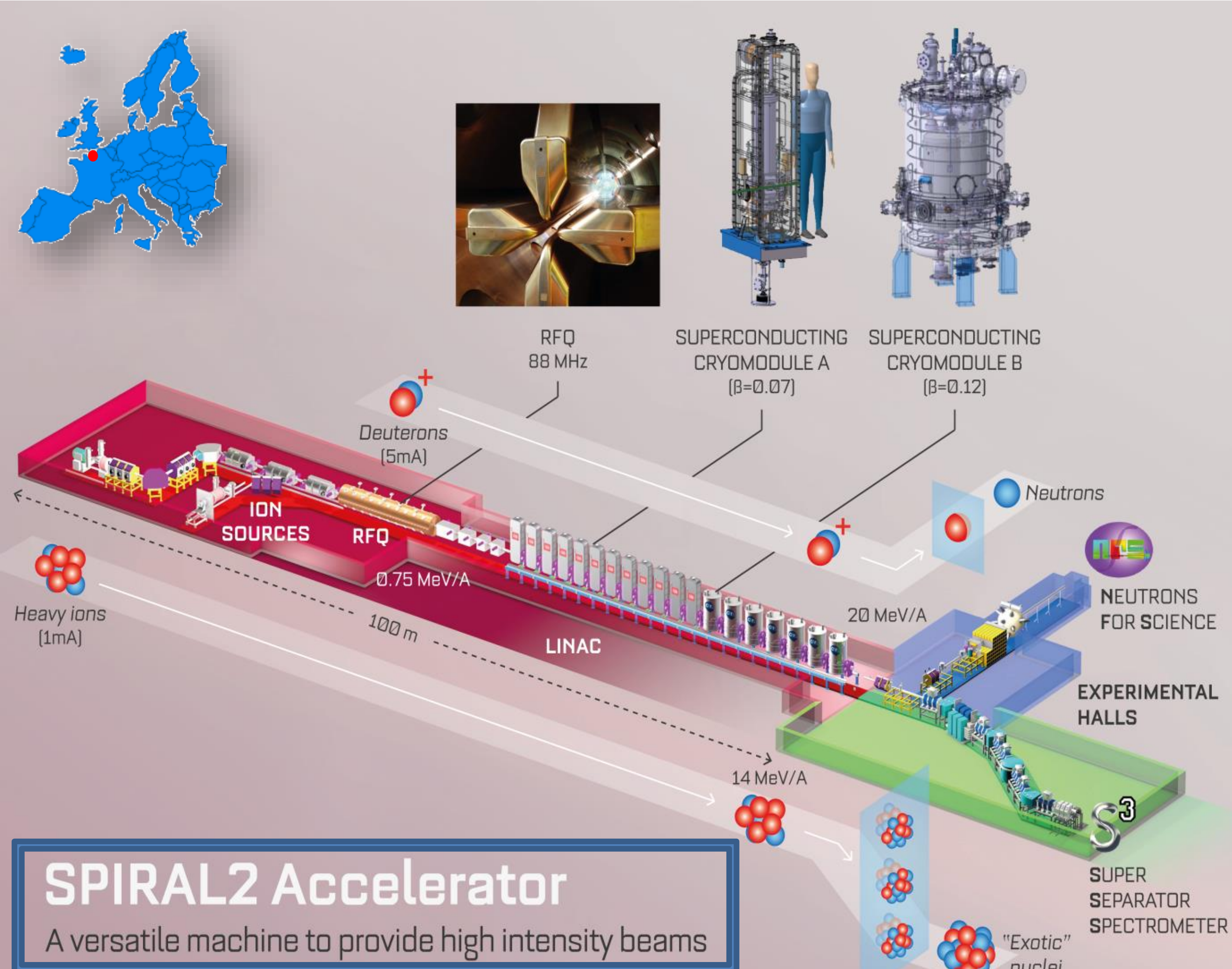
# Commissioning of SPIRAL2

## Beam Diagnostic Feedback

Christophe Jamet – MPS coordinator
on behalf of the GANIL and commissioning teams

# SPIRAL2 accelerator




| Particles | $H^+$ | $D^+$ | ions | option |
|---|---|---|---|---|
| A/Q | 1 | 2 | 3 | 6 or 7 |
| Max I (mA) | 5 | 5 | 1 | 1 |
| Max energy (MeV/A) | 33 | 20 | 15 | 8.5 |
| Max beam power (kW) | 165 | 200 | 44 | 51 |

Built by several French Labs

Collaboration with International labs

# Beam commissioning in 4 phases

- 2009-2012: Qualification of the ion sources and LEBT in the laboratories in charge of the development
- 2014-2018: Qualification of the injector on a Diagnostic Plate (GANIL)
  - ✓ 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 – started in 2016
  - ✓ RF validation of all cavities - 2019
  - ✓ Beam commissioning – Started 2019

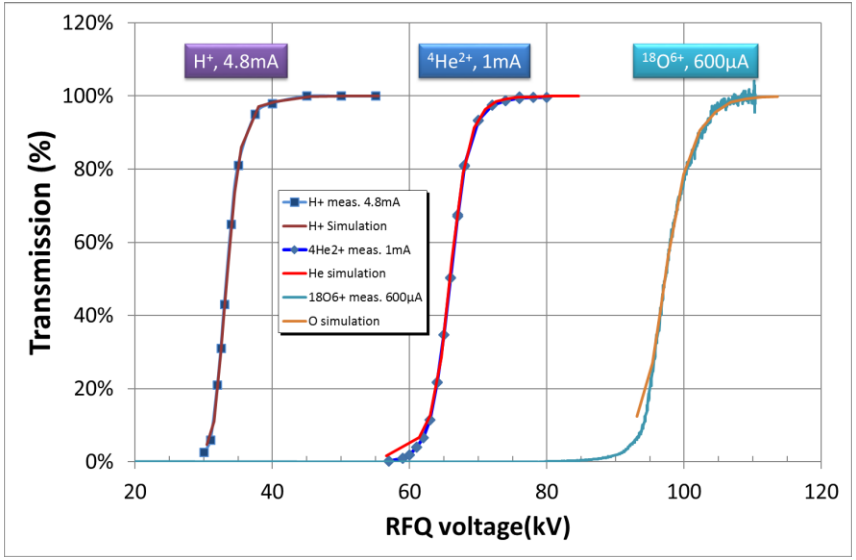
After the authorization from the French Nuclear Safety Authority

- "day-1" experiments to NFS and S3 experimental halls, including commissioning
  - ✓ Started in 2019, First experiment to NFS in 2021

# Injector commissioning


- Objectives:
  - ✓ Sources qualifications
  - ✓ RFQ validation
  - ✓ Obtain beam parameters after RFQ cavity
    - Transmission
    - Beam energy
    - Output emittances in the three planes
    - Bunch extension
  - ✓ Test bench for diagnostics
    (physical separation with the linac)
- Validation with beam
  - ✓ Max beam current
    - 5 mA proton beam
    - 1 mA Oxygen beam
- CW mode
- $D^+$ : preparation with $^4He^{2+}$

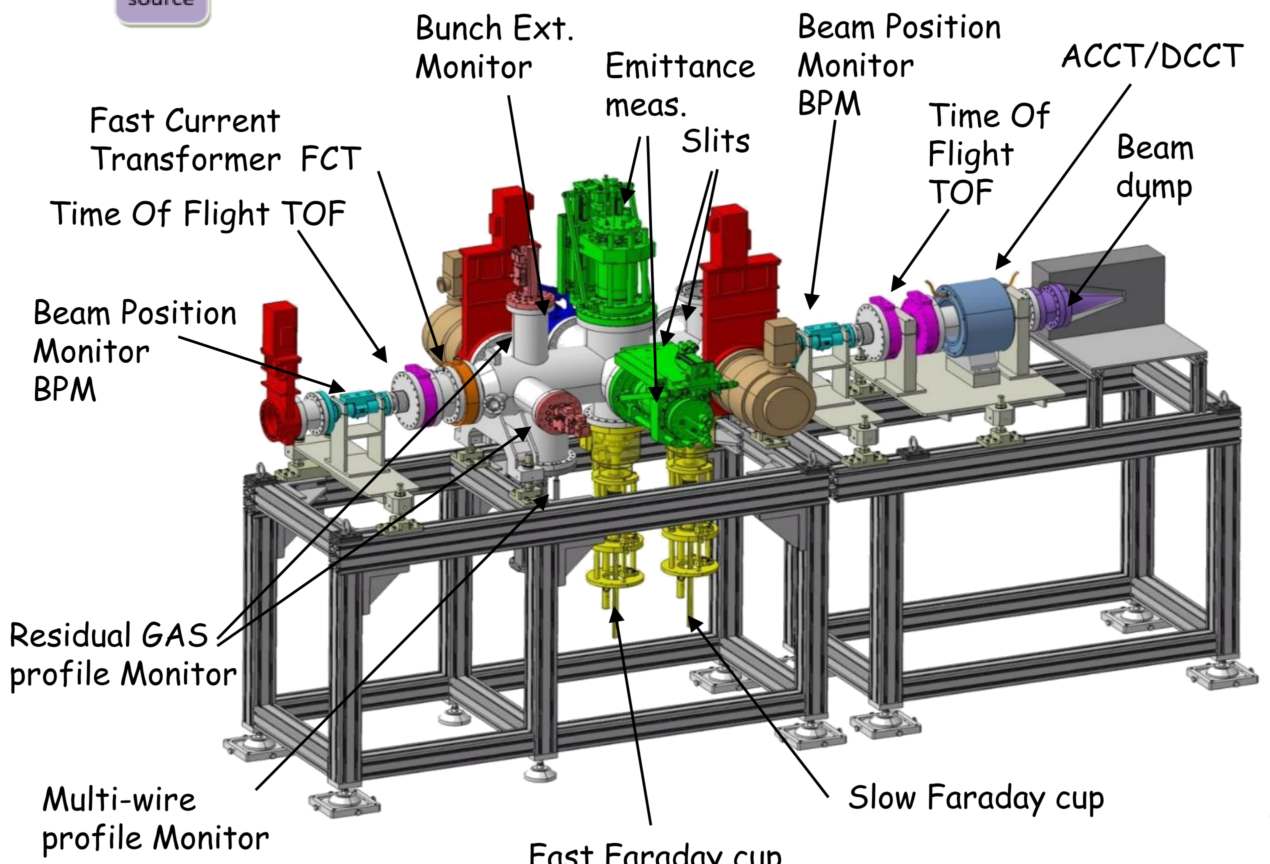
RFQ specifications reached in CW for all particles




*RFQ Transmission comparison with calculation*

# Diagnostic plate


## D-plate removed in November 2018



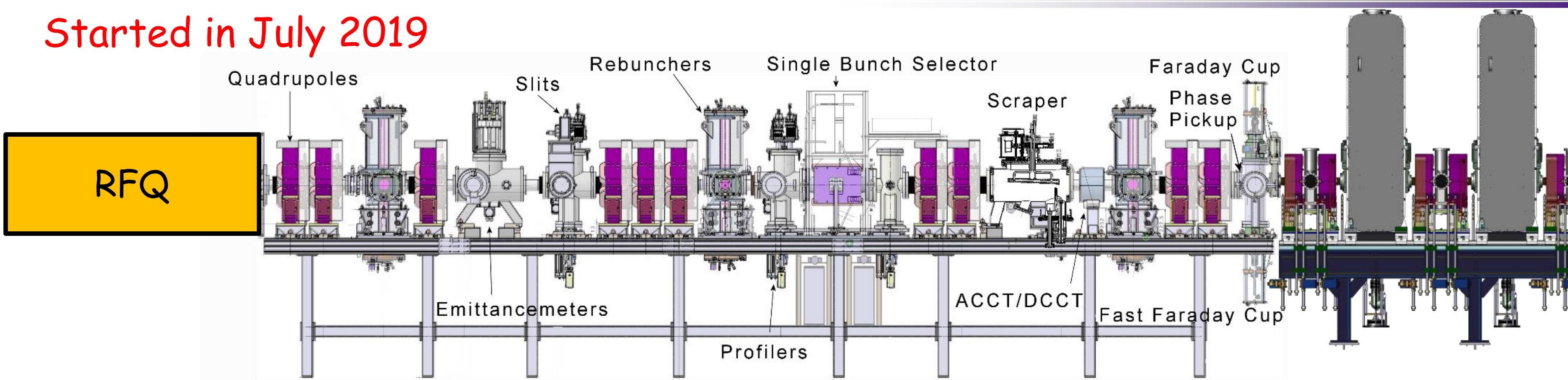

Main goals:

- ✓ Validate RFQ performances
- ✓ Develop and qualify diagnostics
- ✓ Measure beam characteristics

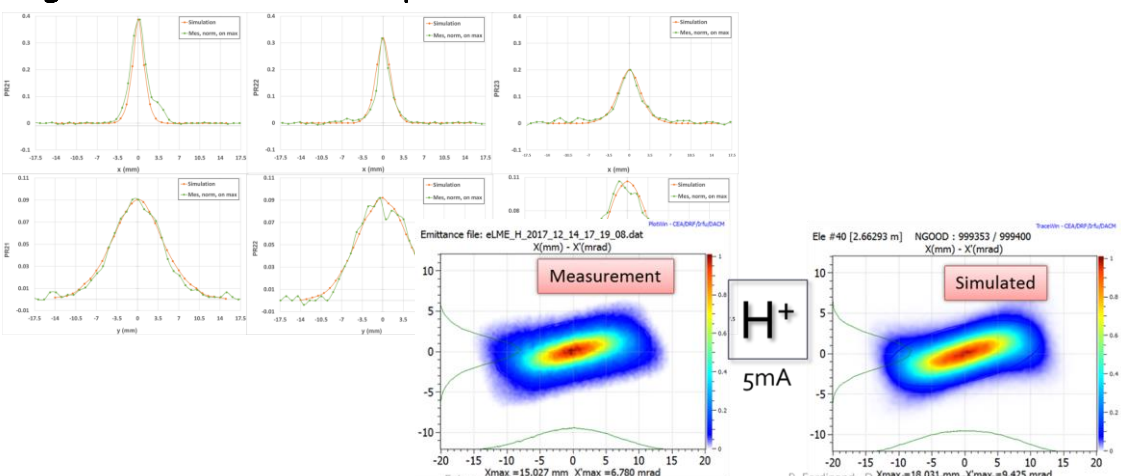
- Intensities with Faraday cups, ACCT and DCCT
- Transverse profiles with classical multi-wire profilers and Residual Gas Monitor (RGM)
- H and V transverse emittances with Allison type scanners
- Energy with Time of Flight monitor (TOF) (3 pick up)
- Phases with 3 electrodes (TOF) and 2 BPMs
- Longitudinal profiles with a Fast Faraday Cup (FFC) and a Beam Extension Monitor (BEM)
- Beam position, ellipticity ($\sigma_x^2$-$\sigma_y^2$) with BPMs

# MEBT transport and emittance

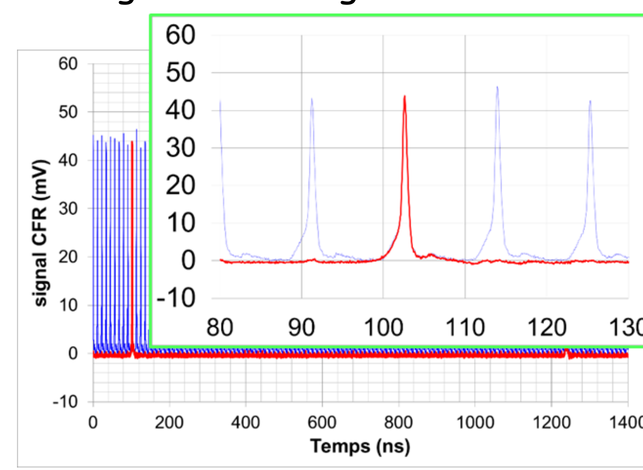
Started in July 2019




Good beam transport agreement between simulation and measurement
Single Bunch Selector operational




FFC signal with Single Bunch Selector



End 2018

# Beam Diagnostics: D-plate Feedback

The commissioning time associated with the D-plate was well invested.

Design of the D-Plate and compatibility between diagnostics have to be well analyzed. Main feedbacks are the following:

- ✓ D-plate design should take all requirements into account
  - ✓ BPM Position & ellipticity qualification required 2 profile monitors, with only one available
  - ✓ The internal diameter difference between diagnostics was a constraint
    - ✓ Electric field not symmetrical around the TOF electrodes => phase shift
    - ✓ After the first BPM installation, losses in relation with posY-phase coupling in the rebuncher. 10° shift => Incompatibility between phase measurements and the first BPM
- ✓ Long test time might be required:
  - ✓ BPM validation of position, ellipticity and phase measurements => Hardware modifications of electronic cards, calibration with beam in presence of development team, evolution of the VHDL and EPICS programs
  - ✓ Bunch Extension monitor qualification : New challenging diagnostic
- ✓ Tests in real situation highlight difficulties not anticipated:
  - ✓ Emittancemeter: EMC modifications to decrease noises, debugging of the measurement analysis
  - ✓ Residual Gaz Profile Monitor out of the specifications

End 2019

# MEBT & linac diagnostic Feedback

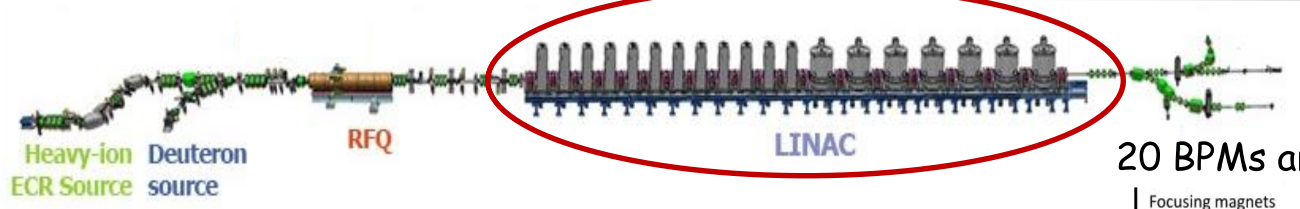
Time for tests and upgrades is required, since there are always missed points.

- ✓ ACCT-DCCT: EMC optimization to reduce disturbances
- ✓ Optimization of the Fast Faraday Cup (mechanical modifications which increase the bandwidth from 1 GHz to 3 GHz)
- ✓ BPM: Validation that the impedance matching of electrodes allows to reduce differences between ellipticity values from the harmonics h1 & h2.
- ✓ Interfaces and bugs required many modifications
- ✓ Intensity measurements on the slits are perturbed by electrons of secondary emission. Problem to protect the slits by monitoring the intensity
- ✓ Limitation in intensity of the multi wire profile monitor. Pb for profilers upstream the chopper

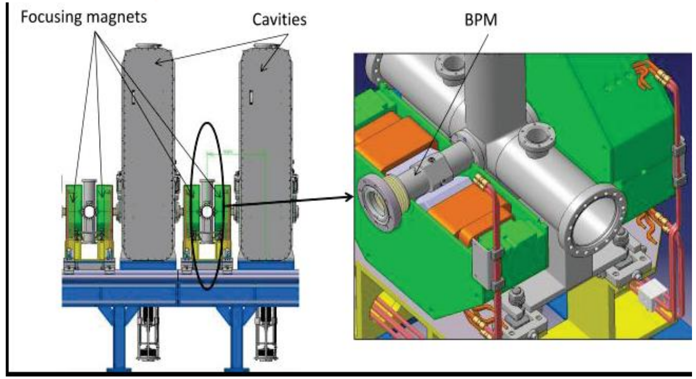
The right Diagnostics are necessary :

- ✓ An emittancemeter in the MEBT is essential
- ✓ Separate transmission measurements between the RFQ and the MEBT is a must have. We miss one current measurement right at the RFQ exit
- ✓ Only one phase pick-up to tune the 3 rebunchers, and the too long distance with the first rebuncher complicate its tuning

# Linac Description



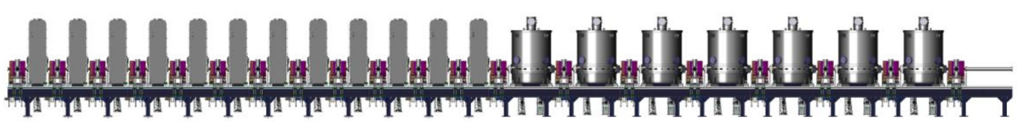

20 BPMs are installed in the warm sections




**26 Nb cavities QWR** at 88 Mhz
T : 4.5K operation.
E $_{acc}$ : 6.5 MV/m

**two cavity families :**
12 Beta = 0.07 (1 cavity / cryomodule type A)
14 Beta = 0.12 (2 cavities / cryomodule type B)

**20 warm sections**
(quadrupoles/diagnostics/pumping)

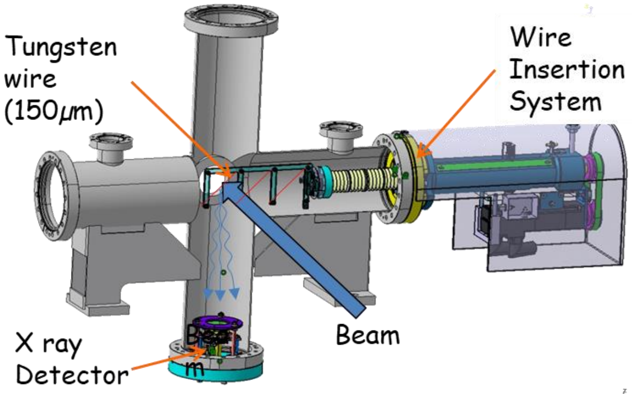


Beta 0.07 energy section

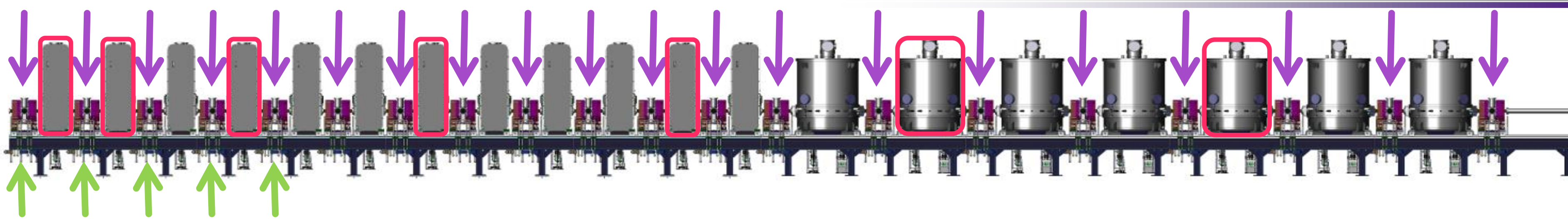
Beta 0.12 energy section

**L~35 m**

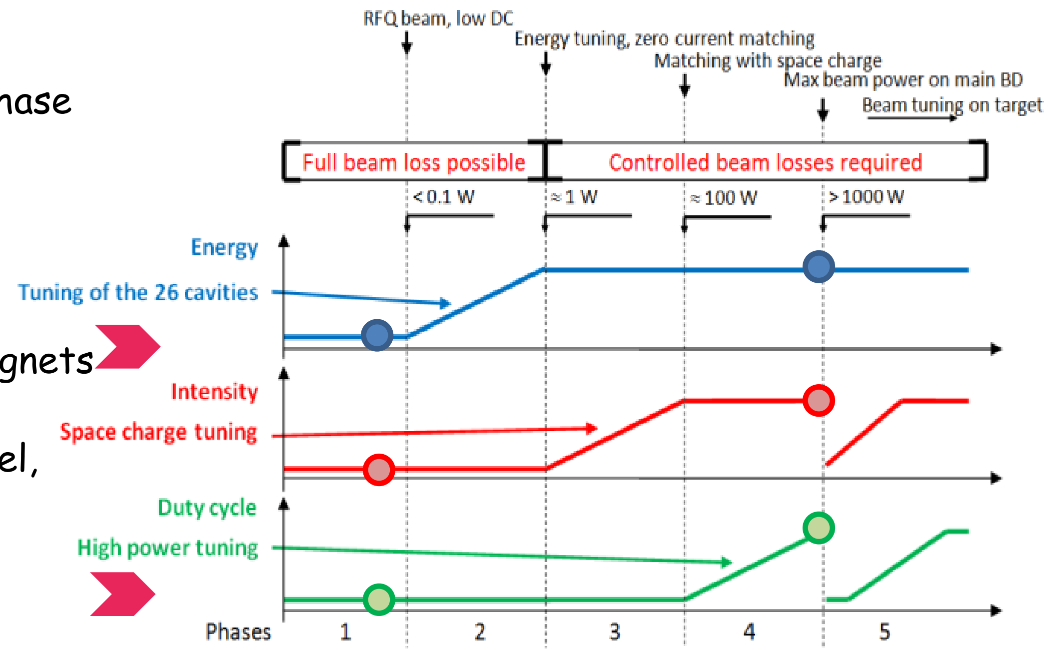
And 5 BEMs in the 5 first sections



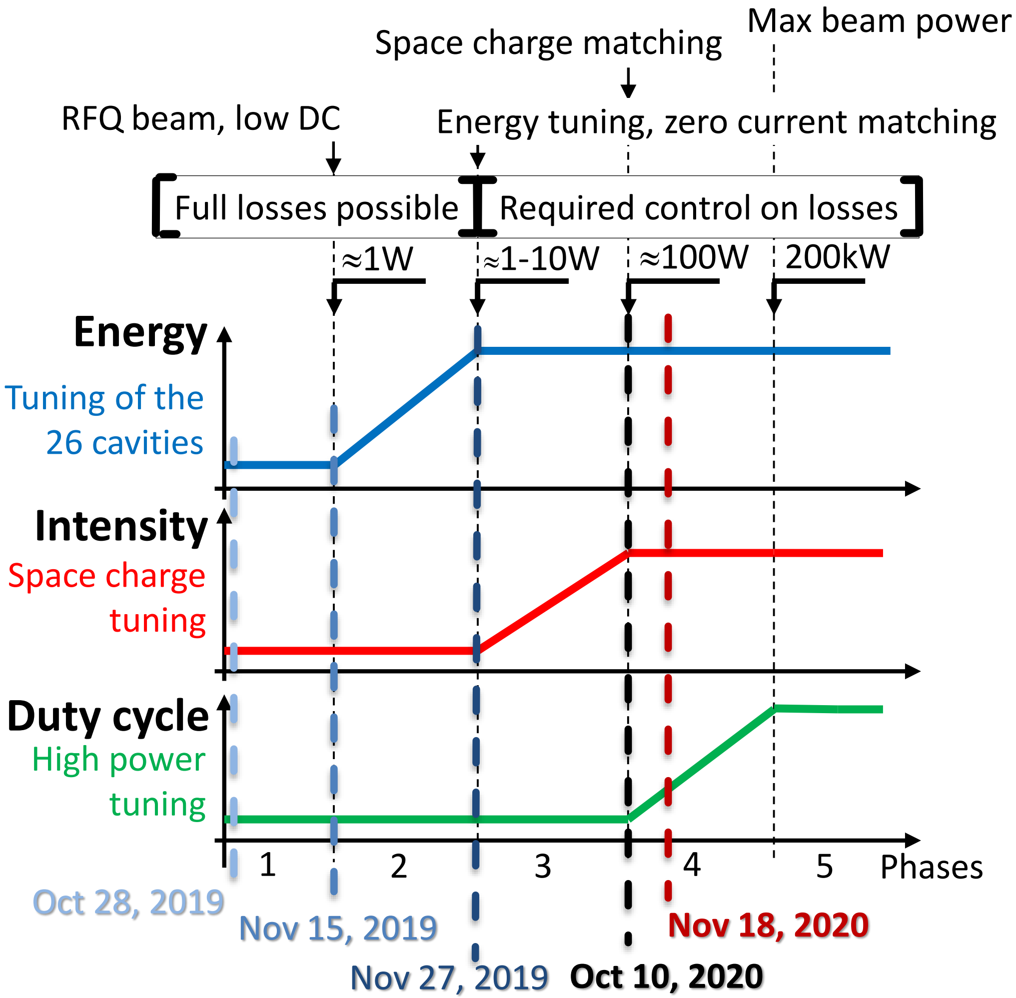
# LINAC tuning



- ✓ Adjust quadrupoles and steerers
  - ◆ BPMs (positions)
- ✓ Tune the first linac cavity (amplitude & phase ➔ signature matching method)
  - ◆ Pencil beam < 1W @linac's end
  - ◆ BPMs (Beam phases and energies)
- ✓ Then all the following cavities
- ✓ Re-adjust all following linac and HEBT magnets at each modification (phase, Energy)
- ✓ Match the MEBT beam to the linac channel,
  - ◆ BPMs (positions & ellipticities)
  - ◆ BEMs (bunch lengths)
- ✓ Slowly increase the beam power
  - ◆ BLMs (beam losses)
  - ◆ ACCT-DCCT (transmissions)



# Proton beam in the SPIRAL2 LINAC




- *October 28, 2019 :*
  MEBT beam inside the linac
- *November 15, 2019 :*
  All cavities tuned in rebuncher mode (RFQ energy: 0.73MeV)
  - 250μA, 5.44ms/s, 1W
- *November 27, 2019 00h33 :*
  *nominal acceleration,* ***33MeV***
  - 200μA, 960μs/s, 6.44W

*Early 2020: 6 months Off for Physics Experiments at GANIL + COVID*

- *October 10, 2020*
  - *4.8mA, 1ms/s, 158W*
- *November 18, 2020*
  - ***2020 Objective: 16 kW*** *of beam power (10 % of the full power)*

End 2020

# Beam Diagnostic Feedback

laboratoire commun CEA/DSM CNRS/IN2P3

- ✓ SPIRAL2 is a challenge for diagnostic monitors in term of intensity dynamic range.
- ✓ All beam diagnostics meet the design specifications but… not yet the physic requirements in term of intensity. (Few 10µA min for the linac tuning, down to 100 nA for physic experiments)
- ✓ BPM : Following BPM measurements in 2019, important changes were made in early 2020.
  - EMC modifications to decrease the disturbances from the RF cavities
  - 50 Ohm matching of the 20*4 BPM electrodes
  - New precise calibration of the 22 modules

  Very good results: Close values of positions and ellipticities calculated from harmonics h1 and h2
- ✓ BEM: Time resolution better than 50 psec but … long measuring time at low intensity (>30min, Ibeam = 200µA, duty cycle 0.1%)
- ✓ BLM : critical fine tuning device for beam losses optimization in the linac + HEBT

  But don't detect losses for a beam energy lower than 10 MeV > Vacuum monitoring under evaluation

  Complicated compromise between sensitivity and saturation

  Can not help to highlight localized versus diffused losses
- ✓ Diagnostic monitors are also used to survey the beam in relation with the Machine Protection System. (intensity, transmission, energy, loss monitoring)
- ✓ ACCT-DCCT : Intensity & transmissions monitoring for MPS. Uncertainties definition
- ✓ TOF: Energy monitoring for MPS. Definition of uncertainties performed

# Conclusion



- All 2020 milestones have been met
  - LINAC has been qualified in proton operation
  - Beam sent to NFS room for convertor qualification and identification of the main difficulties

**p-beam accelerated by the LINAC in nominal beam conditions 16kW, produced (10% DC)**

- Objectives for 2021
  - Nominal deuteron beam current with Single Bunch Selector at nominal energy
  - Availability improvement – strong involvement.
  - Safety constraints management
  - Share time with Physics in NFS

**Become a stable neutron facility at NFS**

# Thank you for your attention

Thanks to GANIL teams and SPIRAL2 collaborations

jamet.christophe@ganil.fr
robin.ferdinand@ganil.fr

http://accelconf.web.cern.ch/ibic2019/papers/mopp036.pdf
https://accelconf.web.cern.ch/ipac2019/papers/mopts006.pdf