# The Realization of Ultra-High Dose Rate and Potential Frontier Applications on 230 MeV SC Cyclotron CYCIAE-230

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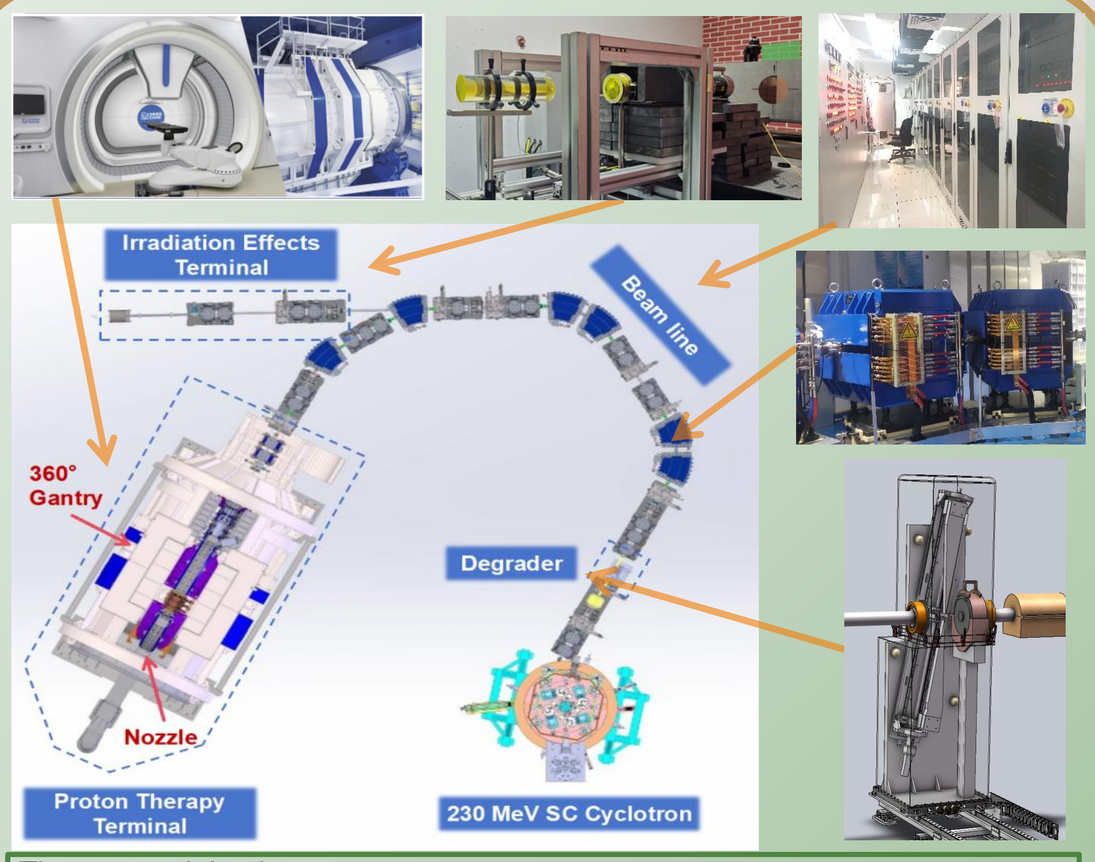
## Abstract

A cyclotron-based proton therapy system developed by CIAE includes a superconducting cyclotron CYCIAE-230, a beam line with a fast energy selection system, a 360° gantry, and a pencil beam scanning nozzle. There is another beam line for proton irradiation, used for research on radiation effects in electronics and power devices. In the past two years, the performance of CYCIAE-230 has been significantly improved. We optimized the insulation structure of the cathode inside the micro-PIG source for high power operation; adjust the first gap in the central region; increase the duty cycle of the acceleration system from 35% to CW; fine tune the first harmonics and positions of HV electrostatic deflectors for beam extraction to increase the efficiency, improve the vacuum around the HV feeding to significantly reduce the multipactoring, and enhance the operational stability. The extracted beam intensity up to 1820 nA has been obtained, providing sufficient current for achieving ultra-high dose rate. Based on conservative estimates, the dose rate of CYCIAE-230 will be much higher than 3600 Gy/s. And as published previously, it is 45 ms the time interval varying one energy step of the degrader and 51 units of the magnets, and it is better than 0.3mm the isocenter of the 360° gantry. It is obvious that the potential frontier applications could be FLASH and Spot-Scanning Arc Therapy. The $5\times10^{11}$p/cm$^2$/s high fluence rate, CW beam, wide energy range, high uniformity proton irradiation facility, based on CYCIAE-230, is also suitable for research on radiation and biological effects.

## A Research Platform Based on a SC Cyclotron




The system inlucdes:

- a **superconducting cyclotron (CYCIAE-230)**,
- a **beamline equipped with a fast energy selection system**,
- a **360° gantry**,
- a **pencil-beam scanning nozzle**, and
- a **proton irradiation terminal**

## The Realization of Ultra-High Dose Rate

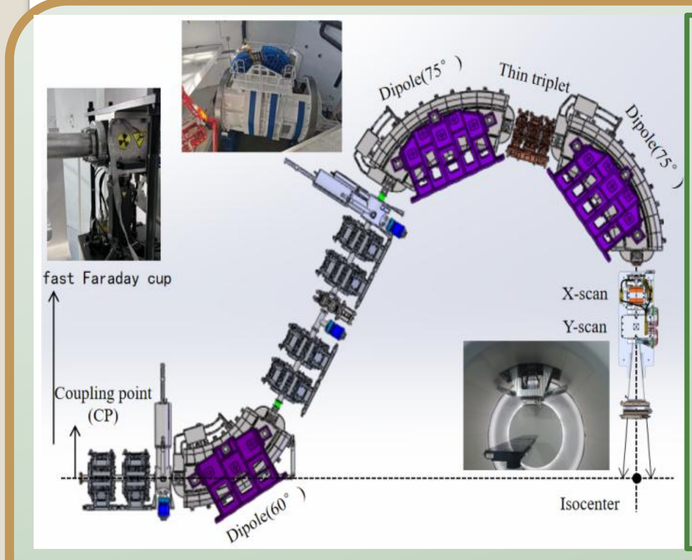
**A series of improvements was implemented on the CYCIAE-230.**

- **Ion Source**: A new ion source body with a shorter chimney was manufactured.
- **RF system**: Adjusting the position of the ceramic window.
- **Superconducting Coil**: Fine-tuning the superconducting coil suspension.
- **Beam Extraction**: Fine-tuning the Dee voltage, the first harmonics and the ESD.

| Trim Rod parameters | Central region beam current | Extracted beam current | Extraction efficiency |
|---|---|---|---|
| 7.5G, 165° | 7.44 nA | 6.24 nA | 83.9% |


Real-Time Tunning Software and High-Intensity Beam Test Results

## Potential Frontier Applications




**Typical Parameters:**

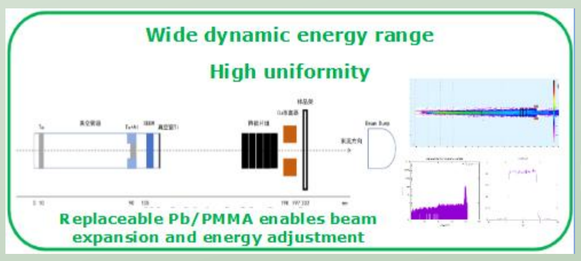
- Rapid energy switching
- (45 ms)
- High positioning accuracy (0.3 mm)
- Ultra-high dose rate.

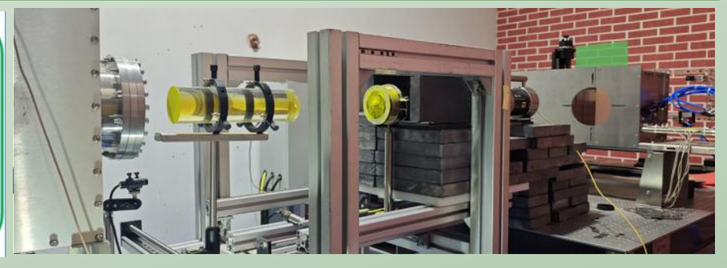
**Applications:**

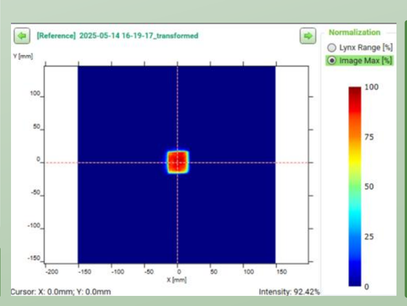
- Spot-Scanning Arc Therapy
- FLASH therapy
- Life-Science Research

Proton Therapy Terminal

### Irradiation Effects Terminal






**Typical Parameters:**

- The uniformity exceeding **90%** was measured within a **30 mm** × **30 mm** irradiation field.
- Energy range from **20 to 242 MeV**

**Applications:**

- Radiation effects in electronics and power devices
- Aviation electronics
- Autonomous driving

## Conclusions

Following commissioning in 2025 and 2026, the CYCIAE-230 superconducting cyclotron has successfully achieved ultra-high dose-rate capability. During this process, the performance of several key cyclotron systems, including the ion source, RF system, magnet system, and extraction system, has been thoroughly investigated and optimized. These optimizations have yielded an average extracted beam current of 1,820 nA under pulsed-RF operation with a duty factor of 84.4%. To date, the facility has established two operational terminals: one dedicated to proton therapy and another for irradiation effects. The proton therapy terminal will support advanced proton therapy research (including FLASH therapy) and life-science studies, while the irradiation effect terminal will continue to expand its application scope to provide a simulation of the space-particle radiation environments.