Performance and Geant4 simulation of particle detection with low-cost CMOS technology

Miguel Bonnett, Rodrigo Helaconde, Carlos Soncco, **José Bazo**, Alberto Gago

jbazo@pucp.edu.pe

Grupo de Altas Energías

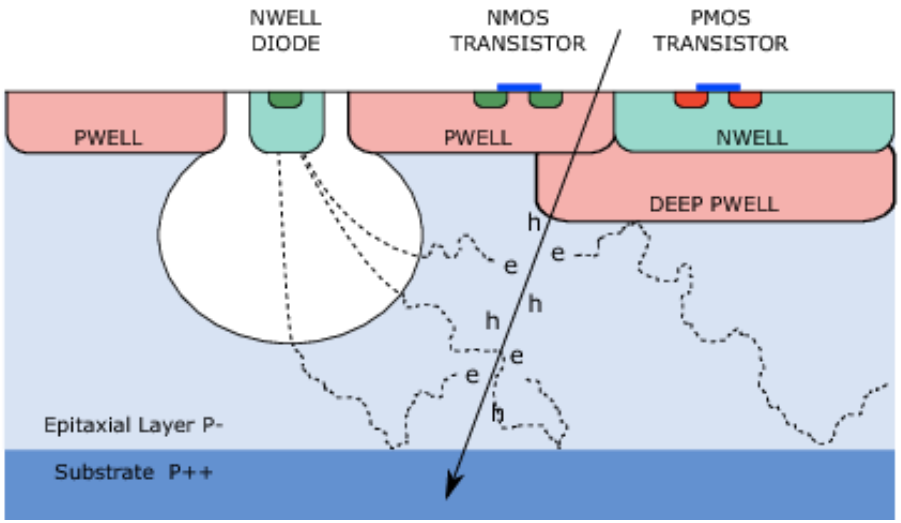
November 14th, Universidad San Francisco de Quito

Imaging sensors

Complementary Metal Oxide Semiconductors (**CMOS**): used to detect particles: gamma rays, electrons, alphas, etc.

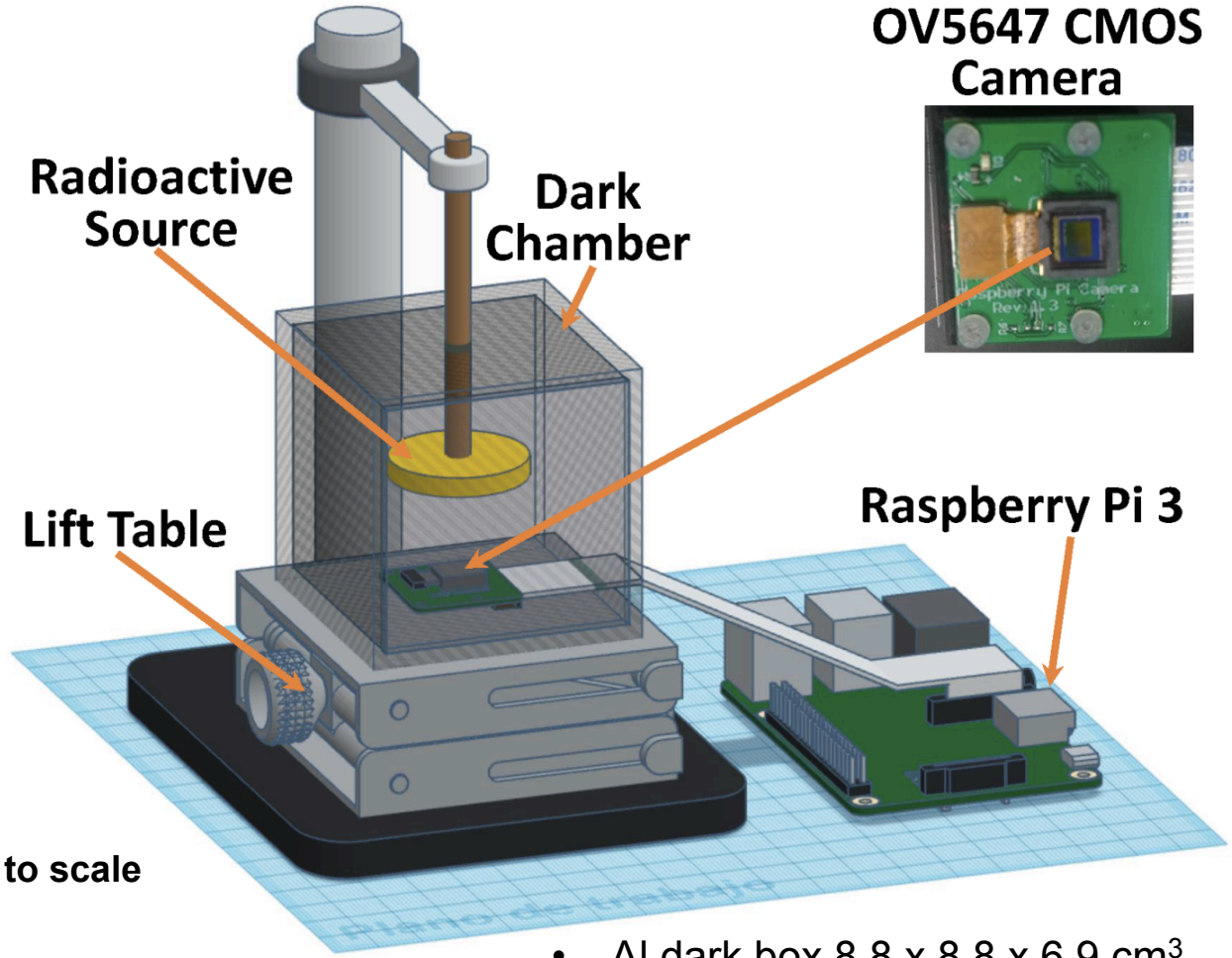
Examples:

- discrimination between alpha and non-alpha particles by identifying ionization events
- photon imaging using fluorescence X-rays and gamma rays



physi.uni-heidelberg.de/~sma/teaching/ParticleDetectors2/

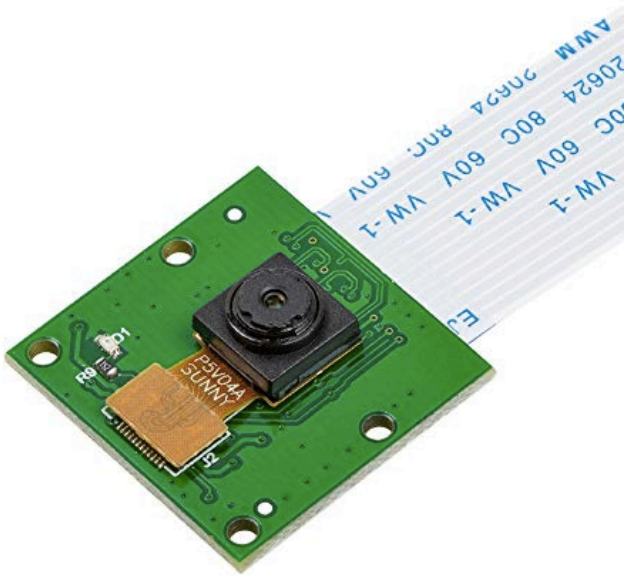
Experimental Setup

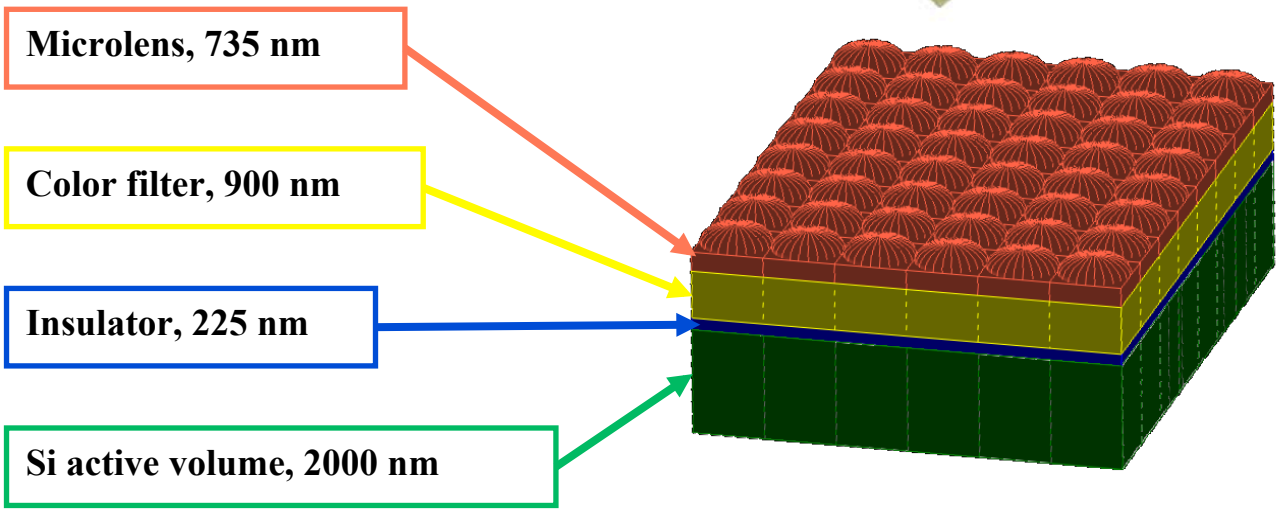


- Al dark box 8.8 x 8.8 x 6.9 cm^3
- Raspberry Pi 3b: small, low-cost single-board computer
- CMOS: 3.67 × 2.73 mm^2 active area
- Radioactive source: 0.6 cm diameter, height of 0.28 cm

OmniVision OV5647 sensor

- **5 Mp** low-cost (<$15) CMOS camera
- Pixel pitch = 1.4 x 1.4 μm^2





OmniVision OV5647 sensor

For **stability** in data acquisition fixed settings:

- **Shutter speed** = 0.5 s (frame exposure time)
- **Image resolution** = 2592x1944$ pixels (5 Mp) = maximum
- **Analog gain** = 8, max stable response without image distortion
- **Digital gain** = 1, no artificial gain
- **White balance** = 1, no color correction

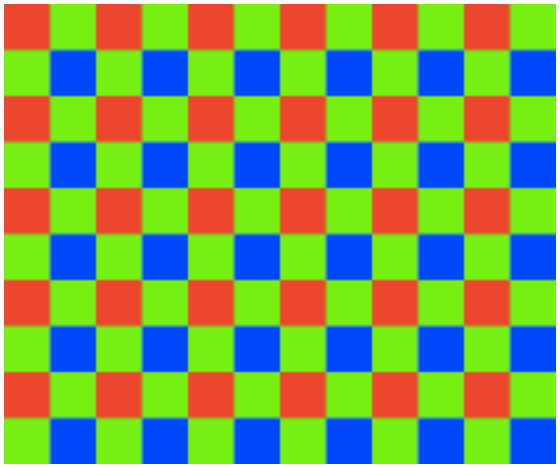


Image capture:

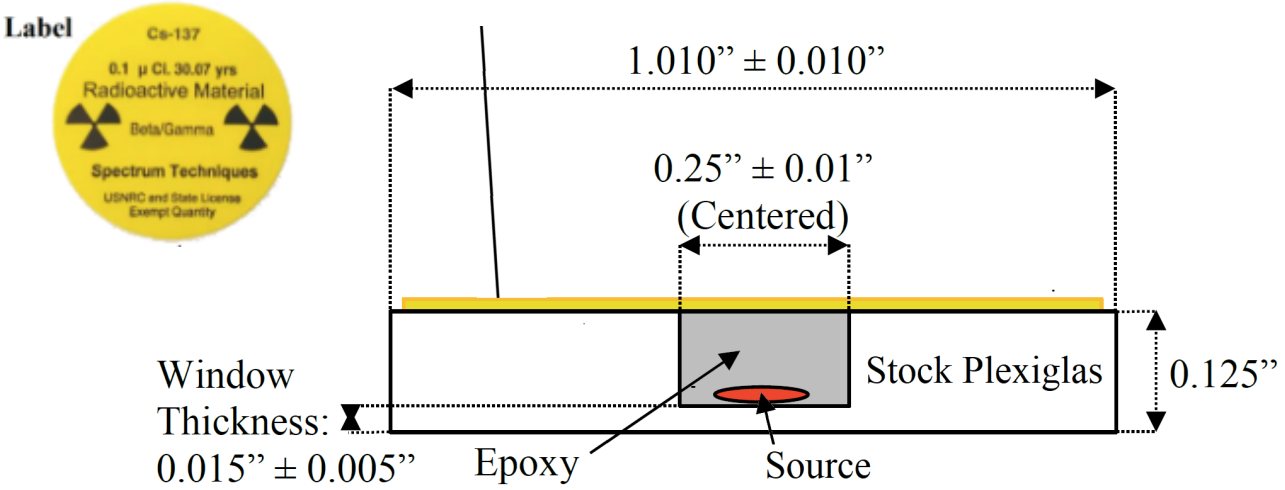
- **10-bit Bayer format:** 3 color matrices R(25%) G(50%) B(25%)
- Measure intensity: add matrices

Radioactive sources

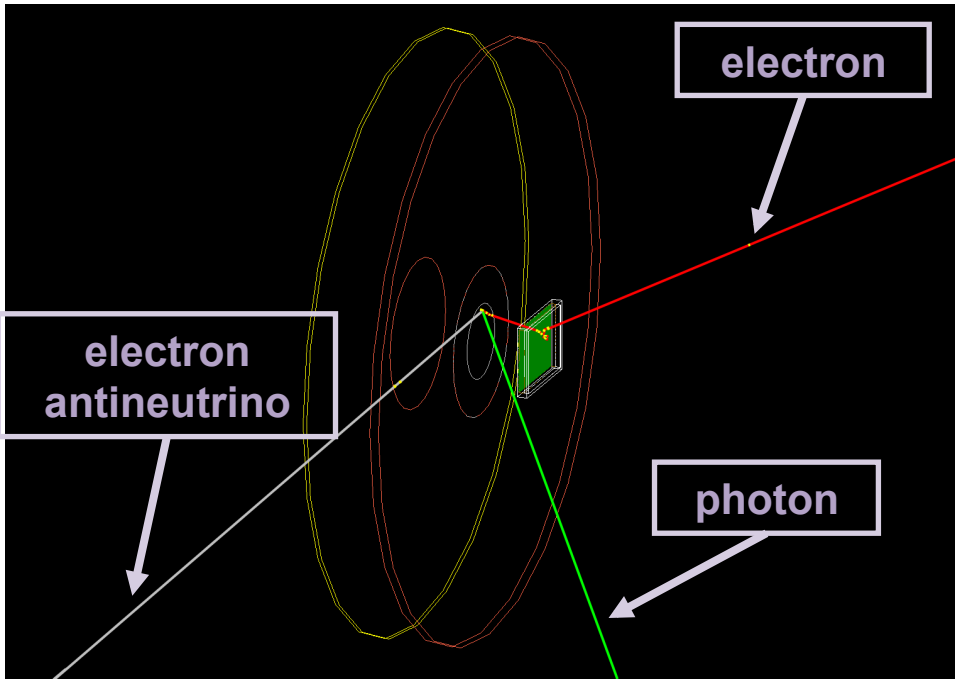
Beta emitters:

- **Sr90**: electrons E_{max}=0.546 MeV -> Y90: electrons E_{max}=2.28 MeV
  Activity: 3174 Bq

- **Cs137**: electrons E=0.514 MeV -> Ba-137m: 0.662 MeV photons
  Activity: 7982 Bq



Geant4 simulation



Simulate 0.5 s:

- Sr90: 1587 events
- Cs137: 3991 events

- Geant4 gives: energy deposited in pixel matrix

Further steps:

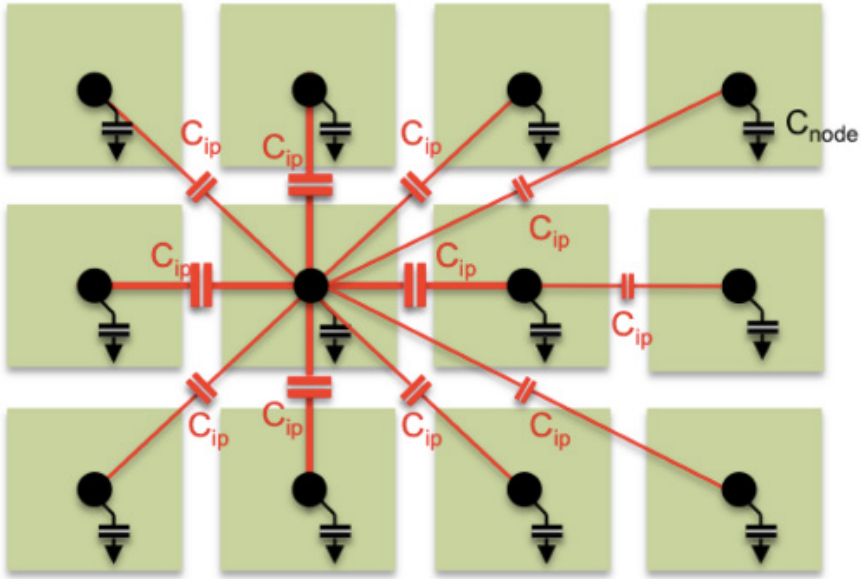
- Convert to electrons in Si using 3.6 eV factor (energy to generate e^-/hole pair)
- Apply Interpixel Capacitance (IPC)
- Convert electron number into ADC counts:

  FWC (full well capacity) = 4300 e^- = 1023 ADC

  Minimum = 5 e^- = 1 ADC

Inter Pixel Capacitance (IPC)

Crosstalk: fringing fields from capacitors in each pixel cause the voltage readings in a pixel to depend on the charges in neighboring pixels



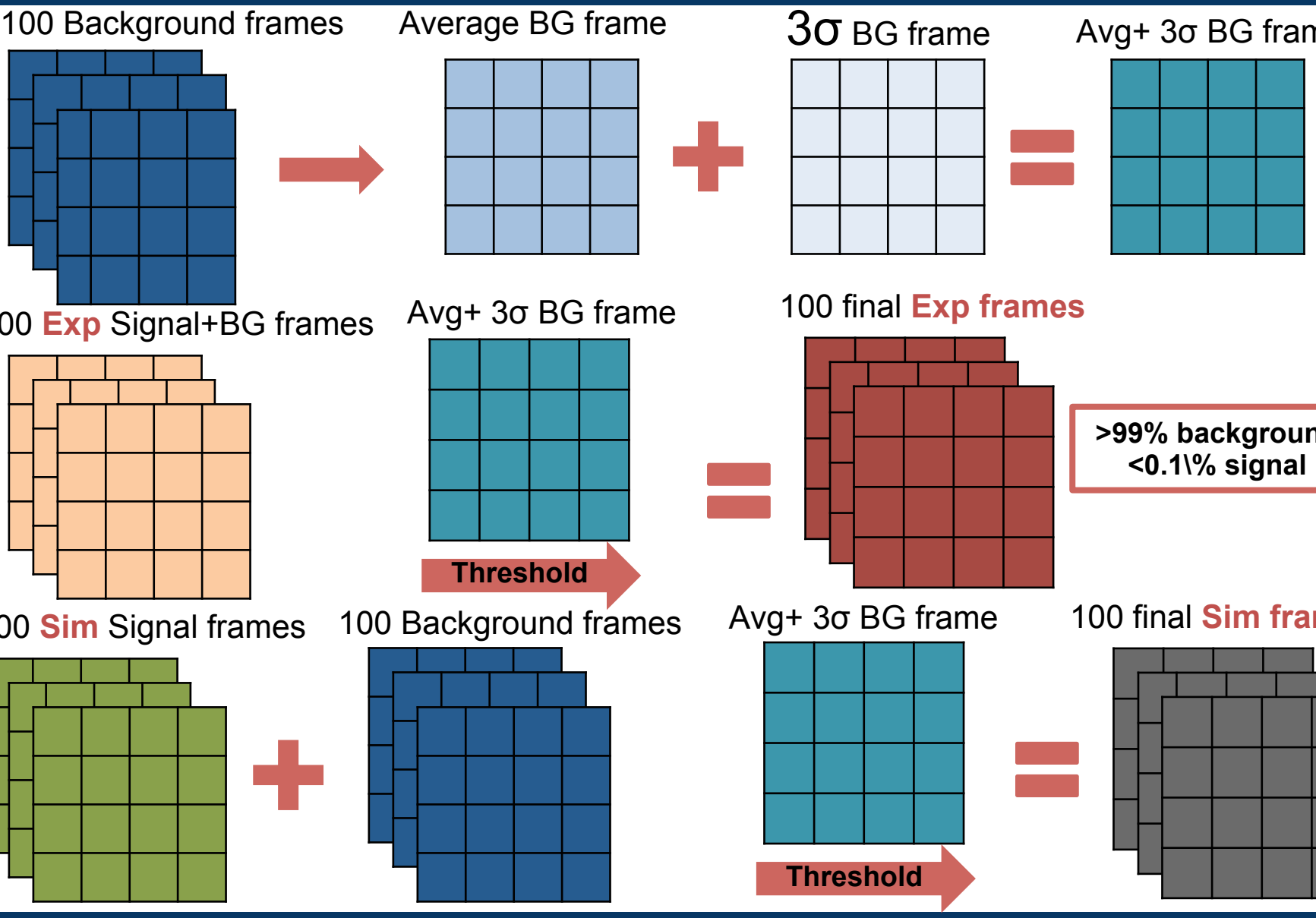
https://doi.org/10.1364/AO.51.002877

Two-dimensional symmetry model

ξ^2	ξ	ξ^2
ξ	$1-4(\xi+\xi^2)$	ξ
ξ^2	ξ	ξ^2

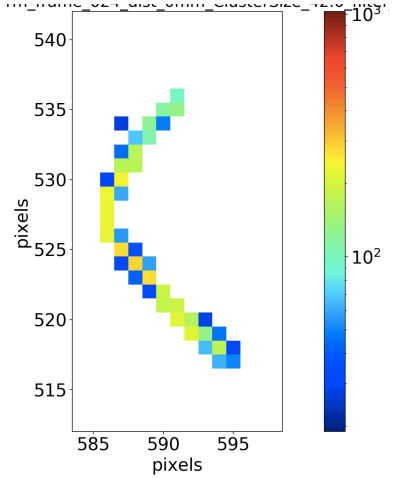
Standard value of ξ=0.075

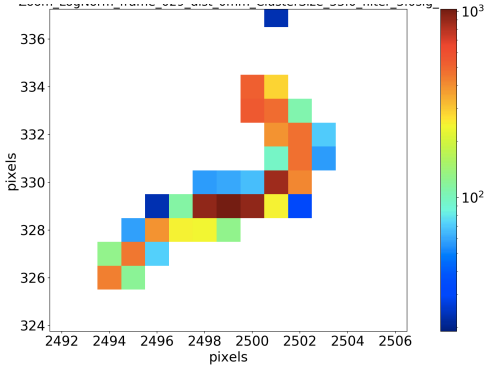
Background subtraction by pixel

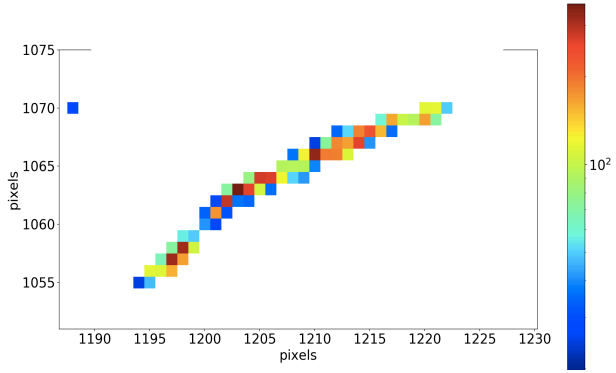


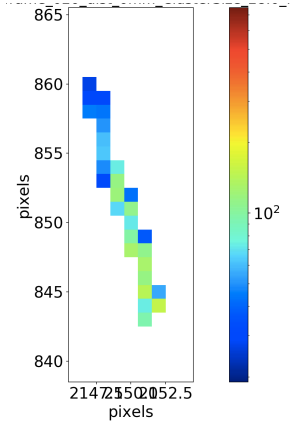
Pixel Clusters

Using **OpenCV libraries** to find clusters:



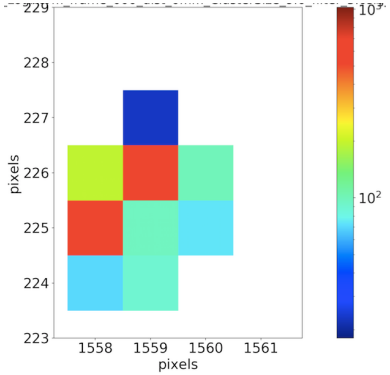


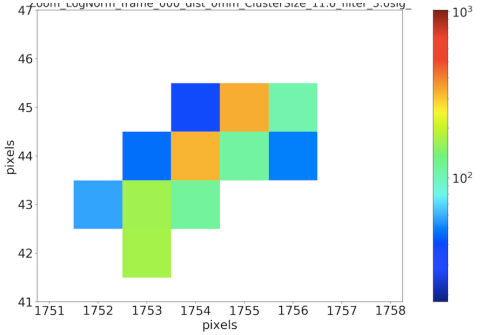


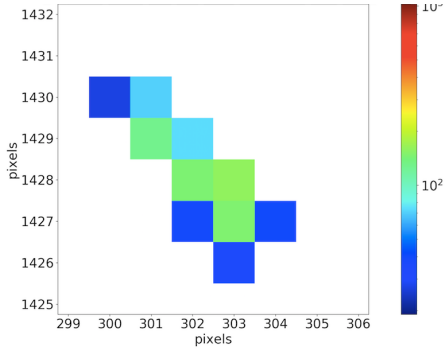


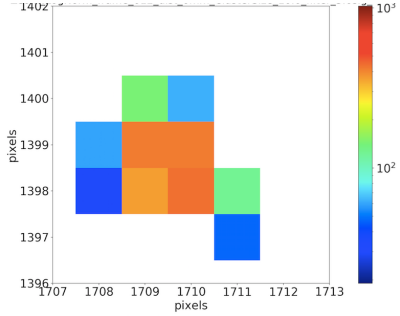
For each cluster calculate:

- **size** (i.e. number of pixels),
- **mean ADC**,
- **maximum ADC**
- **total ADC number**



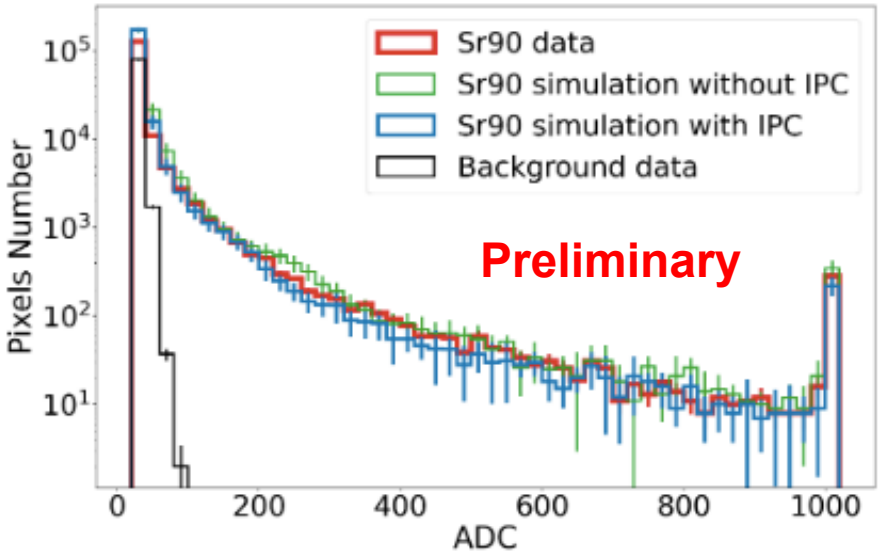


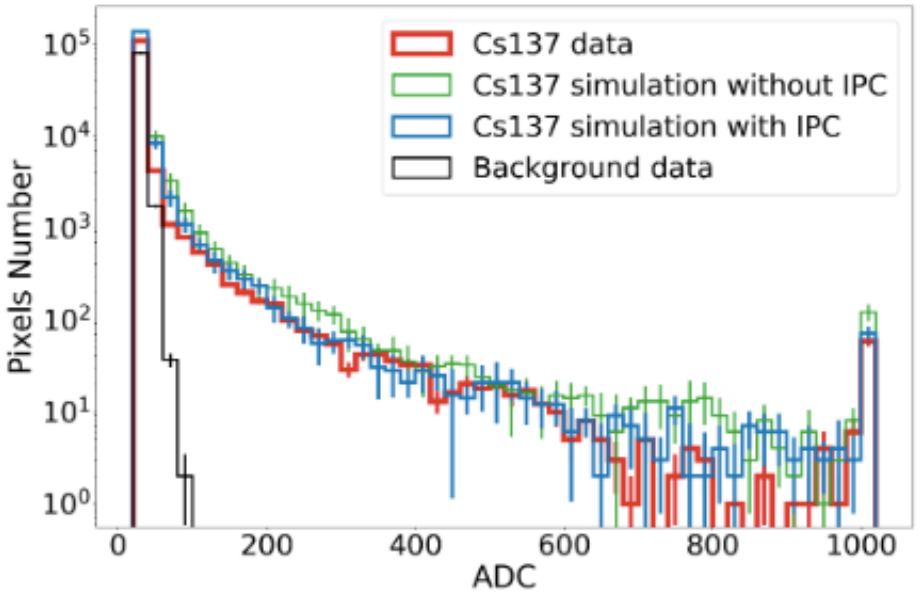




Results

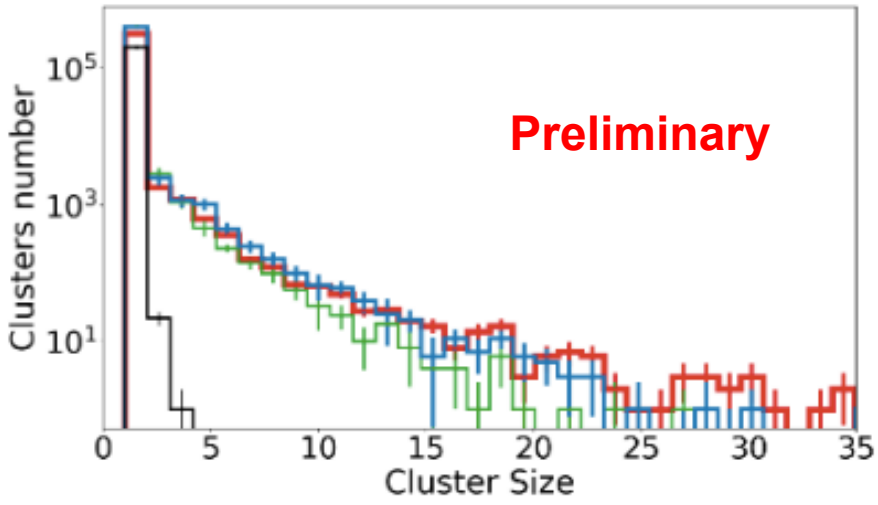
Data/Simulation comparison at pixel level

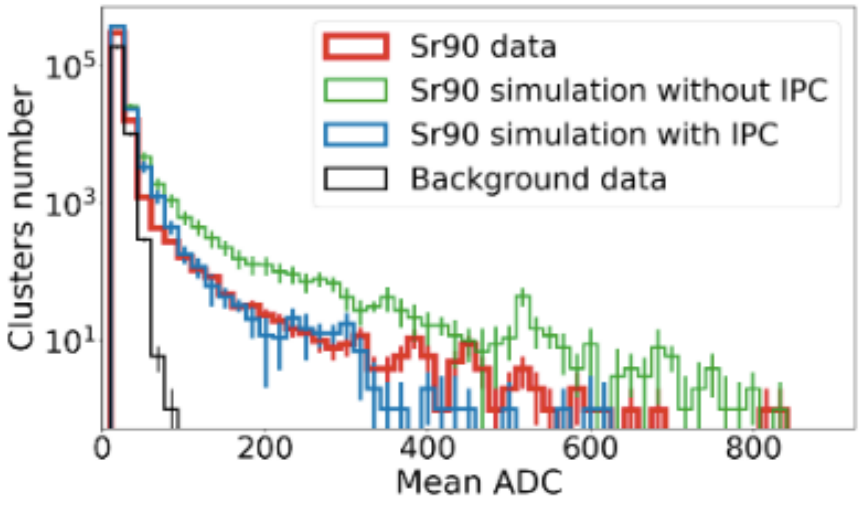


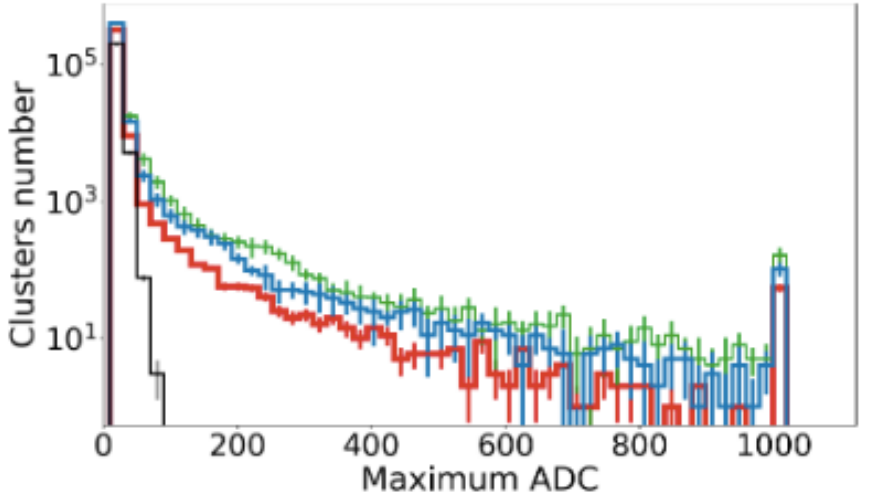


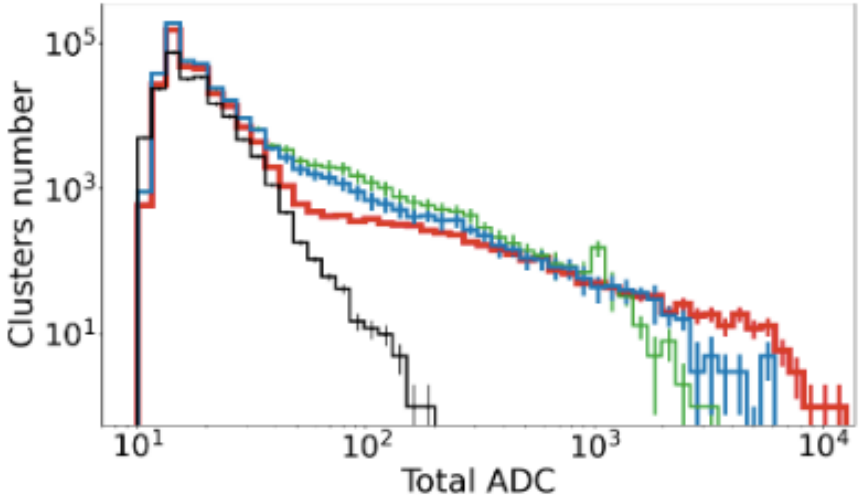
Results

Data/Simulation comparison at cluster level





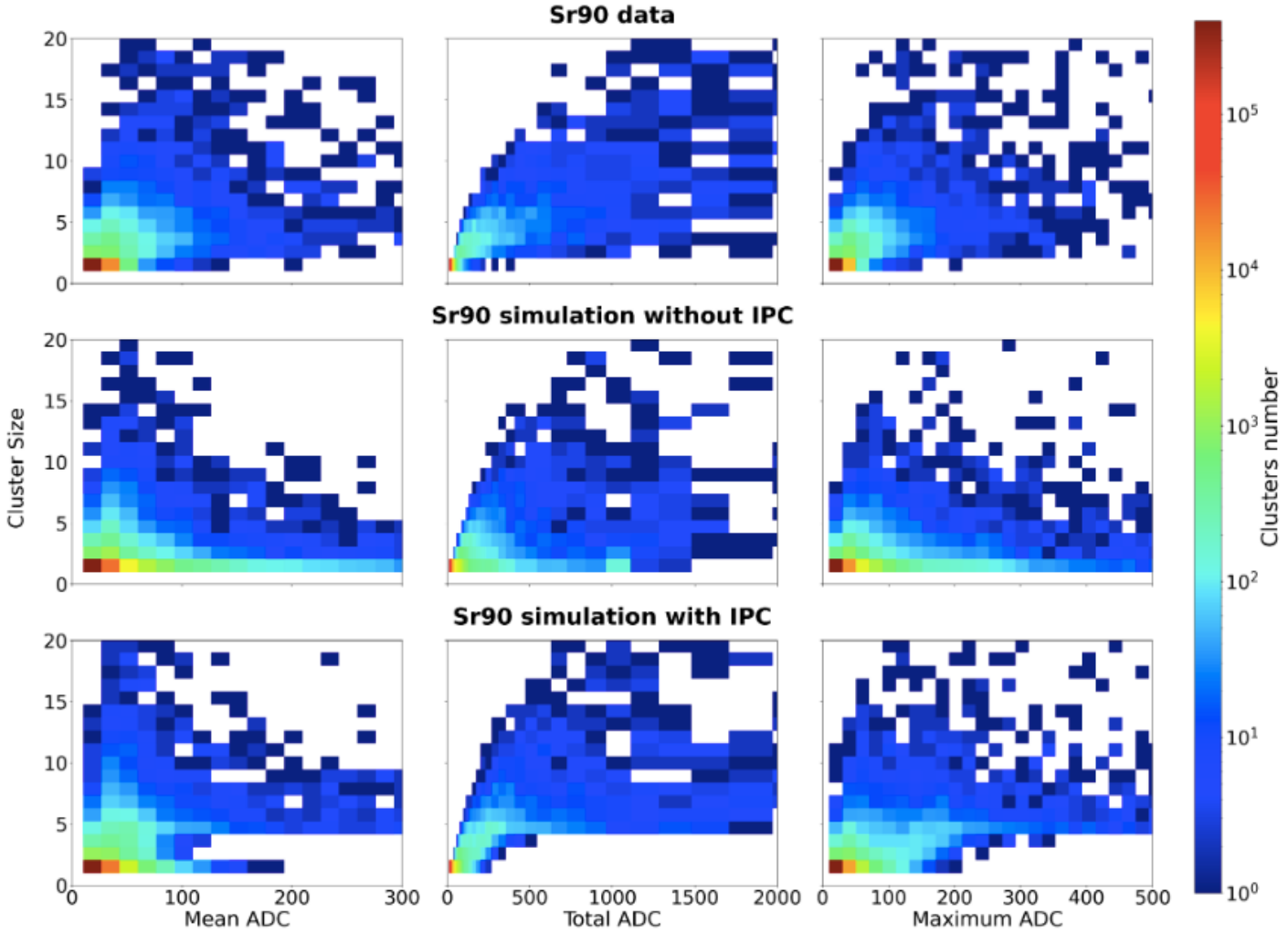




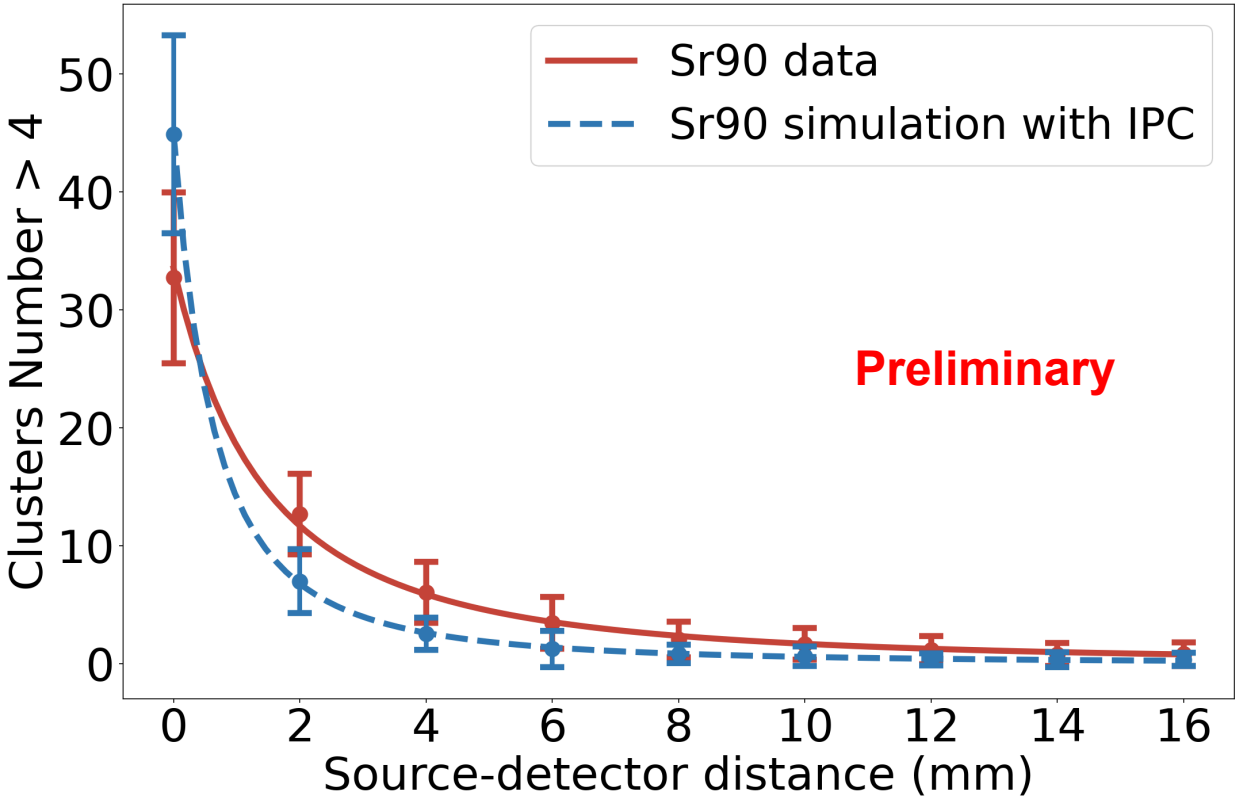
Results

Data/Simulation comparison: variables correlation at cluster level

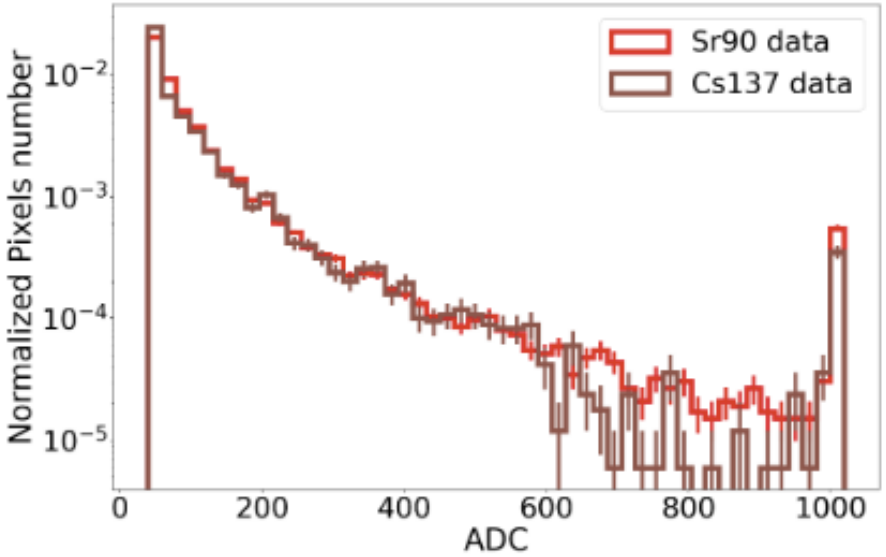
Preliminary

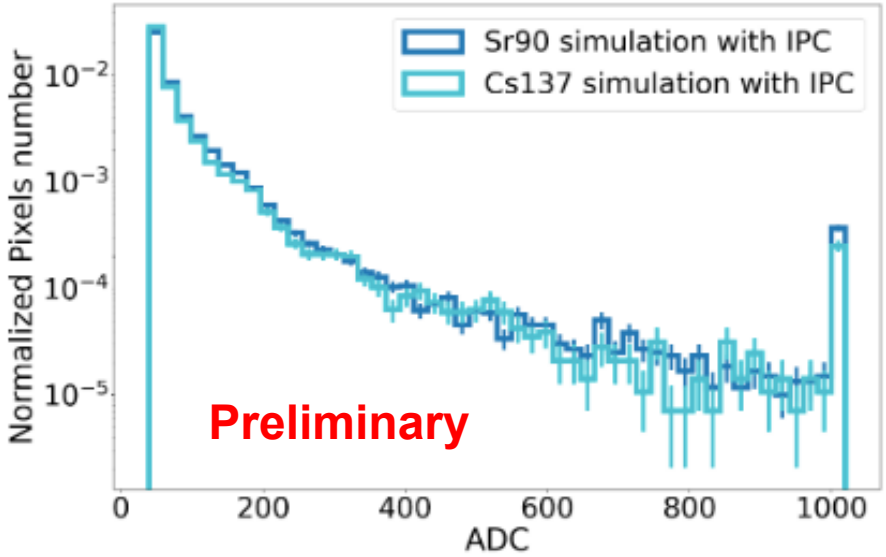


Source distance dependence



Source comparison





Similar distribution between radioactive sources

Conclusions

- Experimental setup for data acquisition with CMOS camera and Raspberry Pi.
- Camera settings for stable and sensitive measurements.
- Background reduction procedure: from 99% pixels to >0.1% signal pixels.
- Implemented detailed Geant4 simulation, including energy to ADC conversion and IPC crosstalk.
- Good agreement (within 1 sigma) between experiment and simulation at pixel, cluster and correlation level.
- Experimental data and simulation follow an inverse square distance distribution.
- It is not possible to distinguish between radioactive sources.

Thanks!

Grupo de Altas Energías (desde 2002)

Profesores Investigadores:

https://investigacion.pucp.edu.pe/grupos/hep/

Dr. Joel Jones

Dr. Alberto Gago
Líder del Grupo

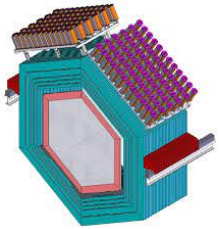
Dr. José Bazo

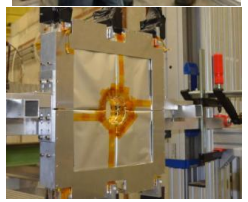
Estudiantes:

- Doctorado: 9
- Maestría: 4
- Egresados: 4
- Pregrado: 9

Graduados: 1 doctorado, 26 maestría, 5 licenciatura

Fermilab

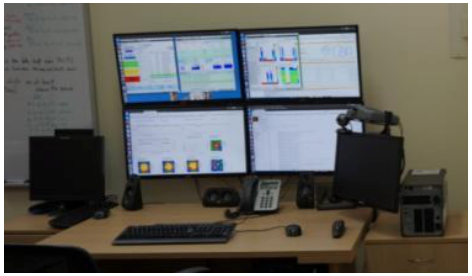




CERN

ALICE

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT



SWGO
The Southern Wide-field Gamma-ray Observatory

Teoría/fenomenología

- Oscilaciones de neutrinos
- Neutrinos pesados
- Supersimetría
- Nueva física en colisionadores
- Astropartículas

Experimentos Internacionales

- MINERvA (2006)
- ALICE (2009)
- DUNE (2017)
- SWGO (2019)

Desarrollo de detectores

- SiPM, webcam,Arduino, Raspberry Pi
- Muones y fuentes radioactivas

Source comparison