InGrid Detectors for Rare & Low Energy X-Rays: Application in CAST

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University of Bonn

7th Symposium on Large TPCs for Low Energy Rare Event Detection
Paris, 16/12/2014

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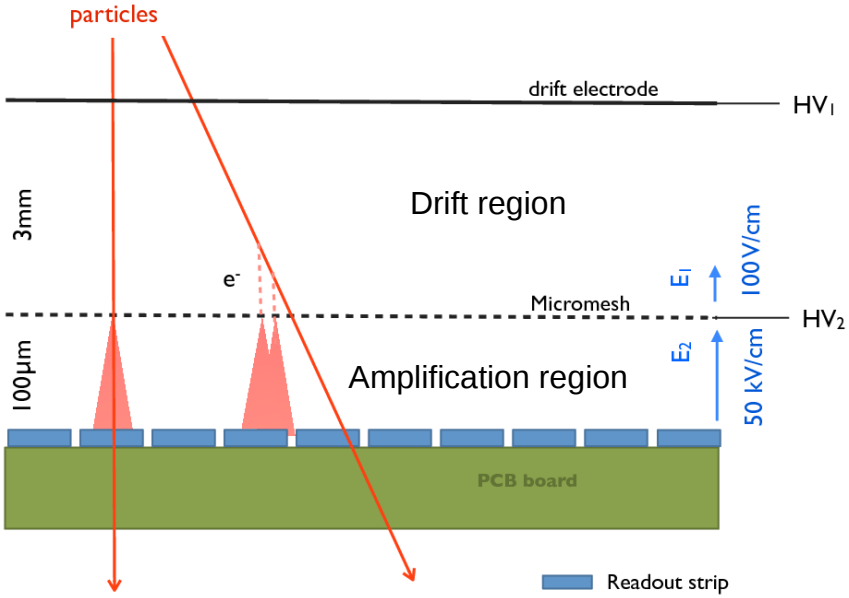
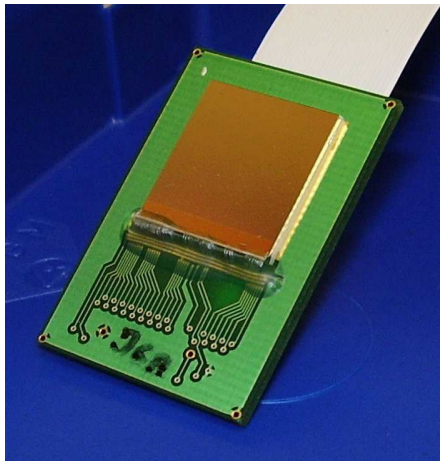
InGrids



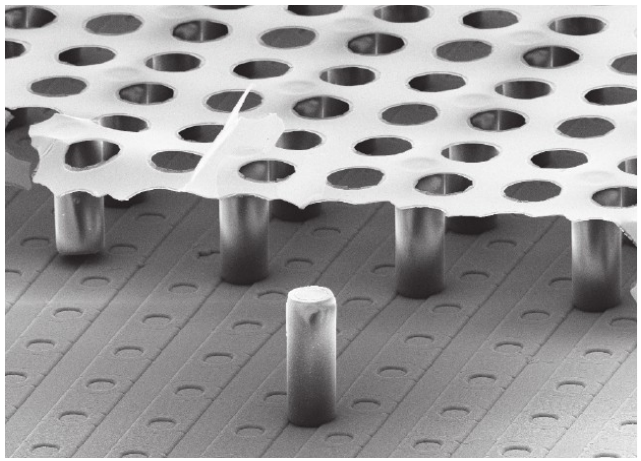
Micromegas mounted on a pixel chip via photolithographic post-processing

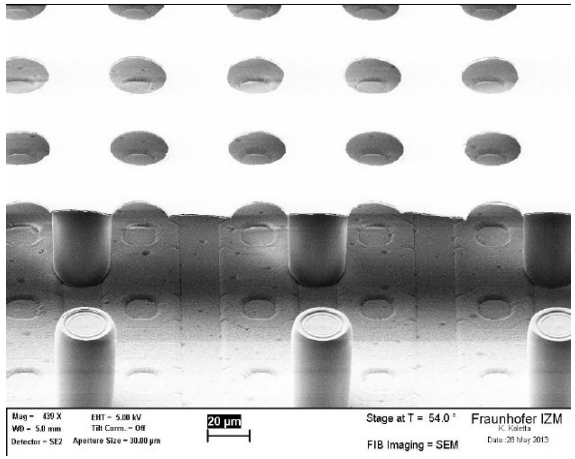
pioneered by U Twente&NIKHEF&CEA
J. Schmitz, M. Chefdeville et al.

Pixel chip: Timepix
256x256 pixels (55x55 µm^2) ~ 2 cm^2
Typical threshold: 500 e$^-$



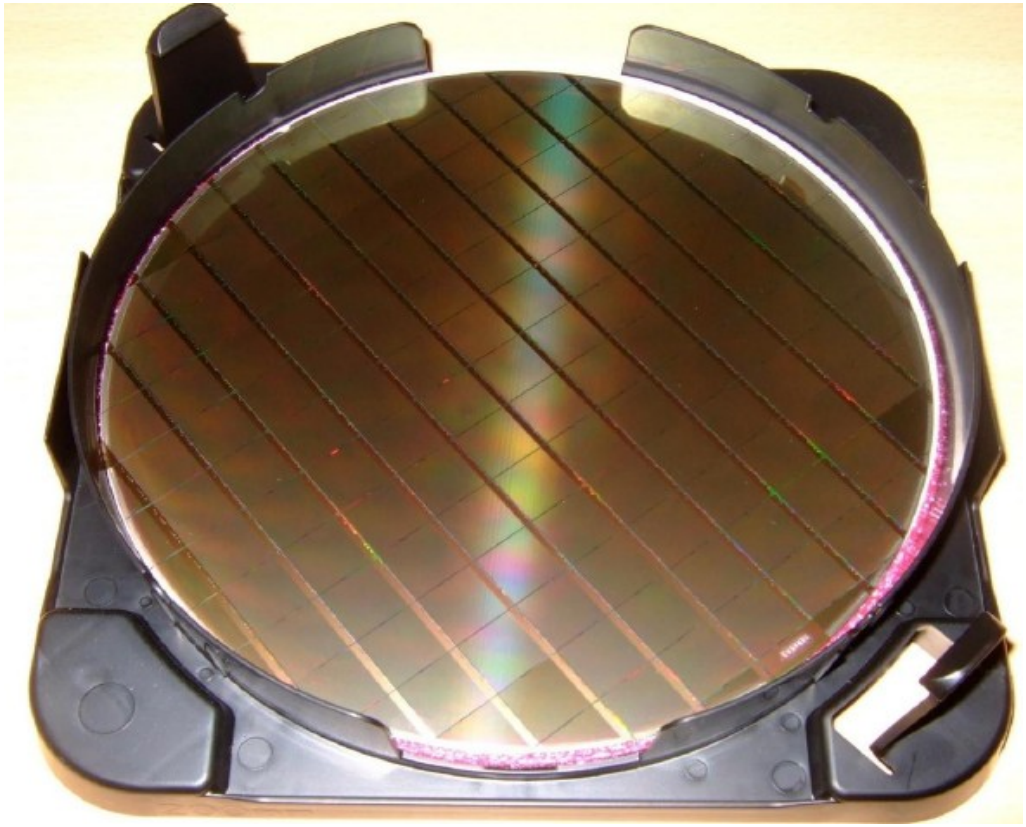
Timepix





InGrid

InGrids: Wafer-based production



Timepix Wafer

- transferred original single-chip process to a whole 8-inch wafer
- produce up to 107 InGrids at once at reasonable cost
- technologically difficult (e.g. SiN layer homogeneity)

Fraunhofer IZM

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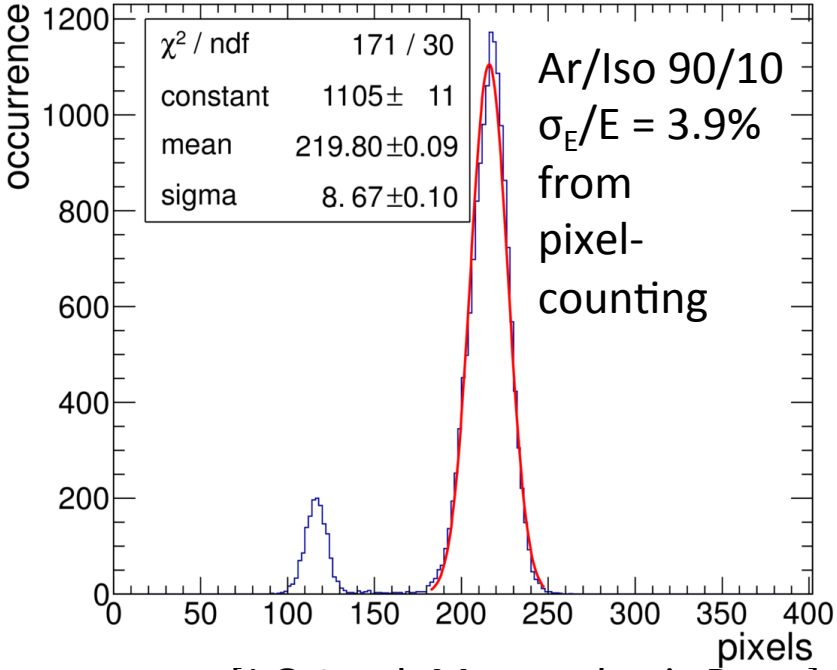
InGrids as X-Ray detectors

- almost 100% single-electron efficiency
- diffusion in drift region → 1 primary electron per pixel →
  - → electron-counting to measure energy
  - → no gain fluctuations
  - → optimal topological suppression of charged background
  - → alternative energy measure: total charge in all pixels

Optimization for E-resolution:

Ar/iC_4H_{10}	U_{grid} / V	Gain	E_{grid}/E_{drift}	R
90/10	380	6346.1 ± 5.1	368	3.85% ± 0.06%
95/5	335	6069.8 ± 3.4	134	4.38% ± 0.05%
96/4	320	6122.0 ± 3.3	163	4.76% ± 0.06%
97/3	300	3735.5 ± 2.3	257	4.60% ± 0.05%
97.7/2.3	280	2381.5 ± 1.4	96	5.33% ± 0.04%
98/2	290	3493.8 ± 2.1	133	5.40% ± 0.06%
99/1	275	2053.7 ± 1.5	169	9.02% ± 0.10%

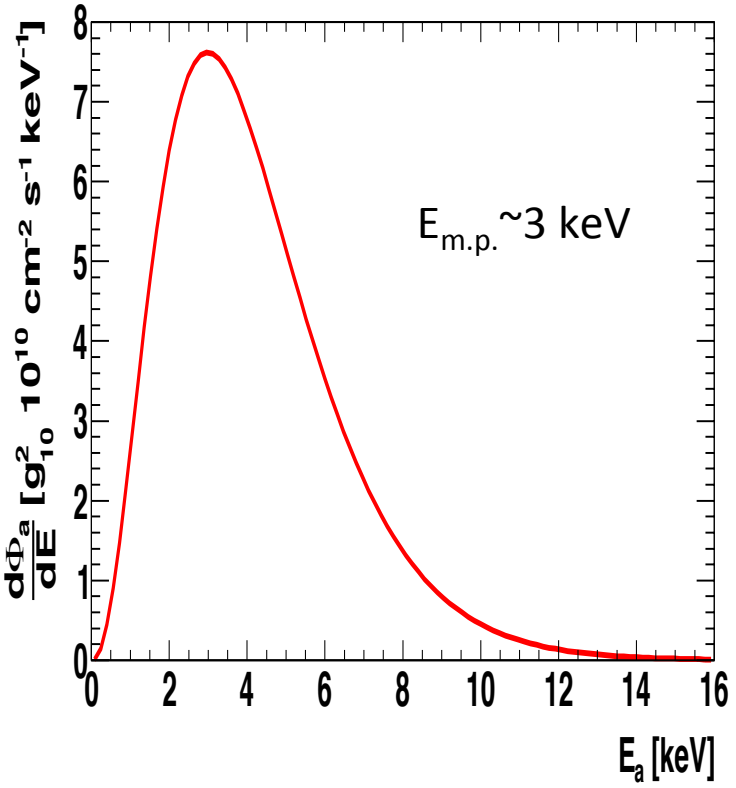
@5.9 keV



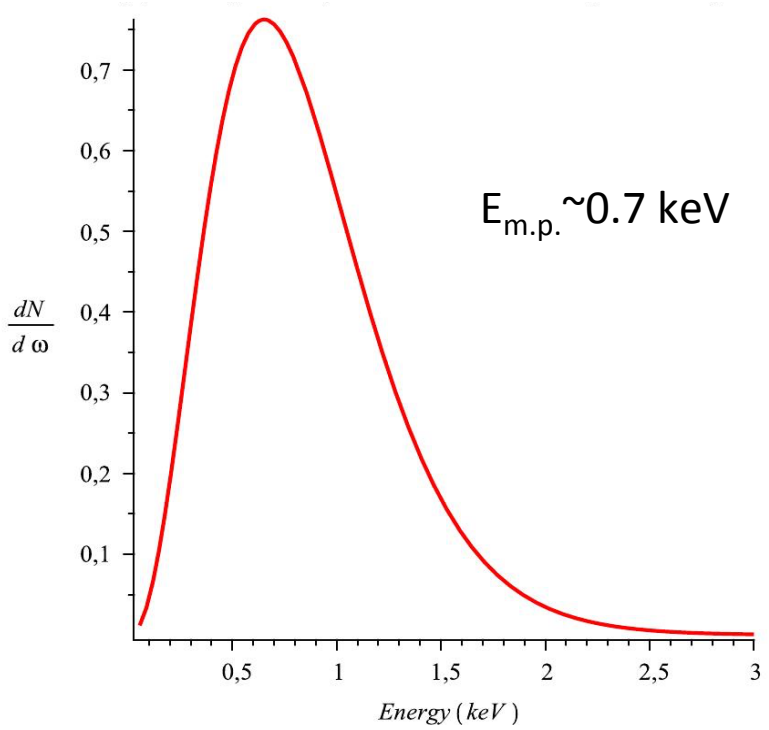
[J.Ottnad, Master thesis Bonn]

Motivation for InGrids at CAST

axions

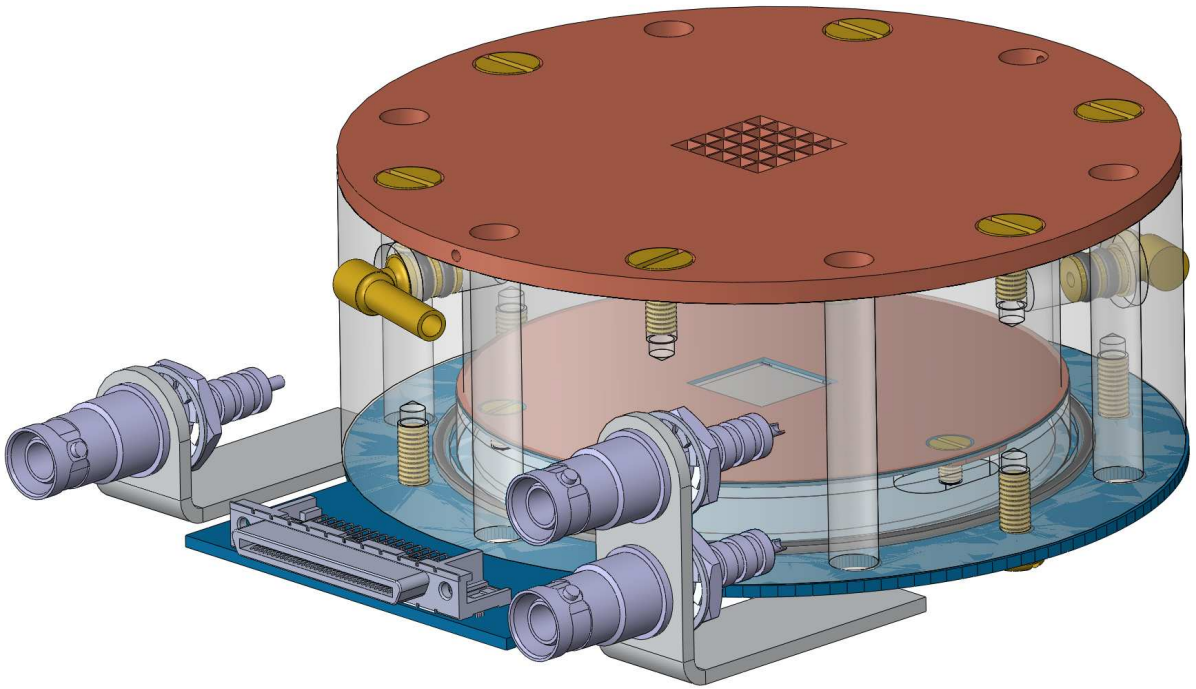


chameleons



- very low energy threshold << 1 keV
- topological background suppression → replace CCD behind MPE X-ray telescope
- potentially very low background

The CAST InGrid Detector



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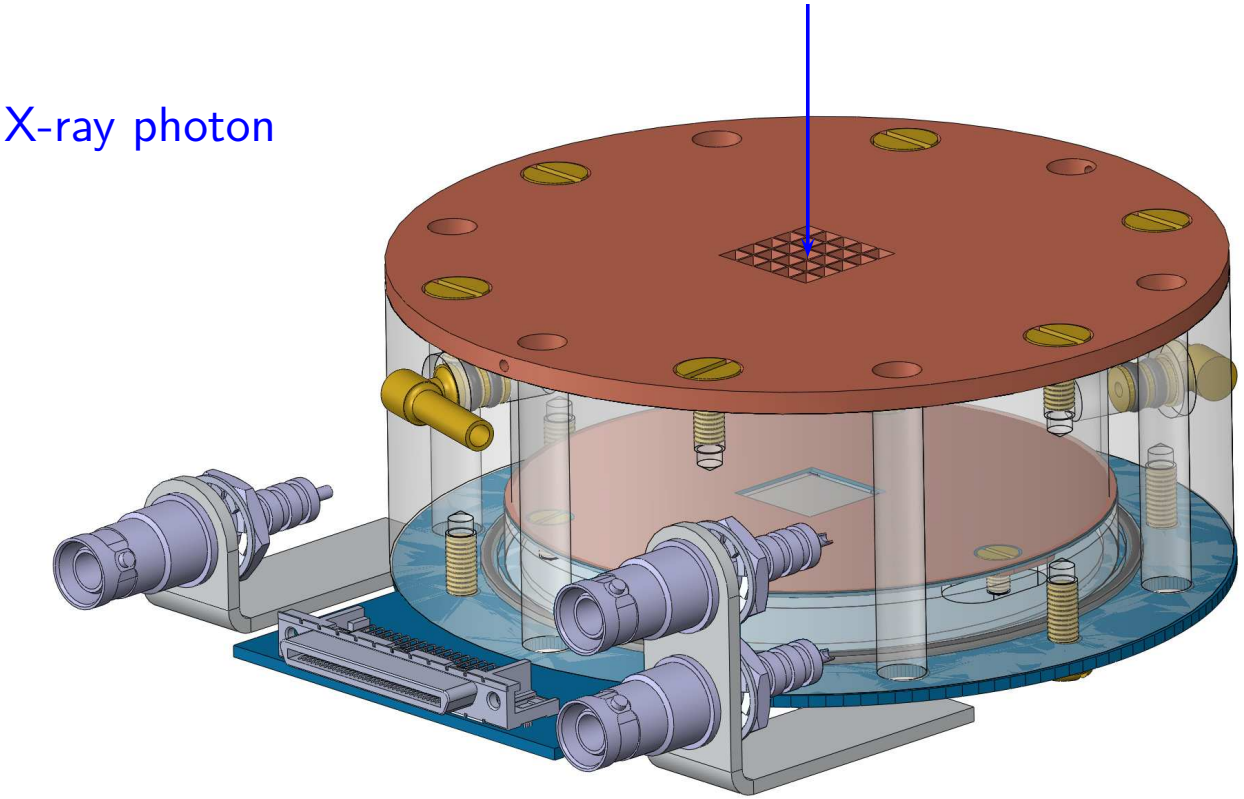
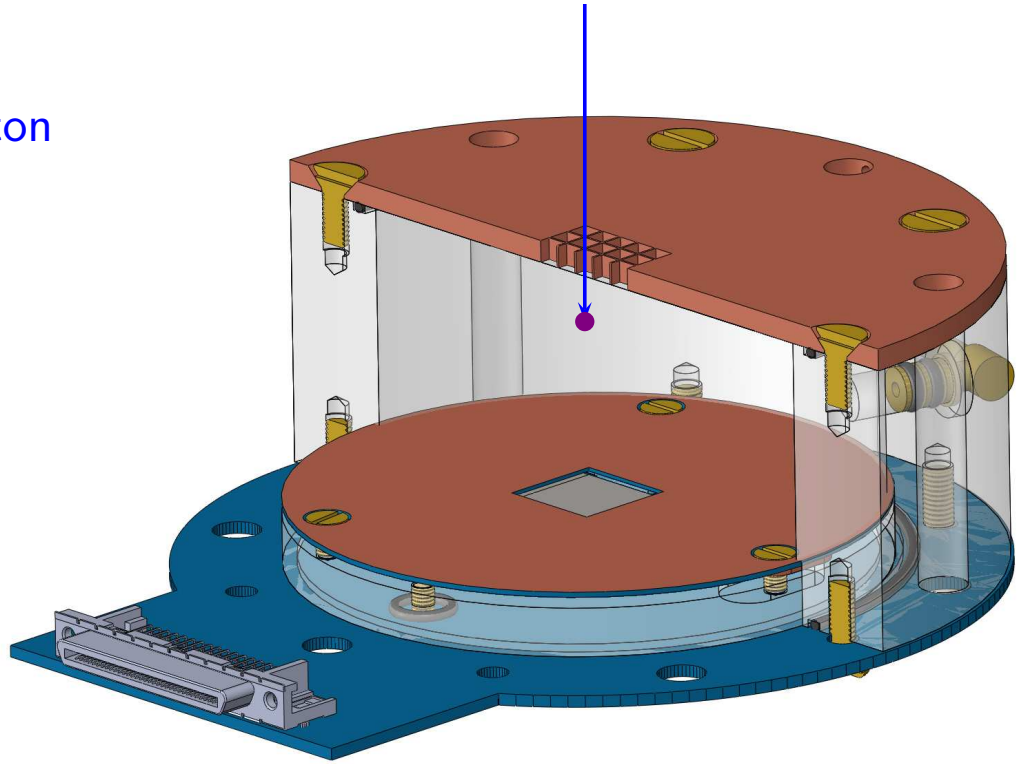


The CAST InGrid Detector

X-ray photon

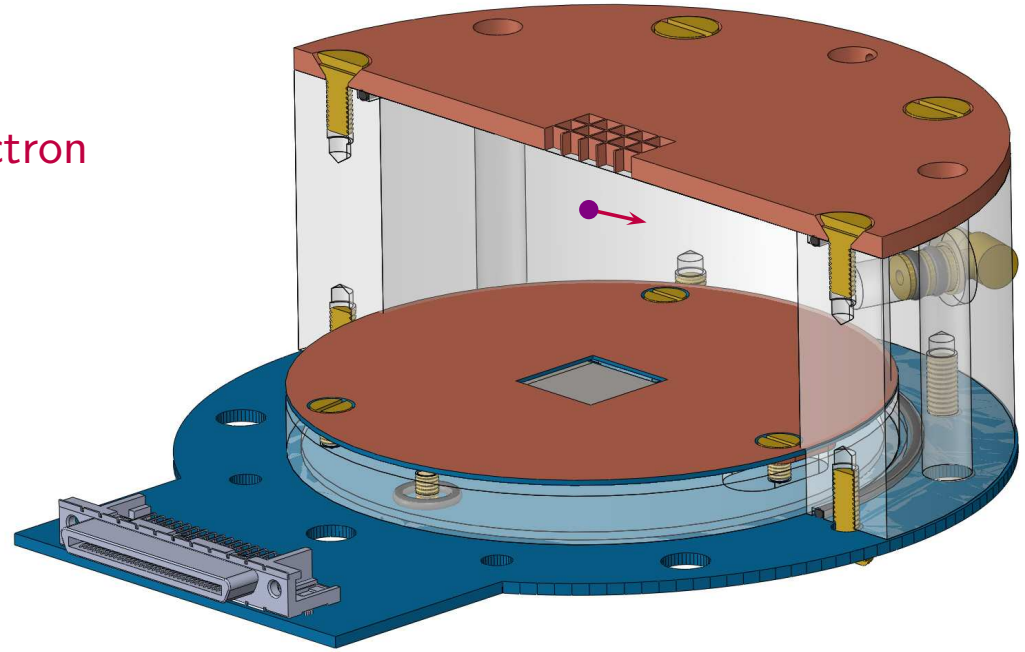
Gas atom



The CAST InGrid Detector

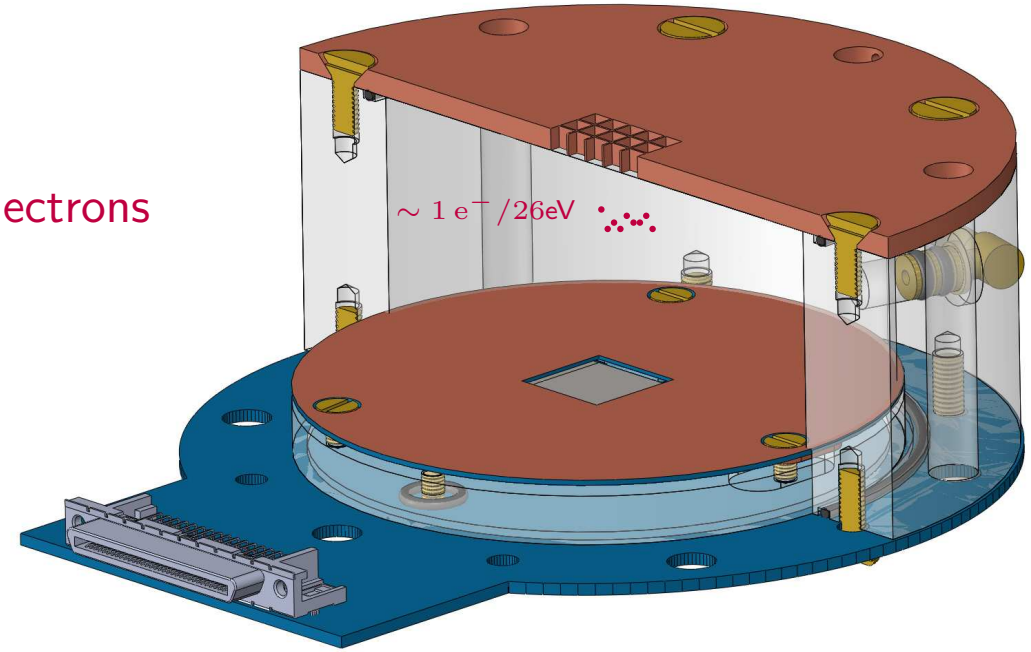
Gas atom

Photo electron



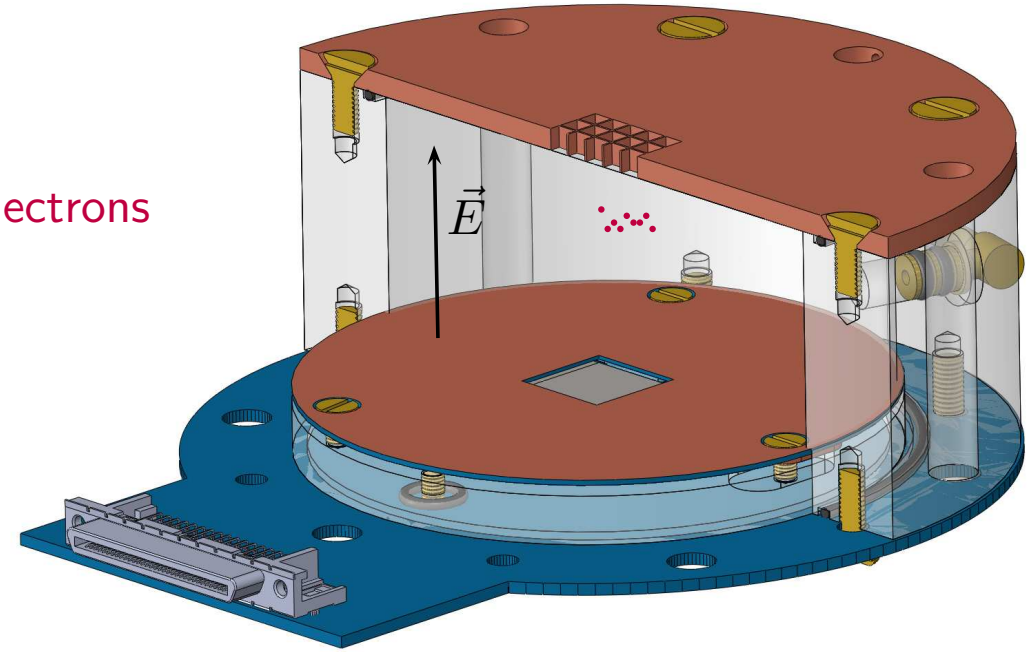
The CAST InGrid Detector

Primary electrons



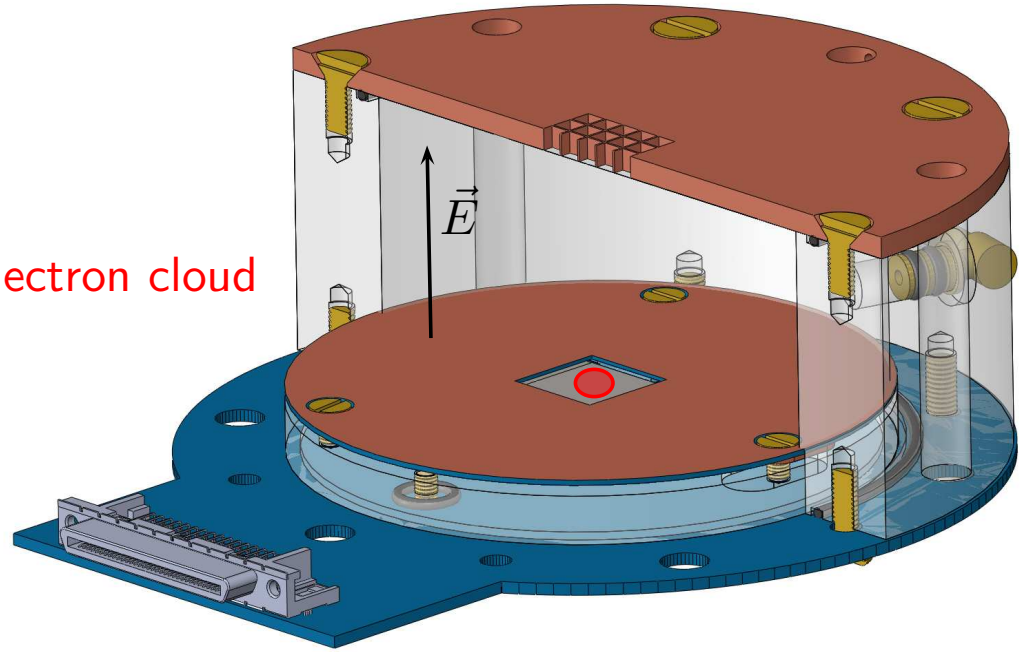
The CAST InGrid Detector

Primary electrons



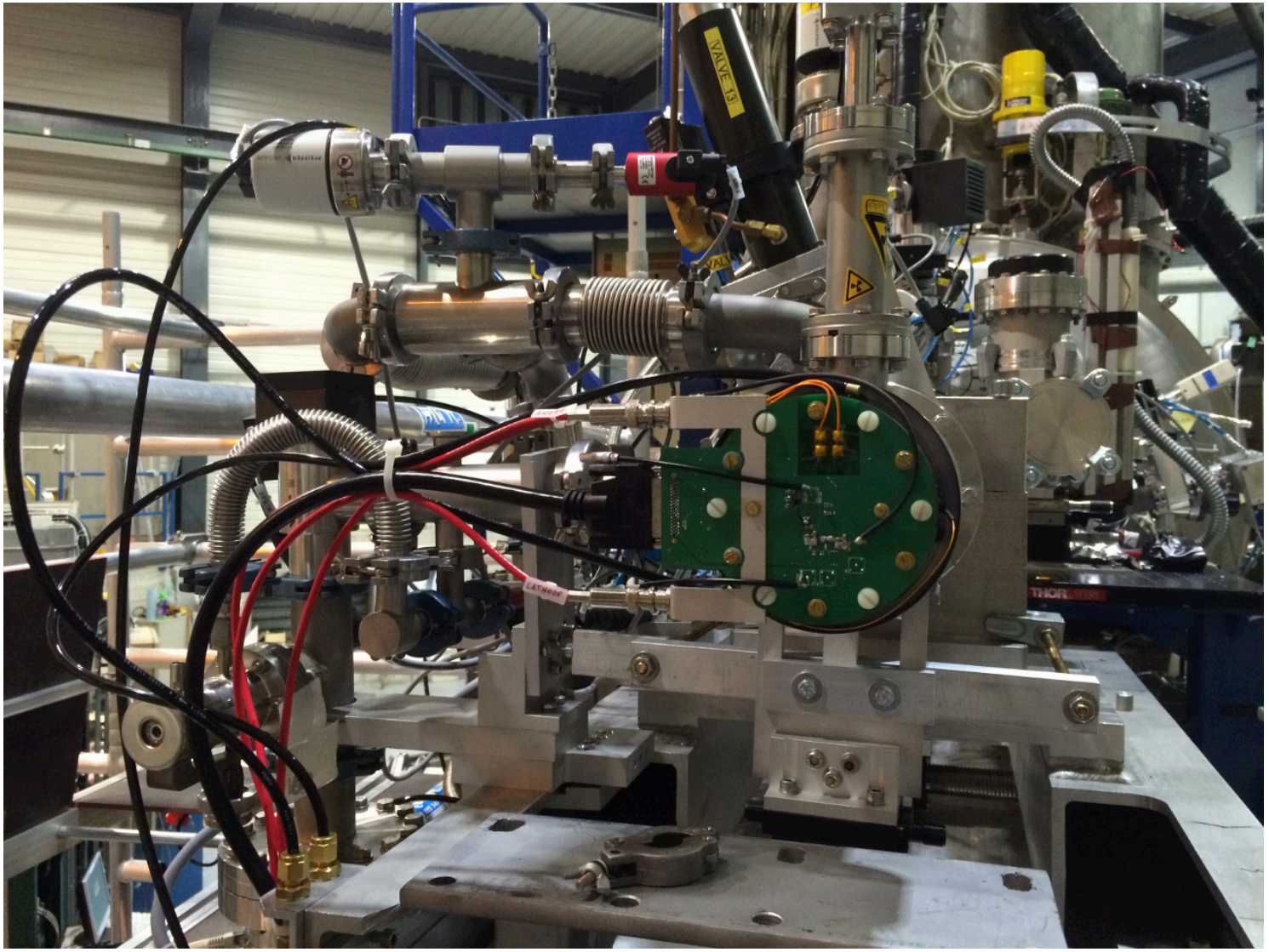
The CAST InGrid Detector

Diffused electron cloud

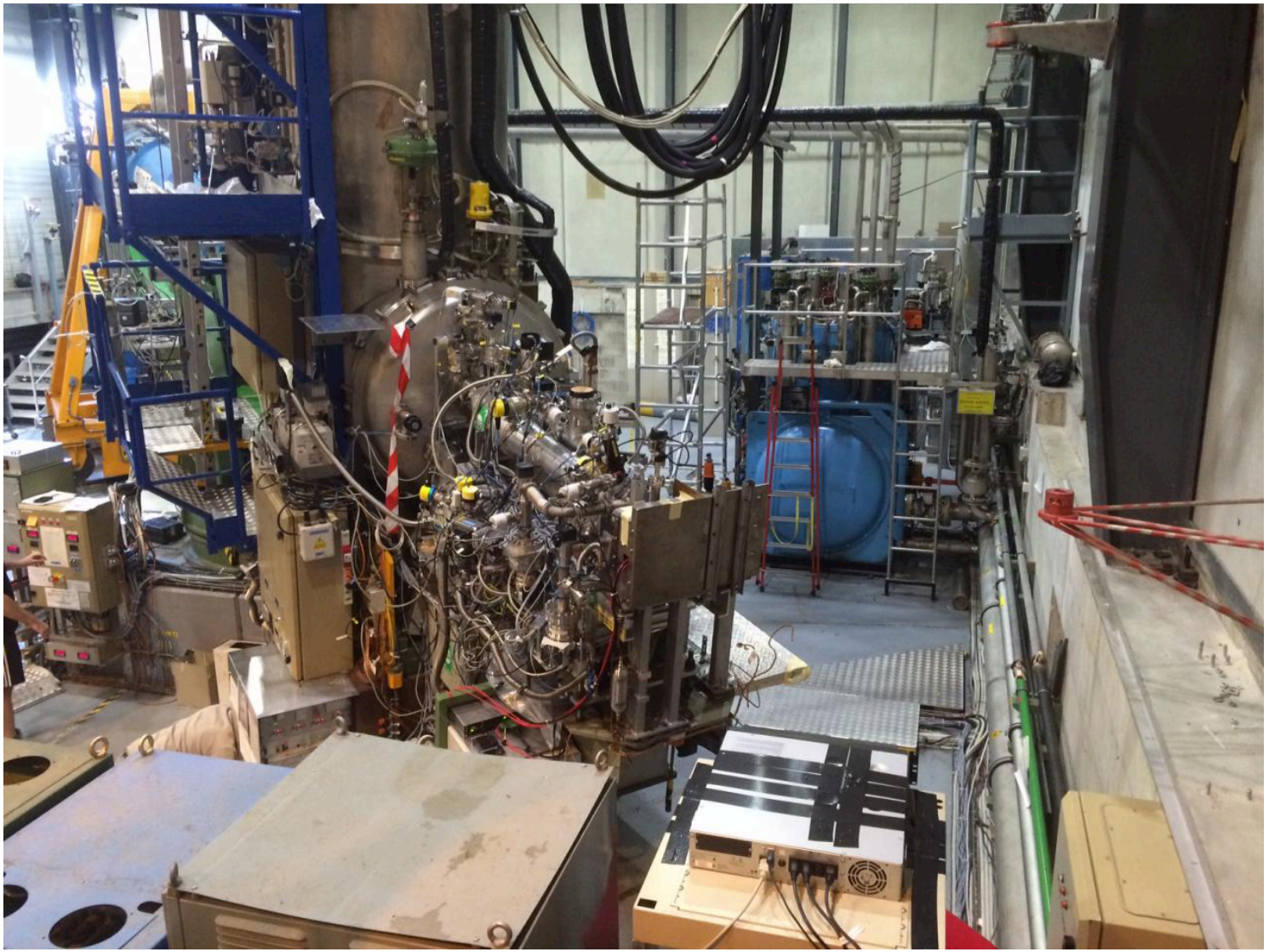


Setup in CAST

Setup in CAST

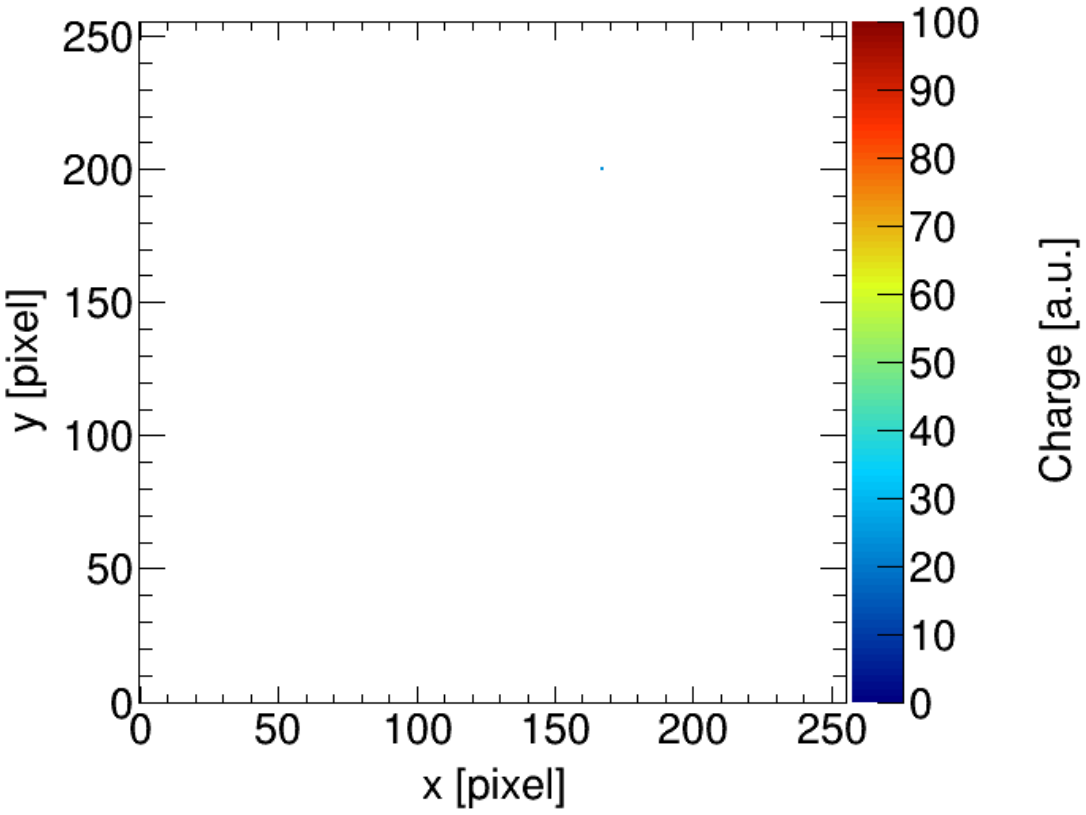


Setup in CAST



Noise? No

Out of 2379029 frames (0.98s) 1988773 frames look like this:



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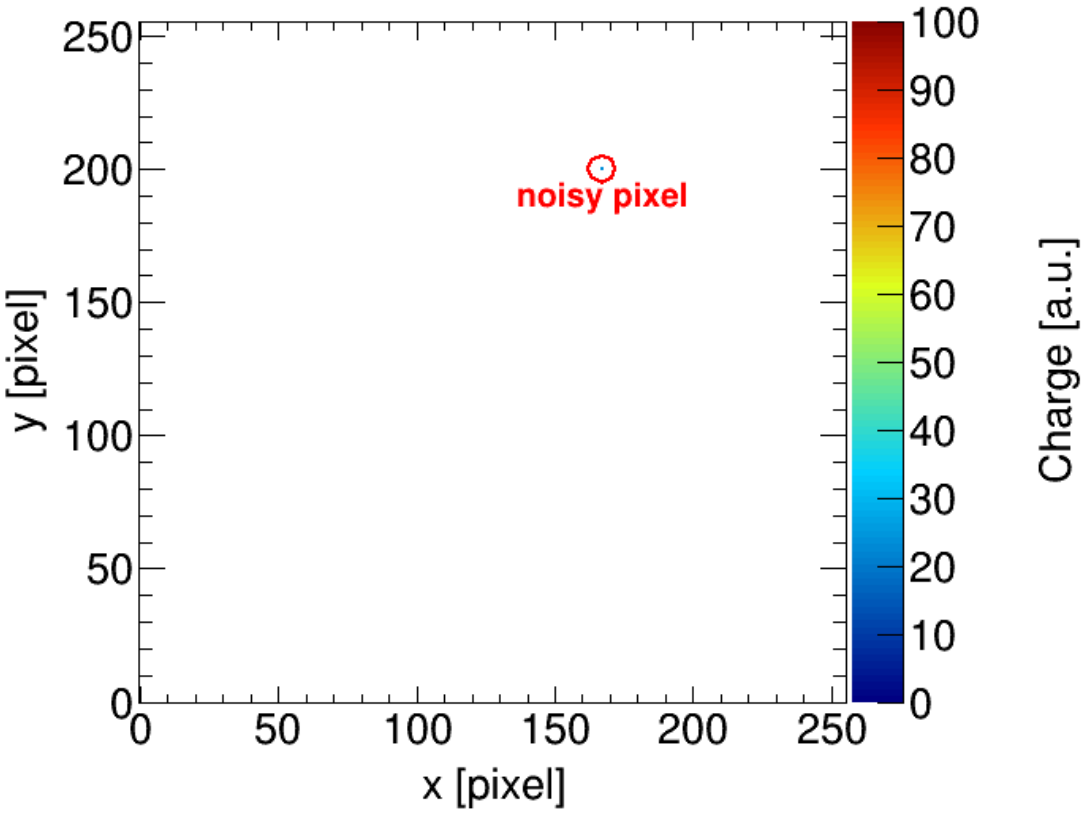
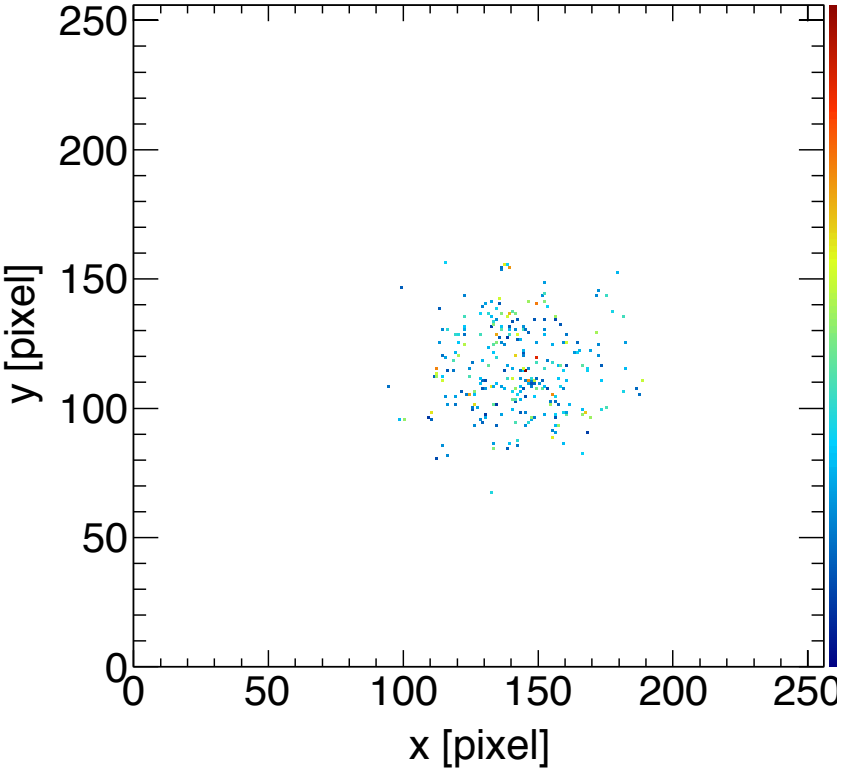


suitable for rare event searches...

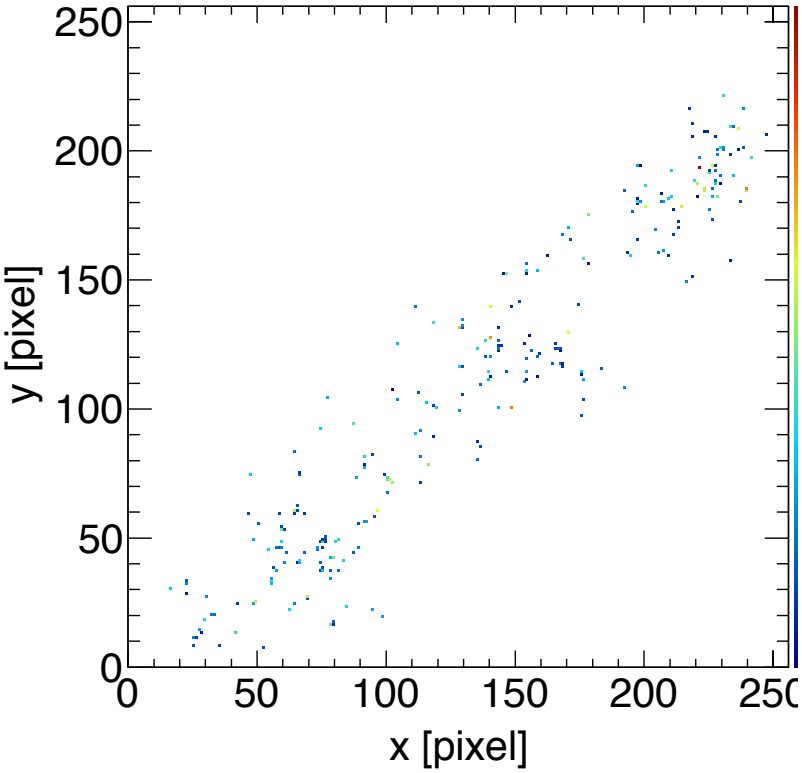
Topological Background Rejection

Distinguish between signal (left) and background (right) using the shape of the pixel hit pattern

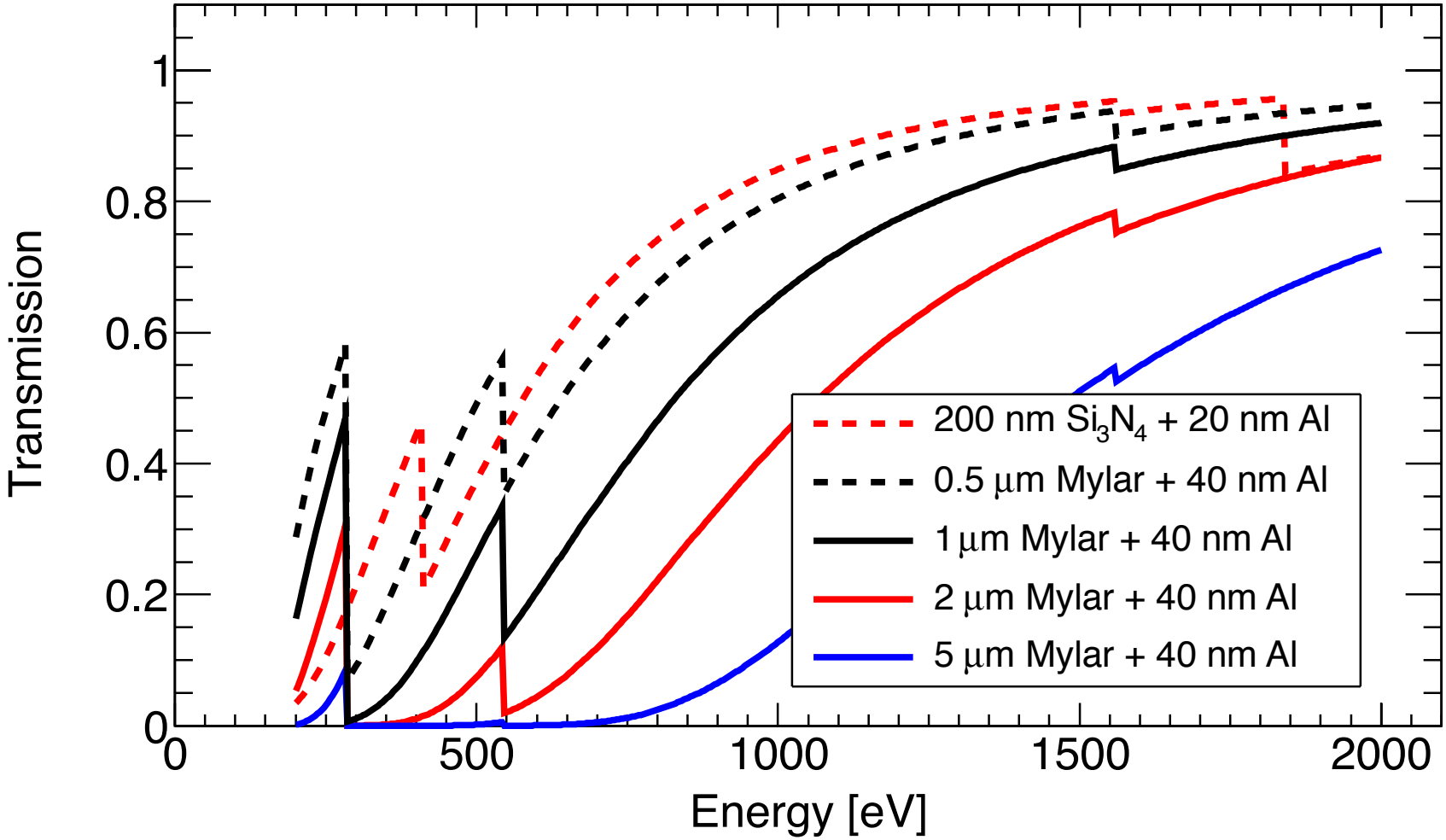
X-Ray (E=5.9 keV)



Cosmic track

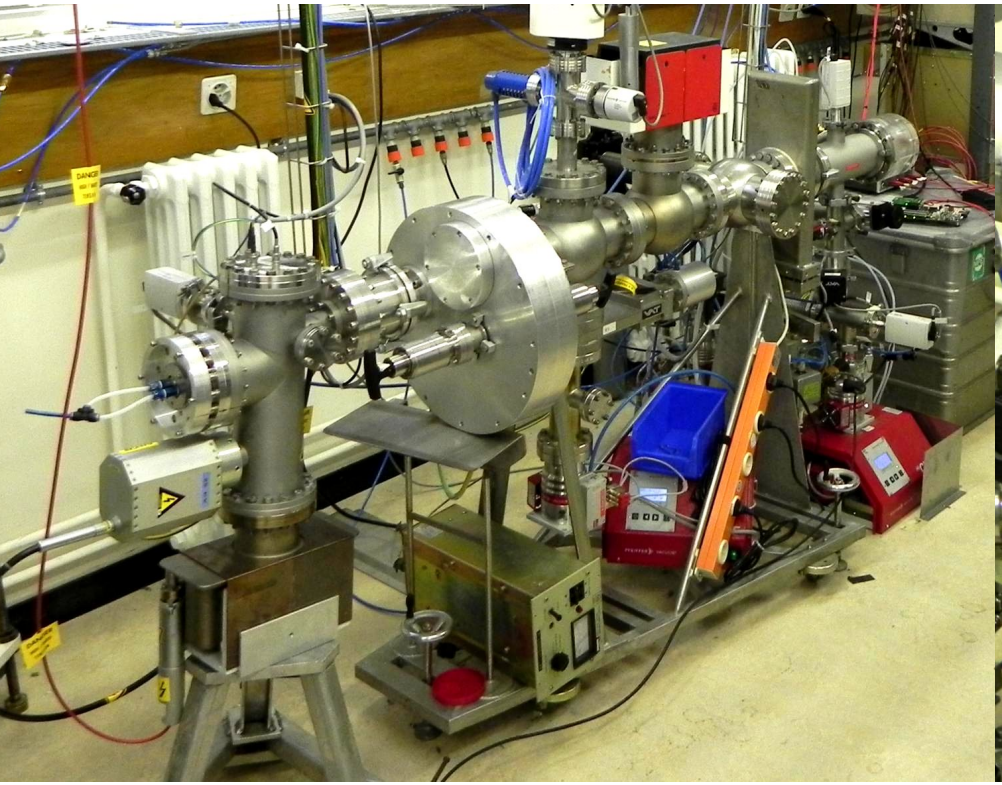


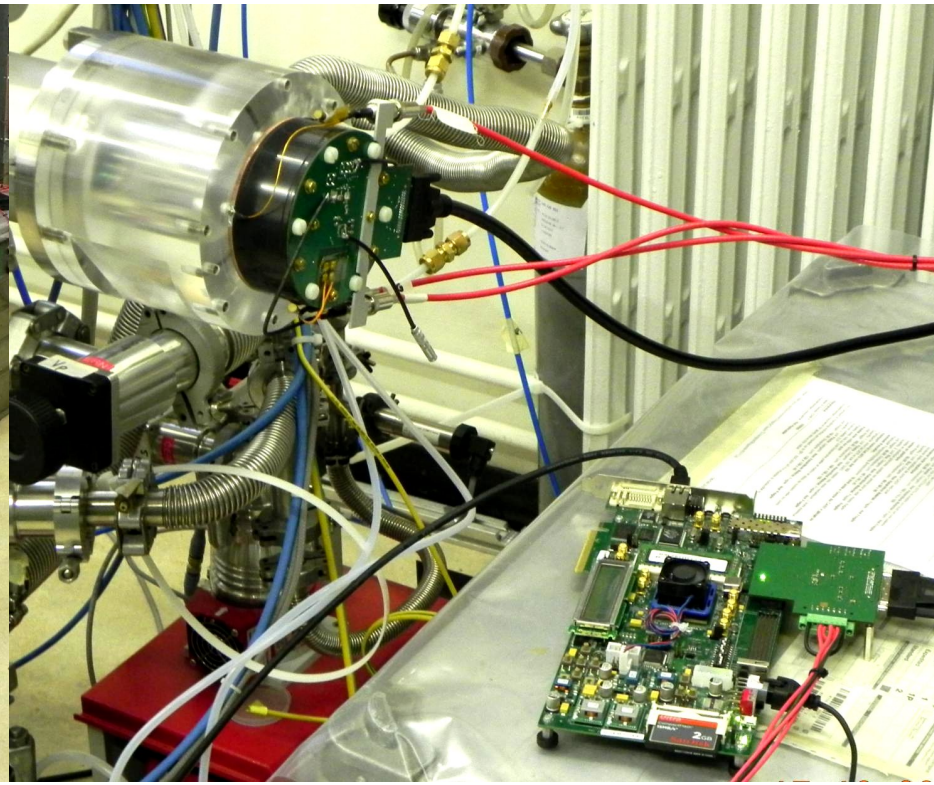
X-Ray Window



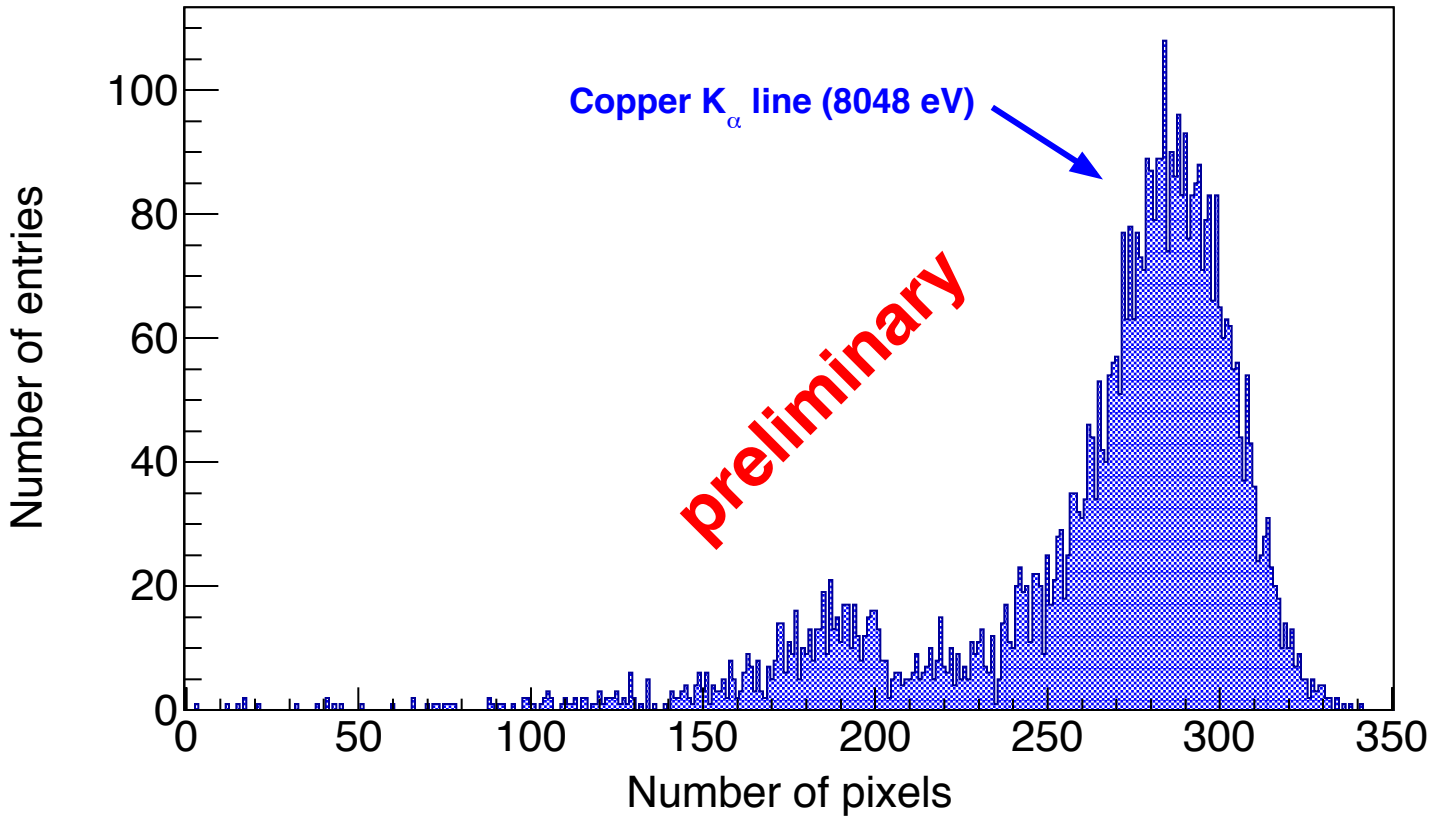
Currently: 2 μm Mylar (aluminized) + Cu strong-back (copied from CAST MMs)

X-ray calibration at CAST detector lab





Calibration



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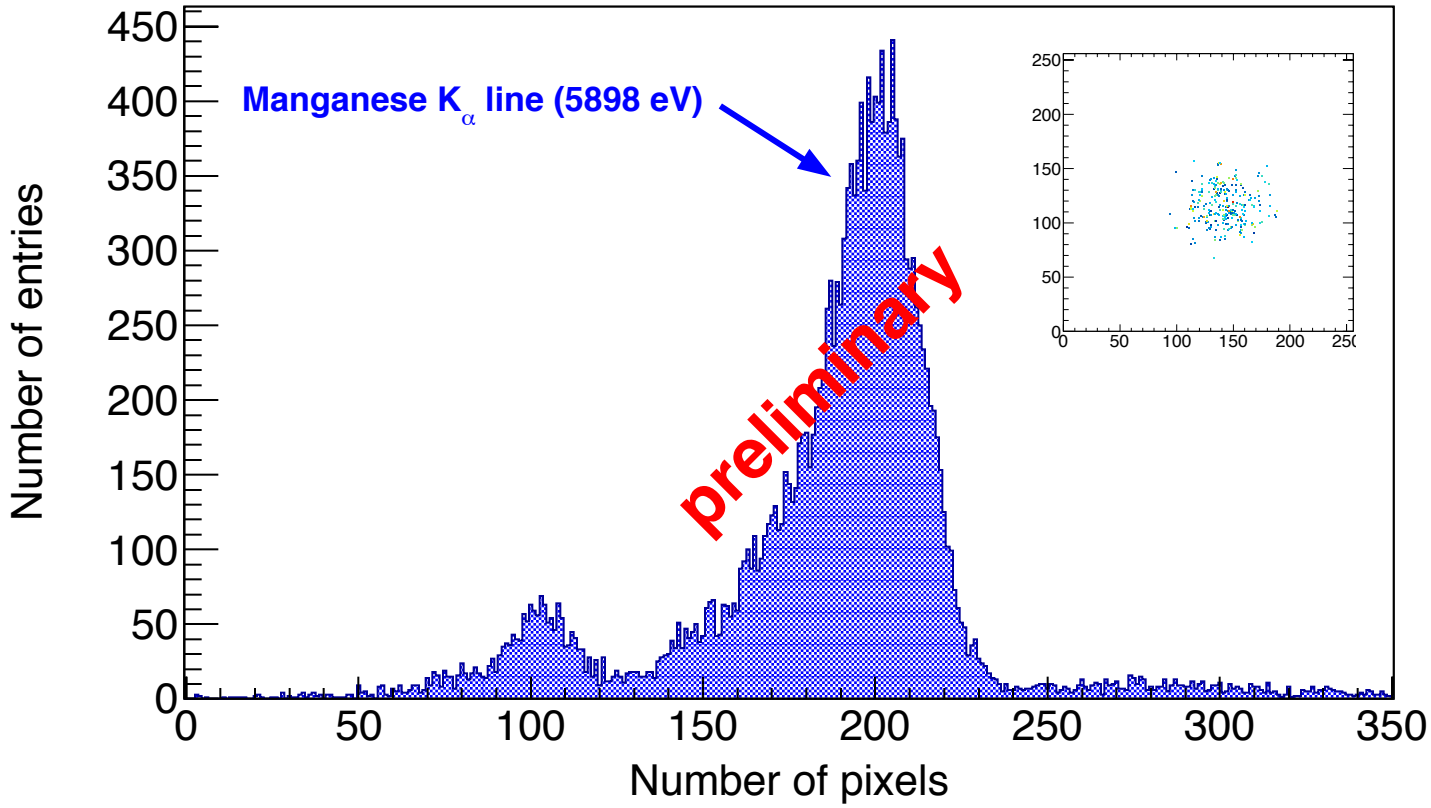

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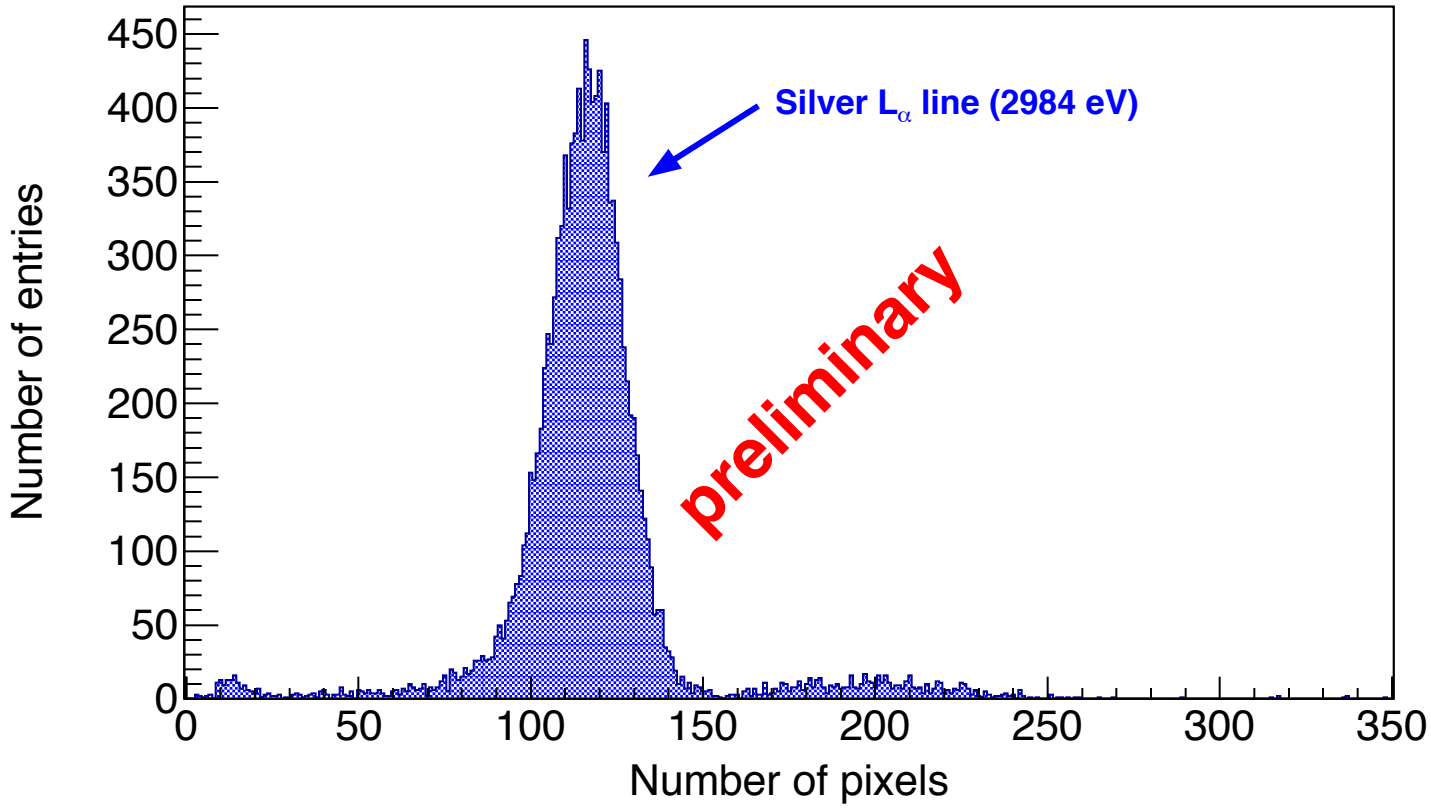

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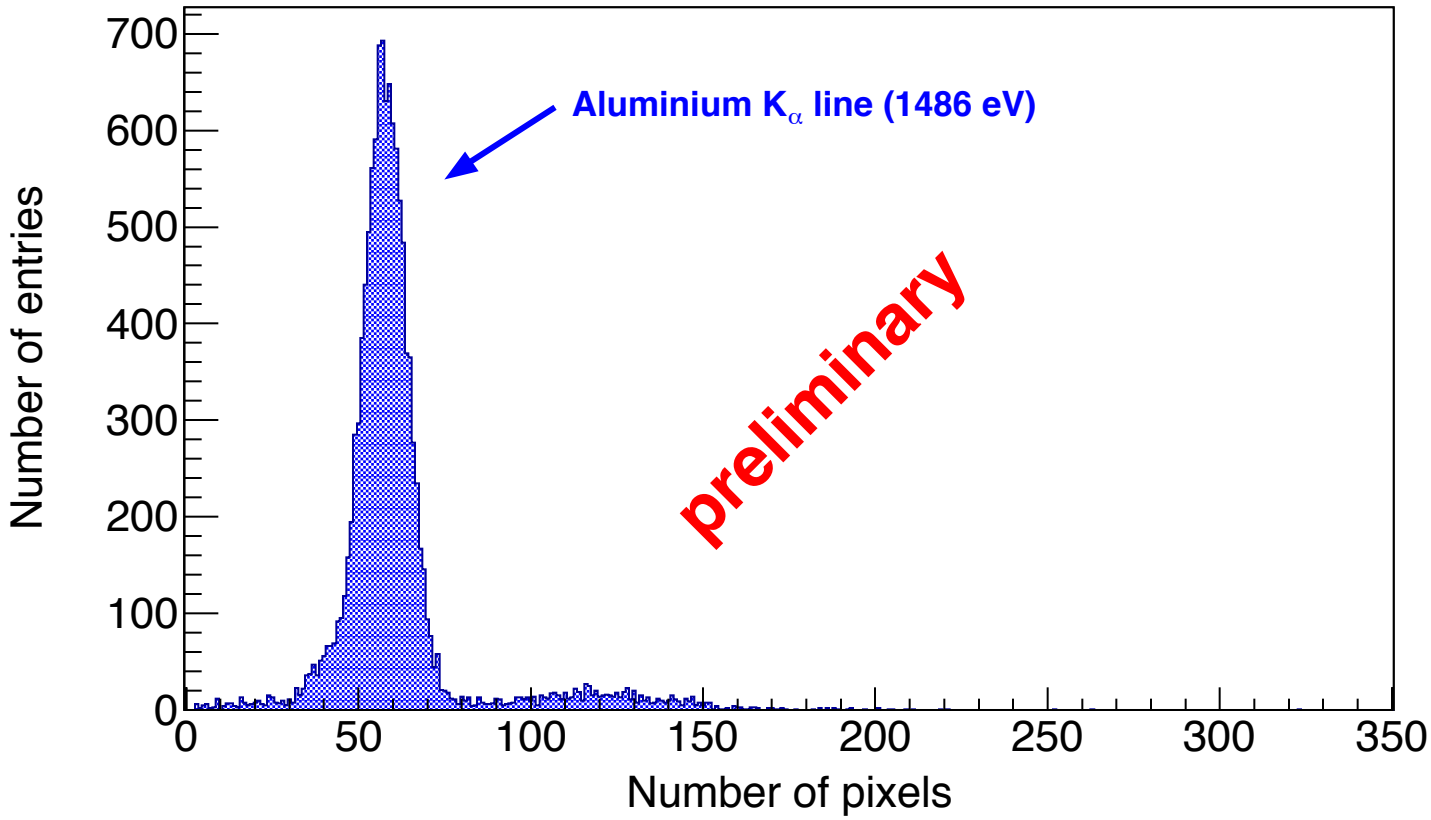

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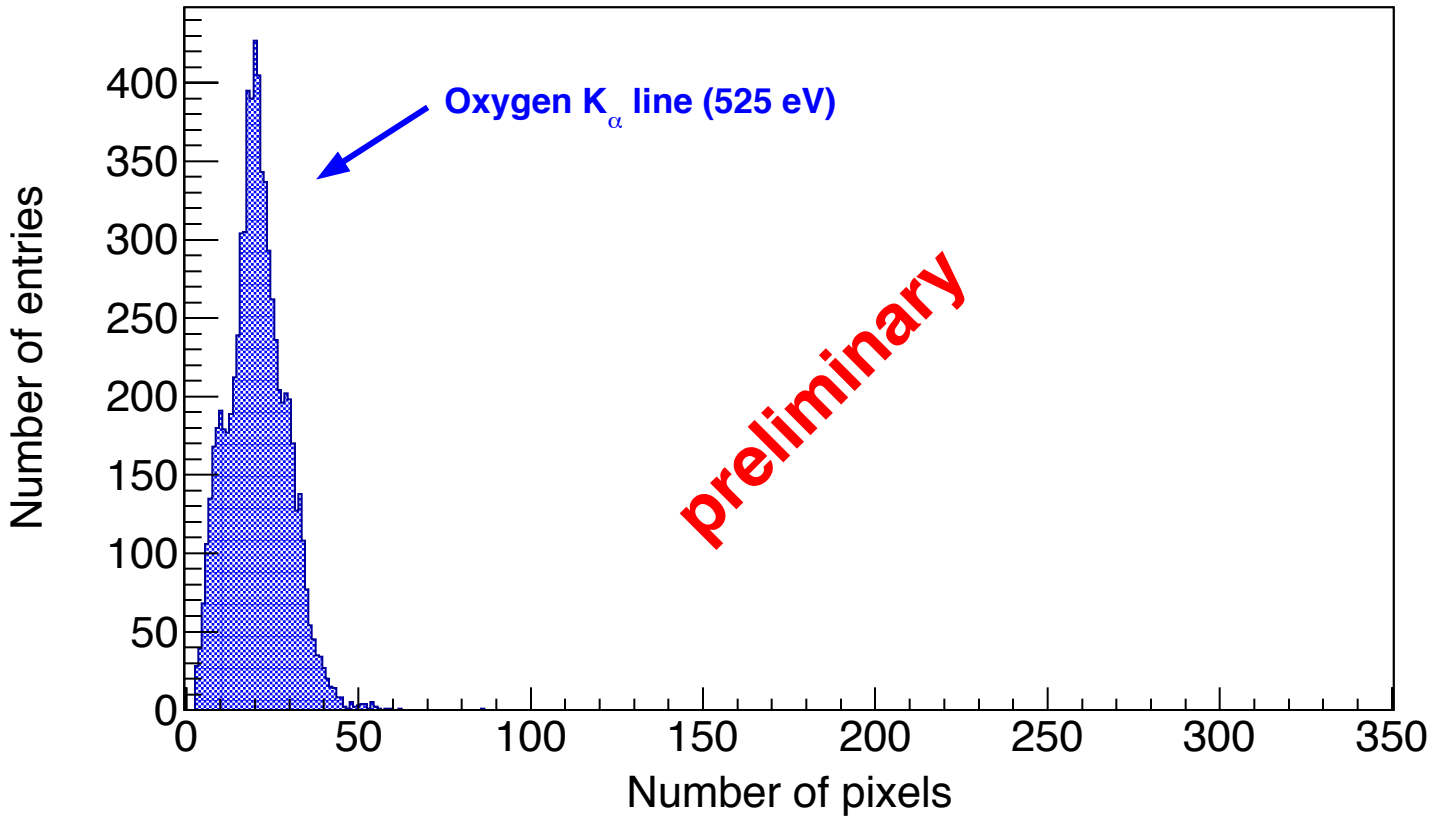

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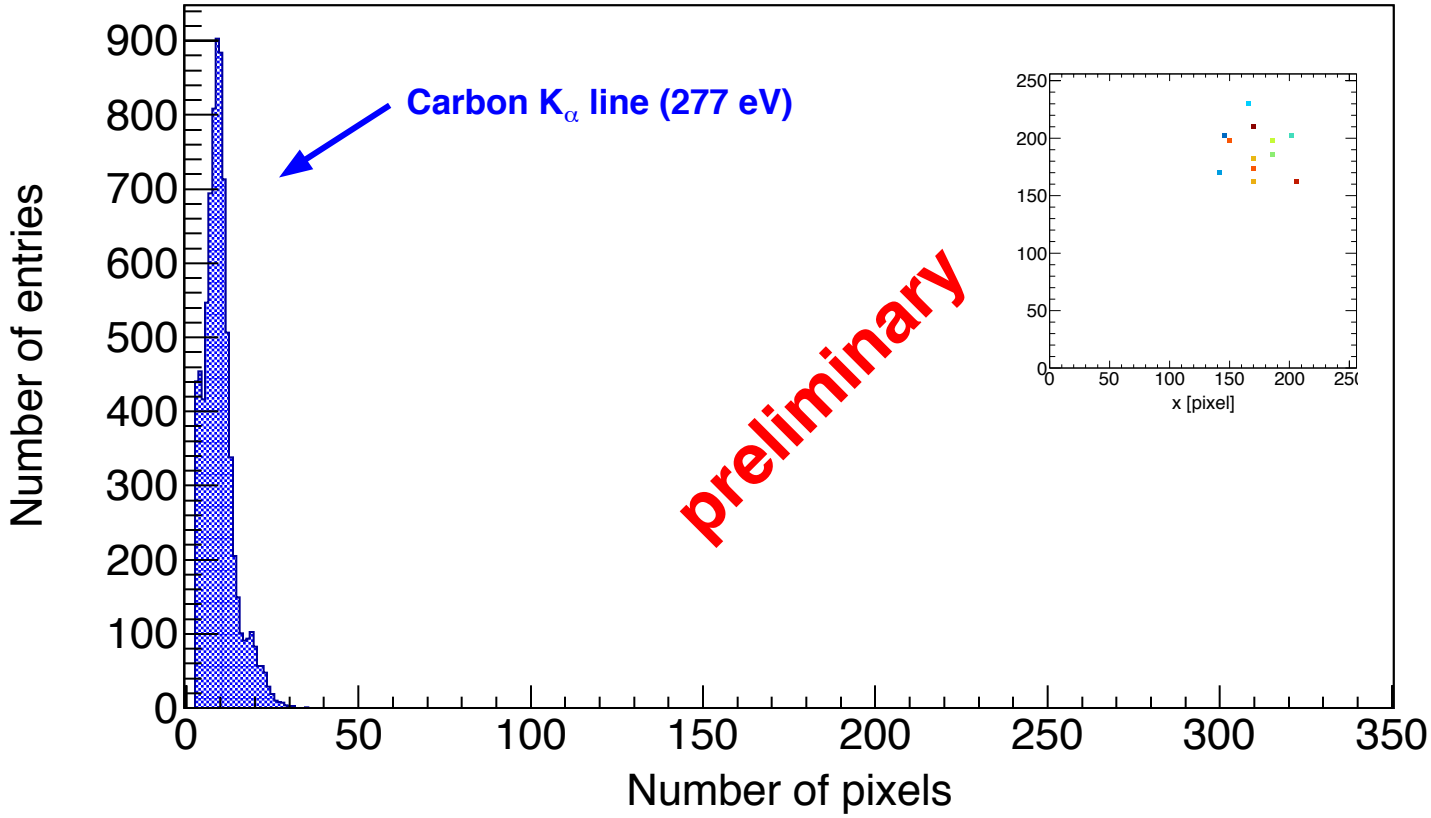
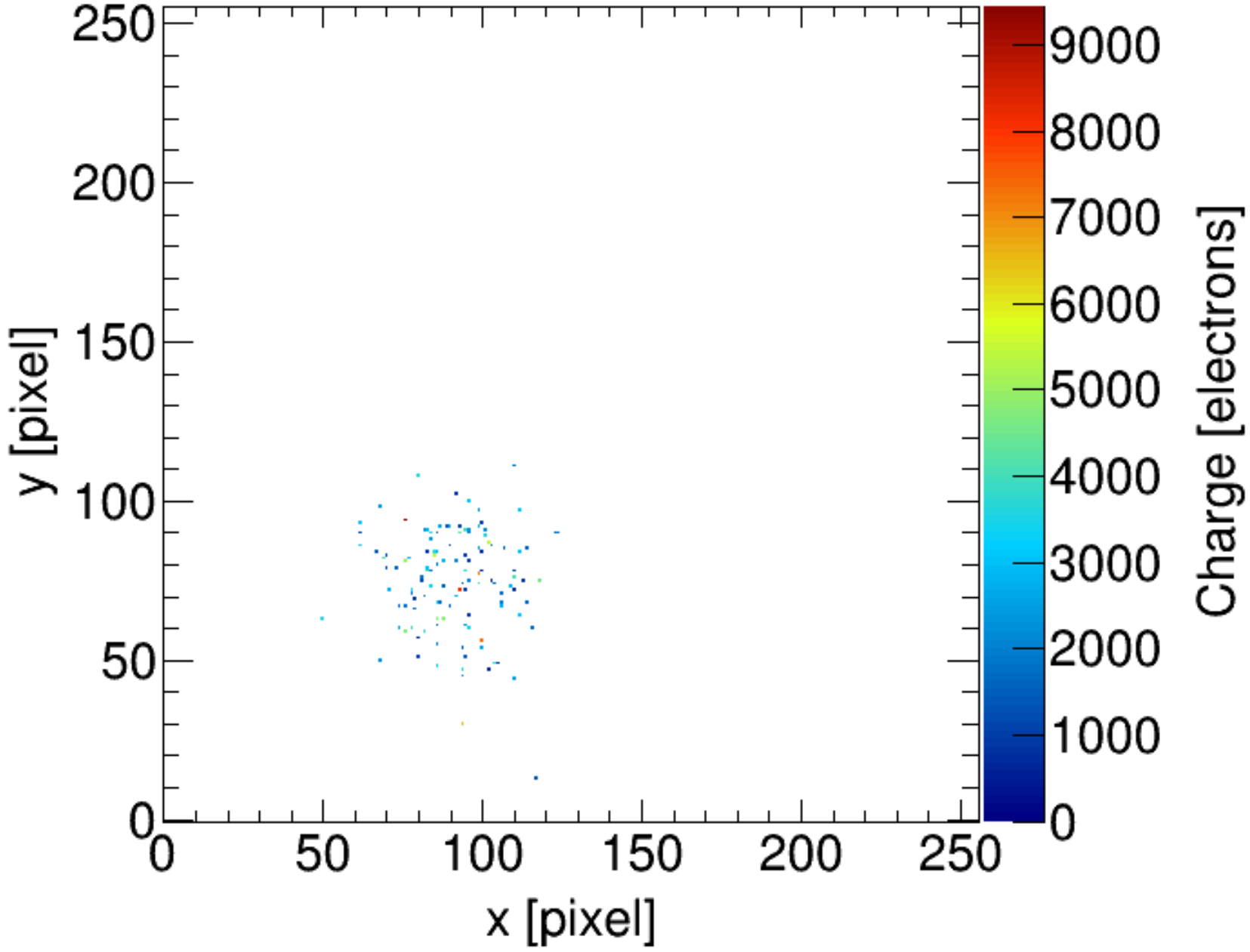


Ag (3 keV) photons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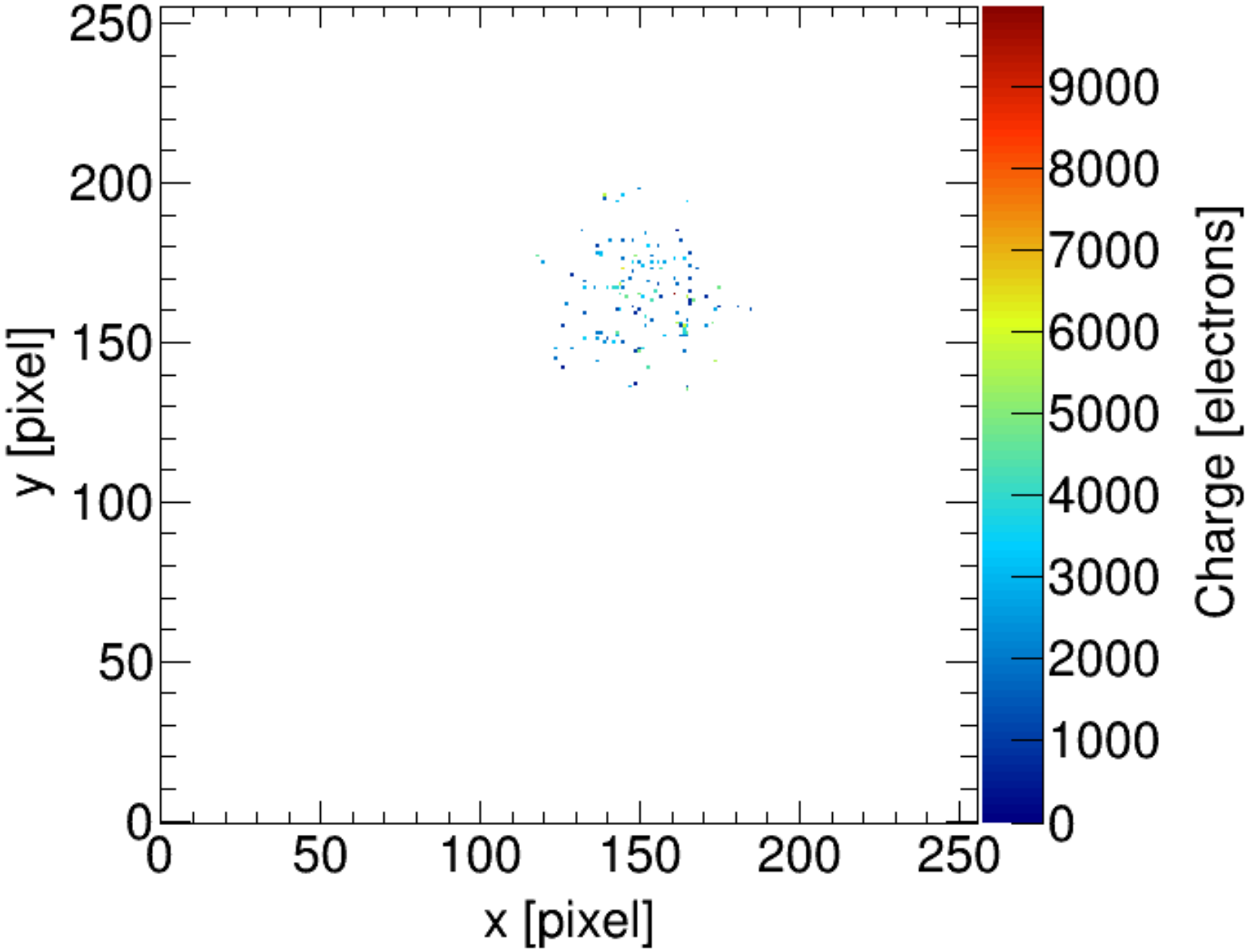
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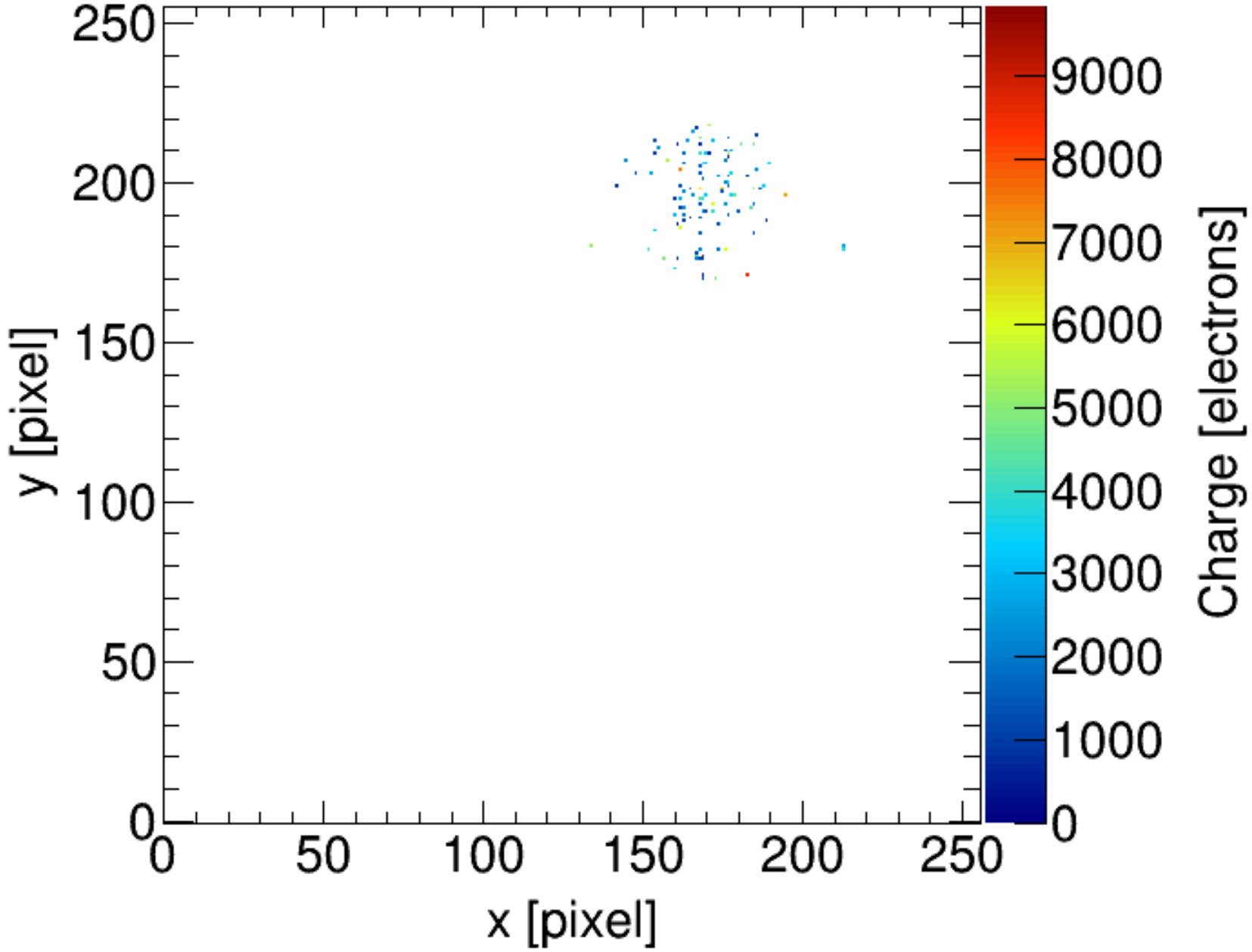
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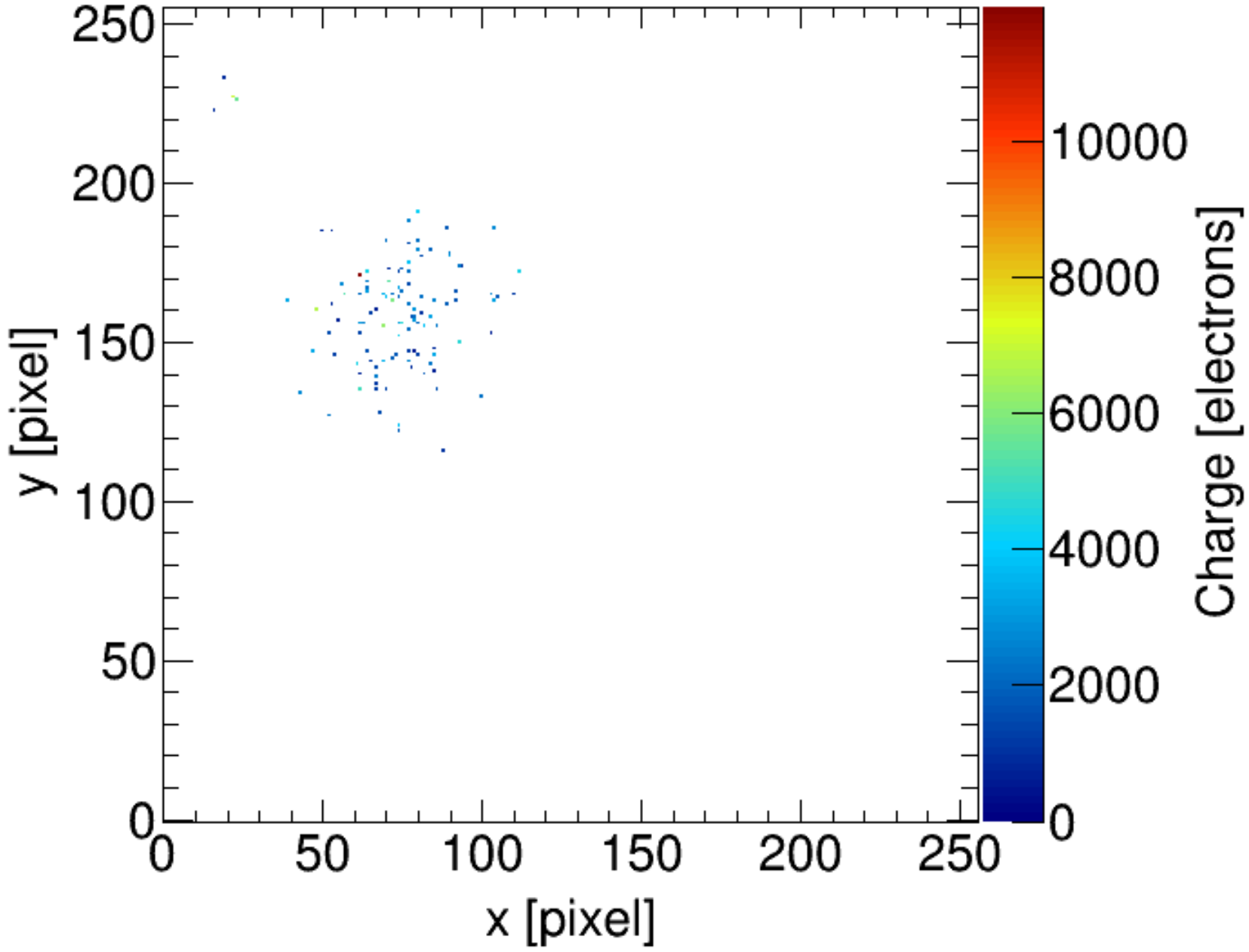
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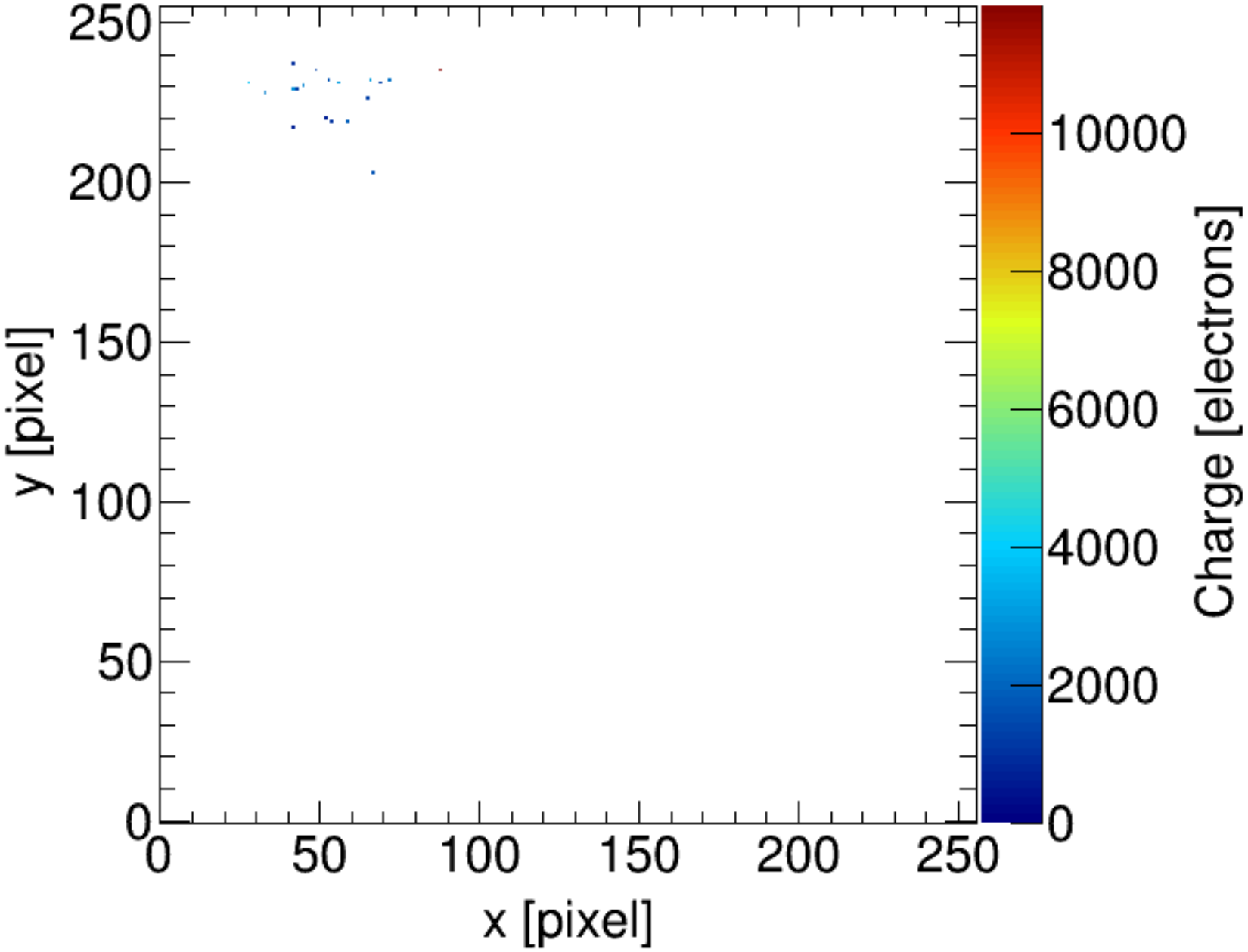
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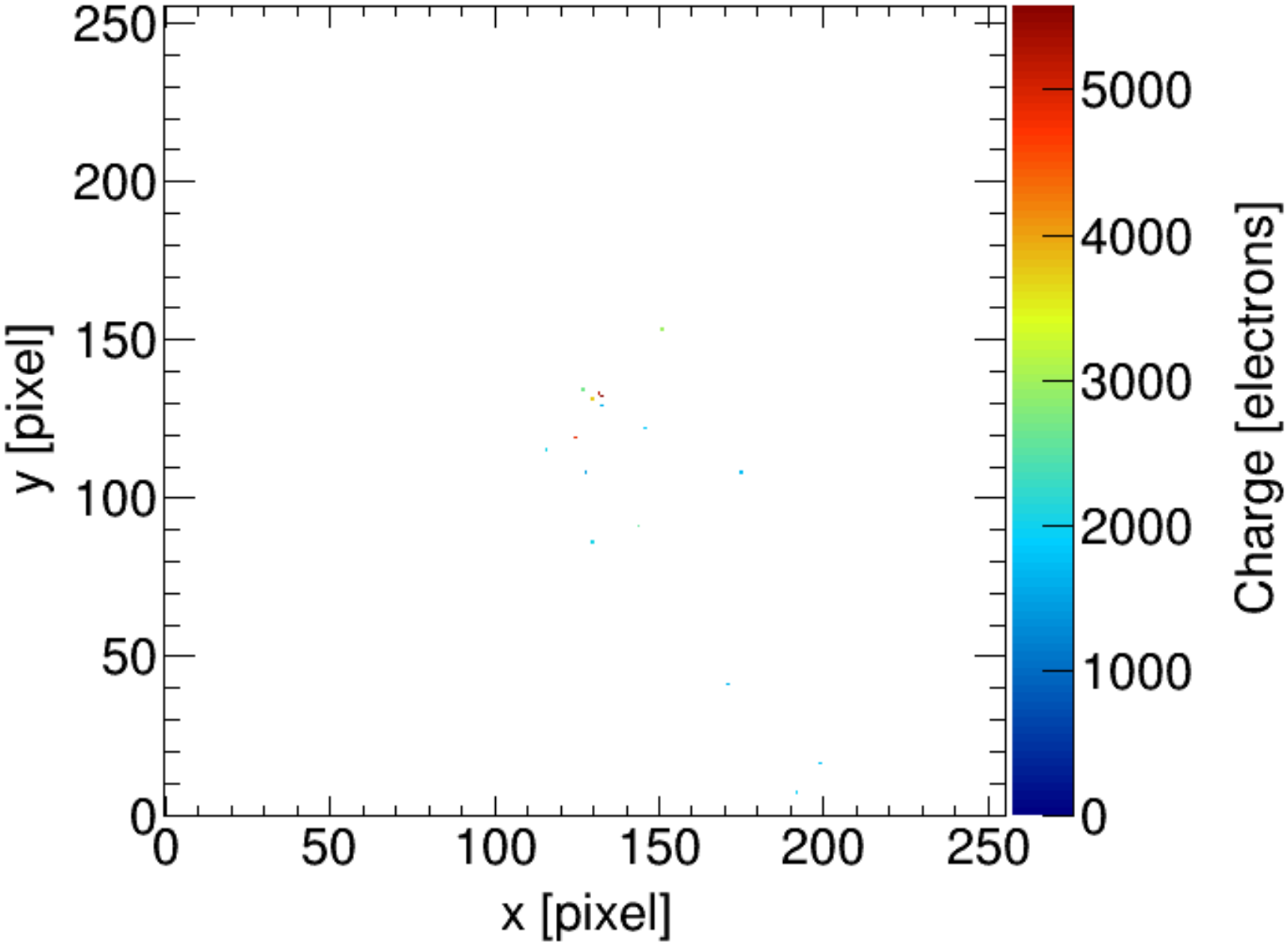
C (277 eV) photons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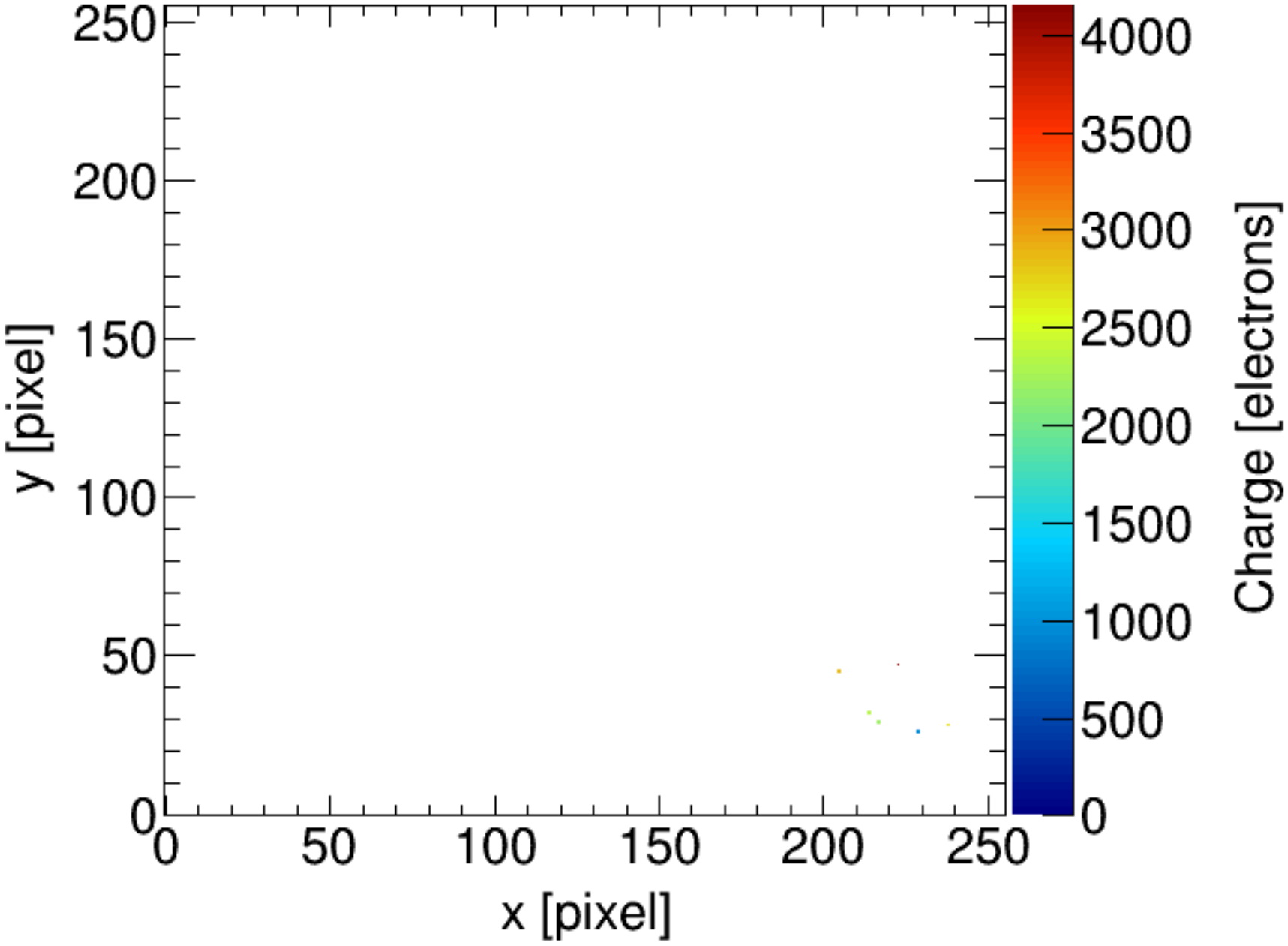
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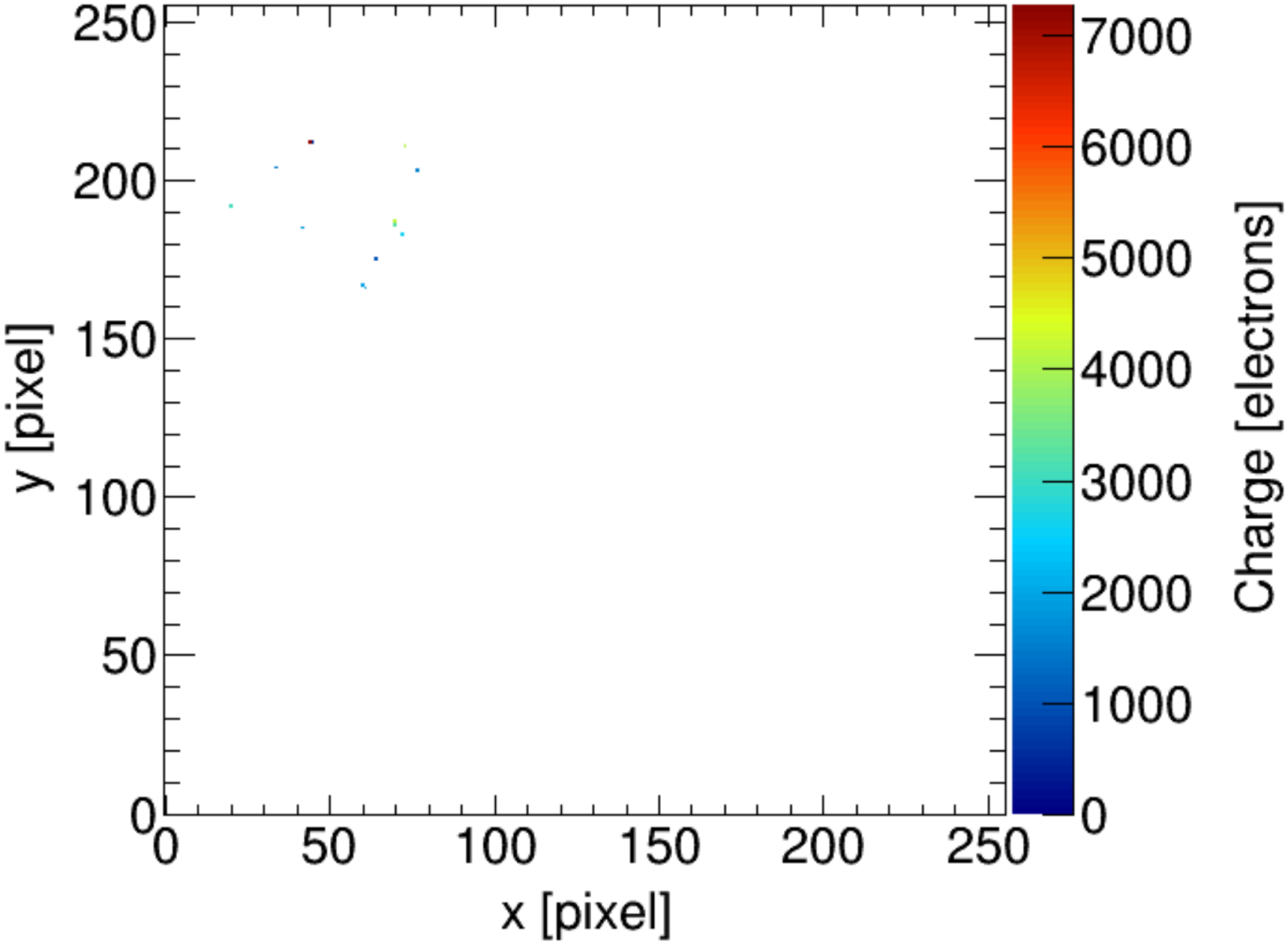
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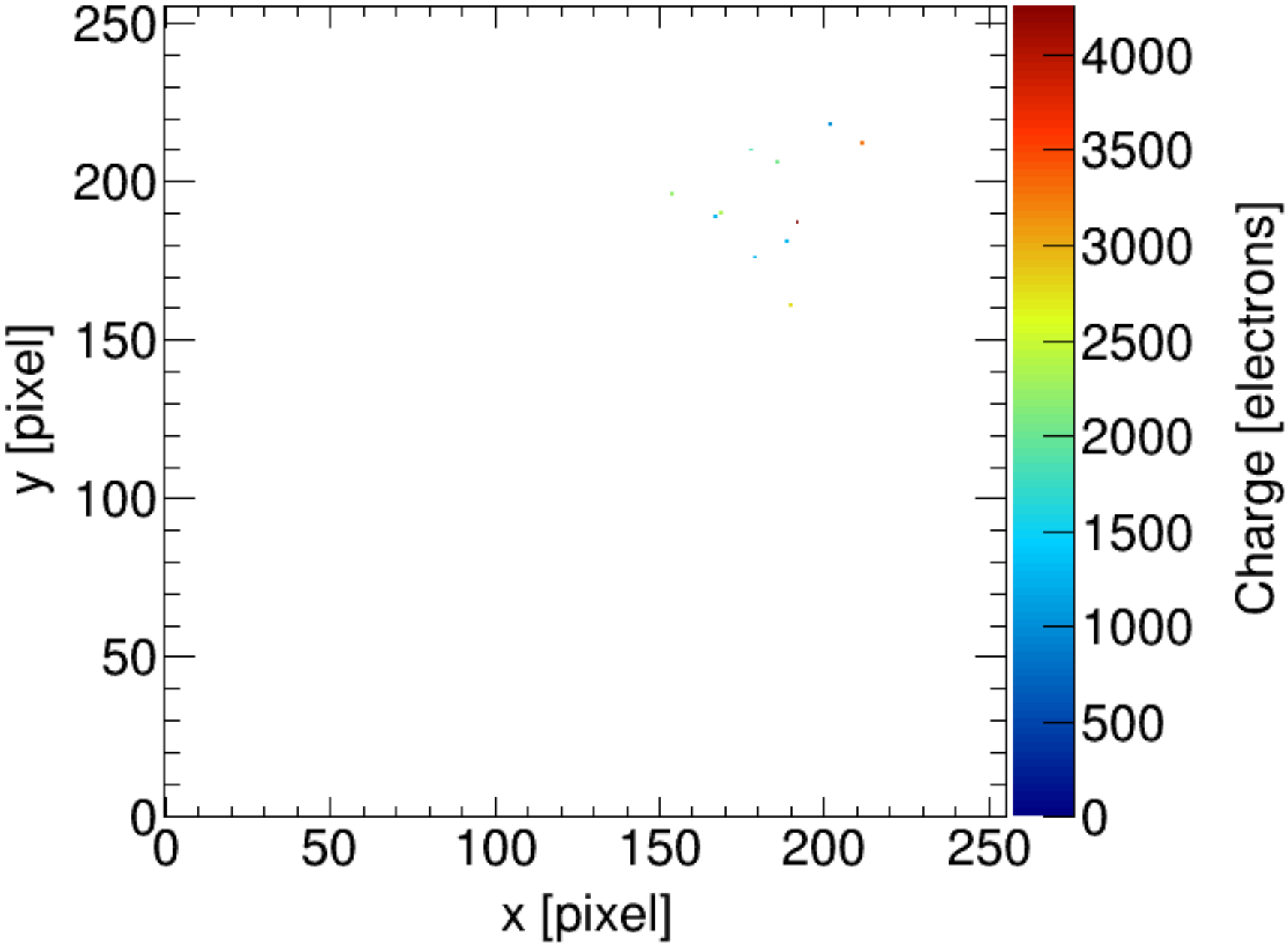
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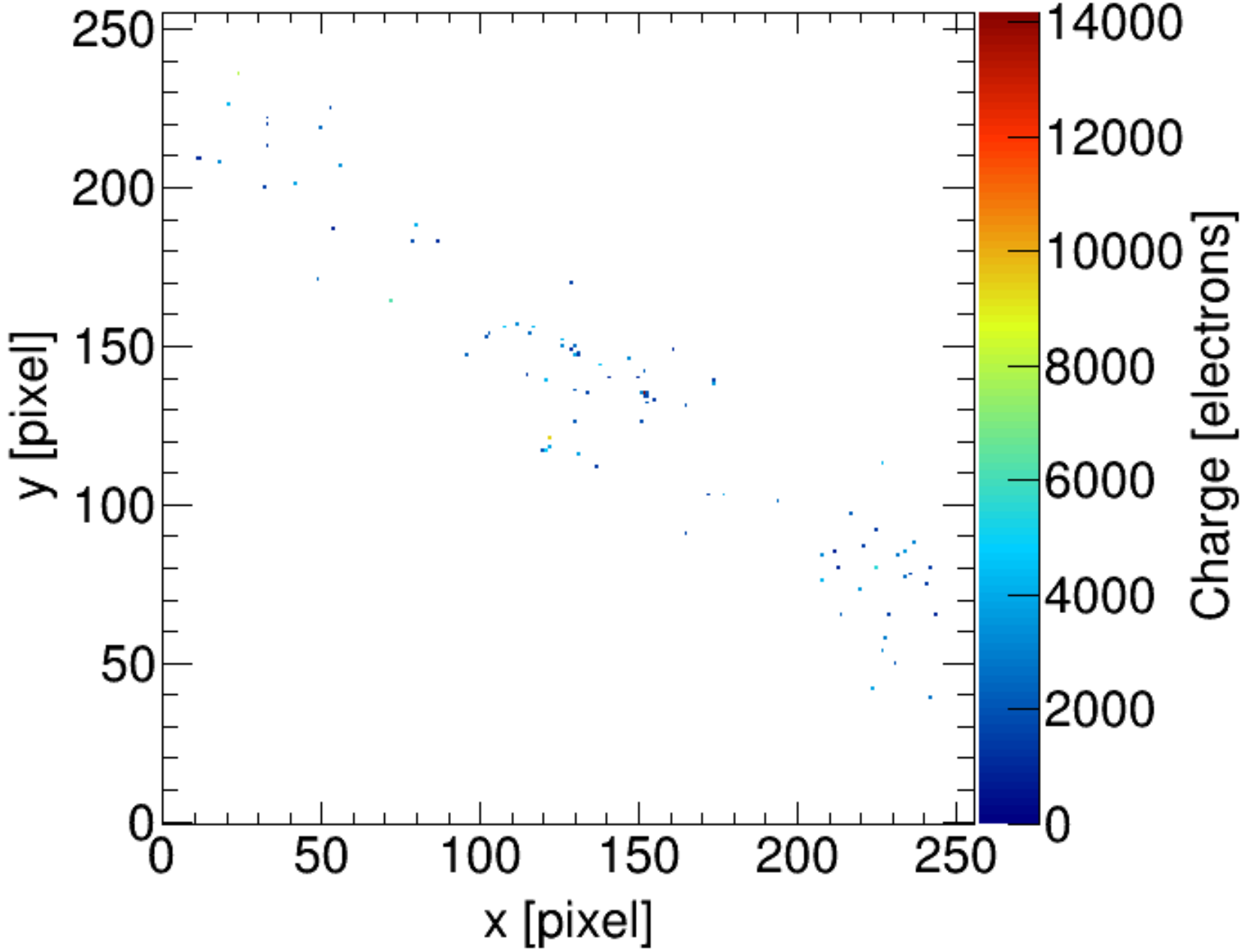
First data taking 2014

- Successful running in CAST in Oct/Nov 2014
- Detector operated without intermission for 27 days
- 2 379 029 frames of 0.98 s each have been recorded
- 27 sun trackings (data still blinded)

- analysis of data is ongoing
- preliminary background spectrum based on full data set (tuned for ~90% software efficiency)

- using simple 3-variable likelihood with real X-rays as reference

Background events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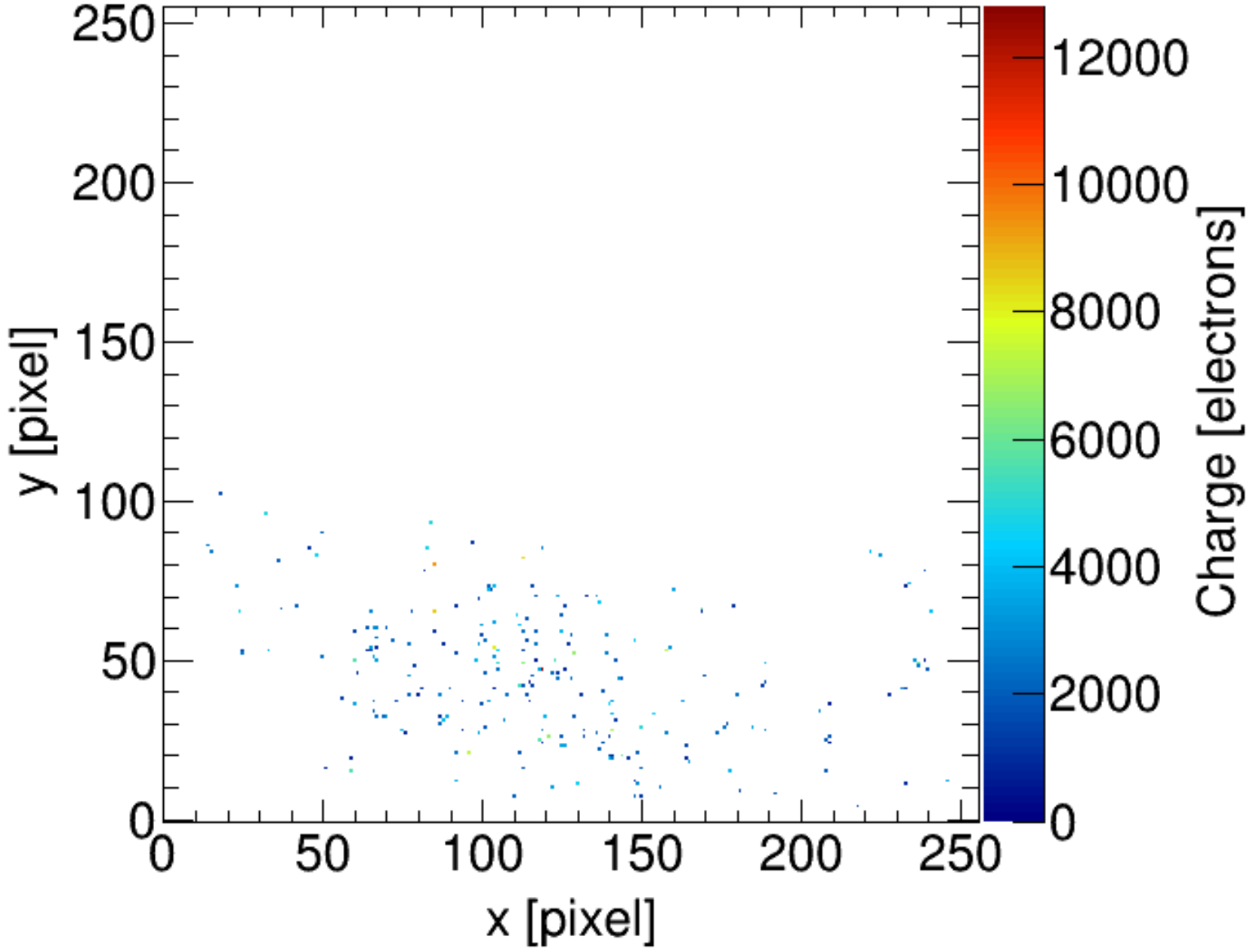
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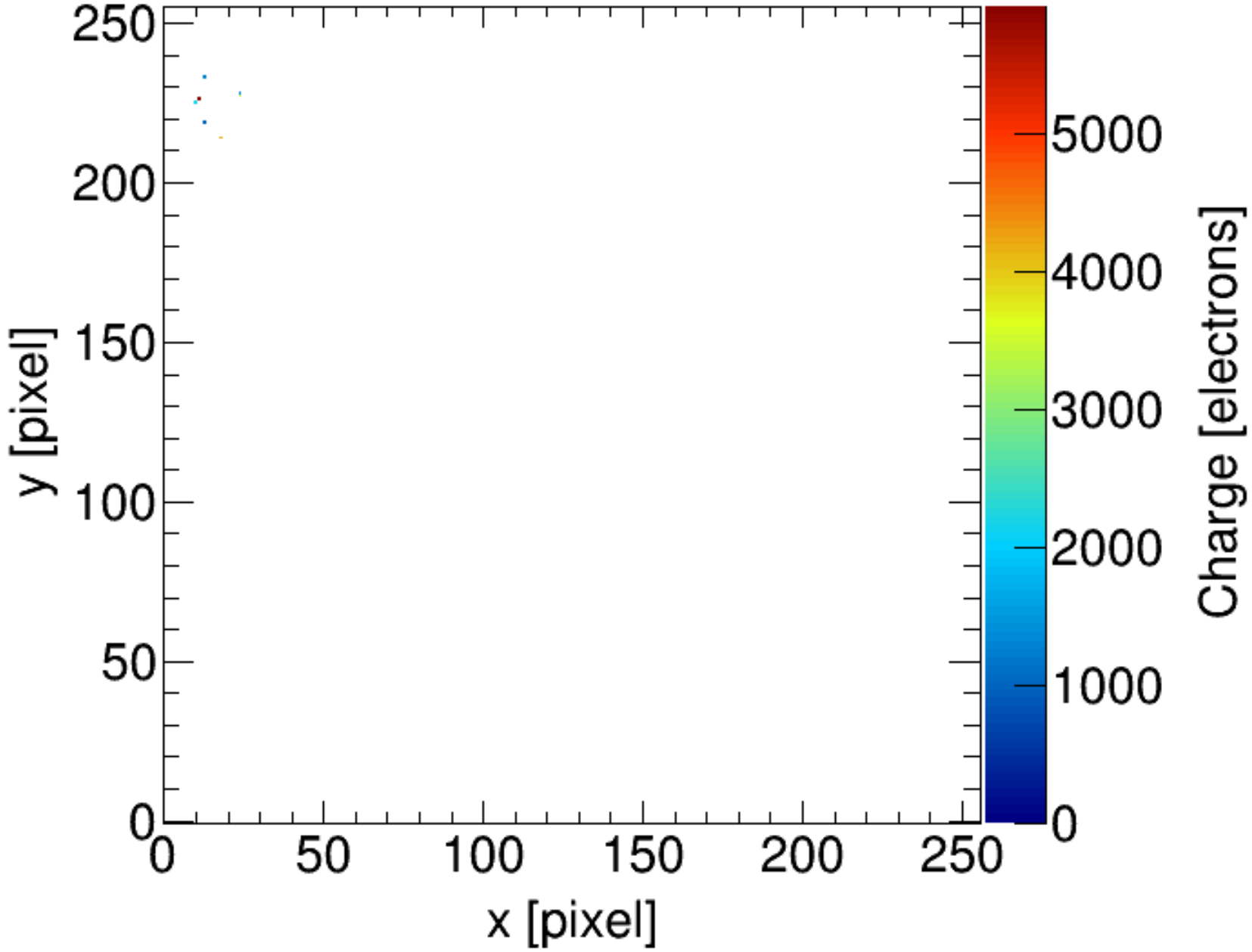
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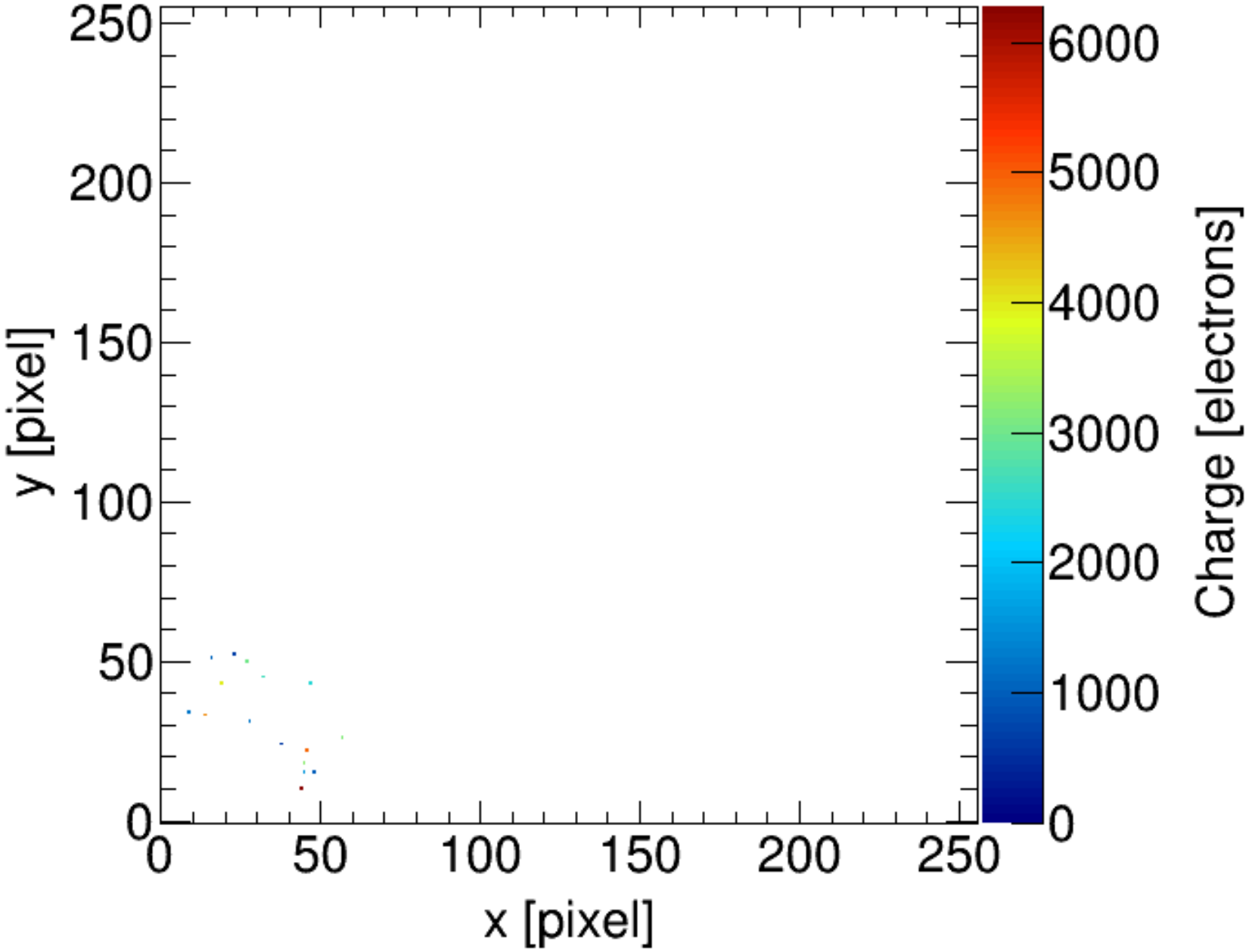
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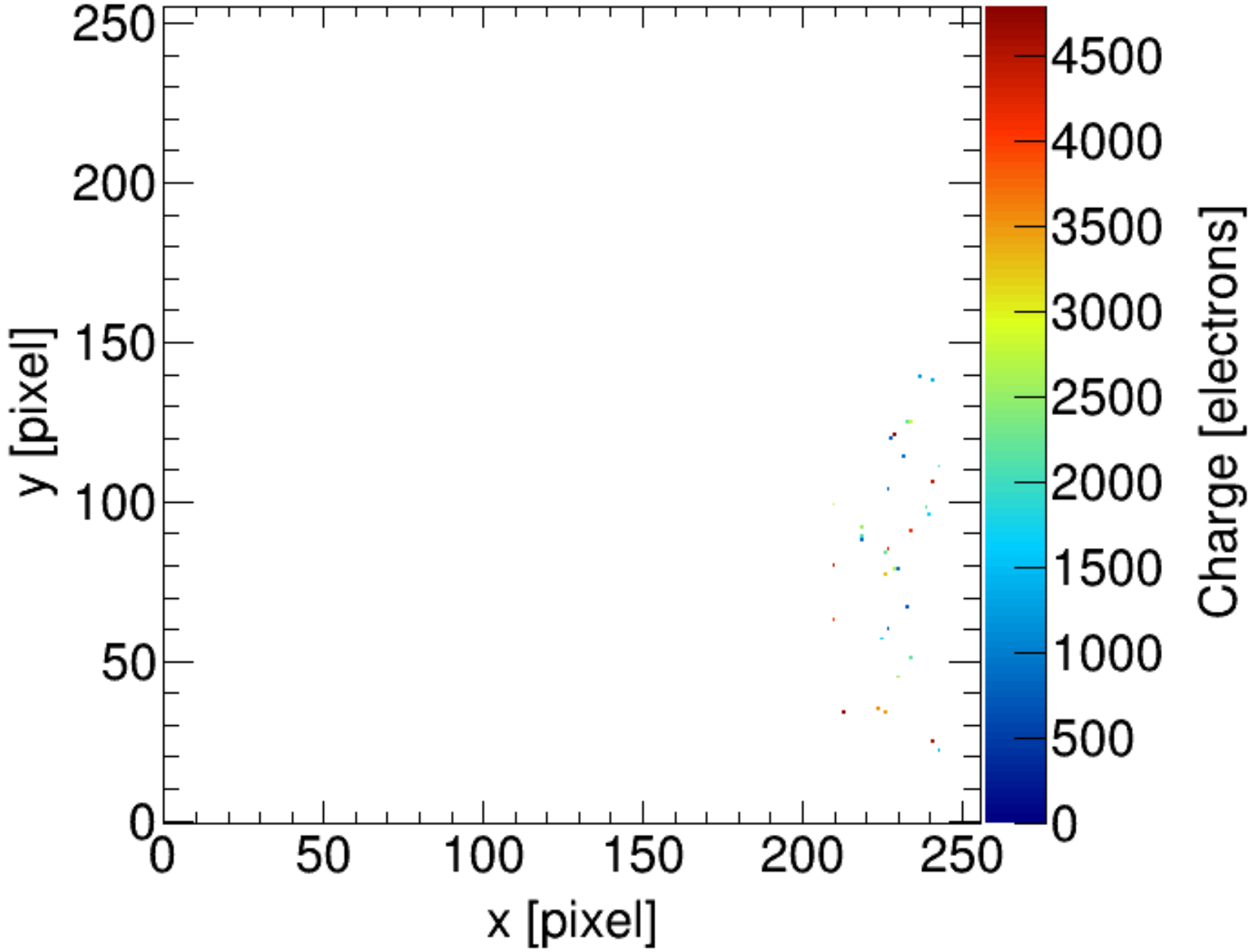
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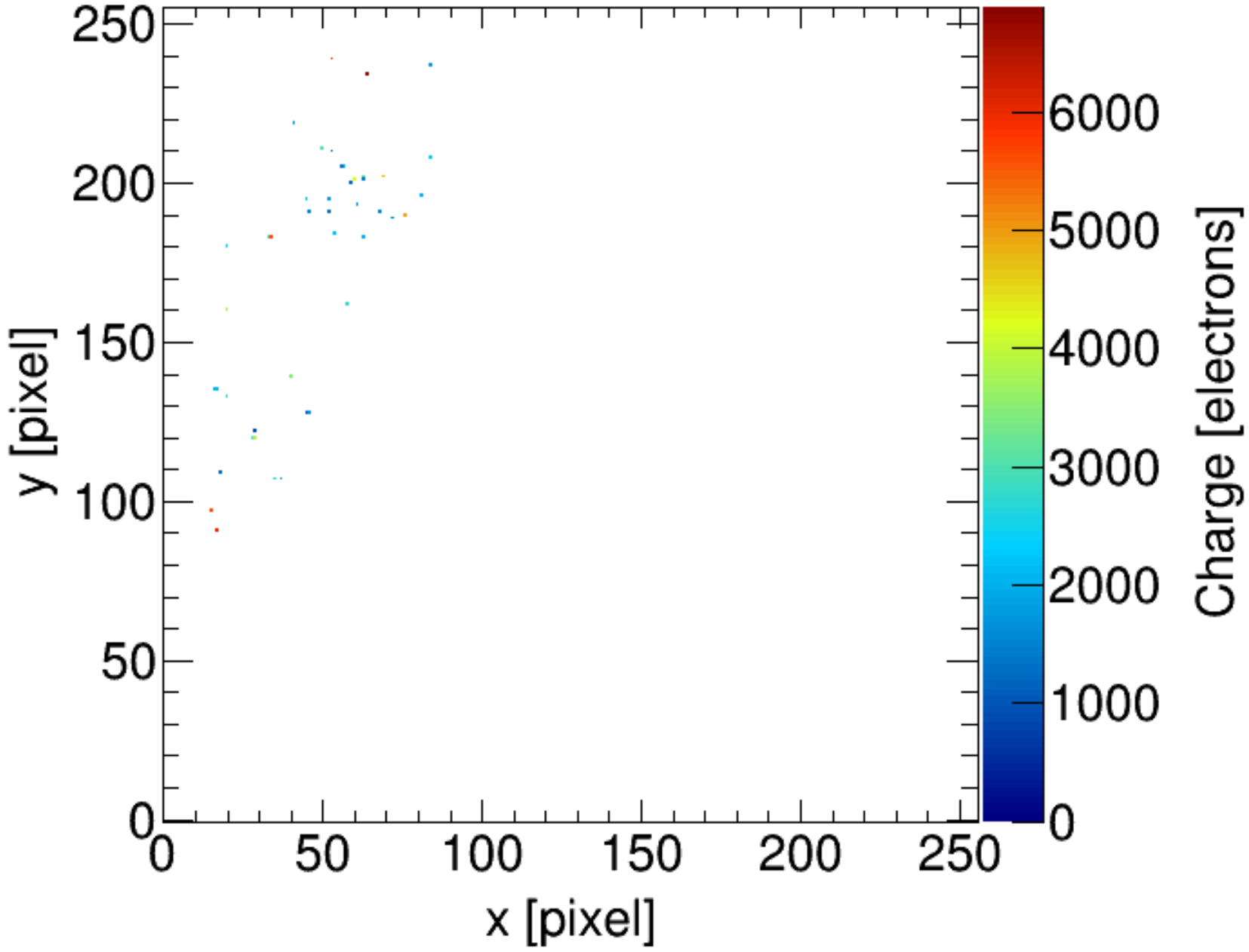
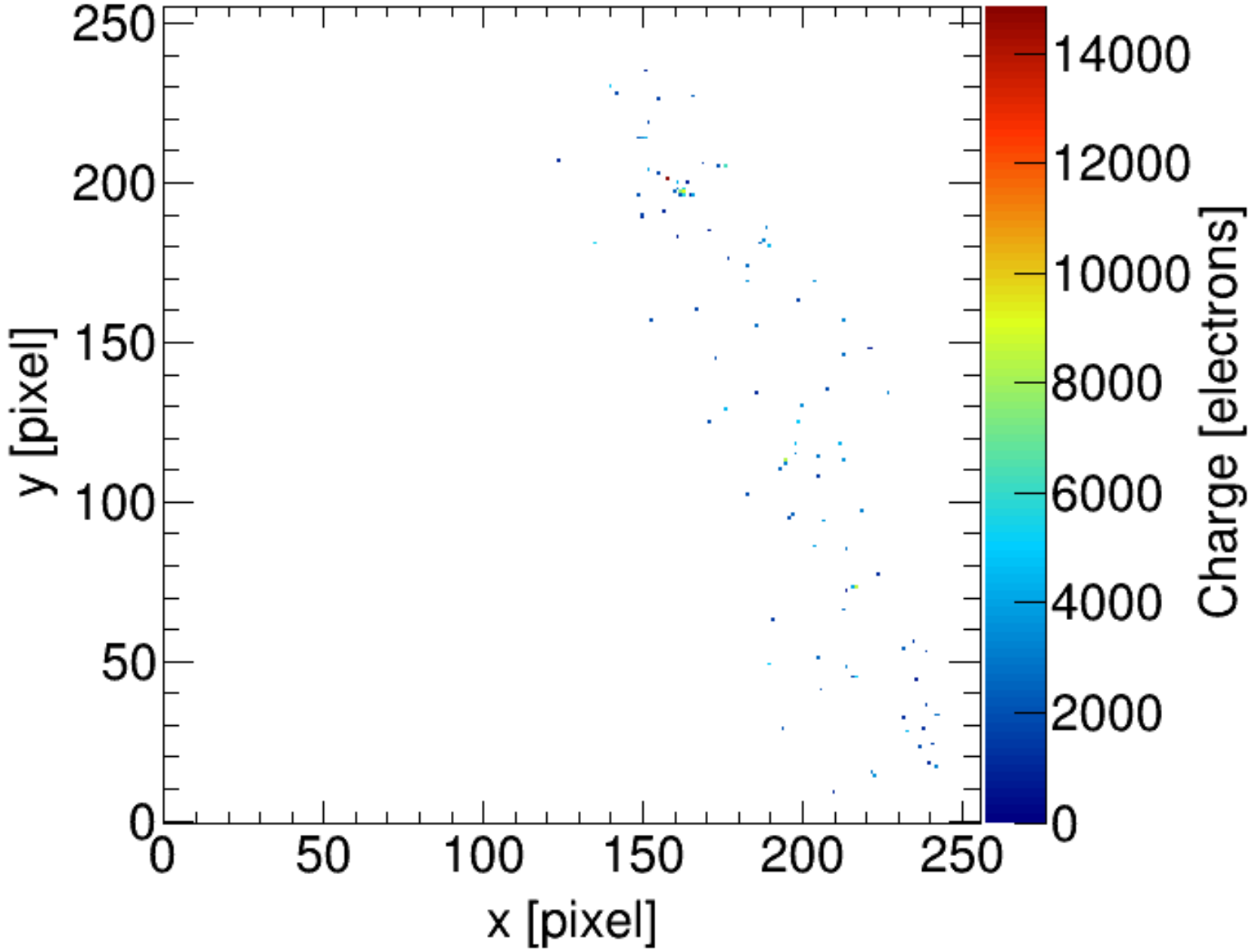
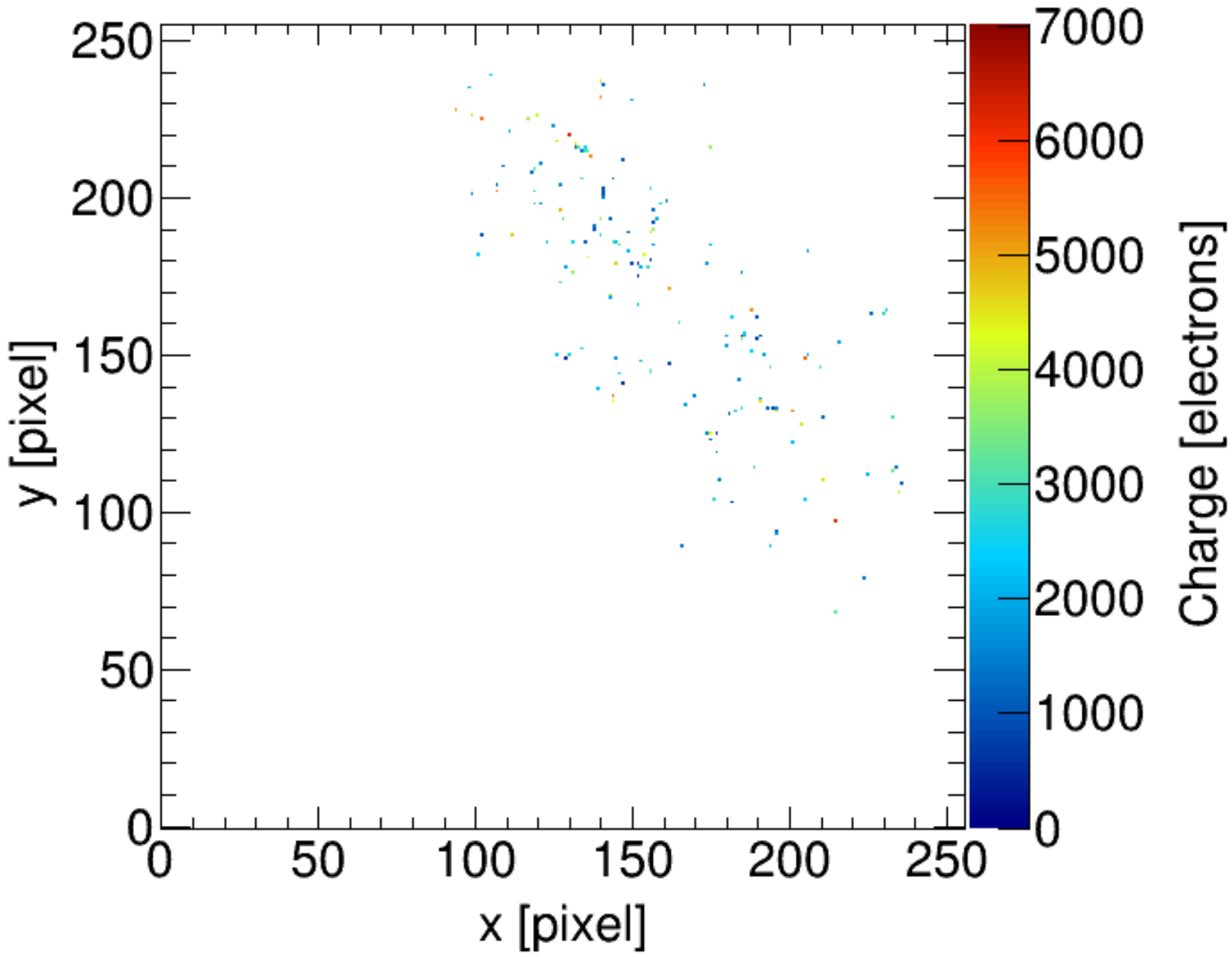
4000
4500


y [pixel]
x [pixel]
Charge [electrons]
0
50
100
150
200
250
0
1000
2000
3000
4000
5000
6000


250
200
150
100
50
0
y [pixel]
0
50
100
150
200
250
x [pixel]
14000
12000
10000
8000
6000
4000
2000
0
Charge [electrons]


y [pixel]
x [pixel]
Charge [electrons]
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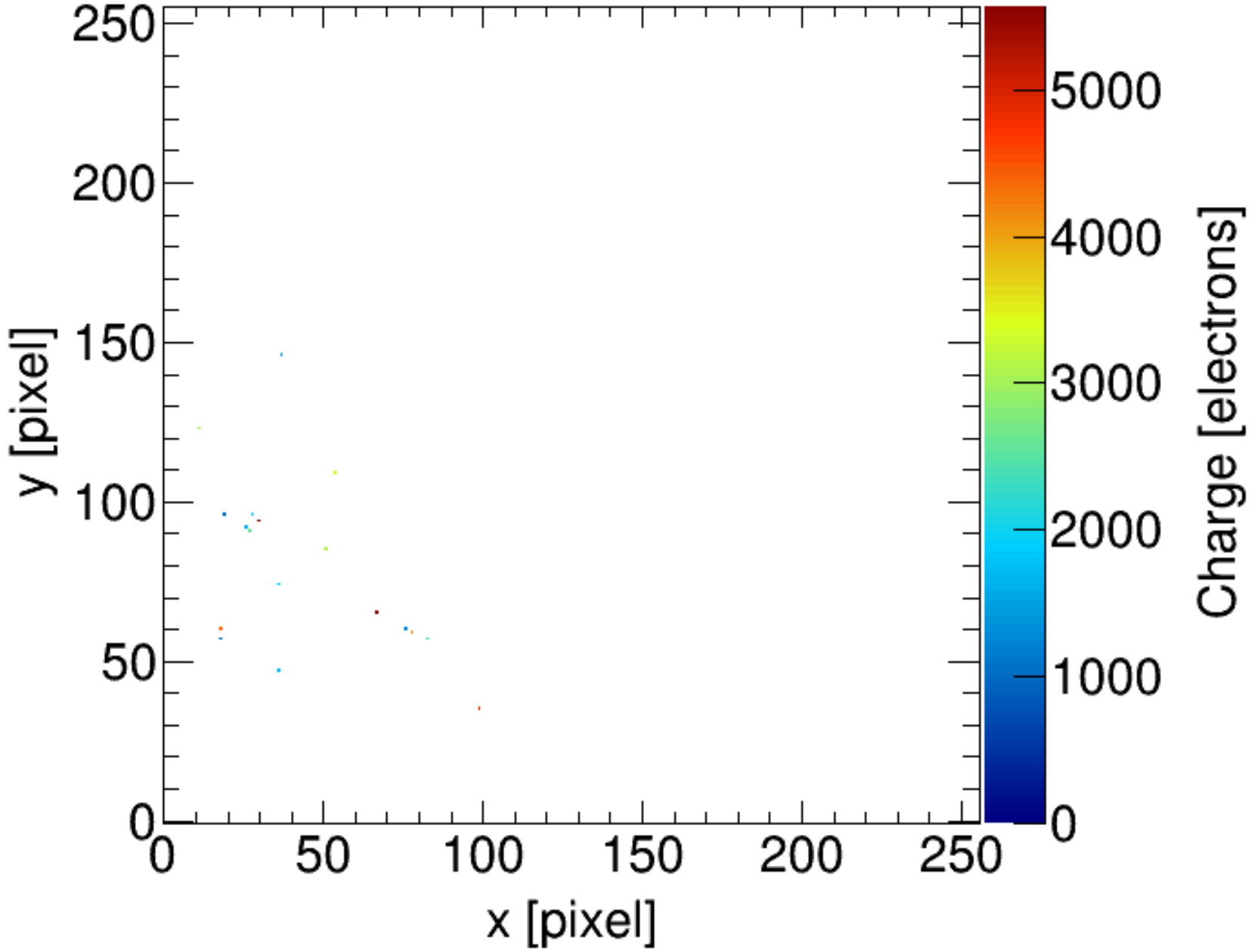
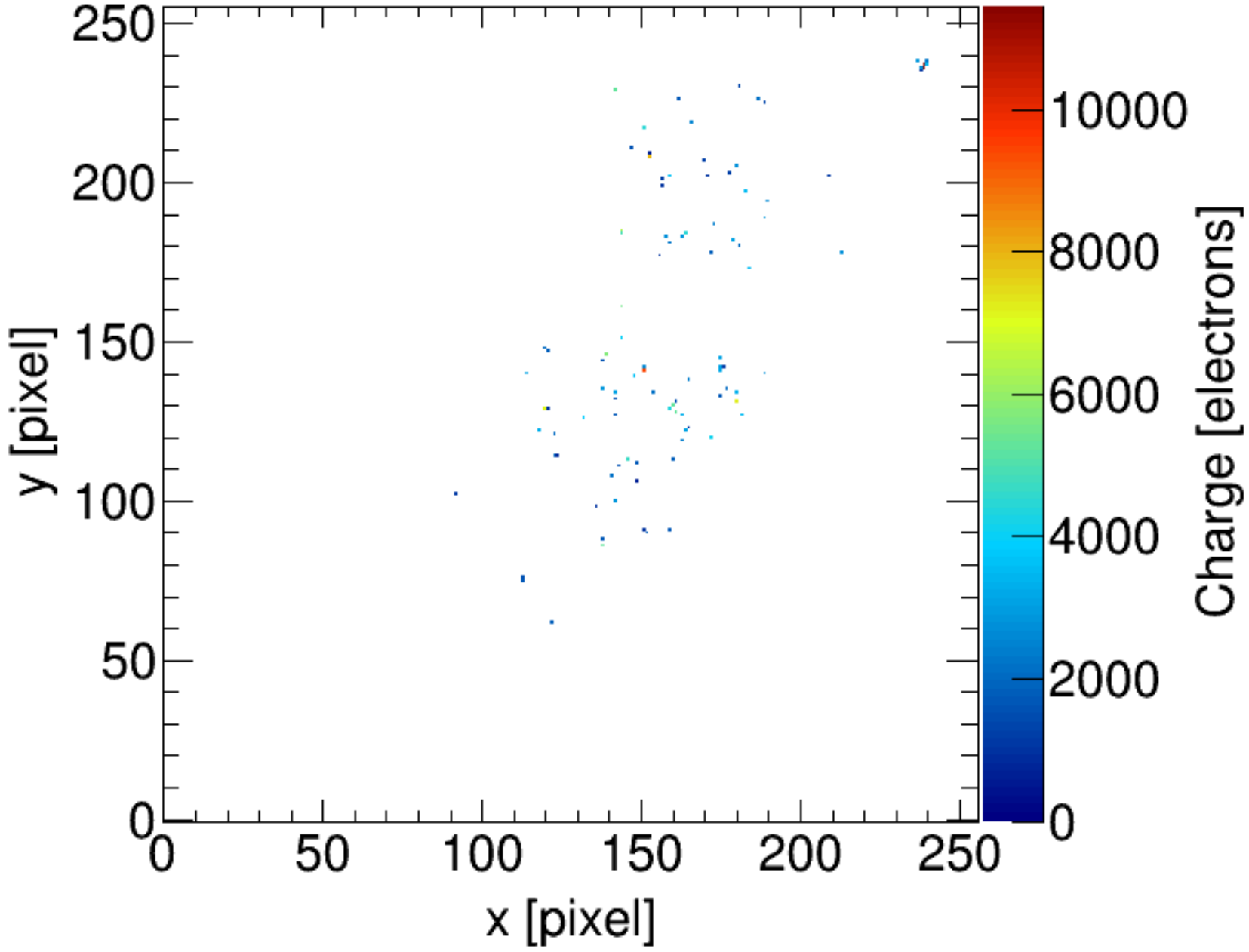
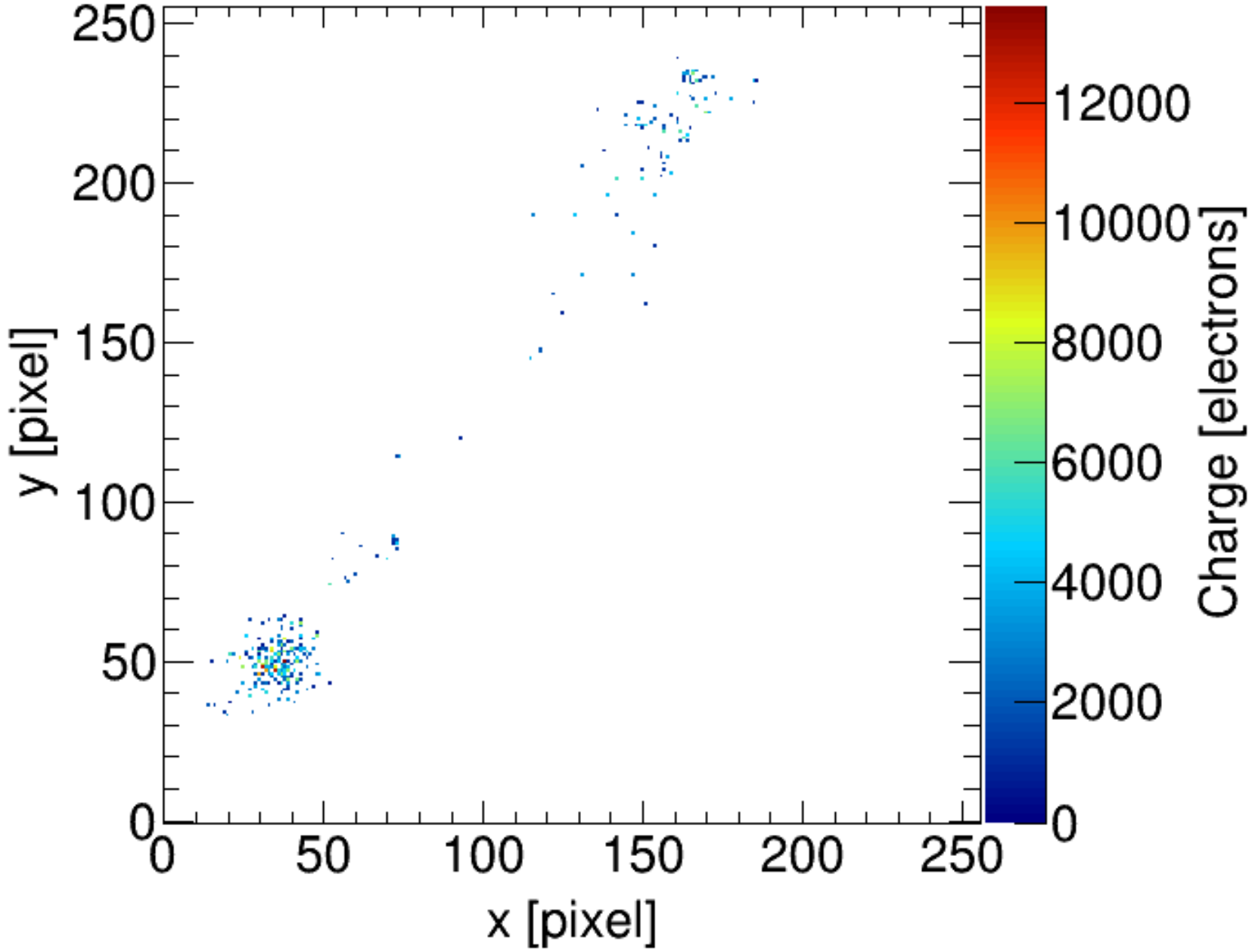
50
100
150
200
250
1000
2000
3000
4000
5000
6000
7000

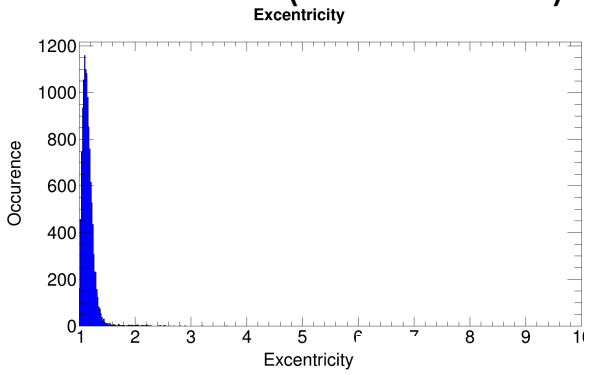

y [pixel]
x [pixel]
Charge [electrons]
0
50
100
150
200
250
0
1000
2000
3000
4000
5000

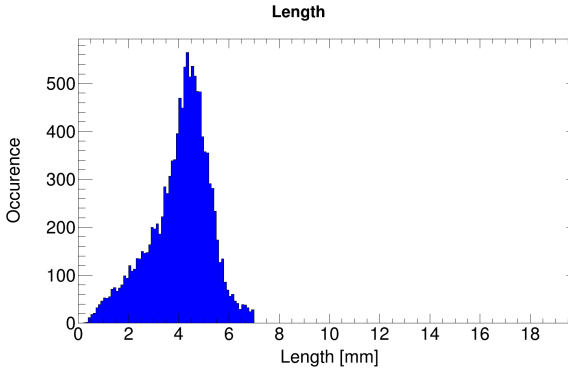

250
200
150
100
50
0
y [pixel]
0
50
100
150
200
250
x [pixel]
10000
8000
6000
4000
2000
0
Charge [electrons]

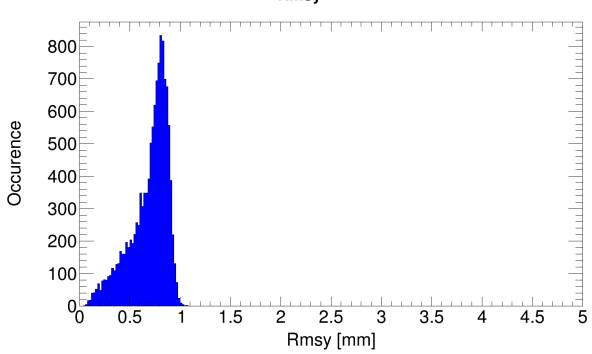

y [pixel]
x [pixel]
Charge [electrons]
0
50
100
150
200
250
2000
4000
6000
8000
10000
12000

Topological variables

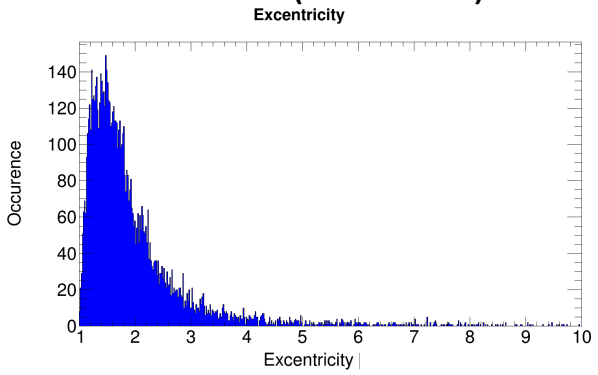
reference (2.1 – 3.2 keV)

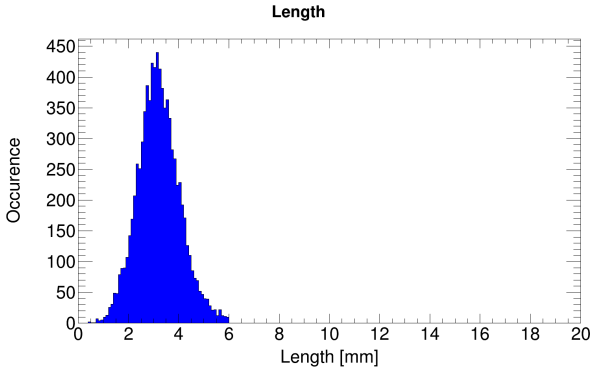


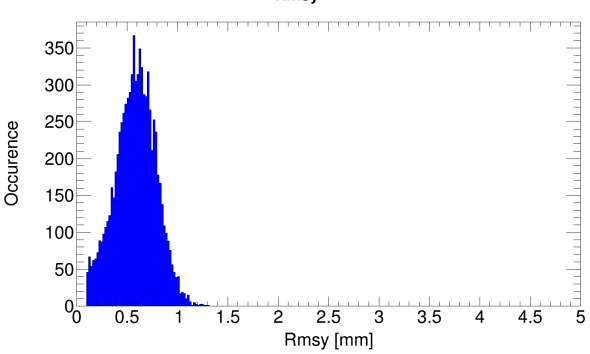




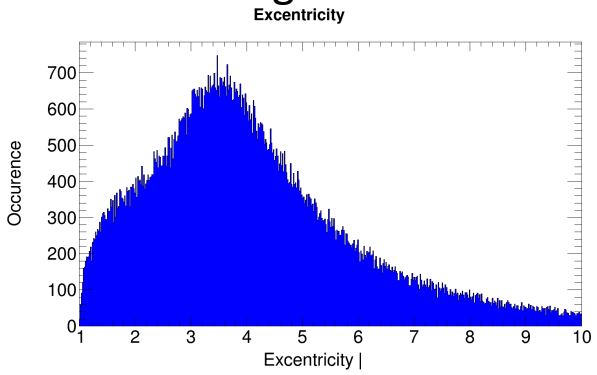
reference (<0.4 keV)

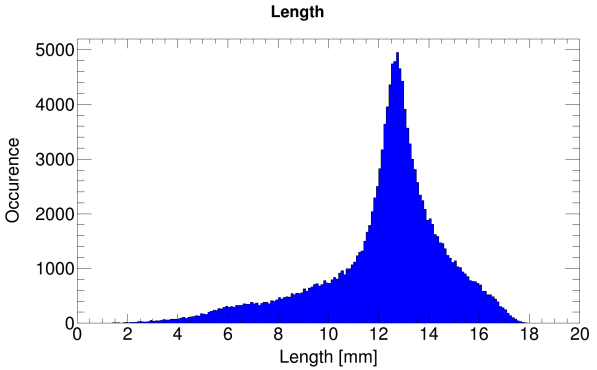


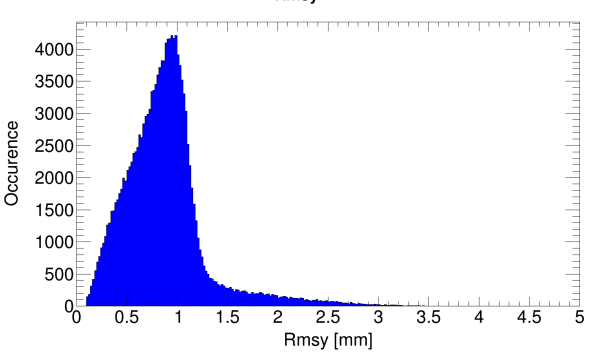




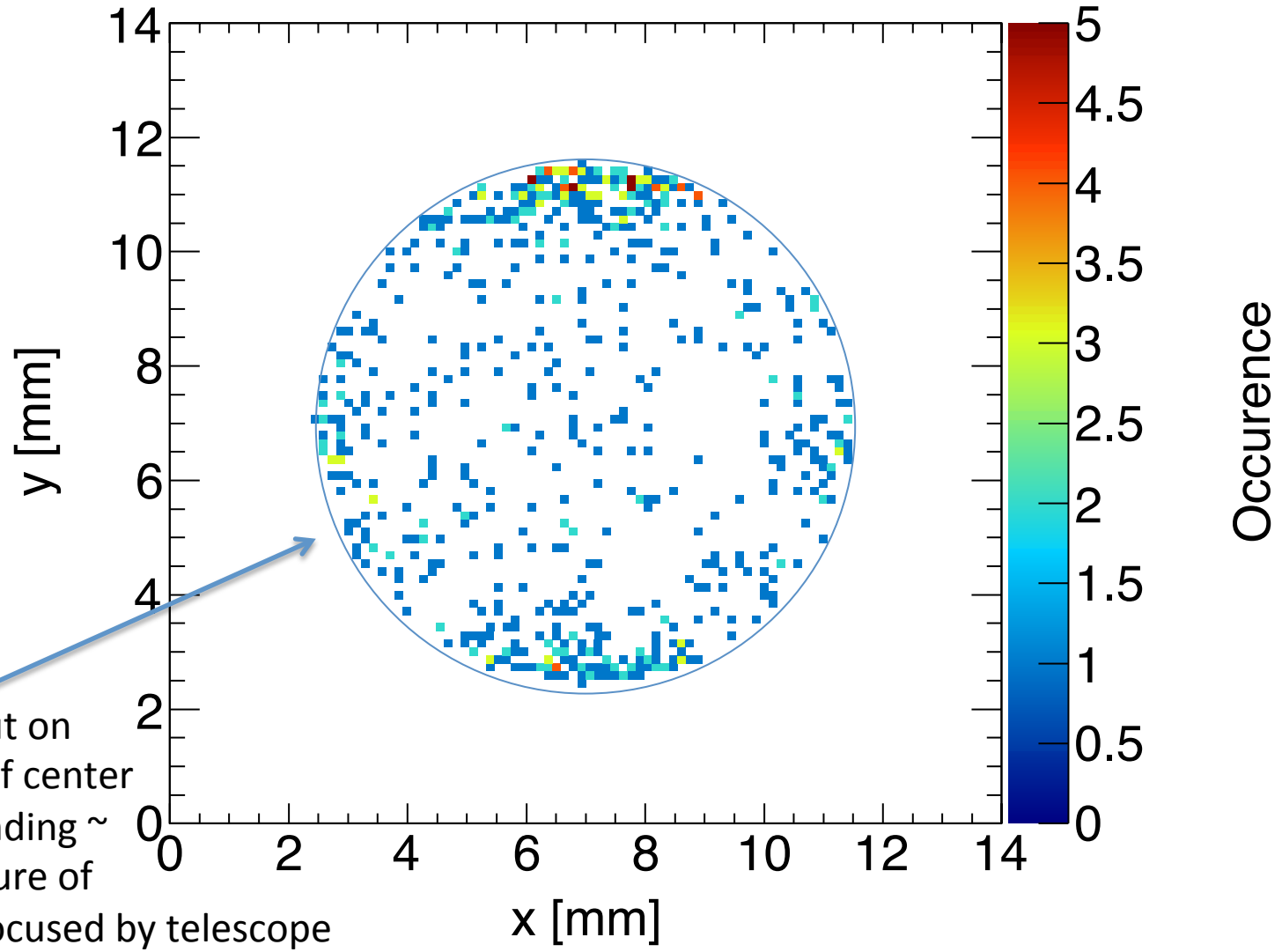
background





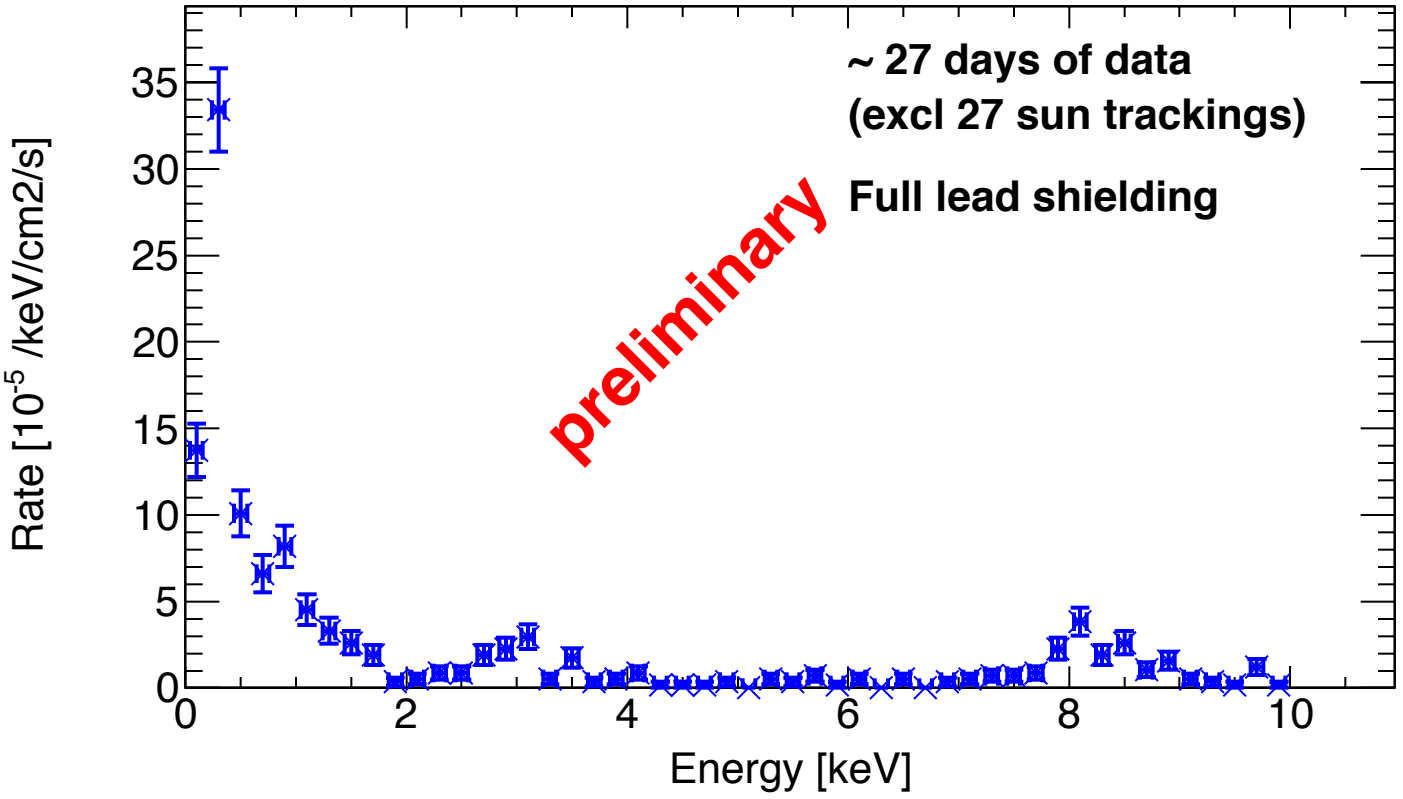


Location of BG events

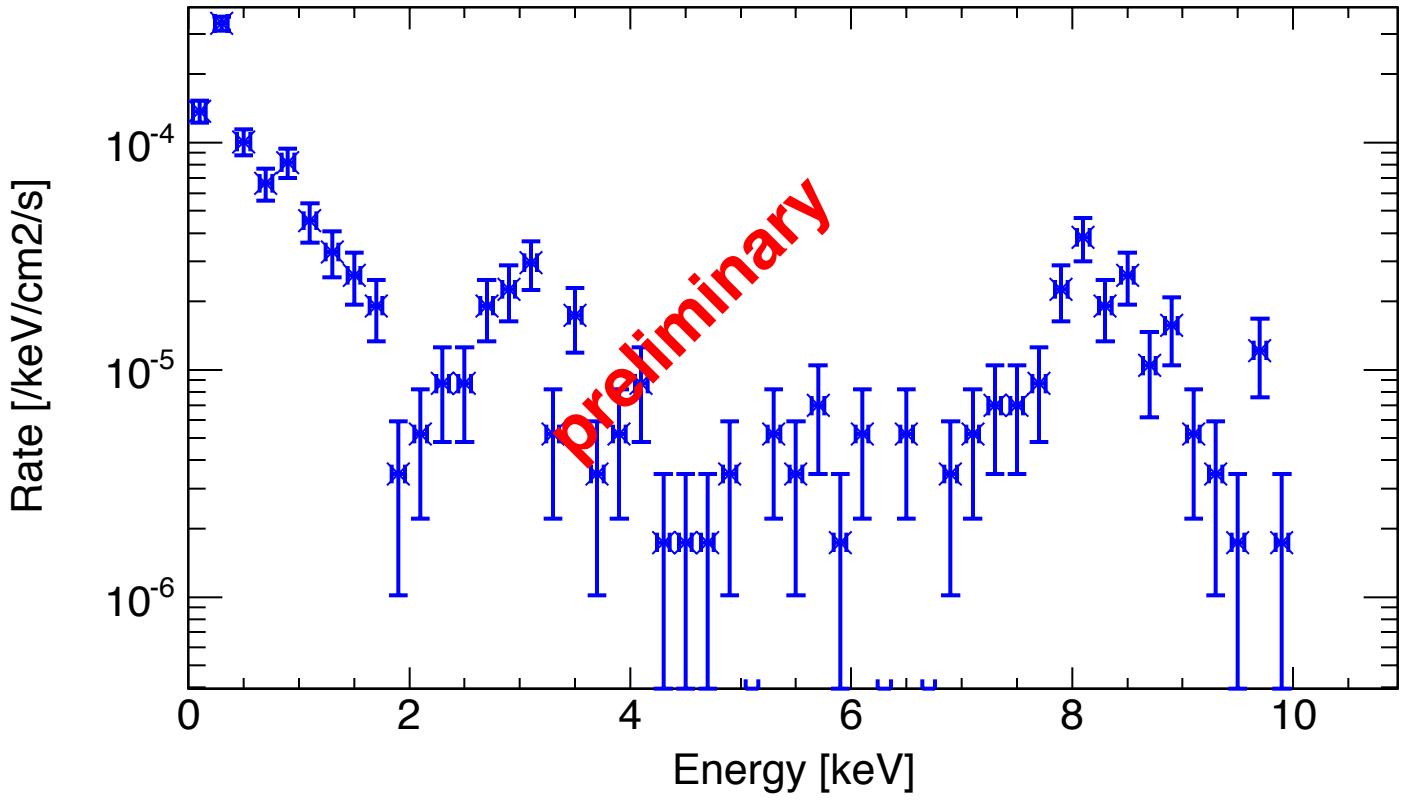


fiducial cut on position of center corresponding ~ to apperture of magnet focused by telescope

Background spectrum: 27 days

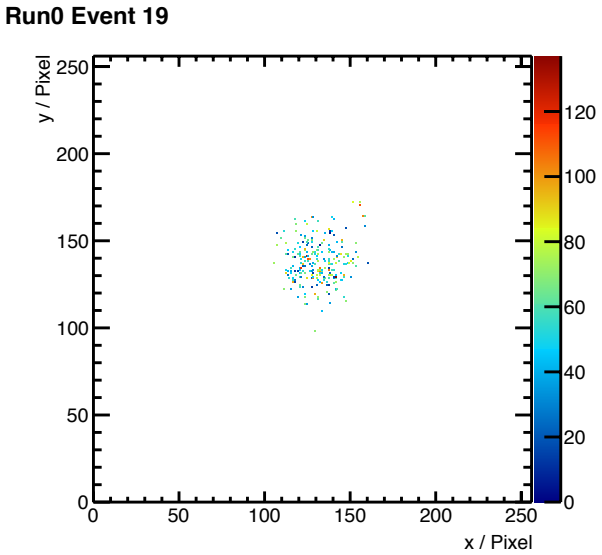


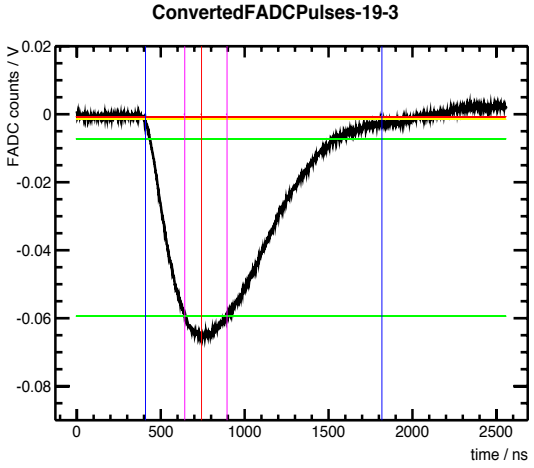
Background spectrum: 27 days



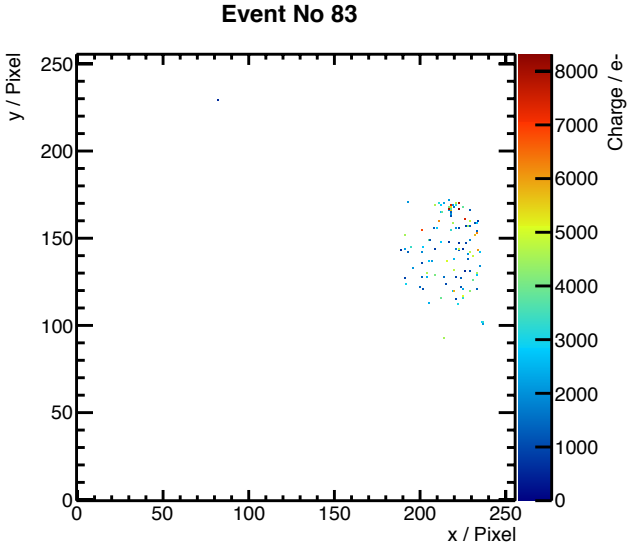
Outlook: Grid signal readout

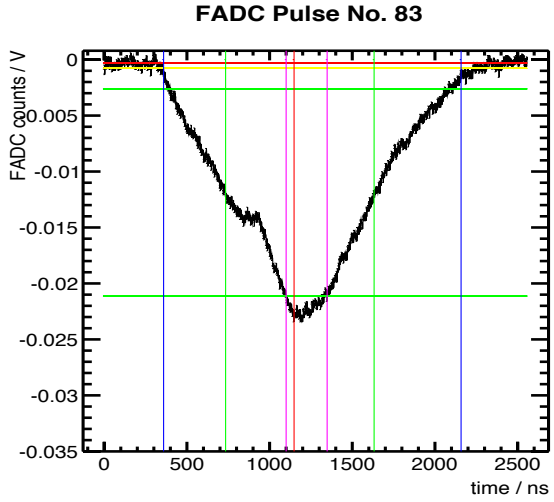
5.9 keV photon:





Perpendicular cosmic track:





Timepix signal

Induced pulse on the grid

Outlook: TimePix-3

Timepix-3 chip available
not equipped with InGrid

- fully data-driven readout
- 640 MHz timing clock
- simultaneous readout of charge (TOT) and time per pixel (TIME)

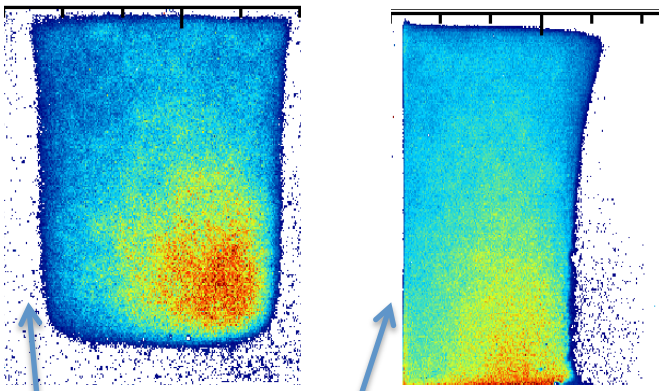
→full 3D reconstruction of charge cloud possible

→improved background rejection for ⊥ cosmics

Outlook: Larger Areas

8-chip InGrid boards existing (Octopuce/Saclay, Octoboard/Bonn)
Challenge (for X-ray detector):

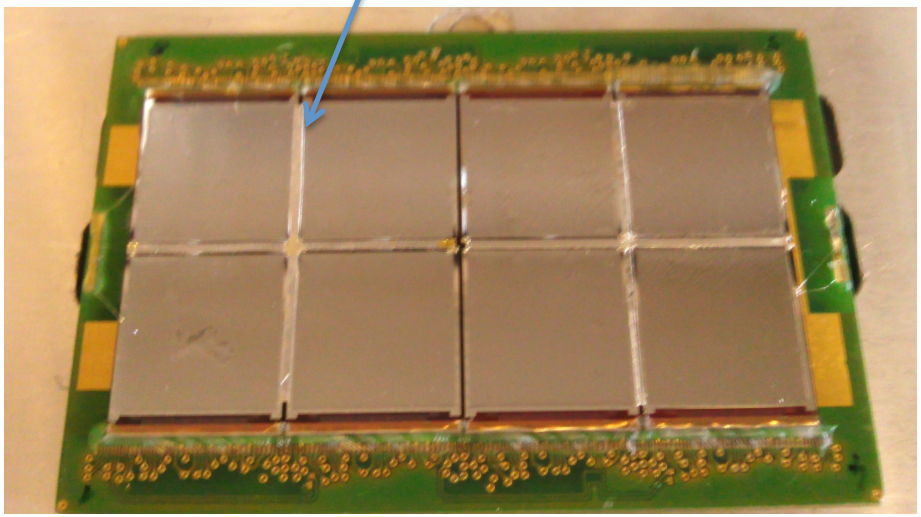
- dead areas between chips
- field distortions



no Al strip with Al strip

(only left edge can be compared)

manually mounted Al strips



promising but better procedure needed...

Summary & Conclusion

- InGrid as low-energy X-Ray detector employed in CAST experiment

- first data taking successful
- sensitivity down to ~200 eV
- perfect stability over many weeks

- data analysis ongoing, sun trackings still blinded
- background rates look promising (optimization still possible)

- several ideas for further improvement towards
  - CAST run in 2015 (short term)
  - IAXO (longer term)

The group in Bonn

Christoph Krieger

Jochen Kaminski

Yevgen Bilevych

Michael Lupberger

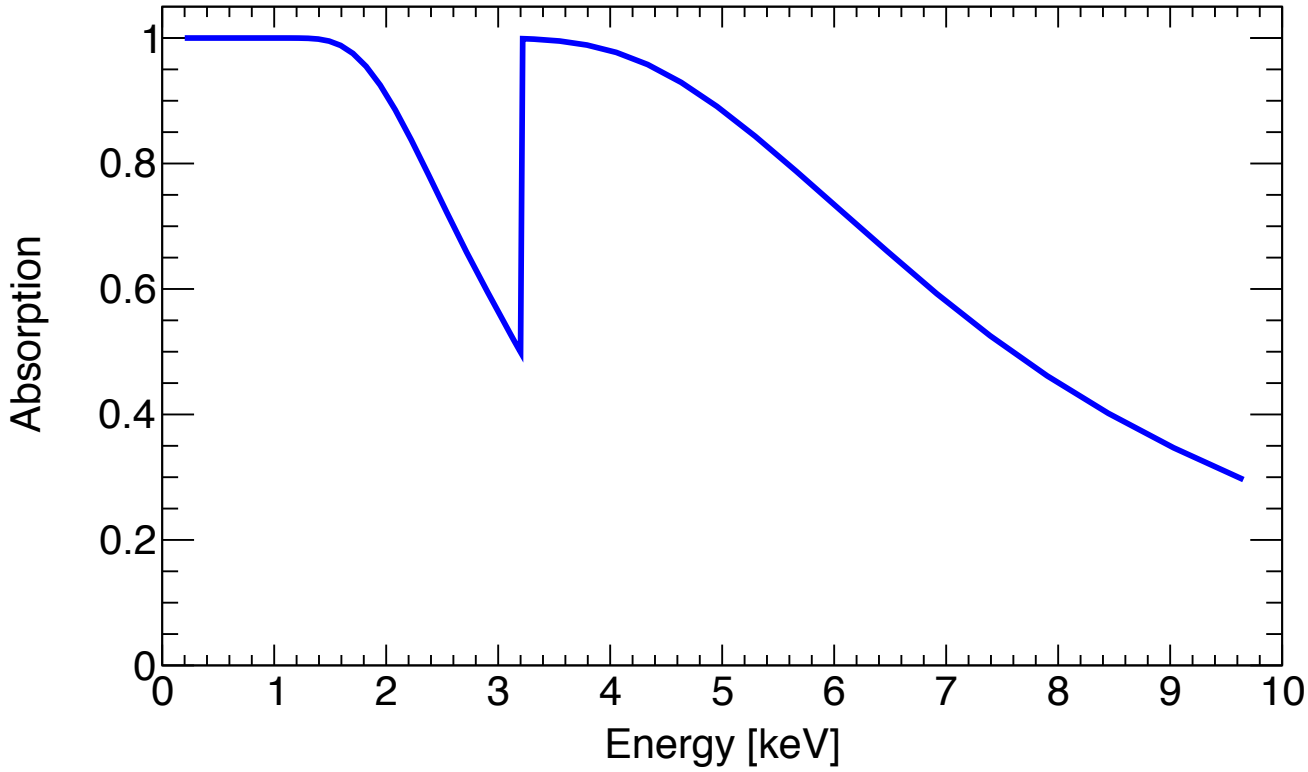
Many thanks to the great CAST collaboration for all their support and for accepting us as „late comers“

CAST

CERN Axion Solar Telescope

Backup

Photon absorption in 3cm Ar

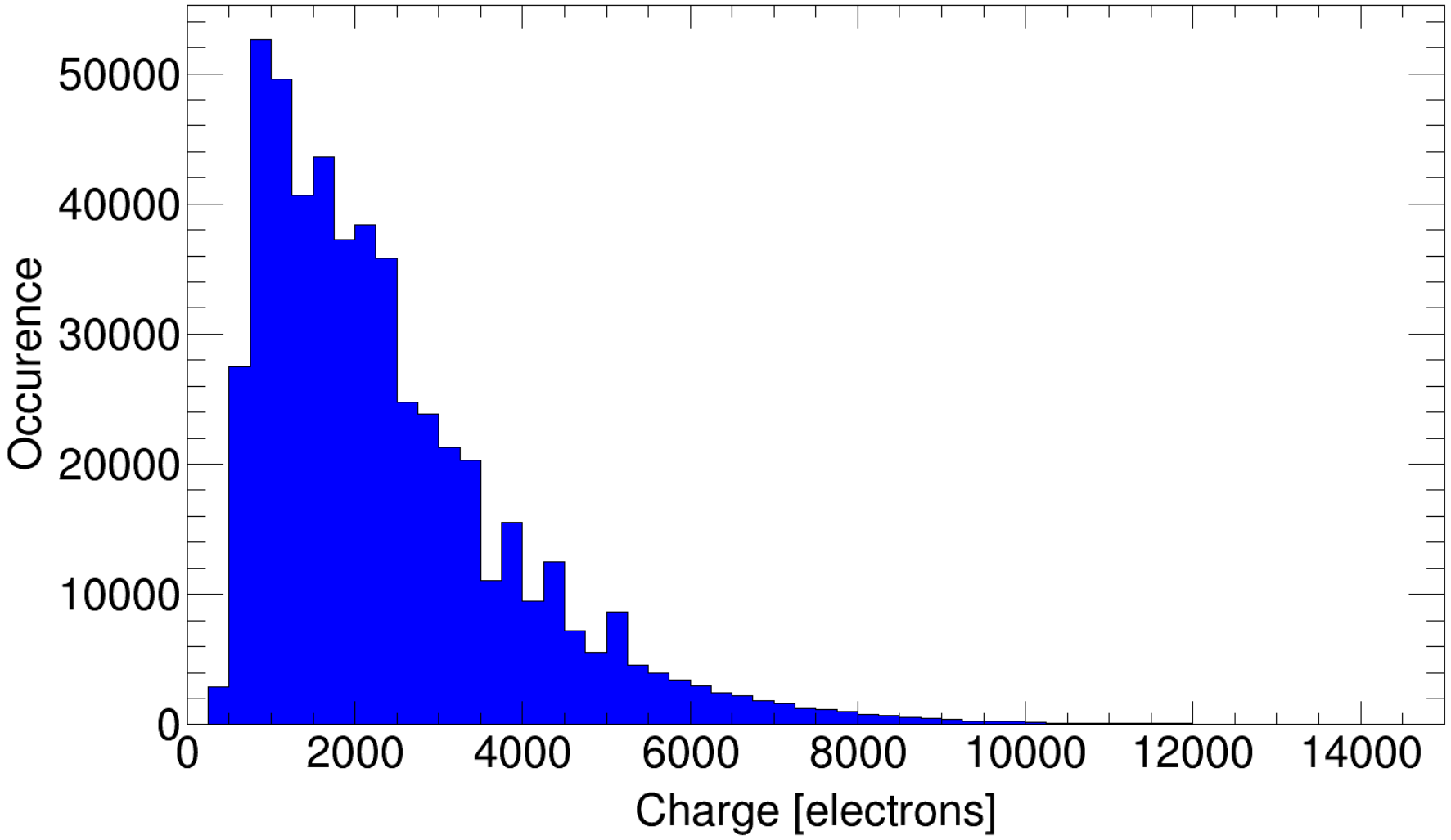


Backup

Detector operational parameters:

U_{grid} = 295 V
E_{drift} = 500 V/cm
l_{drift} = 3 cm
Gas Ar/Isobutane 97.7/2.3
gas gain ~ 2400
threshold: 1000 e^-
$\sigma_E/E \approx 6\%$ @ 5.9 keV

Backup

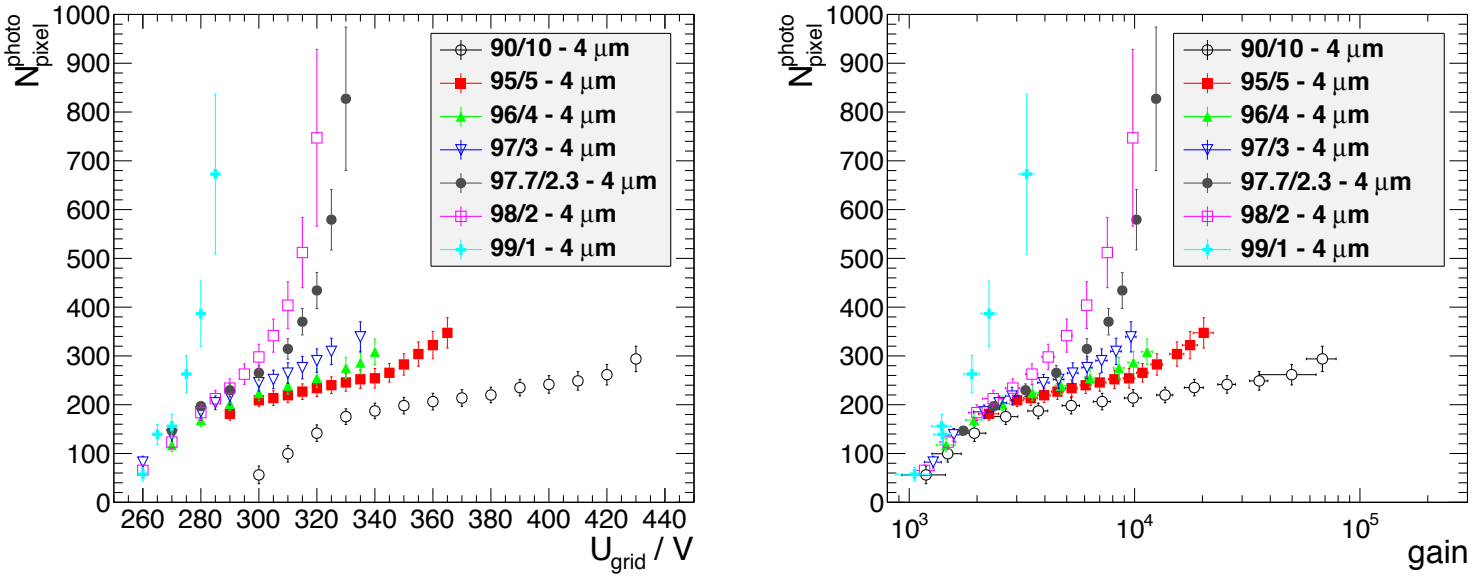

Occurence
50000
40000
30000
20000
10000
0
0
2000
4000
6000
8000
10000
12000
14000
Charge [electrons]

Backup

Energy bins for likelihood

low [keV]	high [keV]	line
0	0.4	C K-alpha
0.4	0.7	O K-alpha
0.7	1.2	Cu L-alpha
1.2	2.1	Al K-alpha
2.1	3.2	Ag L-alpha
3.2	4.9	Ti K-alpha
4.9	6.9	Mn K-alpha
6.9		Cu K-alpha

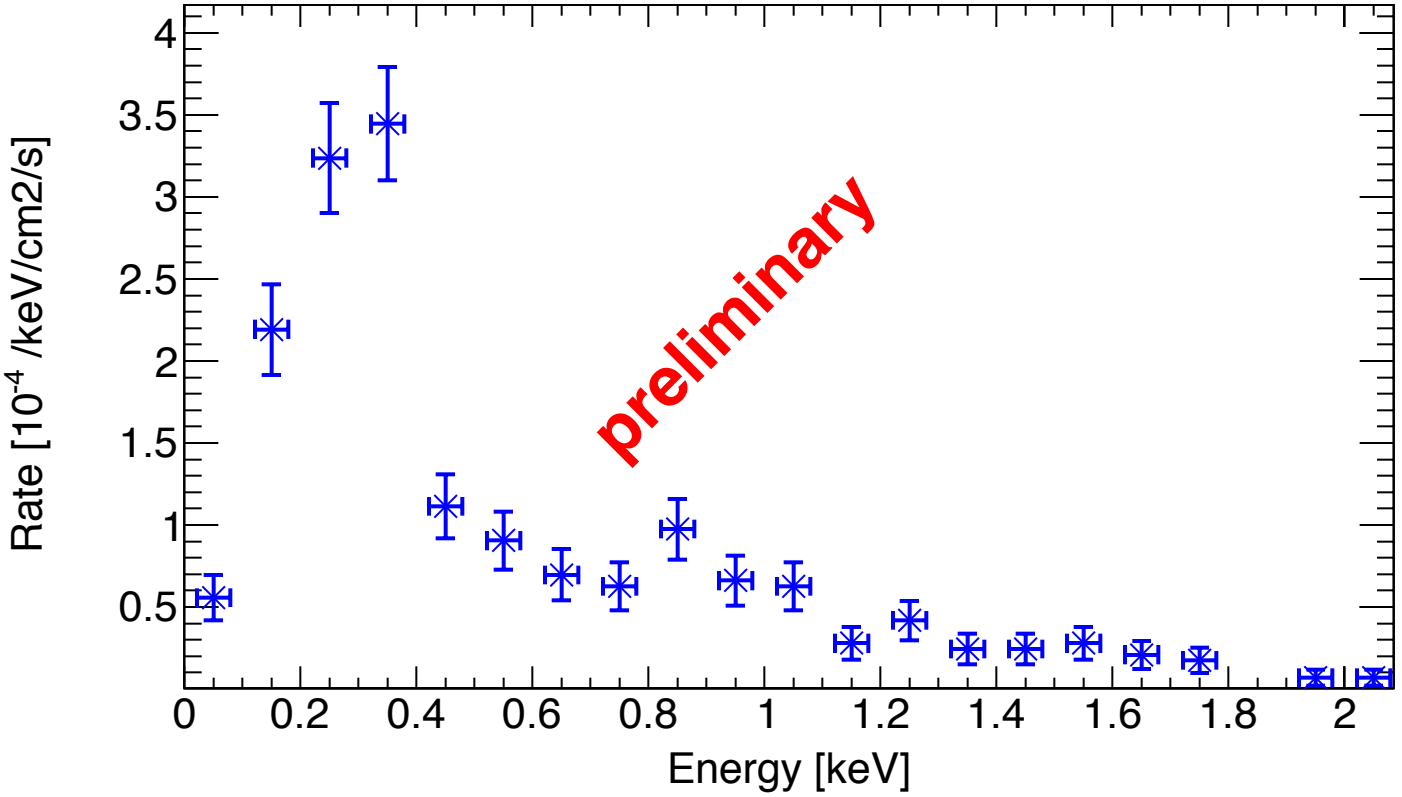
InGrids: Photon feedback and cross talk



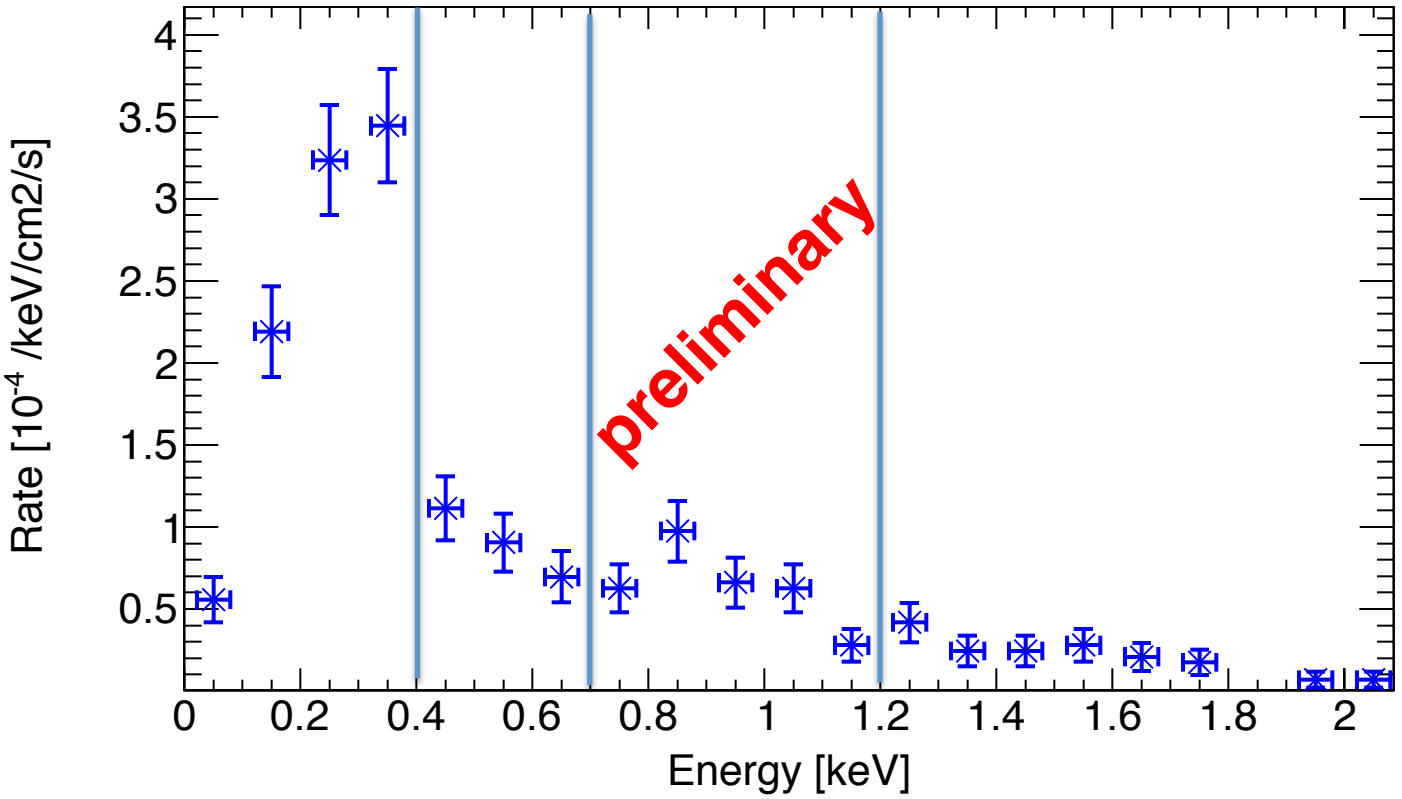
(a) (b)

Figure 9.2: Dependence of the number of pixels over threshold in the photo peak on the grid voltage U_{grid} (a) and the gas gain (b) for different Ar/iC_4H_{10} mixtures. All error bars are inflated by a factor of 100.

Background spectrum: 27 days



Background spectrum: 27 days



horizontal lines: bins for reference distributions