

# SNSPD R&D Highlights

Hsin-Yeh Wu

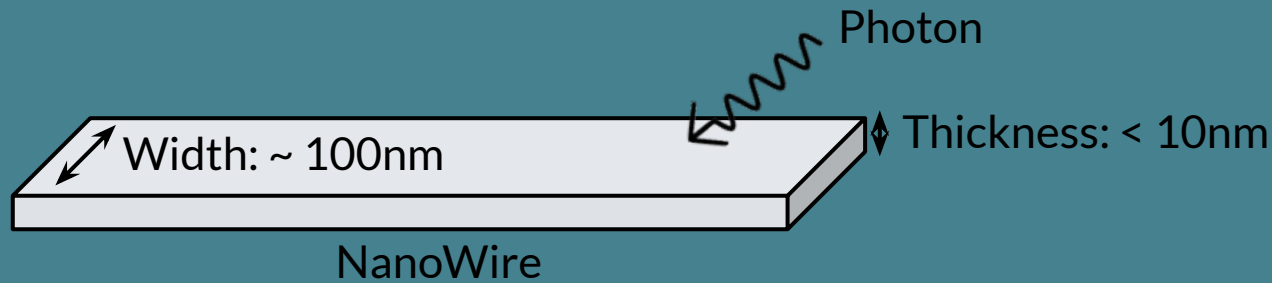
On behalf of the IQSens team

National Taiwan University

TIDC Annual Meeting

7 January, 2026

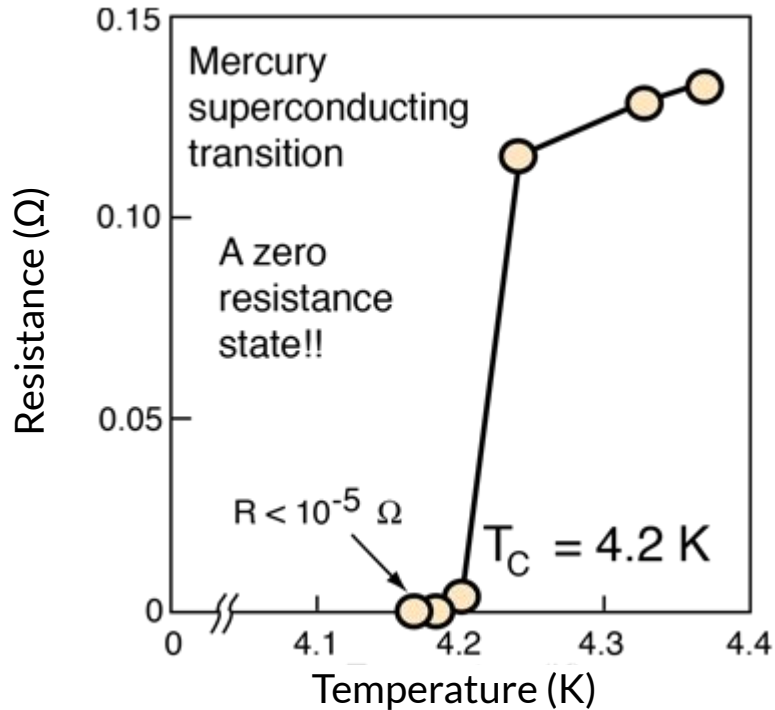




# Superconductivity Nanowire Single Photon Detector (SNSPD)

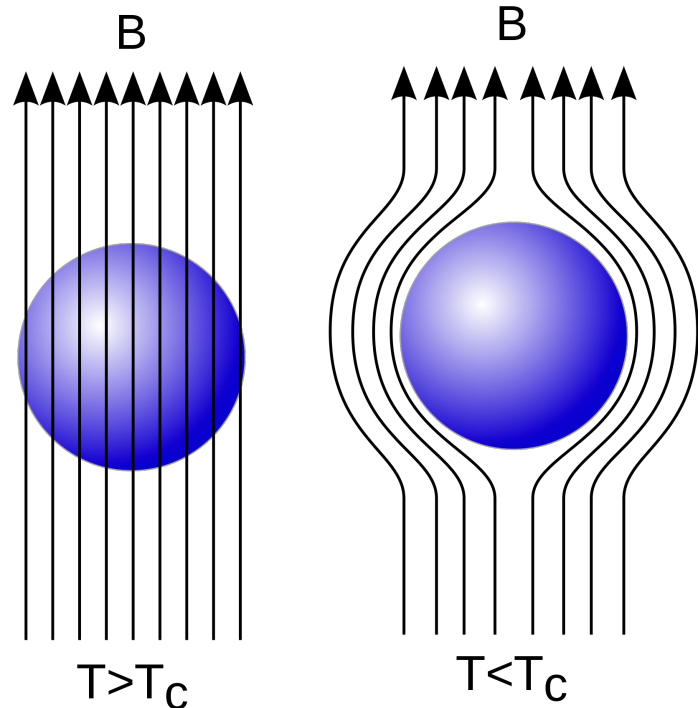
# Superconductivity

## Zero Resistance



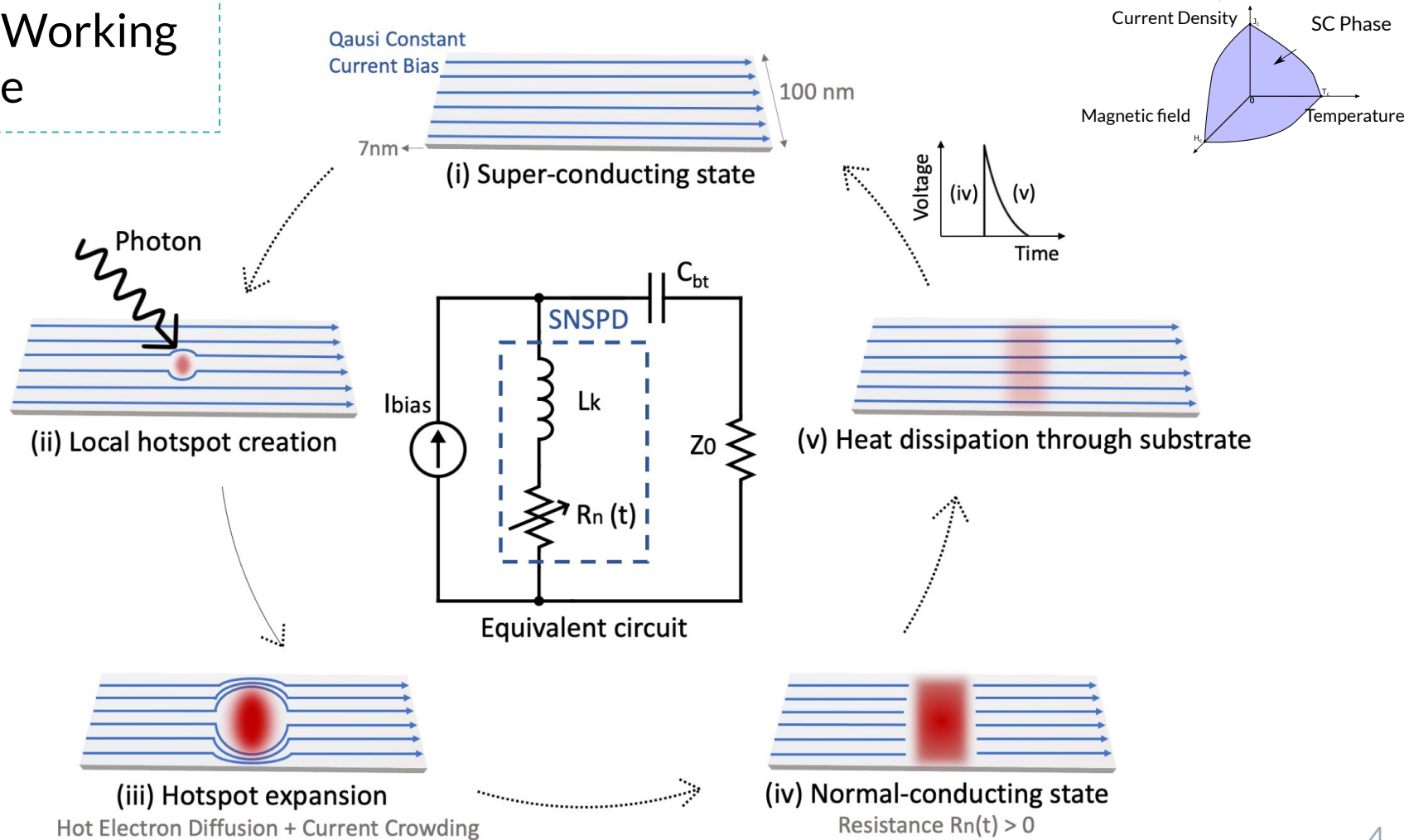
H. K. Onnes, Commun. Phys. Lab.12,120, (1911)

## Meissner Effect Perfect diamagnetic (Superdiamagnetic)



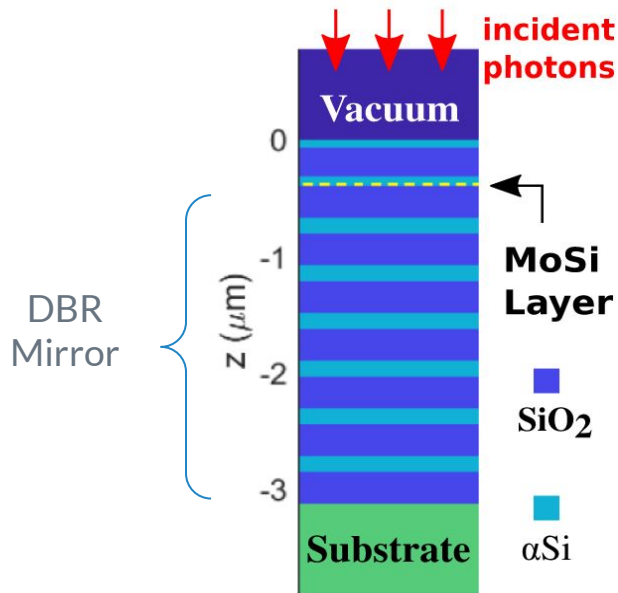
Wikimedia Commons

# SNSPD Working Principle



# State-of-the-art SNSPDs @ 1550nm

Reddy, D. V. et al. Optica 7, 1649 (2020).



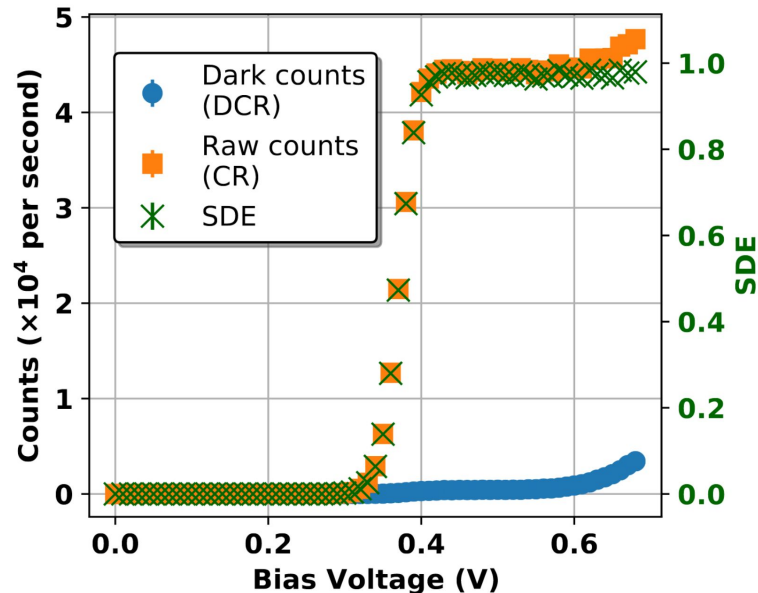
MoSi ( $T_c \sim 5\text{K}$ )

Width: 80nm, Pitch: 140nm

Distributed Bragg Reflector Mirror

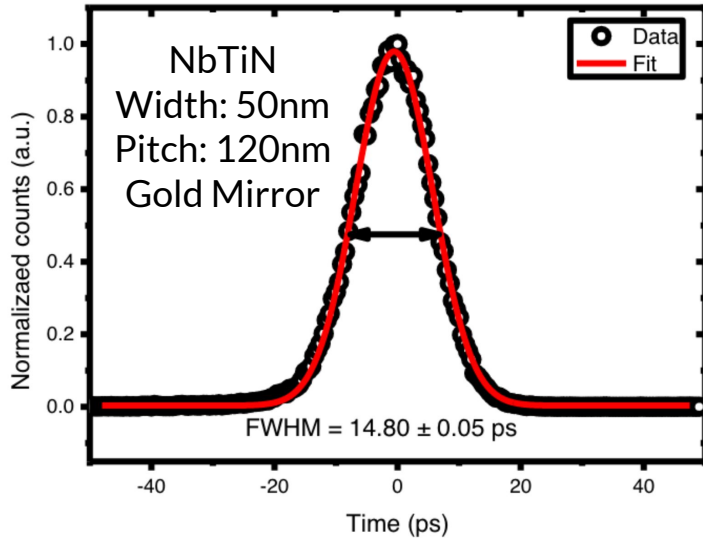
Measure Temperature  $\sim 750\text{mK}$

98% System Detection Efficiency  
High Count Rate  
Low Dark Count Rate



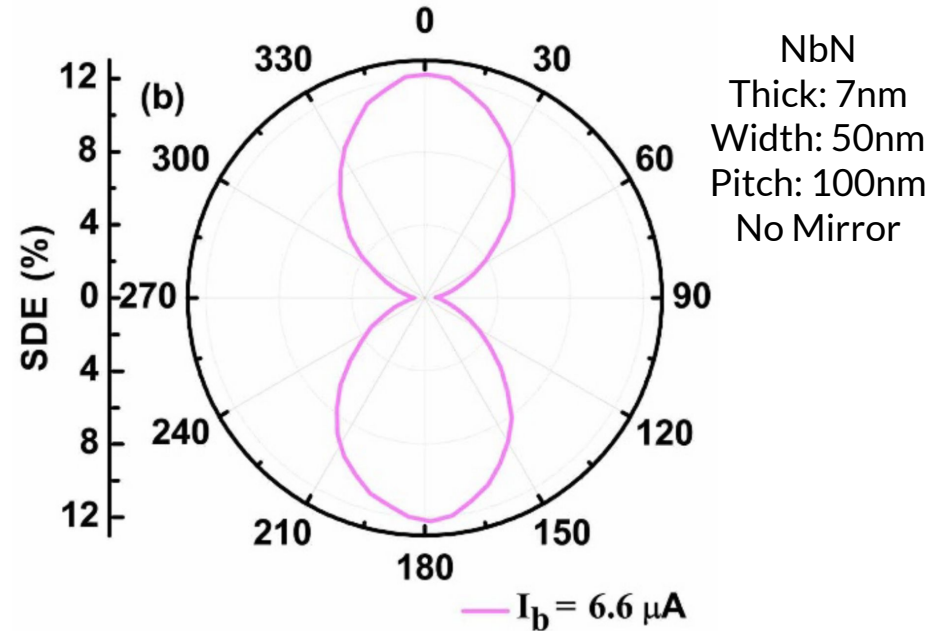
# State-of-the-art SNSPDs @ 1550nm

Time Jitter < 15ps



Esmail Zadeh, I. et al. APL Photonics 2, 111301 (2017).

Polarization Sensitive



Guo, Q. et al. Sci Rep 5, 9616 (2015).

# R&D Goal

## State-of-the-art SNSPD

### Near-IR (0.8 $\mu\text{m}$ -2 $\mu\text{m}$ )

- ~100% efficiency @ 1550nm
- Low timing jitter (<15ps)
- Low Dark Count (<0.01Hz)
- Fast recovery (MHz rate)
- Multi Pixelated array

## R&D Goal

### Extend to Mid-IR (2 $\mu\text{m}$ -20 $\mu\text{m}$ )

- Energy resolving power
- Broadband spectrometry
- Polarization distinguishability

# R&D Goal → Applications

## State-of-the-art SNSPD

### Near-IR (0.8 $\mu\text{m}$ -2 $\mu\text{m}$ )

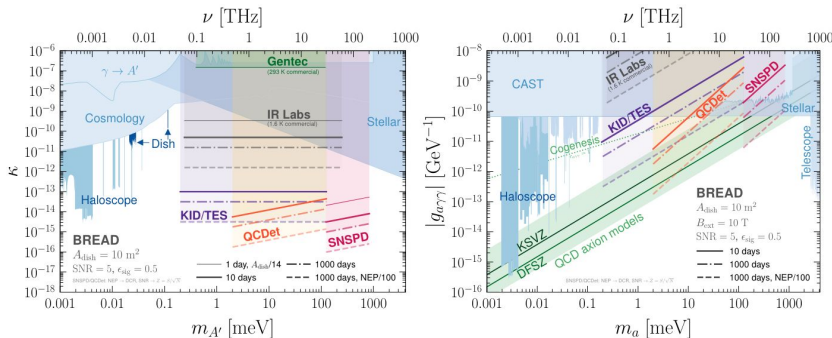
- ~100% efficiency @ 1550nm
- Low timing jitter (<15ps)
- Low Dark Count (<0.01Hz)
- Fast recovery (MHz rate)
- Multi Pixelated array

## R&D Goal

### Extend to Mid-IR (2 $\mu\text{m}$ -20 $\mu\text{m}$ )

- Energy resolving power
- Broadband spectrometry
- Polarization distinguishability

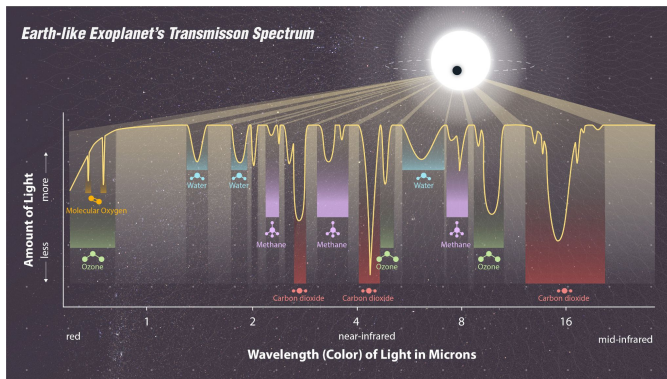
## Dark Matter/ Exotic Searches



Phys. Rev. Lett. 128, 131801 (2022).

WANT MORE?  
[2024 TIDC](#)

## Exoplanet Search



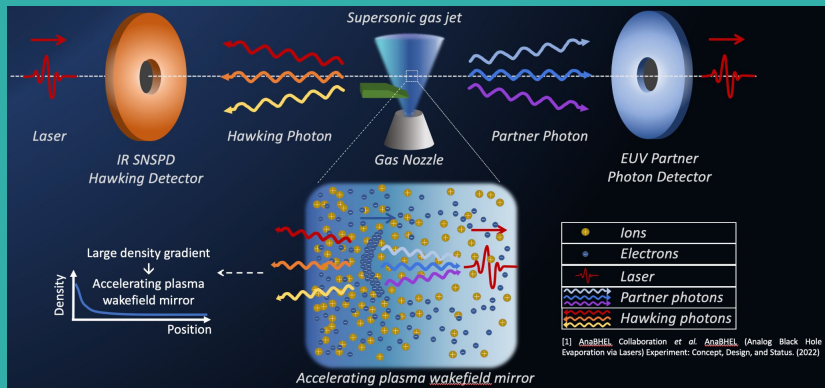
Credit: NASA, ESA, CSA, STScI, Joseph Olmsted (STScI)

## CERN DRD5/RDq

HEP function	Tracking	Calorimetry	Timing	PID	Helicity
Work package					
WP 1 (Quantum systems in traps and beam)	Rydberg TPC	BEC WIMP scattering (recoil)	O(fs) reference clock for time-sensitive synchronization (photon TOF)	Rydberg dE/dx amplifiers	
WP2 (Quantum materials: 0-, 1- and 2-D)	"DoPiV", improved GEM's chromatic tracking (sub-pixel); active scintillators	Chromatic calorimetry	Suspended / embedded quantum dot scintillators	Photonic dE/dx through suspended quantum dots in TPC	
WP 3 (Superconducting quantum devices)	O(ps) SNSPD trackers for diffractive scattering (Roman pot)	FIR, UV & x-ray calorimetry	O(ps) high Tc SNSPD	Milli- & microcharged particle trackers in beam dumps	
WP 4 (scaled-up bulk systems for map's)	Multi-mode trackers (electrons, photons)	Multi-mode calorimeters (electrons, photons, phonons)	Wavefront detection (e.g. O(ps) embedded devices)		Helicity detector via ultra-thin NV optically polarized scattering / tracking stack
WP 5 (Quantum techniques)					Many-to-one entanglement detection of interaction
WP 6 (capacity building)	Technical expertise of future workforce (detector construction); broadened career prospects and thus enhanced attractiveness; cross-departmental networking and collaboration; broadened user base for infrastructure (beam tests, dilution refrigerators, processing technologies)				

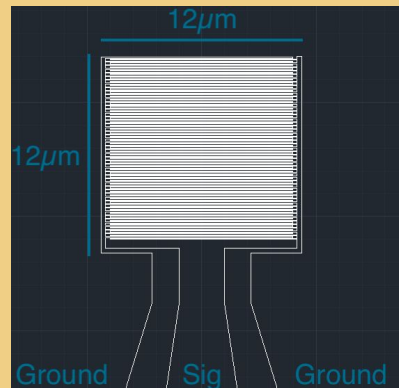
CERN-DRDC-2024-010, Michael Doser

# Applications

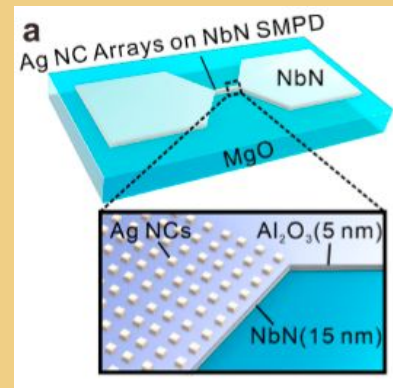


Photonics 2022, 9(12), 1003

# Design and simulation

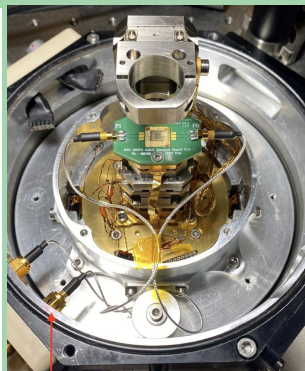
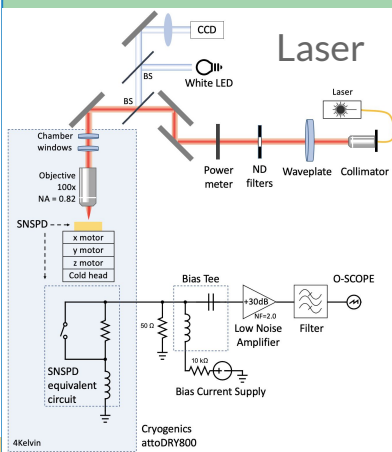


Nanowire meander

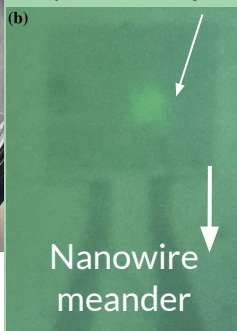


Nanocube plasmonic enhancement structure

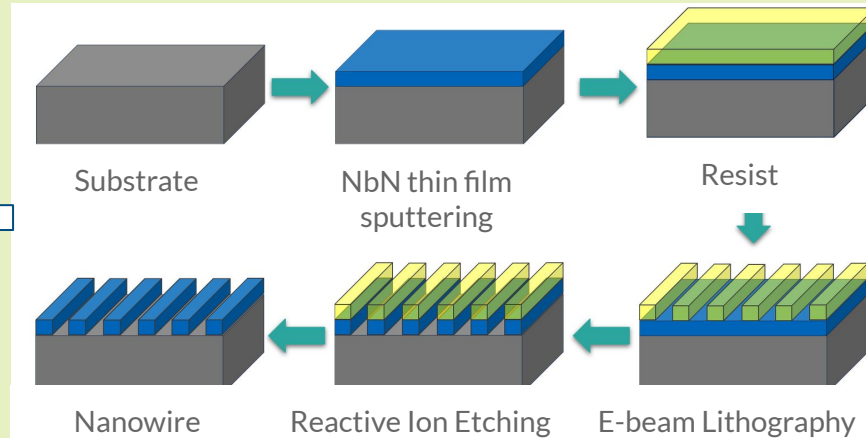
# Characterization



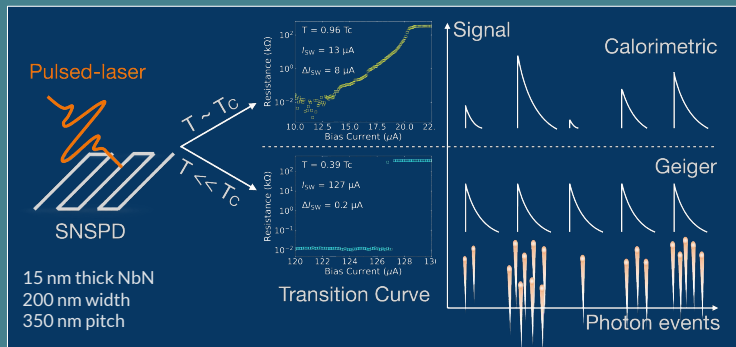
Pulsed-Laser  
100ps width  
3 $\mu$ m laser spot



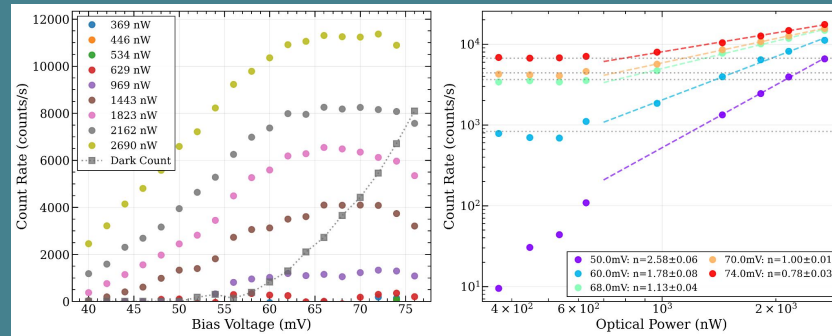
# Fabrication



## Dual Mode Calorimetric SNSPD

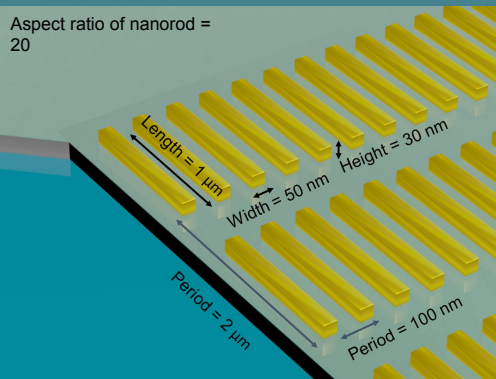


## Single photon sensitivity demonstration

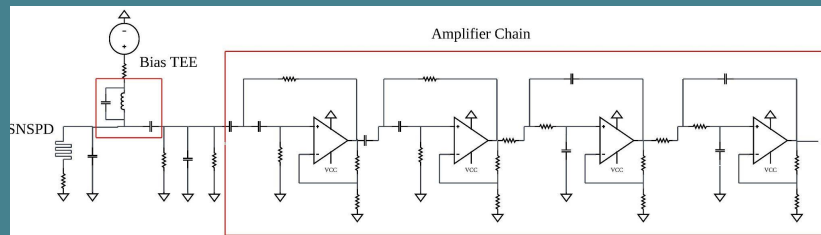


# Highlights of our new results

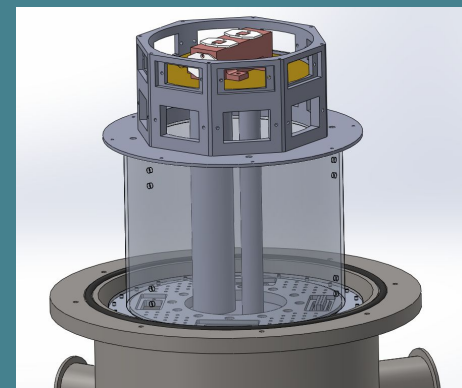
## Plasmonic SMSPD



## LTSPICE simulation

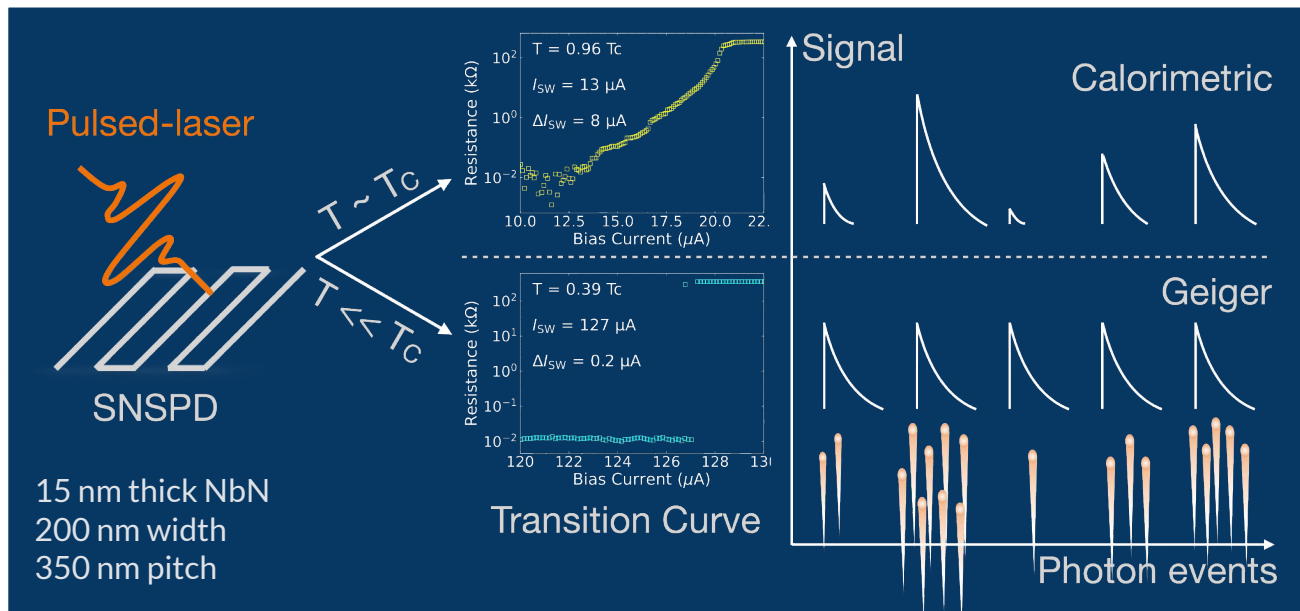


## New Cryostat



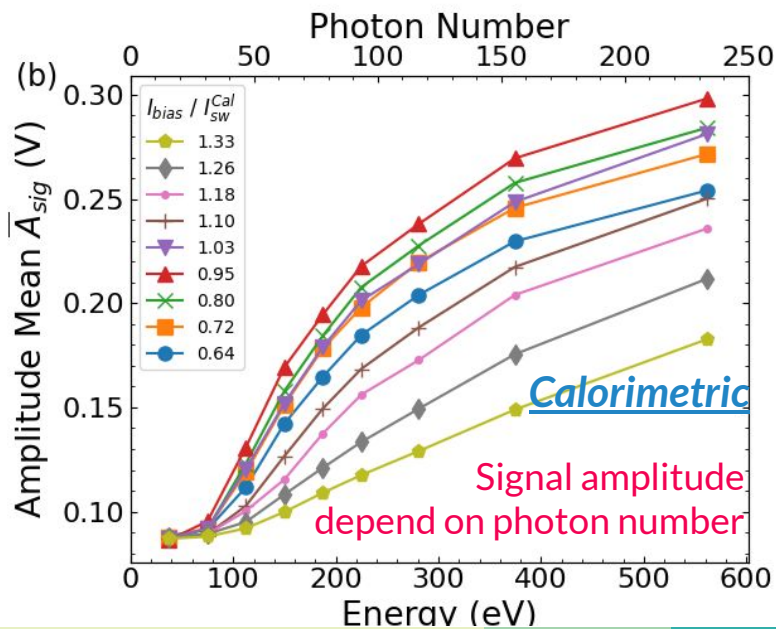
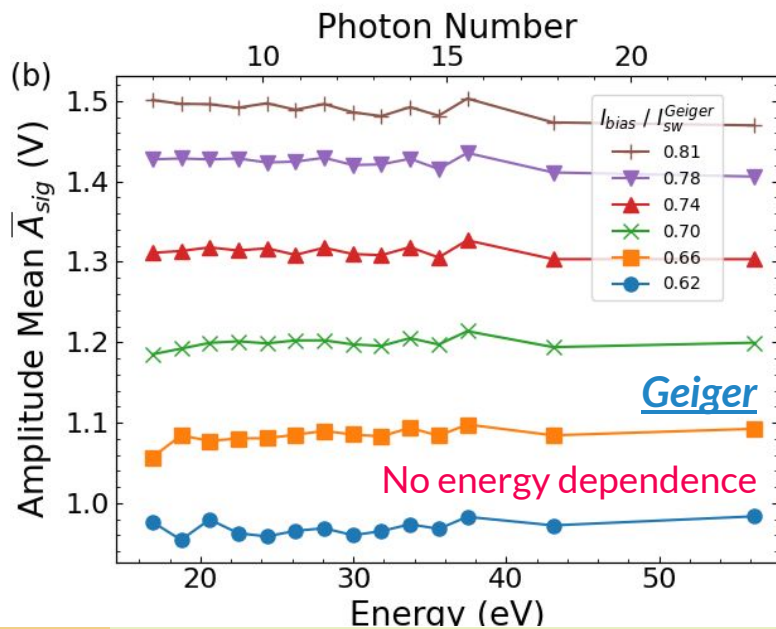
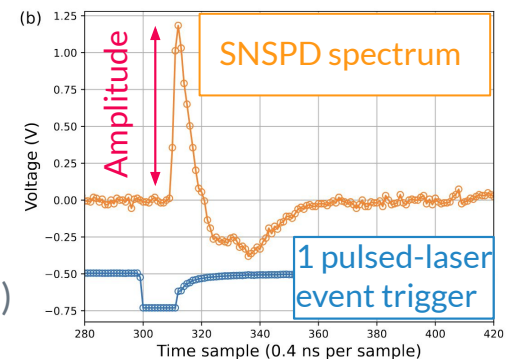
# Dual-operation mode SNSPD

- Paper published at [APL Quantum 2, 026118 \(2025\)](#)
  - Switch between conventional event counting and energy measurement by adjustment of operating temperature and bias current
  - Geiger mode @ 4.7 K ( 0.39 T<sub>c</sub> ) ↔ Calorimetric mode @ 11.5 K ( 0.96 T<sub>c</sub> )



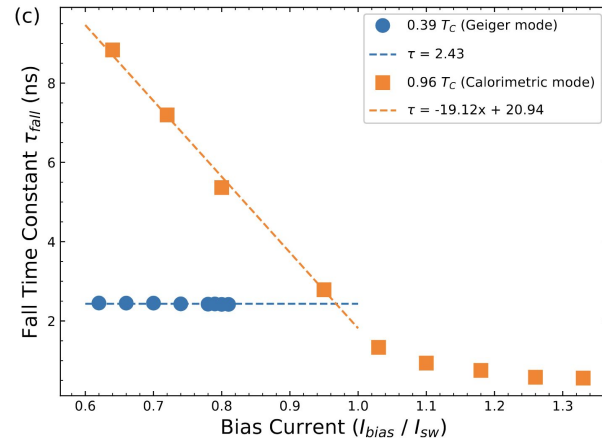
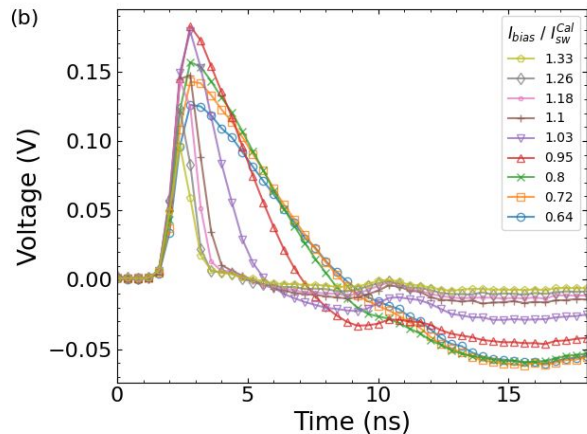
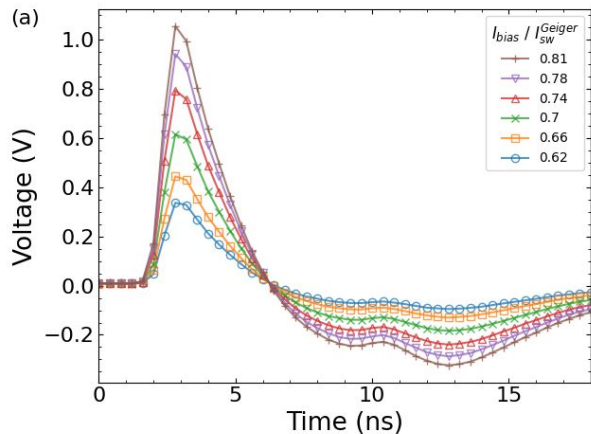
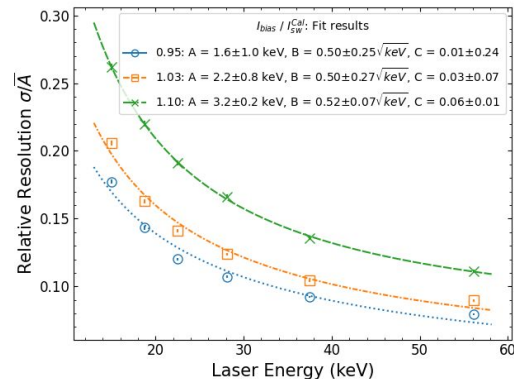
# Results Highlight

- Geiger  $\leftrightarrow$  Calorimetric
  - Vortex-crossing-induced full transition  $\leftrightarrow$  Joule heating partial transition
  - No energy dependence in signal amplitude  $\leftrightarrow$  depend on N(absorbed photon)
  - Fast event counting  $\leftrightarrow$  Potential fast photon number resolving spectroscopy



# Features of Calorimetric SNSPD

- Timing
  - Falling time constant depends on bias current
  - Reaches 560 ps falling time constant, faster than Geiger mode (2.2ns)
- Stable operation
  - No Dark count (Geiger mode around 1Hz)
  - No latching effect (Geiger mode latches at around  $0.81I_C$ )
- Energy resolution around 6% constant term (Dominated by the noise term)



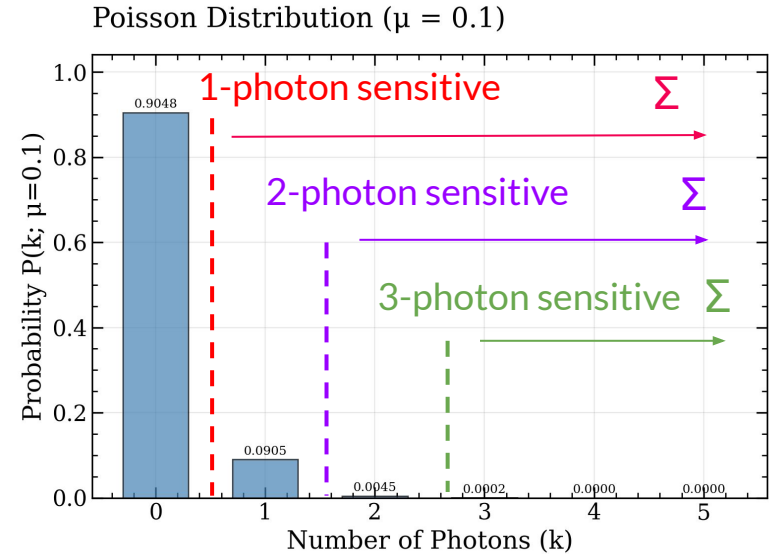
# Single photon sensitivity demonstration

# n-photon-sensitive detection

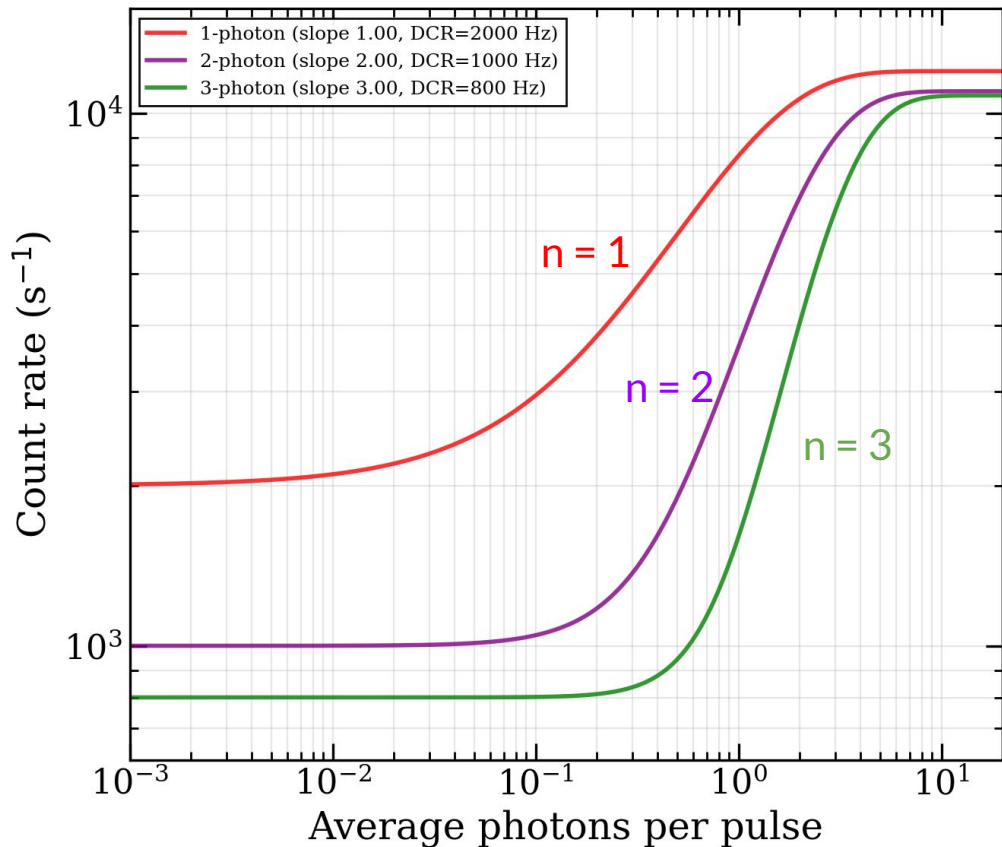
$$P(\text{click} \mid n) = 1 - \text{CDF}(n - 1, \mu)$$

$$P_{\text{click}}(\mu, \eta, n) = \sum_{k=n}^{\infty} \frac{(\eta\mu)^k e^{-\eta\mu}}{k!} = 1 - \sum_{k=0}^{n-1} \frac{(\eta\mu)^k e^{-\eta\mu}}{k!}$$

$$\eta_{\text{sys}} = \eta_{\text{coupling}} \times \eta_{\text{absorption}} \times \eta_{\text{intrinsic}}$$



# Figure of Merit for single photon response



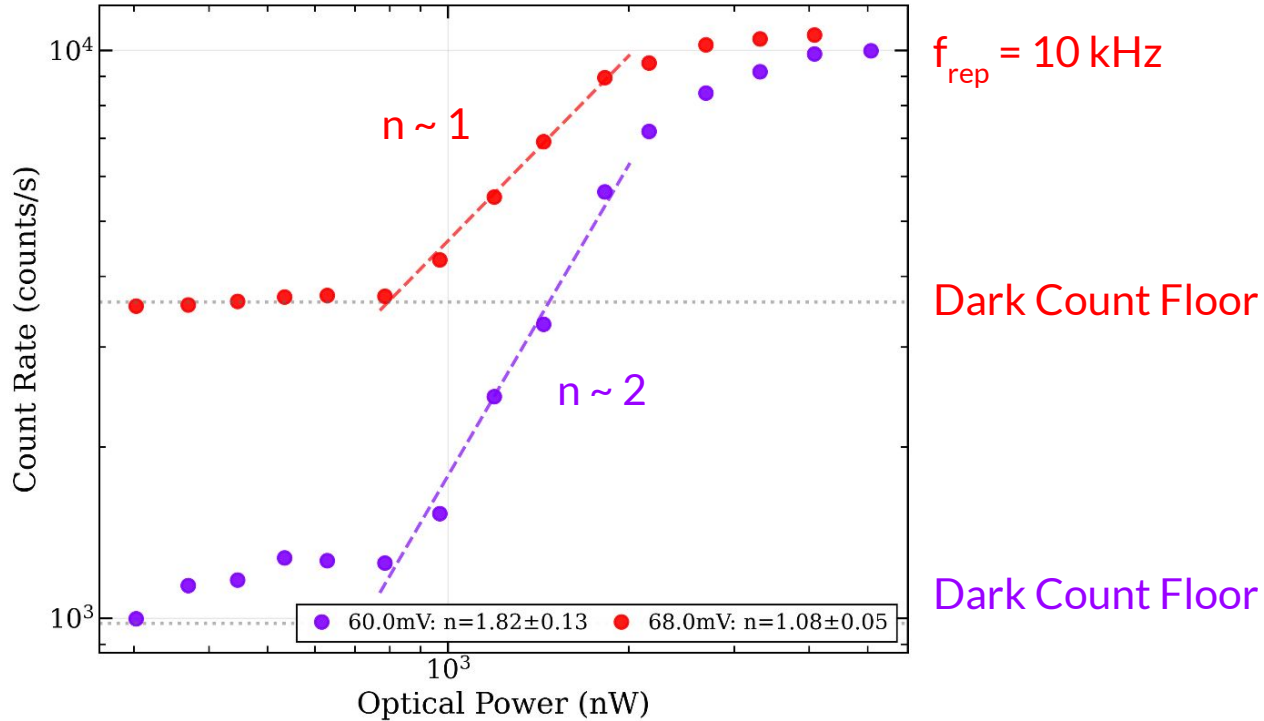
$$R_{\text{total}}(\mu, n) \approx f_{\text{rep}} \frac{(\eta_{\text{sys}} \mu)^n}{n!} + \text{DCR}$$

for  $\eta_{\text{sys}} \mu \ll 1$

$$\log(R_{\text{total}}) \approx n \log(\mu) + \log\left(\frac{f_{\text{rep}} \eta_{\text{sys}}^n}{n!}\right)$$

$$\frac{d \log R}{d \log \mu} = n$$

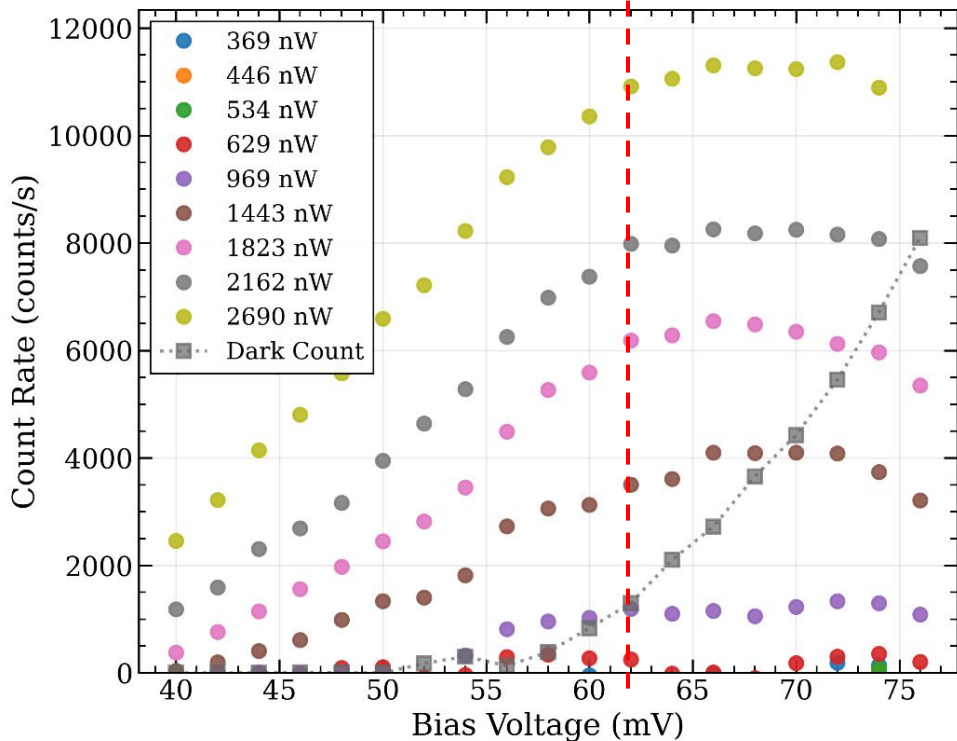
# Single photon sensitivity demonstrated



# Quantum efficiency saturation demonstrated

Quantum efficiency increases with bias current  
→ Multi photon regime

Quantum efficiency saturates  
→ stable operation  
→ single photon detection regime



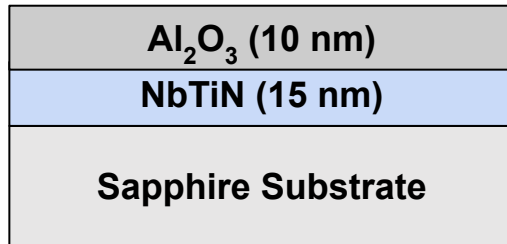
Dark count increases with bias current

# Detection efficiency enhancement via Gap-Plasmon Resonances

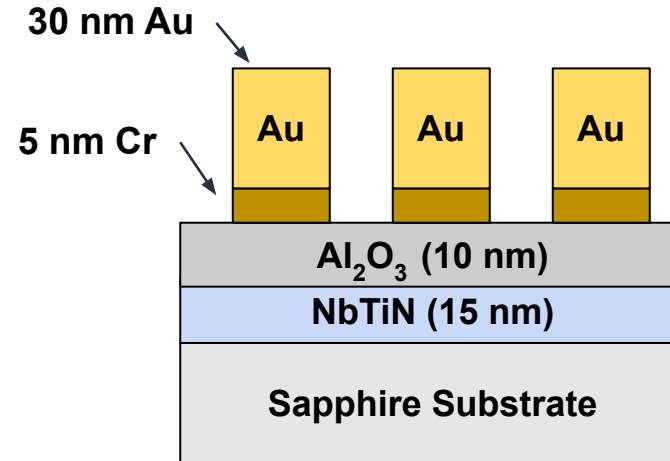
# Plasmonic nanocube structure

Shu-Xiao Liu

Pristine SMSPD

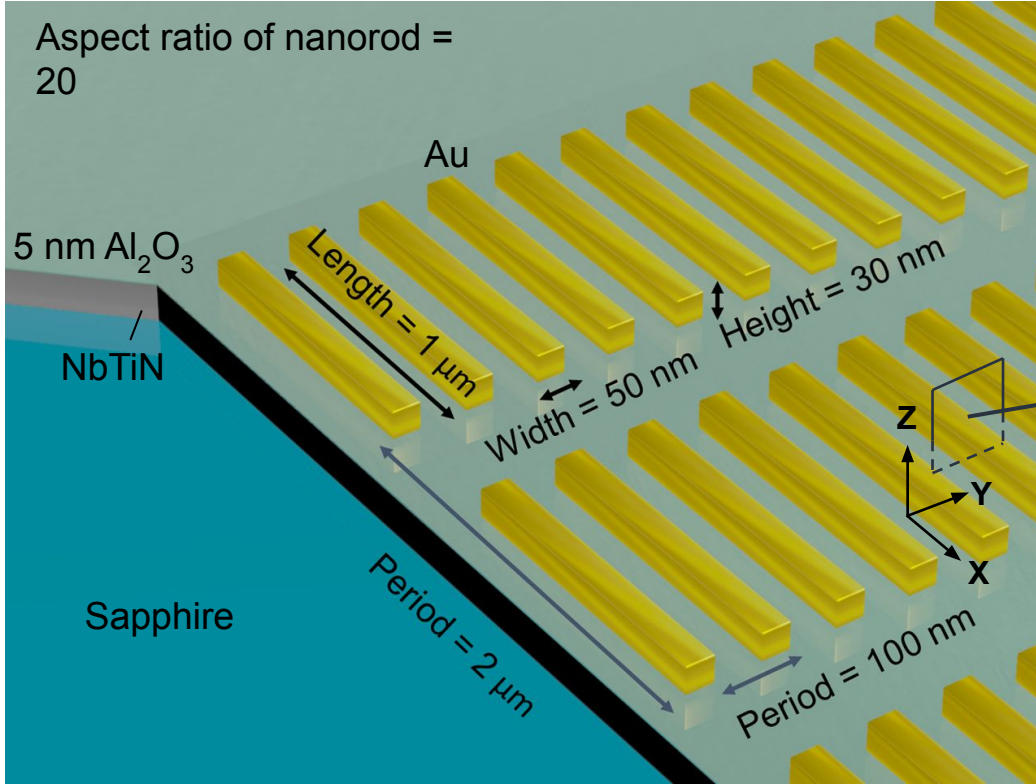


Plasmonic SMSPD

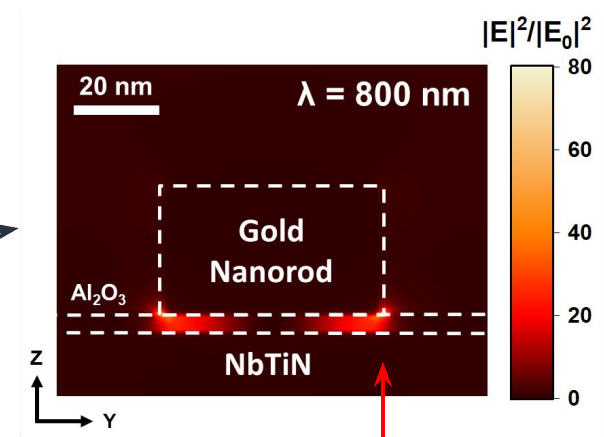


# Gold nanostructure on NbTiN SMSPD

Shu-Xiao Liu



## Finite-Difference Time-Domain (FDTD) Simulation

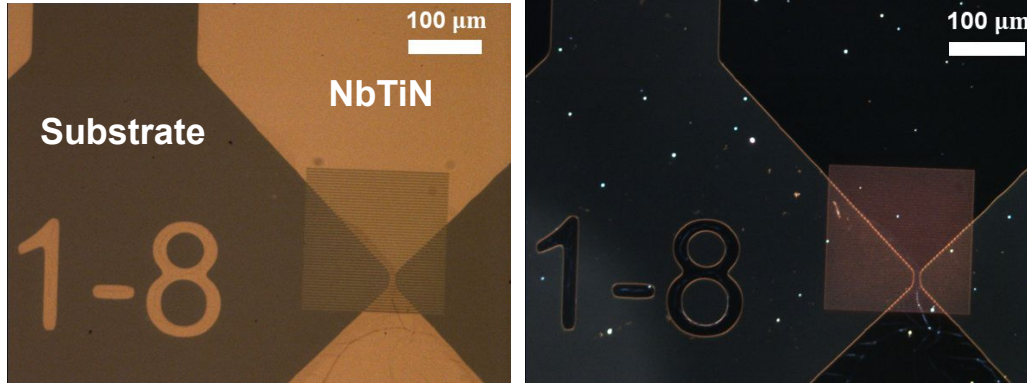


Gap-plasmon resonance

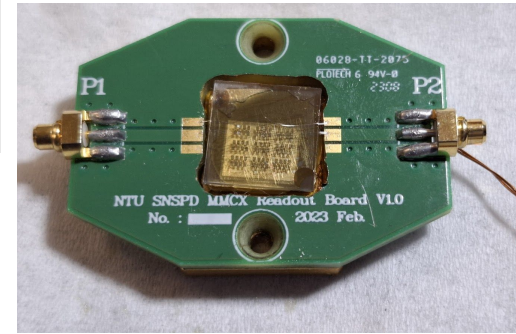
# Plasmonic nanostructure fabrication

Shu-Xiao Liu

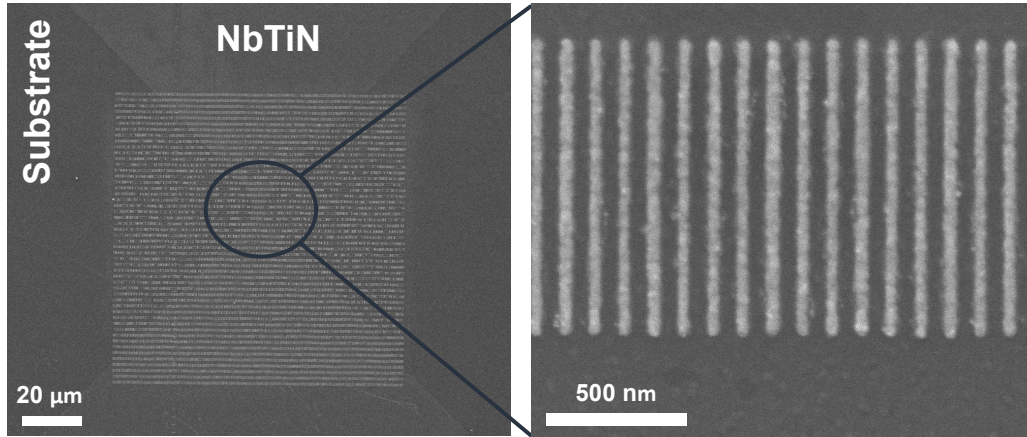
OM Images



SMSPD on PCB Stage



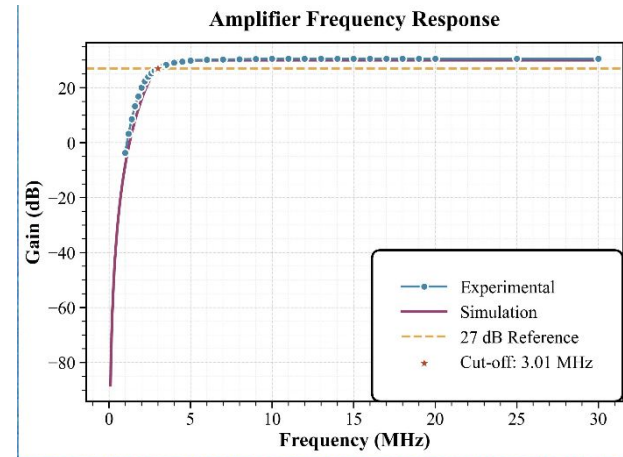
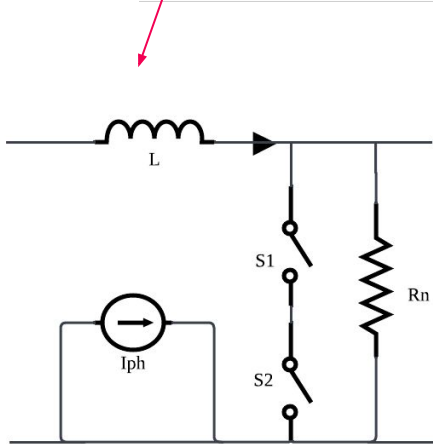
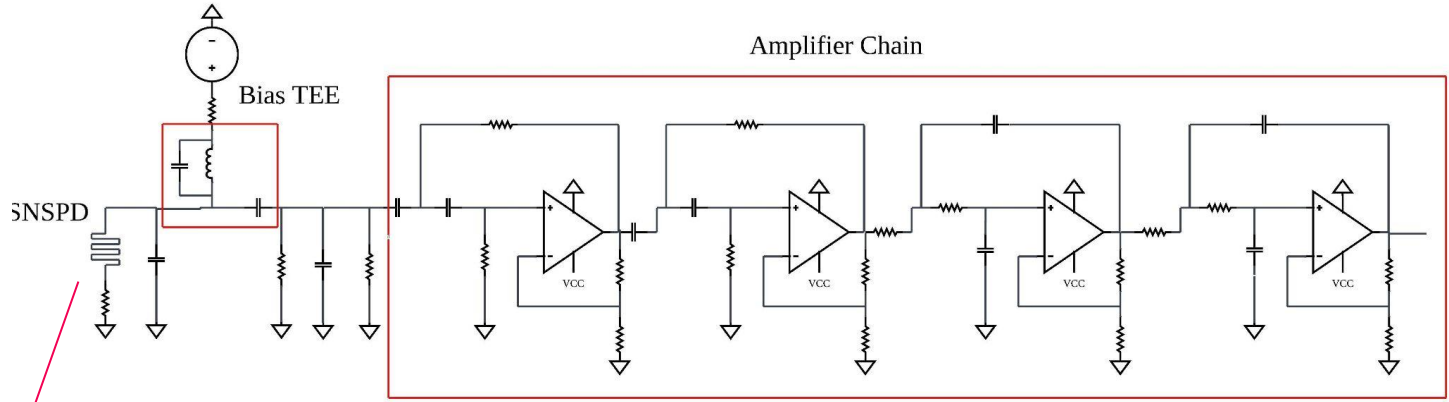
SEM Images



# SNSPD circuit simulation via SPICE

# SPICE simulation

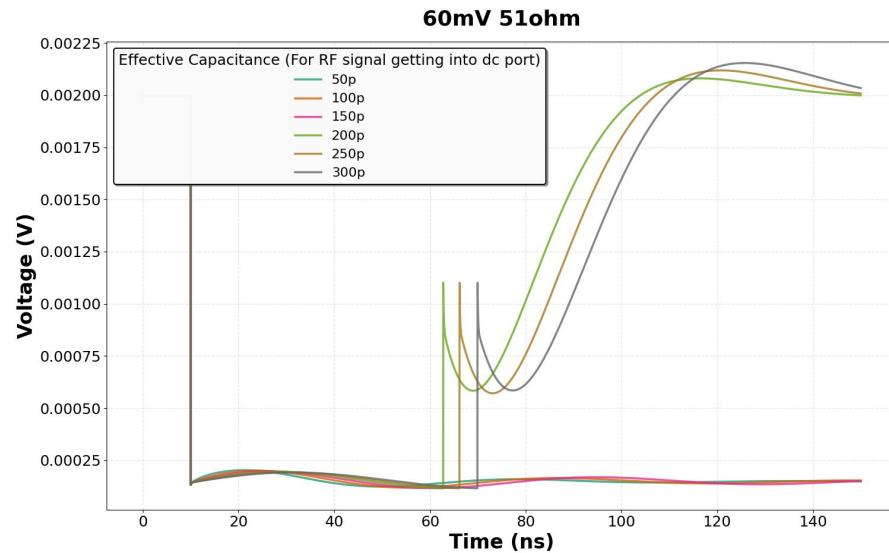
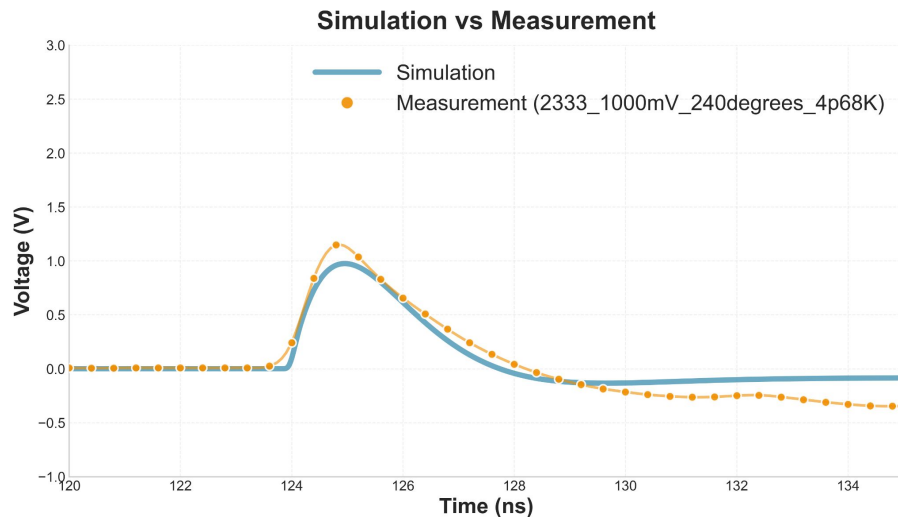
Yi-Ren Wu



# Preliminary results

Parameter estimation by data matching, e.g  
Parasitic capacitance, kinetic inductance, etc

## Latching Analysis



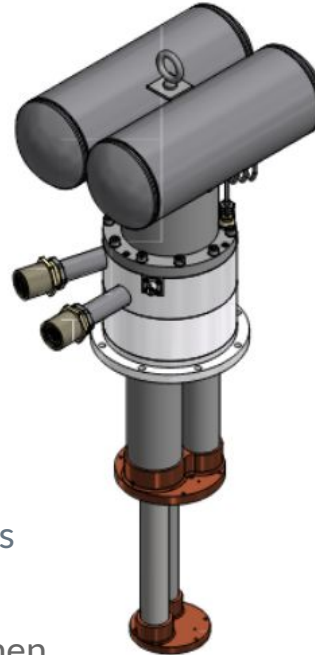
# Cryogenics

# New cryogenics setup @ NTU

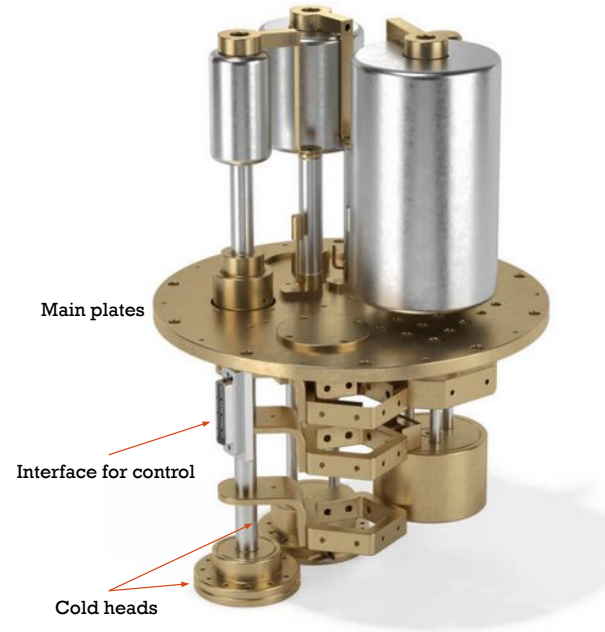
Pu-Kai Wang

- Motivation
  - Dedicated cryogenics for SNSPD
  - Lower temperature
  - Platform for new exotic searches
- Design Goal
  - Larger working space
  - More types of feedthroughs
  - Noise shielding
  - Temperature extend to 300 mK
- Intermediate step
  - Small size for conceptual test
  - Still provide SNSPD testing capabilities
- Pulse tube and sorption cooler from Pisin Chen

Pulse tube  
(PT420 from Cryomech)



sub-Kelvin sorption coolers  
(GL10 from Chase Research Cryogenics)



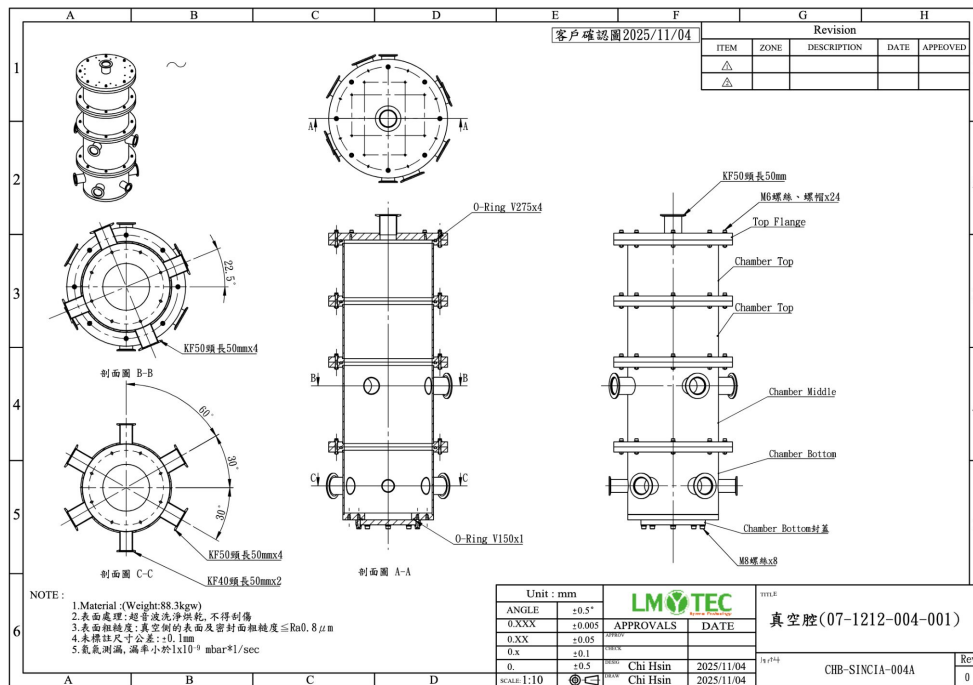
GL10-018

Dimension ~ 15 \* 15 \* 15 cm<sup>3</sup>

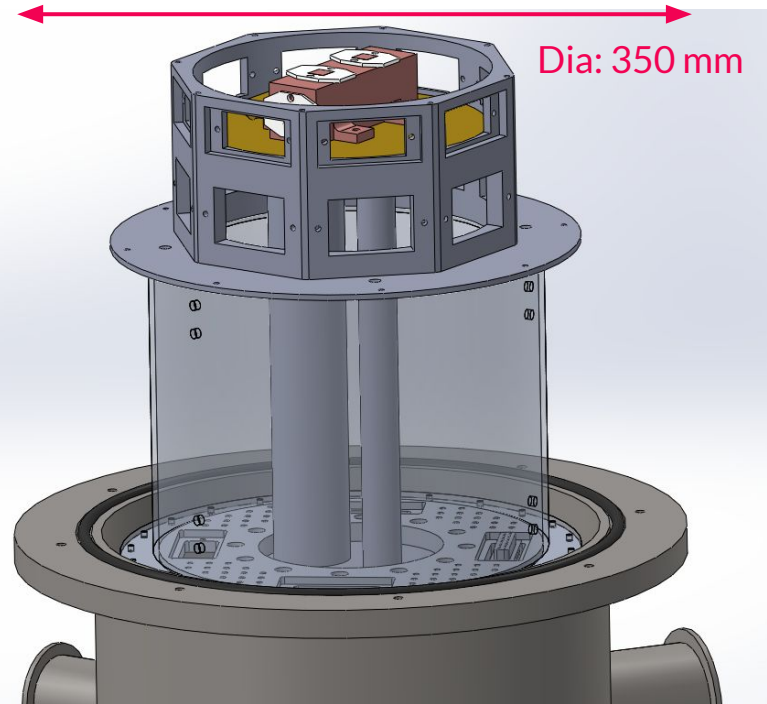
# Cryostat design and production

Pu-Kai Wang

## Vacuum chamber

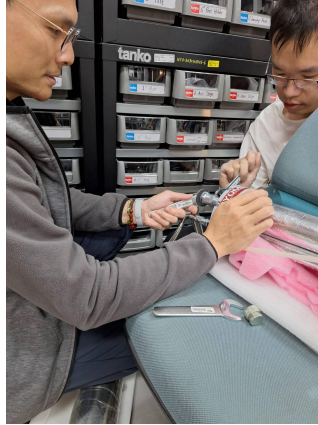


## Inner radiation shield / mounting platform

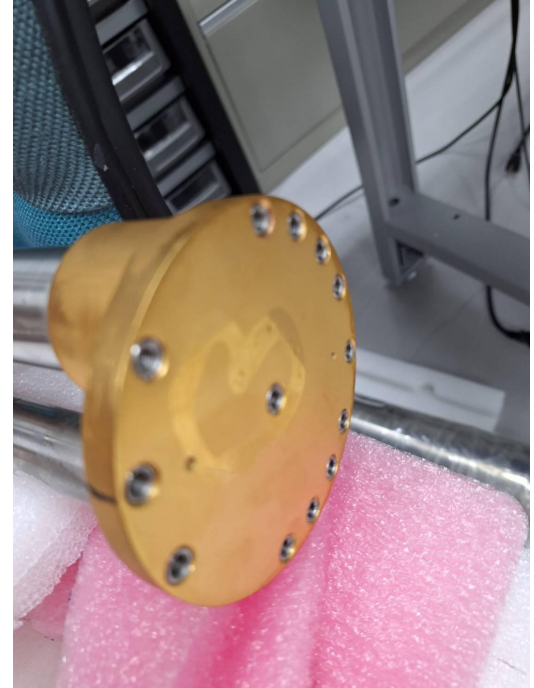


# Pulse tube test w/o vacuum chamber

Pu-Kai Wang



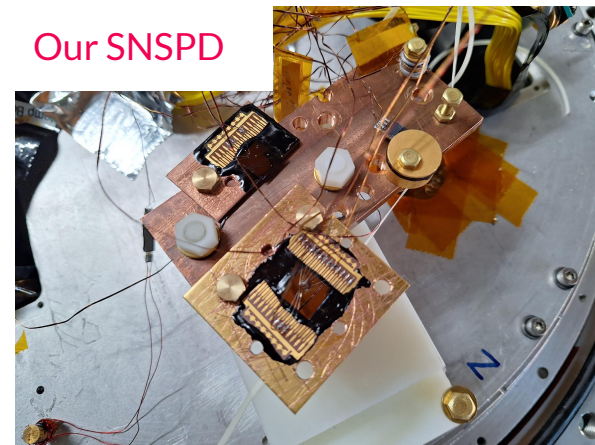
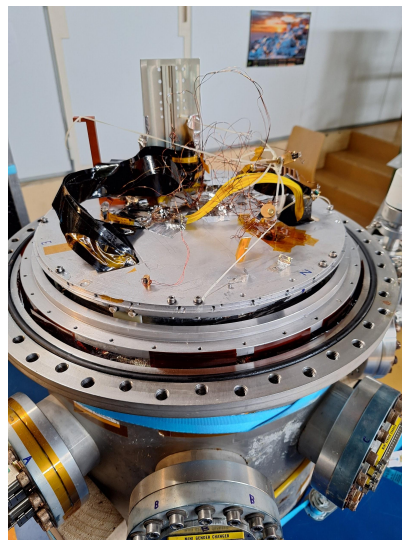
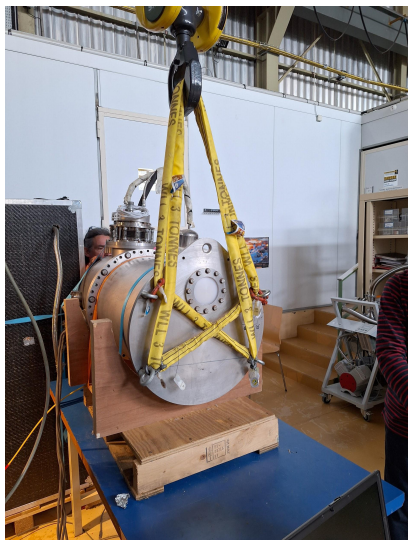
Successfully assembled pulse tube and started cool down pumping for ~ 1 min



# Cryogenics setup at CEA Saclay

Xavier-Francois Navick

- Dedicated to Analog Black Hole experiment
- Reaches  $\sim 250\text{mK}$ , sustains for  $\sim 20\text{hrs}$
- Retired cryogenics from other experiments
- Extensive rework of the cryostat ongoing



# Conclusion

- IQSens project 2nd year highlight
  - Publication on Dual mode Calorimetric SNSPD
  - Single photon sensitivity of our SNSPD demonstrated
  
- IQSens 3rd year expectations
  - Deliver and publish new results on calorimetric SNSPD and polarized plasmonic structures
  - New cryostat setup at NTU
  - Extending sensitivity to IR photons
  
- Invited talk given by Stathes Paganis
  - TPS O5 Session, 16:30, Wednesday, 4Jan2026

# Thanks to all the collaborators!!



National Taiwan University  
High Energy Physics Group



# List of collaborators

## **TIDC / NTU**

OuChen, Jenny, Yi-Ren Wu, Hsin-Yeh Wu, Stathes Paganis

## **Lu Research Lab @Academia Sinica**

Shu-Xiao Liu, Jia-Wern Chen, Yu-Jung Lu

## **Lecospa**

Pisin Chen, Yung-Kun Liu

## **IoP, Academia Sinica**

Pu-Kai, Wang

## **CEA Saclay**

Marc Besançon, Jean-François Glicenstein, Xavier-François Navick, Boris Tuchming