# SPI Performance Monitoring

## MPE Contributions

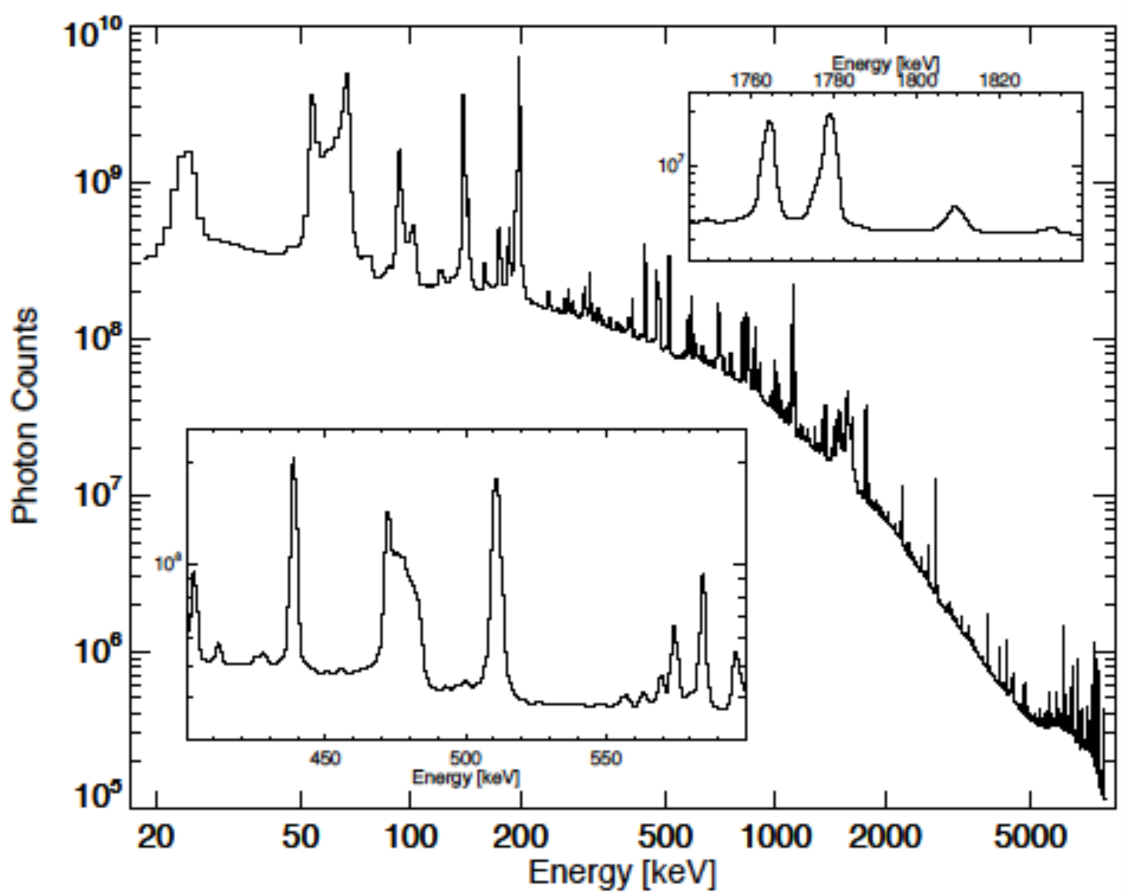
- SPI spectral response
- SPI background
- ACS Status and Calibration
- INTEGRAL @ MPE

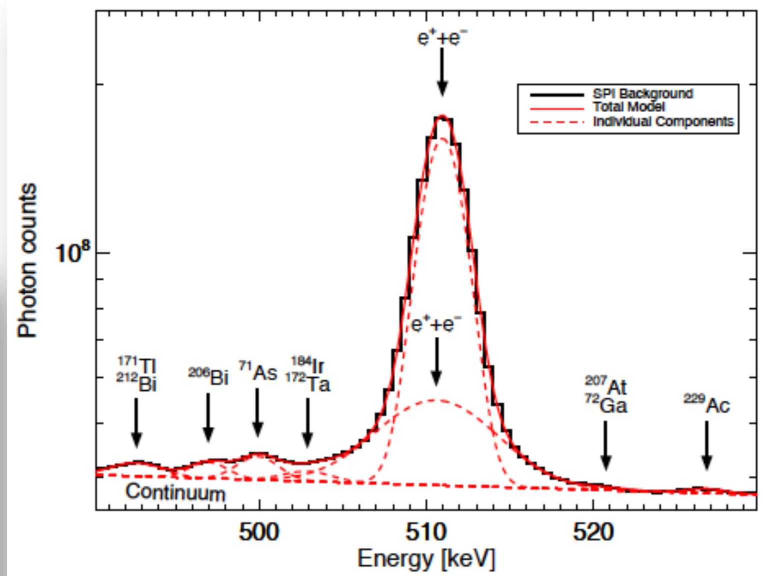
June 2019

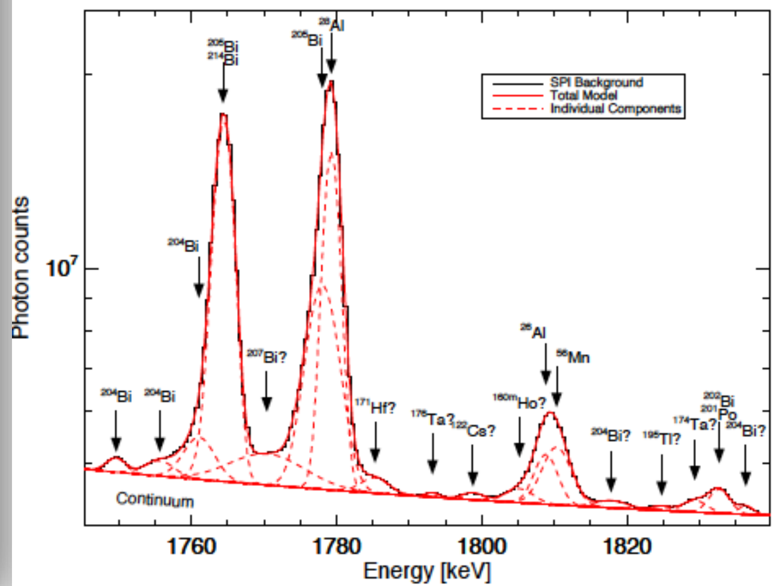
# MPE routine monitoring:Spectral Fitting

- Routine decomposition of SPI detector spectra
  - ☆ spectral performance
  - ☆ background situation
  - → SPI response database (www)

A&A papers Diehl+2018; Siegert+2019



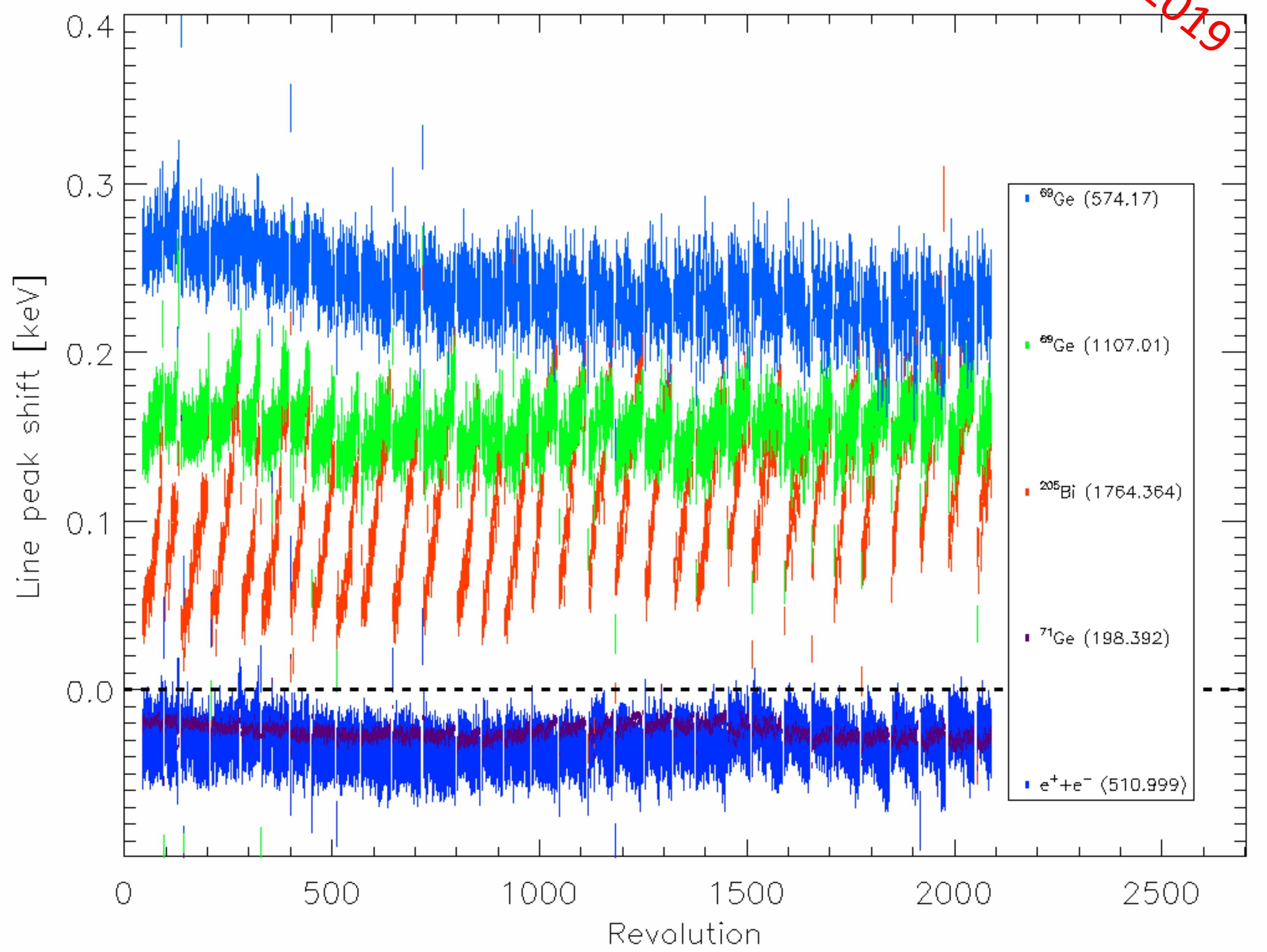



# SPI Performance Monitoring

Jun 2019

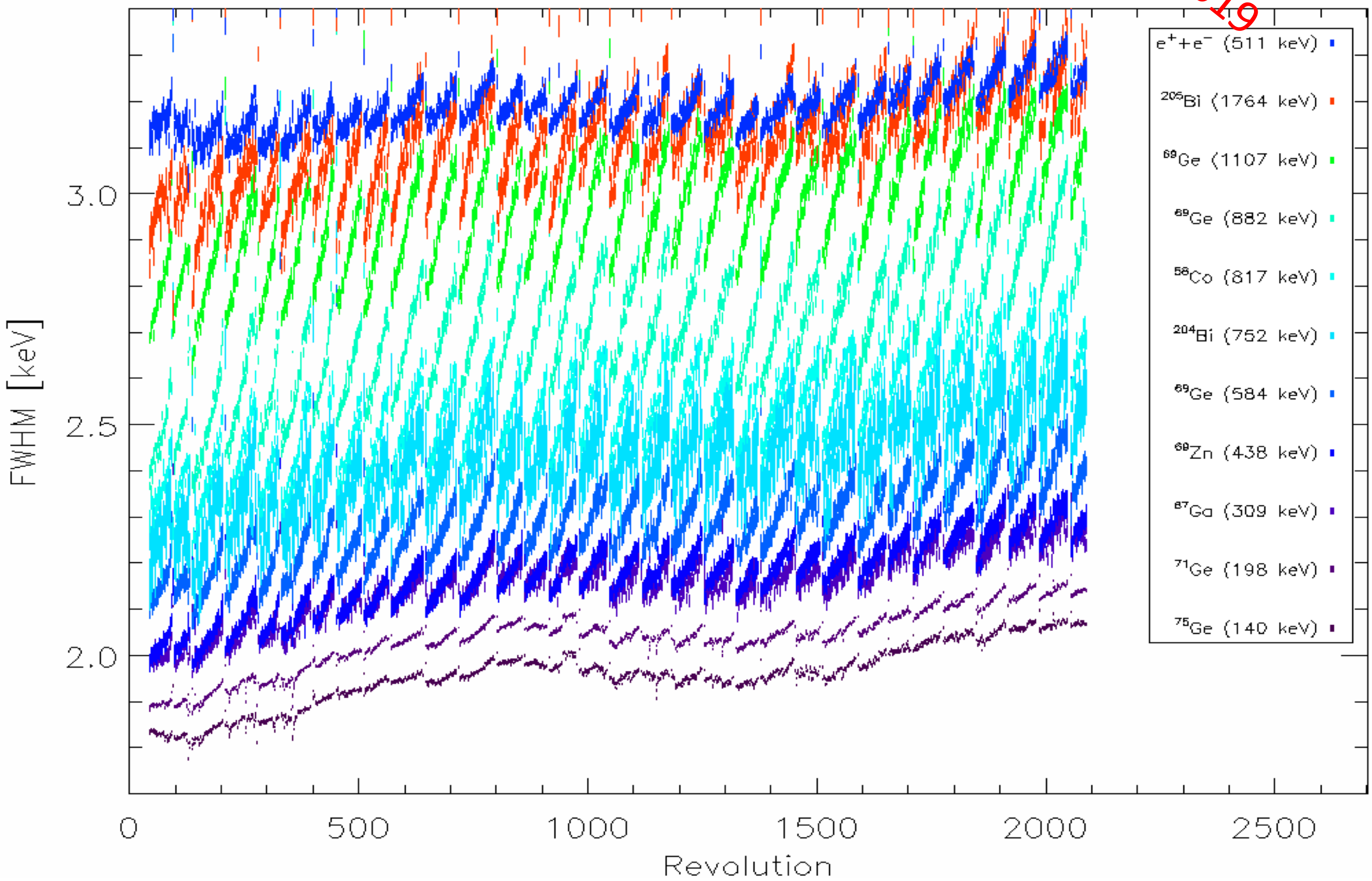
- Monitor Energy Calibration in routine fits



# SPI Performance Monitoring

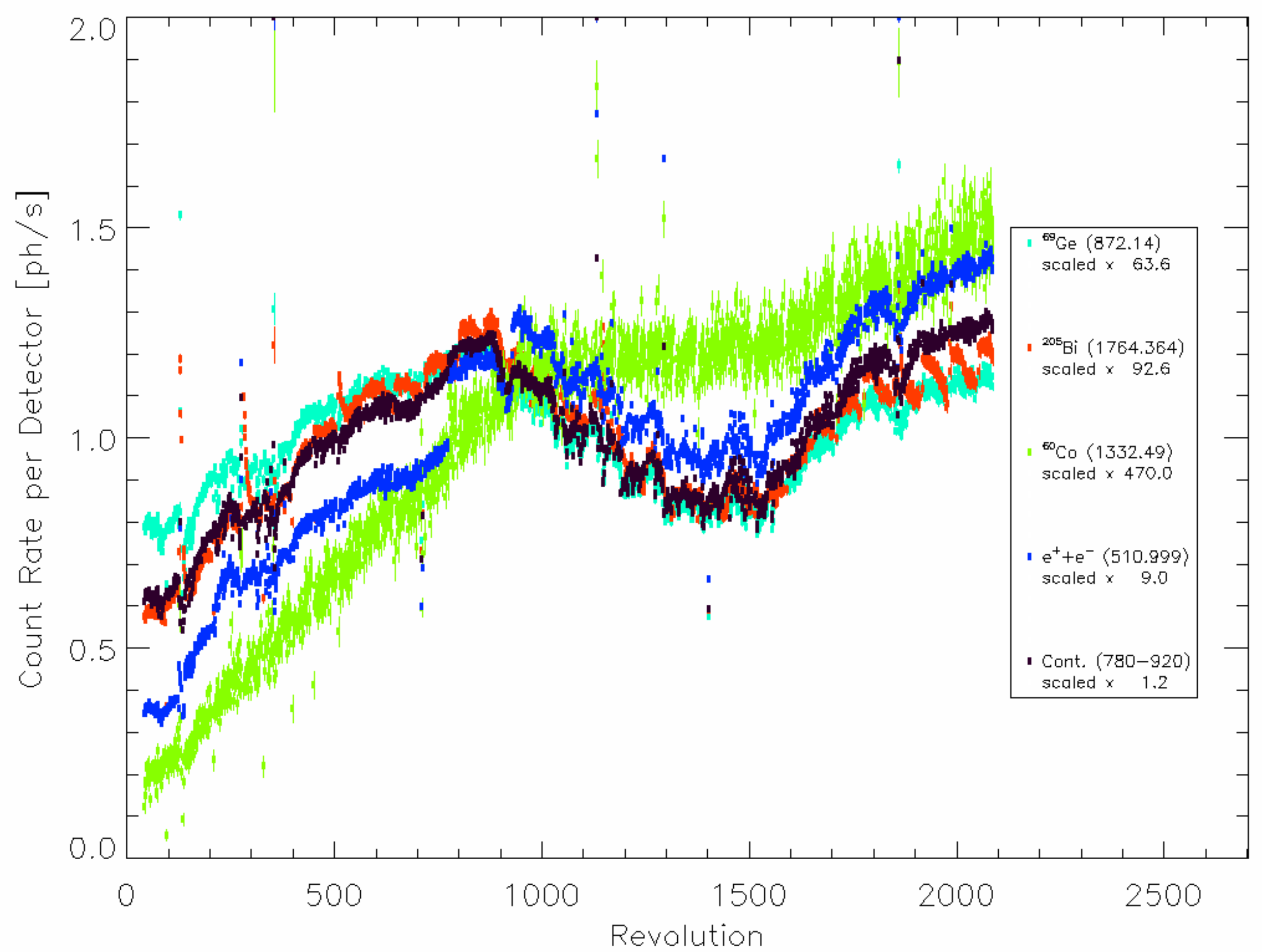
- Status Jun 2019 (rev. 2088)

Jun 2019



# SPI Background Monitoring

- current status (Jun 2019; revolution 2088)



# SPI Annealing Assessment: 2017 crisis →

- MPE backup monitoring and reporting, through ISDC

## SPI Annealing Assessments

*SPI Annealings No. 27-29*

Issued by: MPE / Roland Diehl, with Thomas Siegert & Xiaoling Zhang

Issue Date: 17 Nov 2017
No. of Pages: 32

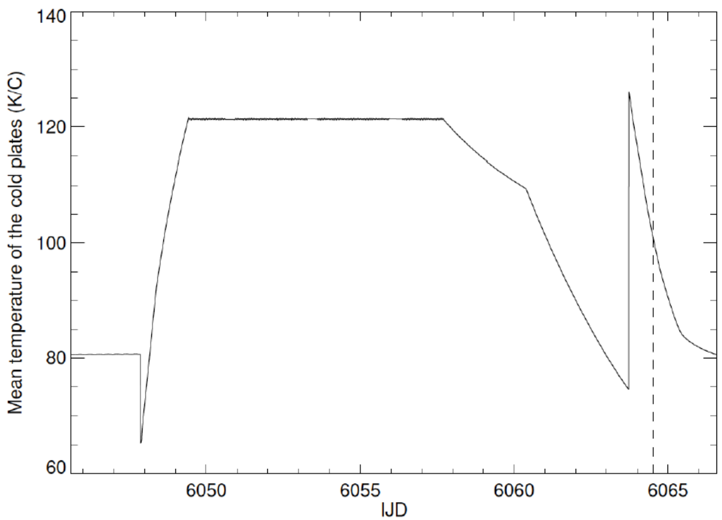
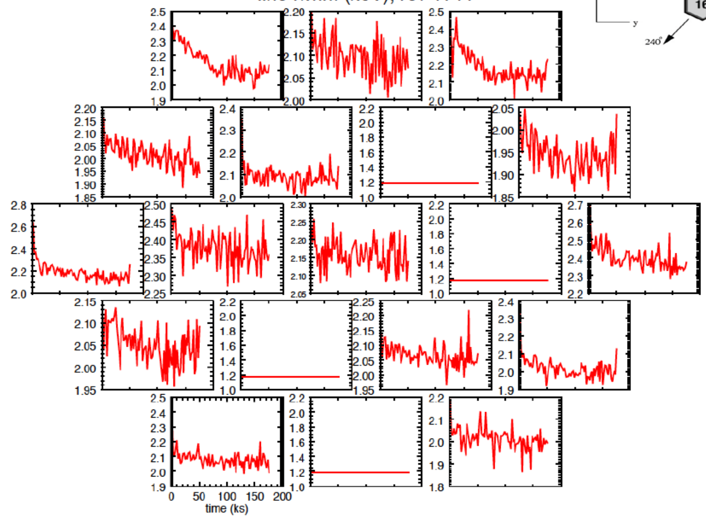



*Fig. 1.1a: Annealing overview: Cold plate temperature across the annealing period. Note the units and scaling of temperature change from Kelvin to approximately ~ºC during the heating period. The SPI switch-on time is marked (dashed line).*

**The detector performance, i.e. the resolution and gain:**



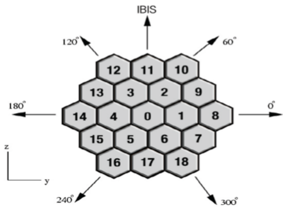




*Fig. 1.7a: Instrument response (198 keV line width) after switch-on, as it evolves with scw's during the first orbit*

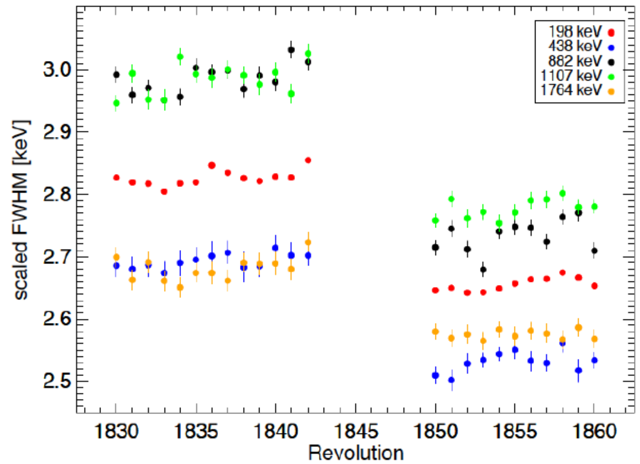



*Fig. 2.2: SPI camera spectral resolution around the current annealings, no. 27-29*

# 32nd Annealing

- 32nd annealing details...

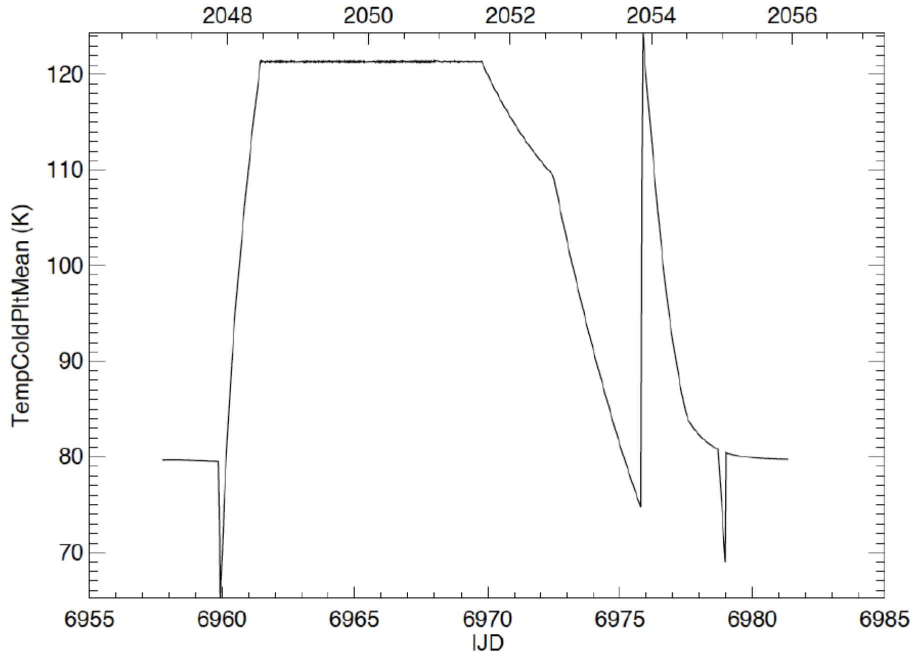



*Fig. 1.1: Annealing overview: Cold plate temperature across the annealing period. Note the units and scaling of temperature change from Kelvin to approximately ~°C during the heating period. The SPI switch-on time is marked (dashed line).*

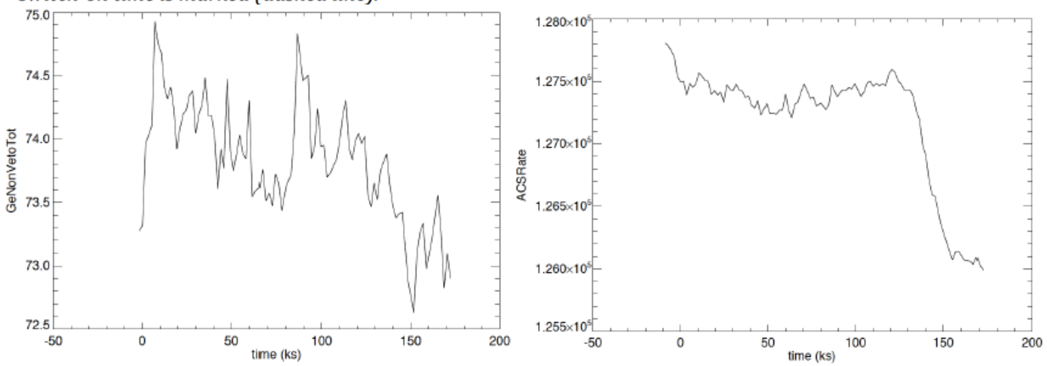



*Fig. 1.2: Event rate evolution for the Ge detectors as compared to ACS*

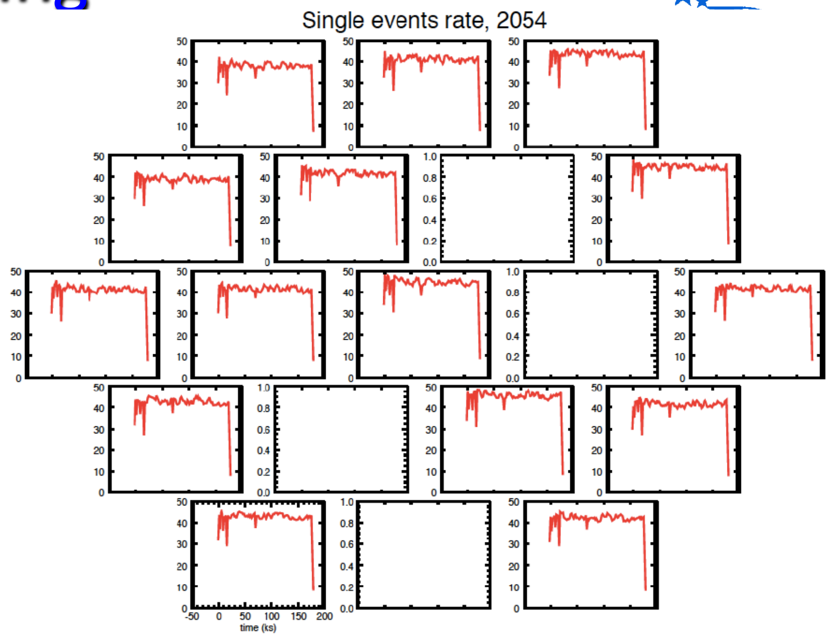



*Fig. 1.6: Instrument settling: Ge detector event rates for one orbit, processed events (SE)*

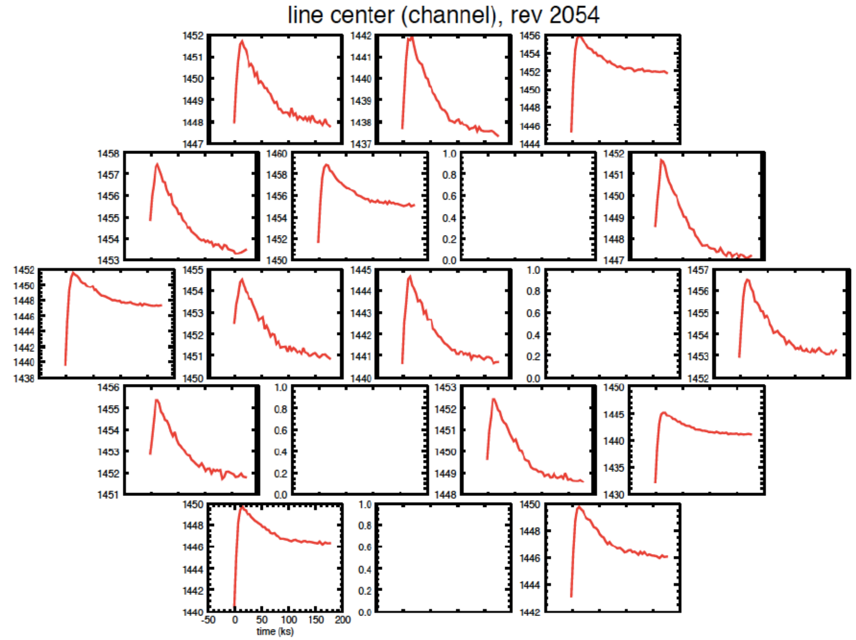



*Fig. 1.8: Instrument response (198 keV line centroid, i.e. gain) after switch-on, as it evolves with scw's during the first orbit*

# 32nd Annealing (Rev 2048-2053; 21 Jan – 05 Feb 2019)

- The recovery after 32th annealing is ~ok

-----------------------------------32th annealing, Revolution 2054 Fitted line width (FWHM, keV)

| HVDetMean (kV) | 1.52 | 2.03 | 2.53 | 2.11 |
|---|---|---|---|---|
| Det | | | | |
| 00 | 2.36 | 2.32 | 2.26 | 2.23 |
| 01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 02 | 0.00 | 0.00 | 0.00 | 0.00 |
| 03 | 2.42 | 2.20 | 2.11 | 2.15 |
| 04 | 2.64 | 2.53 | 2.48 | 2.48 |
| 05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 06 | 2.16 | 2.12 | 2.11 | 2.11 |
| 07 | 2.46 | 2.19 | 2.13 | 2.12 |
| 08 | 2.81 | 2.63 | 2.54 | 2.53 |
| 09 | 2.14 | 2.05 | 2.05 | 2.00 |
| 10 | 2.59 | 2.29 | 2.26 | 2.30 |
| 11 | 2.29 | 2.27 | 2.23 | 2.21 |
| 12 | 2.39 | 2.31 | 2.41 | 2.36 |
| 13 | 2.25 | 2.18 | 2.12 | 2.15 |
| 14 | 3.26 | 3.04 | 2.94 | 2.67 |
| 15 | 2.24 | 2.20 | 2.19 | 2.13 |
| 16 | 2.42 | 2.21 | 2.20 | 2.19 |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 2.33 | 2.12 | 2.13 | 2.12 |

Uncertainty in FWHM is estimated as 0.048 keV

*Table 1.1: Detector settling performance in 198 keV line, for different settings*

**The detector performance, i.e. the resolution and gain:**

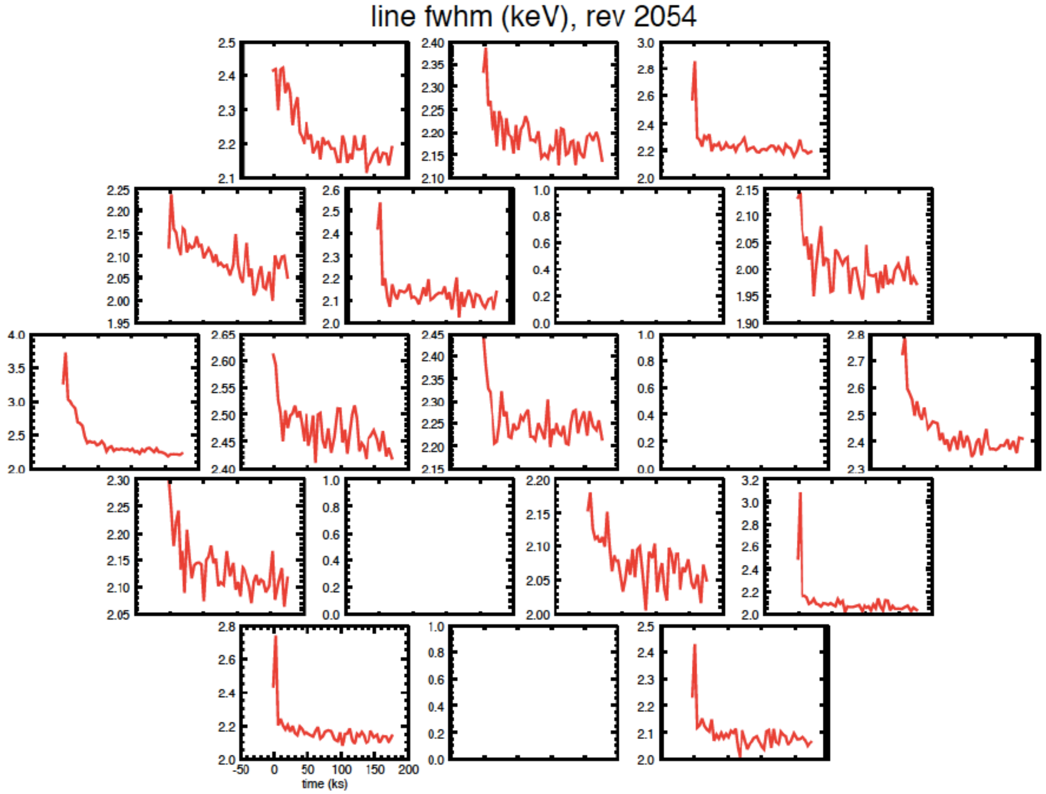



*Fig. 1.7: Instrument response (198 keV line width) after switch-on, as it evolves with scw's during the first orbit*

# The annealings in summary

- Compare resolution recovery for all annealings

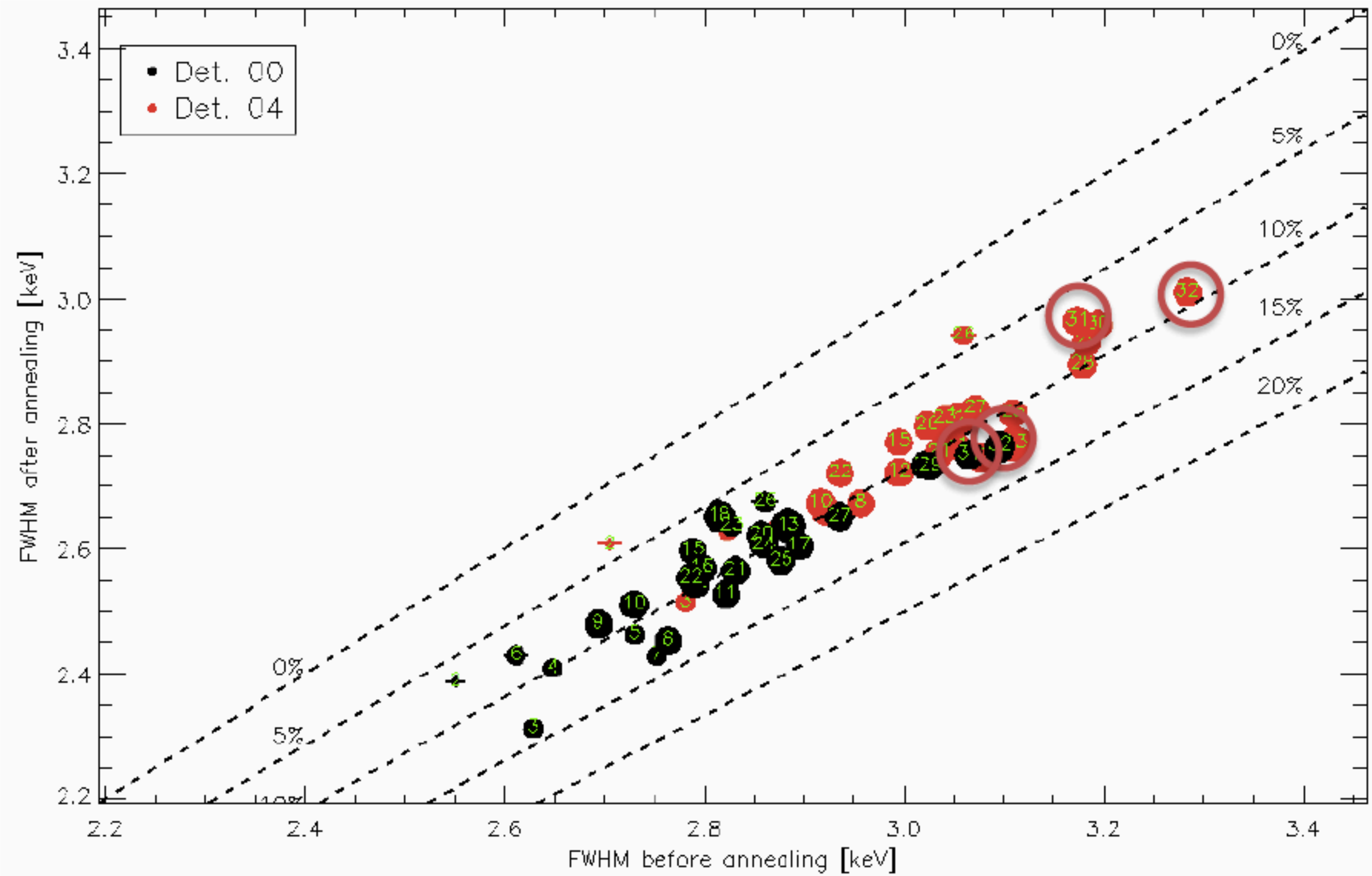
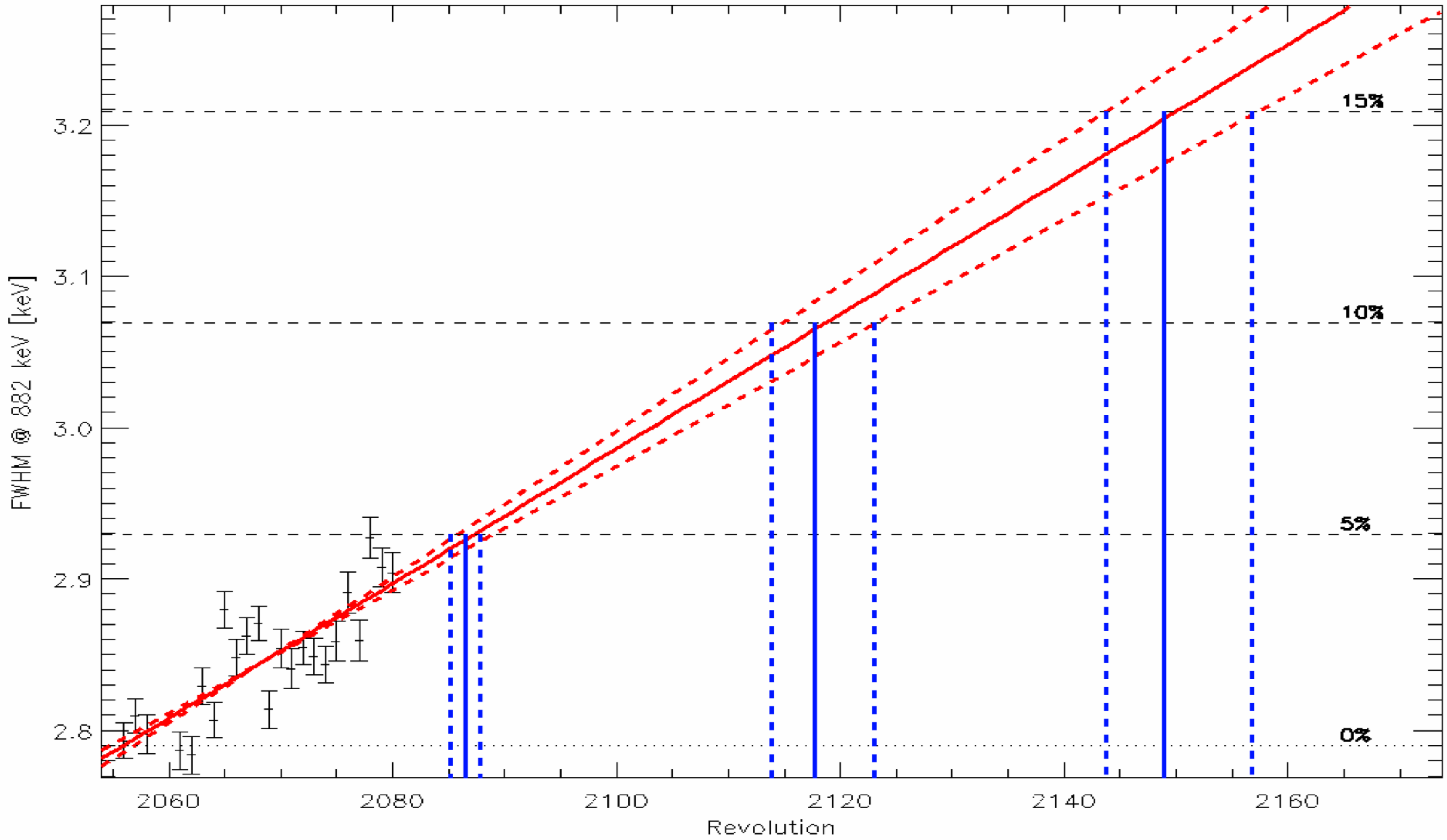



*Fig. 3.1: Spectral resolution before/after the current annealing for two detectors, in context, with data marked from the last two annealings*

# Forecasting the time of the next annealing

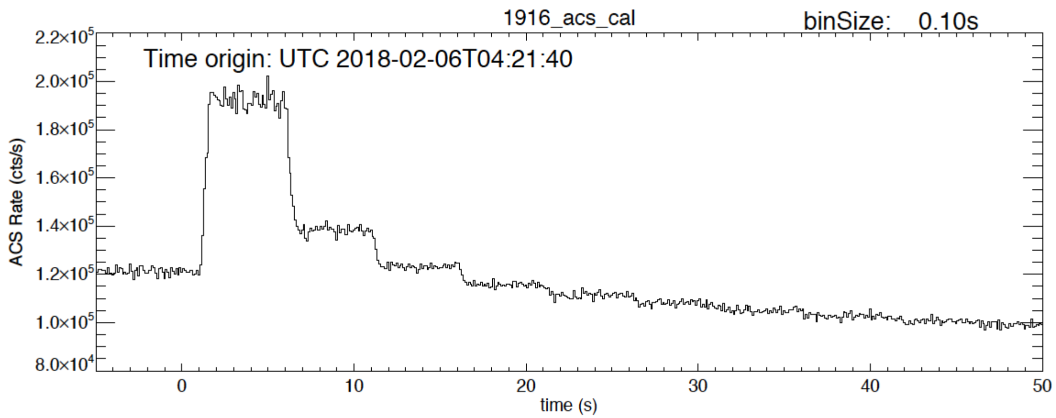
- Latest evolution of spectral resolution (rev 2056 to 2080)
  - ☆ Linear extrapolation of degradation, goal~10%, use uncertainties

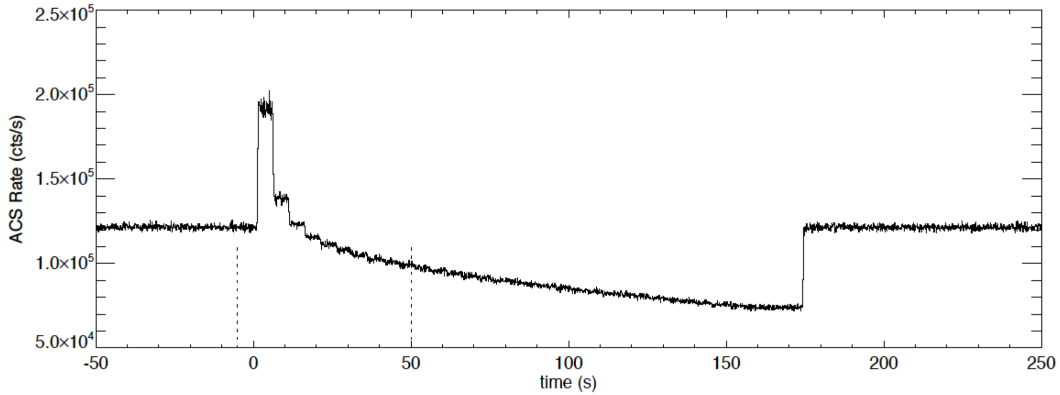
➔ revolutions [2113-2122]

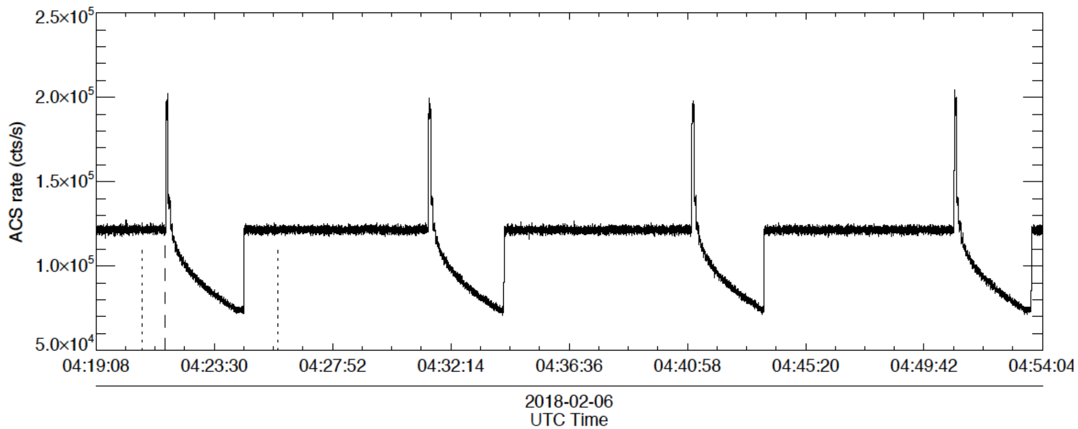


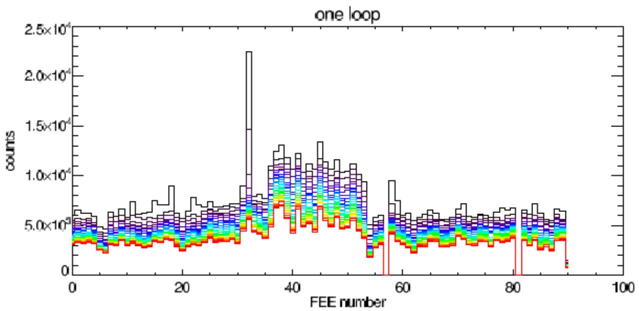
# ACS Calibration

- Regular calibrations of ACS system: threshold steps
  - Rate reduction with increasing threshold (32 steps, ~50 loops)
  - Compare performance for remaining 89 of 91 FEE rate outputs among successive calibrations



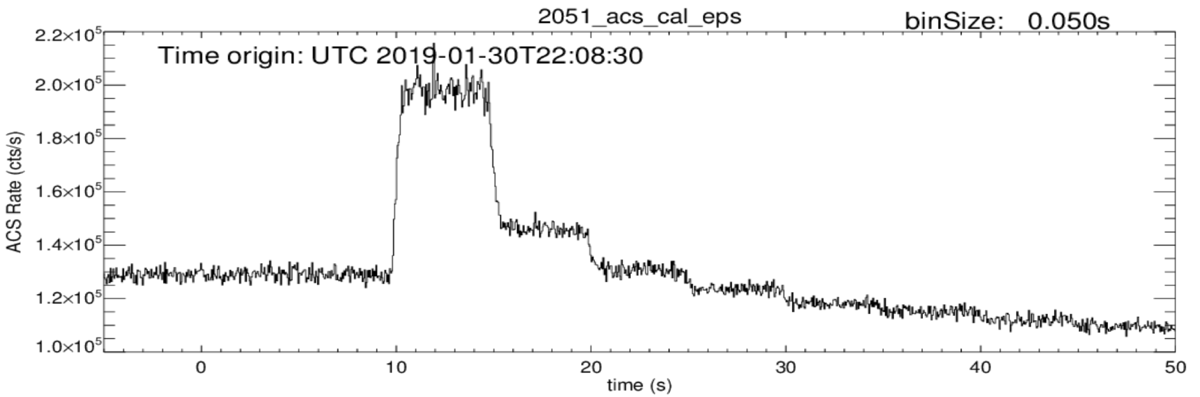



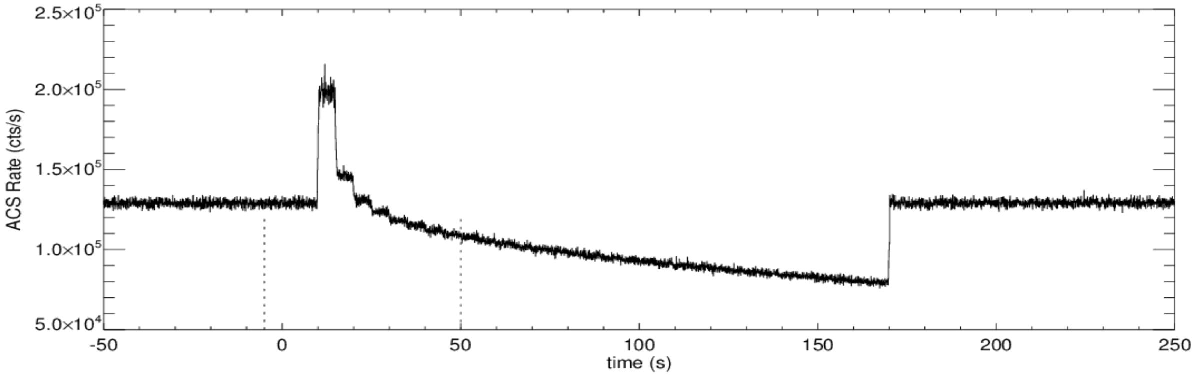



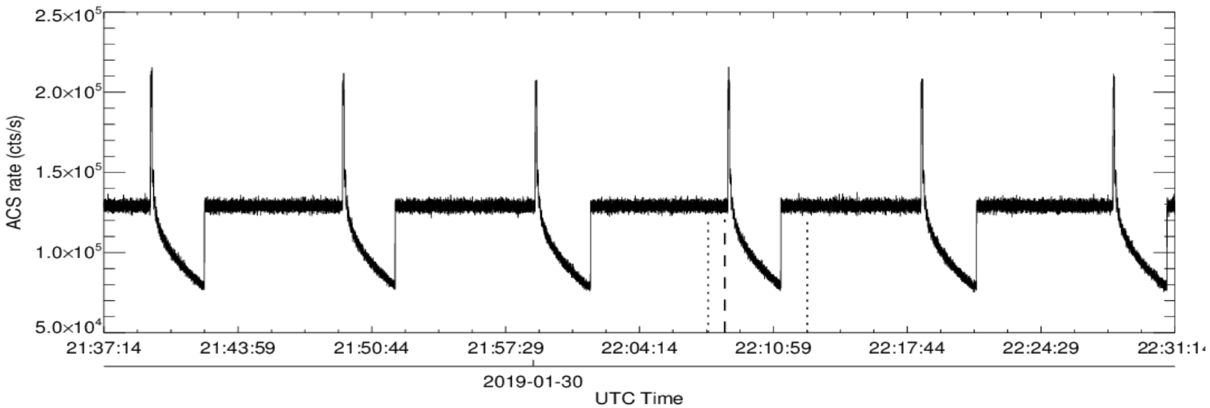



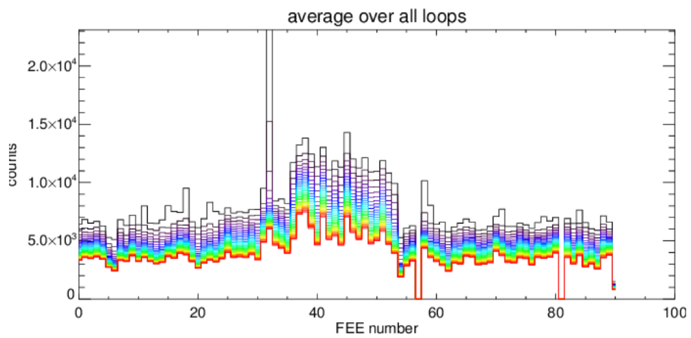
# Latest ACS Calibration (rev 2051)

- Rate reduction with increasing threshold (32 steps, ~50 loops)
- Compare performance for remaining 89 of 91 FEE rate outputs among successive calibrations

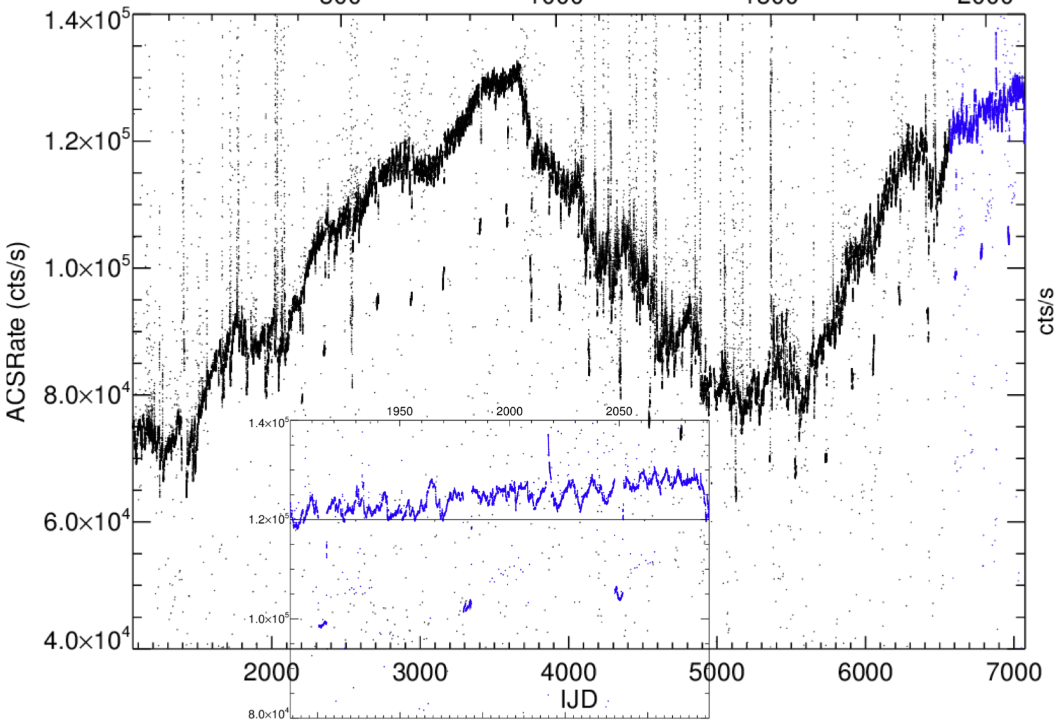


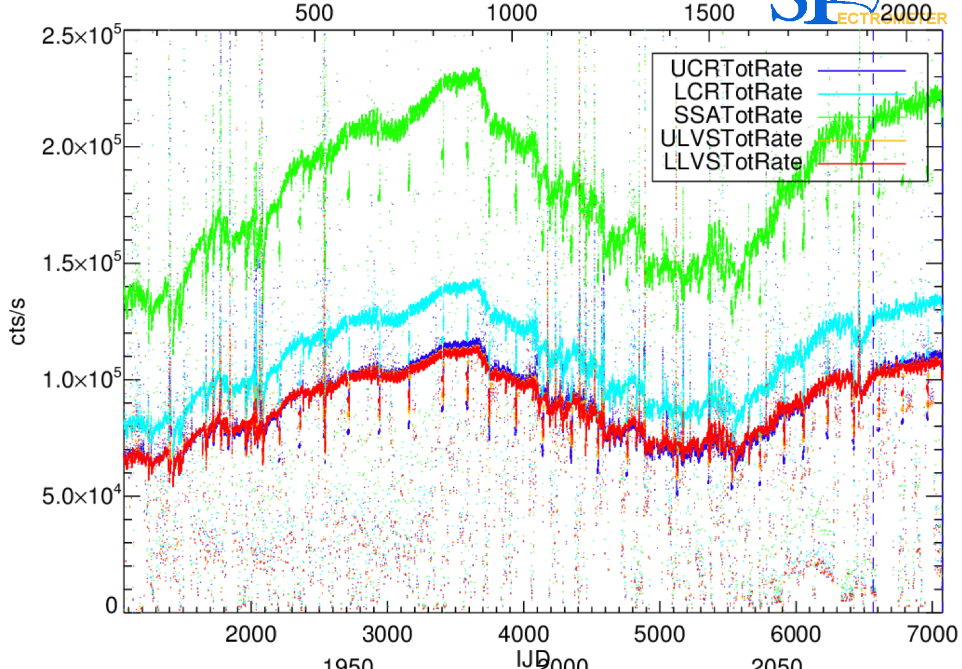



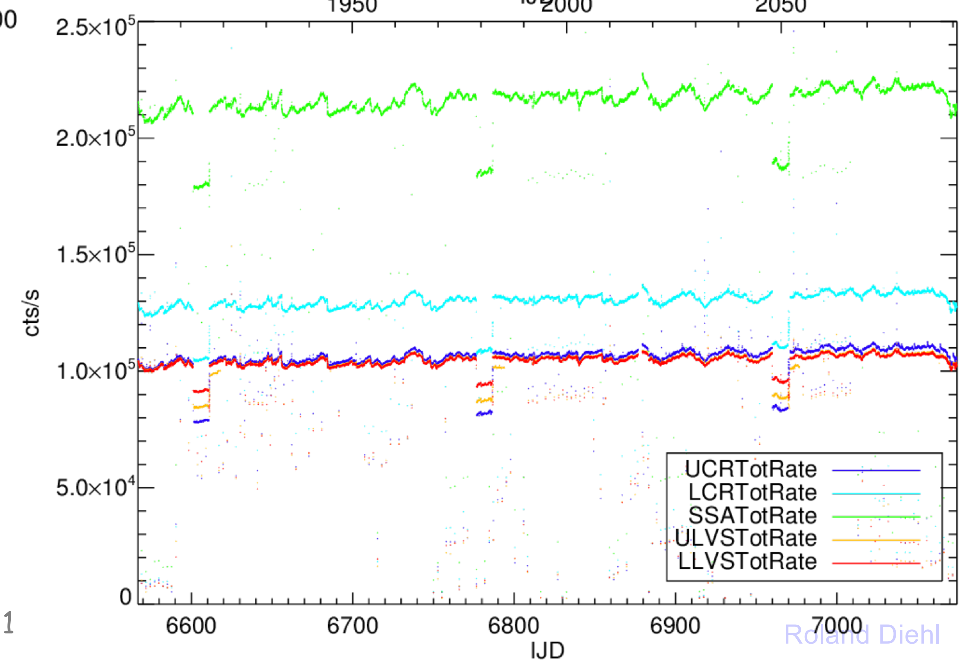



# ACS In-flight performance Rev 2051




- ☆ 'differential' monitoring
  - ☞ any component different from the others?

# In-orbit analysis of ACS calibrations (V2)

*from meeting 4 Sep 2018 (FS, XZ, TS, AvK, RD)*

- Datasets: ~1000 loops through 32 threshold values, for 89 FEE units
  - ☞~$10^7$ data points $D_{aijk} = D_{annealing;cycle;threshold;FEE}$
- Model: count rate results from incident particles (& photons) as seen by BGO integrated above a threshold energy
- Assumptions:
  - Incident particle spectrum can be expressed as an analytical formula, e.g. power-law $I(E) = a_0 \cdot E^{-a_1}$
  - Incident particle spectrum remains constant during one ACS calibration
  - Incident particle spectrum does not change shape between ACS calibrations (i.e., only intensity)
  - threshold electronics implements equal-amplitude steps above their minimum value $E_{j,k} = E_k + j \cdot dE_k$
  - threshold function (i.e. 0 → 1 transition to a module's efficiency) is characterised by a range τ $\varepsilon(E) = \frac{1}{1+e^{-\tau(E-E_j)}}$
  - BGO response has an energy threshold that is not sharp and different for each module $R_k(E) = \frac{\eta_{k0}}{1+e^{-\sigma_k(E-E_{k0})}}$
  - BGO light yields have been calibrated pre-launch with radioactive sources
  - BGO response has weak variations: with temperature, different prelaunch/in-flight, with time $\frac{R_k(E)}{R_l(E)} = \lambda_{kl} \frac{R_{k0}(E)}{R_{l0}(E)}$
- Analysis task:
  - ☆ Fit data $D_{ijk}$ by a model $m(\underbrace{a_0, a_1}_{\text{incident particles}}, \underbrace{E_{jk}, \sigma_k, \eta_{k0}, \lambda_{kl}}_{\text{ACS response}}, \underbrace{\tau_k}_{\text{ACS electronics}})$ that minimises residuals for $D_{jk} = \int_{E_j}^{\infty} \lambda_k R_k \cdot \varepsilon \cdot I \cdot dE$
  - → check if parameters vary among annealings
  - (this could imply variations w temperature, time, or failures)

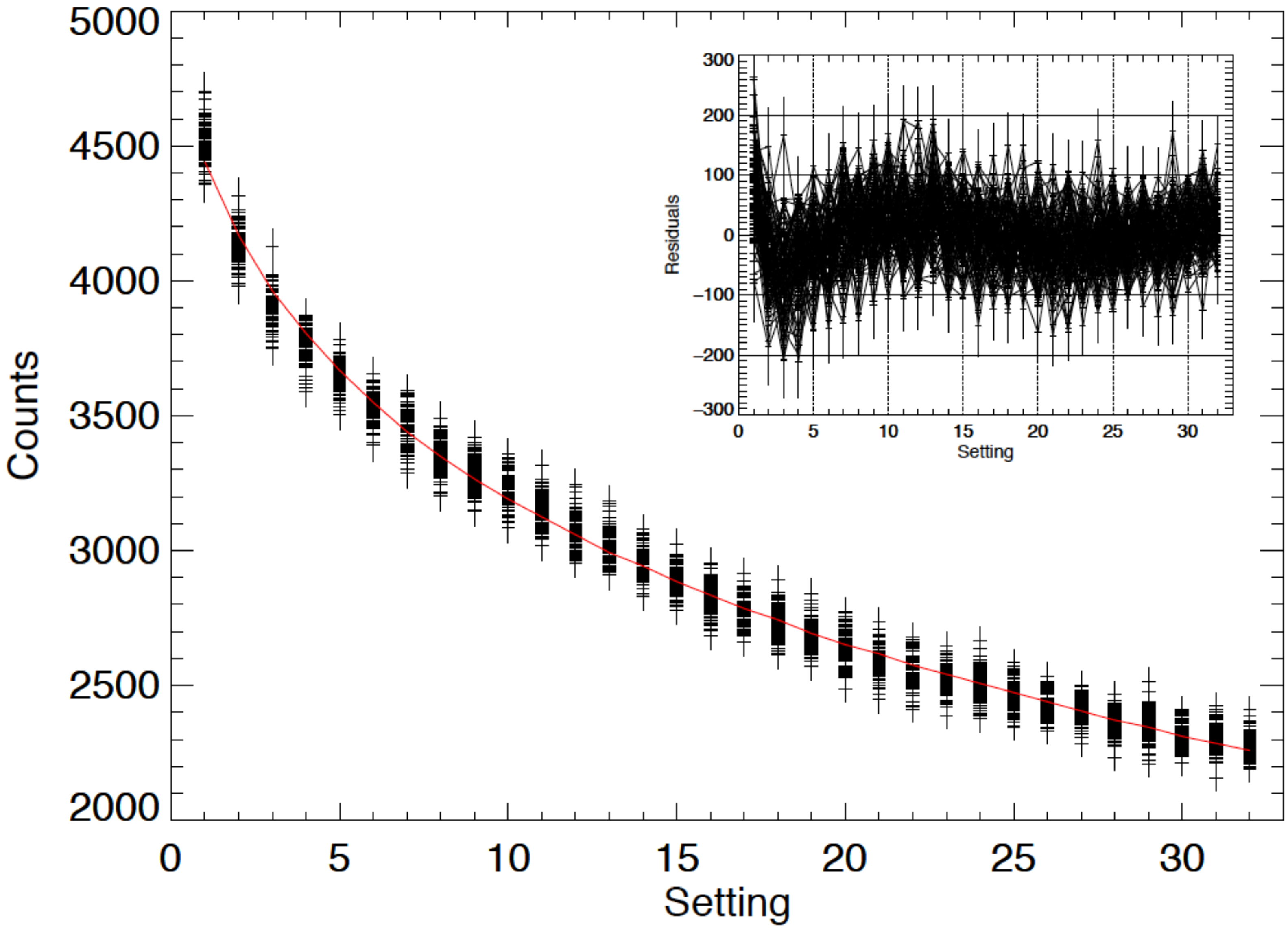
# ACS Performance Assessment: Status Nov 2018

- Prelaunch calibration data re-acquired
  - Individual PMTs (disconnect one of 2 and calibrate with 137Cs source; von Kienlin)
  - Spreadsheet of calibration logs digitised
  - Many inconsistencies: Often no peak recognised in spectra; sometimes "negative" gains; Many useful peak-channel/energy data as well.

- B.Sc. Student project, Felix Schmuckermaier, Aug – Dec 2018

- ACS calibration data per annealing fitted for each FEE
  - ☆ Algorithm shows inadequacy of single powerlaw function for CR spectrum
  - ☆ Degeneracies between threshold parameters and energy steps
  - ☆ Needed to adopt an initial energy calibration

# Threshold loops: fitting each loop, at one annealing

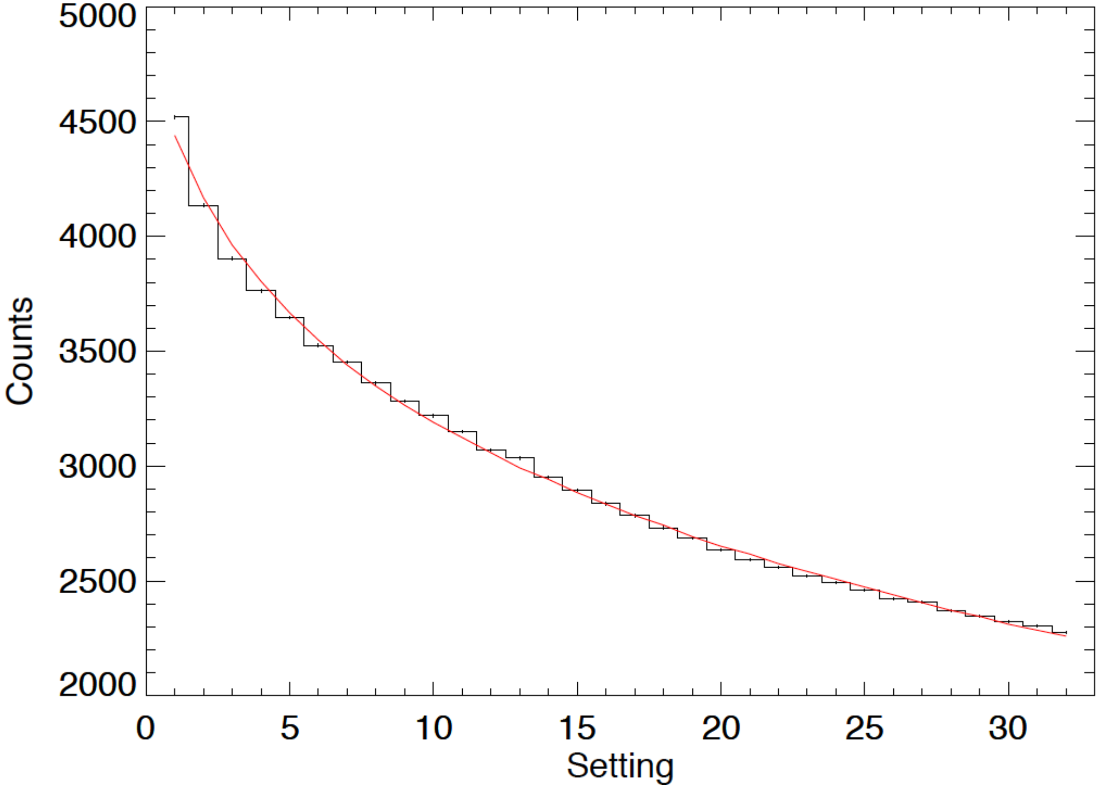


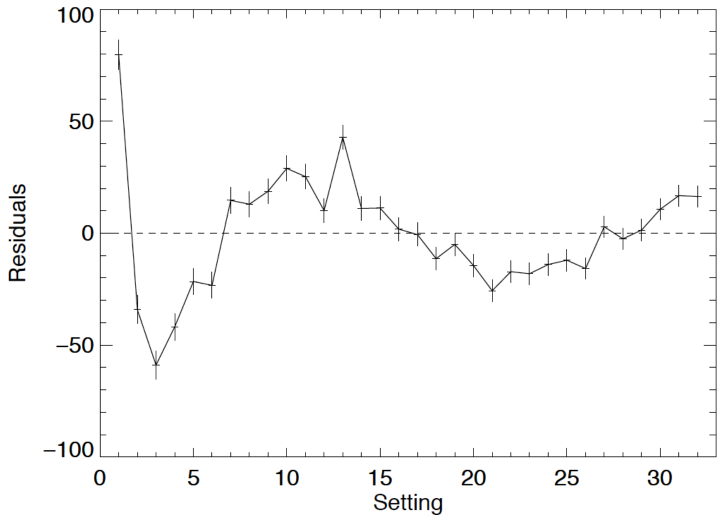
# Threshold loops: all-FEE mean, at one annealing

☆ **The behaviour does not trace one smooth trend**

☞ **Our assumptions are not strictly valid:**

- The 'excitation function' (CRs) may not be a smooth power law
- The steps in energy per threshold setting may not be linear
- The threshold width may not be described by a smoothed step (E, width)



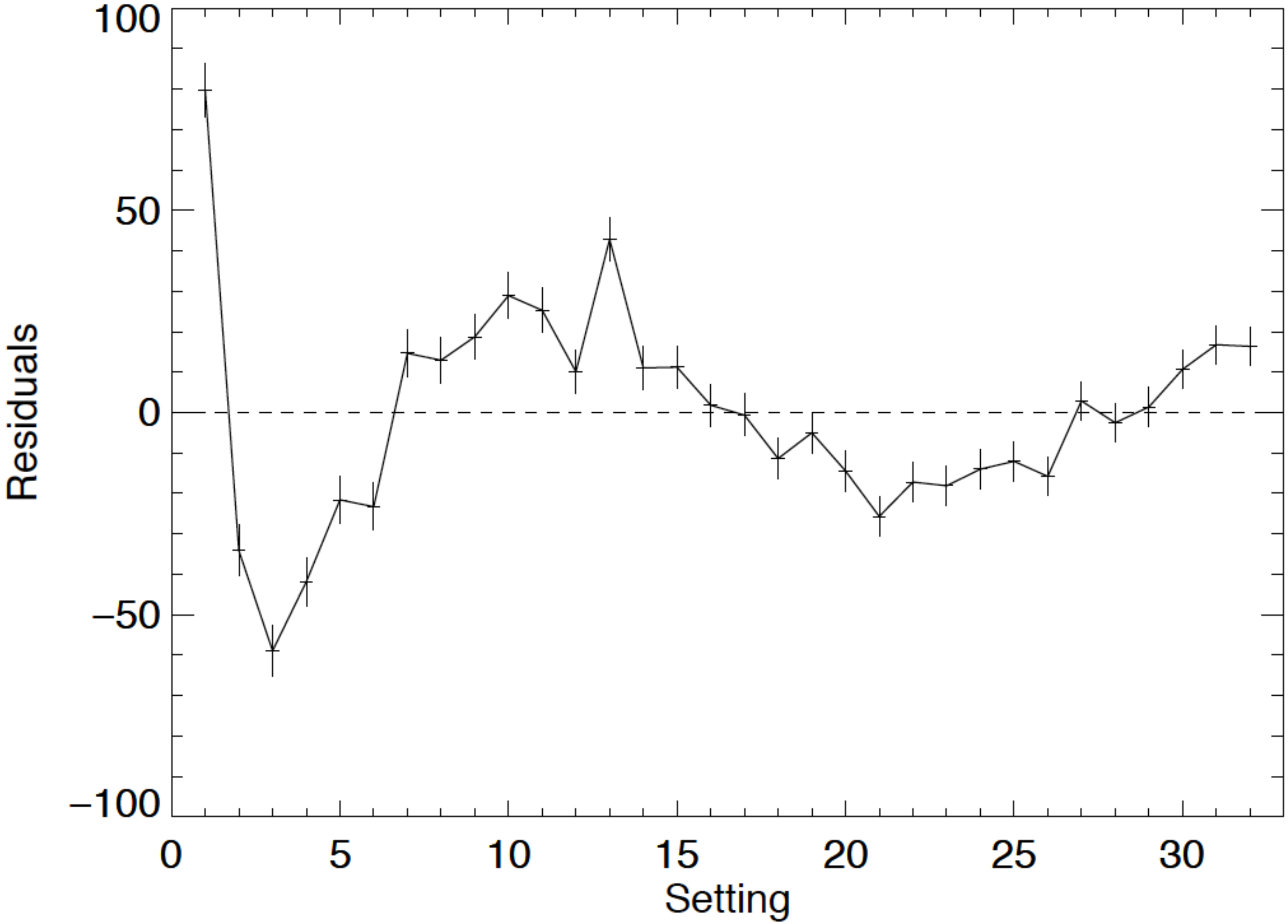

☆ Inspect the residuals from the expected behaviour

☞ Do all FEE/elements show behaviour similarities?

☞ Can we learn about ACS element groups?

# Can we learn from the deviations?

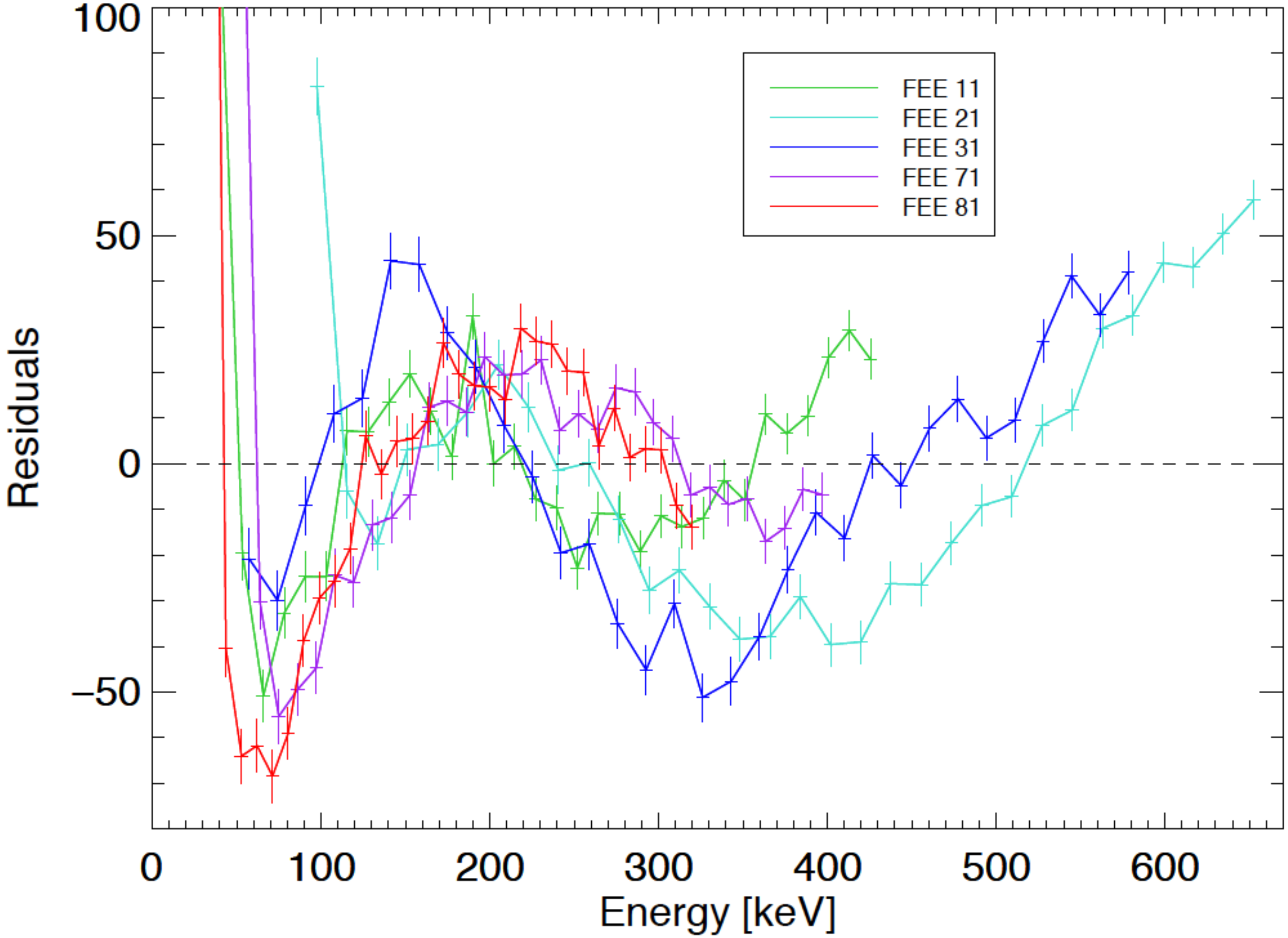
Inspect the residuals from the expected behaviour



# Deviations for different FEE groups

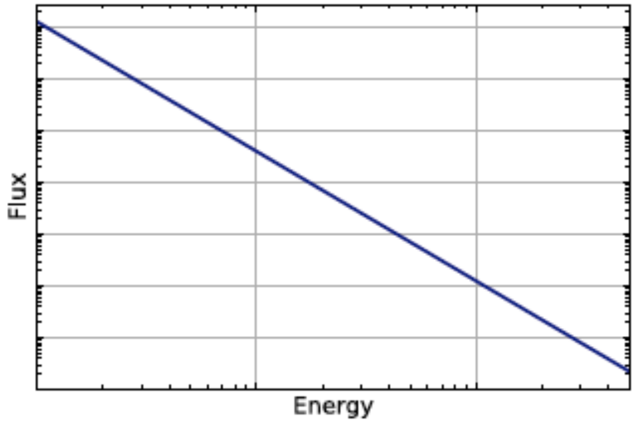
☞ Can we learn about ACS element groups?

☞ → a "stretch" factor for relative normalisation?

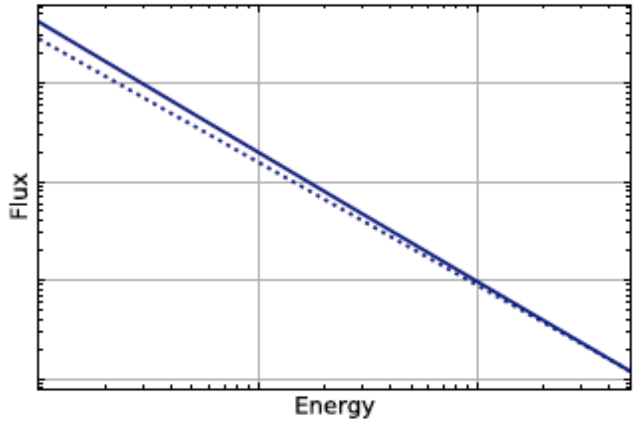


# The incident spectrum: Sophistications

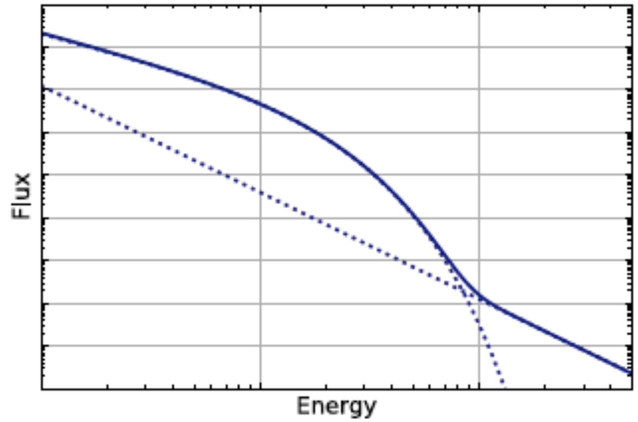
- Plausibly a power law, but there could be alternatives...→ check!



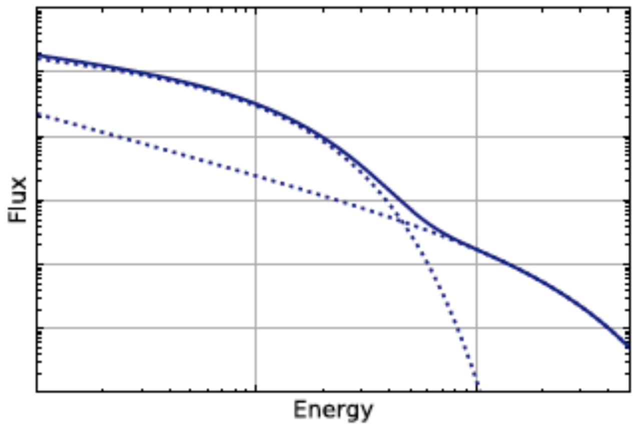

(a) Conventional power law



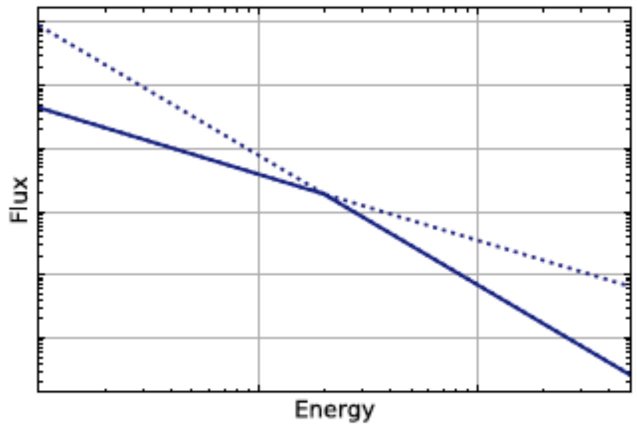

(b) Power law + power law



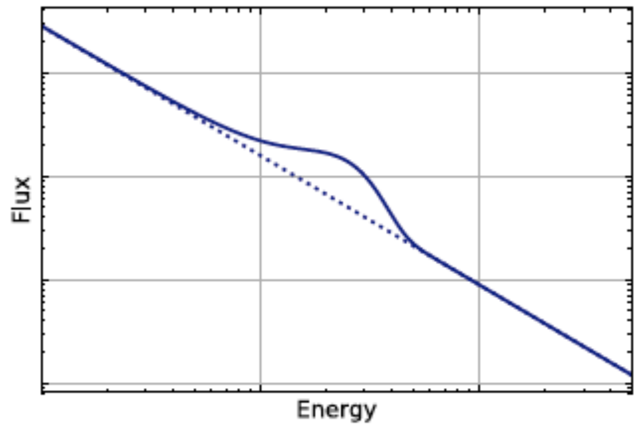

(c) Cutoff power law + power law




(d) Cutoff power law + cutoff power law




(e) Broken power law




(f) Power law + gaussian peak

# Incident spectrum alternatives

- A sum of a PL with cutoff and a second PL? (reduces discrepancies)

**Table 4.1:** Resulting $\chi^2_\nu$ values for the data set of revolution 209

| | | Power law (P.L.) | P.L.+P.L. | Cut. P.L. + P.L. | Cut. P.L. +Cut. P.L. | Broken P.L. | P.L.+line |
|---|---|---|---|---|---|---|---|
| | $\nu$ | 28 | 26 | 25 | 24 | 26 | 25 |
| UCR (-z) | FEE1 | 8.09 | 7.98 | **1.69** | 3.02 | 2.34 | 7.55 |
| | FEE7 | 48.78 | 46.62 | **5.47** | 8.48 | 12.01 | 11.69 |
| | FEE13 | 2.05 | 2.12 | 1.26 | 1.94 | **0.62** | 1.30 |
| UCR (+z) | FEE4 | 6.26 | 2.34 | **2.31** | 3.82 | 3.14 | 5.11 |
| | FEE10 | 9.78 | 8.43 | **3.02** | 6.16 | 8.98 | 10.01 |
| | FEE16 | 267.11 | 269.67 | **12.2** | 22.09 | 128.79 | 84.18 |
| LCR (-z) | FEE19 | 293.72 | 307.12 | **32.4** | 32.76 | 224.03 | 158.55 |
| | FEE25 | 2.54 | 2.62 | **0.92** | 6.99 | 2.05 | 3.08 |
| | FEE31 | 2.72 | 2.60 | 2.18 | 3.45 | 2.37 | **2.14** |
| LCR (+z) | FEE22 | 14.69 | 15.13 | **2.55** | 8.95 | 9.81 | 16.04 |
| | FEE28 | 5.48 | 4.64 | 5.46 | **2.81** | 5.17 | 5.57 |
| | FEE34 | 14.32 | 14.55 | 15.39 | **2.17** | 14.13 | 15.28 |
| LVS (x) | FEE82 | 15.15 | 15.64 | **2.37** | 4.84 | 12.51 | 17.28 |
| | FEE84 | 8.69 | 9.20 | **2.54** | 3.09 | 7.33 | 6.39 |
| | FEE88 | 0.85 | 0.90 | **0.74** | 3.27 | 0.711 | 0.90 |

# Time-dependent effects?

- Calibrations behave ~similar across the mission time... but...?

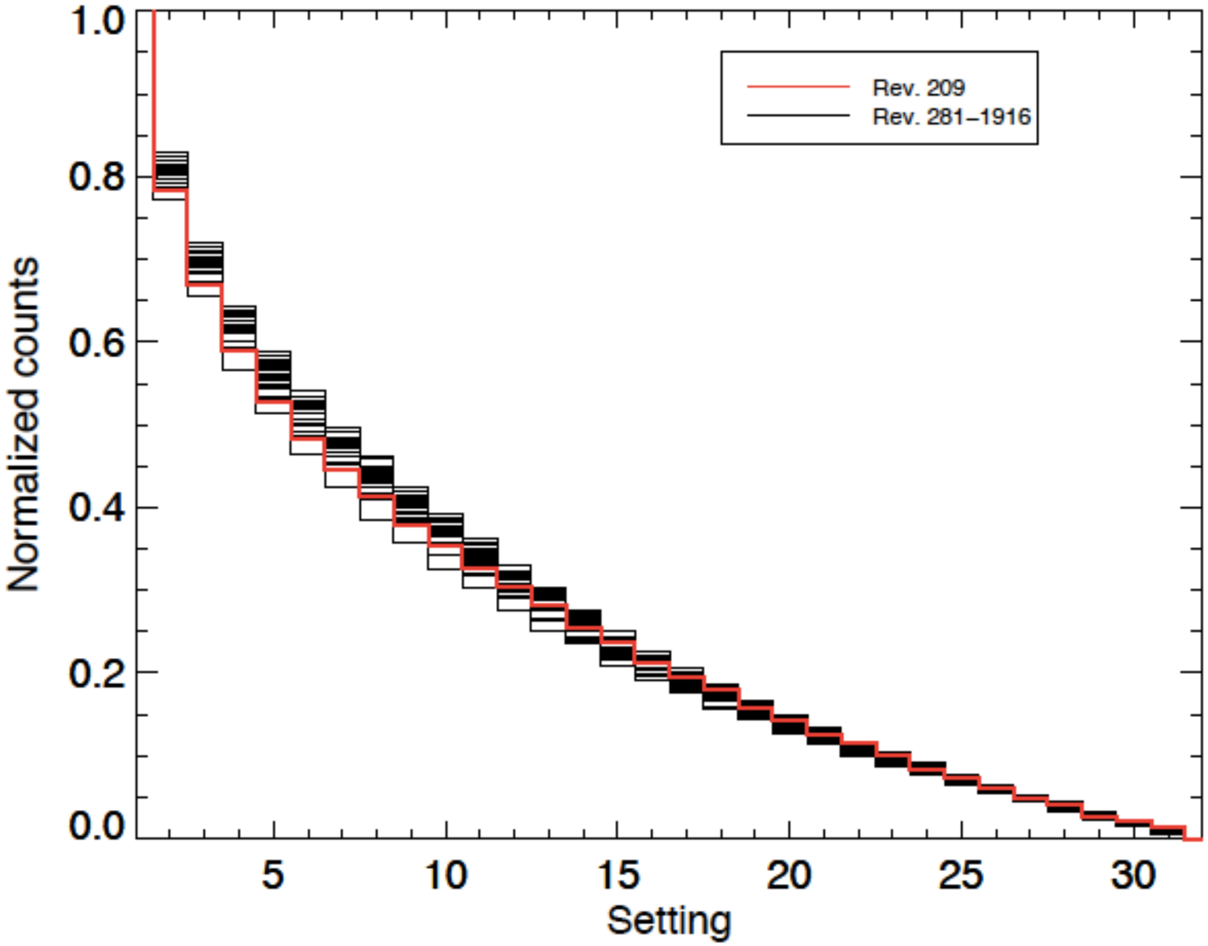



Figure 4.8: Normalized data of all revolutions from FEE 1

☆ In more detail: KS test ("are the patterns the same, within statistics?")

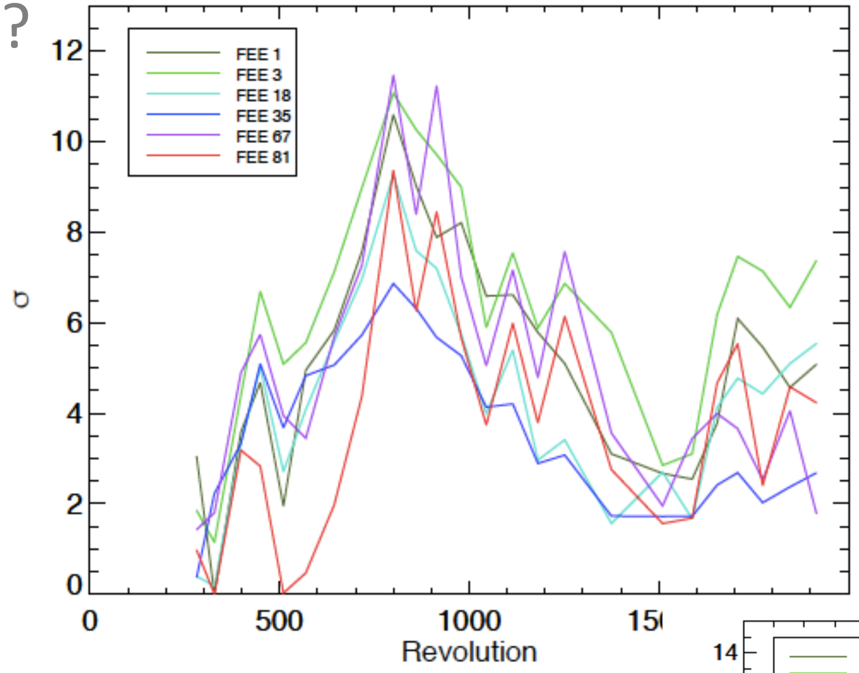
Reference: First ACS calibration.

σ measures significance of calibration not being a statistical sample of the reference.

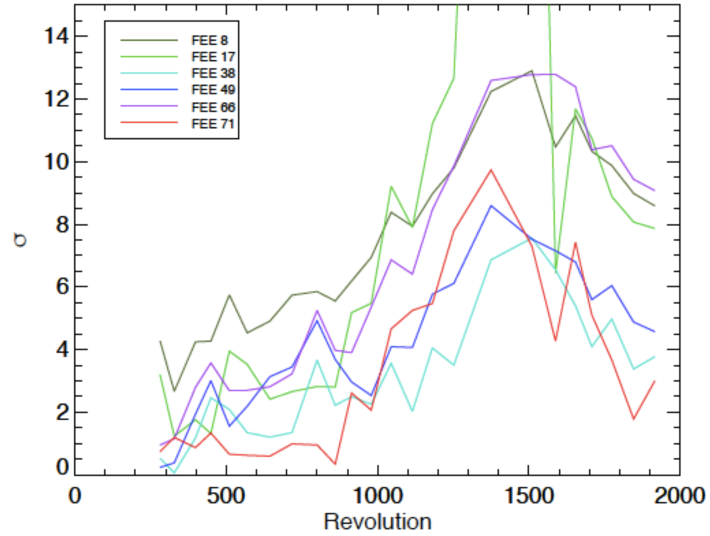
# Differences of calibration datasets with time

Reference: First ACS calibration.
σ measures significance of calibration not being a statistical sample of the reference.

- Solar cycle effects?
  - ☆ As CR flux is higher → differences are larger
  - ☆ But: other FEE groups seem to contradict this...




(a) Pattern with similiarities to the so

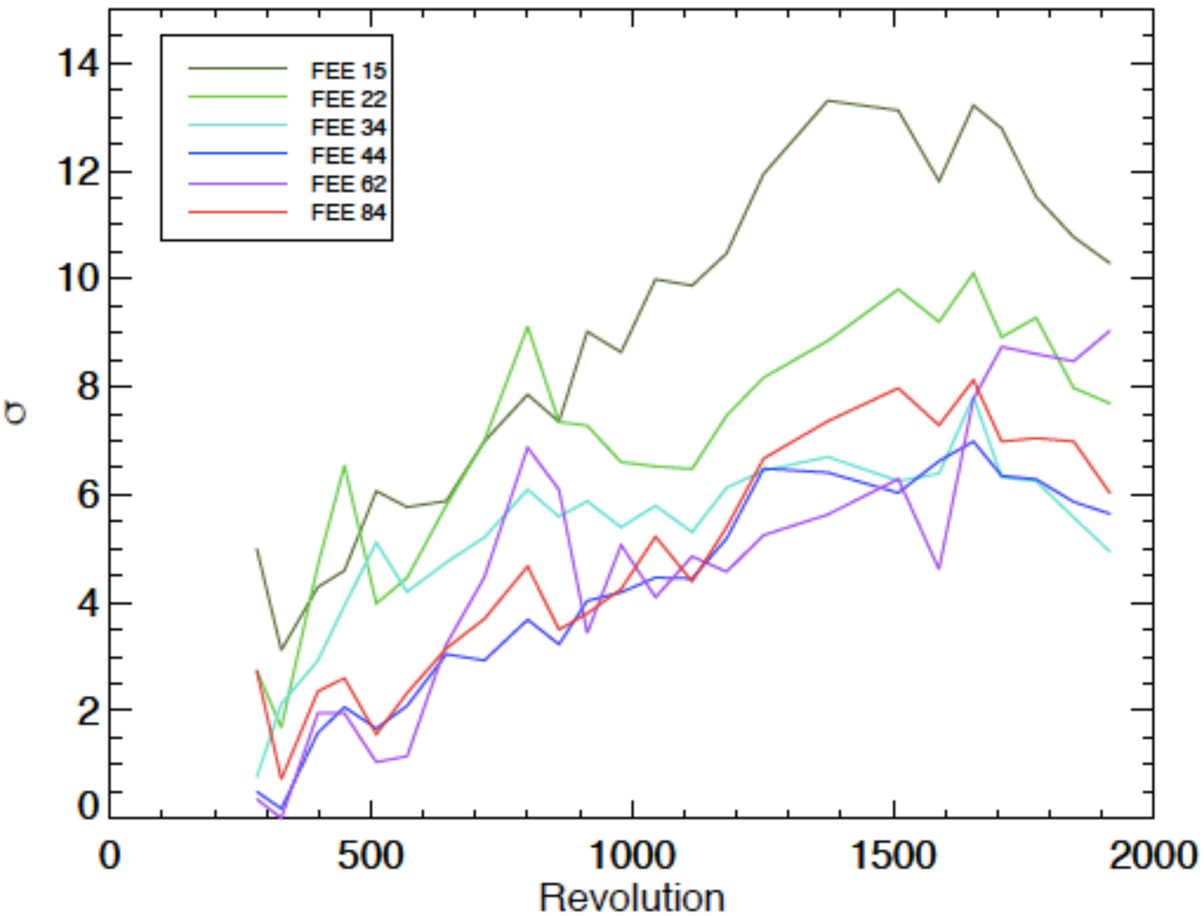



(c) Peak-like pattern of the significance levels

# Differences of calibration datasets with time

- Degradation/changes of ACS detectors with time?

☆ As time proceeds → differences are larger




(b) Steadily growing change of spectral appearance

# ACS Calibration: Status 2019

- B.Sc. Thesis Felix Schmuckermaier (11/2018)
  - ☆ Assessement of Issues
    - Missing prelaunch calibrations
    - A straightforward (PL, linearity) model fails to describe data
    - Residuals show significant unexpected behaviour around 200 keV
    - Grouping of FFEs and ACS sub-units possible?
    - Degeneracies of calibration data fits to our model: No clear external constraints
    - A temporal degradation of ACS detectors could explain observed trend (but so could a change in irradiation/bgd environment)

  → Existing ACS Calibration Data are Insufficient for ACS Response Inflight Calibration

Next?

- Comparison/Validation on GRB data, ACS and GBM?
  - ☆ Discussions with V. Savchenko et al
  - ☆ Detailed description of ACS Response: cmp. VS's approach with our model

# Late-Mission Activities @ MPE 2019+

- Routine procedures (→ automatic; documented)
  - ☆ Data import
  - ☆ Routine processing
  - ☆ Quality checking
  - ☆ Spectral fitting → response database
  - ☆ Performance validation (incl annealings)
  - ☆ Software maintenance
- Multi-instrument analysis software "3ML"
  - ☆ Model parameter fitting
  - ☆ Instrumental response and background treatment encapsulated
  - ☆ Start with GBM, SPI, LAT, …
  - ☆ Python based
- Handover of MPE-INTEGRAL activities 2020 to J Greiner
  - ☆ RD retired 2/2019, has 2 PhD students till 2020/21
  - ☆ DLR support MPE and XZ till 2021
  - ☆ J Greiner involved in high-energy astrophysics science and in SPI