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ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

AI-Legs Status Report

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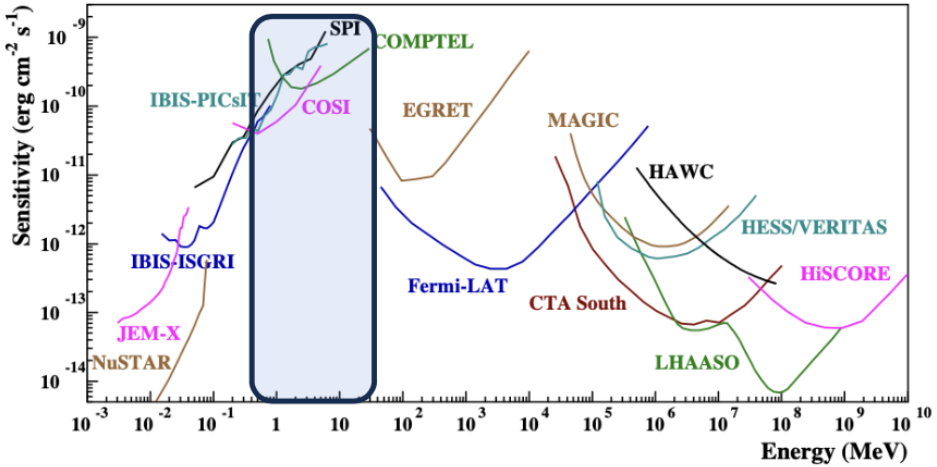
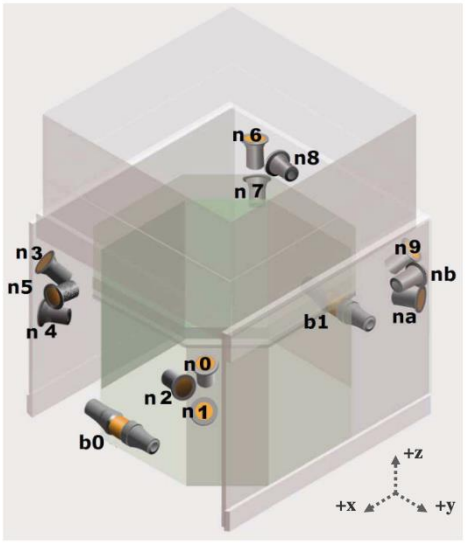
Scientific Rationale

- **The instrumental developments in gamma astronomy in the MeV energy range are a cornerstone for various scientific topics:**
  - **Phenomenology of nuclear processes**
  - **Nature of compact objects**
  - **Cosmic rays sources and gamma-ray bursts (GRBs)**

Gamma-ray astronomy in the MeV energy range shows a lack of sensitivity compared to other gamma-ray energy bands.





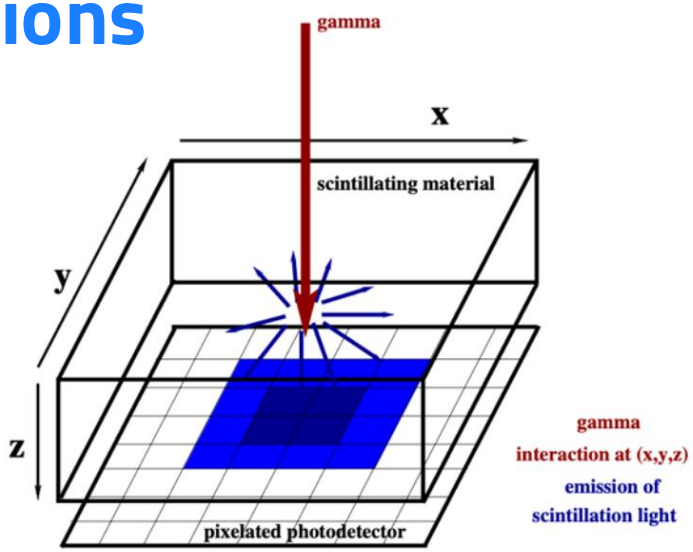
Application for calorimetric modules installed on board space missions

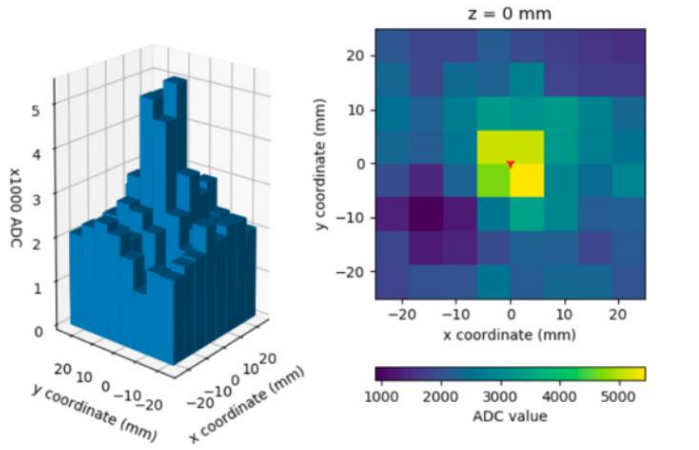
Exp Astron **24**, 47–88 (2009)

The sensitivity of a future space observatory, dedicated to the MeV energy range, should be increased by one to two orders of magnitude compared to past observatories.

Technical Objectives, Methodologies and Solutions

- The goal of this project is to develop and test a DL algorithm based for low energy gamma ray imaging in space calorimeters.
- Test different neural networks (Deep Neural Network, Convolutional Neural Network, Recurrent Neural Network)
- Require a detailed MonteCarlo simulation of the experimental setup → Geant4, MatLab





Simulation overview

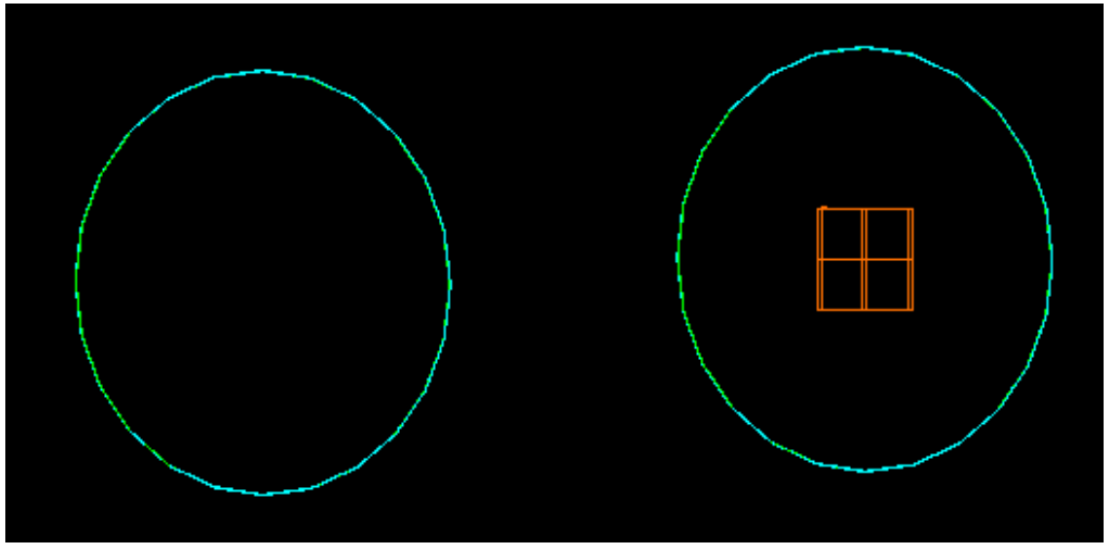
- Simulation of scintillation light detection in single block crystal with photons sensitive area (SiPM proxy)
- Provided with optical photons tracing, crystal rotation and several materials
- Built with Geant4 toolkit on INFN IBISCO cluster in Naples
- SiPM response simulated with external code in MatLab

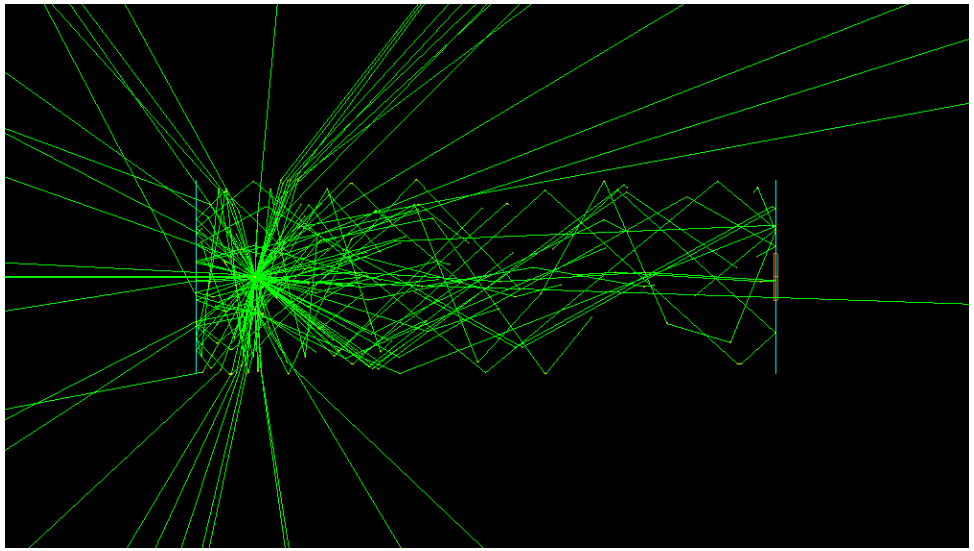
Geometry and beam setup

- single cylindrical calorimeter (15 cm long x 5 cm diameter) with 2x2 SiPM matrix (6x6x1 mm^3)
- Scalable in crystal dimension and size of matrix
- Plastic-plastic border interface between crystal and wrapping, with 0.98 reflectivity

- Results with BGO material, but more available

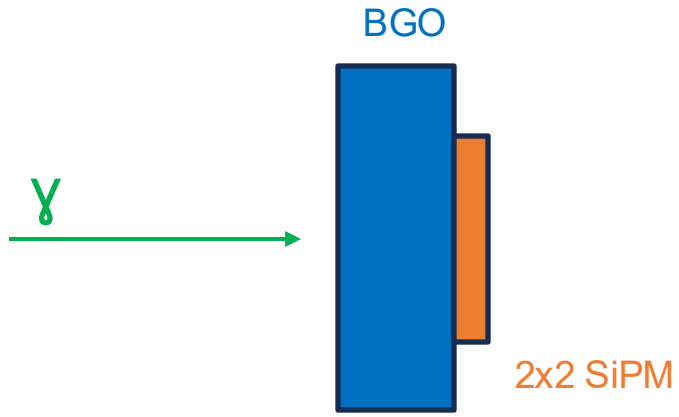
- gamma rays at the MeV scale, monochromatic, fixed central spot and angular direction
- Can change energy value (direction) or introduce transversal or angular dispersion

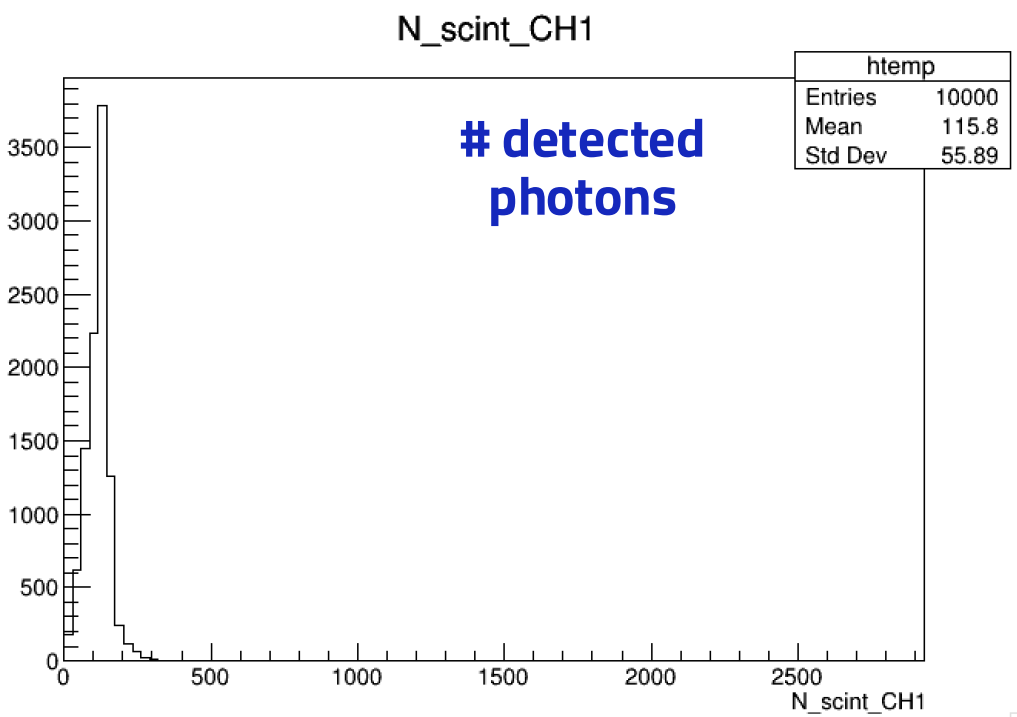


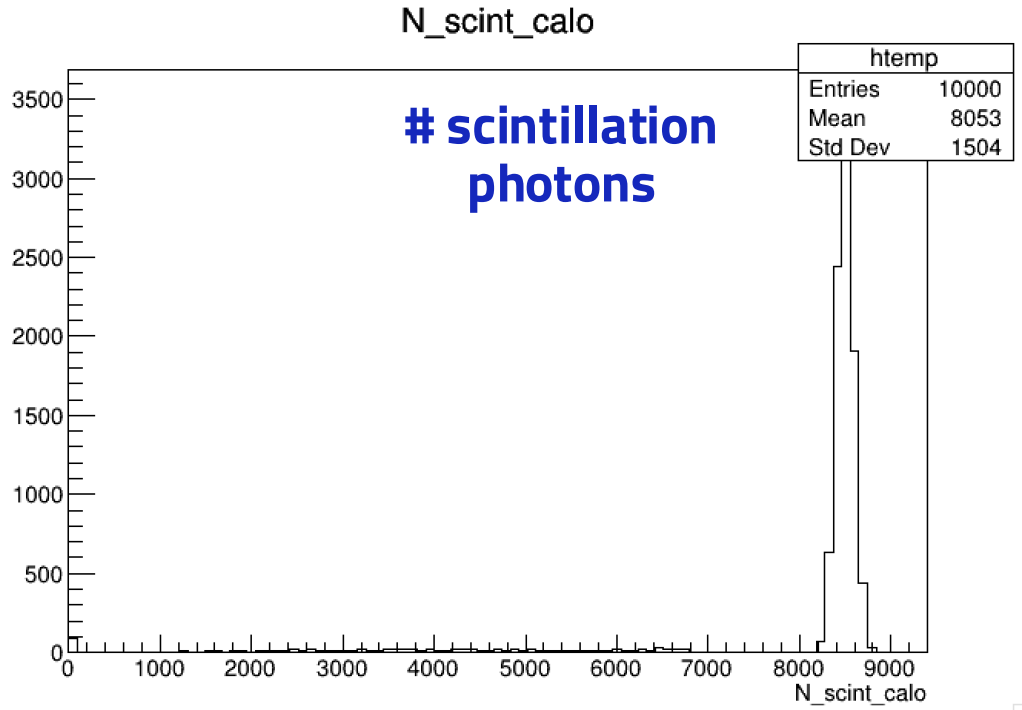


Main results

- 10k gamma particles with 1 MeV energy, aimed at the center of crystal
- Number of scintillation photons produced in crystal and arriving on SiPM volumes (BGO: 8500 photons/MeV)

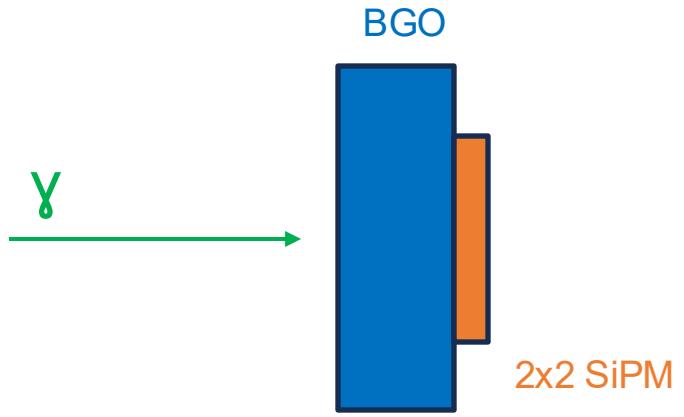


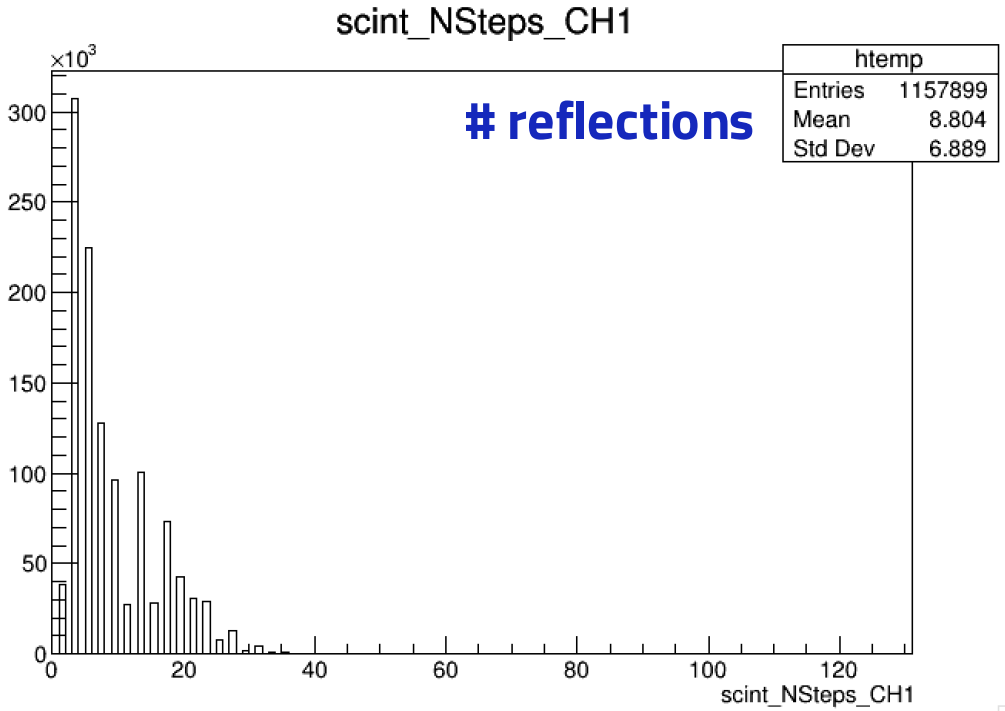


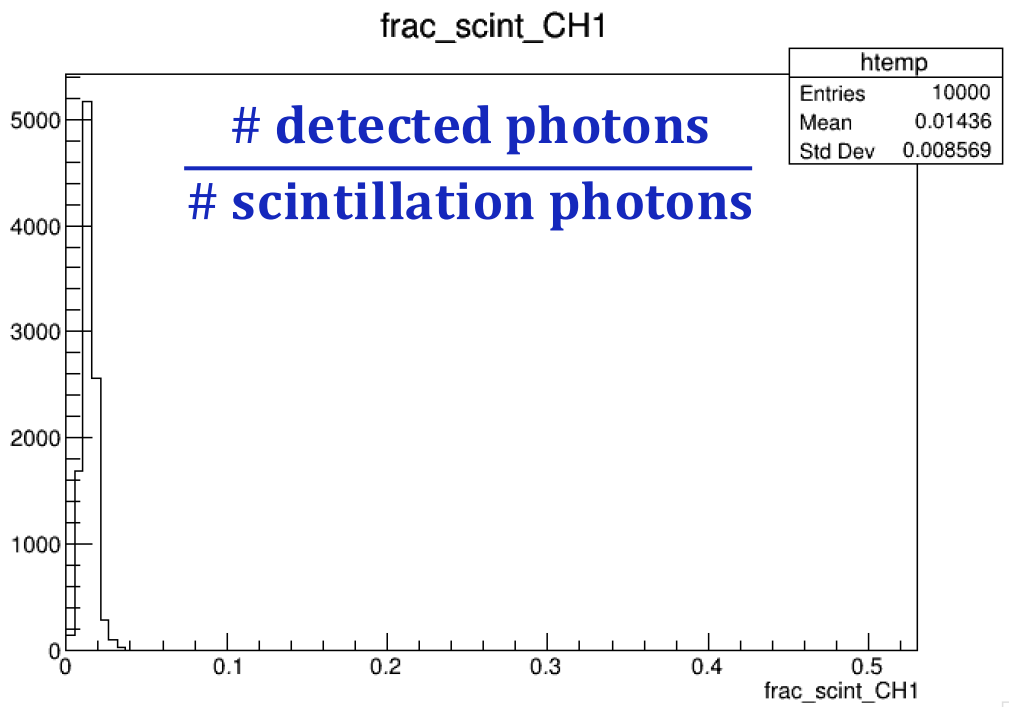


Main results

- 10k gamma particles with 1 MeV energy, aimed at the center of crystal
- Number of reflections and fraction of photons arriving on SiPMs volumes



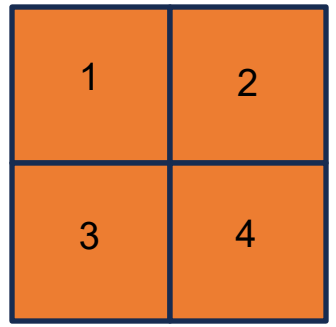


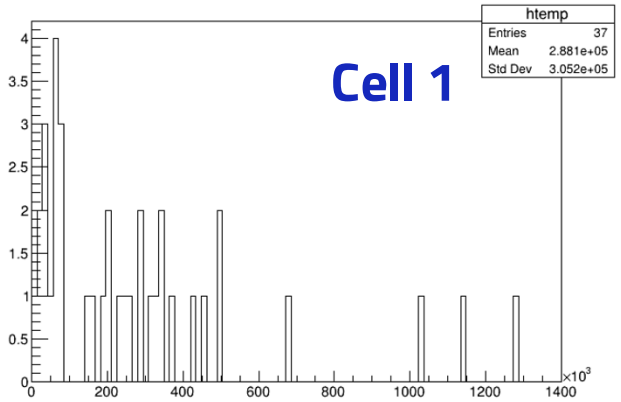


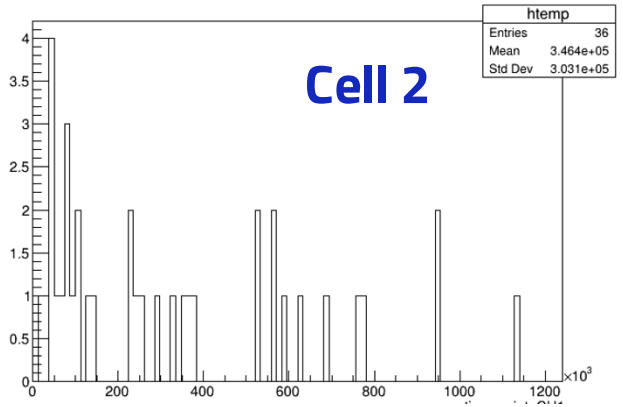
Main results

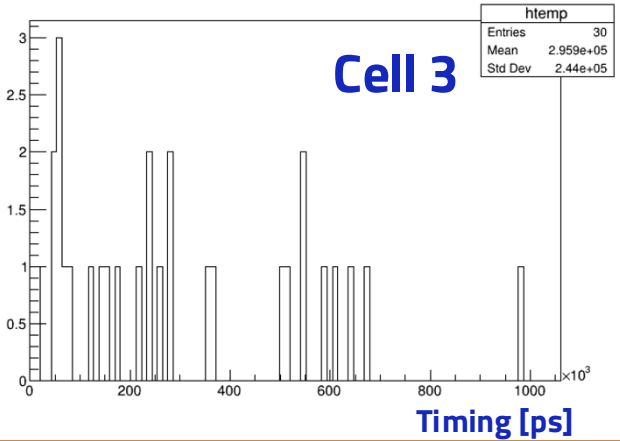
- Time of arrival of photons on SiPMs (decay time τ: 317 ns)
- Cumulative distribution for all events and 2x2 matrix for event with ID 1

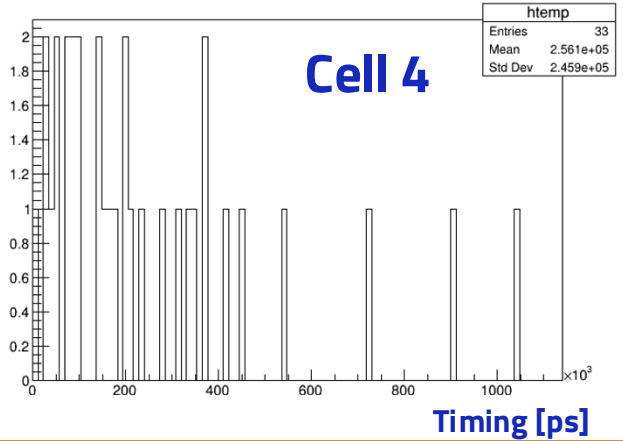
2x2 SiPM

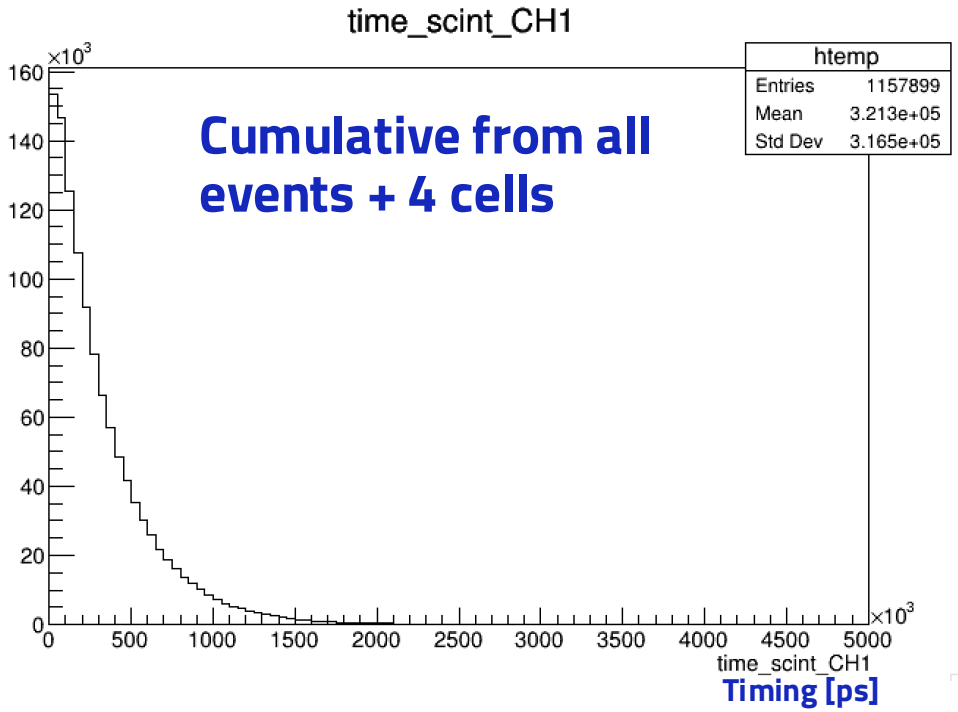








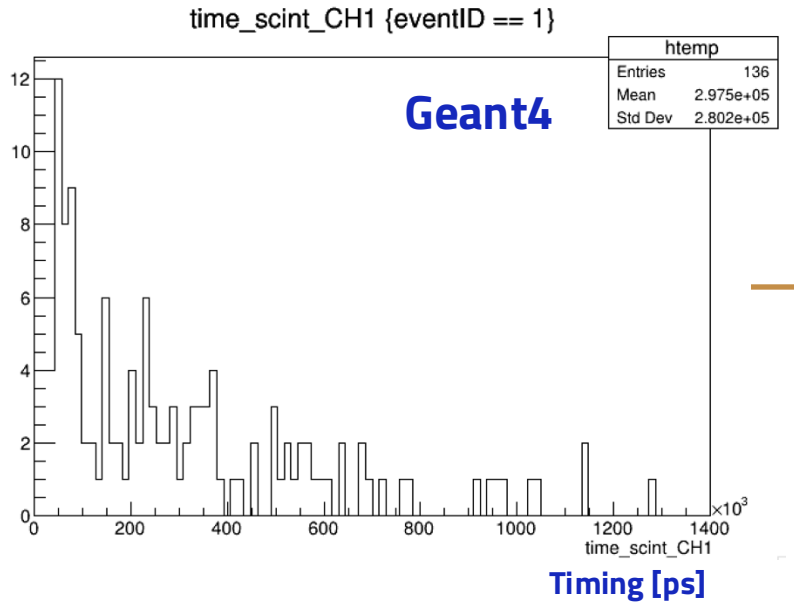


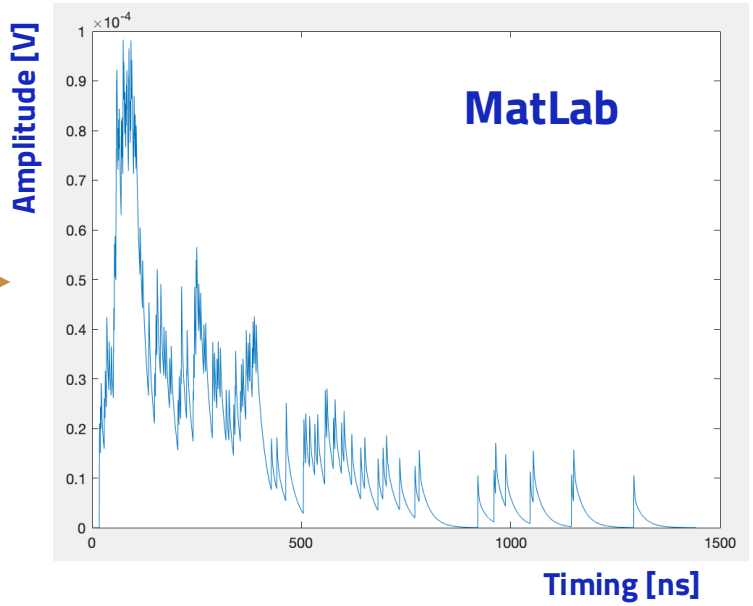


Main results

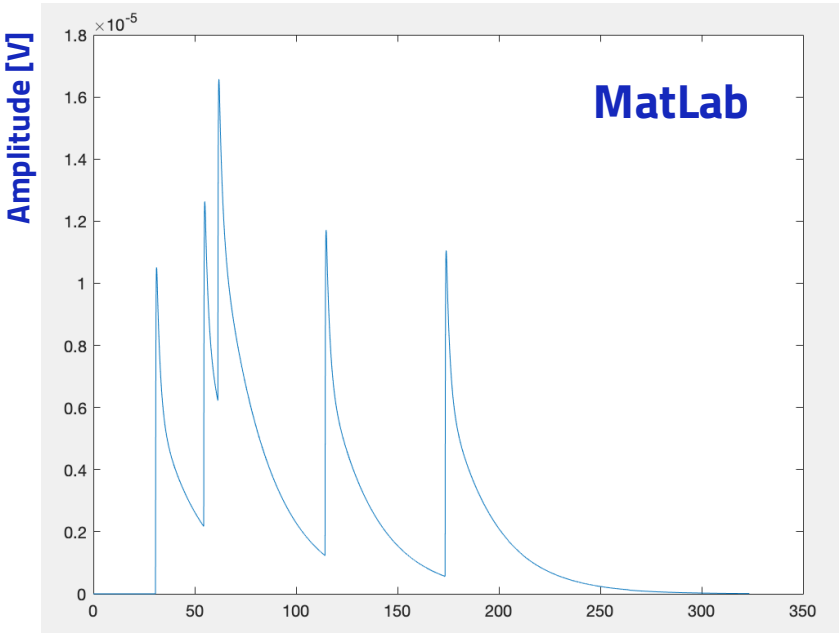
- **Timing output from Geant4 is processed by MatLab code to generate signal waveform**

Gamma signal at 1 MeV





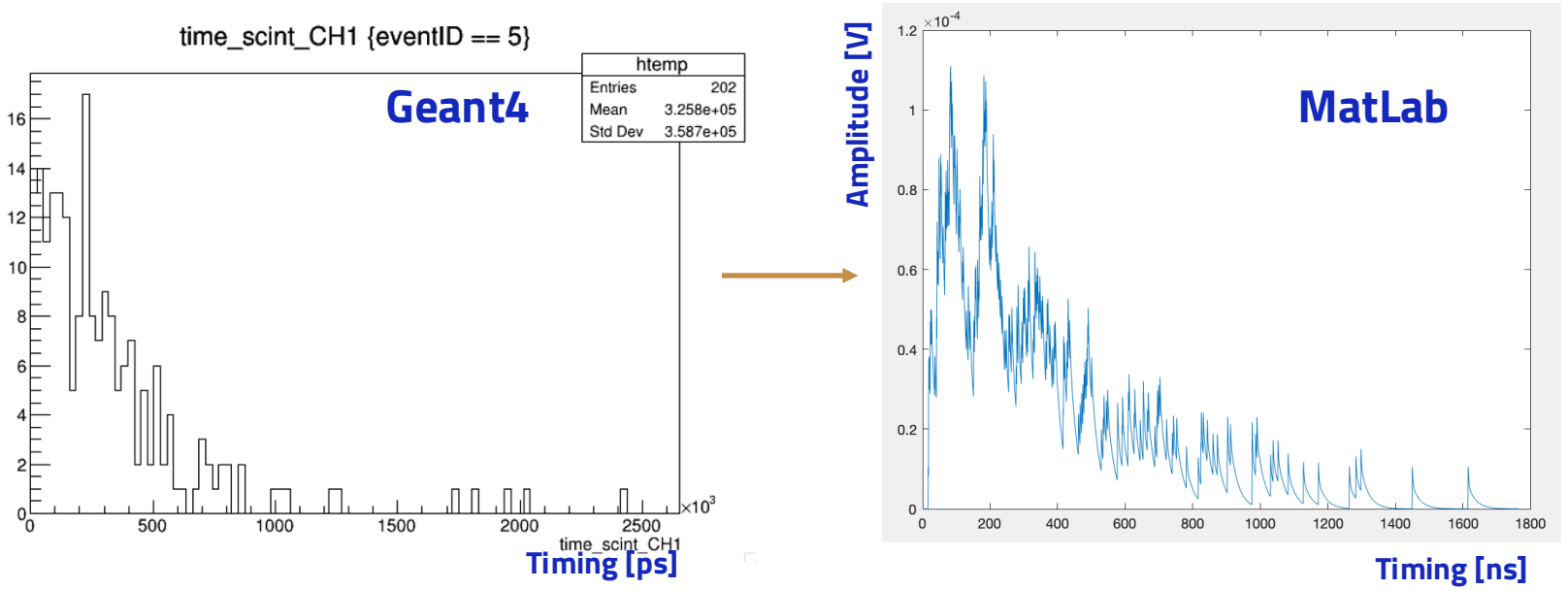
Dark count noise



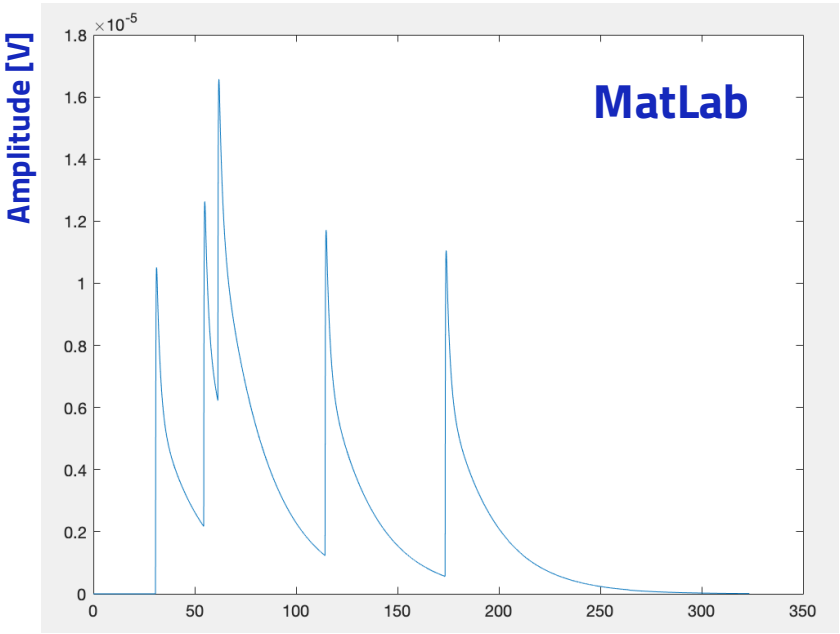
Main results

- **Timing output from Geant4 is processed by MatLab code to generate signal waveform**

Gamma signal at 1.5 MeV

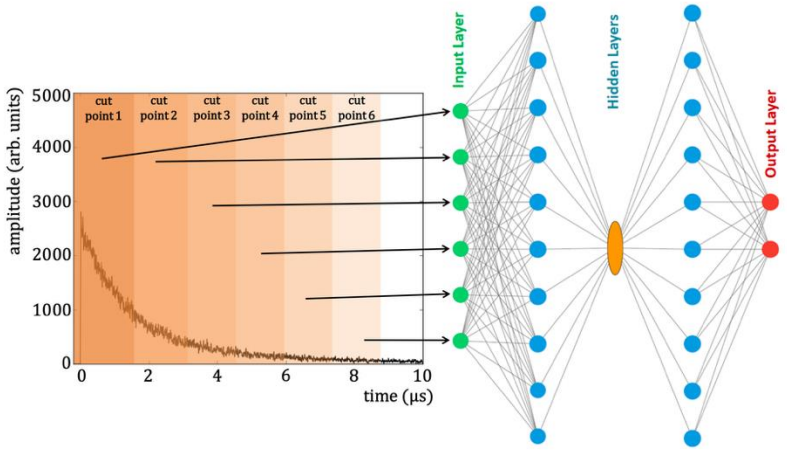


Dark count noise



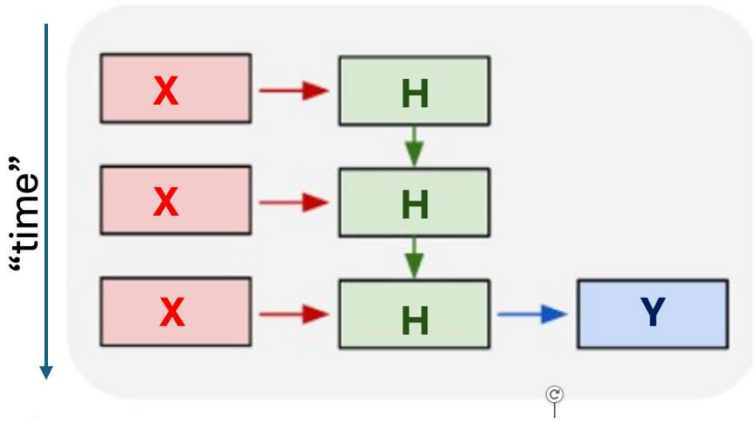
Final Steps: Machine Learning algorithms ideas

Deep Neural Network (DNN)



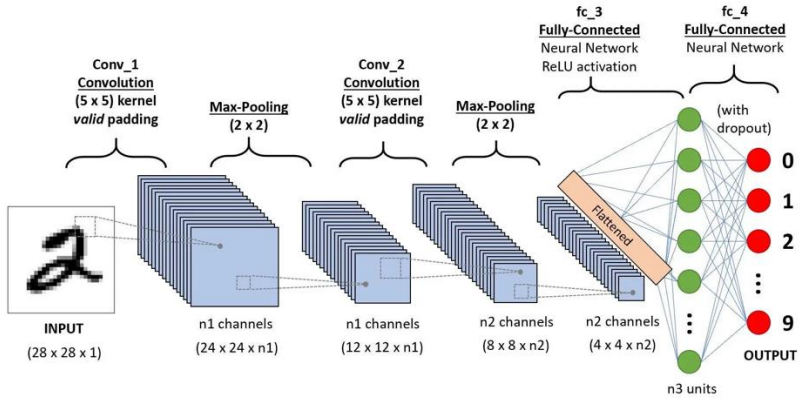
- Expected number of parameters: O(<10^3) → reasonable training and computation time
- Very simple atchitecture

Recurrent Neural Network (RNN)



- The pulse-data that is being given to the RNN as input is a time-series data.
- We could use a LSTM architecture, a RNN with more powerful update function and different backpropagation

Convolutional Neural Network (CNN)



- The waveform figure genrated by the time series is processed by a CNN
- Very powerful since it actually learns the shape of the SiPM impulses, also commonly used in many research fields

Thank you for your attention!