The RISING project

1 Introduction

It is proposed to use the Euroball Cluster and Clover Ge-detectors for experimental campaigns at the GSI facility starting in 2003 to exploit unique opportunities for nuclear structure studies. The SIS/FRS facility at GSI provides challenging new possibilities: by fragmentation or fission of relativistic heavy ions several hundred unstable rare isotopes can be generated with sufficient intensity for in-beam γ-ray spectroscopy for the first time. Secondary beams can even be produced in high spin isomeric states. The beams can be used either at high energies (100-200 MeV/u), for Coulomb excitation and fragmentation reactions, or slowed down to Coulomb barrier energies, enabling fusion and direct reactions.

In a workshop on "Physics with EUROBALL detectors at GSI" held on November 23 - 24, 2000 at GSI, physics topics to be studied within the new project named **RISING** (**R**are **IS**otope **IN**vestigations at **G**SI) were presented. In a first working group meeting held on December 7, 2000 main experimental considerations were discussed. This paper summarizes physics and technique of the RISING project and deals with infrastructure issues.

2 Physics

The physics topics to be studied within the RISING project can be summarized as follows.

- **N$\simeq$Z and the proton dripline**
  The proton dripline, which coincides with the N=Z line and the rp-path beyond ^{56}Ni, is broadly mapped up to ^{100}Sn. The doubly magic nuclei ^{56}Ni and ^{100}Sn, together with ^{48}Ni, provide an excellent testing ground for single particle shell structure and the role of correlations, normally not treated in mean field approaches. At N$\simeq$Z the *quadrupole (shape)* and *spin response (Gamow-Teller and magnetic moment)* of nuclei near the *ls*-open shell closures and the *proton-neutron pairing* are major challenges to large scale shell model, Monte-Carlo shell model, microscopic-macroscopic and mean field predictions. Mirror symmetry around the N=Z line and the isovector mean field components accessible by large T mirror pairs up to ^{48}Ni - ^{48}Ca provide another study ground of N$\simeq$Z nuclear structure investigations.

- **N$\gg$Z**
  The presently accessible medium-heavy neutron-rich nuclei are landmarked by

the doubly-magic ^{48}Ca, ^{78}Ni and ^{132}Sn. For extreme neutron excess, persistence of the shell strength, *shell gap melting* and enforcement of *new (sub)shell closures* are burning questions. The predictive power of mean field calculations is hampered by the poor knowledge of the *isovector part* of the mean field interaction. *Structural* and *dynamical symmetries* of the nuclear many-body system, subject to the symmetries imposed by the nuclear forces, can be studied in selected parts only of the Segré chart, which include regions of extreme isospin projection T_z. Exotic high-spin phenomena such as *super backbending* are accessible at moderate spin values in the K-isomer region in the neutron rich vicinity of stable nuclei.

- **Interdisciplinary studies**
  The knowledge of the nuclear structure near the *r- and rp- paths* provides an important constraint for the study of explosive burning in astrophysical environments. High-precision studies of *Fermi-decay* in N=Z odd-odd nuclei contribute to the unitarity test of the CKM matrix in the standard model. Systematic studies of the RIB spin alignment resp. polarisation will help understand the fragmentation process.

- **Non-RIB applications**
  Alternative possibilities are offered at GSI by the pion beam enabling the study of *hypernuclei*, by stable beams and the SHIP velocity filter allowing studies of the *shell stabilisation in super-heavy elements*, and by the extremely neutron-rich ^{238}U beam, which provides an alternative approach to *$N \gg Z$ nuclei at high spin.* These experiments, however, involve a major effort to re-site the array.

2.1 Types of Experiments

Three classes of experiments with specific technical requirements are envisioned with RIB's at the FRS.

- **Fast beams at $\geq$ 50 A MeV**
  are used for relativistic *Coulex*, *nucleon removal* and *secondary fragmentation* experiments. The latter may lead to rather high angular momentum states. As special application they allow *g-factor measurements* for short lived (ps) states and systematic studies of the *spin alignment/polarisation* of RIB's.

- **Slow beams at 4 - 10 A MeV**
  due to large cross sections can be favorably used for *multiple Coulex* and transfer reaction experiments to measure single particle *spectroscopic factors* and *particle (hole) – particle (hole) effective interactions* near exotic doubly magic nuclei. Due to the low luminosity *deep inelastic* collisions and *fusion-evaporation* reactions may be exploited only in selected cases.

- **Stopped, low-intensity beams with $\leq$ 1/s**
  allow "on-beam" experiments of the radioactive species, such as *β-decay*, *isomer γ-spectroscopy* and the measurements of *halflives in the ps – ns range* and *nuclear moments.*

3 Experimental Technique

It is planned to use 15 Cluster and 26 Clover detectors of the present EUROBALL IV array. These need to be arranged in different, newly designed set-ups fit to the respective RIB velocity.

A beam of radioactive nuclei is produced and separated by the FRS facility usually operated in standard achromatic mode. In contrast to stable beam experiments the RIB species are identified ion-by-ion with respect to mass and atomic number (A,Z). Moreover, the energy and trajectory of each RIB ion is measured.

3.1 Experiments with Fast Beams

For in-beam experiments at relativistic energies the trajectories of the RIB particles in front of and behind the target are measured by three two-dimensional position sensitive detectors (PPAC) which yields the scattering angle of the Coulomb excitation process. In order to distinguish different reaction channels, atomic and mass number Z and A are also measured behind the target.

For these experiments with beam energies up to 200 MeV/u the Ge-detectors have to be positioned at forward and backward angles in order to minimize the Doppler broadening effect. One should note that the largest γ-ray intensity will be measured in forward direction due to the Lorentz boost.

3.2 Experiments with Slowed Down Beams

The RIB produced by fragmentation or fission of relativistic beams can be slowed down behind the FRS in order to perform experiments at the Coulomb barrier. For fusion or Coulomb excitation experiments the Ge-detectors have to be arranged in a more symmetric configuration. Since the beam size may reach several centimeters due to the slowing down process, new quadrupole lenses and special beam tracking detectors are required. The new particle counters have to be designed for beam intensities up to 10^6 particles/s.

3.3 Decay Experiments

For decay experiments the radioactive beams will be slowed down in the fragment separator and then stopped in a catcher surrounded by the EUROBALL detectors. The γ-array may be very compact to obtain a high efficiency for the delayed γ-rays of the radioactive nuclei with beam intensities as low as 0.01 particles/s. The Ge-detector electronics needs to be designed such that signals from the prompt atomic background radiation do not strongly reduce the effective efficiency for delayed events.

3.4 Ancillary detectors

To optimize the sensitivity and selectivity in experiments using RIBs tracking of the beam particles and the reaction products is essential. Therefore it is mandatory that ancillary detectors, serving for identification, filtering and trigger of reaction products and their decay radiation, are incorporated in the project from the very beginning. They are used for tracking and filtering of recoils, for light charged particle and neutron detection, as active implantation detector stacks for recoils, electron, proton and α radiation, and for fast timing and X-ray detection. The main design goals are efficiency, granularity and resolution in the measured parameters energy, time, momentum, mass and charge.

4 Project Realization

As indicated in the previous section experimental set-ups radically different from previous Euroball set-ups have to be developed and built to be able to perform the anticipated physics program.

4.1 Development Tasks

- Geometrical arrangements of the Ge-detectors
- Novel high rate, in-vacuum FRS tracking detectors
- Slowing down method
- Adequate electronics and data acquisition system
- Ancillary detectors

4.2 Cost and Effort

Novel FRS tracking detectors, a variety of ancillary detectors, new mechanical structures and at least partially new electronics will have to be developed and built. Otherwise, most of the previous investment in Euroball will be re-used in the RISING project. Therefore it appears that in particular the cost but also the effort of the project is only a fraction of the previous total investment in the Euroball detectors and their experimental infrastructure. Running costs will be similar to Euroball.

4.3 Time plan

A development and construction time of two years is planned before the Euroball detectors can be employed for experiments at GSI. Taking into account the project effort on one hand and the restrictions imposed on other experimental programs at GSI on the other hand a sensible period for the Euroball detectors to stay is 2-2.5 years. This implies either two or three experimental campaigns. Each campaign should last for at least 9 months.

4.4 Infrastructure support

GSI as host laboratory will provide for each campaign at least 50% of the available FRS beam time, allocated to experiments approved by the GSI Program Advisory Committee. Support by the GSI technical infrastructure groups will be provided. General running costs like electricity, LN2 consumption etc. will be covered by GSI.