Application of plastic scintillator based detectors for range monitoring in proton beam therapy

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INTRODUCTION

Proton Beam Therapy (PBT) is a cancer treatment technique that enables precise delivery of the dose to the tumor as well as for preservation of healthy tissues.

Proton beam deposits maximum dose at the end of proton range in Bragg peak. To ensure complete coverage of the tumor in presence of uncertainties, the safety margins around tumor in the order of 3.5% of proton range in patient body are applied. Due to that fact tumor as well surrounding healthy tissue are irradiated by the therapeutic dose.

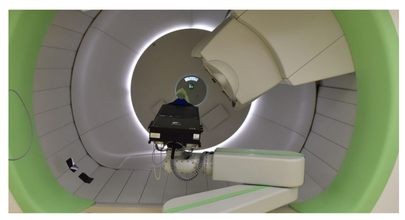
Due to interaction of proton beam with patient tissue a secondary radiation as well as β+ emitters creation are induced. Prompt gamma and gamma from annihilation of positron and electron can be detected by means of PET detectors and used for beam range monitoring.

In frame of collaboration of J-PET and IFJ-PAN research groups, plastic scintillator based J-PET technology is investigated to detect gamma quanta emitted as a secondary radiation from the patient for beam range verification.

IFJ PAN KRAKÓW

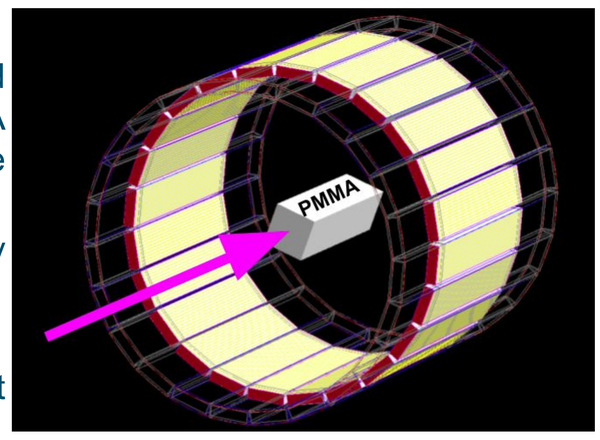
Proton Therapy Centre:
- two Gantry rooms and eye melanoma treatment room
- Proteus C-235 cyclotron (230 MeV)
- Pencil Beam Scanning

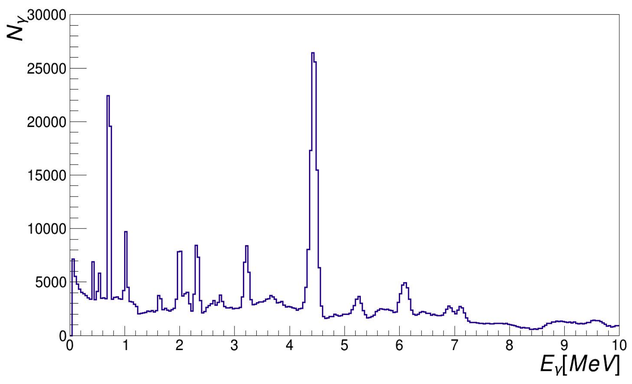
Experimental activities:
- experimental hall
- two rooms for the preparation of biological samples (animal and human material)
- AIC-144 (60 MeV) and Proteus C-235 cyclotron



CURRENT STATUS

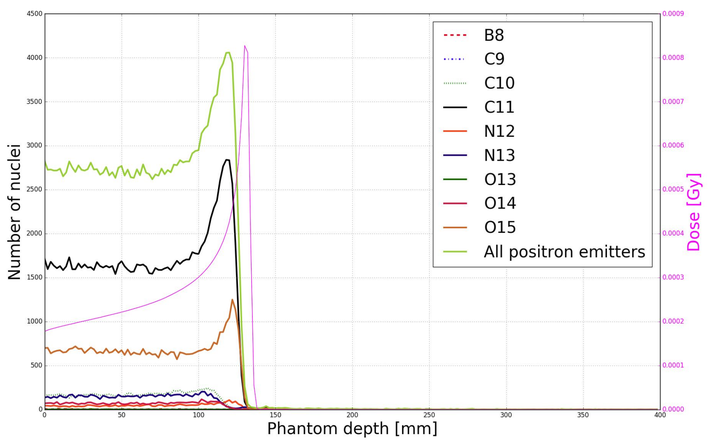
Monte Carlo simulations:
- GATE software
- investigation of β+ signal induced by proton beam in PMMA phantom and detected by the Modular J-PET prototype
- full detector geometry implemented
- physics setting completed
- first simulations of β+ and prompt gamma signal performed





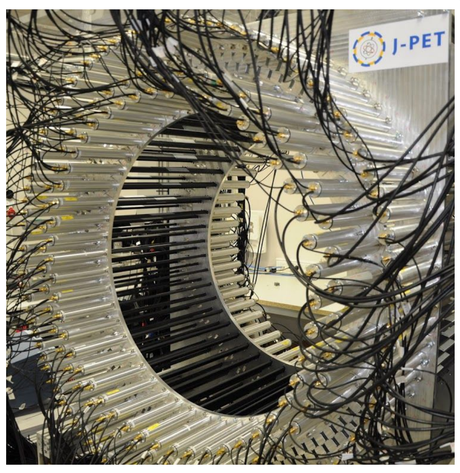
Prompt gamma energy spectrum obtained for PMMA phantom (length = 40 cm) irradiated with 10^7 of protons with energy equal to 150 MeV. Characteristic gamma rays are visible e.g.: 0.718 MeV due to $^{12}C(p,x)^{10}B$, 4.44 MeV due to $^{12}C(p,2p)^{11}B^*$ and 7.115 MeV due to $^{16}O(p,p^*)^{16}O^*$.

Positron emitters stopping position in PMMA phantom (length = 40 cm) irradiated with 10^7 of protons with energy equal to 150 MeV and **dose profile** obtained with GATE software

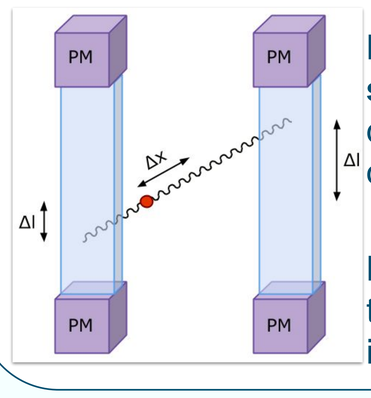


J-PET DETECTOR

The J-PET detector, based on long plastic scintillator strips, was recently constructed at the Jagiellonian University. It consists of 192 detection modules axially arranged into three layers, read out from both sides by dedicated digital front-end electronics. Each signal is probed at four different thresholds.



J-PET uses time information in contrary to commercial PET scanners which utilize mainly energy information.

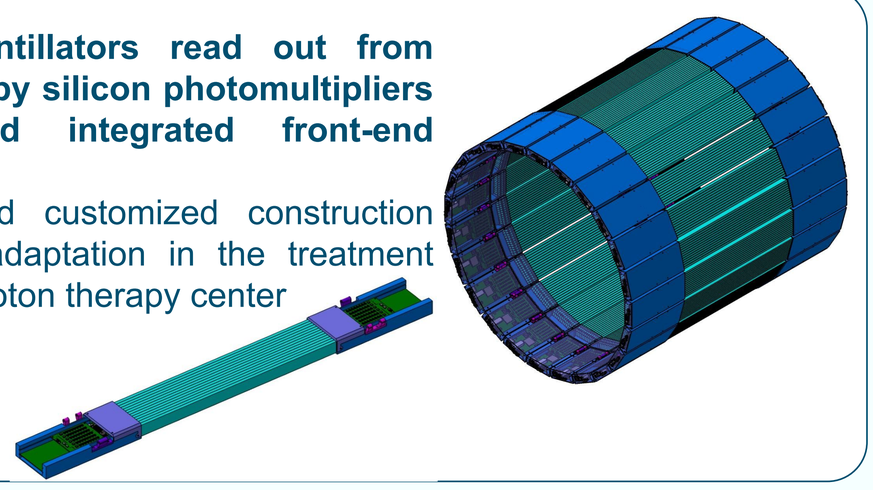


Place and time of γ particle interaction with scintillator material is based on time difference measurements between two ends of the same scintillator strip.

Place of annihilation is determined from time difference between two opposite modules in chamber.

MODULAR J-PET

- **Plastic scintillators read out from both sides by silicon photomultipliers (SiPM) and integrated front-end electronics**
- Modular and customized construction allows for adaptation in the treatment room in a proton therapy center



FUTURE PLANS

- **Modular J-PET will be investigated at the Cyclotron Centre Bronowice Kraków for range verification studies with phantoms**
- **one module will be used for measurement of the secondary radiation signal intensity in in-beam mode (experimental verification of simulations)**
- **geometry of Modular J-PET will be optimized for in-beam, inter-spill and off-beam proton beam range monitoring**
- **preclinical tests of Modular J-PET with off-beam PET method**

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