SPIRAL 2 status and available beams

1 – SPIRAL 2 Commissioning
2 – What the LINAC can do (and how)
3 – Available beams

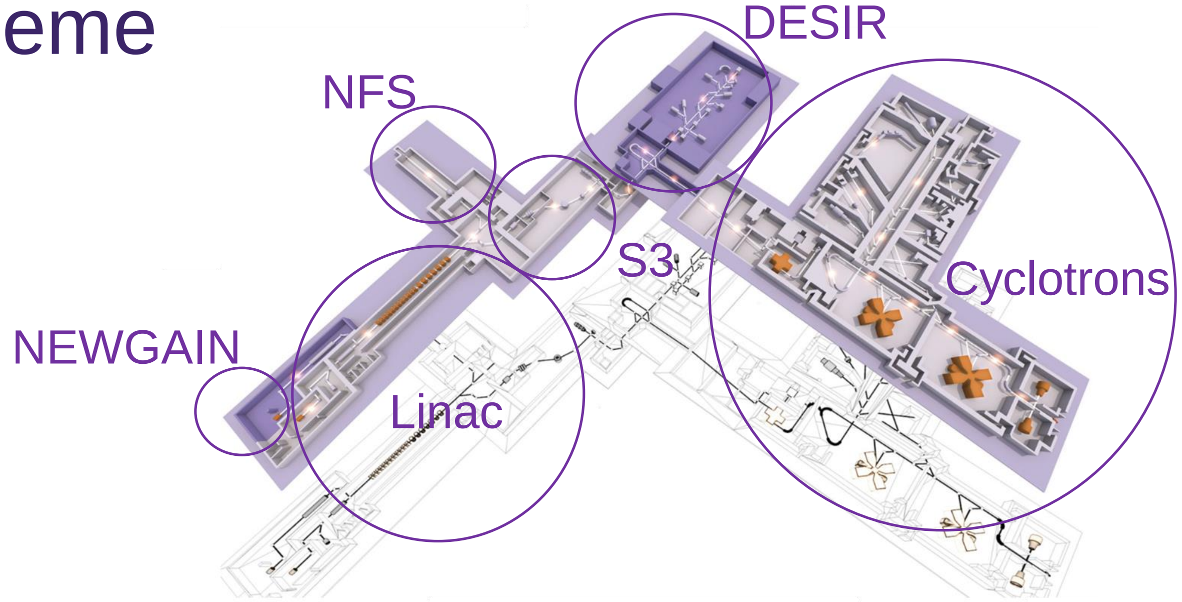
G. Normand GANIL

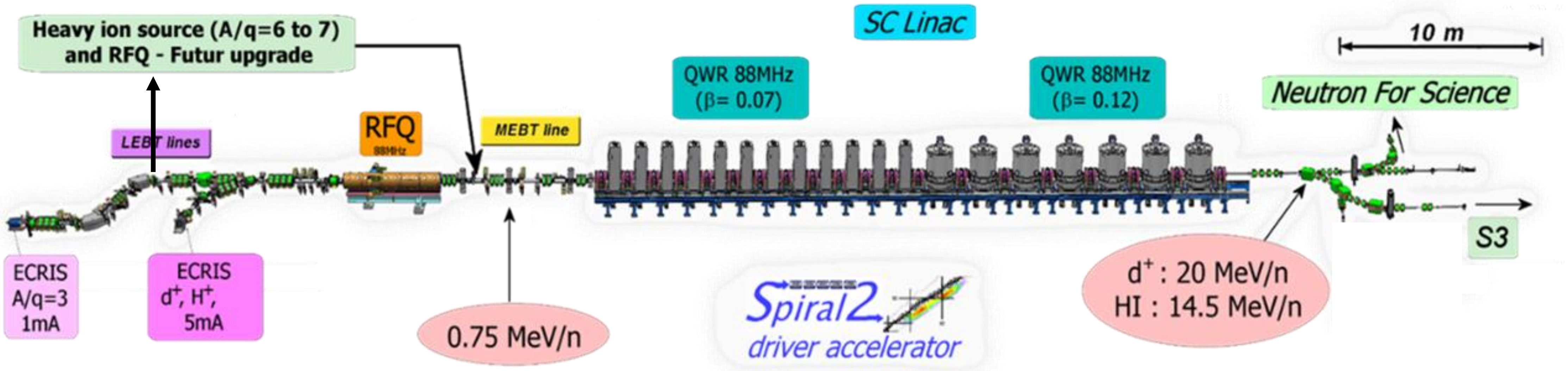
on behalf of the GANIL teams and SPIRAL2 collaborations

Special thanks to: Marco Di Giacomo, Jean-Michel Lagniel , Angie Karina Orduz and Didier Uriot

SP2 commissioning

Spiral 2 scheme





Commissioning timeline

ECRIS A/Q=3 1mA

ECRIS H^+, d^+ 5 mA

LEBT

RFQ

MEBT

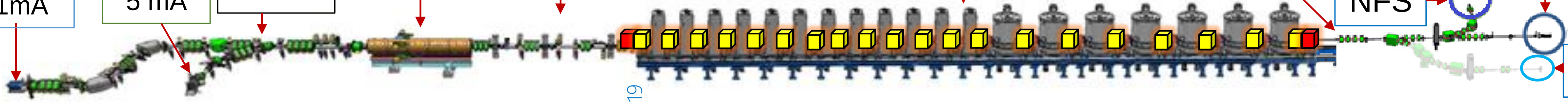
LINAC

HEBT

NFS

Beam dump

S^3



Authorization to operate SPIRAL2, Jul 8th, 2019

2009-2012

Qualification of the ion sources and LEBT

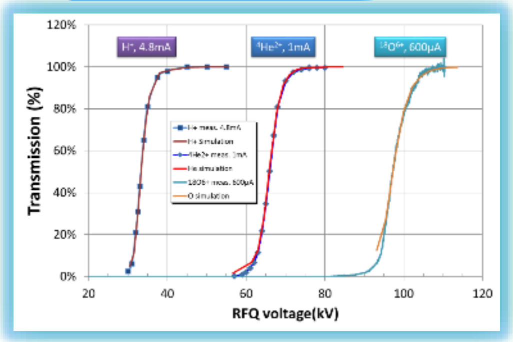
(LPSC-Grenoble and CEA-Saclay)

Construction building and tools

2014-2018

Qualification of the injector on a Diagnostic Plate (GANIL)

- RFQ performance
- 2014 1st H^+ beam @2 mA H/D (Dec)
- 2015 1st Ar^{9+} beam @ 230 µA HI source (Jul) / 1st RFQ H^+ (Dec)
- Beam characteristics at RFQ exit



2019-2021

SC linac beam commissioning up to the main beam dump

1st beam in the linac, Oct. 28th

1st beam in NFS, Dec. 11th

33 MeV H^+ (2019)

40 MeV $^4He^{2+}$, D^+ (2020)

50 µA D^+ NFS (2021)

2022

First year of SPIRAL2 operation in NFS room

50% beam time for physics

Pre-commissioning for S^3

7 MeV/A $^{18}O^{6+}$, $^{18}O^{7+}$, $^{40}Ar^{14+}$

0.73 MeV/A $^{18}O^{6+}$, $^{18}O^{7+}$, $^{40}Ar^{14+}$

First cavity failure test

2023

SPIRAL2 operation

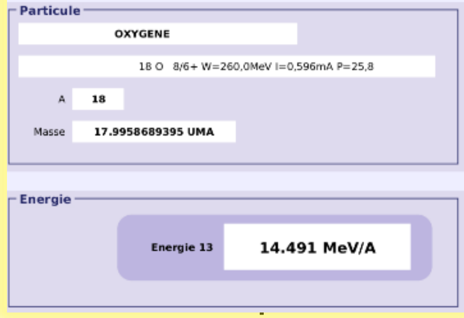
65% beam time for physics

14% for studies

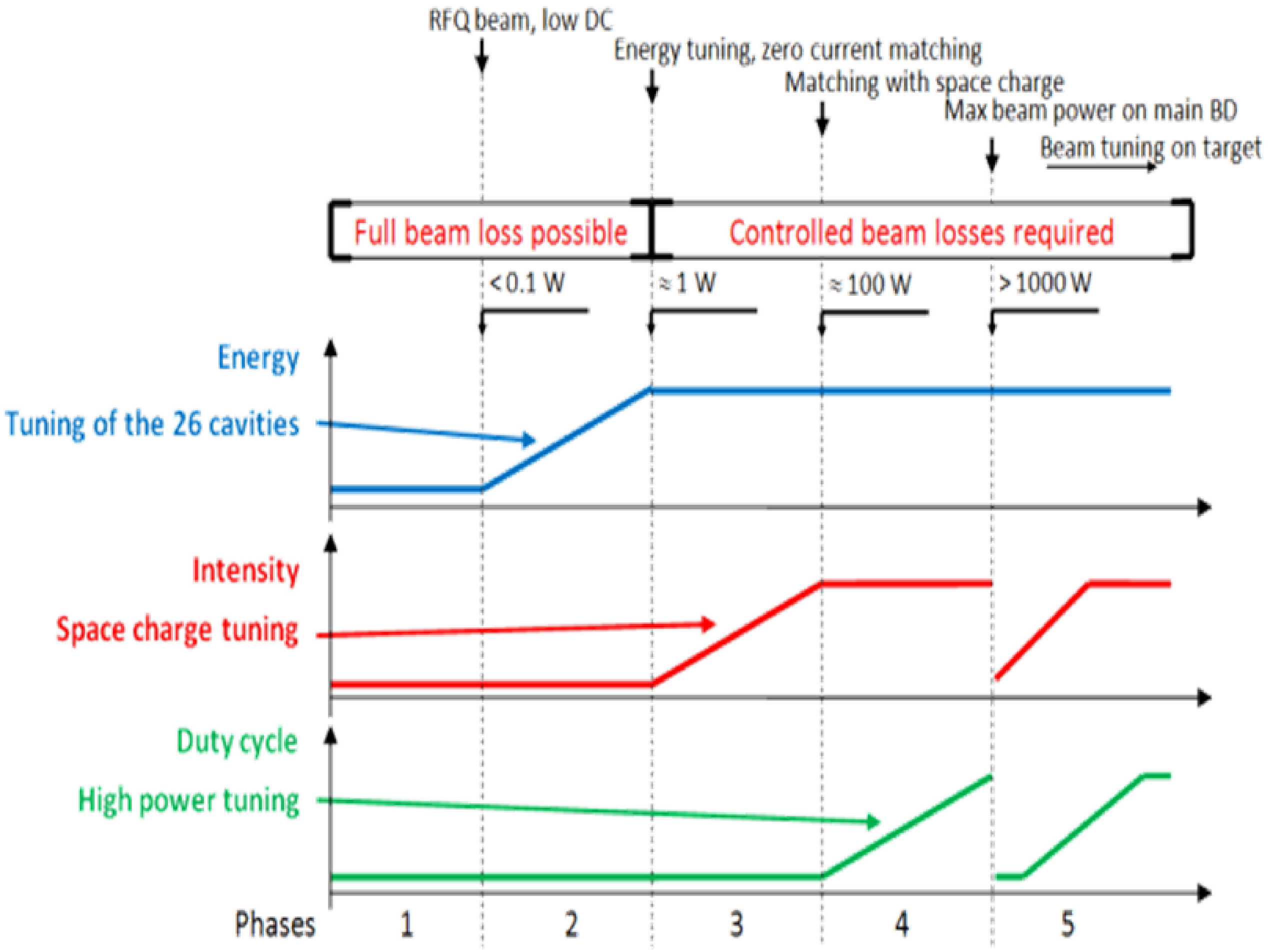
Pre-commissioning for S^3

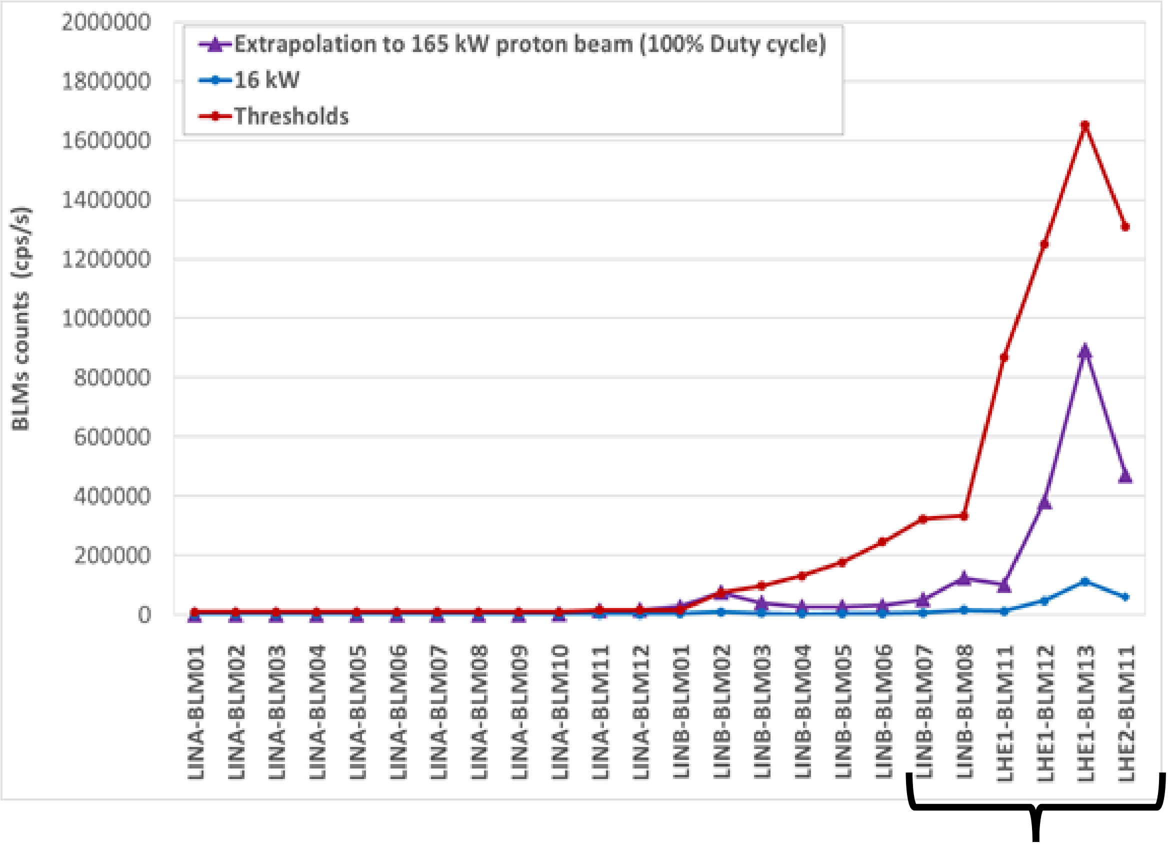
14.5 MeV/A $^{18}O^{6+}$

Cavity failure test and pressure variation in warm sections



Tuning strategy and losses

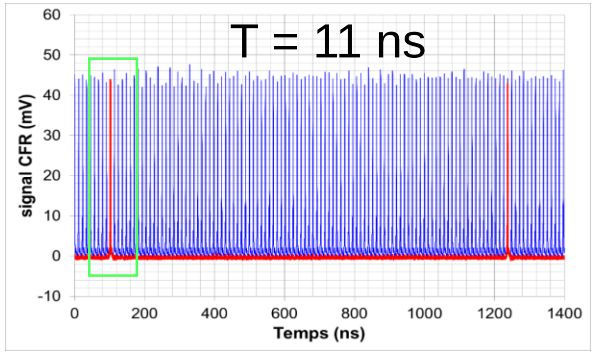


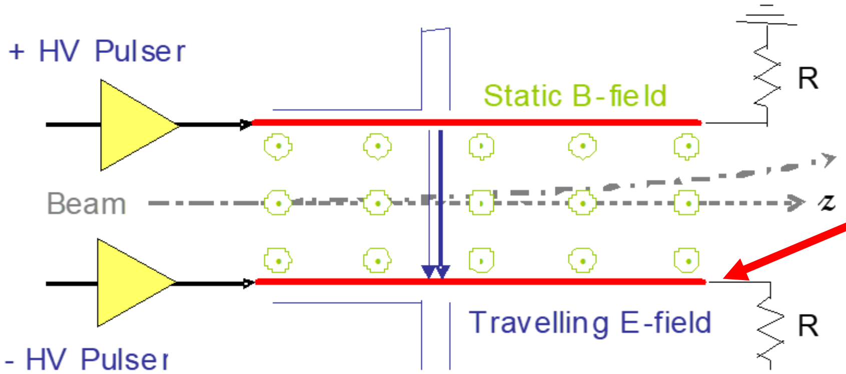


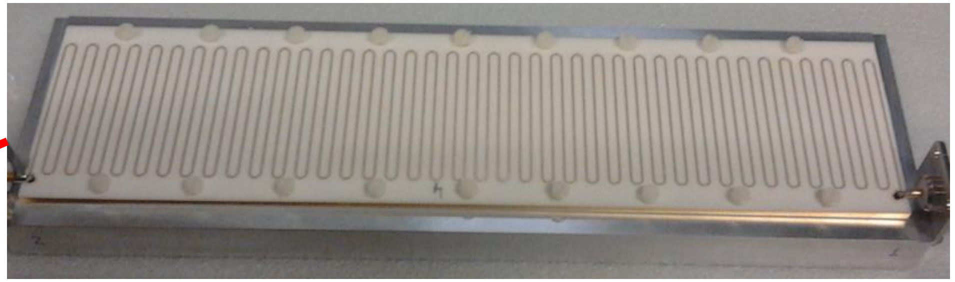
Neutrons backscattered from main beam dump

- Losses < 1 W/m for 165 kW protons and 200 kW deutons
- For heavy ions at energy < 7 MeV/A current transmission and vacuum evolution are more relevant than neutrons : we used them for fine tuning.

Single bunch selector (MEBT), scattering issue

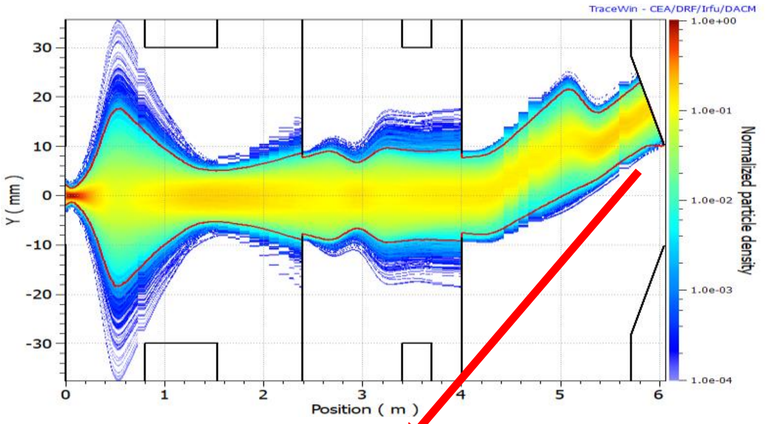






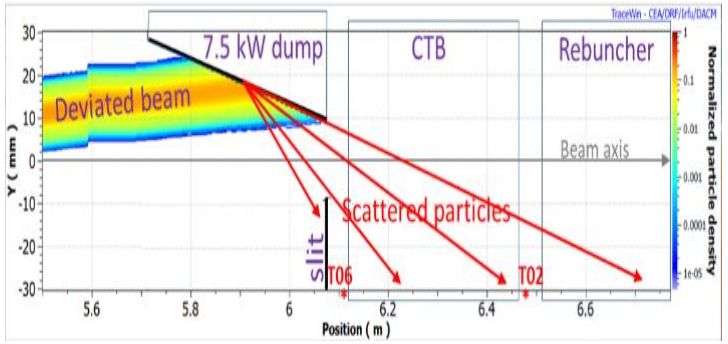
SBS meander to slowdown the E wave

1 bunch selected (~ ns) on 100 (until 10000), for time of flight purpose



SBS beam dump

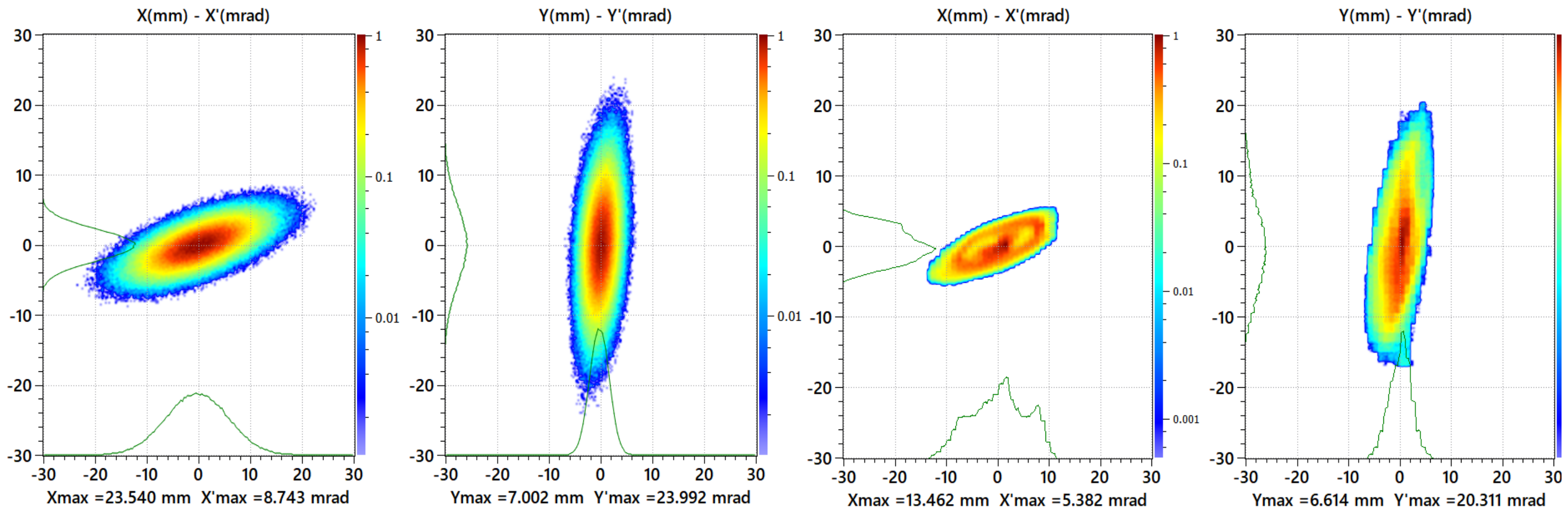
- The beam dump receiving the bunches deviated by the SBS (until 7.5 kW) was affected by Coulomb scattering which has created important heating and beam current measurements issues ($\approx 100\mu A$ in 2019).
- The beam dump was redesigned (surface changed from flat to staircase), which has successfully decreased the temperature and the current offset.



Simulation code Tracewin (IRFU-CEA)

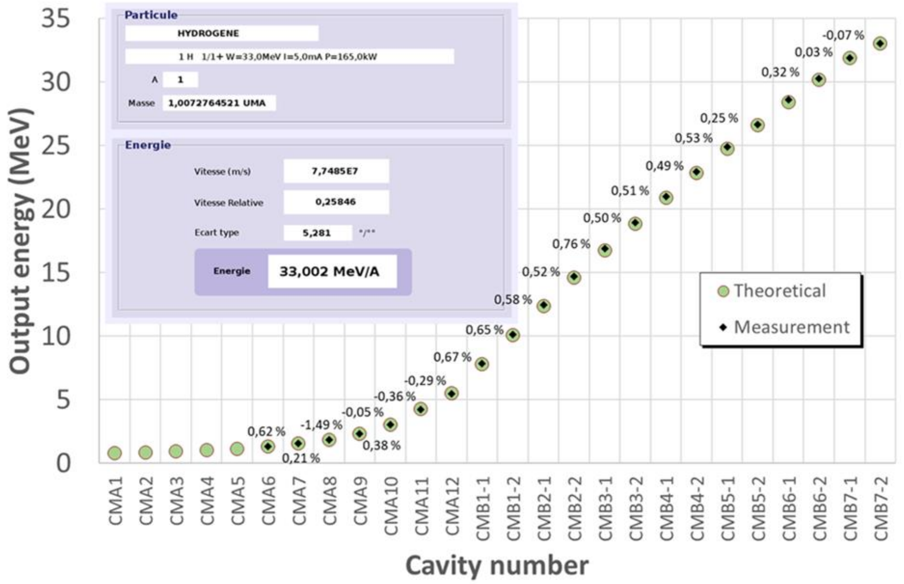
- This code predicts very well the beam behavior after the RFQ if the starting beam distribution is accurate (emittancemeter in MEBT + backtracing).
- Starting from calculated parameters in the machine, very few matching changes, with 4 quadrupoles and one rebuncher, are needed to obtain a well matched beam to the linac with very low losses.

Reference simulation 600 μA $^{18}O^{6+}$ Measurement 600 μA $^{18}O^{6+}$



Transversal emittances in the MEBT

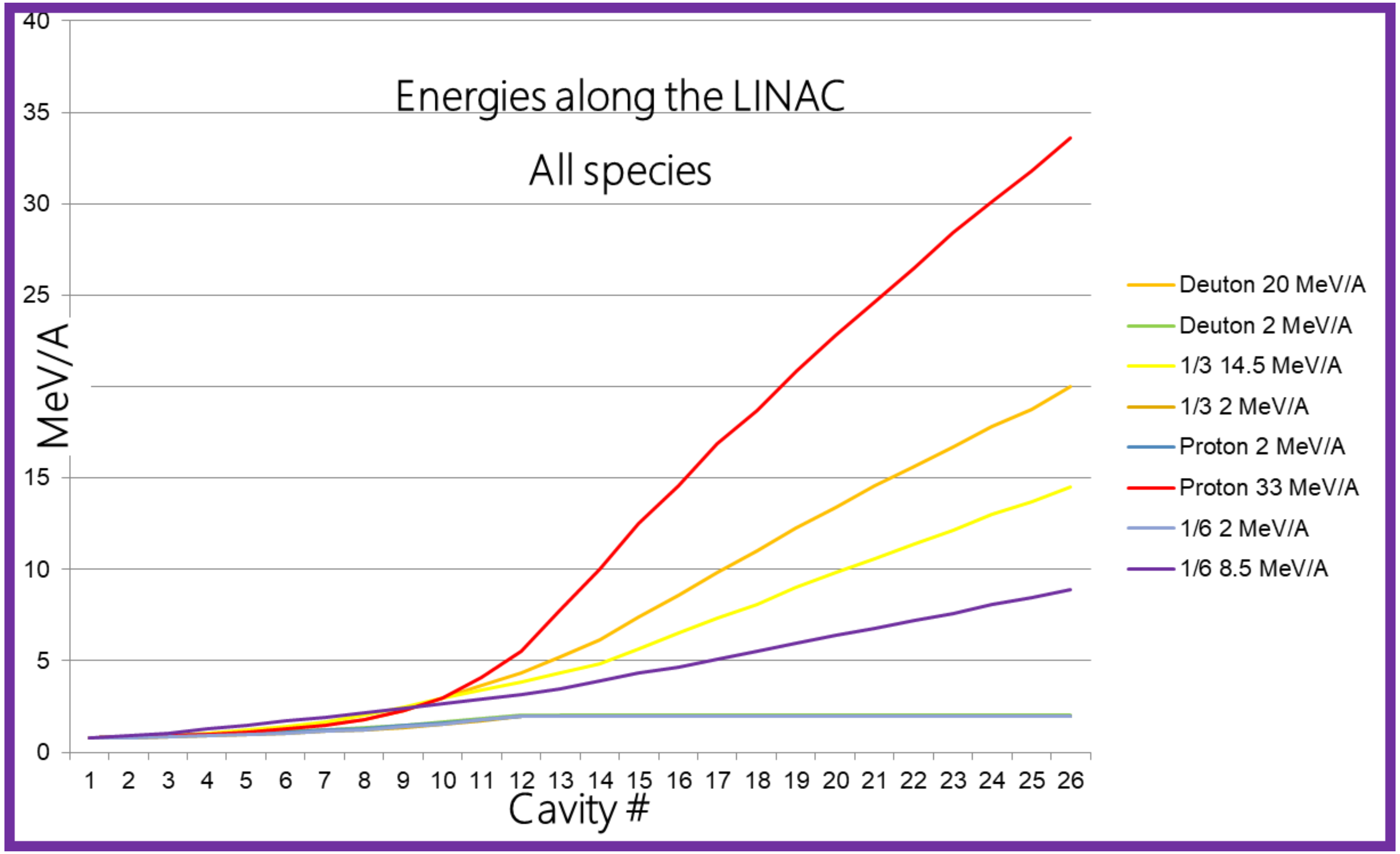
Proton 33 MeV



Energy along the LINAC (Measurement vs Simulation)

What the LINAC can do (and how)

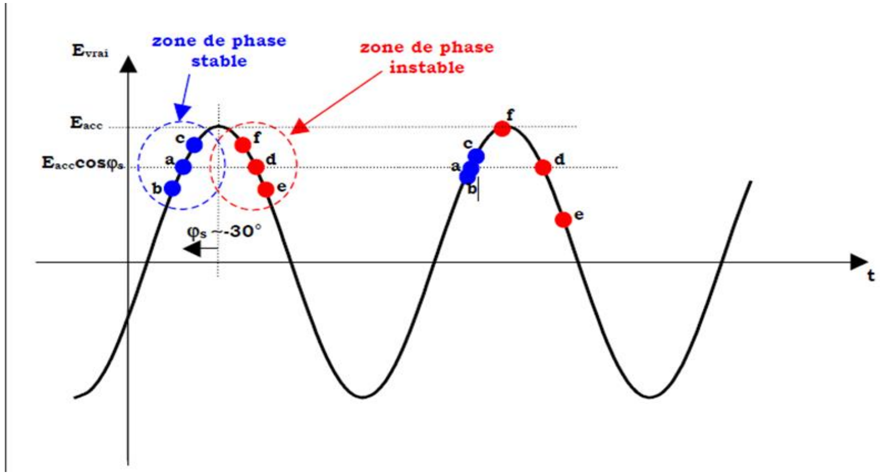
Maximum/minimum energies

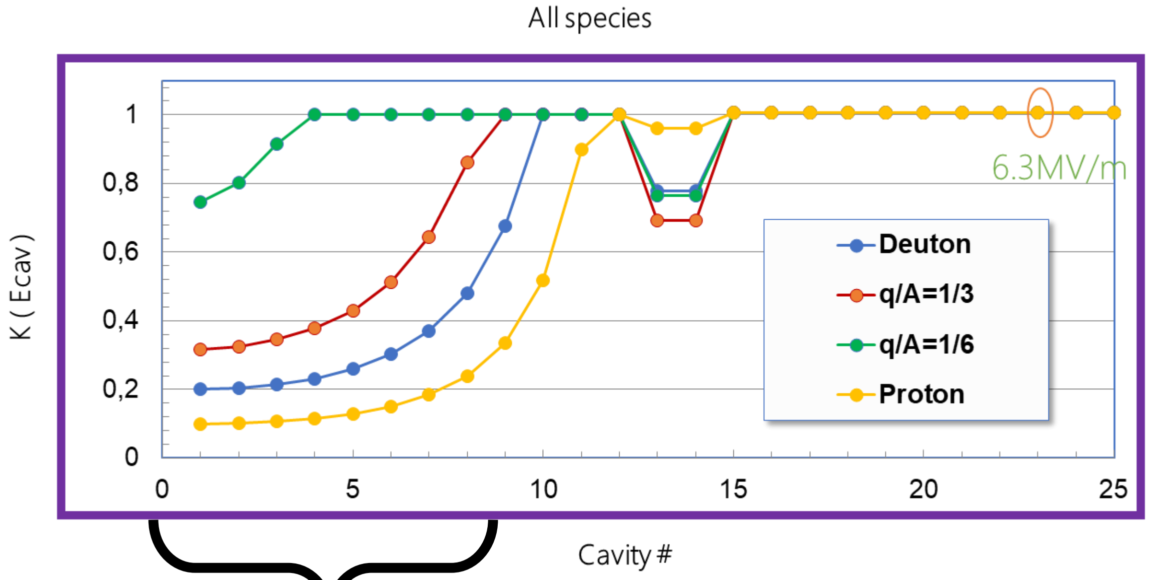


Minimum energy : 0.73 MeV/A (id output energy of the RFQ)

Cavities voltage vs species and acceleration scheme

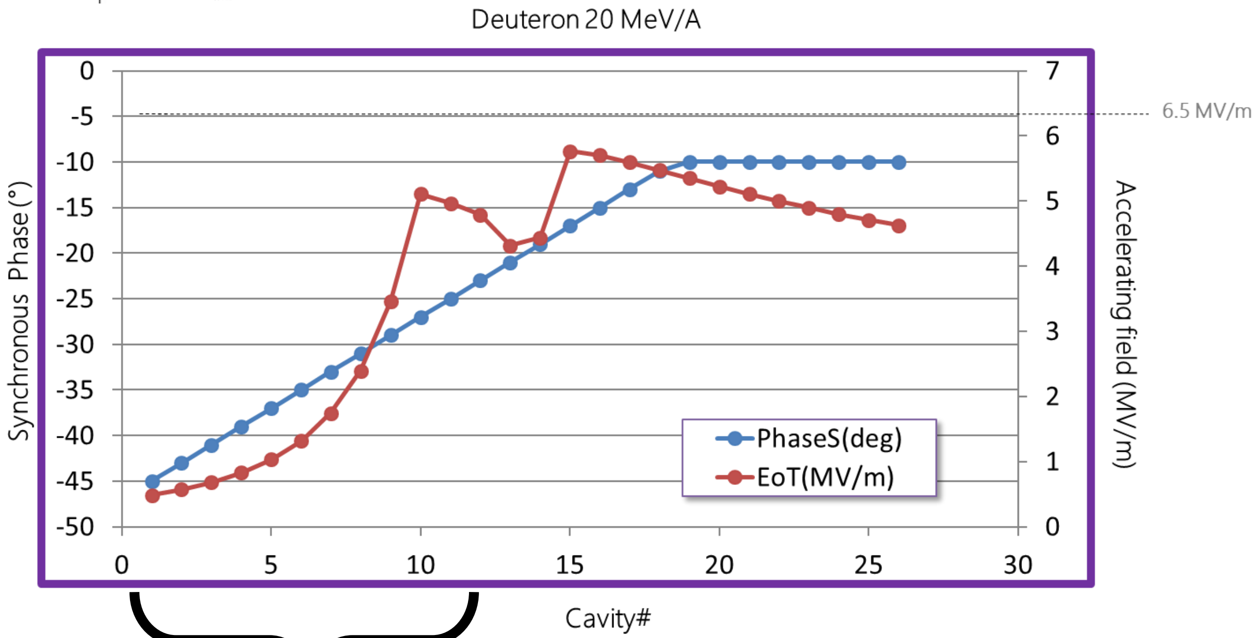
Each cavity must be tuned one after the other :
Voltage and Phase





Electrical field used in each cavity for
different species and energies (k = normalized/max, max = 6.5 MV)

Low electric fields to keep a good acceptance

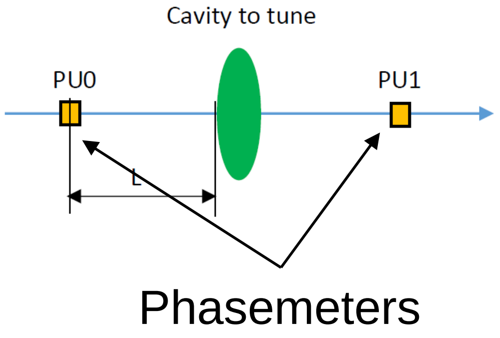


Low synchronous phases to keep a good acceptance

Cavities tuning : time needed

1. Advanced method (1-2 days) - No voltage and phase calibrations known
   - Signature matching + avoid the phase measurements errors (non-linear effects deforming the bunch shape)
   - 1 tuning per year: phase and voltage calibration for all tunings.

2. With reference method (<60 min) - Voltage and phase calibration previously done
   - No detuning, no phase scan.
   - Phase measurement at cavity entrance + simulation.
   - Verification with phase measurement at the PU1.
   - Sensitive to accuracy of phase measurements.

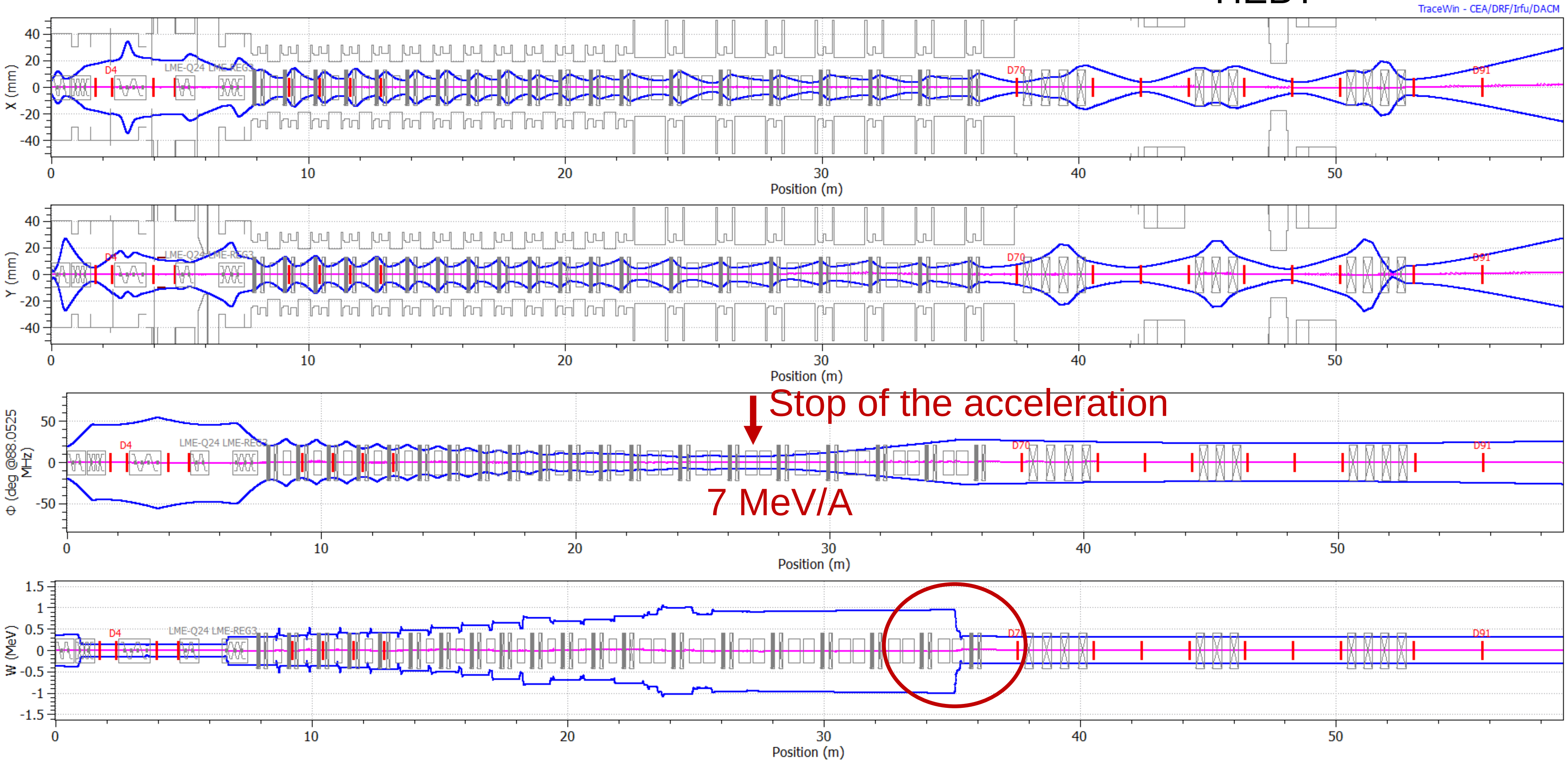


3. Ratio A/Q (<10 min + LBE new tuning)
   - If the BPMs (phasemeters) do not see the beam, a "pilot ion" with a "visible" current and the same acceleration pattern as the one required for the "objective ion" is used for an initial tuning.
   - All the $\vec{E}$ and $\vec{B}$ fields will be multiplied by $c = \frac{A_1/Q_1}{A_2/Q_2}$
   - New tuning of the LEBT for the new ion

Heavy ions

$^{18}O^{6+}$

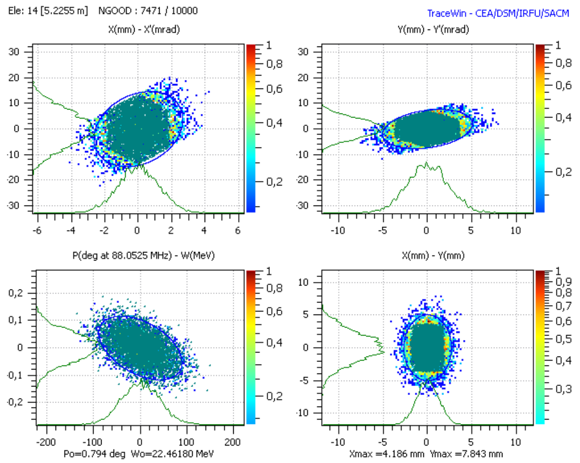
MEBT LINAC HEBT



ΔE/E = 0.1 MeV rms / 126 MeV = 0.08 %

Accelerated with success in 2022

Intensity and energy changes vs tuning strategy



Hexagon of particules kept

Peak intensity

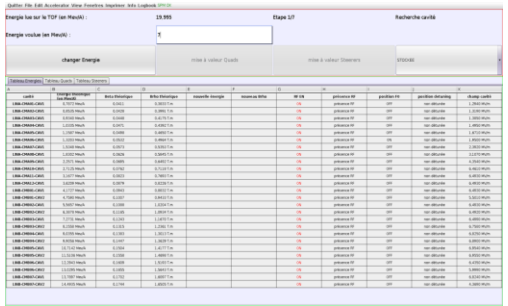
3*2 slits in the LBET to create new emittance definition

- Keeps the space charge, narrow beam, very fast (1').
- Very useful, but produce instable beam intensity if it's closed too much.

Pepper pots to reduce a lot the intensity easily (in 2024).
(1/100 to 1/1000000).

Energy changes

Cavities are stopped and detuned until to reach the wanted energy (starting from the last), the line is set at the new Bhro. Generally around 15' if this is an energy decrease.

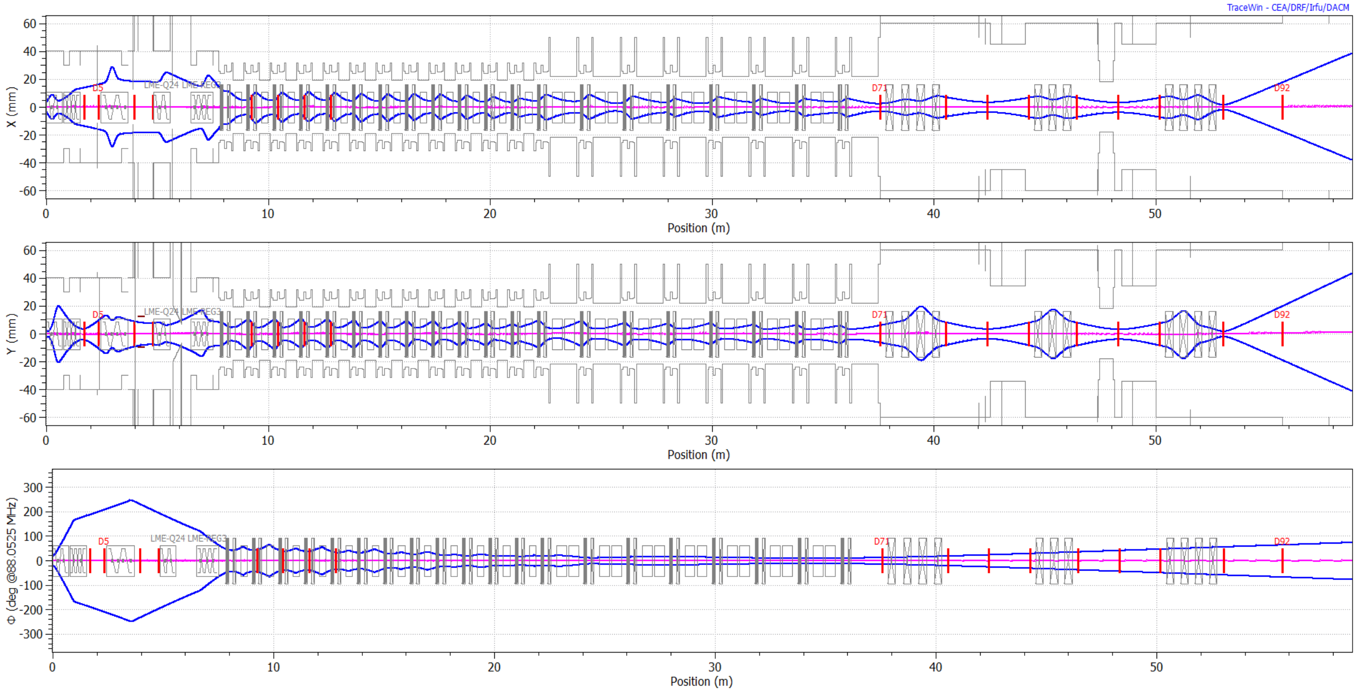


E change application

Only one reference tuning is needed for nearly all the I and E for one species

« Invisible » beams.

Objective : tune the accelerator even for species with very low intensities not seen by some diagnostics (< 10 µA).



Simulation of $^{18}O^{7+}$ in MEBT, linac and HEBT using the scaling method

From $^{18}O^{6+}$ to 7+ (test case):

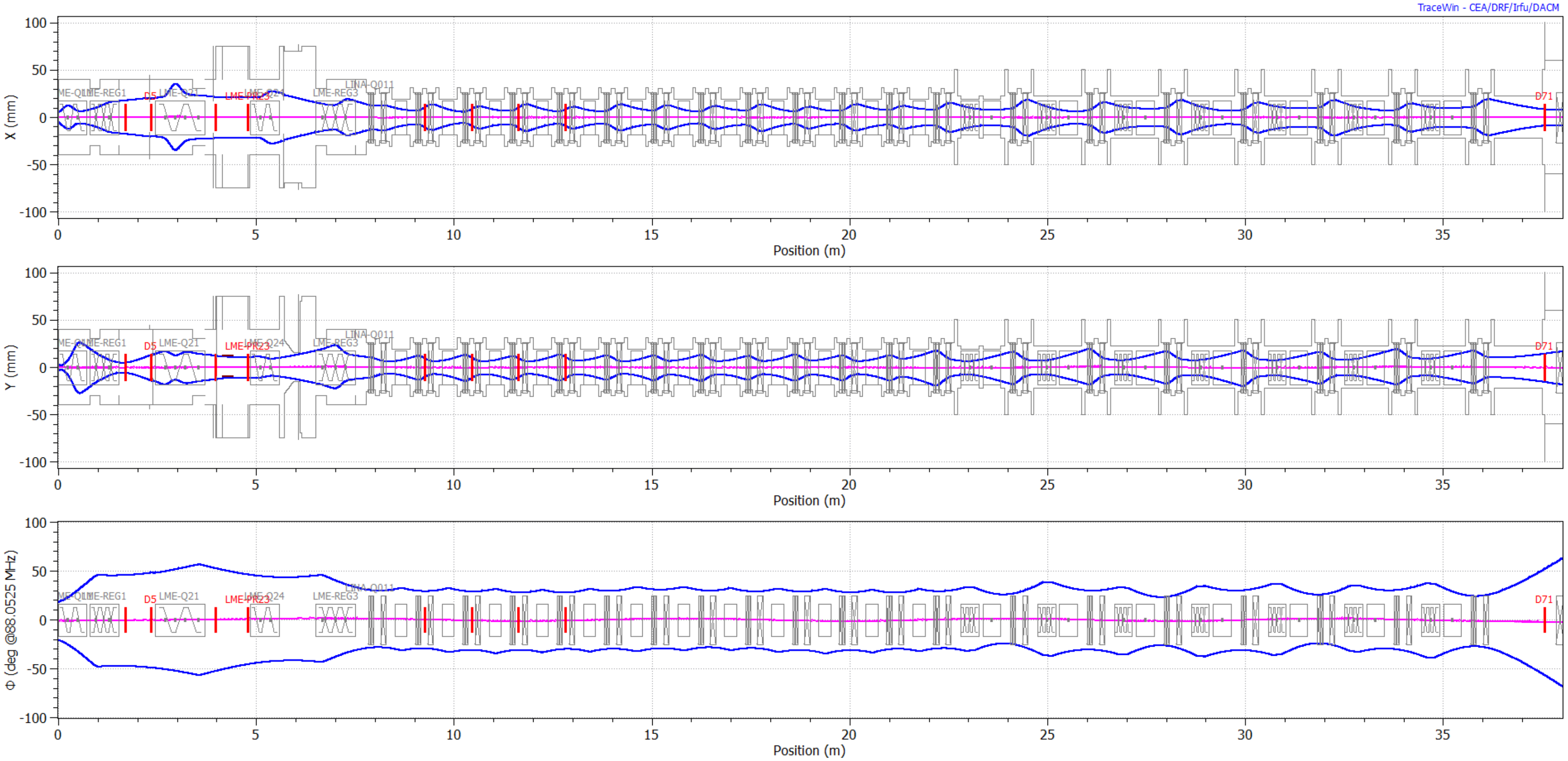
(A1/Q1) / (A2/Q2) = 0,86

Method : multiply all magnetic and electric fields from source voltage until the last quadrupole before the target by this factor.

Used with success in 2022

Linac tuning without acceleration for $^{18}O^{6+}$

Beam requested to tune the spectrometer (0.73 MeV/A).



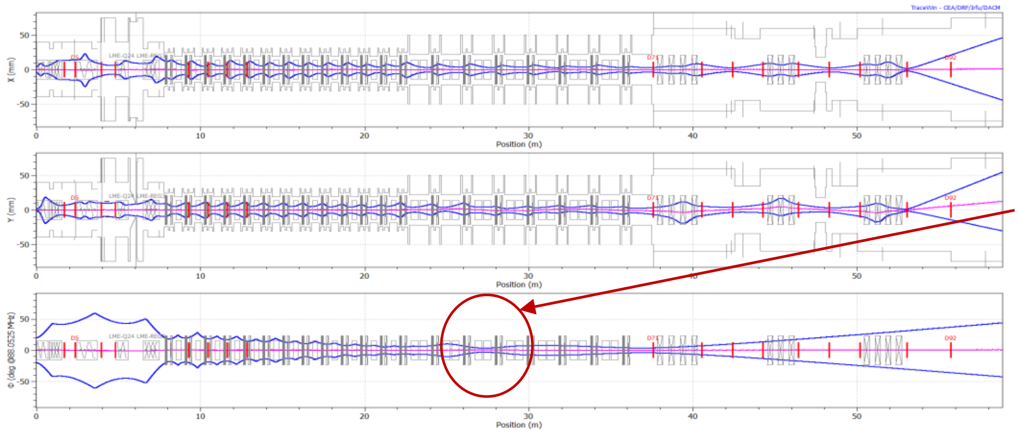
All A cavities and 1 over 2 of the B ones are in rebuncher mode.

… we succed to not accelerate this beam in 2022

Linac tuning if a cavity is out of order

As the energy ↑ the debunching ↓

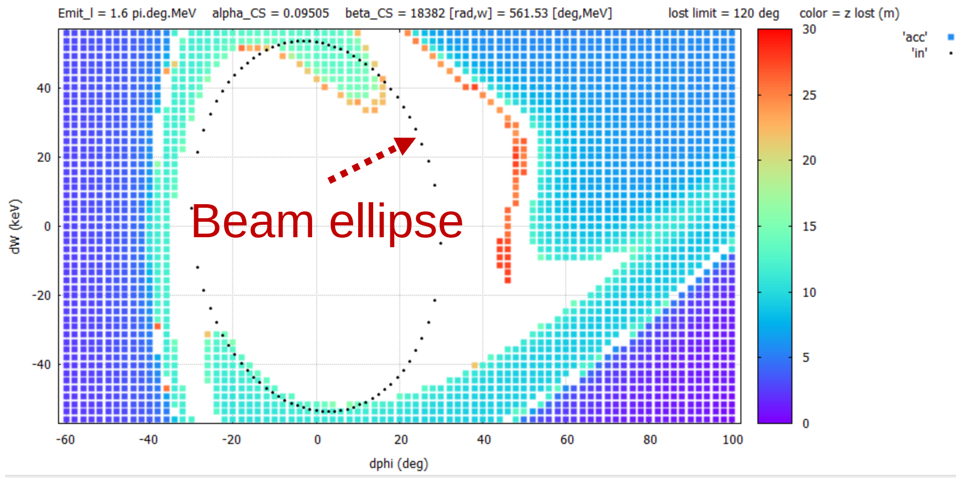
- High β cavity failure: solution easy to find.
- Last low β cavity failure, possible to recover a beam dynamics without losses but not obvious.
- Low β cavity failure: very difficult to tune at low energy due to a high debunching between two cavities.

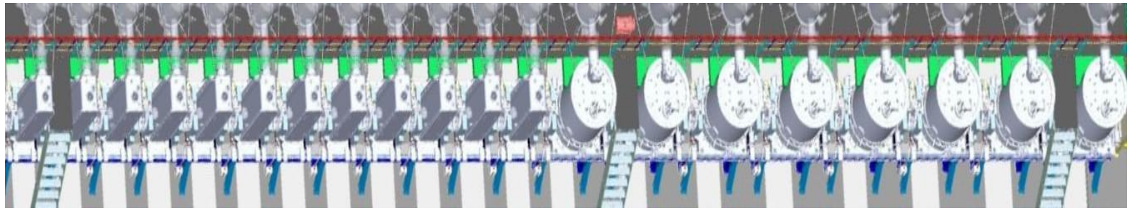


Deutons
CMB1 cav 2 out of order

Work is currently underway :

Longitudinal acceptance (in white)





Low β section

High β section

Retune the up and downstream cavities

- Phase acceptance reduction (more losses, but if 2 KW are requested instead of 200 kW, some margins)
- Reduction of the final energy or/and an increase of the cavity voltages (8 MV/m available now vs 6.5 MV/m at the beginning).

Cavity A6 out of order :
900 µA $^4He^{2+}$ @ 64 MeV (instead of 80)
2 kW produced with success in 2023

Available beams

Heavy ions

	Q/A =1/3 AVAILABLE NOW	Q/A = 1/6 (NEWGAIN) 2028	Q/A = 1/7 (NEWGAIN) >2030
Energies	0.73 to 14.5 MeV/A	0.73 MeV/A to 8.5 MeV/A	0.73 to 6.33 MeV/A, or maybe 7 MeV/A
Maximum power	(if 1 mA) 43.5 kW	<6 kW	(Uranium) 15 kW

INTENSITIES

beam intensities	*injector1* *2023*	NEWGAIN *(injector2)* *2028*	*≥ 2030*
Ions	Intensity (pμA) Phoenix V3 RFQ A/Q≤3	Intensity (pμA) Phoenix V3 RFQ A/Q≤7	Intensity (pμA) SC Ion Source RFQ A/Q≤7
^{18}O	80	*	375
^{19}F	>15	>40	>40
^{36}Ar	16	70	45
^{40}Ar	3.6	70	45
^{36}S	2.3	*	*
^{40}Ca	2.9	10	20
^{48}Ca	1.2	10	20
^{58}Ni	1.1	4	8
^{84}Kr	0.1	10	20
^{139}Xe	0.001	7	>10
^{238}U	<<0.001	0.1	6

Measured Estimated * -> no estimation

Thanks to the ion source GANIL and the NEWGAIN teams

Light ions (p, deutons, ^{4}He)

	I peak	Power already done	With SBS 1/100 (NFS)	Maximum power	Min/Max energy
Deutons	5 mA	10 kW	2 kW	200 kW	0.73 to 20 MeV/A
Proton	5 mA	16 kW	2 kW	165 kW	0.73 to 33 MeV/A
^{4}He	1 mA	10 kW		40 kW	0.73 to 20 MeV/A

Time structure	Min	Max
Duration of macro-pulse LBET Chopper	100 µs*	1 s
Frequency LBET Chopper	1 Hz	100 Hz - 1 kHz (Future)
Selection rate MEBT Single bunch selector	1/10000	1/100

*10 µs available but beam not stable due to space charge compensation time

NEWGAIN

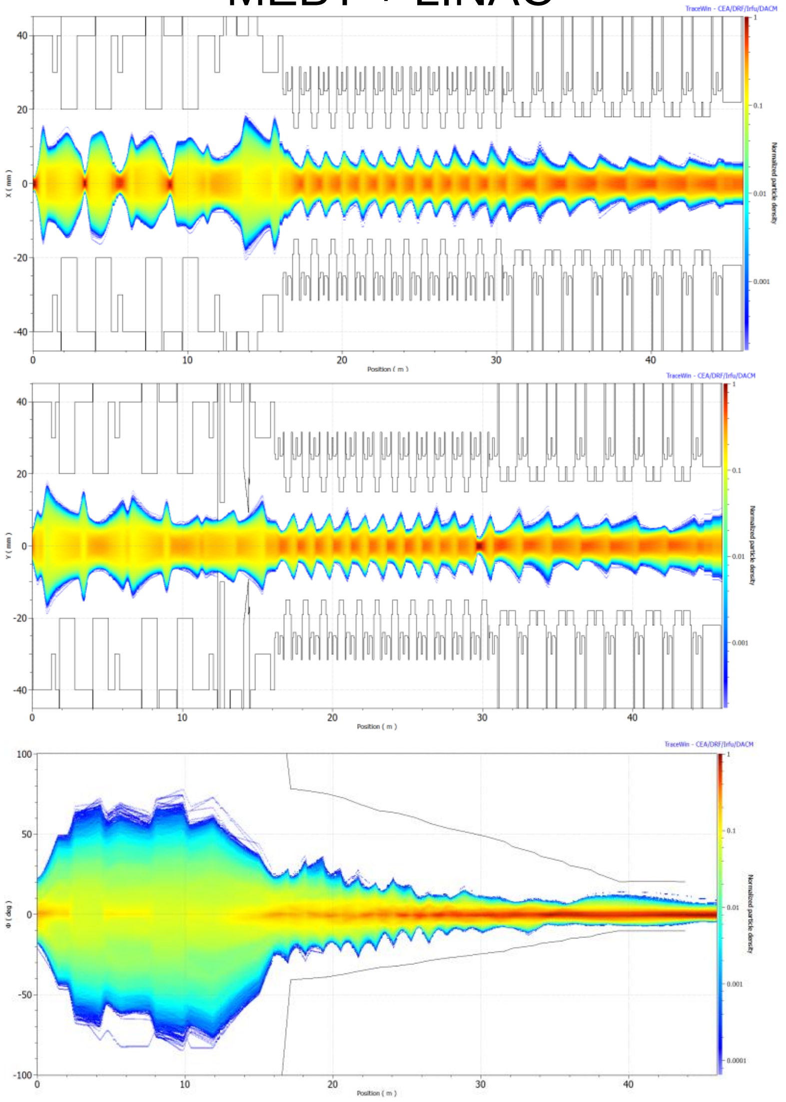
laboratoire commun CEA/DRF CNRS/IN2P3

MEBT + LINAC

x

y

Phi



$^{48}Ca^{11+}$

$^{238}U^{34+}$

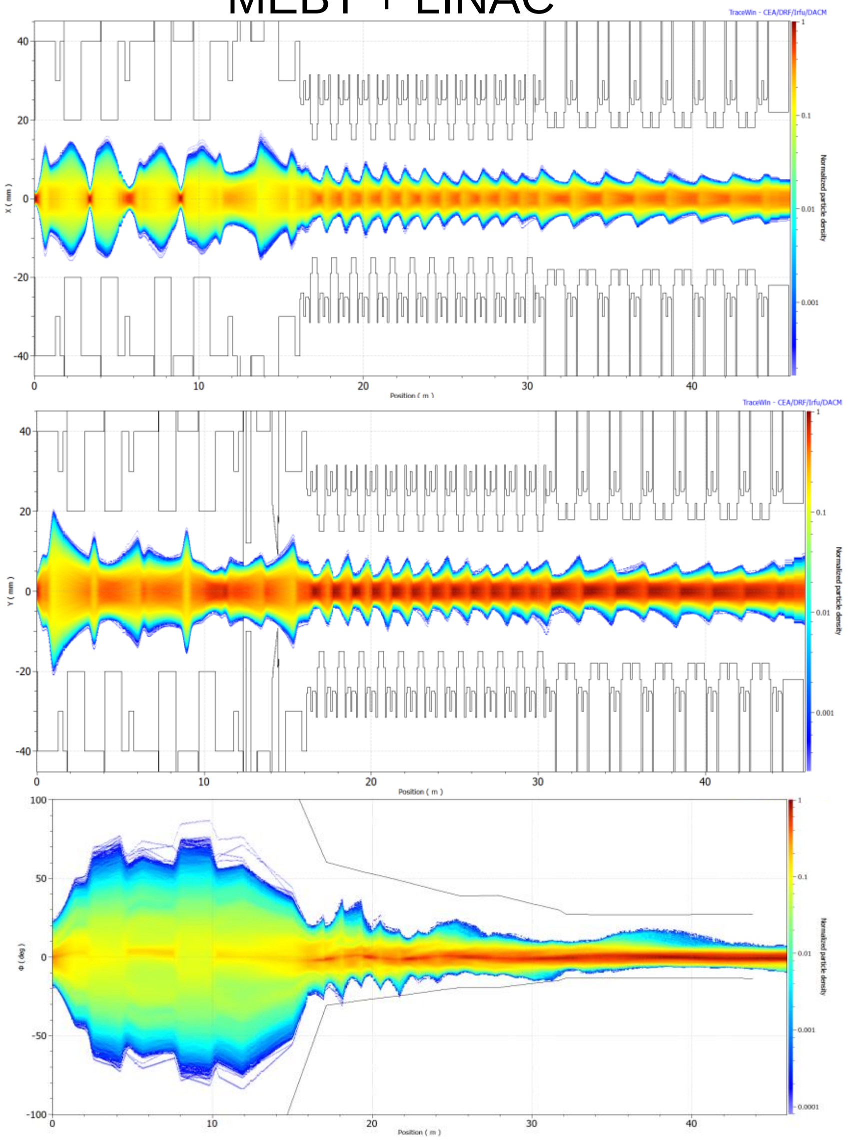
The construction phase has just started

MEBT + LINAC

x

y

Phi



(NEWGAIN beam dynamic team's simulations)

Thank you for your attention, see you in Spiral2