SNSPD Tests in ADR at Fermilab: Results and Plans

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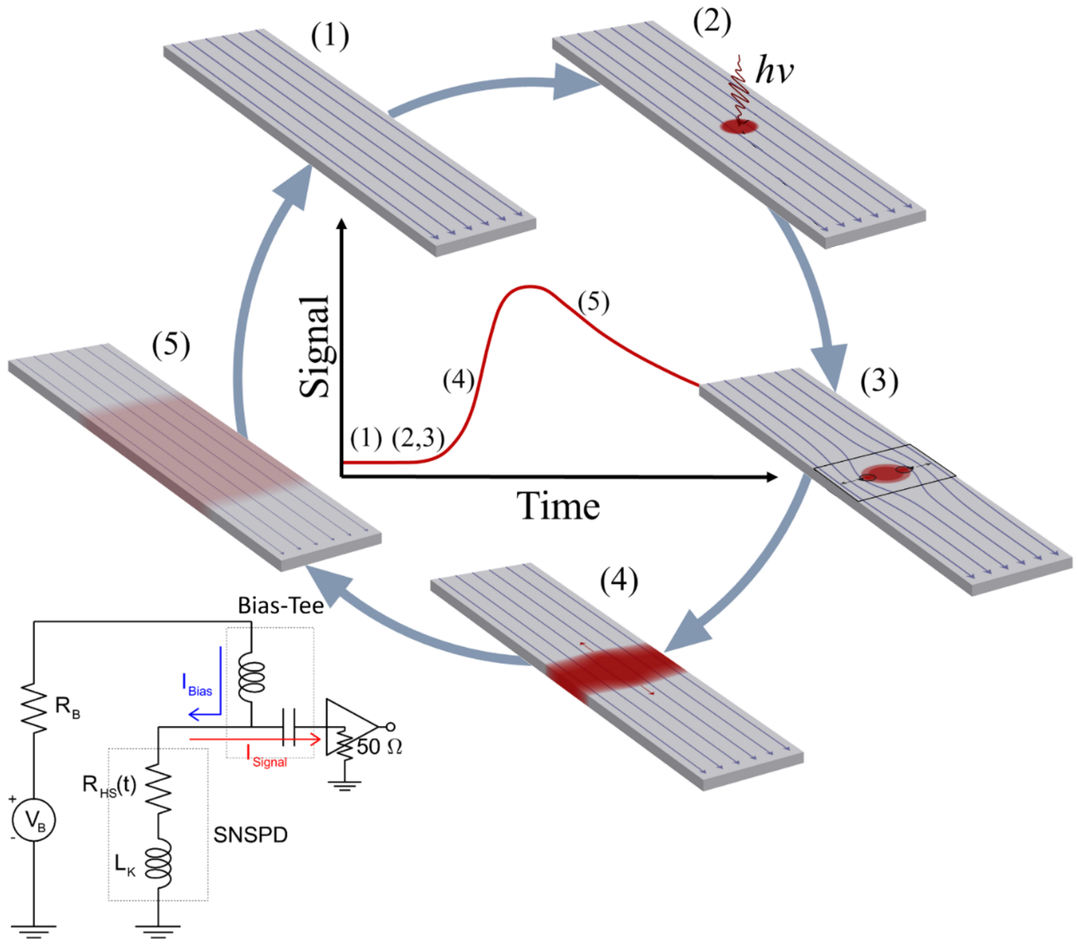
2023 BREAD Collaboration Meeting
10/06/2023

Caltech

BREAD
COLLABORATION

Superconducting Nanowire Single Photon Detector (SNSPD) for BREAD

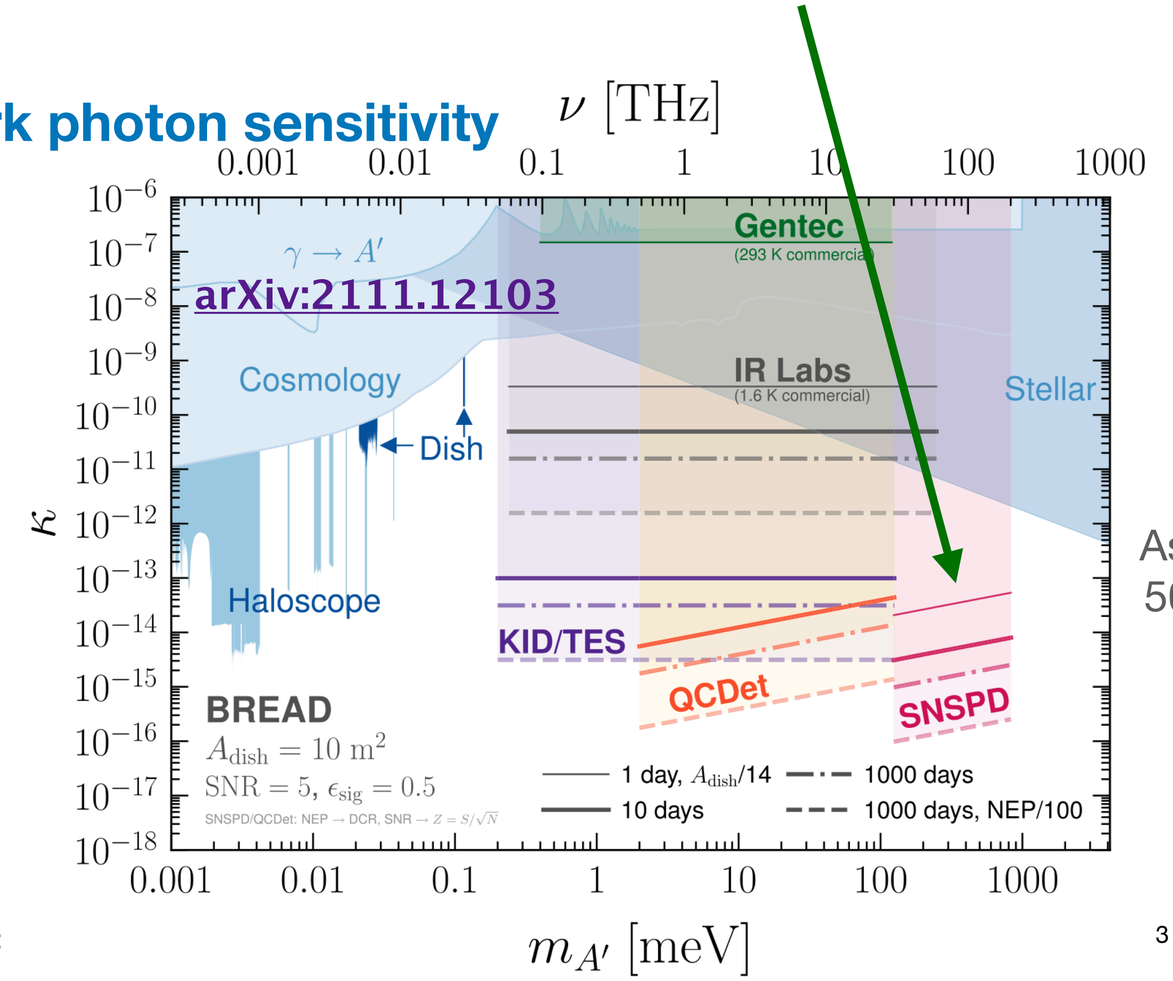


- SNSPDs are ideal photosensors for BREAD:
  - Broad spectral response: ultraviolet to infrared → sensitive to 0.1 - 1 eV dark photon/axions mass
  - Low noise: DCR < 10^{-3} Hz
  - mm^2-size active area
- Detection Mechanism:
  - Operating temperature : 1-4 Kelvin
  - Single photon triggers detector out of superconducting state
  - Resistance quickly (ps) jumps to few kΩ → bias current into readout

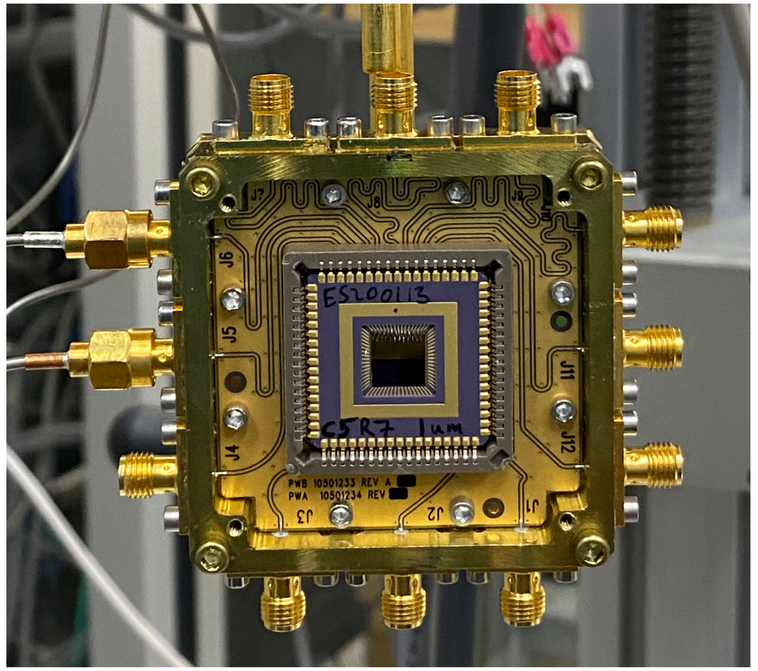
Pilot Experiment with SNSPDs

- SNSPD provides unique sensitivity for 0.1-1 eV dark photons and axions due to its sensitivity for 1-10um photons

Dark photon sensitivity

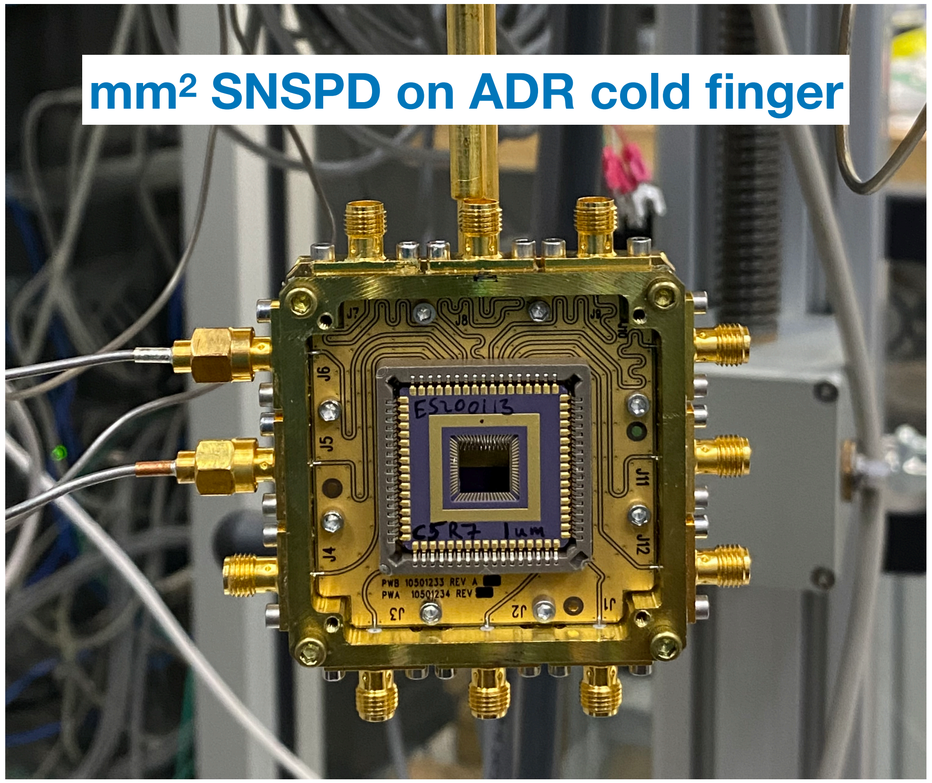


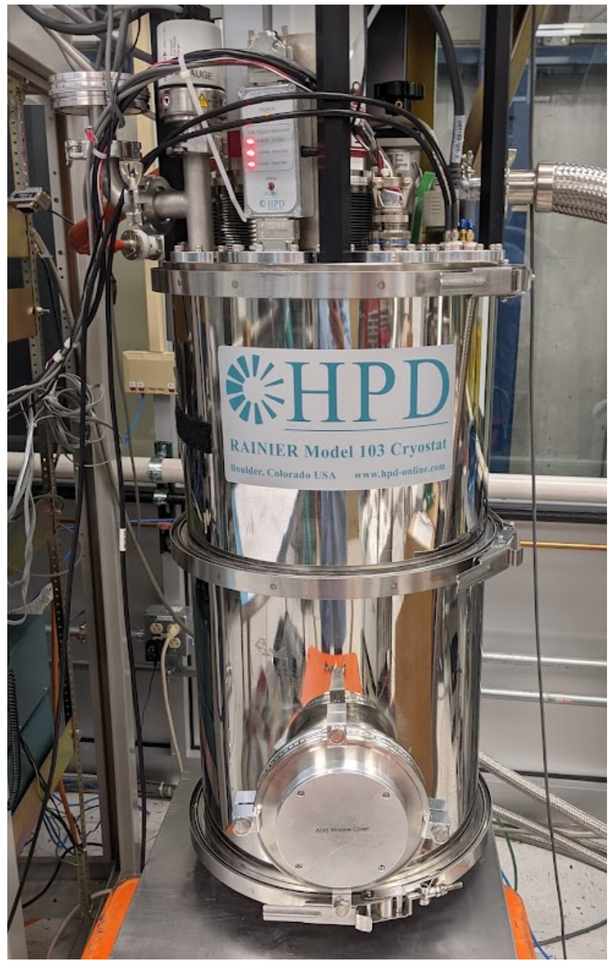
Assuming DCR ~1e-4
50% signal efficiency



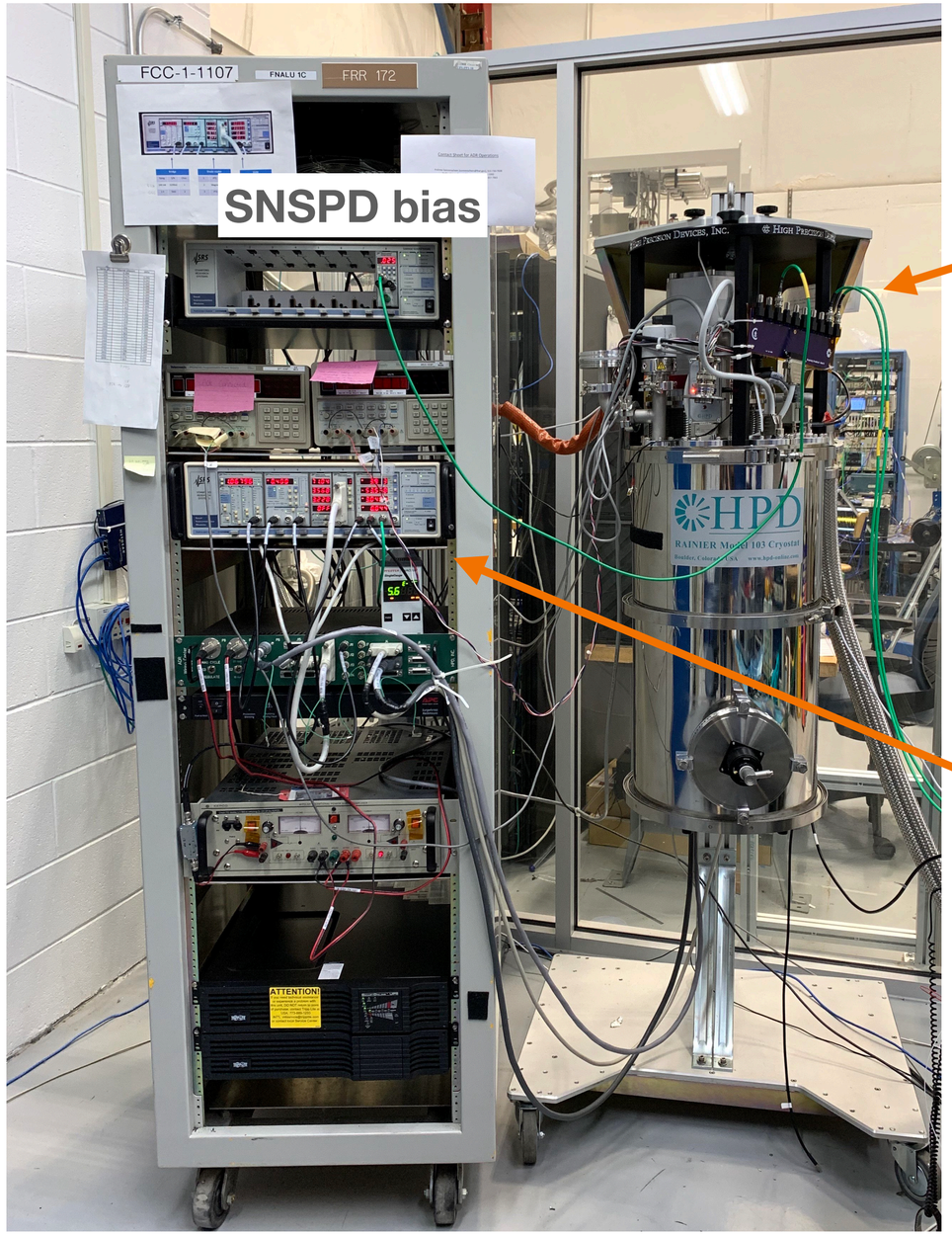
SNSPD Characterization at FNAL

- The sensors are mounted in an Adiabatic Demagnetization Refrigerator (ADR) cryostat in FNAL (0.1K base temperature)
- Our collaborators at JPL developed 8-channel mm^2 SNSPD





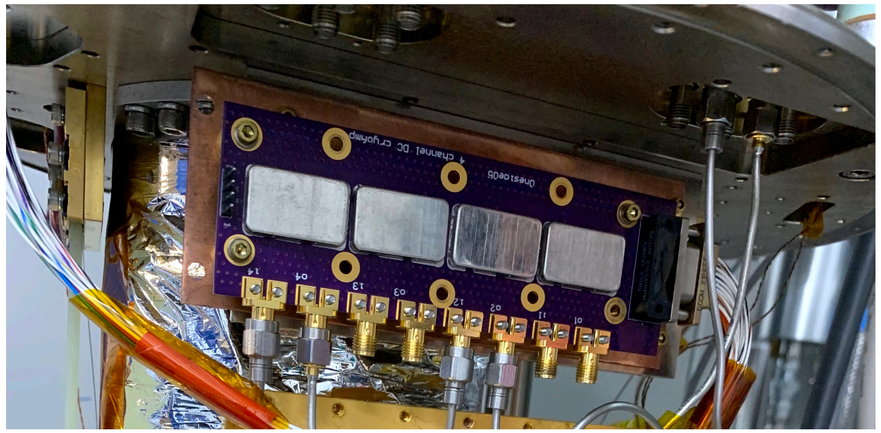
Electronics



Biasing breakout board
(provides bias for SNSPDs and the cryo-amp)

Low noise 4-channel amplifier at 40 K
~30 dB gain from 10-500MHz

Temperature & pressure monitors

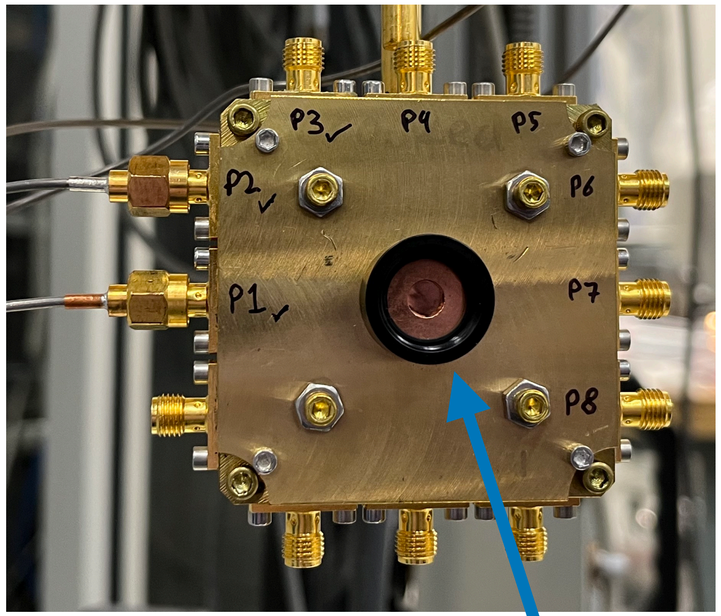


Currently only using 2 channels in the amplifier, will upgrade to 4-channel readout with new RF lines

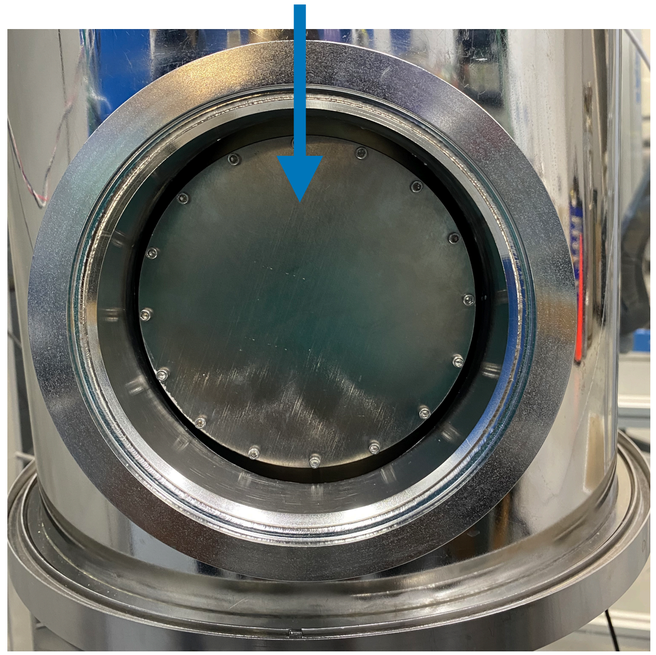
Dark Count Rate

- Measured the DCR with detector lid on, shielding at 40K and room temperature → < 1e-3 DCR
- Working on new dark box for SNSPD to further reduce the noise floor in DCR

SNSPD with lid on

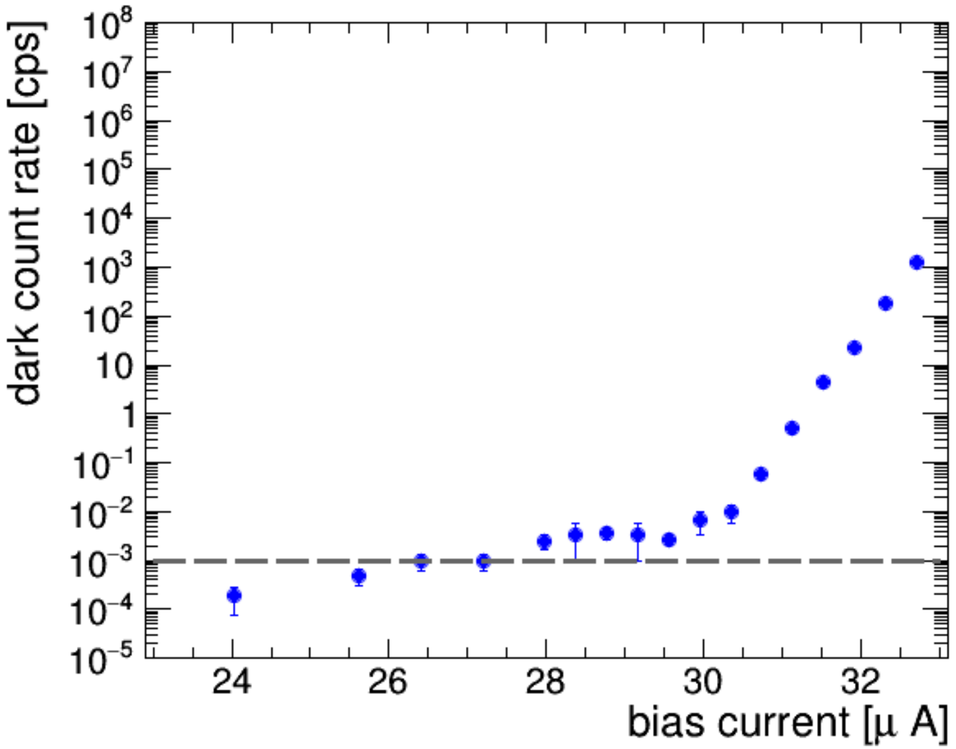


radiation shield at 70K



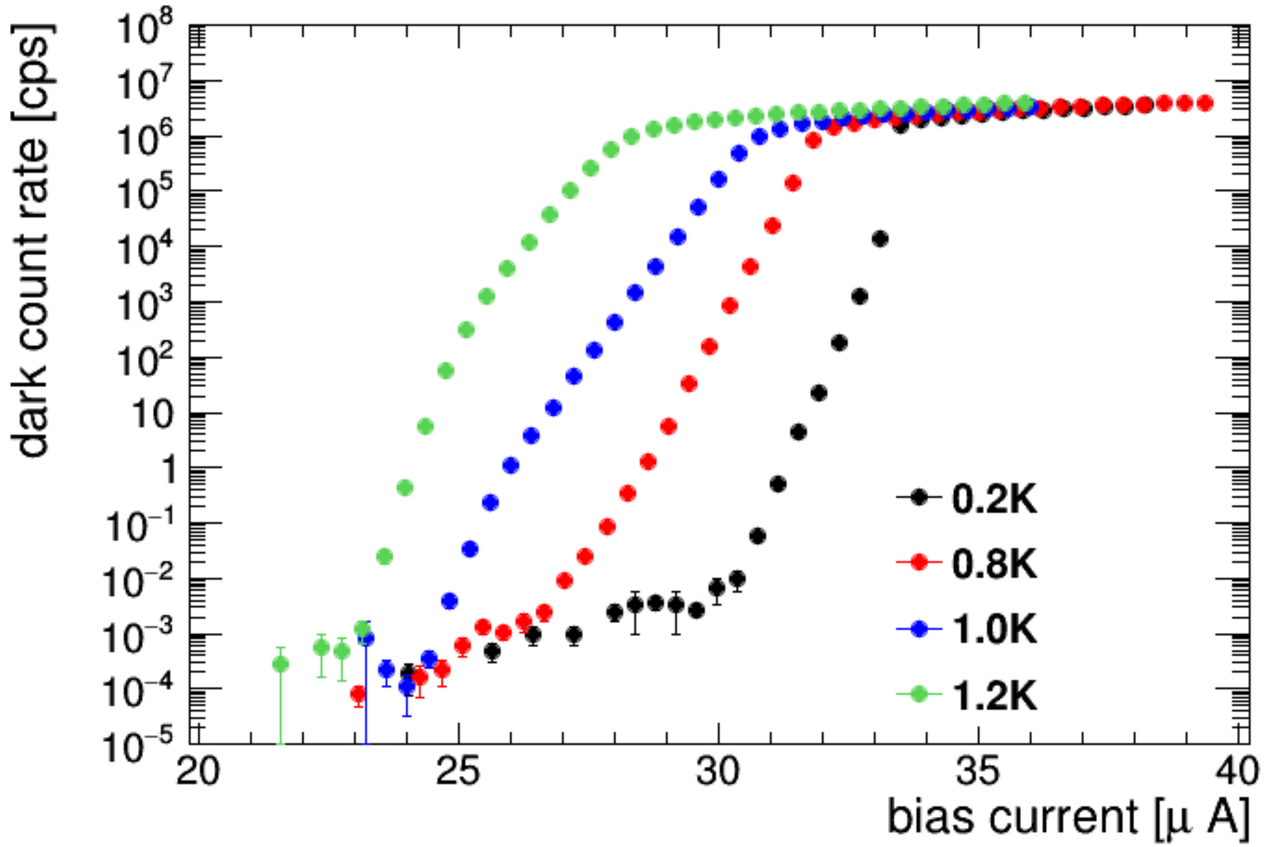
Detector lid

Dark count rate

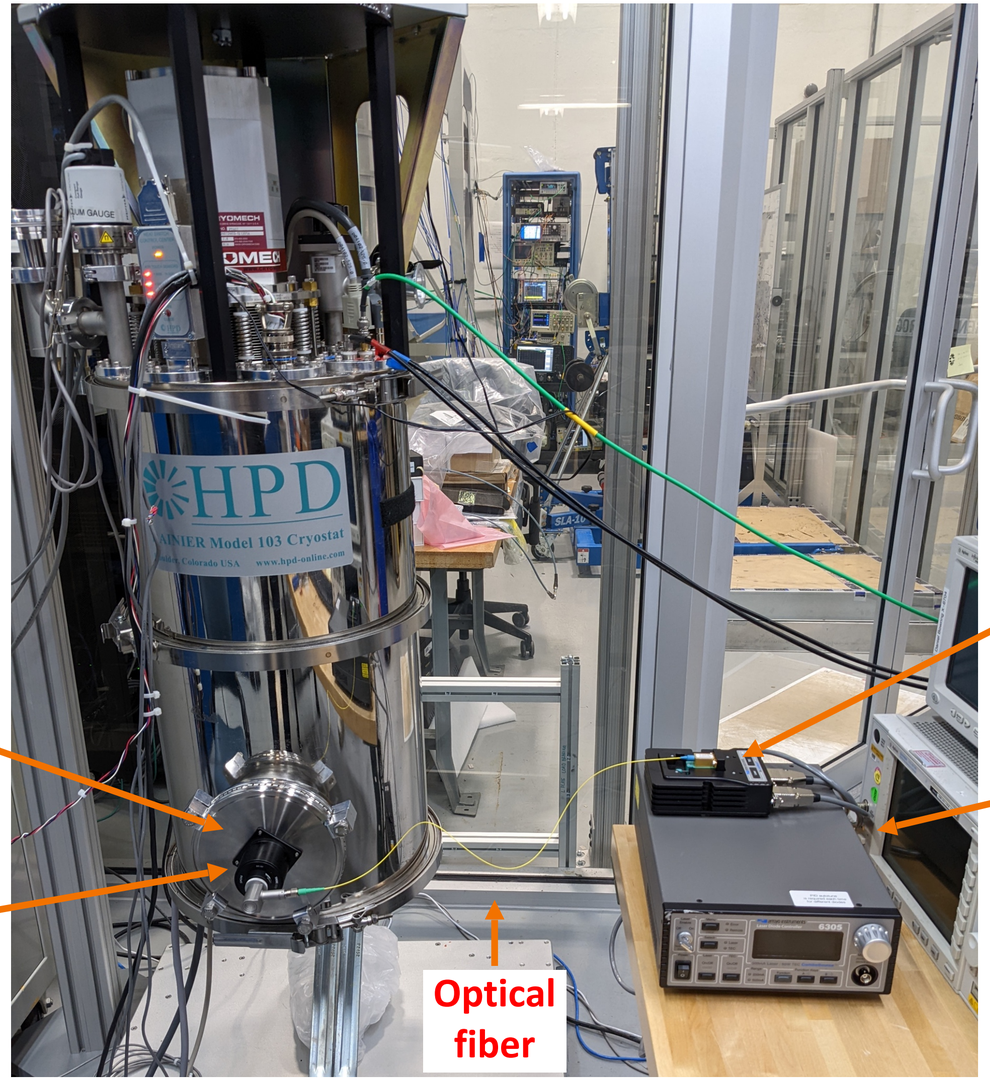


Dark Count Rate at Different Temperature

- DCR shifts to the left significantly at higher temperature → lower DCR at lower temperature
- Demonstrating the advantage to operate at as low temperature as possible

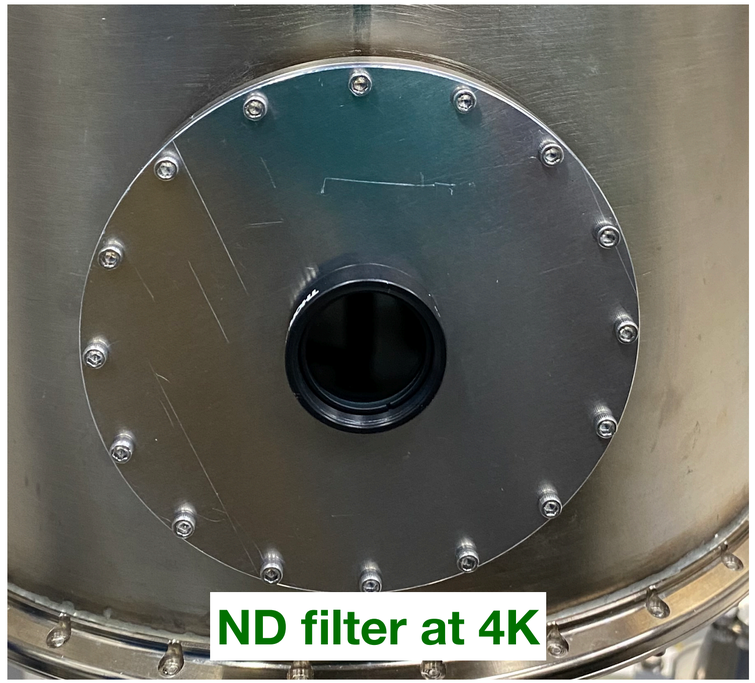


Photon Count Rate Measurement with External Laser



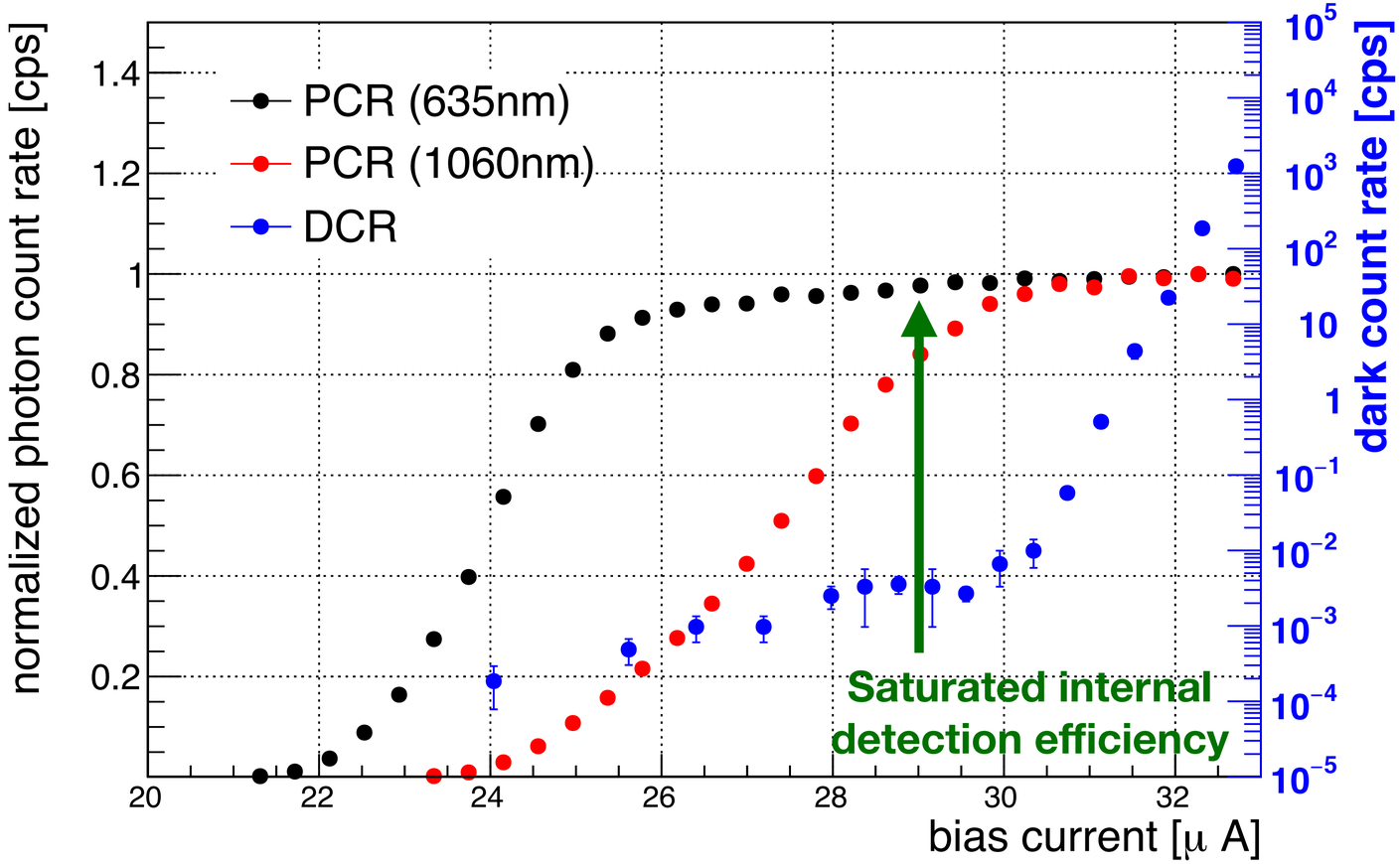
Photon Count Rate

- Previously, we were swamped by the thermal photons that reach the SNSPDs through the windows
- Optical design to reduce dark count rate from thermal photons and accurately measure PCR
  - Glass window + custom coating (40K) to filter out photons with $2 < \lambda < 4.5$ um with OD = 3
  - ND filter from Thorlabs (4K) to filter out $1 < \lambda < 2.6$ um photons with OD = 4
- Background rate reduced to a few counts per second after the filters are applied



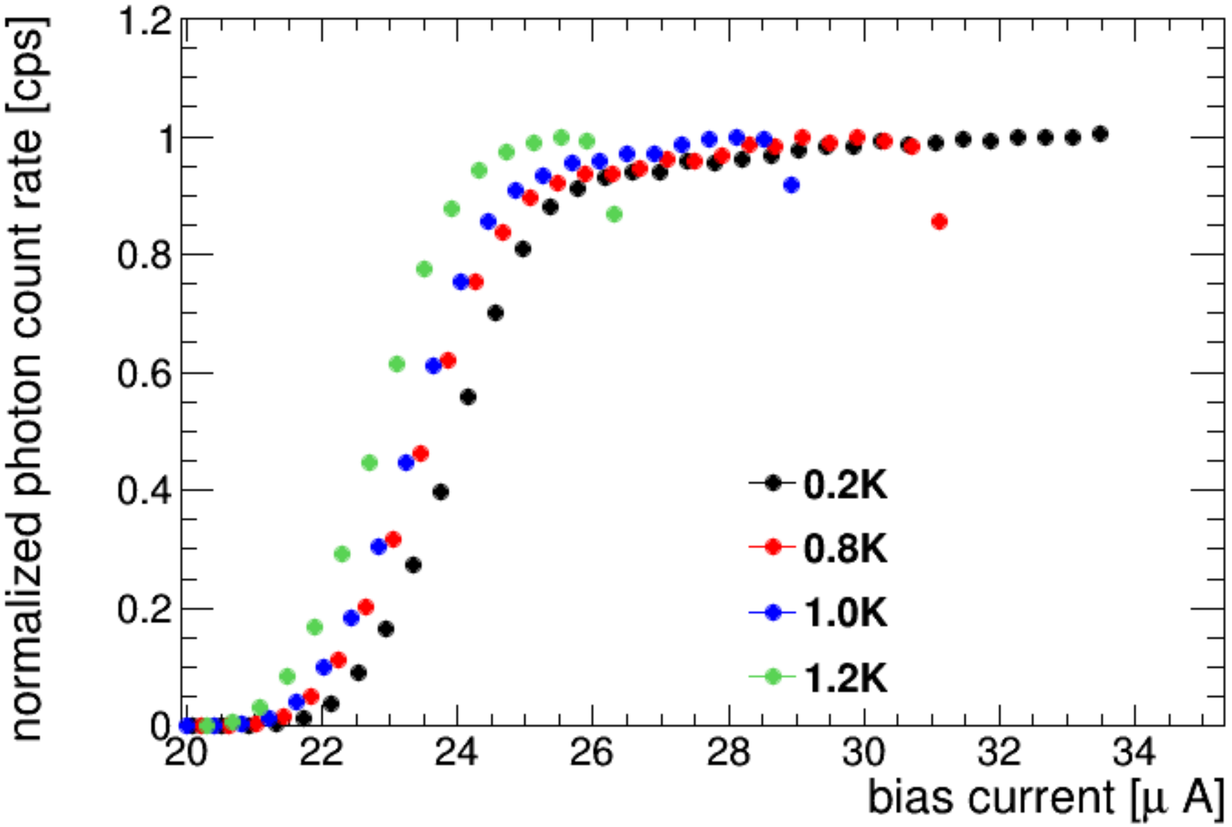
Photon Count Rate & Dark Count Rate

- Measured the photon count rate and dark count rate at 0.2K
- Internal detection efficiency saturated for both 635nm and 1060 nm
- Internal detection efficiency is saturated at a lower bias current for higher photon energy



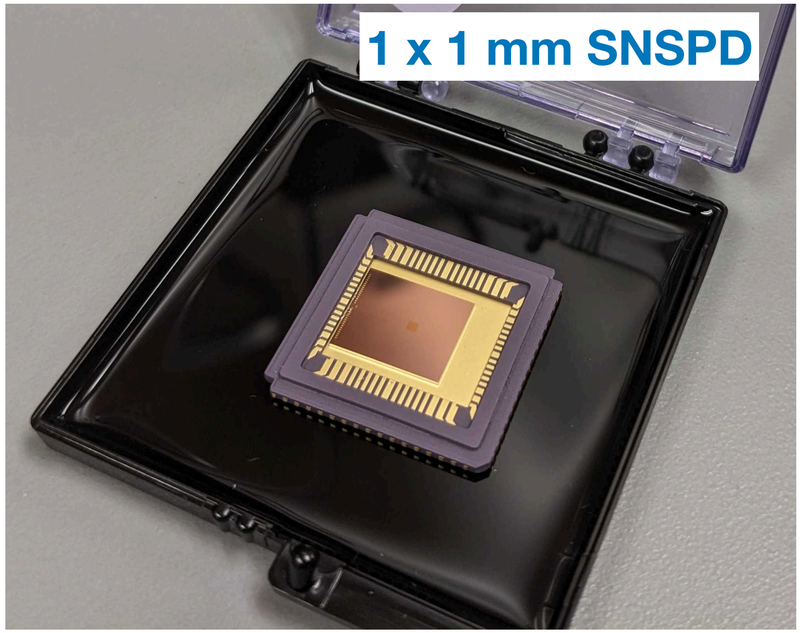
Photon Count Rate at Different Temperature

- Little temperature dependence for PCR curves
- Region for operation is much larger for lower temperature



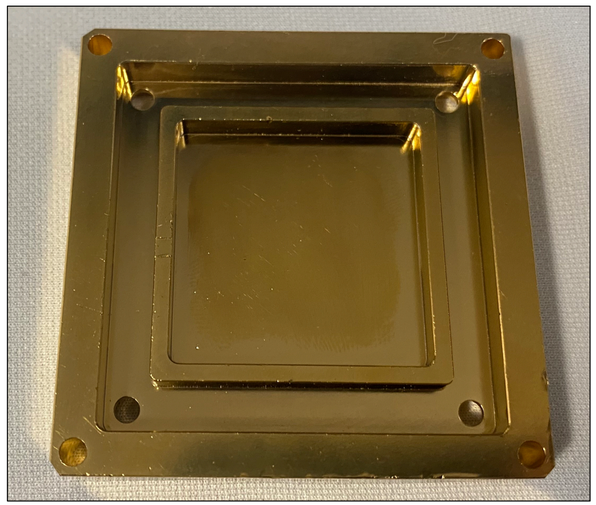
Next Steps

- Will receive new 1x1 mm, 4 pixel arrays in new dark box
  - Wider wires with higher fill factor (40%) → higher efficiency
  - New dark box → lower dark count rate



New dark box

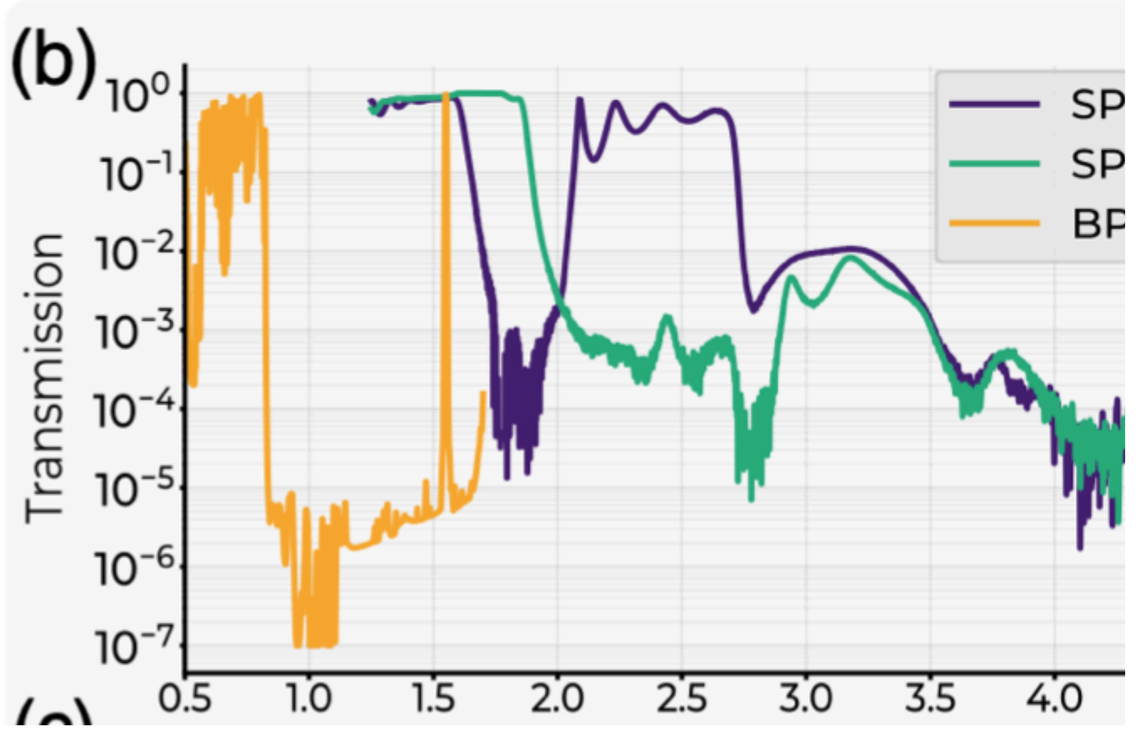
dark box lid

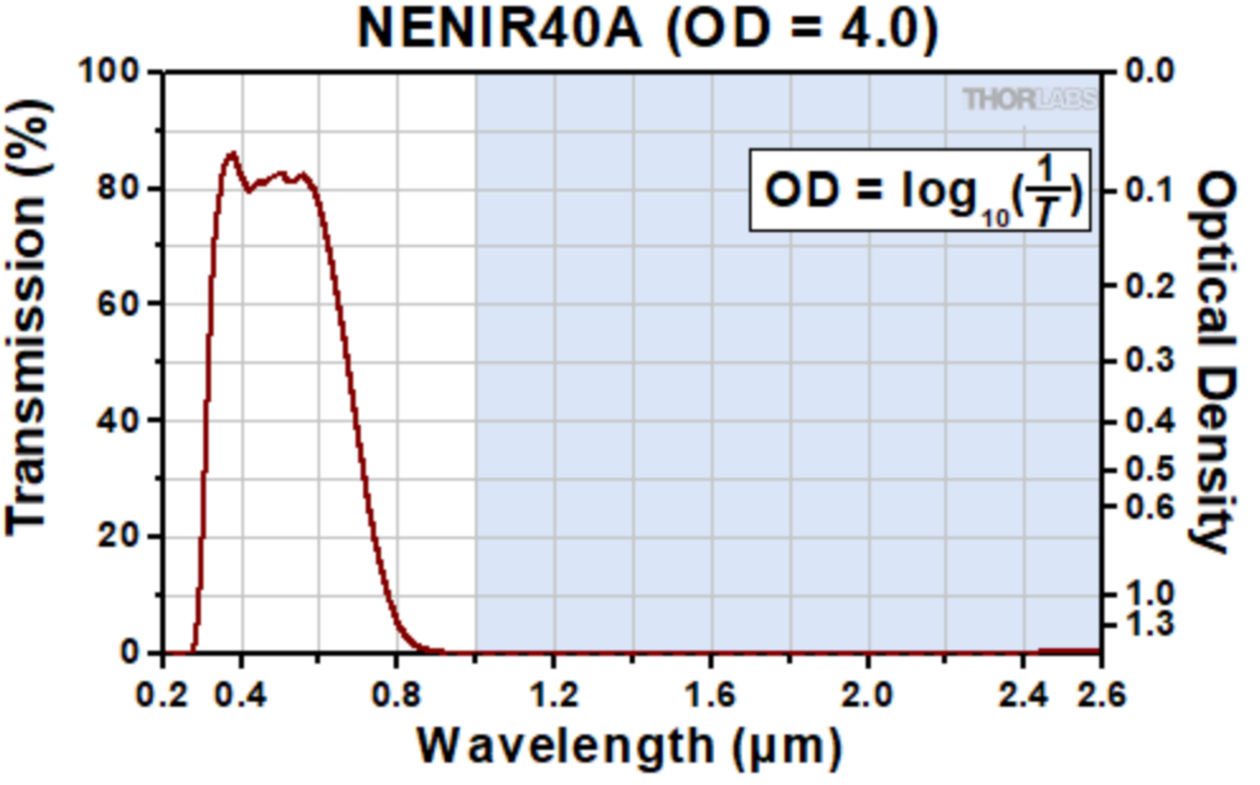


Next steps

- Working towards reading out all 4 pixels simultaneously with new RF lines
- Planning to move ADR to new IARC building to fix the water cooling problem and avoid interfering with other experiments
- Develop system to measure calibrated efficiency as function of photon wavelength and incident angle

Backup Slides

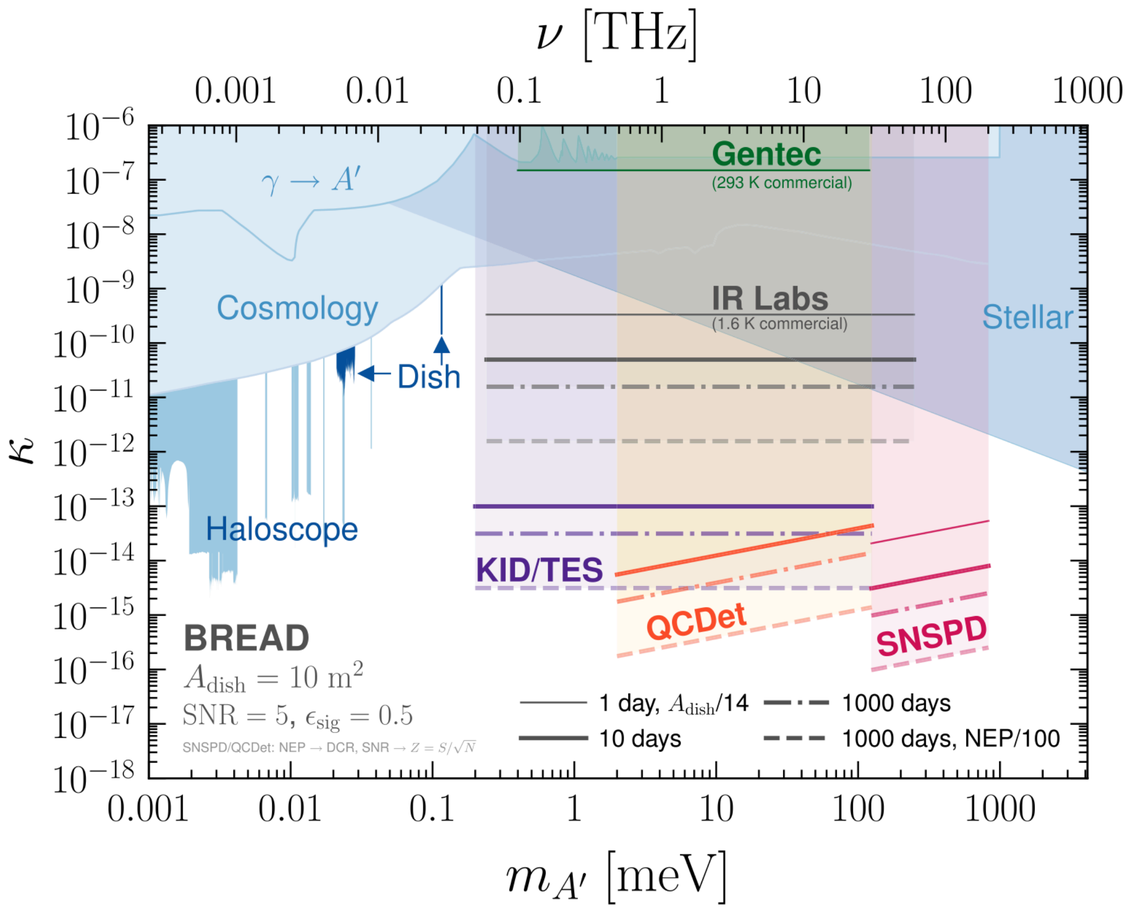

(b)
Transmission
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SP
SP
BP


NENIR40A (OD = 4.0)
THORLABS
$OD = \log_{10}(\frac{1}{T})$
Transmission (%)
Optical Density
Wavelength (μm)
100
80
60
40
20
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1.0
1.3
0.2
0.4
0.8
1.2
1.6
2.0
2.4
2.6

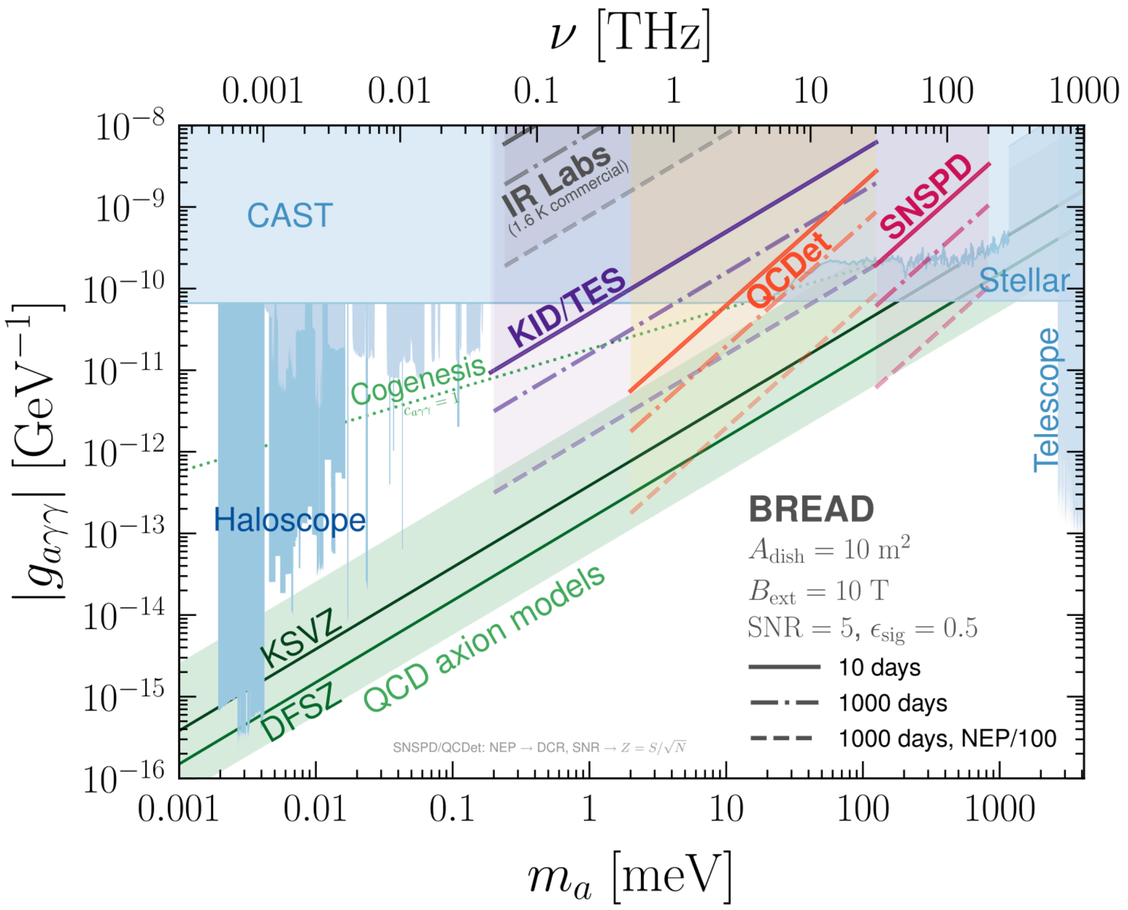
Projected Sensitivity

Phys. Rev. Lett. 128, 131801

Dark photon



Axion



- SNSPD provides unique sensitivity for 0.1-1 eV dark photons and axions due to its sensitivity for 1-10um photons

$$Z = \frac{N_{\rm signal}}{\sqrt{N_{\rm noise}}} = \frac{\epsilon_s R_{\rm DM} \Delta t}{\sqrt{\rm DCR \Delta t}}.$$

Requiring $Z = 5$ for DM reach implies the coupling sensitivity is related to the DCR by

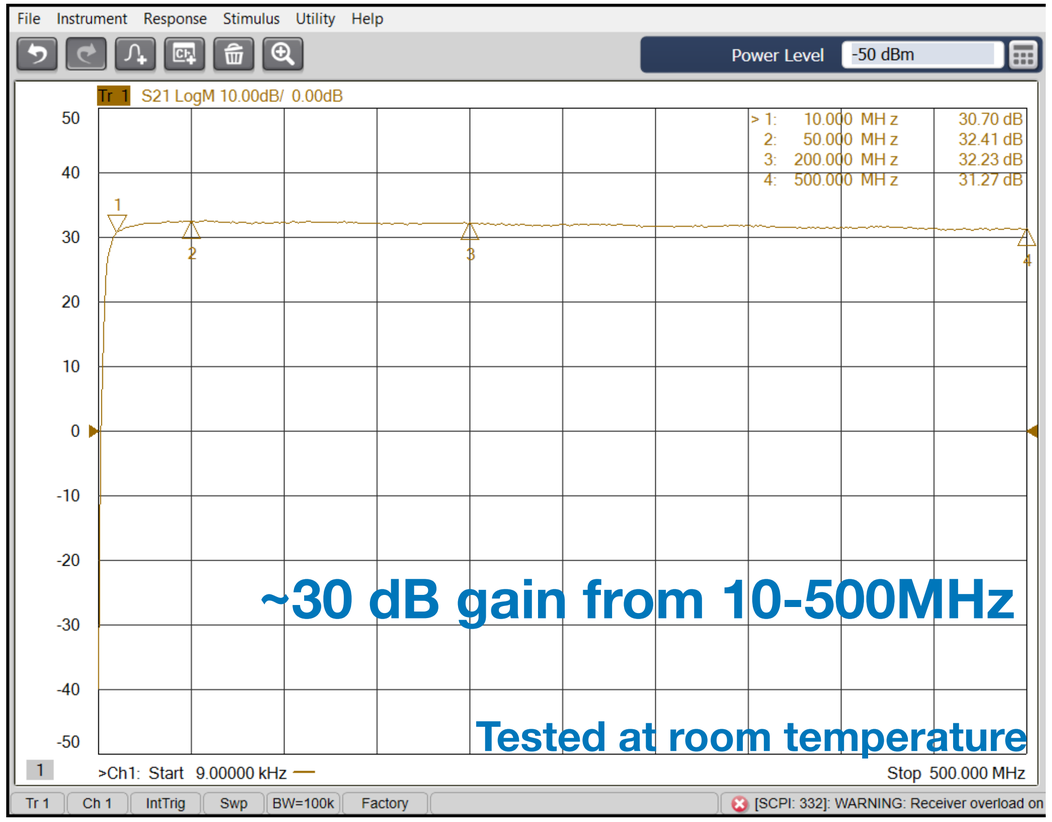
$$\left\{ \begin{array}{c} \left(\frac{g_{a\gamma\gamma}}{10^{-12}}\right)^2 \\ \left(\frac{\kappa}{10^{-15}}\right)^2 \end{array} \right\} = \left\{ \begin{array}{c} \frac{3.0}{\rm GeV^2} \left(\frac{m_a}{\rm meV}\right)^3 \left(\frac{10\,\rm T}{B_{\rm ext}}\right)^2 \\ 11.9 \frac{2/3}{\alpha_{\rm pol}^2} \frac{m_{A'}}{\rm meV} \end{array} \right\} \left(\frac{\rm hour}{\Delta t}\right)^{1/2} \times \frac{10\,\rm m^2}{A_{\rm dish}} \frac{Z}{5} \frac{0.5}{\epsilon_s} \left(\frac{\rm DCR}{10^{-2}\,\rm Hz}\right)^{1/2} \frac{0.45\,\rm GeV/cm^3}{\rho_{\rm DM}}. \quad (11)$$

In photon counting regimes, it is more convenient to consider the DM-induced rate $R_{\rm DM}$ of emitted photons given by $P_{\rm DM}/m_{\rm DM}$:

$$\left\{ \begin{array}{c} \dfrac{R_a}{0.55\,\mathrm{Hz}} \\ \dfrac{R_{A'}}{0.14\,\mathrm{Hz}} \end{array} \right\} = \left\{ \begin{array}{c} \left(\dfrac{g_{a\gamma\gamma}}{10^{-11}\,\mathrm{GeV}^{-1}}\right)^2 \left(\dfrac{\mathrm{meV}}{m_a}\right)^3 \left(\dfrac{B_{\rm ext}}{10\,\mathrm{T}}\right)^2 \\ \dfrac{\alpha_{\rm pol}^2}{2/3} \left(\dfrac{\kappa}{10^{-14}}\right)^2 \dfrac{\mathrm{meV}}{m_{A'}} \end{array} \right\} \times \frac{\rho_{\rm DM}}{0.45\,\mathrm{GeV/cm}^3} \frac{A_{\rm dish}}{10\,\mathrm{m}^2}. \tag{9}$$

Cryogenic Amplifiers

- Low noise 4-channel amplifier at 70 K
- Designed by Lautaro Narvaez
- Populated and characterized by myself at Caltech



ComboSource™ 6300 SERIES

USER'S MANUAL

LASER DIODE CONTROLLER

arroyo instruments

213 DIL LaserMount

$345
US List Price*
How to Buy

At-a-Glance

- 14-pin DIL Lasers
- 8-pin mini-DIL Lasers (electrical only)
- Zero insertion force (ZIF) connection
- Solder-less wiring
- Passive cooling

Manuals and Downloads

Click here for larger image(s)

Overview

The 213 DIL LaserMount is an excellent choice for electrical connection and passive cooling of DIL laser modules.

Mini-DIL Support

The 213 can also be used for mini-DIL lasers, although only electrical connections can be made.

Quick Laser Connections

The 213 makes connections to the laser quick with a zero insertion force socket… simply slide the laser into the socket, screw the device to the mount for passive cooling, and close the lead clamp to make electrical connection. The lead clamps are user replaceable for easy maintenance in production applications.

Accessories

Beyond the mount itself, the 213 works with our optional fiber tray, device cover, and fan base:

The 200-TRAY fiber tray bolts directly to the top of the mount and makes fiber management simple.

The 200-C cover enhances the stability of the laser by minimizing the impact of ambient air currents.

The 200-FAN fan base significantly increases the heat sink performance, from 3°C/W to 1.5°C/W.

Easy Wiring

The underside of the mount houses a simple screw terminal wiring setup, with all wires color coded, and the terminals clearly marked to

RC08APC-P01
Reflective Collimator with Patch Cord Shown Mounted to a Ø1/2" Post

Products Home / Fiber Components / Collimation / Coupling / Reflective Collimators / SMA-Connectorized Protected Silver Reflective Collimator

RC08SMA-P01 - Protected Silver Reflective Collimator, 450 nm - 20 µm, Ø8.5 mm Beam, SMA

Zoom

Complete Product Details

Part Number:	RC08SMA-P01 - Ask a technical question
Package Weight:	0.21 lbs / Each
Available:	Today
RoHS:	RoHS
Price:	$653.60
Add To Cart:	Qty : 1 Add To Cart
Release Date:	Dec 17, 2010

Drawings and Documents:

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eDrawing	
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RoHS	RoHS
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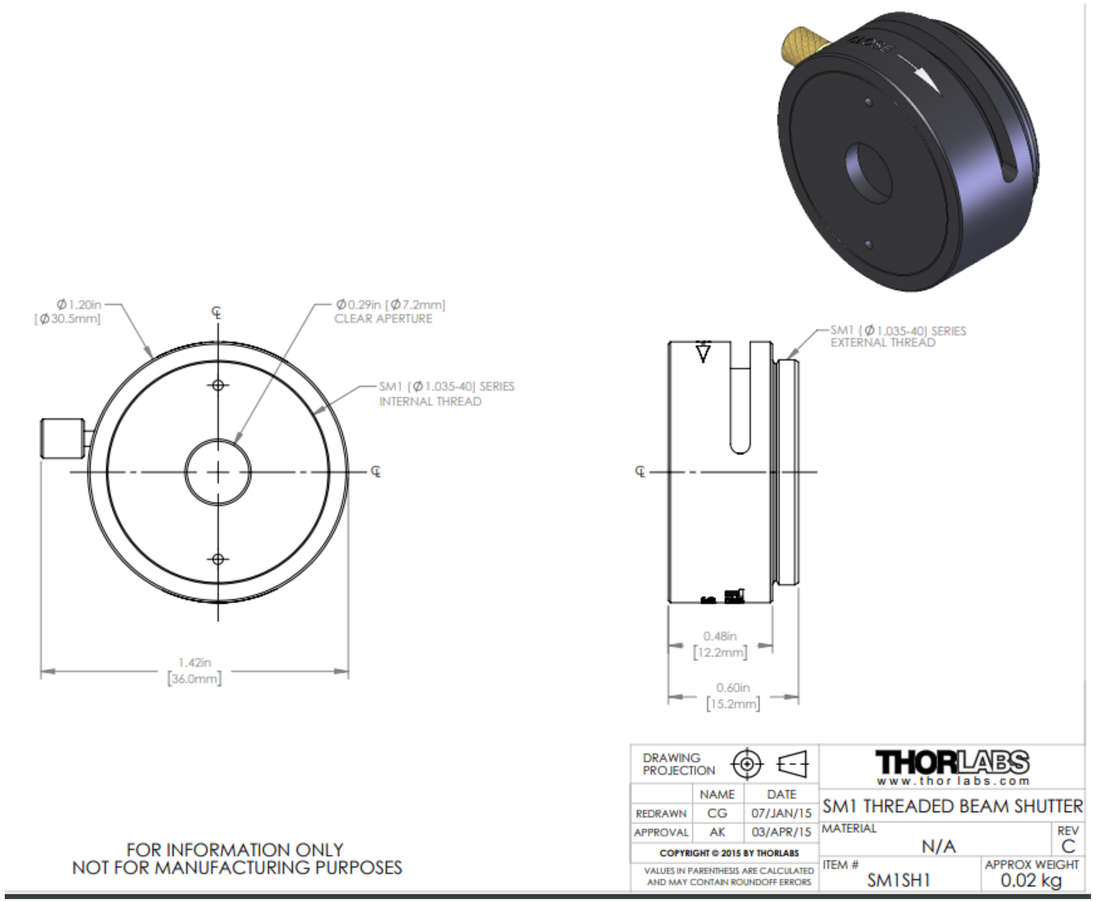
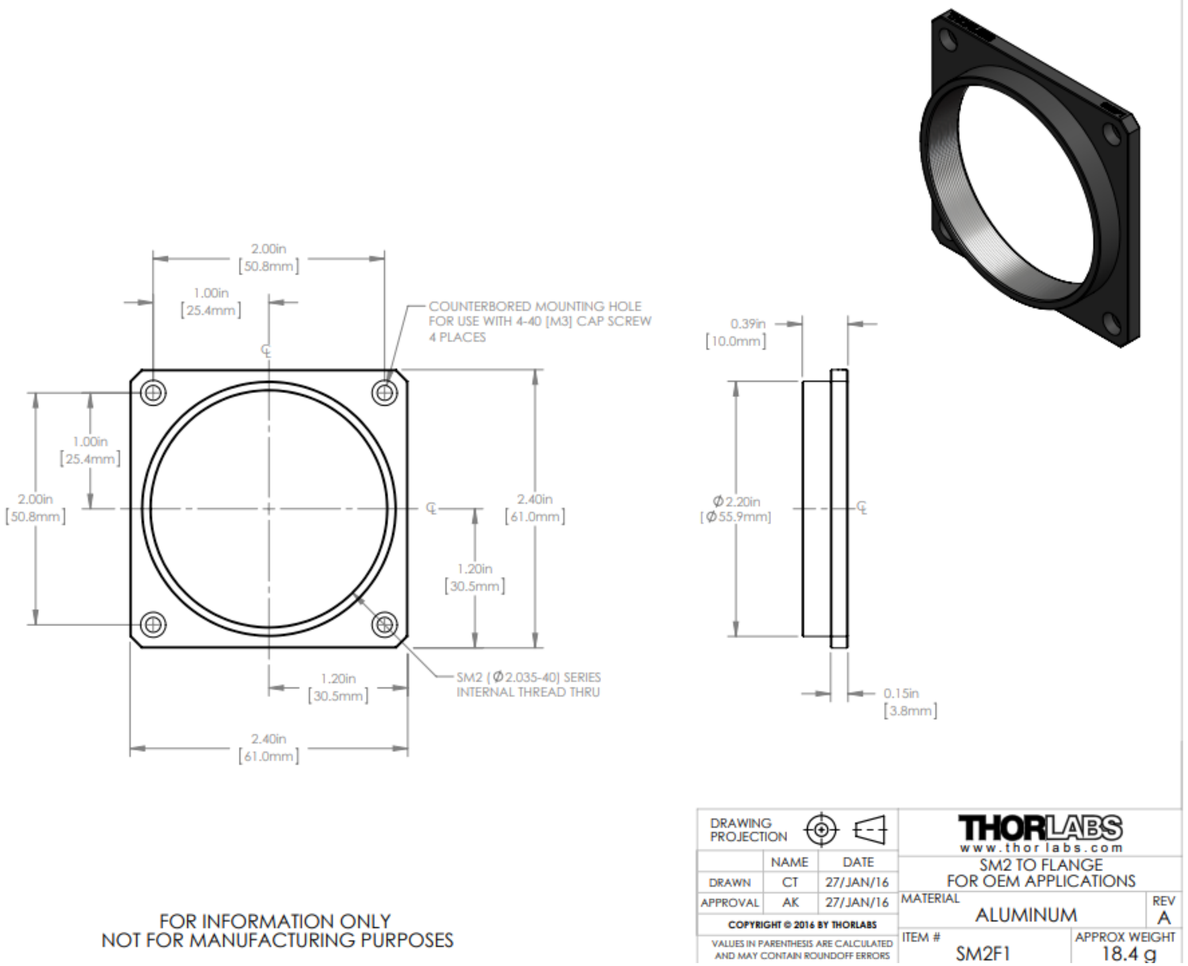
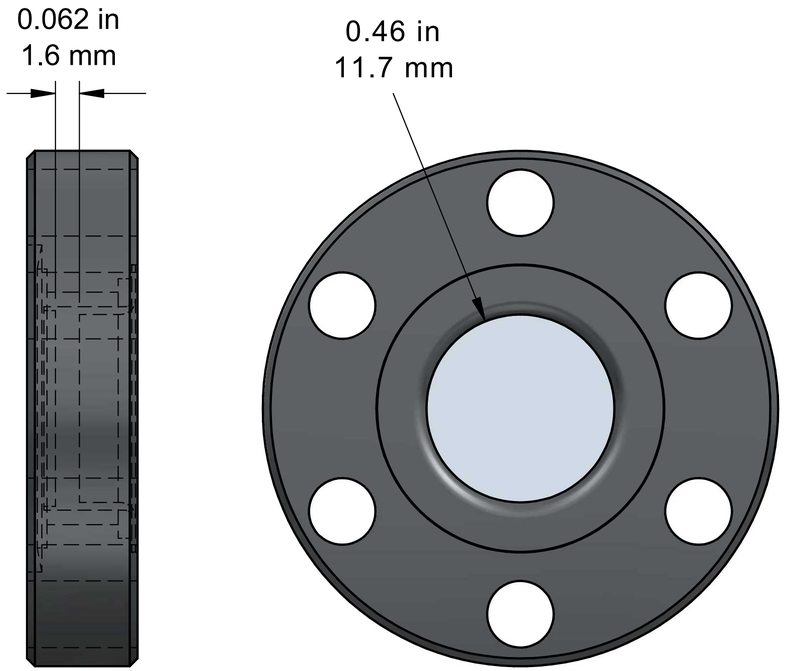
Product Feedback - Let us know what you think about our RC08SMA-P01 product. Click here to leave us your feedback.

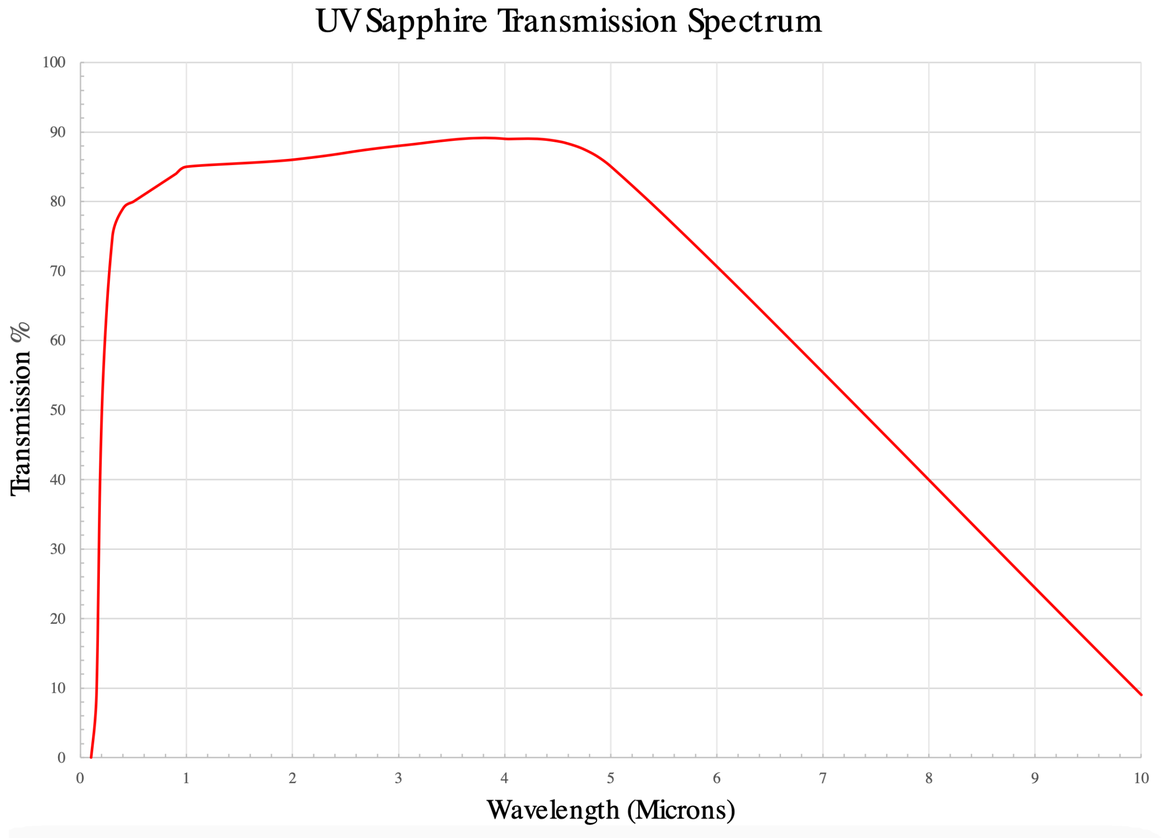
Optical shutter and mounting flange





Sapphire Window





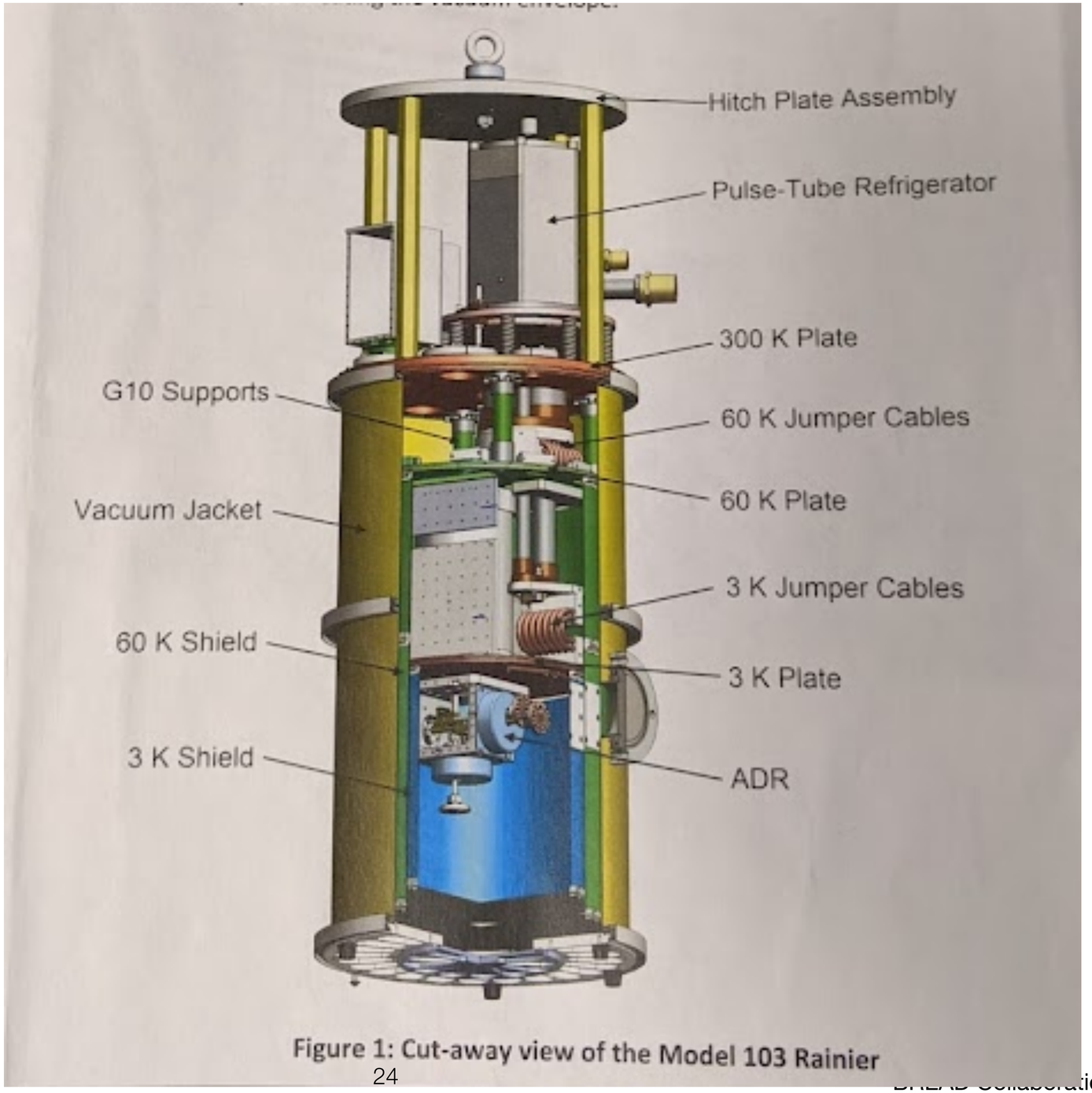


Figure 1: Cut-away view of the Model 103 Rainier

Shwabian Time Tagger

- Can set threshold for signal pulse in software
- Record counts per second
- Can record 70M tags/s
- Data transfer over USB

Calibration of Sensors in ADR with External Laser