

PG measurements of ^{180}As contrast agent for proton range verification

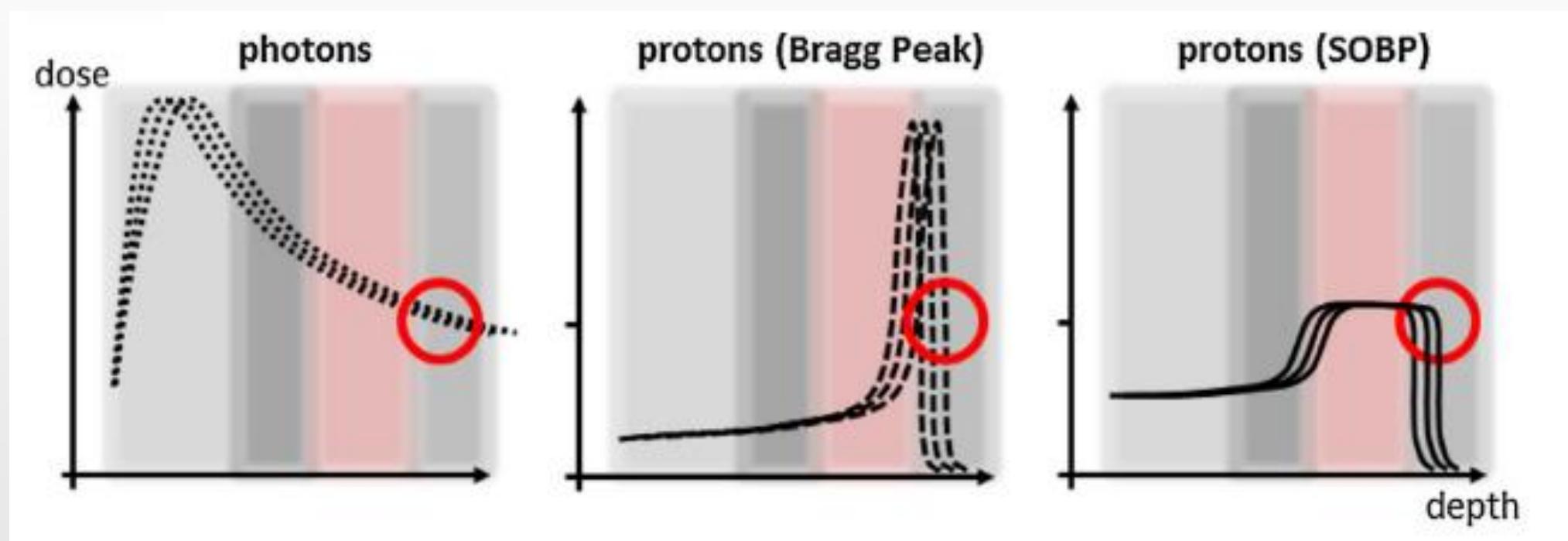
V.V. Onecha, V. Sanchez-Tembleque, A. Espinosa Rodríguez,
P.Ibáñez, M. García-Díez, S. España, D. Sanchez-Parcerisa,
G.García, S. Viñals, J.M. Udías, L.M. Fraile

Talk outline

- Introduction and Motivation
- Reactions $^{18}\text{O}(\text{p},\text{X})\text{B}$
- Set-ups for measurements
- Analysis
- Results
- Conclusions

Proton Range Issue

- Uncertainties in proton therapy are more problematic than in conventional radiotherapy because of the Bragg peak.
- The proton range is one of the most problematic issues in proton therapy.
- Current uncertainties ~3 % of range, limiting dose conformity in tumor.



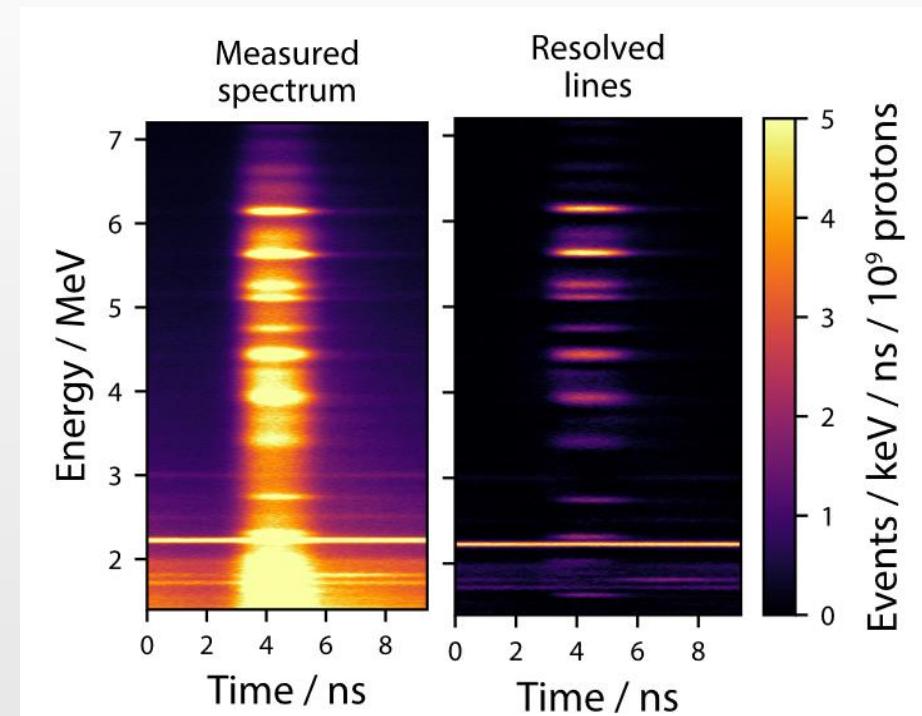
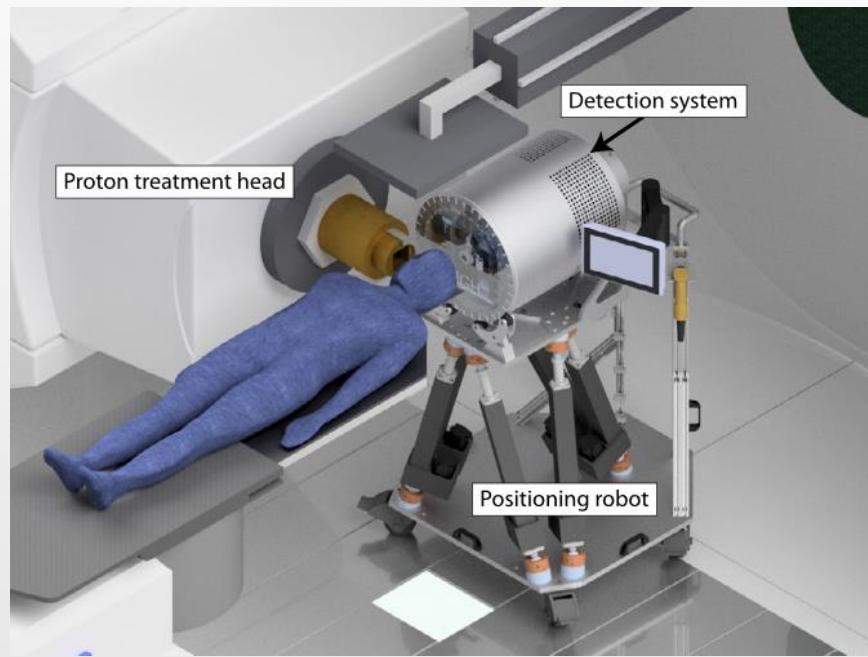
Knopf Antje Christin, Lomax Antony. In vivo proton range verification: A review Physics in Medicine and Biology. 2013. 58, 15. 131–160.

Introduction & Motivation

- It is possible to estimate the proton range and **dose distribution** studying the **secondary radiation** emitted after protons interact with target.

1. Prompt-Gamma (PG) in-vivo

- Nuclear reactions produce PG (time emission ns-ps).
- The intensity of PG is higher close to the BP.



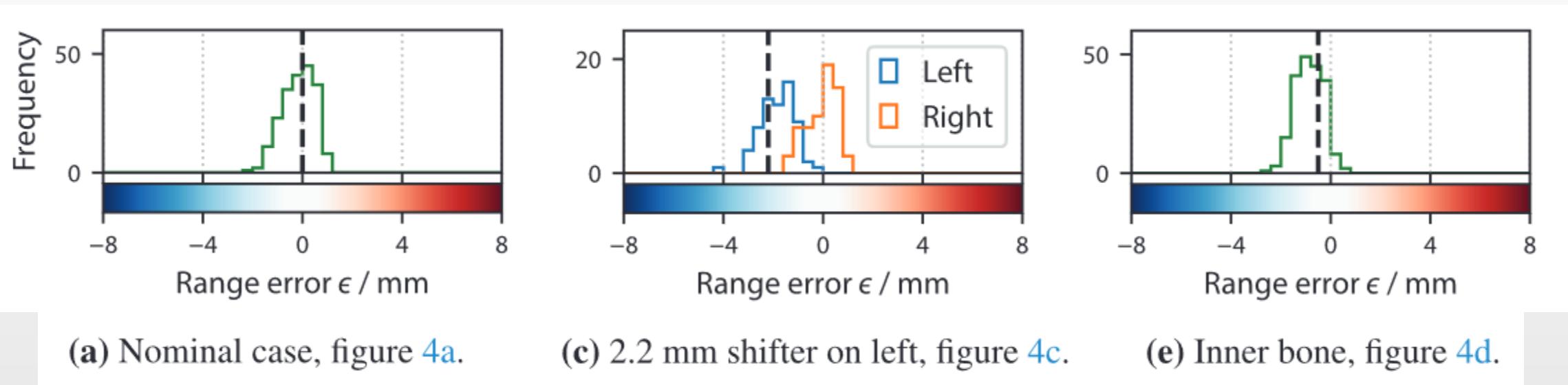
Modified from Fernando Hueso-González *et al* 2018 *Phys. Med. Biol.* **63** 185019

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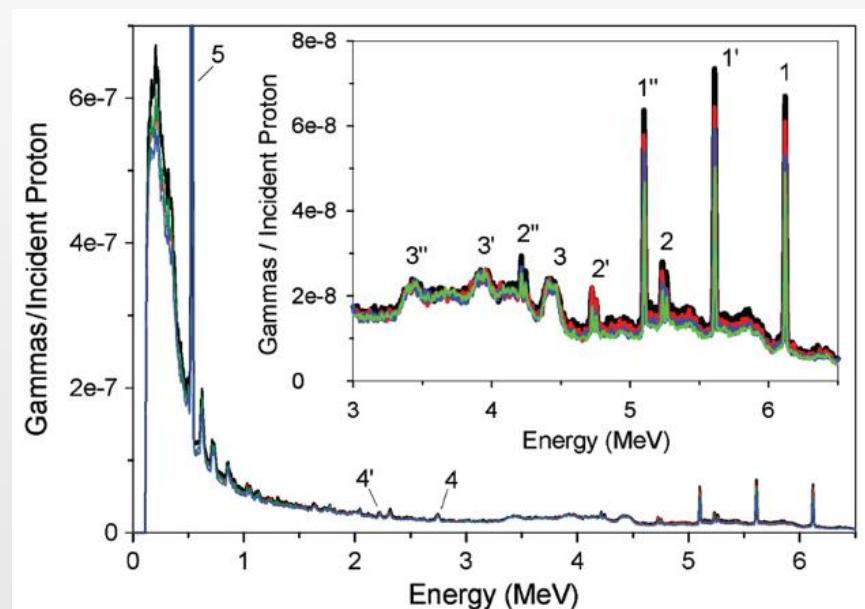
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DRAWBACKS

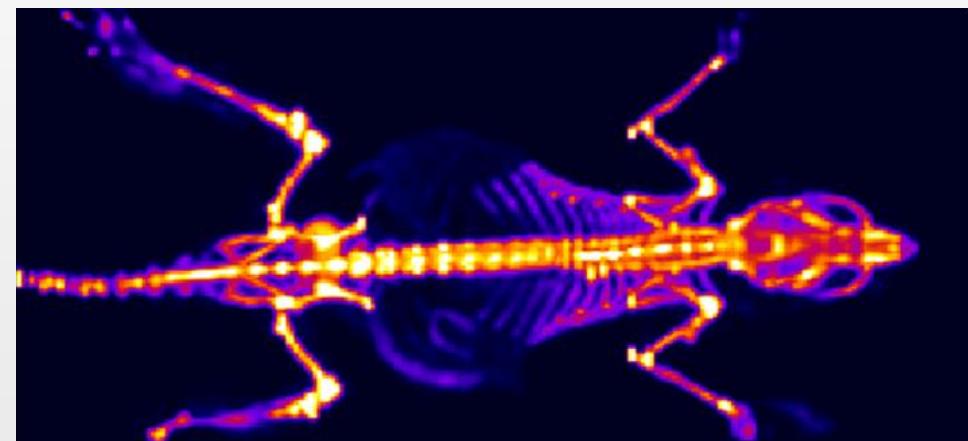
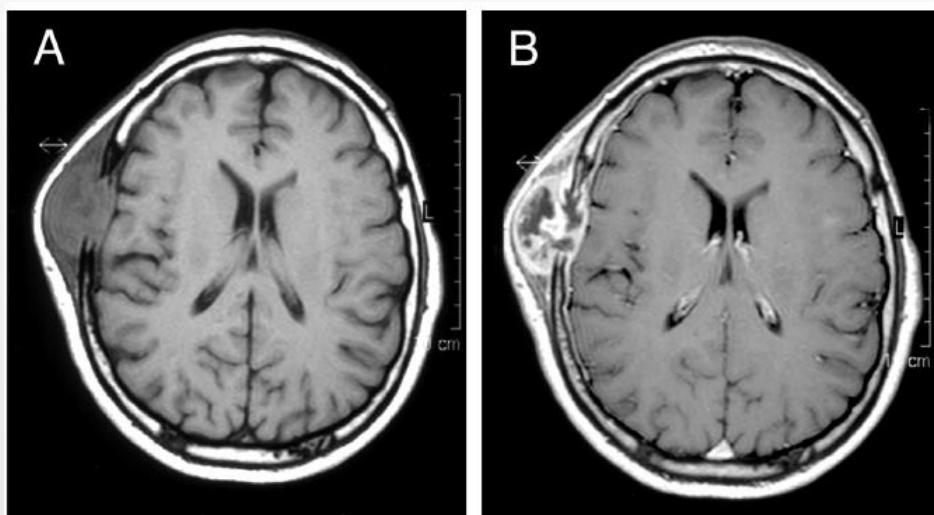
- High rate of gammas/s that saturates detectors.
- Very high energy natural gammas with a low detection efficiency.



- 1) 6.3 MeV - ^{16}O
- 2) 5.2 MeV - ^{15}O
- 3) 4.4 MeV - ^{12}C
- 4) 2.74 MeV - ^{16}O

Contrasts in Medicine

- A contrast is an element which is introduced in the human body to get a better quality in a medical image.
- Its use is very common in different techniques, such as ^{127}I in CT, Gd in Magnetic Resonance and ^{18}F in PET.



El Saghir, Nagi & I Elhajj, Ihab & Geara, Fady & Hourani, Mukbil.
(2005). Trauma-associated growth of suspected micrometastasis.
BMC cancer. 5. 94. 10.1186/1471-2407-5-94.

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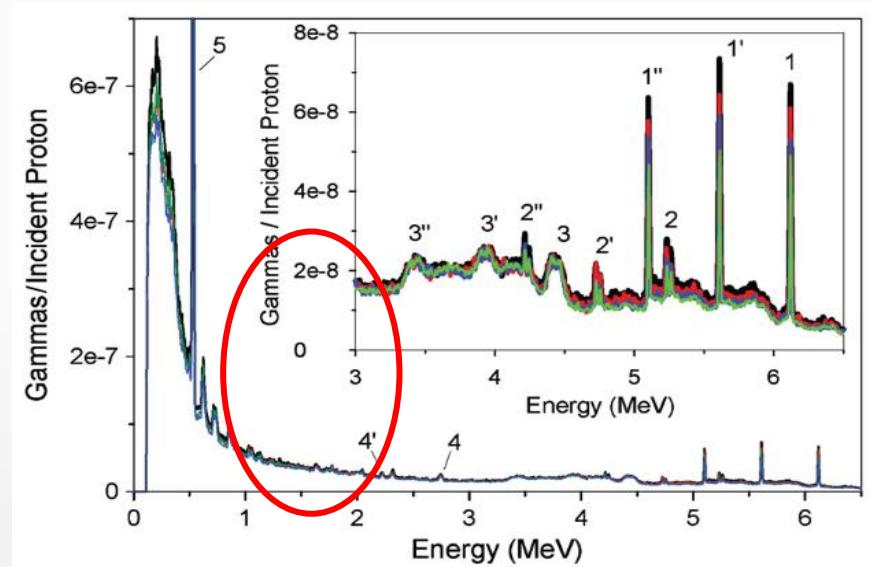
CONTRAST AGENTS

- They would decrease the total gamma-ray emissions at high energies.
- Emissions at low energies (<2MeV) to solve the efficiencies issues.

Reactions $^{18}\text{O}(\text{p},\text{X})\text{B}$

➤ PG lines cross-section

- $^{18}\text{O}(\text{p},\text{p}')^{18}\text{O}^* \rightarrow 1982 \text{ keV}$
- $^{18}\text{O}(\text{p},\text{n})^{18}\text{F}^* \rightarrow 937, 1041 \text{ & } 1080 \text{ keV}$



γ (keV)	Reaction	Isotope	Level (keV)	J^π	M (γ)	L
937.20	p,p'	^{18}F	937.20	3^+	E2	4
1041.55	p,n	^{18}F	1041.55	0^+	M1	2
1080.54	p,n	^{18}F	1080.54	0^-	E1	2
1982.07	p,n	^{18}O	1982.07	2^+	E2	4
5269.16	p, α	^{18}O	5269.16	$5/2^+$	M2+E3	4
5297.82	p, α	^{18}O	5298.82	$1/2^+$	E1	2

NO PREVIOUS DATA !!!

In this work:

- Cross-section
- Angular distribution

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- $^{18}\text{O}(\text{p},\alpha)^{15}\text{N} \rightarrow 5269 \text{ & } 5297 \text{ keV}$

Q-value = + 3979.8 keV
 Energy threshold ~ 1.4 MeV
 We observe this lines at 3 MeV

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Set-up PG measurements

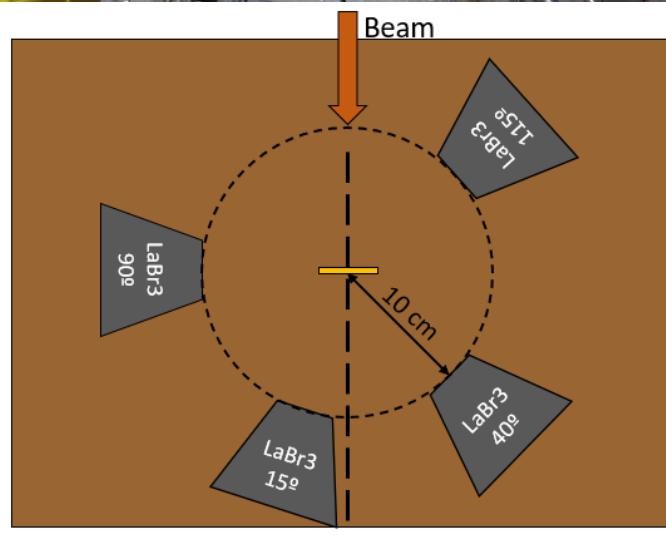
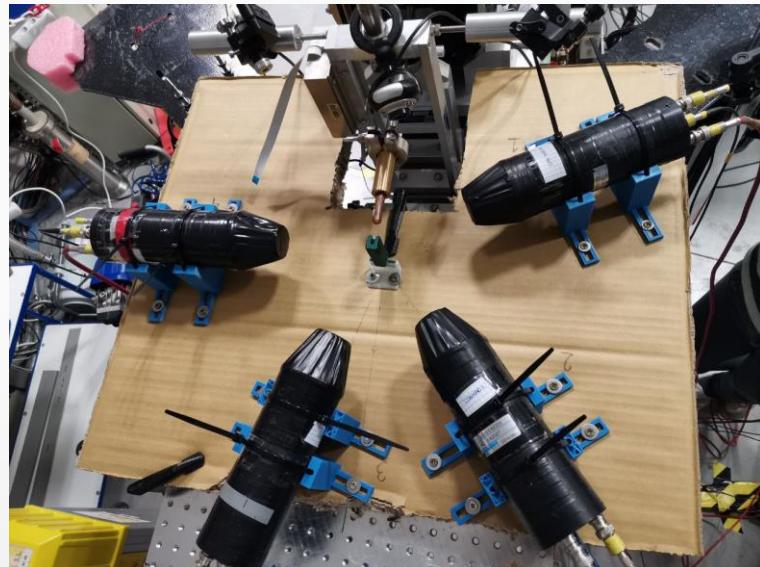


Centre for Micro Analysis of Materials (CMAM)

5MV terminal voltage tandem accelerator
External Microbeam Line
Energy Beams (1-10 MeV)
Beam size less than a 1 mm
Intensity between 0.4 and 7 nA

CMAM <http://cmam.uam.es/>

Set-up PG measurements



DETECTOR SELECTION

4 Conical Truncated
(1" x 1.5" x 1.5")
LaBr₃(Ce)

Fast Scintillator (16 ns
of decay constant)

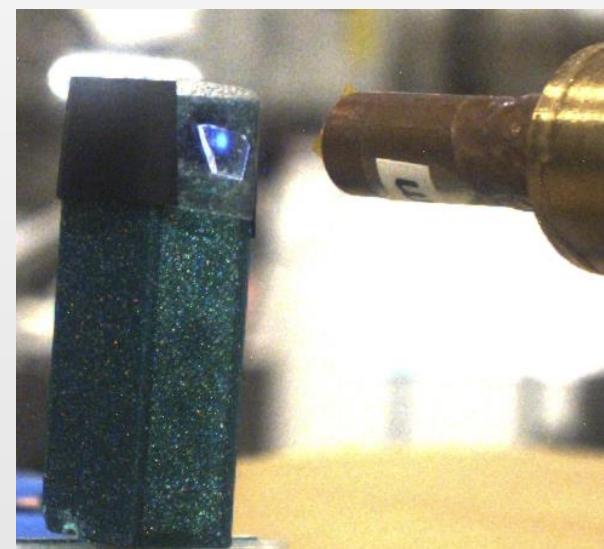
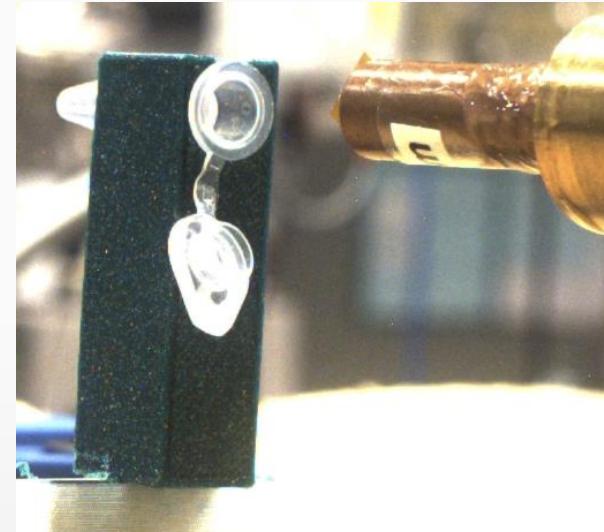
High Photon Yield (63
Photon/keV)

High Density 5,08 g/cm³

TARGET

Sample made by:
70% H₂¹⁸O + 30 % H₂O

Irradiated Energies
2-9 MeV in 0.25 step



Analysis

- Thick target yield approximation for PG and angular distribution

$$Y_\theta(E) = \frac{N}{\epsilon_t \phi t_{irr}}$$

$$W(\theta) = \sum_{l=0}^{l=L} a_l P_l(\cos(\theta)) \quad l = even$$

$$Y_{en,\gamma} = 4\pi a_0$$

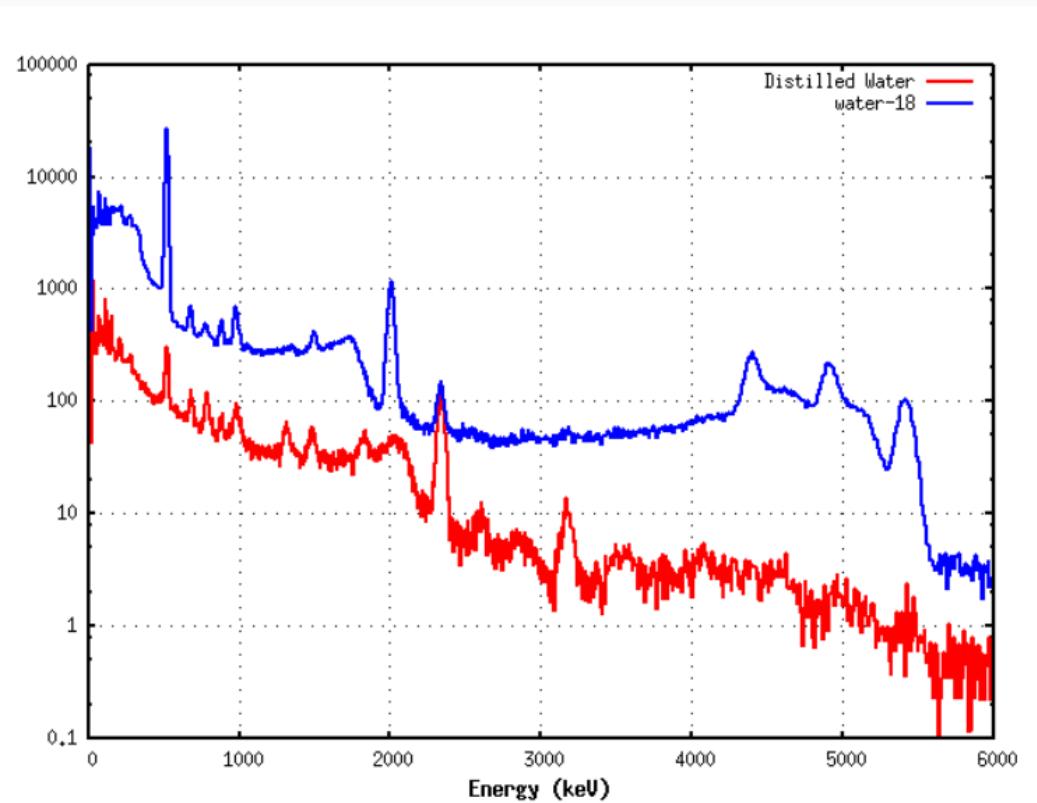
$$\sigma(\bar{E}) = \frac{Y(E_2) + Y(E_1)}{(E_2 - E_1)\rho_{at}} \left(\frac{d\bar{E}}{dx} \right)$$

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RESULTS

Identifying peaks

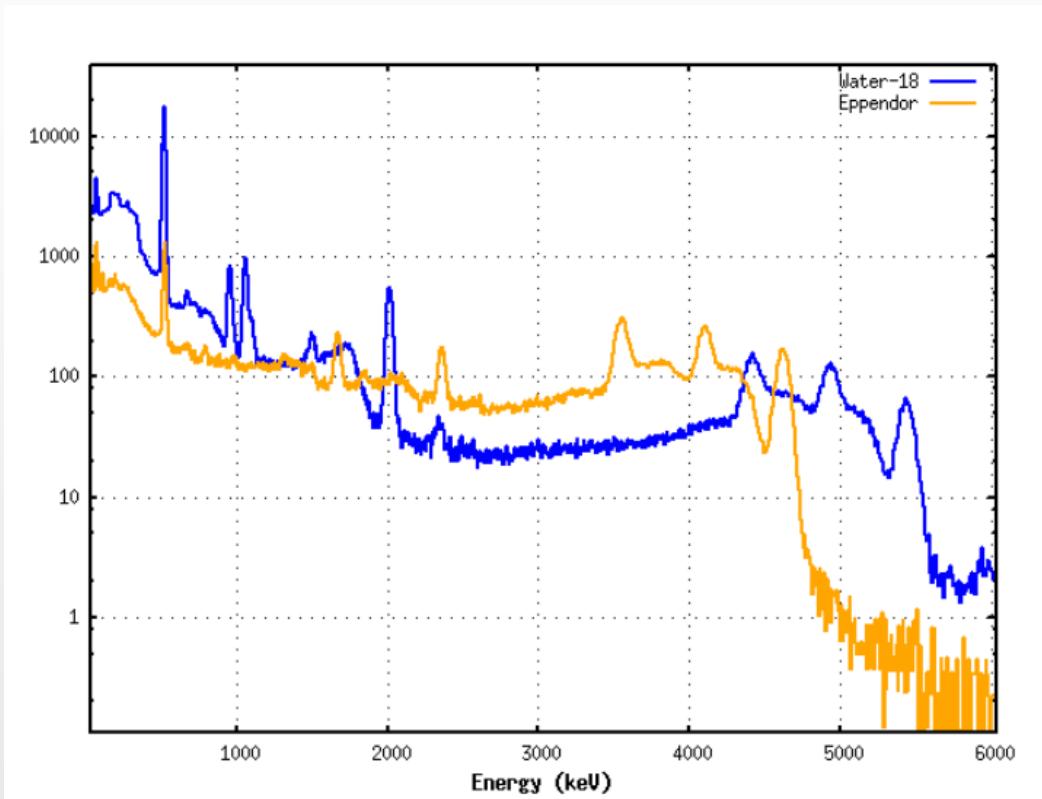
4 MeV Proton beam



Energy (keV)	Target	Reaction	<i>Q</i> -value
184	^{18}O	(p,n) $^{18}\text{F}^*$	-3559.6
940	^{18}O	(p,n) $^{18}\text{F}^*$	-3378.3
1041	^{18}O	(p,n) $^{18}\text{F}^*$	-3479.3
1081	^{18}O	(p,n) $^{18}\text{F}^*$	-3529.3
1635	^{14}N	(p,p') $^{14}\text{N}^*$	-3948.1
1982	^{18}O	(p,p') $^{18}\text{O}^*$	-1982.9
2312	^{14}N	(p,p') $^{14}\text{N}^*$	-2312.8
4439	^{12}C	(p,p') $^{12}\text{C}^*$	-4439.8
5270	^{18}O	(p, α) ^{15}N	-1291.2
5298	^{18}O	(p, α) ^{15}N	-1219.4
6128	^{16}O	(p,p') ^{16}O	-6129.3
6323	^{18}O	(p, α) ^{15}N	-1219.4

Identifying peaks

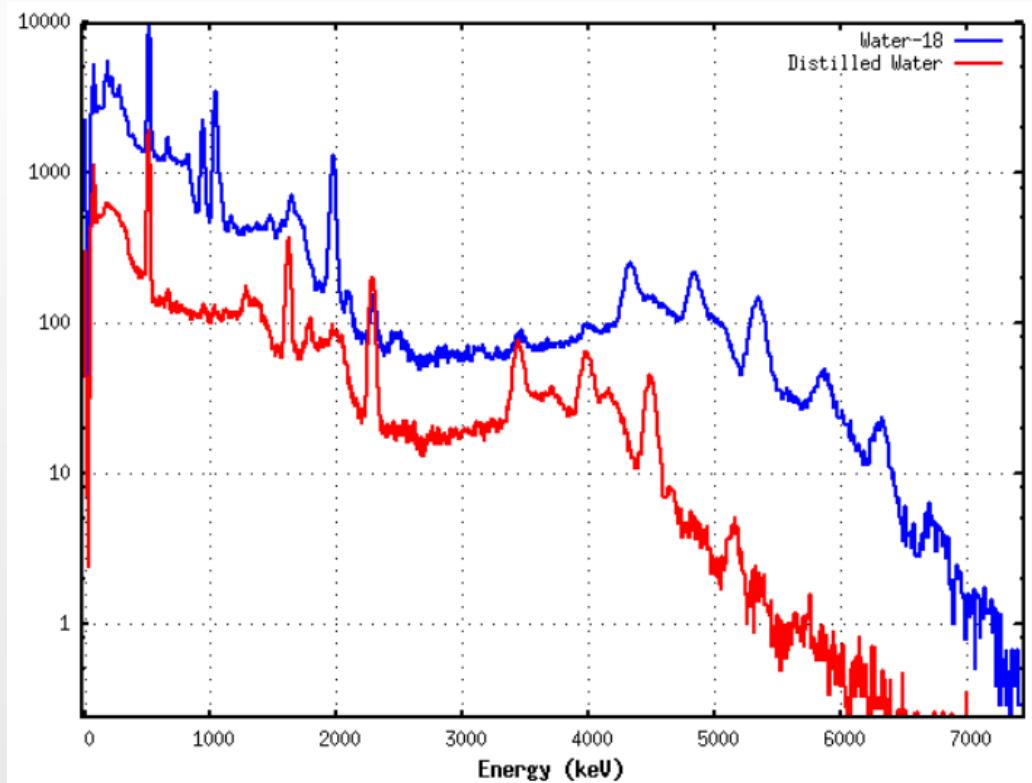
5 MeV Proton beam



Energy (keV)	Target	Reaction	<i>Q</i> -value
184	^{18}O	(p,n) $^{18}\text{F}^*$	-3559.6
940	^{18}O	(p,n) $^{18}\text{F}^*$	-3378.3
1041	^{18}O	(p,n) $^{18}\text{F}^*$	-3479.3
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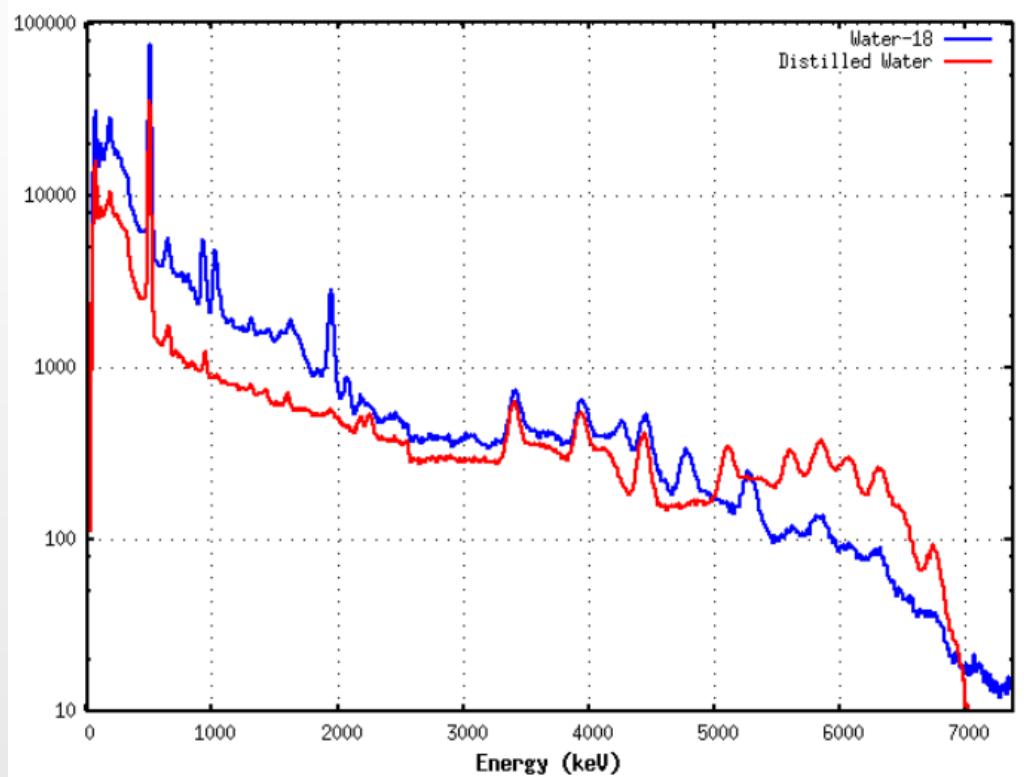
7 MeV Proton beam



Energy (keV)	Target	Reaction	<i>Q</i> -value
184	^{18}O	(p,n) $^{18}\text{F}^*$	-3559.6
940	^{18}O	(p,n) $^{18}\text{F}^*$	-3378.3
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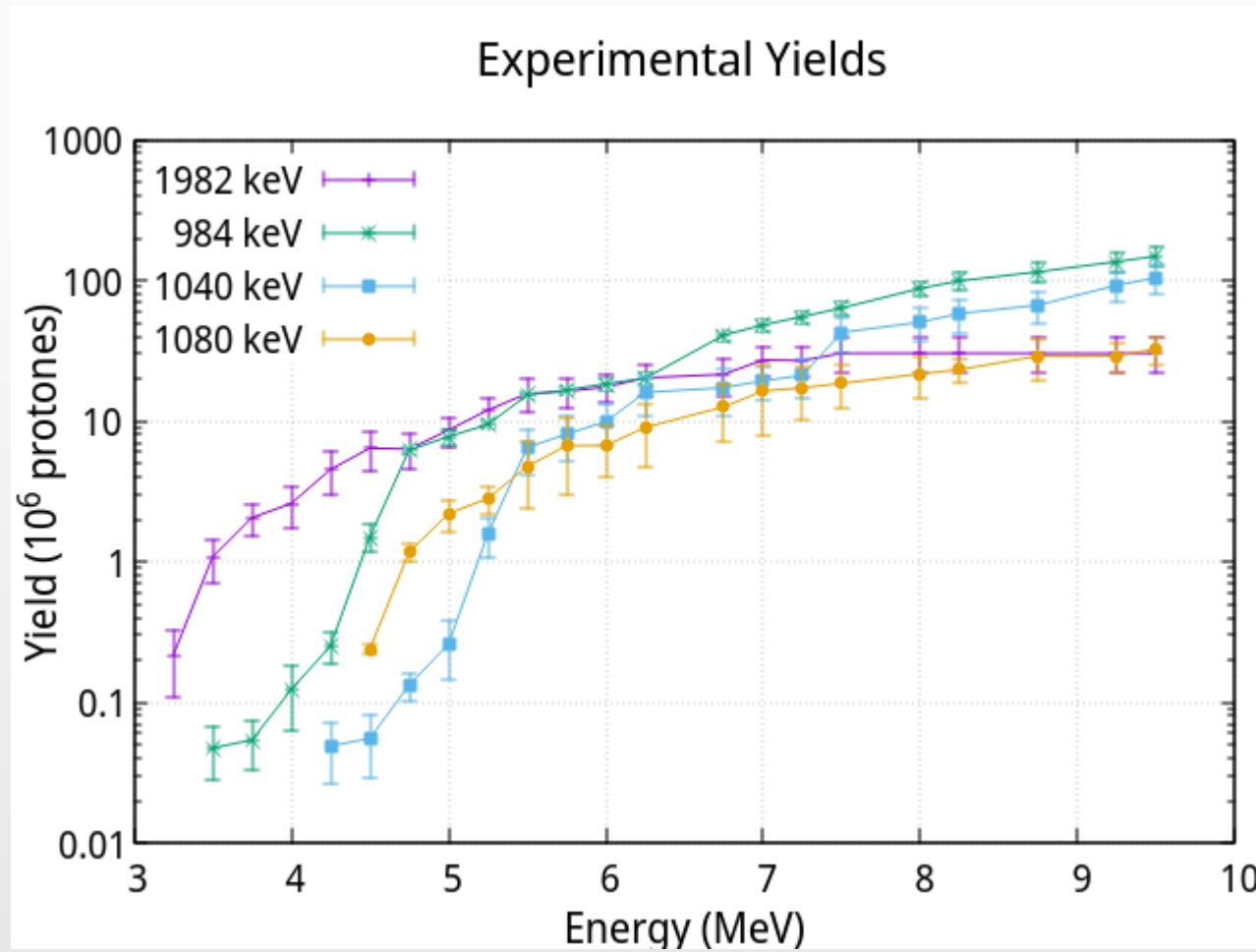
Identifying peaks

10 MeV Proton beam

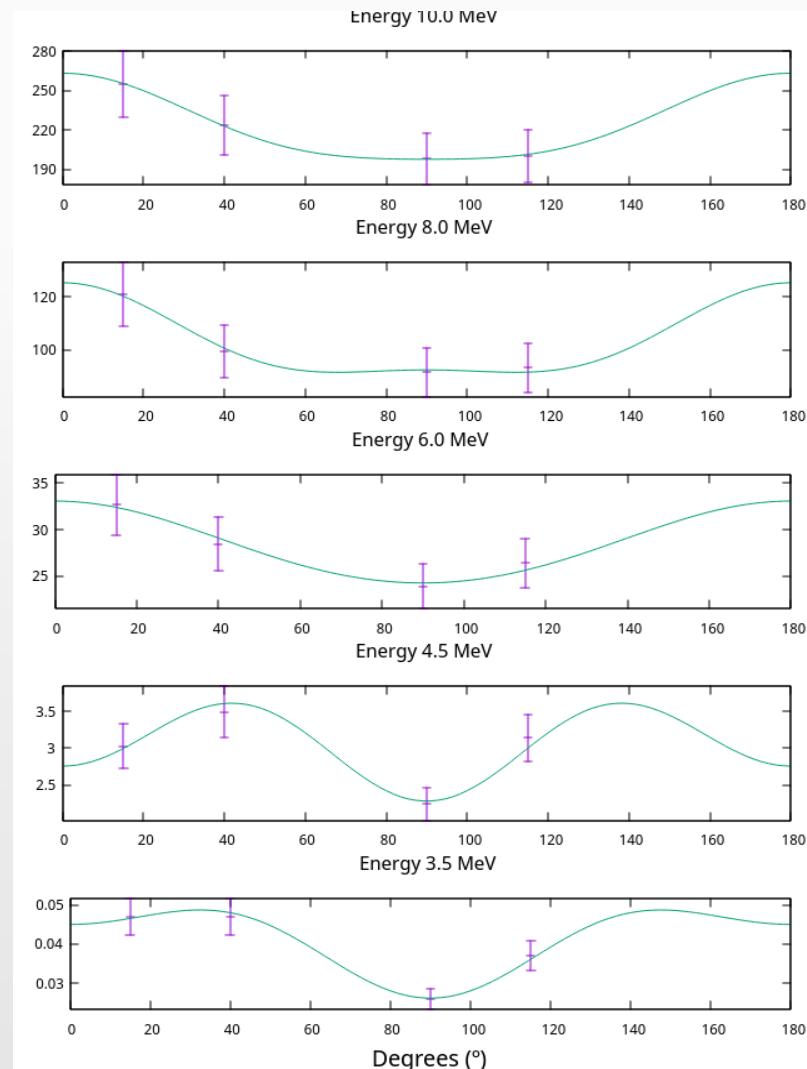


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Yields and angular distribution

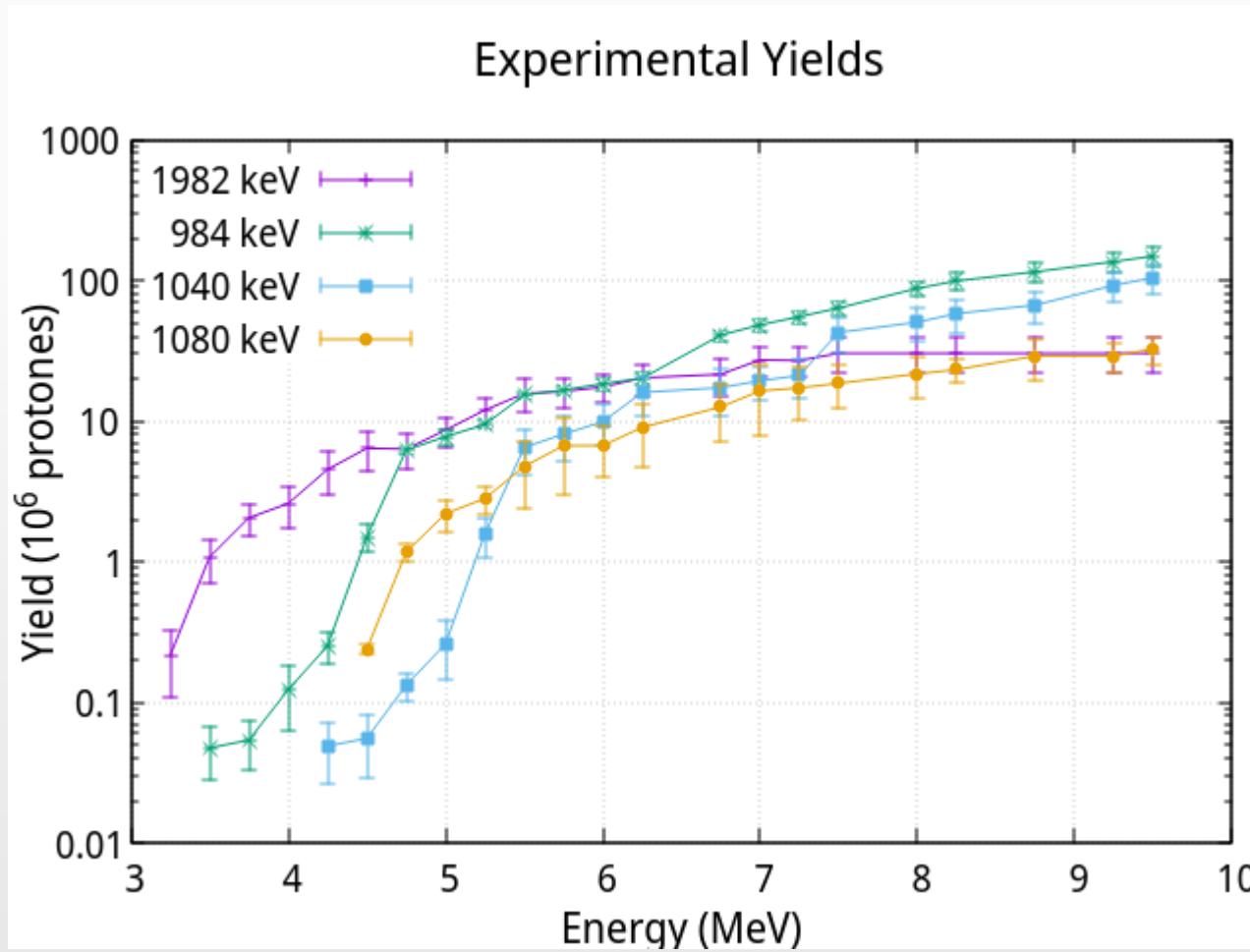


1982 (E2) Angular Distribution

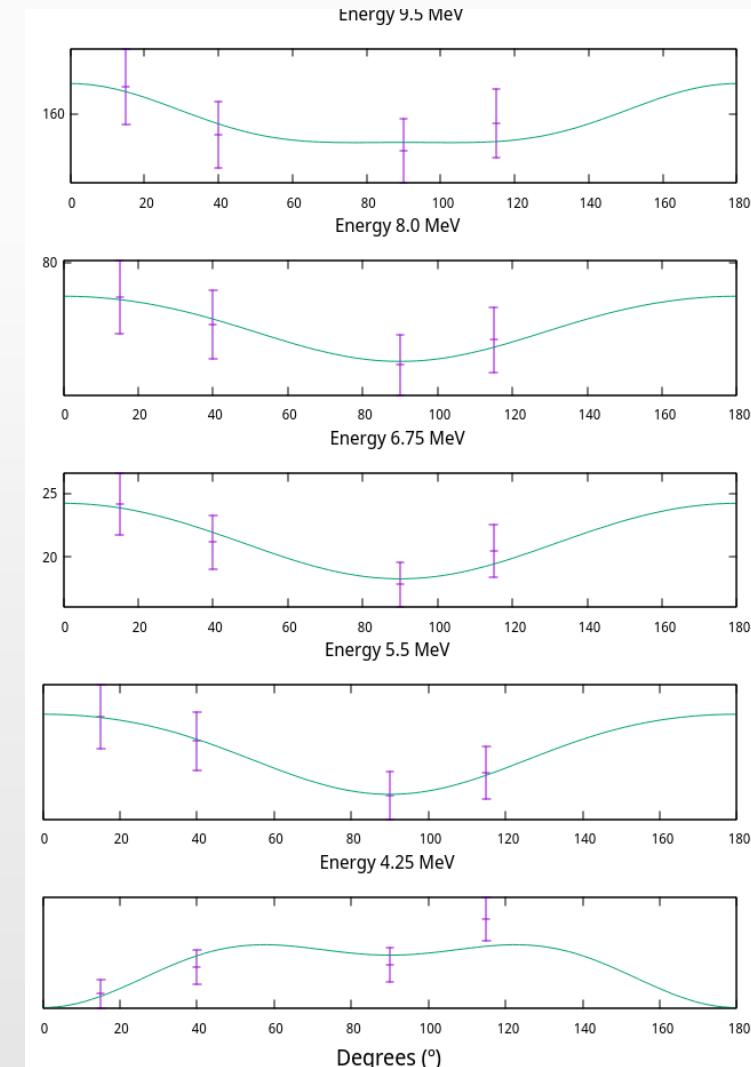


E2

Yields and angular distribution

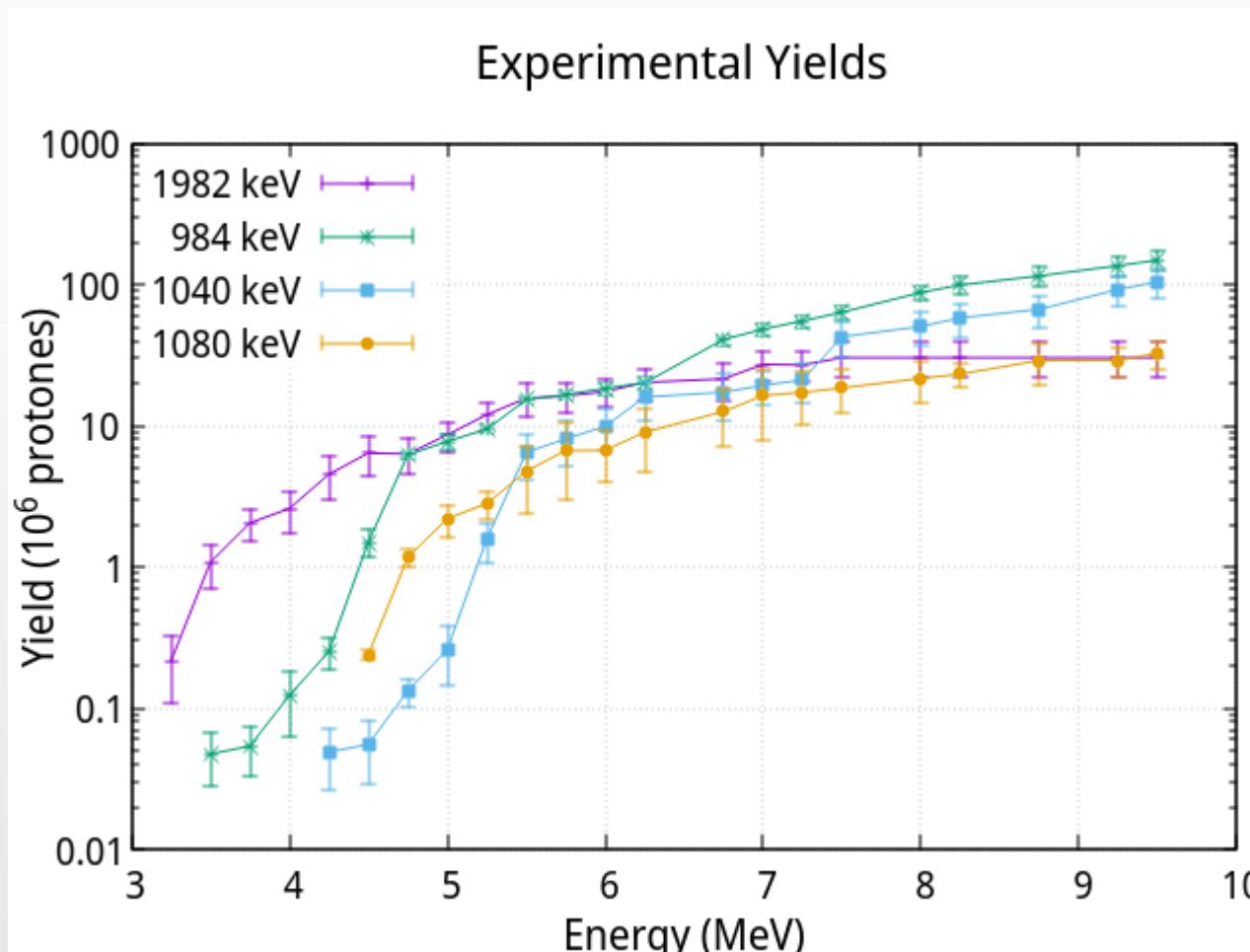


940 (E2) Angular Distribution

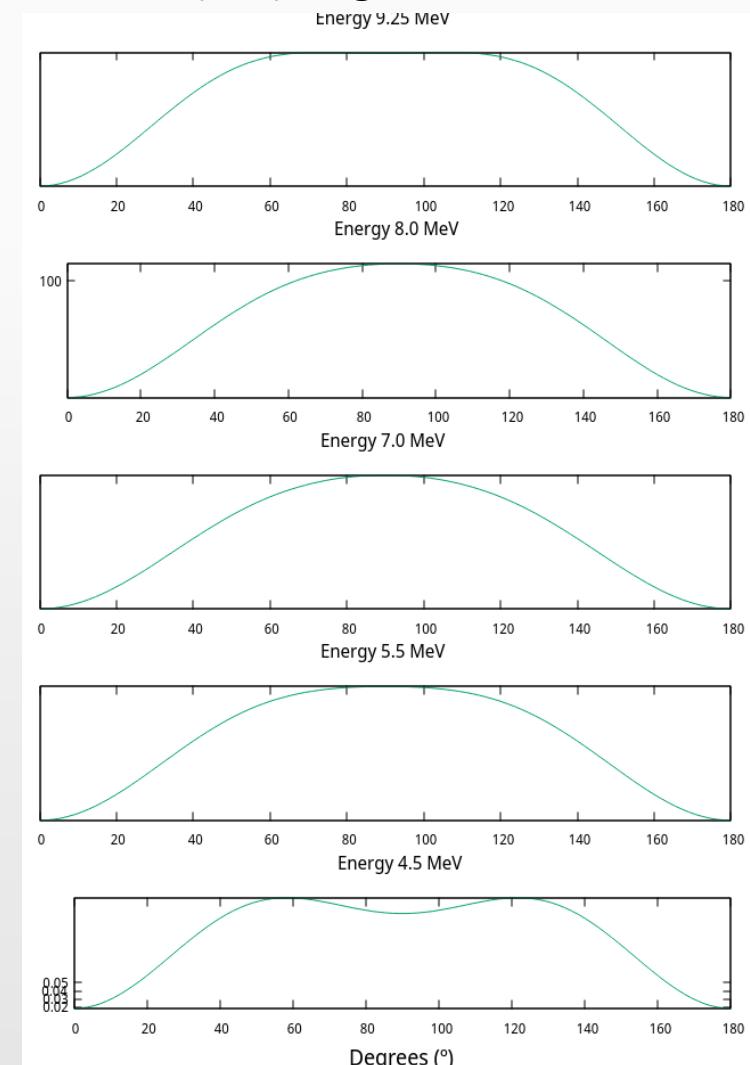


E2

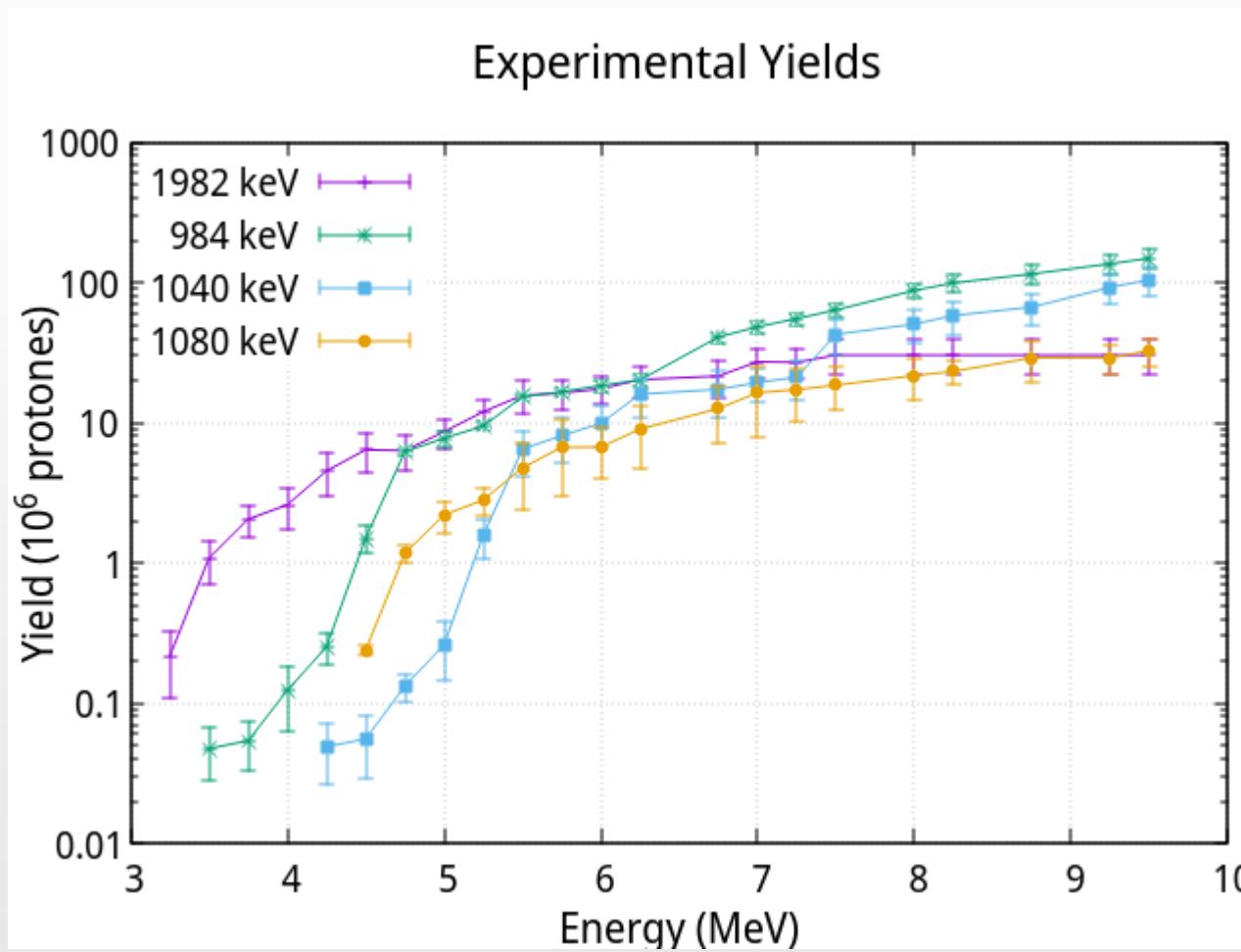
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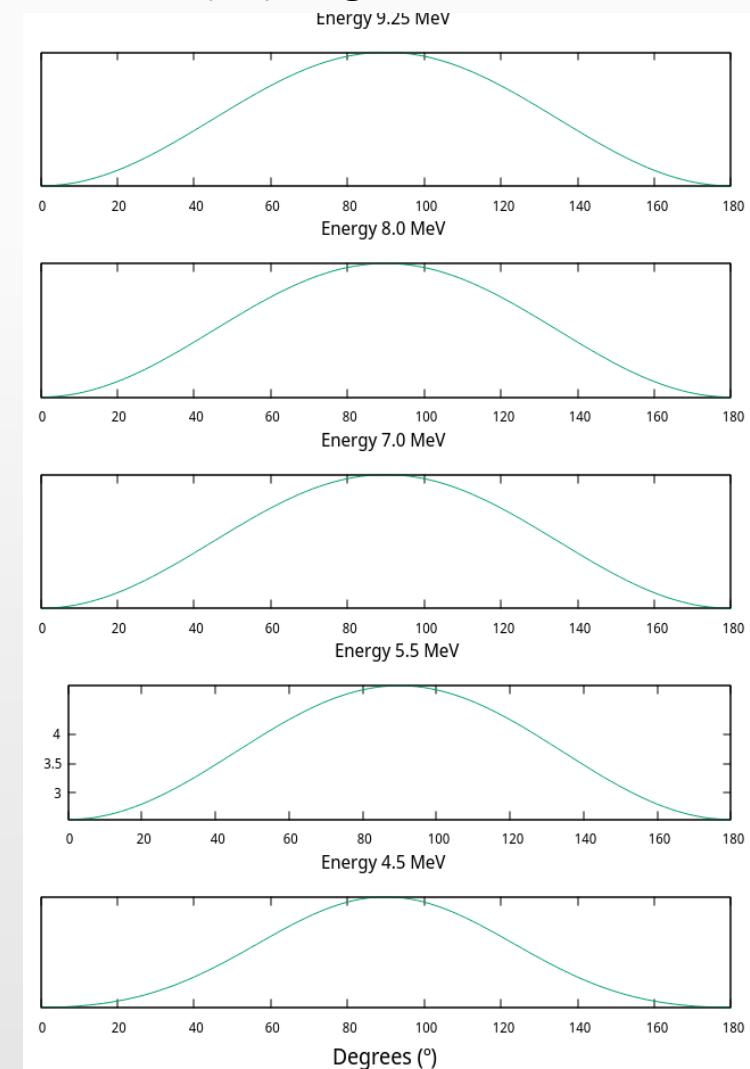
1040 (M1) Angular Distribution



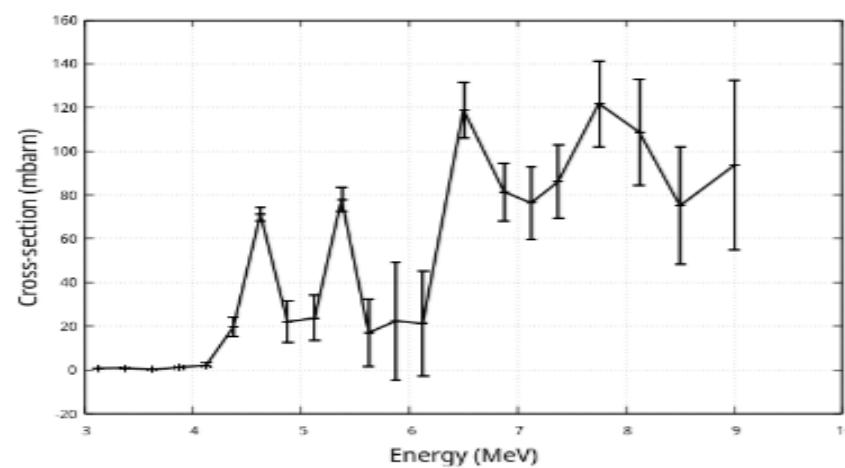
Yields and angular distribution



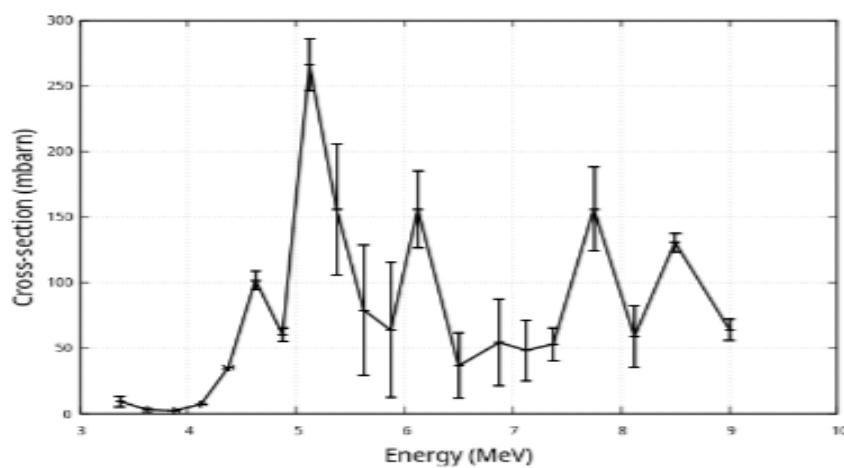
1080 (E1) Angular Distribution



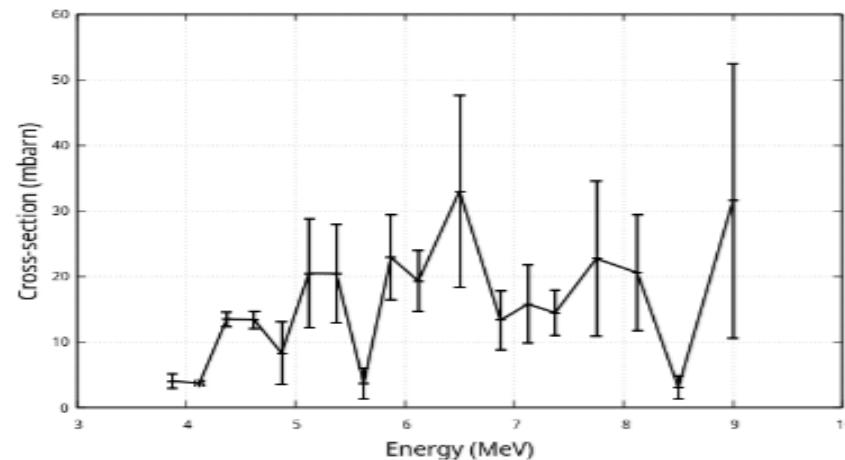
Cross Sections



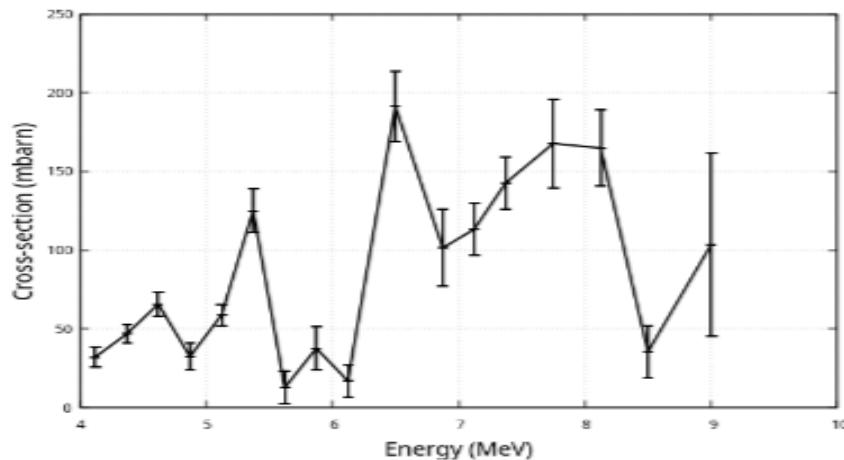
(a) 940 keV



(b) 1040 keV



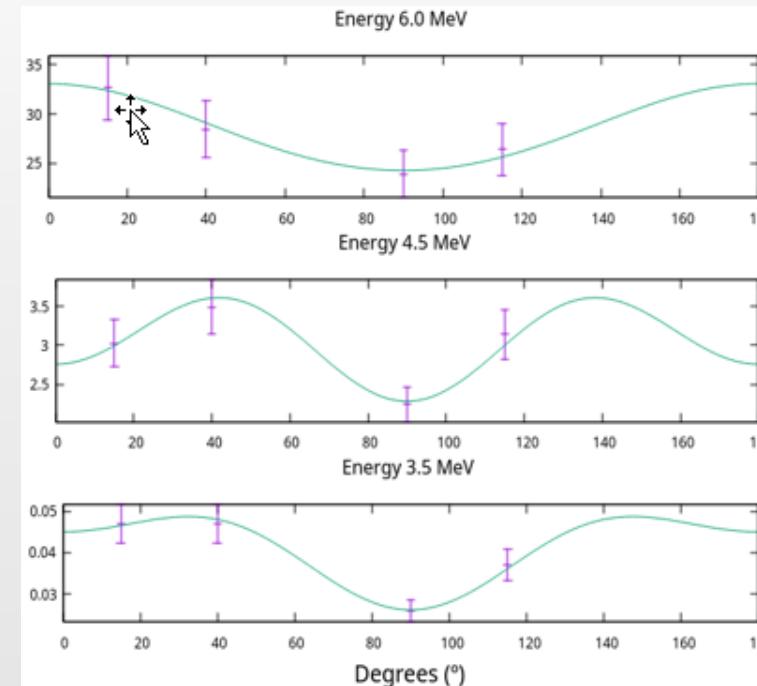
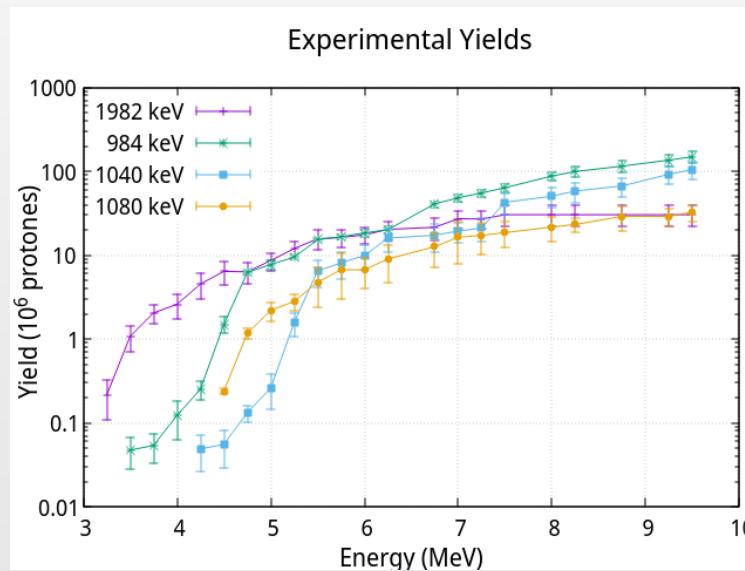
(c) 1080 keV



(d) 1982 keV

Conclusions

- Contrast agents in proton therapy could help to solve some of the main drawbacks of the proton range and dose verification techniques. In PG verification would improve the detector efficiency because of the production of lower energy gamma than the natural ones.
- Cross section measurements of PG emision in the irradiation of ^{18}O with protons.
- Angular distributions of the studied PGs were achievable thanks to the set-up specifically developed for this purpose.



Thank you for your attention



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"Una manera de hacer Europa"

