Image based trigger algorithms

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Reconstruction & analysis meeting - 23/10/2025

Contents

1. Introduction

Motivation

- One major **challenge** for the **CYGNO experiment** in the long term will be to **store and analyse all the data produced by the detector.**
  - Each run containing **400 images** needs **~1.36 Gb** to be stored (Fusion, compressed .mid).
  - A **single day of acquisition** may produce **~266 Gb** of data (Run5 on 26th september).

- The motivation of this work was to study algorithms capable of **distinguishing images or regions** containing a **signal of interest** and **background events.**

- An algorithm capable of doing this task was called **image based trigger algorithm.**

What was done

- Two approaches were proposed:
  - **Image level trigger** using **filtering** and **CNNs.**
  - **Pixel level trigger** using **filtering.**

- A performance analysis was done using simulated and real data from Fusion (focused on **low energy** events):
  - Trigger **detection performance**.
  - Reconstruction comparison.
  - **Processing time.**

Last results

- The **Gaussian filter** may **detect ~80%** of the **0.25 keV NR** and **ER** events with a **~10% false alarm (~0.25** and **0.02 seconds** on **CPU** and **GPU).**

- The **CNN** may **detect ~80%** of the **0.25 keV NR** and **ER** events with a **~0.5% false alarm (~0.55** and **0.2 seconds** on **CPU** and **GPU).**

- Both methods **outperform** the **reconstruction** in **detecting 0.25 keV** events.

- **All methods** can easily **detect** energies **above 0.5 keV.**

Last results

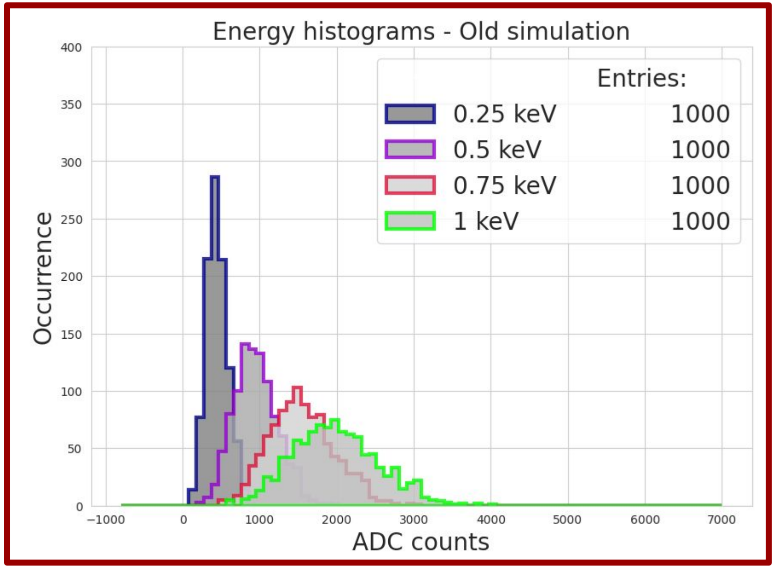
- The **idea** of the **pixel level trigger** is to apply the **Gaussian filter** looking for **high correlation** points and **save** the **region around** them. [1] [2]

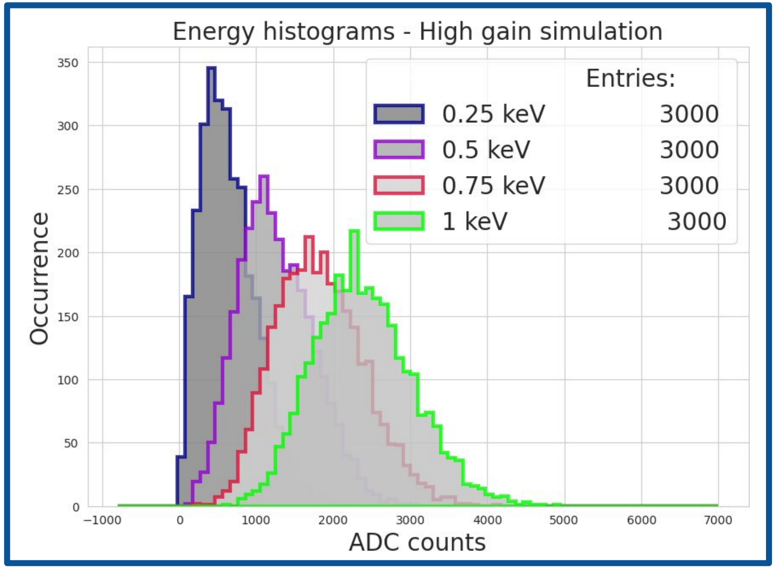
- It **preserved 100%** of **0.5 keV** and **85%** of **0.25 keV** simulated events, while reducing **~50x memory** used to **store** the images (**~20 ms** on **CPU**).

- **These results** were achieved **without** a **proper methodology** to determine an **ideal threshold** to **detect high correlation** points (this will be **explored** with the **new simulation**).

2. Fusion simulations

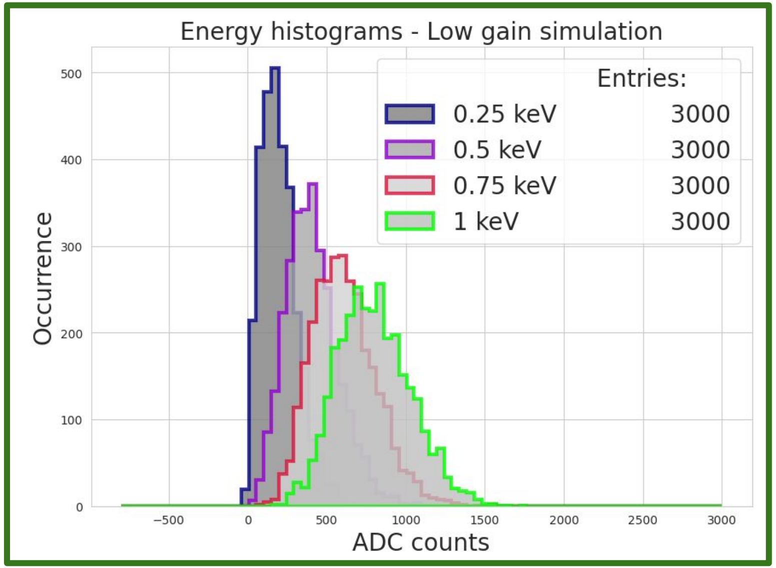
High gain simulation

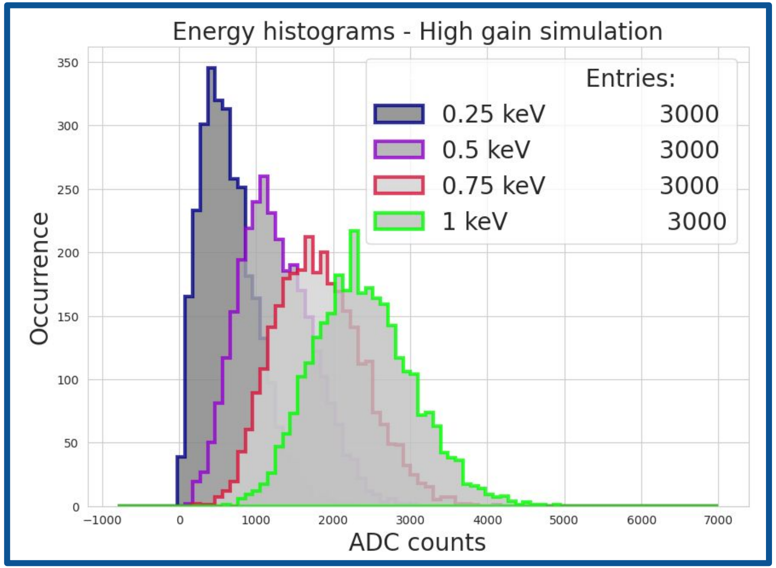




- The new high gain simulation energy in ADC counts is slightly higher and wider.
  - **0.25 keV: [446.17 ± 138.45]** vs **[650.76 ± 367.88]**
  - **0.5 keV: [946.93 ± 278.46]** vs **[1256.11 ± 479.44]**
  - **0.75 keV: [1546.18 ± 418.33]** vs **[1824.22 ± 570.07]**
  - **1 keV: [1992.36 ± 556.59]** vs **[2386.86 ± 639.05]**

Low gain simulation





- The **low gain** simulation energy in **ADC counts** is **~3 times smaller** than **high gain**.
  - **0.25 keV: [200.89 ± 116.91]** vs **[650.76 ± 367.88]**
  - **0.5 keV: [408.99 ± 166.39]** vs **[1256.11 ± 479.44]**
  - **0.75 keV: [609.78 ± 201.59]** vs **[1824.22 ± 570.07]**
  - **1 keV: [801.70 ± 230.01]** vs **[2386.86 ± 639.05]**

- It is **expected** to be **harder** to **detect** these **signals**.

3. Results

Image level trigger

- The **same training procedure** for the **filtering** methods was used with the **new data.**
  - **Gaussian** and **matched filter** still provide the **best results.**
  - **Kernel sizes** of **17 (HG)** and **21 (LG)** were selected.

- The **CNN models trained** with the **old simulation** were used as a **start point.**
  - **New training** will be done in the **future.**

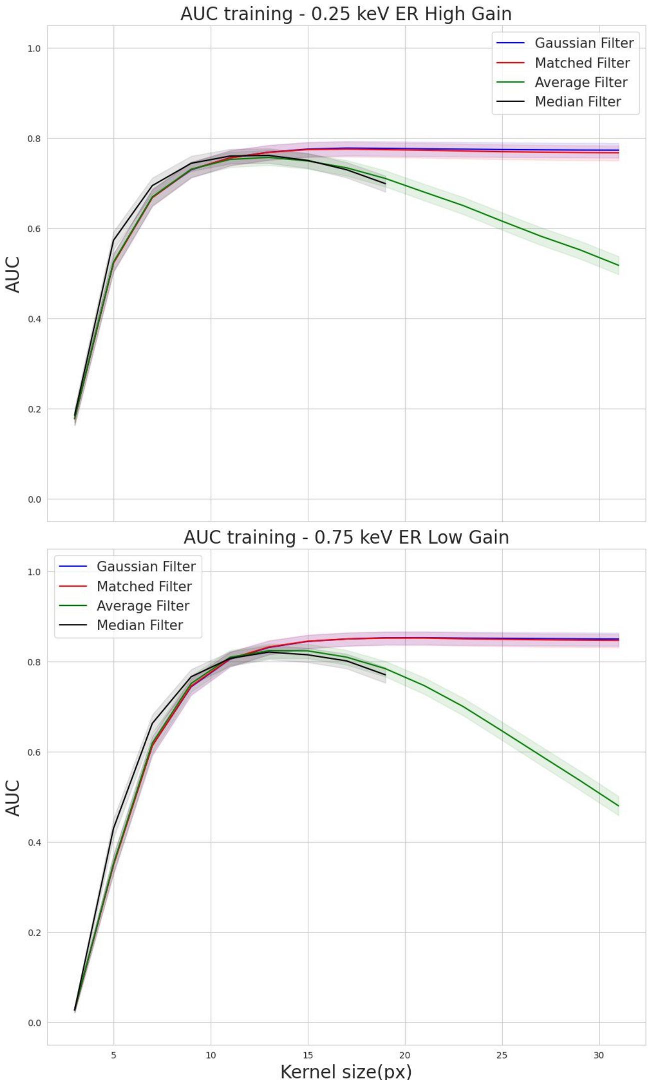
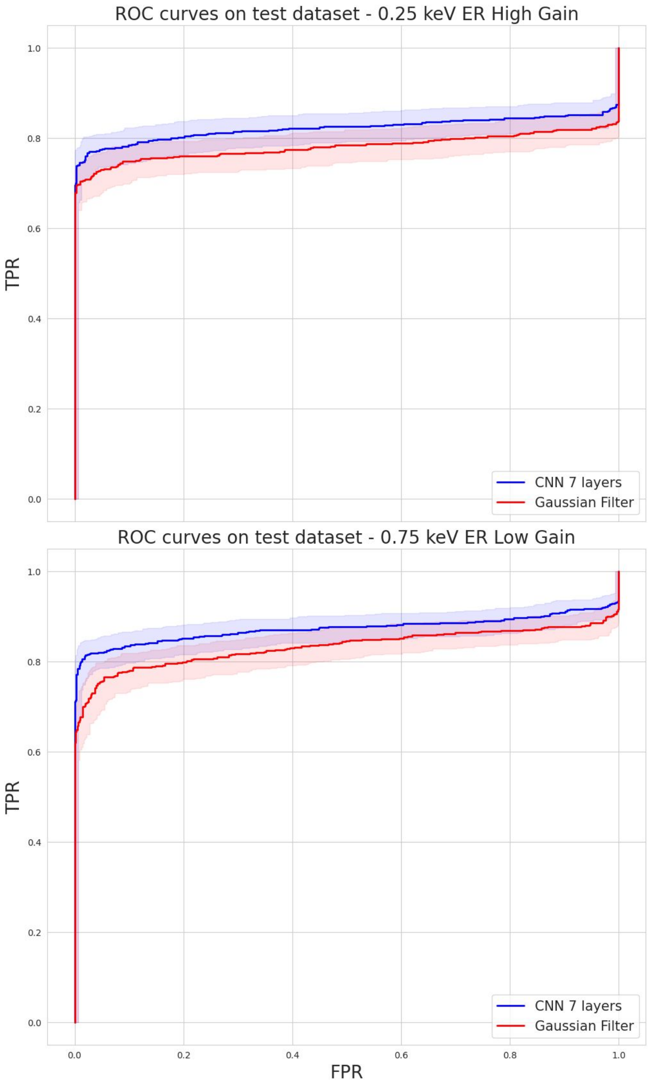


Image level trigger

- The **new high gain simulation** showed **slightly worse results** compared to the **old** one.
    - It has more **low ADC counts events** due to its higher **std**.

- The **low gain 0.75 keV ER** shows **similar** results compared to the **0.25 keV ER** from the old simulation.

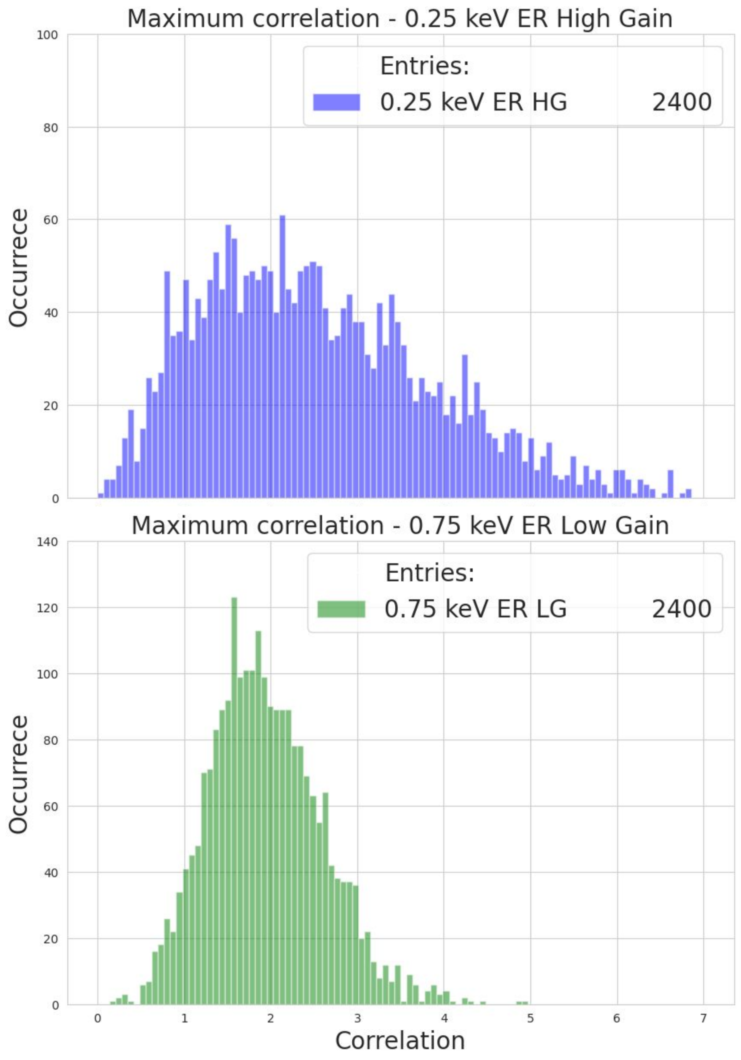
- Further **results** considering **higher energies** will be shown in the **future.**



Pixel level trigger

- The **pixel level trigger** needs **two parameters**: **threshold** (centroid detection) and **radius** (save region).
  - The **threshold** should **detect** as much as possible of the **signal** while **discarding noise.**

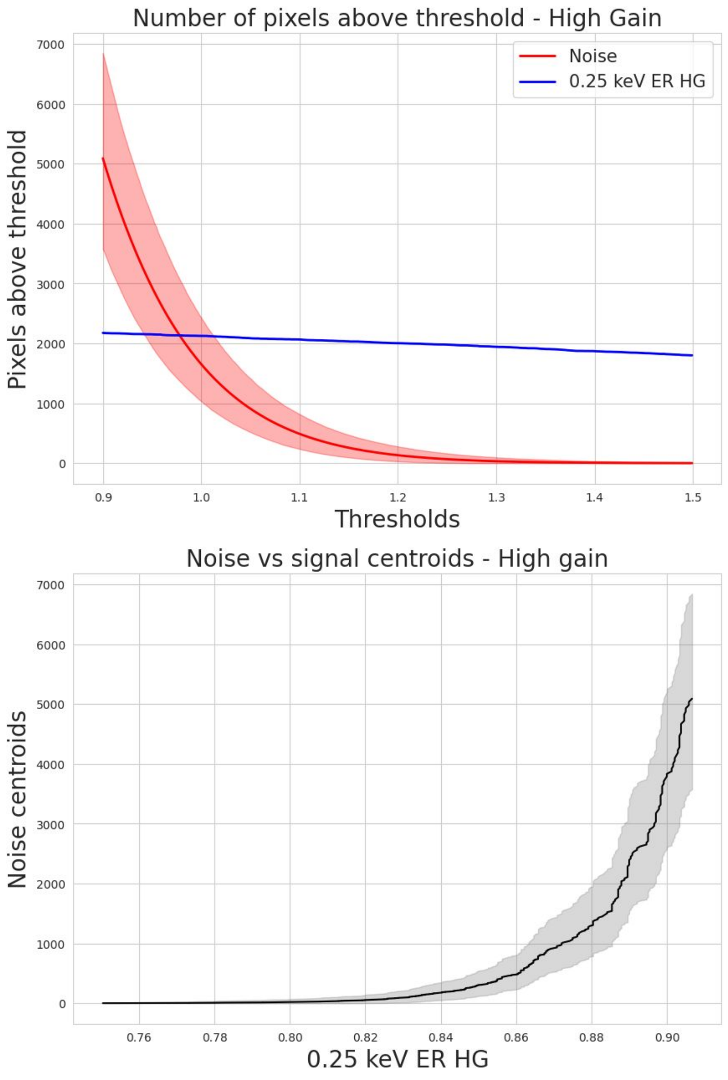
- **Possible ranges** of **thresholds** were selected to see the number of **noise centroids** detected on **noise dataset.**
  - **High gain:** [0.9, 1.5]
  - **Low gain:** [0.8, 1.2]



Pixel level trigger

- The **number** of **noise centroids** detected **start high** and **rapidly decreases** as the **threshold increases**.
    - **5000 centroids** could **retain 2 million pixels** in the image with a **radius** of **20** for example.

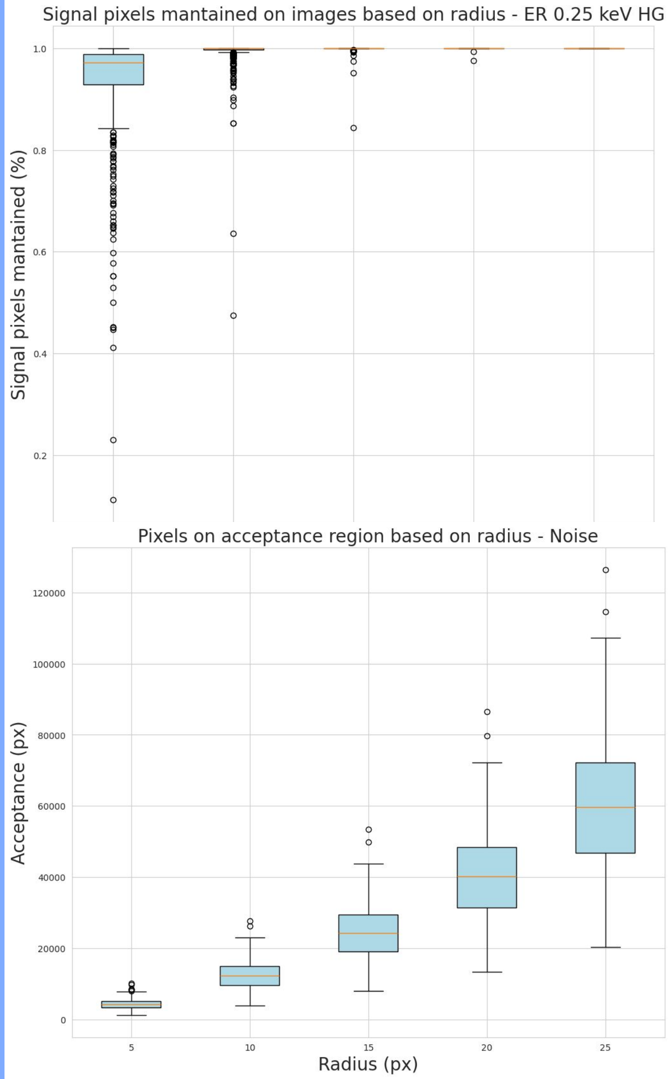
- The **lower plot** gives a better look at the possible i**deal threshold**: the **knee**.
    - **High gain threshold: 1.123**
    - **Low gain threshold: 0.988**



Pixel level trigger HG

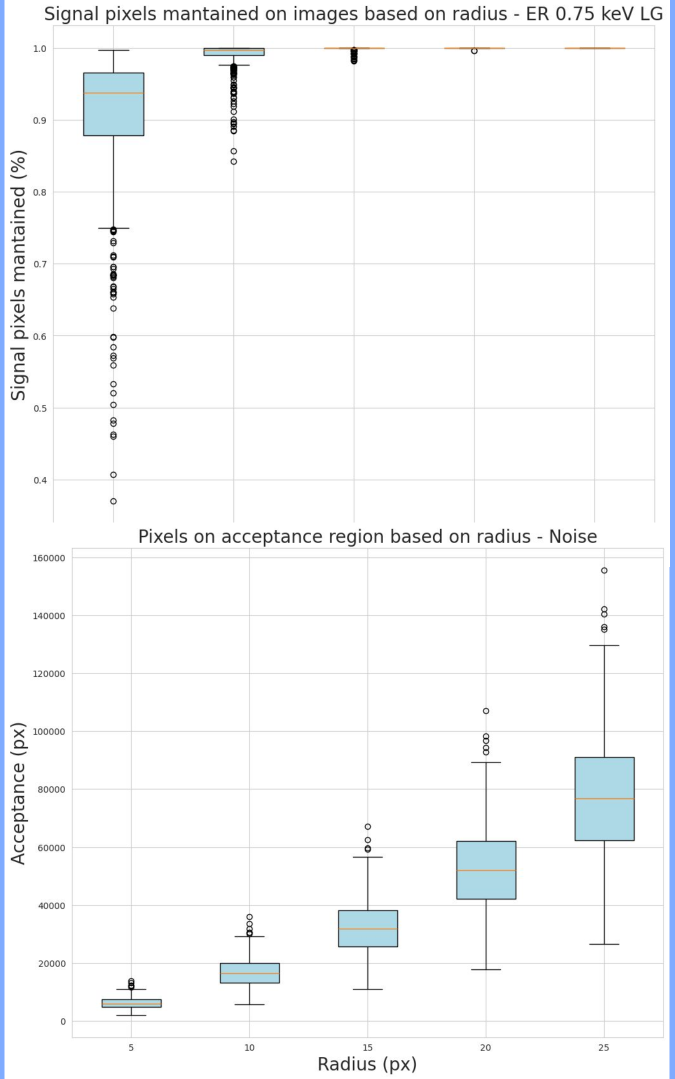
- The algorithm was applied on the **HG** data to select the **radius**.
    - A **radius** of **20** is **enough** to **detect almost all** the **pixels** of the **signal detected.**
    - **~86%** of the **0.25 keV ER HG** were **detected.**

- The test dataset was saved after the algorithm was applied.
    - Original full images: 7.1 GB
    - Images as root histograms: 229 MB
    - Images as sparse arrays (scipy): 185.7 MB
    - Images as sparse arras (root): 188.5 MB



Pixel level trigger LG

- The algorithm was applied on the **LG** data to select the **radius**.
    - A **radius** of **20** is **enough** to **detect almost all** the **pixels** of the **signal detected.**
    - **~93%** of the **0.75 keV ER LG** were **detected.**



3. Conlusions

Conclusions and next steps

- The analysis using the **new simulation** showed **consistent results** and **proves** that the methods are **resilient**.
- The **pixel level trigger** has a **good potential** to **efficiently save memory** on the **data acquisition**.
  - **High energy results** will be shown in the **next presentation.**
- **CNN** will be **retrained** to **try** to **improve performance.**
- **Quest data** will be the **focus** of **analysis** from now on.

Thank you

Credits

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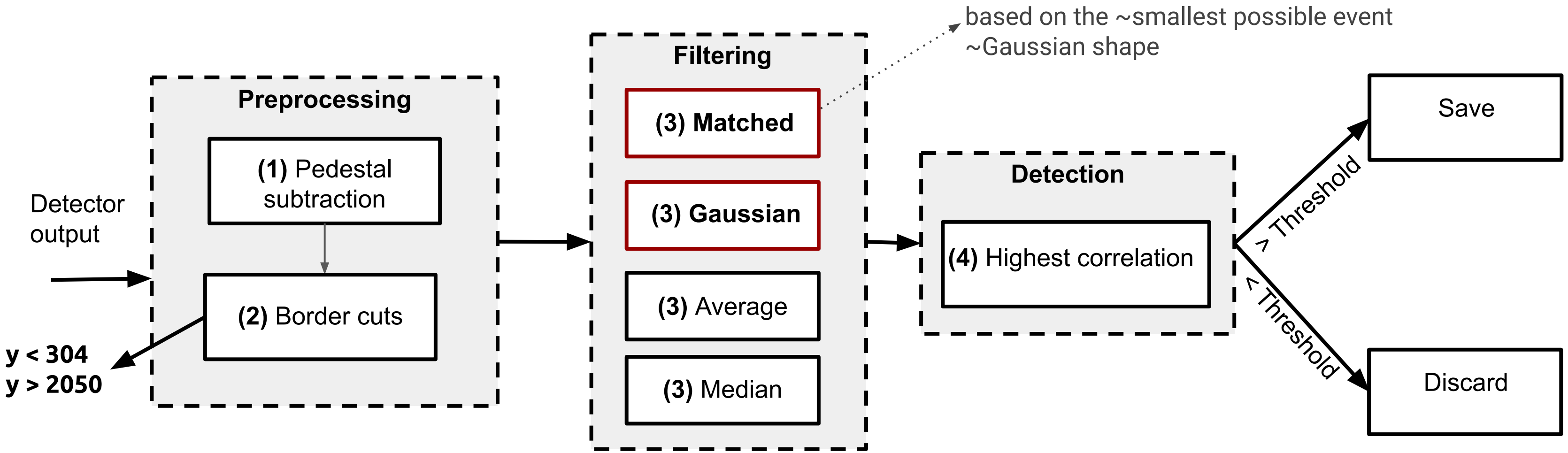
Backup

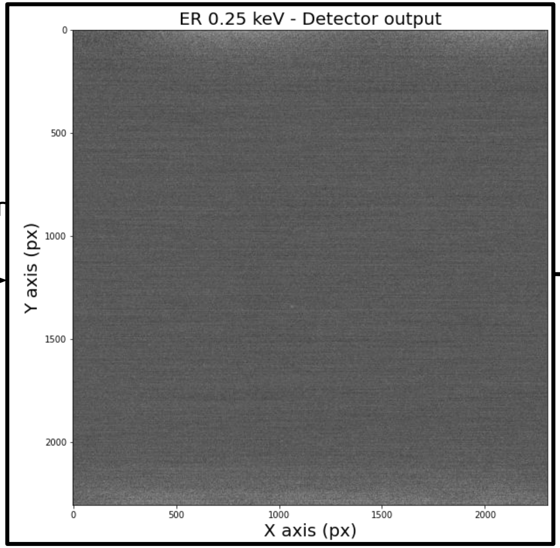
Filtering based trigger

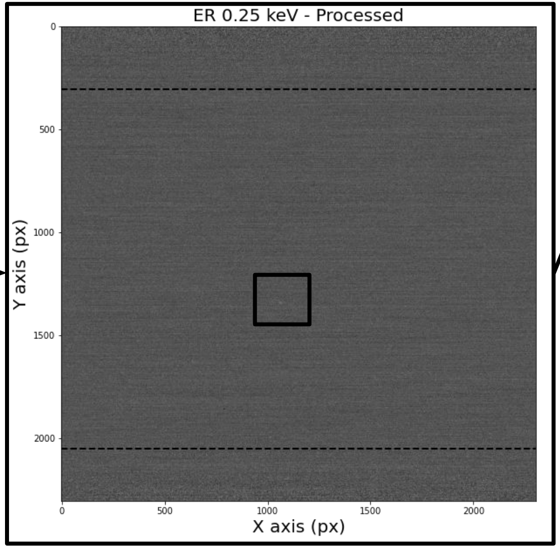


Filter parameters and detection threshold selected based on training data

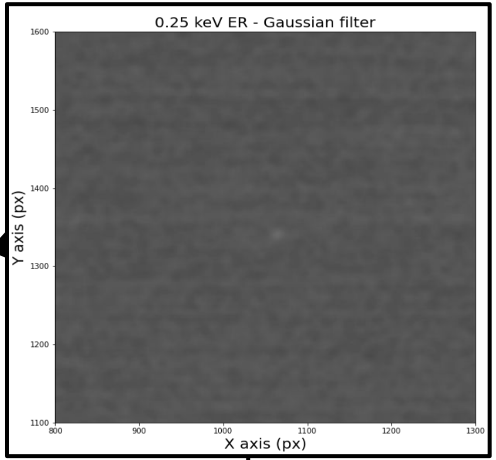
Filtering based trigger

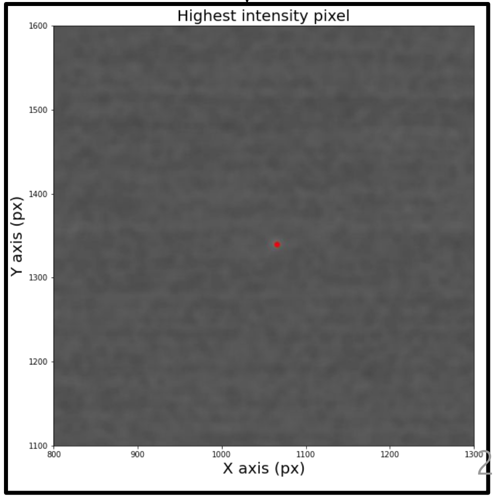
Detector output



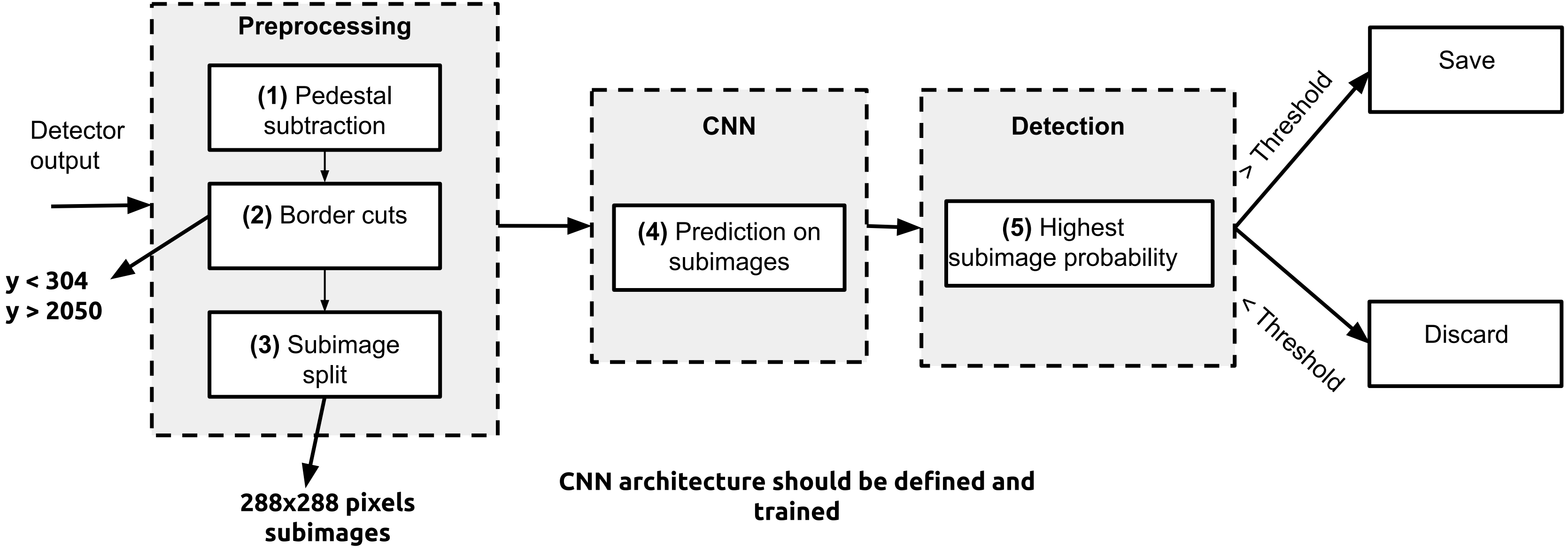


Pedsub + Border cuts





CNN based trigger

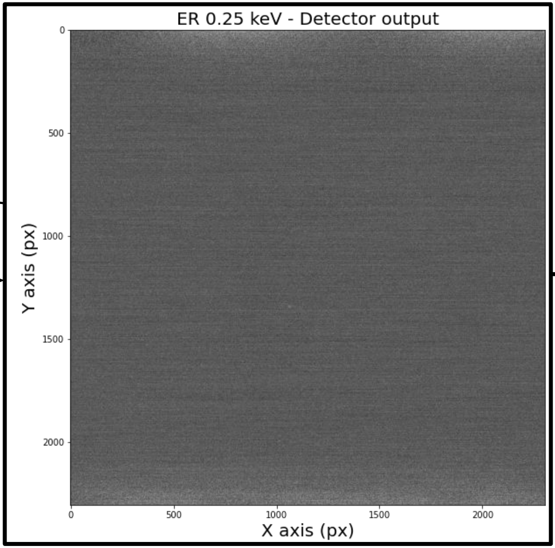


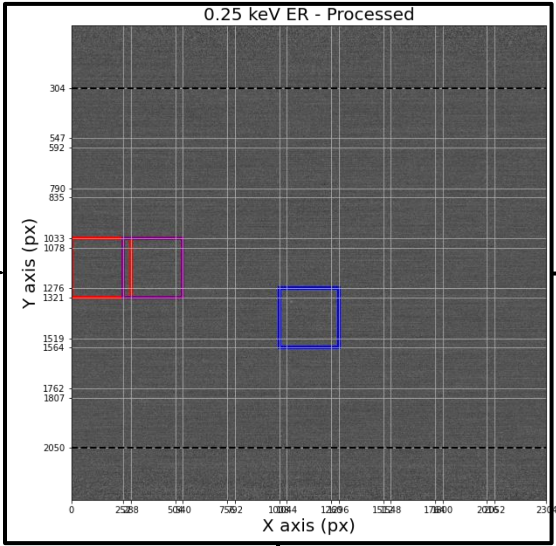
CNN architecture should be defined and trained

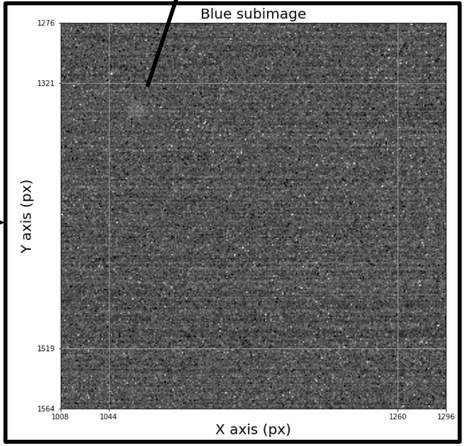
CNN based trigger

Signal Detection

Detector output

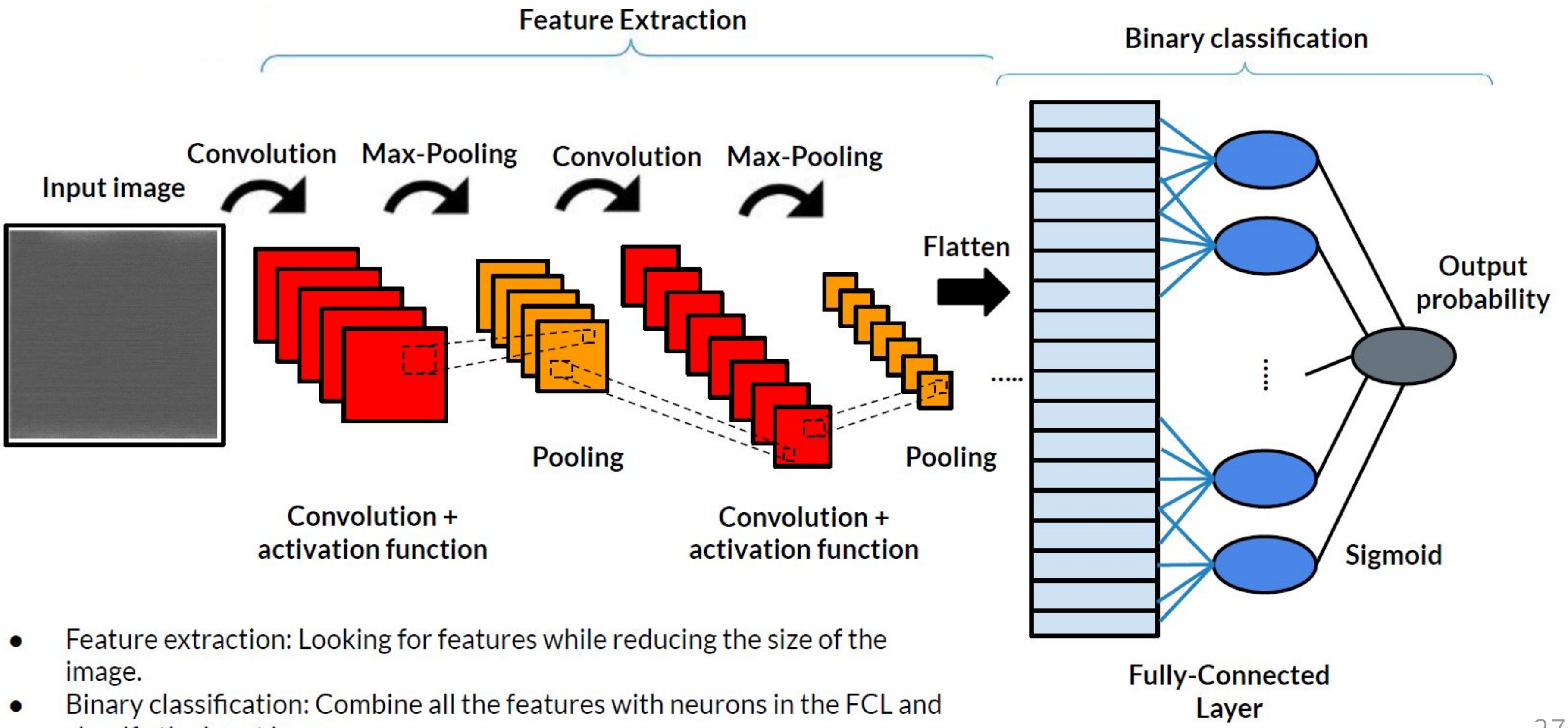






Pedsub + Border cuts + subimage divisions

CNN architecture

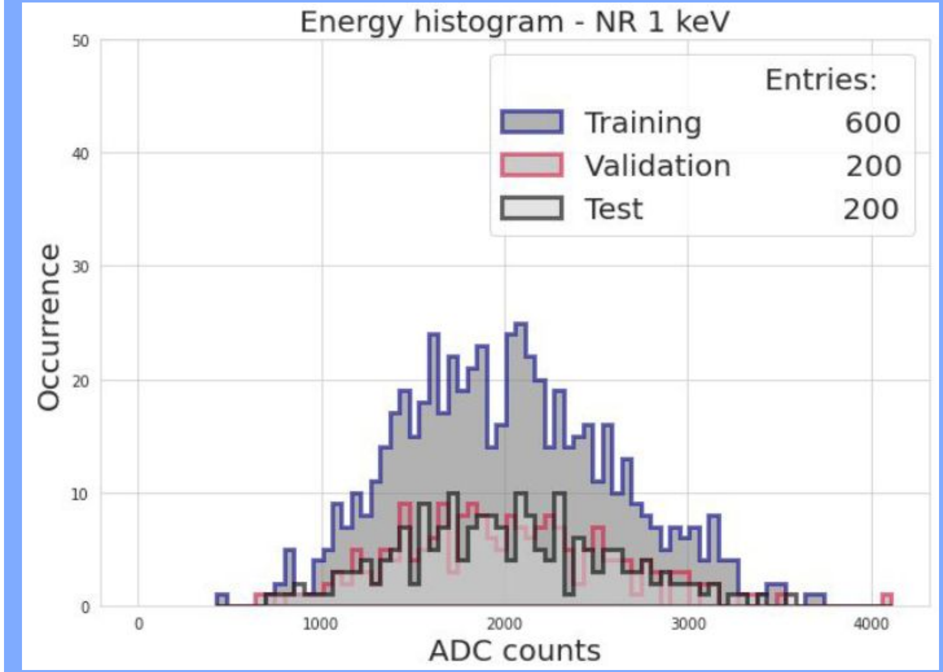


- Feature extraction: Looking for features while reducing the size of the image.
- Binary classification: Combine all the features with neurons in the FCL and classify the input image.

Datasets

- The signal simulation was **divided** considering the **balance in ADC counts** across the three datasets.

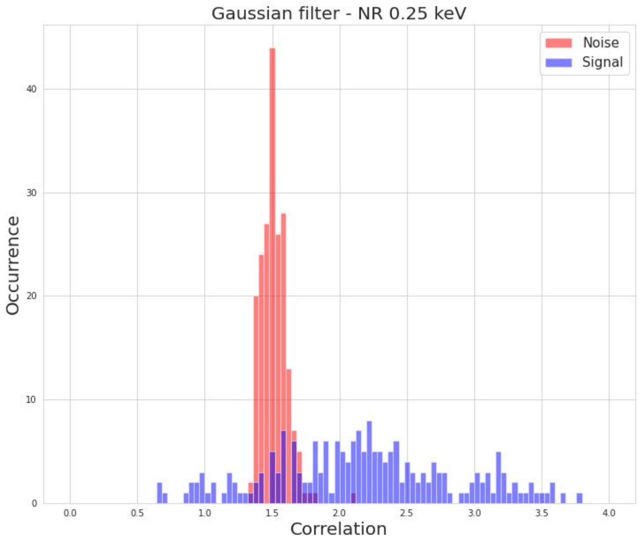
- This prevents the **data split** from **influencing** the results.

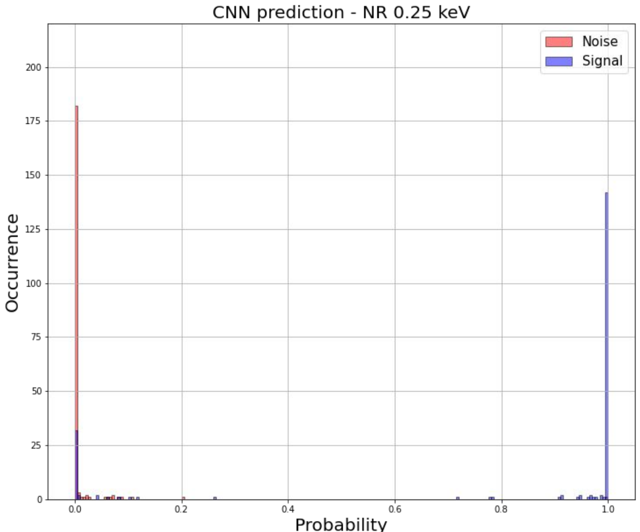


Detection performance

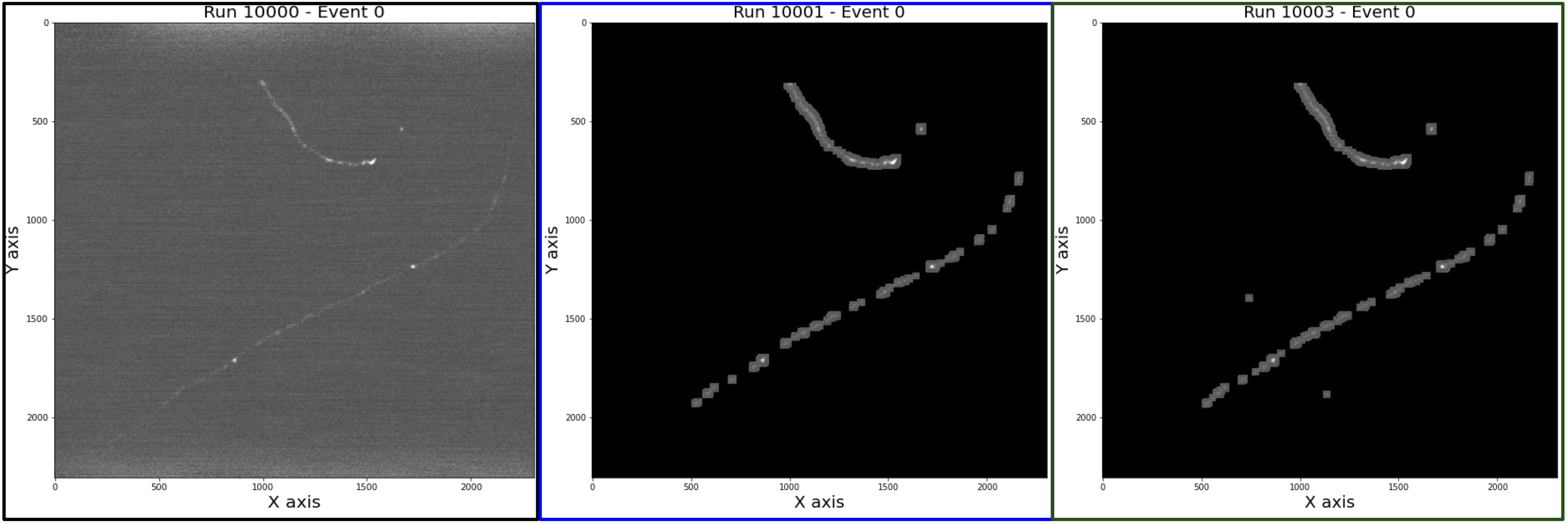
- Applying the trigger algorithms on the test dataset results in **two distributions.**
  - The **Gaussian filter** method **output** is a **correlation.**
  - The **CNN output** is a **probability** (more interpretable)

- These distributions may be used on **ROC curves** to evaluate the results.
  - All possible thresholds are used to measure the true positive rate **(TPR)** and false positive rate **(FPR).**
  - **TPR** is analogue to **signal detection.**
  - **FPR** is analogue to **false alarm.**



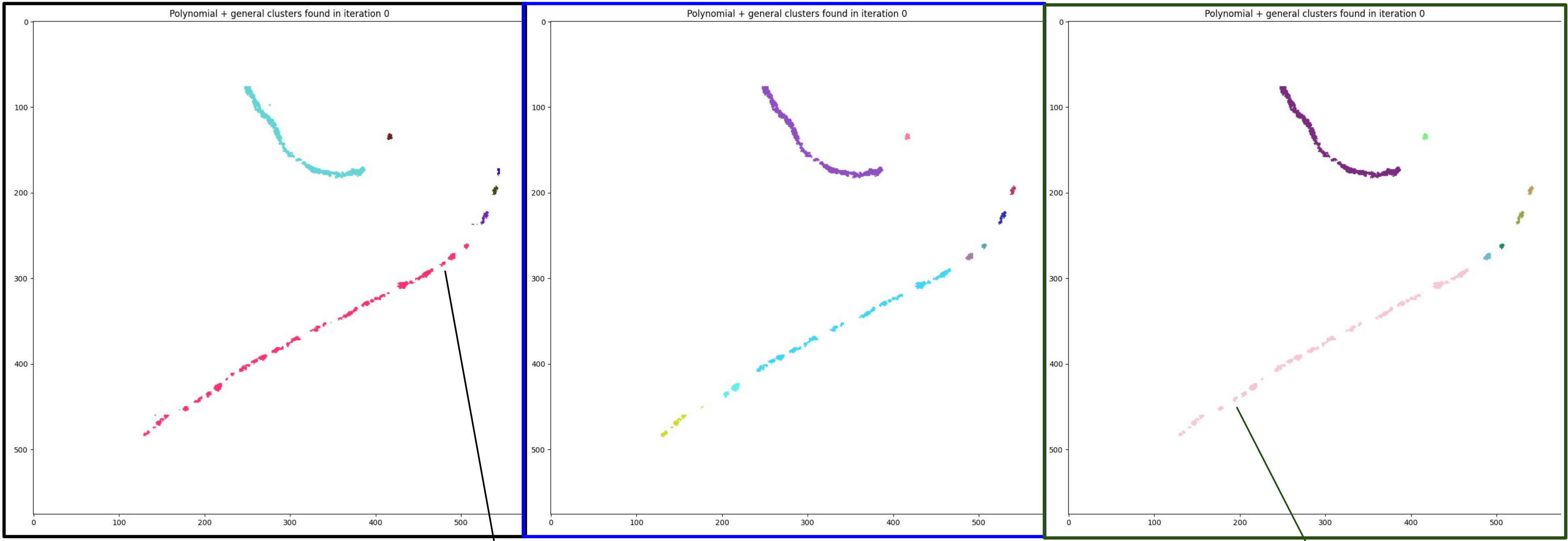


Visual example pixel level trigger



- The **pixel level trigger removes** most **noise pixels** from the images.
- The **extra regions** saved by using a **looser threshold** may keep **noise clusters** or **help** the **iDDBSCAN** to detect the **long track** as a single cluster.

Visual example pixel level trigger



Missing part on images after trigger process.

Small part worked as a bridge on the iDDBSCAN's directional search.

- The iDDBSCAN parameters may be adjusted to work on images containing less noise.