Particle detectors for the observation of rare nuclear decay modes in storage rings

– The ParticLE sIlicon-scintillator DEtector for Storage rings (PLEIADES) detector

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Motivation

Nuclear data such as masses, half-lives, reaction cross-sections and information on decay modes are key to helping us understand nucleosynthetic processes and help to develop and constrain nuclear models.

When nuclei exist as highly-charged ions (HCI), their decay rates and available decay modes may change and can have profound impacts on nucleosynthesis pathways.

Storage rings offer unique options to explore nuclear decays under stellar conditions. Experiments conducted by the ILIMA collaboration aim to use novel detection methods to study these exotic decay modes. The newly commissioned PLEIADES detector will significantly increase the efficiency of these measurements at GSI and in future at FAIR.

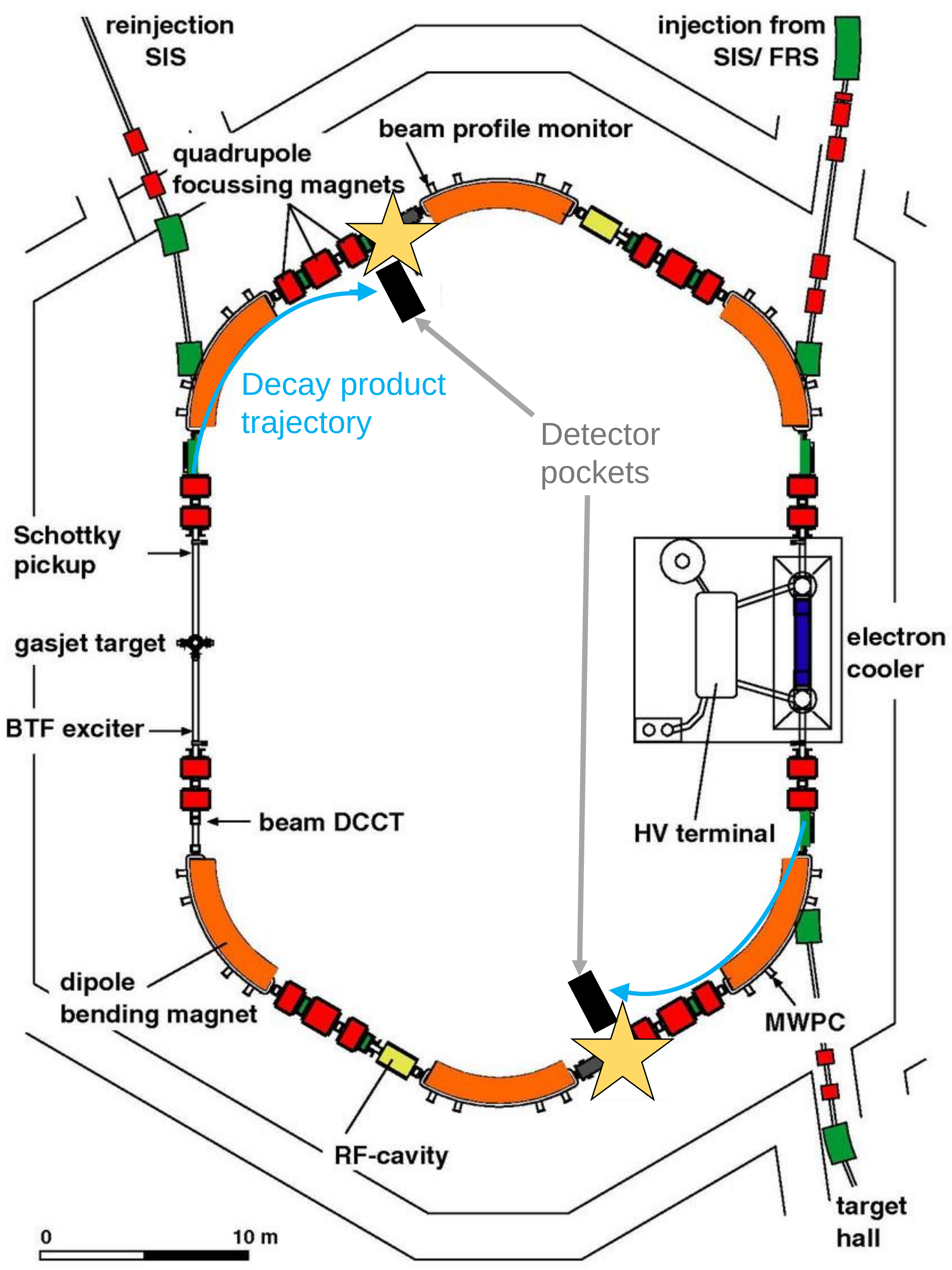


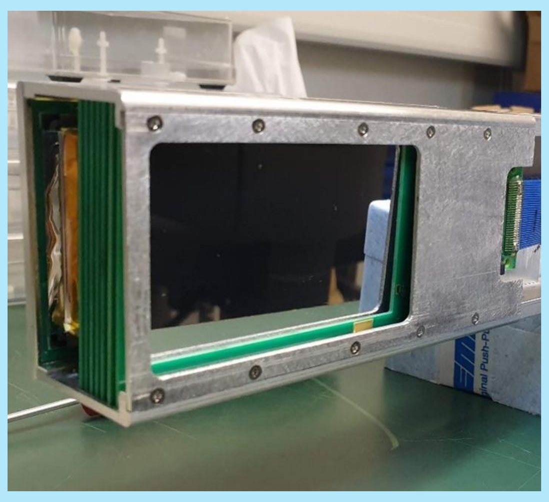
Figure 1. Schematic of the ESR showing the pocket positions (stars) in which the new detector may be installed. Adapted from [1].

Study of HCIs at storage rings

Radioactive nuclei can be stored in the Experimental Storage Ring (ESR) at GSI, Darmstadt, in highly-charged states. As stored ions decay, their mass-to-charge ratio *A/Q* changes and they may move to a different trajectory within the ring or leave the acceptance completely. Ions decaying in the long, straight sections will be deflected by the dipole and detectors placed in pockets offset from the beam axis can be positioned to accept those ions leaving the ring. Complimentary techniques, such as Schottky mass spectrometry allow the symbiotic measurement of multiple decay properties simultaneously.

The PLEIADES detector

The ParticLE sIlicon-scintillAtor DEtector for Storage rings (PLEIADES) detector is a dE-E telescope combining multiple thin silicon detectors with a thick scintillating stopper crystal coupled to a silicon photodiode.



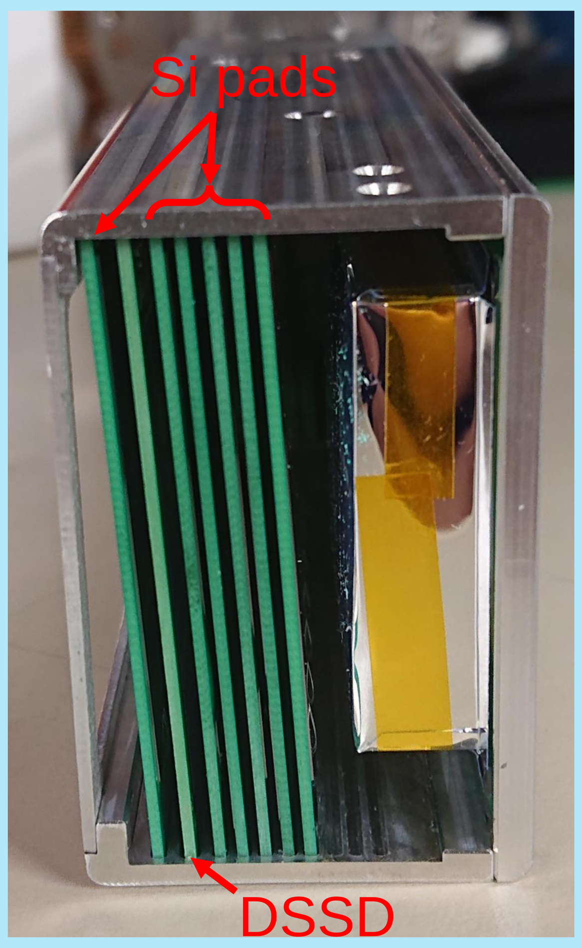


Figure 2. The PLEIADES detector viewed from the front (above) and end (right). Visible is the silicon detector stack, and scintillation crystal wrapped in reflective foil.

PLEIADES is based on the prototype CsISiPHOS [2] detector but makes several upgrades. It is comprised of:

- 6x 500µm Micron SSSDs with an active area of 60 x 40 mm^2 and 7 vertical *p*-side strips for a multi-sampled dE measurement
- 1x 300µm Mirion DSSD with an active area of 60 x 40 mm^2 and 60 x 40 segmentation for *x-y* position sensitivity
- A 55 x 38 x 10 mm^3 scintillating stopper crystal coupled to a silicon photodiode to conduct a total energy measurement. To maximise light collection, the crystals are wrapped in reflective foil.

Three scintillation crystal materials were chosen for a range of stopping powers: CsI (ρ=4.5g cm^{-3}), GAGG (ρ=6.6g cm^{-3}) and BGO (ρ=7.1g cm^{-3}). Energy deposition simulations of 280 MeV/u ^{208}Pb incident upon 3.3 mm of silicon and 10 mm of scintillation material, shown in Fig. 3, demonstrate the enhanced stopping power of both the BGO and GAGG over CsI, enabling lighter nuclei to be effectively stopped. Space for up to 1 mm of additional degrader is also included in the design to further increase stopping power.

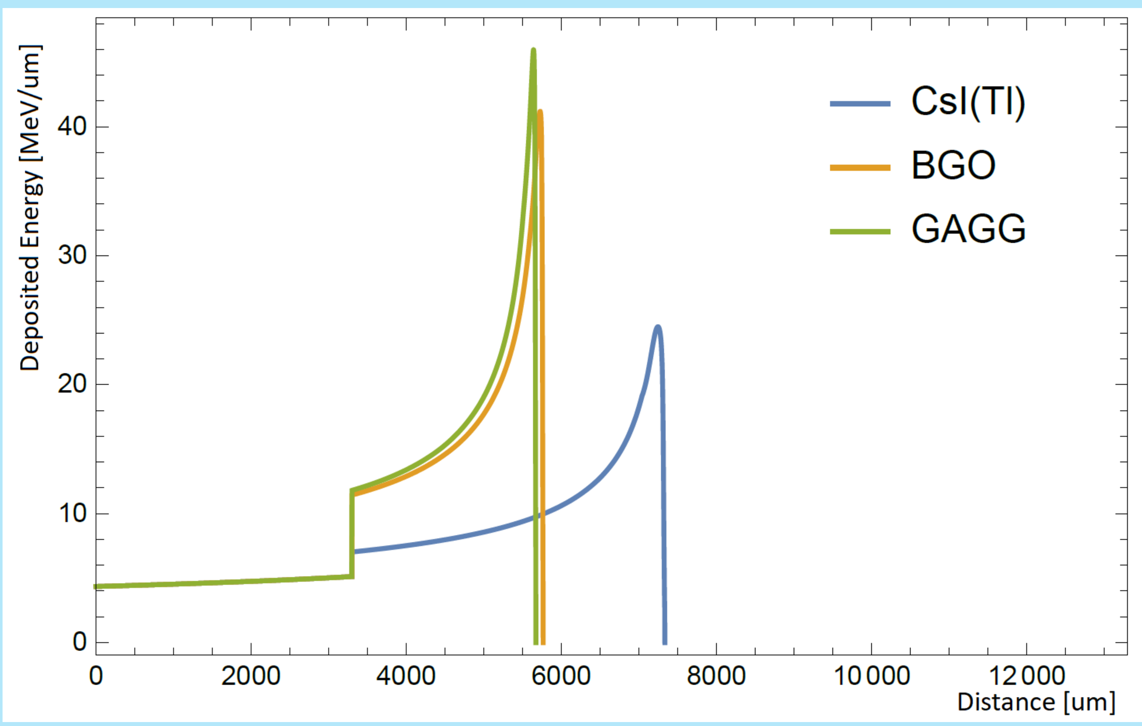


Figure 3. Simulated energy deposition of 280 MeV/u ^{208}Pb in 3.3 mm of silicon and 10 mm of scintillation material.

Installation and testing at the ESR

Following initial testing and construction at TRIUMF, Canada, the detector was installed at the ESR in May 2022. This included the installation and testing of both the PLEIADES detector and an upgraded GSI FEBEX-based data acquisition system (DAQ) [3] for compatibility with future FAIR experiments.

In June 2022, ^{208}Pb^{82+} primary beam was stored in the ESR at 260 MeV/u and ^{208}Pb^{81+} ions were observed in the detector, formed by electron recombination in the electron cooler. This test demonstrated full operation of all detectors, as well as integration with the upgraded FEBEX DAQ.

Fig. 4 shows an example energy spectrum from one of the silicon pad detectors during this test. A band of approximately equal energy deposition can be seen across all seven front strips as well as the rear active area (strip 8).

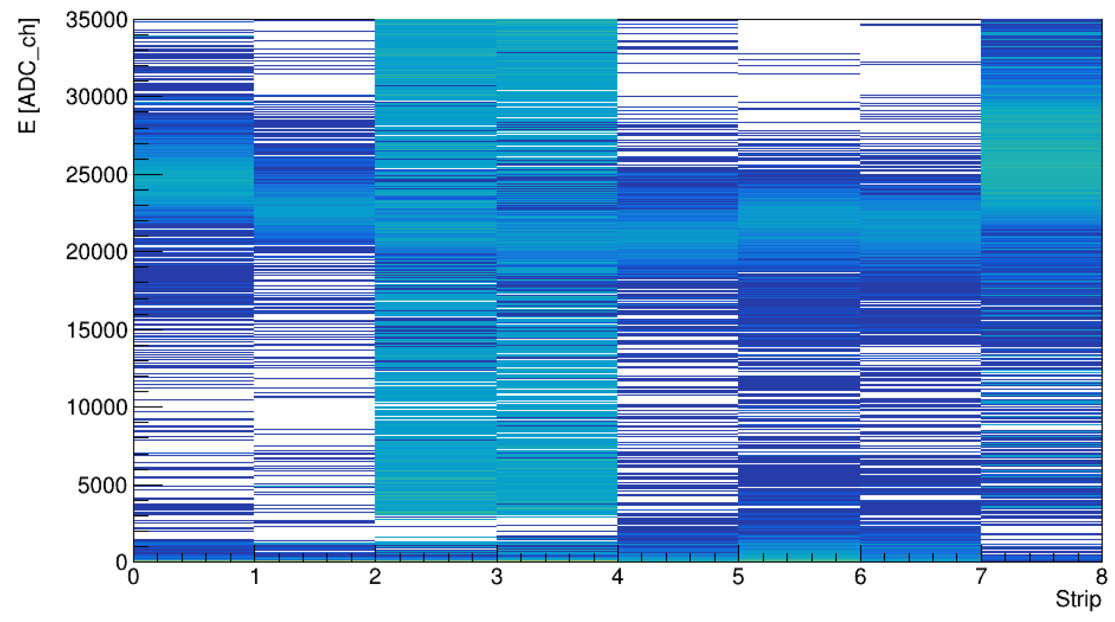


Figure 4. Energy spectrum obtained with 260 MeV/u ^{208}Pb^{81+} ions incident upon a 500µm silicon pad detector. Consistency can be seen between all sever front strips and the rear active area (strip 8).

Outlook

After successful installation and initial tests of the PLEIADES detector at the ESR, the ILIMA collaboration now possesses two powerful dE-E detectors capable of identifying high-energy heavy ions ready for immediate use in the ongoing FAIR Phase-0 campaign and beyond.

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References

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Discovery, accelerated