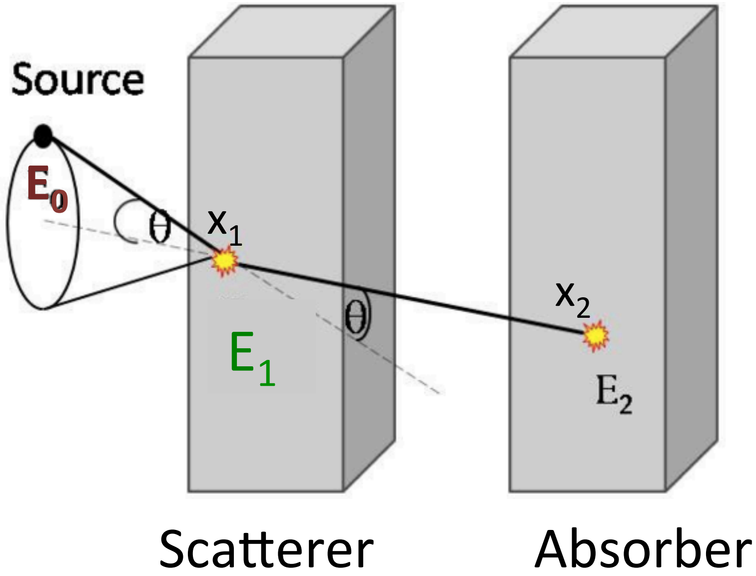
A dedicated GATE module for Compton camera imaging

A. Etxebeste[1], D. Dauvergne[2], M. Fontana[3], J. M. Létang[1], G. Llosá[4], E. Muñoz[4], J. F. Oliver[4], É. Testa[3] and D. Sarrut[1]

[1]Université de Lyon, CREATIS, CNRS UMR5220, Inserm U1044, INSA-Lyon, Université Lyon 1, France
[2]LPSC, Université Grenoble-Alpes, CNRS/IN2P3, UMR 5821, Grenoble, France
[3]Université de Lyon, CNRS/IN2P3, UMR 5822, IPNL, F-69622 Villeurbanne, France
[4]Instituto de Física Corpuscular, Valencia, CSIC/Universitat de València, Spain

Compton Cameras (CC)



Compton kinematics to reconstruct the cone shell where the source must be contained

$$\cos(\theta) = 1 - \frac{E_1 m_e c^2}{E_0 (E_0 - E_1)}$$

Expectations

- high efficiency (electronic collimation)
- may provide higher spatial resolution
- 3D capability

Applications: Astronomy,
Homeland security

Potential applications (still research):

Nuclear medicine (CC (CLaRyS) vs SPECT, *Fontana PMB 2017)*

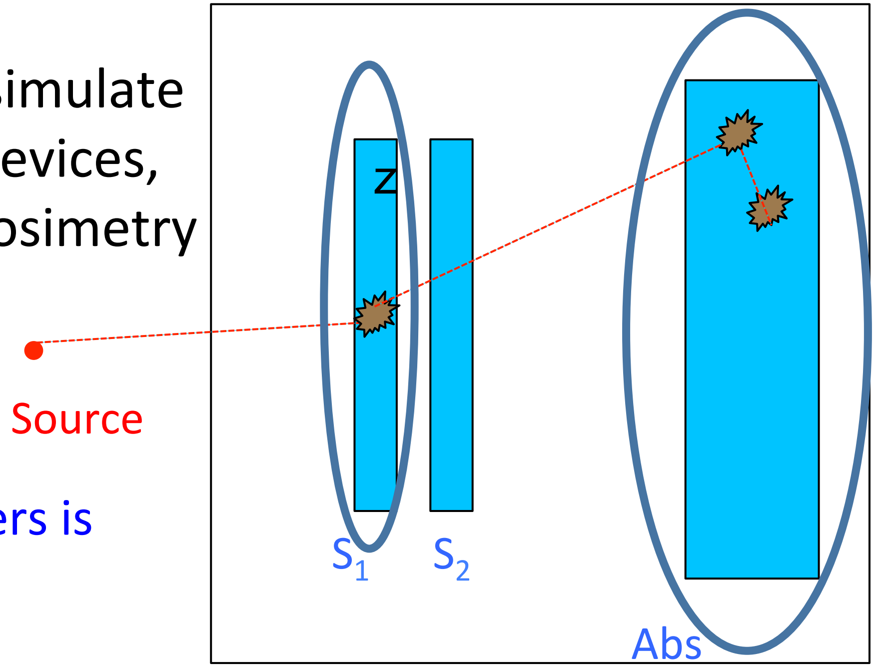
Hadron therapy monitoring: prototype development in France, Germany, Spain, Japan , US…

Monte Carlo simulations: CC Actor (GATE Toolkit)

MC simulation essential tool:

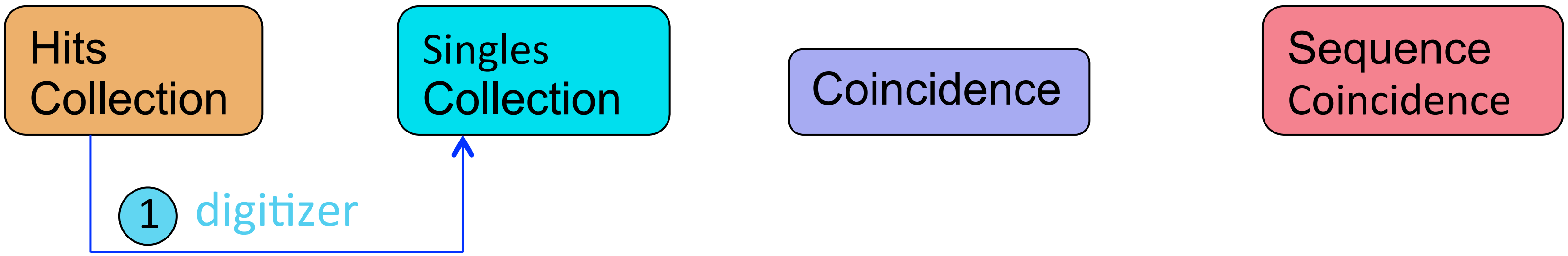
- Design, optimize and predict the potential of the system
- Understand experimental data
- Study background rejection techniques
- Test reconstruction algorithms

GATE is a powerful tool which allows to simulate easily by using macros, several imaging devices, radiotherapy treatments and calculate dosimetry all in the same framework



Information of the interactions in the layers is stored in what it is called Hit collection

Structure of the Compton Camera Actor

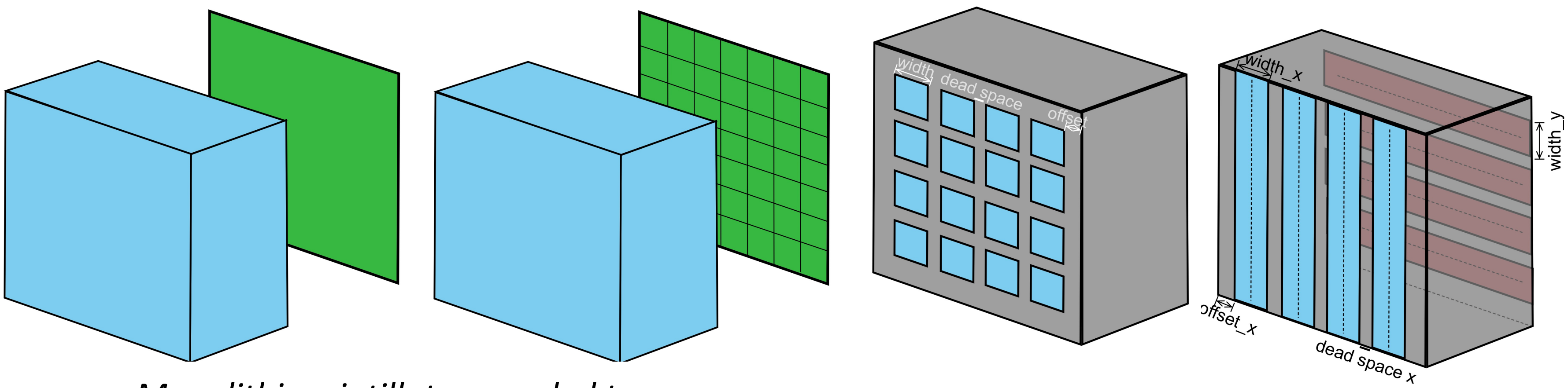


1. A chain of digitizer modules applied to the different detector layers to model the detector response or to recover ideal Compton kinematics

Structure of the Compton Camera Actor

1 Digitizer modules:

- Implemented modules to model the response of some of the most commonly employed detectors



Monolithic scintillator coupled to position sensitive/insensitive detector

Pixelated crystals

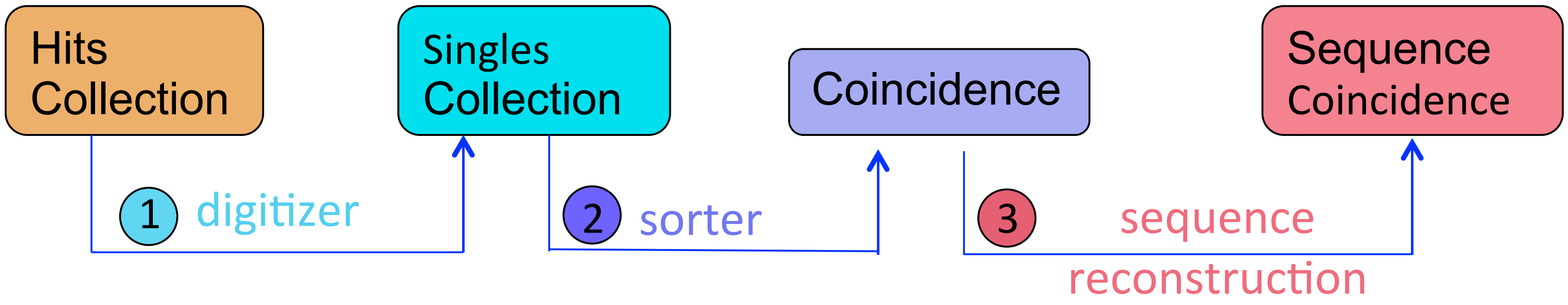
Strip detectors

Different modules developed: clustering, strip-discretization, energy/time resolution, DoI modelling, energy thresholds, ...

- Ideal adder, implemented module to recover ideal Compton kinematics

- Additional processors can be easily added by the users

Structure of the Compton Camera Actor



1. A chain of digitizer modules applied to the different detector layers to model the detector response or to recover ideal Compton kinematics

2. Time coincidence between the pulses in the different layers

3. Sequence reconstruction: order singles within a coincidence

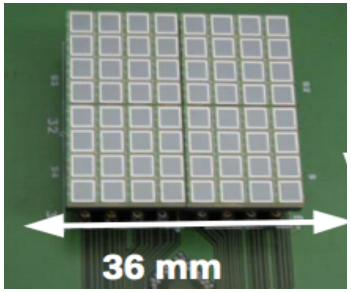
Output data available at each step
Processing steps (1,2,3) may be performed on-the-fly or offline
Same data structure as for PET/SPECT sys to be able to share developed processors

Validation of the module: experimental data

MACACO prototype (IFIC-Valencia)

Muñoz PMB 2017

$LaBr_3$ scintillator

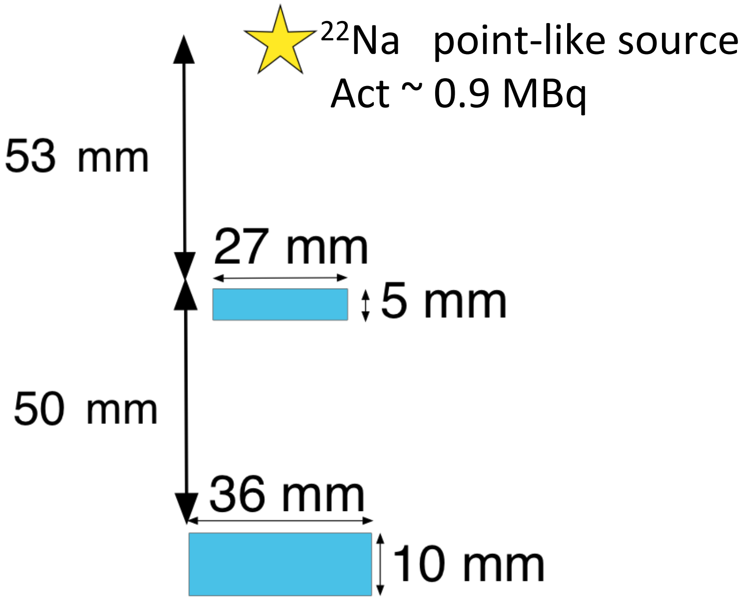


SiPM array

Detector layers (scatterer/absorber):

Continuous crystals readout by SiPMs

Set-up: 2-layer configuration

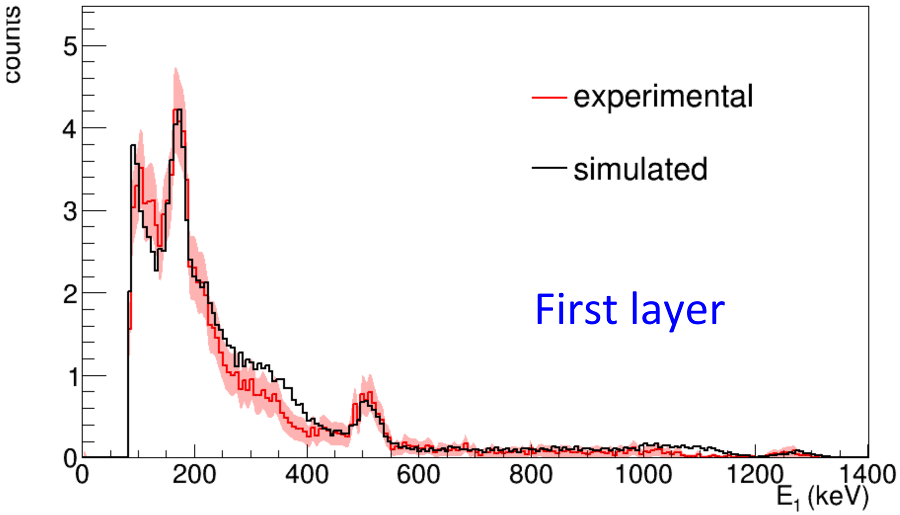


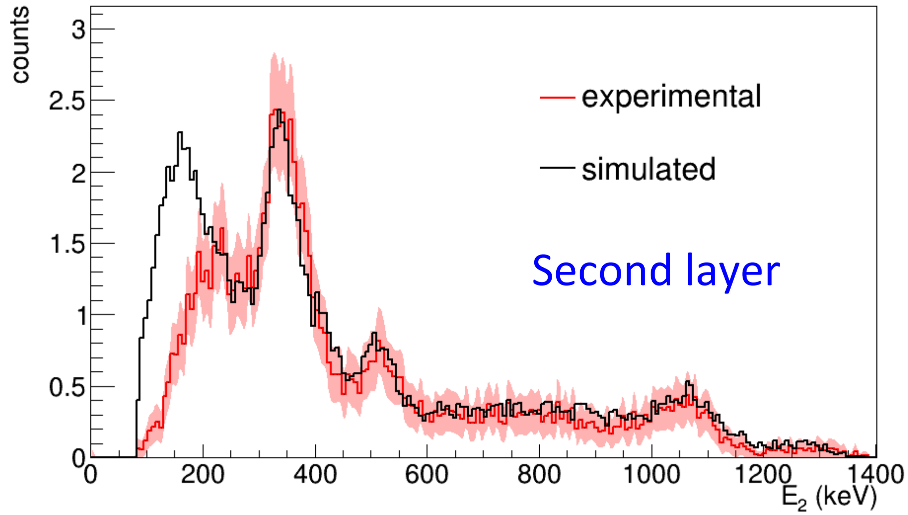
Characteristics included in the simulation

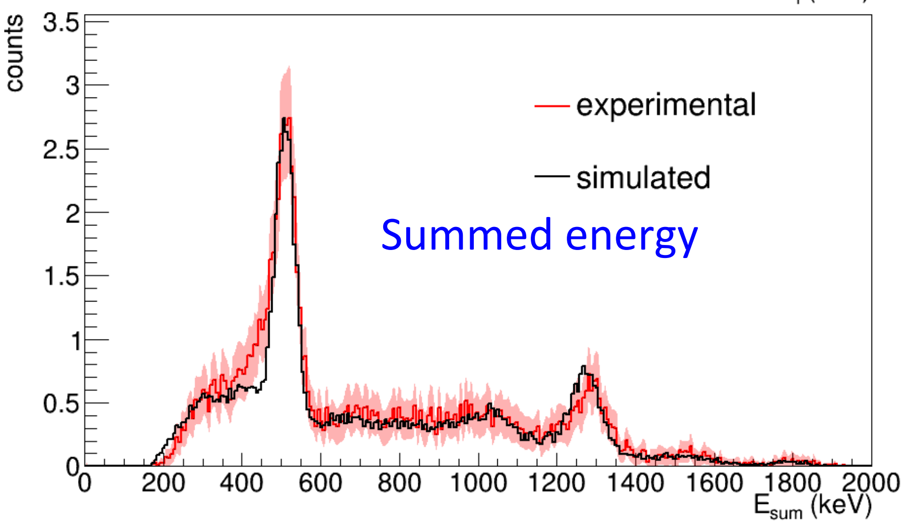
- Digitizer
  - -Discriminator THR at pixel level
  - -Energy resolution
    (8.5% and 12.5% @ 511 keV)
  - -X-Y spatial resolution
    Gaussian blurring 2 mm sigma
  - -DoI resolution
    Exponential model (Cabello PMB 2015)
- Sorter (TCW=50 ns)
- Sequence reconstruction
  - -forward scattering assumption

Validation of the module: energy spectra

Energy spectra of the coincidences



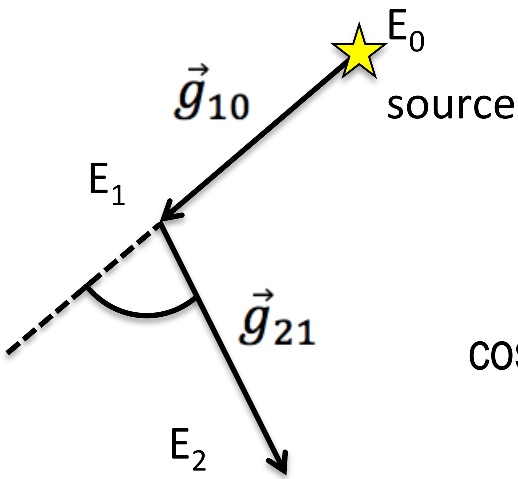




Good agreement despite small differences at low energies

Validation of the module: ARM

ARM (Angular Resolution measure)



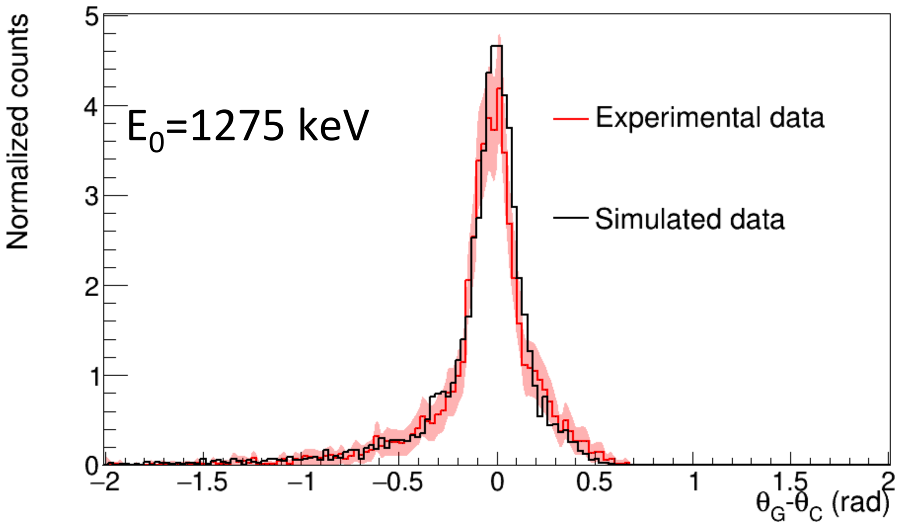
Criteria for incident energy (E_o)

$E_1+E_2<600$ keV, $E_0=511$ keV

$E_1+E_2>600$ keV, $E_0=1275$ keV

$$\cos(\theta_G)= \frac{\vec{g}_{10} \cdot \vec{g}_{21}}{|\vec{g}_{10}||\vec{g}_{21}|}$$

$$\cos(\theta_C)= 1 - \frac{m_e c^2 E_1}{E_0(E_0 - E_1)}$$

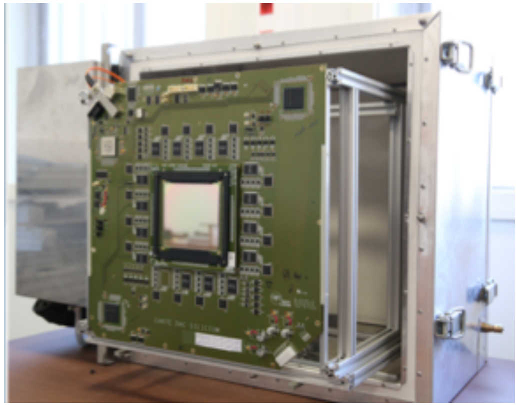


ARM_{exp}= (13.2± 0.2) deg
ARM_{sim}= (12.3± 0.2) deg

(Lorentzian fit)

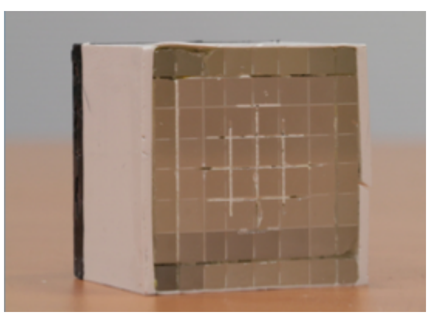
CLARYS prototype

SCATTERER



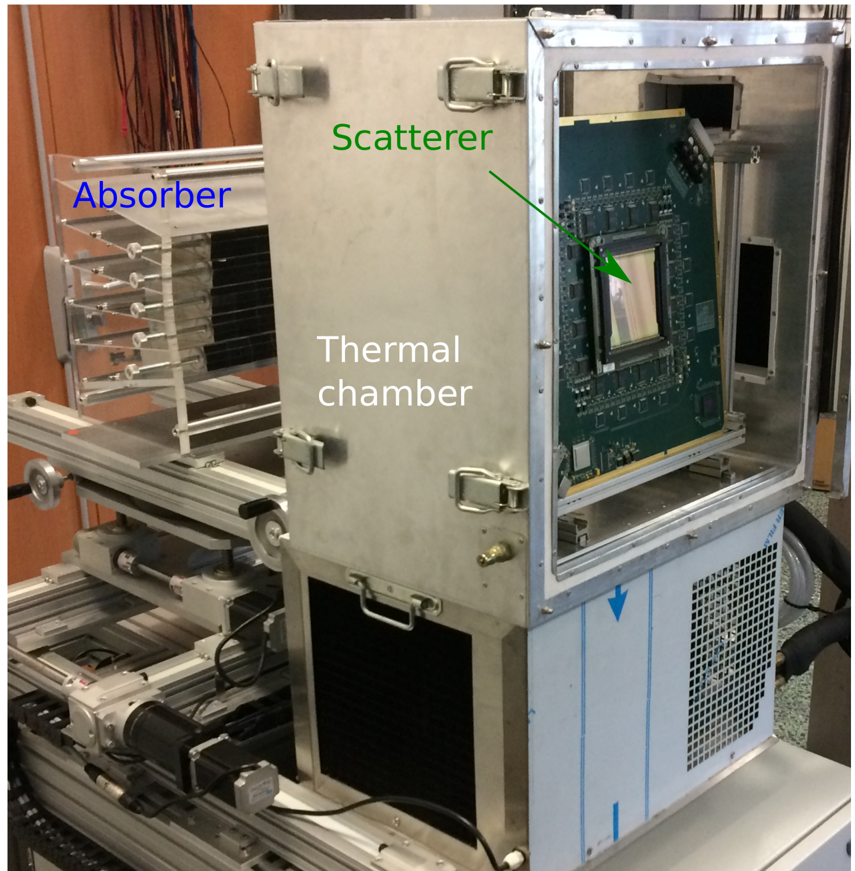
7 DSSD (low Z).
XY position sensitive

ABSORBER



segmented BGO (high Z)

Design for HT monitoring (+ hodoscope)
Proved good results in Nuclear Medicine *Fontana PMB 2017*

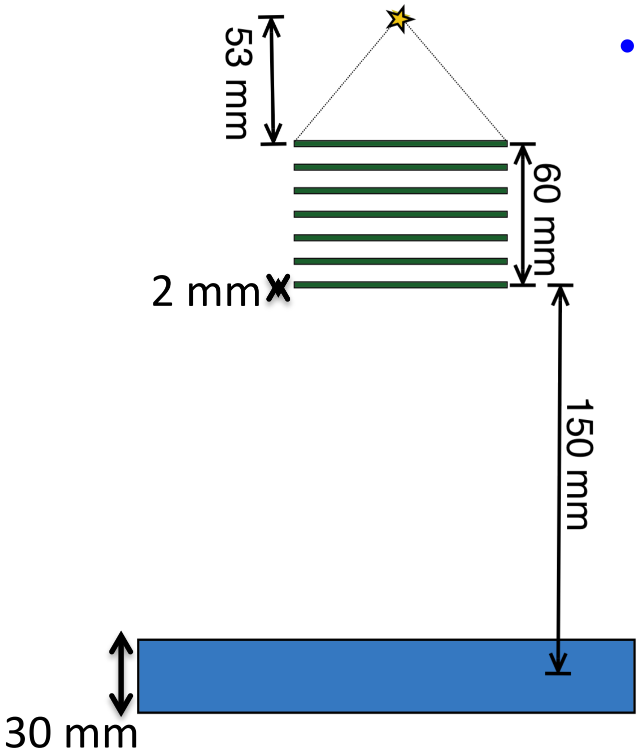


Krimmer NIMA 2015

No experimental data taken with the whole prototype yet

CLARYS prototype simulation characteristics

Design of the prototype for Nuclear Medicine *Fontana PMB 2017*



- Digitizer

  Scatterer (64 strips, pitch=1.4 mm, active size 1.3 mm)

  -THR=50 keV at strip intersection

  -Energy resolution (2.5% @ 200 keV)

  -DoI, centre of the layer

  Absorber (6x8 blocks, 8x8 pixels of 4.4 mm)

  -Readout at block level

  -THR of 100 keV

  -Energy resolution (21% @ 662 keV)

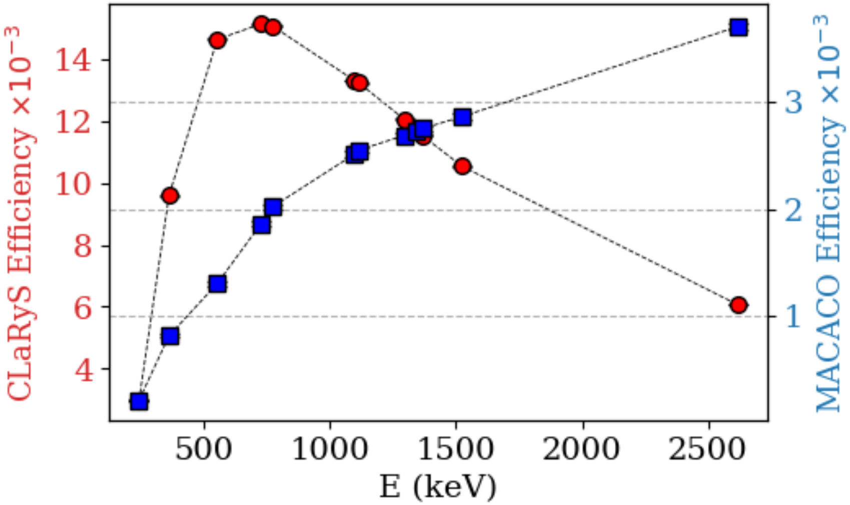
  -DoI centre of the layer

- Sorter (TCW=50 ns)
- Sequence reconstruction (forward scattering assumption)

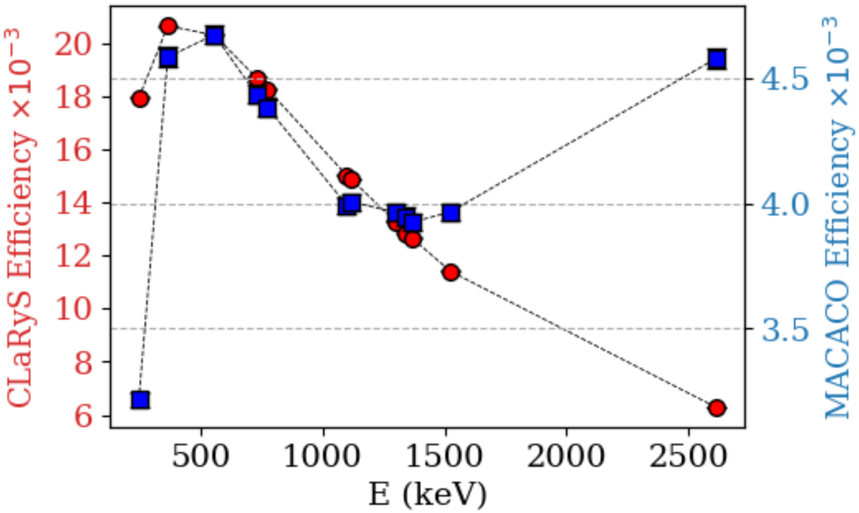
Comparison of the prototypes: Efficiency

Detection efficiency normalized to the scatterer geometrical efficiency

CLaRyS: THR_{scatt}=50 keV , THR_{abs}= 100 keV
MACACO: 85 keV



THR: 10 keV for both systems



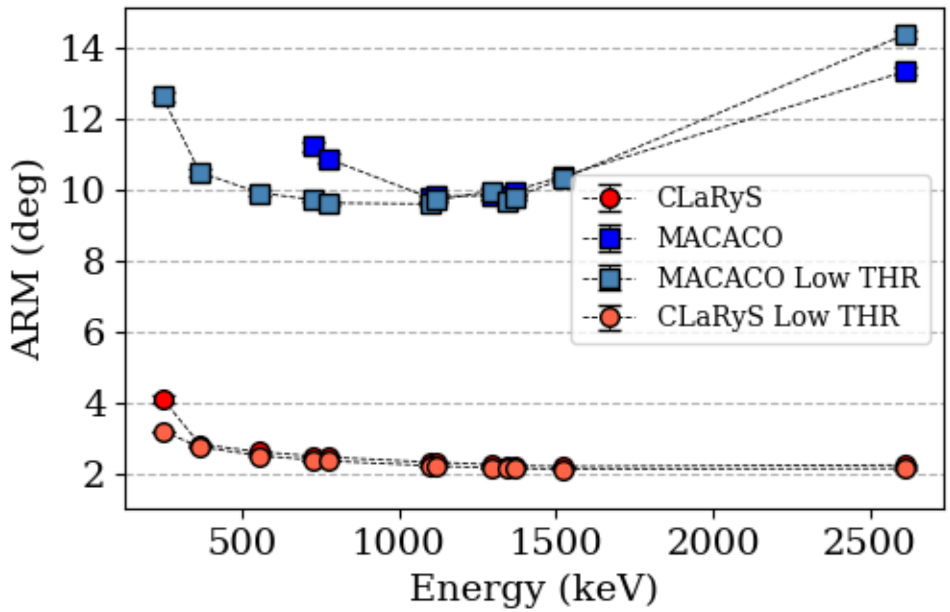
Only 2-single-coincidences are considered

CLaRyS compared to MACACO

- higher efficiency values in this energy range (mainly due to the thicker absorber)
- less sensitive to the energy THR due to the higher scattering acceptance angle
- stronger decrease with energy (thinner scatterer layer)
- pair creation is less significant (lower Z scatterer)

Comparison of the prototypes: ARM

Angular Resolution measure



Energy Resolution in the scatterer

MACACO: 8.5% @ 511 keV
CLaRyS: 1.56% @ 511 keV

X-Y spatial resolution

MACACO: 2 mm sigma
CLaRyS: 0.4 mm sigma
(assuming normal distribution in the 1.4 mm strip)

Better results for ClaRys mainly due to better energy resolution in the scatterer

Conclusions and Future work

Conclusions

- A versatile module to simulate Compton Cameras within Gate has been developed
- The module has been successfully validated against experimental data
- The module will facilitate the investigation of new prototypes (no need for code development)
- The module allows to compare easily the performance of different prototypes (under the same analysis)

Future

- This module will be added in the next GATE release
- A publication is currently being written

Thank you for your attention