Advancements in Nuclear Reaction Analysis: A Data Science Approach with the mini-eTPC Detector

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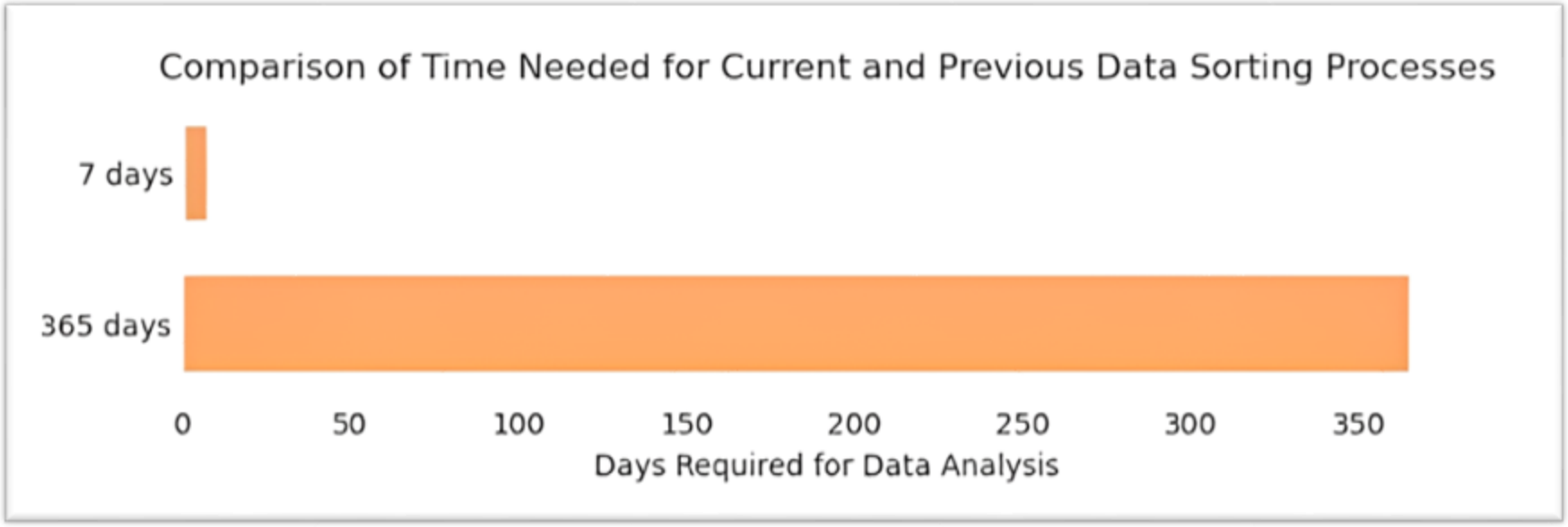
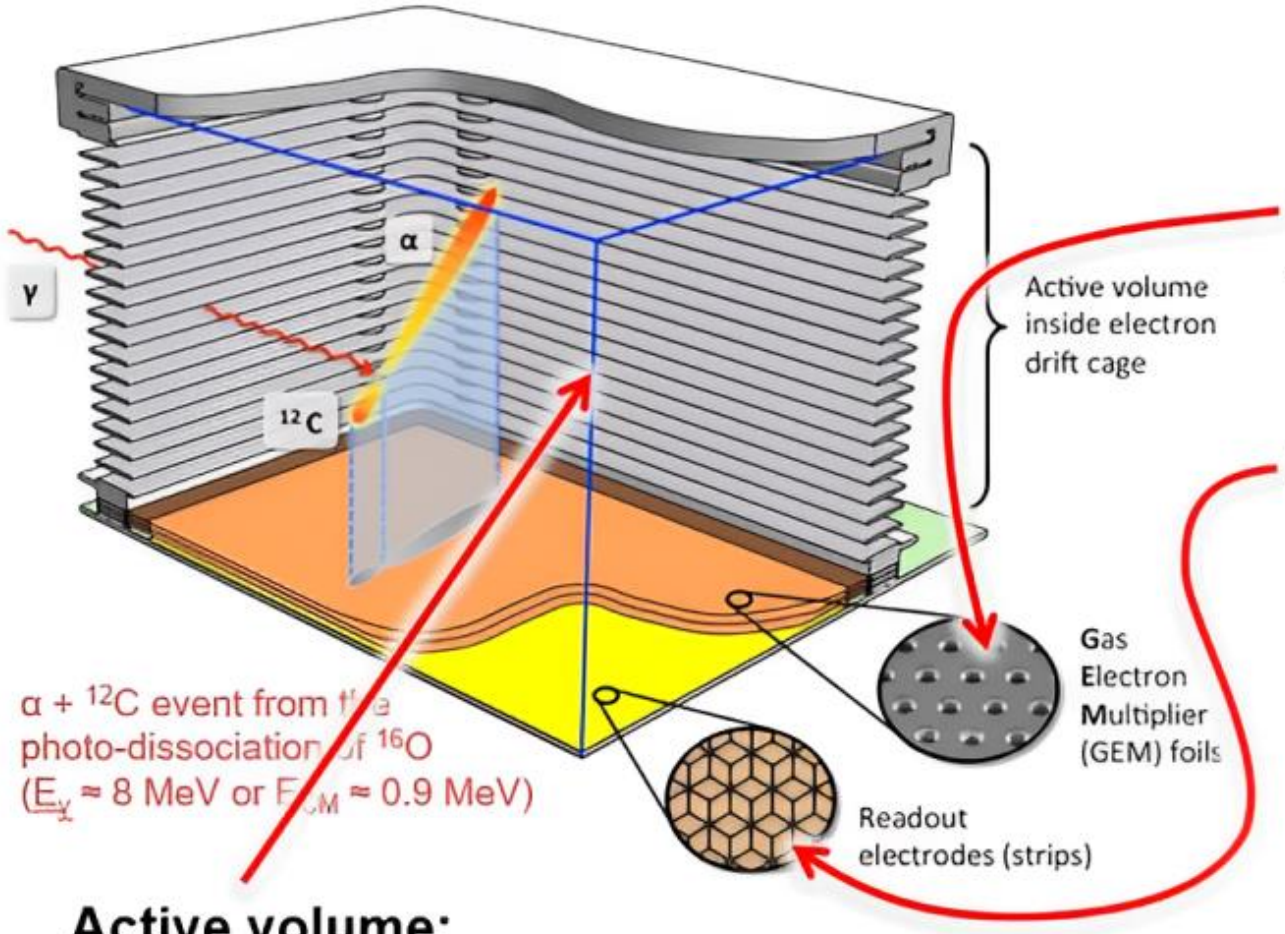
Initial Problem and Our Innovative Solution

- **Problem**: For an experiment spanning multiple days, the data analysis process required over a year.
- **Solution**: We addressed this challenge by implementing cutting-edge data science algorithms, significantly streamlining the data analysis workflow.
- **Difference**:



Part I: Operational Principles of the ELITPC Detector

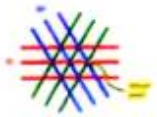
TPC at ELI-NP



Charge amplification:

- *Gas Electron Multiplier* (GEM) structures

Readout

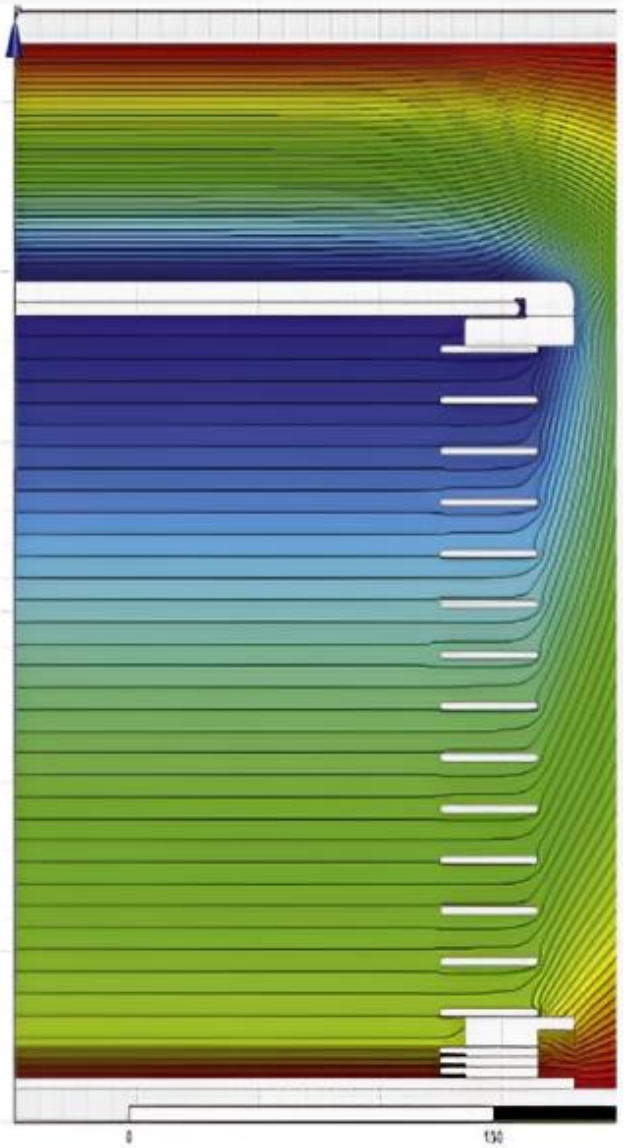


- Planar, 3-coordinate, redundant strip arrays
- About 250 channels
- Generic Electronics for Time Projection Chambers (GET) for signal amplification

Active volume:

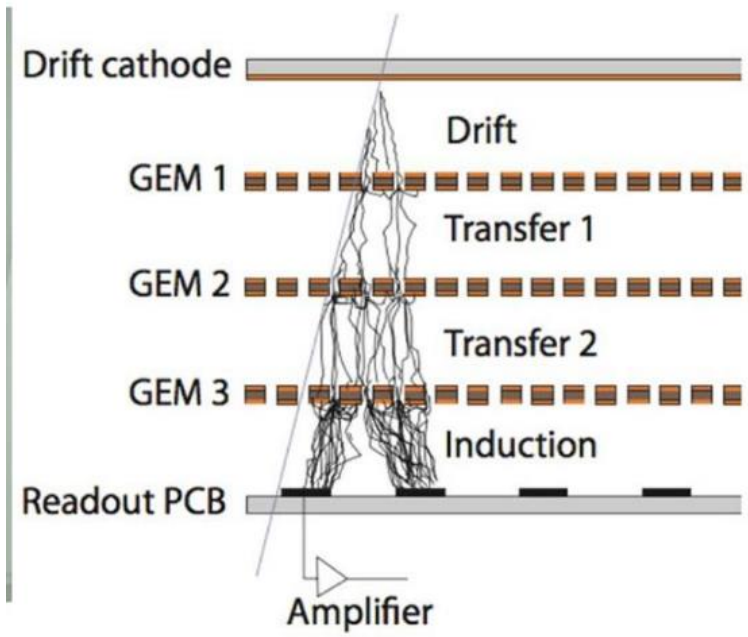
- 10x10x10 cm^3 with a future planned 32 x 20 x 20 cm^3
- gas pressure ~100 mbar ⇒ increase track lengths

O. Tesileanu et al, Rom. Rep. Phys. 68, S699

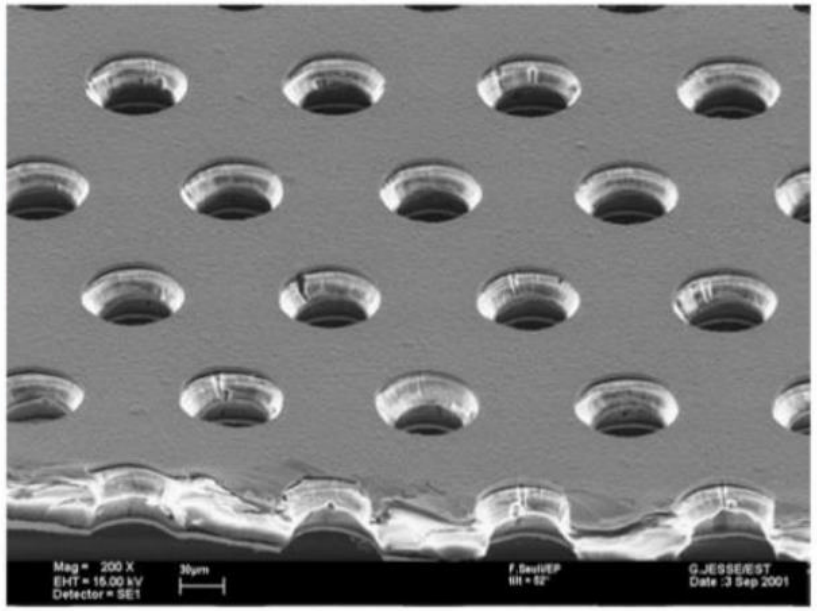


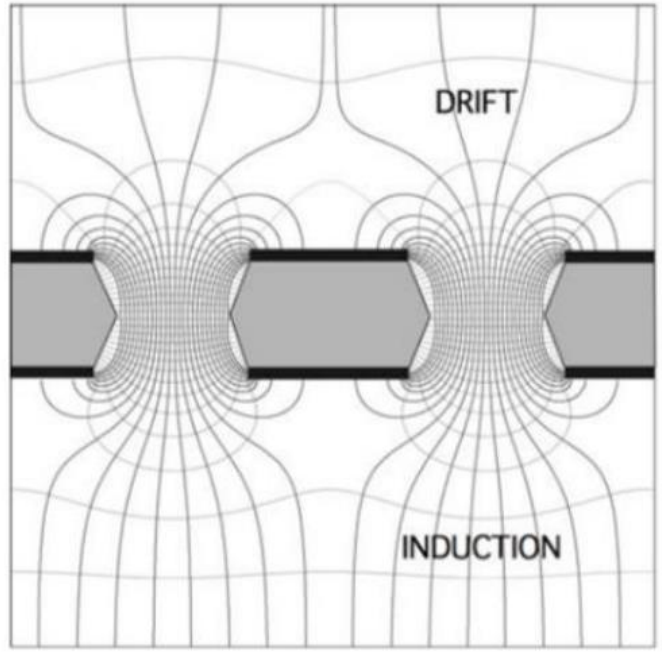
GEM structures

- **GEM charge amplification structures:**
  - Developed at CERN in late 1990's
  - Thickness: Kapton - 50 µm, Copper – 5 µm
  - Several GEM foils can be stacked together
  - Electric fields of ~40 kV/cm, electron charge gain ~10^3



F. Sauli, NIM A386 (1997) 531

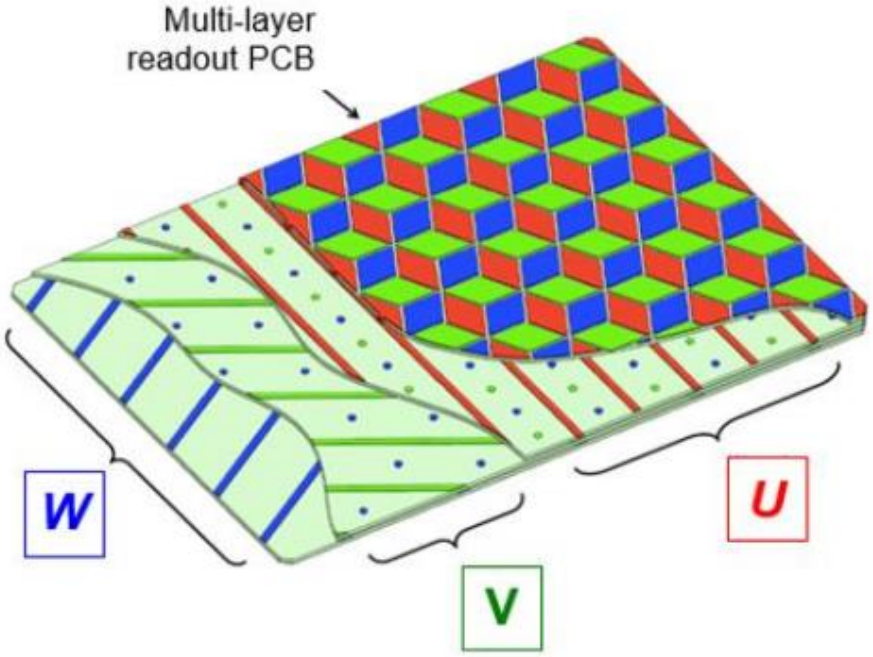


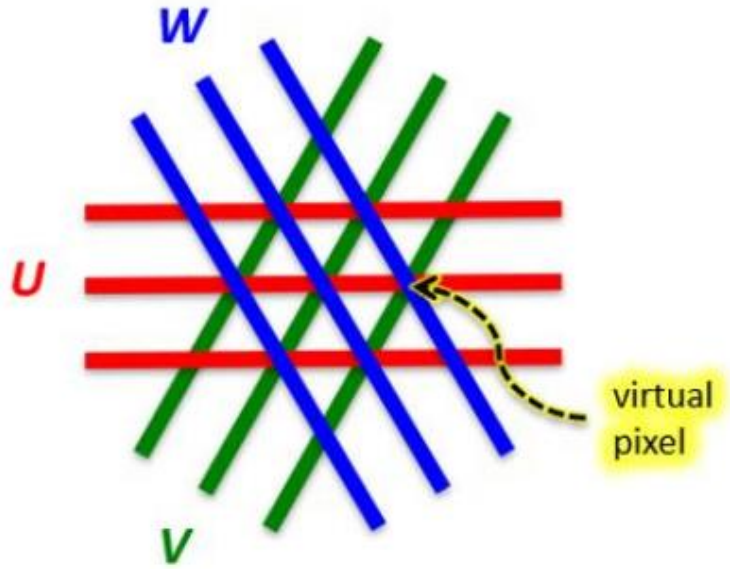


Segmented anode read-out

3 grids of strips – crossed at 60° :

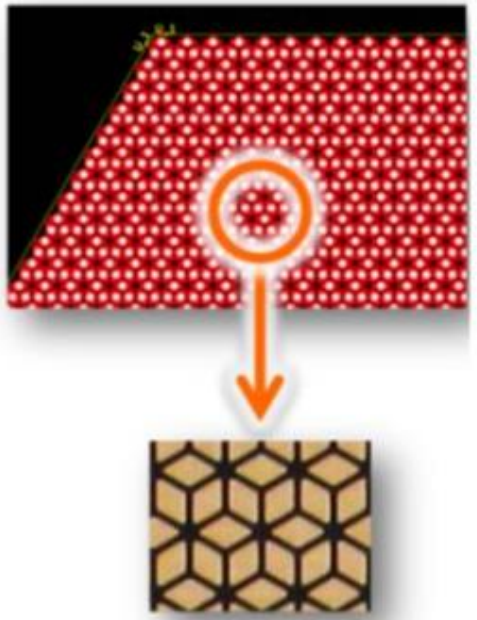
- 3-coordinate, planar, redundant strip readout, 1.5 mm strip pitch
- ***U-V-W*** strip arrays on XY plane + Z-coordinate from drift time → virtual 3D pixels
- Simple event topologies → expect only few tracks per event
- Moderate cost of electronics → only ***O*(10³)** channels are needed



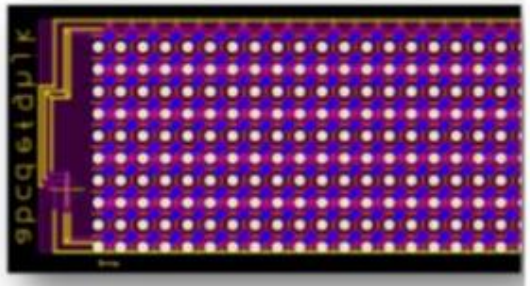


S. Bachmann et al., NIMA 478 (2002) 104
V. Ableev et al., NIMA 535 (2004) 294
M. Ćwiok, Acta Phys. Pol. B 47 (2016) 707
J. Bihałowicz et al., Proc. of SPIE 9290 (2014) 92902C

Active area segmented
into pads & strips

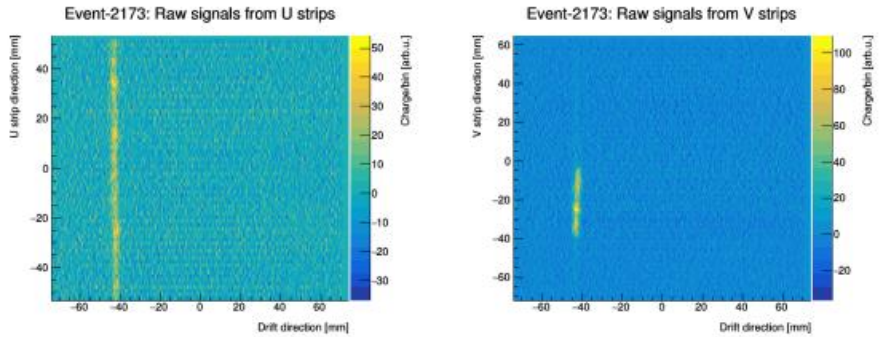


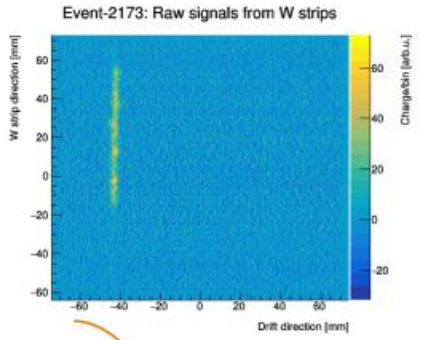
Signal extraction points

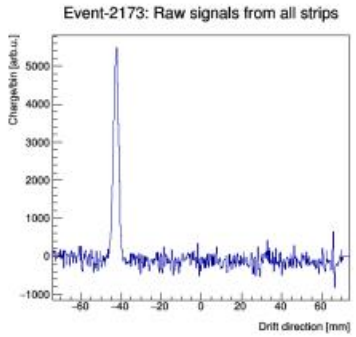


Part II: Manual data analysis approach

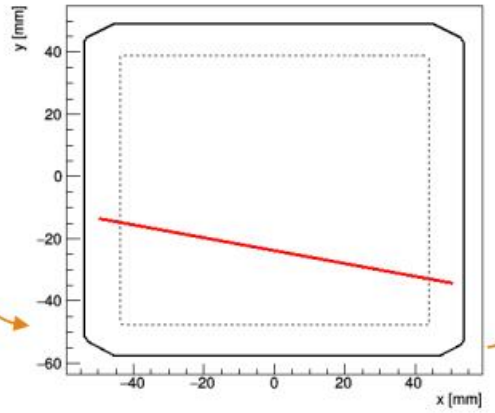
Simple alpha events

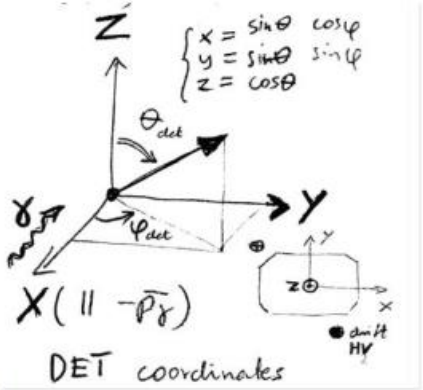


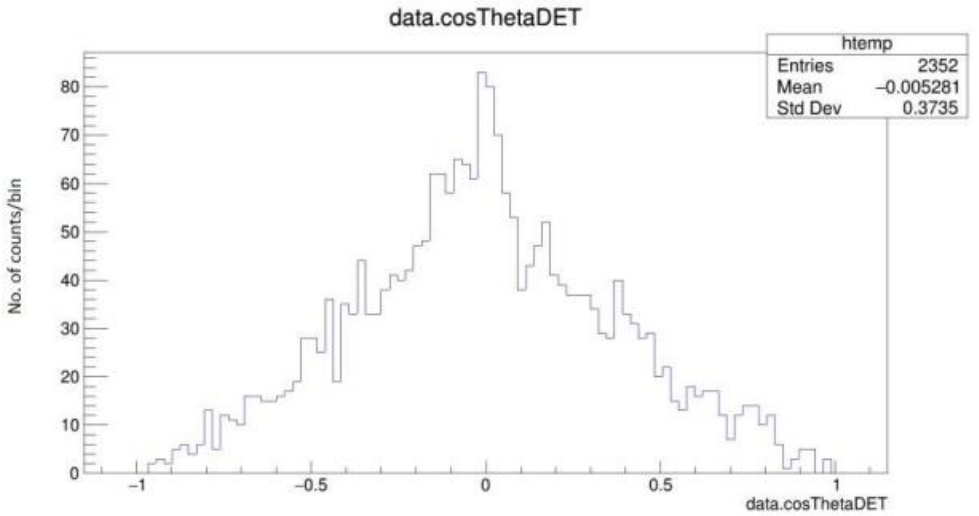


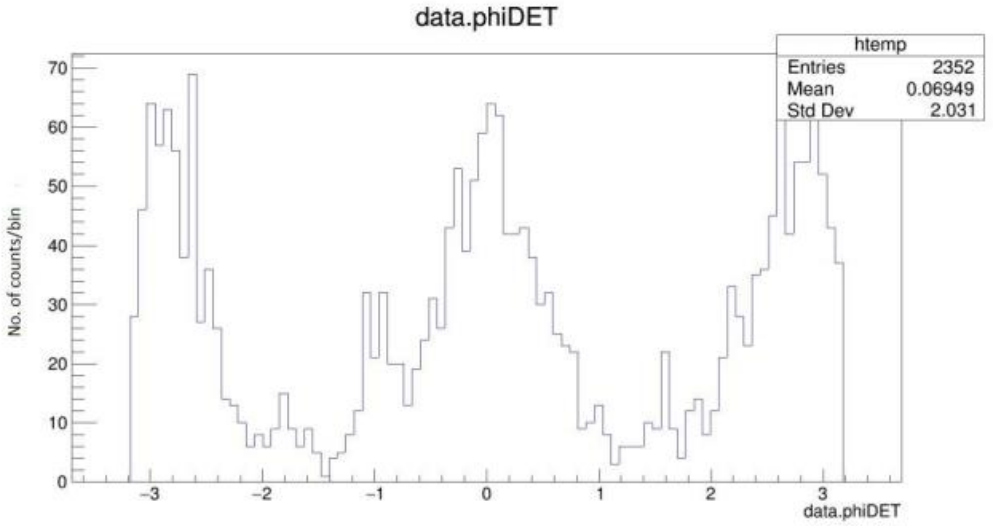


2D reconstruction

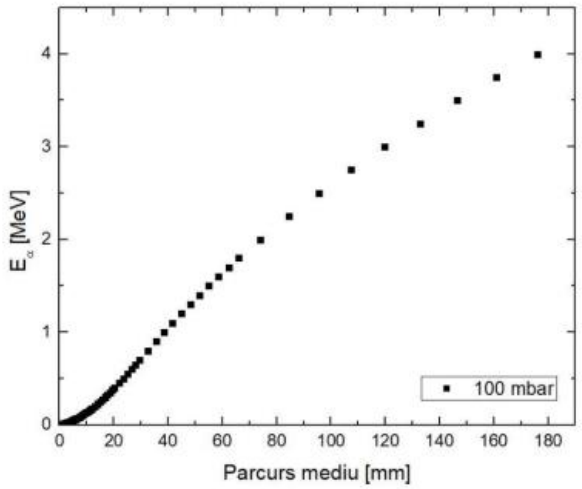




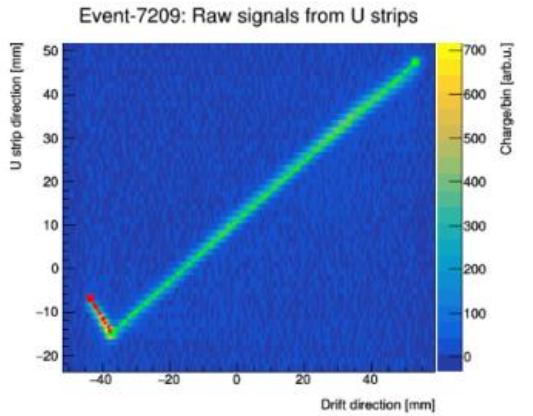


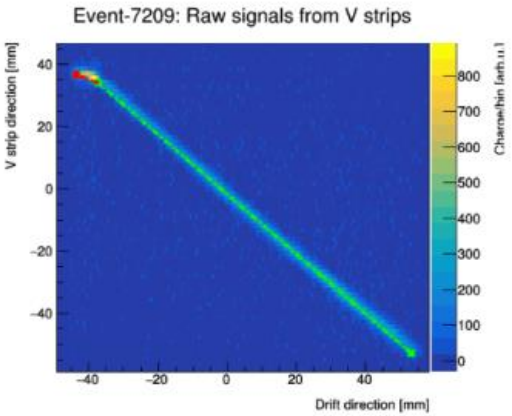


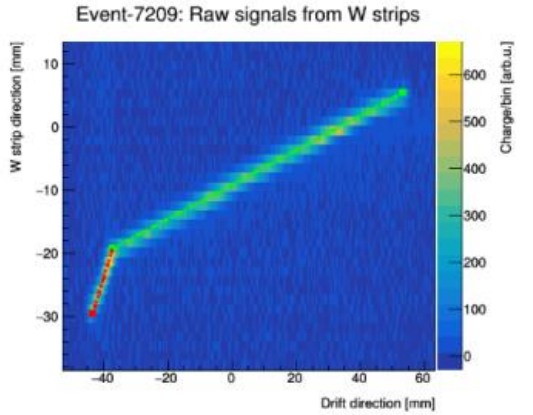
Scattered alpha event



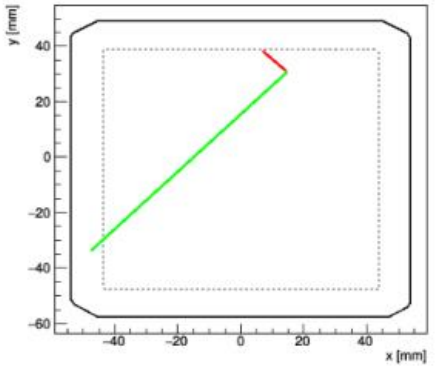
The 2D reconstruction allows one to extract the mean projected range of the reaction products



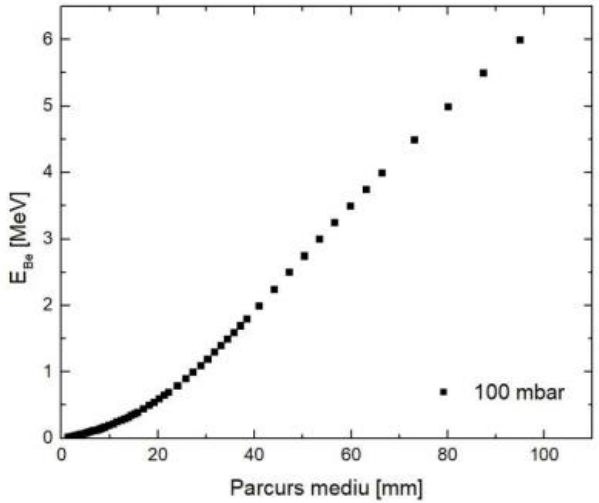




$^{12}C + {}^{1}n \rightarrow {}^{4}\alpha + {}^{9}Be$

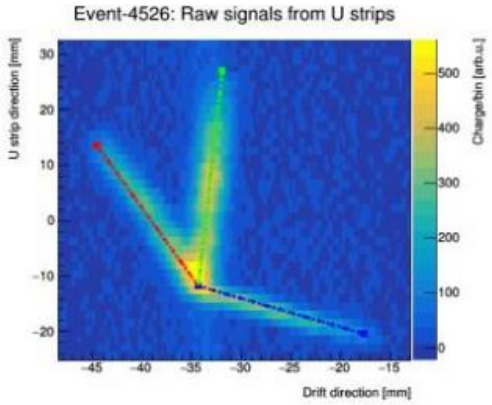


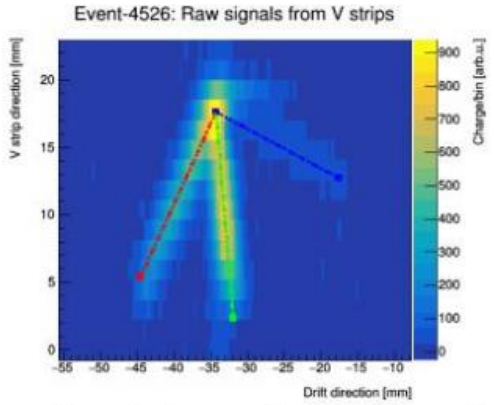
SRIM simulations were computed for both α and ^{9}Be projectils on a 100 mbar CO_2 gas target

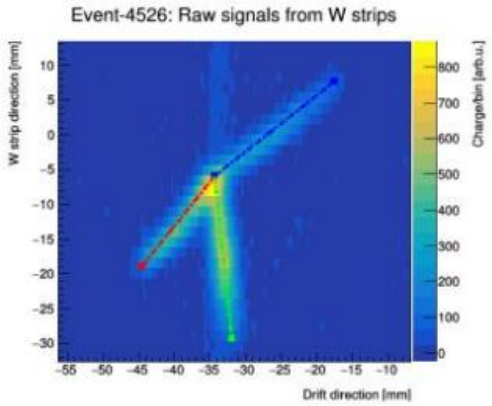


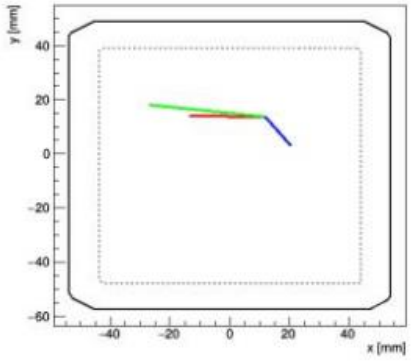
Red trace: $^{9}Be \rightarrow 12.3$ mm $\rightarrow 0.275$ MeV
Green trace: $^{4}He \rightarrow 128.3$ mm $\rightarrow 3.25$ MeV

Triple alpha events





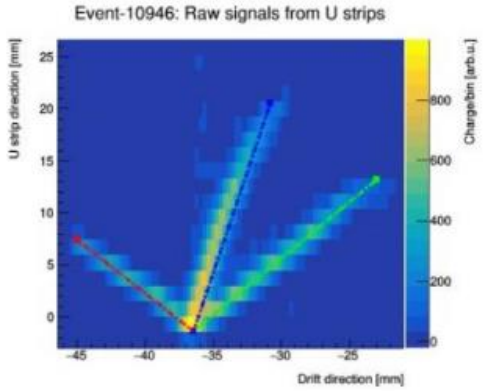


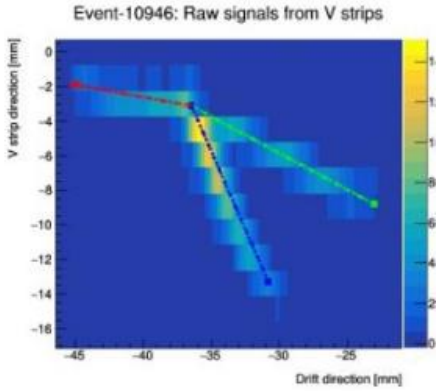


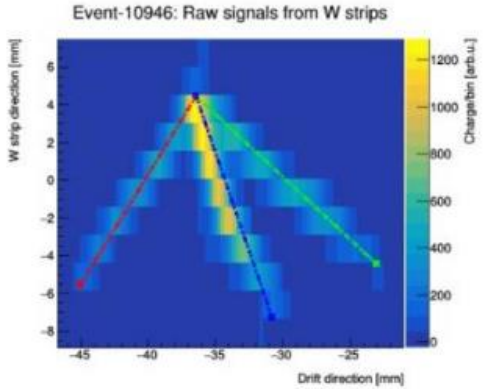
$^{12}C + {}^{1}n \rightarrow {}^{4}\alpha_1 + {}^{4}\alpha_2 + {}^{4}\alpha_3 + {}^{1}n$

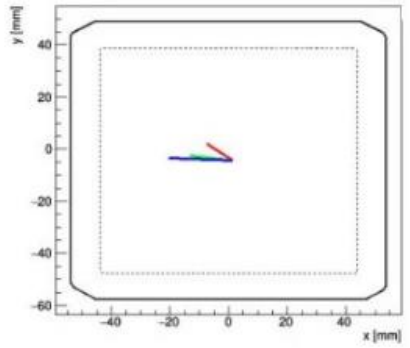
$\alpha_1 \rightarrow 35.6$ mm $\rightarrow 0.90$ MeV
$\alpha_2 \rightarrow 27.8$ mm $\rightarrow 0.65$ MeV
$\alpha_3 \rightarrow 21.1$ mm $\rightarrow 0.45$ MeV

$\alpha_1 \rightarrow 13.7$ mm $\rightarrow 0.20$ MeV
$\alpha_2 \rightarrow 21.8$ mm $\rightarrow 0.45$ MeV
$\alpha_3 \rightarrow 19.6$ mm $\rightarrow 0.375$ MeV









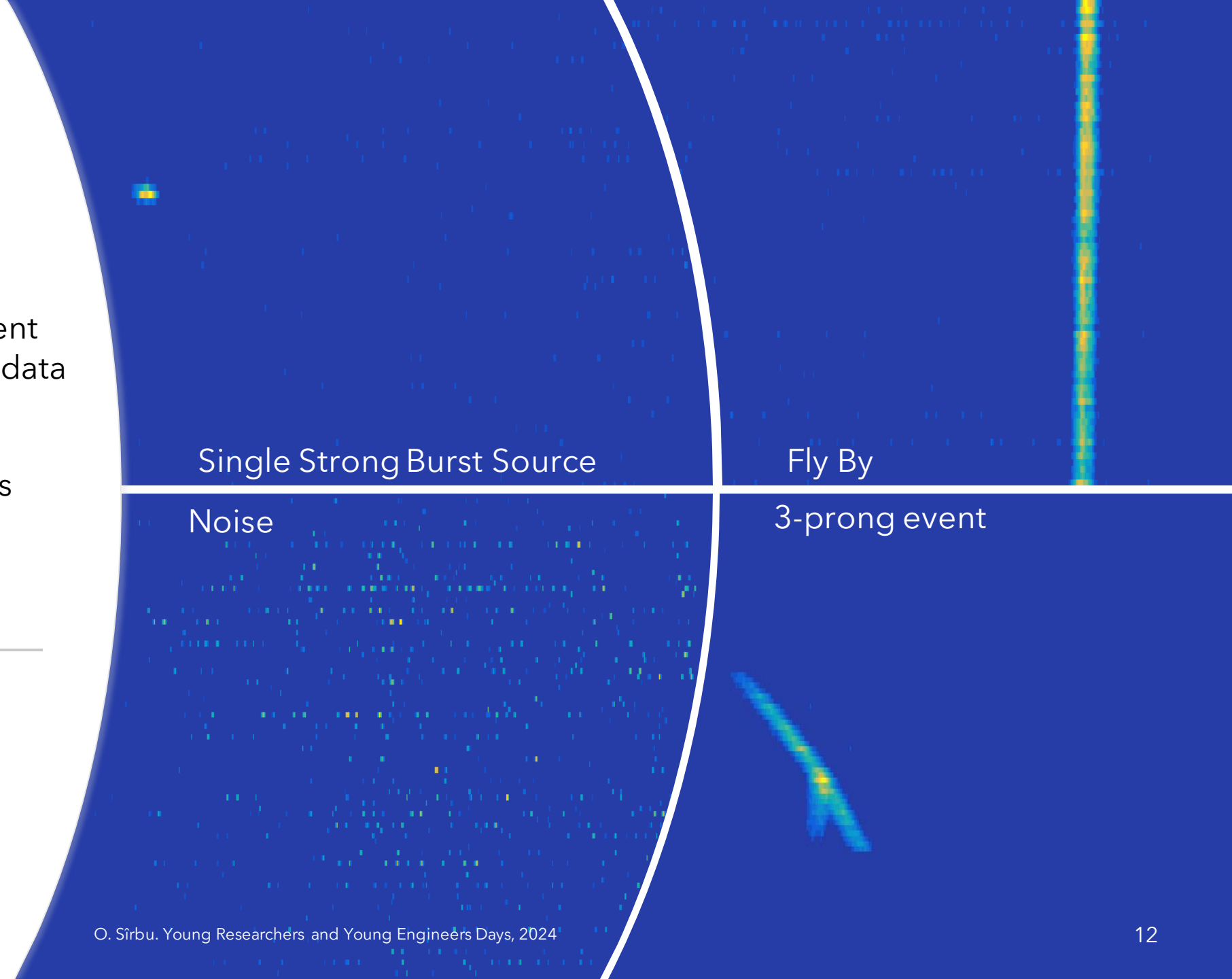
Part III: Data Science approach

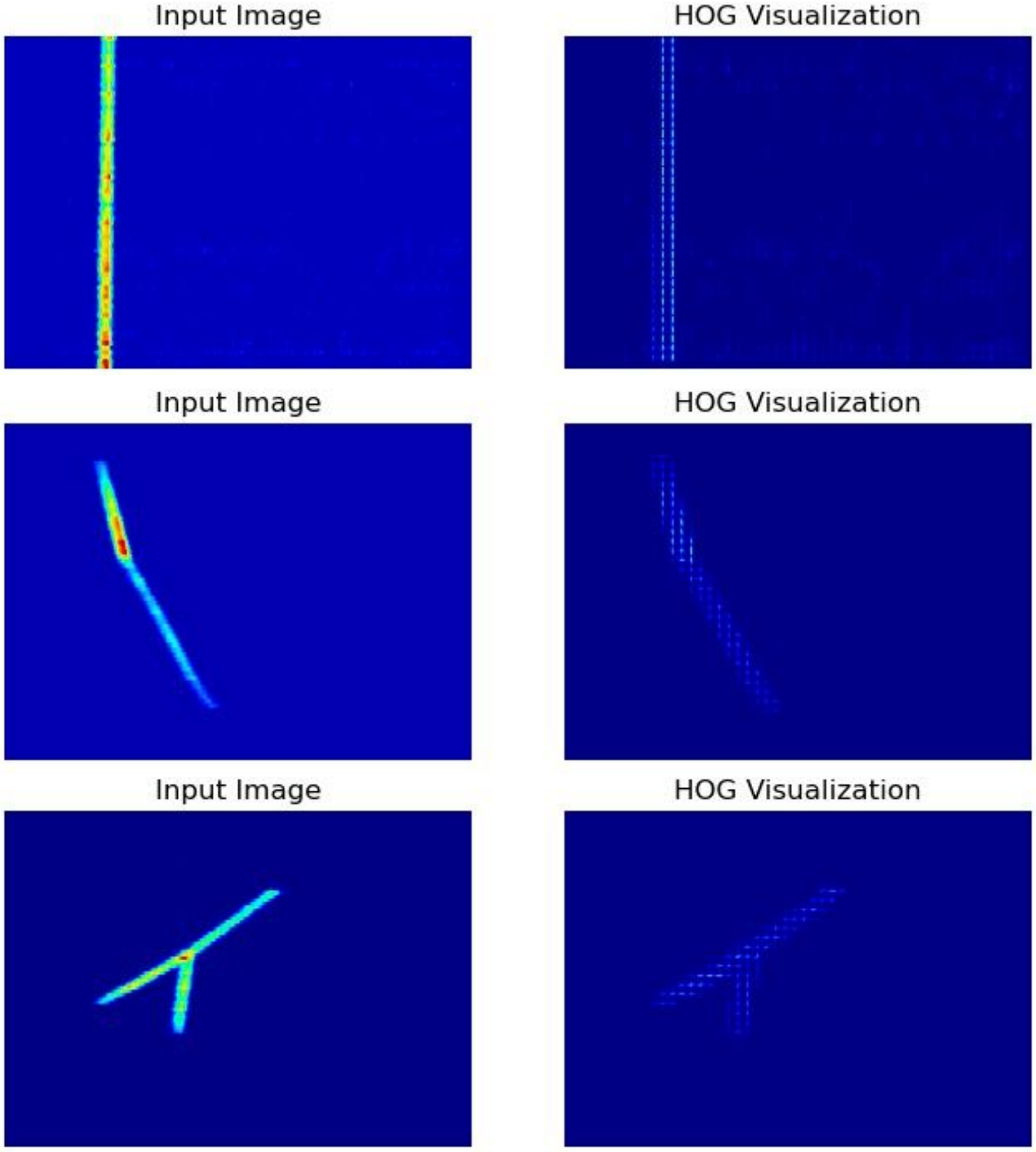
New perspective
Data as Images

- The comissioning experiment generated approx. 500 GB data in .root format
- With data compressed as images, the total data size is reduced to approx. 10 GB

What we aimed to do:

- Categorize data based on various thresholds
- Facilitate further analysis
- Eliminate unwanted data (such as Noise)





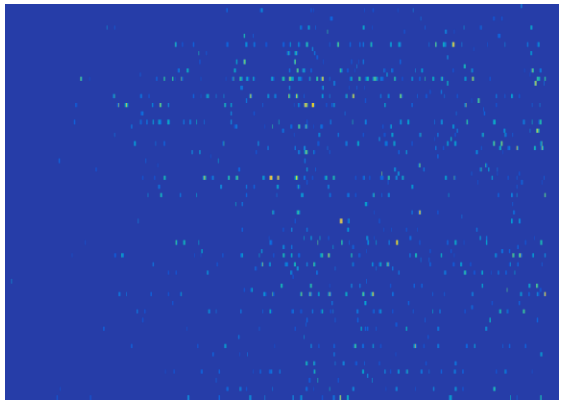
One idea: extracting HOG features

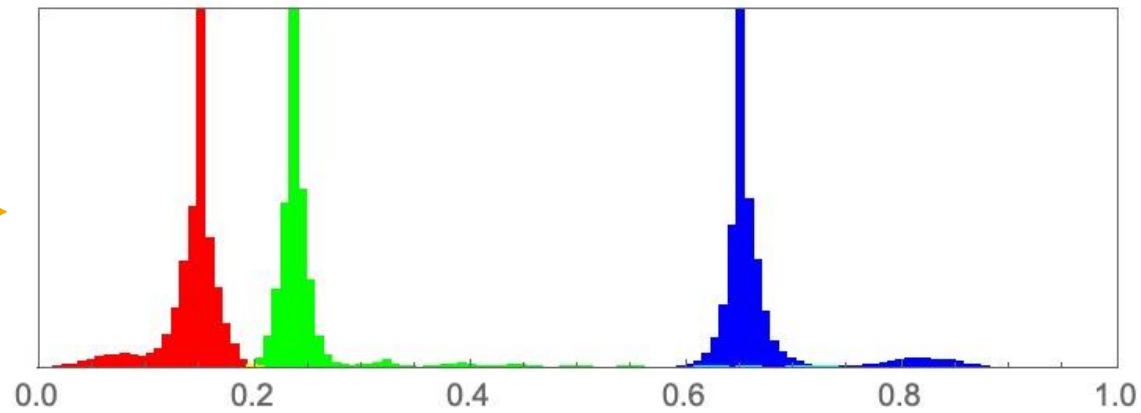
- One strategy involved calculating the **H**istogram **o**f **G**radients for each image to identify specific patterns, facilitating the data sorting process.
- Despite its promising nature, it was not used for the final data sorting phase.

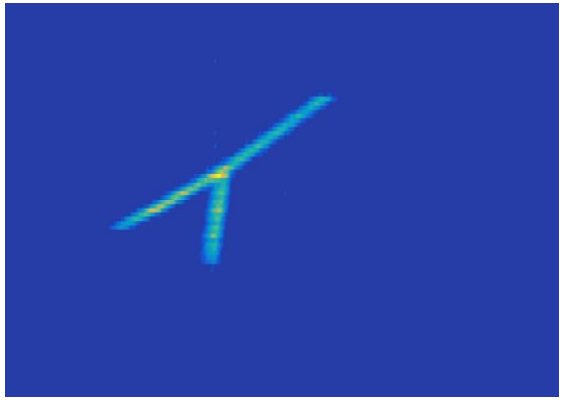
Image color analysis

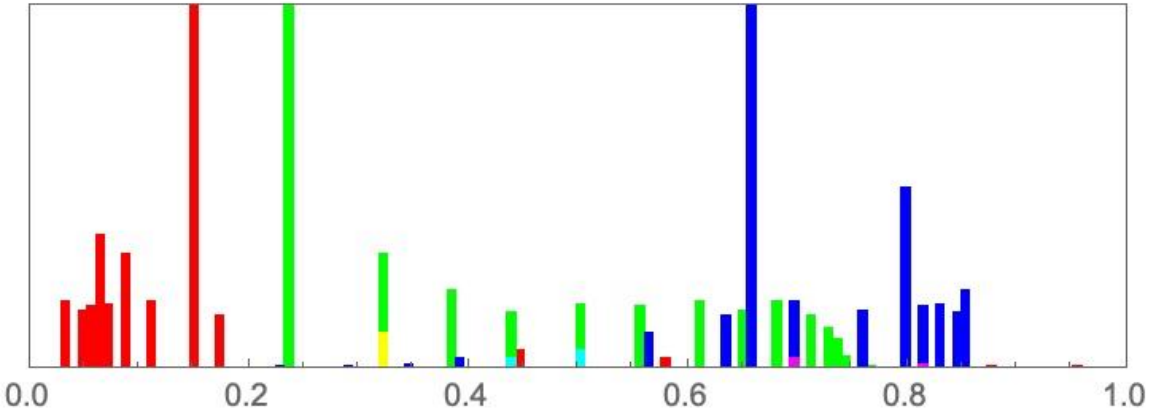
~ the most efficient classification method ~

- The **histogram of colors** in an image provides a concise representation of the distribution of pixel intensities across different color channels.
- This distribution is an important feature for distinguishing between different objects (in our case, events) in an image.









Thank you!