# Preliminary results of ND Photocathode coupled to THGEMs

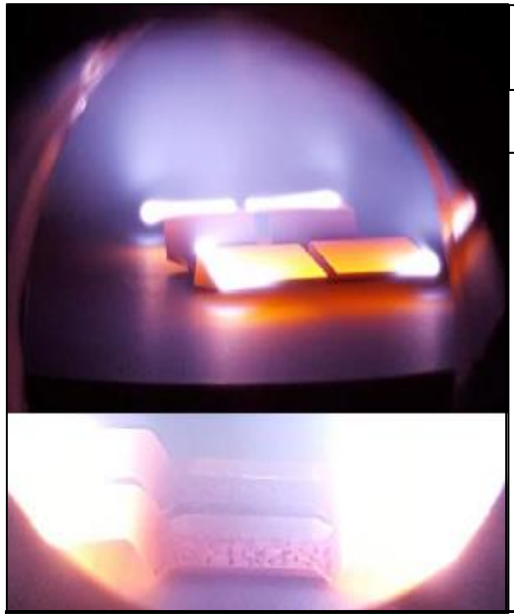
S. Dasgupta and Triloki

On Behalf of a INFN, Trieste & INFN, Bari collaboration

## Outline

- Motivation
- QE Setup in Bari
- QE measurement in Bari
- ASSET @ CERN
- Preliminary measurement with ASSET
- Conclusion

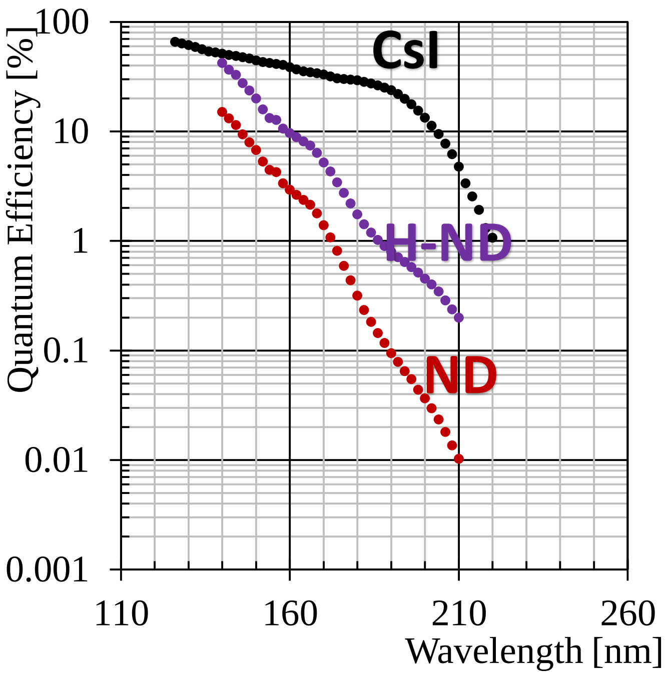
# Why and which Nano Diamond



## Comparison CsI to Nano Diamond

| H – ND | CsI |
|---|---|
| • *Low electron affinity ► 0.35 – 0.5 eV*<br>• *Wide band gap ► 5.5 eV*<br>• *Preliminary measured QE ► 30 – 40% @ 140 nm for Hydrogenated samples. (We mes 7.7% after one year H – ND in $H_2O$).*<br>• *Chemically inert*<br>• *Radiation hard*<br>• *Good thermal conductivity* | • *Low electron affinity ► 0.1 eV*<br>• *Wide band gap ► 6.2 eV*<br>• *Typical Quantum Efficiency ► 35 – 50% @ 140 nm*<br>• *CsI has hygroscopic nature*<br>• *Aging ► Ion Accumulation ►Degradation in QE of PC* |

**Comparative QE: CsI: ND/HND**




- CsI [NIM-A-438 (1999) 94]
- ND [APL-108 (2016) 083503]
- HND [APL-108 (2016) 083503]

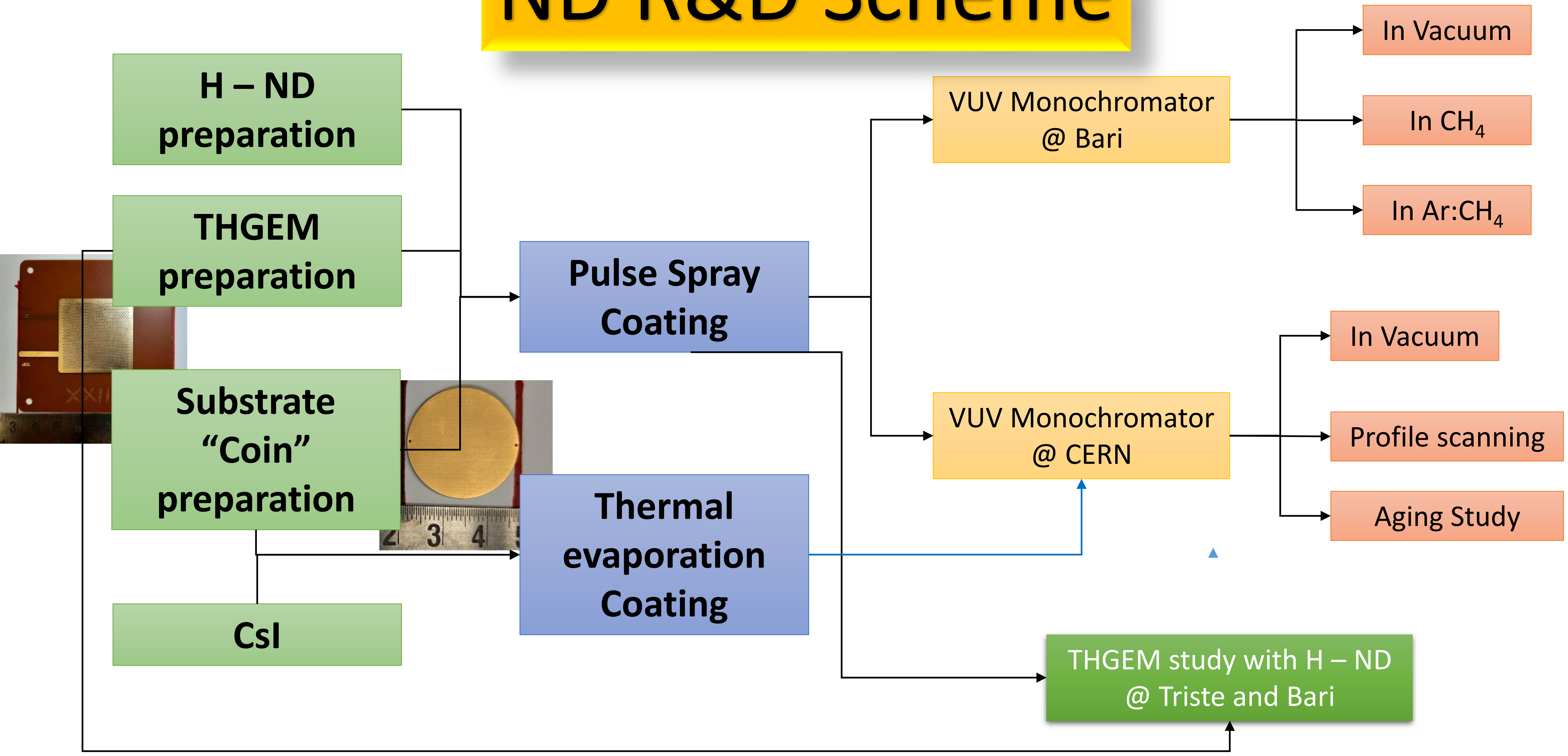
- Microwave Plasma Enhanced Chemical Vapour Deposited (MWPECVD) diamond films are used for thermionic current generation and for UV photocathodes, because they exhibit a better stability than CsI.
- Production of diamond films by MWPECVD technique at 800OC. Peculiarity: hydrogenated surface!! Moves down Negative Electron Affinity (N.E.A.) to -1.27 eV. A crucial parameter for electron photo and thermo emission. Maximum Q.E. achieved for the MWPECVD based diamond is 12% at 140 nm

As described by **Prof. Valentini**

# Motivation of this specific R & D

- Demand of a compact RICH for the future EIC ►short radiator length (Limited number of Photons)
- As standard quartz window is opaque below 165 nm ► **windowless RICH** is a possible approach ►Gaseous detectors
- **CsI** most used, however ageing due to **humidity and ion bombardment** ► quest for novel PC with sensitivity in the far UV region
- **H-ND** powder as possible **more robust** alternative photocathode of CsI
- Our R & D; H-ND coupled to THGEM
- We report here some preliminary results on the initial phase of these studies

# ND R&D Scheme



H – ND preparation
THGEM preparation
Substrate “Coin” preparation
CsI
Pulse Spray Coating
Thermal evaporation Coating
VUV Monochromator @ Bari
VUV Monochromator @ CERN
In Vacuum
In $CH_4$
In $Ar:CH_4$
In Vacuum
Profile scanning
Aging Study
THGEM study with H – ND @ Triste and Bari

# Photocurrent measurement @ Bari

# Pulsed spray thin film coating setup:
# No of Shots determine the coating thickness

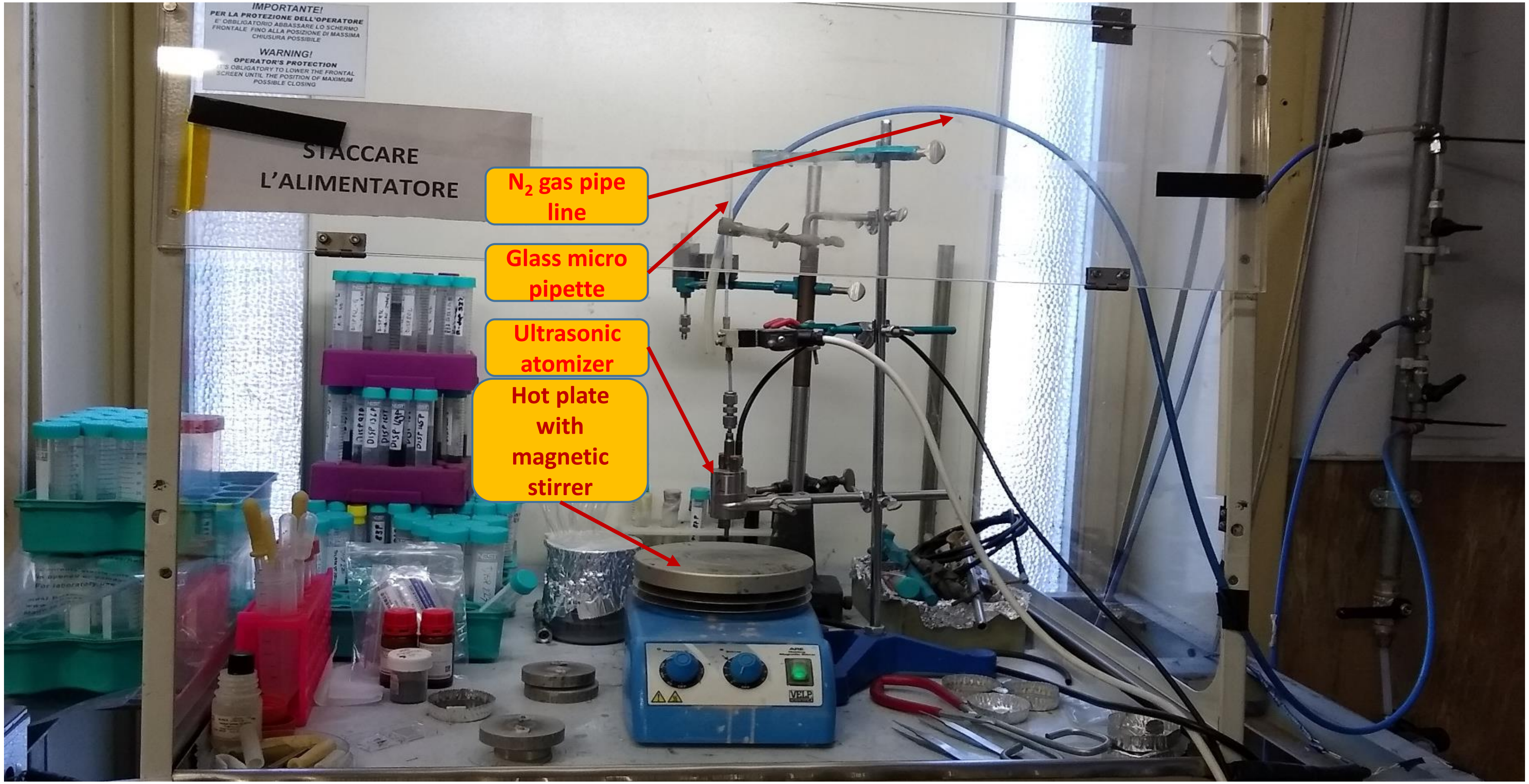



Figure : The pulsed spray technique for thin film coating, equipped with an ultrasonic atomizer and with a heater at INFN Bari, Italy

# Pictorial view of photoemission measurement setup:

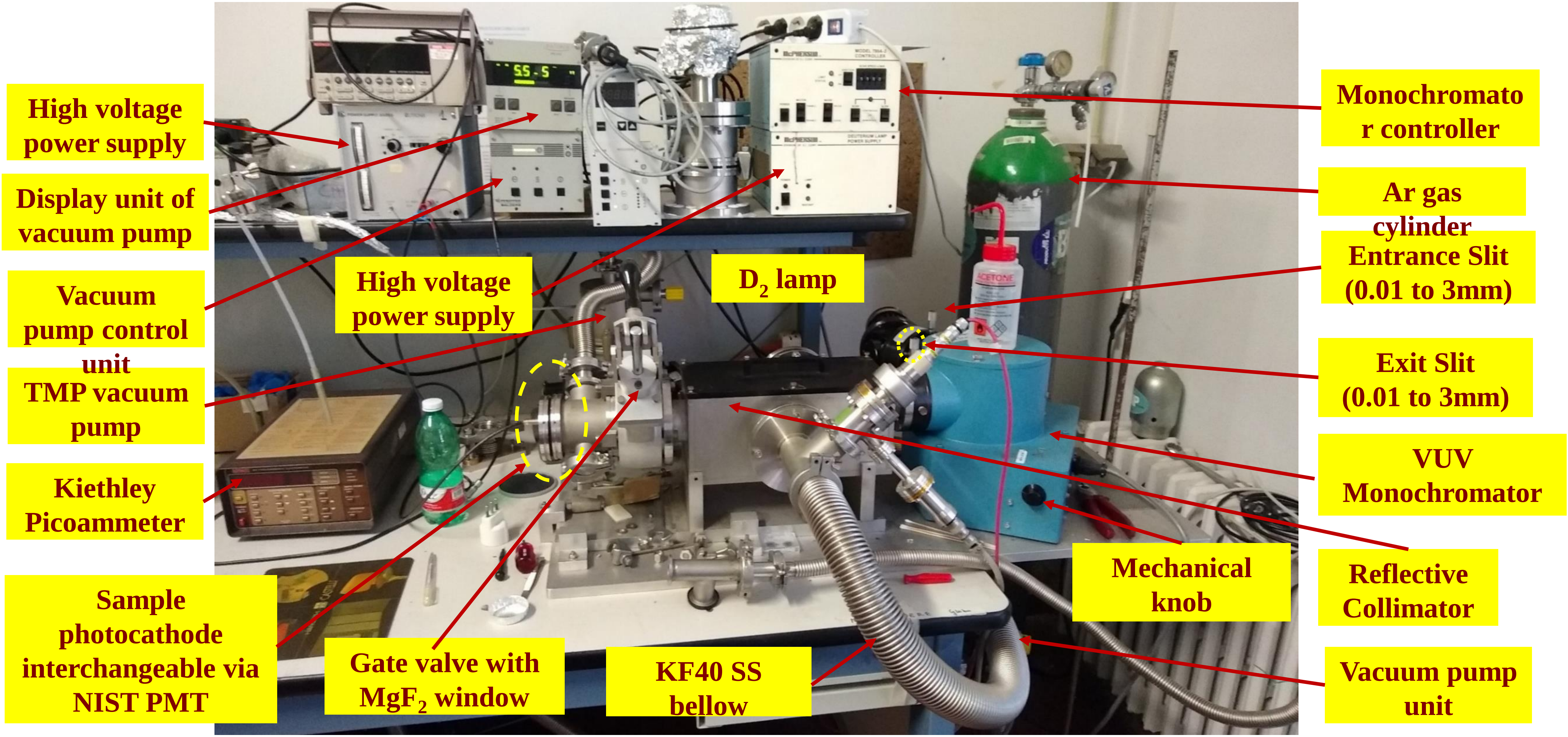


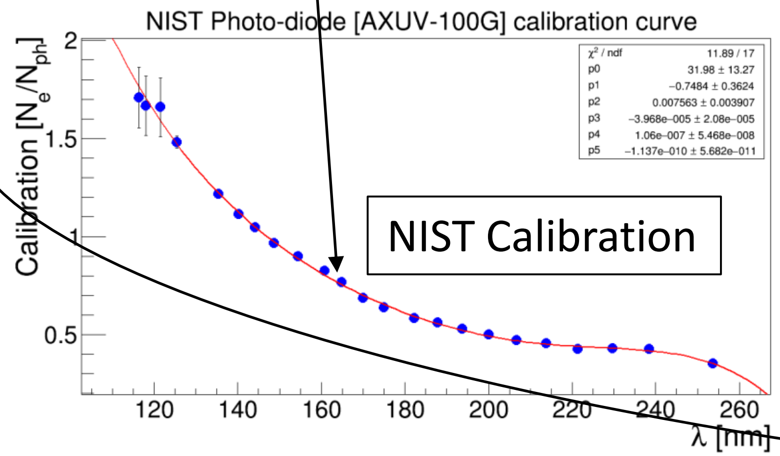

Figure : McPherson VUV monochromator for the photocurrent measurement at INFN Bari, Italy

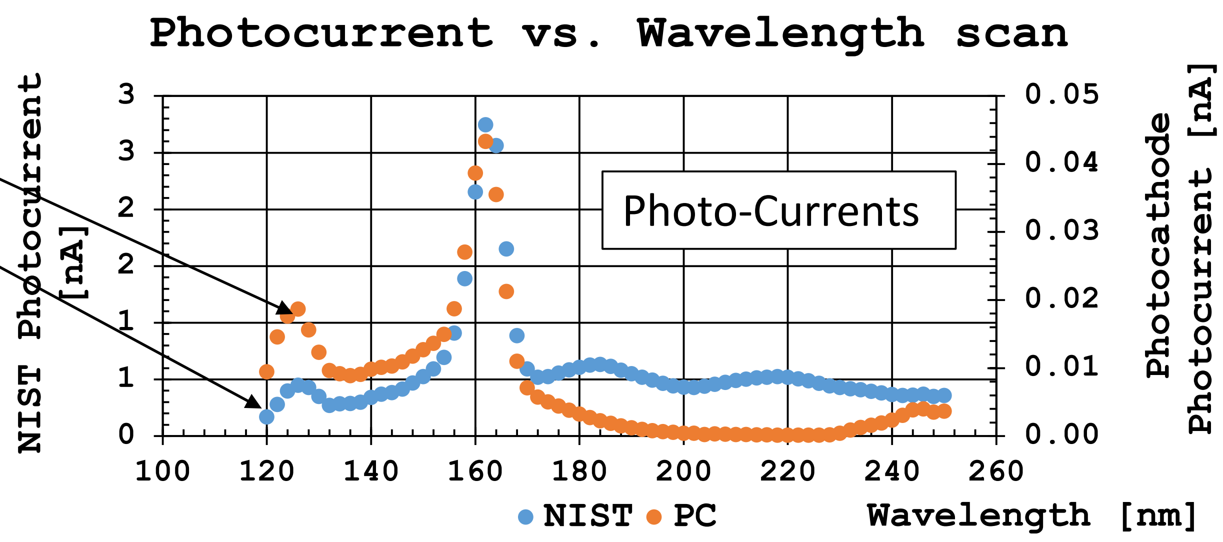
# Quantum Efficiency Formula Bari

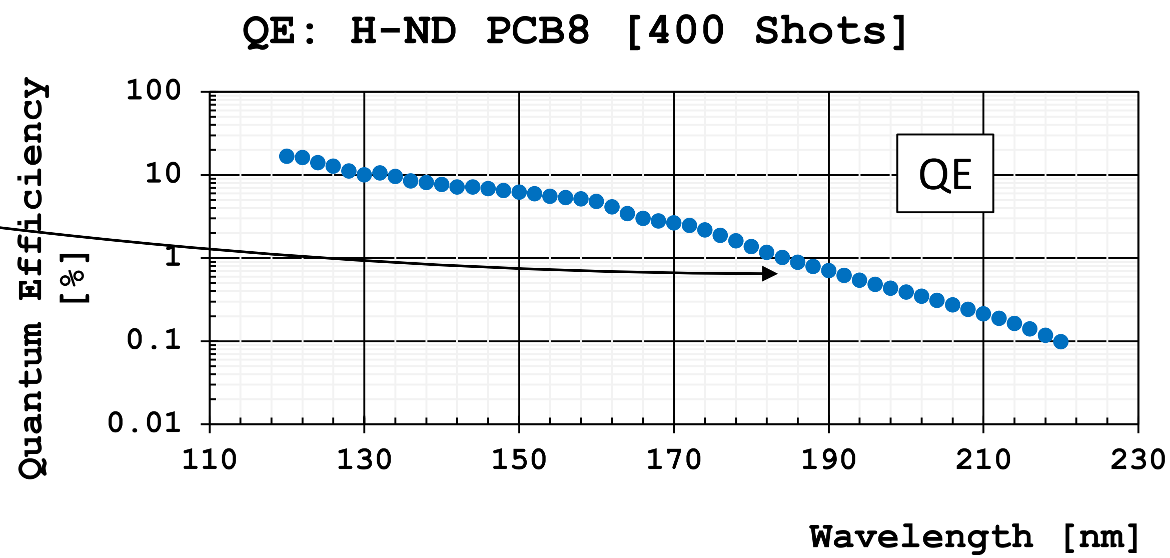
$$QE_{PC}(\lambda) = \frac{N_e}{N_{ph}} = Calibration_{NIST(\lambda)} \times \frac{I_{PC(\lambda)} - I_{DC(PC)}}{I_{NIST(\lambda)} - I_{DC(NIST)}}$$

$$N_{ph} = \frac{I_{NIST}}{e} \times \frac{1}{Calibration_{NIST}}; \quad N_e = \frac{I_{PC}}{e};$$

$$Calibration_{NIST} = \frac{N_{e\_NIST}}{N_{ph\_NIST}}; \quad e \cong 1.602 \times 10^{-19}\ C;$$

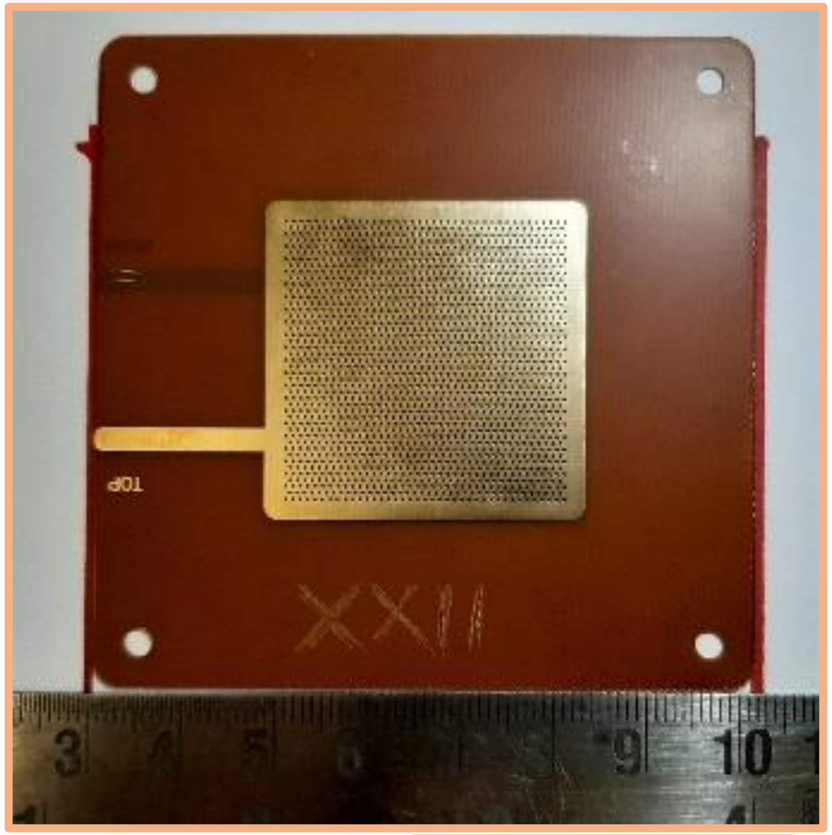


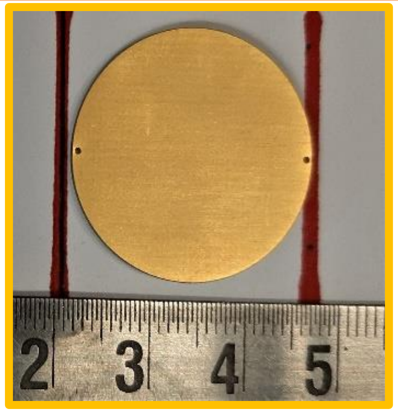




Where :

- $QE_{PC}(\lambda)$ = Quantum efficiency of the photocathode
- $I_{PC}(\lambda)$ = Measured photocurrent value of the photocathode
- $I_{NIST}(\lambda)$ = Measured photocurrent value of the NIST Photodiode.
- $Calibration_{NIST}(\lambda)$ = Known calibration factor to estimate number of incident photons from $I_{NIST}$.
- $I_{DC}$ = Estimated dark current.



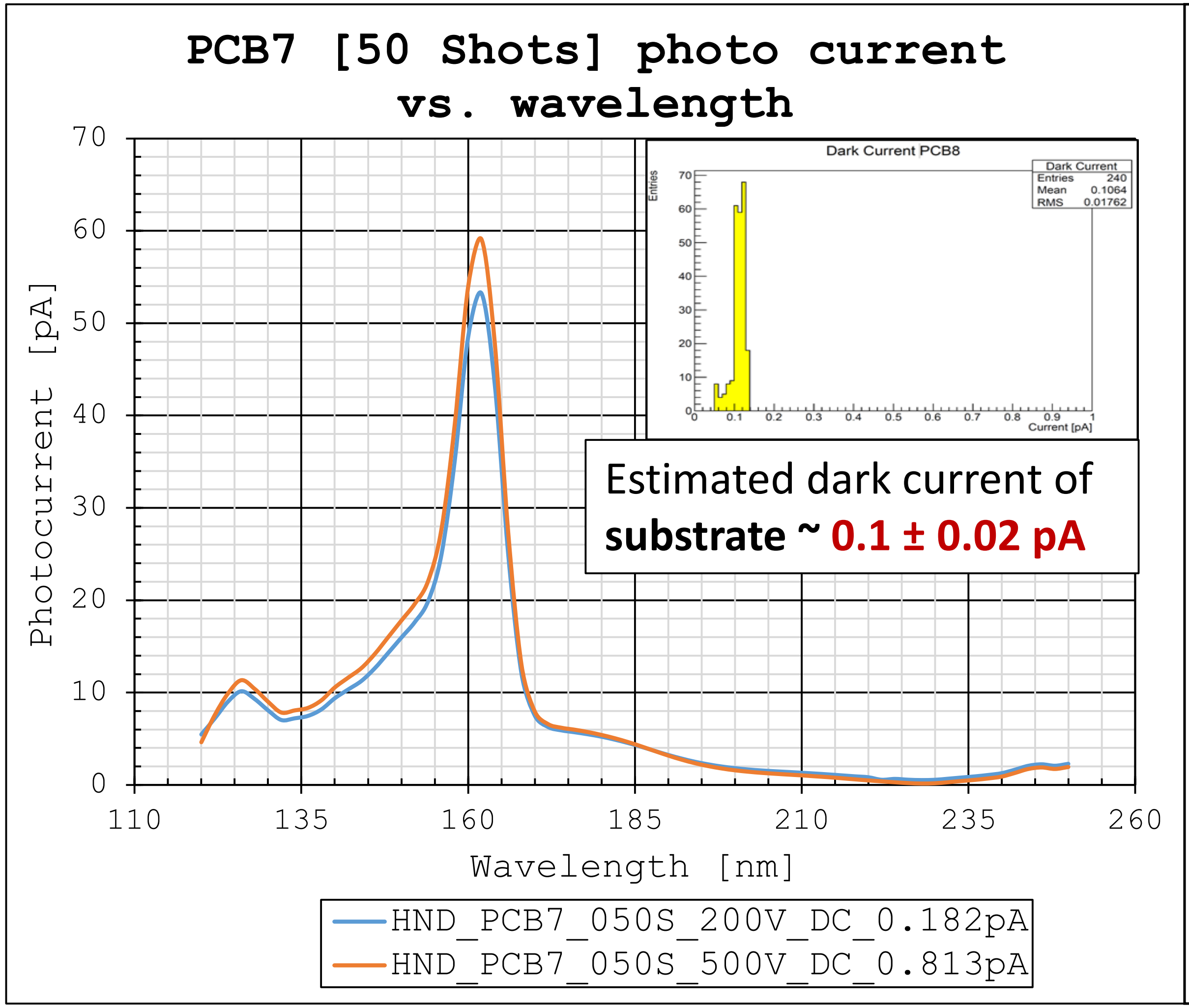



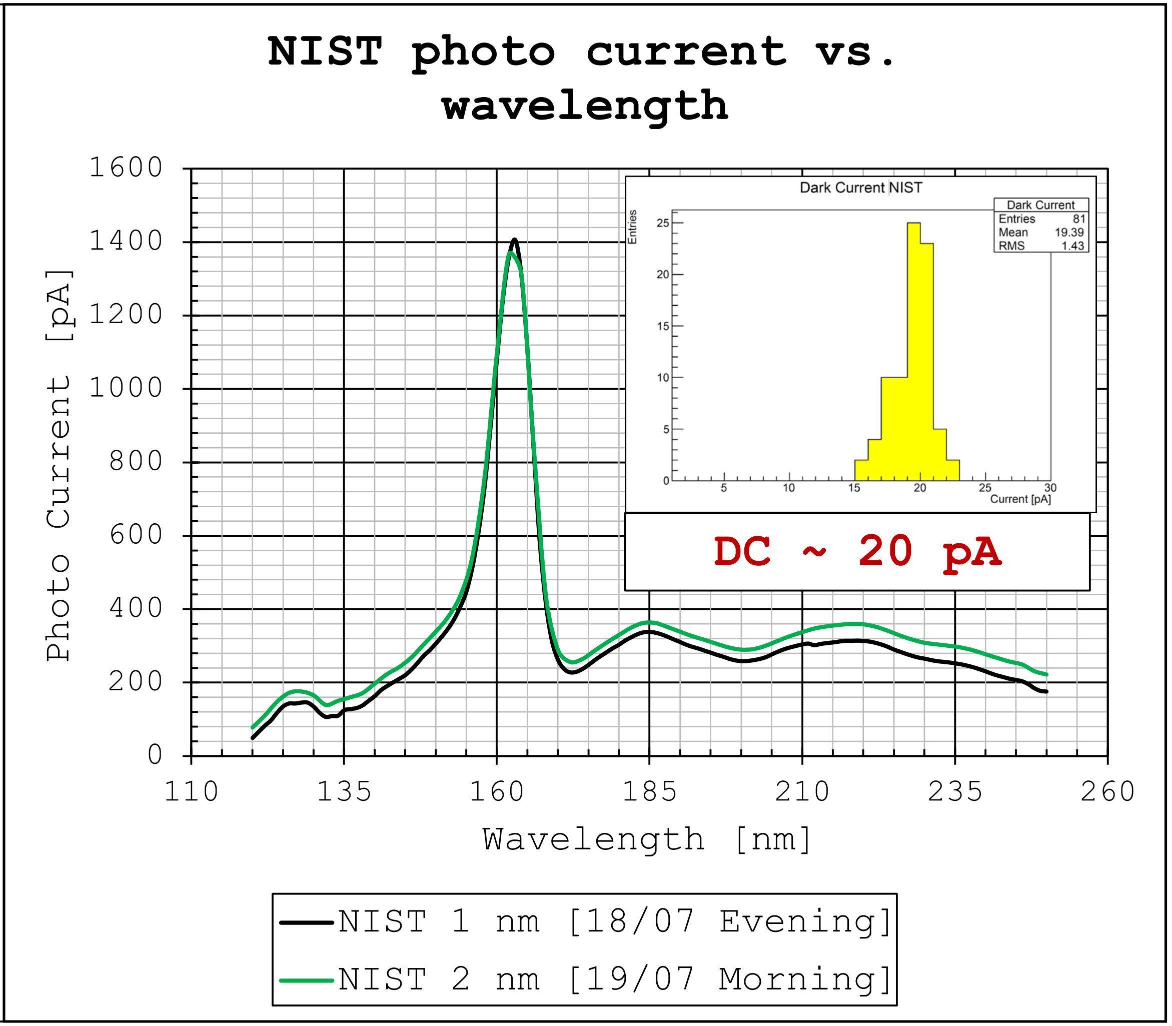
# Coating Details

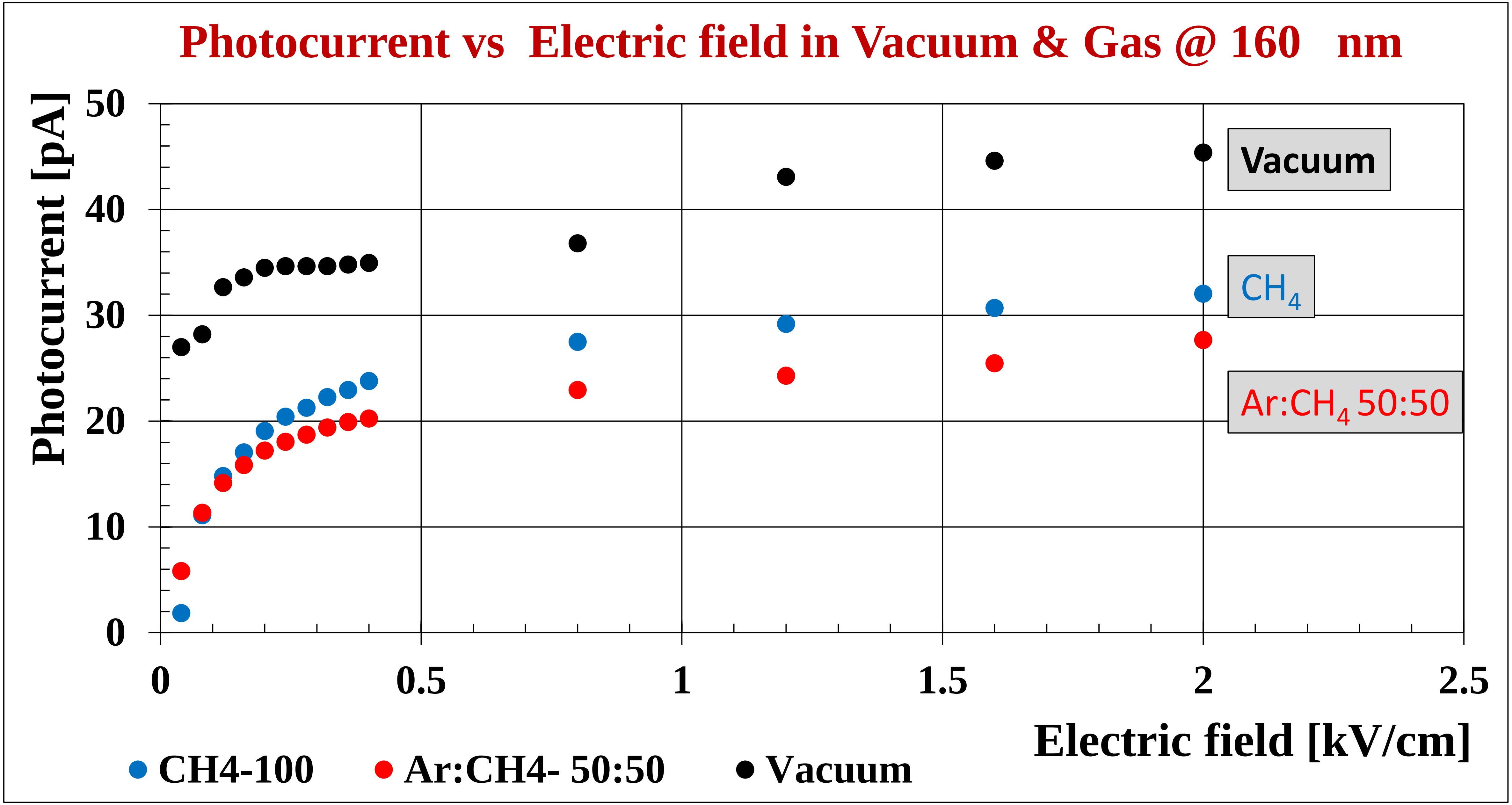
| Coated Substrate/THGEMs | Type of ND | #Shots |
|---|---|---|
| TB IX | ND | 300 |
| TB VIII | H-ND | 140 |
| TB III | H-ND | 43 |
| TBVII | H-ND | 55 |
| TB XIX | H-ND | 59 |
| TB XI | H-ND | 250 |
| PCB9 | H-ND | 25 |
| PCB7 | H-ND | 50 |
| PCB10 | H-ND | 100 |
| PCB11 | H-ND | 200 |
| PCB8 | H-ND | 400 |
| PCB1 | ND | 100 |
| PCB2 | ND | 100 |
| PCB3 | ND | 200 |
| PCB4 | ND | 200 |
| PCB5 | ND | 50 |
| PCB6 | H-ND | 50 |

# Noise, Reproducibility and Electric field scan @INFN Bari

# Noise and Reproducibility



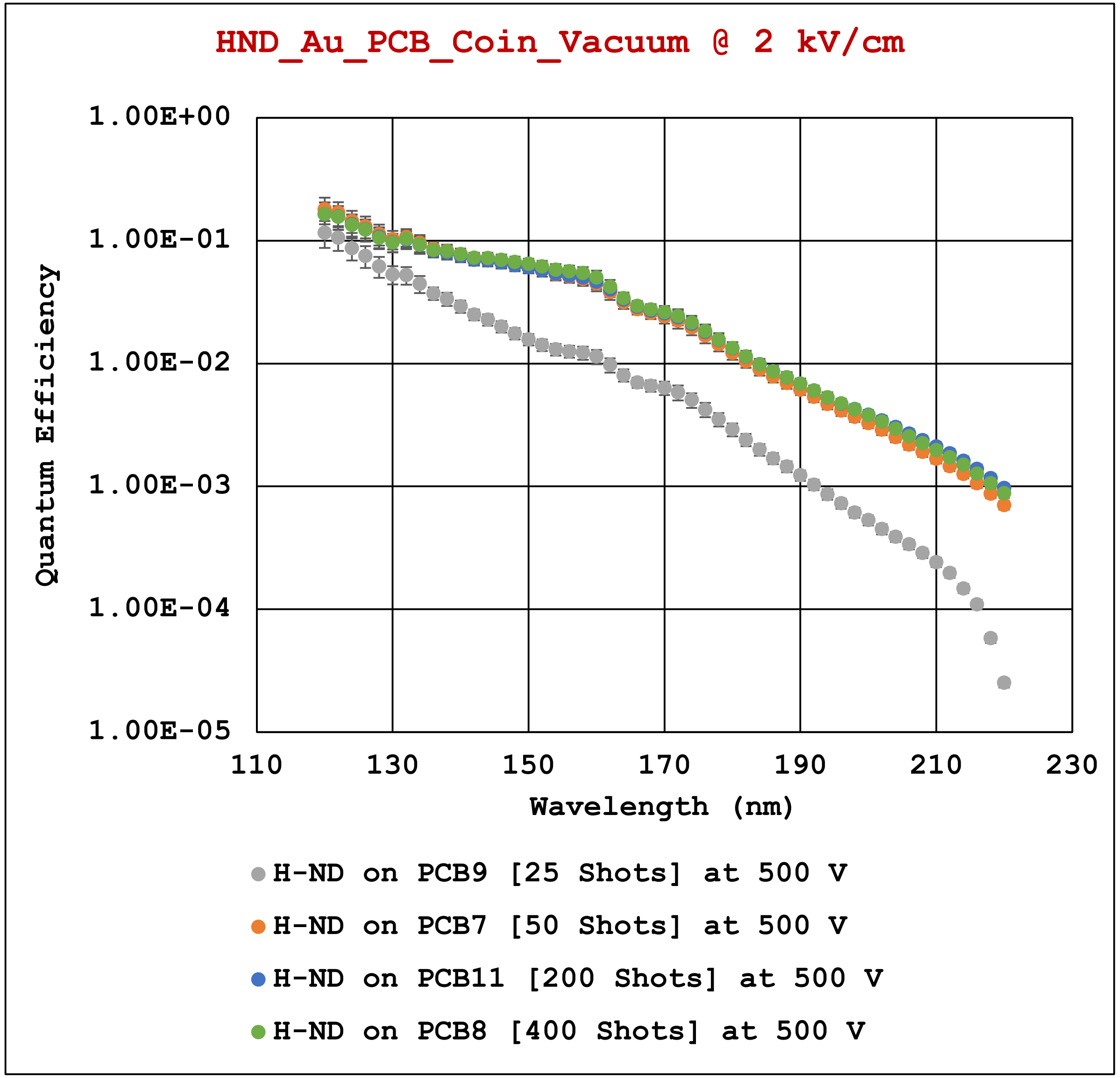



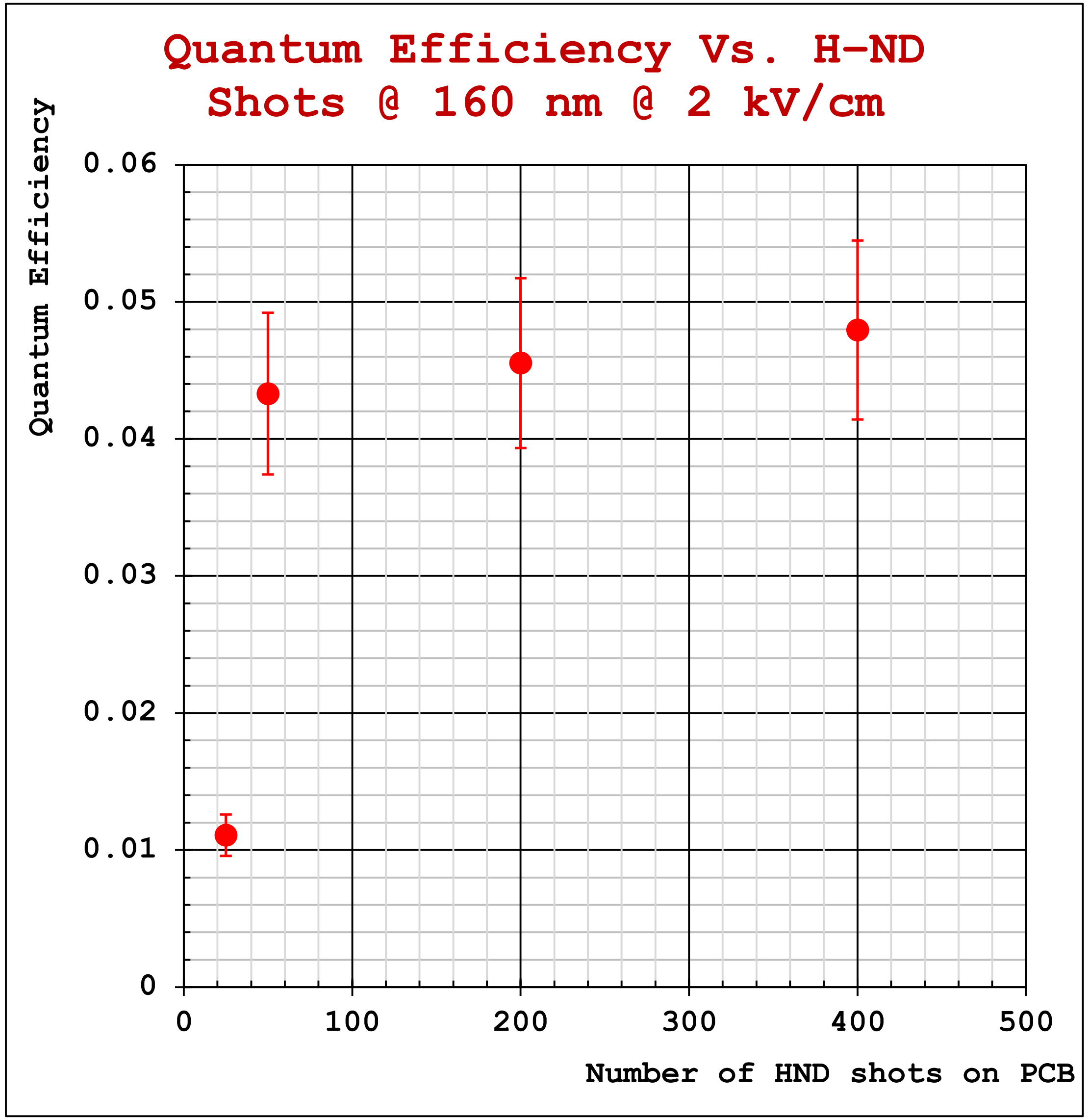


Photocurrent vs Electric field in Vacuum & Gas @ 160 nm
Photocurrent [pA]
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
Electric field [kV/cm]
Vacuum
$CH_4$
$Ar:CH_4$ 50:50
CH4-100
Ar:CH4- 50:50
Vacuum

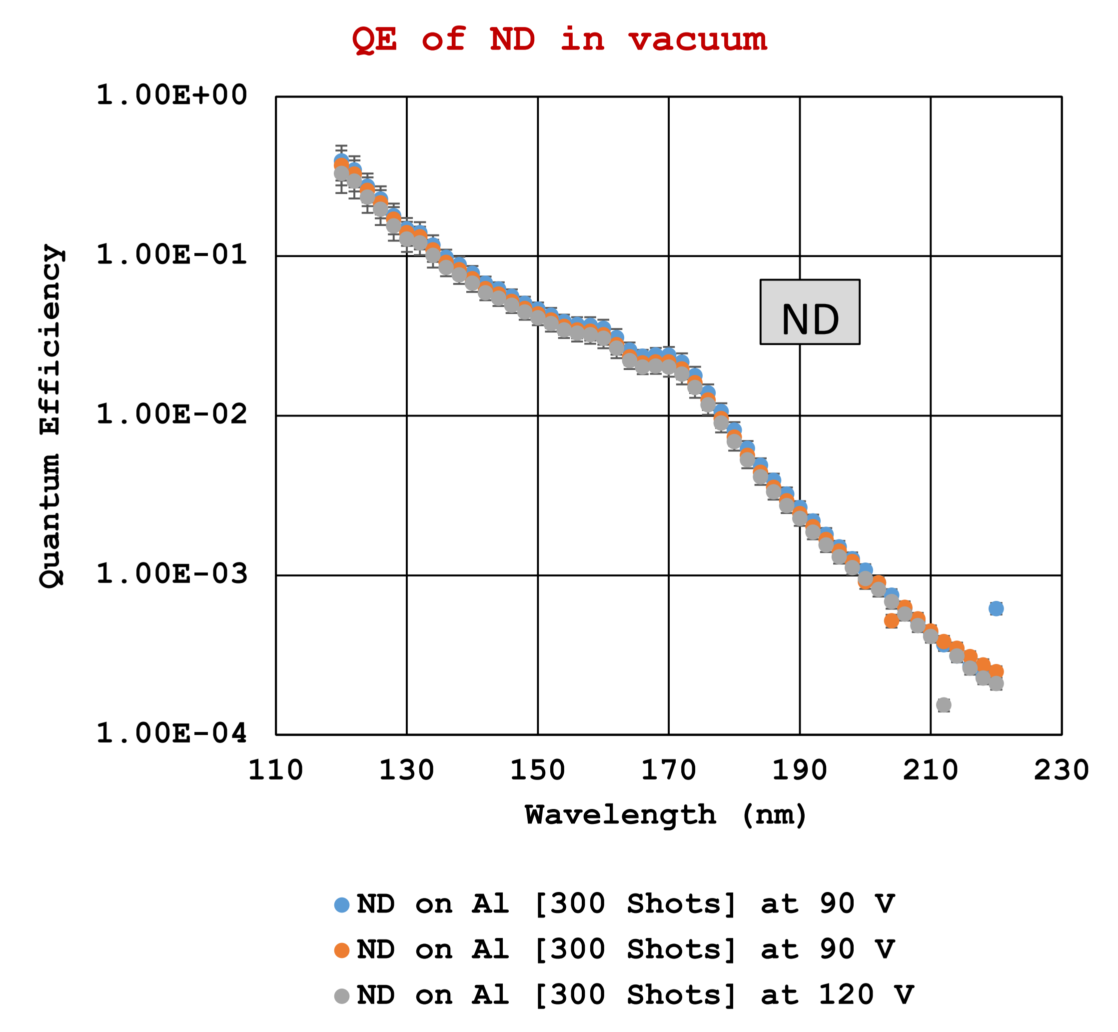
# Photocurrent Results

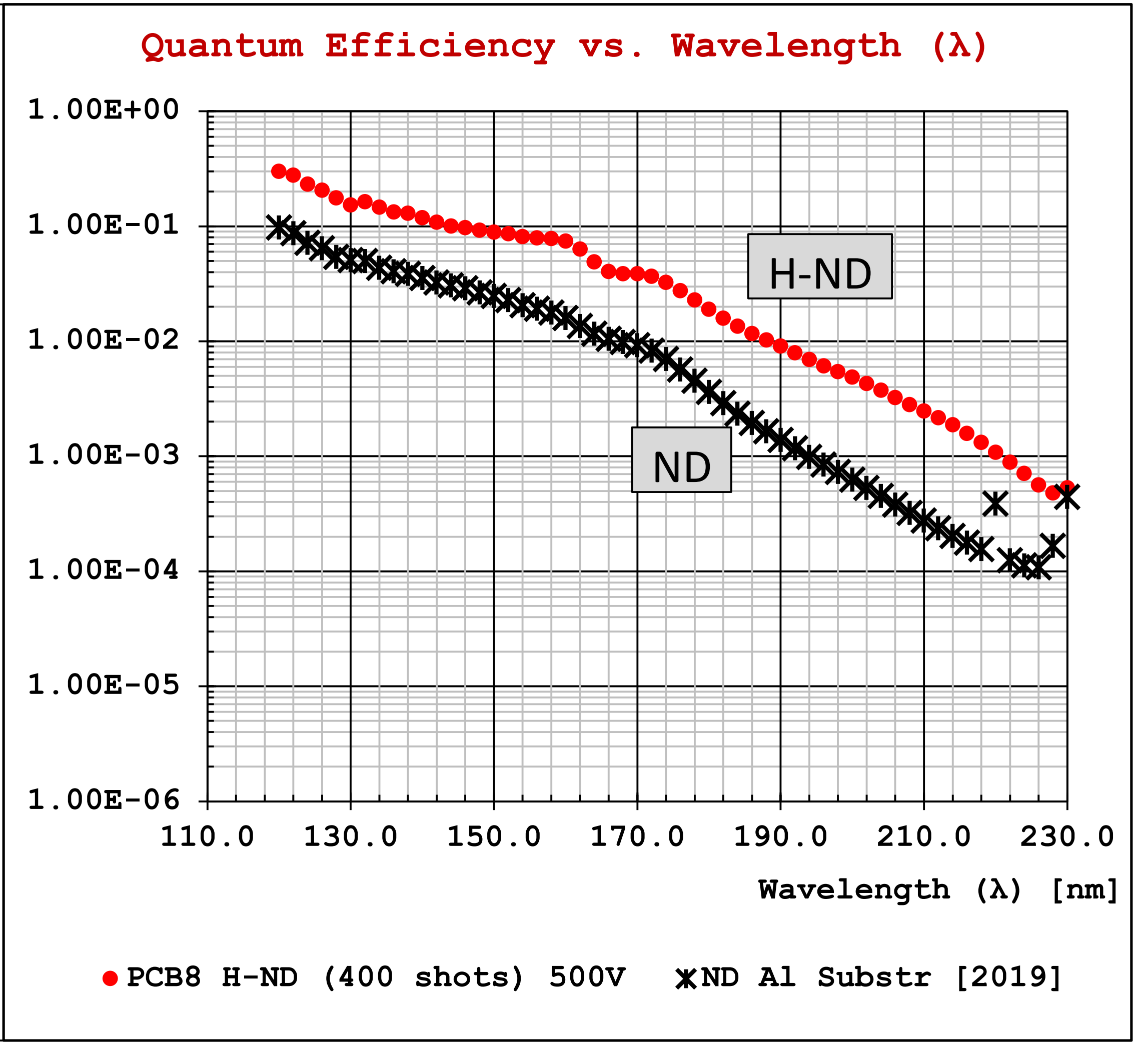
# QE vs λ for various H-ND shots on PCB Coin



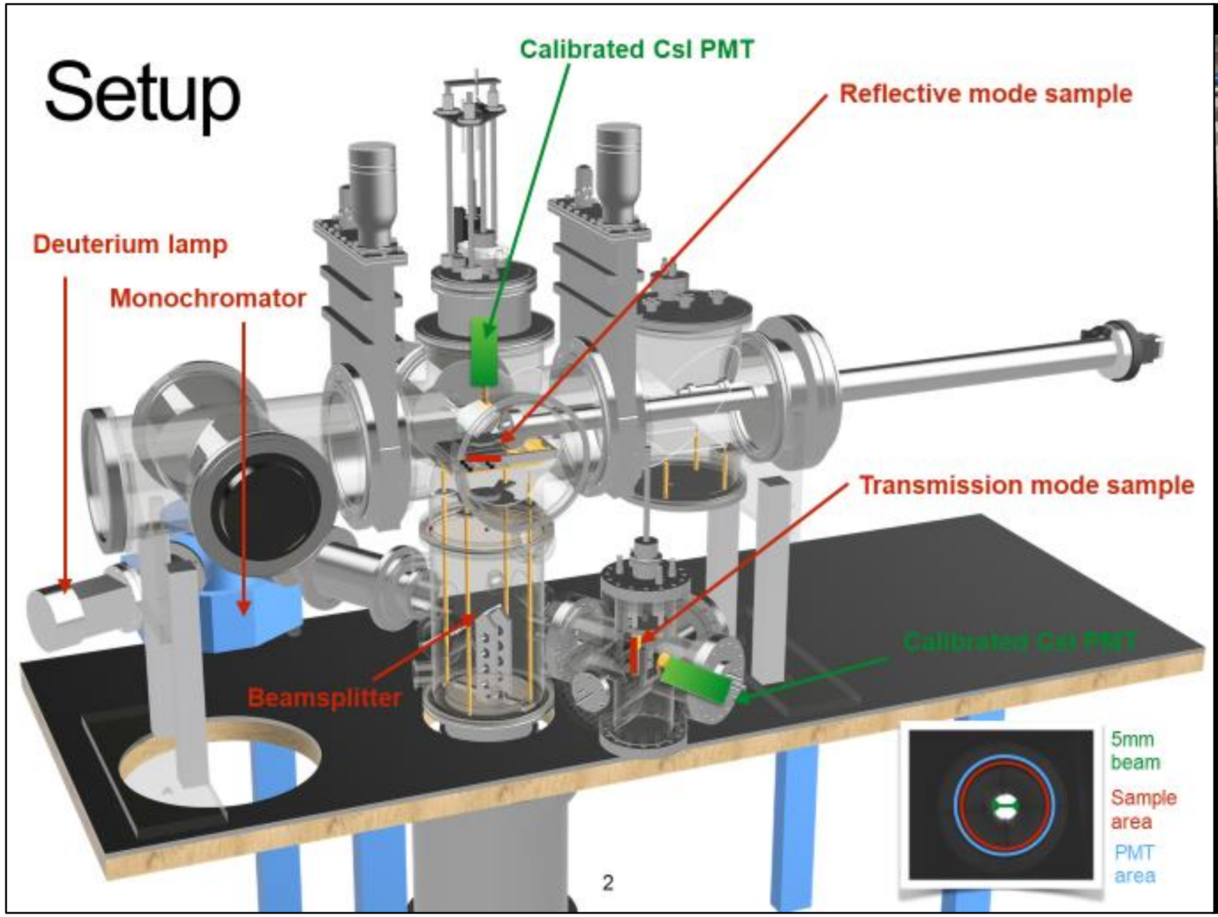
# Quantum Efficiency of ND and H-ND

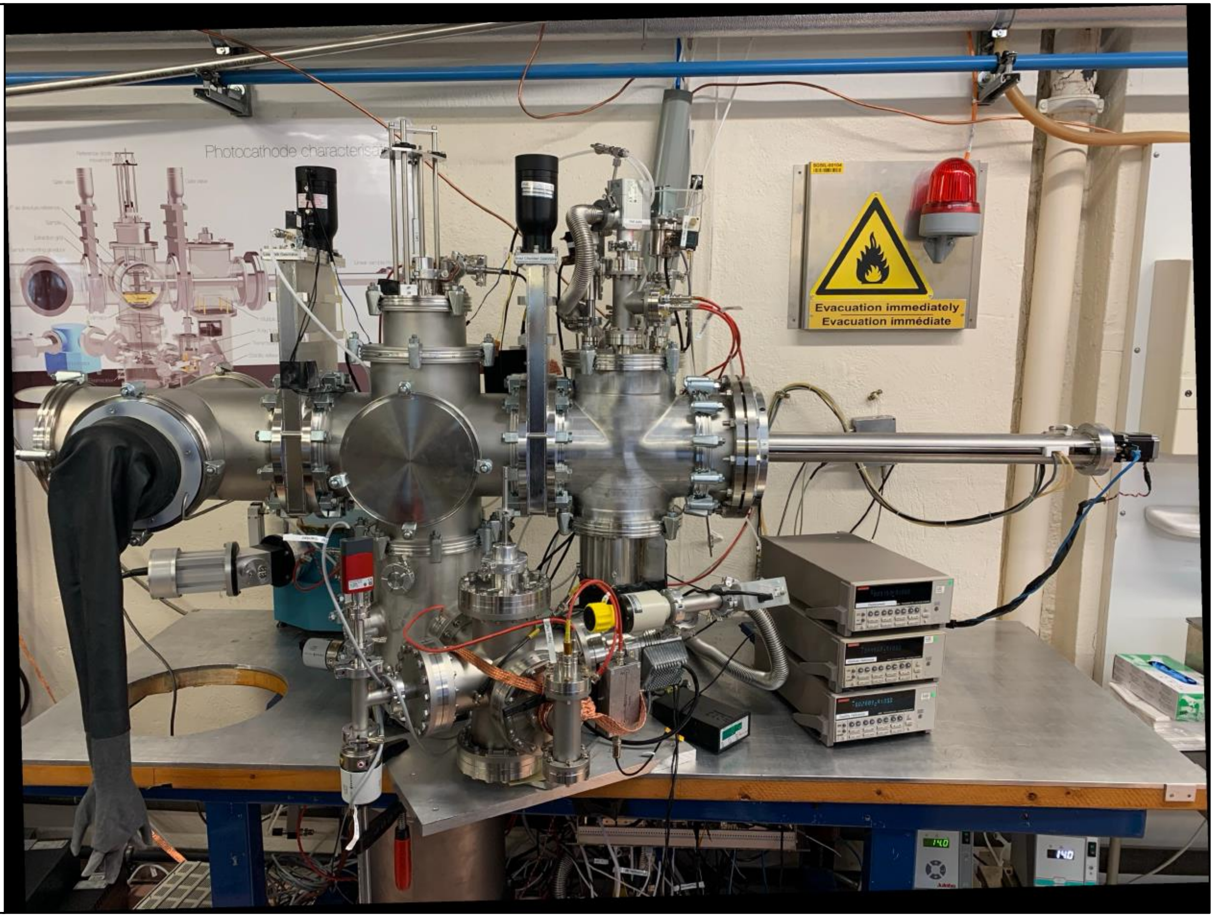


# Photocurrent measurement @ CERN

# Schematic & Pictorial view of photoemission measurement setup: ASSET




ASSET, described by **Marta**

# Quantum Efficiency Formula CERN

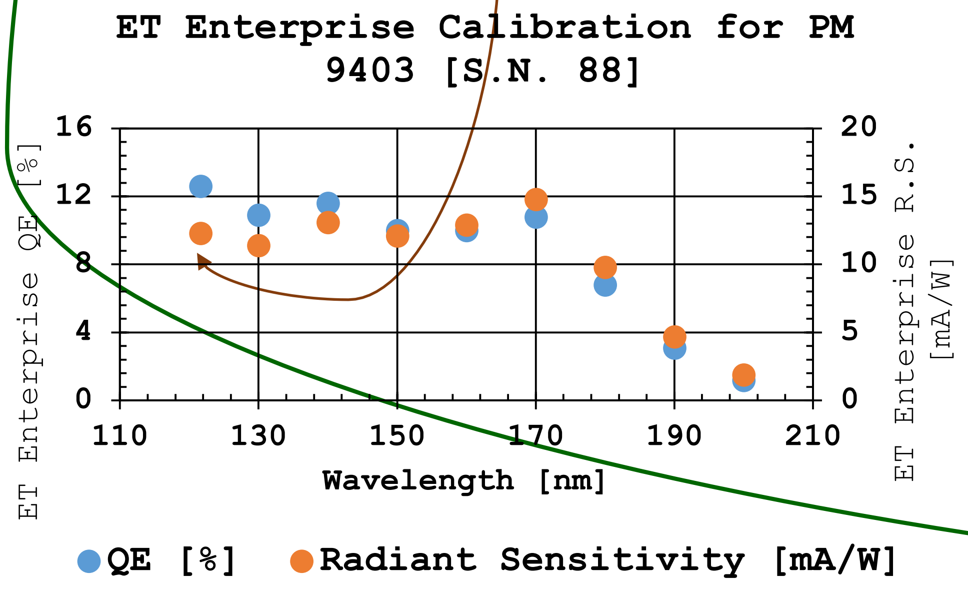
$$QE_{PC}(\lambda) = \frac{N_{pe}}{N_{ph}} = \frac{(I_{PC}/e)}{\left(factor(\lambda) \times I_{ref(abs)}\right)}$$

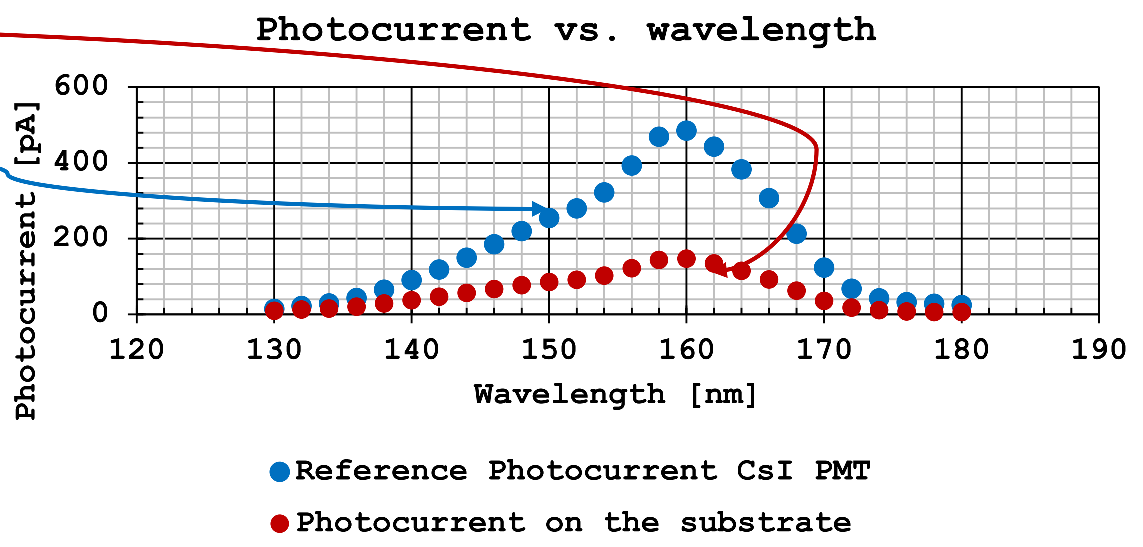
$$I_{ref(abs)} = I_{ref} \times \frac{I_{PMT(Top)}}{I_{PMT(Bottom)}};$$

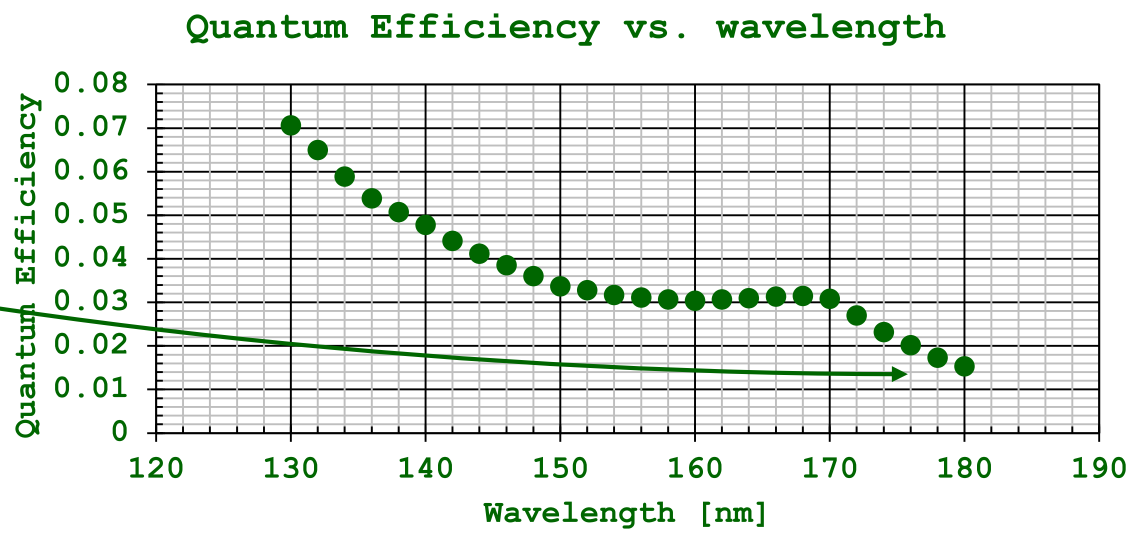
$$where\ I_{ref} = I_{PMT(Bottom_{withPC})}$$

$$factor(\lambda) = \frac{\lambda}{h \times c \times radiant\ sensitivity}$$

$\lambda = wavelength; h = Plank's\ constant; c = velocity\ of\ light\ in\ vacuum$



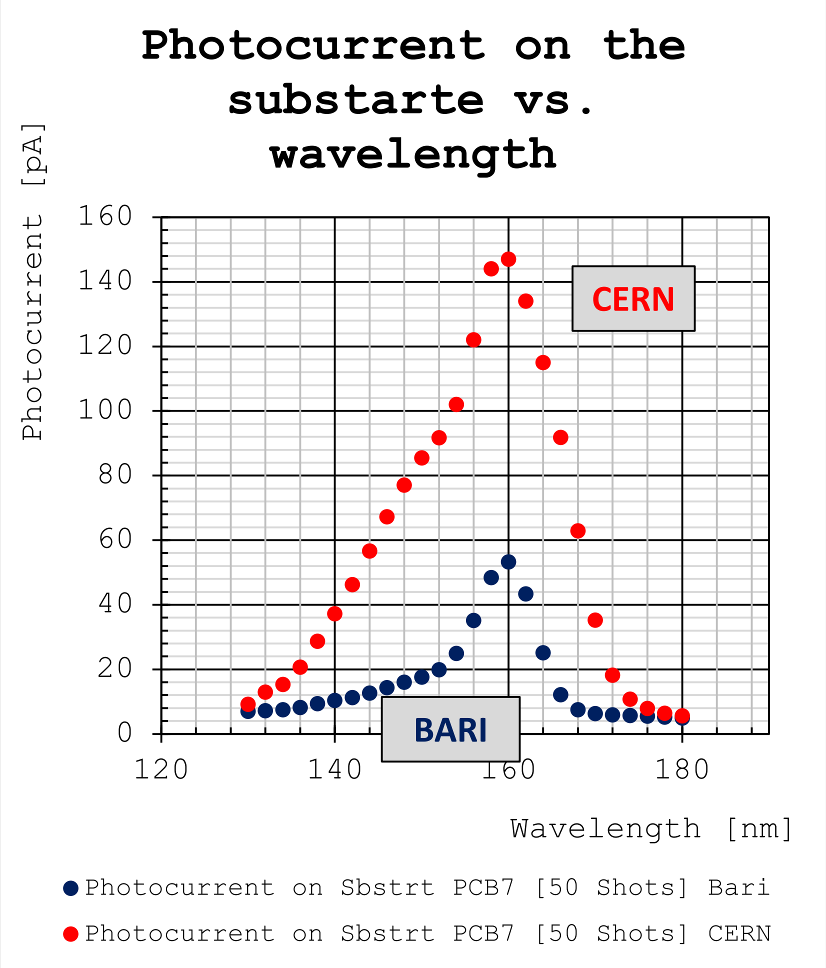



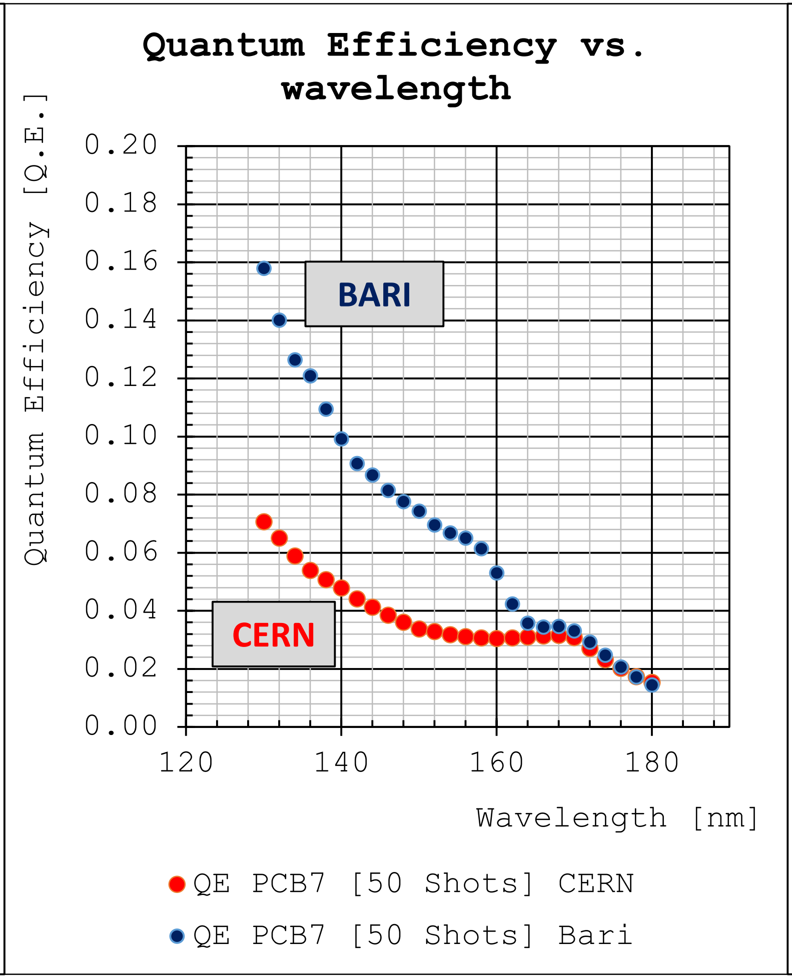



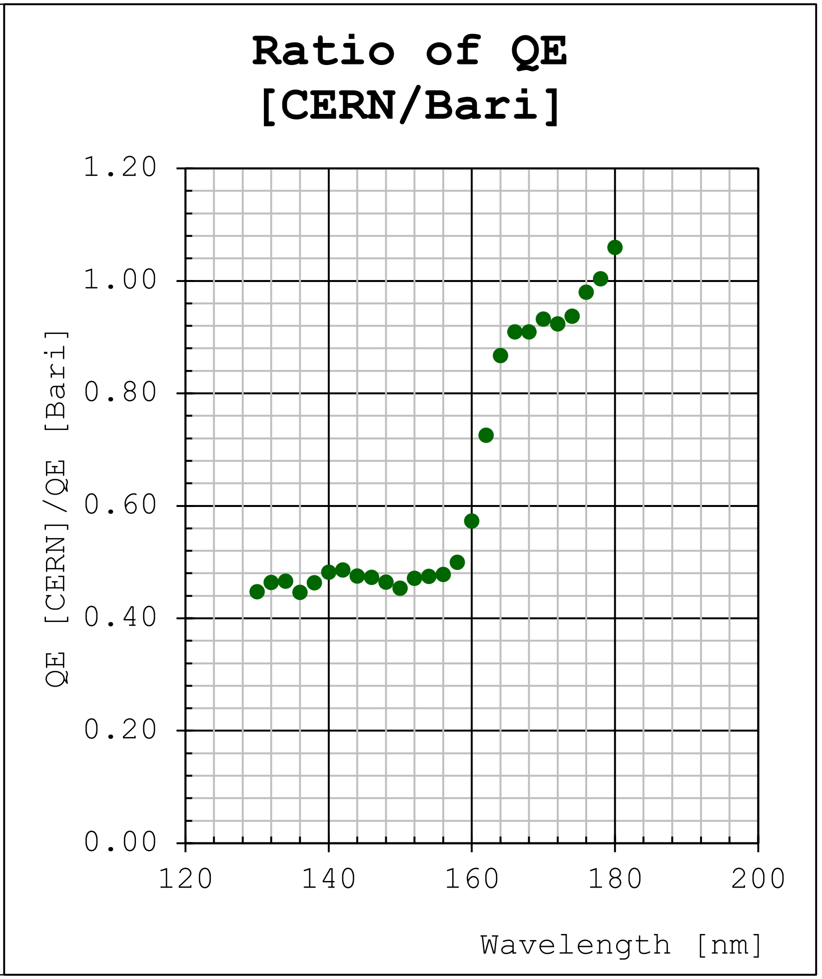

Where :

- $QE_{PC}(\lambda)$ = Quantum efficiency of the photocathode
- $factor(\lambda)$ = extrapolated as shown from data sheet
- $I_{PC}(\lambda)$ = Measured photocurrent value of the photocathode

# Comparison of Bari and CERN results



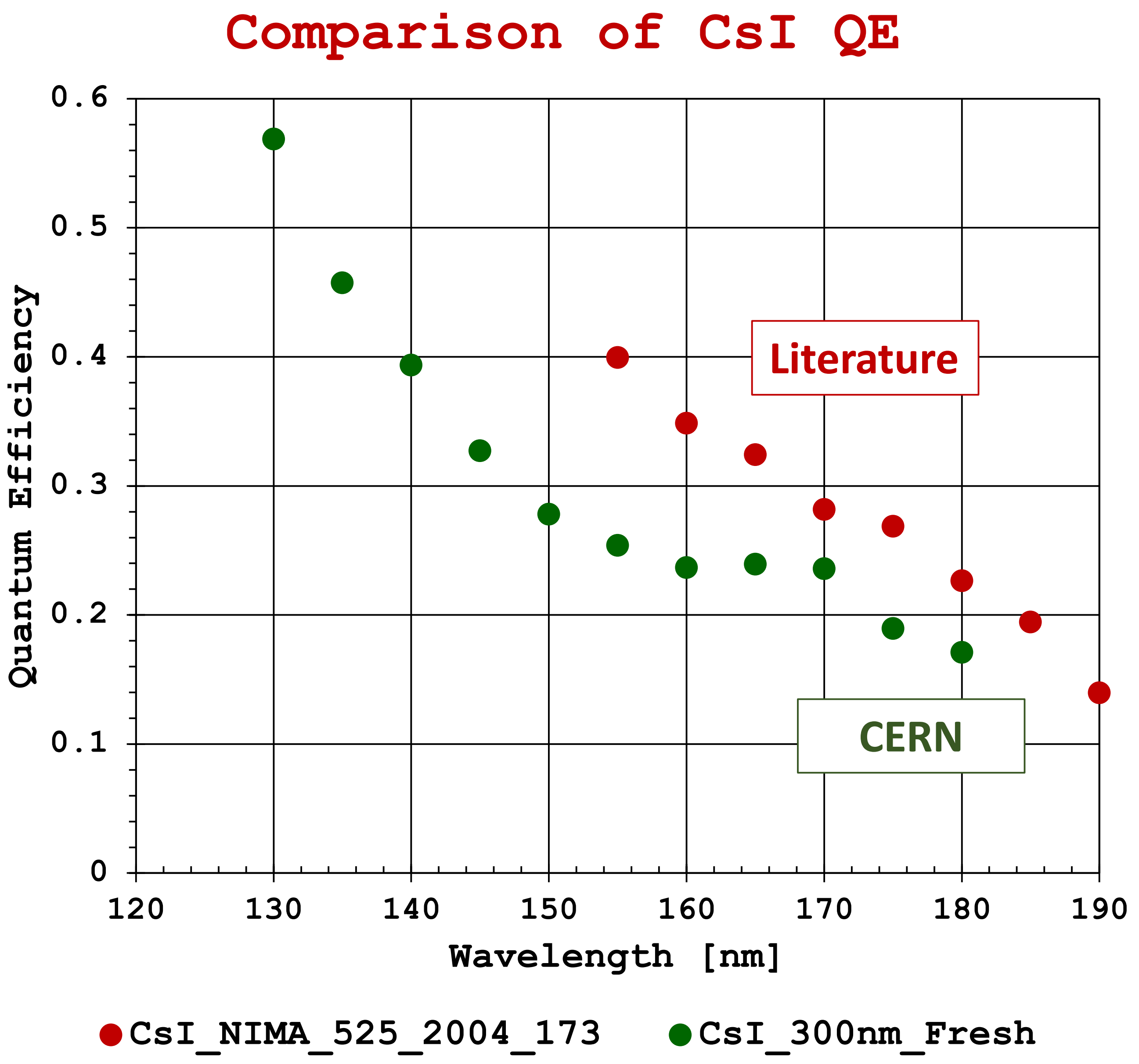



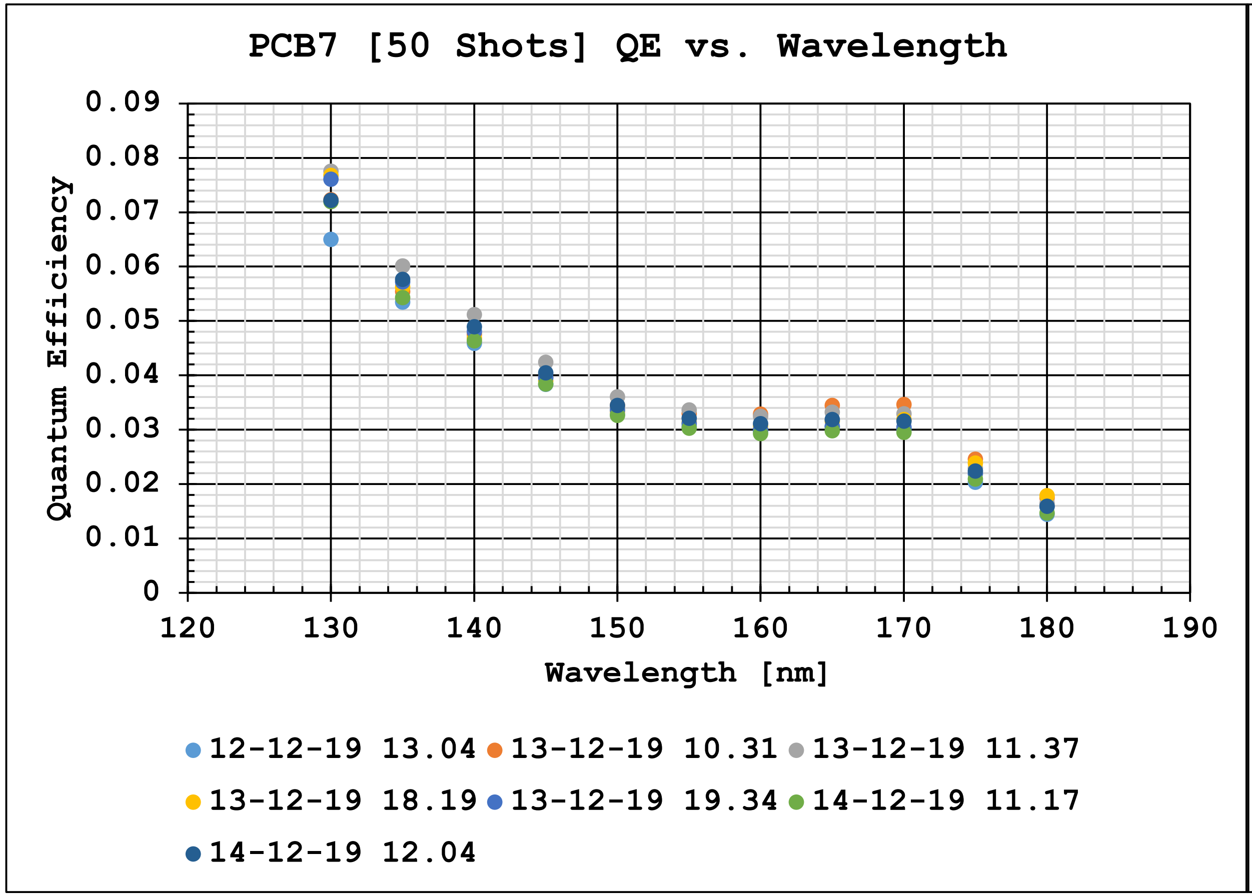

ASSET is in building up state, comparative analyses are useful

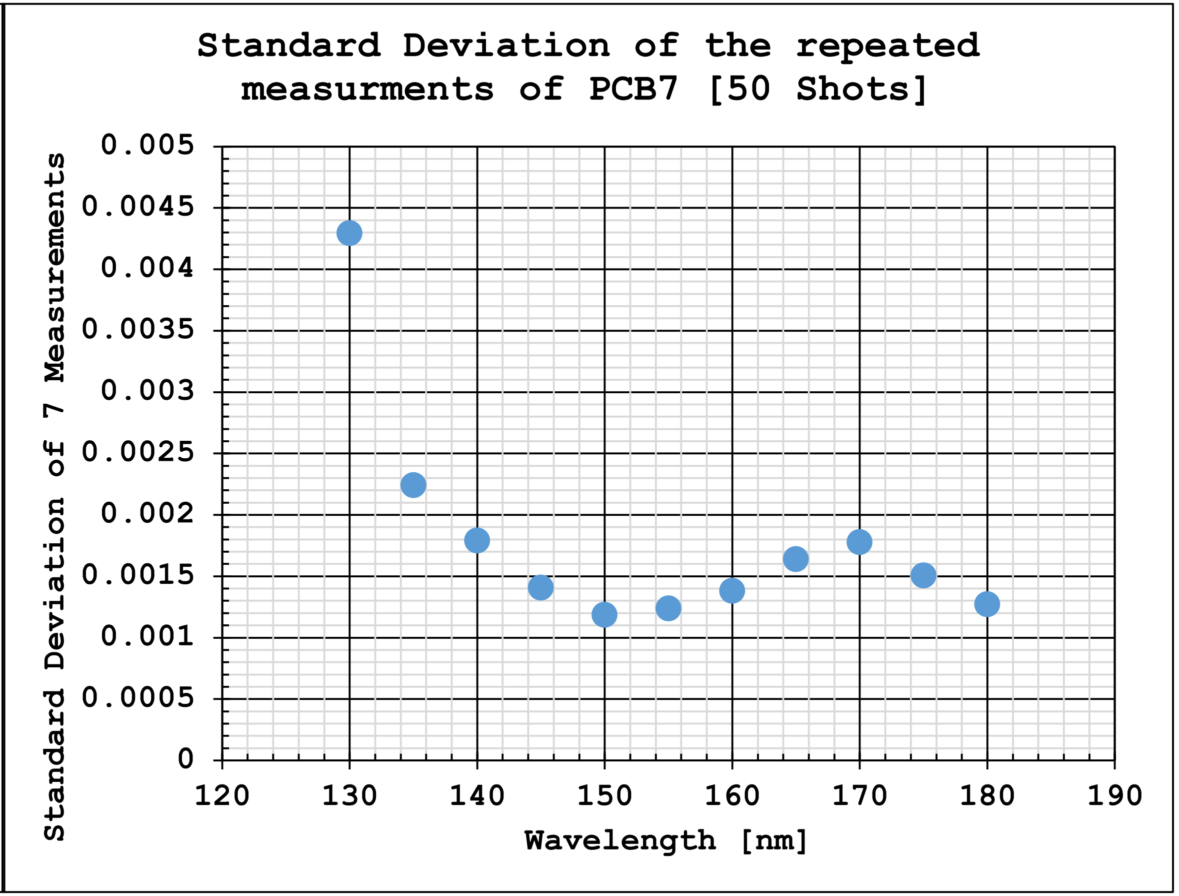
# Comparison with literature

- Deposited by Miranda and Thomas in CERN.
- Substrate used: Au PCB coin
- Measured in ASSET @ GDD lab.
- **QE: ~ 23.6% @ CERN & ~34.8 in literature for λ = 160 nm**

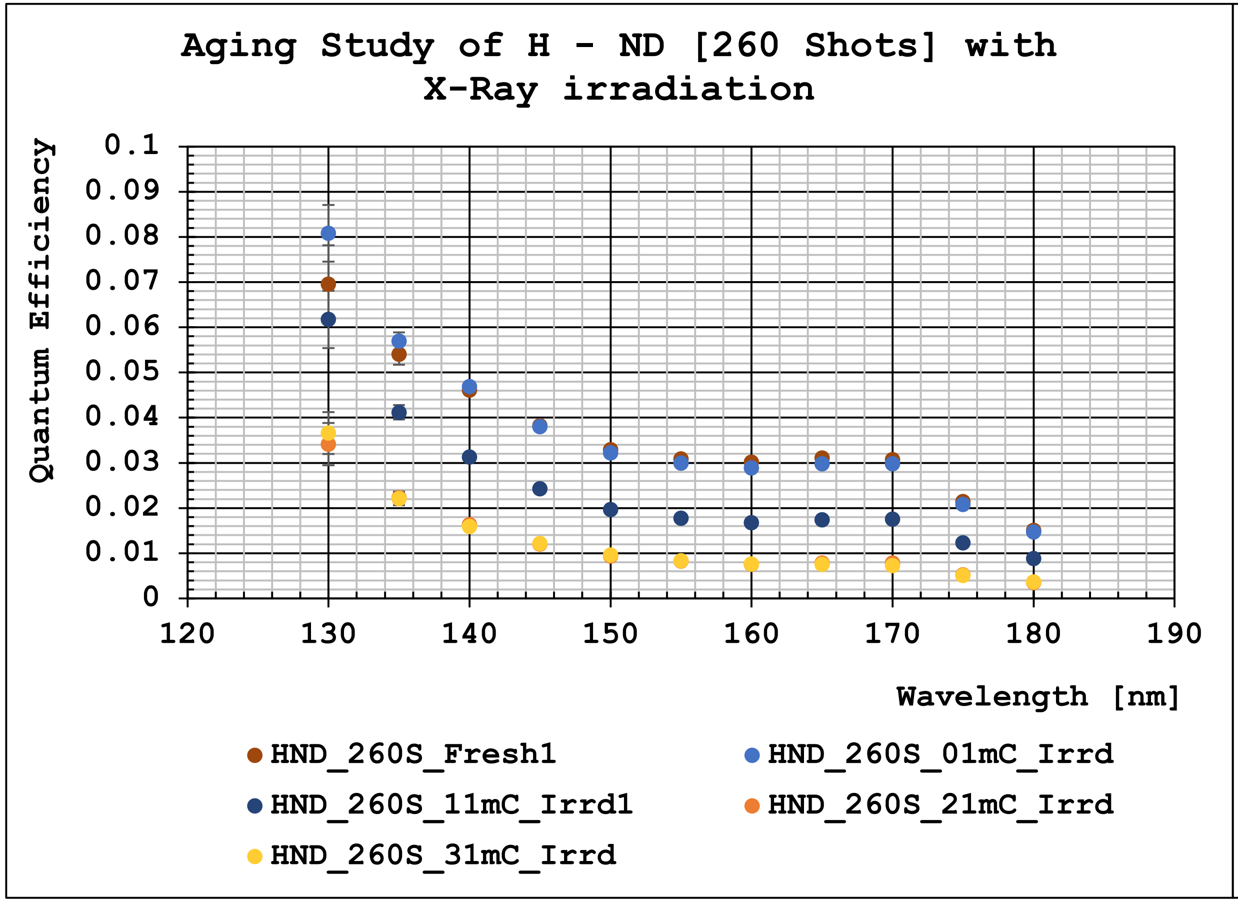


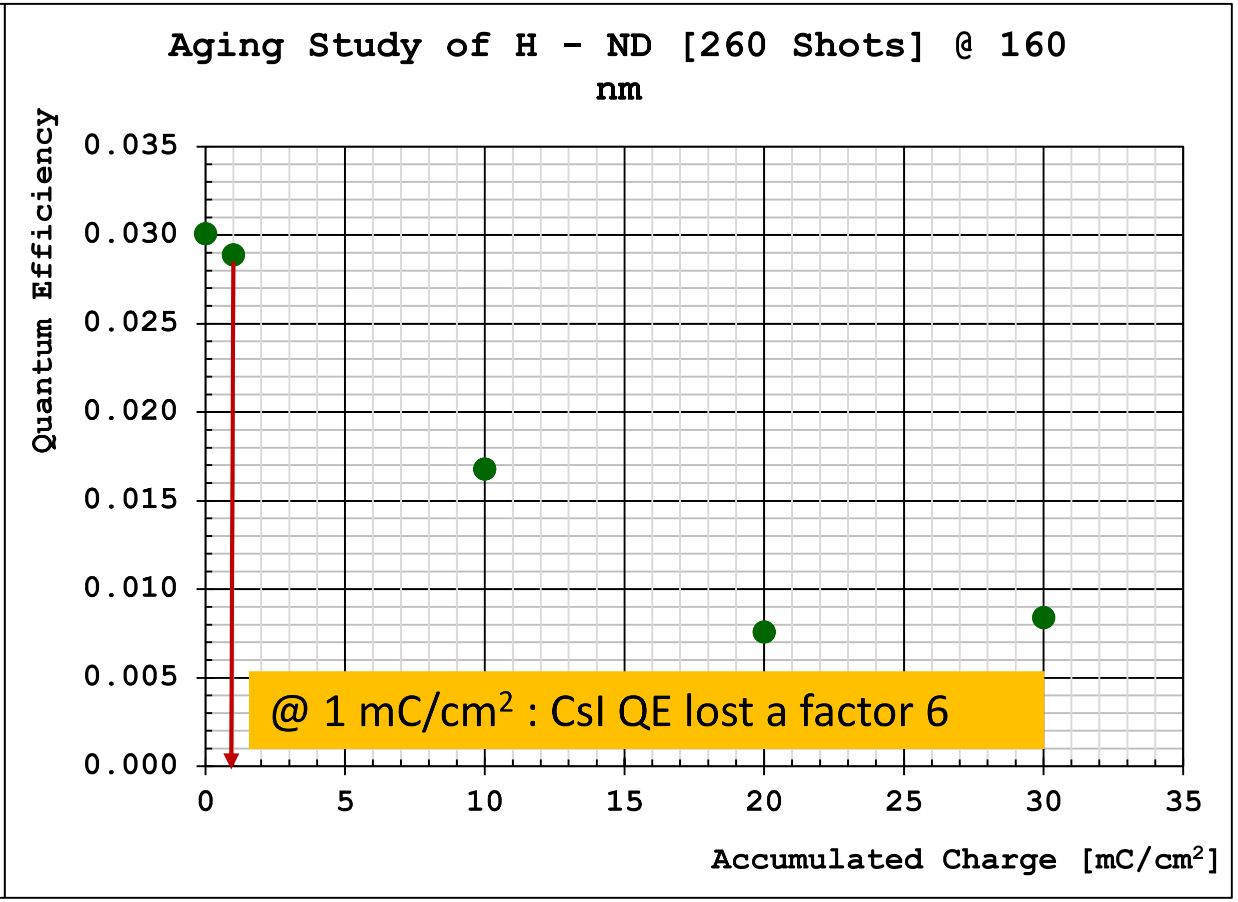
# Reproducibility @ CERN



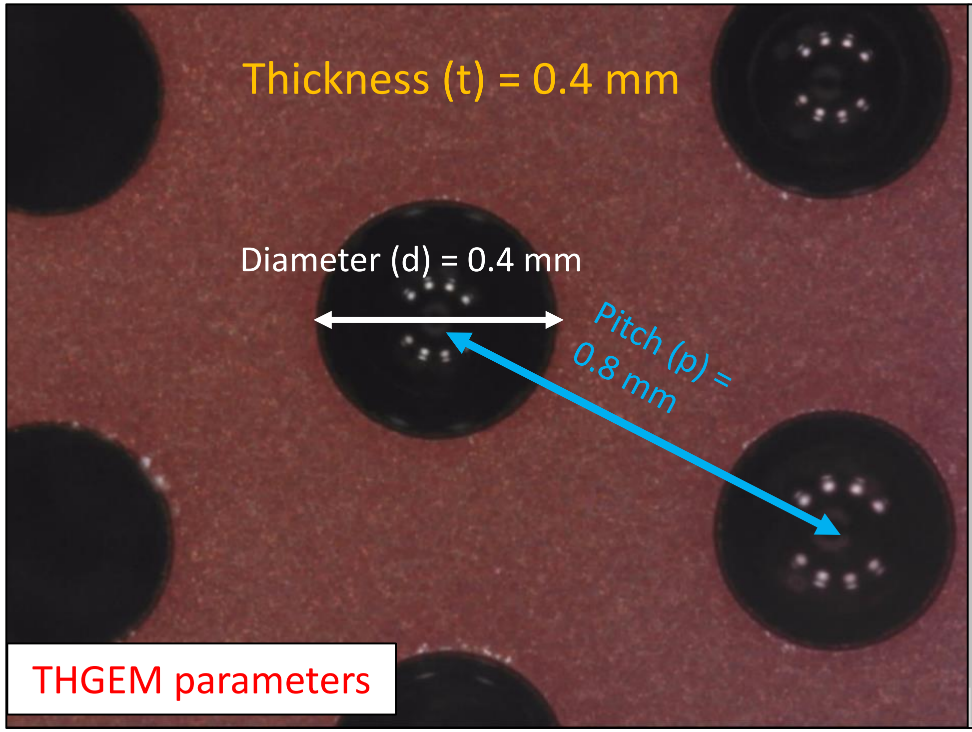



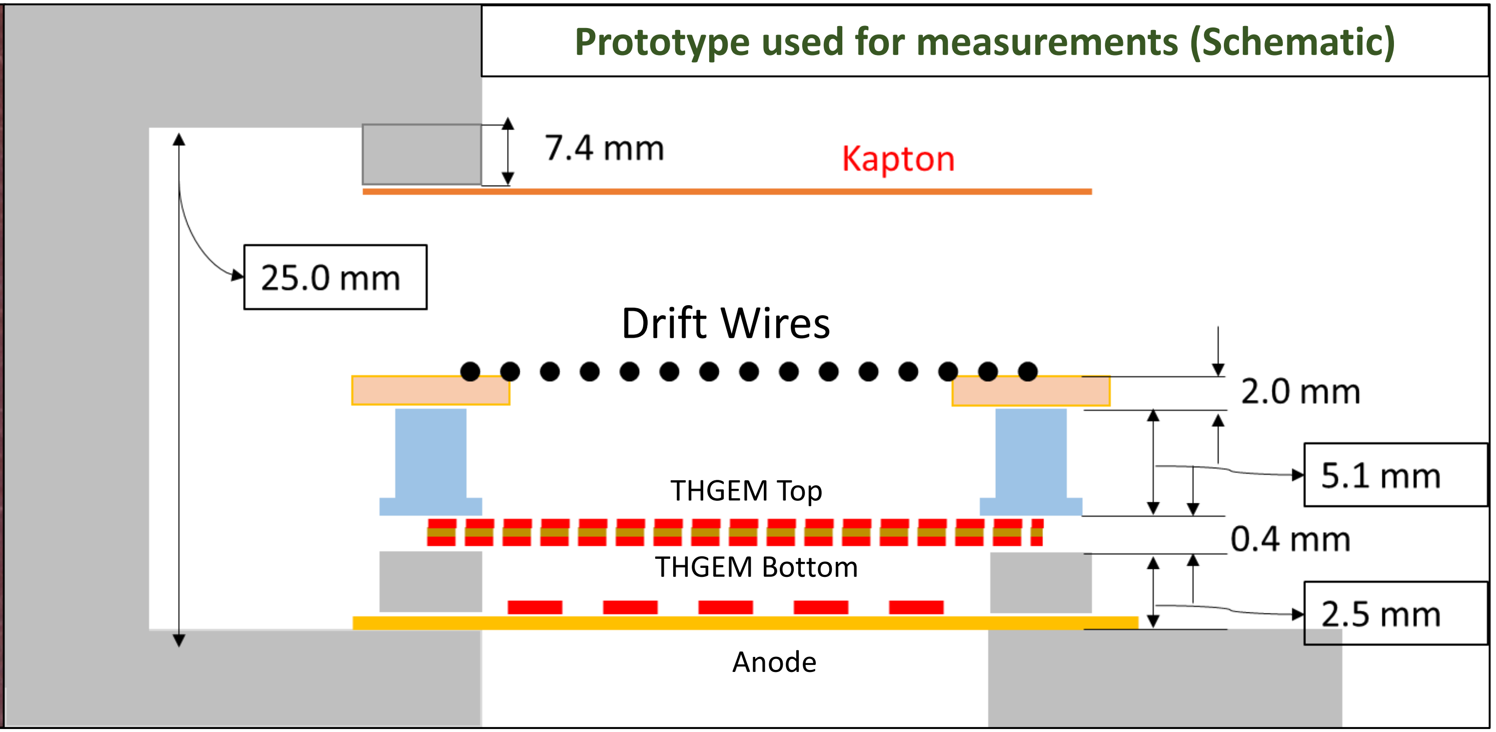
# Aging study with X-Ray irradiation of H – ND



# THGEM Characterization




- THGEMs are standard Printed Circuit Boards (PCBs) with holes produced by mechanical drilling.
- Like in GEMs, in the presence of a correct electrical bias and in a proper gas mixture, each hole acts as an electron multiplier.
- The signal generated by the gas multiplication is collected at the anode.
- The geometrical parameters of our THGEMs are: hole diameter (d) = 0.4 mm; hole pitch (p) = 0.8 mm; thickness of the fiberglass (t) = 0.4 mm; and rim around holes < 5 um.

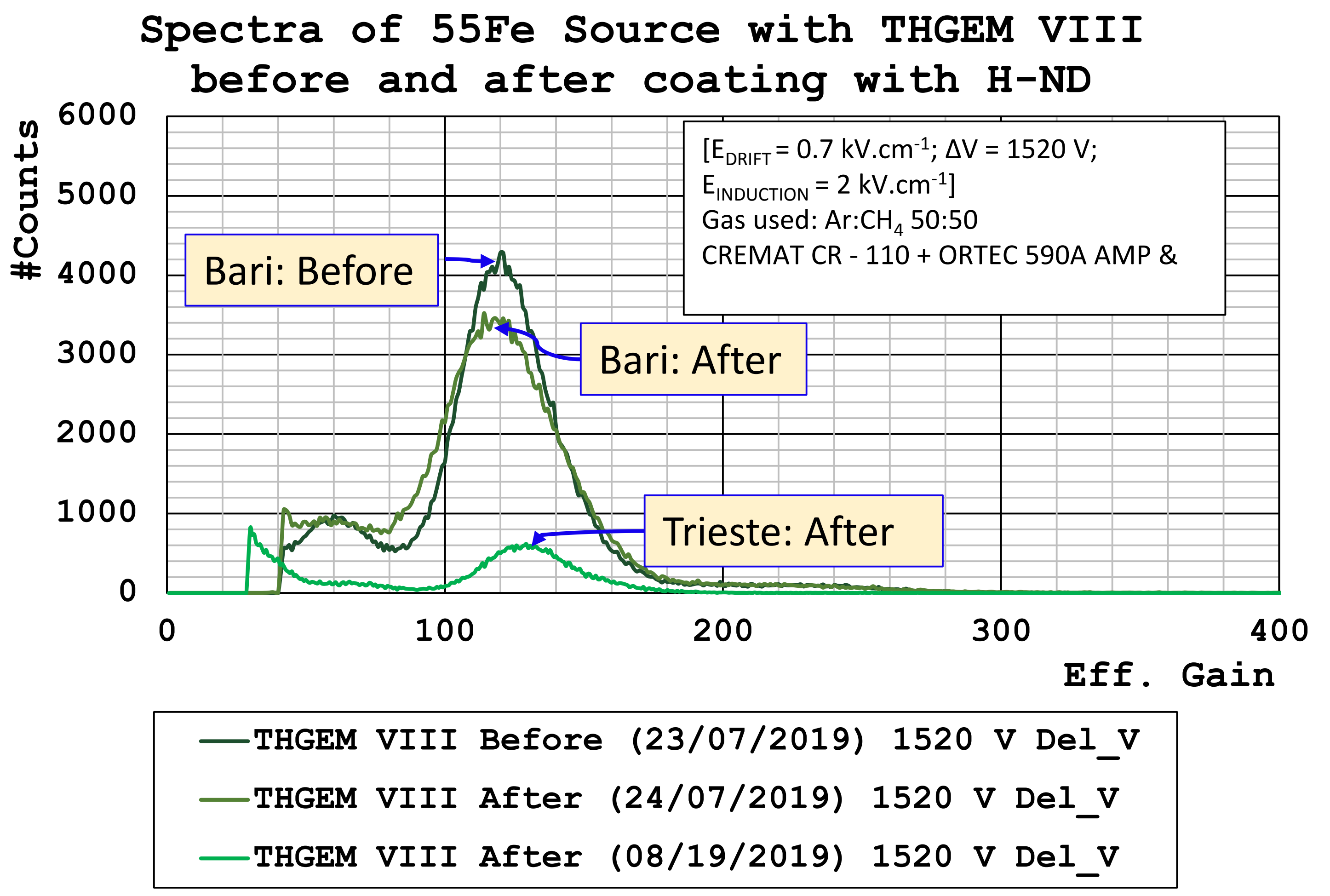
- For measurements the gas mixture used is: **Ar:$CH_4$ 50:50**
- **CAEN N1471H** HV PS has been used.
- CREMAT **CR-110** Preamplifier with CREMAT **CR-150** r5 evaluation board has been used to read the signal from the detector.
- **Ortec 672** Spectroscopy amplifier with **AMPTEK MCA 8000A** has been used for processing the signal and for saving the data.

# What we did so far

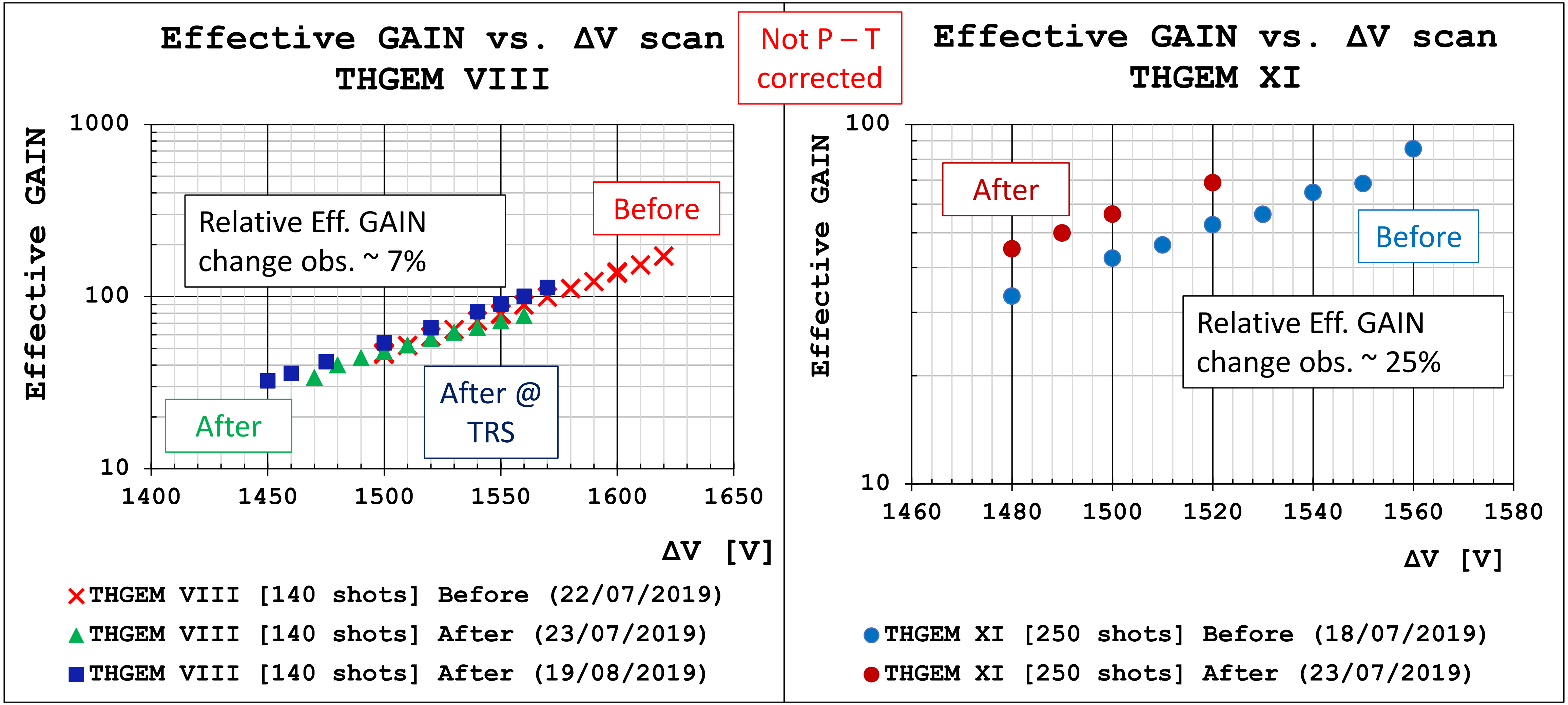
- We coated few old 30 X 30 $mm^2$ prototypes and as some of them showing pathologies we produced 25 new prototypes with COMPASS standard $[\emptyset = 0.4\ mm; t = 0.4\ mm; p = 0.8\ mm; RIM < 5\ \mu m]$.
- After postproduction they are characterized in Trieste LAB.
- To be sure we bring a small setup in Bari and characterized them before and after coating.
- First results are already presented in RICH 2018 and MPGD 2019 as a poster. RICH-2018 Proceeding is Published in NIMA_952_2020_161967.
- A very brief overview in next slide.

# THGEM Characterization in Bari

- THGEM used: THGEM IX [d = 0.4 mm; t = 0.4 mm; p = 0.8 mm; RIM < 5 µm];
- Gas Misxture: **Ar:$CH_4$ 50:50**.
- **CAEN N1471H HV PS**
- Voltage Configuration: Drift = 2520 V; Top = 2020 V; Bottom = 500 V;
- **$^{55}$Fe X – Ray source**.
- **Cremat CR – 110** Preamp + ORTEC 590A Amplifier + AMPTEK MCA 8000A.
- Calc. Eff. Gain ~ 122
- Heat treatment after coating introduced (24 h at 120° C): W/O treatment THGEM does not stand HV

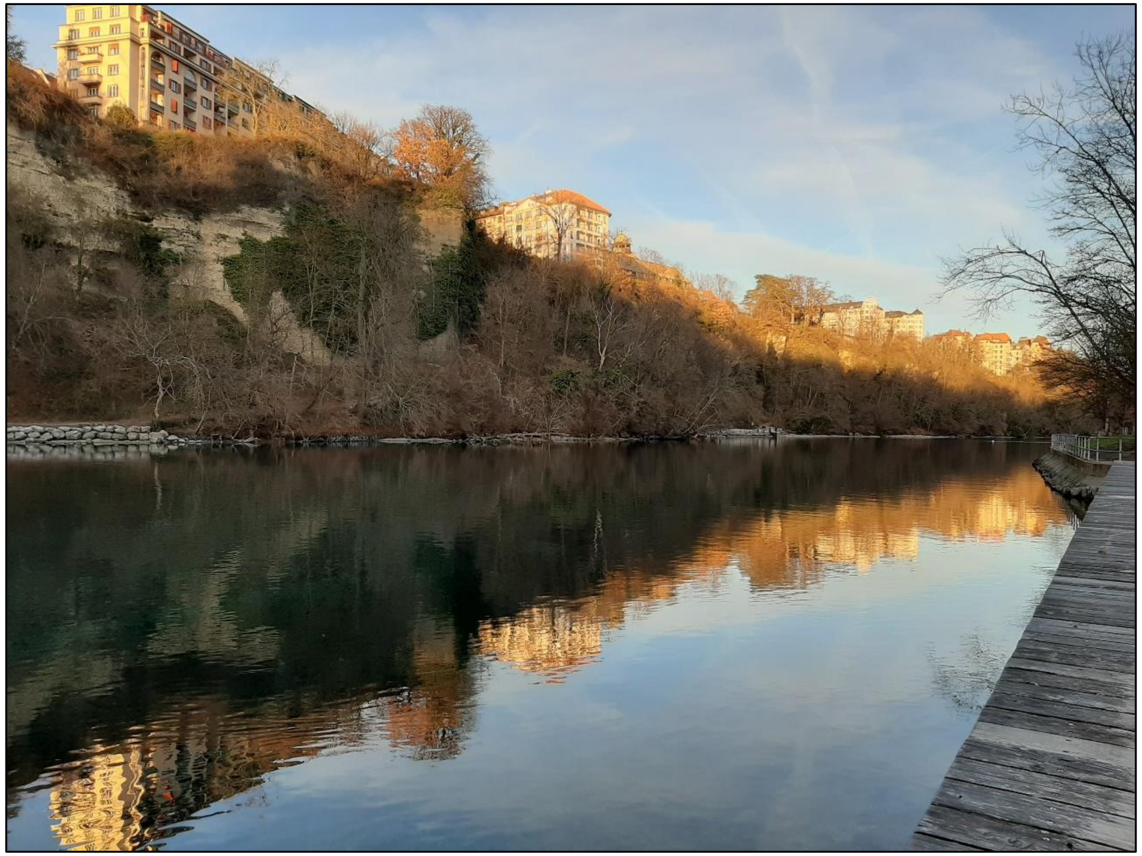


# THGEMs with H – ND



# Conclusion

- A systematic R&D has been started to explore the characteristics and possibilities of ND photocathode.
- Preliminary measurements has been performed and found promising results.
- It is observed that H – ND is having comparable QE to CsI @ 140 nm.
- Aging studies has been started.
- H – ND has been applied on THGEMs and R&D towards a detector of single photon based on hybrid (THGEM + MM) MPGD technology with H – ND photocathode has been started.
- Coated THGEM perform nicely thanks to heat treatment
- Both BARI and CERN setup useful:
  - BARI: (H-)ND photocathodes can be produced, mature setup for absolute QE measurement
  - CERN, flexible setup where measurements like radiation damage profile scanning  are possible



THANK YOU

# Backup slides

# QE Setup Details: INFN, Bari Vs RD-51 lab, CERN

## INFN, Bari

- Vacuum of the order of ~ $10^{-5}$ mbar.
- Monochromator part in ~ $10^{-5}$ mbar order of vacuum.
- TMP is pre-pumped by a oil based baking pump.
- Monochromator chamber and working chamber is separated by a gate valve
- Having a collimating optical mirrors
- Wavelength range 120 nm-250 nm
- Monochromator model: McPherson 302
- Slit width opening = 100 µm
- NIST photodiode : for calibration
- No reference PMT use to monitor the light fluctuation during the measurement

## RD 51 lab, CERN

- Vacuum of the order of ~ $10^{-7}$ mbar.
- Monochromator part in Dry N2 gas environment
- TMP is pre-pumped by a oil based baking pump.
- Monochromator chamber and working chamber is separated by a $MgF_2$ window
- VUV beam is focused by a lens
- Wavelength range 130 nm-180 nm
- Monochromator model: McPherson 302
- Slit width opening = 3 mm
- CsI PMT : for calibration
- A reference PMT use to monitor the light fluctuation during the measurement

# Quantum Efficiency Formula CERN

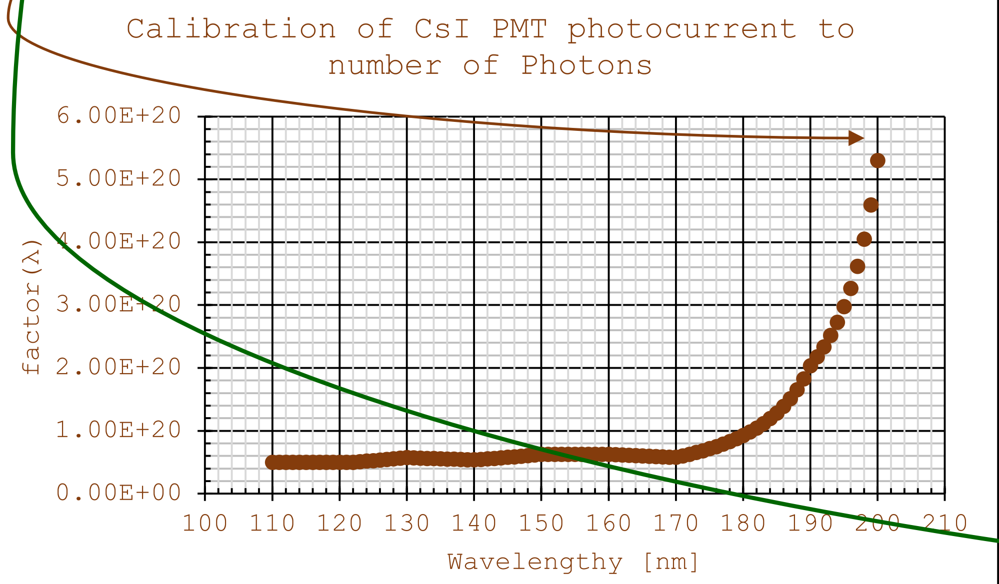
$$QE_{PC}(\lambda) = \frac{N_{pe}}{N_{ph}} = \frac{(I_{PC}/e)}{\left(factor(\lambda) \times I_{ref(abs)}\right)}$$

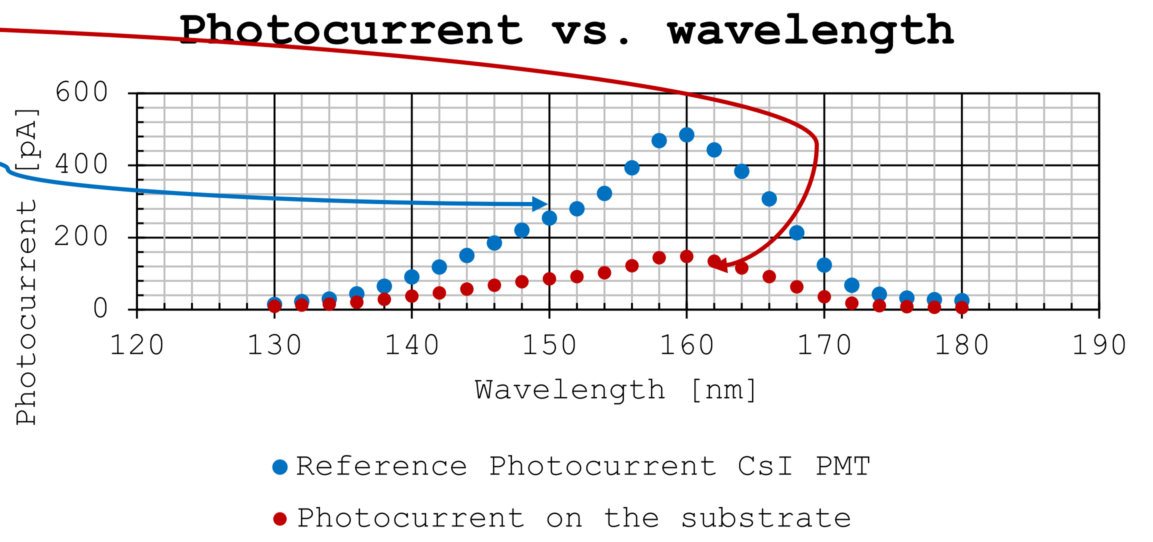
$$I_{ref(abs)} = I_{ref} \times \frac{I_{PMT(Top)}}{I_{PMT(Bottom)}};$$

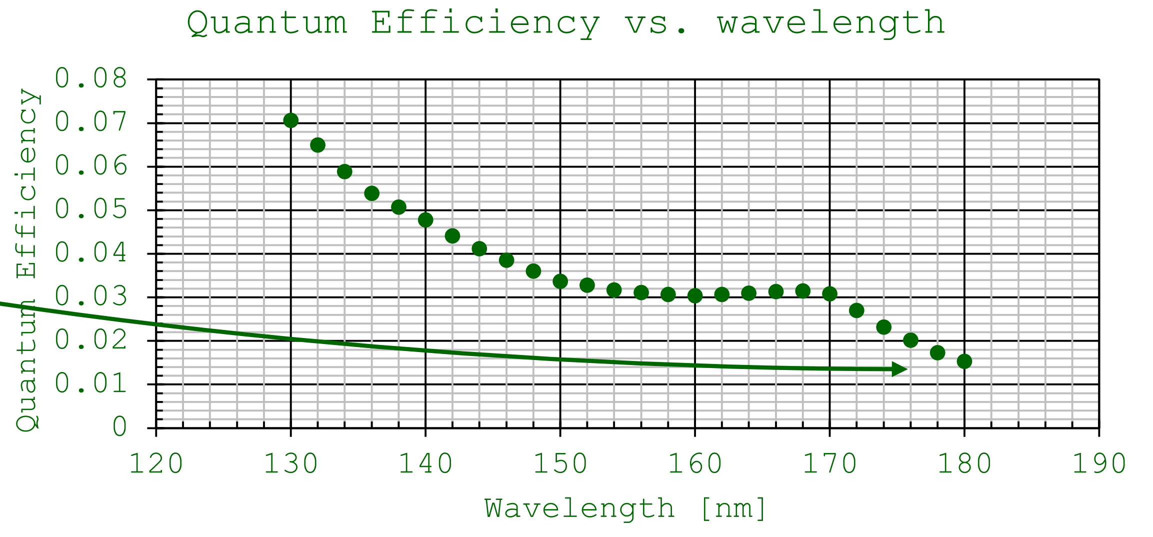
$$\text{where } I_{ref} = I_{PMT(Bottom_{withPC})}$$

$$factor(\lambda) = \frac{\lambda}{h \times c \times radiant\ sensitivity}$$

$\lambda$ = wavelength; $h$ = Plank's constant; $c$ = velocity of light in vacuum

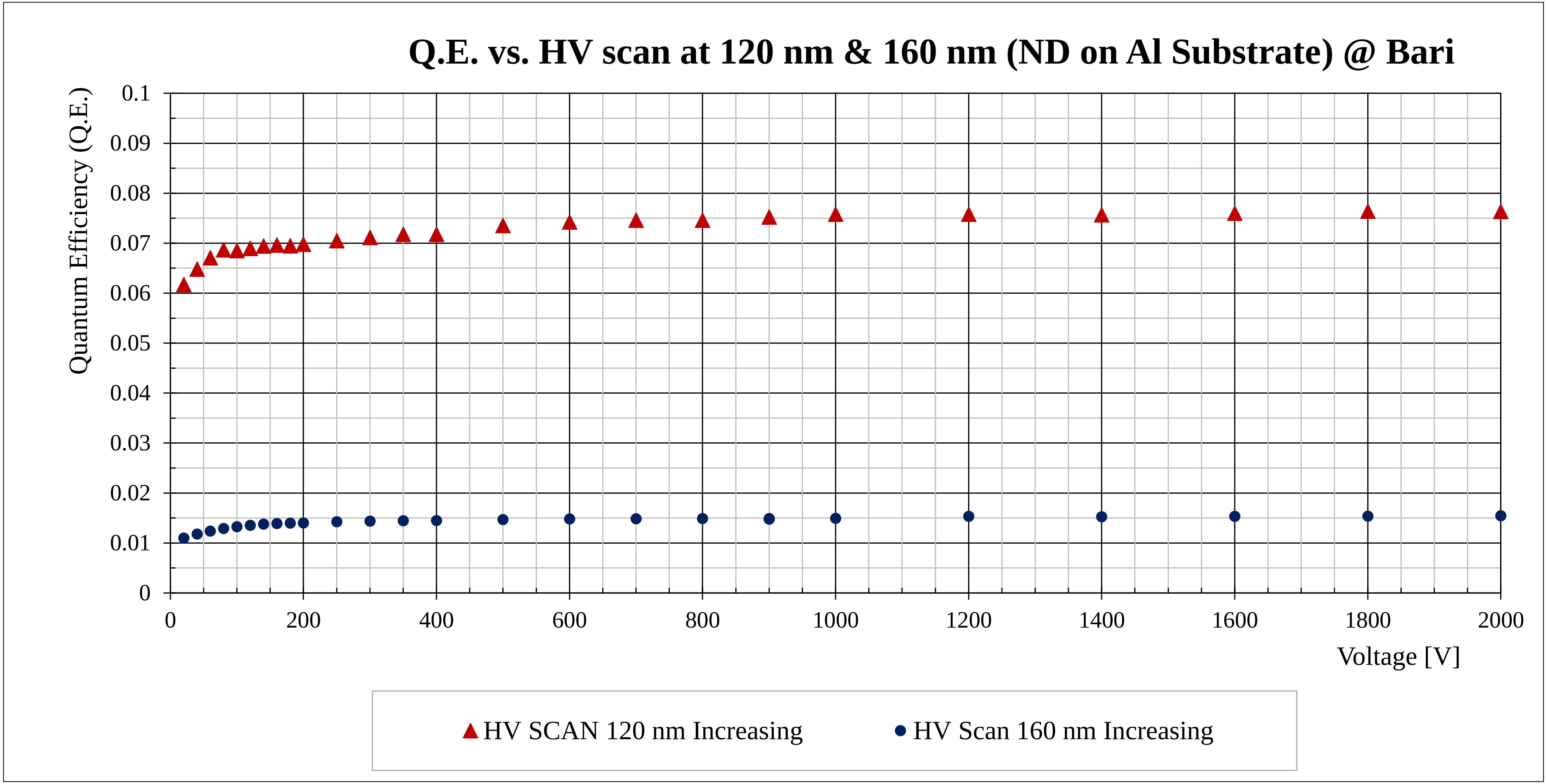


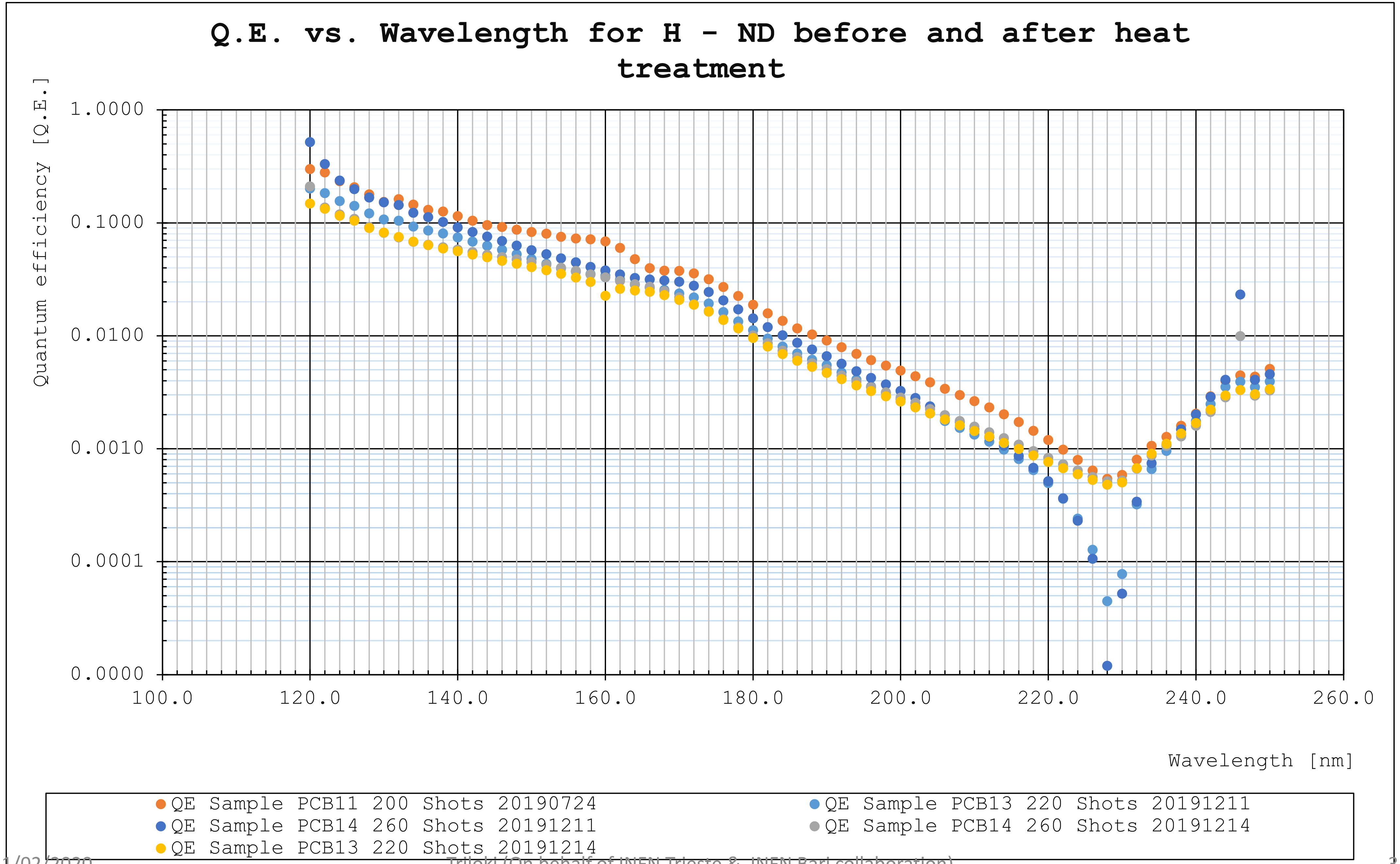



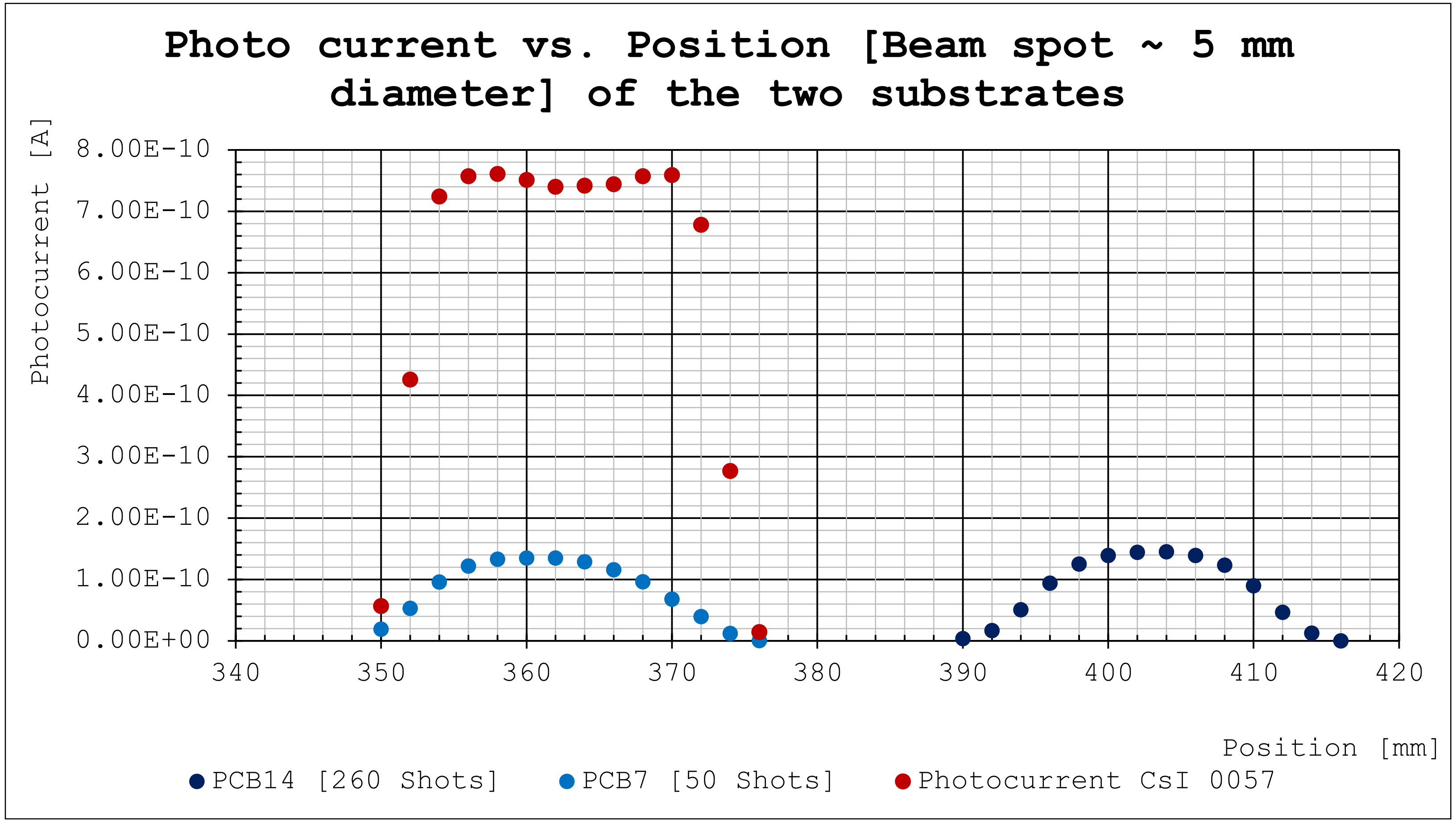

Where :

- $QE_{PC}(\lambda)$ = Quantum efficiency of the photocathode
- $factor(\lambda)$ = extrapolated as shown from data sheet
- $I_{PC}(\lambda)$ = Measured photocurrent value of the photocathode

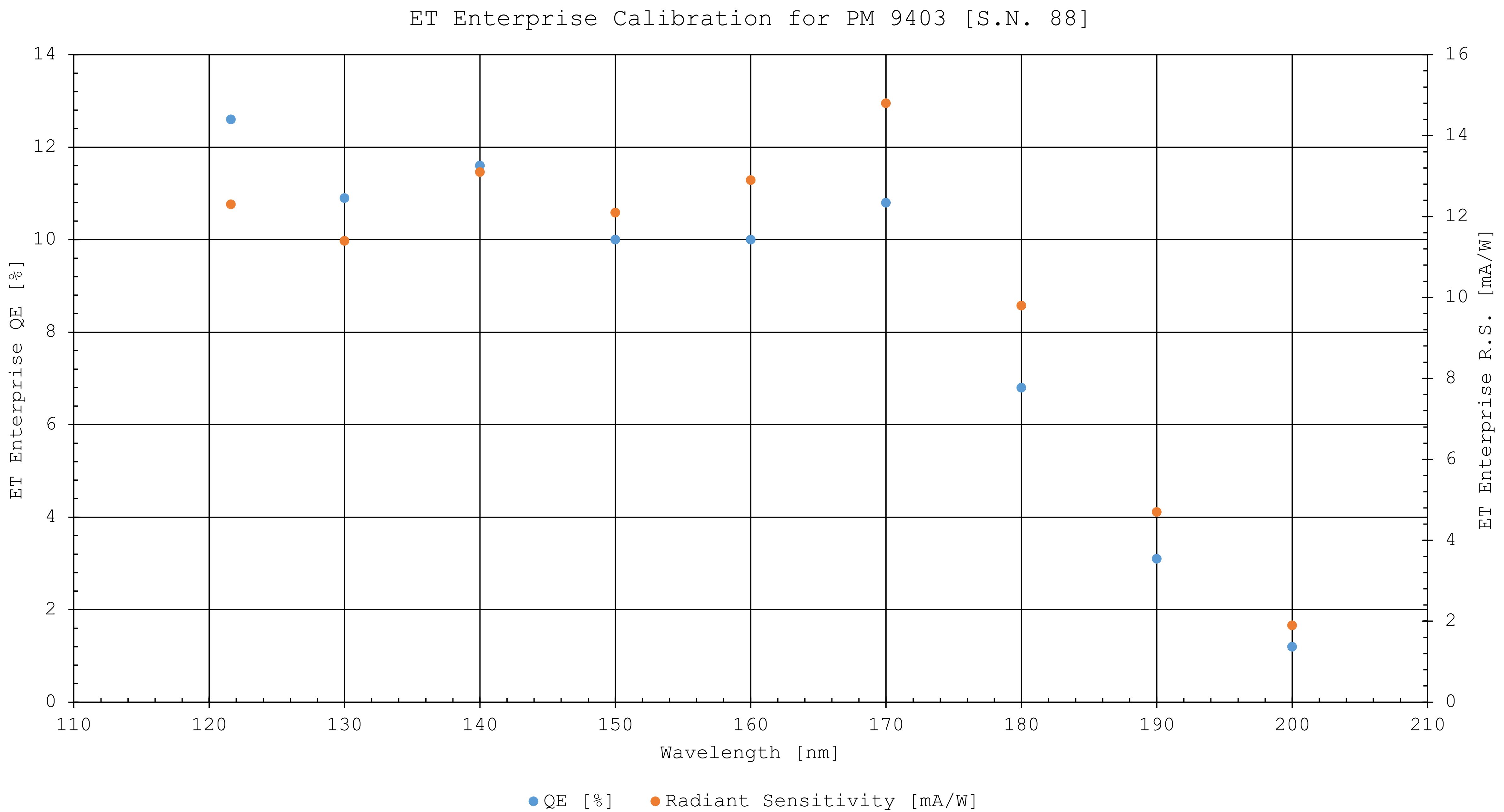

Q.E. vs. HV scan at 120 nm & 160 nm (ND on Al Substrate) @ Bari
Quantum Efficiency (Q.E.)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Voltage [V]
HV SCAN 120 nm Increasing
HV Scan 160 nm Increasing


Q.E. vs. Wavelength for H - ND before and after heat treatment
Quantum efficiency [Q.E.]
1.0000
0.1000
0.0100
0.0010
0.0001
0.0000
100.0
120.0
140.0
160.0
180.0
200.0
220.0
240.0
260.0
Wavelength [nm]
QE Sample PCB11 200 Shots 20190724
QE Sample PCB14 260 Shots 20191211
QE Sample PCB13 220 Shots 20191214
QE Sample PCB13 220 Shots 20191211
QE Sample PCB14 260 Shots 20191214

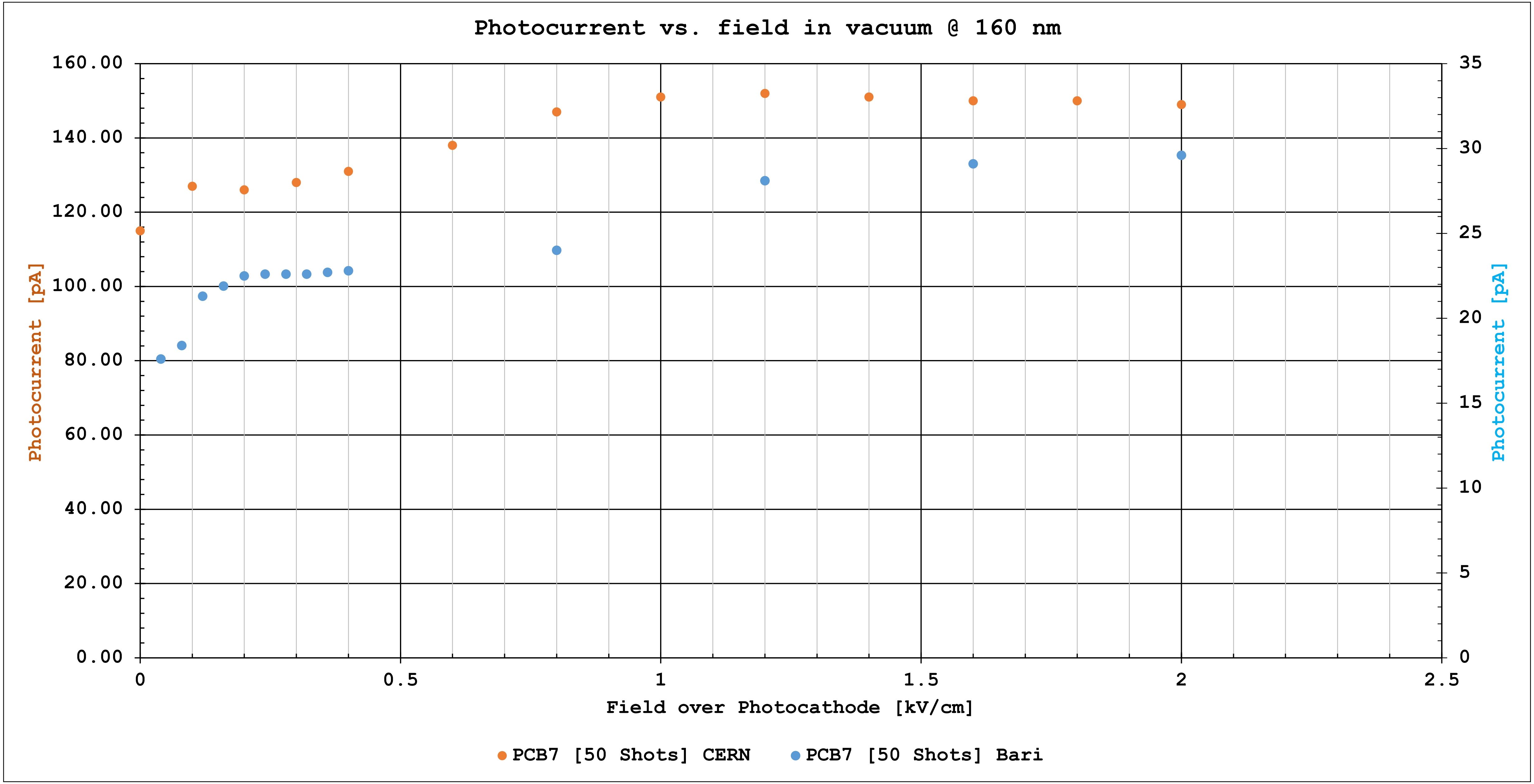
# Position scanning

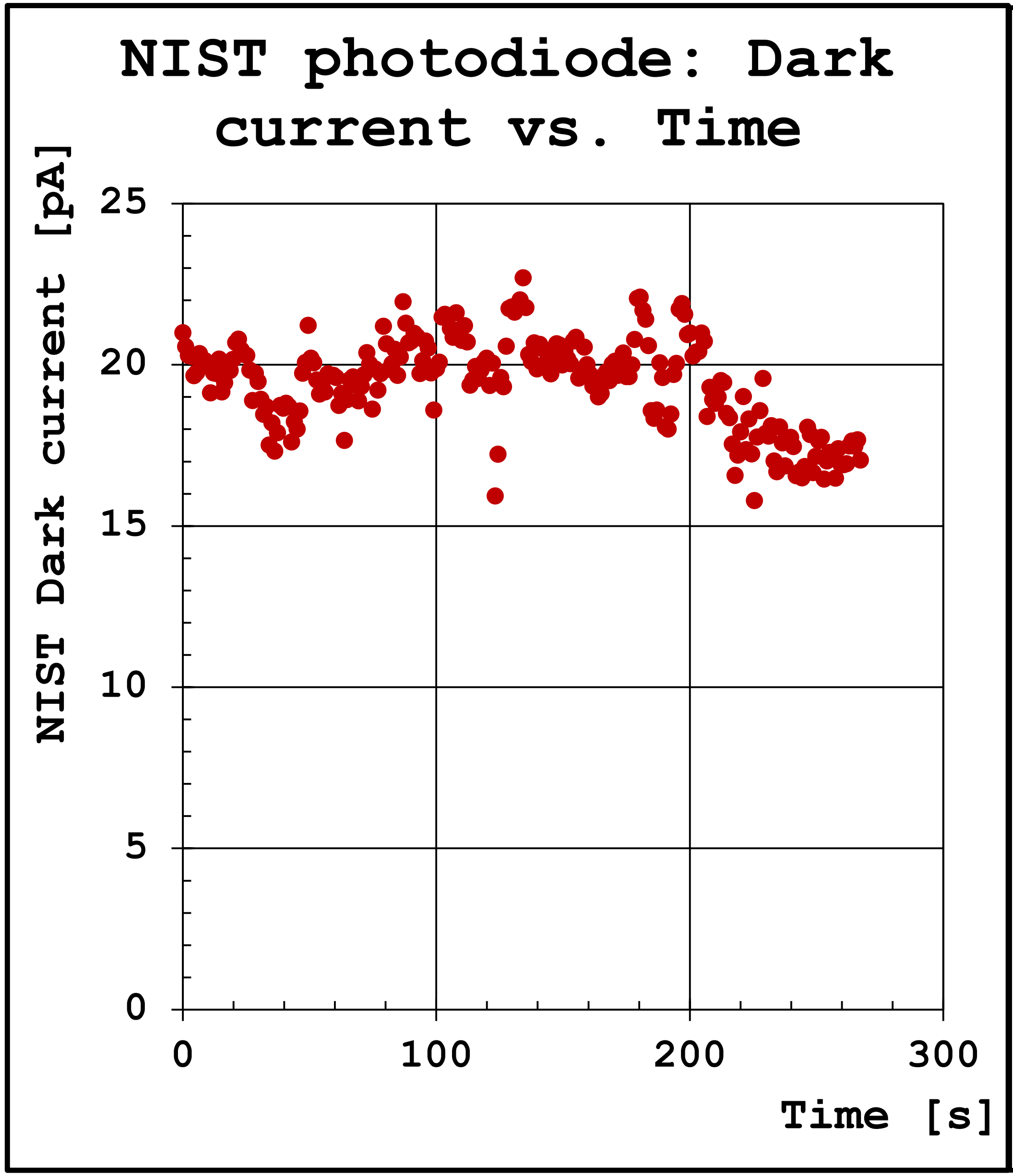


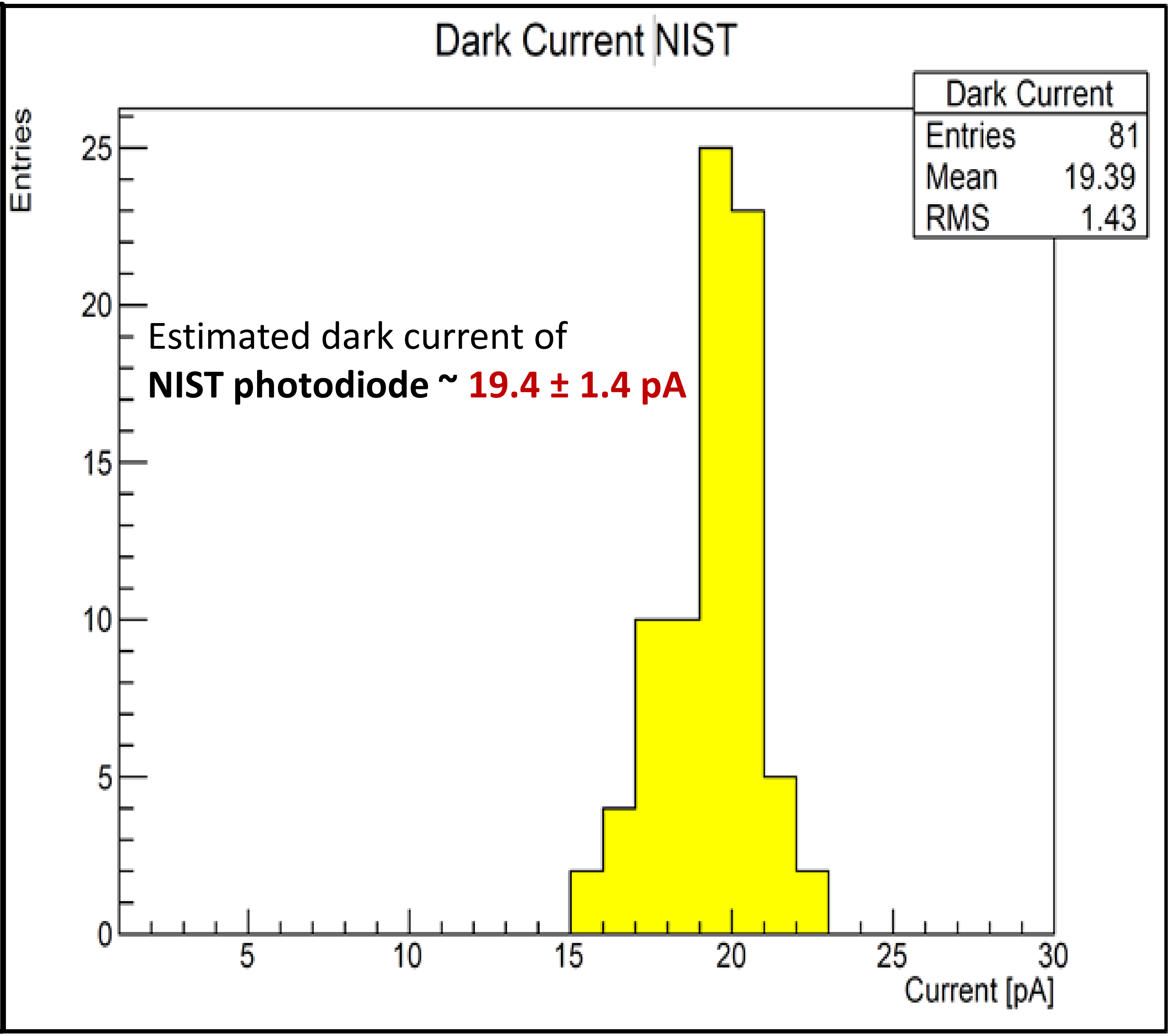

- We scanned two of our samples with 2 mm @ 0 nm wavelength to see the profile.
- A clear difference between CsI and H – ND can be seen.
- The reduced photocurrent is due to lower QE (?).



ET Enterprise Calibration for PM 9403 [S.N. 88]
ET Enterprise QE [%]
ET Enterprise R.S. [mA/W]
Wavelength [nm]
0
2
4
6
8
10
12
14
16
110
120
130
140
150
160
170
180
190
200
210
QE [%]
Radiant Sensitivity [mA/W]


Photocurrent vs. field in vacuum @ 160 nm
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Photocurrent [pA]
35
30
25
20
15
10
5
0
Photocurrent [pA]
0
0.5
1
1.5
2
2.5
Field over Photocathode [kV/cm]
PCB7 [50 Shots] CERN
PCB7 [50 Shots] Bari


NIST photodiode: Dark current vs. Time
NIST Dark current [pA]
25
20
15
10
5
0
0
100
200
300
Time [s]


Dark Current NIST
Dark Current
Entries 81
Mean 19.39
RMS 1.43
Entries
25
20
15
10
5
0
5
10
15
20
25
30
Current [pA]
Estimated dark current of
NIST photodiode ~ 19.4 ± 1.4 pA