

# We3B

# Development of W-Band Dual-Polarization Kinetic Inductance Detectors on Silicon

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D. Granados<sup>3</sup>, E. Artal<sup>2</sup> and A. Gomez<sup>1</sup>

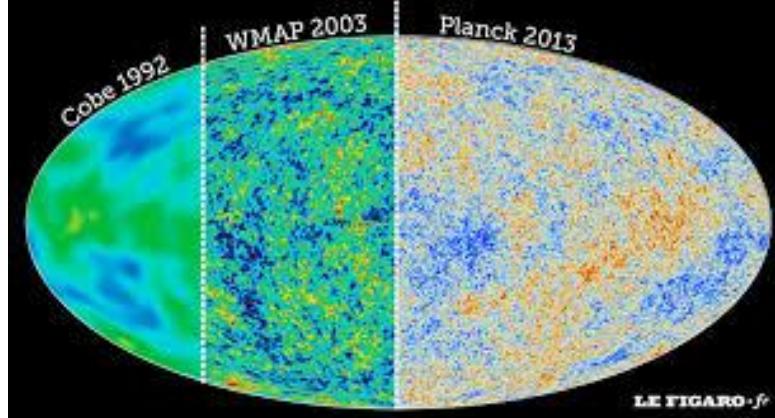
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- ❖ Introduction and motivation
  - ❖ Pair breaking detectors. Frequency cut-off
  - ❖ Dual-polarization LEKIDs
- ❖ BiKIDs - LEKIDs for W-Band
  - ❖ Frequency cut-off → Ti/Al bilayers
  - ❖ W-Band Optical Design
  - ❖ Detector performance
- ❖ Conclusions and future work

# Introduction



## Cosmic Microwave Background (CMB)

Large arrays of sensitive detectors:

- ❖ 60 – 600 GHz
- ❖ Polarization sensitive

## SUPERCONDUCTING DETECTORS FOR MM/SUBMM BANDS:

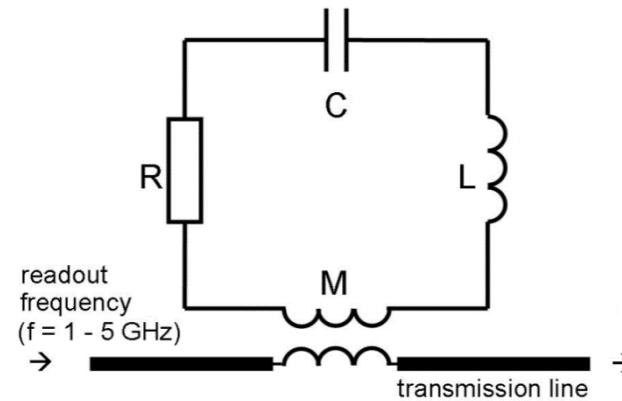
- Superconducting Tunnel Junctions (STJ)
- Transition Edge Sensors (TES)
- Kinetic Inductance Detectors (KIDs)

- Very sensitive (photon noise limited)
- Broad band
- Intrinsically multiplexable

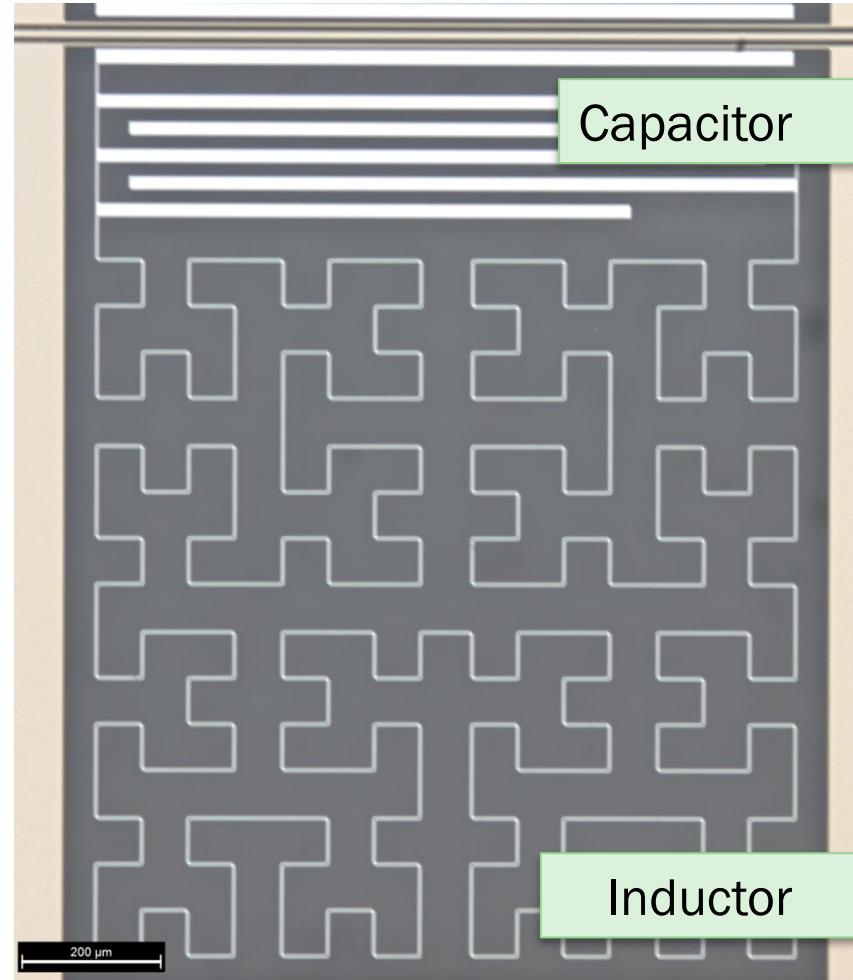
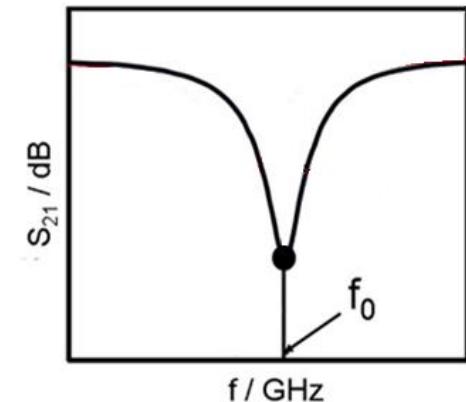


# Introduction

## KINETIC INDUCTANCE DETECTORS



$$f_0 = \frac{1}{\sqrt{LC}}$$



Lumped Element-KIDs (LEKIDs)

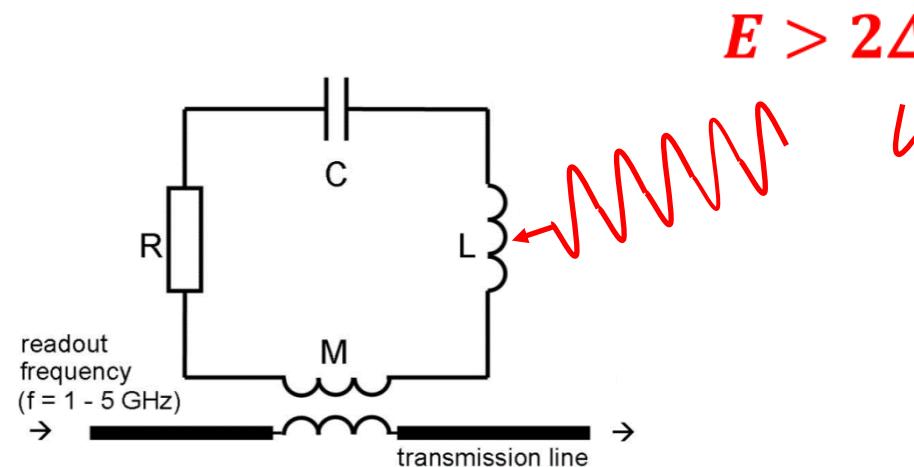
Current uniformly distributed in the inductor

Effective optical absorbing area

Doyle et al., JLTP (2007)

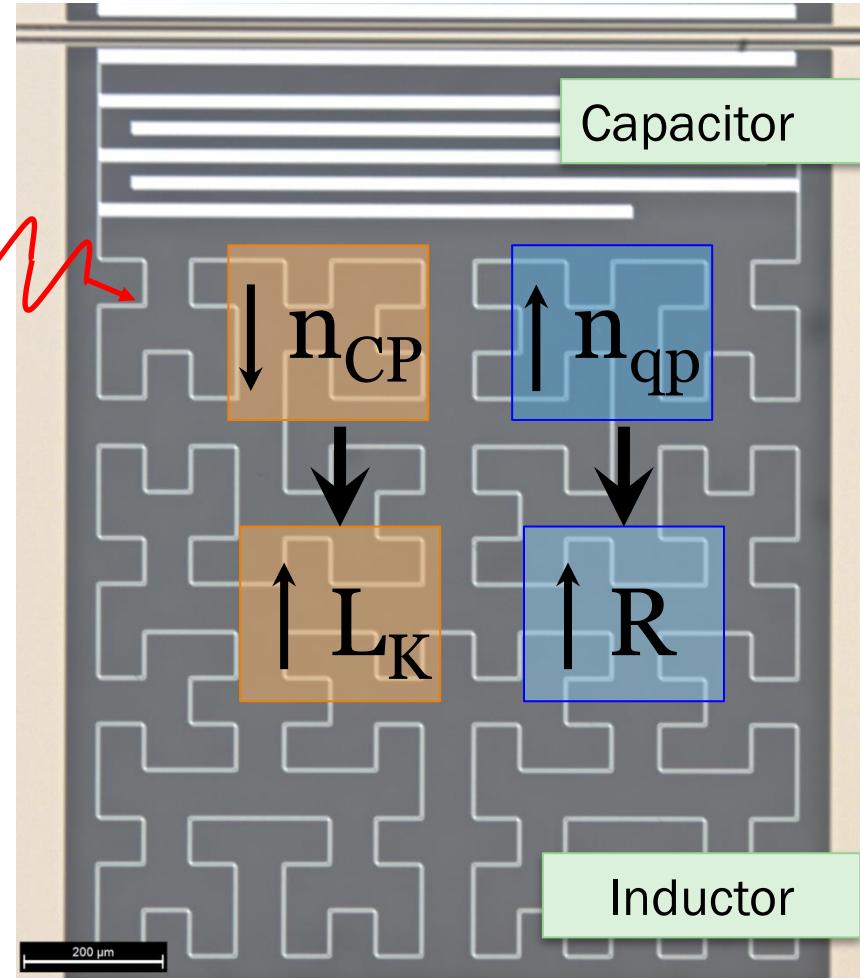
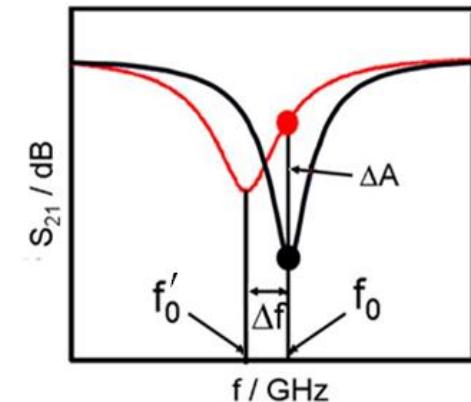
# Introduction

## KINETIC INDUCTANCE DETECTORS



$$f_0 = \frac{1}{\sqrt{LC}}$$

$$f' = \frac{1}{\sqrt{L'C}}$$



Lumped Element-KIDs (LEKIDs)

Current uniformly distributed in the inductor

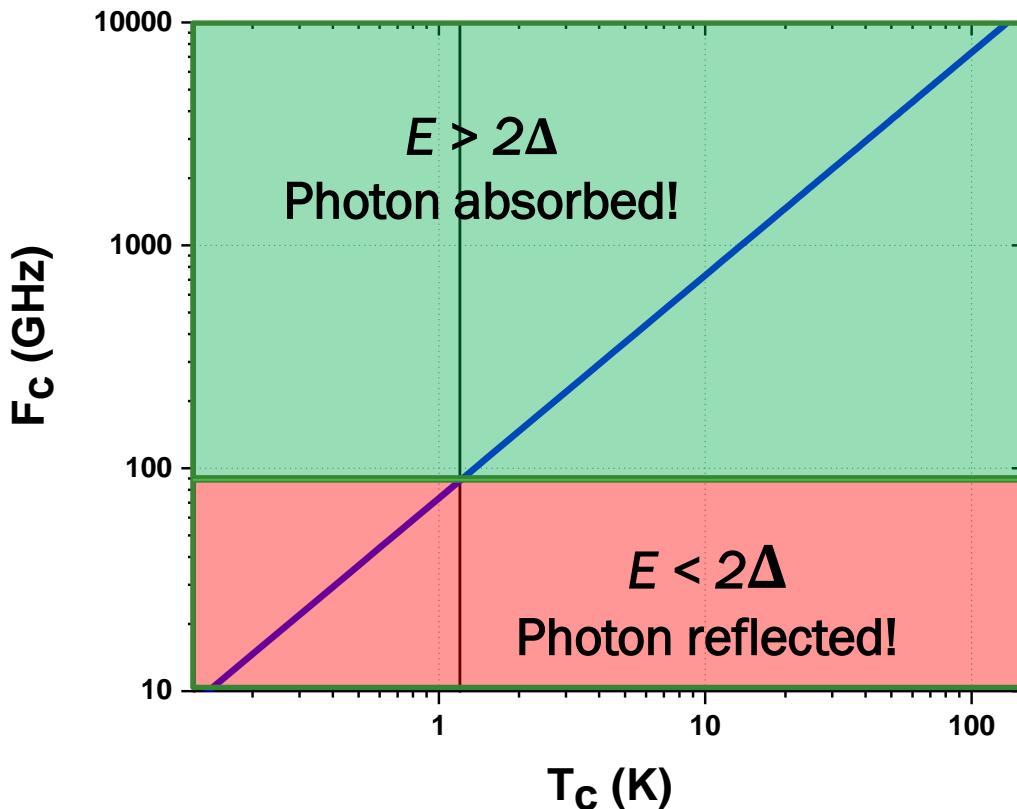
Effective optical absorbing area

Doyle et al., JLTP (2007)

# Introduction

## Frequency cut-off

KID → Pair-breaking detectors →  $E_{\text{photon}} > 2\Delta_{\text{gap}}$  and  $2\Delta_{\text{gap}} \sim 3.52K_B T_c$



Al →  $f_c \approx 100$  GHz  
 Ta →  $f_c \approx 340$  GHz  
 Nb →  $f_c \approx 700$  GHz

W-band : 75-110 GHz → Al not suitable

Doping, Superconducting proximity effect → Adjustable  $T_c$

Al:Mn, TiN<sub>x</sub>, Nb<sub>x</sub>Si, Ti/Al...

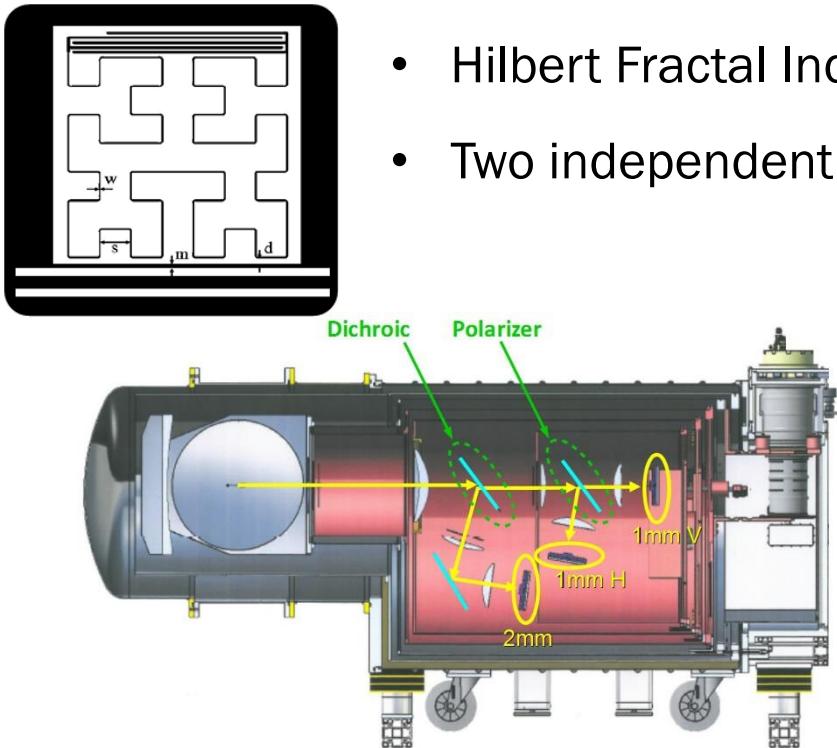
A. Catalano *et al.* A&A (2015)

# Introduction

## Polarization Sensitive LEKIDs

### NIKA2

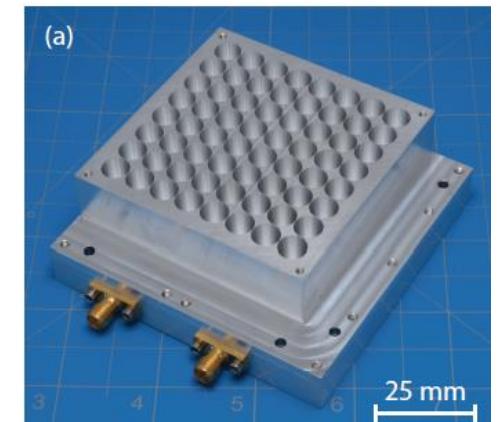
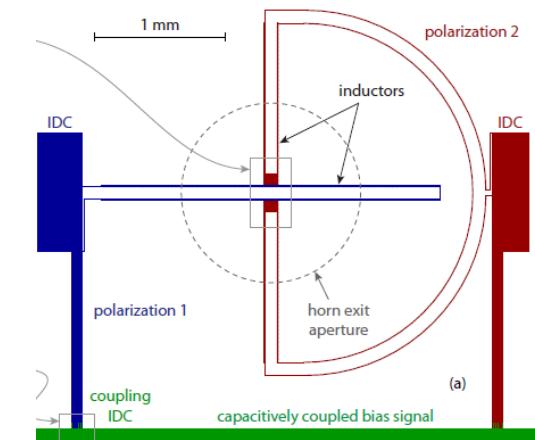
- Hilbert Fractal Inductor
- Two independent Arrays + Polarizer



L. Perotto et al. A&A (2018)

### BLAST-TNG, ToITEC, CCAT-prime

- Two LEKIDs sensitive to orthogonal polarizations
- Horn-coupled LEKIDs

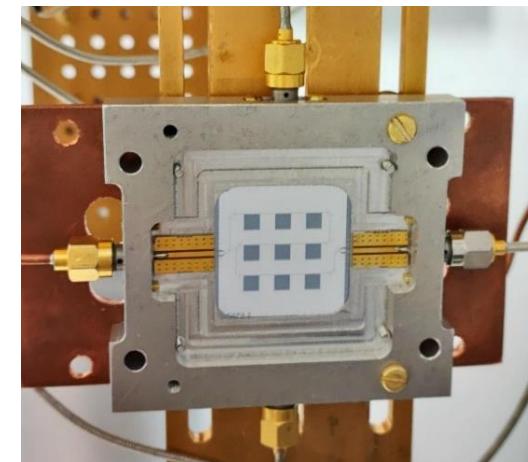
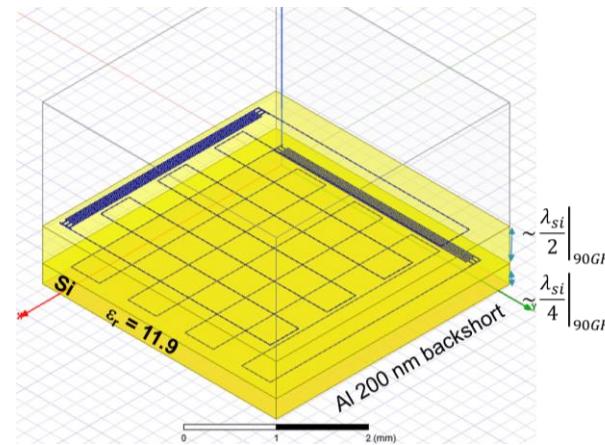
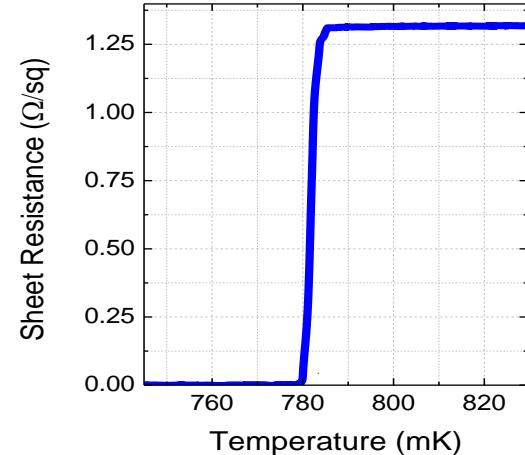


H. McCarrick et al. A&A (2018)

# Introduction

## Polarization Sensitive LEKIDs

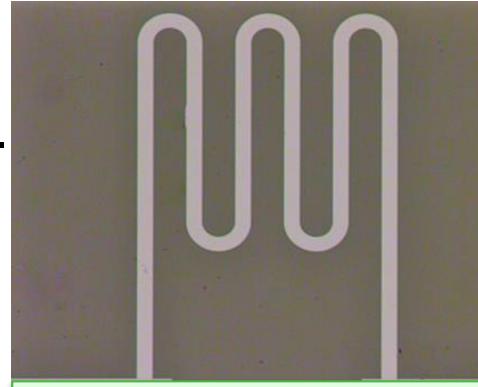
*Ti/Al bilayer Kinetic Inductance Detectors in BiKID configuration for CMB experiments*



# Nanofabrication process

## CLEAN ROOM FABRICATION:

1. High Resistive Si Wafer + HF cleaning (native oxide etching).
2. AJA Int. Confocal Sputtering: Ti/Al bilayer,  $P_{\text{base}} < 1 \cdot 10^{-8}$  Torr.
3. Maskless Laser Writer lithography : AZ2070 nLOF.
4. Wet etching.  
 Ti:  $\text{HNO}_3$  5% + HF 0.05%  
 Al:  $\text{H}_3\text{PO}_4:\text{CH}_3\text{COOH}:\text{HNO}_3:\text{H}_2\text{O}$  [7.5:6:3.5:16]
5. 200 nm Al layer backshort sputtering deposition.



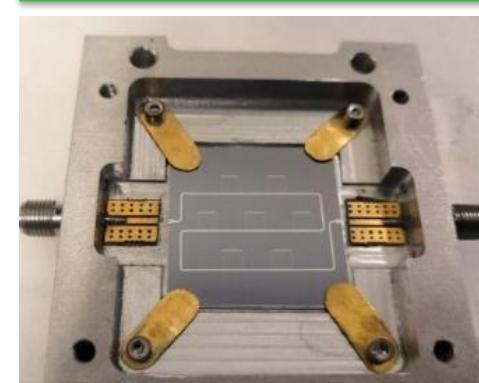
*RT Characterization*



*LEKID*



*Optical Characterization*

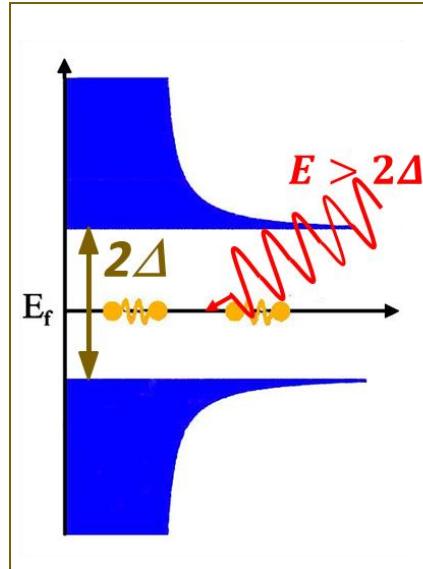


*Low Temperature Characterization*

# W-Band Optical Design

## Tuning operational frequency band: Superconducting Materials

KIDs:  
 Pair-breaking detectors



$$\text{Al} \rightarrow T_c = 1.2 \text{ K} \rightarrow f_c \approx 100 \text{ GHz}$$

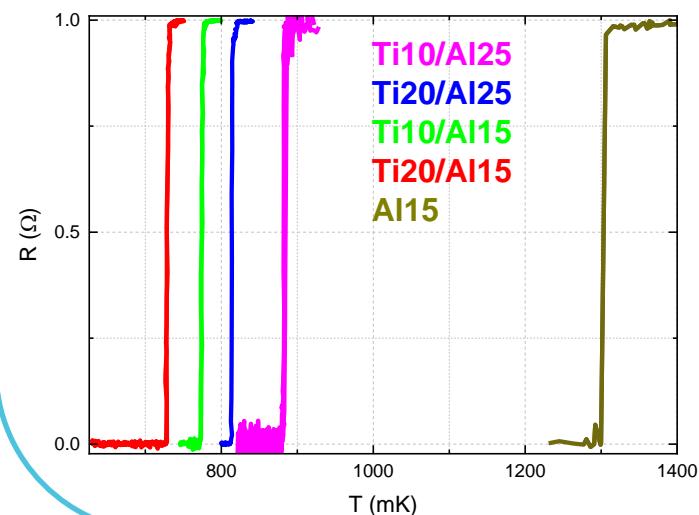
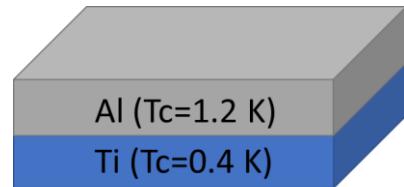
W-band : 75-110 GHz → Al not suitable

$$2\Delta = 3.5 k_B T_c$$

*Detection cut-off frequency:*  
*Limited by the superconducting gap*

Proximity Effect

Titanium/Aluminum bilayers



Ti (10 nm) / Al (25 nm)

$$T_c = 778 \pm 2 \text{ mK}$$

$$R_s = 4 \text{ Ohm/sq (300 K)}$$

$$R_s = 2.16 \text{ Ohm/sq (1 K)}$$

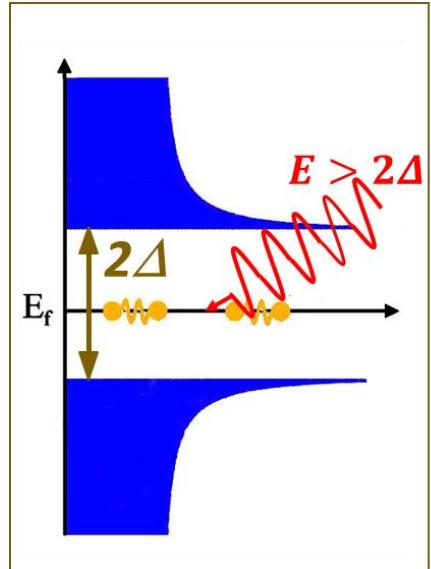
Kinetic Inductance:

$$L_{ksq} = \frac{h R_s}{2\pi^2 \Delta} = 2.24 \text{ pH/sq}$$

# W-Band Optical Design

## Tuning operational frequency band: Superconducting Materials

KIDs:  
 Pair-breaking detectors



$2\Delta = 3.5 k_B T_c$

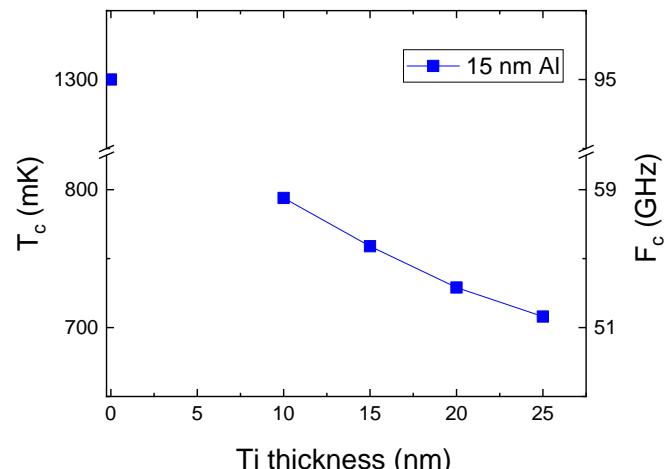
*Detection cut-off frequency:  
 Limited by the superconducting gap*

$$Al \rightarrow T_c = 1.2 K \rightarrow f_c \approx 100 GHz$$

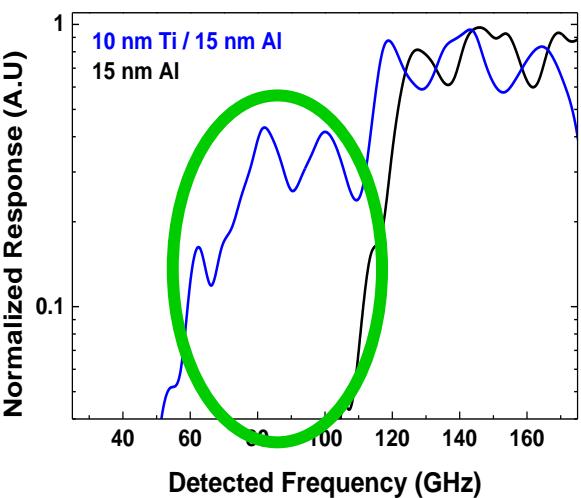
W-band : 75-110 GHz → Al not suitable

Proximity Effect

Titanium/Aluminum bilayers



W-band Sensitivity

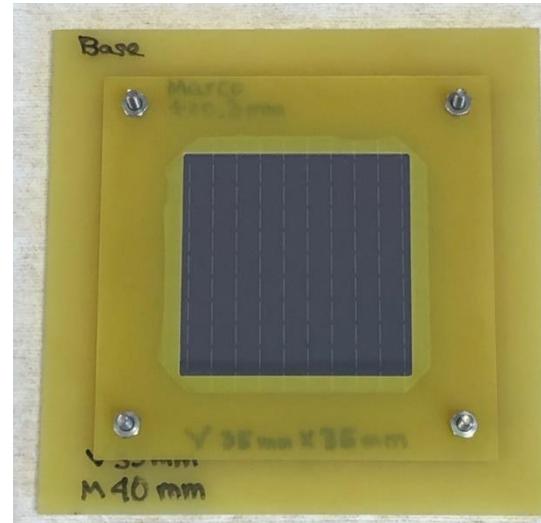


# W-Band Optical Performance

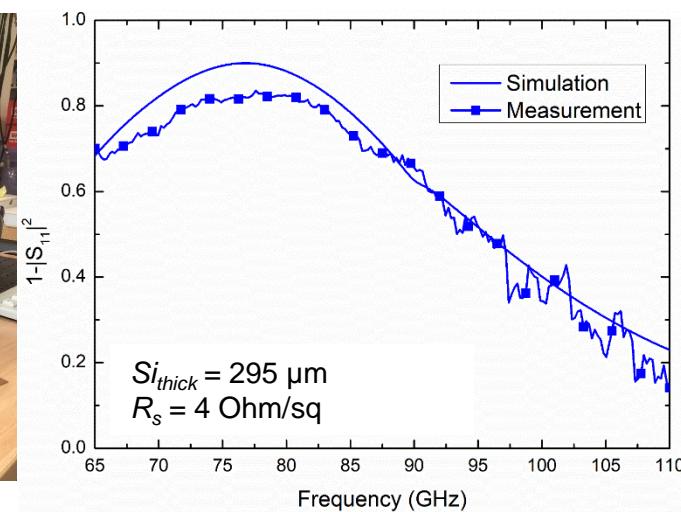
## SINGLE POLARIZATION LEKID

Matched to  $\eta_0 = 377 \text{ Ohm}$  at 90 GHz

- Impedance Matching:
  - Inductor: strip grating  
Width =  $3 \mu\text{m}$   
Gaps =  $440 \mu\text{m}$
  - Backshort at the rear side of a  $0.275\lambda$  thick Silicon (Si) substrate ( $\epsilon_r = 11.9$ ).
- LEKID area  $\sim \lambda^2$  at the absorption frequency.



40 mm X 40 mm

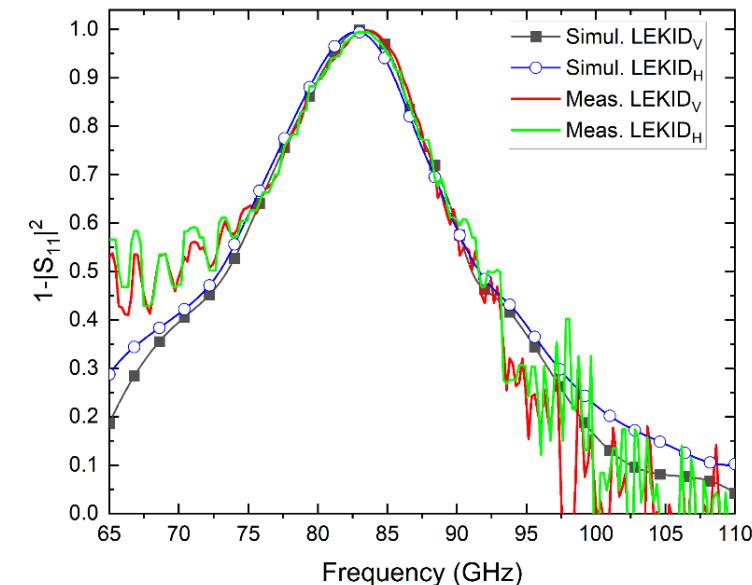
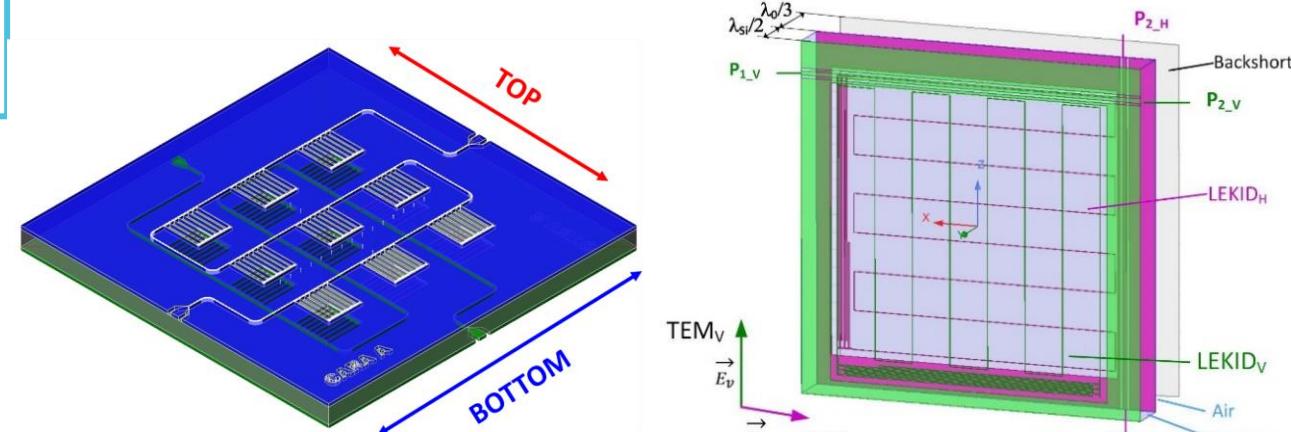


Aja et al., IEEE IMS (2020)

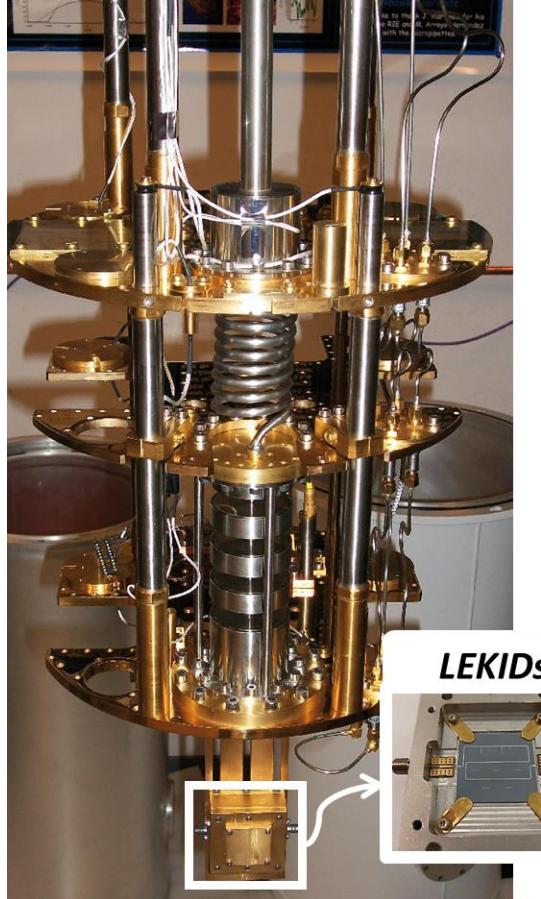
## DUAL POLARIZATION LEKID

**BiKID:** Two stacked LEKIDs sensitive to perpendicular polarizations

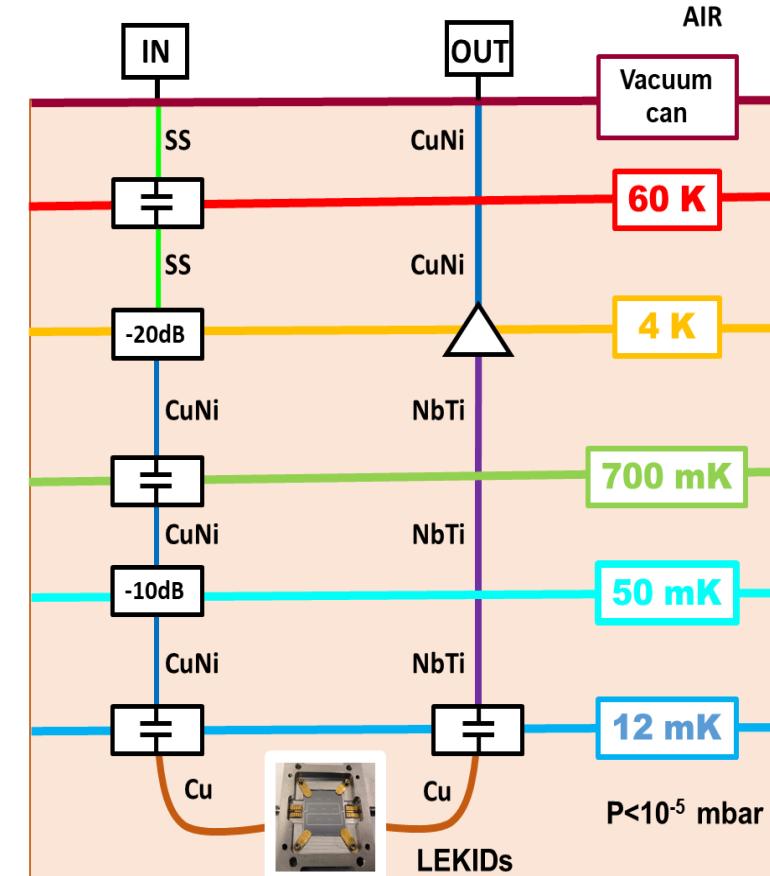
- Inductor: strip grating  
Width = 3  $\mu\text{m}$   
Gaps = 440  $\mu\text{m}$
- Impedance Matching:
  - Distance between LEKIDs  $\ell_2 = \lambda_{\text{Si}}/2 = 483 \mu\text{m}$ .
  - Backshort at the rear side of the BiKID structure  $\ell_1 = 300 \mu\text{m}$ .
- LEKID area  $\sim \lambda^2$  at the absorption frequency



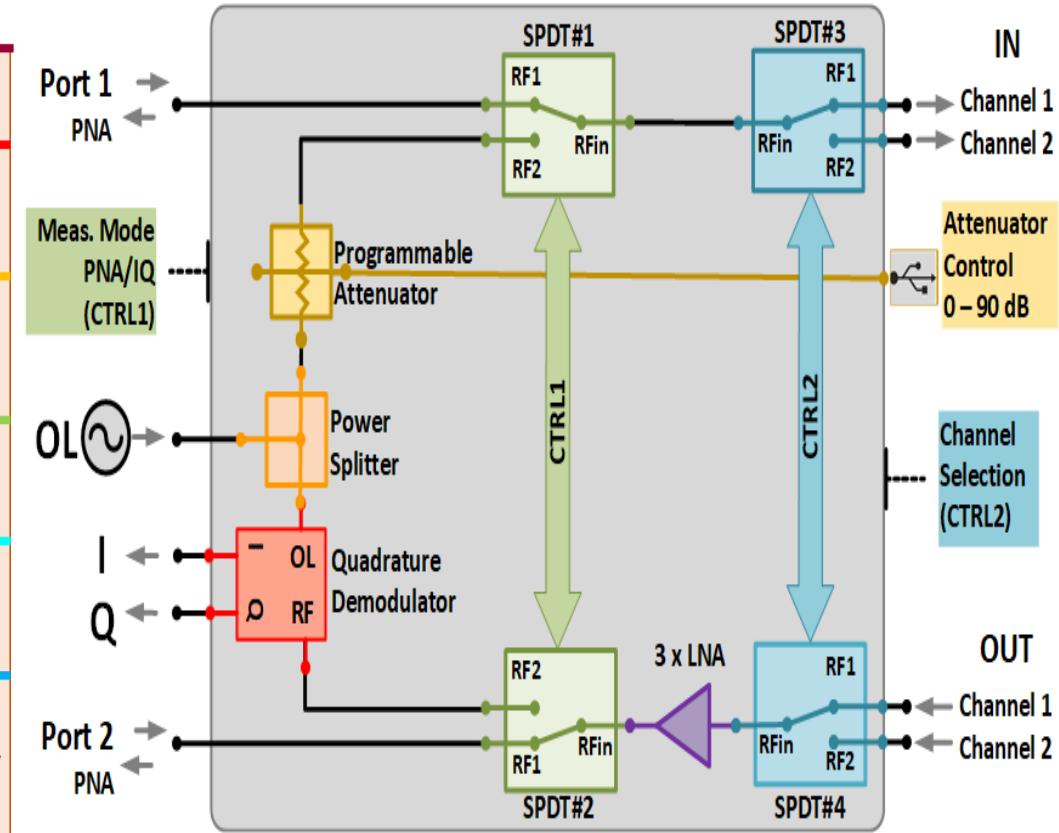
## DILUTION REFRIGERATOR



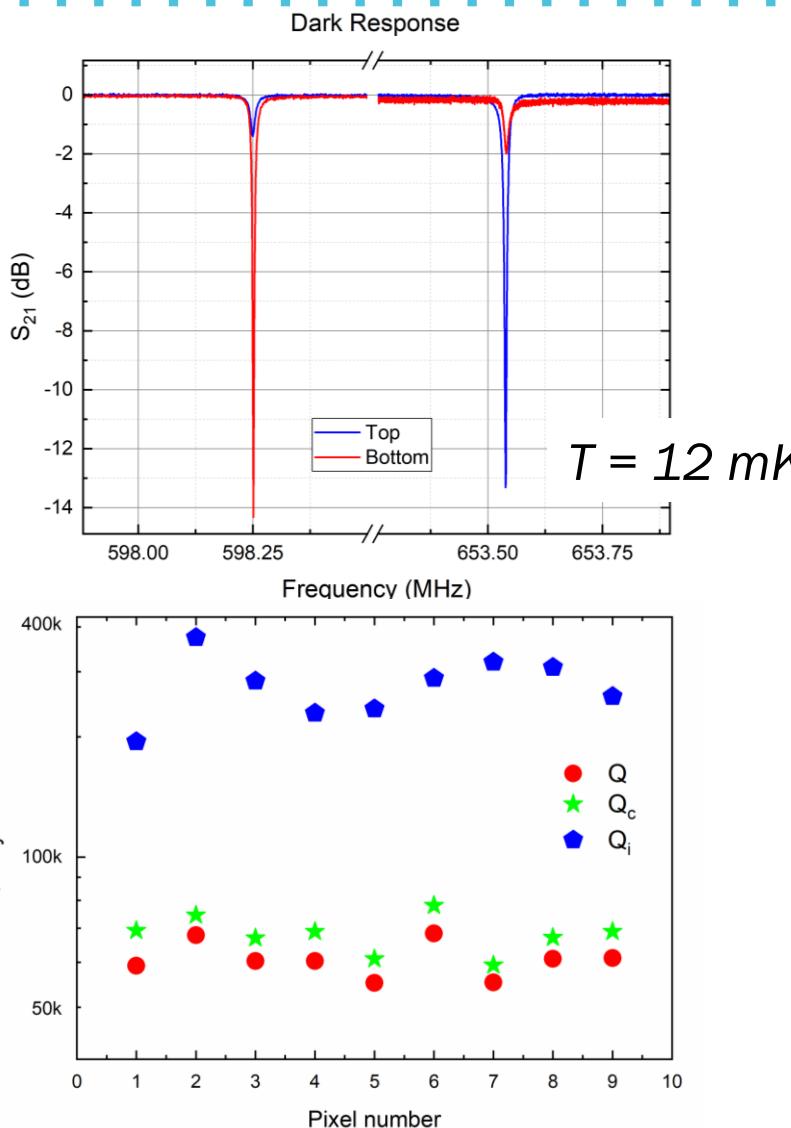
## CRYOGENIC HARNESS



## ROOM TEMPERATURE CIRCUITRY



# Low temperature characterization

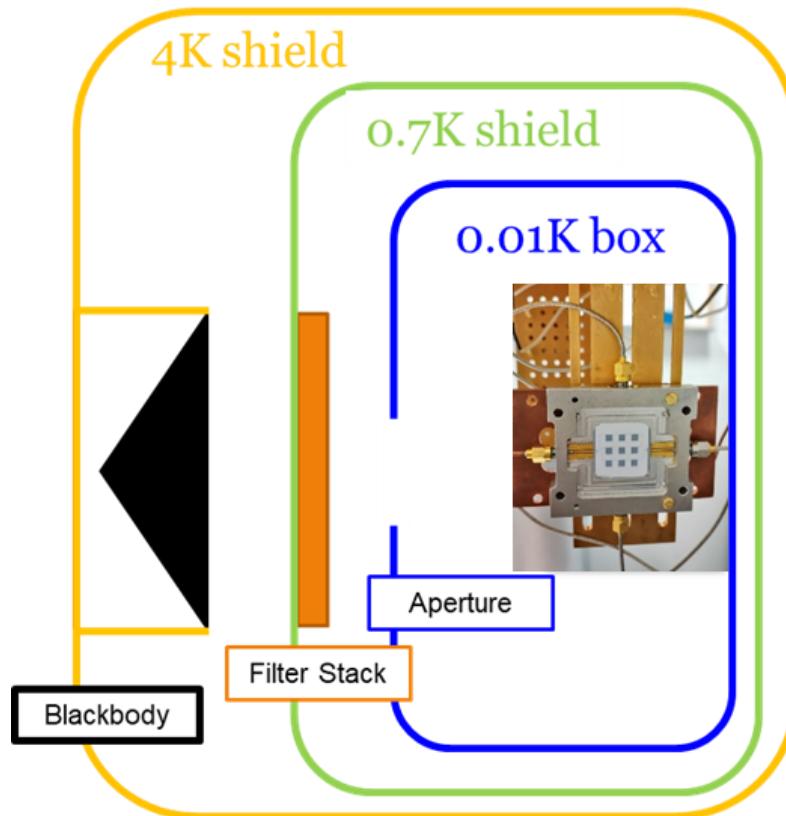


## DARK CHARACTERIZATION

- Kinetic fraction  $\rightarrow \alpha \equiv \frac{L_k}{L_{total}} = 1 - \left( \frac{f_{exp}}{f_{simLk=0}} \right)^2 \approx 0.57$
- $Q_i > 10^6 \rightarrow$  High internal quality factor  
*Good superconducting film quality*
- $Q_c \rightarrow 60\text{K} \rightarrow$  Agrees with Low frequency design
- *LEKIDs coupling on both faces*

## Filter Stack:

- 110 GHz low pass filter
- Linear polarizer



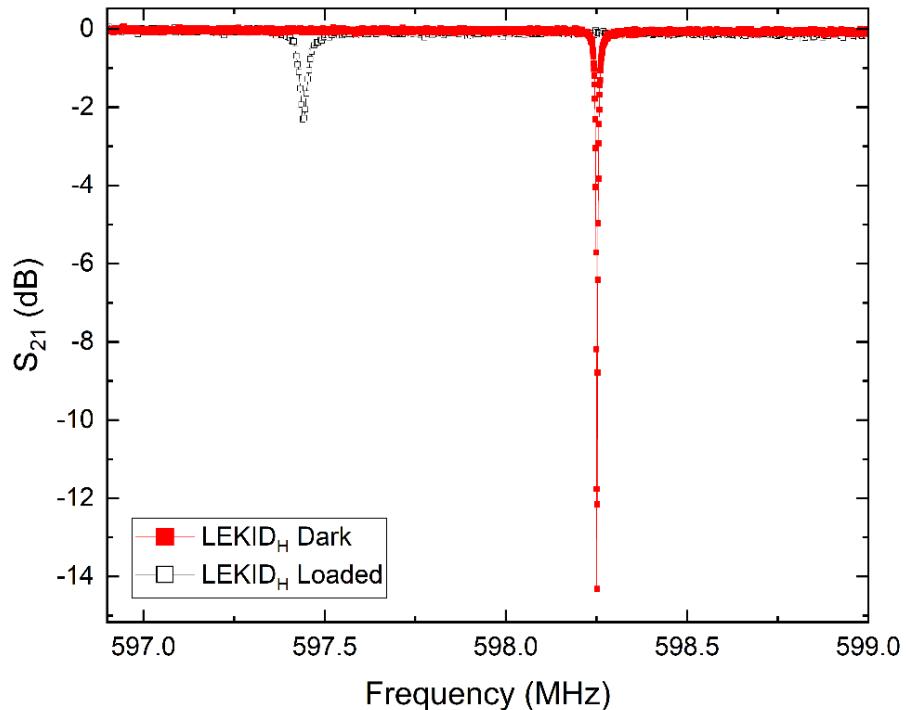
## OPTICAL CHARACTERIZATION

$$1 \text{ pixel} \rightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$$

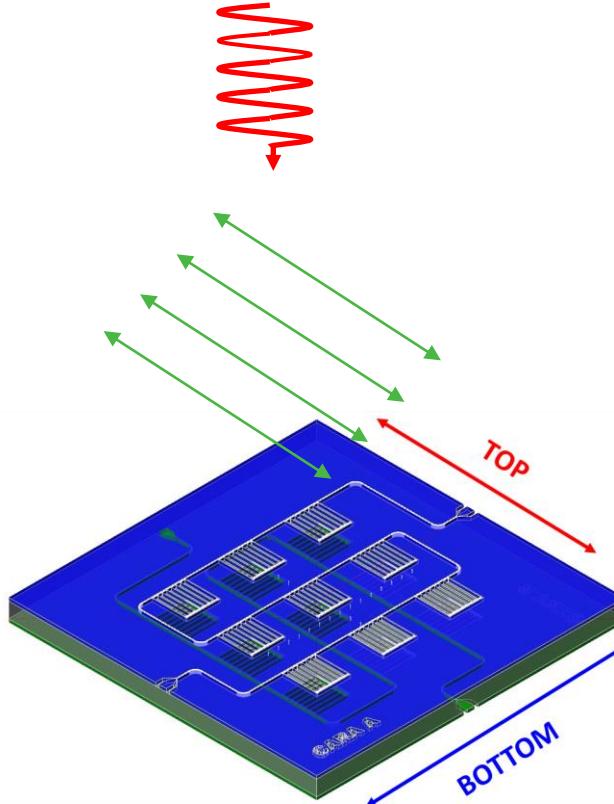


$$\uparrow L_K \rightarrow \downarrow f_0$$

Sensitive to  
W-band radiation

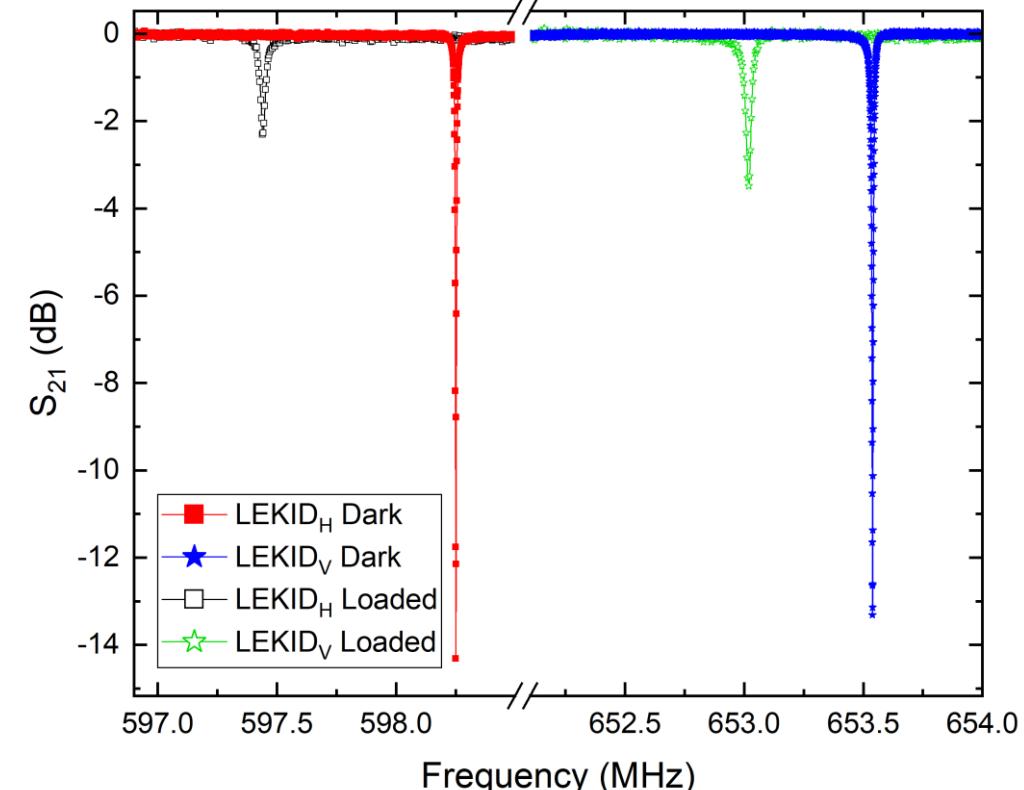


## OPTICAL CHARACTERIZATION



Polarization sensitivity?

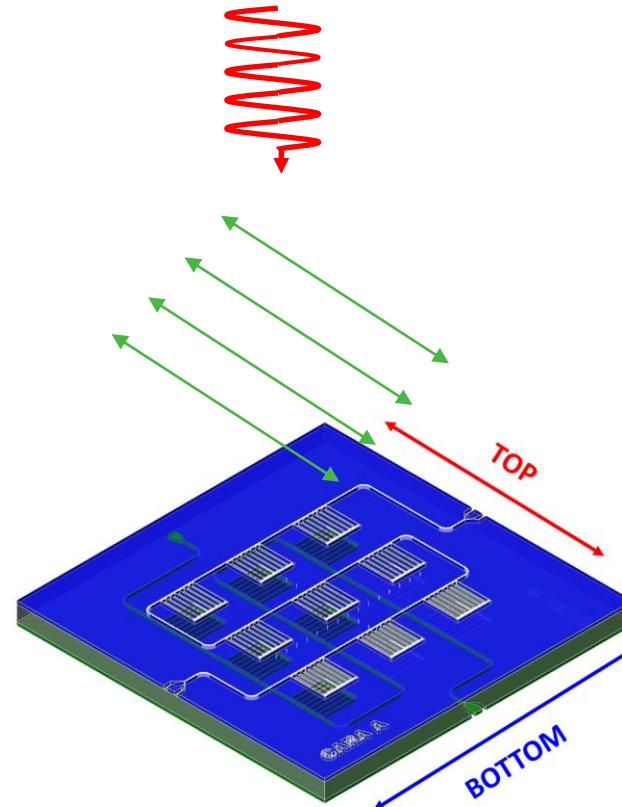
✗ Shift in both faces?



Crosstalk  $\text{LEKID}_H$  vs  $\text{LEKID}_V$



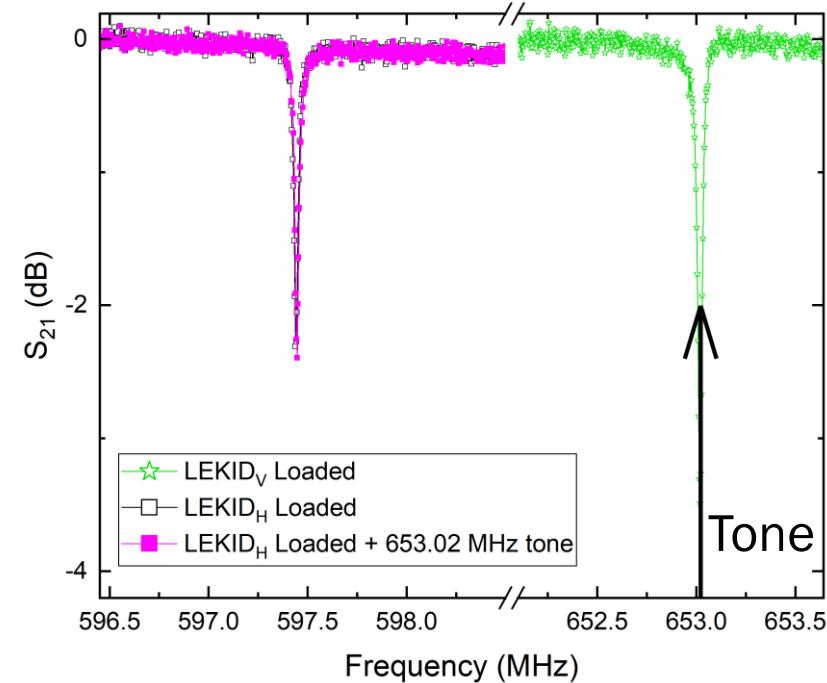
# Low temperature characterization



## OPTICAL CHARACTERIZATION:

Polarization sensitivity?

✗ Shift in both faces?



Crosstalk  $\text{LEKID}_V$  vs  $\text{LEKID}_H$

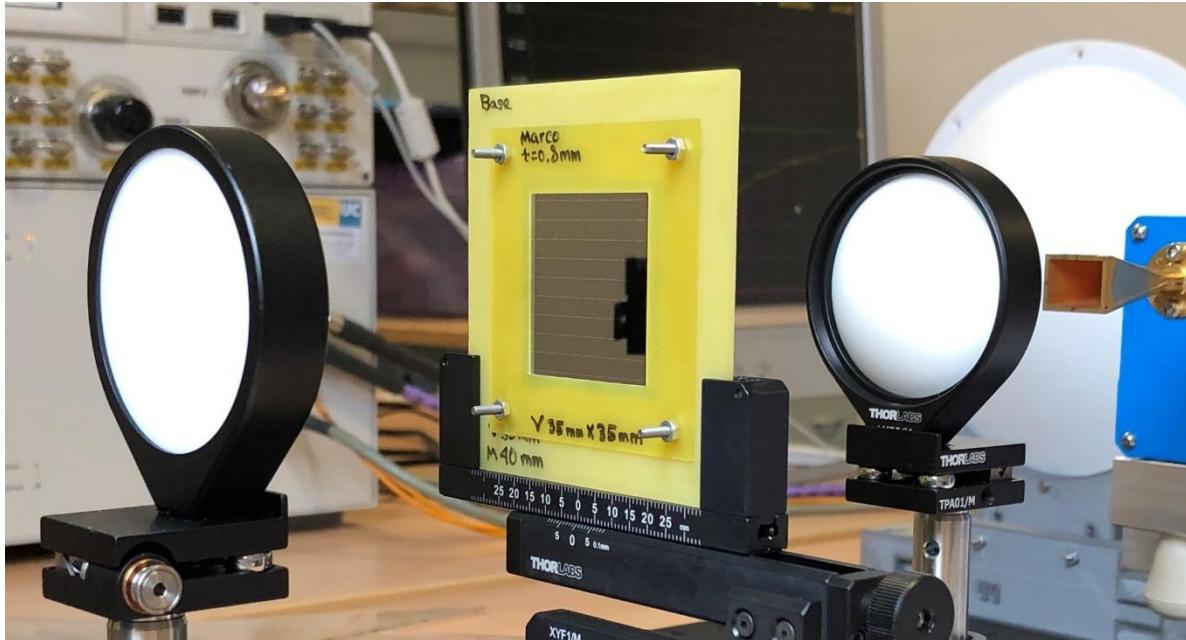


Pump – probe technique

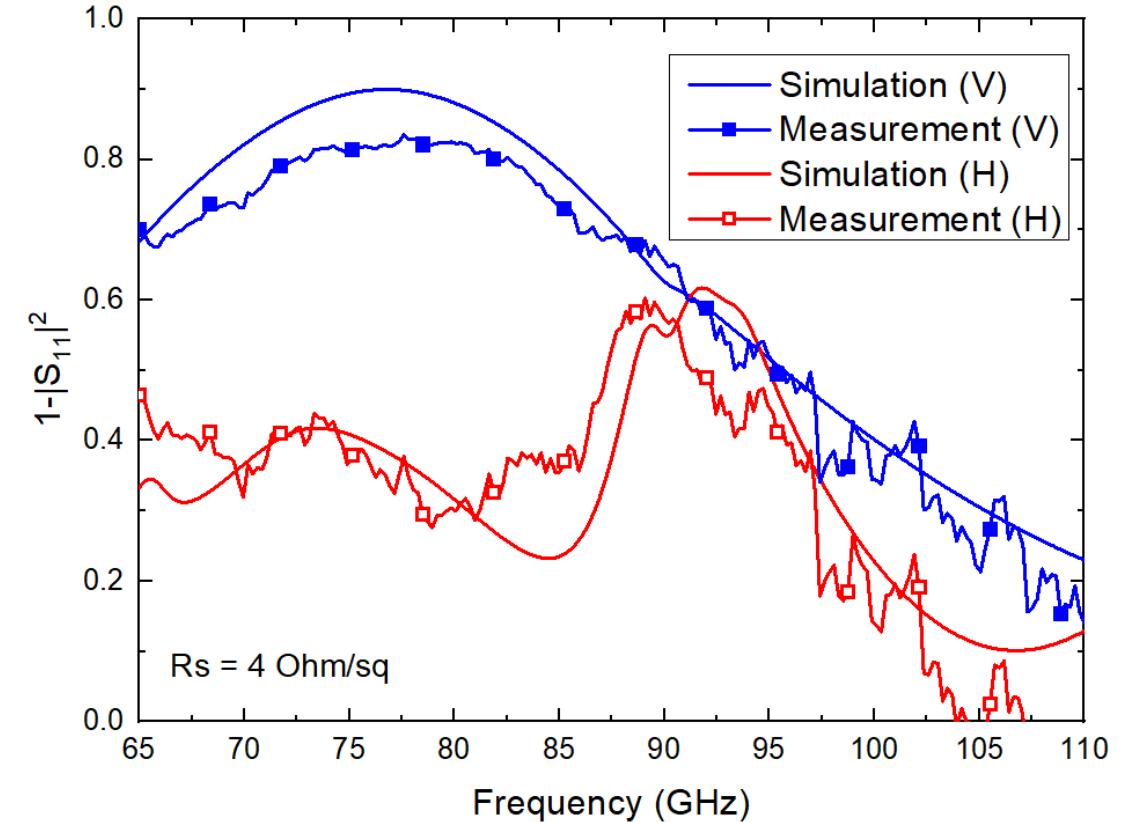
✓ Negligible shift  $\text{LEKID}_H$

# W-Band Optical Performance

## SINGLE POLARIZATION LEKIDs ARRAY



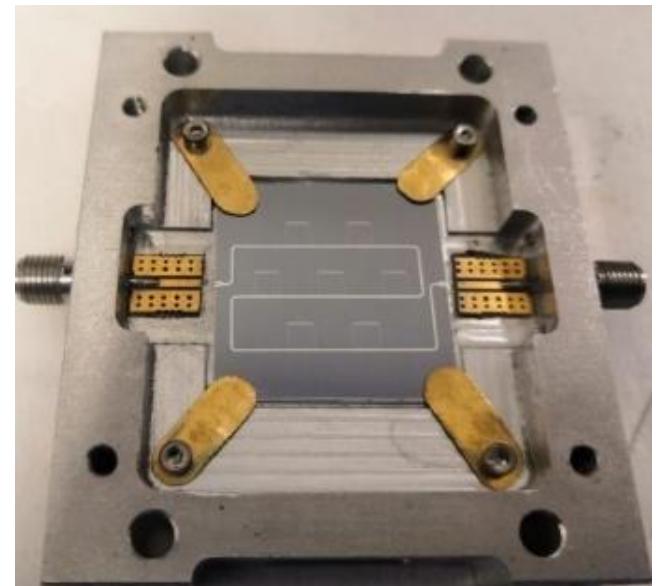
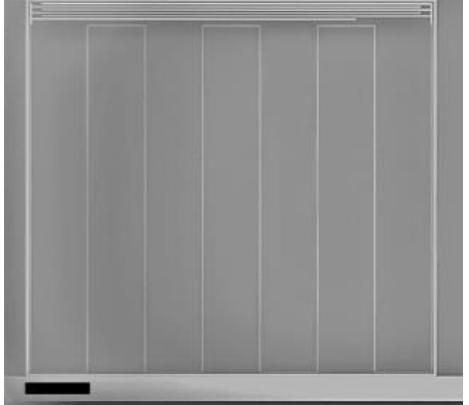
Room Temperature  
Simulation and measurement



- Absorption in both polarizations → Crosspolarization  $\sim 0.5$

# Conclusions and Future Work

- Development of W-band LEKIDs for future CMB experiments.
- Ti/Al proximity effect diminishes frequency cut-off.
- Ti/Al BiKID structure fabricated and tested. Good quality and agrees simulation.
- No cross talk between parallel pixels in both detector sides.
- W-band absorption tested at low and high temperature.
- Large crosspolarization between faces → Requires extra calibration.
- Developing new designs for upgrading BIKID performance.



# Low temperature characterization

## LEKIDs CALIBRATION:

Background ( $T \sim T_c$ ):

$$Z_i^b = |Z_i^b| \exp(i\theta_i^b)$$

LEKIDs Calibration:

$$Z_i = \frac{|Z'_i|}{|Z_i^b|} \exp \left( \theta'_i(\text{rad}) - \theta_i^b(\text{rad}) \right) = |Z_i| \exp(i\theta(\text{rad}))$$

$$\text{Im}(V) =$$

$$|Z_i| \cos(\theta(\text{rad}))$$

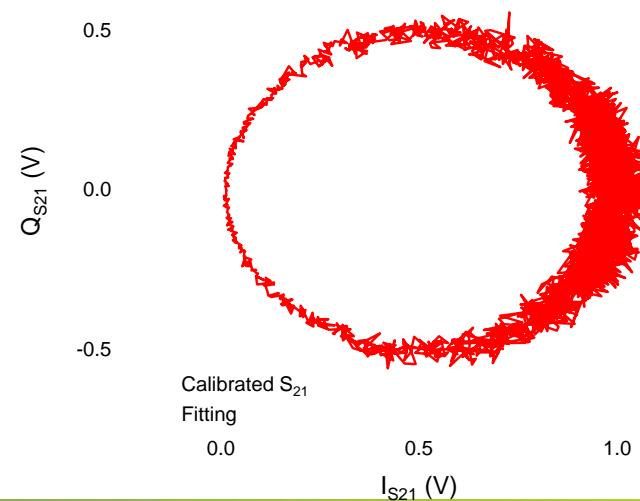
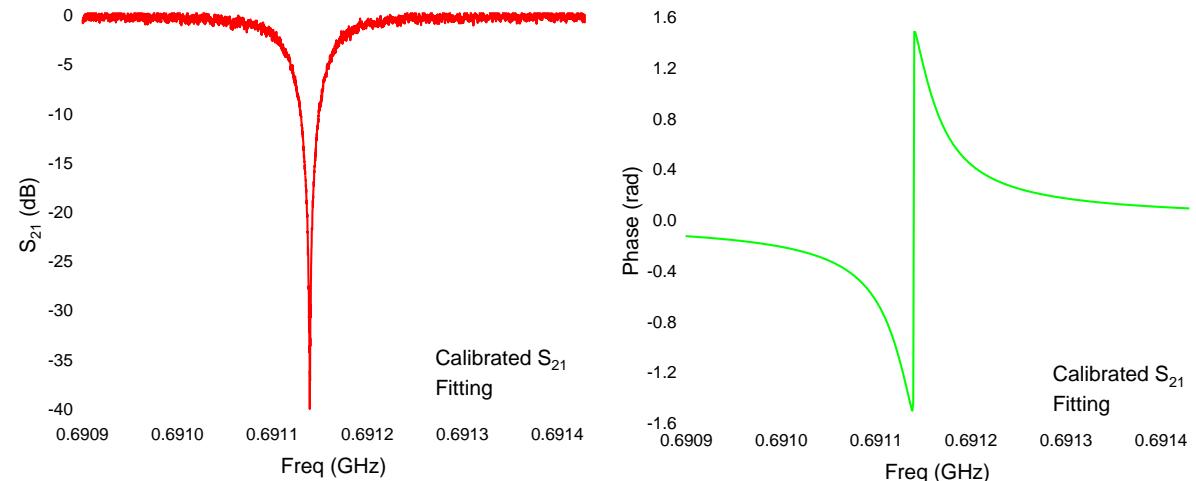
Fitting:

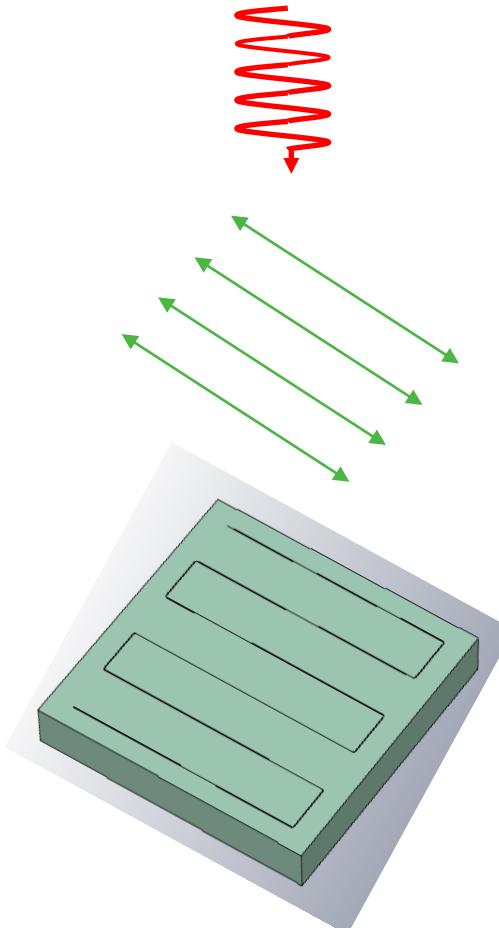
$$\text{Re}(V) =$$

$$|Z_i| \sin(\theta(\text{rad}))$$

$$S_{21} = 1 - \frac{Q_l}{Q_c} \frac{e^{j\phi}}{1 + 2jQ_l(f/f_0 - 1)}$$

Probst et al., Rev. Sci. Instrum. (2015)



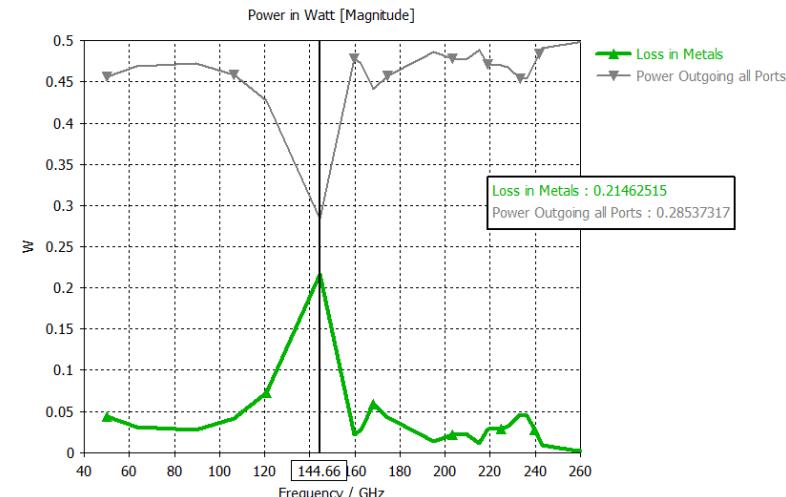


## OPTICAL CHARACTERIZATION: Electromagnetic simulations

Polarization sensitivity?

✗ Shift in both polarizations ?

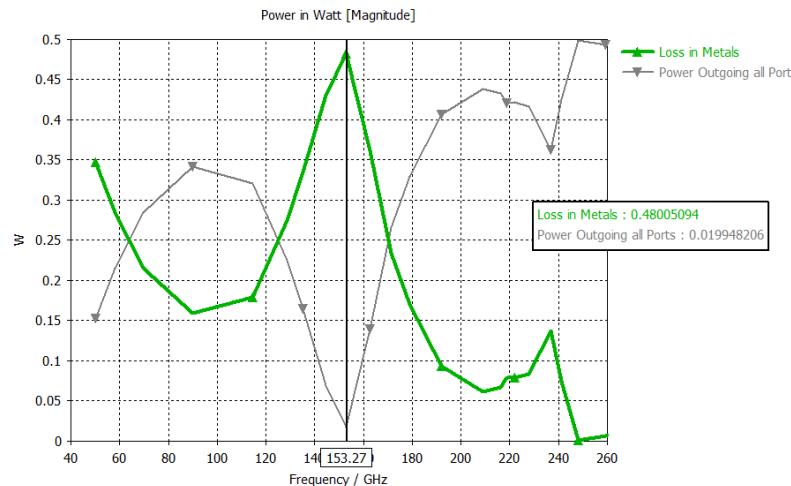
Horizontal Excitation



$$\text{AbsH} = 0.215 / 0.5 = 0.43$$

$$\text{CP} = 0.43 / 0.96 = 0.45$$

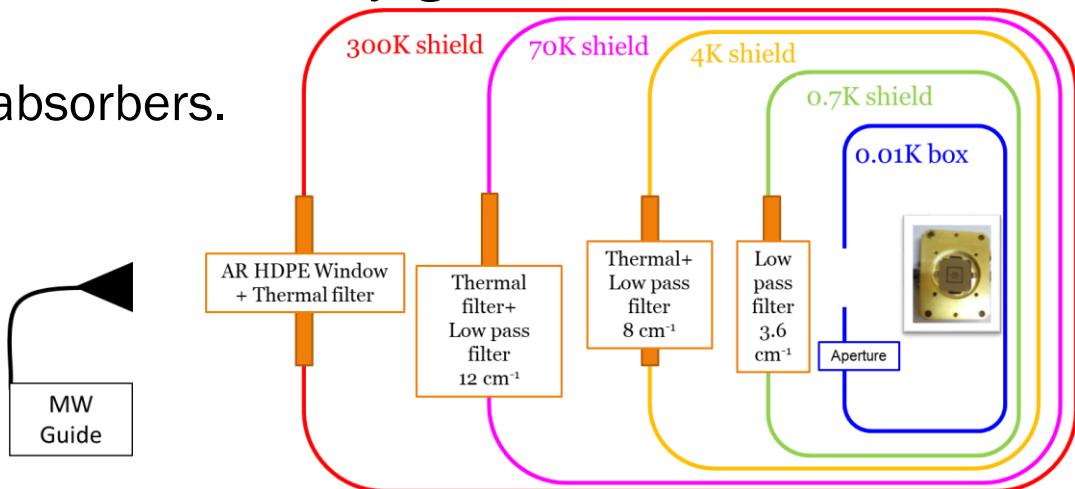
Vertical Excitation



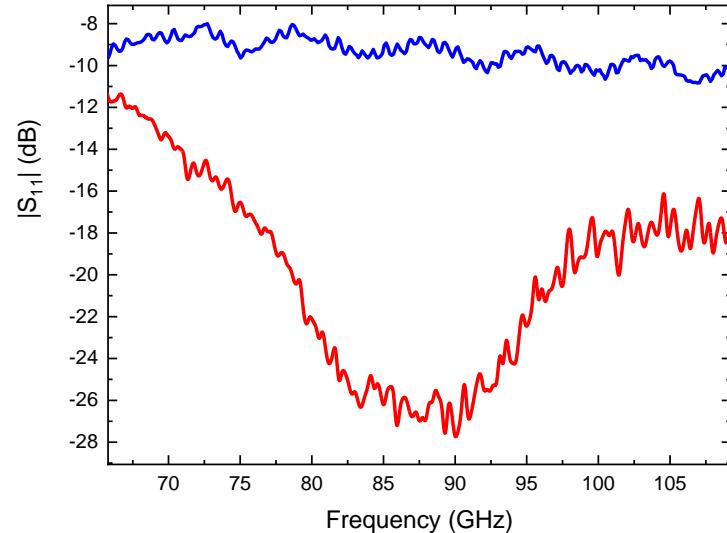
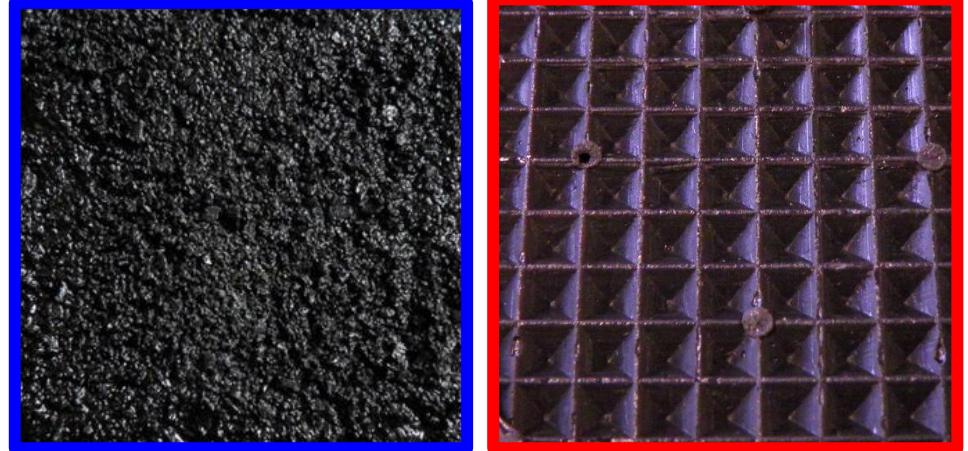
$$\text{AbsV} = 0.48 / 0.5 = 0.96$$

## CRYOGENIC OPTICAL DESIGN:

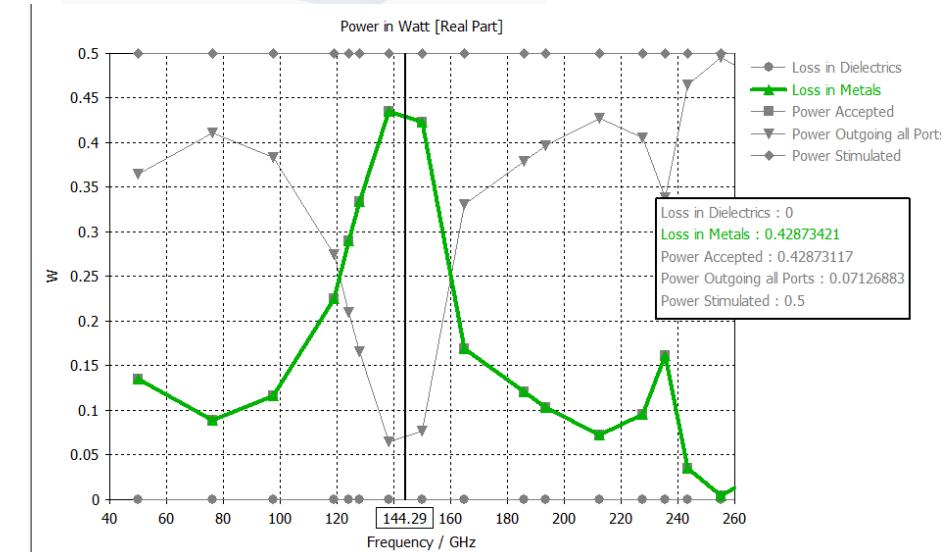
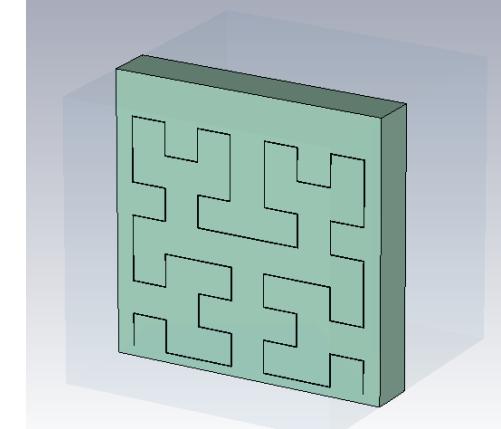
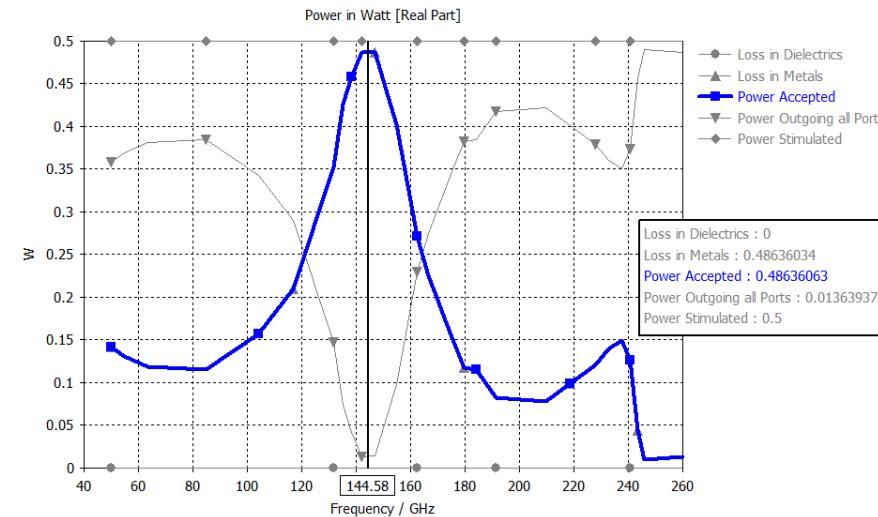
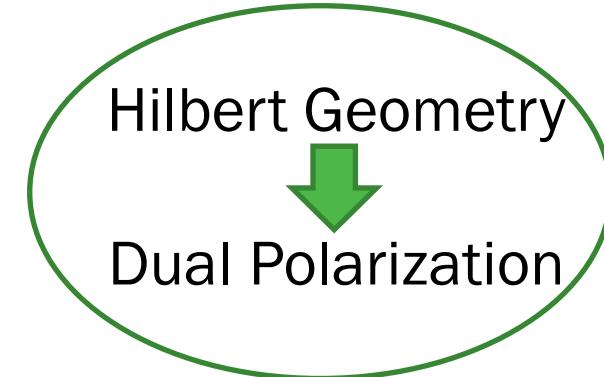
- Reduction of IR radiation.
- Telecentric configuration.
- Rotable HWP for polarization characterization.
- Reduction of straylight radiation → W band absorbers.



Stycast + SiC grains + Carbon powder

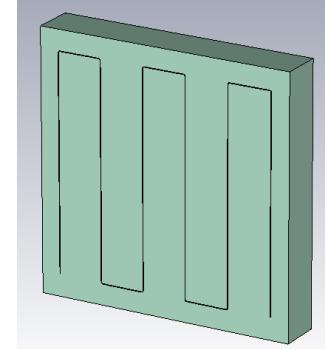
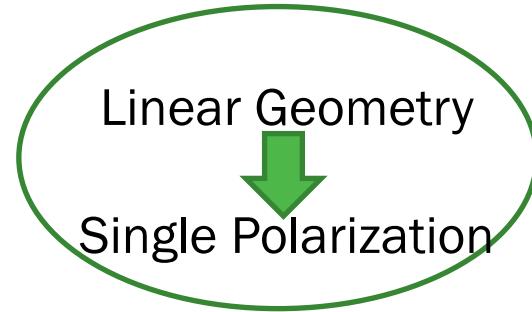


## Electromagnetic simulations → Optics response – Polarization sensitivity

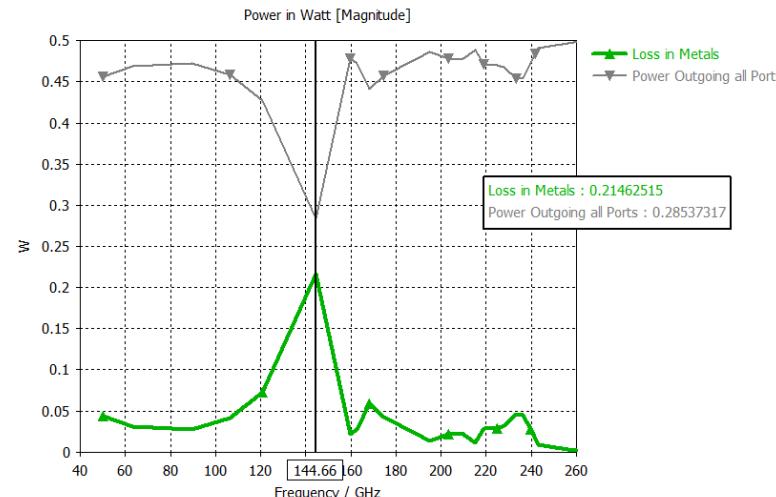


$$\text{AbsH} = 0.486/0.5 = 0.97 \quad \text{CP} = 0.86/0.97 = 0.89 \quad \text{AbsV} = 0.429/0.5 = 0.86$$

## Electromagnetic simulations → Optics response – Polarization sensitivity



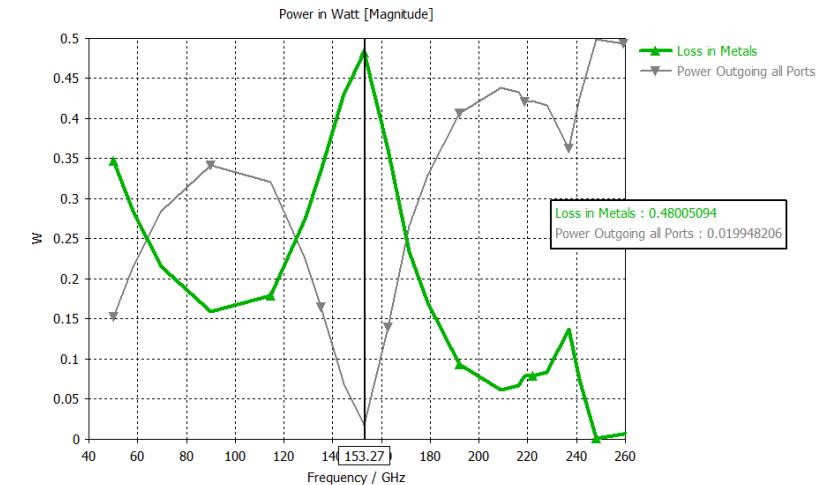
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Vertical Excitation



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