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Test and characterization of the CLaRyS camera's absorber with its final acquisition chain

O. Allegrini¹, J.P. Cachemiche², C.P.C Caplan², B. Carlus¹, X. Chen¹, S. Curtoni³, D. Dauvergne³, R. Della Negra¹, M. L. Gallin-Martel³, L. Gallin-Martel³, J. Hérault⁴, J. M. Létang⁴, S. Marcatili³, C. Morel², É. Testa¹, Y. Zoccarato¹

¹Université de Lyon, Université Claude Bernard Lyon 1, CNRS/IN2P3, Institut de Physique Des 2 Infinis de Lyon, 69622 Villeurbanne, France, ²Aix-Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France, ³Université Grenoble Alpes, Laboratoire de Physique Subatomique et de Cosmologie, CNRS/IN2P3, Grenoble, France, ⁴Centre Antoine Lacassagne, Cyclotron Biomédical, 227 Avenue de la Lanterne, F-06200 Nice, France, ⁵CREATIS, Université de Lyon; CNRS UMR5220; INSERM U1044; INSA-Lyon; Université Lyon 1; Centre Léon Bérard, Lyon, France

1. Introduction

- **Ion-range uncertainties** are currently a major concern in ion beam therapy. These are due to anatomical changes of the patient during the treatment and to uncertainties of imaging modalities (used for treatment planning) and of treatment planning systems.
- As a consequence, the most widespread treatment planning techniques are based on the use of **several beam incidences**, which increases the healthy tissues irradiation and **additional margins** are applied around the tumor to ensure the whole tumor irradiation.
- In order to fully take benefit from ballistic properties of ion beam therapy, **in-vivo ion-range verification** techniques are currently under development by several groups in the world. In this context, the CLaRyS collaboration (IP2I, CPPM, LPSC, CREATIS) develops **gamma cameras prototypes** coupled to a beam hodoscope [1] to perform prompt gamma (PG) detection **with TOF measurement**.

2. Material

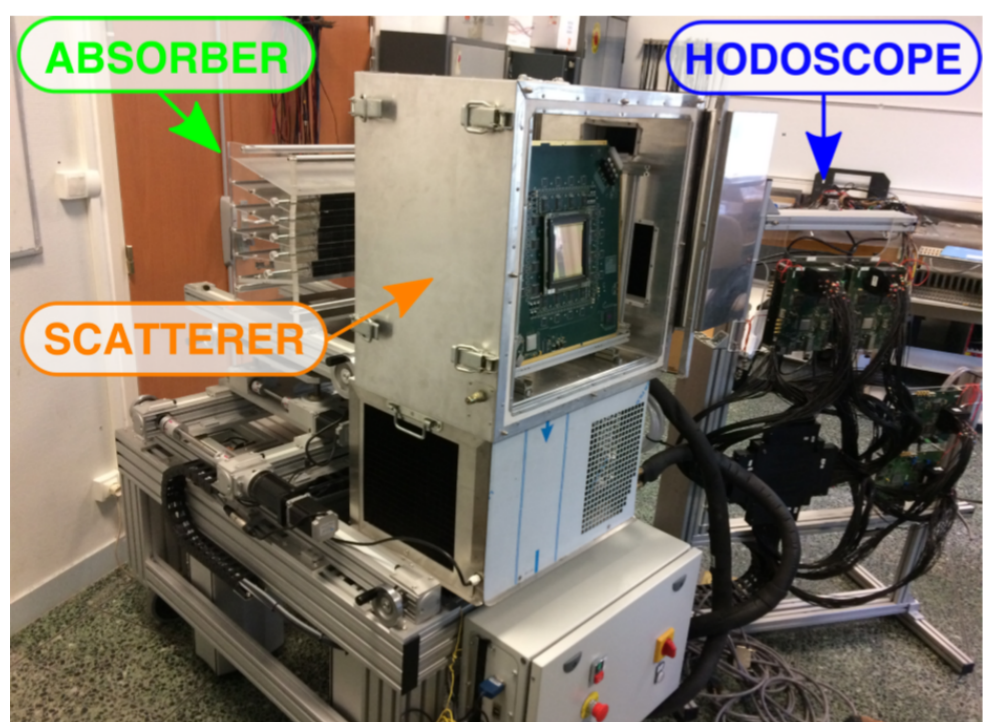
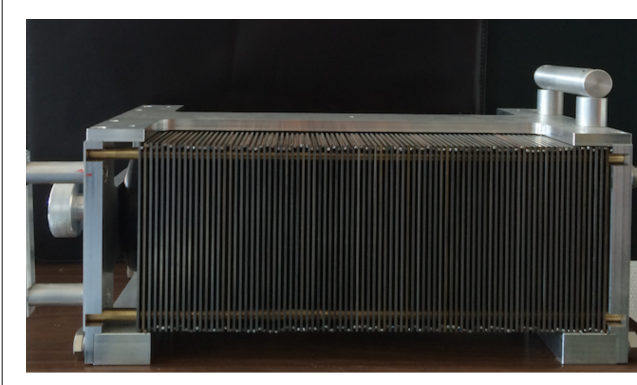


Figure 1: View of the Compton camera assembly with the beam hodoscope

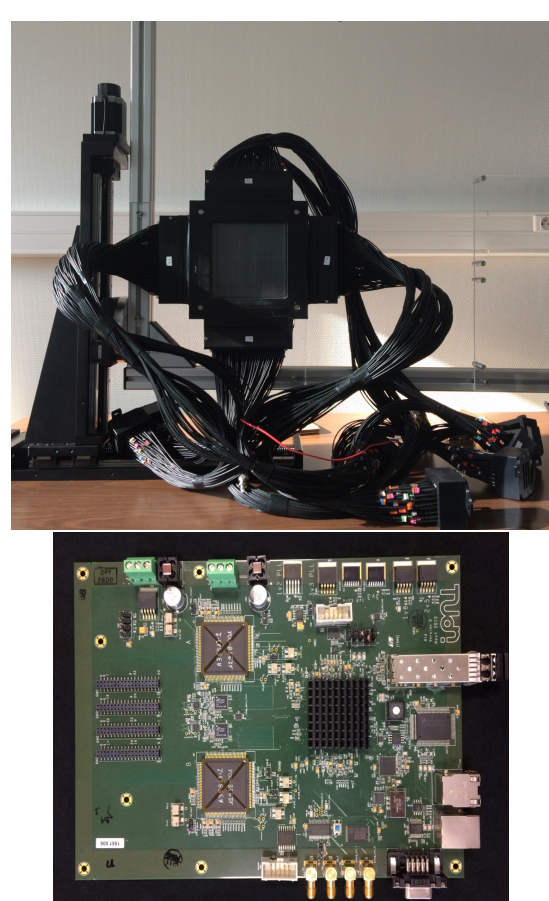
Collimator:

- 1.5×120×170 mm³ tungsten alloy slabs
- Adjustable gap between slabs



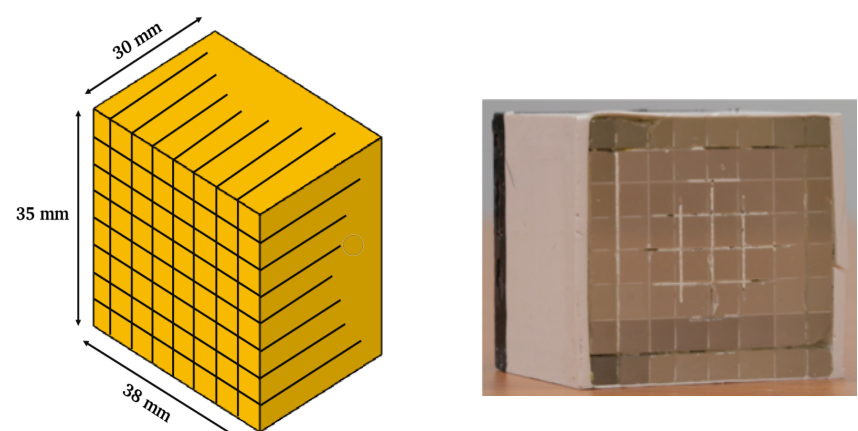
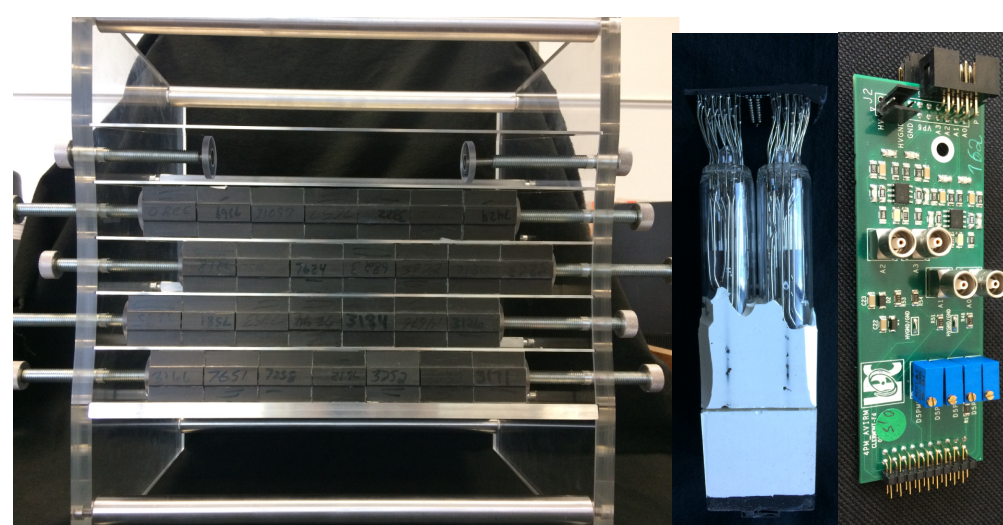
Hodoscope:

- 2 perpendicular planes for a 2D mapping
- 128 BCF-12 scintillating fibers per plane
- 1 mm² squared section
- 8 multi-anode PMs for a two side read-out
- Signal handling ensured by 8 FE cards including 64 input channels, 2 ASIC and 1 FPGA



Absorber:

- 32 BGO blocks (35×38×30 mm³) (BGO particularly interesting for high energy photons [2])
- 8×8 pseudo-pixels / block
- 4 photomultipliers (PMs) / block
- Dedicated front-end (FE) card (ASM) [3]
 - ❖ Reading time for 1024 samples: ~ 50 μs
 - ❖ Triggering: logical combination of thresholds applied on each block channel



BGO blocks performances:

Spatial resolution:
Limited to pixel size (4.75mm)
⇒ A sub-pixel spatial resolution is not achievable [4]

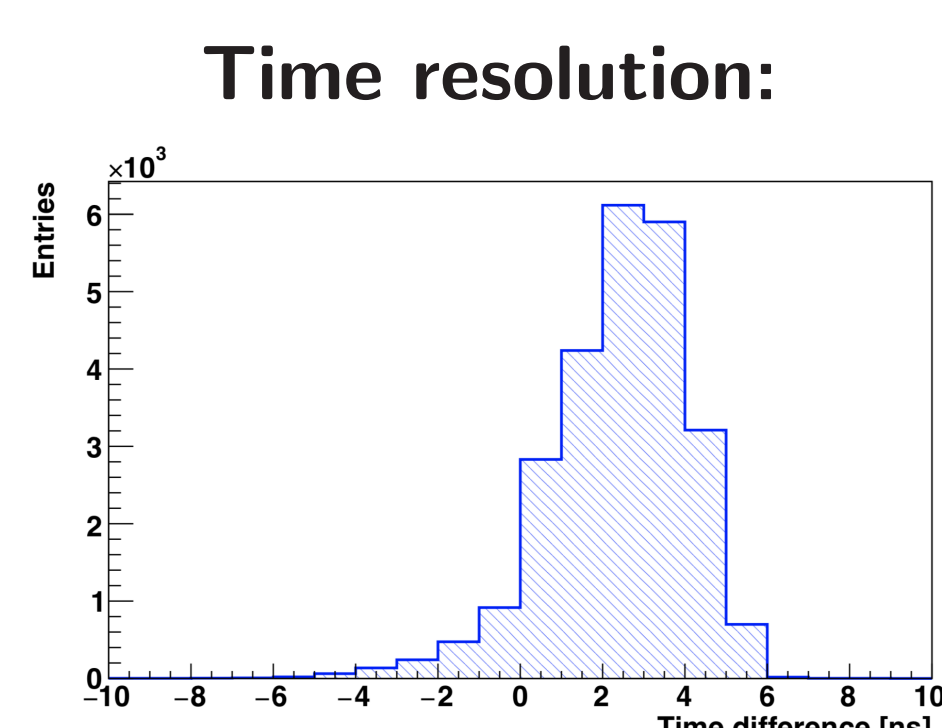


Figure 2: Distribution of arrival time differences between reference scintillator (a BaF₂ mono-block detector with 1 ns FWHM time resolution) and BGO block [4]

Energy resolution:

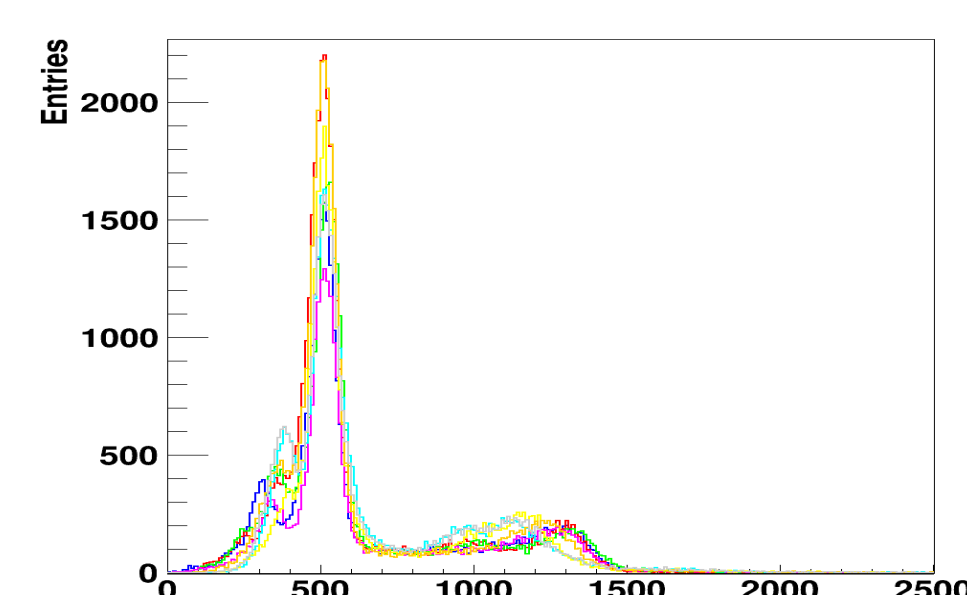


Figure 3: Energy spectra in 8 selected regions of a block showing a FWHM ~ 17% at 511 keV and ~ 20-25% at 1275 keV

5. Conclusion and perspectives

- **Physical results:**
 - ❖ First measurement of PG profile with the final acquisition system of the CLaRyS prototype at clinical beam intensity
 - ❖ The PG profile corresponds to the expectations in terms of count rate (analytic model [5]) and profile length (~ 3 cm).
- **Perspectives:**
 - ❖ Physical analysis: Complete analysis and comparison with simulations
 - ❖ Slow control improvements:
 - Make the BGO block calibration automatic
 - Tuning of the correlation between the beam hodoscope and the absorber
 - ❖ Next experiment: Use of the beam hodoscope to perform TOF measurement and reduce the background induced by neutrons (of utmost interest for high energy proton beam)
 - ❖ Absorber upgrade: High dead time with the current ASM board ⇒ Need for a new FE card

3. Method

In-lab BGO blocks characterization:

- Manual equalization of PMs gain
- High voltage (HV) adjustment to detect PG up to 6 MeV with low saturation rate.
 - Increase of HV (HV1) until signal saturation with ²²Na source (0.511 and 1.275 MeV gammas)
 - Decrease of HV (HV2) by a factor of 4.7 (6/1.275) to ensure 6 MeV PG detection

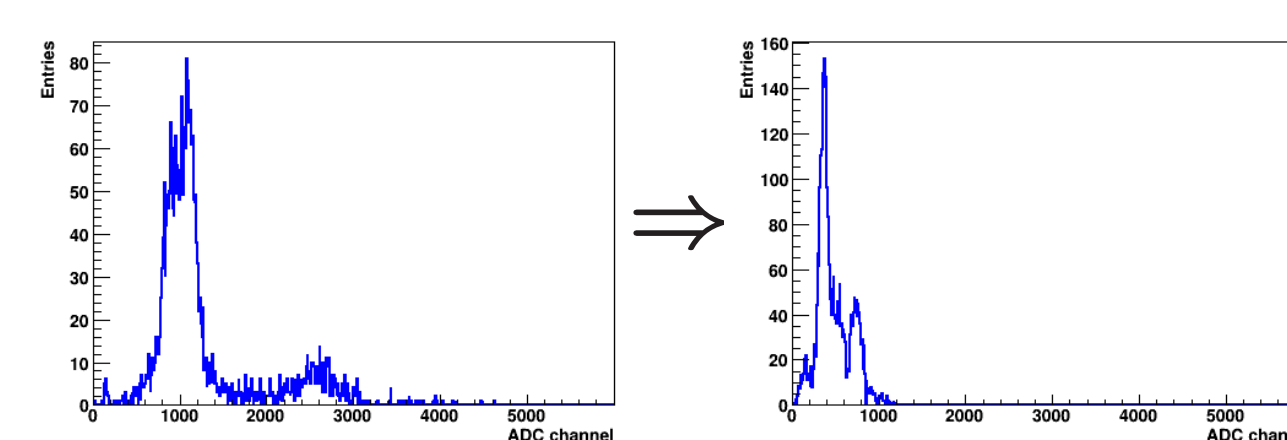


Figure 4: Energy spectra with HV1 (left) and HV2 values (right).

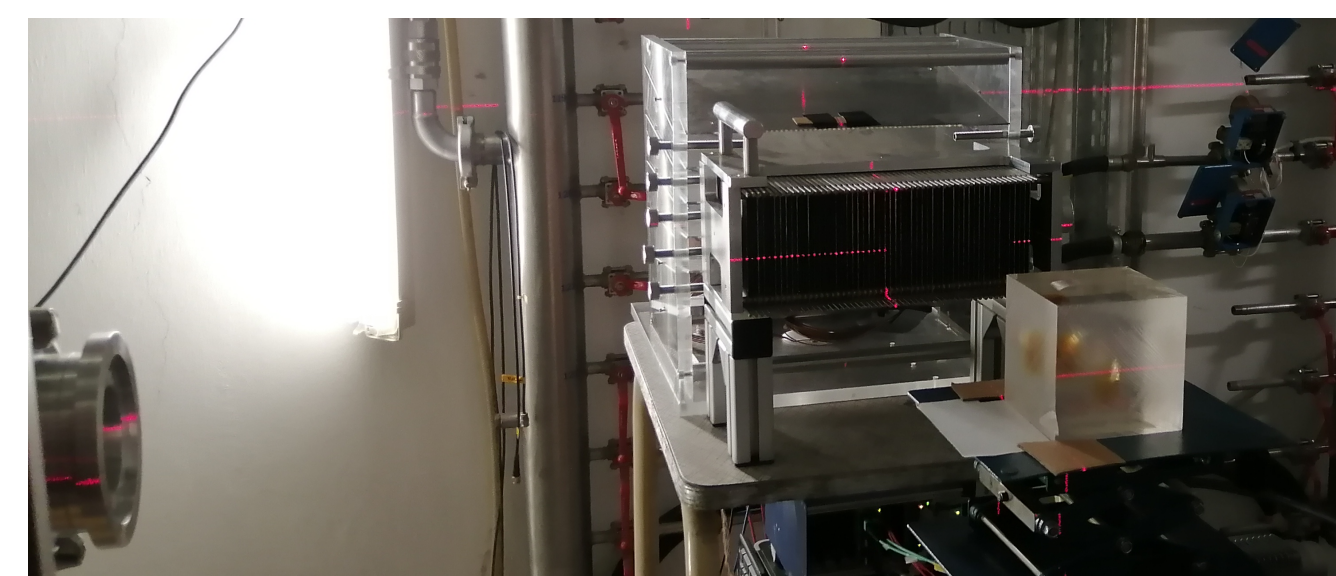


Figure 5: Picture of the experimental setup

In-beam test experimental setup:

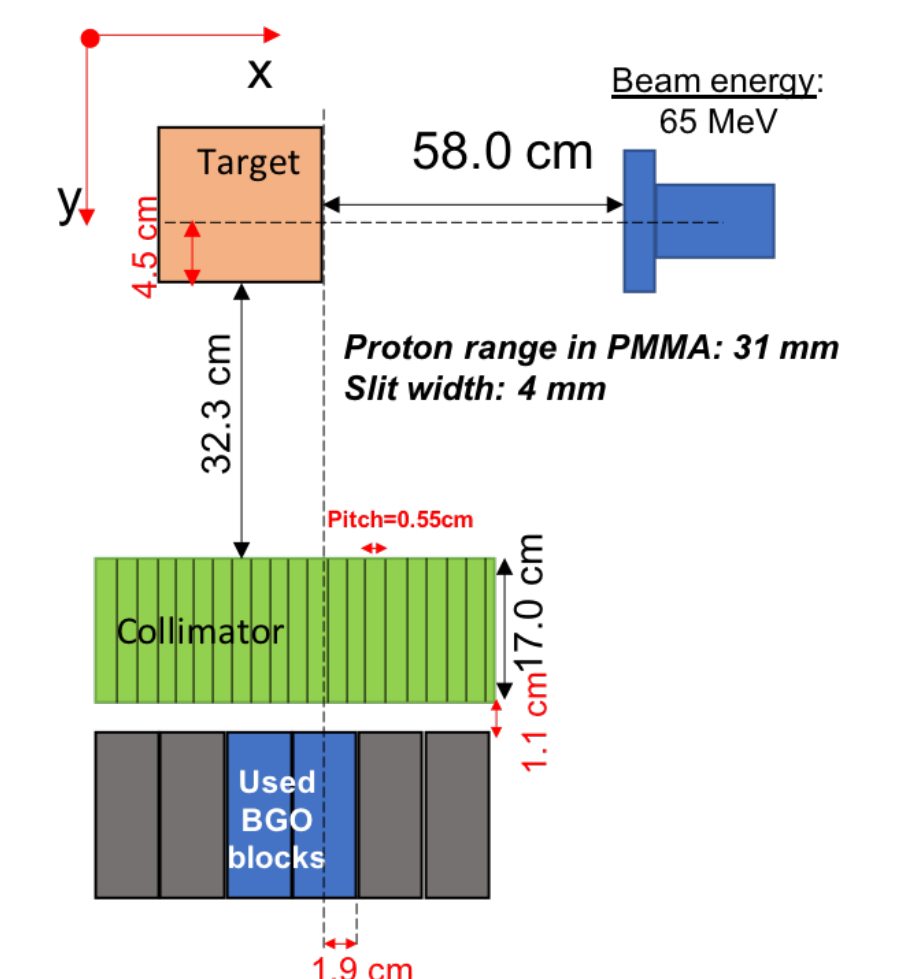


Figure 6: Scheme of the experimental setup in top view

- **Number of blocks used:** 4
- **Trigger conditions:** 1 PM signal over a high threshold OR 2 PM signals over a low threshold
- **Beam intensity** = 3.5 nA (measured in a Faraday cage with ~ 10% uncertainties)
- **System acquisition dead time rate** = 90.8% (evaluated by successive acquisitions with various intensity and comparison to paralyzable model)
- A calibration of the energy threshold has to be performed in-lab ⇒ Energy threshold not defined at this time

4. In-beam test results

- Acquisition without collimator
- Acquisition with collimator
Large variation of the efficiency within blocks ⇒ Need for normalization

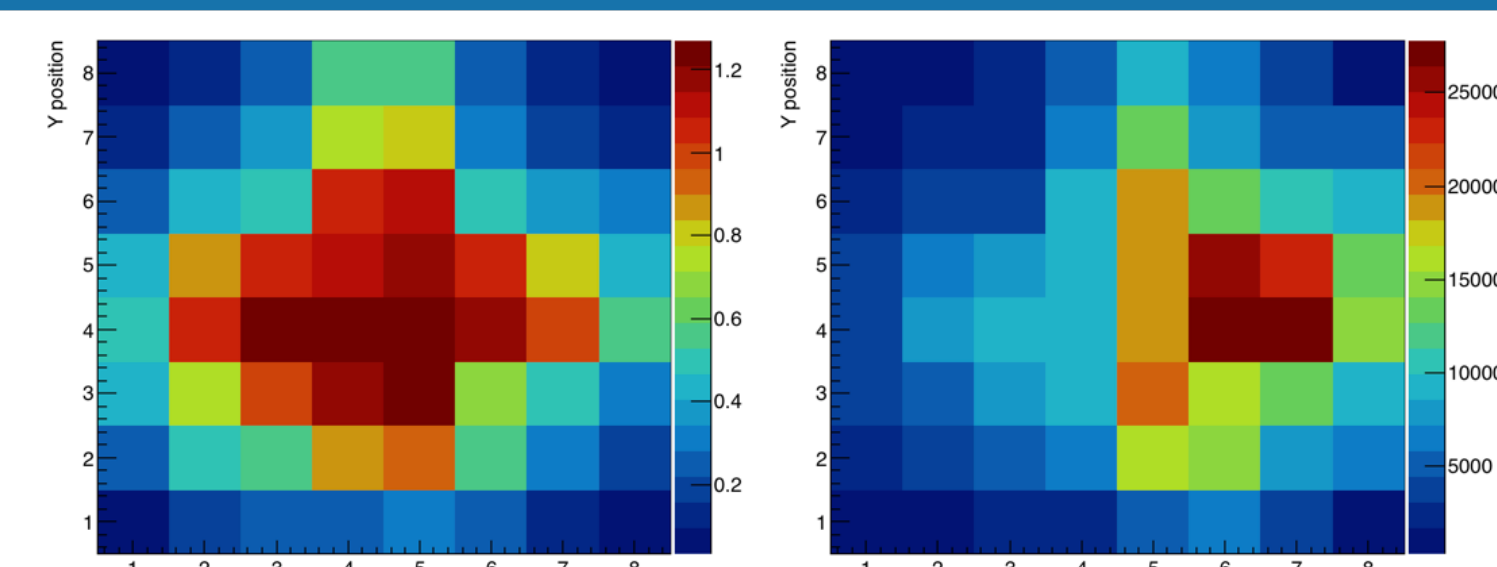


Figure 7: Assignment of events to pixels in a single block for acquisition without ① and with ② collimator.

- Normalization of the acquisition with collimator with respect to the one without collimator
 - N_B : Number of blocks
 - C_i : Mean value of the four pixels in the center of block i .
 - M : Average value of the mean values of the four pixels of the center of blocks

$$M = \frac{1}{N_B} \sum_{i=1}^{N_B} C_i$$

- N_{norm} : Counts in each normalized pixels
- $$N_{norm} = \frac{N_C}{\frac{N_{NC}}{M} \times N_{protons}}$$

where N_C , N_{NC} and $N_{protons}$ are respectively the pixel values obtained for the collimated and the non-collimated acquisitions and the number of protons.

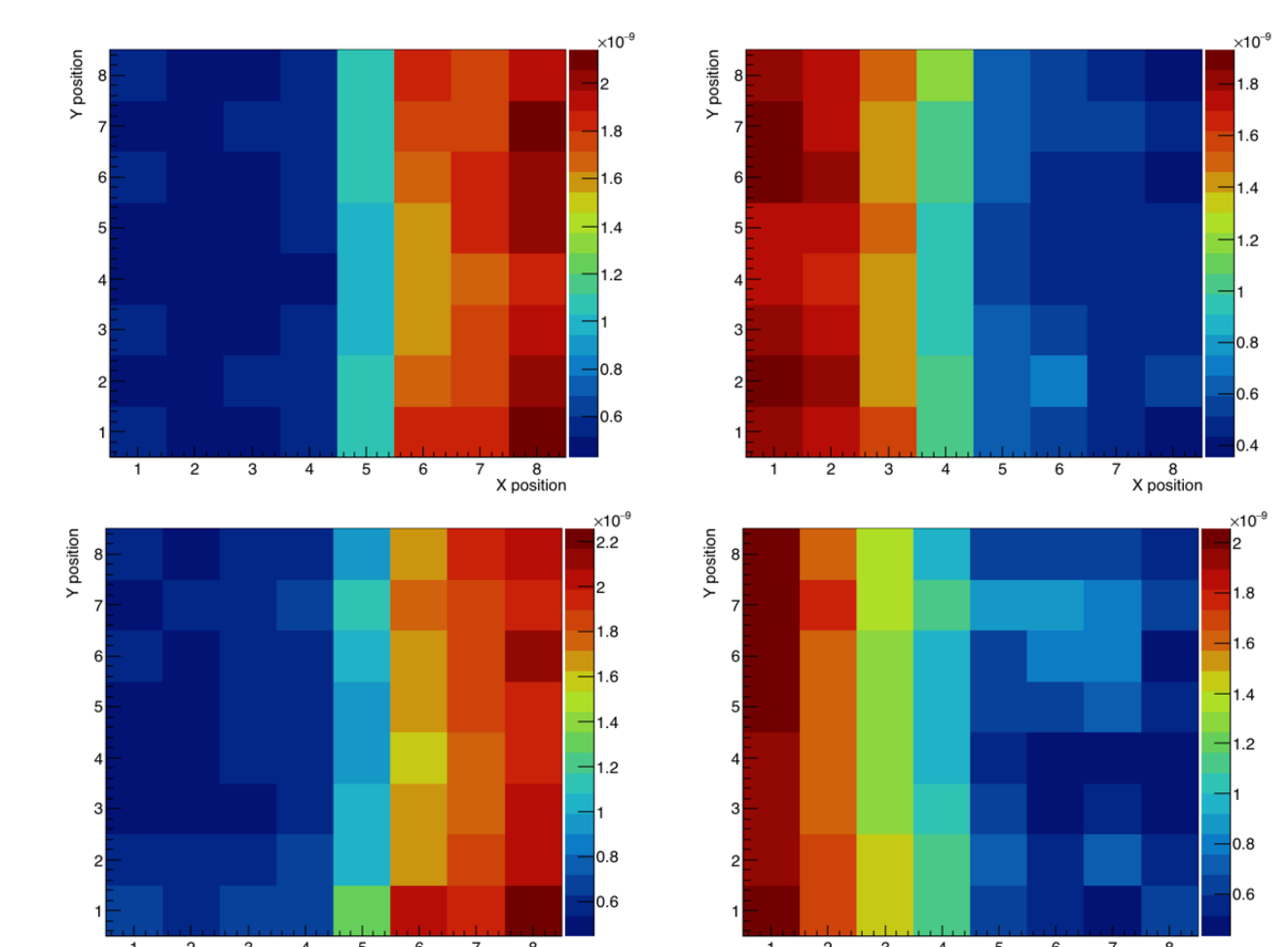
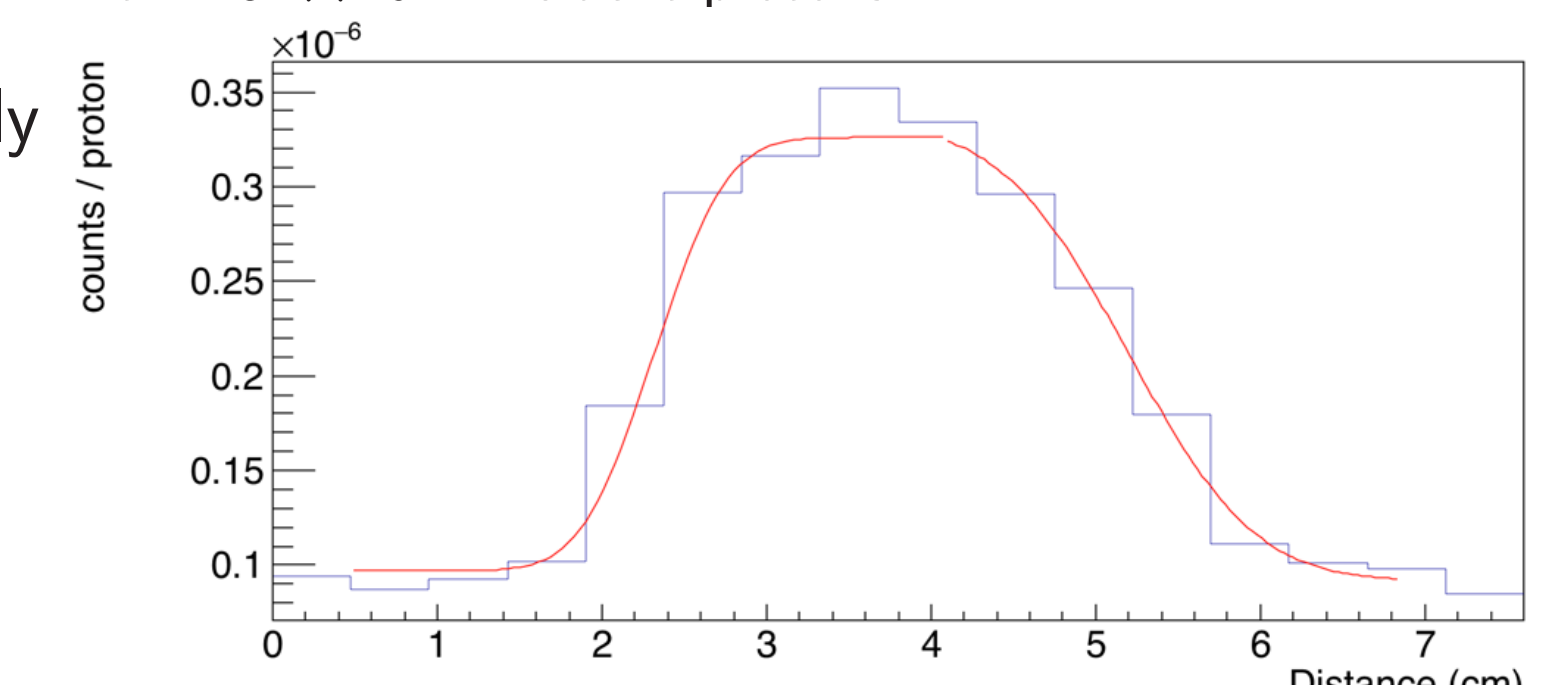


Figure 8: PG profile (with dead time correction) obtained with 1.31×10^{13} incident protons



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