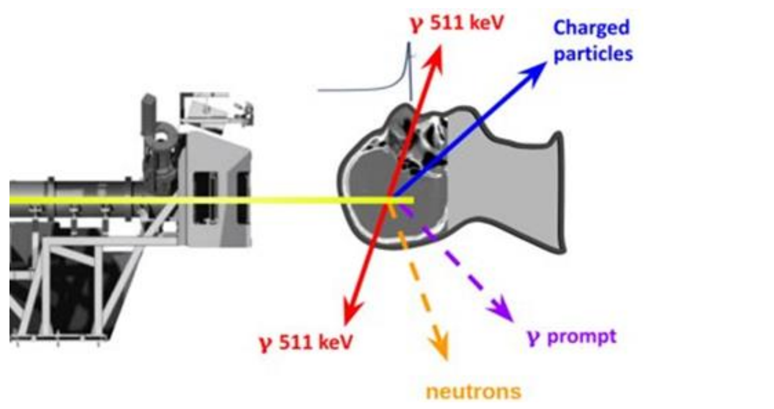
Performance analysis of in-beam PET range verification system for carbon ion beams

Sahar Ranjbar[1, 2], Felix Mas Milian[2,3], Emanuele Maria Data[1,2], Davide Bersani[4], Piergiorgio Cerello[2], Roberto Cirio[1, 2], Marco Donetti[5], Mohammad Fadavi Mazinani[2], Veronica Ferrero[2], MohammadAmin Hosseini[1,2], Simona Giordanengo[2], Diango Manuel Montalvan Olivares[1,2], Marco Pullia[5], Roberto Sacchi[1,2] Anna Vignati [1,2], Julius Friedemann Werner[6], Francesco Pennazio[2], **Elisa Fiorina**[2]

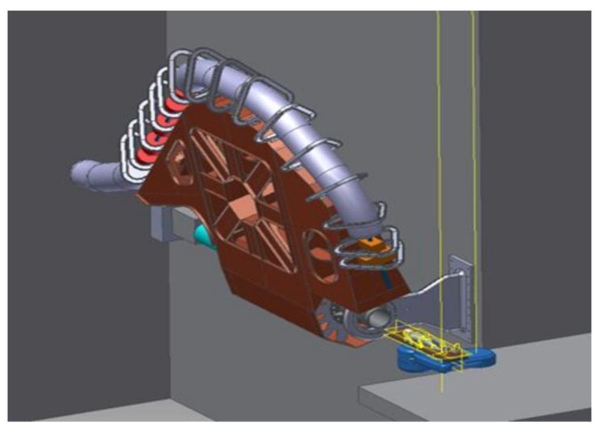
1.University of Turin, Department of Physics, Torino, Italy
2.INFN Torino, Torino, Italy
3.State University of Santa Cruz, Ilhéus, BA, Brazil
4.INFN Pisa, Pisa, Italy
5.Fondazione CNAO
6.Institute of Medical Engineering, Universität zu Lübeck, Germany

Background

The SIG (Superconducting Ion Gantry) project aims to develop a reliable range verification system to integrate in a multi-ion gantry.



During the treatment, beta+ emitters, prompt photons and charged particles escape the patient and can be used for treatment monitoring



Sketch of the ion gantry in the treatment room

In-beam PET range verification systems, detecting signals from positron emitters generated by nuclear interaction between primary particles and human tissues, have the main advantage of online data acquisition during the treatment and hence provide early treatment quality feedback. In-beam PET systems are a promising solution for carbon ion treatments to detect activity enhancement just before the Bragg peak due to projectile activation (1).

Aim

The goal of this study is to analyse the performance of an in-beam PET range verification system for carbon ion beams, evaluating the impact of the number of coincidences to be considered in image reconstruction on range difference measurements and opening the possibility to study new approaches to image reconstruction to highlight the fast isotope contributions.

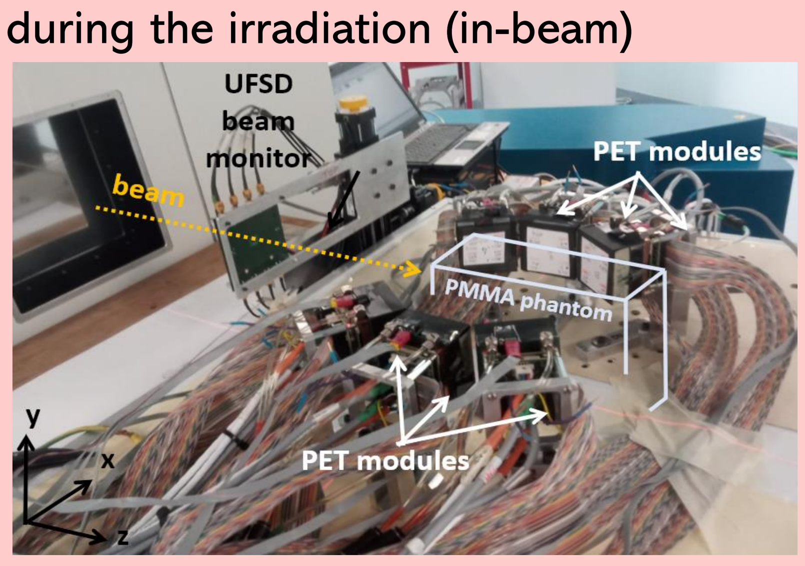
Methods

The experimental setup consists of:

- 6 PET modules arranged in hexagonal geometry (3*3 partial ring configuration), radius 98mm. Each detector block features 16×16 pixels, 3.2mm pitch, of segmented Luthetium Fine Silicate (LFS) scintillator crystals, coupled to Silicon Photomultiplier matrices (2).

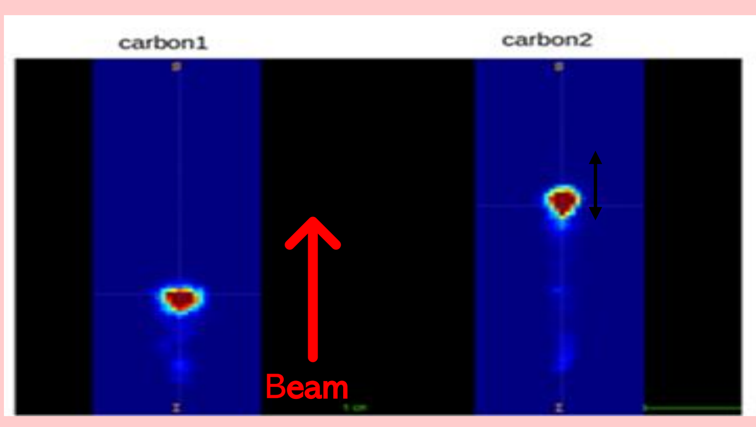
Beam test with carbon ions

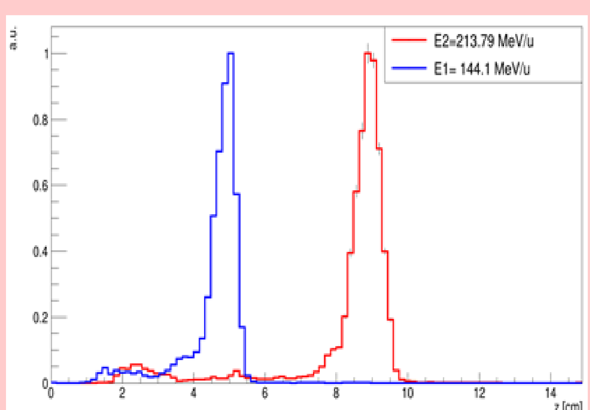
- two energies (144 MeV/u and 213 MeV/u) on homogeneous PMMA phantoms at the Italian National Center for Oncological Hadrontherapy (CNAO). Data were acquired during the irradiation (in-beam)



Experimental setup at CNAO

Each coincidence data set (carbon1 and carbon2) :



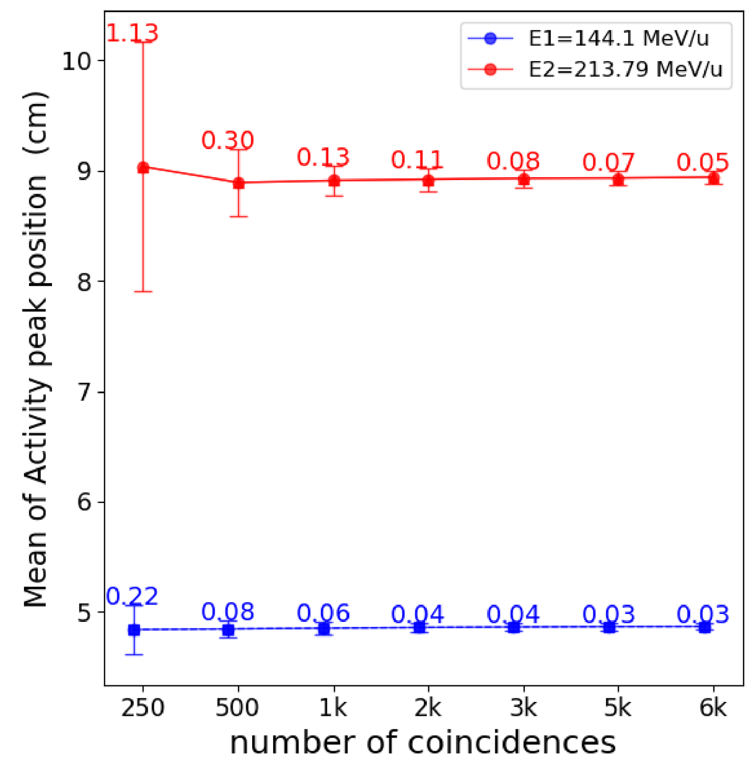


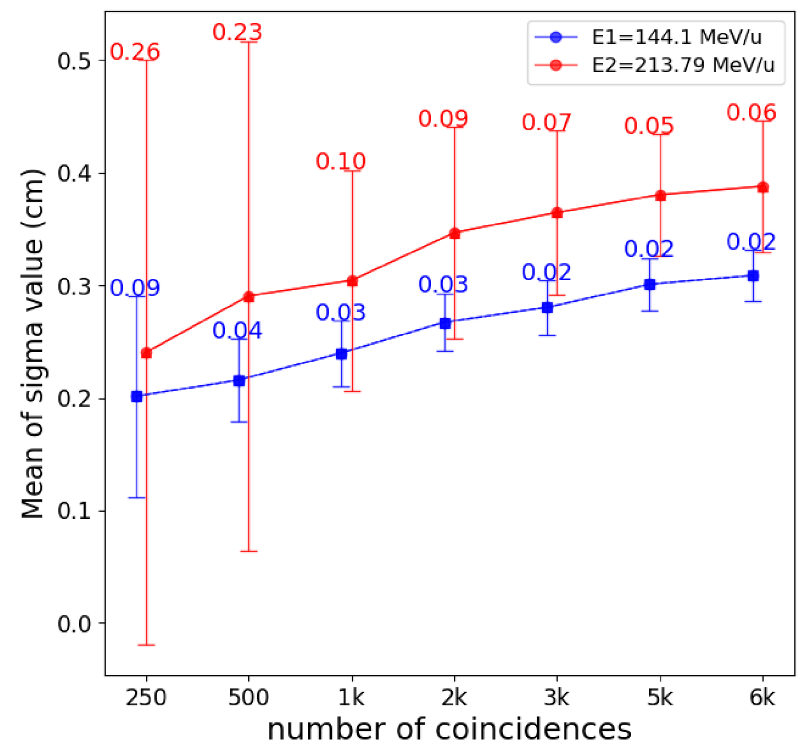
1. Divide into several subsets with the same number of PET coincidences. Seven subset sizes were considered
2. PET images were reconstructed using a custom MLEM algorithm (with 9 iterations)
3. Median filter was applied
4. The activity peak due to projectile activation was fitted with a Gaussian function

Results

Results considering seven different subset sizes were obtained.

Projectile activation peak position and width (average and sigma values from Gaussian fit) for the different subset sizes





Range difference value for different numbers of coincidences

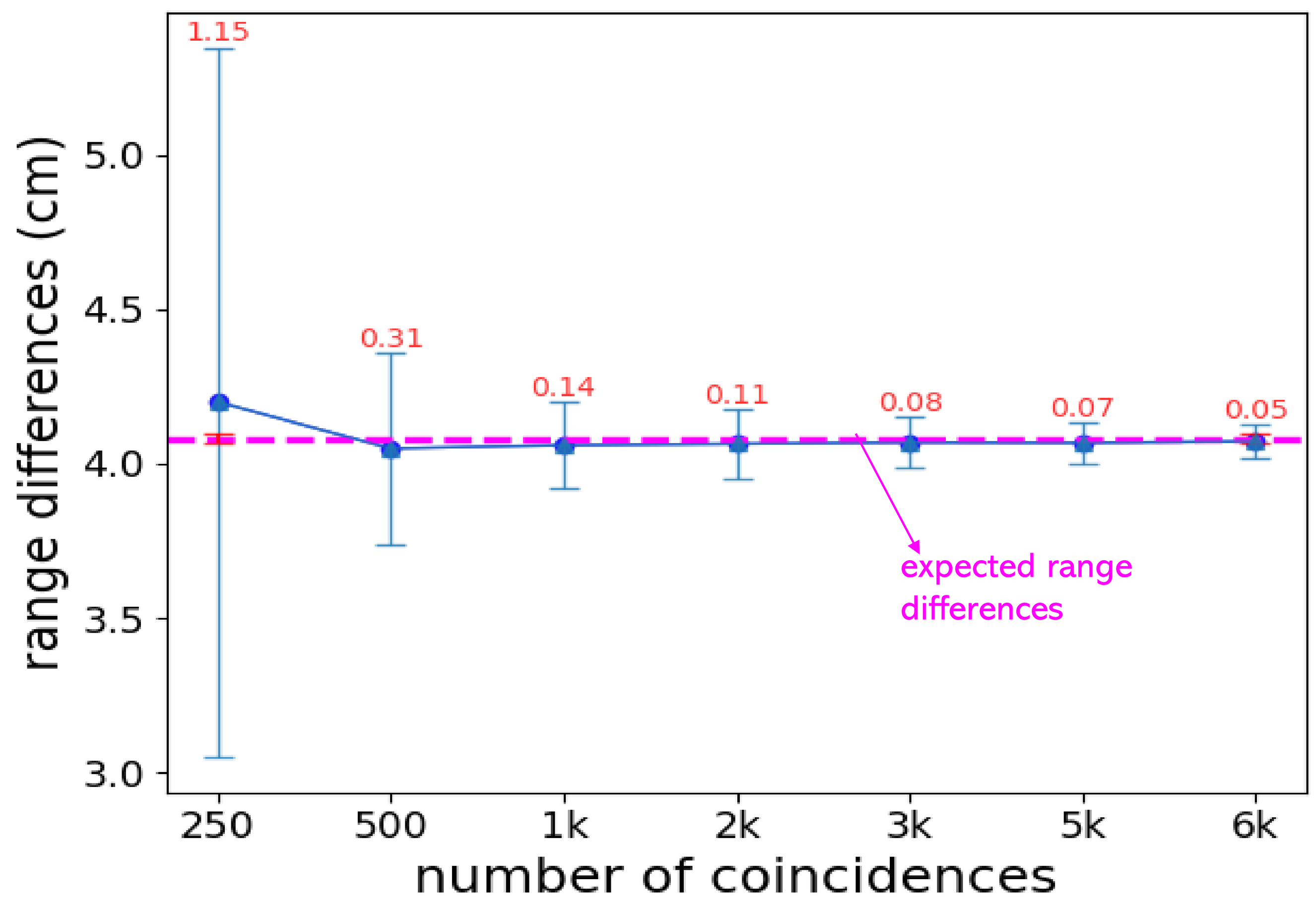


TABLE I
RANGE DIFFERENCE VALUE, PEAK VALUE

Number of coincidences	Range difference (cm)	Peak position (carbon1) (cm)	Peak position (carbon2) (cm)
250	4.20 ± 1.15	4.84±0.22	9.04±1.13
500	4.05 ± 0.31	4.84±0.08	8.89±0.30
1k	4.06 ± 0.14	4.85±0.06	8.91±0.13
2k	4.06 ± 0.11	4.86±0.04	8.92±0.11
3k	4.07 ± 0.08	4.86±0.04	8.93±0.08
5k	4.07 ± 0.07	4.87±0.03	8.93±0.07
6k	4.07 ± 0.05	4.87±0.03	8.94±0.05

Experimental range differences are fully compatible with the expected range differences (4.08 ± 0.014 cm).

Conclusion

The PET system performance is not strongly dependent on the statistics included in the PET images. The results will be useful for designing and implementing a custom image reconstruction for fast isotope highlighting.

Acknowledgment

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References

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