High-dose-rate precise ionization chamber with real-time electronics for SC cyclotron-based proton therapy system

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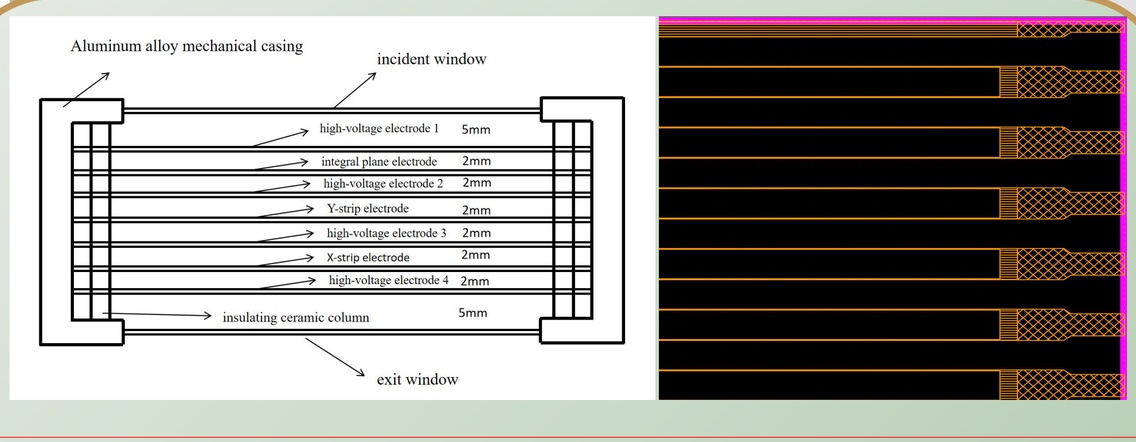
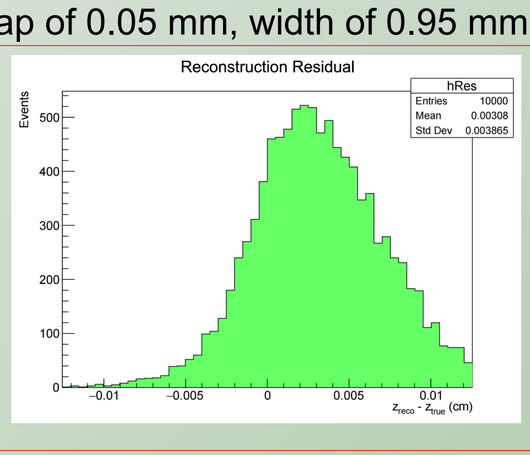
Abstract

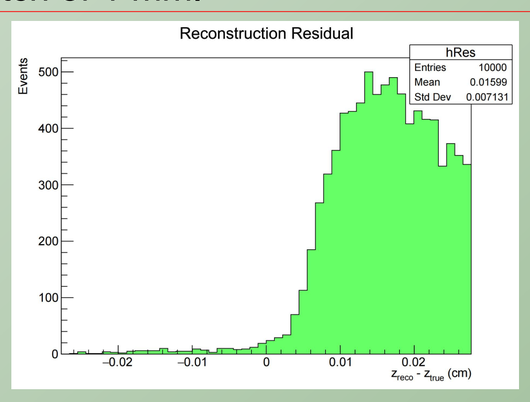
A 240 MeV microampere-level extracted beam is now available from the superconducting cyclotron CYCIAE230, a non-intercept high-dose-rate ionization chamber (IC) system is designed and tested at the cyclotron exit, providing real-time proton beam current measurements for feedback control. The same design is used for the irradiation station downstream of the beamline, for proton FLASH studies, and the radioactive-effect studies of integrated circuits in aerospace applications. A laser-etched, ultra-thin, gold-plated PI film is selected for both the integral plane and the multi-strip cathode in this design to increase the IC's lifetime, aided by a dry nitrogen gas system. Environmental compensation circuits, integral circuits, and front-end 128-channel ADCs are integrated into the IC to improve the system's signal-to-noise ratio and accuracy. The multichannel charge readouts are acquired via an ultra-thin multichannel coaxial cable that provides high-speed digital communication between the ADCs and the readout SOCs. A bare-metal C++ program is developed to run on a ZYNQ processor and provide real-time current and charge readings. The IC and its readout electronics have been integrated and tested with a proton beamline of the CYCIAE230 cyclotron. The preliminary test results show that high accuracy and repeatability can be achieved after calibration using the Faraday cup downstream.

Overall structure and Position resolution



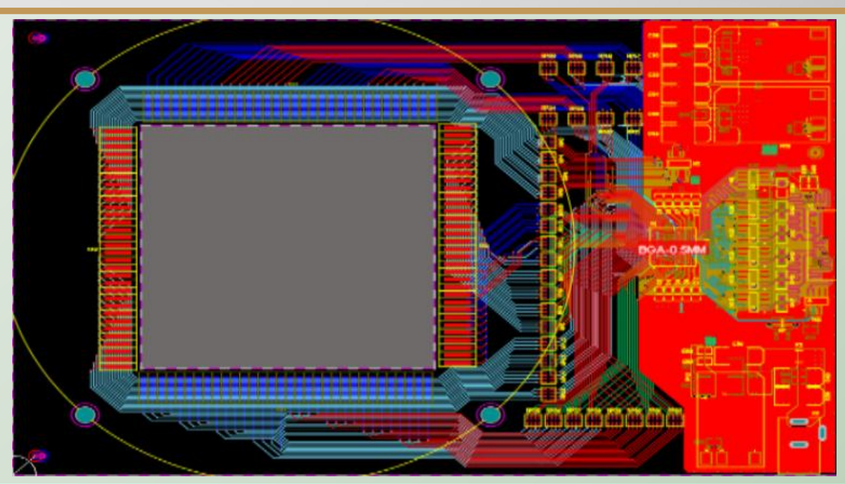
Selection of electrode material : A laser-etched, ultra-thin, gold-plated PI film
Selection of working gas : dry nitrogen
gap of 0.05 mm, width of 0.95 mm, pitch of 1 mm.



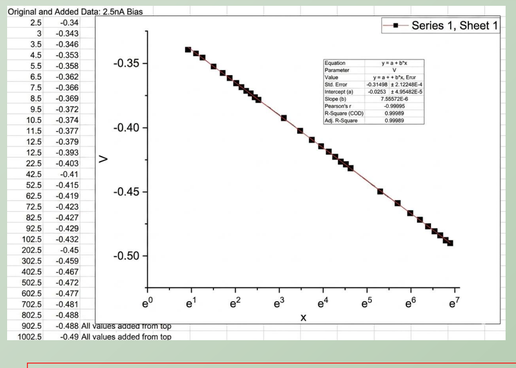


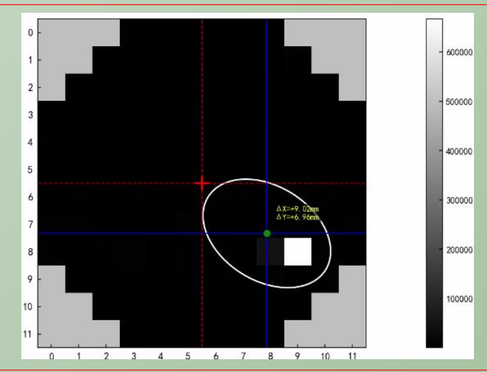
Intrinsic resolution : 38.7 μm

Electronics Realisation



The architecture of the proposed system is built around three core units: a custom-designed ionization chamber, a dedicated ionization chamber controller, and a host computer.The ADAS1128 converter chips are precision_x0002_soldered directly onto the rear side of the ionization chamber's signal electrode board.





Dose and location map

Experimental results

The system integrates environment compensation circuit, charge integration circuit, 128 channel front-end ADC, ultra-thin multi-core coaxial cable and readout system based on zynq SOC, and develops bare metal c++real-time software

A front-end electronics with a phase detector was designed to detect beam phase drift. Additionally, an envelope detector has been included to quantify the beam intensity. An FPGA processes the amplitude and phase difference and ultimately transmits to the host computer.

Conclusions

A high-dose-rate ionization chamber beam monitoring system has been designed and tested for the CYCIAE230 superconducting cyclotron. The electronics chain—comprising an environmental compensation circuit, a dual-range charge integration circuit, a 128-channel synchronous front-end ADC, an ultra-thin multichannel coaxial cable, and a ZYNQ SoC readout board with bare-metal C++ firmware—delivers real-time beam current and transverse profile measurements with better than 0.5% linearity and 0.18% RSD repeatability after Faraday cup calibration. The system meets the monitoring requirements for both proton FLASH radiotherapy research and aerospace IC single-event effect studies.