Calibration using Sparse Wire Grid (SWG)

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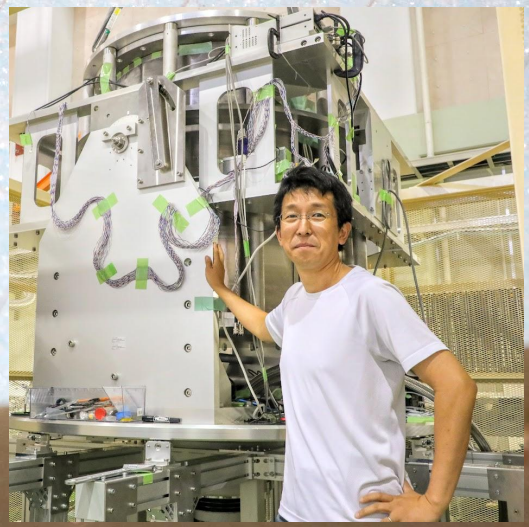
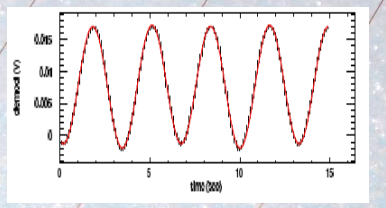


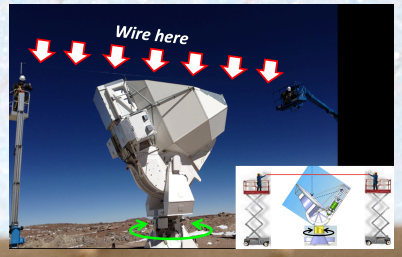
Calibration using Sparse Wire Grid

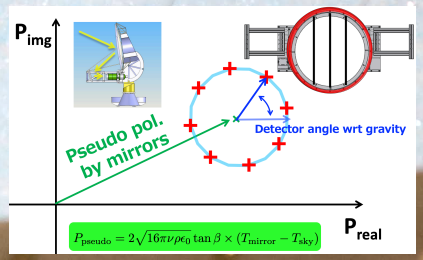
- **Easy & simple method with blackbody like pol. signal**
- **Useful tool in the lab as well as in the field**
  - QUIET's receiver commission and the PB2a of Simons Array

- **Excellent with a continuous rotating HWP**
  - Well demonstrated by ABS and POLARBEAR



- **Absolute angle is obtained with gravity reference**
  - Simons Array and Simons Observatory (SAT) will achieve $\theta_{\mathrm{wire}} < 0.1^{\circ}$
- **"A wire" method is applicable for large aperture telescopes**
  - Poof of concepts by POLARBEAR
  - Ability for the absolute angle

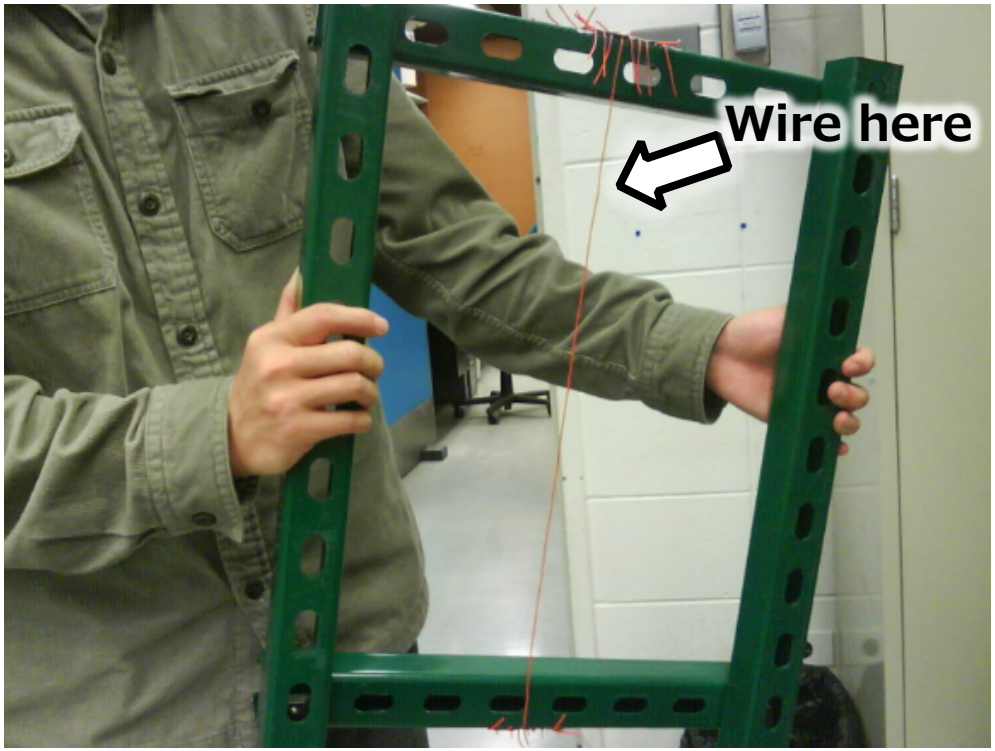




- **Systematic error study is important**

Contents

- **Motivation & Principle**
- **QUIET “the inventor”**
- **ABS “with HWP”**
- **POLARBEAR “a wire”**
- **Simons Array**
- **Simons Observatory**
- **Summary**



The first prototype for QUIET
proof of concepts in 2008

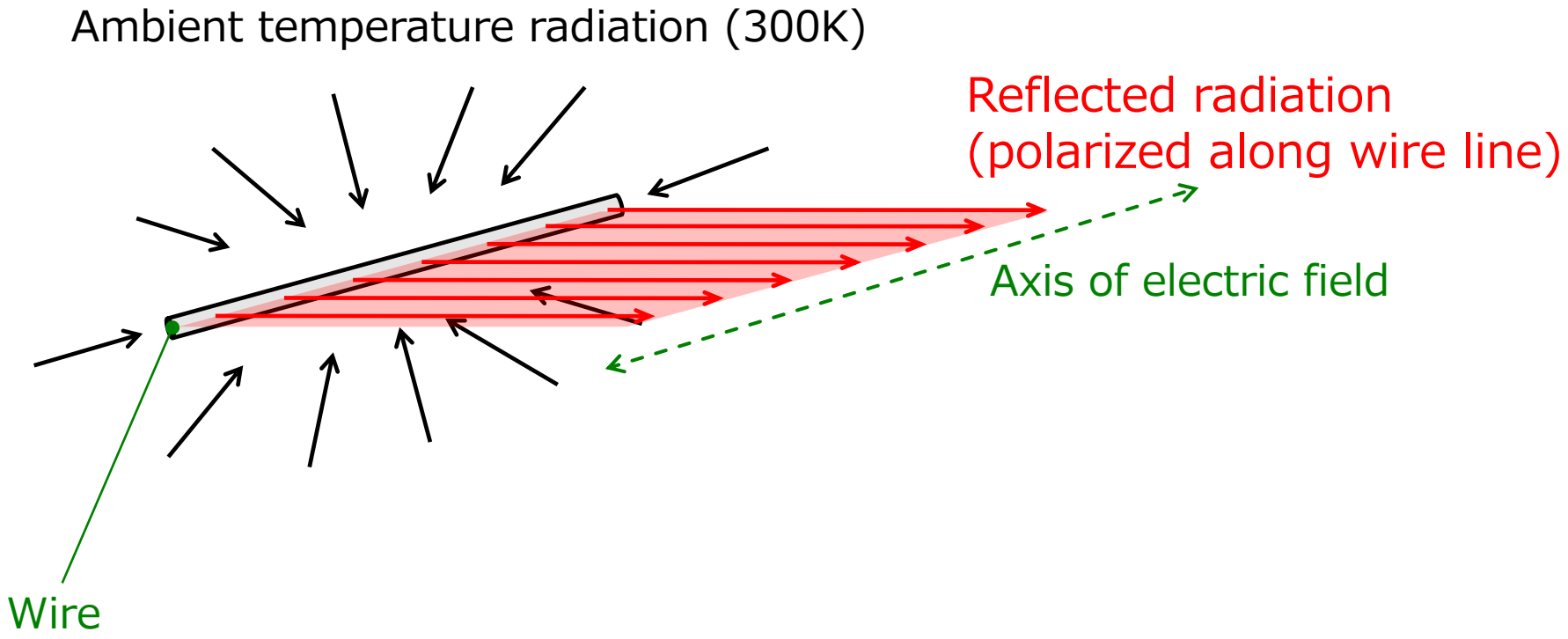
Motivations & requirements

- **Detector angle and responsivity to polarized signal are important**
- **We have not been satisfied systematic error and observability of astronomical sources, e.g. TauA yet**
- **We need artificial polarization source**
  - Bright signal, O(100 mK) ~ O(1 K)
  - Blackbody (like) signal for wide frequency coverage
  - Capability to rotate the direction of polarization
  - Capability to illuminate all focal plane detectors simultaneously
  - …

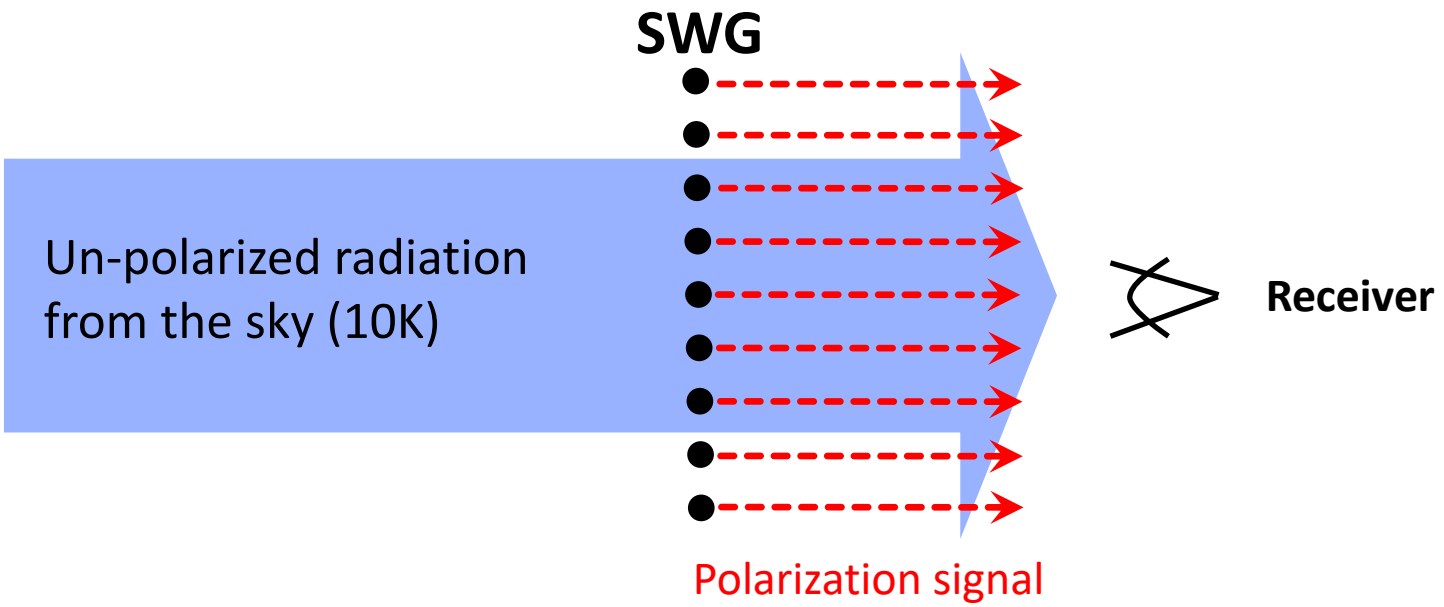
SWG calibration meets requirements

Principle of pol. signal generation

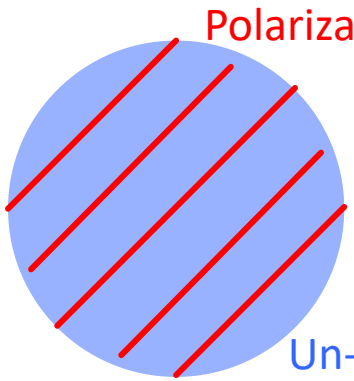
Linear polarization
⇔ Radiation whose E-field axis is aligned



Observed signal

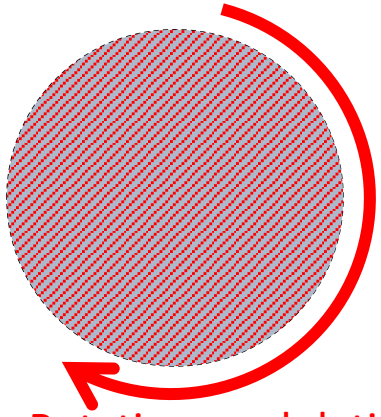


View from receiver side



Smeared by
beam profile

Receiver observes uniform signal

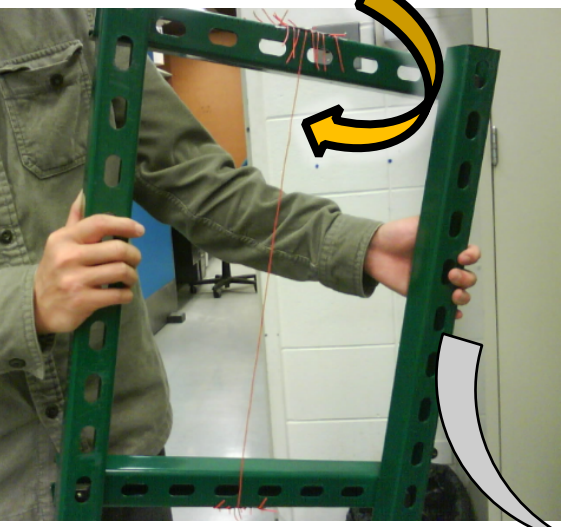


Intensity is proportional to
- wire density
- diff. btw T_{sky} and $T_{ambient}$

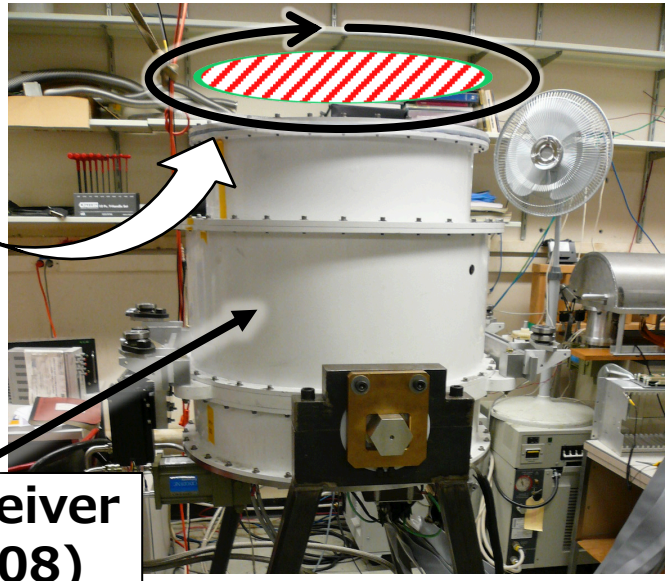
T_{pol} was approximately 1 K
in the QUIET's configuration

Proof of concepts in lab.

Metal wire cable

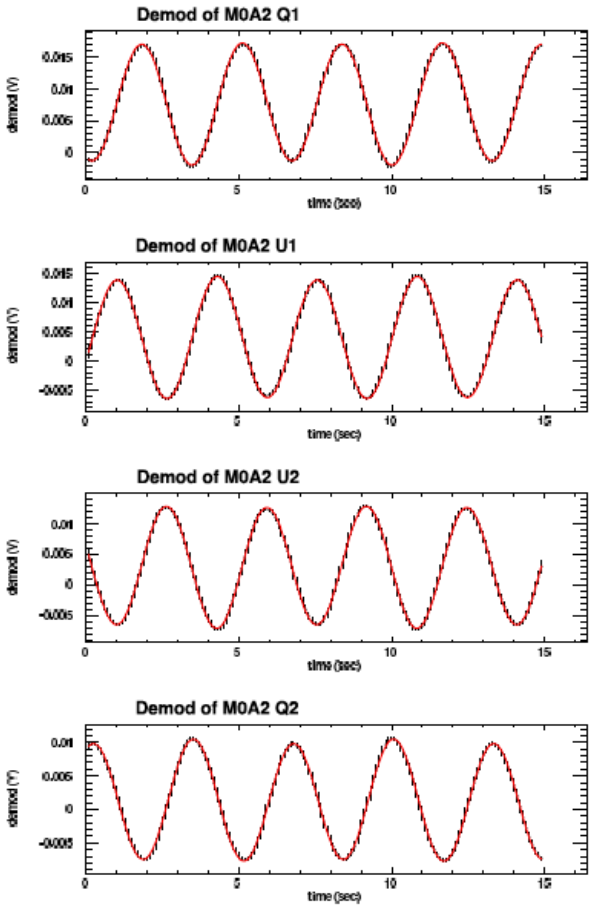


Under LN_2 sky,
i.e. T_{sky} = 77 K

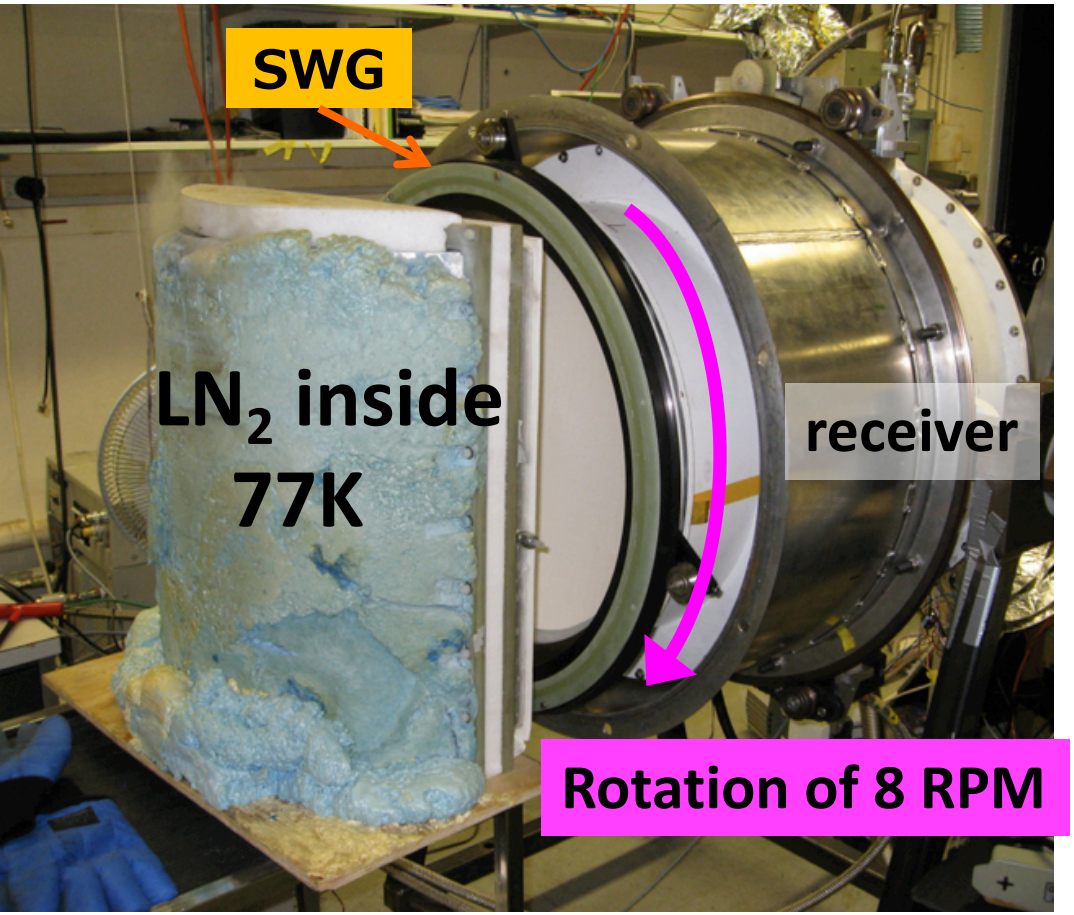


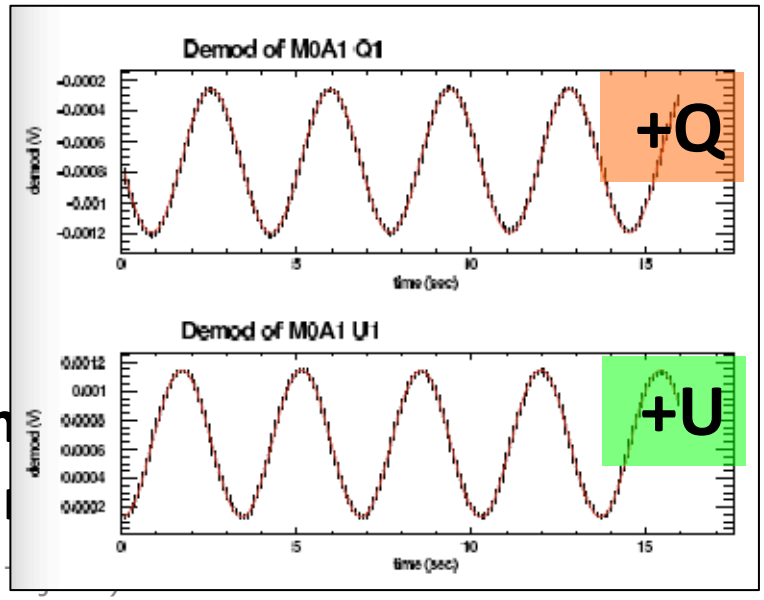
QUIET's W-band receiver
in Chicago lab. (2008)

Stokes Q, U response



Receiver commission using SWG

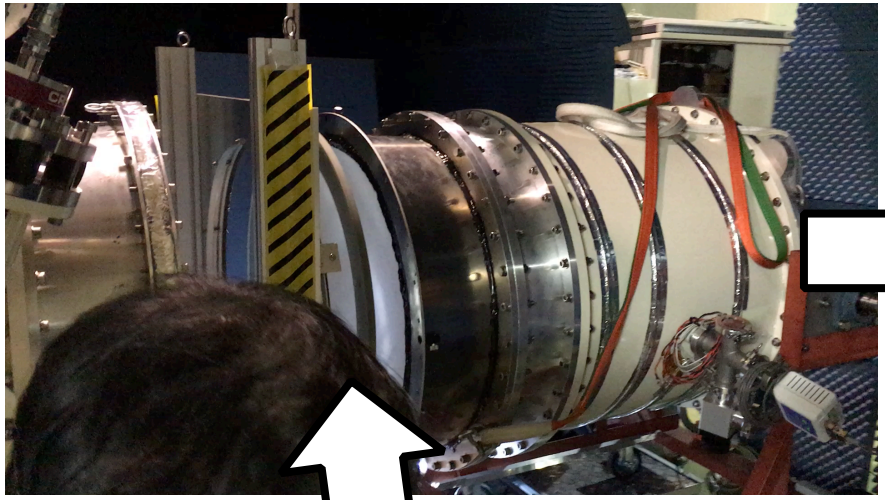


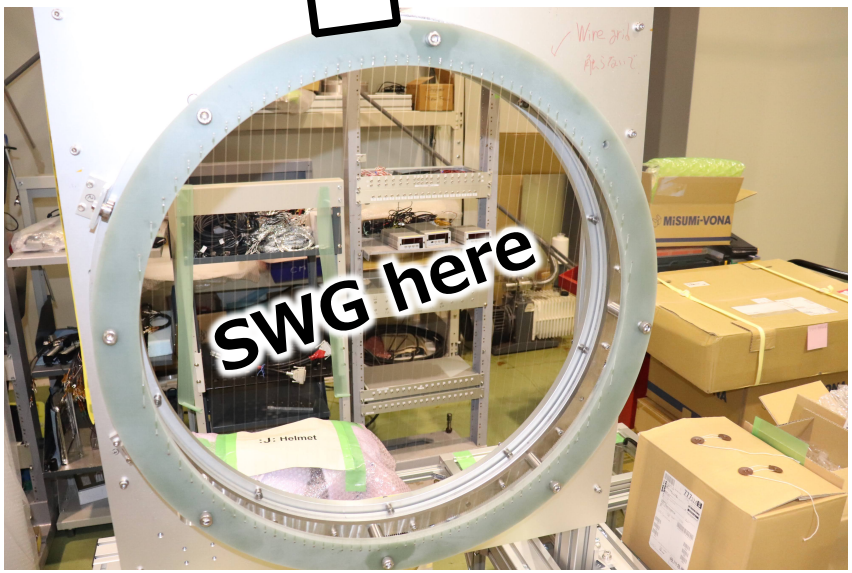


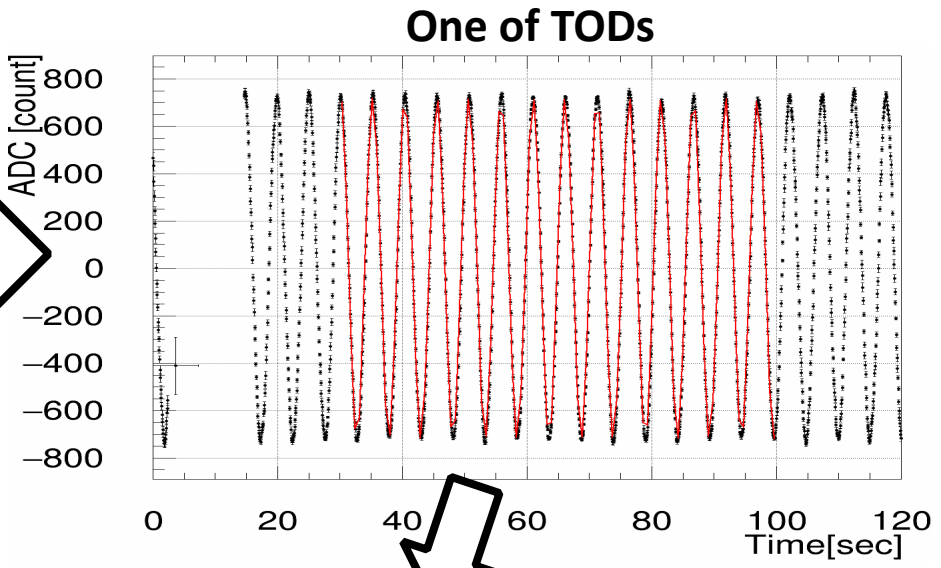
SWG and rotation system were n

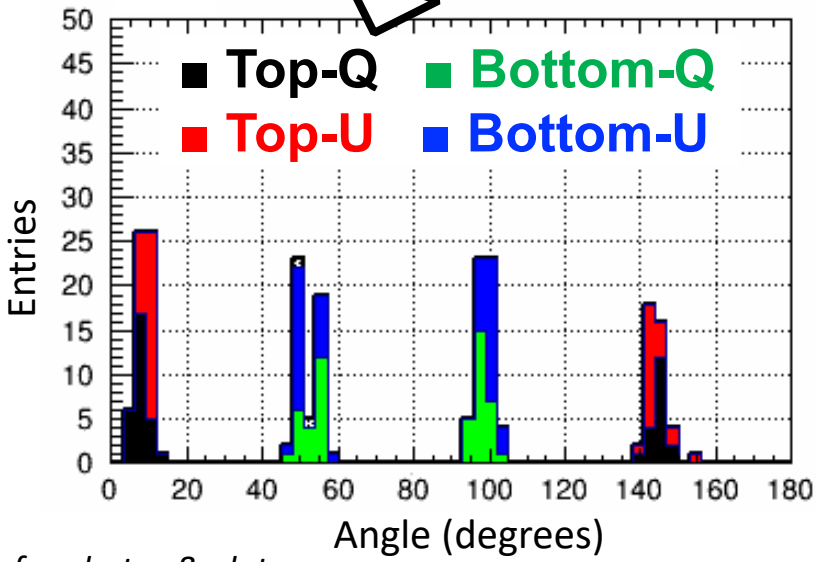
Tungsten wires (ø25 µm) on G10

PB2a lab commission using SWG





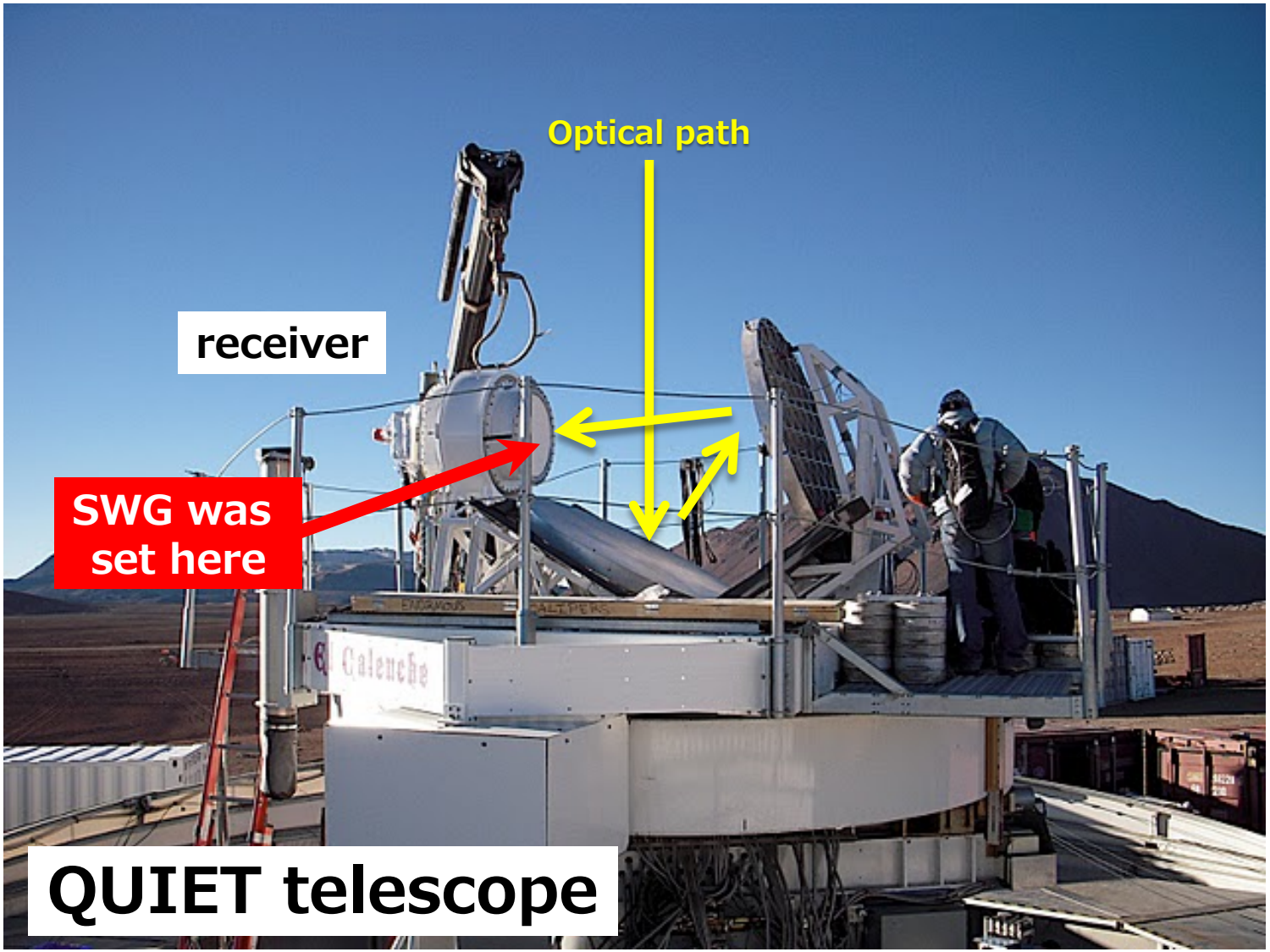




Acknowledgement M. Hasegawa for photos & plots

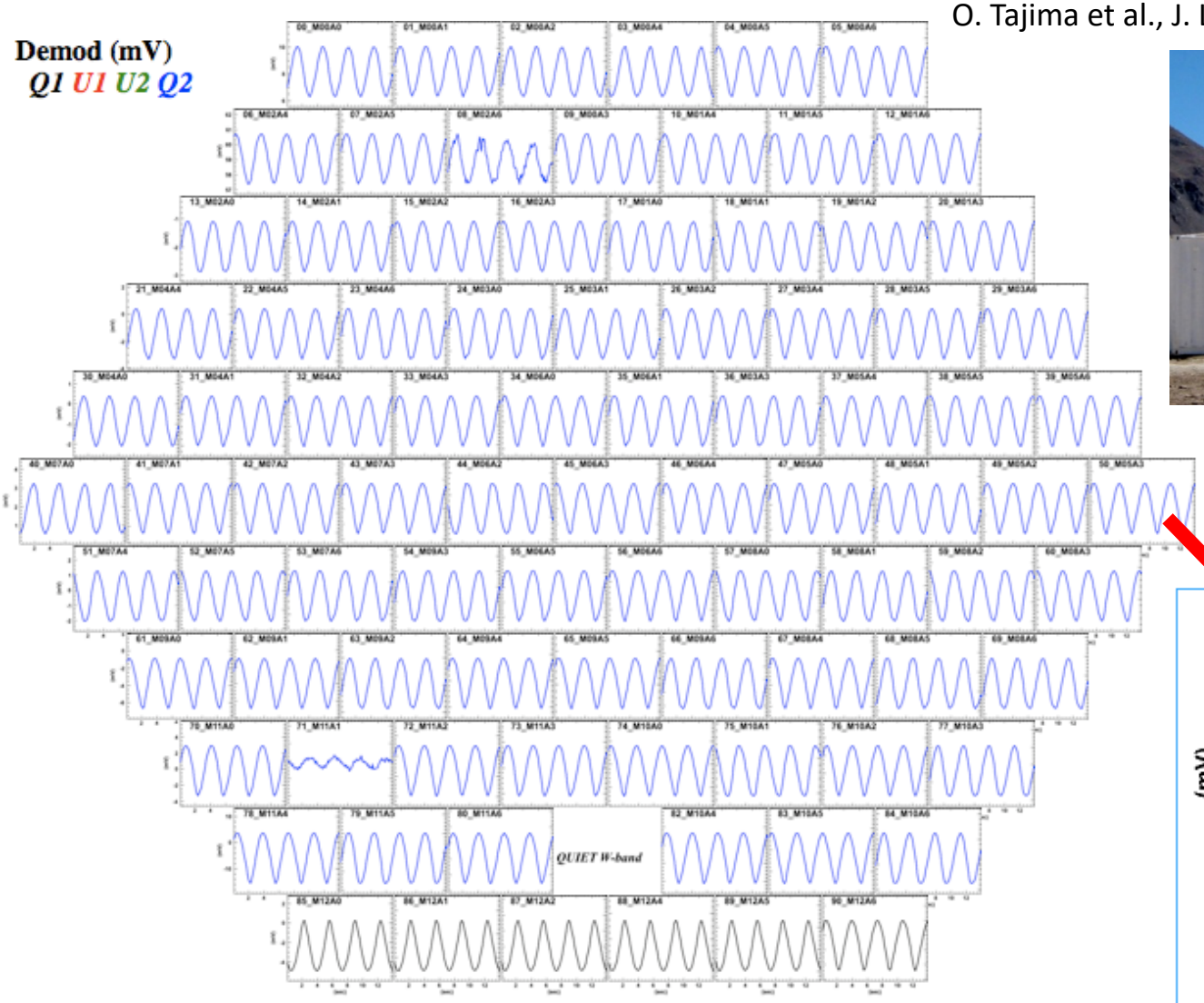
SWG Calibration in the field

Calibration under the sky

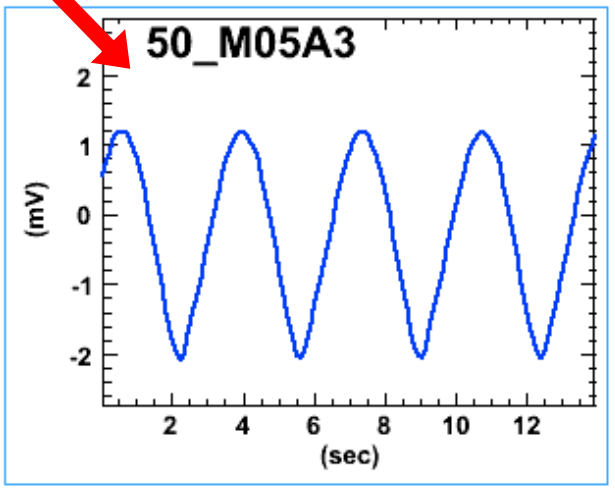


We saw excellent sinusoidal curves in all detectors!

O. Tajima et al., J. Low Temp. Phys. 167, 936-942 (2012).

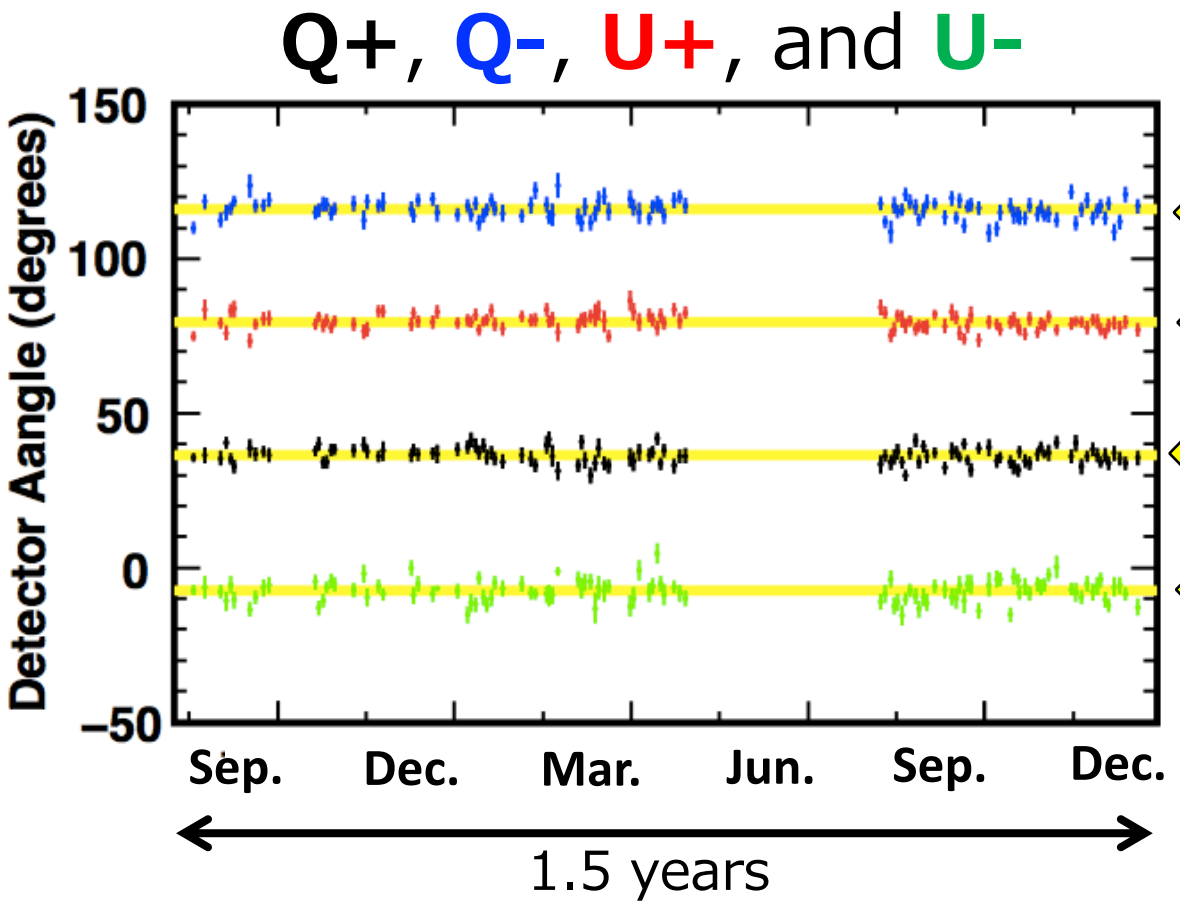


QUIET telescope with W-band receiver



Consist with TauA

Dots are measurements using TauA for center module



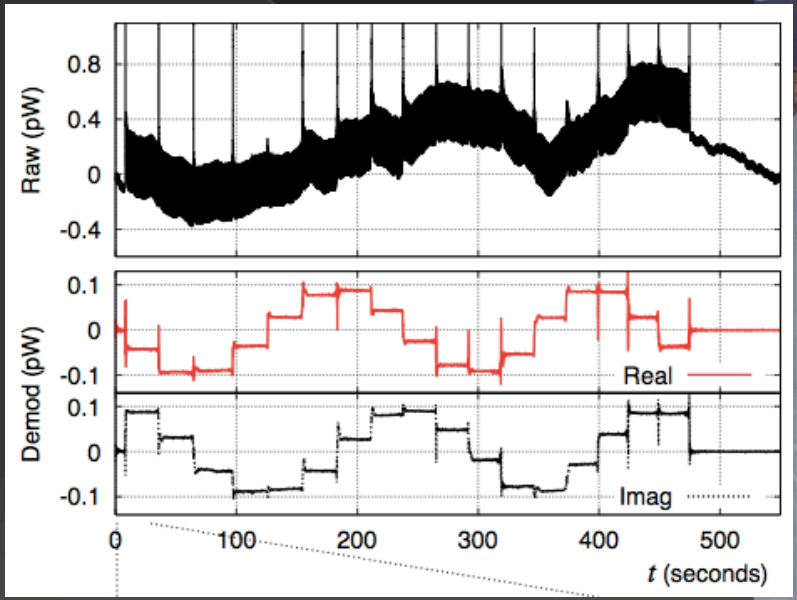
Angles by SWG in Dec.

Application in ABS

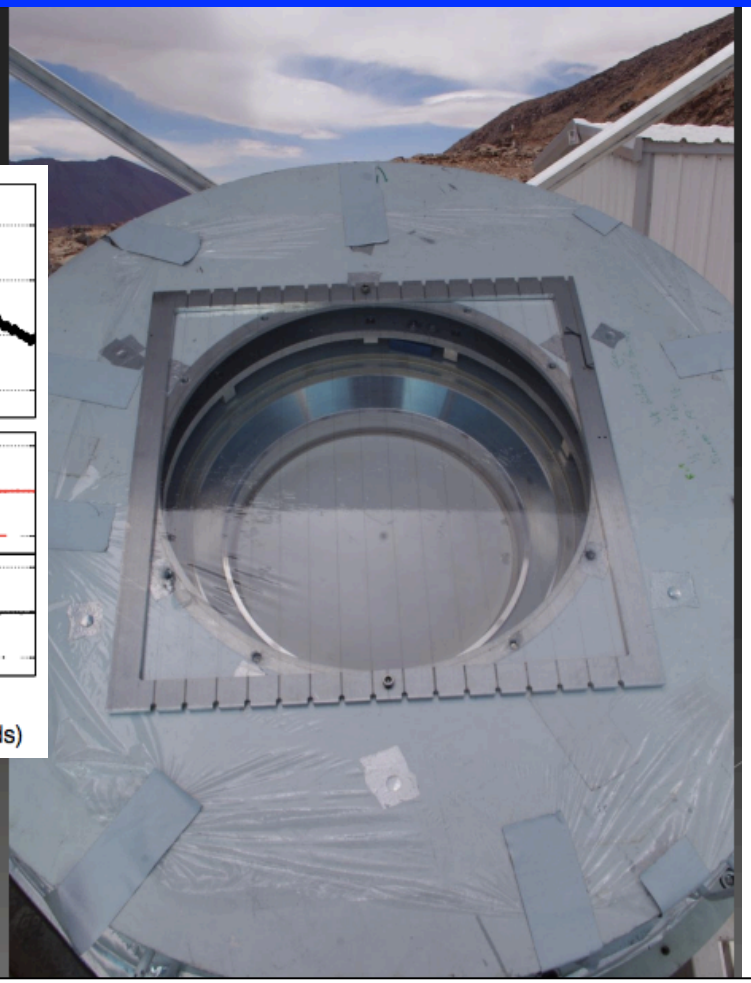
The first combination of SWG and HWP

Time constant cal. as a by-product

Wiregrid

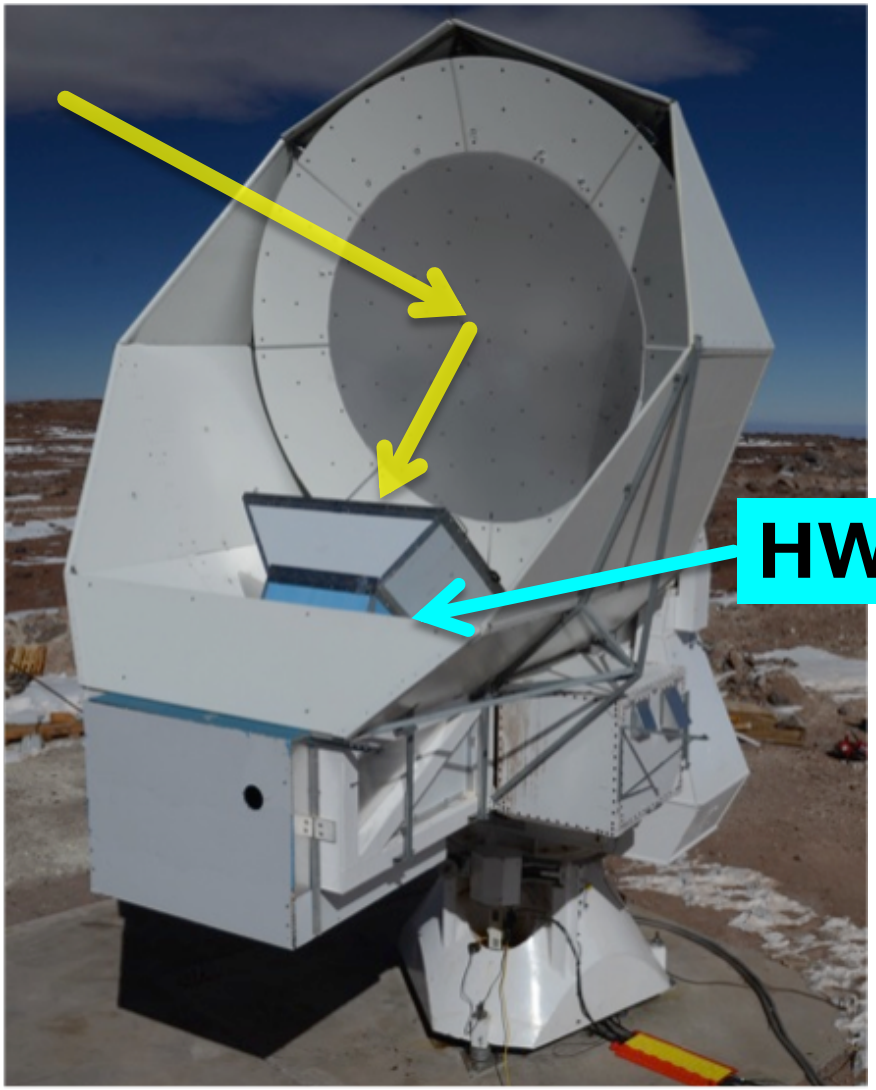


Stepwise rotation (22.5° step)

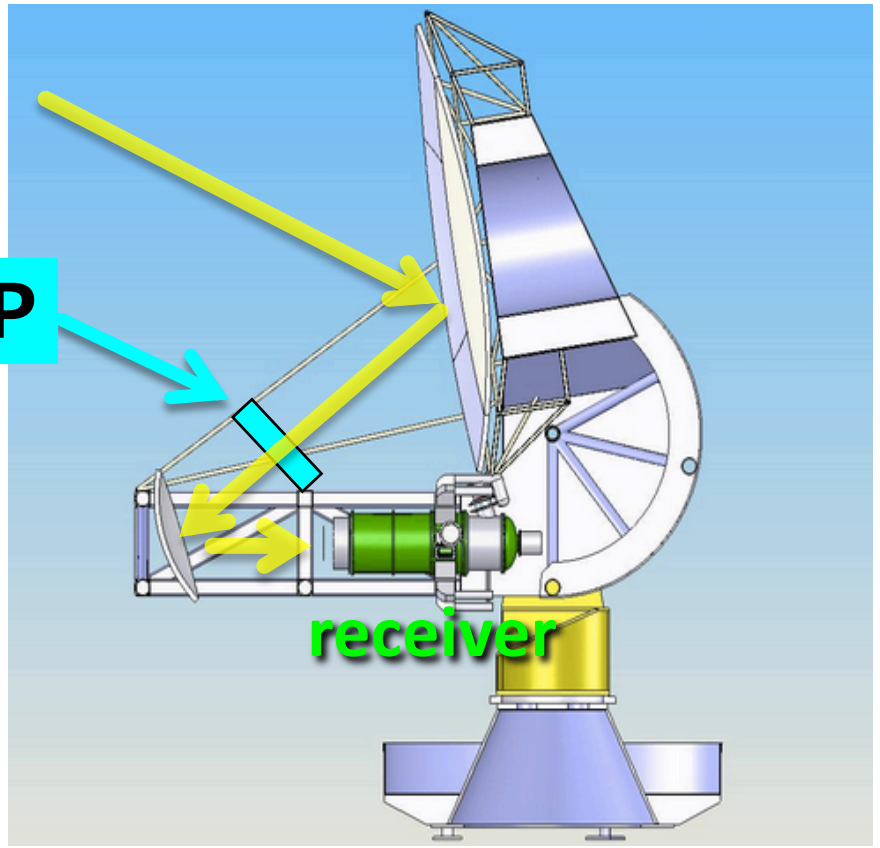


A. Kusaka's slides in Okinawa conference in 2013, and Rev. Sci. Instrum., 85, 024501 (2014).

Application in POLARBEAR

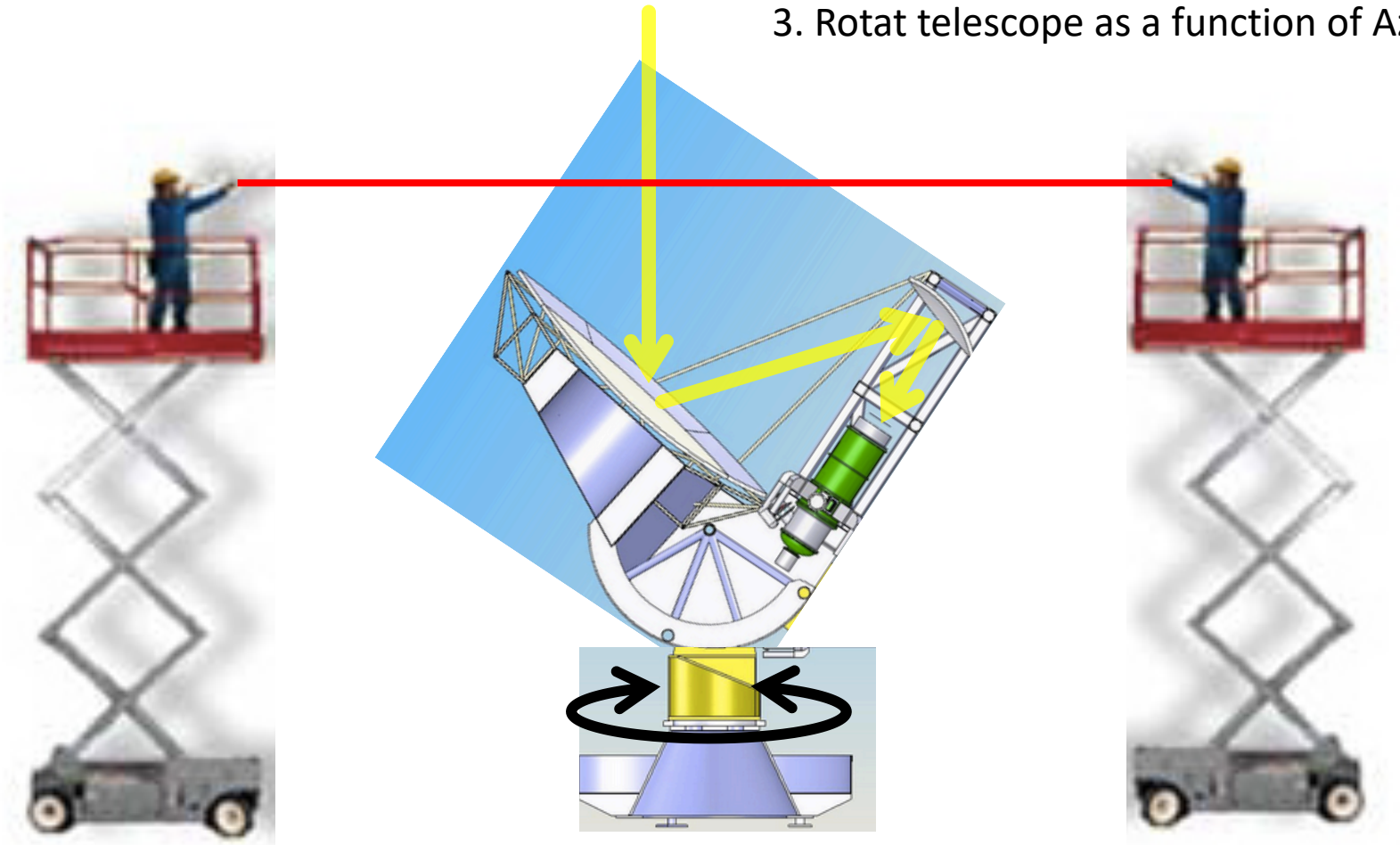


We want to set SWG at the upstream from HWP



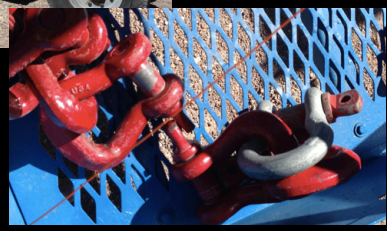
A wire calibration

1. Point to Zenith
2. Set a wire above the telescope
3. Rotat telescope as a function of Azimuth

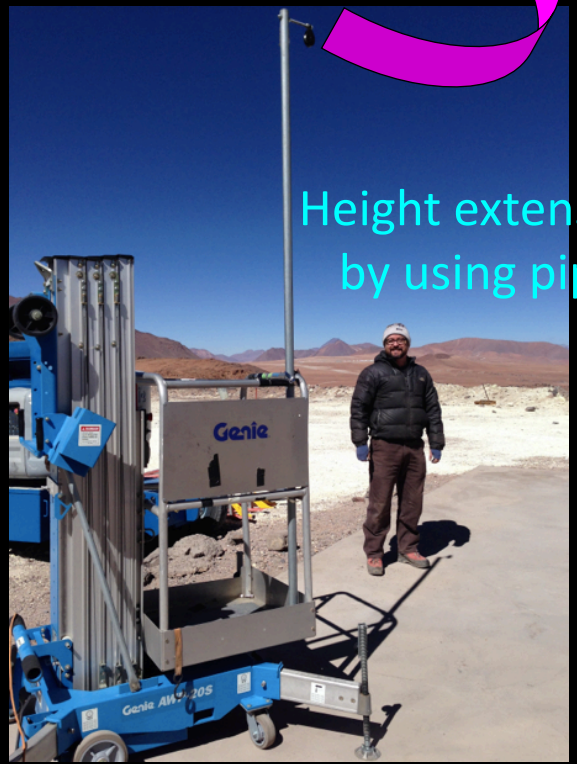


On-site construction

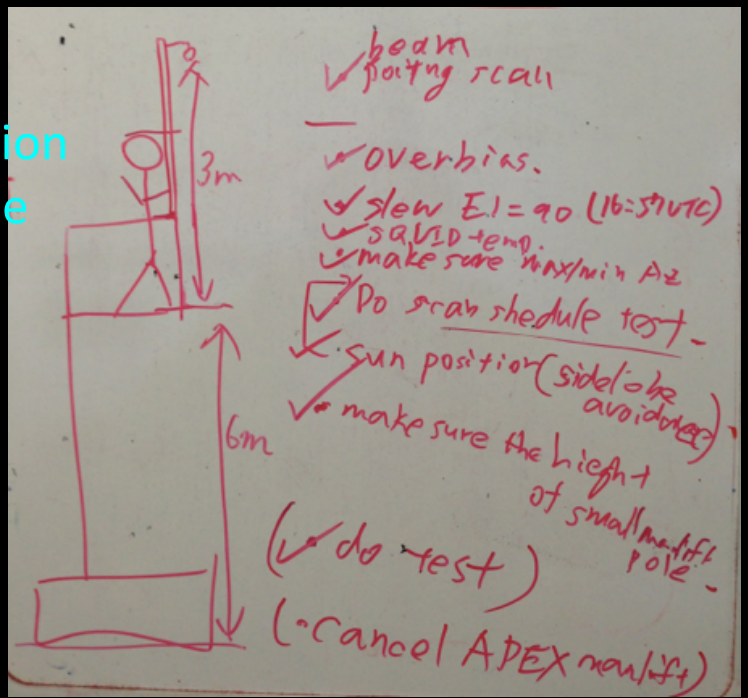
Pulleys to hang wire



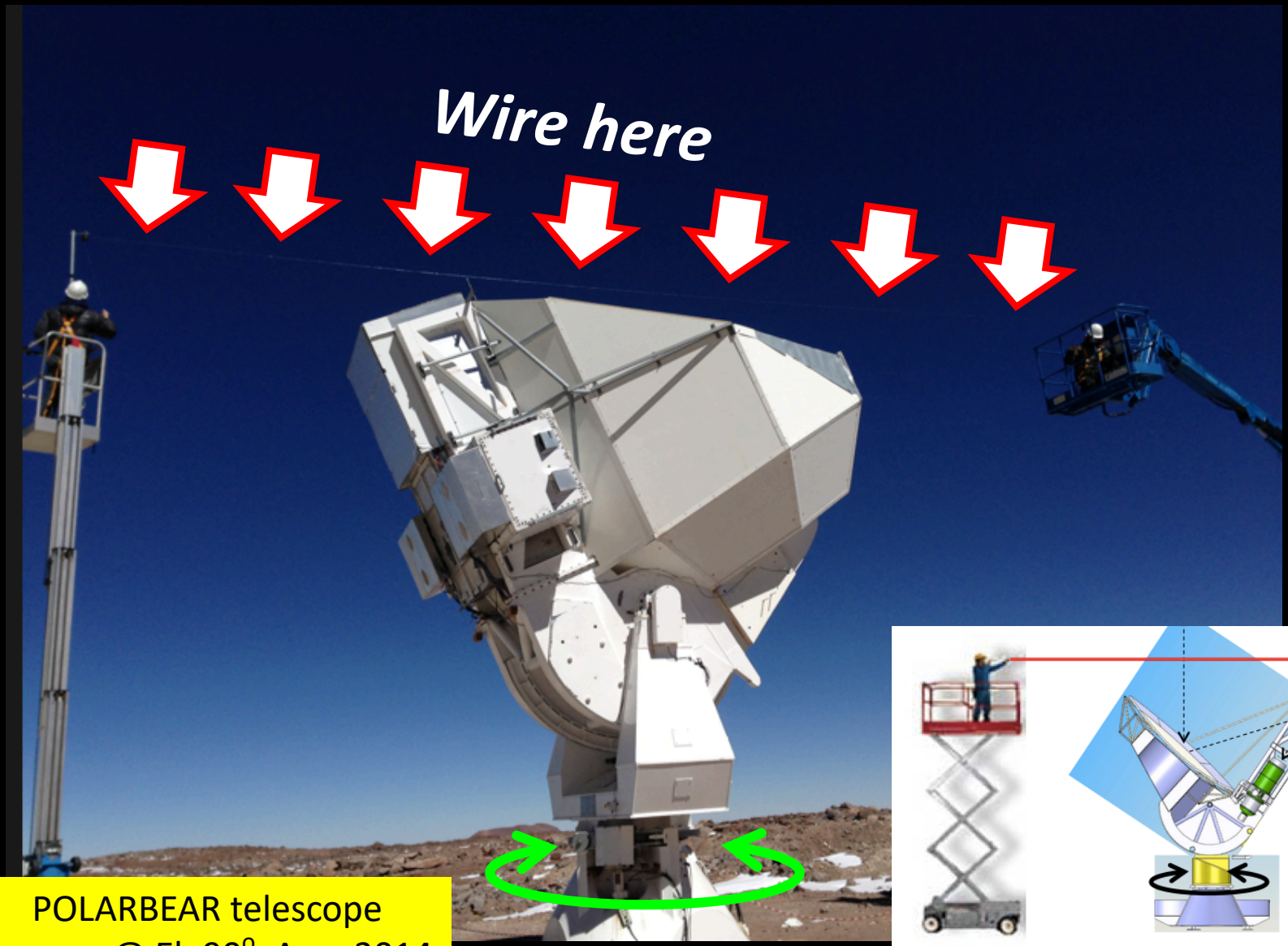
Wire & weights
for tension control



Height extension
by using pipe



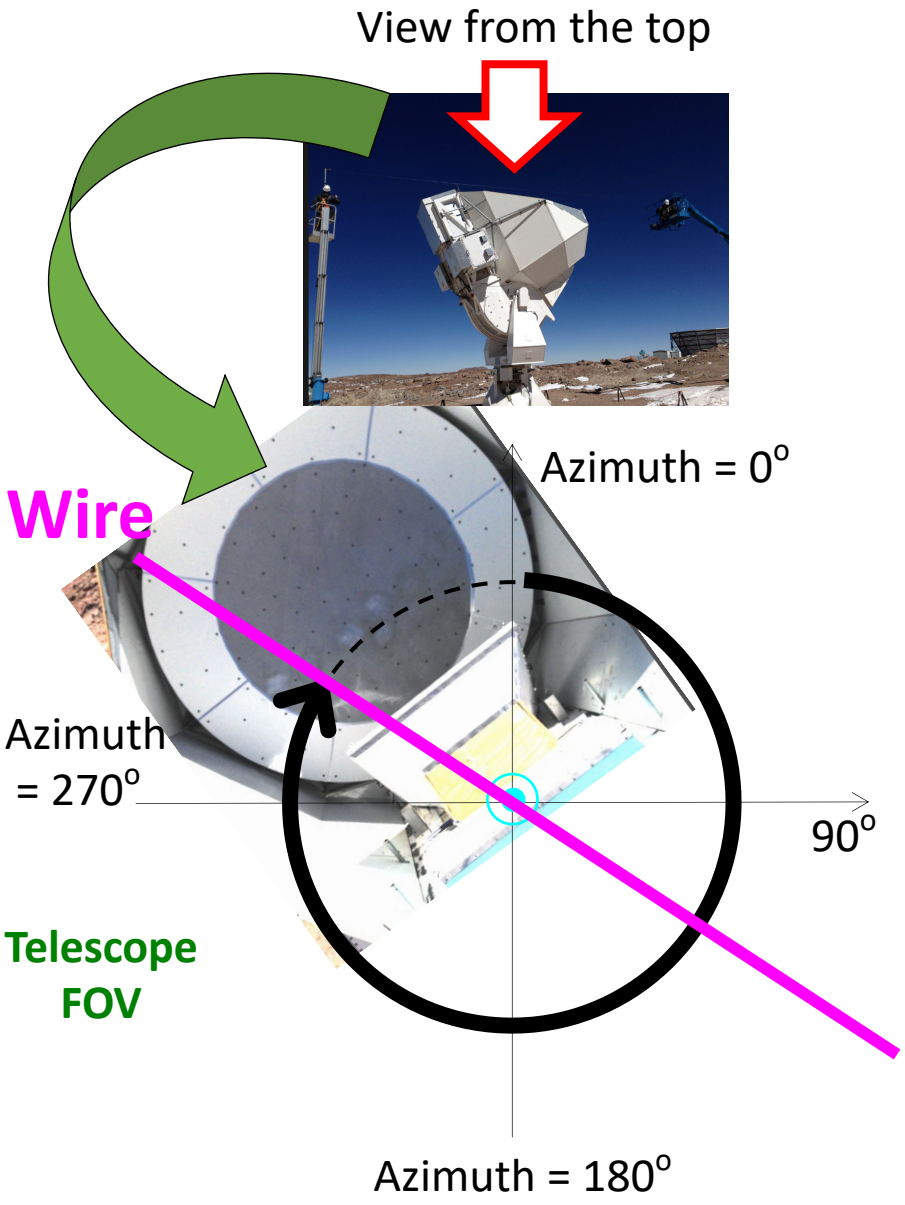
A wire calibration for PB



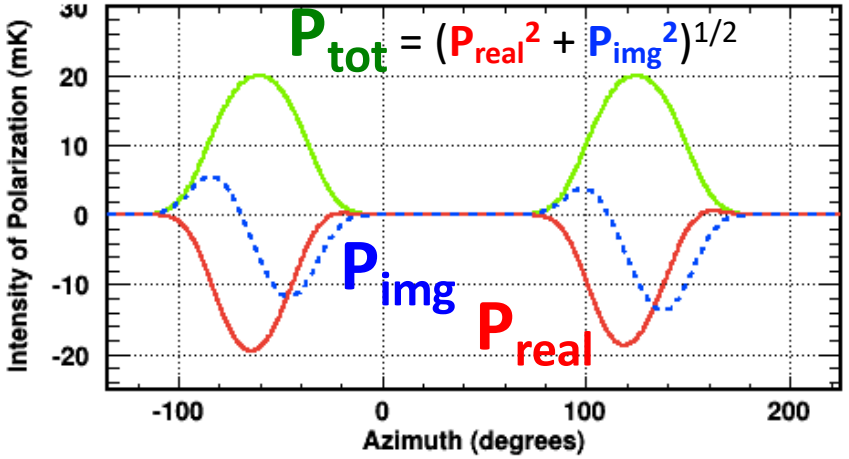
POLARBEAR telescope
Az-scan @ El=90°, Aug. 2014

A wire calibration for PB

Expected Pol. Response?



Simulation of detector responses in demodulated TOD



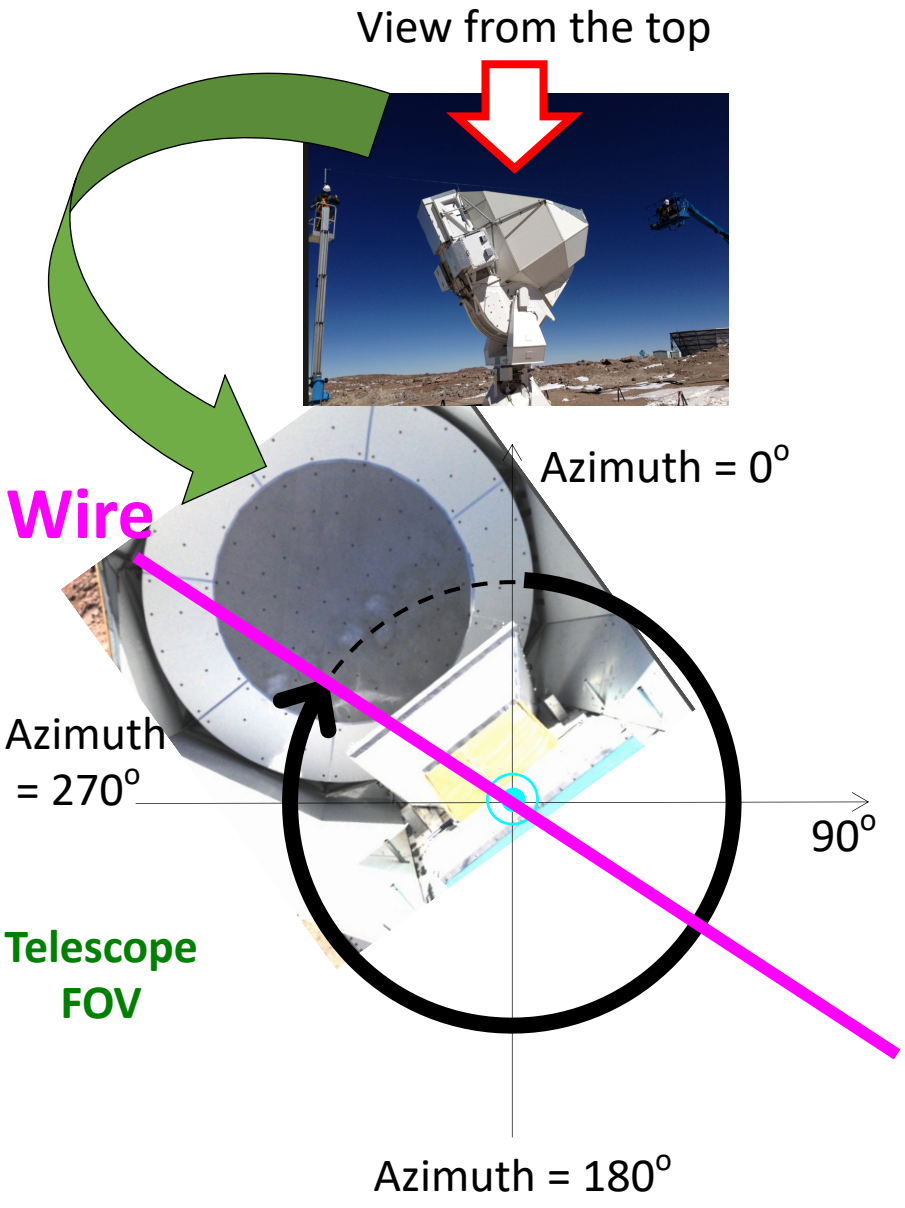
P_{tot} ∝ wire length in telescope FoV

➔ Self-alignment of wire direction

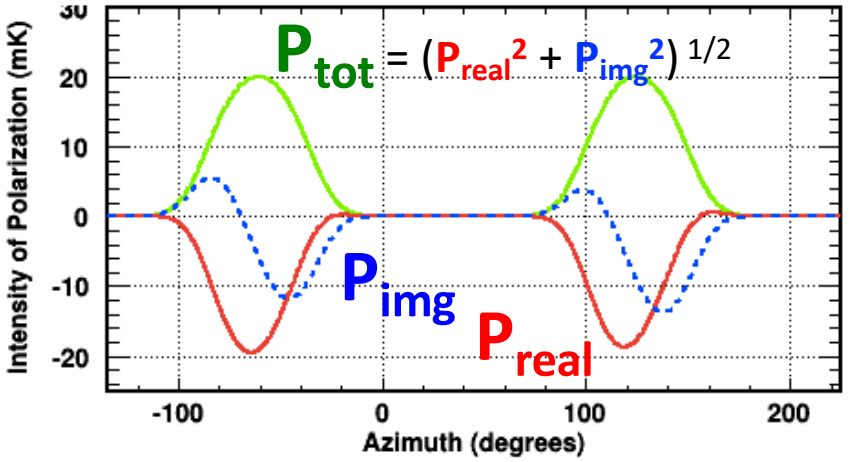
Pol. response w.r.t. wire direction

➔ Orientation of antenna

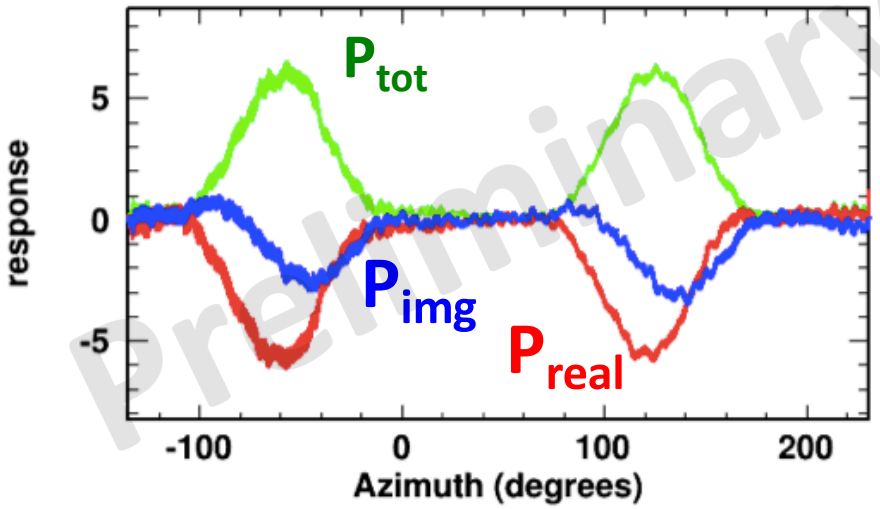
Observation of signal as expected



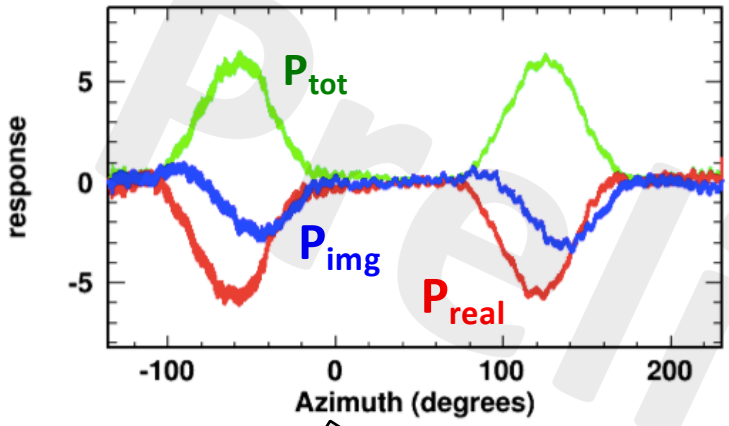
simulation



real data

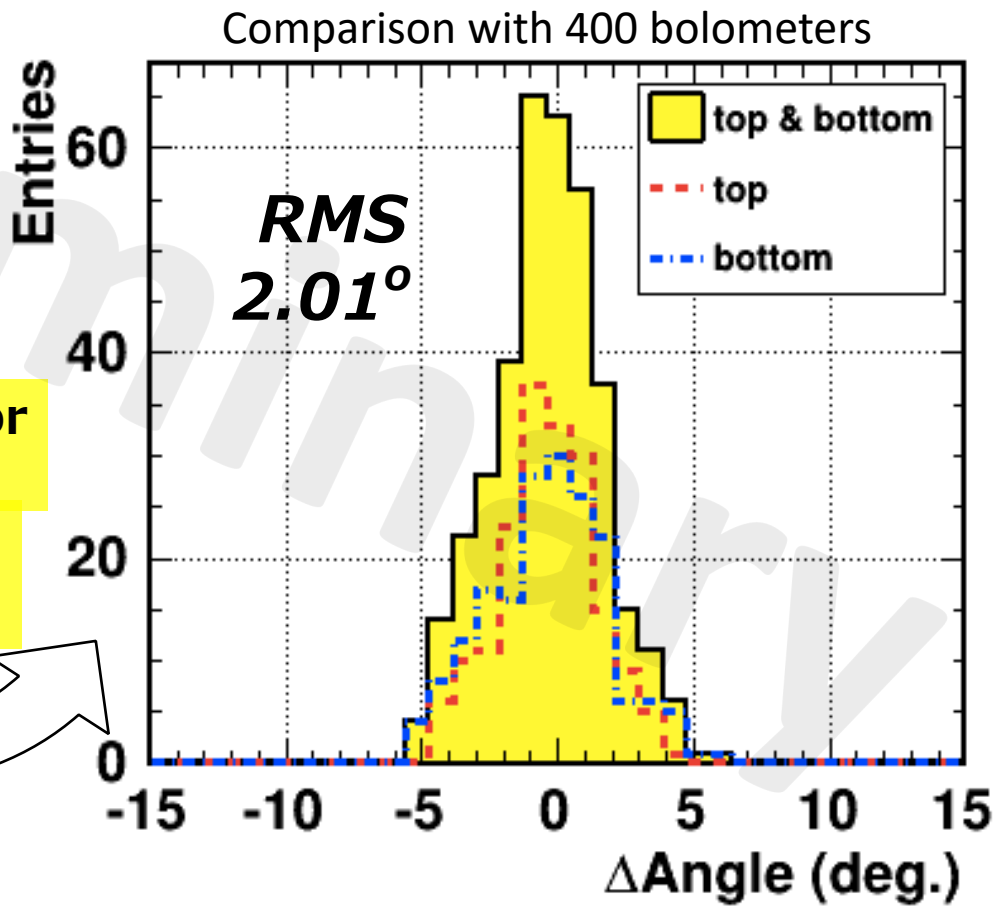


Relative angles are consistent with TauA

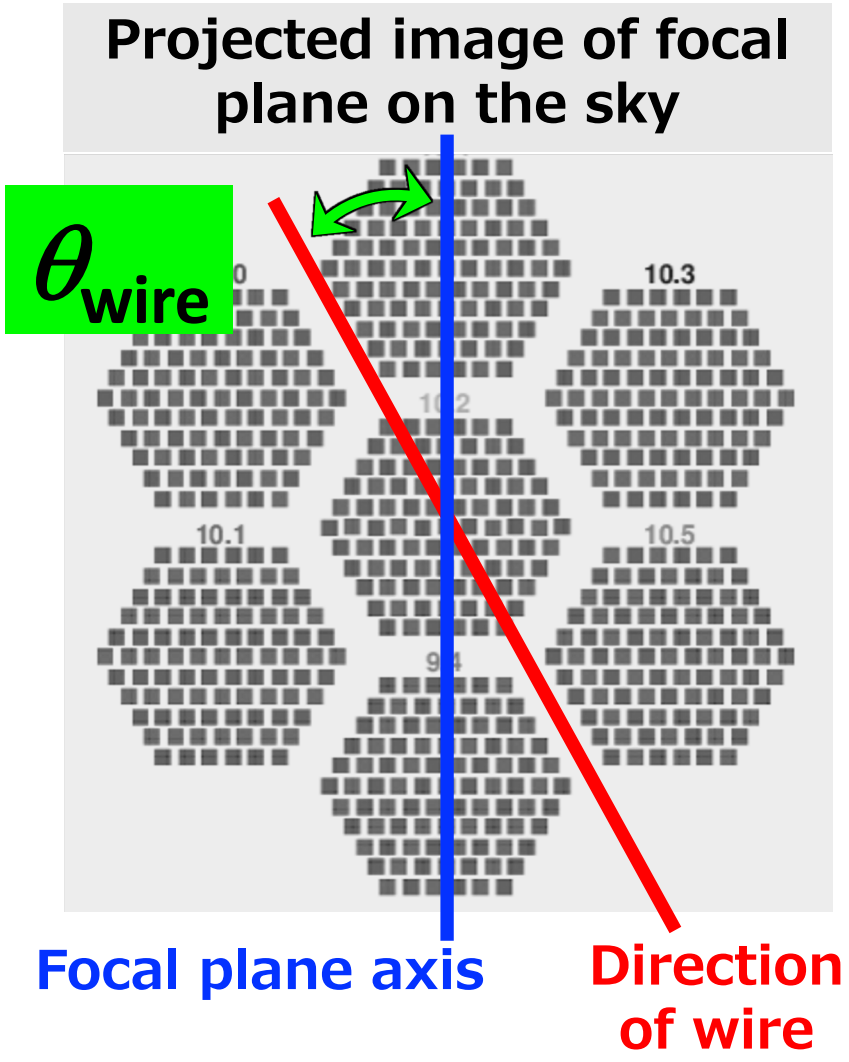


Relative angles for each detector
(angles w.r.t. focal plane axis)

$$\theta_{\mathrm{atan}} \equiv \frac{1}{2}\tan^{-1}(P_{\mathrm{img}}/P_{\mathrm{real}})$$



Extraction of Absolute Angle?



$$\theta_{absolute} = \theta_{atan} - \theta_{wire}$$

Relative angle w.r.t focal plane axis

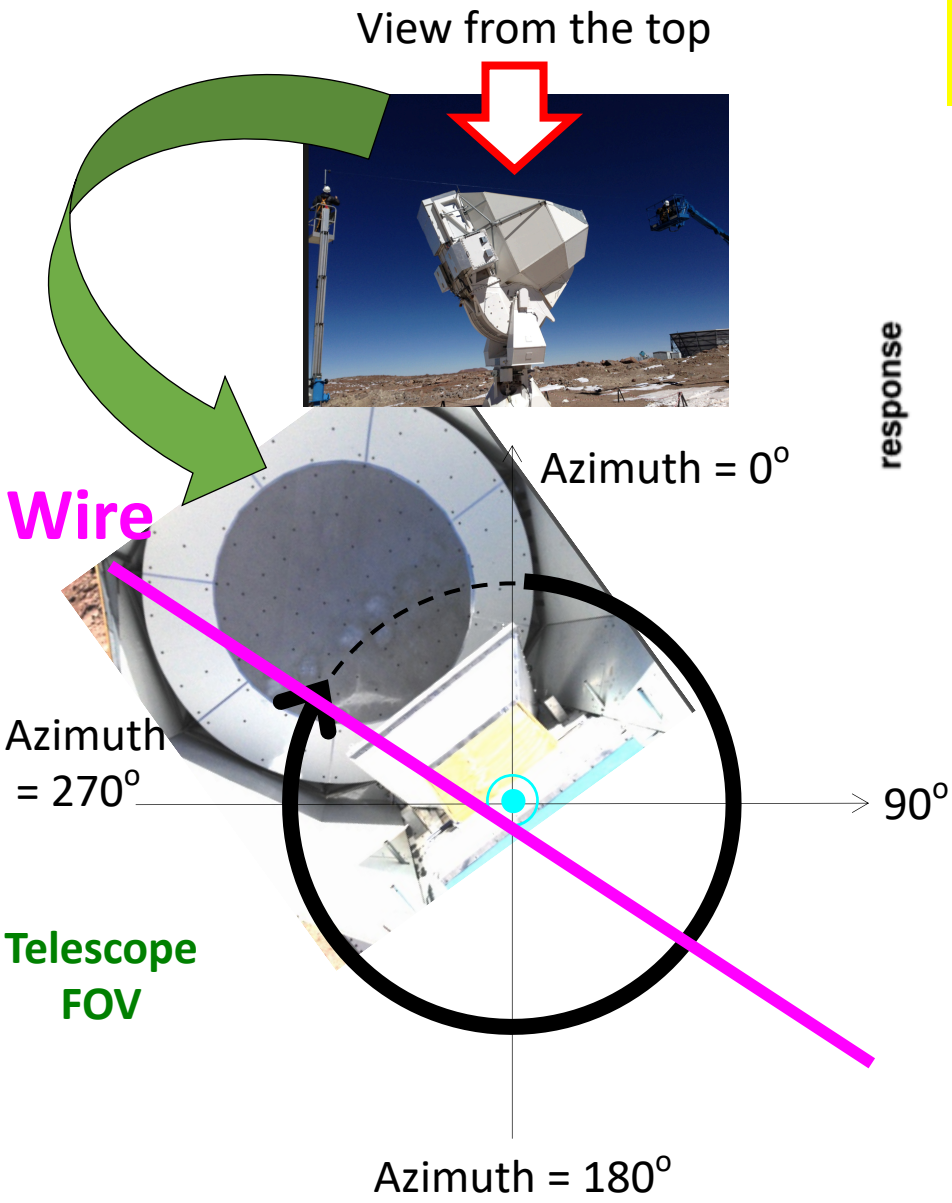
$$\theta_{\mathrm{atan}} \equiv \frac{1}{2}\tan^{-1}(P_{\mathrm{img}}/P_{\mathrm{real}})$$

Accuracy of focal plane axis relys on pointing calibration

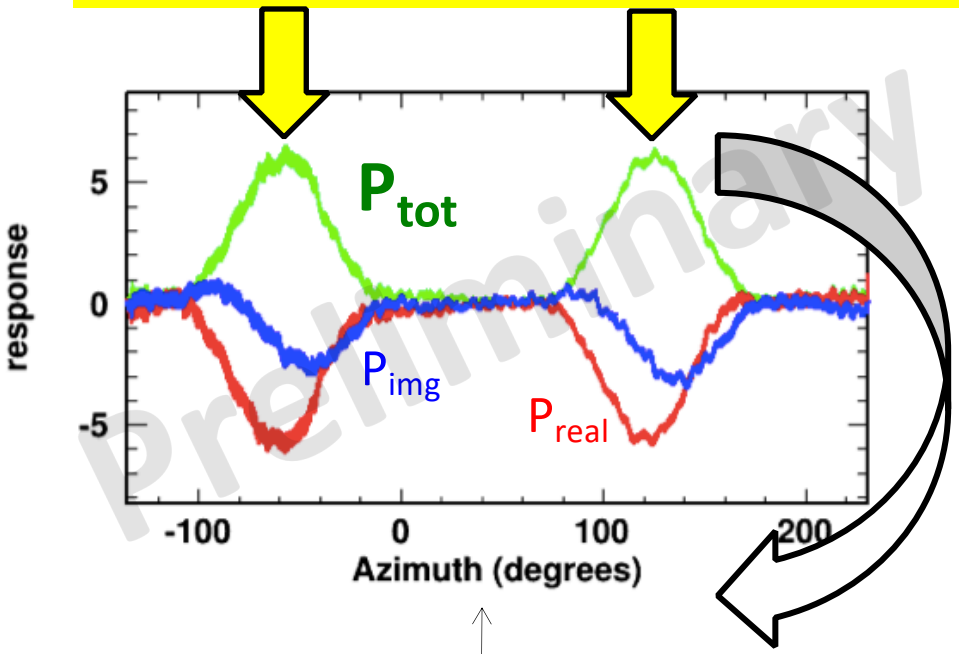
It must be better than beam width << 0.1°

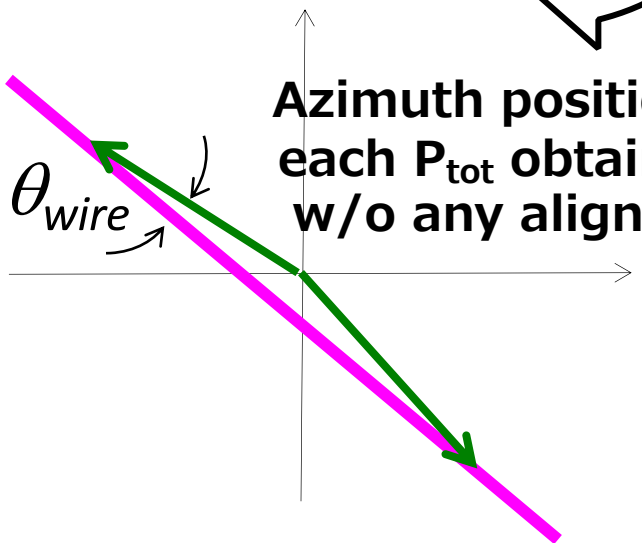
Determination of θ_{wire} is key

Determination of wire direction



Peak position of P_{tot}
⇔ maximum coverage of wire above mirror

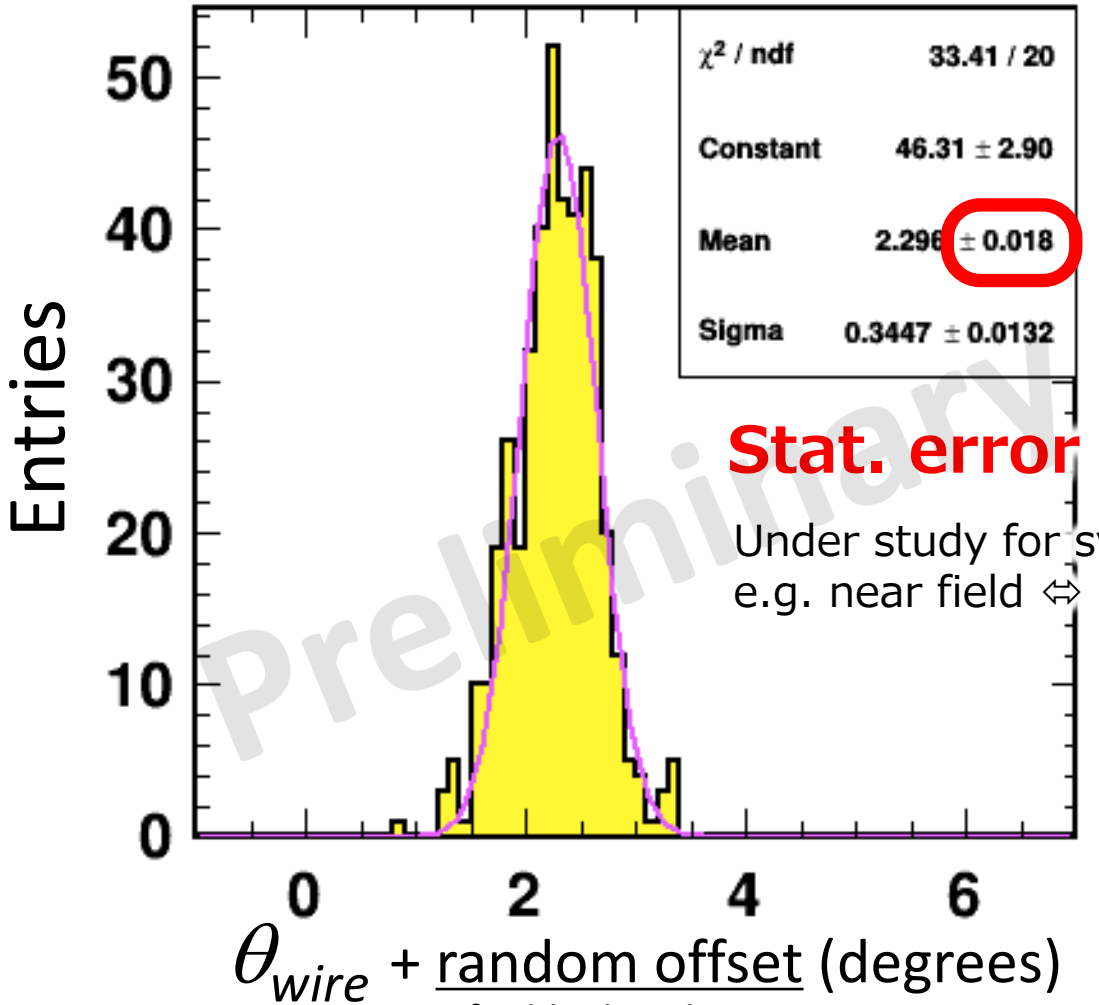




Azimuth positions of each P_{tot} obtain θ_{wire} w/o any alignment

Determination of wire direction

Histogram of θ_{wire} measured by ≈400 detectors



Stat. error <<0.1°

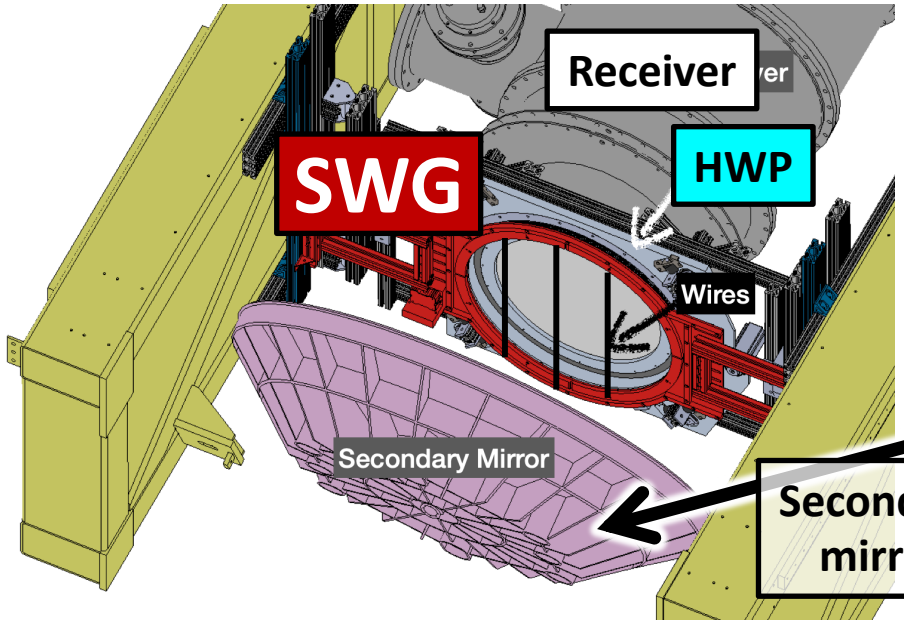
Under study for syst. error,
e.g. near field ⇔ far field

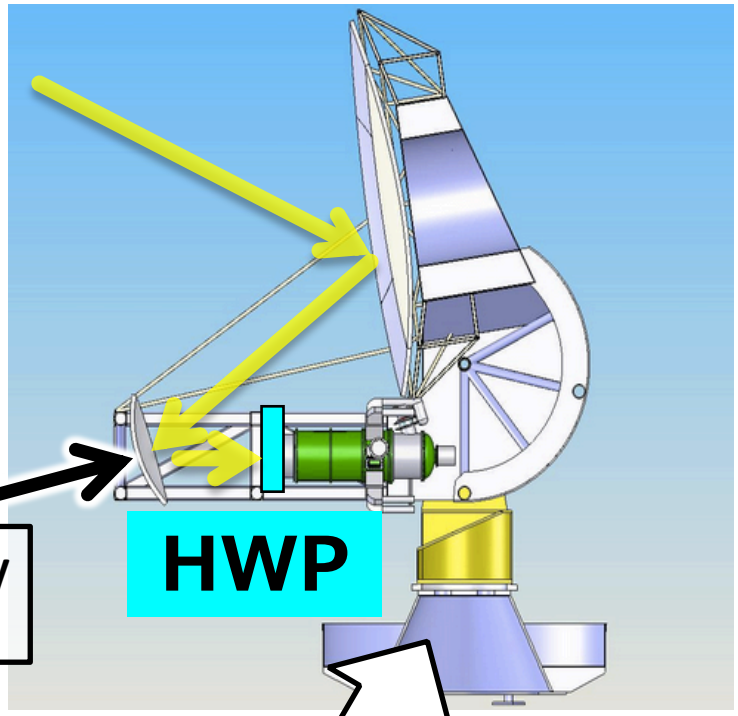
Gravity reference to θ_{wire} pursues absolute pol. angle

Simons Array
Simons Observatory
(Small Aperture Telescope)

Simons Array (SA)

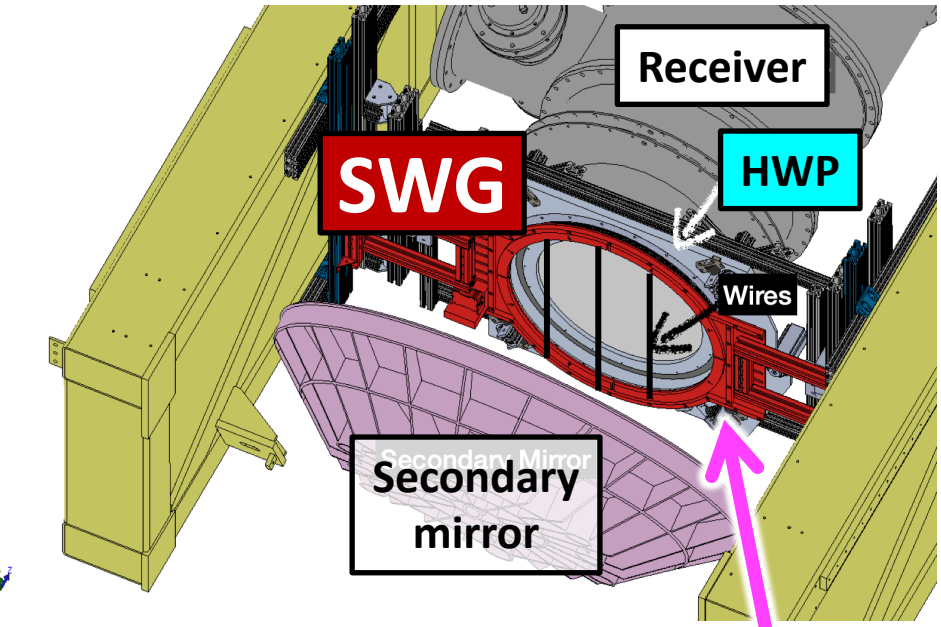
PB telescope x3 using upgraded receivers

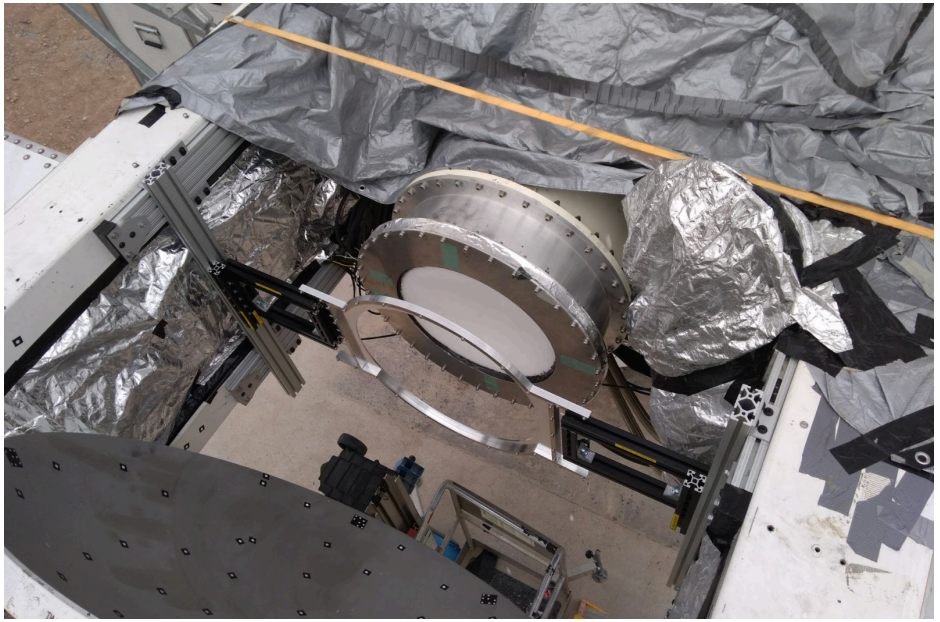




Secondary mirror

SWG for SA : hardware





Tungsten wires

ø 0.1 mm

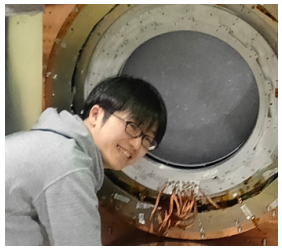
Gravity reference

Degi-pas DWL-5000

$\Delta\theta_{wire} < 0.05^\circ$

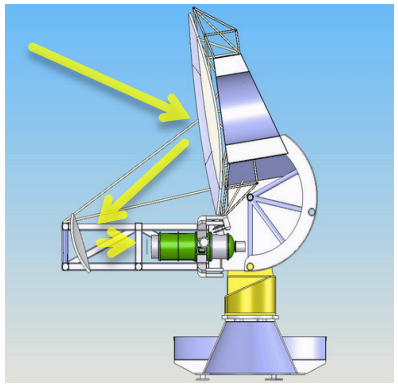
Combination with HWP

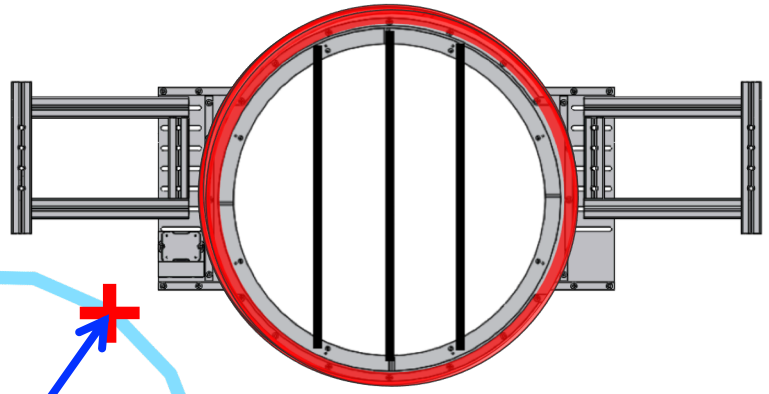
Stepwise rotation every 22.5°



← S. Adachi and **T. Abe →** **(Kyoto U.)**

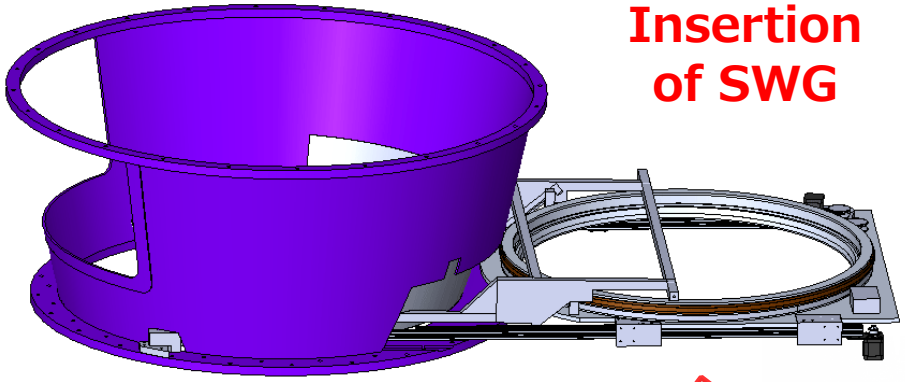
SWG for SA : concepts

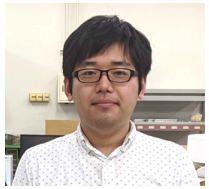




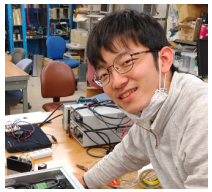
$$P_{\mathrm{pseudo}} = 2\sqrt{16\pi\nu\rho\epsilon_0}\tan\beta \times (T_{\mathrm{mirror}} - T_{\mathrm{sky}})$$

SWG cal. for SO-SAT





M. Murata
(UTokyo)

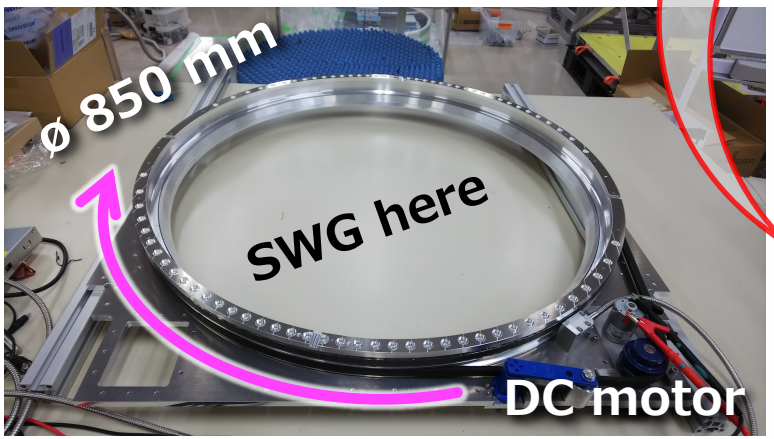


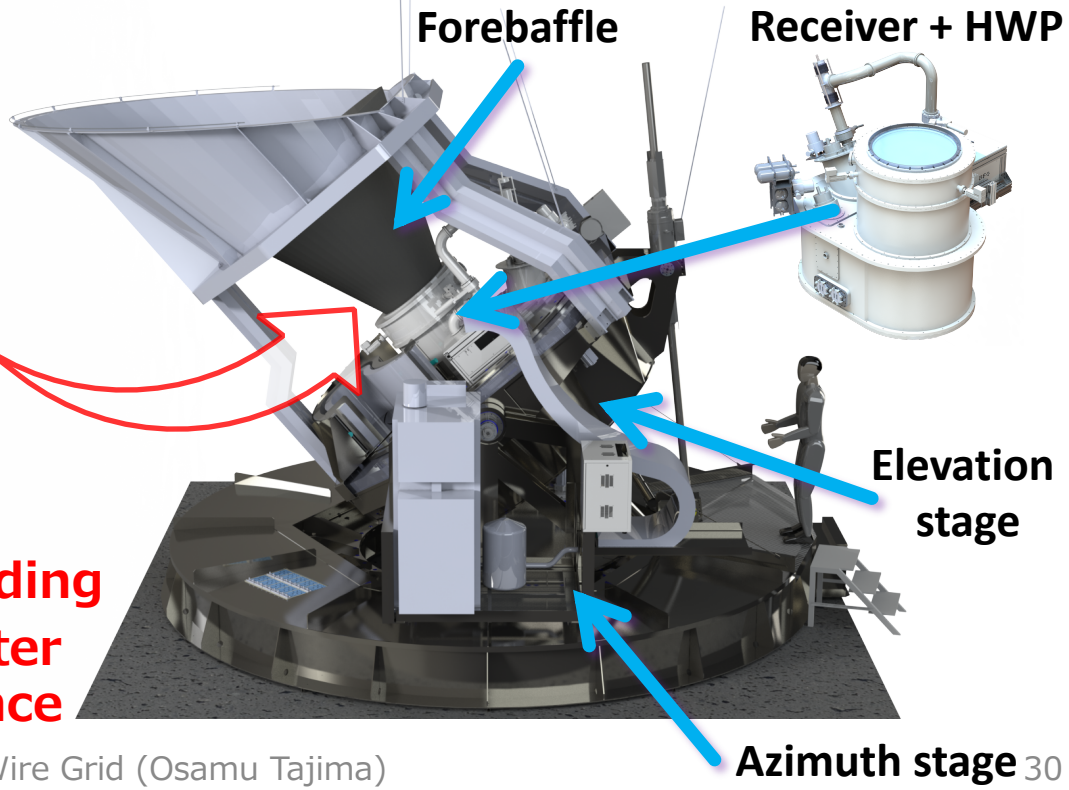
H. Nakata
(Kyoto U.)

From left to right
K. Kiuchi (UTokyo)
S. Adachi (Kyoto U.)
F. Matsuda (Kavli IPMU)

Movie & photo from Murata's JPS slides

To be installed at the bottom of forebaffle, i.e. above the receiver window





- **Rotatable with direction encoding**
- **Target accuracy of θ_{wire} is better than 0.1° with gravity reference**

Discussions

✓Statistical error

- Signal to noise is high enough

• Systematic error

- Mechanical precisions with respect to the gravity or telescope axis can be controlled less than 0.1°
- Possible rotation of angle from near field to far field

“Gravity reference” method

- (I feel) it is not big issue unless beam ellipticity is low enough

“A wire” method

- It may not be naïve
- This method relies on pointing model

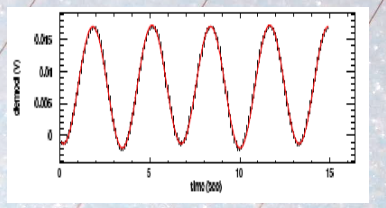
One of homework

Establishment of methodologies for systematic error

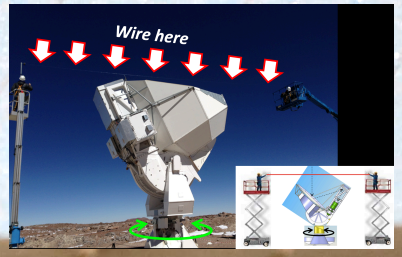
Calibration using Sparse Wire Grid

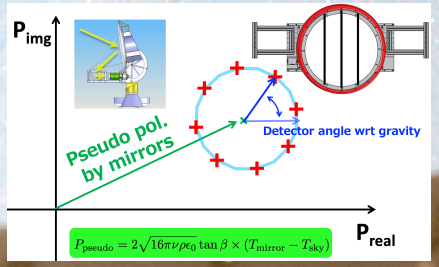
- **Easy & simple method with blackbody like pol. signal**
- **Useful tool in the lab as well as in the field**
  - QUIET's receiver commission and the PB2a of Simons Array

- **Excellent with a continuous rotating HWP**
  - Well demonstrated by ABS and POLARBEAR



- **Absolute angle is obtained with gravity reference**
  - Simons Array and Simons Observatory (SAT) will achieve $\theta_{\mathrm{wire}} < 0.1^{\circ}$
- **"A wire" method is applicable for large aperture telescopes**
  - Poof of concepts by POLARBEAR
  - Ability for the absolute angle





- **Systematic error study is important**

End