

XMM EPIC-pn energy scale at 8 keV for Full Frame and Extended Full Frame modes using Cu-K α

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Outline

- Modelling the long-term CTI correction (LTC) for copper: two step approach
 - Results: **EPN_CTI_0055/0056.CCF**
 - Release note: XMM-CCF-REL-389
 - Technical note: CAL-TN-0231
 - Pattern offsets
 - Spectral resolution
- Spatial CTI correction (Sanders et al. 2020, Gatuazz et al. 2022)
- Future improvements

Updates to energy scale for FF and EFF modes

XMM-Newton Calibration Technical Note

XMM-CCF-REL-389

XMM-Newton EPIC-pn: long-term CTI update

Ivan Valtchanov, Michael Smith

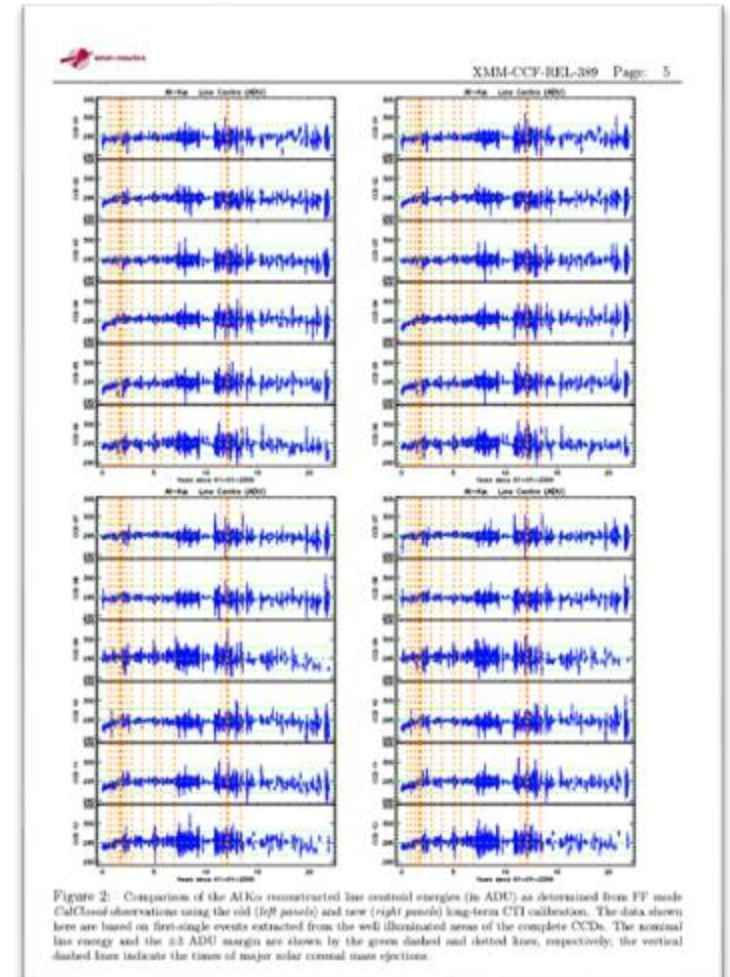
March 31, 2022

1 CCF components

Name of CCF	VALDATE	EVALDATE	Blocks changed	CAL version	XSCS flag
EPN_CTI_0055.CCF	2000-01-01T00:00:00		LONG_TERM_CTI	3.240	NO
EPN_CTI_0056.CCF	2000-03-23T05:00:00		COMB_EVT_OFFSET LONG_TERM_CTI COMB_EVT_OFFSET	3.240	NO

2 Changes

To date, the empirical EPIC-pn long-term charge-transfer inefficiency correction (LTCTI) for Full Frame (FF) and Extended Full Frame modes (EFF) is derived using the Al K α (1.486 keV) and Mn K α (5.8988 keV) emission lines, which are produced by the radioactive Fe-55 source in *CalClosed* exposures.

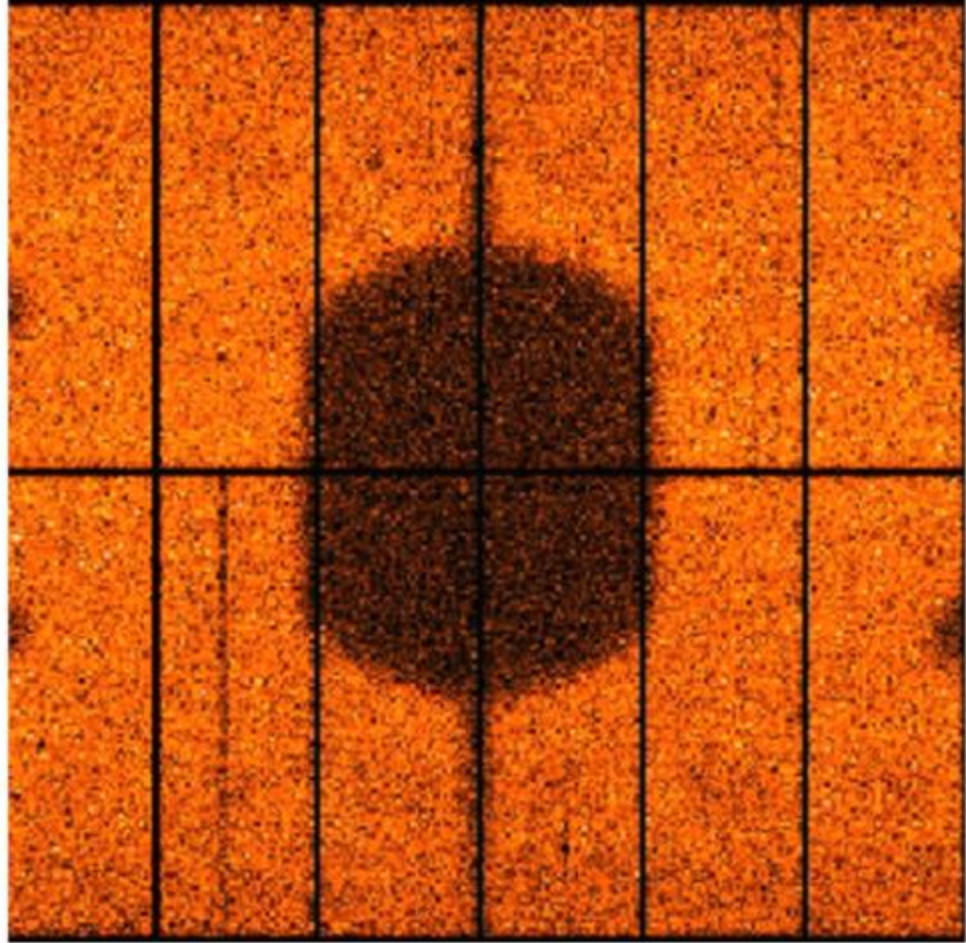


CalClosed observations

Al K α (1.5 keV) and Mn K α (6 keV)

Using Cu K α to extend energy scale up to 8

EPIC pn : Cu-K α [7.8–8.2 keV]



EPIC-pn FF and EFF modes

Spatial distribution:
a hole, masked in next analysis

Mask boundaries follow Sanders et al. (2020)

Only affects central CCDs (1,4=boresight,7,10)

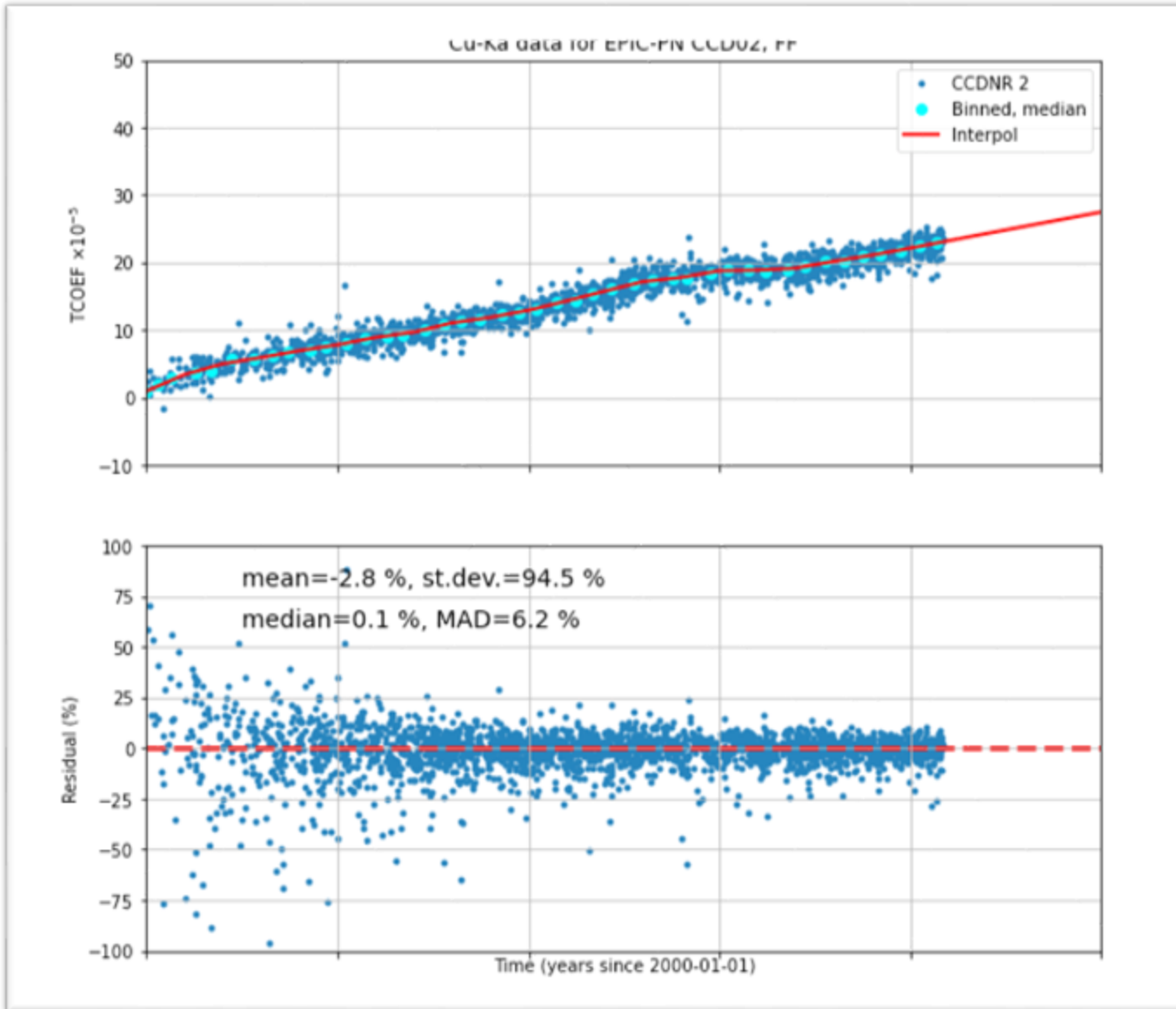
Masking helps avoiding OoT events

For non-central CCDs we use the full CCD area:
RAWX in (1,64), RAWY in (1,200)

Processing with no LTC correction

- Using all science observations up to TIME = 21.2 years (since 2000-01-01), last one during rev. 3891
 - ~9000 FF observations (CCDNR dependent)
 - ~1600 EFF observations (CCDNR dependent)
- Processing with no LTC but with QBG correction (see XMM-CCF-REL-0358) and
(FLAG==0) && (PATTERN==0) && (PAT_SEQ==0)
- Fit for Cu K α line: best fit energy, sigma, amplitude...
- For each CCD: use full area outside the mask (full range of RAWY)
- Filter fit results:
 - Observations with exposure time > 10 ks
 - More than 10 DoF for the fit
 - Error on best-fit line energy less than 30 eV
 - Best-fit sigma/FWHM in [16,84]% quantiles (to avoid unrealistic line fit).

Example for modelling the LTC, CCD02



TCOEF model:

$$1 - (1-a) \times Q(t)^{\{1/RAWY\}},$$

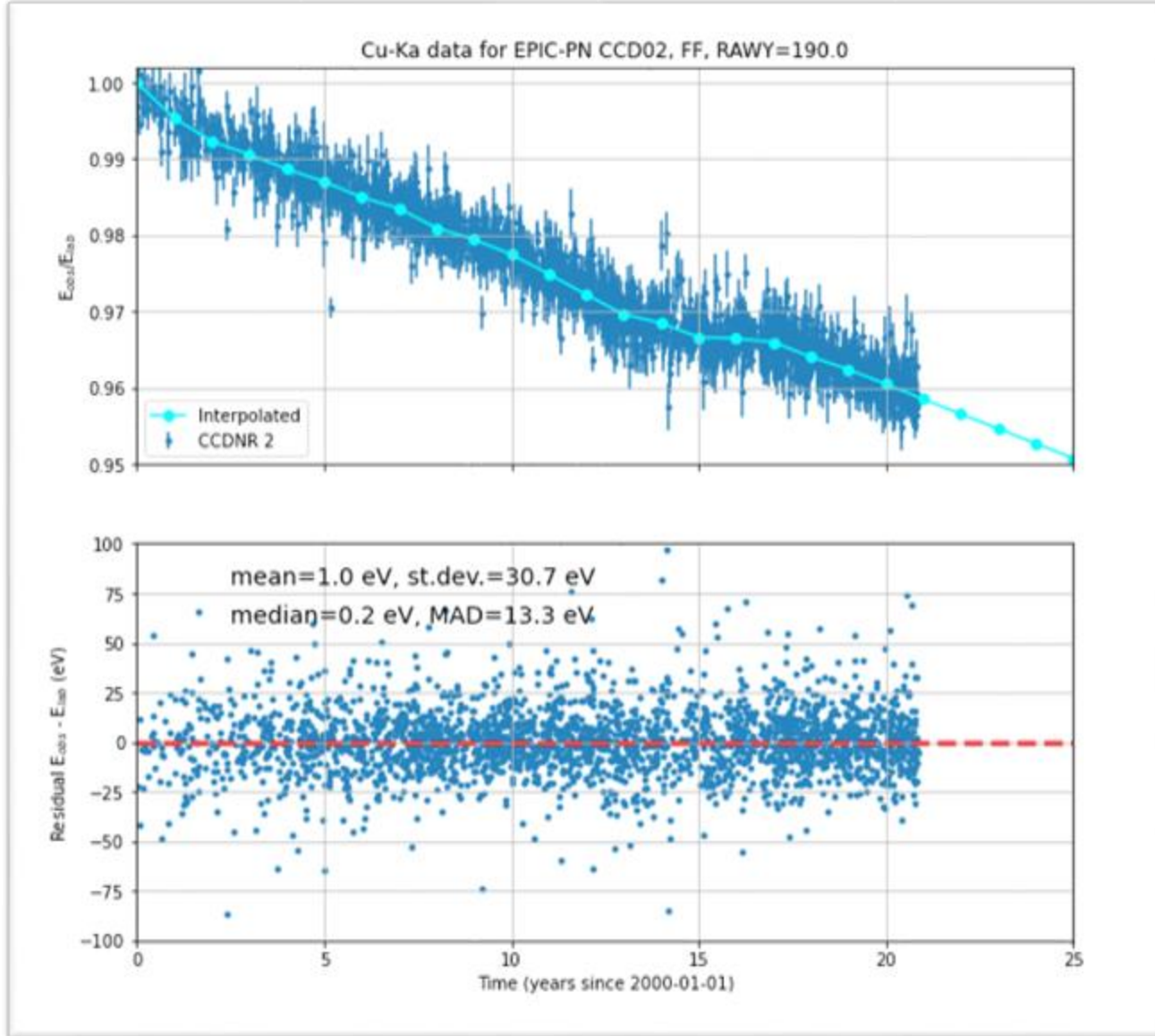
where a is normalisation and by design
 $a = \text{TCOEF}(t=0)$

$$Q(t) = E_{\text{obs}}/8.04 \text{ keV}$$

Using $\langle \text{RAWY} \rangle$ per observation

Running average per 0.3 years bins
(red curve)

Example for modelling the LTC, CCD02

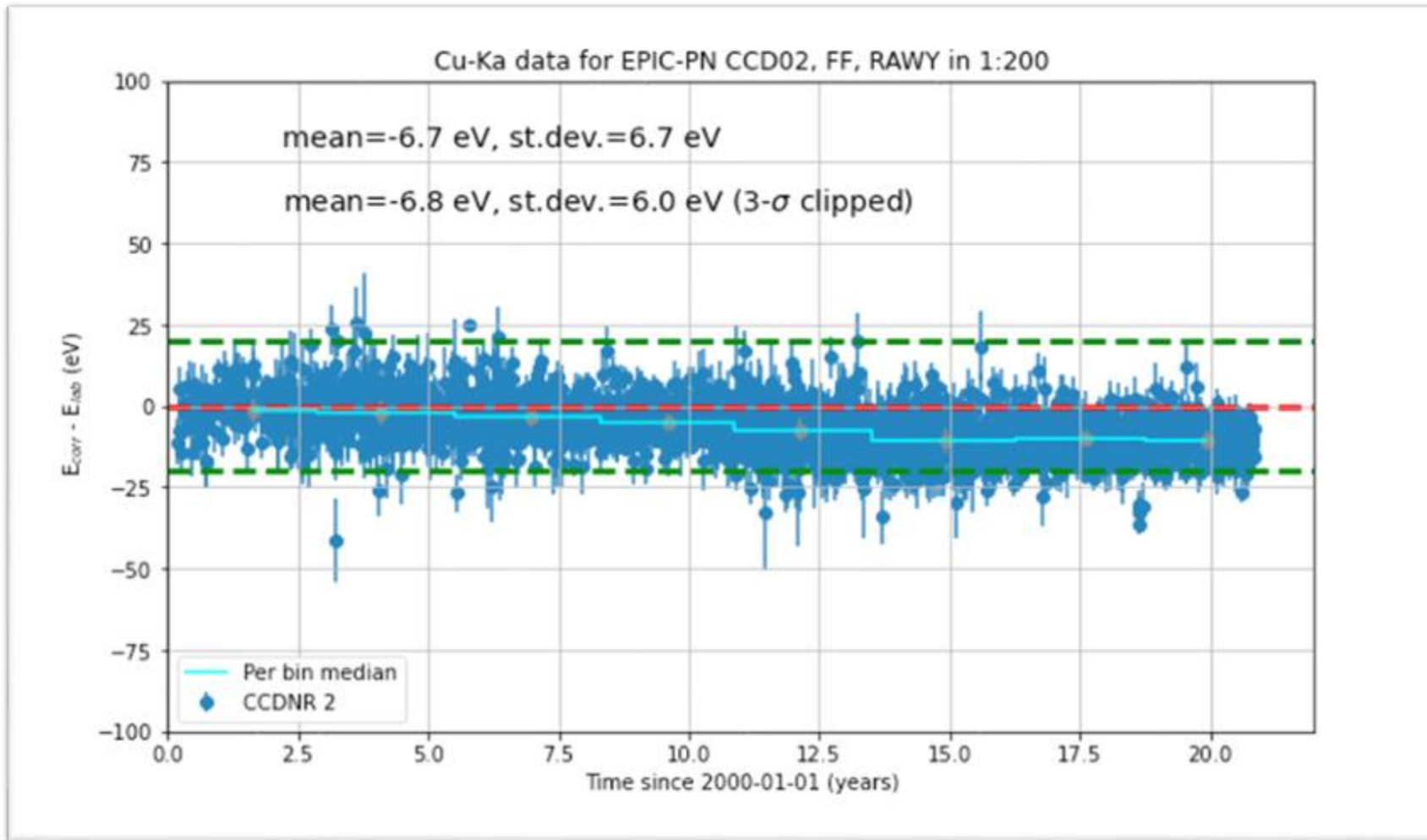


$$Q(t) = E_{\text{obs}}/8.04$$

$$\text{Cyan curve: } [(1-\text{TCOEF}(t))/(1-a)]^{\{190\}}$$

Using $\langle \text{RAWY} \rangle$ for all observations

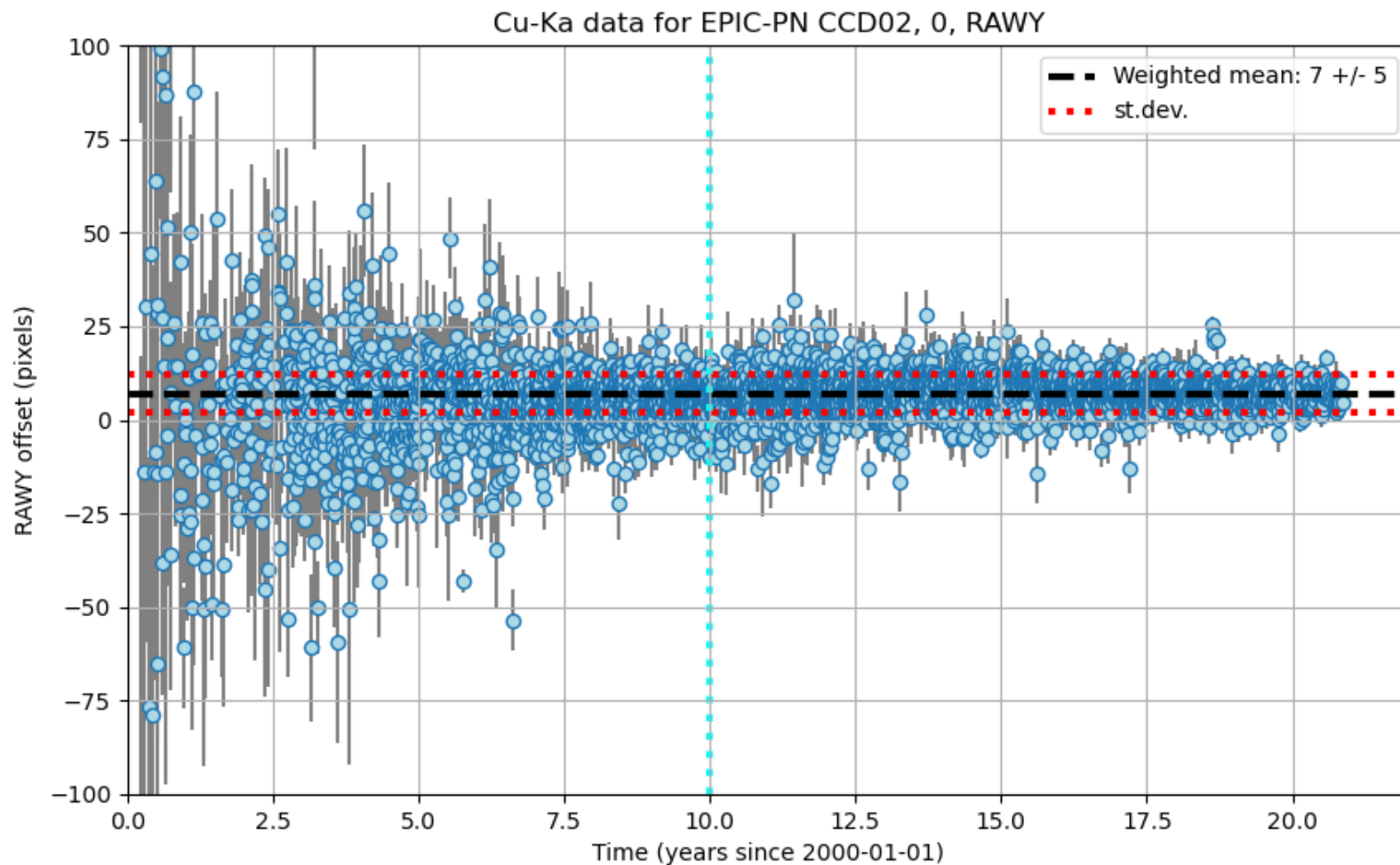
Results, CCD02:



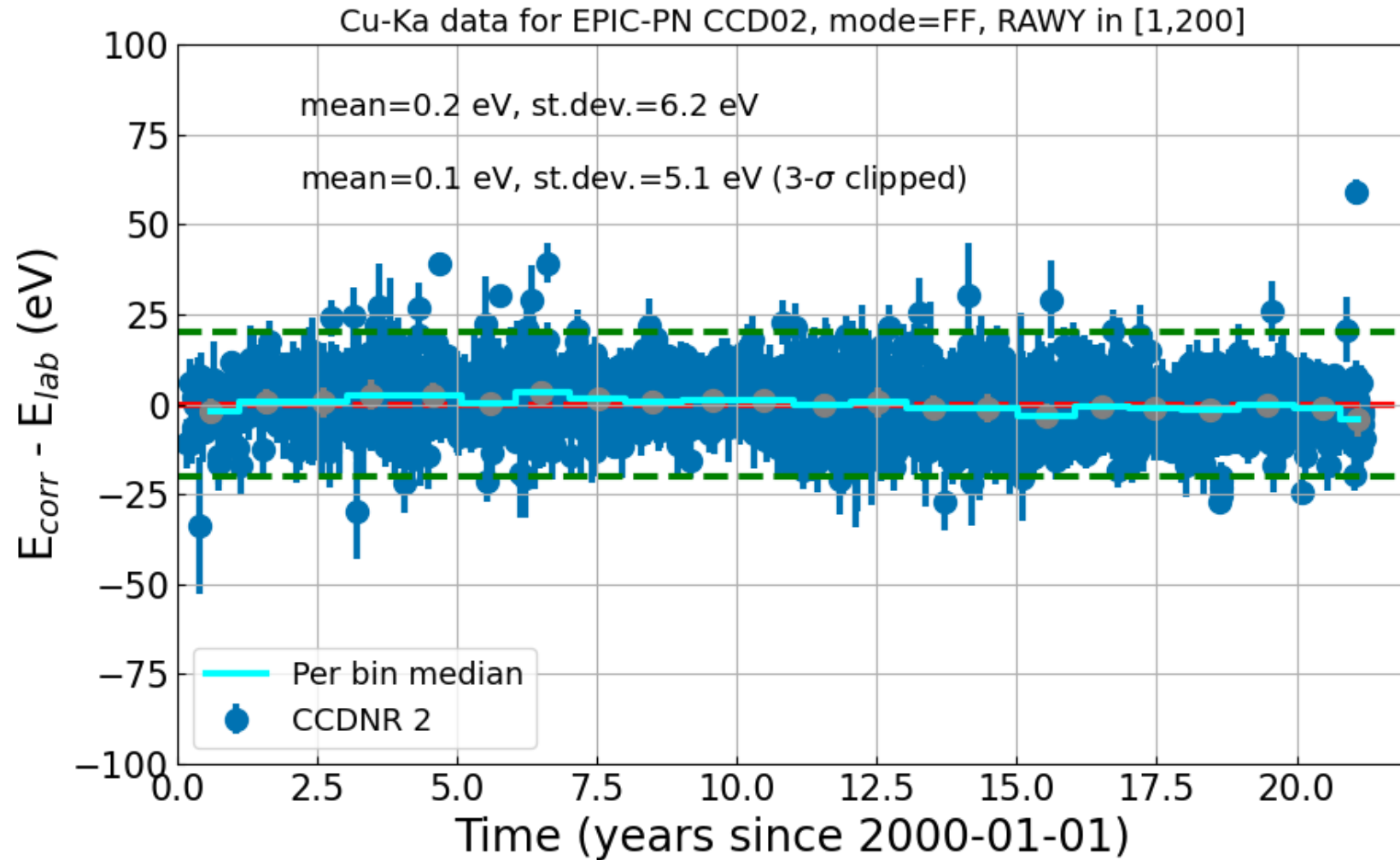
Systematic offsets

Mean residual per
500 revs (cyan)

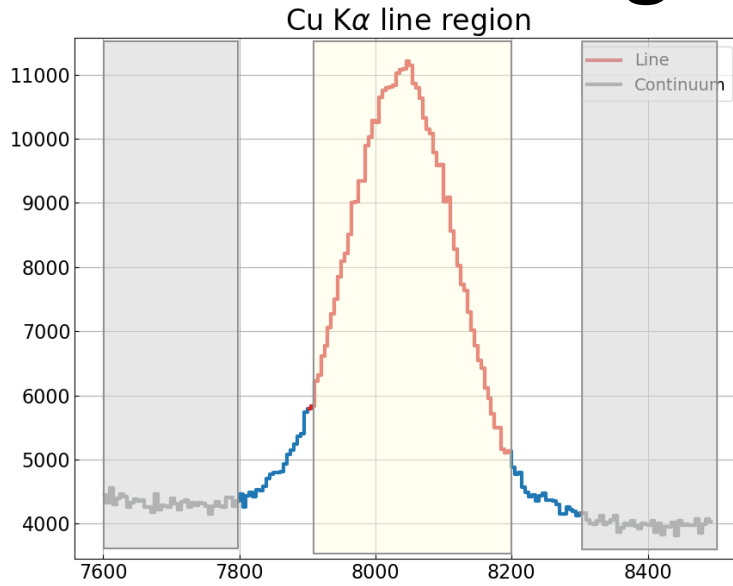
Second step, RAWY offset



Second step, residuals



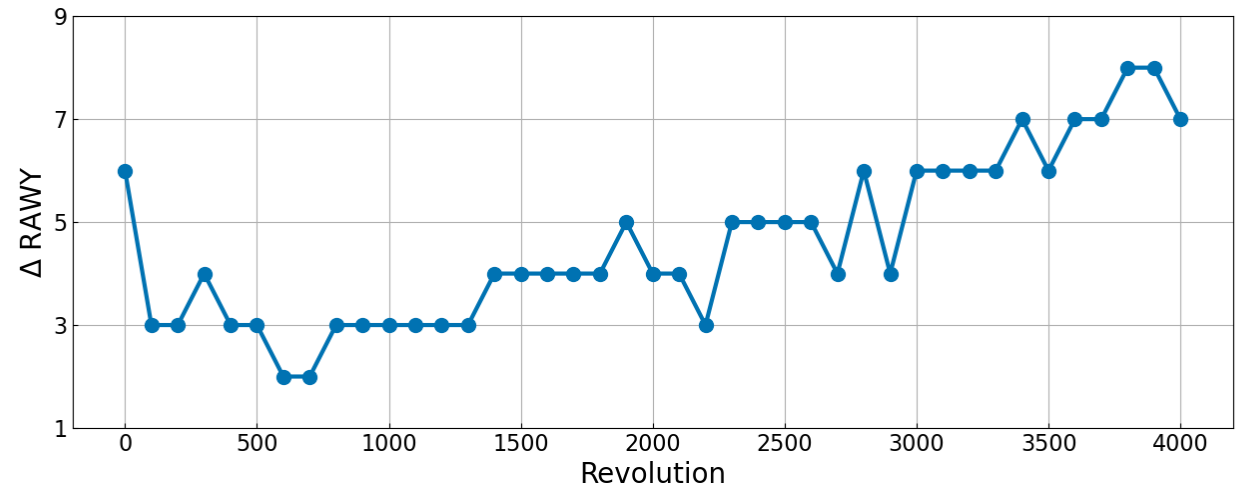
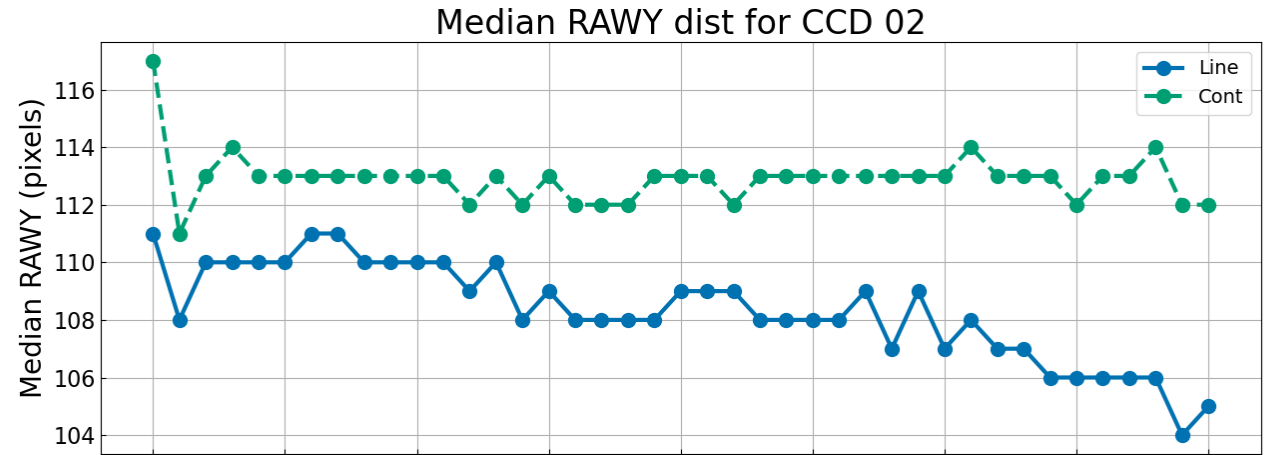
RAWY offset origin?



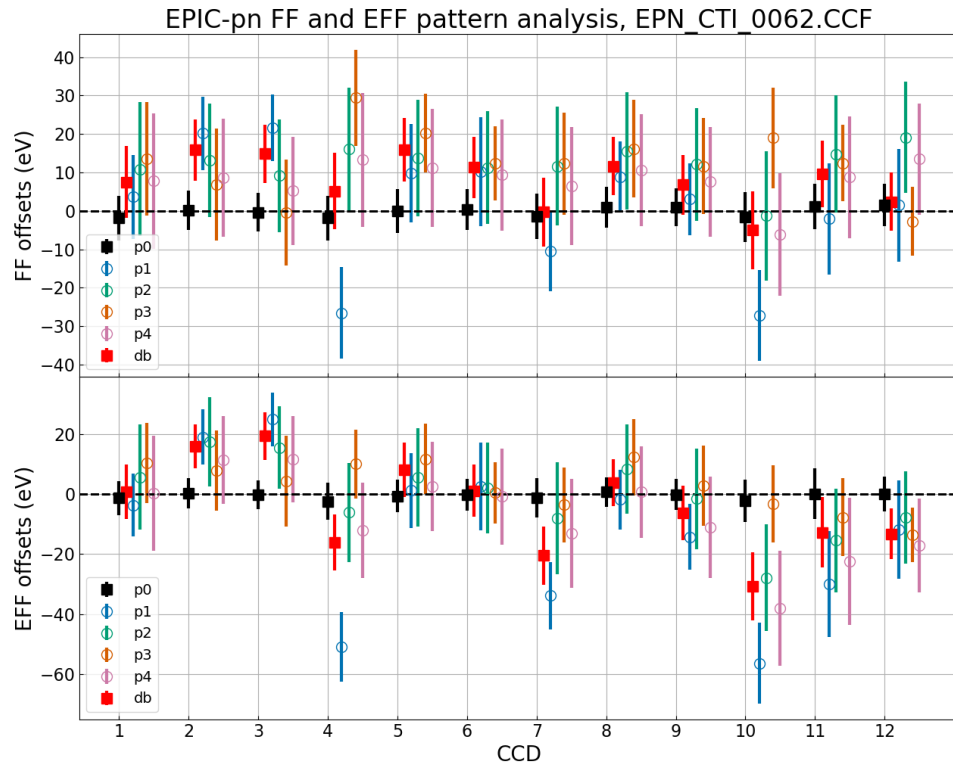
Credit: Jean Ballet

Next long-term CTI modelling
will properly incorporate the line RAWY
distribution!

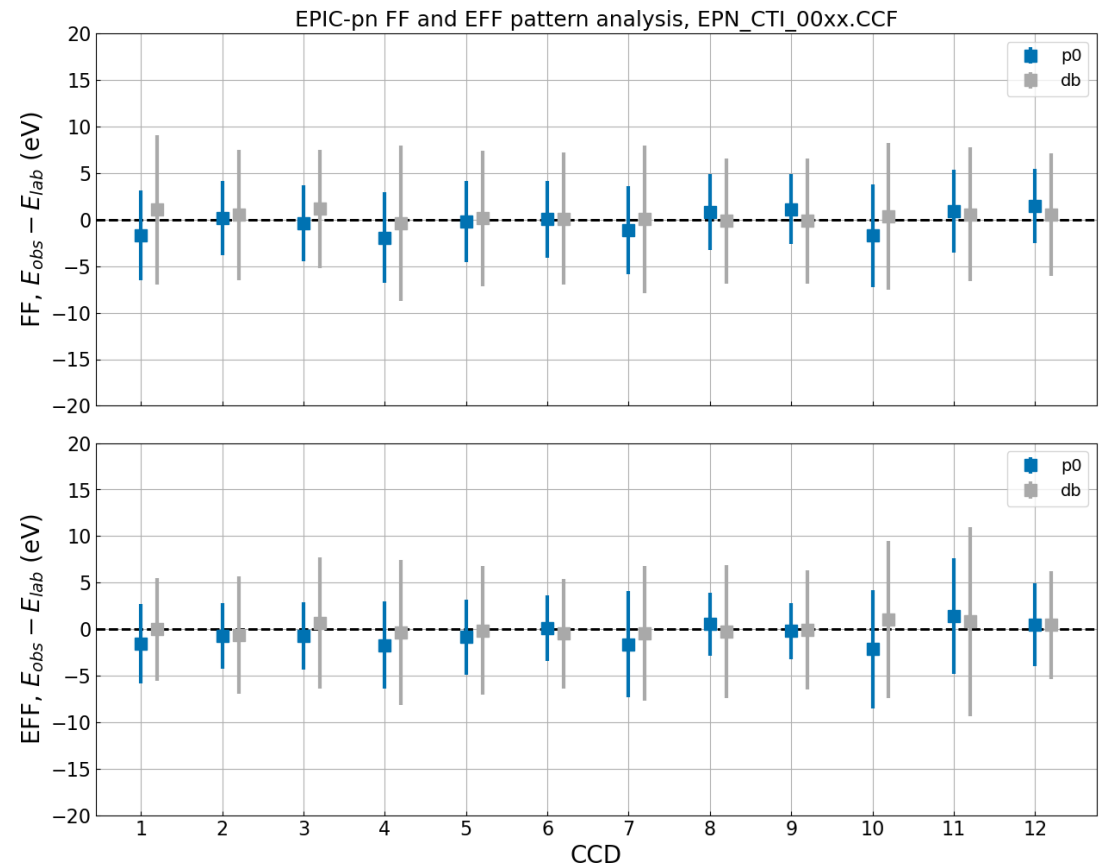
No need for two-step approach!?



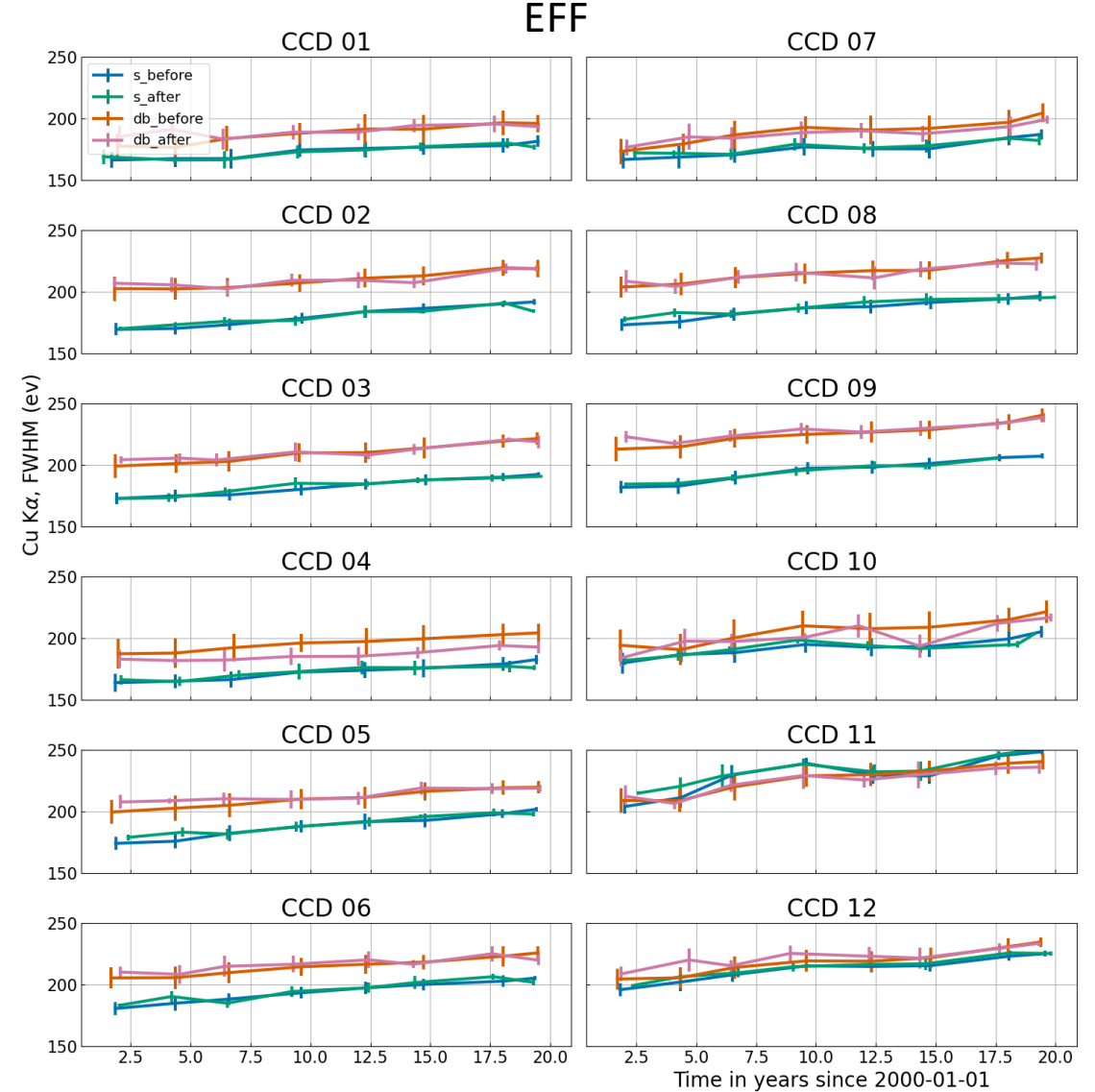
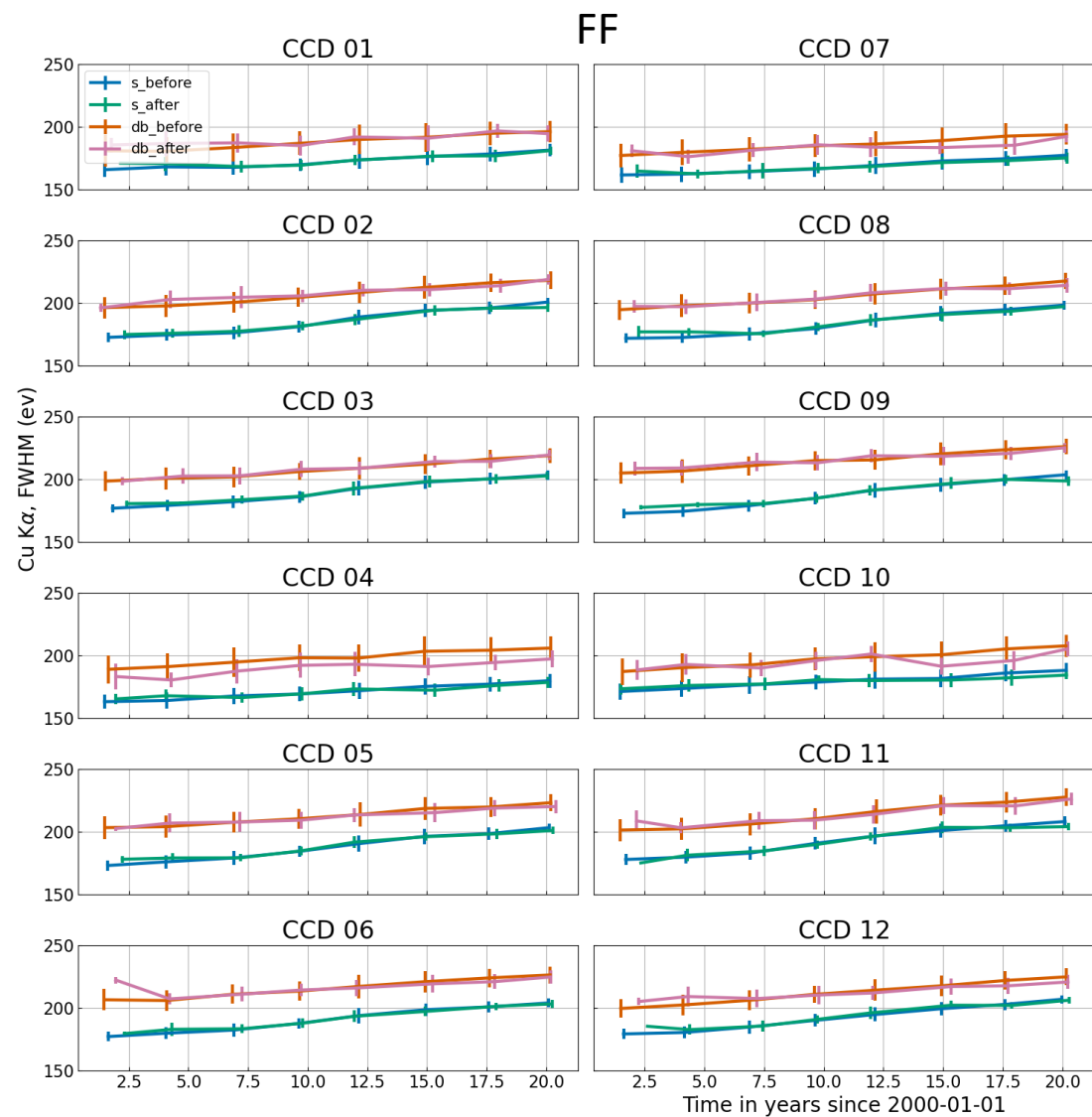
Pattern offsets from Cu $K\alpha$



Add the offsets in the CCF file
No time or energy dependency!

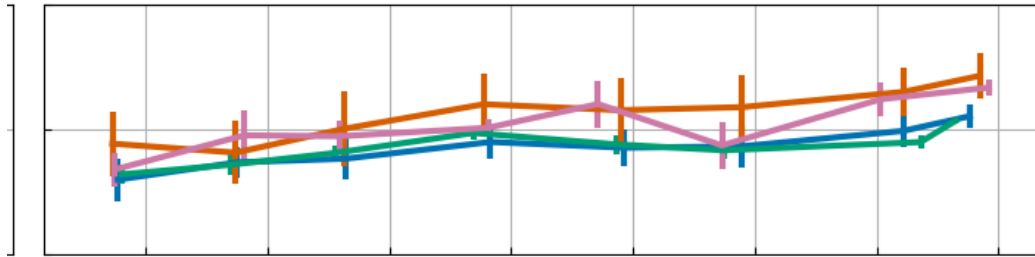


Spectral resolution (FWHM of Cu K α line), s & d

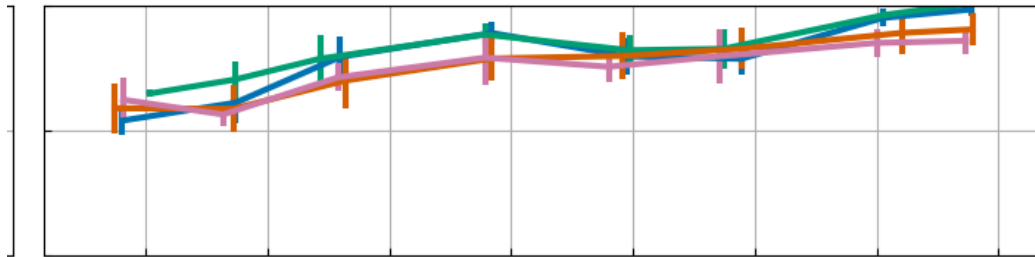


Quadrant 3 in EFF?

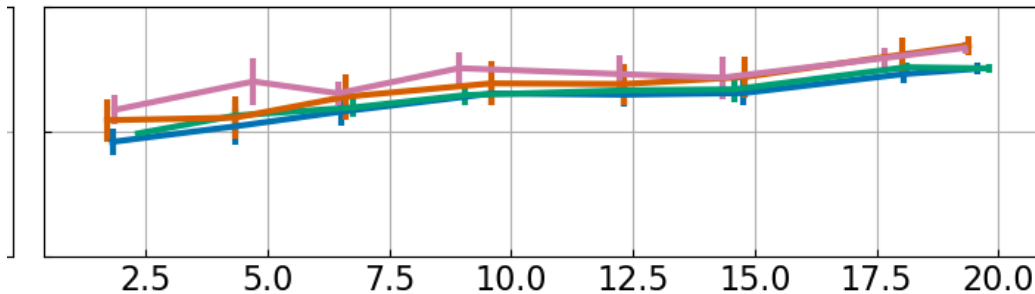
CCD 10



CCD 11



CCD 12



Unlike all the other quadrants, in FF and EFF

The FWHM for singles and doubles are quite similar.
Why?

On spectral resolution

- No changes in spectral resolution for doubles after applying the derived energy offsets (with respect to single events).
- Time dependency on the best-fit FWHM of the Cu K α line, can be modelled linearly
 - At t=0, FWHM= $\sim$ 200 eV (CCD02) and $\sim$ 230 eV at t=20.

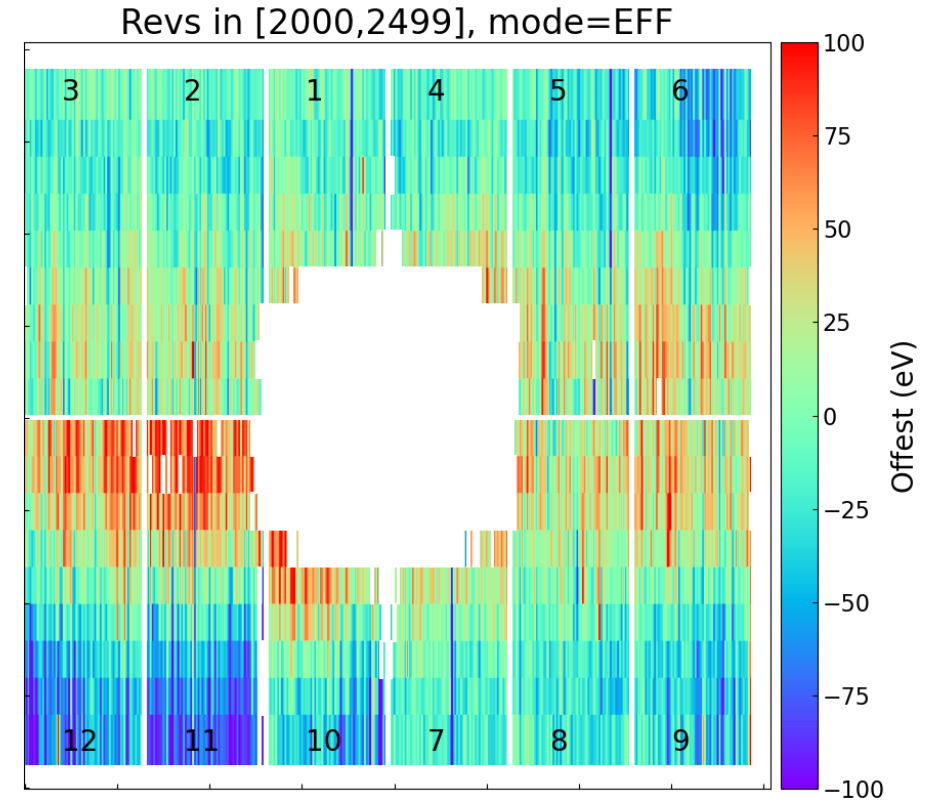
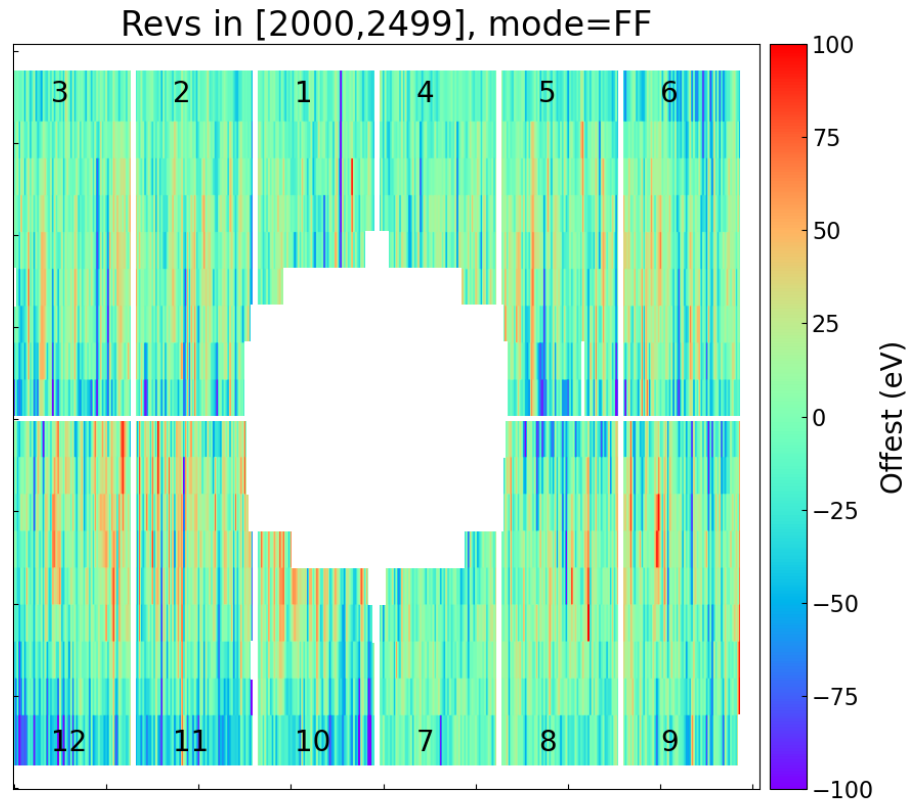
TODO

- Check how the time dependency of the resolution at copper corresponds to that currently contained in the CCFs (derived from a couple of observations of the Circinus Galaxy (Fe emission) in CCD4).
 - Do we need to introduce energy dependence?

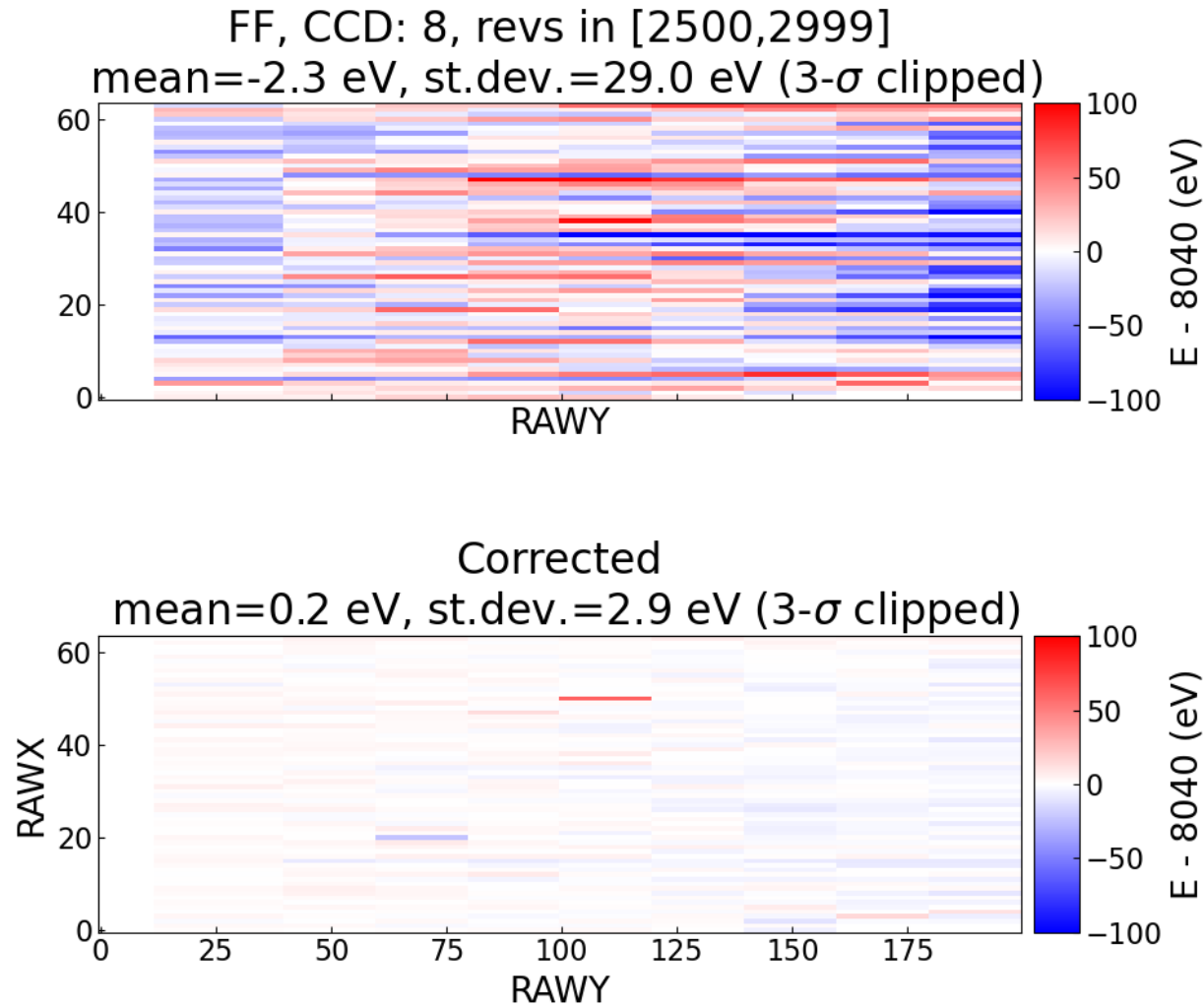
Spatial CTI offsets

- Following Sanders et al. (2020):
 1. Apply the derived per-CCD long-term CTI correction for Cu K α
 2. Stack event lists in bins of 500 revolutions, with step 250 (overlap)
 3. For each stacked table, extract spectra for each CCD, RAWX (64) and in bins of 20 pixels on RAWY.
 4. Fit the Cu K α line and derive the residual → the spatial offsets as function of epoch, CCDNR, RAWX, RAWY.
- → Spatial offset table dimensions: mode, epoch, CCDNR, RAWX, RAWY
→ 5-dimensional table: 2 x 8 x 12 x 64 x 200

Results, FF & EFF



Example, correction

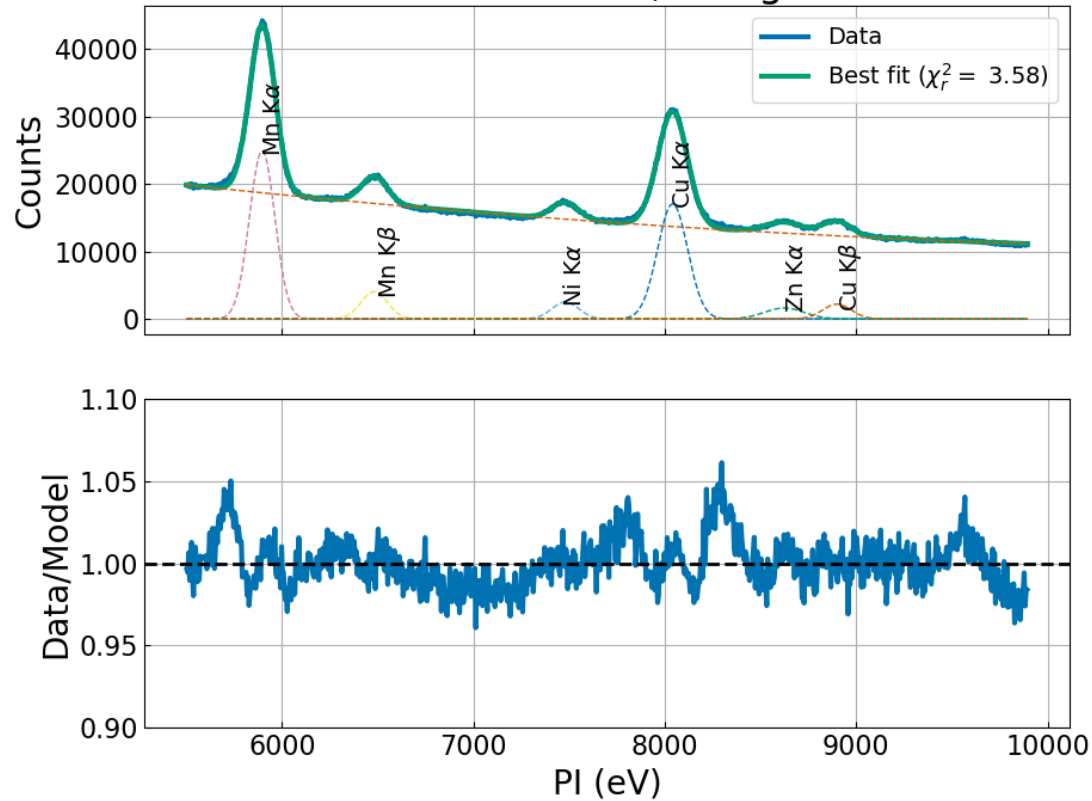


In progress

- Check if applying the spatial CTI offsets, as derived from copper, will improve the spatial CTI offsets at Mn K α (5.8988 keV), with stacked event lists.
 - Complicated check as the Iron-55 source is rather weak after rev 2000
- Apply the spatial CTI offsets to Perseus cluster (and other mosaic observations, Virgo) as in Sanders et al. (2020), GatuZZ et al. (2022) and check if the Fe line redshift, as function of location, is in agreement with published results.
- Third stage correction: energy scale in 6 to 9 keV with six line model
 - Check if this is really needed
 - Model the energy scale compression as in Sanders et al.

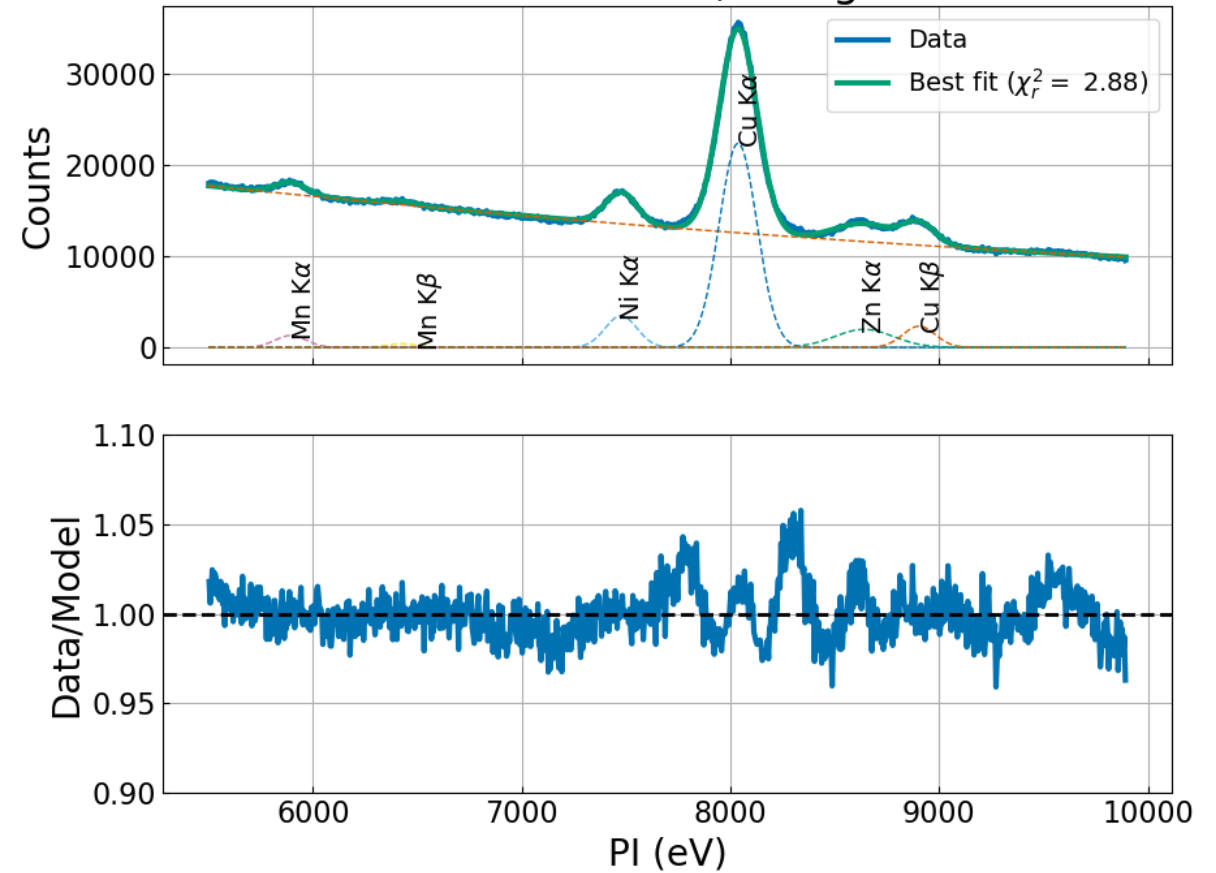
6-lines model examples

6-lines model, using PI



Rev in [500,999]

6-lines model, using PI



Rev in [2500,2999]

Preliminary results on energy scale

Results for FF and CCDNR = 02

After applying long-term CTI but no spatial offsets!

Using 4-lines model for now:

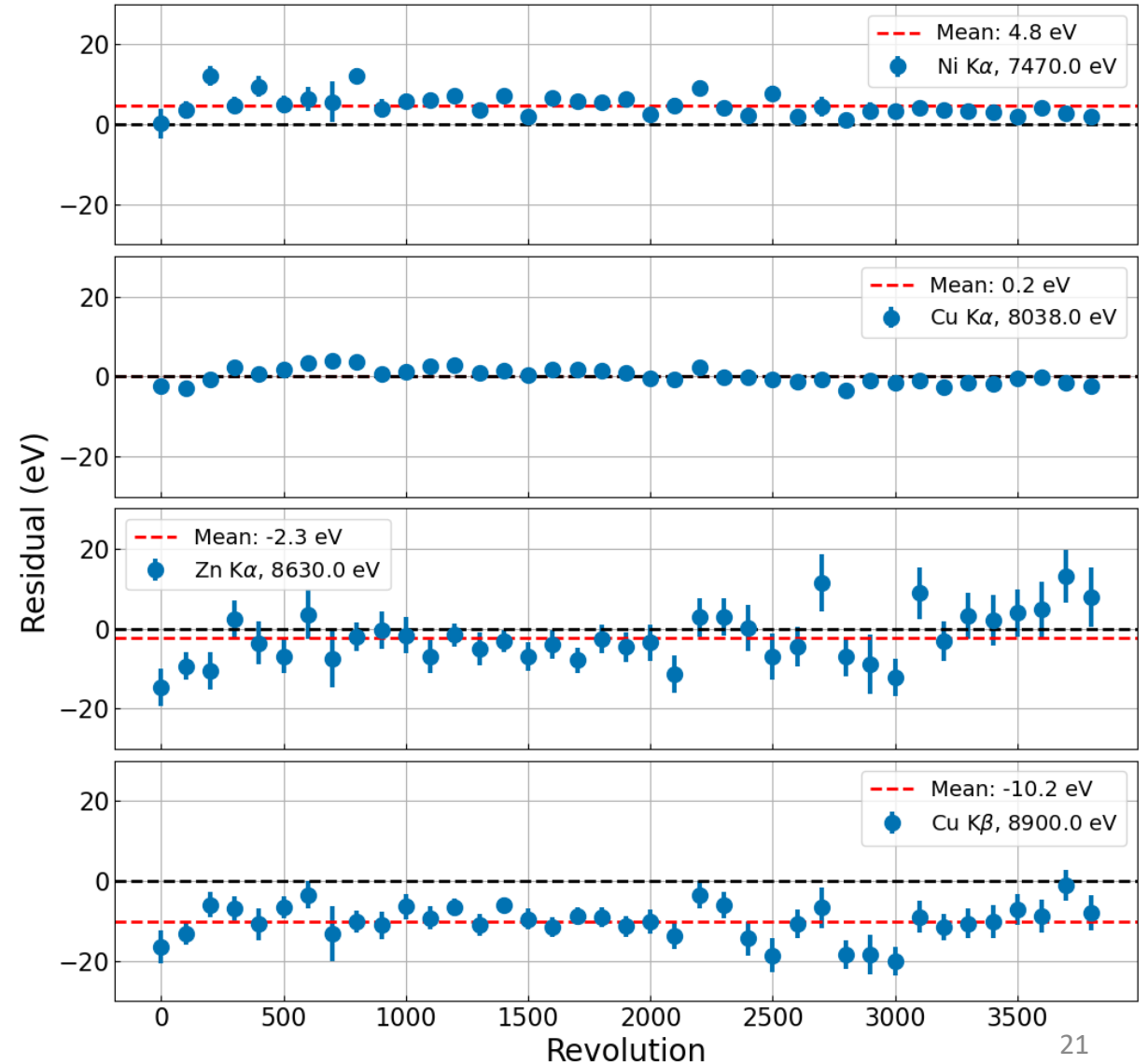
Ni K α (7470 eV)

Cu K α (8038 eV)

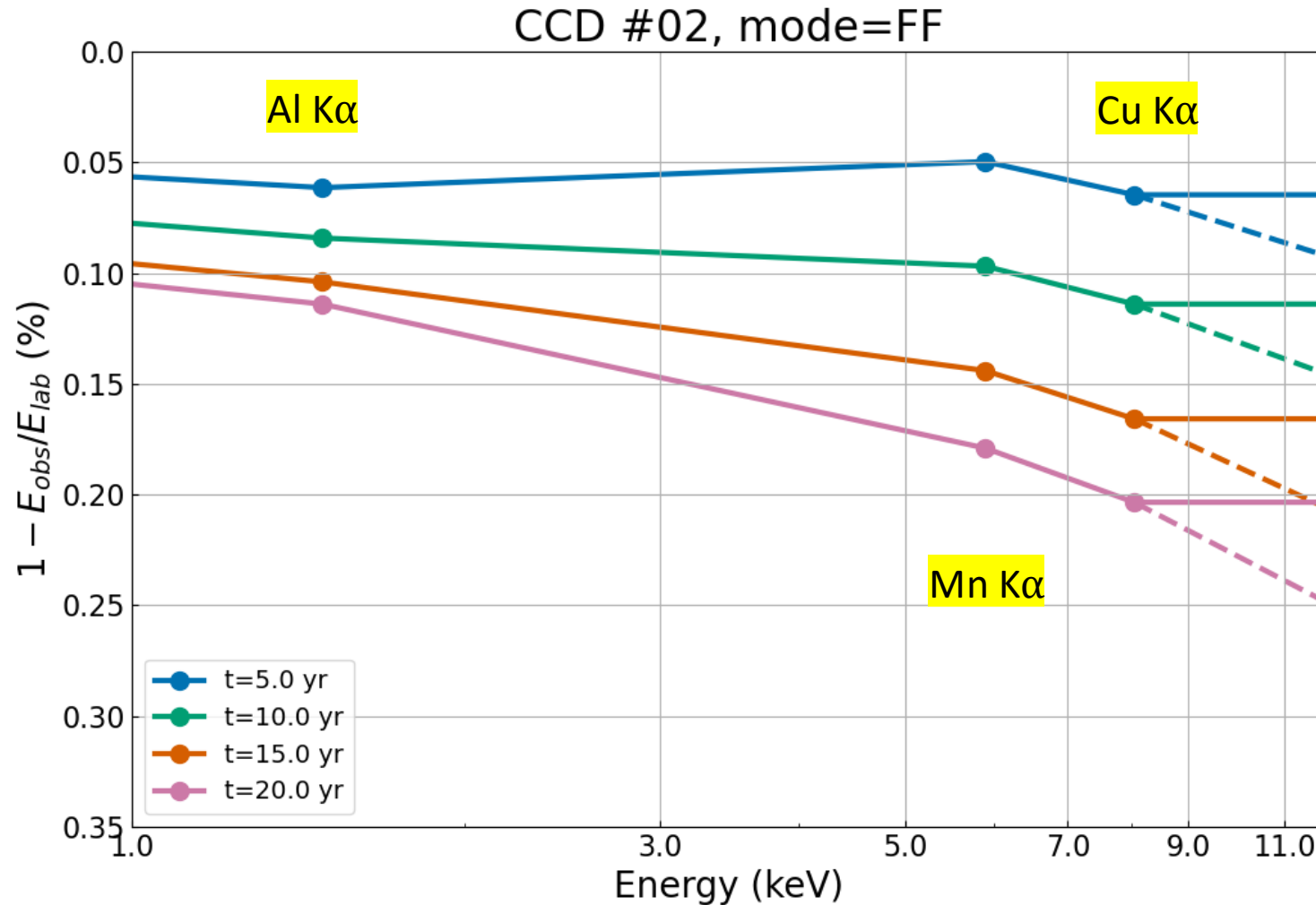
Zn K α (8630 eV)

Cu K β (8900 eV)

TODO: full 6-line model after applying the spatial CTI offset



Energy dependence of the long-term CTI



Conclusions and on-going works

- Update to EPN_CTI CCF file released and available:
 - CalClosed update to Al $K\alpha$ and Mn $K\alpha$ for FF and EFF modes
 - New long-term CTI curves for Cu $K\alpha$ fluorescent line for FF and EFF
 - Pattern offsets derived with Cu $K\alpha$
- Work-in-progress:
 - Spatial CTI offsets derived and validated for Cu $K\alpha$, with prototype python script → SAS tool under discussion. Add the table as extension to EPN_CTI or a new CCF?
 - In progress: checks with Mn $K\alpha$ and Fe $K\alpha$ (galaxy clusters)
 - In progress: energy scale compression in 6 to 9 keV with 6-lines model
- Future work:
 - Next update to long-term CTI: combine CalClosed and fluorescent line analysis. Properly address the RAWY distribution in line core. Correction is extremely sensitive to RAWY!
 - Attempt simultaneous long-term CTI and quiescent background correction

The end