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

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

Heavy ion source (A/q=6 to 7) and RFQ - Futur upgrade

0.75 MeV/n

QWR 88MHz ($\beta = 0.07$)

QWR 88MHz ($\beta = 0.12$)

SC Linac

Neutron For Science

S3

RIBs production

d$^+ : 20$ MeV/n

HI : 14.5 MeV/n

ECRIS $A/q=3$

1mA

ECRIS $d^+, H^+$, 5mA

LEBT lines

RFQ

MEBT line

10 m

20/10/2022

Caen
Energies along the LINAC

All species

- 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

MeV/A

Cavity #
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

- Signature-matching
- Advanced
- Simplified
- With-reference
- Zero-crossing *

Rebunchers tuning

Beam → Phasemeter PU0 → Cavity to tune → Phasemeter PU1 → Detuned Cavity → Phasemeter PU2

1 to 2 days to tune the linac
1 to 2 hours to tune the linac

… or simply recall previous parameters from an old tuning from data base if phase and voltage calibration have not been changed
This initial calibration with « advanced method » allows to use the fast method « with reference » now.

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

\[ \beta_{\text{out}} = 2 \times \frac{\text{output RFQ cell length}}{\text{rf wave length}} = 0.03948 \Rightarrow W_{\text{out}} = 732 \text{ keV/A for all ions} \]

- For M/Q = 3, RFQ voltage = 113.5 kV theoretically, 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

$\Delta E/E = 0.1 \text{ MeV rms} / 126 \text{ MeV} = 0.08 \%$

Stop of the acceleration

7 MeV/A
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.
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).

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

\[
\frac{(A1/Q1)}{(A2/Q2)} = 0.86
\]

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

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

\[ I \sim 78 \mu A \]

\[ I \sim 94\% \]
Linac tuning without acceleration for $^{18}\text{O}^{6+}$

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 $^{18}\text{O}^6+$, 2022

Transmission through the linac: 99%

Duty cycle 100%

$I = 50 \mu$A

Power = 100 W

$E = 0.72$ MeV/A

No specific difficulties ($\Delta E/E \sim 0.5\%$)
Next steps

A/Q = 2 to 3 linac beam tunings
Outlook

Tests before the end of this year:
- From $^{18}\text{O}^{6+}$ to $^{40}\text{Ar}^{14+}$
- More O tuning studies
- Cavity out of order firsts cases studies

Next year:
- Continue to develop 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 exactly 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