Studying magnet-induced wire-bond oscillations for the ATLAS ITk Strip Detector

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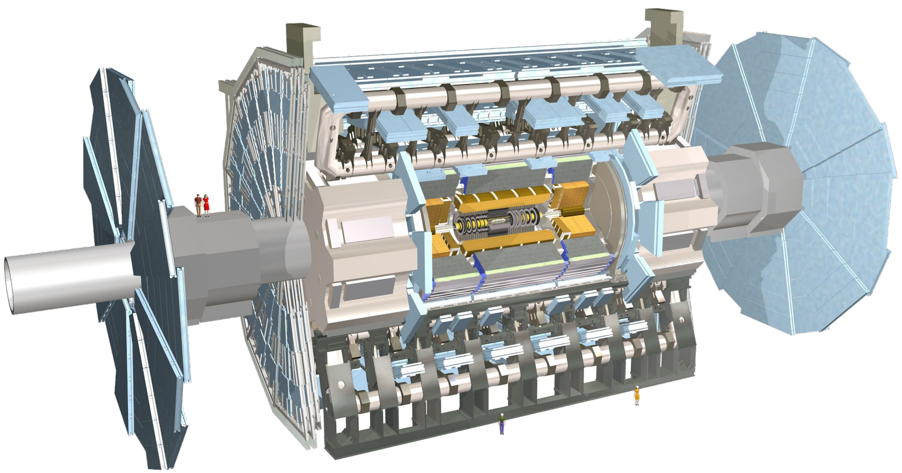
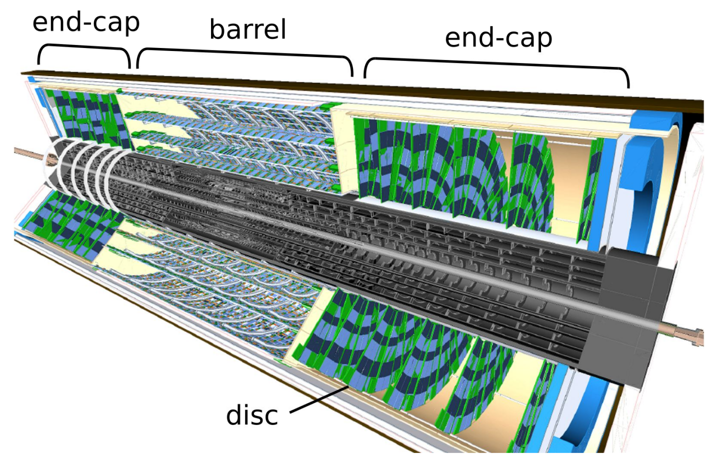
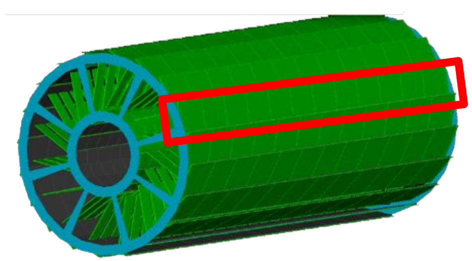
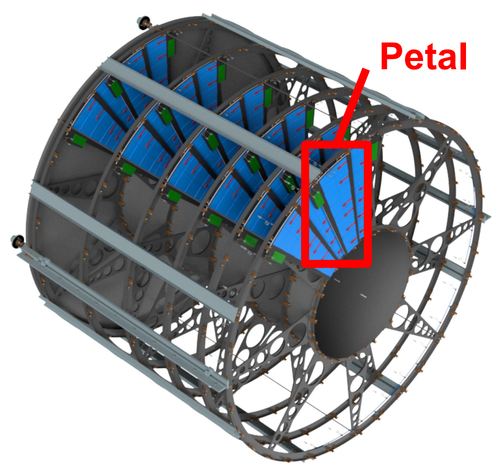
HL-LHC and the ITk

- Precision measurements of the Standard Model and the search for exotic particles require high integrated luminosity → HL-LHC
- ATLAS Inner Detector cannot handle radiation damage and higher fluences → Replacement Inner Tracker (ITk)



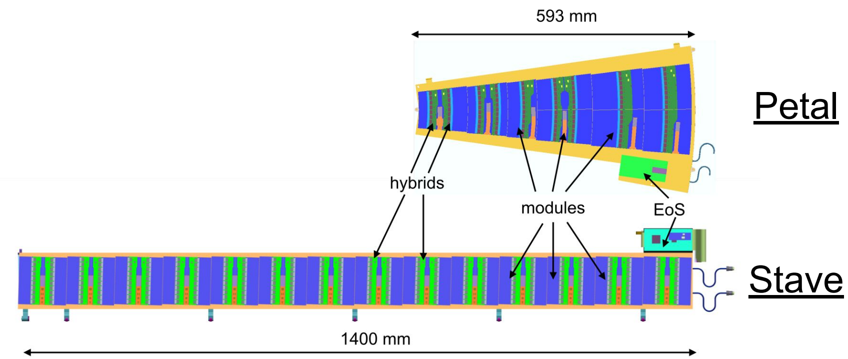


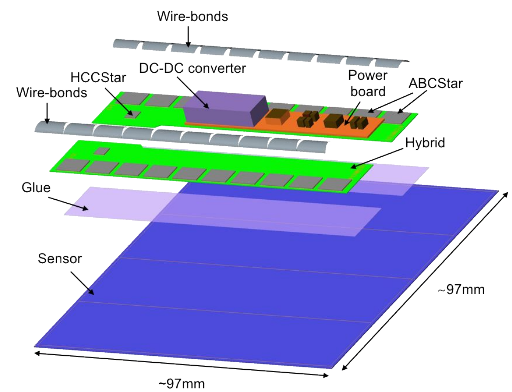


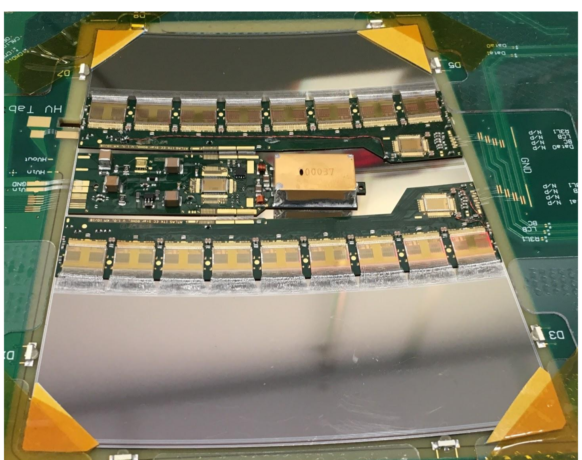


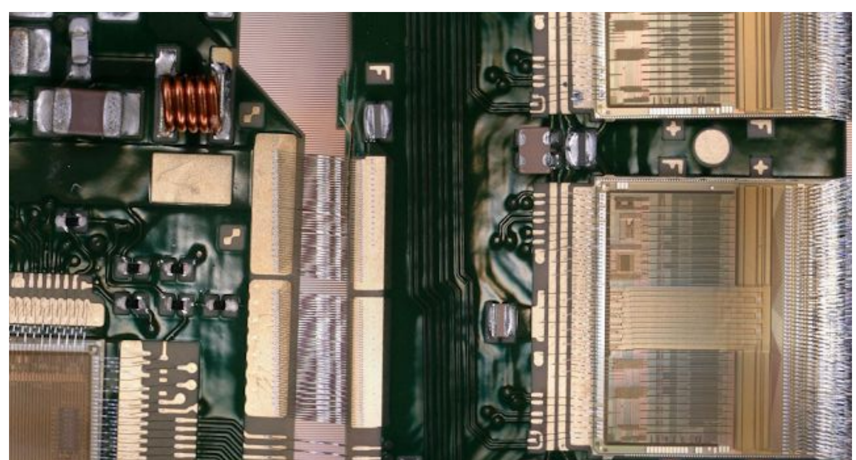
ITk Strip Module and Wirebonds

- ITk Strip Module = Sensor + Hybrid + Powerboard
- Hybrid = Printed Circuit Board (PCB) + read-out chip + input/output management chip
- Powerboard = PCB + Monitoring chip + voltage converter chip
- Wire-bonds = 25 µm thick aluminium wires

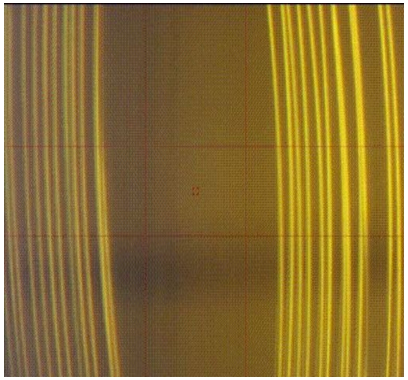




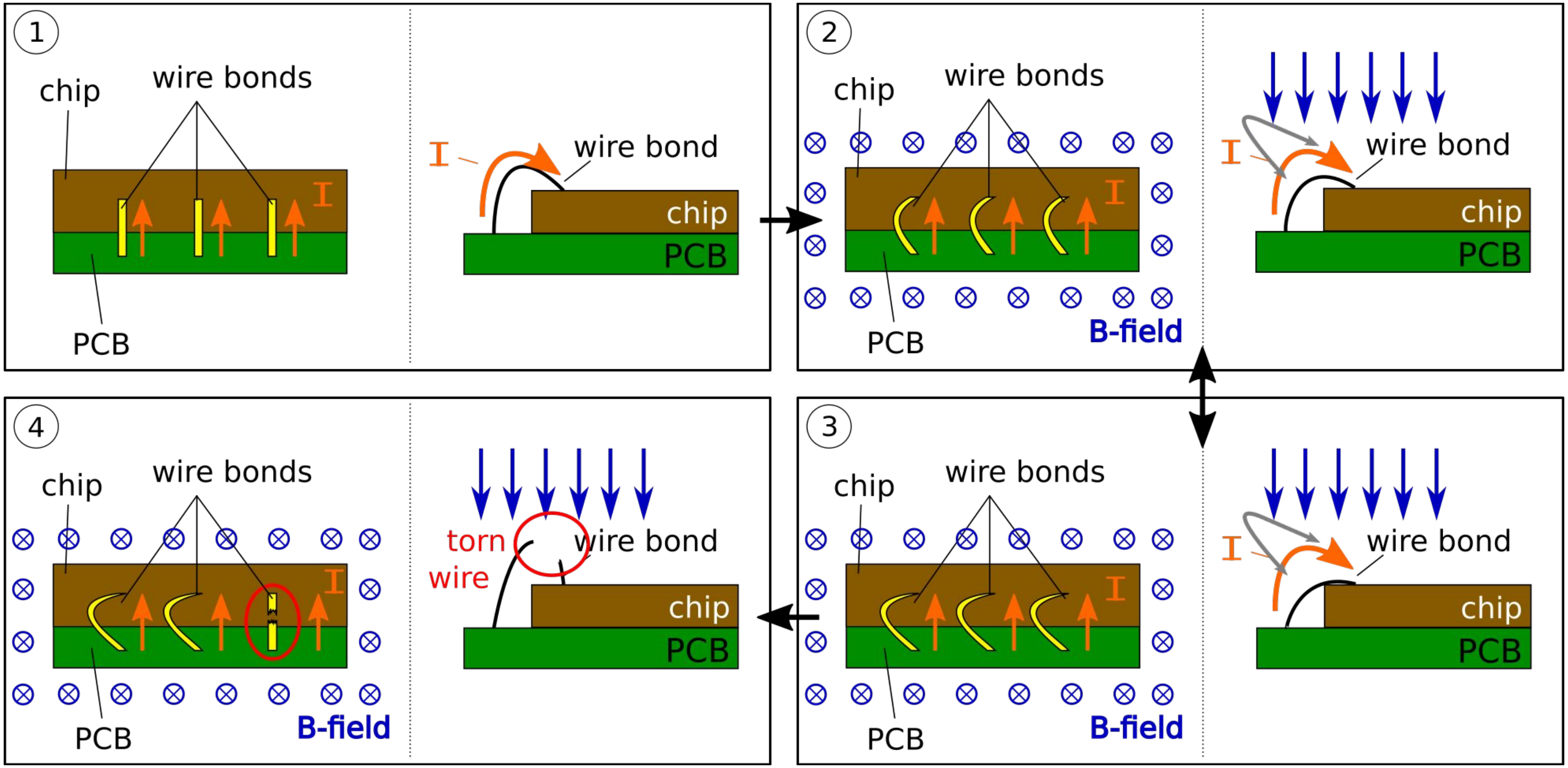




Wire-bond Oscillations



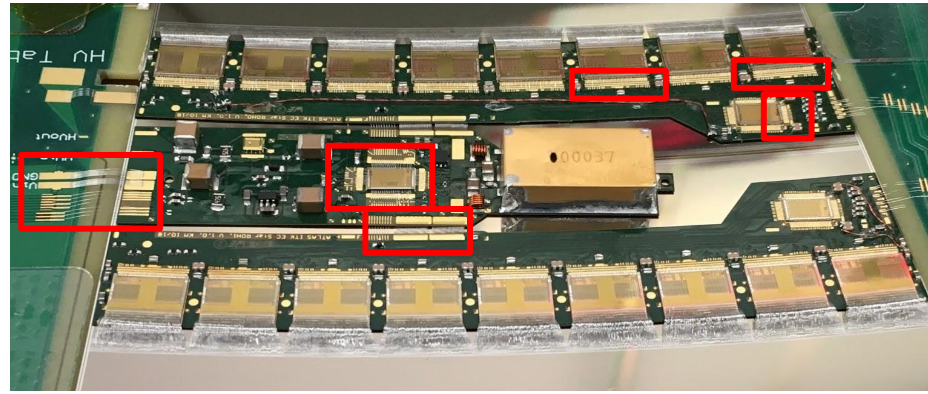
- Currents in wire-bonds can make them oscillate in magnetic fields (e.g. CDF@Tevatron, DBM@ATLAS)
  → can be trigger frequency induced
- Typical resonance frequencies: O(10 kHz)

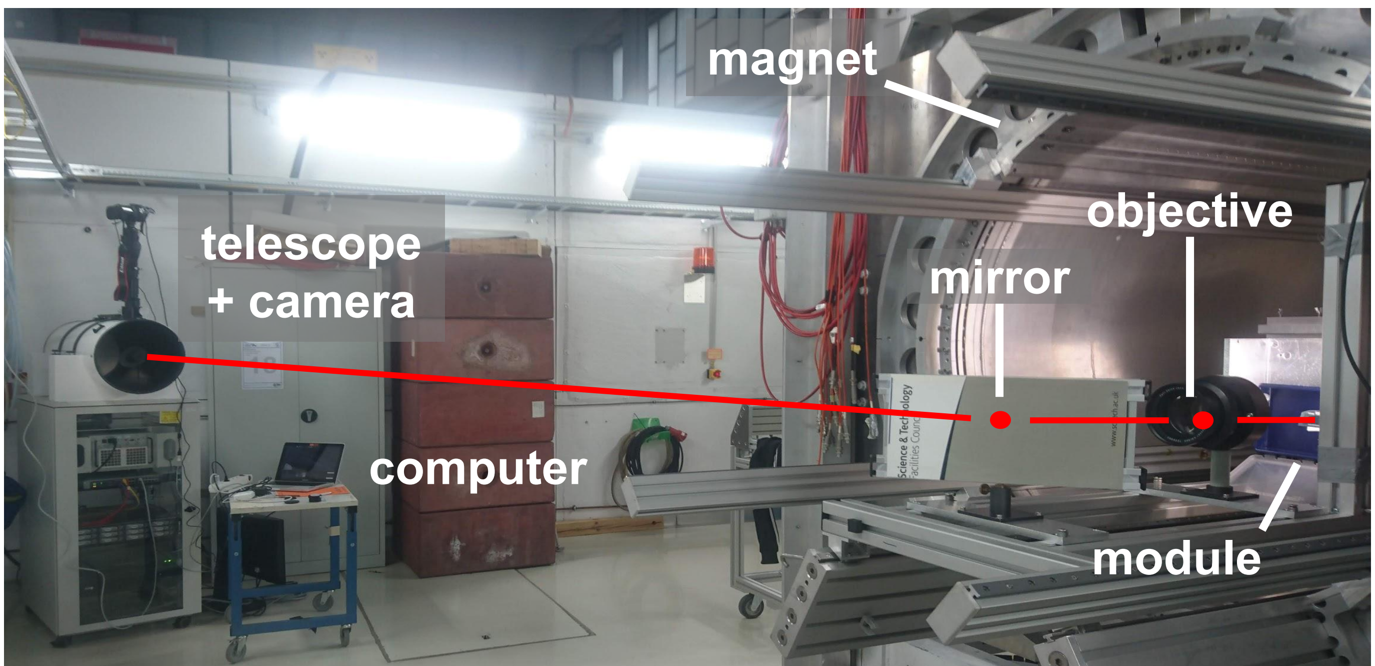


Wire-bond oscillation studies

- Studies in 1 T magnet at DESY Hamburg. Frequencies:
  - 1 - 350 kHz; steps 0.5 / 1 kHz
  - 0.1 - 35 kHz; steps 0.1 kHz

$$\nu_n = \frac{d}{l^2} \cdot \frac{\kappa_n^2}{8\pi} \sqrt{\frac{E}{\rho}}$$

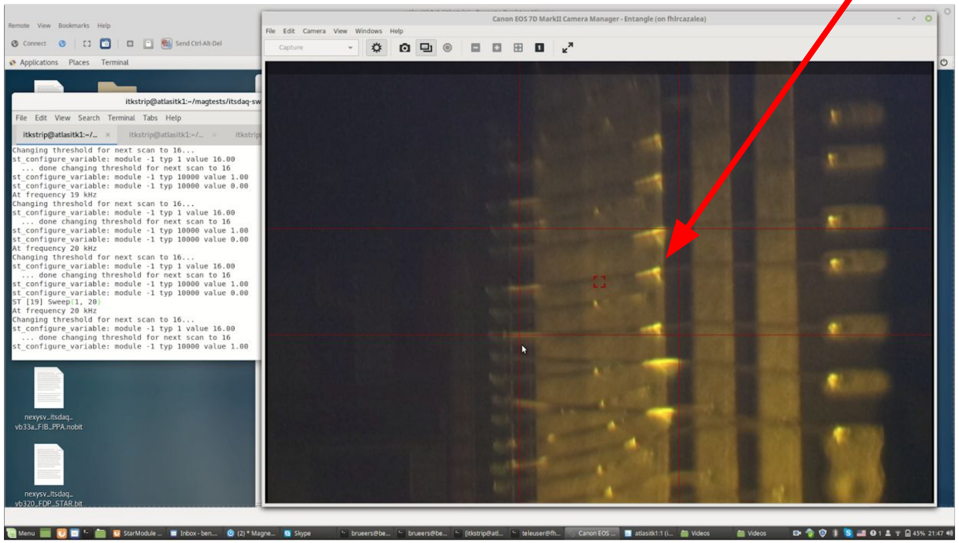


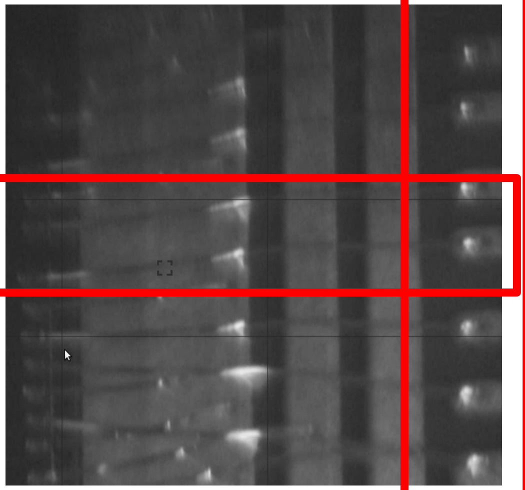


Broad steps per video frame

1. **Cropping**: Crop frame to region of interest (defined in first frame)
2. **Colorspace conversion**: Convert the frame to a black and white image

reflection from wirebond top



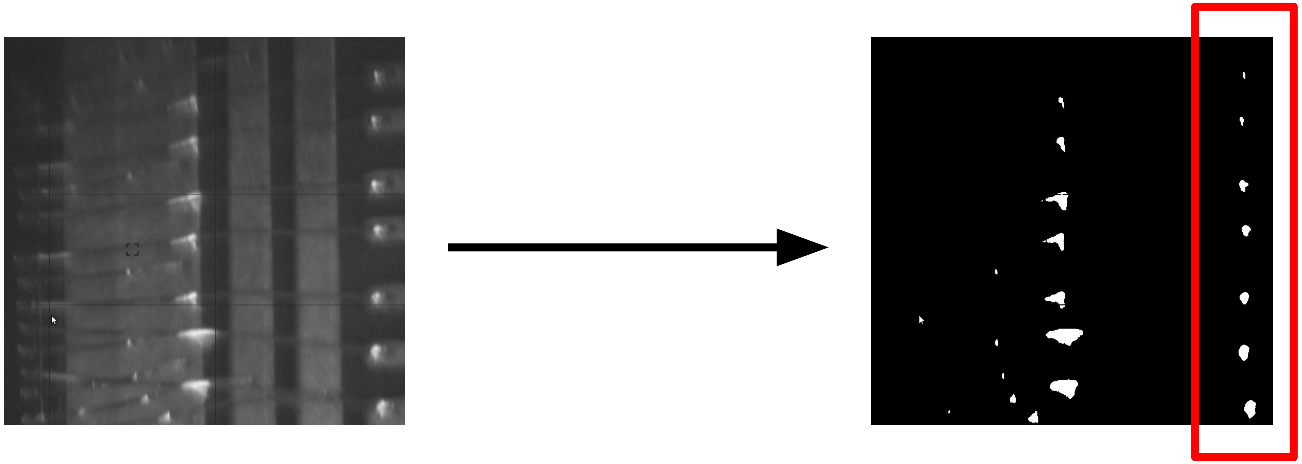


These are the wire-bond feet.
They will act as reference later!

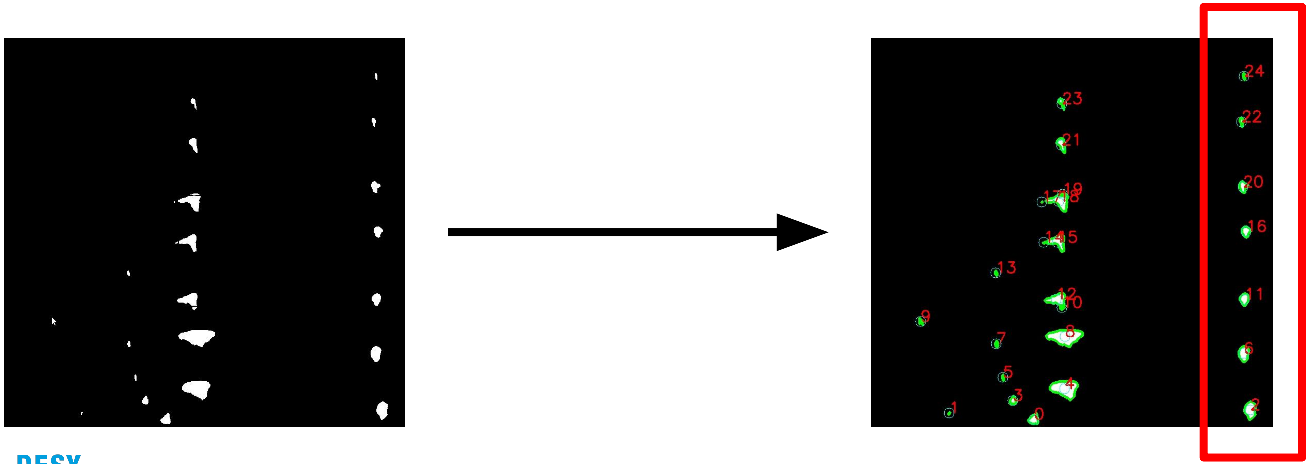
The wire-bond

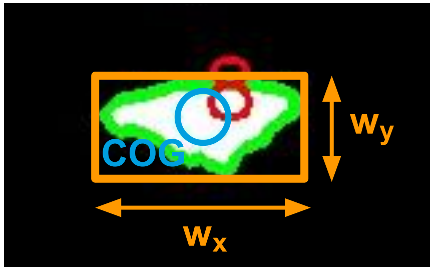
Broad steps per video frame

3. **Thresholding**: Apply a threshold, that means: all pixels of brightness below threshold are turned black, all pixels above threshold are turned white



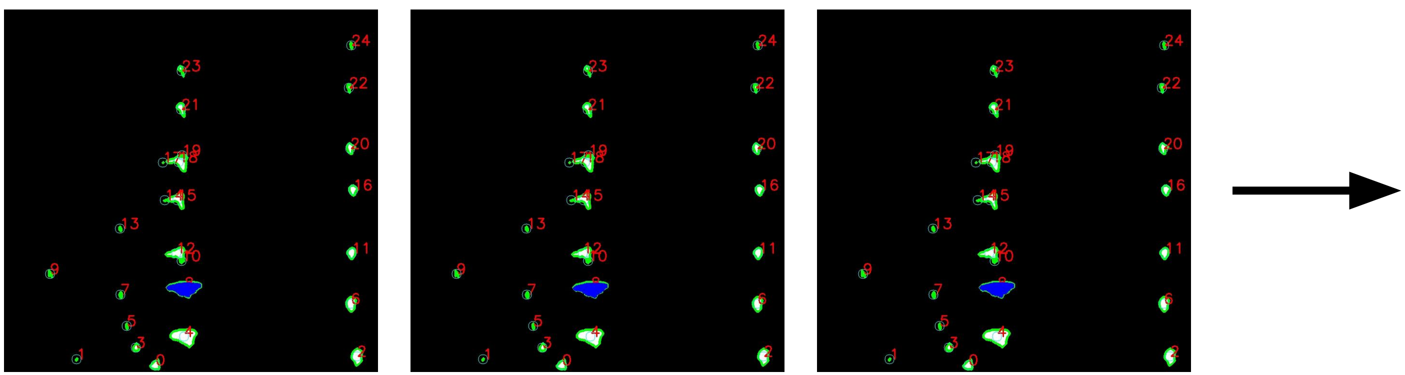
4. **Find contours**: Find the contours of the white objects in the image. Calculate their centre-of-"gravity" (COG), width in x- and y, area, average intensity, etc.





Broad steps per video frame

5. **Association of contours**:
    - COGs should not move due to oscillation, oscillation smears image (speed of camera << oscillations)
    - Compare contour COGs of each frame ←→ first frame
    - Associate, if distance(COG(this frame) - COG(first frame)) < 5



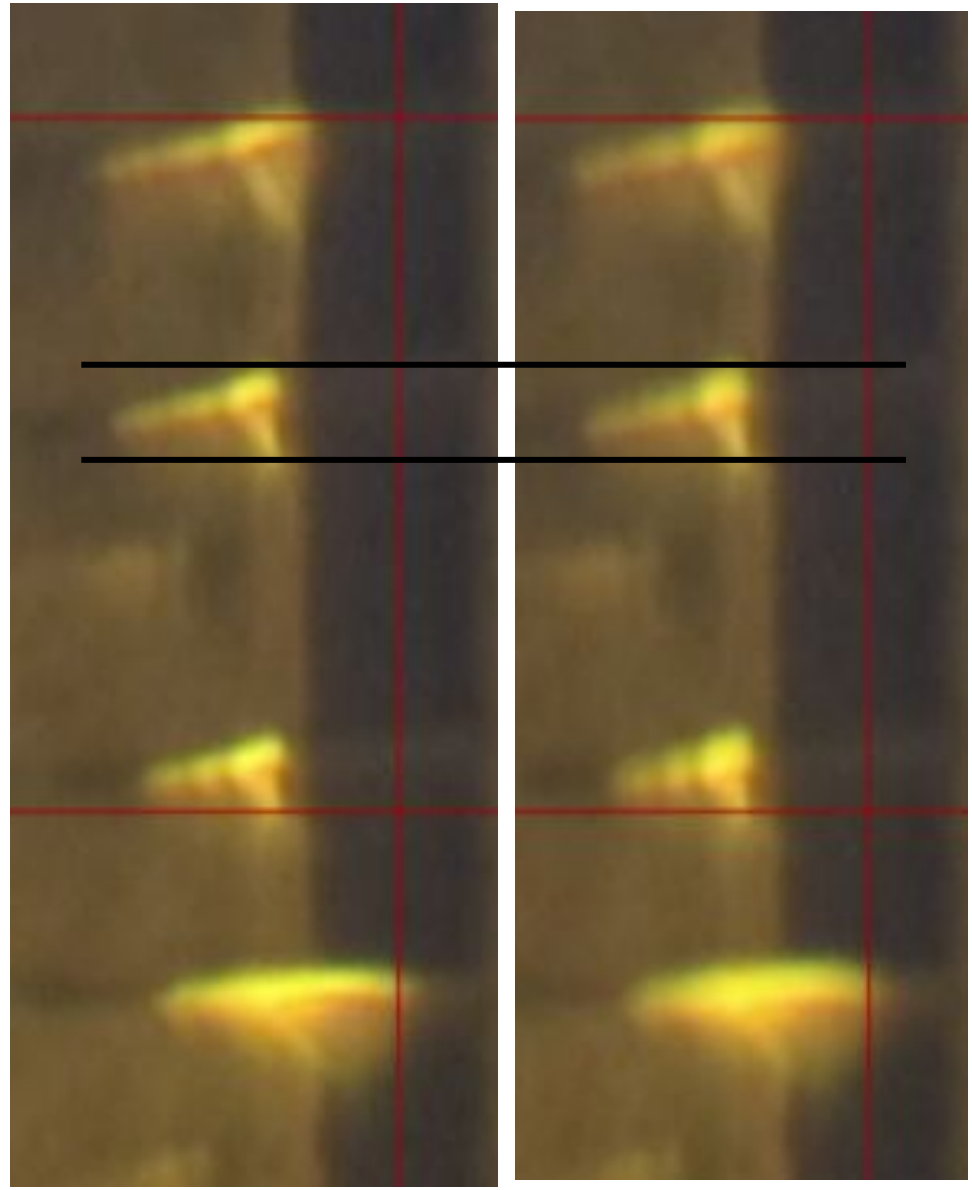
Contour 8

6. **Compare**: Compare properties of the different contours and their evolution.

Quantities to study

- Magnet vibrates at 2 Hz
- Change in y-width → too little luminescence
- Mean intensity → **considered for further study**
- Sharpness reduced → should be visible in 2D Fourier transform

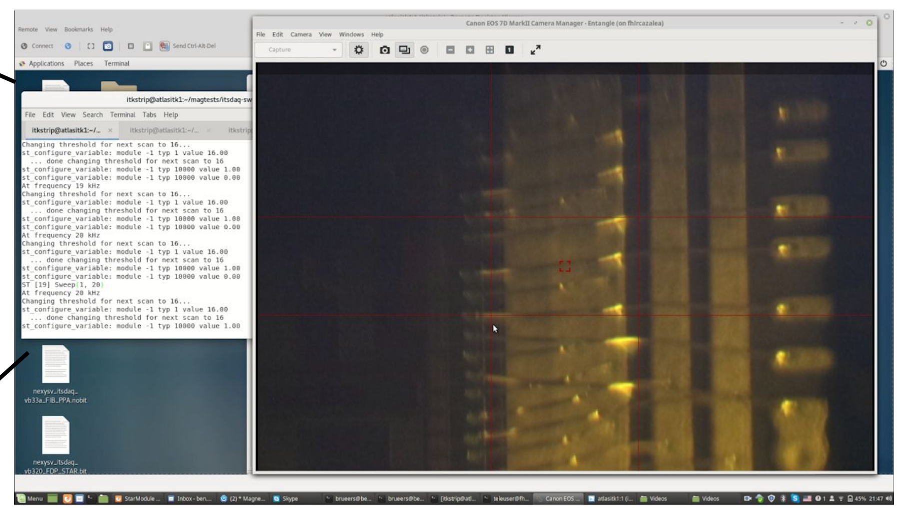
No vibrations | Magnet vibrations



Some notes for the upcoming results

- Only considering one particular video
- Scanned 20 kHz to 1 kHz, then 1kHz to 20 kHz in 1 kHz steps
  - No oscillations expected in this frequency range
  - Studied as proof-of-principle sample
- Use machine learning to identify the trigger frequency

$$\nu_n = \frac{d}{l^2} \cdot \frac{\kappa_n^2}{8\pi} \sqrt{\frac{E}{\rho}}$$

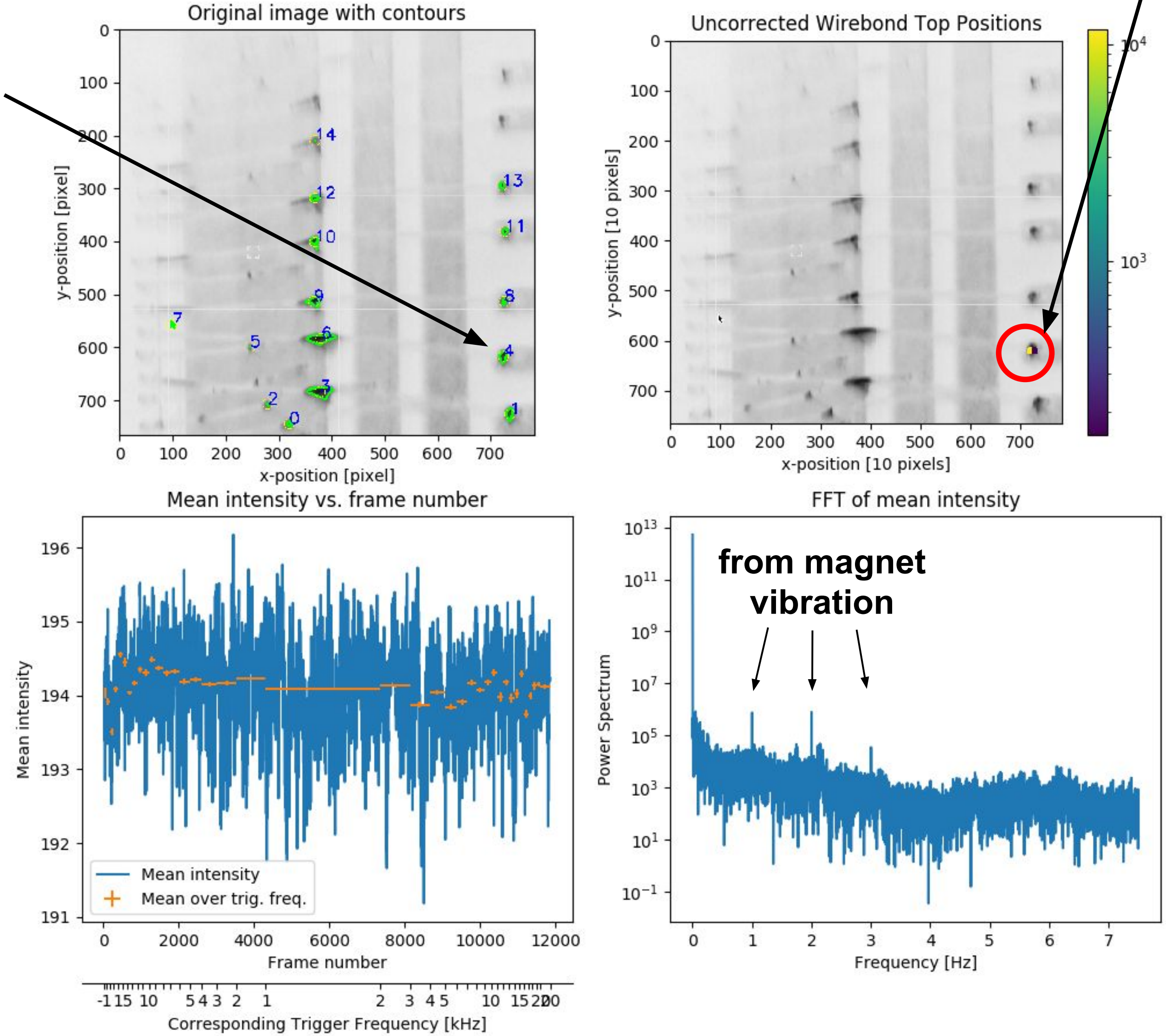


Mean Intensity: Contour 4 (non-moving foot)

contour4 (reference object)

Looking at this contour (from first frame)

2D histogram of associated contour COGs



Color: How often was COG found here.

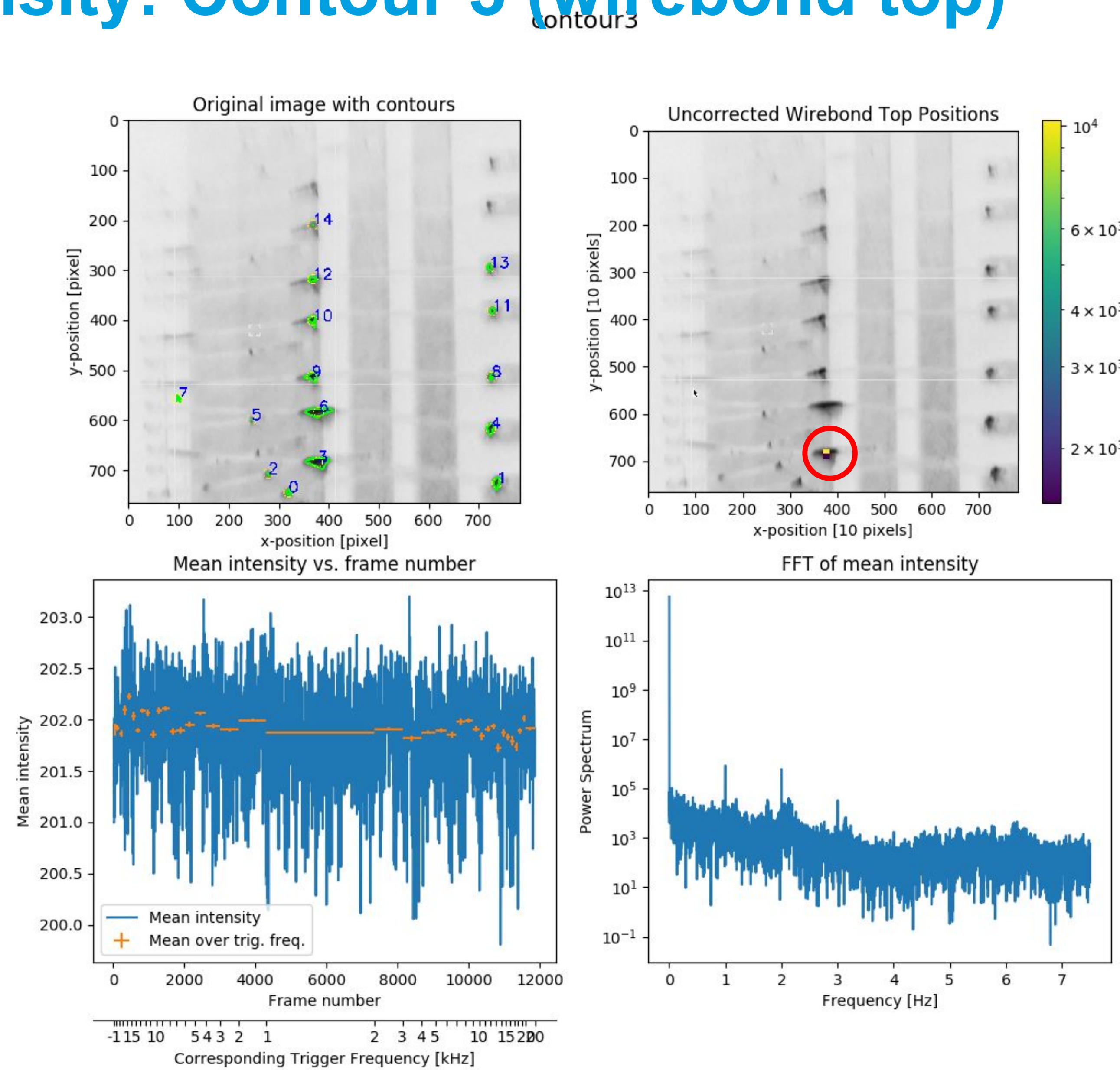
NOTE: 1 bin = 10 pixels

- **Mean intensity versus time**
- **Mean intensity per trigger frequency**
- **Errorbar = std. dev. / sqrt(n)**

Fourier transform of plot on the left

Mean Intensity: Contour 3 (wirebond top)

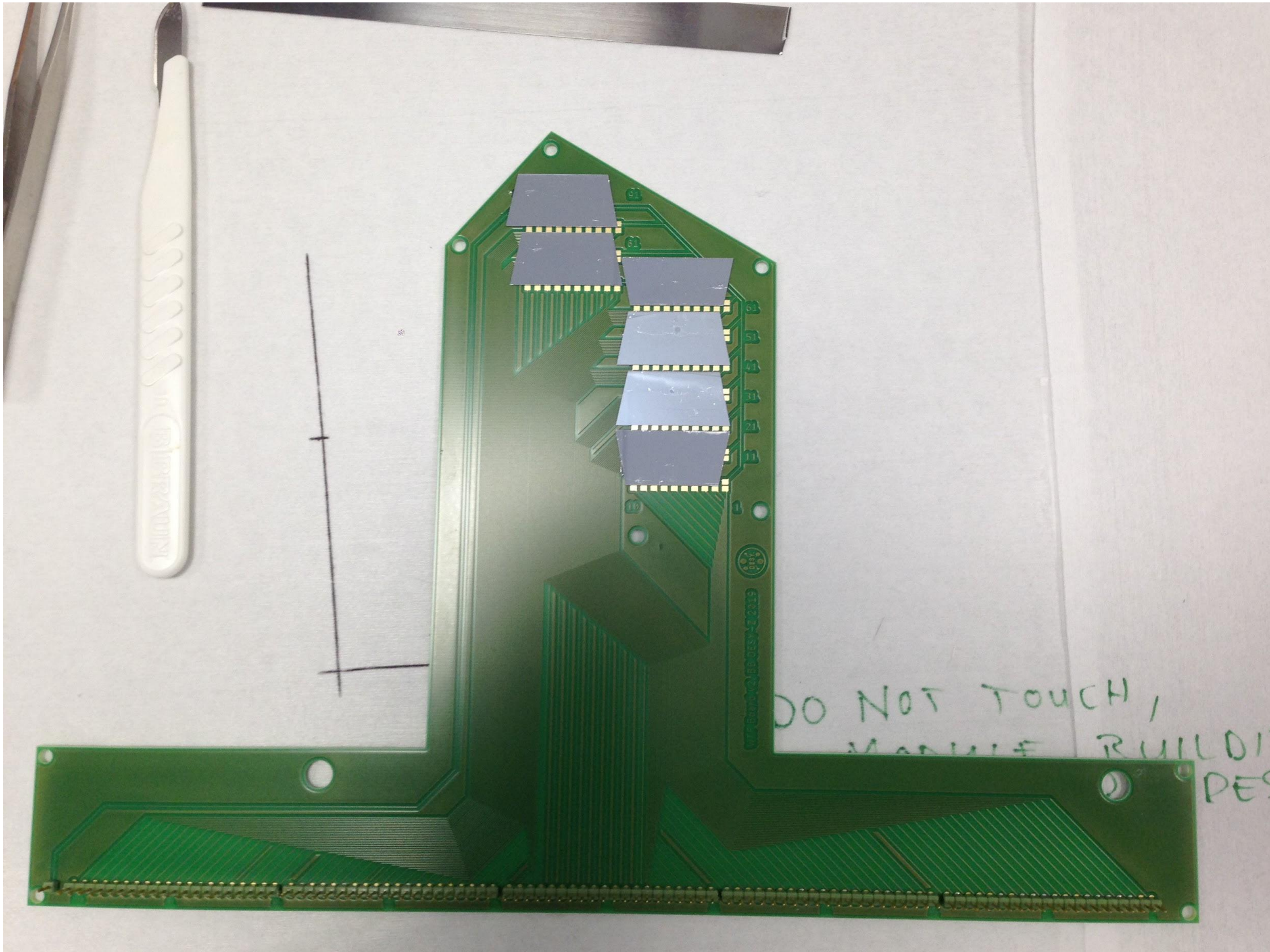
- Standard deviation of mean intensity similar to non-moving foot
- Expect **decrease** in mean intensity for a moving bond
- No obvious evidence for oscillation here
- This is true for all contours of this video



Summary

- Wirebond oscillations can damage detector
  - Studying them is important to understand
    - General sensitivity to the magnetic field
    - Dangerous trigger frequencies
- 1 module, 1 week, 1 T magnet, 0.1 kHz - 350 kHz → No damage observed
- First video without expected oscillations analysed → No indications for oscillations
- Next steps:
  - Analyse longer videos with frequencies in dangerous regions. Oscillations visible?
  - Repeat test in 2 T magnet
  - Try to investigate resonance frequencies more precisely using a dedicated setup

WTF v2 ASIC Emulator (WTFv2AE)



Thank you

Backup slides

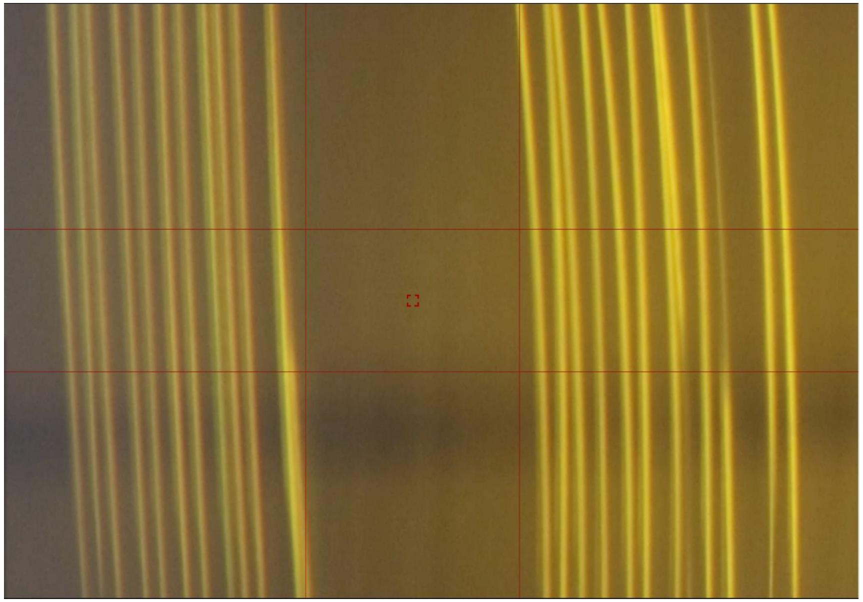
Wirebond potting

- If current too high/frequencies as resonance too broad or dangerous, wirebonds have to be protected against oscillations
- Done, by covering wirebonds in glue, called “wirebond potting”
  - Also prevents corrosion of wirebonds by humidity
- Drawbacks: usually the glue touches the PCB
  - If a module is under mechanical stress, the glue can lift off wirebonds from a PCB and destroy all electrical connections → not desired

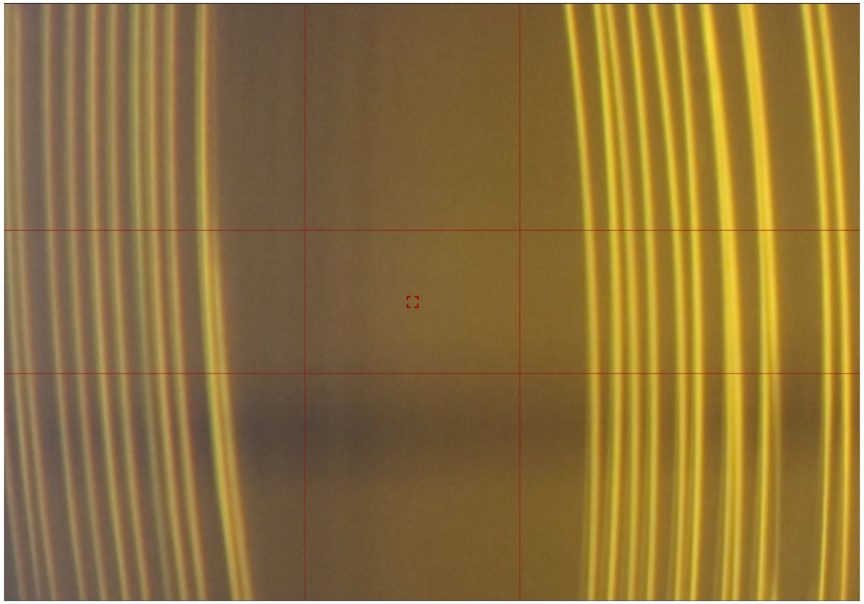
Movement of wirebonds by magnet

Testframe to powerboard wirebonds

Power OFF



Power ON

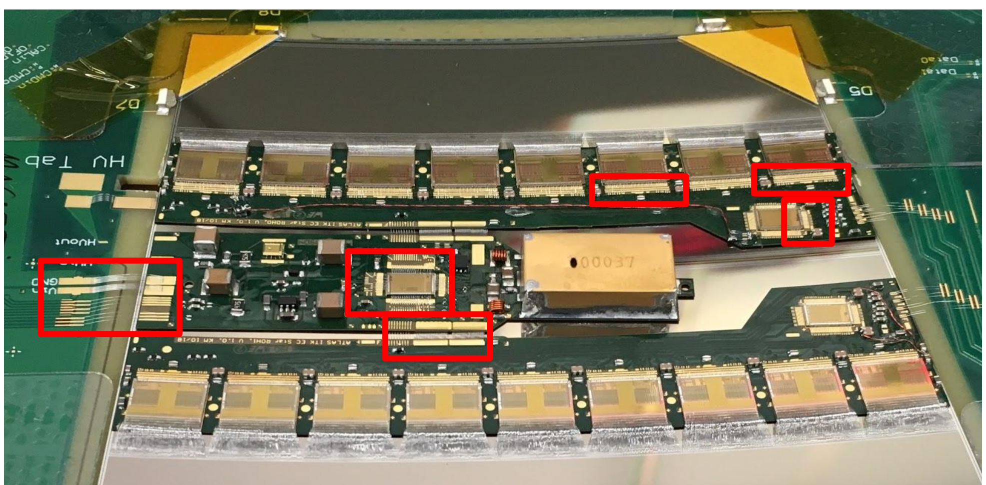


More on the setup

- Triggers to module generated by frequency generator
- Expected resonance frequencies estimated by length of the wirebonds ([formula by Thomas Lohse])

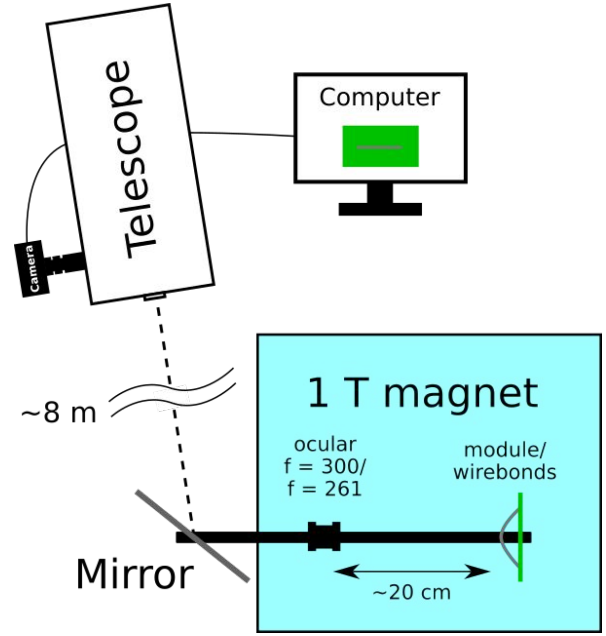
$$\nu_n = \kappa_n^2 \frac{d}{8\pi\ell^2}\sqrt{\frac{E}{\rho}}$$

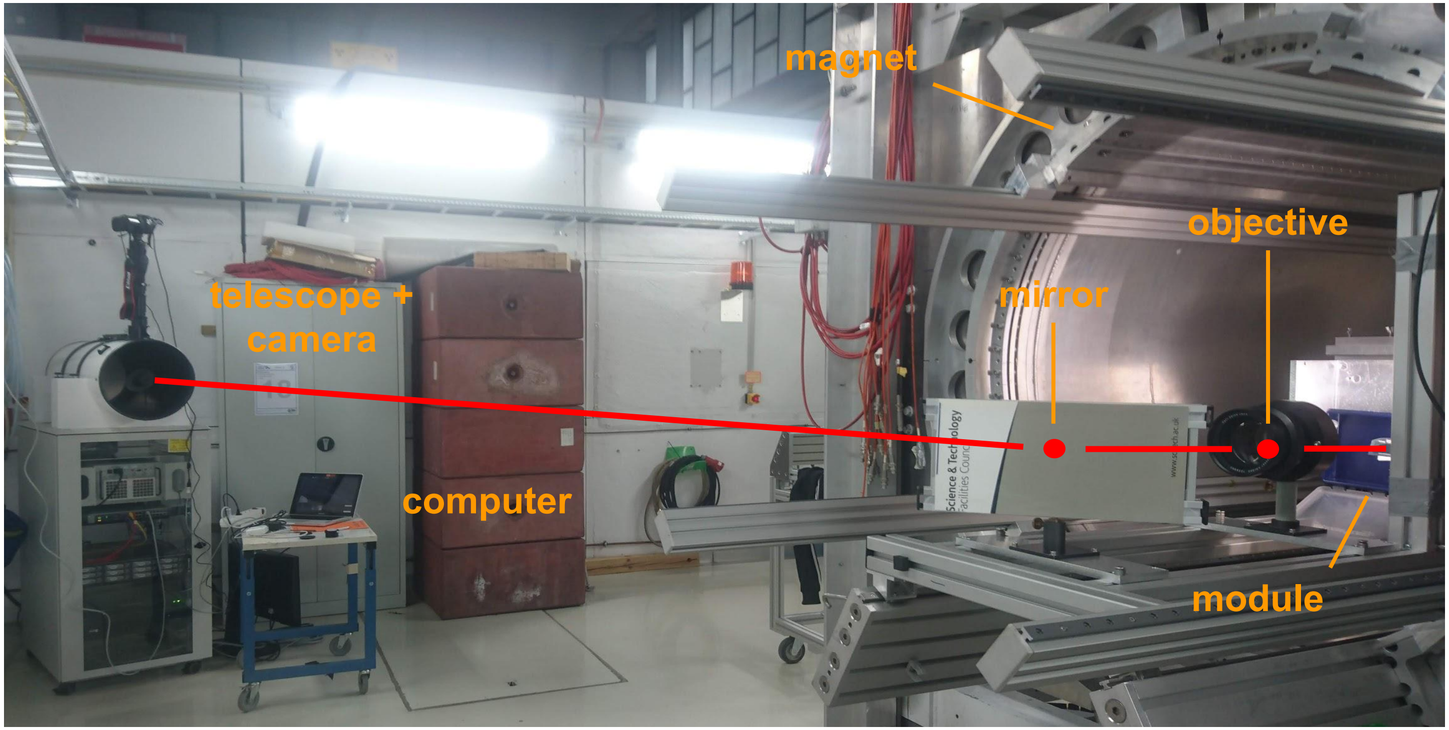
  - Sweeped from 1 kHz - 350 kHz in steps 1 kHz or 0.5 kHz steps; 0.1 kHz - 35 kHz in steps of 0.1 kHz
- Cannot target all wirebonds under test at once with the optical setup
  - Need to move the telescope to cover all



Device	**Wirebonds Observed**
ABC	PRLP
	DATA to HCC
ABC - Power	DVSS, DVDD, GNDD, VDDD, DVSSA, VDDA, GNDA, AVDD, GNDIT
HCC - Power	DVDD, GND
Power to hybrid	Powerboard to hybrid bonds
AMAC	HVOSC0 (high volt. charge pump)
	HRSTB[x,y] (HCC reset)
	DCDCEn (DCDC on/off)
	LD[x,y][0,1,2]En (LV on/off)
Testframe to Powerboard	

More on the setup (2)





Some notes for the upcoming results

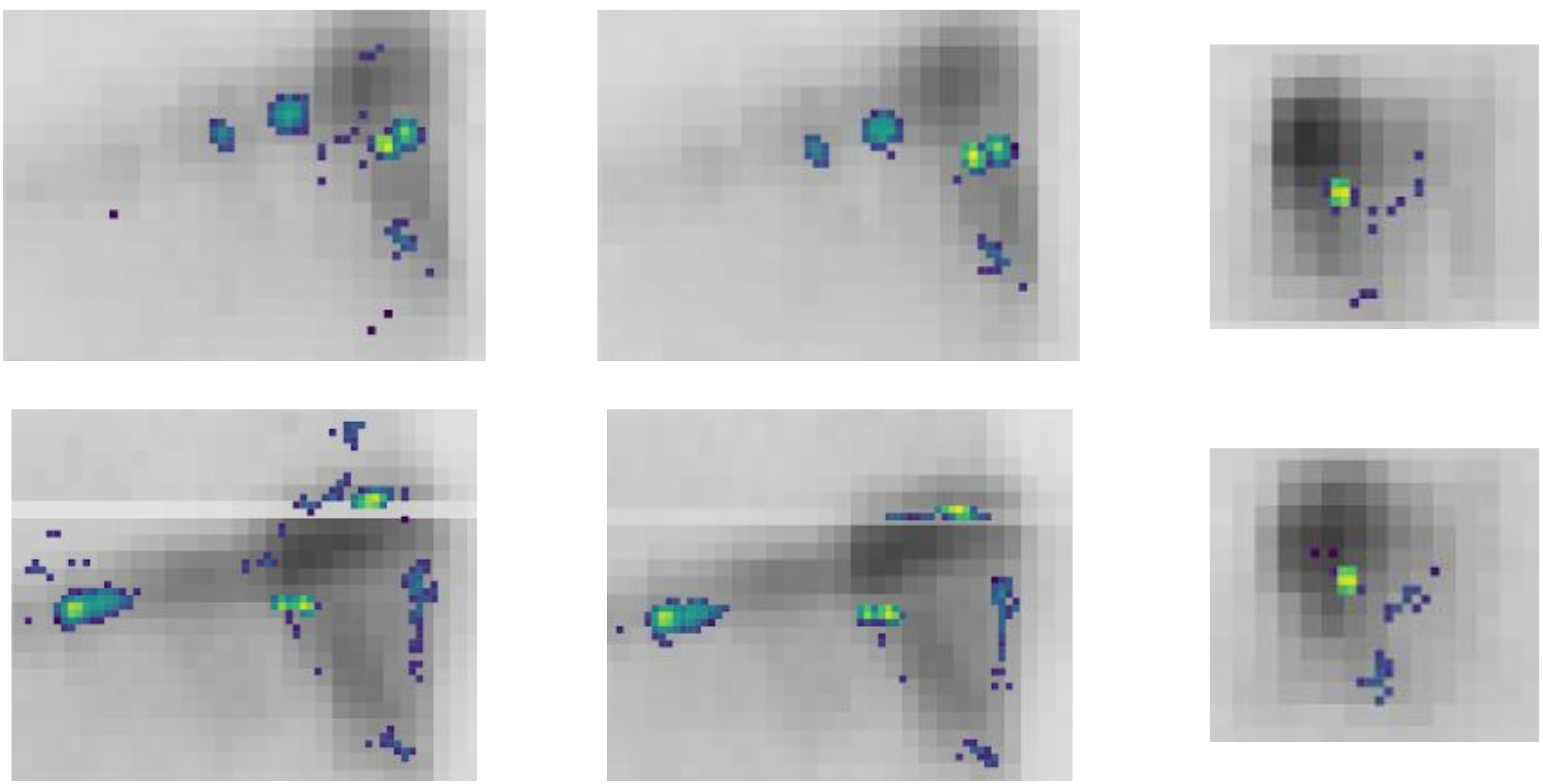
- Only considering run 3 (runlist, logbook), focussing on PRLP wirebonds
- Analysed frame 30 - 11850 → 11821 frames in total
- Scanned 20 kHz to 1 kHz, then 1kHz to 20 kHz in 1 kHz steps → No oscillations expected in this frequency range → Analysis done, as video short and a good first test object to gain experience
- Each frequency was held for 100,000 triggers
  - 1 kHz visible for 100s (twice!)
  - 20 kHz visible for 5s (twice!)
- The video frame rate was 15 fps
  - 1 kHz: 1500 frames → if resonance there, shown in ~3000 images
  - 20 kHz: 75 frames → if resonance there, shown in ~150 images
- Use machine learning to identify the trigger frequency

Following slides are for a threshold of 127

Correcting the COGs by the reference COGs

- Did not stabilise the COGs significantly in first approach → discarded (probably algorithm was bad, corrected interest contour by closest reference contour)
- It is not expected that oscillations change COG
- Could be reconsidered by plotting frame-number vs COG for reference and interest COGs and studying correlation

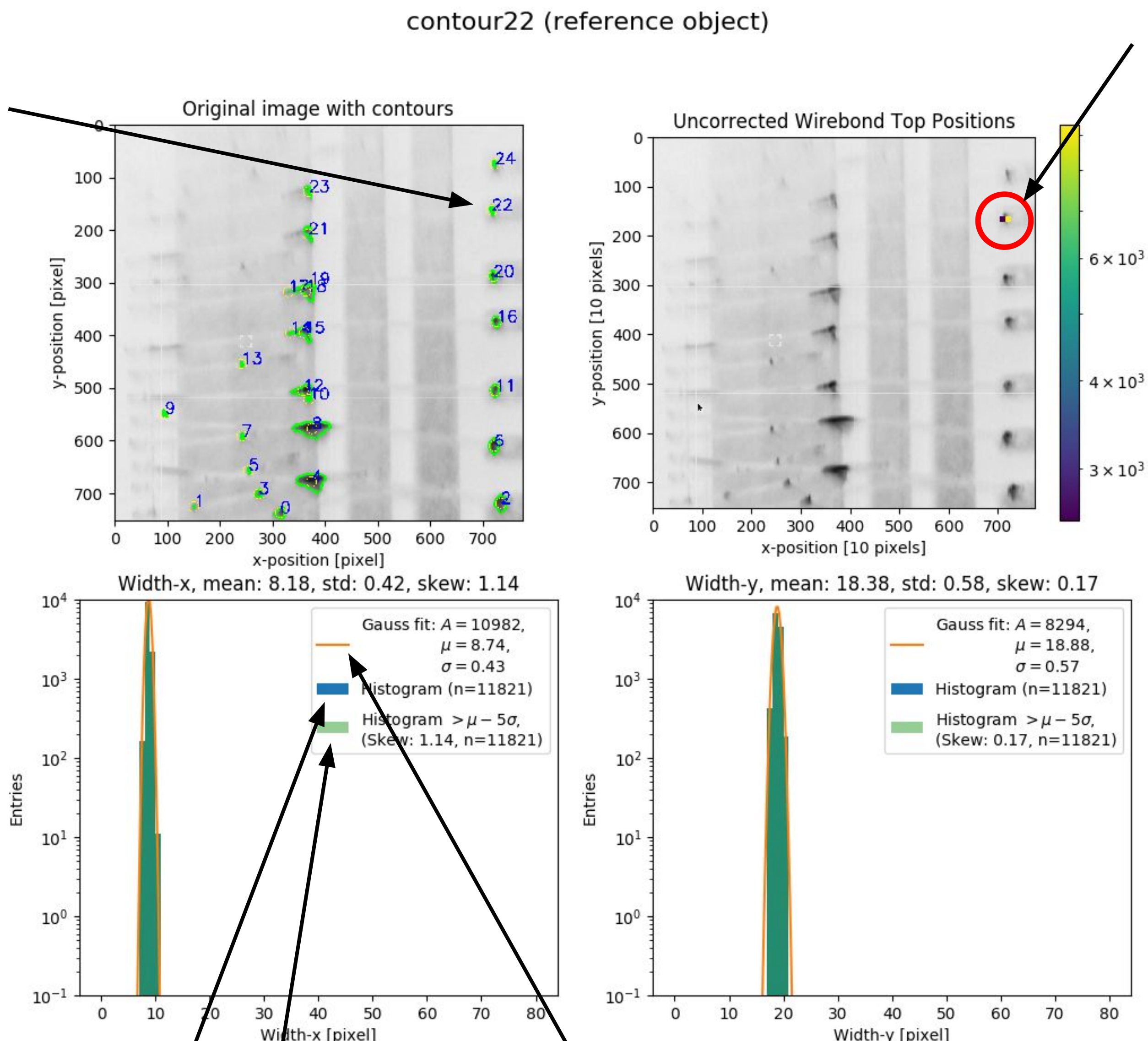
Interest COGs: corrected by reference | Interest COGs: **not** corrected by reference | Reference COGs



1. Widths histograms: Contour 22

Looking at this contour (from first frame)

2D histogram of associated contour COGs



Color:
How often was COG found here.

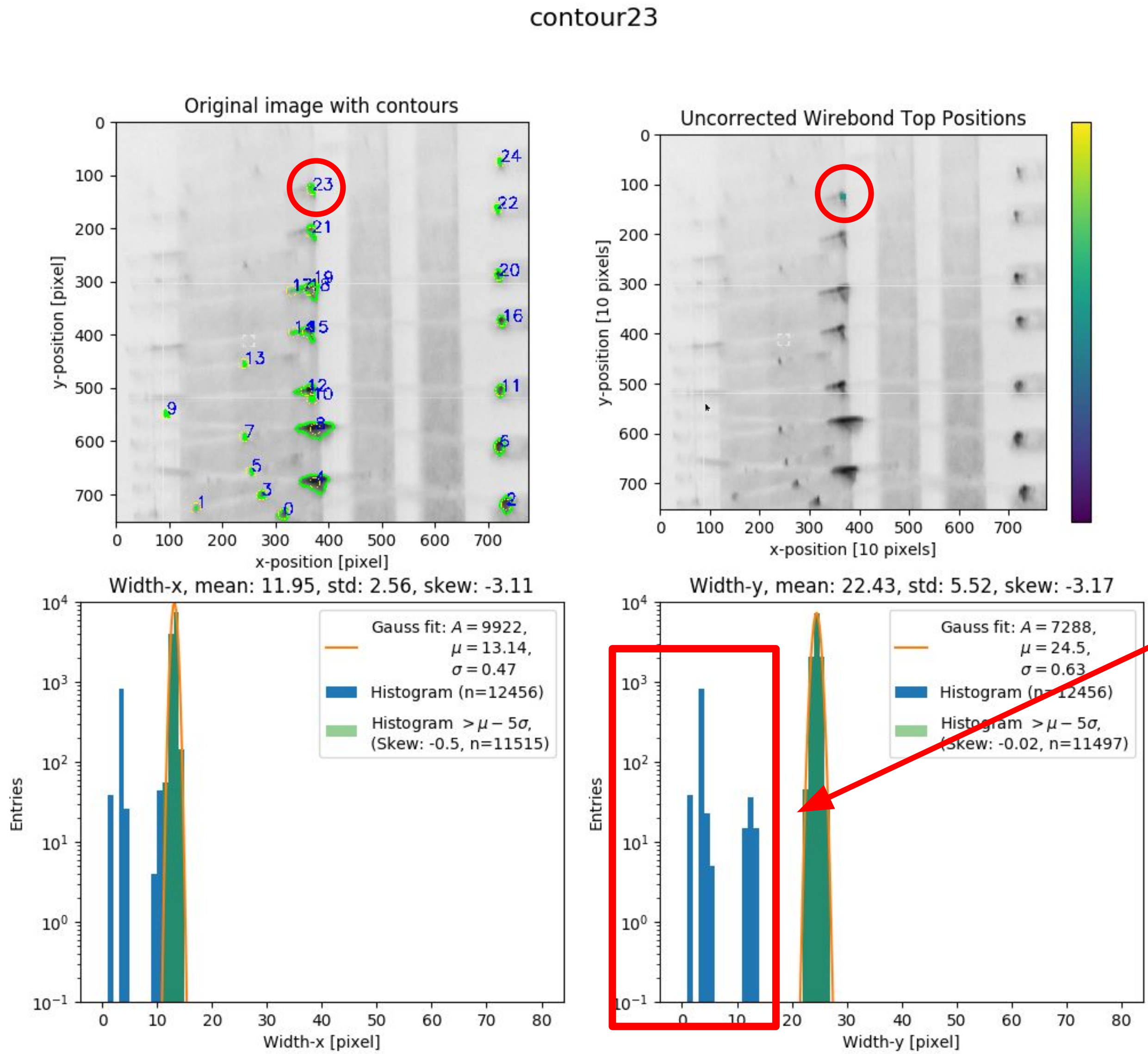
NOTE:
1 bin = 10 pixels

Histogram of the width in x of associated contours

Histogram of the width in y of associated contours

Blue = original histogram, Orange = Gaussian fit to original histogram
Green = original histogram, cut: width > μ - 5σ (μ, σ from fit)

1. Widths histograms: Contour 23



What happens here?

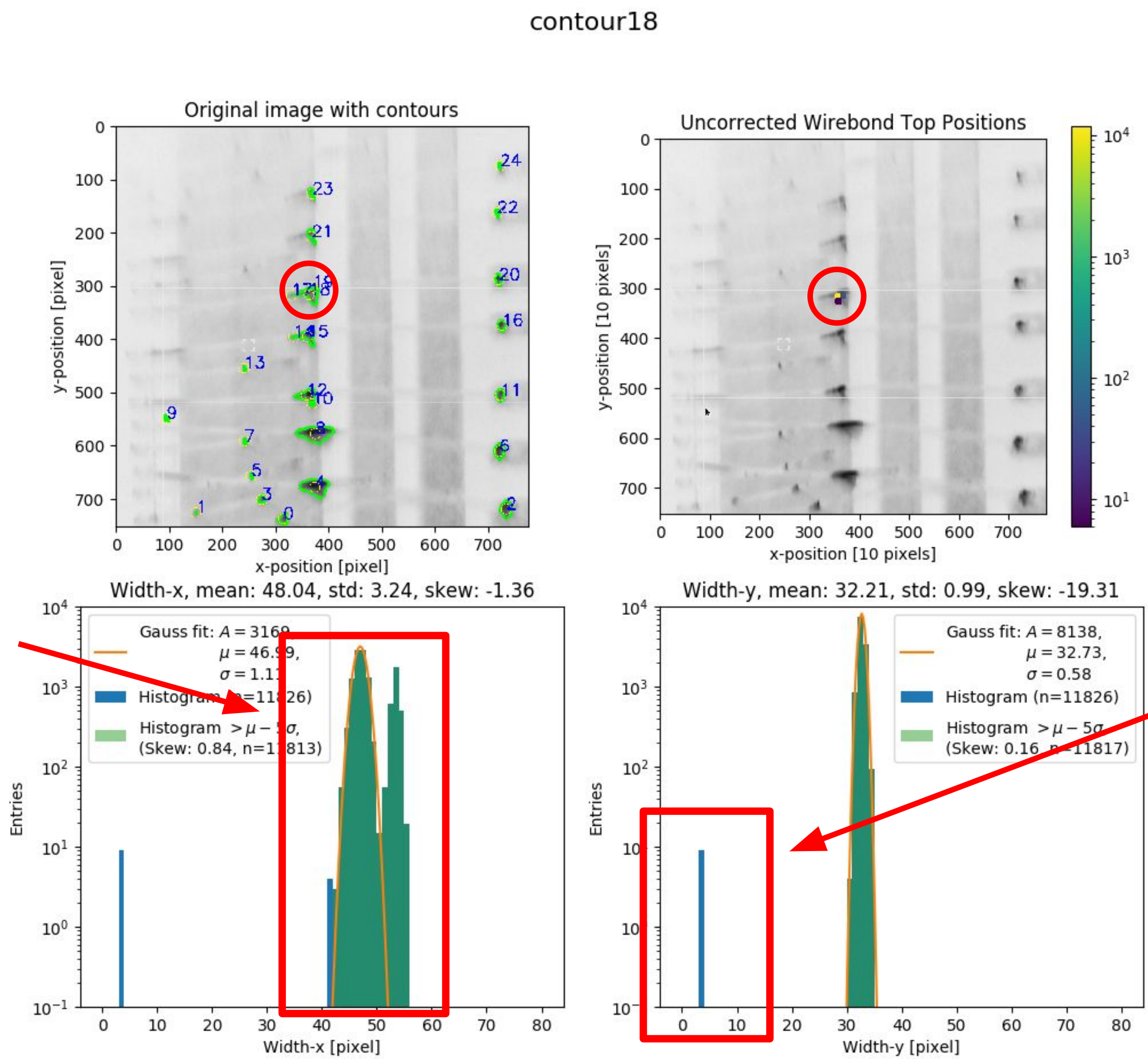
No contour

Small contour (blue dot)

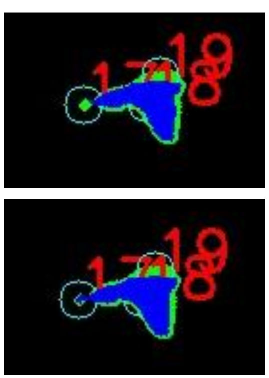
Large contour

Blue = original histogram, **Orange** = Gaussian fit to original histogram
Green = original histogram, cut: width > μ - 5σ (μ, σ from fit)

1. Widths histograms: Contour 18



Double peak: sometimes contour 17 & 18 merge.



Single peak: occasionally blue spot associated with contour 18

Blue = original histogram, Orange = Gaussian fit to original histogram
Green = original histogram, cut: width > μ - 5σ (μ, σ from fit)

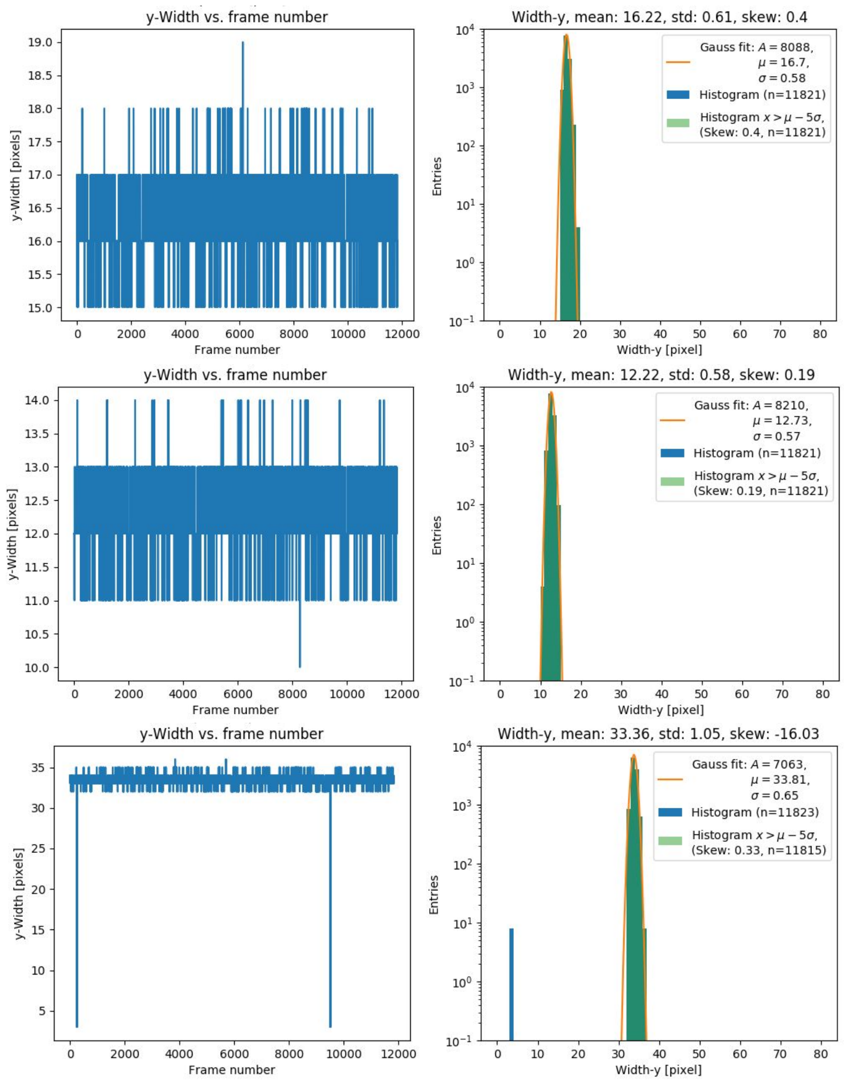
2. Can we see magnet vibrations?

- Thank to Edo for pointing this out!
- Considering three contours:

Contour 3

Contour 5

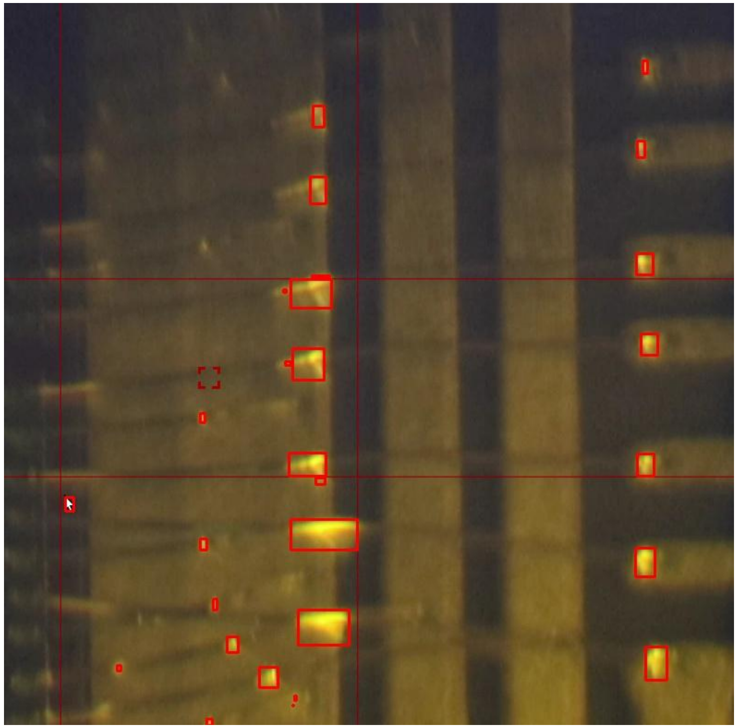
Contour 15

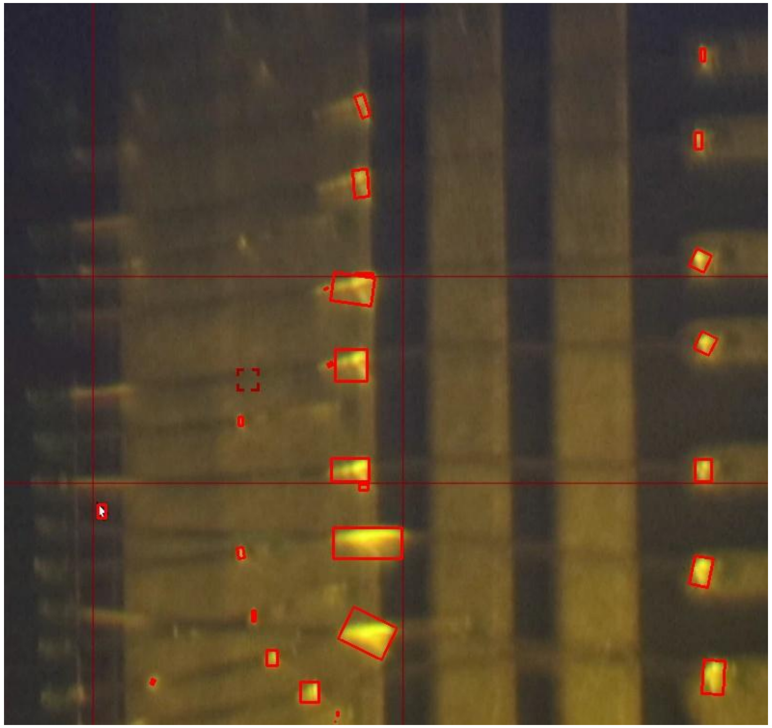


- We cannot see the magnet vibrations in the y-widths (peaks in y-width vs frame number to not relate to magnet vibrations)
- We should be able to see them
- Important closure test for method

2a. Shall we do a principle axis transformation of the contours instead?

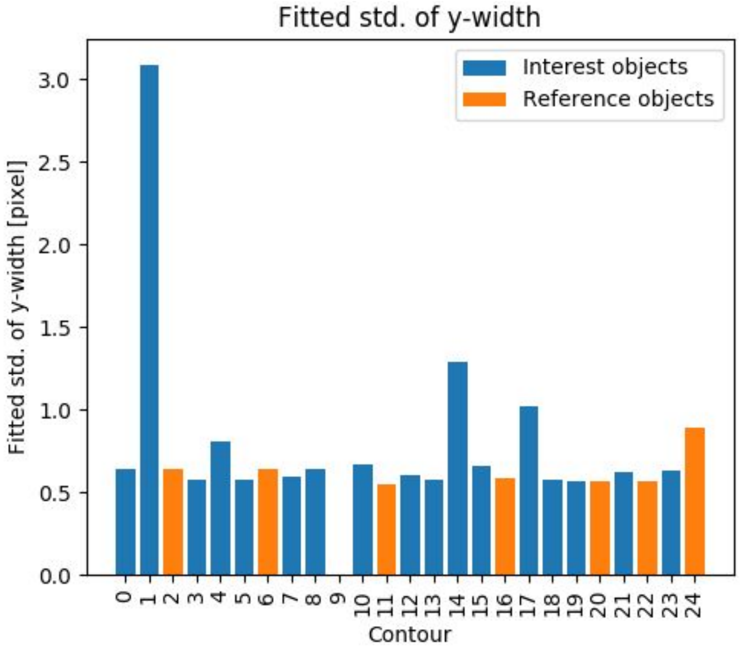
- Does not give desired result, unless we manage to cut away reflections efficiently





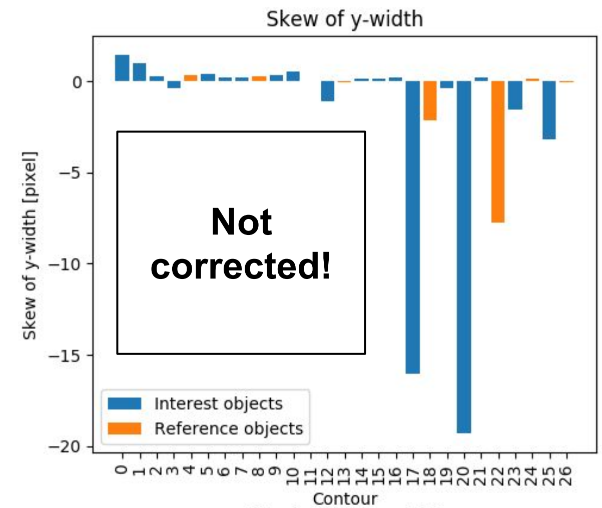
y-widths: Fitted standard deviation

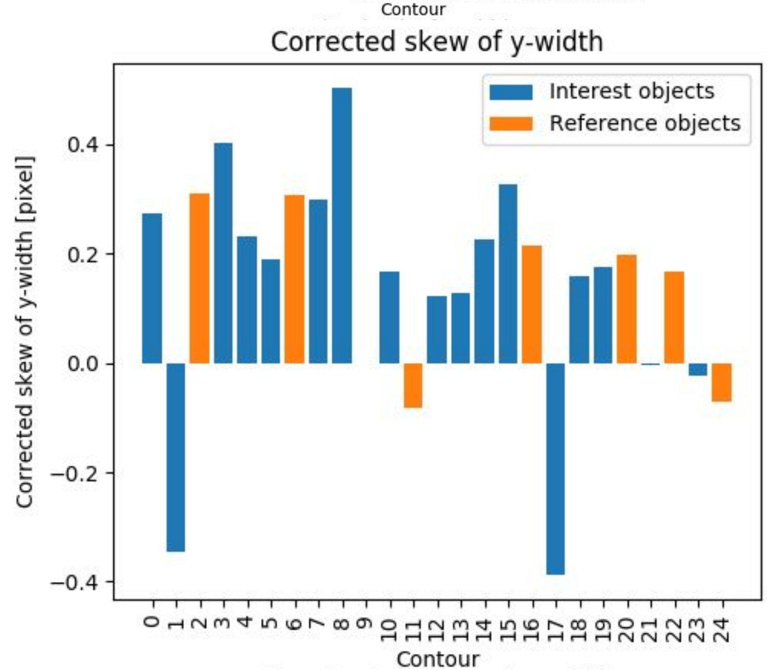
- Here: standard deviation of y-width per contour
- Outlier contour 1:
  - light on contour 1 bad → fluctuations expected
- Outlier contour 14:
  - Small stats, easily merges with contour 15
- Outlier contour 17:
  - Easily merges with contour 18 → either disappears or gets very small



y-widths: Corrected skew (from histograms with cut)

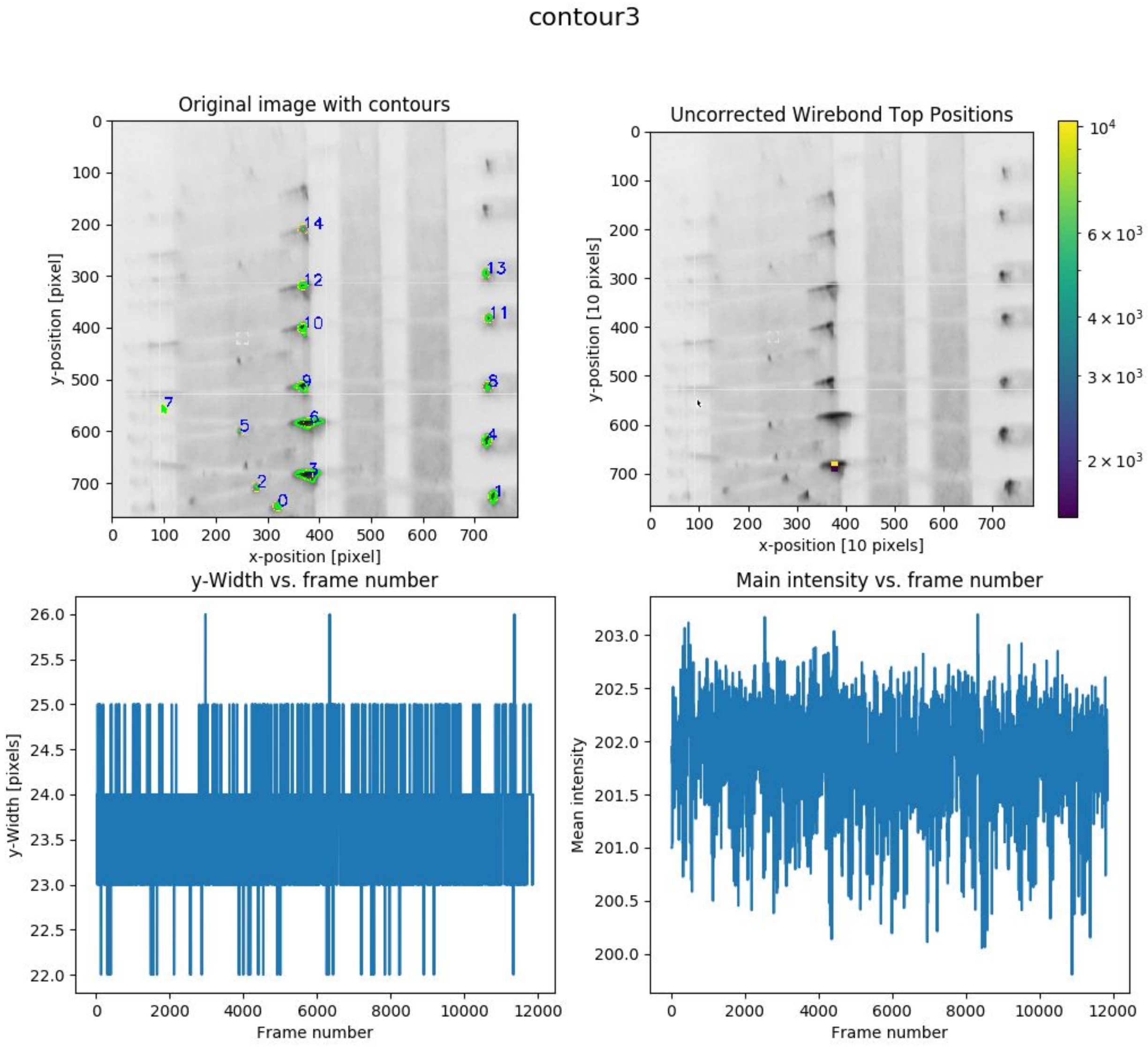
- Histograms with cut created in order to get more meaningful skew
- The skew quantifies how much the distribution deviates from a normal distribution, definition
    - Skew > 0: more weight on right side of peak
    - Skew < 0: more weight on left side of peak
- Expect skew > 0 during oscillations
- Contour 3, 8, 15 seem unusually high, oscillations here?





Confirming insensitivity of the y-width

- Threshold of 170 used here!
- Wavy structure visible in mean intensity, not in y-width → y-width not sensitive to magnet vibrations



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