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Determining Y-Walk Corrections for the COS FUV Detector

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ABSTRACT

The COS FUV detector comprises two microchannel plate segments (FUVA, FUVB) with cross delay line anodes to report the dispersion (x) and cross-dispersion (y) location of the charge cloud generated from a photon event. The electronic settings used to measure the locations were optimized during ground testing, but as the detector ages with usage, these positions shift due to the lowered pulse height amplitude (PHA) of the charge cloud, a phenomenon known as "walk". In this work, we use a wide range of archival COS data across Lifetime Positions (LPs) 1–5 to determine the corrections needed to remove walk in the y direction. Prior to this work, a Y-walk correction that was independent of detector location was applied to all COS FUV data. However, we find that the Y-walk shifts, dy, become increasingly steeper with PHA at locations above LP1 and shallower below. We use these dy measurements to create a YWLKFILE reference file that applies a correction based on YCORR location. This new correction, when combined with the updated GEOFILE, results in straighter spectral traces at LPs 1–6, and ensures that low gain events registered at the LP furthest below LP1 (i.e. LP4) remain in the spectral extraction region as expected.

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1. Introduction

The Cosmic Origins Spectrograph (COS) far-ultraviolet (FUV) detector is a photon-counting device utilizing two sets of microchannel plate (MCP) stacks to register incident photon events from the FUV spectrograph gratings. It employs cross delay line readouts to determine the dispersion (x) and cross-dispersion (y) position of where a photon is incident upon the MCPs (Indriolo et al. 2025). Each segment (FUVA and FUVB) is digitized such that events are assigned pixel locations within a 16384$\times$1024 (x $\times$ y) grid. However, the accuracy to which these positions can be measured by the detector electronics depends on the size, or pulse height amplitude (PHA), of the charge cloud generated by the MCPs. Charge clouds with lower or higher PHAs than those calibrated during ground testing have their positions systematically misassigned in both the x and y directions, shifts referred to as "walk". Specifically, because the number of electrons generated by the MCPs, i.e, the gain, decreases with usage in different regions due to charge depletion from repeated illumination, it is important to determine the variation of walk with PHA level so that the positions can be corrected.

A correction for Y-walk has been implemented and applied to COS FUV data since 2011. This correction was derived from measurements at the gain-sagged Lyman-α region on FUVB for the first lifetime position (LP1, which was the only lifetime position at that time) and was found to be a simple linear relation between Y-walk and PHA (Sahnow et al. 2011). It was initially applied via a WALKTAB reference file specifying the linear coefficients, but a 2017 CalCOS update separated the correction into x and y components, with corrections applied via XWLKFILE and YWLKFILE lookup image files, respectively. These were designed to accommodate any suspected dependence of walk on x, and as PHA is a digitized value from 0 to 31 (Indriolo et al. 2025), they have dimensions of 16384 $\times$ 32. In lieu of any spatial information at the time, YWLKFILE contained the same values at each x location from the linear relation with PHA as given by Sahnow et al (2011).

While this Y-walk correction appeared to shift the y location of low-gain events to the proper location for LP1 data, recent analyses of data at other LPs have revealed that Y-walk changes as a function of YCORR location, where YCORR refers to the thermal and geometrically corrected cross-dispersion location on the detector (see e.g., Section 3.4.4 and Section 3.4.5 of the COS Data Handbook). Specifically, low gain events at the LP4 Primary Science Aperture (PSA) region ($\sim$ 50 pixels below the LP1 PSA region) are being overcorrected by the LP1 correction, so much so that they were beginning to fall outside of the spectral extraction boxes. As we also have found no relation of Y-walk with x, a new YWLKFILE file has been developed of dimensions 1024 $\times$ 32 to handle the dependence on y location and dropping the condition on x. This has required a change to CalCOS to apply Y-walk as function of YCORR instead of XCORR. Note that the old and new YWLKFILEs are not interchangeable.

In this work we use an assortment of data taken across LPs 1–5 throughout the lifetime of COS to measure the Y-walk at a range of FUV detector locations. We then interpolate and extrapolate these measurements to create a YWLKFILE that contains the Y-walk corrections at each YCORR location and PHA. We find that, for both segments, the Y-walk correction is relatively flat (little change in the correction, dy, as a function of PHA) at low YCORR locations (e.g., the LP4 PSA region) and steeper than the LP1 correction at LPs above LP1 (e.g., the LP5 PSA region). The data we compiled and calibrated are described in Section 2. Measurements are described in Section 3 and the interpolation/extrapolation methods are described in Section 4. An example of some improvements to the data are shown in Section 5, and a full description of how the new YWLKFILE combined with the GEOFILE results in generally straighter spectral traces across all LPs can be found in Hasselquist et al. (2025). Finally, the work is summarized in Section 6.

Table 1. Observations used for measuring Y-walk.

LP (PSA)	**Description**	**PIDs**
LP5/LP6	X-walk for FUVA, Lyα for FUVB	12793 and many for Lyman α
LP2	X-walk	12793
LP1	WD0947+857 observations	11897, 12424, 12715, 12795, 12096
LP3	HV Sensitivity	13971
LP4	Hot Spot a34 for FUVA, Lyα for FUVB	Many[a]

[a]See Section 2.2 for a list of Hot Spot a34 exposures

2. Data Used and Calibration Procedure

To measure detector walk at any location on the COS FUV detector one must obtain data taken at a range of PHAs. The ideal way to do this is to take exposures of the same source at a wide range of detector high voltage (HV) levels and measure the position of events at each PHA. While such programs have been conducted (described in more detail below), they do not exist for every COS cross-dispersion (YCORR) location. However, we can also measure walk from exposures of continuum sources that have been taken over a long period of time at each LP, such that detector gain sag ultimately results in a wide range of PHAs at a single detector location. There are also local, temporary reductions in gain at hot spots, when counts are occurring so quickly that charge in the MCP pores cannot be replenished.

We combine data from all of these scenarios to obtain at least one measure of Y-walk at each LP PSA region for each segment. The data used are summarized in Table 1, and described in detail below. We divide the datasets into "full spectrum datasets" (X-walk, HV Sensitivity, LP1 WD0947+857 observations), Lyman α, and hot spot. We also show a schematic in Figure 1 visually highlighting which datasets are used to measure Y-walk at each LP PSA location. Due to the close proximity of LP5 to LP6 as well as the paucity of low-gain LP6 data taken at the time of this analysis, we consider corrections derived at the LP5 location to be good enough to apply to LP6.

2.1 Full Spectrum Datasets

The X-walk and HV Sensitivity datasets consist of multiple exposures of the wavecal lamp and WD0308-565, respectively, with each exposure taken at a different detector HV. This results in a spectrum of the same source at a wide range of PHA, allowing for Y-walk measurements. The X-walk dataset was taken near the LP2/lower LP5 PSA region of the detector, and the HV Sensitivity dataset was taken at the LP3 PSA region. To measure Y-walk at LP1, we use a large number of exposures of WD0947+857 taken throughout the entire lifetime of LP1 such that they span a wide range of PHA. These data are from cenwaves 1105, 1291, and 1309. As detailed in Section 3.1, these full spectrum datasets allow us to measure the Y-walk both as a function of XCORR and YCORR location, although we do not find that Y-walk is dependent on XCORR

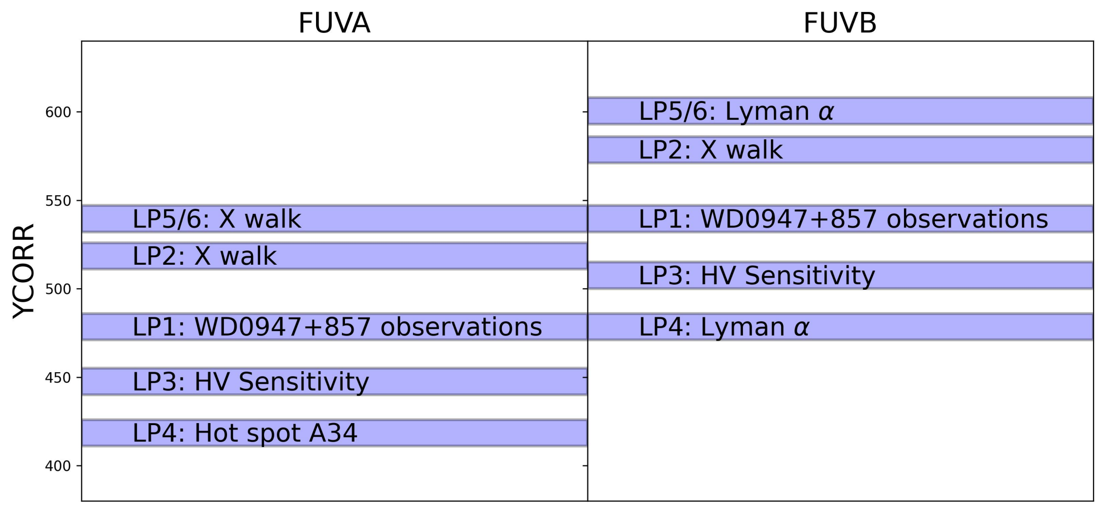

Figure 1. Graphical version of Table 1 showing the approximate YCORR location of each dataset used to measure Y-walk for FUVA (left) and FUVB (right). Each YCORR location is labeled by the nominal lifetime position (LP) of the PSA region. The offset in YCORR between FUVA and FUVB is not a physical offset, but an artifact of the way the detectors are digitized.

location, at least at these PSA regions.

2.2 Lyman α and Hot Spot a34

To determine the correction at LPs 4 and 5 for FUVB we measure the YCORR location of gain-sagged Lyman α regions, as was done at LP1 by Sahnow et al. (2011). The high count rate of Lyman α geocoronal emission causes this region of the detector to be gain-sagged faster than all other regions, meaning for the more recent LPs we can still measure Y-walk down to the lowest PHAs. To build this dataset, we queried MAST for all COS G130M/1291 observations taken at LPs 4 and 5.

To obtain a measurement for Y-walk at the LP4 region of FUVA, where Lyman α gain sag is not present, we use observations of a hot spot. Hot spots may occur when some foreign particulate, usually a dust particle, is on the detector or in an MCP pore and gets charged by high voltage, causing it to become ionized and glow. The count rates from these hot spots can be so high that the charge in the MCPs is not replaced fast enough, and the modal gain temporarily drops. This means that we can get counts at a wide range of PHAs for something that is expected to be at a fixed location on the detector. We use hot spot "a34", which lies just above the LP4 PSA region on FUVA (YCORR $\sim$ 410) and at XCORR $\sim$ 10570. The PIDs and exposures used to make this measurement are 16375: lemuady6q; 16717: lend03w0q, lend04s6q, lend51hjq; 16677: lene04s4q, lene07c0q, lene07ccq, lene14bcq; 16650: leo502kpq, leo514krq, leo514ktq; 16679: leo909u7q; 16591: lepc1ltgq; 16599: leqp1dioq; 16643: leqr05o0q; 16697:

leqs01lbq; 16853: leso2dv8q; 16931: letz01cyq; 16920: leu403b2q, leu403b2q; 16810: leuj1ef7q.

2.3 Calibration

Initially, rather than reprocessing all data using CalCOS with YWLKCORR = 'OMIT', we simply use the existing YWLKFILE ("14o2013rl_ywalk.fits") to apply an anti-walk correction to all data as they are on MAST and then measure the Y-walk. This Y-walk correction is then applied to the data used to derive the new GEOFILE (Indriolo et al. 2025). The GEOFILE contains the corrections that are applied to the x and y location of each photon event via the GEOCORR module in CalCOS to correct for the difference between the inferred and actual pixel sizes of the FUV array (see e.g., Section 3.4.5 of the COS Data Handbook). After the new GEOFILE was created, we then recalibrated all data with YWLKCORR = 'OMIT' and remeasured the Y-walk from these datasets. The analysis, including the plots in this report, all relied on measurements from the datasets after this new GEOFILE, although we only found small (<1 pixel) changes in the Y-walk measurements between the iterations.

3. Measurements

In general, the measurement procedure for each type of dataset is similar in that the mean YCORR locations are calculated for events at fixed PHAs. The reported Y-walk is then the difference, dy, between the YCORR measurement of a given PHA and that for the PHA we define as the zero point. In all cases, we initially determined dy relative to PHA = 9 for FUVA and PHA = 11 for FUVB, as these are the highest PHAs for which we can measure accurate YCORR locations across all datasets. As explained in more detail in Section 4, we later move the zero points to PHA = 11 for FUVA and PHA = 14 for FUVB. This was done to minimize the induction of shifts during the creation of the GEOFILE, as we correct the thermal vac (TV03) data for Y-walk before the GEOFILE is recreated.

3.1 Full Spectrum Datasets

To measure the Y-walk from the full spectrum datasets described in Section 2.1, we first combine all exposures within each LP to create a corrtag file that contains the locations and PHAs of every photon event. We then divide each exposure into XCORR bins of size 1000 pixels and measure the median YCORR location of photon events that occur in the PSA region separately for each PHA. An example of the measurements is shown in Figure 2 for G160M/1623 exposures of the HV Sensitivity dataset taken at the LP3 PSA region. The mean YCORR location is lower at lower PHAs, although this relationship is slightly steeper for FUVB than it is for FUVA. All XCORR locations have similar slopes of YCORR with PHA, with the offset between high and low XCORR seen for

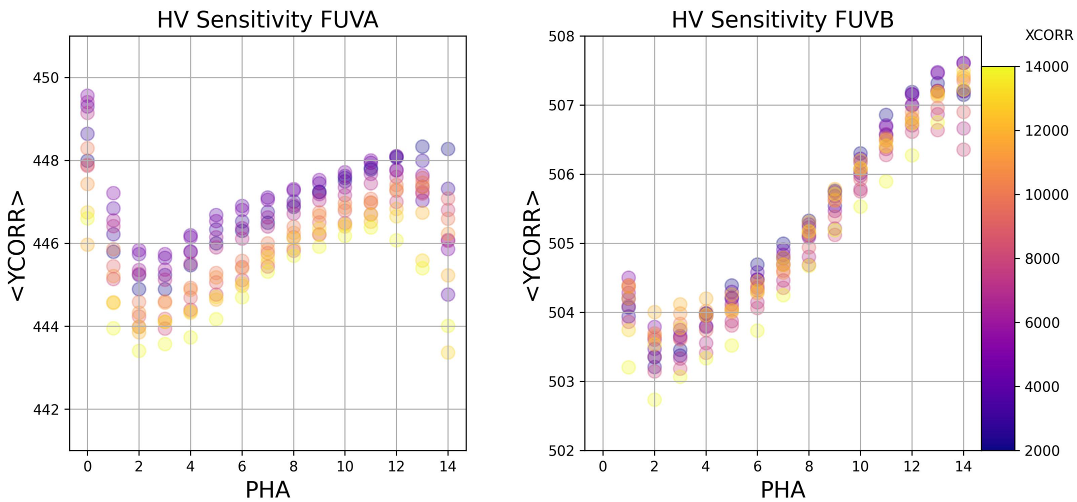

Figure 2. The median YCORR location (<YCORR>) as a function of PHA in bins of XCORR of size 1000 pixels for the G130M/1623 observations of the HV Sensitivity data set (LP3 PSA region) for FUVA (left) and FUVB (right). Points are colored according to the XCORR bin from which they were measured. The apparent dependence of Y-walk on XCORR for FUVA is likely due to an imperfect geometric correction, as the <YCORR> vs. PHA trends are still parallel for the higher and lower XCORR tracks, implying similar Y-walk.

FUVA likely a result of an imperfect geometric correction for this region (although this separation is still < 1 pixel in YCORR). Due to the high S/N of these observations, typical 1σ uncertainties for these mean measurements are on the order of 0.02-0.1 pixels. For FUVB, we were unable to measure the Y-walk of PHA = 0 events due to insufficient number of events as the gain was not low enough even for the lowest HV exposures.

We perform similar measurements for the LP1 datasets and the X-walk dataset. While most of the X-walk dataset visits were taken at the LP2 PSA region, Visit 12 was taken at the lower end of the LP5 PSA region. Due to the close proximity of LP6 to LP5, Visit 12 serves as a Y-walk measurement for both LP5 and LP6, although we ultimately use the Lyman α measurements for FUVB at LP5 as they are taken exactly at the LP5 PSA region.

3.2 Lyman α

To measure Y-walk at LPs 4 and 5 for FUVB, we follow Sahnow et al. (2011) and measure the change in YCORR of the Lyman α region of the detector as a function of PHA. To do this, we use all G130M/1291 data taken at LPs 4 and 5 through October 2022 and isolate the XCORR location of Lyman α and measure its YCORR location in each exposure at three gain levels: the modal gain, one PHA bin below the modal

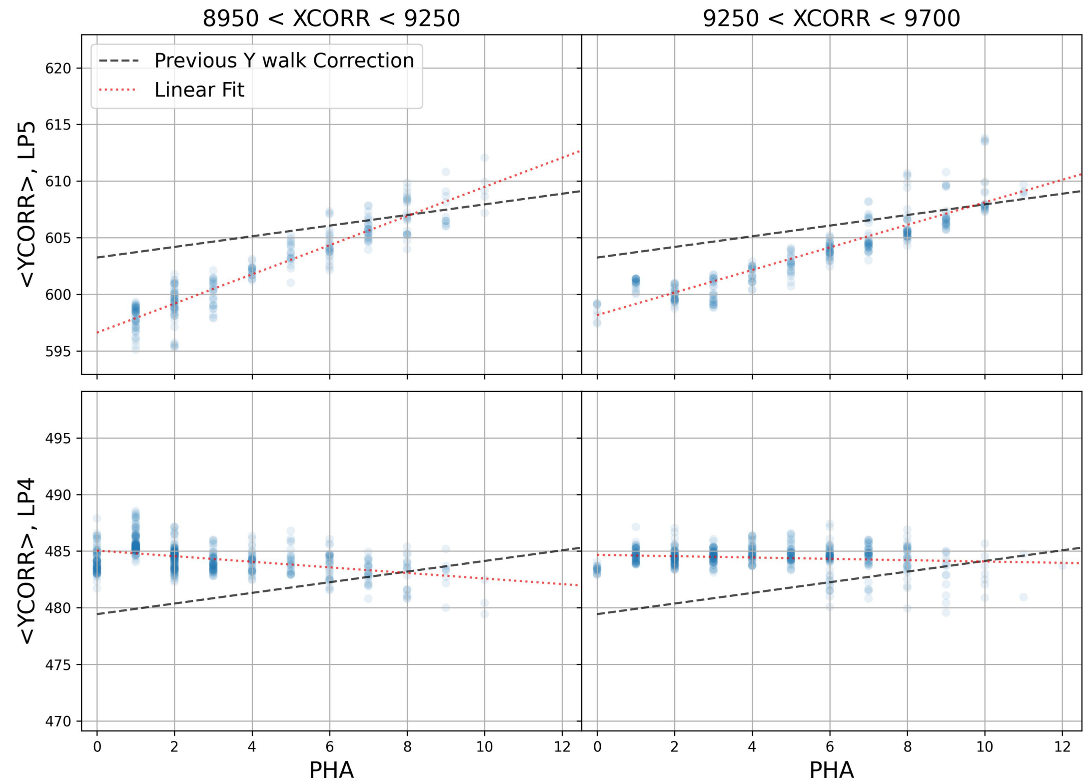

Figure 3. The mean YCORR location (<YCORR>) as a function of PHA for two Lyman α regions on FUVB for the LP5 PSA region (top row) and LP4 PSA region (bottom row). Each point is the measurement of the YCORR position of the Lyman α for a fixed PHA from an individual G130M/1291 observation. The black dashed line reproduced in each panel is the existing correction found in the YWLKFILE delivered and activated on June 15, 2017 ("14o2013rl_ywalk.fits"). The red dotted line is a linear fit to the data in each Lyman α region.

gain, and one PHA bin above it. We use just 3 PHA bins as they result in the highest S/N measurement of the Lyman α location. For events at a fixed PHA, we fit Gaussians to the YCORR distribution and take the mean from this fit to be the mean location of Lyman α. For each exposure we then have three measurements of the position of Lyman α at three individual PHAs. We then fit a line to all of these measurements across all exposures and use this line as the Y-walk. The measurements along with the linear fits are shown in Figure 3. Typical uncertainties on the Lyman α locations are 0.02-0.08 pixels. For comparison, we include black dashed lines for the Y-walk that was derived from LP1 Lyman α by Sahnow et al. (2011). This comparison demonstrates that the Y-walk is steeper with PHA above LP1 and nearly flat with PHA at the lower LP4 region of the detector.

3.3 Hot Spots

At the time of this work there are no LP4 data that cover a sufficient range of PHA such that Y-walk can be measured at this PSA location for FUVA. However, the COS team maintains an internal list of detector hot spots, and one of these, a34, is near the LP4 PSA region of FUVA. Because a hot spot is thought to be due to a physical feature on the detector, any change in its recorded location with PHA must be due to walk. To measure the Y-walk from this hot spot, we fit Gaussians to the distribution of YCORR locations at each PHA, as demonstrated in Figure 4. In this case, its mean YCORR location is largely unchanged with PHA, indicating that the Y-walk correction is relatively flat at the LP4 PSA region for FUVA, just like it was for FUVB as indicated by the Lyman α measurements (Section 3.2).

Ideally, one could use all COS observations recording the presence of a hot spot to measure both X- and Y-walk at various locations on the detector. However, because we are generally only interested in where these hot spots affect the PSA or WCA regions, a more concentrated effort to automatically identify and measure the location of the hotspots for each PHA would be required. Therefore, here we only use a single hot spot to supplement where other measurements do not exist, which is FUVA at LP4.

3.4 Measurement Summary

For some LP/segment combinations we only have a single measurement of Y-walk whereas for others we have multiple. To avoid overfitting during the interpolation step, we first average all of the measurements that fall within a single LP. The final values that are used to create the YWLKFILE are shown in Figure 5. While we do measure nearly identical Y-walk as Sahnow et al. (2011) did for LP1, we find that for both segments the Y-walk (dy) is steeper with PHA above LP1 and shallower to completely flat below LP1.

4. Extrapolation and Interpolation

The measurements must be interpolated between and extrapolated beyond available YCORR positions such that a YWLKFILE that is of dimensions 1024×32 can be created for FUVA and FUVB. For each segment, we first extrapolate these measurements to higher PHAs. To do this, we fit a line to the dy measurements at each LP for 4 < PHA < 11 for FUVA and 4 < PHA < 14 for FUVB, as the relationship is approximately linear across this range for all LPs. This linear function is then extrapolated to all PHAs at and above the upper limits mentioned above. COS rarely obtains science data at such high gain, so the uncertainty of the extrapolation to PHA > 14 is not expected to impact science observations. We then shift the line such that PHA = 11 for FUVA and PHA = 14 for FUVB have Y-walk of zero to minimize applying large shifts to the TV03 data used to derive the geometric correction.

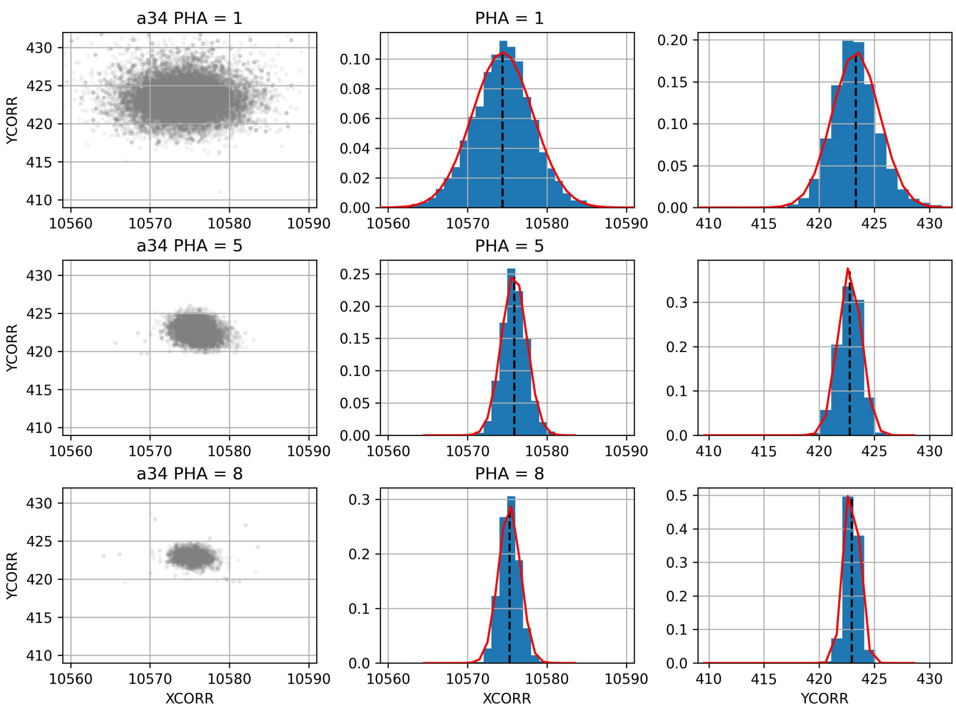

Figure 4. Left column: XCORR-YCORR scatterplot of hot spot a34 from the exposures listed in Section 2.2 for PHA = 1 events (top), PHA = 5 events (middle), and PHA = 8 events (bottom). The middle and right columns show Gaussian fits to the XCORR and YCORR distributions, respectively, of this hot spot, which we use to measure Y-walk. Dashed black lines indicate the mean of each Gaussian fit. For this hotspot, which is in the LP4 PSA region of FUVA, we measure almost no Y-walk, consistent with the expectation that the previous Y-walk correction was overcorrecting this region of the detector.

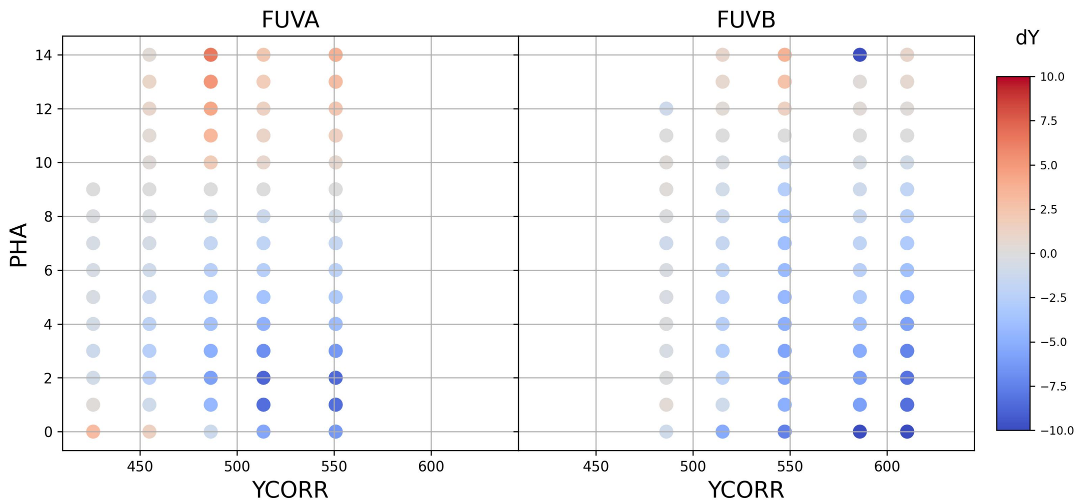

Figure 5. PHA vs. YCORR colored by Y-walk measurement, dy, for each PSA region for FUVA (left) and FUVB (right). The PSA regions with multiple measurements have their measurements averaged together, as described in more detail in the text.

We then interpolate/extrapolate in YCORR between the measurements for each segment. Since we have average dy values at only the five LP YCORR positions, we decided to adopt a simple piecewise linear interpolation/extrapolation, fitting lines to the points above LP1 and below LP1, including LP1 in both cases for the fits. Examples of these fits are shown in orange in Figure 6, and these values are what ultimately populate the YWLKFILE reference file. For comparison, we include in Figure 6 cubic spline (red) and quadratic fits (blue) to all points, demonstrating that these methods result in similar corrections over which we have data, but diverge in an unconstrained way beyond that, making the piecewise linear the simpler choice for both interpolation and extrapolation.

Using these interpolation and extrapolation methods, we generate the YWLKFILE that is illustrated in Figure 7. Regions interior to the black dashed lines indicate the YCORR versus PHA parameter space constrained by measurements and interpolation, while exterior regions required extrapolation. Any future LPs that use data outside of this black dashed area would benefit from additional Y-walk measurements, either from hot spots or dedicated calibration programs. To populate the YWLKFILE beyond the region of active area (outside the plot range shown in Figure 7) we simply use the value at the lowest or highest YCORR value of the active area and extrapolate that value to all regions below and above the active area, respectively.

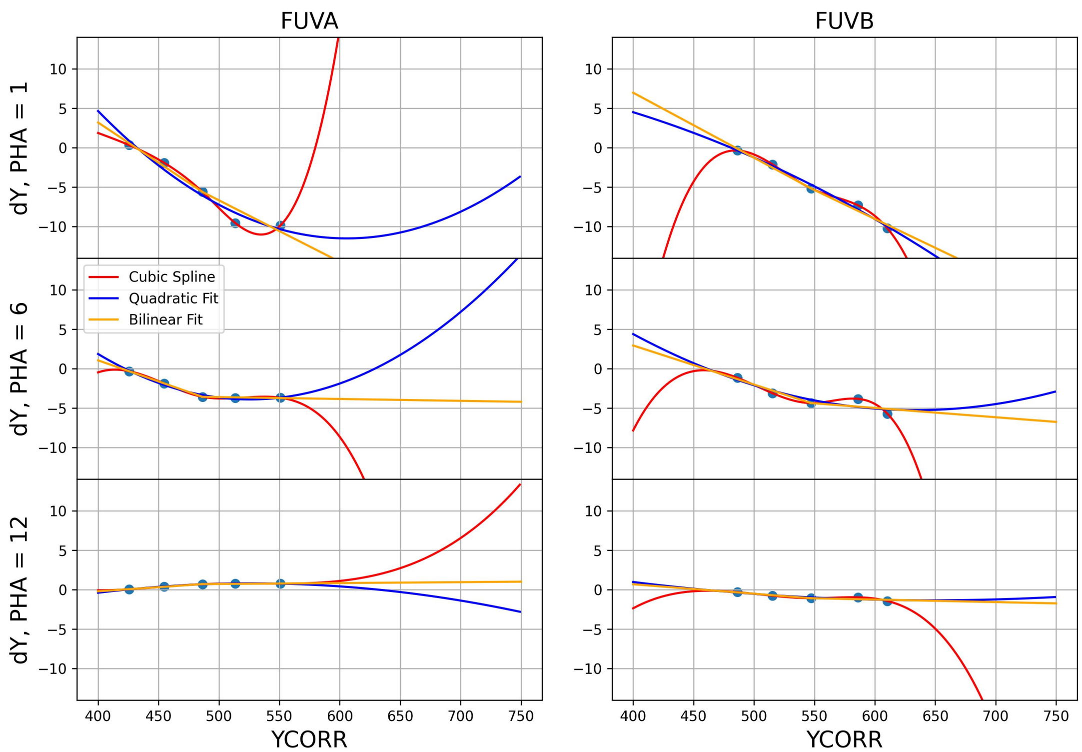

Figure 6. Y-walk measurements, dy, as a function of YCORR locations along with several interpolation schemes for select PHAs for FUVA (left) and FUVB (right). We adopt the piecewise linear interpolation (orange) to avoid unconstrained divergence beyond the region for which we have data, but note that both a cubic spline and quadratic fit give similar results over the regions for which we have data.

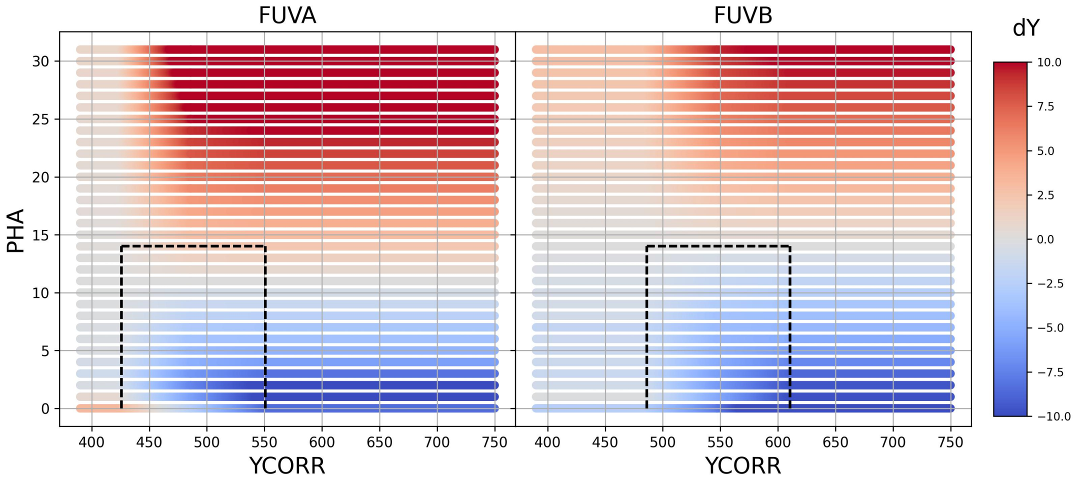

Figure 7. Visual representation of the YWLKFILE after interpolation and extrapolation (orange lines from Figure 6). The black dashed rectangle indicates the region of parameter space for which we had actual Y-walk measurements. Regions outside of this box are using an extrapolated correction.

5. Testing

This new YCORR-dependent Y-walk correction subtly improves the spectral traces at LP6 and LP4, as these LPs were previously receiving Y-walk corrections that were incorrect. A full description of how the spectral traces improve at all LPs due to both this YWLKFILE and the new GEOFILE can be found in Hasselquist et al. (2025). To demonstrate improvement we show in Figure 8 that the new YWLKFILE created in this work corrects the YCORR location of gain-sagged regions at LP1 as well as the previous YWLKFILE did, but now the new YWLKFILE does not over-correct the gain-sagged area at LP4 as we discovered the Y-walk correction should be much flatter at this region of the detector.

6. Summary

We have used data taken across the lifetime of COS at various regions of the FUV detector to measure Y-walk at five different PSA locations (LPs 1–5) for both FUVA and FUVB. While we measure the same Y-walk at LP1 as Sahnow et al. (2011), we find that the Y-walk is steeper with PHA above LP1 and shallower to flat below LP1. We used these measurements to interpolate and extrapolate a YWLKFILE that is of dimensions 1024$\times$32, containing a Y-walk correction that depends on the YCORR location and PHA. The new YWLKFILE has been applied to the data using a new y-dependent Y-walk build of CalCOS (rather than x-dependent Y-walk) to verify that LP4 data are

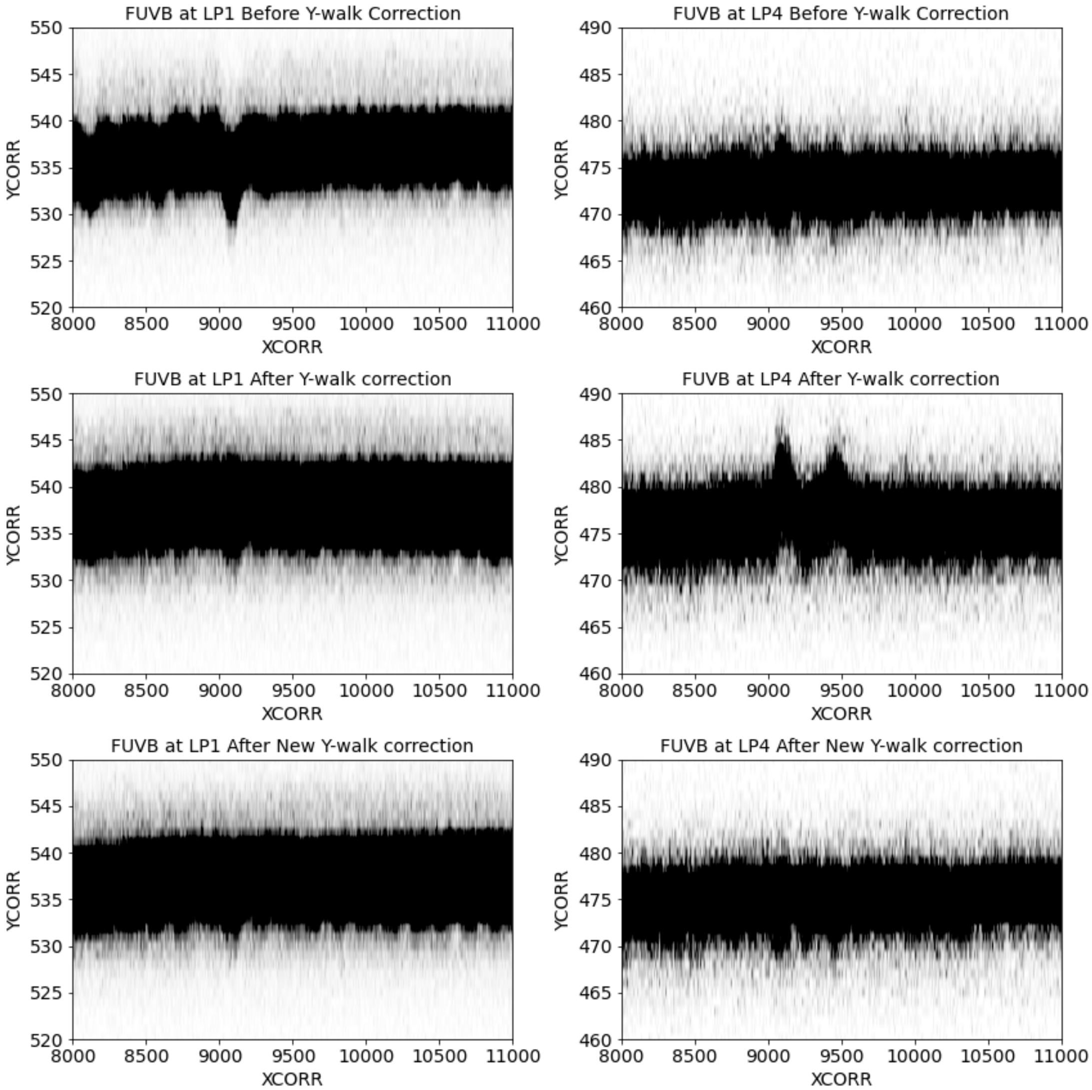

Figure 8. Demonstration of visual improvements with the new YWLKFILE. The top row shows FLT images of the Lyman α gain-sagged region of FUVB for data before any Y-walk correction is applied at the LP1 PSA region (left, exposure lbo2hvljq) and the LP4 PSA region (right, exposure lefe01pxq). The middle panel shows the same images for the data after the Sahnow et al. (2011) correction, which well-corrects the data at LP1 but over-corrects the data at LP4. The bottom panel shows that after using the new YCORR-dependent YWLKFILE derived in this work, the Lyman α gain-sagged region is corrected for both LP1 and LP4.

no longer being over-corrected, resulting in smooth, straighter traces with all counts falling within the XTRACTAB bounds. Further discussion of improvements on the spectral traces and profiles can be found in Hasselquist et al. (2025). As new LPs are commissioned, those LPs that fall below LP4 or above LP6 should analyze hot spots or conduct dedicated calibration programs to ensure that the extrapolated Y-walk correction derived here is still an accurate characterization of detector Y-walk.

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References

Hasselquist et al. 2025, COS Instrument Science Report 2025-10
Indriolo et al. 2025, COS Instrument Science Report 2025-07
Sahnow, D., et al., 2011, Proceedings of the SPIE, Volume 8145, id. 81450Q
Soderblom, D., et al. 2022, COS Data Handbook, Version 5.1, (Baltimore: STScI).