Preparation of the Recoil Filter Detector- *RFD* for High Resolution Gamma-Spectroscopy Experiments with Ge Detector Arrays (*GALILEO*, *AGATA*) at Stable and Radioactive Ion Beams

P. Bednarczyk[1], M. Ciemała[1], B. Fornal[1], J. Grębosz[1], M. Kmiecik[1], J. Kotuła[1], M. Krzysiek[1], A. Maj[1], M. Matejska-Minda[1], B. Sowicki[1], M. Ziębliński[1], G. de Angelis[2], A. Goasduff[2], A. Illana Sison[2], D.R. Napoli[2], N. Toniolo[2], J.J. Valiente-Dobon[2], D. Bazzacco[3], R. Isocrate[3], D. Mengoni[3], F. Recchia[3], G. Benzoni[4], C. Boiano[4], S. Bottoni[4], A. Bracco[4], S. Brambilla[4], S. Ceruti[4], F. Crespi[4], S. Leoni[4], B. Million[4]

[1] *Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland.*
[2] *INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy.* [3] *INFN, Sezione di Padova, Italy.*
[4] *Dipartimento di Fisica dell'Università di Milano and INFN, Sezione di Milano, Italy.*

.

INTRODUCTION

A considerable improvement of measured γ-ray energy spectra can be achieved when γ-rays are detected in coincidence with fusion-evaporation reaction residues-*ER* selected by the Recoil Filter Detector (*RFD*) [1]. *RFD* consists of 18 ion sensors distributed around the beam axis. Ions hitting a thin Mylar foil induce secondary electrons which are then accelerated by a tension of 20 kV and focus onto a thin, fast plastic scintillator mounted on a photomultiplier.

RFD registers forward focused recoils and measures their time of flight in event-by-event mode, thus providing a velocity vector for a single *ER*. The γ-recoil coincidence condition and selection of a *ToF* range specific for *ER*, allows to suppress γ-rays of interest from those coming from competing reaction channels as fission and, moreover, from transfer processes, Coulomb excitation, target contaminations, etc. Typical *ER* detection efficiency of *RFD* is 20-50% and depends on the reaction kinematics; it can be optimized accordingly by adjusting the flight distance from the target, and hence the *RFD* opening angle.
For fast *ER* of $v/c \gg 1\%$ the velocity vector determination enables a significant minimization of γ-lines Doppler broadening.

COUPLING *RFD* TO *GALILEO*

In the past *RFD* was installed in *LNL* at the *GASP* Ge detector array [2] and used in γ-ray spectroscopy experiments [3,4]. In 2018 the detector was implemented to be coupled with the *GALILEO* and *EUCLIDES* arrays. The installation included the construction a new interface to the reaction chamber and the adaptation of the existing *RFD* frame. The detector was put on the *GALILEO* beam line and successfully connected to the *TANDEM*/*ALPI* vacuum system. In the current stage the *GALILEO* array consists of 35 *GASP*-like detectors. To assure free space for *RFD* a part of the *GALILEO* structure holding the most forward 5 germanium detectors are removed. The complete setup is shown in Figure 1.

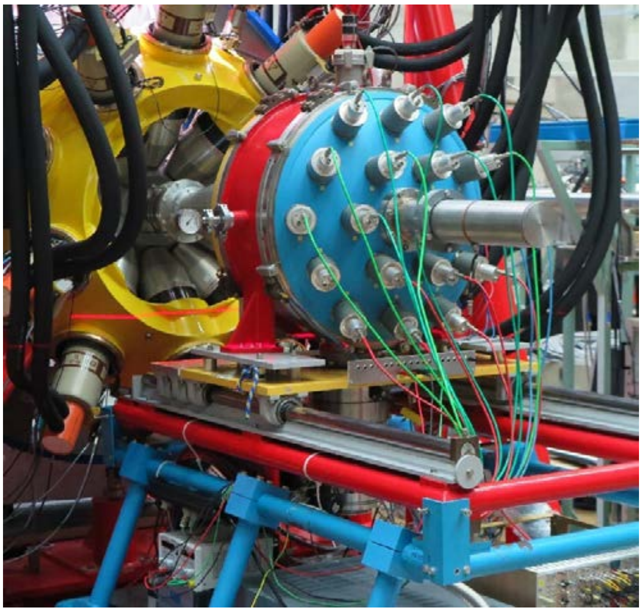

Fig.1 The Recoil Filter Detector coupled with the GALILEO array at LNL.

Each of the *RFD* elements provides a fast signal which is processed in order to extract information on the energy loss of the detected ion together with its arrival time, which is defined with respect to the start signal *T0* derived by a *RF* pulse with ns precision. It was proposed and partially tested a new *RFD* data acquisition system based on a digital readout. In this approach preamplified *RFD* signals will be connected to the *MEGAMP* shaping amplifier with integrated *CFD* and *TAC*, which time and amplitude outputs will be sampled and analyzed by the *GALILEO* digitizers and marked by a common timestamp provided by *GTS*. In this way the *RFD* information can be directly merged with the *GALILEO* and *EUCLIDES* data stream.

The overall performance of the *GALILEO-EUCLIDES-RFD* setup will be tested in beam in 2019, then an experimental campaign will follow. A series of experiments will comprise high spin γ-ray spectroscopy of light A~40 superdeformed nuclei as well as octupole deformed transactinides.

PERSPECTIVES

RFD is also considered as an ancillary detector for *AGATA* in the forthcoming campaign at *LNL*, making use of stable- *TANDEM/ALPI* and radioactive- *SPES* beams.

The unprecedented *AGATA* sensibility could be fully exploited when incorporating *RFD*, for example in experiments focused on high spin spectroscopy of heavy nuclei. Intense *n*-rich *SPES* radioactive beams as $^{90\text{-}94}$Rb at energies of about 400 MeV impinging on a ^{130}Te target can induce fusion-evaporation reactions leading to octupole deformed isotopes of Actinium and Francium [5]. These evaporation residues can be produced at relatively high spins $J \gg 30\hbar$, although the fusion-fission process will dominate the reaction yield. Figure 2 shows the expected two dimential distribution, velocity versus emission angle (in the laboratory frame), calculated using *GEMINI*++ for the reaction of 375 MeV ^{92}Rb on the ^{130}Te target.

The A~220 *ER* are concentrated in the narrow spot at $v/c{\sim}4\%, \theta < 10°$ and are well separated from the broad distribution of fission fragments. Using *RFD* coupled to *AGATA*, weak γ-ray cascades from these fusion-evaporation residues can be clearly selected, moreover the excessive Doppler broadening of the γ-lines, due to the high recoil velocity, can be compensated.

The use of a wide range of heavy intense *RIBs* expected at *SPES*, combined with the application of *AGATA* with *RFD* and other ancillary detectors may open new perspectives for studying the structure of nuclei excited in fusion-evaporation reactions, difficult to access with stable beams.

This work was supported by the National Science Center, Poland (NCN) under HARMONIA contract No. 2013/08/M/ST2/00591.

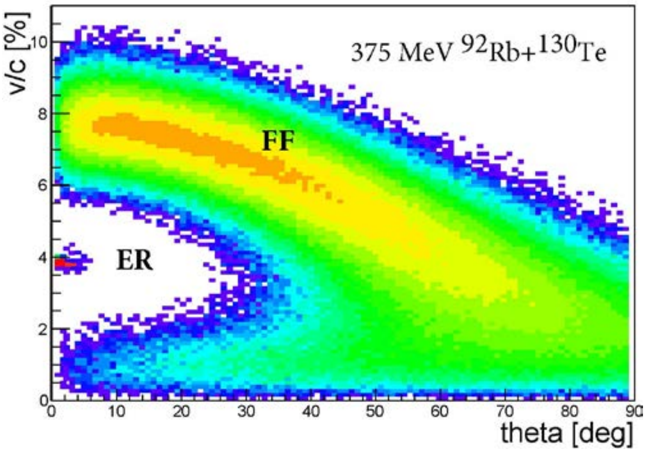

Fig. 2. Distribution of fission fragments (FF) and evaporation residues (ER) produced in the reaction of 375 MeV ^{92}Rb radioactive beam on ^{130}Te target, calculated with the GEMINI++ code. Fast, forward focused ER (mainly Ac and Fr isotopes) can be produced at high spins.

[1] W. Meczynski et al., Nuc. Ins. Meth. A580, (2007) 1310,
[2] W. Meczynski et al., LNL Annual Report, (2008) 54,
[3] P. Bednarczyk et al., LNL Annual Report, (2009) 8,
[4] M.Matejska-Minda et al., PhD thesis (2014), to be published,
[5] P. Bednarczyk et al., SPES Letter of Intent (2016).