ENERGY AND LONGITUDINAL BUNCH MEASUREMENTS AT THE SPIRAL2 RFQ EXIT

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International Beam Instrumentation Conference IBIC 11 - 15 September 2016 Barcelona

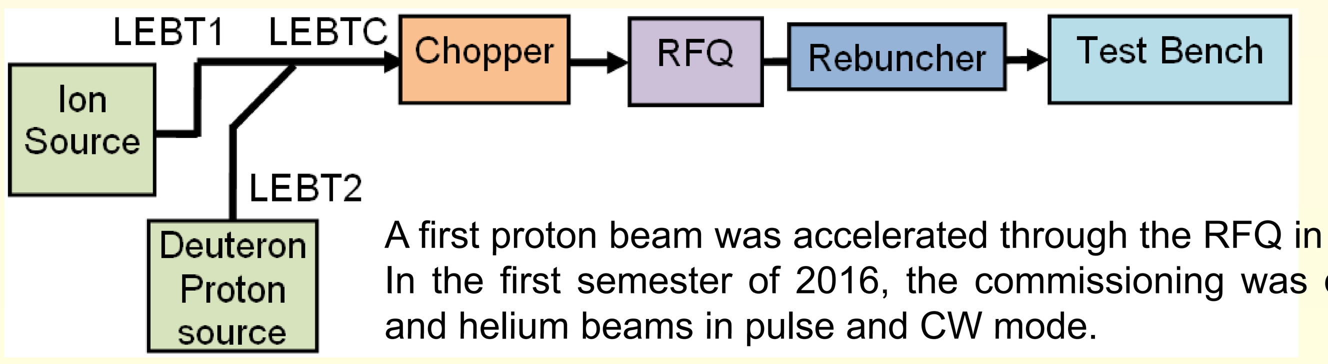
A new step of the SPIRAL2 commissioning started in December 2015 with the acceleration of a first proton beam at the RFQ exit. A test bench, with all the different diagnostics which will be used on the SPIRAL2 accelerator, was installed directly after the first rebuncher of the MEBT line in order to qualify beams but also to test and make reliable the diagnostic monitors.

In 2016, different ion beams are qualified by the diagnostic test bench. This paper describes the results of the energy measurements done by a Time of Flight monitor and the longitudinal measurements using a fast faraday cup.

INTRODUCTION

The SPIRAL2 driver is designed to accelerate and deliver proton beams, deuteron and ion beams with q/A=1/3 to NFS (Neutron for Science) and S3 (Super Separator Spectrometer) experimental rooms.

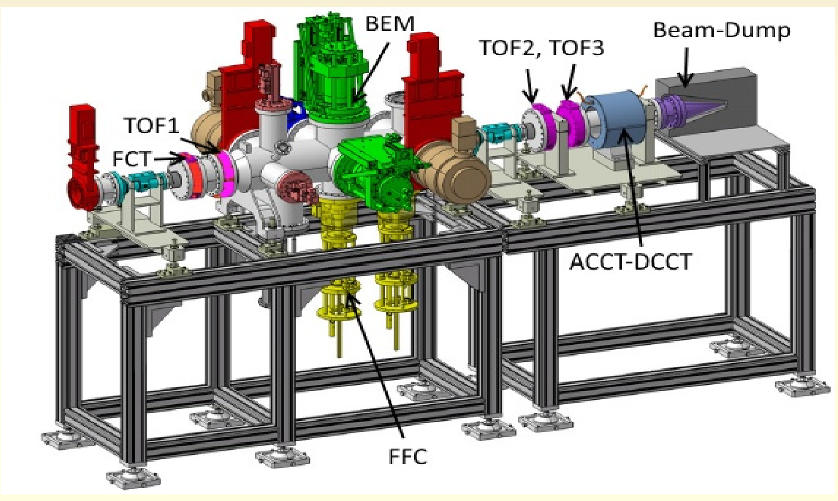
Currently, an Intermediate Test Bench is installed in the MEBT line. The commissioning is in progress in the accelerator part composed by 2 sources (a proton/deuteron source and an ion source with a q/A=1/3), the LEBT lines, a chopper, a RFQ, a rebuncher.



A first proton beam was accelerated through the RFQ in December 2015. In the first semester of 2016, the commissioning was done with proton and helium beams in pulse and CW mode.

INTERMEDIATE TEST BENCH

The "Intermediate Test Bench" or "Diagnostic Plate" was built to test all the different diagnostics:



- Intensity with ACCT, DCCT and FC
- Transverse Profiles
- Transverse emittance
- Phases and Energy with the Time of Flight (TOF) monitor
- Longitudinal profile with a Fast Faraday Cup (FFC) and a Beam Extension Monitor (BEM)
- Beam Position, Phase and Ellipticity with 2 Beam Position Monitors (BPM)

BEAM ENERGY PRINCIPLE

The beam energy is measured by using 3 electrodes pick-up. The energy is calculated, by a Time of flight method, from the electrode phases and the distances between each electrode.
A dedicated electronic measures, by an I/Q demodulation method, the In-phase component I(t) and the Quadrature component Q(t) of the first harmonic.
An EPICS Interface, connected to the TOF electronic device by a Modbus-TCP link , calculates the phases and the amplitudes from these components following by the energy calculation.

BEAM ENERGY MEASUREMENTS

Beam and TOF Features

The beam features were the following :

- Proton Intensity: from few 10µA to 5mA
- Helium $^4He^{2+}$ Intensity: few 10 µA to 1 mA
- Slow Chopper duty cycle: From 1/10000 to 1/1
- Chopper Frequency: 1Hz to 5 Hz

Features	Values
Frequency (MHz)	88.052 5
Period (ns)	11.36
Energy E (MeV/A)	0.75
Velocity β=v/c	0.04
Length between 2 bunches Lacc (cm)	13.6
Length between TOF1-TOF2 (m)	1.616
Length between TOF2-TOF (cm)	13
Bunch number between TOF1-TOF3	12
Electrode diameter (mm)	80

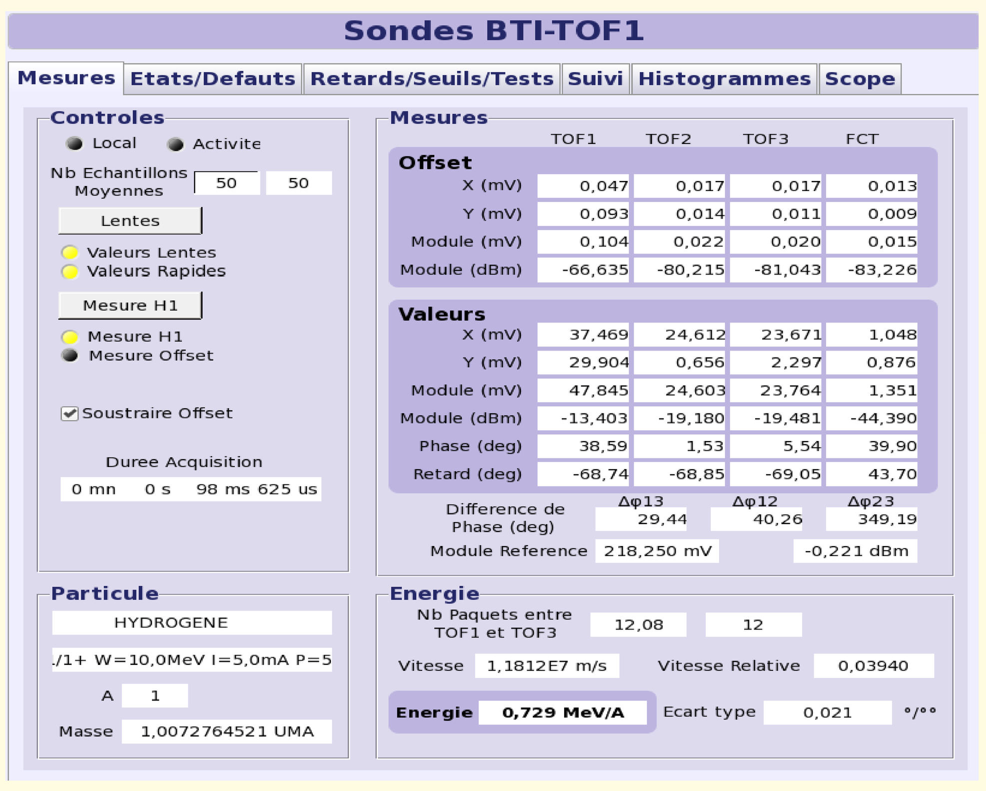
Proton energy measurements

The beam energy is firstly measured with the RFQ "on" and the rebuncher "off" with different beam intensities. VRFQ = 50 kV, I beam crest = 3.9 mA

The table "Valeurs" in the page "Mesures" of the graphical Interface indicates:

- The X and Y signal components
- The calculated modules and phases
- The bunch number

In the "Energie" frame
- The energy between TOF1 and TOF3
- The energy standard deviation



Helium energy measurements

VRFQ = 80 kV, I crest = 1.1 mA,
The energy is also calculated between each electrode. The 3 values are very similar.

Energy (keV)	Rebuncher off	Rebuncher on V = 75 kV, φ = -67,9°
E 12 (TOF1-TOF2)	727.95	727.28
E 13 (TOF1-TOF3)	727.96	727.28
E 23 (TOF2-TOF3)	728.07	727.30

Optimization and improvements

When the rebuncher is started and when its phase is shifted, the beam is accelerated or decelerated in function of the phase. The bunch numbers between TOF1/TOF2 and TOF1/TOF3 change. The solution consists to choose E12 or E13 in function of N12 and N13. The bunch number that is farthest from the value change is chosen with its corresponding energy.

LONGITUDINAL BUNCH MEASUREMENTS

A Fast Faraday Cup (FFC) will be positioned at the end of the MEBT to visualize, characterize the bunch lengths and will be used to tune the 3 rebunchers of the MEBT.

Beam Features

The different beam features useful for the FFC are in the following table :

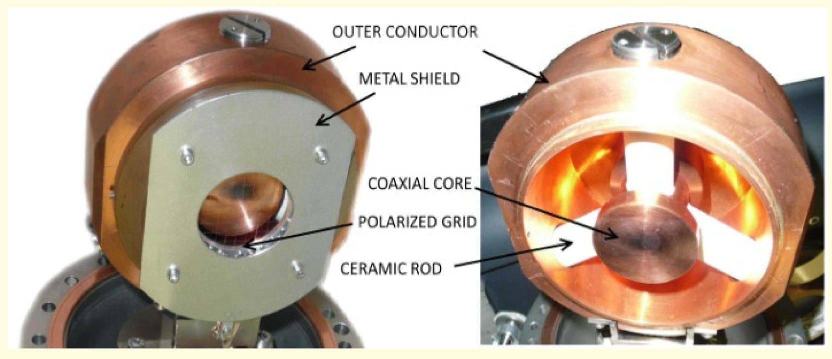
Features	Values
Maximum Intensity (mA)	5
Maximum power (deuterons) (kW)	7,5
σφ rms min	7°
σt rms min	220 ps

Diagnostic description

The FFC is a coaxial Faraday Cup with a water-cooled on the outer conductor. The inner conductor (central part) is cooled by conduction via tree ceramic rods. A polarized grid is used to shield the cup against the bunch advanced field and to suppress the secondary electrons effects.

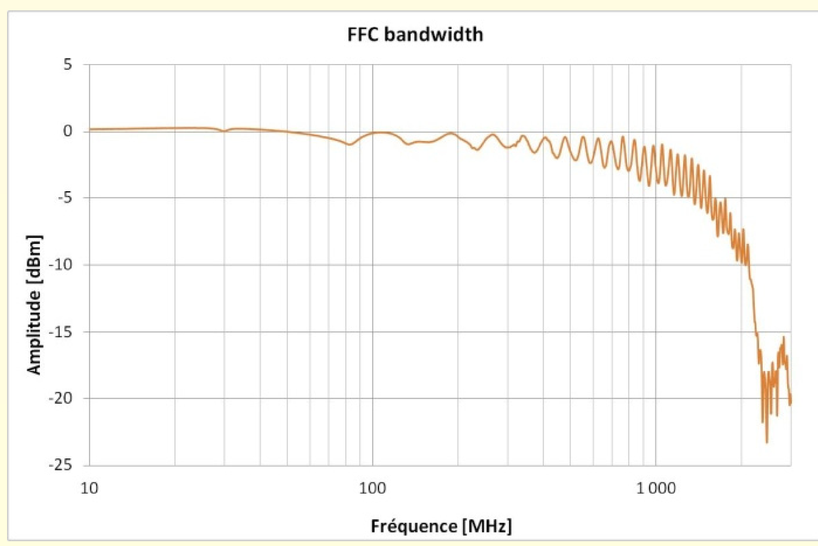
The central part diameter is 45 mm.
Thermal calculations give the following limits:
The central part limitation:
- 400 W in continuous beam
- 10ms/200ms with a pulse power of 7.5 kW

The grid limitation:
- 1ms/200ms with a pulse power of 7.5 kW



FFC bandwidth

The FFC bandwidth is measured with a Vector Network Analyzer, Agilent 8753 ES by reflection.
The FFC bandwidth at -10 dBm is 2 GHz.

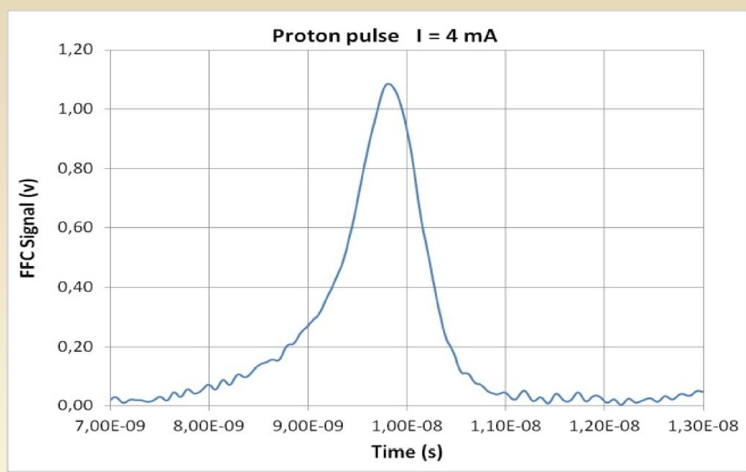


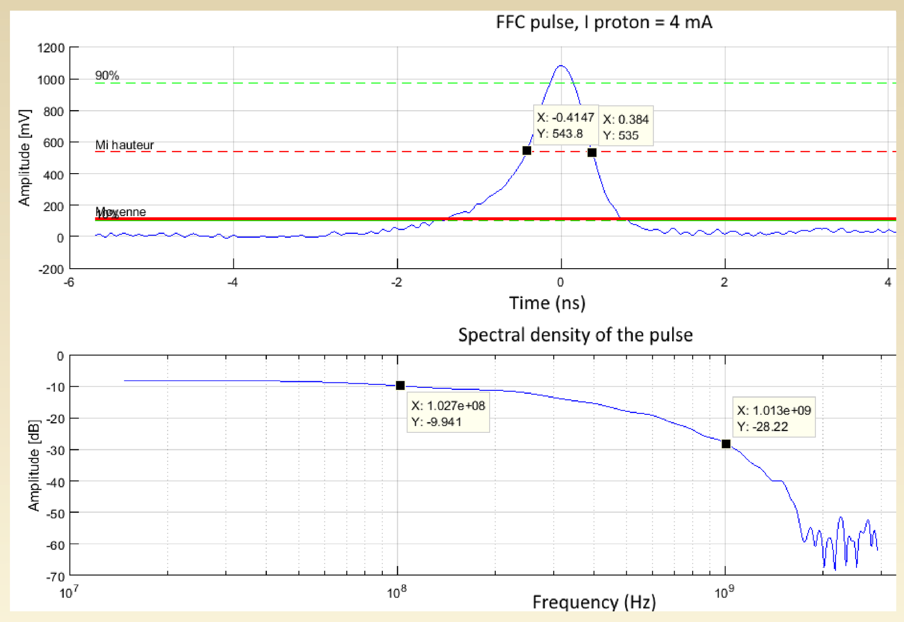
Acquisition system

An oscilloscope Agilent DSO9404A with 4 analog channels and bandwidths of 4GHz digitalizes the pulse FFC signal. This oscilloscope was chosen also for these EPICS drivers.

Proton bunch measurements

VRFQ = 50 kV, Vrebuncher = 45 kV,
I beam = 4 mA





FWHM: 800 ps, σt calculated from the pulse = 328 ps, σt simulated with tracewin = 220 ps

The spectral density is determined from the pulse signal by a matlab program.

Helium bunch measurements

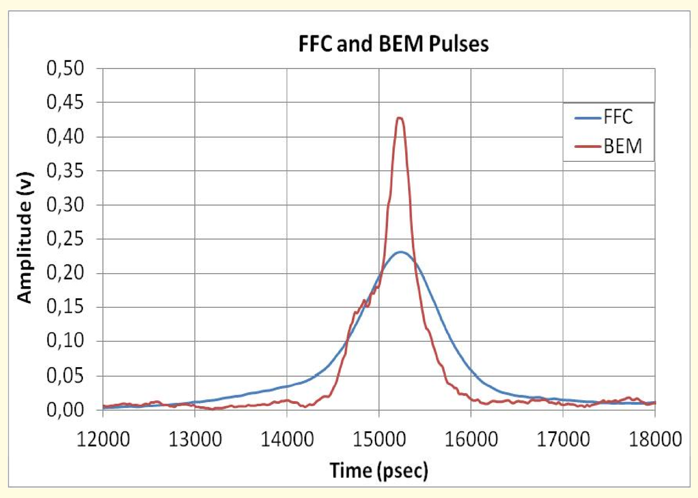
VRFQ = 80 kV, I beam = 1,1 mA
The bunch length is optimized at 75 kV and the pulse time values at this voltage are:
FWHM: 1,05 ns, σt calculated from the pulse = 443 ps, σt simulated with tracewin = 280 ps

BEM and FFC comparison

A Bunch Extension Monitor (BEM) is installed at the same location than the FFC on the Test Bench. (see poster TUPG59)

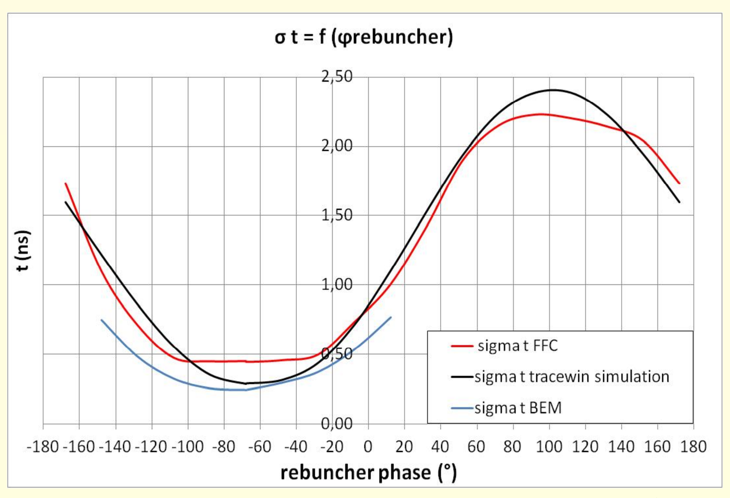
The BEM amplitude is normalised to have the same pulse area than the FFC one.

The FFC pulse shape is larger than the BEM pulse.



At 75kV, the rebuncher phase is shifted on 360°, the pulse width is calculated in function of this phase .

The FFC curve shows a limitation in time.
The minimum value of σt is equal to 440 ps.



In comparison, the BEM time go down to 244 ps with a tracewin simulated σt = 280 ps.
Following these measurements, the pulse enlargement due to the FFC limited bandwidth and cable distortion is estimated between 120 to 160 ps.

CONCLUSION

The SPIRAL2 RFQ injector commissioning is started since the beginning of 2016 with proton and helium beams. It will soon continue with heavier ion beams.
As shown, the results of the energy and bunch length monitors are encouraging. Their functioning responds to the needs and will allow the characterization of the various injector beams.
For the TOF monitor, studies will be done to compare signal amplitude with simulations, to measure the ratio signal/noise in function of the beam intensity and to compare the measurements with the calculated accuracy.
A signal processing of the Fast Faraday Cup should minimize the signal enlargement caused by the limited bandwidth of the Faraday cup.