

Machine Dosimetry in Synchrotrons: Neutron and Photon Mapping Using Alanine and CR-39 Detectors

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Summary

- 1 Introduction
- 2 Alanine Dosimetry and CR-39
- 3 Previous Results
- 4 New Results and Integrated Analysis
- 5 Conclusions and Next Steps

Summary

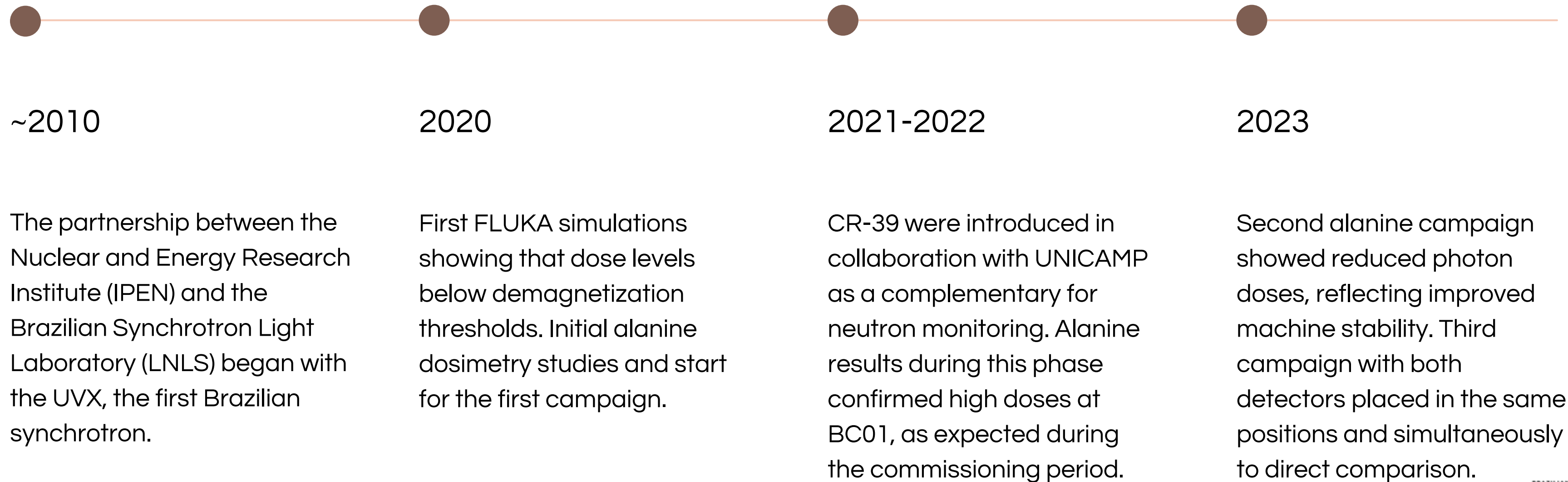
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Demagnetization of magnetic
lattice components?

How to measured it?

Timeline



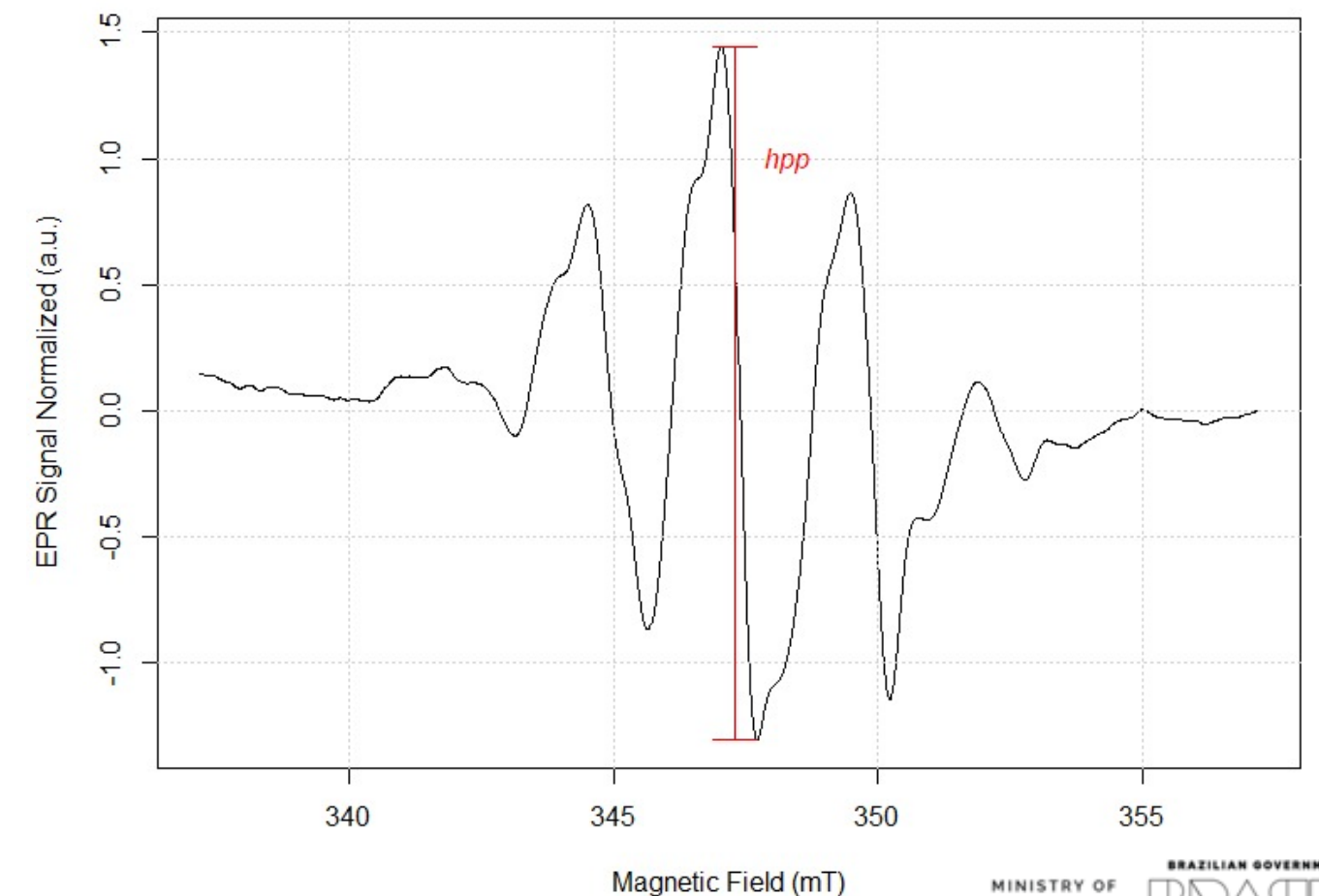
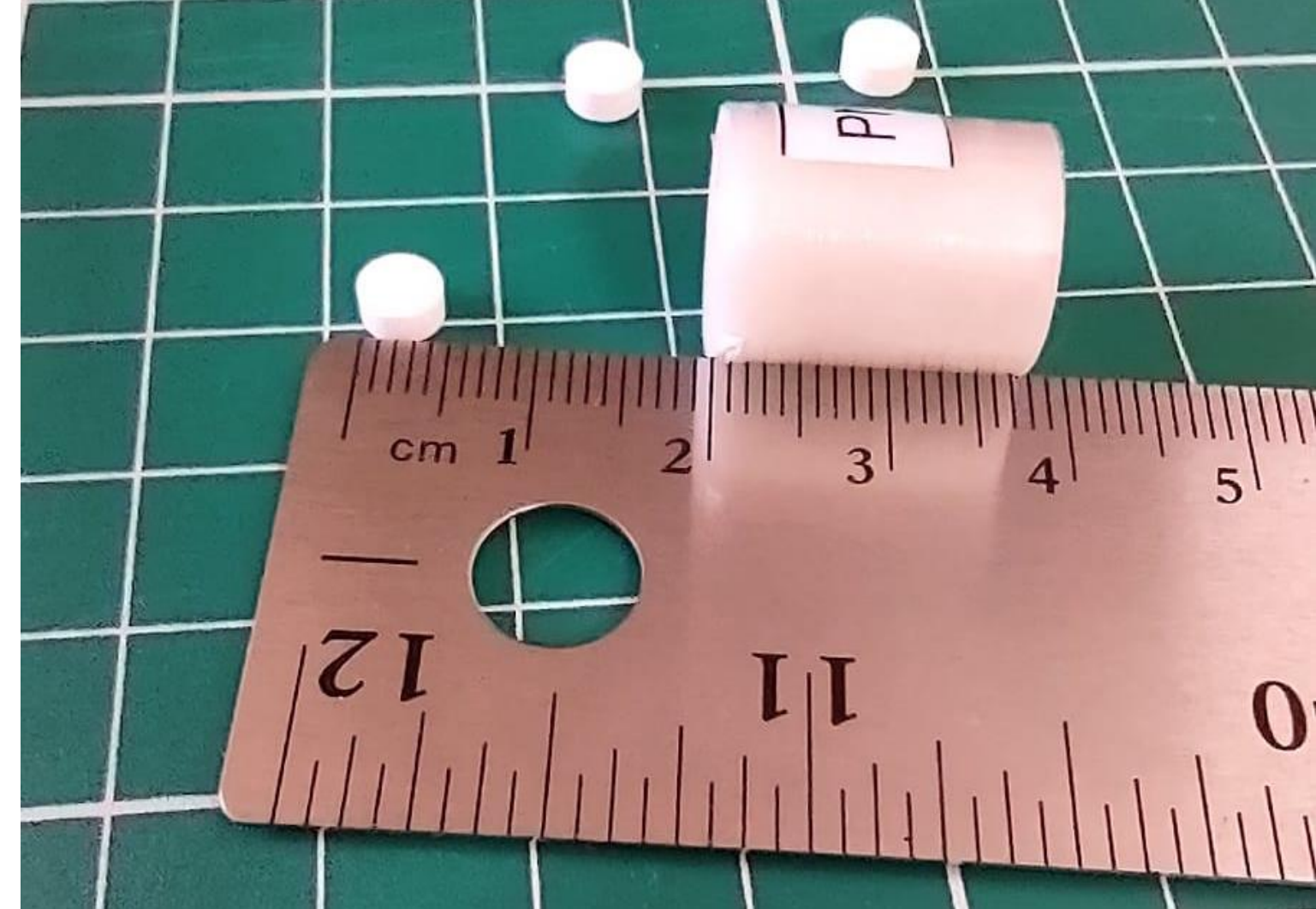
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Alanine Dosimetry

Solid-state nuclear track detectors

- The alanine dosimeter is made of pure alanine crystals, which are highly sensitive to radiation and undergo structural changes when exposed.
- When an alanine molecule is irradiated, it produces a stable free radical, $\text{CH}_3\text{-CH-COOH}$.
- Secondary standard method for radiotherapy dosimetry and industrial applications.
- Dose range of 10 Gy to 100 kGy.
- Low signal decay and a dose uncertainty of $< 3\%$.
- Calibration with Co-60 (1.3 MeV and 1.17 MeV).

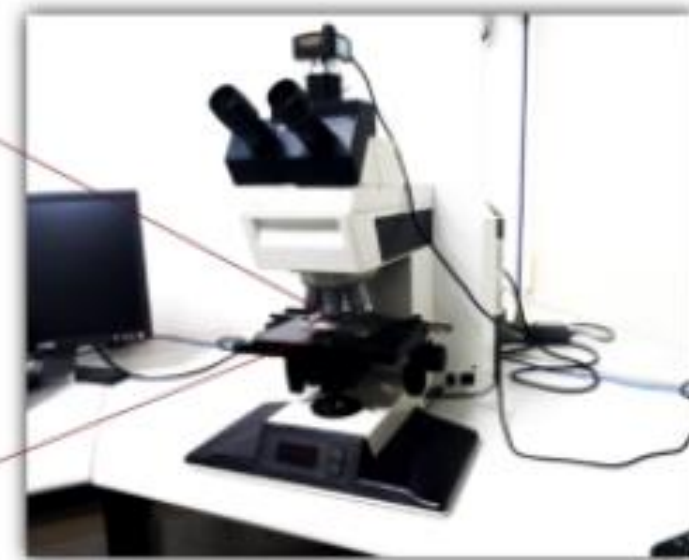
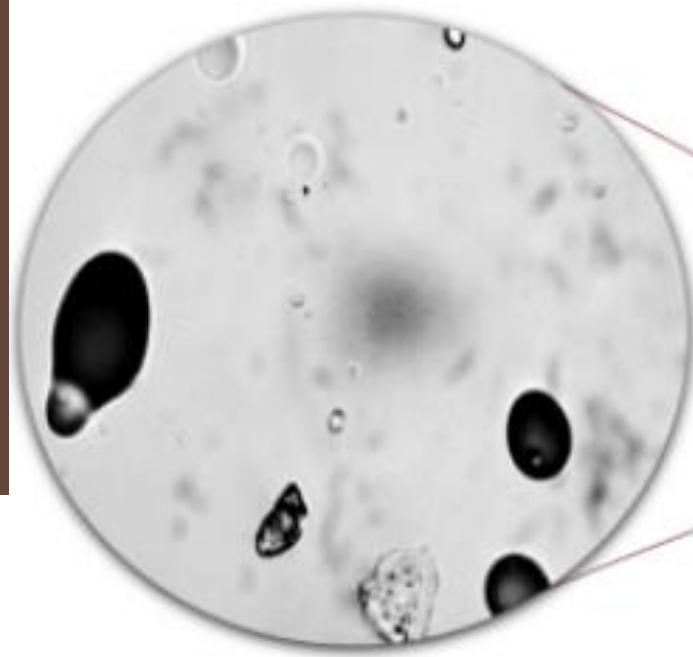
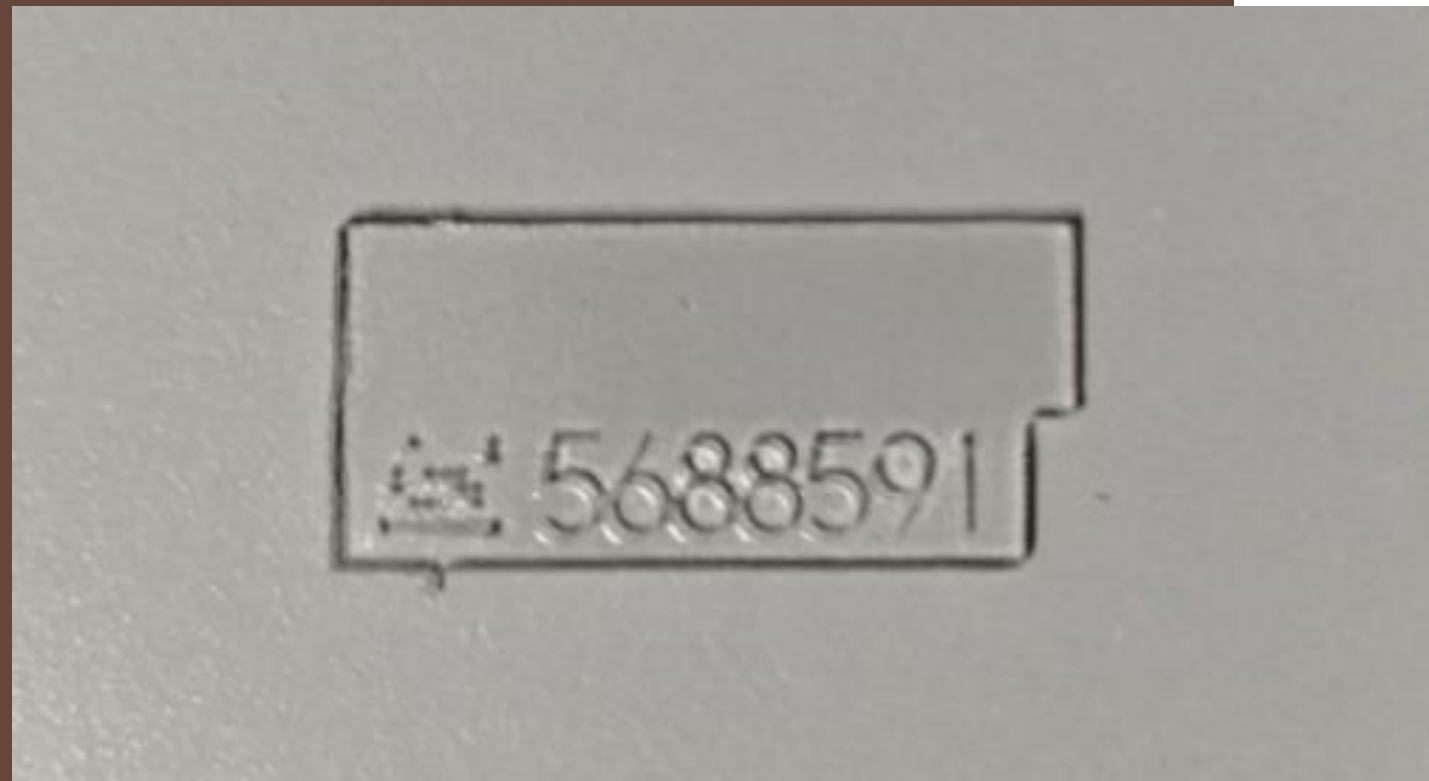


CR-39

Solid-state nuclear track detectors

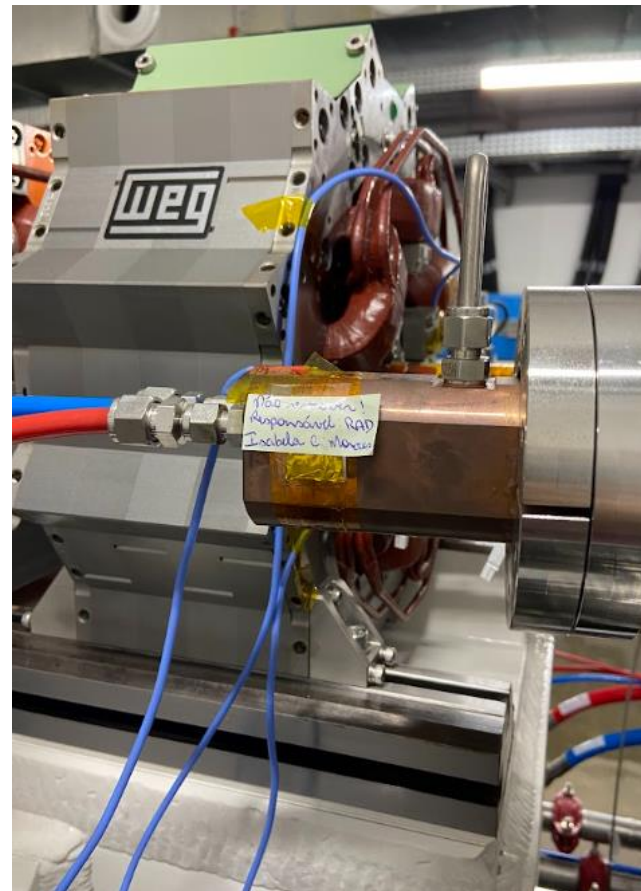
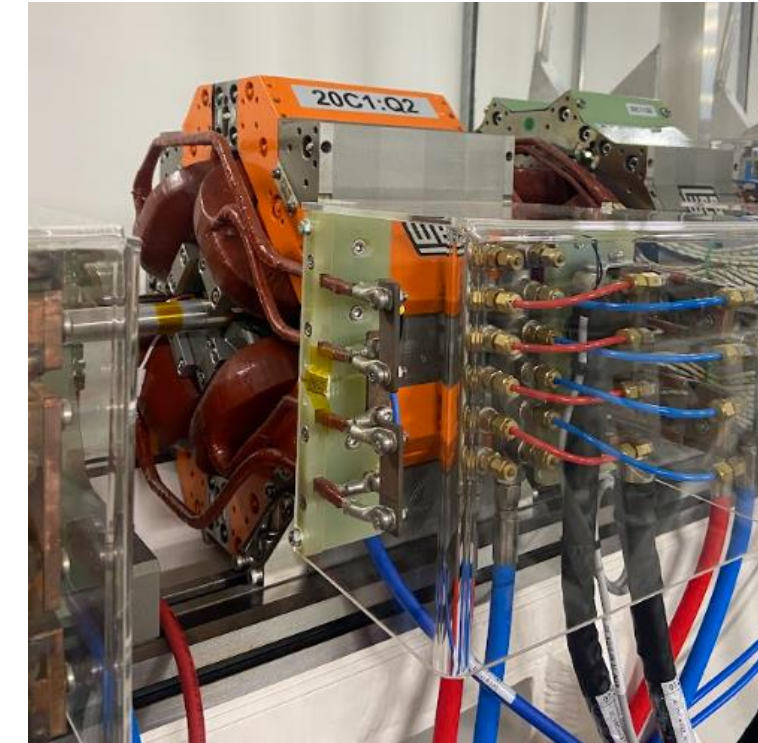
- Detect charged particles from neutron interactions by recording microscopic tracks revealed through chemical etching.
- CR-39 is essential for mixed-field environments.
- Method for discriminate fast neutrons and thermal neutrons.

- Beyond BCs → Installed in dipoles, quadrupoles, undulators, absorbers, and other radiation-sensitive areas (show a position map).



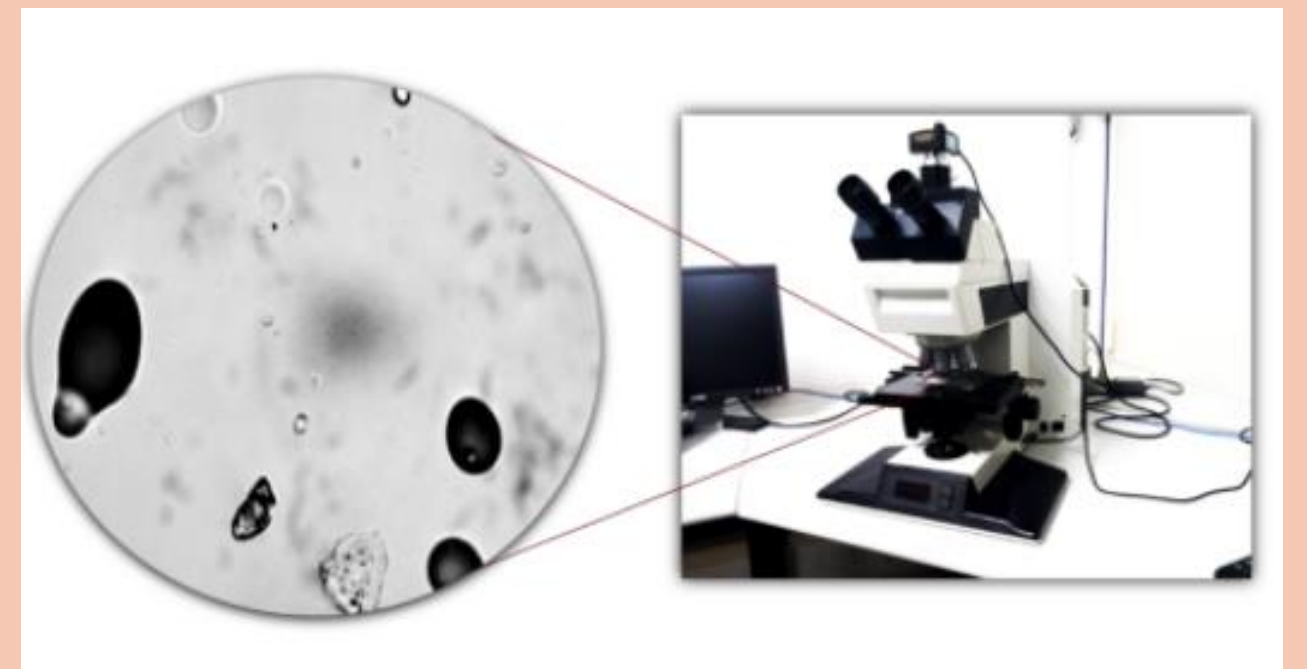
Materials and method

- Alanines:
 - Central Bending Magnets (BC)
- CR-39:
 - Central Bending Magnets (BC);
 - Dipoles;
 - Quadrupoles;
 - Sextupoles;
 - Ondulators;
 - Copper absorber;
 - Personal Chicane.



Materials and method

- High-dose dosimeters composed of alanine and read by Electron Paramagnetic Resonance (EPR) (Figure 1)
- CR-39 solid-state nuclear track detectors (SSNTDs), chemical etching in NaOH solution for read out by optical microscopy (Figure 2)



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Campaigns

RADSYNCH 23

12 months:
2020 to 2021
@ 5 to 40 mA

06 months:
2021 to 2022
@ 60-80 mA

12 months:
2023 to 2024
@ 100 mA top-up

Previous Results - RADSYNCH 2023

Zero means less than 1.5

1st experiment: 12 months (20/jan - 21/jan)		
Point	Dose (Gy)	Uncertainty (%)
BC01-I	17,8	2,3
BC01-M	386,6	2,9
BC-01-F	32,4	0,5
BC03-I	0	0
BC03-M	0	0
BC03-F	16,8	0,5
BC05-I	0	0
BC05-M	0	0
BC05-F	2,5	1,1
BC09-I	0	0
BC09-M	0	0
BC13-I	0	0
BC13-M	3,3	0,8

2nd exp.: 6 months (21/jun- 22/jan)		
Point	Dose (Gy)	Uncertainty (%)
BC01-M	3,29	0,7
BC01-F	2,17	1
BC03-F	2,69	1,1
BC04-M	0	0
BC04-F	1,98	0,7
BC08-M	0	0
BC08-F	1,95	0,7
BC11-M	2,2	0,7
BC11-F	0	0
BC12-M	0	0
BC12-F	3,45	1,5
BC16-M	1,53	1,1
BC16-F	9,02	1,1
BC20-M	0	0
BC20-F	3,02	0,5

Decrease in photon dose over time → Indicates reduction in electron losses → Confirms improved beam dynamics and machine stability.

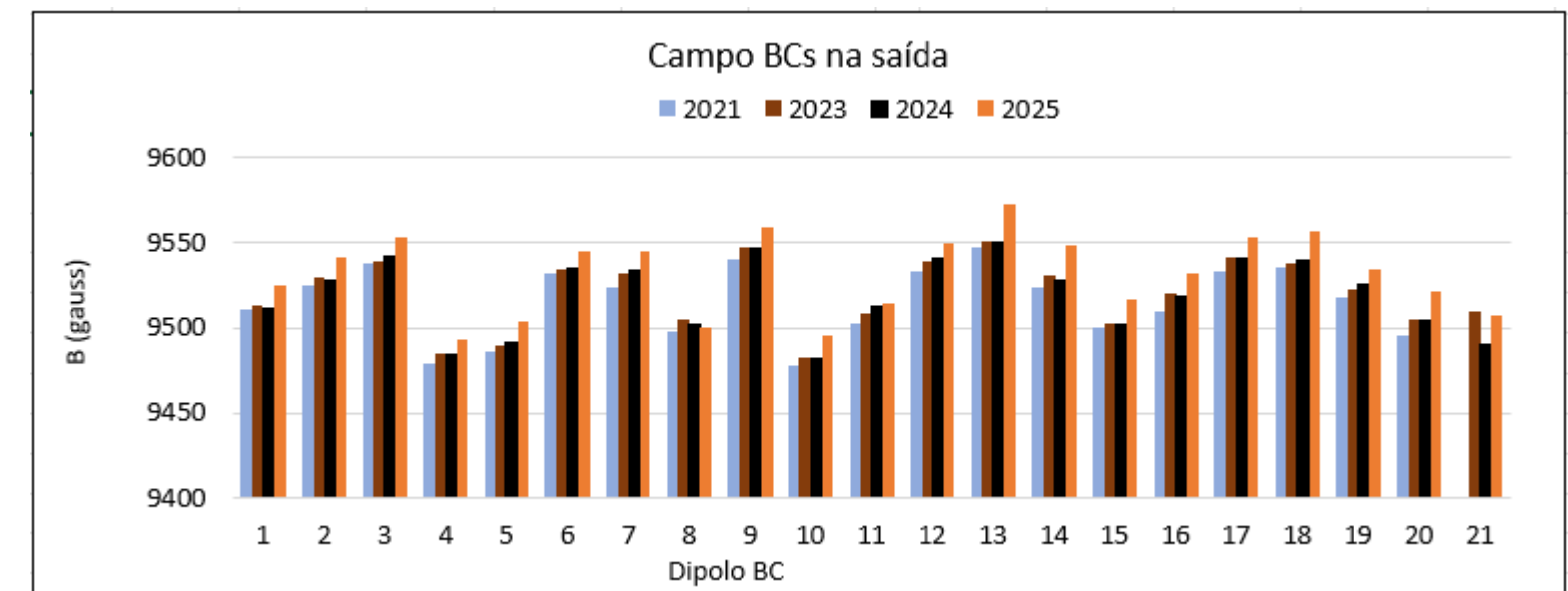
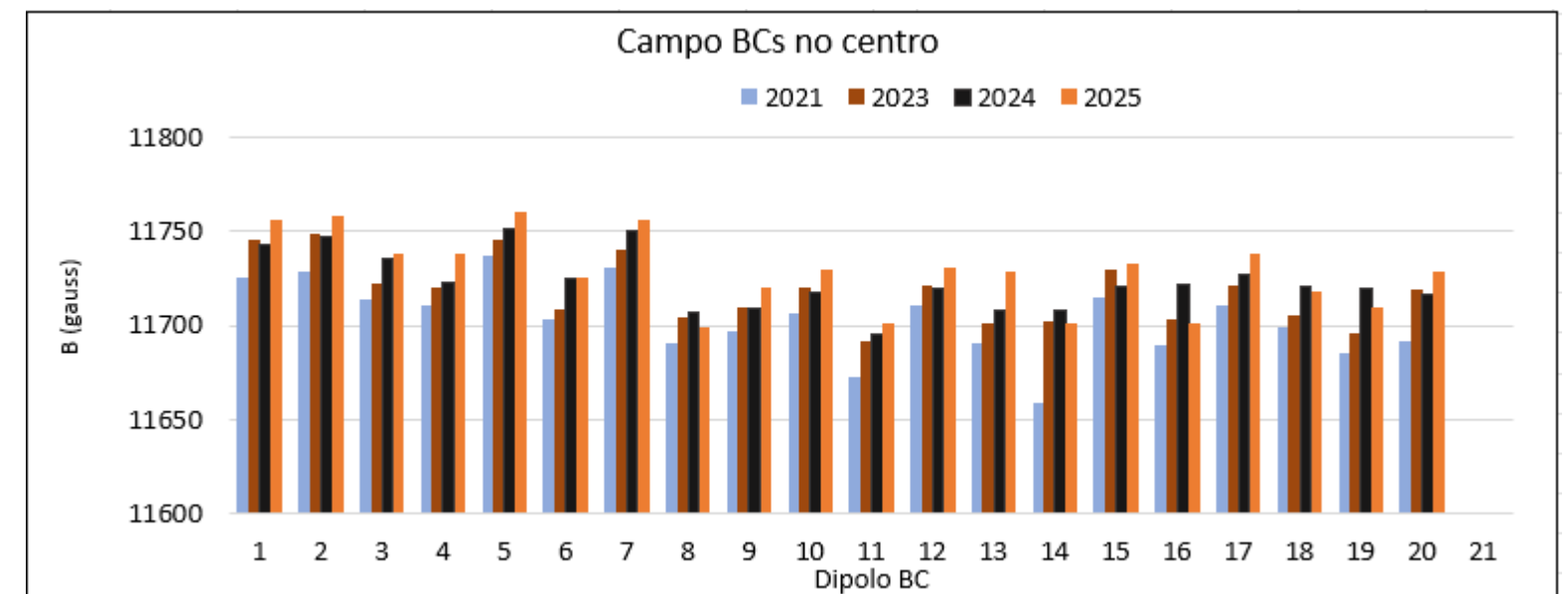
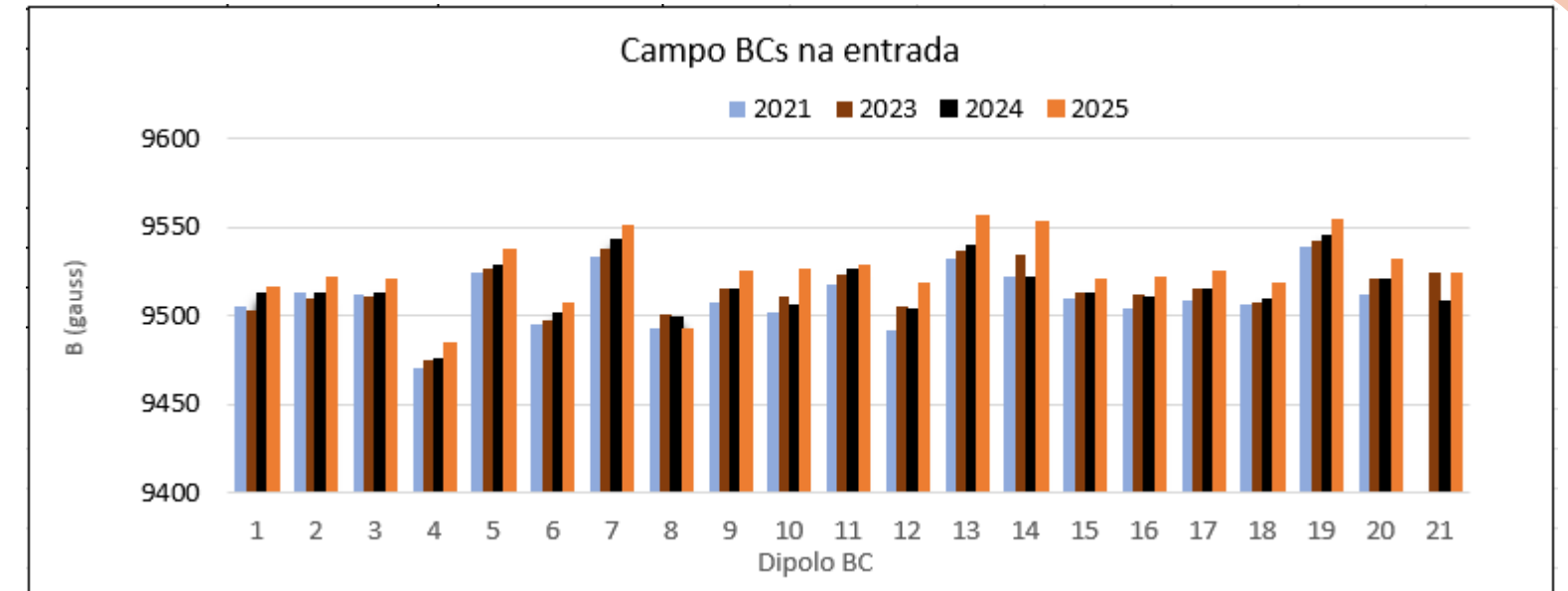


Summary

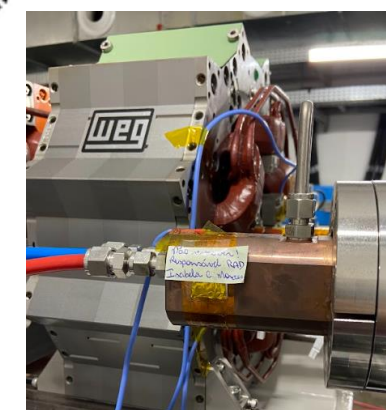
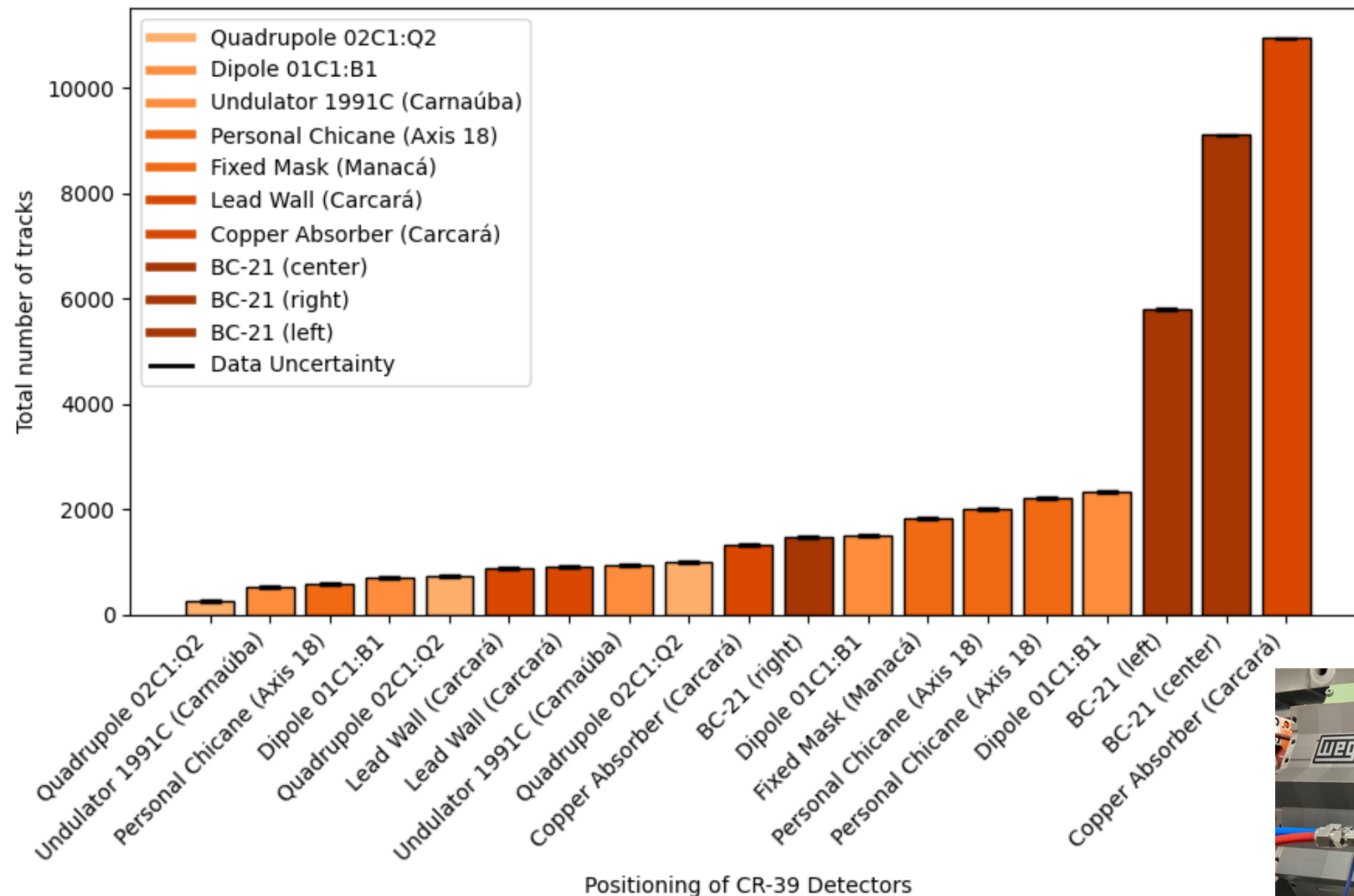
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BENDING FIELD MEASUREMENT

- No significant field variation was observed beyond the measurement uncertainty, indicating no evidence of long-term degradation or demagnetization.
- In 2025, a slight increase in magnetic field was observed in some components.
- This is explained by a lower water temperature in the cooling system during this period.
- NdFeB magnets are temperature-sensitive, and lower temperatures increase their magnetic field strength due to their negative temperature coefficient.



CR-39

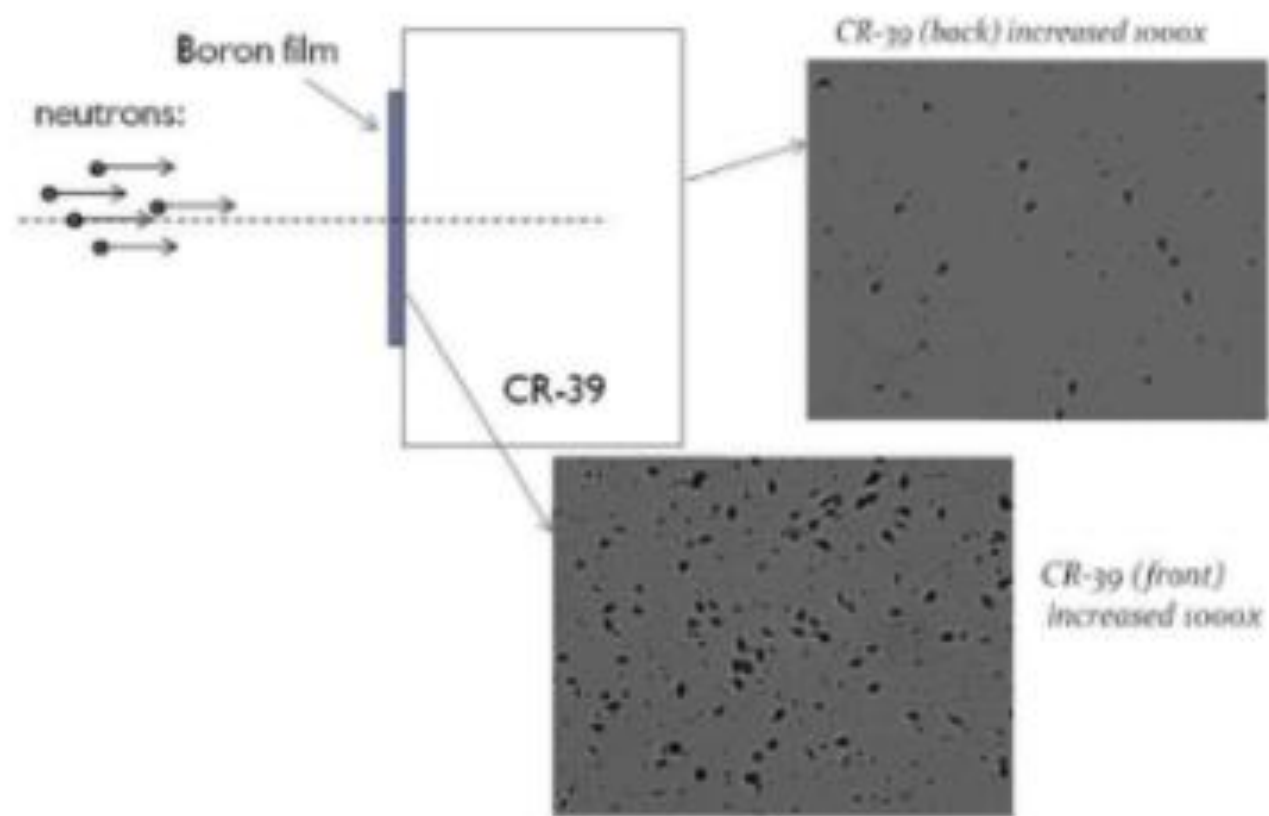


Results - Tracks per region:

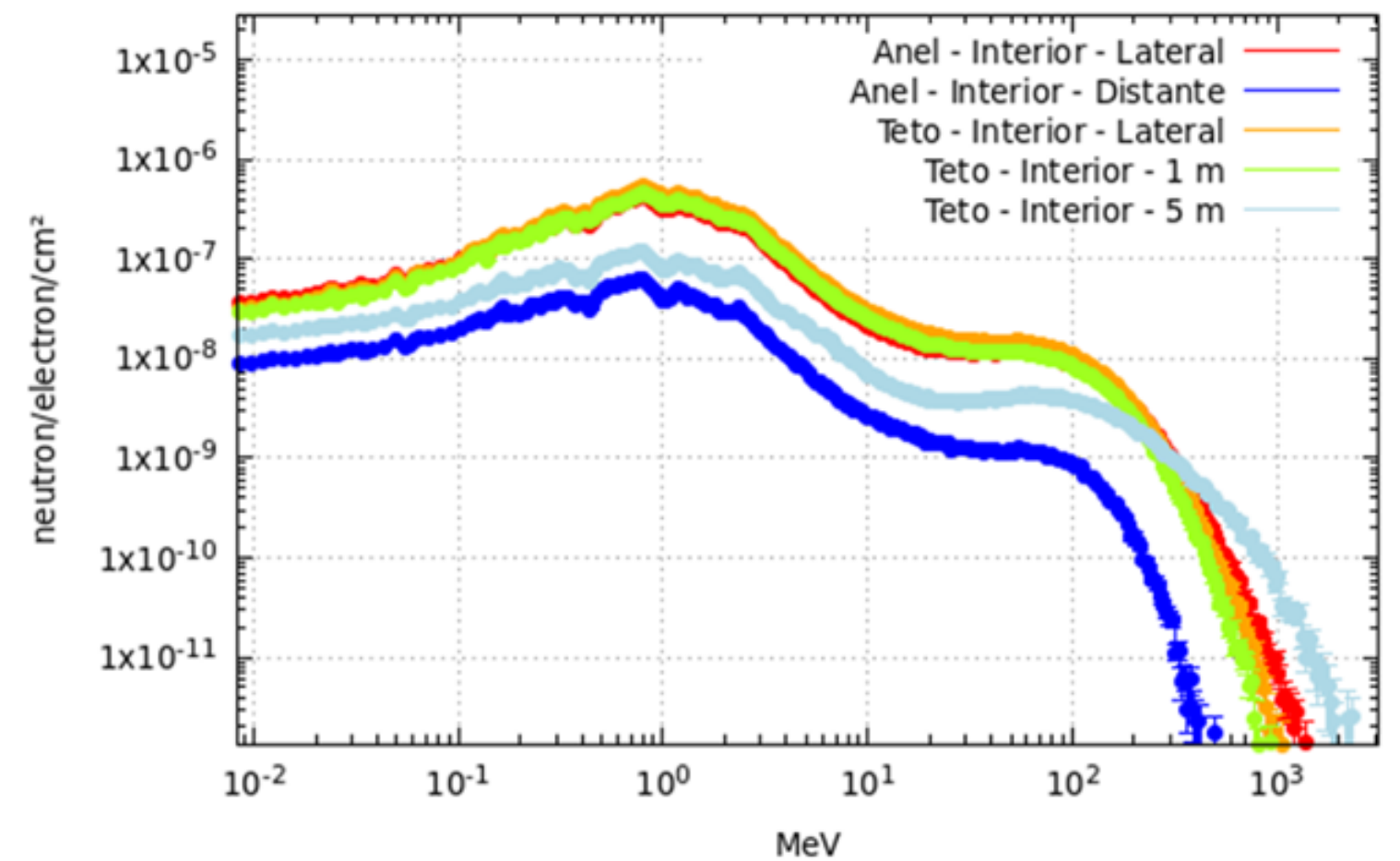
- Evaluated the statistical consistency and variability of the CR-39 data developed by João Vitor da Silva, funding by CNPq.
- BC01 remains the area with the highest neutron exposure, consistent with photon results from alanine.
- A significant neutron hotspot was detected near the copper absorber located at the end of the bending magnet.
- This result is explained by:
 - The location of this component, placed next to a section of the transfer line, where higher electron losses are expected.
 - The high-energy photons that interacts with the copper material, generating neutrons

CR-39

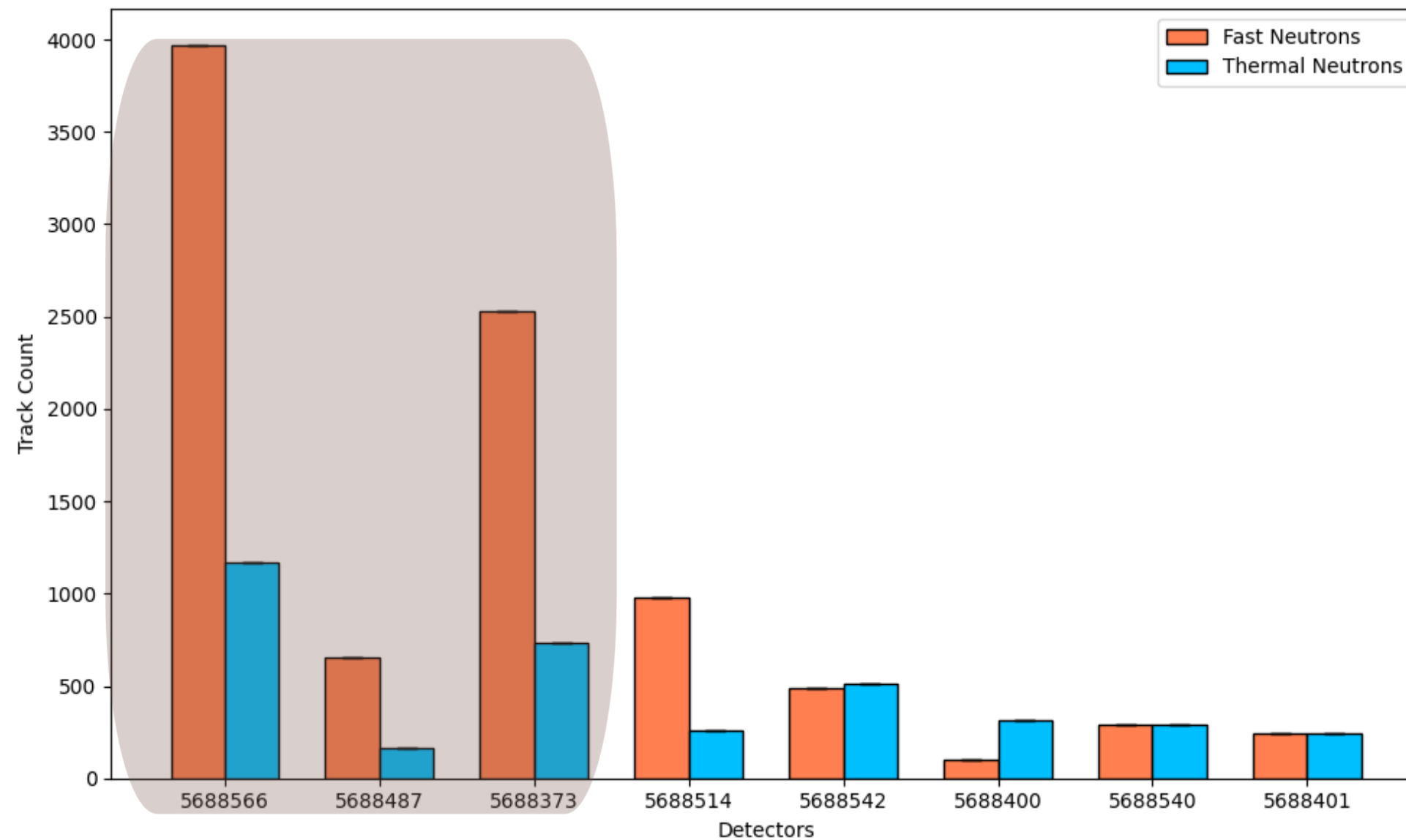
- Use of boron film to detect thermal and fast neutrons.



Neutron Spectra by simulations



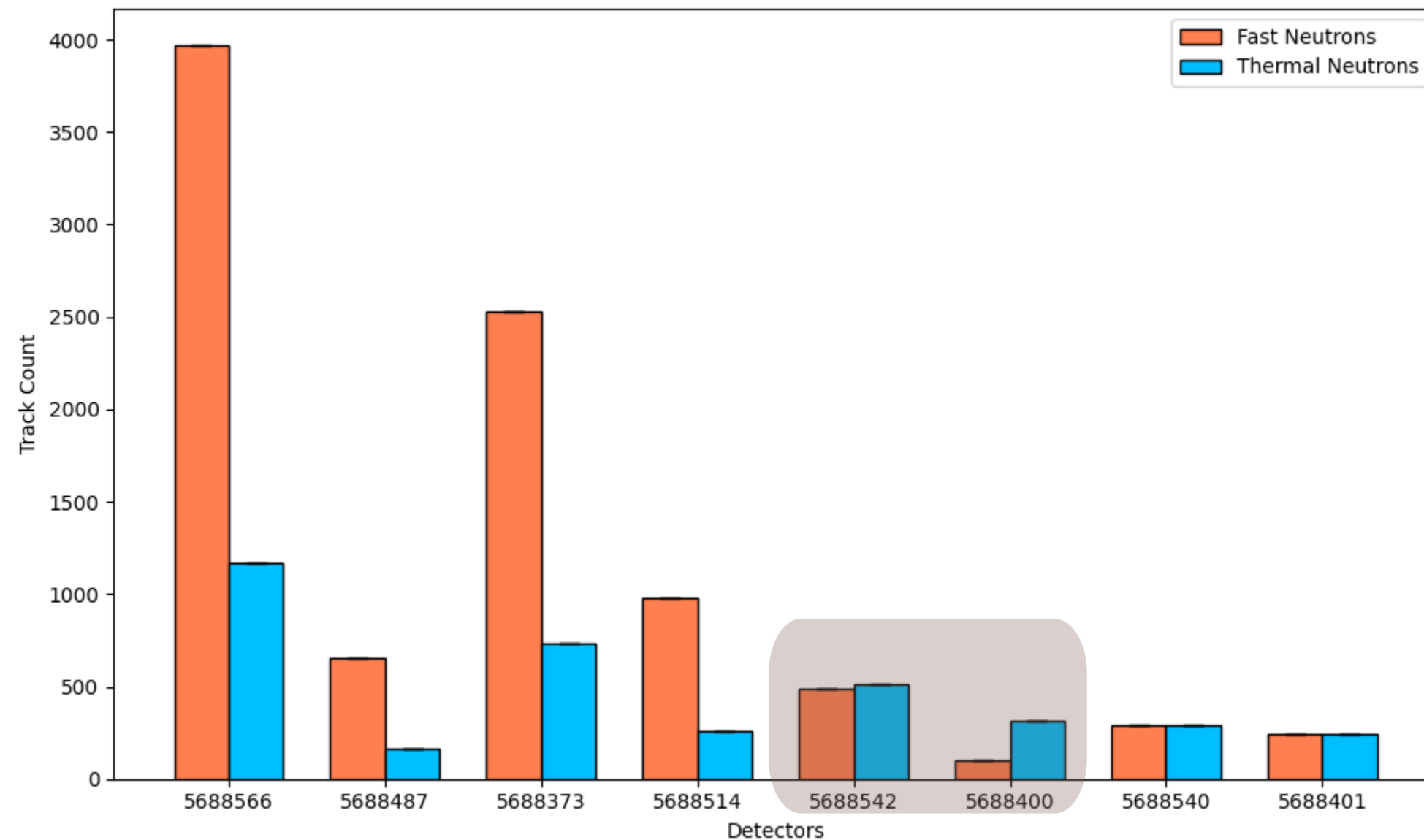
CR-39



Neutron Distribution - BC:

- Fast neutrons dominate in most locations, particularly in high-loss regions.
- The highest fast neutron count was recorded at detector 5688566, 5688487, and 5688373, related to positions of the BC. It's consistent with the expected high electron losses in this region.

CR-39



Neutron Distribution - Dipoles:

- Detector 5688542 and 5688400, located in two dipoles.
 - The first presents a remarkably balanced ratio between thermal and fast neutrons, with almost equivalent counts.
 - The second has thermal neutrons are slightly higher than fast neutrons. This indicates regions with greater moderation efficiency or lower contribution from primary high-energy sources.

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Conclusions and Next Steps

1. Validation of Radiation Behavior in New Operation Mode

- Evaluate radiation levels with both alanine and CR-39 detectors under the new Sirius operation mode, including the superconducting RF cavity and beam current increase to 200 mA.

2. Neutron Dosimetry Calibration

- How to calibrate the CR-39 for this mixed low flux field?
- Convert CR-39 track densities into dose equivalents, enabling direct and quantitative comparisons with other dosimetric methods.

3. Cross-Comparison Between Dosimetry Methods

- Compare doses obtained from CR-39 (neutron-sensitive) with alanine-equivalent responses for neutron fields, ensuring consistency and complementarity between photon and neutron measurements.

4. Long-Term Monitoring of Machine Components

- Continue assessing machine response, focusing on the long-term integrity of permanent magnets and other important components, supported by periodic radiation monitoring campaigns.



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Obrigada!

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Orlando Rodrigues

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