TRIUMF 520 MeV Cyclotron Developments: Past, Present and Future

Lige Zhang

On behalf of beam physics group
and cyclotron machine development team

TRIUMF science week

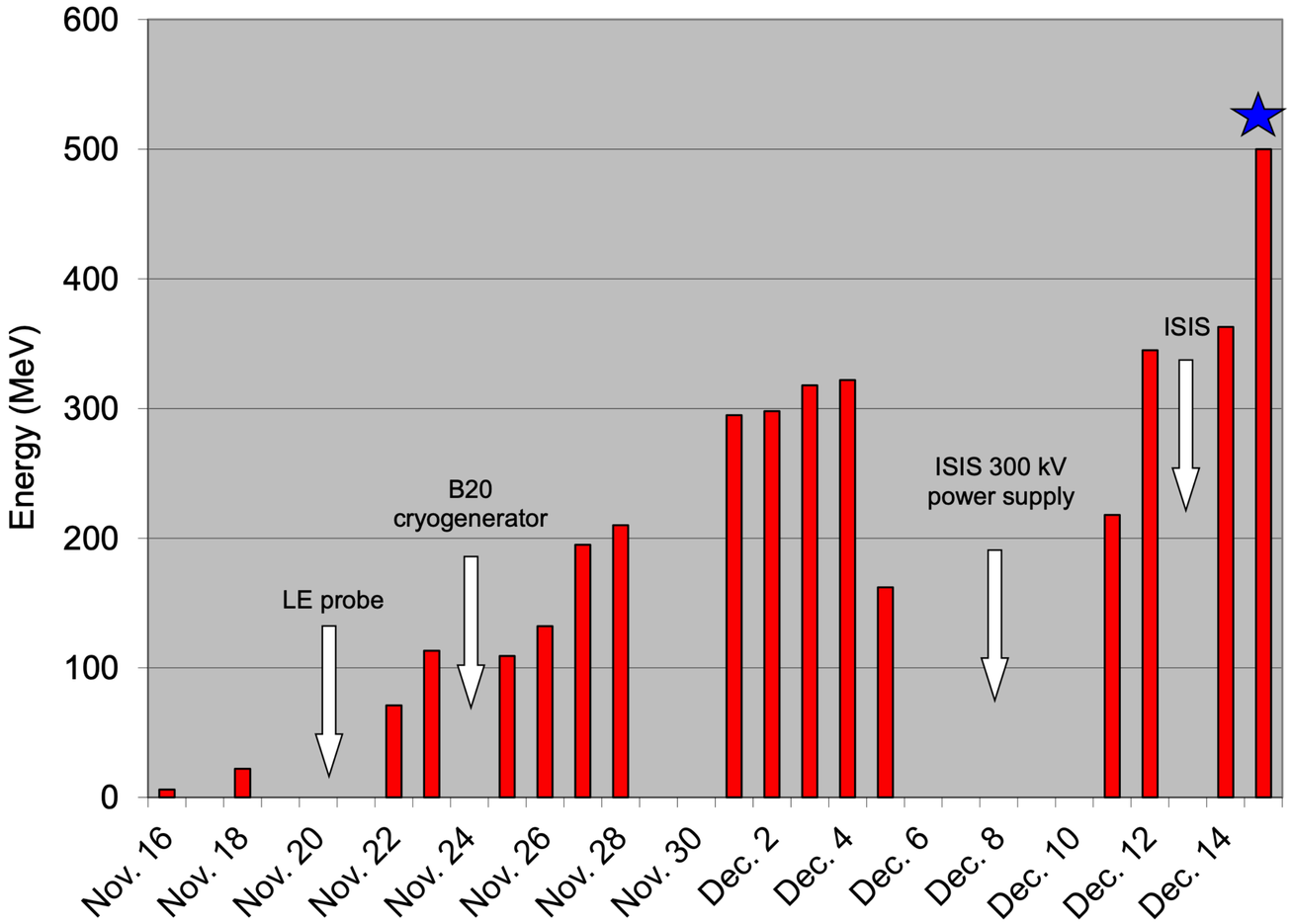
July, 2024

Discovery, accelerated

Outline

- Fifty years of TRIUMF cyclotron developments
- Present work on reducing the beam loss and improving magnet reproducibility
  - Experimental and theoretical study on error field and linear coupling
  - New procedures to ramp up the massive main magnet
- Future Plans

First beam in 1974



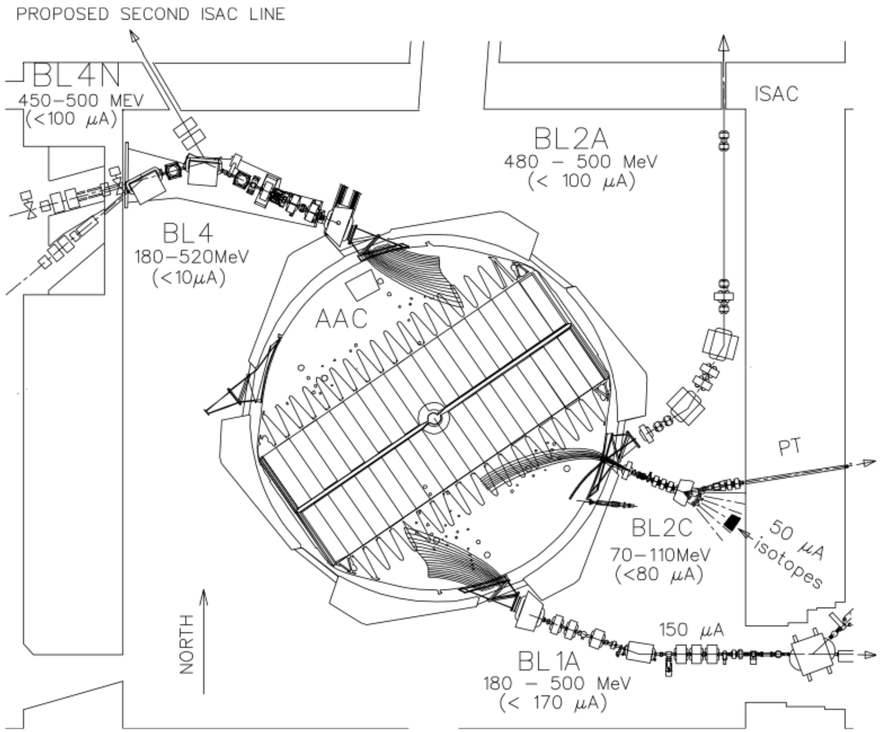
By November 1974, the ISIS injection, RF resonators, cryopanels, diagnostic and extraction probes had all been installed, and the cyclotron was ready for beam.

Richardson manually adjusted the 54 circular trim coils and 78 harmonic coils.

· *Michael Craddock, 2014 "40 Years On – Reflections on the History of TRIUMF from Conception to the First Beam"*

High intensity developments

1974, 15 nA — 1977, 100 uA target — 1984, CW 200 uA — 1987, pulsed 400 uA — 1990, 200 uA~ 300 uA — 2002, above 300 uA



The TRIUMF cyclotron was originally designed for a maximum current of 100 μA up to 500 MeV.

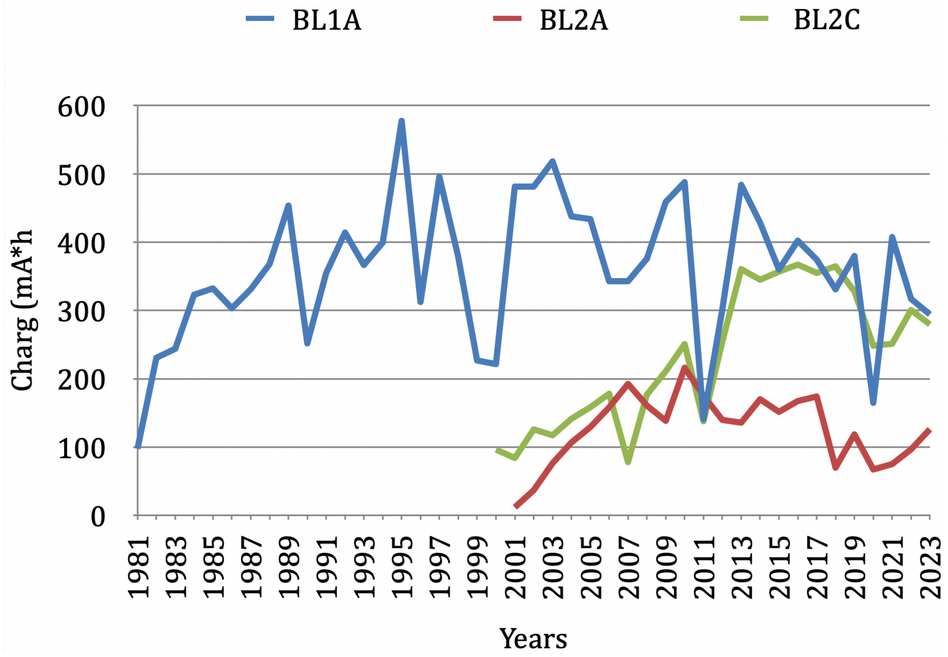
However, higher intensity has been demanded by users.

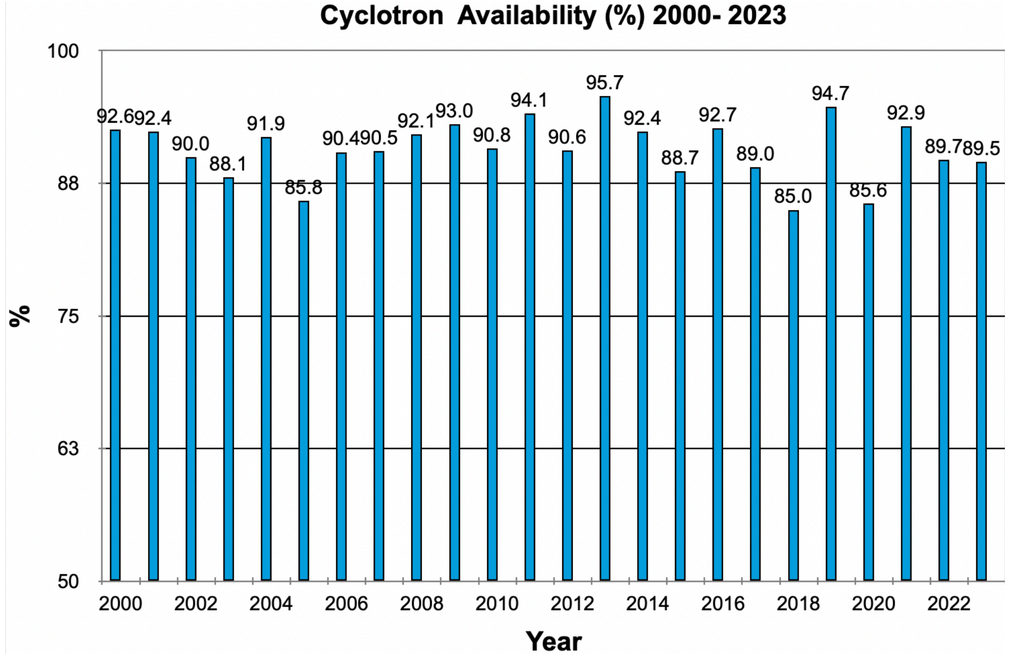
Development work since the cyclotron's commissioning has gradually increased its intensity.

*G. Dutto et al, "The Upgrading of the TRIUMF Facility to 500 μA Operation"
R. Baartman et al, "The TRIUMF 500 MeV Cyclotron: Present Operation and Intensity Upgrade"

Maintain reliability

The TRIUMF 520 MeV H- cyclotron has been delivering beams to users for 5 decades, reaching yearly 3*5,000 beam hours and a 90% availability.





**Data from Angela Lang*

Y. Bylinskii et al, "TRIUMF 500 MeV Cyclotron Refurbishment"

R. Baartman et al, "Reliable Production of Multiple High Intensity Beams with the 500 MeV TRIUMF Cyclotron"

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Redundancy in the field survey data

Inherited field survey data for beam dynamic study

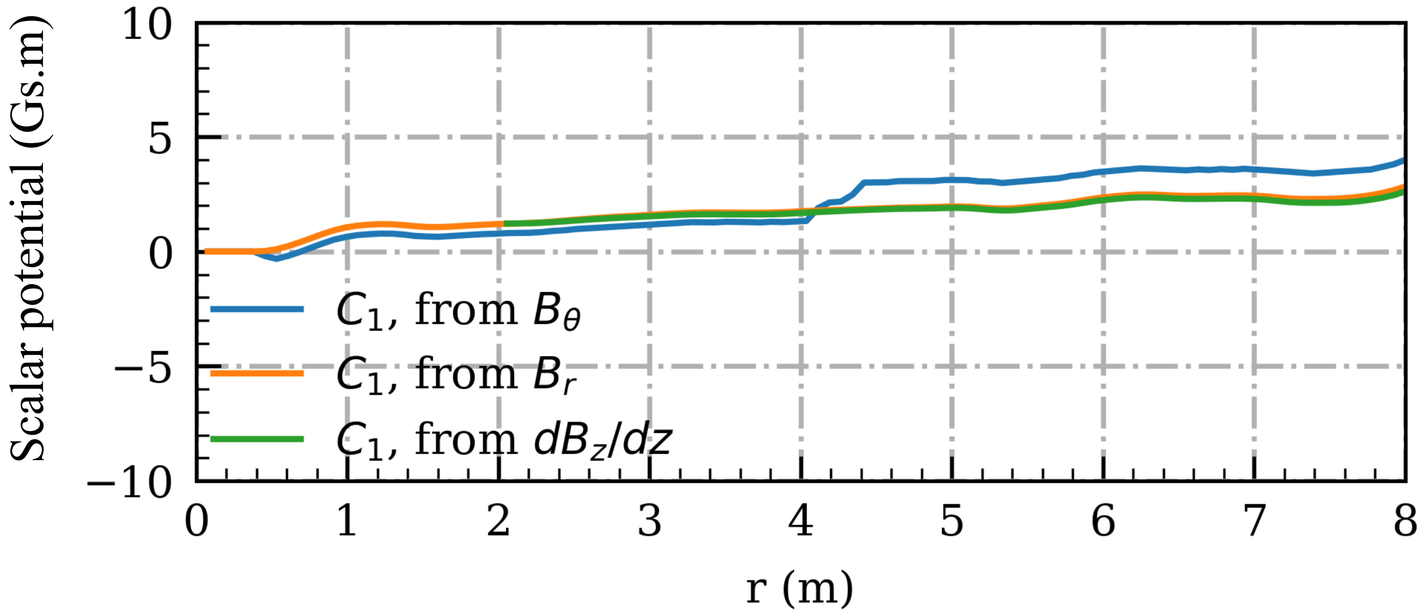
Axial field:
B_z

Error field:
B_r, B_θ, dB_z/dz

Redundancy revealed by Maxwell's equation

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{B} = 0 \quad \text{(Free space, } \mathbf{J}=0\text{)}$$

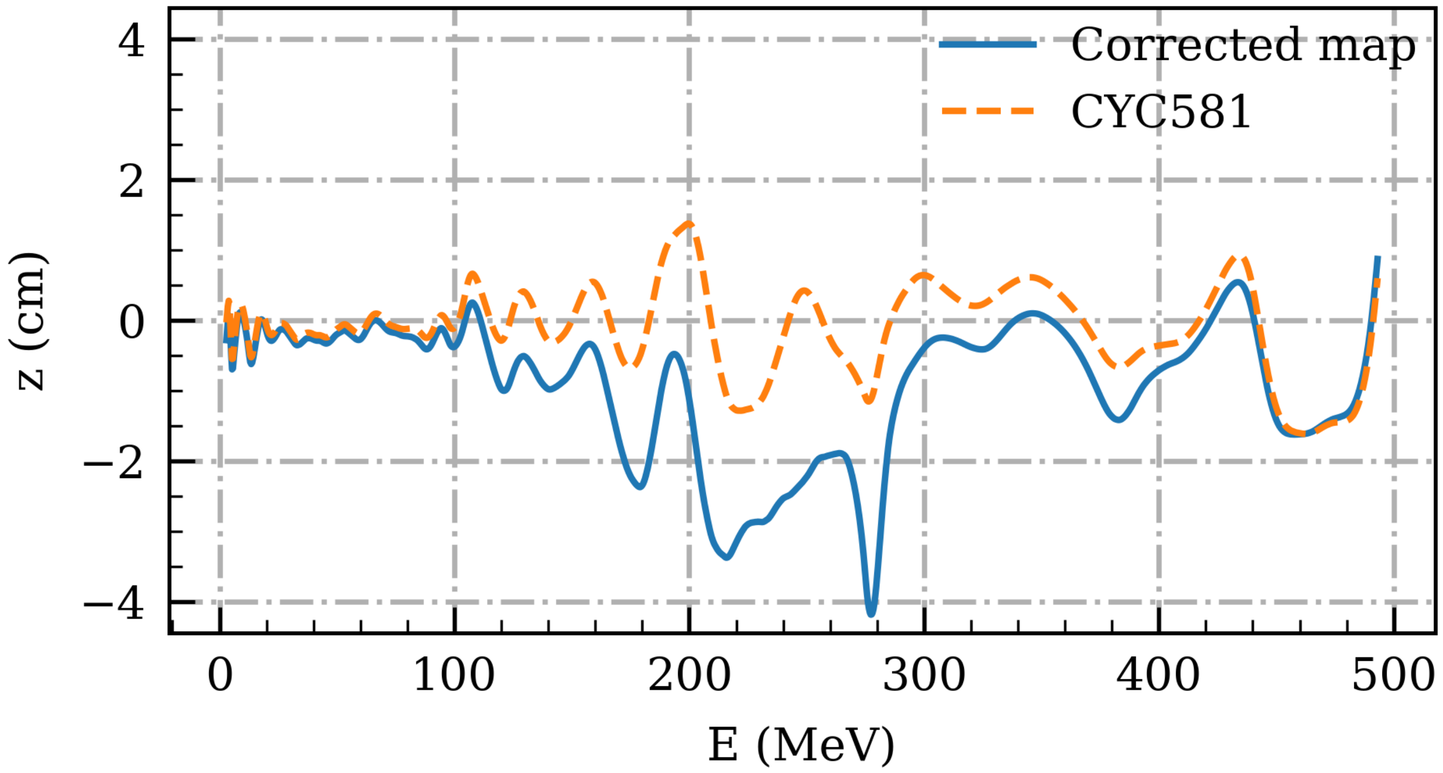


*L.G. Zhang et al, "Redundant Field Survey Data of Cyclotron with Imperfect Median Plane"

Correcting the error in the field survey data

>1” centering error between 200 MeV and 300 MeV

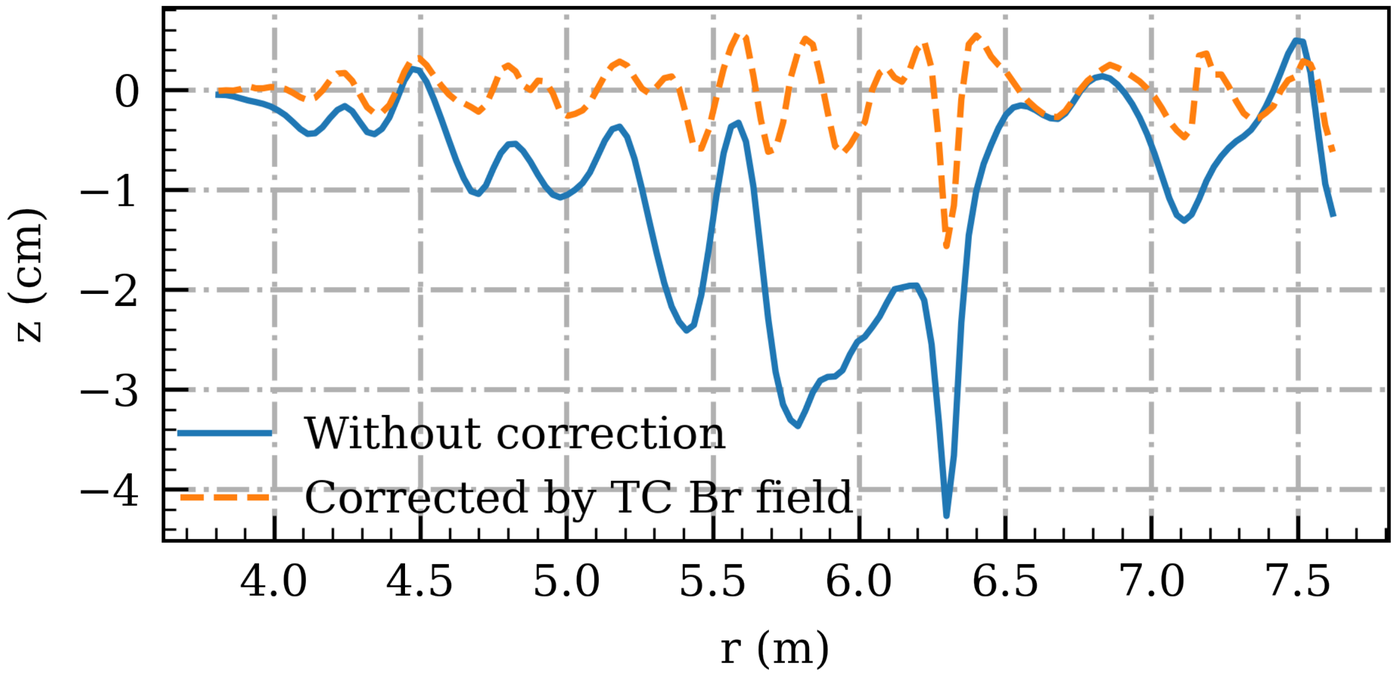
Vertical aperture is limited by scraper gap of 2”



Correcting the error in the field survey data

Vertical centering error corrected by TC radial field

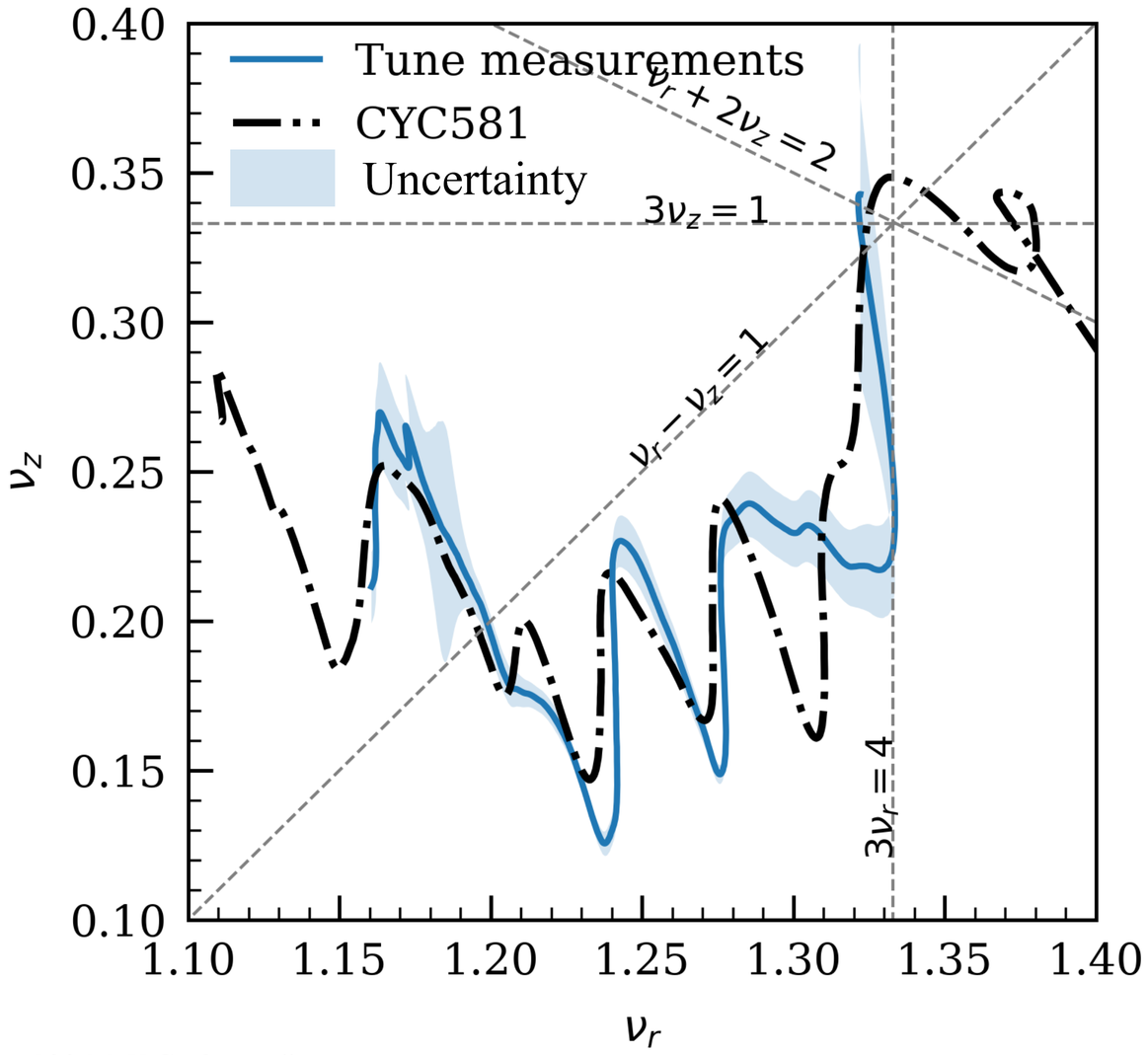
$$\Delta z = \frac{\overline{R}}{\overline{B}_z} \frac{\Delta \overline{B_r}}{\nu_z^2},$$



Cyclotron tune

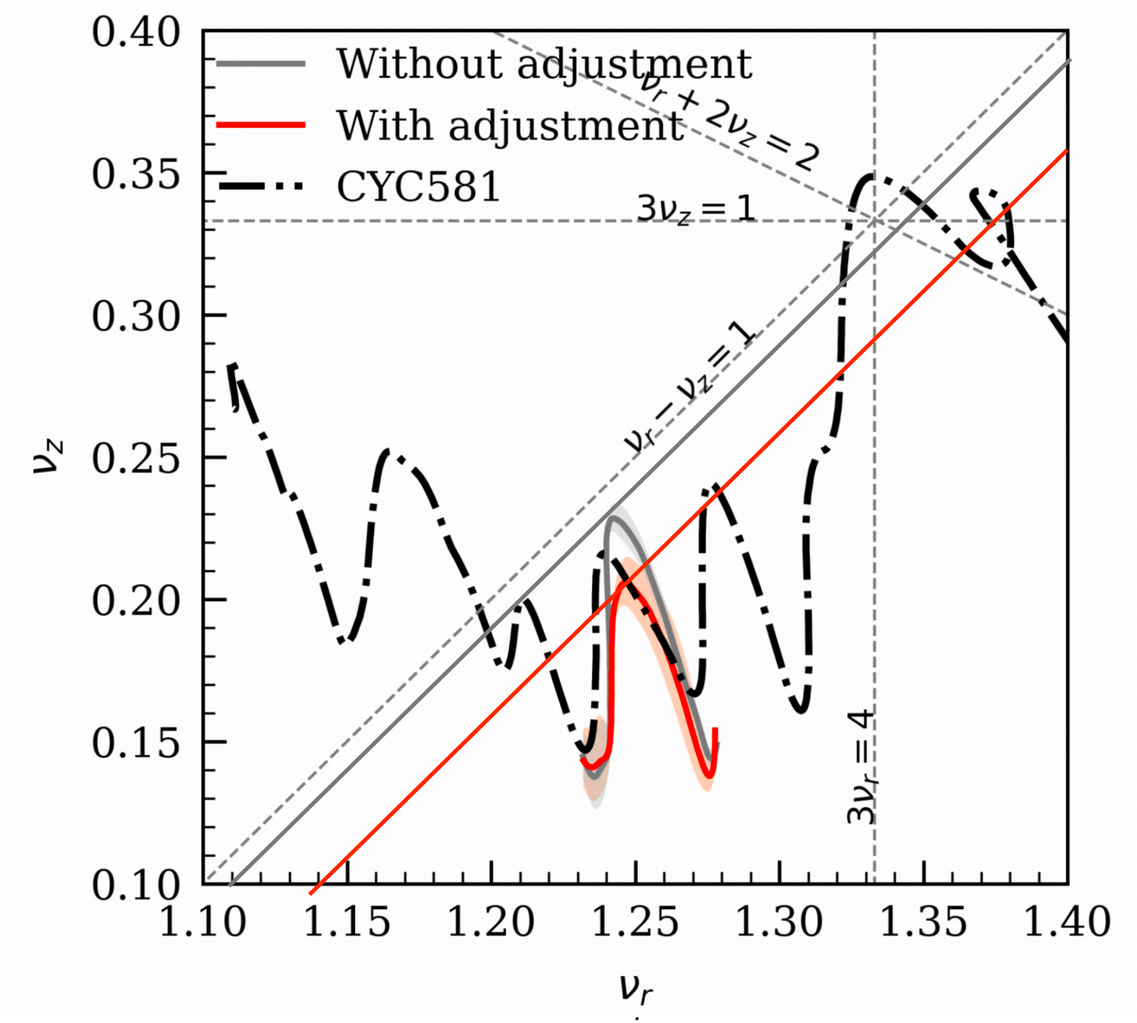
Measured by scanning the trim coil radial field.

$$\Delta z = \frac{\overline{R}}{\overline{B}_z} \frac{\Delta \overline{B_r}}{\nu_z^2},$$



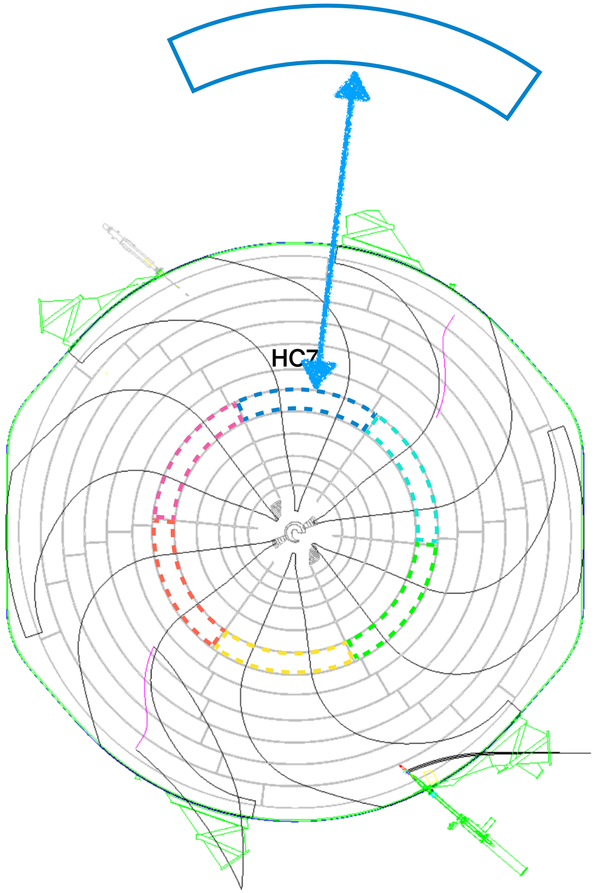
*L.G. Zhang et al, "Linear Coupling and Tune Adjustment for the 500 MeV Cyclotron"

Optimize the vertical tune



Tune is optimized to avoid the linear coupling resonance.

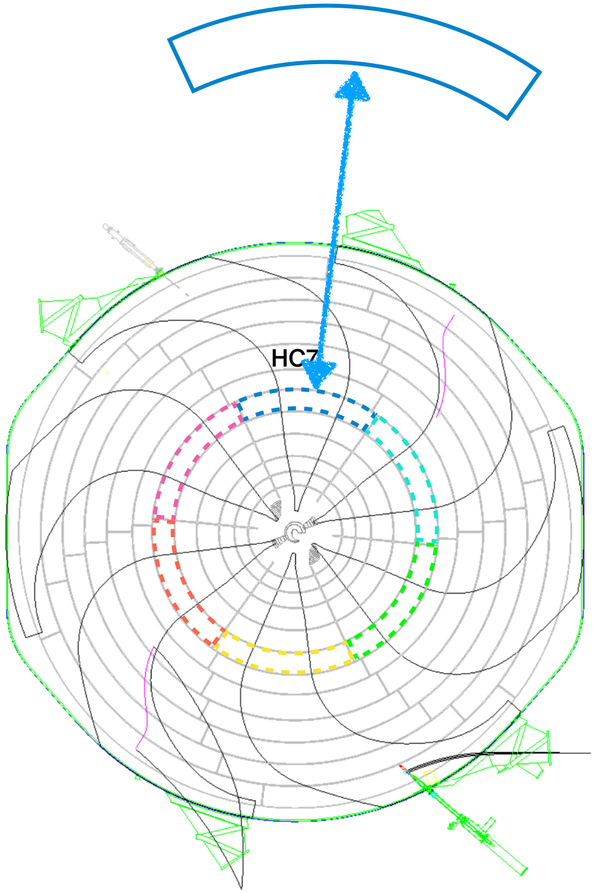
Correcting the linear coupling resonance



The error field driving the linear coupling is corrected using groups of HCs.

*Y.-N. Rao et al, “Correction of Linear Coupling Resonance in the TRIUMF Cyclotron”

Correcting the linear coupling resonance



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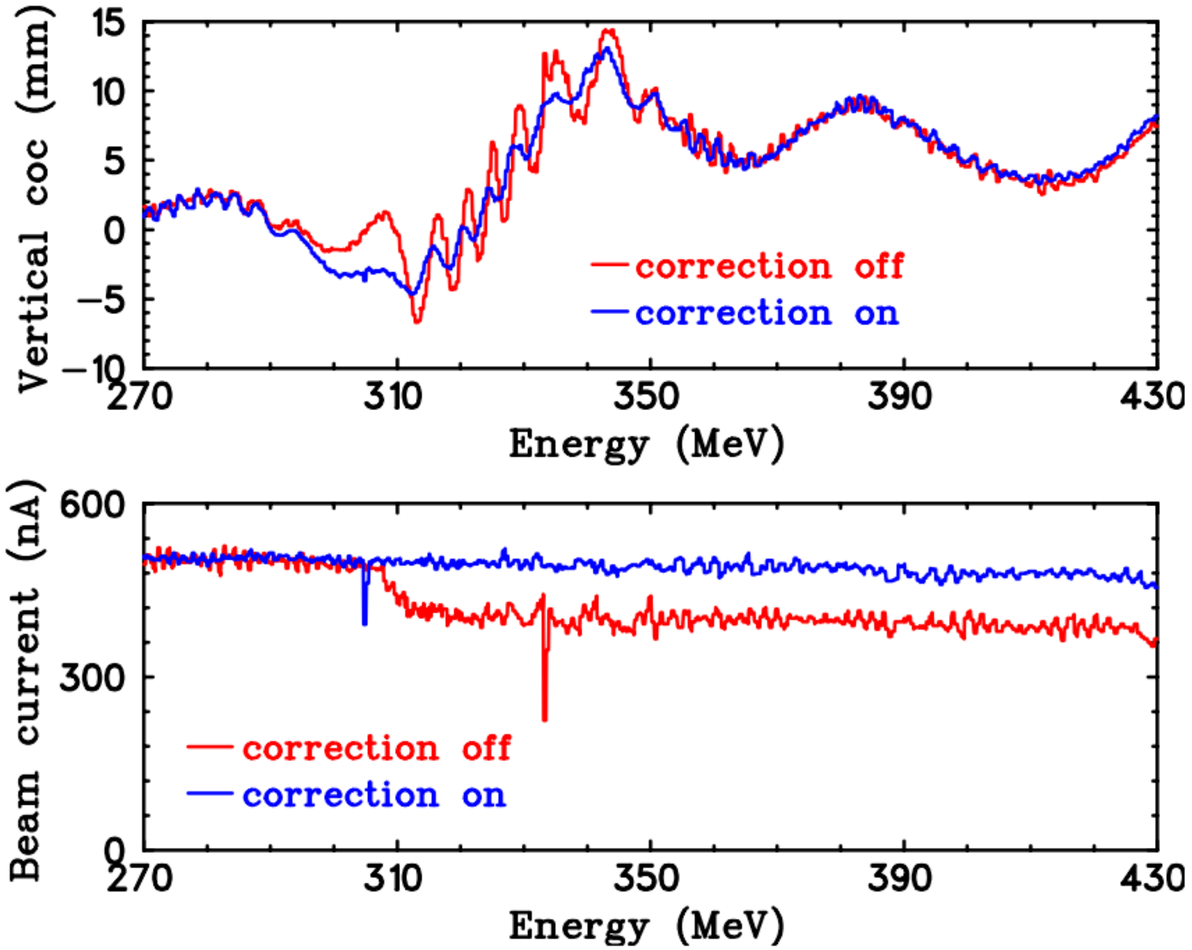
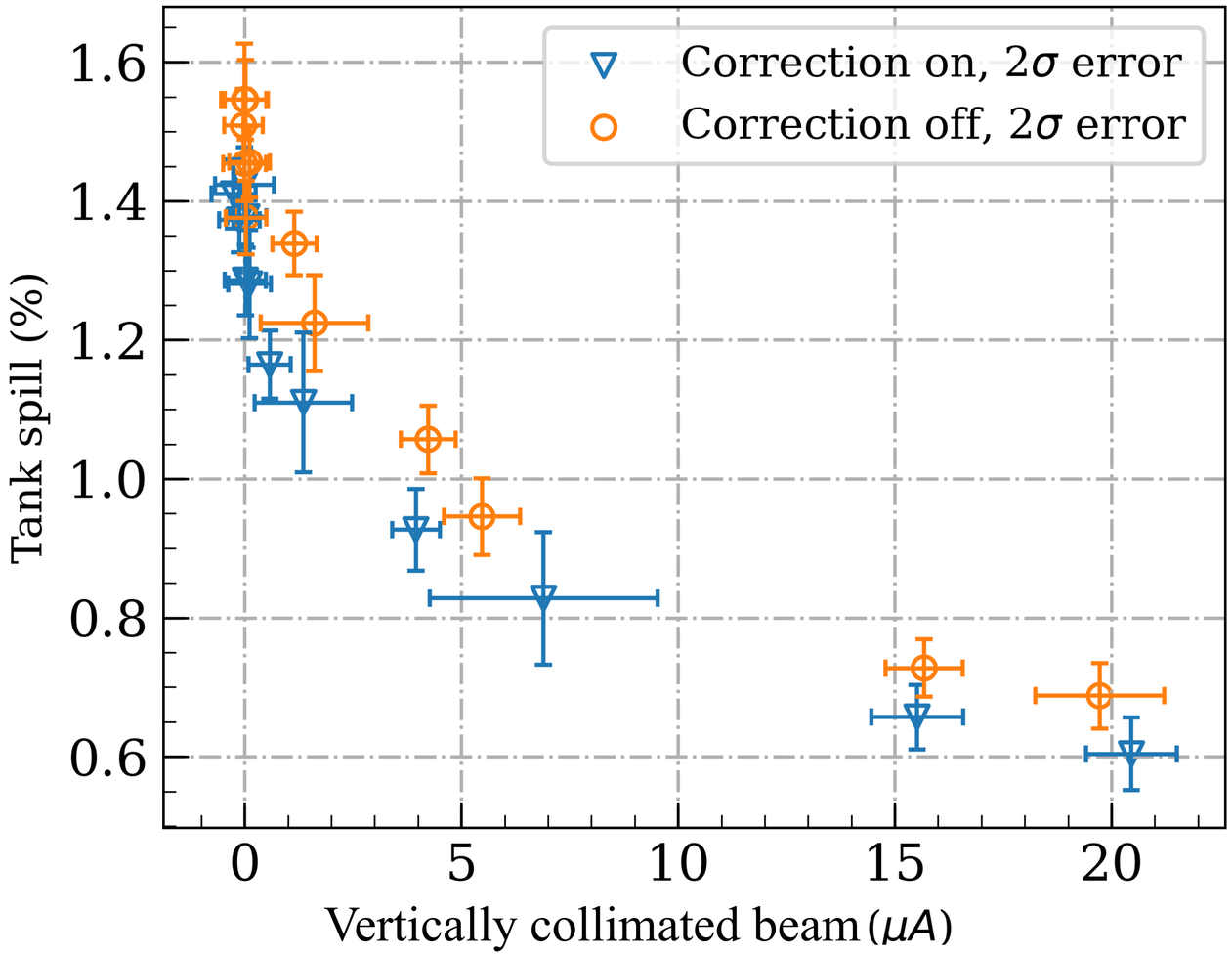


*Y.-N. Rao et al, "Correction of Linear Coupling Resonance in the TRIUMF Cyclotron"

Beam loss

Beam loss is reduced by ~ 15%.



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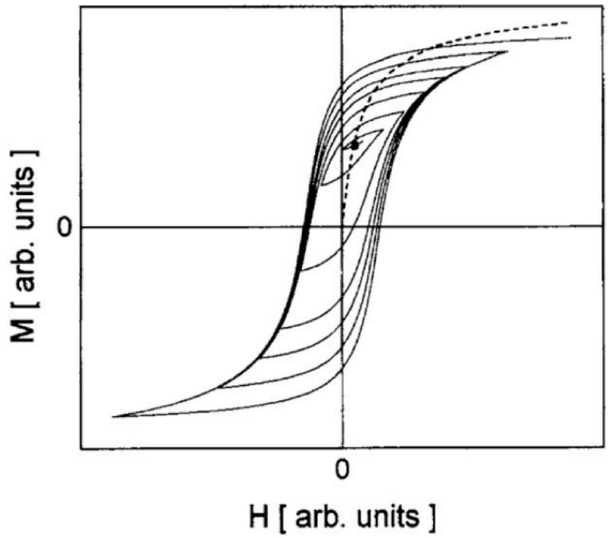
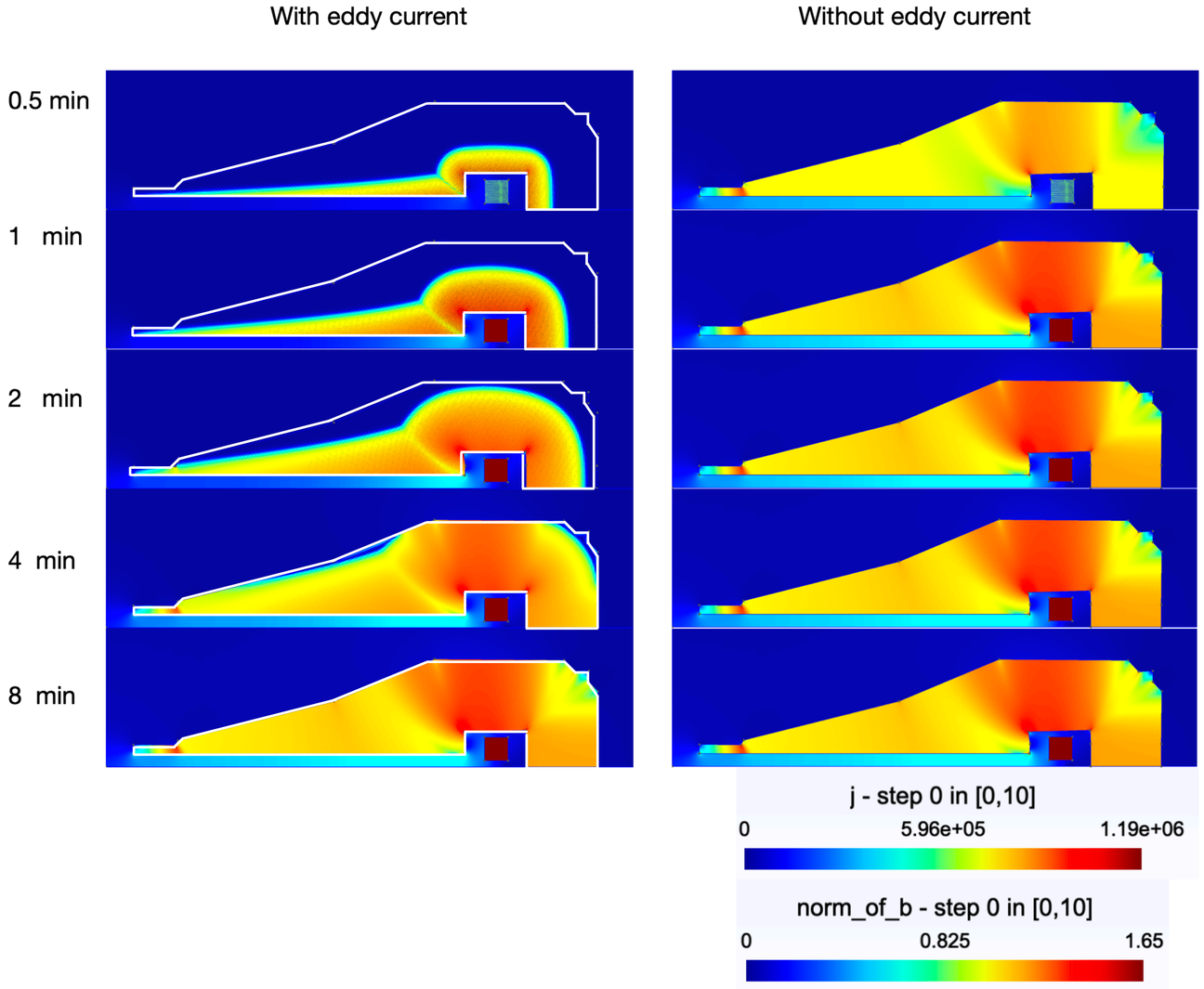
Hysteresis and eddy current

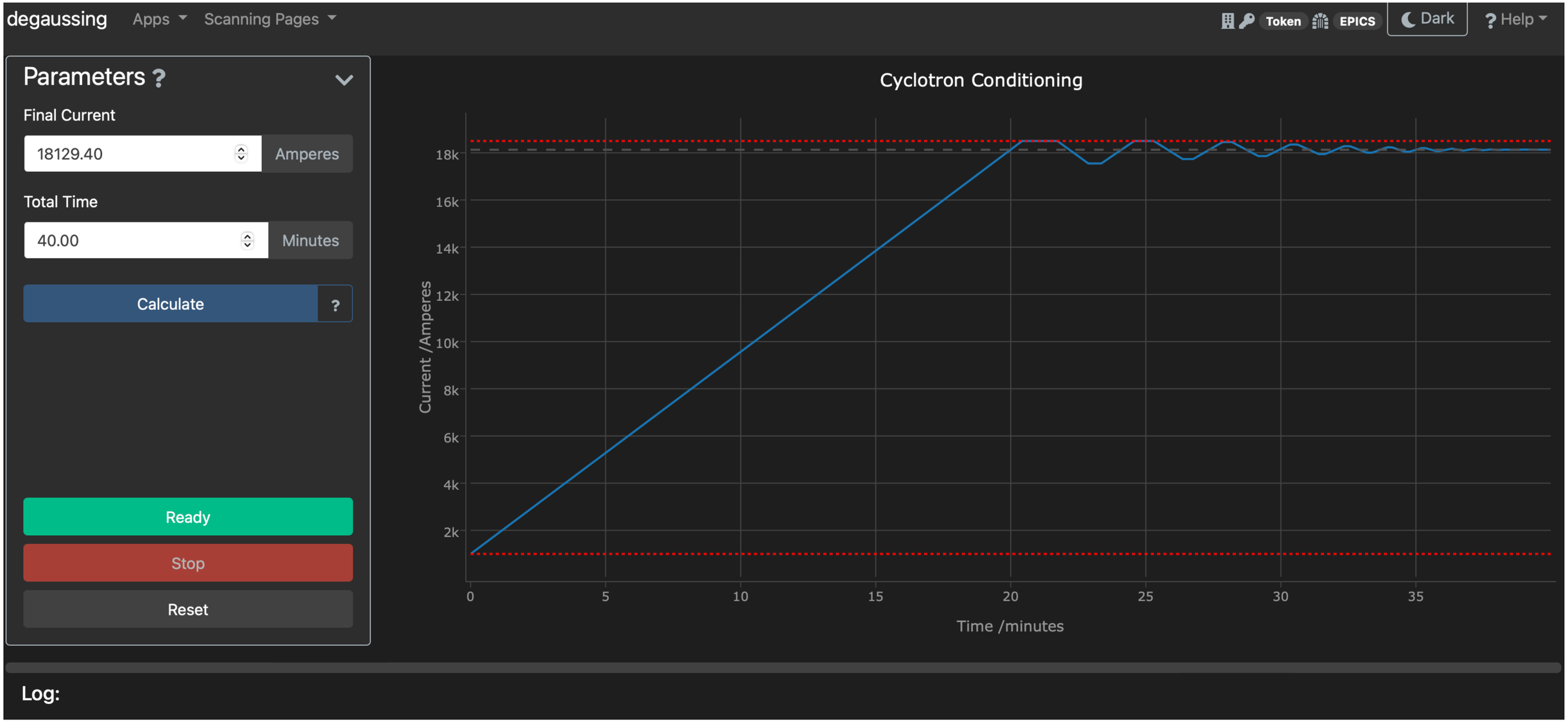


A cyclic field of variable amplitude is applied to allow the magnet jump between different hysteresis loop.

Varying frequency of the degauss curve is also important for triumf cyclotron due to the eddy current.



Programed magnet ramp

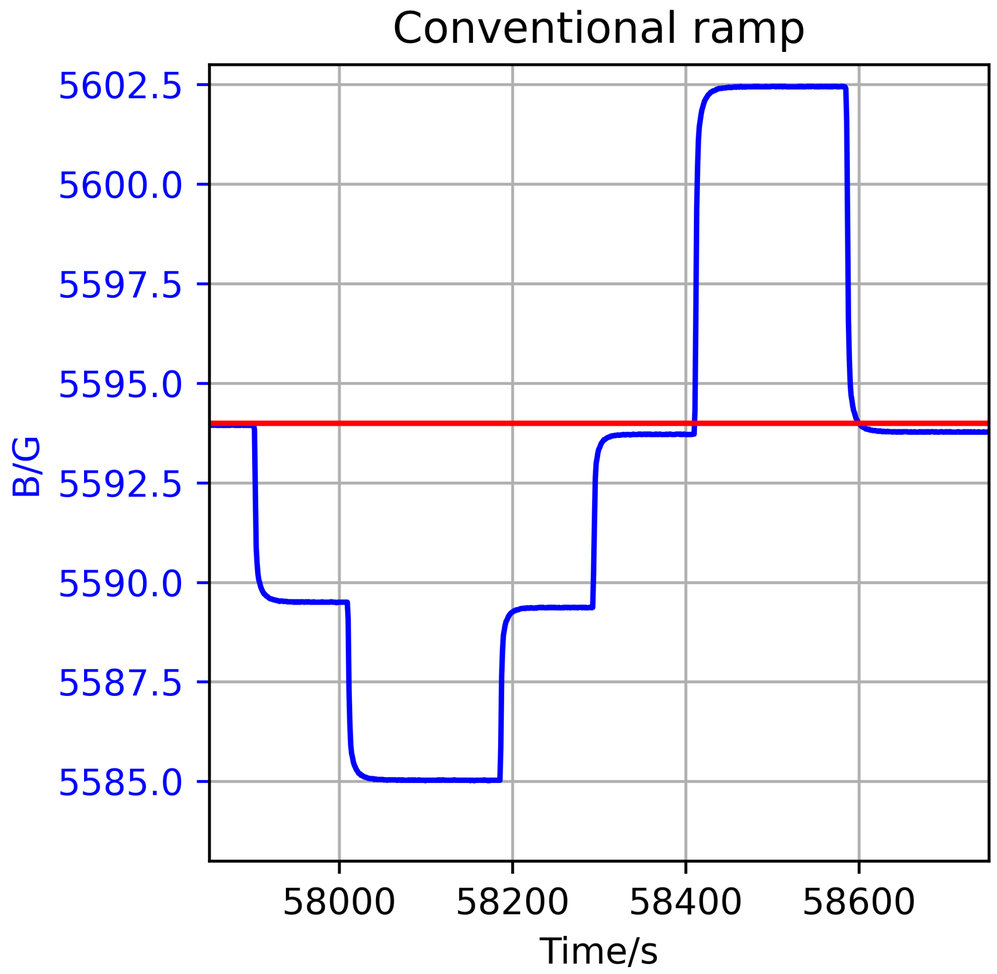


*T. Planche et al, "Magnet Measurement during the Cyclotron Main Magnet Ramp-up of April 2023"

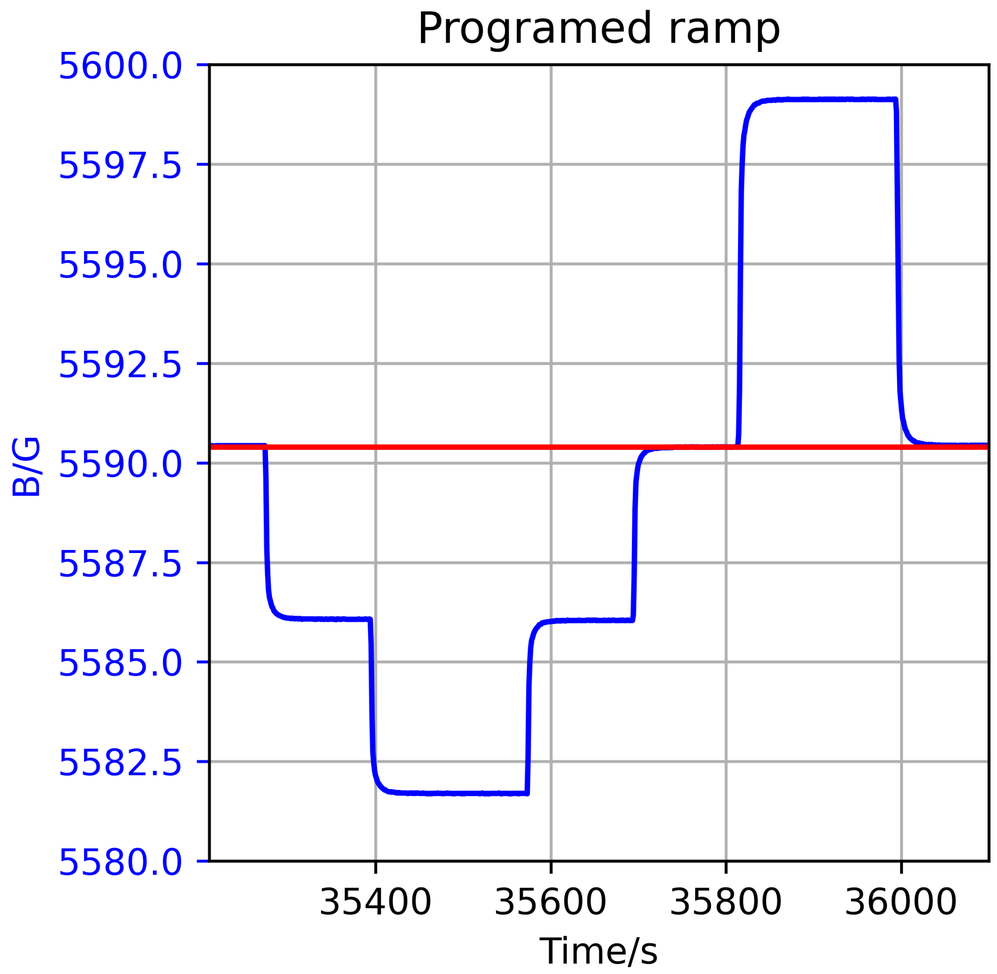
Field reproducibility

Magnetic field flux density reading from NMR probe

Maximum field change is 250 mG (±22 ppm)



Maximum field change is 40 mG (±3.5 ppm)

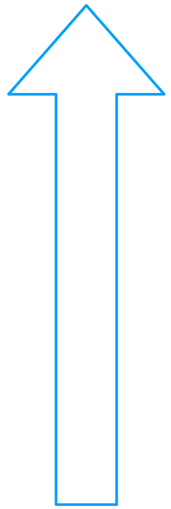


Future plans

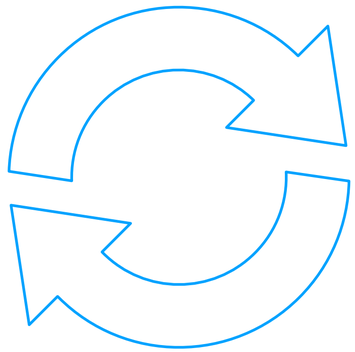
Cutting edge accelerator researches to develop reliable high intensity beam

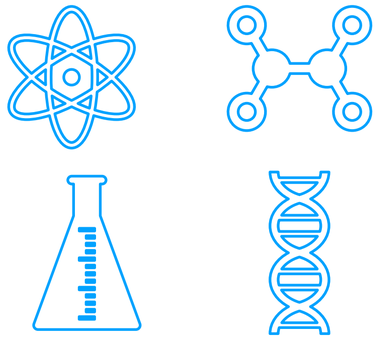
Source brightness
Injection
Space charge in the central region
Beam loss in the high energy region
.....

Boost support for users

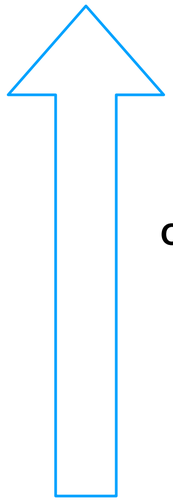


Cyclotron





Users



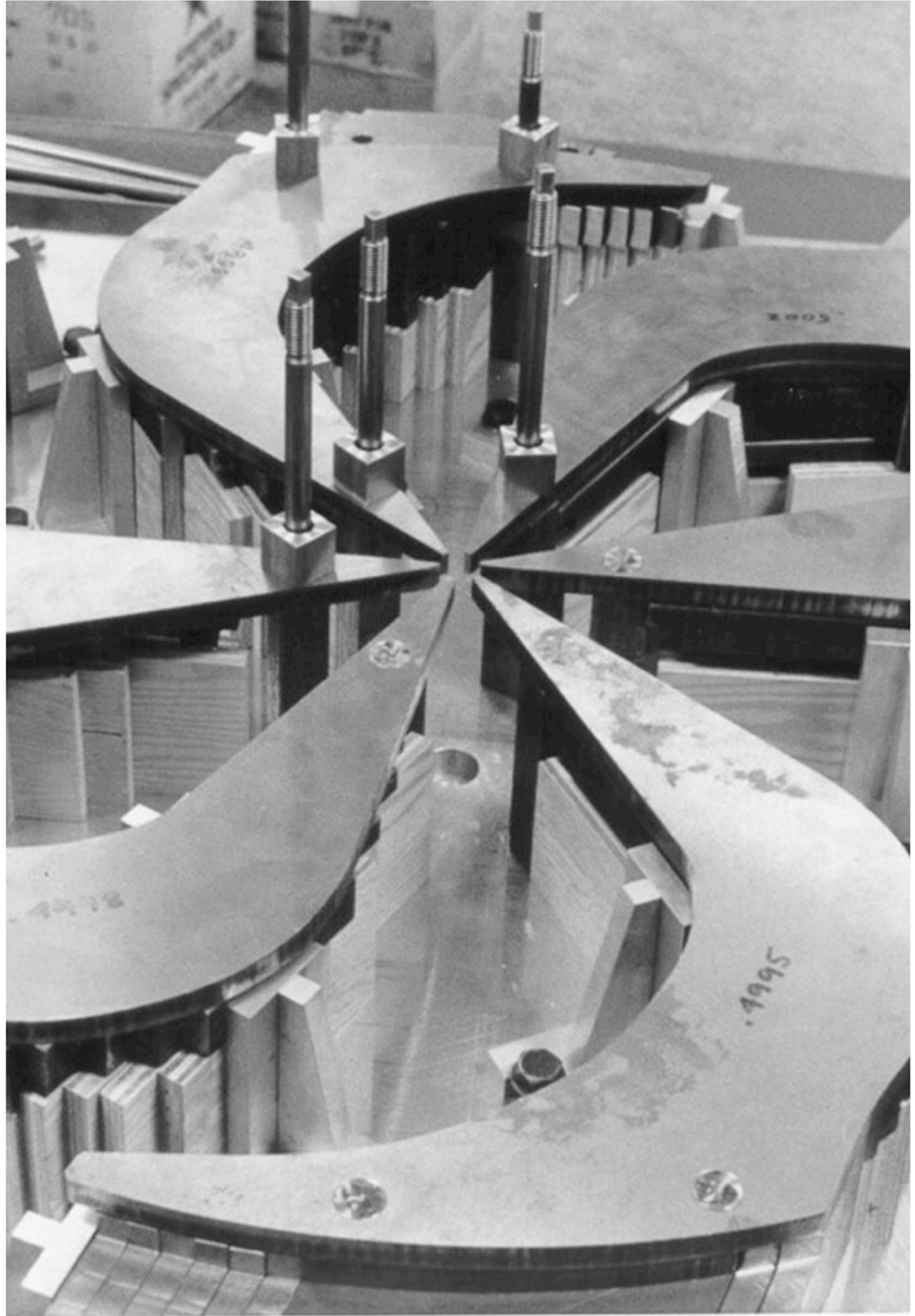
New projects conducted by the TRIUMF community and new partner

New demand for cyclotron

Thank you
Merci

www.triumf.ca

Follow us **@TRIUMFLab**



Discovery, accelerated