INVESTIGATION ON THE INJECTION OF THE ARRONAX CYCLOTRON 70XP

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Abstract

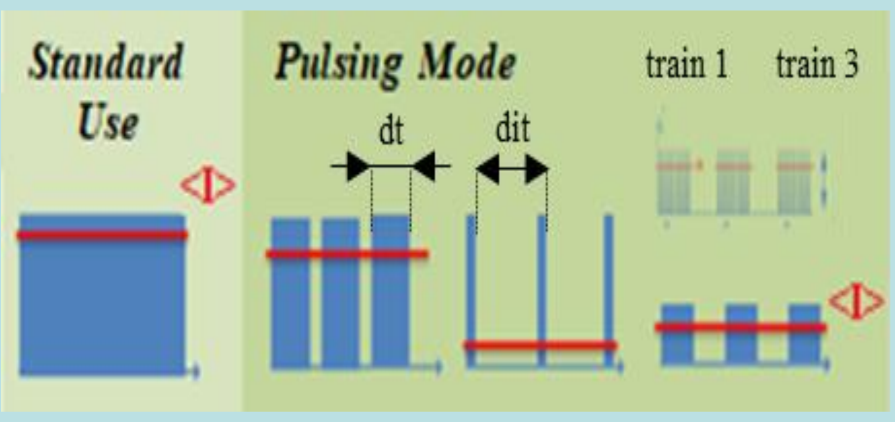
A 70 MeV cyclotron is being used at the Arronax GIP (Interest Public Group), France, for various types of R&D on nuclear, biological and chemical reactions with beams and radioisotopes production. In order to adapt its usage for experiments and users demands of high peak intensity, above an equivalent average of a few µA, the injection is being adapted. Several studies are thus being performed in this section. These include the newly in-stalled chopper-based system and the injection collimator. This paper details the various studies, specifically the signal purity obtained in the pulsed mode. A mode particularly adapted for flash irradiation.

INTRODUCTION

ARRONAX, an acronym for "Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique", is located in Nantes, France [1,2].

- Bunches interspaced by 32.84 ns (RF frequency=30.45MHz) at average intensities at least up to 375 µA for proton and 50 µA for alpha. This translates respectively into 7.8 10^7 and 5.1 10^6 particles per bunch.
- **Pulsing chopper** based system is designed to provide a variable number of trains of bunches to users from an initial continuous bunch structure.
- Modify:
  - **Train duration *dt***
  - Repetition ($={}^{1}/_{dit}$ with *dit* the inter ending-train duration)
- At the fastest, the system can provide trains of 164 ns length at 50 kHz repetition i.e. 5 bunches every 200 µs.

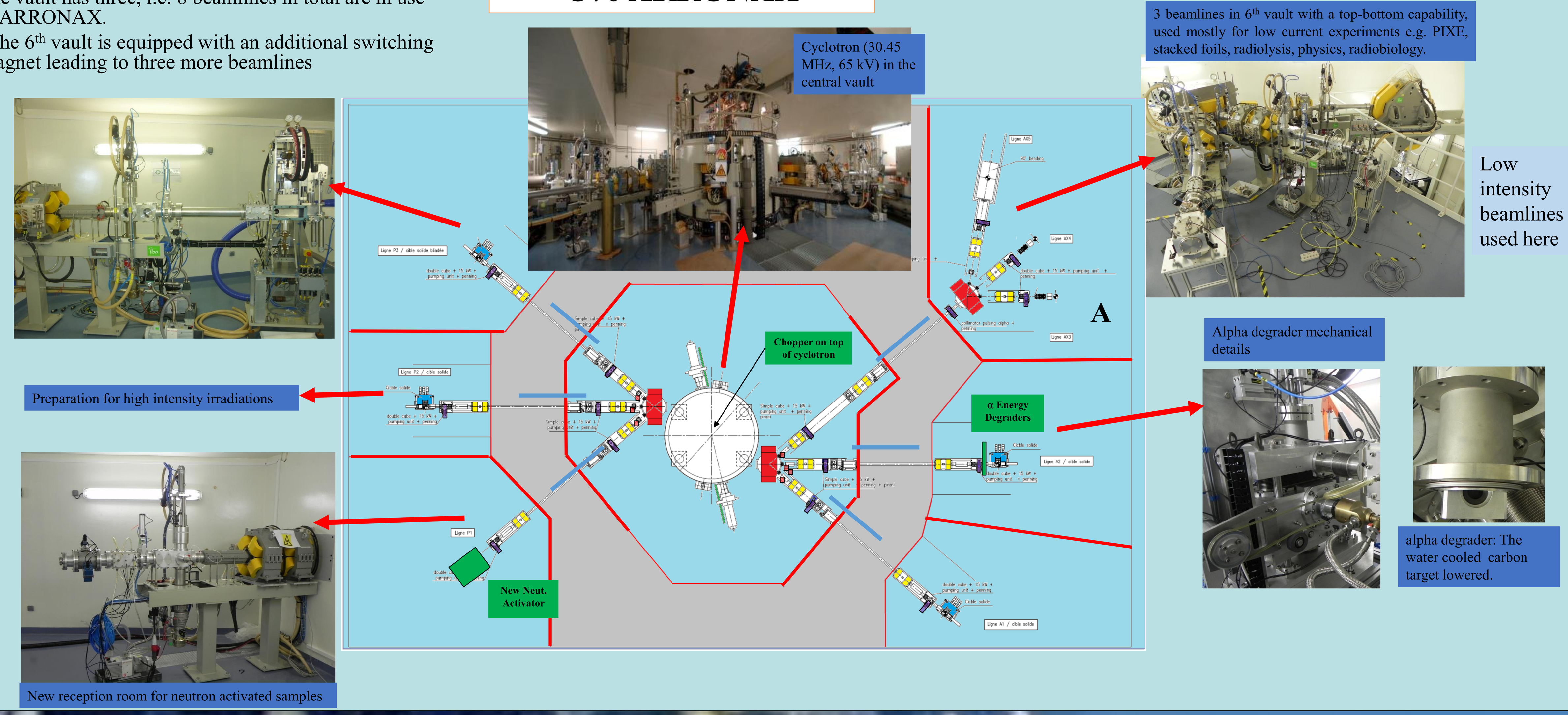
Examples:



Examples of variable time structure with the new pulsing chopper-based system. 3 trains of bunches are represented.

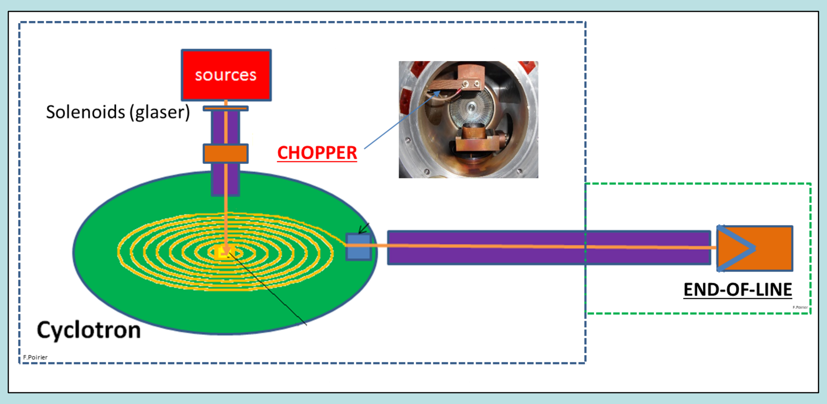
C70 ARRONAX

- Five vaults each houses a single end-station [1,2], and one vault has three, i.e. 8 beamlines in total are in use at ARRONAX.
- The 6th vault is equipped with an additional switching magnet leading to three more beamlines



Chopper system and Control

Chopper in the cyclotron injection:



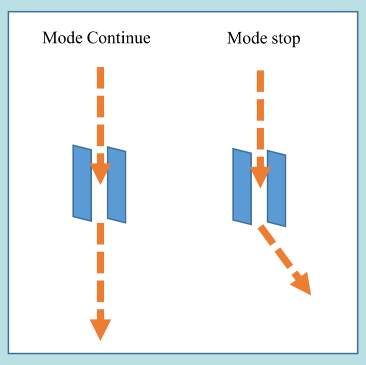
- Power supply room hosts the control electronics, a 10 kV variable high power supply and a Raspberry Pi3 [3]
- **Switch is a Behlke FSWP 51-02 [4]**
- Cyclotron vault houses the removable switch box

Operational studies:

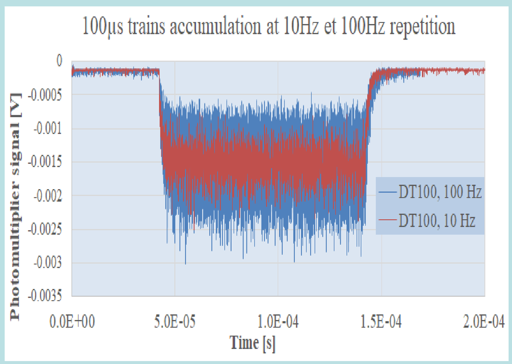
With proton and alpha particle, modification of beam dynamics. Control system of the chopper allows to choose several modes:

- **"Sequence mode":** time structure according to the setting of the control system
- **"Stop-mode":** plates at the maximum available voltage, the beam is bent away
- **"Continuous-mode":** plates at ground level and the beam goes through the injection.

Stop and continuous mode:



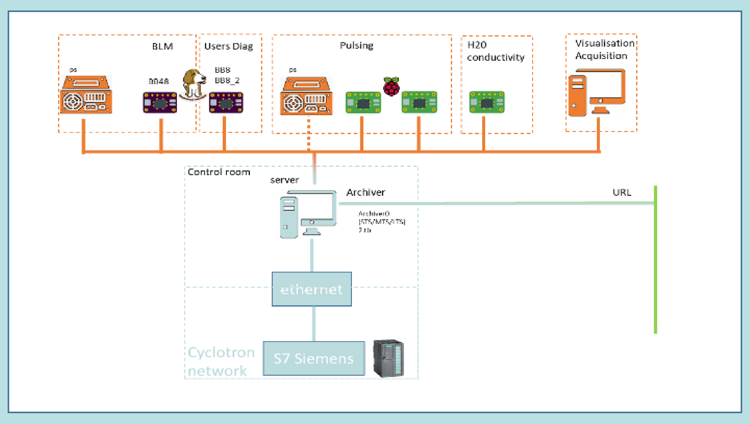
Sequence mode:



Computing environment & Injection Capacities

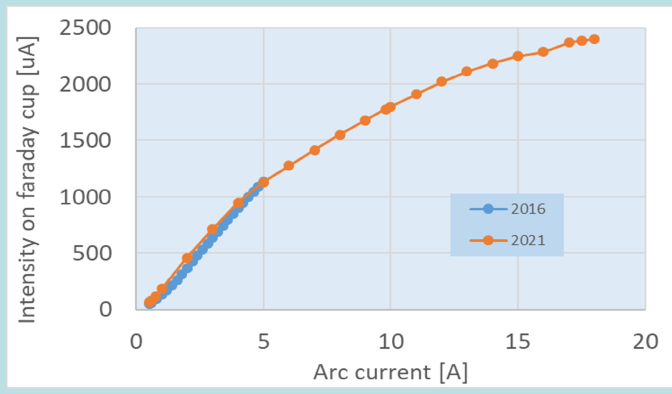
EPICS network encompasses the chopper system (pulsing):

- Electronics
- Raspberry Pi3
- Voltage power supply



Source Studies:

Continuous -mode Intensity on injection faraday vs the arc current of the multicusp source: **2.4 mA**



For R&D users, the continuous mode is optimized to 10 or 23 µA

Stop mode & background noise

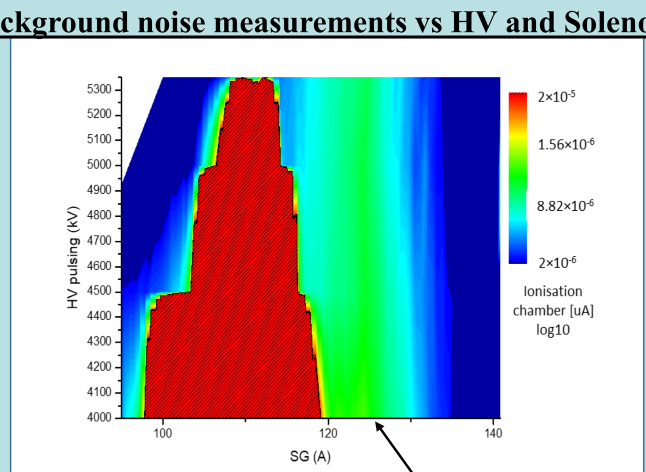
In the Sequence mode:

- Importance of the rise/fall time of the train of bunches.
  - **User's signal measured to be ~3 µs**
  - **Ok at the present time**

Ideally stop mode = no particles to the users
In reality, there can be some particles going through and depends on:

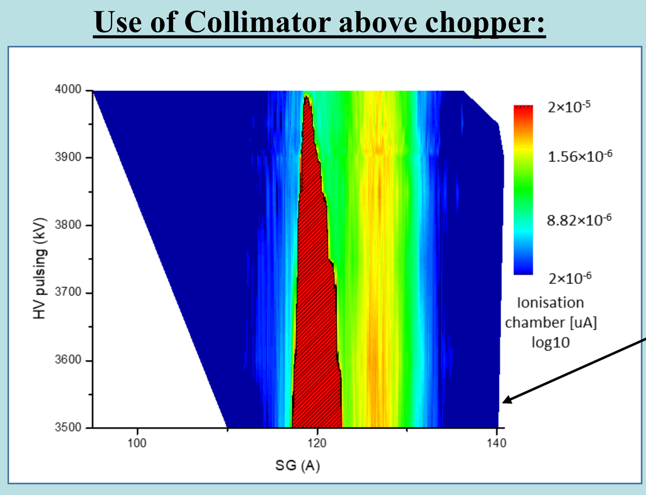
- Characteristics of the beam (emittance)
- Efficiency of chopper
- Settings of the source & magnets in front of chopper

Background noise measurements vs HV and Solenoid:



- Background noise not dependent on HV but on solenoids settings

Use of Collimator above chopper:

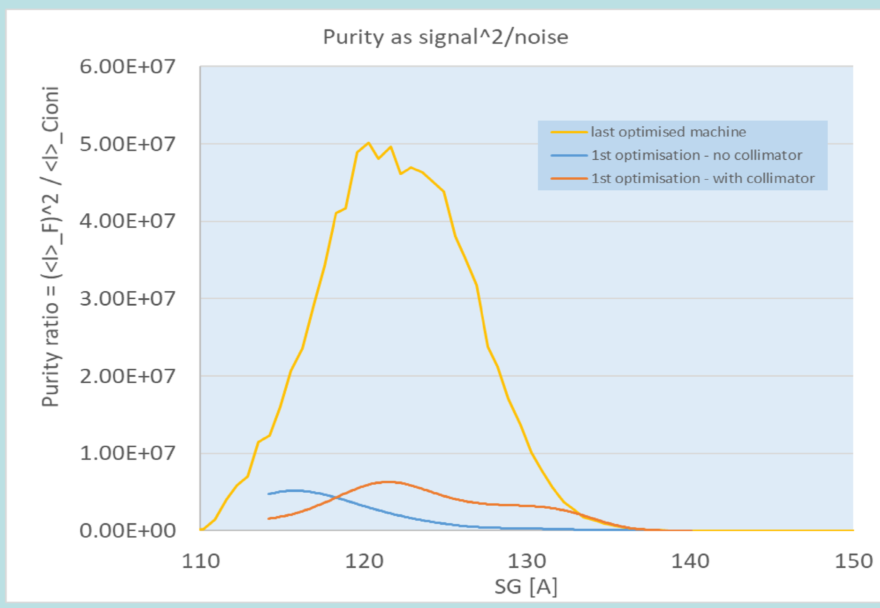


- Background slightly higher than before.
- Cutoff at a a value of the solenoid

Purity of the signal

Purity ~ continuous mode intensity / stop mode intensity
= <I>_signal² / noise
After several optimisation (all settings of magnets and source, vacuum, gaz pressure)

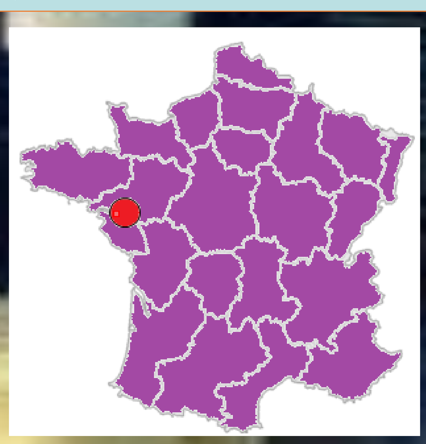
Purity = 5×10^7



Tuning the injection for best transmission with minimum background noise depends on the beam characteristics and magnets settings. A great care has to be taken for the beam optimisation when the chopper system is used. A specifically designed set of scrappers might be of help to limit the setting range and ease the operation, though background will have to be studied with this configuration. The **background** which is measured in 2nd region is not affected by the chopper system, but by the solenoid only. This points to potential **neutral particles** in the injection.

CONCLUSION

Further studies of the use of the chopper system at Arronax are being performed. They show the capacity to reach high intensity for the train with a high purity of the signal, i.e. low background noise. Though these are dependent on the many settings in the injection and source, of which some are presented here.
Beyond the optimisation protocol that has been used to improve the beam transmission and purity, scan techniques applied here can be used to characterise the beam with respect to the settings in the source and injection as several other magnets settings can be favoured for the users. Nonetheless, the technique is being used for flash proton therapy such as zebra fish embryos and radiolysis irradiations.
In Addition, in the last years, at the demand of the users, a set of magnet settings has been found which help to switch the machine from a pulsation mode above 20uA to a low intensity continuous mode. To help further the investigation in the injection, an emittance-meter has been used and analysis are on-going.



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