Characterization of the VeloPix Detector Gain Response to Fe-55 Irradiation

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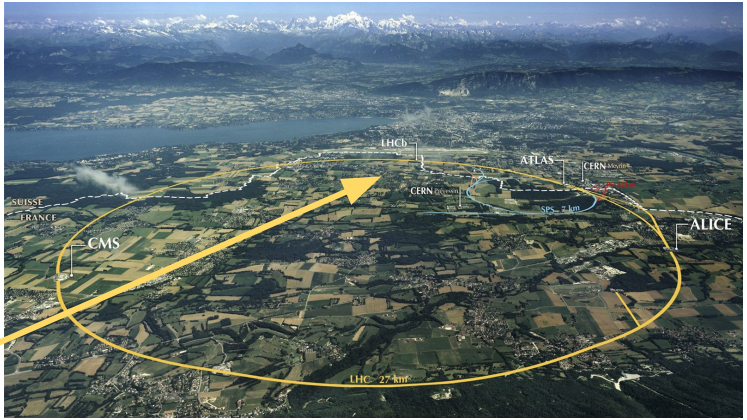
Nikhef

LHCb

Introduction

Large Hadron Collider (LHC):

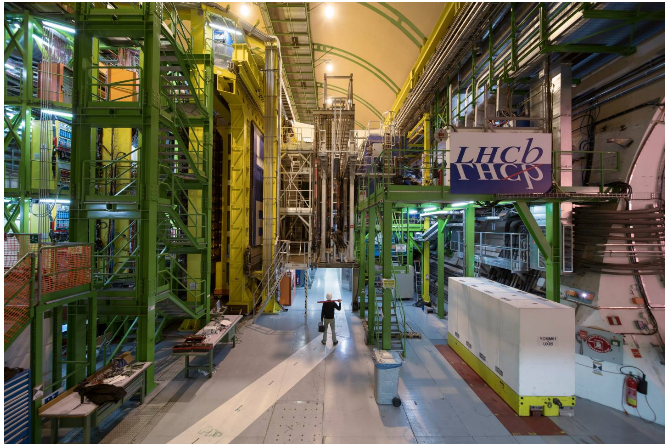
is the largest particle accelerator in the world



Various experiments, but among them LHCb

Improvement of measurements ⇒ Upgrade

Vertex Locator (VELO) detector upgraded!



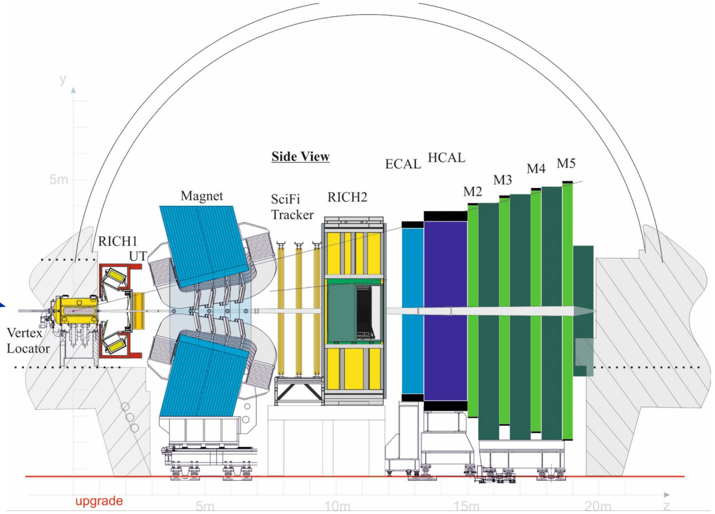
Vertex Locator (VELO)

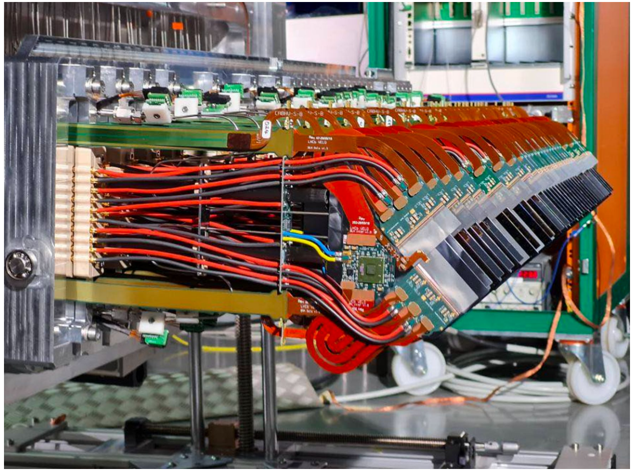
First sub-detector particles encounter

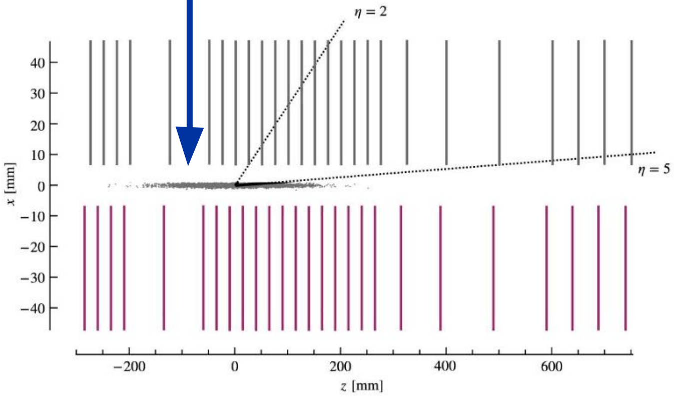
Measures the ionising particles paths

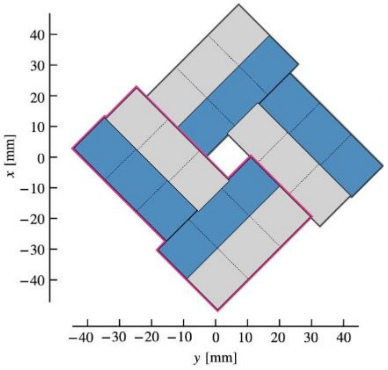
52 Modules along travelling direction

Surrounds *pp* interaction region



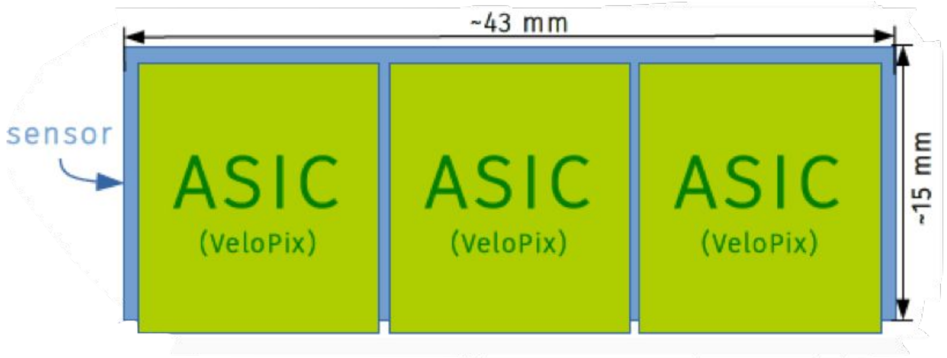


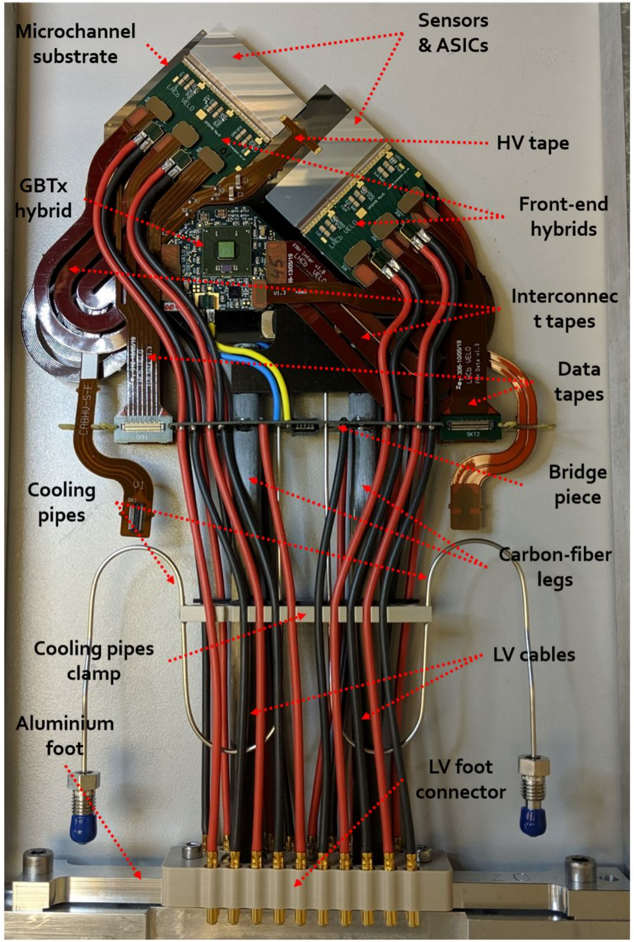




Vertex Locator (VELO)

One module = 4 sensors with 3 VeloPix ASICs each





Application-Specific Integrated Circuits (ASICs)
Digital to Analog Converter (DAC)

Velopix

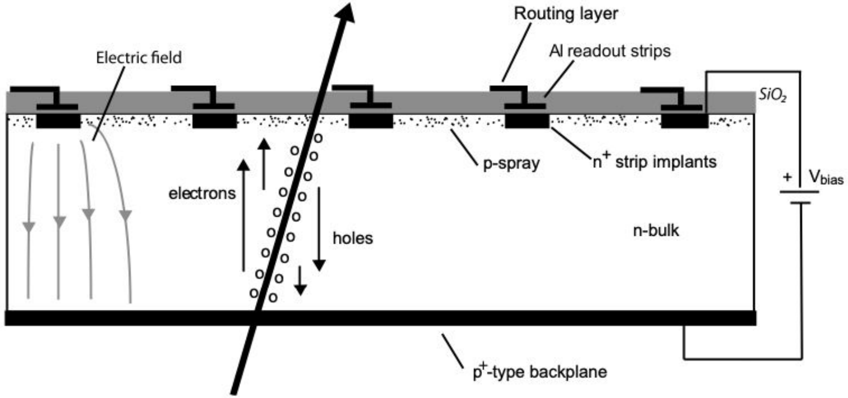
ASIC

256x256 pixels/ASIC

200 µm n-on-p Silicon depletion zone

Detection Process:

- Creation of electron-hole pairs (ehp)
- Collect current
- Digital signal [DAC]



ASIC Pixel Schematic with incident ionising particle

Application-Specific Integrated Circuits (ASICs)
Digital to Analog Converter (DAC)

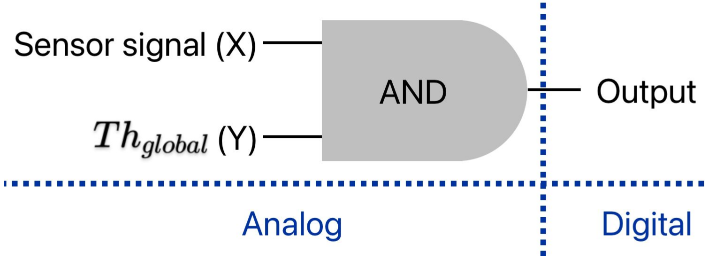
Signals, Noise and Thresholds

Threshold [DAC] : minimum signal amplitude required for a pixel to register a hit.

[DAC] = Unit used by ASICs. Associates a Digital value to an Analog voltage or current.

Global Threshold Th_{global} :

Discern between *noise* or *hit* from particle.



Digital to Analog Converter (DAC)

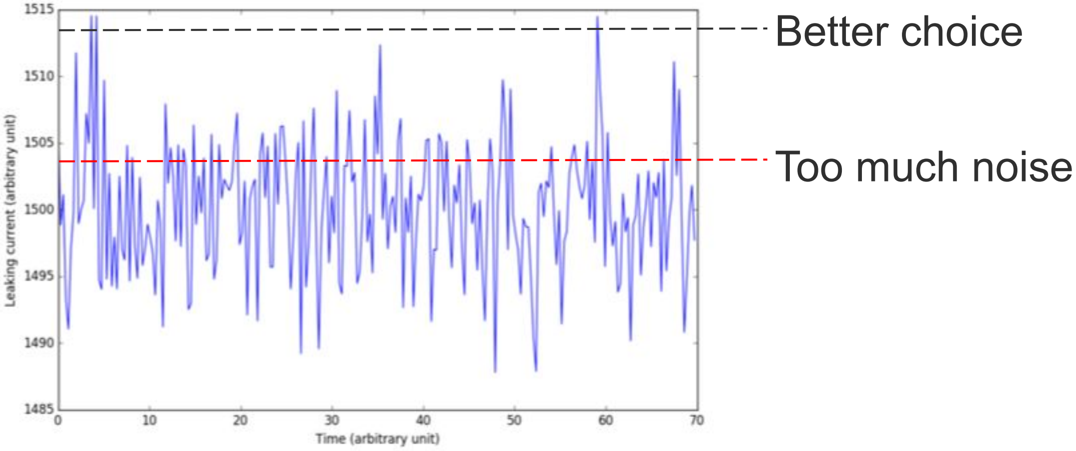


Figure 3: A simulation on the noise of a pixel.

https://fse.studenttheses.ub.rug.nl/24770/1/bPHYS_2021_VosM.pdf

Overview

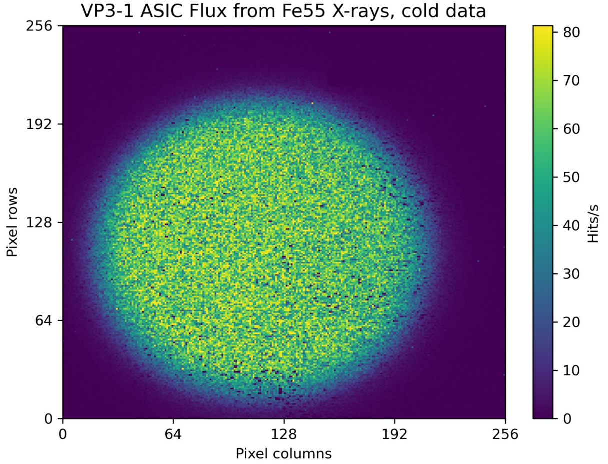
Calibration and project goal:

- Conversion factor or Gain, K [e-/DAC]

  Controlled scenario with radiation source $\Rightarrow K$ [e-/DAC] *for ASIC*

- Compare to VeloPix ASIC design paper estimate

$$K_{est}\ [\text{e-/DAC}] = 15.45 \pm 0.51$$



Application-Specific Integrated Circuits (ASICs)
Digital to Analog Converter (DAC)

Overview

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- Conversion factor or Gain, K [e-/DAC]

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$$K_{est}\ [\text{e-/DAC}] = 15.45 \pm 0.51$$

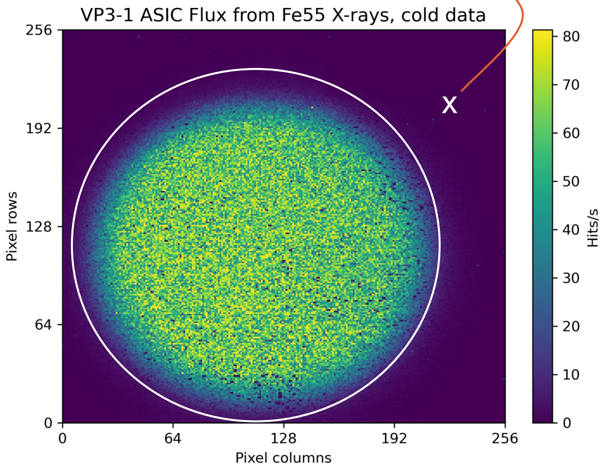
Other goals:

- Explore individual vs ASIC behaviour

- Explore possible biases

Application-Specific Integrated Circuits (ASICs)
Digital to Analog Converter (DAC)

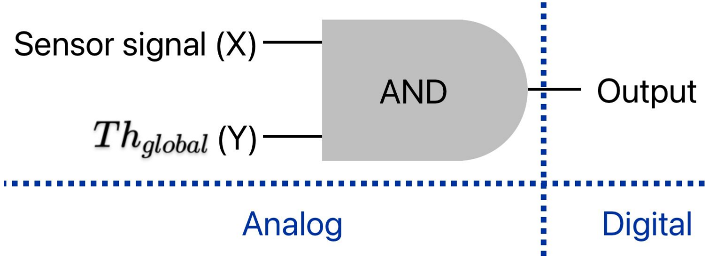
$$K\ [\text{e-/DAC}] = x \pm \Delta x$$



Theory: Signals, Noise and Thresholds

Pixel-to-pixel variations exist ⇒ can be fixed with small configuration setting in pixels

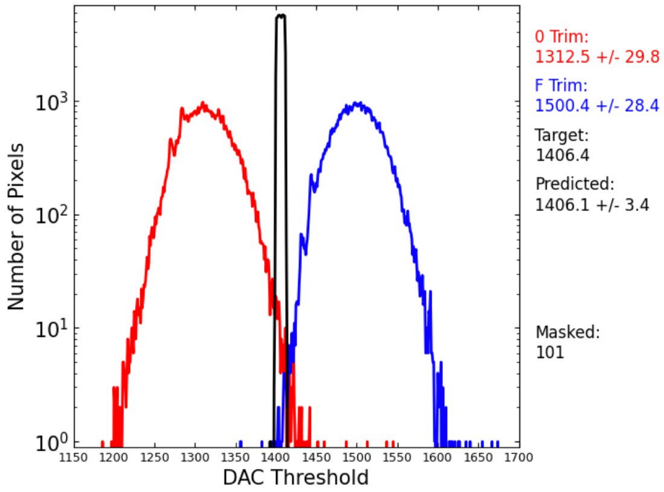
⇒ Trim setting: Acts as current offset added to input signal



$$Hit_{detected} = Signal_{input} + Trim > Th_{global}$$

Equalisation process:

1. Best Trim setting matrix
2. Global threshold and noise baseline for ASIC
3. Masked pixel matrix



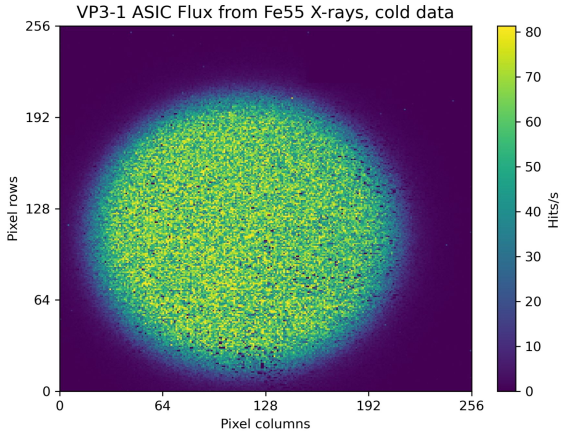
Theory: Signals, Noise and Thresholds

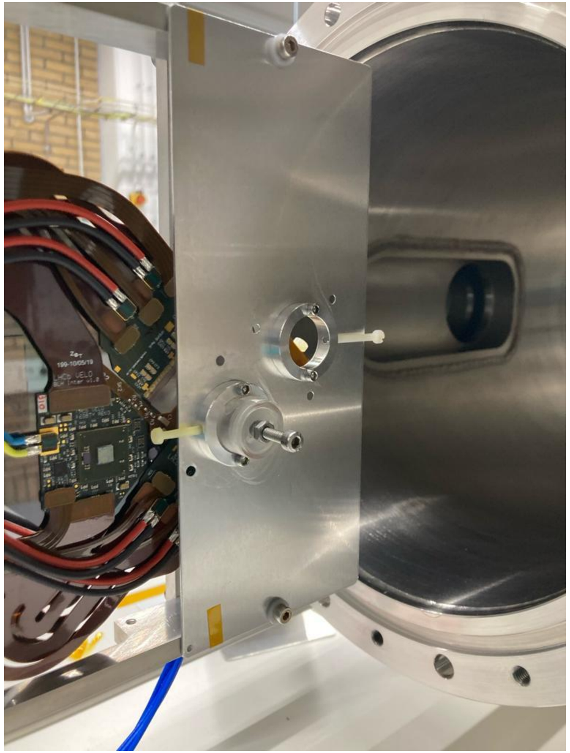
Fe55 source:

- 60% Auger e- with energy 5.19 keV, not measured
- 28% X-rays with energy 5.9 keV
- 12% other not relevant processes

Only X-ray flux detected on ASIC

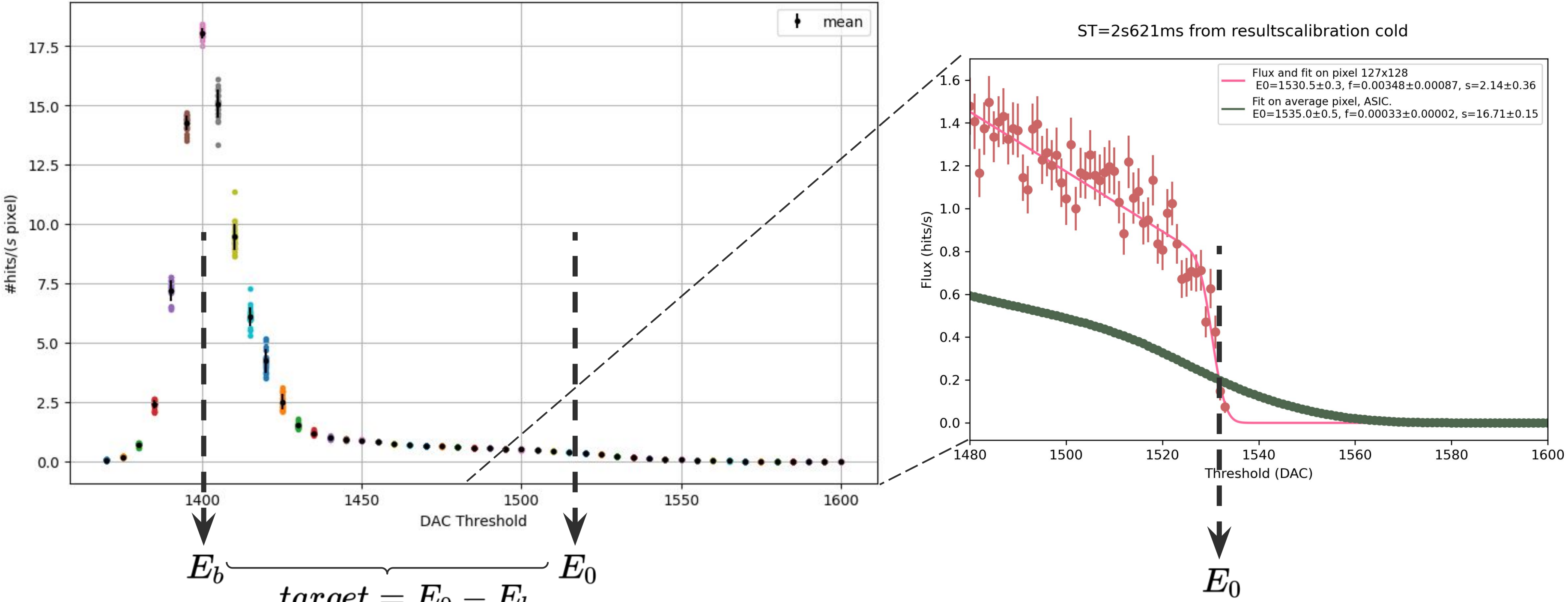
$$E_\gamma = 5.9\text{keV}$$





Theory: Signals, Noise and Thresholds

Flux vs Threshold scan



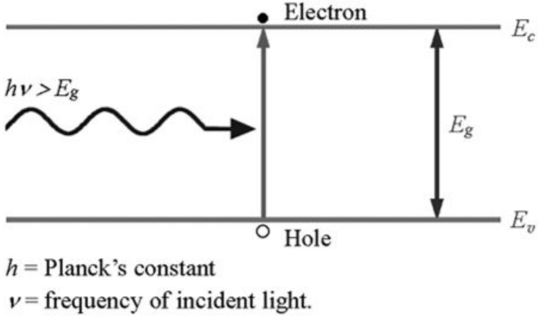
$$target = E_0 - E_b$$

Theory: Source and Detection

Processes:

1. Photoelectric effect, $E_g = 1.12\text{eV}$

$E_\gamma = 5.9\text{keV}$



$$E = E_\gamma - E_g \Rightarrow E \approx E_\gamma$$

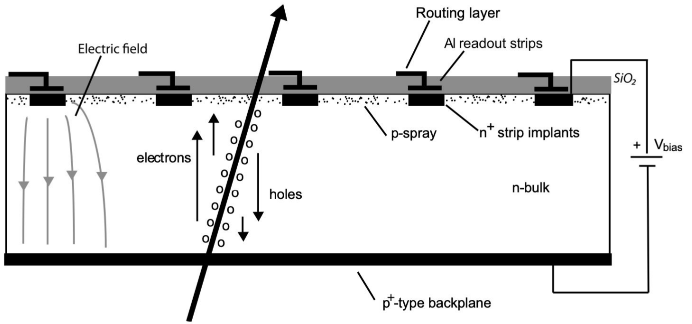
2. Average electron-hole pair-creation energy in Si: $E_{ehp} = 3.69 \pm 0.11 \text{ eV/ehp}$

$$\rightarrow n_{ehp} = \frac{E_\gamma}{E_{ehp}} = \frac{5900 \text{ eV}}{3.69 \text{ eV/ehp}} = 1598.92 \text{ ehp}$$

Energy deposition

$$\rightarrow target = E_0 - E_b \text{ , } n_{ehp}$$

$$K\left[\frac{e^-}{DAC}\right] = \frac{n_{e^-}}{target} = \frac{E_\gamma}{E_{ehp}} \frac{1}{(E_0 - E_b)}$$



Theory: Flux Models

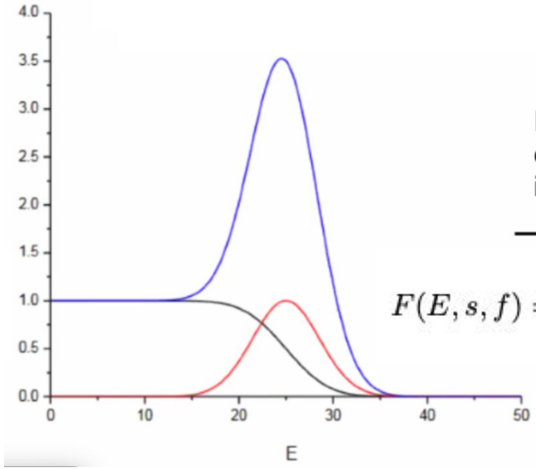
Flux model structure

- Blue: Signal 1 pixel $(1-f)\cdot\frac{1}{s\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{E-E0}{s}\right)^2}$
- Black: charge sharing $f\cdot\frac{1}{2}\,\mathrm{erfc}\left(\frac{E-E0}{s}\right)$

$$\left.\begin{array}{l}(1-f)\cdot\frac{1}{s\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{E-E0}{s}\right)^2}\\ f\cdot\frac{1}{2}\,\mathrm{erfc}\left(\frac{E-E0}{s}\right)\end{array}\right\} f(E,s,f)$$

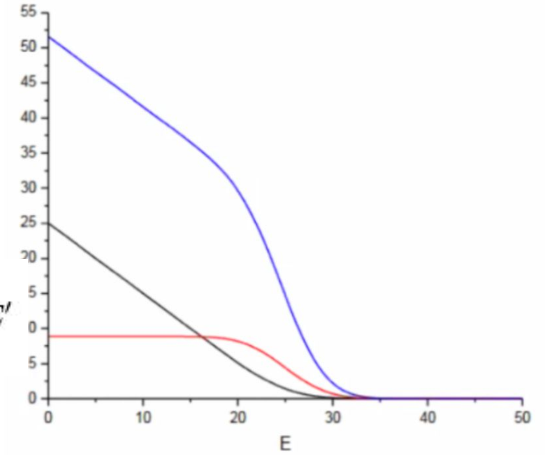
$$\mathrm{erfc}(x) = 1 - \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\,dt$$

Graph by MD Galati



Integrating from our threshold E to infinity

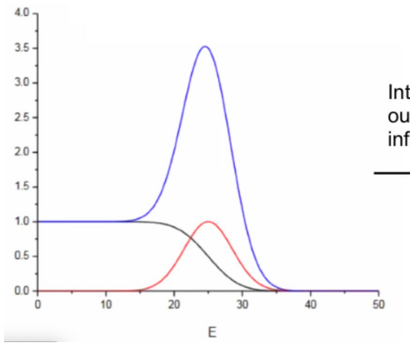
$$F(E,s,f) = \int_E^{\infty} f(E',s,f)\,dE'$$



Theory: Flux Models

Flux model structure

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



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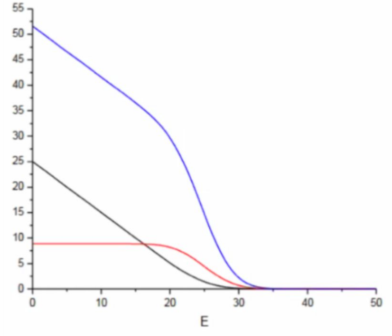

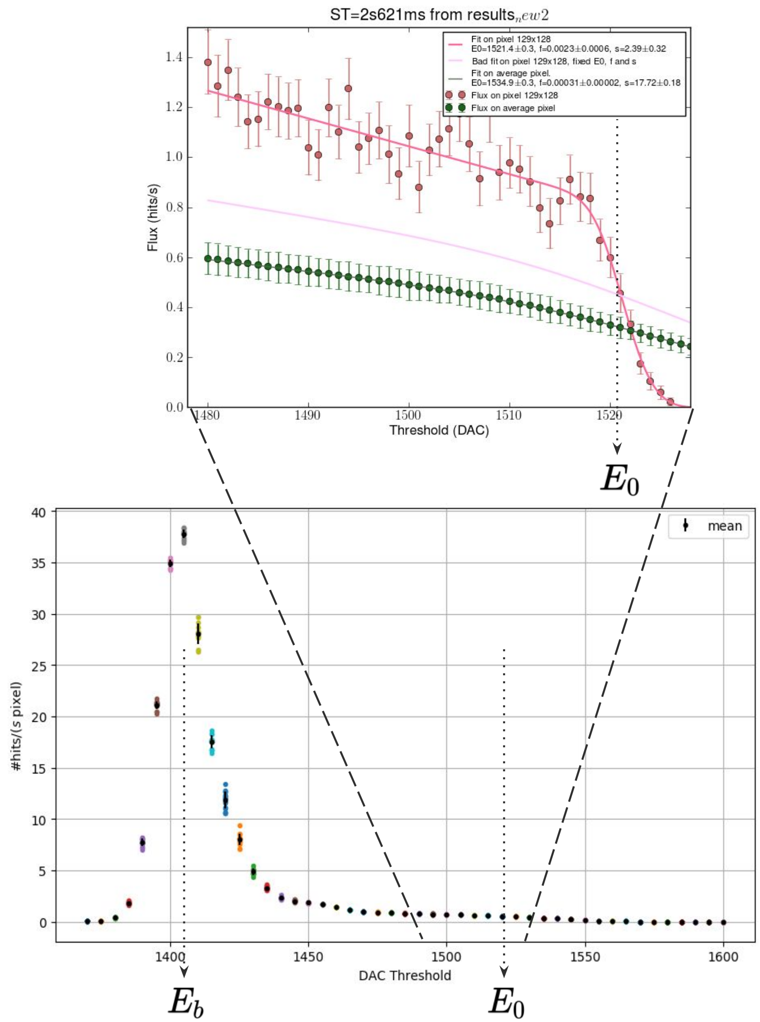

Theory: Flux Models

Other possibilities:

$$F_{1,0}(E) = Af \cdot \frac{1}{2}\left(\frac{s}{\sqrt{\pi}} e^{-\left(\frac{E-E0}{s}\right)^2} + (E0 - E) \cdot \operatorname{erfc}\left(\frac{E-E0}{s}\right)\right) + A(1-f) \cdot \frac{1}{s\sqrt{8\pi}} \cdot \operatorname{erfc}\left(\frac{E-E0}{s\sqrt{2}}\right)$$

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

Notation

$F_{1,0}$

Model name, with term0

Using a different parametrization: *AB model* $A^* = \frac{1}{2} f A, \quad B^* = \frac{1}{2}(1-f)A$

$$F_{AB,0}(E) = A^* \cdot \left(\frac{s}{\sqrt{\pi}} e^{-\left(\frac{E-E0}{s}\right)^2} + (E0 - E) \cdot \operatorname{erfc}\left(\frac{E-E0}{s}\right)\right) + B^* \cdot \frac{1}{s\sqrt{2\pi}} \cdot \operatorname{erfc}\left(\frac{E-E0}{s\sqrt{2}}\right)$$

$$F_{AB}(E) = A^* \cdot (E0 - E) \operatorname{erfc}\left(\frac{E-E0}{s}\right) + B^* \cdot \frac{1}{s\sqrt{2\pi}} \cdot \operatorname{erfc}\left(\frac{E-E0}{s\sqrt{2}}\right)$$

Theory: Flux Models

Other possibilities:

$$F_{1,0}(E) = Af \cdot \frac{1}{2}\left(\frac{s}{\sqrt{\pi}} e^{-\left(\frac{E-E0}{s}\right)^2} + (E0 - E) \cdot \mathrm{erfc}\left(\frac{E - E0}{s}\right)\right) + A(1-f) \cdot \frac{1}{s\sqrt{8\pi}} \cdot \mathrm{erfc}\left(\frac{E - E0}{s\sqrt{2}}\right)$$

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Notation

$F_{1,0}$

Model name, with term0

Using various *s* parameters: *2s* model

$$F_{2s,0}(E) = Af \cdot \frac{1}{2}\left(\frac{s_1}{\sqrt{\pi}} e^{-\left(\frac{E-E0}{s_1}\right)^2} + (E0 - E) \cdot \mathrm{erfc}\left(\frac{E-E0}{s_1}\right)\right) + A(1-f) \cdot \frac{1}{s_2\sqrt{8\pi}} \cdot \mathrm{erfc}\left(\frac{E-E0}{s_2\sqrt{2}}\right)$$

$$F_{2s}(E) = \frac{1}{2} fA \cdot (E0 - E)\, \mathrm{erfc}\left(\frac{E-E0}{s_1}\right) + \frac{1}{2}(1-f)A \cdot \frac{1}{s_2\sqrt{2\pi}} \cdot \mathrm{erfc}\left(\frac{E-E0}{s_2\sqrt{2}}\right)$$

$$F_{2s,AB}(E) = A^* \cdot (E0 - E) \cdot \mathrm{erfc}\left(\frac{E-E0}{s_1}\right) + B^* \cdot \frac{1}{s_2\sqrt{2\pi}} \cdot \mathrm{erfc}\left(\frac{E-E0}{s_2\sqrt{2}}\right)$$

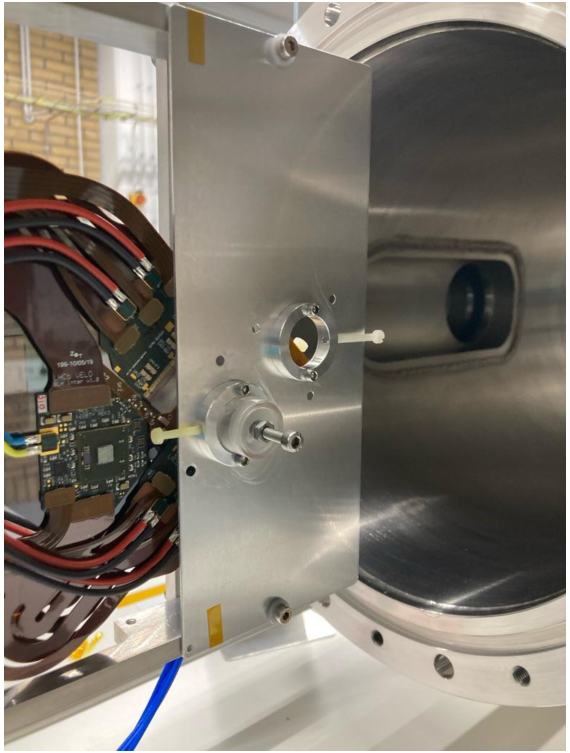
Data and other specifics

Setup:

- Module at Nikhef for testing
- Cooling system used for data taking

Some data specifics:

- Two module temperatures, with same distance
- “Module production” equalisation
- MiniDAQ2 (data acquisition equipment)



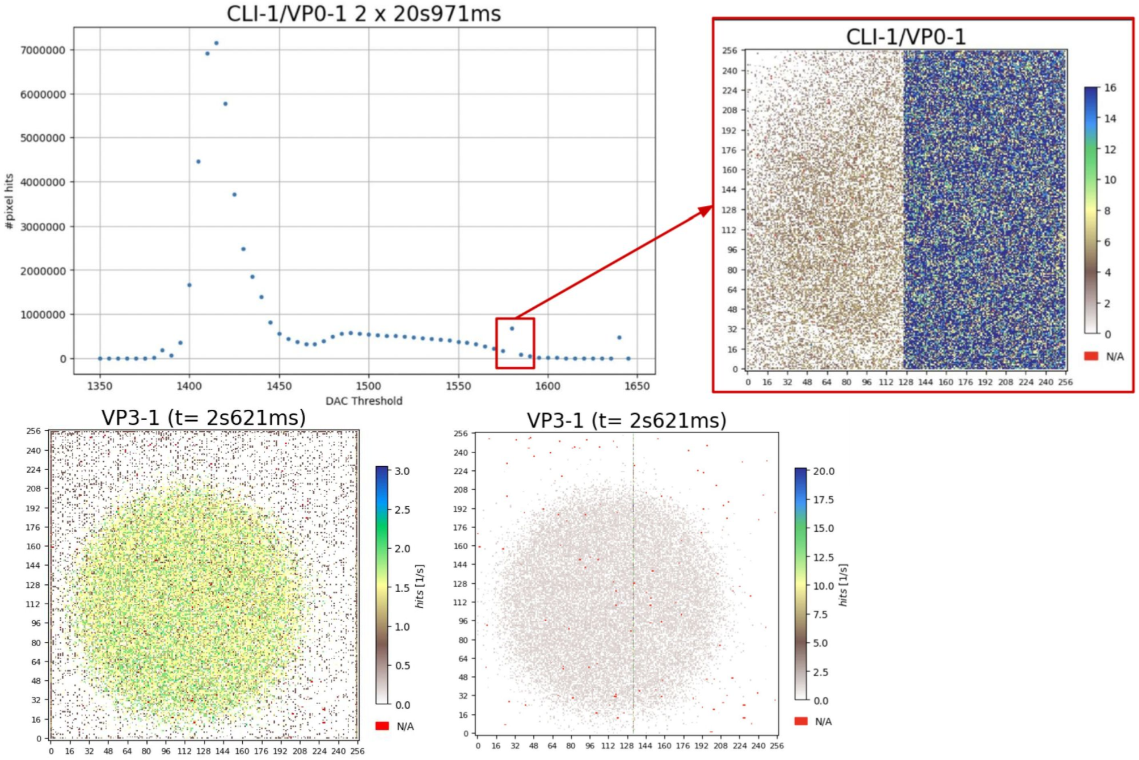
Set	Label	Module Temp.	ASIC	ST	nacq	Thr_{min}	Thr_{max}	Thr_{step}	Total time (h)
1	Cold	-20ºC	VP3-1	2 s621 ms	50	1480	1600	1	4.36
2	Warm	20ºC	VP3-1	2 s621 ms	100	1480	1600	1	8.73

Data and other specifics

Filtering:

Anomalies are removed.

Acquisitions that are empty or considered bad



thr=1494, acq=18

thr=1527, acq=78

Data and other specifics

Fitting and Pixel Categorisation:

$$\chi^2 = \sum_i \left(\frac{O_i - F_i}{U_i} \right)^2 ,$$

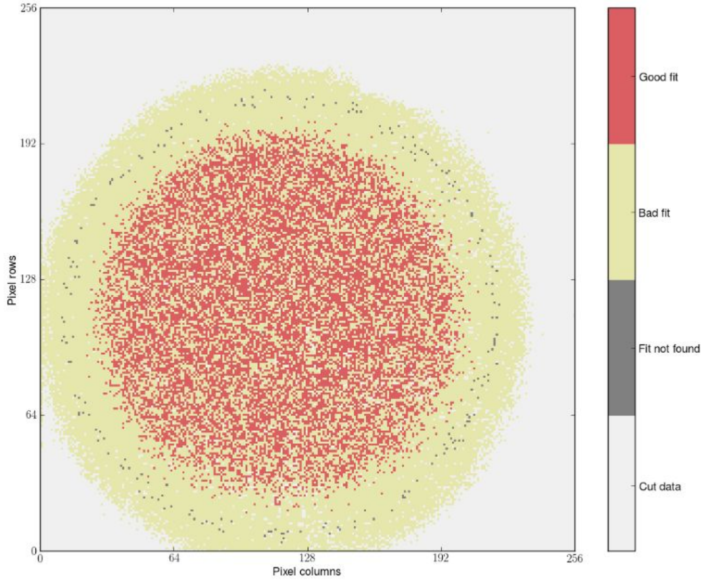
χ_c^2 with $\alpha = 0.05$ and dof $= n - 4$

Good: fit found and $\chi^2 < \chi_c^2$

Bad: fit found but $\chi^2 > \chi_c^2$ or unphysical parameters

Fit not found: not converging

Cut data: no enough data, faulty or masked



Cold

Data and other specifics

Average behaviour of pixels:

- **Mean**
- **ASIC**
  - *Represents the average flux on the whole ASIC.*
  - *Takes into account bad fit pixels → not an accurate representation?*
- **ASICgood**
  - *Uses only good fit pixels → probably less biased*

Throughout analysis looking at:

Distributions + Mean, ASIC & ASICgood

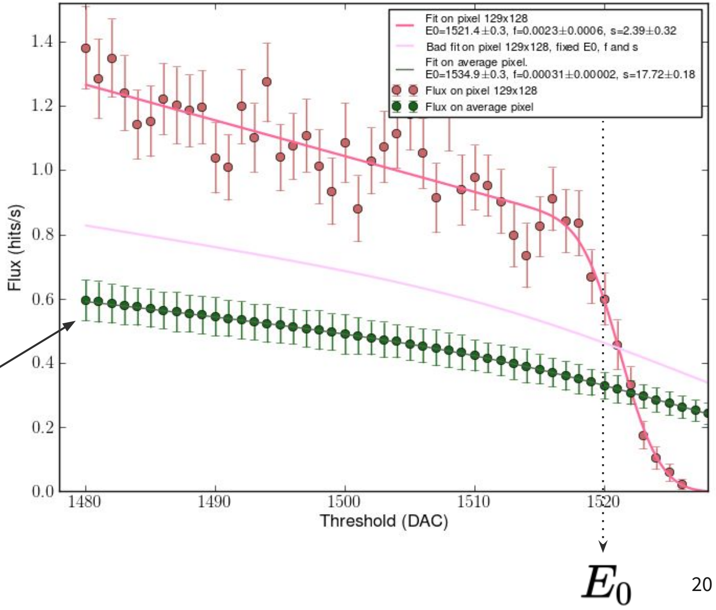
Can we say anything about the individual pixels from looking at the ASIC flux?

Analysis

Fit the data to the Flux equation allows us to:

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

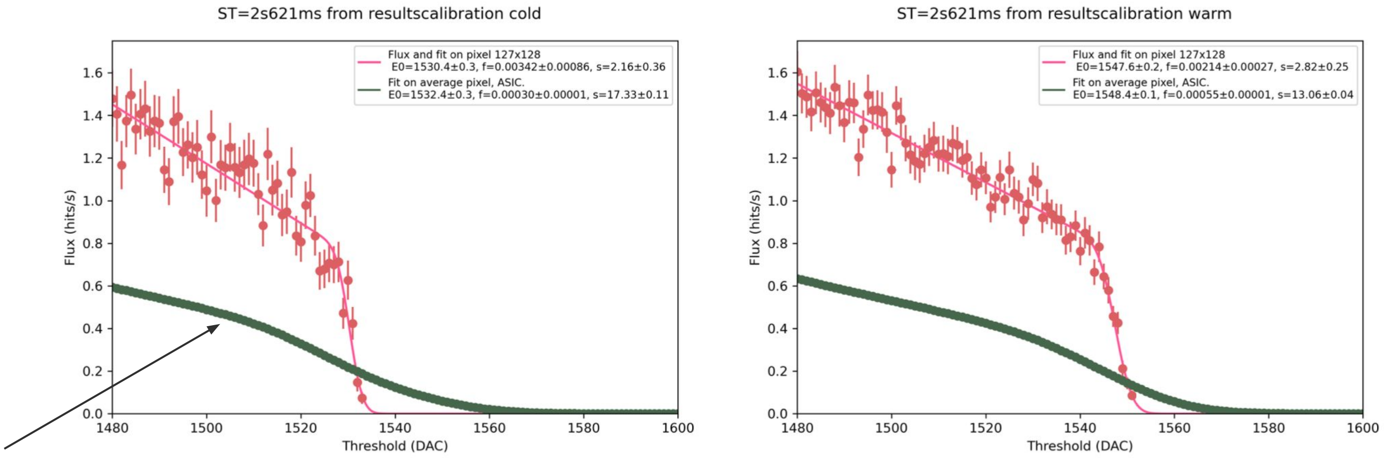
- Categorise pixels
- Obtain physical parameters: E0
- Target and gain K[e-/DAC]



ASIC / average

Analysis: Flux

Individual vs Average/ASIC



ASIC / average

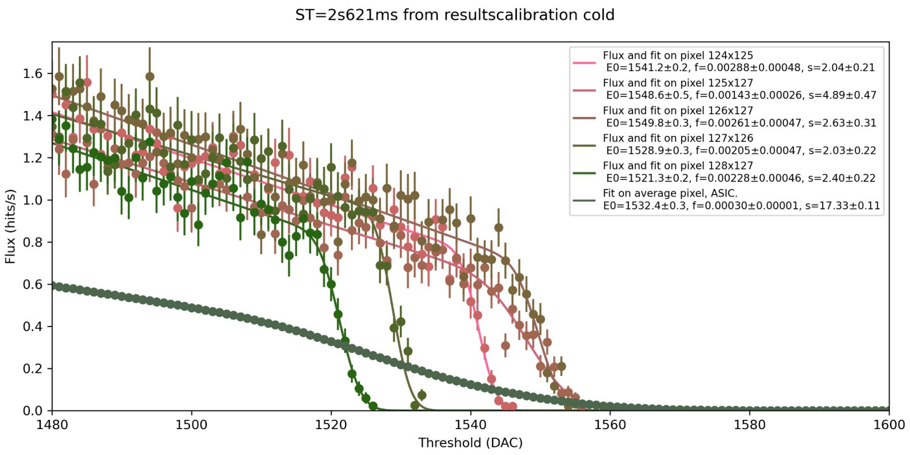
(a) Flux over threshold from the cold dataset.

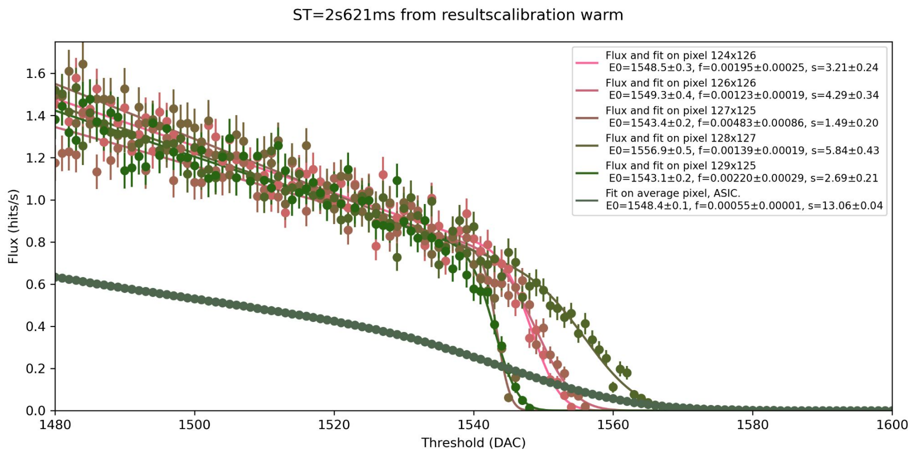
(b) Flux over threshold from the warm dataset.

Figure 9: Average and individual pixel 127 x 128 flux comparison for both the cold and warm dataset. The pink data points and line correspond to the individual pixel and the green data points and line to the average/ASIC flux.

Analysis: Flux

Individual vs Average/ASIC



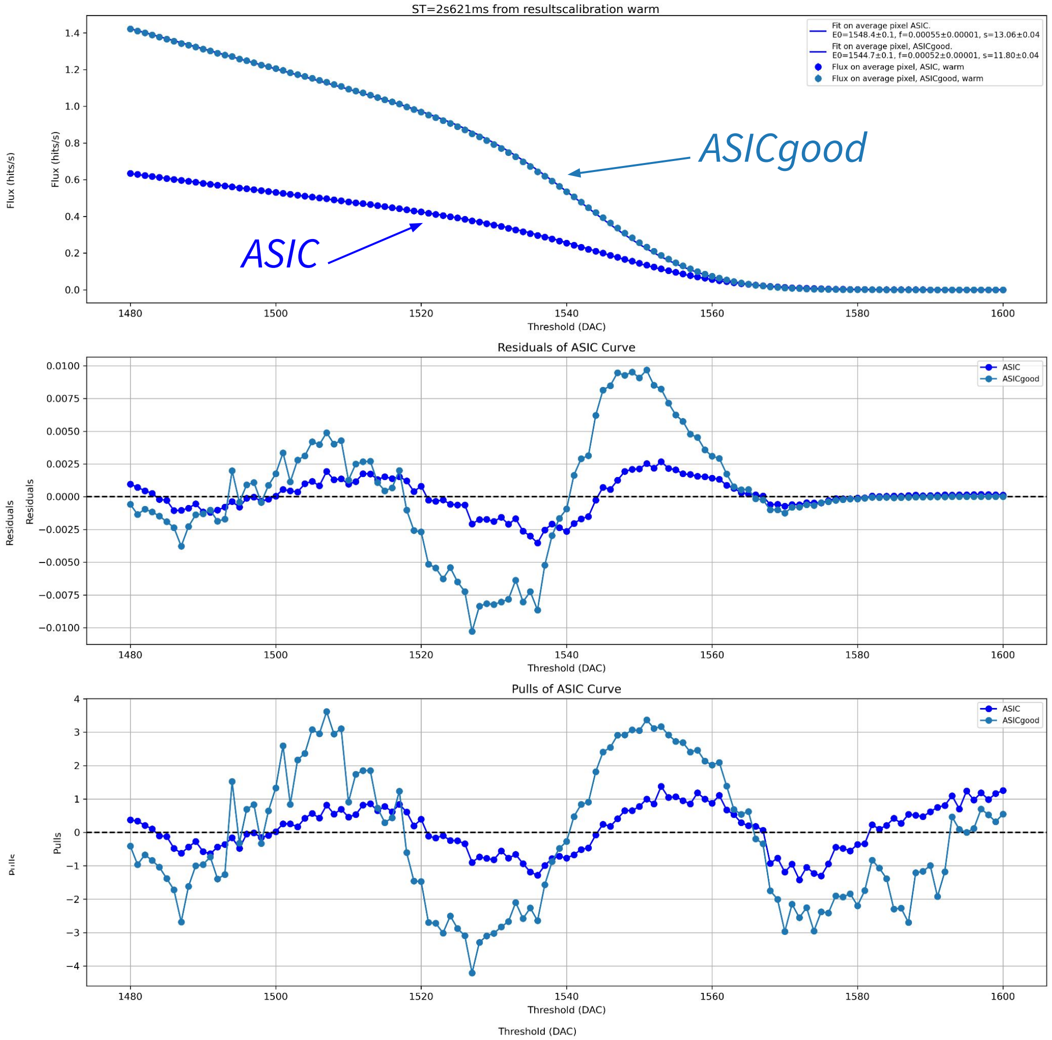


Analysis: Fitting

Individual vs Average/ASIC

Best flux model used here: $F_{1,0}$

$$p_{thr} = \frac{r_{thr}}{\Delta F_{\text{raw },thr}} = \frac{F_{\text{raw },thr} - F_{\text{fit },\text{thr}}}{\Delta F_{\text{raw },thr}}$$



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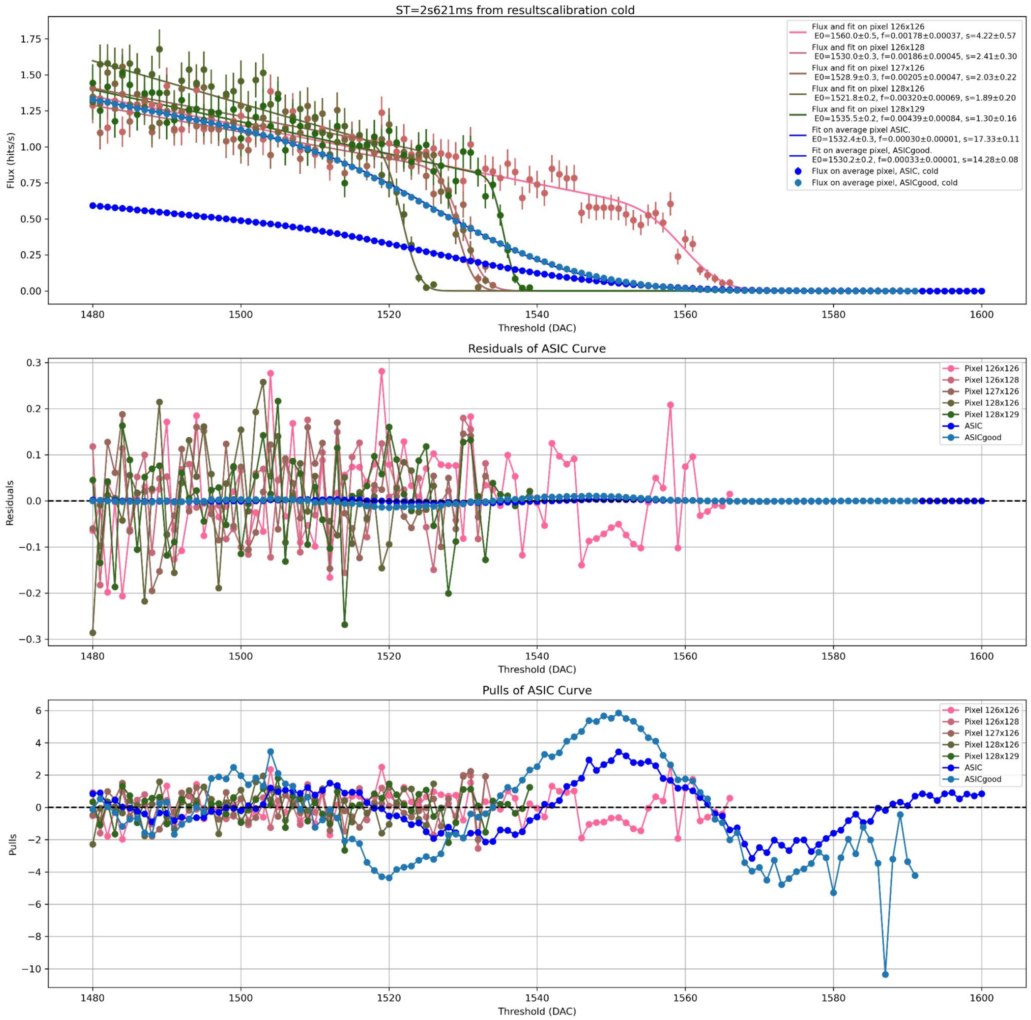

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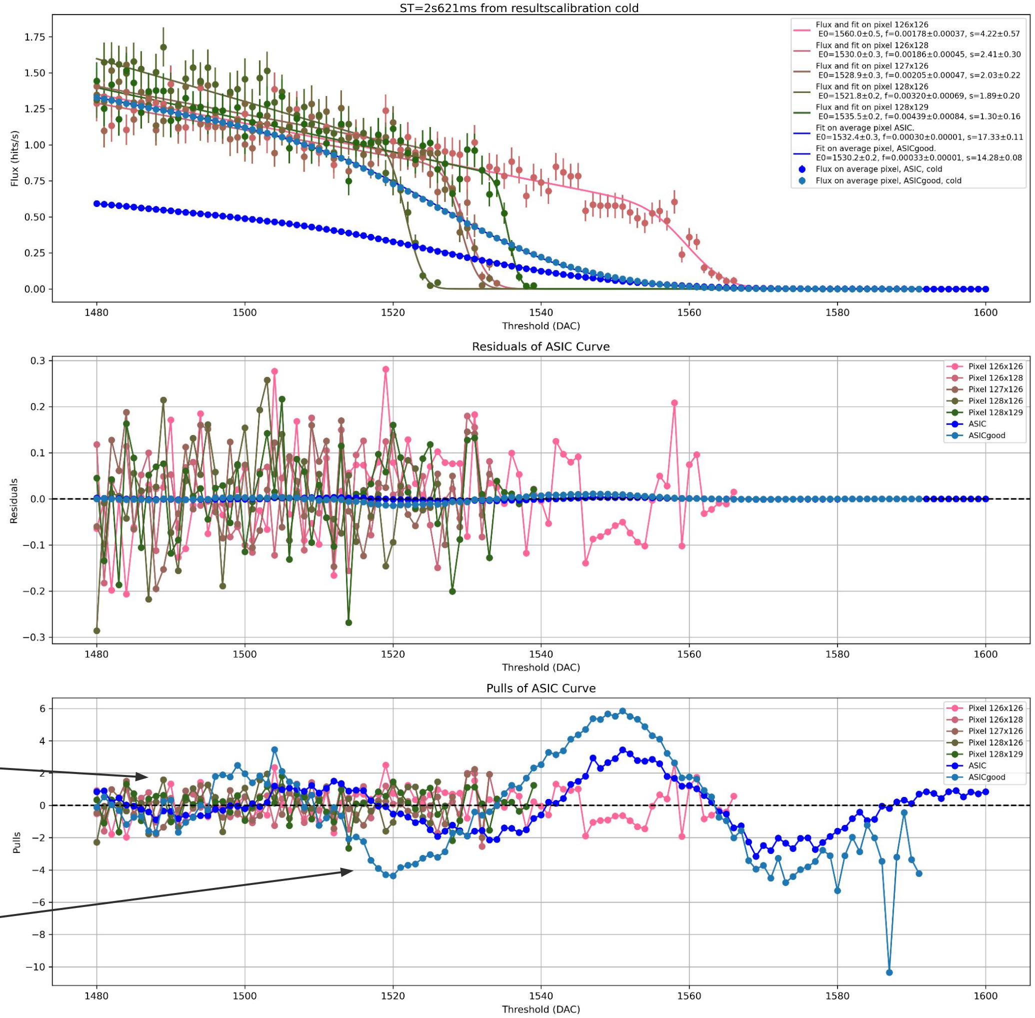
Pixels:

Fits are still acceptable

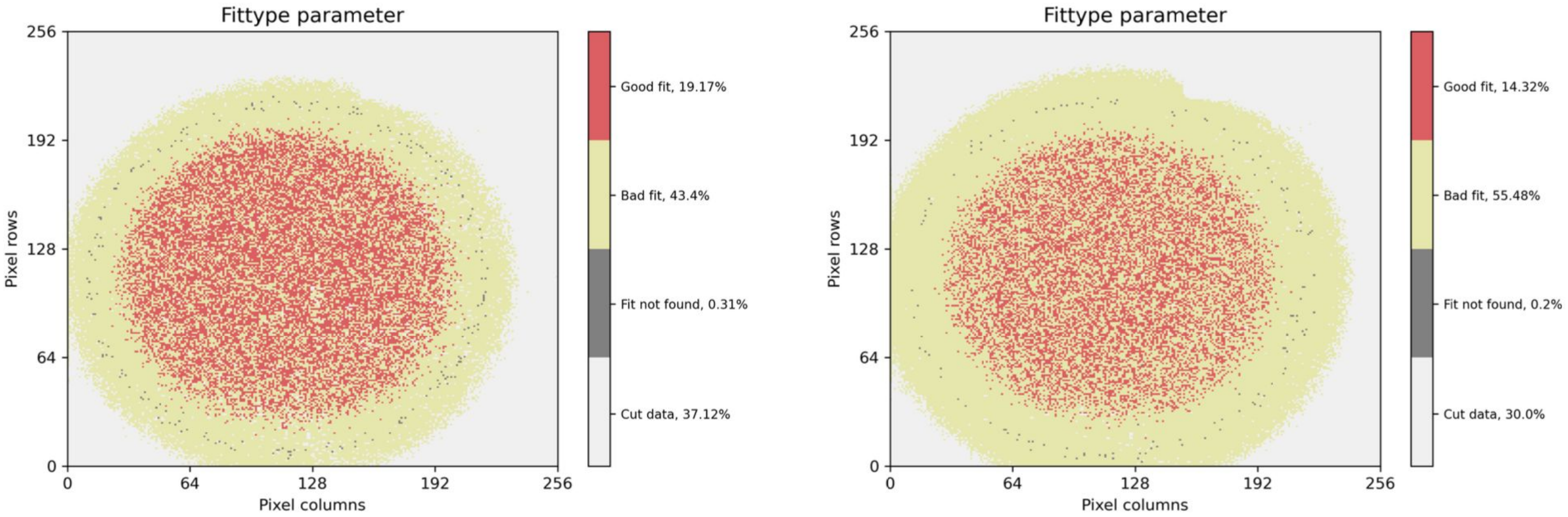
***ASIC*:**

Regions with clear fitting issues



Analysis: Fitting

Pixel Categorisation



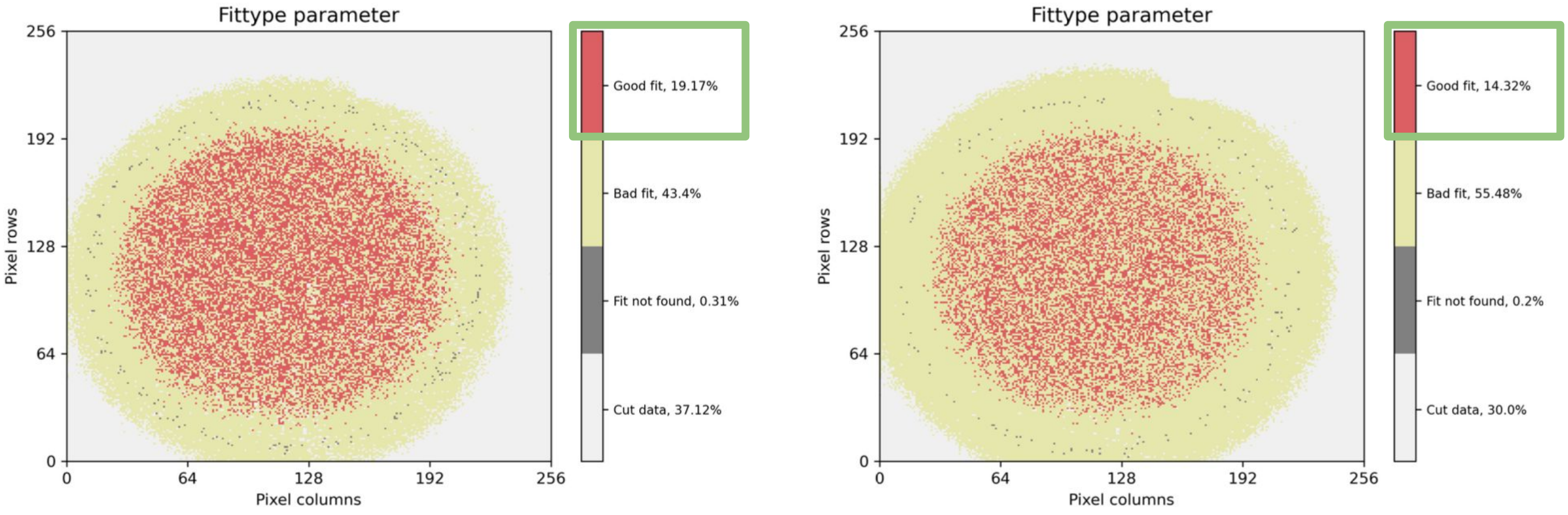
(a) Cold dataset.

(b) Warm dataset.

Figure 13: Heatmaps showing fit type category given to the individual pixels for the *cold* and *warm* dataset.

Analysis: Fitting

Pixel Categorisation

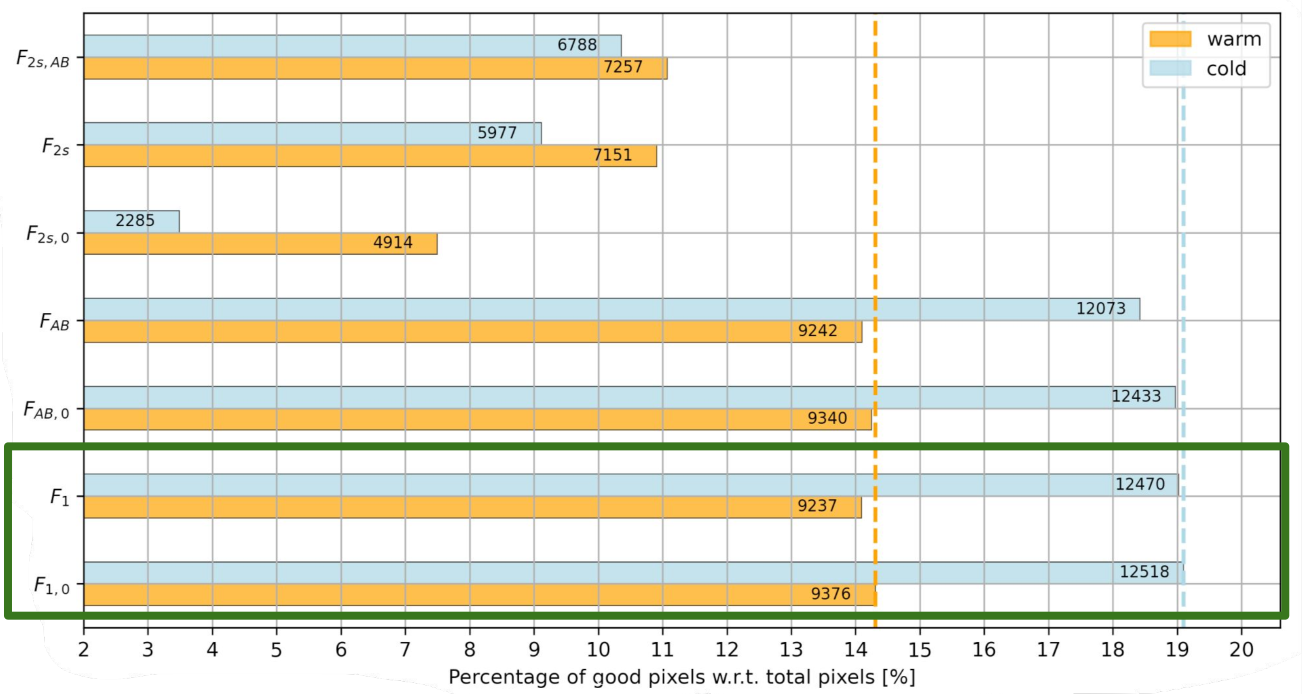


(a) Cold dataset. (b) Warm dataset.

Figure 13: Heatmaps showing fit type category given to the individual pixels for the *cold* and *warm* dataset.

Analysis: Fitting

Testing other flux models



Main model used

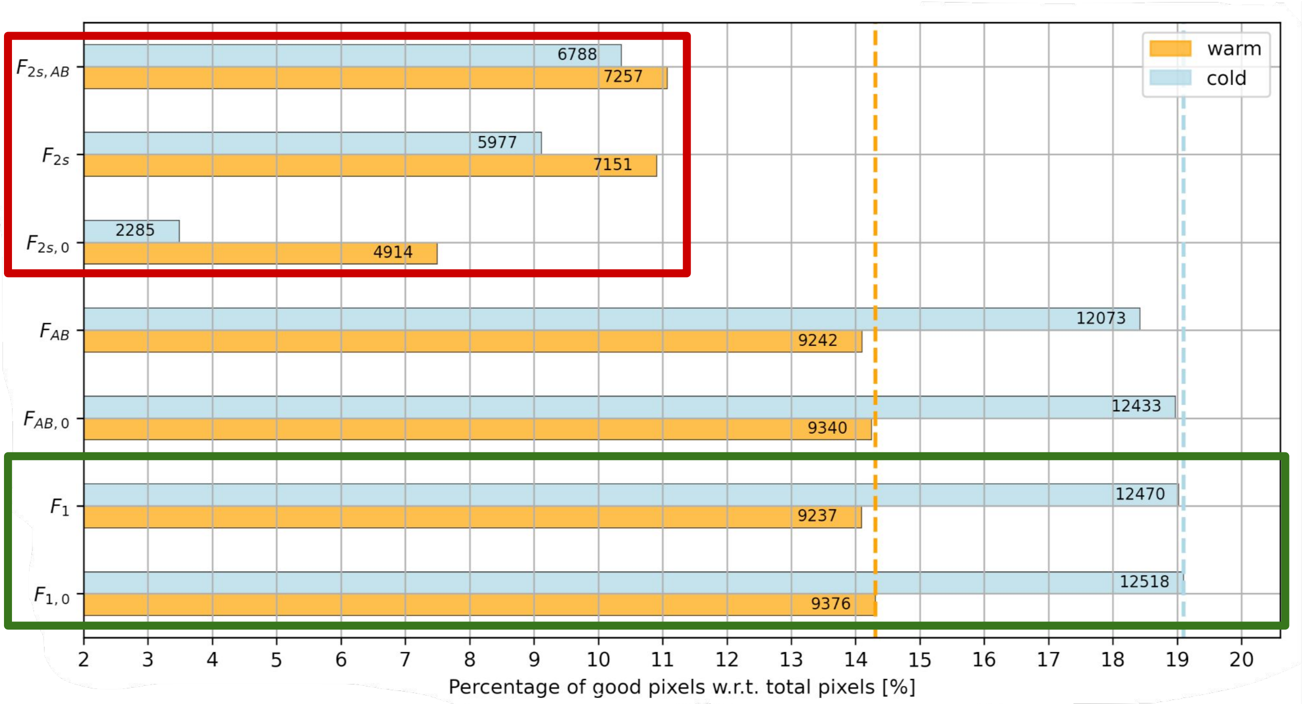
Analysis: Fitting

Testing other flux models

2s model:

It does not fit well

Main model used



Analysis: Fitting

Testing other flux models

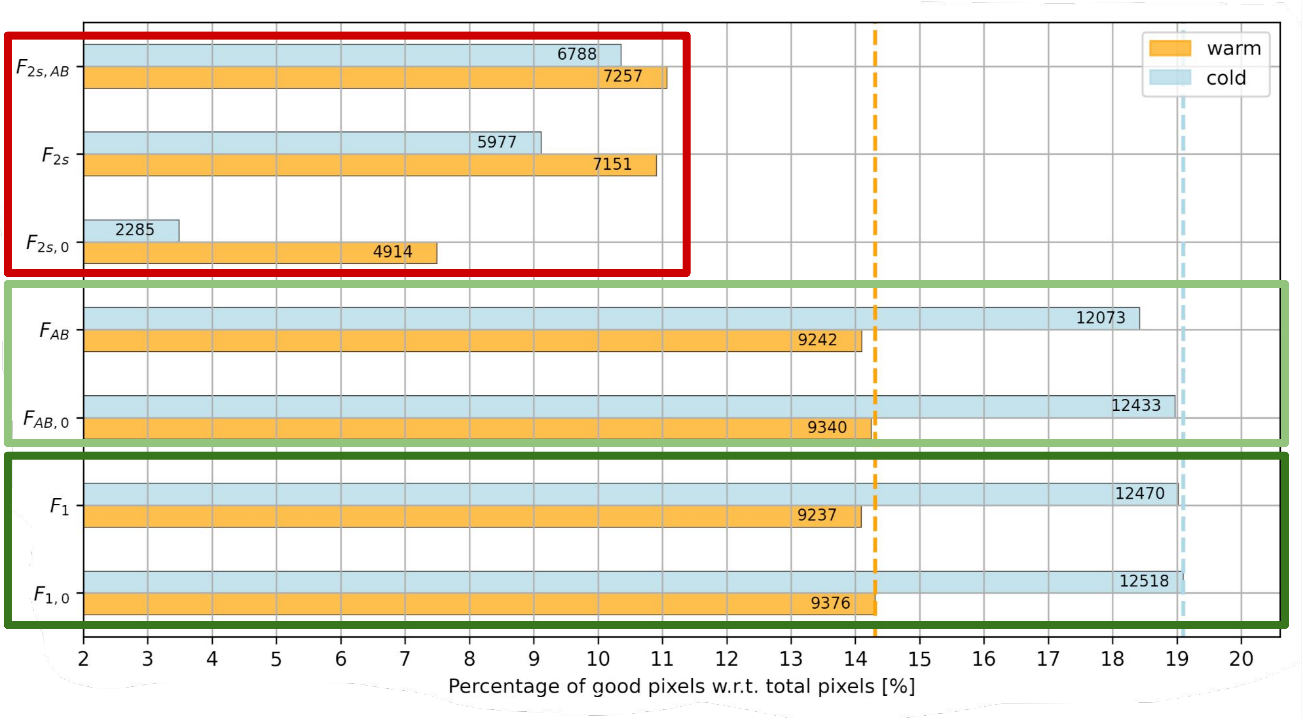
2s model:

It does not fit well

AB model:

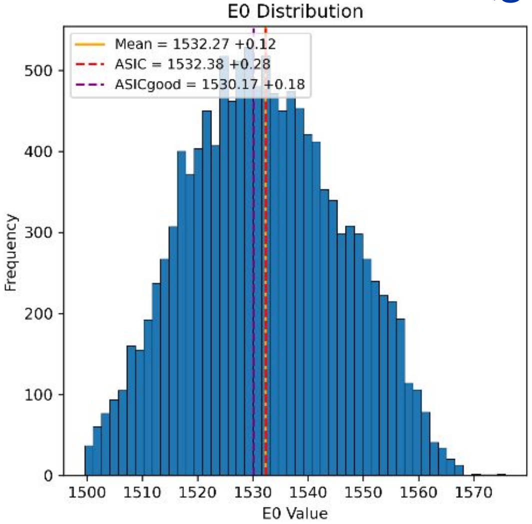
Equivalent to

Main model used

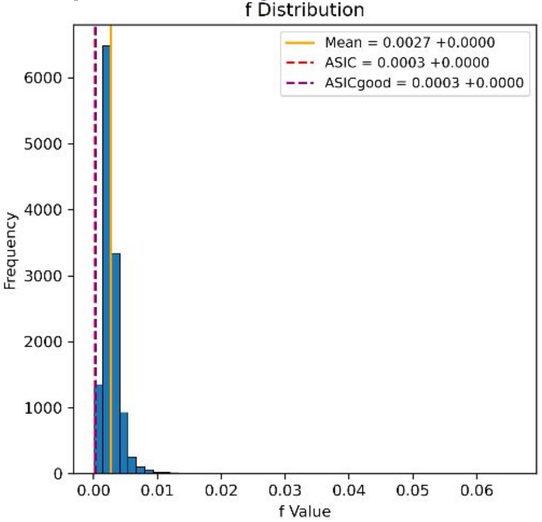


Analysis: Parameters

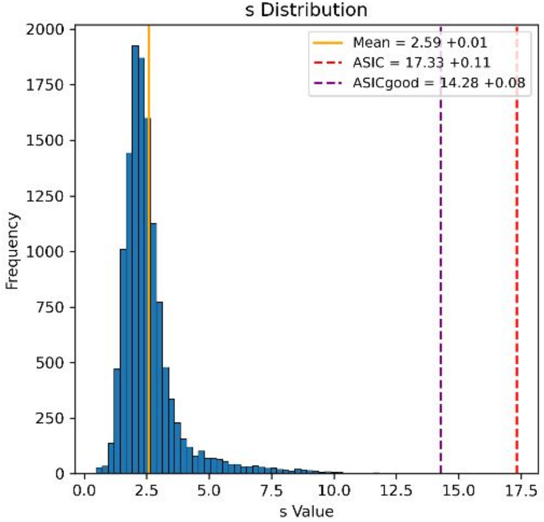
Parameter distributions (good pixels only)



E0: Threshold of flux drop



f: Charge sharing fraction

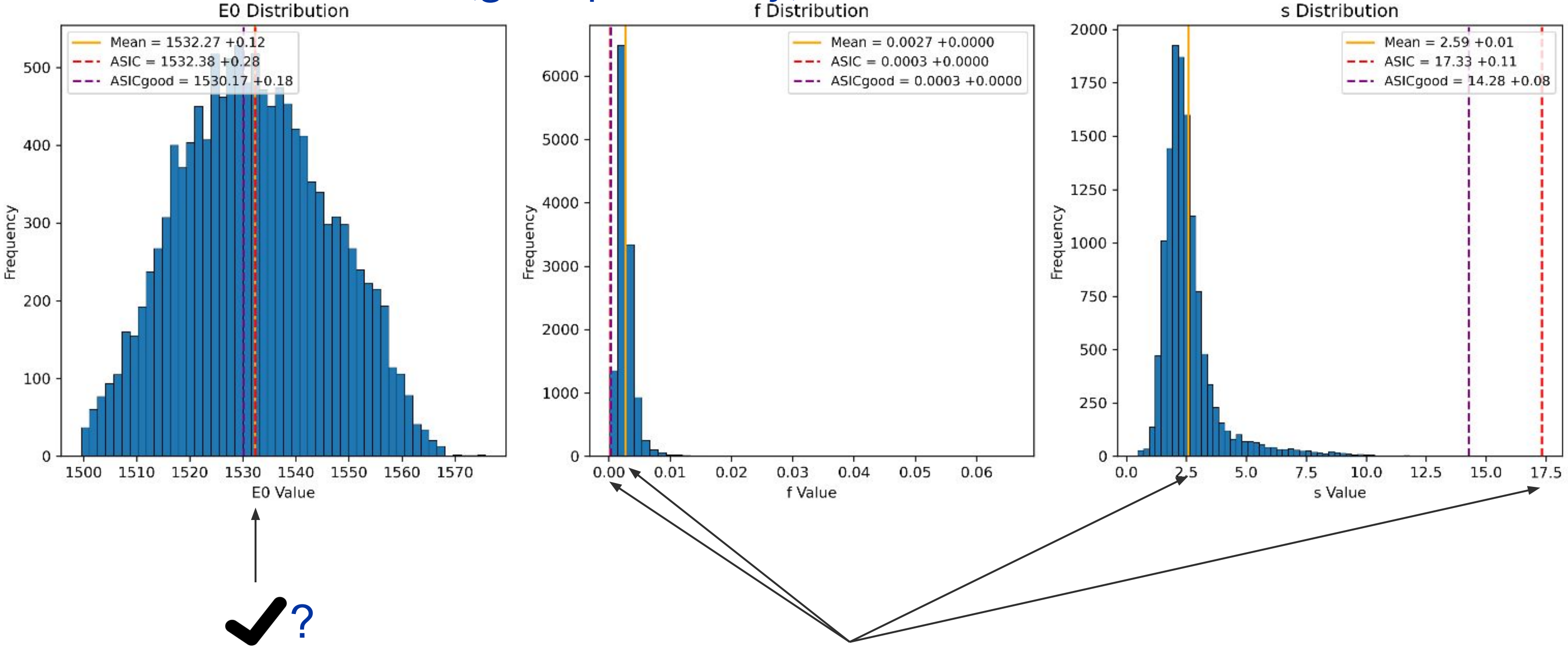


s: Spread around E0, Sharpness of flux drop

Cold

Analysis: Parameters

Parameter distributions (good pixels only)



Cold

Difference between individual vs ASIC ⇒ Is ASIC value a good choice?

Analysis: Target

We know that:

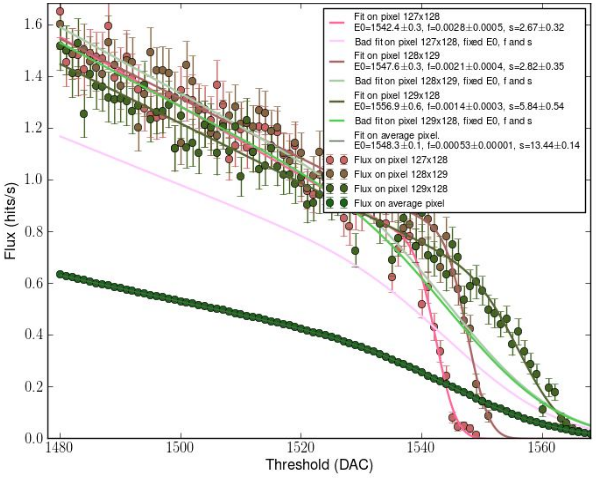
All pixels should agree on the energy deposition

Shift in E_0 due to pixel variations

We can use $target = E_0 - E_b$ to:

- Correct for pixel-to-pixel variations
- Obtain energy deposition

Cold



Analysis: Target

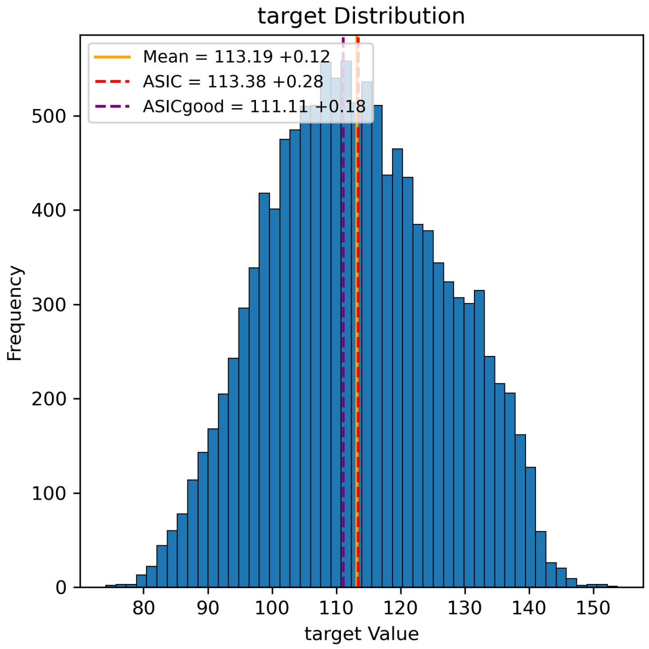
Calculation of $target = E_0 - E_b$ **→ need** E_b

Individual pixel values

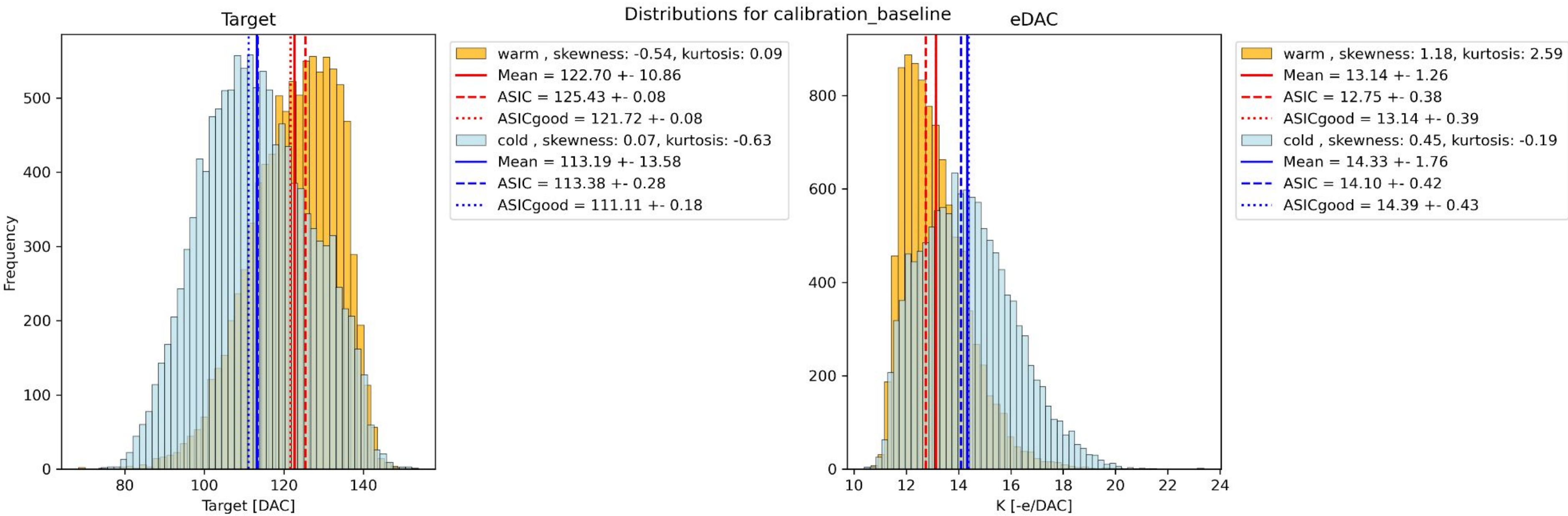
- E_b using the best prediction from equalisation

ASIC and ASICgood

- $E_{bASIC} = \overline{E_b}$, $target_{ASIC} = E_{0ASIC} - E_{bASIC}$

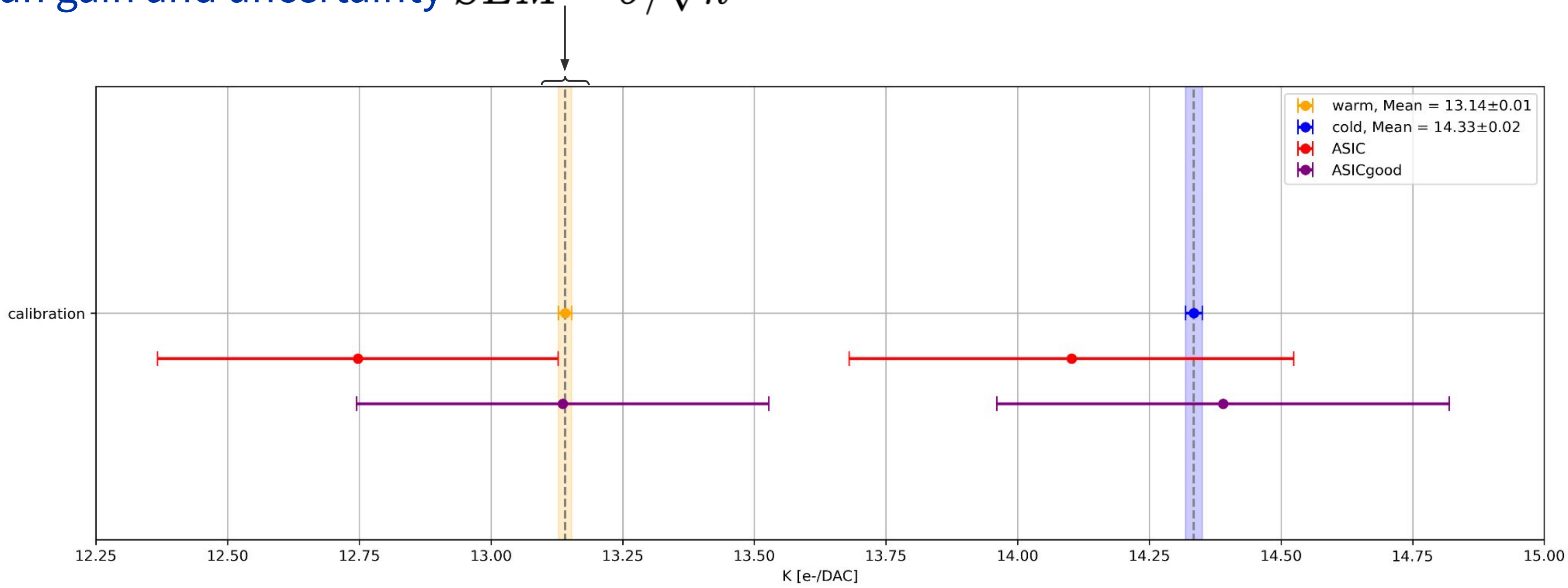


Analysis: Target and e-/DAC



Analysis: Gain K [e-/DAC]

Mean gain and uncertainty $SEM = \sigma/\sqrt{n}$



Systematic uncertainties and biases

Exposure time influence

Warm dataset has twice as much exposure time

Set	Label	Module Temp.	ASIC	ST	nacq	Thr_{min}	Thr_{max}	Thr_{step}	Total time (h)
1	Cold	-20ºC	VP3-1	2 s621 ms	50	1480	1600	1	4.36
2	Warm	20ºC	VP3-1	2 s621 ms	100	1480	1600	1	8.73

New dataset variations with equal exposure time on both *warm* and *cold*:

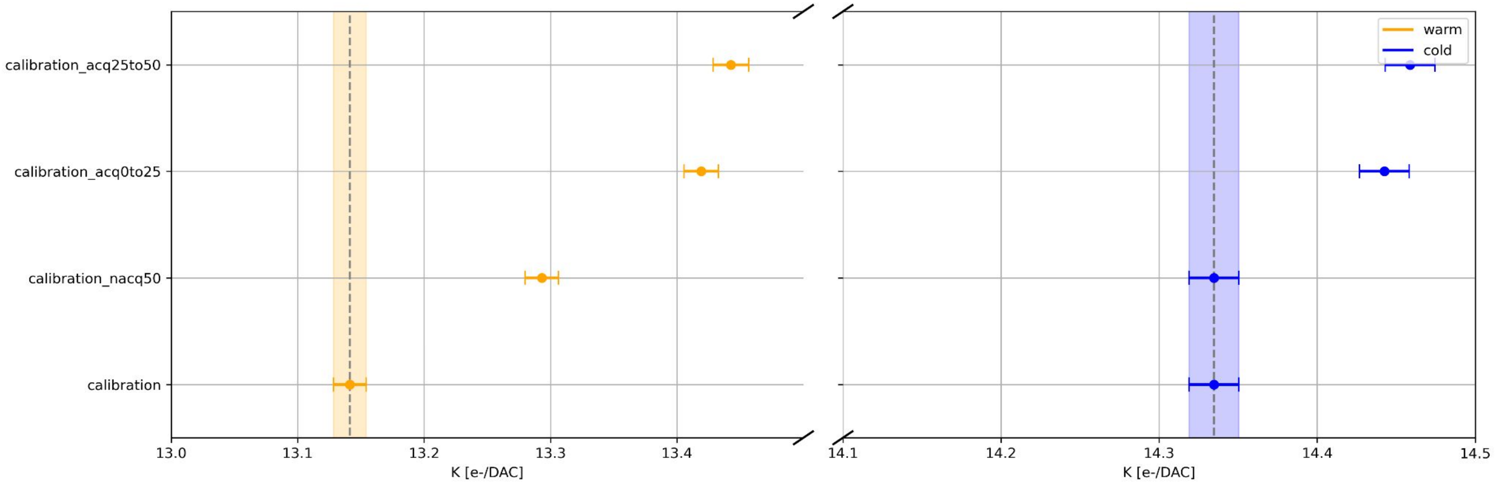
calibration_nacq50: using acquisitions in the [0,50] range.

calibration_acq0to25: acqs in [0,25] range

calibration_acq25to50: acqs in [25,50] range

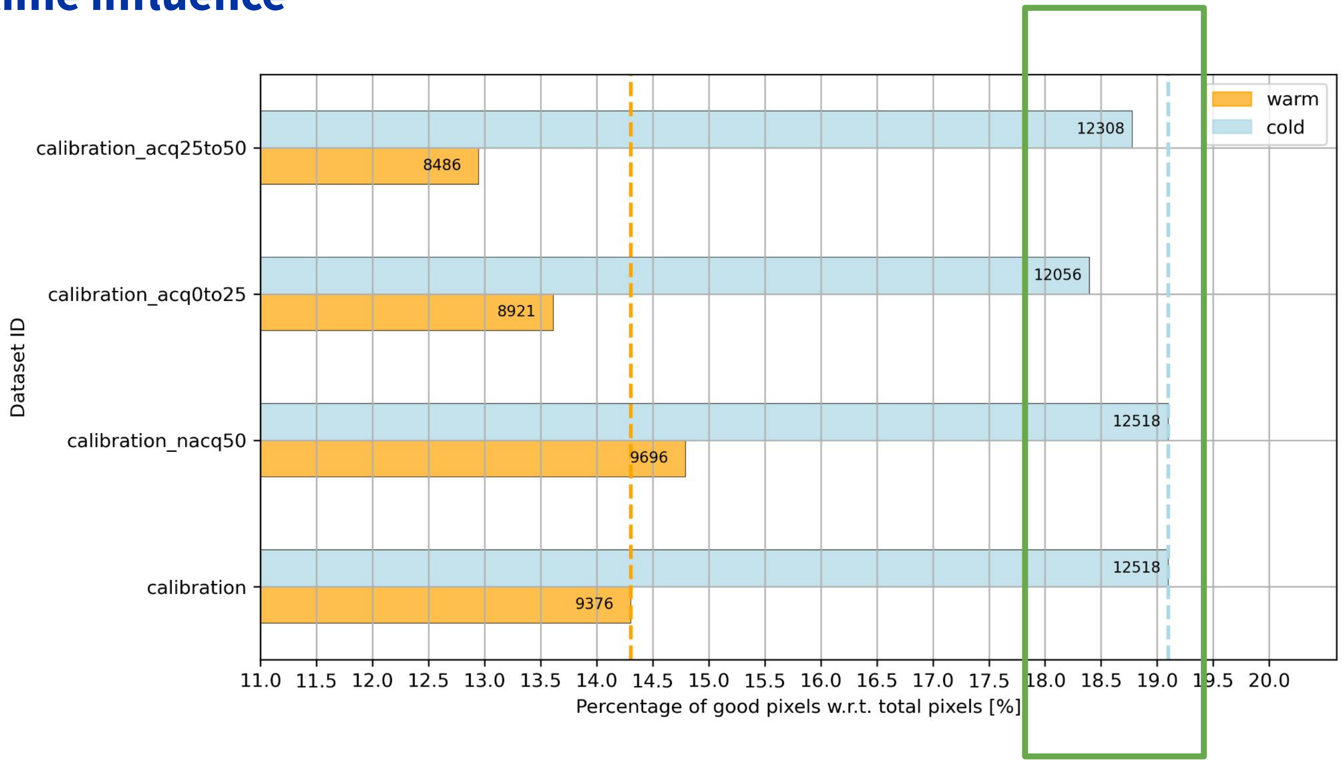
Systematic uncertainties and biases

Exposure time influence



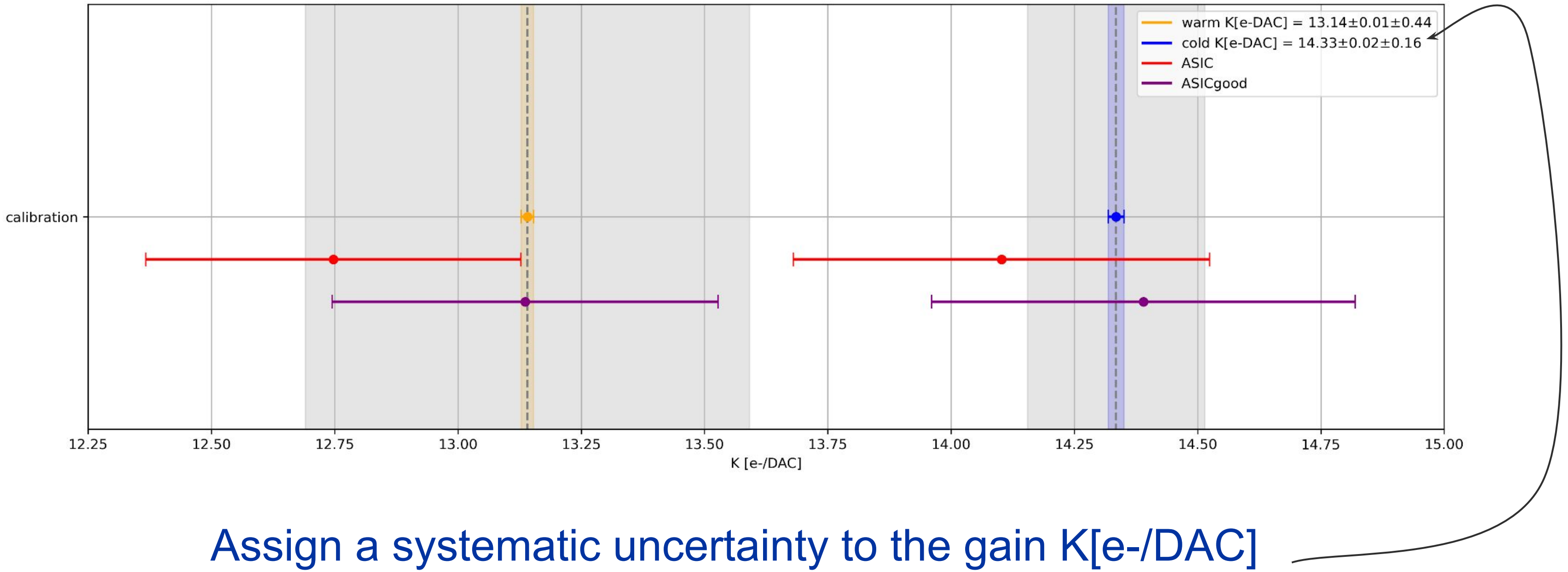
Systematic uncertainties and biases

Exposure time influence



Systematic uncertainties and biases

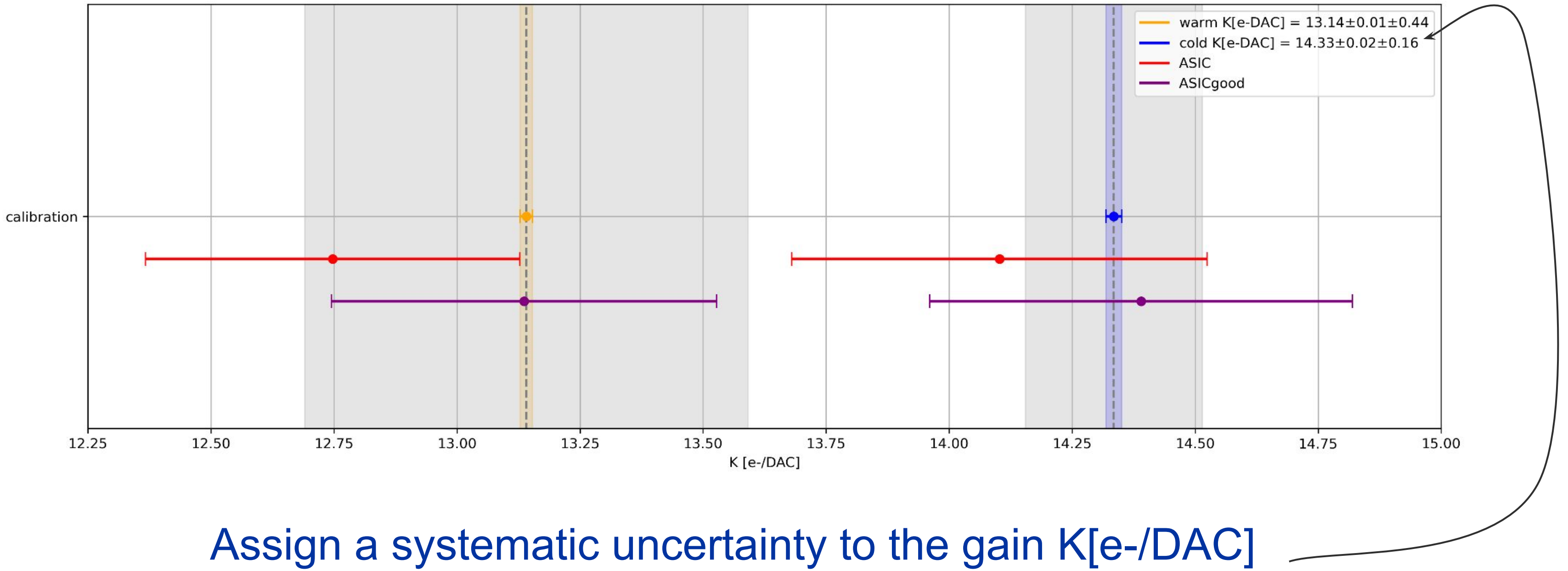
Exposure time influence



Assign a systematic uncertainty to the gain K[e-/DAC]

Systematic uncertainties and biases

Exposure time influence



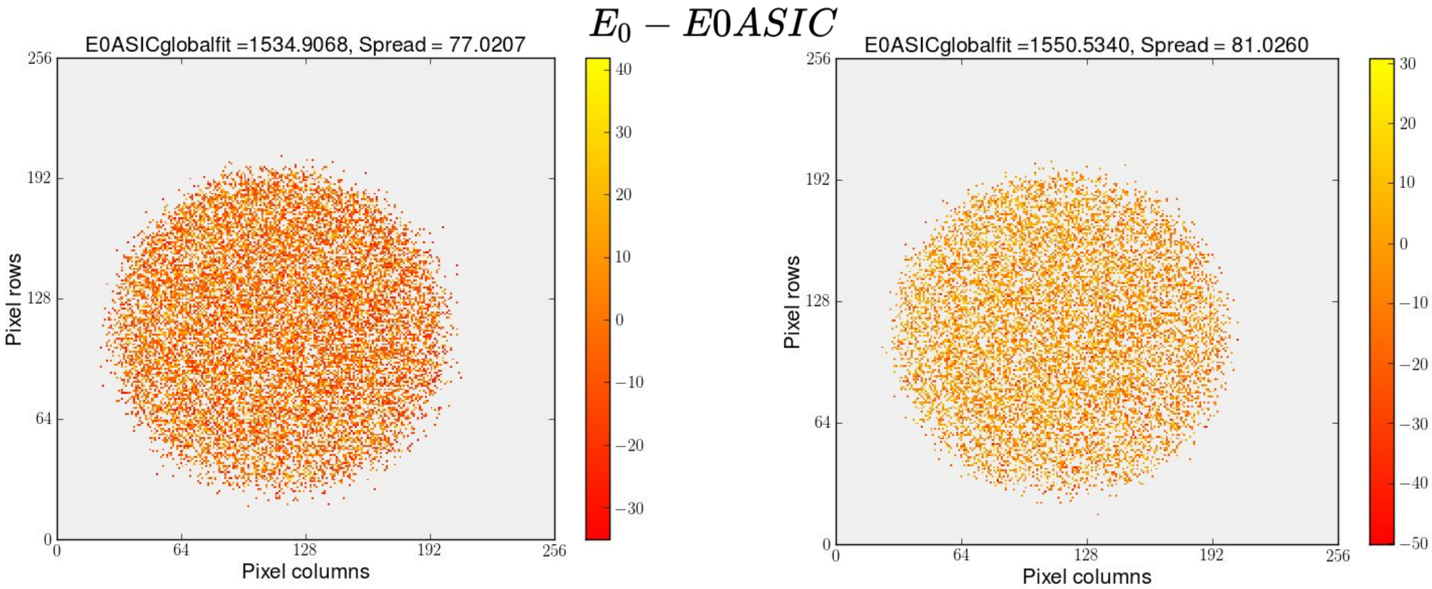
Assign a systematic uncertainty to the gain K[e-/DAC]

ASIC Gain makes a *good* prediction of Mean Gain

Systematic uncertainties and biases

Pixel coordinate bias

Cold



Warm

No correlation of pixel coordinate and value of E0

Systematic uncertainties and biases

Pixel coordinate bias

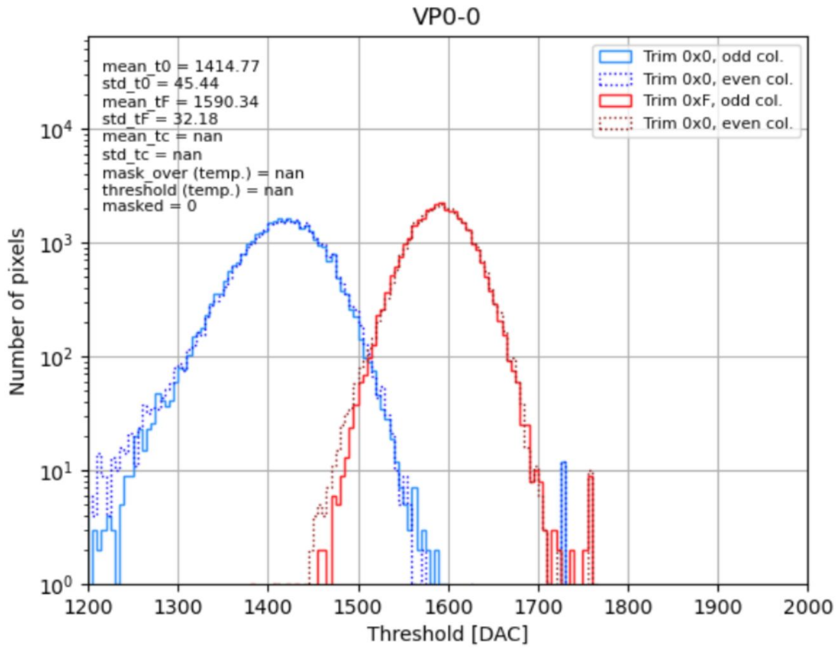
Pattern observed in equalisation

Groups: *even* and *odd* columns + 16ths rows

Based on equalisation approach:

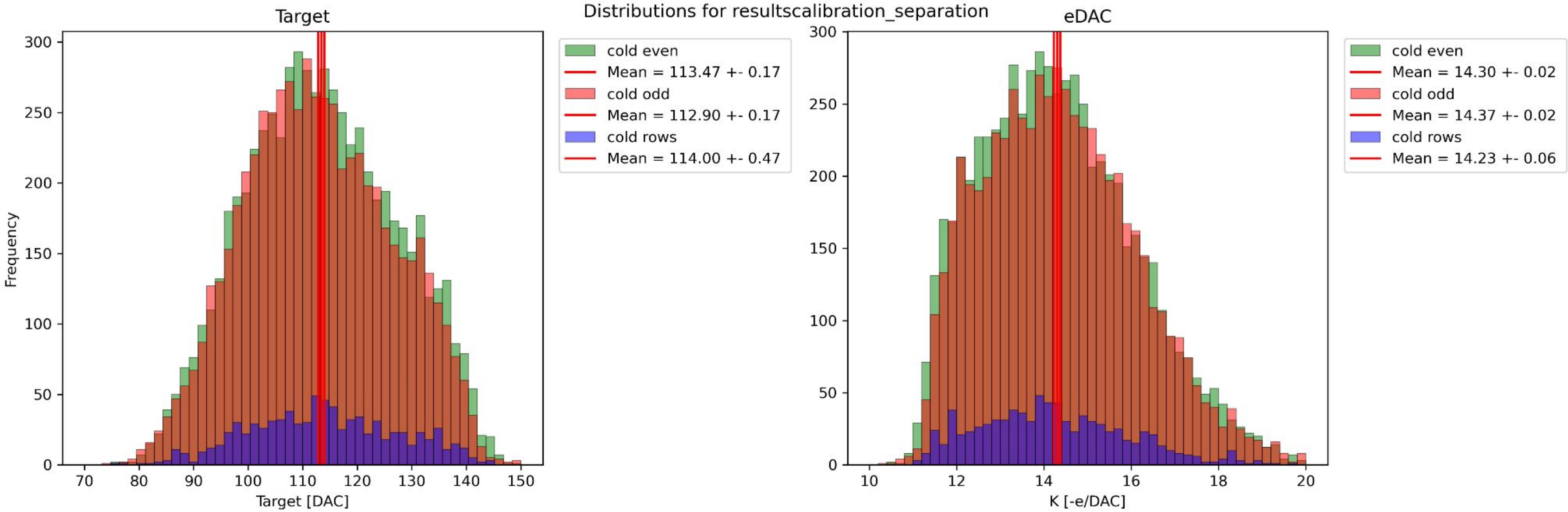
1. Same 3 groups

2. Analyse each group with same procedure



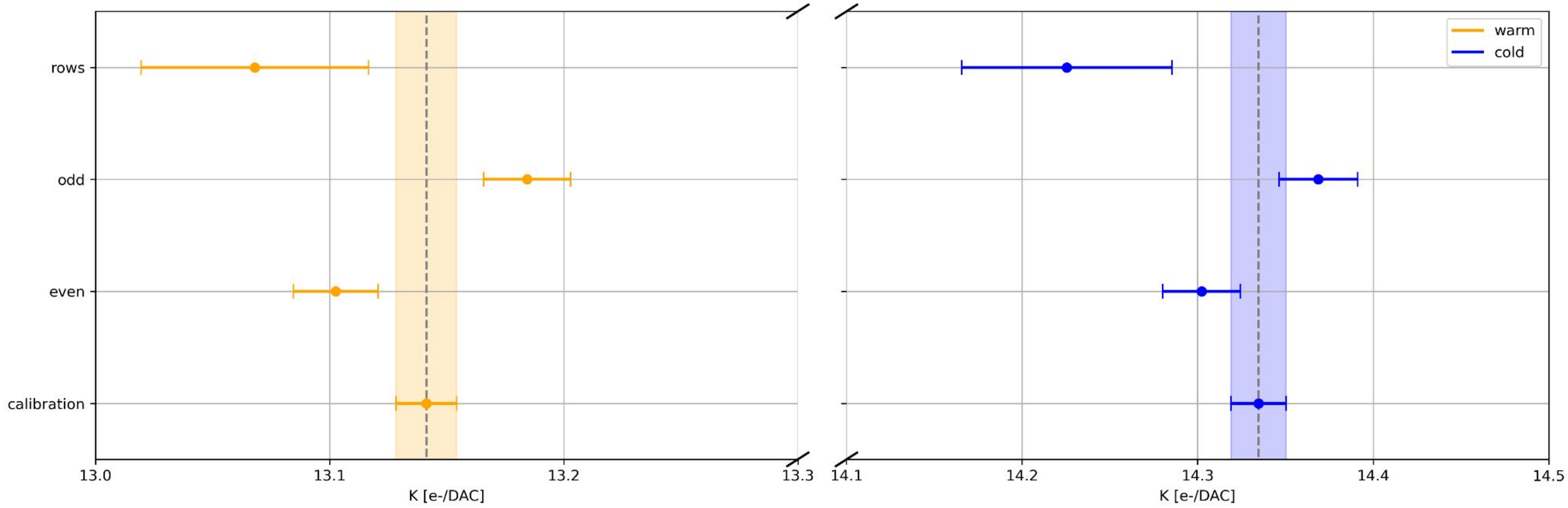
Systematic uncertainties and biases

Pixel coordinate bias



Systematic uncertainties and biases

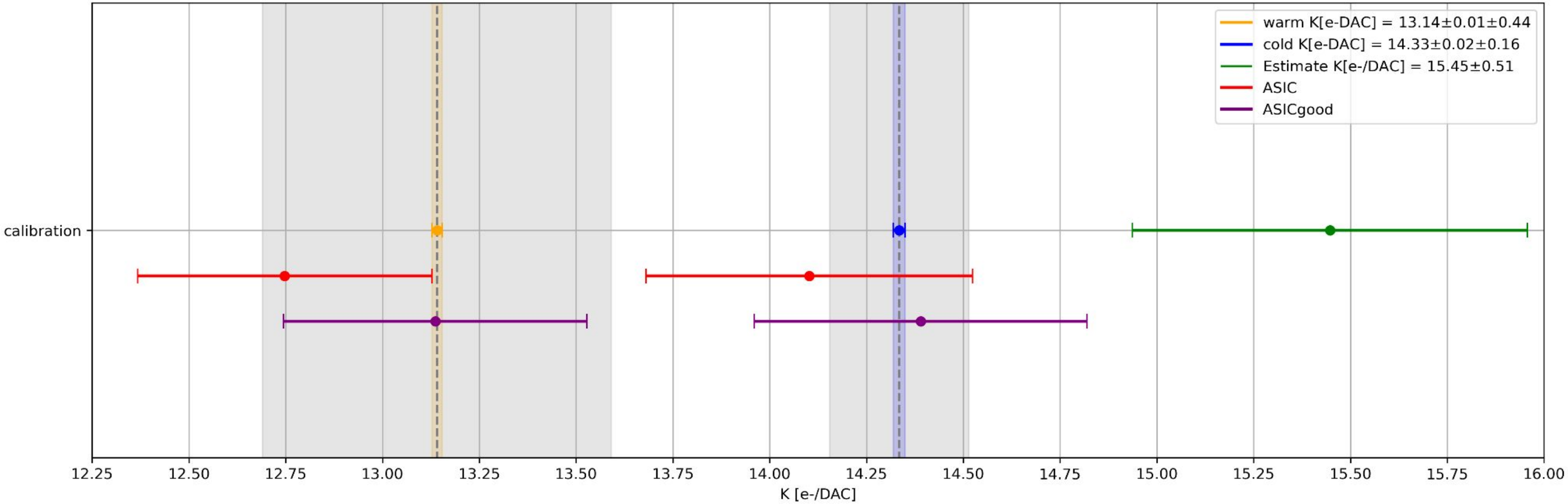
Pixel coordinate bias



Disagreement on mean gain among groups. Bias coming from pixel position.

Conclusions

K [e-/DAC] obtained for two datasets with Fe55 irradiation:

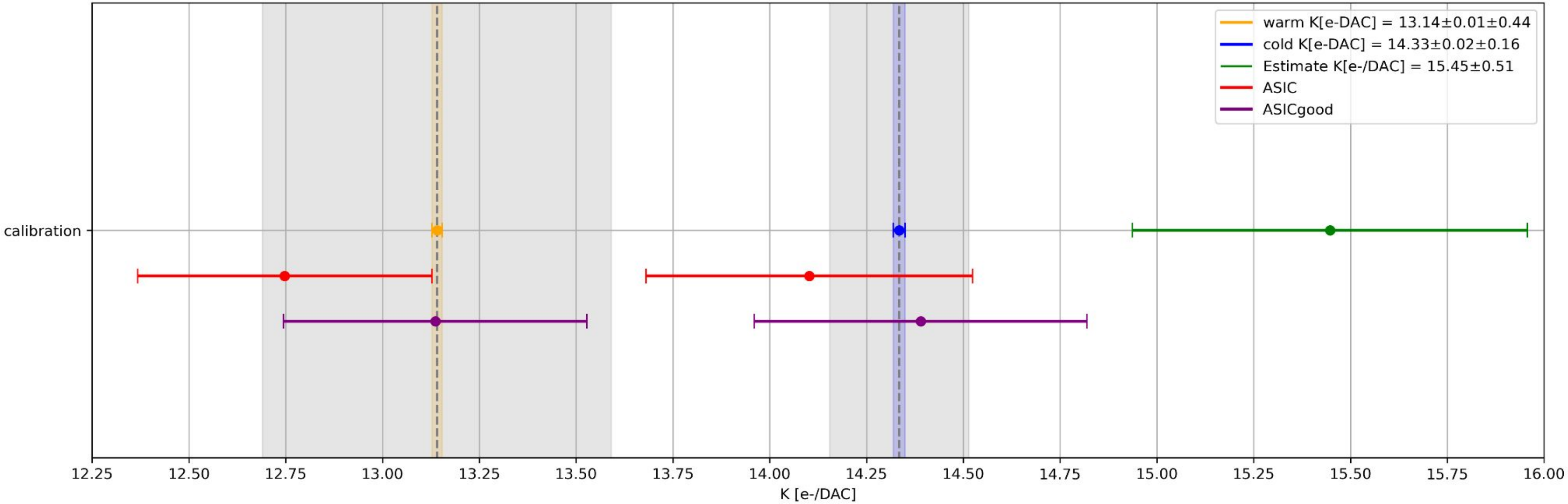


Estimate and cold Mean differ by 2.07σ

Mean Gain found is still somewhat *compatible* with Paper Estimate

Conclusions

K [e-/DAC] obtained for two datasets with Fe55 irradiation:



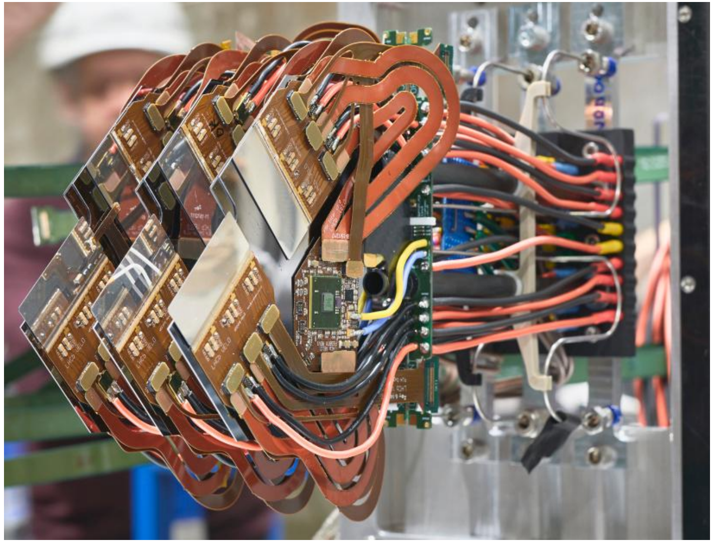
Maybe lower temperatures ⇒ Mean gain from data approaches Estimate Gain?

Label	Module Temp.	ASIC	Total time(h)	Gain K_{mean} [e-/DAC]
Cold	-20°C	VP3-1	4.36	$14.33 \pm 0.02 \pm 0.16$
Warm	20°C	VP3-1	8.73	$13.14 \pm 0.01 \pm 0.44$

Conclusions

Summary:

- Method to obtain Gain from irradiation of ASICs
- ASIC flux is not bad predictor for Mean Gain
- Positional bias observed



Label	Module Temp.	ASIC	Total time(h)	Gain K_{mean} [e-/DAC]
Cold	$-20^{\circ}C$	VP3-1	4.36	$14.33 \pm 0.02 \pm 0.16$
Warm	$20^{\circ}C$	VP3-1	8.73	$13.14 \pm 0.01 \pm 0.44$

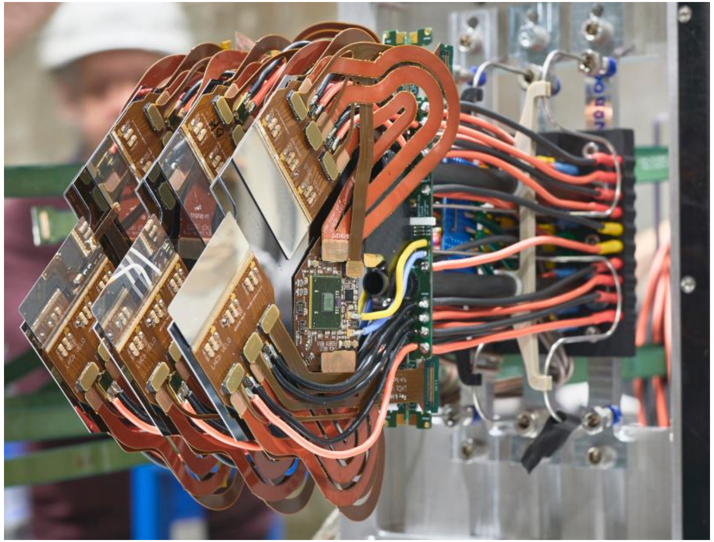
Conclusions

Future:

- Repeat analysis with new data and new equalisation running on MiniDAQ3

- Better determination of sys. uncertainty

- Repeat on other ASICs and temperatures



Label	Module Temp.	ASIC	Total time(h)	Gain K_{mean} [e-/DAC]
Cold	-20°C	VP3-1	4.36	$14.33 \pm 0.02 \pm 0.16$
Warm	20°C	VP3-1	8.73	$13.14 \pm 0.01 \pm 0.44$

Thank you for your attention.

Questions or suggestions?

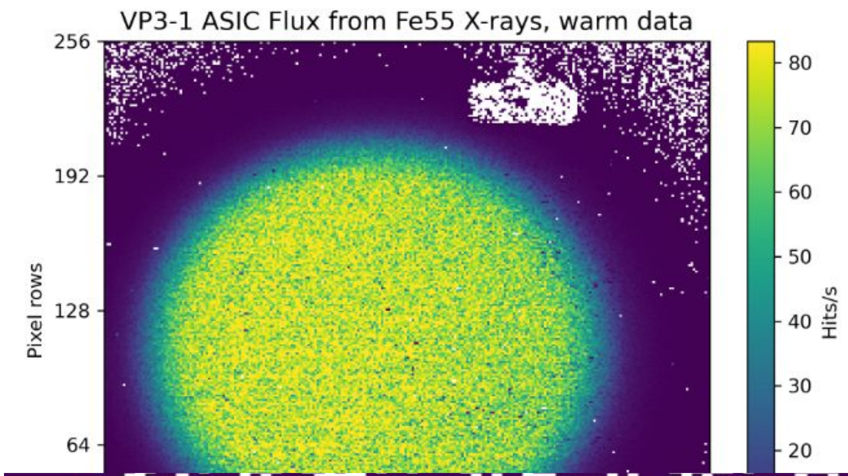
Extra slides

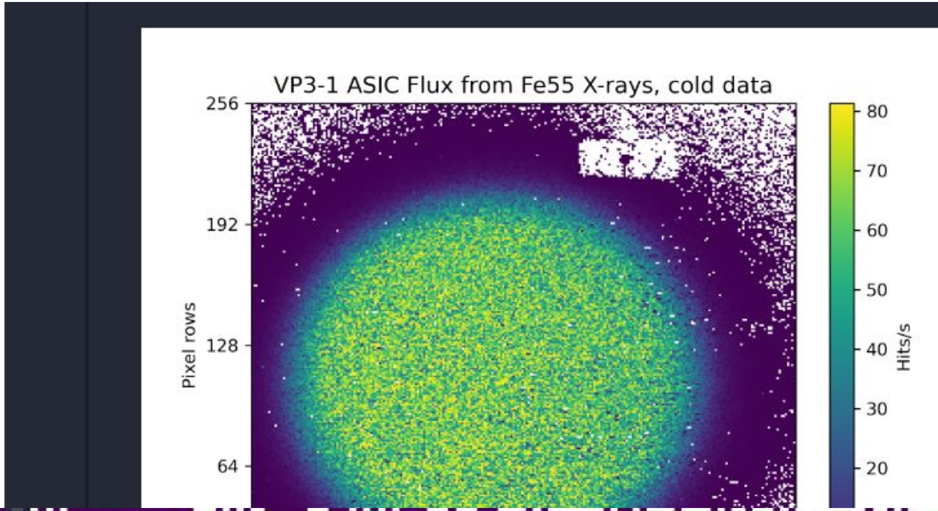
Vertex Locator (VELO)

Table 1. Specifications of the upgraded VELO compared to those of the original version.

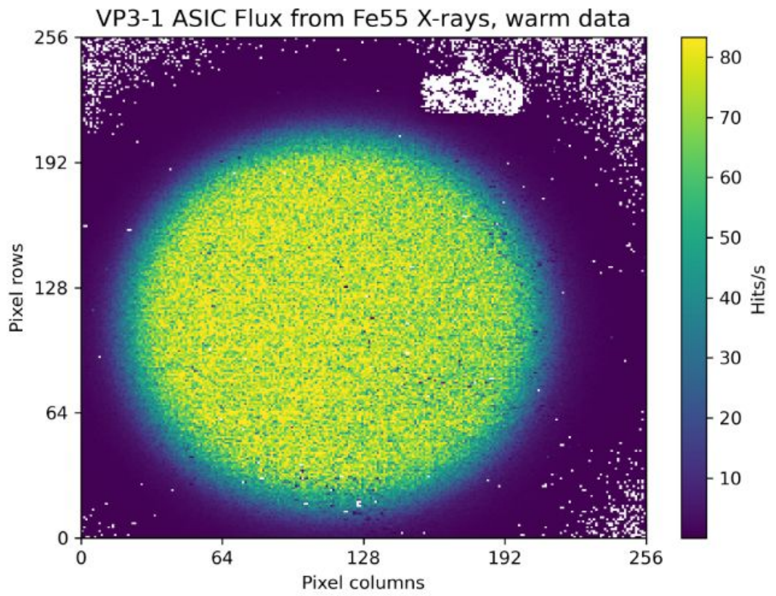
	2009–2018	2022
RF box inner radius (minimum thickness)	5.5 mm (300 µm)	3.5 mm (150 µm)
Inner radius of active silicon detector	8.2 mm	5.1 mm
Total fluence (silicon tip) [n_{eq}/cm^2]	4×10^{14}	$\sim 8 \times 10^{15}$
Sensor segmentation	$r - \phi$ strips	square pixels
Total active area of Si detectors	0.22 m^2	0.12 m^2
Pitch (strip or pixel)	37–97 µm	55 µm
Technology	n-on-n	n-on-p
Number of modules	42	52
Total number of channels	172 thousand	41 million
Readout rate [MHz]	1, analogue	40, zero suppressed
Whole-VELO data rate	150 Gbit/s	~ 2 Tbit/s
Total power dissipation (in vacuum)	800 W	~ 2 kW

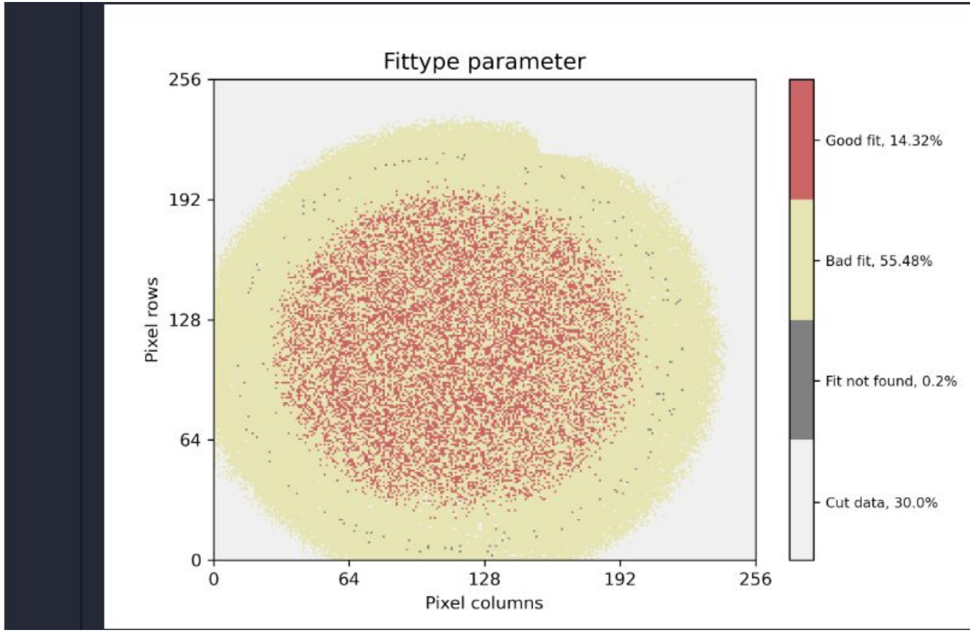
Vertex Locator (VELO)





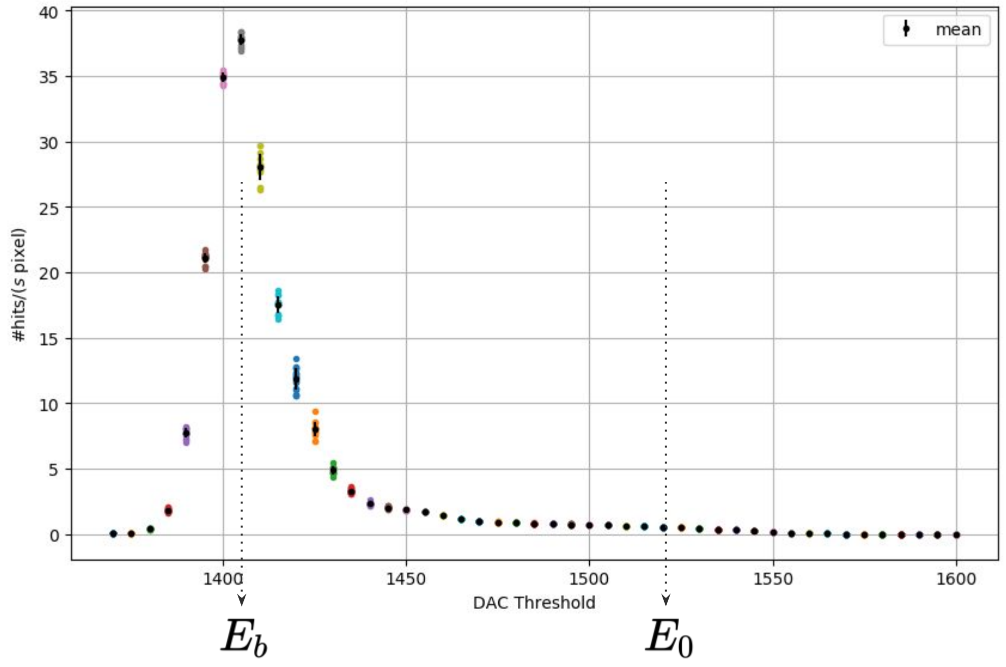
Vertex Locator (VELO)

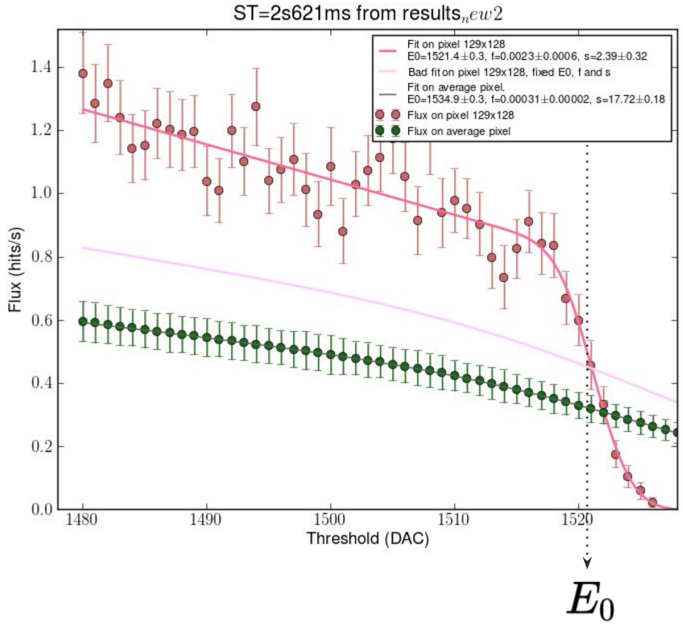


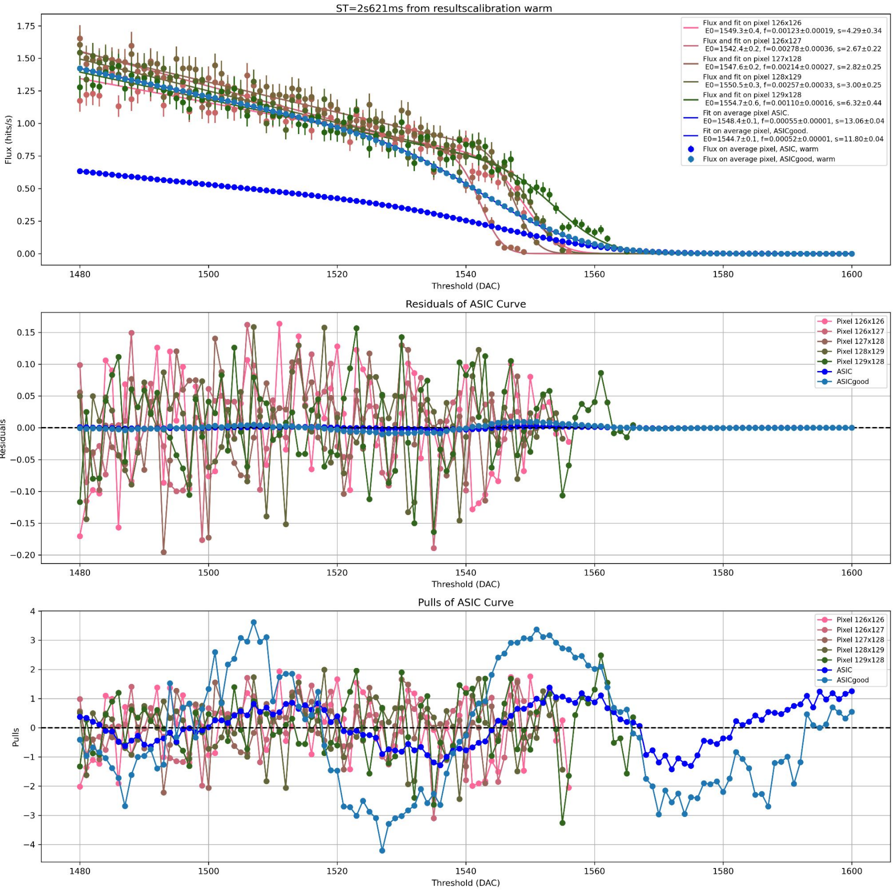
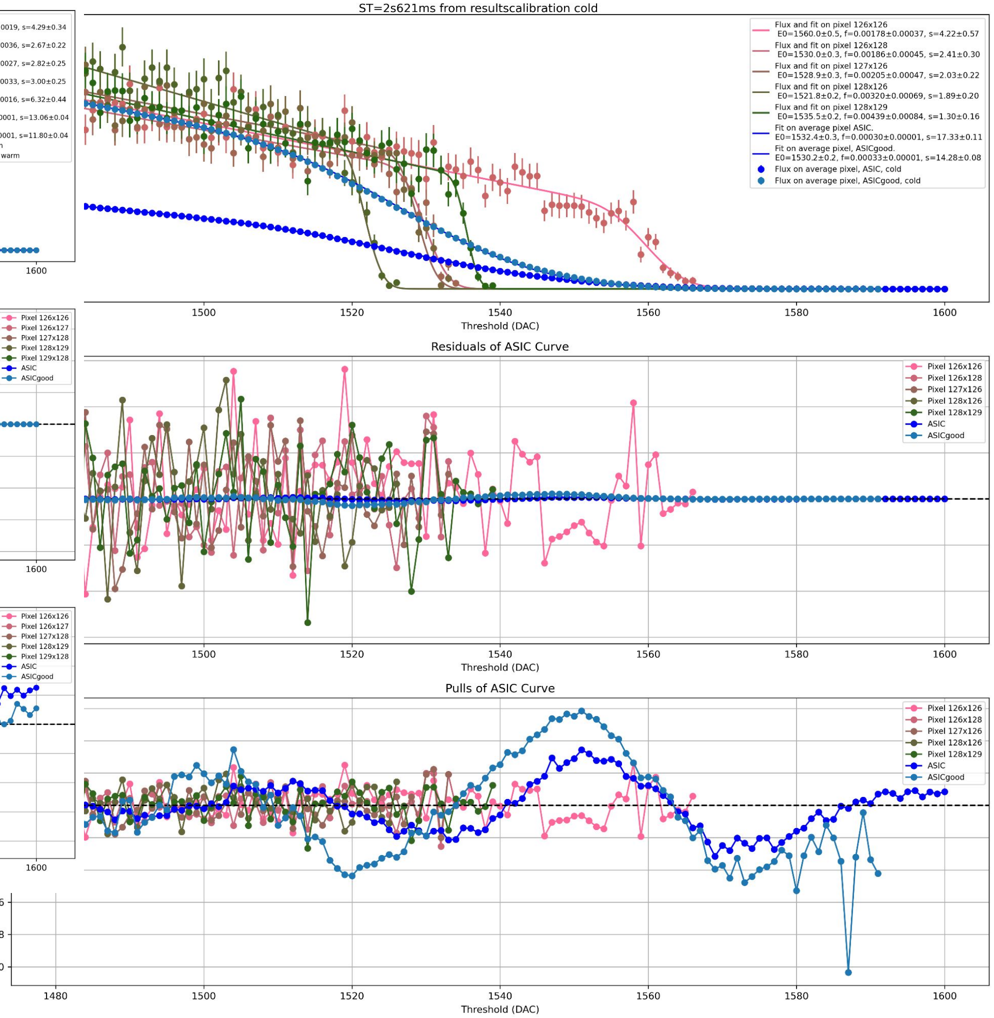


Flux over thr

Flux vs Thr [DAC]



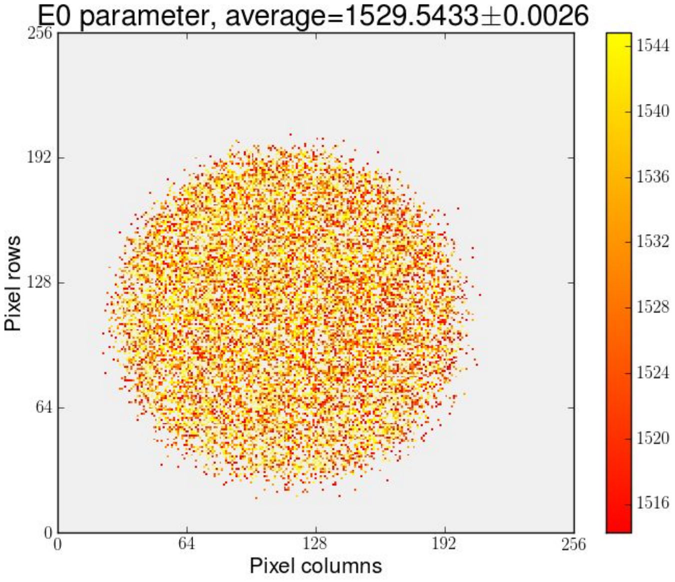


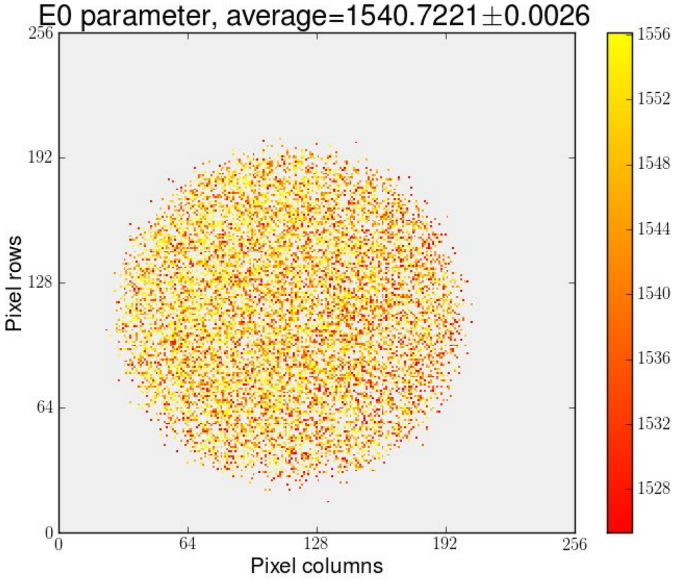

ST=2s621ms from resultscalibration warm
Flux and fit on pixel 126x126
E0=1549.3±0.4, f=0.00123±0.00019, s=4.29±0.34
Flux and fit on pixel 126x127
E0=1542.4±0.2, f=0.00278±0.00036, s=2.67±0.22
Flux and fit on pixel 127x128
E0=1547.6±0.2, f=0.00214±0.00027, s=2.82±0.25
Flux and fit on pixel 128x129
E0=1550.5±0.3, f=0.00257±0.00033, s=3.00±0.25
Flux and fit on pixel 129x128
E0=1554.7±0.6, f=0.00110±0.00016, s=6.32±0.44
Fit on average pixel ASIC.
E0=1548.4±0.1, f=0.00055±0.00001, s=13.06±0.04
Fit on average pixel, ASICgood.
E0=1544.7±0.1, f=0.00052±0.00001, s=11.80±0.04
Flux on average pixel, ASIC, warm
Flux on average pixel, ASICgood, warm
Flux (hits/s)
Threshold (DAC)
Residuals of ASIC Curve
Pixel 126x126
Pixel 126x127
Pixel 127x128
Pixel 128x129
Pixel 129x128
ASIC
ASICgood
Residuals
Threshold (DAC)
Pulls of ASIC Curve
Pixel 126x126
Pixel 126x127
Pixel 127x128
Pixel 128x129
Pixel 129x128
ASIC
ASICgood
Pulls
Threshold (DAC)

ST=2s621ms from resultscalibration cold
Flux and fit on pixel 126x126
E0=1560.0±0.5, f=0.00178±0.00037, s=4.22±0.57
Flux and fit on pixel 126x128
E0=1530.0±0.3, f=0.00186±0.00045, s=2.41±0.30
Flux and fit on pixel 127x126
E0=1528.9±0.3, f=0.00205±0.00047, s=2.03±0.22
Flux and fit on pixel 128x126
E0=1521.8±0.2, f=0.00320±0.00069, s=1.89±0.20
Flux and fit on pixel 128x129
E0=1535.5±0.2, f=0.00439±0.00084, s=1.30±0.16
Fit on average pixel ASIC.
E0=1532.4±0.3, f=0.00030±0.00001, s=17.33±0.11
Fit on average pixel, ASICgood.
E0=1530.2±0.2, f=0.00033±0.00001, s=14.28±0.08
Flux on average pixel, ASIC, cold
Flux on average pixel, ASICgood, cold
Threshold (DAC)
Residuals of ASIC Curve
Pixel 126x126
Pixel 126x128
Pixel 127x126
Pixel 128x126
Pixel 128x129
ASIC
ASICgood
Threshold (DAC)
Pulls of ASIC Curve
Pixel 126x126
Pixel 126x128
Pixel 127x126
Pixel 128x126
Pixel 128x129
ASIC
ASICgood
Threshold (DAC)

E0 Analysis

Heatmap of E0

Cold





Warm

Analysis: Target

Calculation of $target = E_0 - E_b$ → need E_b

Individual pixel values

- E_b using the best prediction from equalisation

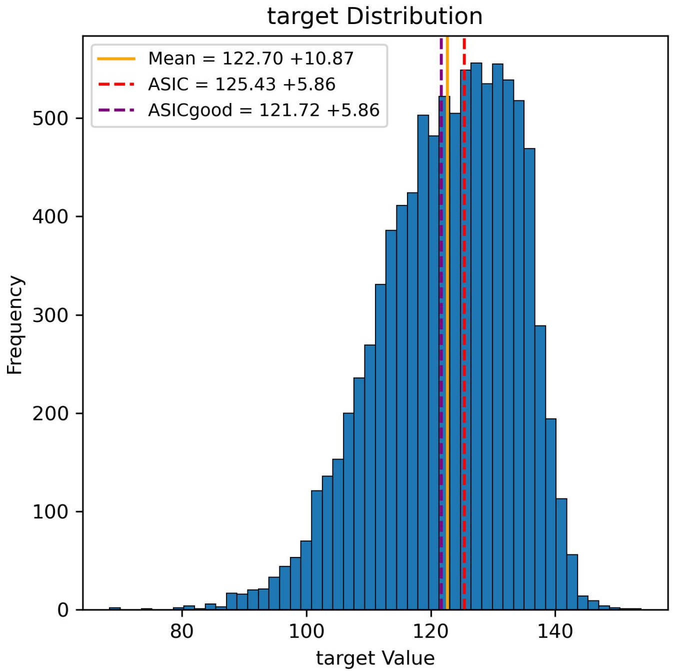
- ΔE_b noise width of either Trim0 or TrimF

ASIC

$$target_{ASIC} = E_{0ASIC} - mean(E_b)$$

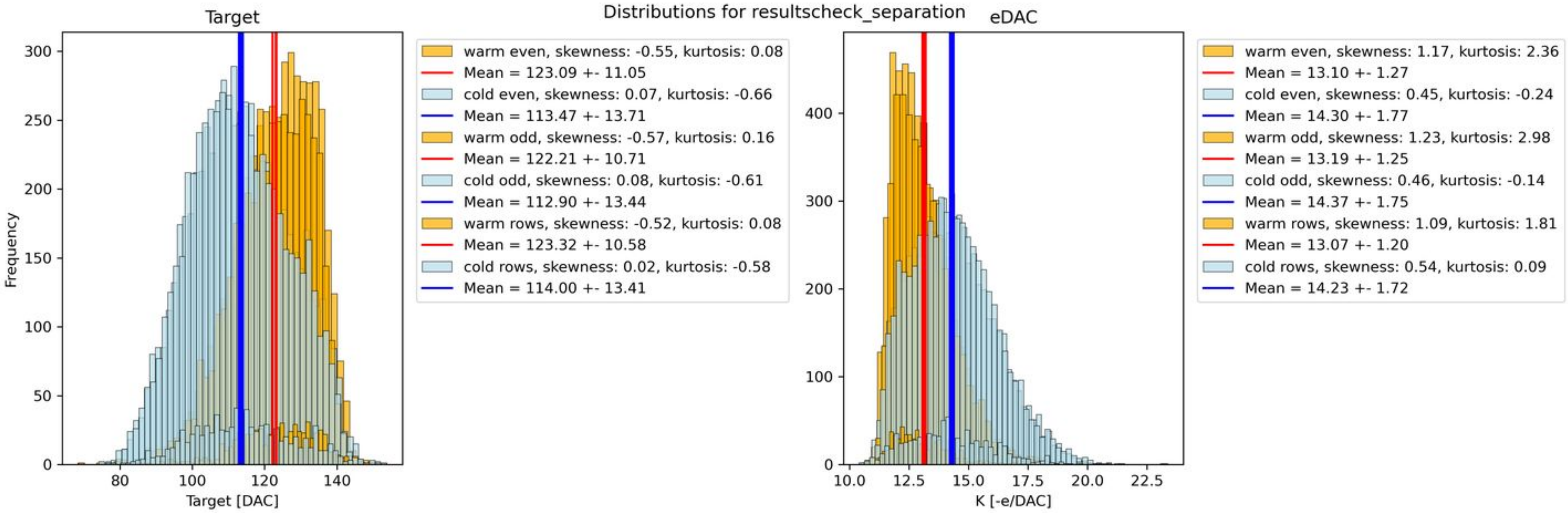
$$\Delta targetASIC = \sqrt{(\Delta E0_{ASIC})^2 + (\overline{\Delta E_{bASIC}})^2}$$

ASICgood (same as ASIC)



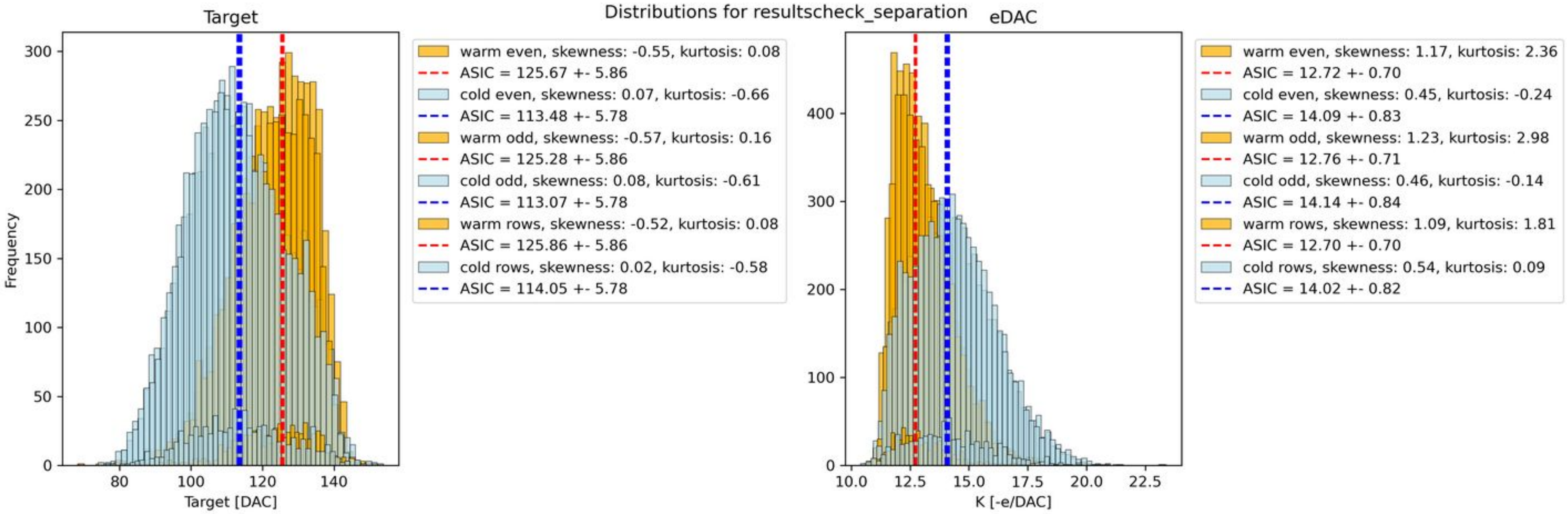
Separation: even, odd, 16th rows

Means



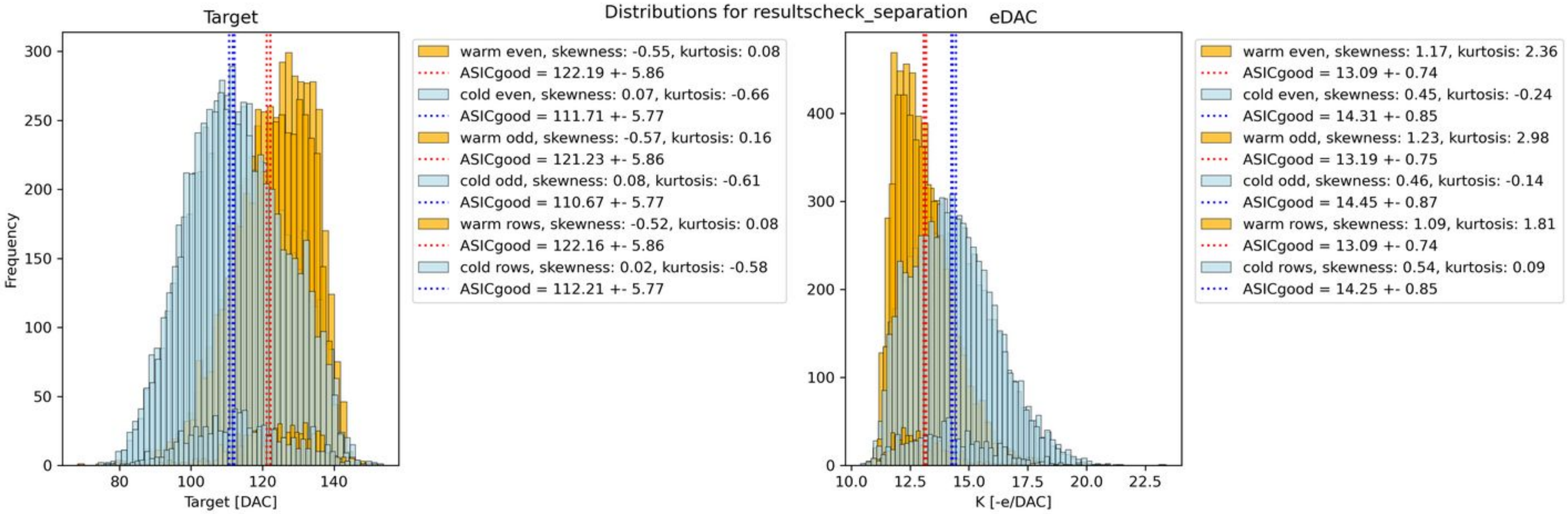
Separation: even, odd, 16th rows

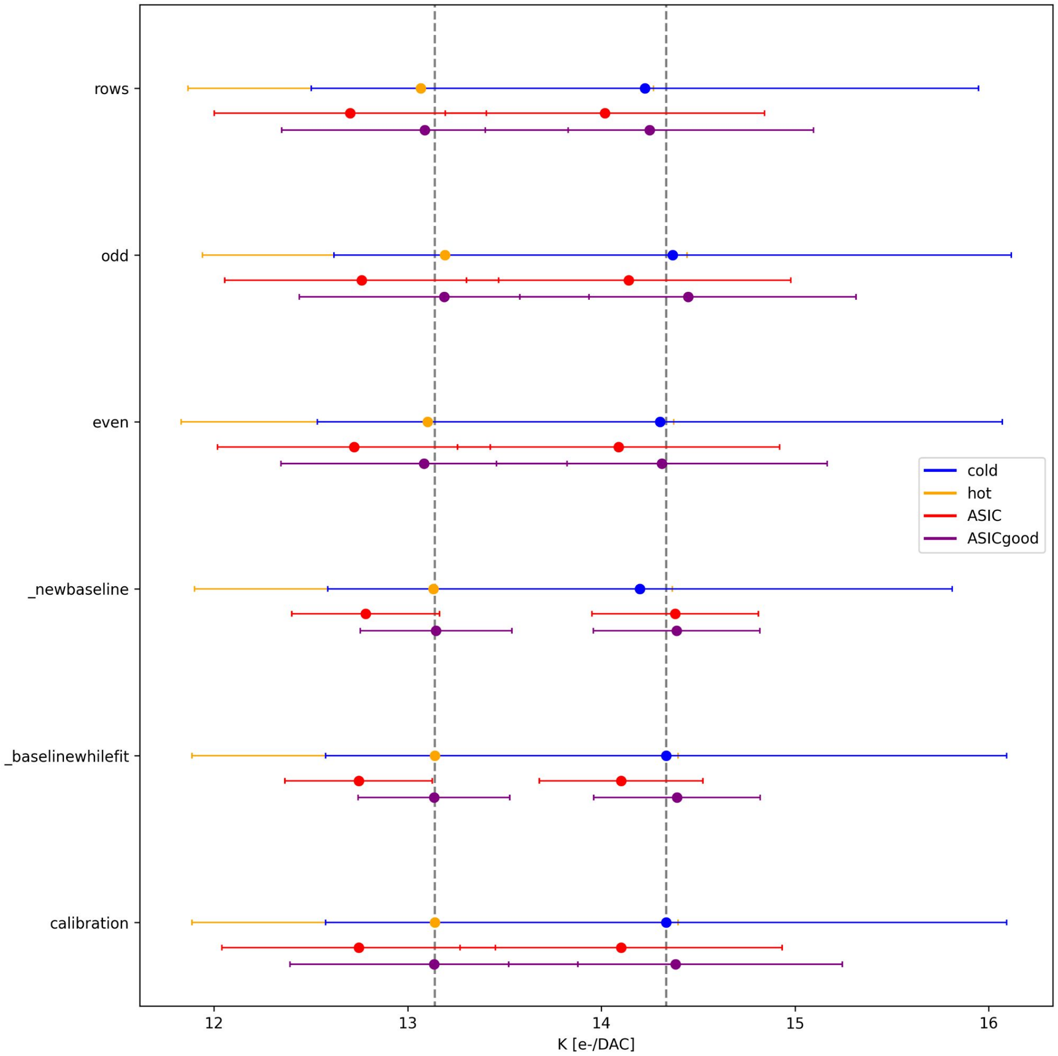
ASIC



Separation: even, odd, 16th rows

ASICgood

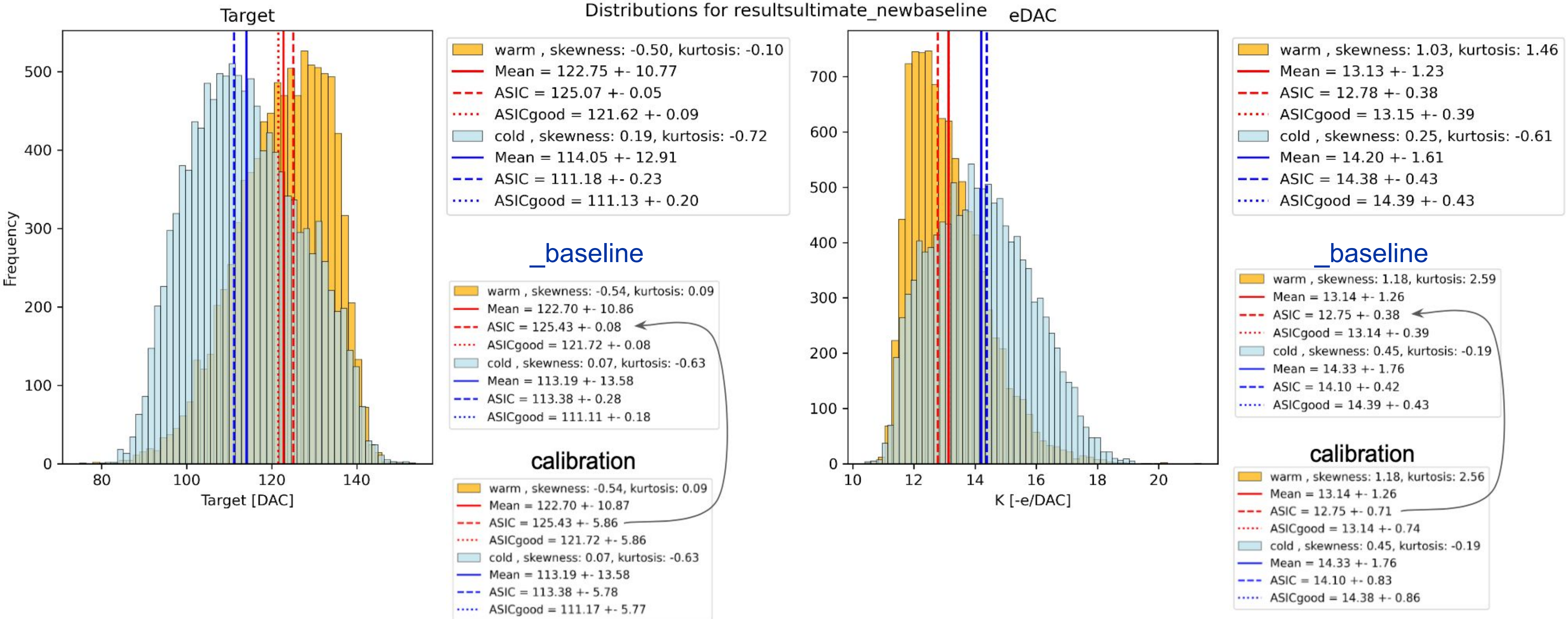




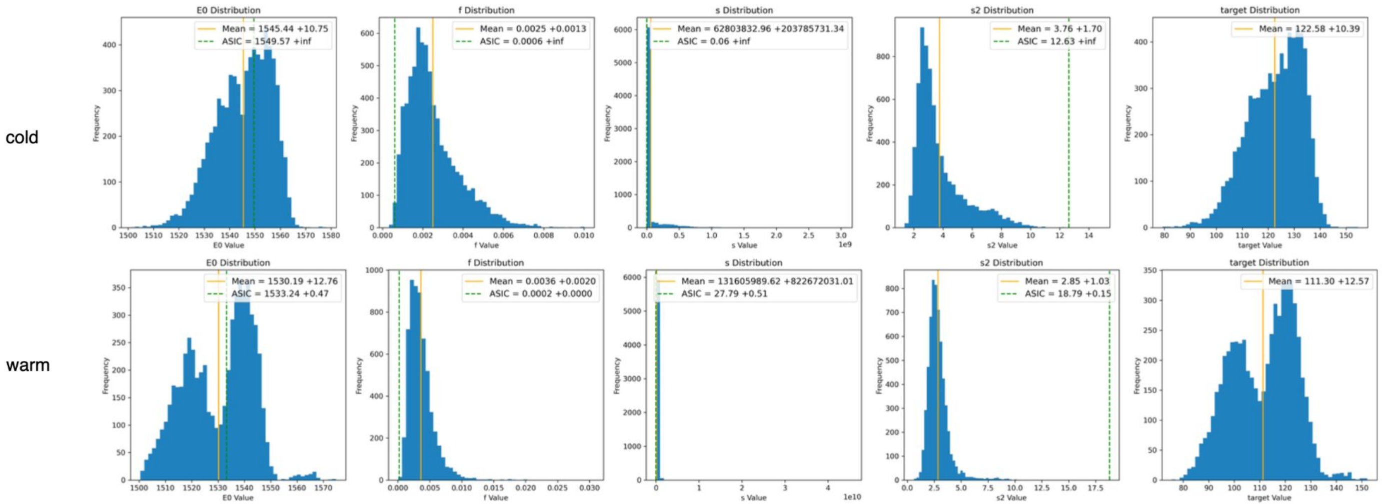
rows
odd
even
_newbaseline
_baselinewhilefit
calibration
cold
hot
ASIC
ASICgood
12
13
14
15
16
K [e-/DAC]

Baseline inclusion approaches

_newbaseline: shift in generation of flux files.



Double s parameter in Flux equation

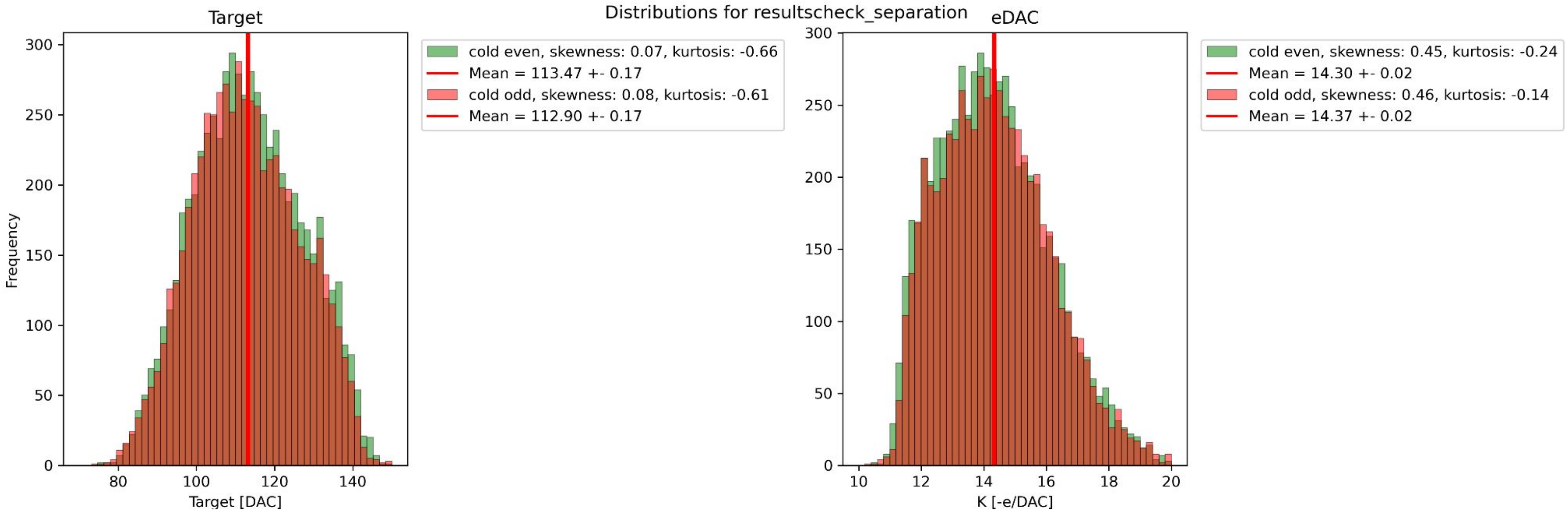


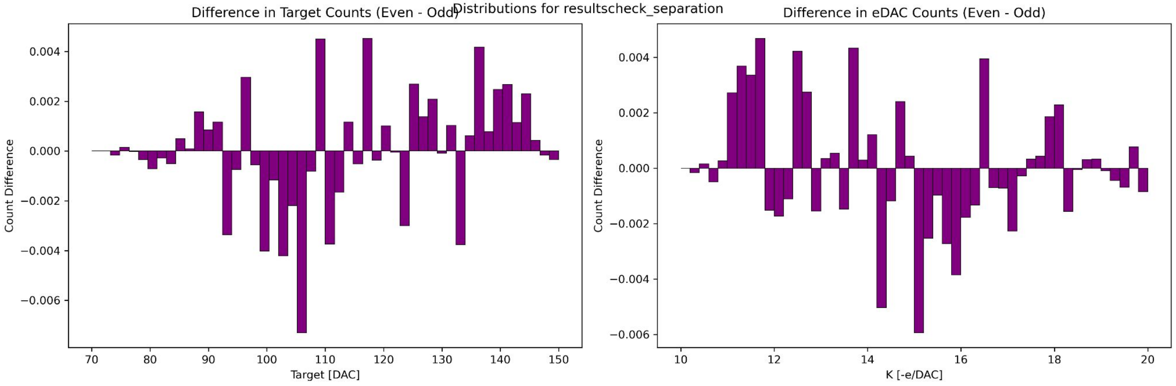
$$F(E) = Af \cdot \frac{1}{2}\left([\text{illegible}] + (E0 - E)\cdot \operatorname{erfc}\left(\frac{E - E0}{s}\right)\right)$$

$$+A(1-f)\cdot \frac{1}{s_2\sqrt{8\pi}} \cdot \operatorname{erfc}\left(\frac{E-E0}{s_2\sqrt{2}}\right)$$

```
KASIC = n_ehp/targetASIC
uKASIC = KASIC*np.sqrt((n_ehp_err/n_ehp)**2 + (utargetASIC/targetASIC)**2)

KASICgood =n_ehp/targetASICgood
uKASICgood = KASICgood*np.sqrt((n_ehp_err/n_ehp)**2 + (utargetASICgood/targetASICgood)**2)
```


Distributions for resultscheck_separation
Target
eDAC
cold even, skewness: 0.07, kurtosis: -0.66
Mean = 113.47 +- 0.17
cold odd, skewness: 0.08, kurtosis: -0.61
Mean = 112.90 +- 0.17
cold even, skewness: 0.45, kurtosis: -0.24
Mean = 14.30 +- 0.02
cold odd, skewness: 0.46, kurtosis: -0.14
Mean = 14.37 +- 0.02
Frequency
Target [DAC]
K [-e/DAC]


Distributions for resultscheck_separation
Difference in Target Counts (Even - Odd)
Difference in eDAC Counts (Even - Odd)
Count Difference
Target [DAC]
K [-e/DAC]

Approaches on baseline inclusion

Shifting E0 by baseline before or after fit should lead to the same target result.

Calibration: shift after fitting. Get E0, then →

$$target = E_0 - E_b$$

$$target_{ASIC} = E_{0ASIC} - mean(E_b)$$

baselinewhilefit: shift while fitting. Get *target* directly from fit, also for ASIC

$$\Delta targetASIC = \sqrt{\ldots}$$

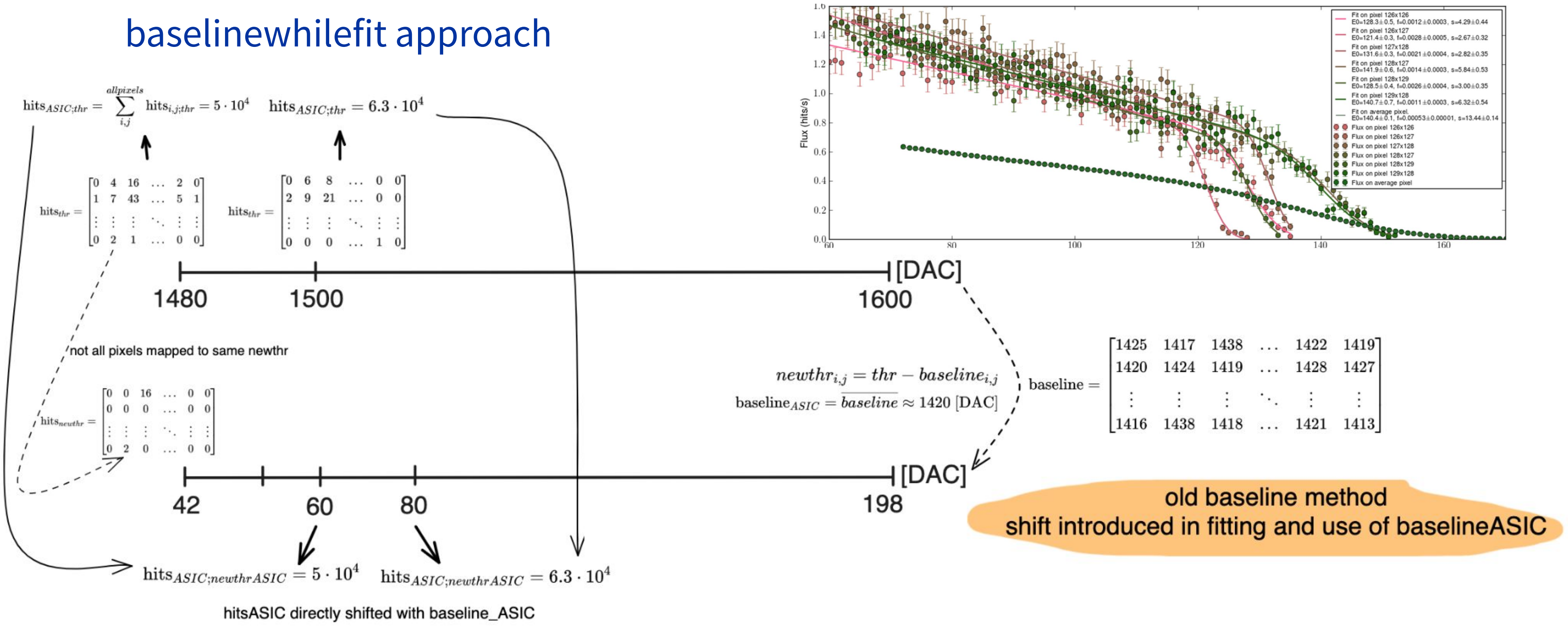
_newbaseline: shift in generation flux files

$$target_{ASIC} = E_{0ASIC} - mean(E_b)$$

$$\Delta targetASIC = \sqrt{(\Delta E0_{ASIC})^2 + (\Delta E_{bASIC})^2}$$

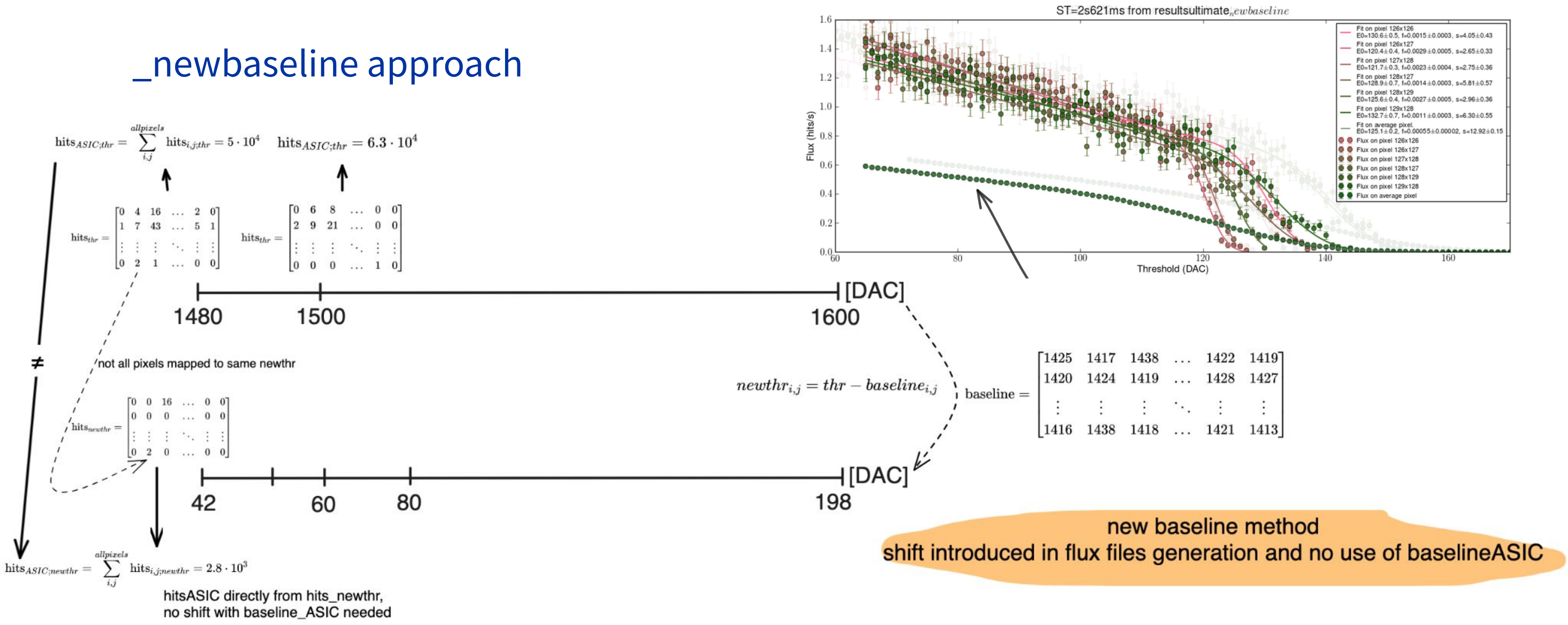
Approaches on baseline inclusion

baselinewhilefit approach



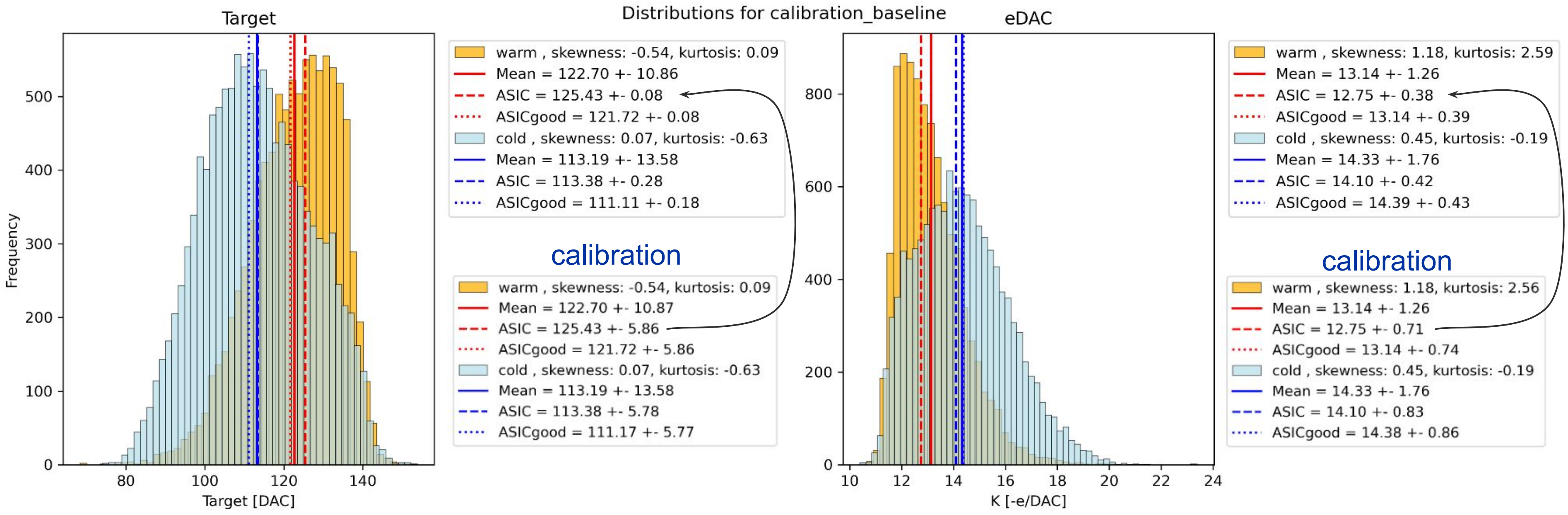
Approaches on baseline inclusion

_newbaseline approach

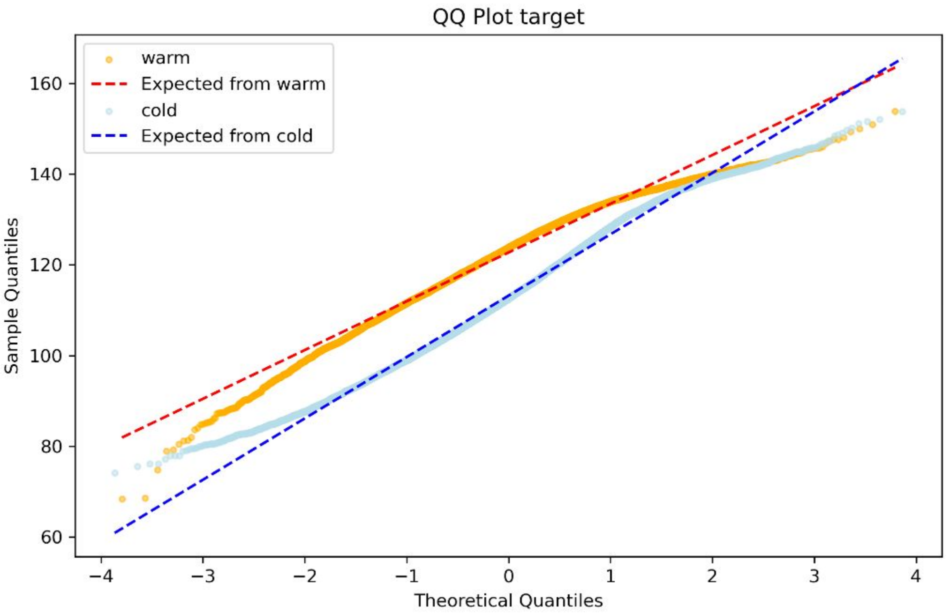


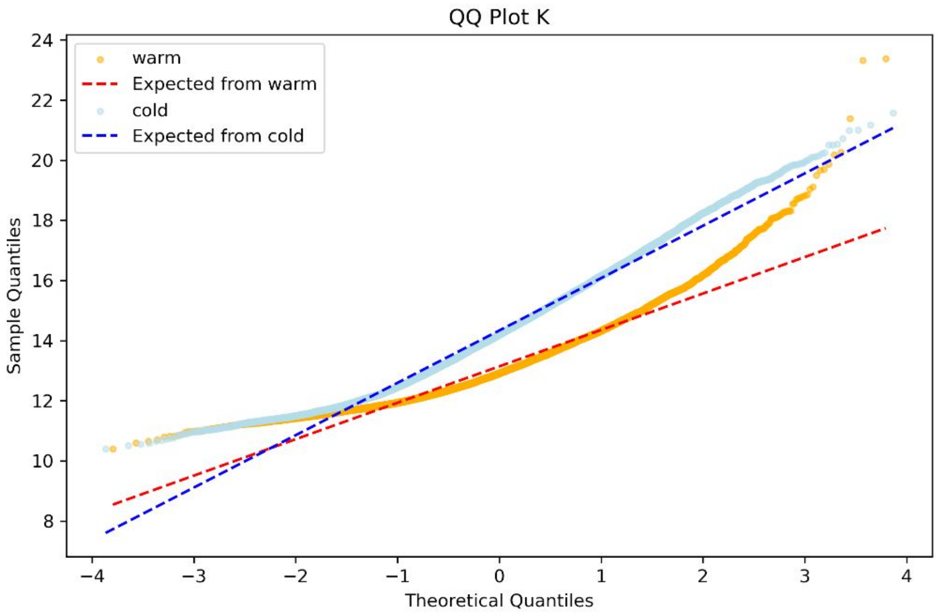
Approaches on baseline inclusion

baselinewhilefit: shift while fitting. Get *target* directly from fit, also for ASIC



How Gaussian is the data?





Conclusions

K [e-/DAC] obtained for two datasets of Fe55:

Comparing (cold) ASIC and ASICgood to :

- Mean Gain

```
Comparing cold dataset to KASIC ...
Distance in standard deviations from KASIC: -0.51
Comparing cold dataset to KASICgood ...
Distance in standard deviations from KASICgood: 0.12
```

- Estimate Gain

```
Comparing cold to KASIC ...
Distance in standard deviations from KASIC: -1.97
Comparing cold to KASICgood ...
Distance in standard deviations from KASICgood: -1.54
```