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

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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, Gatuzz 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

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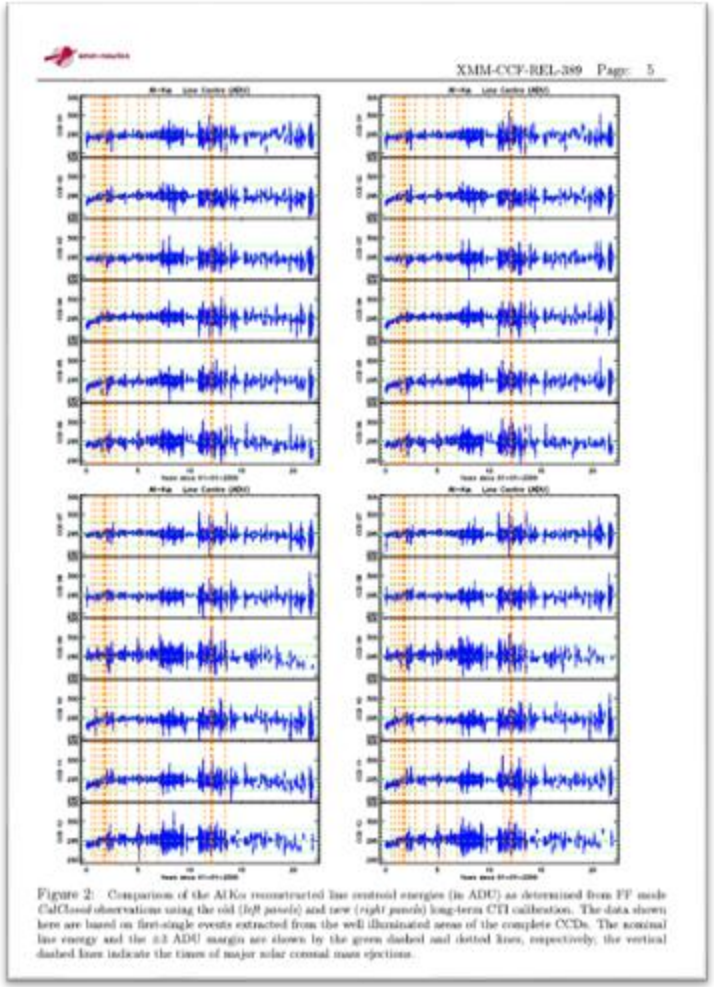
March 31, 2022

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 COMB_EVT_OFFSET	3.240	NO
EPN_CTI_0056.CCF	2000-03-23T05:00:00		LONG_TERM_CTI COMB_EVT_OFFSET	3.240	NO

2 Changes

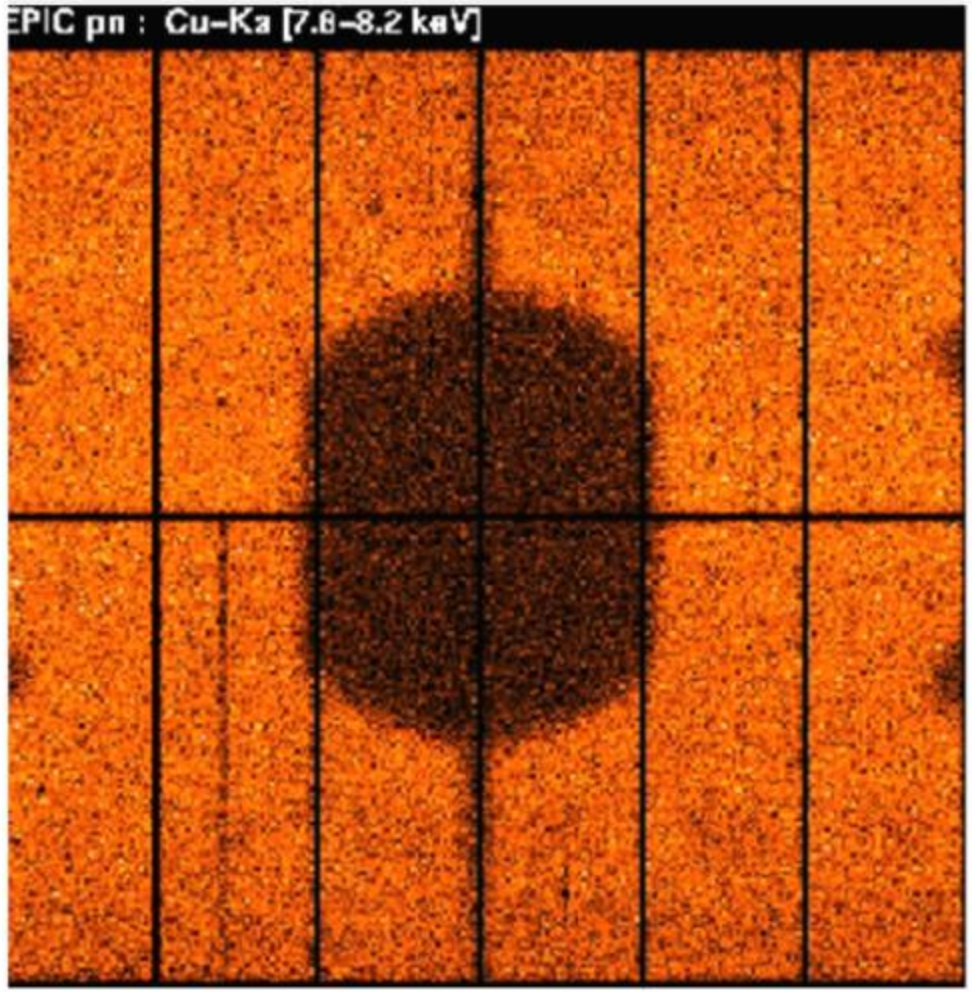
To date, the empirical EPIC-pn long-term charge-transfer inefficiency correction (LTCTI) for Full Frame (FF) and Extended Full Frame modes (EFF) is derived using the Al Kα (1.486 keV) and Mn Kα (5.8988 keV) emission lines, which are produced by the radioactive Fe-55 source in *CalClosed* exposures.



CalClosed observations

Al Kα (1.5 keV) and Mn Kα (6 keV)

Using Cu Kα to extend energy scale up to 8



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

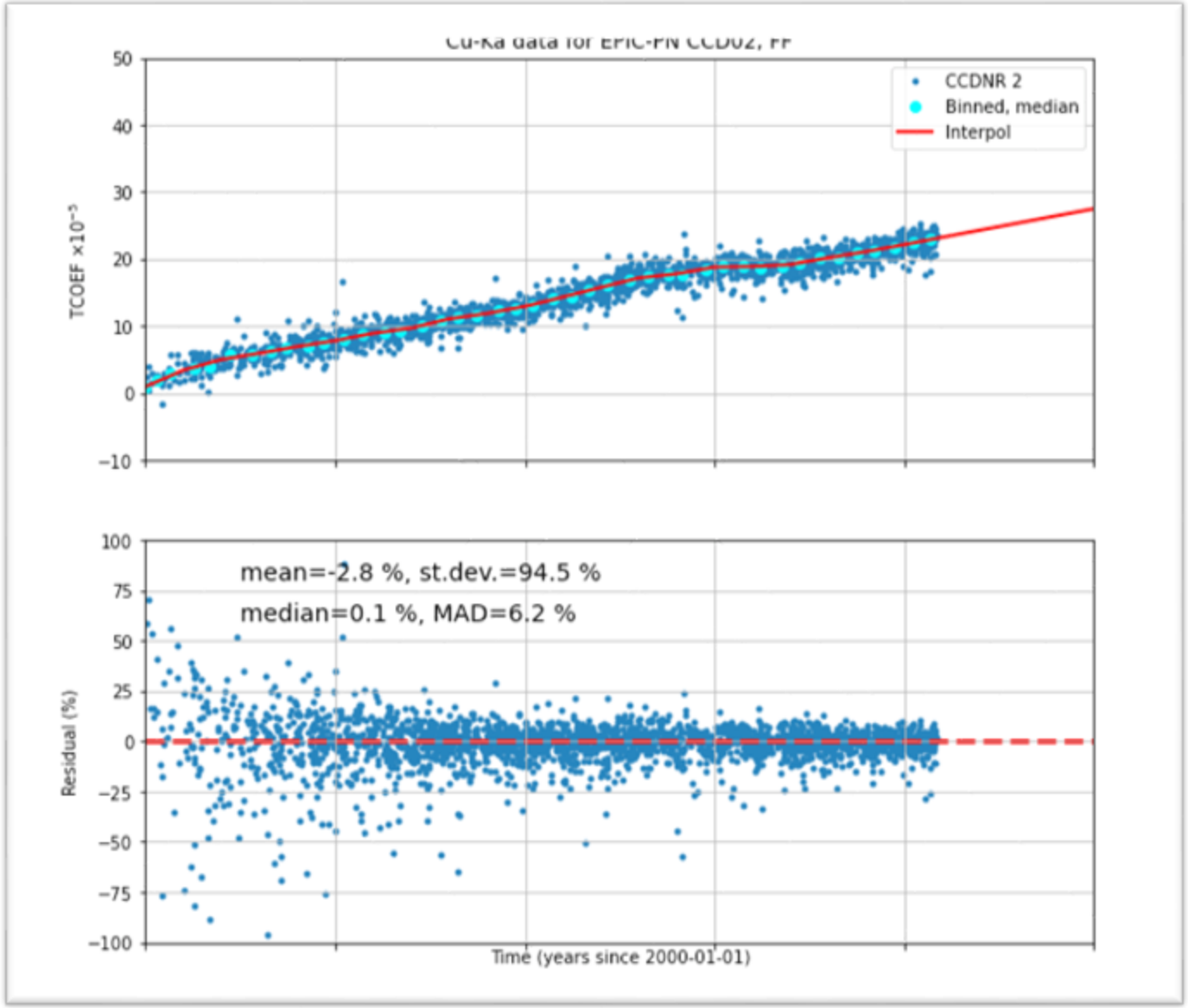
For non-central CCDs we use the full CCD area:
RAWX in (1,64), RAWY in (1,200)

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 Kα 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) x Q(t)^{1/RAWY},

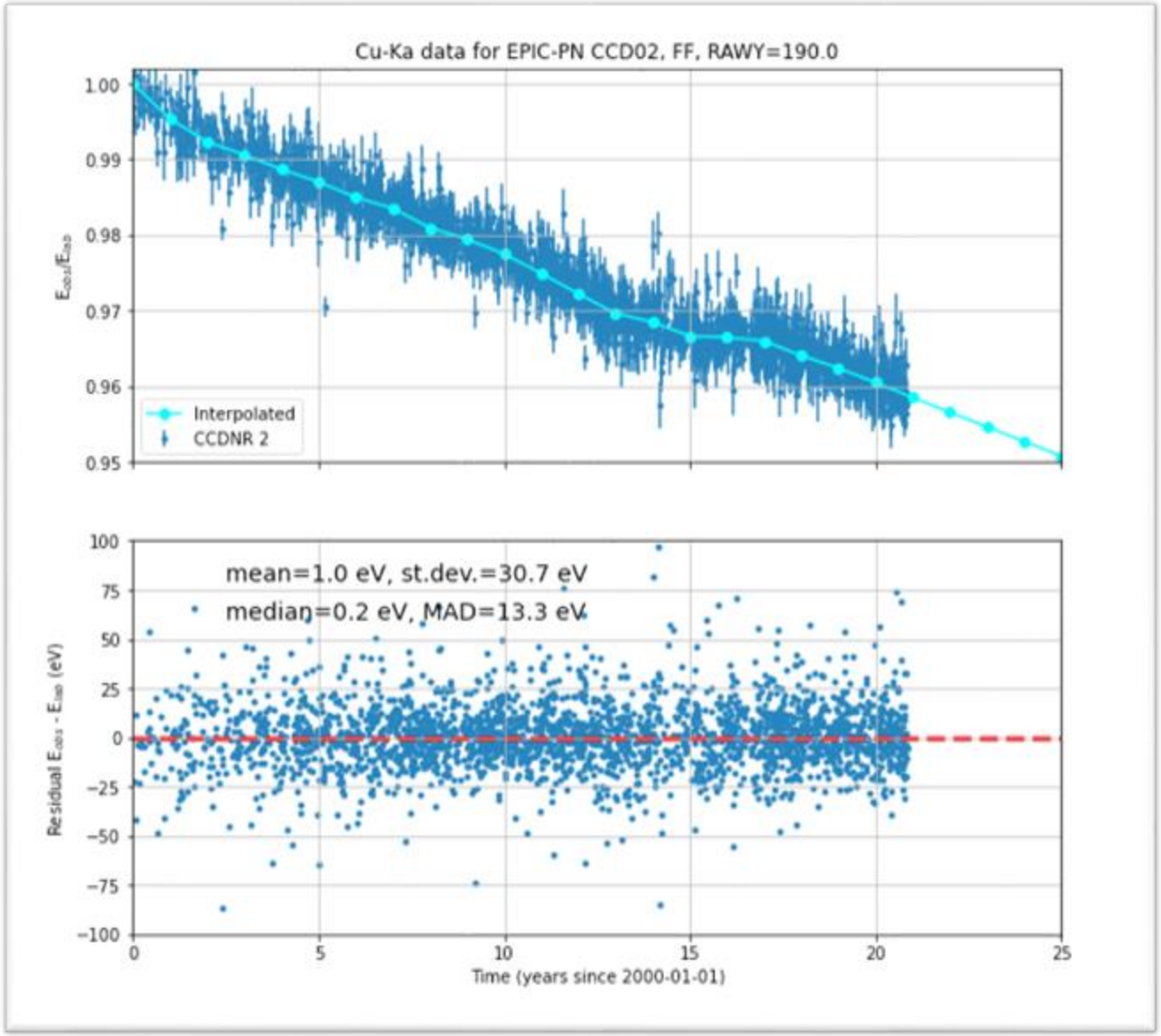
where a is normalisation and by design
a = TCOEF(t=0)

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

Using <RAWY> per observation

Running average per 0.3 years bins
(red curve)

Example for modelling the LTC, CCD02

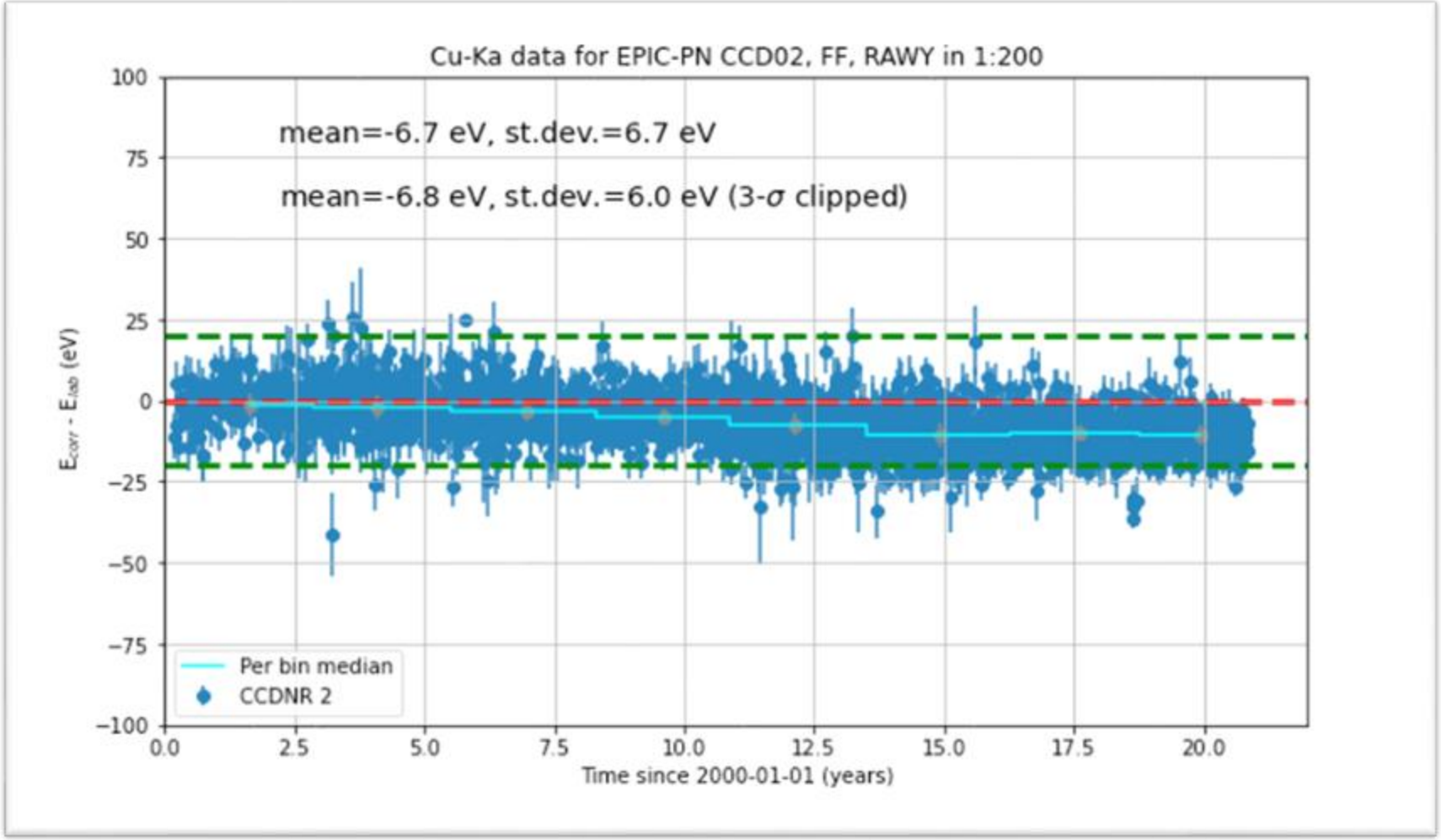


$Q(t) = E_{obs}/8.04$

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

Using <RAWY> for all observations

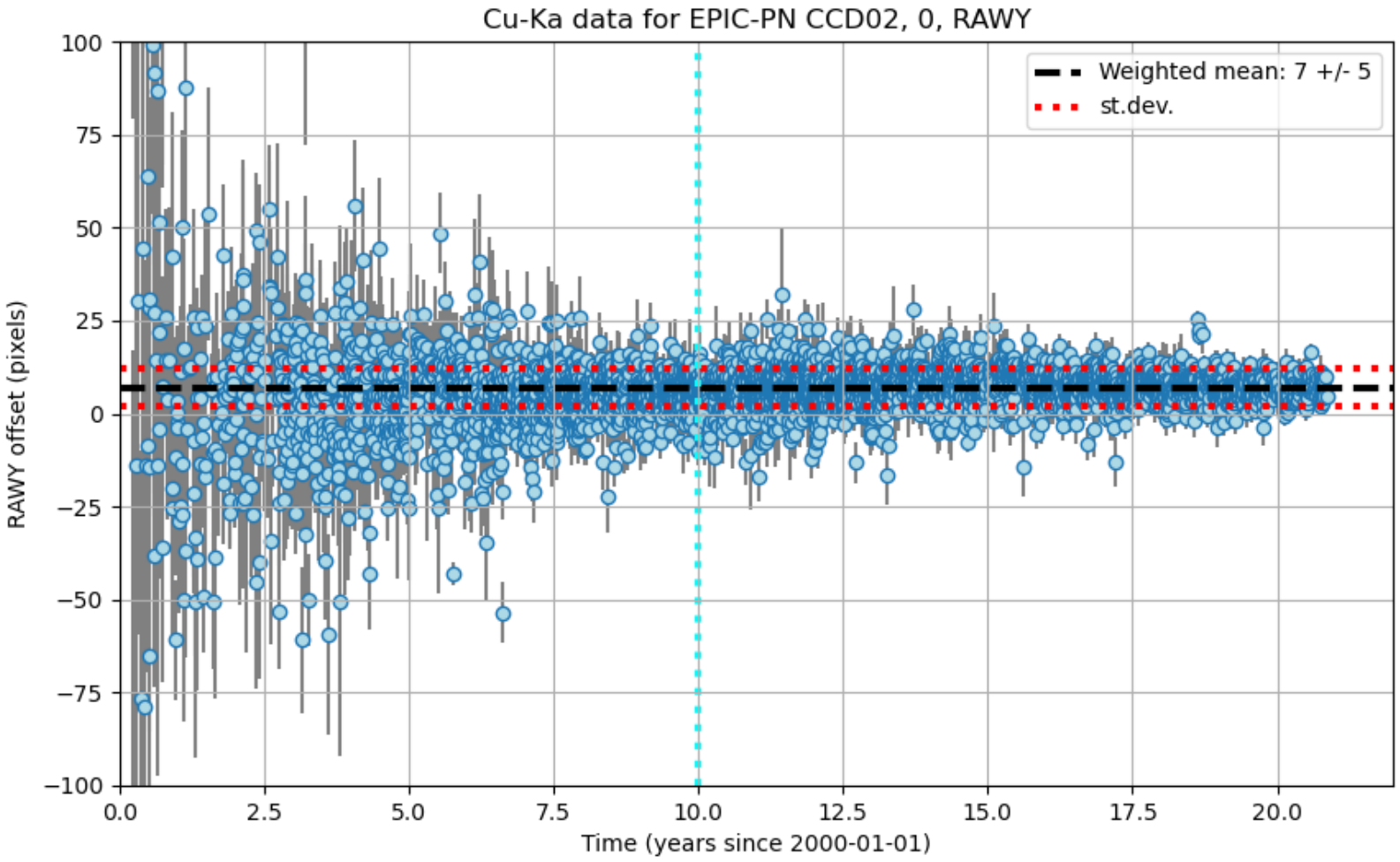
Results, CCD02:



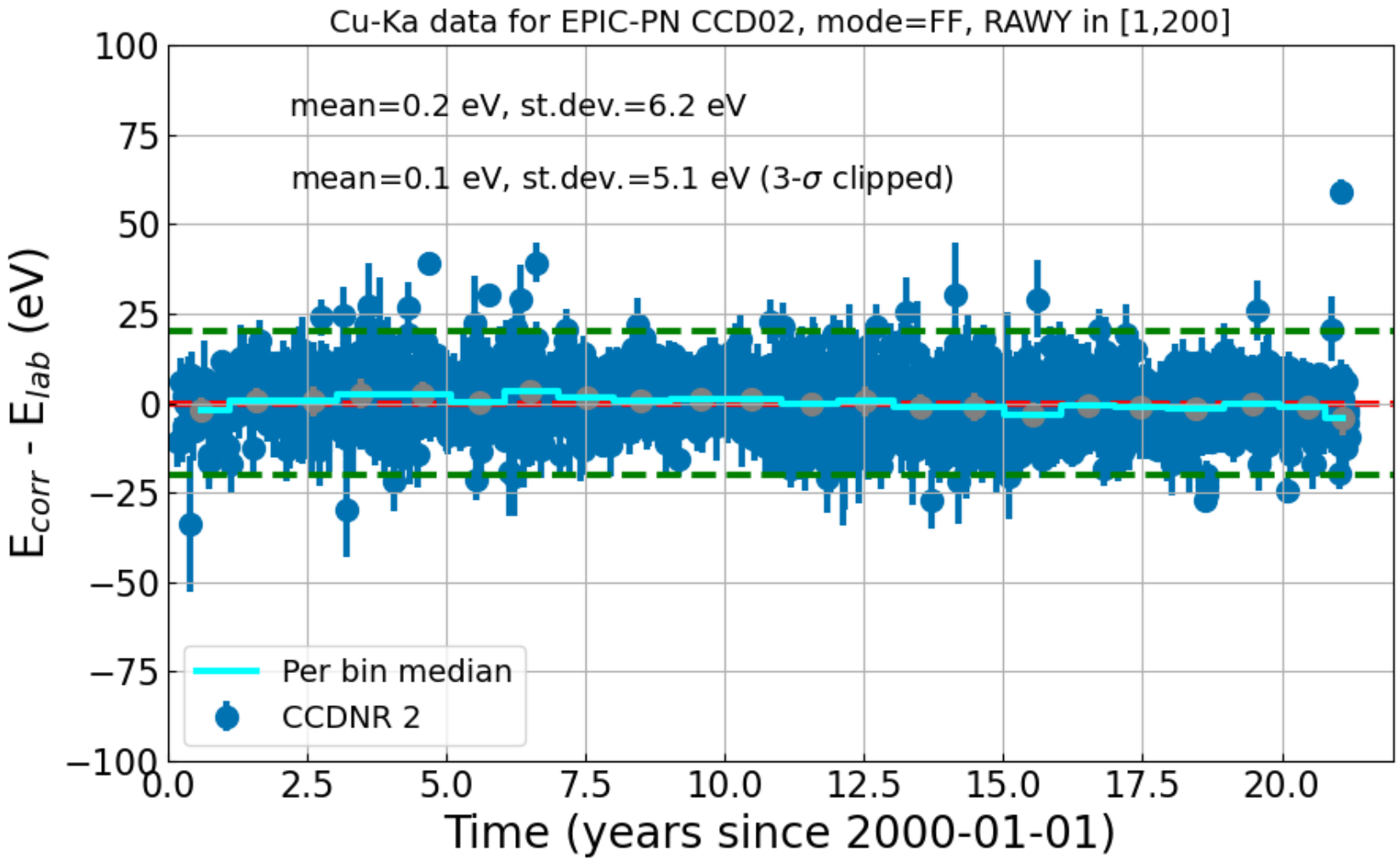
Systematic offsets

Mean residual per
500 revs (cyan)

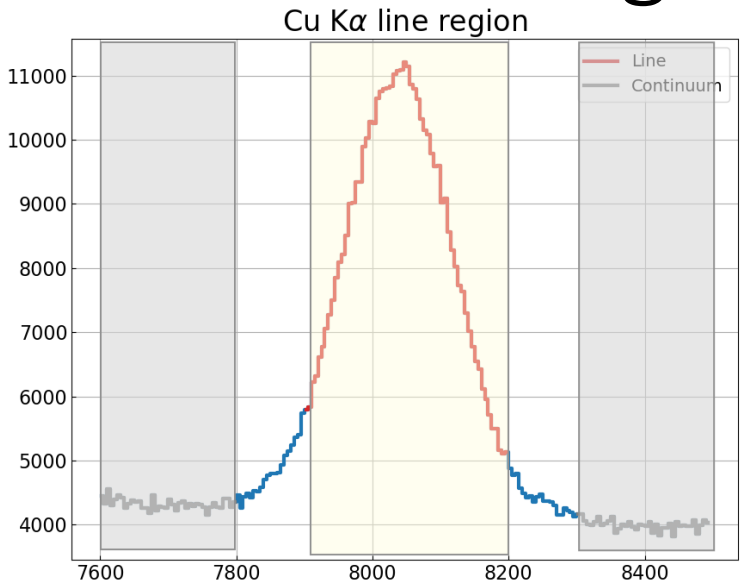
Second step, RAWY offset



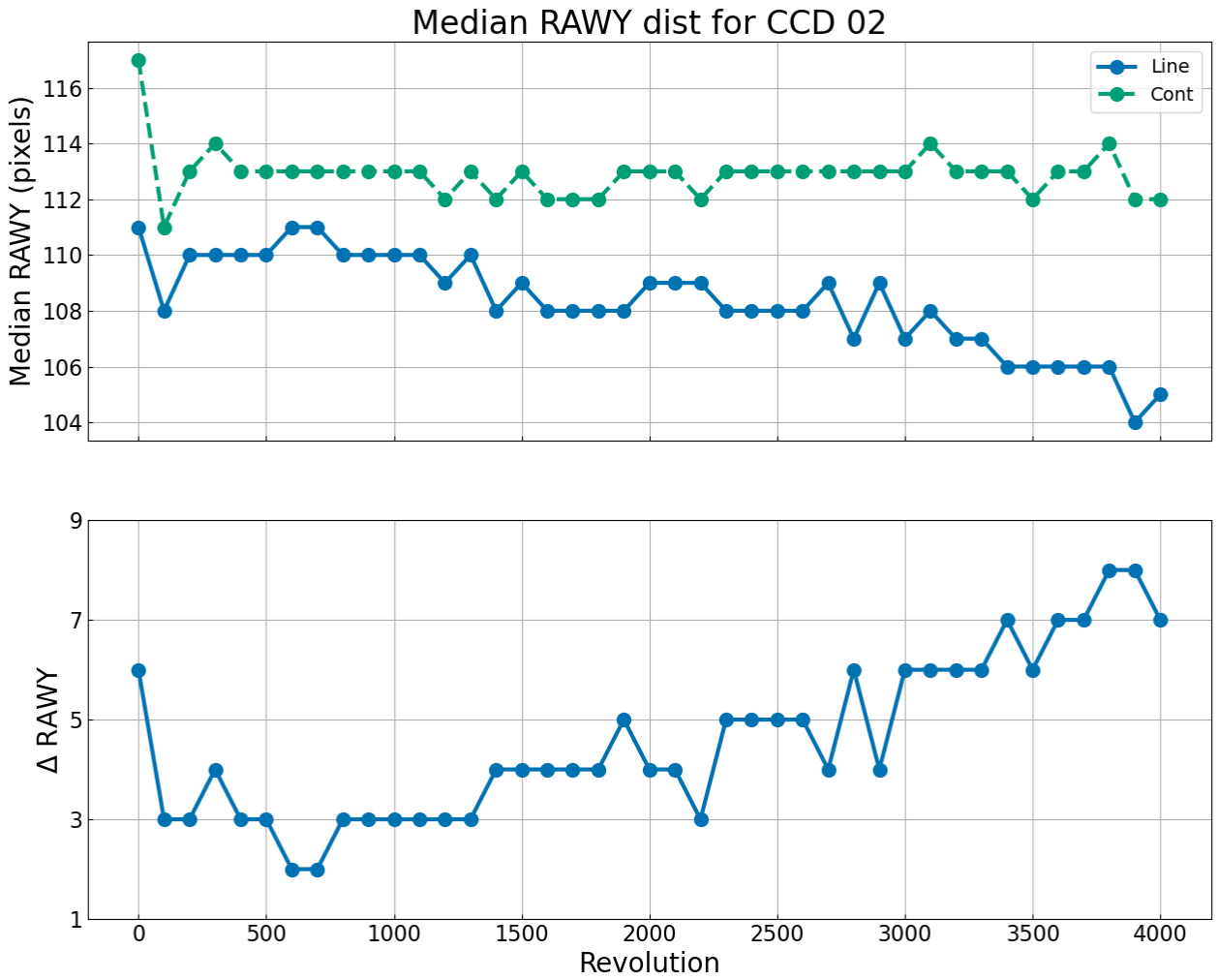
Second step, residuals



RAWY offset origin?



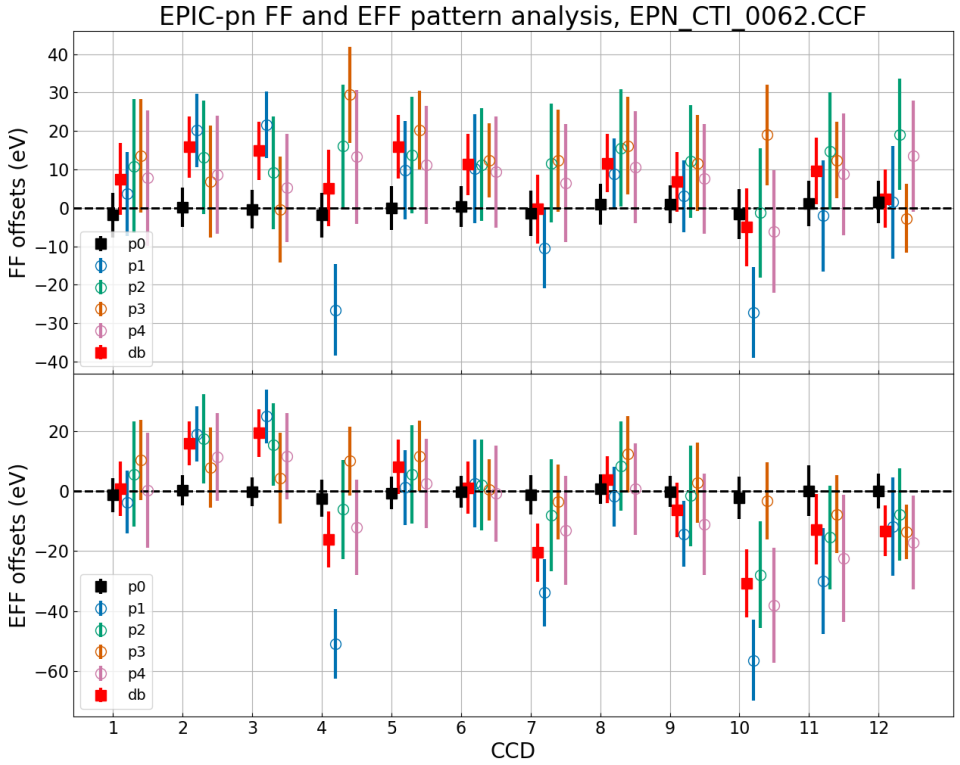
Credit: Jean Ballet

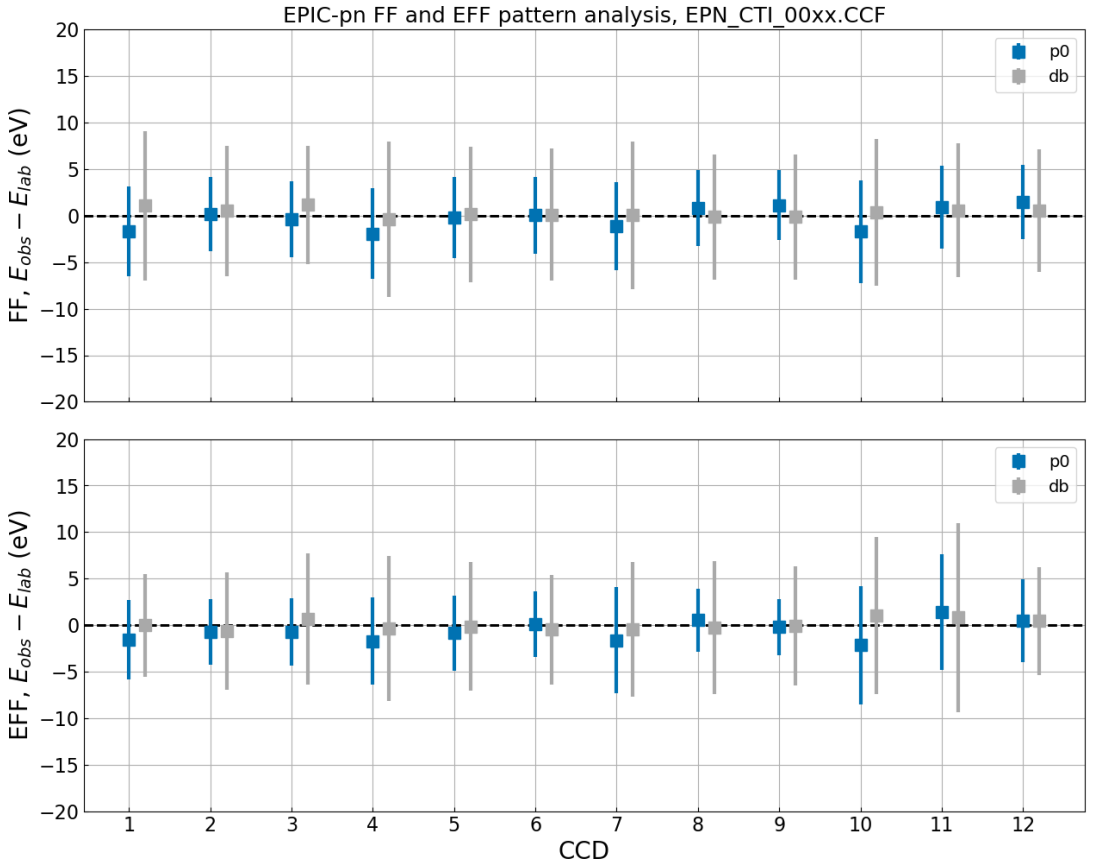


Next long-term CTI modelling will properly incorporate the line RAWY distribution!

No need for two-step approach!?

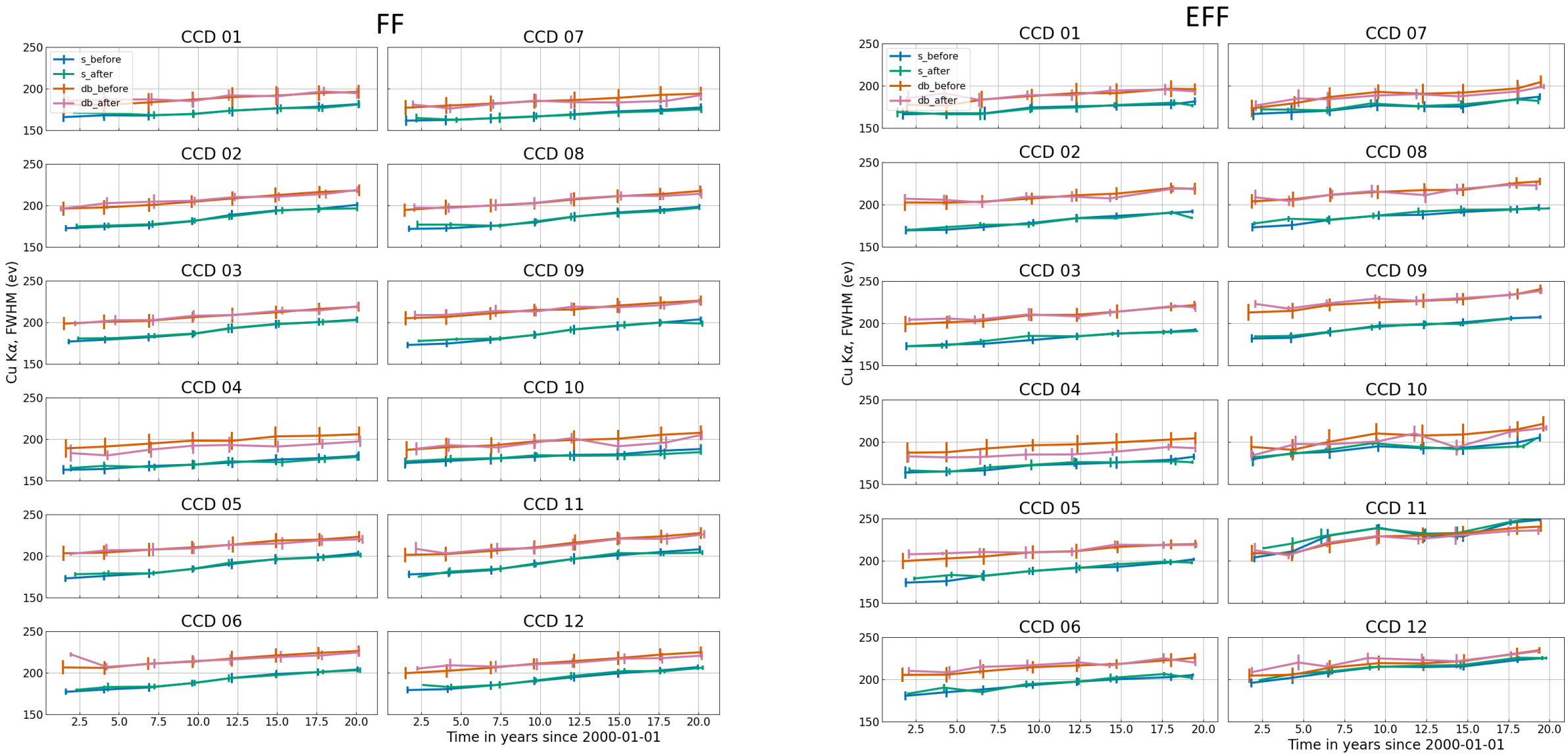
Pattern offsets from Cu Kα



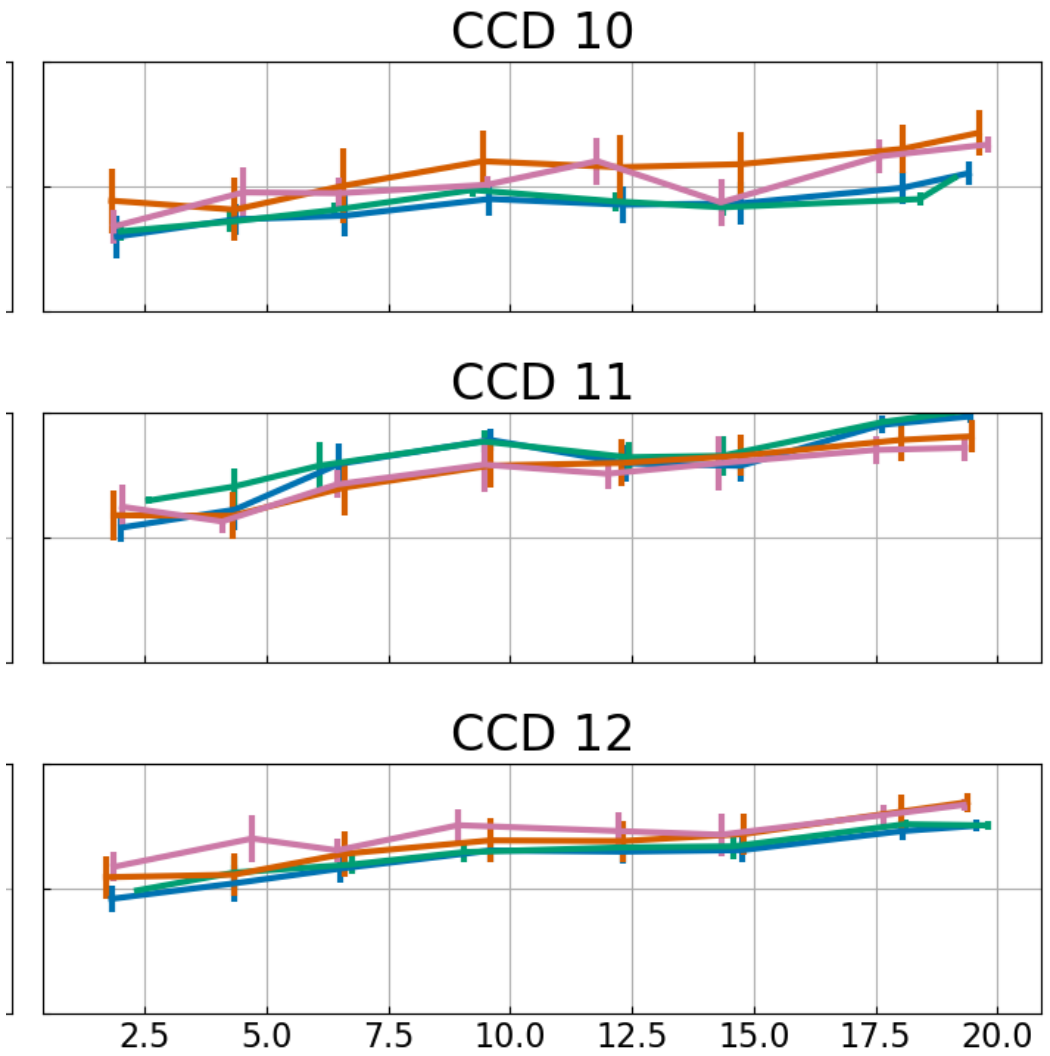


Add the offsets in the CCF file
No time or energy dependency!

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



Quadrant 3 in EFF?



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 Kα line, can be modelled linearly
    - At t=0, FWHM=~200 eV (CCD02) and ~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?

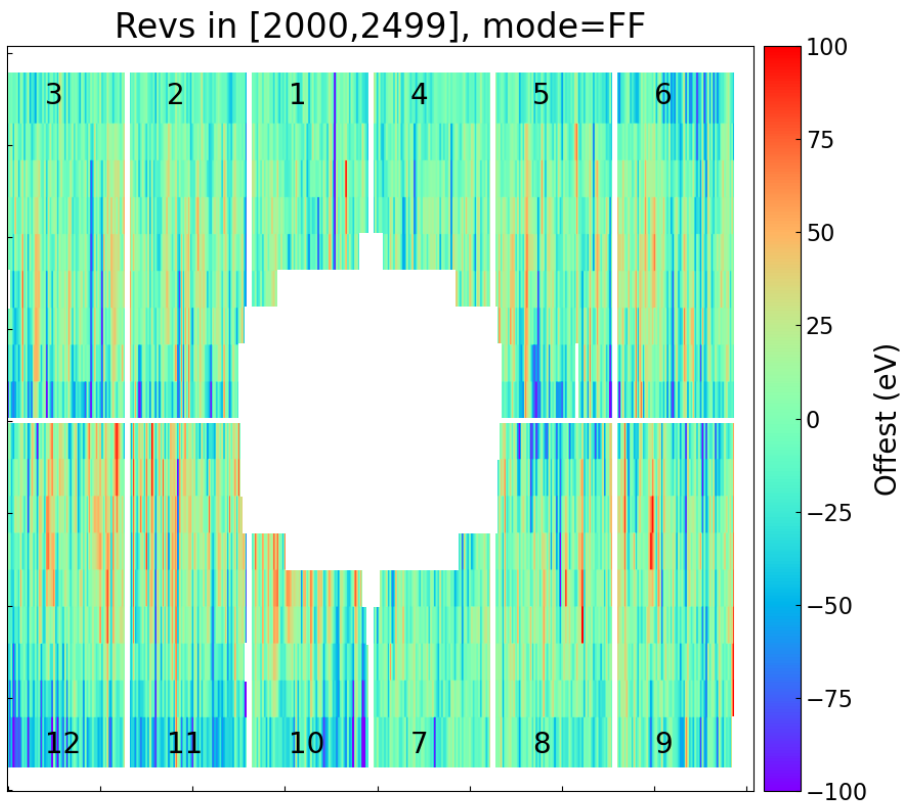
Spatial CTI offsets

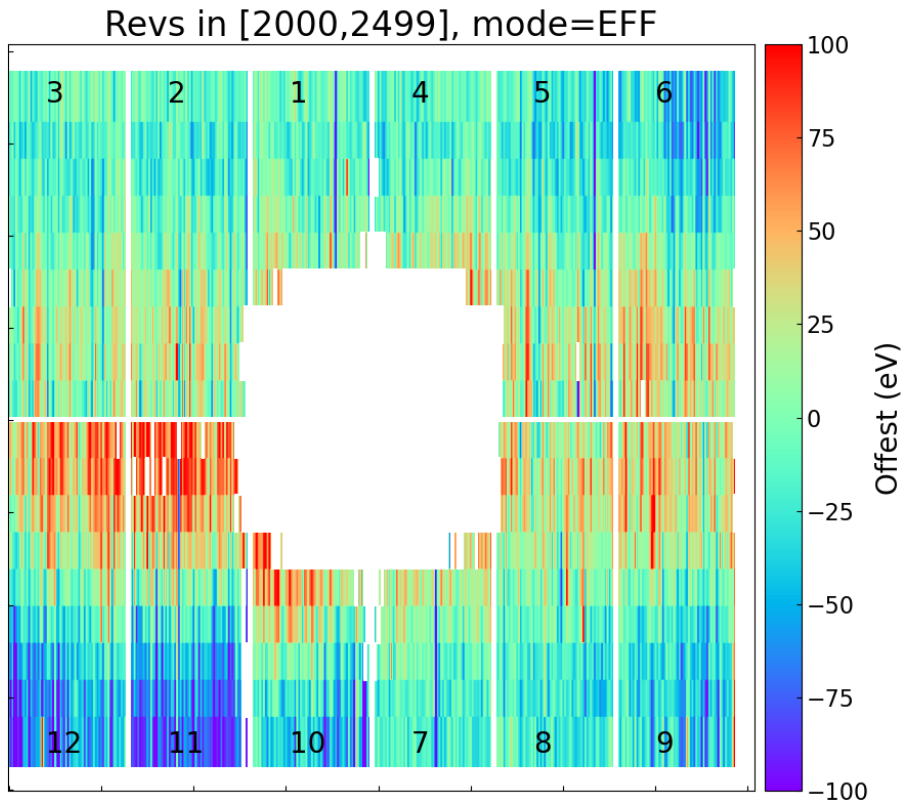
- Following Sanders et al. (2020):

1. Apply the derived per-CCD long-term CTI correction for Cu Kα
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 Kα line and derive the residual ➔ the spatial offsets as function of epoch, CCDNR, RAWX, RAWY.

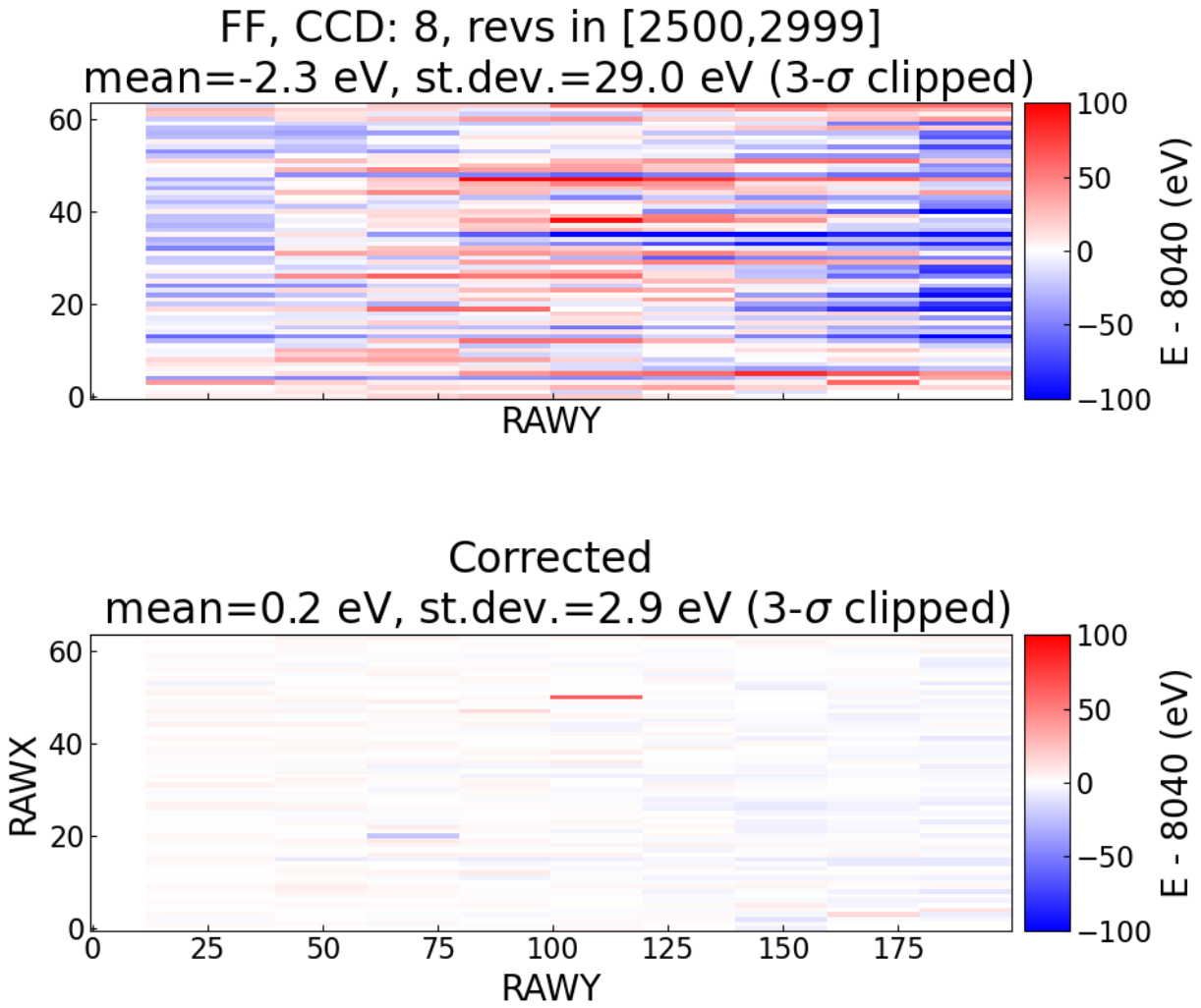
- ➔ Spatial offset table dimensions: mode,epoch,CCDNR,RAWX,RAWY
  ➔ 5-dimensional table: 2 x 8 x 12 x 64 x 200

Results, FF & EFF





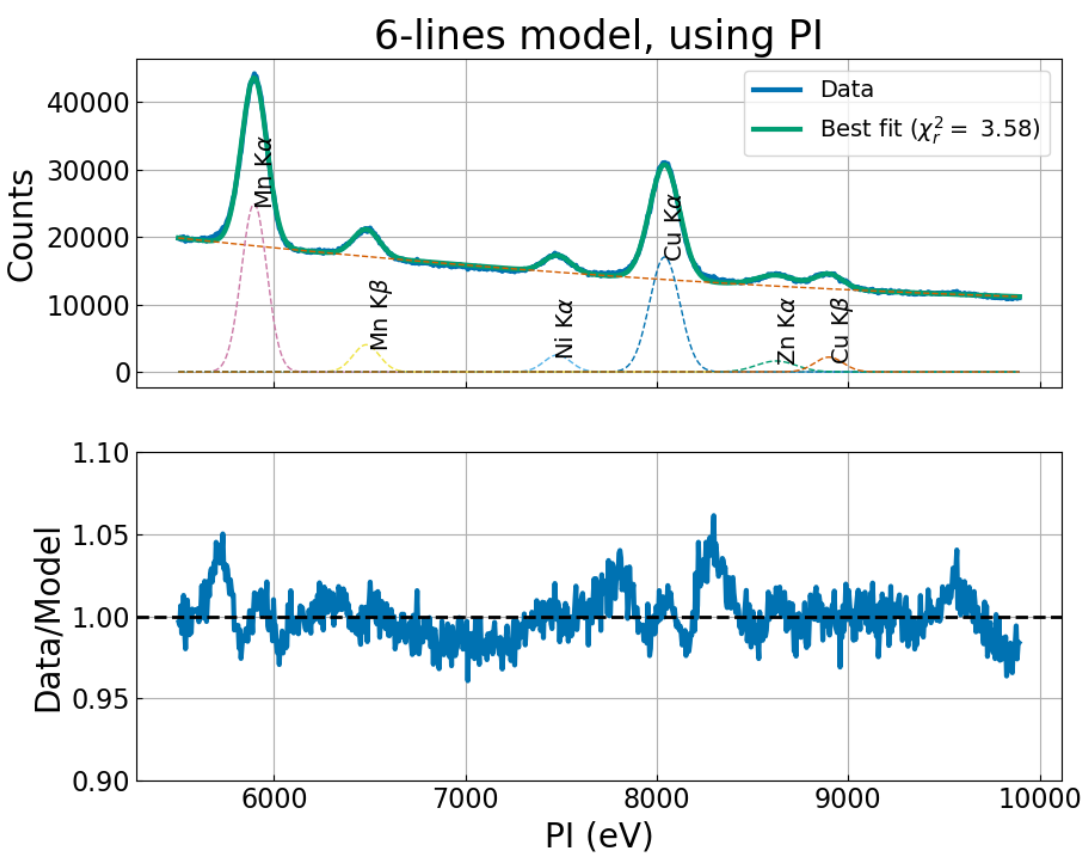
Example, correction



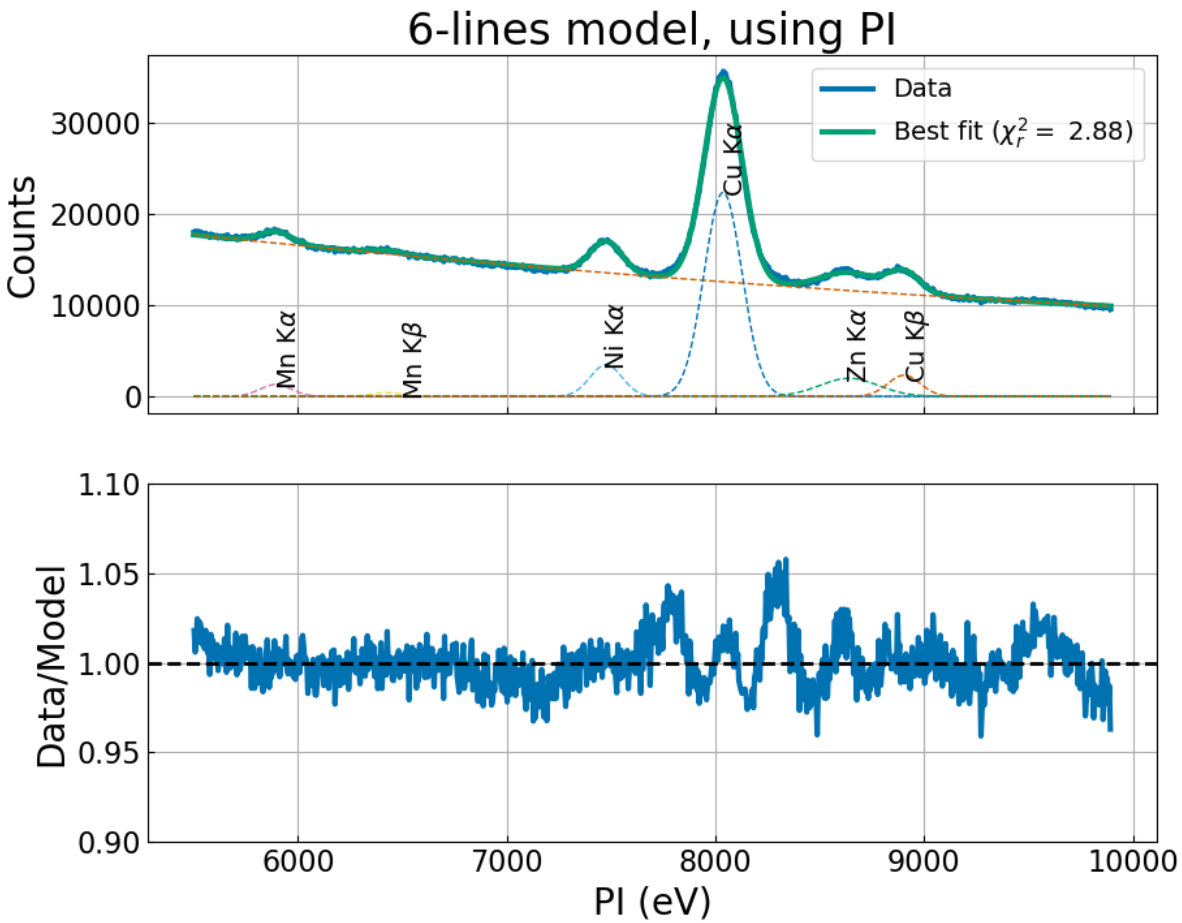
In progress

- Check if applying the spatial CTI offsets, as derived from copper, will improve the spatial CTI offsets at Mn Kα (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



Rev in [500,999]



Rev in [2500,2999]

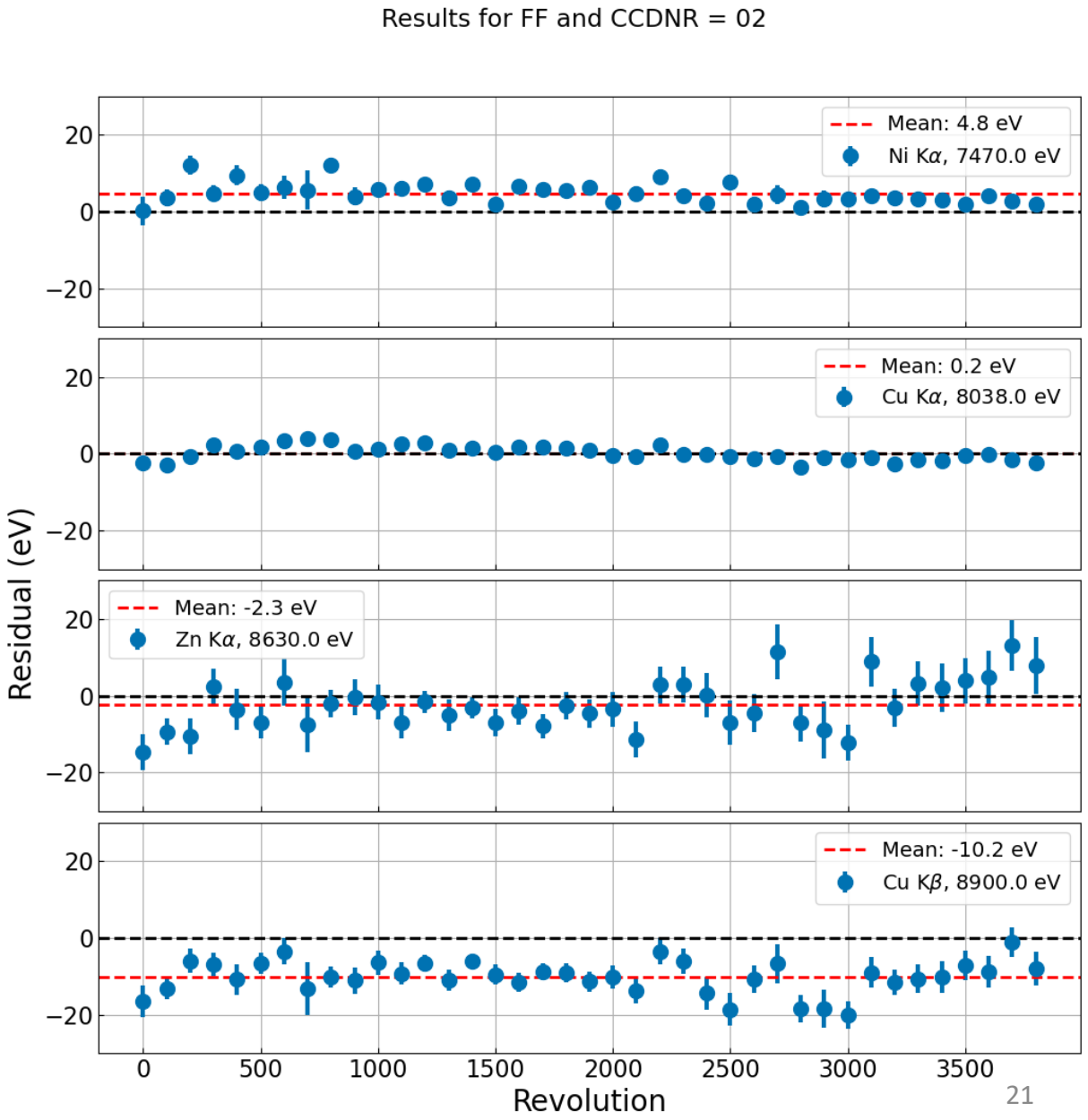
Preliminary results on energy scale

After applying long-term CTI but no spatial offsets!

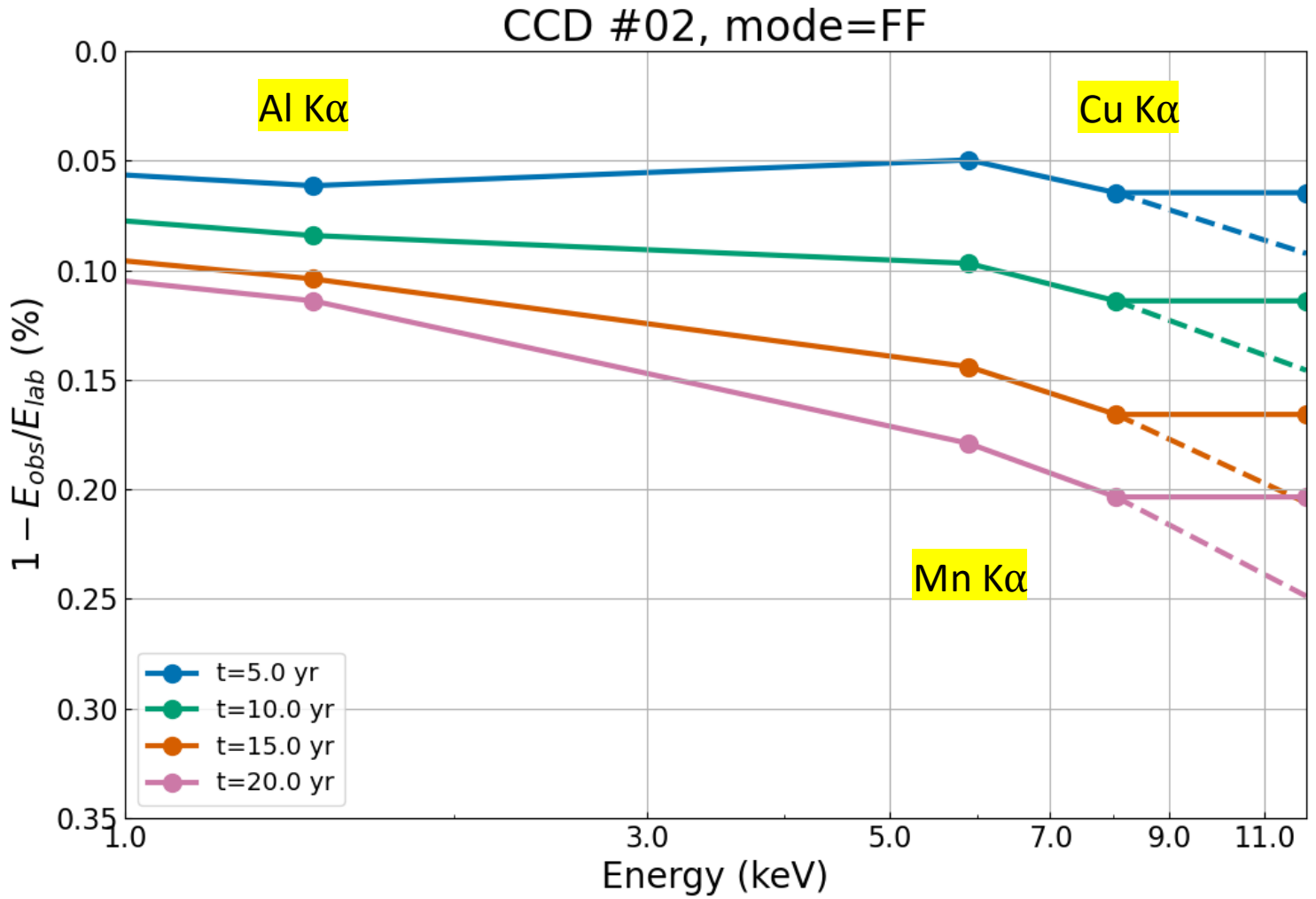
Using 4-lines model for now:

Ni K**α** (7470 eV)
Cu K**α** (8038 eV)
Zn K**α** (8630 eV)
Cu Kβ (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 Kα and Mn Kα for FF and EFF modes
  - New long-term CTI curves for Cu Kα fluorescent line for FF and EFF
  - Pattern offsets derived with Cu Kα
- Work-in-progress:
  - Spatial CTI offsets derived and validated for Cu Kα, 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 Kα and Fe Kα (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