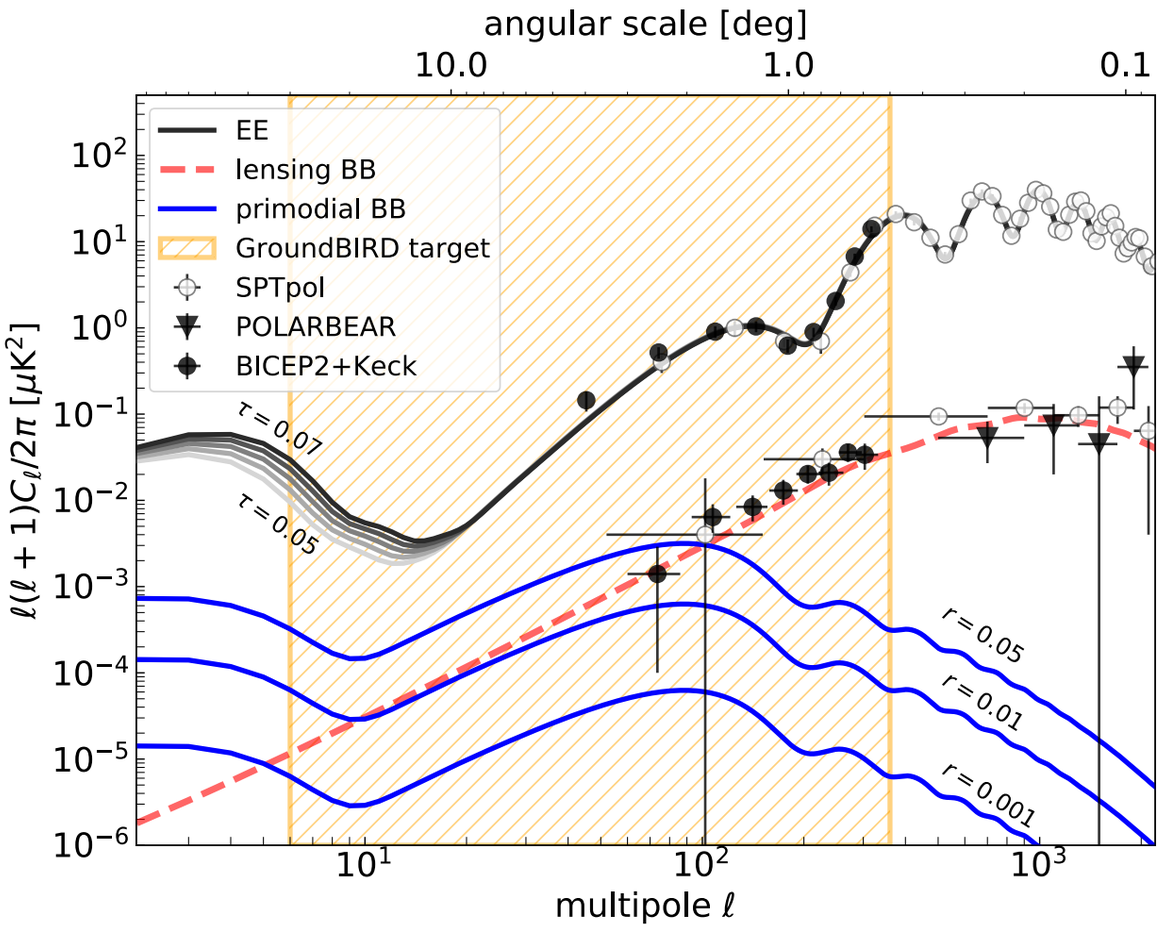
GroundBIRD

A Fast-Rotating Polarimeter for Large-Scale CMB Polarization Measurements

Kyoto University
Junya Suzuki for GroundBIRD collaboration

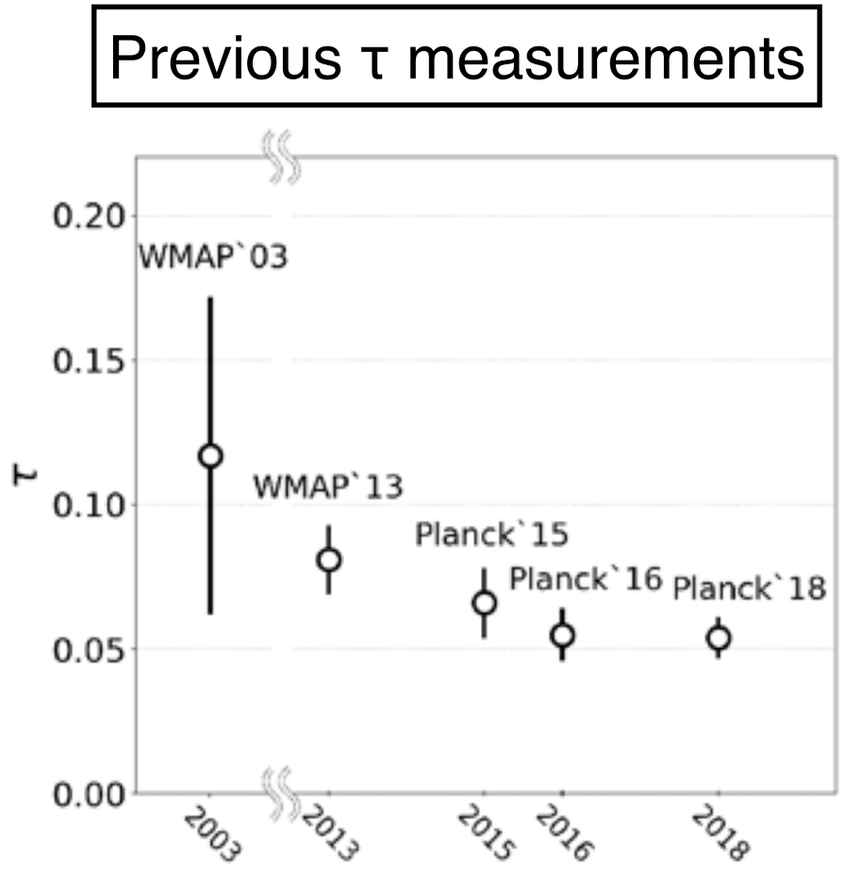
GroundBIRD

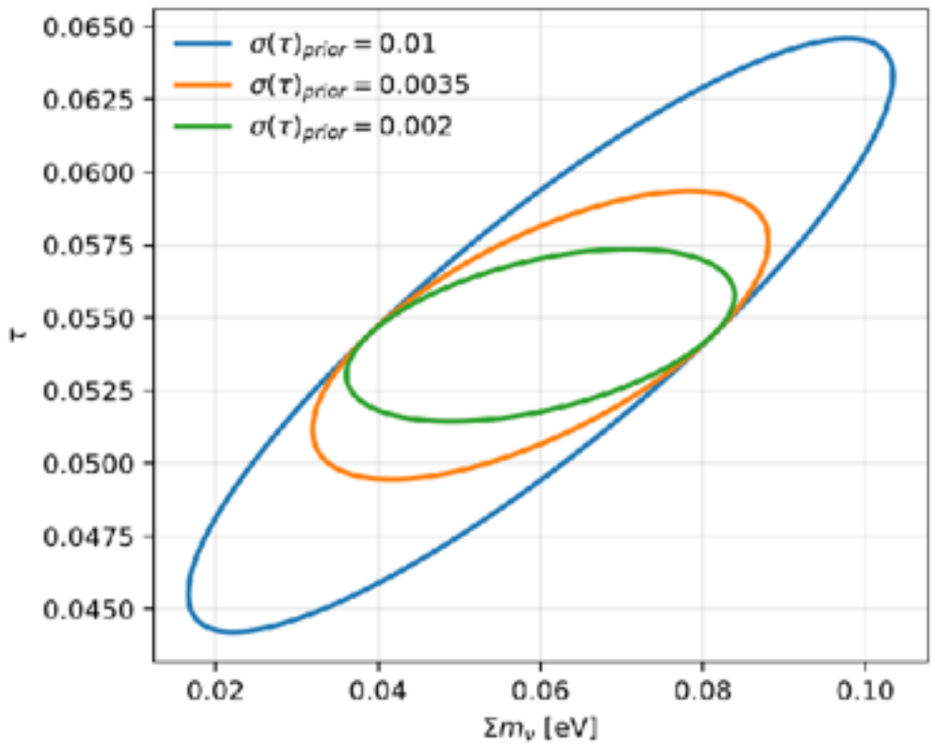
- CMB polarimeter for low-ℓ observation
  - High-speed rotation scan modulation to mitigate atmospheric fluctuation

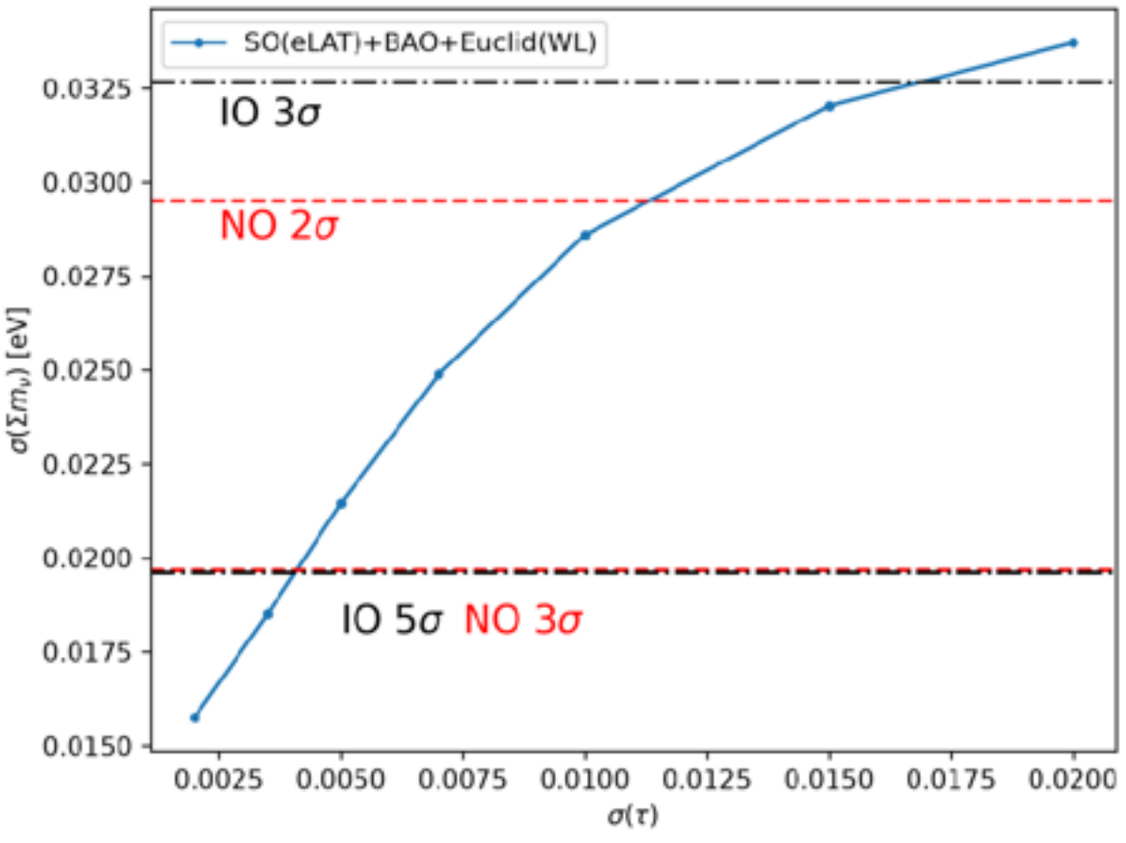


Science target

- Determination of Σm_ν requires τ measurement
- GroundBIRD + QUIJOTE expects $\sigma(\tau) \sim 0.01$ level independent measurement from the ground







GroundBIRD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(IAC)
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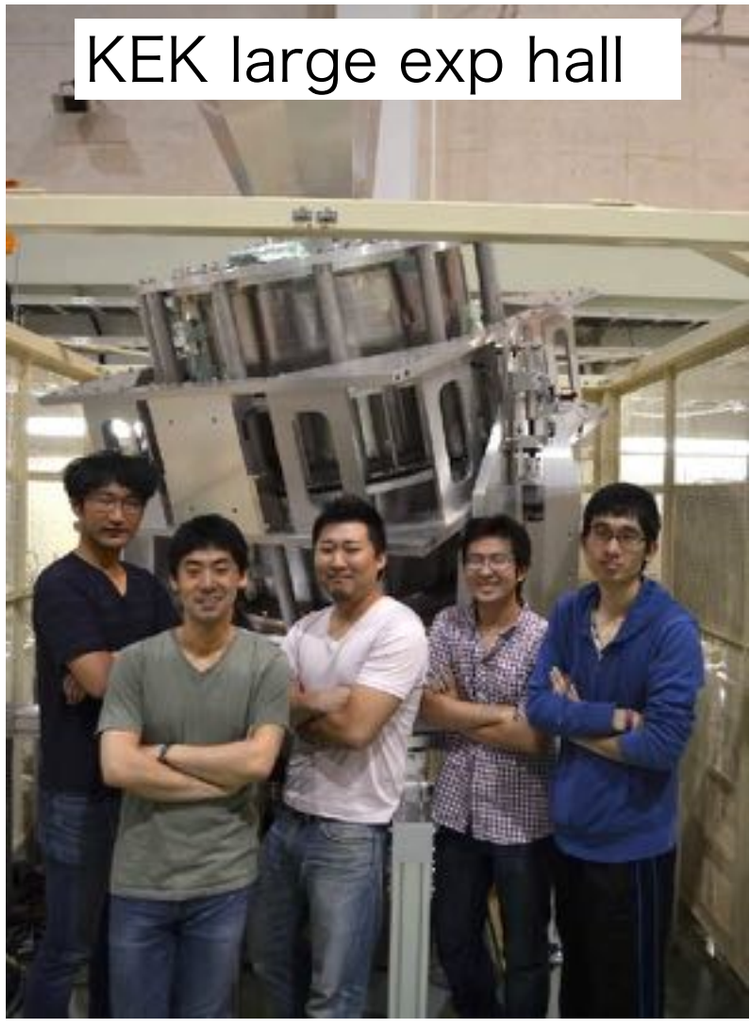
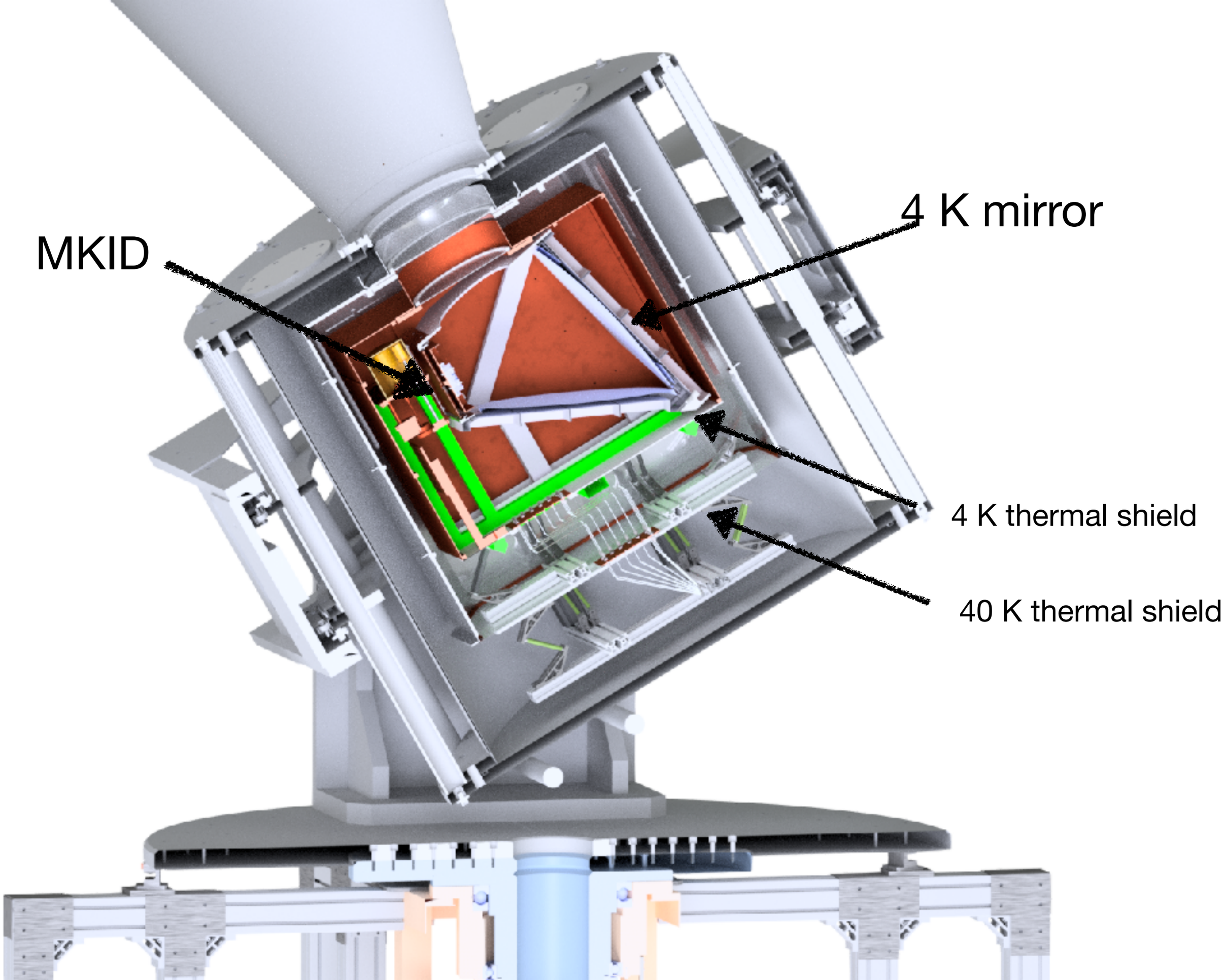
J. Suzuki
Kyoto U.
S. Honda
U. Tsukuba
S. Oguri
JAXA
Y. Sueno
Kyoto U.

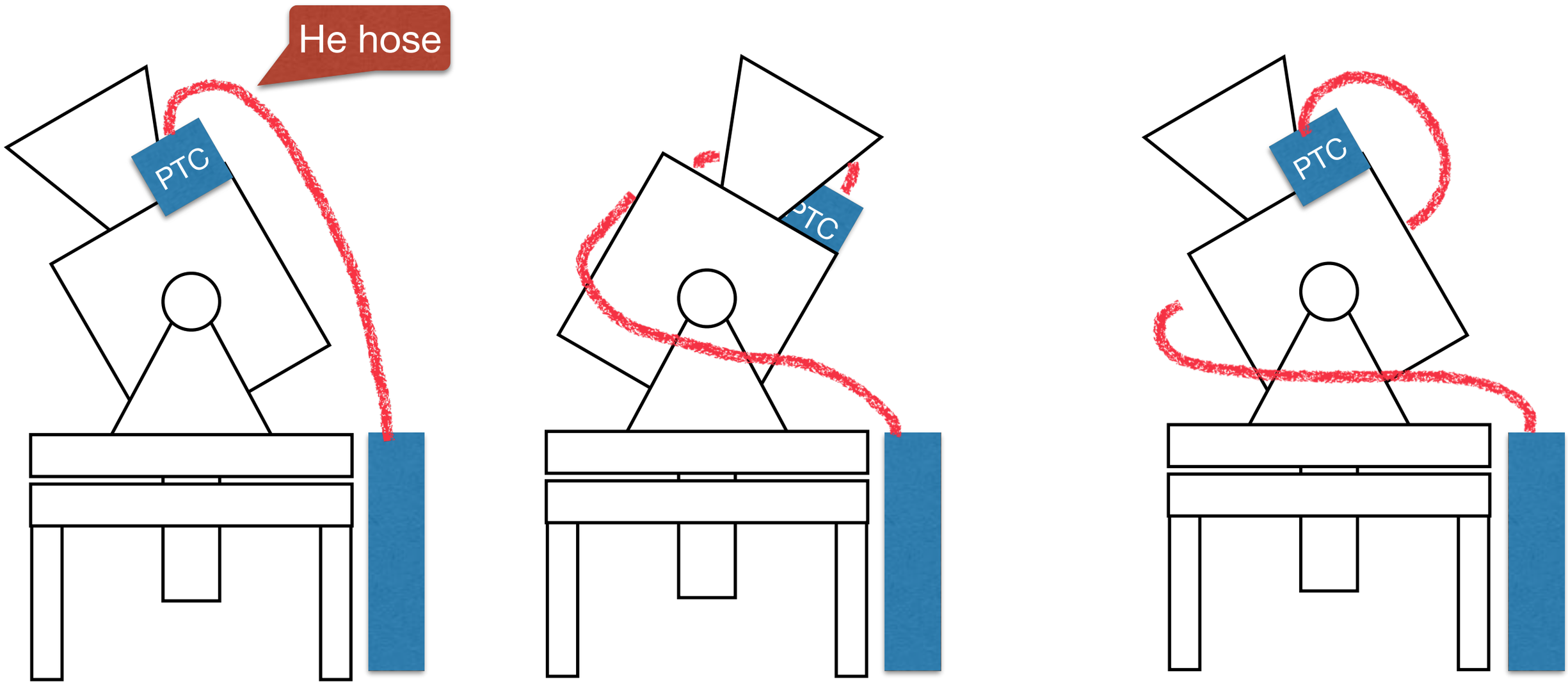


Short history

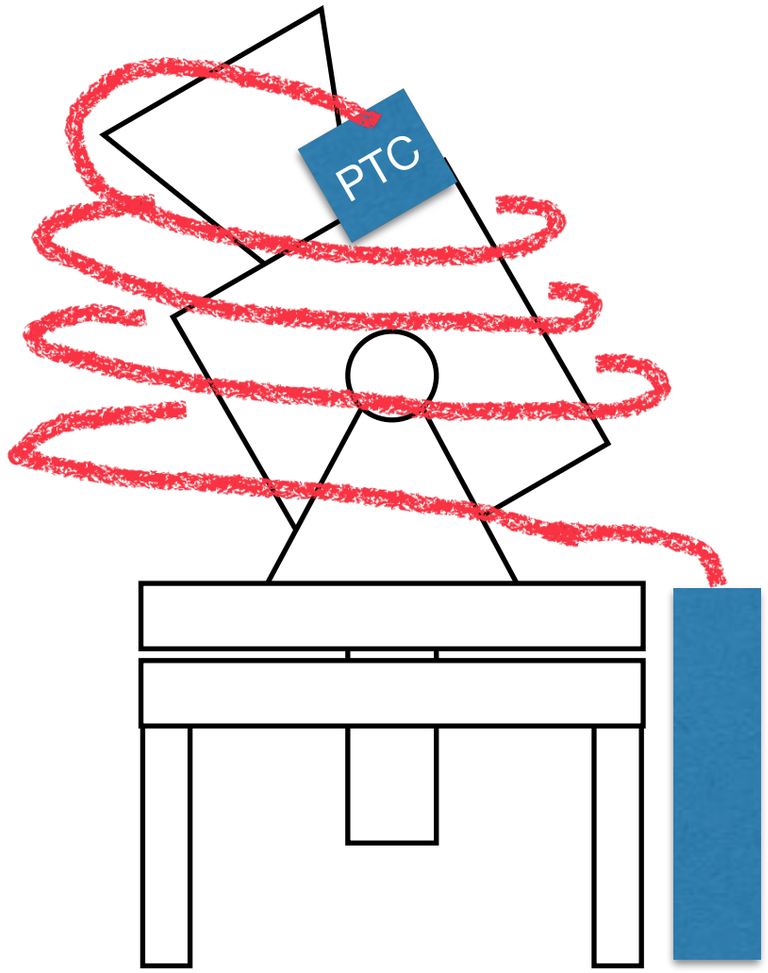
- GroundBIRD was prepared and partially evaluated at KEK and shipped to Tenerife in 2019.
- After the COVID outbreak, full KIDs array was installed in 2023.


MKID
4 K mirror
4 K thermal shield
40 K thermal shield

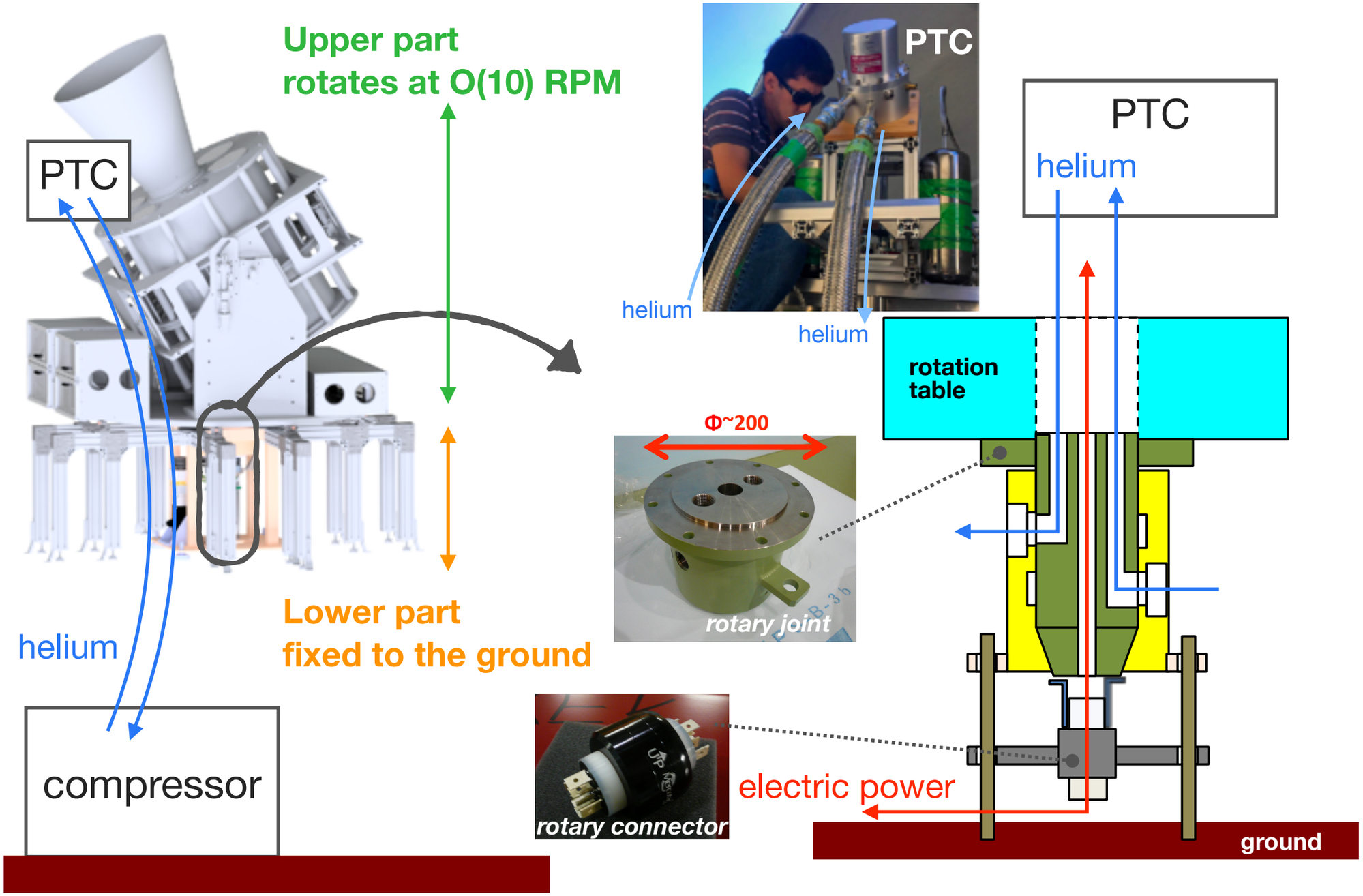
Rotation scan

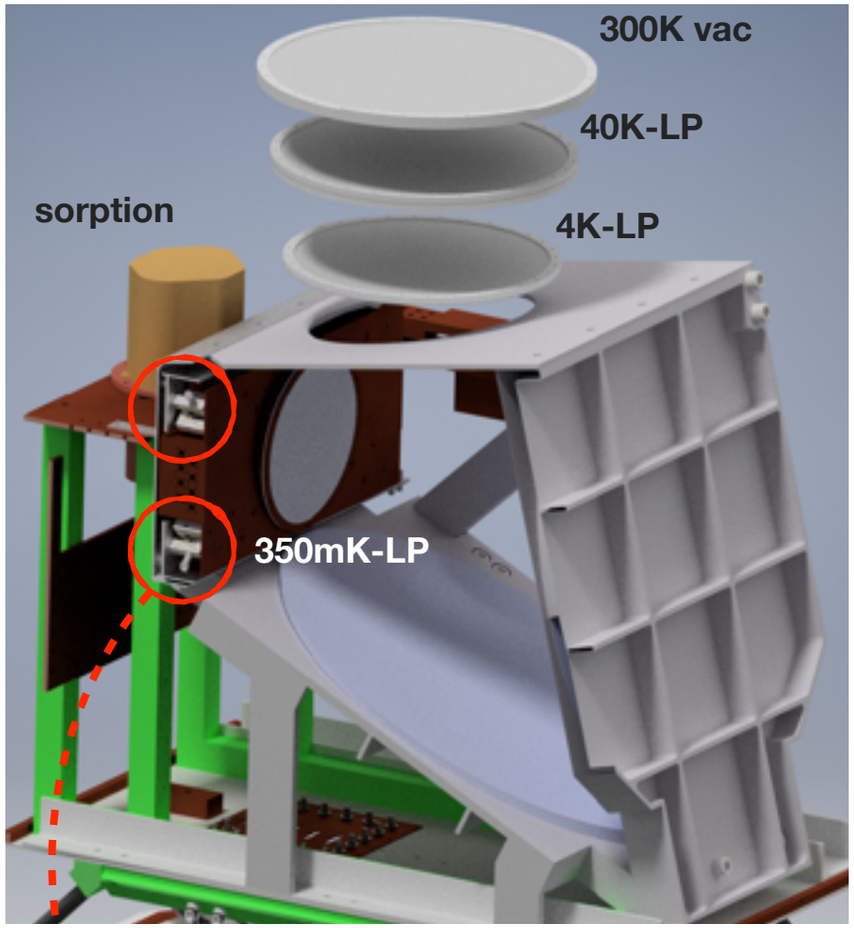


Rotation scan

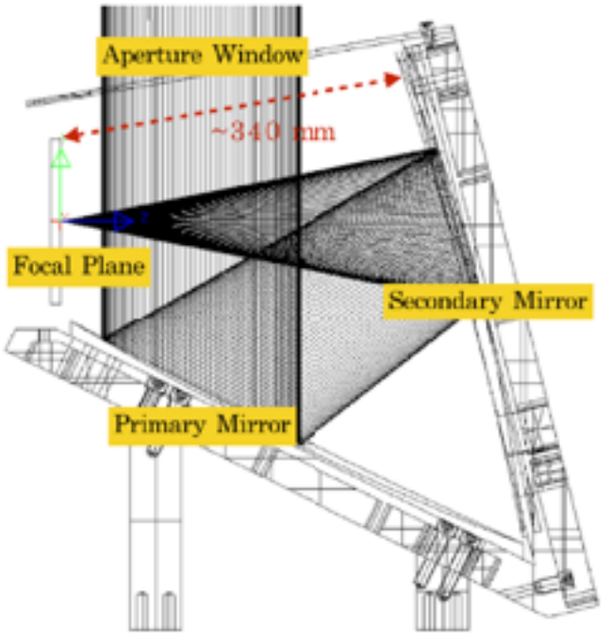


Solution: He rotary joint





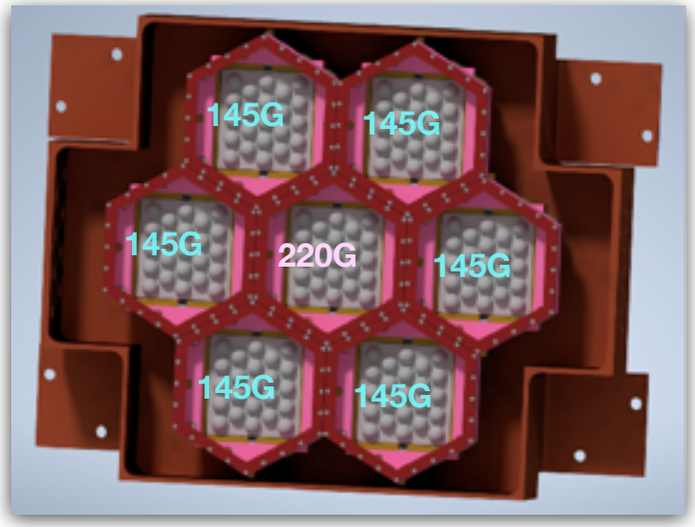
mirror design



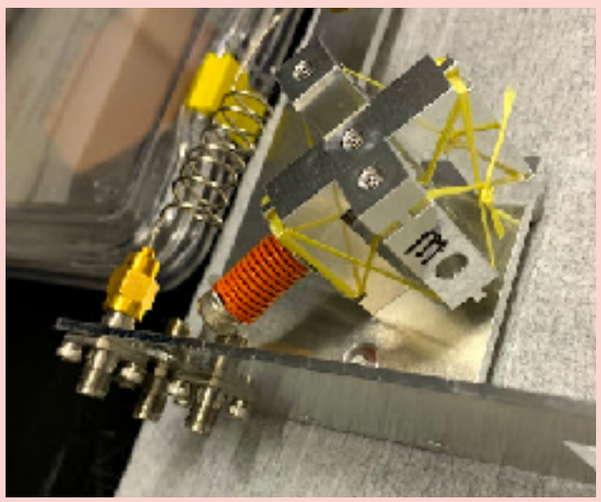
7 wafers on the focal plane

23pix. for each wafer

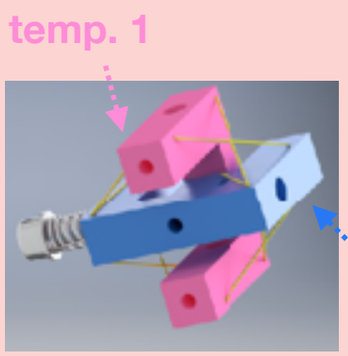
- 138 pix. with 145GHz for CMB
- 23 pix. with 220GHz for dust



Kevlar small jigs for thermal isolation

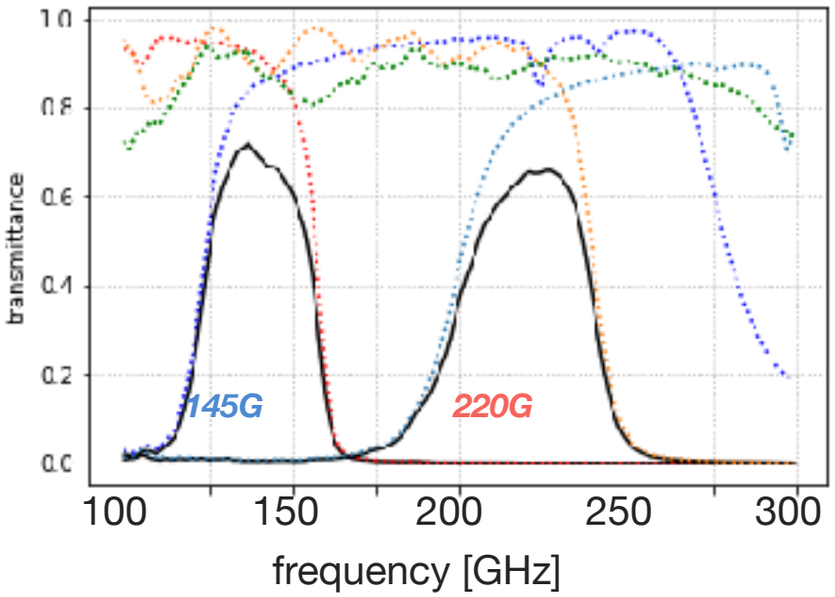


Thermal isolation well achieved by tensions of Kevlar wires

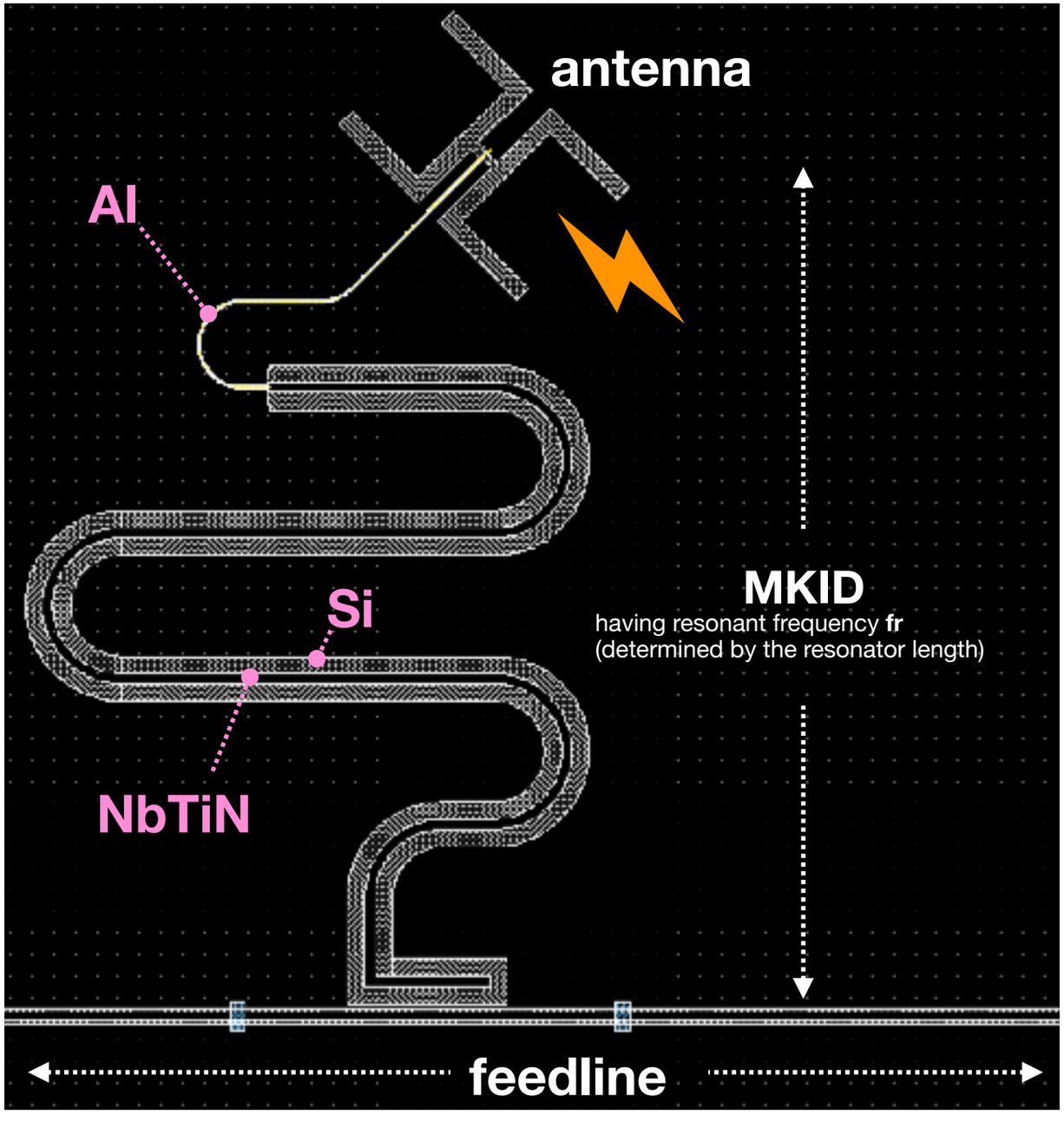


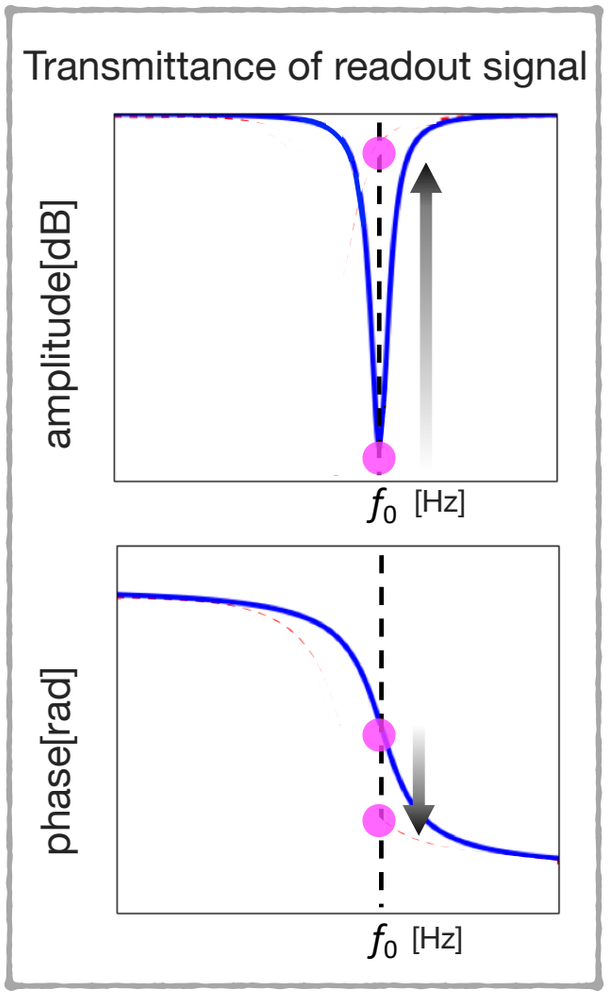
thermal conductivity
~ 0.0064 [mW/K]

spec. of optical filters at focal plane



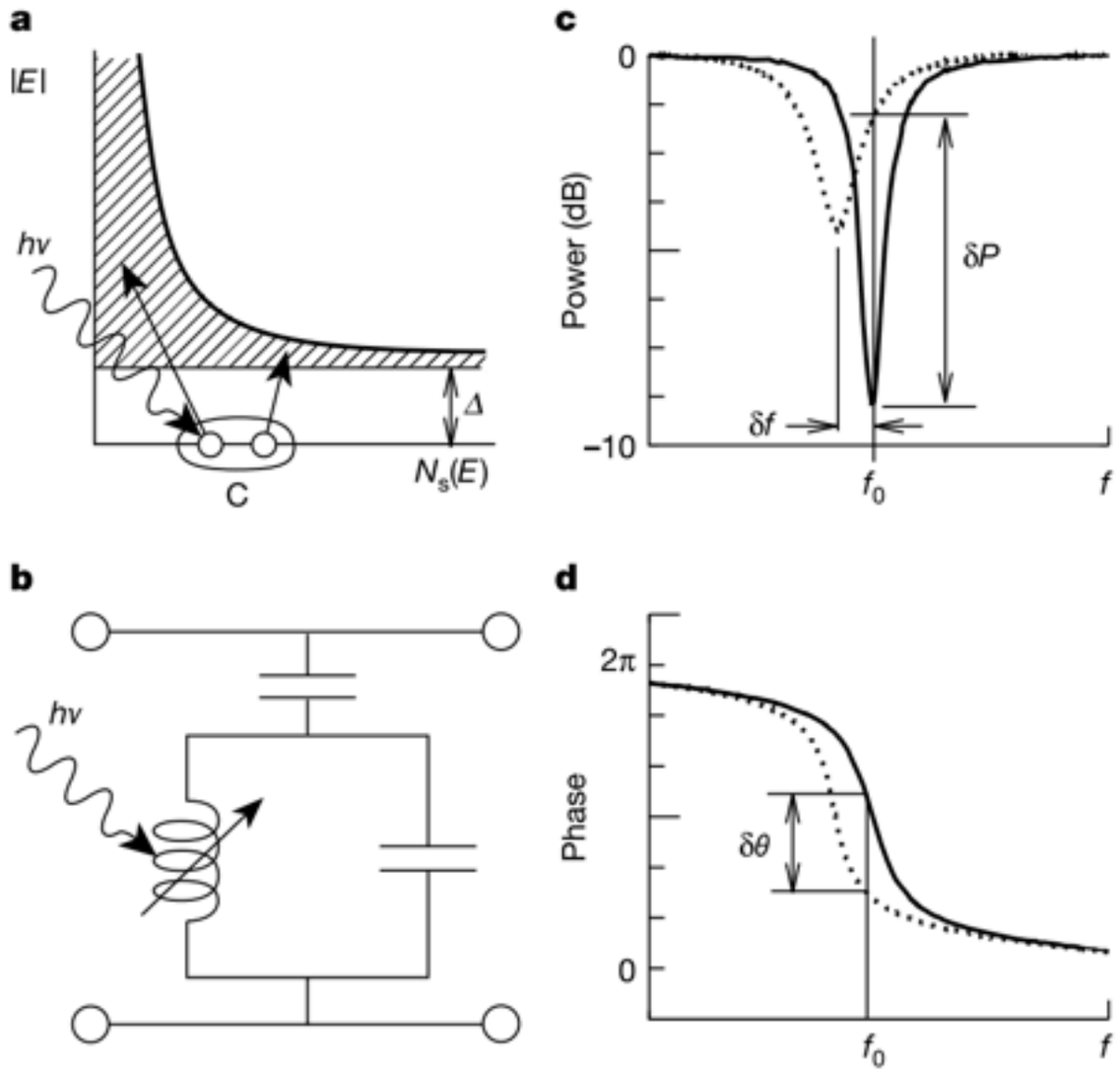
Microwave Kinetic Inductance Detector





MKID

Cooper-pair breaking by incident photon



Resonator frequency/depth change

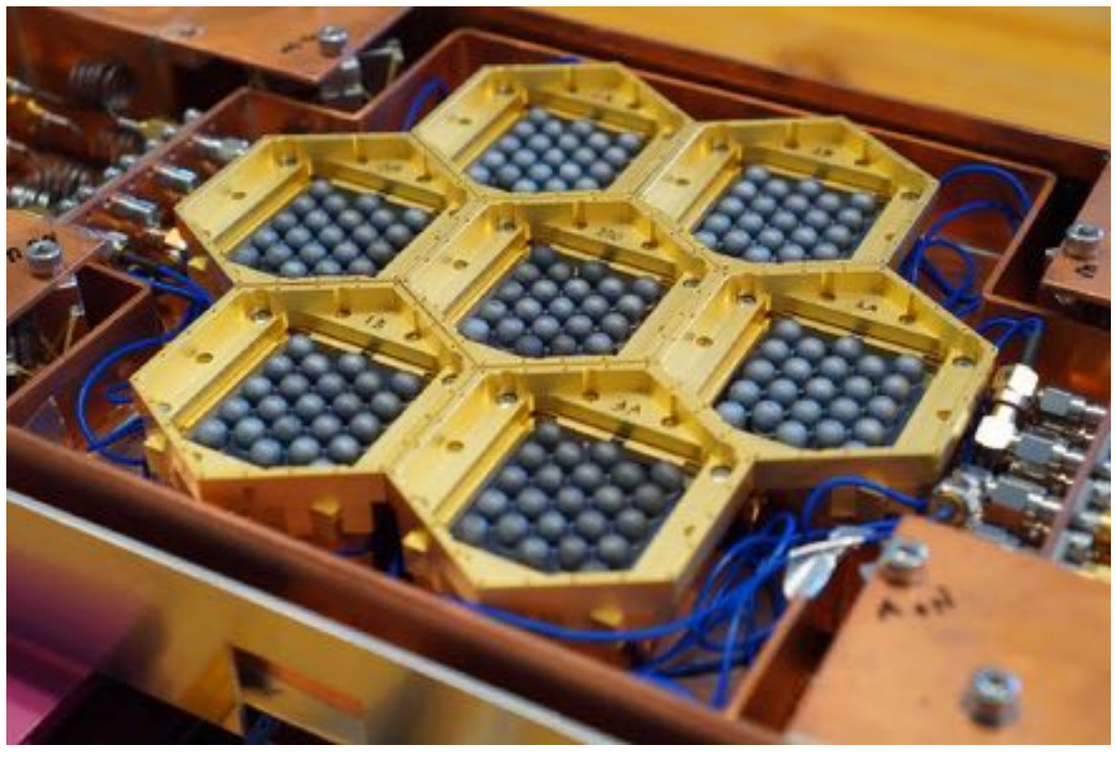
Inductance change

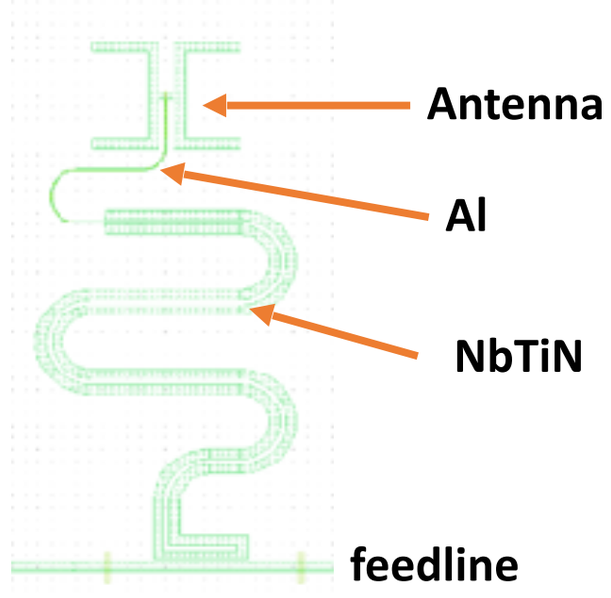
Day, Peter K., et al., Nature 425.6960 (2003): 817-821.

MKIDs for GroundBIRD

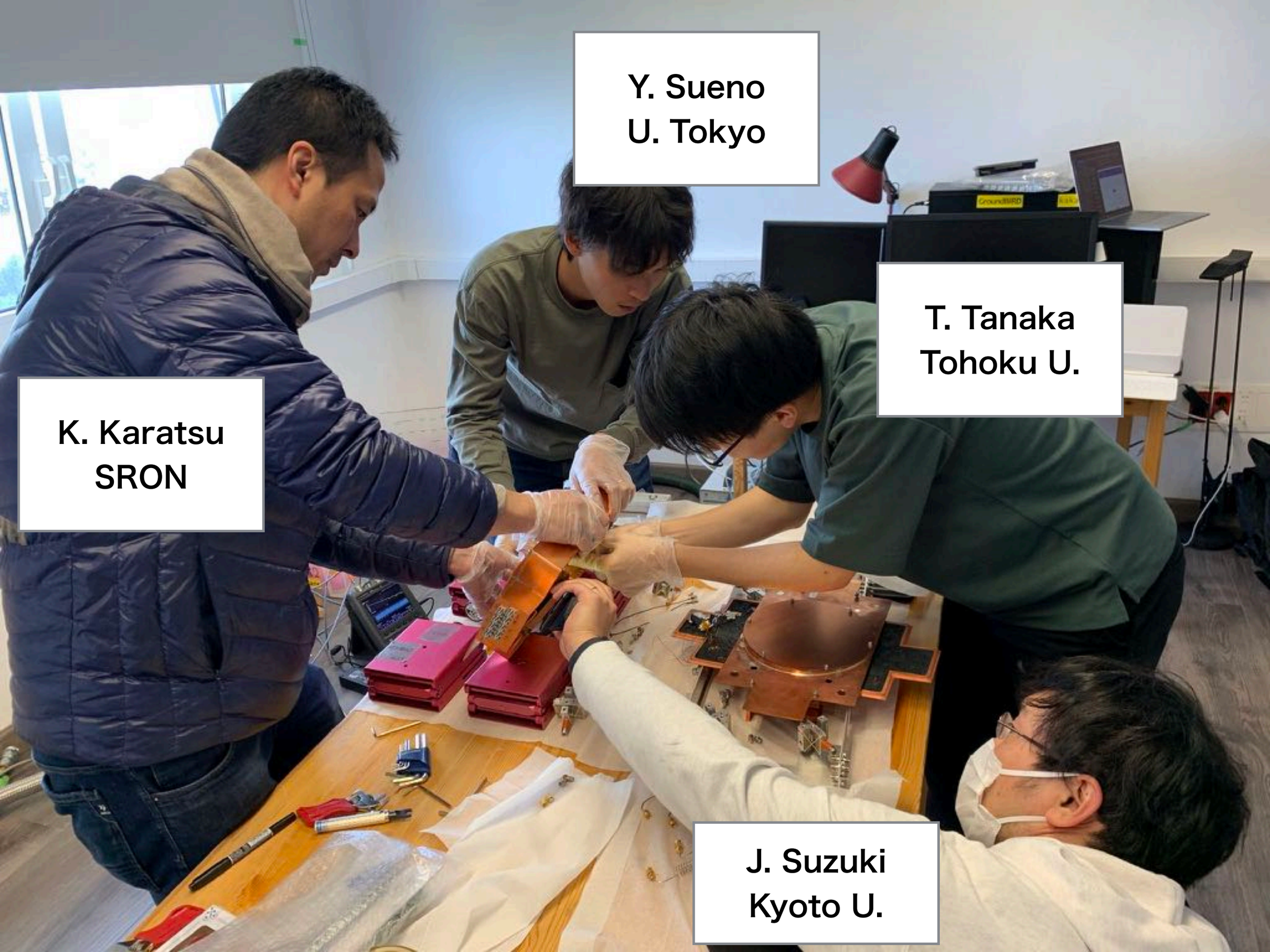
Collaboration with
SRON / TUDelft

- 23 pix / wafer
- Al/NbTiN Hybrid



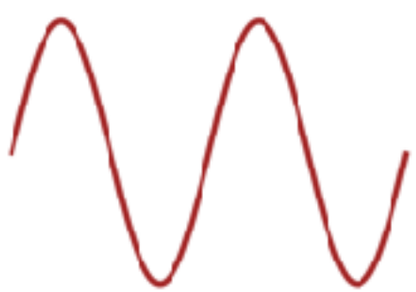


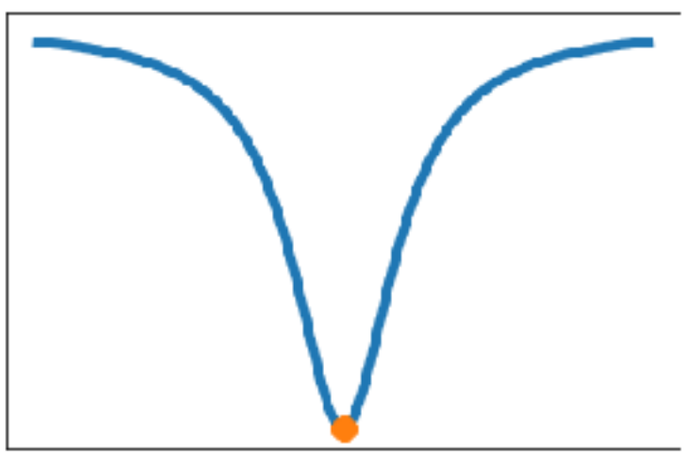
MKID design


Y. Sueno
U. Tokyo
T. Tanaka
Tohoku U.
K. Karatsu
SRON
J. Suzuki
Kyoto U.

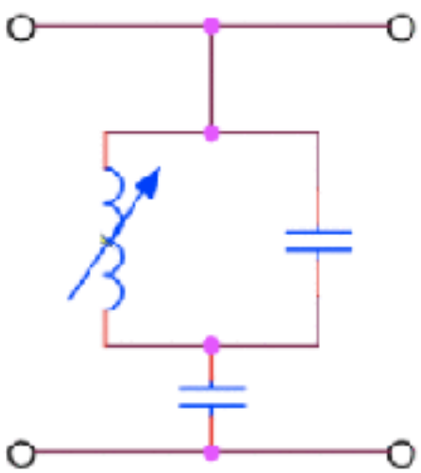
Basics of KIDs readout

Input





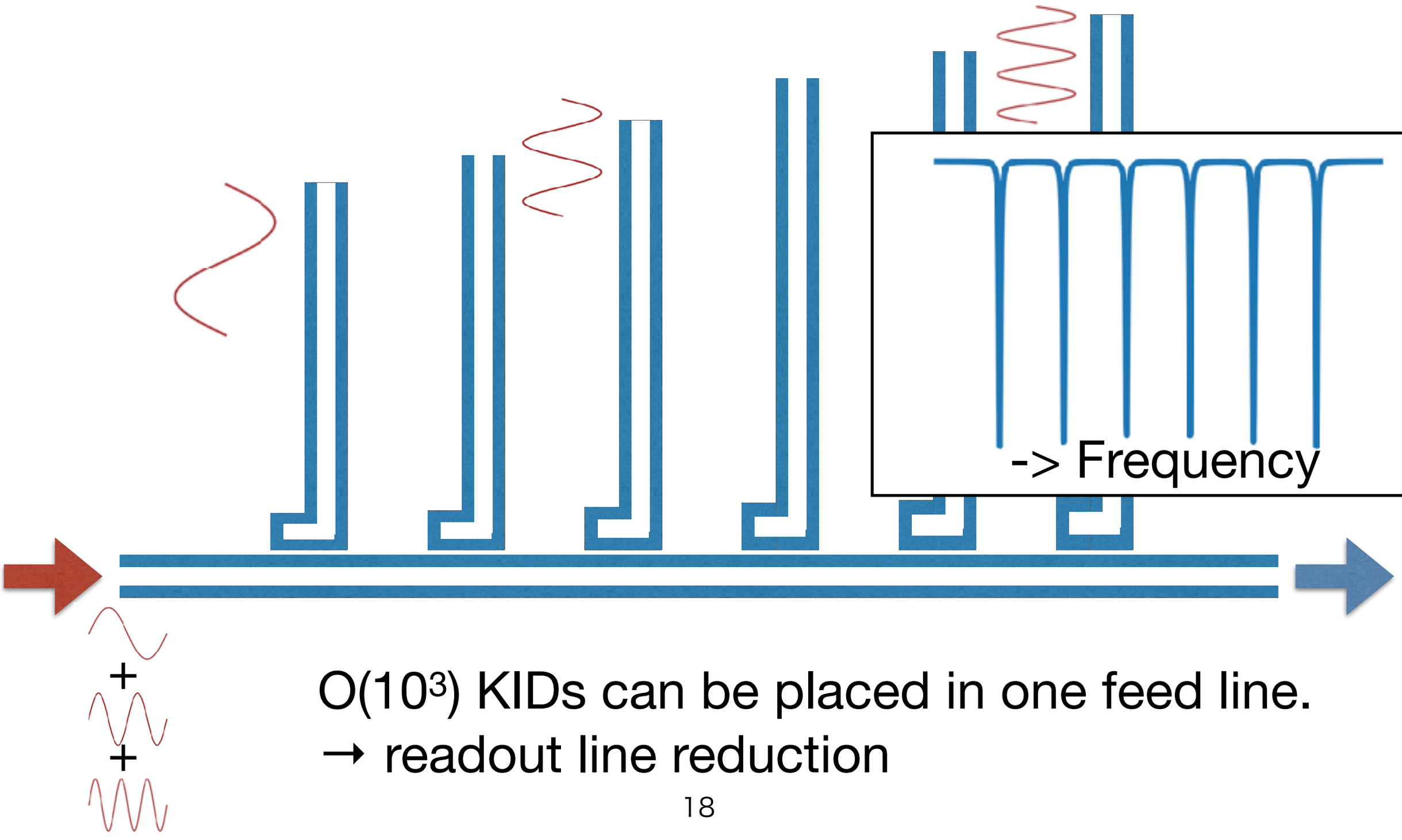
Output



Output / Input

Time →

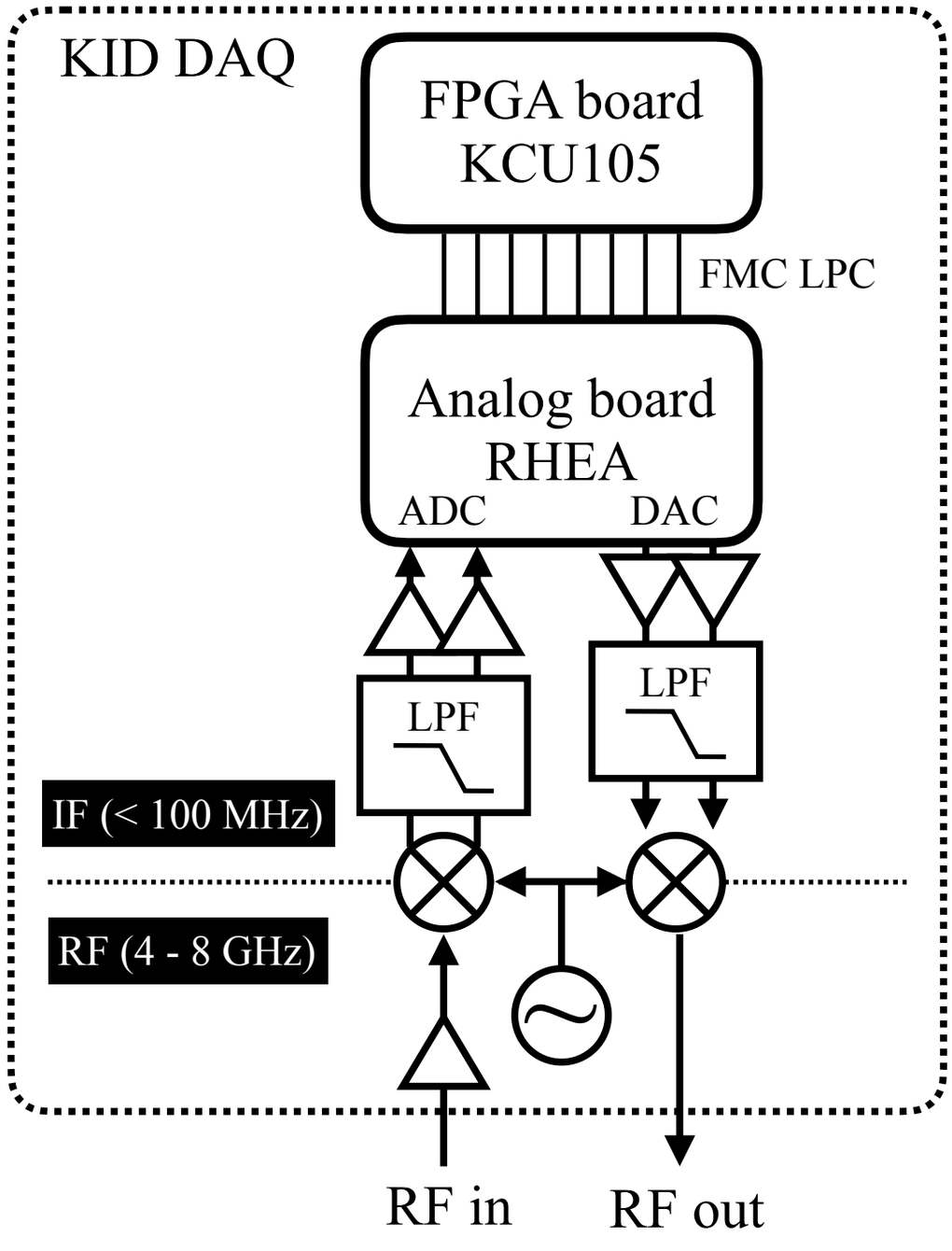
Multiplexing



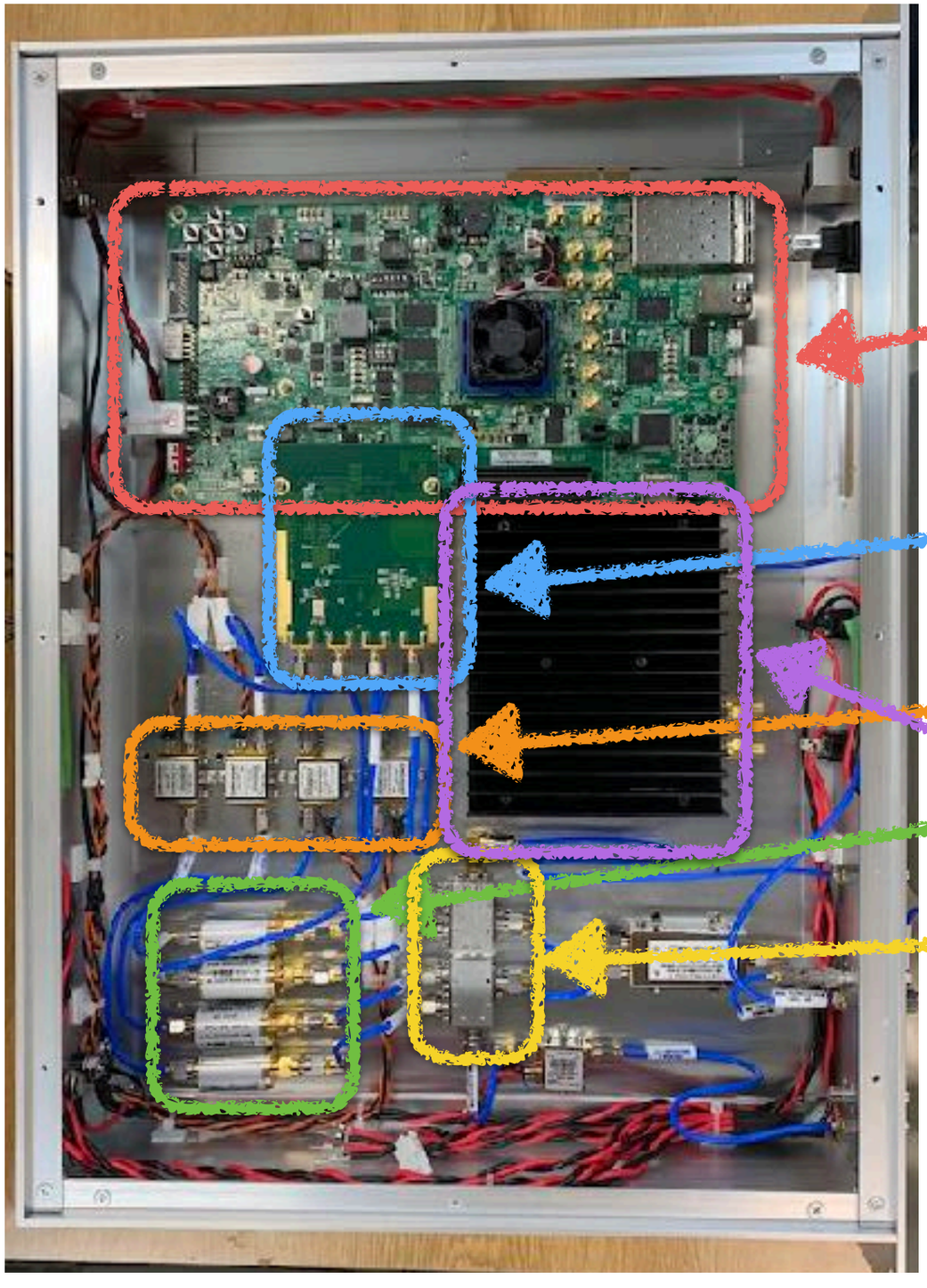
O(10^3) KIDs can be placed in one feed line.

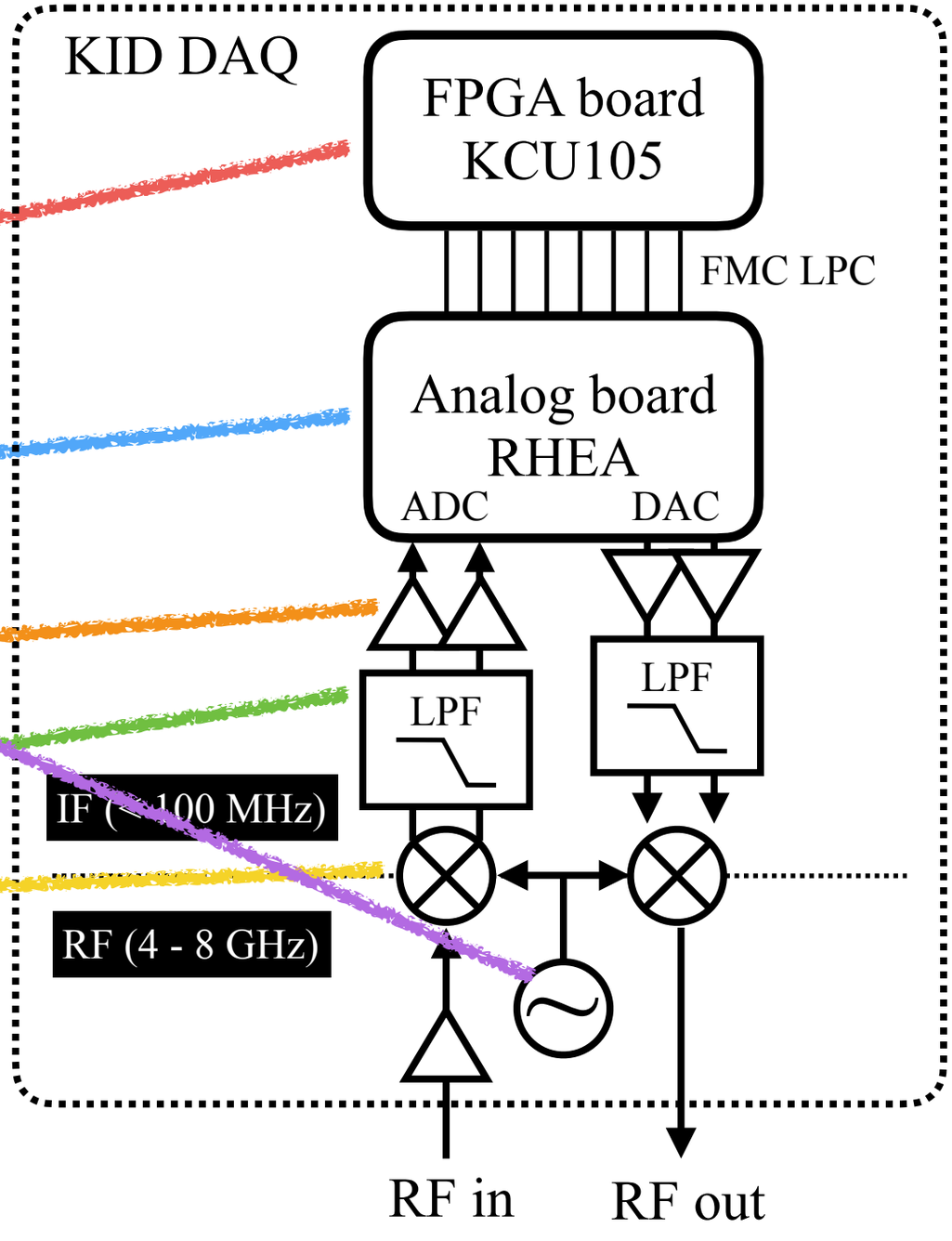
→ readout line reduction

KIDs readout system



KIDs readout system

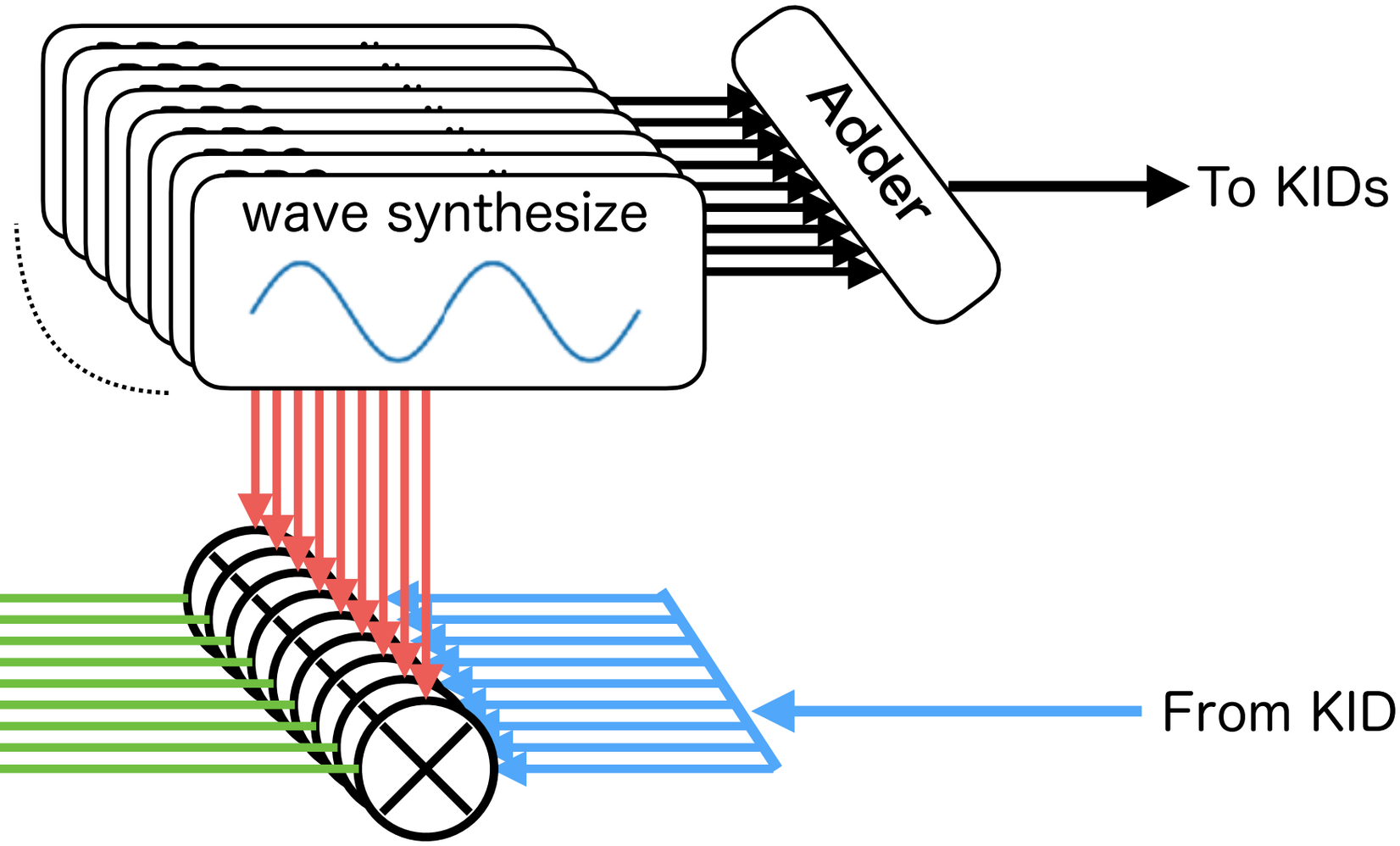




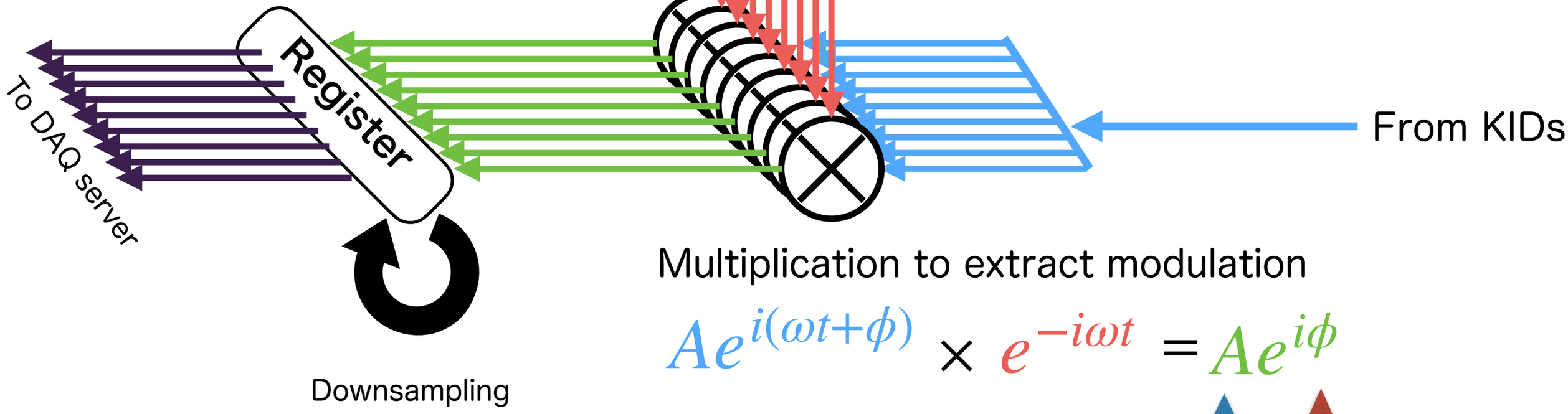
Digital signal processing

DDS (synthesis)

(# of KIDs) ✖



DDC (decompose)



Downsampling

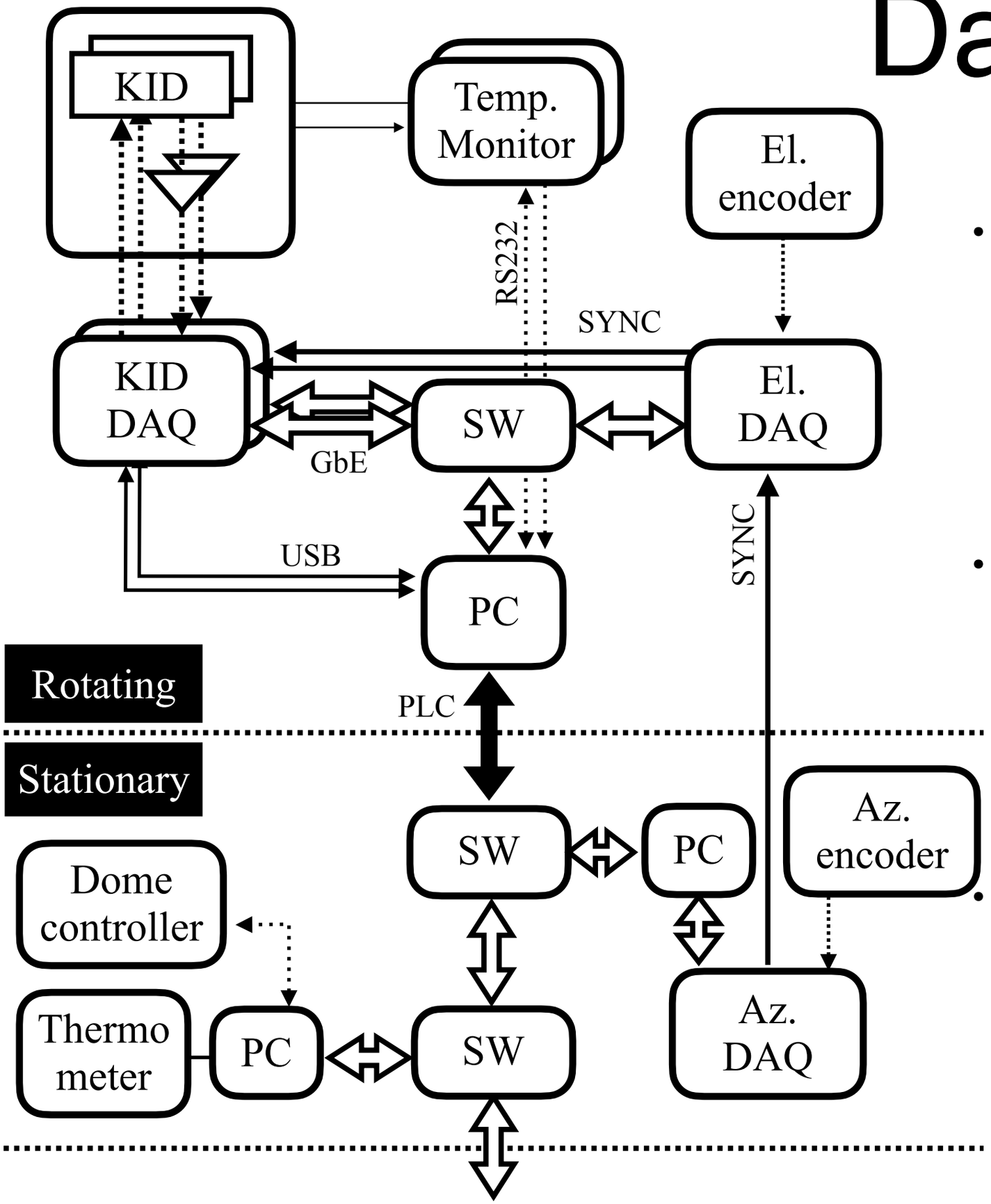
Multiplication to extract modulation

$$Ae^{i(\omega t+\phi)} \times e^{-i\omega t} = Ae^{i\phi}$$

Amplitude

Phase

Data acquisition

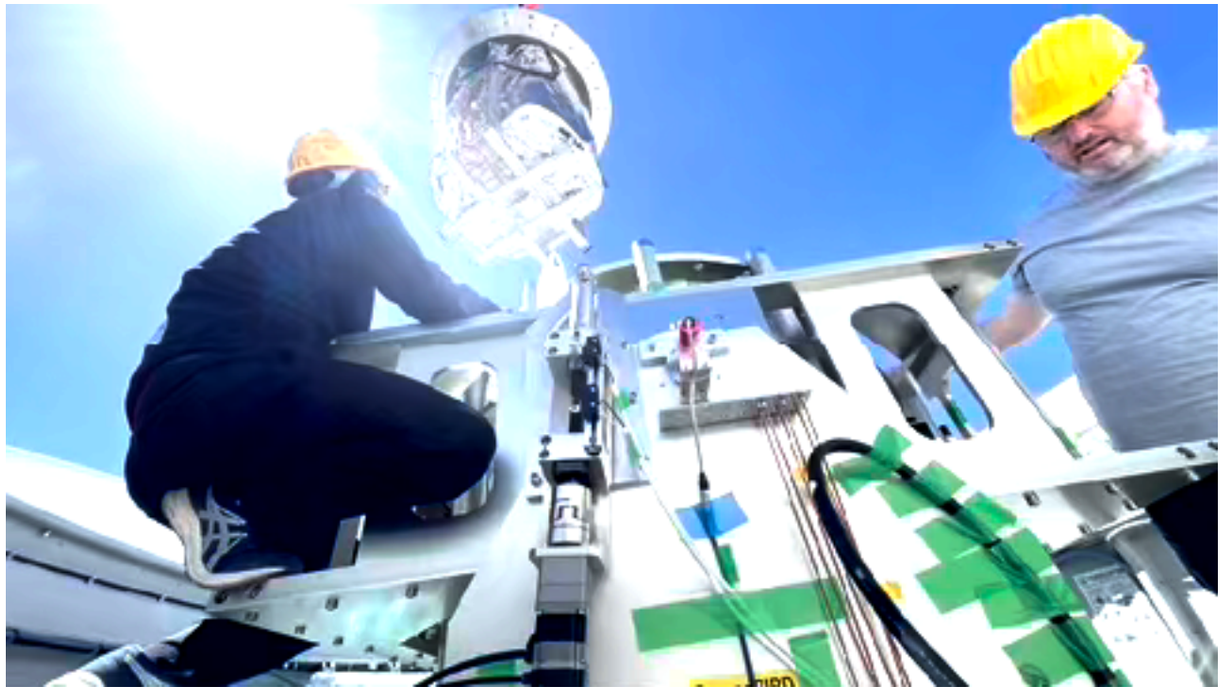


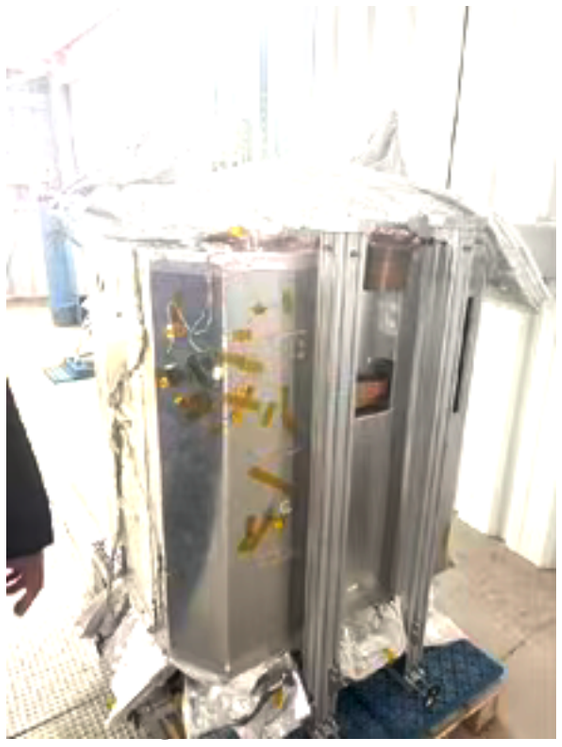
- Rotating part and stationary part are connected through rotary joint of electricity (AC100V)
- Power Line Connection (PLC) is used for data transfer through the electricity line.

Data acquisition is synced using a signal through rotary joint as well.

On-site work

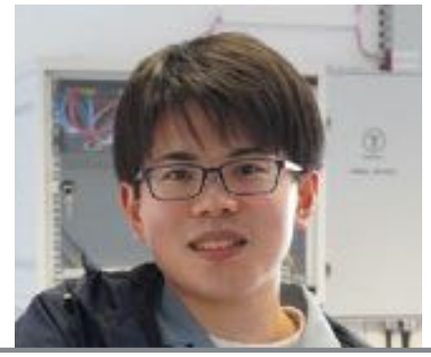
- We use crane track to open the chamber
- Thermal shields are attached to the top of the OVC
- We can decompose the telescope by hands after taking off the top flange





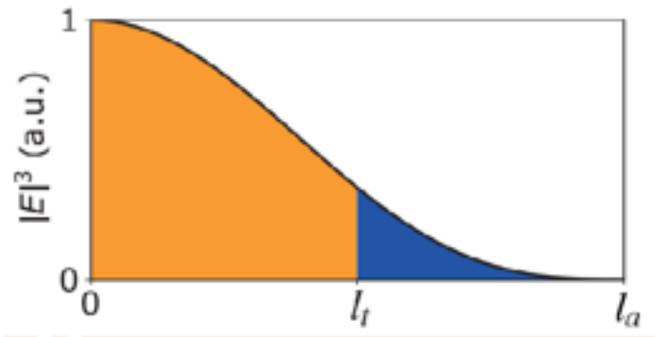
Perfomance evaluation / analysis

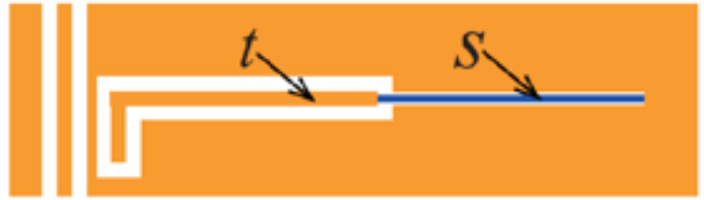
Detector design and performance eval.



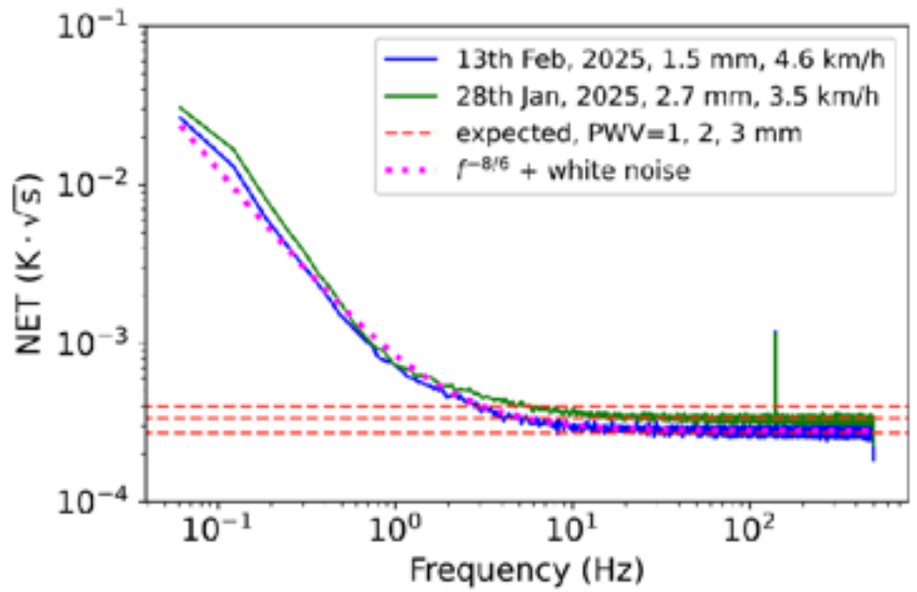
T. Tanaka
Tohoku U.

- Detector design was done to reduce the effect of KID's intrinsic noise (TLS)





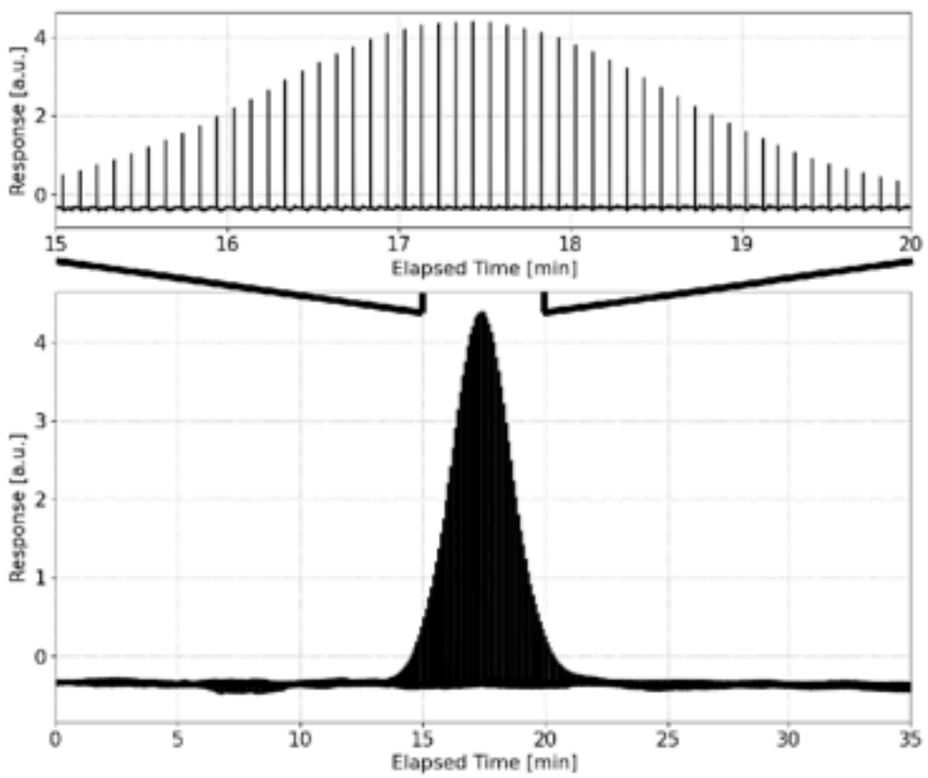
- The result of the on-site evaluation of the detector will be publish soon.

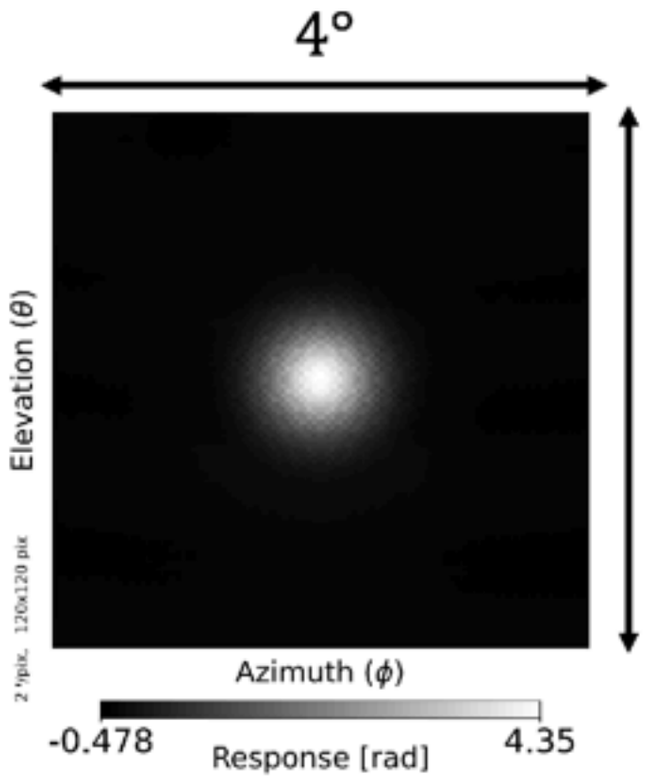


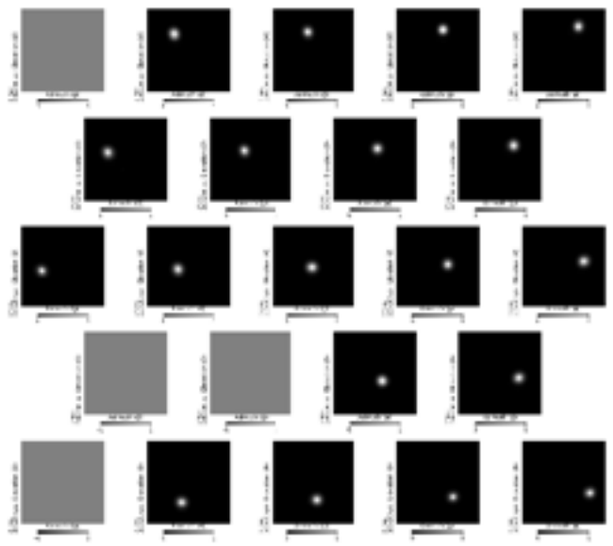
Pointing model from the moon observation

Y. Sueno
U. Tokyo

- Moon is used to get the pointing model of the focal plane detectors.
- Reconstruction of the image from rotation scan data → position calibration.



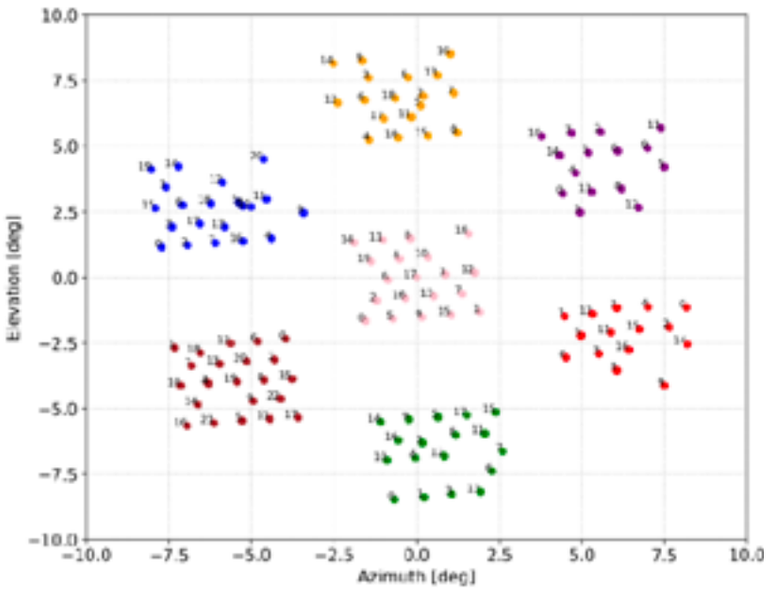


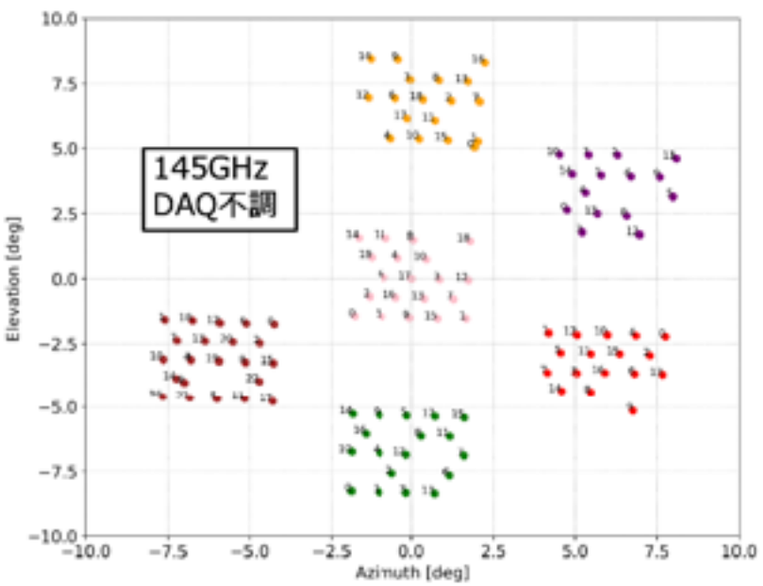


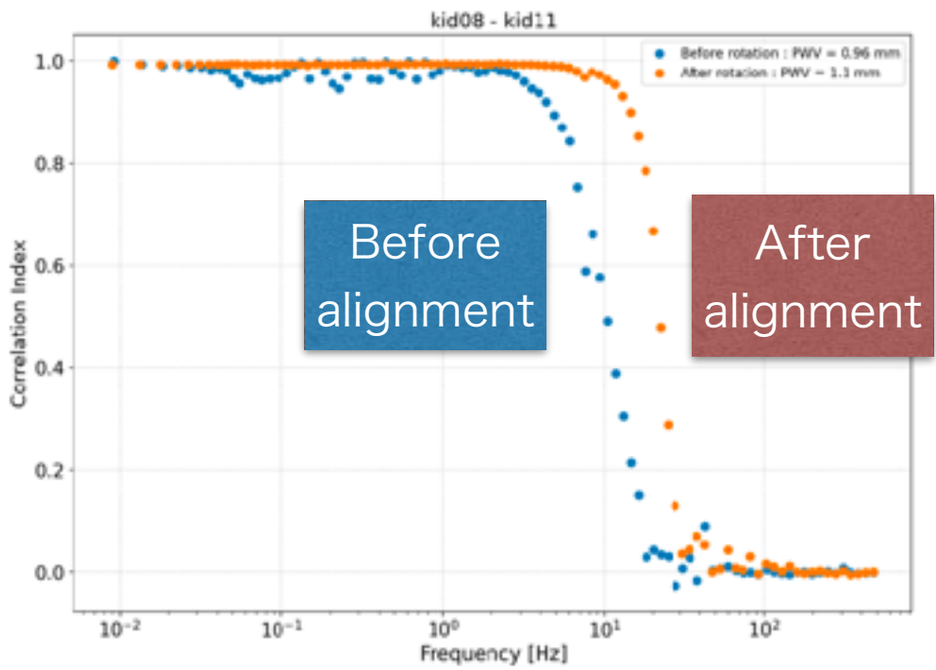
Boresight rotation

K. Kataoka
Kyoto U.

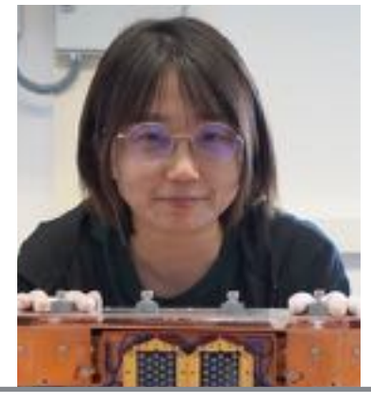
- GroundBIRD receiver is hold by outer frame and can be rotated along boresight.
- Pointing calibration was done with several boresight setup to build pointing model and align detectors on sky.
- Alignment effect was also seen on noise correlation between detectors.





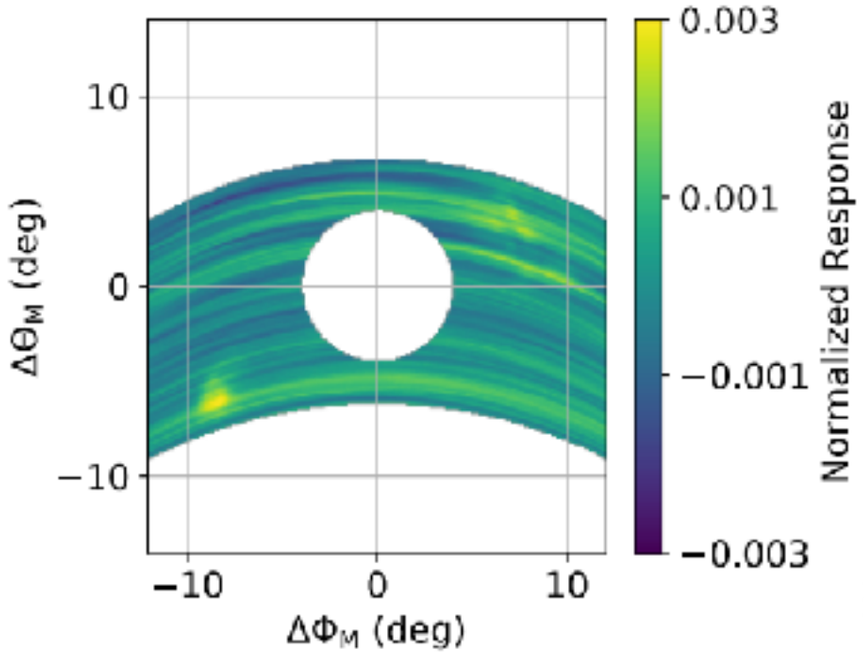


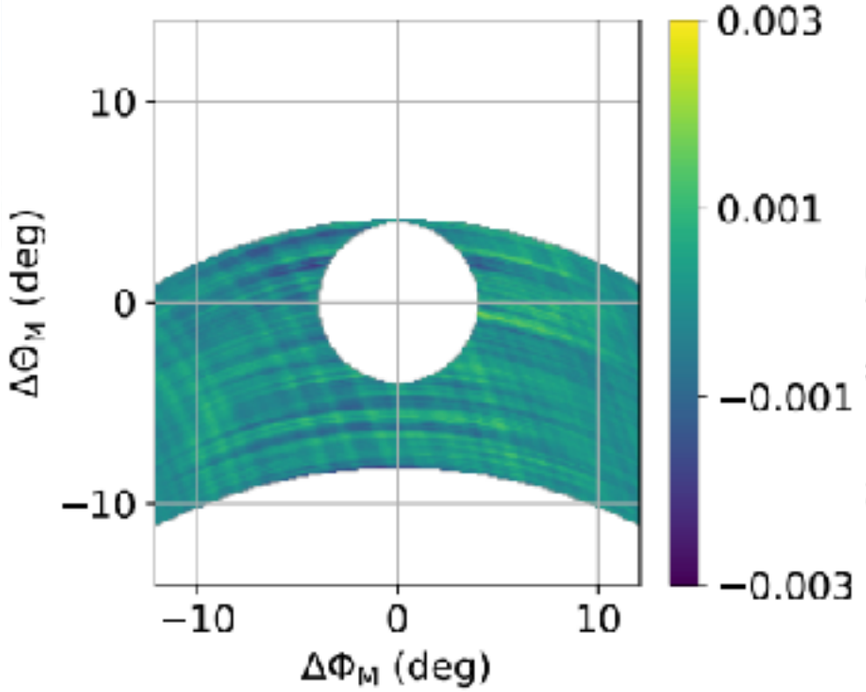
Forebaffle optimization and evaluation



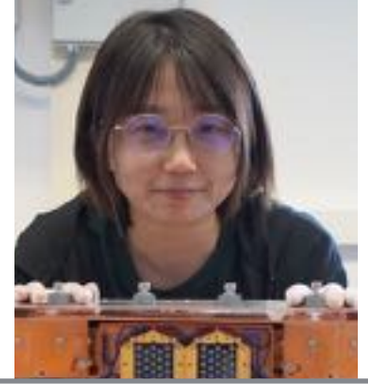
M. Tsujii
Tohoku U.

- Forebaffle was redesigned to mitigate stray light. Detailed simulation was perfomed to optimize the design.
- Analysis using Moon data showed clear improvement for stray light rejection.





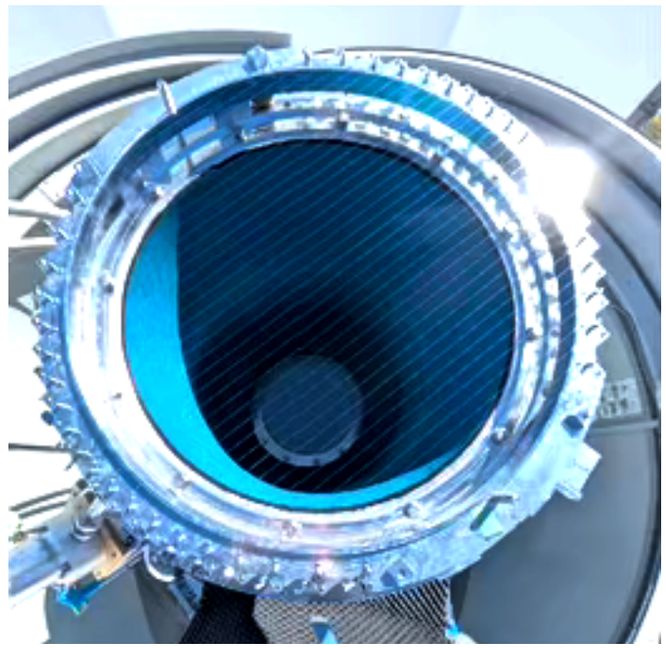
Polarization angle calibration

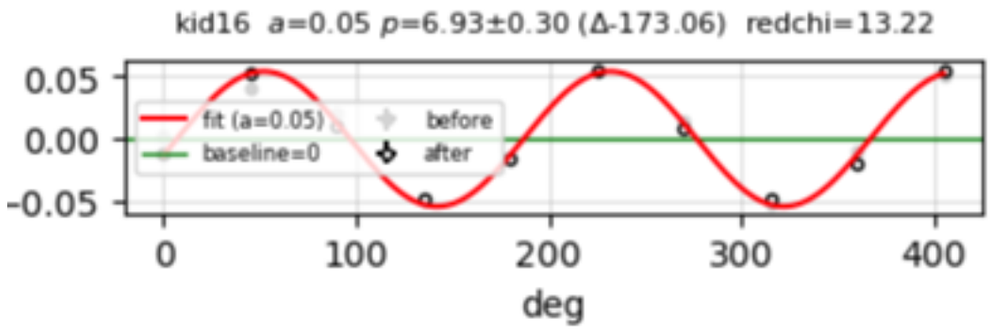


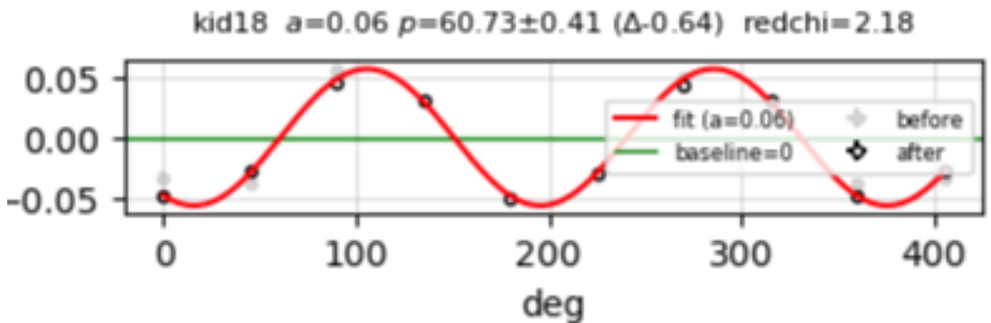
M. Tsujii
Tohoku U.

- Polarization angle calibration was performed using a sparse wire grid placed on top of the forebaffle.

- Miku will present about the status of the analysis in the following talk.





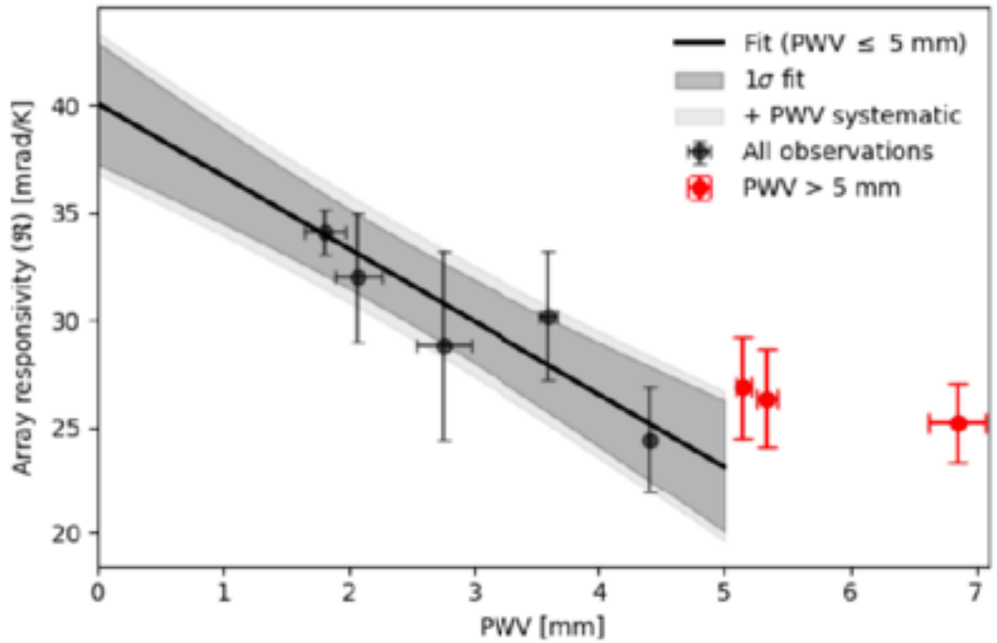


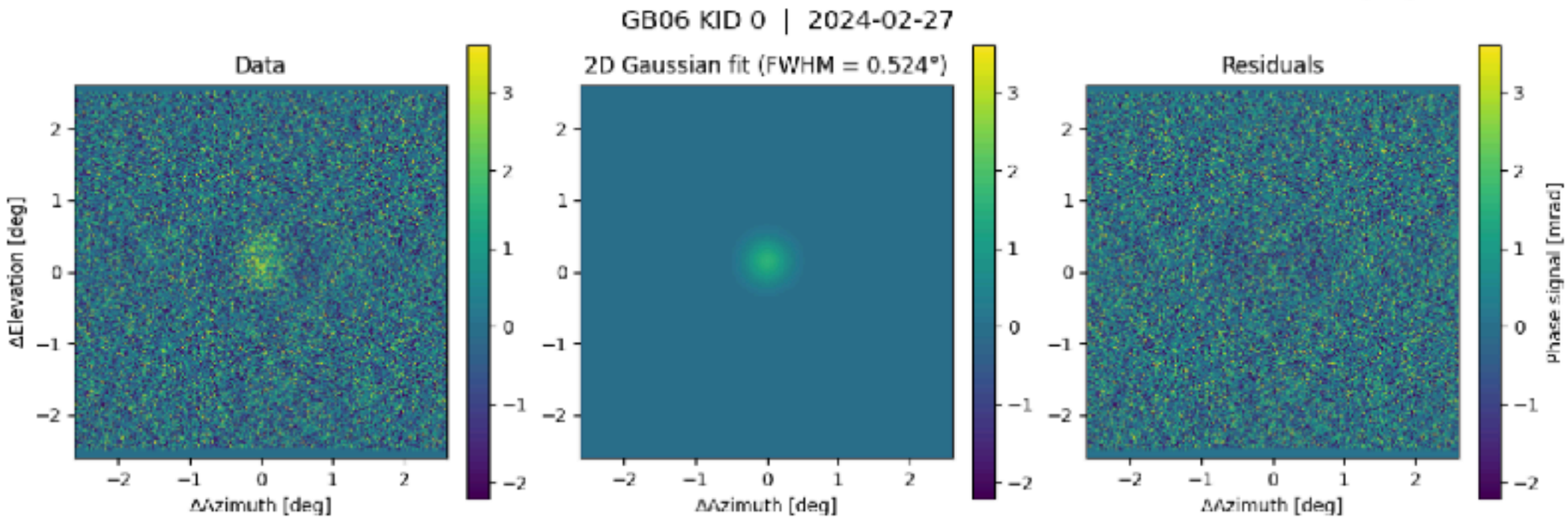
Gain calibration using a point source

A. Fasano
IAC

- Gain calibration and the beam stability were under study using Jupiter observation data.

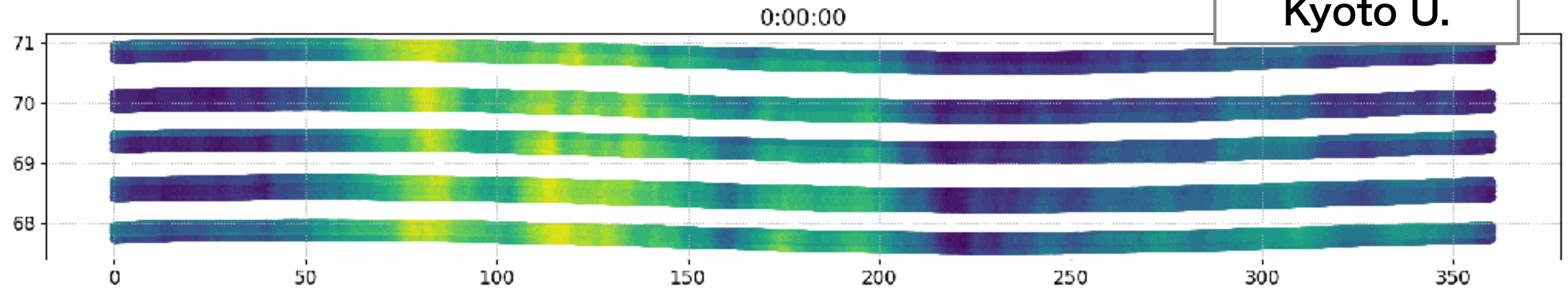
- Result will be presented in the comming SPIE conference.





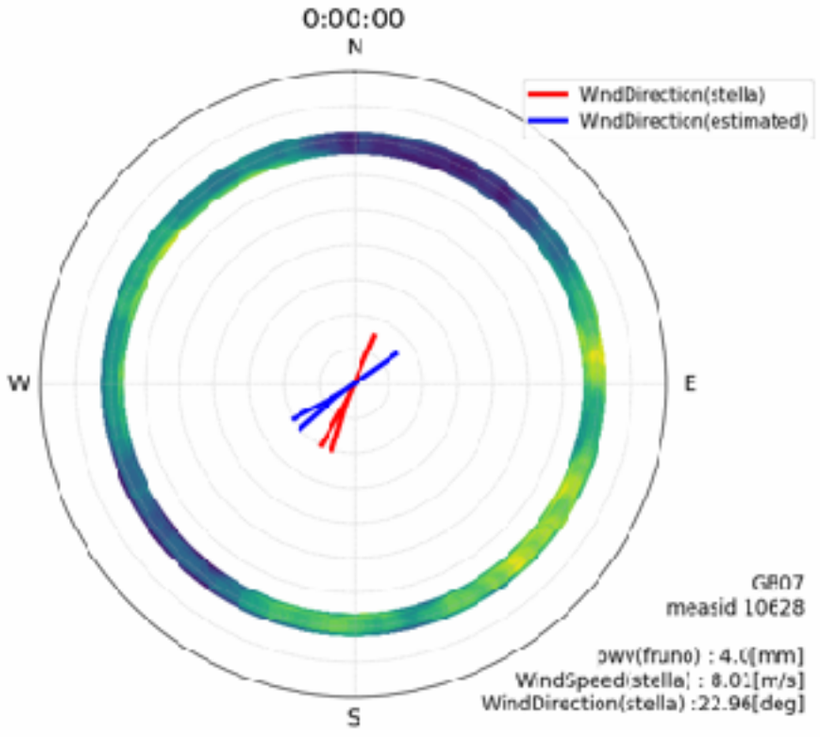
Atmospheric flow analysis

S. Takeichi
Kyoto U.



- We can trace atmospheric flow using fast-rotating feature of the GroundBIRD telescope

- Wind direction estimation roughly agrees with weather station data



Summary

- GroundBIRD is a fast-rotating polarimeter for large scale CMB polarization measurements
  - Primary target: optical depth to reionizaion τ

- GroundBIRD uses KIDs for its focal plane detectors
  - The result of lab / on-sky evaluation of the detector arrays will be published soon.

- Several instrumental / atmospheric analysis and pipeline construction works are now going on!
  - Pol angle, gain cal w point sources / el-nods, atmospheric characterization

Backup

Telescope	Frequency band [GHz]	Noise level ($\mu K \cdot arcmin$)
QUIJOTE	11	3600
QUIJOTE	13	3600
QUIJOTE	17	5100
QUIJOTE	19	5100
QUIJOTE	30	160
QUIJOTE	40	91
GroundBIRD	145	110
GroundBIRD	220	780