# LLRF for the RFQ prototype of the MYRRHA project

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Contact : joly@ipno.in2p3.fr

Christophe Joly*, Sylvain Berthelot, Beng-Yun Ky,Thomas Lester, Wladimir Sarlin, Jean-François Yaniche
Institut de Physique Nucléaire (UMR 8608)- CNRS/ IN2P3-Université Paris-Sud, Orsay, France

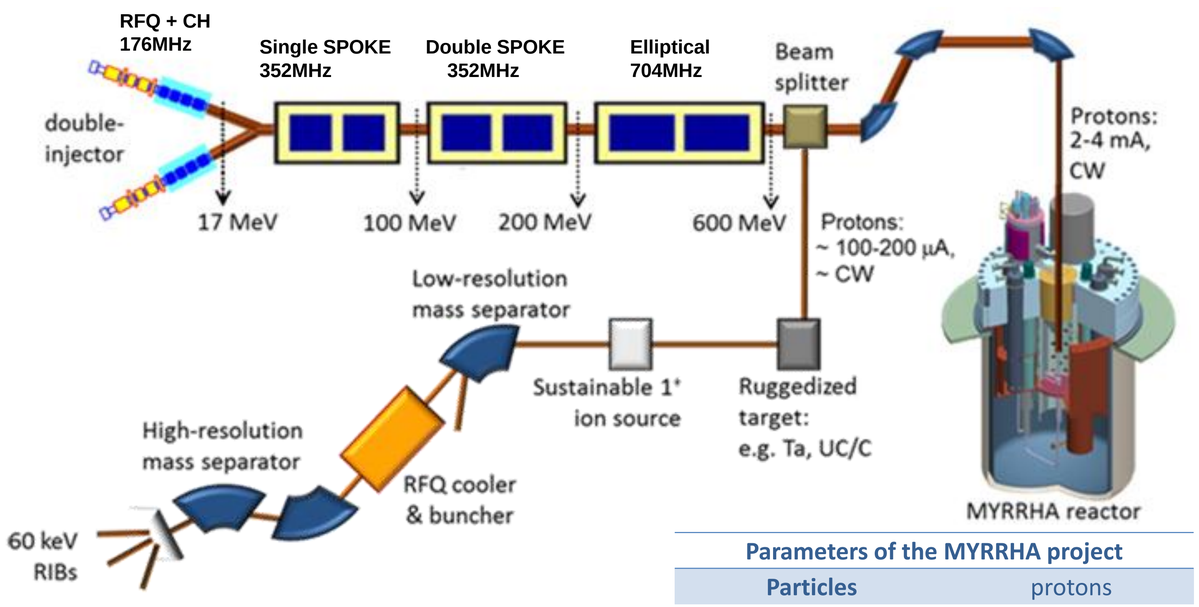
Holger Podlech
Johann Wolfgang Goethe Universitaet (Institute of Applied Physics) Frankfurt am Main, Germany

Dirk Vandeplassche
Centre d'études et de recherche Nucléaire (SCK*CEN), Mol, Belgium



The goal of the European project called MYRTE (MYRRHA Research and Transmutation Endeavour), is to perform research to support the development of the MYRRHA facility (Accelerator Driven System) with a main topic for the "Accelerator R&D for ADS/MYRRHA" Work Package (WP2): the Injector demonstration. Within this framework, a Low Level Radio Frequency system for the Radio Frequency Quadrupole (RFQ) is developed by IPNO with an in-house standalone digital board including 2 FMC boards associated to a FPGA linked to a processor ARM by PCIe. A Phase References generation system has been also realized and tested with the expected performance. This poster presents the project and focuses to the hardware developments and to some results before the tests with the RFQ planned in May 2018.


## Conceptual layout of the MYRRHA Facility




| Parameters of the MYRRHA project | |
|---|---|
| Particles | protons |
| Energy [MeV] | 600 |
| Frequency [MHz] | 176.1 - 352.2 -704.4 |
| Duty Factor [%] | 100 (cw) |
| I [mA] | 4 |
| Beam power [MW] | 2.4 |
| MTBF [Hour] | 250 |
| Energy stability [%] | ±1 |
| Current stability [%] | ±2 |
| Reactor power th [MW] | ≈60 |
| keff | ≈0.95 |
| Fuel | MOX |
| Target | Eutectic Pb-Bi |

Goals :

- Build a hybrid reactor demonstrator for transmuting radiotoxic waste, (ADS).
- Radio Isotopes production to medicine
- Fundamental research

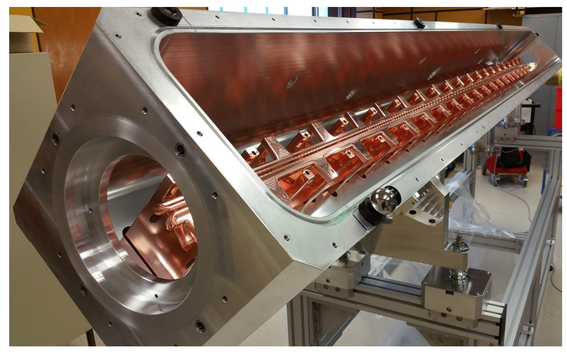
MYRRHA Research and Transmutation Endeavour

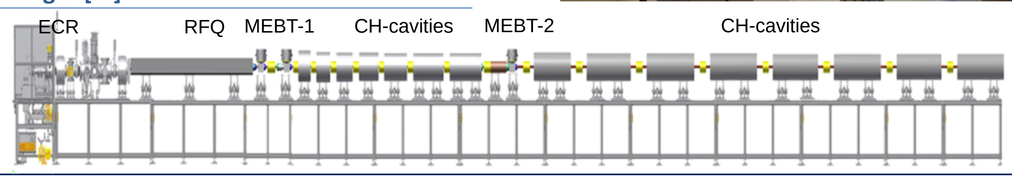

This work is supported by the European Atomic Energy Community's (Euratom) H2020 Program me under grant agreement n°662186186 (MYRTE Project).


## RFQ

| RFQ Parameters | |
|---|---|
| RF Structure | 4.Rod |
| Frequency [MHz] | 176.1 |
| Beam current [mA] | 5 |
| Duty factor [%] | 100 |
| $E_{out}$ [MeV] | 1.5 |
| $R_p$ [kWm] | 72 |
| RF Power [kW] | 113 |
| Specific power [kW/m] | 26.5 |
| Voltage [kV] | 44 |
| Length [m] | 4 |

RFQ assembly in progress at NTG facility






Injector in detail (new design)

## LLRF Requirements

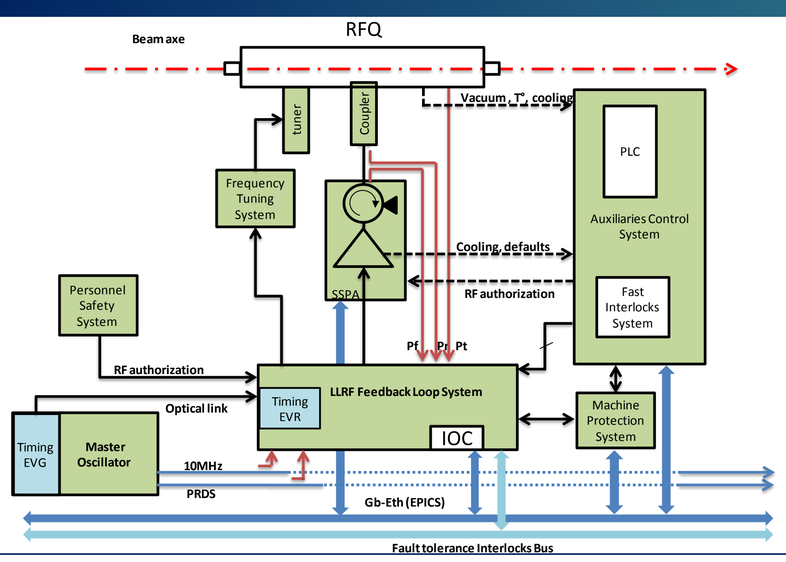
Due to beam dynamics studies of the global accelerator and the RFQ characteristics, the stabilities requirements will be better than ±0.3% rms and ±0.3° rms.
In this respect, a budget has been defined for the complete LLRF system composed to the Master oscillator (MO), the Phase Reference Distribution System (PRDS) and the LLRF Feedback loop system.
Then other parameters must be taken into account as accelerator length, temperature variation into the tunnel, etc.

| LLRF requirements | |
|---|---|
| Amplitude stability [%] | ±0.2 rms |
| Phase stability [Degree] | ±0.2 rms |
| Frequency [MHz] | 176.1 |
| Bandwidth [kHz] | > 84 |

Distribution by subsystem

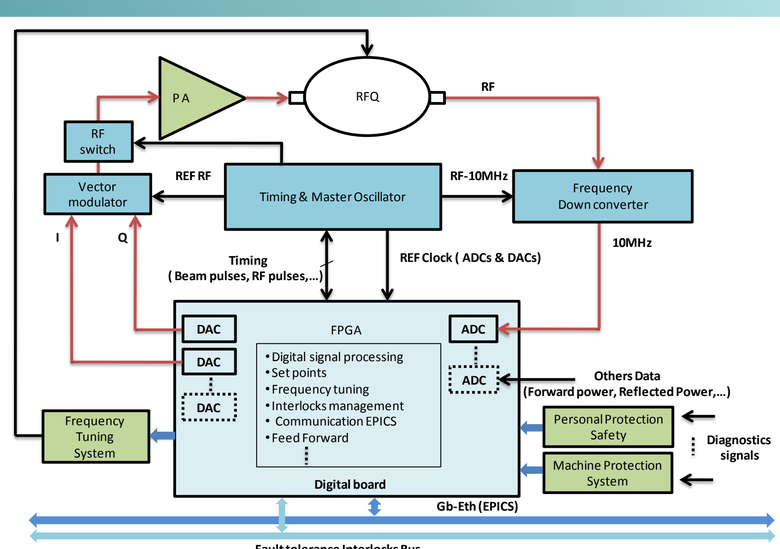
| LLRF FB System | Master Oscillator | REF Distribution |
|---|---|---|
| ±0.2 | - | - |
| ±0.1 | ±0.1 | ±0.1 |

## LLRF FB loop system

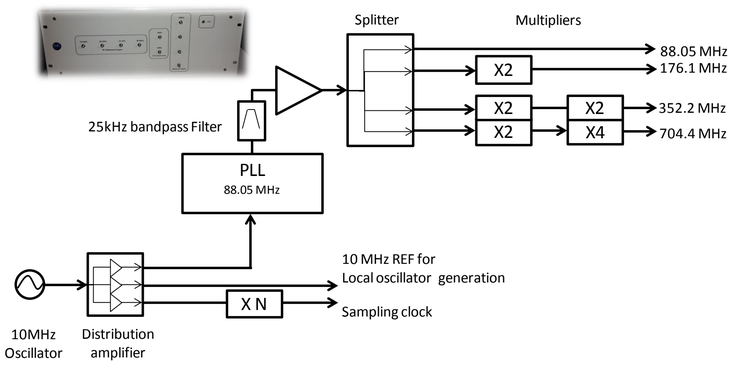



The LLRF system for the RFQ is based on a in-house digital mother board called DALTON using a FPGA linked to a processor ARM by PCIe, with two FMC slots.
**For HW and SW details, see *P-38 "EPICS and VHDL developments in the LLRF for MYRRHA Project's RFQ prototype"* poster.**

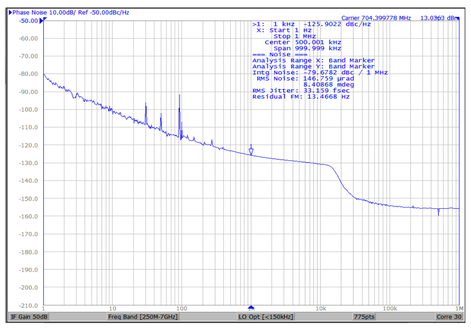
The regulation loop principle is based on the processing of the RF cavity pick-up signal which is down-converted to an 10 MHz Intermediate Frequency (IF) signal. This IF signal is then sampled by an ADC (FMC104-4DSP) to be processed into the FPGA. The result is two I/Q control signals which are converted by 2 DACs ( and used to modulate the RF reference signal feeding the cavity, via a vector modulator. The MO provides the Phase reference at 176.1MHz and the 10MHz need to produce the Local oscillator (LO) signal, used by the down converter.




## MO




Results and measurement@704.4MHz

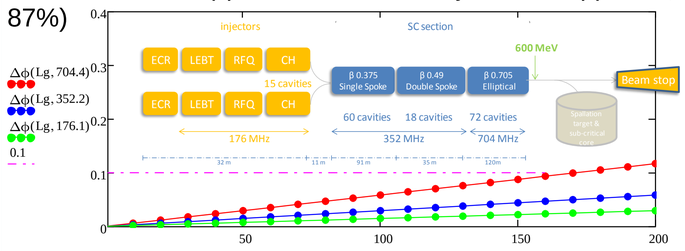


The Master Oscillator is realized using parts with Phase Noise requirements very hard providing by *ar Electronique* (OCXO, PLL) and *Wenzel Associates* (multipliers). A narrow bandpass filter allows reducing the PLL noise as it is shown on the plot.

| Frequency [MHz] | Jitter rms [mDeg] | Jitter rms [fs] |
|---|---|---|
| 88.05 | 1.6 | 50 |
| 176.1 | 2.0 | 33 |
| 352.2 | 4.5 | 36 |
| 704.4 | 8.4 | 33 |

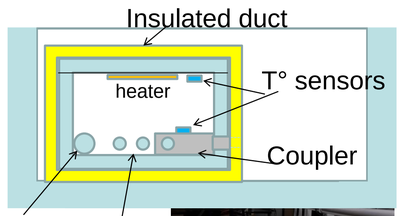
## PRDS

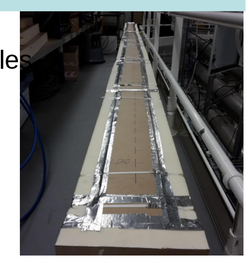
Phase stability versus length for 0.1°C temperature variation using a LCF38-50J FN( phase vs T° stability coef <6 ppm/°C, velocity : 87%)

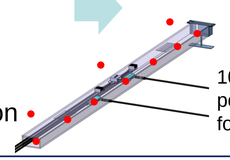



Phase stability and RF level distribution Requirements
Distribution type & MO location
Cable requirements ( phase versus T° stability & diameter)
Coupling value
T° regulation solution (heater, water, ...)

A PRDS 9m prototype is realized to test several T° regulation and insulation solution. The tests are in progress.





10 Tc (K type) per 3 m section positioned inside and outside for a profile of temperature.

## Conclusion

The LLRF prototype for the RFQ composed of the MO, PRDS and the FB loop will be tested in real condition in 2018 at Louvain-La-Neuve in Belgium where will be installed the injector until 6 MeV. The Master Oscillator prototype gives very good phase noise results with a jitter inferior to 50fs for all references. The PRDS needs more tests to conclude about the T° regulation. The FB loop hardware and software (VHDL and EPICS) are close to be operational and in parallel, we are studying a MTCA based version adapted to the MYRRHA reliability requirements. Thank you to the IAP, SCK*CEN and IPNO teams for their support.