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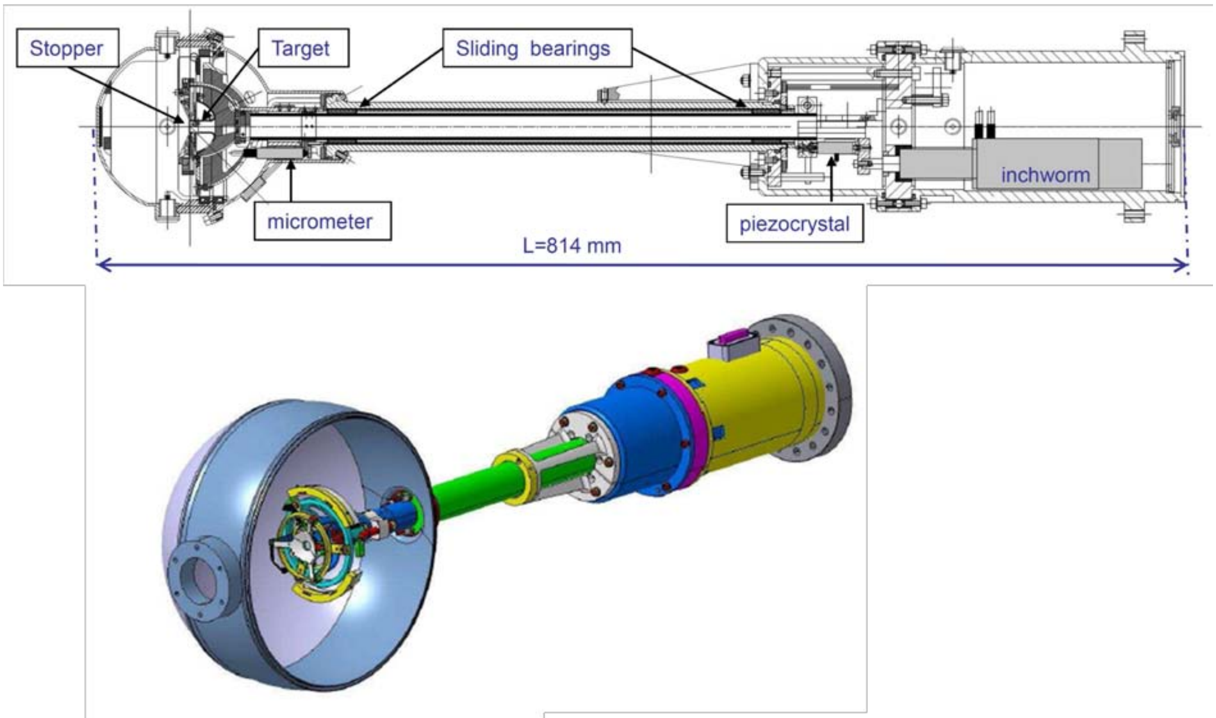
Plunger device with tracking capabilities

Lifetimes of excited nuclear states are critical experimental parameters in determining the reduced transition probabilities in a model independent way. A basic technique for lifetime measurements is the Recoil Distance Method (RDM) which so far was applied to experiments with stable beams and recently a proof of principle at intermediate energies was done. The goal of this task is to develop new plunger designs at IFIN-HH in collaboration with Uni Köln, where so far world-wide state-of-the-art plunger instruments were designed and set operational. This technique was not developed yet for several RIB energy regimes, e.g. relativistic beams at GSI. Therefore, new plunger devices for intermediate and relativistic RIB were designed. A prototype of a new plunger device with tracking capabilities was built.

Please find the technical design report in the following pages.

The Bucharest plunger



Plunger detector chamber

A plunger device with tracking capabilities dedicated to high intensity stable beams facilities

I. INTRODUCTION

A plunger device is an mechanical device widely used in γ-ray spectroscopy to measure lifetimes of excited nuclear states in the picosecond range by the Recoil Distance Doppler Shift (RDDS) method. The method compares the lifetime of a nuclear level emitting a γ-ray with the time taken by the recoiling nucleus to travel in vacuum between two foils separated by distances in the range 2 μm to 2 cm. The RDDS method relies on the plunger device to achieve the characteristic micrometric separation distances between the target and stopper foils and on HPGe detectors to separate between the Doppler shifted in-flight component and the unshifted stopped component. A recent review [1] describes in detail the RDDS method and plunger devices.

A plunger device must be able to align the target and stopper foils (which should be flat to better than 1 μm), parallel to each other (again the required accuracy is better than 1 μm) and perpendicular to the beam direction, and to modify the separation distance in a continuous and controlled way down to 2 μm. Another important requirement is that the plunger device should be designed to minimize the γ-ray absortion in its components and to fit in most modern day 4 π spectrometers. The most succesfull design prouved to be the coincidence plunger, developed in IKP, Cologne and used in RDDS experiments at most γ-ray spectrometers such as EUROBALL, GAMMASPHERE, GASP, EXOGAM, and others. Two plunger devices based on the same design were constructed in IFIN-HH (Bucharest, Romania) and WSNL (Yale, USA).

Figure 1 shows a schematic view of the standard plunger device. The device's major components are:

- A large diameter tubular part housing the piezoelectric linear actuator (”inchworm” motor) that drives the motion of the target in respect of the stopper and a piezoceramic stack (”piezocrystal”) that allows corrections of the inherent thermal drifts. Both components are placed off axis to allow the accelerated ion beam to pass through.
- A small diameter tubular part that houses a system of concentric tubes and sliding bearings that transmits the motion of the motor and piezocrystal ensamble to the target support. This part assures that the accuracy achieved by the linear actuator is kept by the motion of the entire system.

- A spherical target chamber that houses the fixed stopper support, the movable target support and an inductive micrometric probe placed off axis. The design of the target chamber and mounting supports is optimised in regard to γ detection especially at small angles (both forward and backward).

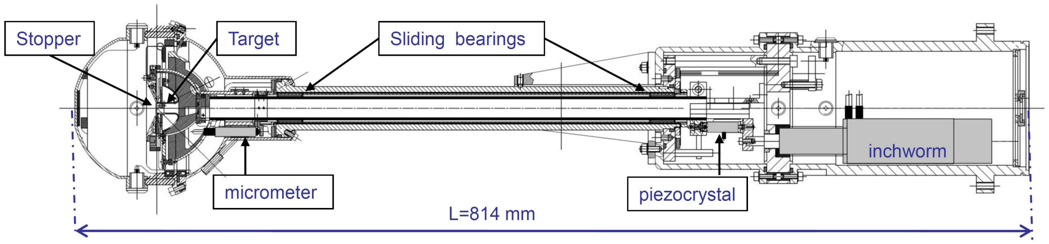


FIG. 1: A schematic view of the standard plunger device. The device's major components are marked.

The operation of the coincidence plunger is computer controlled and includes the readout and control of the electronic components and a feed-back loop for the correction of thermal drifts and beam-induced distance modifications.

Charged particle detection was prouven to be an useful tool in γ-ray spectroscopy and, in particular in the RDDS method, especially after Coulomb excitation in the few MeV/u energy range or in fusion-evaporation reactions for charged particle reaction channels. Of particular importance to the RDDS method is the abilitity to track and identify the evaporated particles or scattered beam ions. The tracking capability is correlated with the granularity of the charged particle detectors, while the identification capability is given by the use of E-ΔE telescopes. Thus, possible solutions for charged particle detection in RDDS experiments are a high granularity array of E-ΔE telescopes or Si photodiodes and a highly segmented Double Sided Strip Si Detector (DSSSD) annular E-ΔE telescope. However, the limited space available in the target chamber of the coincidence plunger makes impossible the use of such detector systems. The design of a plunger device with tracking capabilities is centered on the design of a new endcap for the plunger device that will allow the use of tracking detectors.

II. TECHNICAL DESIGN

The design of a new endcap for the plunger device dedicated to charged particle detection should consider several requirements:

- The geometry of the γ-ray spectrometers used in RDDS experiments. Most arrays have a spherical geometry, the HPGe detectors being mounted on rings around the target chamber at typical distances of $\sim$20 cm.
- The geometry of the tracking detectors. The endcap should be designed in a flexible way, that would allow to mount the highly segmented DSSSD annular detectors (that requires the most space) or arrays of E-ΔE telescopes or Si photodiodes and the associated cabling.
- The possibility to couple the plunger device to a magnetic spectrometer or to mount a beam dump downstream of the target and stopper foils and tracking detectors.
- Easy acces to the target and stopper foils in order to properly align them in respect to each other.

In order to meet this requirements, the design of the endcap should provide more space inside the target chamber, especially downstream of the target and stopper foils, while allowing to keep the same distance to the HPGe detectors. The proposed design solutions are to extend the reaction chamber in the direction of the beam, resulting in more cylindrical shape or to extend the diameter of the chamber, keeping a spherical symmetry. In both design solutions, the outer dimensions should be chosen in a way that the chamber fits into a sphere with a maximum radius of 20 cm. It should be possible to open the target chamber in a manner that easy access is provided to the target and stopper/degrader foils as well as to the particle detectors used.

In the following we will discuss several endcap designs that fulfill this requirements and the several tracking solutions.

A. Endcap design

The first design proposed, shown in Fig. 2, is suited for a sphere-like geometry of the Ge-array, where the beam enters on the central axis of the plunger device which is oriented perpendicular to the target plane. A modifed plunger-end cap was designed which provides space and meets all necessary criteria needed to install and operate a particle detector array. The design presented here allows the installation of particle detectors like an array of photo diodes or, alternatively, a double-sided silicon strip detector (DSSD) in forward direction at variable distances with respect to the target. With these detector systems it is possible to detect recoiling nuclei which are produced via a nuclear reaction inside the target.

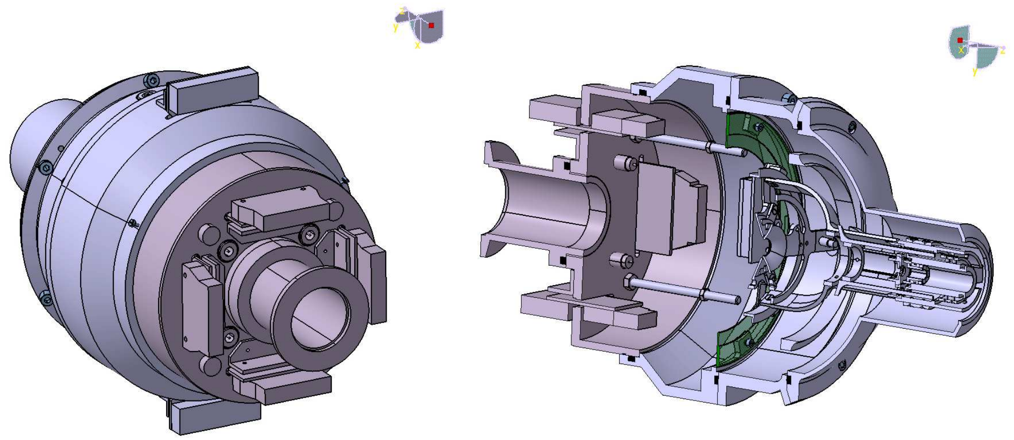


FIG. 2: (*Left*) Back view of a plunger-detector chamber. Four feedthroughs to read out the detector signals and four additional LEMO connectors can be seen. A vacuum flange in ISO KF standard is located at the back end. (*Right*) Cut through a plunger-detector chamber. A detector ring and its fixing with threaded rods can be seen.

The presented set-up allows for a relatively easy access to the plunger foils despite of the particle detectors which are mounted in a short distance to the target and stopper/degrader foils. Also the particle detectors can be exchanged quite easily even during an experiment as the detector cabling is simply plugged to the multi-wire electrical feedthroughs.

The chamber which hosts the particle detector arrays as well as all necessary electrical feedthroughs is directly screwed to the half-sphere of the plunger-target chamber. The chamber is vacuum sealed by a viton O-ring. The chamber is also equipped with a wide ISO KF 40 standard flange to enable additional pumping of the target chamber from downstream of the target foil. This is necessary to reduce the carbon build up on the plunger foils since the out-gasing of the detector, cable connectors and the detector support frame can be quite large.

The second design proposed, shown in Fig. 3, is better suited to house large area DSSSD annular detectors. The modified endcap is a hemisphere with an 87.5 mm radius, equipped with a ISO KF 40 standard flange to enable additional pumping and the installation of additional electrical feedthroughs. Easy access to the plunger foils and particle detectors is again assured.

The endcap that houses the detectors is vacuum sealed by a viton O-ring, but in order to reduce space the endcap is mounted without any screws on a flat large diameter disc mounted on the existing the plunger hemisphere. This design is compatible with most HPGe arrays, as its diameter is close to the maximum diameter of the standard plunger device, which was given by

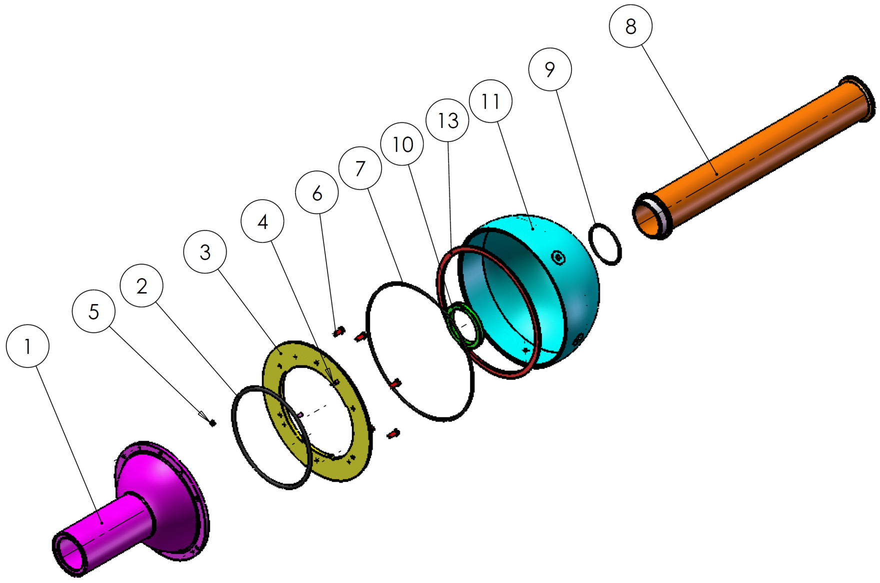


FIG. 3: View of a hemispherical plunger-detector chamber. On the lefthand side, the existing plunger hemisphere is shown, while on the righthand side the extended hemisphere that will house the particle detectors is shown. LEMO feedthroughs to read out the detector signals can be seen. A vacuum flange in ISO KF standard is located at the back end.

the flange where the two hemispheres were joined with screws.

Both designs presented here are add-on pieces to the standard plunger device, that are not requiring any modifications to the device other than replacing the standard endcap. In Fig. 4 a concept for a plunger device specifically designed to house tracking detectors is presented. In this design, the standard two piece spherical chamber of the plunger device is replaced by a large diameter three piece spherical chamber joined together without screws to maximize space. The central piece is fixed and will act like a support point for the tracking detectors and feedthrough connectors while the two side hemispheres, vacuum sealed with viton O-rings, can be easily unmounted to offer acces to the tracking detectors and target and stopper/degreder foils. A CF50 flange on the central piece will enable additional pumping required by the large volume of the chamber and considerable out-gasing of the detectors, mounting suports and cabling. The design presented in Fig. 4 is a concept design that with a diameter choosen to fit a specific Ge array and tracking detectors making this a dedicated device.

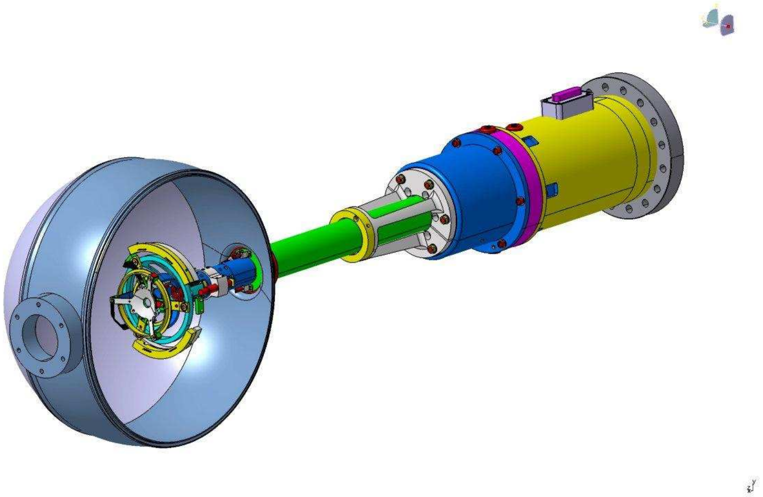


FIG. 4: View of a spherical plunger-detector chamber. The target and stopper/degrader supports are visible inside a three piece spherical chamber. The central piece is fixed and will provide suport for the particle detectors while the two side hemisphere can be unmounted, giving easy access to the particle detectors and target and stopper/degrader foils

B. Tracking detectors

As mentioned in the Introduction, several detectors systems where considered to be used for the tracking plunger design. The first solution is an array of photodiodes arranged in a matrix, providing the highest granularity at small scattering angles. An example of such an array made up of 32 photodiodes is presented in Fig. 5. The main disadvantage of this array is that the photodiodes array lacks the particle identification feature. The advantages are the low cost/unit and the good energy resolution obtained, making them usefull in experiments in which the scattered ions are tracked.

A second solution is a highly segmented Double Sided Strip Si Detector (DSSSD) annular E-ΔE telescope. An example of a annular DSSSD detector, segmented in 24 rings and 32 sectors is presented in Fig. 6. This detectors can be used in pair as annular E-ΔE telescope, thus providing particle identification. DSSSD detectors are available comercially with variable thickness and segmentation.

The high granularity of the segmented annular DSSSD provides excellent position sensitivity, good energy resolution and the capacity to sustain high counting rates. The disadvantadges are the high cost/unit and the high number of electronic channels requiring a complex data acquisition system. The cabling and vacuum feedthroughs for this detectors are based on commercially

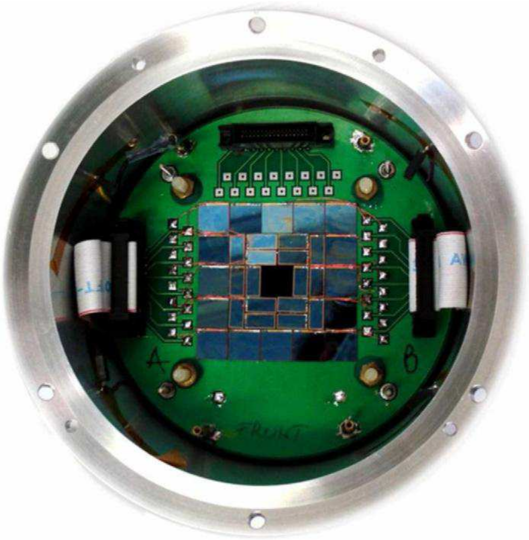


FIG. 5: Example of a 32 photodiodes array

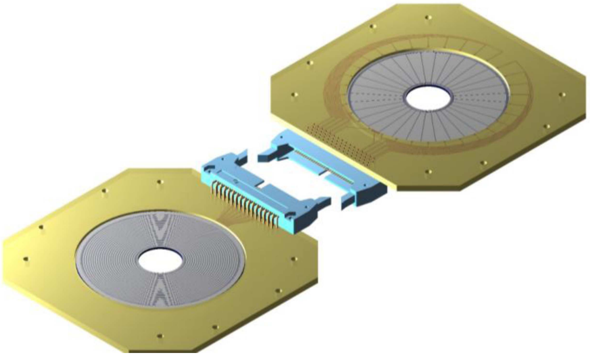


FIG. 6: Example of a annular double sided strip silicon detector (DSSSD), segmented into 24 rings and 32 sectors

available high density LEMMO connectors.

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[1] A. Dewald, O. Möller and P. Petkov, Prog. Part. Nucl. Phys. **67**, (2012), 786-839.