Spectral Calibration of AstroSat CZT-Imager: Current Status

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On behalf of CZTI team

AstroSat Calibration Meeting

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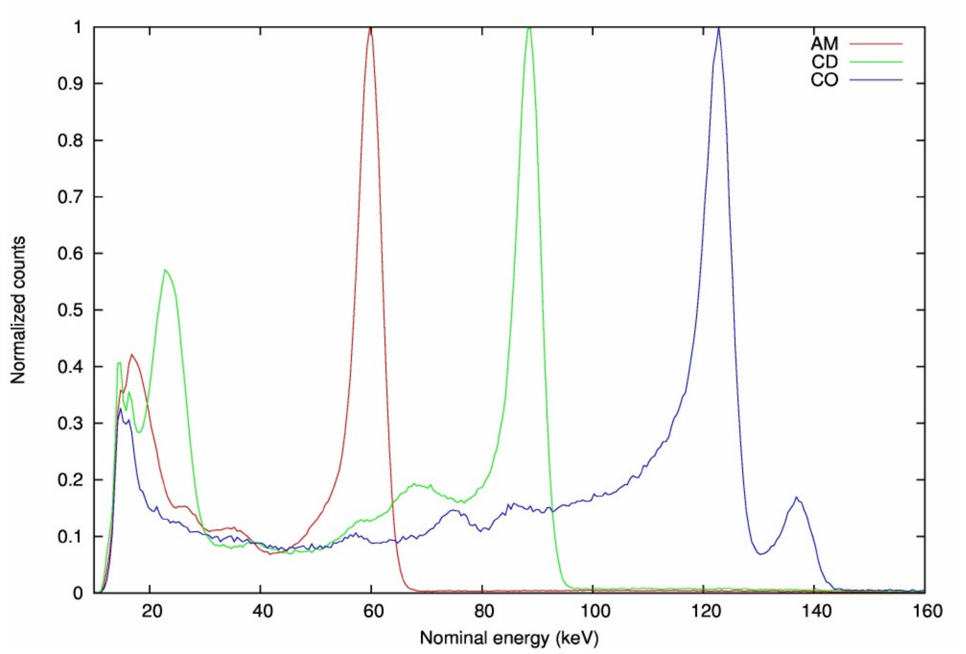
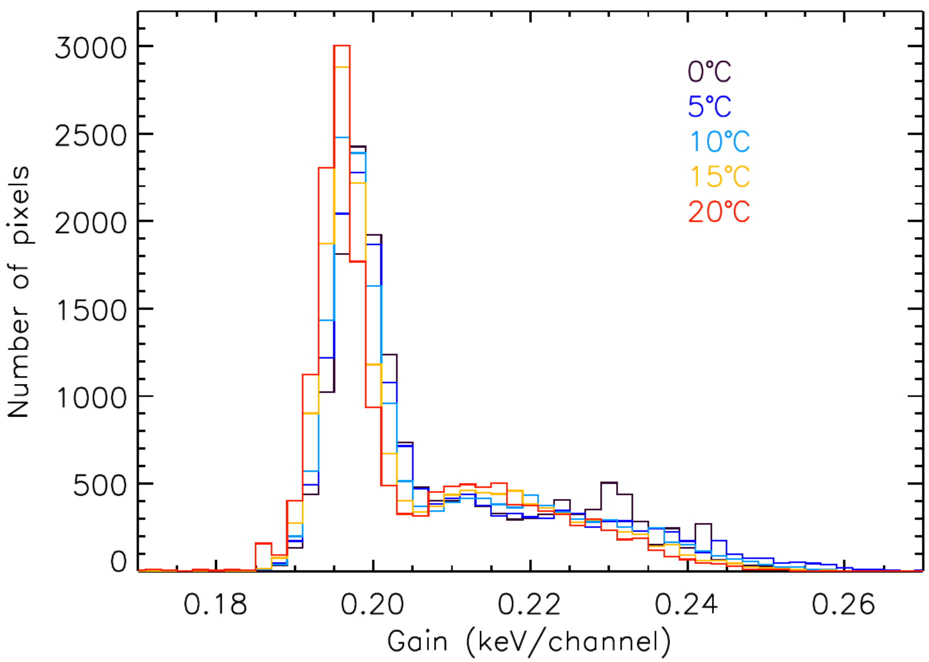
Overview

- Brief summary of ground calibration
- In-flight pixel gains, LLD, ULD
- Mask-weighting: Background subtraction
- Efficacy of background substraction and sensitivity
- Quadrant, detector, mask alignment
- Crab spectra and additional response corrections

Ground calibration: Pixel gains and pixel quality

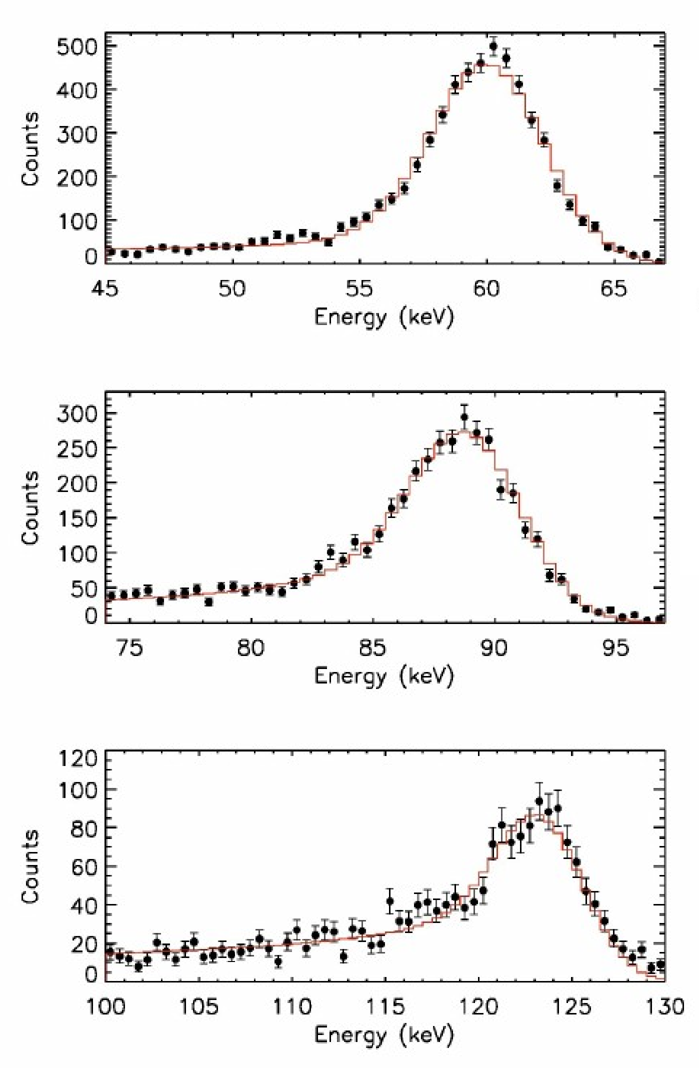


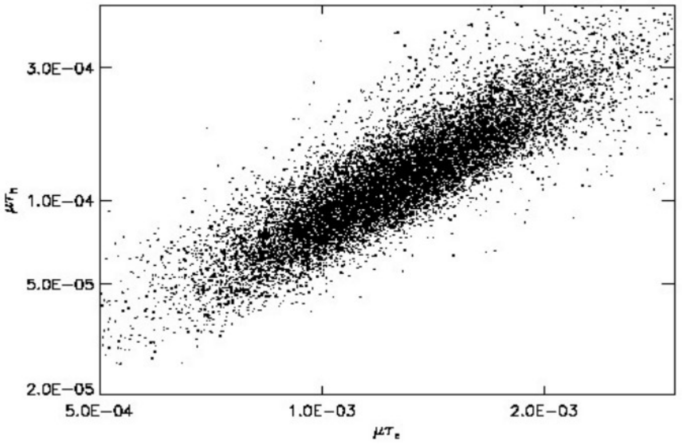


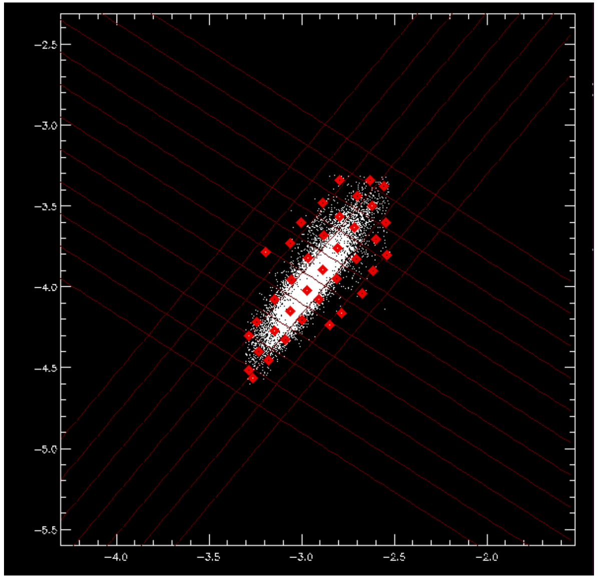
Spectra acquired with Am, Cd, and Co at different temperatures: Fit to each of 16384 pixels to give gain and offset at each temperature

Consistently noisy pixels on ground disabled: 5% pixels

Ground calibration: Spectral redistribution



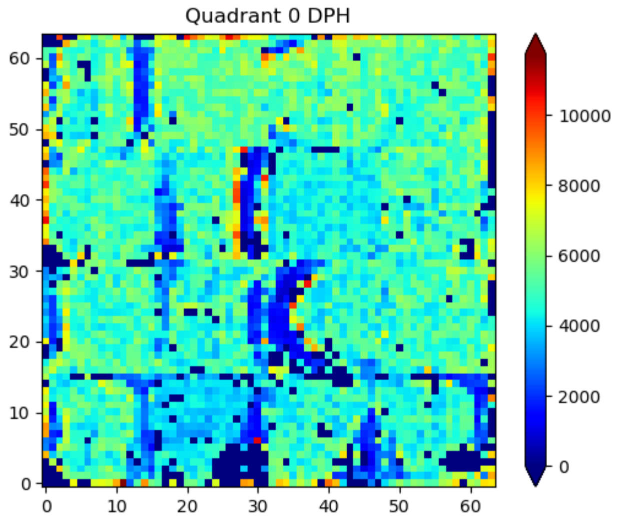


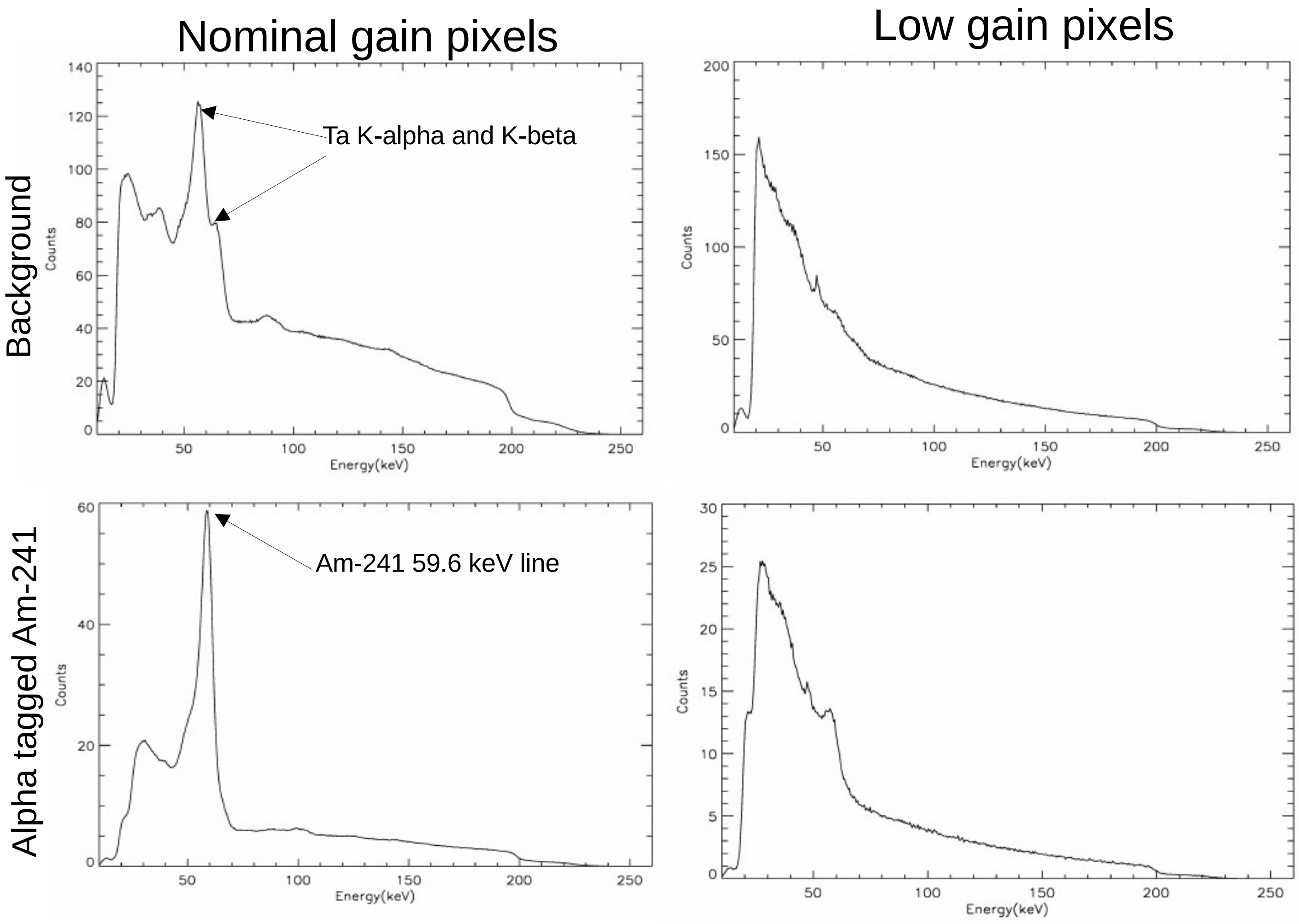


Line profile model incorporating incomplete charge collection and charge sharing effects: Simultaneous fit to get pixelwise parameters : mutau_e, mutau_h, resolutionpar, chargecloud radius

Grouped pixels having similar parameters: 270 groups of RMF precomputed using the parameters and Geant4 simulations and included in CALDB

In-flight gain calibration: Two classes of pixels



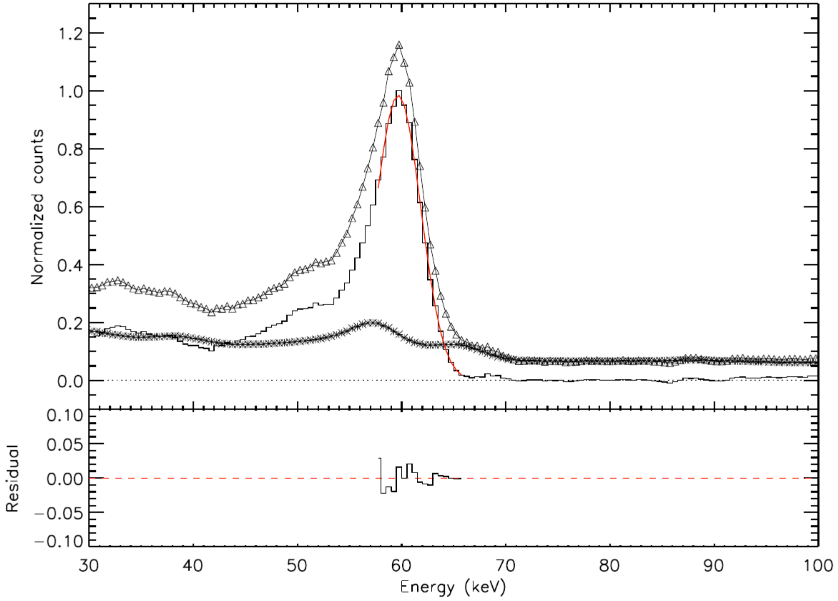


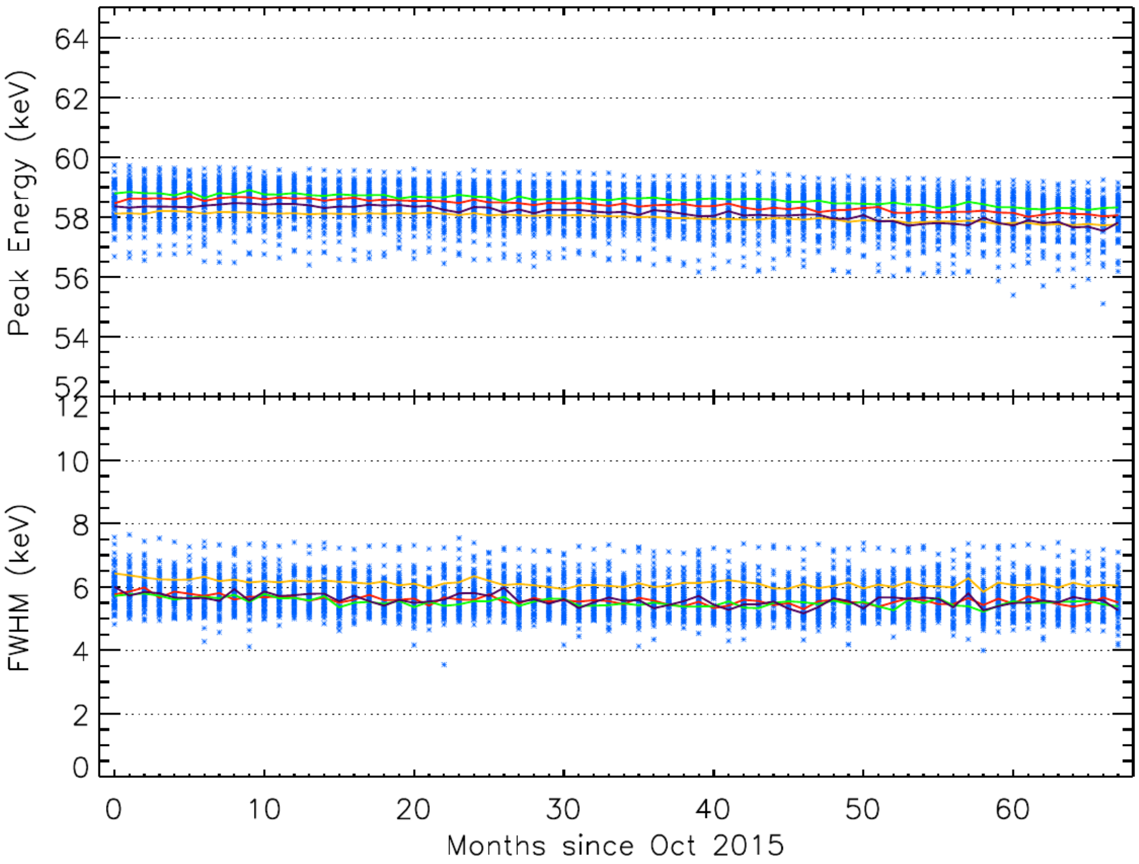
After launch, ~20% pixels showed low counts

These pixels don’t show expected lines in background or the Am-241 line

Identified that these pixels have lower gain: LLD ~> 70 keV going up to ~500-600 keV

Modulewise Am-241 spectra: Gain variations



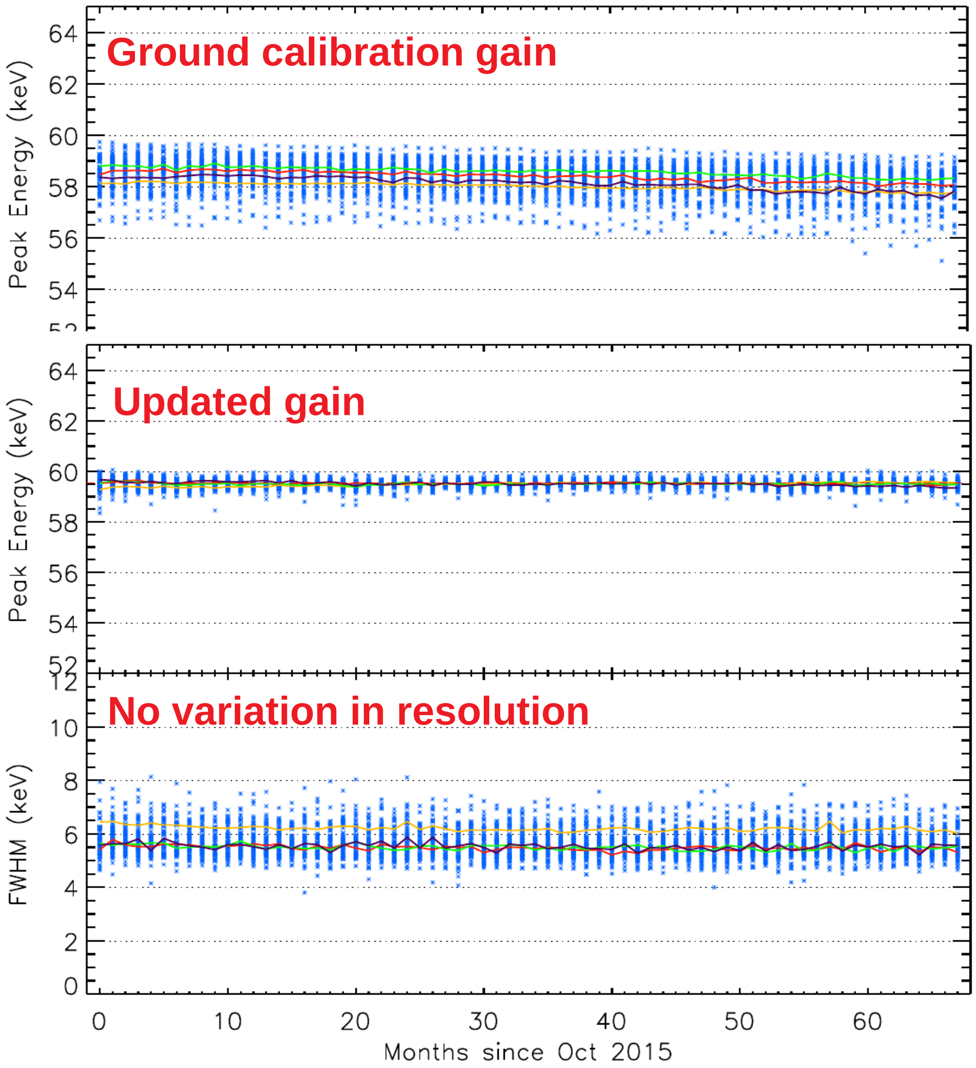


Module wise alpha tagged Am-241 spectra for each month fitted to get peak energy

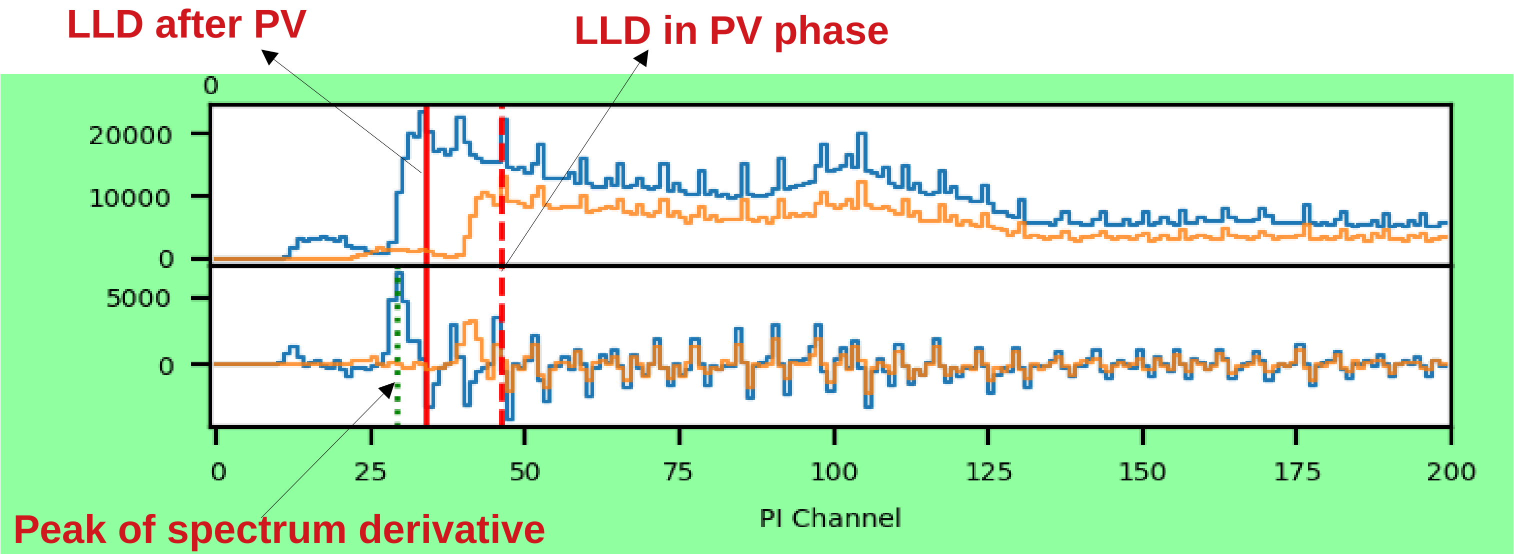
Scatter in actual energy between modules as well as a slow trend of change in gain with time observed

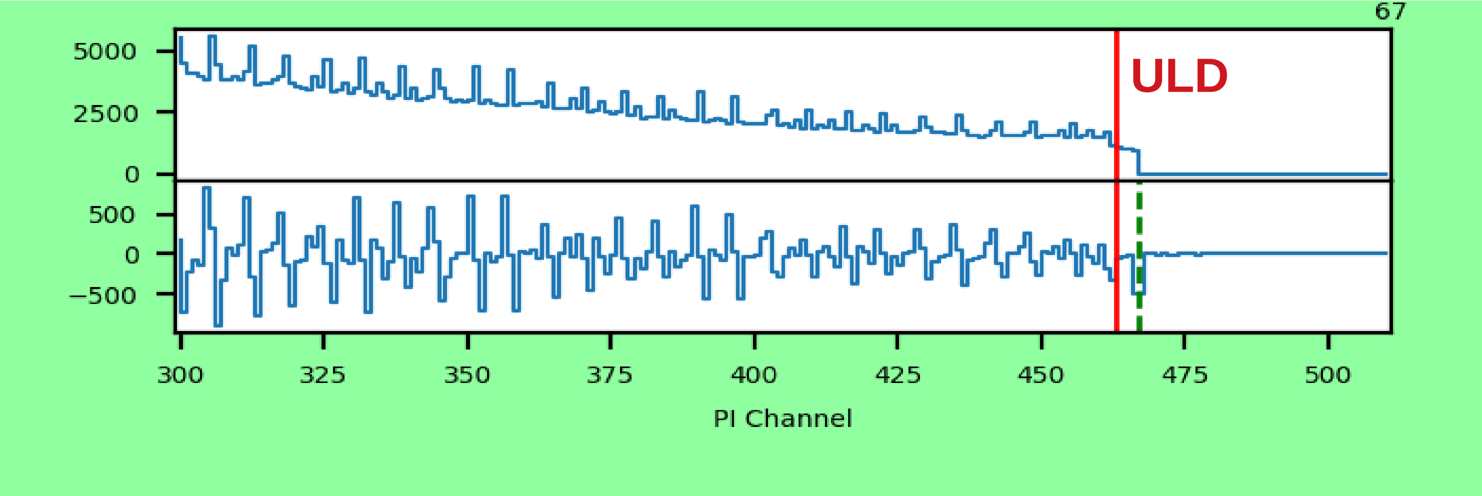
Gain correction factor: Time-independant and time dependant

- Average Am-241 spectrum for each good pixel fitted to get time-independant correction factor
- Additional time-dependant correction
  - Tgcor = c + m*ndays
- With updated pixel-wise gains: Line energies within +-0.5 keV
- No variations seen in the spectral resolution: Ground calibration RMFs consistent with the inflight observed line profiles



LLD and ULD of pixels





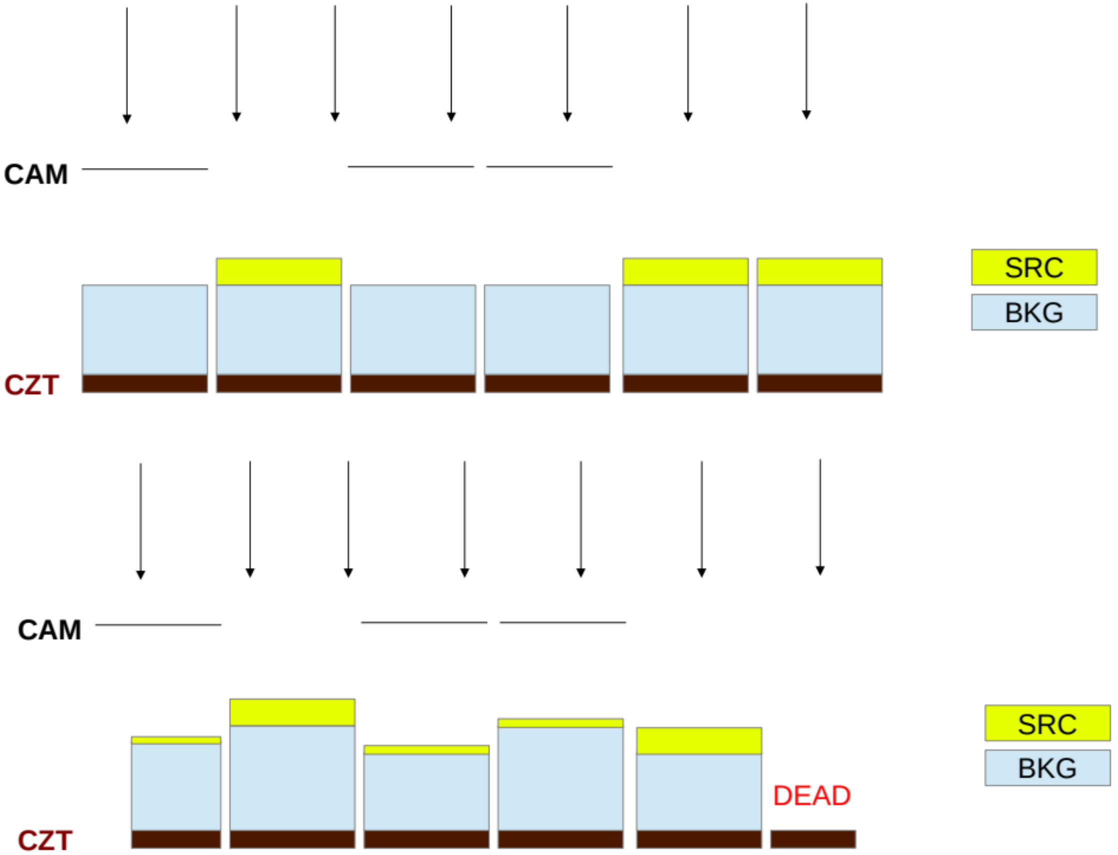
Updates in pipeline and CALDB

- Additional gain correction factors, revised LLD, ULD and pixel classification to be part of revised CALDB

- New pipeline module to apply additional gain correction to existing event files

- Updates in pipeline module to generate spectra to take into account the gain correction while generating the spectrum in case the event files are not corrected for this

Extracting source spectrum: Mask-weighting



$$w_i{}' = 2\ f_i - 1$$

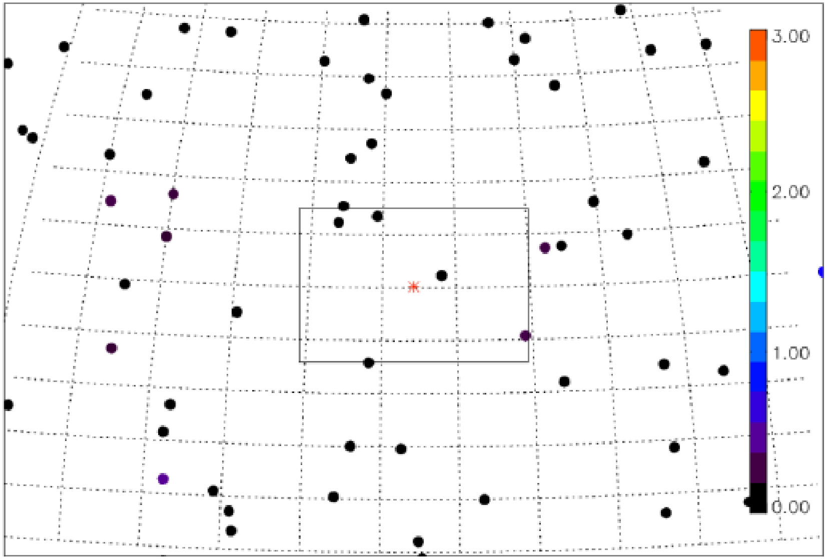
$$\mathbf{D} = \frac{\sum_i w_i{}'\ \mathbf{B_i}}{\sum_i \mathbf{B_i}}$$

$$\mathbf{w_i} = w_i{}' - \mathbf{D}$$

$$\mathbf{S} = \sum_i \mathbf{w_i} * \mathbf{C_i}$$

Requirement: Bi – background spectrum across detector plane

Background non-uniformity templates



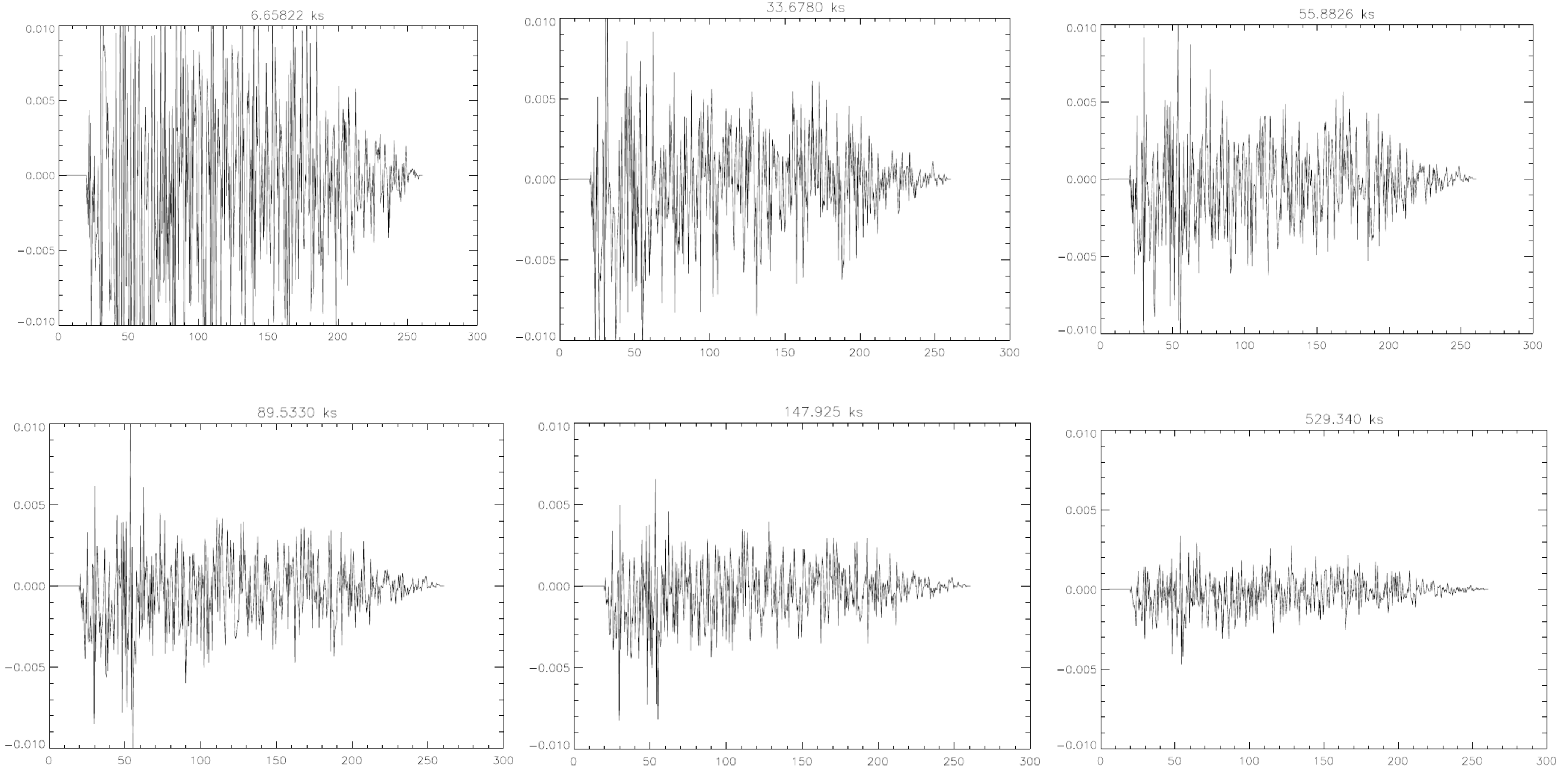
2 Ms observations of fields with no BAT sources brighter than 1 mCrab

Data reduced to get background spectra for each pixel

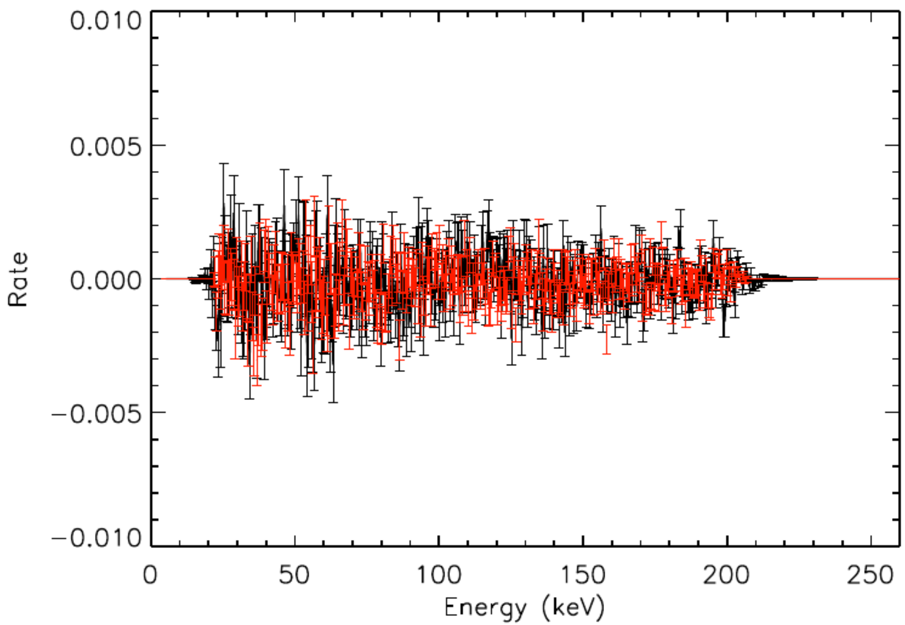
Coadded pixel wise spectra – template for background spectral non-unformity across detector plane: Included in new CALDB

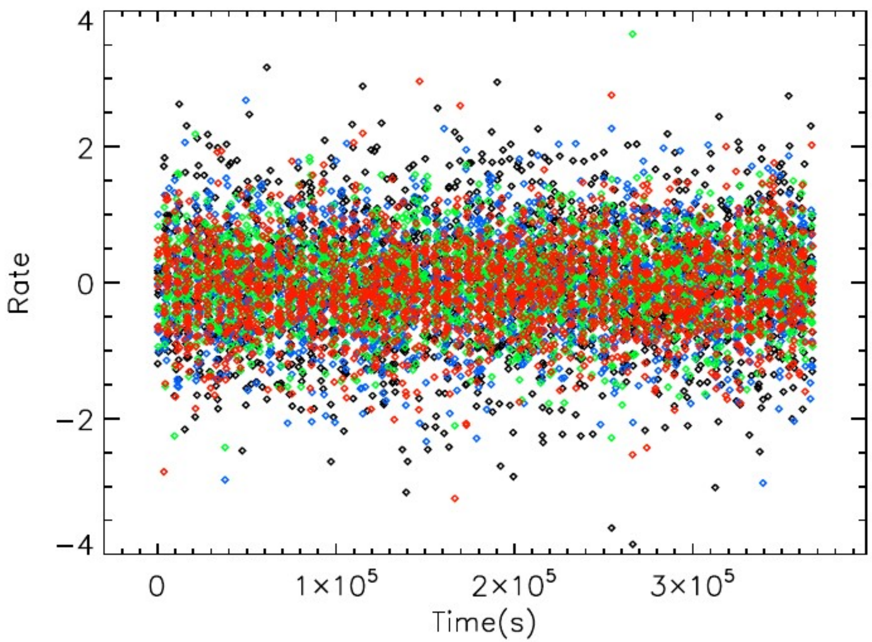
More about this in background session

Efficacy of background subtraction: Other blank sky spectra



Blank sky spectrum and light curve

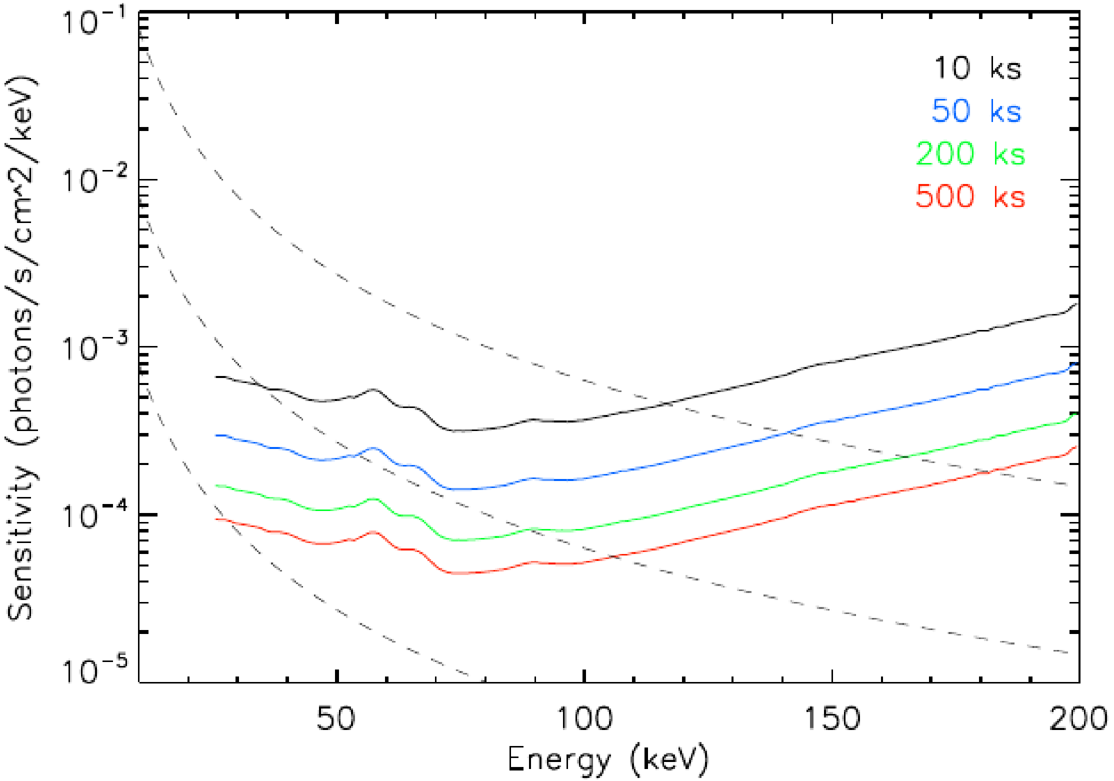




Mask-weighted light curves and spectra consistent with zero for blank sky observations of 200 ks exposures

Background subtraction limited by statistics upto about 500 ks exposure

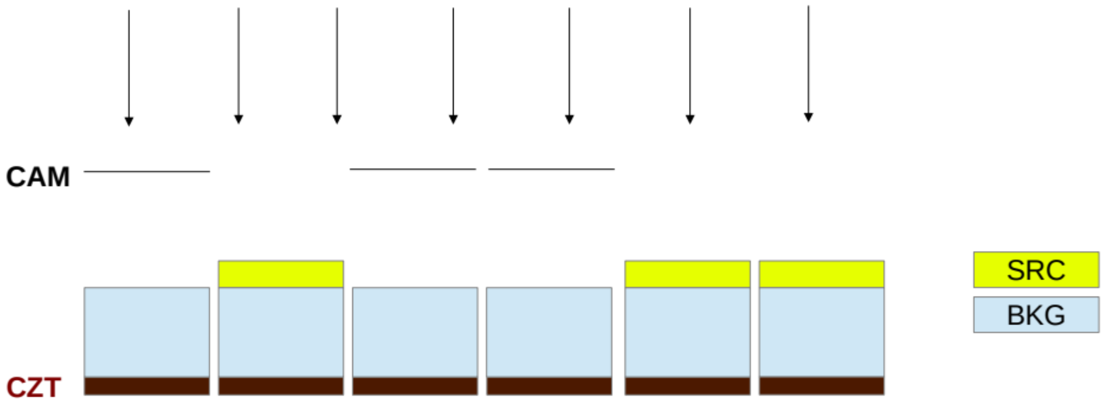
Spectroscopic sensitivity of CZTI



With the new background subtraction technique, the spectroscopic sensitivity is now limited only by statistics for typical observations with exposures up to ~ 500 ks

This is for 1 keV bins with one quadrant: Better with log-E binning and all quadrants added

Alignment of detectors with spacecraft axis



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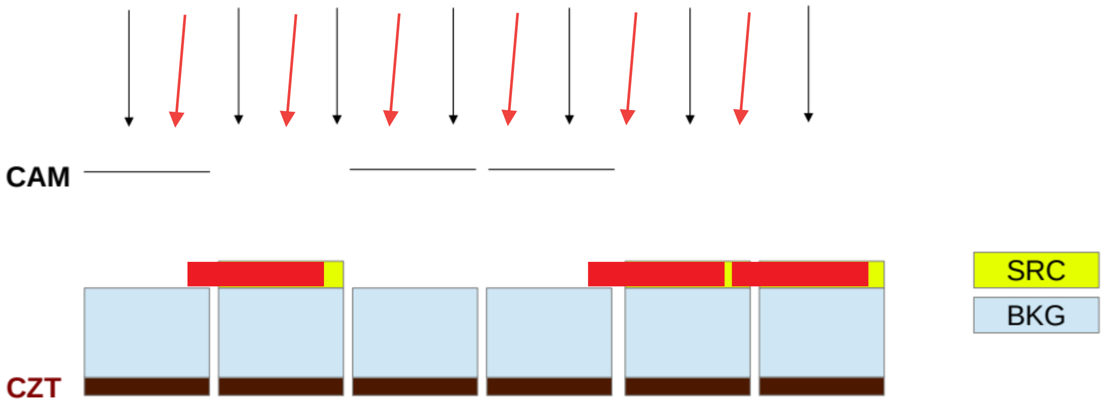

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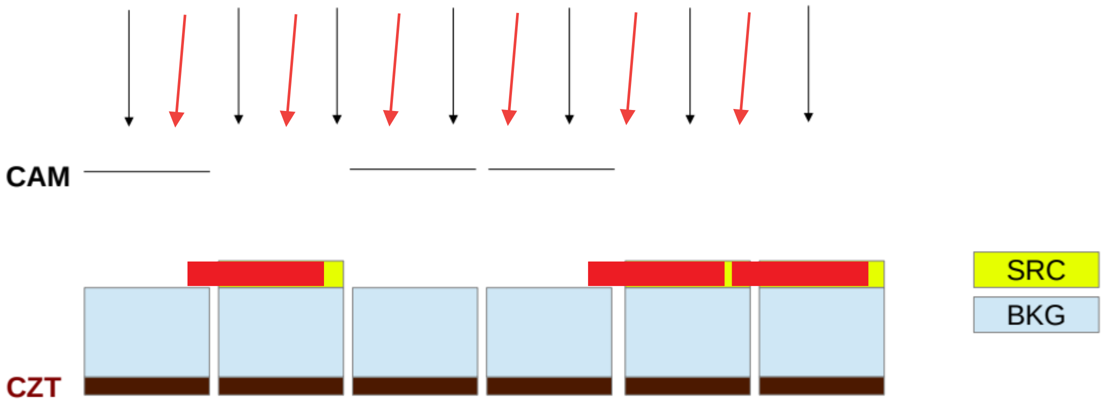
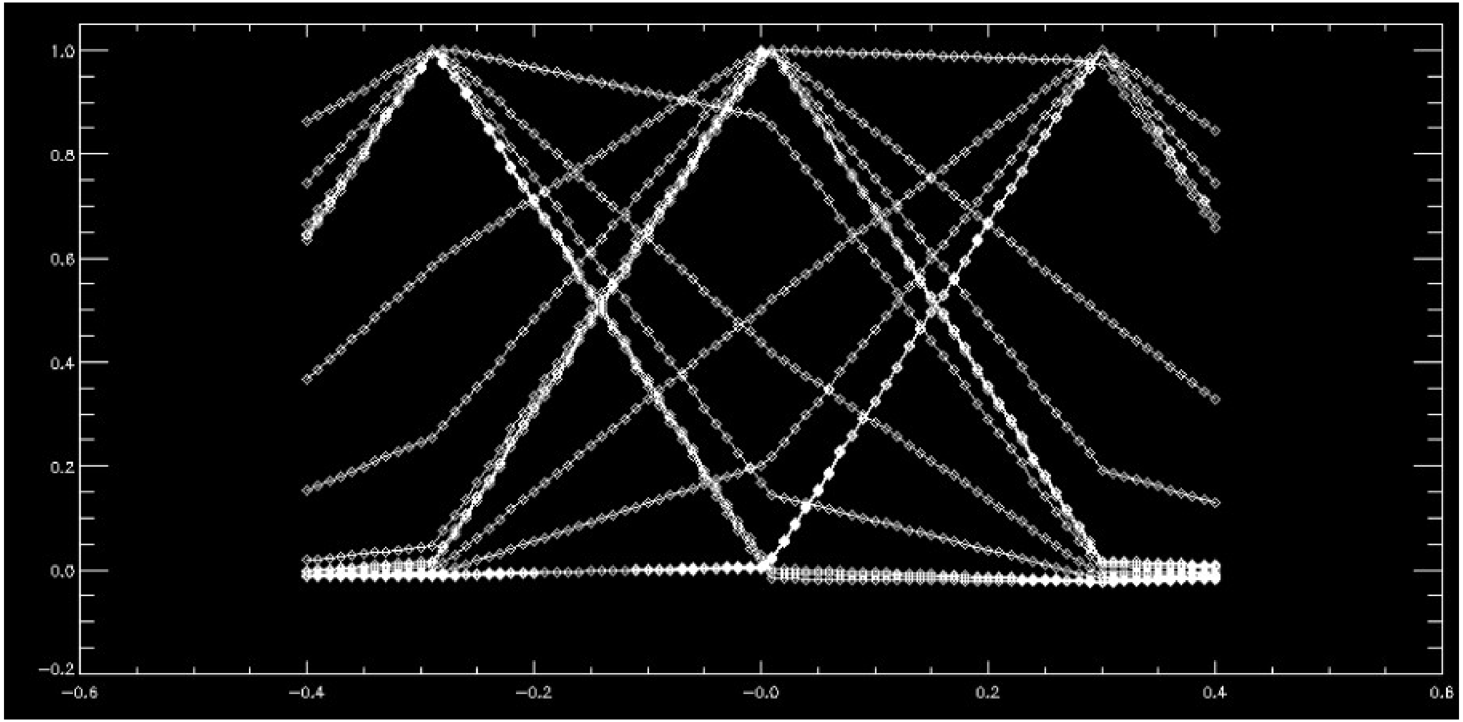
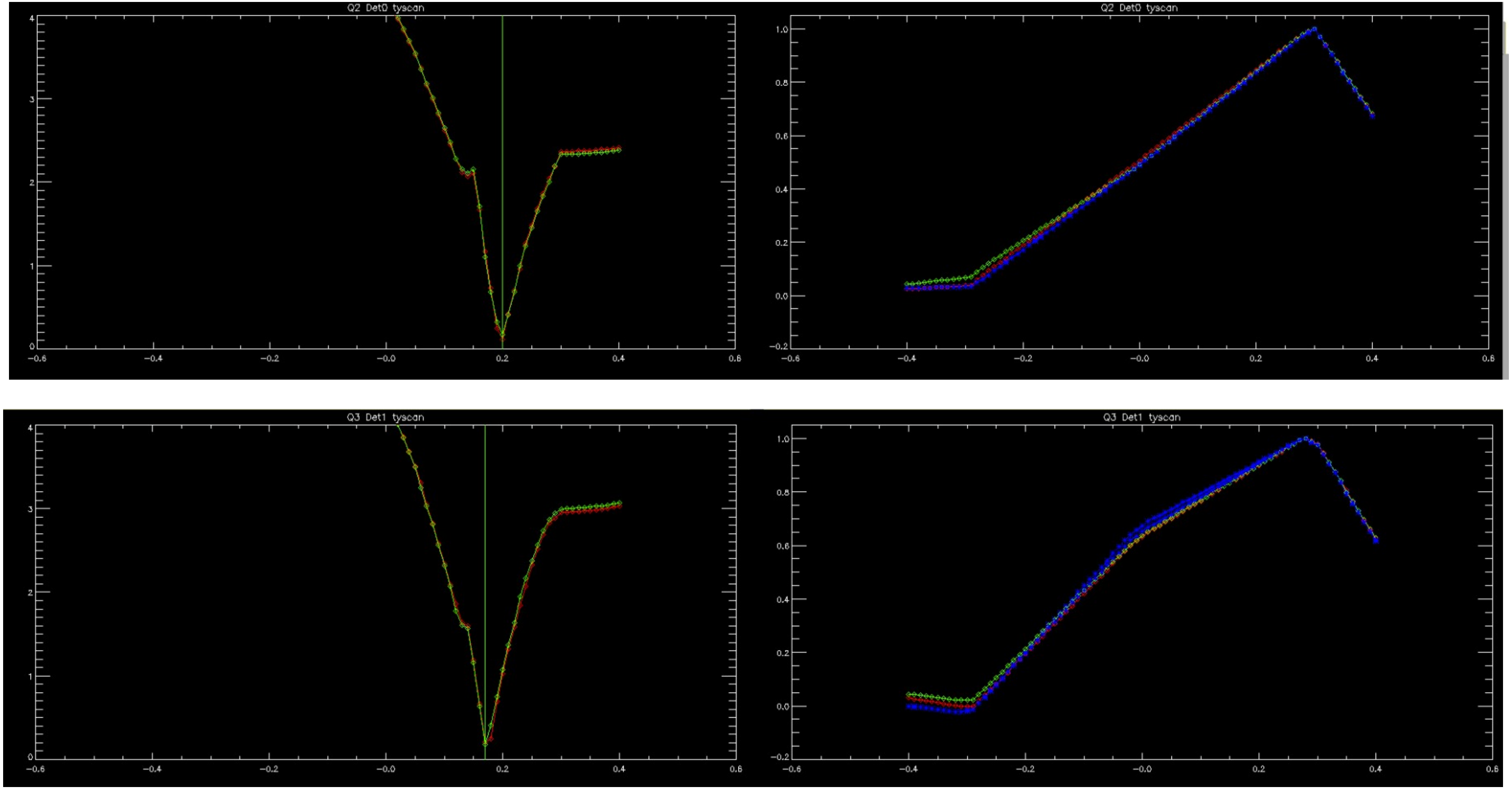


- Mask open fractions and mask-weighted source flux very sensitive to the source location
- Information of alignment of individual detector module + mask system with spacecraft axes is essential
- Without this, incorrect source flux estimates – source flux will be lost
- Imaging analysis provided quadrant level shifts with respect to the S/C axes
- Mask-weighted count profiles: Can be used to determine the angular offsets of individual detectors

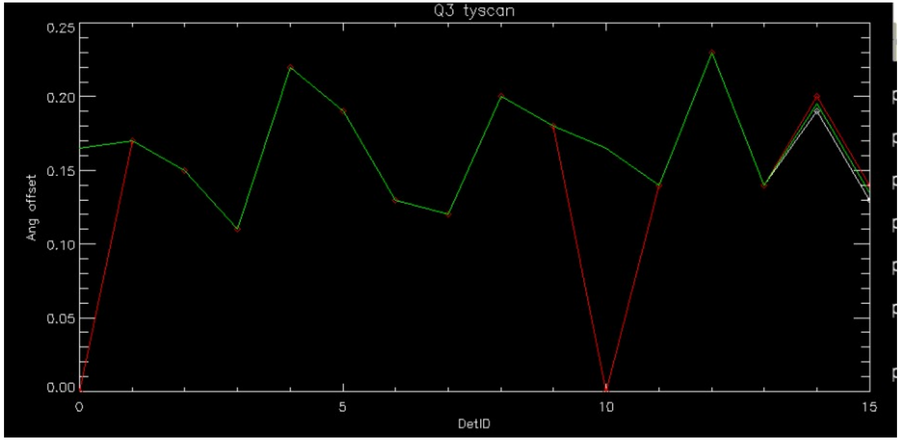
Measuring angular shifts with mask-weighted count profile

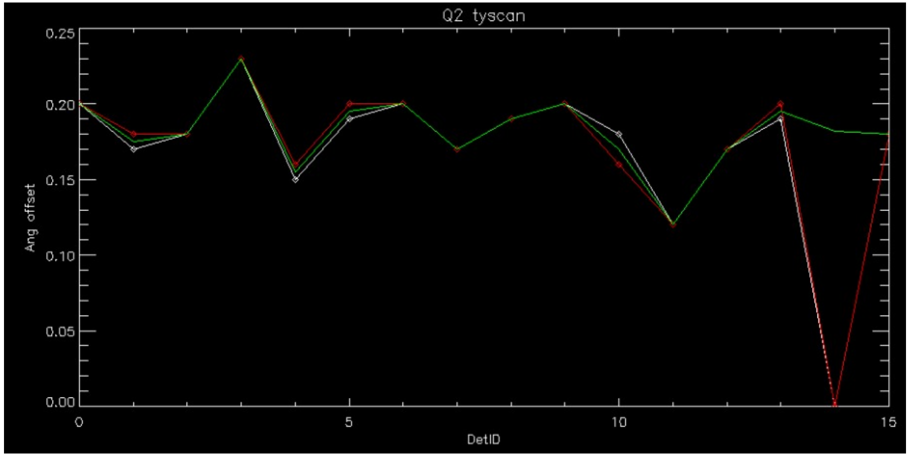


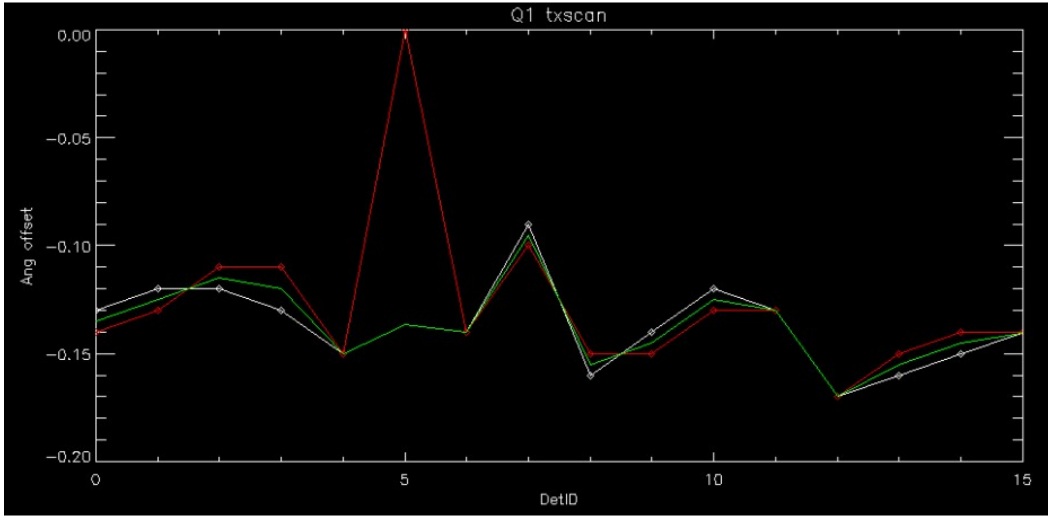
Measuring angular shifts: Examples



Measured angular offsets

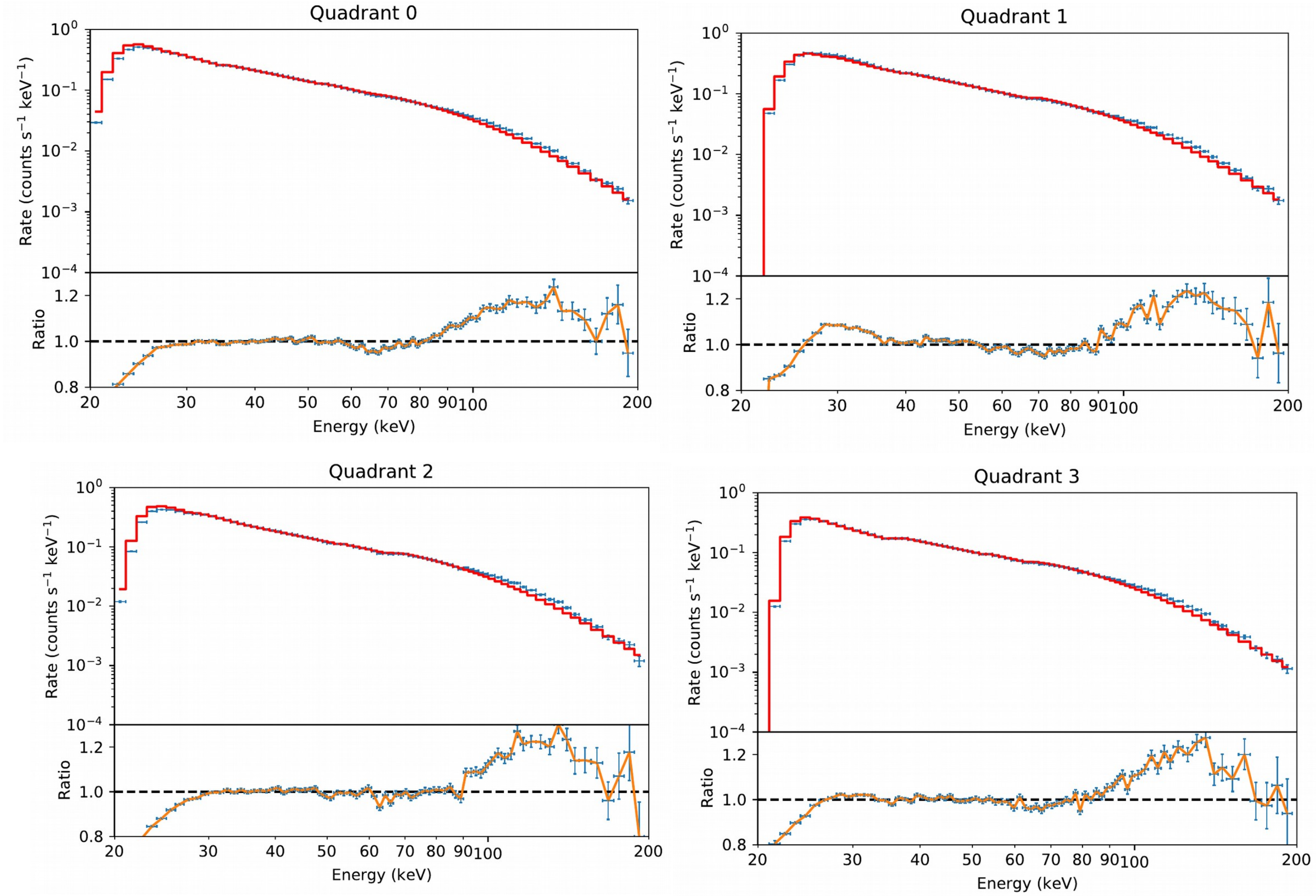






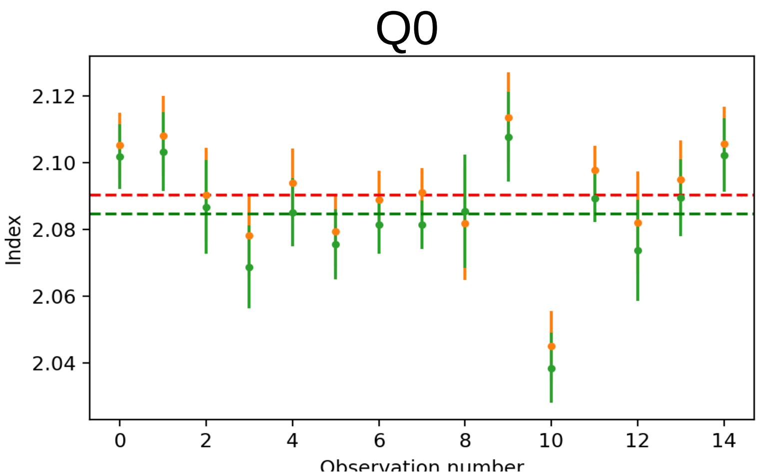
Effective area calibration with Crab: Residuals wrt canonical model

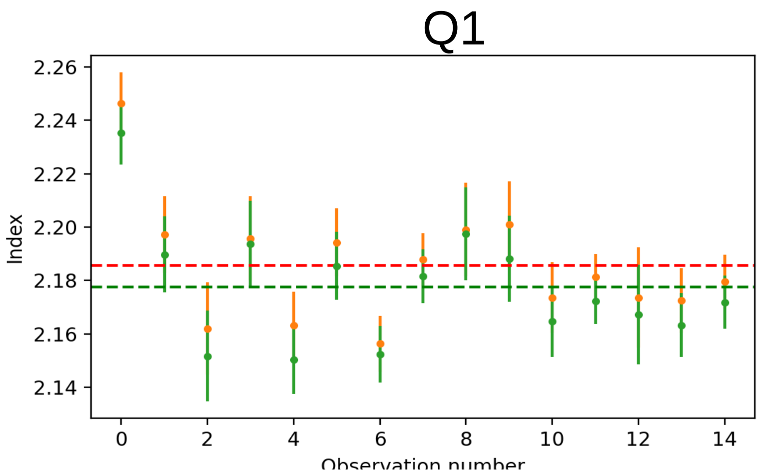
- Coadded crab spectrum from 15 observations: effective exposure of 1.5 Ms
- Ratio of observed spectrum with canonical crab model of powerlaw with index 2.1
- Mostly ~30-100 keV matches with canonical model
- <30 keV and >~100 keV: consistent residuals

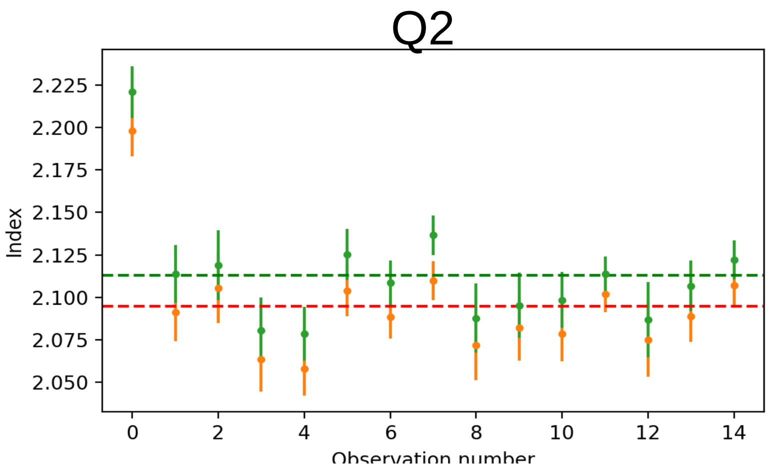


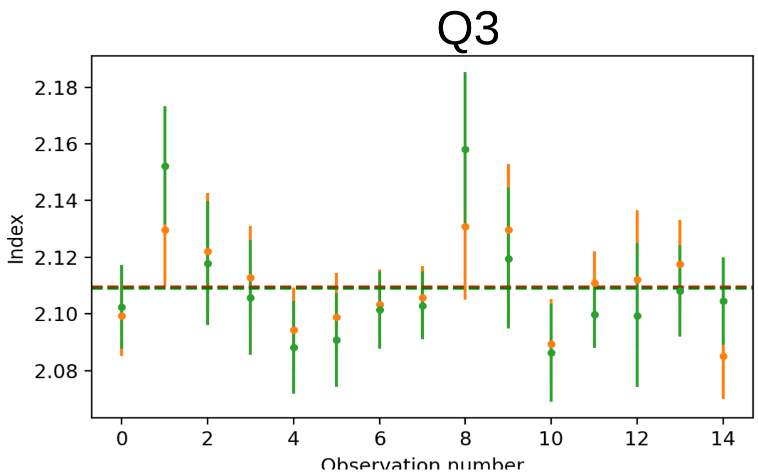
Crab spectral parameters over time: 30-100 keV

Old quadrant wise shift and new modulewise shift









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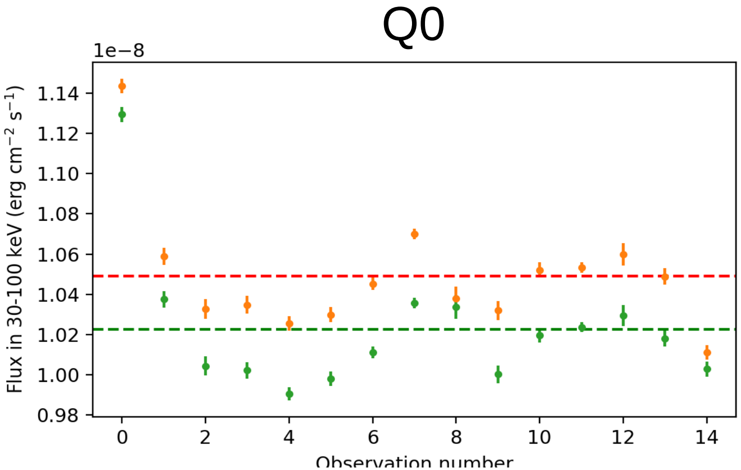
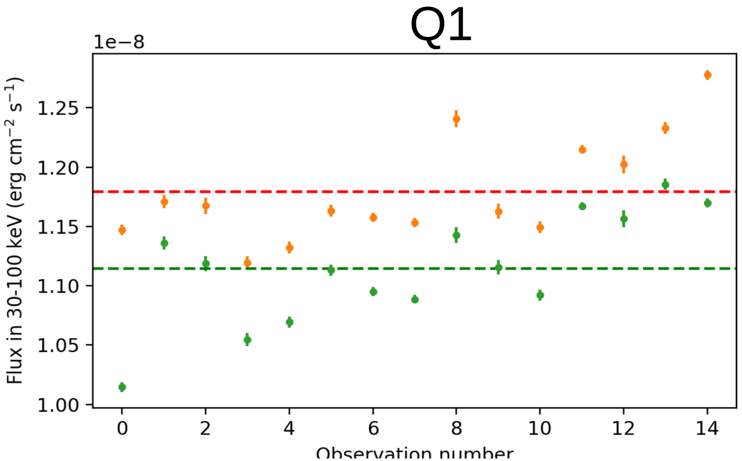
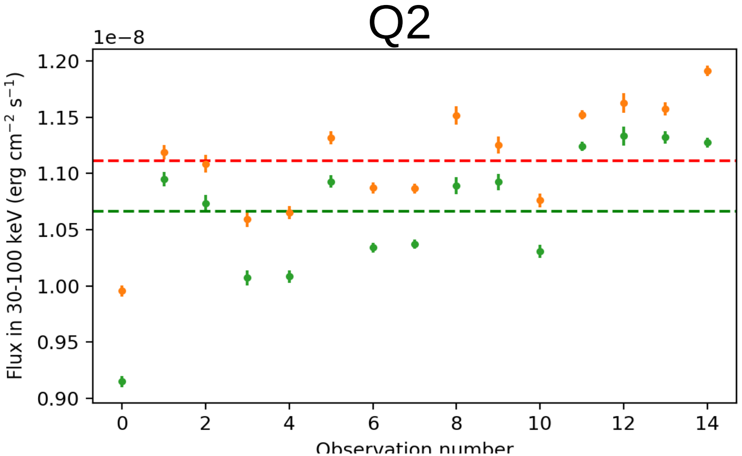
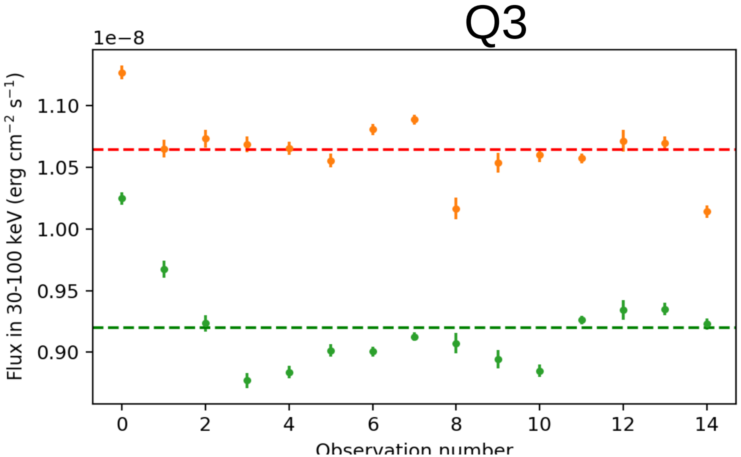
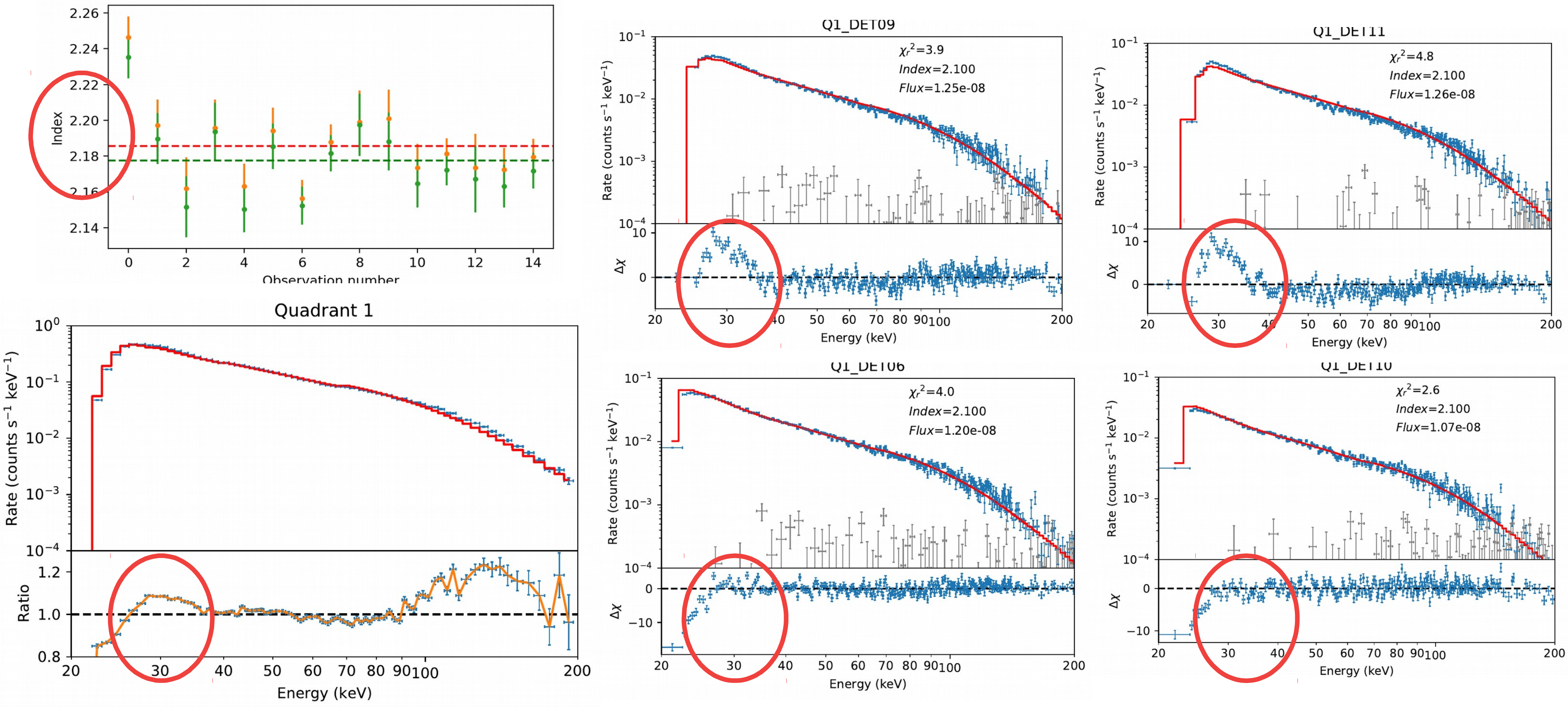








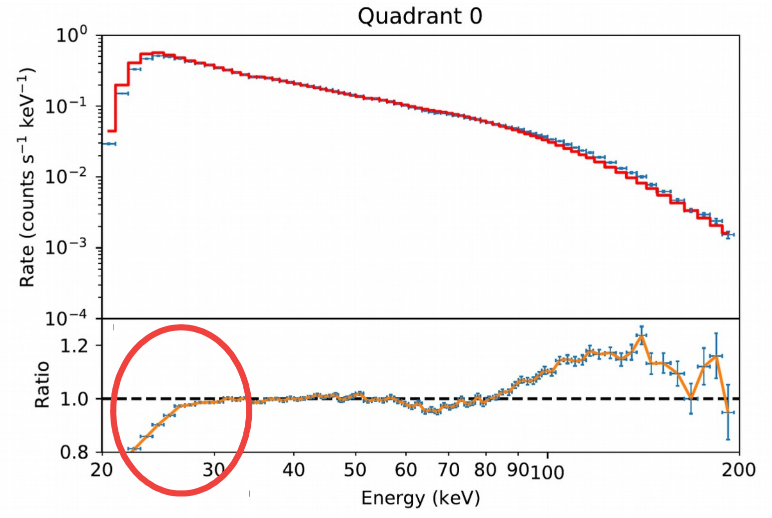
Quadrant 1: Low energy excess and softer index

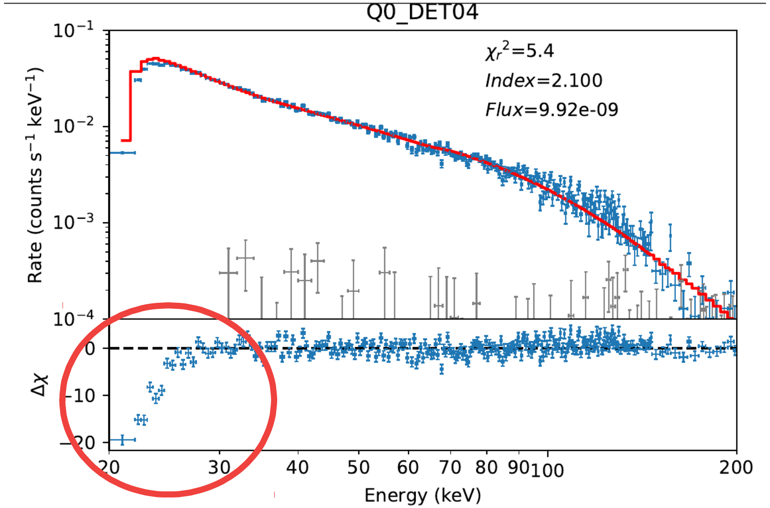


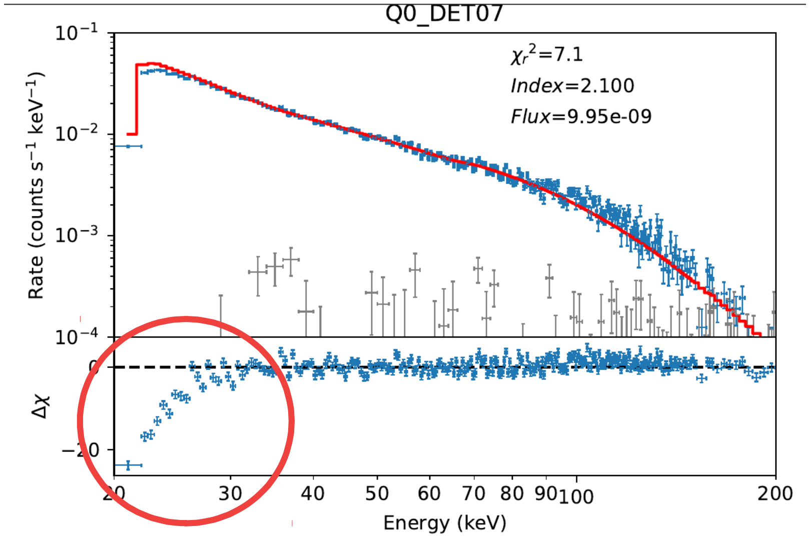
Excess counts in <40 keV spectrum for some modules

Reason unknown: Ignore that part of spectrum for those modules

Low energy residuals and correction

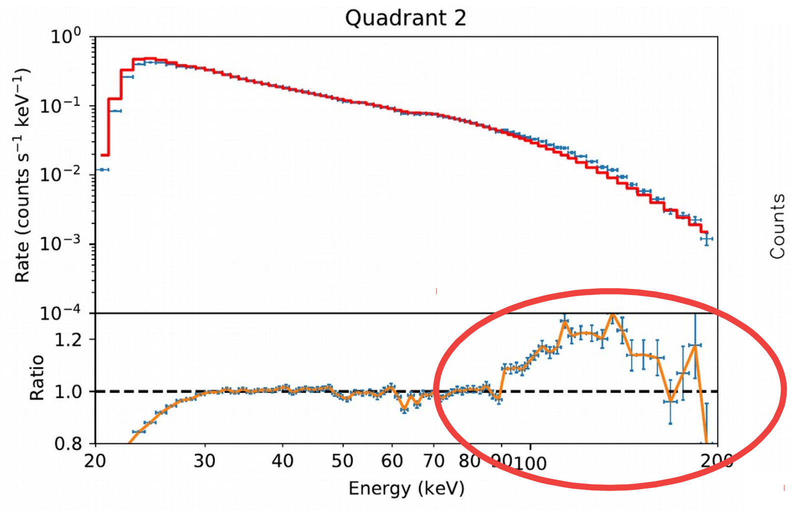




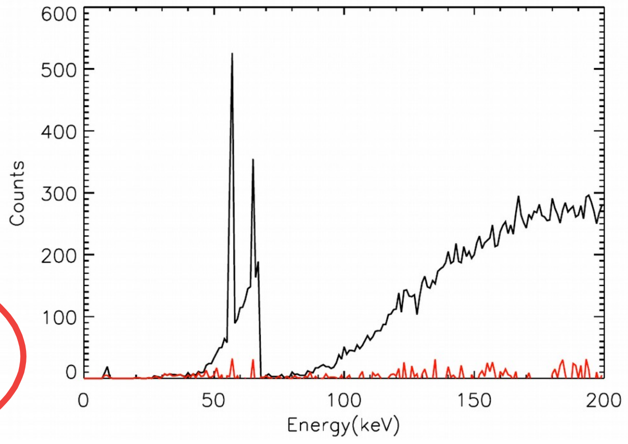


- Consistently less counts than model prediction at lower energies
- Seen for all modules near its LLD unless the LLDs are chosen agressively high: Constant over time
- Thought to be arising from triggering efficiency: Detection probability of events near LLD not always 1
- Emprirical correction derived for each individual detector module being included in response

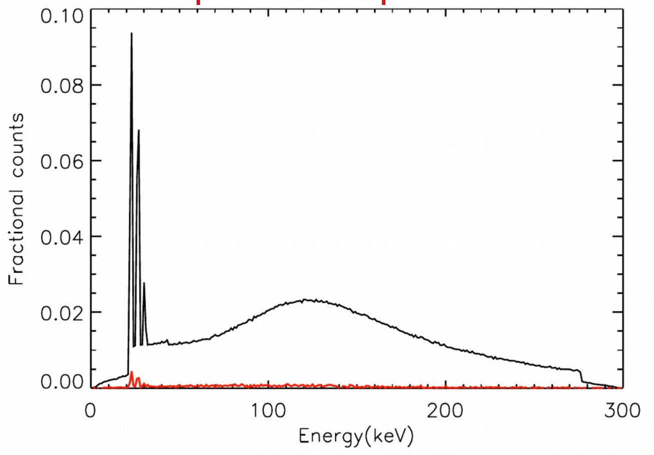
High energy residuals and its origin



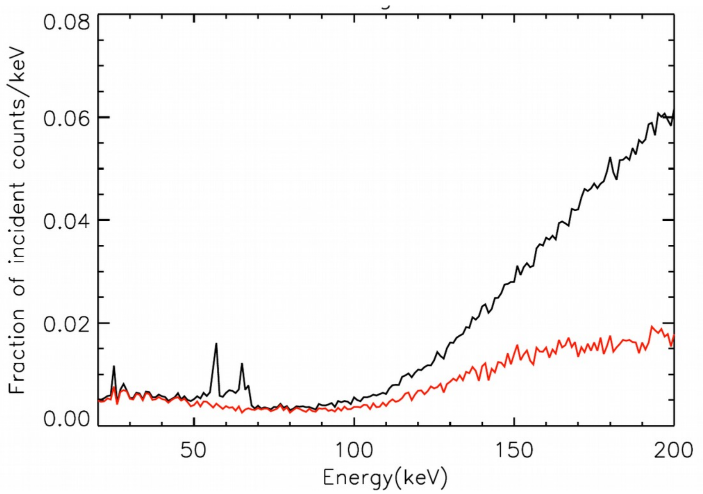
Scattering from mask



Orphan Compton event



Scattering from material within CZT module



- Excess counts at energies above 80-100 keV
- Present in all modules, quadrants in identical manner: Some effect not included in response
- Photons undergoing Compton/Rayleigh scattering from other parts of instrument as a possibility: Only scattered event near detector will survive mask weighting

Work in progress and future plans

- Empirical correction for near LLD response based on Crab spectra
- Incoporation scattering effects with empirical scaling factor to account for high energy residuals
- Appropriate energy dependant systematic errors in <30 keV and >90 keV (should be negligible for <50 ks exposures) to be included in the spectrum after the response corrections
- Next version of pipeline and CALDB release to include all these updates

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Thank you!