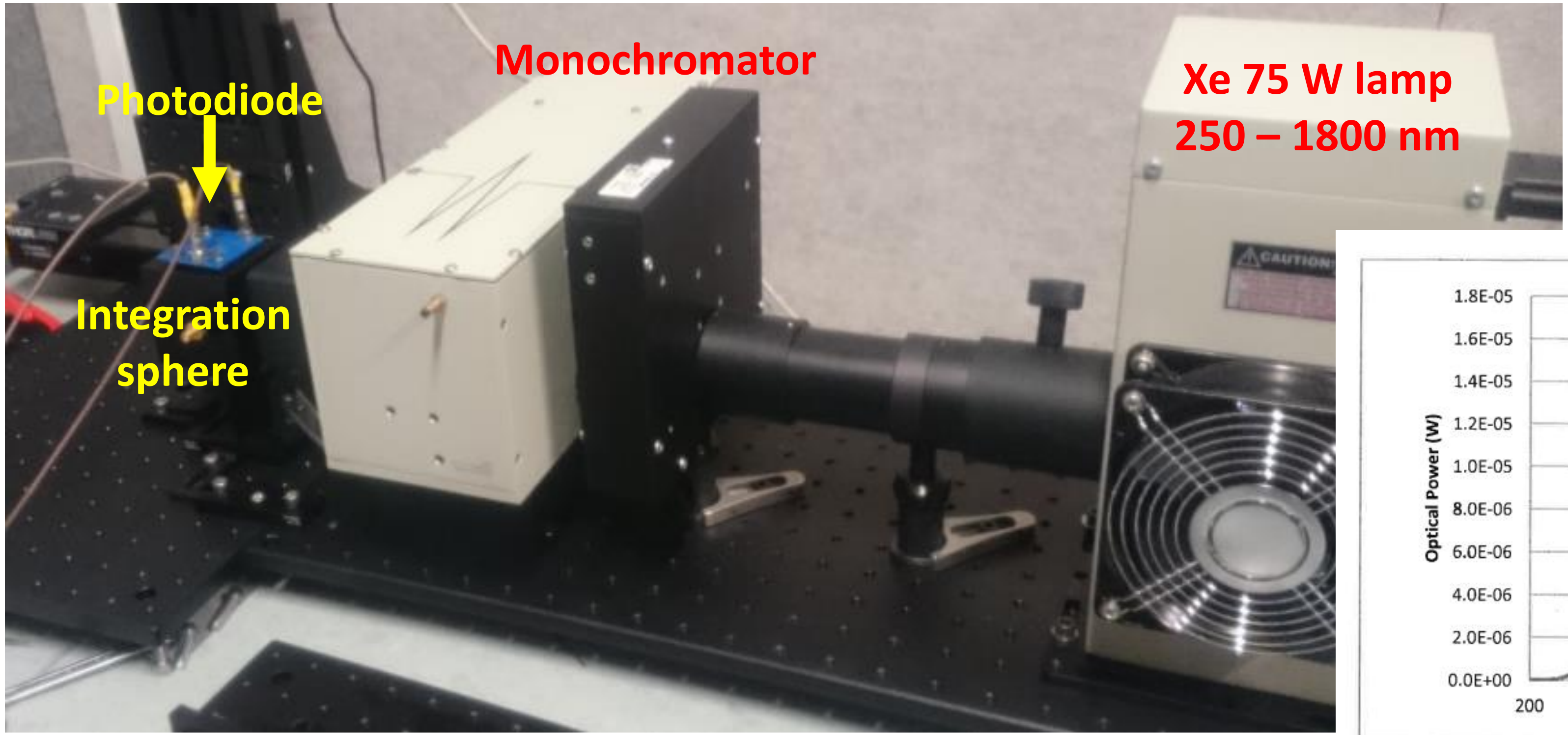
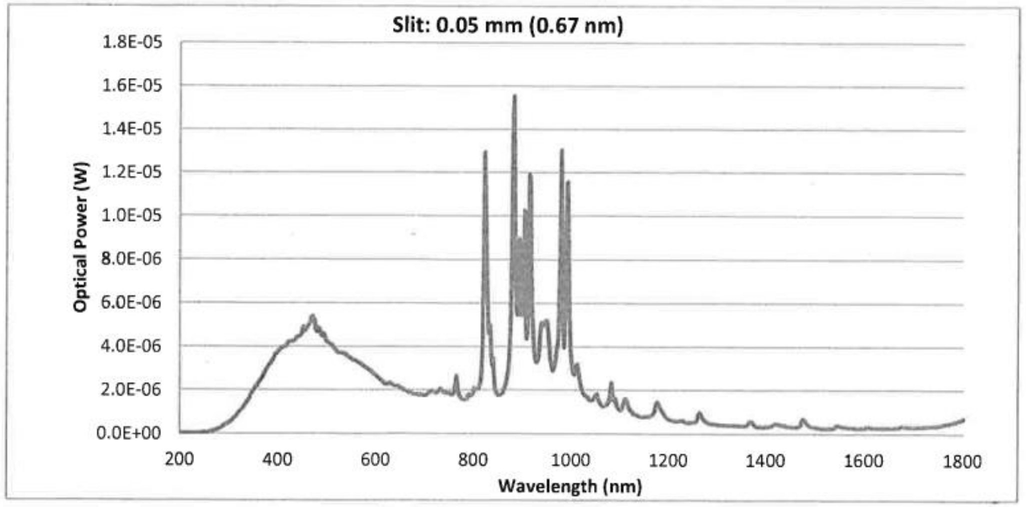
XArapuca test with monochromatic light source

Umut KOSE

The method



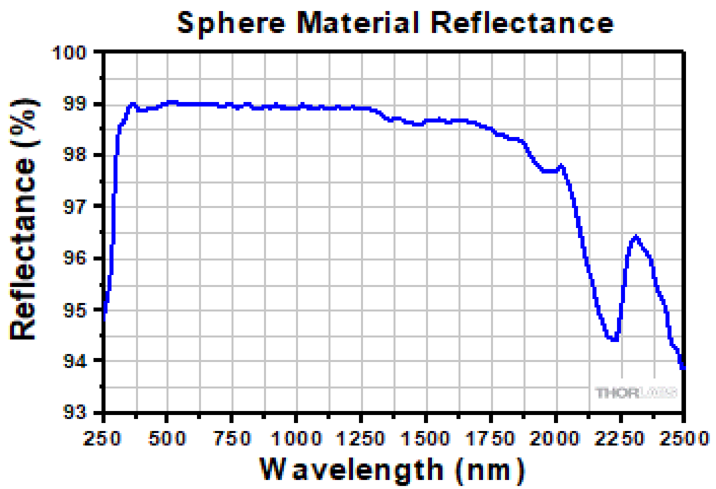


- Continuous monochromatic light source
- Xe lamp operated with a slit width of 0.05 nm to have enough light. The resolution on the wavelength is about 0.7 nm.
- Scan from 300 nm to 600 nm with a step of 10 nm (step of 2 nm @ 400-420nm)
- To ensure both detectors are exposed to the same amount of photons, an integration sphere is used to diffuse the light.
- To illuminate XArapuca module with different light density, a Neutral Density Filter (ND Filters) is inserted between the integration sphere output port and the XArapuca.
- To determine how many photons impinged into XArapuca, photodiodes are used.

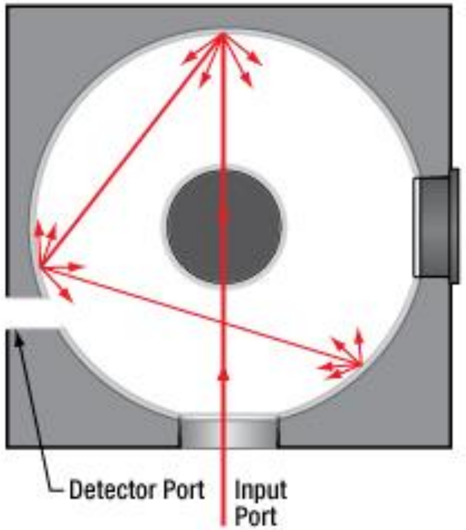
Integration sphere

Overview | **Specs** | Shipping List | Insights | Feedback

Item #	IS200	IS200-4	IS236A	IS236A-4	IS210C
Detector Type	No Detector		Si		InGaAs
Detector	-		SM05PD1B		Anode-Grounded SM05PD4A
Detector Wavelength	-		350 - 1100 nm		900 - 1700 nm
Sphere Reflectance	~99% @ 350 to 1500 nm; >95% @ 250 to 2500 nm				
Sphere Diameter	2"				
Port Diameter	0.5"				
Ports	3 at 0°, 90°, and Top	4 at 0°, 90°, 180°, and Top	3 at 0°, 90°, and Top	4 at 0°, 90°, 180°, and Top	3 at 0°, 90°, and Top
Photodiode Port	Ø3 mm for SM05PD				
Thermal Stability	Up to 250°C				
Laser Damage Threshold	2 kW/cm², 7 J/cm²				
Dimensions	61 mm x 61 mm x 65 mm (2.4" x 2.4" x 2.56")				
Weight	0.35 kg (0.77 lb)				



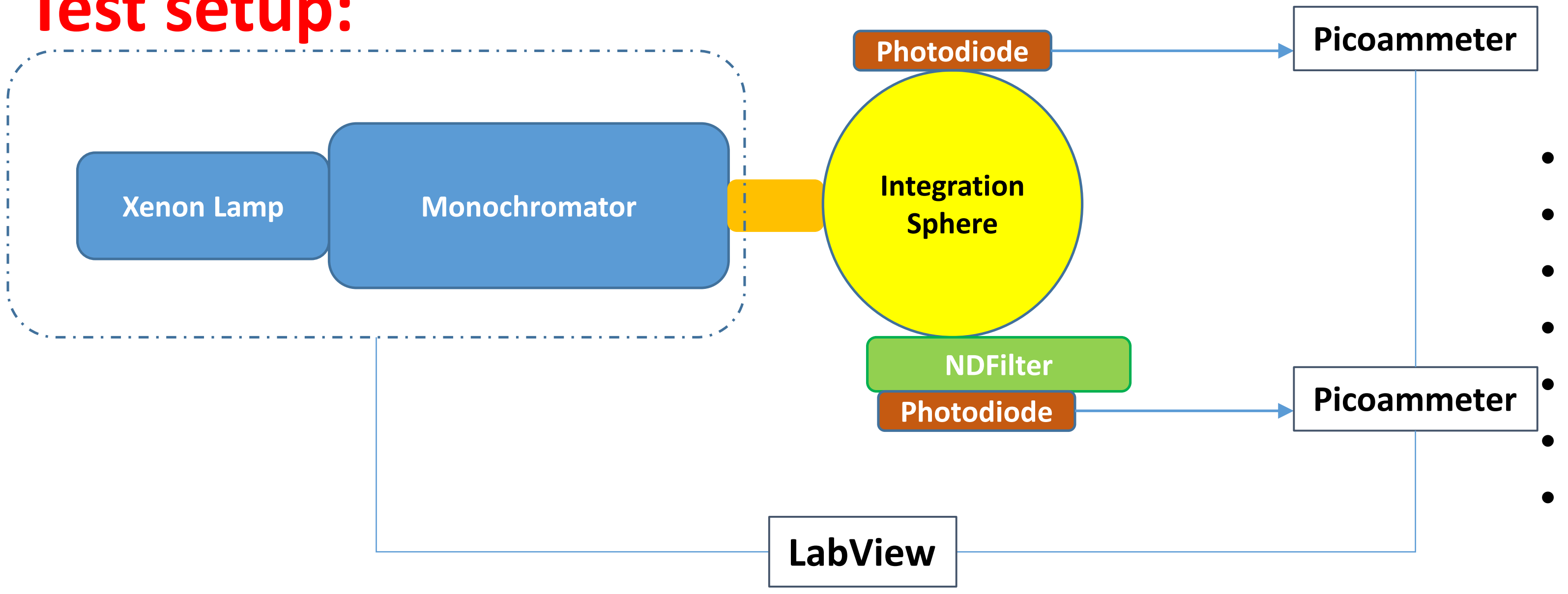
Click to Enlarge
Integrating Sphere Material Reflectance



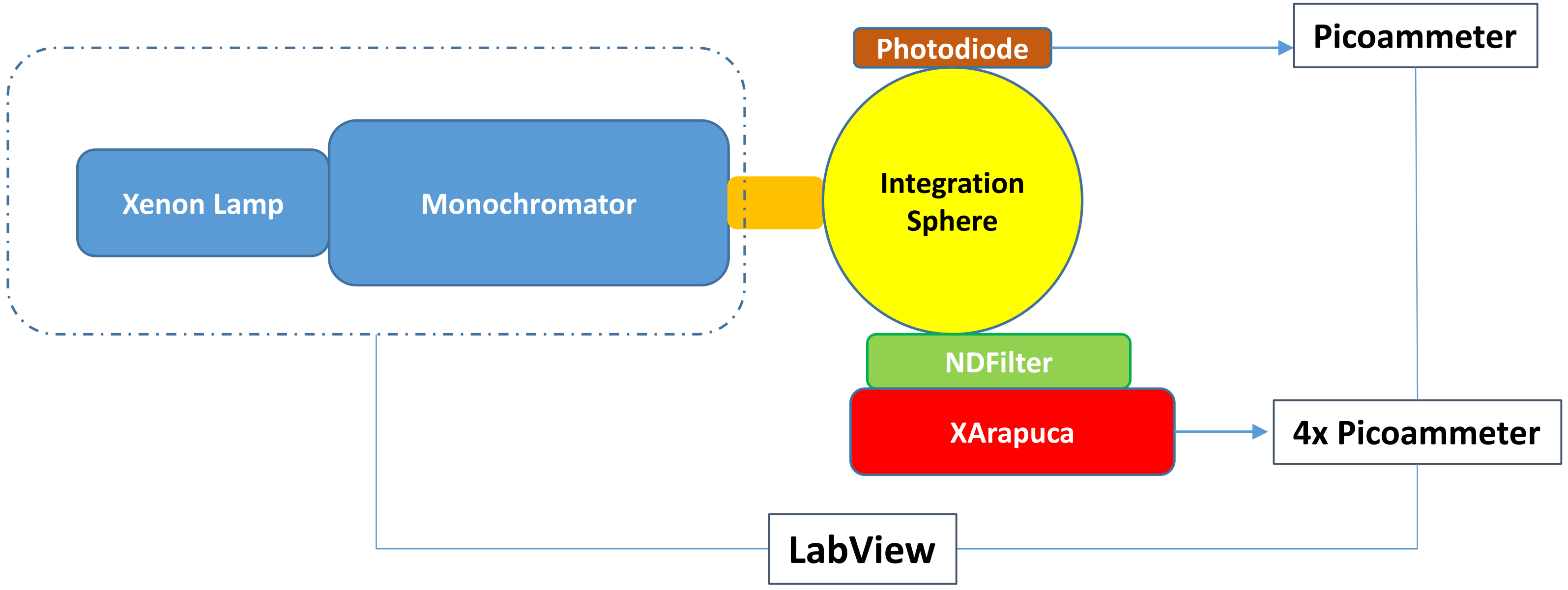
- **An integrating sphere evenly spreads the incoming light by multiple reflections over the entire sphere surface.**
- **The sphere is manufactured from PTFE based bulk material that has high reflectance in the 250 - 2500 nm wavelength range**

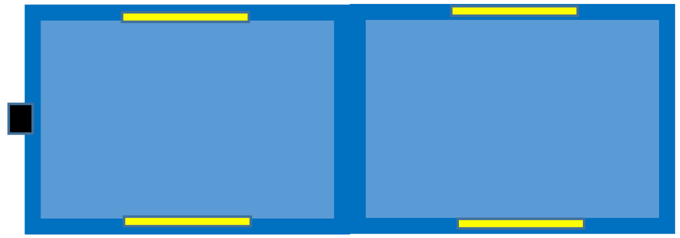
https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=1658

Test setup:



- Xenon Lamp
- MonoChromator
- Integration Sphere
- ND Filters
- Calibrated Hamamatsu S1337-1010BQ
- Keithley 6847 Picoammeter/Voltage Source
- LabView 2015

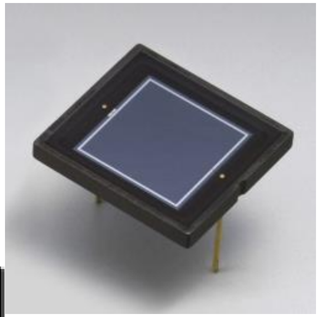


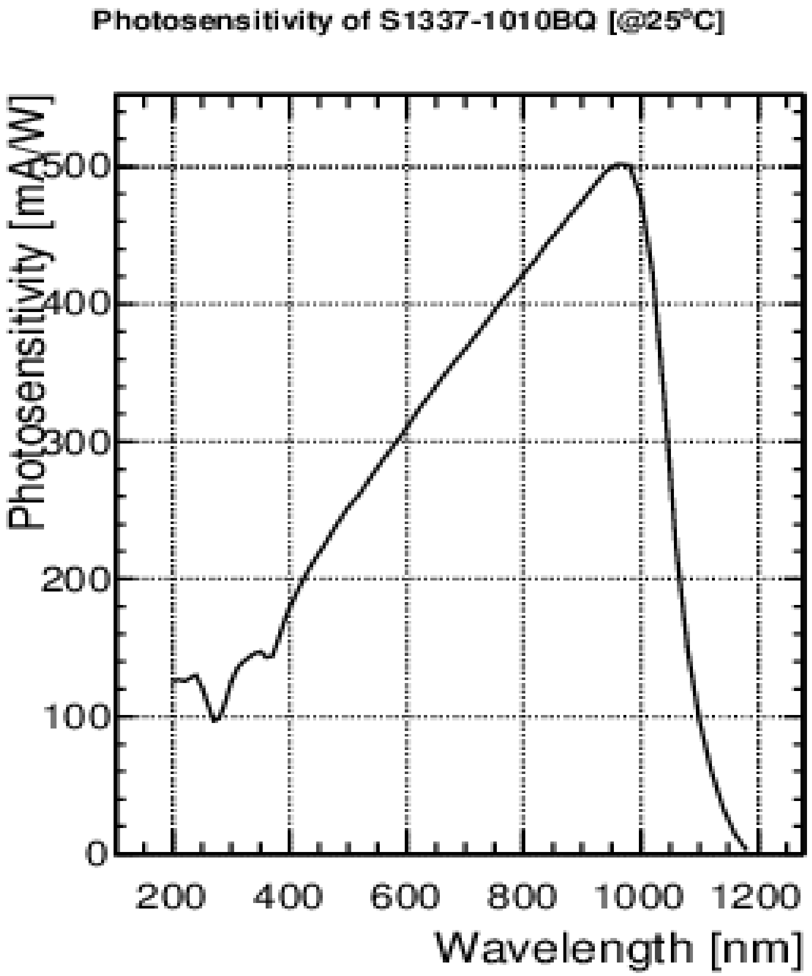


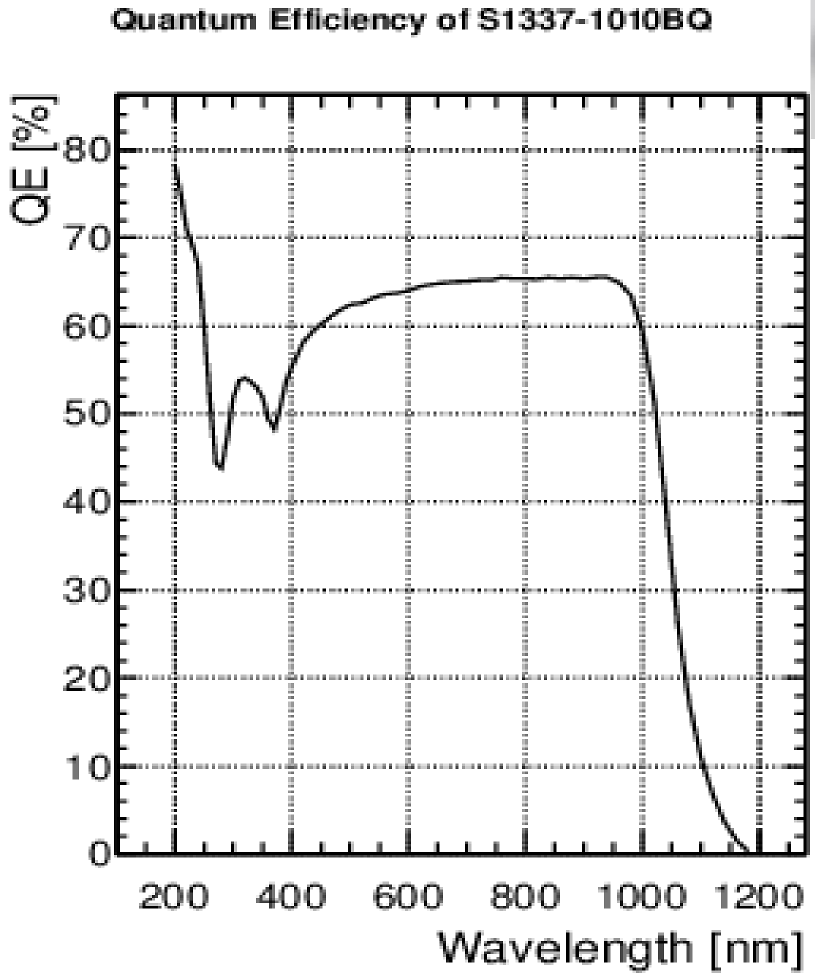
XArapuca module placed inside 2cm thick foam

$3 \times 2.5\ cm^2$ window on the foam allows photons to enter from integration sphere output port at 90°

Si Photodiode (Hamamatsu S1337-1010BQ: For UV to IR)

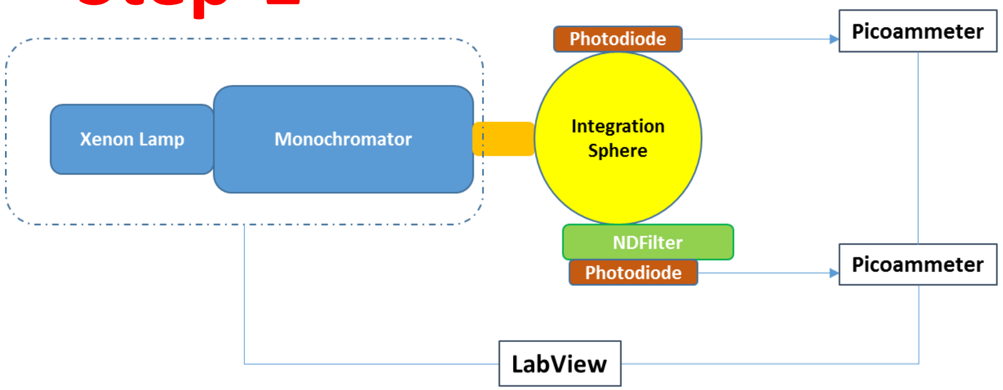


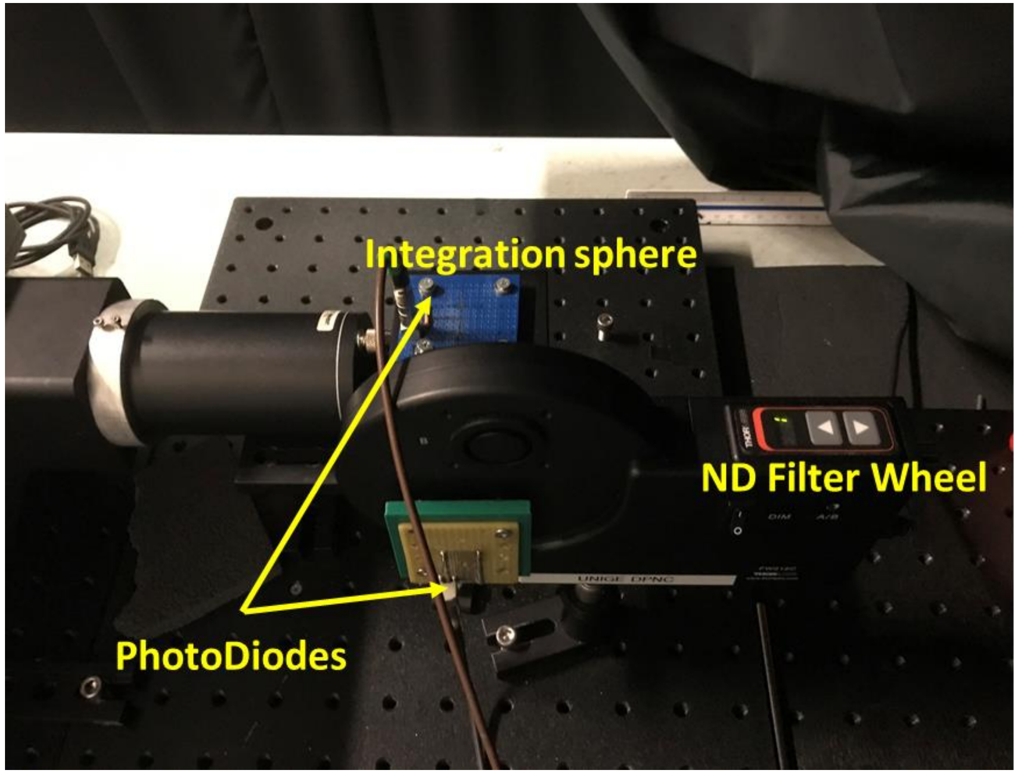


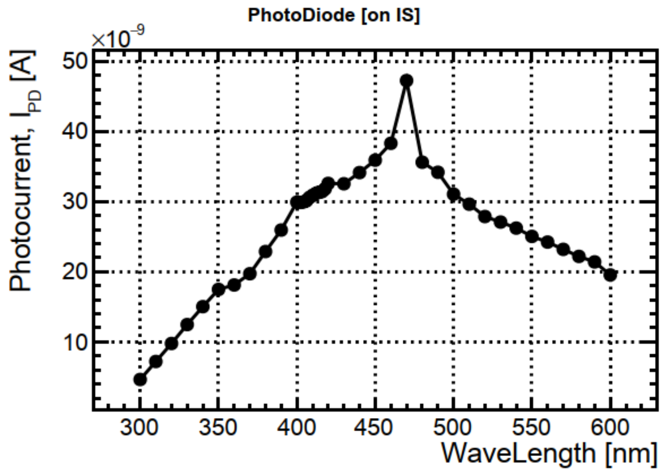


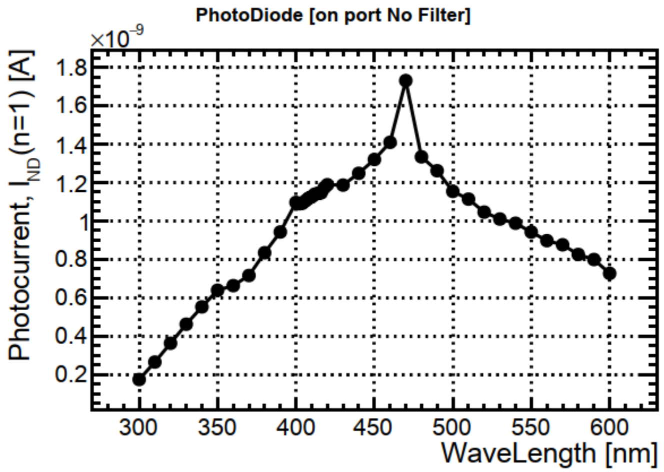
A calibrated photodiode: S13370-1010BQ to determine the absolute amount of light scattered in the IS ports, in order to estimate the number of photons impinging on XArapuca Cell

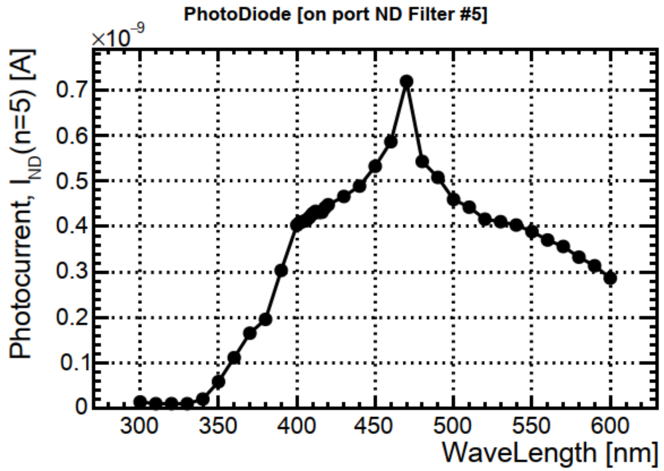
Step-1

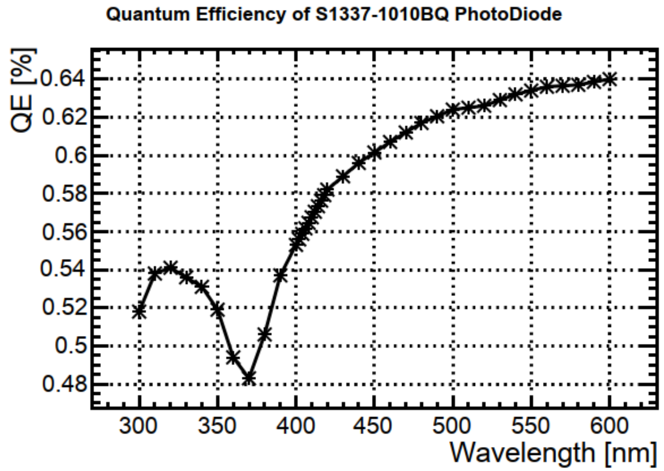




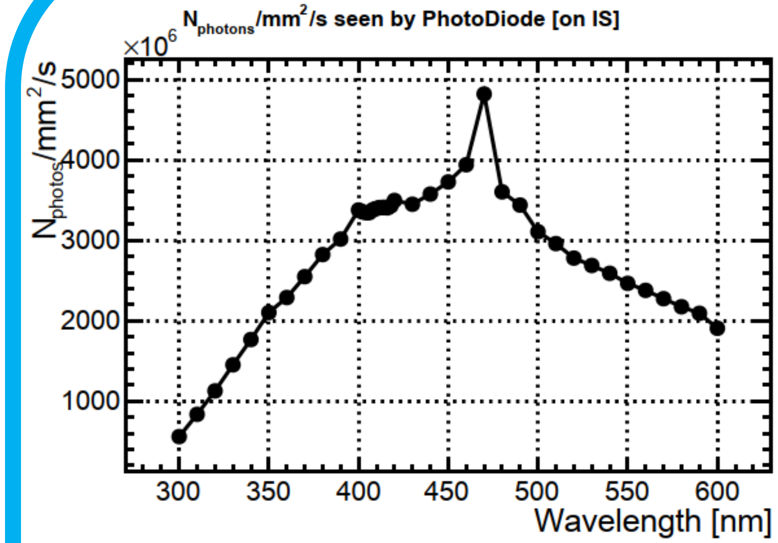


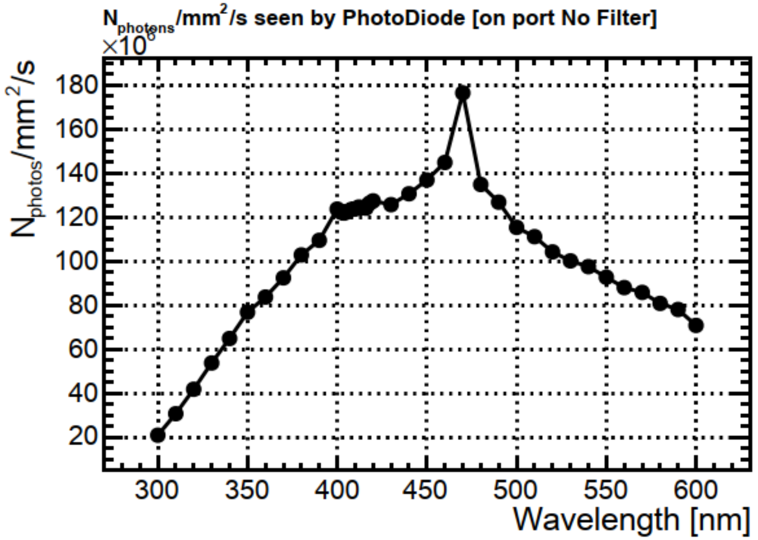


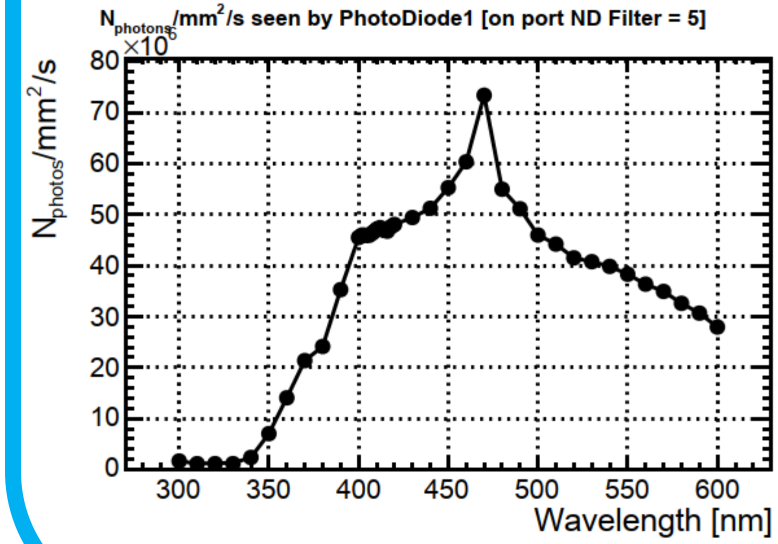


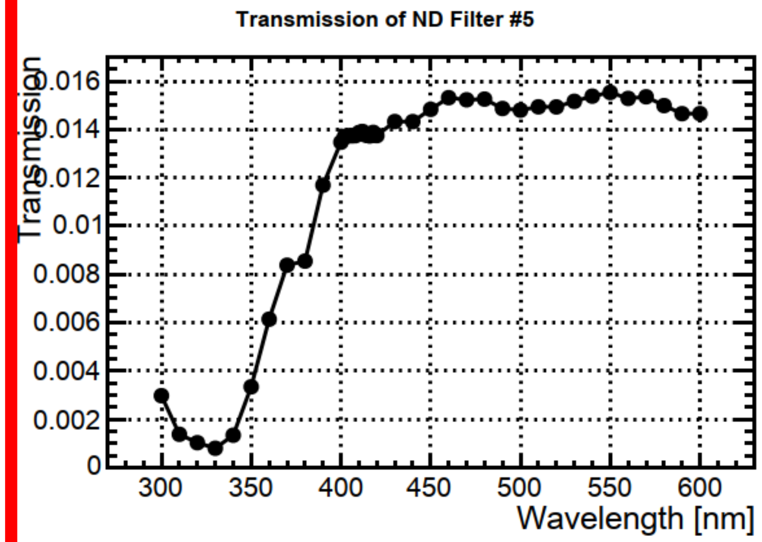


Scanning from 300 to 600 nm with a step of 10 nm (400-420 nm step of 2nm)!









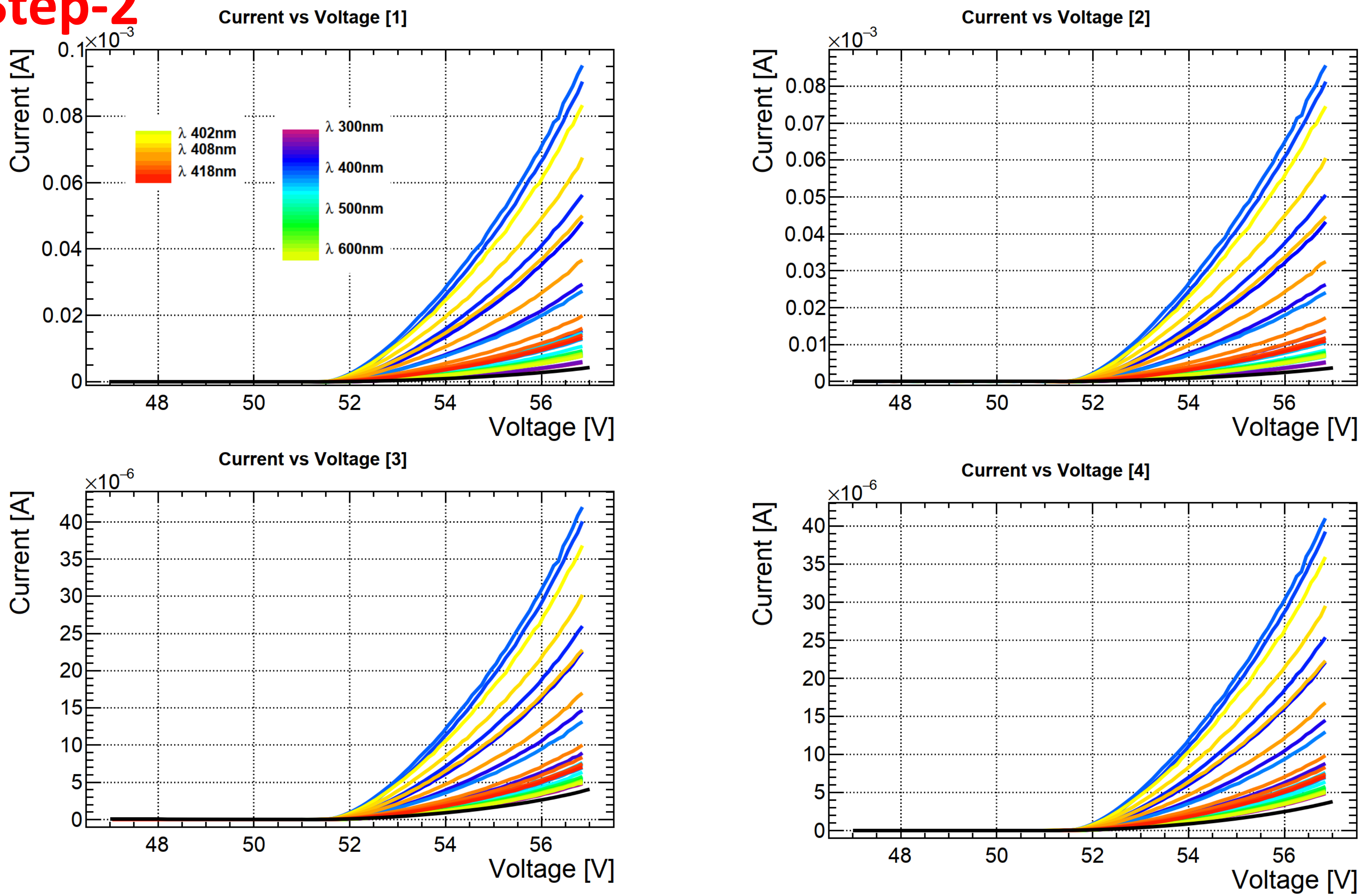
$$I_{ph} = I^{ph}_{light} - I^{ph}_{dark};$$

$$N^{ph}_{photons} = \frac{I_{ph}}{QE_{ph} * e * S_{ph}}$$

$$Transmissions = \frac{NPhotons^{ND(n=5)}_{PD}}{NPhotons_{PD}}$$

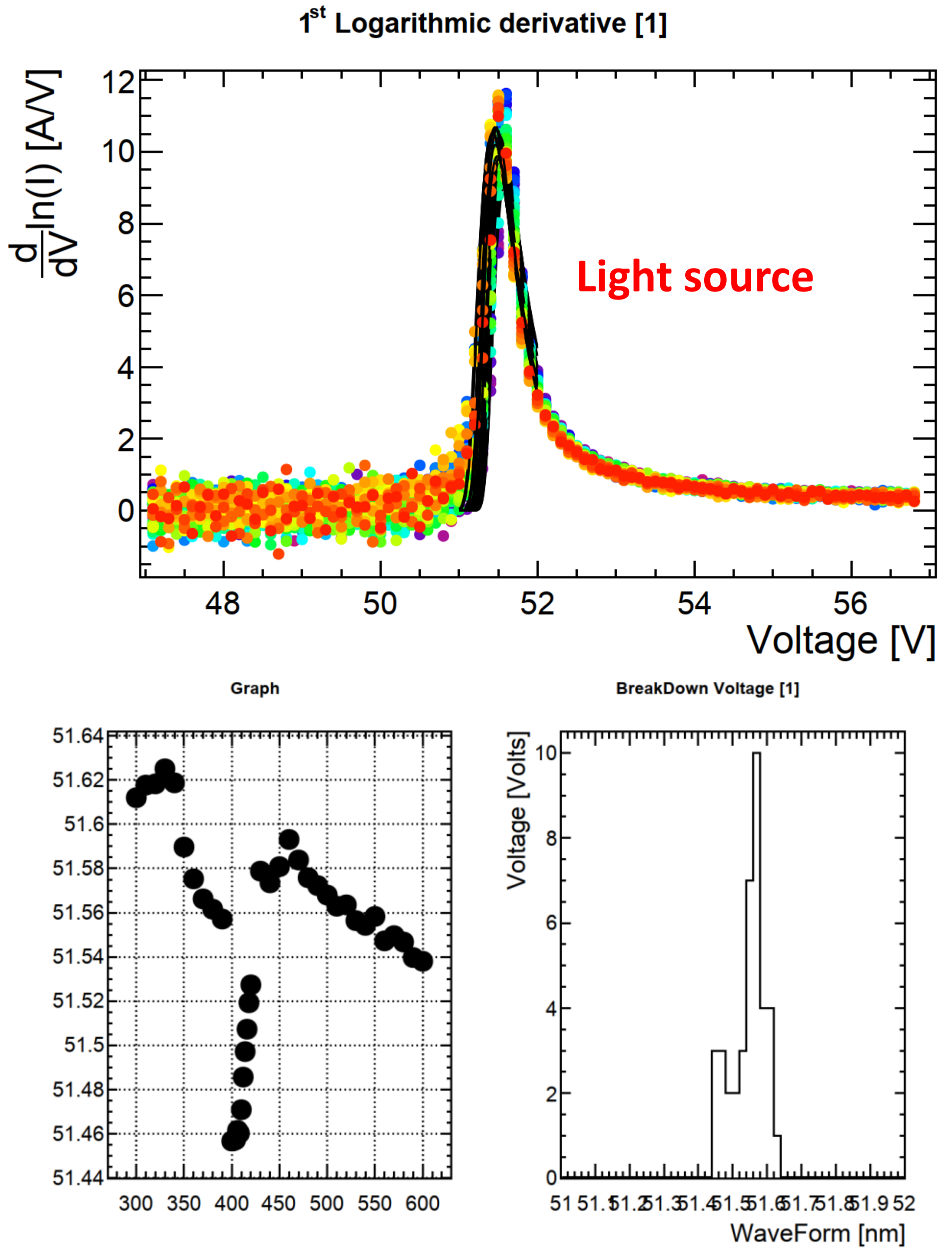
S_{ph} active surface of photodiode 100 mm2

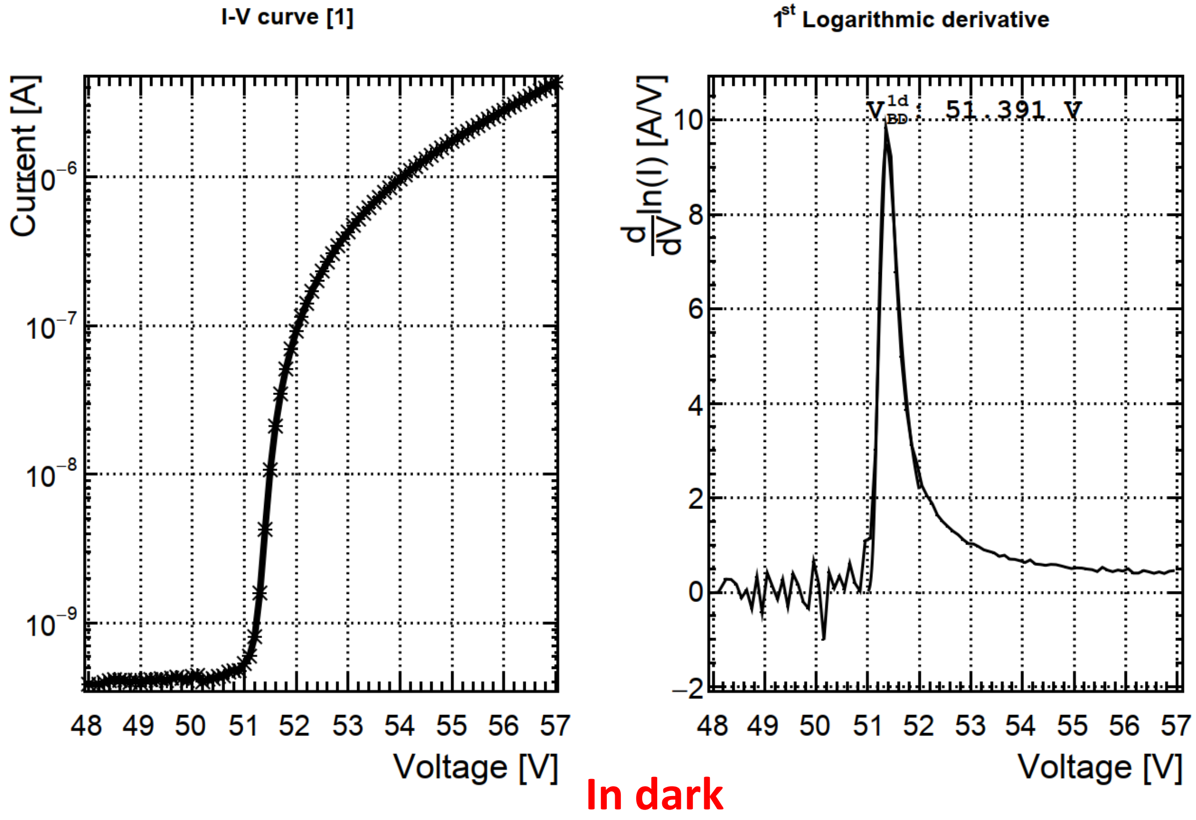
Step-2



XArapuca illuminated by continuous light for various from 300 to 600 nm (39 wavelengths) and in dark shown in black.

Just for curiosity checking the breakdown voltage of an array using 1st logarithmic derivative:





Number of photons illuminated to XArapuca:

$$N_{photons}^{port\ (n=5)} = \frac{I_{PD}^{IS}}{QE_{PD} * e * S_{PD}} * transmission$$

S_{PD} active surface of the photodiode 100 mm^2

Number of photons seen by XArapuca:

$$I_{XA} = I_{light}^{XA} - I_{dark}^{XA}$$

$$N_{photons}^{XA} = \frac{I_{XA}}{Gain * e * S_{XA}}$$

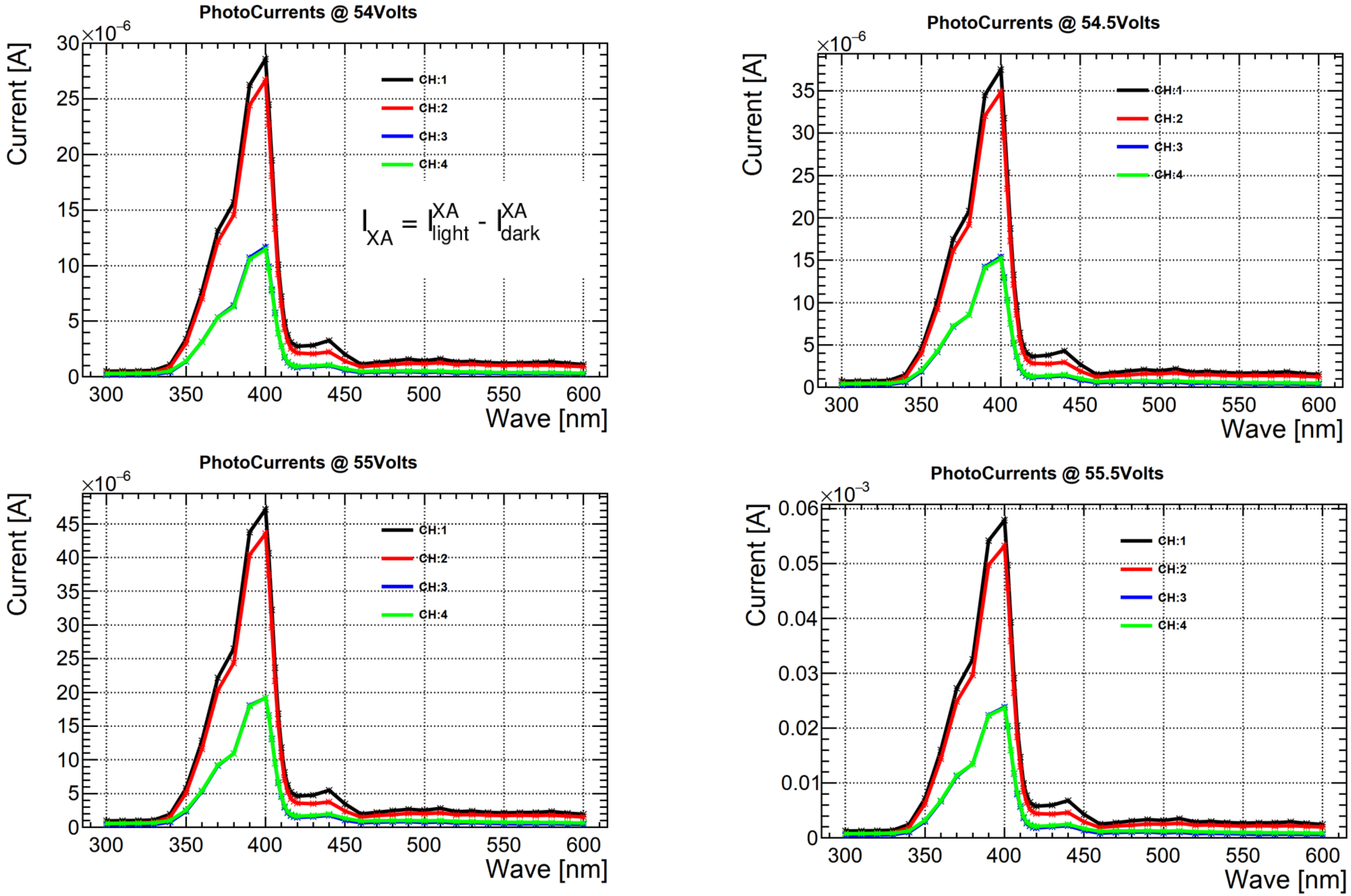
S_{XA} active surface of one channel on XArapuca 144 mm^2

Now we have photocurrents readout on each channels for different Voltage and Wavelengths

Next steps:

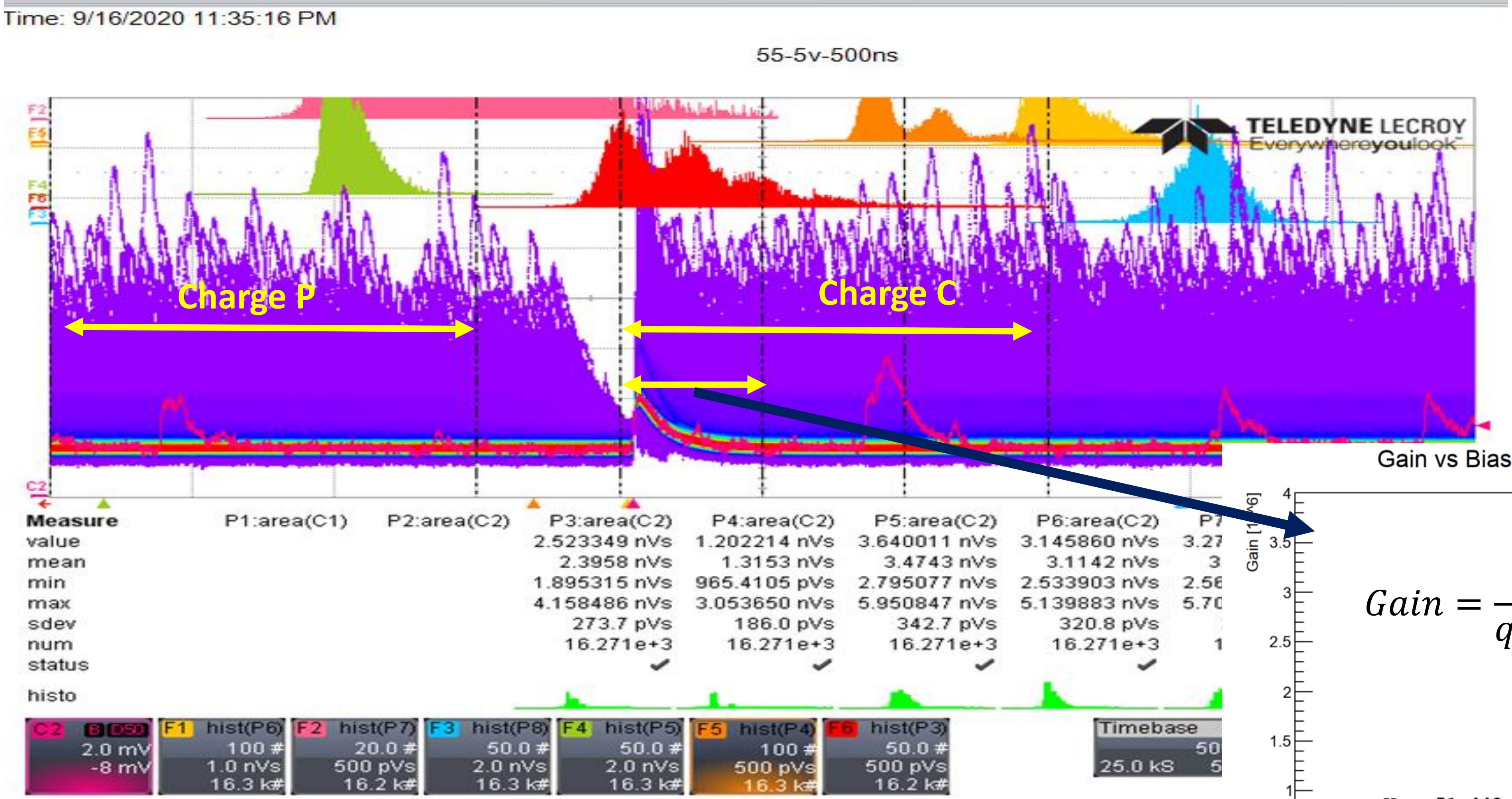
- **In order to study the efficiency of the photon detector as function of over voltage, the photocurrents for the following bias voltage extracted 54, 54.5, 55, 55.5 Volts**
- **Gain of SiPM is extracted using S13360-6050CS in dark (trying to extract the gain taking into account all the secondary effects such as cross-talk and afterpulses).**

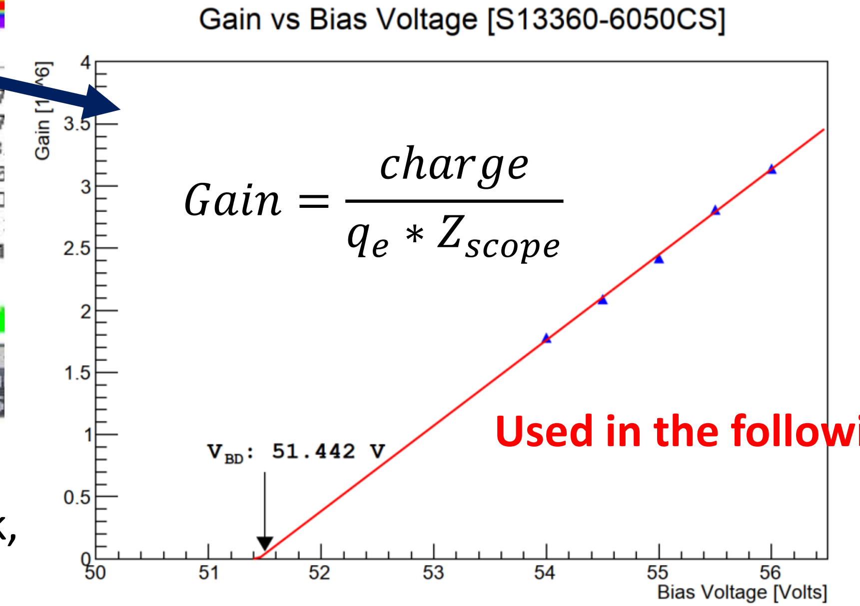
PhotoCurrent on XArapuca channels



Summing up all channels for a given bias voltage

Gain measurements:





Used in the following

$$Gain_{eff} = \frac{(C - P)}{q_e * Z_{scope}}$$

takes into account all secondary effects: crosstalk, afterpulses. SiPM too noisy at room temp!

V. Chaumat et. al. Proceedings of Science, 2012.

Number of photons illuminated to XArapuca:

$$N_{photons}^{port\,(n=5)} = \frac{I_{PD}^{IS}}{QE_{PD} * e * S_{PD}} * transmission$$

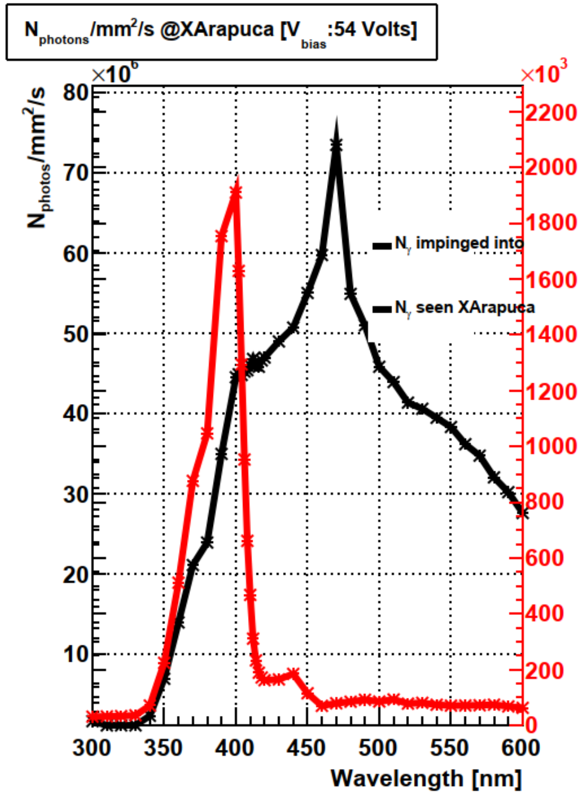
Number of photons seen by XArapuca:

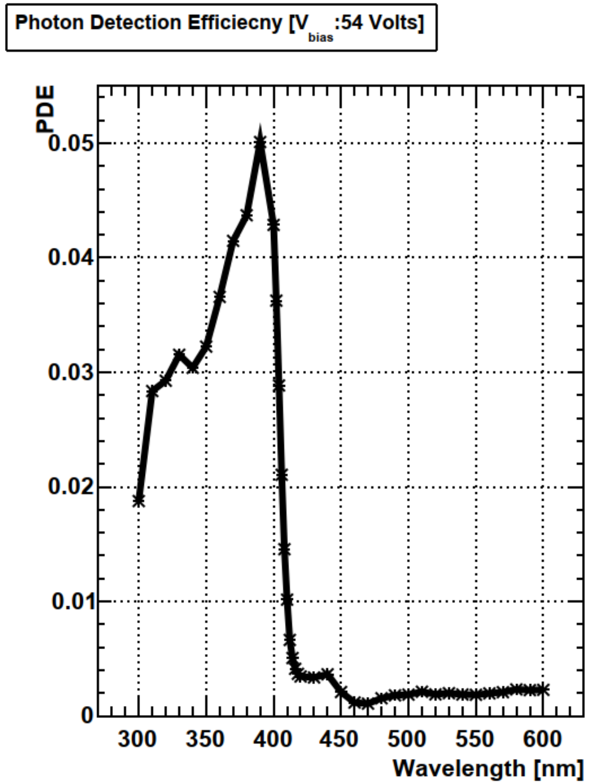
$$I_{XA} = I_{light}^{XA} - I_{dark}^{XA}$$

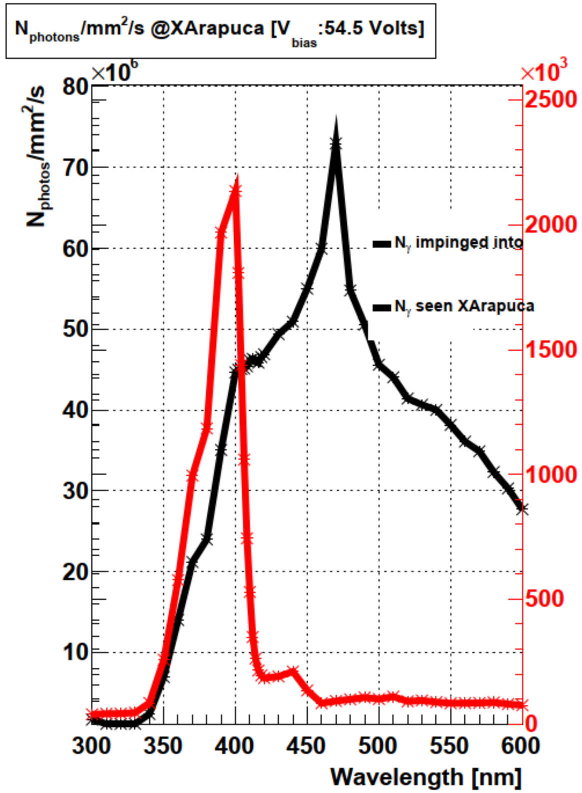
$$N_{photons}^{XA} = \frac{I_{XA}}{Gain * e * S_{XA}}$$

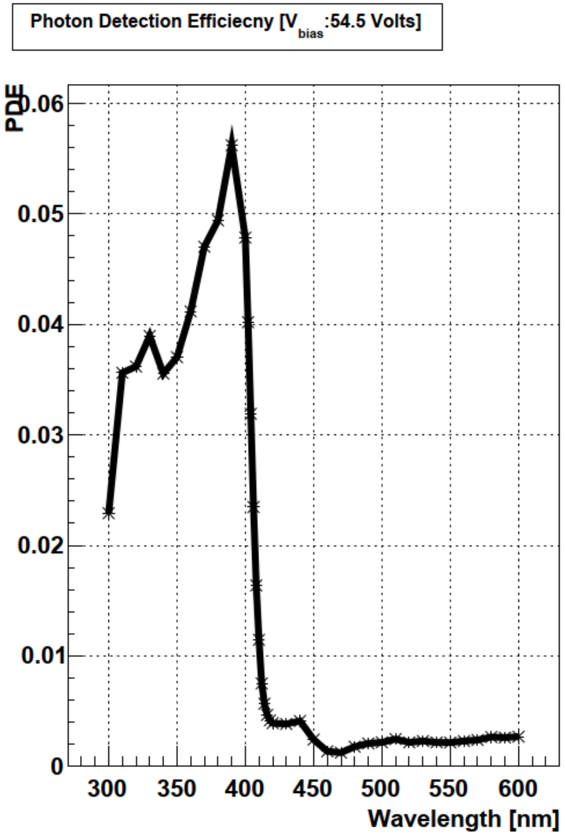
Then:

$$Efficiency = \frac{\sum_{channels} N_{photons}^{XA}}{N_{photons}^{port\,(n=5)}}$$

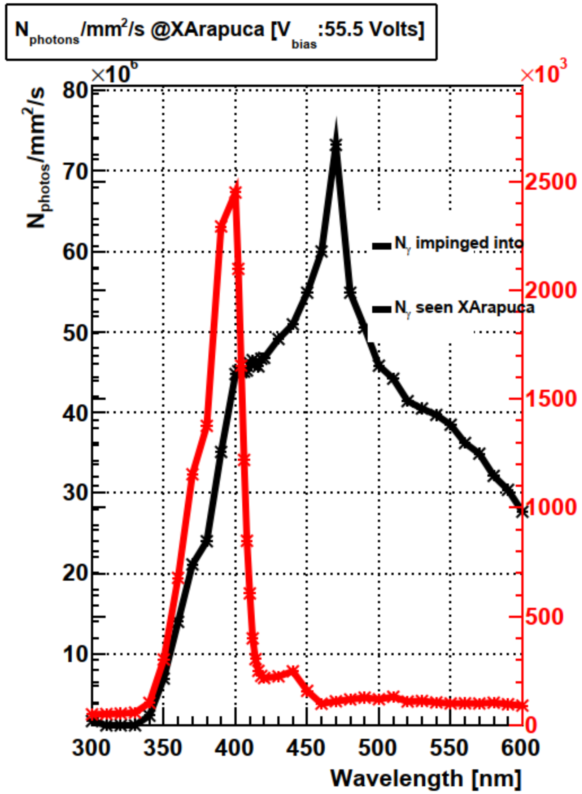


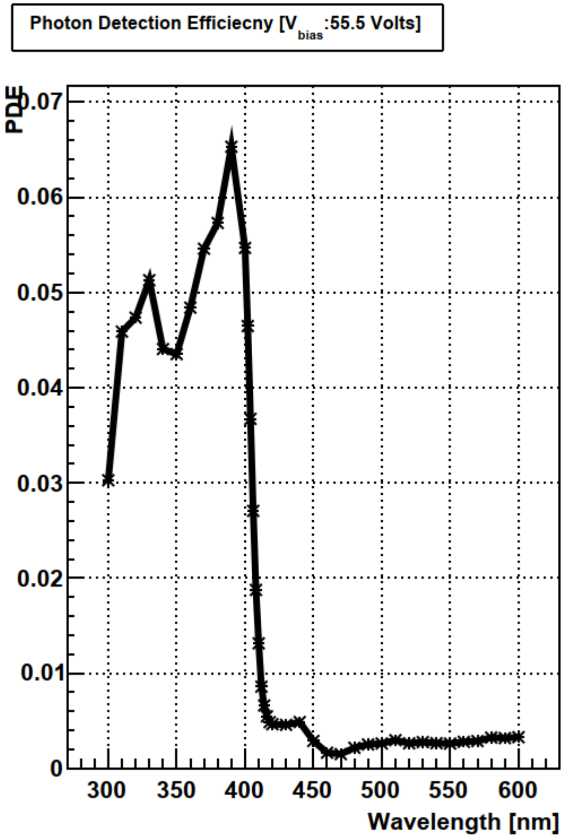


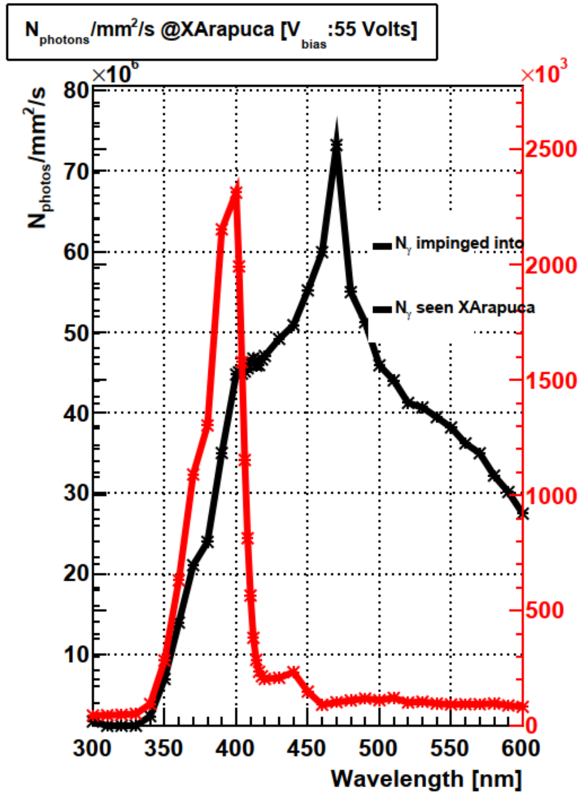


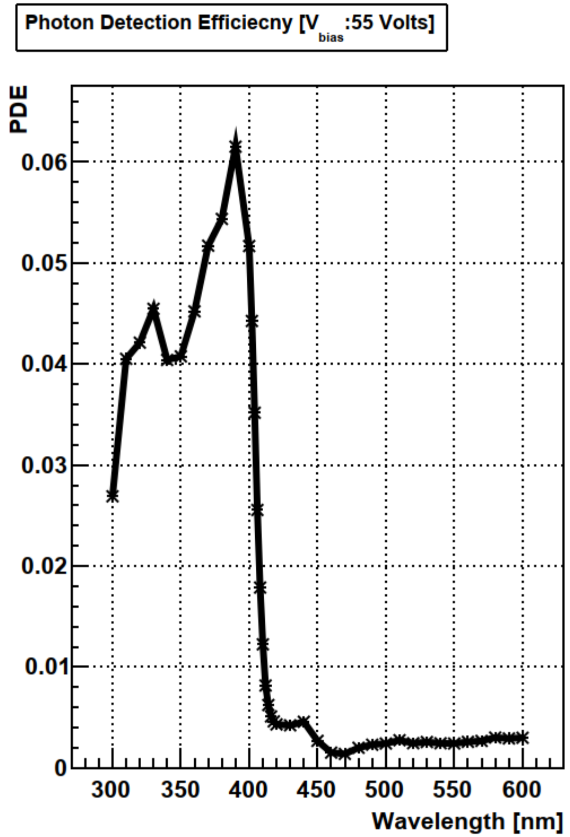


$$Efficiency = \frac{\sum_{channels} N_{photons}^{XA}}{N_{photons}^{port\ (n=5)}}$$

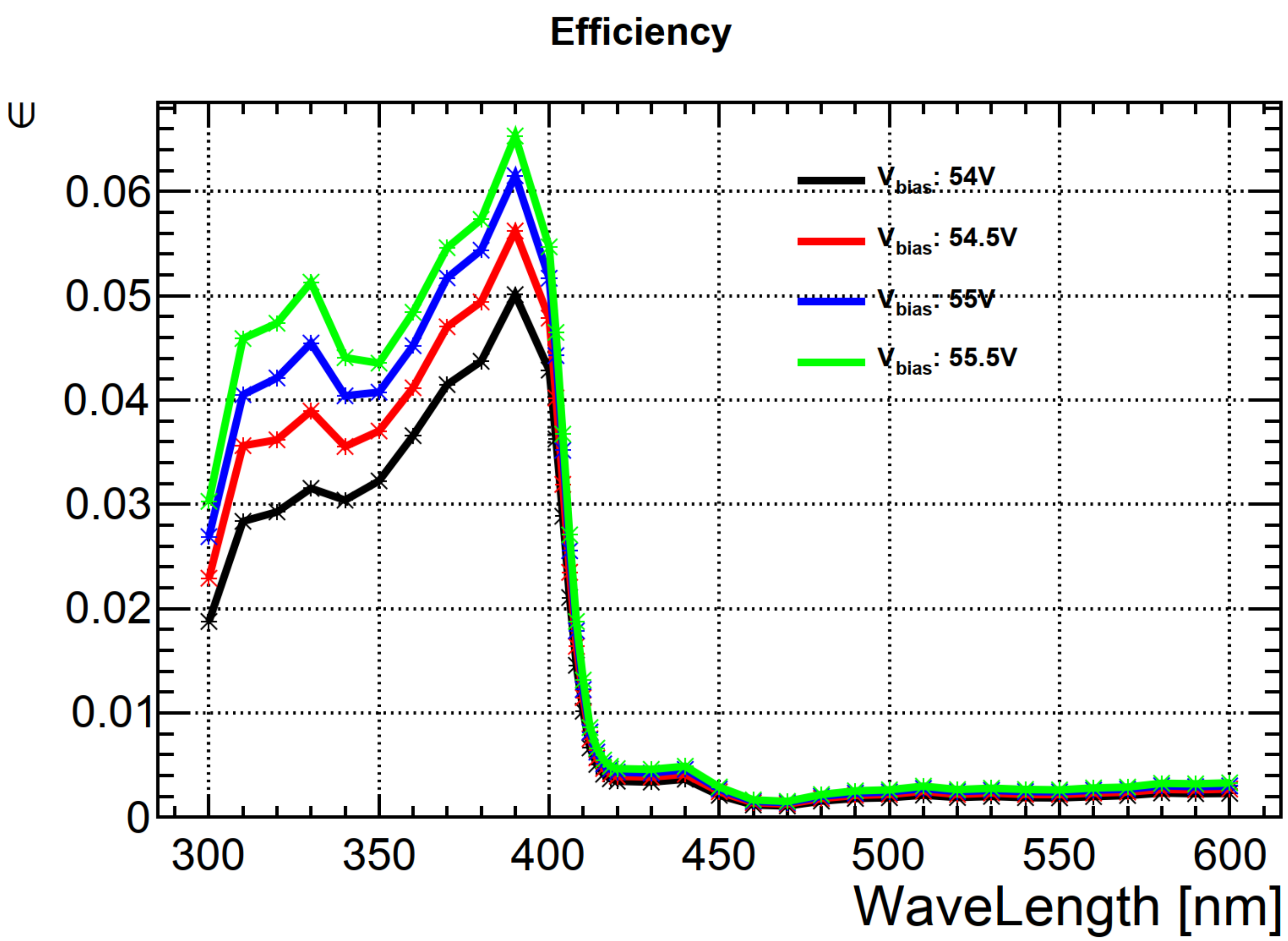








$$Efficiency = \frac{\sum_{channels} N_{photons}^{XA}}{N_{photons}^{port\ (n=5)}}$$



Efficiency
ε
0.06
0.05
0.04
0.03
0.02
0.01
0
300
350
400
450
500
550
600
WaveLength [nm]
V_bias: 54V
V_bias: 54.5V
V_bias: 55V
V_bias: 55.5V

- **XArapuca w/o Quartz window tested under Monochromatic light source.**
- **PhotoCurrent method used to study the performance at different wavelength in room temp.**
- **XArapuca is blind to the light above 400 nm (cut off dichroic filters)**
- **It would be interesting to test the device in cold and also for lower wavelength.**
- **Preparing a note where all the steps of the discussed analysis are explained..**

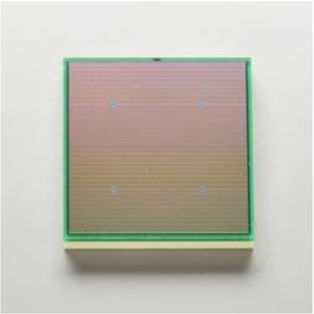
Back-up

SiPM used in XArapuca modules

Electrical and optical characteristics (Ta=25 °C, Vover=3 V, unless otherwise noted)

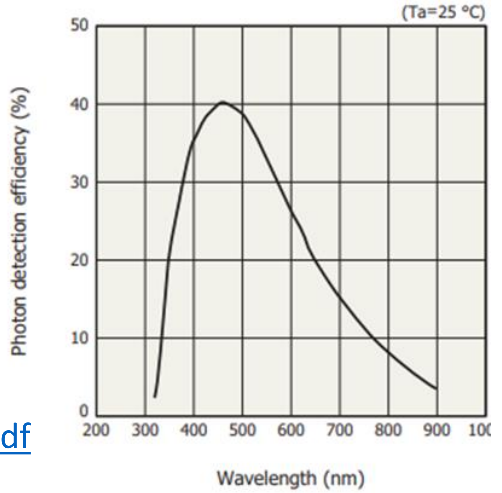
Parameter		Symbol	S13360 -2050VE	S13360 -3050VE	S13360 -6050VE	Unit
Spectral response range		λ	320 to 900			nm
Peak sensitivity wavelength		λp	450			nm
Photon detection efficiency (λ=λp)[*3]		PDE	40			%
Dark count[*4]	Typ.	-	0.3	0.5	2	Mcps
	Max.		0.9	1.5	6	Mcps
Terminal capacitance		Ct	140	320	1300	pF
Gain		M	1.7×10^6			-
Breakdown voltage[*5]		V_{BR}	53 ± 5			V
Recommended operating voltage		Vop	V_{BR} + 3			V
Temperature coefficient of recommended operating voltage		ΔTVop	54			mV/°C

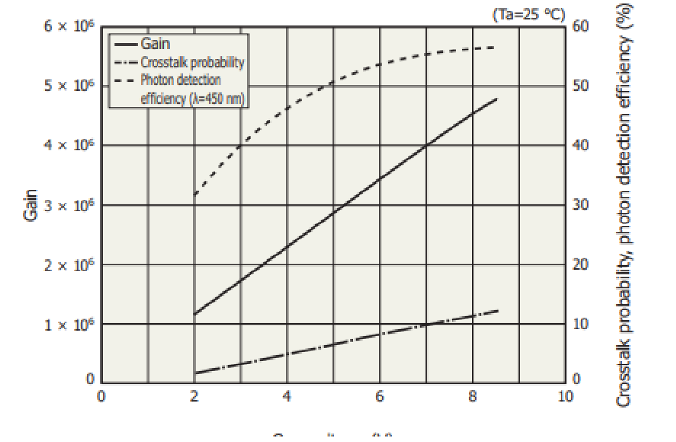
*3: Photon detection efficiency does not include crosstalk or afterpulses.
*4: Threshold=0.5 p.e.
*5: If you have any requests of breakdown voltage selection, please feel free to contact us.
Note: The above characteristics were measured at the operating voltage that yields the listed gain.
(See the data attached to each product.)



S13360-6050VE

Photon detection efficiency vs. wavelength (typical example)

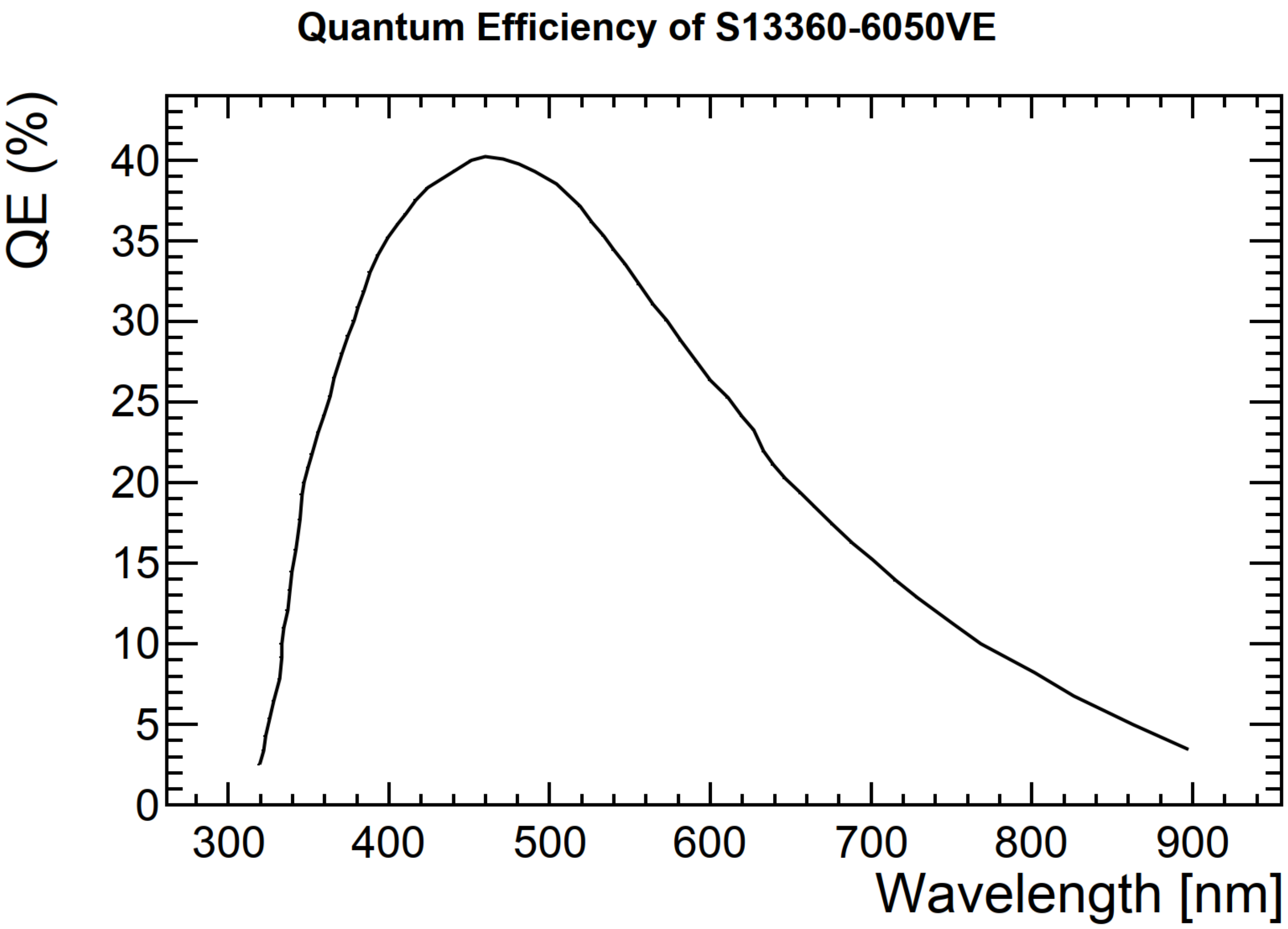




4-SiPMs per channel → 144 mm2 active surface

@ 2V over voltage gain ~1E6

https://www.hamamatsu.com/resources/pdf/ssd/s13360-2050ve_etc_kapd1053e.pdf



Quantum Efficiency of S13360-6050VE
QE (%)
0
5
10
15
20
25
30
35
40
300
400
500
600
700
800
900
Wavelength [nm]