Wobbelling wires and moving magnets

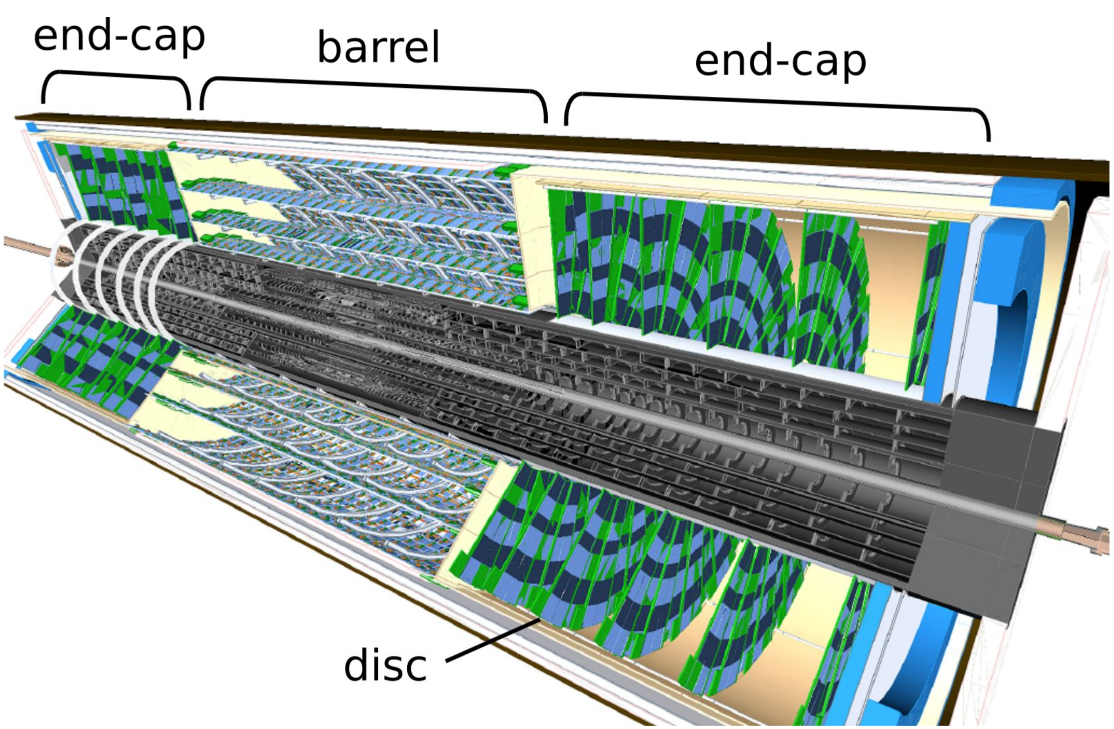
Ben Brüers, Ruchi Gupta, Ksenia Solovieva, Edoardo Rossi, Sarah Heim, Ingo Bloch, Rickard Ström (all DESY), Craig Sawyer (RAL), Dennis Sperlich (Freiburg)

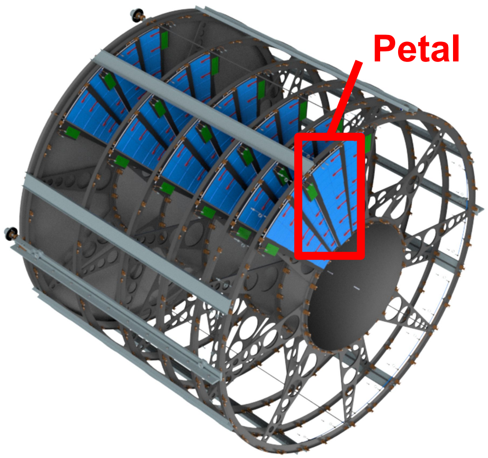
DESY (Zeuthen site), 28.11.2019

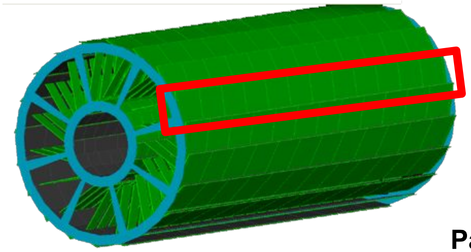
Introduction

Reminder: ITk

- At HL-LHC: ATLAS Inner Detector cannot handle radiation damage and higher fluences
    - → Replacement necessary: called Inner Tracker (ITk)
- ITk is an all silicon system (i.e. no TRT), made of a pixel and a strip subsystem
- Focussing on strip subsystem here

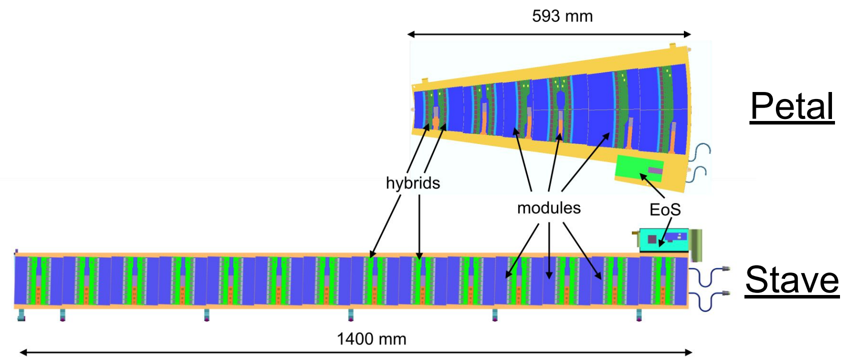


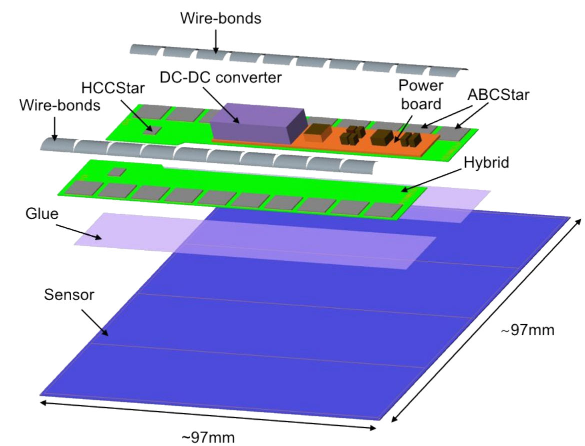


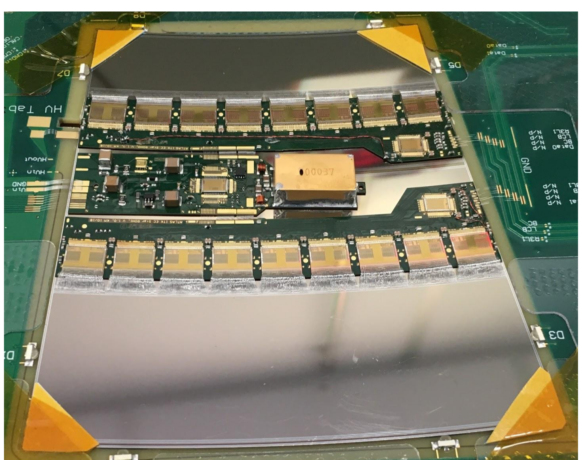


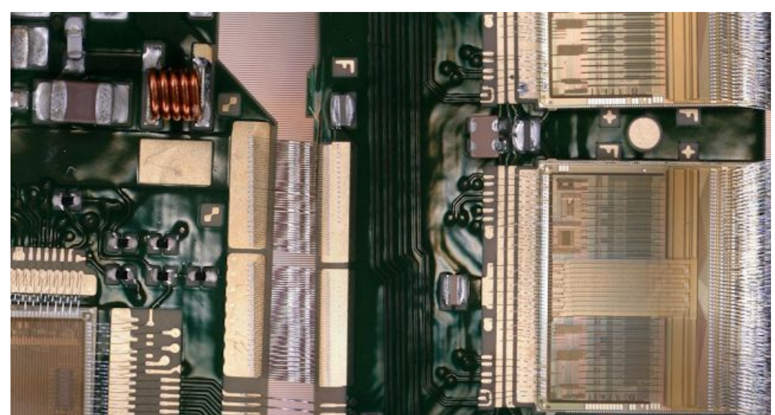
Reminder: ITk Strips Module and Wirebonds

- ITk Strip Module = Sensor + Hybrid + Powerboard
- Hybrid = Printed Circuit Board (PCB) + read-out chip + input/output management chip
- Powerboard = PCB + Monitoring chip (AMAC) + voltage converter chip (FEAST)
- Wirebonds = 25 μm thick aluminium wires
- Wirebonds establish electrical connection from
  - sensor to read-out chip
  - all chips (ASICs) to PCBs
  - data and power to/from a module



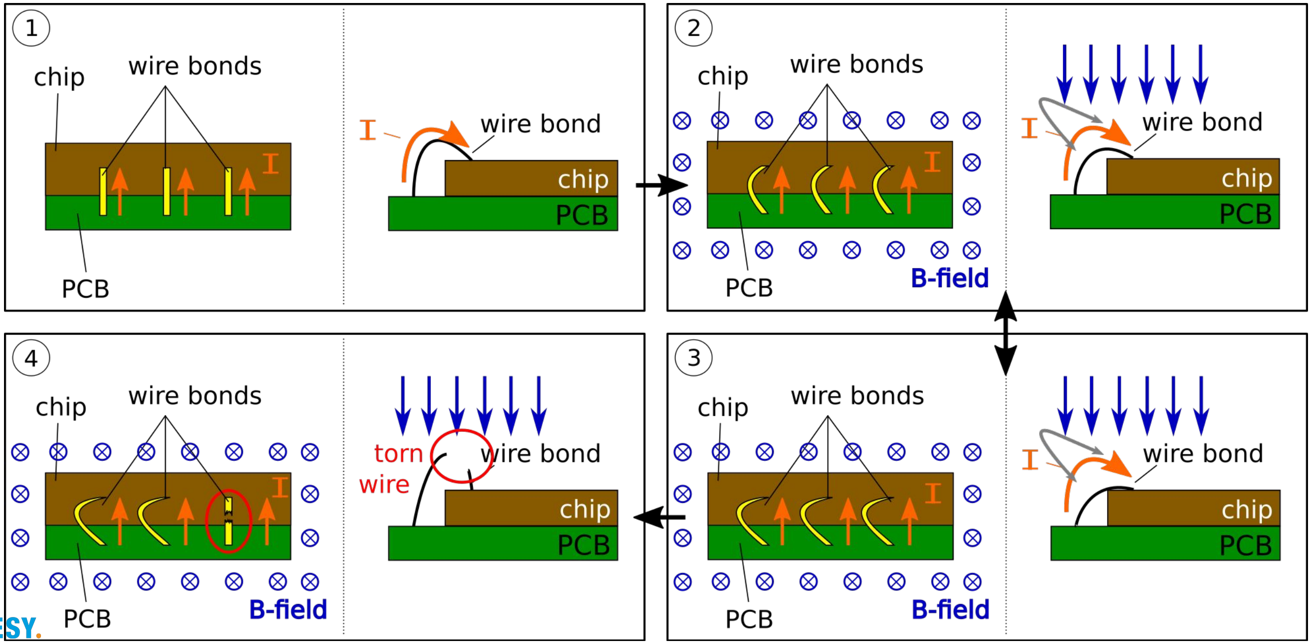


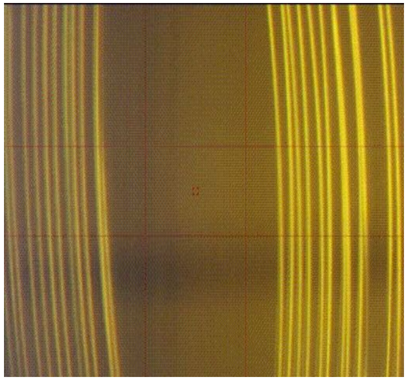




Reminder: Wirebond Oscillations

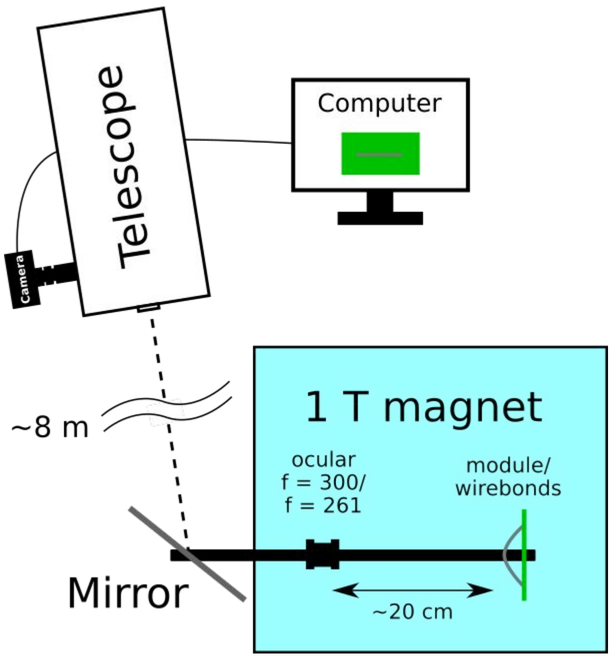
- Current in wirebonds may alternate (e.g. data signals, clocks etc.)
- In ATLAS solenoid 2 T magnetic field → oscillations → damage if hit resonance frequency (e.g. by the trigger frequency)
- Damage by trigger frequency observed in past at CDF (Tevatron), suspected in ATLAS (DBM)
- Protection system in place for ATLAS SCT and Pixel (Fixed Frequency Trigger Veto / [FFTV]); 2 - 40 kHz damped

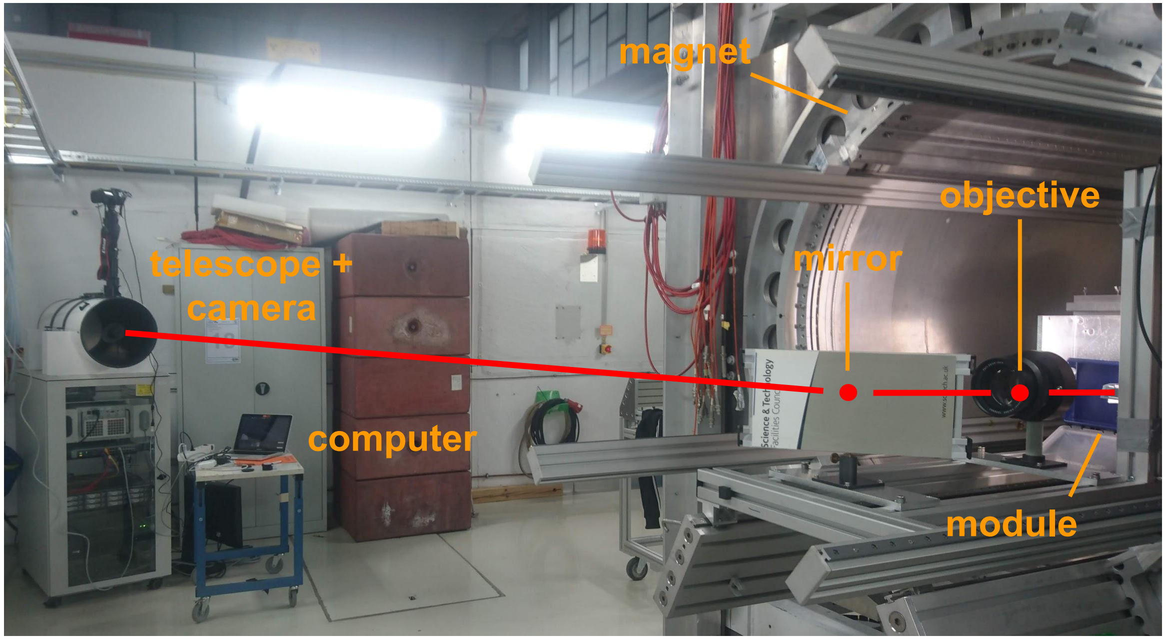




Why do wirebond oscillation studies?

- Find out, which trigger frequencies to avoid in the FFTV
- Check sensitivity of strip modules to oscillations
- Preliminary studies at 1 T magnet at DESY Hamburg in August → 2 T tests planned
  - Telescope + optics necessary, microscope not magnet safe and €€€



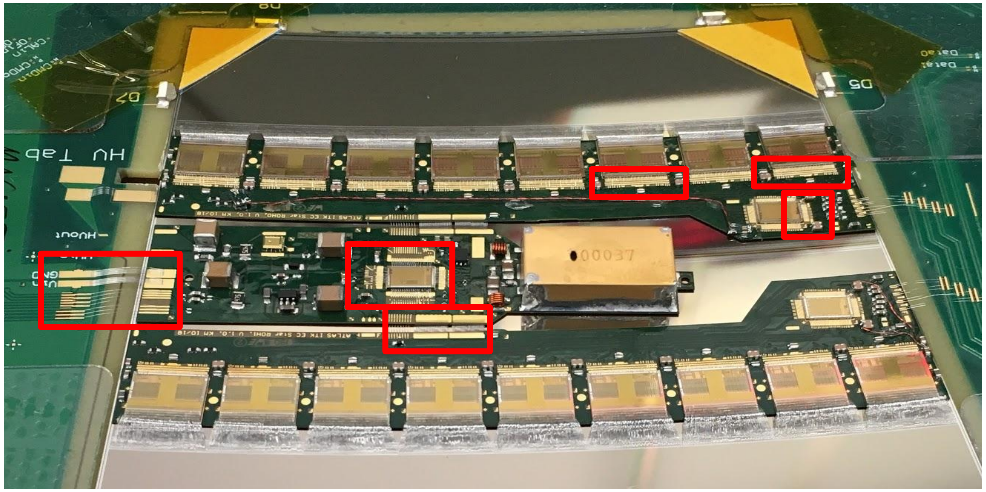


More on the setup

- 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 telescope
- Oscillation hard to see by eye → Took videos for later analysis
- **Today: Will present analysis of such a video**
- **Module still functional after test**

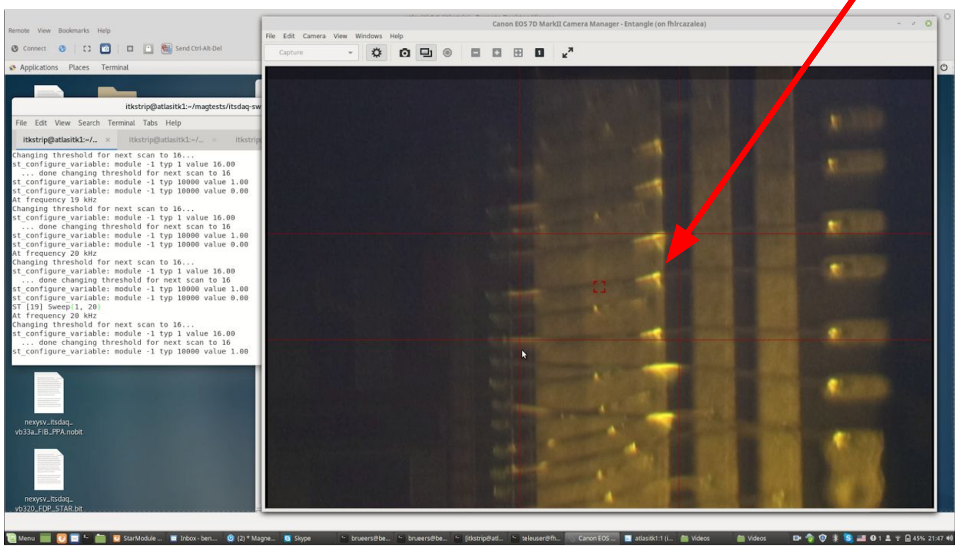


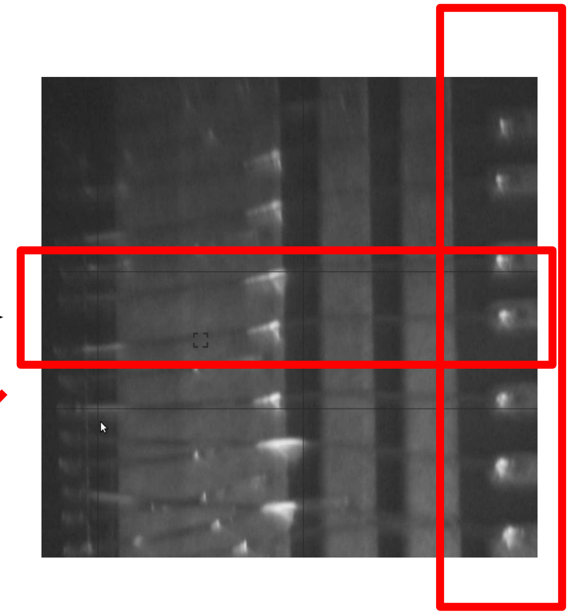
Analysis Procedure

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



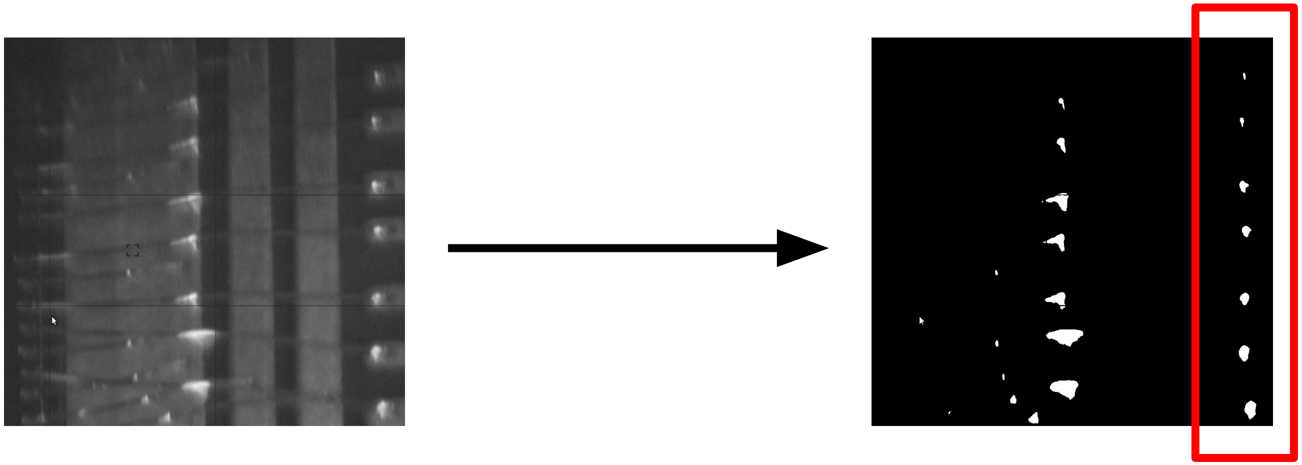


These are the wirebond feet.
They will act as reference later!

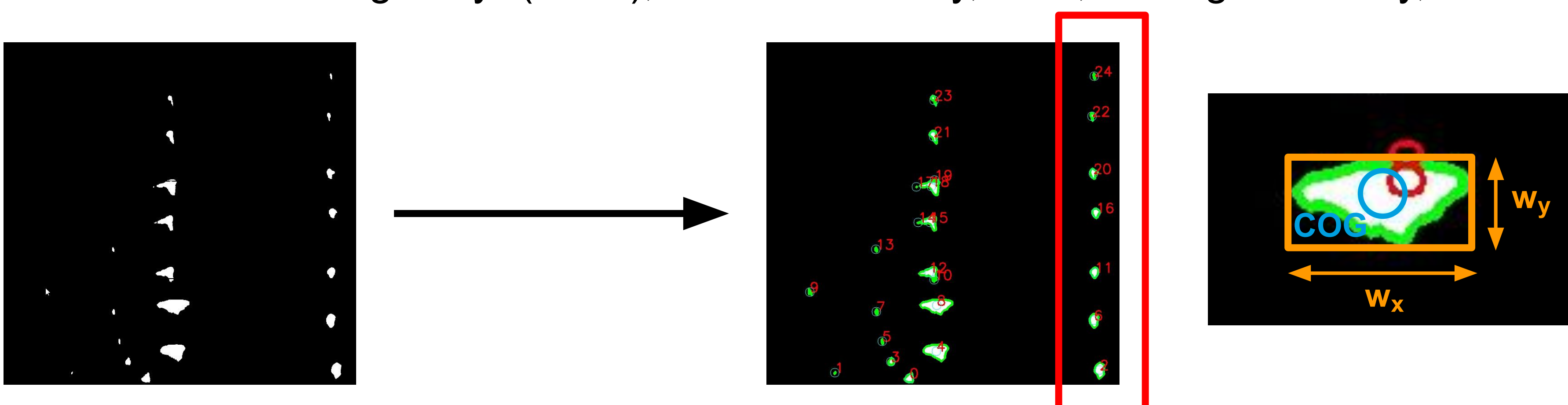
Bonds focussed on: PRLP

Broad steps per video frame

3. **Thresholding**: Apply a threshold of 170, that means: all pixels of brightness <170 are turned black, all pixels of brightness >=170 are turned white



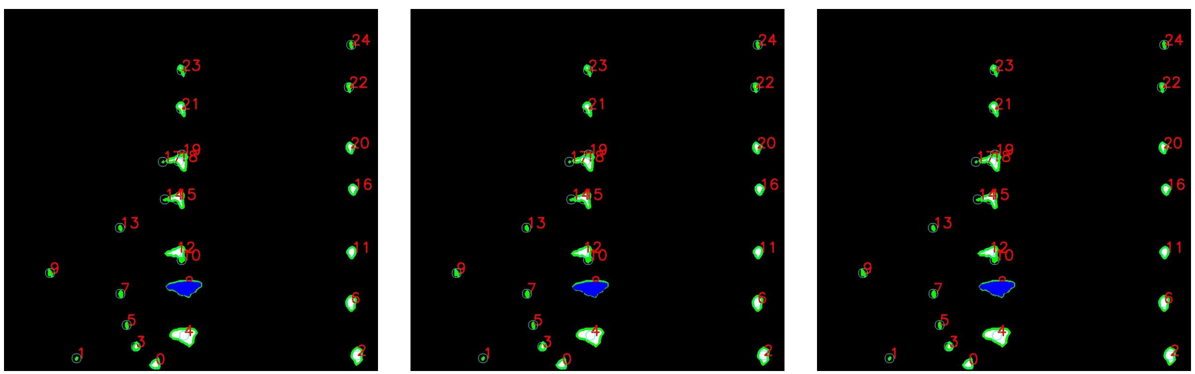
4. **Find contours**: Find the contours of the white objects in the image. Calculate their centre-of-"gravity" (COG), width in x- and y, area, average intensity, etc.



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 this frame ←→ first frame
    - Associate, if distance(COG(this frame) - COG(first frame)) < 5



Contour 8

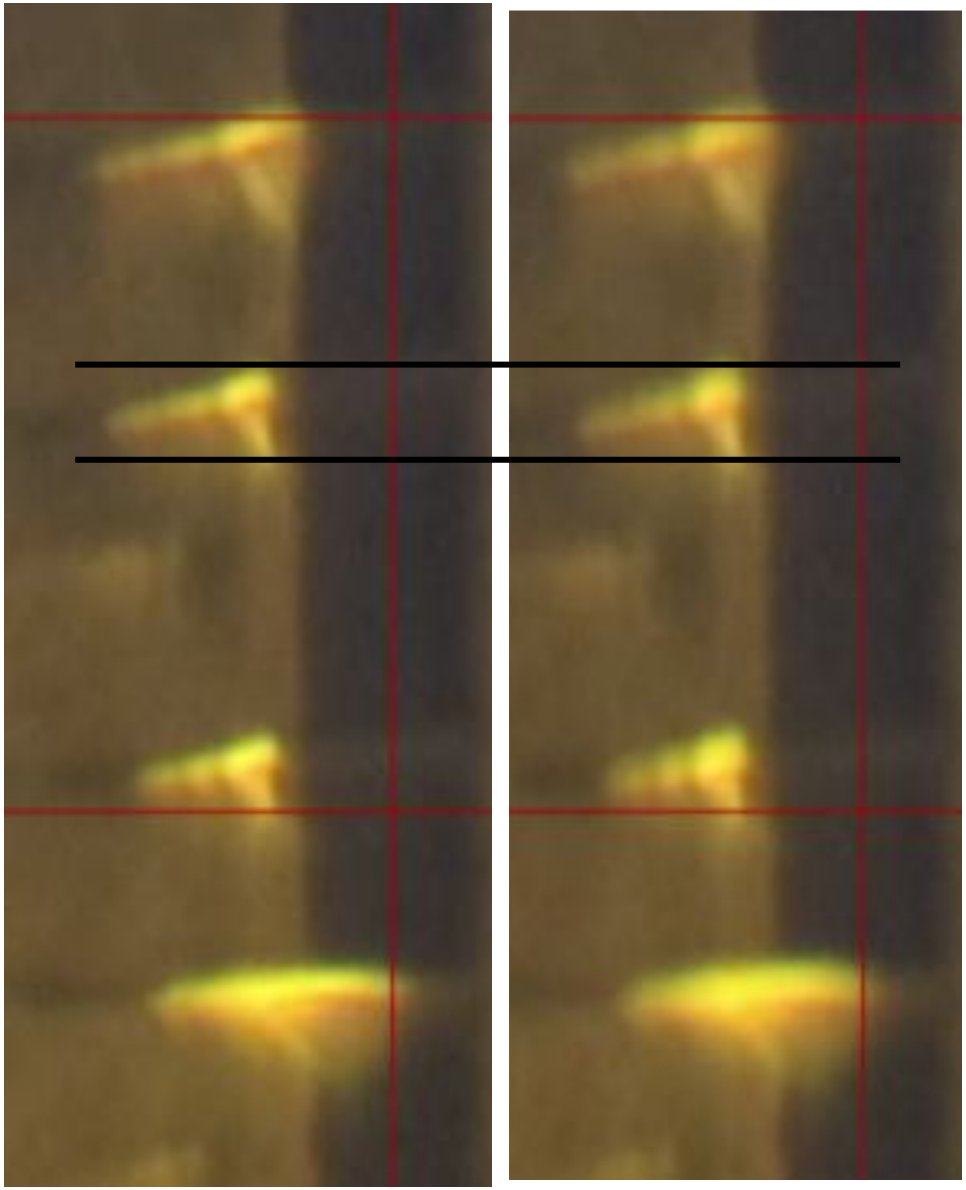
6. **Compare**: Compare the quantities of the different contours and their evolution.

Quantities to study

- Magnet vibrates at 2 Hz → blurs wirebonds
    - expect to see the same with oscillation
- Small change in y-width with little luminescence → not very sensitive to oscillations → confirmed
- Mean intensity altered → **considered for further study**
- Sharpness reduced → should be visible in 2d Fourier transform → not studied, yet

No vibrations

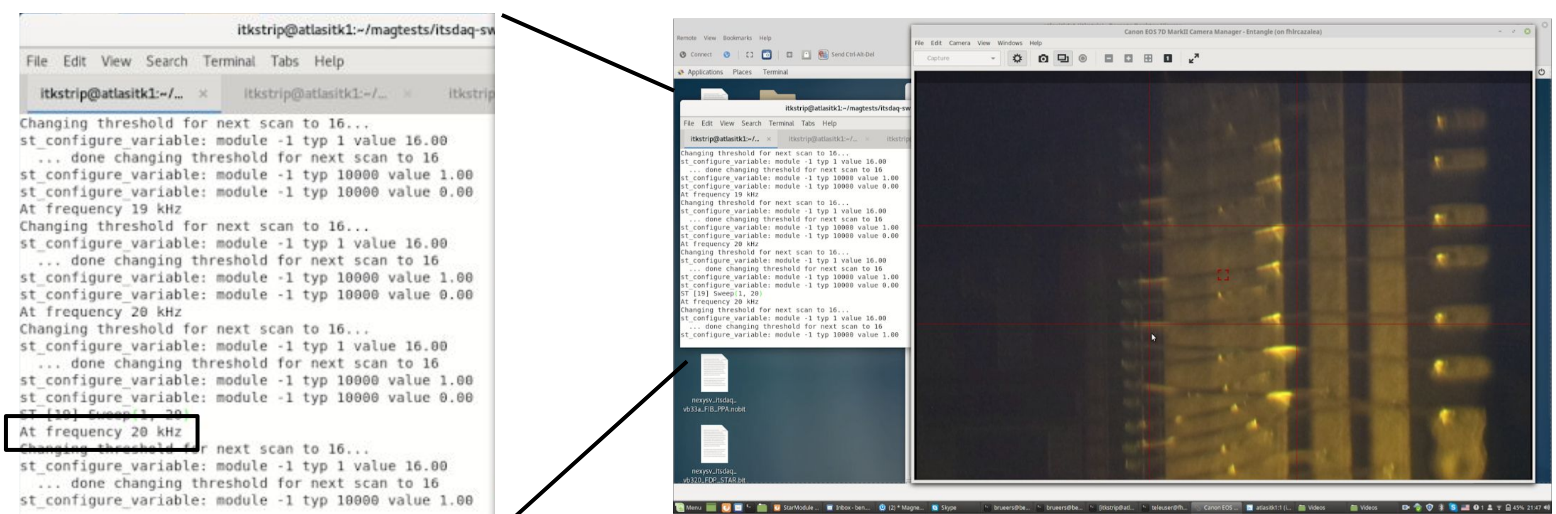
Magnet vibrations



Results

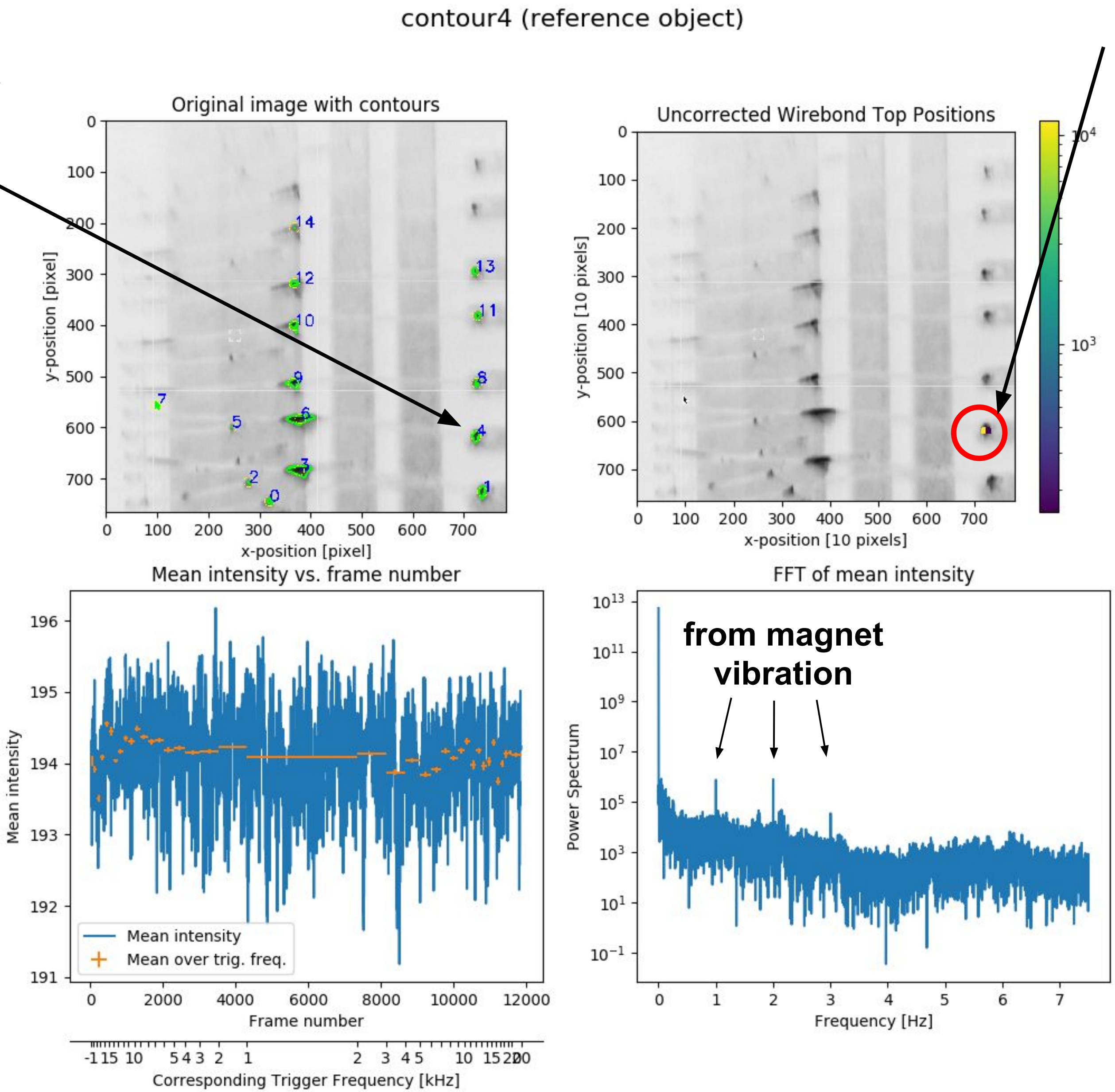
Some notes for the upcoming results

- Only considering one particular video (run 3, see runlist, logbook)
- Scanned 20 kHz to 1 kHz, then 1kHz to 20 kHz in 1 kHz steps
  - No oscillations expected in this frequency range (and width of resonance unknown!!)
  - Analysis done, as video short and a good first test object to gain experience
- Each frequency was held for 100,000 triggers
- Use machine learning to identify the trigger frequency



Mean Intensity: Contour 4 (non-moving foot)

Looking at this contour (from first frame)



2D histogram of associated contour COGs

<u>Color</u>:
How often was COG found here.

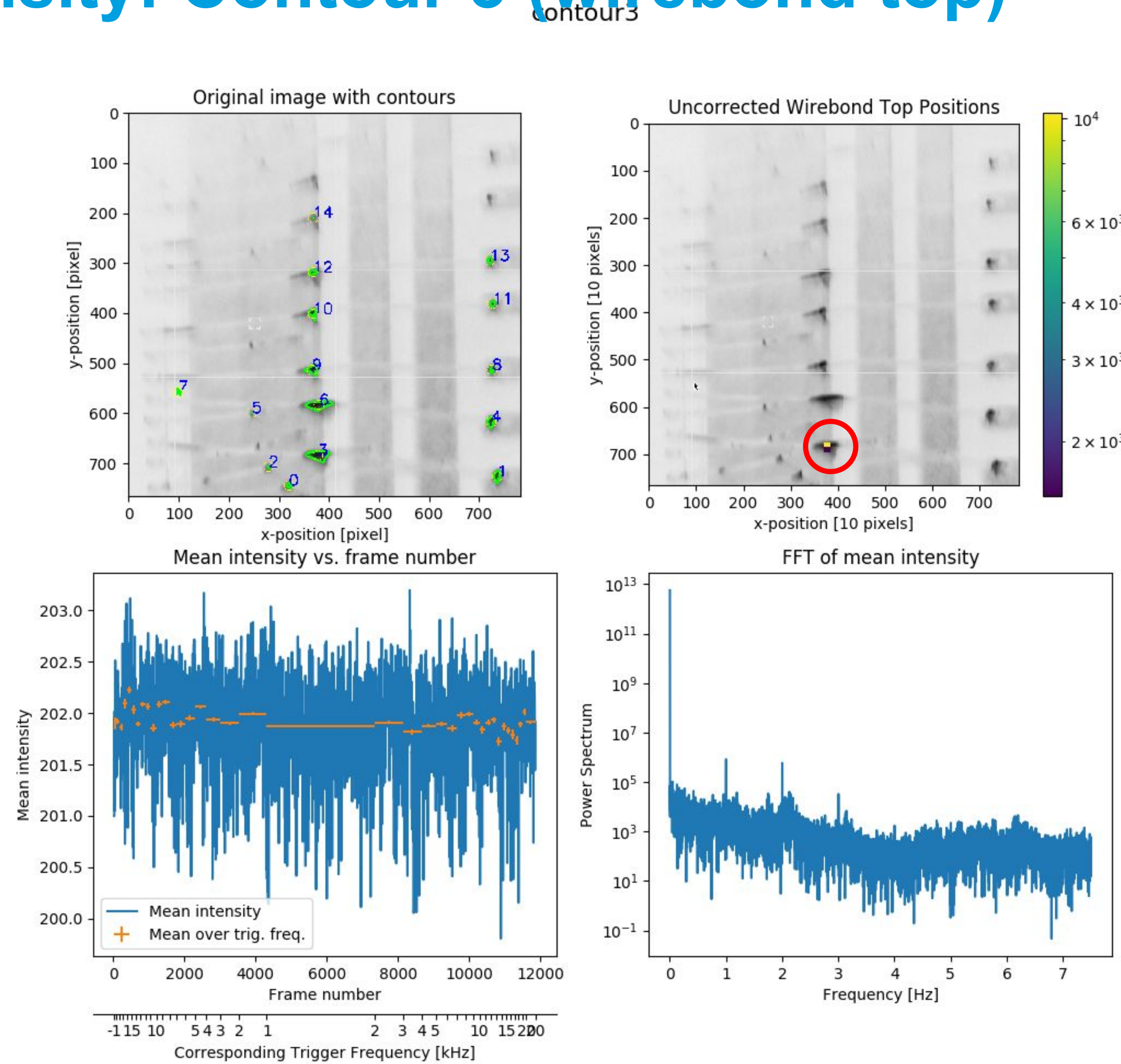
<u>NOTE</u>:
1 bin = 10 pixels

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

Fourier transform of plot on the left

Mean Intensity: Contour 3 (wirebond top)

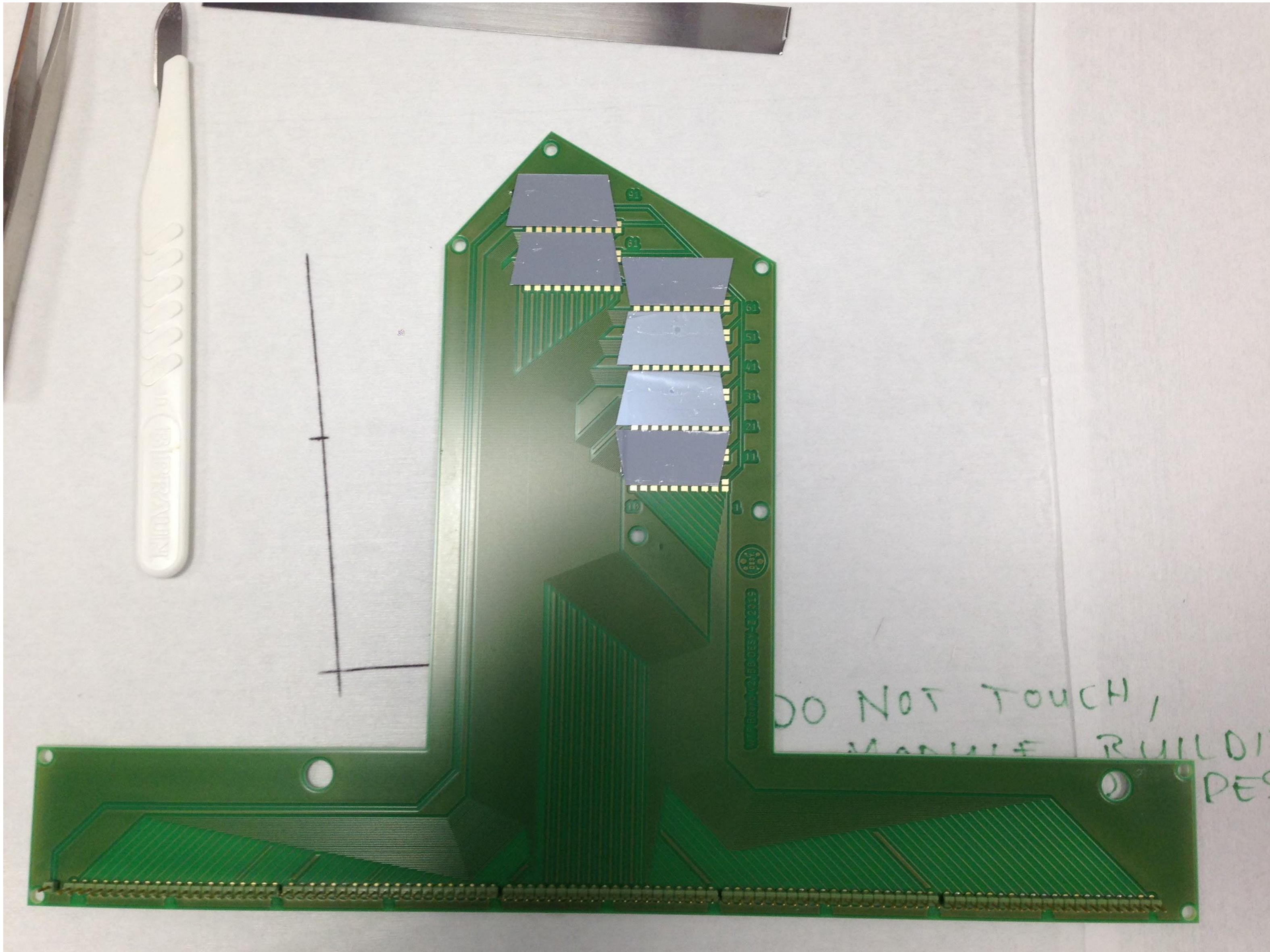
- Standard deviation of mean intensity similar to non-moving foot
- Expect increase in mean intensity for a moving bond
- No obvious evidence for oscillation here → still to be quantified!!
- This is true for all contours of this video



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 → Indeed no indications for oscillations so far, needs further quantification
- Next steps:
  - Analyse longer videos with frequencies in dangerous regions. Oscillations visible?
  - Repeat test in 2 T magnet field at DESY HH
  - Try to investigate resonance frequencies more precisely using a dedicated setup (see next slide)

WTF v2 ASIC Emulator (WTFv2AE)



Thank you

Backup slides

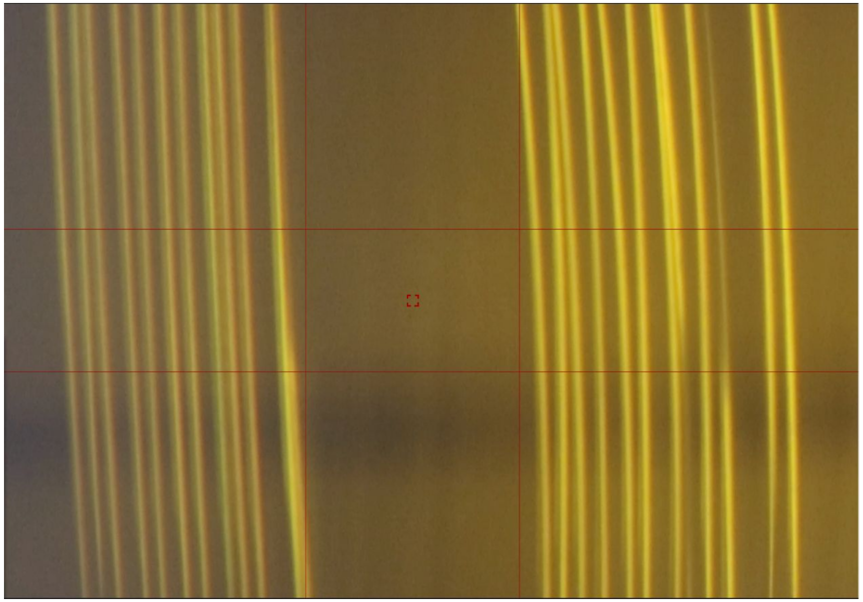
Wirebond potting

- 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

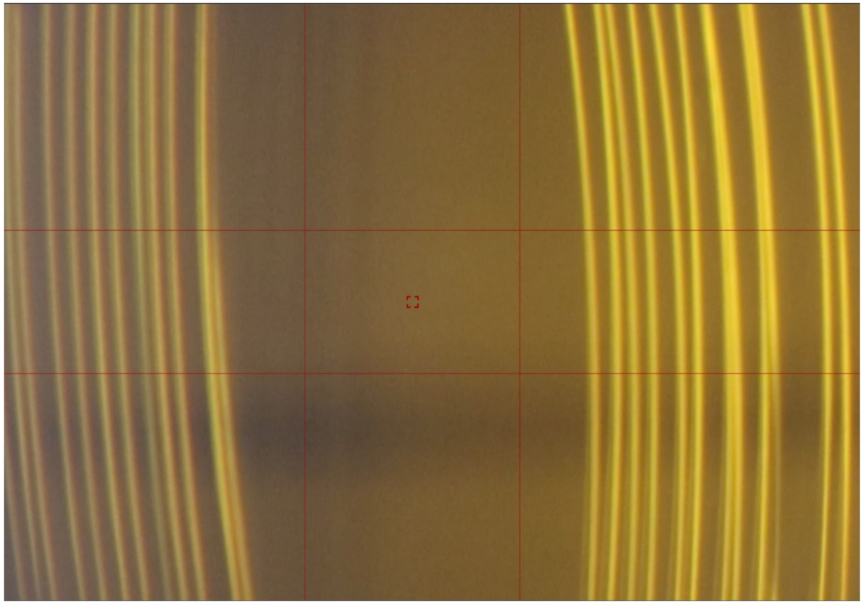
Movement of wirebonds by magnet

Testframe to powerboard wirebonds

Power OFF



Power ON

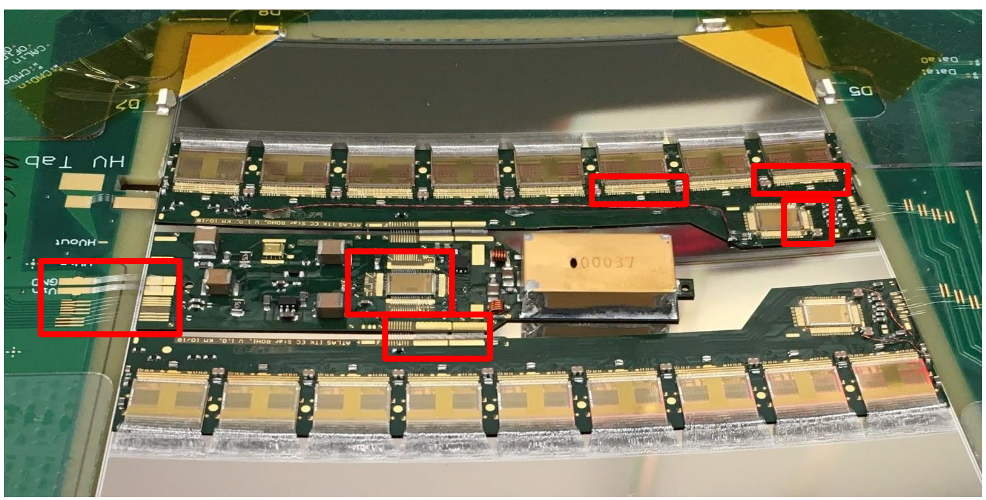


More on the setup

- 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	

Some notes for the upcoming results

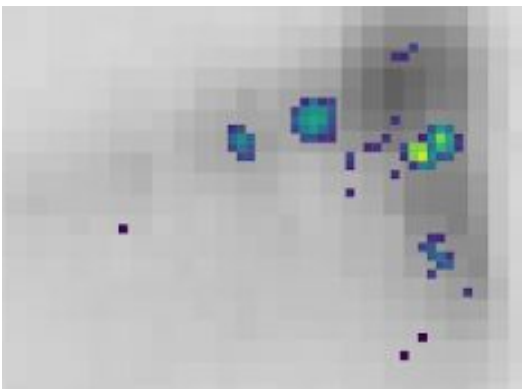
- Only considering run 3 (runlist, logbook), focussing on PRLP wirebonds
- Analysed frame 30 - 11850 → 11821 frames in total
- Scanned 20 kHz to 1 kHz, then 1kHz to 20 kHz in 1 kHz steps → No oscillations expected in this frequency range → Analysis done, as video short and a good first test object to 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

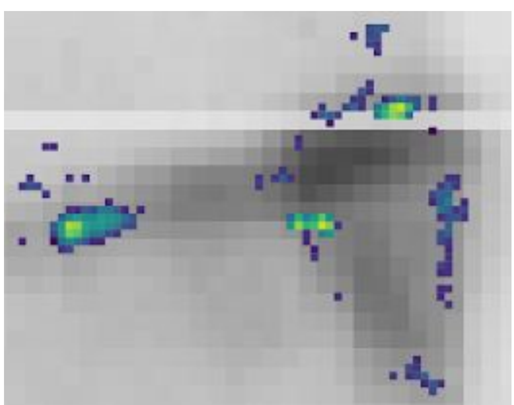
Following slides are for a threshold of 127

Correcting the COGs by the reference COGs

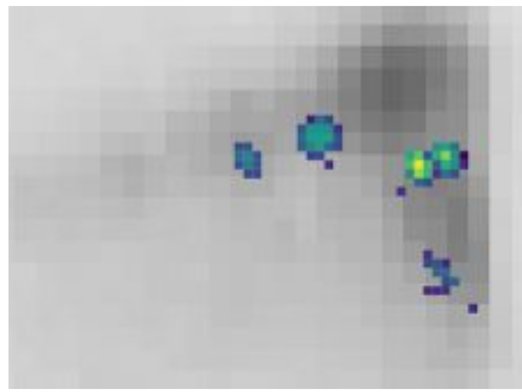
- Did not stabilise the COGs significantly in first approach → discarded (probably algorithm was bad, corrected interest contour by closest reference contour)
- It is not expected that oscillations change COG
- Could be reconsidered by plotting frame-number vs COG for reference and interest COGs and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

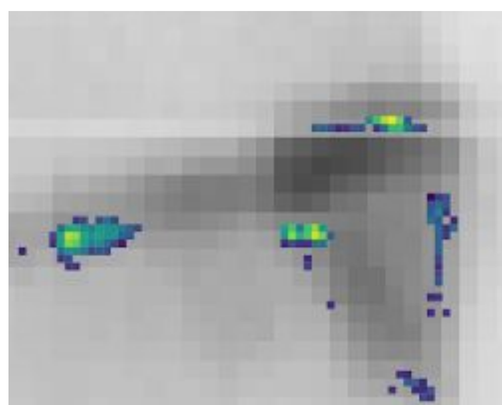
Interest COGs:
corrected by reference



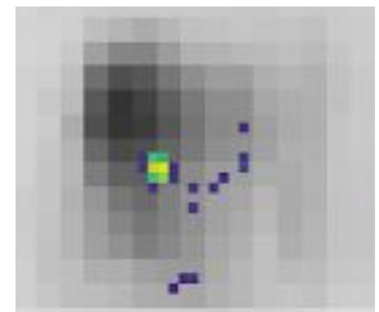


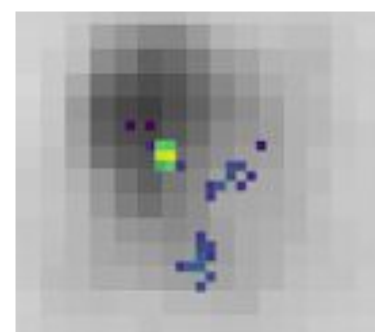
Interest COGs:
not corrected by reference





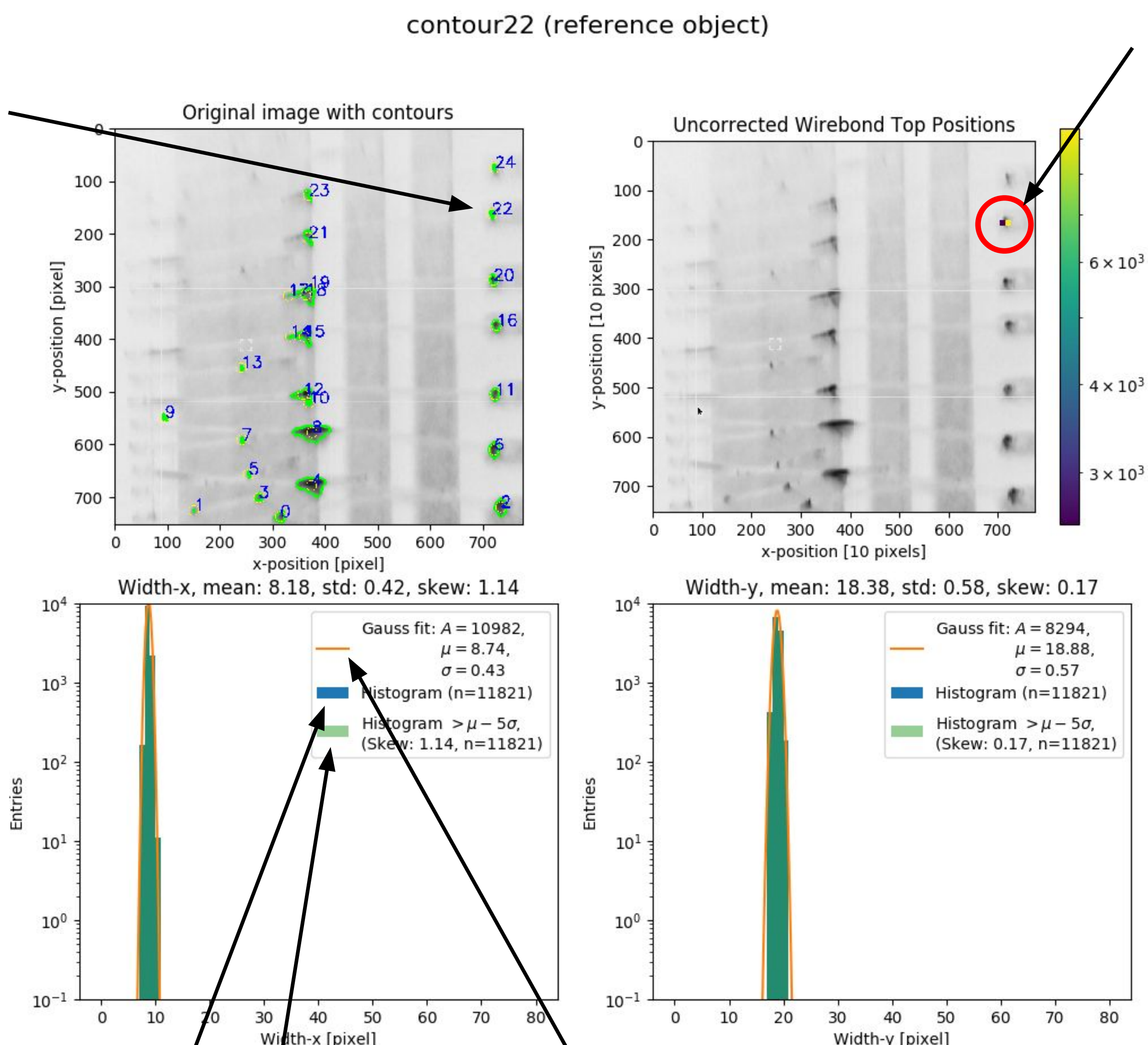
Reference COGs





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.

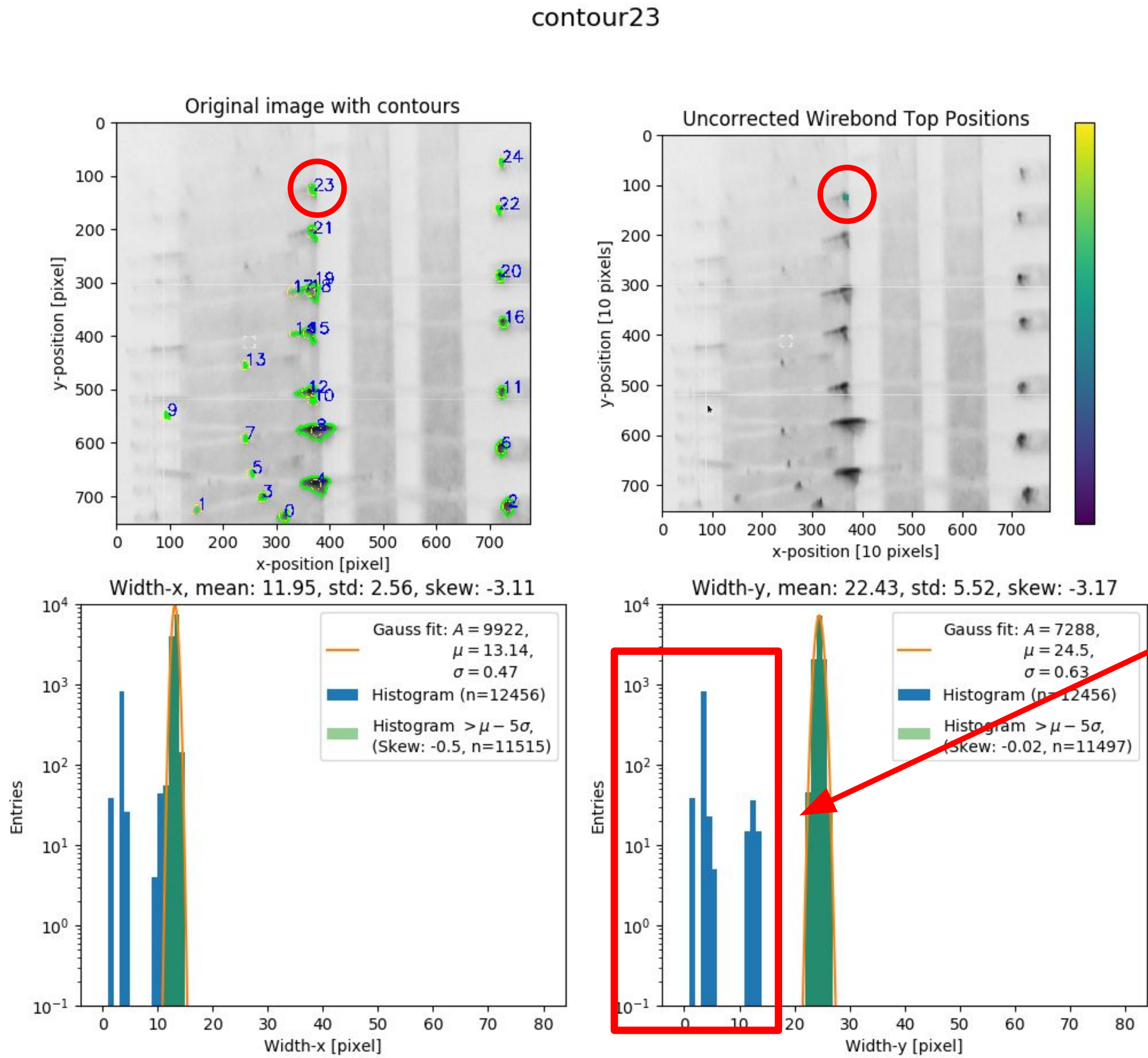
NOTE: 1 bin = 10 pixels

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?

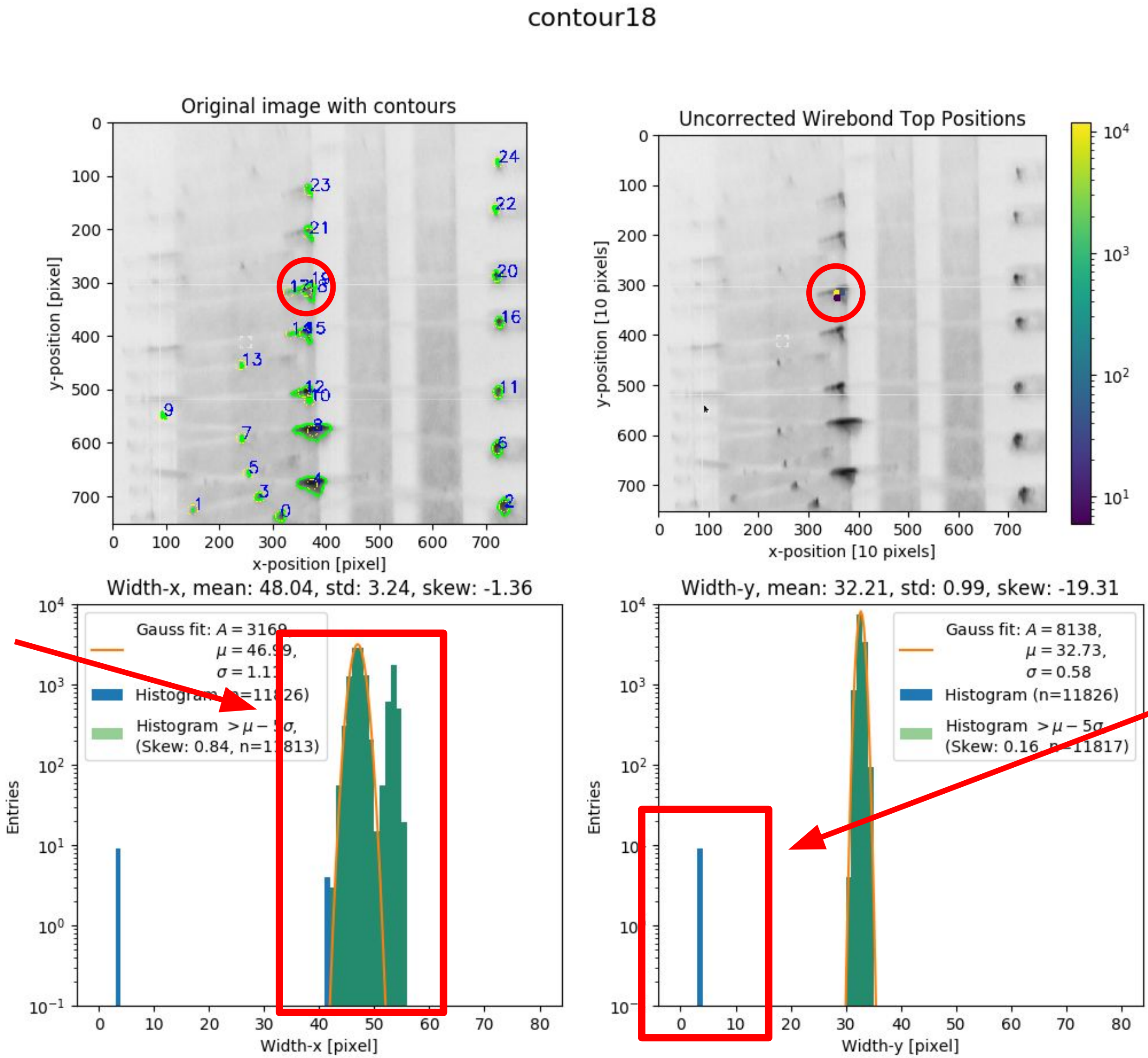
No contour

Small contour (blue dot)

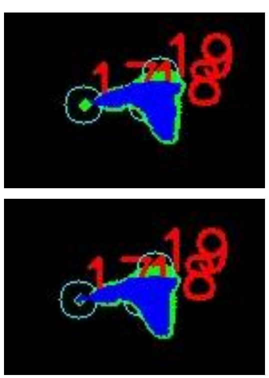
Large contour

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.



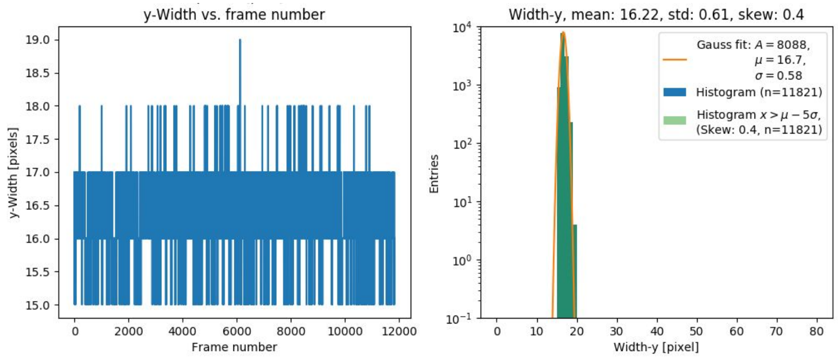
Single peak: occasionally blue spot associated with contour 18

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

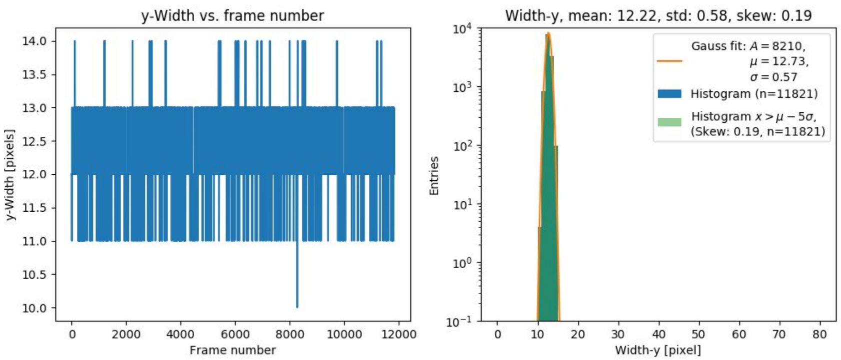
2. Can we see magnet vibrations?

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

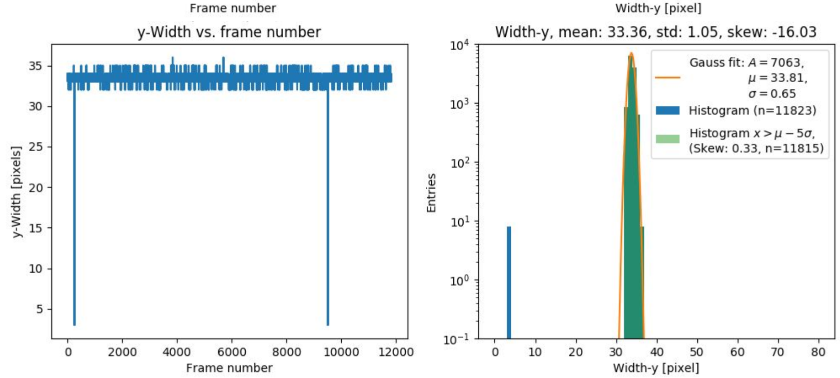
Contour 3



Contour 5



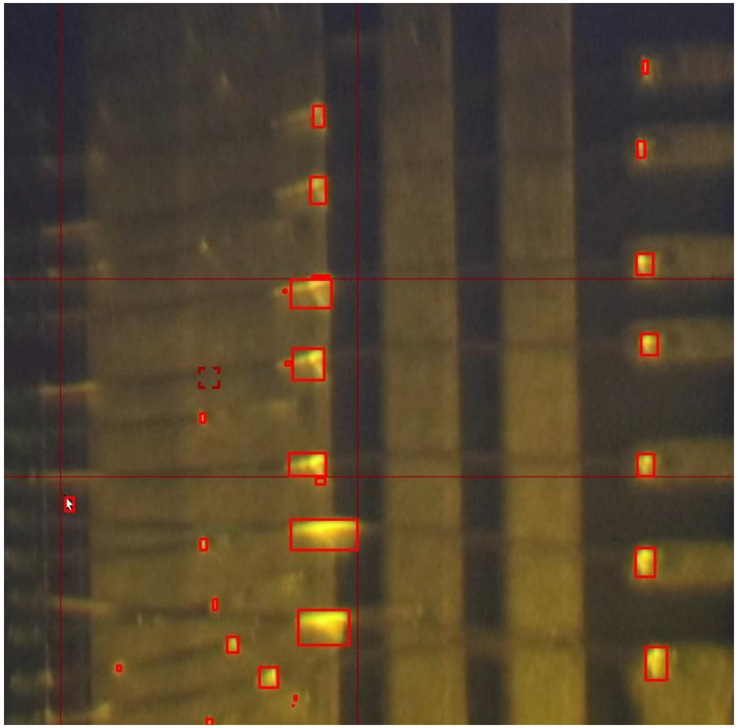
Contour 15

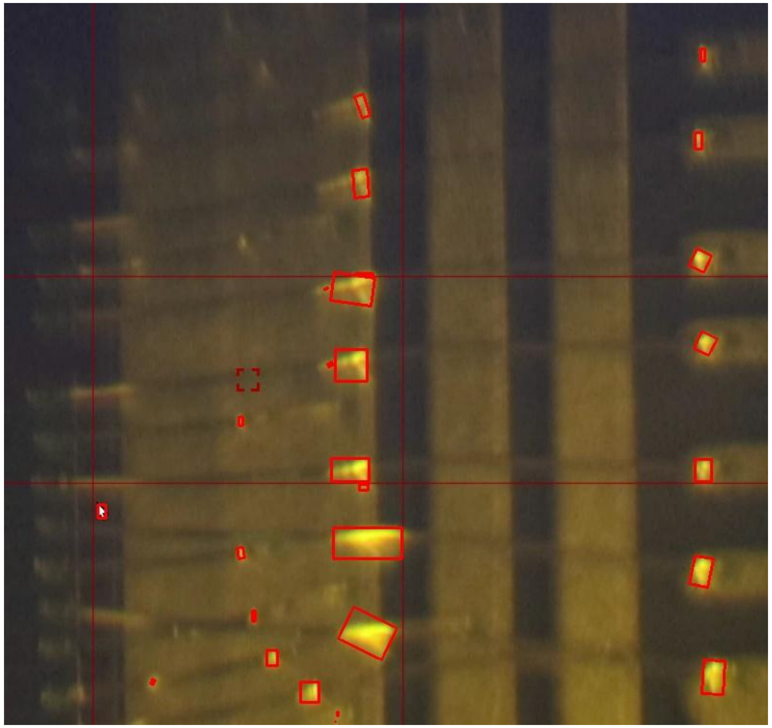


- We cannot see the magnet vibrations in the y-widths (peaks in y-width vs frame number to not relate to magnet vibrations)
- We should be able to see them
- Important closure test for method

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

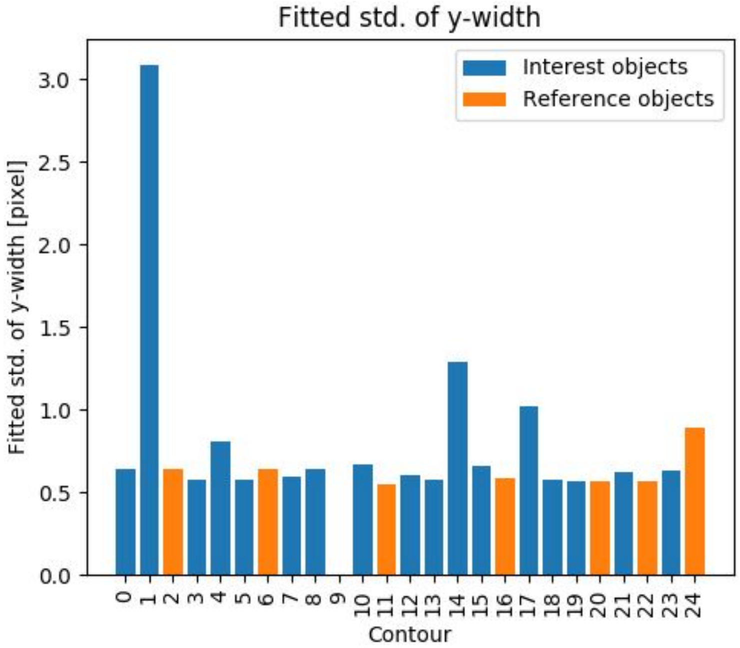
- Does not give desired result, unless we manage to cut away reflections efficiently





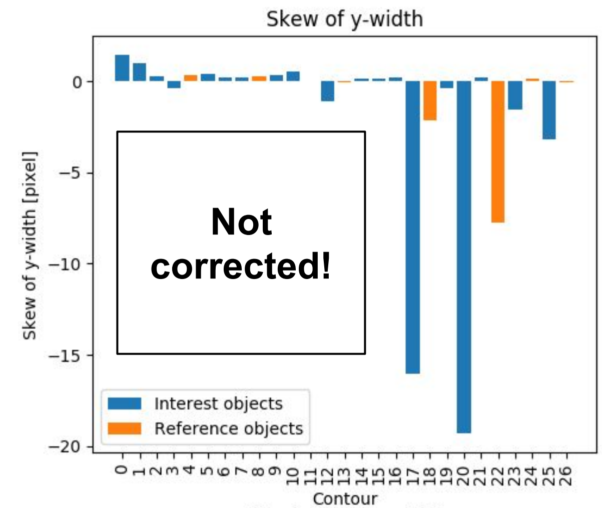
y-widths: Fitted standard deviation

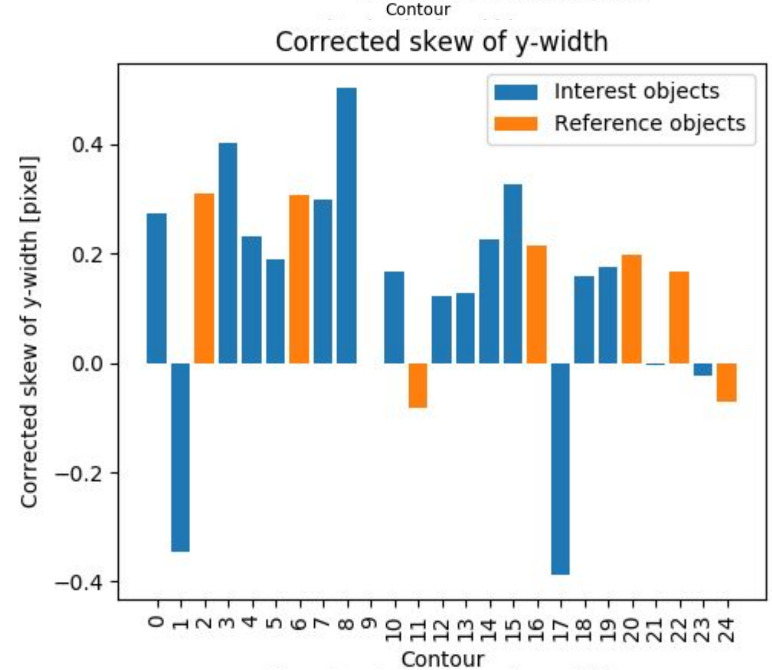
- Here: standard deviation of y-width per contour
- Outlier contour 1:
  - light on contour 1 bad → fluctuations expected
- Outlier contour 14:
  - Small stats, easily merges with contour 15
- Outlier contour 17:
  - Easily merges with contour 18 → either disappears or gets very small



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

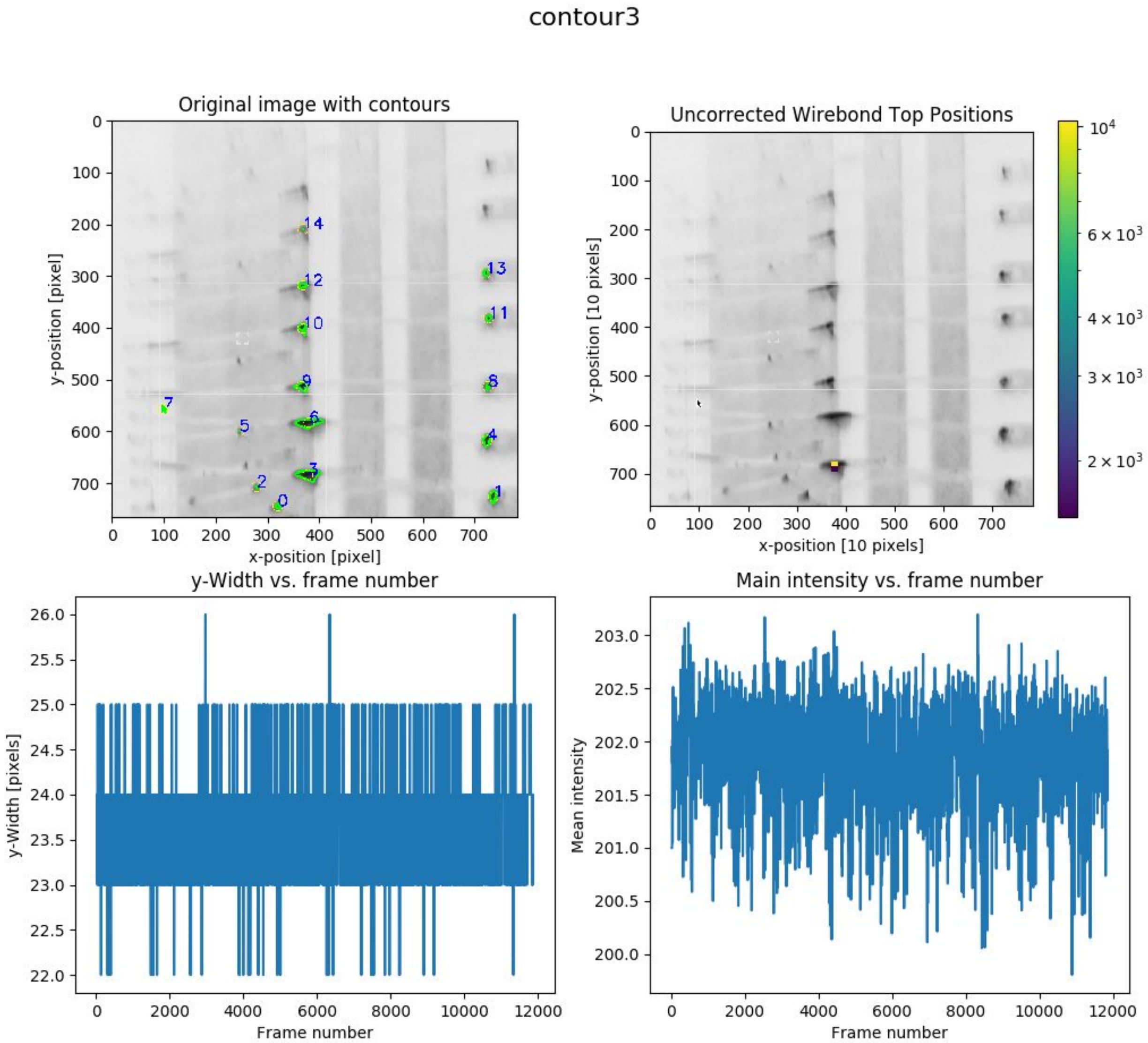
- Histograms with cut created in order to get more meaningful skew
- The skew quantifies how much the distribution deviates from a normal distribution, [definition]
    - Skew > 0: more weight on right side of peak
    - Skew < 0: more weight on left side of peak
- Expect skew > 0 during oscillations
- 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



Contact

DESY.
Deutsches Elektronen-Synchrotron

www.desy.de

Ben Brüers
ATLAS group (Zeuthen)
ben.brueers@desy.de
+49 33762 7-7646