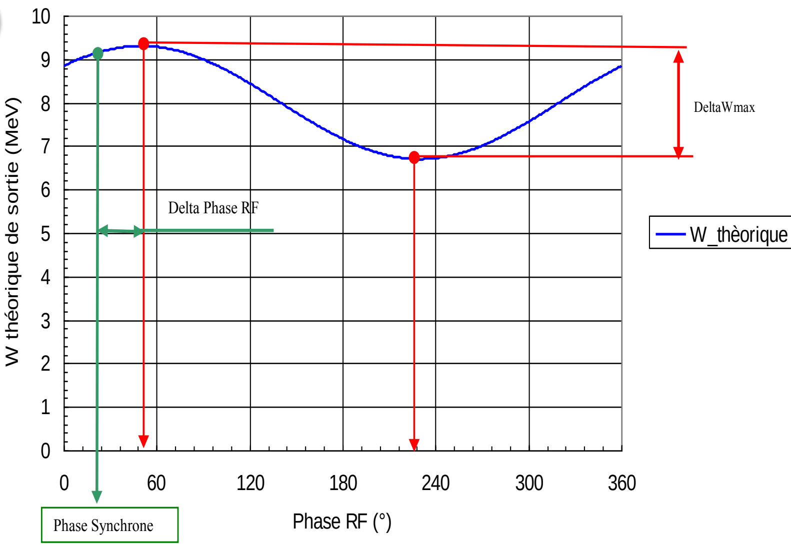
❑ **Pre-tuning of the full MEBT**



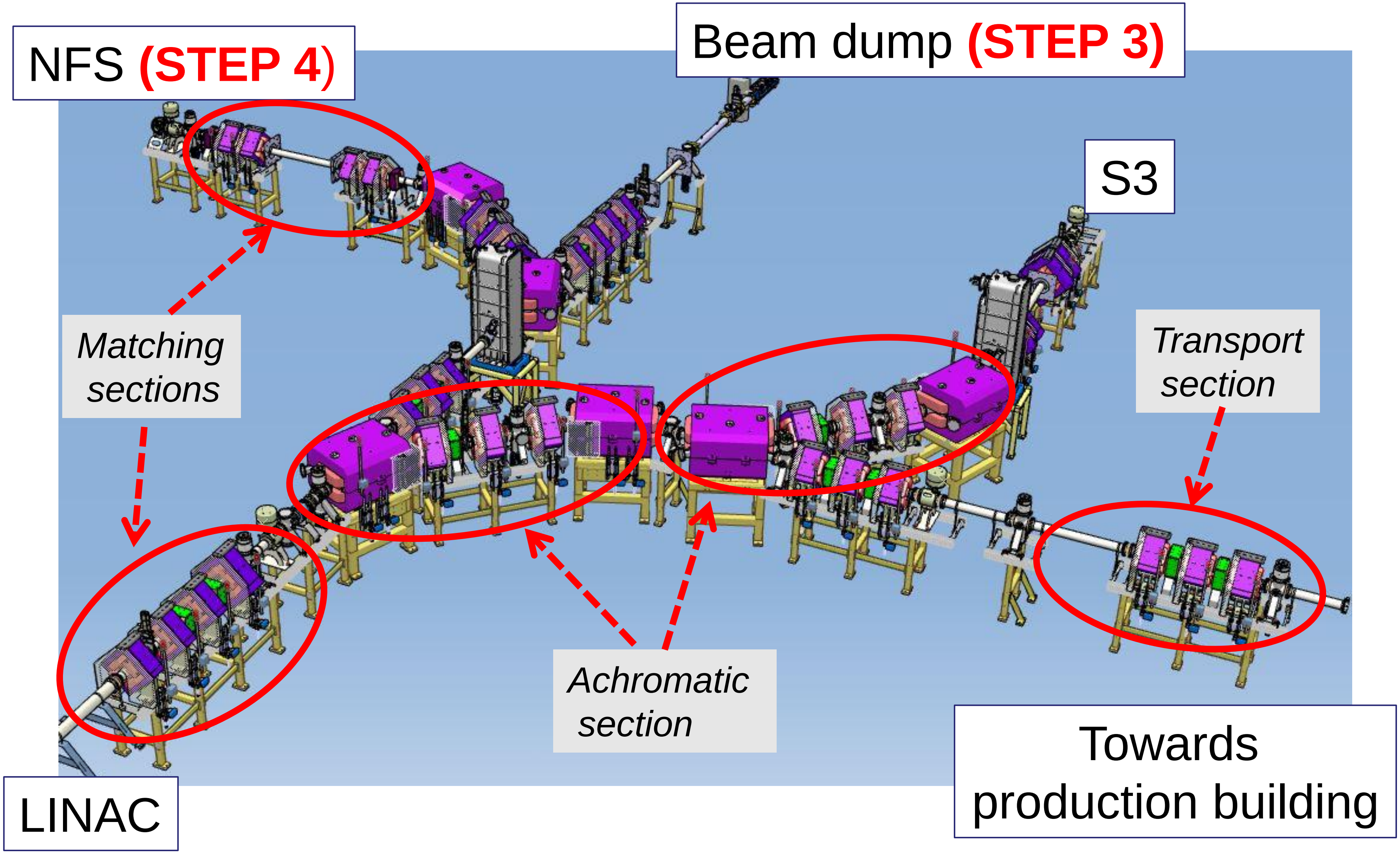
- ✓ Transverse pre-tuning
- ✓ Longitudinal pre-tuning

❑ **Create the SC linac periodic channel, step by step**

- ✓ Adjust all the linac and HEBT1 quadrupoles for RFQ energy
- ✓ Tune the first cavity (amplitude & phase) using BPMs (ToF method)
- ✓ Re-adjust all linac quadrupoles
- ✓ Tune the second cavity
- ✓ And so on for the 26 cavities…



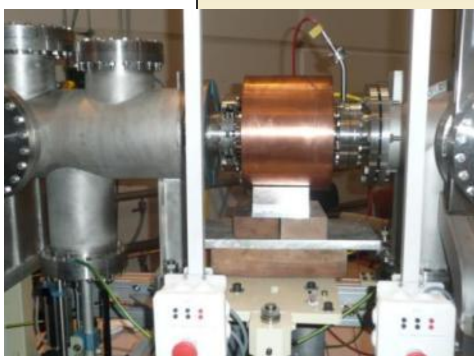
STEP 3: HEBT1 from Linac to Beam Dump

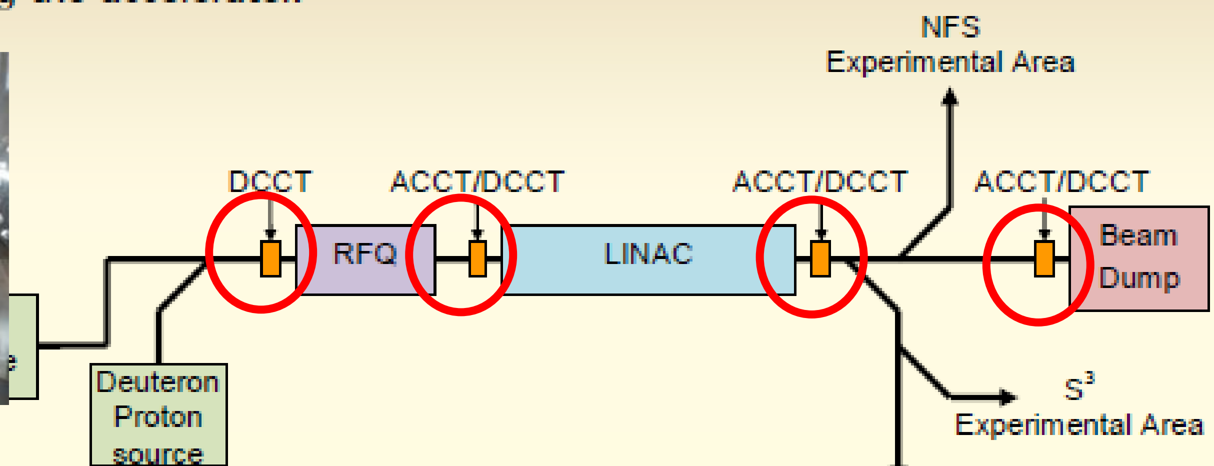


STEP3: Intensity → locations of ACCT/DCCTs

NON DESTRUCTIVE BEAM INTENSITY MEASUREMENTS

In order to control continuously the intensities and the losses, ACCT and DCCT are set up along the accelerator.





DCCTs : Bergoz NPCT-175-C030-HR
ACCTs : Homemade

The measurements of intensities and transmissions are required for the accelerator tuning and the beam controls for safety.

S. Leloir et al. “MEASUREMENT AND CONTROL OF THE BEAM INTENSITY FOR THE SPIRAL2 ACCELERATOR” , IBIC 2013

STEP3: ENERGY →location of TOF pick up

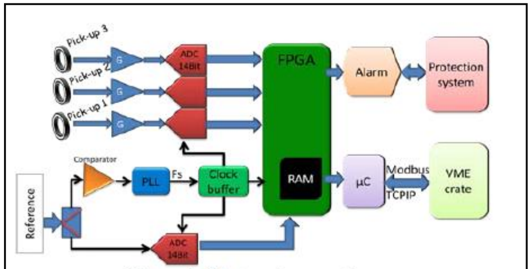
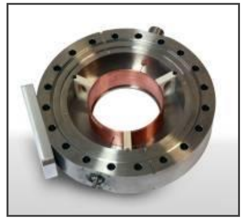
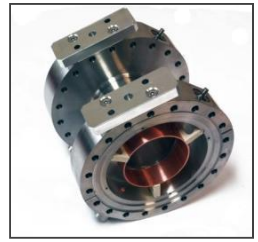


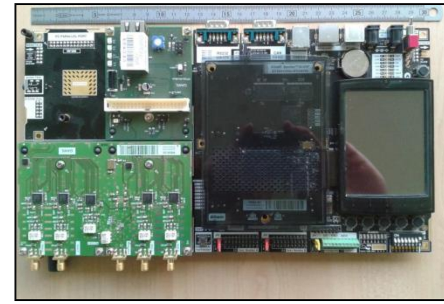
Figure 1: Electronic synoptic

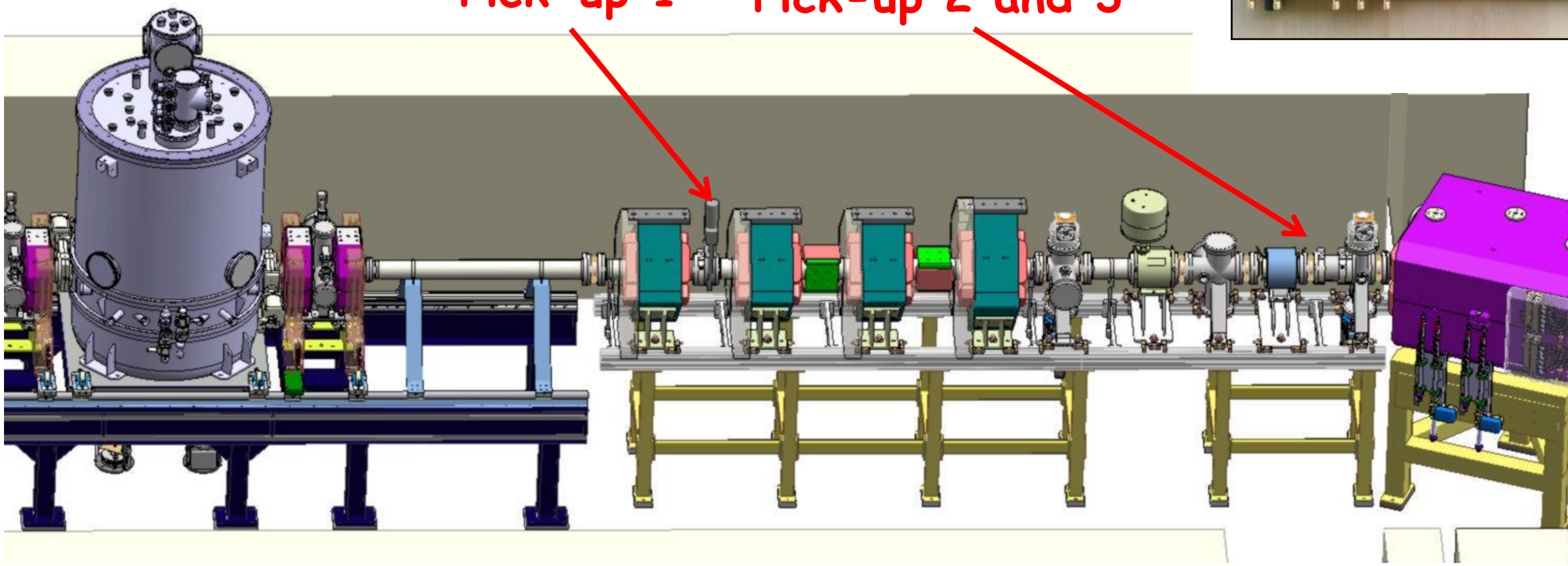


Pick-up 1



Pick-up 2 and 3





End Linac

Begining HEBT

W. Lecoz et al. "MEASUREMENT AND CONTROL OF THE BEAM ENERGY FOR THE SPIRAL2 ACCELERATOR" , IBIC 2013

One interesting Theorem

(without space charge…)

- ✓ Consider an accelerator (for example Spiral2…),
- ✓ Consider a tuning of the machine realised for a given beam (q/m) with a given Energy in Mev/u,
- ✓ Suppose we want to tune another beam q'/m' at the same final energy per nucleon,
- ✓ **Then we just to MULTIPLY all the voltages and magnetic fields by the ratio (q/m)/(q'/m') to obtain the new tuning**
- ✓ The theorem is correct in relativistic case !

Examples : He4 2+ → Deuteron
O16 6+ → any heavy ion…

CONCLUSION

The beam pre-commissioning performed at IRFU/Saclay and LPSC/Grenoble was essential:

- to make our labs work together in many domains
- to validate our low energy design and simulations,
- to operate many technical tests with the EPICS philosophy and our Command/Control.
- to gain time during full commissioning at GANIL

We enter now in the complete beam commissioning, which constitutes a great motivation for all our partners and for us.

THANK YOU !