

# Design and Implementation of a Space Radiation Microdosimetric Detection Prototype

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## INTRODUCTION

Space Radiation Environment and Its Sources:

- SPE (Solar Particle Event): Protons
- GCR (Galactic Cosmic Ray): Protons,  $\alpha$  particles, and high-energy heavy ions
- TPR (Trapped Particle Radiation): Protons, electrons

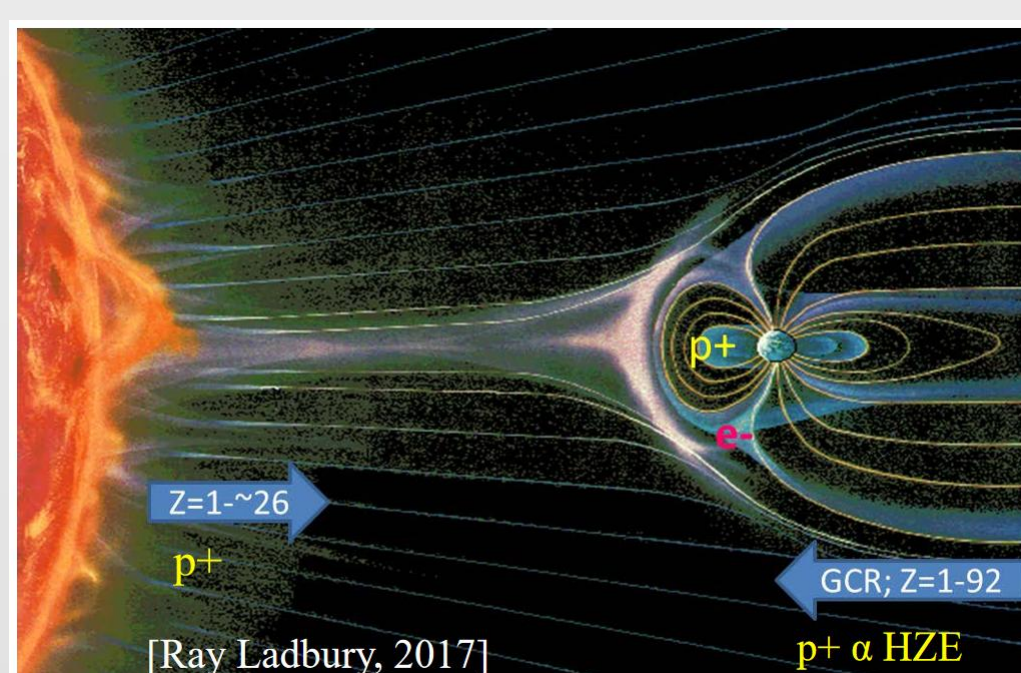


Fig.1. Space Radiation Environment (Source: NASA)

Charged-particle energy deposition in DNA may induce DNA damage, gene mutations, and increased cancer risk, **microdosimetry systems** are important tools for studying microscopic energy deposition and related biological effects.

## STACKED PIXEL DETECTOR STRUCTURE

A **stacked silicon pixel detector system with an integrated microfluidic cell-culture chip** has been developed for space radiation microdosimetry to study radiation effects on human cells at the micrometre scale.

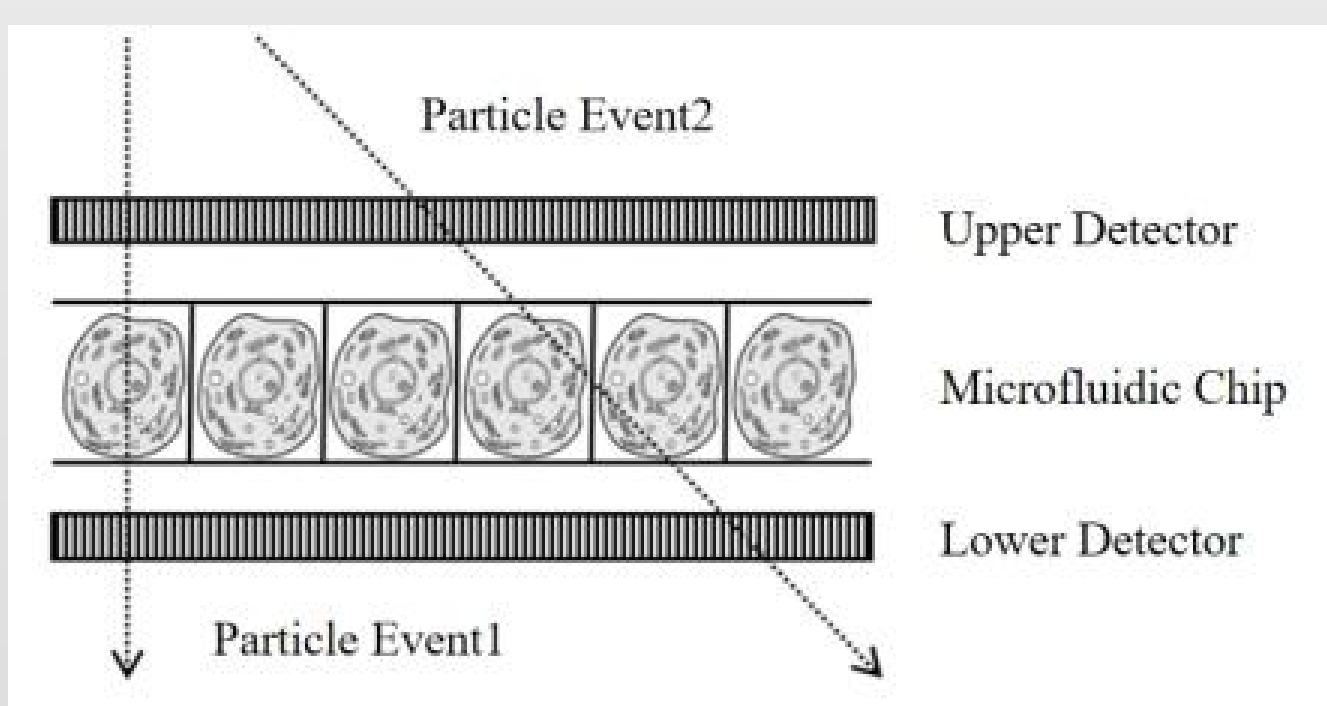


Fig. 2. Schematic of Stacked Layout

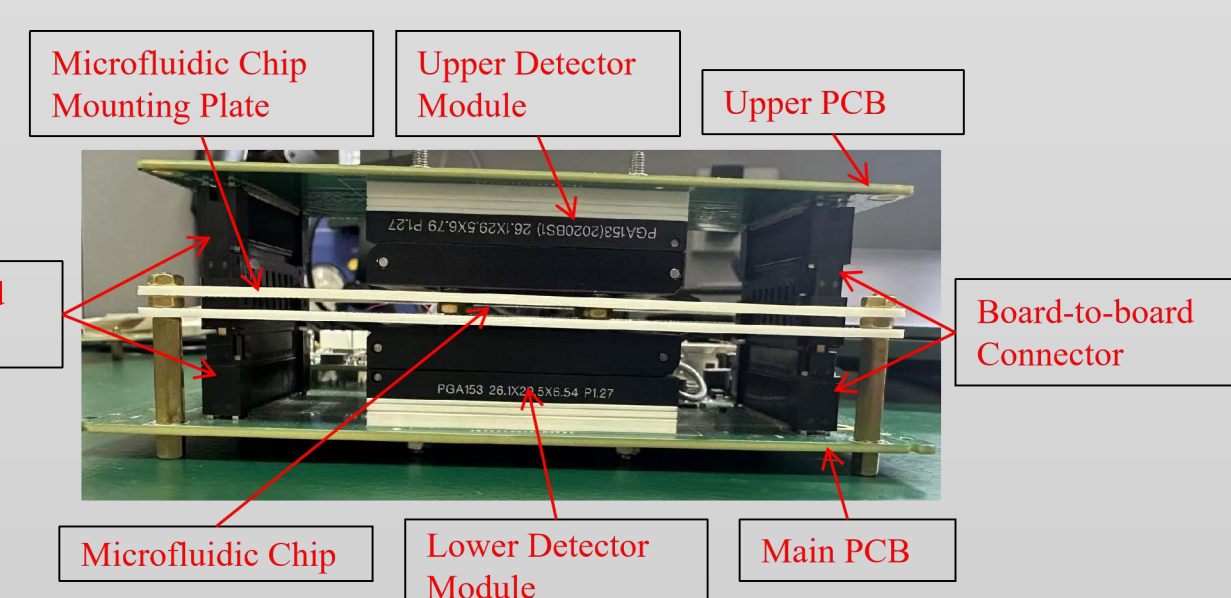


Fig. 3. Physical Layout of the Stacked Structure

Tab.I Silicon Pixel Detector Specifications

Parameter	Value
Si Thickness	10um
Pixel Size	$6.5 \times 6.5 \mu\text{m}^2$
Total Pixels	$2048 \times 2048$
Detection Area	$13.3 \times 13.3 \text{mm}^2$
Pixel Clock Frequency	600MHz
Date Rate	4.8Gbps

## REAL-TIME READOUT SYSTEM

Based on a **Xilinx Kria K26 SOM (Zynq UltraScale+ MPSoC)**, a modular synchronized readout system integrates multi-rail power supply, detector configuration, timing control, data alignment, continuous image acquisition, and high-speed transmission.

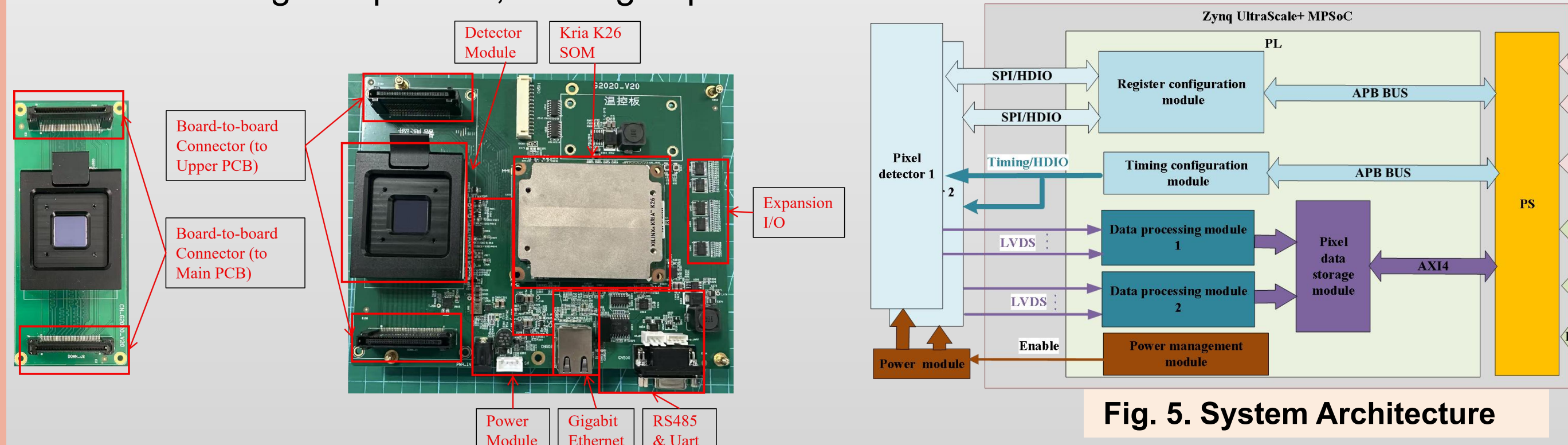


Fig. 5. System Architecture

**PL** side: Drives detector operation and stores acquired data.

**PS** side: Receives configuration information and transmits data.

**Advantages** of the board-to-board direct connection:

- Detector Alignment
- Shortened Signal Transmission Paths

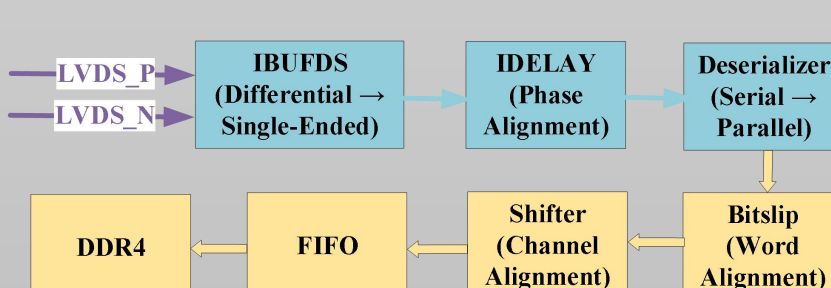


Fig. 6.Pixel Data flow

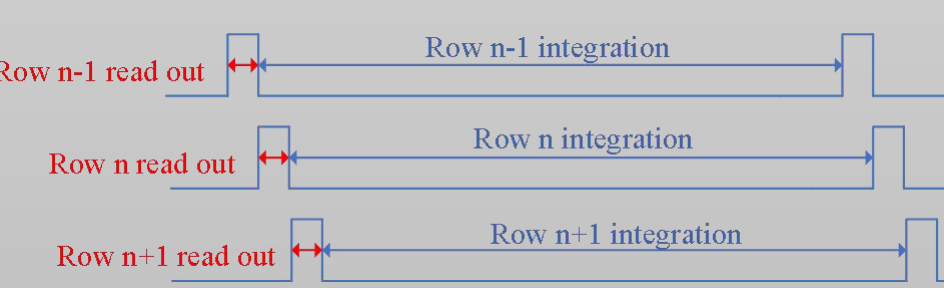


Fig. 7.Rolling Shutter Mode

**In rolling shutter mode, the system dead time is equal to the single-row readout time (0.94  $\mu\text{s}$ ).**

## DARK FRAME UNIFORMITY

The same detector was mounted on the **upper and lower PCBs** to acquire dark-field mean images, from which the row/column means and RMS values were calculated.

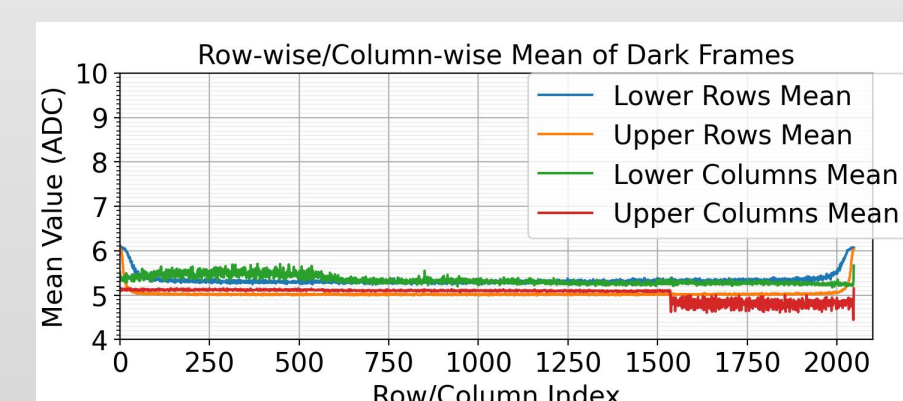


Fig. 8. Baseline Mean Curve

Tab.II RMS Distribution

RMS Range	Lower Detector		Upper Detector	
	Row-Wise	Column-Wise	Row-Wise	Column-Wise
[0, 0.5)	13.23% (271)	41.85% (857)	16.41% (336)	63.09% (1292)
[0.5, 1)	86.43% (1770)	57.91% (1186)	83.25% (1705)	36.67% (751)
[1, 1.5)	0.34% (7)	0.24% (5)	0.34% (7)	0.24% (5)

## $\gamma$ -RAY AND $\beta$ -PARTICLE RESPONSE

The prototype system was irradiated with  $^{60}\text{Co}$  and  $^{90}\text{Sr}$  sources to evaluate its response to  **$\gamma$ -rays and  $\beta$ -particles**.

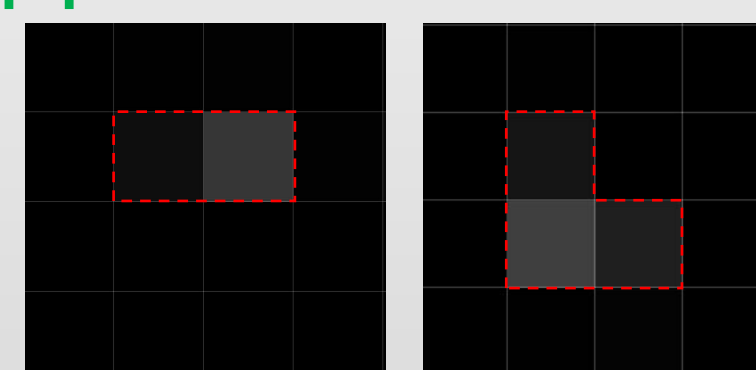


Fig. 9.  $\beta$ -Particle Event Image

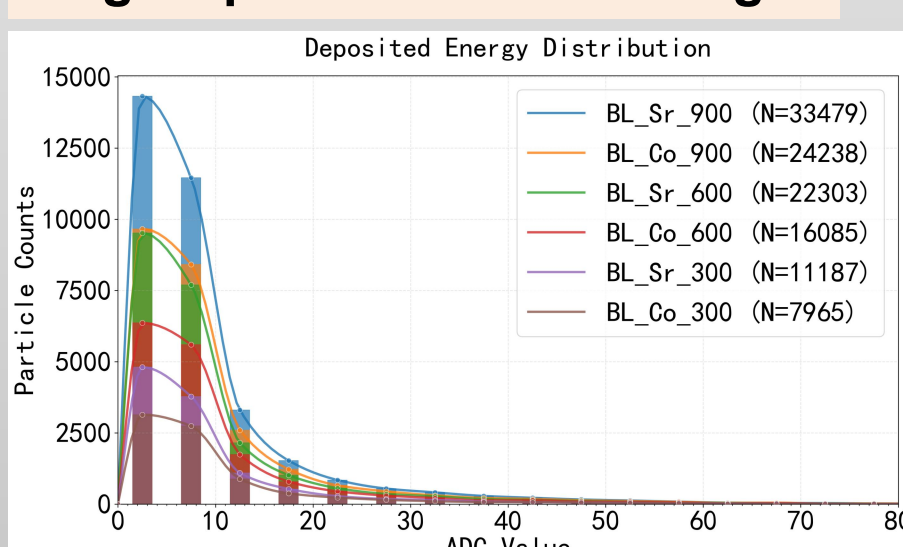


Fig. 10. Radioactive Source Deposited Energy Distribution

## PROTON BEAM IRRADIATION

**Proton beam irradiation** experiments were conducted using the Varian ProBeam system. The prototype was placed on the treatment couch, with the detector sensitive region center laterally offset by approximately 120 mm from the beam axis. The vertical distances from the beam exit window to the upper and lower detector planes were 657.55 mm and 682.45 mm, respectively.

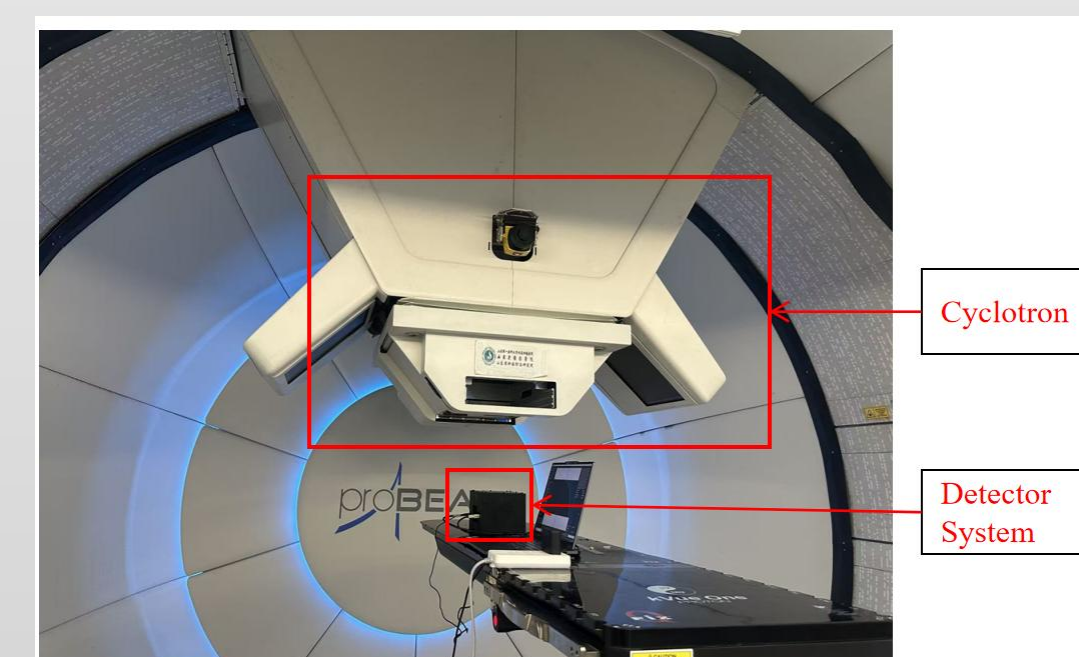
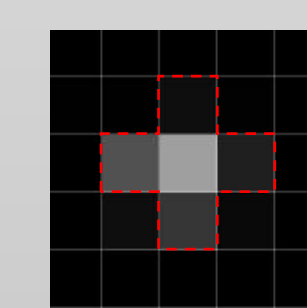
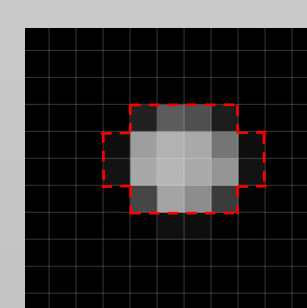


Fig. 11.Proton Beam Experimental Environment



Proton Image



Heavy Ion Image

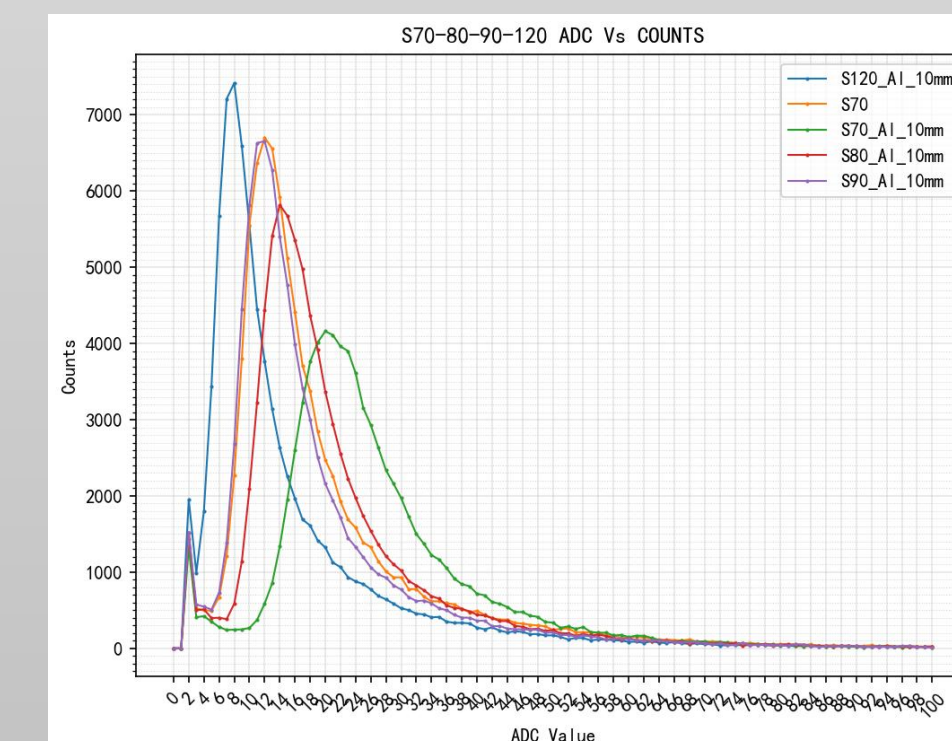


Fig. 12.Proton Deposited Energy Distribution

## CONCLUSION

- The electronic system exhibits good baseline consistency and noise stability.
- The system can distinguish particle types and incidence positions from event morphology.
- **Particle event correlations between the upper and lower detectors have not yet been observed.**