Production cross section of the short-lived β+ emitters ^{12}N, ^{29}P and ^{38m}K for online PET verification in proton therapy

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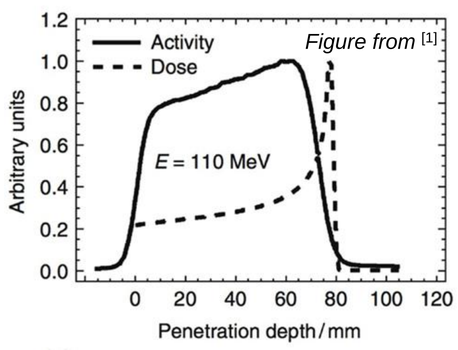
1. In-vivo PET range verification



- Comparison between measured and expected (MC codes) β+ activity distributions required [2,3]
- The accuracy of expected activity distributions depends on the underlying cross section data (input of the MC code)

Need of more accurate measurement of cross-section values in the full energy range (up to 250 MeV) so PET range verification method could give mm accuracy [4,5]

- Long-lived β+ emitters: ^{11}C, ^{13}N (offline monitoring)
- Short-lived β+ emitters: ^{12}N, ^{38m}K, ^{29}P (online monitoring)

2. PET isotopes for beam-on range verification

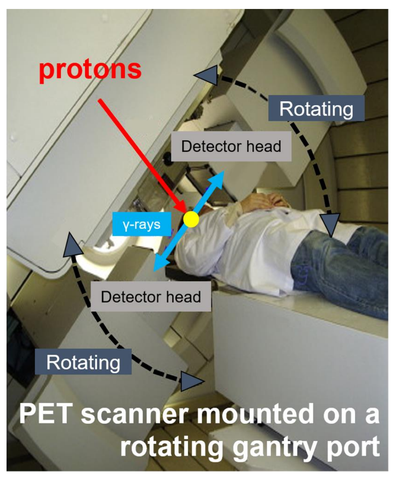
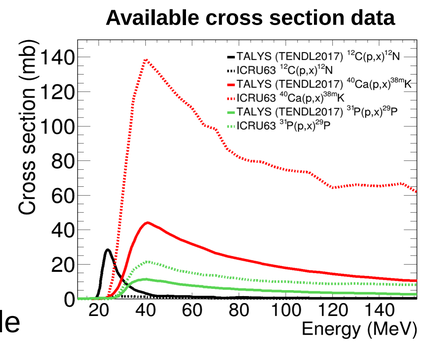
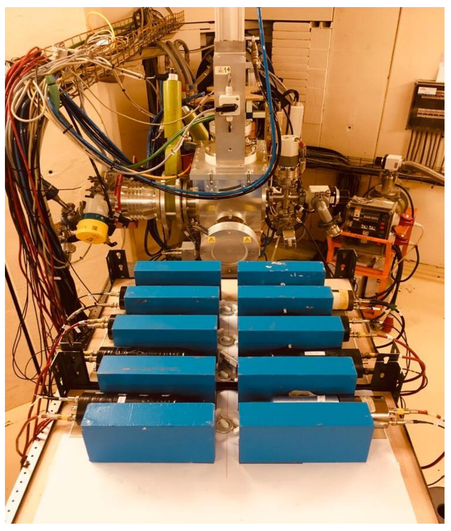


Figure from [9]

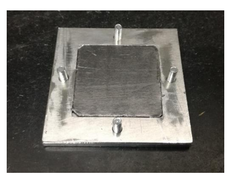
- Compared to long-lived β+ emitters, the short-lived provide real-time feedback on the dose delivered, a largest number of counts and are less susceptible to biological wash-out.[6]
- State of the art:
  - Measurement of the integral prod. yield below 55 MeV. [7]
  - Measurements below 48 MeV for ^{12}N. [8]
  - Significant discrepancies between different available cross section data sets.



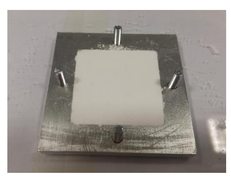
3. Experimental setup @ KVI-CART



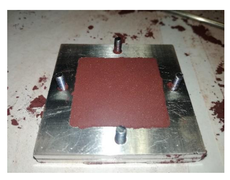
- We have irradiated films of graphite, CaF_2 and P between 3 mm thick aluminium plates (the β+ to γ-ray ε_{conv} ranges from 30% for ^{12}N to 60% for ^{29}P)



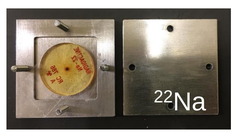
Graphite
1 mm thickness

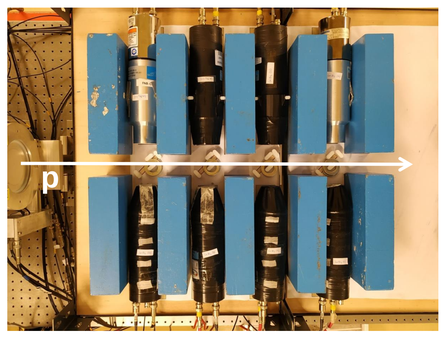


CaF_2
2 mm thickness

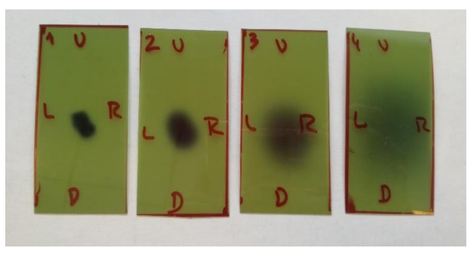


P
3 mm thickness



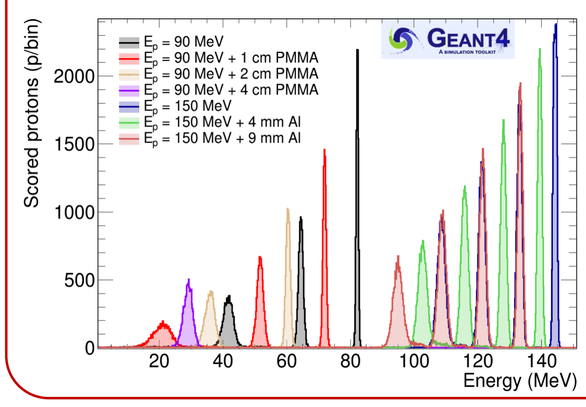


- The 511 keV photons are detected by cylindrical (1.5''x1.5'') and conical (height 1.5'', bases 1.5'' and 1'') $LaBr_3$(Ce) detectors opperating in coincidence.
- The absolute single and coincidence detection efficiencies are determined with a ^{22}Na source.

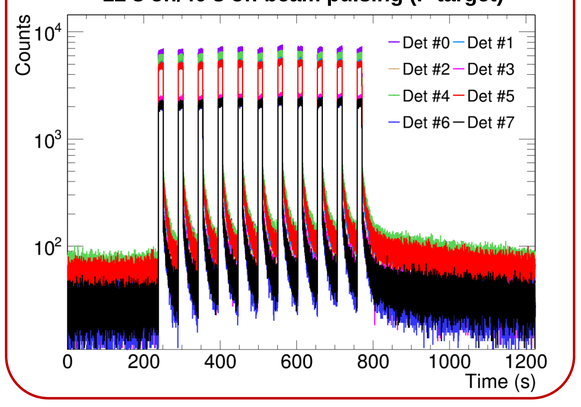


- The beam current is monitored with a beam ionization chamber placed before the first target.
- The alignment has been checked using Gafchromic films placed before and after each target.

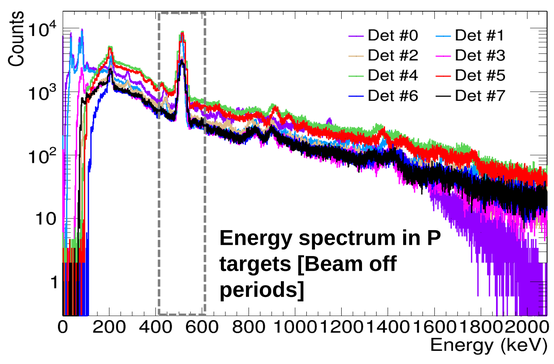
Irradiations at 90 and 150 MeV with several degraders: the overlap of two irradiation energies validates the measurements.



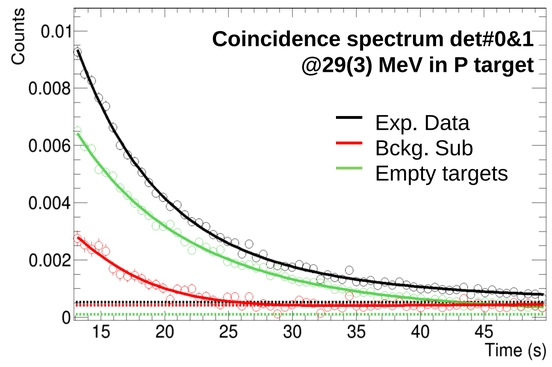
The beam-on/off cycles of the proton beam depends on the half-life of interest.



4. Preliminary analysis



- The production yield in each target is obtained looking at the 511 keV photons in coincidence (emitted mostly outside the target, somewhere in the converters).
- In case of the emission of characteristic γ-rays, they are also measured (emitted from inside the target).



- The production in the Al layers is also measured with empty targets (subtracted to total production).
- The decay curve (in red) is fitted to:

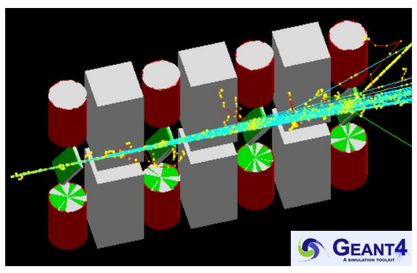
$$A(t) = A_{^{29}P} e^{-\lambda_{^{29}P} t} + C,$$

to obtain the production cross section.

Geant4 Monte Carlo simulations (validated with the measurement of the induced activity of ^{63}Zn in 2 mm ^{nat}Cu with 18 MeV protons at CNA)

The corrections applied to the measured annihilation photon intensities are:

- the attenuation of the 511 keV photons in the degraders/converters.
- the escape of a fraction of the positrons from the converters.



5. Conclusions & outlook

- Production yields between 20 and 150 MeV measured at KVI-CART, analisys ongoing.
- Geant4 simulations validated at CNA.
- Measurement at higher energies (up to 190 MeV) planned in 2020.
- Measurement below 55 MeV with better energy resolution (single shots) planed for 2020.

References

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