Status report on the development of a matrix detector for CRYRING@ESR

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ABSTRACT

The CRYRING@ESR facility at FAIR requires beam diagnostics systems compatible with **ultra-high vacuum** (UHV) conditions 10^{-12} mbar, high **mechanical strength**, **temperature resistance**, and **radiation tolerance**. Within the **RoCRYDET** project (2021–2023), a state-of-the-art YAP:Ce detector was installed, meeting these stringent criteria and now used in in-beam experiments. However, its bulk scintillator lacks position sensitivity, a key feature for the upcoming **MaDeIRo** project (2023 - present).

EXPERIMENTAL SETUP AT CRYRING@ESR

In the experiments conducted at CRYRING@ESR, one of the initial research directions focused on the use of YAP:Ce scintillating crystals for the detection of heavy ions. These crystals were selected due to their scintillation properties and their ability to withstand MHz-level counting rates under ion energies ranging from a few hundred keV/u to 14.8 MeV/u for $^{238}U^{92+}$.

YAP:Ce Detector - RoCRYDET

- ➢ The detector meets stringent performance criteria:
  - ★ UHV compatibility,
  - ★ high radiation hardness,
  - ★ and excellent timing resolution.
- ➢ Two RoCRYDET versions were tested with an ^{241}Am source under UHV (2×10^{-8} mbar).
- ➢ Results showed a detector efficiency of 0.98 (+0.02, -0.06).
- ➢ The RoCRYDET project led to the successful installation of a YAP:Ce detector at CRYRING@ESR, now used in in-beam experiments.
- ➢ However, the YAP:Ce bulk scintillator lacks position sensitivity, crucial for the **MaDeIRo project.**

Matrix Detector - MaDeIRo

We developed an experimental system, based on the RoCRYDET project, for testing various radiation sensors using both a radioactive source and an ion beam from a 3 MV Tandetron accelerator. The system configuration consists of two main components: the electronic measurement and control assembly and the vacuum components assembly. It includes a six-way cross chamber that simulates ultra-high vacuum (UHV) conditions, with pressures as low as 1×10^{-11} mbar, allowing precise positioning of sensors for radiation exposure.

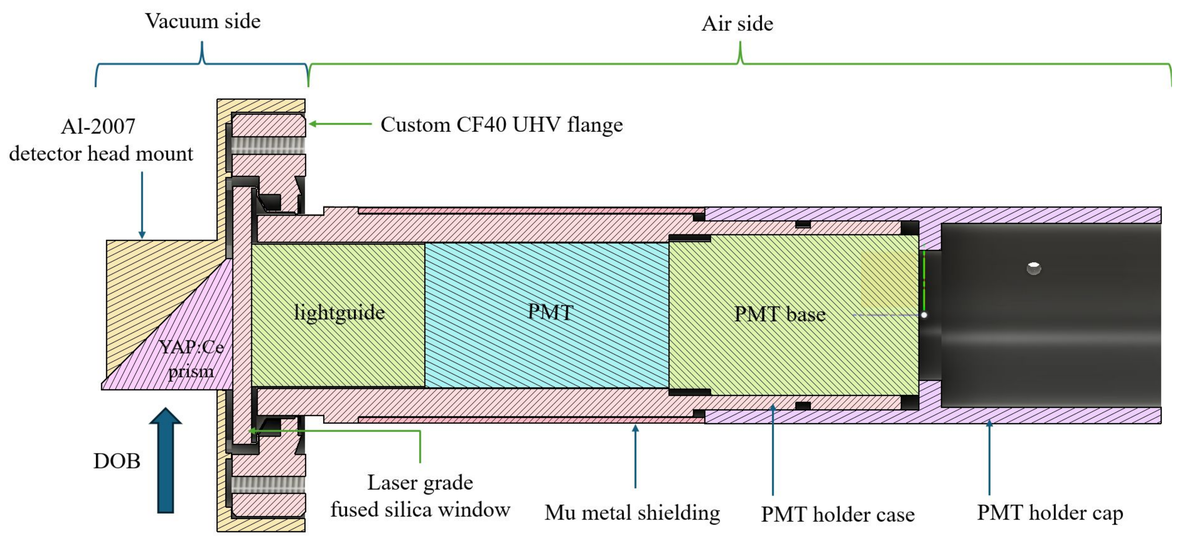

Figure 1 Schematics of the RoCRYDET installed at CRYRING@ESR

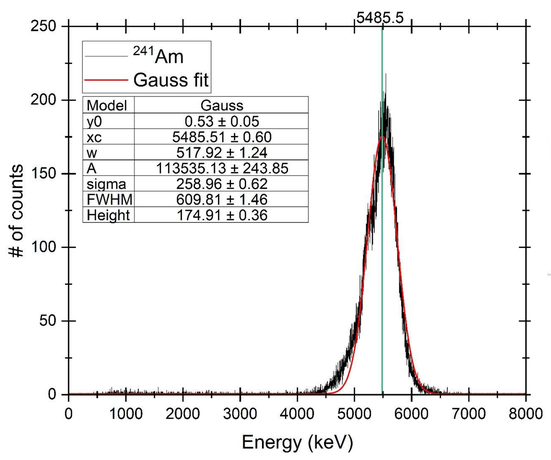

Figure 2 Energy spectrum for the ^{241}Am radioactive source

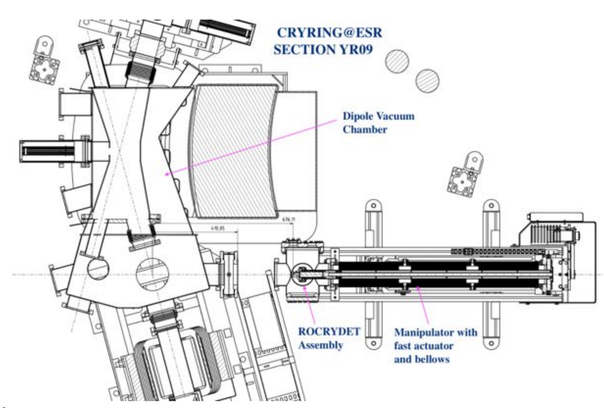

Figure 3 CRYRING@ESR YR09 Dipole Magnet cross-section

Experimental tests

Photodiode Analysis and Ion Beam Exposure

In this study, we focused on the analysis of PDB-C613-2 silicon photodiodes, using Rutherford Backscattering Spectrometry (RBS) and Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX). The RBS technique, employing a 2.6 MeV He beam from a 3 MV Tandetron accelerator, was used to investigate the surface of the polycrystalline silicon. The RBS spectra, simulated with SIMNRA (v7.02), confirmed that the silicon layer was much thicker than the profiling capability of the beam. No impurities were detected on the surface, suggesting either their absence or a concentration below the detection limit.

We performed SEM-EDX on two photodiodes: one exposed to ion beam experiments and one pristine sample. The irradiated photodiode showed visible damage with craters ranging from 50 to 200 microns, while the untouched sample remained intact with no surface alterations.

Figure 4 Images of the photodiodes used and positioned on the sample holder of the SEM-EDX microscope, in cross-section and horizontal layout.

Monte Carlo Simulations of Ion-Silicon Interaction

Monte Carlo simulations, conducted with the FLUKA code, were used to study the interaction of ion beams with silicon in the CRYRING@ESR energy range. Results revealed that high-energy ions (uranium, gold, and protons) penetrate 100-300 μm into the silicon, while low-energy ions have a range of less than 5 μm. These findings suggest that the minimum thickness of the detector should be at least 300 μm. Simulations involving 5 MeV alpha particles in 510 μm silicon solar cells showed that all alpha particles were stopped inside the cells. The position of the Bragg peak is crucial for defect generation, which was confirmed by the SEM-EDX analysis of the irradiated solar cells.

Energy resolution was determined at ~6%, with a Full Width at Half Maximum (FWHM) of around 250 channels at a peak position near channel 4090. The energy spectrum, obtained from a ^{241}Am radioactive source, demonstrates the system's promising performance.

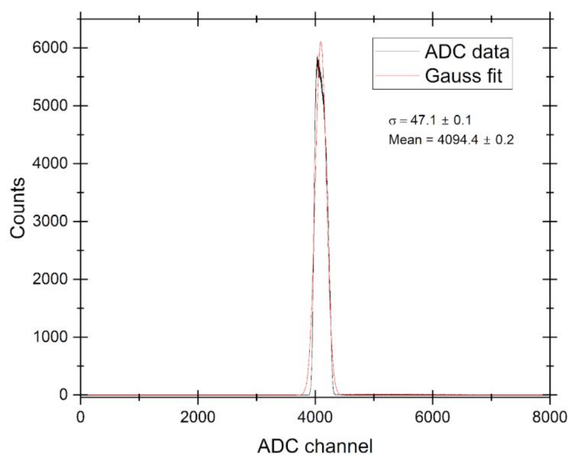

Figure 5 Energy spectrum for the ^{241}Am radioactive source recorded by the PDB-C613-2 photodiode.

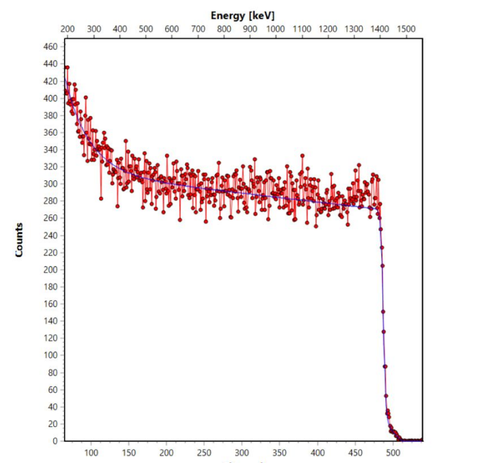

Figure 6 The RBS spectrum of a polycrystalline Si wafer

CONCLUSIONS

Photodiode analysis using RBS and SEM-EDX confirmed significant surface damage after ion exposure, with crater formations up to 200 microns, while pristine samples remained intact. Monte Carlo simulations using FLUKA revealed that high-energy ions penetrate 100-300 μm into silicon, emphasizing the need for detectors with a minimum thickness of 300 μm.

Preliminary energy resolution measurements yielded a promising ~6% resolution, with a FWHM of around 250 channels. The system's performance, confirmed by energy spectra from a ^{241}Am source, supports its suitability for future ion beam experiments at CRYRING@ESR.

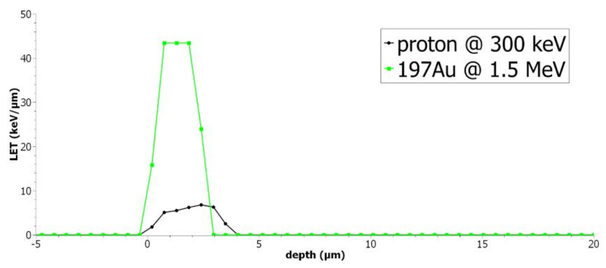

Figure 7 LET of different ions inside silicon at the lower boundary of the CRYRING@ESR energy range

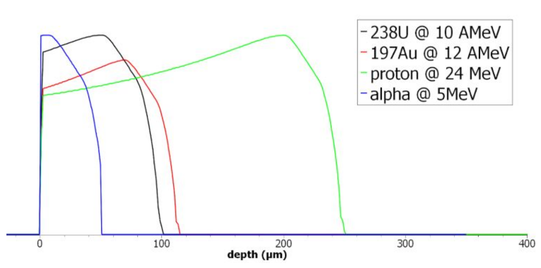

Figure 8 LET of different ions inside silicon at the upper boundary of the CRYRING@ESR energy range

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