Using XMM-Newton for Athena WFI Background study

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SAO contribution to the US Athena WFI background investigation (PI: David Burrows) in collaboration with

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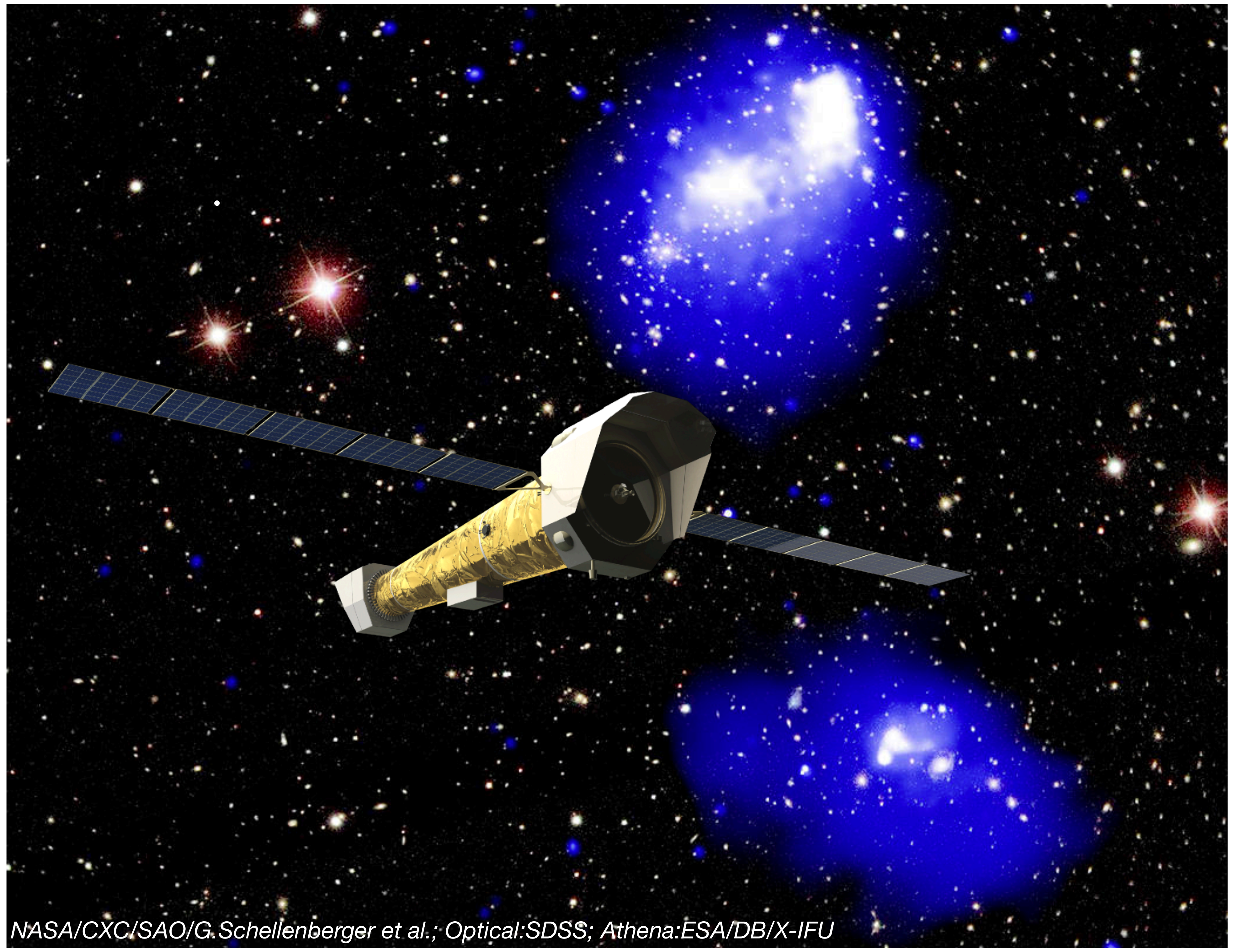
Dan Wilkins, Steven Allen, Sven Herrmann (Stanford)
Amanpreet Kaur, David Burrows, Abe Falcone (PSU)

and the Athena WFI background working group

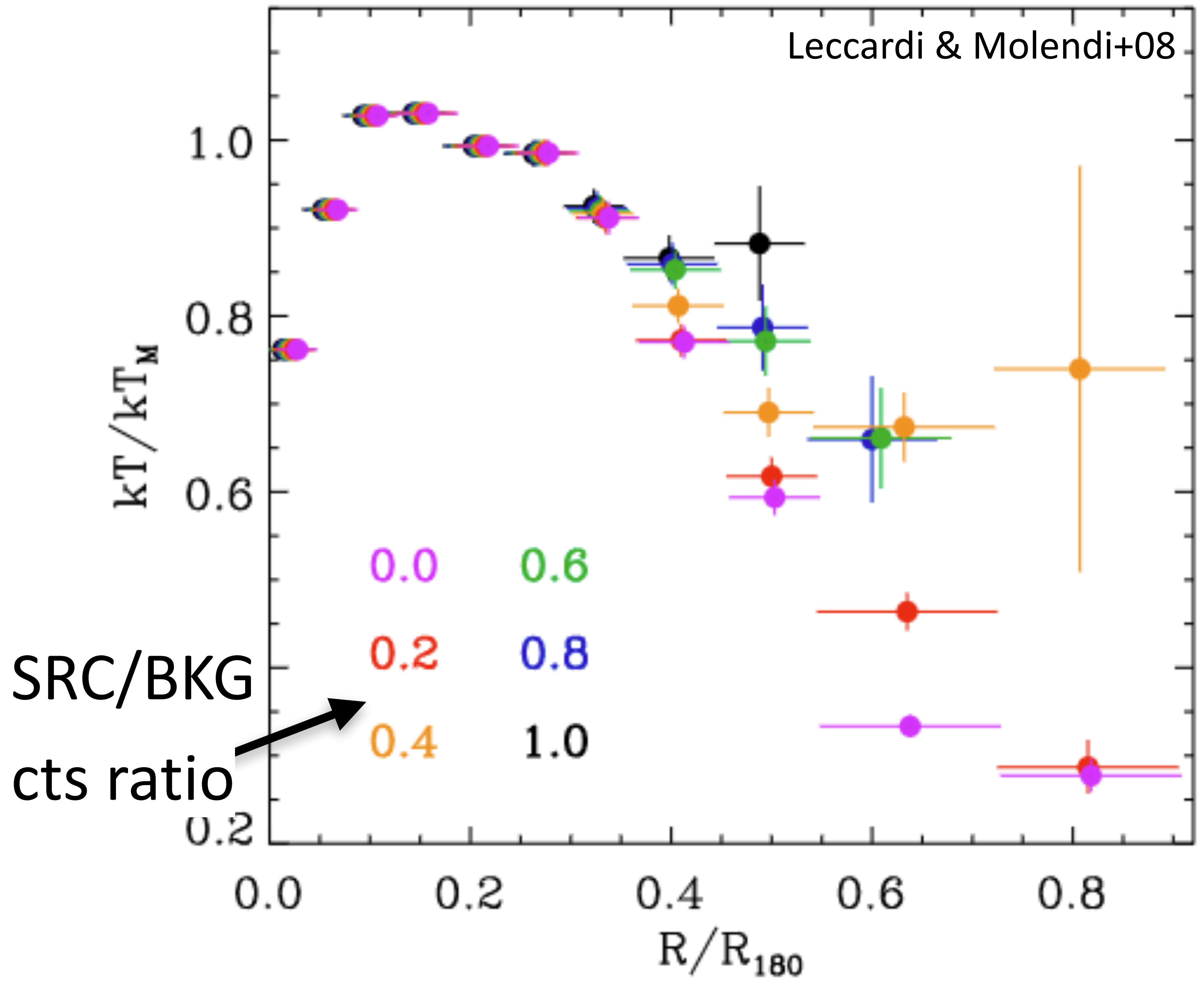


Motivation

Science capabilities are of current and future X-ray missions are critically limited by the level and knowledge of the instrumental background.

Current paradigm of blank-sky/local background will not be sufficient for Athena science goals.

Example: Faint regions in cluster outskirts require long exposures to achieve a better signal to noise. However, the knowledge of the background is uncertain and sets a fundamental limit to the science that can be done (longer exposures do not help).



Our goal is twofold:

- reduce the level of instrumental background
- Reduce the systematic uncertainty of the instrumental background

Results from this work can be applied to all future large-area X-ray missions (Athena, Lynx, AXIS..)

PN Small Window Mode

To achieve this we will develop a much deeper understanding of the particle background in pixelated Si detectors, beyond previous efforts for Chandra or XMM

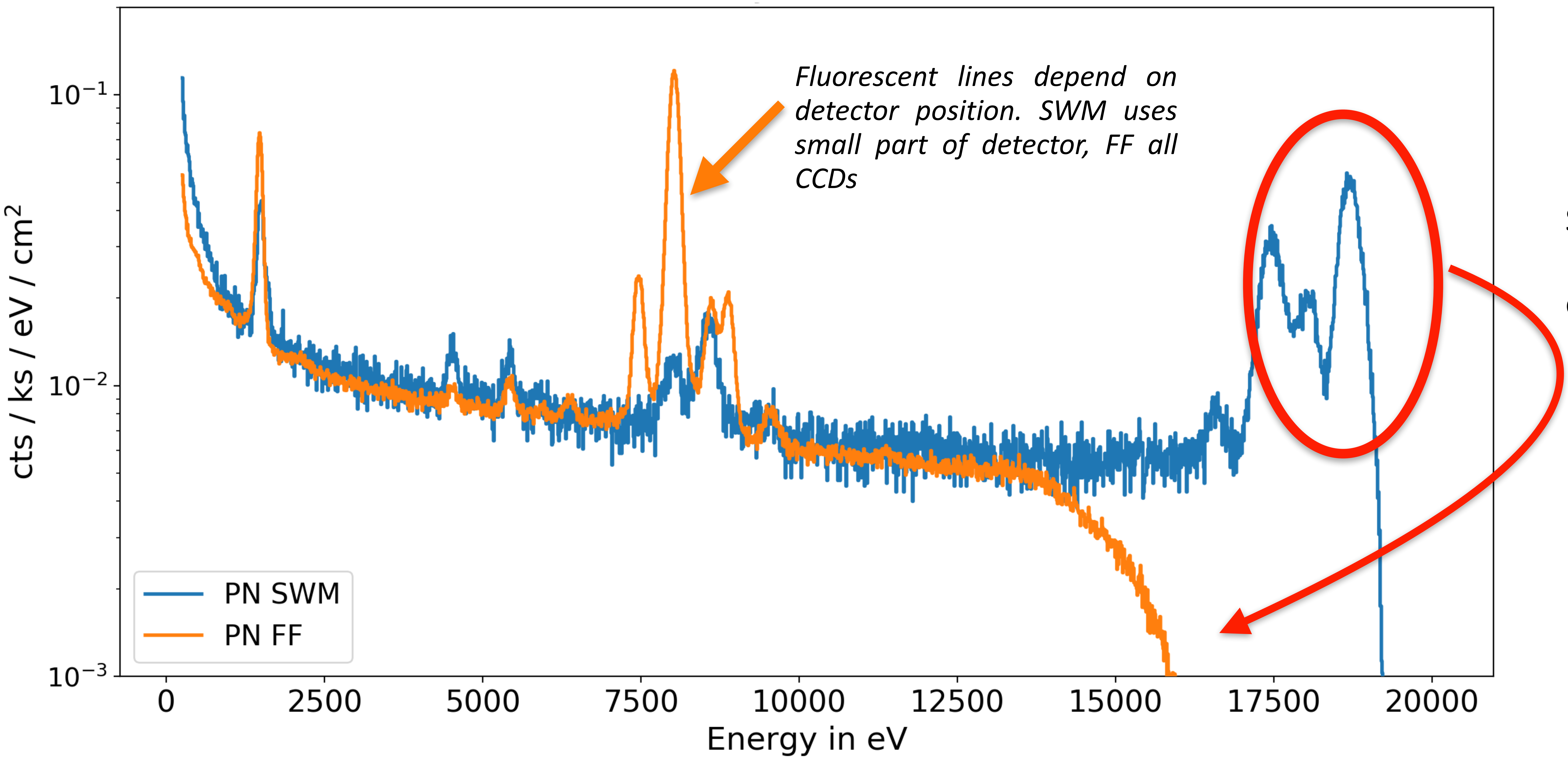
We focus on analyzing data from XMM-Newton PN camera in Small Window Mode (SWM) to characterize the relationship between charged particles and events that would pass the grade and PHA thresholding (i.e. the valid events that constitute the instrumental background).

Only the PN-SWM is unique that it has a **frame time** similar to Athena/WFI, and **no onboard MIP thresholding** is performed — All events are telemetered to the ground and can be analyzed **(default mode for Athena WFI)**.

Comparison with tailored Geant4 simulations for deeper understanding of the detector background.

Minimum Ionizing Particles

Energetic particles (GCR) interact with the detector and deposit a large amount of charge. Reading out affected pixels results in a maximum adu value after amplifier/adu converter.



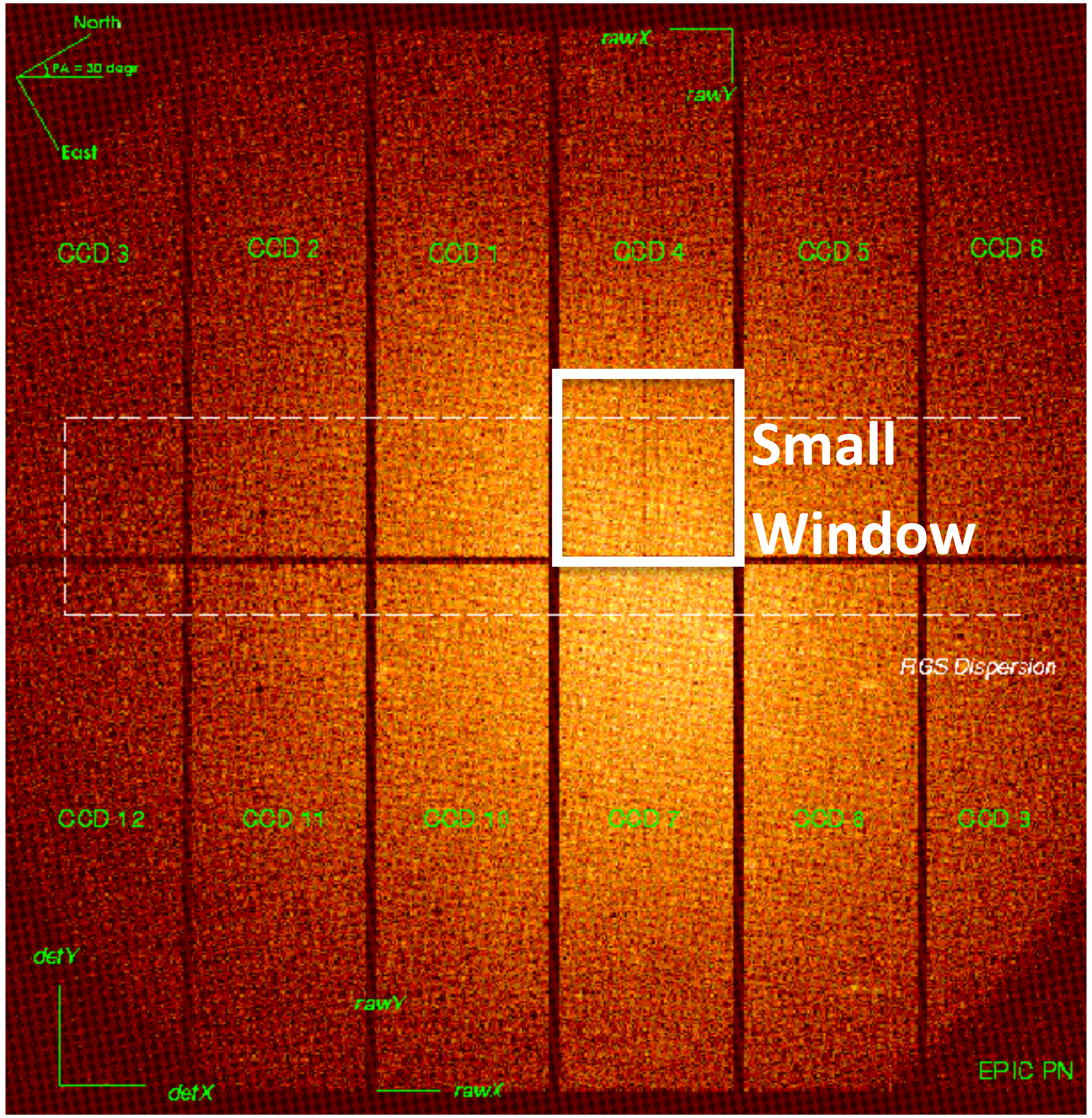
Standard onboard processing: high PHA event columns rejected including neighboring columns.

EPIC PN detector

12 pn-CCDs, arranged in 4 quadrants

Comparing WFI and PN (SWM):

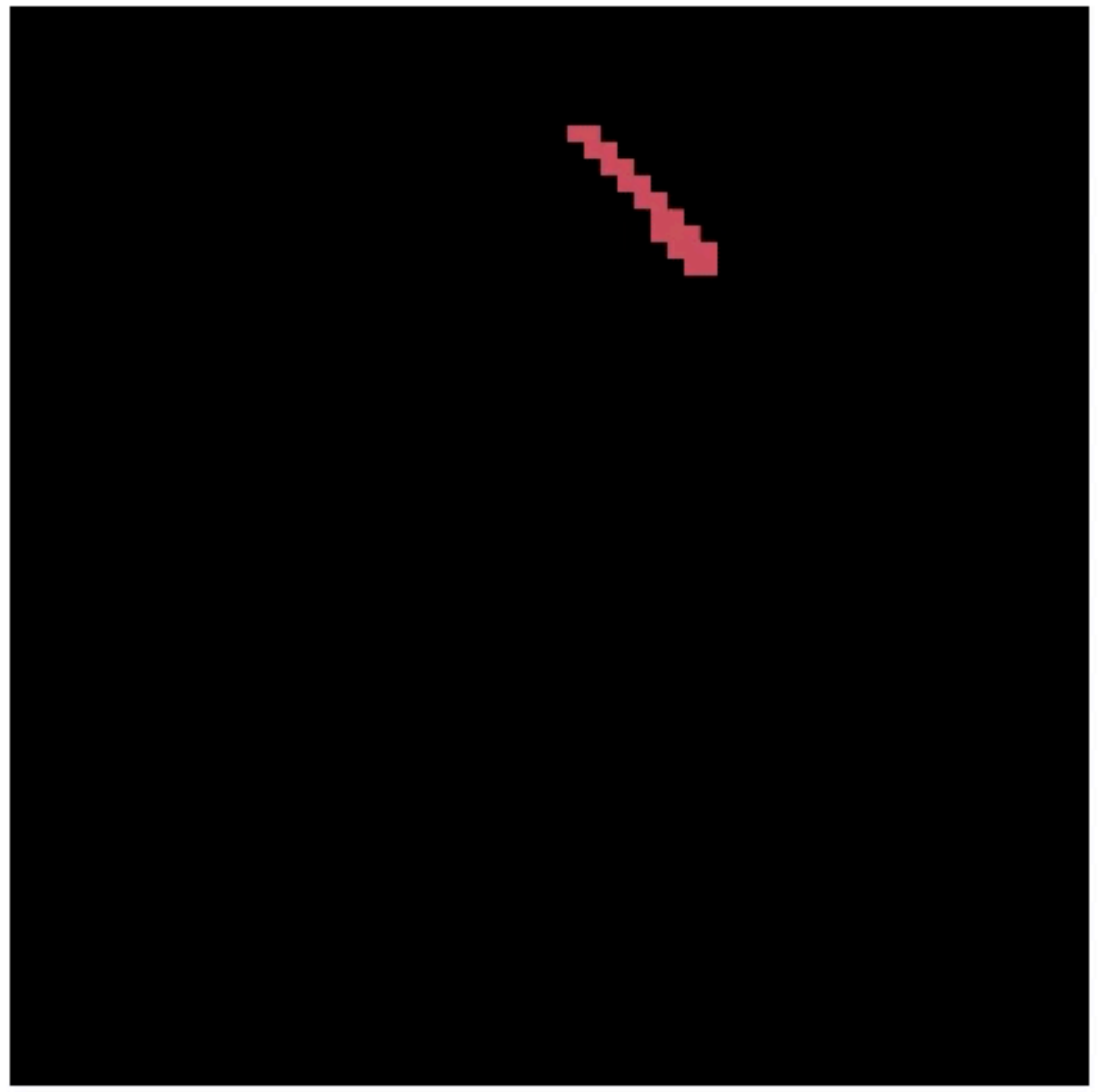
	Athena WFI	XMM-PN
Pixel Size (micron)	130 x 130	150 x 150
Depletion Depth (microns)	450	280
Frame time	2.5-5ms	5.7ms (SWM)



Three Frame types

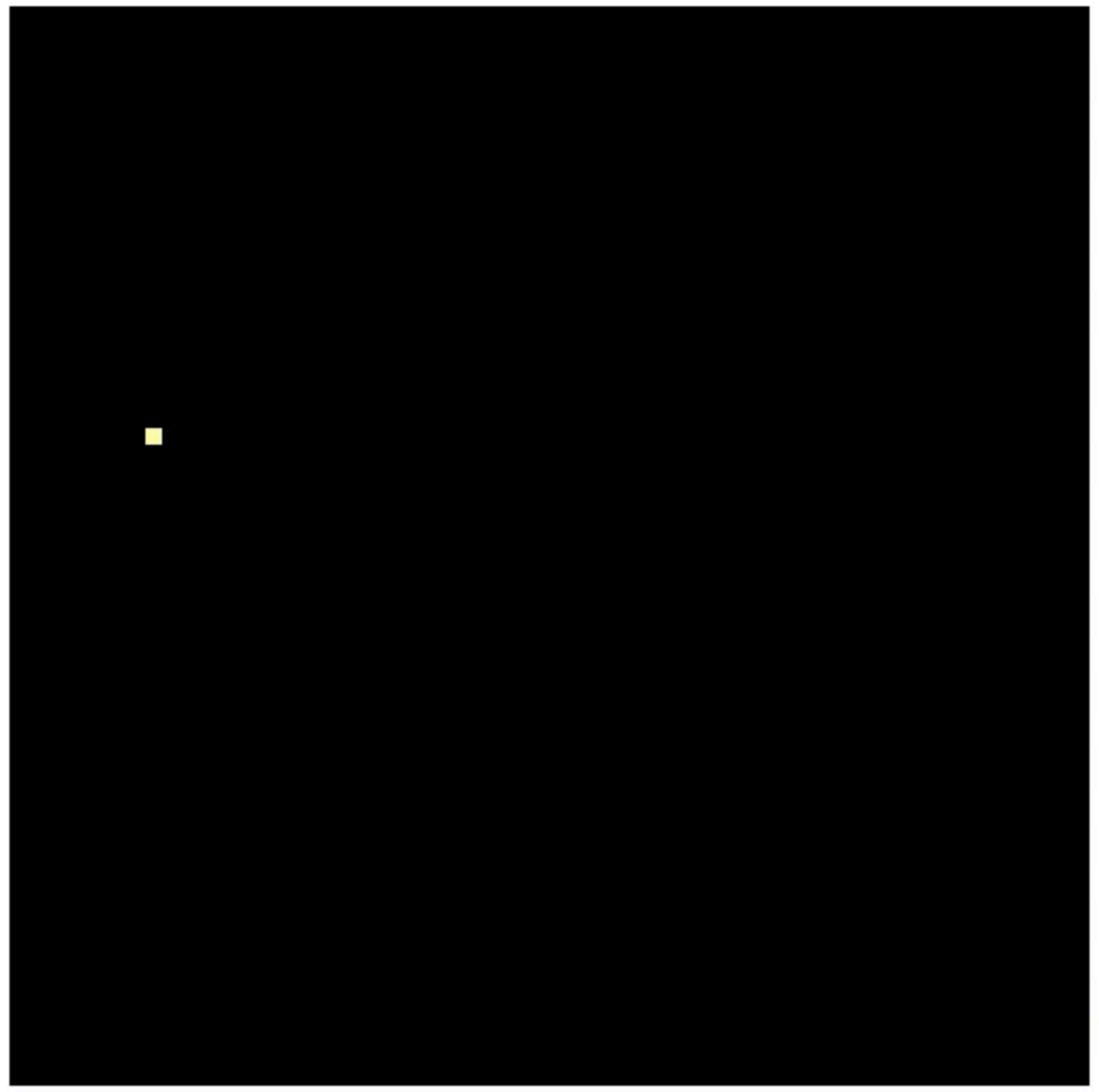
Slew observations between science targets of XMM observations in Small Window Mode provide a large dataset to explore.

Frame has invalid but no valid events



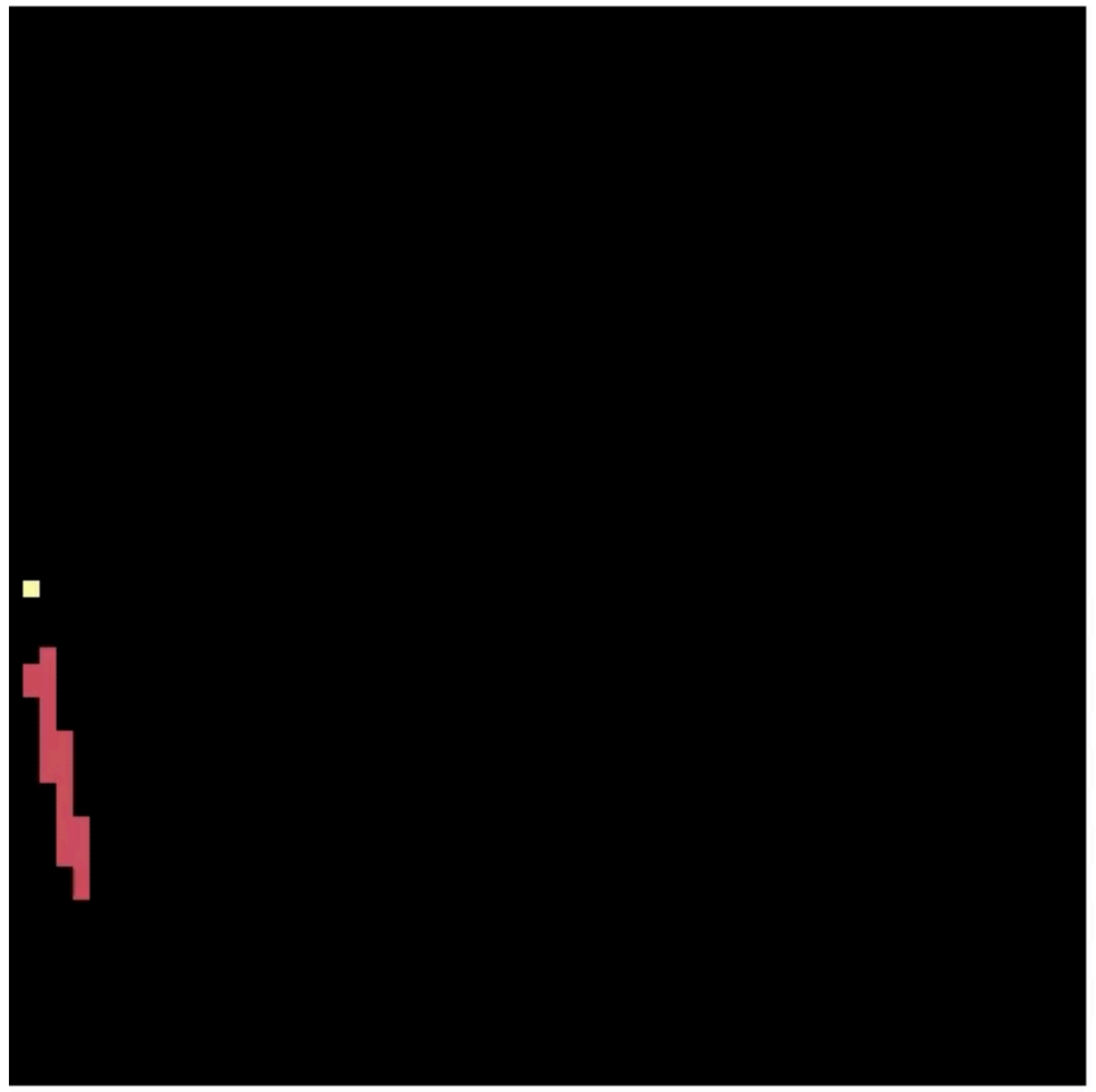
Case A

Frame has valid but no invalid events



Case B

Frame has both

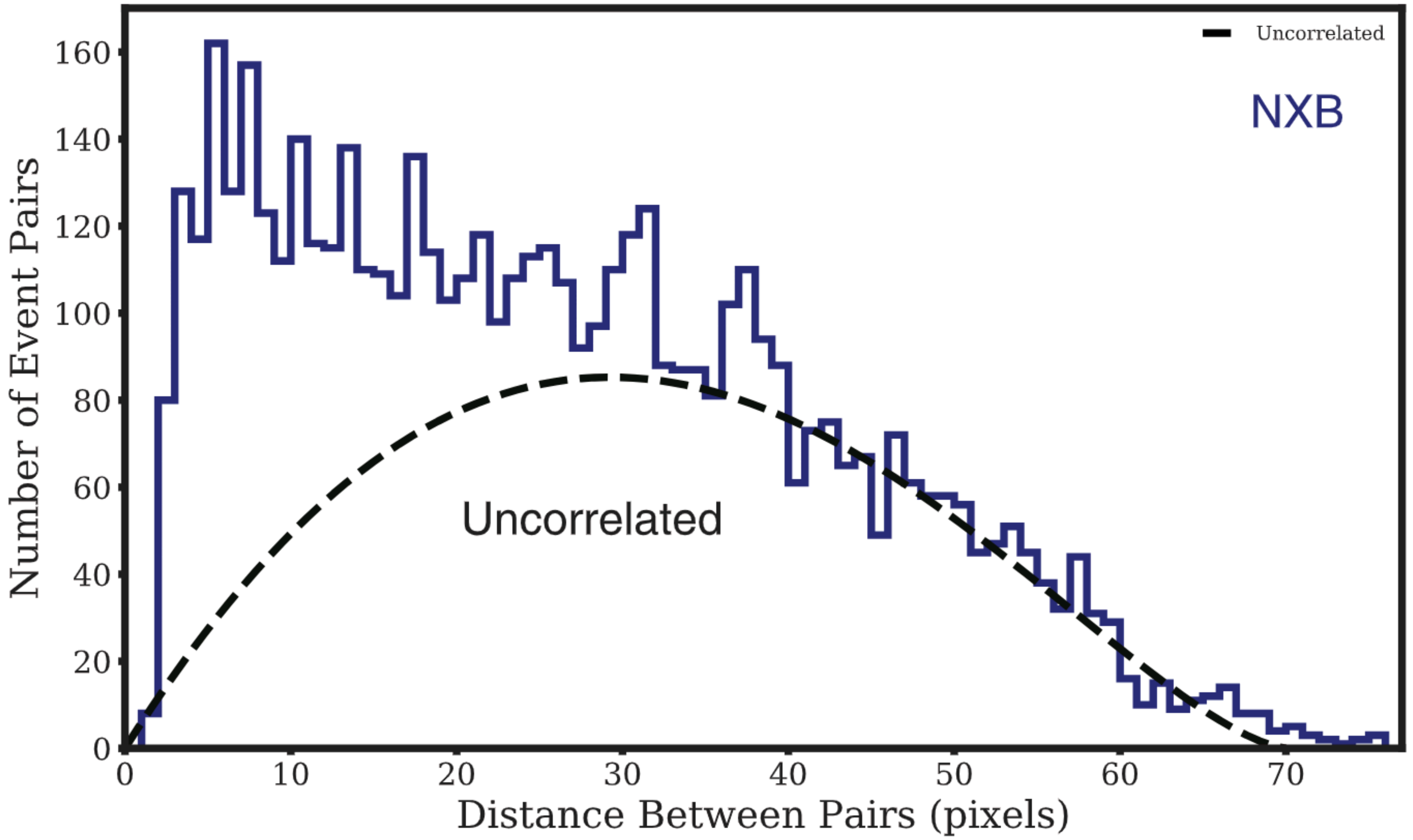


Case C

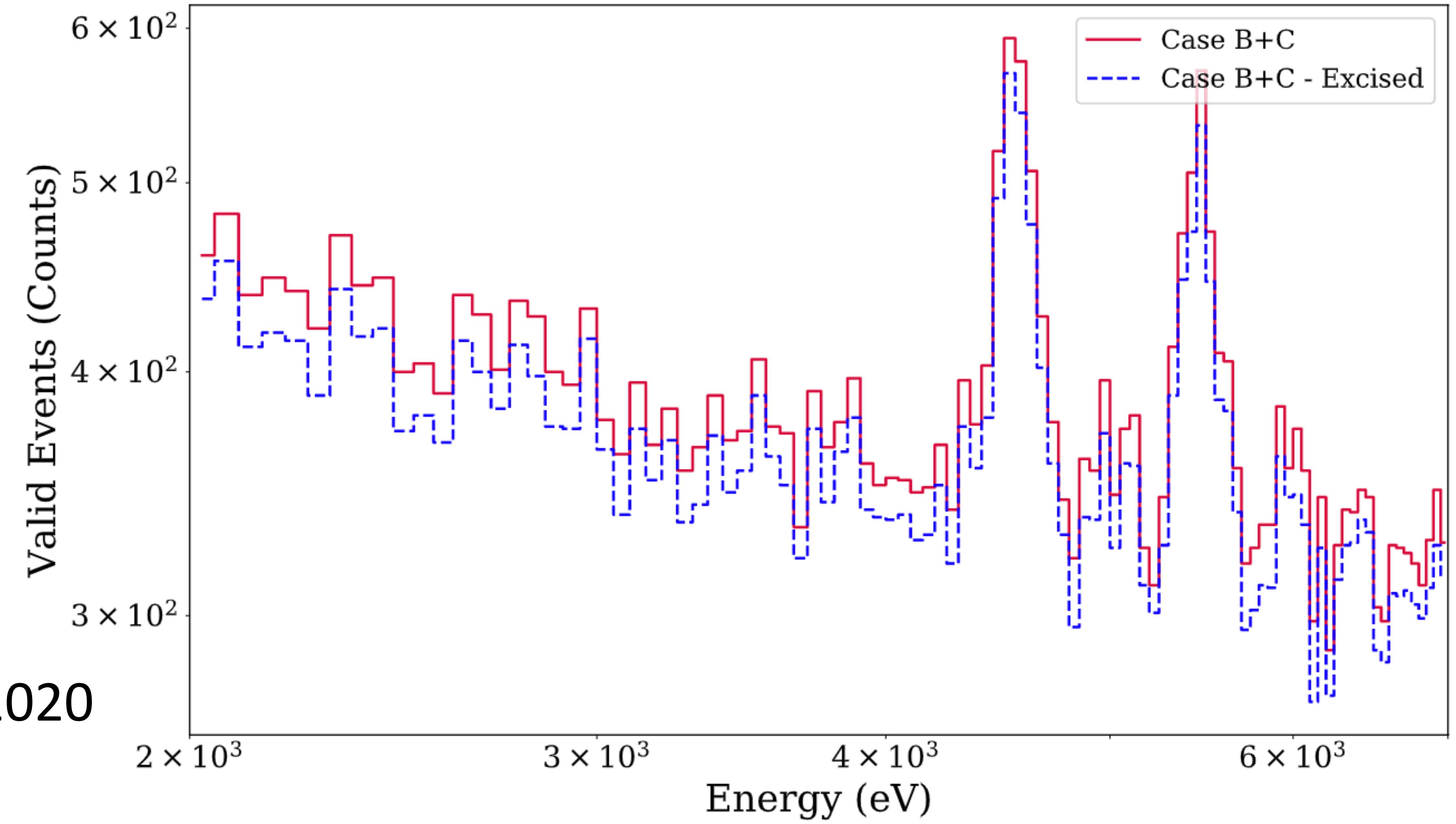
First step: Study the Slew observations in closed filter mode, i.e. **only particle background events are recorded**. Case C events are especially important to understand how particle events produce X-ray-like features.

Frame types

Self Anti-Coincidence: Correlation found at small spatial distances of Case C valid and invalid events. Excluding these events at small distances reduces the background by 10% in a hard band.



Bulbul+2020



Next steps are crucial:

Understand spectral behavior in the full band

What uncertainties are introduced in long and short term variability

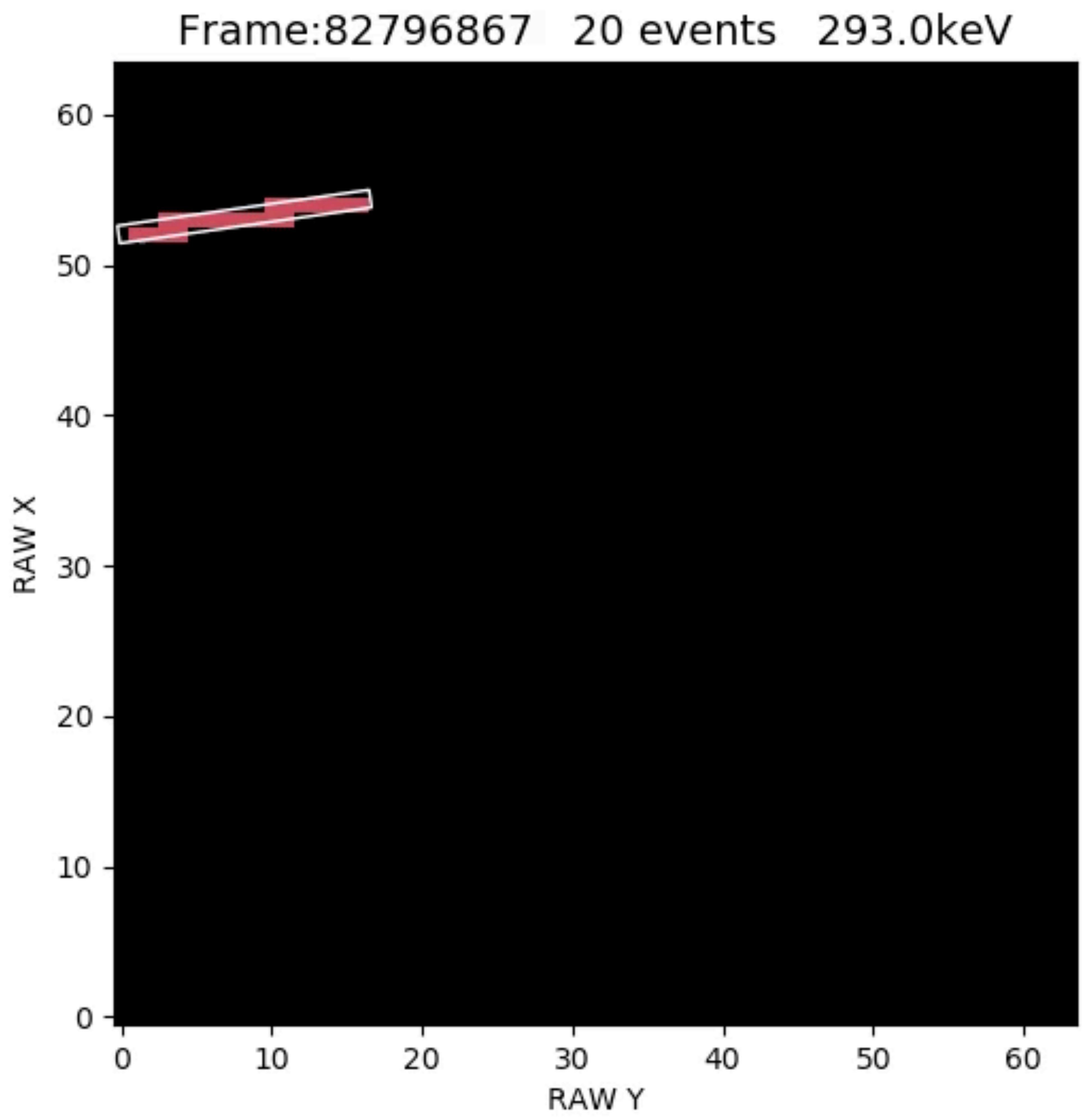
Do we understand the imprints of the charged particles in the SWM? Look at Case A frames

Island classification

Adjacent events in same frame are classified as Island

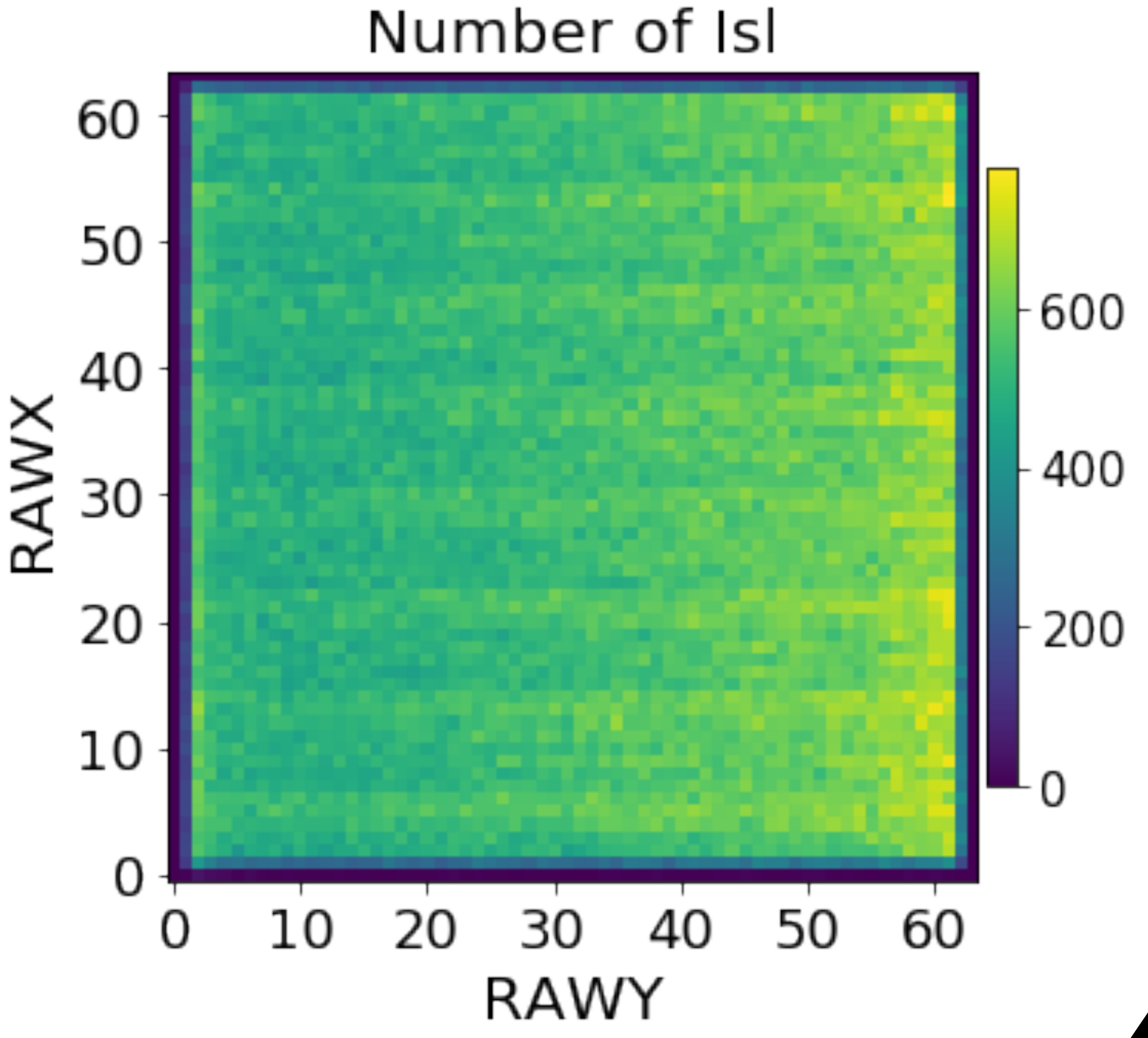
Island segmentation algorithm defines a box around the events.
Parameters to characterize the particle track are
- Number of pixels in the Island
- Total Energy of the Island
- Island center coordinates
- Maximum distance of pixels within the Island
- Pixels inside the box
- Elongation
- Rotation angle

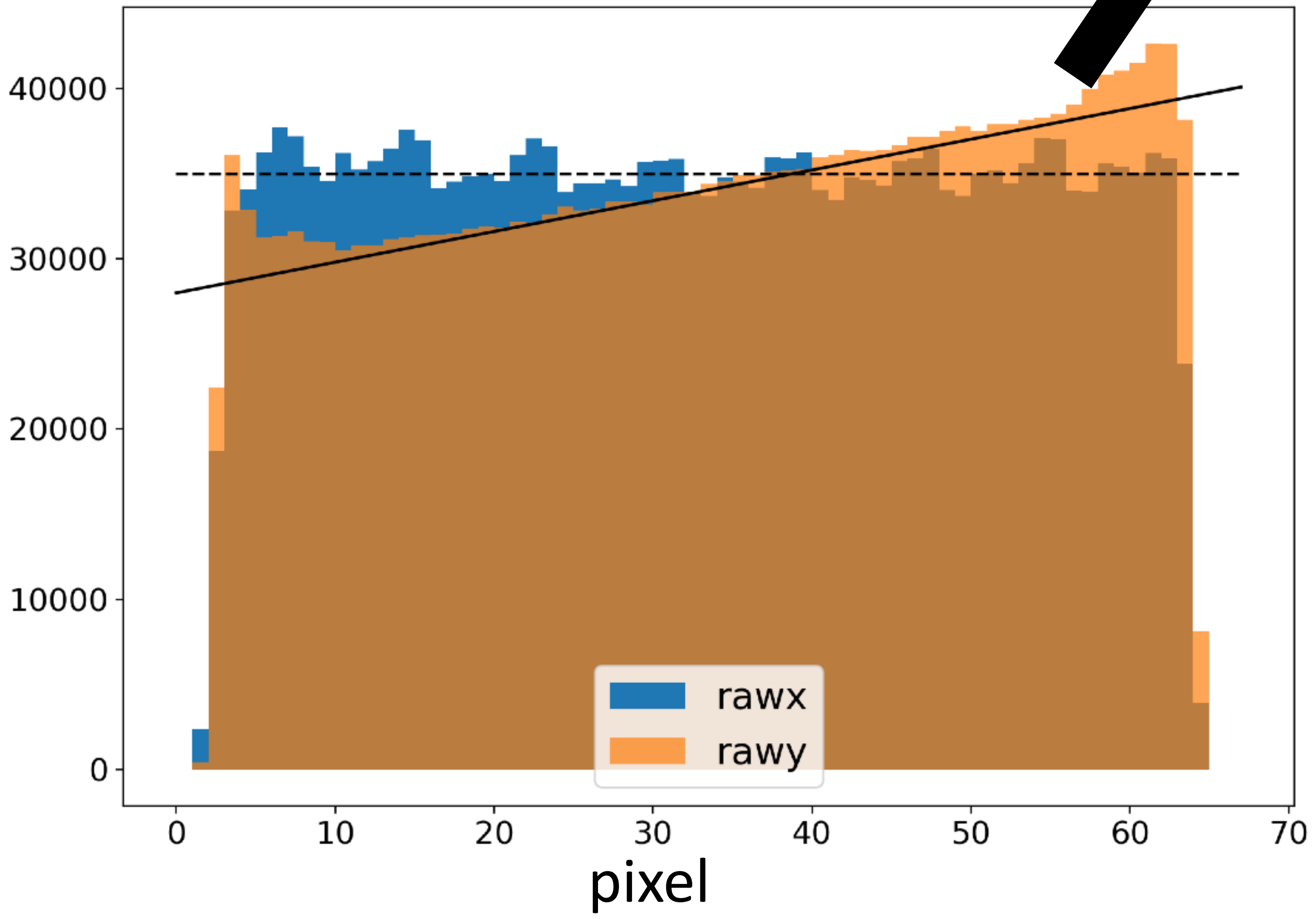
The ratio of pixels inside the box and total events gives an estimate of the goodness of fit



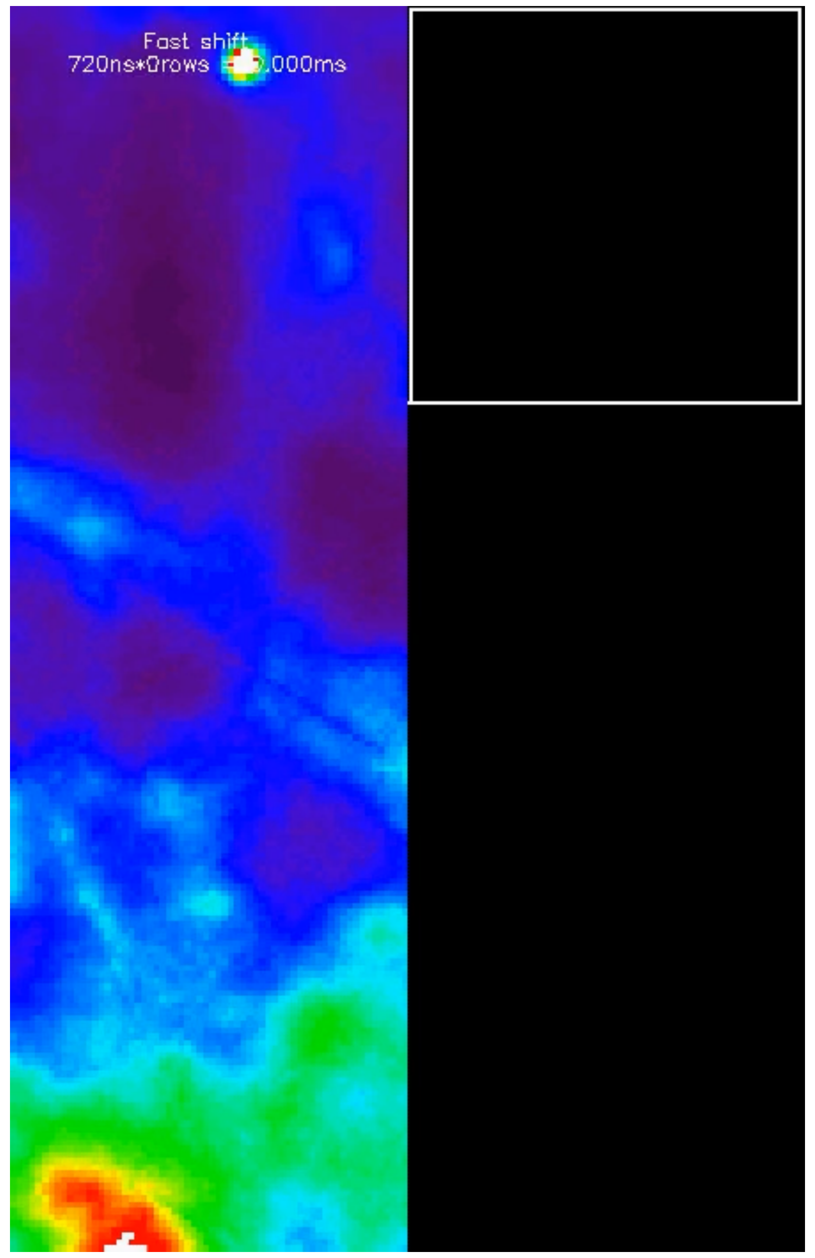
Well-behaved longer particle tracks

Island classification



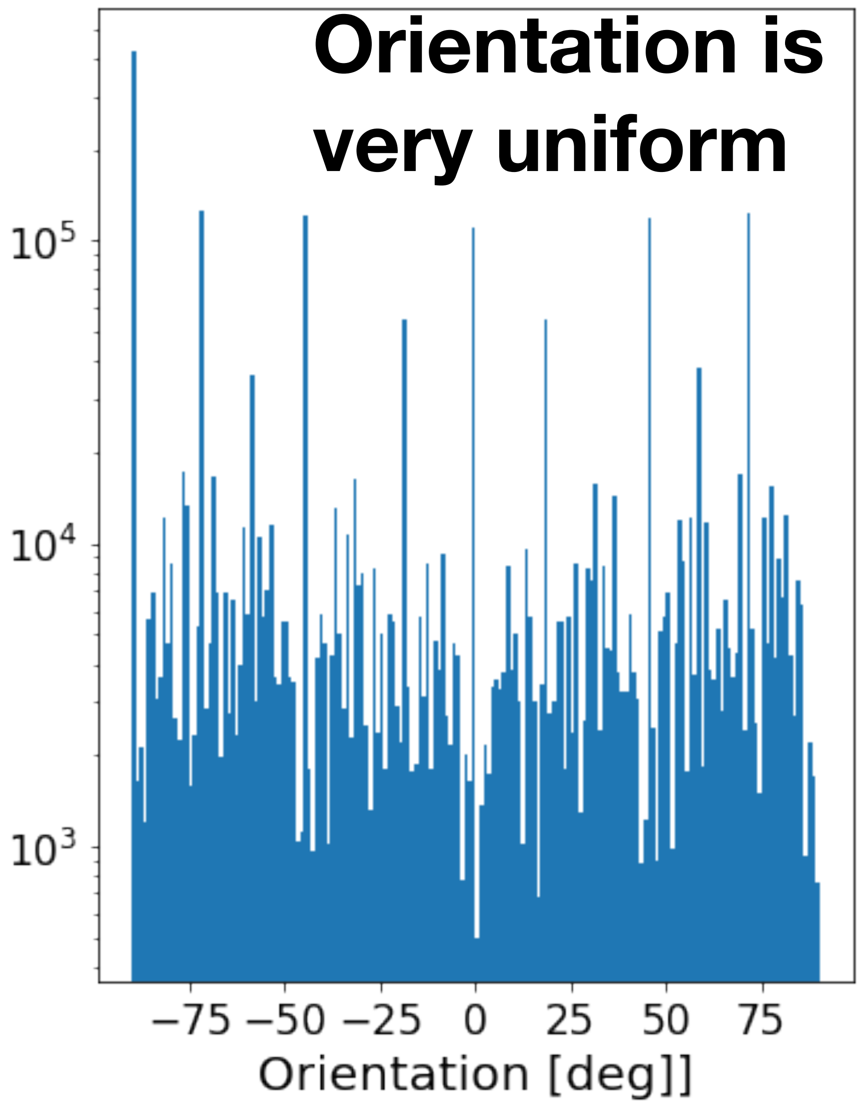


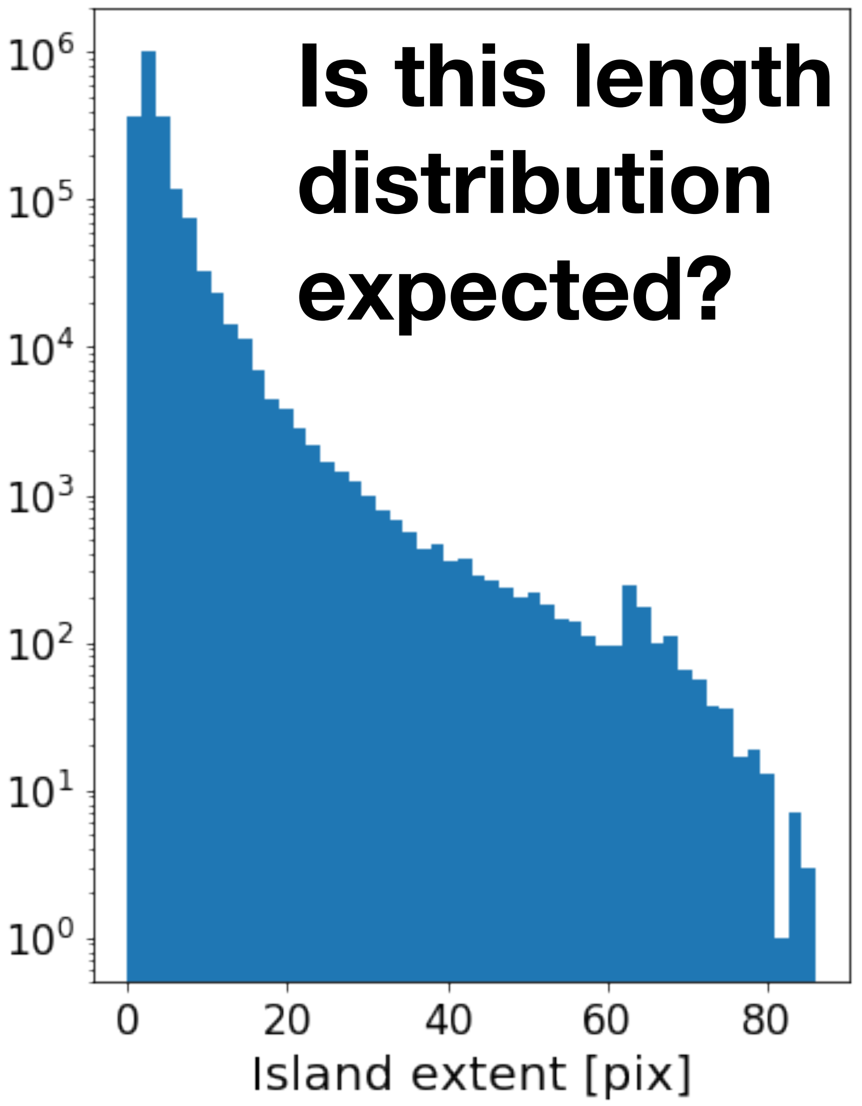
Increase of about 33% in number of particle tracks for pixels further away from the readout (large RawY).



SWM Readout exposes high RAWY pixels to more particle background.

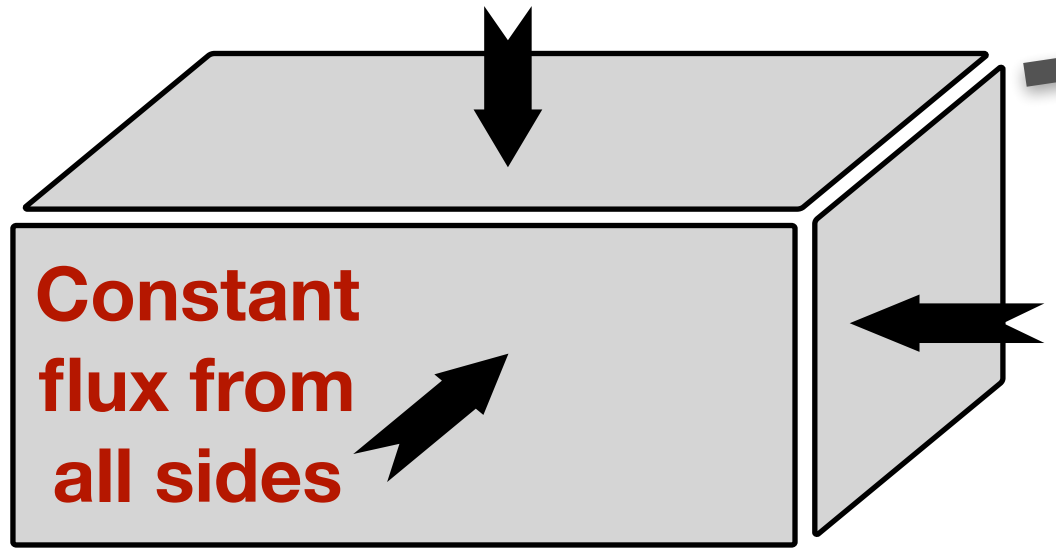
Other particle track properties can be compared to simple models / simulations

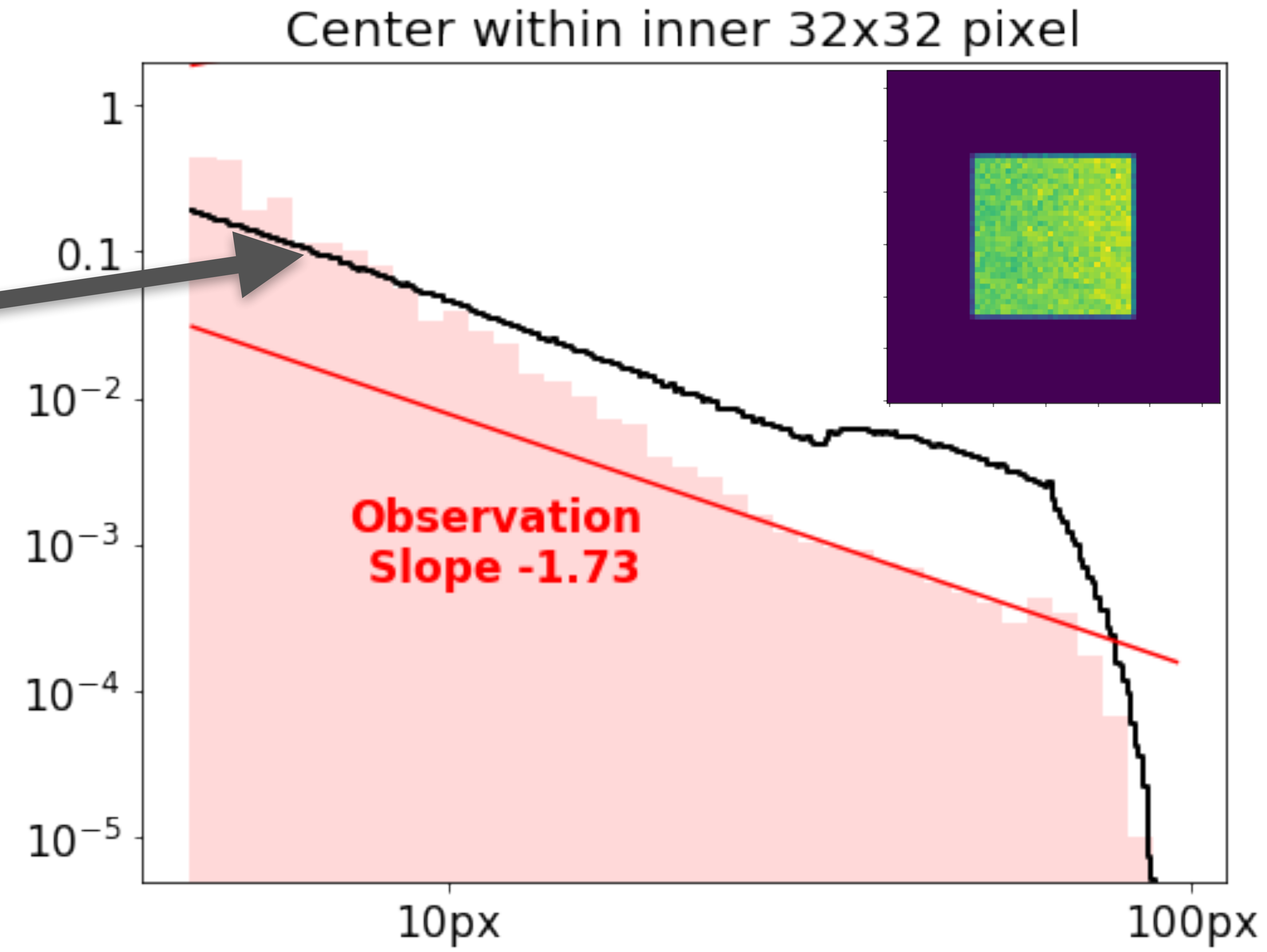




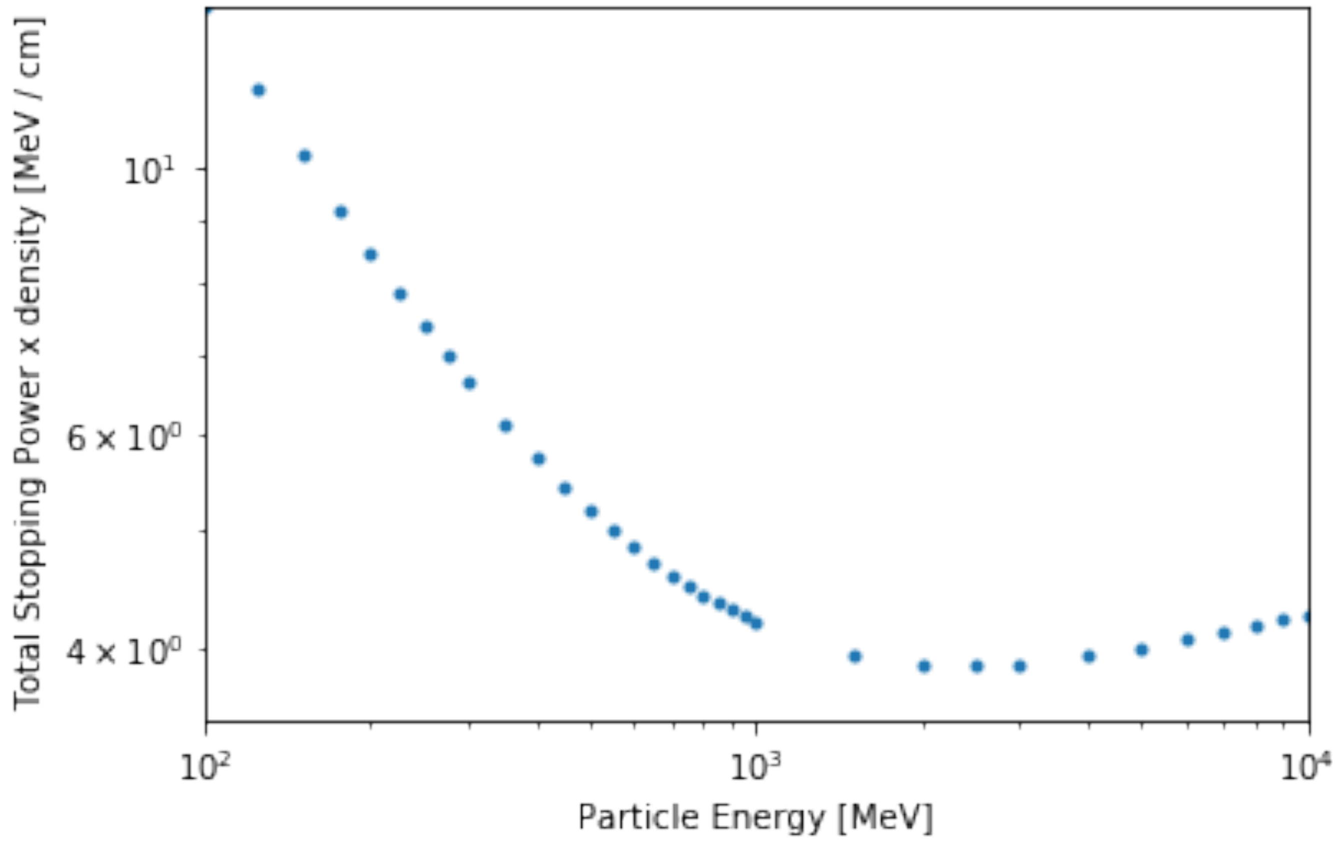
Track length distribution

Does the particle track length distribution match simple expectations?





We seem to be missing some of the longer tracks. Are particles stopped in the detector?



The stopping power of high energy protons through various materials is well documented.

For PN particles along the optical axis „see“ only 280µm of Si, parallel to the detector (through the depletion layer) it is around 1cm of Si.

Protons with an energy above 50MeV are not stopped in 1cm of Si.

We expect typical MIPs to have much larger energies. For a realistic estimate of the contributions of shielding a comparison with more realistic simulations has to be done.

Conclusions

- **PN SWM to investigate particle tracks in CCD detectors: Necessary to verify particle background models used for predictions of Athena WFI's science capabilities**
- **Self Anti-Coincidence already successful in reducing the background level over a smaller band**
- **Particle properties**
  - **2D particle distribution**
  - **Particle length**
- **Wider band for spectral behavior of background components and increased statistics**
- **Next immediate steps**
  - **Filter open data to study other background components (soft protons, SWCX)**