Measurement of β^+ emitters production cross sections of interest for range verification in protontherapy

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Master Thesis of J. Saiz y T. Rodriguez (U. Sevilla)

University of Sevilla and MediNet

University of Sevilla joined MediNet (task 1) in 2017

Initial line of research: *Determination of production yields of β+ emitter for range verification*

(n,*) cross sections for astrophysics and technology

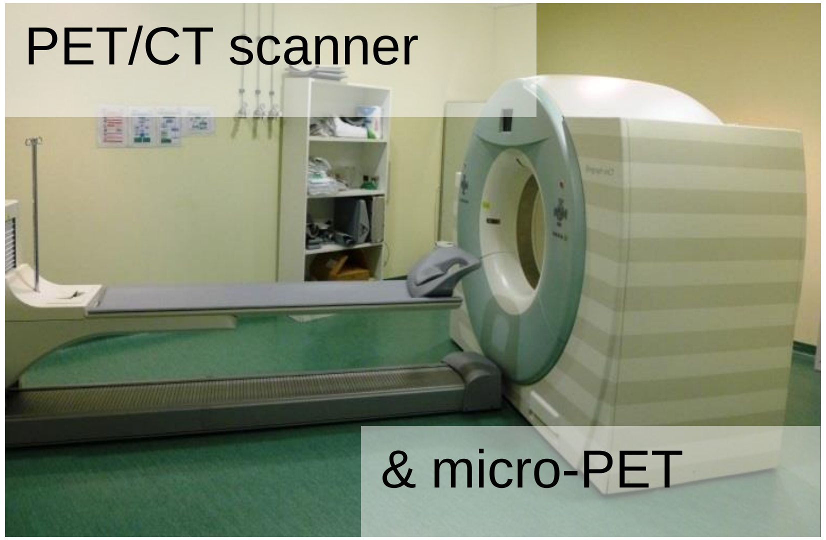
(p,*) cross sections for protontherapy

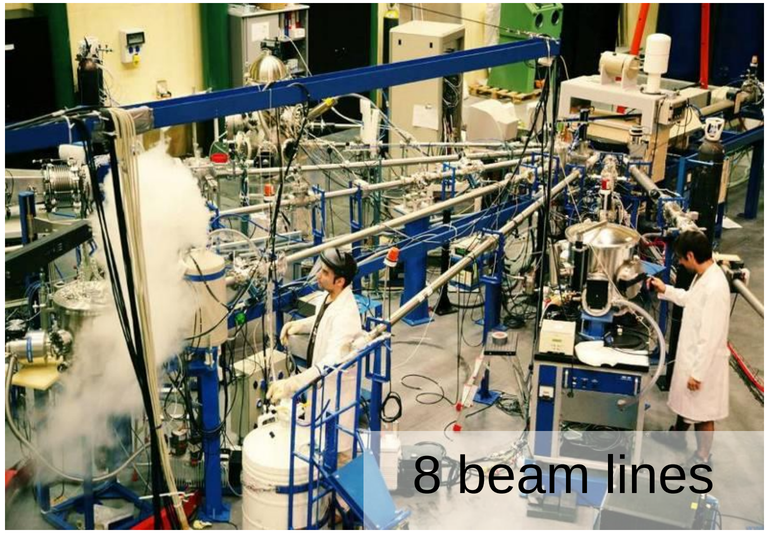
Looking forward to establish collaborations on this & closely related topics

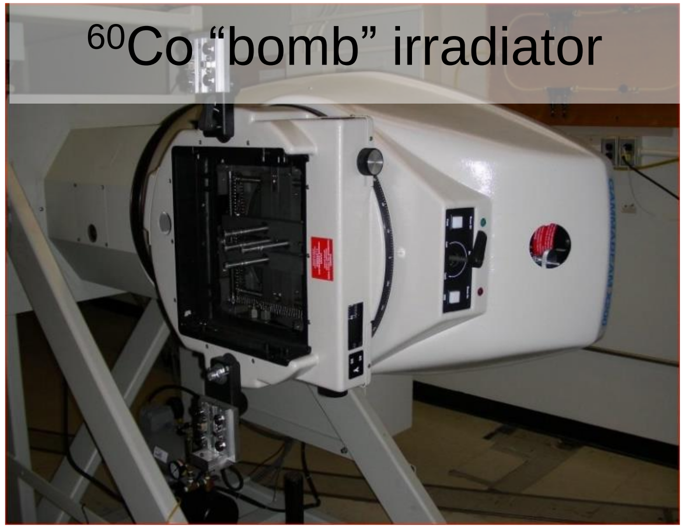
U. Sevilla and CNA (Centro Nacional de Aceleradores)

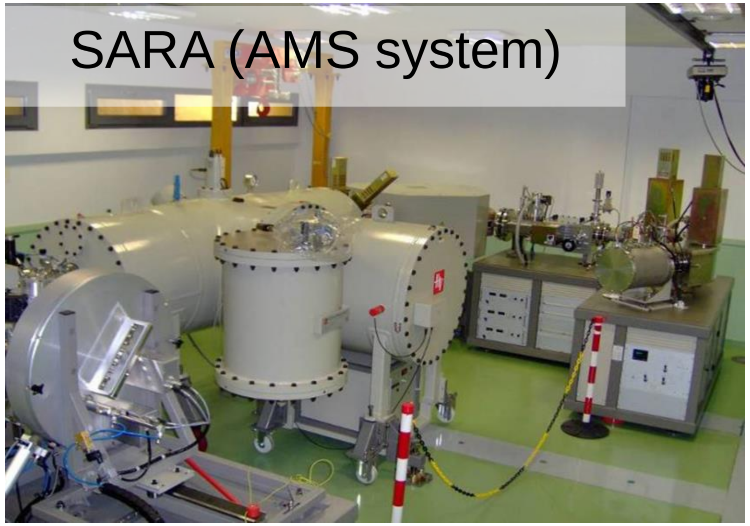

3 MV Tandem


18/9 MeV cycotron
with external beam

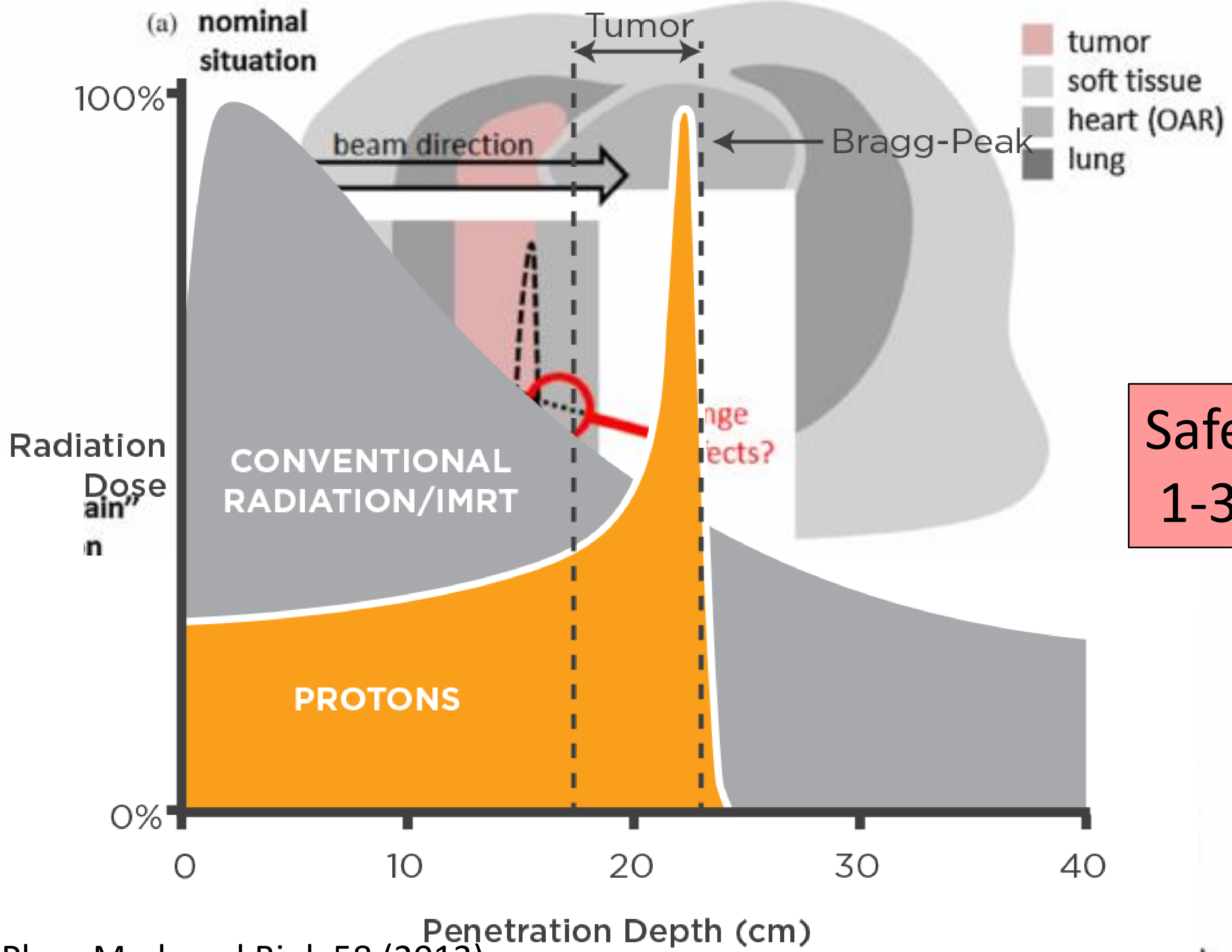

PET/CT scanner
& micro-PET


8 beam lines


^{60}Co “bomb” irradiator


SARA (AMS system)

Proton therapy for cancer treatment: the Bragg peak



Safety margin:
1-3% (up to 1 cm!)

Knopf and Lomax, Phys. Med. and Biol. 58 (2013)

Range verification in protontherapy

Look for fingerprints of the beam interaction with the body.

Among others:

- **Neutron emission**
- **Ionoacoustics** (detection of thermoacoustic signals)
- **Prompt gamma imaging**
    - Profile as function of depth P(z)
    - Time distribution (looking from z<0)
- **Delayed gamma imaging (~PET)**
    - From "activation" products:

$^{14}N(p,\alpha)^{11}C$	$(t_{1/2}=20{,}36\ m)$	PET scan right after treatment
$^{16}O(p,\alpha)^{13}N$	$(t_{1/2}=9{,}97\ m)$	
$^{16}O(p,pn)^{15}O$	$(t_{1/2}=2{,}04\ m)$	
$^{31}P(p,p2n)^{29}P$	$(t_{1/2}=4{,}1\ s)$	
$^{12}C(p,n)^{12}N$	$(t_{1/2} = 11\ ms)$	In between short pulses

Dendooven et al., PMB 60 (2015)
Buitenhuis et al., PMB 62 (2017)

Need for cross section data: some explicit references

España et al., "***The reliability of proton-nuclear interaction cross-section data to predict proton-induced PET images in proton therapy***", Phys. Med. Biol. 56(9) (2011)

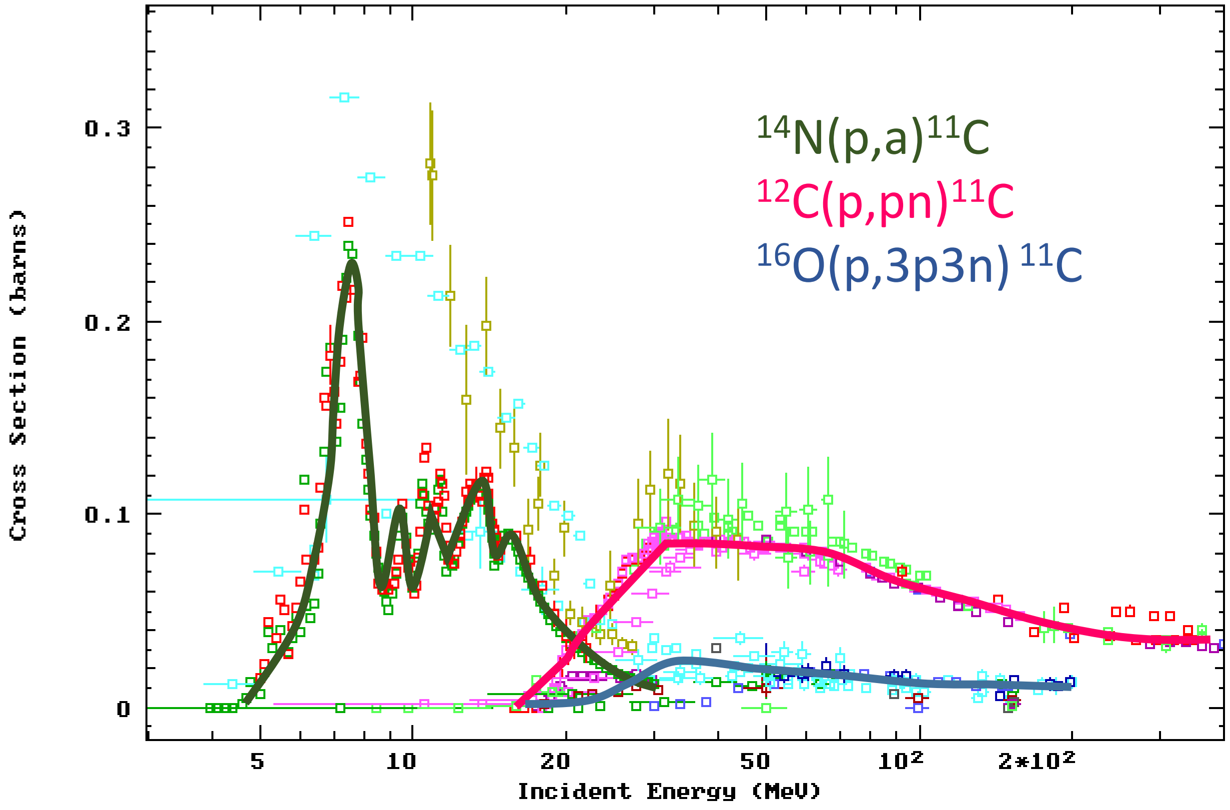
The results presented herein emphasize ***the need of more accurate measurement of cross-section values*** *of the reaction channels contributing to the production of PET isotopes by proton beams before this in vivo range verification method can give mm accuracy.*

Seravalli et al., "***Monte Carlo calculations of positron emitter yields in proton radiotherapy***", Phys. Med. Biol. 57(6) (2012)

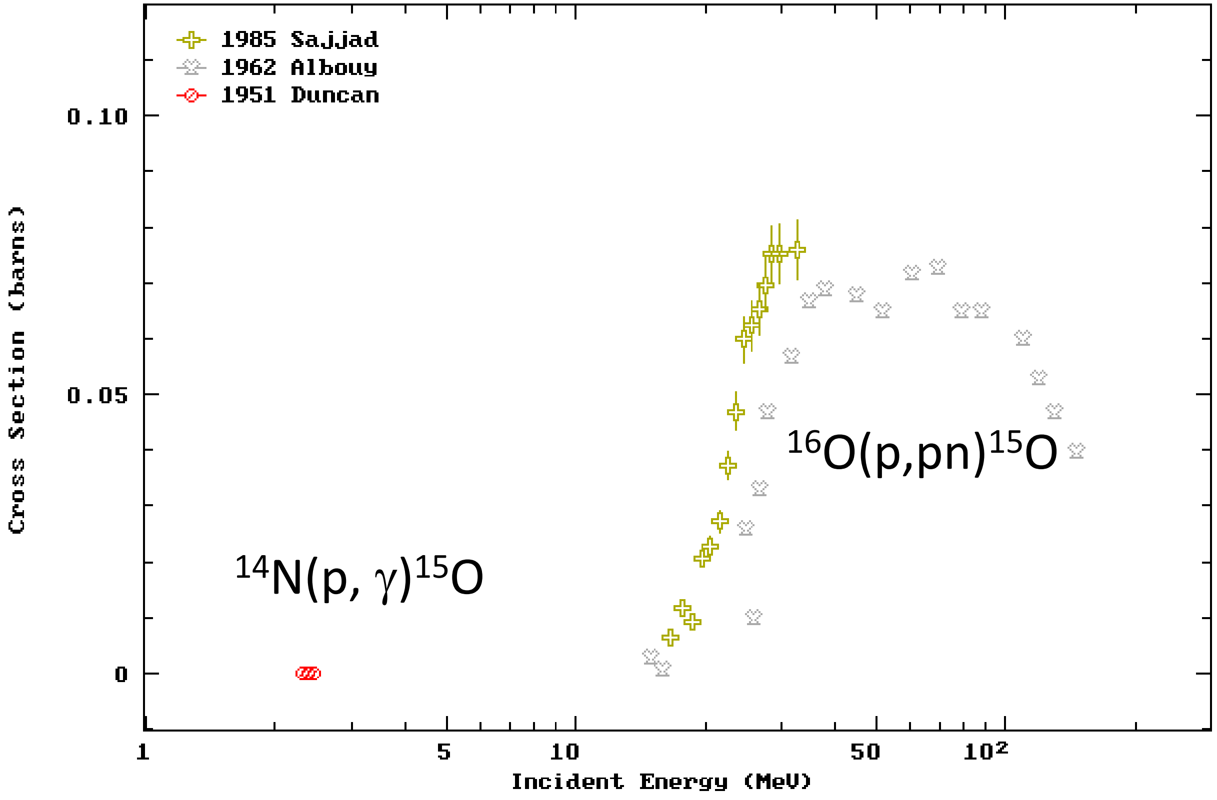
The internal phenomenological models of the MC codes produce positron emitter yields and depth profiles that are quite different from the ones obtained when using the experimental cross-sectional data. Therefore, ***there is a clear need for experimental data to validate the models used by the MC codes especially when the codes are used for charged particle therapy monitoring applications where high accuracy is required****. In the meanwhile, the usage of external experimentally validated cross section as an alternative to the usage of the nuclear internal models of the codes is recommended.*

Need for cross section data: status in EXFOR

EXFOR search for (p,*) giving: ^{11}C



EXFOR search for (p,*) giving: ^{12}N, ^{15}O, ^{29}P & ^{38m}K



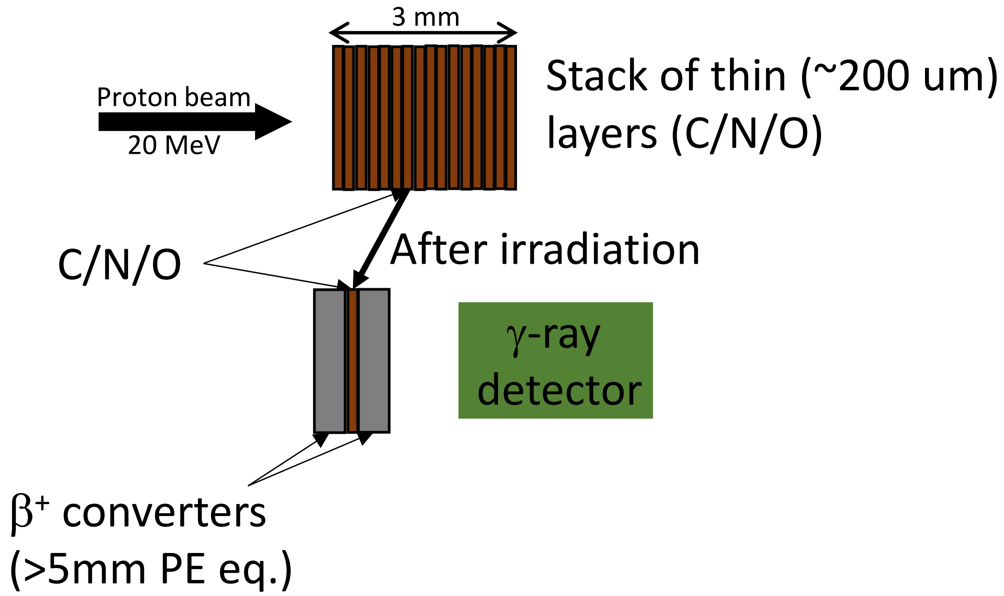
Our project for measuring cross sections for protontherapy

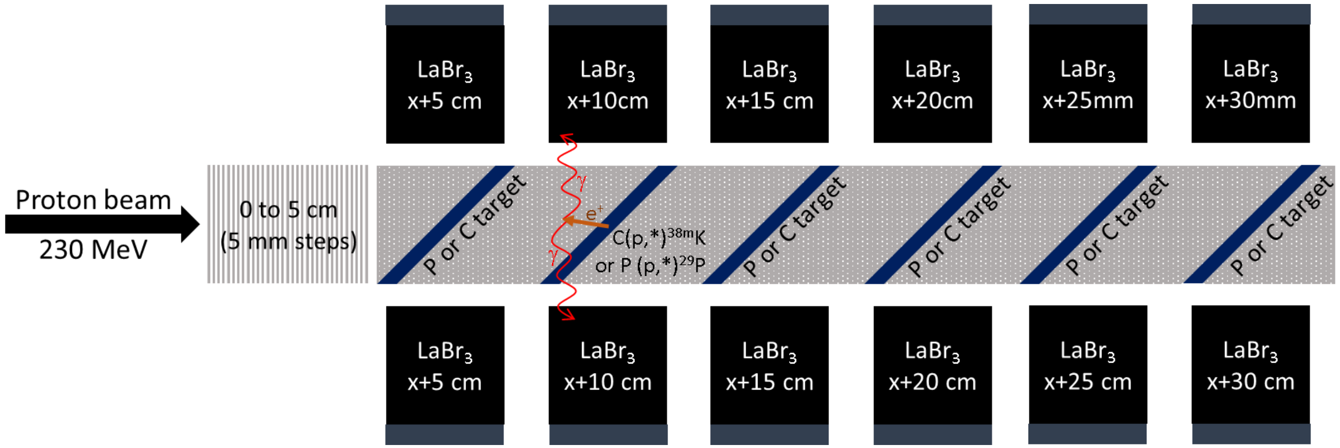
Production yields up to 250 MeV as a function of energy:

^{11}C and ^{13}N in C,N and O => $t_{1/2}$>5 minutes

^{15}O in O, ^{12}N in C, ^{29}P in P and ^{38m}K in Ca => $t_{1/2}$< minutes

1. Use of fixed fixed energy beams to cover the full range: 0-20, 20-90 and 90-250 MeV
2. Cover ALL energies within each interval in "one or few irradiations" (degraders/spacers)
3. Always need of "converters", care with effect of e+ range (up to a few cm)

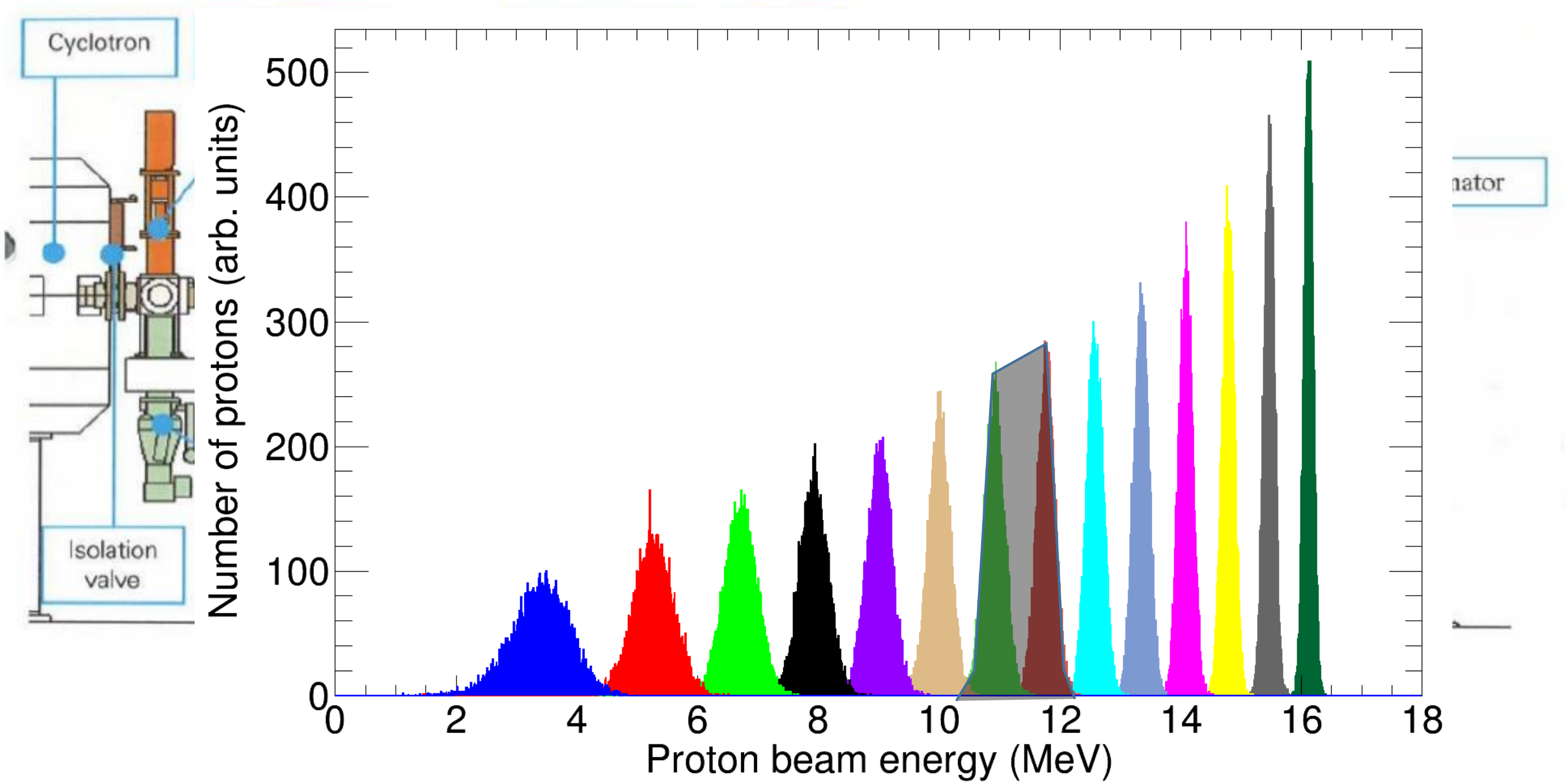


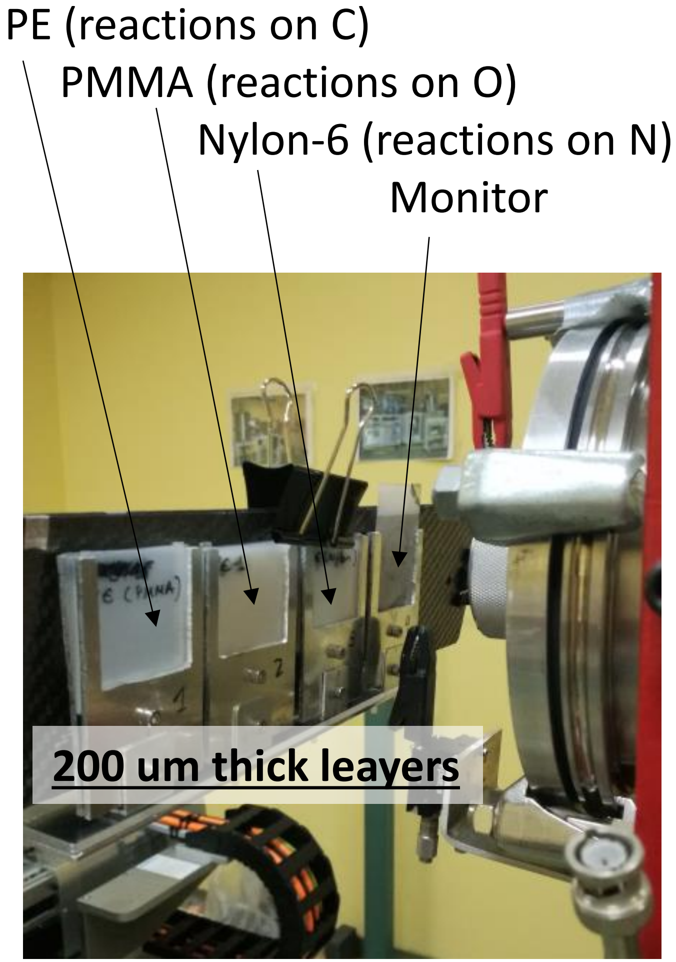


Production yields of ^{11}C and ^{13}N below 18 MeV

Irradiations at CNA (18 MeV cyclotron): multi-layer targets

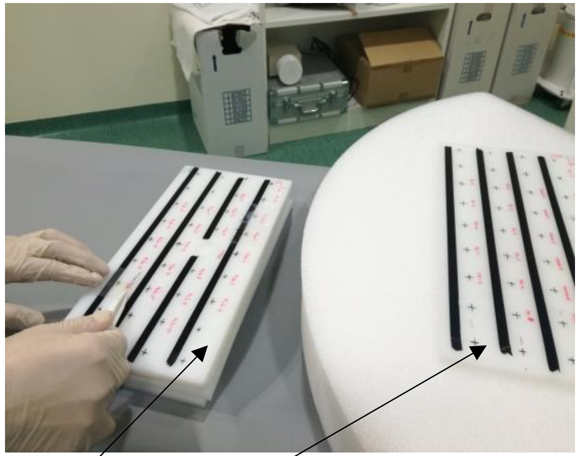
Sequential irradiations at ~30 nA for 5 minutes

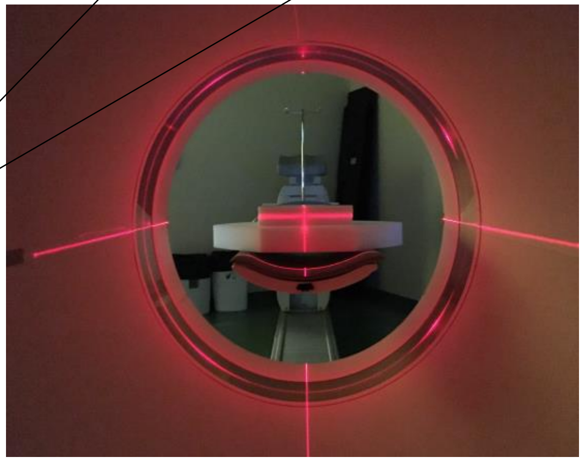


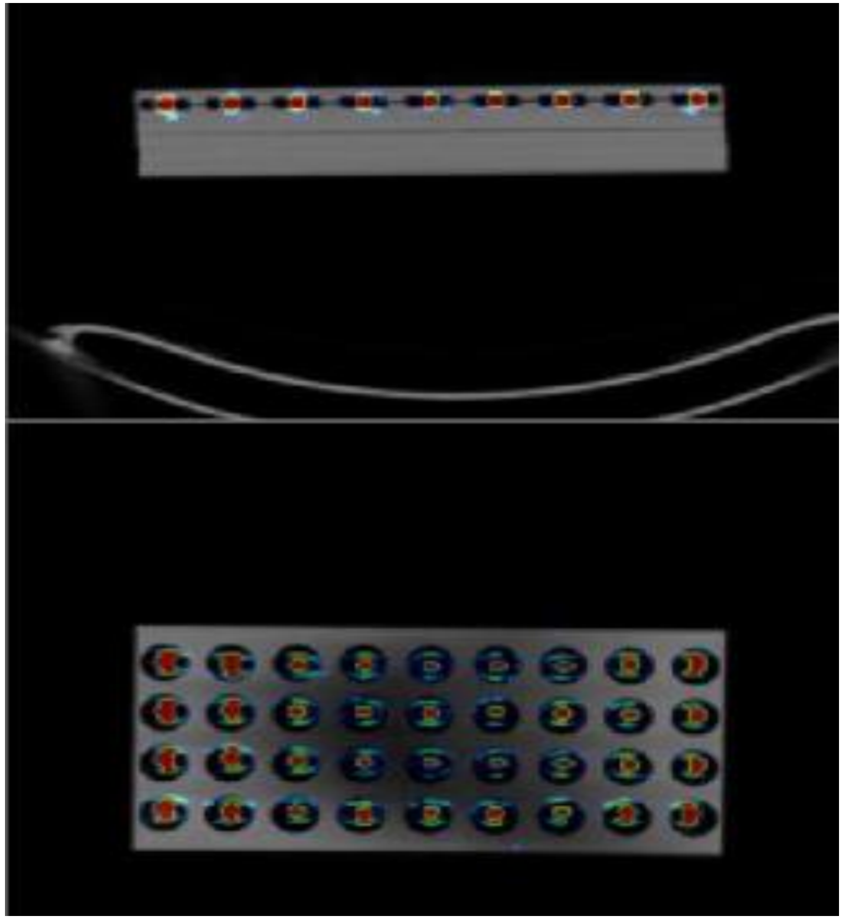


Detection system: PET/CT scanner at CNA

Within minutes from the irradiation, the 46 layers of PE, PMMA and Nylon (plus monitors) are already being monitored in dynamic mode (1 minute stories) at the PET (two planes), previously calibrated as function of (x,y,z)

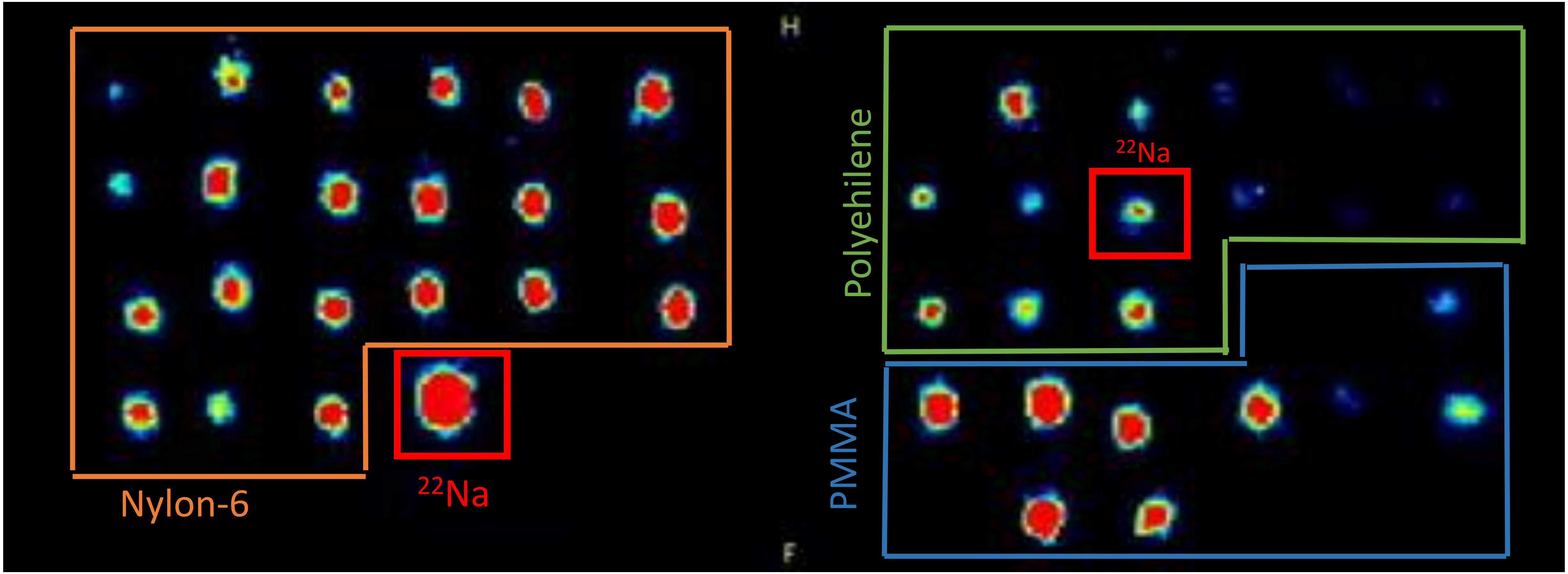




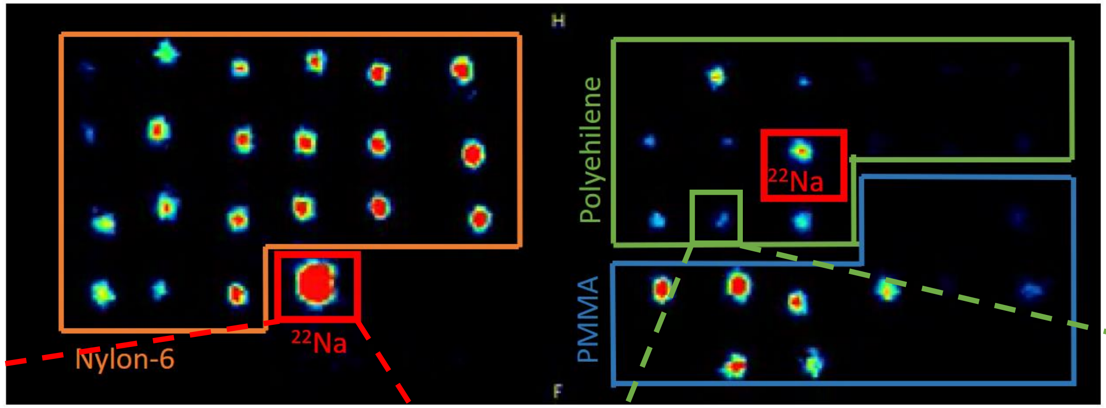


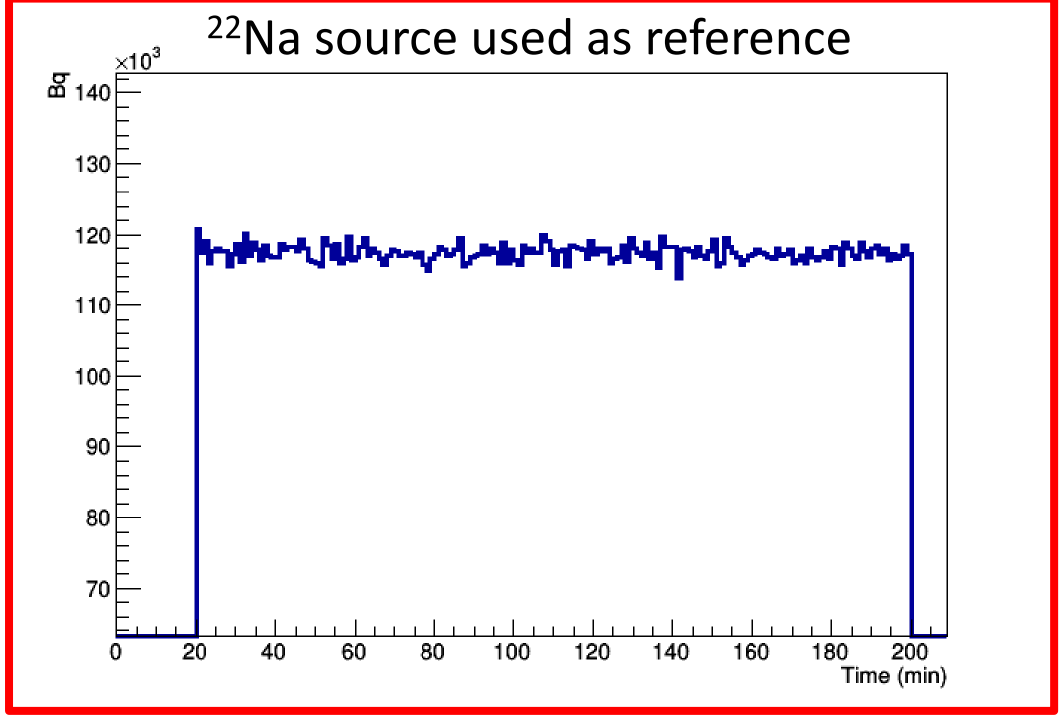
A PE matrix serves for positioning the films and as positron converter

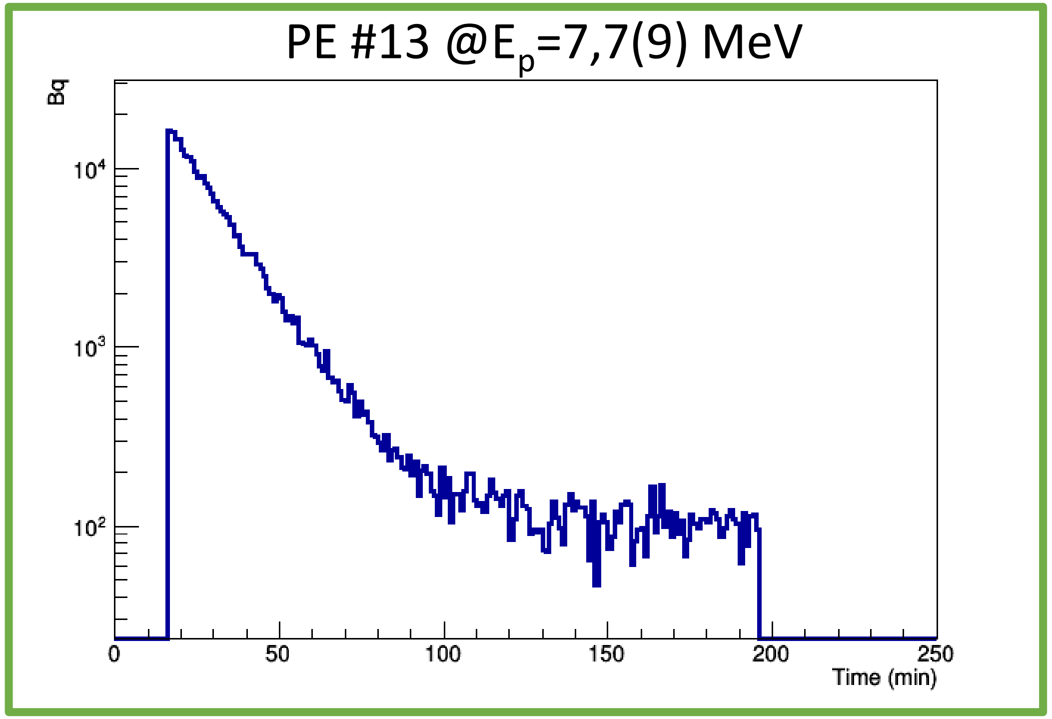
Activity curve in PET scanner (from previous test)



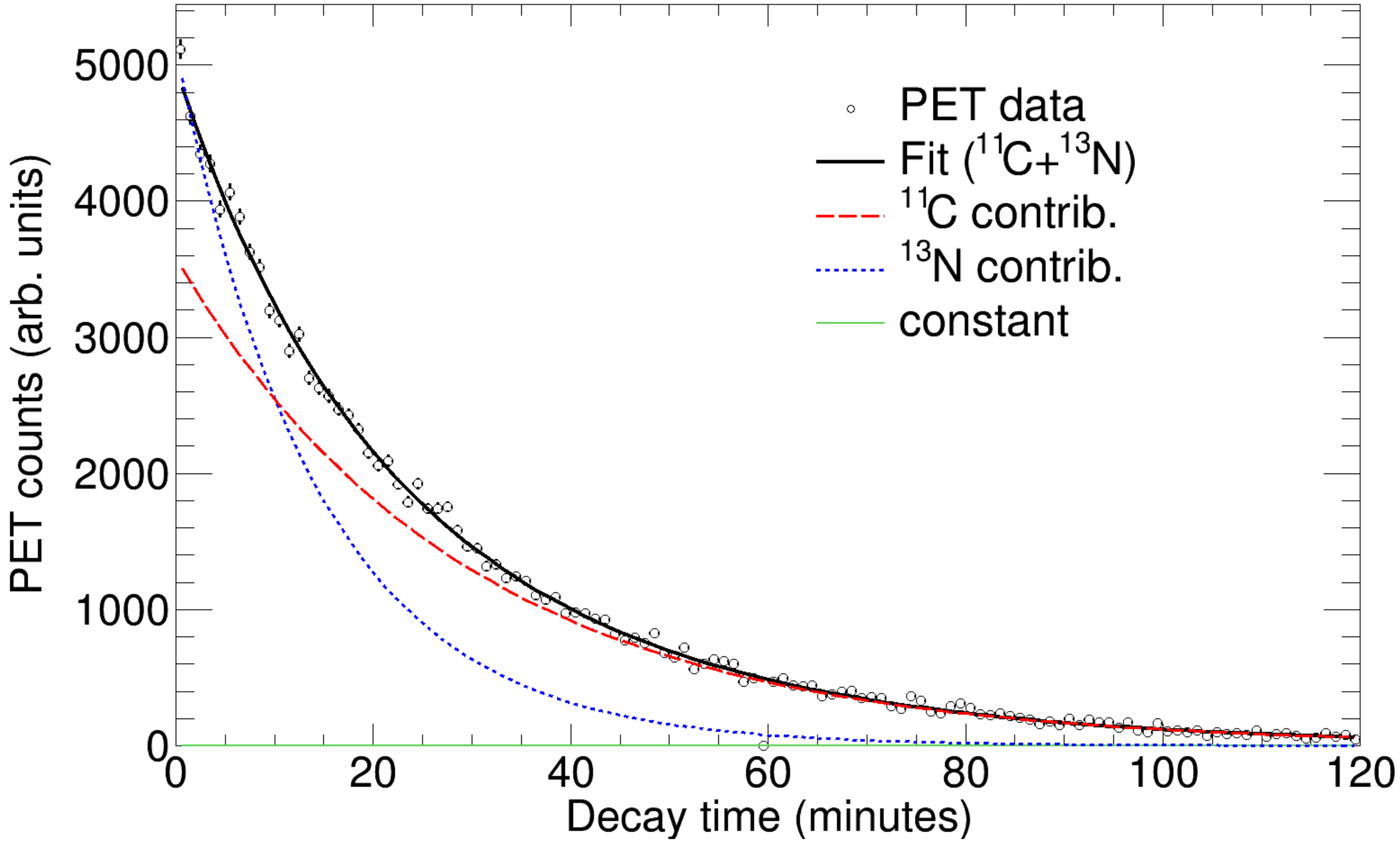
Activity curve in PET scanner (from previous test)



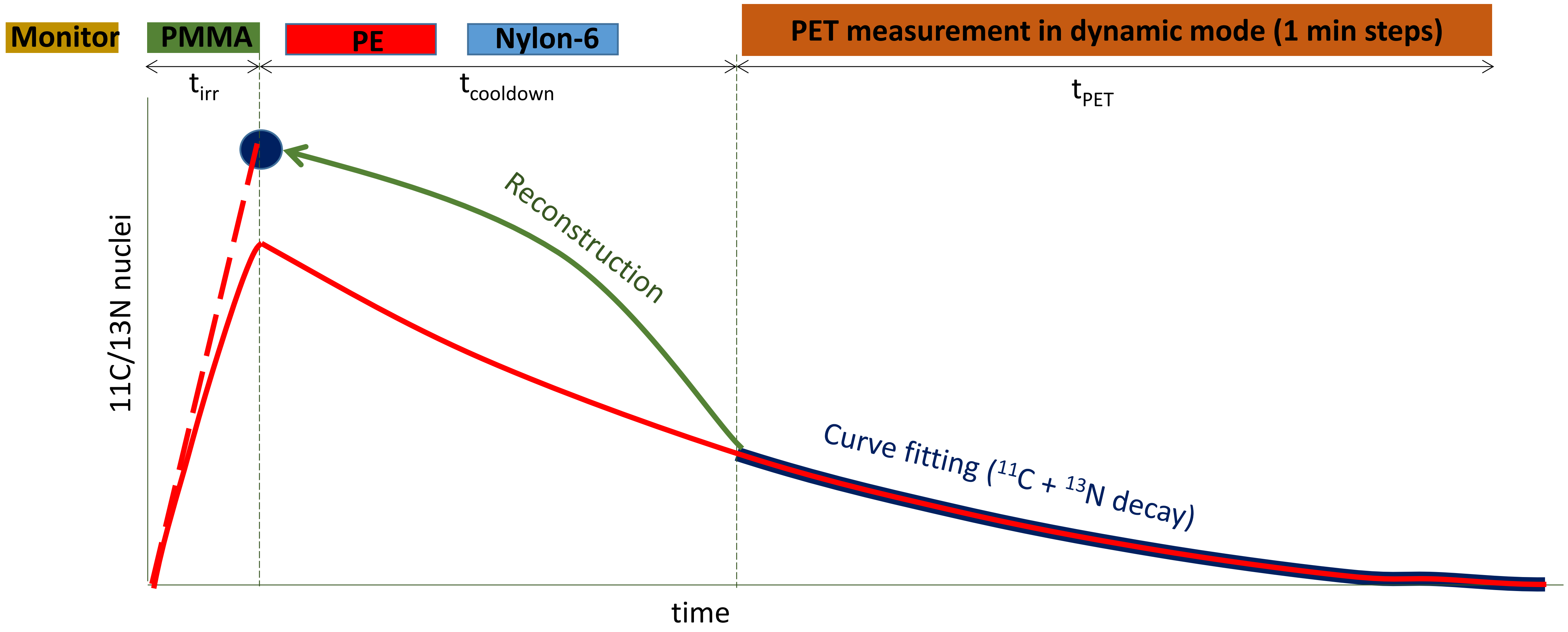




Curve fitting: proton beam production of ^{11}C and ^{13}N

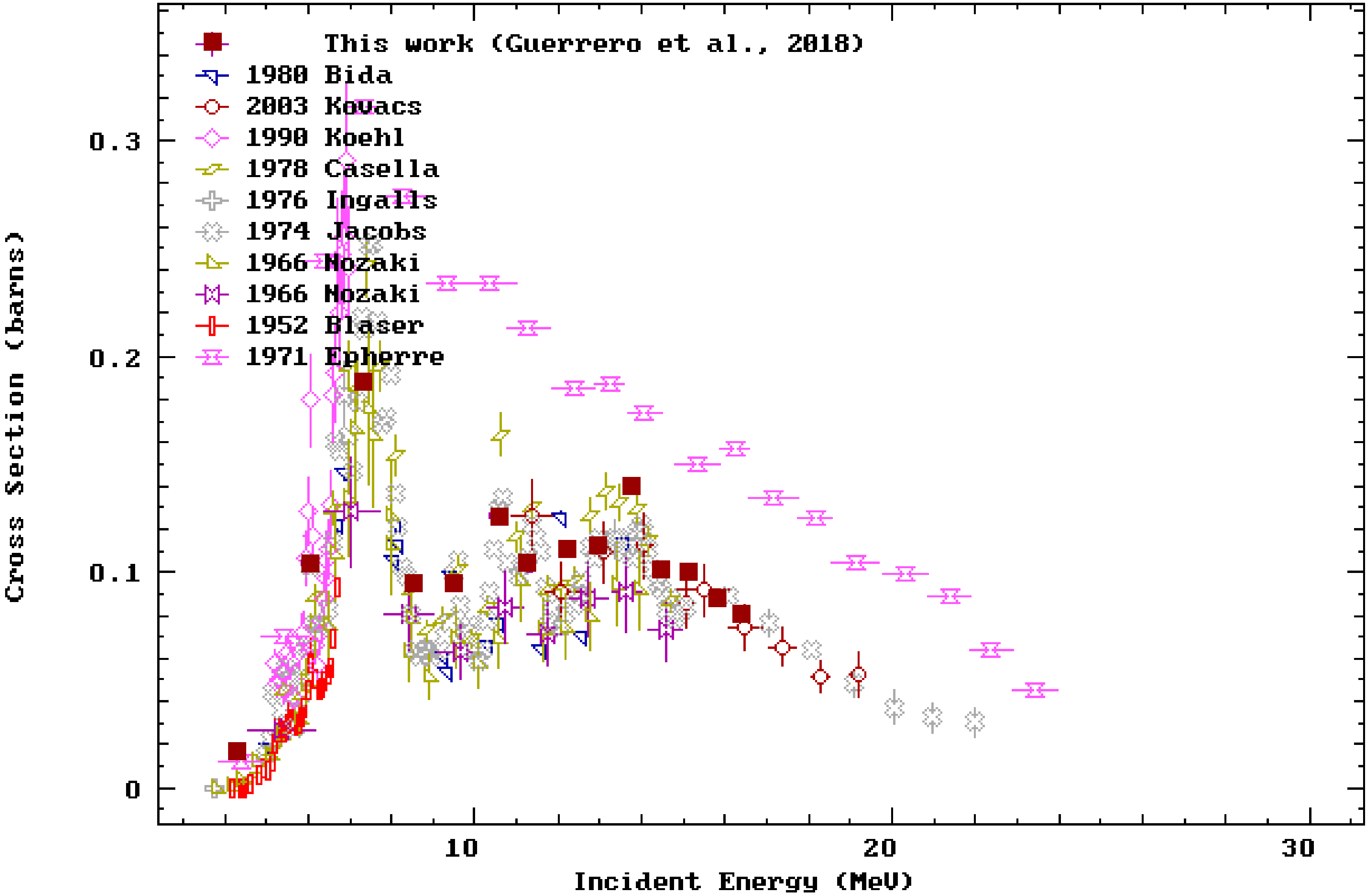


Decay during irradiation and cooldown

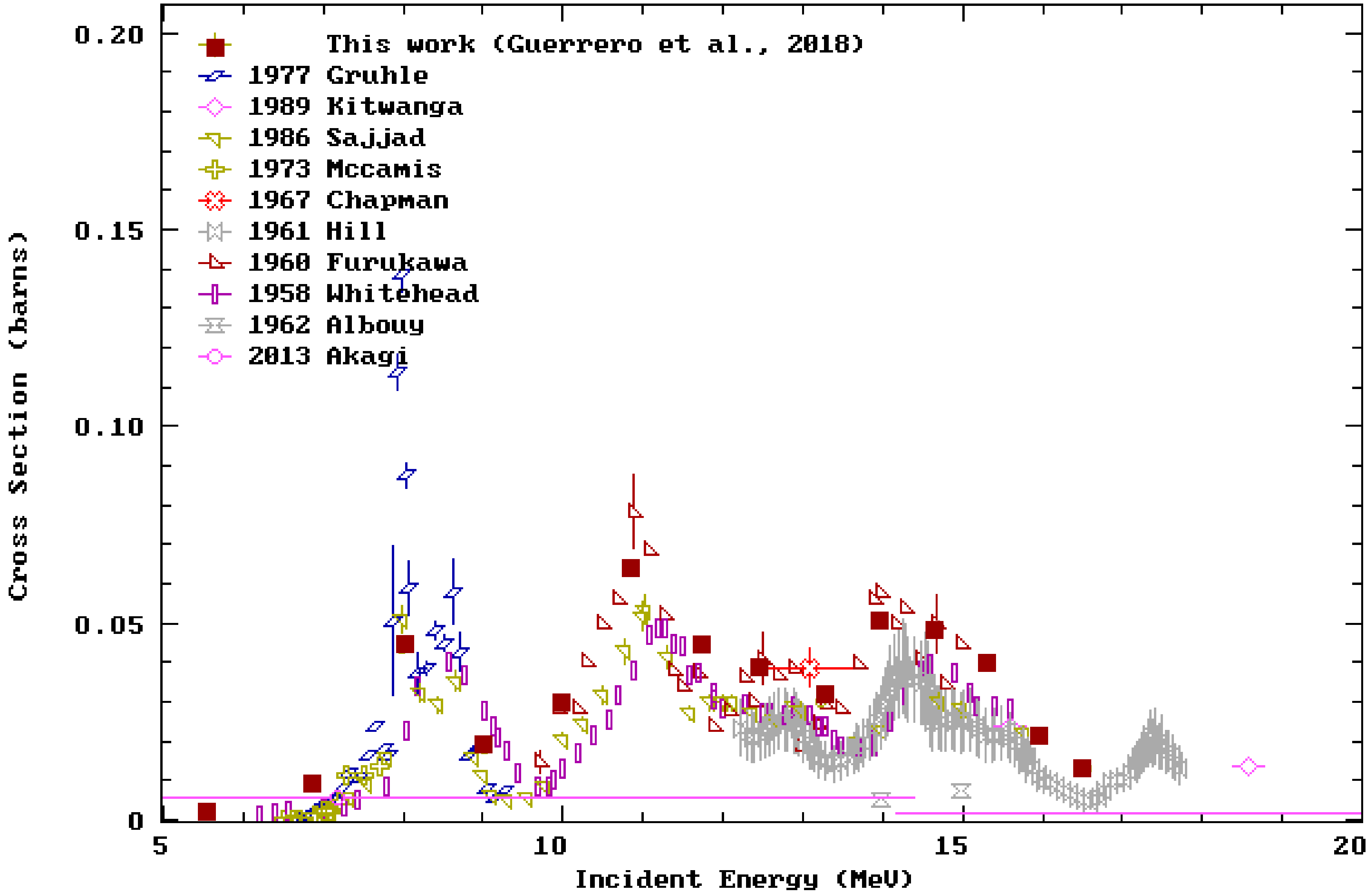


The first layer of all target stacks is PMMA: cross check for beam intensity and irr./cooldown decay corrections

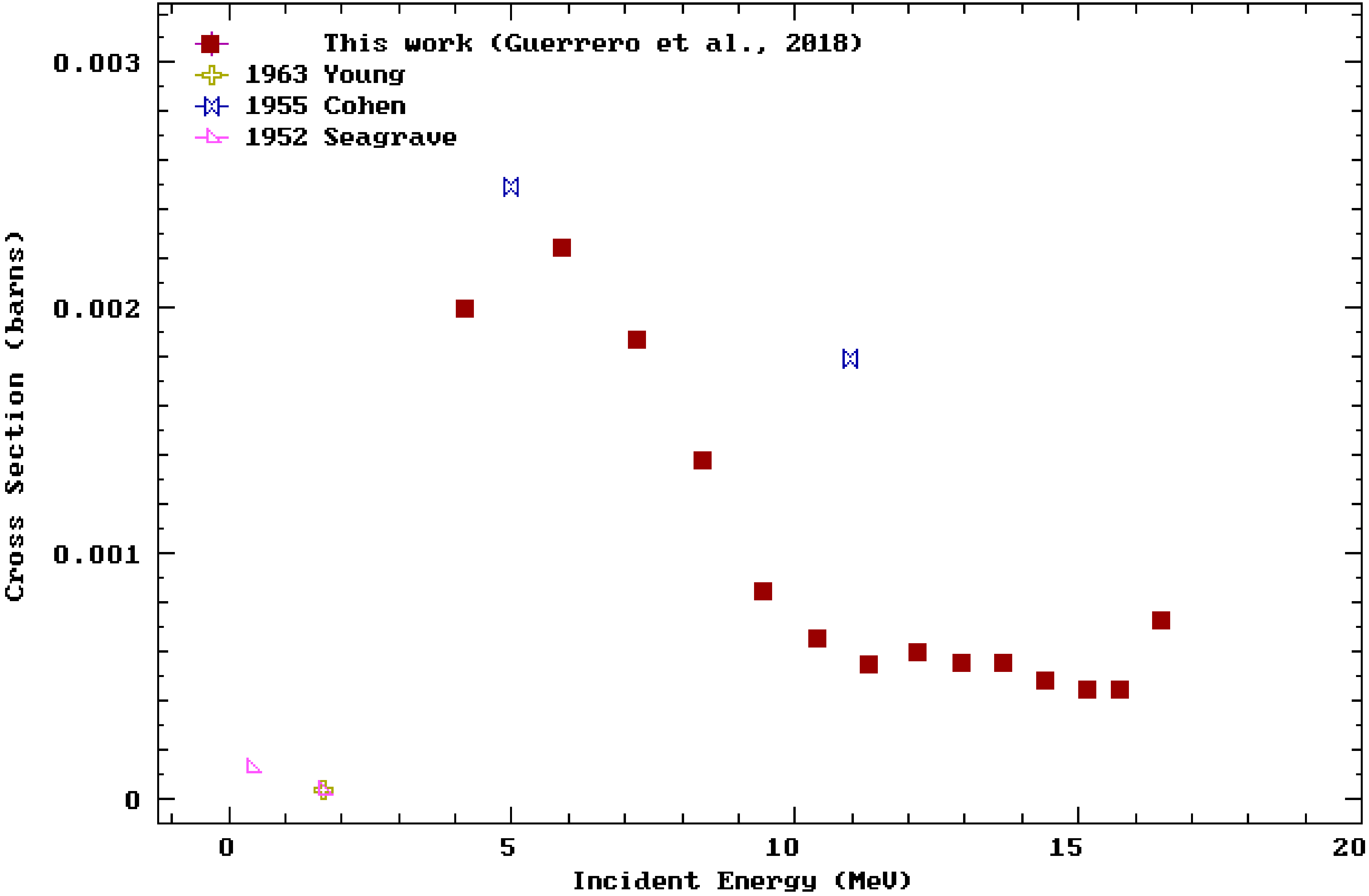
Results: ^{11}C on Nitrogen (Nylon-6) => $^{14}N(p,\alpha)^{11}C$



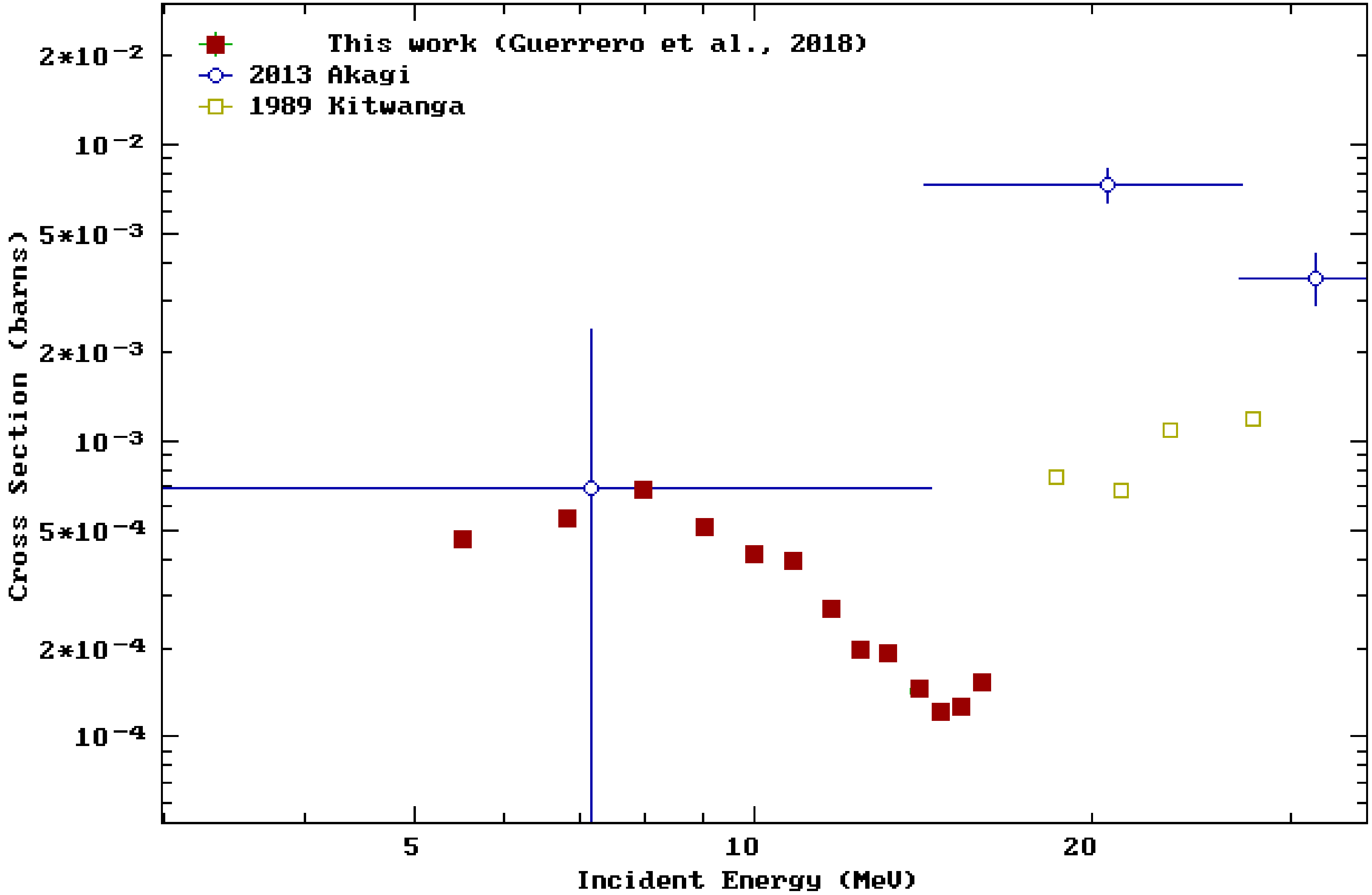
Results: ^{13}N on Oxygen (PMMA targets) => $^{16}O(p,\alpha)^{13}N$



Results: ^{13}N on Carbon (PE targets) => $^{12}C(p,\gamma)^{13}N$



Results: ^{13}N on Carbon (PE targets) => $^{16}O(p,3p3n)^{11}C$



Conclusions & Outlook

CONCLUSIONS

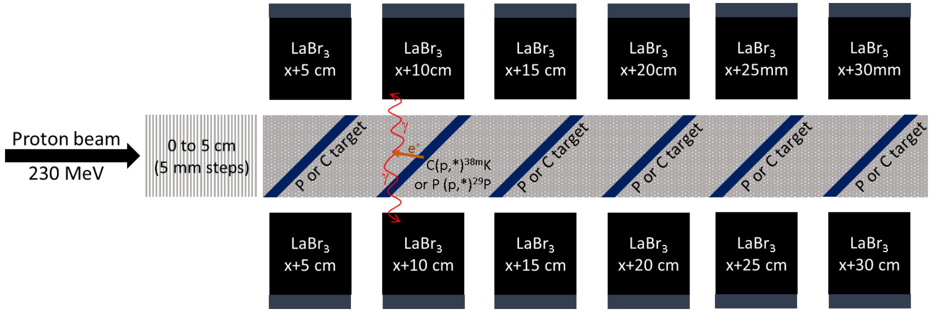
- First approach to the measurement of β^+ emitter cross sections at the **Centro Nacional de Aceleradores (CNA)** with application in range verification in proton therapy:
  → **Irradiation, detection, simulation and analysis tools developed**

- The result of this work is a set of **experimental cross sections for four different reactions** (^{11}C and ^{13}N production in C, O and N) in the energy range between 4 and 17 MeV, some of which have barely been measured before (according to EXFOR).

OUTLOOK

- Use the off-line PET technique with multi-layer targets to measure the production of ^{11}C and ^{13}N using clinical beams of ~90 and 230 MeV.

- Test a nd develop the set-up to measure yields for short-lived β^+ emitters (i.e. ^{10}C, ^{12}N, ^{29}P, ^{38m}K) at "pulsed" clinical beams of ~90 and 230 MeV.



Currently looking for the most suited facilities!

2nd Workshop Español en Protonterapia (WEP2018)

ProSAS: a proposal for a (1st public) protontherapy center in Seville