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Novel Upright CBCT Image-Guided Technology

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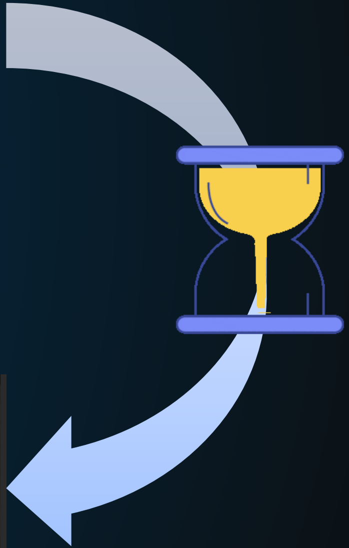
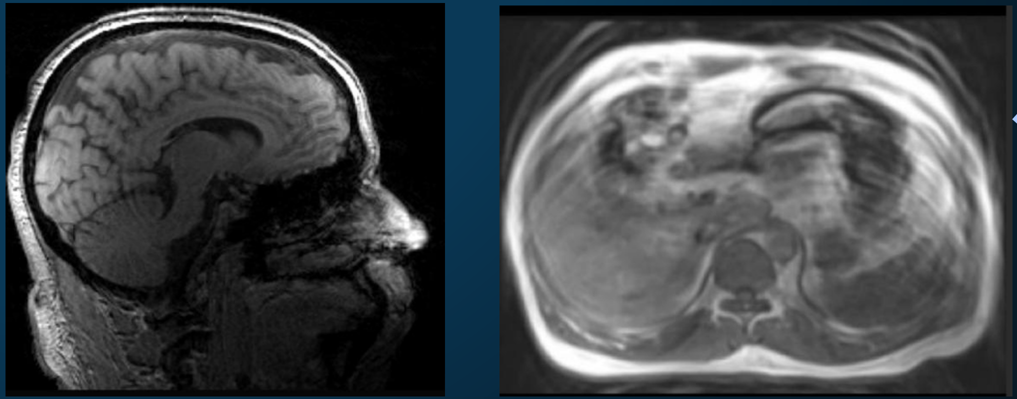
Gantry-based CBCT Problems

In proton therapy, conventional gantry-based cone-beam CT (CBCT) systems suffer from problems

- **Prolonged imaging time**
- **Significant motion artifacts**
- **Non-uniform Sampling**



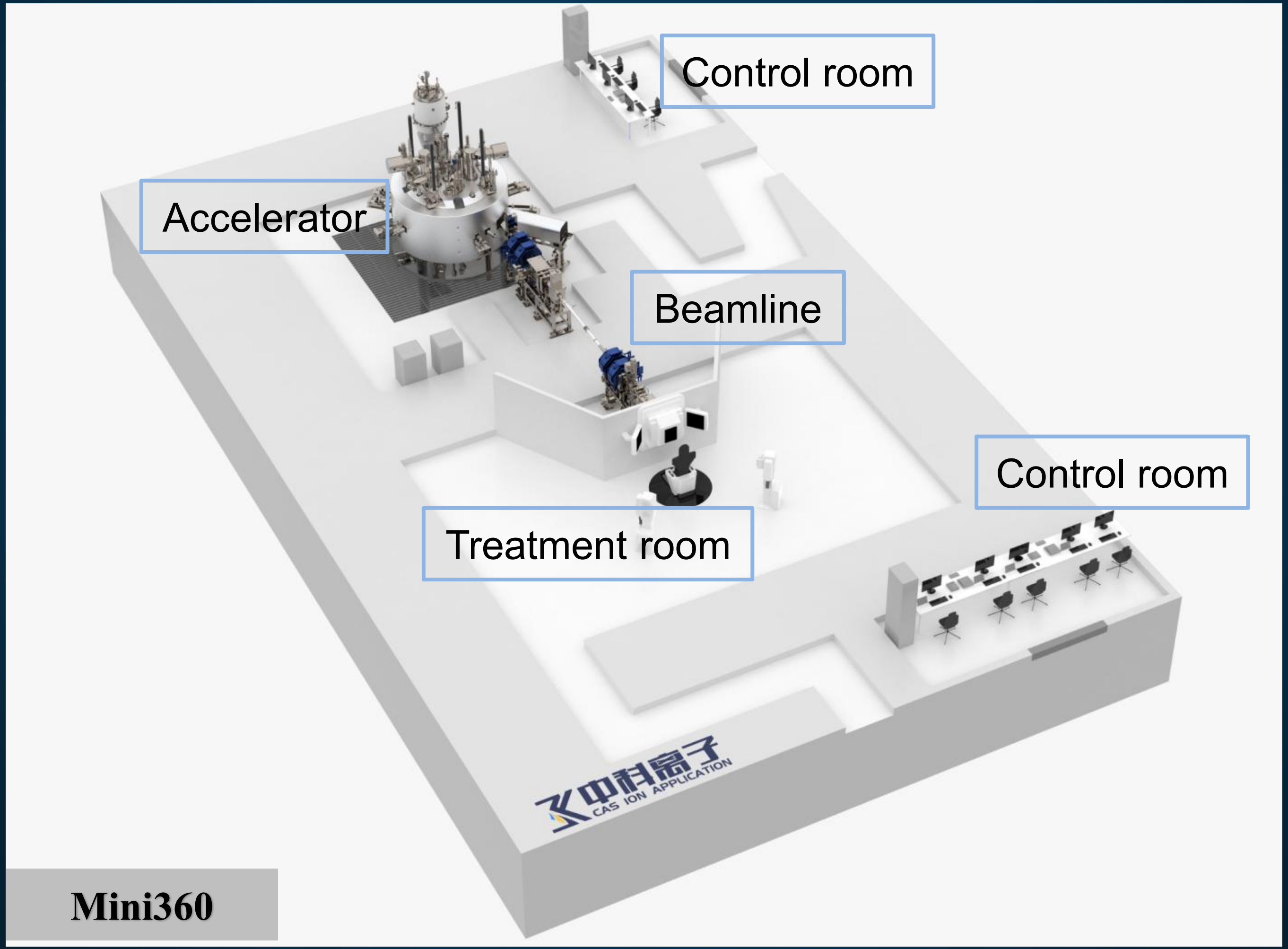
Limit the efficiency and accuracy of real-time image guidance during treatment.



motion artifacts during CBCT

The Solution Introduction of Mini360

Our team develops an Upright and Rotational solution of Mini360, that integrates a vertical rotating treatment chair with millisecond-level temporally controlled CBCT imaging.

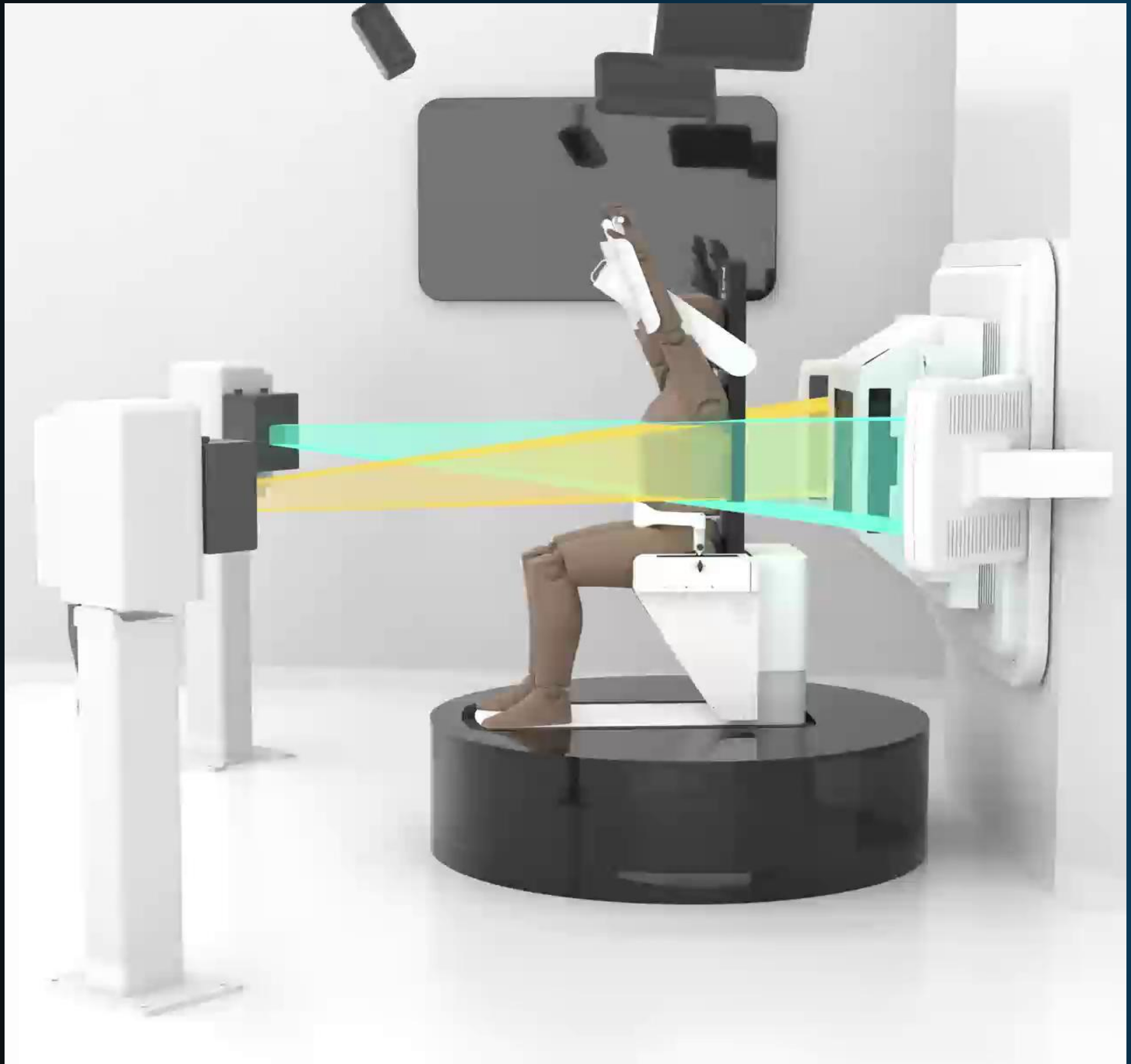


Mechanical Design of the System

Mini360 Treatment Room

Mini360 patient position system includes vertical CBCT, upright rotating treatment chair and optical surface tracking system.

Parameter of the System



Rotating speed of treatment chair：6~18°/s
CBCT rapid scan reconstruction: completed within 30s

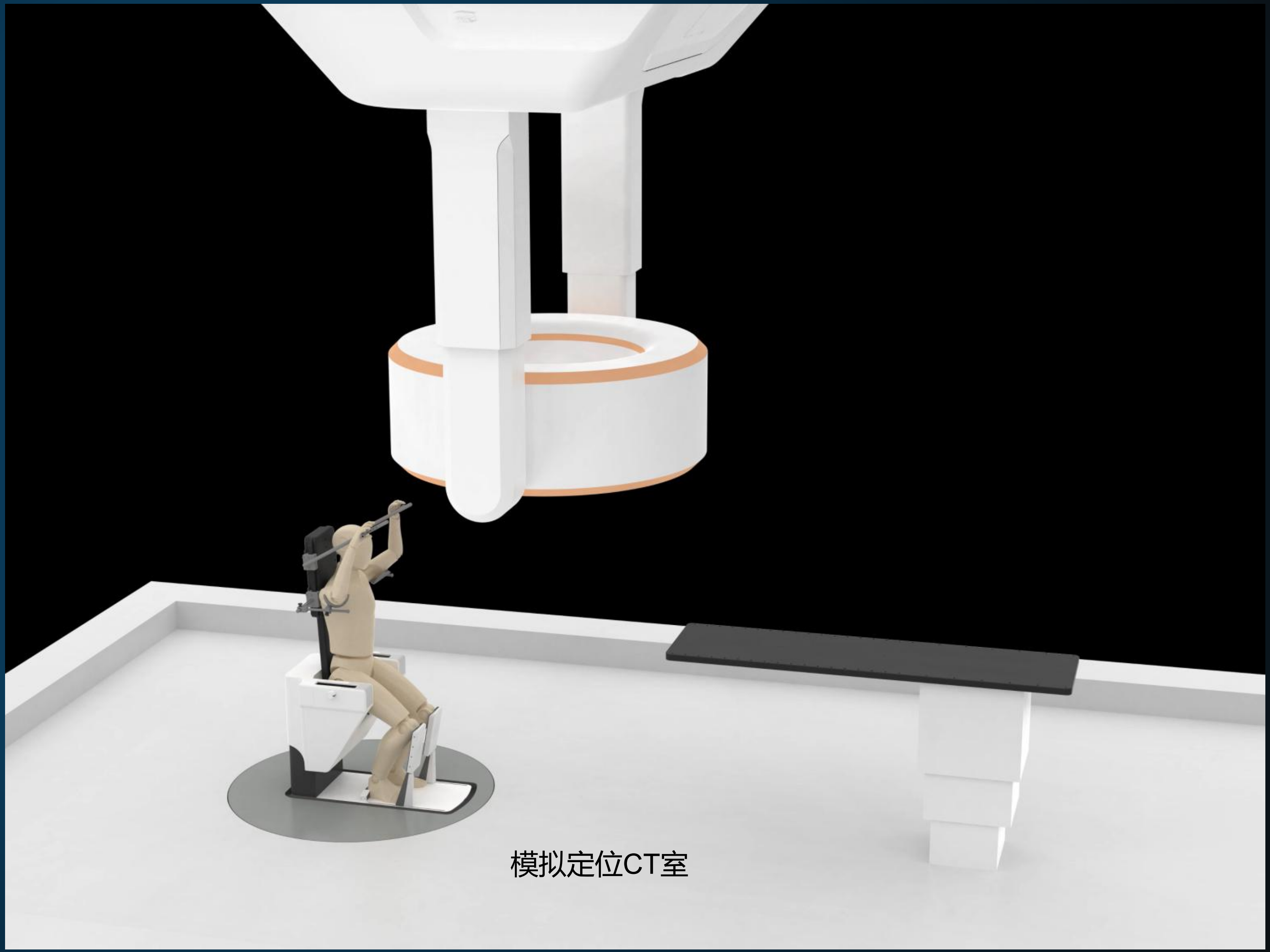
- Support CBCT rotation scanning;
- 3D reconstruction (FDK/iCBCT);
- 3D-3D image registration
- Support two-dimensional orthogonal DR shooting and 2D-3D image registration

- Source Axis Distance(SAD)：2000mm
- Source Image Distance(SID)：3000mm
- Valid Imaging Area:427mm×427mm
- CBCT Imaging Radiation Field:
  Full-fan:273mm*280mm
  Half-fan:266mm*490mm

Solution for Vertical sim CT Image

- Dual-Posture CT (Upright and Supine)

- Compatible with both conventional supine CT images and sitting CT images.



Key Technologies of Vertical CBCT

Timing Control of Millisecond High Frequency Exposure

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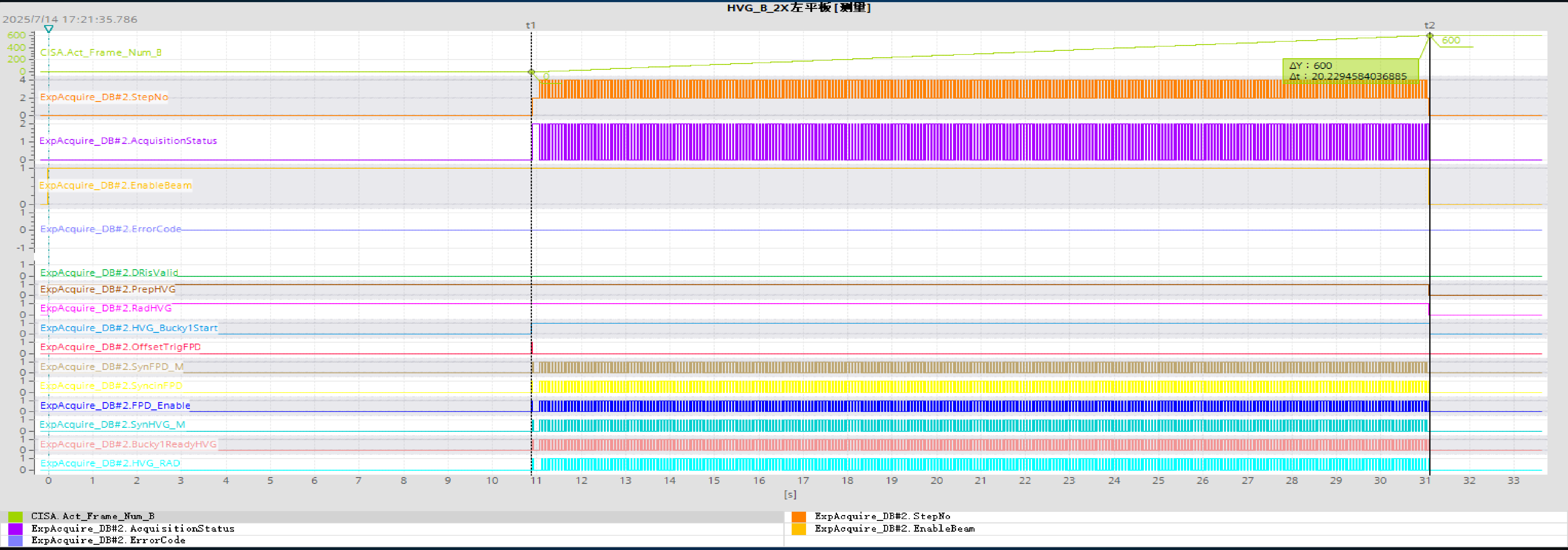
Monitoring signal during exposure:

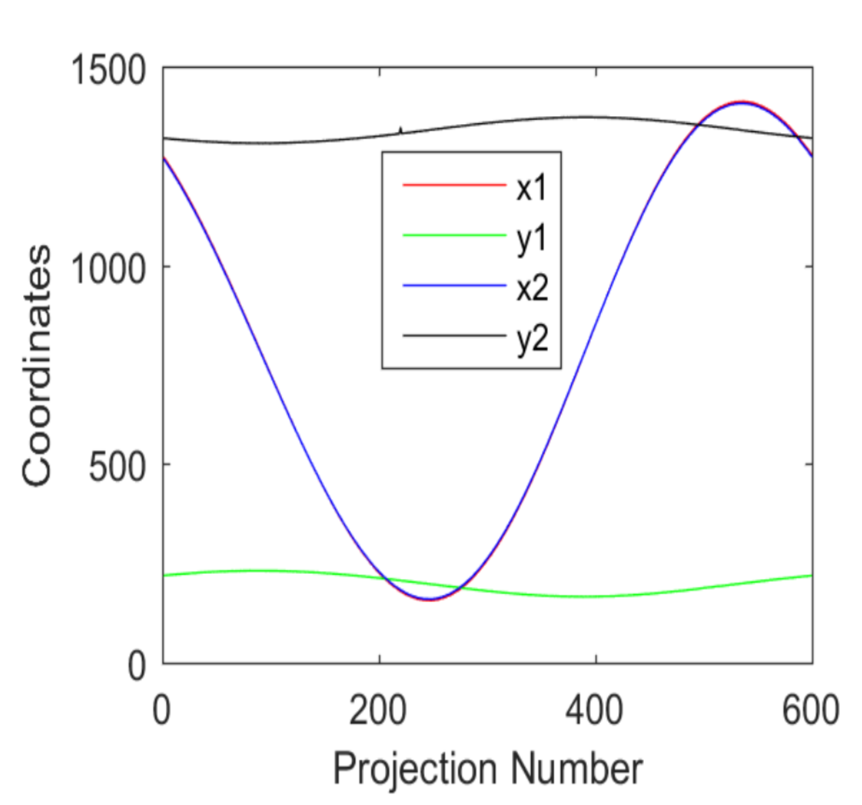
- Number of captured image frames: 600 frames
- Acquisition duration: 20.23 seconds
- Rotation speed of treatment chair: 18 ° /s

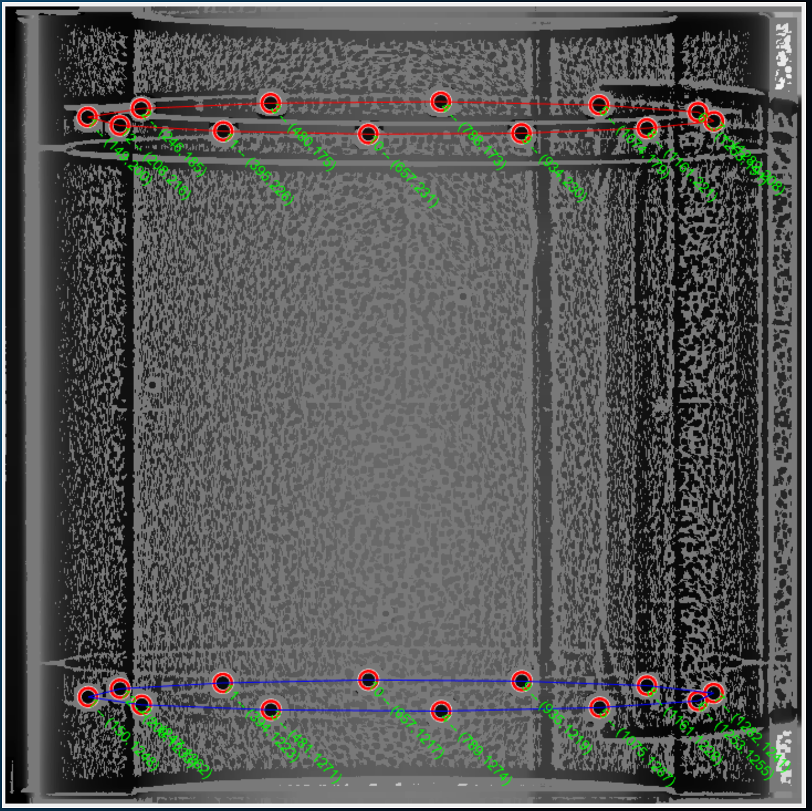
Exposure Stability: ≤ 2ms



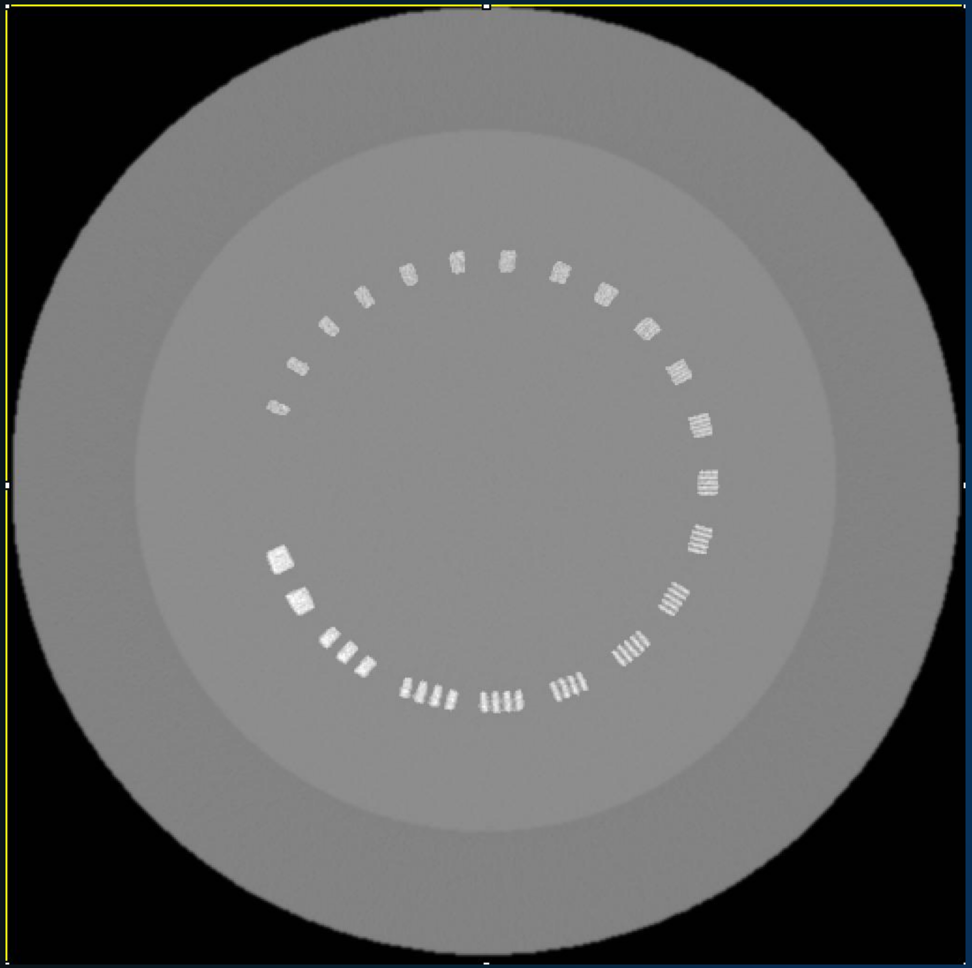
Dynamic Calibration of Image Acquisition

- Obtain the geometric parameters of the precise position of each frame of exposure image for reconstruction in real time
- Establish dynamic reconstruction geometric parameter table
- During image reconstruction, the image reconstruction quality is optimized based on the geometric parameters table of each frame





Iterative Cone-Beam CT Technology (iCBCT)



High-contrast resolution of ≥ 8 lp/cm can be achieved when reconstructing the Catphan 500 phantom with iCBCT

What we have done with iCBCT?

- Scatter correction
- Beam hardening correction
- Metal artifact correction
- Synchronous acquisition and reconstruction

the actual time from the end of scanning to the completion of reconstruction is approximately 25 seconds.

iCBCT—Scatter Correction

Based on Boltzmann equation, accurately describe the transmission and scattering process of X-ray photons in matter, and solve the scattering problem (CT accuracy is within ±5HU)

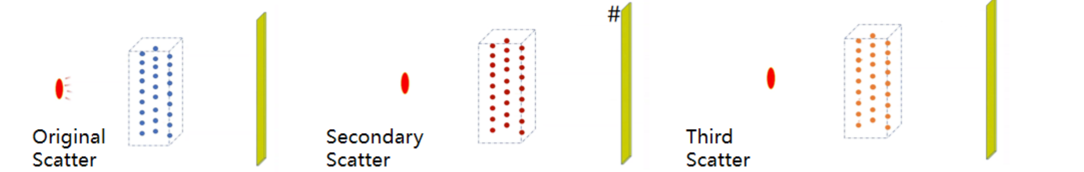
Multi-level scattered signals calculated level by level

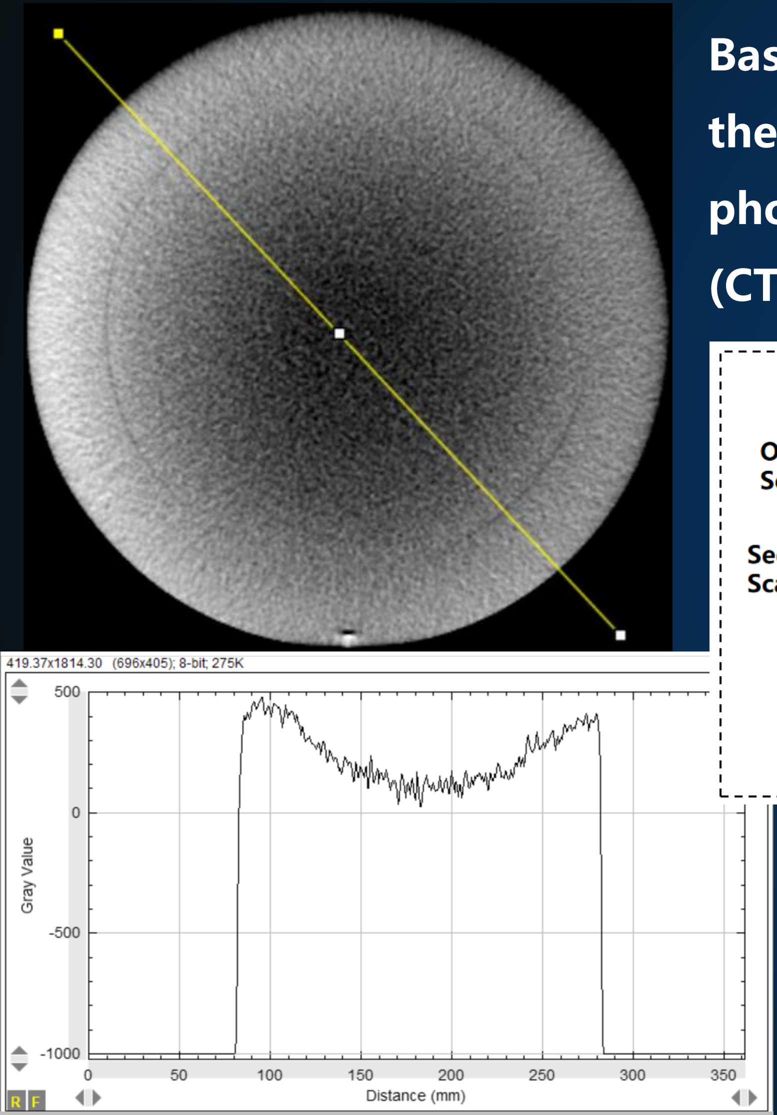
Original Scatter

$$f^{(0)}(\vec{x}, p_1, \hat{\omega}_1) = \frac{X(\vec{x}_0, p_1, \hat{\omega}_1)}{(\vec{x}_1 - \vec{x}_0)^2} \exp\left[-\sum_{(ijk)\in\mathcal{P}_2} \Delta l_{ijk}\mu_t(\vec{x}_{ijk}, p_1)\right]$$

Secondary Scatter

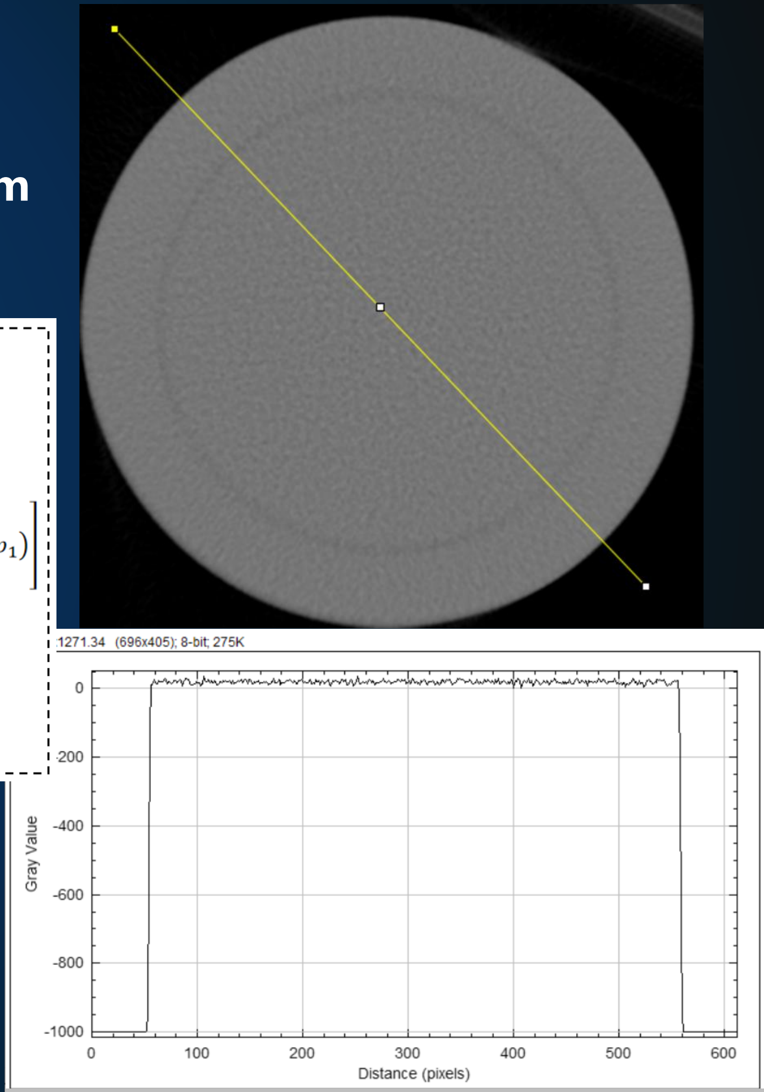
$$f^{(n)}(\vec{x}_1, p_1, \hat{\omega}_1) = \sum_{(i,j,k)\in\mathcal{P}_1} \Delta l_{ijk} X^{(n)}(\vec{x}_{ijk}, p_1, \hat{\omega}_1) \times \exp\left[-\sum_{(i_1,i_2,i_3)\in\mathcal{P}_2} \Delta l_{i_1 i_2 i_3}\mu_t(\vec{x}_{i_1 i_2 i_3}, p_1)\right]$$





Conventional FDK Reconstruction

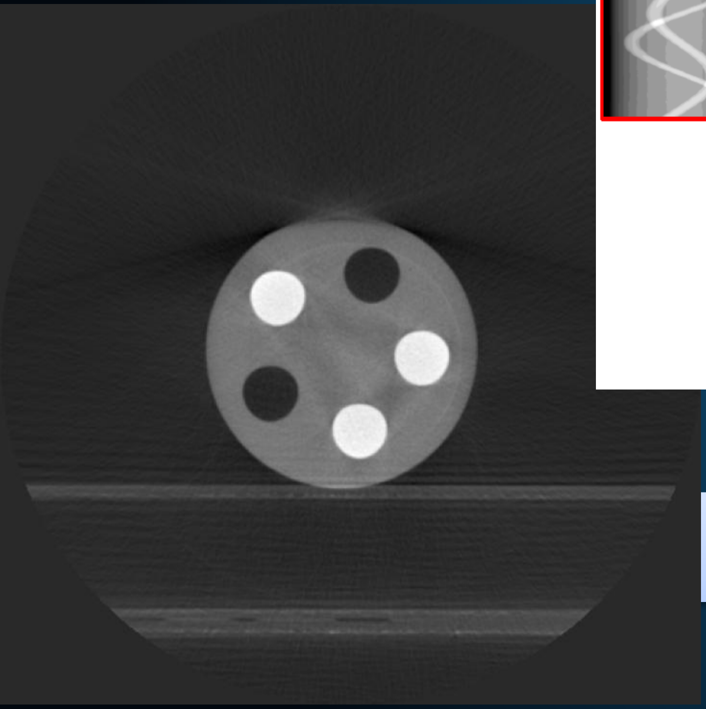
Image Domain-Based Analytical Scatter Correction

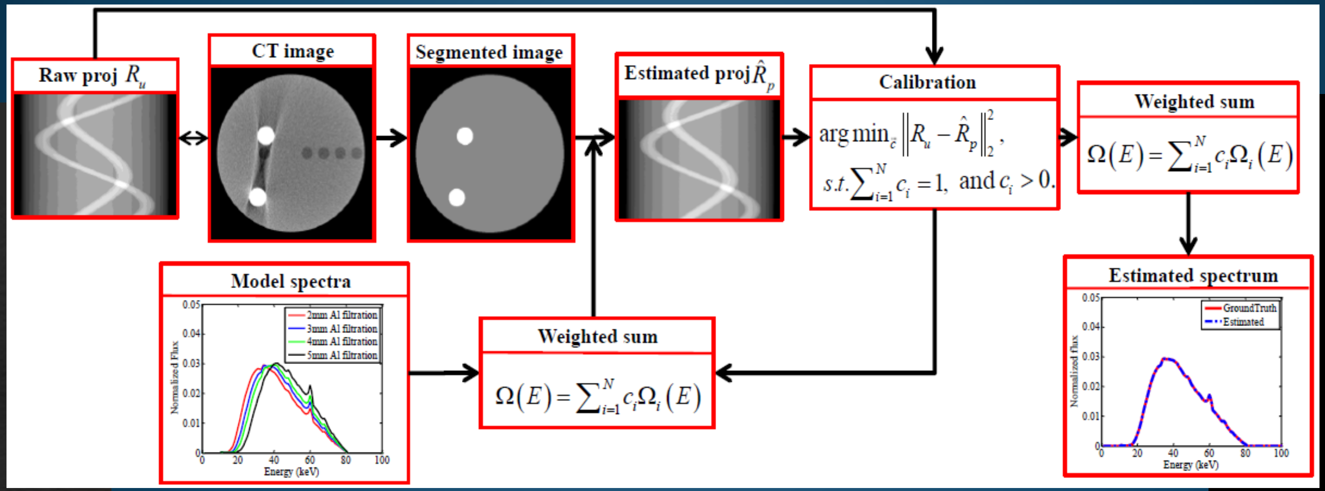


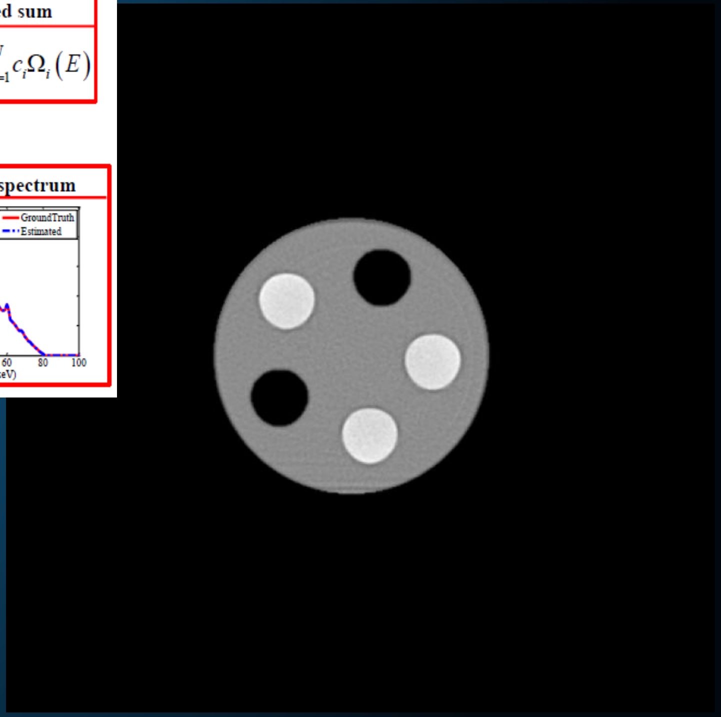
iCBCT Reconstruction

iCBCT—Beam Hardening Correction

- **Physics-based modeling method, reproject the polychromatic spectrum, calculate the difference between monochromatic and polychromatic energies, map this difference to the original projections, and convert the data into equivalent monochromatic energy to eliminate beam hardening artifacts.**
- **The contrast-to-noise ratio (CNR) in artifact regions is improved by 20% compared with FDK methods.**







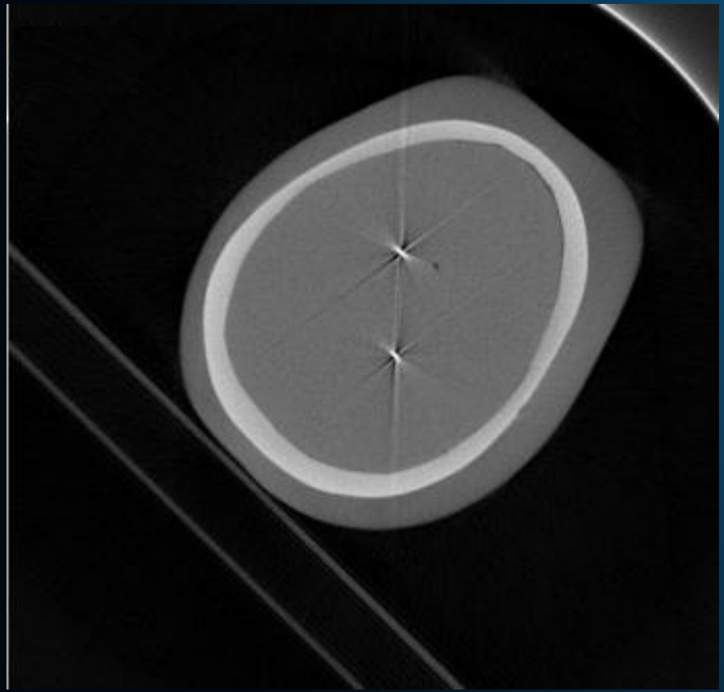
Robust Correction Method for CT Beam Hardening Artifacts Using Spectral Modeling

Conventional FDK Reconstruction

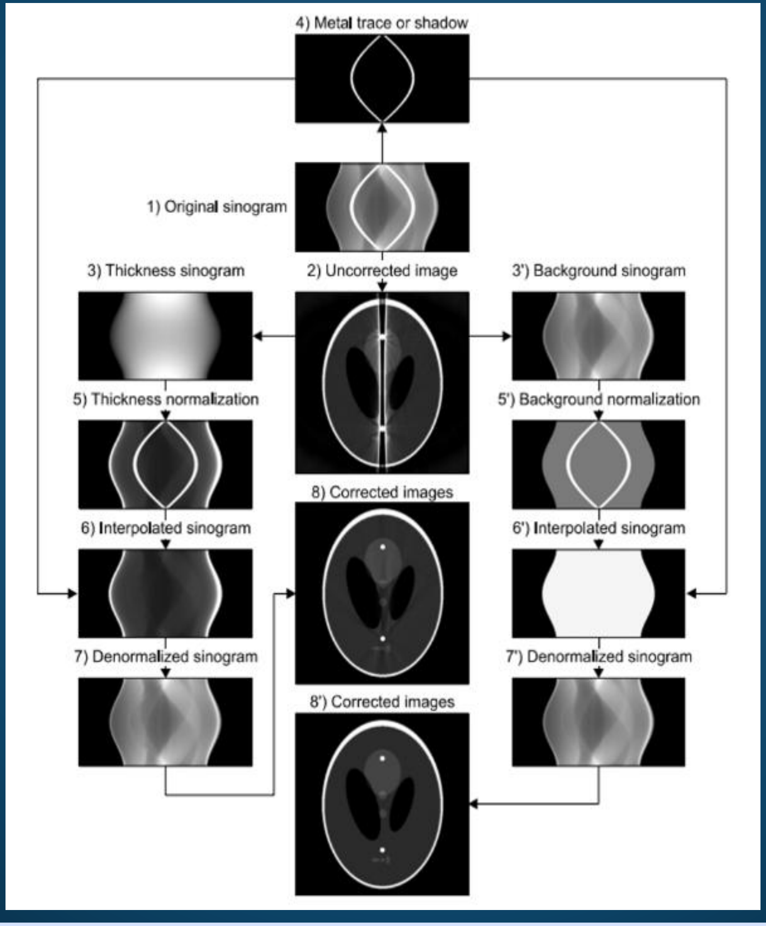
iCBCT Reconstruction

iCBCT—Metal Artifact Correction

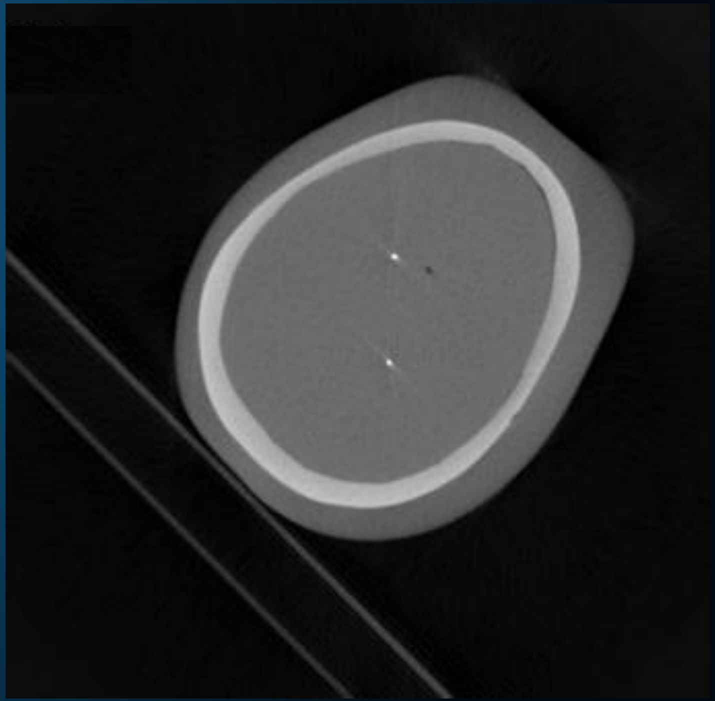
Metal artifacts are reduced using sinogram normalization, followed by linear interpolation at metal trajectories and then denormalization reconstruction, achieving a significant artifact reduction effect.



Conventional FDK Reconstruction



Sinogram Normalization Algorithm



iCBCT Reconstruction

Fast Image Registration Technology

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3D-3D image registration

- Manual registration
- based on Hu value range
- based on frame selected region
- **Registration time: ≤ 15S**

2D-3D image registration

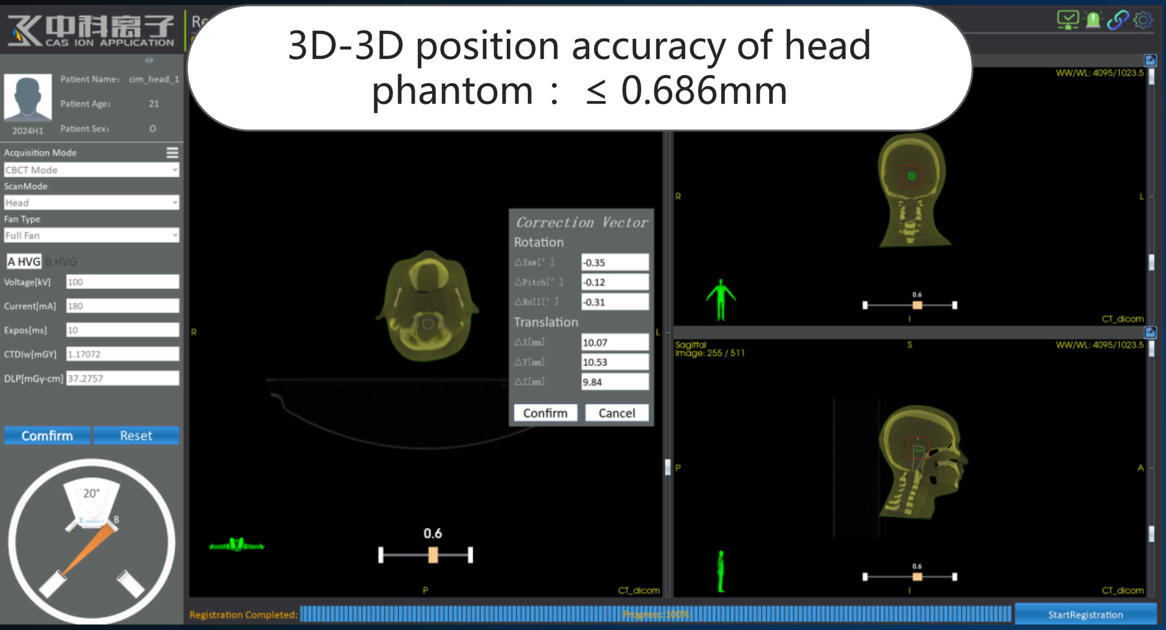
- **Registration time: ≤ 15S**

Based on GPU-accelerated iCBCT reconstruction performance, fast rigid registration technology is adopted to achieve rapid registration and localization of 3D and 2D images, ensuring the speed of registration.

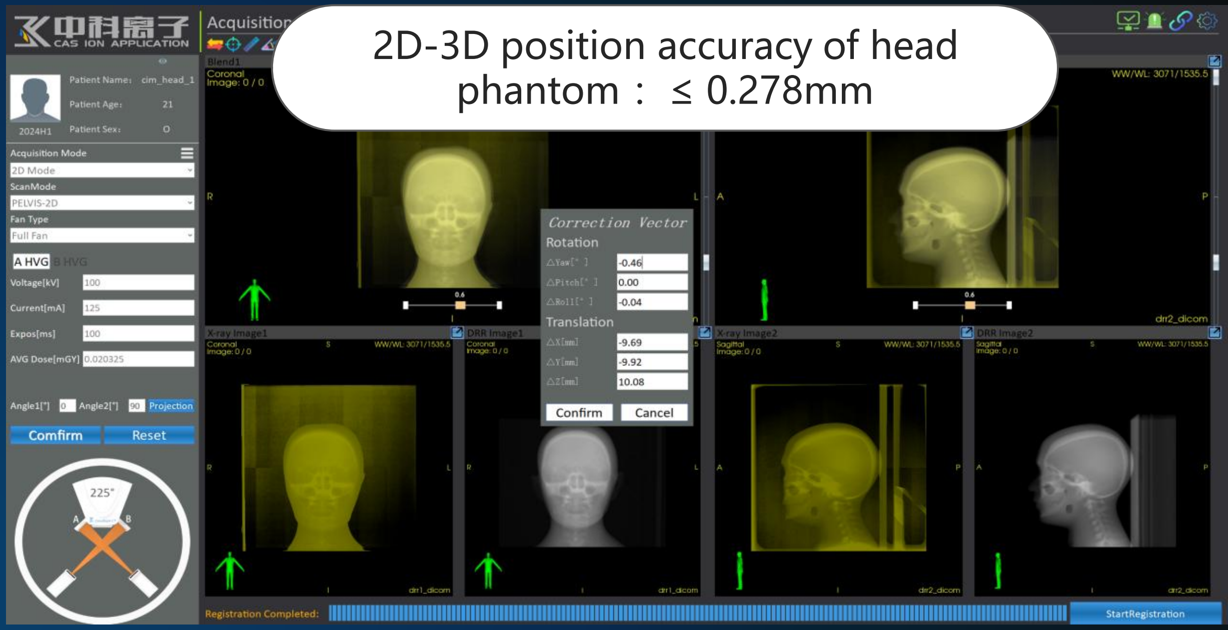
Head / Chest registration positioning accuracy

- **head phantom≤ 0.7mm**
- **chest phantom≤ 0.9mm**

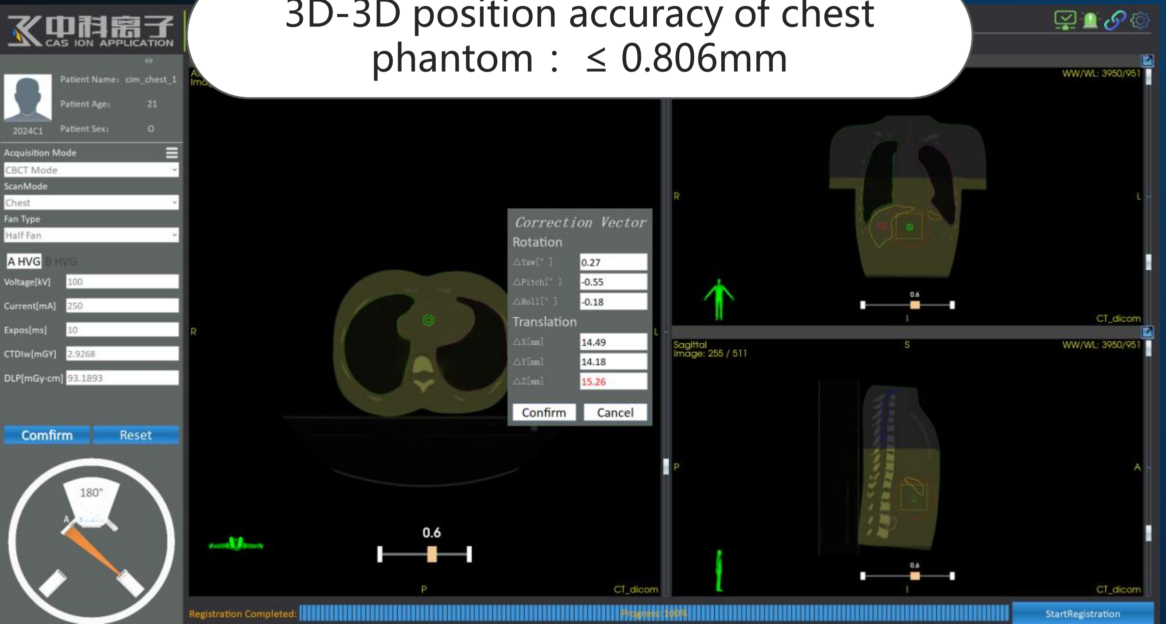
Fast Image Registration Technology



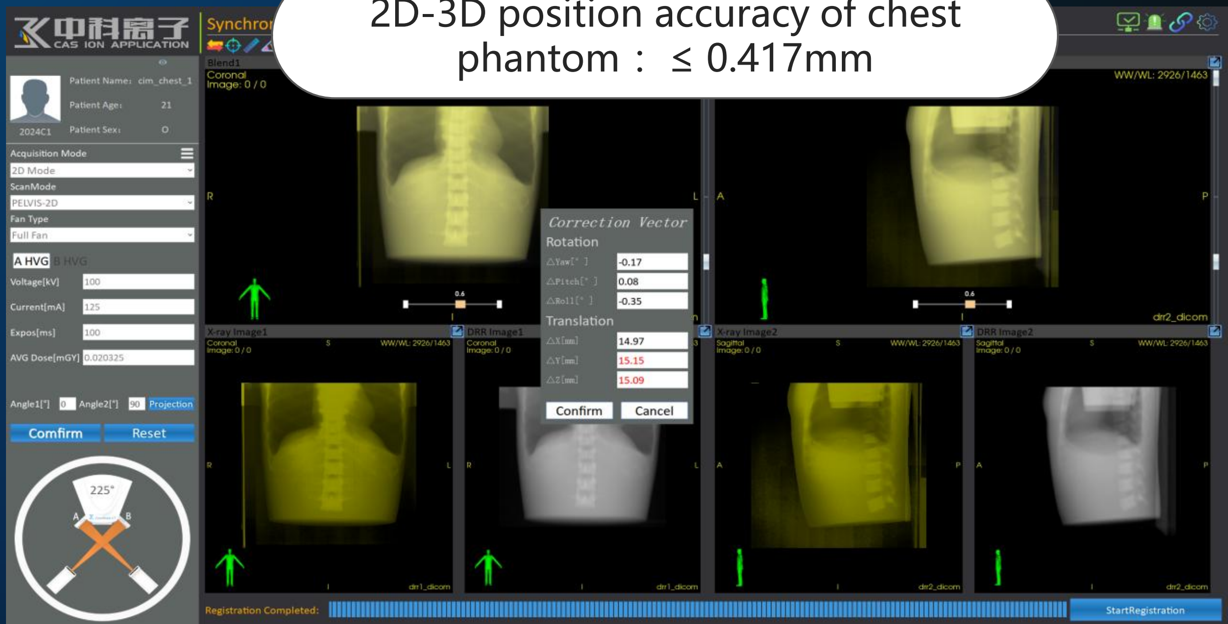
3D-3D position accuracy of head phantom： ≤ 0.686mm



2D-3D position accuracy of head phantom： ≤ 0.278mm



3D-3D position accuracy of chest phantom： ≤ 0.806mm



2D-3D position accuracy of chest phantom： ≤ 0.417mm

Takeaways

- Through millisecond-level exposure control and GPU-accelerated reconstruction, the upright image-guided positioning system reduces the full-process 3D imaging time to 30 seconds.
- Compared with traditional CBCT systems, it significantly improves scanning efficiency and effectively mitigates motion artifacts thanks to the application of iCBCT technology.
- It verifies the feasibility of rapid imaging and reconstruction in proton therapy and provides technical support for future clinical real-time adaptive radiotherapy.

Summary: This system addresses the key pain points of traditional CBCT in radiotherapy and demonstrates excellent performance in terms of imaging speed, resolution, and clinical applicability.

Outlook: In the future, the performance of the system can be further optimized, and its application can be expanded to more radiotherapy scenarios to promote the development of real-time adaptive radiotherapy technology


Phase I of Hefei Ion Medical Center(Varian Proton System)
Phase II of Hefei Ion Medical Center(HFCIM Proton System)
● Mini 360

The Hefei Government and the Chinese Academy of Sciences jointly established Hefei CAS Ion Medical and technical devices Co., Ltd. （HFCIM） in 2016. Currently, it mainly committed to the R&D and industrialization of medical proton therapy systems and their medical superconducting proton cyclotrons.

Cyclotron Series Products from HFCIM

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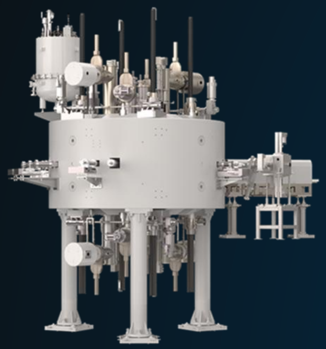
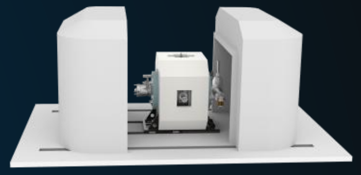
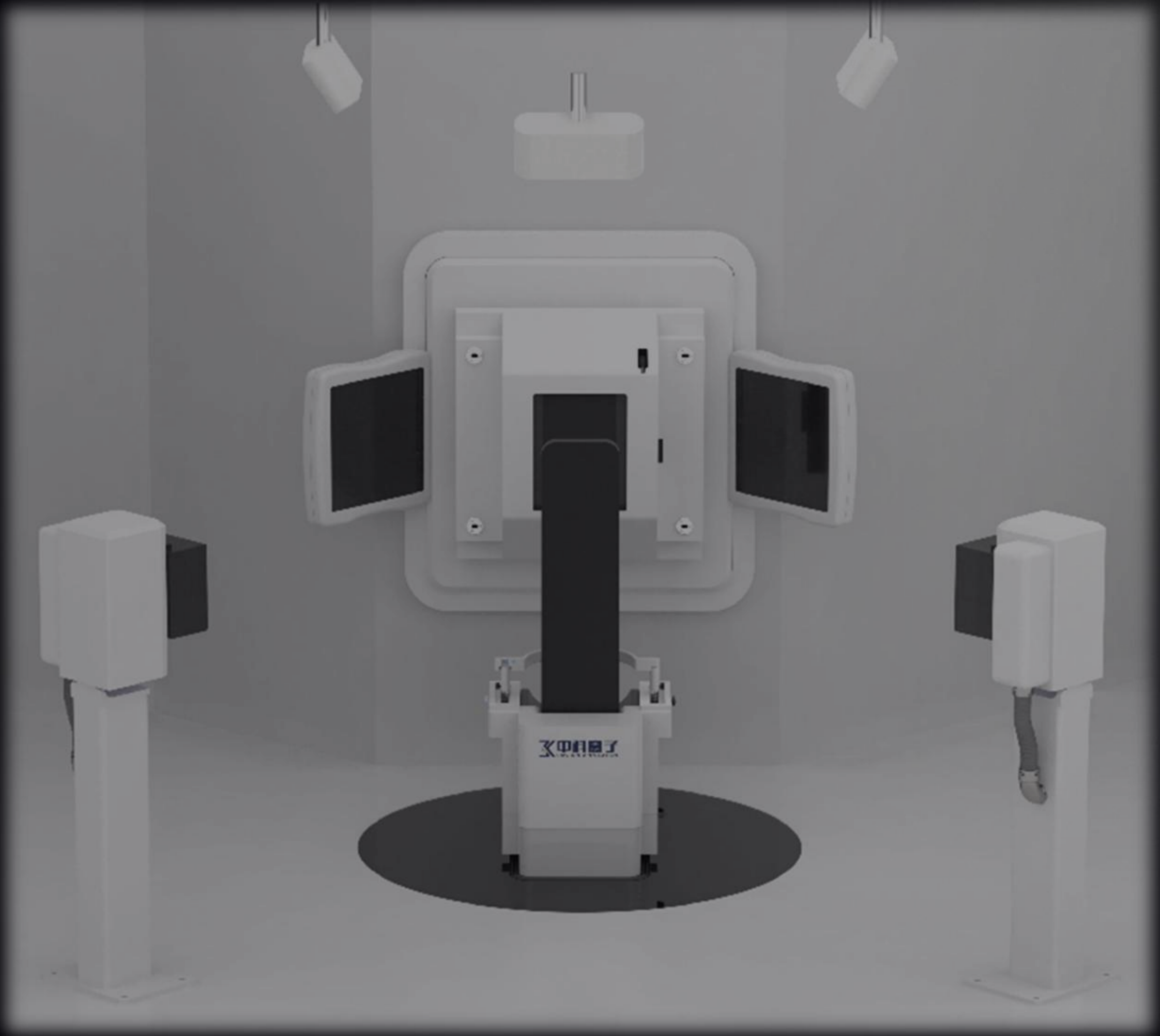




SC240 Superconducting Proton Cyclotron	**SC240M** Superconducting Proton-Helium Integrated Cyclotron	**SC150** Radioactive Nuclide Cyclotron	**CIM-A30** Helium Radionuclide Cyclotron	**CIM14-A** Proton Radionuclide Cyclotron	**CIM-F8** Proton Radionuclide Cyclotron
P	α /P	P	α	P	P
240 MeV	220 AMeV 240 MeV	150 MeV	30 MeV	14 MeV	8 MeV
800 nA	200 euA	200 euA	50 eμA	100 μA	10 uA



Thanks for listening