ST 13 – Creation of an integrated platform for spatial resolution determination in a monolithic scintillator

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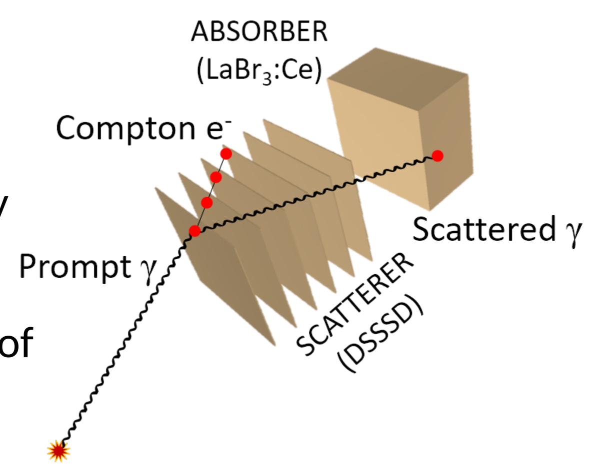
Motivation

→ Proton and carbon ion beams offer the possibility to accurately target tumors thanks to their rising dose distribution culminating at the **Bragg peak**

→ Fully exploiting the treatment accuracy of particle therapy is presently limited by the range uncertainties of the particle beams

→ The existence of the Bragg peak requires a high-precision monitoring of the beam stopping range in the tissue



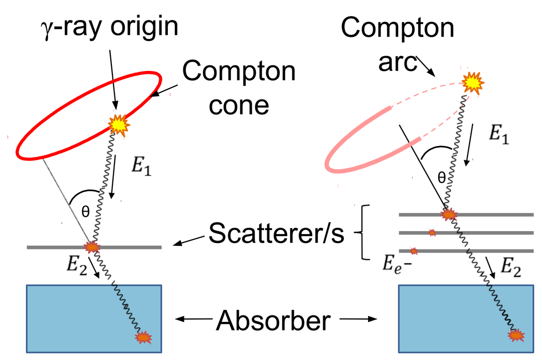
→ The correlation between the **spatial prompt γ -ray distribution,** emitted from nuclear reactions of the beam, with biological samples and the Bragg peak position enables to use prompt γ emission to verify the **range of the hadron beam** [1]

→ The clinical application requires determination of the prompt γ emission position in **real time**

Introduction

→ A Compton Camera (CC) system can provide an in-vivo ion beam range monitoring via detecting secondary prompt γ–rays

→ The CC system is based on the Compton scattering kinematics: the system is composed by a scatter and an absorber component



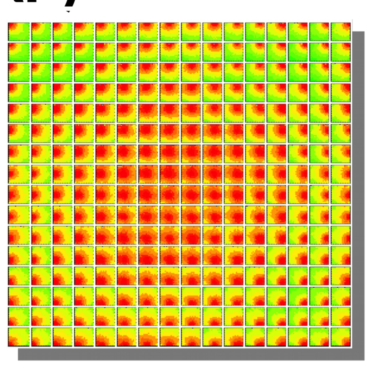
$$cos\vartheta = 1 - m_e c^2 \left[\frac{1}{E_2} - \frac{1}{E_1}\right]$$

→ By acquiring energy and position information for each event from the scatterer and the absorber it is possible to reconstruct a **Compton cone/arc,** and by the intersection of all of those, the position of the emitted γ -rays

Methods

Categorical Average Pattern Algorithm (CAP)

Algorithms enabling γ -ray position reconstruction in a monolithic scintillator rely on a comparison of the measured 2D light amplitude to a set of 2D reference library events [2]



16x16 set of 2D light distributions: Source: ^{60}Co (1.3 MeV)

1) Choose *k* best matching signals in a given irradiation position

⬇

2) Calculate average light distribution of chosen *k* events

⬇

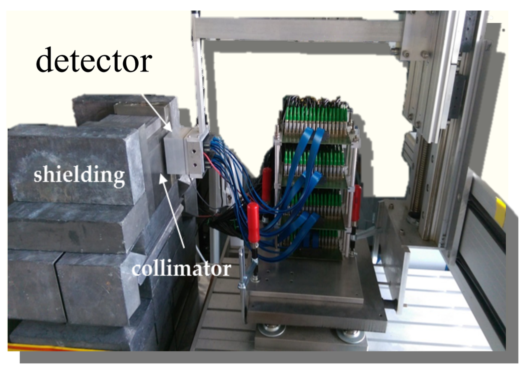
3) Repeat **1)** & **2)** for every irradiation position

⬇

4) The best matching, averaged light distribution determines the position of an unknown event

Reference library

Reference events are generated by irradiation of the monolithic detector surface by a tightly collimated γ -ray source



→ about 100x100 irradiated positions

→ 400 photopeak events in every position

→ **In total 4x10^6 library entries**

Spatial resolution

→ The "leave-one-out" method requires application of the algorithm for every event in the library

→ At least **1.6x10^{13}** comparisons of events (each described by **256** light amplitude values) need to be executed

⬇

Approach giving good performance (spatial resolution 2.9(1) mm for energy 1.3 MeV, ^{60}Co source [3]) but still time and memory consuming

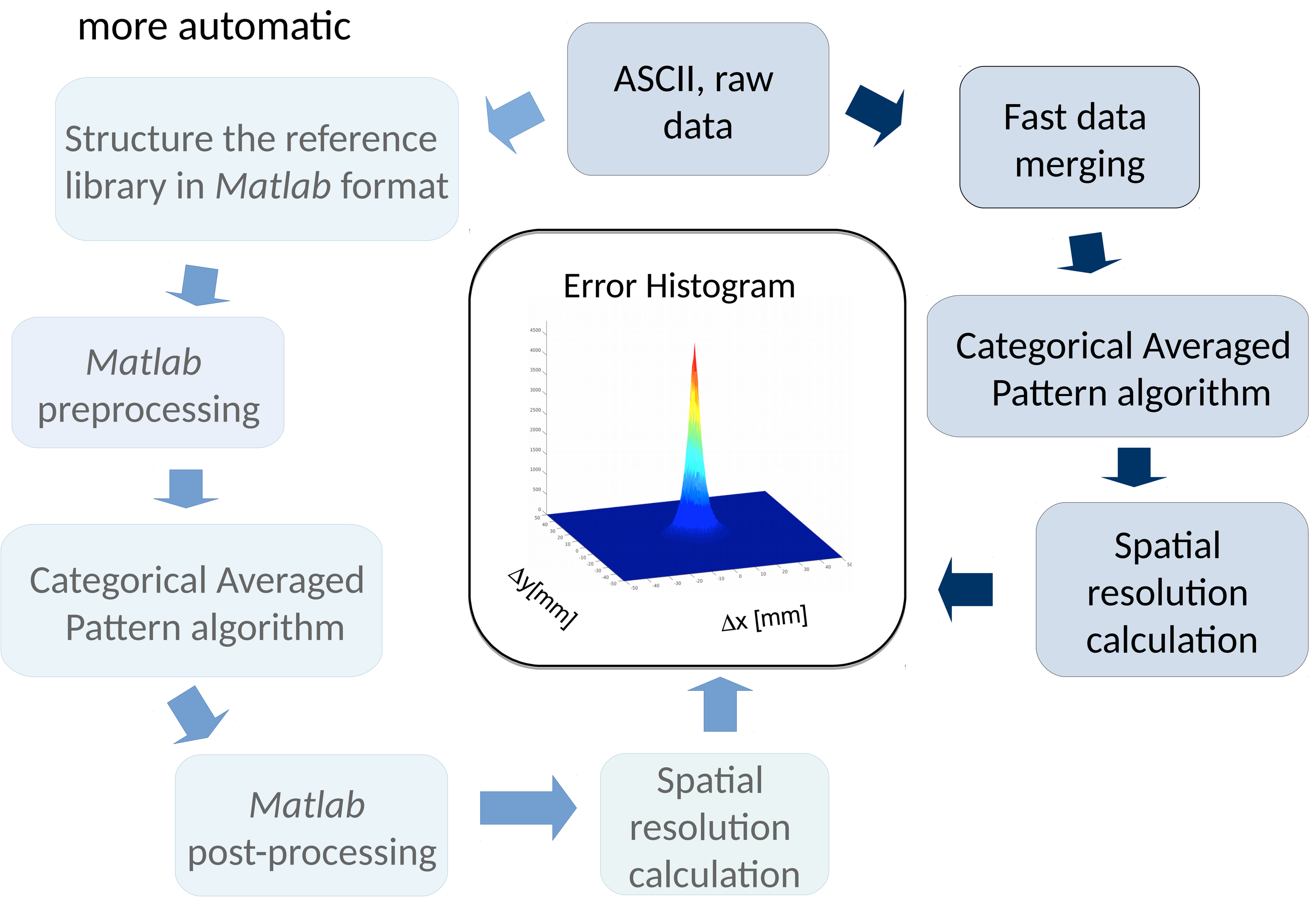
Results

Platform structure

→ New approach is based solely on C++

→ Requires less memory in comparison to previous solution (1 GB instead of 10^2 GB)

→ It enables to merge different steps together and make the procedure more automatic



Spatial resolution verification

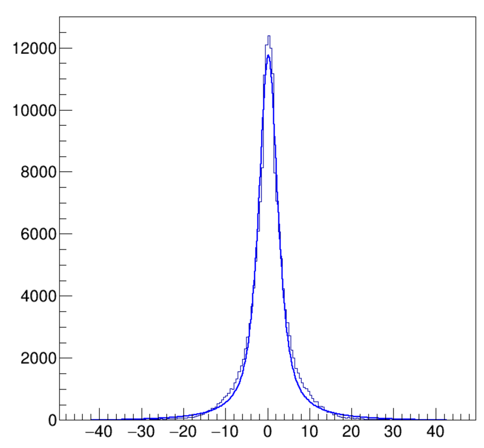
Spatial resolution calculated for cesium reference library:

→ source: ^{137}Cs (0.662 MeV)

→ step size: 0.5 mm

→ 100x100 irradiated positions

→ 400 photopeak events per position



Error histogram with fitted Pseudo-Voight function

→ Fitting Pseudo-Voight profiles along two perpendicular axes

→ Average of two FWHM values (along x and y axis) determines the spatial resolution of the CAP algorithm for a given library

→ Result for Cs library: **4.68(2) mm**

⬇

The spatial resolution obtained using the new platform is consistent with previous result of 4.71(1) mm[3]

→ The platform structure was also checked for an unknown event position reconstruction using a data set previously acquired in a CC setup [4]

Conclusions & Outlook

→ With the newly developed integrated platform we are able to achieve the same spatial resolution performance as with the previous procedure

→ The new platform allows us to reduce the memory usage by a factor of 10^2, therefore it allows to run the reconstruction process without the need of high performance computers (HPC-cluster)

→ The number of steps needed to obtain the spatial resolution or to reconstruct positions of unknown photopeak events is reduced.

→ The whole procedure is more automatic thus decreasing the error probability

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→ All the amount of reference events contained in the library is necessary to achieve the same spatial resolution performance

→ The reconstruction time is highly dependent on the size of the reference library. The presently used amount of data requires a minimum amount of time that is not further reducible

→ The structure of the data was carefully analyzed and there appeared new perspectives to use, for example, *Deep Learning* or *Artificial Neural Network* methods what can reduce reconstruction time [5]. The idea for the first trial will be based on the TMVA, ROOT framework [6]

Acknowledgement

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References

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[3] S. Liprandi et al.: Sub-3mm spatial resolution from a large monolithic $LaBr_3$ (Ce) scintillator, *Current Directions in Biomedical Engineering 3(2): 655-659, 2017.*
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[6] ROOT Data Analysis Framework, TMVA, https://root.cern.ch/tmva