# Trigger Implementation for DESPEC and FRS

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*Fragment Separator (FRS) represents a system of linked detectors, each delivering important information on secondary particles; mass, charge, half-life.. for later complete particle identification. Considering the amount of data recieved during the beam time, it is necessary to find a method with which we will be able to filter those information as required, without burdening data acquisition system. Two concepts for running a data acquisition system are widely used: triggered and free-running. A modern general-purpose data acquisition should be able to accommodate both modes and also to deal with legacy electronics if needed.*

## 1 Introduction

The region south of $^{208}$Pb nuclei along the $N = 126$ line has been identified as a region of key interest for the NUSTAR collaboration at GSI/FAIR; it is of high interest for nuclear structure studies and nuclear astrophysics application. We are aiming to extend the frontiers of known isotopes and to obtain nuclear structure data on gross properties. NUSTAR experiments address front-line physics questions at the limit of feasibility, and reach a level of complexity that requires not only new and innovative detector concepts, but also calls for an adequate integrated data acquisition system.

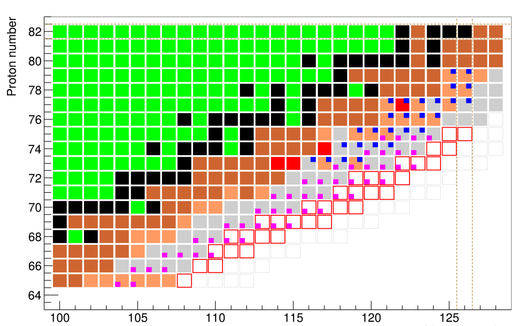



Fig. 1: *The region of interest in the chart of nuclei*

## 2 Experimental setup

The main goal of the experiment is to produce and identify new neutron-rich isotopes in the element range between terbium and rhenium and to measure their production cross section. This will be achieved by extraction of $1GeV$ $^{208}$Pb$^{67+}$ primary beam from the SIS-18 and focusing it on the production target at the entrance of the FRS. A target of $2.5g/cm^2$ Be with $223mg/cm^2$ Nb backing, will be used to produce the isotopes of interest via projectile fragmentation.

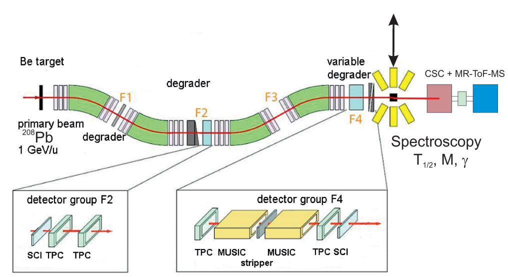



Fig. 2: *Schematic view of the FRS setup*

New NUSTAR equipment, at least as prototypes or start versions, are used for experiment in phase-0. In the FRS, new TPC and MUSIC detectors are used for beam monitoring and particle identification. At the final focus (S4 area), the FRS Ion Catcher and detectors of the DESPEC collaboration (AIDA+FATIMA) are being used for the first time. It is the combined use of these novel instruments, which allows these pioneering studies and the rich nuclear data harvest in short time.[1]

### *2.1 Equipment*

Two types of experiments are planned by the HI/DESPEC collaboration, both of which are planned to be located in the low energy branch of the FRS. A typical in-flight spectroscopy experiment employs tracking detectors after a secondary target at the final focal plane of the FRS. The secondary target is surrounded with gamma ray detectors. At a later stage of the project, the addition of a particle tracking detector around it to perform particle detection in knockout studies, is planned.

The other part of the collaboration is dedicated to investigate decay spectroscopy of exotic nuclei produced by the FRS. Here, depending on the decay modes of the studied nuclei and the observable of interest, different detectors can be used, sometimes in combination.

#### 2.1.1 AIDA

AIDA (Advanced Implantation Detector Array) is a silicon array for implanting exotic ions that will be positioned at the center of the DESPEC setup. The ASICs connected too the silicon detectors are equipped with fast-recovery preamplifiers able to identify implantation events and the subsequent beta decay. The ASIC is read out with the same system as the $R_3B$ silicon tracker and is integrated into NDAQ via white rabbit time stamping and data flow coupling. The AIDA array is located at the center of the DESPEC setup.

#### 2.1.2 FATIMA

FATIMA (Fast TIMing Array) made of $LaBr_3$ is optimized to perform gamma-gamma or beta-gamma measurements to determine life times of nuclear levels. The timing requirement for the electronic are quite stringent.

#### 2.1.3 DEGAS

DEGAS will be the work horse germanium detector array of DESPEC. In phase-1 it will use the Euroball detectors in a new geometric configuration with updated electronics, running as a hardware-triggered system.

The other goal is to measure masses in a new region with FRS Ion Catcher setup: this combination permits to implant the ions in the Cryogenic Stopping Cell (CSC) and to extract them to the Multi-Reflection Time-Of-Flight Mass Spectrometer (MR-ToF-MS), where their mass can be measured with high ($60keV$) accuracy even for very low yields (10 ions in total).[2]

## 3 NDAQ and triggers

All NUSTAR experiments use radioactive beams and rely on tracking; Time-of-Flight (ToF) and energy-loss information delivered by detectors of the FRS. Therefore, the ability to correlate data streams of the FRS with those of the experiments is crucial. Thus a common data acquisition infrastructure is critical for an optimal operation of NUSTAR experiment. There are a number of characteristics such an integrated data acquisition system (NUSTAR Data AcQuisition NDAQ) has to have.

The most important one is the necessary flexibility to handle different detectors and readout electronic type. NDAQ also needs to be able to incorporate future developments. It has to provide not only a maximum interoperability between the readout systems of different detector systems, but also of different detector generations. This means handling of different operating modes, the ability to cope with large data rate while assuring data integrity, and more complex control and command tasks.

### *3.1 Hardware-triggered mode*

In the hardware-triggered mode, local trigger signals, generated from individual detectors, are combined logically via a coincidence matrix in a Signal Loging Box (SLB) to generate and to dispatch a Master Start (MS) to set of detectors (e.g. FRS/FATIMA). The detectors recieving the MS can depend on the trigger condition that generated it; the trigger is defined according to the physics requirements of the given experiment.

The transmission times of signals between different subsystems is, especially for large distances, a critical issue. For correct separation and identification of secondary beams, data from the FRS is required by all NUSTAR experiments using NDAQ. The ions pass through the FRS detectros a relatively long time before the trigger decision can be drawn. A system with digitization after reception of trigger-based gate requires all analog FRS signals to be delayed for several $\mu s$ to several $ns$ until the arrival of the trigger.

The solution is to have a buffer chain for every channel in the front-end electronics, where all digitized signales are stored with time stamps. Data transmission waits for a validation signal which causes the extraction of the data from the readout within the time window based on a trigger provided by the experiment.

### 3.2 Software triggered free-running mode

The free-running operating mode, together with a software-triggered event selection, constitutes an advantage because it is independent of signal latencies and allows for a significant reduction of the global dead time. All digitized signals are read out and trigger coincidences are constructed in software or firmware.

In the free-running mode, subsystems are working asynchronously and every channel is self-triggered: each analog signal passing a local treshold is digitized and time stamped. The event is generated later in the DAQ recording chain by a more advanced trigger logic. But, the recording of all uncorrelated signals in a free-running experiment leads to very large amounts of data that waste computing and data storage resources, and is not favoured.

The requirements to handle this operating mode are to provide properly scaled bandwidth according to the requirements of the subsystems, a back pressure mechanism which is able to detect and manage any saturation of the data flow from individual detectors or detectors components.[2]

### 3.3 TRLO II

The VULOM-based trigger logics (firmware) replaces several crates of NIM and CAMAC electronics used for trigger decisions, counting and dead-time locking and open up many new possibilities for handling pending and calibration triggers. As the TRIDI modules need similar kinds of logics, and actually could serve as small local trigger systems for stand-alone test operations, the same code is used for both, with minor tweaks for the different inputs and outputs. All logics run with one 100 MHz clock. The bold intention is that this firmware should be suitable for (almost) any triggered nuclear physics experiment.[3]

## 4 Results

The goal of the project was to implement the trigger system allowing to run alternatively both setups at the end of the FRS: (i) active stopper and CSC cell to perform mass and beta life time measurements or (ii) the DESPEC setup with AIDA, DEGAS and FATIMA. Figure 3 shows a schematic view the different systems and their information used to build this general trigger system.

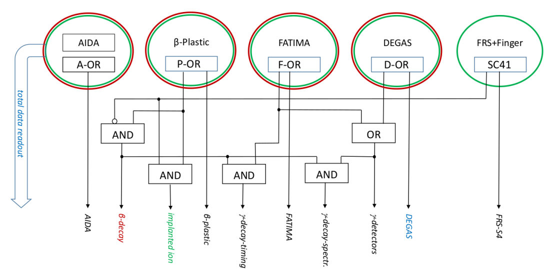



Fig. 3: *Schematic representation of logic gates for the FRS*

The triggers were encoded in the VULOM-TRLO II confiugration using the configuration file based on the scheme in Figure 3. A printout of the implemented configuration is shown in Figure 4 as a trigger matrix. To do this 7 inputs were used, namely: (i) "or" signal from AIDA electronic, (ii) "or" signal from the beta-plastic, (iii) "or" signal from the FATIMA detectors, (iv) "or" signal of DEGAS, (v) scintillator "41" (SC41) of the FRS (first in the final focal plane) which means an ion passed throught the FRS, (vi) scintillator "43" (SC43) of the FRS (last in the final focal plane) and (vii) "or" signal of all active stopper silicons. With those, fourteen triggers were built, as listed below:

(i) AIDA trigger; used for calibration purposes and as a counter

(ii) Beta-plastic with a veto on incoming particle; this trigger is used as the main beta-trigger with the DESPEC setup

(iii) Implantation trigger for the main DESPEC setup which is the beta-plastic in coincidence with the SC41 to confirm the ion passing through the FRS is really reaching AIDA

(iv) Beta-plastic alone; for calibration purposes or test measurement (not disciminating implantation and decay)

(v) As Trigger 3, but with a coincidence with FATIMA; for prompt beta-gamma coincidence, used for specific settings without isomers or for calibration

(vi) FATIMA trigger alone; for calibration purposes

(vii) As Trigger 3, but having any of the two gamma detectors (FATIMA or DEGAS) in coincidence; for pure prompt beta-gamma trigger

(viii) "or" of DEGAS and FATIMA; for gamma calibration purposes

(ix) DEGAS trigger alone; for calibration purposes

(x) SC41 alone (main FRS trigger) to detect particles incoming in the FRS; for FRS calibration and tuning

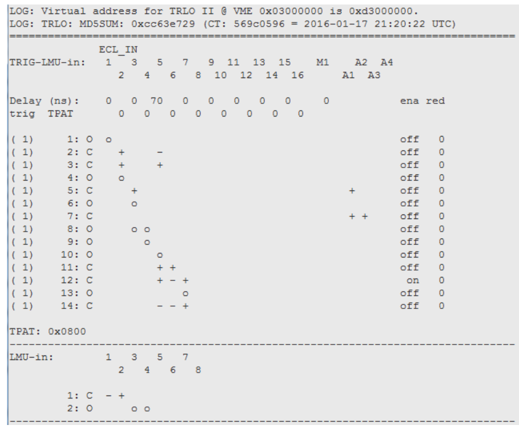
(xi) SC41 and SC43; which is particle passing through the active stopper and being implanted in CSC (Cryogenic Stopping Cell) to have the identification of them

(xii) SC41 in coincidence with the active stopper and anti-coincidence with SC43; for active stopper implantation trigger

(xiii) Active stopper trigger, both implantation and decay; for calibration purposes

(xiv) Active stopper and anti-coincidence with SC41; for beta-decay for the active stopper runs

Because of the delay in the beam time, scheduling active stopper, AIDA, DEGAS and FATIMA, were not mounted at S4 by the end of the project. Nevertheless the logic was tested for trigger 10, 11, 12 and 13 using pulser signals simulating the detectors and was shown to work. The delay to implement for the coincidence (or anti-coincidence) in the module was equivalent to the one added intentionally on the pulser signals. Trigger 14 is defined with a bit more refinement than trigger 4. This is due to the presence of the scintillator SC43 in the setup with the active stopper. Indeed the SC41 threshold could be high and it is selected to assure the best time of flight for the FRS. The SC43 plastics can have a really low threshold. This means that really light particles (protons) passing through the FRS could trigger the active stopper, but would pass through SC41 and the active stopper and would then trigger SC43 and the active stopper. So in this case they will not induce fake beta-trigger in the active stopper. For the DESPEC setup we can not protect from such trigger, but those spurious events have to be removed in the analysis.



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LOG: Virtual address for TRLO II @ VME 0x03000000 is 0xd3000000.
LOG: TRLO: MD5SUM: 0xcc63e729 (CT: 569c0596 = 2016-01-17 21:20:22 UTC)
===============================================================================
              ECL_IN
TRIG-LMU-in:   1   3   5   7   9  11  13  15    M1    A2  A4
                 2   4   6   8  10  12  14  16     A1  A3

Delay (ns):    0   0  70   0   0   0   0   0     0           ena red
trig  TPAT       0   0   0   0   0   0   0   0

( 1)     1: O  o                                             off   0
( 1)     2: C    +     -                                     off   0
( 1)     3: C    +     +                                     off   0
( 1)     4: O    o                                           off   0
( 1)     5: C      +                                 +       off   0
( 1)     6: O      o                                         off   0
( 1)     7: C                                        + +     off   0
( 1)     8: O      o o                                       off   0
( 1)     9: O        o                                       off   0
( 1)    10: O          o                                     off   0
( 1)    11: C          + +                                   off   0
( 1)    12: C          + - +                                  on   0
( 1)    13: O              o                                 off   0
( 1)    14: C          - - +                                 off   0

TPAT: 0x0800
-------------------------------------------------------------------------------
LMU-in:        1   3   5   7
                 2   4   6   8


         1: C  - +
         2: O      o o
-------------------------------------------------------------------------------
```

Fig. 4: *Trigger matrix*

## Acknowledgments

Many thanks to dr. Stephane Pietri, for his patience and guidence throughout this experience and also to dr. Hans Törnqvist, for his assistance.

## References

[1] S. Pietri, *Proposal: Search for new neutron-rich isotopes and exploratory studies in the element range from terbium to rhenium*

[2] H. Simon, *Technical Report for the Design of the NUSTAR Data AcQuisition System*, (2016)

[3] H.T. Johansson, *TRLO II - flexible FPGA trigger control*, (2010)