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Setup of a batch test facility for the characterization of photomultipliers for the SSD-Upgrade of the Pierre Auger Observatory

Astroparticle School - Obertrubach-Bärnfels

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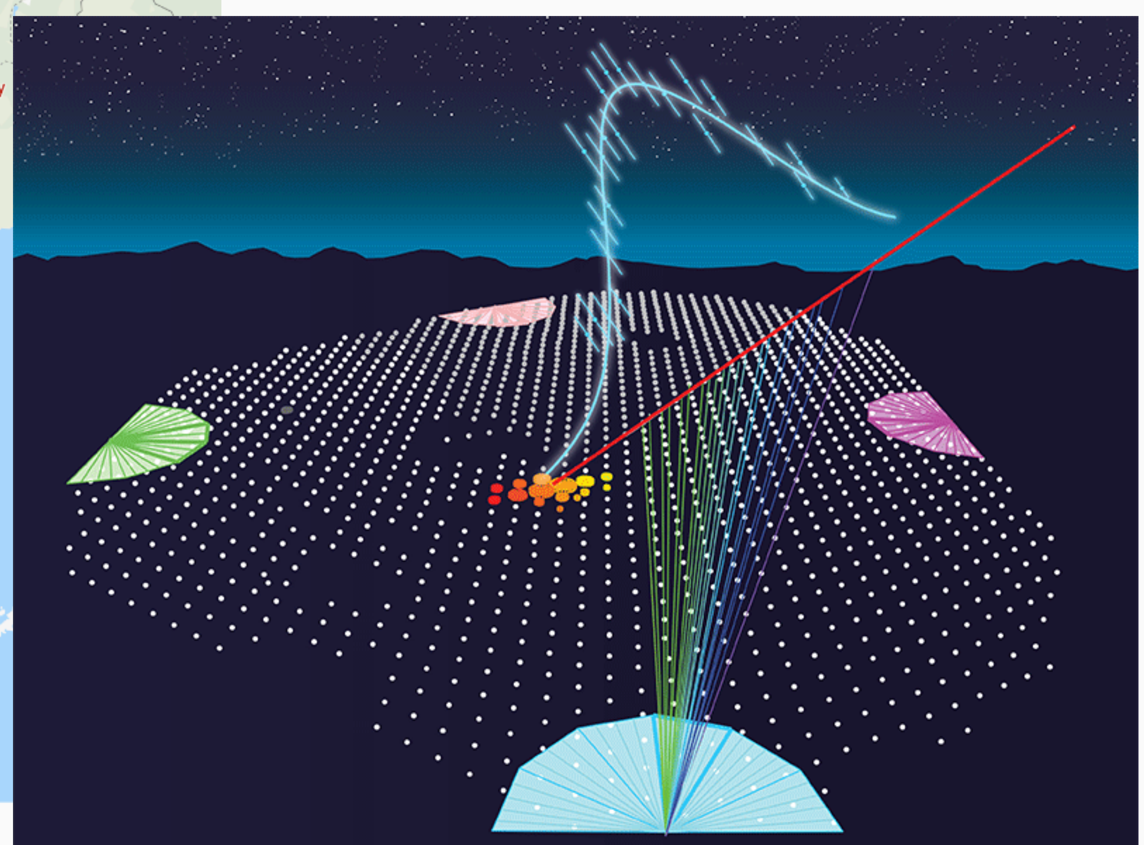
University of Wuppertal
October 10, 2018

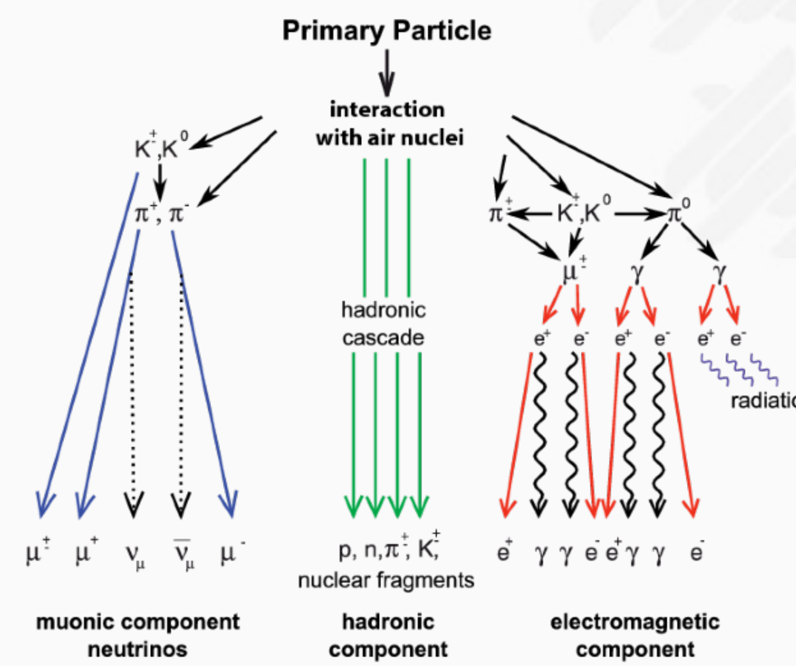
Bundesministerium für Bildung und Forschung

The Pierre Auger Observatory

Hybrid detection of cosmic rays:

- measure longitudinal profile (FD) of dE/dx
- measure footprint (SD) of μ/em-component
  about 1660 water-Cherenkov detectors on





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AugerPrime: Upgrade of all 1660 stations

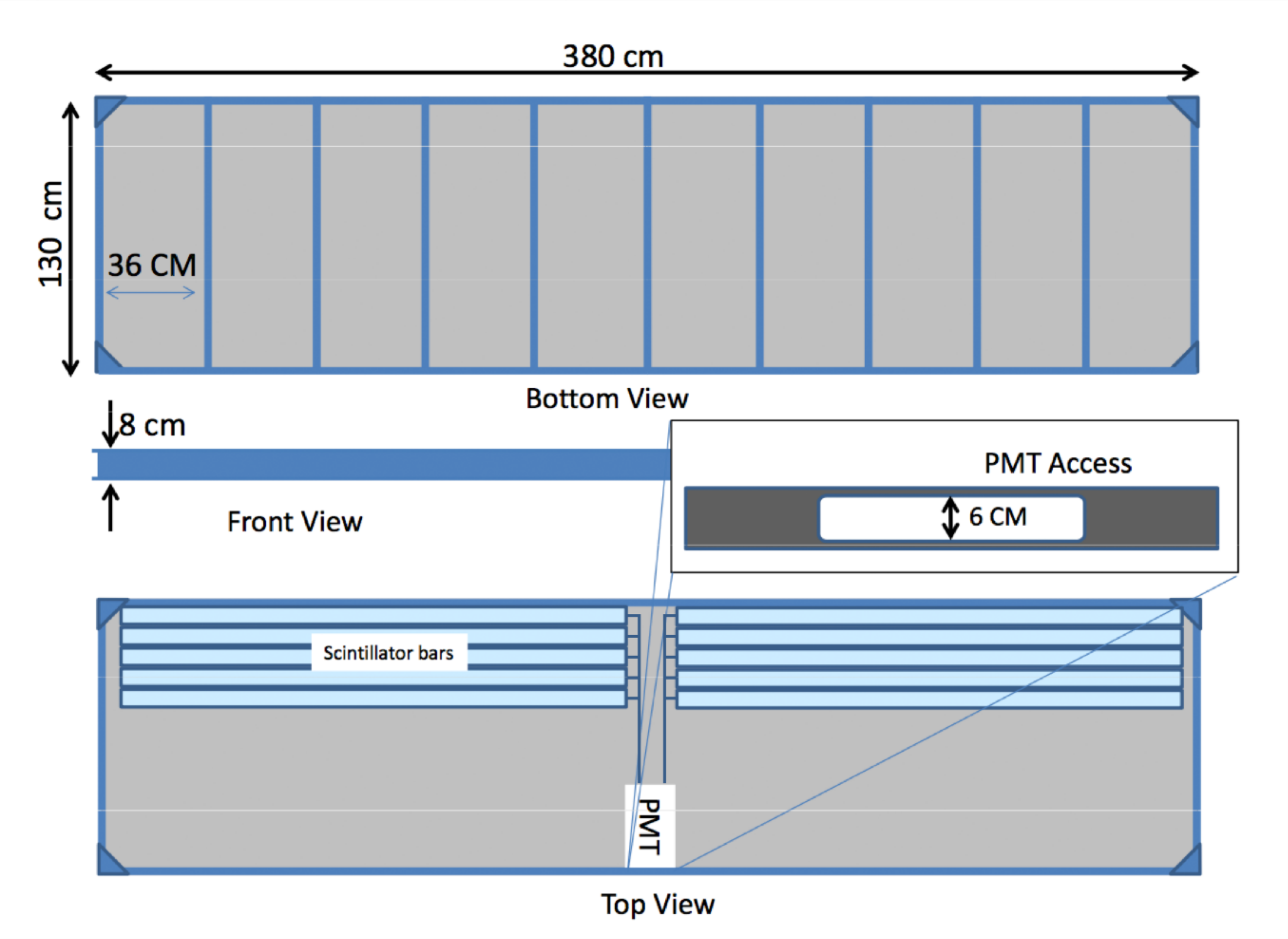
$4m^2$ plastic scintillator plane on top of every water-Cherenkov detector

Detector station with SSD Upgrade [1]

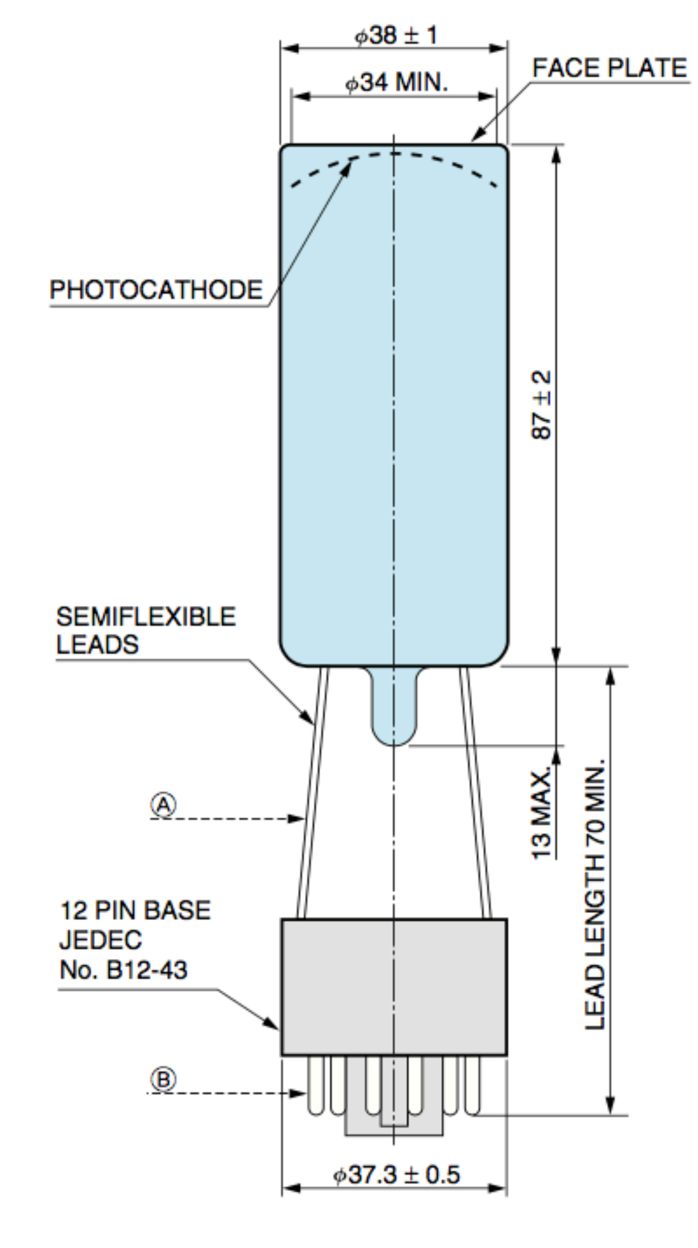
Benefits:

- better separation of μ/em-component
- increase mass composition sensitivity
- doubling event statistics until 2024
- reducing systematic uncertainty
- possibility of comparison with TA due to scintillator plates

PMT Specifications



Schematic view of external aluminum box [2] - modied

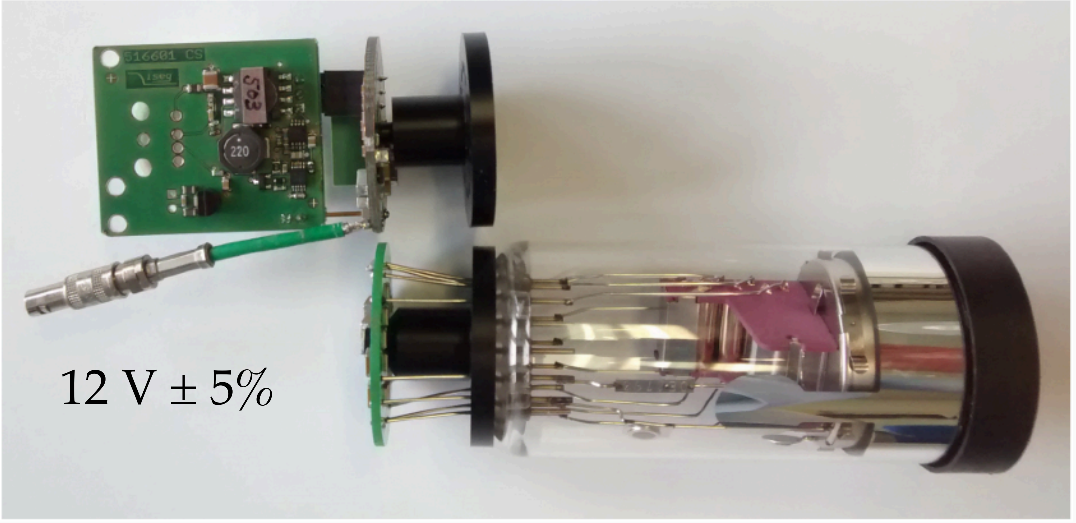


Schematic view of R9420 PMT [3]

PMT Face plate: Ø38 mm, operation of 8 Dynode-Stages

integrated HV shows clear benefits in comparison with external HV:

- no external HV cabling and supply
- cost reduction
- reduced power dissipation
- high temperature stability



Hamamatsu R9420 PMT with soldered and separated ISEG base [2]

Hamamatsu R9420 PMT fully mounted and soldered

PMT Specifications

some Key Specifications for SSD PMTs - from Tender

Dark Current: < 10nA at 20°C temperature after 30 min in darkness

Quantum Efficiency > 18%

→ **Homogeneity** of photo cathode: Response should not vary by more than ± 25% over active area

Spectral Response 300 nm - 650 nm

Gain: 8 amplification stages, standard operation at 5×10^4 (at 850 V ± 100 V)

Linearity: linear response within better than 5% over dynamic range of at least 2×10^4 up to maximum anode current of 150 mA

PMT Specifications

BERGISCHE UNIVERSITÄT WUPPERTAL

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Spectral Response 300 nm - 650 nm

Gai … operation at 5 x 10^4

(at 8

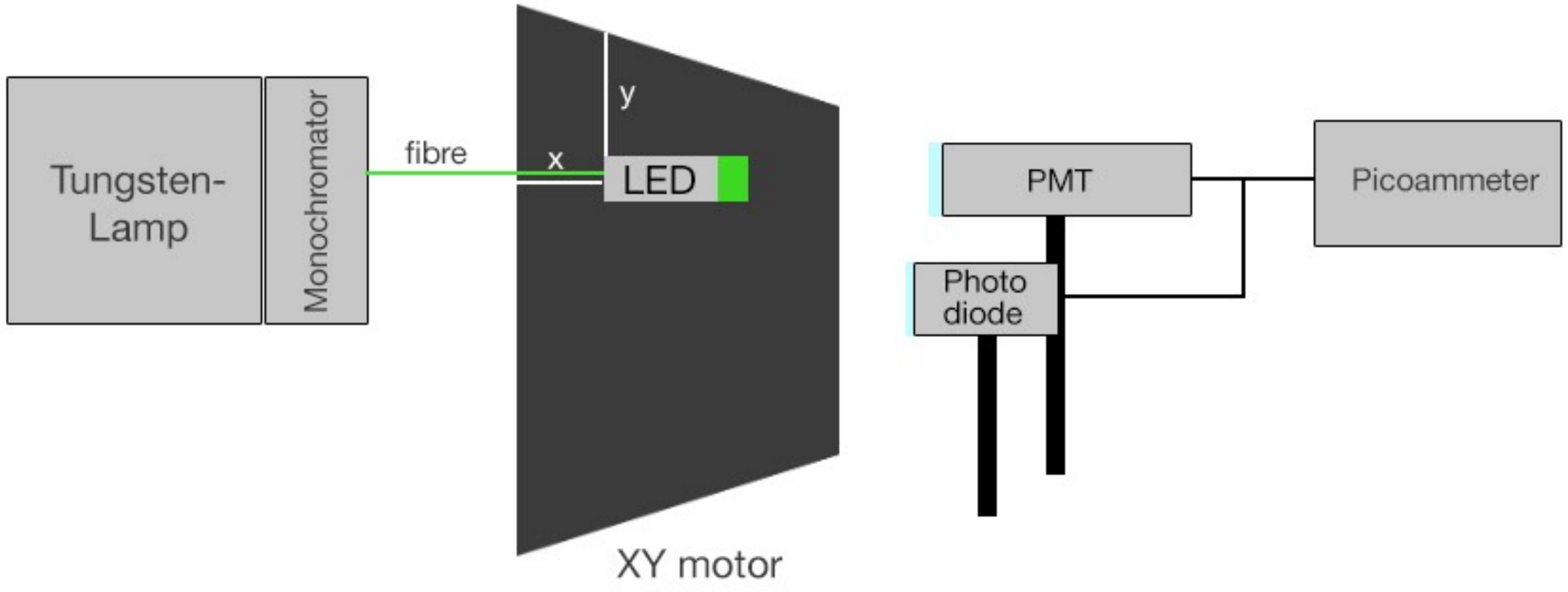
Line … than 5 … e of at least

2 x 1 … f 150 m

results when test bench ready

PMT Specifications

Brief overview of QE Setup (already built up)

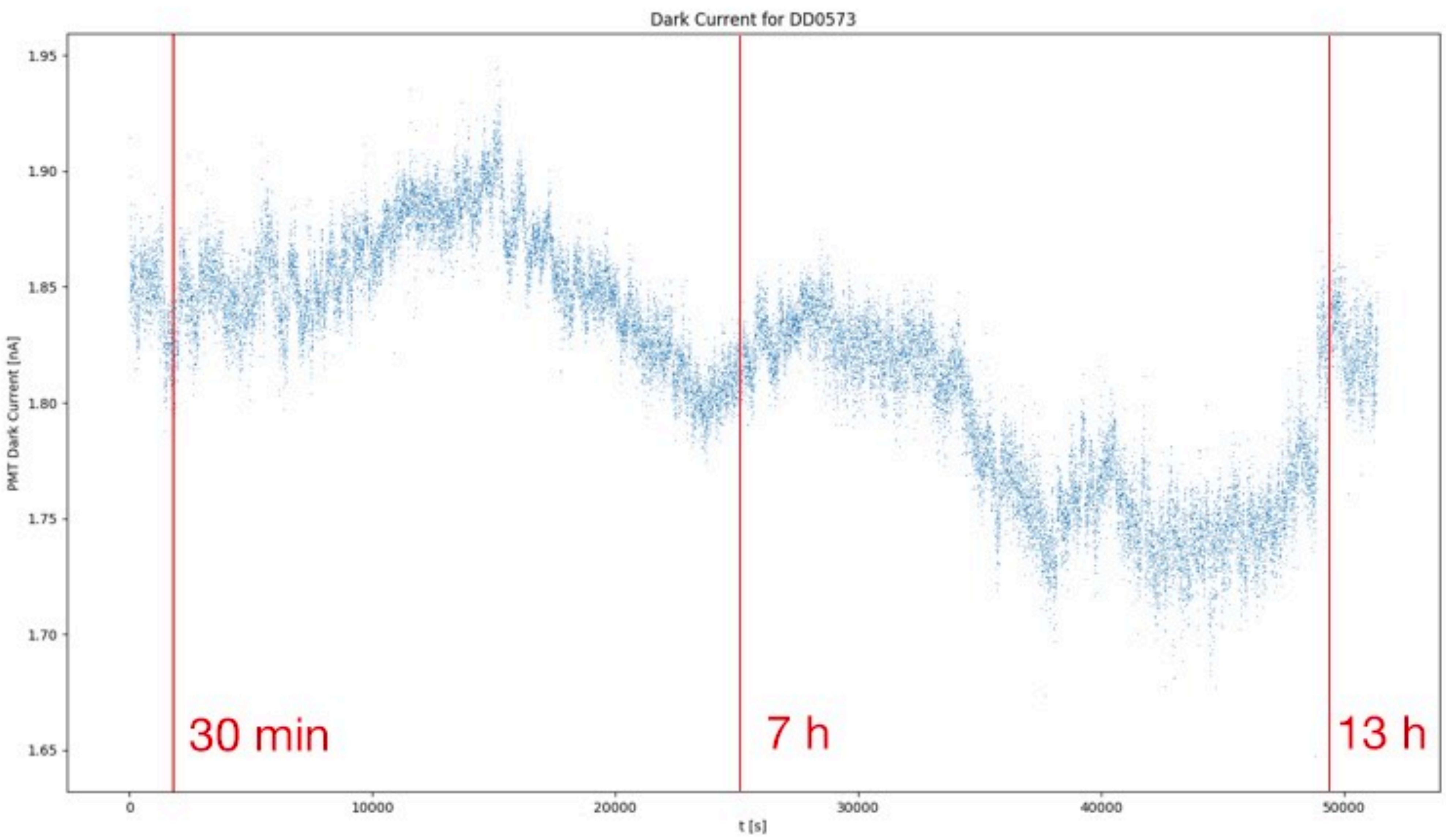


Calculation of QE: $$Q_{PMT} = \frac{I_{PMT} - I_{DC,PMT}}{I_{Diode} - I_{DC,Diode}} \cdot Q_{Diode}$$

PMT Specifications

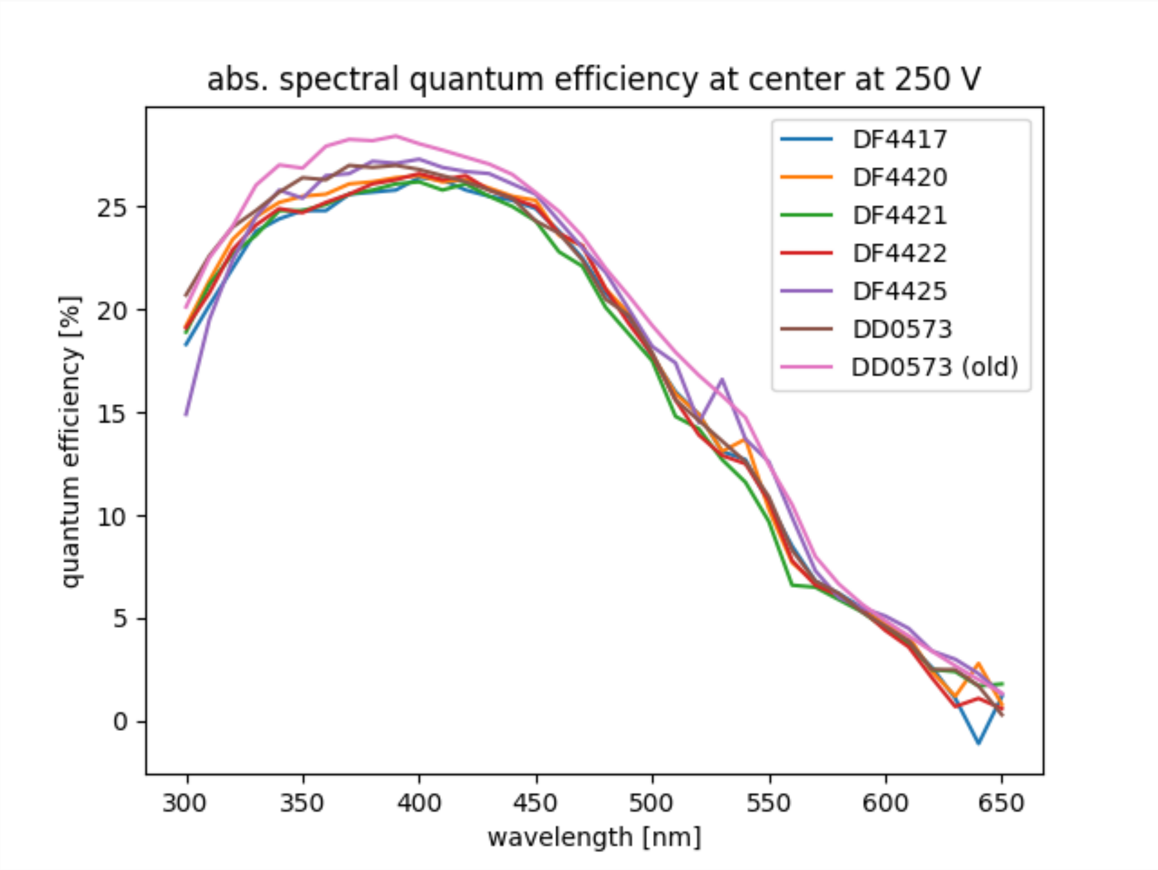
(Photocathode) Dark Current at all times < 10nA

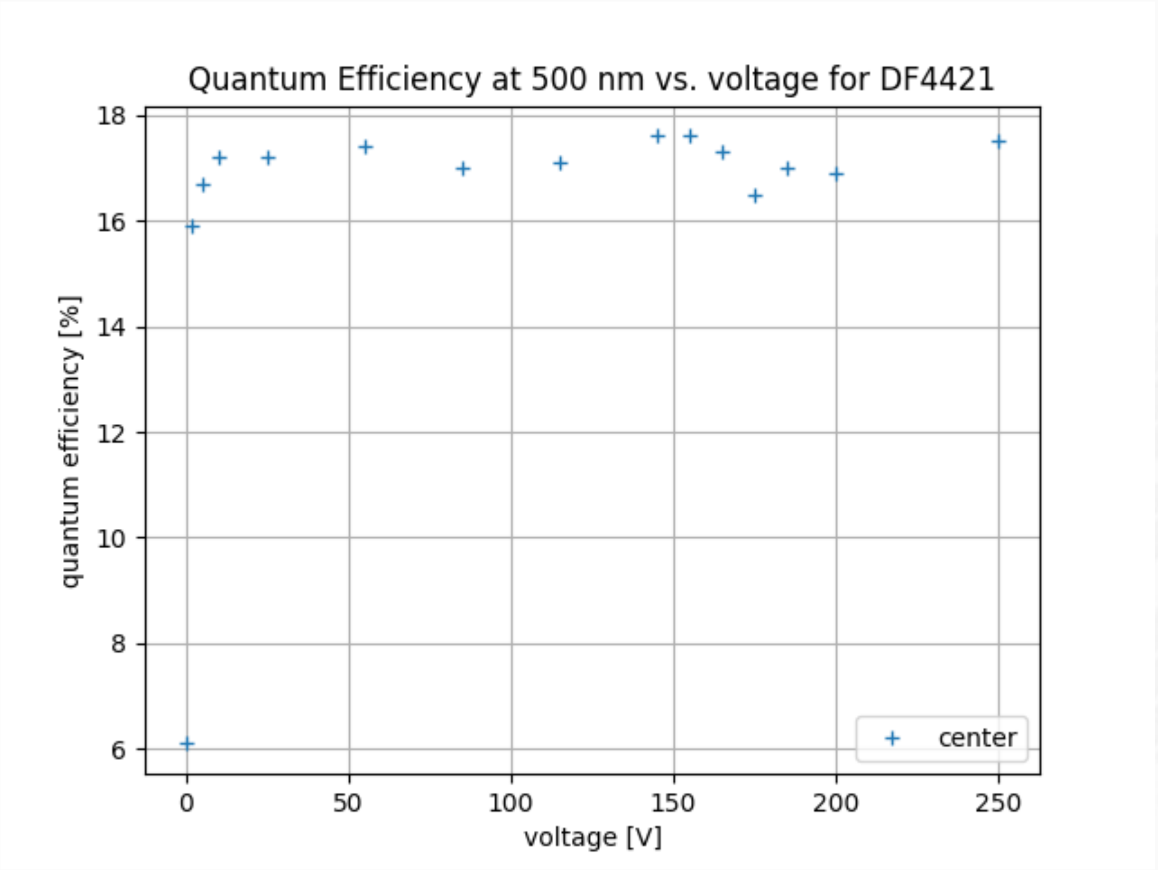
(Measurement in dark box in a dark room)



PMT Specifications

Quantum Efficiency





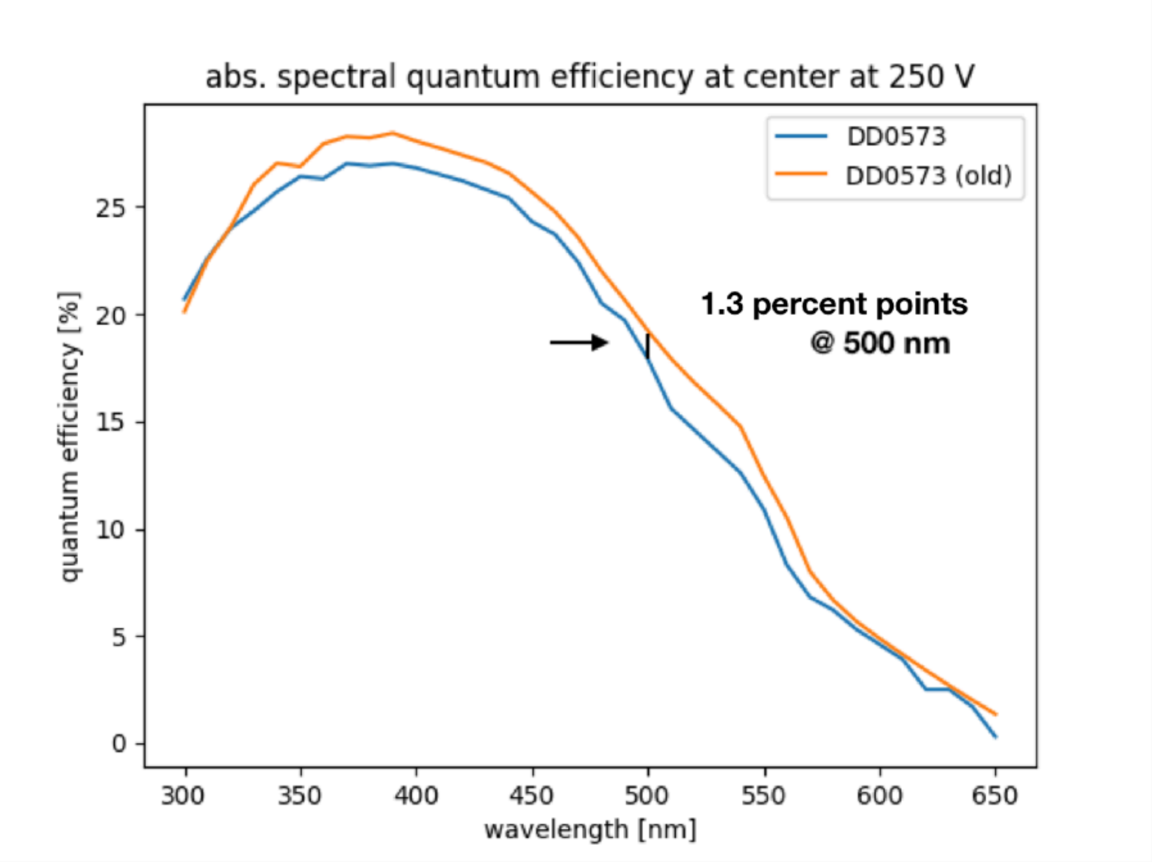
slightly low QE - possible reasons:

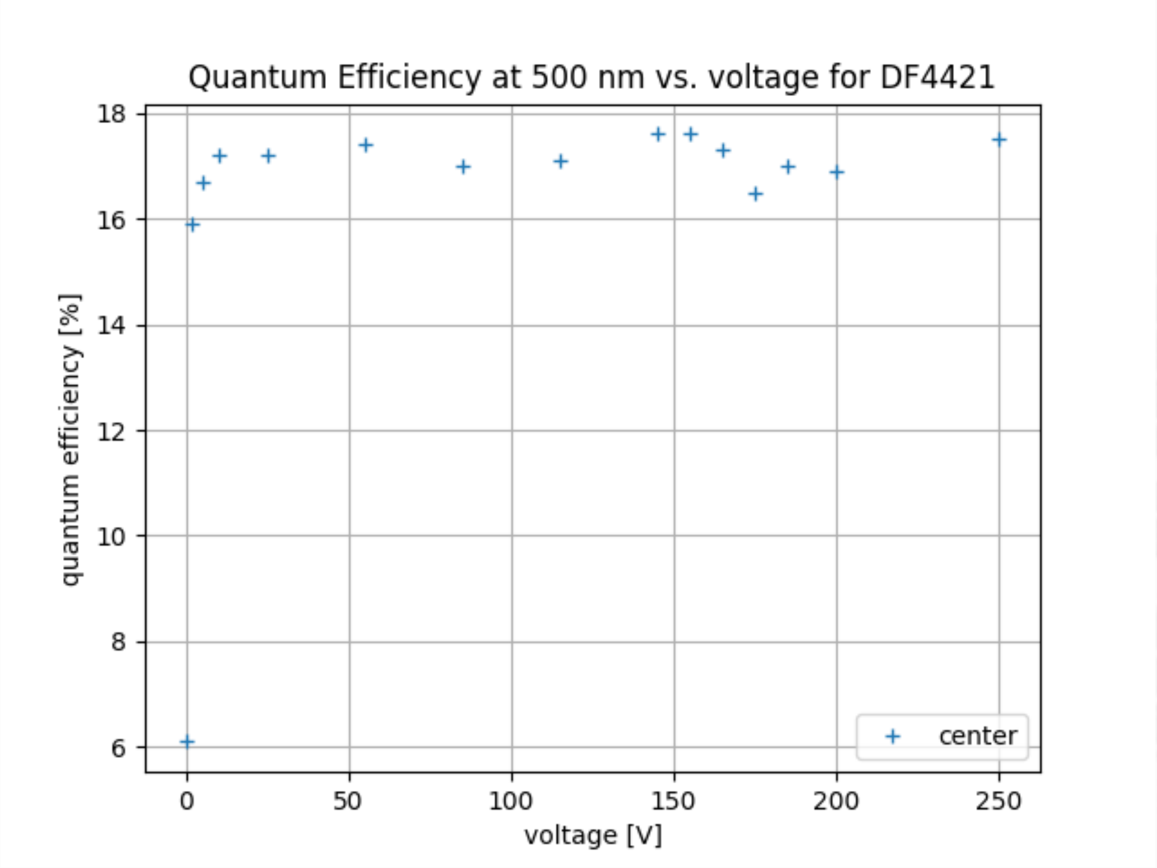
- warmup of Tungsten lamp
- incorrect applied HV
- HV effect stabilization
- instable dark current
- unprecise positions

collection efficiency stabilizes for low HV

PMT Specifications

Quantum Efficiency





slightly low QE - possible reasons:

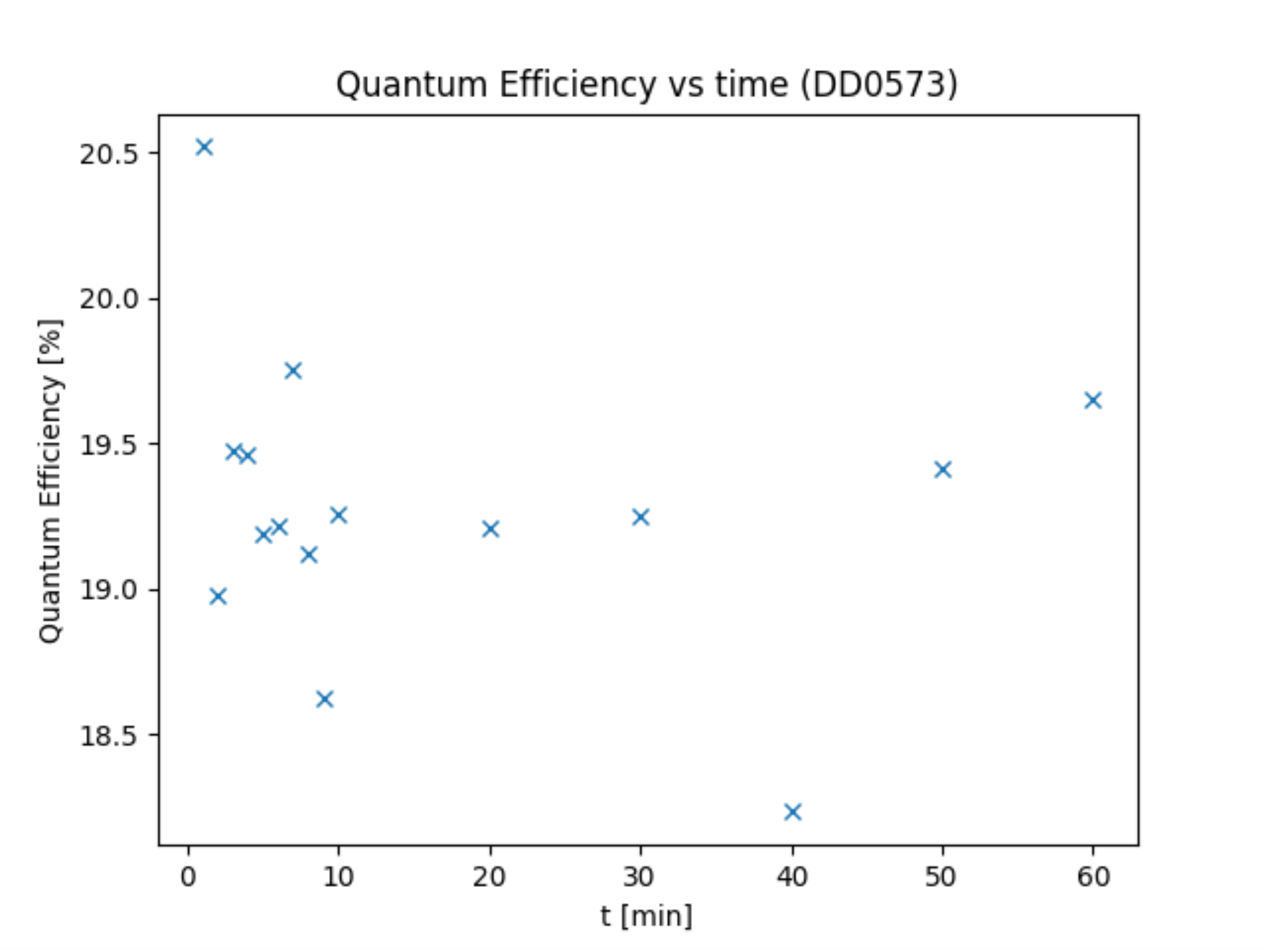
- warmup of Tungsten lamp
- incorrect applied HV
- HV effect stabilization
- instable dark current
- unprecise positions

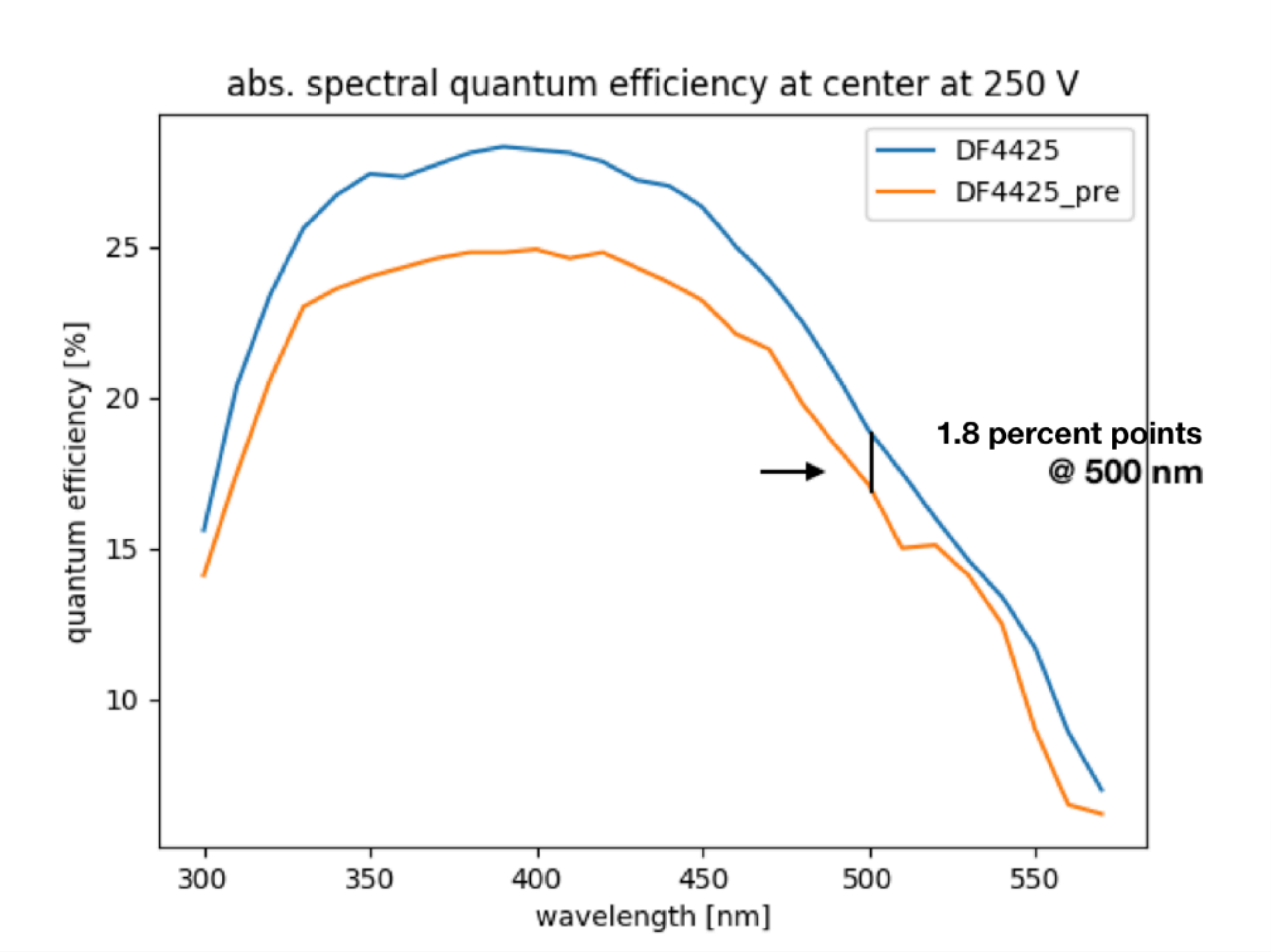
QE stabilizes already for low voltage

PMT Specifications

Quantum Efficiency

new measurements





HV (250 V) taking effect (500 nm)

at 500 nm: ~ abs. 1.8% difference

PMT Specifications

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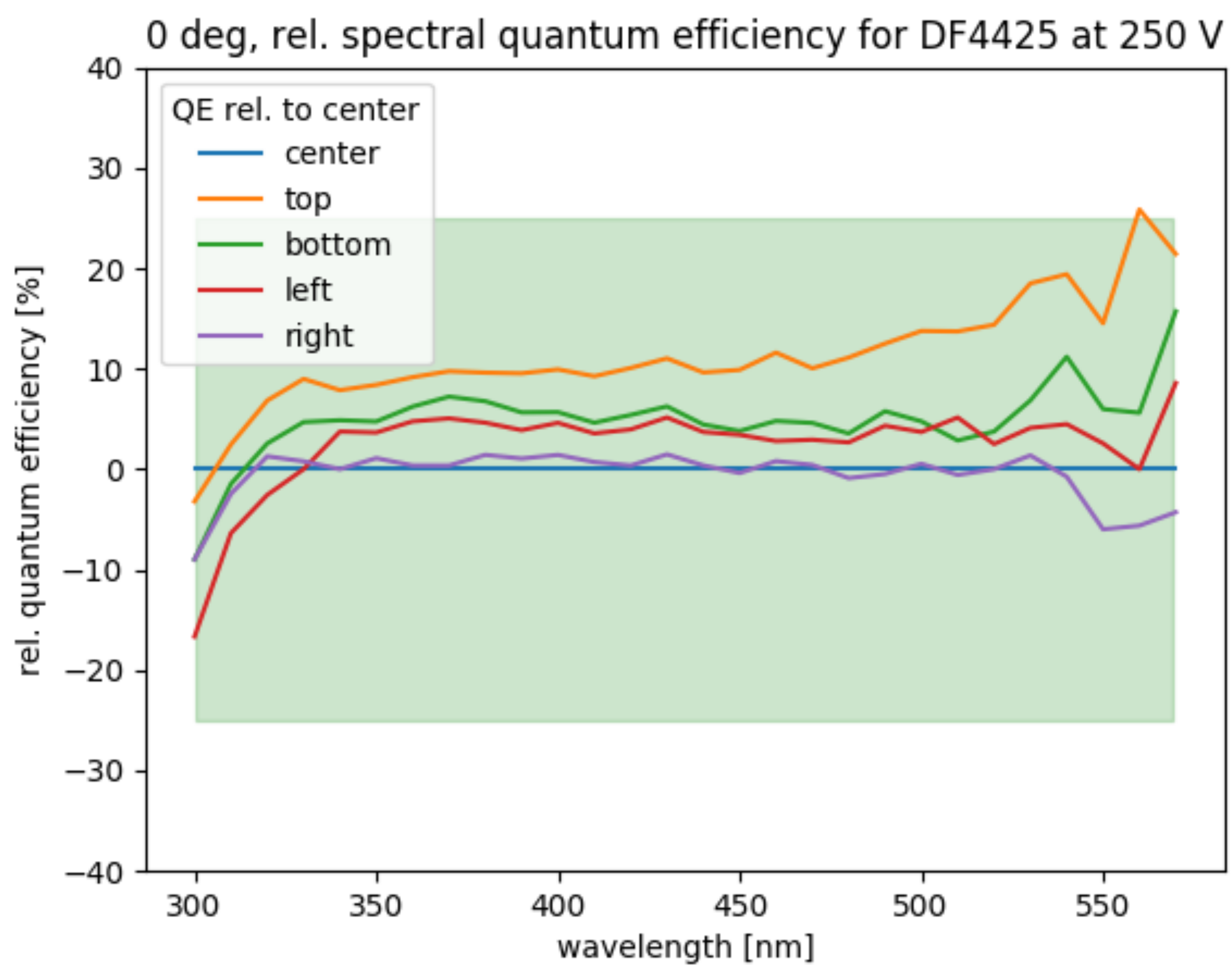
Homogeneity of photo cathode



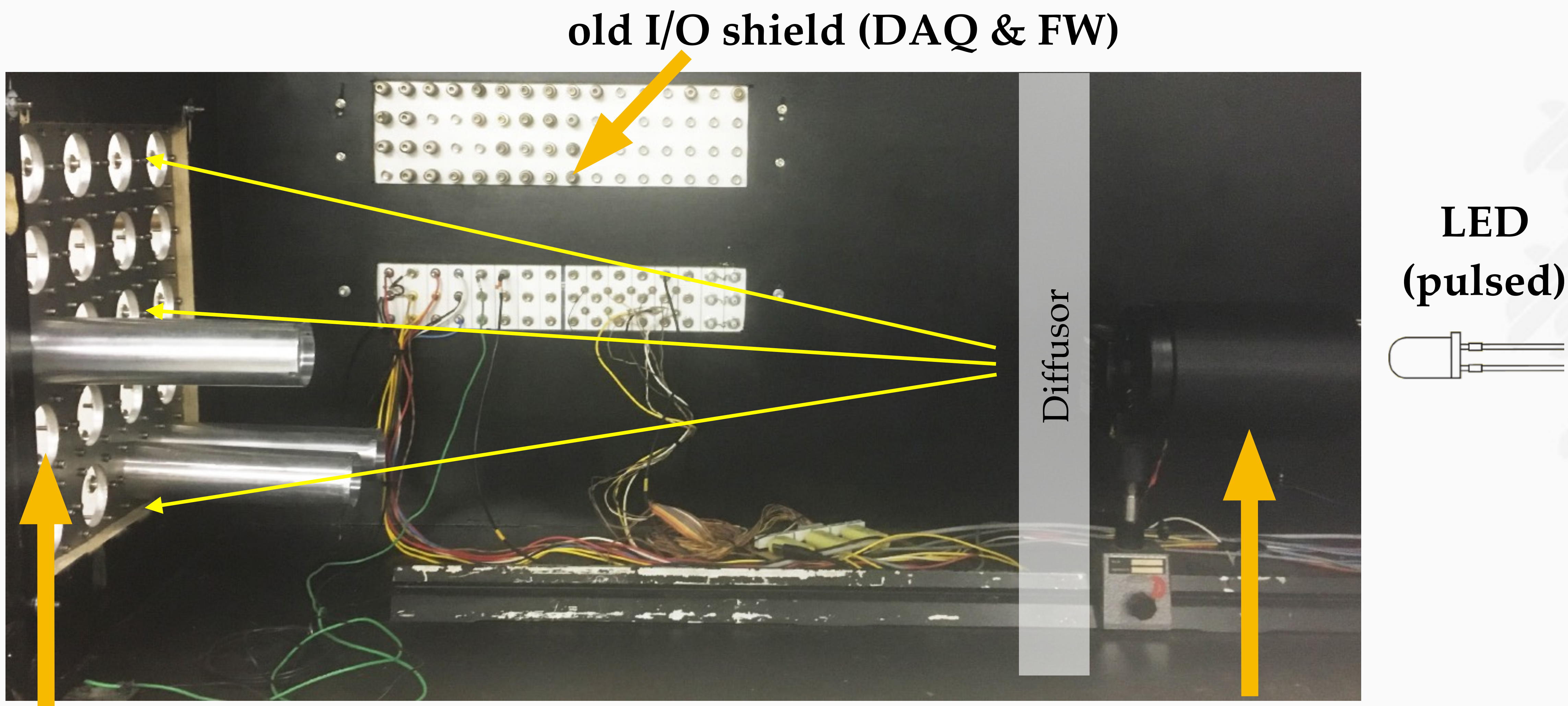
$$QE_{\text{rel}} = \frac{QE_{\text{pos}} - QE_{\text{center}}}{QE_{\text{center}}}$$

=> QE deviations within 25%

Test setup

PMT batch test box still in preparation

Reminder: Aim to measure Linearity and Gain



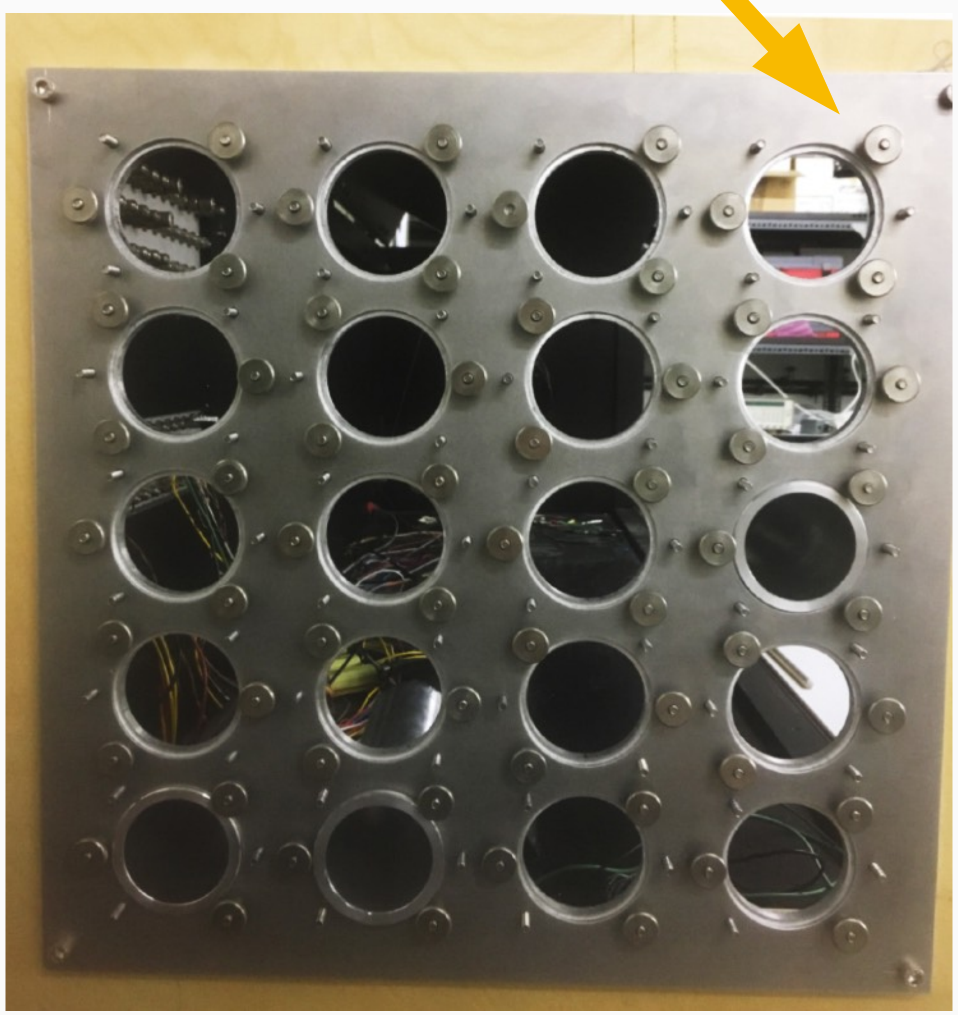
planned new DAQ and slow control

Thorlabs Filterwheel (FW212)

Test setup

PMT batch test bench in preparation:

easy PMT change by using knurled screws



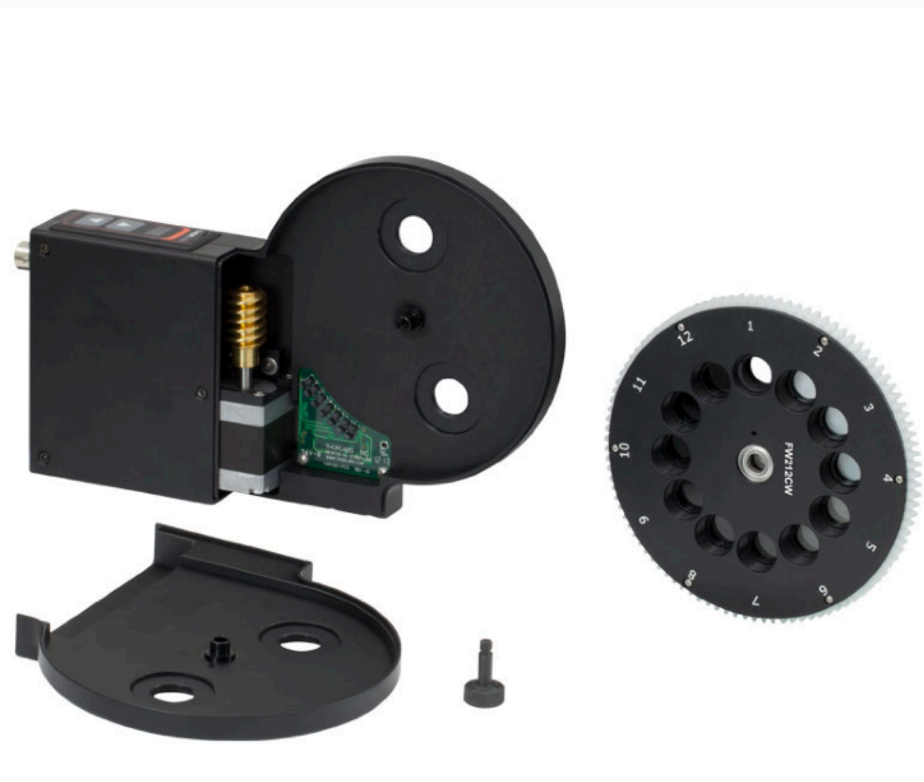
Aluminium front plate for batch testing of 20 PMTs simultaneously

Hamamatsu R9420 PMT fully mounted and soldered

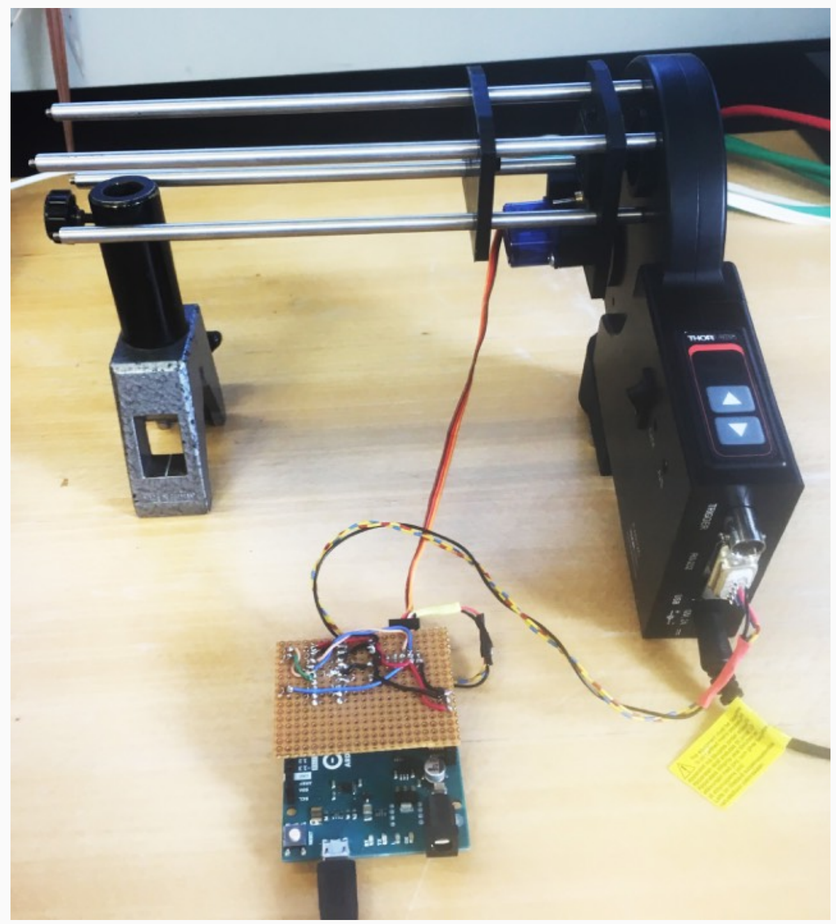
Test setup

Combination of Iris & Filterwheel for different attenuation factors

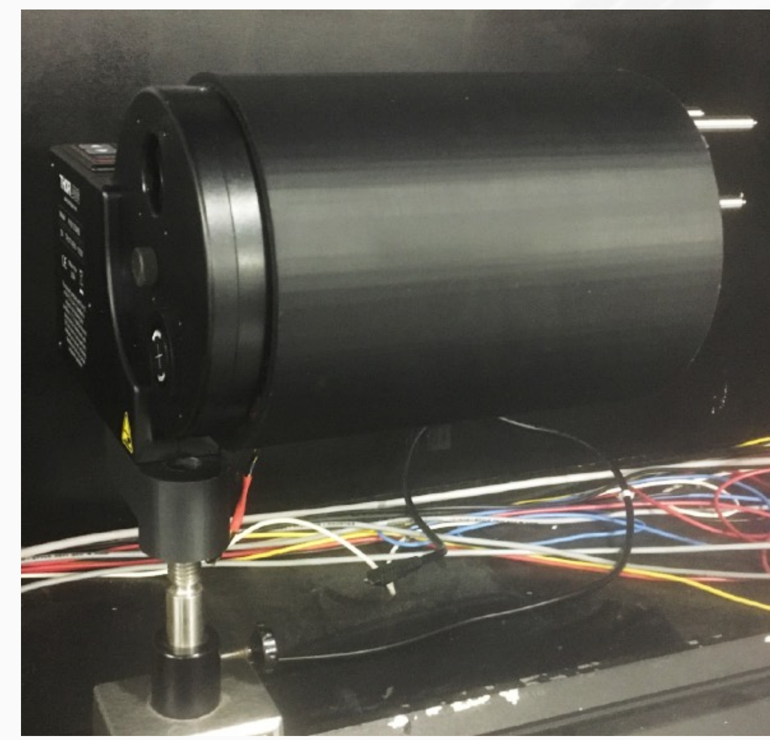
Simultaneous control structure via Serial Bus through Arduino



Thorlabs Filterwheel FW212C [4]



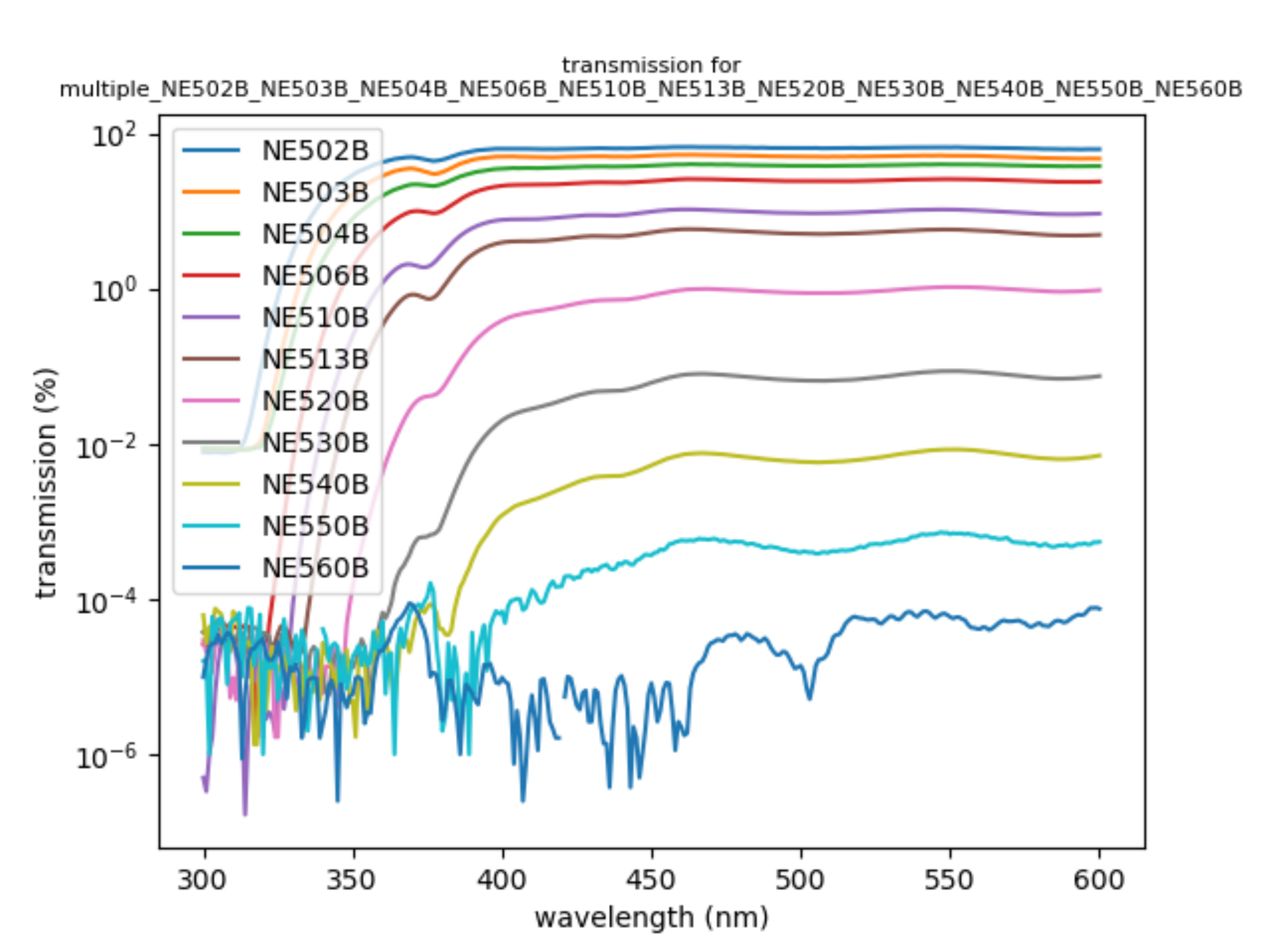
Filterwheel, Iris, Arduino



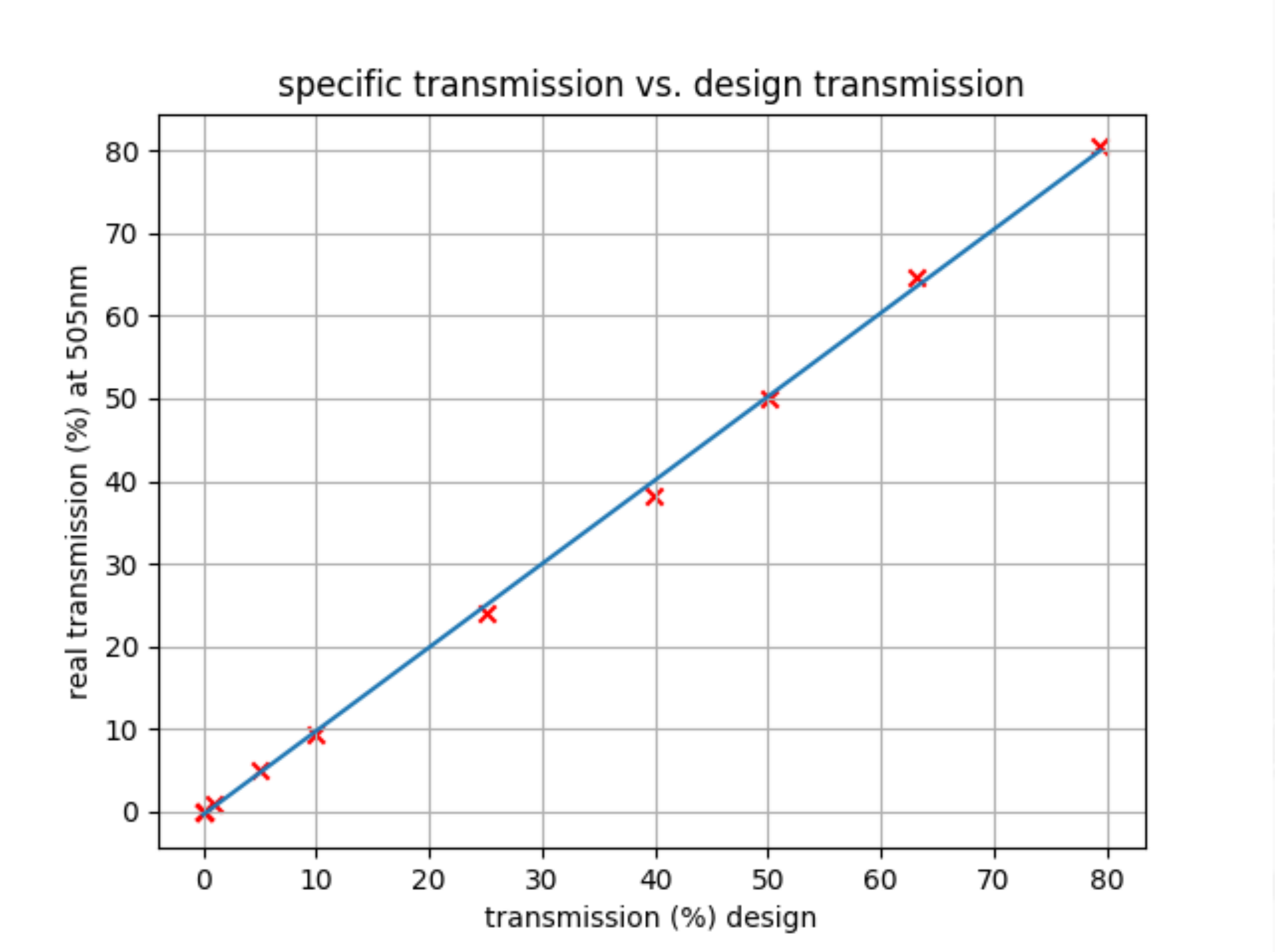
Filterwheel, Iris, Arduino mounted within printed shell, LED 500 nm

Test setup

ND filter attenuation - with respect to specific wavelength



wavelength vs. transmission - factory values form Thorlabs

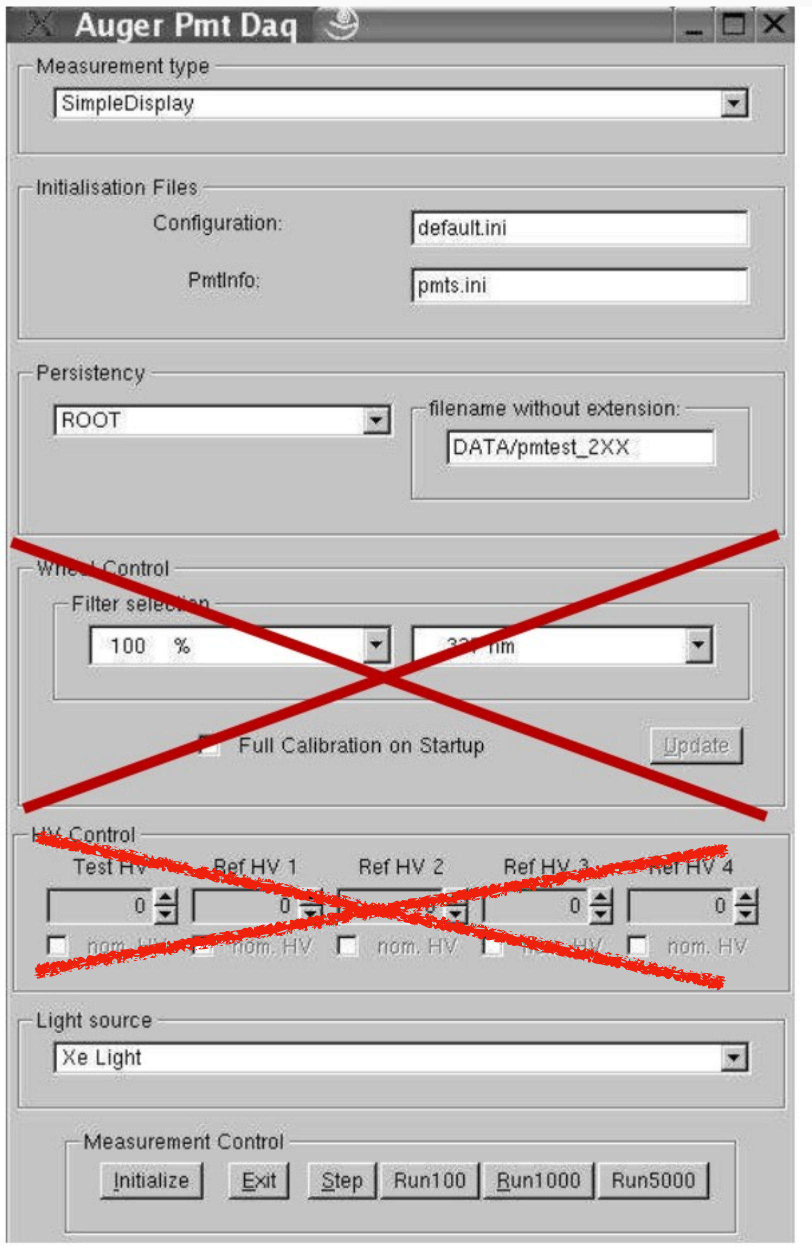


design transmission vs. real transmission at specific wavelength

→ test lower limit of detection dynamic range:
Single Photon Condition

Test setup

ROOT GUI



Settings PMT batch

Output format

New implementation:
- Iris & Filterwheel (separated/combined)
- HV control

High pulse number of LED
for adequate statistics

Outlook & Summary

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- **Measurements difficult because of various error sources but tendencies are mostly within specs**
- **PMT batch test box in preparation**
- **Slow Control, Filterwheel and Iris control integration into existing ROOT GUI**
- **doing measurements of mentioned PMT specifications**
- **sending PMTs to the field end of 2018/beginning 2019**
- **inserting relevant PMT parameters to MySQL DB for offline analysis**

Thank you for your attention! 🙂

References:

1. The Pierre Auger Observatory Upgrade - Preliminary Design Report
   The Pierre Auger Collaboration, 2016
2. Integrated HV-Supply for SSD PMTs, Gap Note, S. Querchfeld, K.H. Becker, K.-H. Kampert, Julian Rautenberg, 2017
3. Hamamatsu R9420 Specifications Datasheet, retrieved on 03.09.2018
4. Thorlabs Website, www.thorlabs.com, retrieved on 03.09.2018

Backup

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TECHNICAL INFORMATION

TENTATIVE
Feb. 2018

R9420 SEL

For Pierre Auger Observatory, Fast time response,
38 mm (1.5 inch) Diameter, Bialkali Photocathode, 8-stage, Head-On Type

GENERAL

Parameter		Description / Value	Unit
Spectral Response		300 to 650	nm
Peak Wavelength of Cathode Radiant Sensitivity		420	nm
Window	Material	Borosilicate glass	-
	Shape	Plano concave	-
Photocathode	Material	Bialkali	-
	Minimum Effective Area	ϕ34	mm
Dynode Structure / Number of Stages		Linear Focused / 8	-
Operating Ambient Temperature (with Socket)		-30 to +50	ºC
Storage Temperature (w/o Socket)		-80 to +50	ºC
Suitable Socket		E678-12A	-
Recommended Supply Voltage between Anode and Cathode		1300	V

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	1500	V
	Between Anode and Last Dynode	350	V
Average Anode Current		0.1	mA

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

Electrodes	K		Dy1		Dy2		Dy3		Dy4		Dy5		Dy6		Dy7		Dy8		P
Ratio		4		1.5		1.5		1		1		1		1		1		1	

Supply Voltage: 1300 V, K: Cathode, Dy: Dynode, P: Anode

MAXIMUM RATINGS (Absolute Maximum Values)

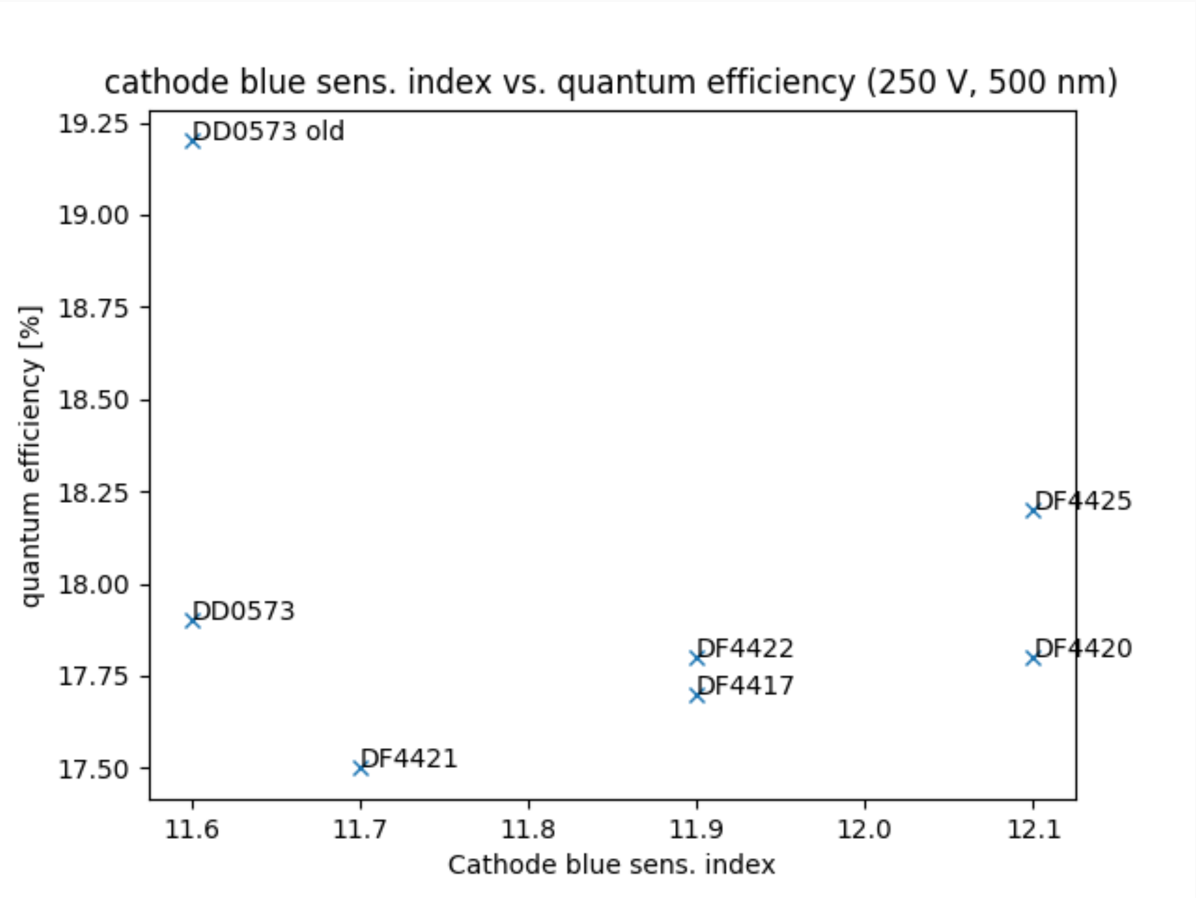
Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	1500	V
	Between Anode and Last Dynode	350	V
Average Anode Current		0.1	mA

CHARACTERISTICS (at 25 ºC)

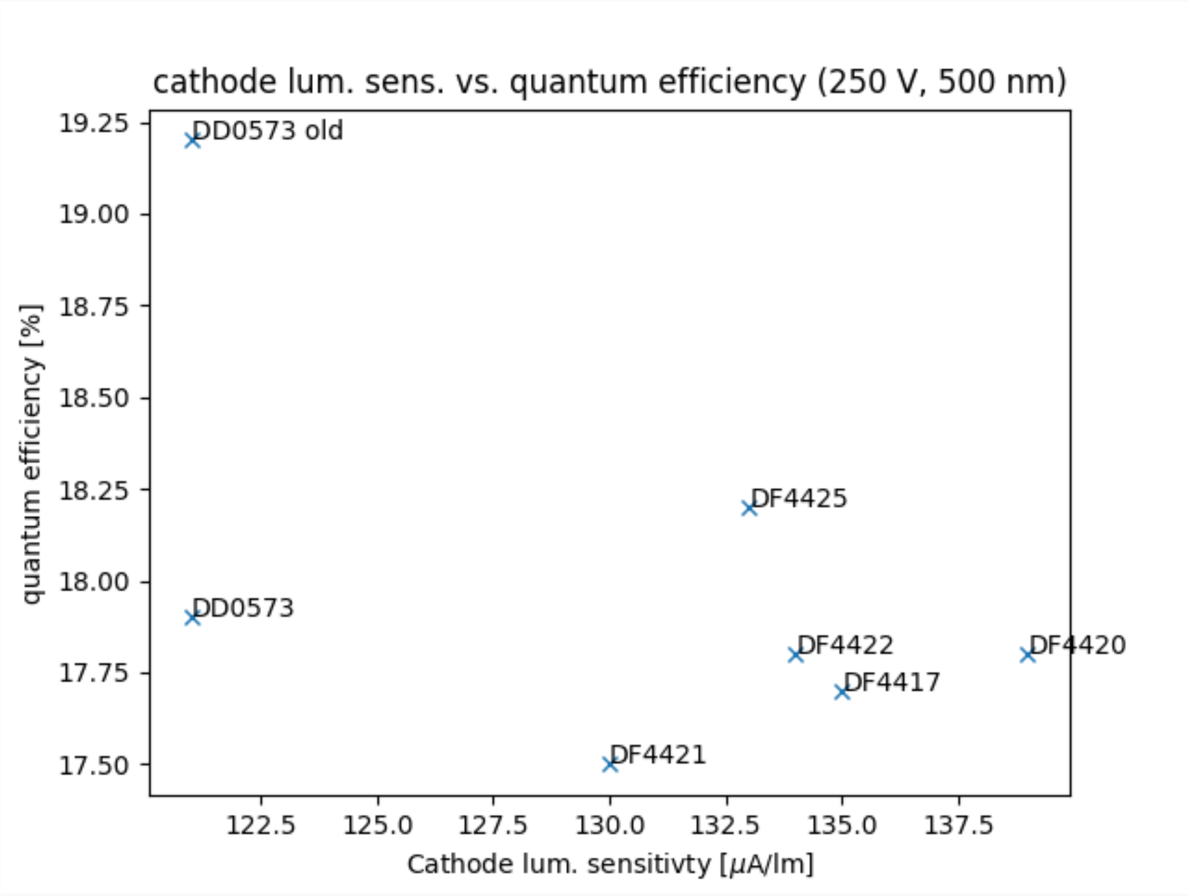
Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856K)	120	-	-	µA/lm
Cathode Blue Sensitivity Index (Cs 5-58)		9.0	11.0	-	-
Cathode Radiant Sensitivity (at 400 nm)		-	88	-	mA/W
Quantum Efficiency (at 500 nm) (Guaranteed)		18	-	-	%
Anode Sensitivity	Luminous (2856K)	-	50	-	A/lm
Ebbv (Nominal Voltage)	Gain 5×10^4	750	-	950	V
	Gain 7×10^5	-	1250	-	V
Ebbi (Dark Current at Ebbv)*	Gain 5×10^4	-	3.0	10	nA
	Gain 7×10^5	-	6.0	-	nA
Anode Output Rise Time at Ebbv (for Gain 5×10^4) (Guaranteed)		-	-	5.0	ns
Pulse Linearity at Ebbv(for Gain 7×10^5) (± 5% deviation) ** (Guaranteed)		150	-	-	mA
Cathode Uniformity in effective area (at 500 nm) (Guaranteed)		-25	-	25	%

NOTE: Anode characteristics are measured with the special voltage distribution ratio (Tapered ratio) and supply voltage shown next page.
NOTE*: Measured after 30min storage in the darkbox.
NOTE**: Detailed conditions are described on the next page.

Backup

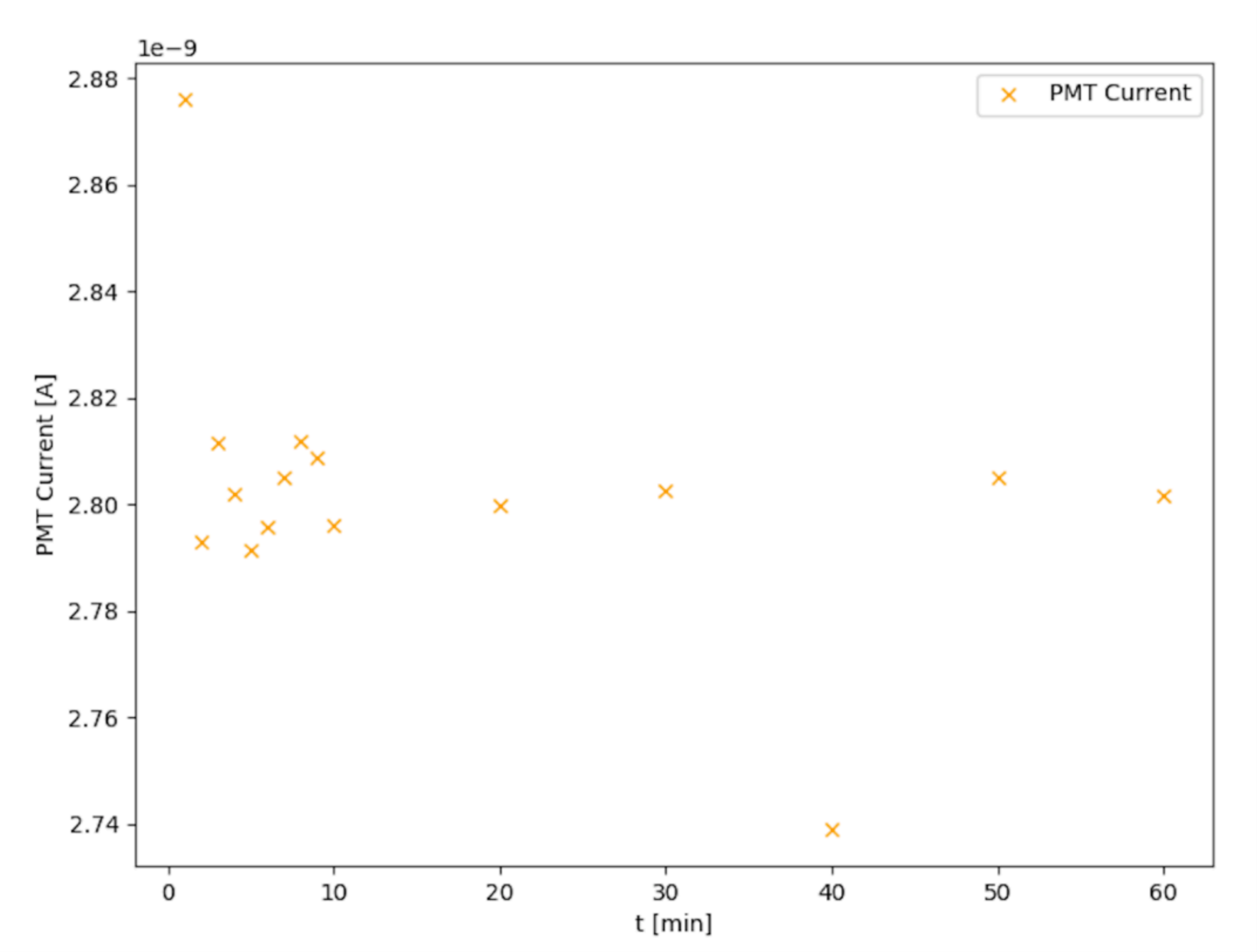


QE vs Cath. Blue Sens. Index

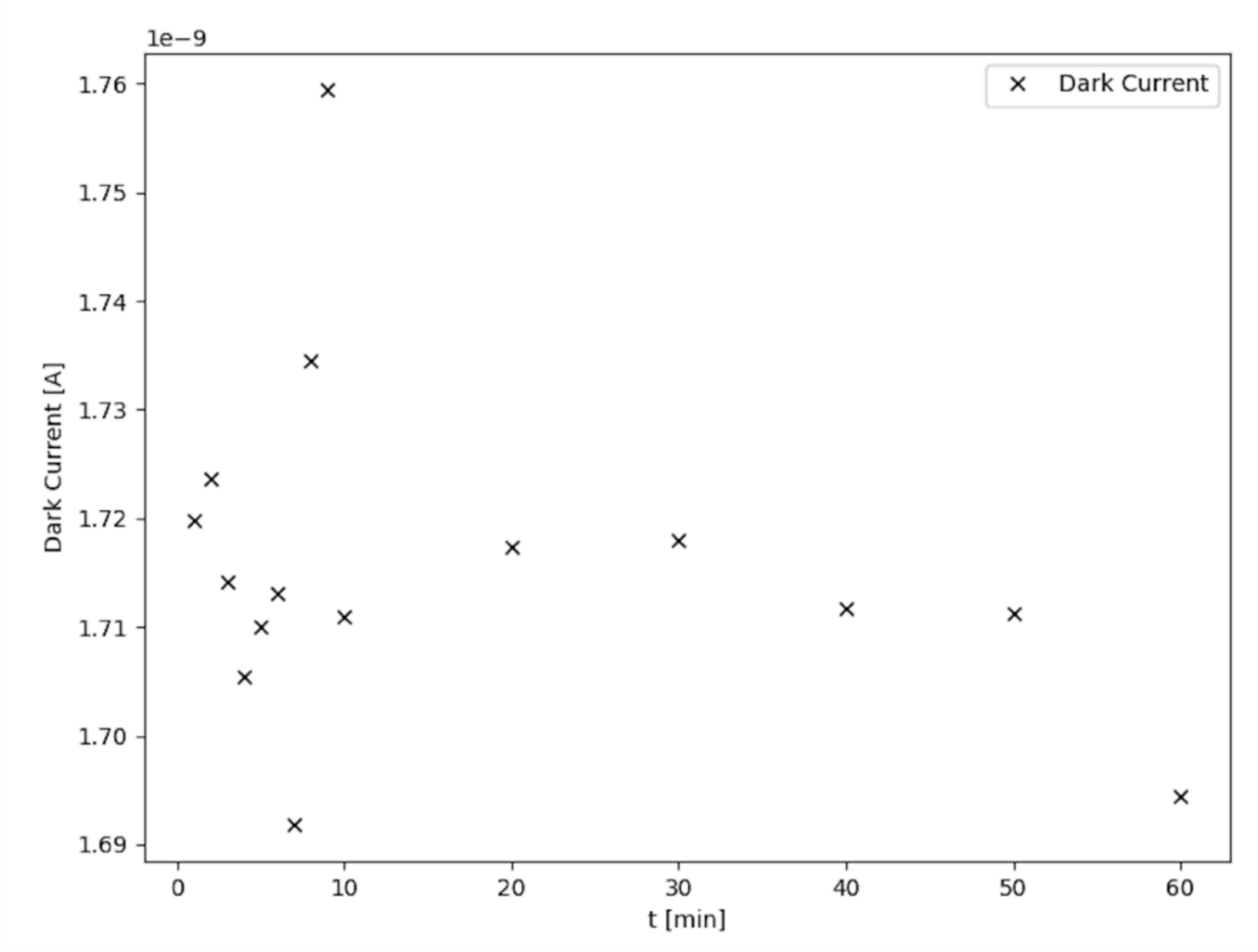


QE vs Cath. Lum Sens. Index

Backup

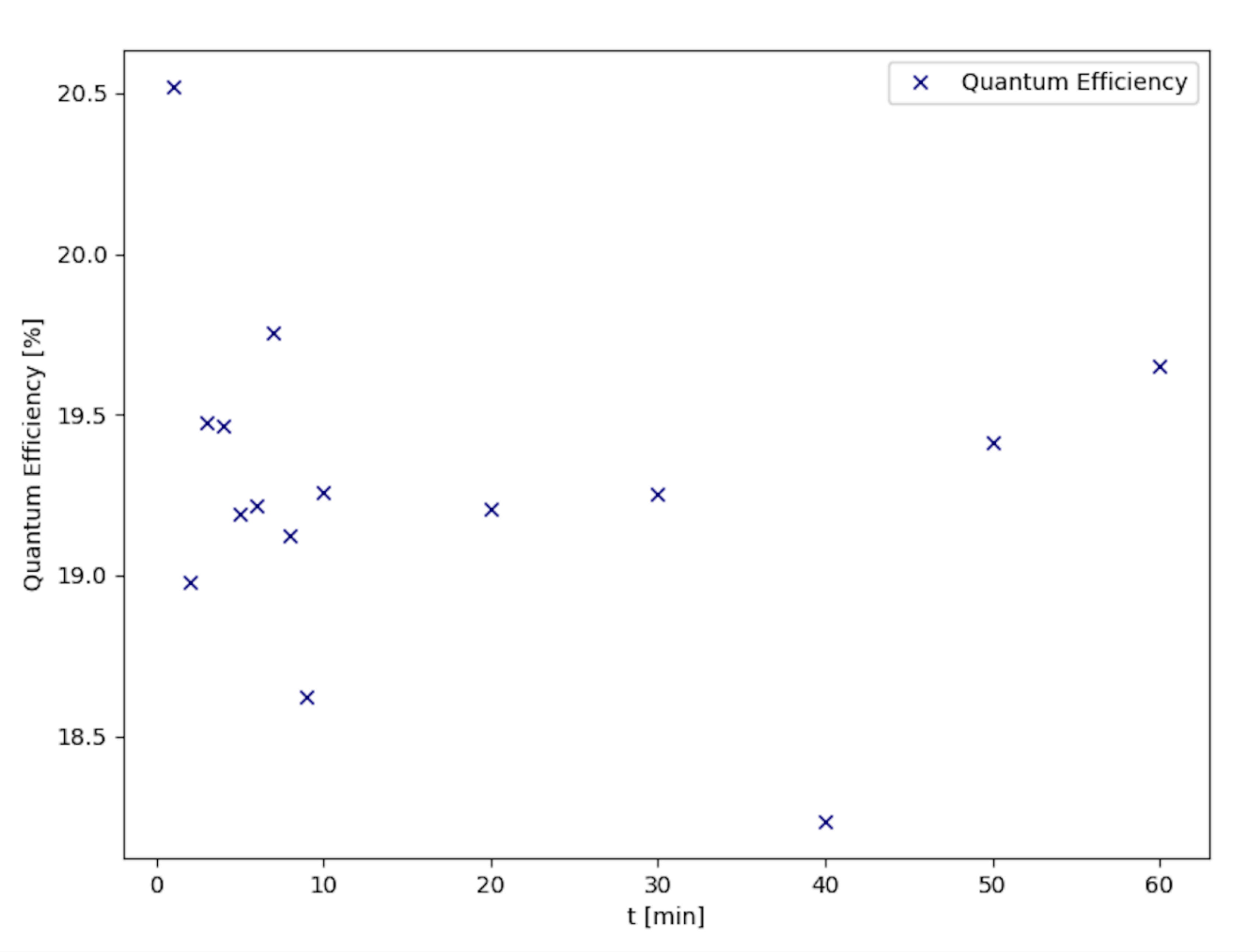


1e−9
PMT Current
PMT Current [A]
2.88
2.86
2.84
2.82
2.80
2.78
2.76
2.74
0
10
20
30
40
50
60
t [min]

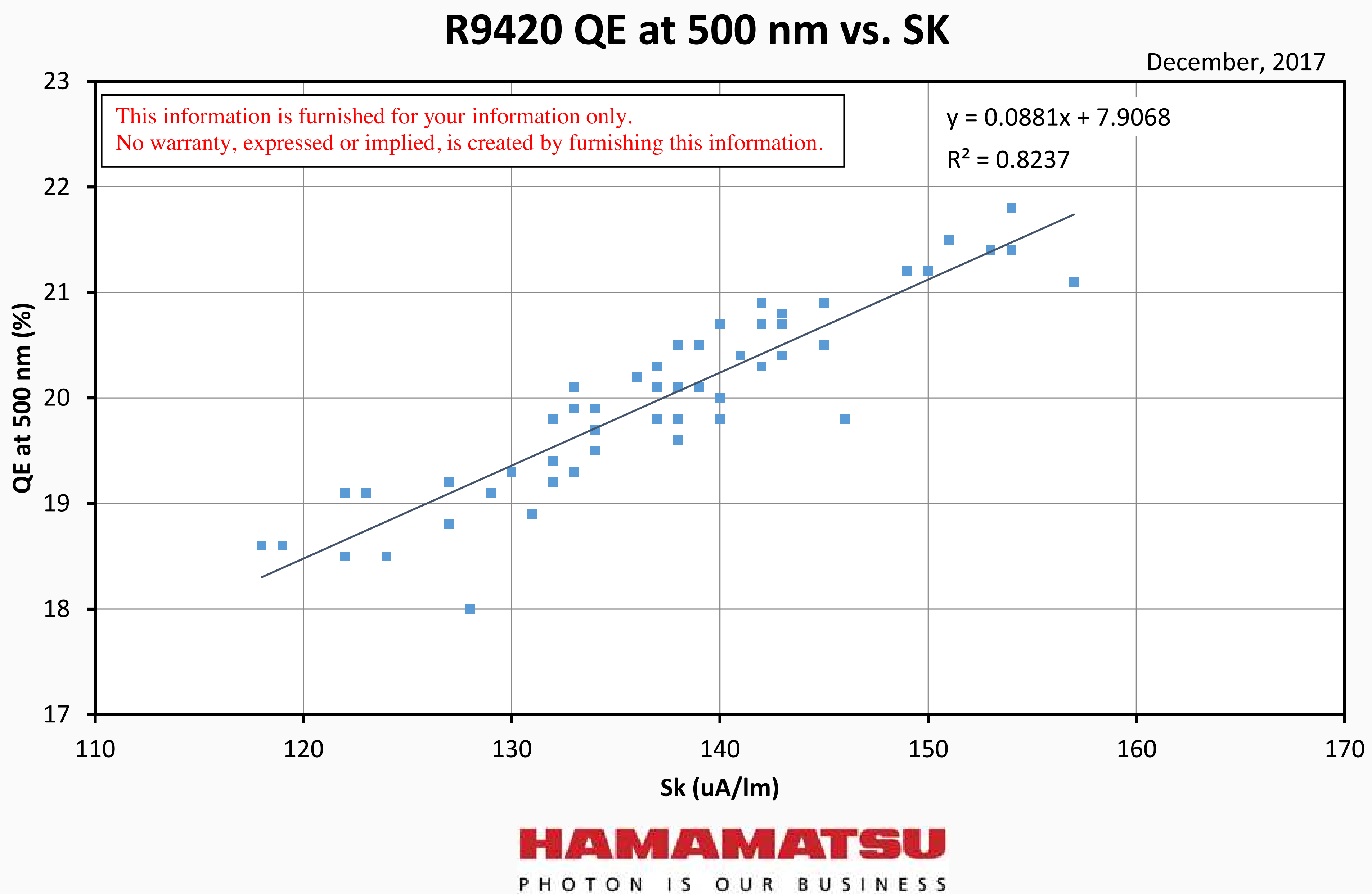


1e−9
Dark Current
Dark Current [A]
1.76
1.75
1.74
1.73
1.72
1.71
1.70
1.69
0
10
20
30
40
50
60
t [min]

Backup



Quantum Efficiency
Quantum Efficiency [%]
20.5
20.0
19.5
19.0
18.5
0
10
20
30
40
50
60
t [min]

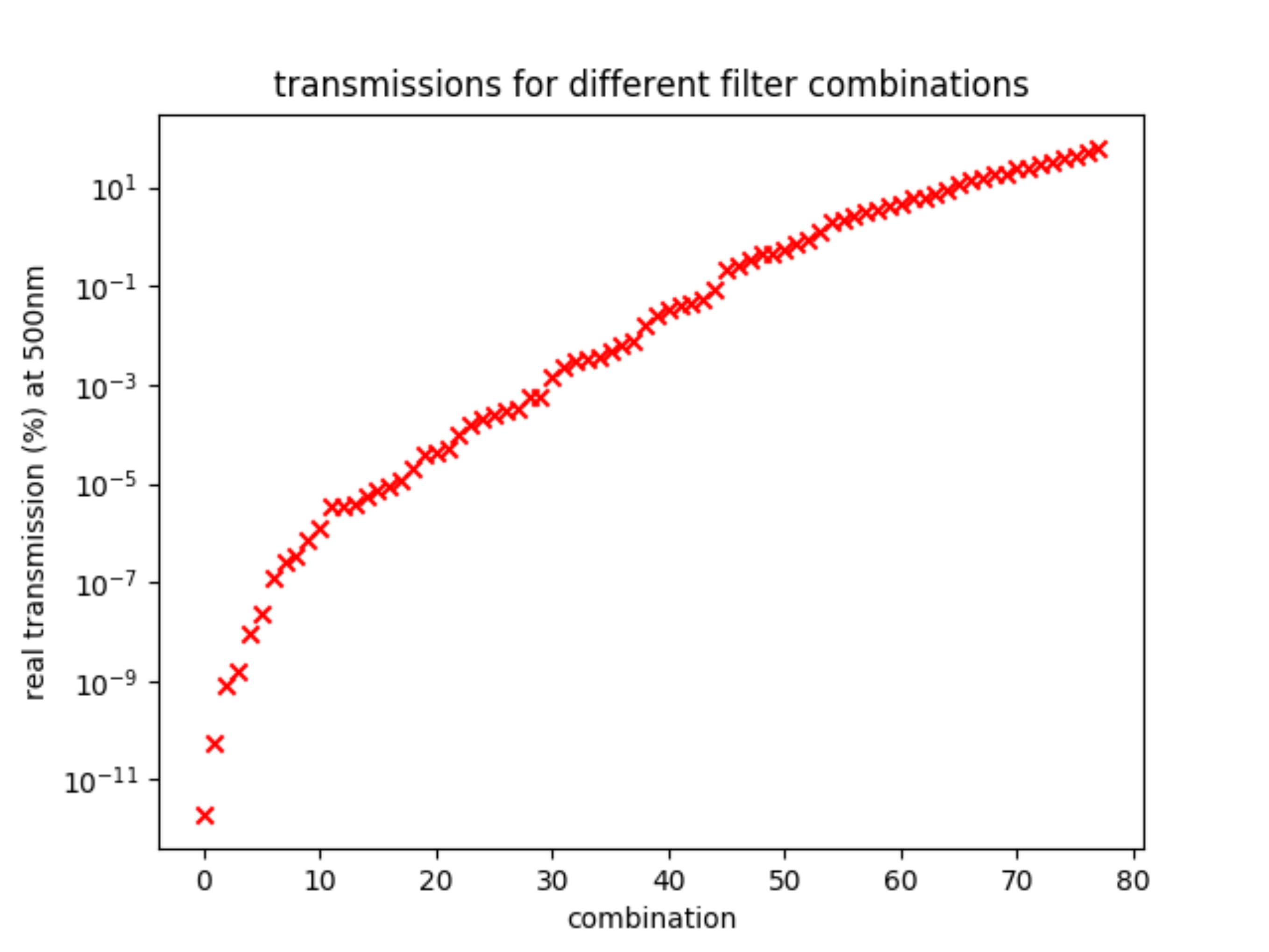


cathode luminous sensitvity

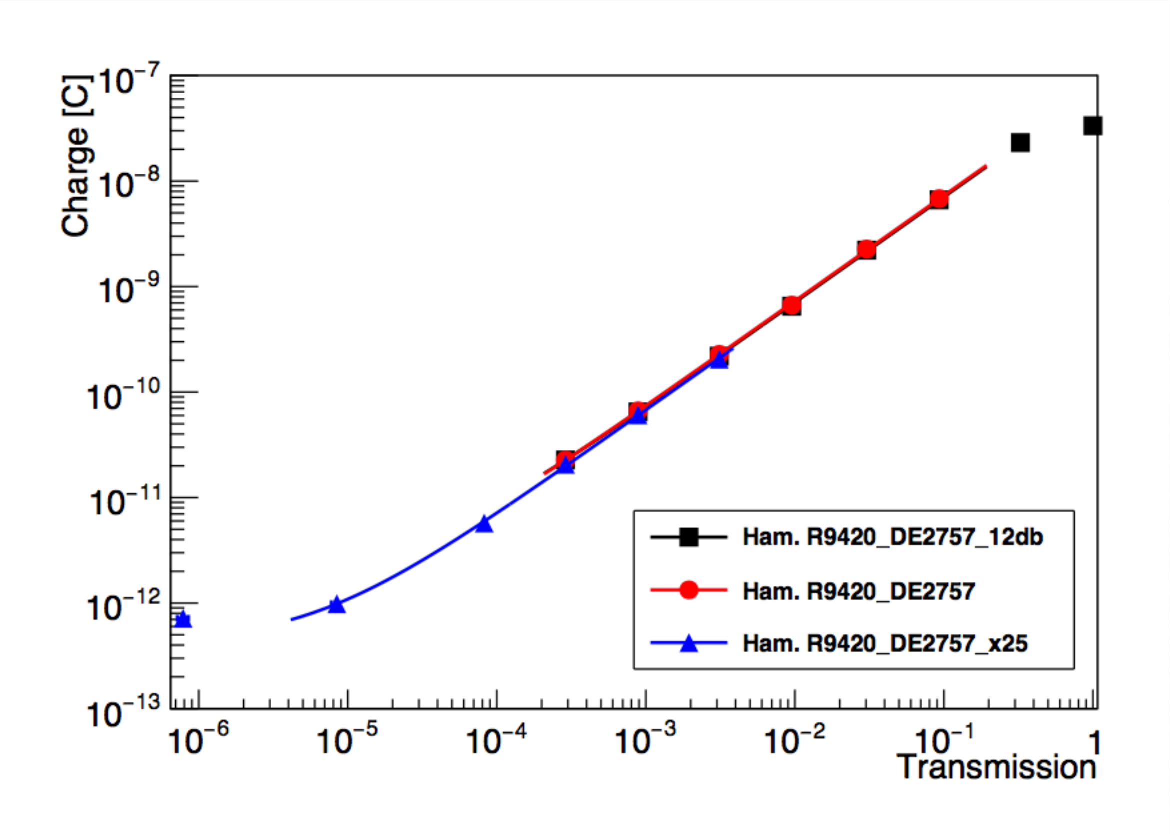
photoelectric current from cathode per incident light flux from tungsten lamp operated at 2856K

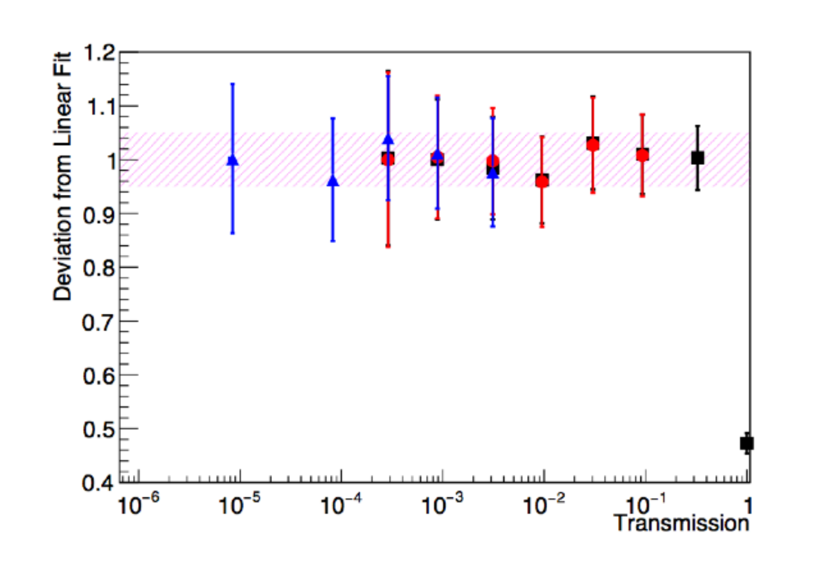
Linearity measurements

combining set of filters (12) - achievable attenuation factors



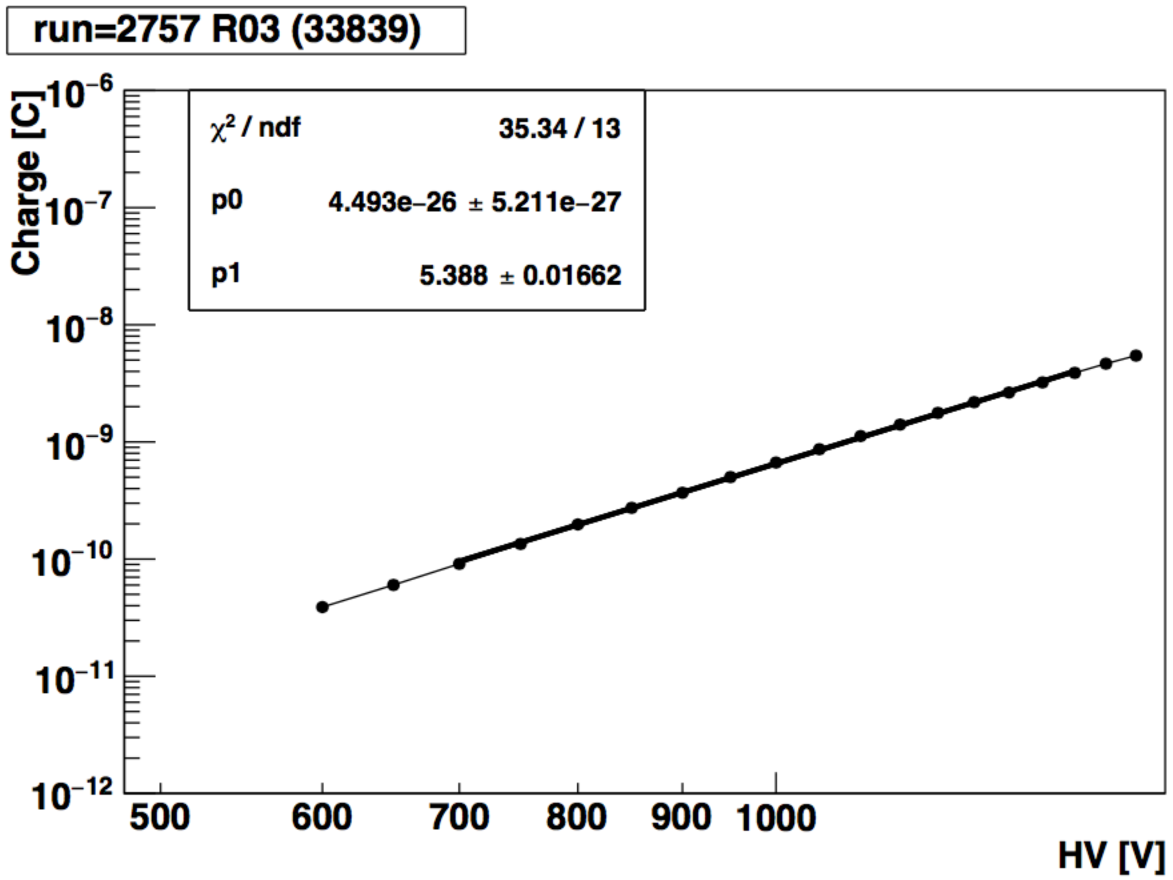
achievable transmissions - factory values form Thorlabs



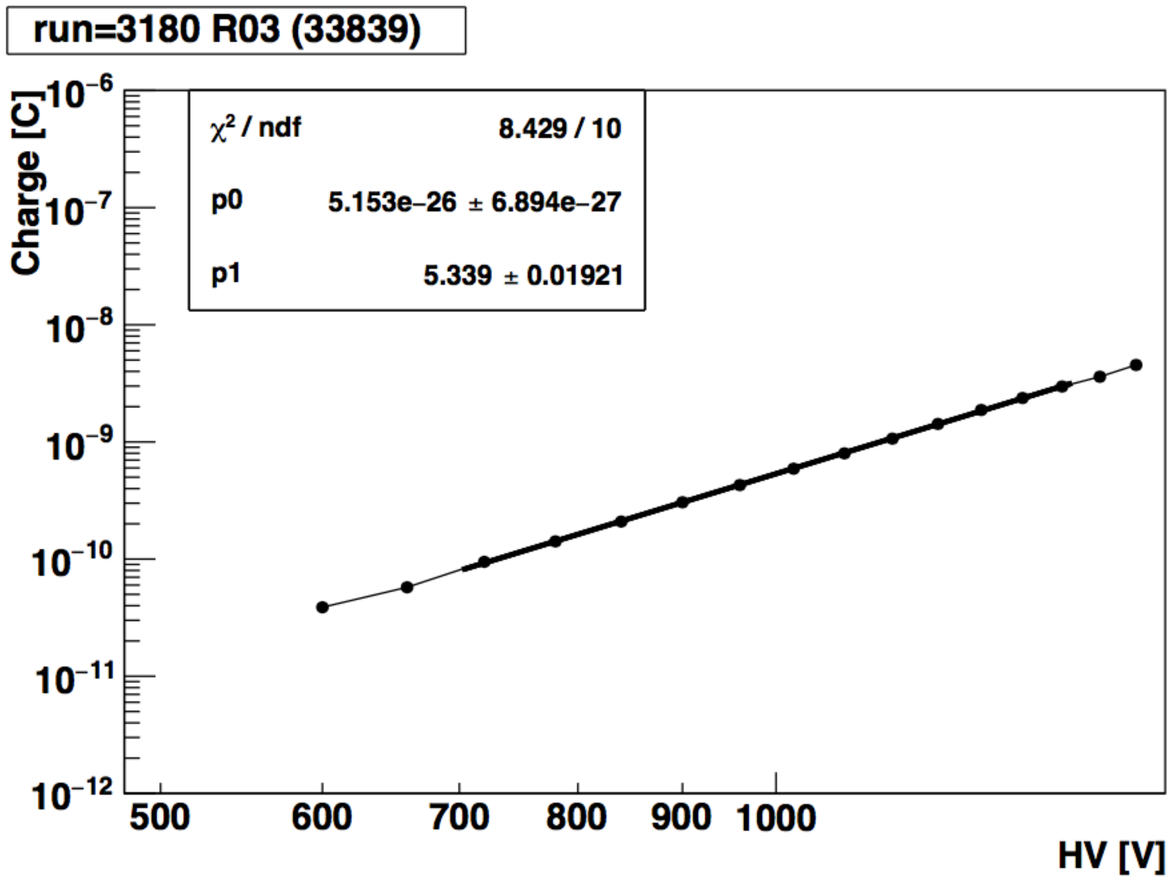


(S. Querchfeld*, K.-H. Becker, K.-H. Kampert, J. Rautenberg)

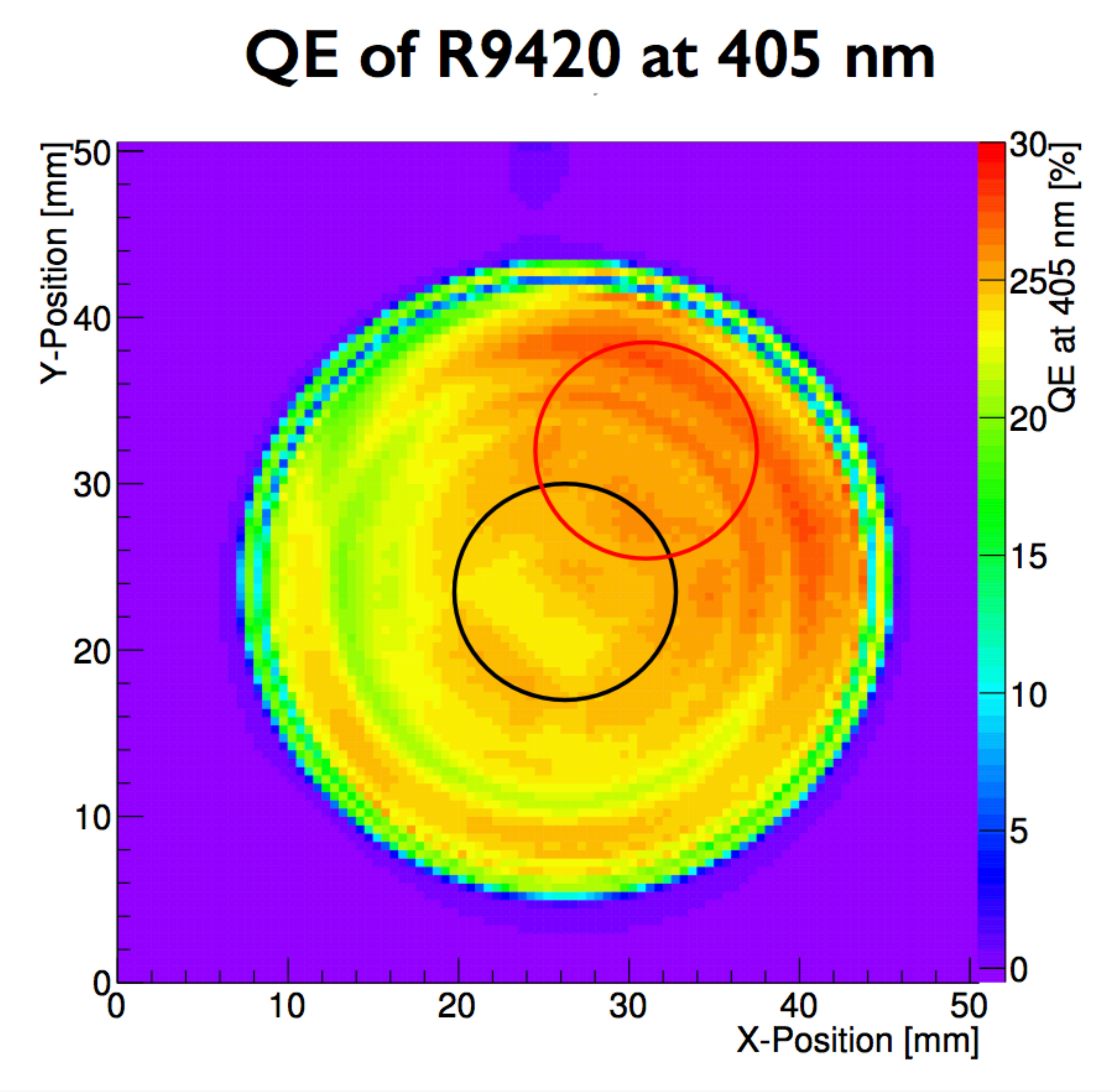
Gain measurements



external HV



integrated HV


QE of R9420 at 405 nm
Y-Position [mm]
X-Position [mm]
QE at 405 nm [%]
0
10
20
30
40
50
0
5
10
15
20
25
30

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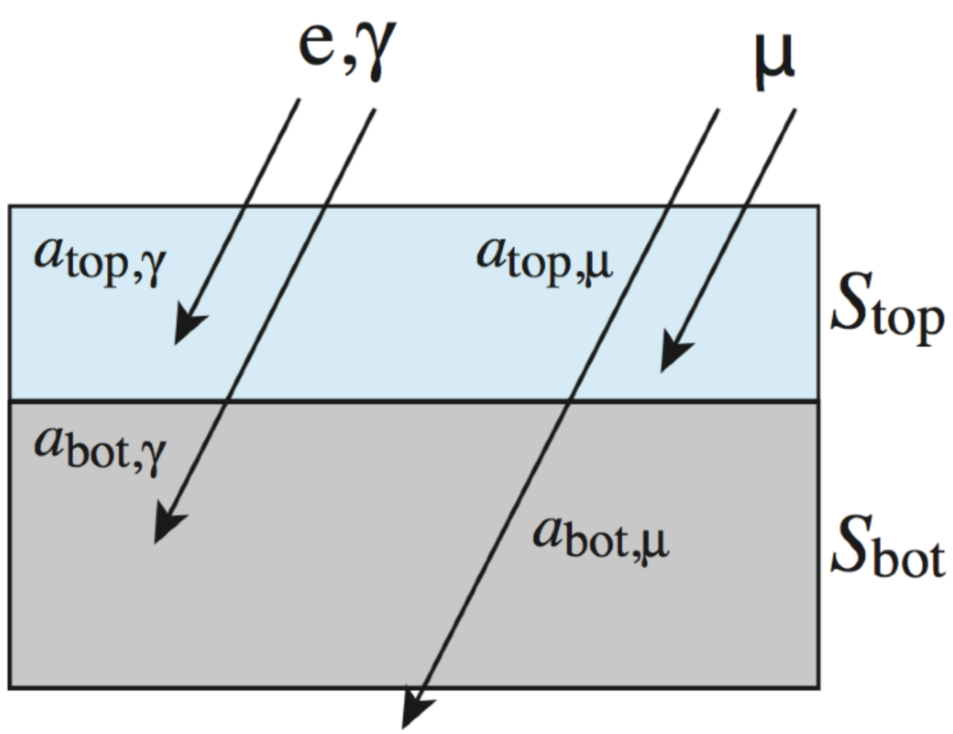


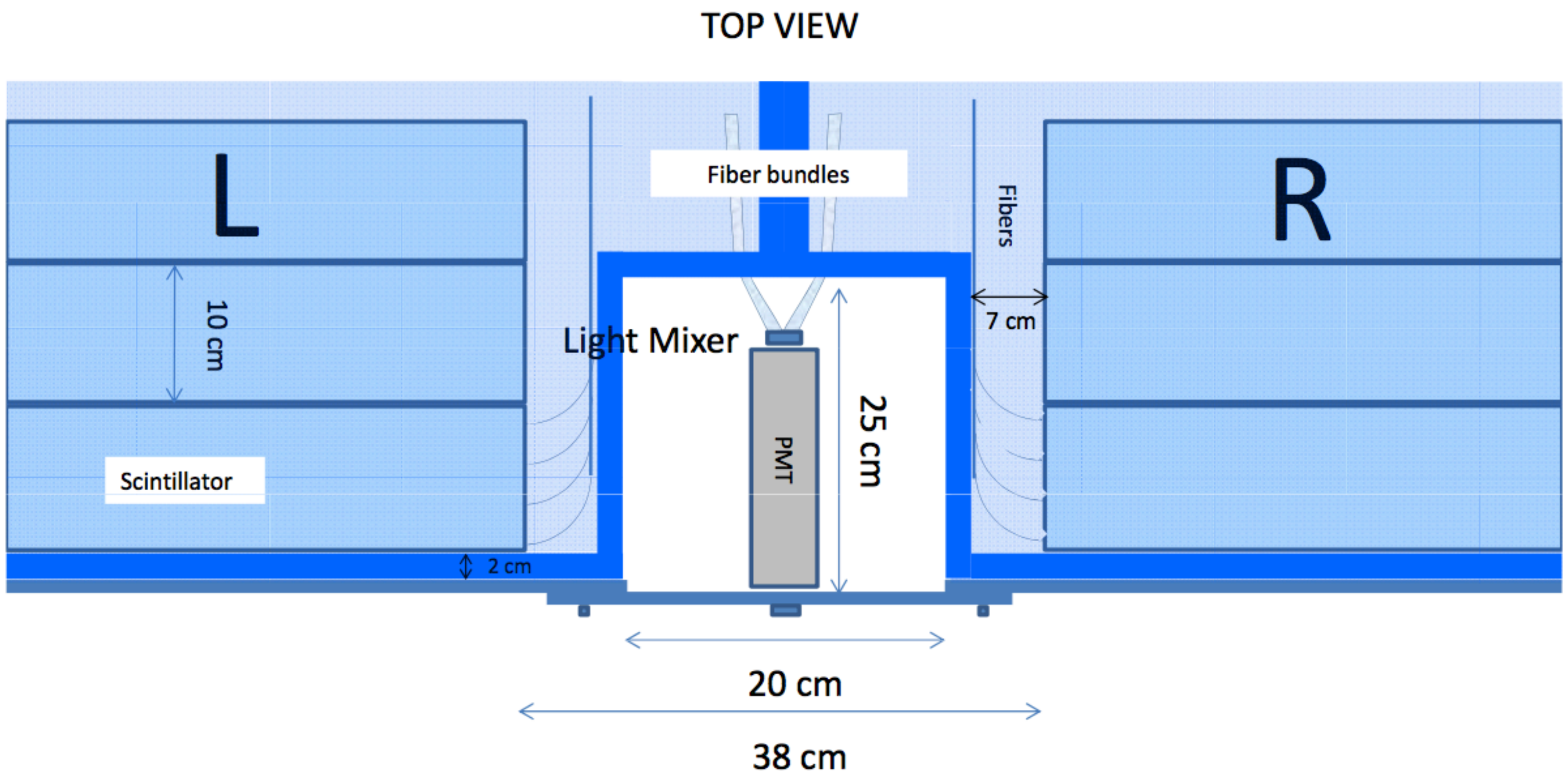
$$\begin{pmatrix} S_{\mathrm{top}} \\ S_{\mathrm{bot}} \end{pmatrix} = \begin{pmatrix} a_{\mathrm{top},\gamma} & a_{\mathrm{top},\mu} \\ a_{\mathrm{bot},\gamma} & a_{\mathrm{top},\mu} \end{pmatrix} \begin{pmatrix} S_{\gamma} \\ S_{\mu} \end{pmatrix}$$

$$a_{\gamma\gamma} + a_{\mu\gamma} = a_{\mu\mu} + a_{\gamma\mu} = 1$$

shower at 10^{20} eV, θ = 38° - peak signal in 4 m^2 SSD at 200 m from the core

=> 12,000 MIP (Minimum Ionizing Particles),

Backup


TOP VIEW
L
R
Fiber bundles
Fibers
10 cm
7 cm
Light Mixer
PMT
25 cm
Scintillator
2 cm
20 cm
38 cm