Study of Prompt Gamma emission $^{12}C(p,p'\gamma)^{12}C$ nuclear reactions close to a Bragg Peak

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RDP workshop **ASPECT OF SYMMETRY**, 7 November, 2021

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Achim Stahl

Outline

- Description of Technique of proton therapy monitoring - Prompt Gamma Imaging (PGI)
- Experimental results
  - Prompt Gamma correlation with Bragg Peak
  - Prompt Gamma Spectra (4.4 MeV line)
- How Prompt Gamma emission is implemented in Geant4 simulation
  - The spectrum
  - Angular distribution
  - Kinematic effects
  - conclusion
- Fitting of experimental results
- Outlook of the research

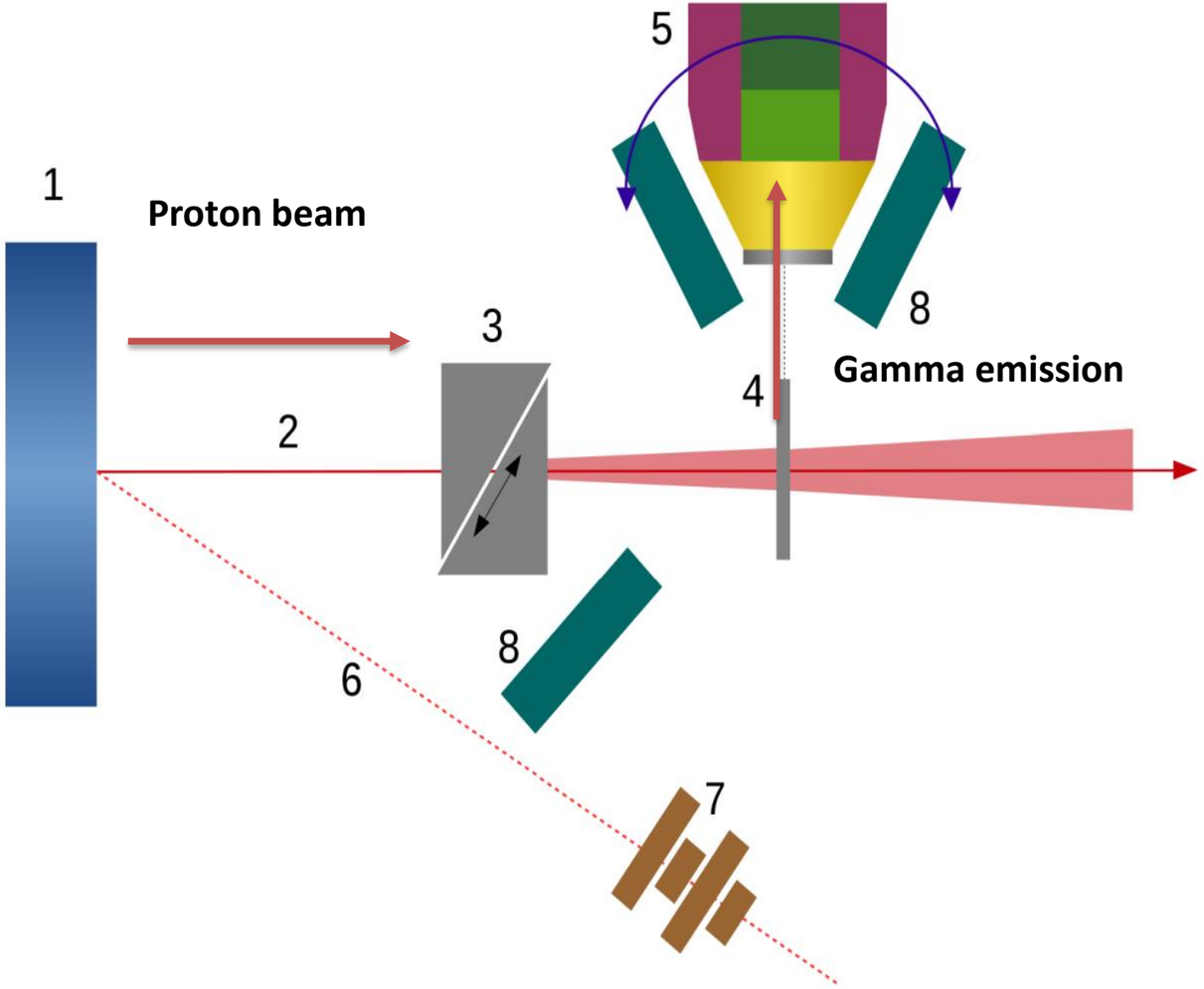
Motivation

- PGI has an advantage over PET monitoring

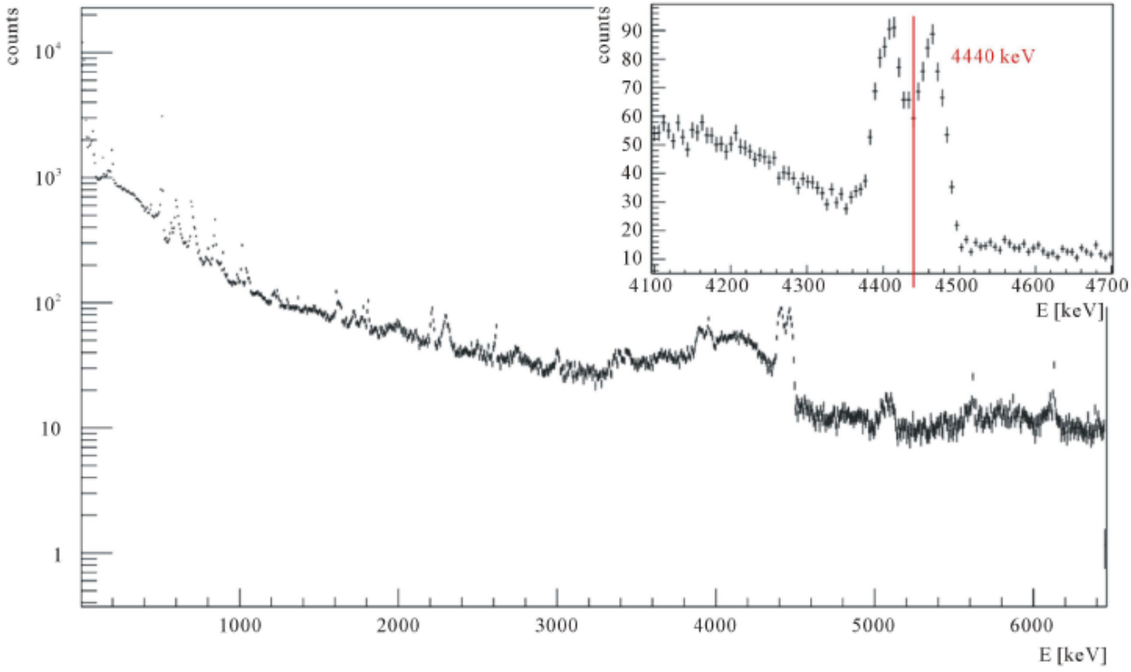
- The study of properties of properties of each peak in a PG spectra is important for PGI imaging development
  - Shape and angular distribution of 4.4 MeV peak depends on the phase space of incoming proton beam (*Experiment at (HIT), 2015*)
  - The intensity of each peak correlates with Bragg Peak position (*Experiment at (HIT), 2015*)
  - The study of these properties might be important for detector positioning

- Hadron Therapy Center at Kutaisi international University

Description of Technique of proton therapy monitoring - Prompt Gamma Imaging (PGI)

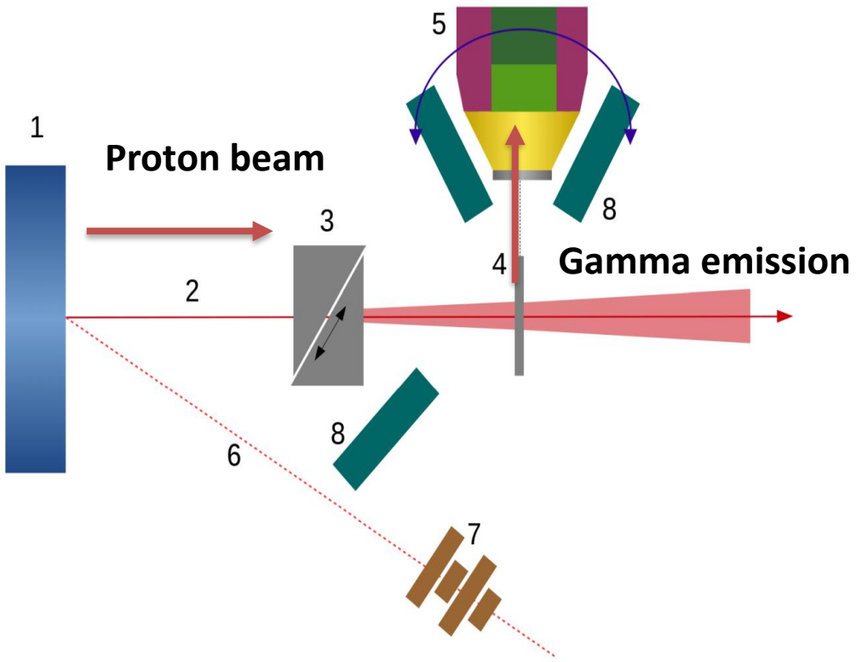


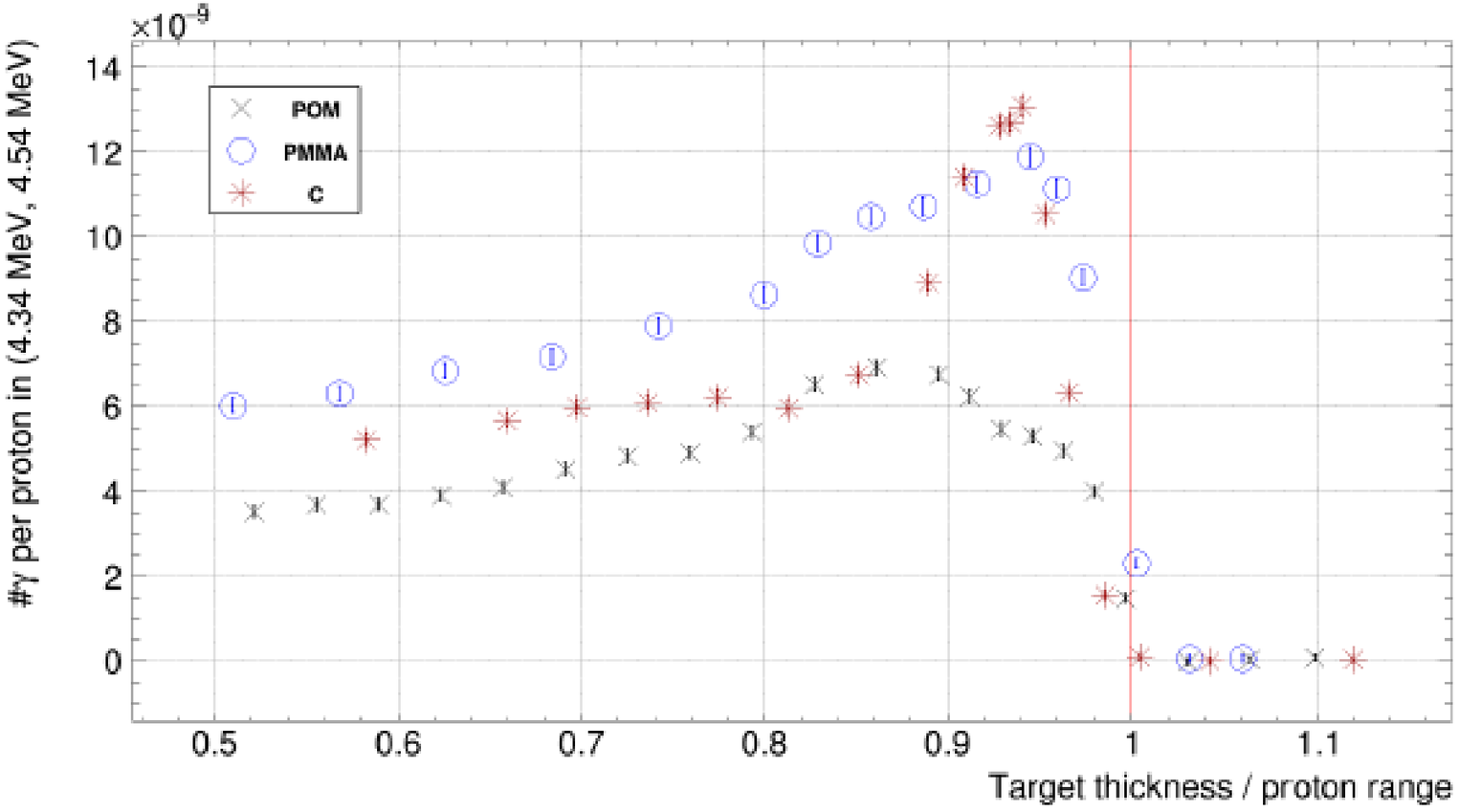
gamma spectrum



Typical gamma spectrum registered from the thin target in described experiment. Average energy of protons inside the thin target was 16.13 MeV.

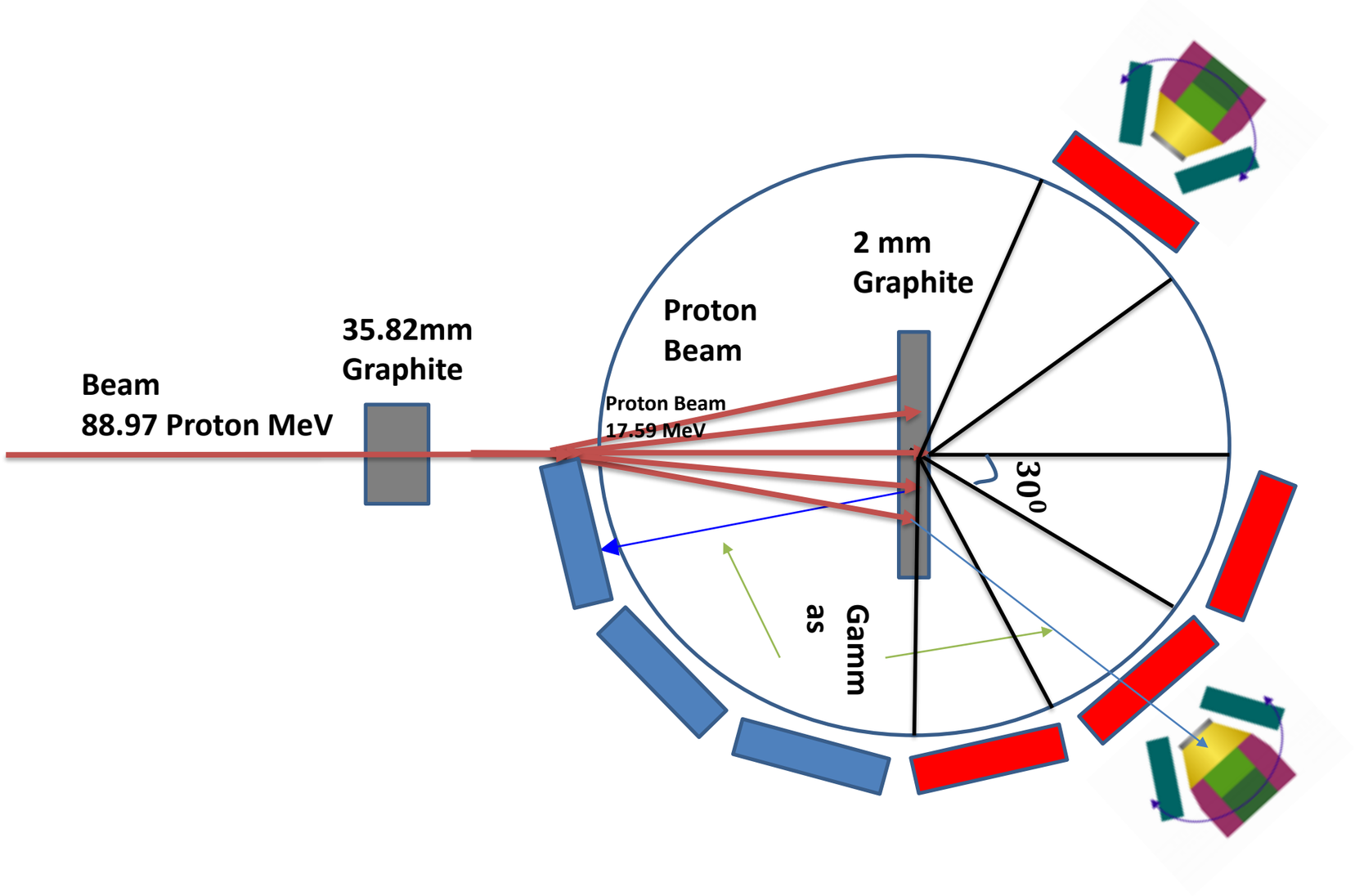
Prompt Gamma correlation with Bragg Peak





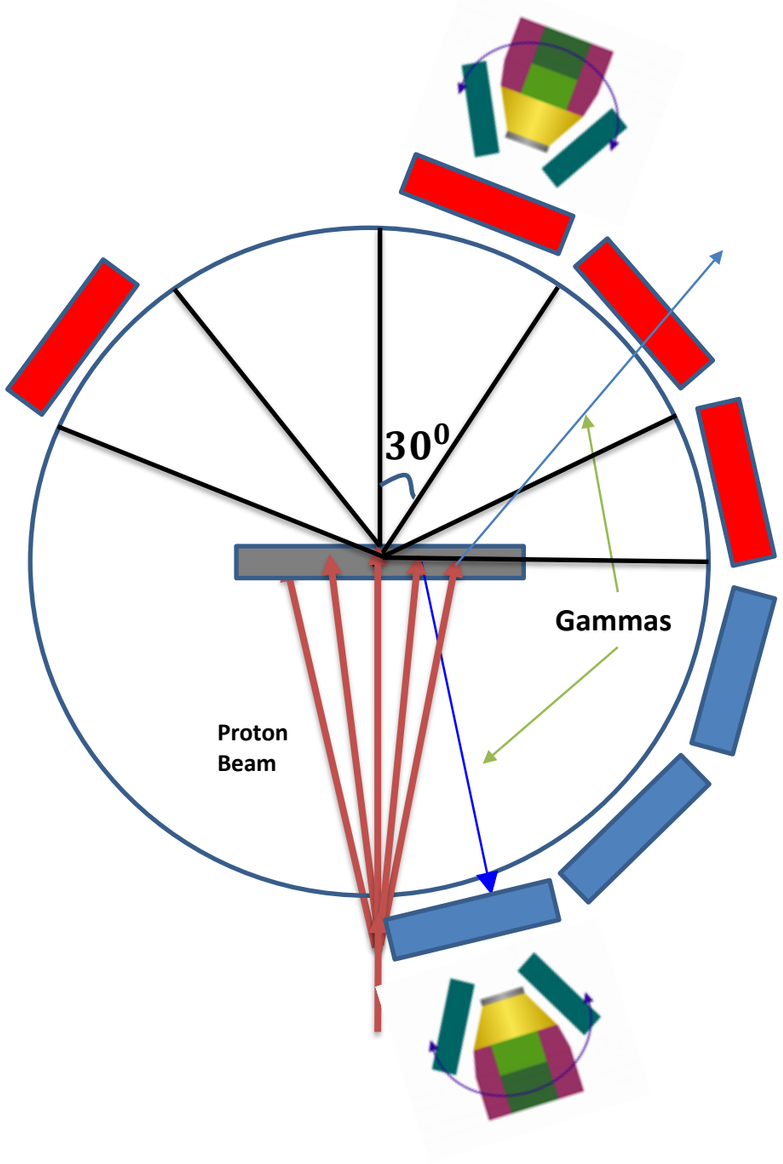
Gamma yield of PMMA, POM and graphite for the 4,4 MeV-peak at 70MeV beam energy and 90 observation angle. Heidelberger Ionenstrahl-Therapiezentrum . Experiment at (HIT), 2015

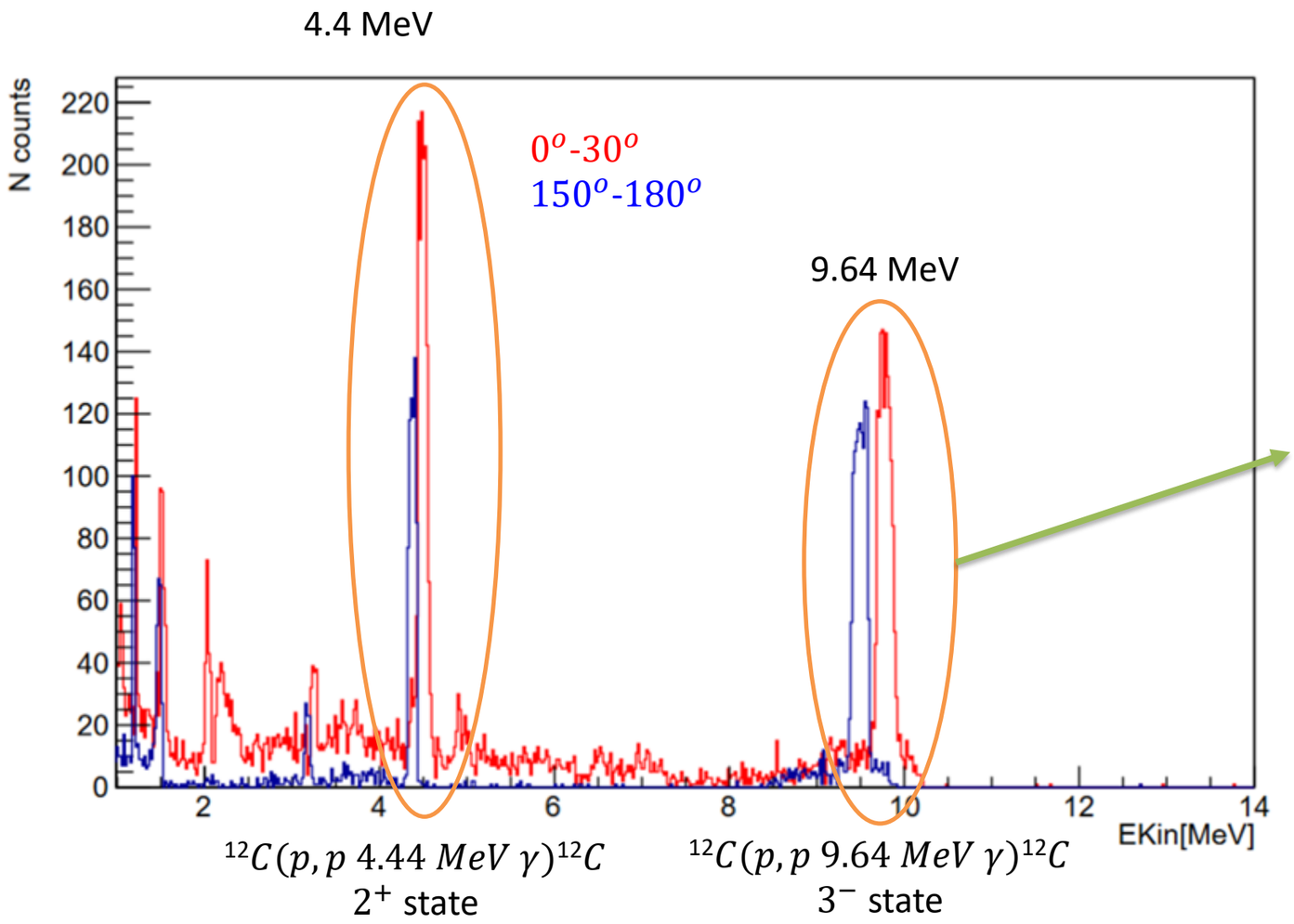
How Prompt Gamma simulations with Geant4 - description of Geometry



Physical model: QGSP_BIC

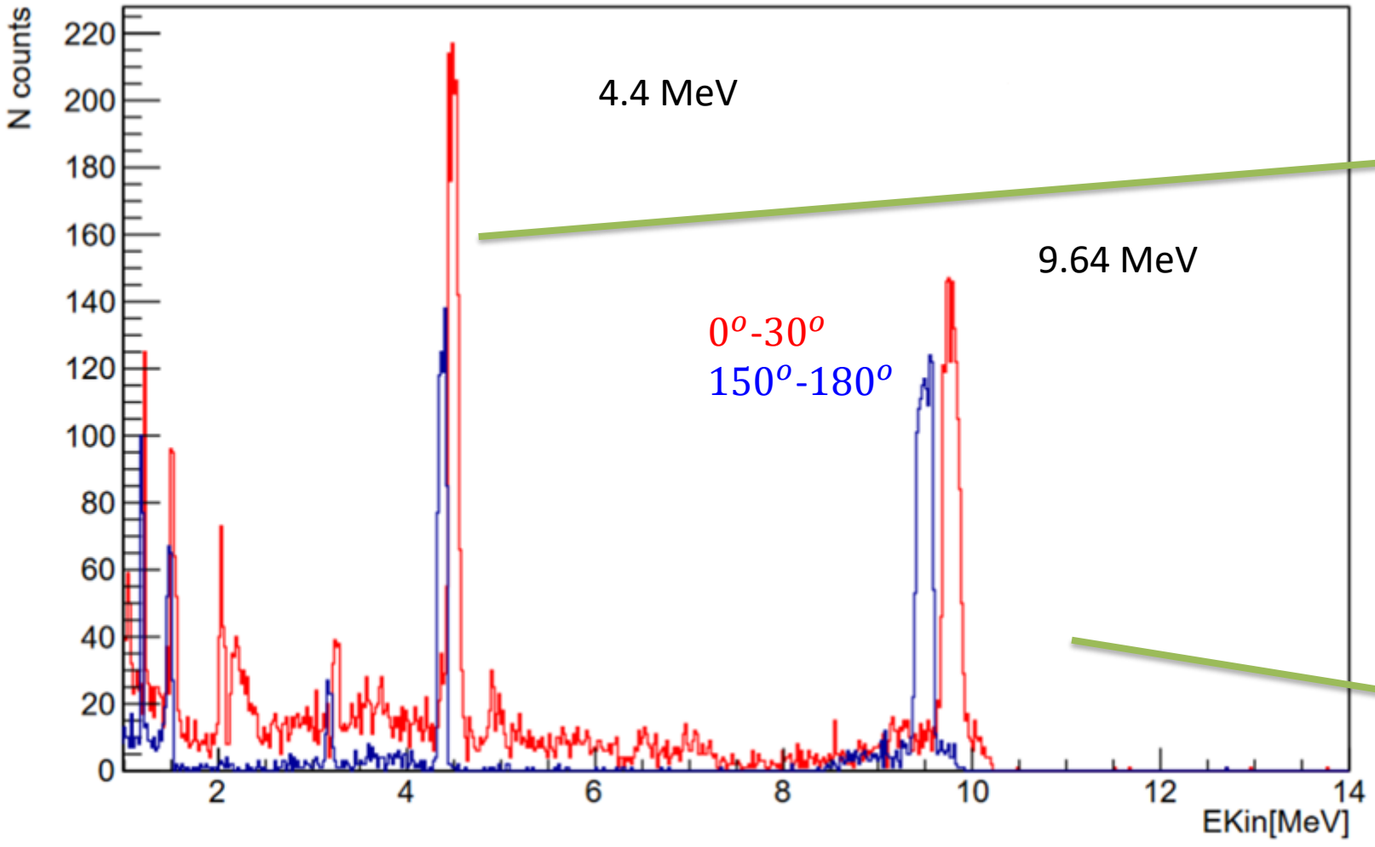
How Prompt Gamma emission is implemented in Monte-Carlo simulation

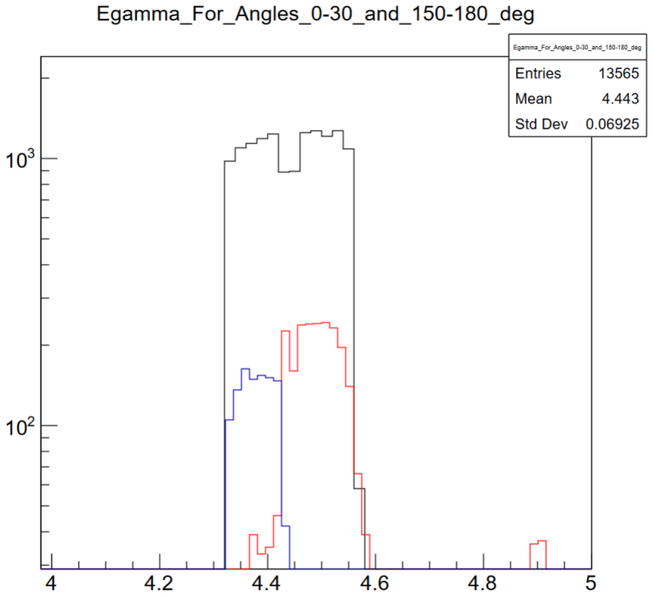


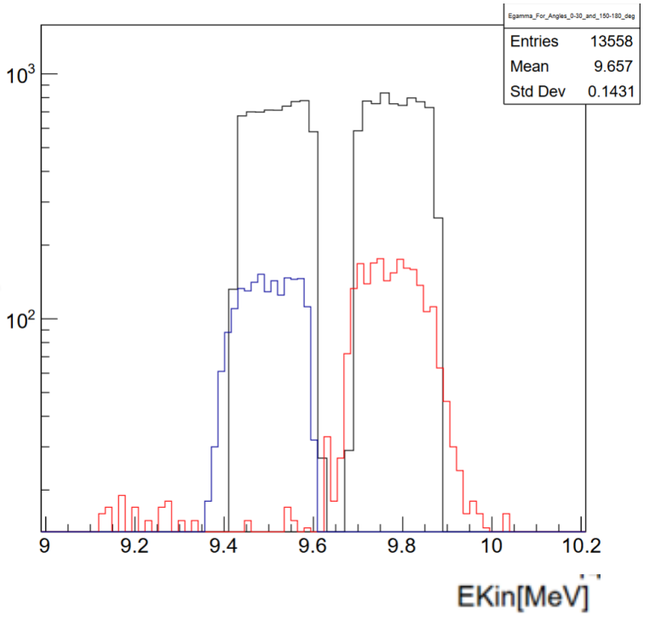


The energy difference in peaks detected with different angles is due to kinematic effects.

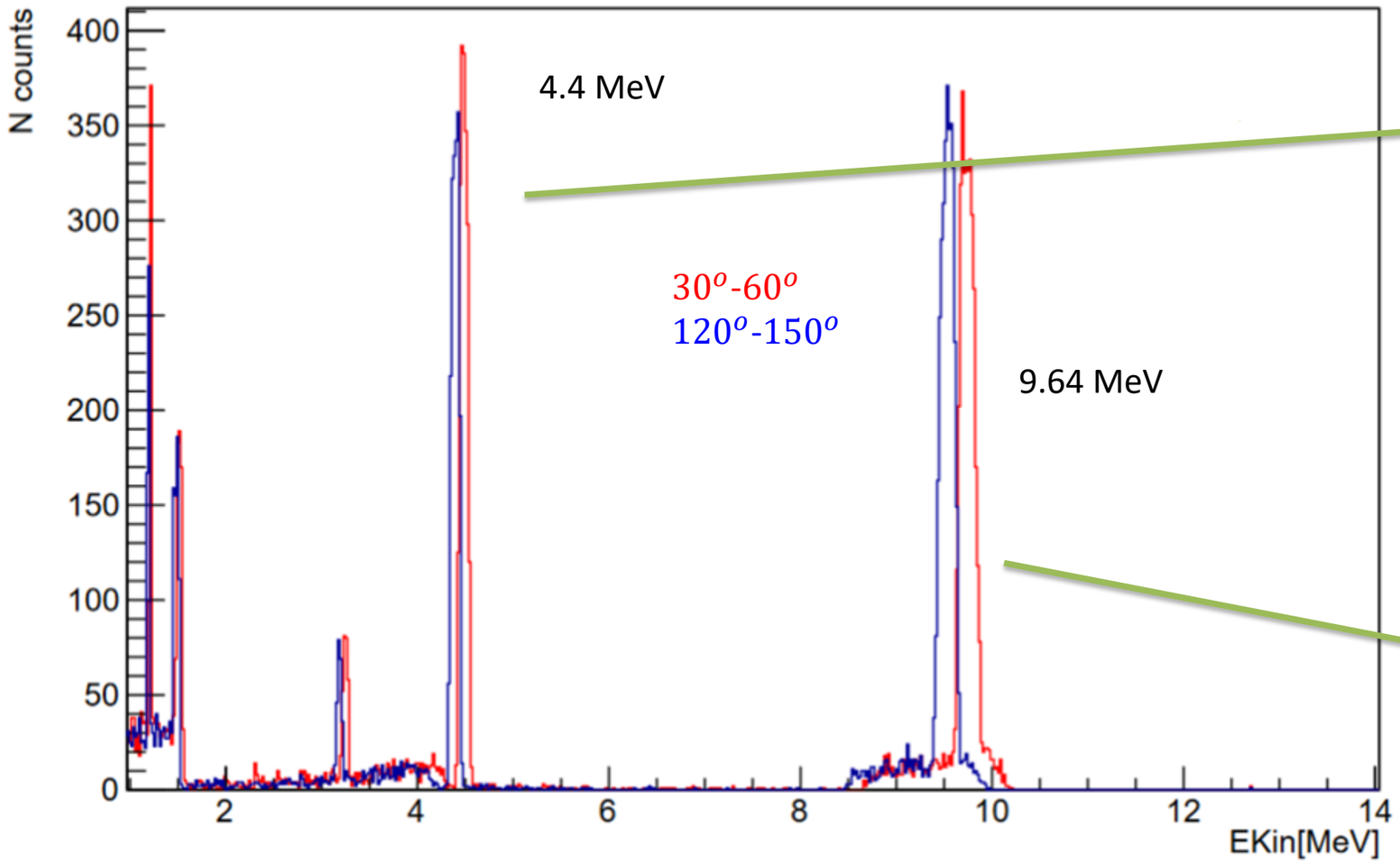
Comparison the results from Geant4 and toy Monte-Carlo simulations

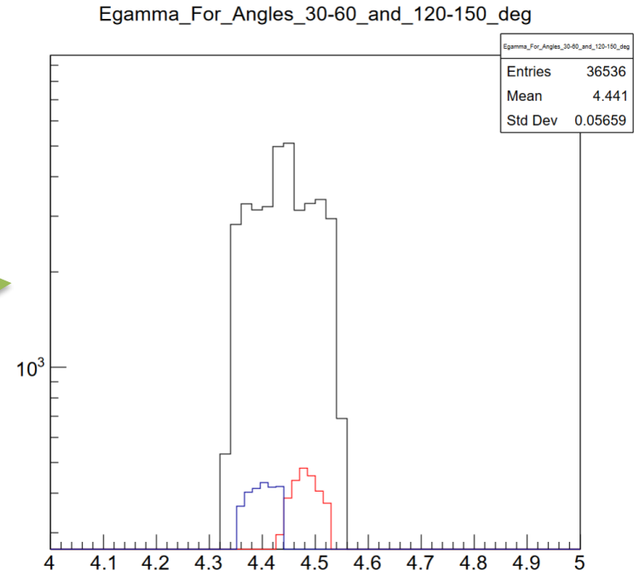


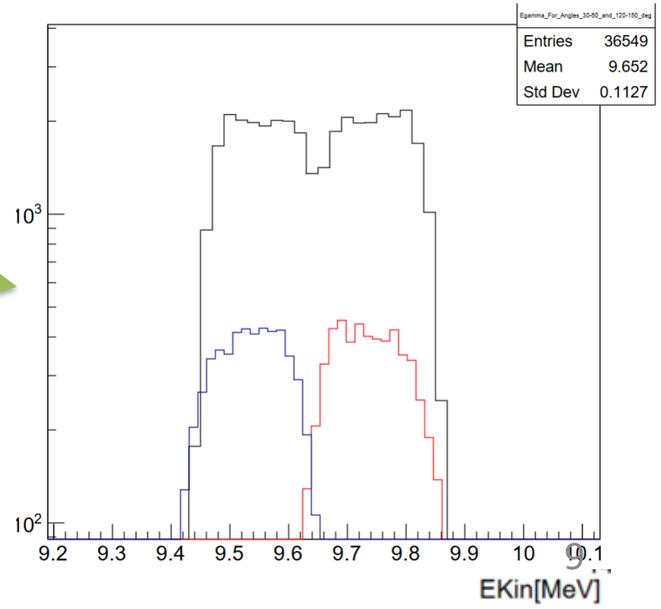




Comparison the results from simulations and toy Monte-Carlo







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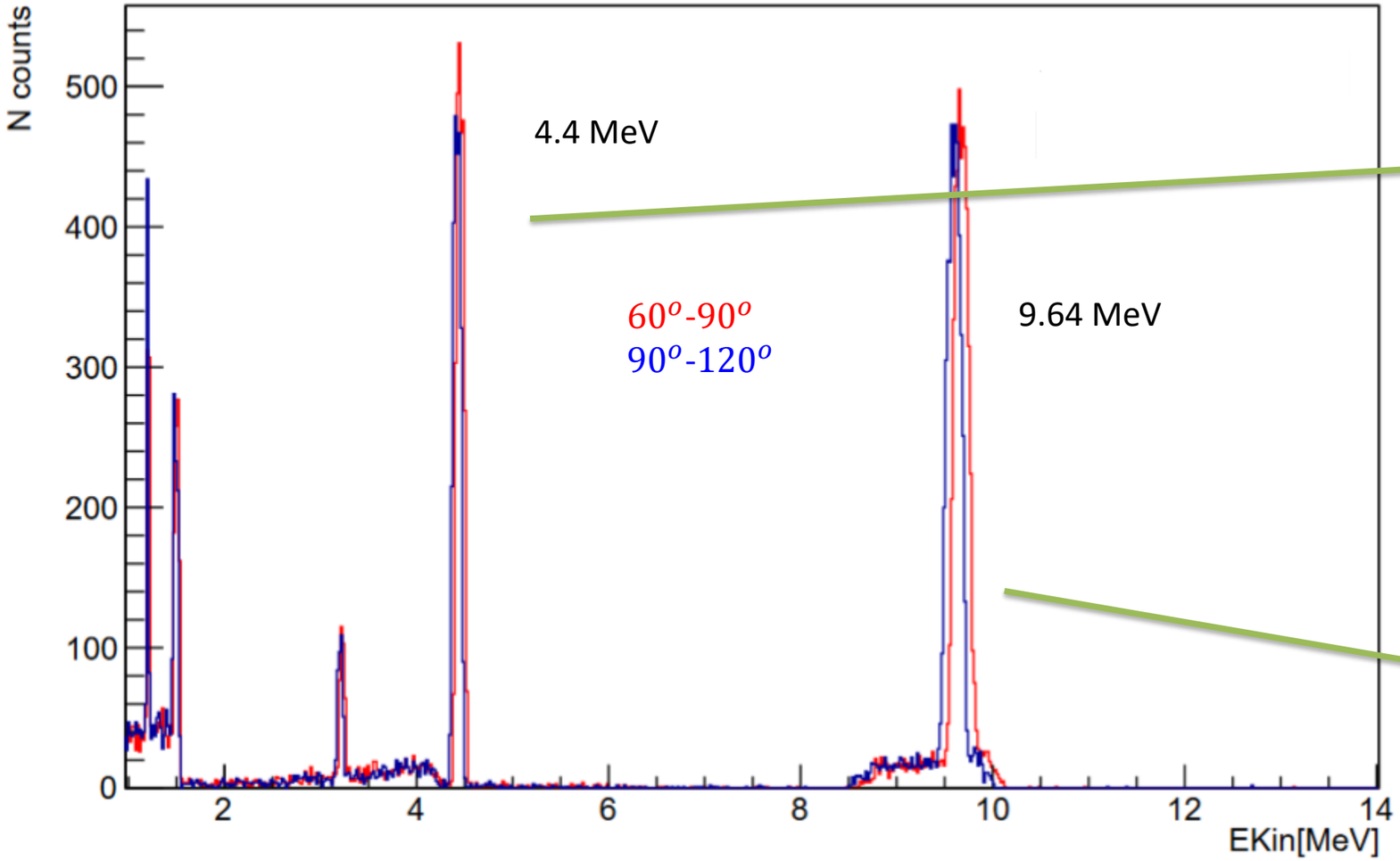
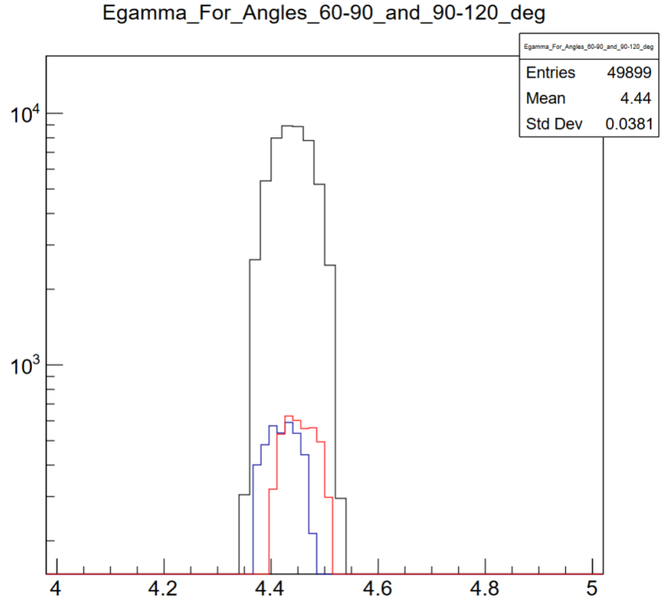
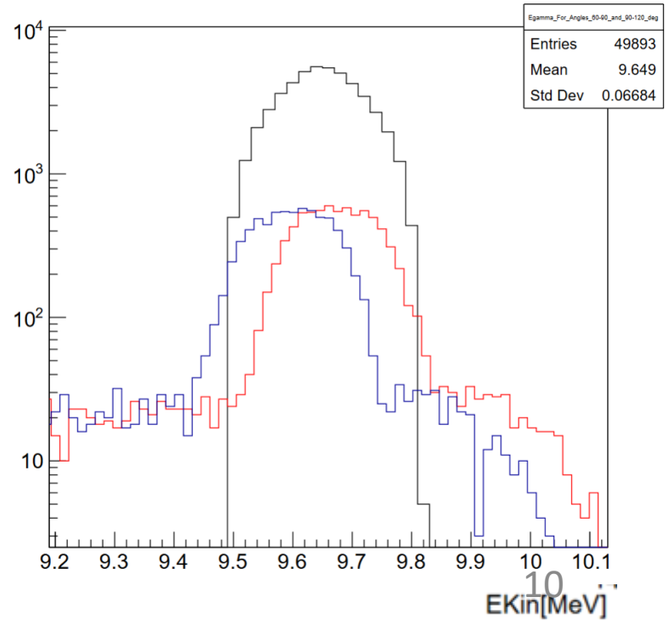
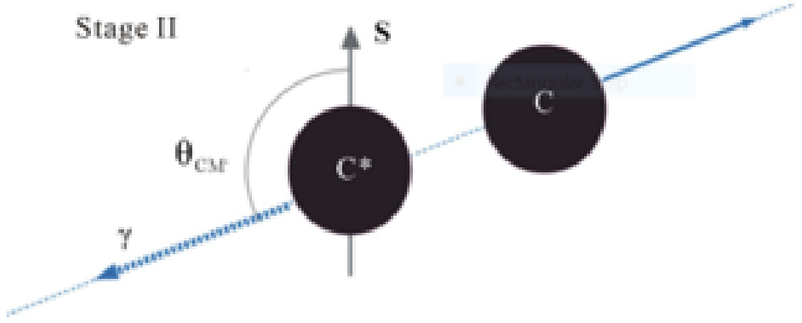






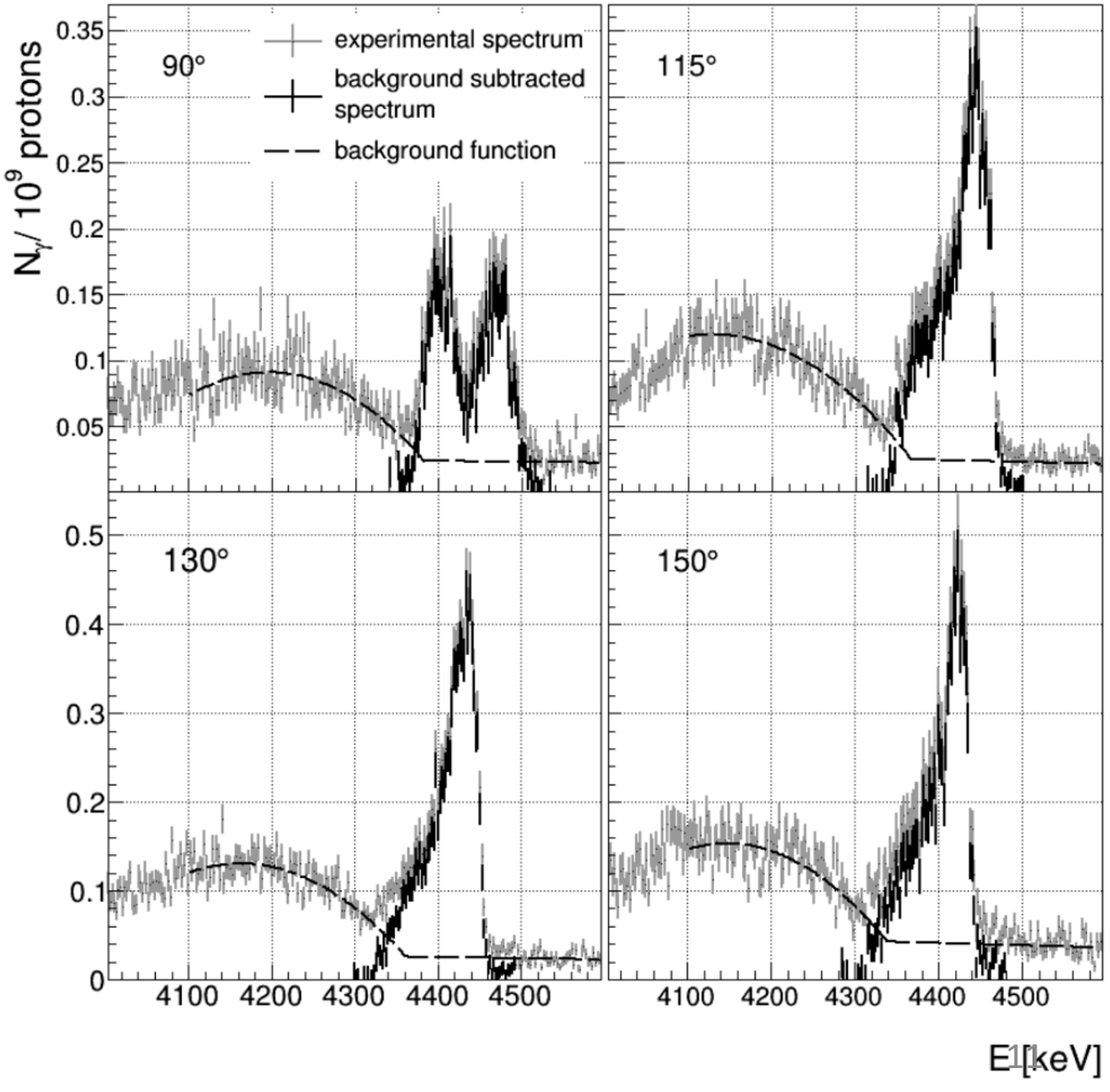
Fitting of experimental results



The angular distribution of this process in the rest frame of the excited carbon nucleus is given by and a_m parameters were fitted

$$W_2\left(\theta_\gamma^{\mathrm{CM}}\right) = \sum_{m=-2}^{m=2} a_m F_2^m\left(\theta_\gamma^{\mathrm{CM}}\right)$$

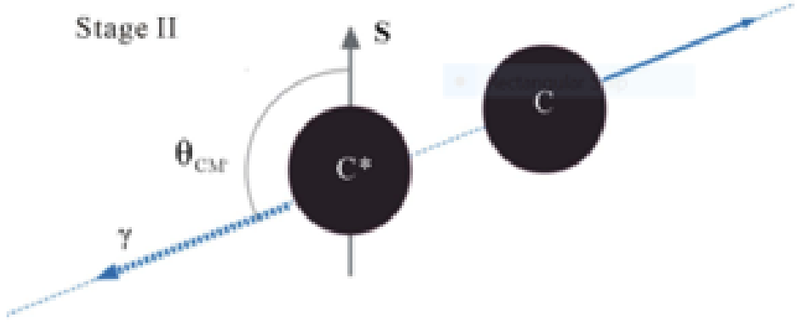
Where only first three polynomials are considered and there probabilities obey the equation a_0+a_1+a_2 = 1



SHAPE OF THE SPECTRAL LINE AND GAMMA ANGULAR DISTRIBUTION OF THE 12C(p; p04:44)12C REACTION

Katarzyna Rusiecka

Fitting of experimental results



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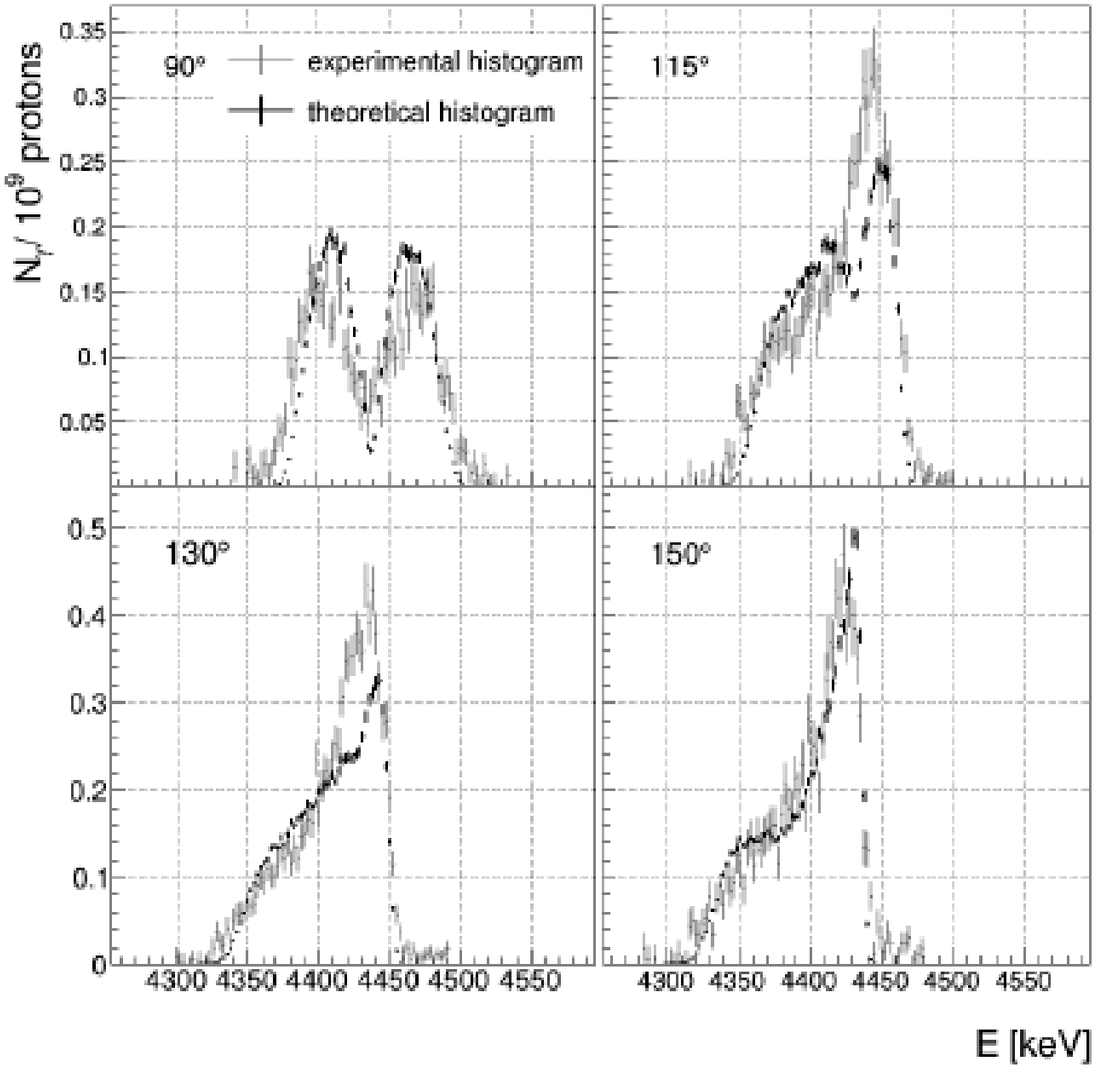
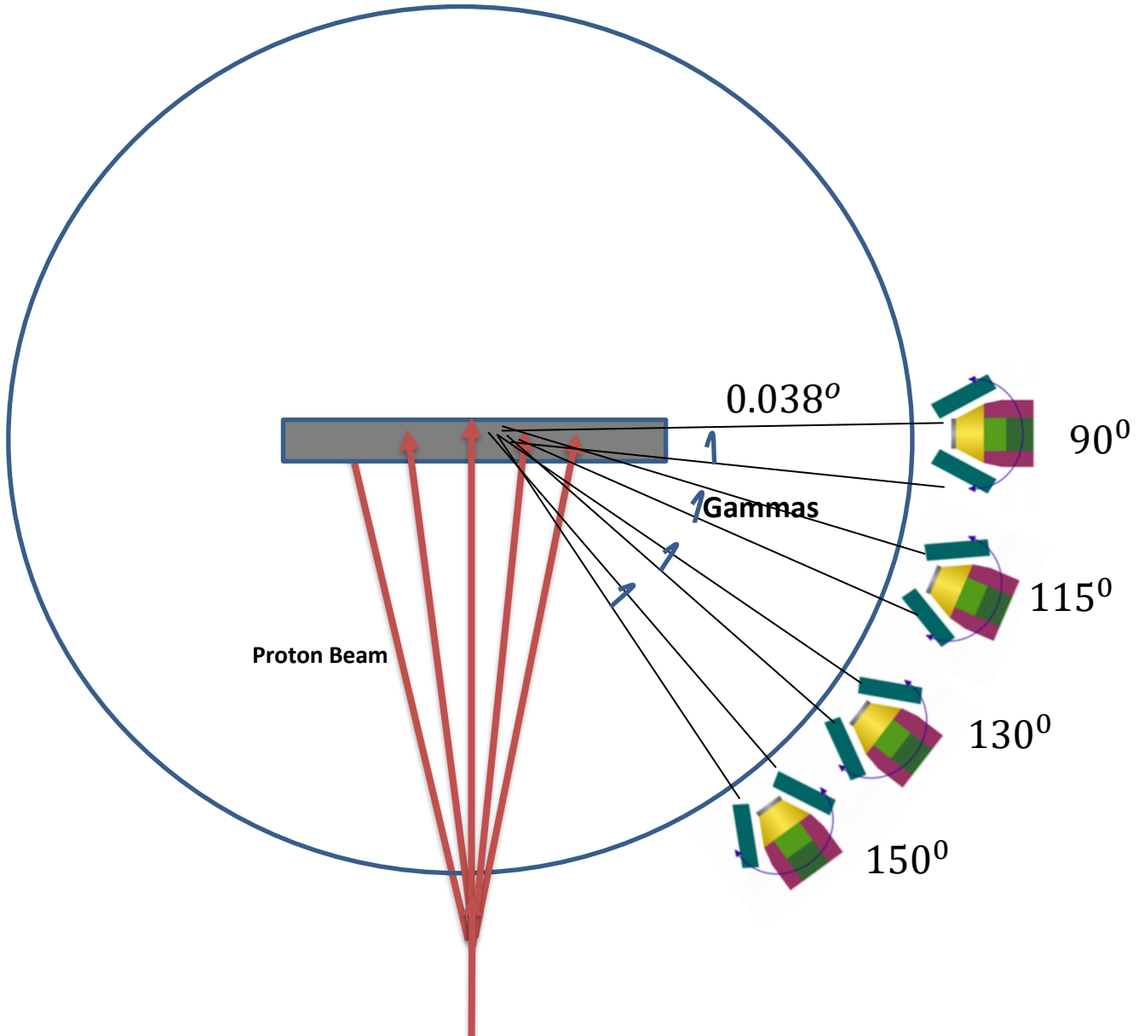
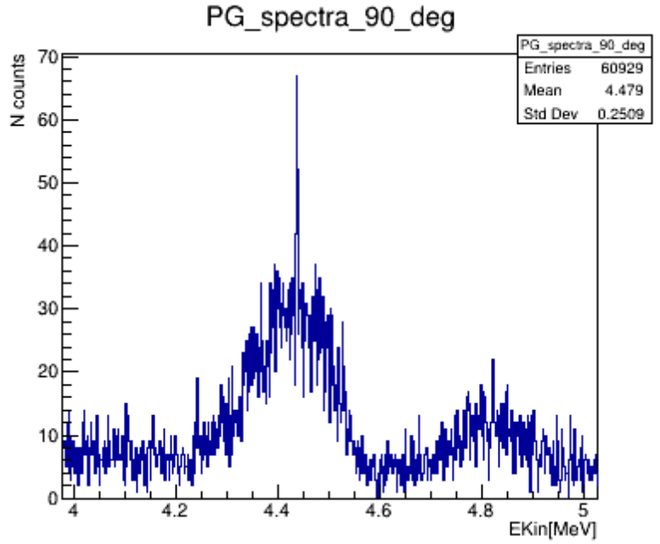
Parameter	Series A	Series B
a_0	$-0.010(70)$	$0.1675(69)$
a_2	$0.51(12)$	$0.337(27)$

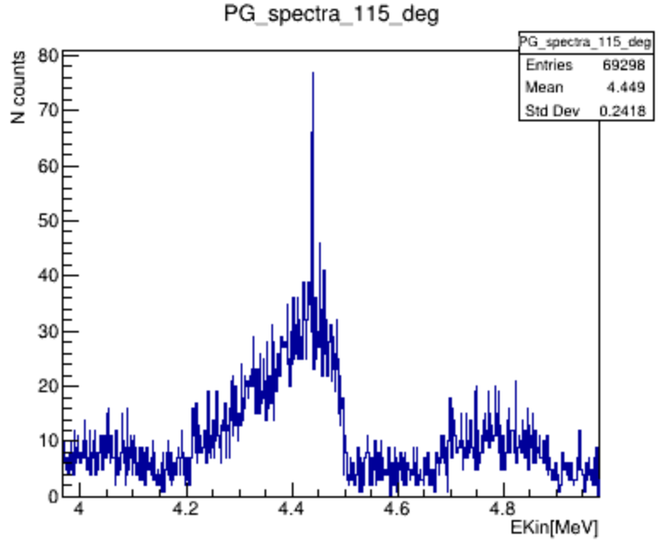


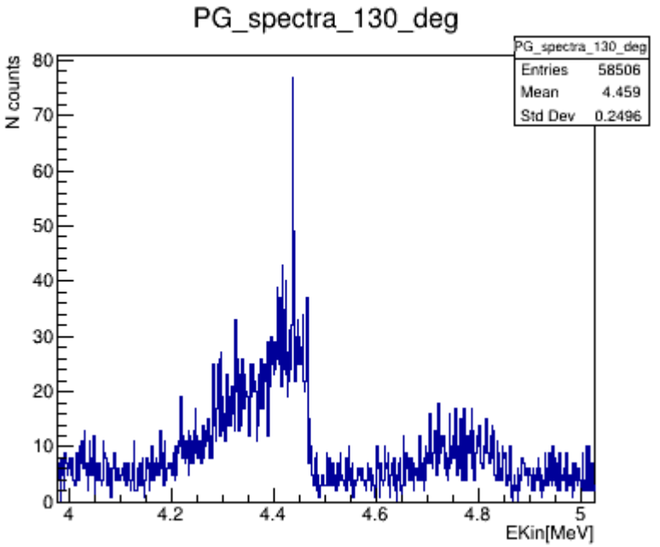
Corresponding data from simulations

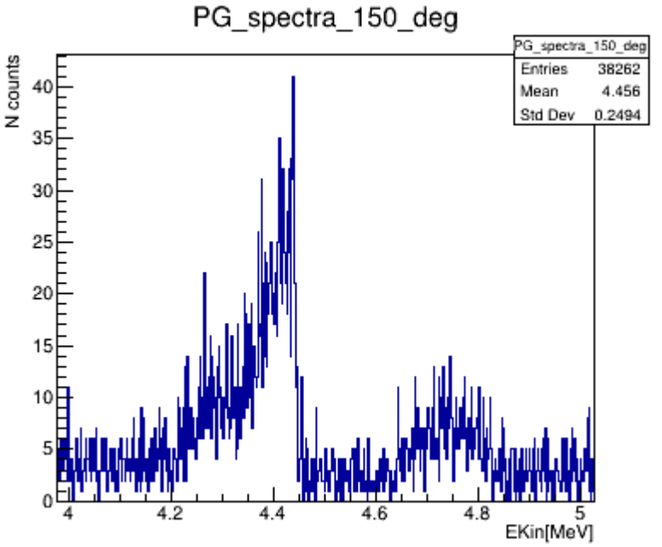
10^9 Events









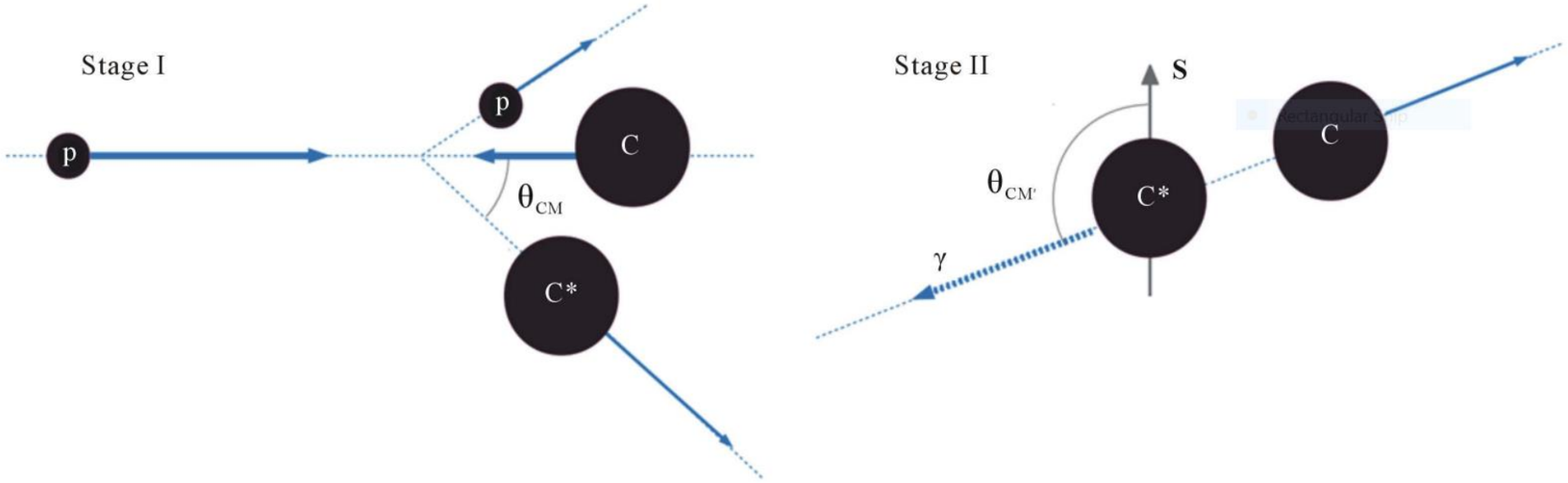


Conclusion

- There is homogeneous angular distribution for gamma particles emission from excited Carbon nuclei in software toolkit models which do not describes the experiment.

- The only inhomogeneity for the gamma particles emission, which is implemented in simulations is due to with kinematical affects.

Outlook of the research



- The next steps of research might be use fit parameters to modify results obtained from simulations.
- Possible explanations for 4.4 MeV line Double structure
  - Double peak might be blurred by the Doppler effect.
  - Investigation if the shape in center of mass frame.

Thanks for your Attention

Reference:

1) L. Kelleter, A. Wro´nska, *Spectroscopic study of prompt-gamma emission for range verification in proton therapy*, Physics Institute 3B, RWTH Aachen University, Aachen, Germany.
2) A. Wrońskaa , A. Anees Ahmeda, *EXPERIMENTAL VERIFICATION OF KEY CROSS SECTIONS FOR PROMPT-GAMMA IMAGING IN PROTON THERAPY*, The M. Smoluchowski Institute of Physics, Jagiellonian University Kraków, Poland bRWTH Aachen University, Aachen, Germany. August 21, 2017.
3) K. Rusiecka1, A. Wrońska, *Determination of Gamma Angular Distribution from the Shape of Spectral Line for the First Excited State of Carbon Nucleus,* Marian Smoluchowski Institute of Physics, Jagiellonian University, Kraków, Poland 2 Henryk Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland 3 RWTH Aachen University, Aachen, Germany. 11 January 2016
4) K. Rusiecka† , A. Wrońska, *SHAPE OF THE SPECTRAL LINE AND GAMMA ANGULAR DISTRIBUTION OF THE 12C(p, p0γ4.44) 12C REACTION,* Department of Nuclear Physics and Its Applications, Institute of Physics University of Silesia, Katowice, Poland. July 17, 2018