i-TED Crystals xyz-characterization using Machine Learning [Short]

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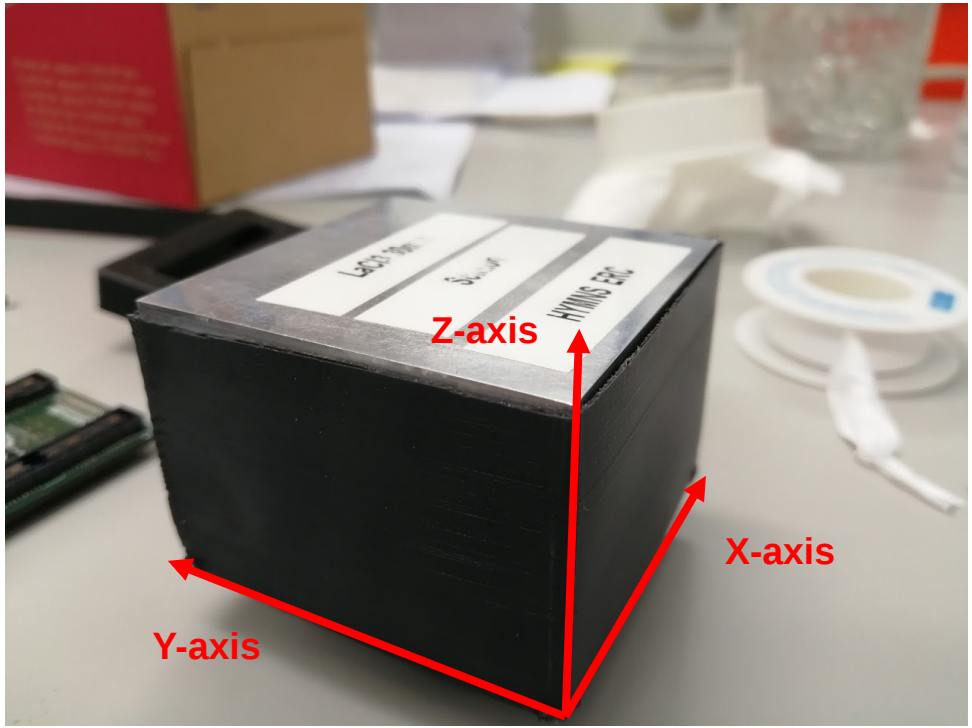
The n_TOF Collaboration

n_TOF Collaboration Meeting, CERN, 10th June 2020

Outline

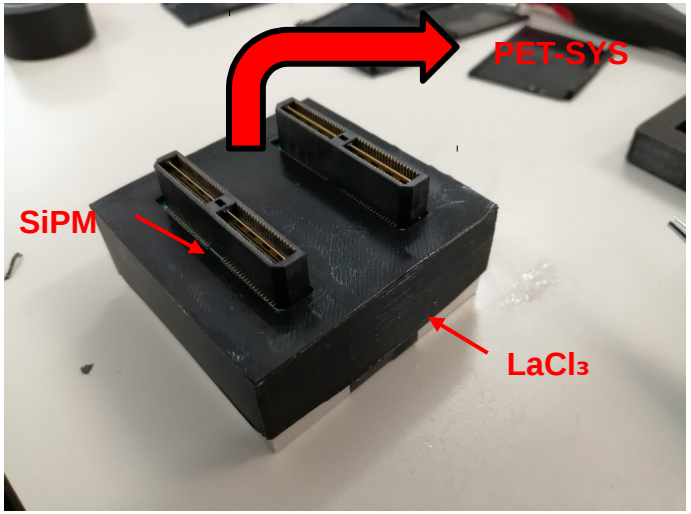
- Motivation.
- Experimental setup:
  - x-y axis configuration.
  - z axis configuration.
- x-y axis characterization:
  - Robust covariance fit.
  - x-y position results.
  - x-y Machine Learning correction.
- z axis calibration:
  - Fitting procedure for z calibration.
  - Calibration curves.
- Summary and conclusions.



Motivation: Why a characterization is needed?

One detector in one module of iTED is a complex system per se:

- Monolithic $LaCl_3$ crystals.
- Optical photons read by 8x8 SiPM matrix.
- The whole system processed through PET-SYS system.

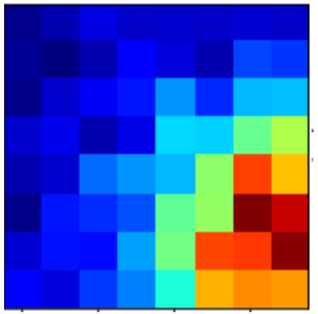


Primary data from PET-SYS

"Raw" data

Channel	Timestamp [ps]	Integral [ADC]
Channel	Timestamp [ps]	Integral [ADC]
Channel	Timestamp [ps]	Integral [ADC]
...	...	....
Channel	Timestamp [ps]	Integral [ADC]

Coincidences



Light map

Calibration

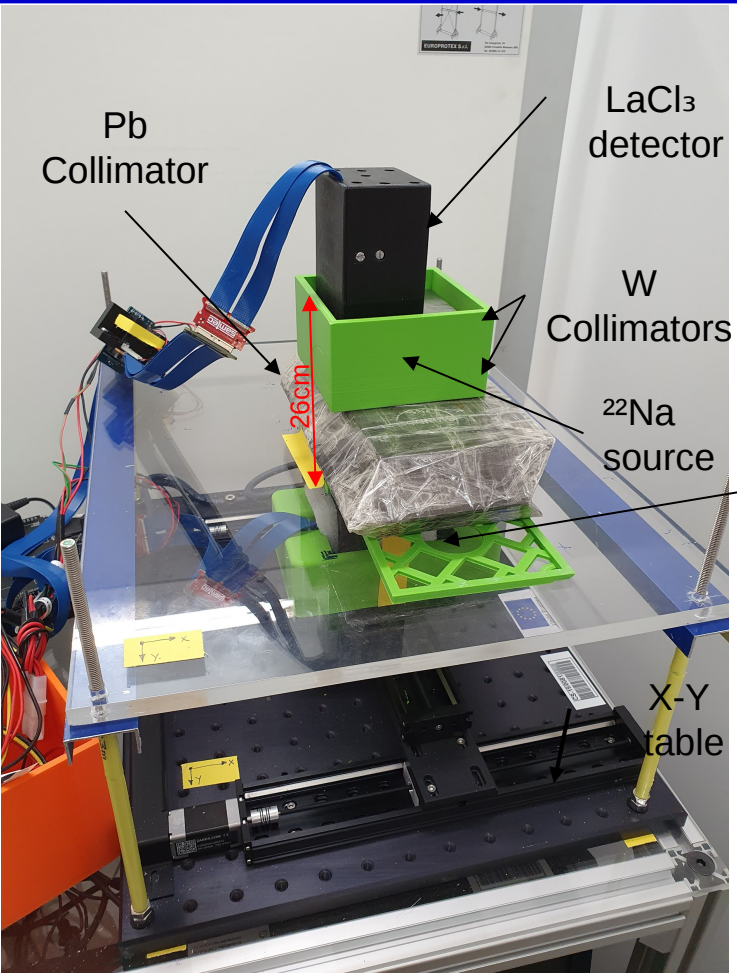
Energy Calibration ($E_\gamma \propto \sum L_i$).

Compton imaging + ML

Position Calibration (x_r, y_r, z_r).

J.Lerendegui and V. Babiano Talks!

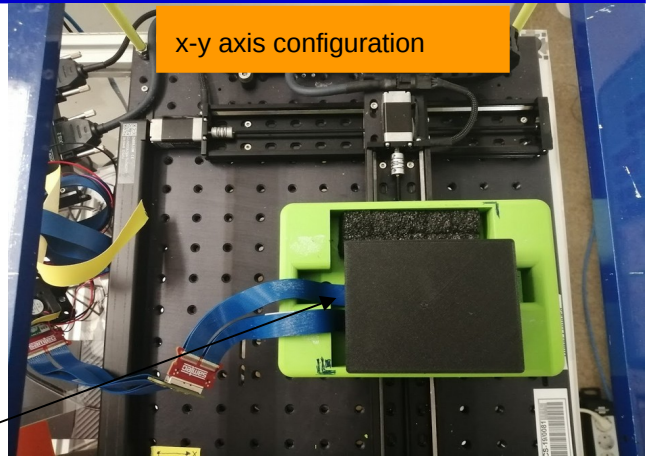
Experimental setup

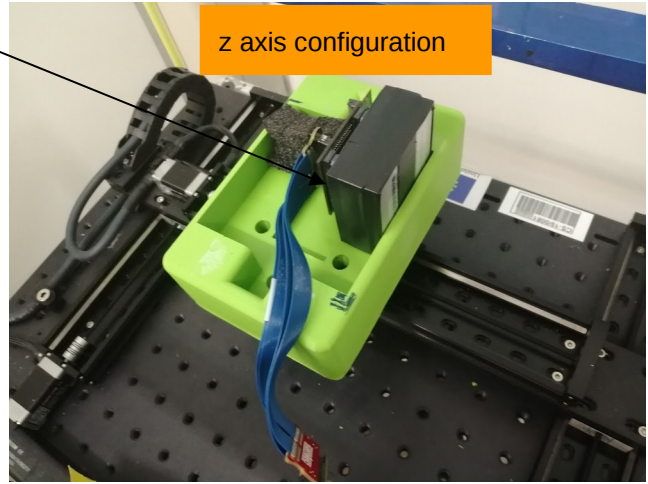


Exp Setup:

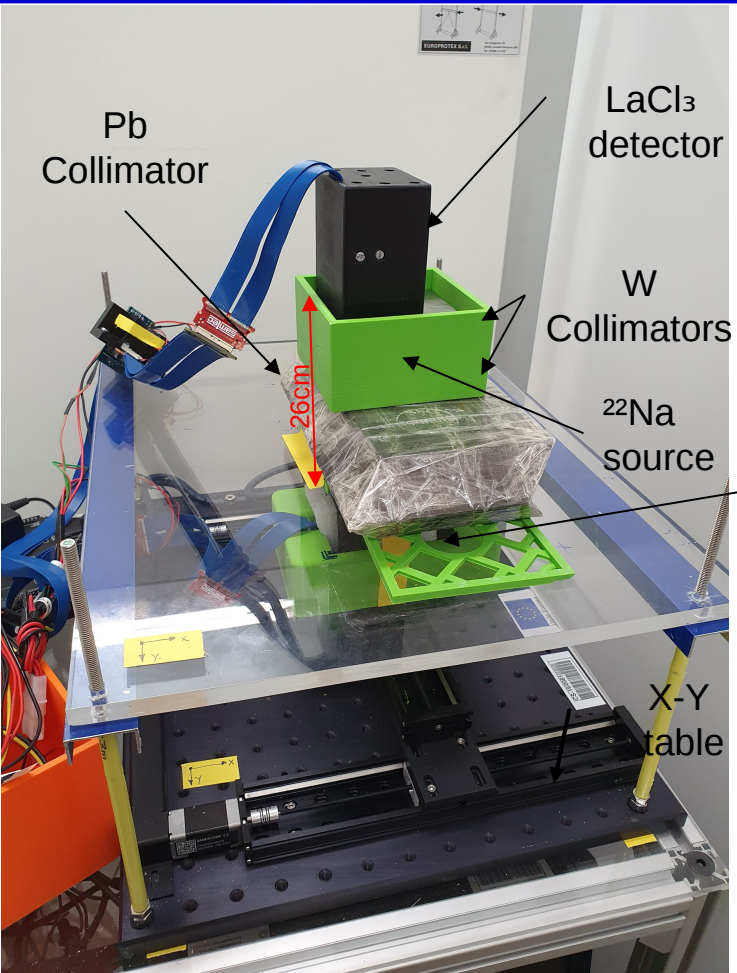
- 2 $LaCl_3$ detectors.
- **Collimated ^{22}Na** source.
- XY position table.

$LaCl_3$ detector





Experimental setup



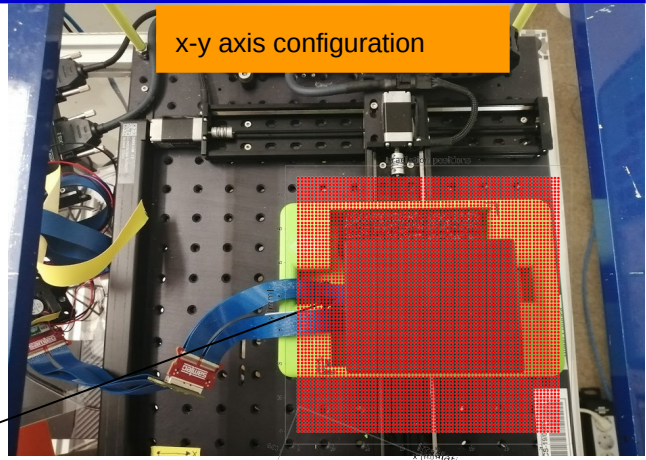
Exp Setup:

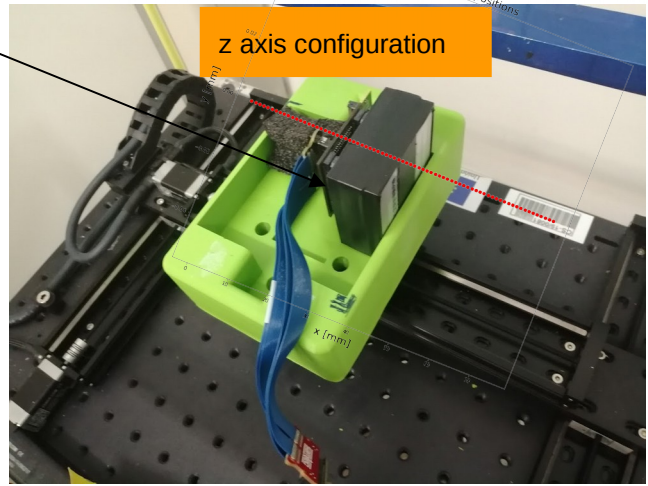
- 2 $LaCl_3$ detectors.
- **Collimated ^{22}Na** source.
- XY position table.

$LaCl_3$ detector

Exp. configurations:

- **x-y axis characterization**: Mesh of **1 mm pitch**
- **z axis characterization:** Mesh of **0.5 mm pitch**





Detection of the detectors' edge

Reduction of random coincidences:

- Eɣ= **511 keV**.
- Δt($LaCl_3$)= **100 ns**.

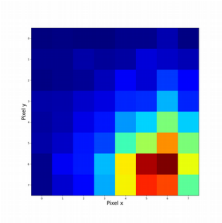
Edges of the crystals:

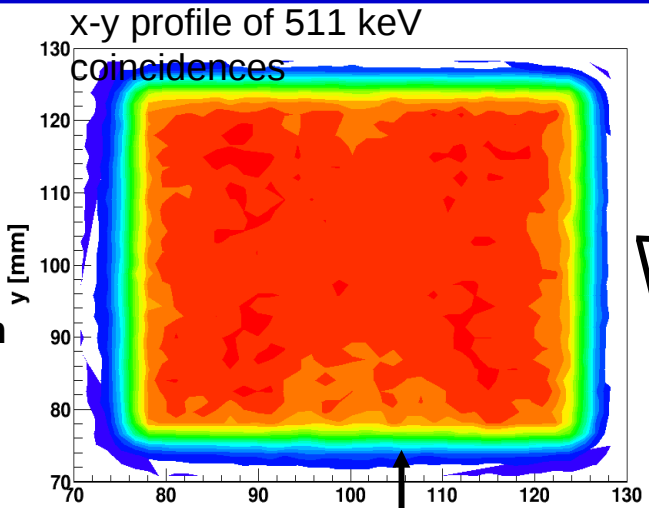
- **50%** of the **maximum** counting rate.

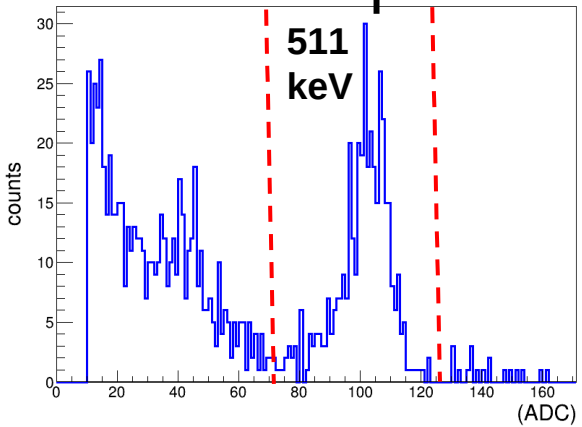
Effective/Ideal area [mm²]:

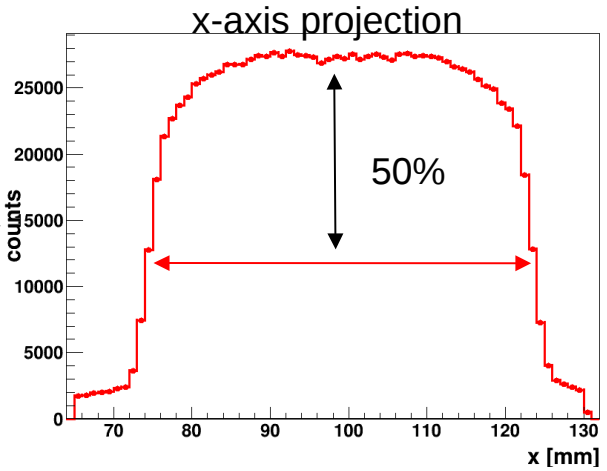
- 10mm: 48x48/*50x50*.
- 15mm: 48x48/*50x50*.
- 20mm: 47x47/*50x50*.
- 25mm: 49x48/*50x50*.
- 30mm: 48x49/*50x50*.

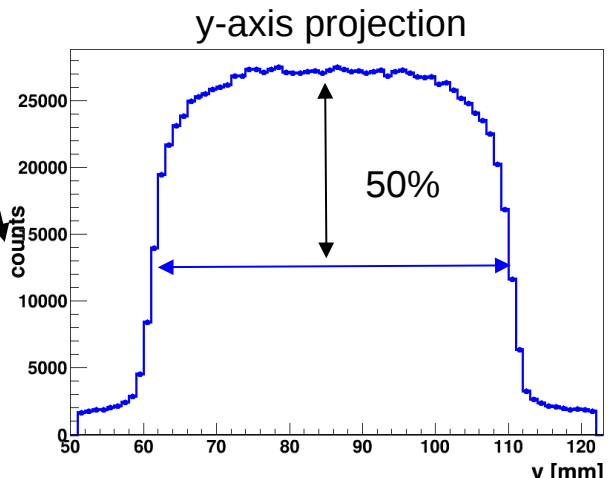
Event:



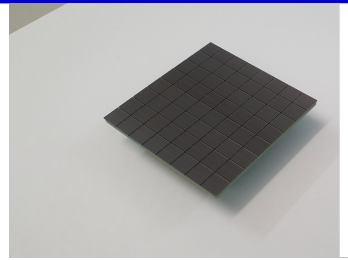


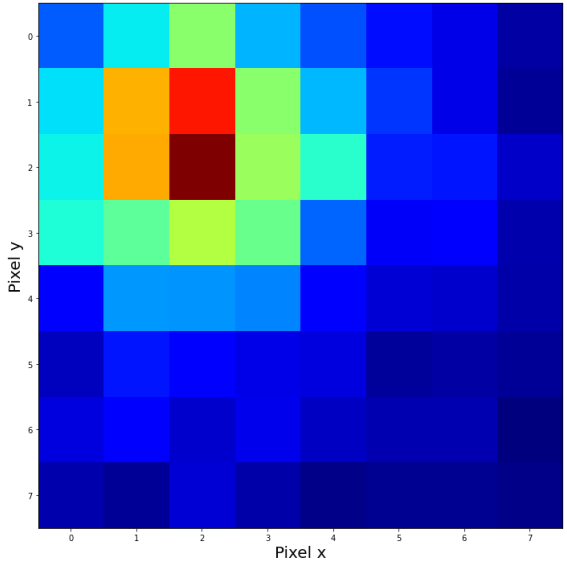






x-y position reconstruction methodology





Light map from SiPM for a single event.

(x_r, y_r, z_r)

GPUFIT:
Scientific Reports,
vol. 7, 15722 (2017)

- Li [kernel-14]

Phys. Med. Biol. 55 (2010) 6515-6532

- Gauss [kernel-22]

Phys. Med. Biol. 53 (2008) 1843–1863

- Gauss(ρ) [kernel-23]

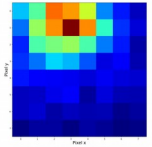
$\rho=Cov(x,y)/\sigma_x\sigma_Y$

- Cauchy(ρ) [kernel-24]

$\rho=Cov(x,y)/\sigma_x\sigma_Y$

TensorFlow + Keras

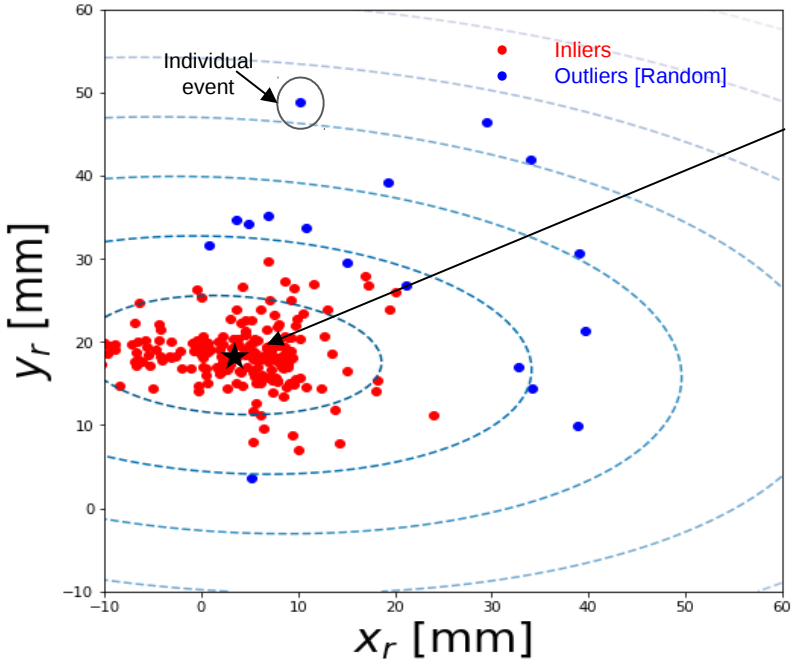
3D keras models for the individual crystals



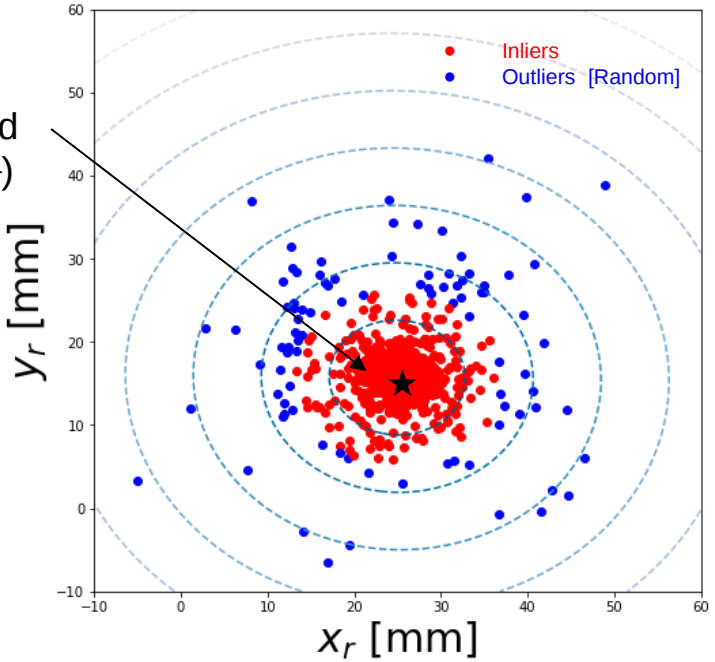
Optical Photons simulation:
P. Olleros et al 2018 JINST13 P03014

x-y axis characterization

x-y position reconstruction for a single irradiation



Reconstructed position (x_r,y_r) for a single irradiation



Reconstructed positions from the different models in the individual irradiations were fitted using the **robust covariance method** [1]**.**

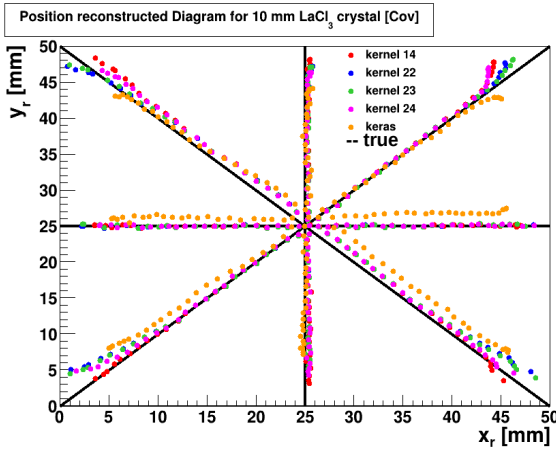
https://scikit-learn.org/stable/auto_examples/covariance/plot_mahalanobis_distances.html#sphx-glr-auto-examples-covariance-plot-mahalanobis-distances-py

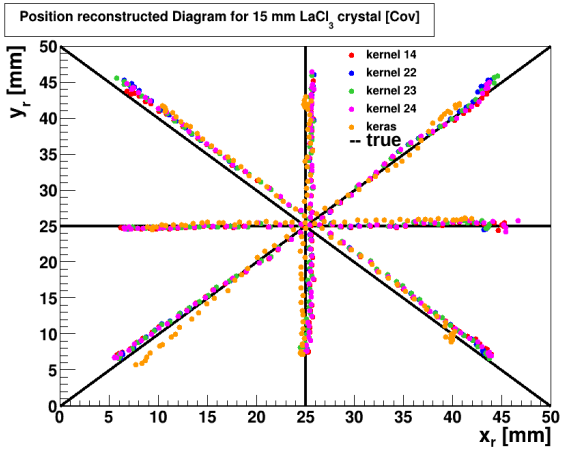
[1] P. J. Rousseeuw. Least median of squares regression. J. Am. Stat Ass, 79:871, 1984
Mahalanobis distances for outlier detection

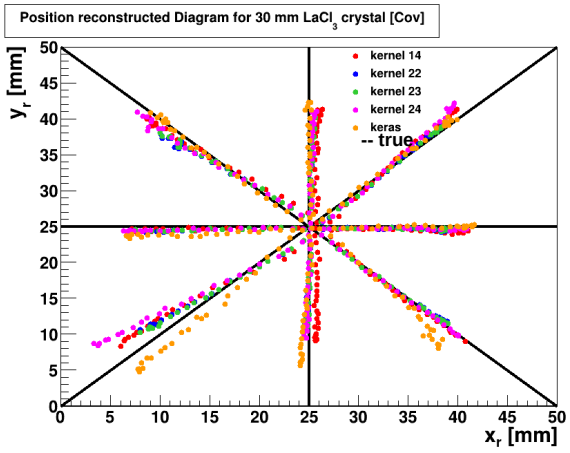
Goals:

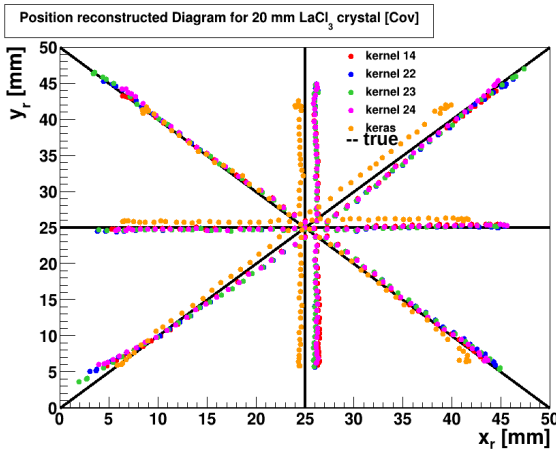
- Evaluation of (x_r,y_r) <--> (x,y) (**Linearity,compression,distortions...**).
- Evaluation of uncertainty in (x_r,y_r) (MC distributions).

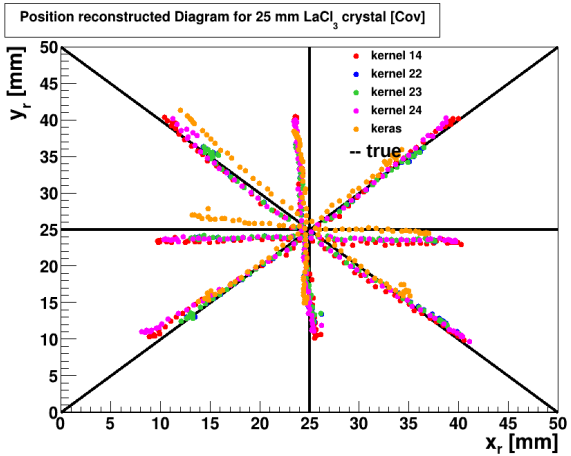
x-y position reconstruction results











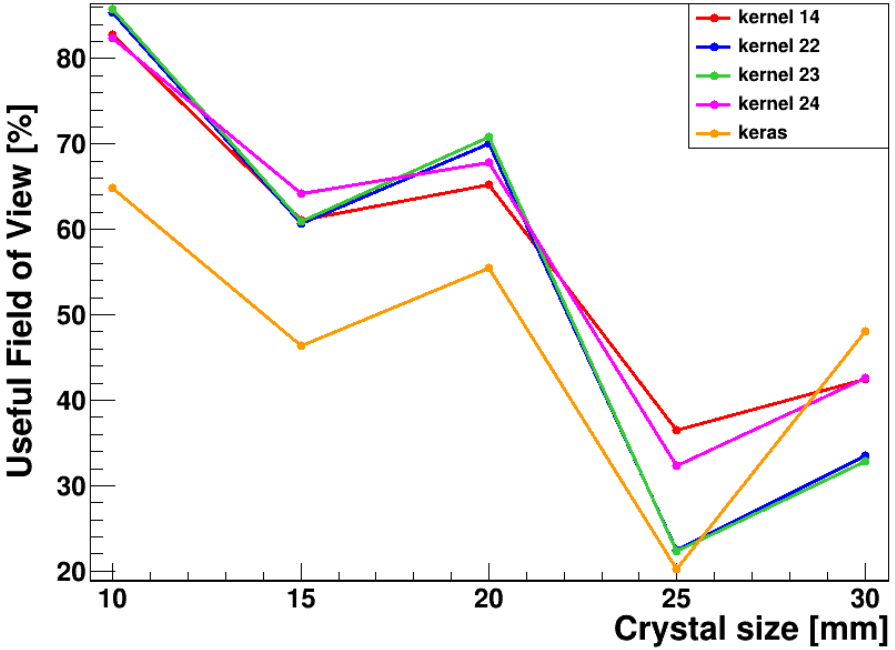
Representative results from irradiations:

- Horizontal and vertical lines.
- D1 and D2 diagonals.

Good linearity for all the crystals and methodologies!

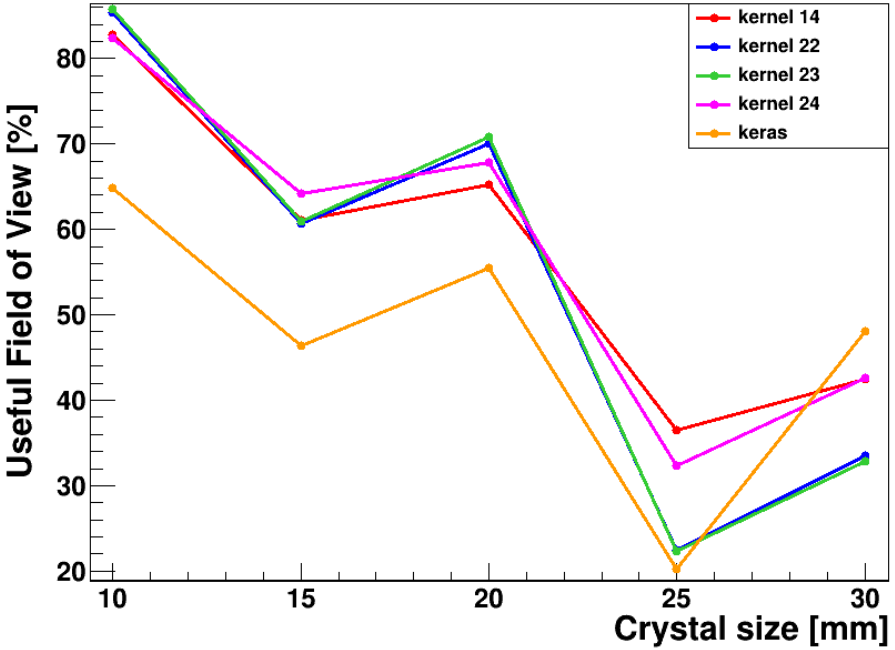
Compression in the output image as a function of the thickness!

x-y position reconstruction correction



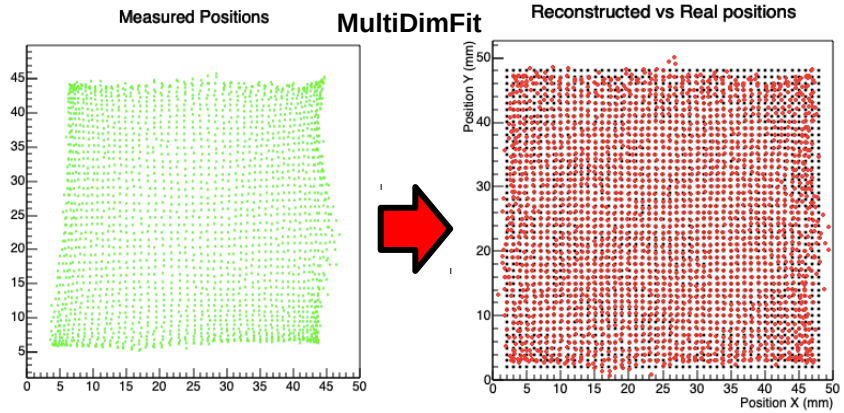
Useful Field of View= Reconstructed Area/Effective Area.

x-y position reconstruction correction



Useful Field of View= Reconstructed Area/Effective Area.

Position reconstructed (x_r,y_r) were fitted to the "known" real positions (x,y) using different techniques.



Technique	Result
MultiDimFit (ROOT)	😀
Random Forest (ML)	😑
Support Vector (ML)	😀
XGboost (ML)	😐

https://scikit-learn.org/stable/
https://root.cern.ch/doc/master/classTMultiDimFit.html
https://xgboost.readthedocs.io/en/latest/

x-y position reconstructed after correction

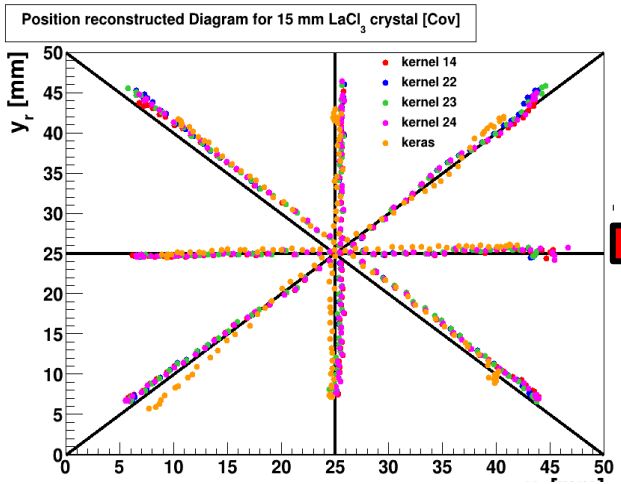
All the statistics processed again applying the correction.

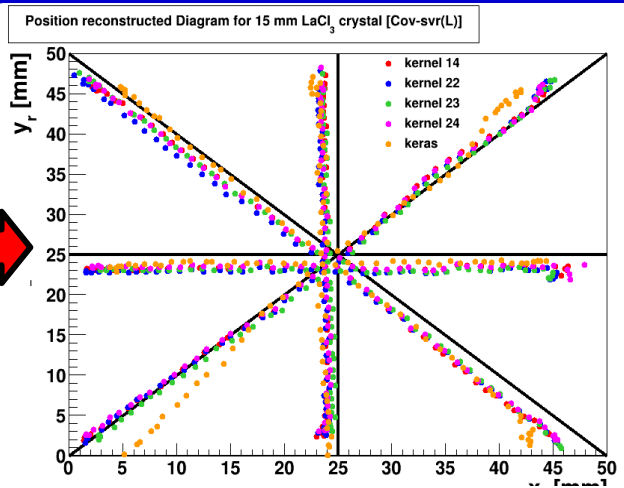
Robust covariance fit.

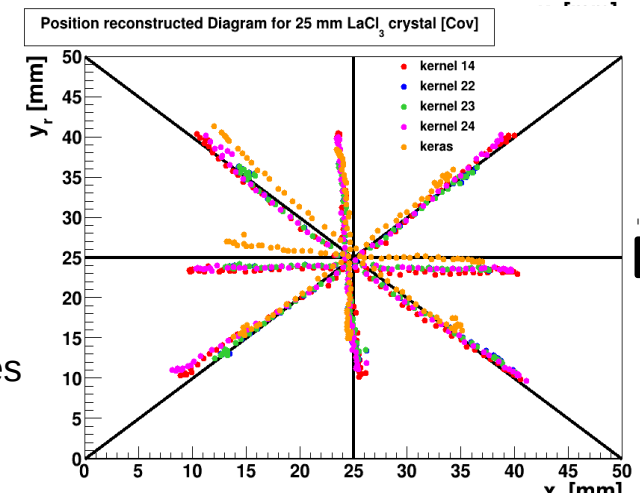
Results from **SVR** correction:

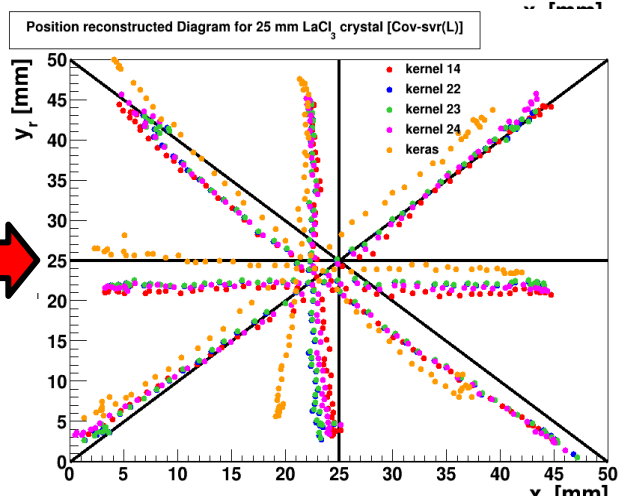
- **Compression reduced**.
- Good linearity.
- **Problem in 25 mm** crystal thickness **under investigation**.
- **Important!**: **Offset**

Crystal axis → **XY table** axis does not correspond exactly!

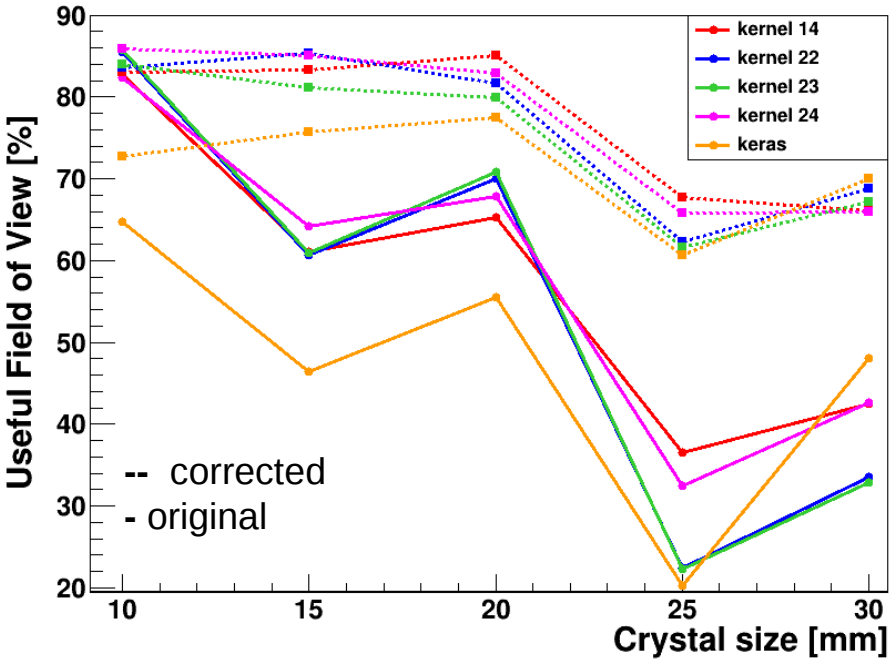








x-y position results

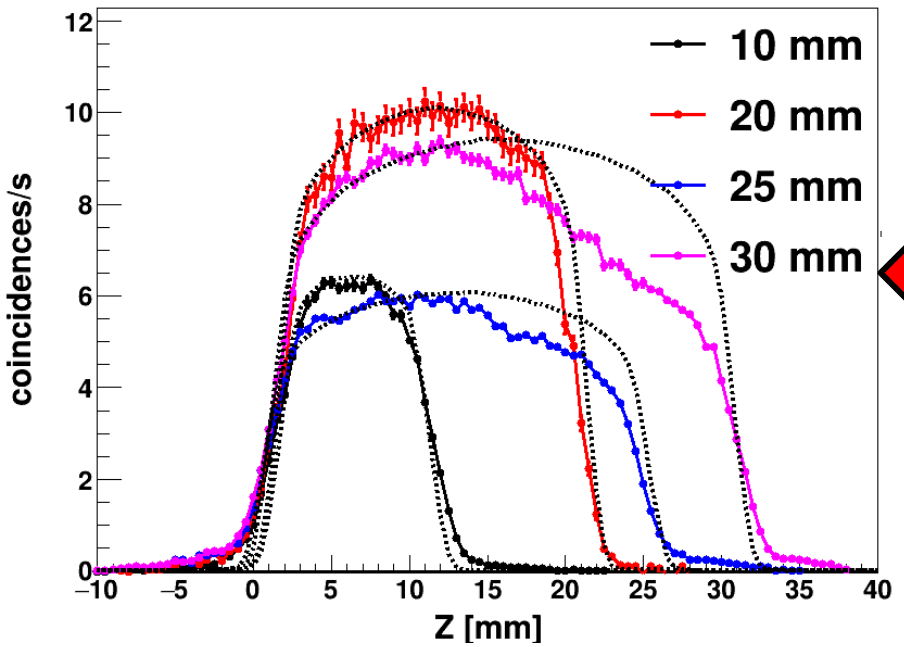


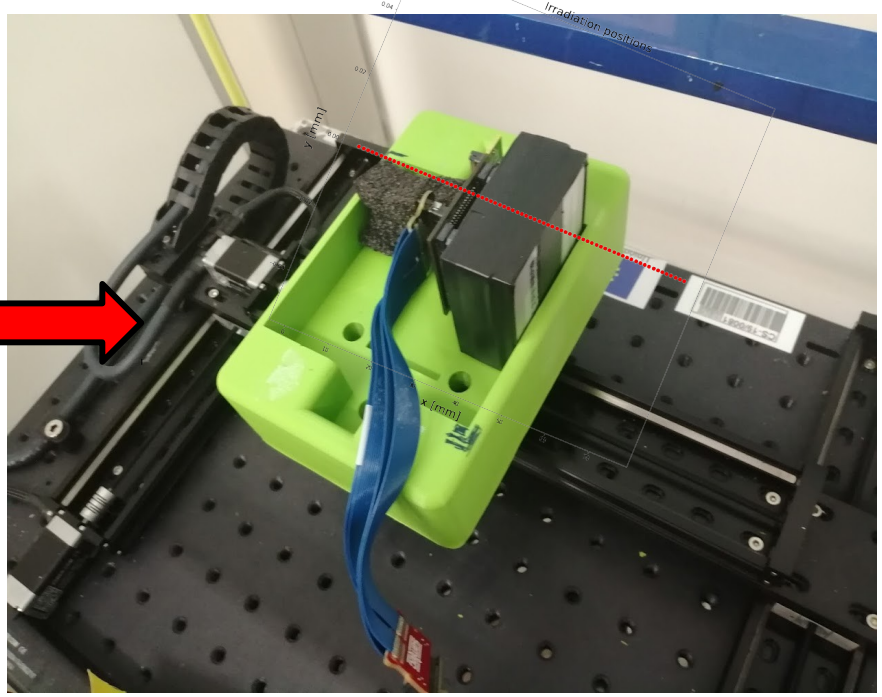
Machine Learning correction applied:

- **Best results** for **support vector machine** algorithm (ML)!
- All Useful Field of View improved for all the crystals and methods!

z axis calibration

z-axis experimental data analysis



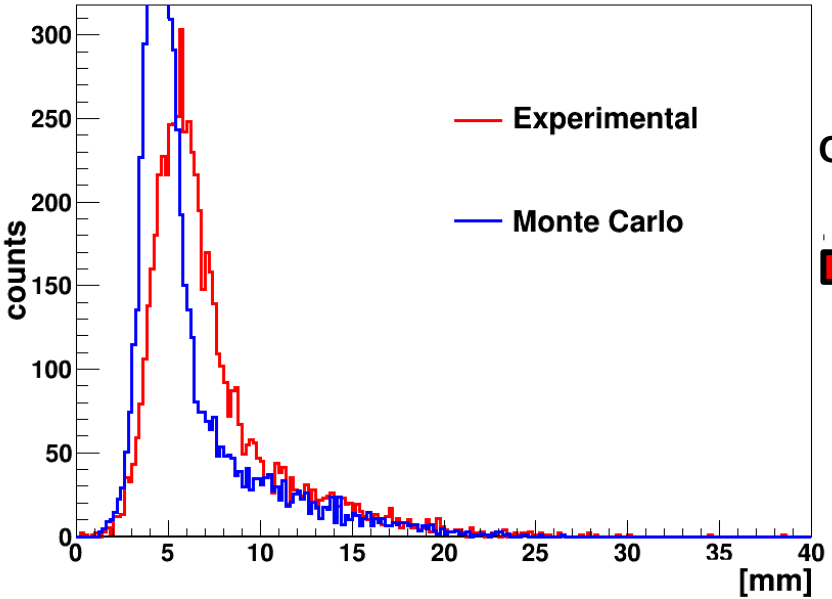


Similar analysis performed to the z-axis scan:

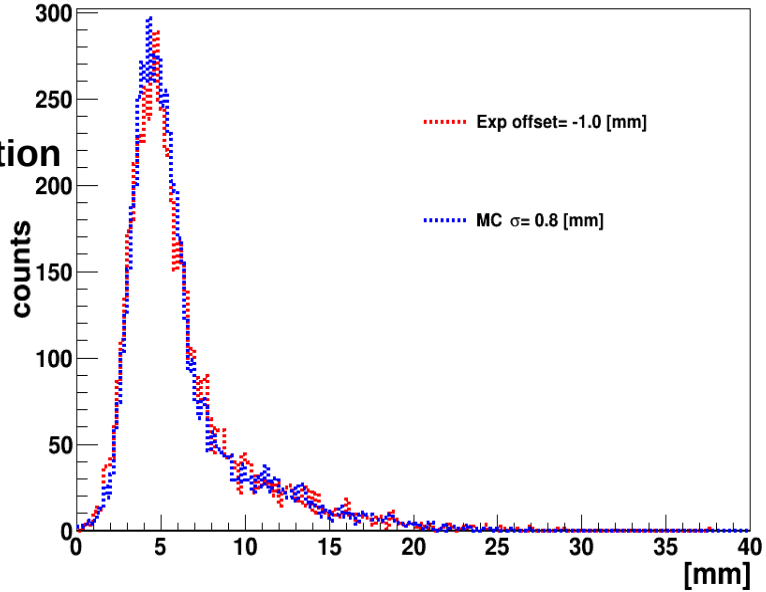
- **MC simulation** of the experimental setup included in the analysis **for z calibration**.
- **Efficiency decrease** as a function of the **depth** for some of the crystals! **No explanation found yet**!
- Remark: **Only kernel 14** results will be shown.

z-axis calibration procedure

Z_{MC}= 6.5 [mm]



Calibration



The reconstructed z position (z_r) does not correspond correspond to the real position z:

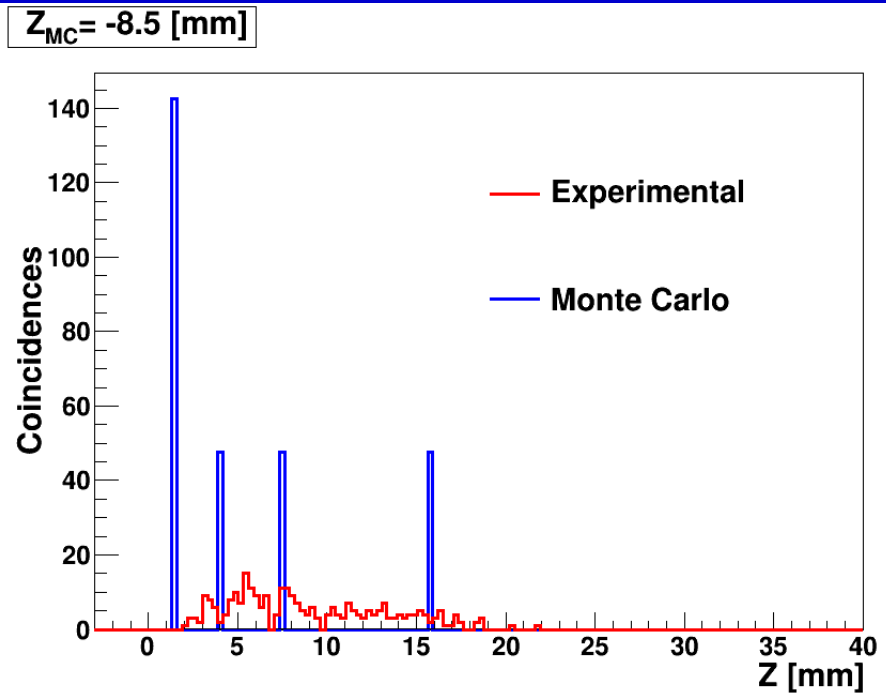
- Expected from previous MC study.
  J. Lerendegui, *Det. Meeting Feb. 2020*
- Also expected Non-linearity at the end of the crystal.

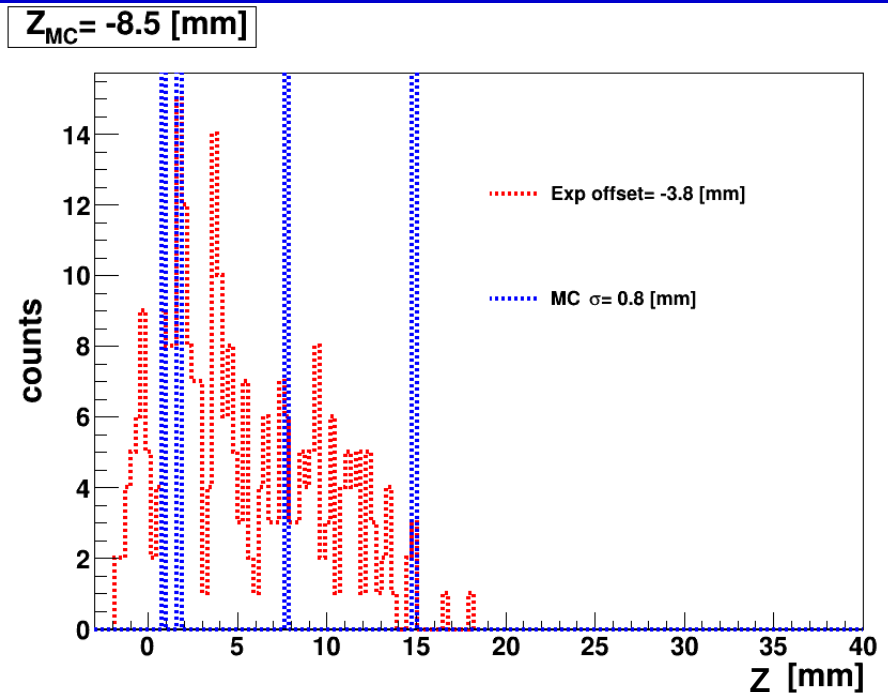
Calibration procedure adopted:

χ^2 minimization (Offset[z], fixed σ) between experimental and MC distributions for the individual irradiations.

Relative good agreement after calibration

z-axis calibration example for 25mm $LaCl_3$ detector

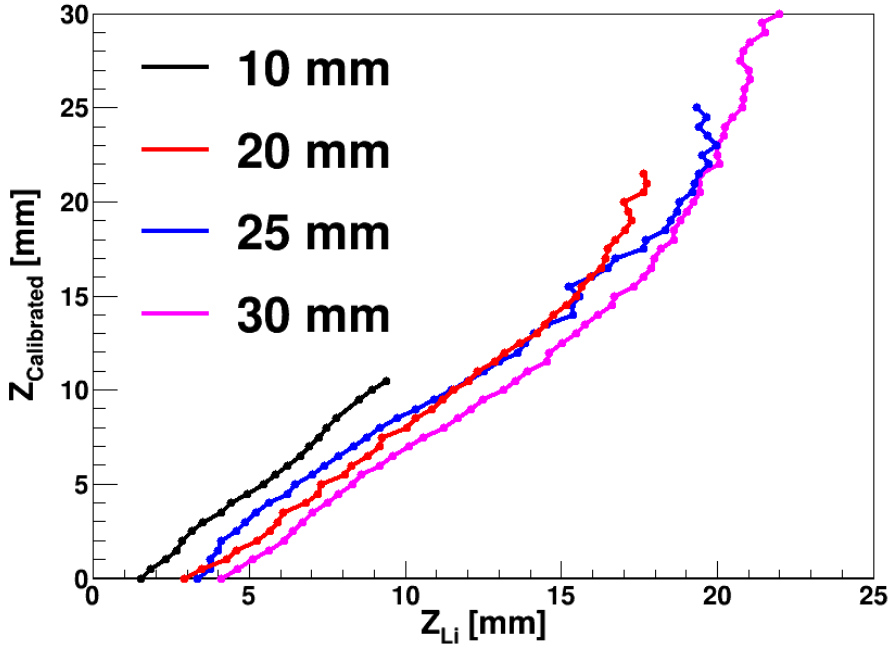




For every irradiation, the z_r/z is calculated resulting in a calibration curve (z,z_r)

- Same procedure applied to four out of five crystals (10mm, 20mm,25mm and 30mm).
- Calculations for 15 mm thickness in progress.
- Calculation for other kernels in progress.

z-axis calibration



Calibration performed in z-axis for four out of the five crystals:

- Similar calibration curve for all the crystals calibrated.
- Non linearity increase with crystal thickness as expected from MC.

Summary and outlook

x-y axis

Five $LaCl_3$ detectors of different thickness were characterized in x-y plane:

- Good linearity.
- **Compression(thickness)**.

Machine Learning correction applied:

- **Best results** for **support vector machine** algorithm (ML)!
- All Useful Field of View improved!

Outlook:

- Problems with **25 mm under investigation**.
- Position reconstruction **uncertainty** (in progress).
- Checking results with new $LaCl_3$ batch.

z axis

Four out of five $LaCl_3$ detectors characterized in the z-axis:

- **Decrease of efficiency** as a function of z
  -> No explanation yet.
- **Only kernel 14 calibrated** (so far!).
- All **calibration curves** have quite **similar trend!**

Outlook:

- **Improve fitting** methodology.
- Produce all calibration curves for all the kernels/crystals.
- Quantify uncertainty in z-axis.

WORK IN PROGRESS!

Thank you very much for your kind attention!