PET imaging of radioactive carbon beams for tumor therapy

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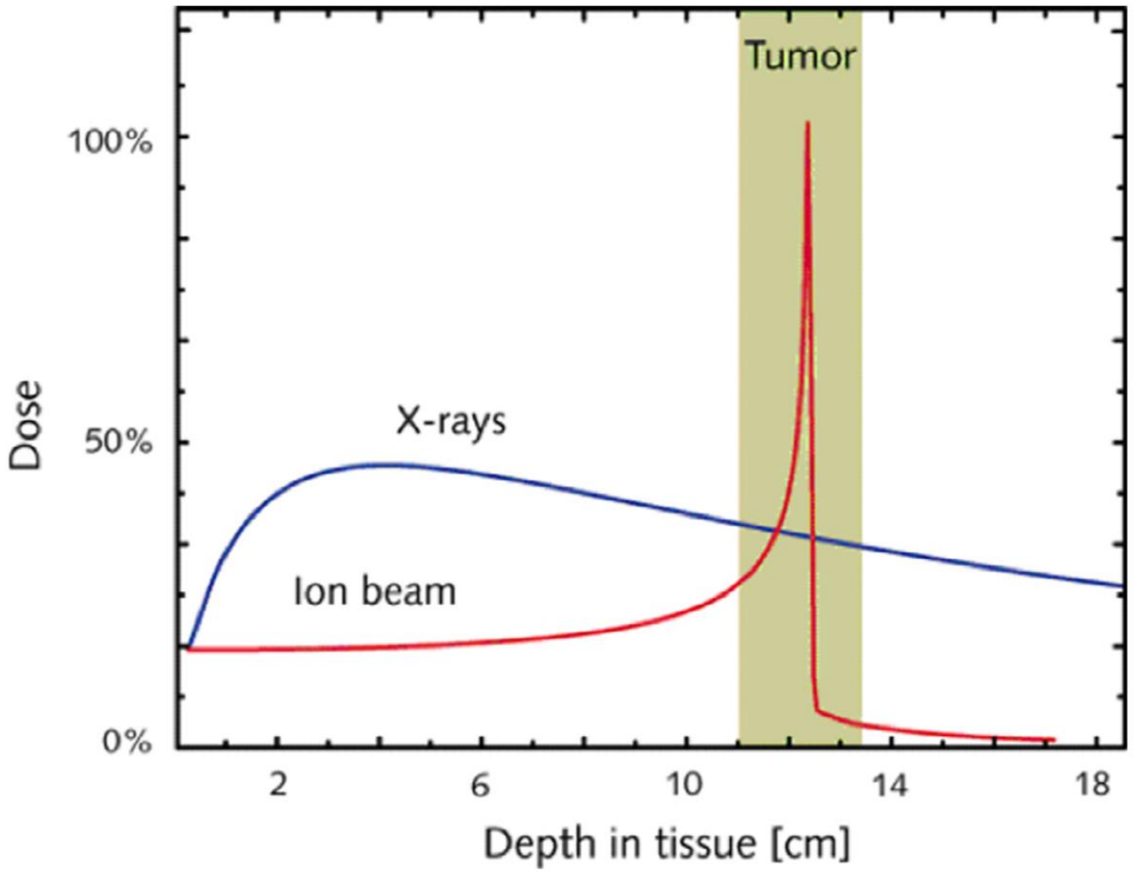
Introduction

Radiotherapy with:

- **X-rays.** Large volume of normal tissue surrounding tumor is exposed.
- **Charged particles.** Deposit of the highest dose toward the end of the range in tissue (the Bragg peak).

Charged-particle therapy:

- Sensitive to the uncertainties because of the steep dose profile.
- Range verification is desirable, e.g. with PET imaging.



Depth dose distribution of high-energy photons vs charged particles.

Figure from [M. Durante, J. Flanz, Seminars in Oncology 46, 219-225 (2019)]

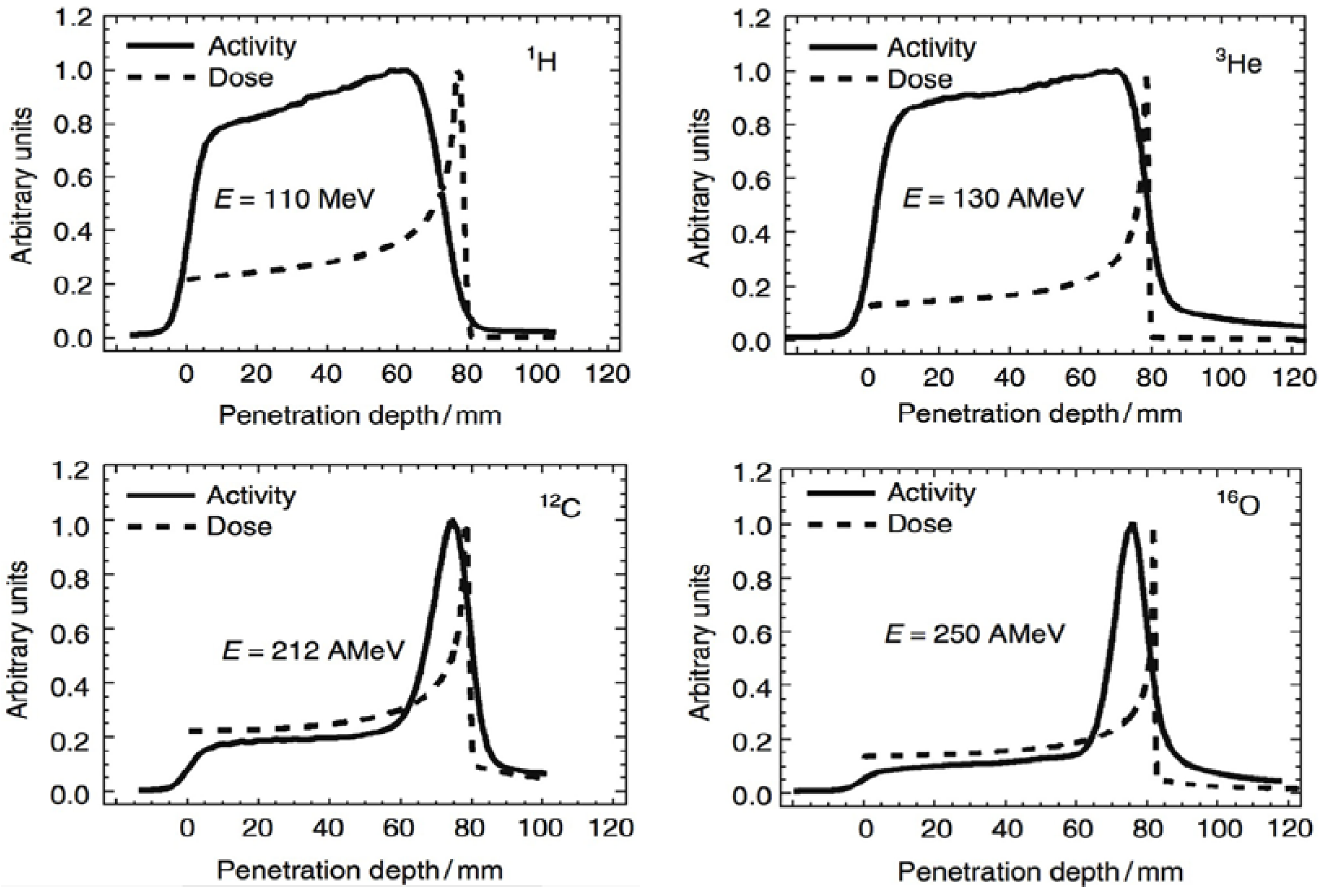
Introduction

Limitations of PET imaging in hadron therapy using stable ions:

- Non-matching activity and dose distributions;
- Positron emitters are produced via projectile and target fragmentation, so PET signal is weak.

Way forward?

Hadron therapy with positron emitting beams



Measured activity and dose profiles in PMMA for protons, ^{3}He, ^{12}C and ^{16}O

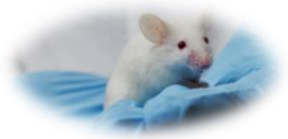
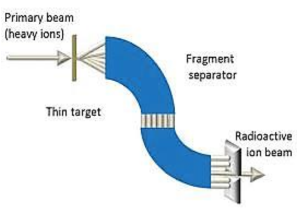
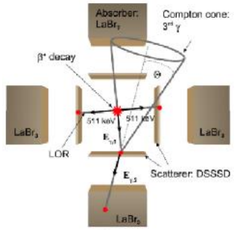
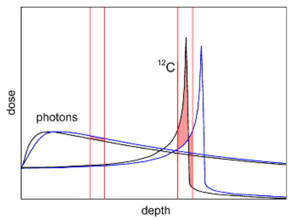
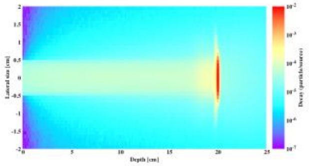
Figure from [Fiedler F. et.al., Ion Beam Therapy 527, (2012)]

BARB ERC grant: Biomedical Applications of Radioactive ion Beams

Goals:

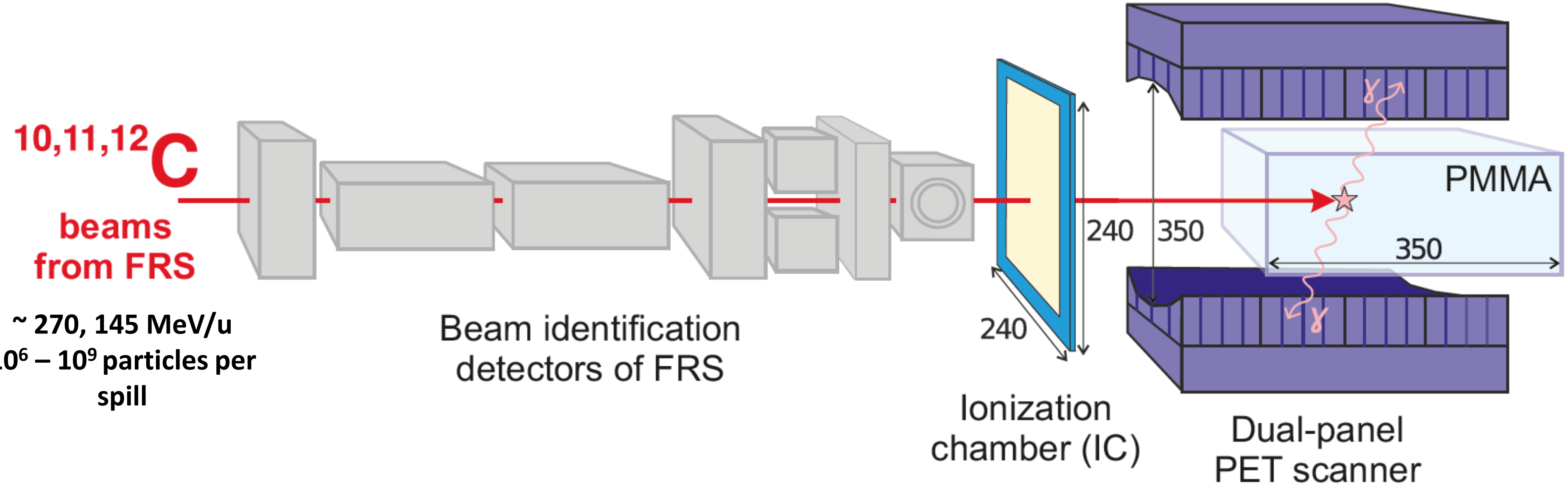
- Develop an intense and isotopically-pure positron-emitting beams for therapy
- Preclinical validation by small animal irradiation

M. Durante: Principal investigator
K. Parodi: Imaging
C. Scheidenberger: RIB production

	Nuclear Physics	Engineering	Medical Physics	Imaging	Radiobiology
OBJECTIVES	Measure maximum achievable intensity for ^{12}C- and ^{16}O-derived RIB	Design hybrid γ-PET detector superior to state-of-the-art PET	Select best high-intensity RIB for therapy	Define maximum accuracy and resolution for RIB CPT	Validate therapeutic potential of RIB in animals
					
METHODOLOGY	Produce light RIB using fragment separator at GSI	Development of hybrid γ-PET detector through collaboration with LMU	Conduct biophysical dosimetric studies in phantoms and mammalian cells	Visualize RIB using hybrid γ-PET detector	Assess tumour growth post-irradiation in soft-tissue sarcoma model
					
OUTCOMES	Production of high-intensity RIB for first-time therapeutic use	Real-time imaging and monitoring of high-intensity RIB	Identification of RIB suitable for therapeutic applications	Unprecedented imaging accuracy for therapeutic beam delivery	Improved precision of RIB CPT for cancer and other indications

Experimental setup at final focal plane of fragment separator FRS

Idea of the measurement: in-beam PET imaging using positron-emitting isotopes of carbon.



~ 270, 145 MeV/u
10^6 – 10^9 particles per spill

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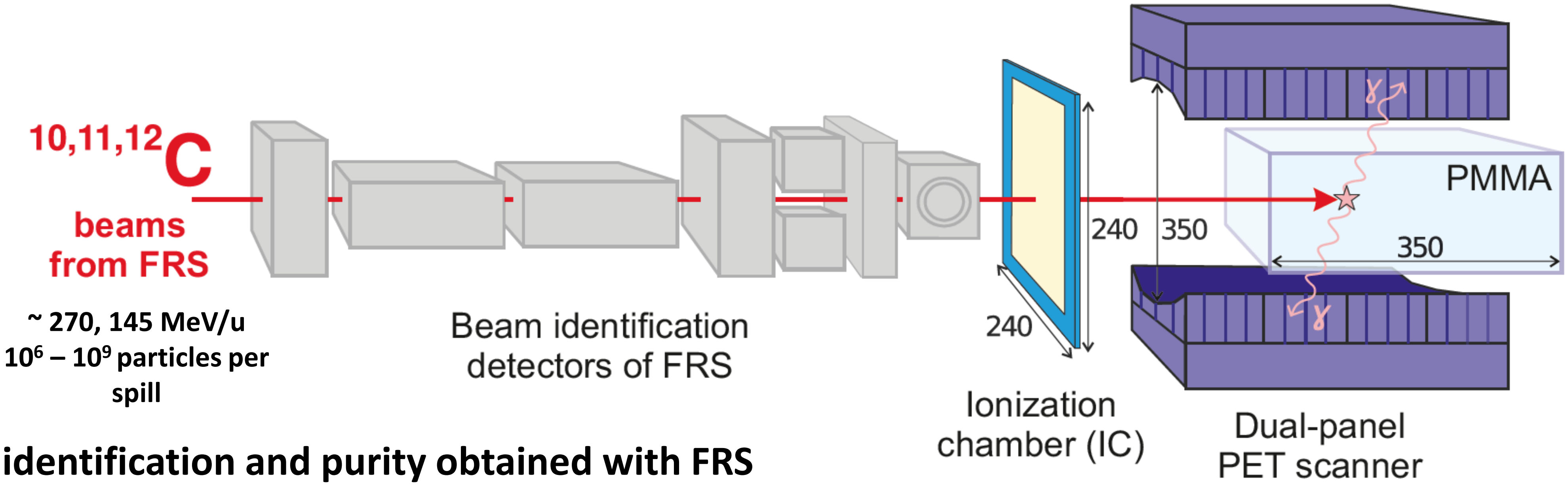

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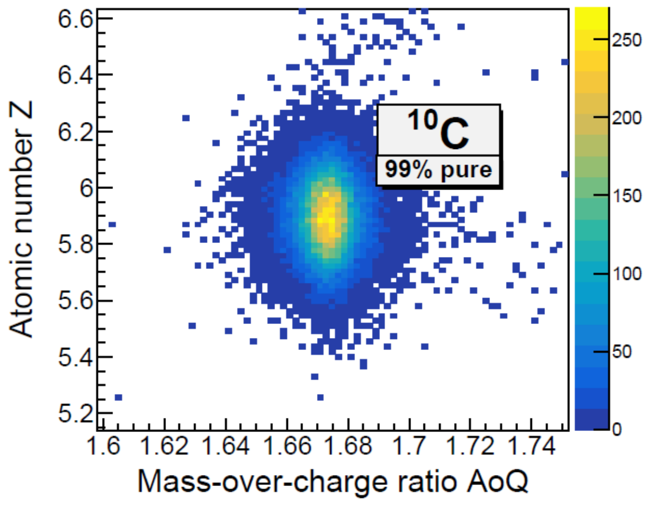
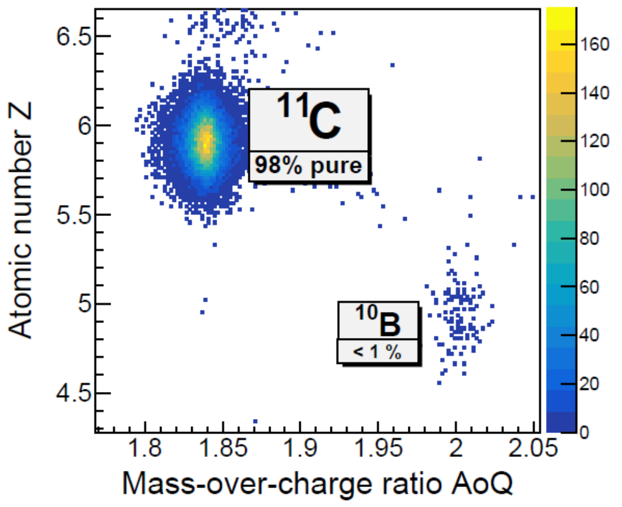
Beam identification and purity obtained with FRS





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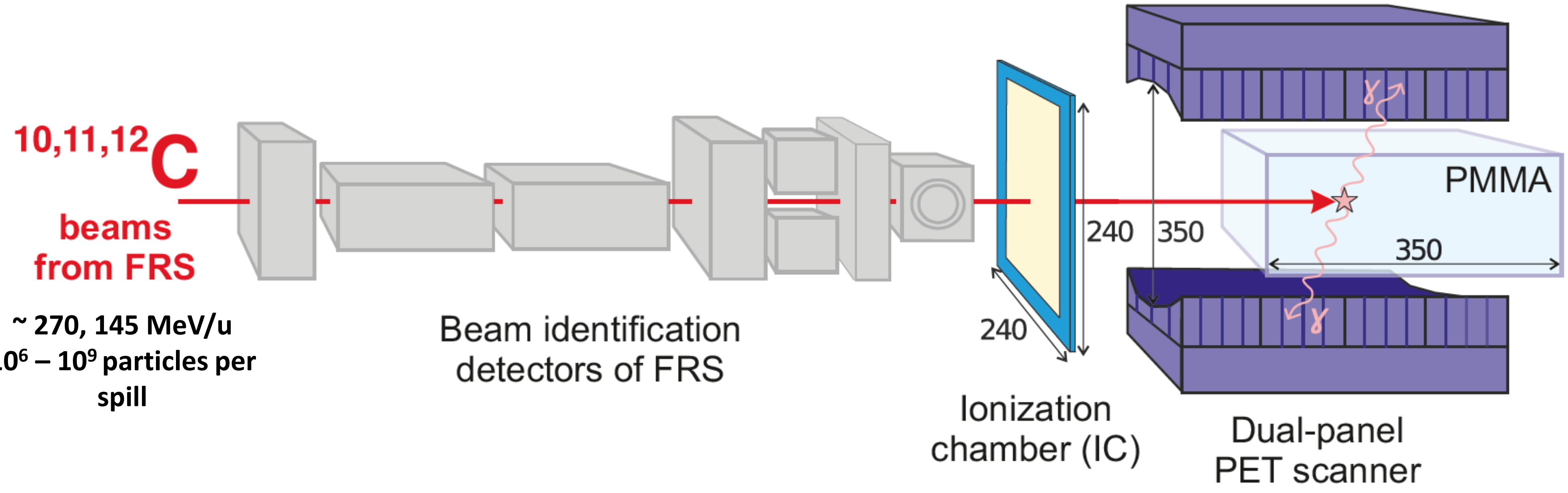

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PET scanner is 1/6 of a Siemens Biograph mCT :
- coincidence events from crystals in opposite panels

Operational parameters:
- energy window of 435-650 keV
- time window of 5 ns

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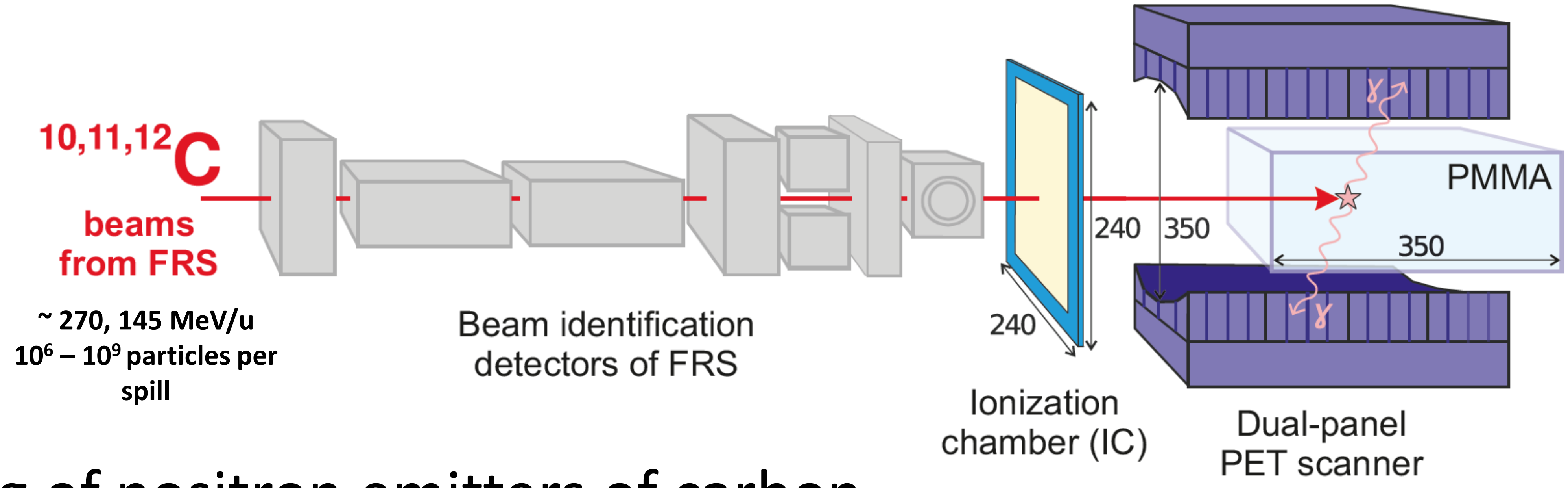
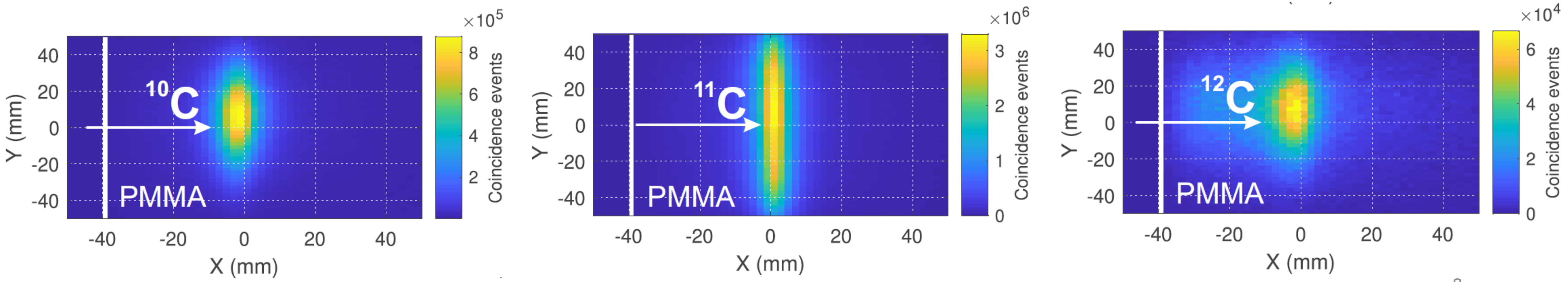
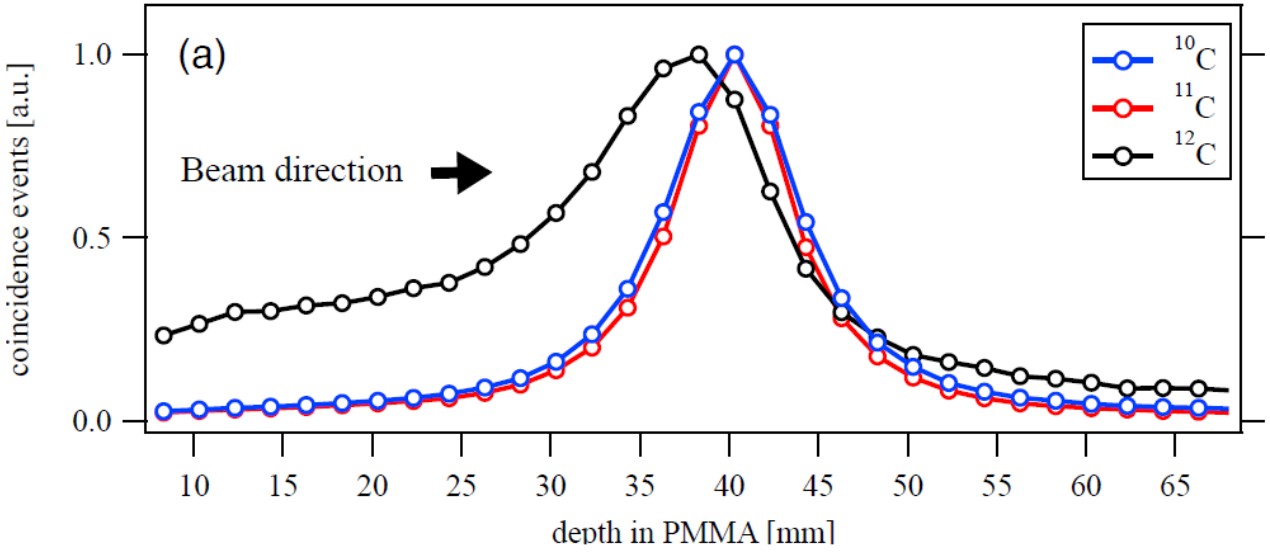


Imaging of positron emitters of carbon

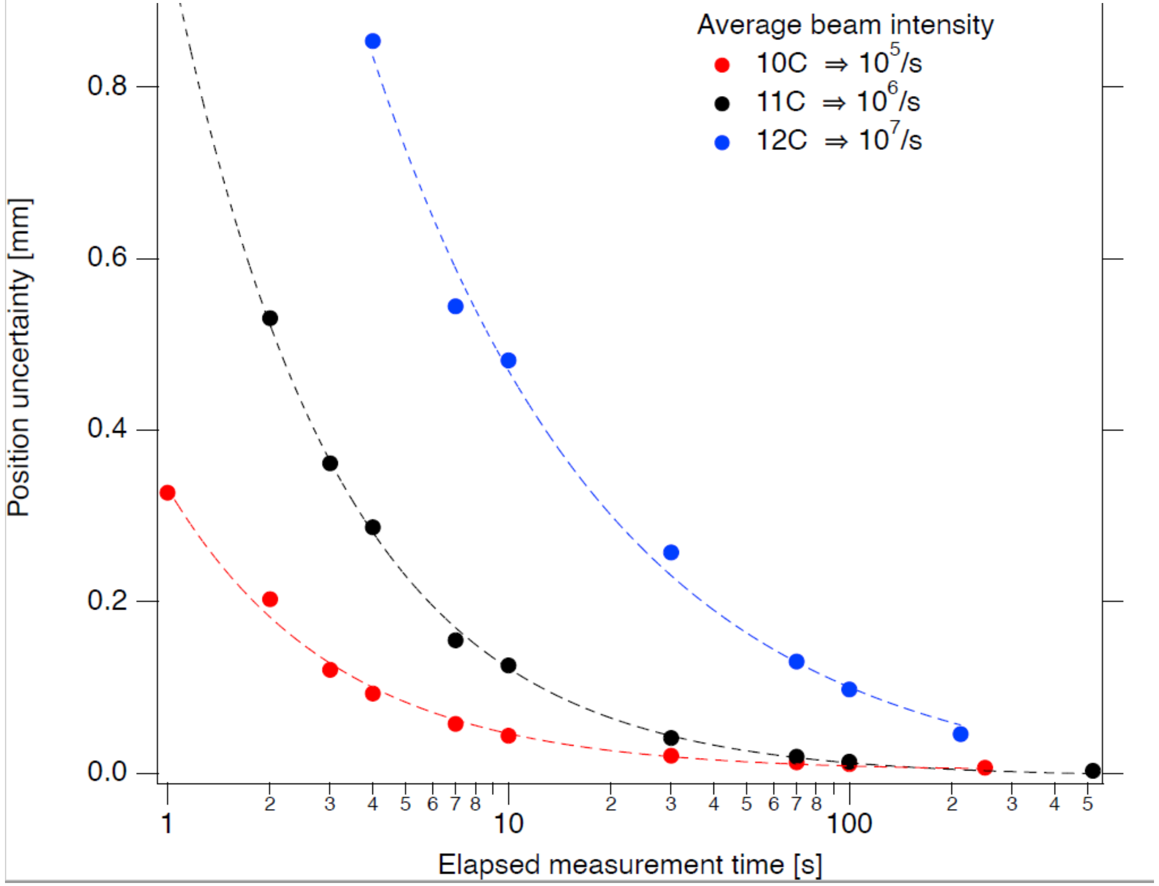


Results and conclusions

PET activity profiles obtained with $^{10,11,12}C$ beams



Uncertainty in PET position measurement vs elapsed time for beams of $^{10,11,12}C$ ions



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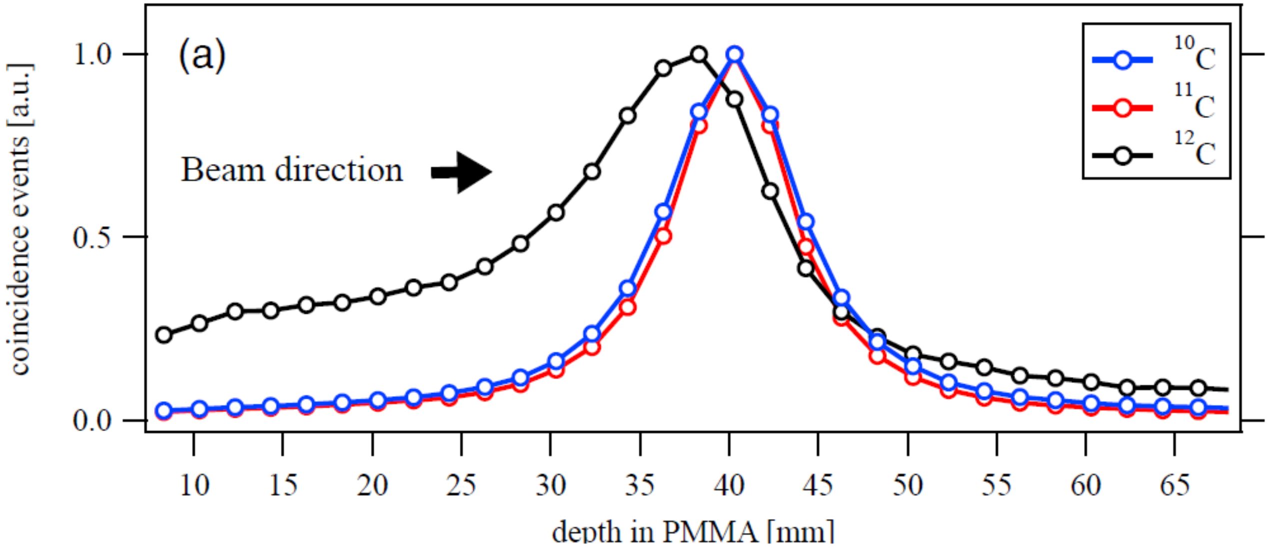

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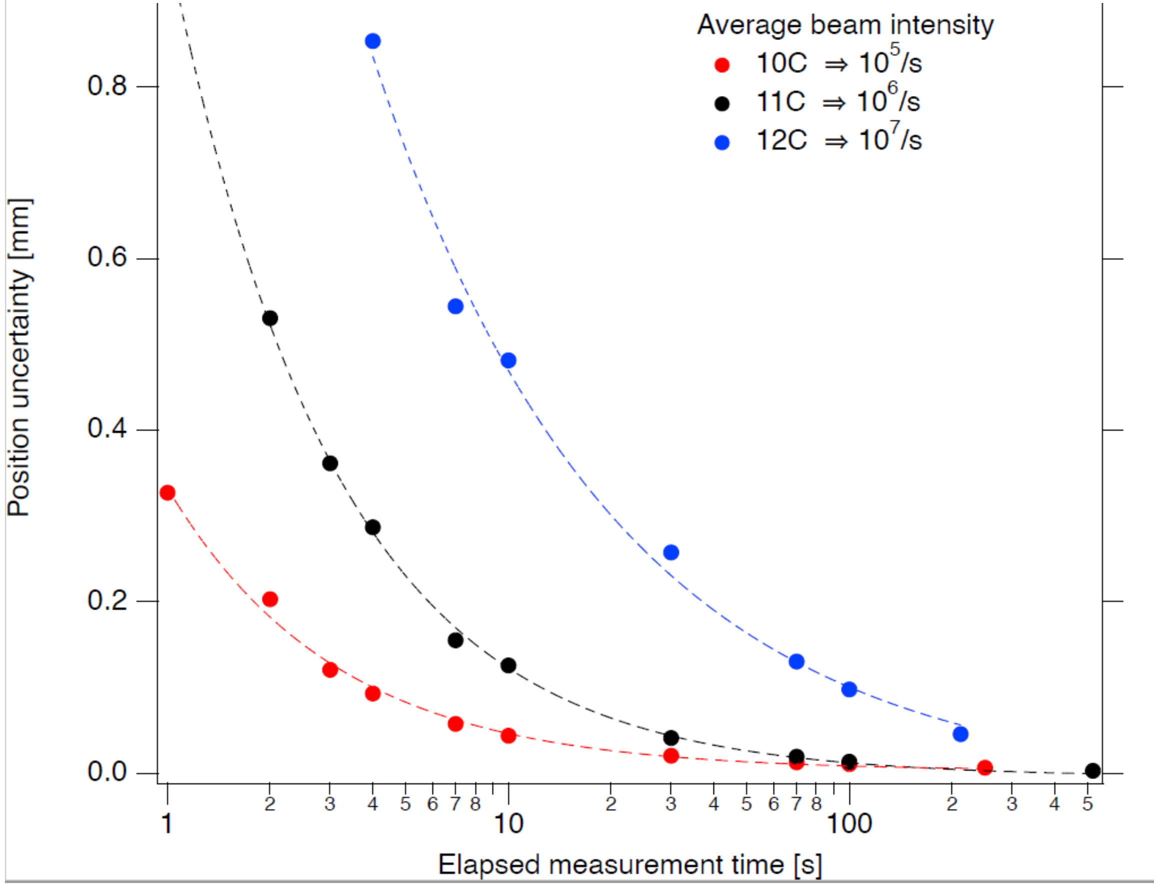
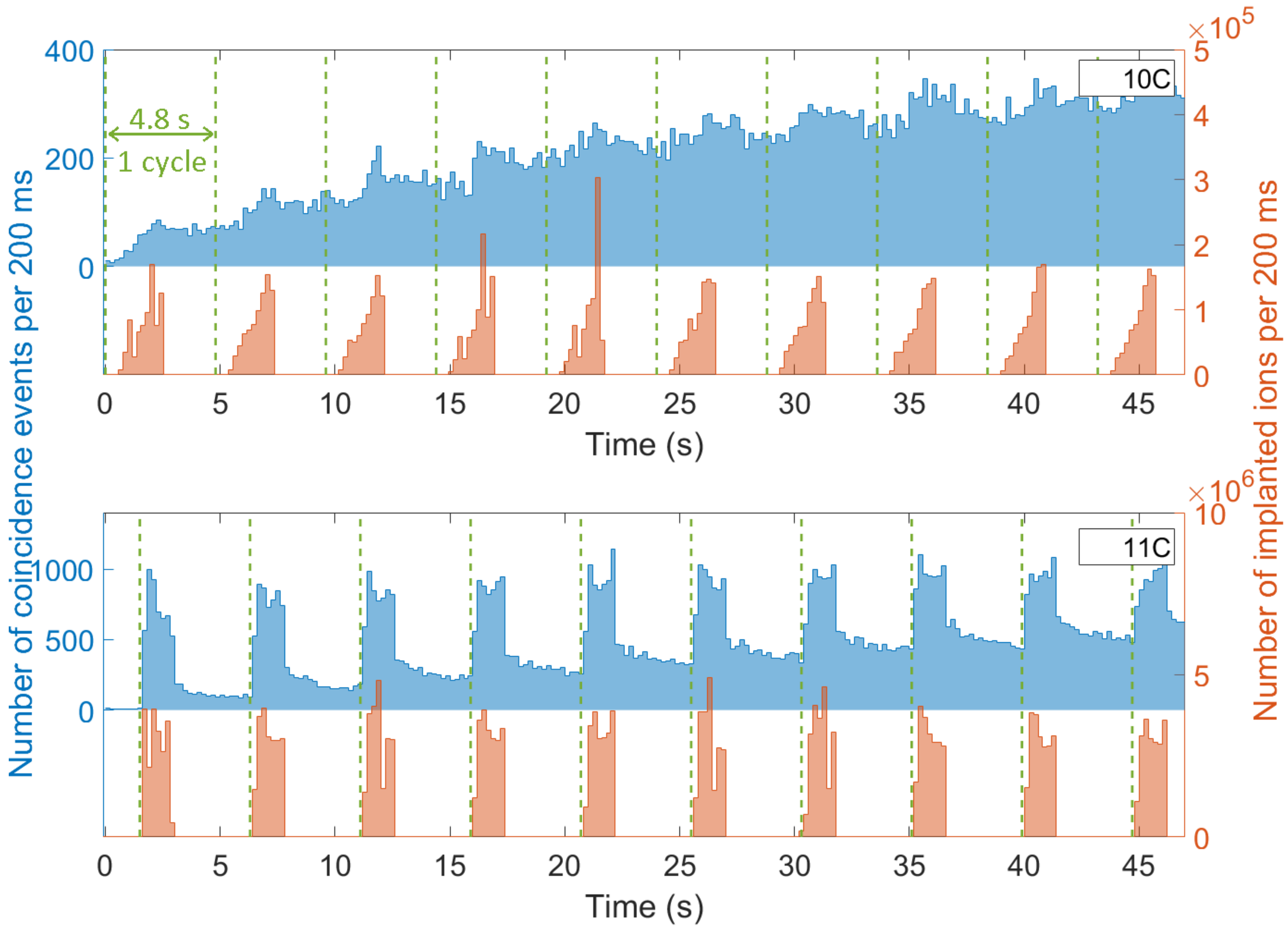


- ^{10}C (half-life 19.3 s)**.** The best candidate for real-time PET range verification. Accuracy of << mm is reached with lower number of implanted ions and within shorter time.
- ^{11}C (half-life 20.4 min)**.** Due to its longer half-life, the higher doses have to be accumulated for reliable range verification.
- ^{12}C (stable). Mismatch between PET activity peak and range.

Backup slides

Time structure of implanted beams



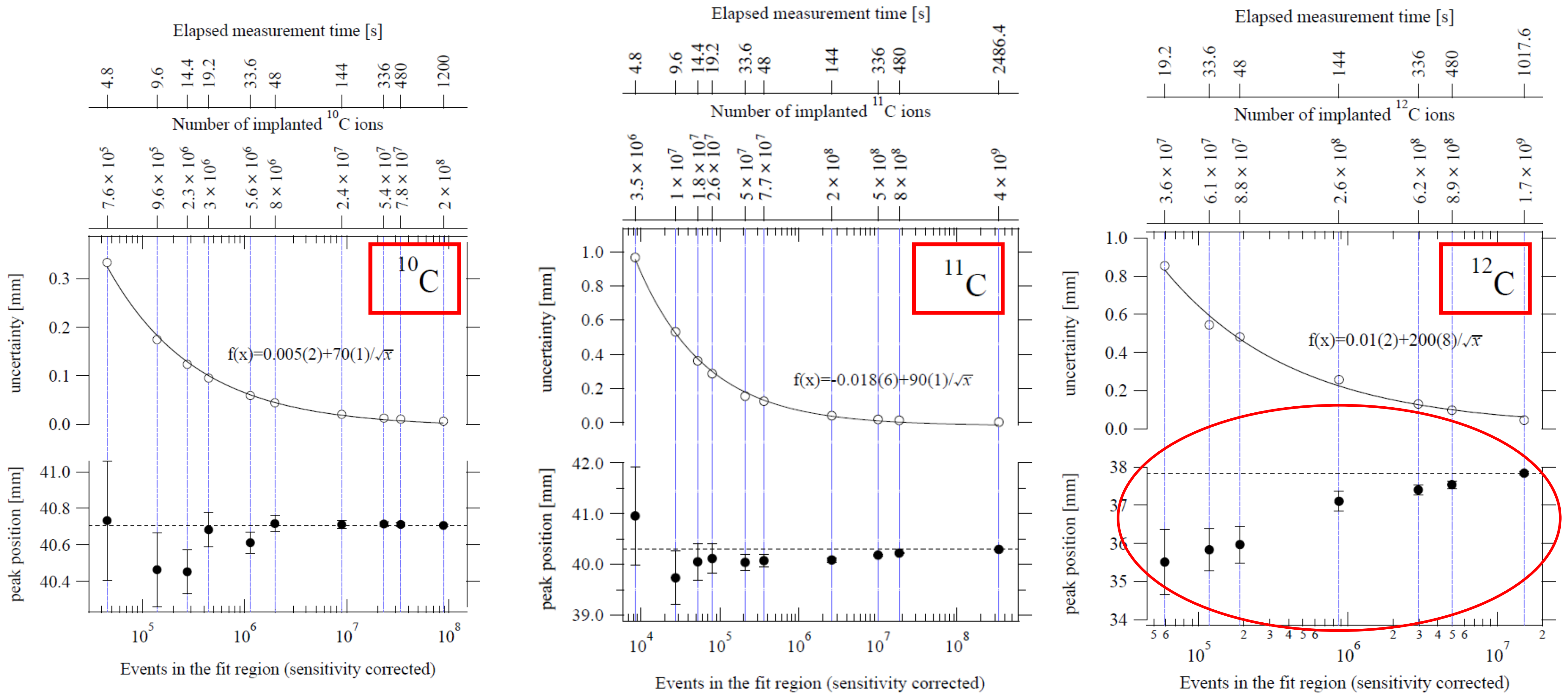
PET scanner

Ionization chamber

1 cycles = 4.8 s:

- beam on = 2 s
- beam off = 2.8 s

The measured peak position and associated statistical uncertainty



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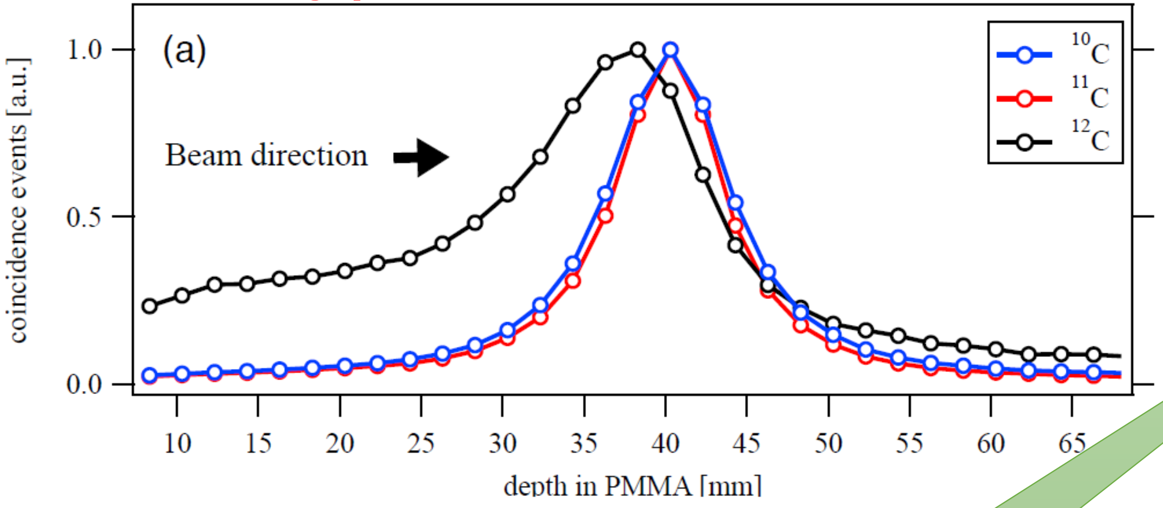
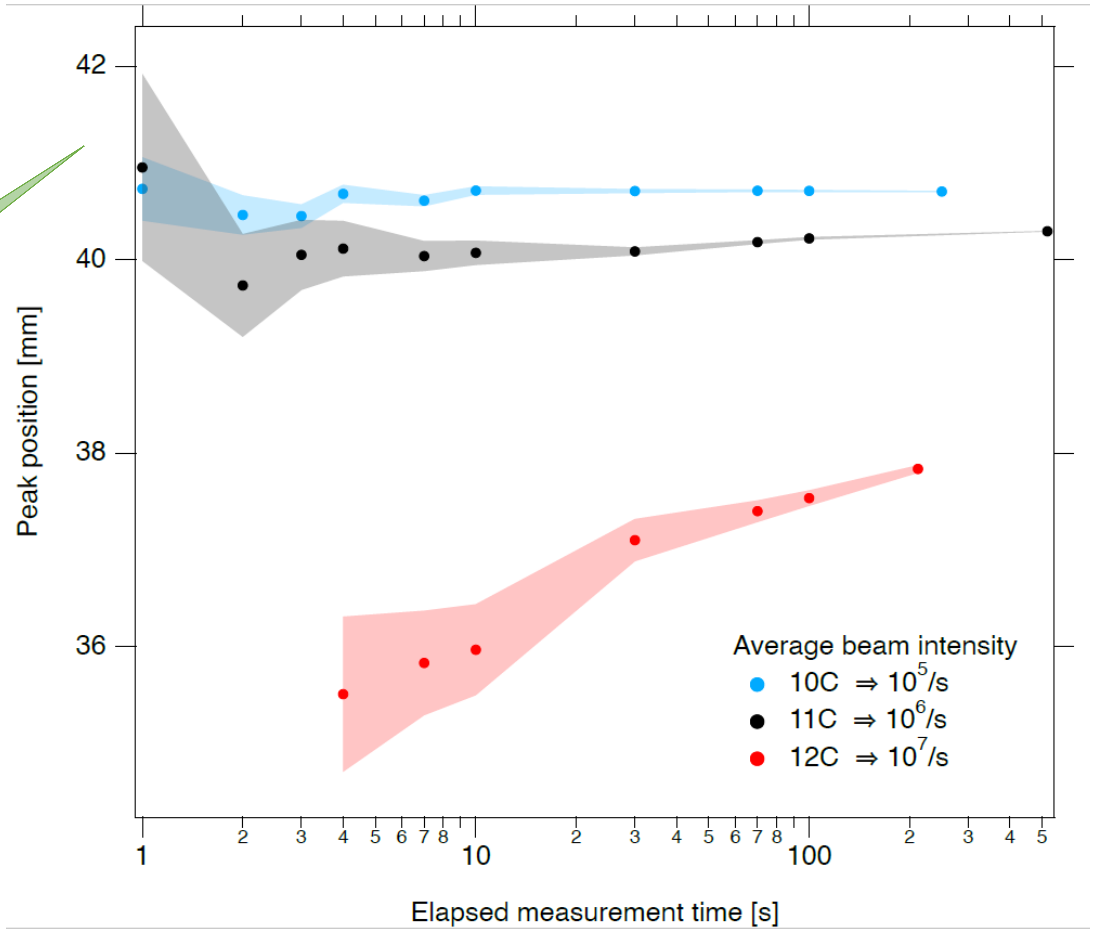


Uncertainty in PET peak position vs number of implanted $^{10,11,12}C$ ions



^{10}C Accuracy of << mm is reached within short time

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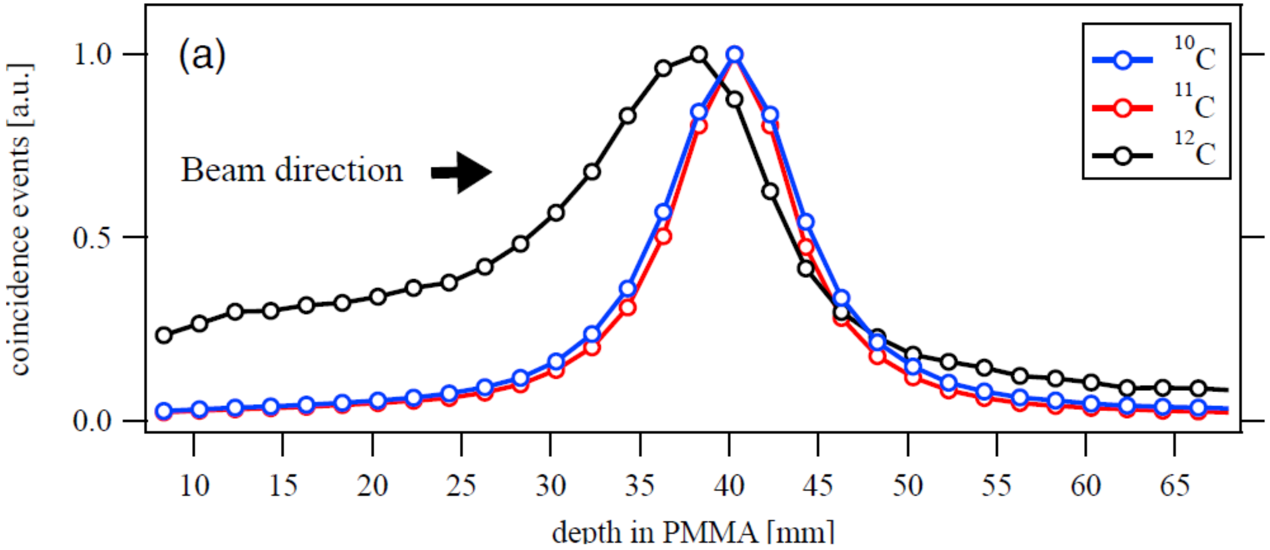

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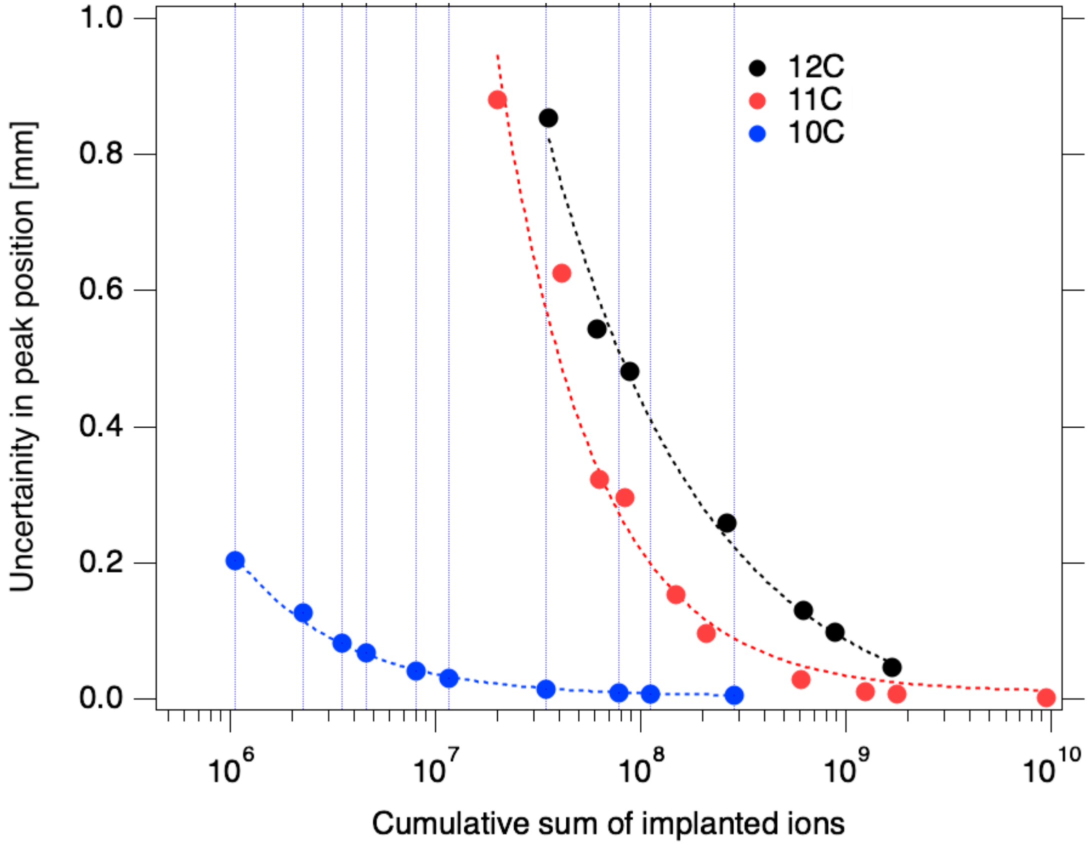

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