laboratoire commun CEA/DRF CNRS/IN2P3

M/Q = 2 to 3 linac beam tunings

1 – Previous results and methods with M/Q = 1 and 2

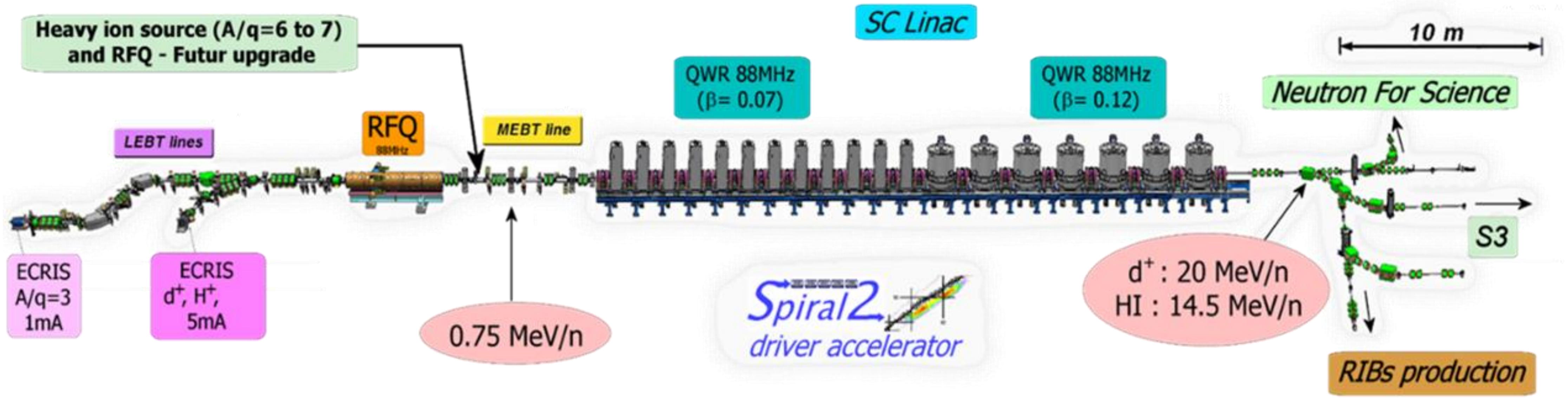
2 – Results of this year for heavy ions

3 – Next steps

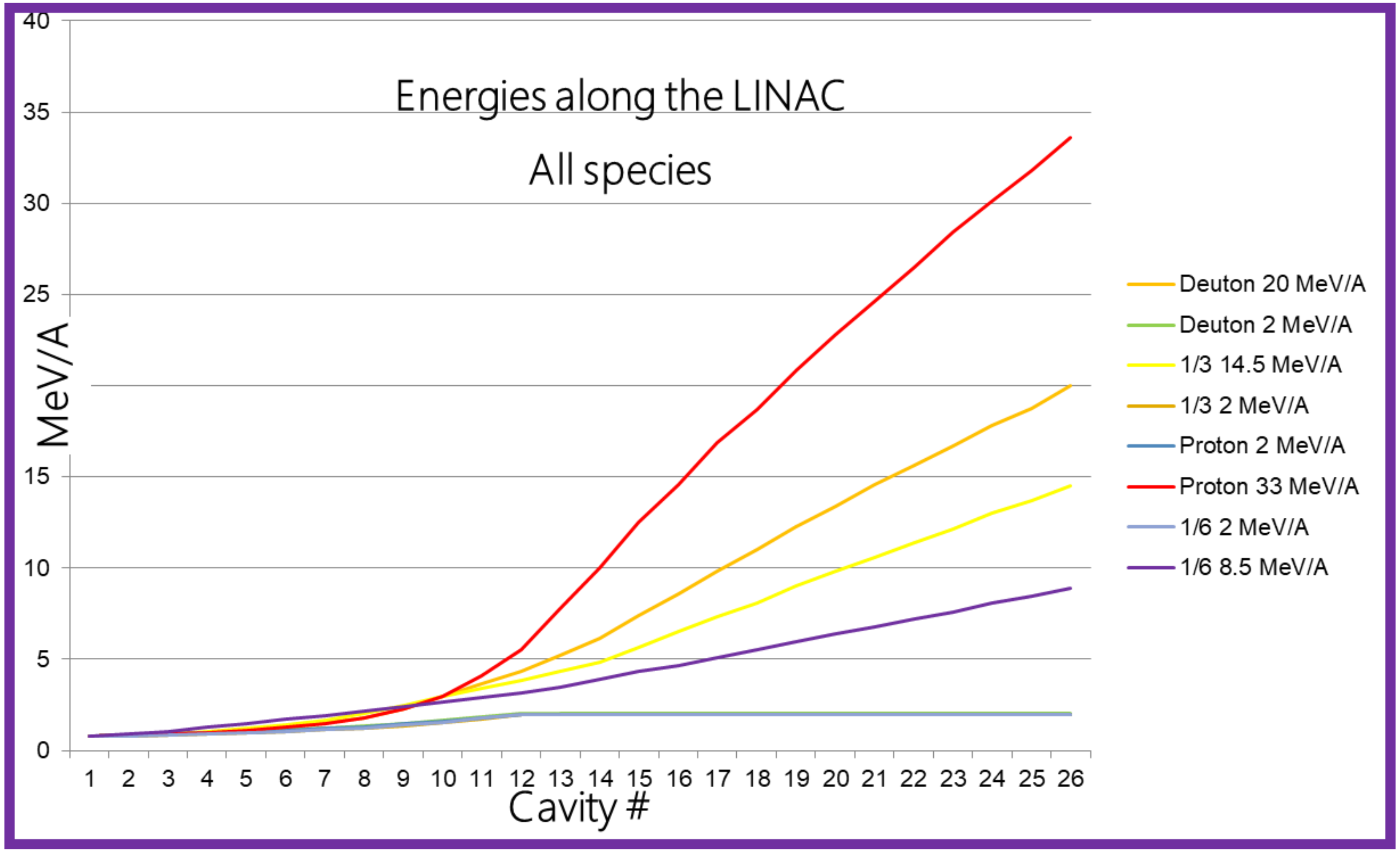
G. Normand GANIL

Lessons of previous results and methods
A/Q = 1 and 2

Spiral 2 scheme

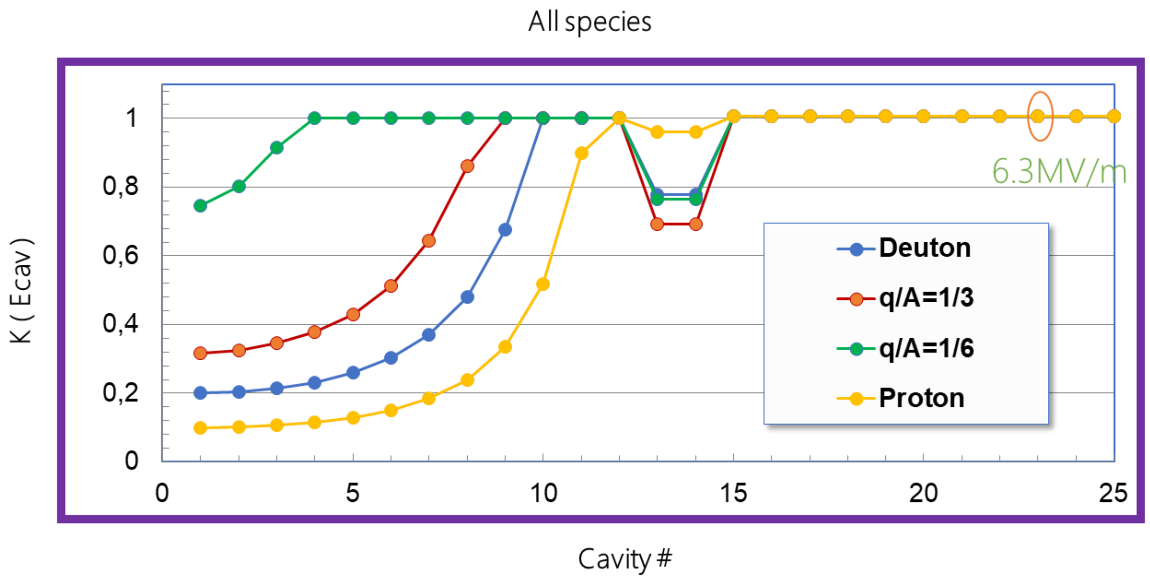


Energies

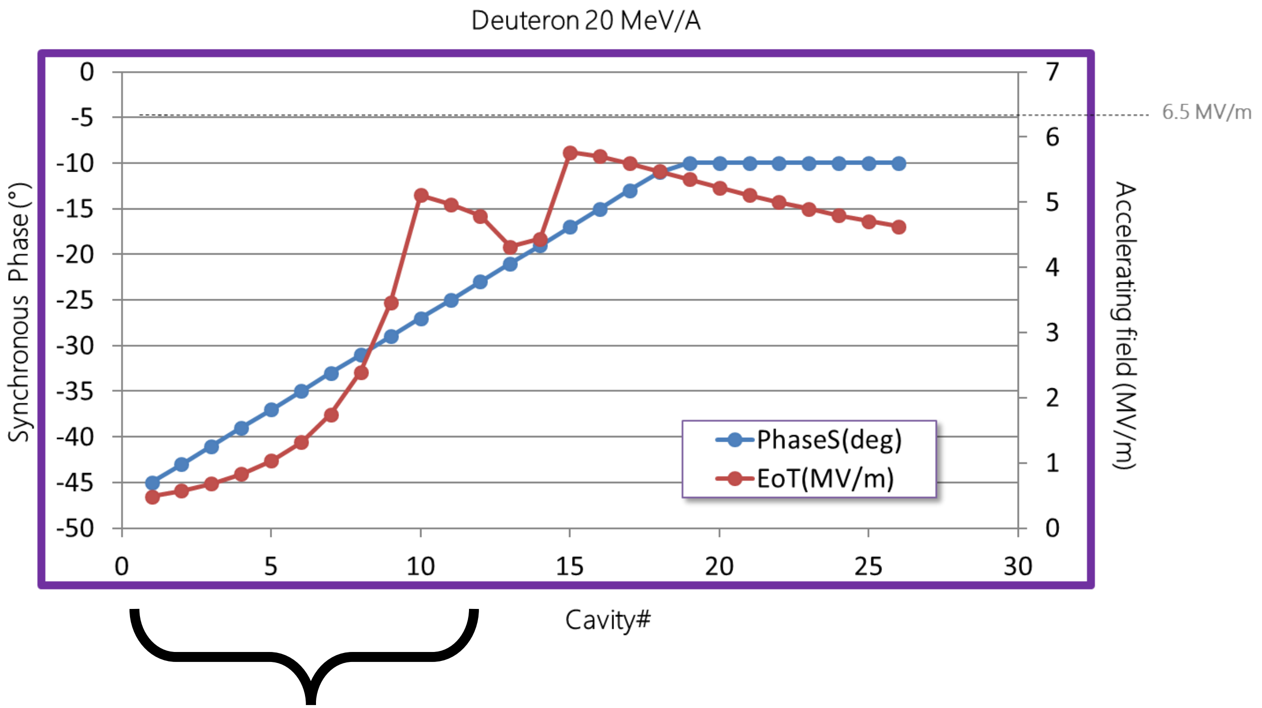


Energies along the LINAC
All species
MeV/A
Cavity #
0
5
10
15
25
30
35
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Deuton 20 MeV/A
Deuton 2 MeV/A
1/3 14.5 MeV/A
1/3 2 MeV/A
Proton 2 MeV/A
Proton 33 MeV/A
1/6 2 MeV/A
1/6 8.5 MeV/A

Cavities voltage vs species and acceleration scheme



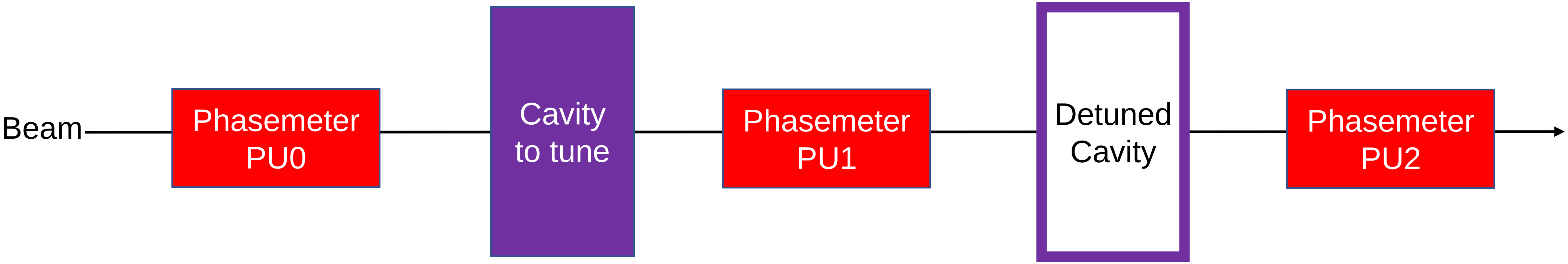
Electrical field used in each cavity for
different species and energies (k = normalized/max, max = 6.5 MV)



Low synchronous phase
to keep a good acceptance

How to tune the cavities (voltage, phase)

Several methods to face several situations



Method	PU0	Detune cav N	PU1	Detune cav N+1	PU2	Ucav tuning	360° scan	fine scan
Signature-matching		Y	Y	Y	Y	Y	Y	
Advanced	Y	Y	Y	Y	Y	Y	Y	Y
Simplified	Y	Y	Y			Y		Y
With-reference	Y		Y					
Zero-crossing *		Y	Y			Y	Y	Y

Rebunchers tuning → Zero-crossing *

Signature-matching, Advanced → 1 to 2 days to tune the linac

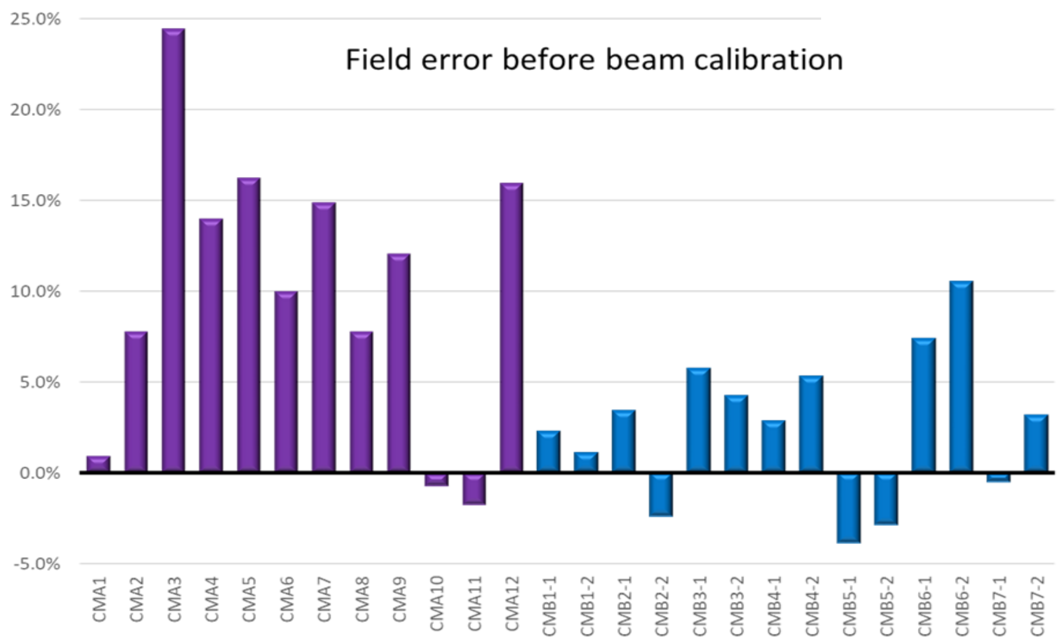
Simplified, With-reference → 1 to 2 hours to tune the linac

PU0, PU1, PU2 : Y when the PU is used,
PU0 : Y when the PU can be used to measure Win PU1 : Y the PU can be used to check the tuning
Detune cav : Y when the cavity must be detuned
Ucav tuning : Y when the method allows a cavity voltage tuning
* rebunchers only

… or simply recall previous parameters from an old tuning from data base if phase and voltage calibration have not been changed

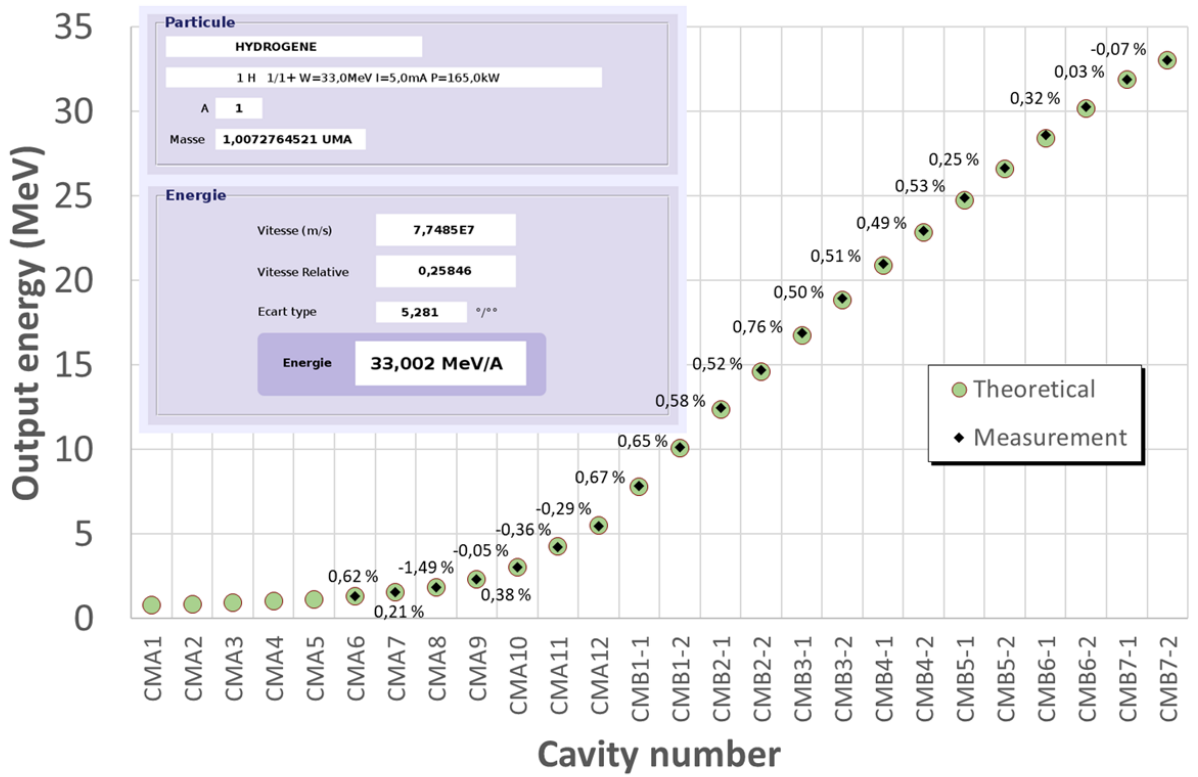
Cavities voltage calibration

Voltage calibration



This initial calibration with « advanced method » allows to use the fast method « with reference » now.

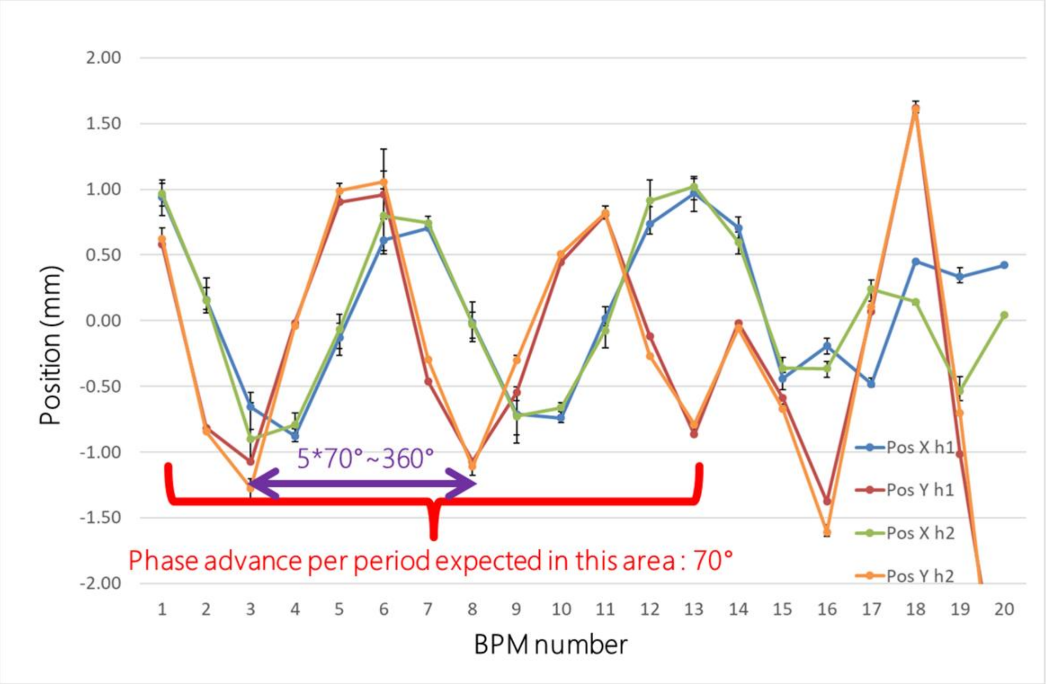
Proton 33 MeV tuning results



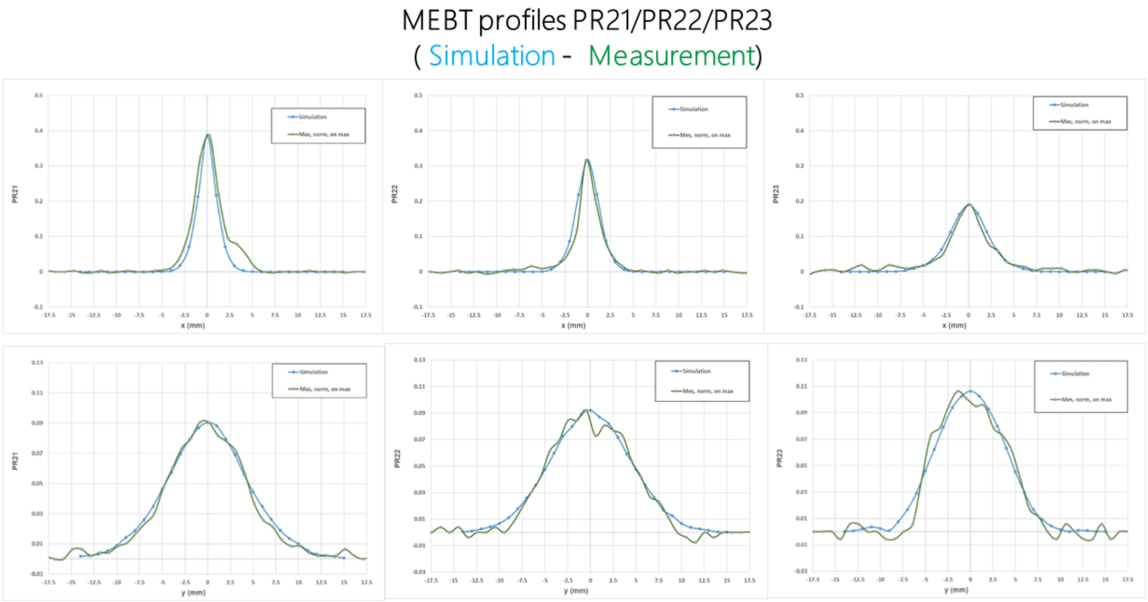
Simulation code allows a good prediction and understanding of the longitudinal beam behavior

Simulations vs reality, transverse plan

Transversal phase advance

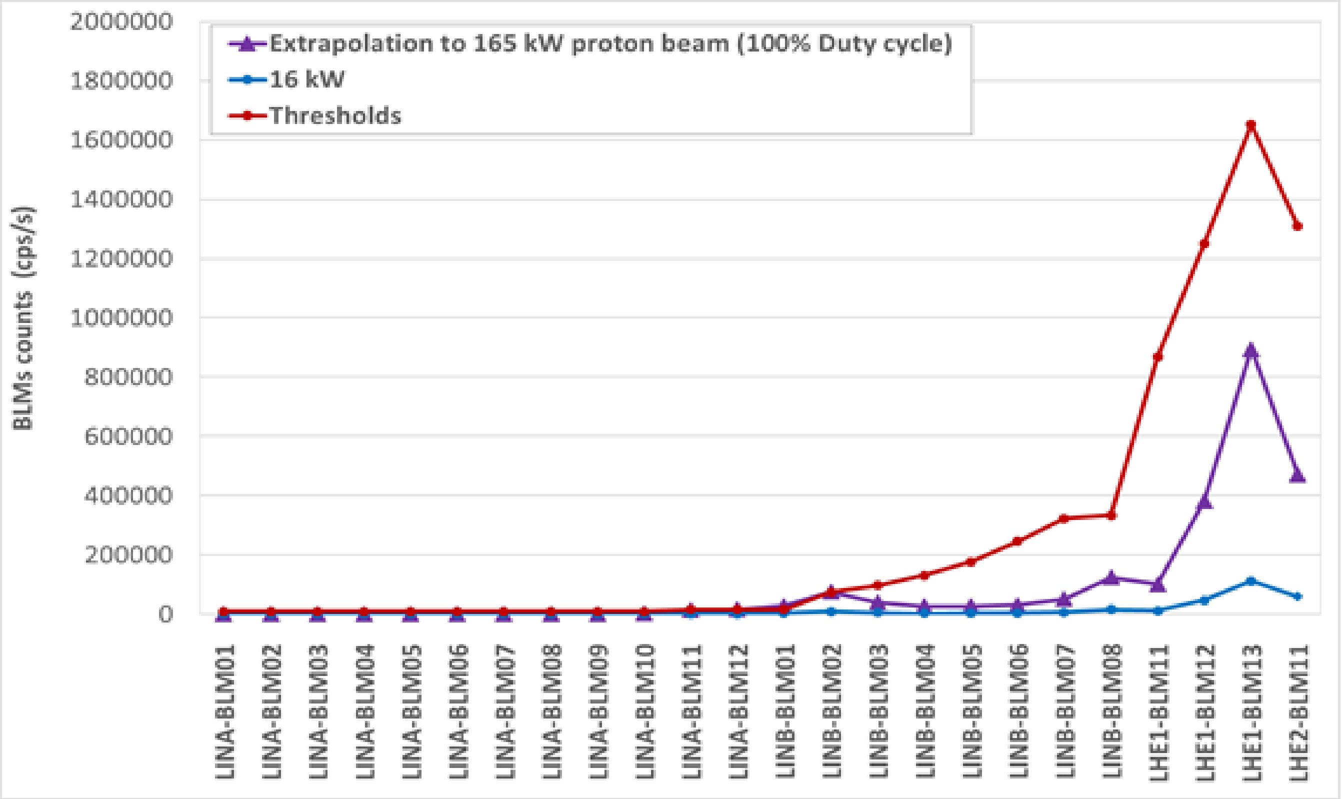


Profiles



→ Simulation code reproduce the measurements also in transversal plan

Loss issues, diagnostics tools



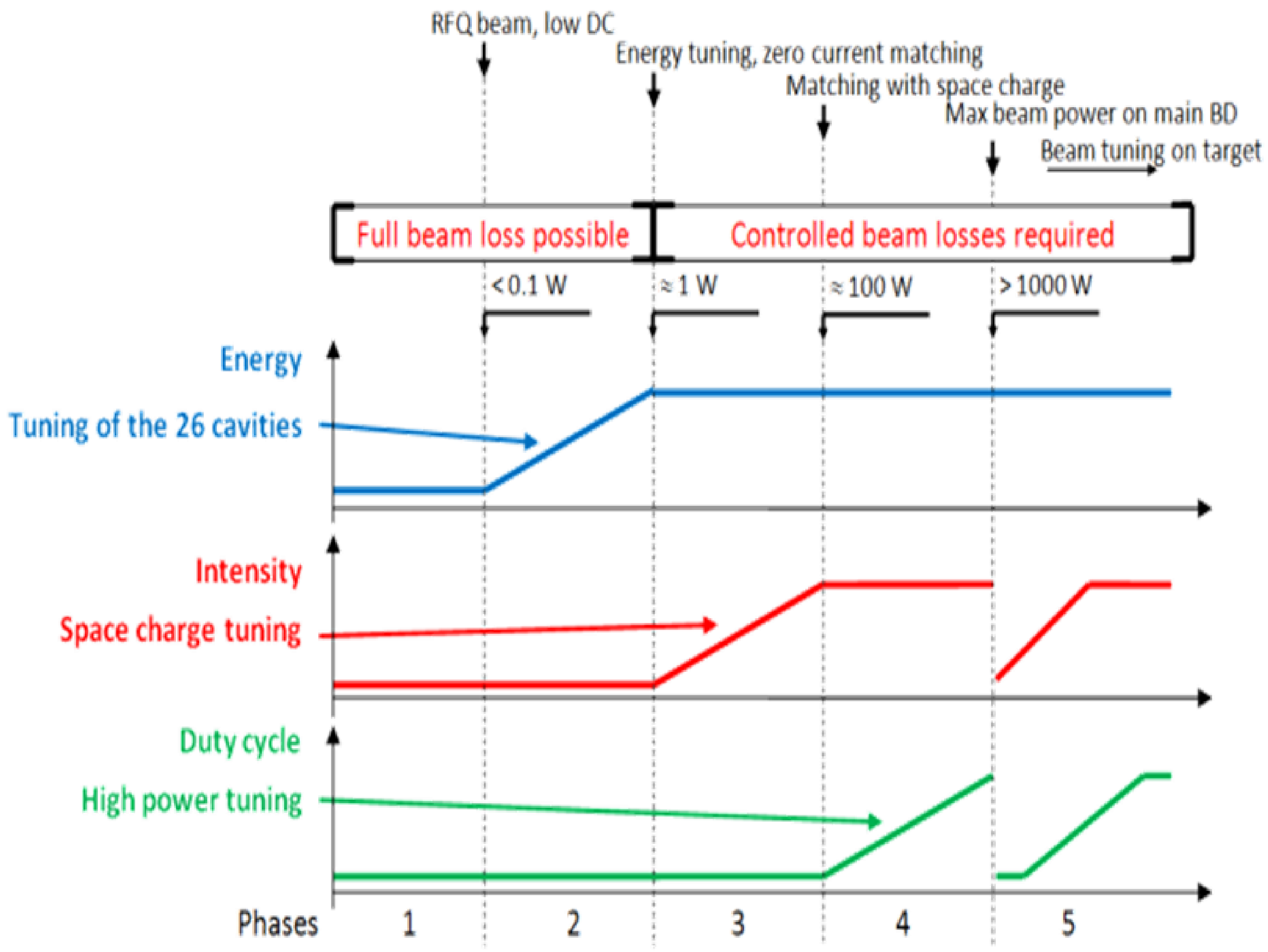
- Losses are under 1 W/m for 165 kW protons (extrapolated from 16 kW beam)

- For several kW of heavy ions at energy < 7 MeV/A, neutrons production will not be the difficult point (and then not a good tuning tool).

- Current transmission and vacuum evolution will be more relevant.

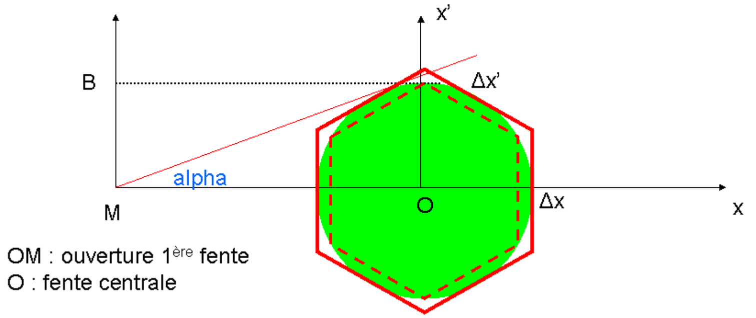
Neutrons backscattered from beam dump SAFARI

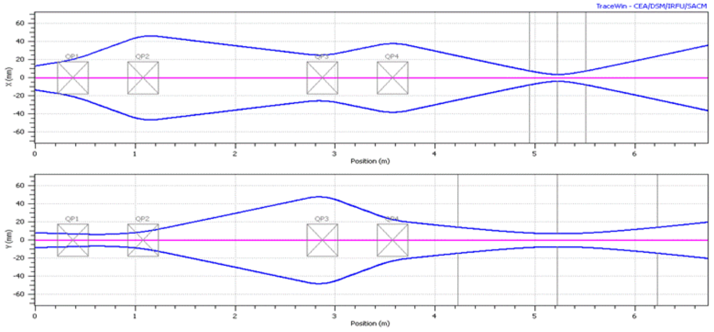
Tuning strategy for heavy ions



… the same that for light ions

Intensity and energy changes vs tuning strategy



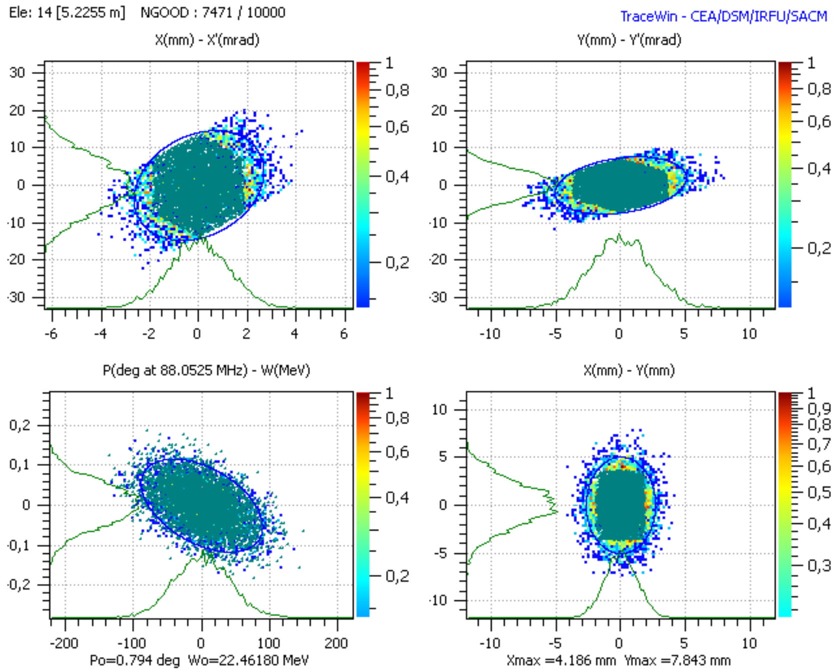


Intensity

3*2 slits in the LBET

-> emittance definition

- ~ Keeps the space charge
- Narrow beam.
- Very useful, but instable beam intensity if closed too much.



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 between 15' and 45' by now.

→ **Only one reference tuning is needed for nearly all of the I and E for A/Q = 3**

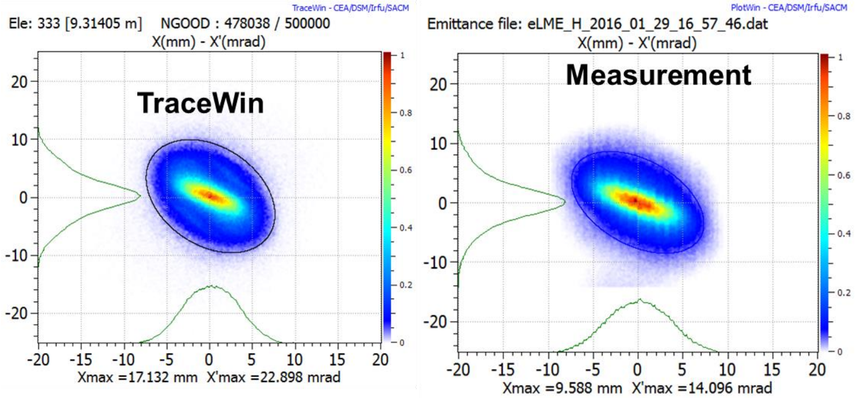
LINAC tuning, A/Q = 3

Spiral 2 RFQ for heavy ions

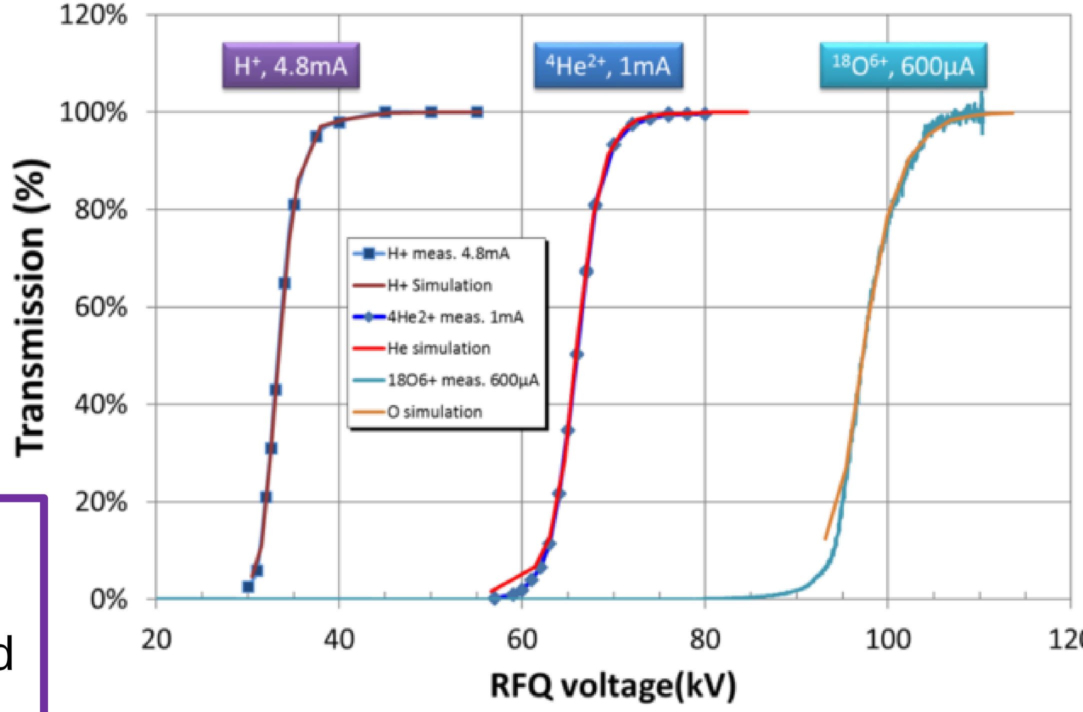
RFQ input energy : 20.1 keV/A

RFQ output energy : (mainly) imposed by the RFQ geometry

βout = 2 x (output RFQ cell length) / (rf wave length) = 0.03948 => **Wout = 732 keV/A for all ions**

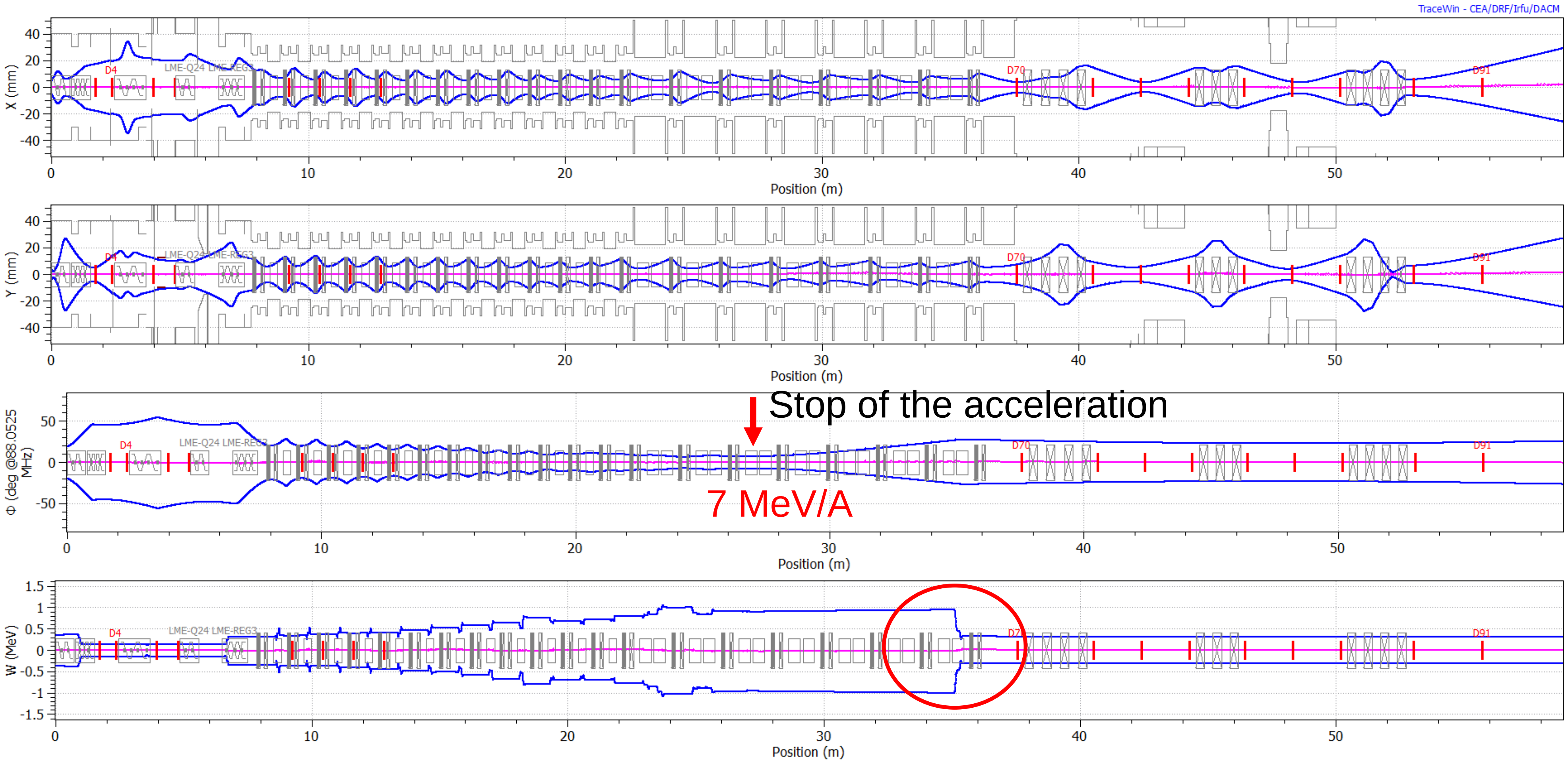


RFQ simulations vs measurement



- For M/Q = 3, RFQ voltage = 113.5 kV theorically, but due to technical problems, 105 kV have been used.
- The longitudinal emittance is similar in both voltage cases and the transmission is 93 % instead of 100 % (measurements of previous years)

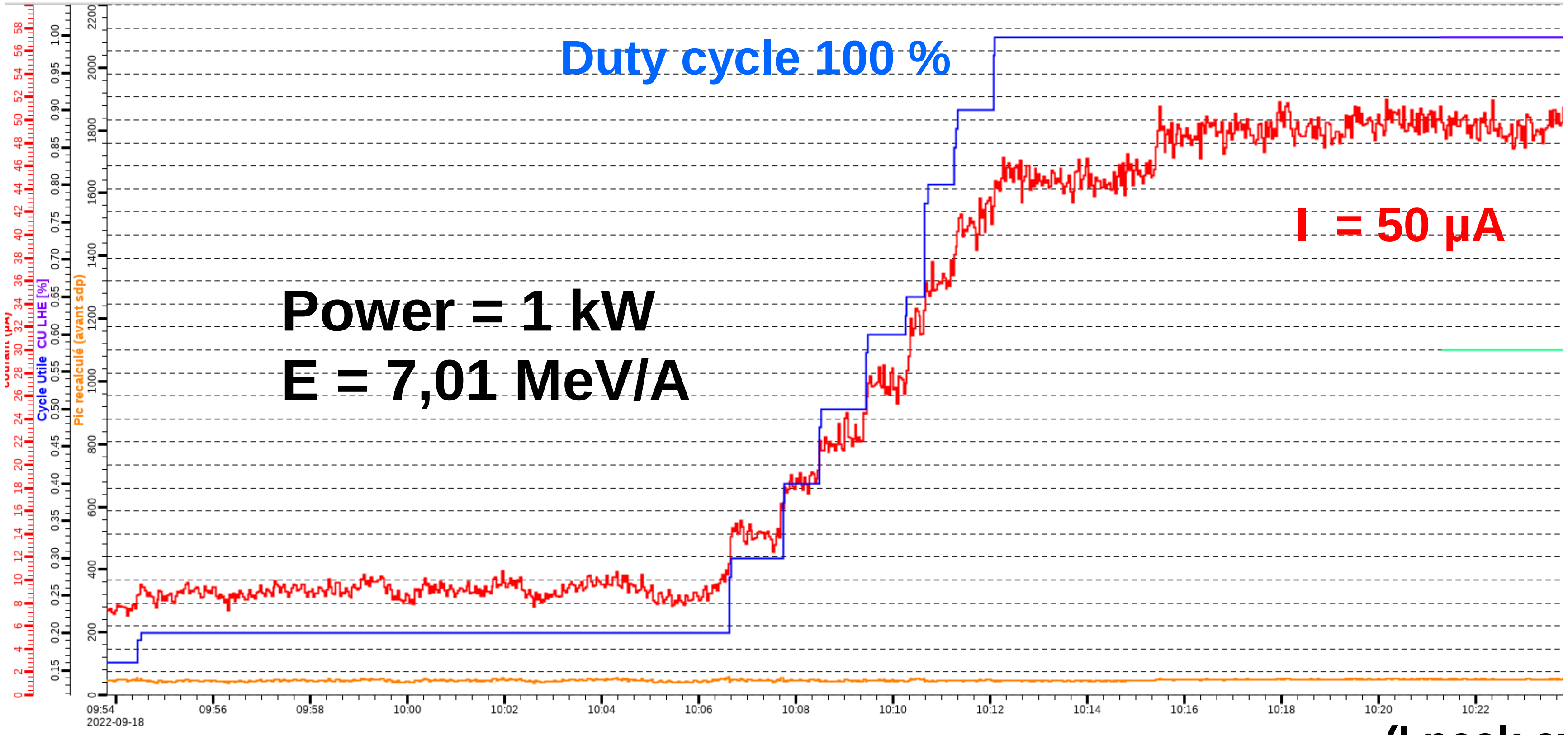
$^{18}O^{6+}$ simulation and strategy



ΔE/E = 0.1 MeV rms / 126 MeV = 0.08 %

$^{18}O^{6+}$ results of 2022, power ramp up

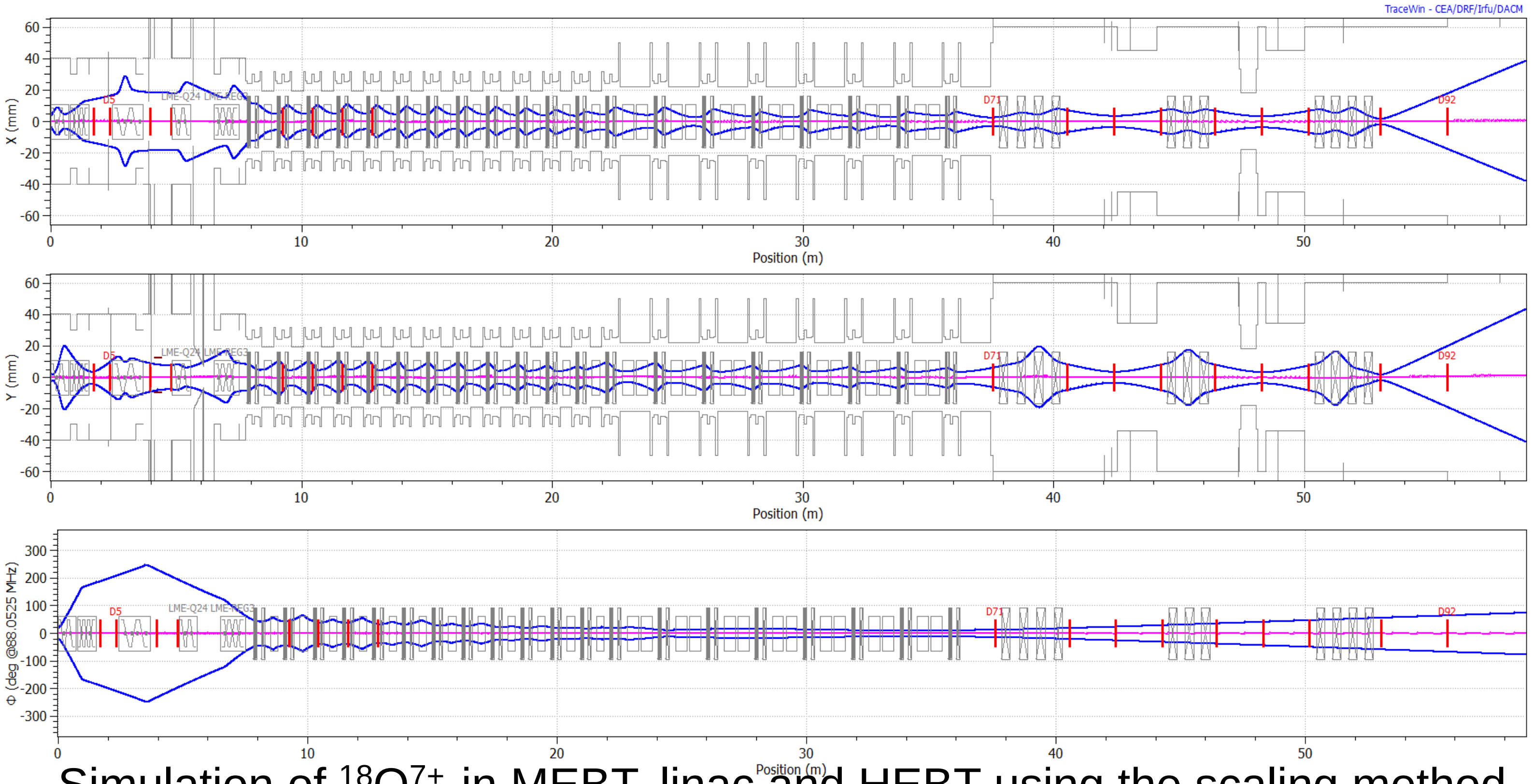
Objectives :
- 7 MeV/A (more than energy asked by nuclear physicists for the moment),
- 50 µA continuous beam (1 kW).
- No obvious difficulties to go beyond these energy and intensity, but must be tested.



(I peak available ~700 µA)

$^{18}O^{7+}$ tuning from $^{18}O^{6+}$ tuning

- Objective : be able to tune the accelerator even for species with very low intensities not seen by some diagnostics (< 10 µA).
- Why from O to O in the first test ? Because both charge state are clearly visible for diagnostics (> 70 µA).



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

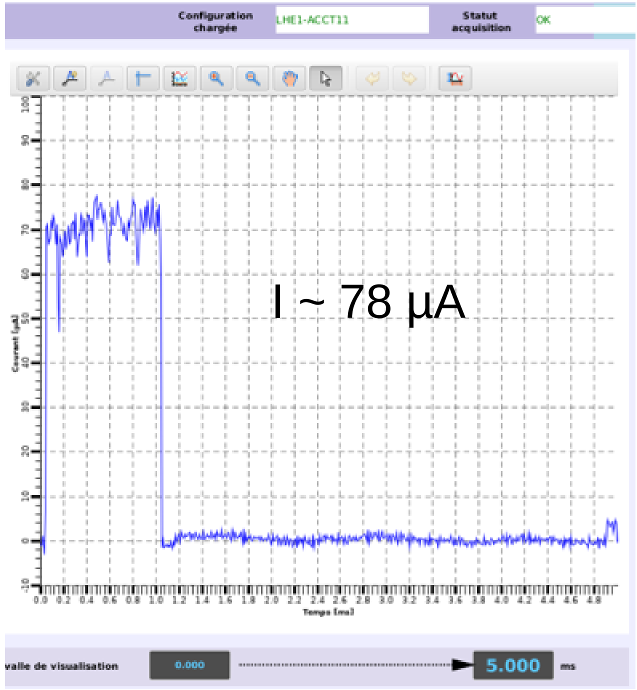
From $^{18}O^{6+}$ to 7+ :
“42 the answer to almost everything” ?
… not in our case :

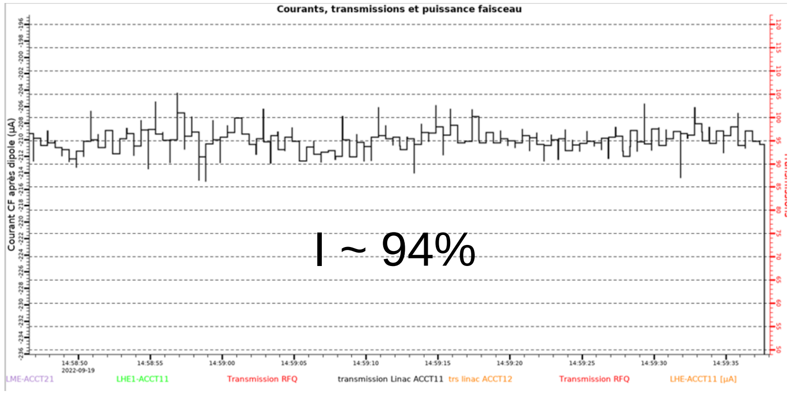
(A1/Q1) / (A2/Q2) = 0,86

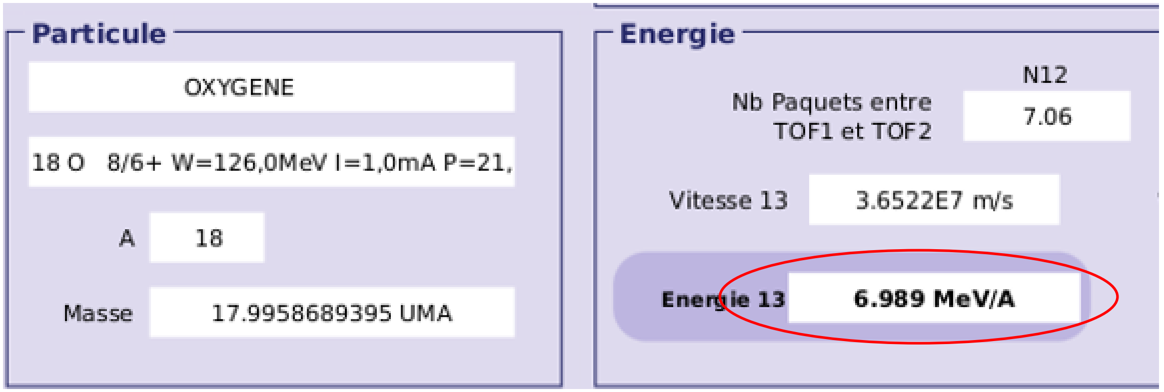
Method : multiply all magnetic and electric fields from source voltage until the last quadrupole before the target by this factor.

$^{18}O^{7+}$ Results of 2022

- Measurement after the global multiplication : 35 µA at the end of the linac, ~80 µA were expected.
- But 98 % transmission into the linac (where we are blind).
- After some optimizations only into the LBET (with profiles and faraday cup) + RFQ at nominal voltage : I = 78 µA (0,7 pi mm mrad) at the end of the accelerator (~ 94 % transmission through the linac).
- The energy given by the TOF is still 6,99 MeV/A.

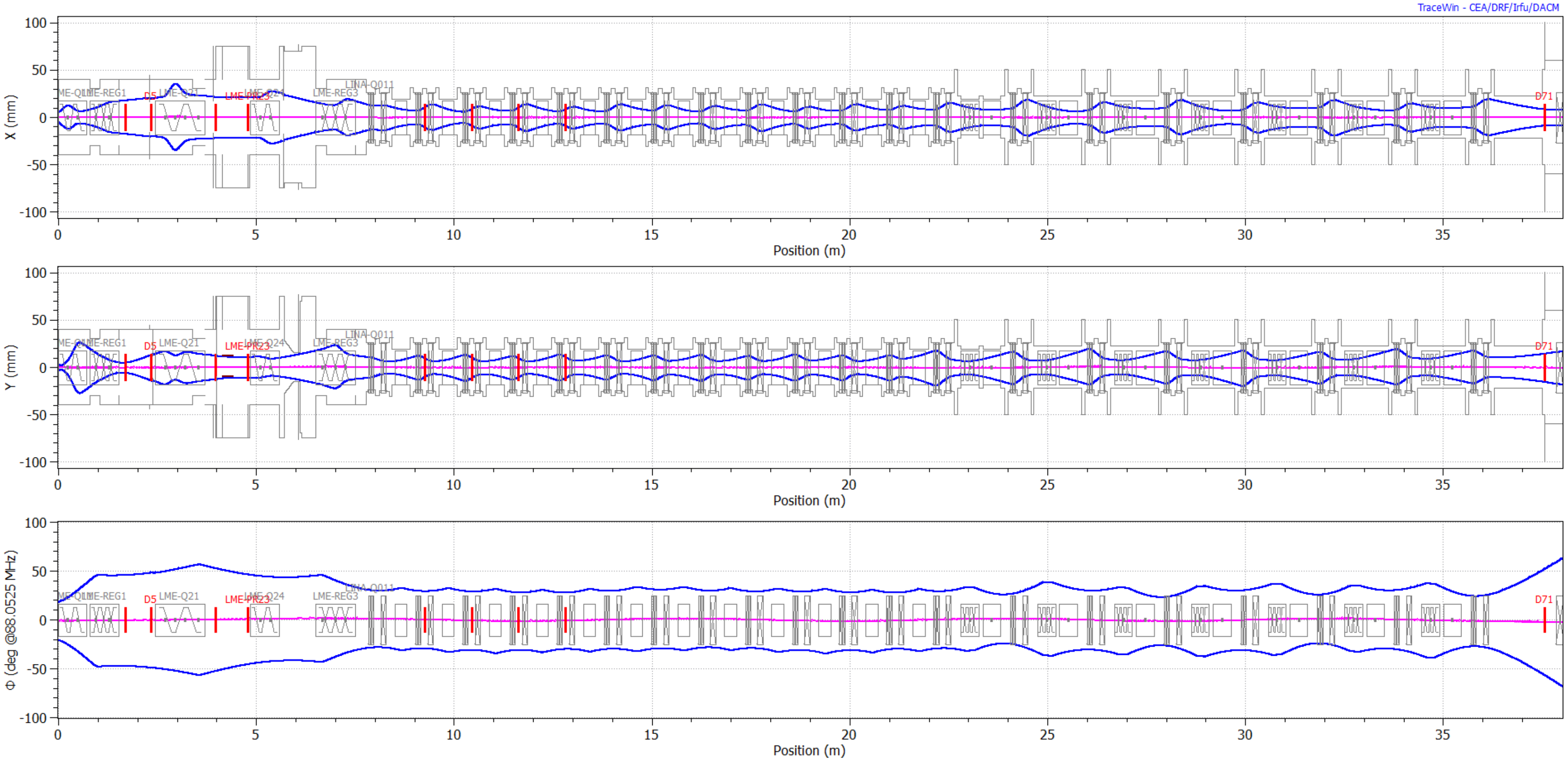






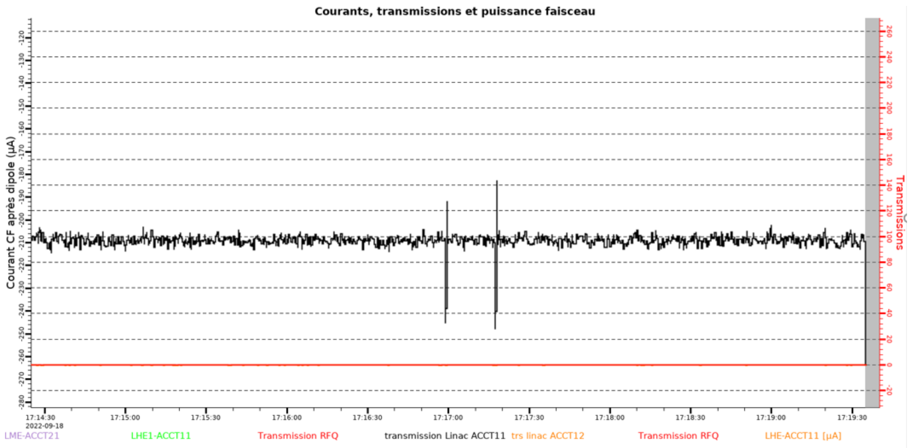
Linac tuning without acceleration for $^{18}O^{6+}$

Beam requested to tune the spectrometer.

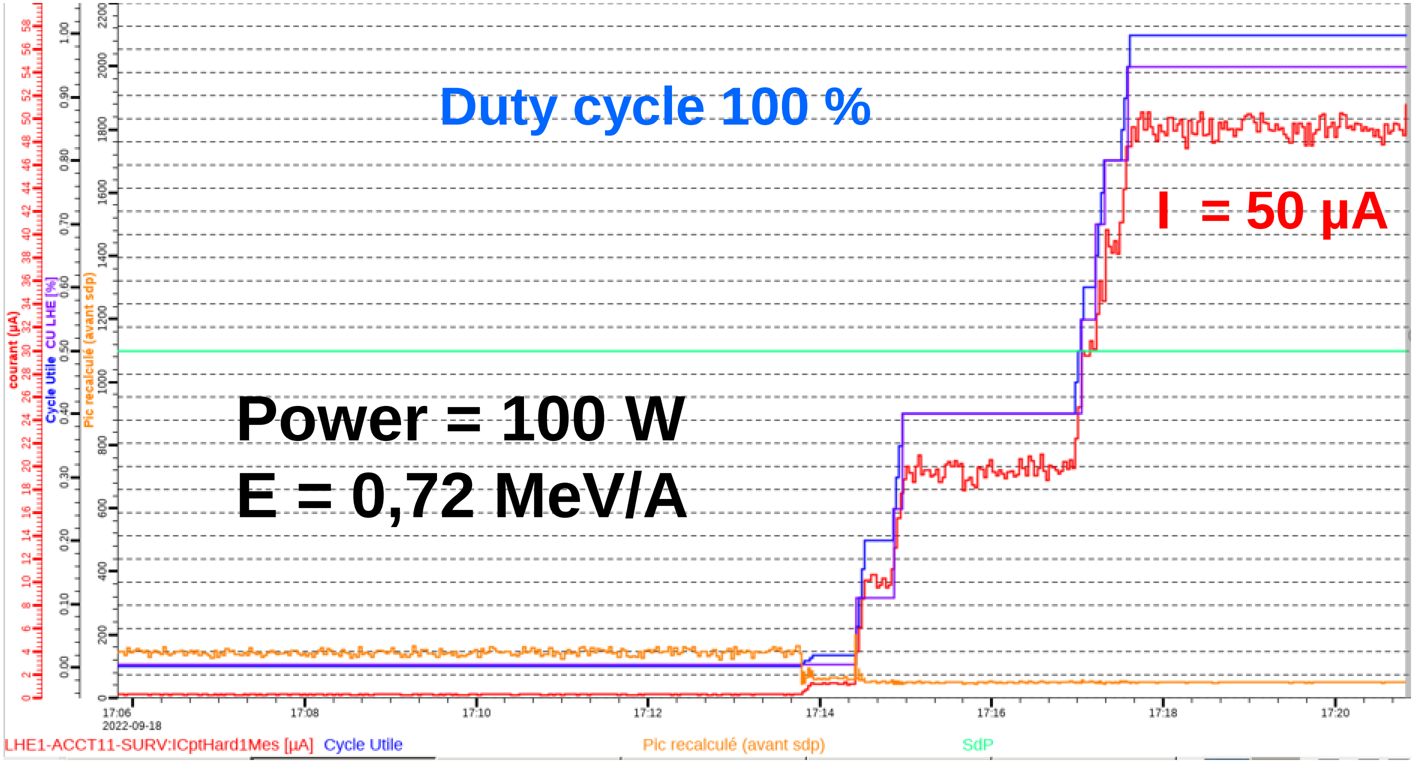


Rebunchers mode for all A cavities and 1 over 2 of the B ones.

Linac tuning without acceleration for $^{18}O^{6+}$, 2022



Transmission through the linac : 99 %



No specific difficulties ($\Delta E/E$ ~ 0,5 %)

Next steps

Outlook

Tests before the end of this year :

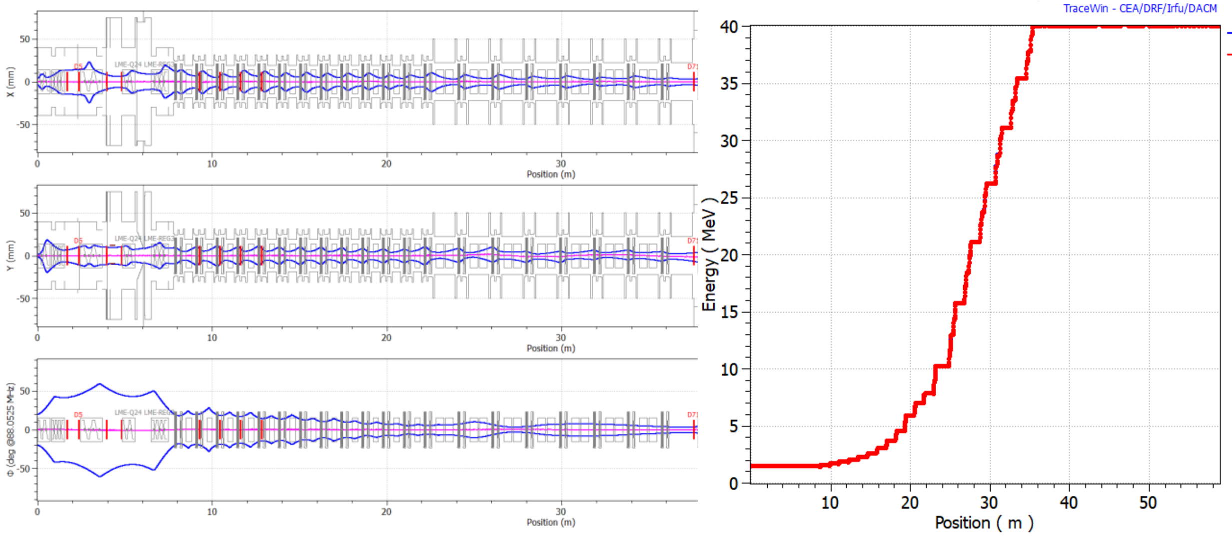
- From $^{18}O^{6+}$ to $^{40}Ar^{14+}$
- More O tuning studies
- Cavity out of order firsts cases studies

Next year :

- Continue to developpe simulations, methods and applications to tune faster.
- Improve tunings and knowledge of the beams
- Design and build pepper pots to reduce intensity easily (1/100 to 1/1000000).
- Cavity out of order cases studies
- Prepare the spectrometer tuning
- …

Linac tuning with missing cavity

Deuton, CMB1 cav 2 out of order



… more complex for first cavities

A possible summary

We have worked to be able to

- Accelerate ~ 0 mA beams at exacly 7 MeV/A (or less)…
- Give 0 energy to a beam with the linac…

… to allow the study of heavy ions that do not exist !

(…yet) 

Thank you for your attention