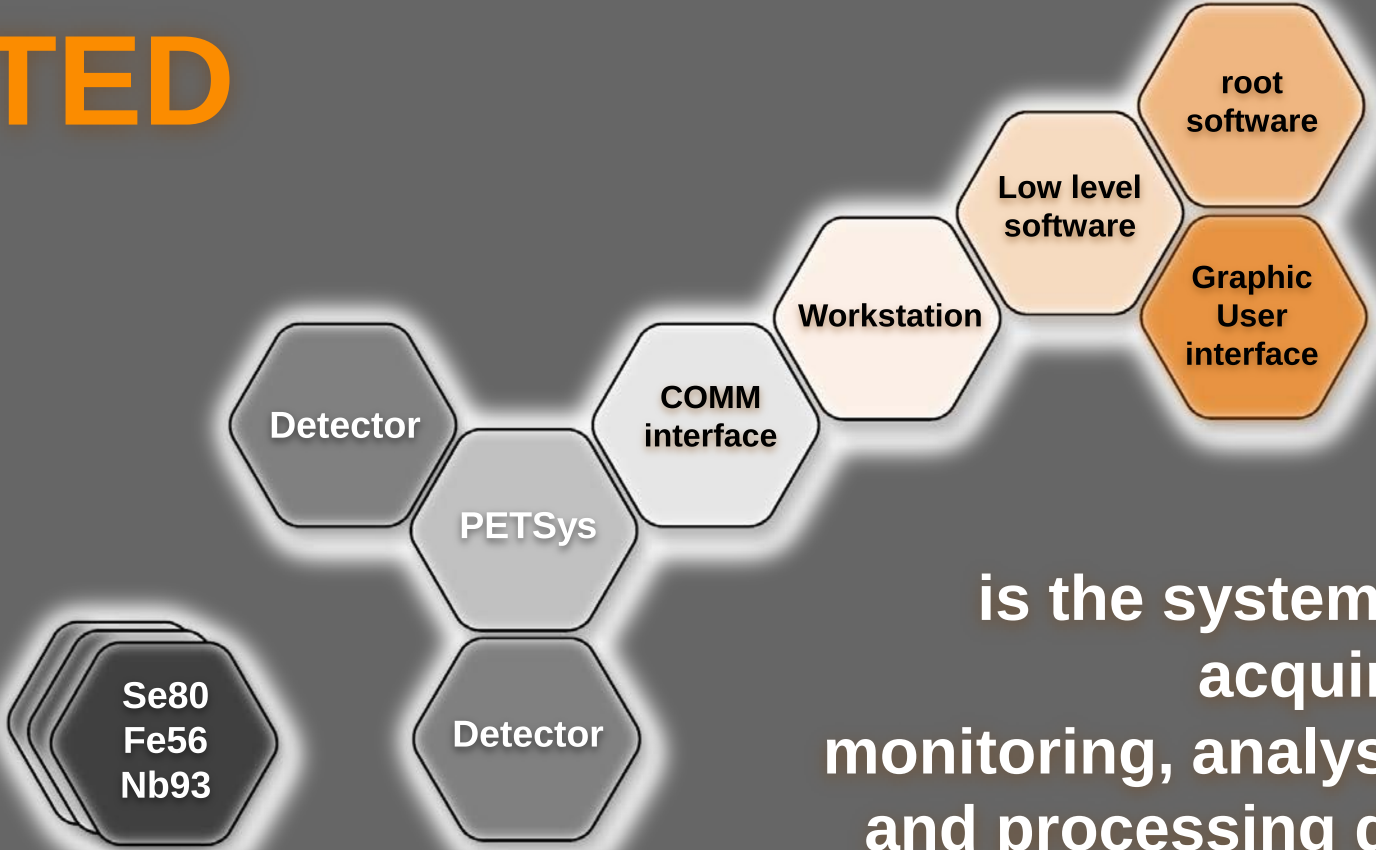
i-TED spatial calibration

Detectors using monolithic crystals and pixelated photomultipliers need an energy and spatial calibration. This characterization will improve the position determination of the gamma-ray hit.

HYMNS High-sensitivitY Measurements of key stellar Nucleo-Synthesis reactions

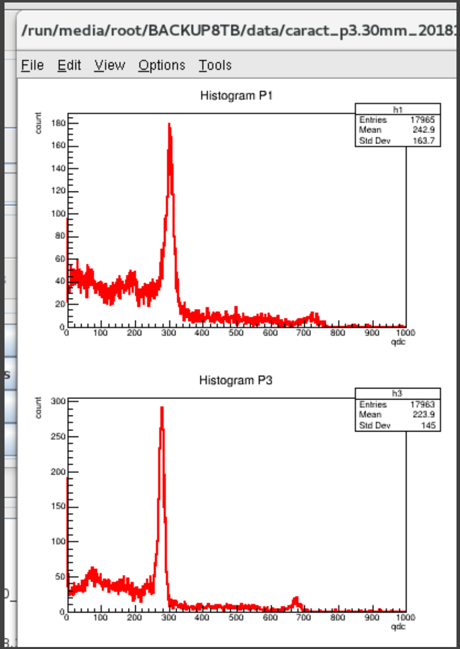
Cesar Domingo, Luis Caballero, Victor Babiano, Ion Ladarescu, David Calvo, Pablo Olleros, José Luis Taín, Francisco Calviño, Adría Casanovas, Ariel Tarifeño, Victor Alcayne, Carlos Guerrero, Mª Angeles Millán, Mª Teresa Rodriguez, n_TOF Collaborations & many collaborators

i-TED



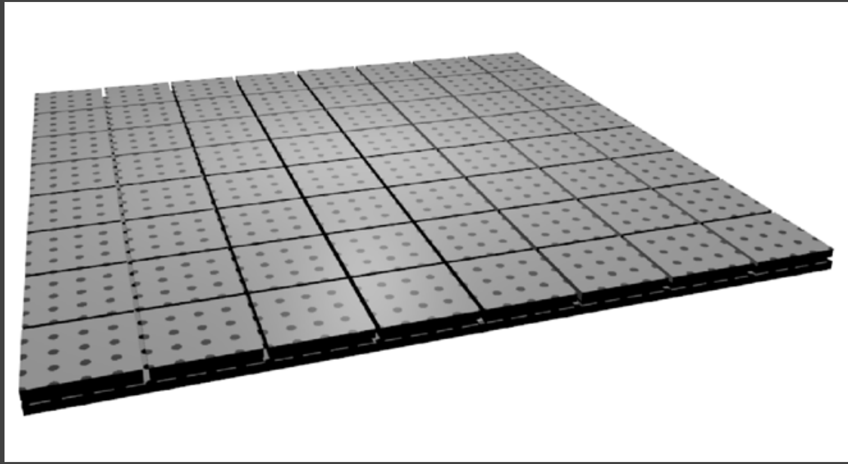
is the system for acquiring monitoring, analysing and processing data

Energy calibration and Spatial calibration



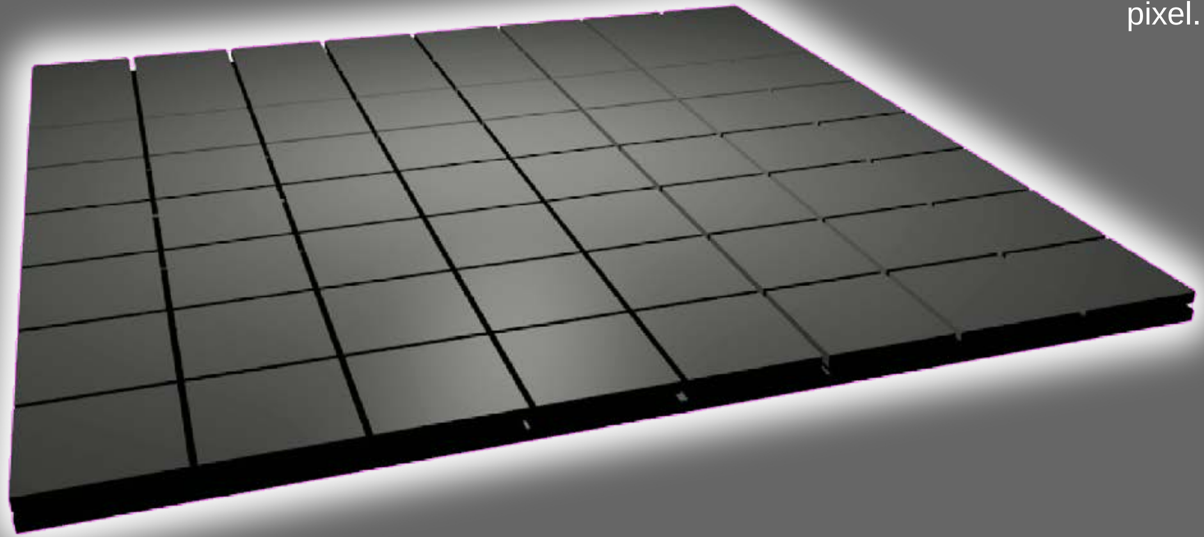
For good results of data processing we need a energy calibration and a spatial calibration.

➔ **Spatial calibration**
characterization of each detector using a pointer source collimated that points to many defined positions along the detector surface.



➔ **Energy calibration**
we are using known radioactive sources as Na22, Cs137, Eu152, Ba130

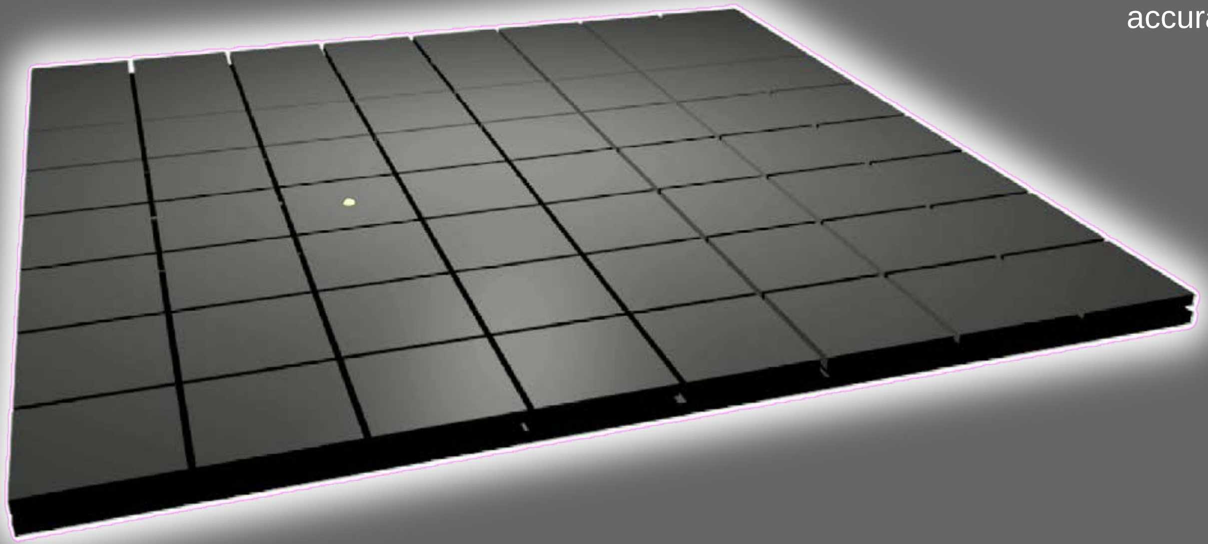
Spatial calibration



→ **Pixelated crystals**

Using **pixelated crystals** and SiPM, we would get one pixel fired, no matter the position of the gamma-ray hit within the pixel. The best spatial resolution that one can get is conditioned by the size of the pixel.

Spatial calibration



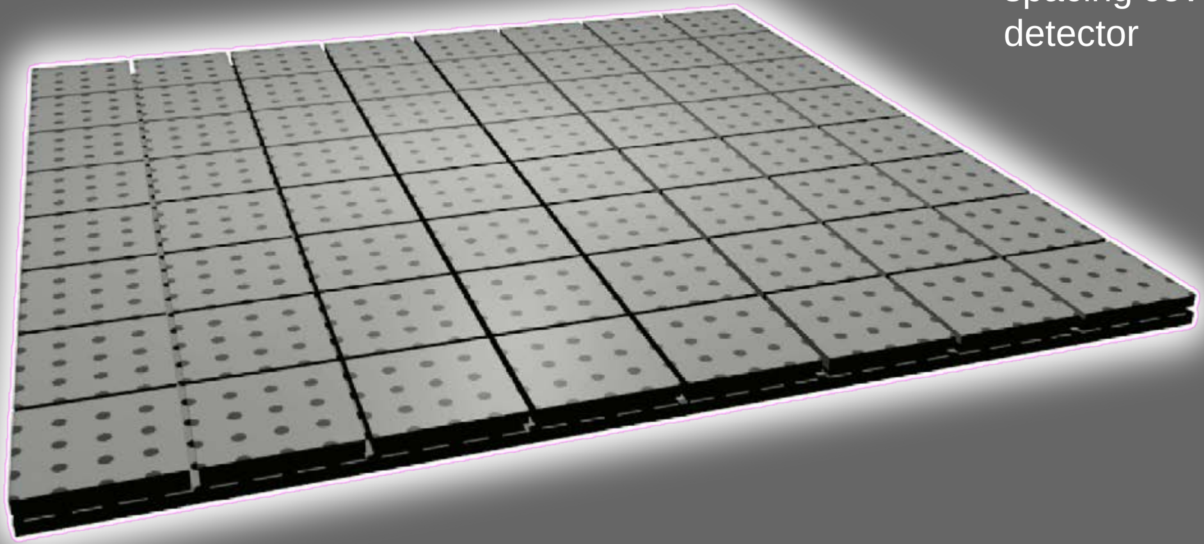
→ **Monolithic crystals**

Using **monolithic crystals** and SiPM, we get more than one pixel fired. Depending on the position where the gamma-ray hits, and analysing the scintillation-light distribution, we can get a sub-pixel position accuracy.

Spatial calibration

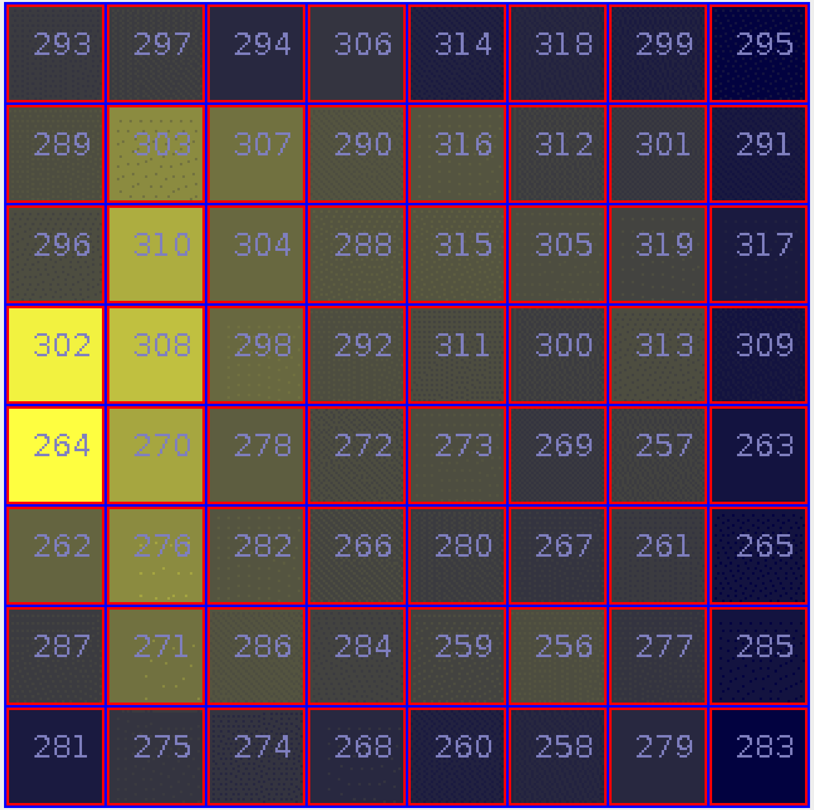
➔ **Monolithic crystals and pixelated SiPM**

Spatial calibration is 1225 distributions for 35x35 symmetric positions with 1.5mm spacing covering entire surface of the detector

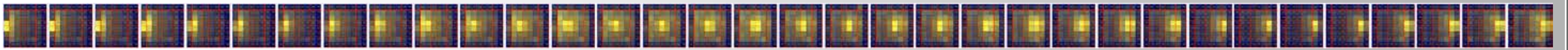


Eg: Analysing the 35 acquisitions scanned in the middle horizontal line, we can observe how the distribution changes.

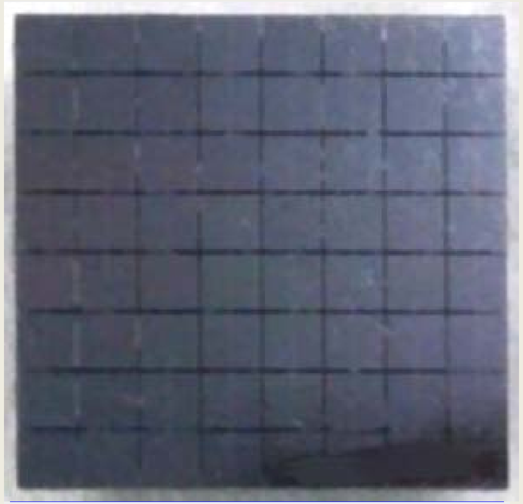
Spatial distribution



Each frame of this animation is an acquisition for one position and represents the energy sum of all events that has been fired.

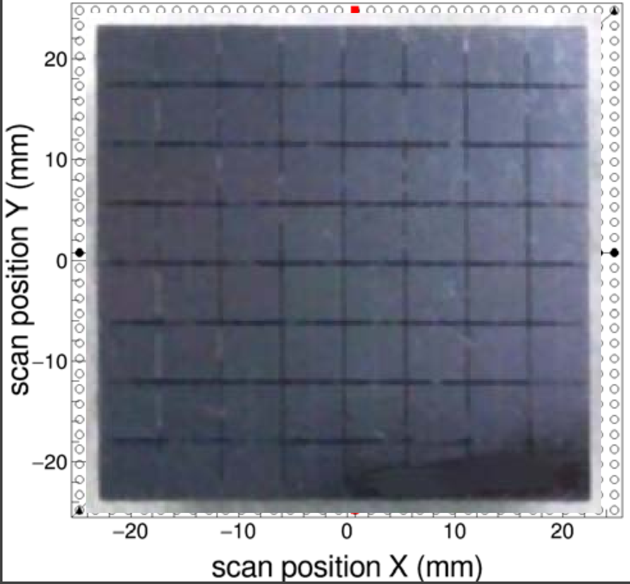


- ➔ Systematic scan with a series of collimated gamma-ray source measurements in many positions (35x 35y) covering the full detection surface
- ➔ Get data acquisition and calculate the accumulated distribution of each scan-position
- ➔ Use analytic and artificial neural network techniques to correlate the position of the gamma-ray hit with the measured scintillation-light distribution



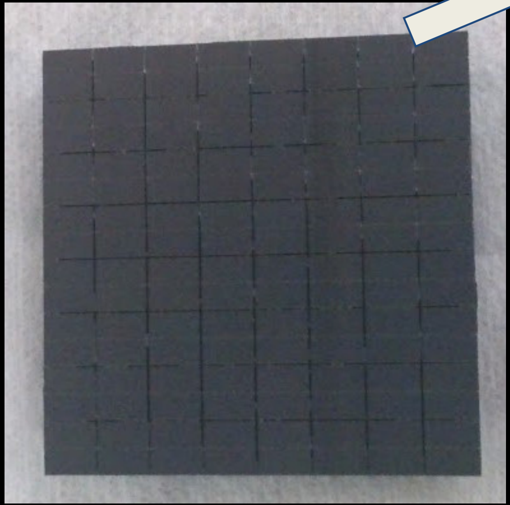
Channel map

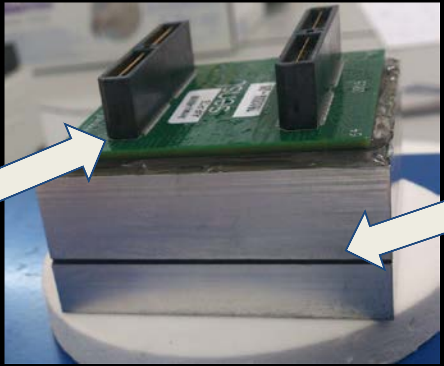
Strategy



Mounting i-TED Detectors

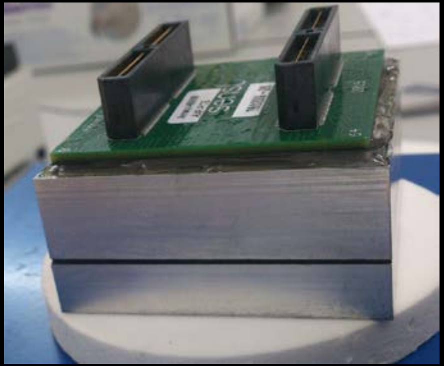
➔ **pixelated SiPM**
matrix of 8x8 px - 6x6mm/pixel.





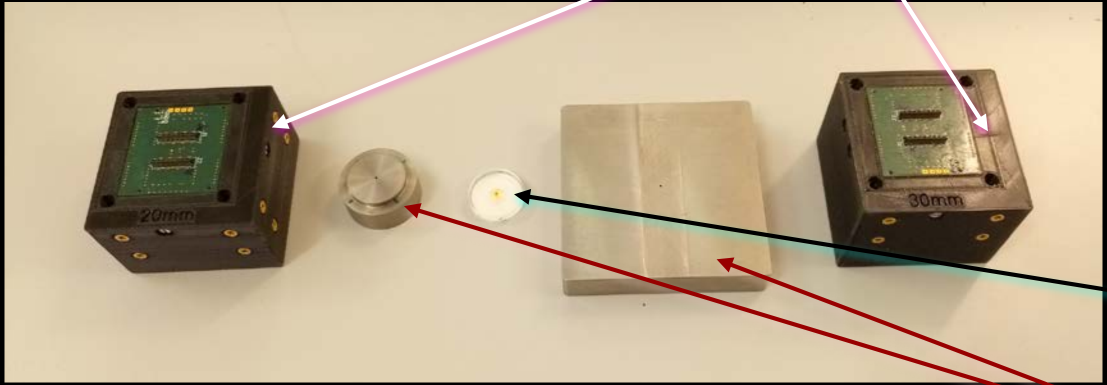
Detectors has LaCl3 crystals and SiPM photomultipliers

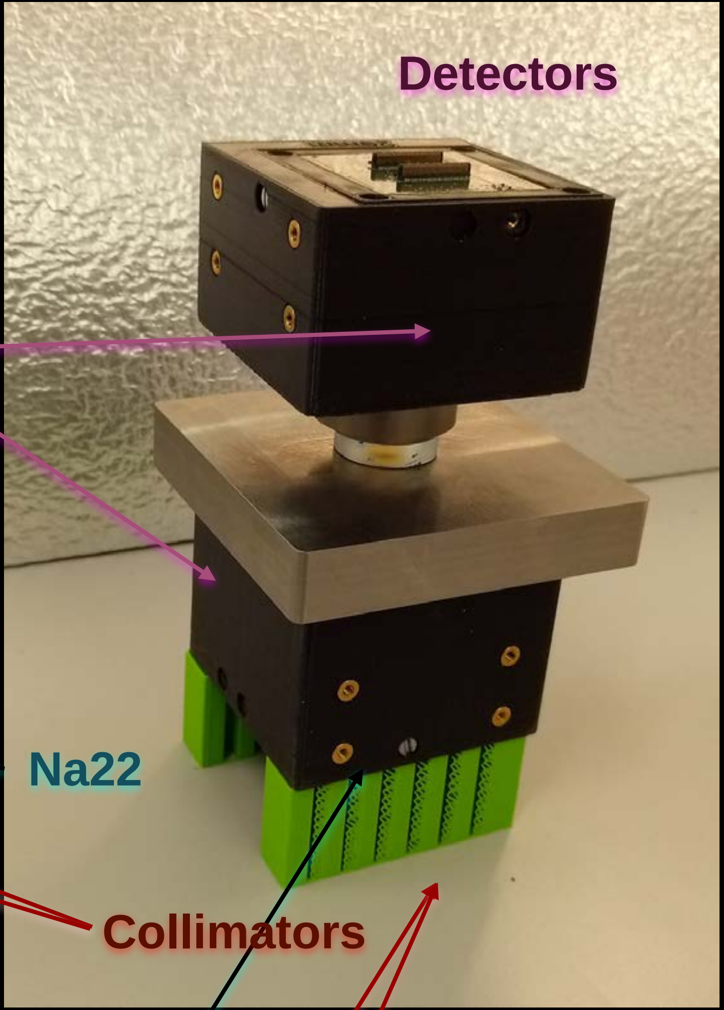
➔ **LaCl3 CONTINUOUS crystals**
thicknesses: 10, 20 and 30mm 50x50mm,

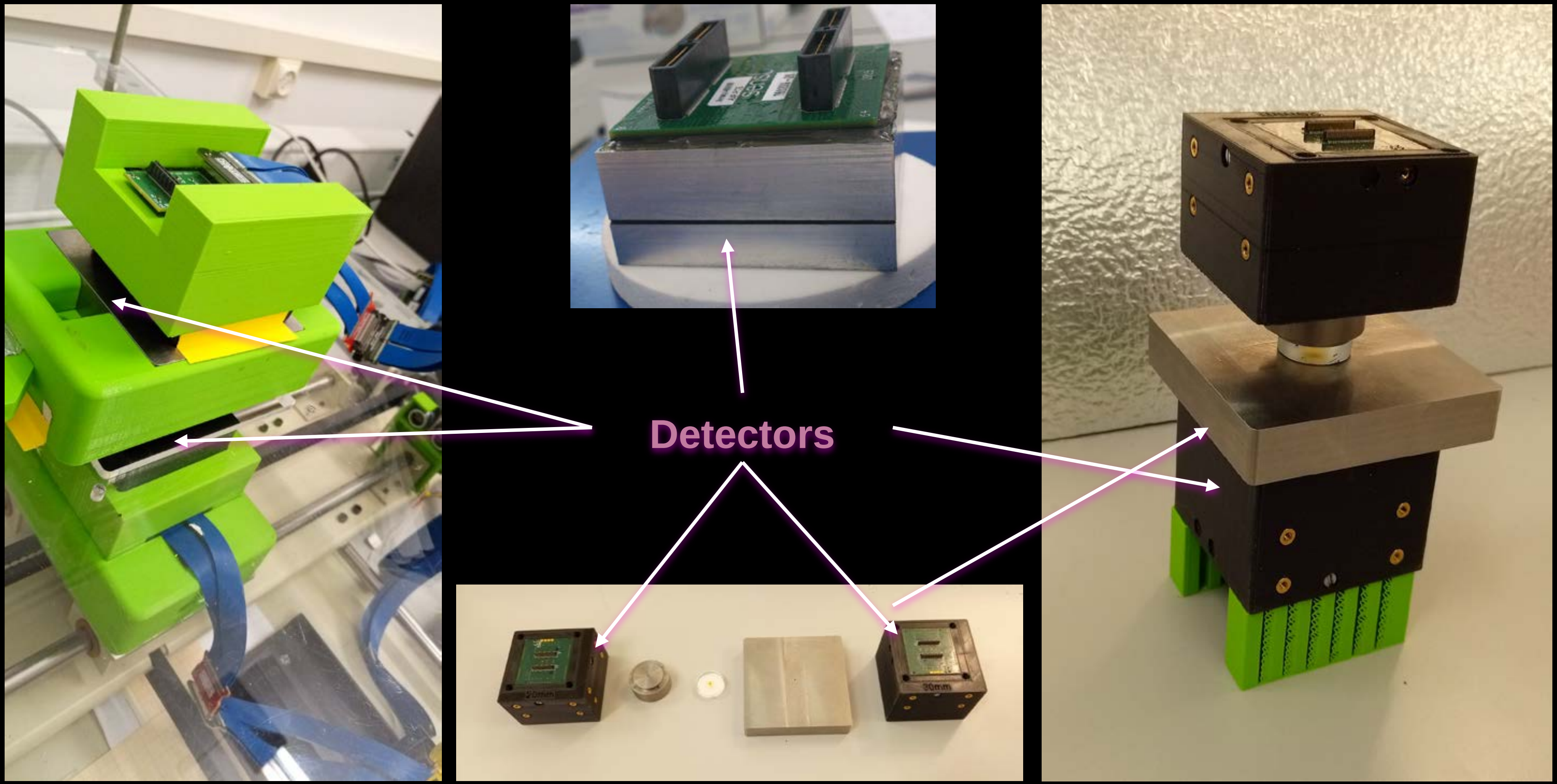


Detector naked

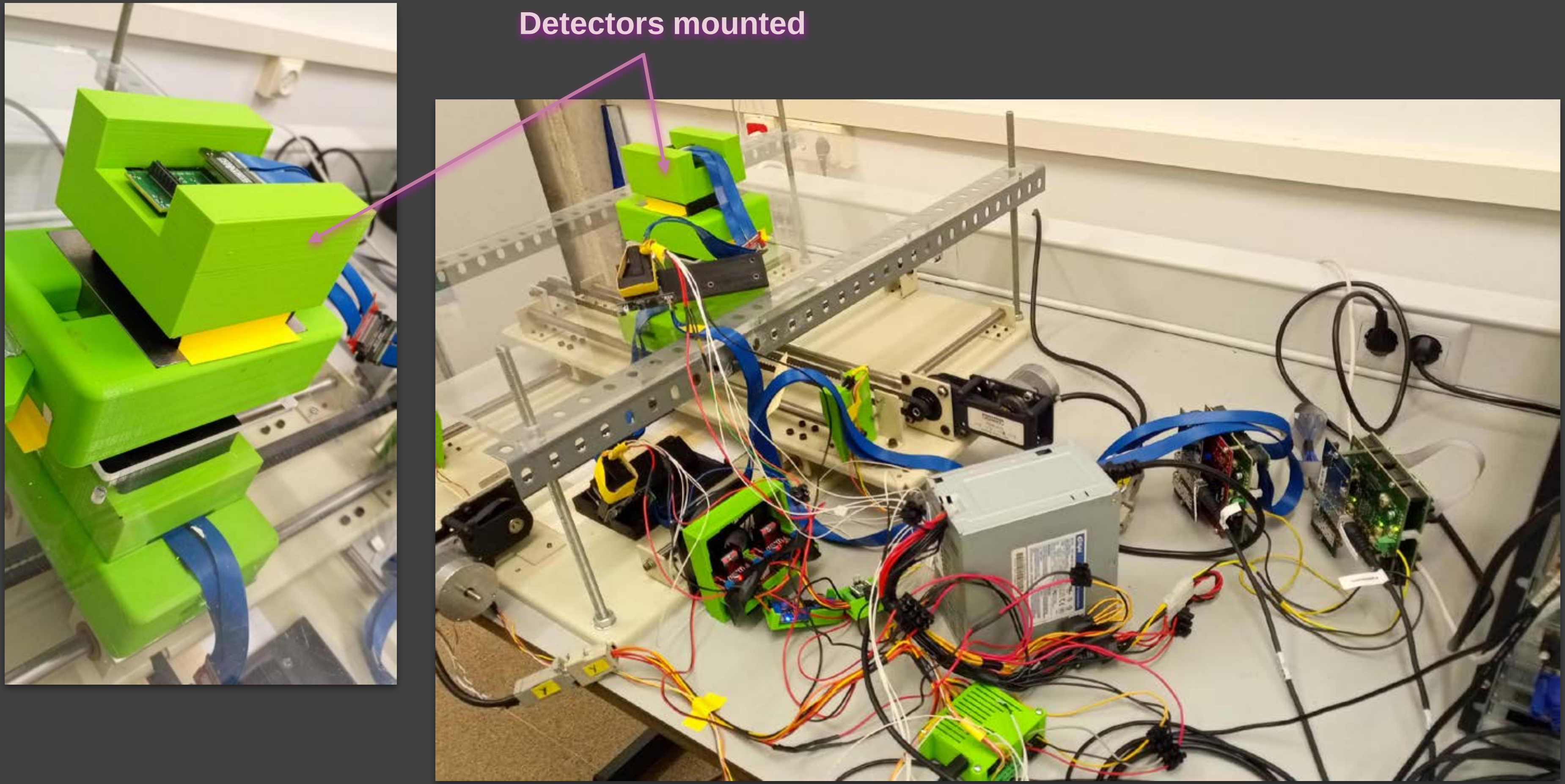
Detectors



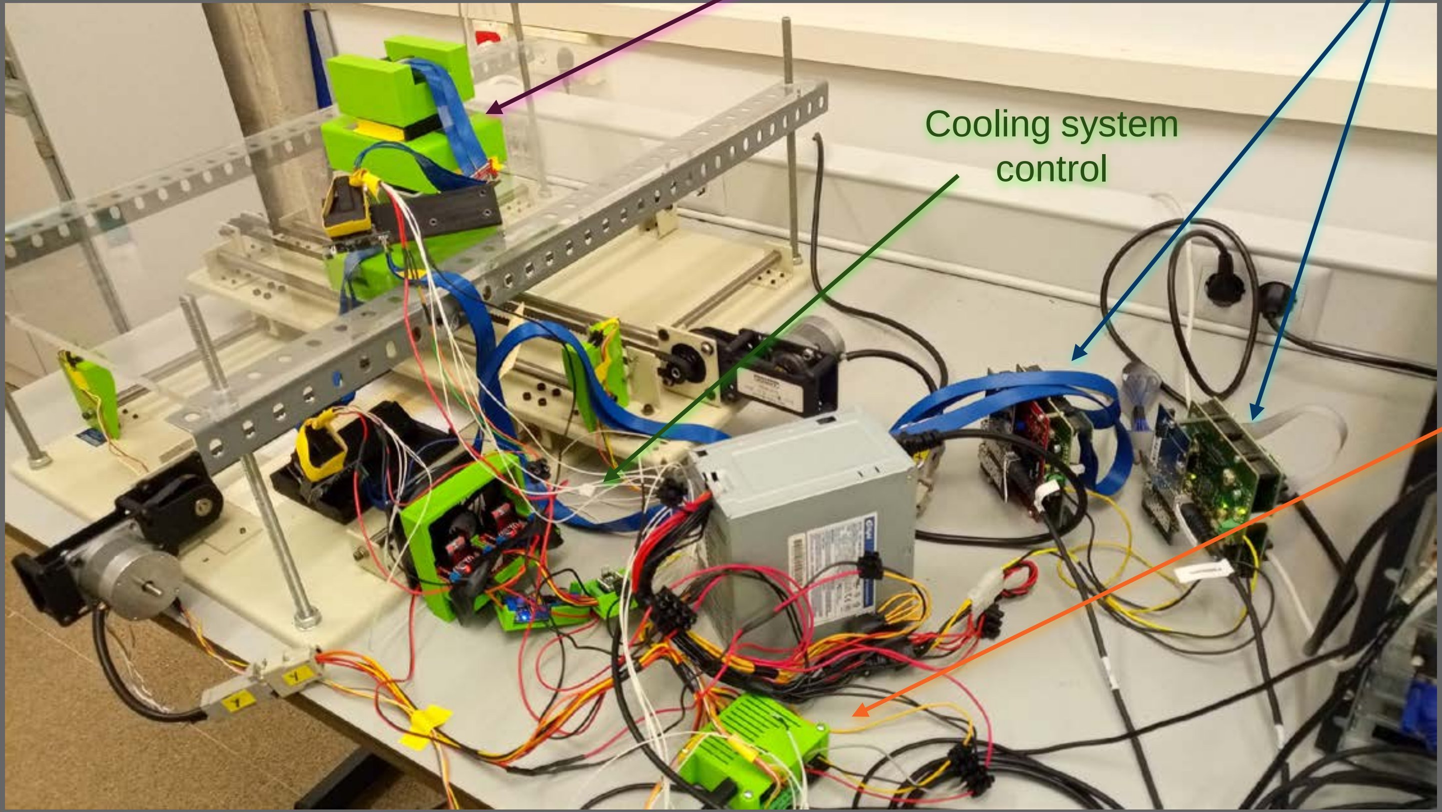



Detectors

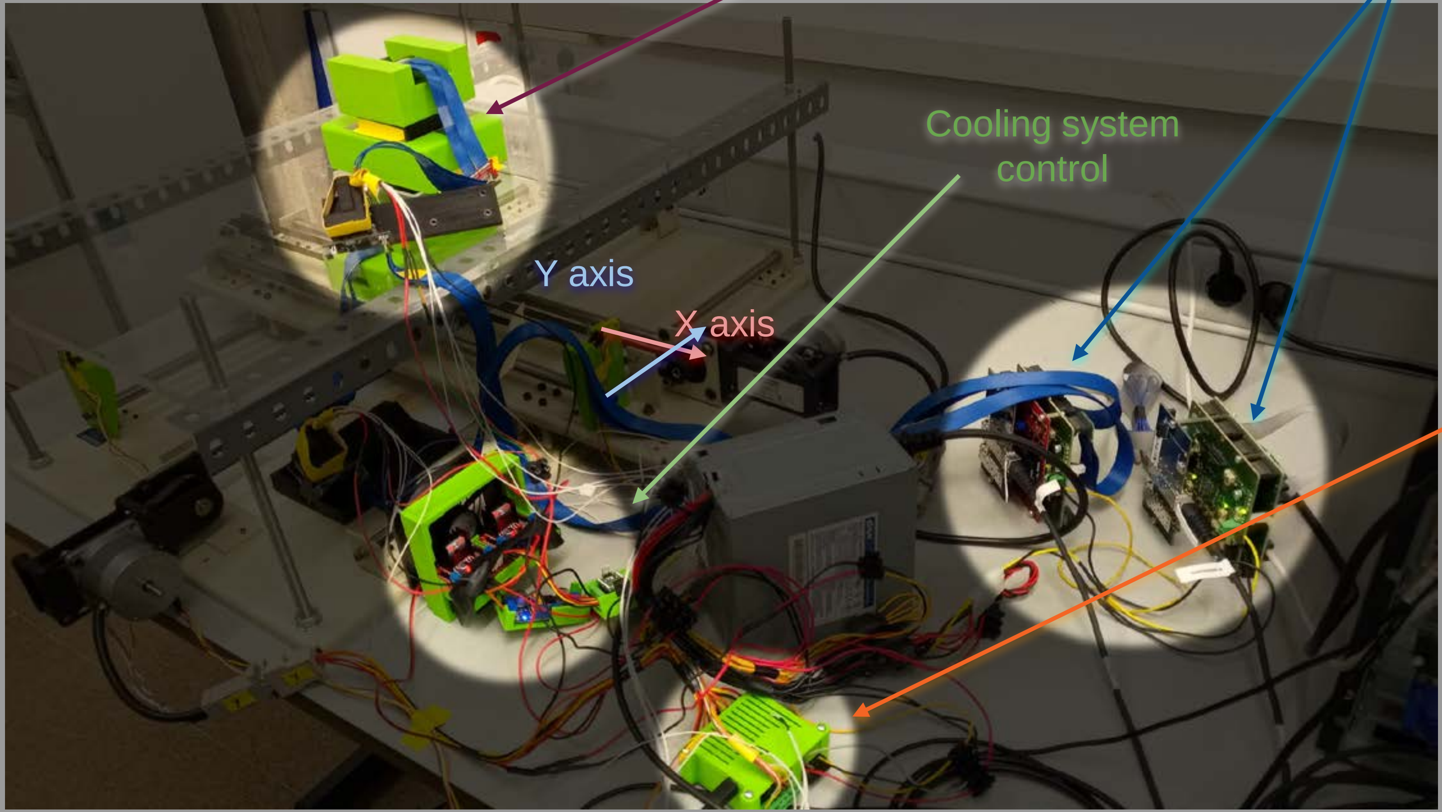
Detectors mounted



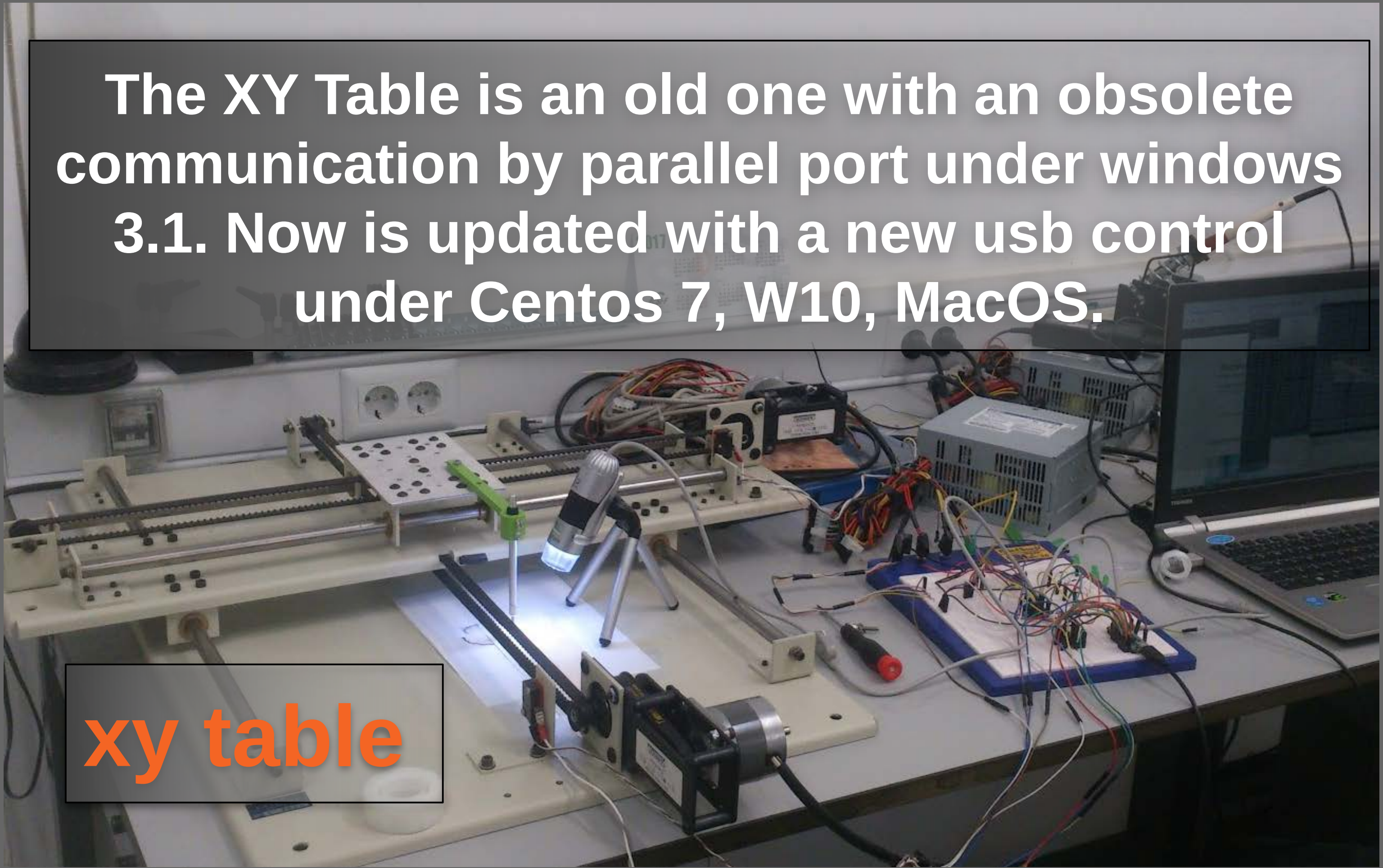
Characterization



Characterization

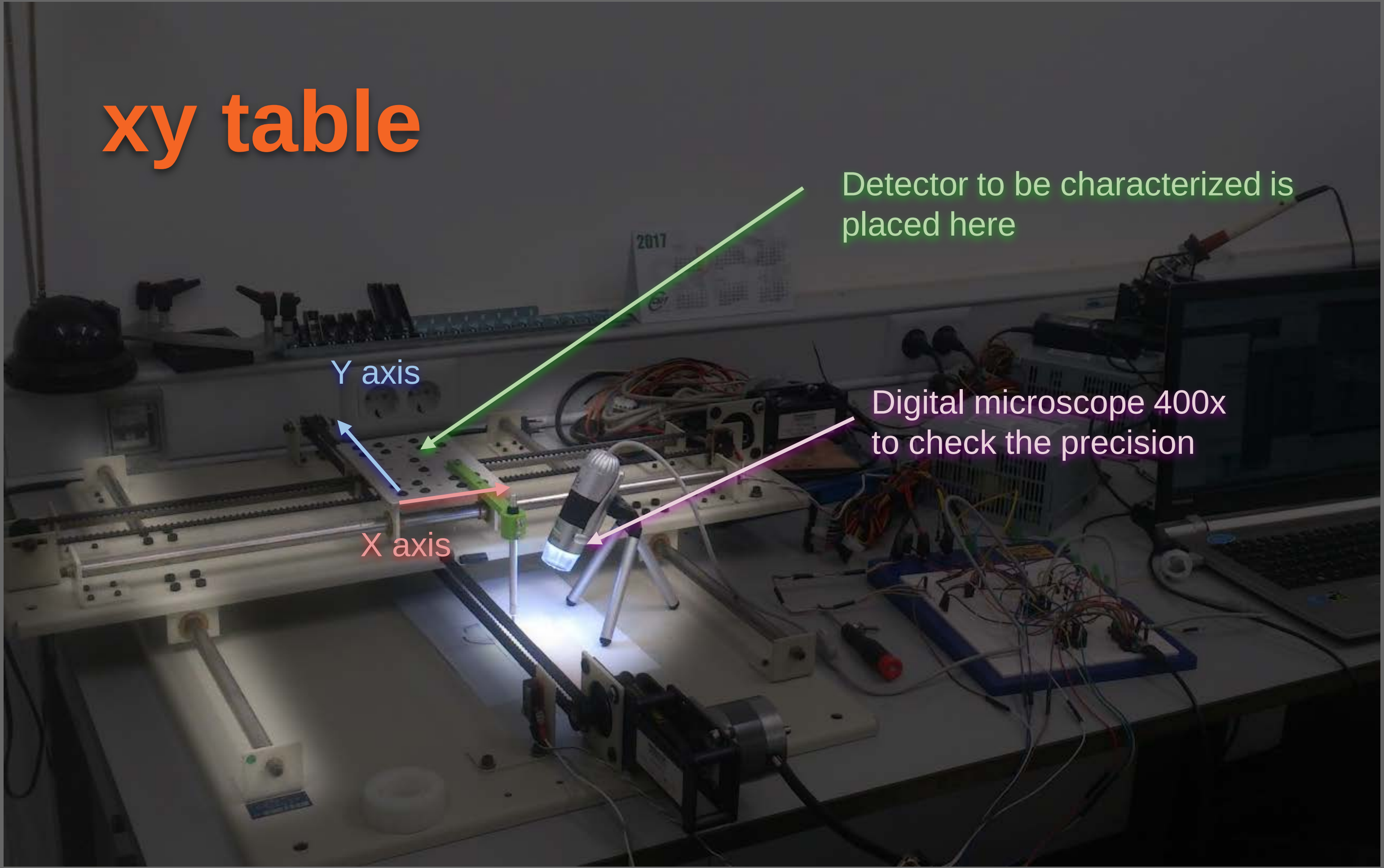


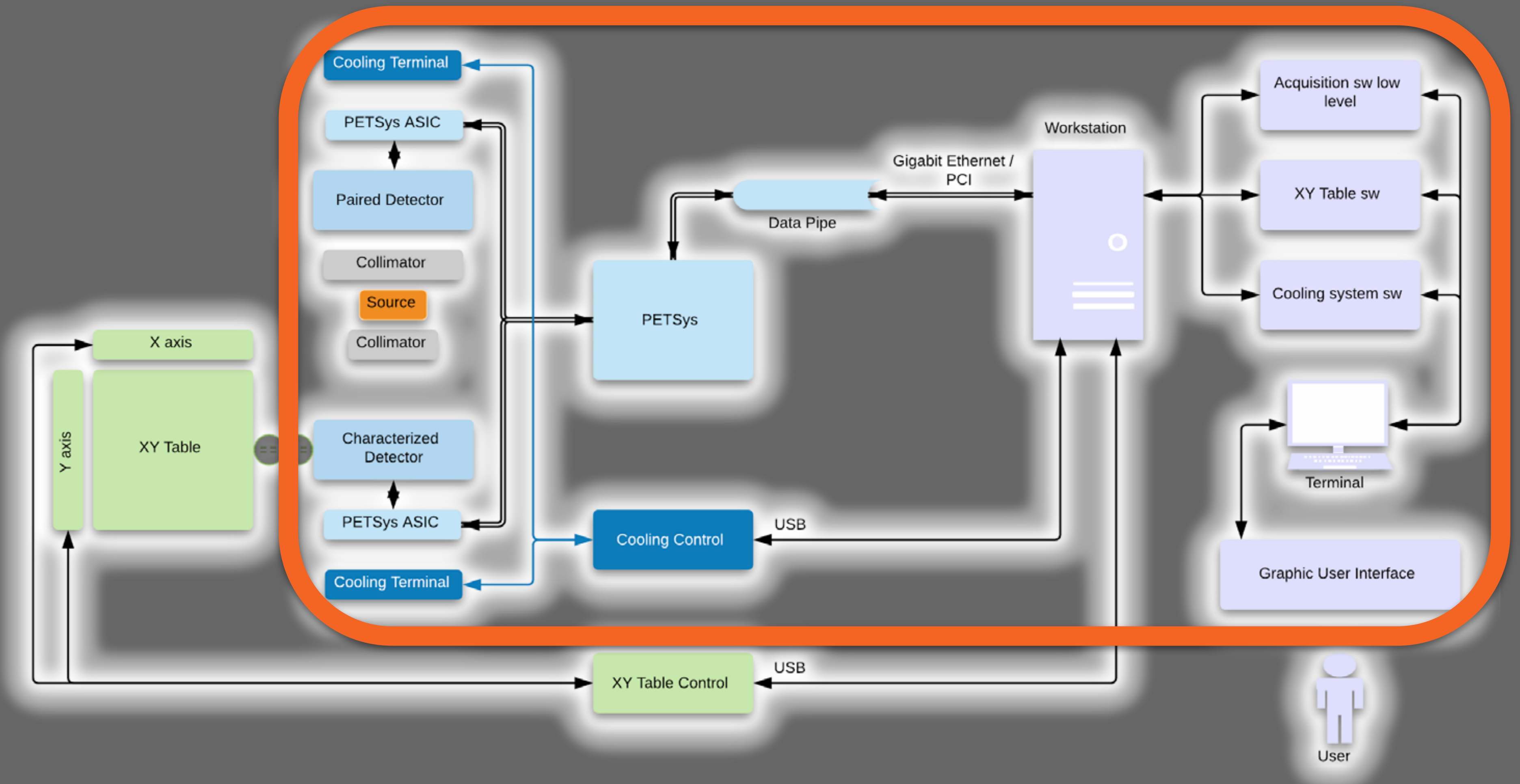
The XY Table is an old one with an obsolete communication by parallel port under windows 3.1. Now is updated with a new usb control under Centos 7, W10, MacOS.



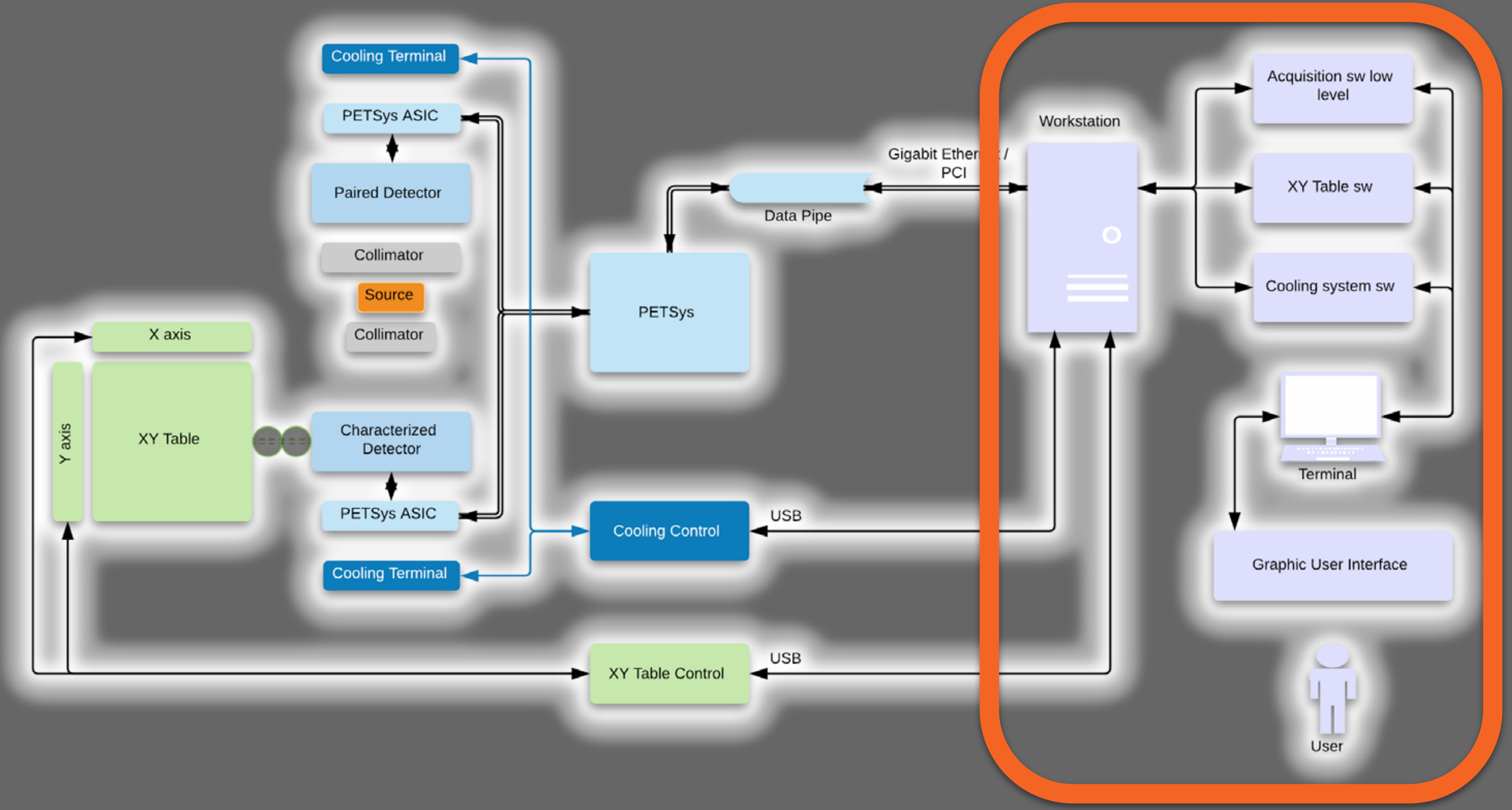
xy table

xy table

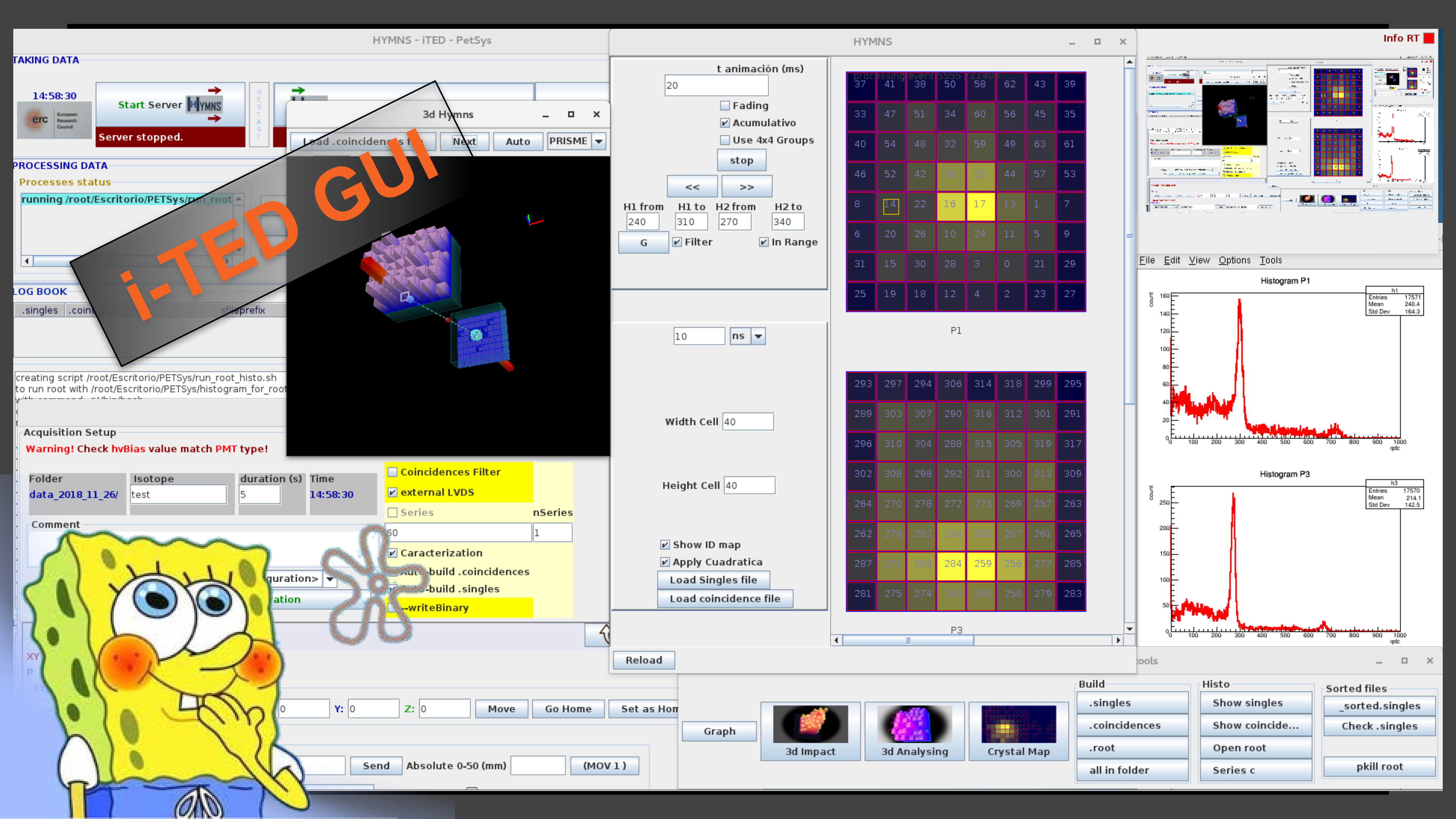

Detector to be characterized is placed here
Y axis
X axis
Digital microscope 400x to check the precision
2017



Cooling Terminal
PETSys ASIC
Paired Detector
Collimator
Source
Collimator
X axis
Y axis
XY Table
Characterized Detector
PETSys ASIC
Cooling Terminal
PETSys
Data Pipe
Gigabit Ethernet / PCI
Workstation
Acquisition sw low level
XY Table sw
Cooling system sw
Terminal
Graphic User Interface
Cooling Control
USB
XY Table Control
USB
User

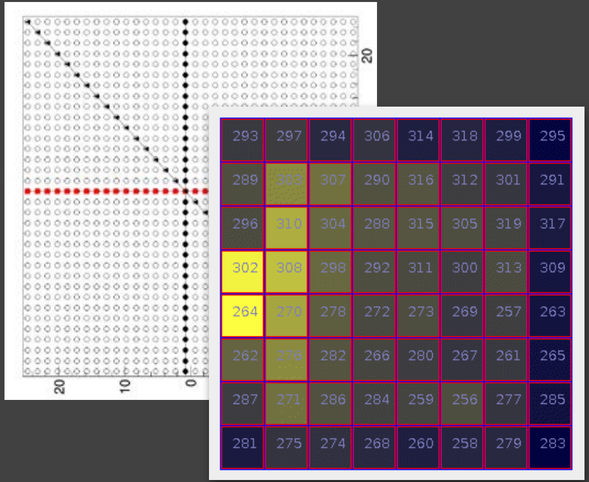


Cooling Terminal
PETSys ASIC
Paired Detector
Collimator
Source
Collimator
X axis
Y axis
XY Table
Characterized Detector
PETSys ASIC
Cooling Terminal
PETSys
Data Pipe
Gigabit Ether
PCI
Cooling Control
USB
XY Table Control
USB
Workstation
Acquisition sw low level
XY Table sw
Cooling system sw
Terminal
Graphic User Interface
User

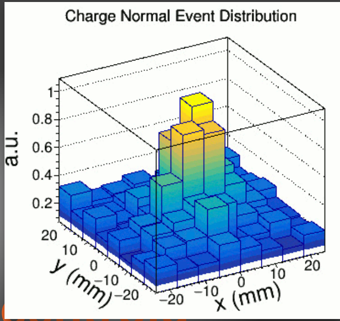

i-TED GUI
HYMNS - iTED - PetSys
TAKING DATA
14:58:30
Start Server
Server stopped.
PROCESSING DATA
Processes status
running /root/Escritorio/PETSys/run_root
LOG BOOK
.singles
creating script /root/Escritorio/PETSys/run_root_histo.sh
to run root with /root/Escritorio/PETSys/histogram_for_root
Acquisition Setup
Warning! Check hvBias value match PMT type!
Folder
data_2018_11_26/
Isotope
test
duration (s)
5
Time
14:58:30
Comment
Coincidences Filter
external LVDS
Series
nSeries
Caracterization
Move
Go Home
Send
Absolute 0-50 (mm)
(MOV 1)
3d Hymns
Next
Auto
PRISME
HYMNS
t animación (ms)
20
Fading
Acumulativo
Use 4x4 Groups
stop
<<
>>
H1 from
H1 to
H2 from
H2 to
240
310
270
340
G
Filter
In Range
10
ns
Width Cell
40
Height Cell
40
Show ID map
Apply Cuadratica
Load Singles file
Load coincidence file
Reload
P1
P3
Info RT
File
Edit
View
Options
Tools
Histogram P1
Histogram P3
Graph
3d Impact
3d Analysing
Crystal Map
Build
.singles
.coincidences
.root
all in folder
Histo
Show singles
Show coincide...
Open root
Series c
Sorted files
_sorted.singles
Check .singles
pkill root

```
load_xy_positions_in_list();
for each xy_position{
move_detector_to xy_position();
start_acquisition_400s();
//process raw data -> singles data
open_new_thread_for_data_processing();
}

load_singles_processed_data_files_list();
for each single data file{
        calculate_events();
        apply_algorithm_for_xy_accurate_position()
;
        print_results();
}
```



Position Reconstruction Techniques Researched

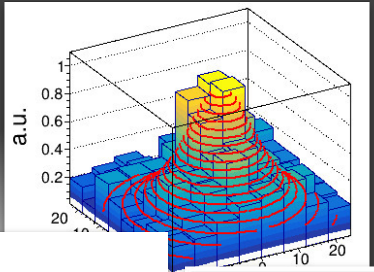


→ Anger (centroid method)

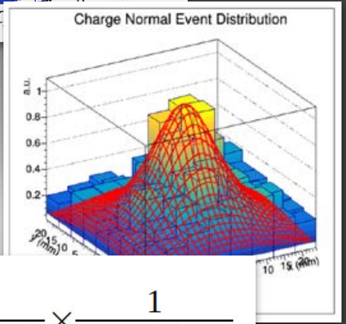
fast, conventional approach

→ Analytical Fit

Lerche, Li



$$L(\vec{r}) \approx \frac{L_0}{(\vec{r}-\vec{r}_0)^2}\alpha e^{-\alpha|\vec{r}-\vec{r}_0|}+\tau, \quad \vec{r} \neq \vec{r}_0$$

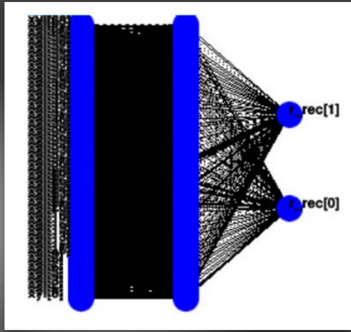


$$f = A_0 \times \frac{z}{((x-x_i)^2+(y-y_i)^2+z^2)^{3/2}} \times \frac{1}{1+e^{-\beta\times(\theta_C-\theta)}}$$

$$\theta = \arctan\left[\frac{\sqrt{(x-x_i)^2+(y-y_i)^2}}{z}\right]$$

→ Artificial Neural Networks

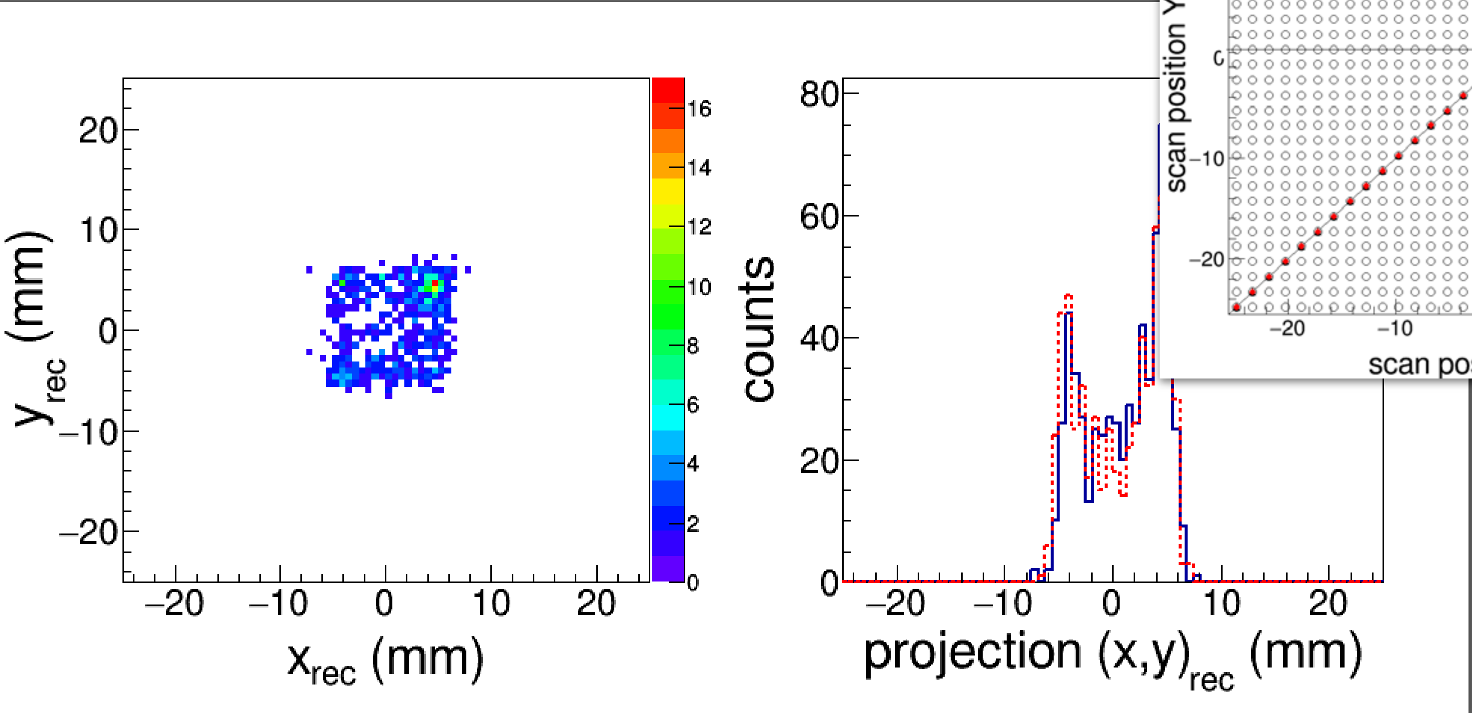
fast and accurate

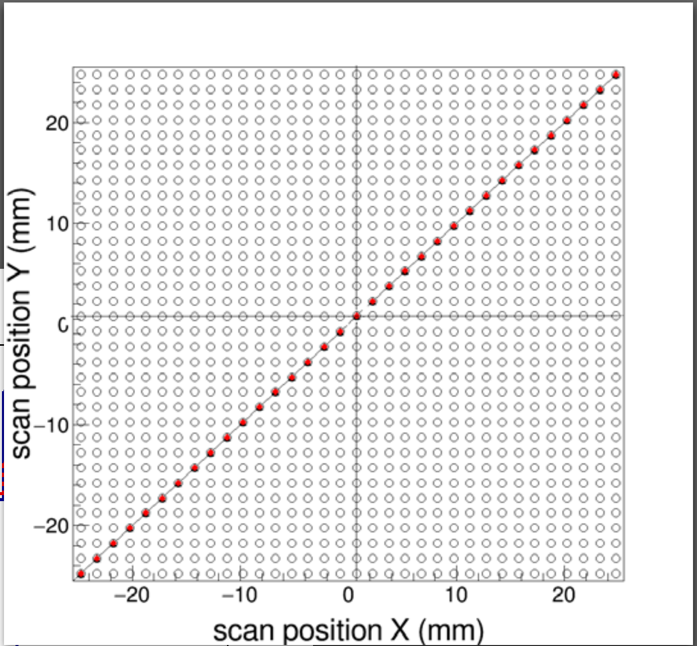


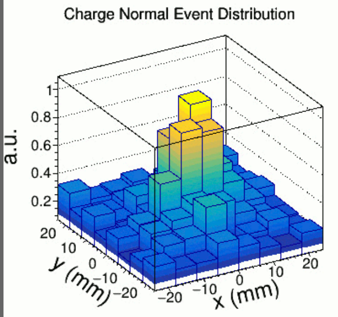
Anger

Centroid of the distribution

FWHM 8mm



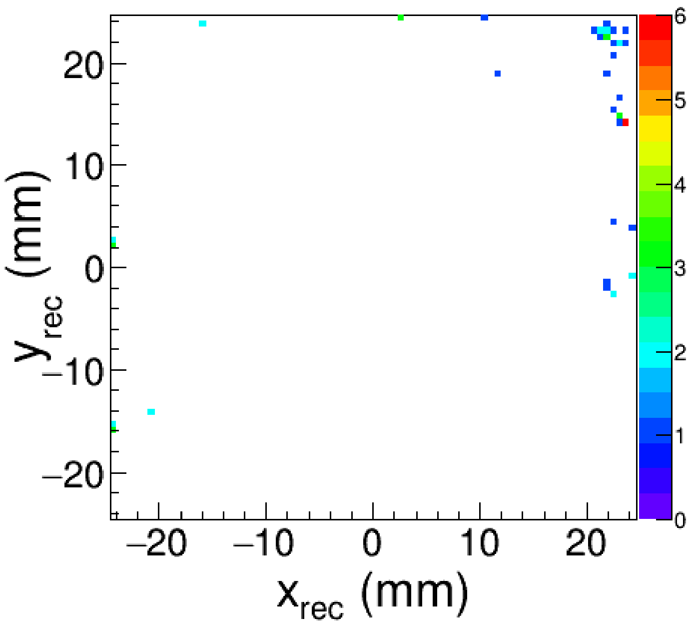


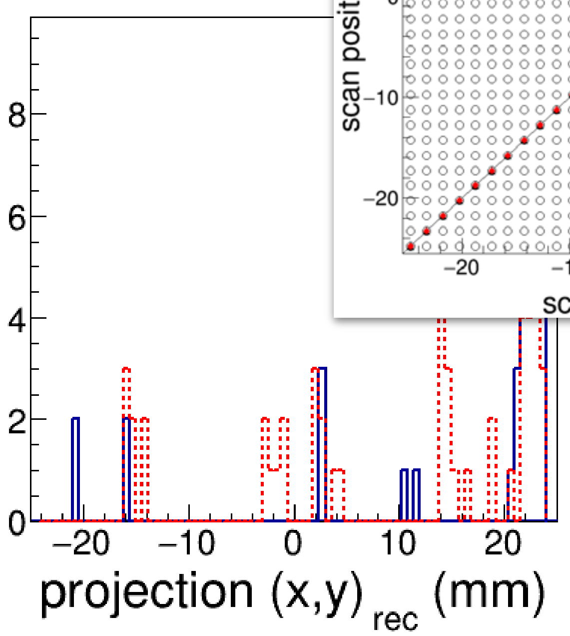


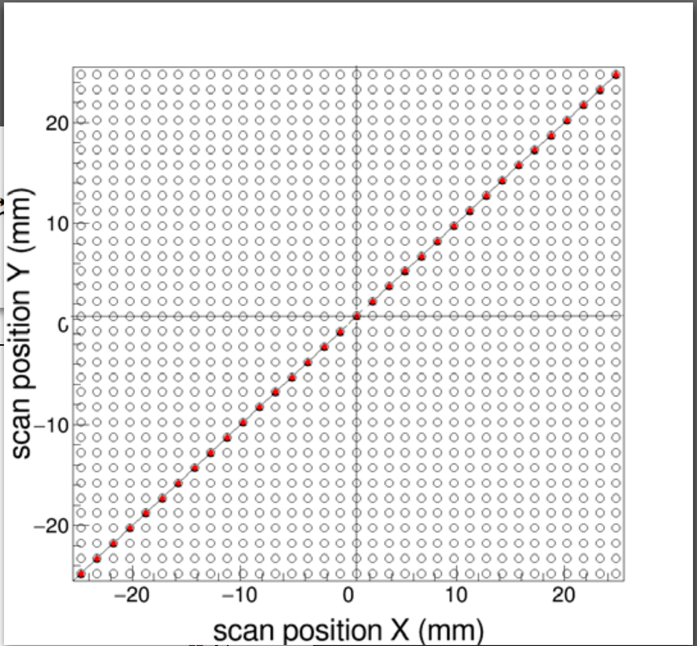
Analytical Fit Lerche

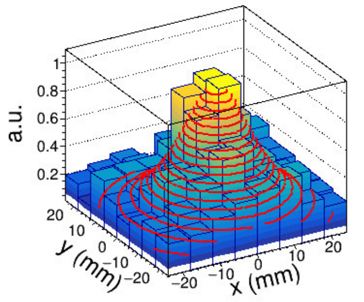
FWHM 1mm

$$L(\vec{r}) \approx \frac{L_0}{(\vec{r}-\vec{r}_0)^2} \alpha e^{-\alpha|\vec{r}-\vec{r}_0|} + \tau, \quad \vec{r}$$





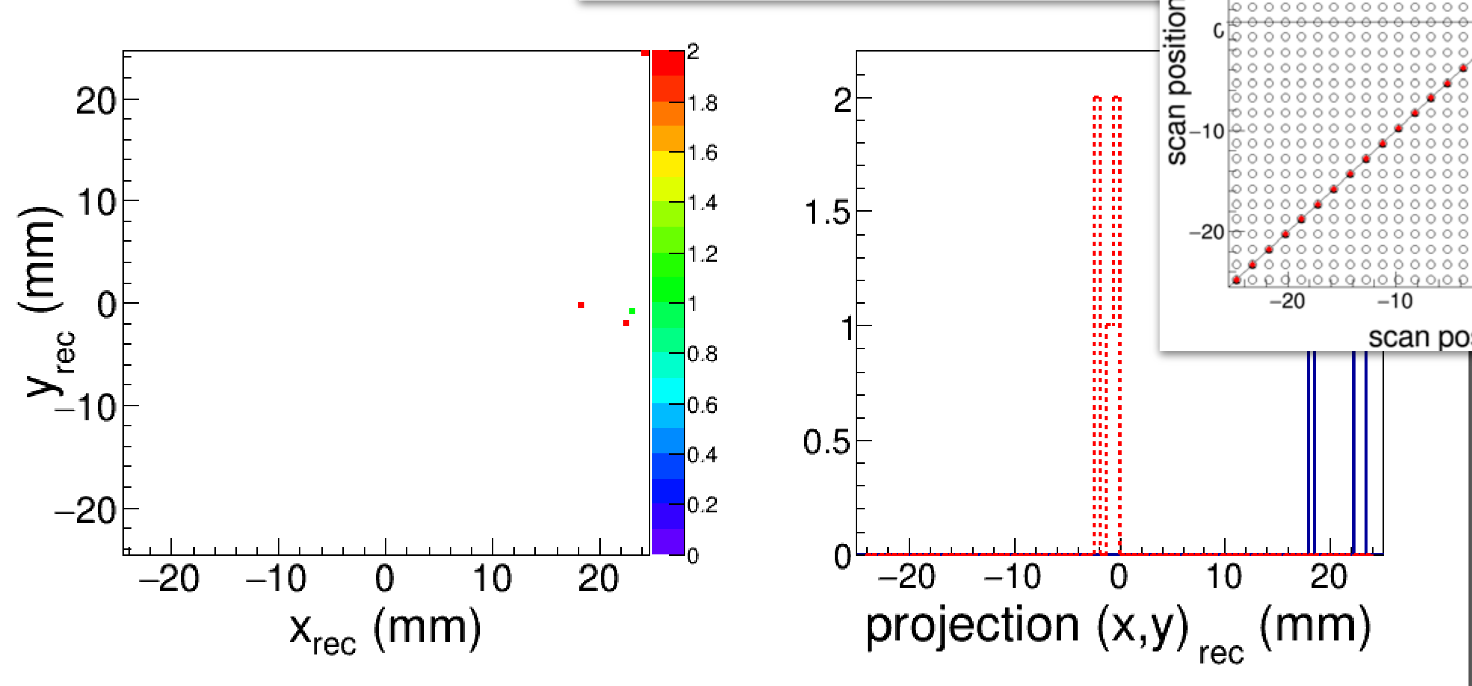


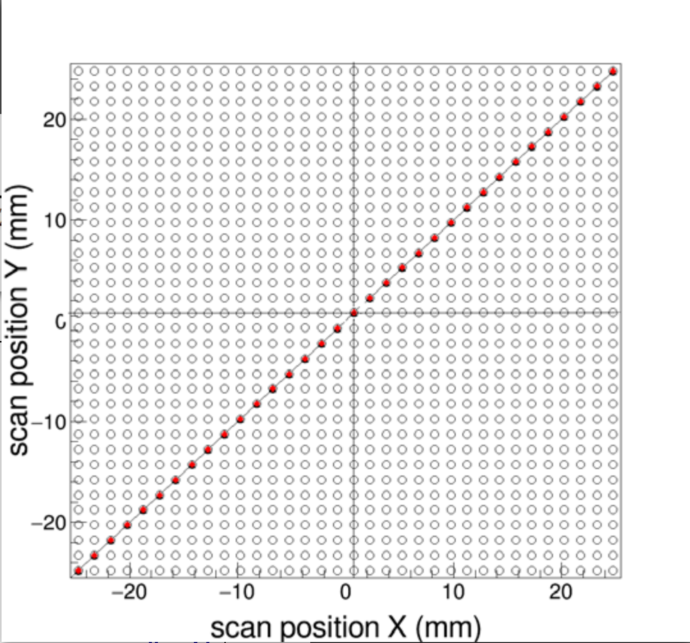


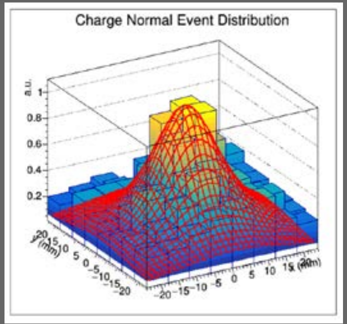
Analytical Fit Li

FWHM 1mm

$$f = A_0 \times \frac{z}{\left(\left(x-x_i\right)^2+\left(y-y_i\right)^2+z^2\right)^{3/2}}$$

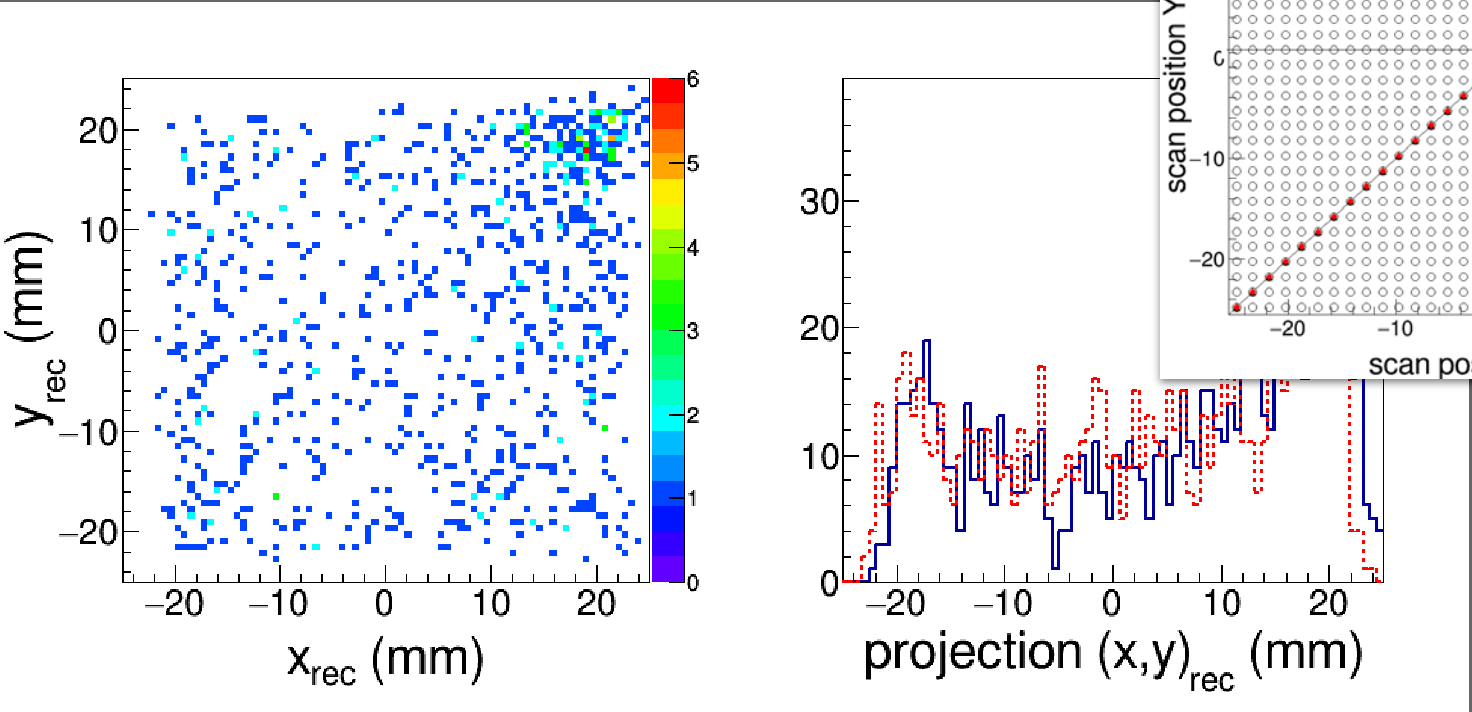


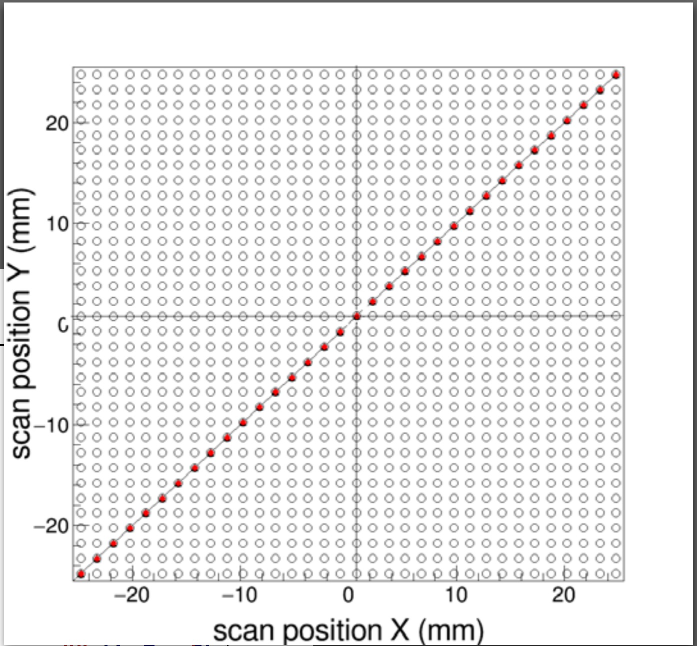


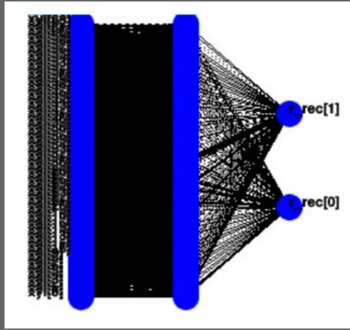


Artificial Neural Network

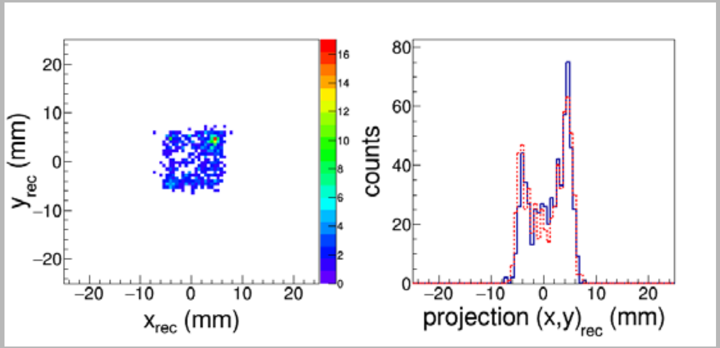
FWHM 3mm



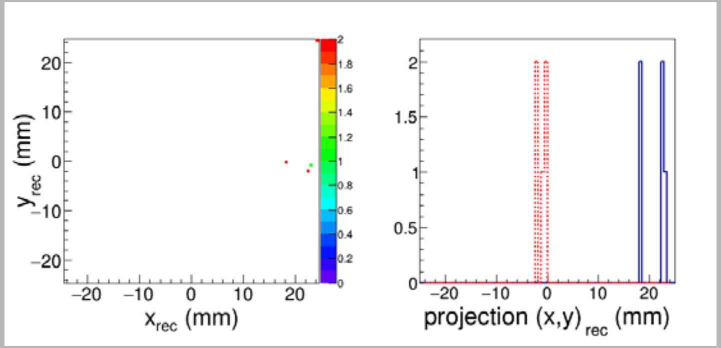




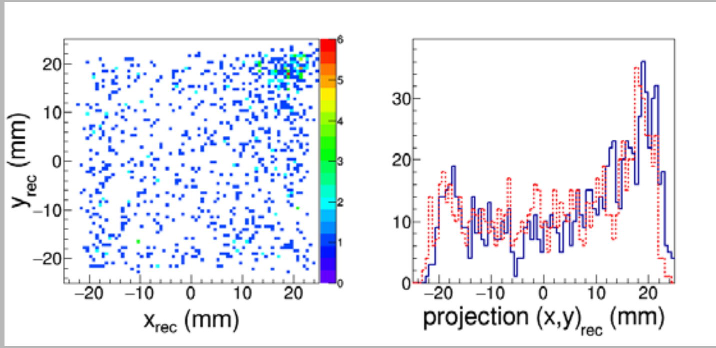
Anger



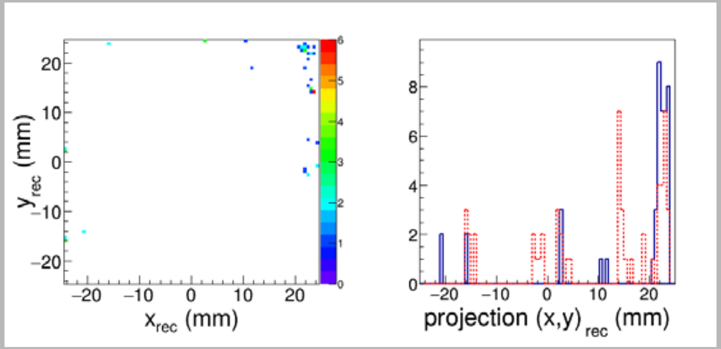
Li



ANN

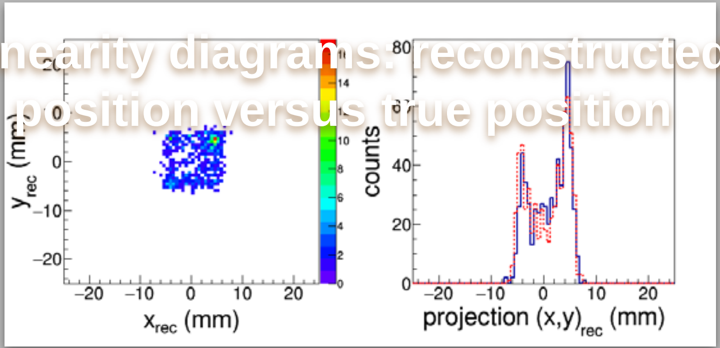


Lerche

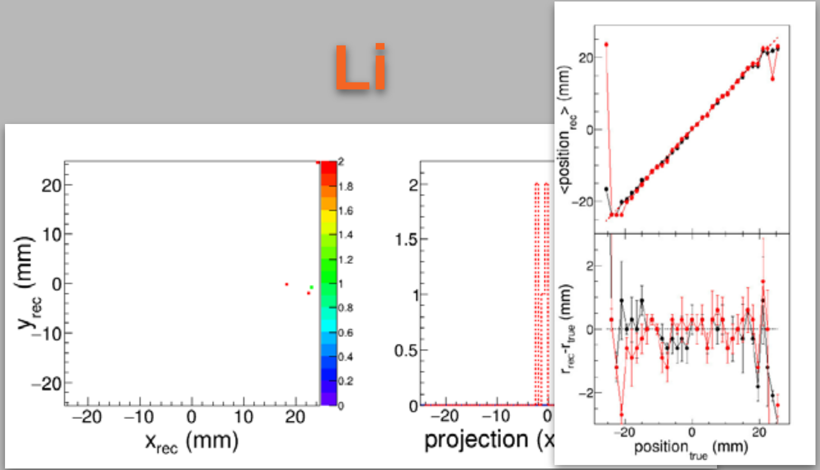


Linearity diagrams: reconstructed position versus true position

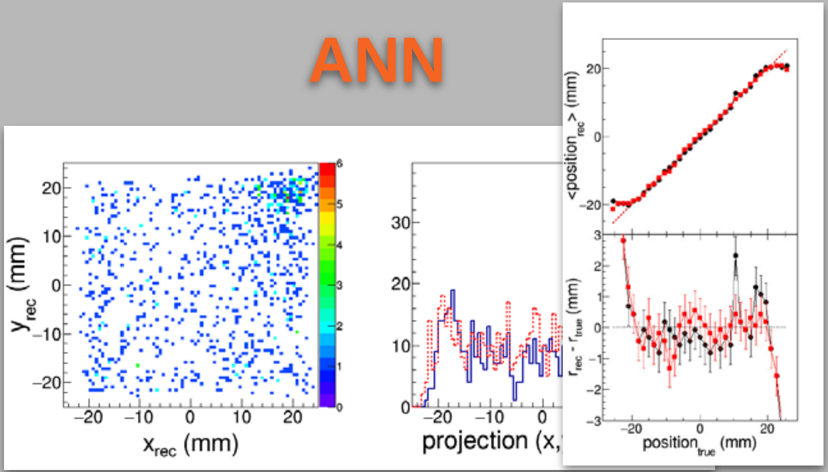
Anger



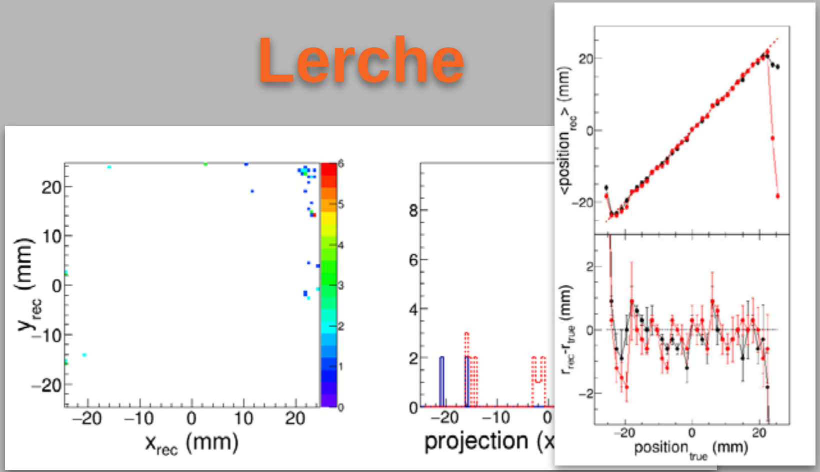
Li



ANN

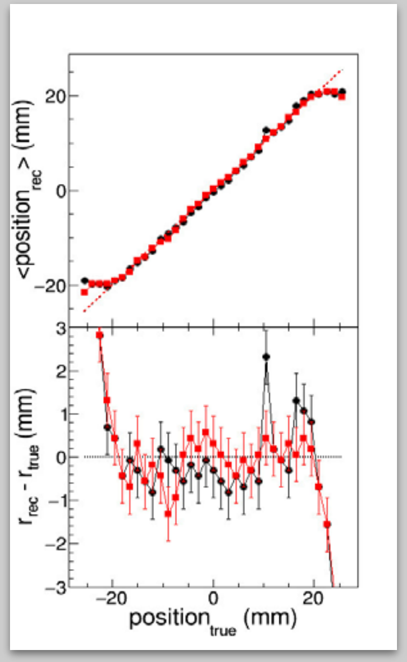


Lerche

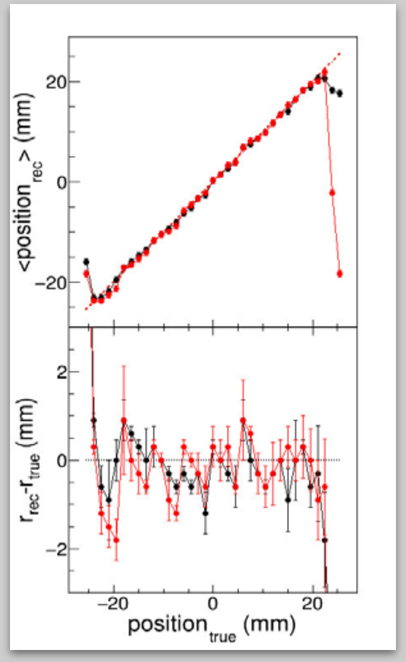


Linearity diagrams: reconstructed position versus true position

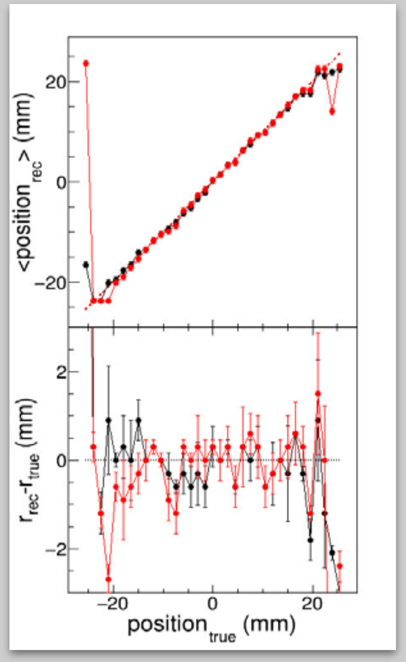
ANN



Lerche



Li



V.Babiano et al. “γ-Ray position reconstruction in large monolithic LaCl3(Ce) crystals with SiPM readout”, submitted to NIM-A, https://arxiv.org/abs/1811.05469

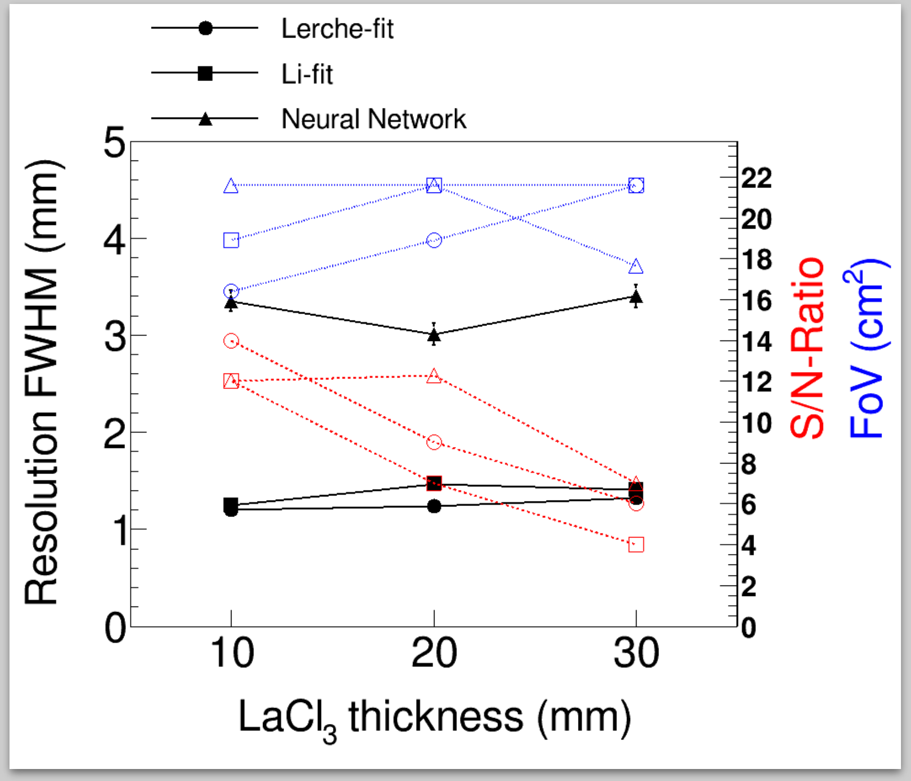
Summary

Compton Imaging, deltaE, LaCl3, NN

We have developed a characterization method for spatial reconstruction for iTED

HYMNS, 2018

V.Babiano et al. “γ-Ray position reconstruction in large monolithic LaCl3(Ce) crystals with SiPM readout”, submitted to NIM-A, https://arxiv.org/abs/1811.05469



i-TED spatial calibration

- We have developed an instrumentation (XY-scan table integrated with DACQ) and methodology to perform an accurate and systematic spatial characterization of the i-TED detectors.
- We have explored both analytical and machine-learning based methods.
- Analytical methods provide the best spatial resolution (~1mm FWHM) and high-linearity and largest field-of-view (<25cm2), but suffer of very low reconstruction efficiency (30-50%).
- Neural-Network methods provide a sufficiently good spatial resolution (~3mm FWHM), a high linearity too and large field-of-view (<25cm2) and 100% reconstruction efficiency.
- Presently NN-based methods are preferred for i-TED because the Compton imaging resolution is still limited by the energy resolution (5% at 662keV) rather than by the spatial resolution.
- We plan to further improve position reconstruction by means of more sophisticated NN-methods.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 681740).

HYMNS High-sensitivitY Measurements of key stellar Nucleo-Synthesis reactions