1 mm array

# Progress on NIKA2 future development


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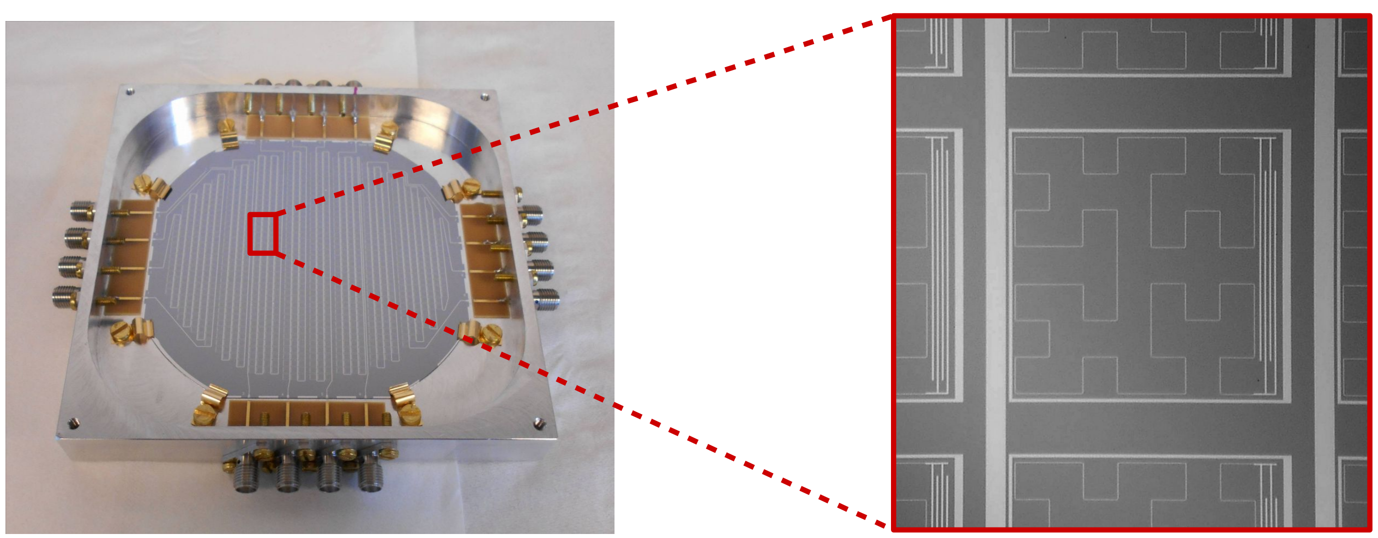
On behalf of the NIKA2 instrument team

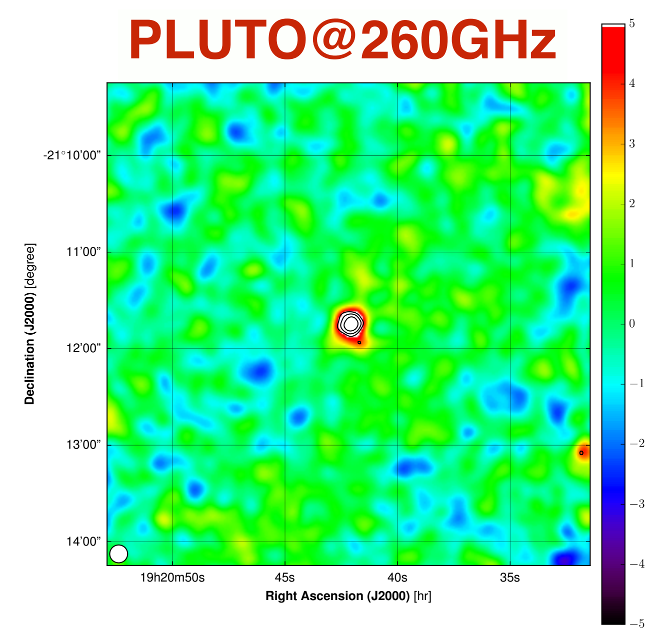
# THE INSTRUMENT: DETECTORS

- Hilbert-type LEKID pixels
- Microstrip feedline
- 18 nm aluminium

| | A1 (1mmV) | A2 (2mm) | A3 (1mmH) |
|---|---|---|---|
| Pixel count | **1140** | **616** | **1140** |
| Pixel size | 2x2 mm$^2$ | 2.8x2.8 mm$^2$ | 2x2 mm$^2$ |
| $F{\cdot}\lambda$ | 1 | 1 | 1 |
| $f_{reso}$ | 1.9–2.5GHz | 0.9–1.4GHz | 1.9–2.5GHz |

- Frequency band determined by substrate thickness (3λ/4 for 1mm = 250 μm)



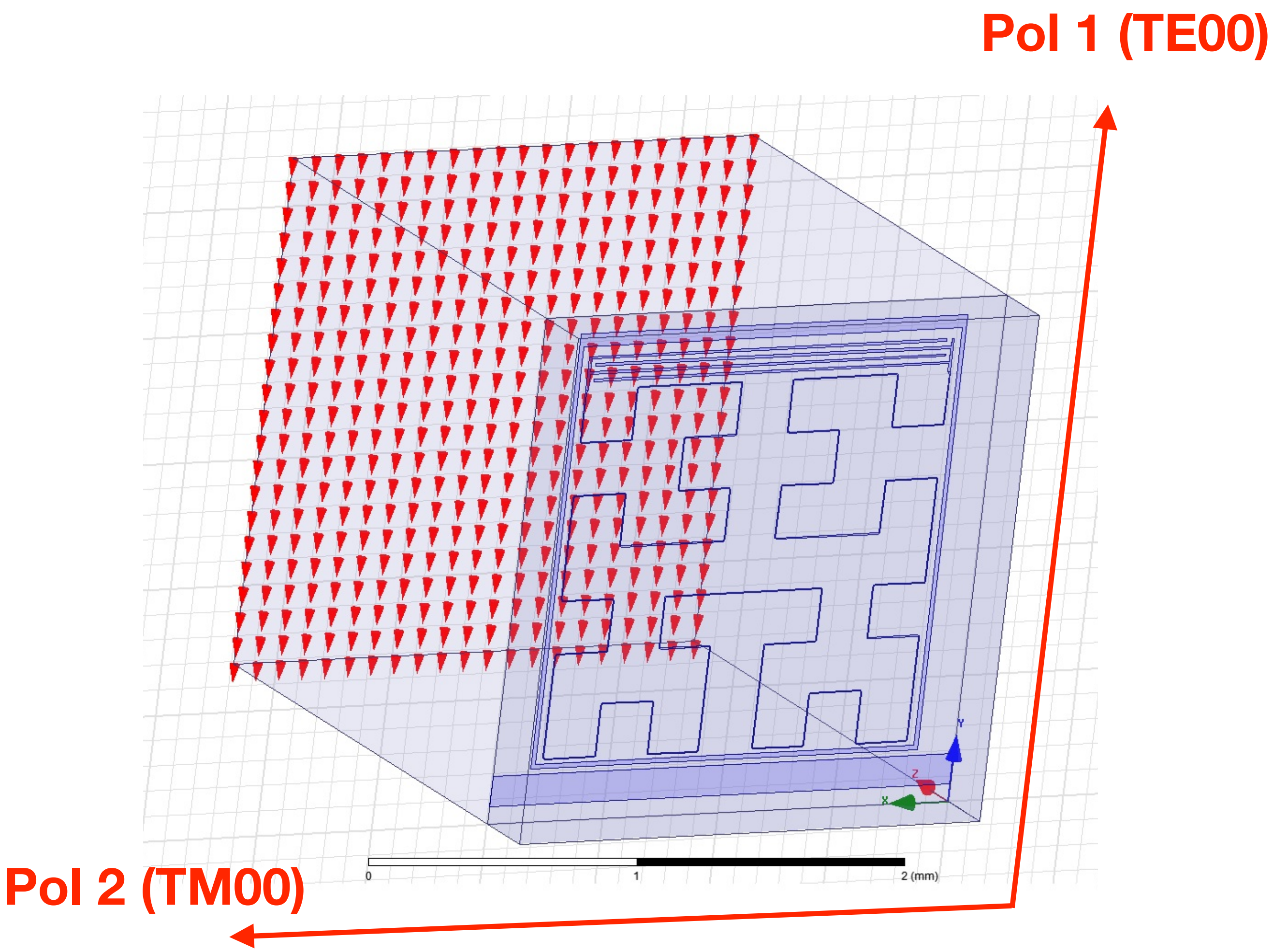


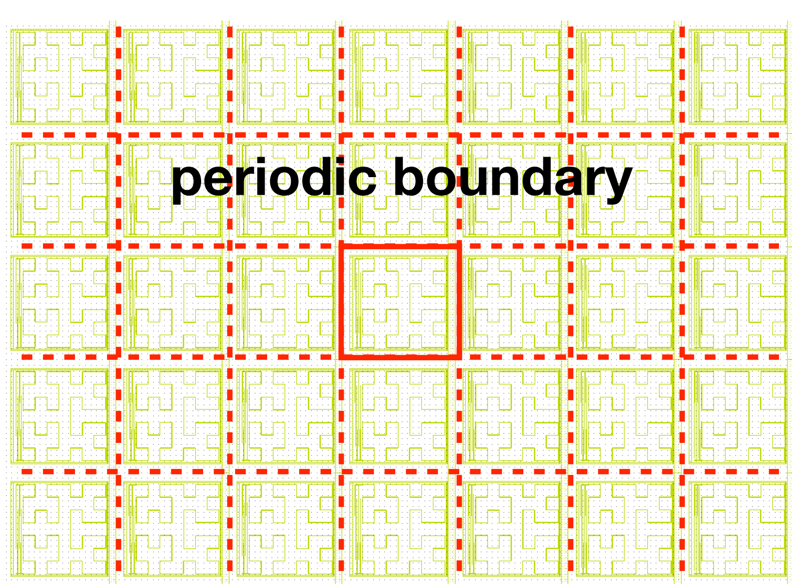

R. Adam et al., A&A **609**, A115 (2018).

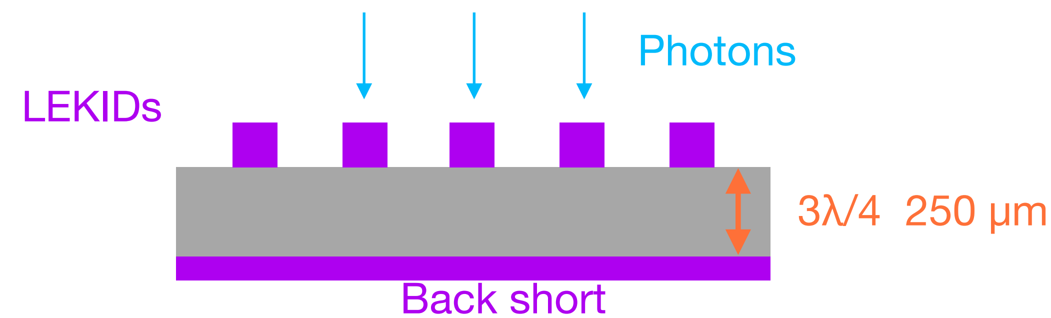
# Future developments of NIKA2

- **Optical response of NIKA2 1mm array**
- Higher angular resolution
- More working pixels
- A 4” full-frame test array

# Optical response of LEKID arrays

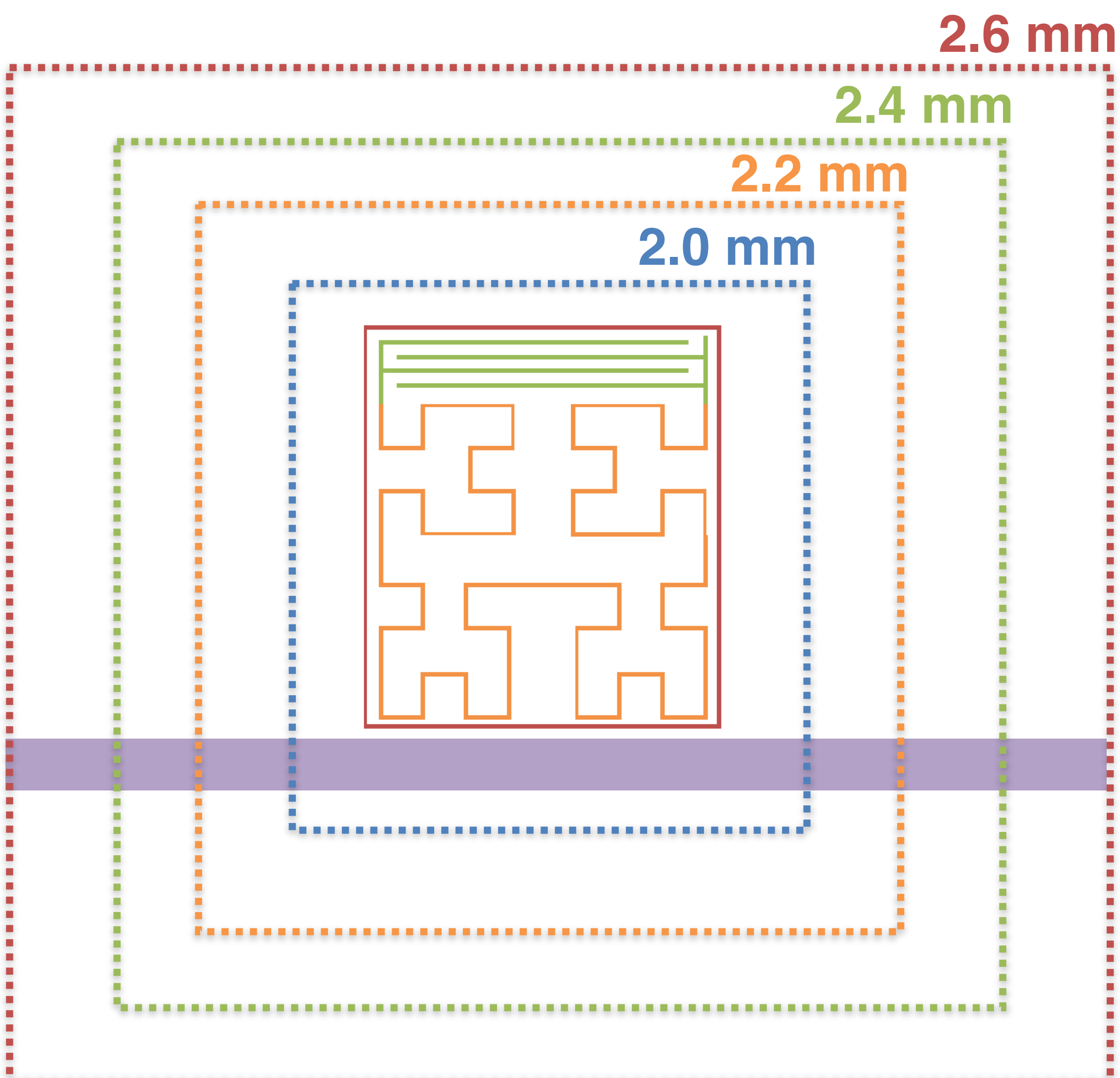



- **Floquet port: a plain wave expansion**
- **18 modes for 150 - 350 GHz**
- **Two polarizations**
- **1.6 Ohm/sq for 20 nm Al**
- **250 µm Si substrate**

# Optical response of LEKID arrays




inductor area: 1.5*1.6 mm$^2$

$$\text{filling factor} = \frac{\text{inductor area}}{\text{pitch size}^2}$$

| Pitch size [mm] | filling factor | Pol 1 | Pol 2 |
|---|---|---|---|
| 2.0 | 60.0% | 61.7% | 41.2% |
| 2.2 | 49.6% | 48.2% | 35.8% |
| 2.4 | 41.7% | 44.8% | 31.0% |
| 2.6 | 35.5% | 41.7% | 28.4% |

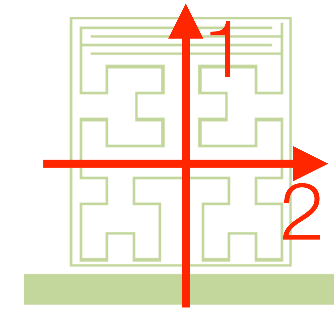
Averaged absorption efficiency

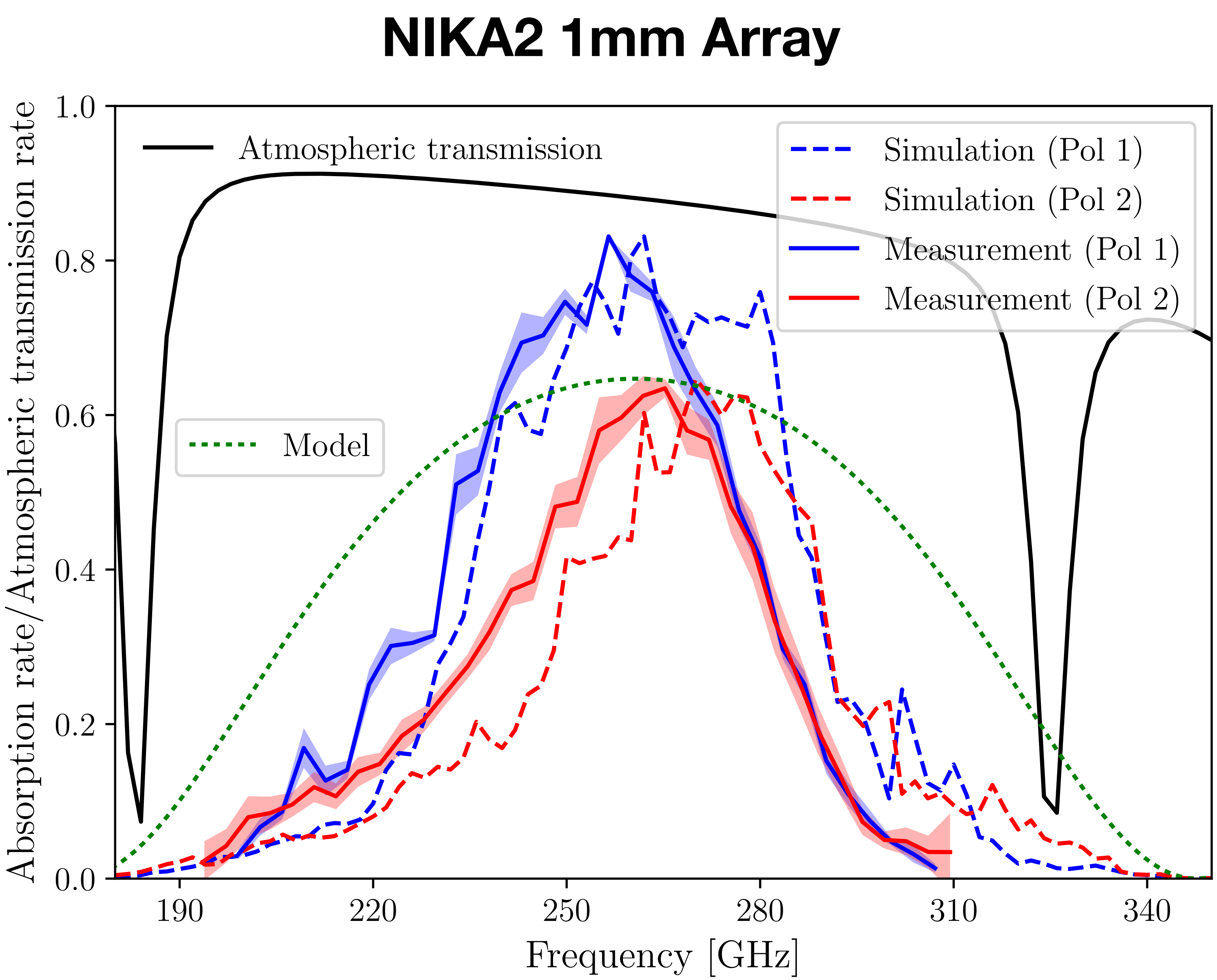
Absorption efficiency of inductor (230 - 290 GHz)

≈ 100% for Pol 1

≈ 70% for Pol 2

# Optical response of LEKID arrays



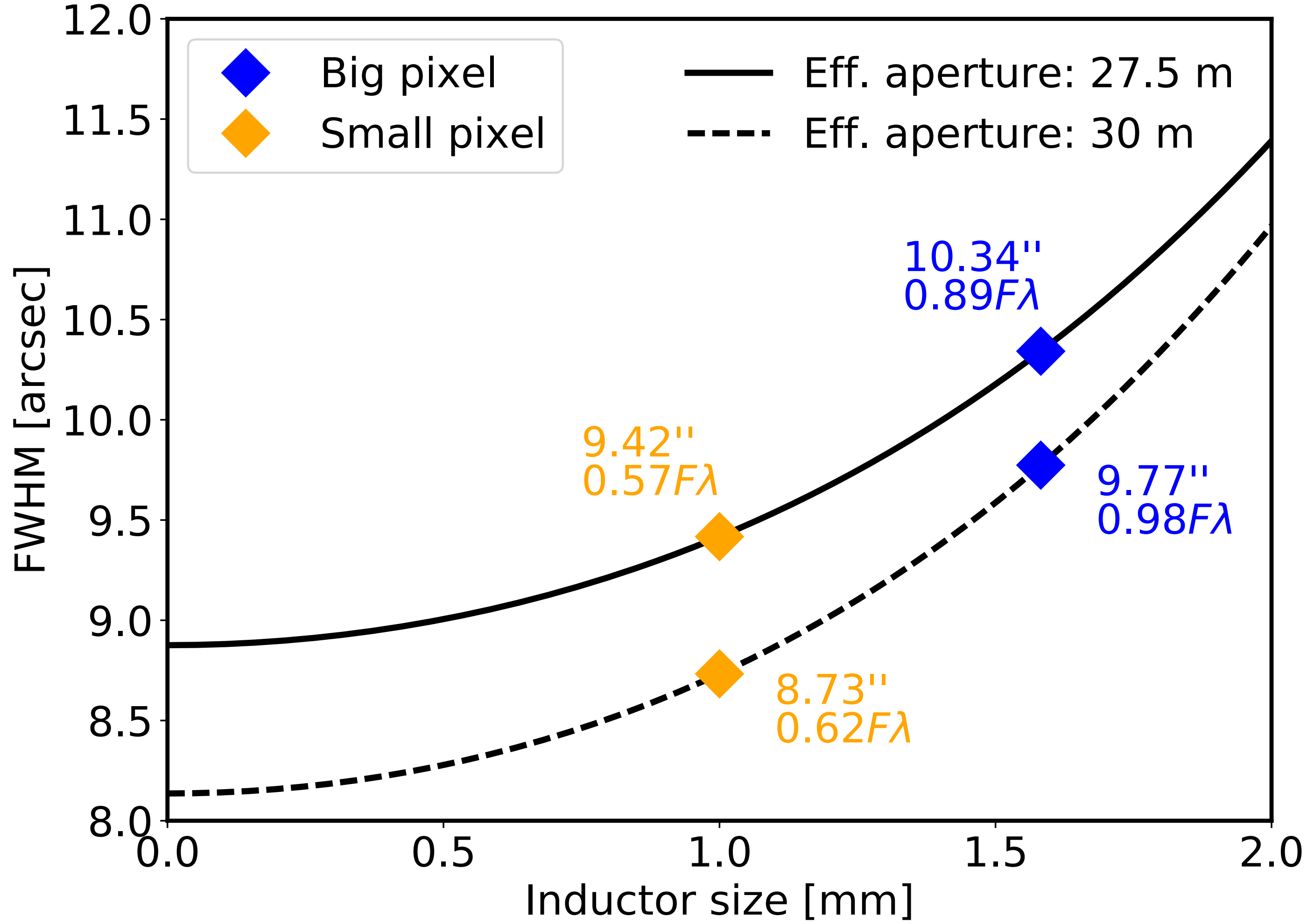

| Average absorption (230-290 GHz) | Pol 1 | Pol 2 |
|---|---|---|
| All components together | 73.1% | 50.5% |
| Other components than the inductor | 10.9% | 9.3% |
| **Inductor only** | 61.7% | 41.2% |
| **Model** | 61.5% | |
| Measurement (220-280 GHz) | 60.0% | 42.2% |

- **Si wafer thickness:**
  **250 µm -> 260 µm = 10 GHz shift**

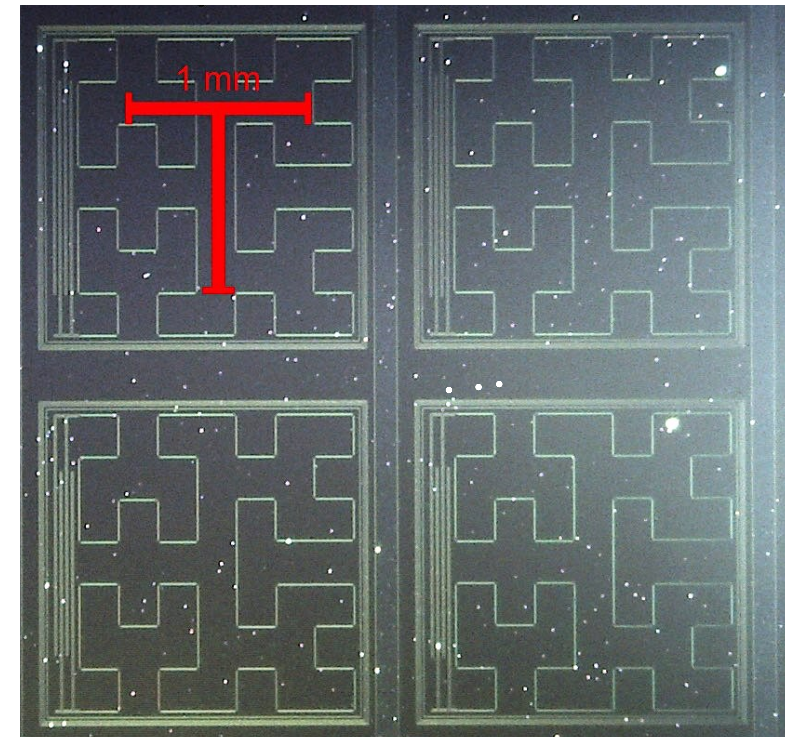
# Future developments of NIKA2

- Optical response of NIKA2 1mm array
- **Higher angular resolution**
- More working pixels
- A 4” full-frame test array

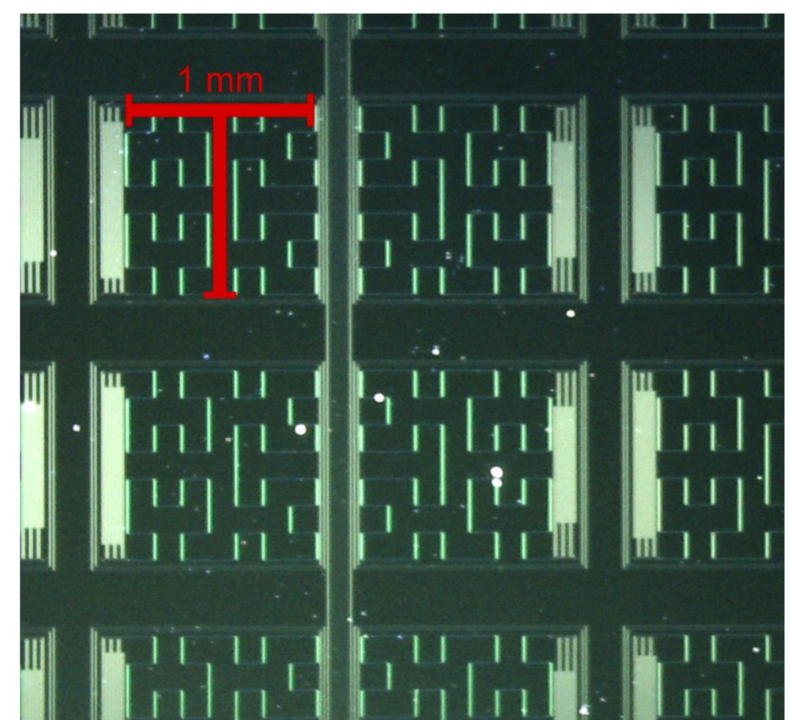
# High angular resolution pixel




- Diffraction limit of the 30-m telescope
- Lower the confusion limit
- Doubled number of pixel
- Smaller inductor volume

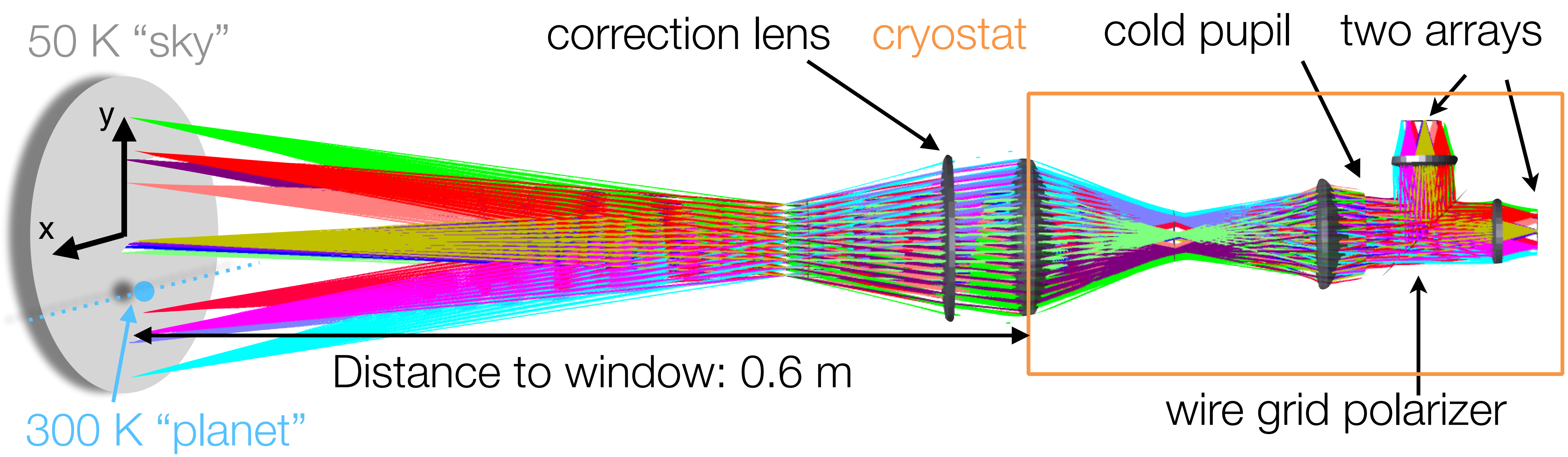



Big pixel array

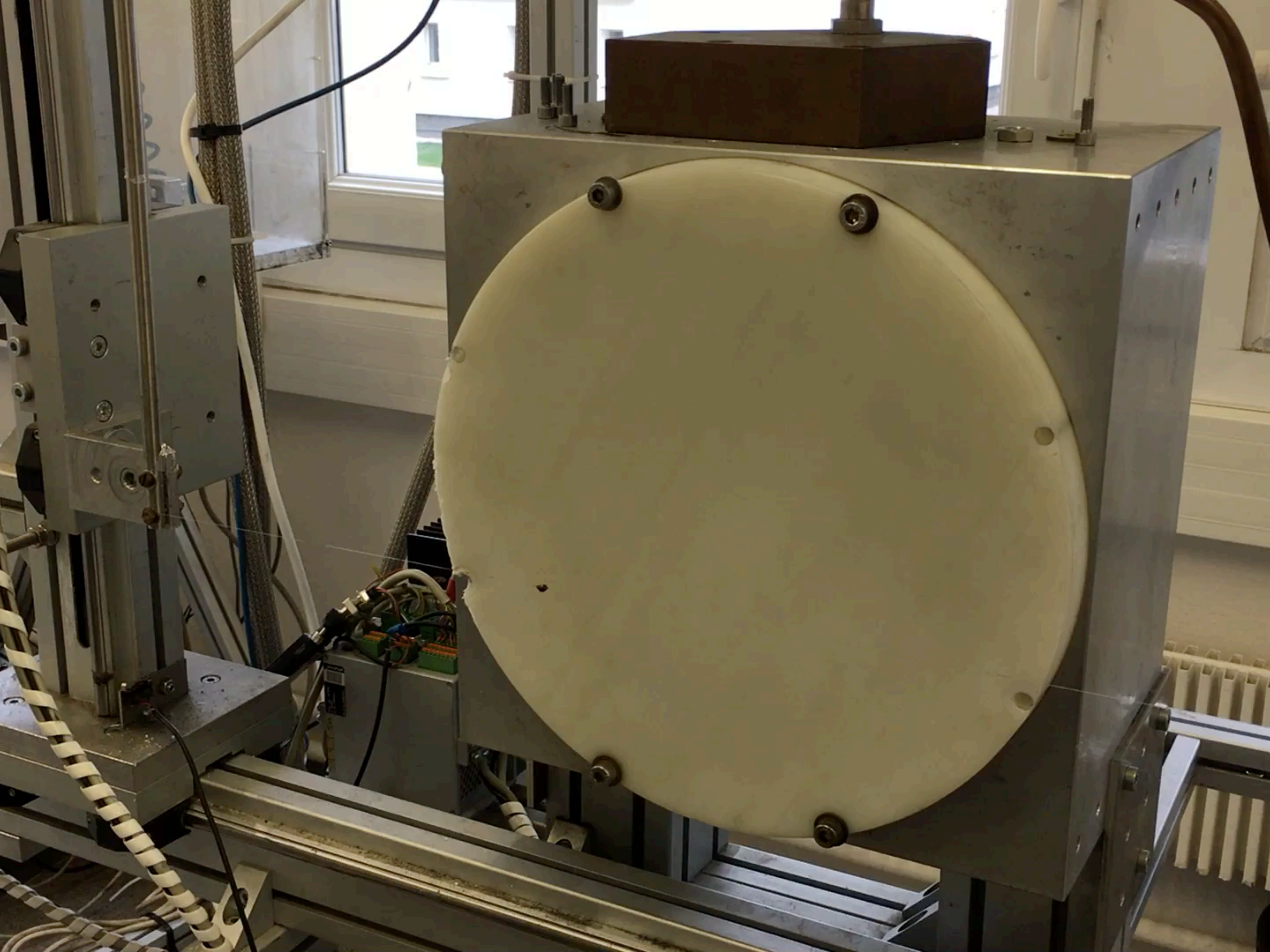



Small pixel array

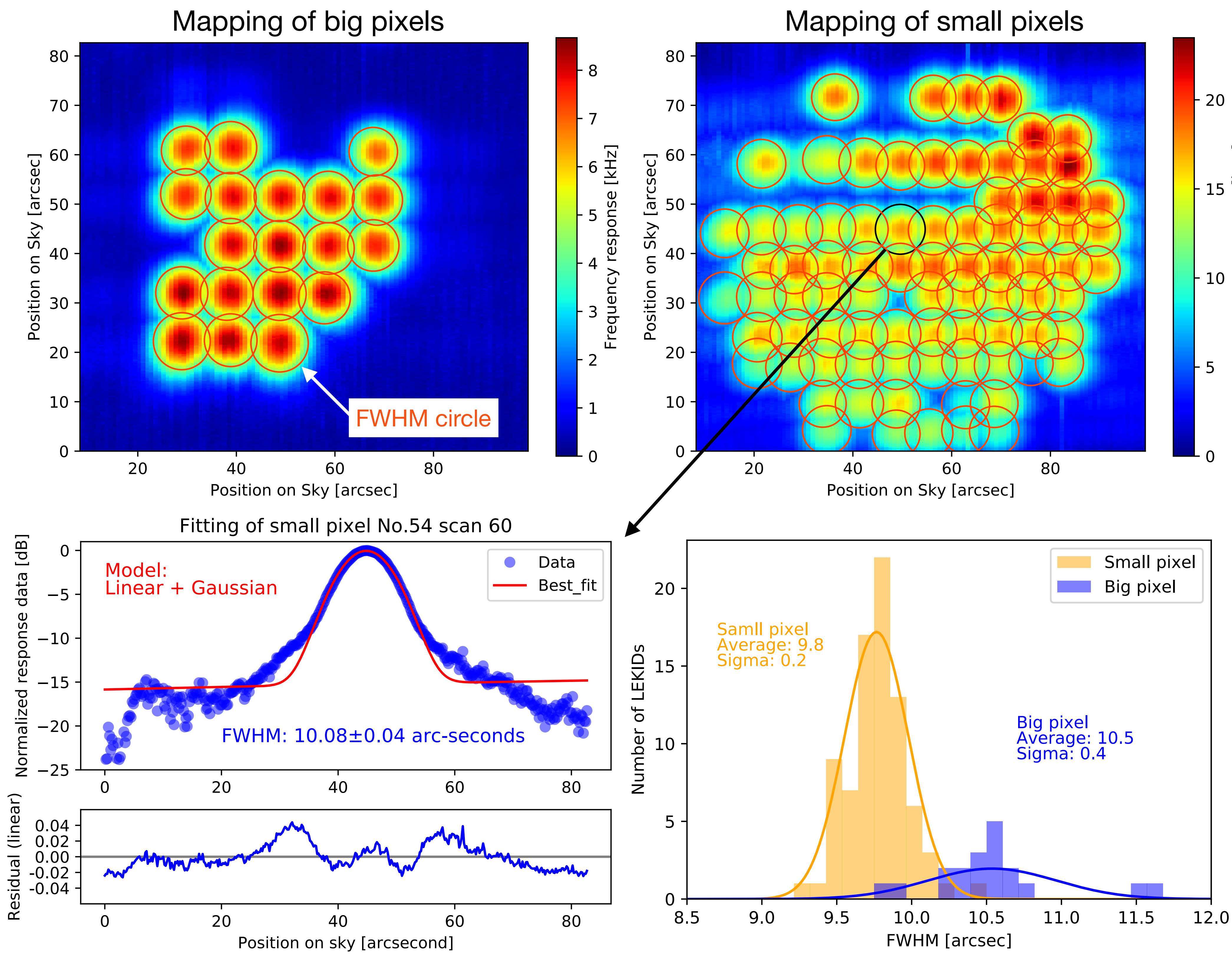
# High angular resolution pixel



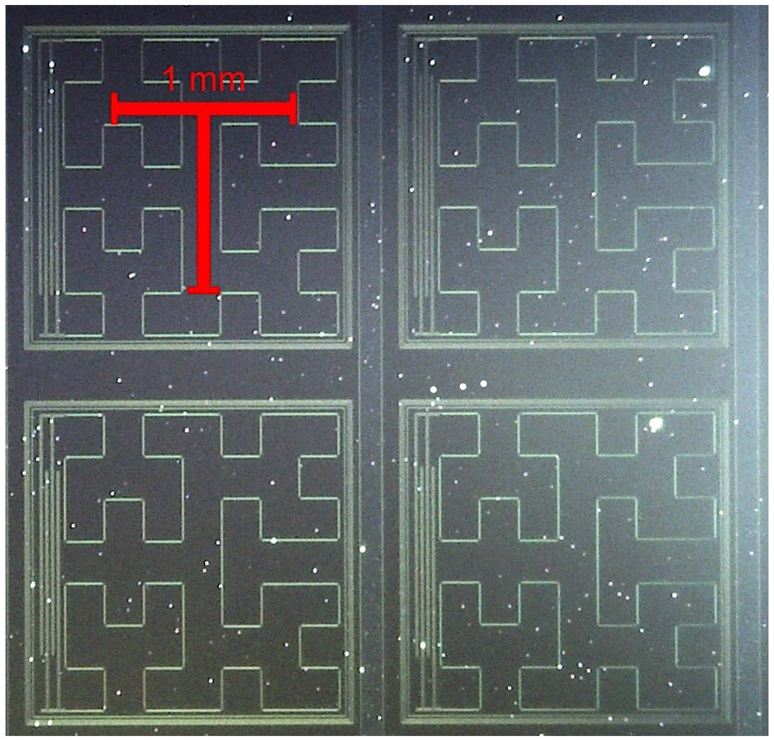

- the planet image on focal plane <-> point spread function on telescope
- Mapping: move the planet in y-direction at fixed x position
- X step: 1 mm = 0.17 mm on the array
- The metal ball diameter: 4 mm (0.68 mm on the array)



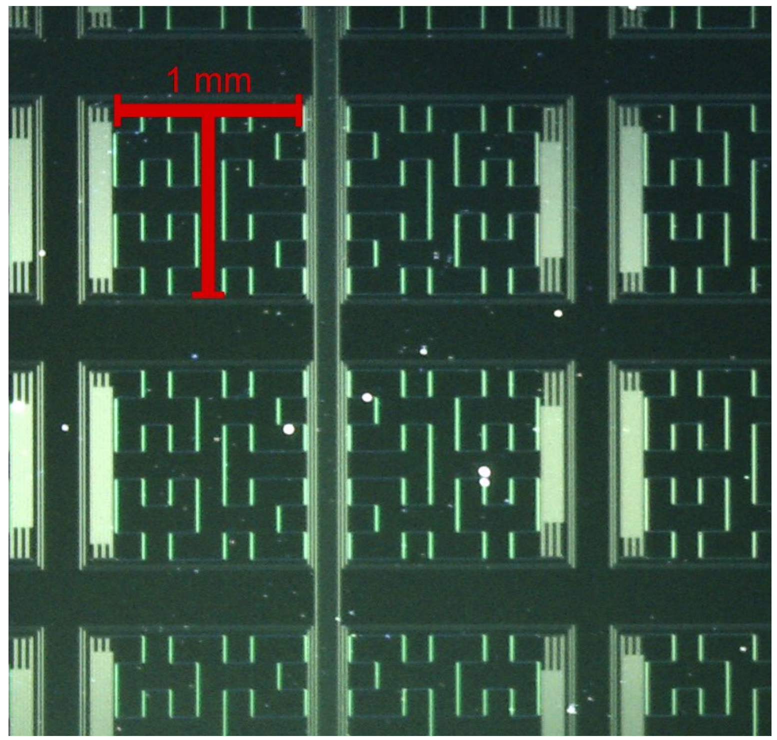
# High angular resolution pixel



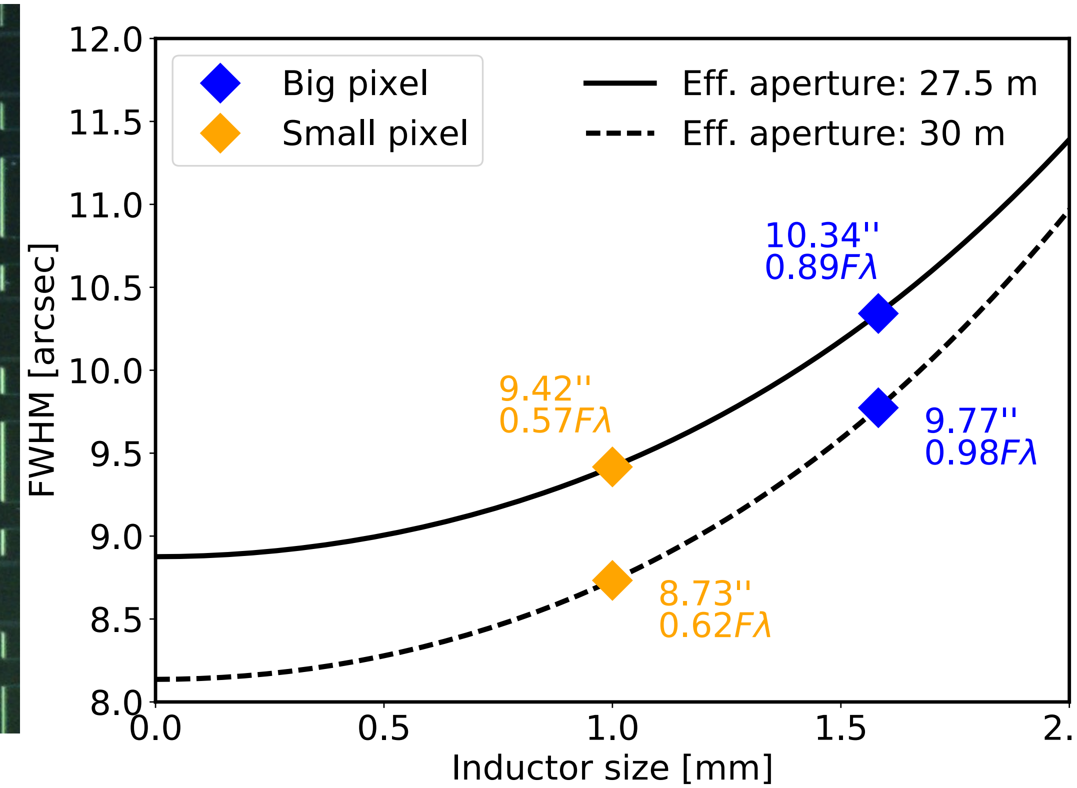
# High angular resolution pixel




Big pixel array




Small pixel array

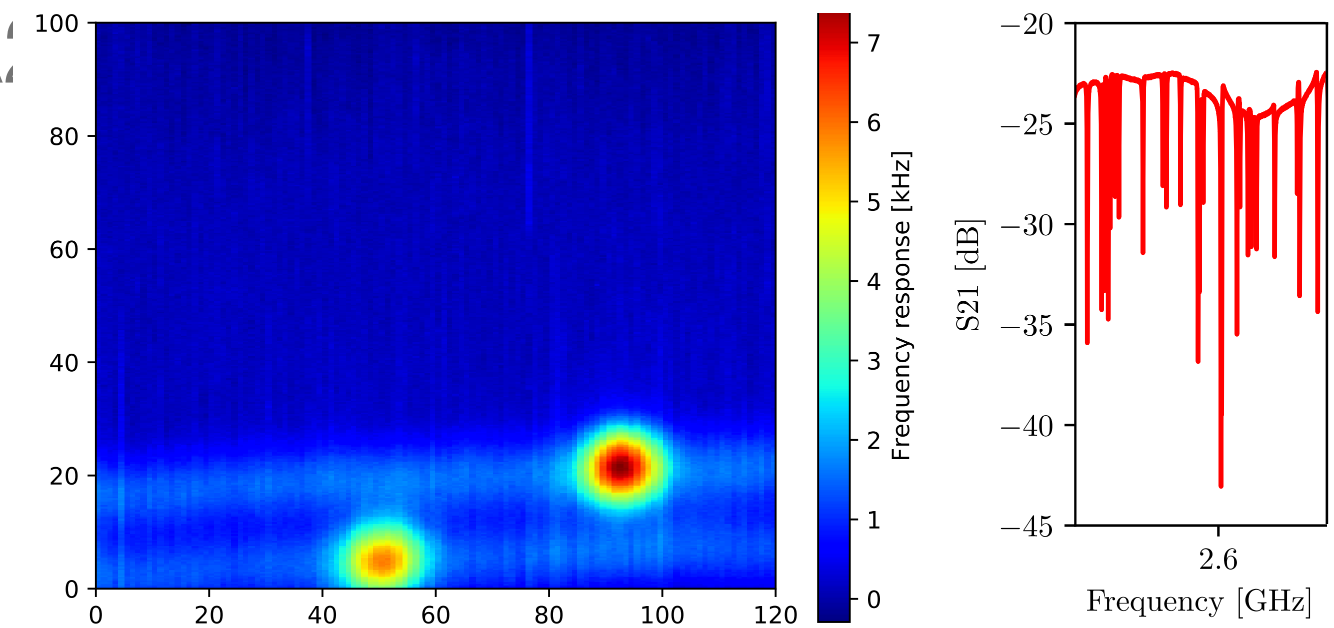



| | Inductor size [mm$^2$] | Inductor volume | Pitch [mm$^2$] | Resolution in-lab | Resolution on-sky | Responsivity [kHz] |
|---|---|---|---|---|---|---|
| Big pixel | $1.6 \times 1.5$ | $1149\,\mu m^3$ | $2 \times 2$ | $10.5 \pm 0.4''$ | $10.9''$[9] | $106 \pm 6$ |
| Small pixel | $1.0 \times 1.0$ | $449\,\mu m^3$ | $1.4 \times 1.4$ | $9.8 \pm 0.2''$ | $10.2''$(expected) | $202 \pm 32$ |

$$\text{Responsivity} \propto \frac{\alpha Q}{V} = 1.7$$

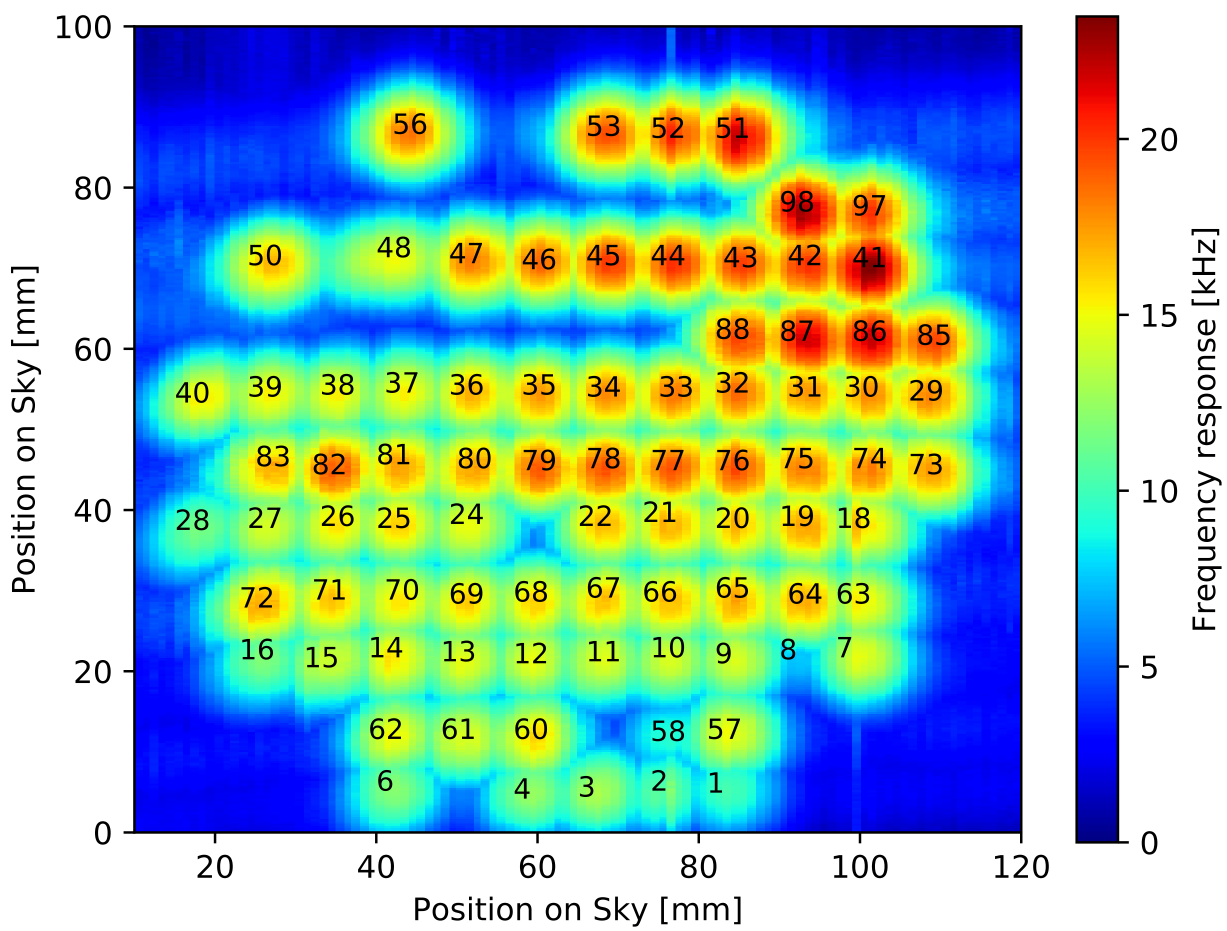
# Future developments of NIKA2

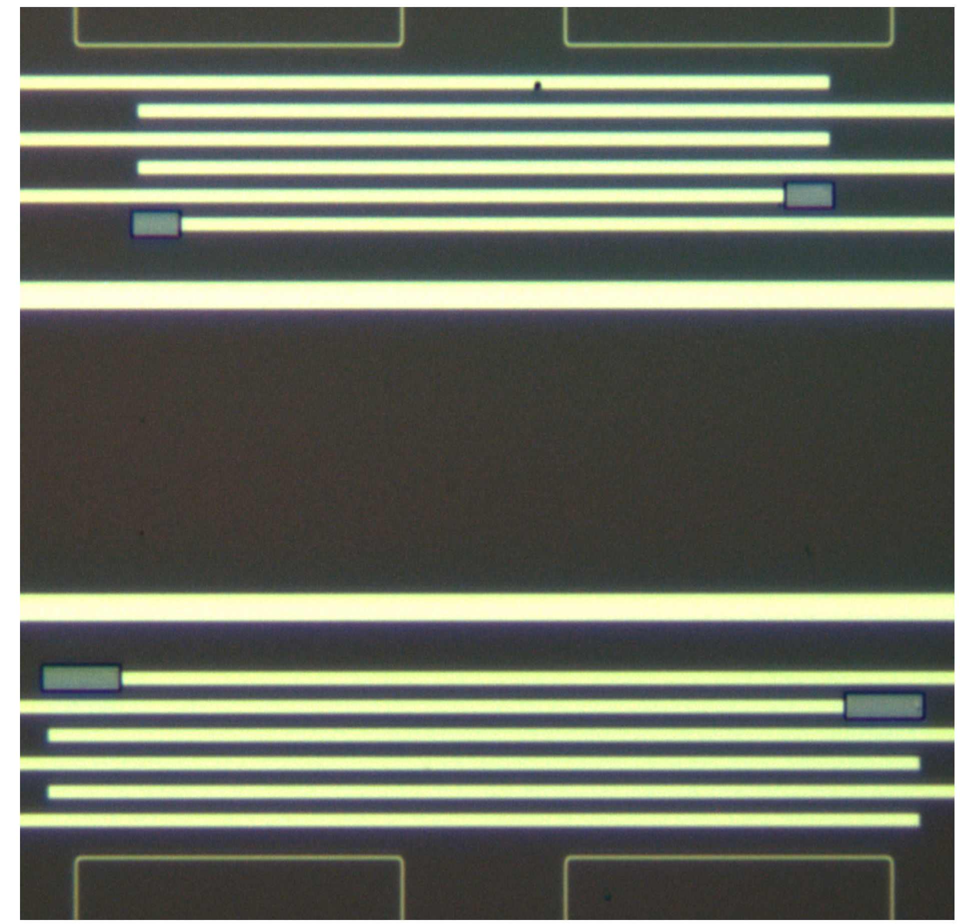
- Optical response of NIKA
- Higher angular resolution
- **More working pixels**

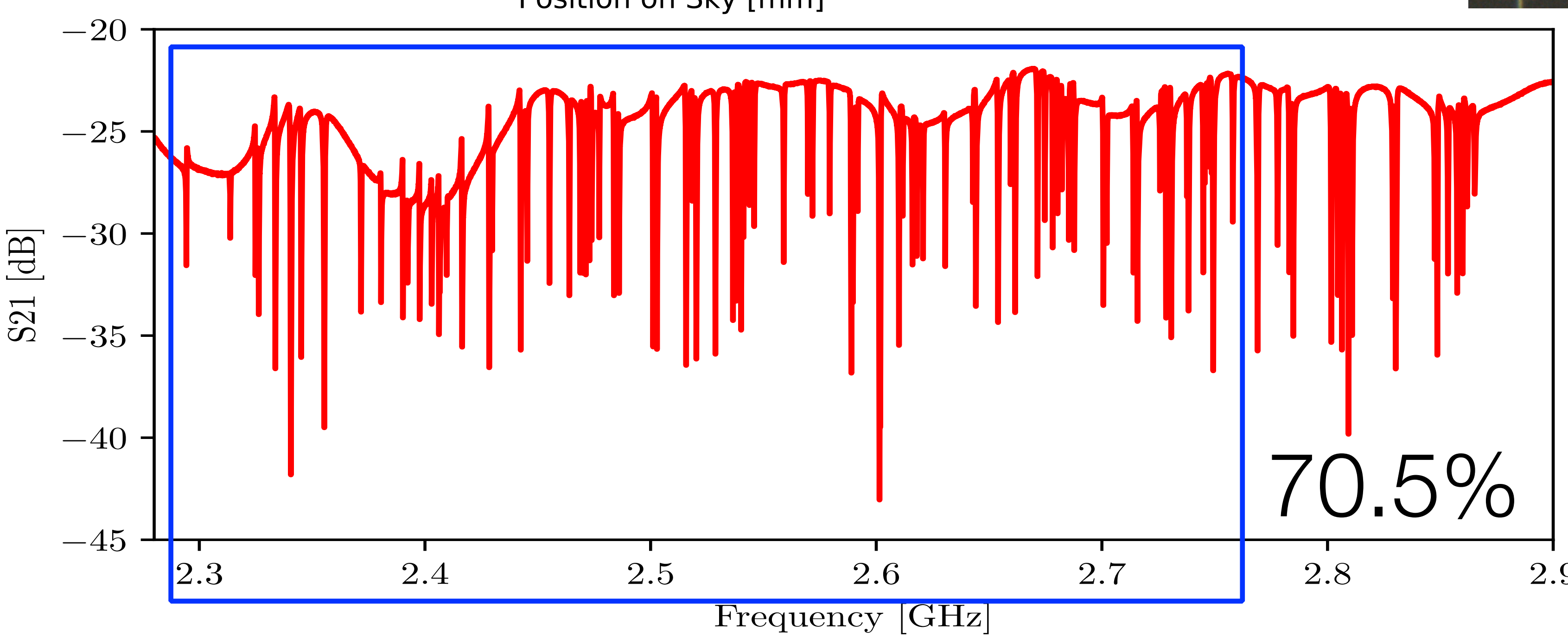



| Wavelength (central) [mm] | 2.0 | 1.2 | 1.2 (A1) | 1.2 (A3) |
|---|---|---|---|---|
| Frequency (central) [GHz] | 150 | 260 | | |
| Measured central frequency [GHz] | 152 | 257 | 256 | 258 |
| NEFD(1) [mJy×s$^{1/2}$/beam] goal | 10 | 15 | | |
| NEFD(1) [mJy×s$^{1/2}$/beam] specification | 20 | 30 | | |
| Measured NEFD(1) [mJy×s$^{1/2}$ /beam] | $\lesssim$ 10 [TBC] | $\lesssim$ 40 [TBC] | $\lesssim$ 60 [TBC] | $\lesssim$ 50 [TBC] |
| Fraction of usable pixels (KID) | 90 % | 84 % | 84 % | 84 % |
| Fraction of used pixels (KID) | 70% | 60% | 58% | 64% |

# Trimming KIDs

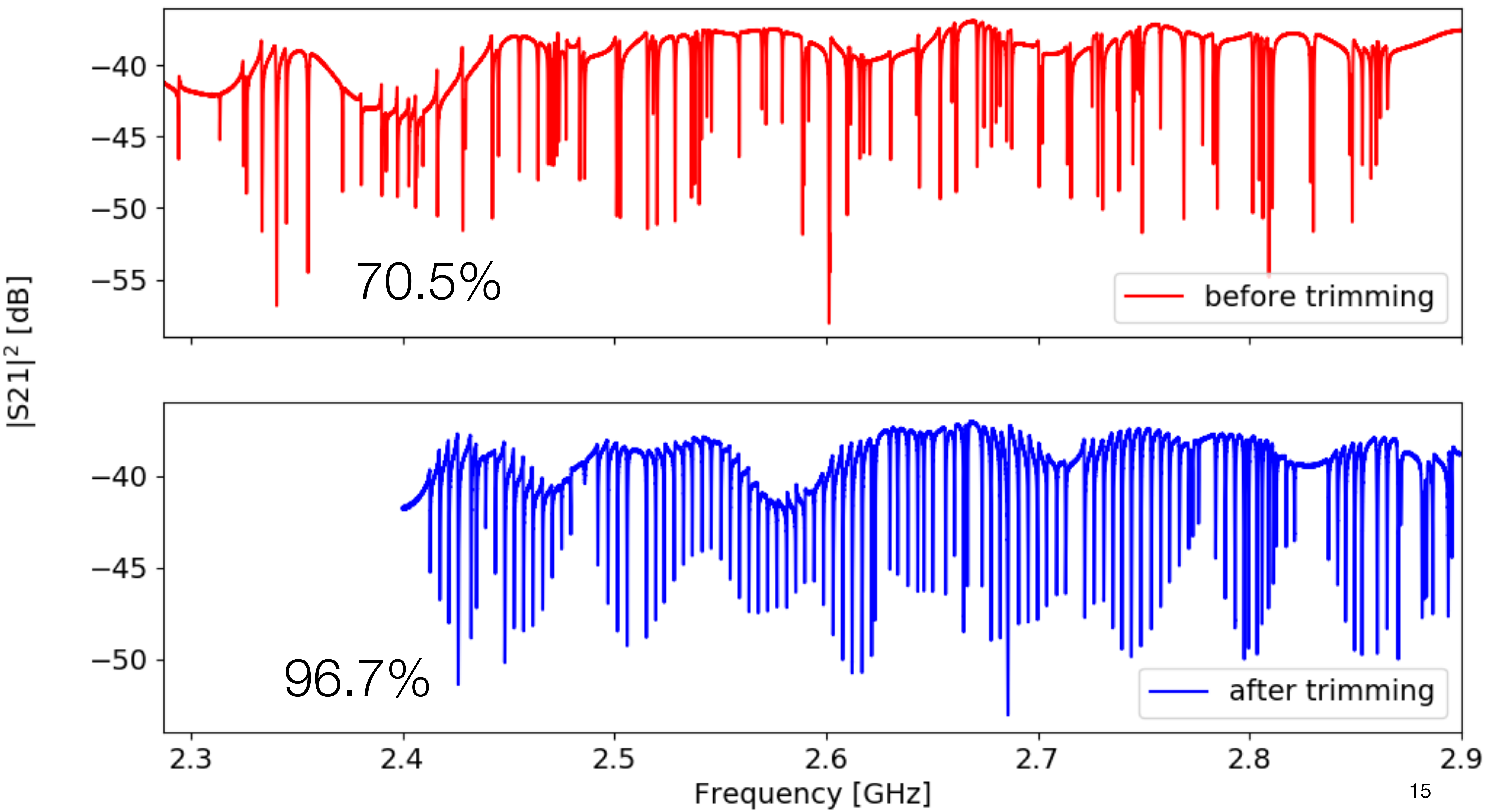


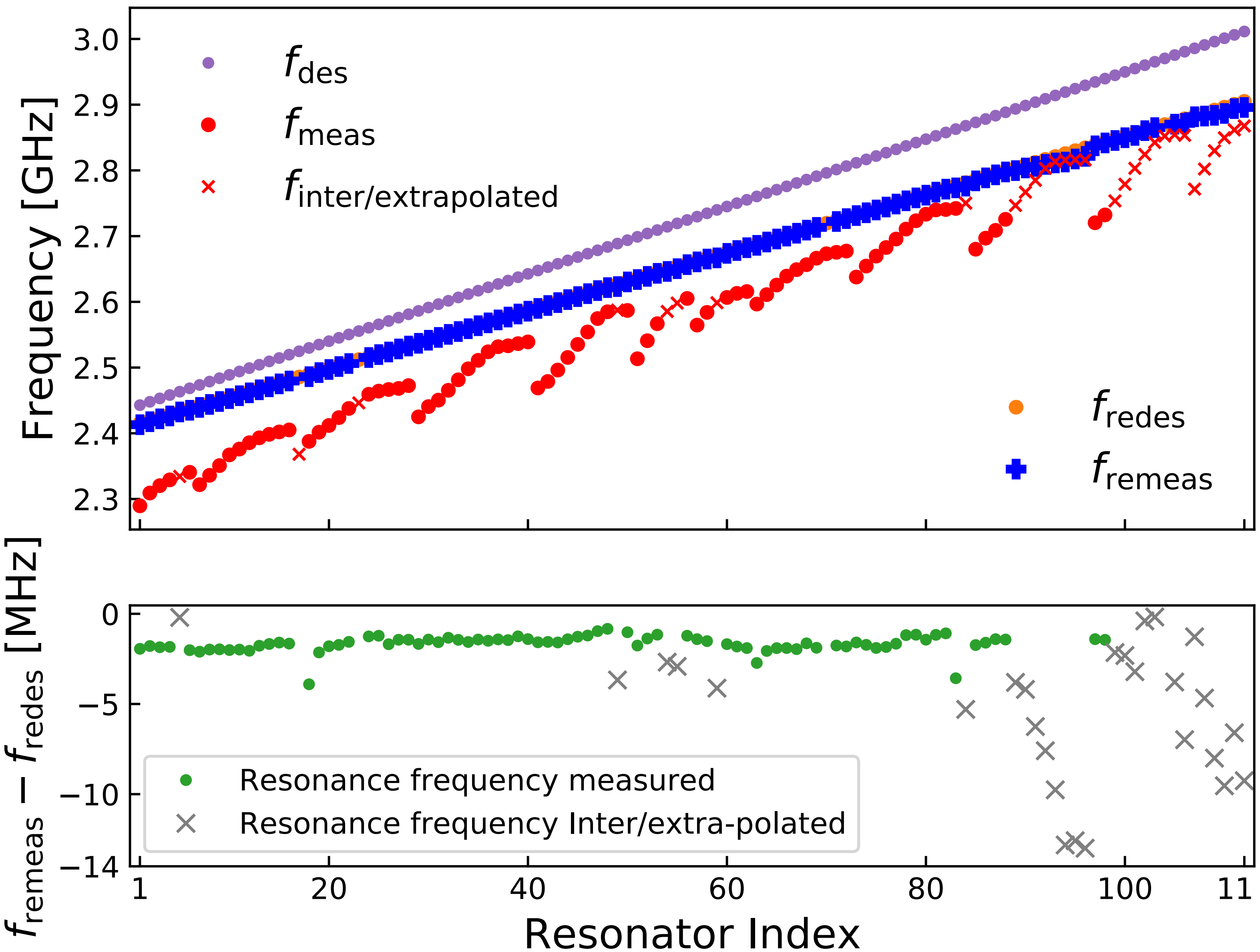


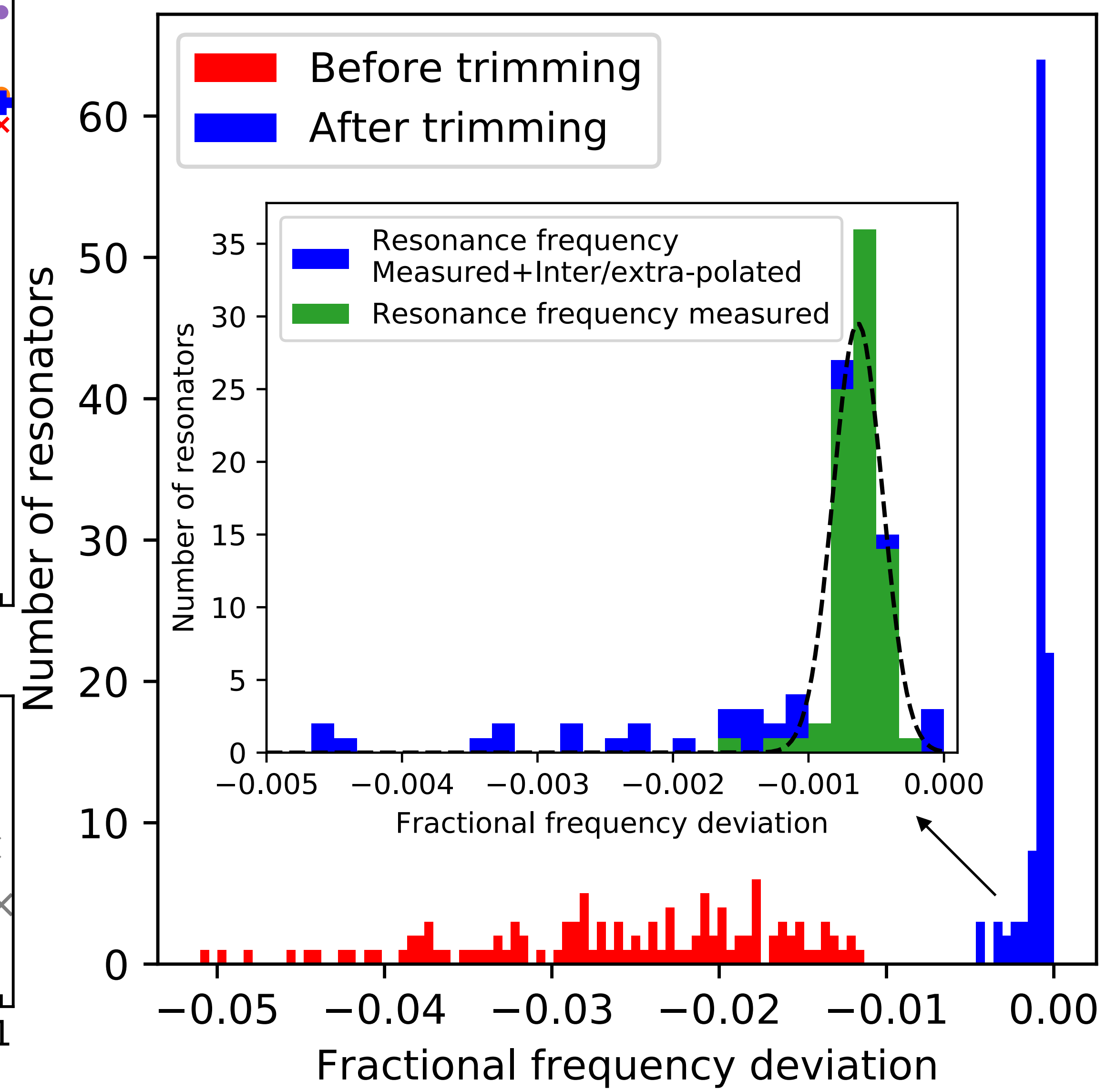

- Frequency collision
- Limited bandwidth

# Trimming KIDs



# Trimming KIDs

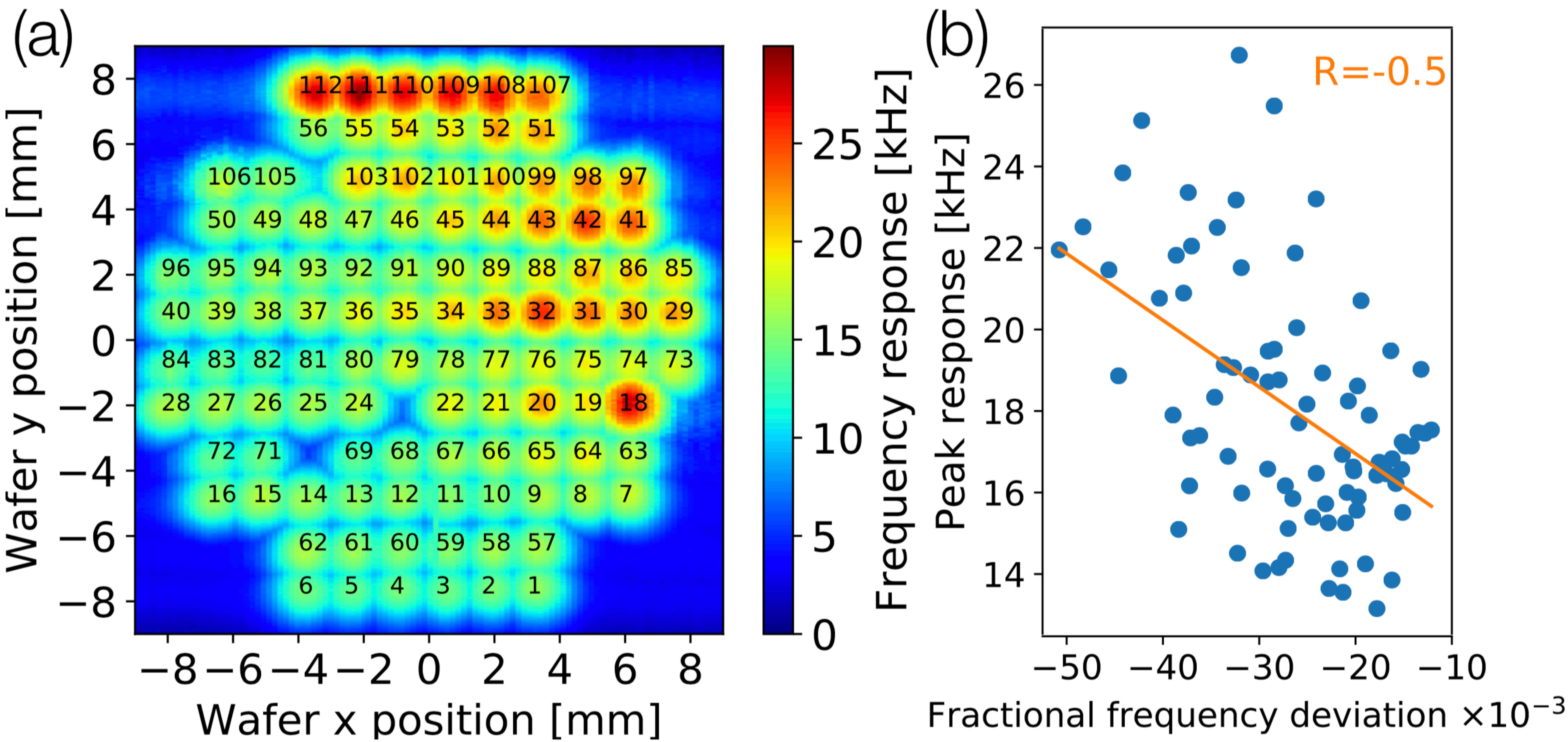



- Absolute deviation $f_{meas}$-$f_{des}$: μ=-1.7 MHz σ=0.46 MHz
- Fractional deviation ($f_{meas}$-$f_{des}$)/$f_{des}$: μ=-6.4e-4 σ=1.8e-4

Shu et al. (2018) APL, 113(8), 082603

# Trimming KIDs



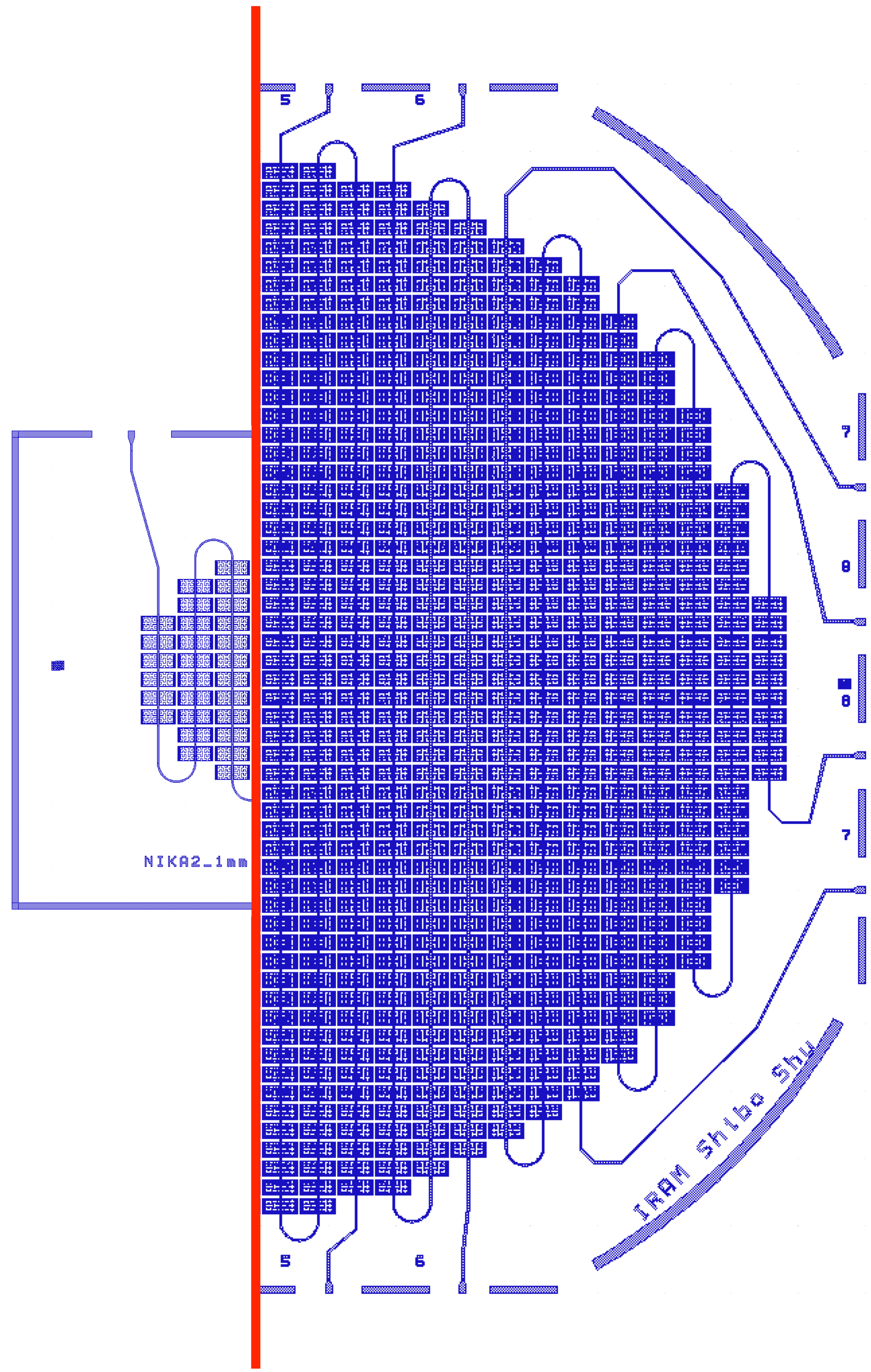

108 out of 112 pixels: 96.7%

# Future developments of NIKA2

- Optical response of NIKA2 1mm array
- Higher angular resolution
- More working pixels
- **A 4" full-frame test array**

iram
Institut de Radioastronomie Millimétrique

# A 4” full-frame test array




Trimming test array

- 1-inch wafer
- 112 pixels
- 1*500 MHz
- 112 pixels per readout line
- 4.5 MHz spacing
- Filling factor: 51%
- Trimming accuracy 0.25-0.5MHz

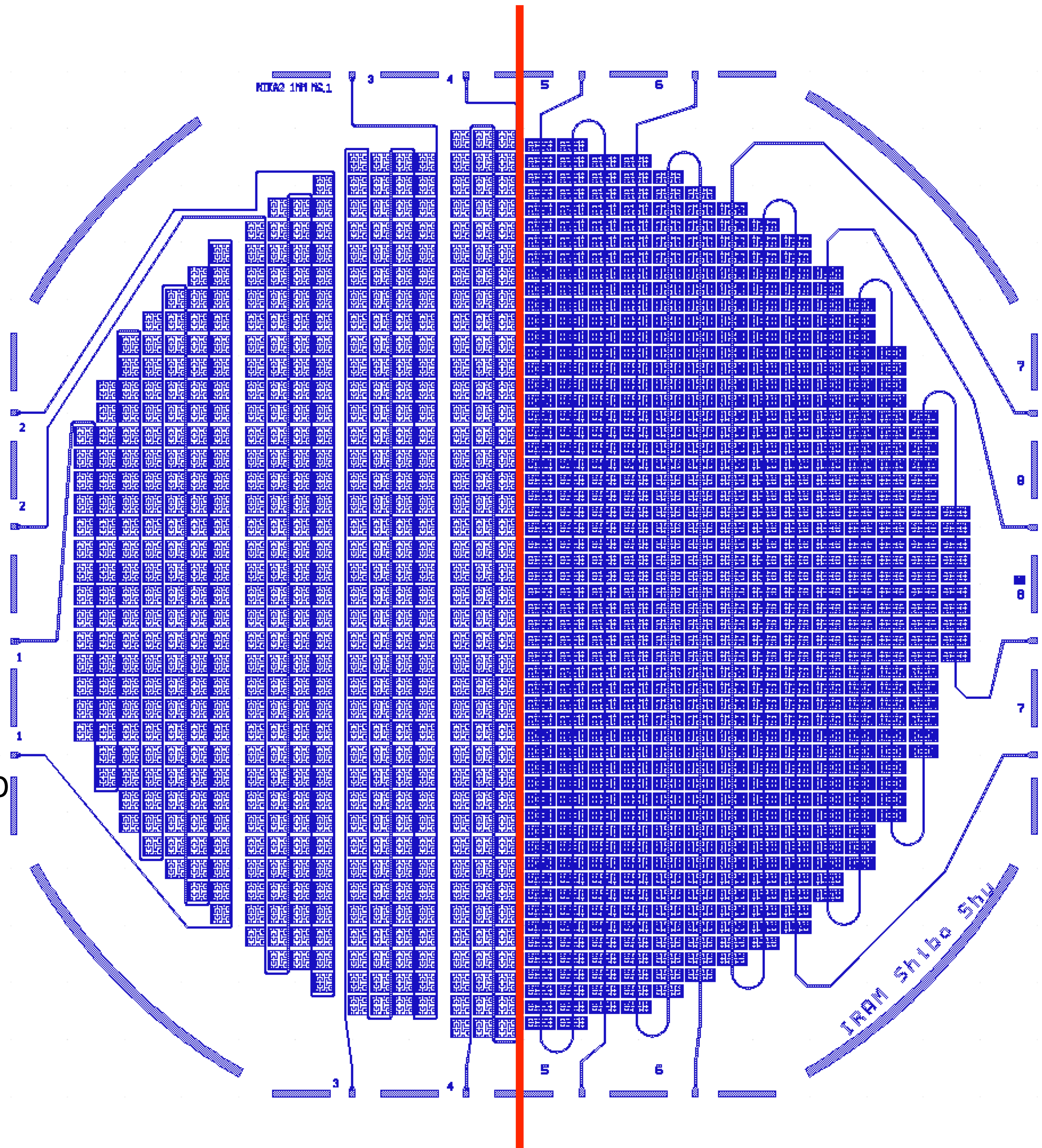
New 1mm array

- 4-inch wafer
- 2392 pixels
- 8*500 MHz
- ~300 pixels per readout line
- 1.6 MHz spacing
- Filling factor: 51%
- Trimming accuracy 0.18-0.44MHz

# A 4” full-frame test array

Current 1mm array

- 4-inch wafer
- 1140 pixels
- 8*500 MHz
- ~140 pixels per readout line
- 3.6 MHz spacing
- Filling factor: 60%




New 1mm array

- 4-inch wafer
- 2392 pixels
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- ~300 pixels per readout line
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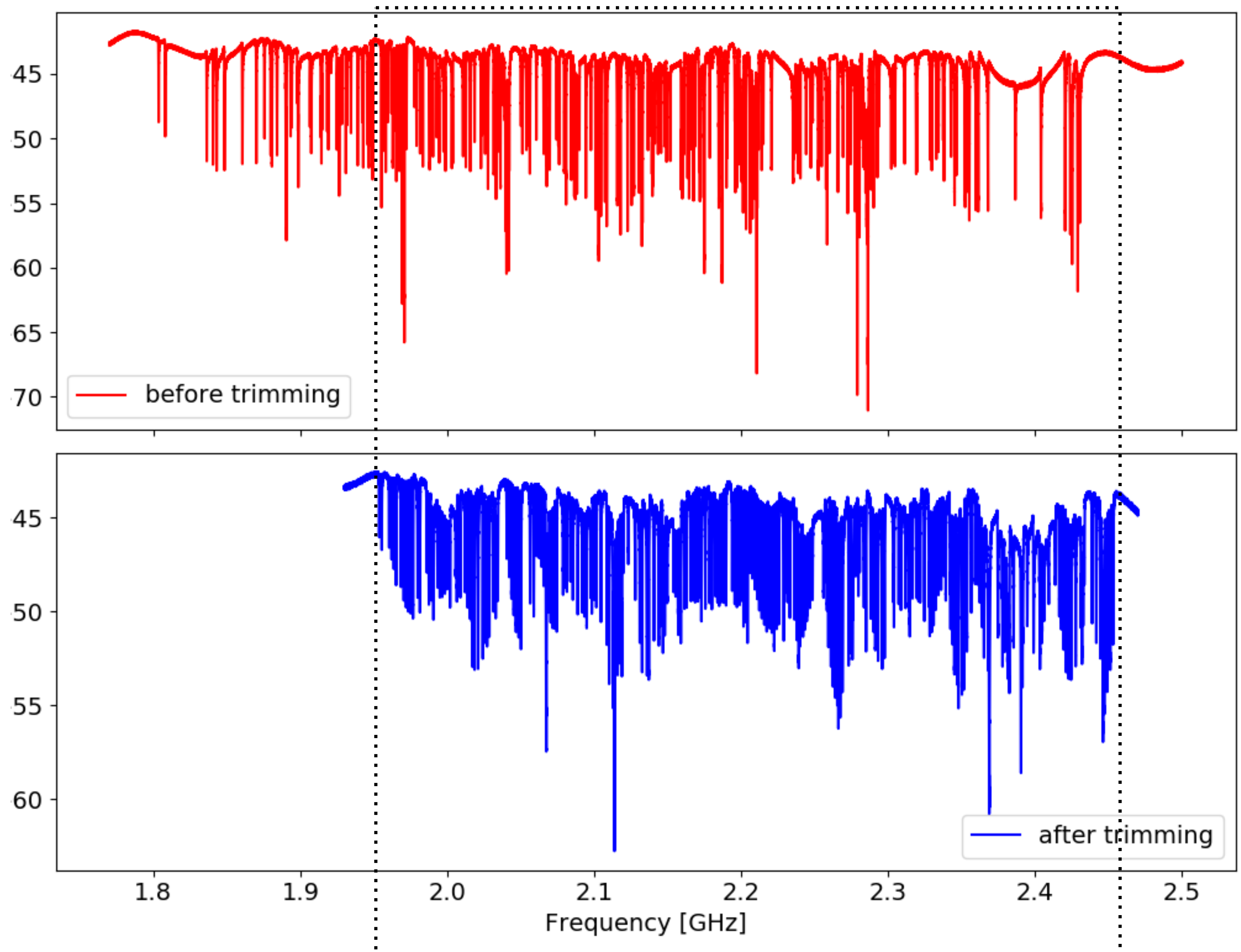
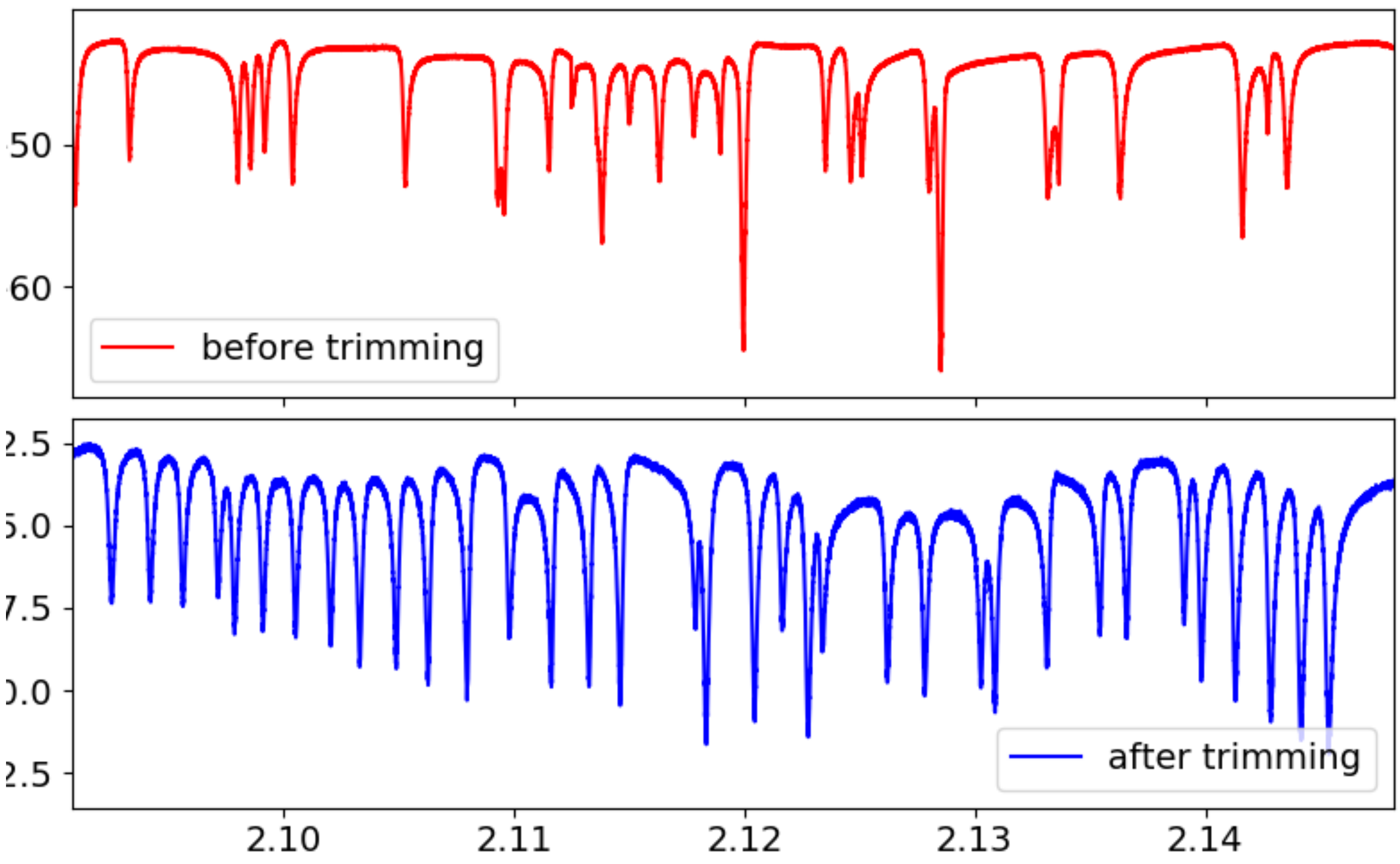
- Trimming accuracy 0.18-0.44MHz

# A 4” full-frame test array

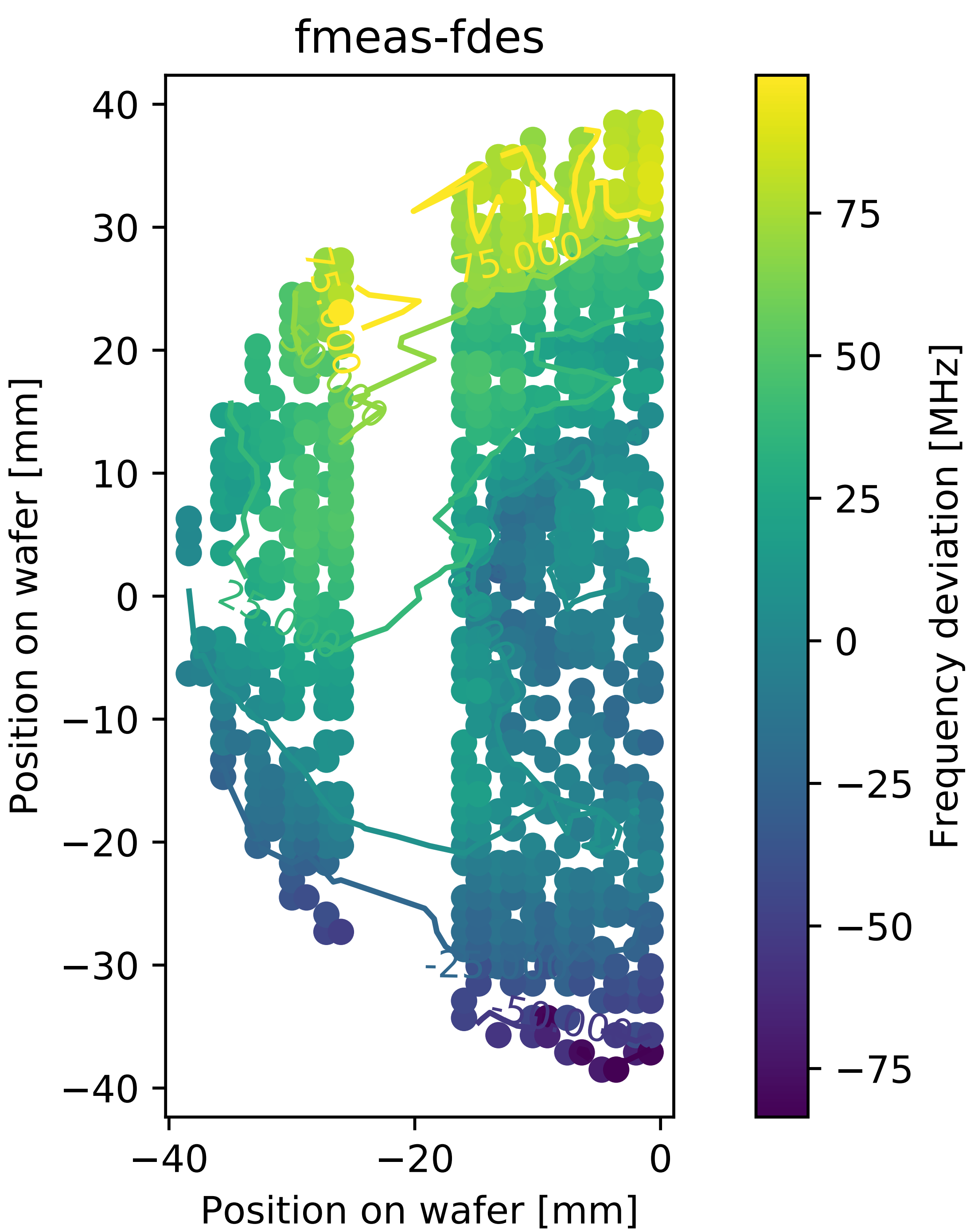


# A 4” full-frame test array

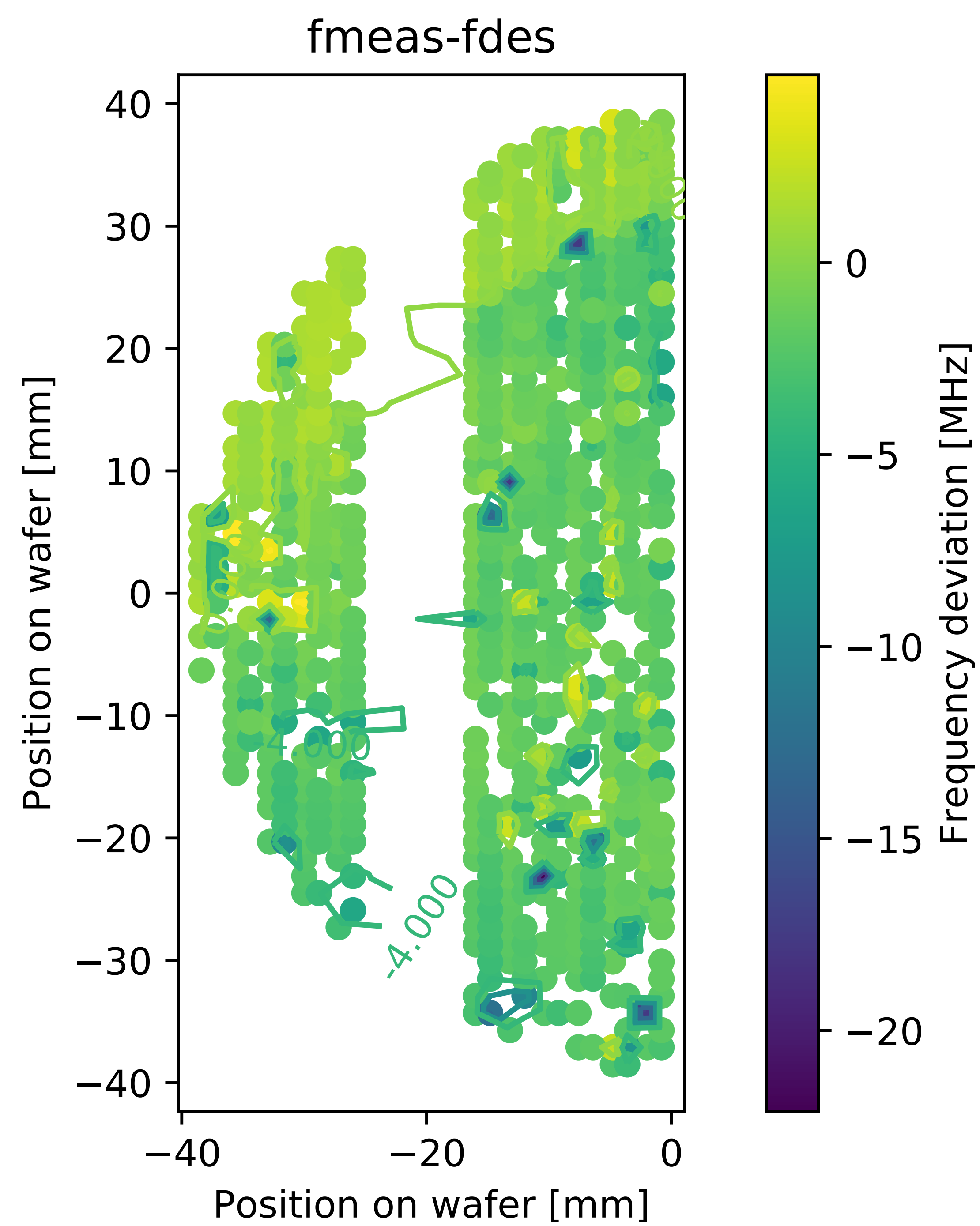


# A 4” full-frame test array

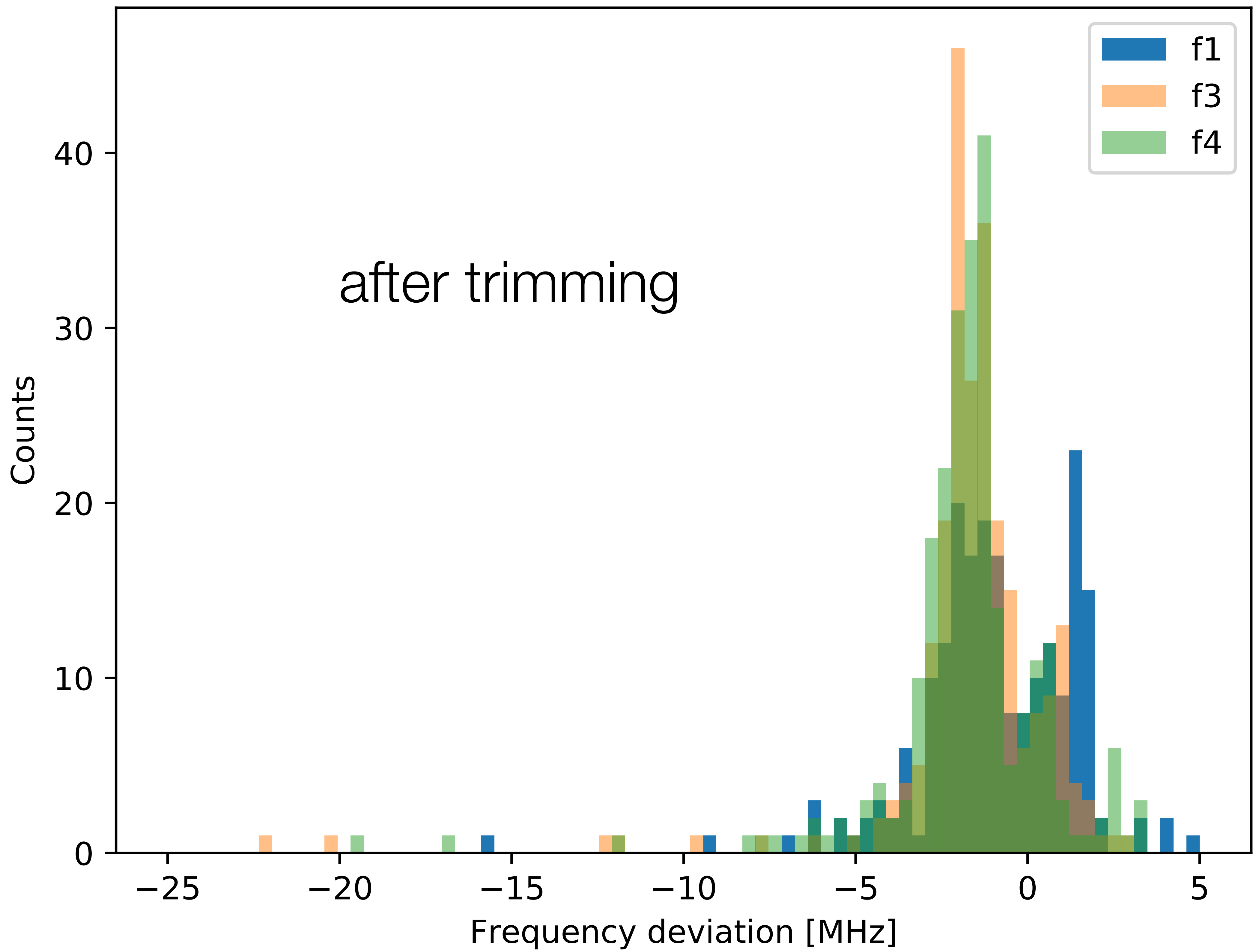
## before trimming




## after trimming



# A 4” full-frame test array



| Feedline | 1 | 3 | 4 | All |
|---|---|---|---|---|
| Number in design | 276 | 312 | 332 | 920 |
| Mapped before trimming | 182 | 228 | 225 | 635 |
| Mapping yield before trimming | 65.9% | 73.1% | 67.8% | 69.0% |
| Mapped after trimming | 210 | 242 | 249 | 701 |
| Mapping yield after trimming | 76.1% | 77.6% | 75% | 76.2% |
| Readout problem | 9 | 15 | 21 | 45 |
| Total resonances | 219 | 257 | 270 | 746 |
| Fabrication yield | 79.3% | 82.4% | 81.3% | 81.1% |

20% pixels are already broken before trimming

# Conclusions

- Current NIKA2 1mm band pixel has 100% absorption efficiency in one polarization and 70% for another polarization.
- Angular resolution 10.9” -> 10.2” with 1mm inductor.
- Optical yield 70.7% -> 96.4% with 0.46 MHz deviation (1.8e-4).
- A ~2400 pixel 4” array is tested:
  - Limited by fabrication yield: 80%
  - Readout board: maximum 250 pixels
  - Film property: aging problem
  - One 4-inch trimmed array = 4 cool-downs
  - 4-week measurement + 1-week analysis + 1-week production = 6 weeks