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Timepix3-based mini-tracker of charged nuclear fragments to detect anatomical changes in radiotherapy with carbon ions

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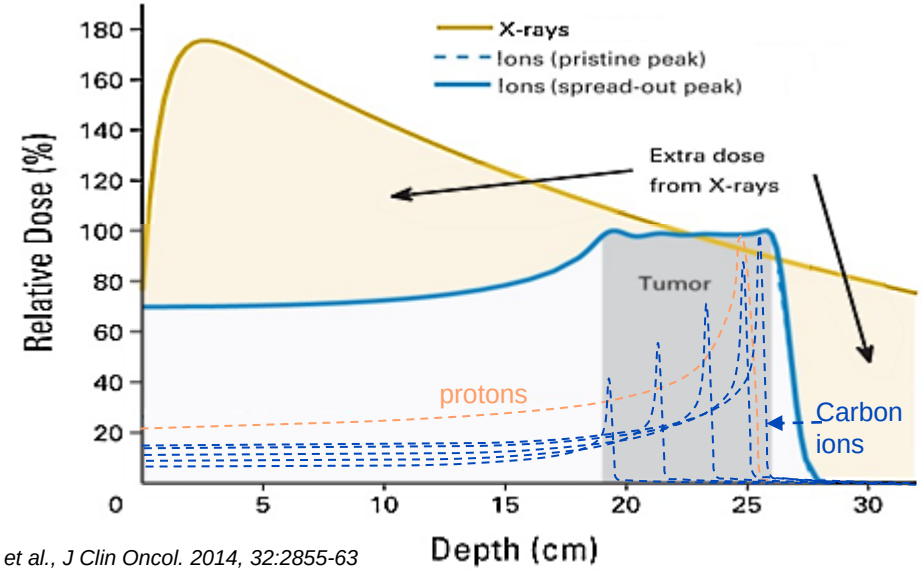
X-rays vs Ions

Ions:

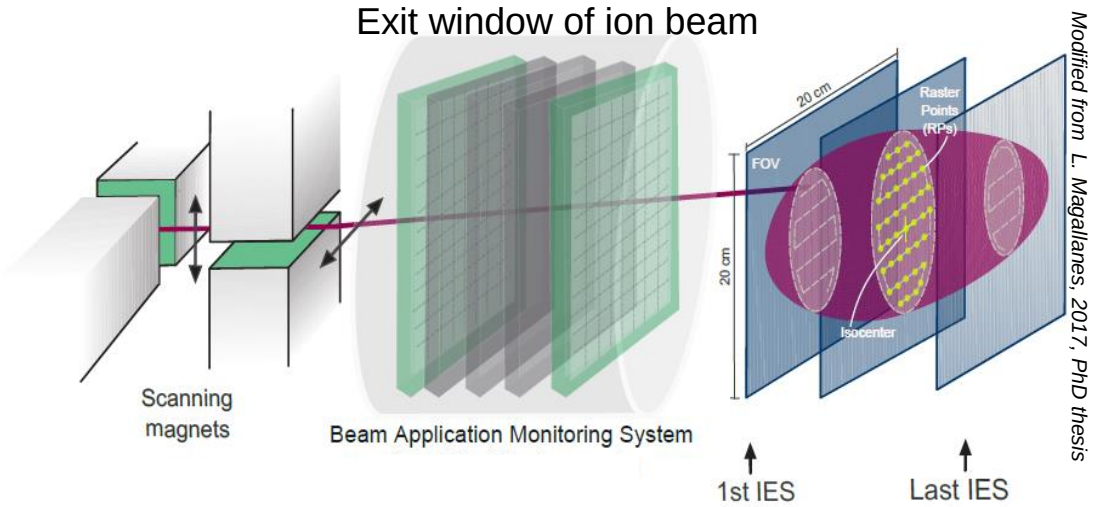
- Have finite range
- Release maximum of energy the end of the range (Bragg peak)
- Allow high concentration of dose in tumor
- Minimize damage to surrounding healthy tissue



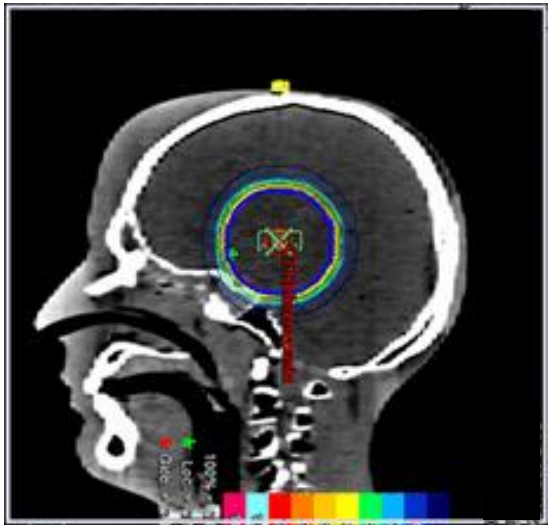
Adapted from Mitin et al., J Clin Oncol. 2014, 32:2855-63

Ion beam delivery

- Treatments performed at Heidelberg Ion Beam Therapy facility: **raster scanning technique**
- Tumor volume virtually segmented in depth
- 3D controlled spot scanning delivery system

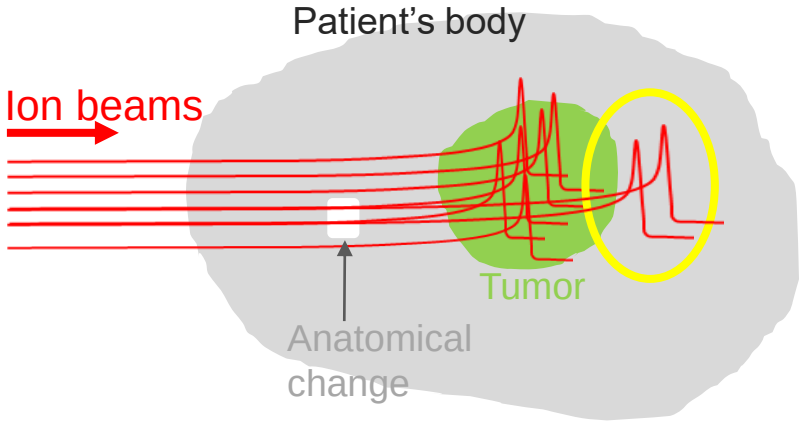


Modified from L. Magallanes, 2017, PhD thesis



Anatomical changes

- Treatment course lasts many days
- Anatomical changes can appear between treatment days



Maximum energy deposition at the end of ion range!!!

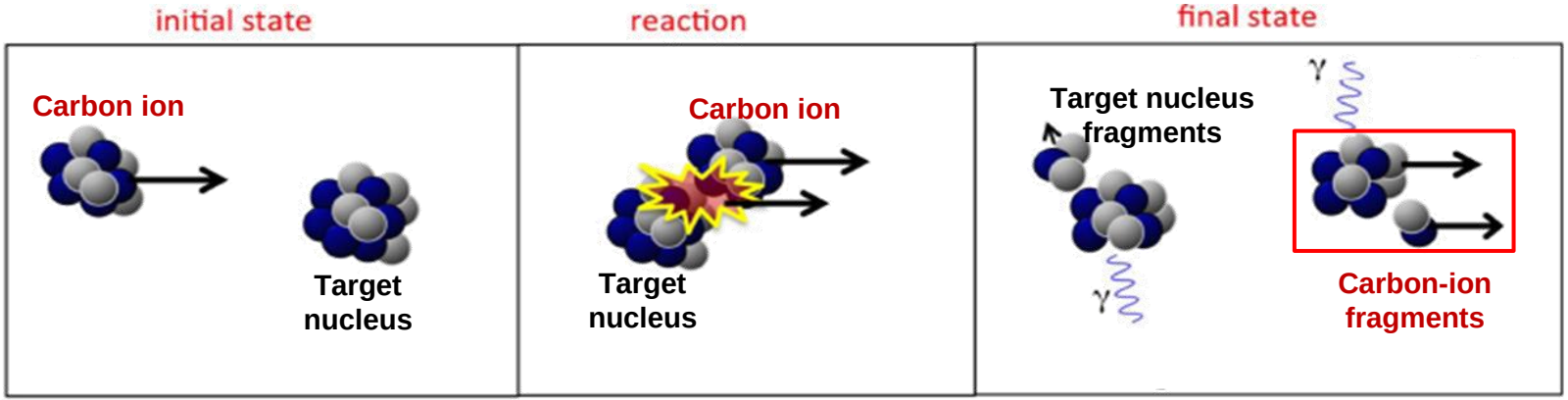
Anatomical changes can lead to:

→ Overdosage of organs at risk/healthy tissue

→ Underdosage of tumor region

Monitoring methods

- Desirable non-invasive monitoring methods:
  - Anatomical change detection **during treatment in the patient**
  - **No extra dose** administrated to the patient
- Monitoring methodology based on **detection of charged nuclear fragments**

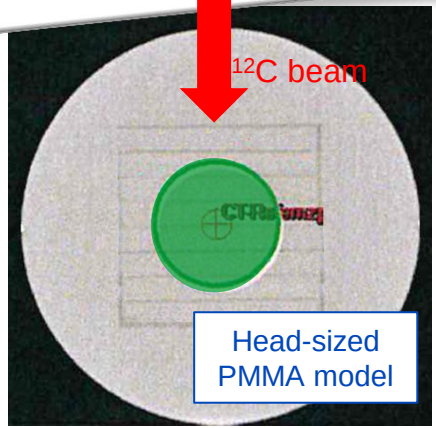


Modified from Kraan, Front Oncol 2015, 5:150

Treatment plan & Mini-tracker

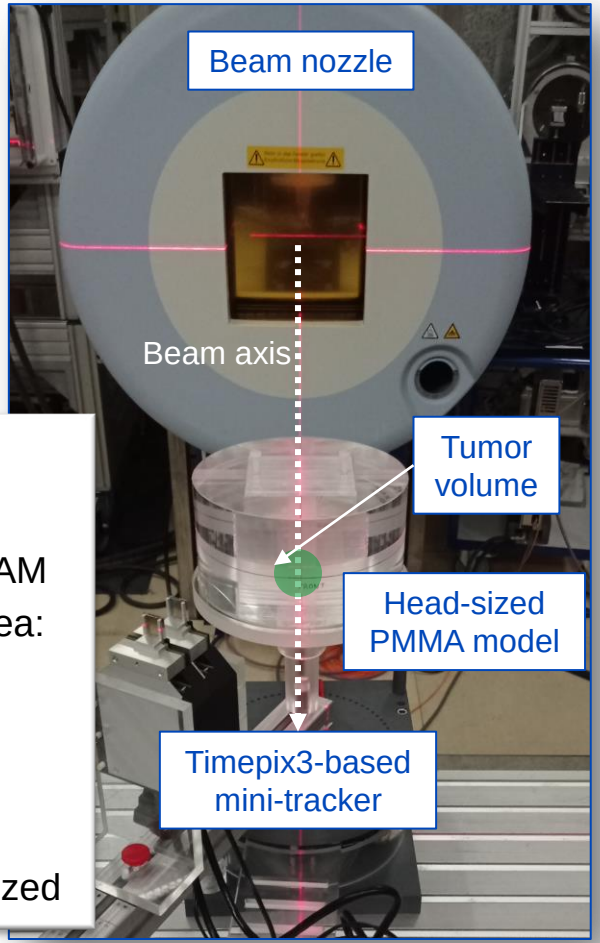
Carbon-ion treatment plan

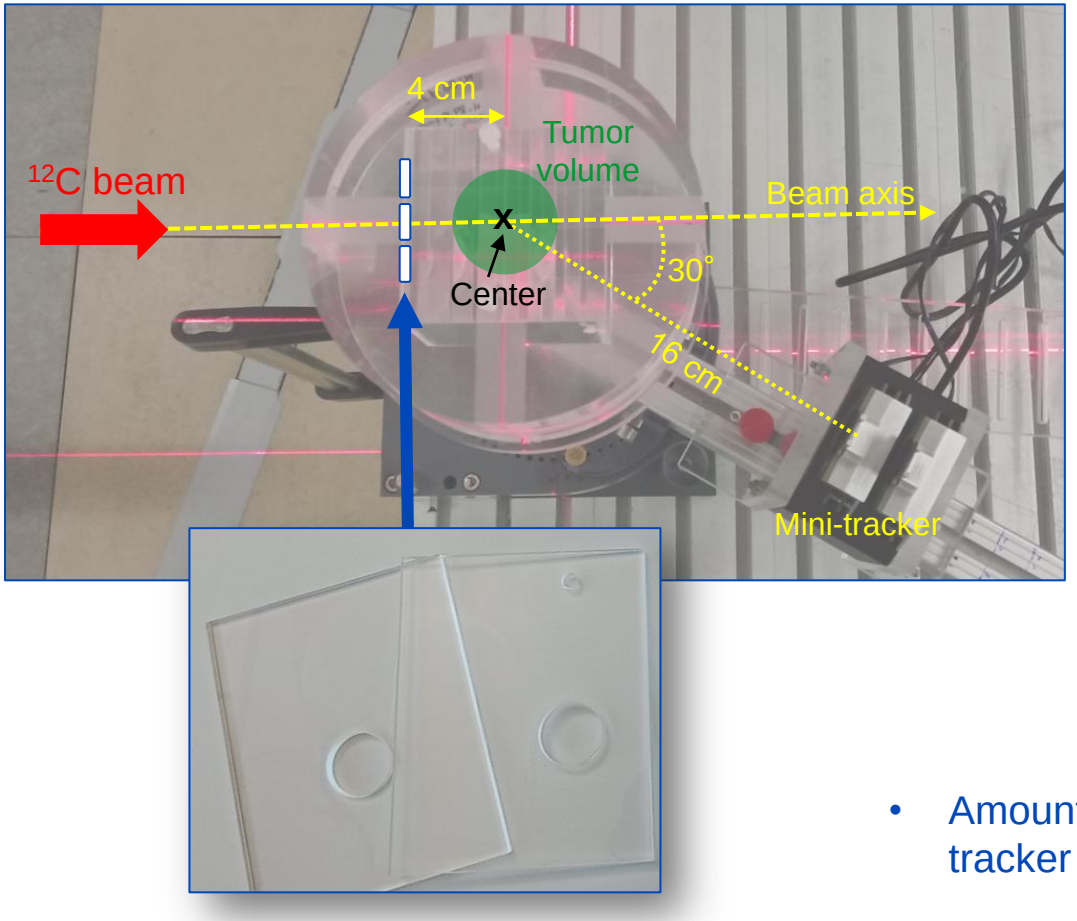
- Typical dose: 3 Gy(RBE)
- Tumor volume: 50 cm^3
- Beam energy range: 175 MeV/n to 245 MeV/n
- Irradiations at HIT center



Mini-tracker

- Two Timepix3 detectors purchased from ADVACAM
- Pixel silicon sensitive area:
  - 14×14 mm^2
  - 300 µm thickness
- Time resolution: 1.56 ns
- Bias voltage: 30 V
- Two detectors synchronized





- Air cavity size:

  2 cm Ø; 0.4 cm thickness (1.26 cm^3)

- Cavity depth:

  4 cm before center

- Cavity positions:

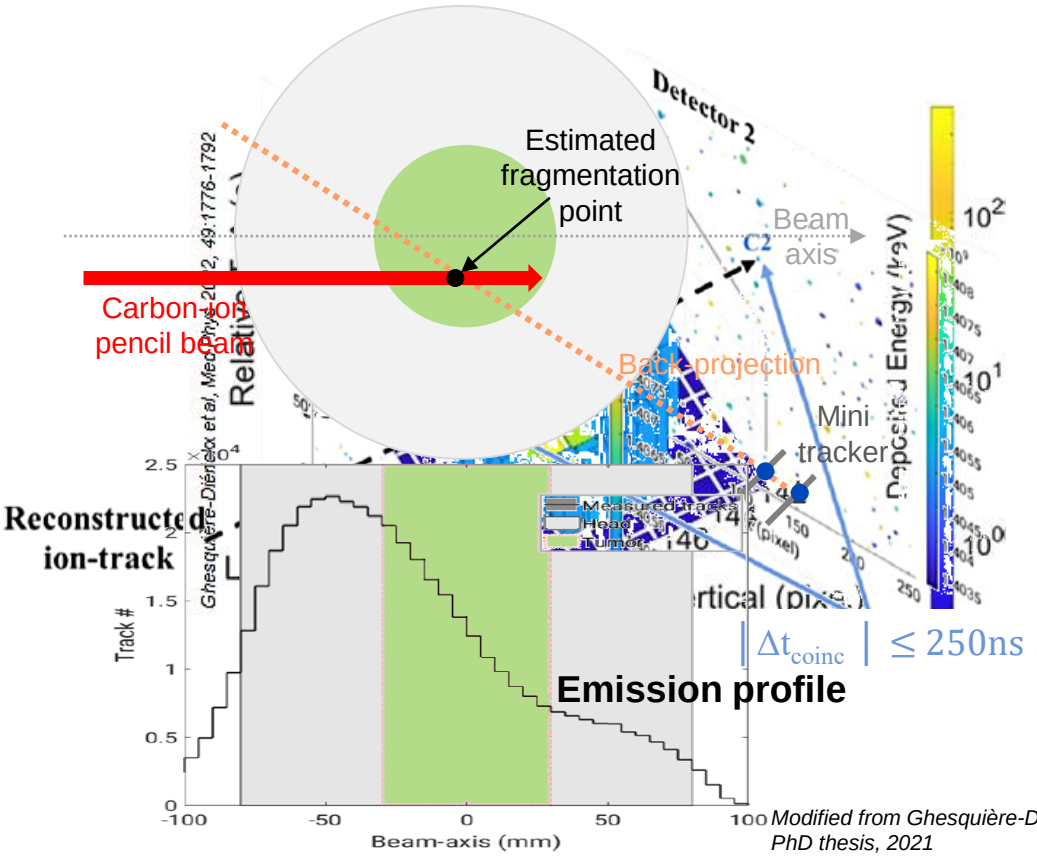
  On beam axis

  Close to mini-tracker

  Far from mini-tracker

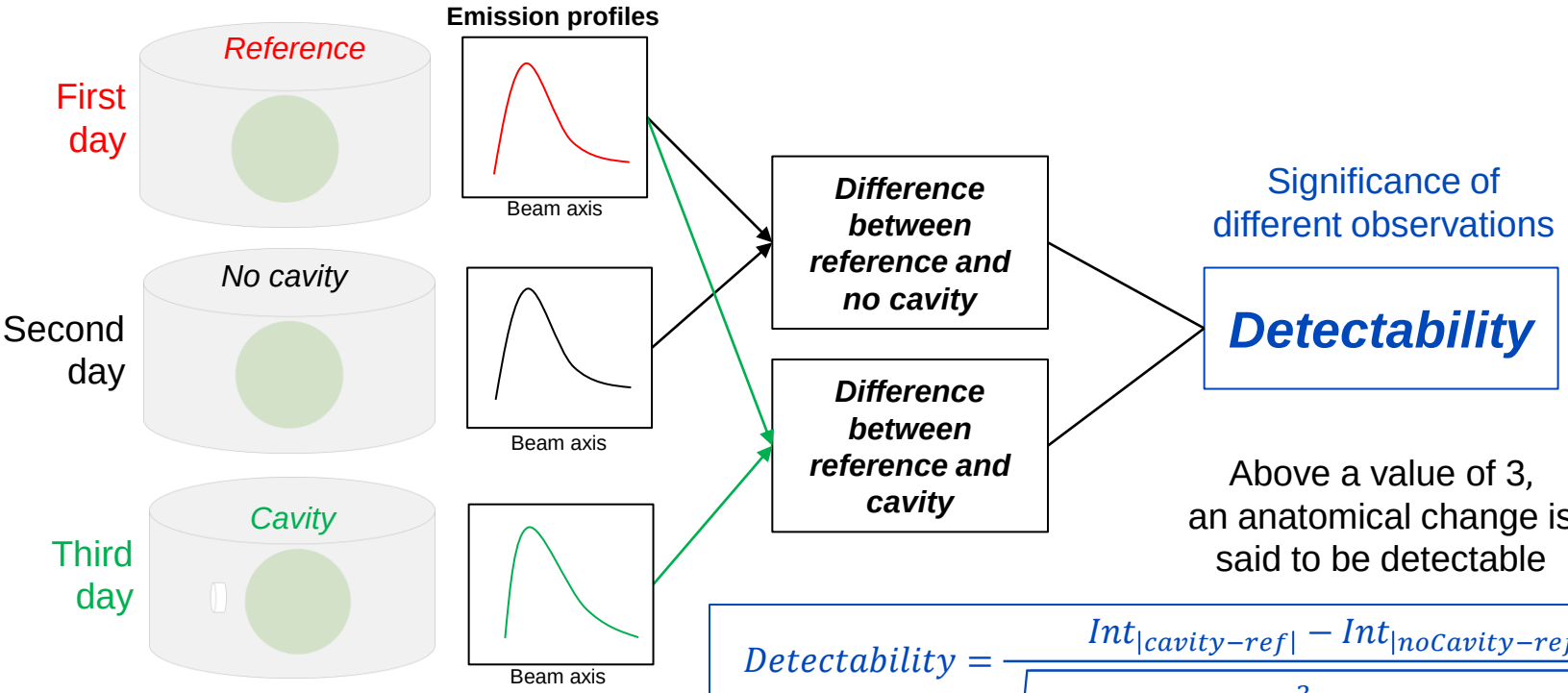
- Amount of data corresponding to upcoming tracker with 14 times bigger detection area

- Finding hits of single fragments
- Fragment track reconstruction
- Profiles of emission fragments



Modified from Ghesquière-Diérickx, PhD thesis, 2021

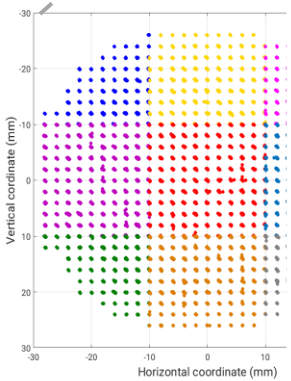
Workflow of data analysis



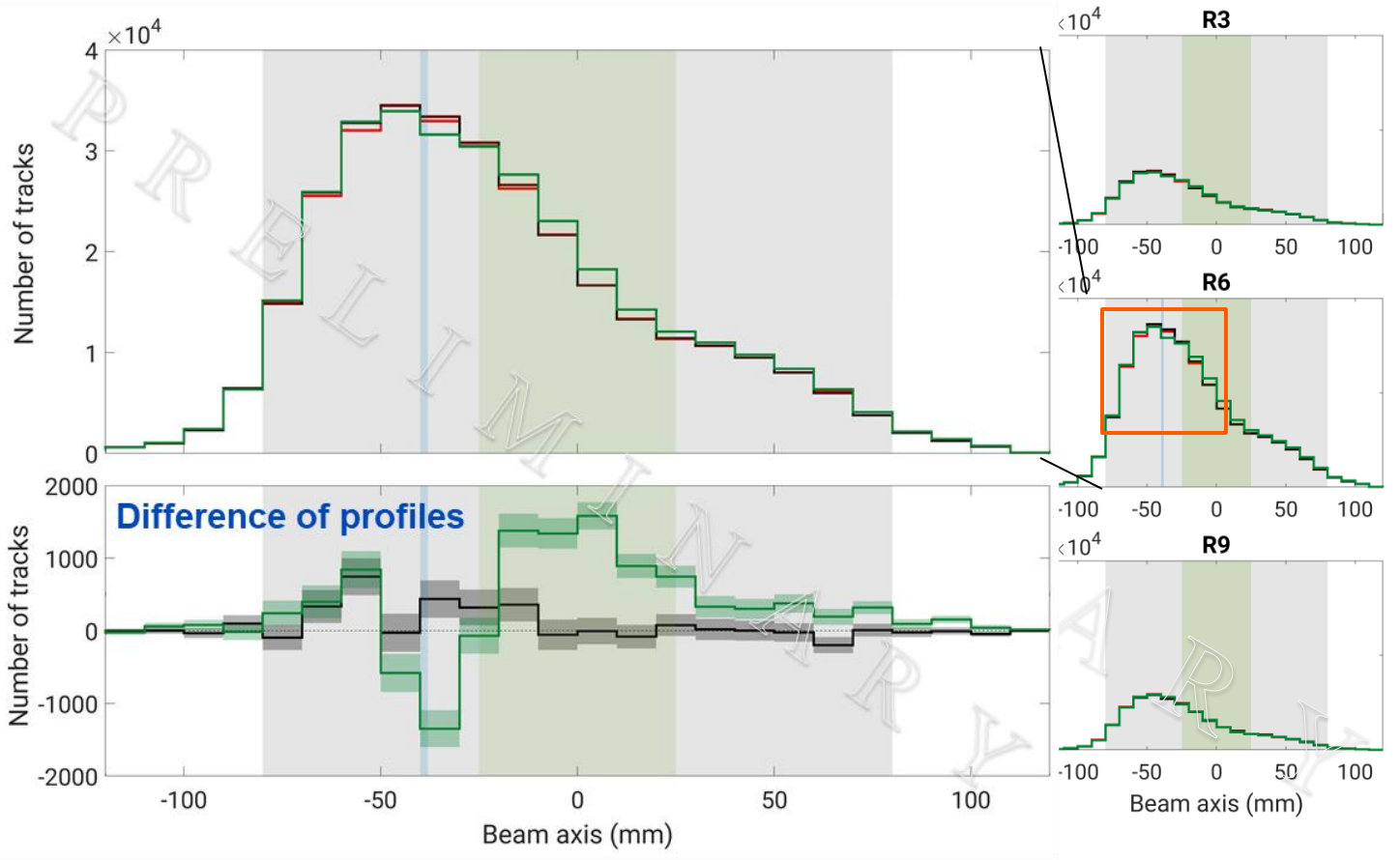
$$Detectability = \frac{Int_{|cavity-ref|} - Int_{|noCavity-ref|}}{\sqrt{\sigma\left(Int_{|cavity-ref|}\right)^2 - \sigma\left(Int_{|noCavity-ref|}\right)^2}}$$

Profiles & differences

- Exploiting the monitoring meth
  - Separation of region into sul

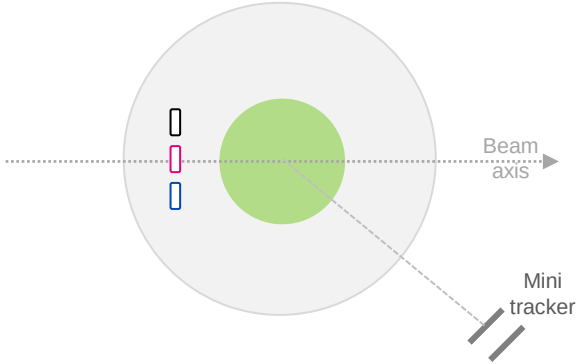


  - To localize ai

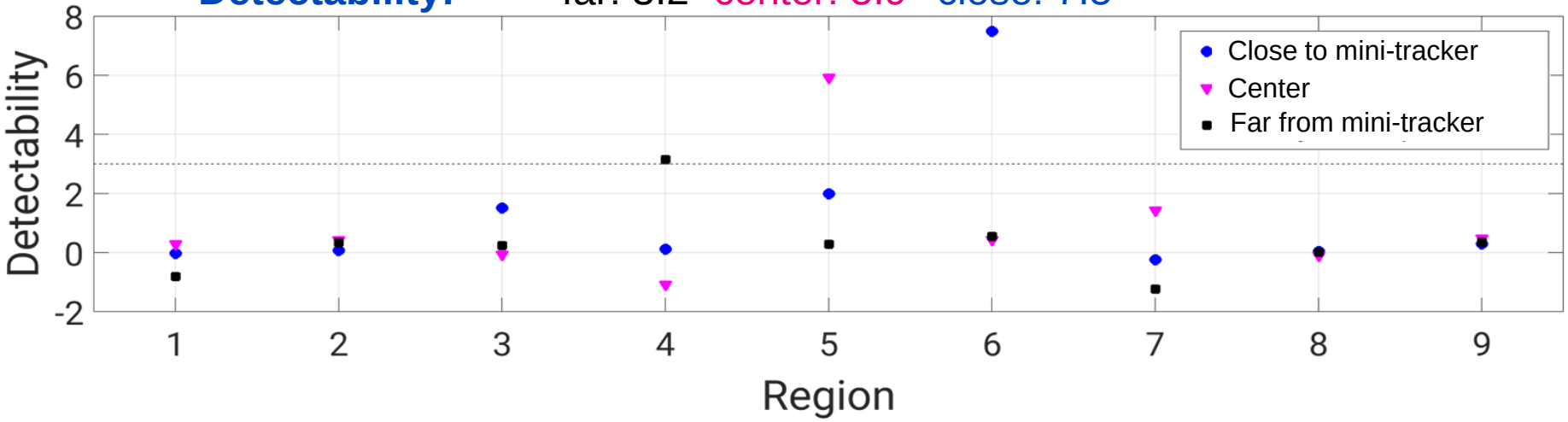


Significance:

2 cm diameter
0.4 cm thickness



Detectability: far: 3.2 center: 5.9 close: 7.5



Conclusions

- The ability of a 2-cm^2 Timepix3-based mini-tracker to detect charged nuclear fragments in carbon-ion beam therapy was demonstrated
- A non-invasive monitoring method to detect small anatomical changes in realistic treatment deliveries was quantitatively evaluated
  - All three positions were detected
- Different cavity sizes and depths, and detection angles have to be further assessed
- The obtained results in this work are of high clinical relevance
- Therefore, this method is promising to be further applied in clinical trials

Thank you for your attention!

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Image taken from https://www.germany.travel/en/cities-culture/heidelberg.html

dkfz.