A setup to measure HRPPD QE

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* Funded by CFNS Stony Brook University and BNL

Brookhaven National Laboratory

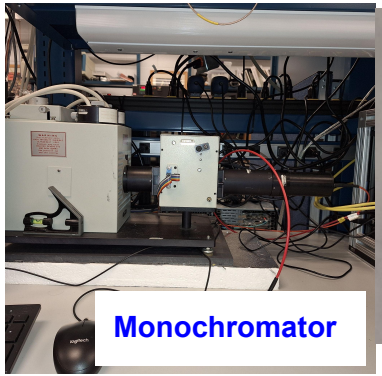
Stony Brook University

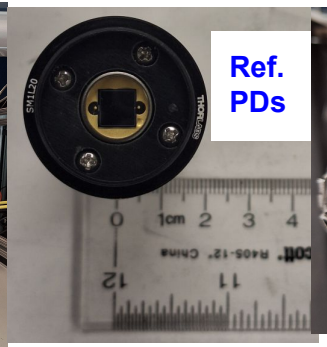
Outline

1. To build up a setup that can measure the QE of the HRPPDs.
2. To ensure measurements of meaningful quantities.
3. Perform wavelength scan and uniformity scan of the HRPPDs.

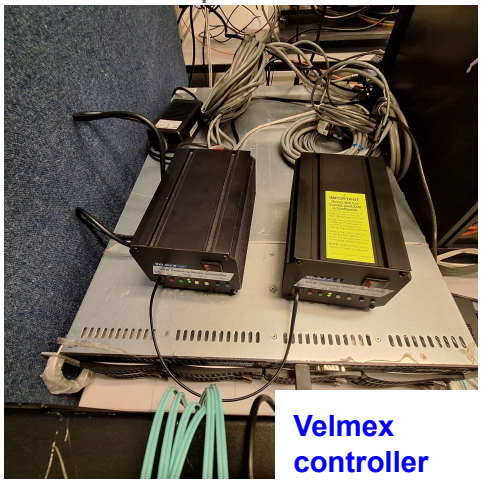
Available instrumentations

1. Oriel monochromator with a Xenon lamp.
2. Keithley 6487 picoammeters X 2
3. Velmex motor setup moveable in X,Y,Z.
4. Photodiodes S1226-8BQ (Hamamatsu) X 2 and **NewPort Calibrated Photodiode!**
5. Custom made set-up to provide power to HRPPD phtocathode using Keithely
6. MSE Sapphire window as a beam splitter
7. UV grade fused silica lens for focalization.
8. Amscope 3.1 MP camera, 3.2 um pixel

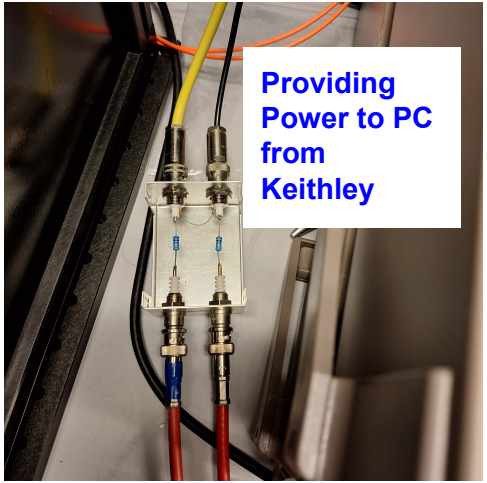

Monochromator

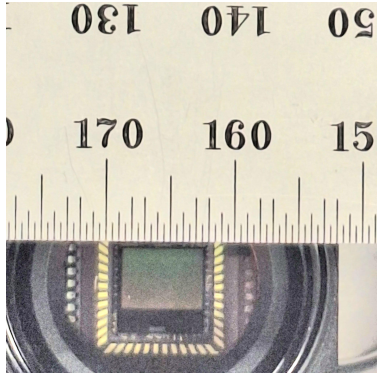

Ref. PDs

Newport


Velmex controller

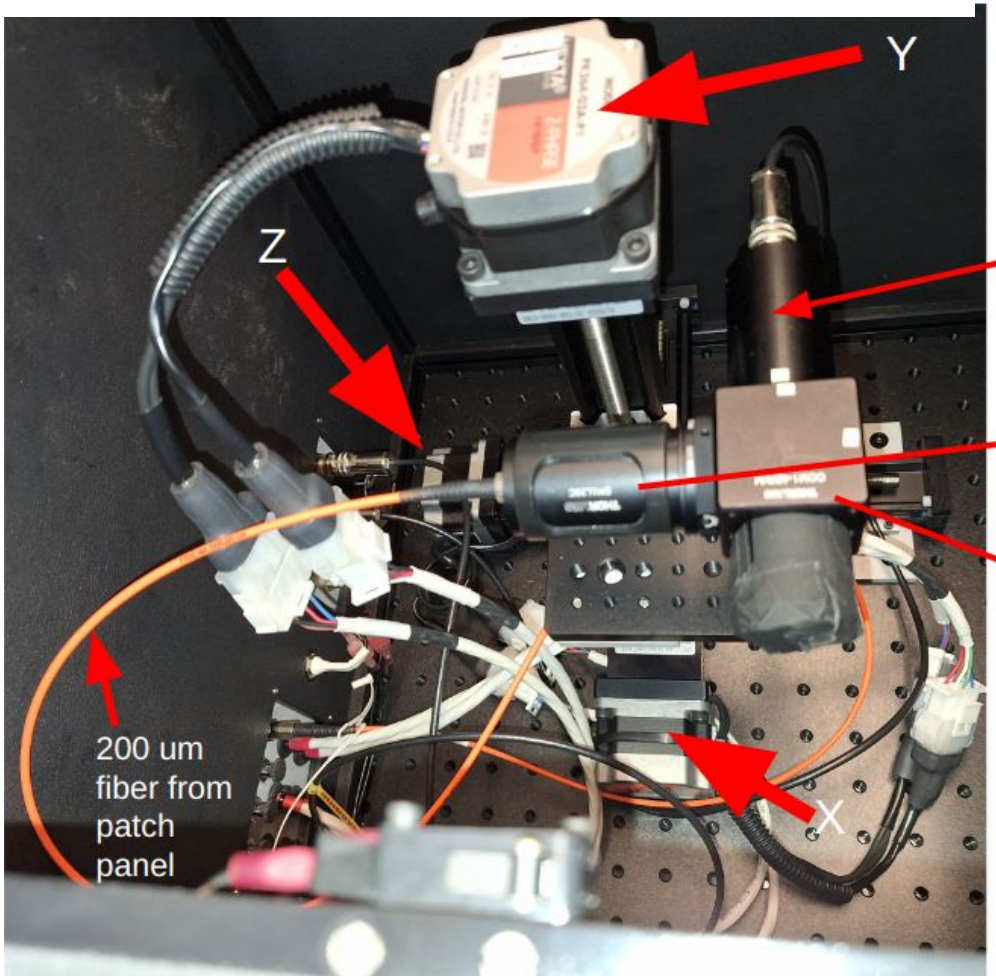
Keithley 6487

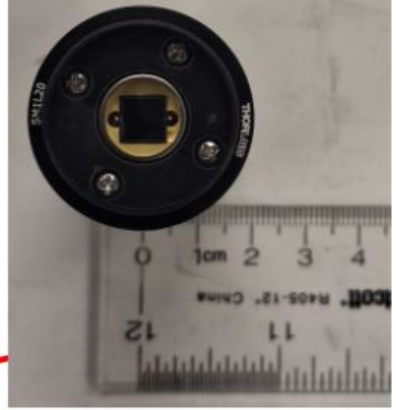

Providing Power to PC from Keithley



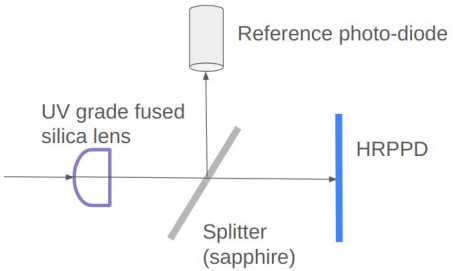
Amscope camera

Our scheme (labeled set-up)



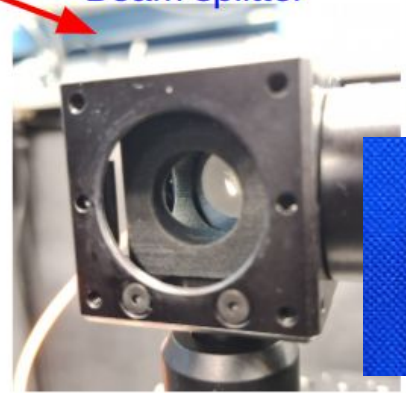


Ref photodiode

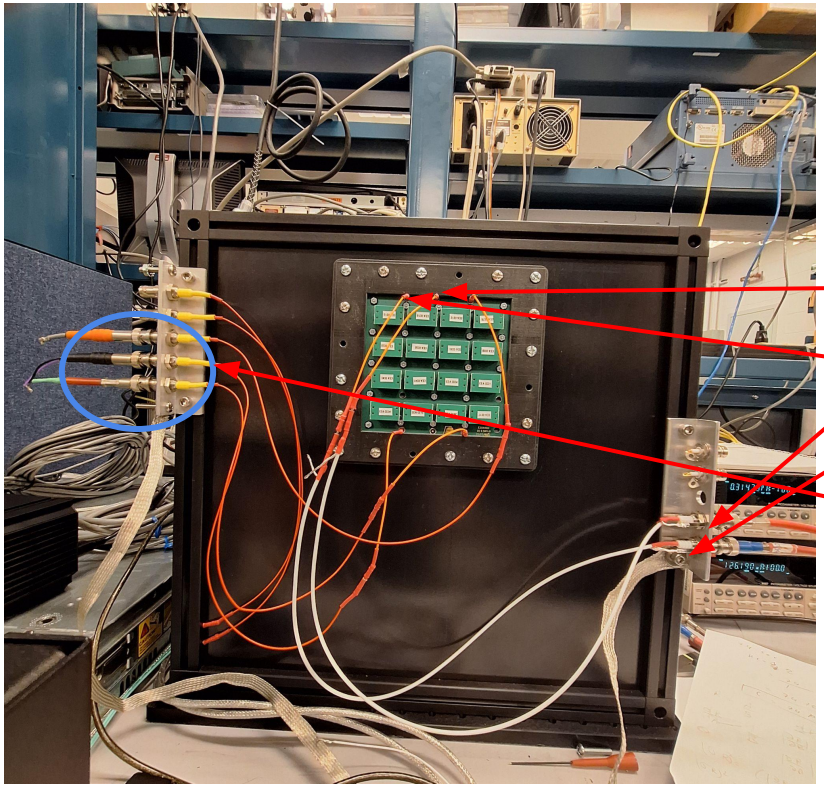


Focalizing lens

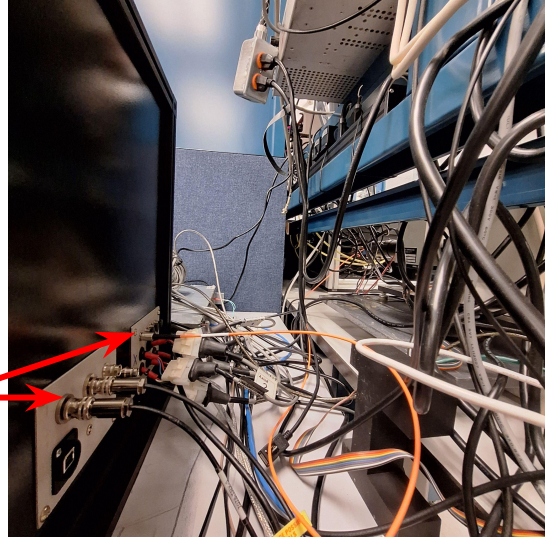
Beam splitter



Dark-box and circuitry



Backward Patch-panels (Keithley, Velmex, Fiber)

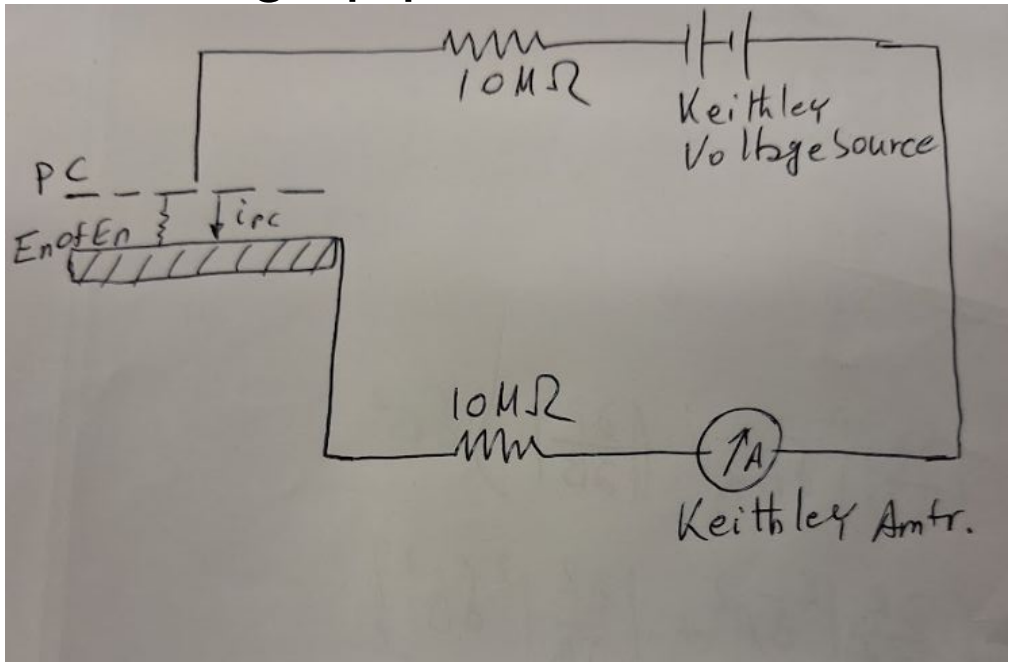


Voltage to PC

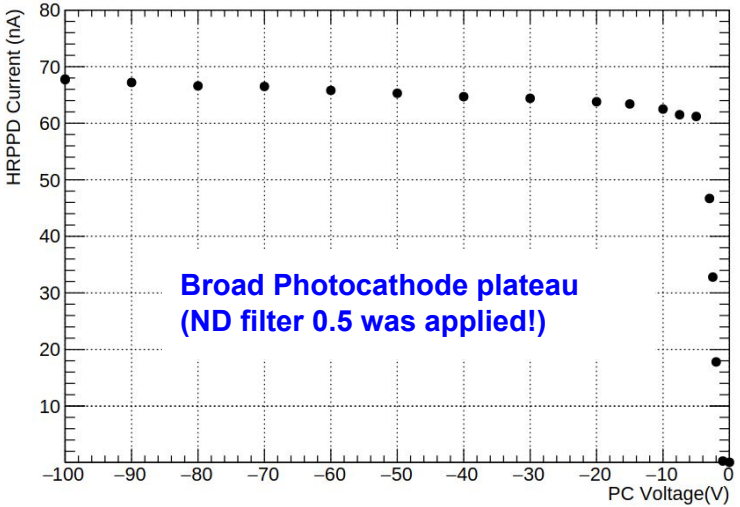
To entry of entry

Other electrodes grounded

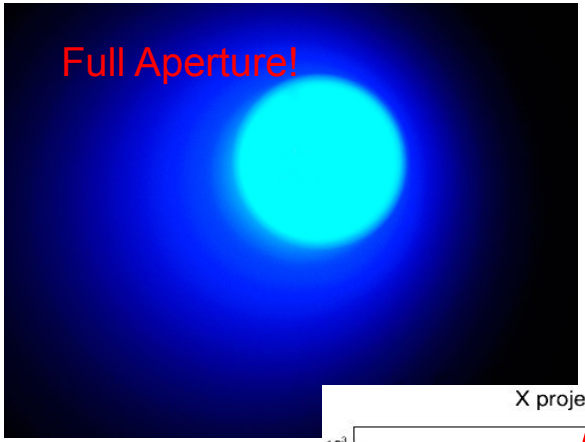
Powering up photocathode

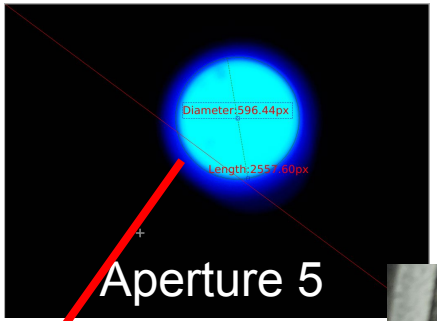


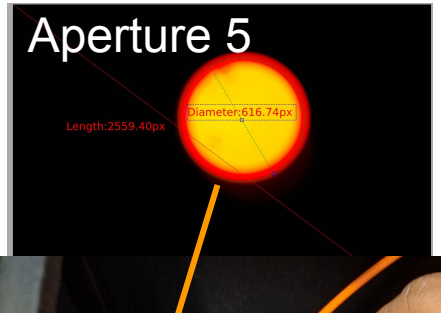
- The photocathode voltage has been provided by the Keithley voltage source.
- The circuit has been tested with a known resistance.
- Drift scan has been made to monitor photo-current as a function of applied voltage to PC. Broad plateau.
- Currently - 100V has been applied to the PC (after a drift scan).

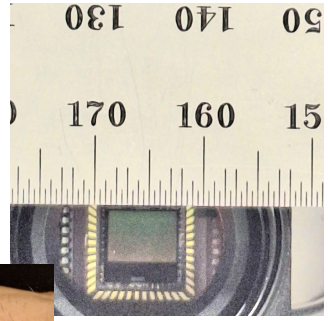


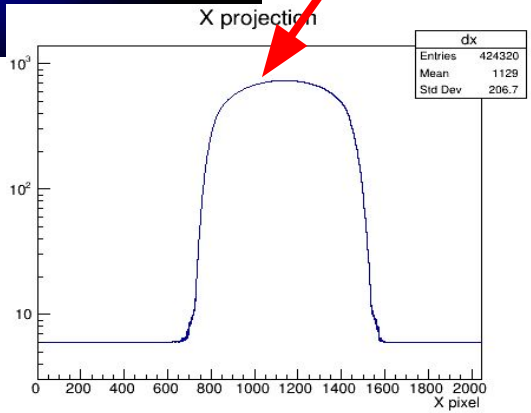
Beam spot and scanning step size

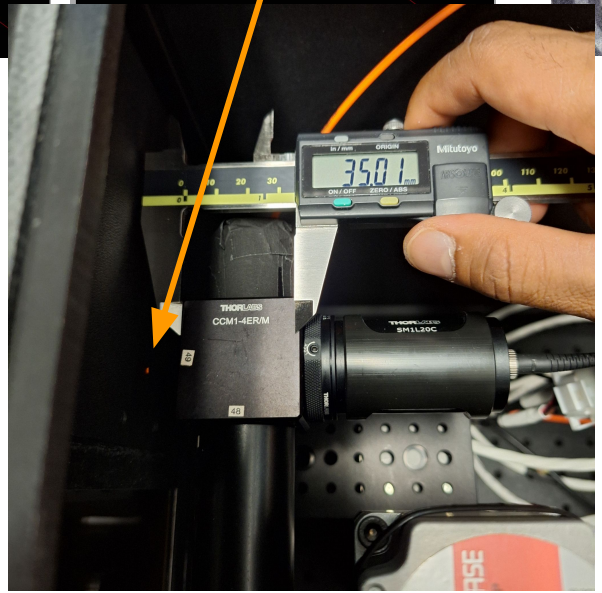












Diameter ~550-600 px → 1.7 to 1.8 mm spot

Scanning in step of 1.5 mm (grid of 80X80) HRPPD+2 steps of dead area

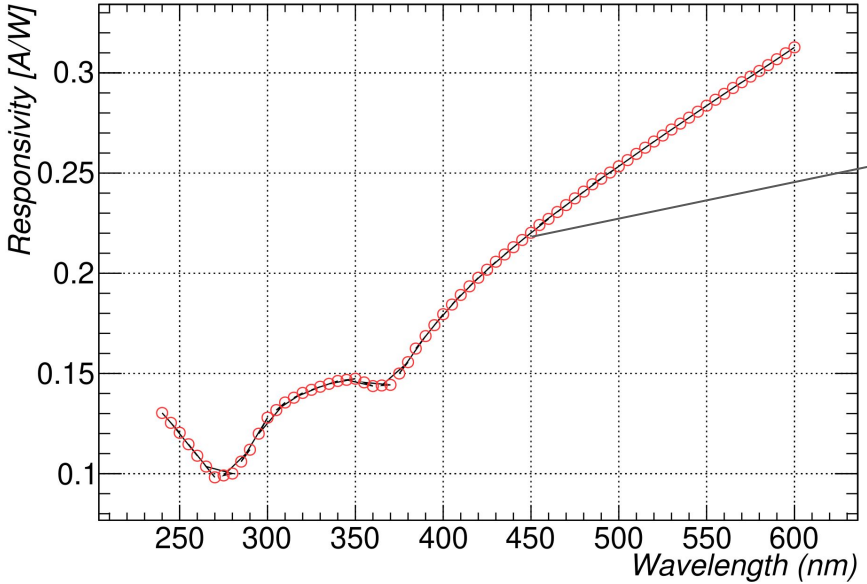
Calibrated Newport QE

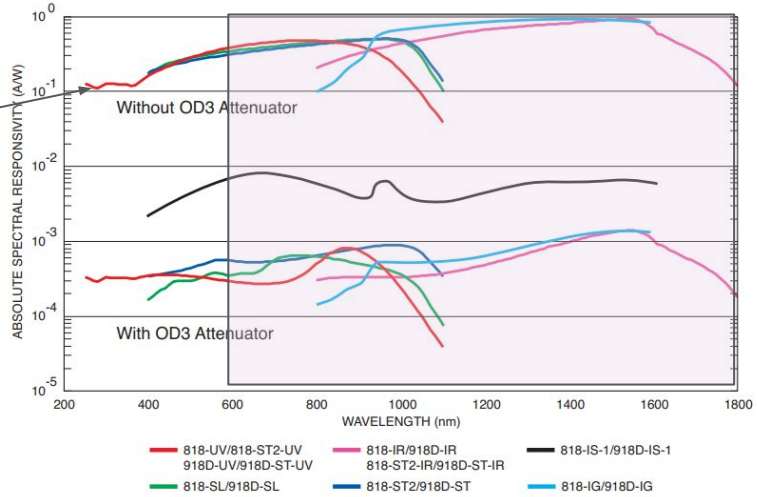
Newport calibrated photodiode 818-UV/DB has been chosen for purchase.

Advantage:

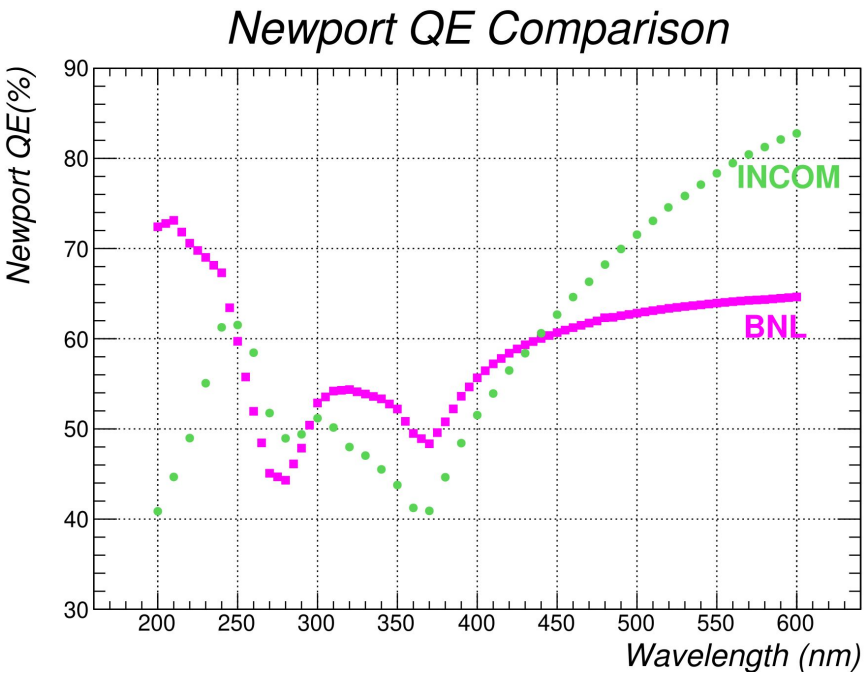
1) **Calibrated with ~1.5% uncertainty in our working range.**
2) **Similar device as of INCOM.**

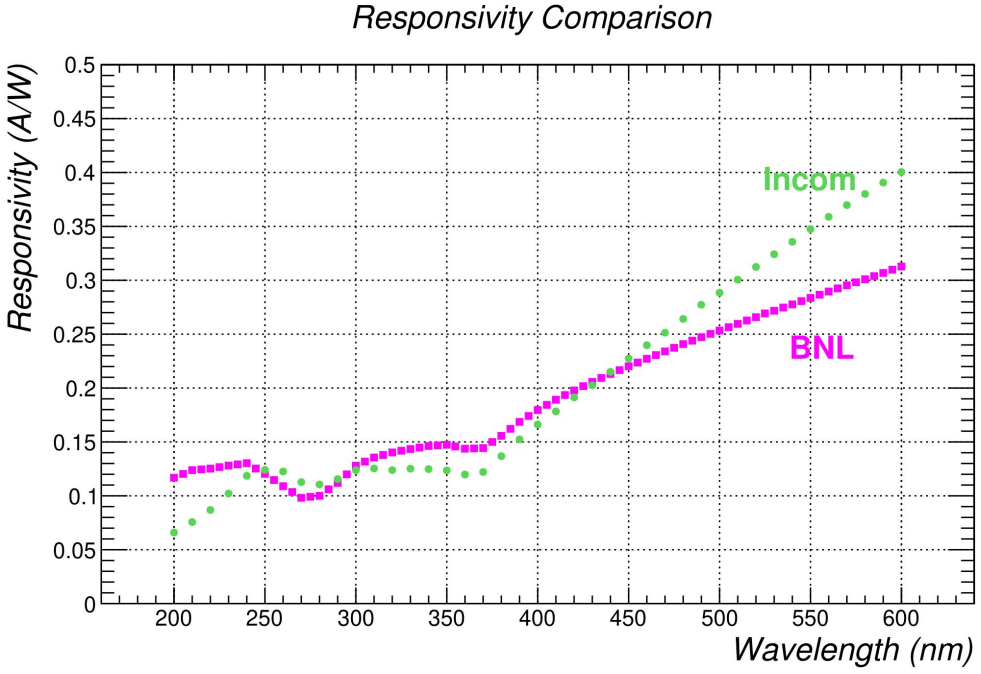
Calibrated Responsivity (A/W)





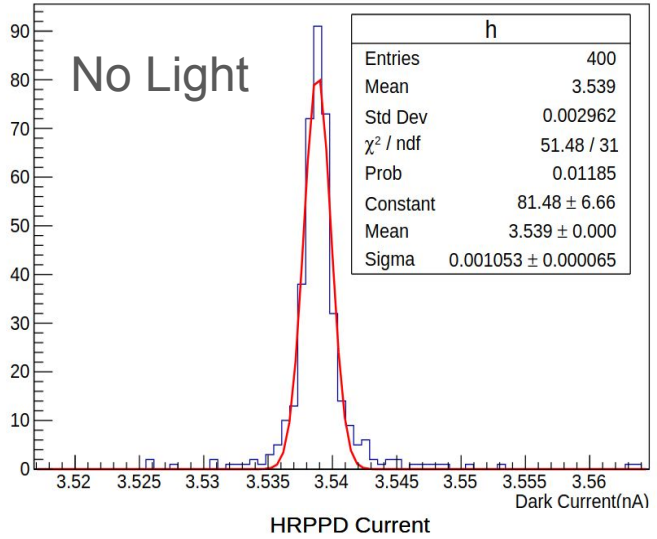
Comparison with Incom calibrated photodiode



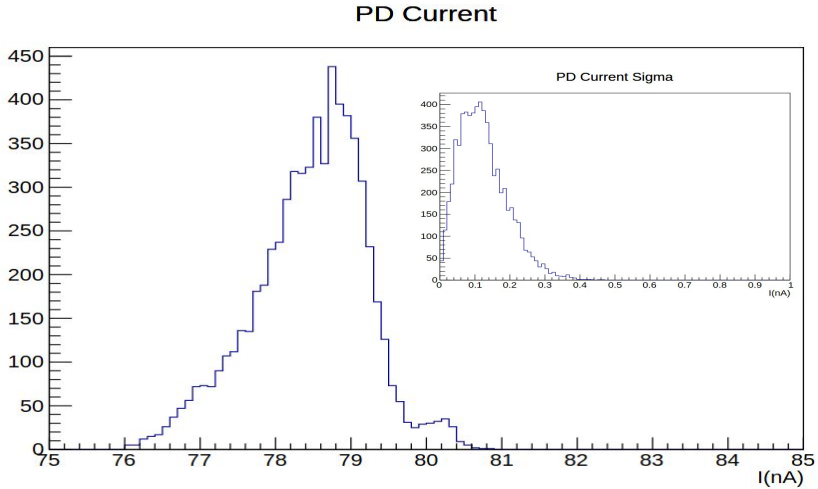


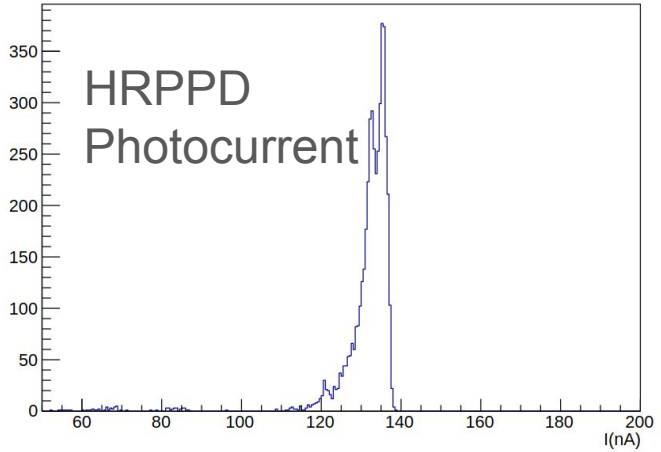
Dark Currents and photocurrents

- It is known that LAPPD dark current and photocurrent are of similar values.
- In case of HRPPD the dark current is significantly smaller. Example: 3.5 nA of dark current measured after 30 mins of powering up. Photocurrent was 120-140 nA (@ 450 nm).
- For the photodiode the dark current is close to zero (order of some tenths of pA)



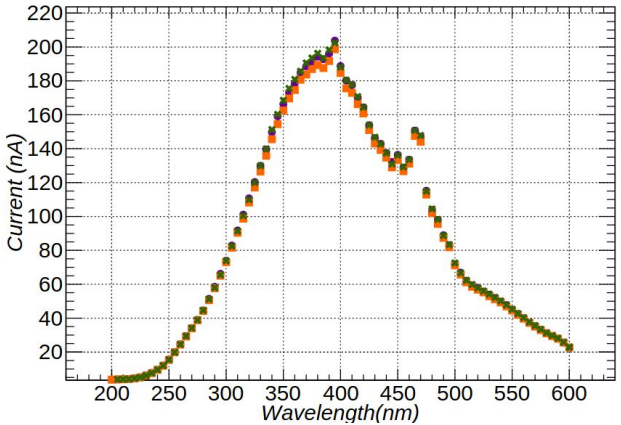
HRPPD Current



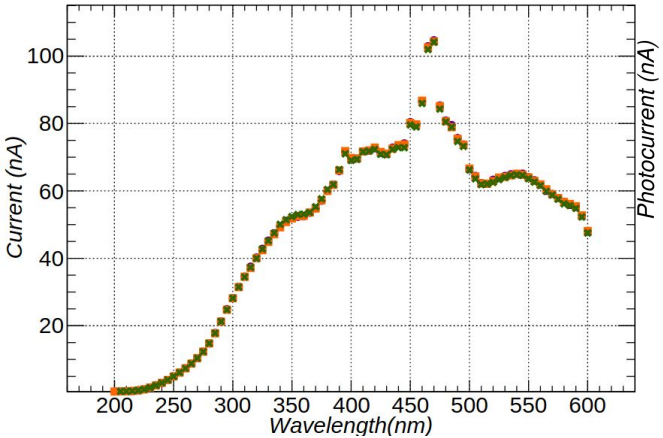


Scanning as a function of Wavelength

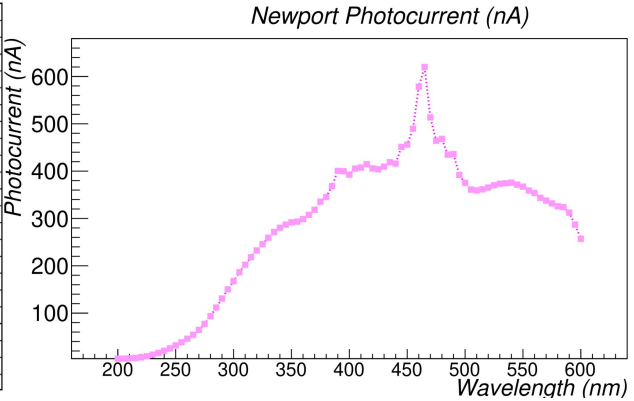
- Test has been made to check dependency with photocathode voltage.
- Final scan has been made with 5 nm steps at the centre of the quadrants and at the tile centre.
- Monochromator does not provide any light below 225 nm.
- Xenon characteristic peak at 475 nm can be identified.



HRPPD

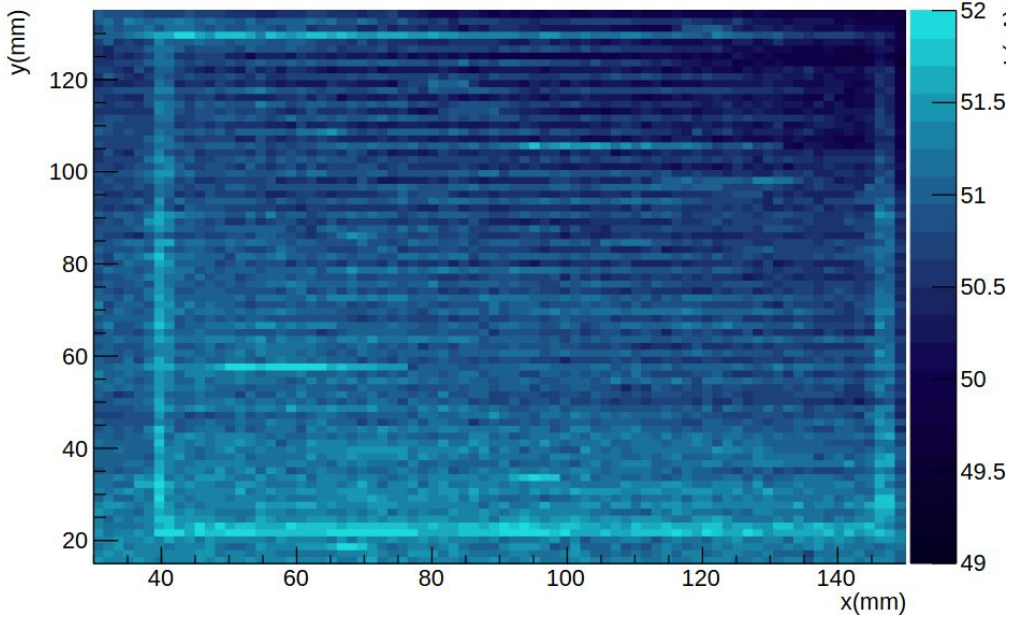


Ref. Photodiode

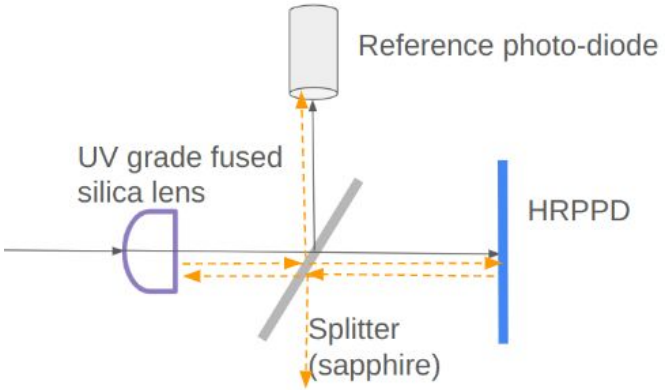


Newport Photodiode

Photodiode current (Examples of two wavelengths)

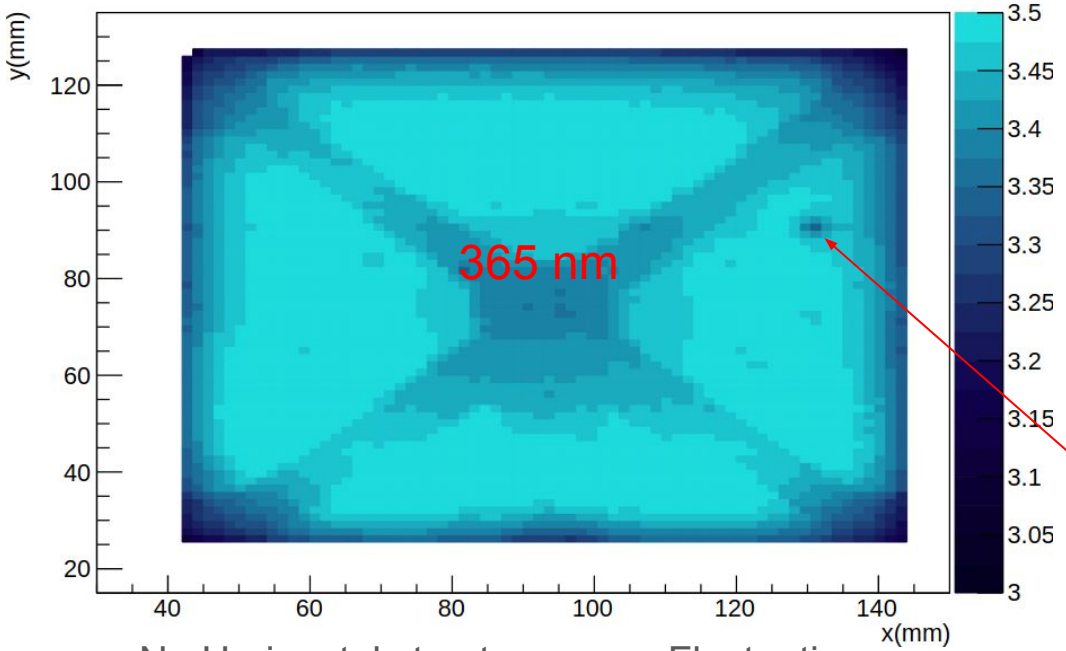


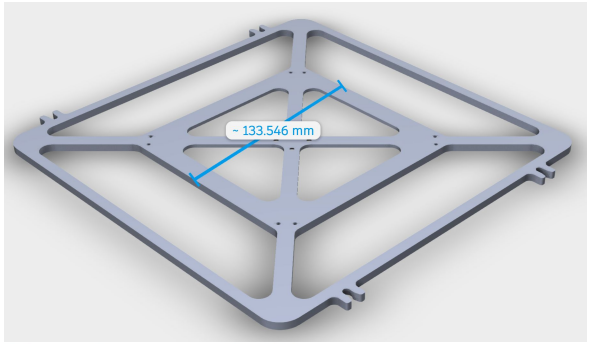
Light fluctuation structure seen along scanning direction! Image of the HRPPD border.

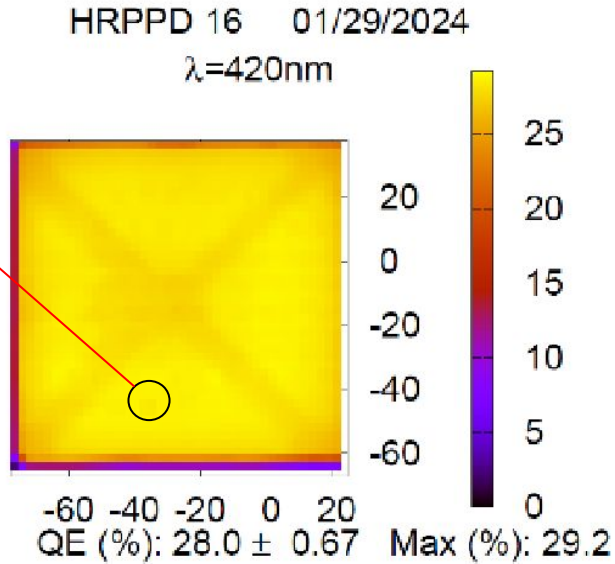


- We have verified it is indeed a reflection mechanism by placing a mirror.
- Limited only around the border. Active area is not affected.

Uniformity in current ratio

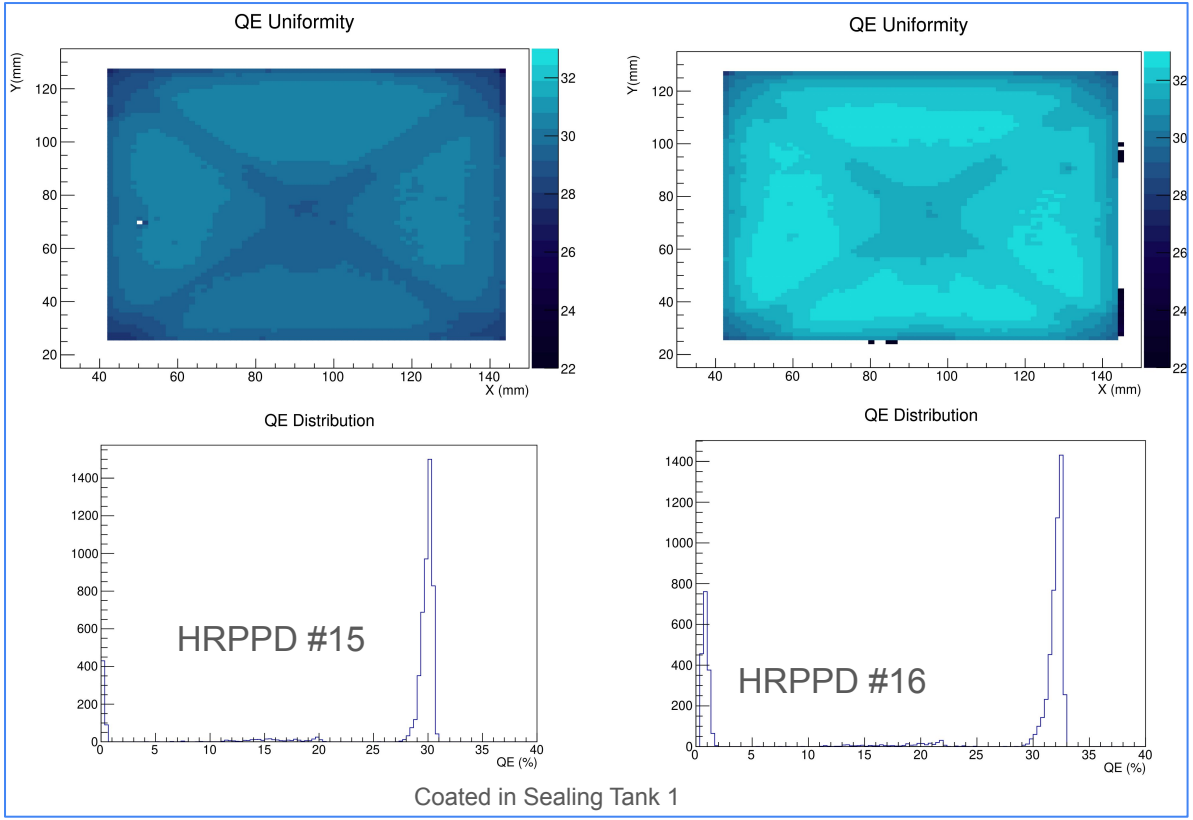




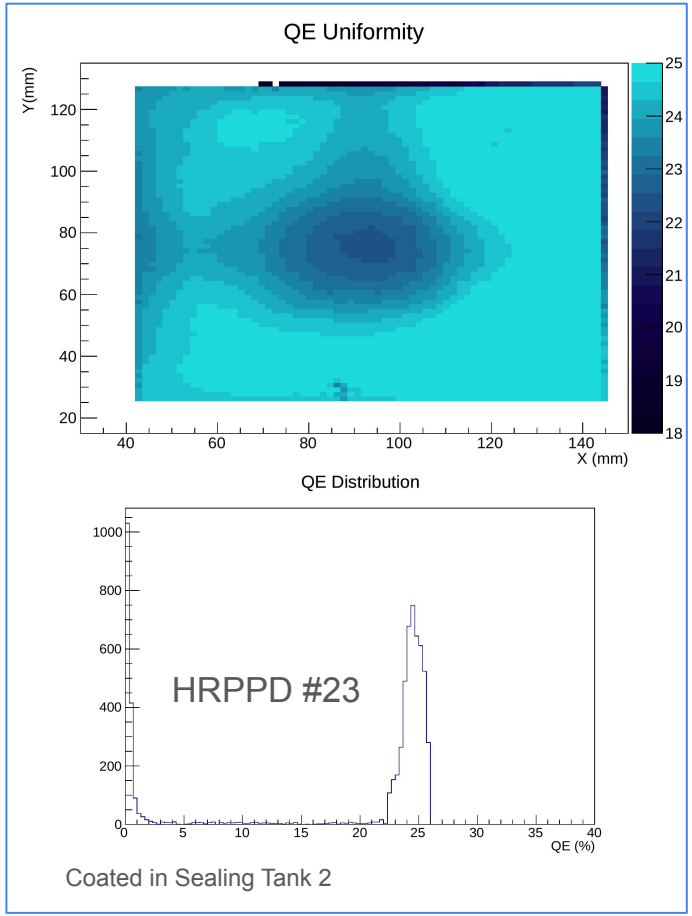


- No Horizontal structure seen. Fluctuations cancel out!
- Other observed structures are also seen in INCOM reference manual.
- Our Orientation is rotated by 90^{O}

HRPPD QE Surface scan (@365 nm)



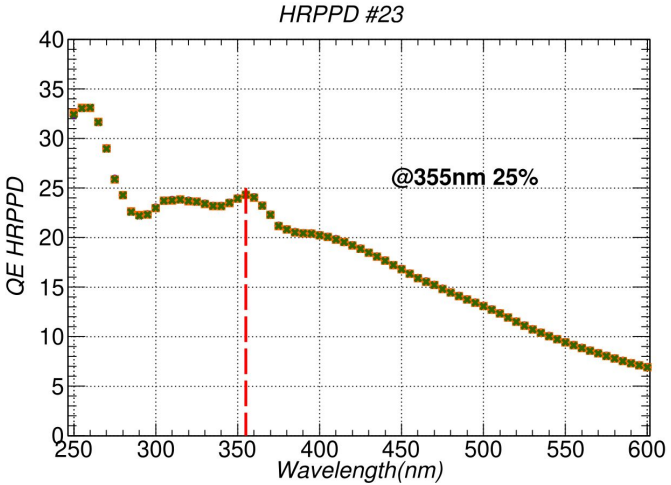
Coated in Sealing Tank 1

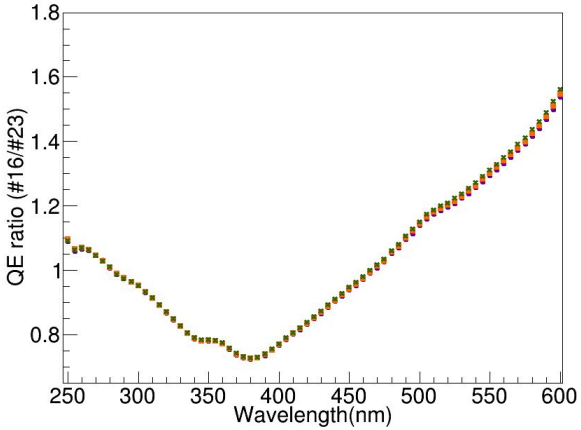


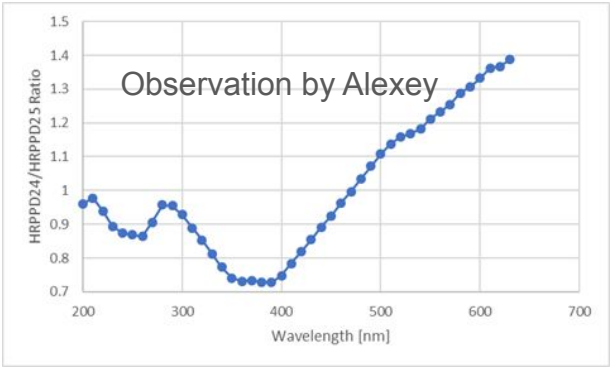
Coated in Sealing Tank 2

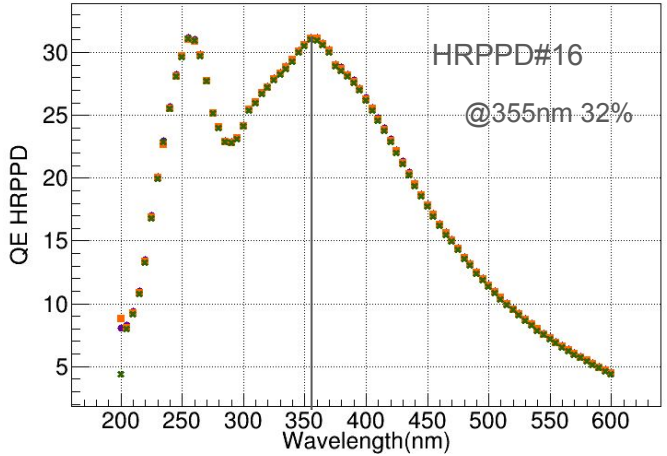
- Our observed QE (mean vals) are similar to the reports. #15 #16 #23 (30%, 32%, 25%) compared to (33%,34%,27%). However, we have systematically 2% lower observed values for Absolute QE.
- The central values are quoted with +- 1.7%.

QE of HRPPDs versus Lambda



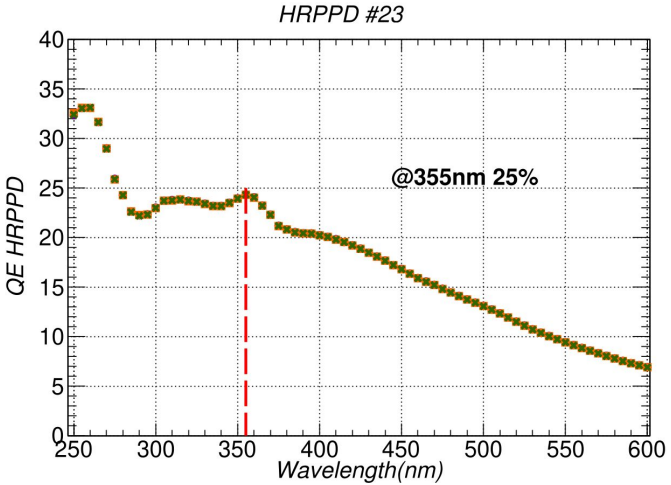


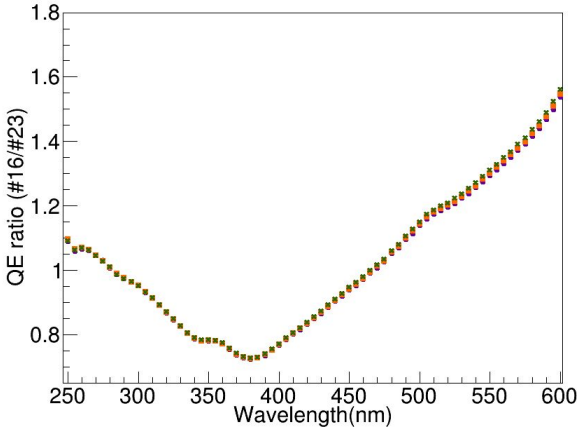


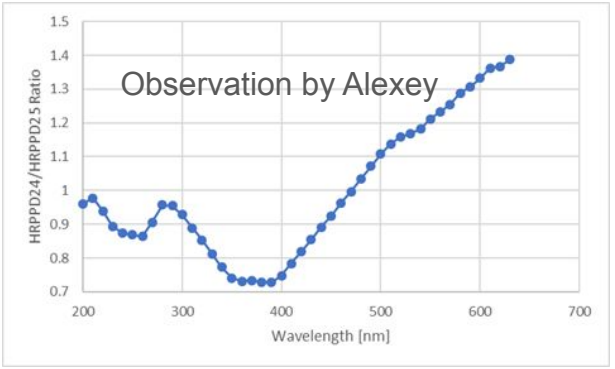


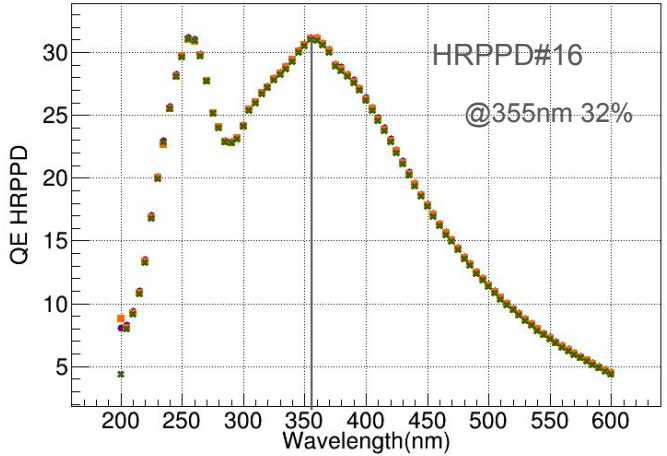
- Sealing Tank #1 and #2 have different temperature control set-up.
- Although he has not measured the same two HRPPDs we see here, different HRPPDs coated in the ST#1 and ST#2 shows similar behavior. We have also seen same pattern in HRPPD #15 (coated in ST#1)
- *"The ST1 temperature control system is now being overhauled to provide a smoother temperature control. All the thermocouples in the ST1 had exposed wires that could sometimes result in a faulty reading in the temperature controller and thus over/under heating in some areas of the system. I ordered new shielded thermocouples to replace the original ones. That hopefully would improve overall temperature control and would provide higher QE photocathodes."*

QE of HRPPDs versus Lambda









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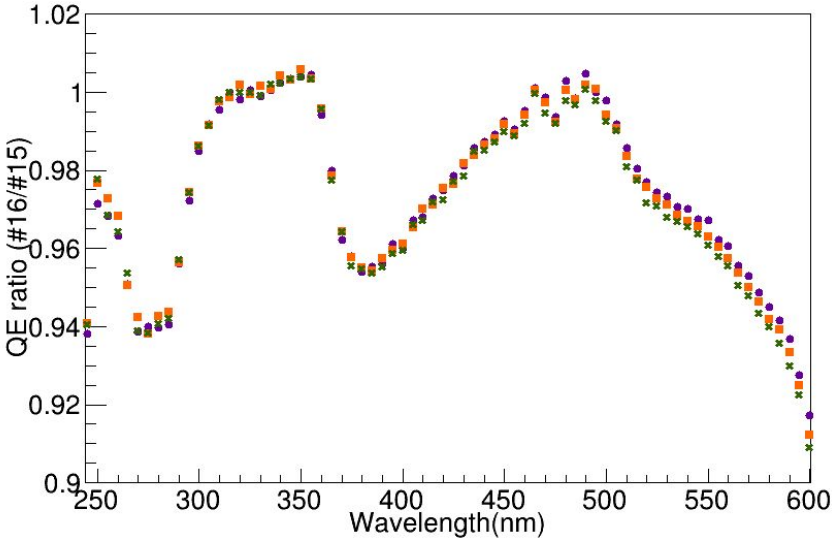
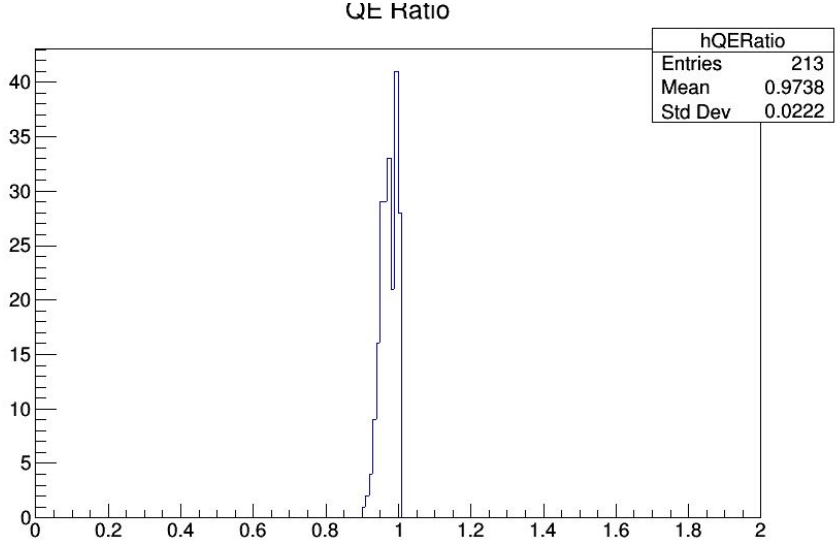
HRPPD coated in same Tank





Residual fluctuations have been seen ~5% level.

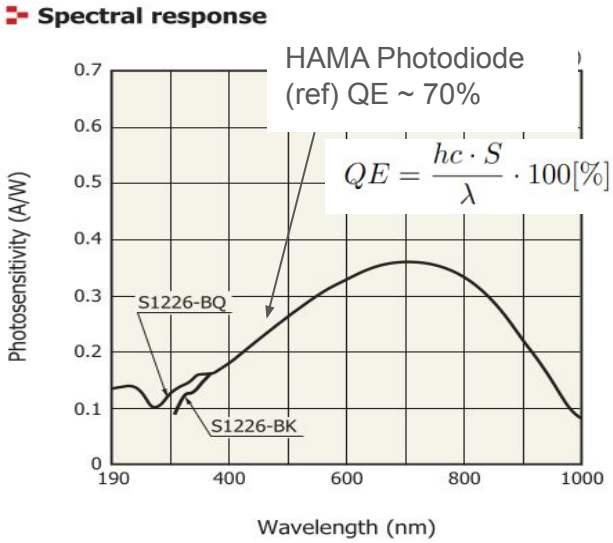
Summary

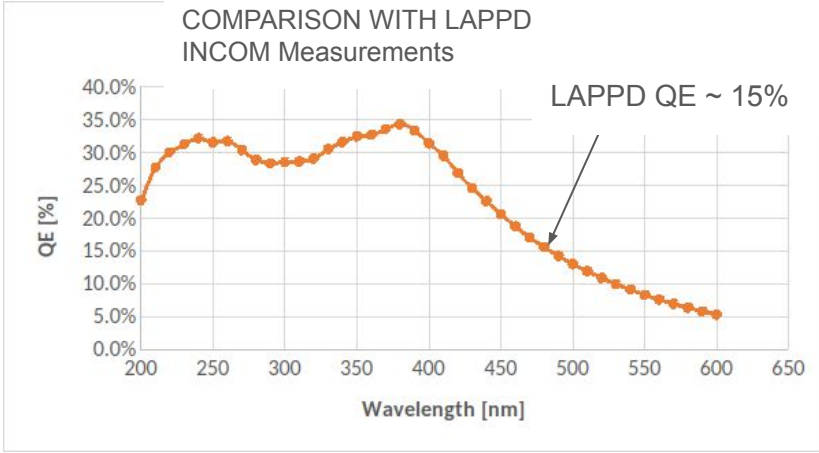
1. The Newport calibrated Photodiode has arrived and absolute QE has been measured.
2. At 365 nm we observed ~30% QE for HRPPDS that have been coated in ST#1. Their QE uniformity structures are similar. Different uniformity shape is observed in HRPPD #23 that was coated in ST#2. It also has lower QE ~20% @365 nm. Similar behavior has been observed by Alexey and different temperature control set-up is possibly causing such dependencies.
3. For HRPPDs coated in same ST, there is residual fluctuations of about 5%! Also some wavelength dependencies are found.
4. Overall, we have a working setup that can perform a fixed lambda position scan in about 3h.

Backups

Verification of observed HRPPD Currents

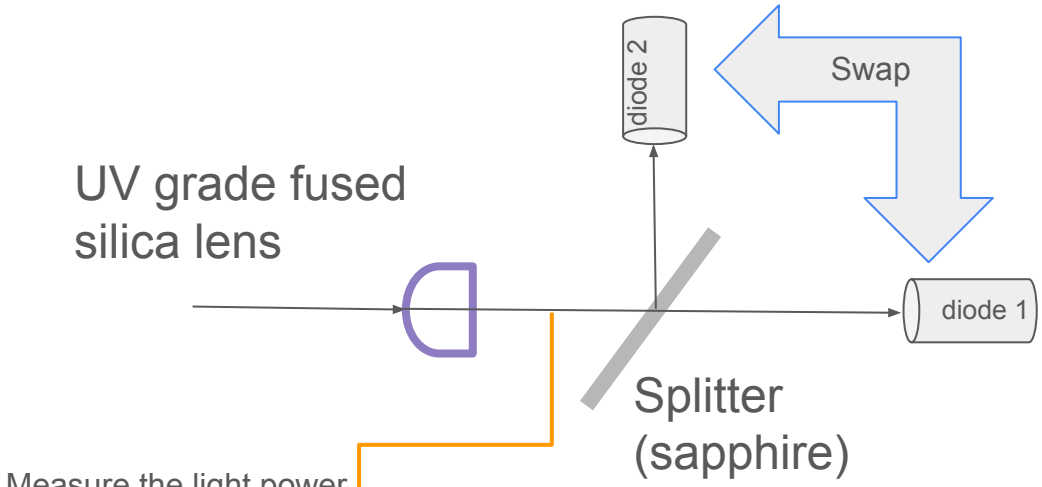
- **First order compatibility of current values with LAPPD reference plot at 475 nm (Measured by Alexy):**
- With 0.5 ND filter we had seen ~67 nA currents at 475 nm. The photodiode current was ~156 nA (only 15% of light due to splitter).
- If HRPPD had had same QE of photodiode, it should have monitored (156/0.15)*0.85*0.3 (due to ND 0.5) ~ 270 nA. Almost factor 4 less current.
- The average photosensitivity of the **photodiode** around 475 is **0.25A/W**~QE (diode) about **70%**. So HRPPD QE should be around **17%!**
  Matches **within ~10% Alexey's (ICNOM) QE measurement of one LAPPD (~15%)!**



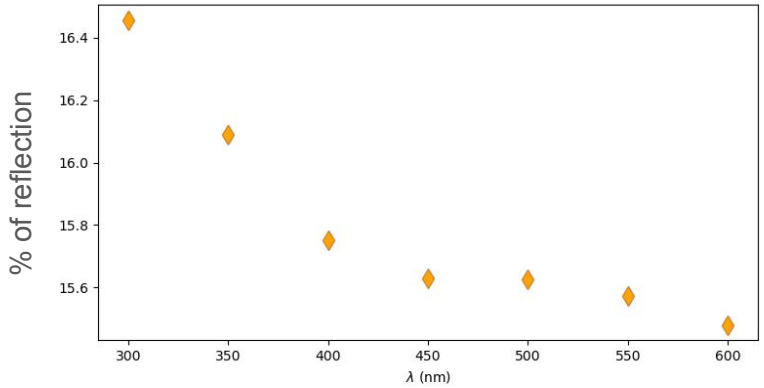


We are seeing photocurrents and they are meaningful !!

Our original plan for calibrated QE



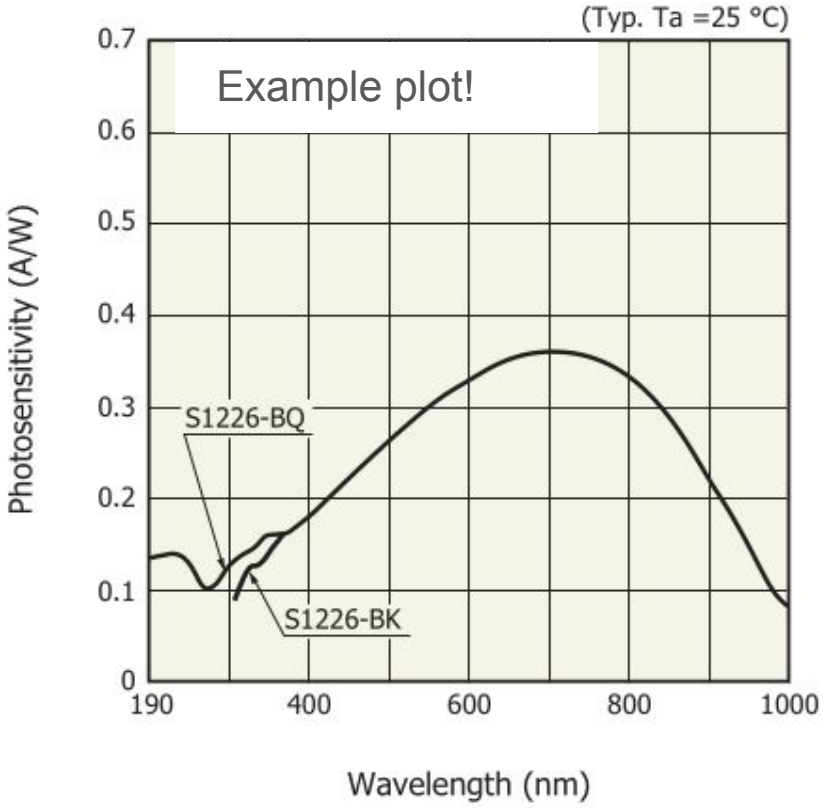
$$N1(\lambda) \cdot R(\lambda) \cdot \eta_2(\lambda) = I_2(\lambda)$$
$$N1(\lambda) \cdot T(\lambda) \cdot \eta_1(\lambda) = I_1(\lambda)$$
$$N1(\lambda)^S \cdot R(\lambda) \cdot \eta_1(\lambda) = I_1^S(\lambda)$$
$$N1(\lambda)^S \cdot T(\lambda) \cdot \eta_2(\lambda) = I_2^S(\lambda)$$
$$\frac{N1(\lambda) \cdot R(\lambda) \cdot \eta_2(\lambda)}{N1(\lambda) \cdot T(\lambda) \cdot \eta_1(\lambda)} \cdot \frac{N1(\lambda)^S \cdot R(\lambda) \cdot \eta_1(\lambda)}{N1(\lambda)^S \cdot T(\lambda) \cdot \eta_2(\lambda)} = \frac{I_2}{I_1} \cdot \frac{I_1^s}{I_2^s} = f$$
$$(\frac{R(\lambda)}{T(\lambda)})^2 = f$$
$$R(\lambda) = \frac{\sqrt{f}}{\sqrt{f}+1}$$



Calibrate our photodiodes and use one of the two for the QE estimation.

Photosensitivity and Quantum efficiency

Spectral response



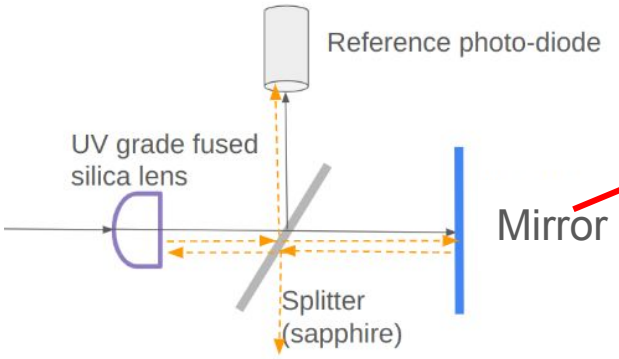
$$S = \frac{[A]}{[W]} = \frac{Photocurrent}{Power} = \frac{QE \cdot N_{ph}/s}{h\nu \cdot N_{ph}/s} = \frac{QE}{h\nu}$$

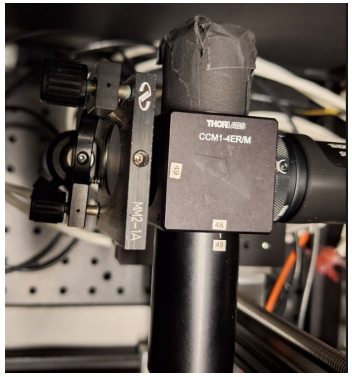
$$QE = \frac{hc \cdot S}{\lambda}$$

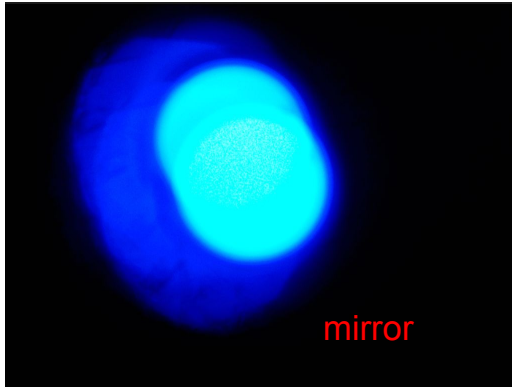
$$QE = \frac{hc \cdot S}{\lambda} \cdot 100[\%]$$

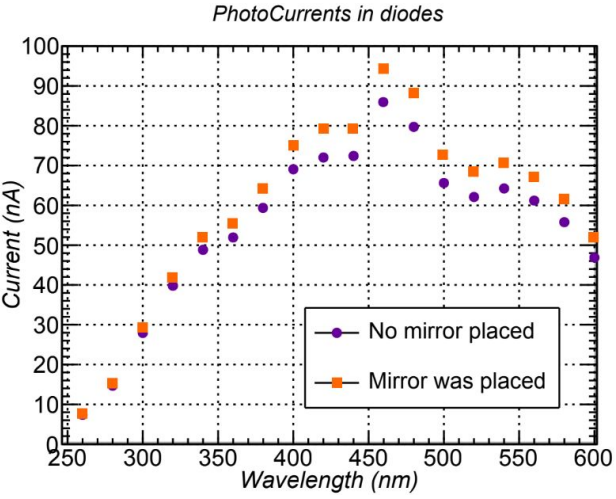
- Given well known responsivity, one can measure any unknown QE curve.
- Photon rate will be monitored w.r.t a reference photodiode whose QE is not required.

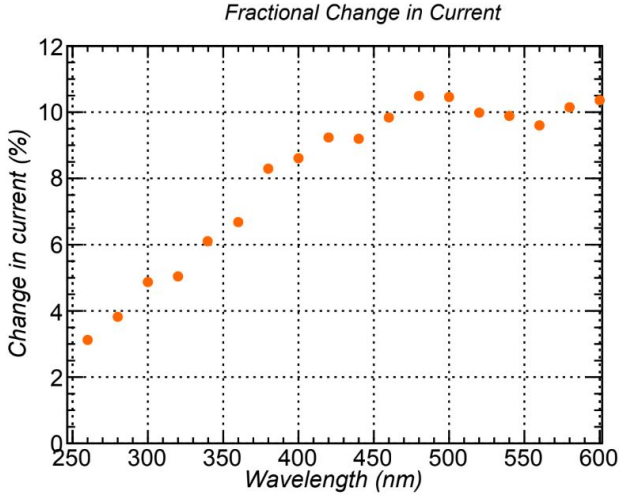
Image of HRPPD metallic border?





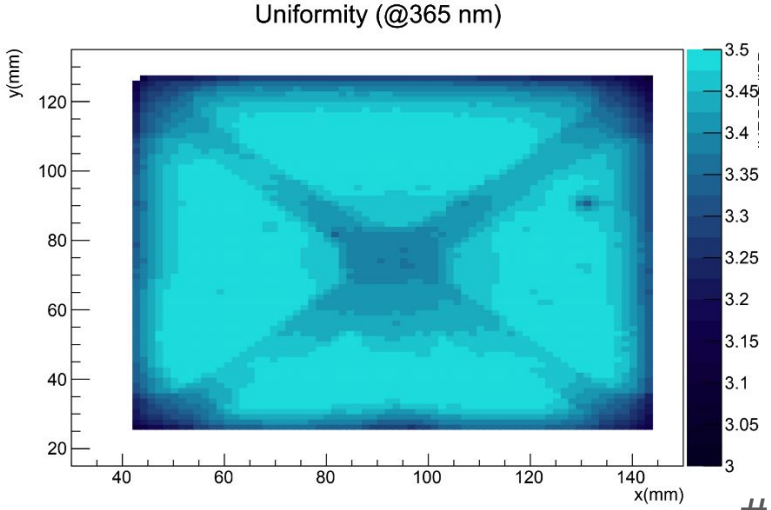




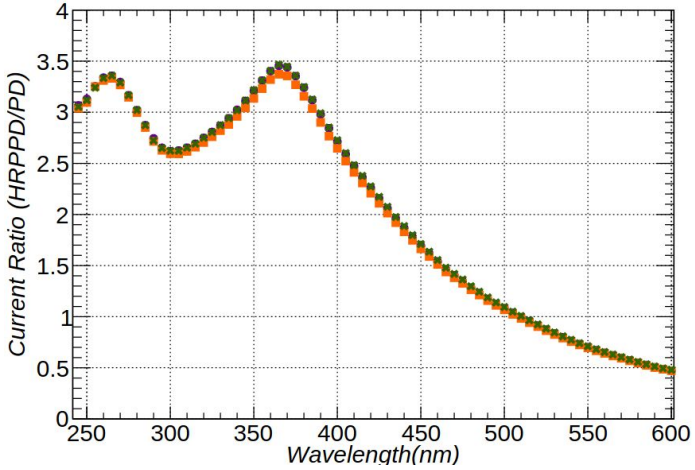


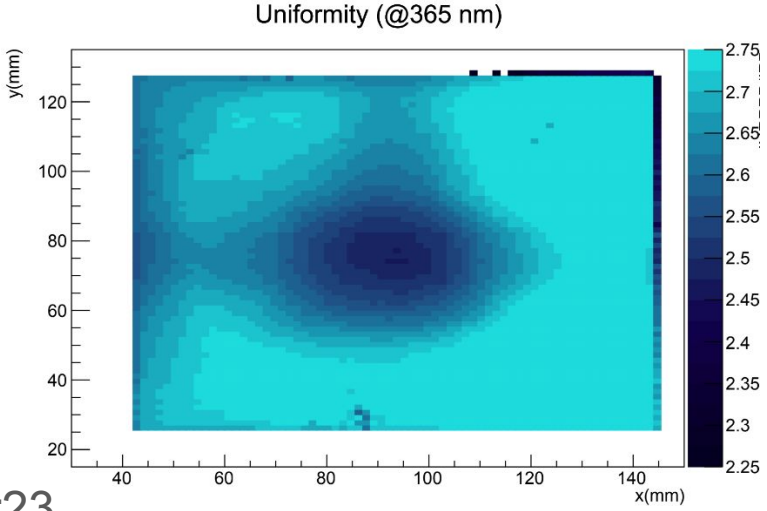
- The currents are systematically higher in the presence of reflective surface.
- For 90% reflective mirror we expect 5-10% extra current!

Comparison between two HRPPDs

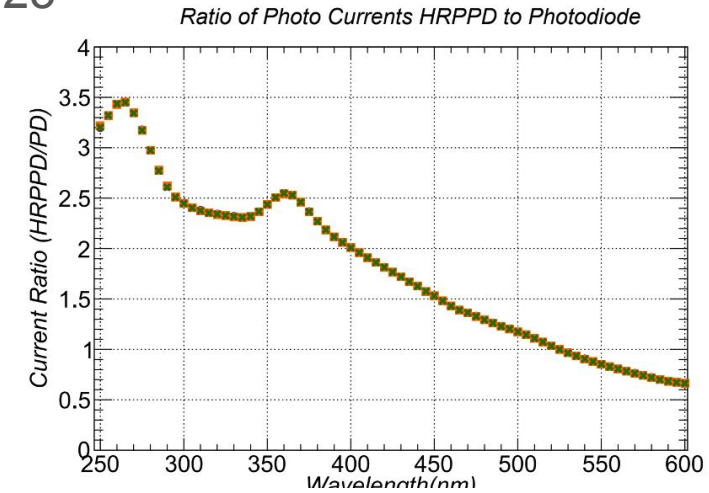


#16

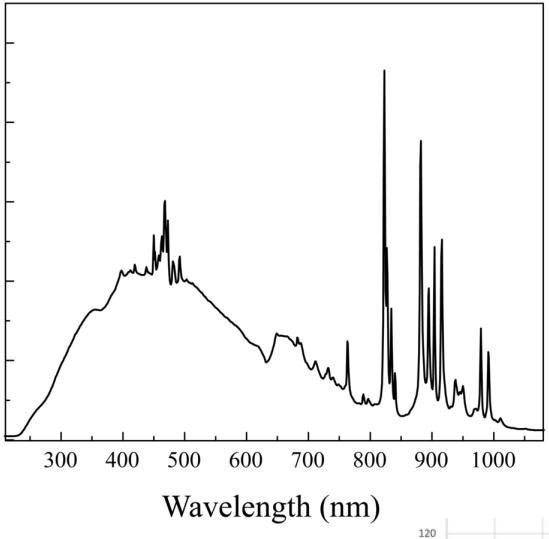


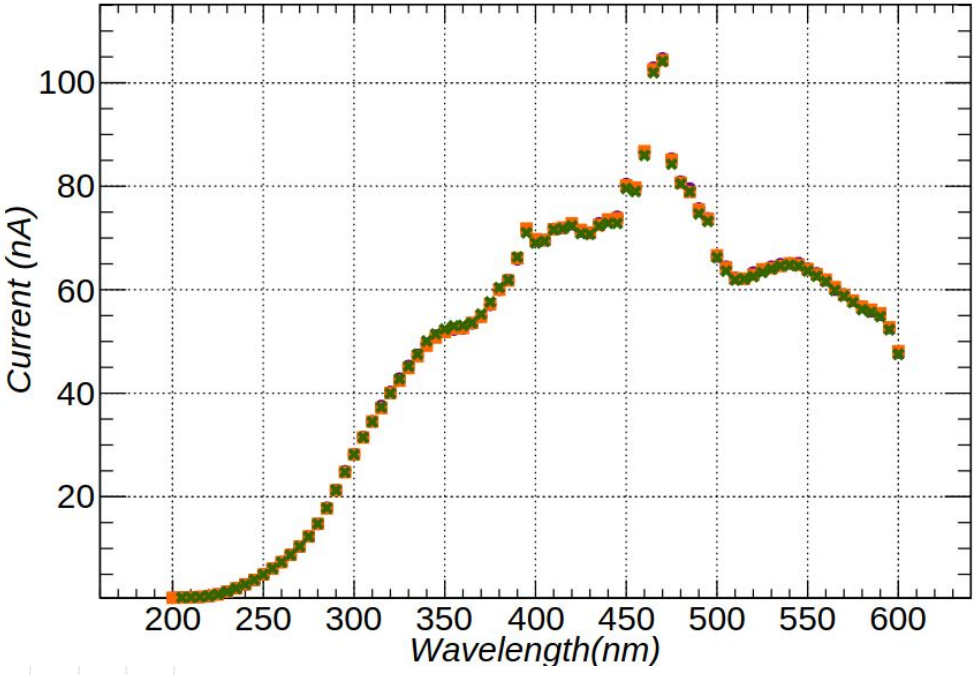


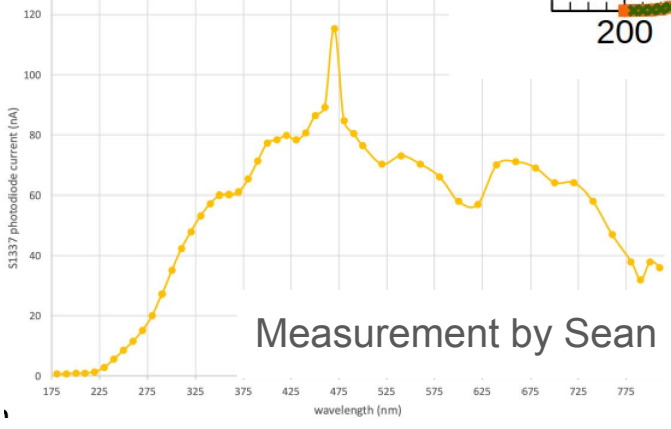
#23



Xenon spectrum

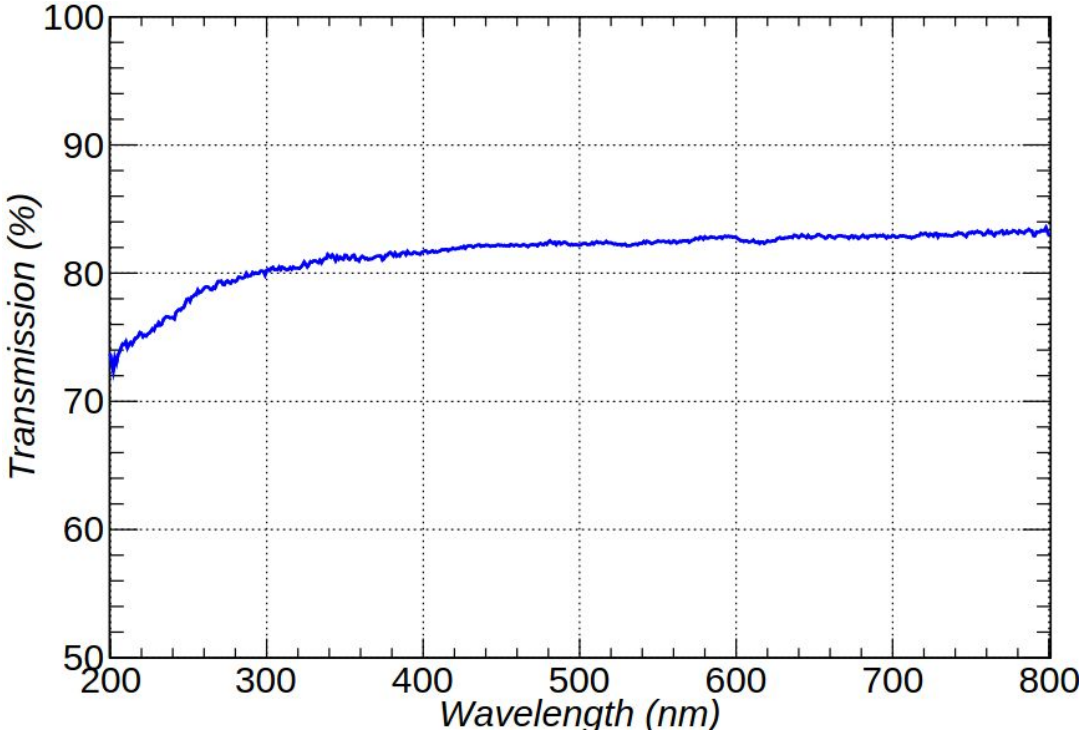


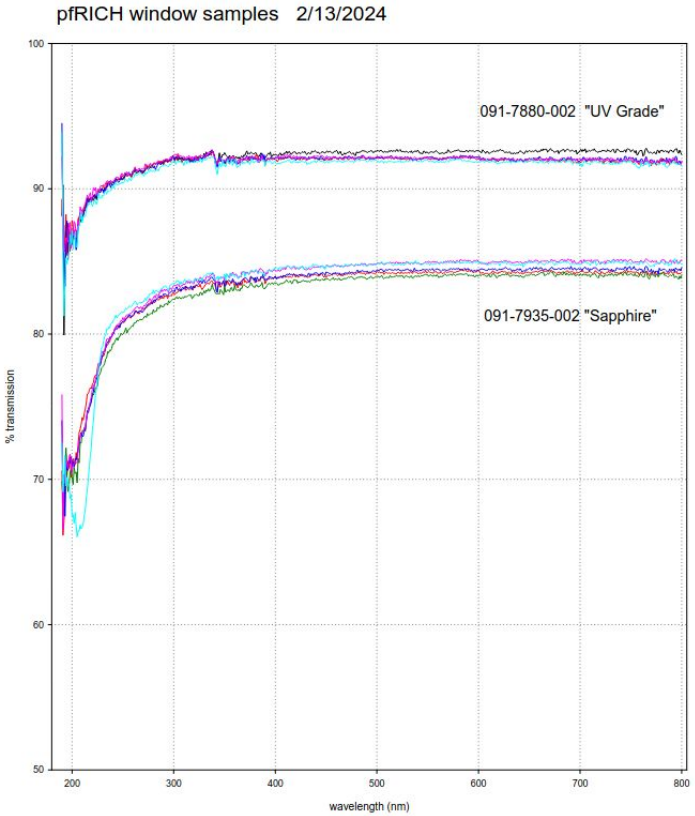




Measurement by Sean

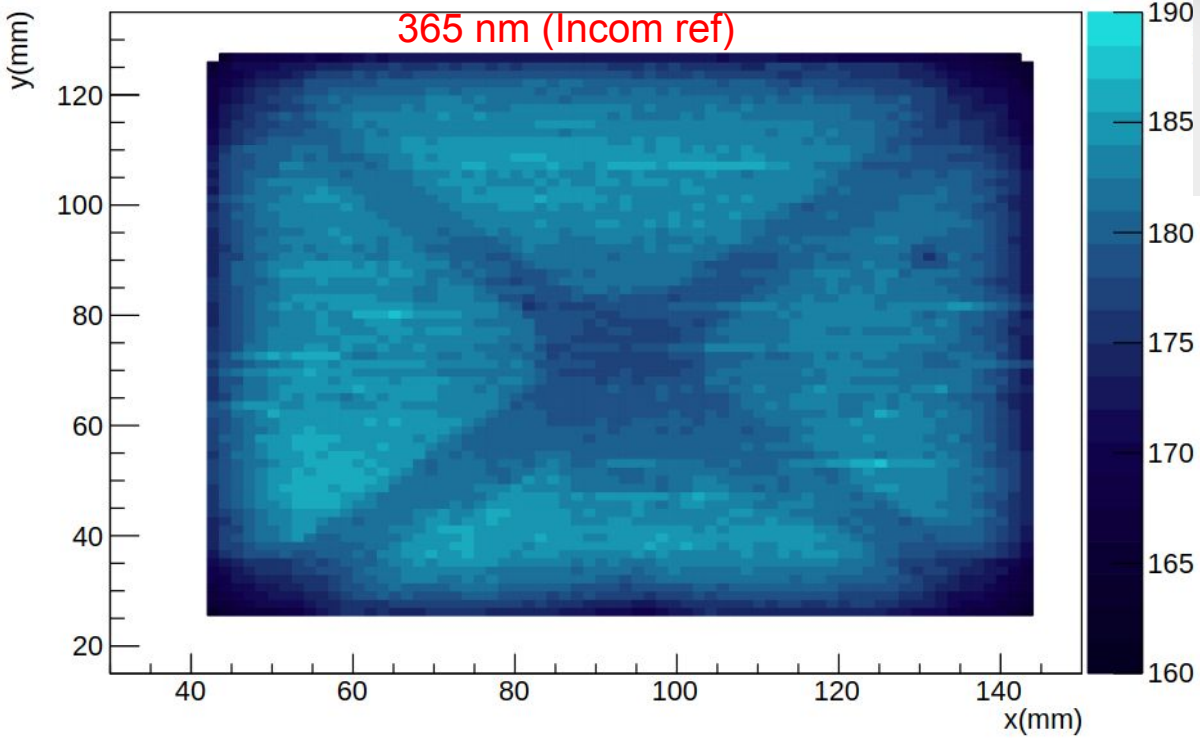
Sapphire Window

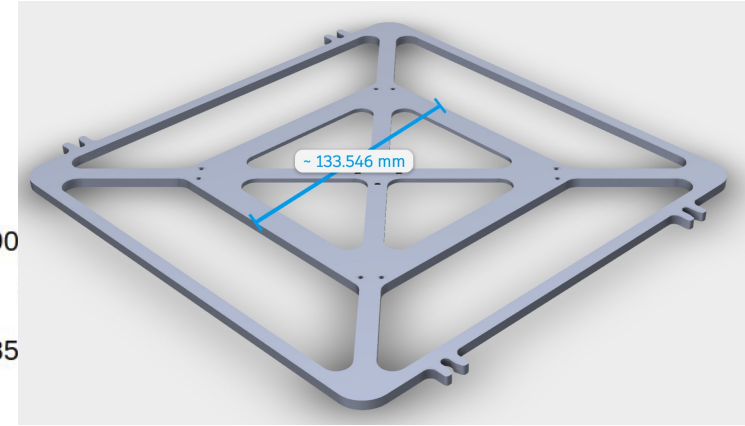




Box was opened and Realignment have been done with Amscope images and PD photocurrent

HRPPD current uniformity (Tile #16)

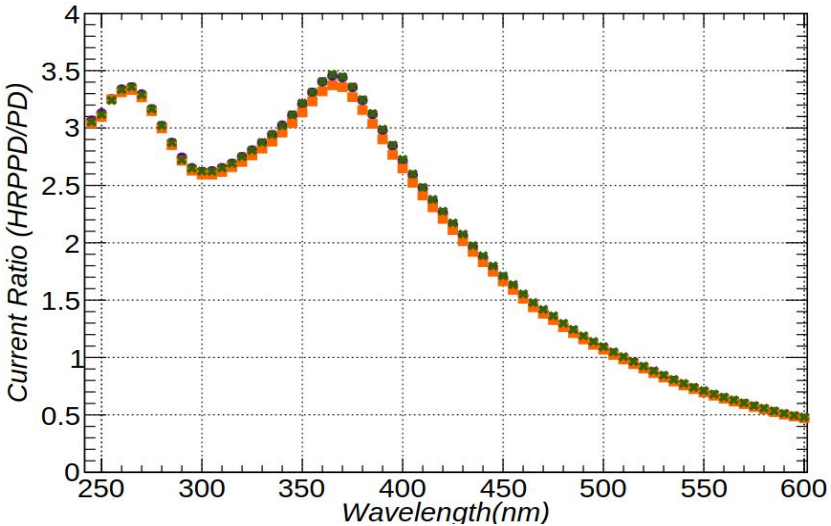




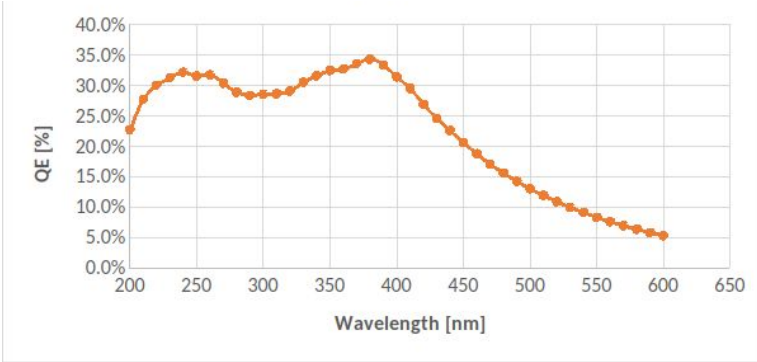
- We can clearly notice the holder structure!
- Horizontal strips are also present along the direction of scanning (light fluctuations) like the photodiode.
- Some microscopic hot-zones and dark-zones are seen.

Scanning as a function of Wavelength

- Test has been made to check dependency with photocathode voltage.
- Final scan has been made with 5 nm steps at the centre of the quadrants and at the tile centre.
- Monochromator does not provide any light below 225 nm.

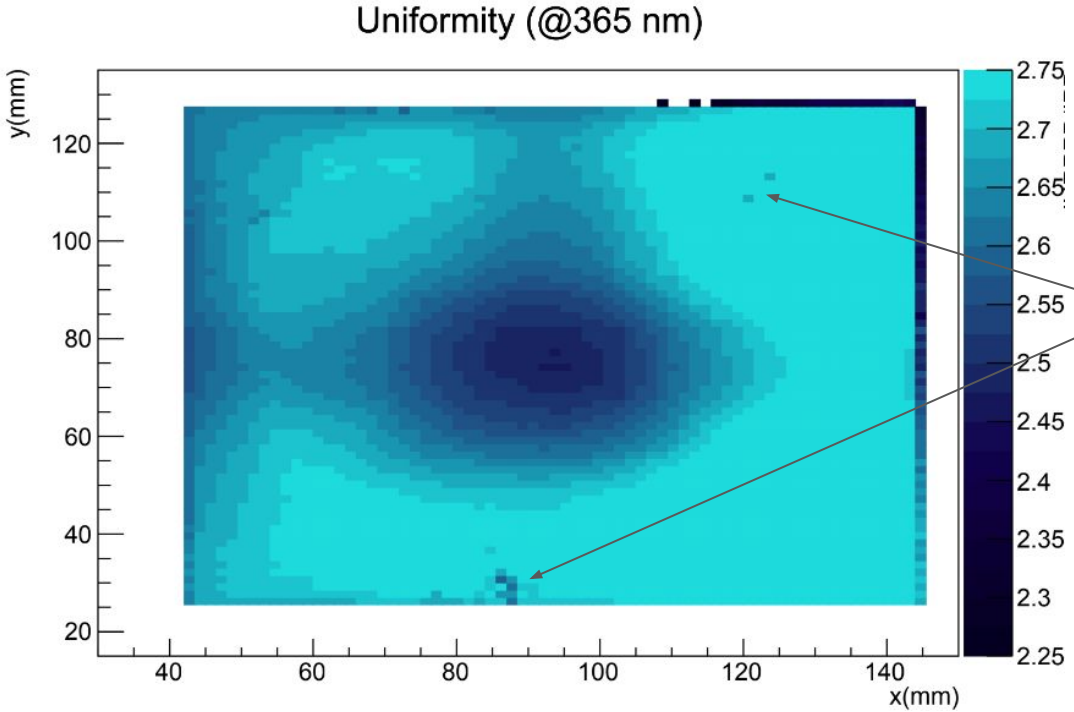


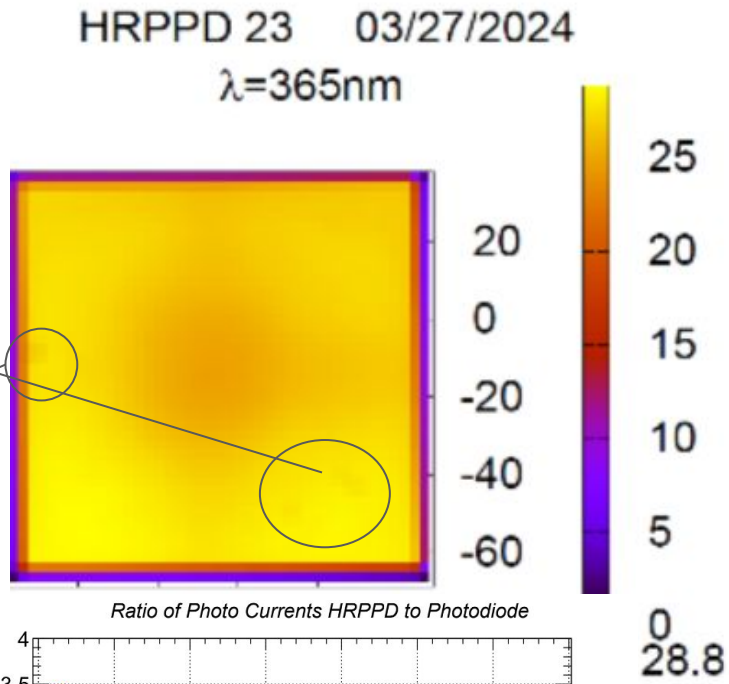
INCOM Measurement (LAPPD)

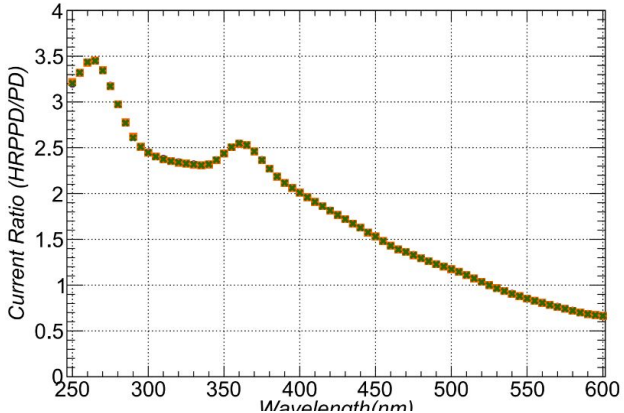


The current ratio is very stable (and smooth), shape is qualitatively similar to the QE measurement of INCOM!

HRPPD scanning #23

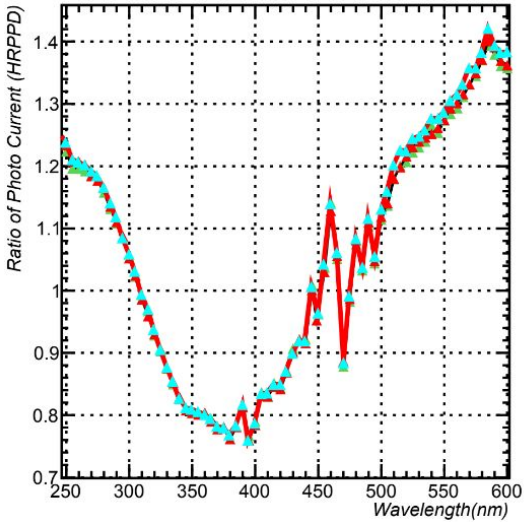


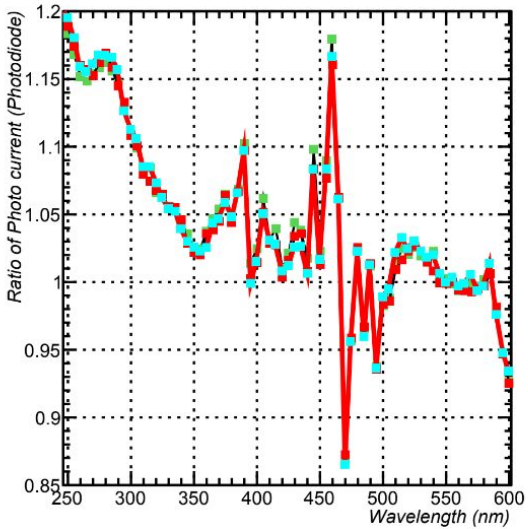


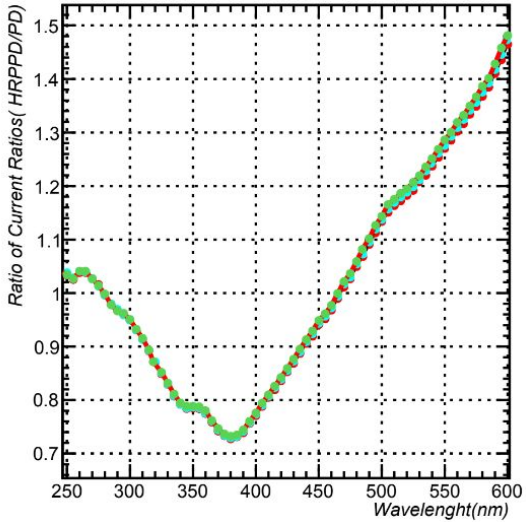


- Substantially different structures!
- Current ratio versus wavelength has similar two peaks, but different ratios between them.
- Coated in a different tank of smaller size. Distance from source to surface can cause, different thicknesses of coating material

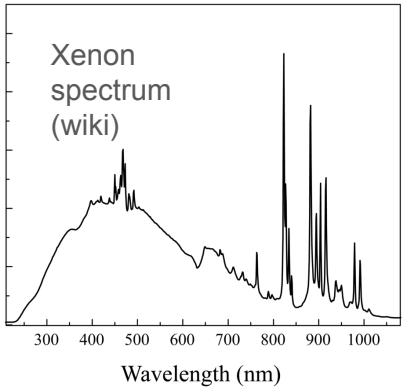
Comparison between two HRPPDs



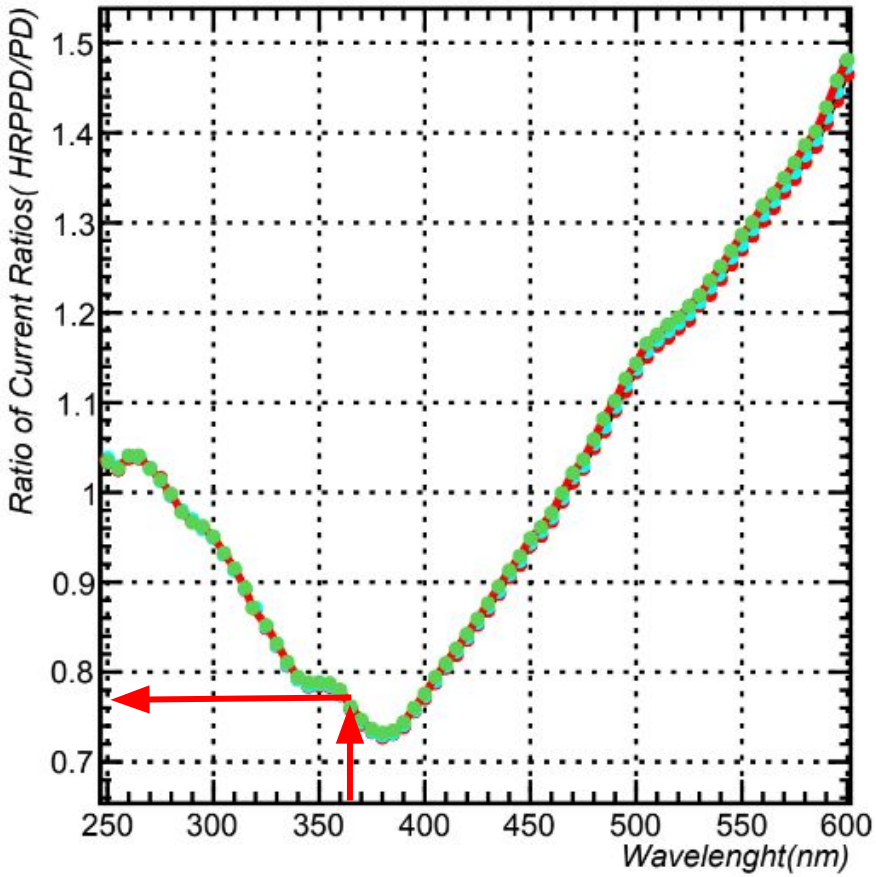


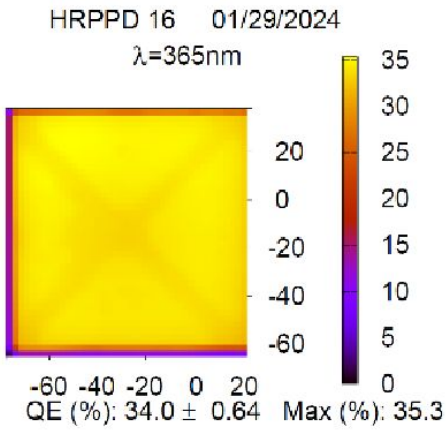


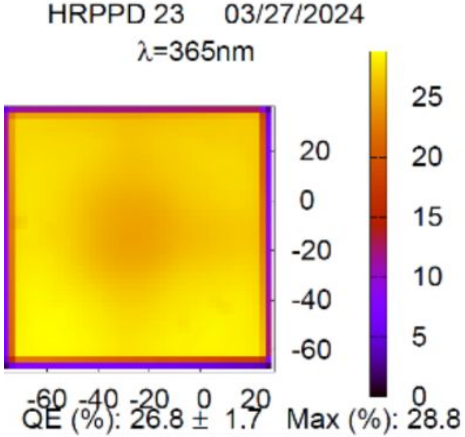
- Photo-currents are constant within 5% level
- Some structures can be seen below 300 nm:
  → Monochromator light intensity decreases.
  → Current values are small (much below 20 nA), sensitive to fluctuations.
  → Similar trend is seen in HRPPD as well. But, afterwards sharper drop.
- Double ratio cancels out systematics and residual fluctuations.



Comparison between two HRPPDs

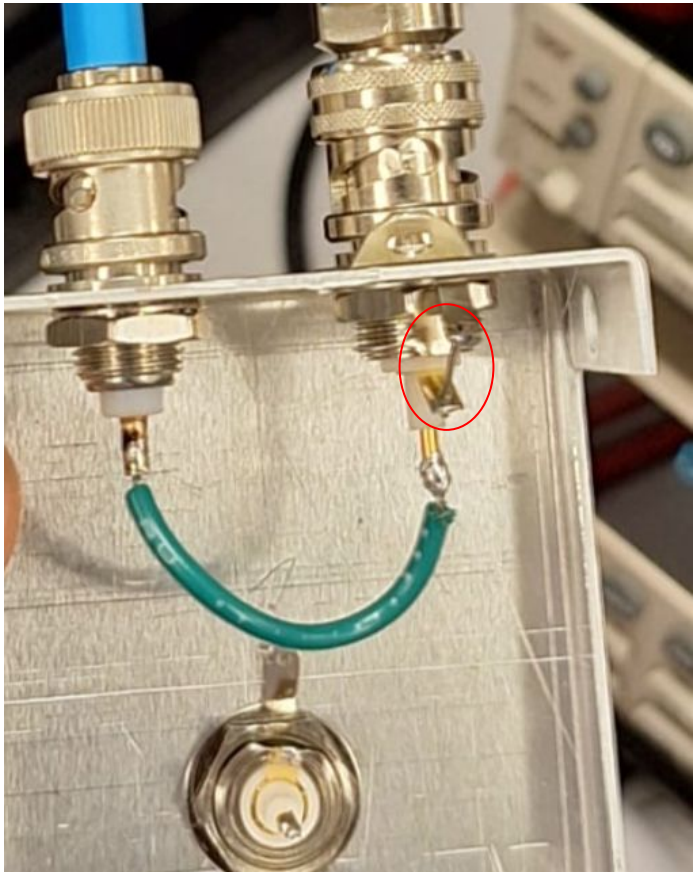


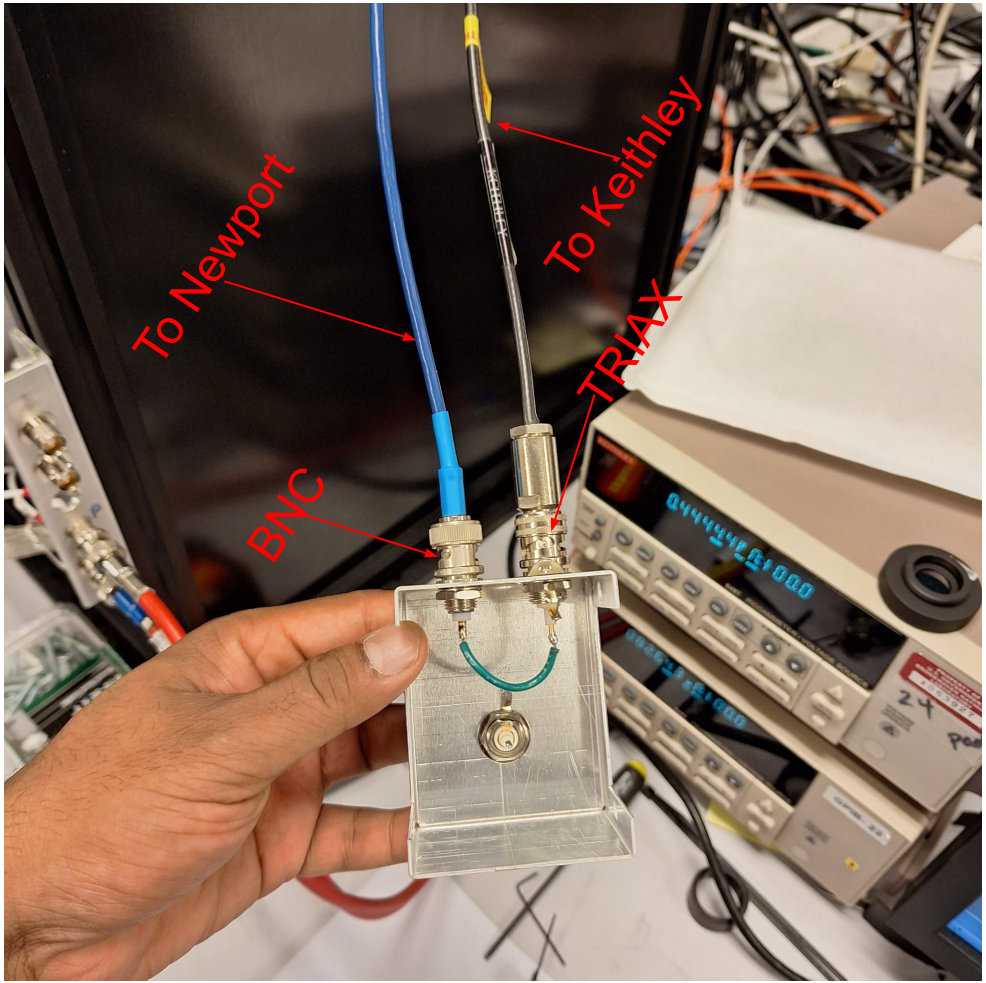




- The double ratio indicates that at 365 nm we are **~22-23% lower conversion for HRPPD #23**.
- The quoted QEs suggest **HRPPD #23 is smaller by 21.1+-0.067%.**
- The results are **consistent** within measurement uncertainties.

Newport Circuit

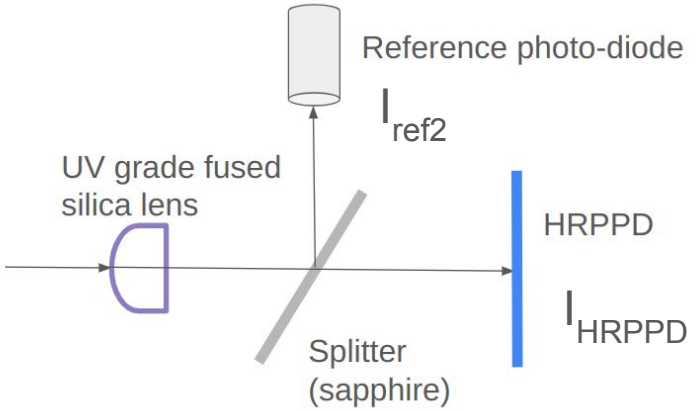




Measurement of Quantum Efficiency

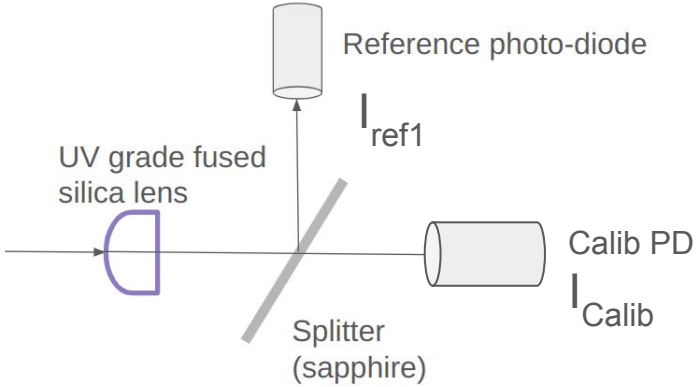
$$(QE)_{theo.} = \frac{N_{el}^{ejected}}{N_{ph}^{incident}}$$

$$(QE)_{mes.} = (QE)_{calib} \cdot \frac{I_{calib}^{pc} - I_{calib}^{dark}}{I_{HRPPD}^{pc} - I_{HRPPD}^{dark}} \cdot \frac{I_{ref2}^{pc} - I_{ref2}^{dark}}{I_{ref1}^{pc} - I_{ref1}^{dark}}$$

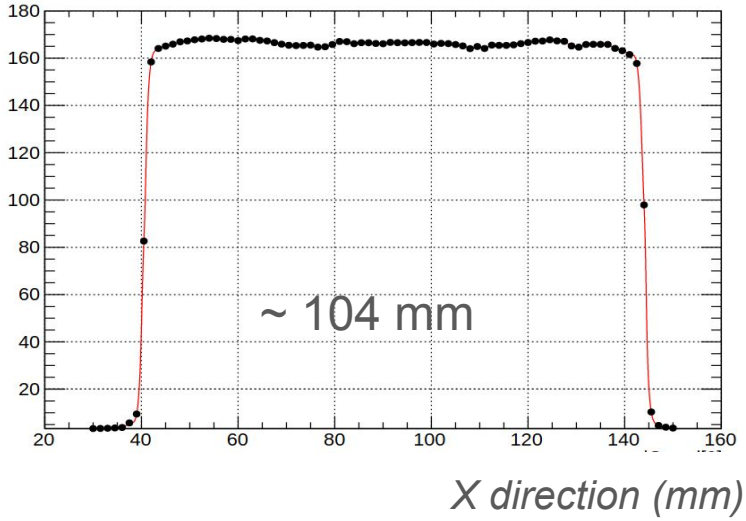


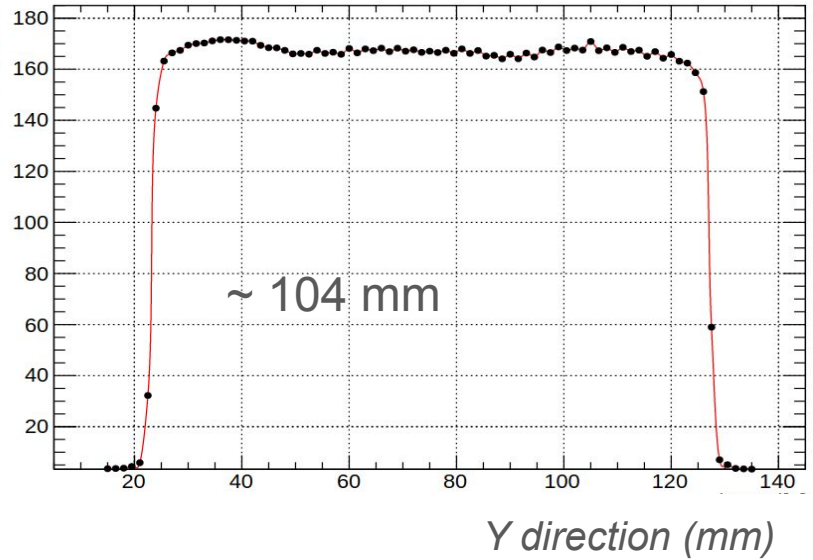
Principal source/s of uncertainty:

- ❏ Determination of the photon flux
  → Monitor stability of the photon source over time. Same photodiode is used to monitor light fluctuations for HRPPD photocurrent and calibrated photodiode photocurrent measurements.
- ❏ Fluctuation in dark current
  → Monitoring of dark-current frequently (if possible during measurement)
- ❏ Accuracy of QE of reference calibration
  → A calibrated photodiode with known Q.E. to rescale the HRPPD photocurrents.
  → High accuracy in photosensitivity of the Calibrated photodiode.



Active Area of HRPPDs





Active area of the HRPPDs are consistent. Both #23 and #16 have an active area of 104 mm. They are similar in both X and Y coordinates.