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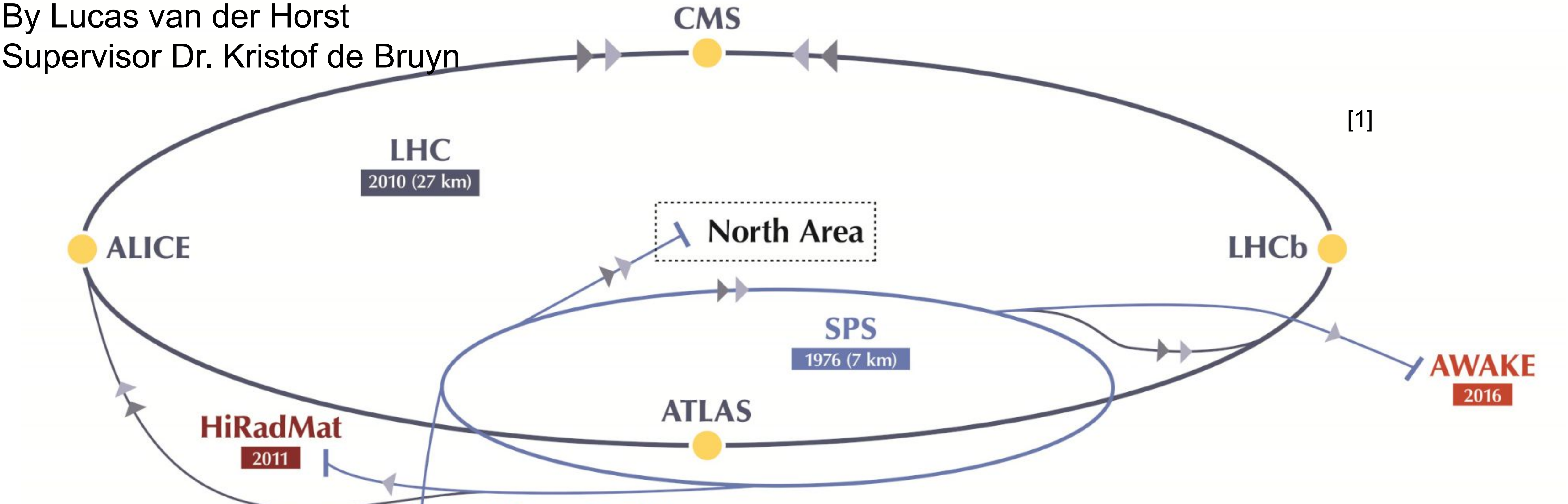
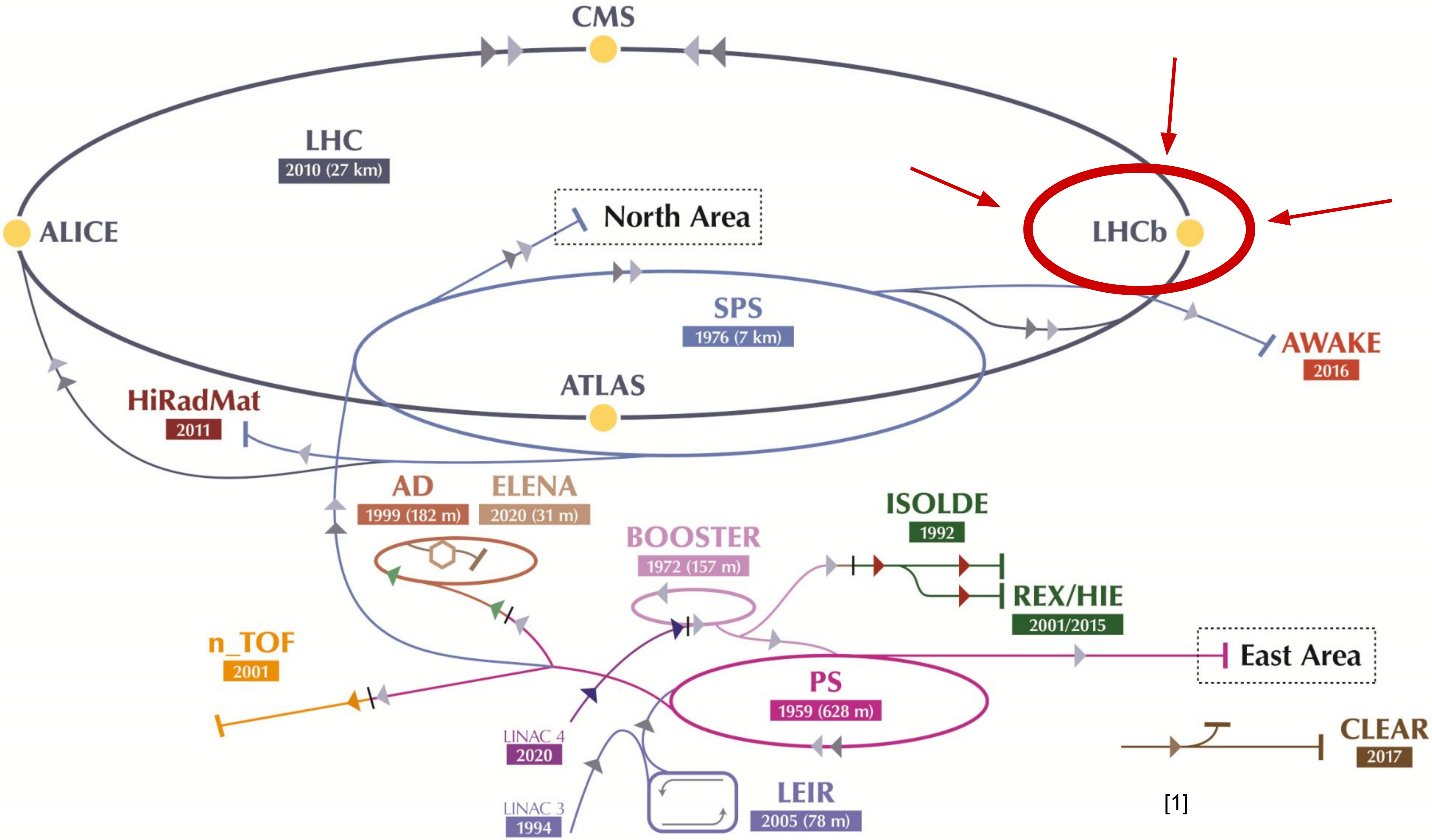
Heterogeneity of VELO's pixel response to a monochromatic radiation Fe55 source

By Lucas van der Horst
Supervisor Dr. Kristof de Bruyn



[1]

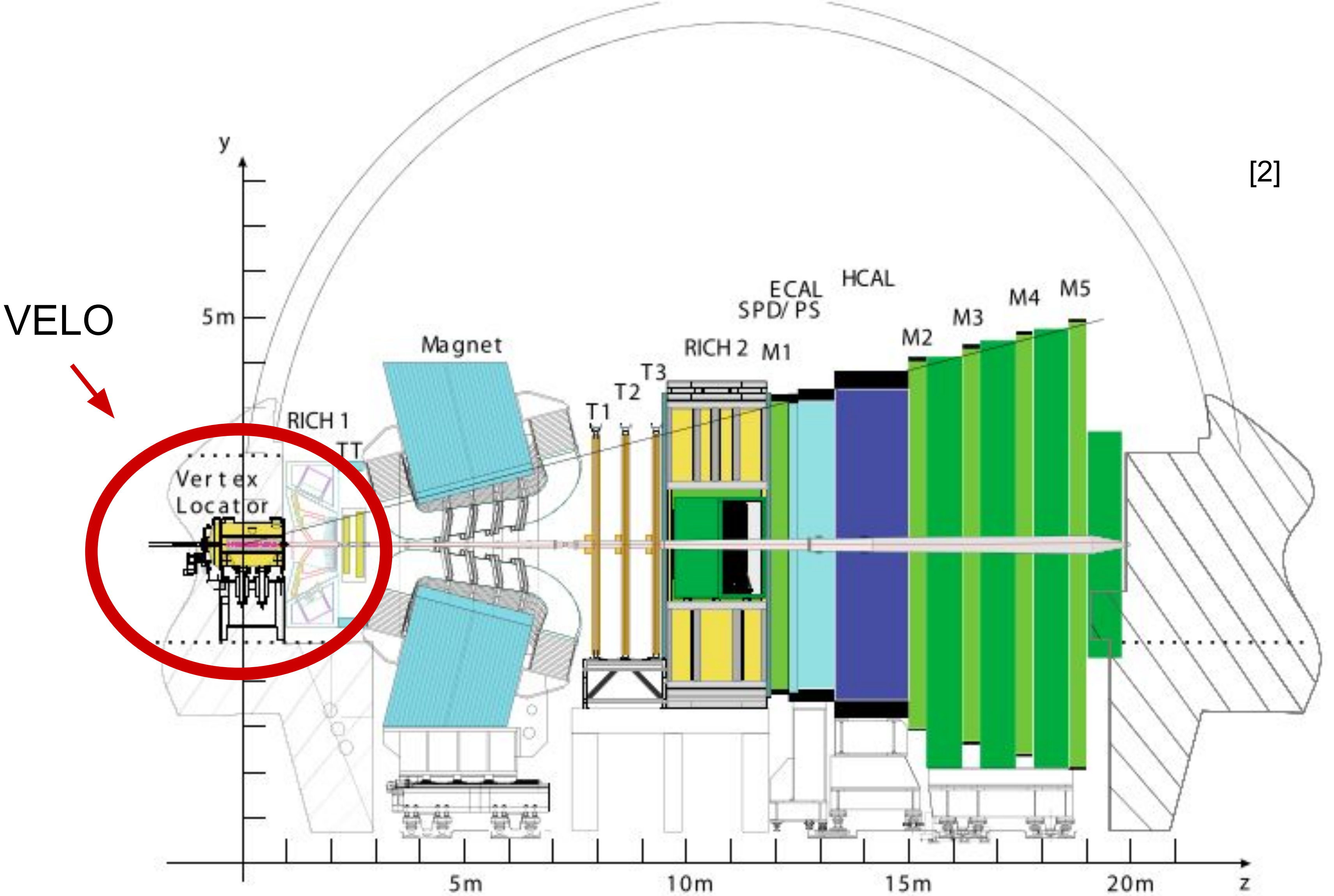
To study the fundamentals of the universe, CERN is founded in 1954


CMS
LHC
2010 (27 km)
North Area
ALICE
LHCb
SPS
1976 (7 km)
AWAKE
2016
ATLAS
HiRadMat
2011
AD
1999 (182 m)
ELENA
2020 (31 m)
ISOLDE
1992
BOOSTER
1972 (157 m)
REX/HIE
2001/2015
East Area
n_TOF
2001
PS
1959 (628 m)
LINAC 4
2020
CLEAR
2017
LINAC 3
1994
LEIR
2005 (78 m)

[1]

Introduction - LHCb

Studying the matter antimatter asymmetry

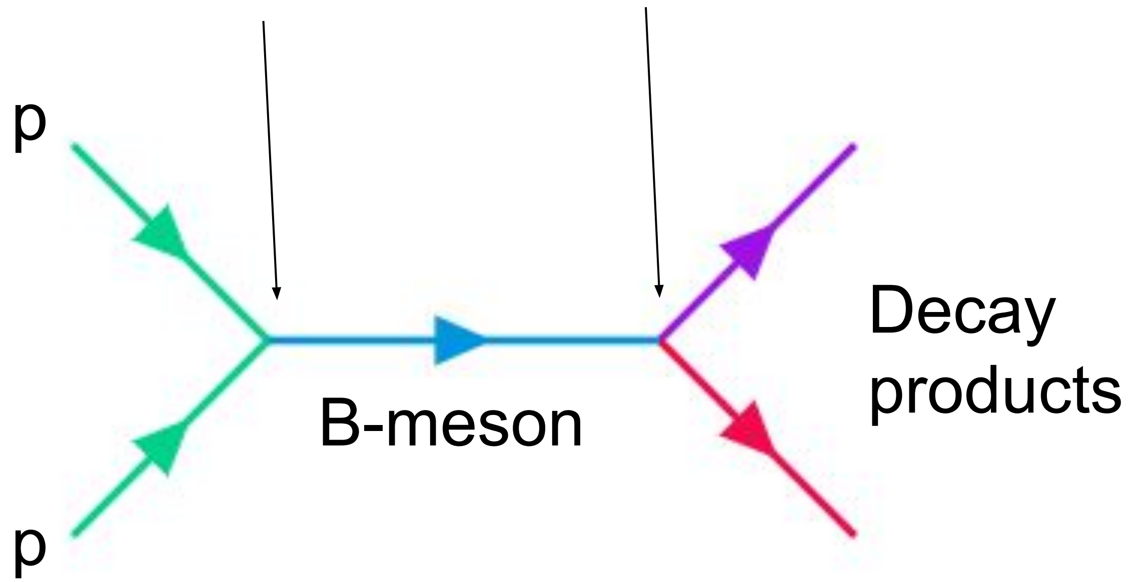


[2]

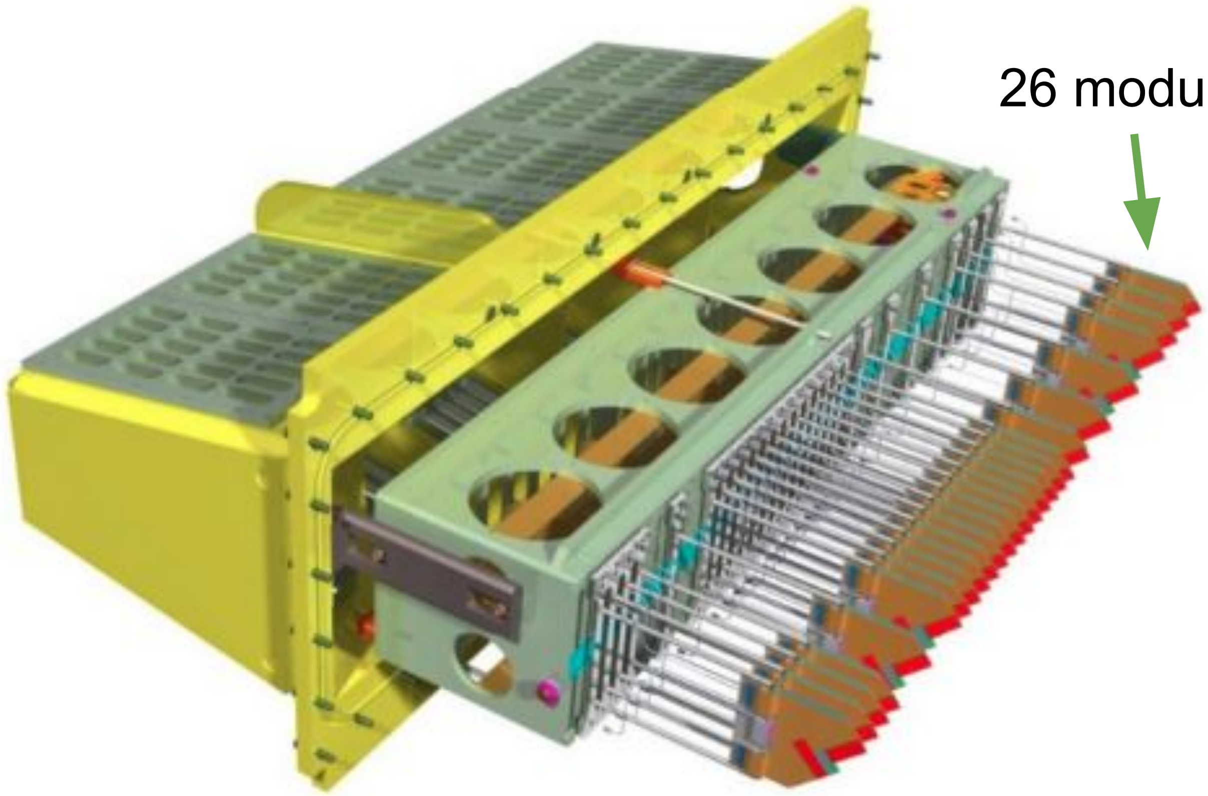
Introduction - VELO's purpose

To measure the passing of charged particles

From this: impact parameters, primary and secondary vertices



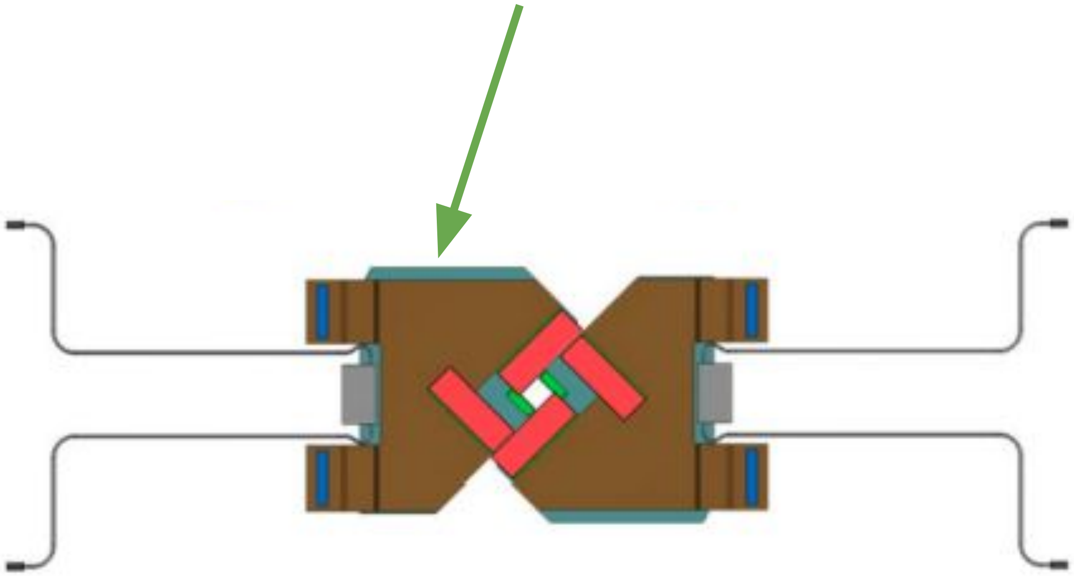
Introduction - Upgraded VELO



26 modules

Half of the upgraded VELO detector [2]

12 ASICs - circuit boards of 256x256 silicon-based pixels



Two closed modules [2]

Introduction - Functioning of pixels

- Charged particles ionize silicon
- Creating a measurable charge
- Pixel registers hit if charge > set threshold

Introduction - Challenge

Next step:

- Calibrate pixels using monochromatic radiation Fe55 source threshold scan

However,

- Pixel are not identical:
    - Manufacturing variations
    - Impurities
    - Electronics

Research question

How does the response of the pixels to the Fe55 source threshold scan compare to that of the average pixel?

Research subquestions

➔ If any, what is the nature of their difference?

➔ Are longer exposure times required for proper calibration?

Theory

Threshold energy

Charge sharing

Energy of radiated particles

$$I(E) = f \cdot \frac{1}{2}\mathrm{erfc}\left(\frac{E - E0}{s}\right) + (1 - f) \cdot \frac{1}{s\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{E-E0}{s}\right)^2}$$

Spectrum

Detector's resolution

Normal distribution

Theory - Flux spectrum

Integrating *I(E)* from *E* to infinity:

$$F(E) = Af \cdot \frac{1}{2}\left(\frac{s}{\sqrt{\pi}} e^{-\left(\frac{E-E0}{s}\right)^2} + (E0 - E) \cdot \mathbf{erfc}\left(\frac{E-E0}{s}\right)\right)$$
$$+ A(1-f) \cdot \frac{1}{s\sqrt{8\pi}} \cdot \mathbf{erfc}\left(\frac{E-E0}{s\sqrt{2}}\right)$$

Particle flux spectrum

Normalization factor

Method - Data acquisition

VELO exposed to monochromatic (5.19keV) radiation (electrons) Fe55 source for a range of different thresholds

Four data sets available, hits stored in 256x256 matrices:

- 2nd and 4th data sets have largest exposure times

- In this presentation, 2nd data set is considered

Method - Data processing

- Initial masking (faulty pixels)
- Elimination of bad acquisitions (strange behaviour)
- Trimming of thresholds were no hits were measured
- Mask pixel if no hits were measured for more than 80% of the thresholds
- Compute particle flux

Method - Analysis

- Fit *F*(*E*) to spectrum of average pixel

- Fit *F*(*E*) to spectra of each pixel
  - Fixing the fitting parameters except for *A* to those obtained from average pixel
  - Free fit

- Chi-square test for goodness of fit

Results

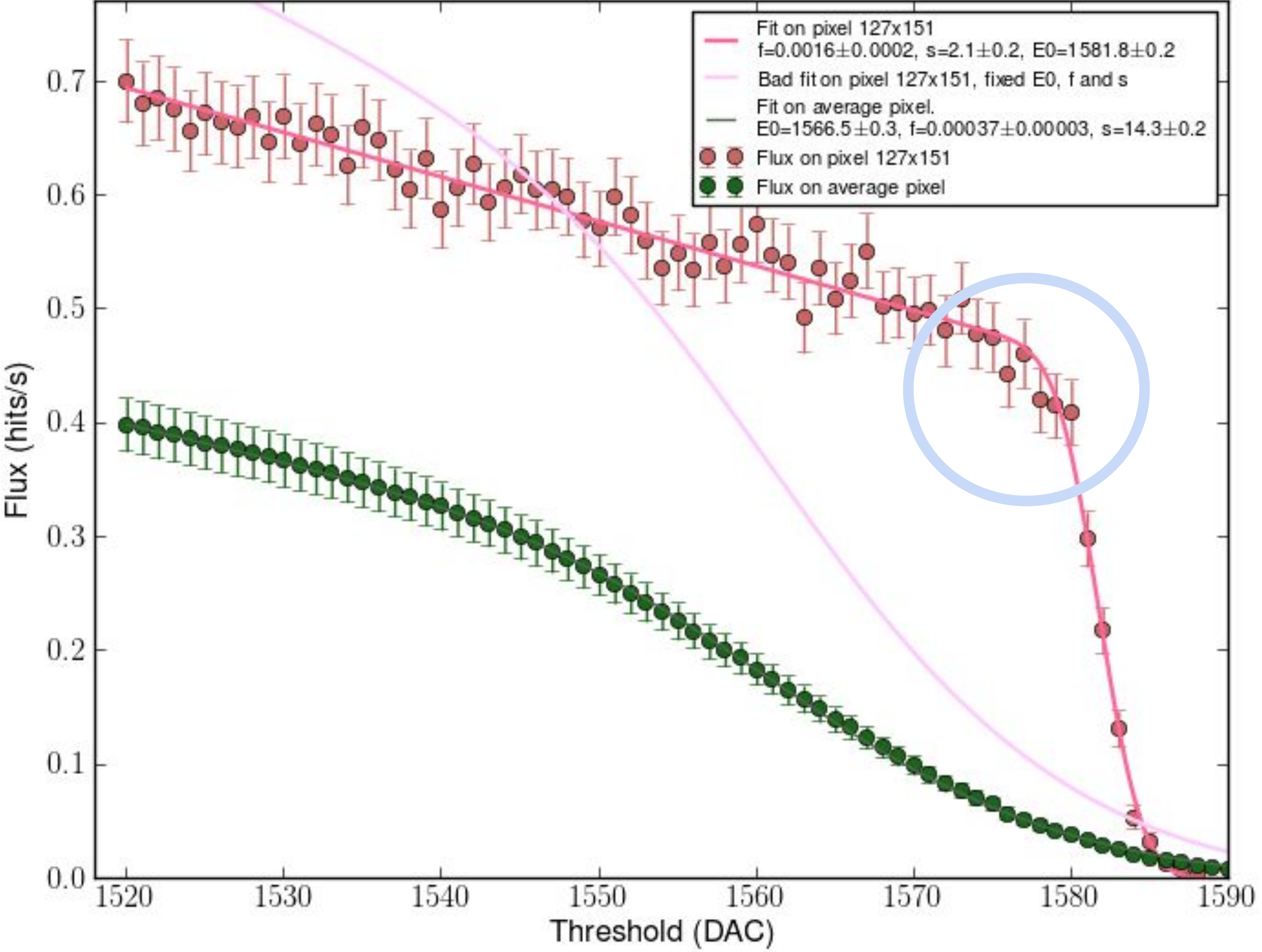
Spectra

Pixel 127x151
2nd data set

Sharp drop

Pixel of center, hot region. Higher flux than average

Free fit performs better



Results

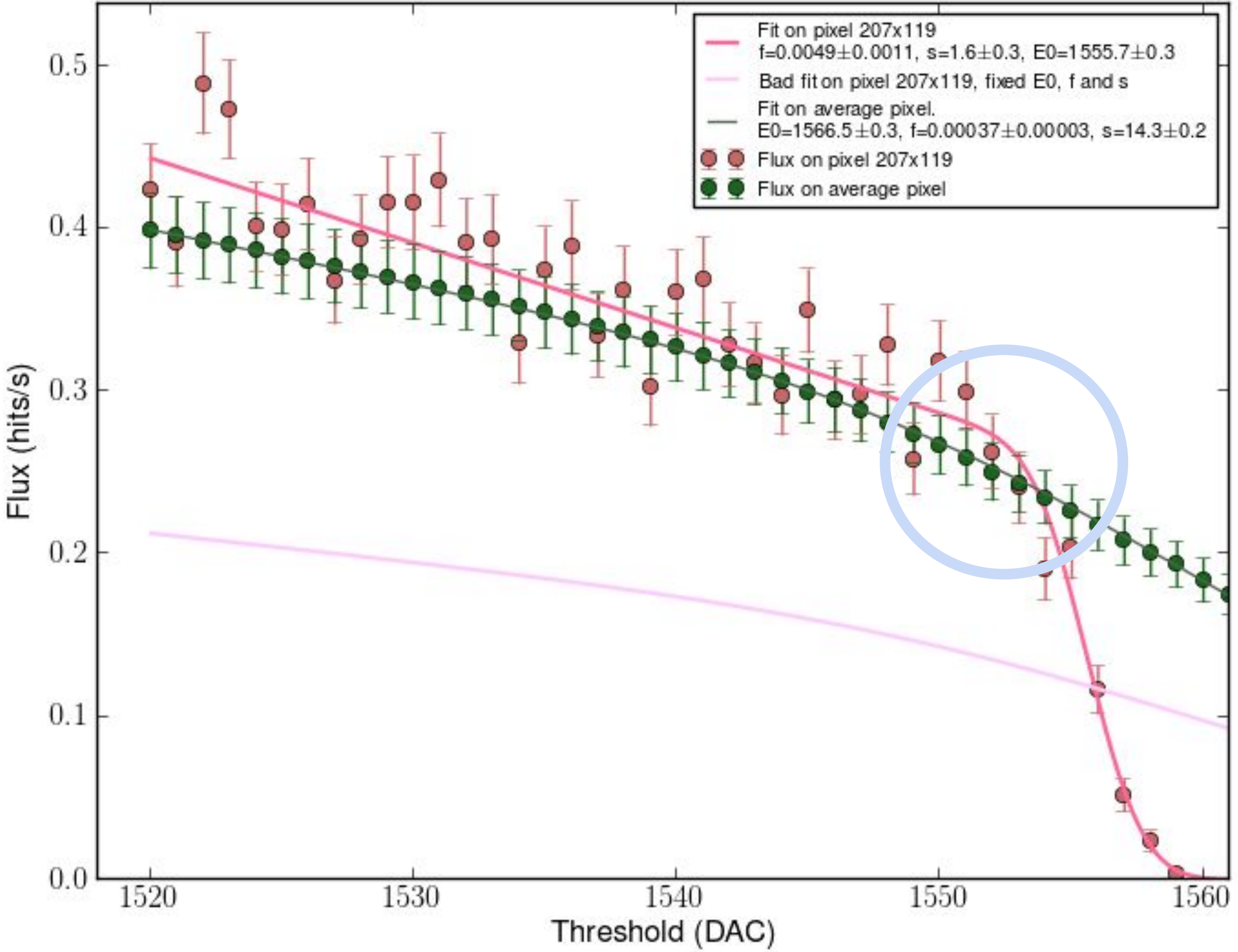
Spectra

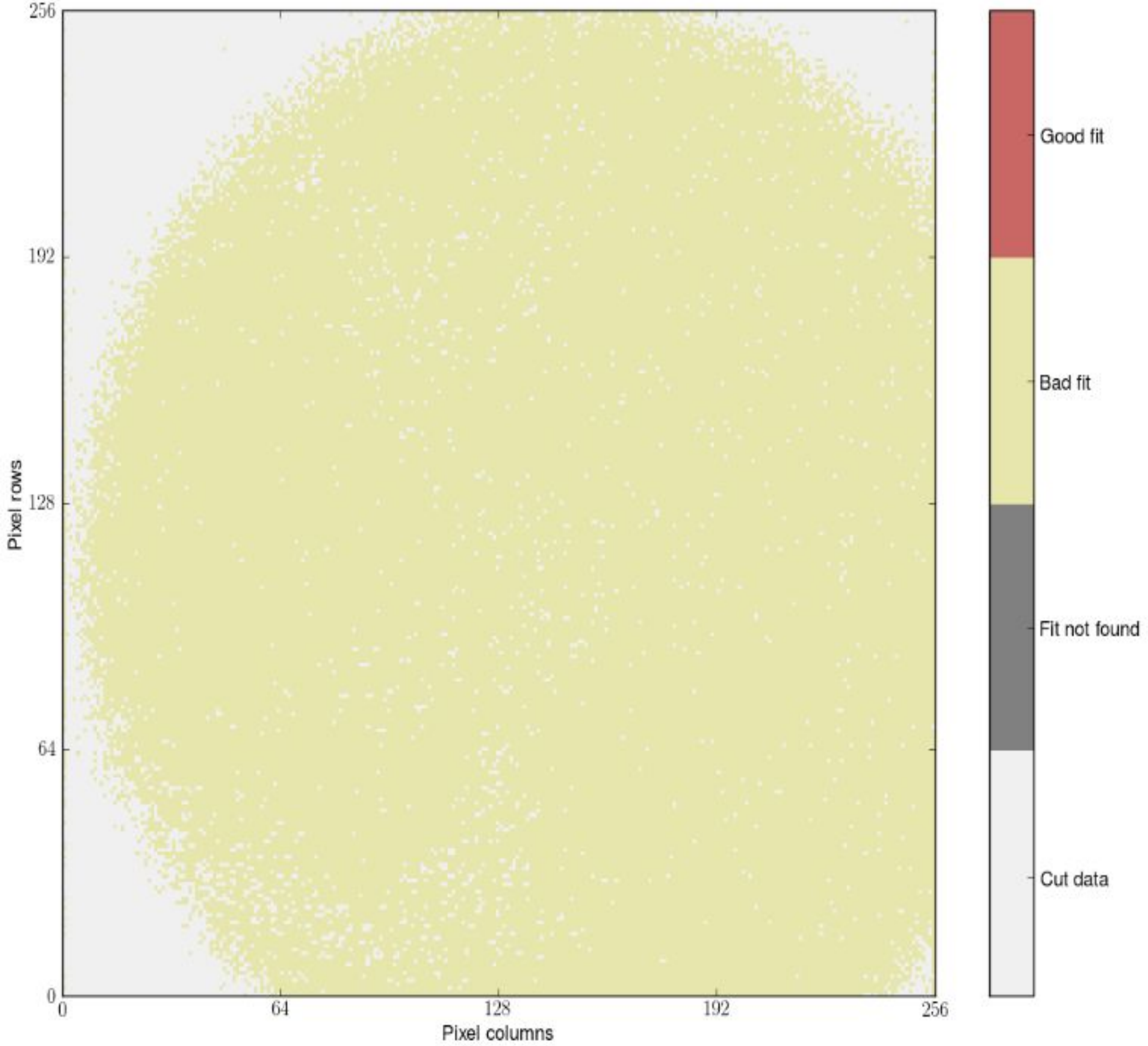
Pixel 207x119
2nd data set

Sharp drop

Pixel further from center, colder region. Flux matches average

Free fit performs better





0%

84%

0

16%

Results

Fixed fit type

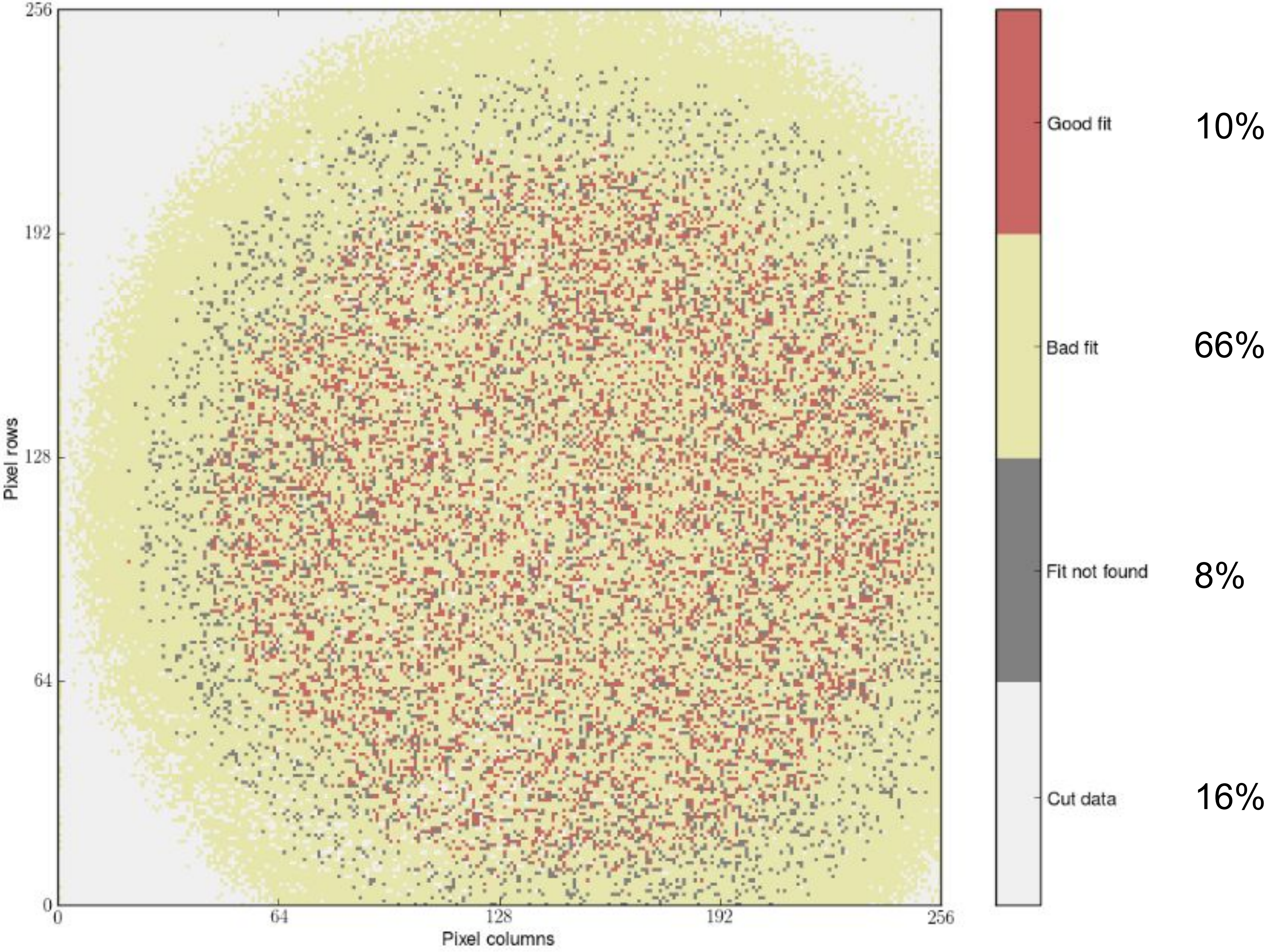
2nd data set

None of the fits pass the chi-square test

Results

<u>Free</u> fit type

2nd data set



10% of fits pass chi-square test, concentrated in the hot region

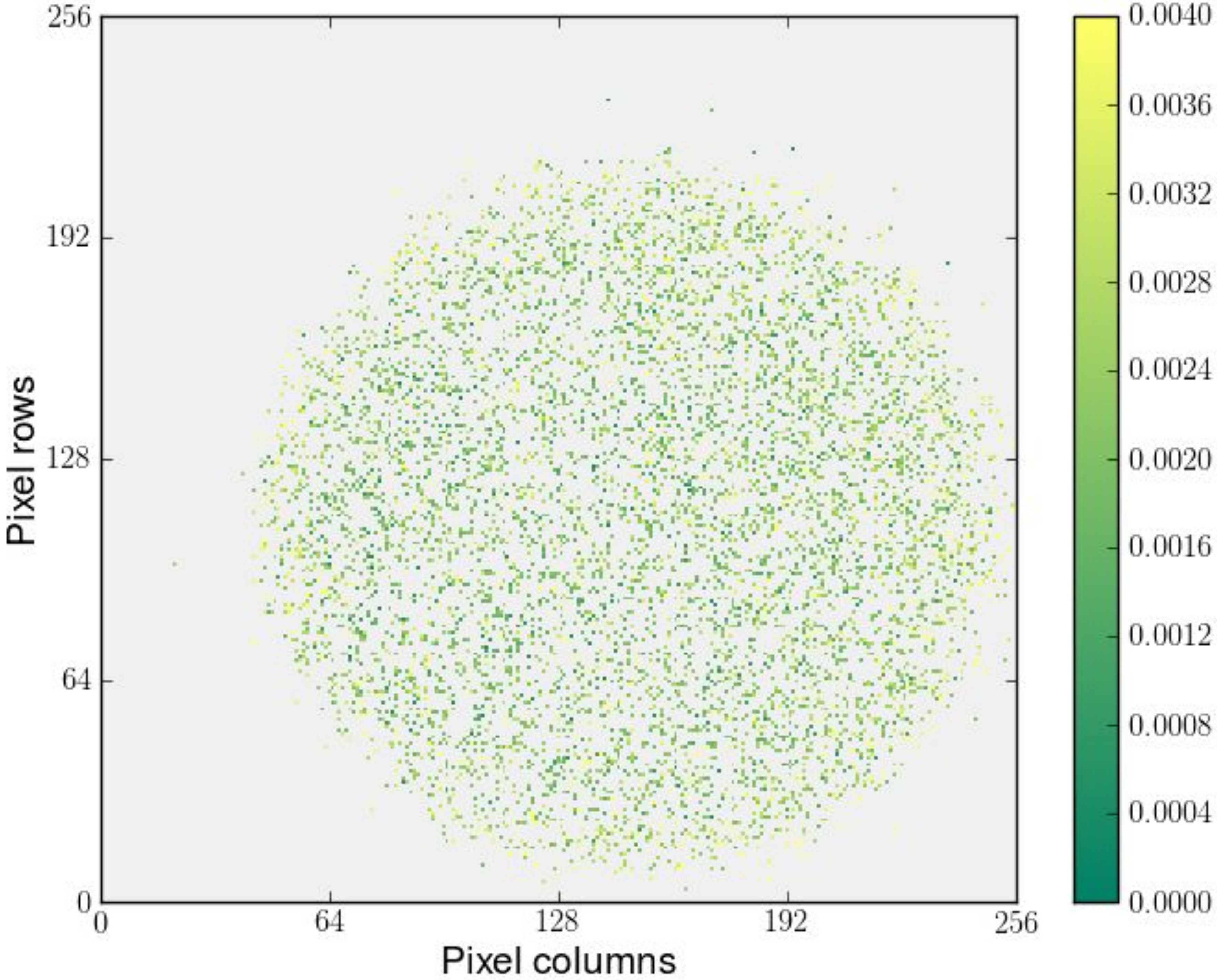
Results

f heatmap

2nd data set

f values are 1 order of magnitude higher than for the spectrum of the average pixel

Values possibly in accordance with predictions from [3]



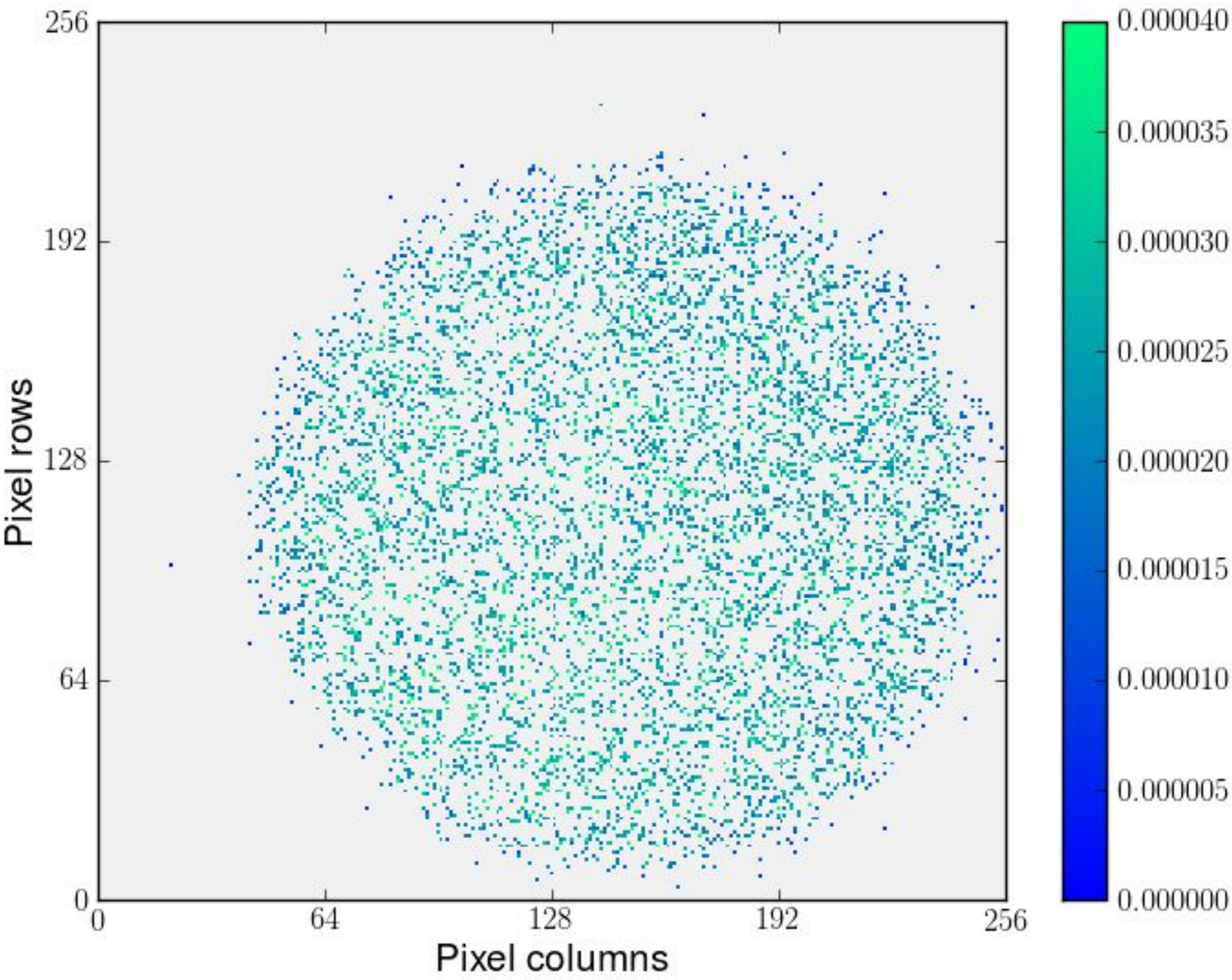
Results

s heatmap

2nd data set

s values are 6 order of magnitude higher than for the spectrum of the average pixel

Drop in spectra explained by low resolution → *s* parameter controls that feature



Discussion & Conclusion

- → The response of single pixels differs from the average pixel
  - Notable flux drop for higher but not equal thresholds
    - Due to low resolution
    - Feature vanishes when averaged
  - Free fit works much better than fixed fit

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Discussion & Conclusion

- ➔ The response of single pixels differs from the average pixel
  - Notable flux drop for higher but not equal thresholds
    - Due to low resolution
    - Feature vanishes when averaged
  - Free fit works much better than fixed fit

- ➔ A lot of data cut and failed chi-square test for lack of hits (exposure time)
  - 2nd data set had 14.5h total exposure time. More is needed

References

[1] CERN. https://panoramas-outreach.cern.ch/index.html. Accessed: 28/06/2023.

[2] K. Hennessy, “LHCb VELO upgrade,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 845, pp. 97–100, feb 2017.

[3] K. Mathieson et al. , “Charge sharing in silicon pixel detectors,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 487, no. 1-2, pp. 113–122, 2002.

Additional figures

Results

Spectra

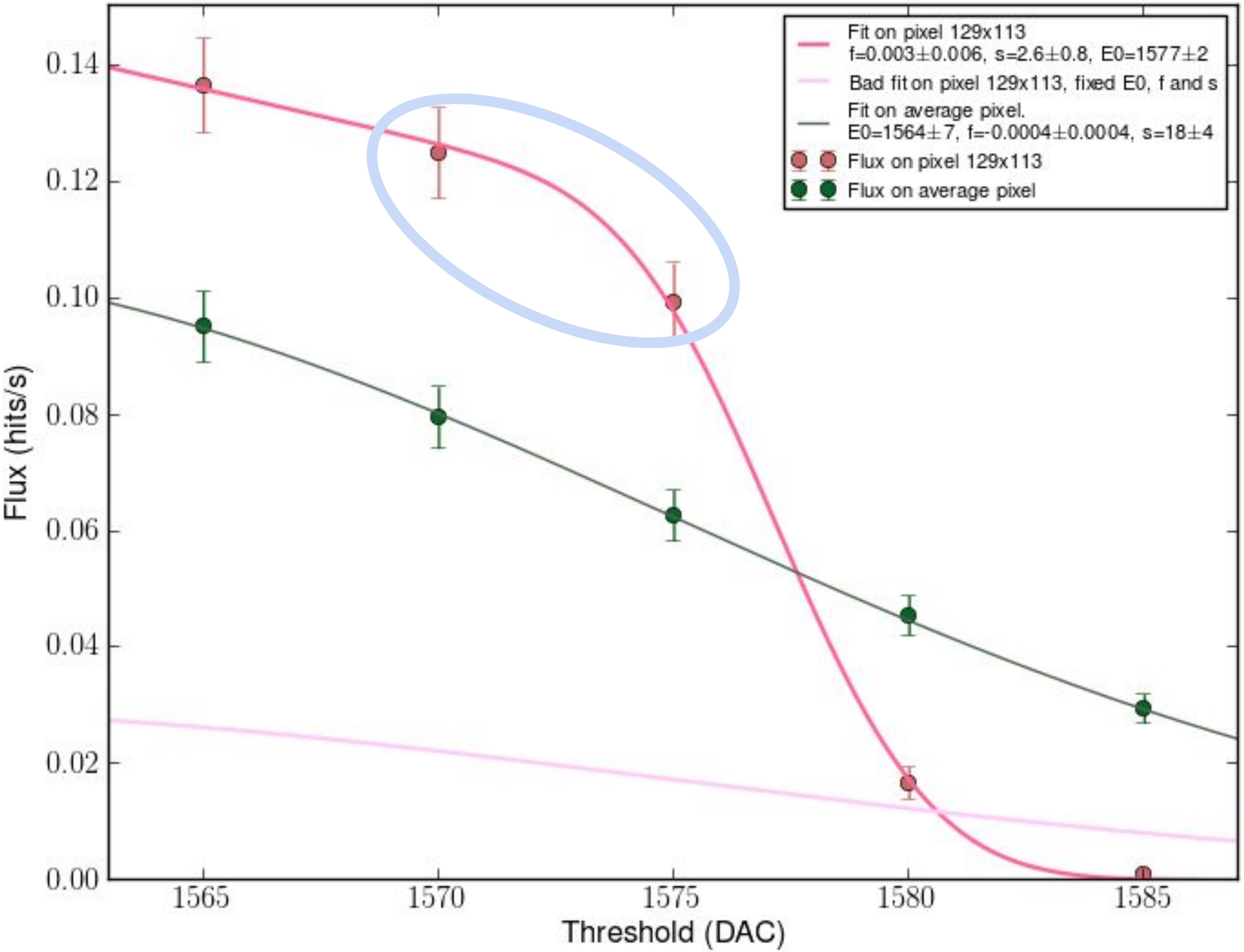
Pixel 129x113

4th data set

Sharp drop

Pixel of center, hot region

Free fit performs better

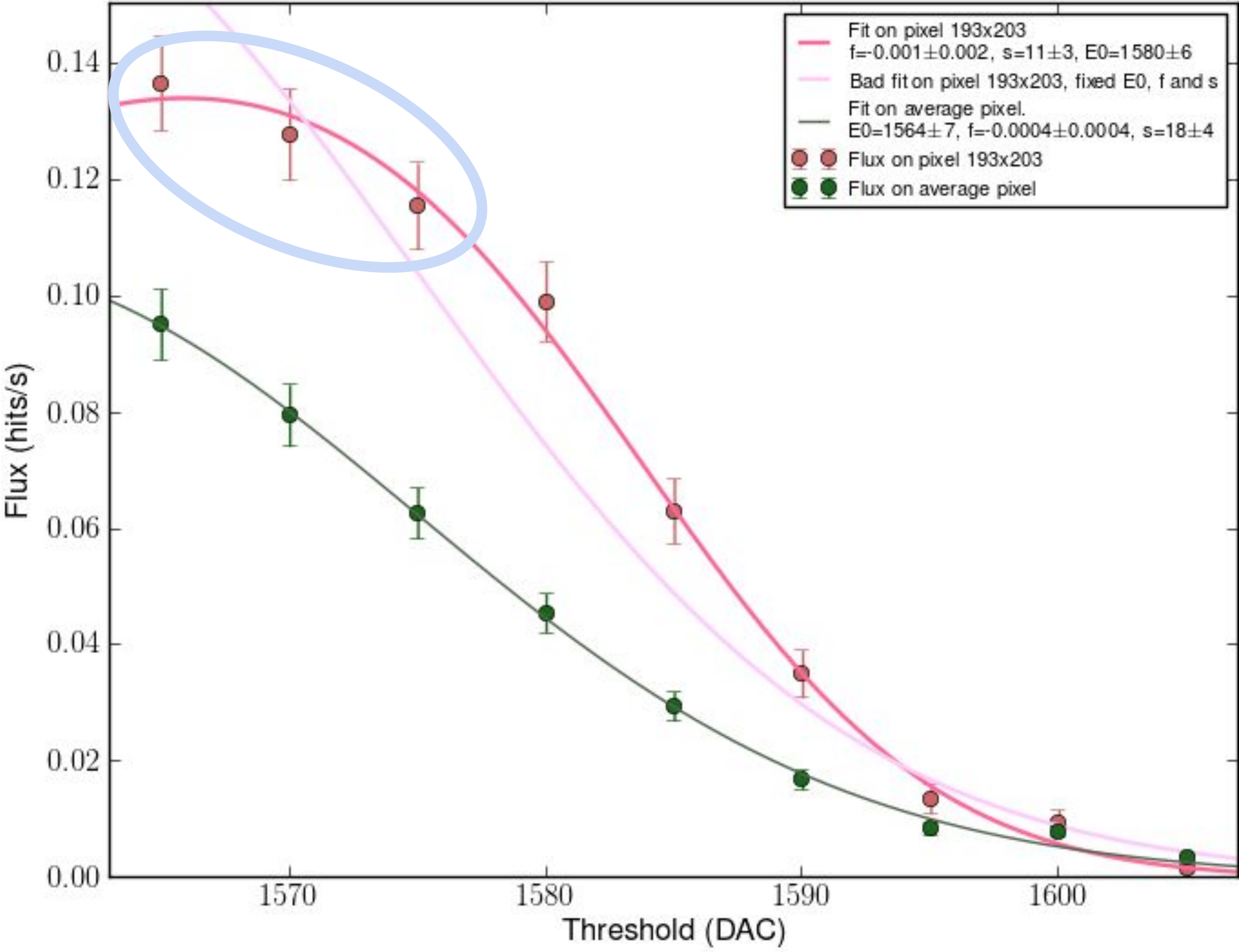


Results
Spectra
Pixel 193x203
4th data set

Sharp drop

Pixel further from center, colder region.

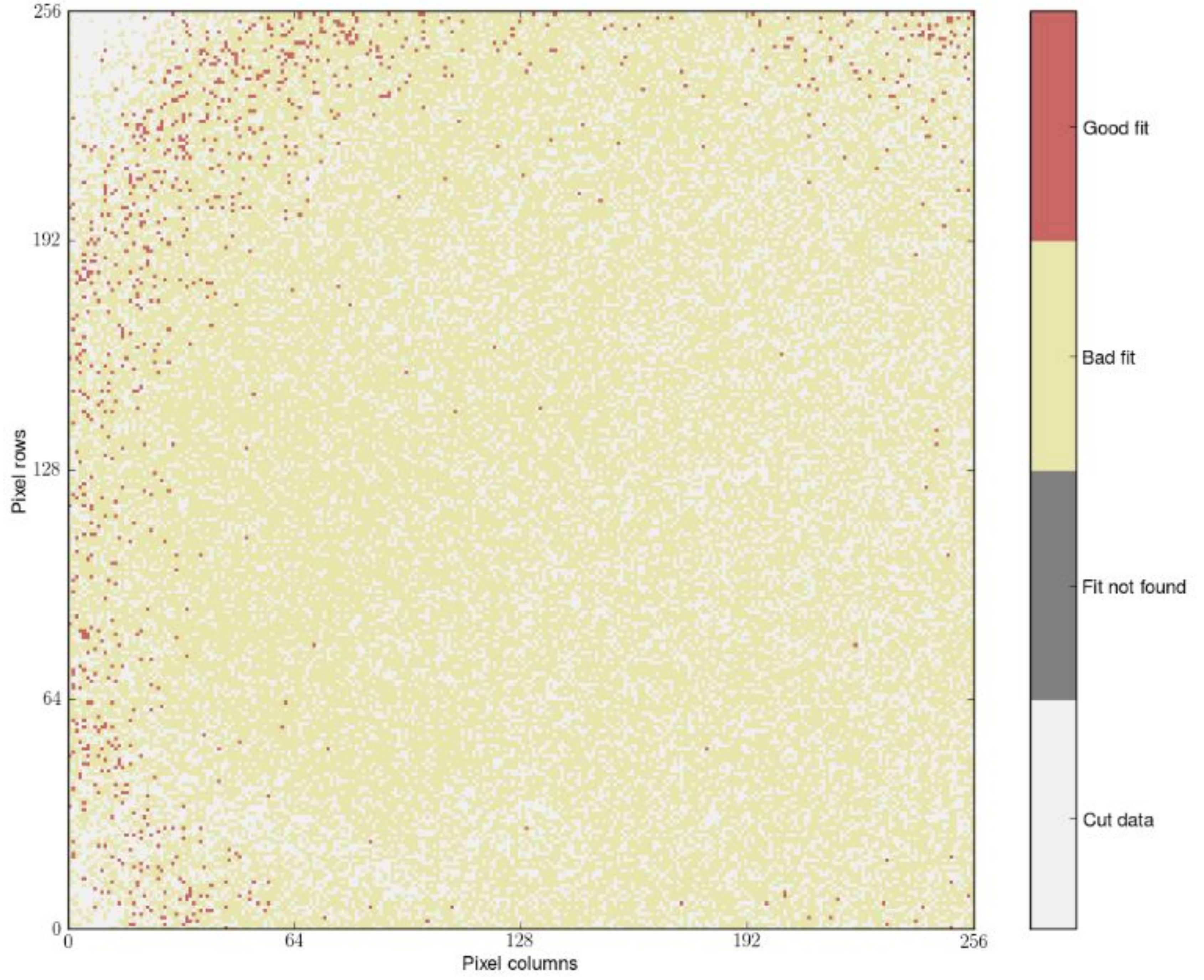
Free fit performs better



Results

<u>Fixed</u> fit type

4th data set



1%

66%

0

33%

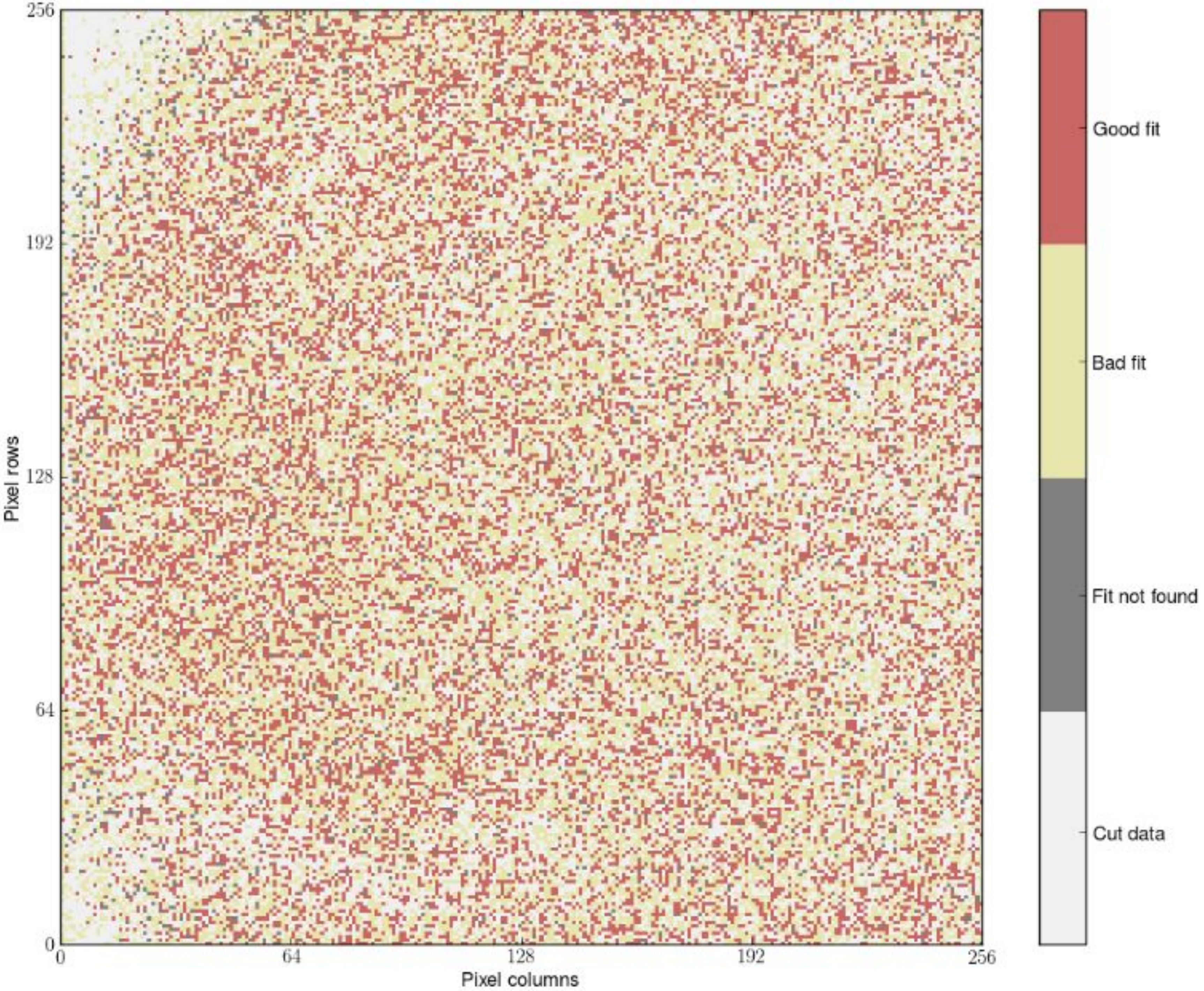
Only 1% have a good fit

Hot region is larger than 2nd data set → source is further away

Results

<u>Free</u> fit type

4th data set



27%

38%

2%

33%

27% of fits pass chi-square test

Hot region spans the entire grid

35h total exposure time