

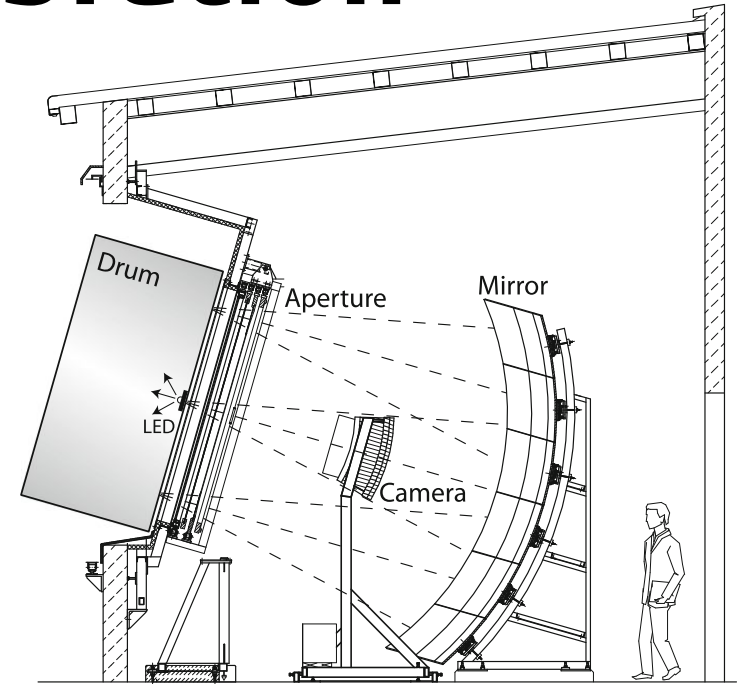
PIERRE
AUGER
OBSERVATORY

The XY-Scanner

Absolute FD Calibration and Cross-Calibration between Telescopes

Operations and Long Term Performance Meeting, 30.05.2023

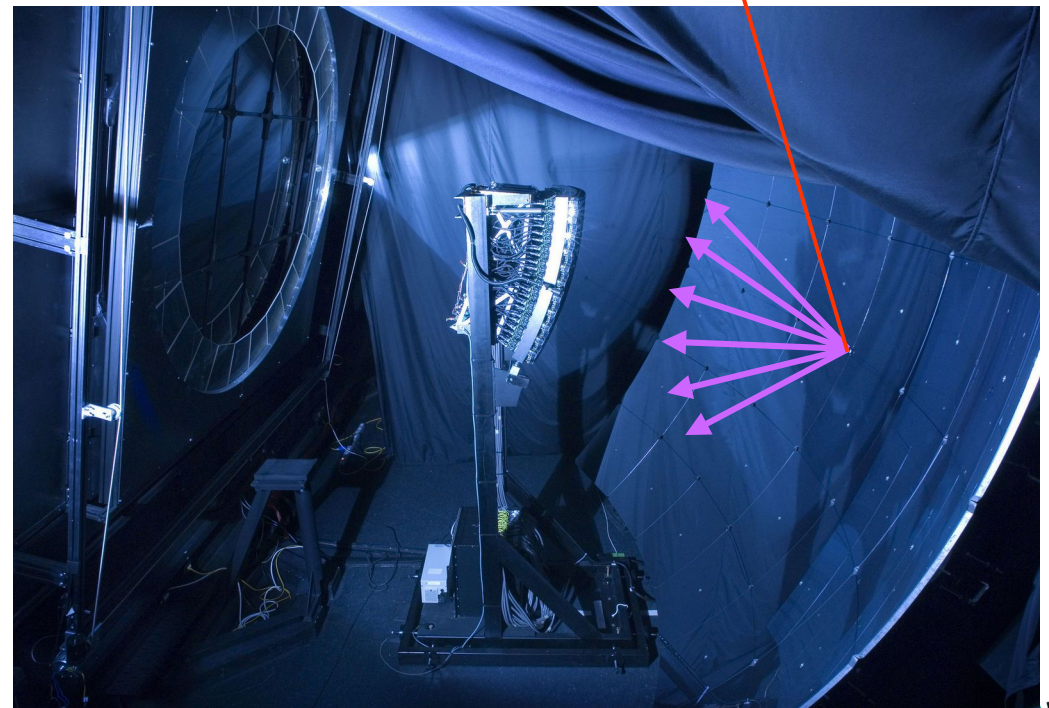
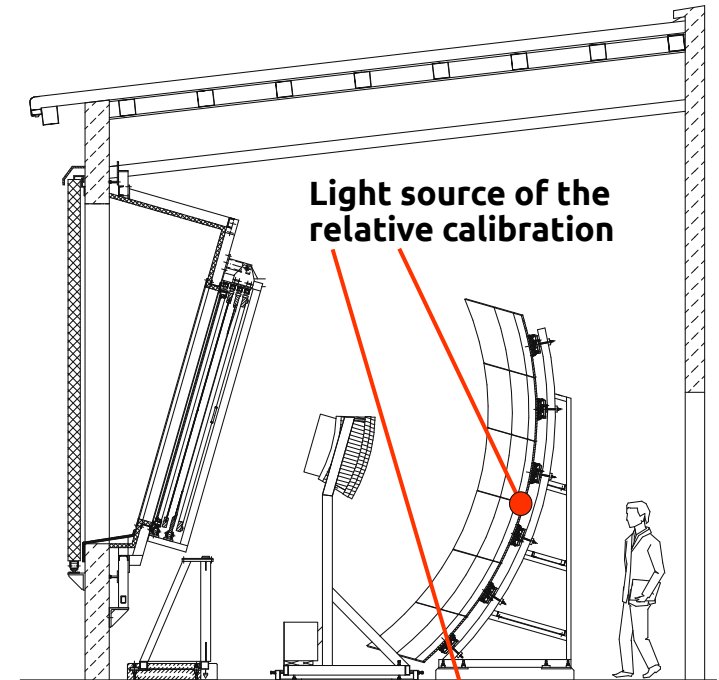
Current Absolute Calibration



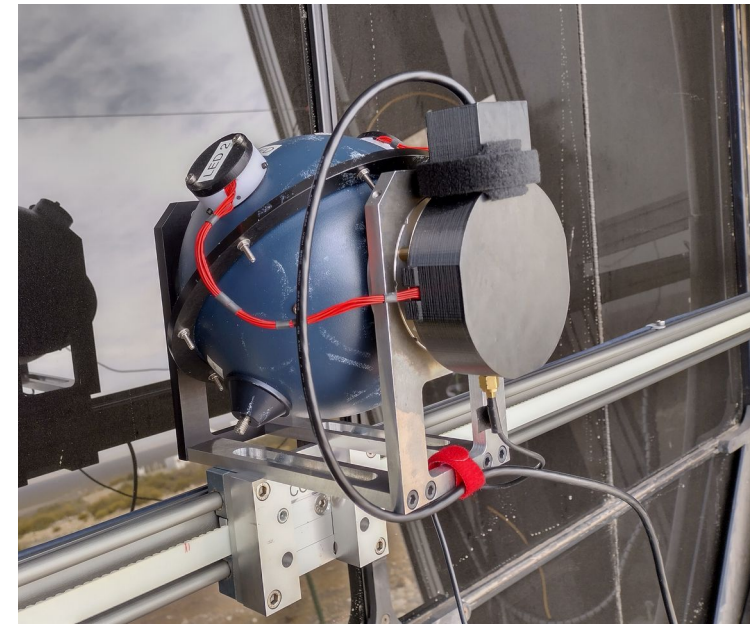
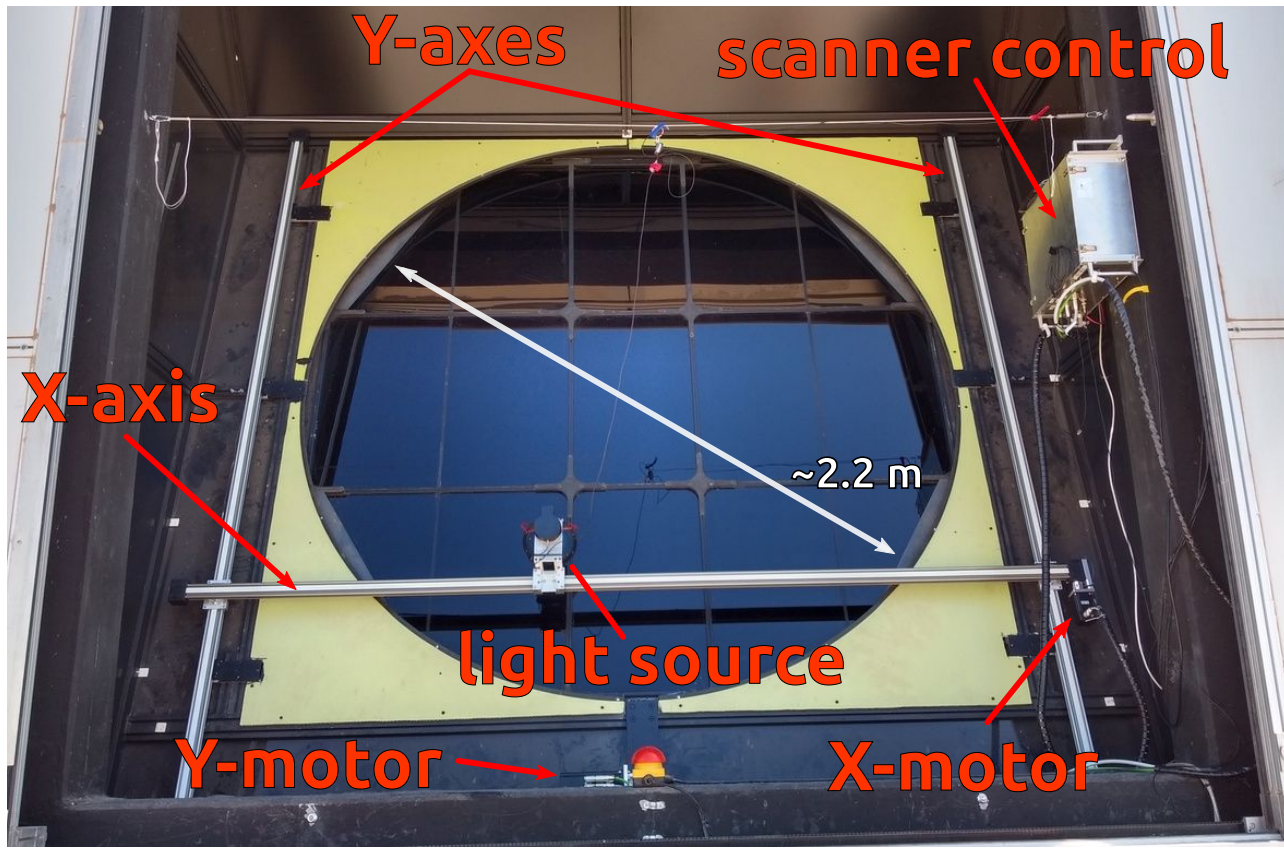
- Large-diameter light-source (*Drum*) covers entire aperture
 - **~9%** uncertainty on the absolute FD calibration
- **No drum measurements performed since 2013**

Relative Calibration

- Used to track the absolute calibration to each night
- Light source in the center of the mirror pointing towards the camera
- Performed at the start and end of each data-taking night
- **Only sensitive** to changes in **PMT camera**
- Blind to changes in filter or mirror
- **CalA tacking** uses the results from the **2010** drum campaign



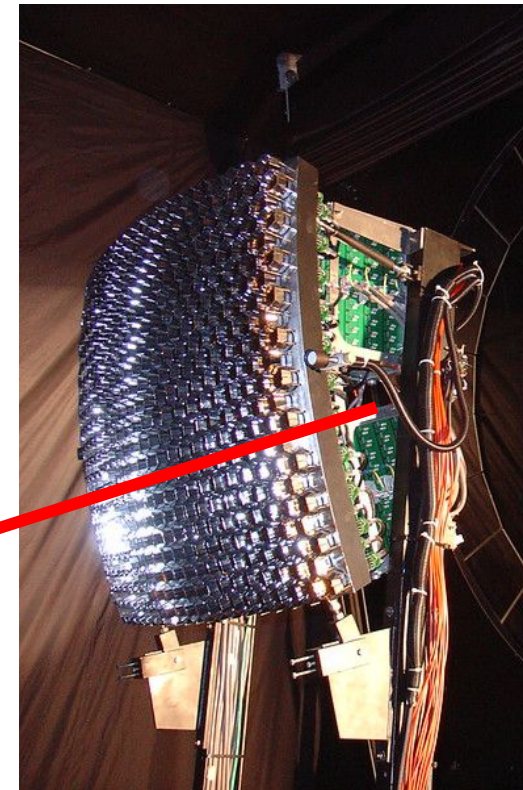
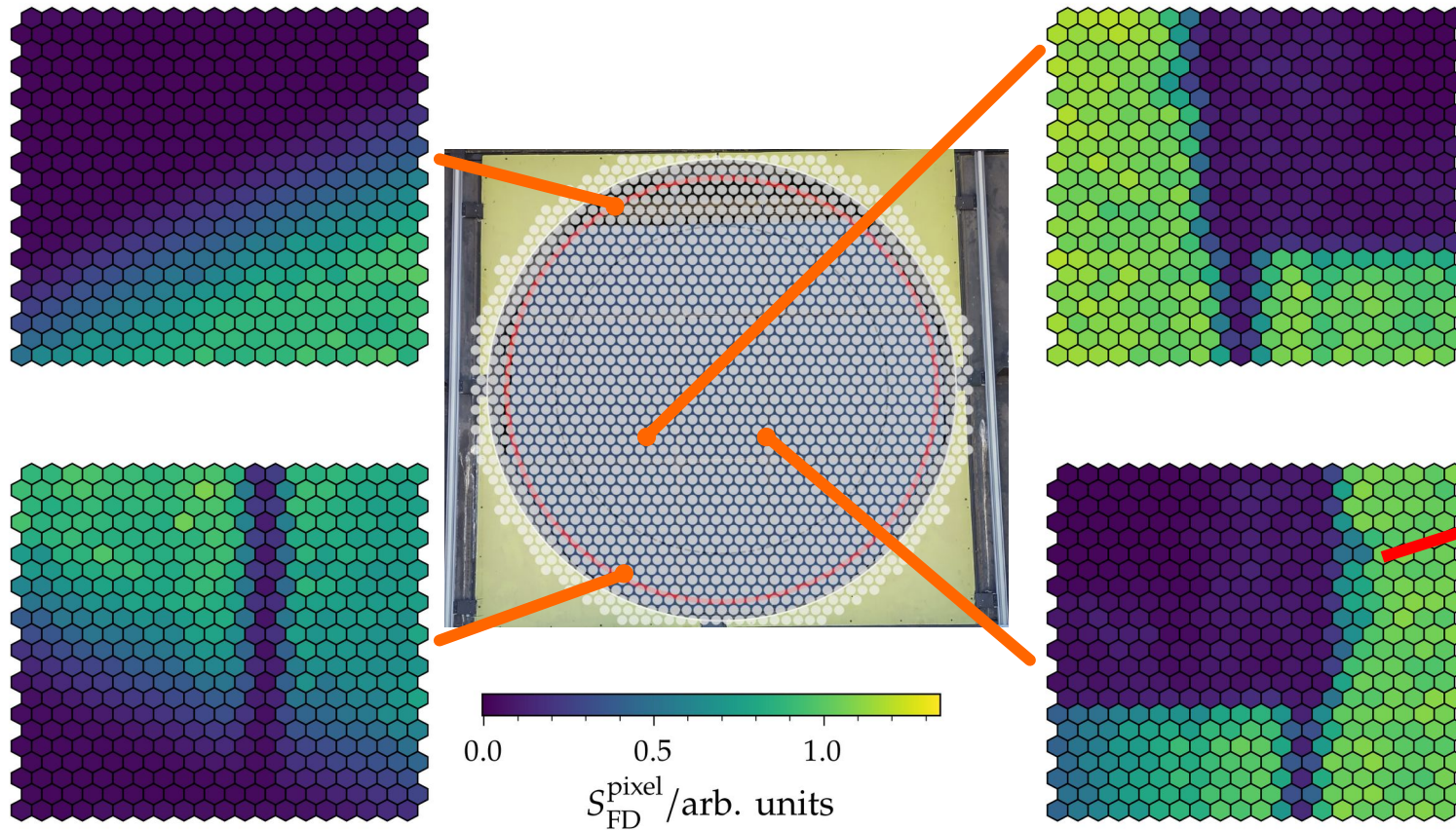
The XY-Scanner



- Systems installed on all 27 FD telescopes
- Light source scanned across the aperture
- Entire camera readout for each flash of the light source (limits to ~1Hz)
- Depending on position density
 - Up to 1700 positions (6cm steps)
 - 3-6 telescope per night

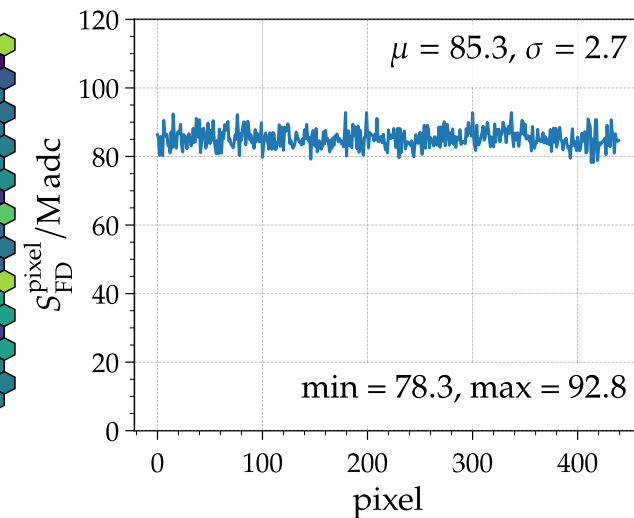
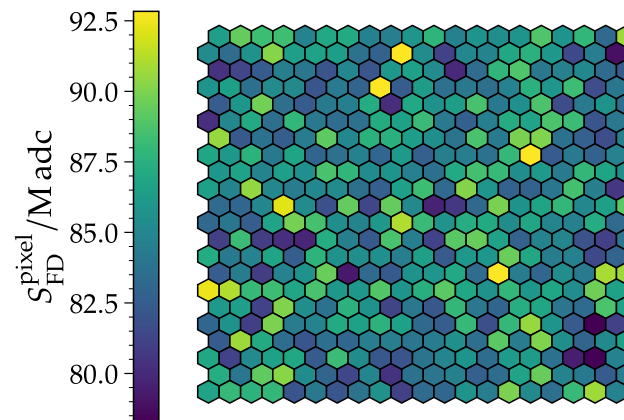
- Integrating spheres
 - UV-LED (365 nm)
 - Fits into carry-on luggage
 - 5.08 cm exit port
 - Internal reflections lead to Lambertian emission
- Directional emission profile measured
- Absolutely calibrated

XY-Scanner Events



Mimic illumination of the entire aperture as sum of individual light source positions

$$S_{FD}^{pixel} = \sum_{P_{xy}} S_{pixel}^{ADC}(P_{xy})$$



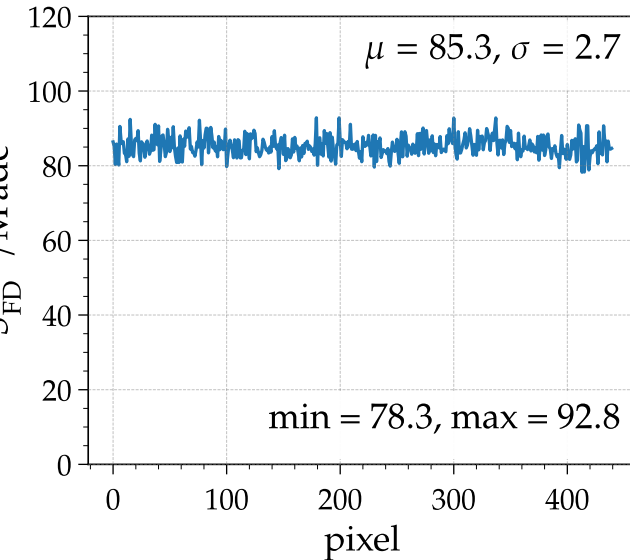
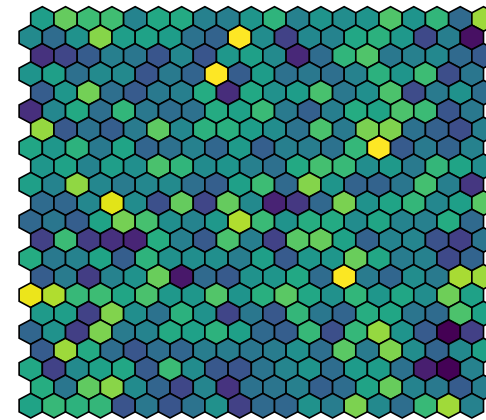
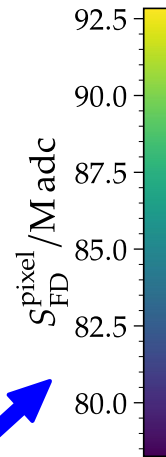
Cross Calibration Method

- XY-Scanner light source is stable
- Photon signal in FD camera as sum over all positions and pixels

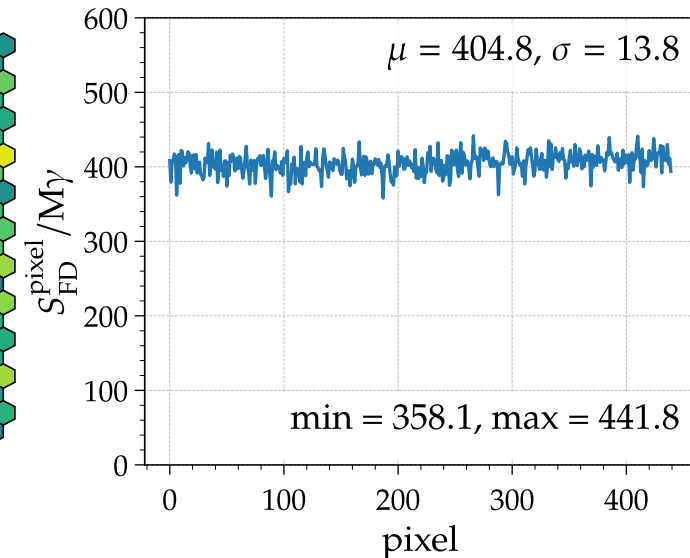
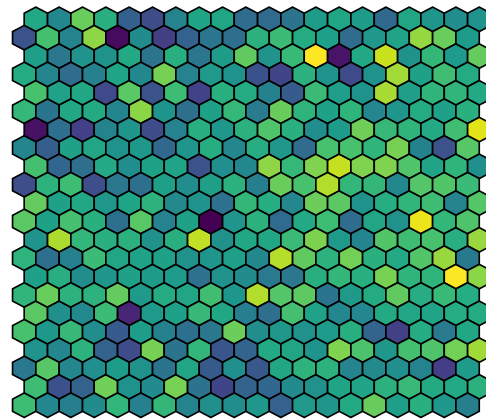
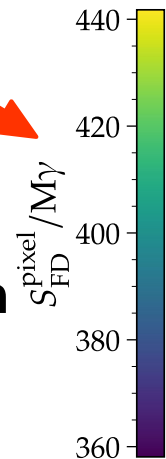
$$S_{\text{FD}} = \sum_{\text{pixel}} \left(C_{\text{pixel}}^{\text{std}} \sum_{P_{xy}} S_{\text{pixel}}^{\text{ADC}}(P_{xy}) \right)$$

- Cross calibration between telescope A and B

$$R_{AB} = \frac{S_A}{S_B}$$

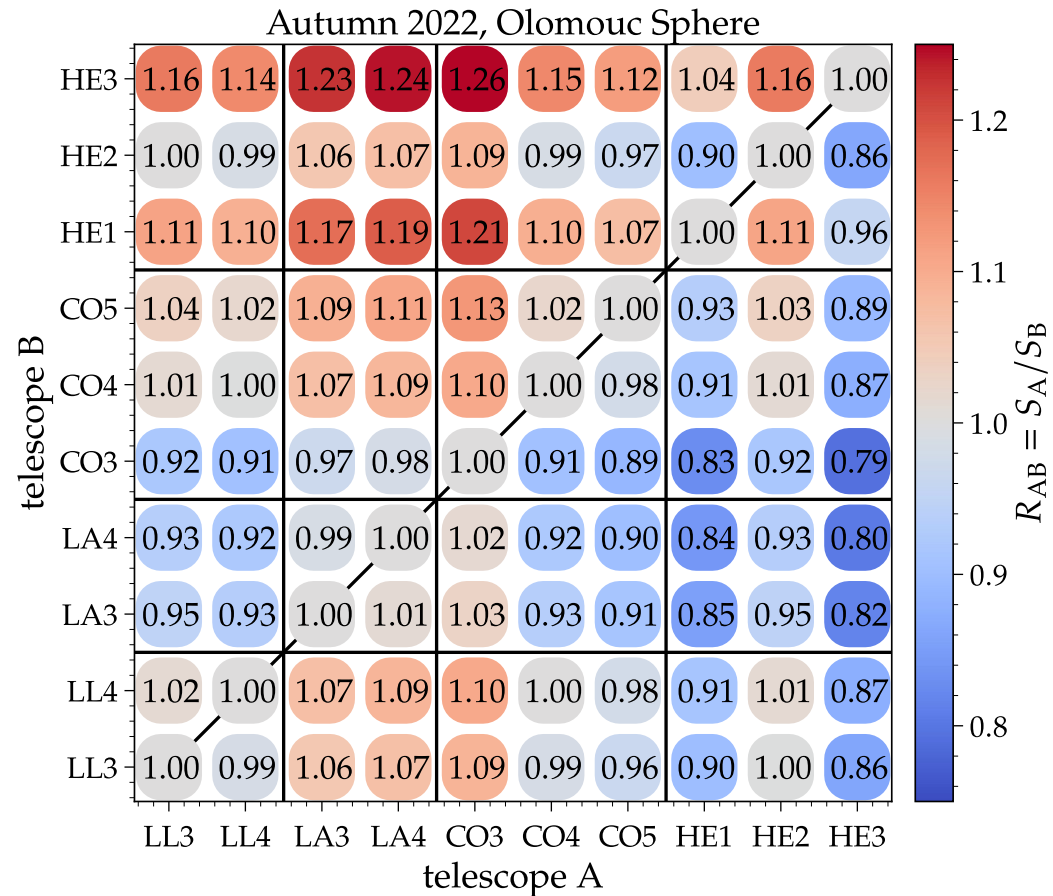
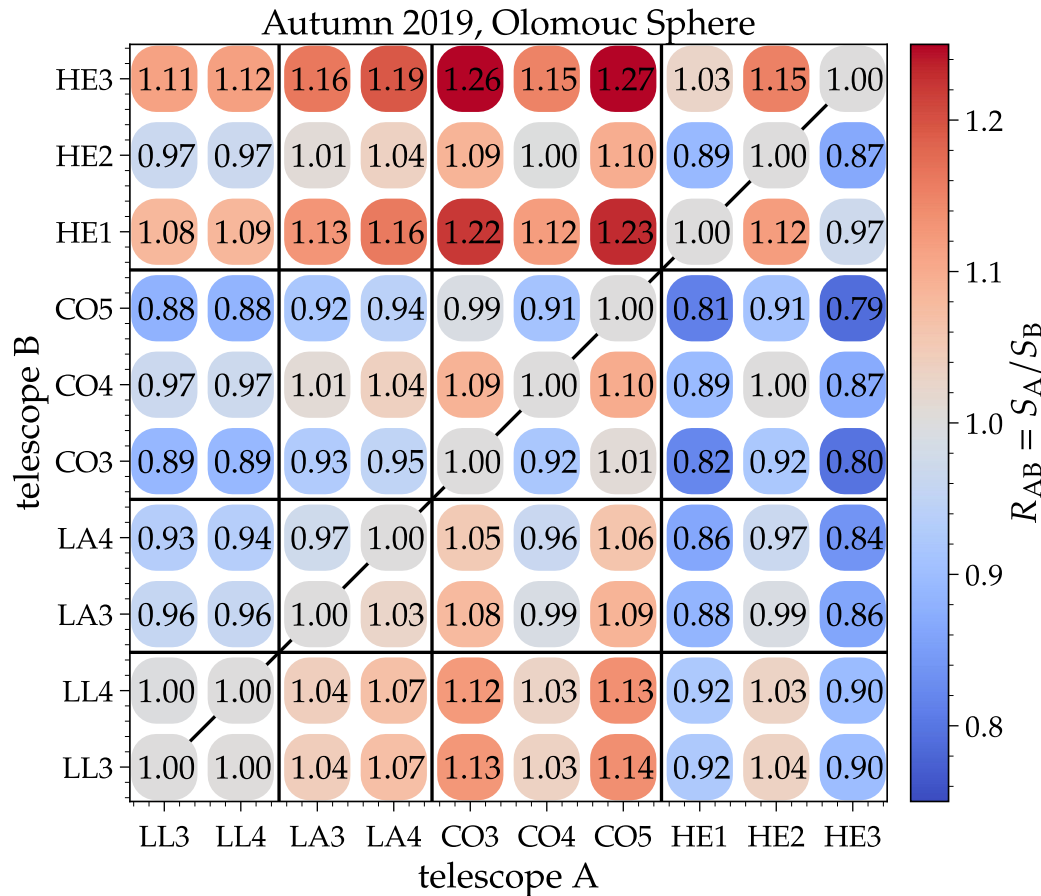


apply
CalA



Cross Calibration Telescopes

$$S_{\text{FD}} = \sum_{\text{pixel}} \left(C_{\text{pixel}}^{\text{std}} \sum_{P_{xy}} S_{\text{pixel}}^{\text{ADC}}(P_{xy}) \right)$$



- Smaller ratios for telescopes within one FD site
- Largest difference observed for the HEAT telescopes
- Autumn 2022 analysis uses preliminary CalA

Cross Calibration He & Co



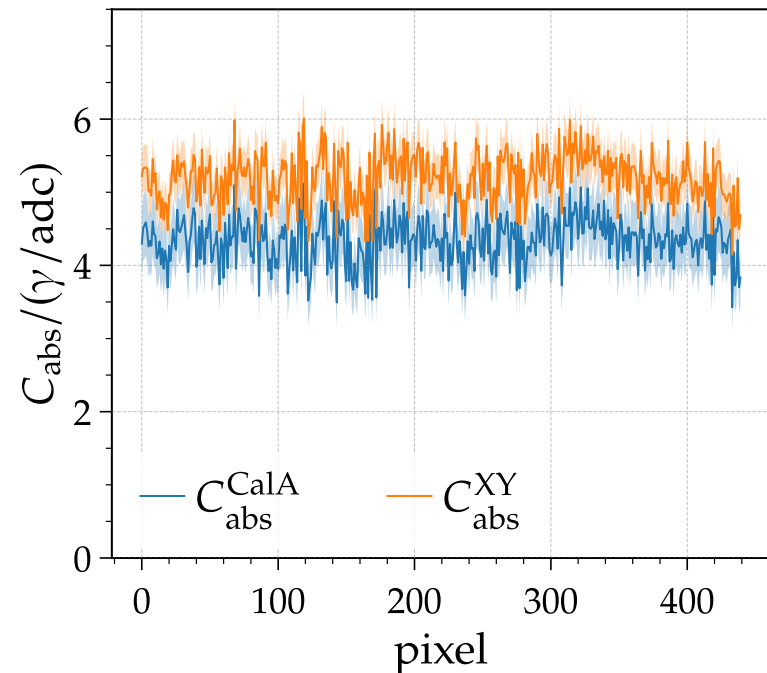
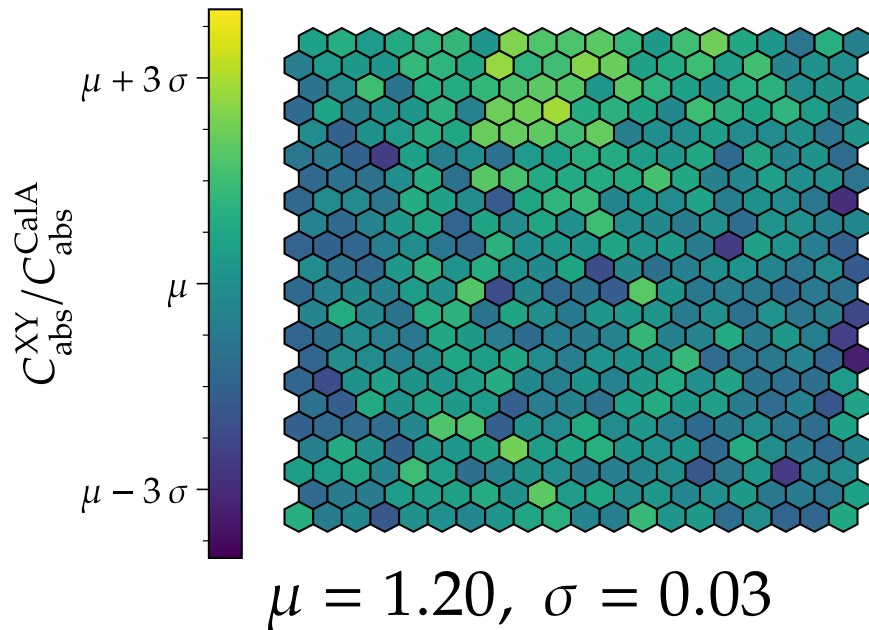
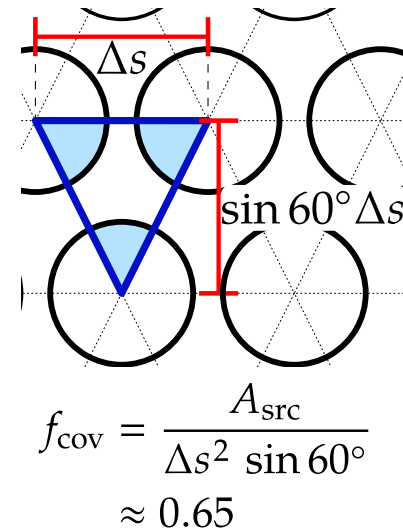
- **FD_TelRelCalib_0_A (v0_AS)**
 - Only available until 2021
- Agreement for both 2019 XY-Scanner campaigns

Absolute Calibration of Telescopes

Lab measurements Simulations Geometry of scanning grid

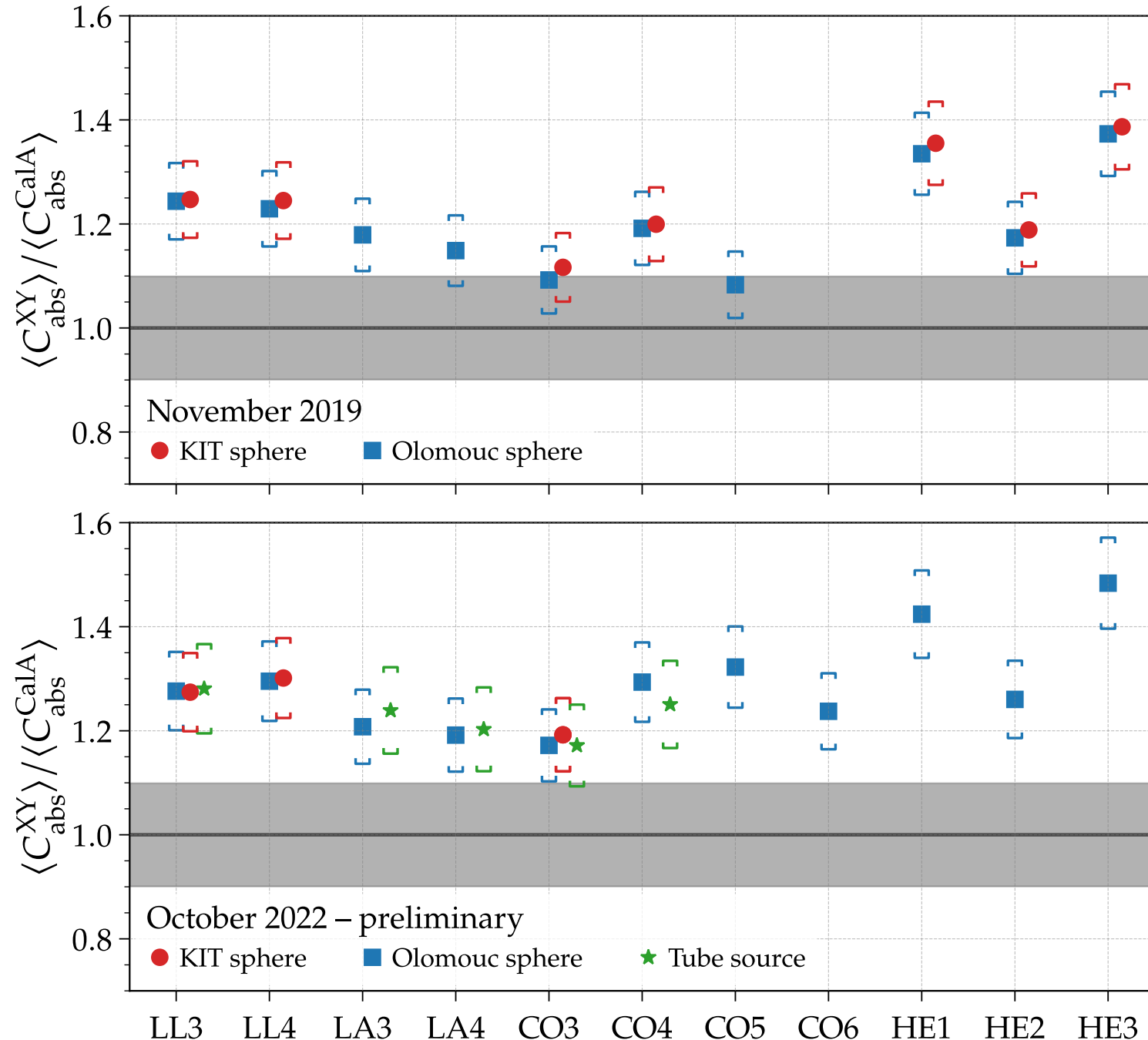
$$C_{\text{abs}}^{XY} = \frac{N_{\gamma}^{\text{pixel}}}{S_{\text{ADC}}^{\text{pixel}}} = \frac{L_{\text{src}} \xi_{\text{pixel}} c_{\text{pixel}}^{\text{halo}} f_{\text{cov}} A_{\text{aperture}} \Omega_{\text{pixel}}}{S_{\text{ADC}}^{\text{pixel}}}$$

FD measurement Telescope geometry (fixed values)

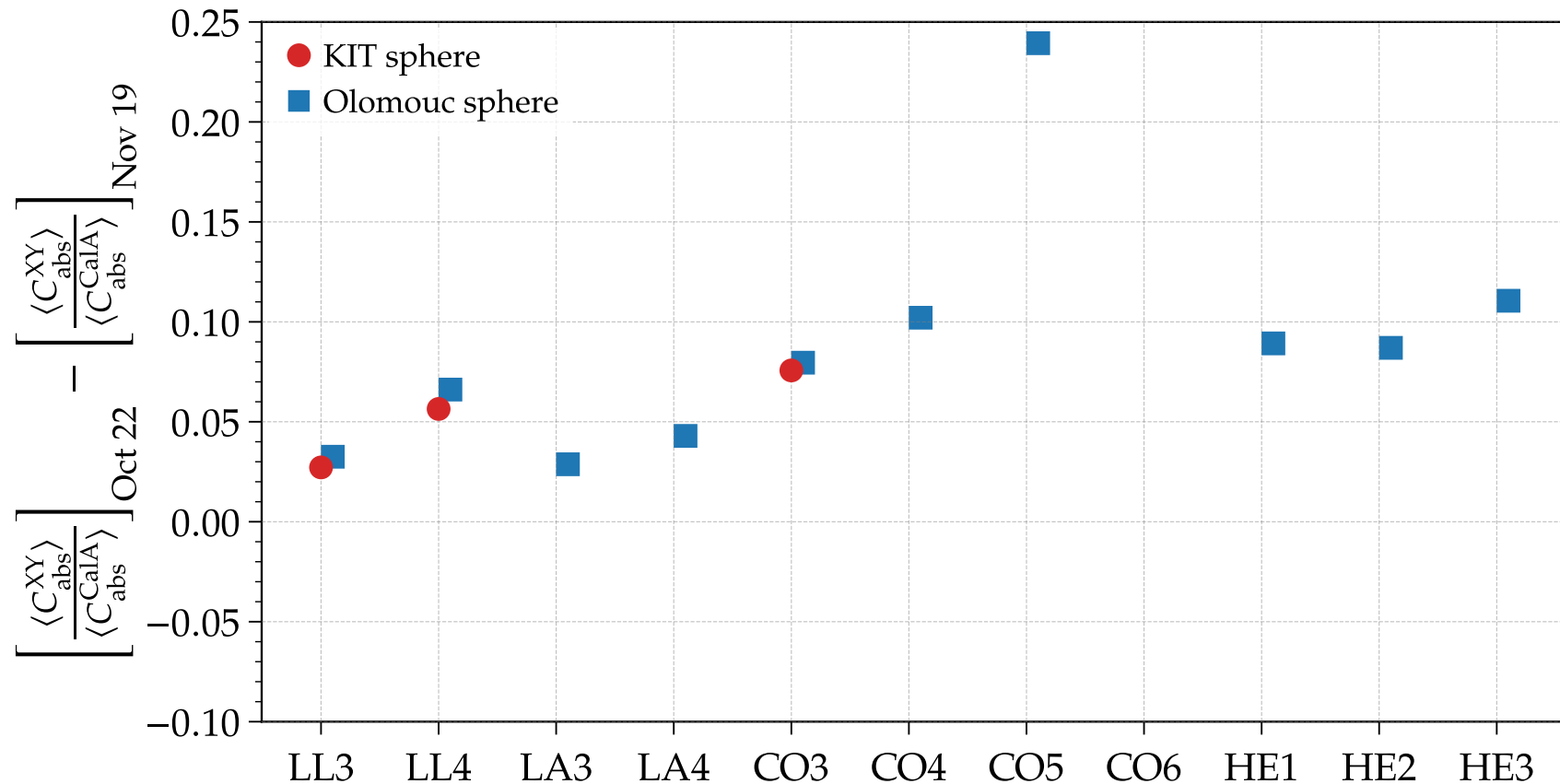


Absolute FD Calibration

- Calibration constant for different light source consistent
- Grey band current 9.9% uncertainty of FD calibration
- Brackets ~6% uncertainty of the XY-Scanner calibration
- ~20% difference
- Even larger for 2022



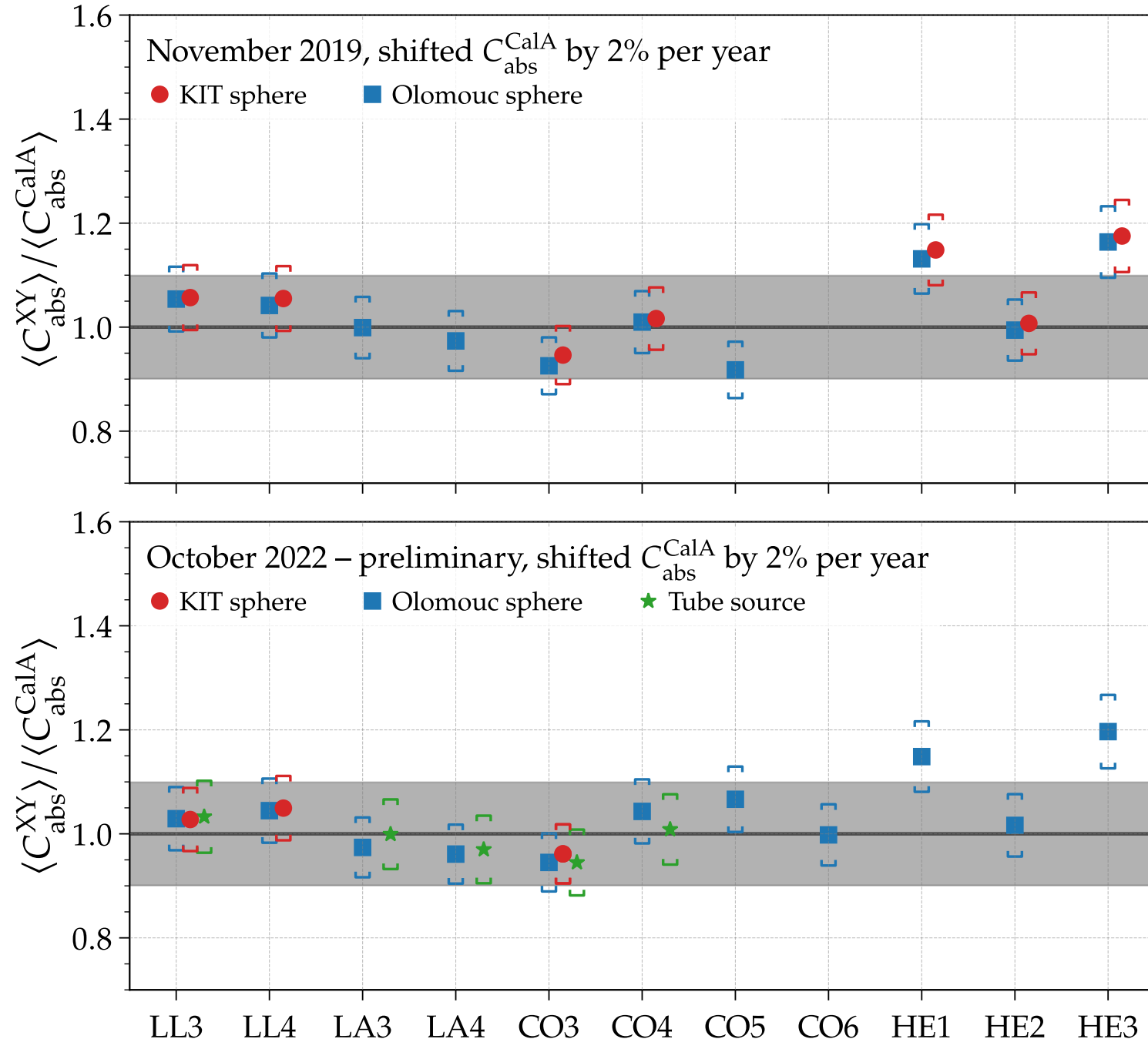
Difference 2019 - 2022



- Difference between 2019 and 2022 on average ~8%
 - Excluding CO5: ~6.6%
- Drift of ~2% per year

Drift of CalA

- **Relative calibration (CalA) only sensitive to camera**
- **Include 2% drift per year in CalA to account for telescope changes since 2010**
- **XY-Scanner and CalA agree for most telescope**



Summary

- **XY-Scanner measurements used to obtain cross calibration between FD telescope**
 - **Maximal ~15% difference between standard FD telescopes**
 - **~25% for the HEAT**
 - **HeCo results are in agreement with the NSB analysis**
- **Absolute calibration with XY-Scanner**
 - **Agreement for different light sources**
 - **~20% (2019) and ~25% (2022) difference to the standard calibration (Drum + CalA)**
 - **Including 2% per year drift of CalA brings calibrations in agreement**

Backup