Nanodiamond photocathodes for MPGD-based single photon detectors

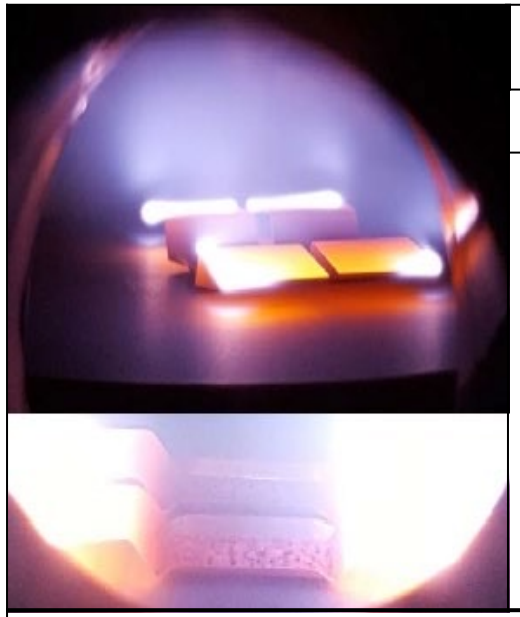
Richa Rai
ICTP-INFN Trieste

On Behalf of Trieste, Bari, & CERN collaboration

- Introduction
- Hydrogenation and coating
- Pervious studies on HND
- Transmittance of HND
- Photoemission measurement
- Summary

Why and which Nano Diamond

in the framework R&D programme, coupling of H-ND and THGEMs are investigated

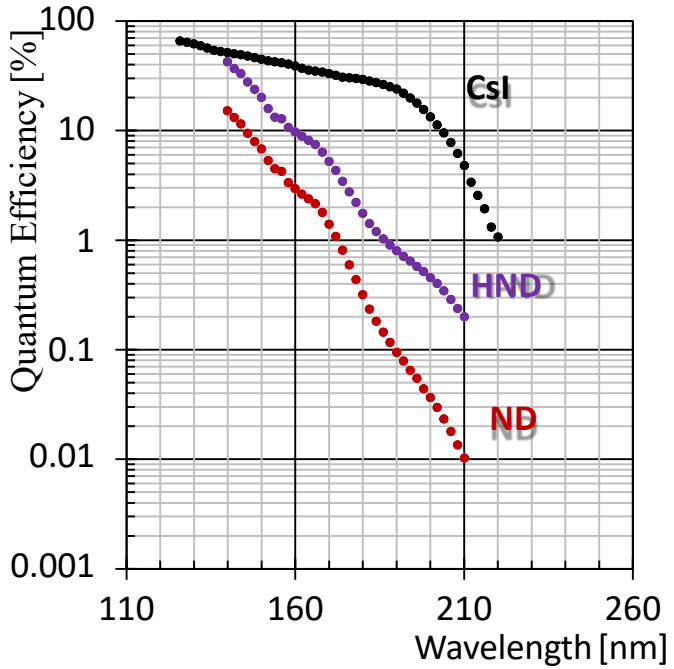


Comparison CsI to Nano Diamond

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

- 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 800 ^{O}C. 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

Comparative QE: CsI: ND/HND



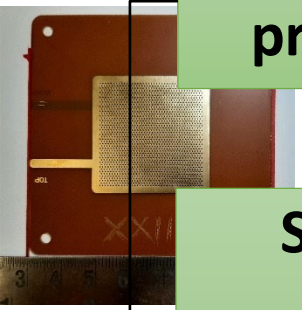
- CsI [NIM-A-438 (1999) 94]
- ND [APL-108 (2016) 083503]
- HND [APL-108 (2016) 083503]

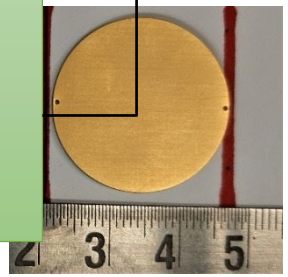
ND R&D Scheme

HND preparation

THGEM preparation

Substrate "Coin" preparation





Pulse Spray Coating

VUV Monochromator @ Bari

- In Vacuum
- In CH_4
- In $Ar:CH_4$

Surface Morphology @ IOM CNR Elletra Trieste

VUV Monochromator @ CERN

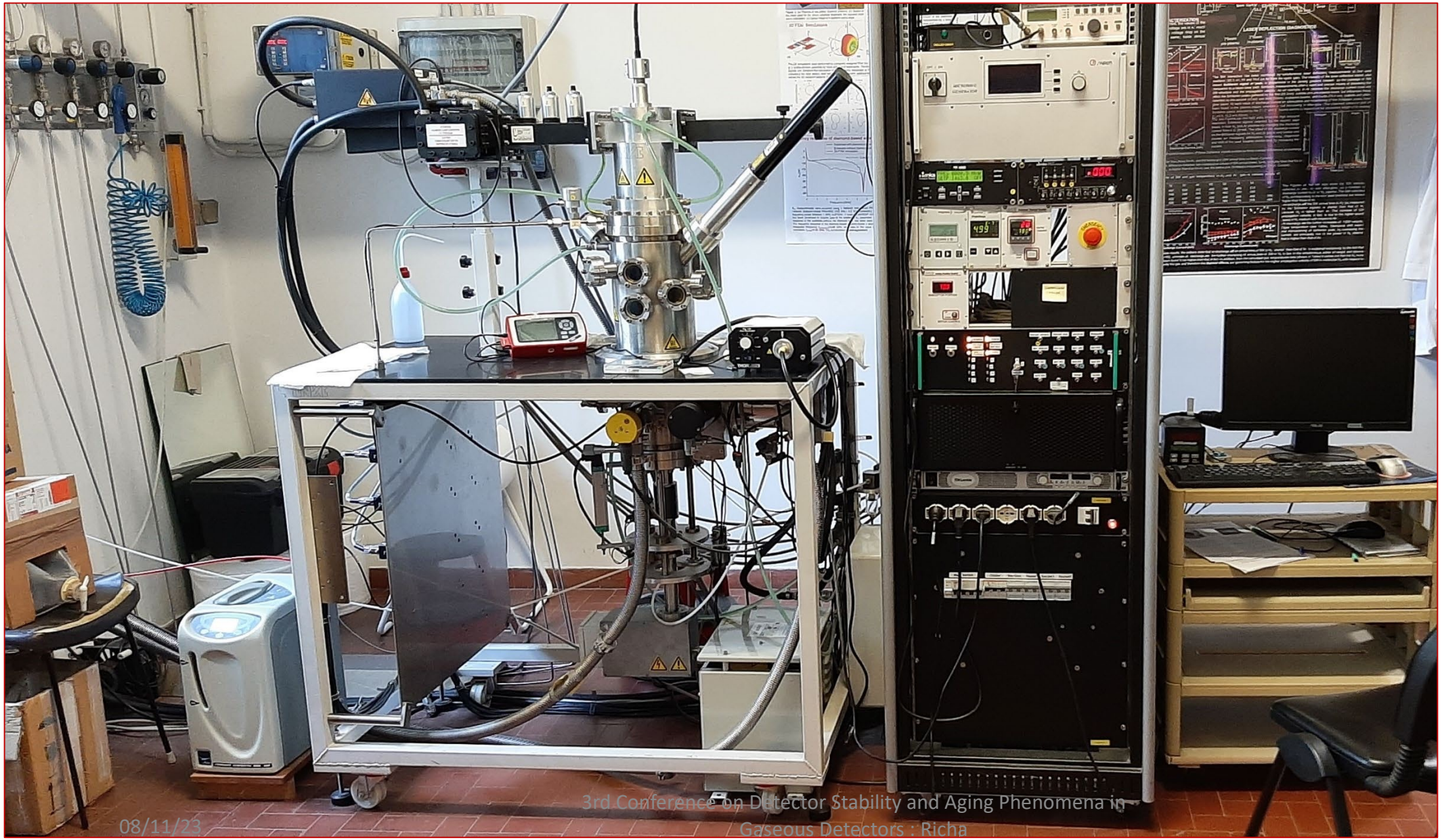
- In Vacuum
- Profile scanning
- Aging Study

THGEM study with H – ND @ Triste and Bari

Hydrogenation and Photocathode coating at INFN Bari

- ND coating by pulsed spray technique

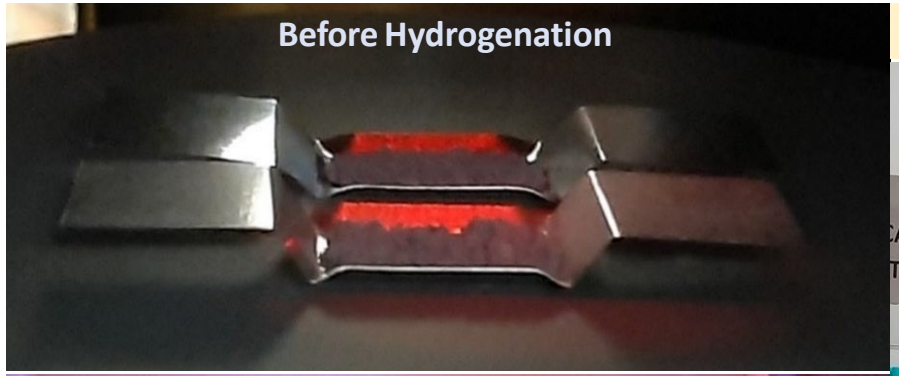
Hydrogenation of ND: MWPECVD setup @ INFN Bari

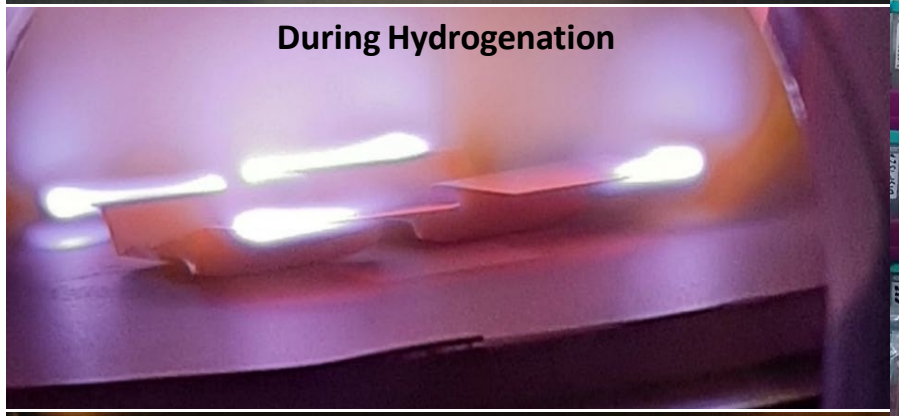


Hydrogenation details:

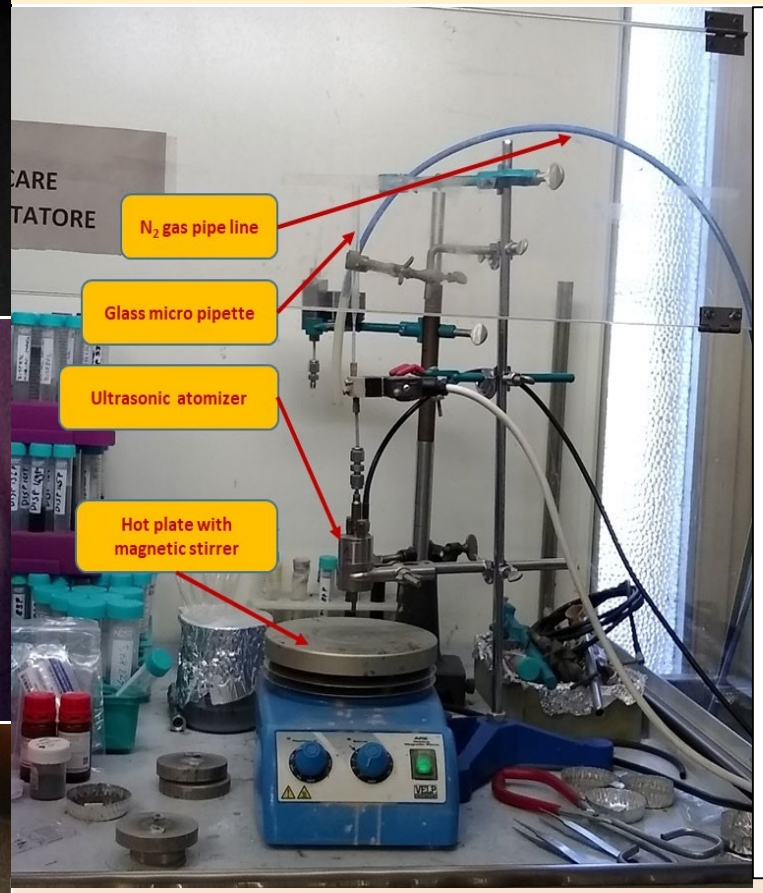
- Order of vacuum **~6.5x10^{-6}** mbar.
- **70 mm** distance kept between H_2 source and ND powder.
- H_2 gas is generated by electrolysis process using distilled water & H_2 gas flow rate controlled to **200 sccm**.
- Hydrogenation of ND powder is performed for **1 hour @ 43 mbar pressure.**
- 1380 W microwave power used to reach **1000 ^{0}C** temperature with 830 ^{0}C substrate holder temperature.
- 1250 W microwave power used to reach **810 ^{0}C** temperature with 650 ^{0}C substrate holder temperature.

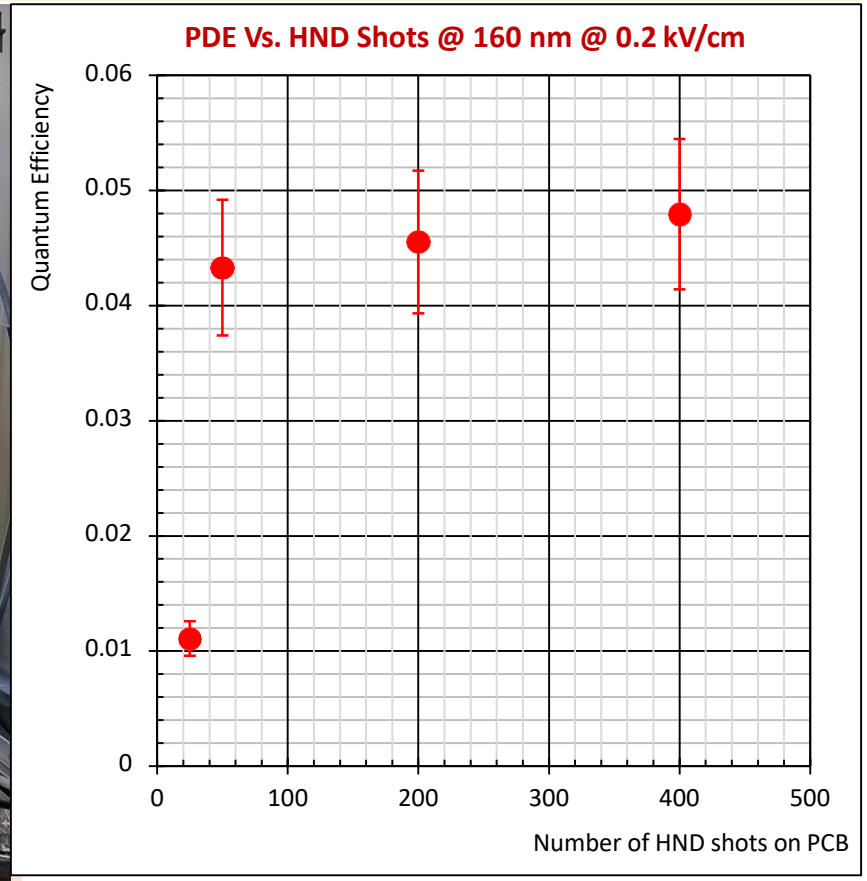
Hydrogenation & Coating of ND : @ INFN Bari





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





Types of Nano-Diamond Powder

- ND - D&T
- ND - E6
- ND – BDD

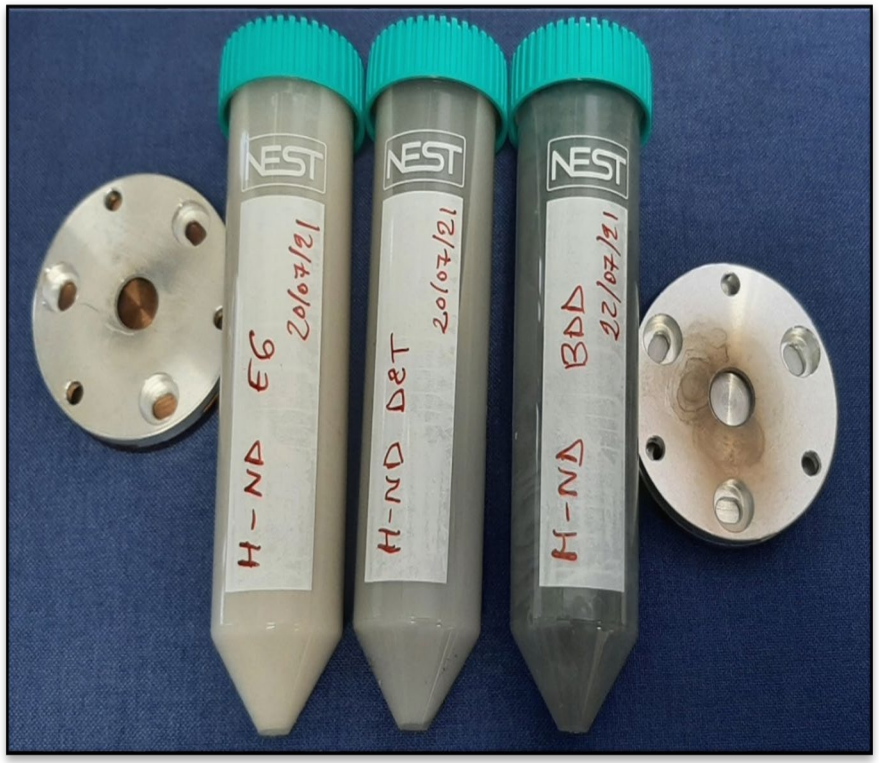
[*ChangSha 3 Better Ultra-hard materials Co.,LTD*]

SONICATED in distilled water with 1:1 ratio

Coating Details:

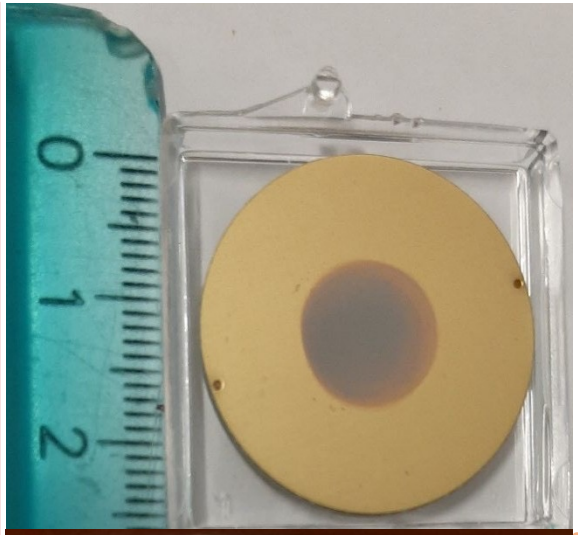
- ❑ For all PCB/Substrate : 1000 shots on 10 mm diameter area
- ❑ Each shot duration : 250 mSec
- ❑ Pause duration after each shot : 1000 mSec
- ❑ Temperature : 150 ^{0}C
- ❑ Distance between substrate and PSC spray point : 10 mm

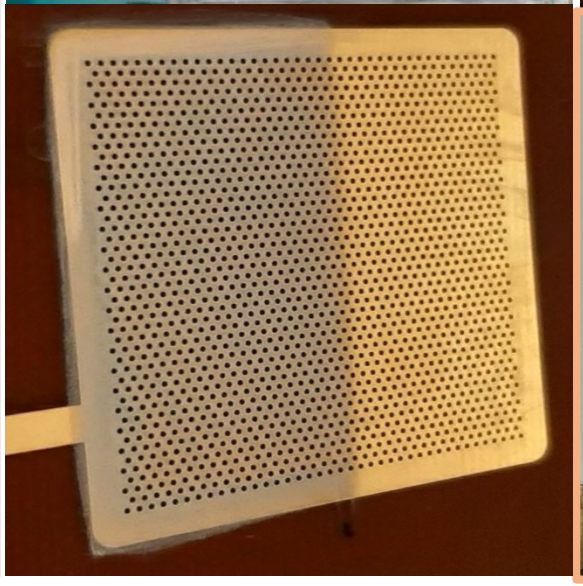
NDs solutions & their coating

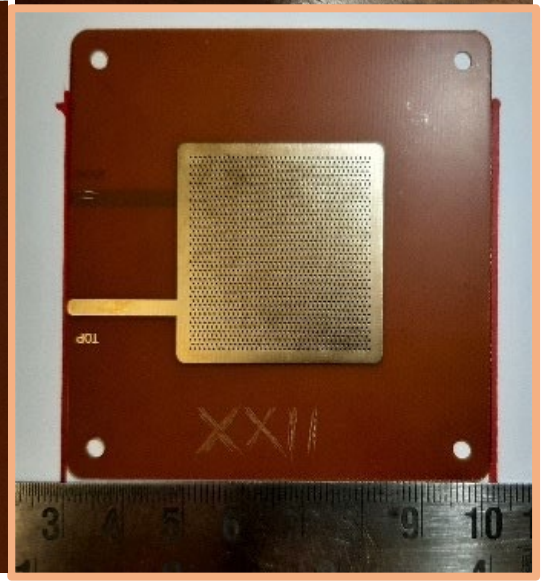


Coated THGEMs and PCB Coins

- ND & HND coted on 14 PCB coins
- ND & HND coted on 06 TEM Grids
- Non-hydrogenated ND full THGEMs (Four)
- Hydrogenated ND full THGEMs (Five)

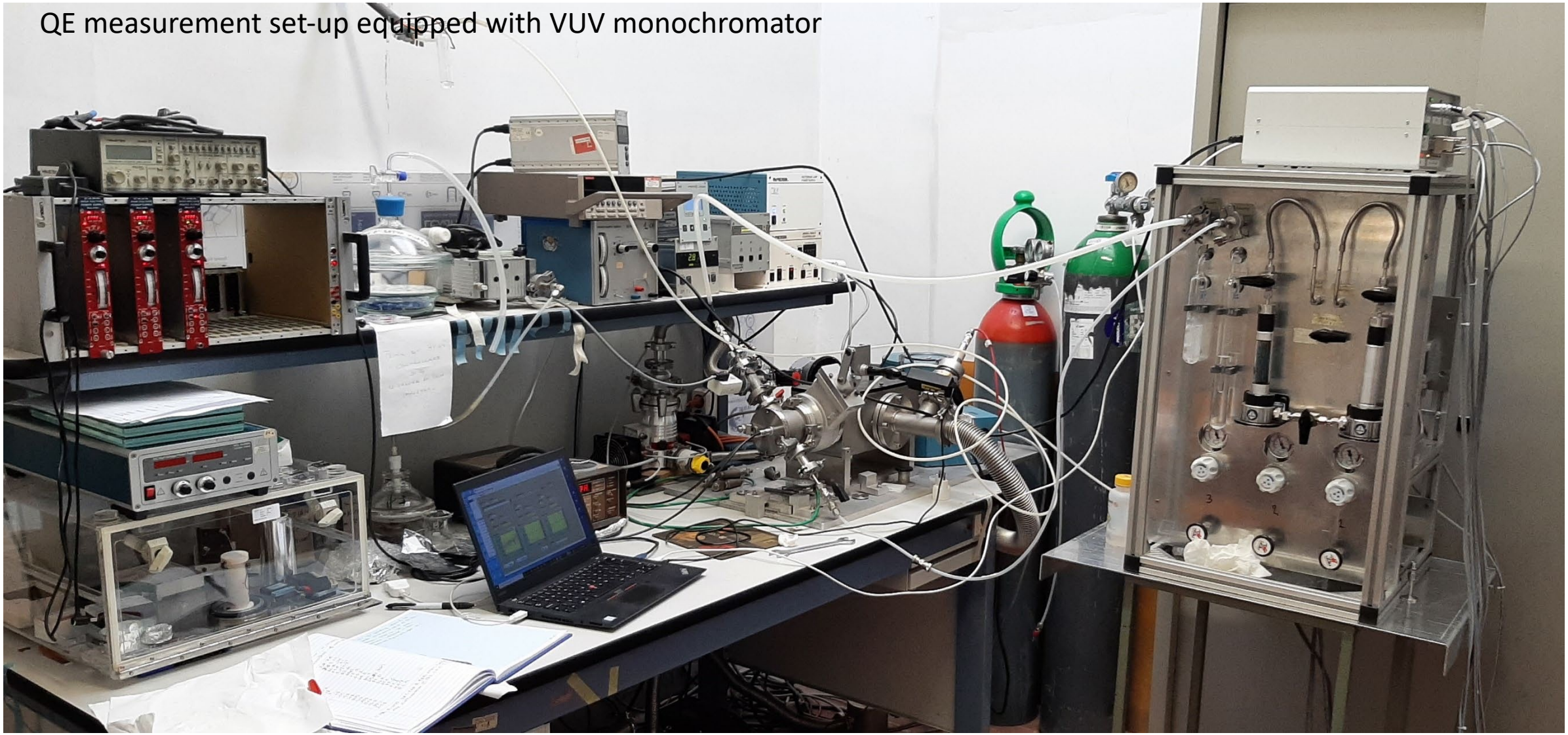




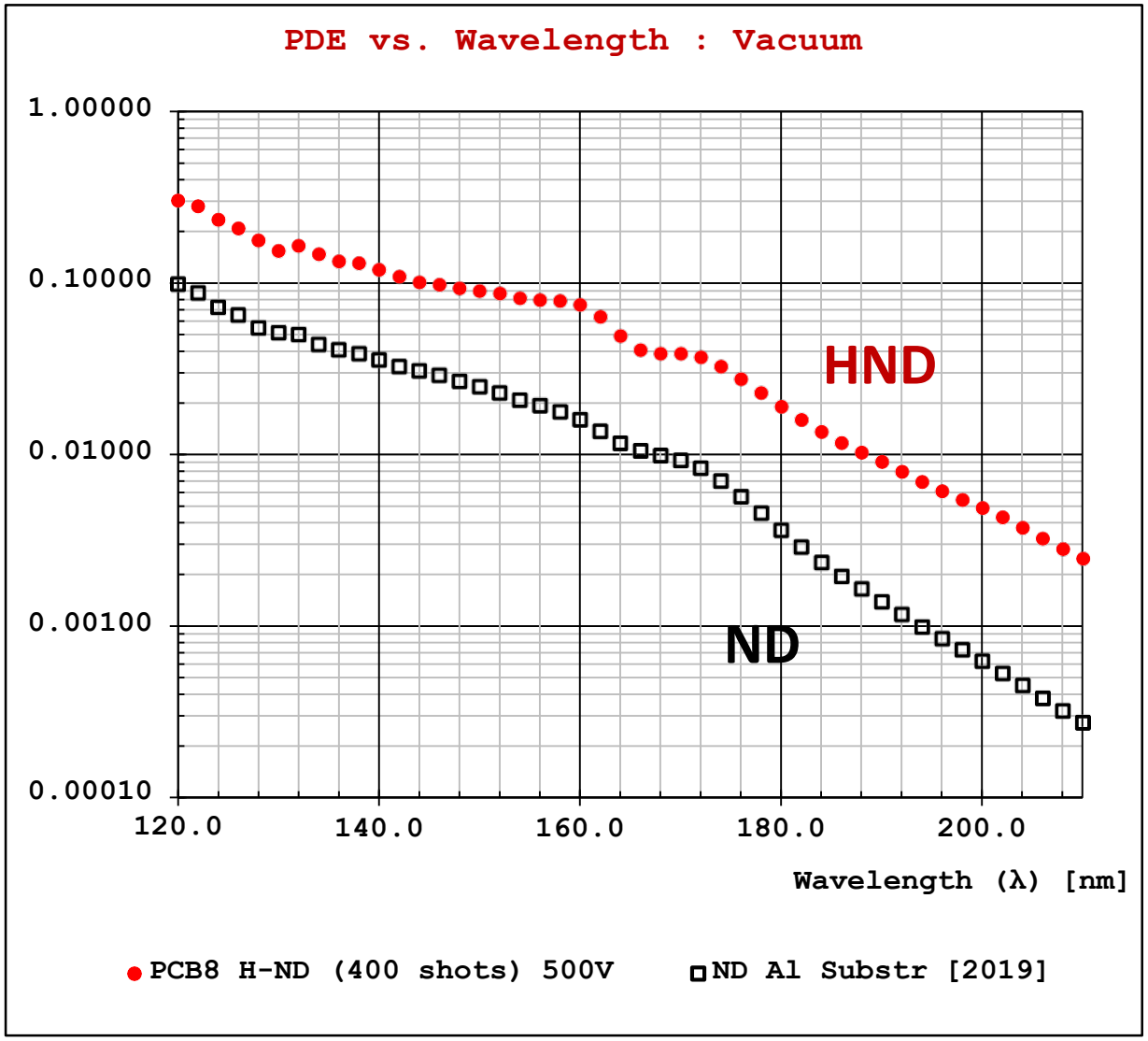


Photoemission measurements

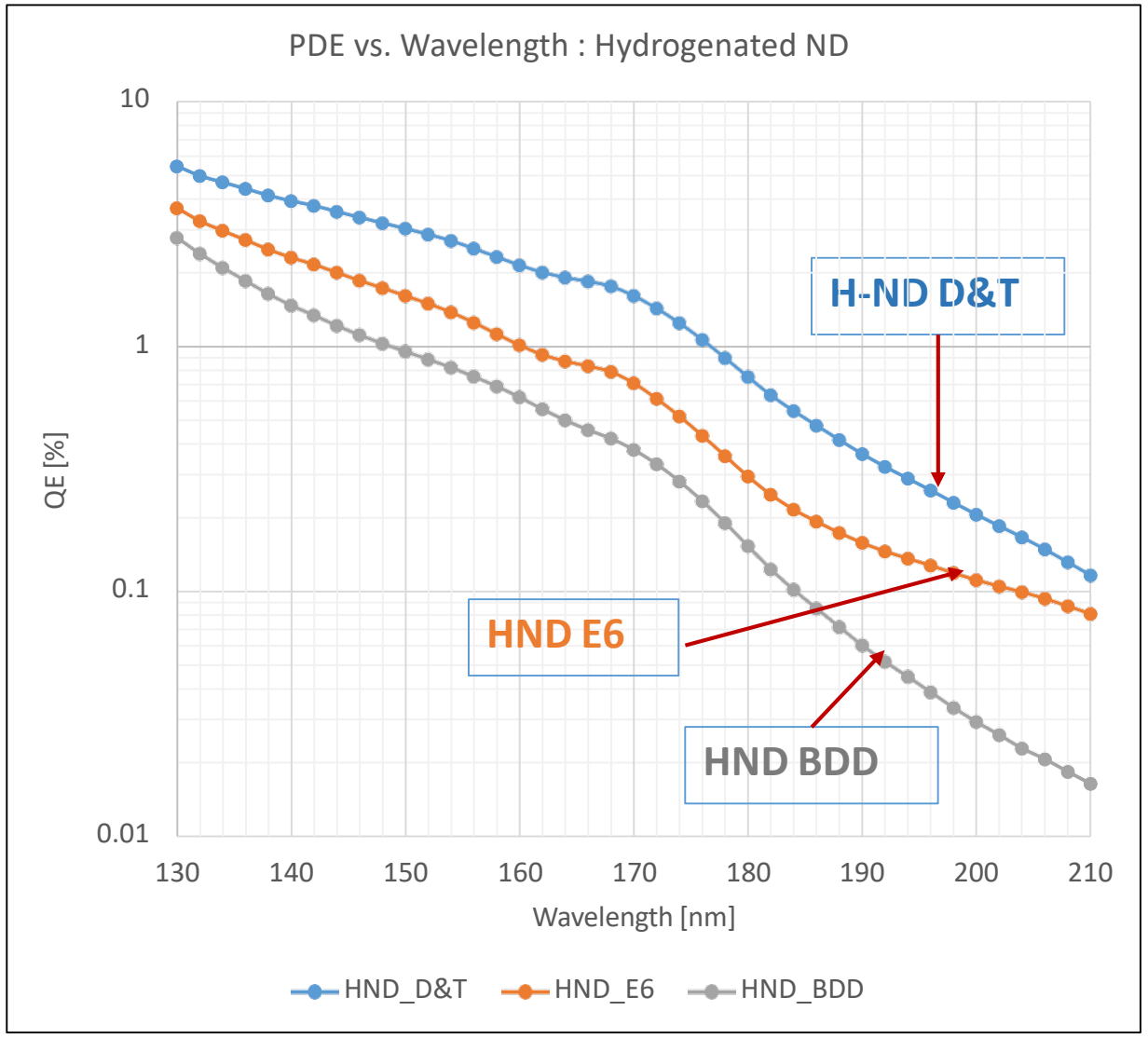
Photoemission setup and gas mixing unit



OLD ND, HND [D&T]- 2019

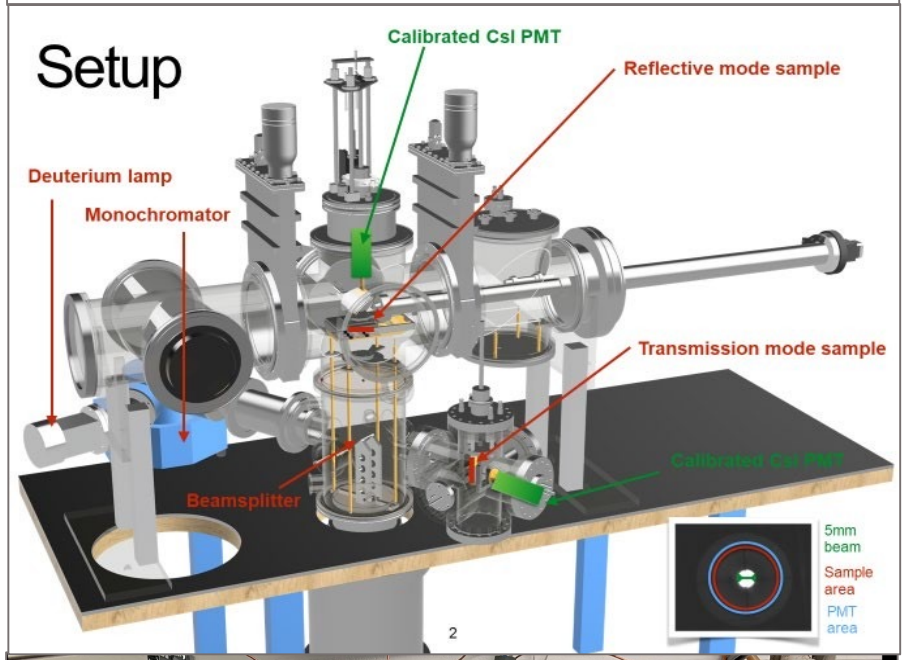


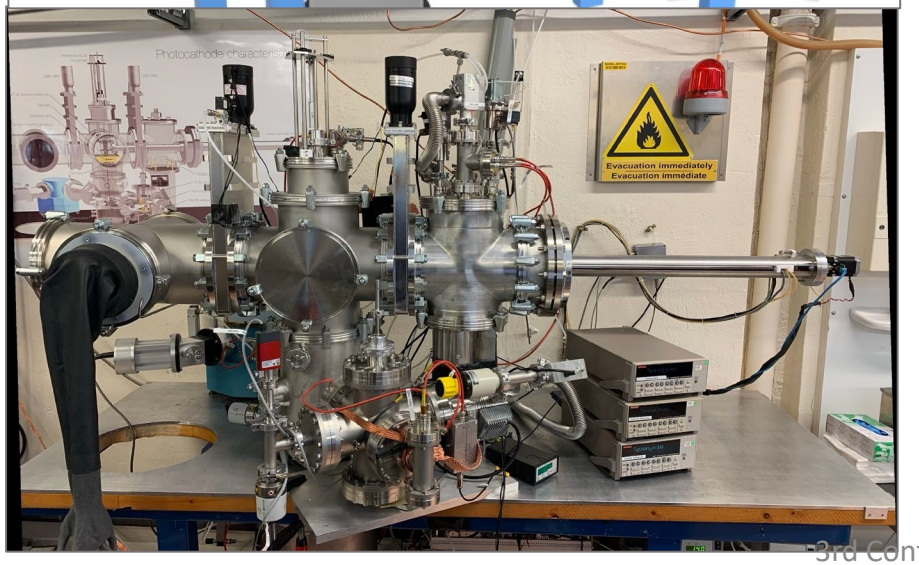
New HND [D&T, E6, and BDD]- 2021



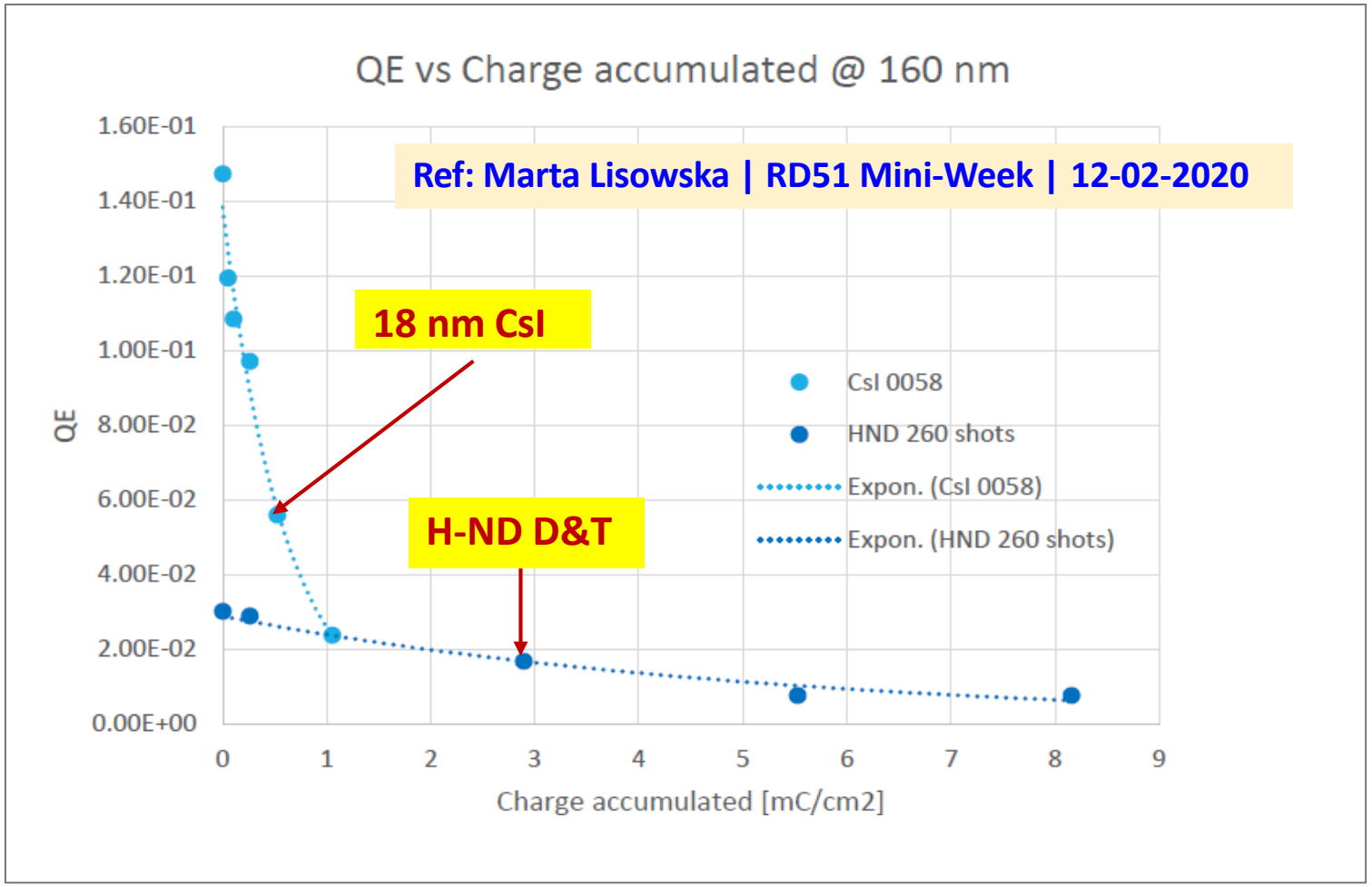
***Photocurrent values : H-ND Old/H-ND new factor ~3 for Vacuum @160 nm**

Schematic & Pictorial view of photoemission measurement setup: ASSET @ RD51 CERN





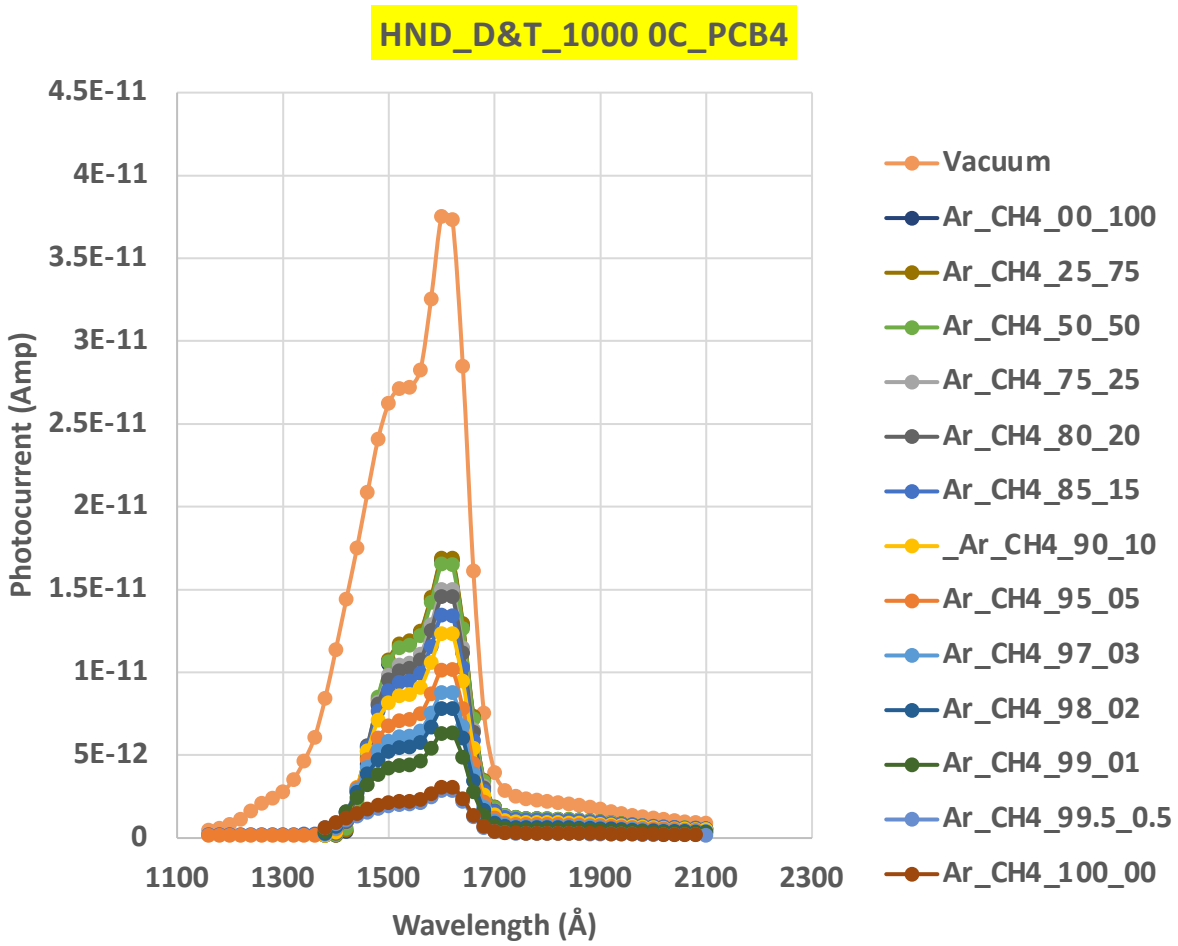
Aging study with X-Ray irradiation of HND PC @ RD51 CERN



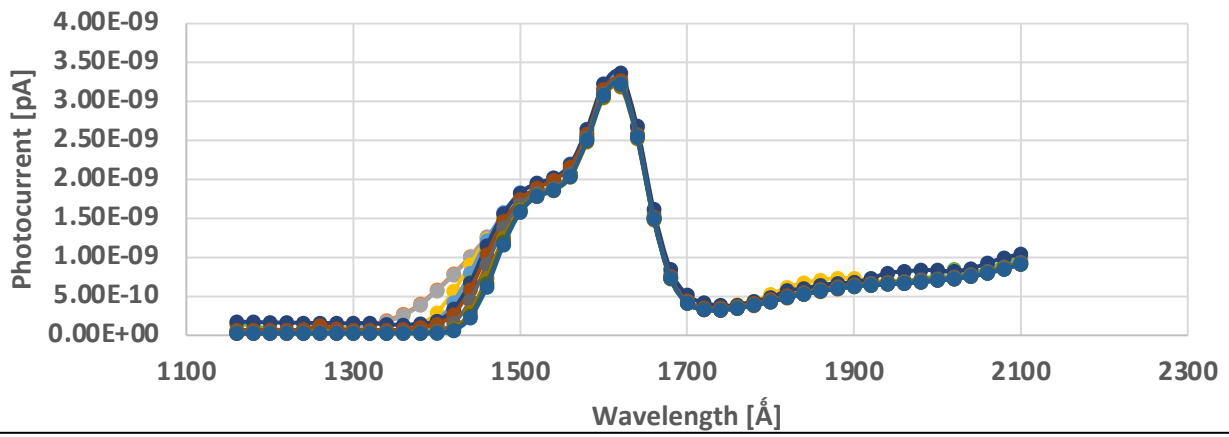
- ***This is the first preliminary irradiation ageing study of HND photocathodes ever performed.***
- ***HND photocathodes are quite robust compared to CsI to X-ray Irradiation***
- ***CsI PDE lowered down by factor ~5 at 1 mC/cm² of charge accumulation***

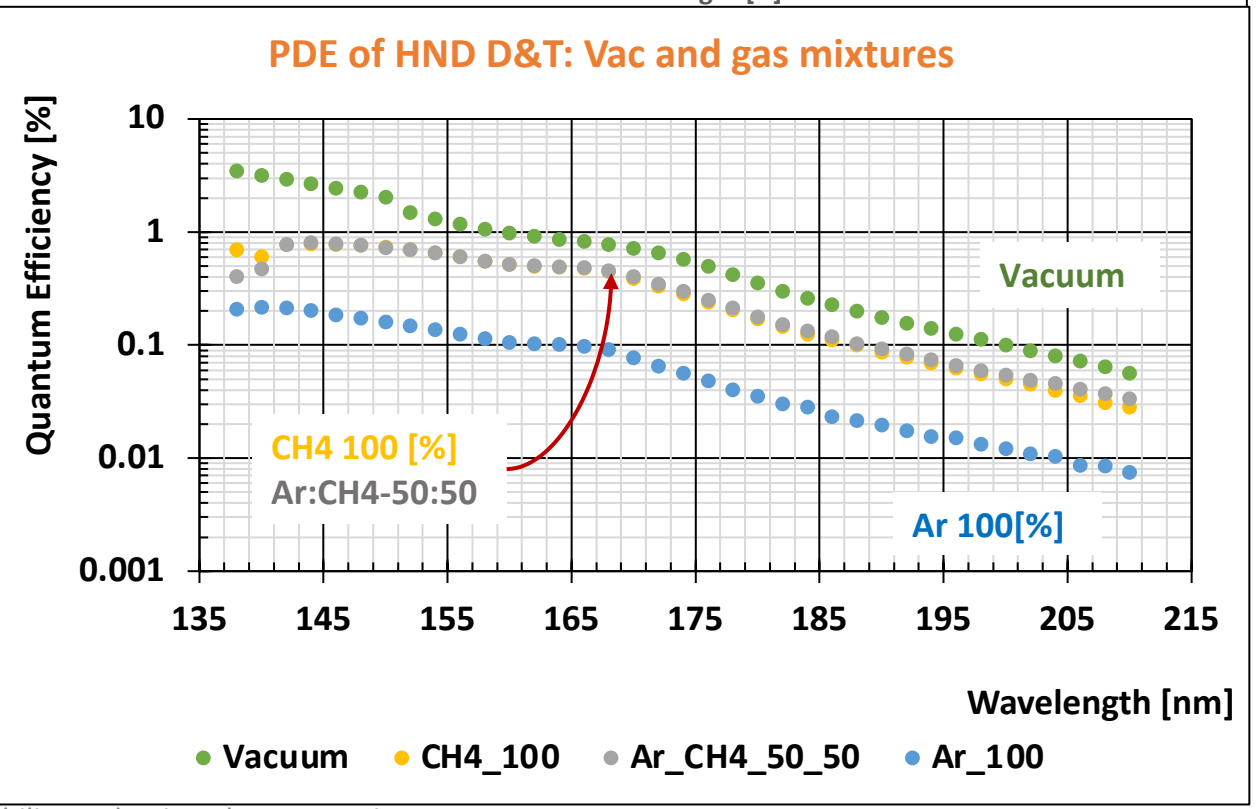
Wavelength Scan: @ 90 V [~0.2 kV/cm]

Photocurrent measurement in vacuum and in gas



- H-ND from D&T having max QE
- In vacuum QE is max compared to gas mixtures
- QE is min in pure Ar gas & increases with an increase of CH4



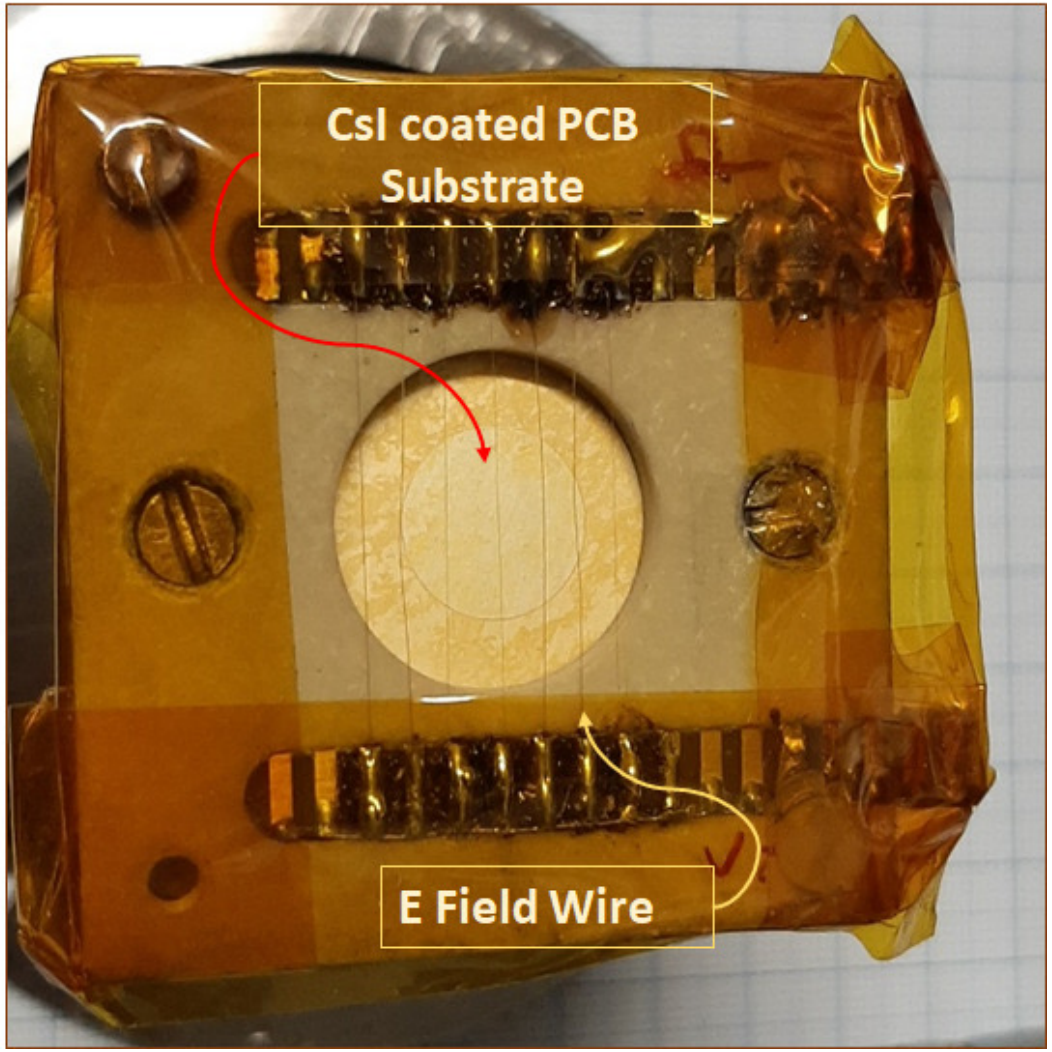


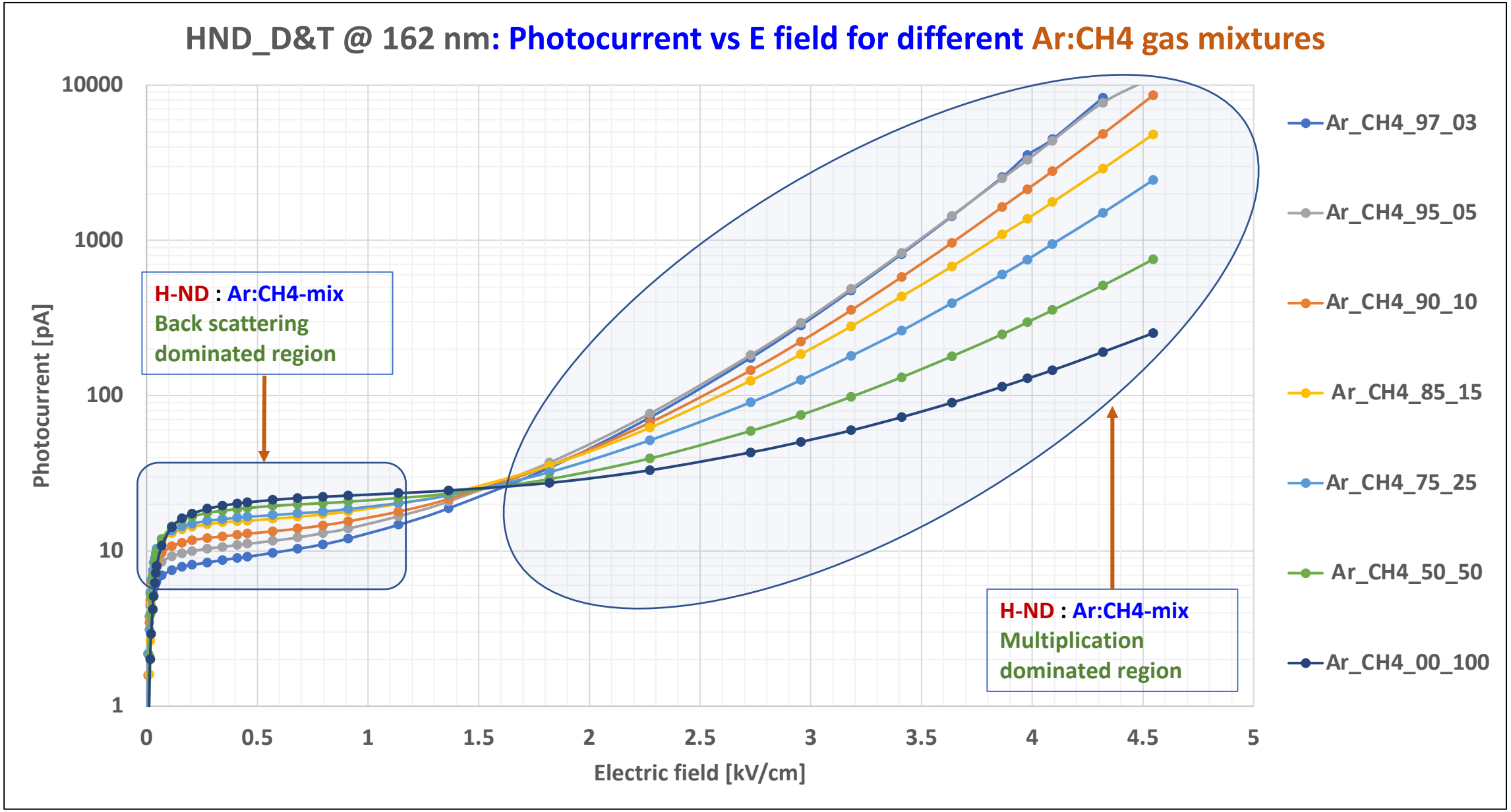
E Field Scan : @λ = 162 nm

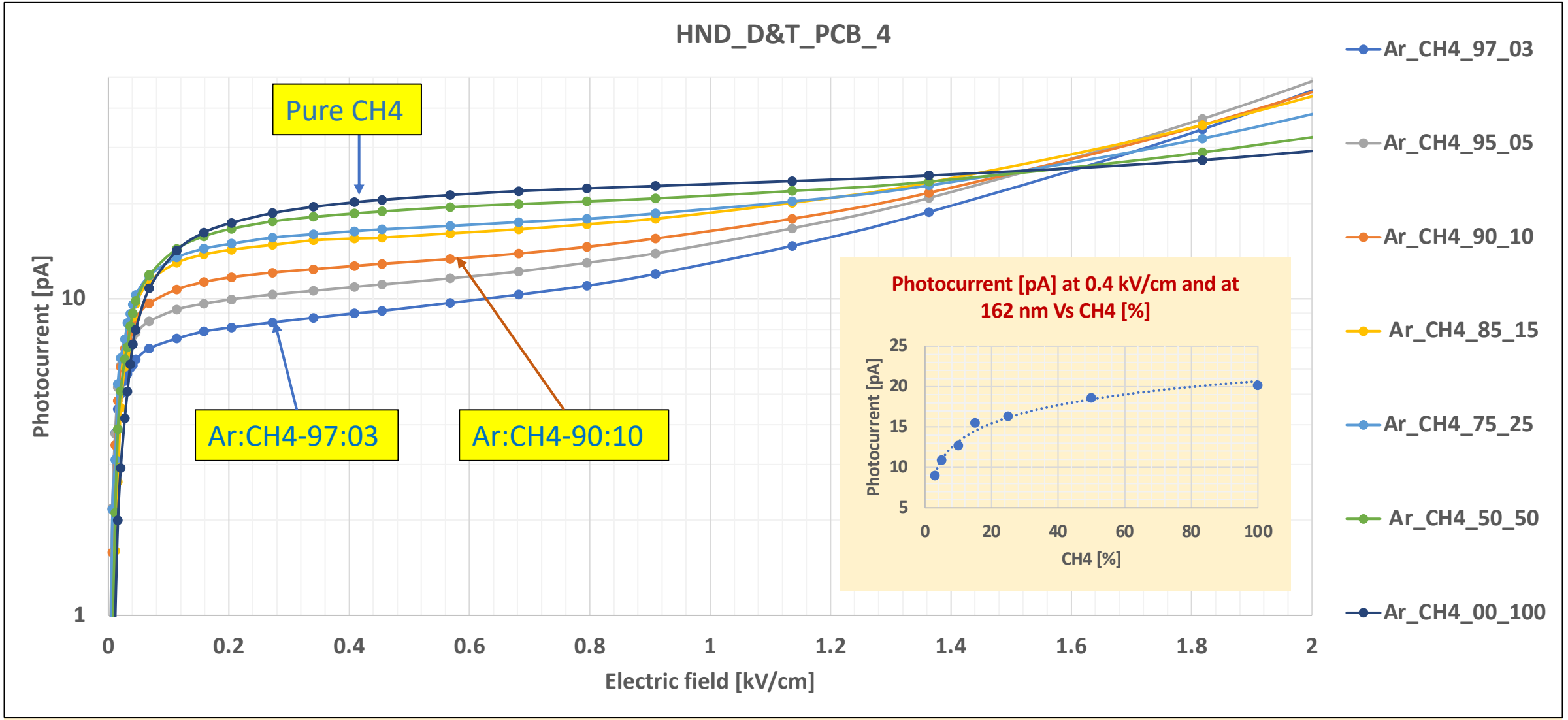
H-ND D&T

- Gap between substrate and electric wire is **4.4 mm**.
- Wavelength is fixed at 162 nm for E filed scan
- Wavelength scan and E Field scan performed with **MgF2 window** in vacuum as well as in Ar:CH4 gas mixtures

Substrate holder for photo current measurement




HND_D&T @ 162 nm: Photocurrent vs E field for different Ar:CH4 gas mixtures
Photocurrent [pA]
10000
1000
100
10
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Electric field [kV/cm]
H-ND : Ar:CH4-mix
Back scattering
dominated region
H-ND : Ar:CH4-mix
Multiplication
dominated region
Ar_CH4_97_03
Ar_CH4_95_05
Ar_CH4_90_10
Ar_CH4_85_15
Ar_CH4_75_25
Ar_CH4_50_50
Ar_CH4_00_100

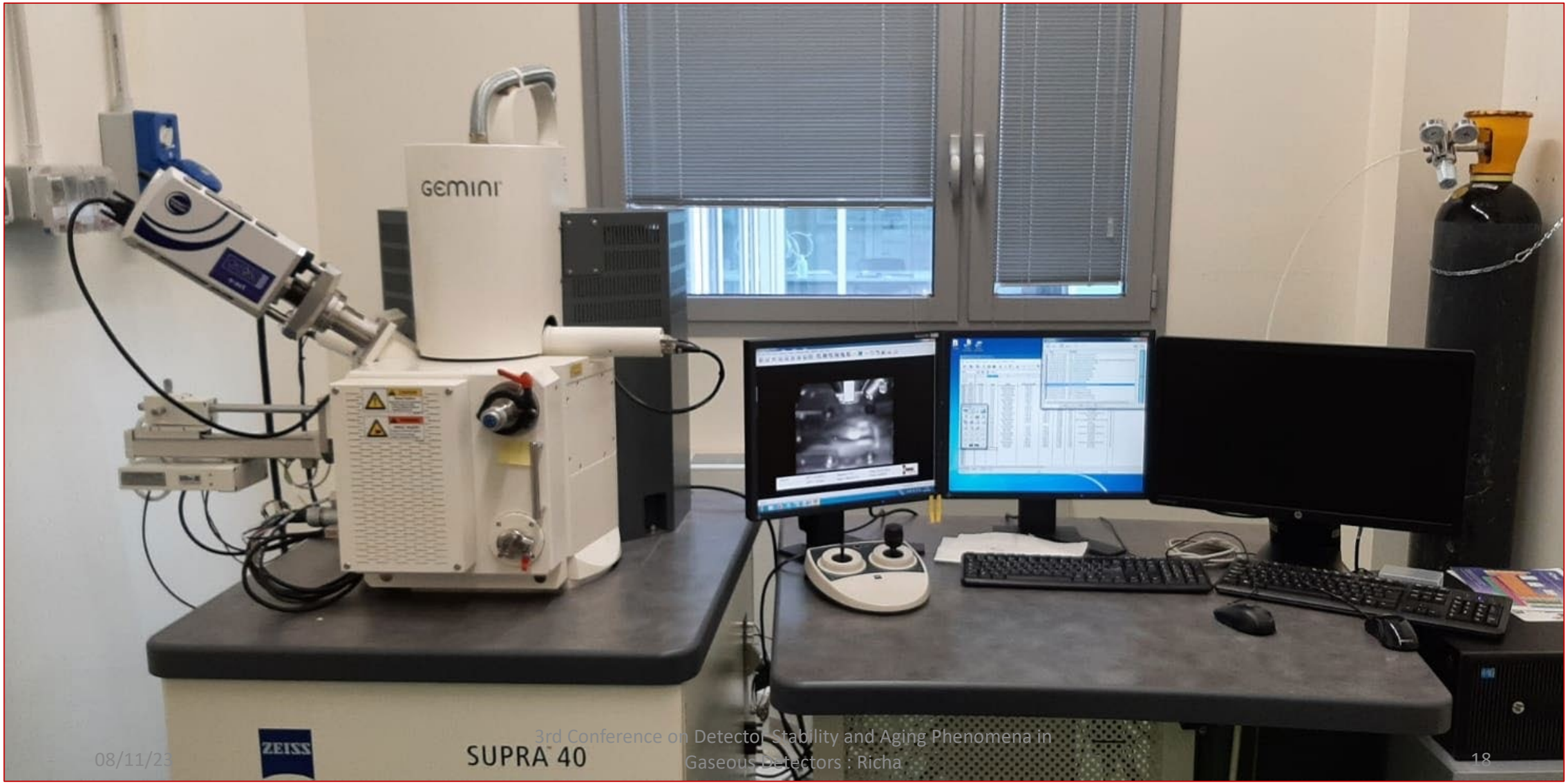


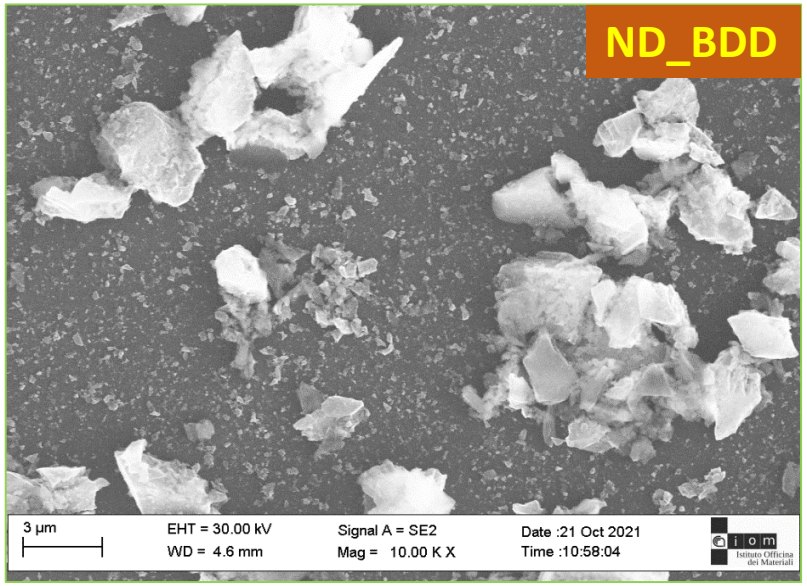
- Ar:CH4_50:50 ~9% lower PDE compared to Pure CH4
- Ar:CH4_75:25 ~24% lower PDE compared to Pure CH4
- Ar:CH4-97:03 ~55% lower PDE compared to Pure CH4

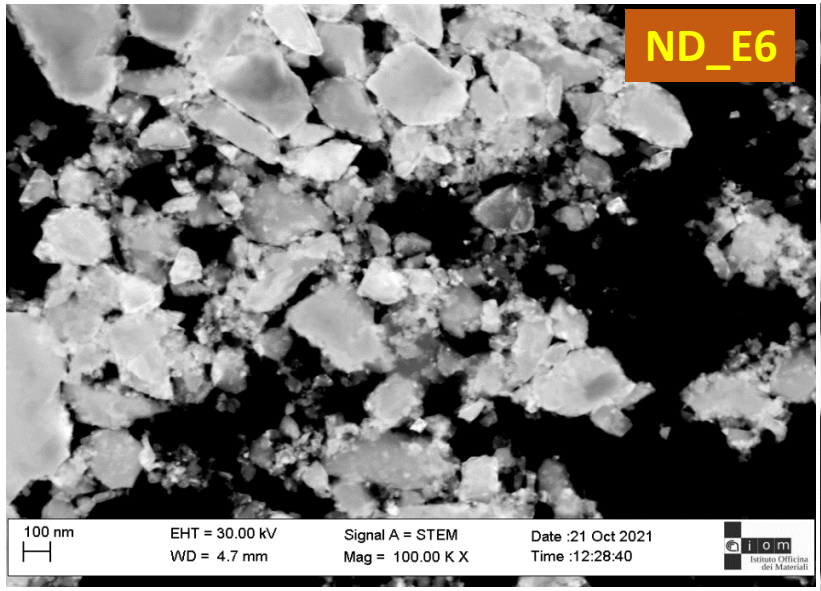
Surface morphology analysis of NDs by Scanning /Transmission electron microscopy

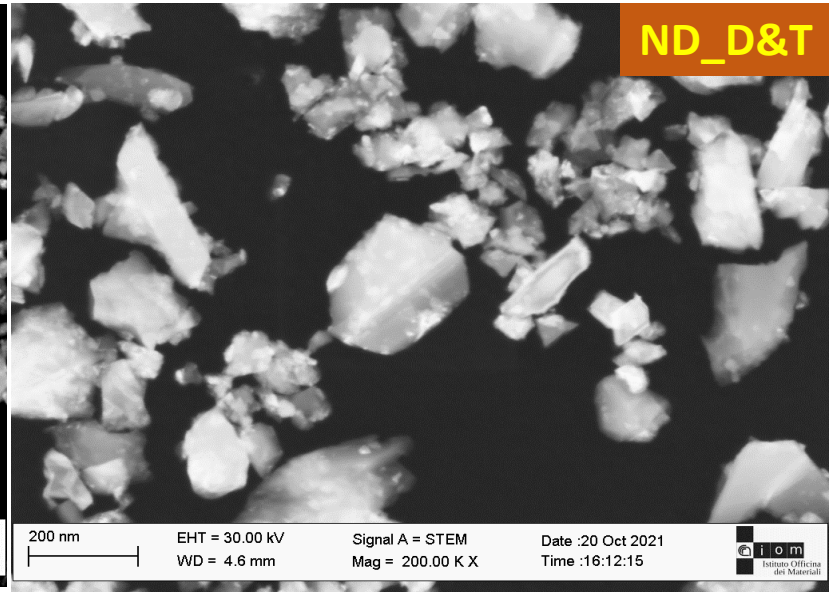
@ IOM CNR Elletra – Trieste Italy

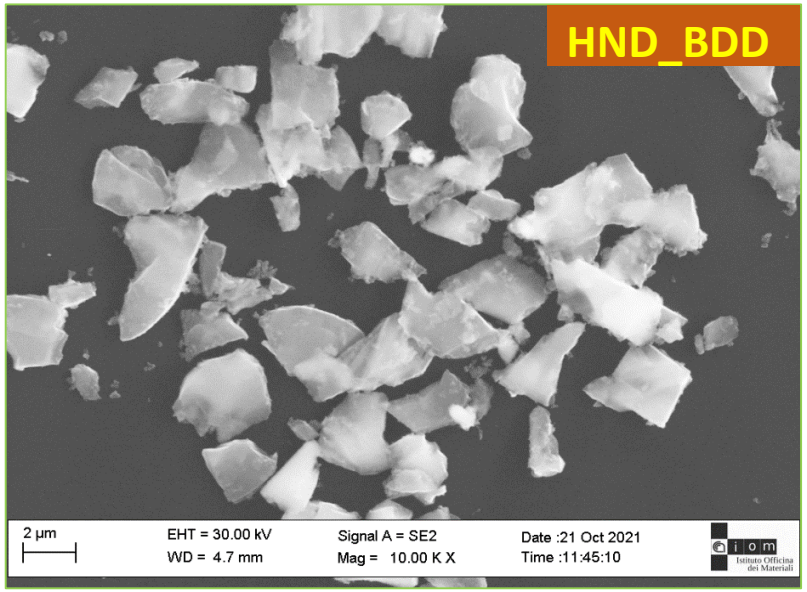
SEM/STEM setup @ IOM-CNR, Elletra

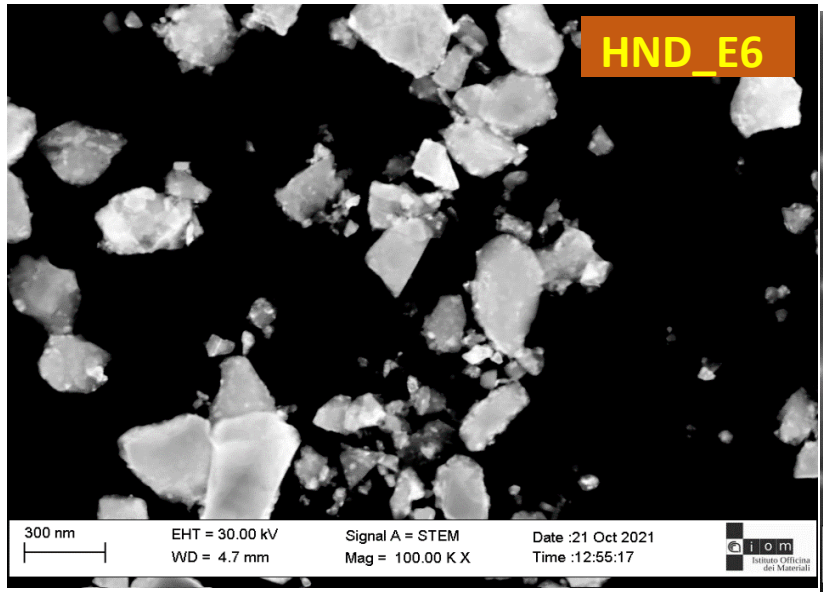


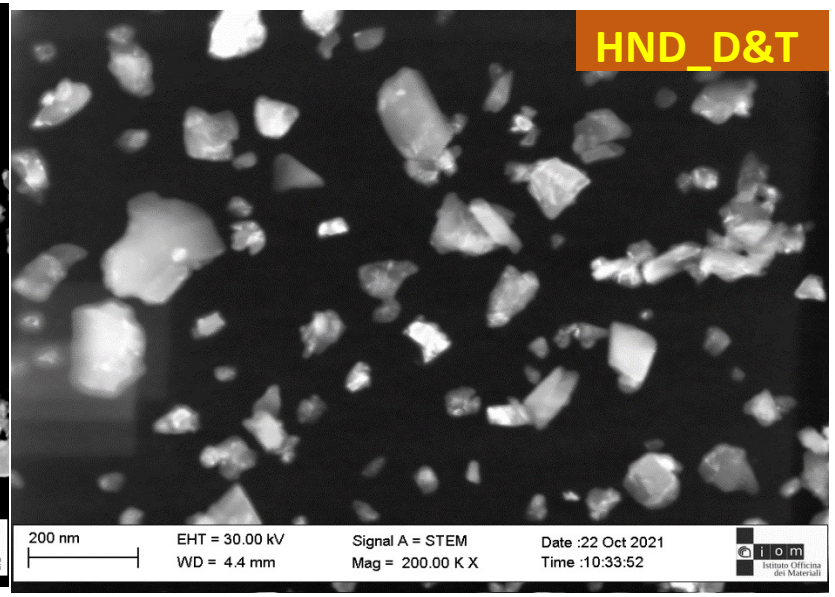






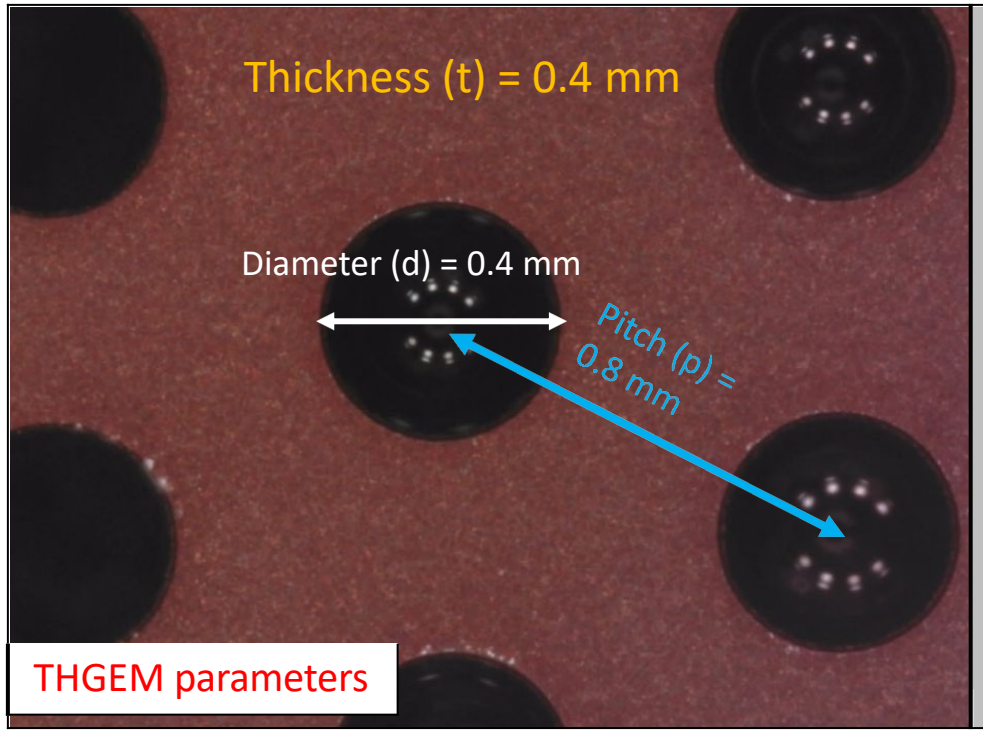


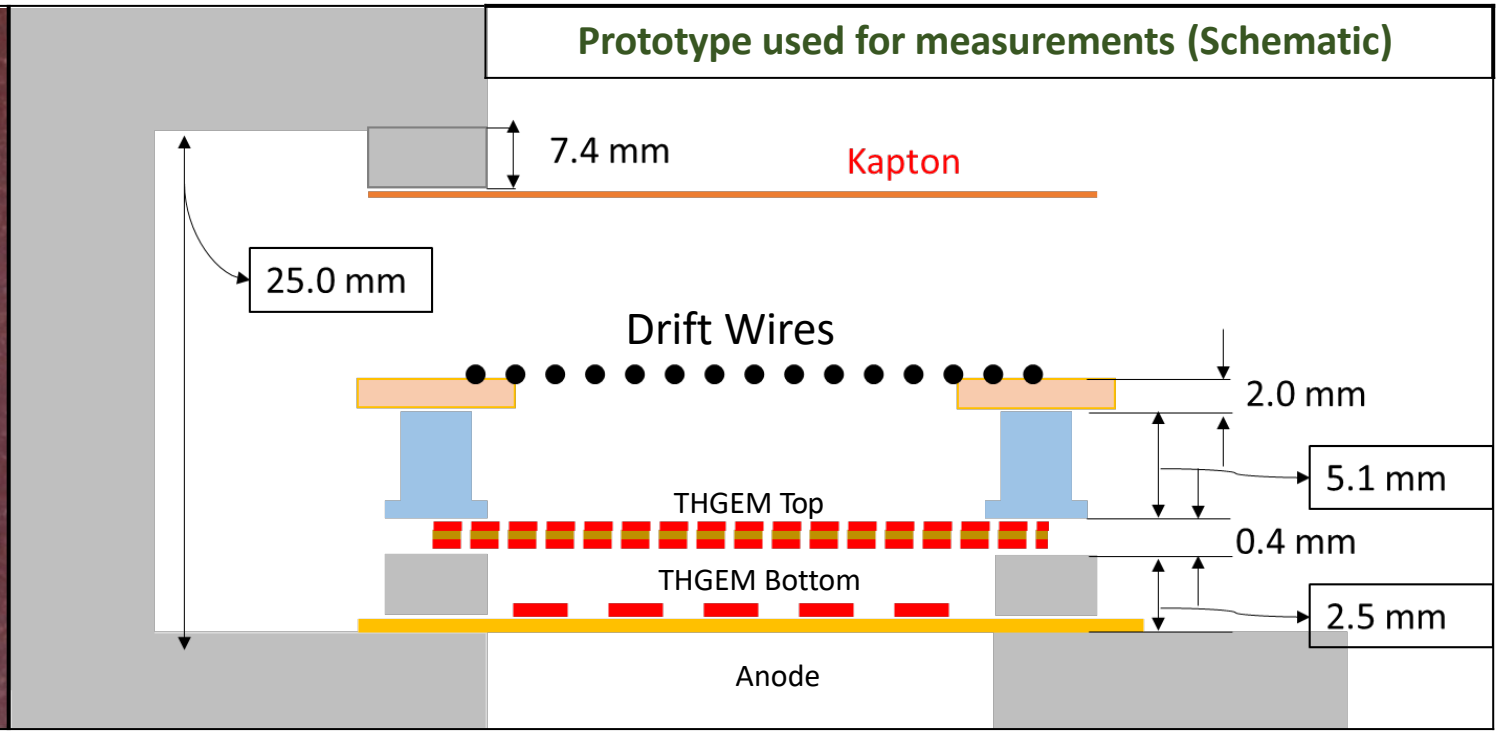




STEM images of 10 shots of ND and HND powders coated on TEM grid.

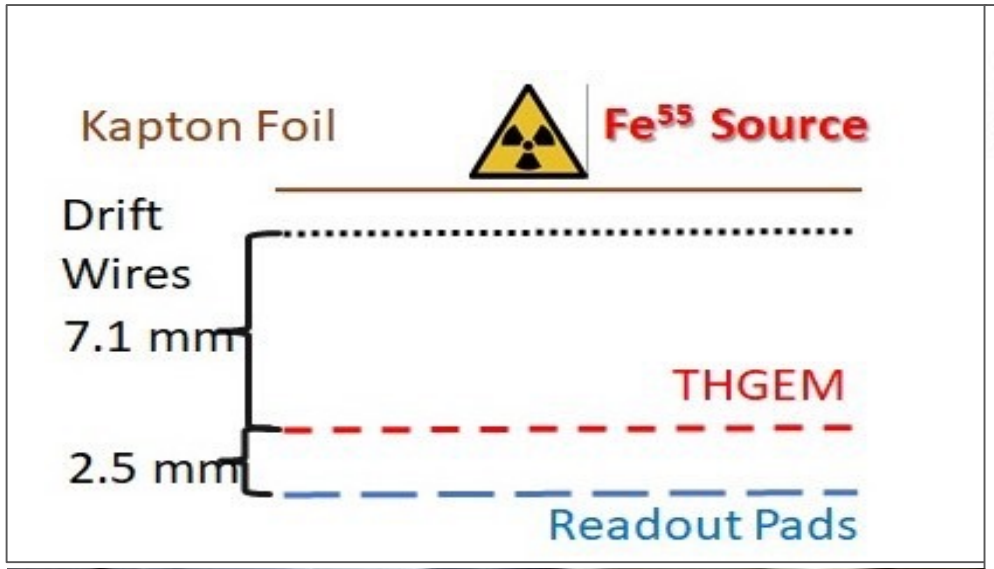
THGEM with Nanodiamond Photocathode

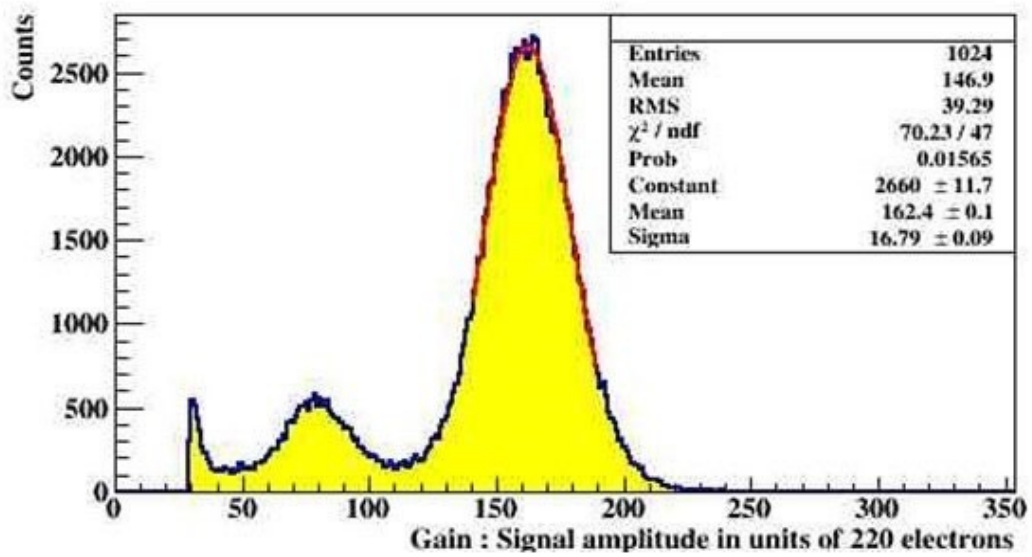


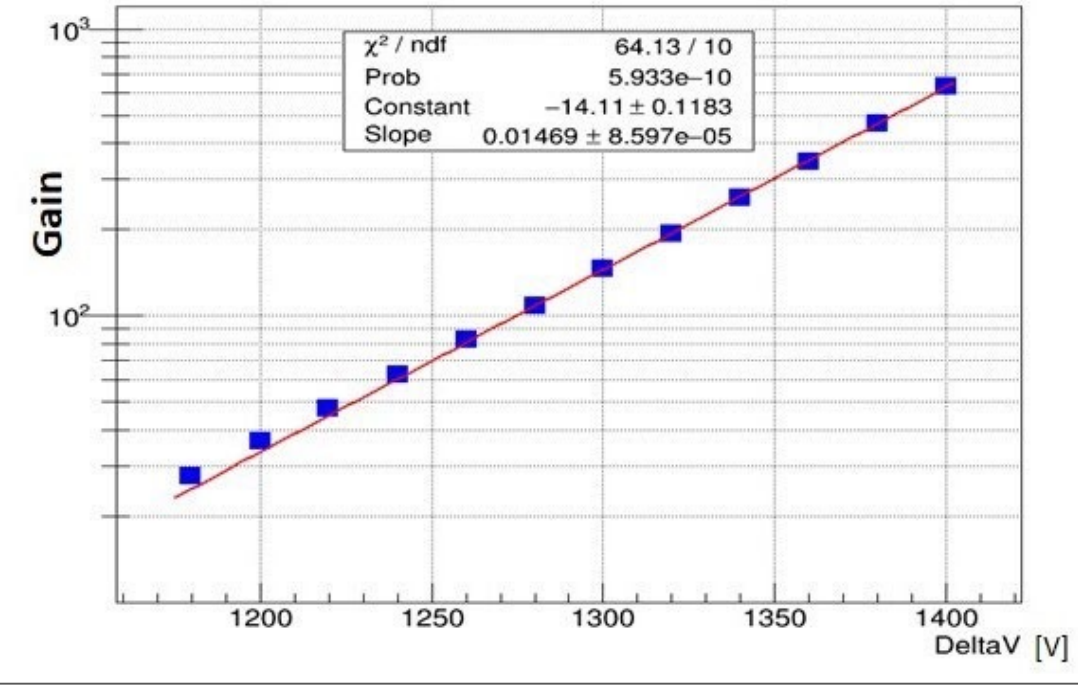


- THGEMs are standard Printed Circuit Boards (PCBs) with holes produced by mechanical drilling.
- Like in GEMs, in the presence of a correct electrical bias and in a proper gas mixture, each hole acts as an electron multiplier.
- The signal generated by the gas multiplication is collected at the anode.
- 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:CO_2 70:30
- 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.







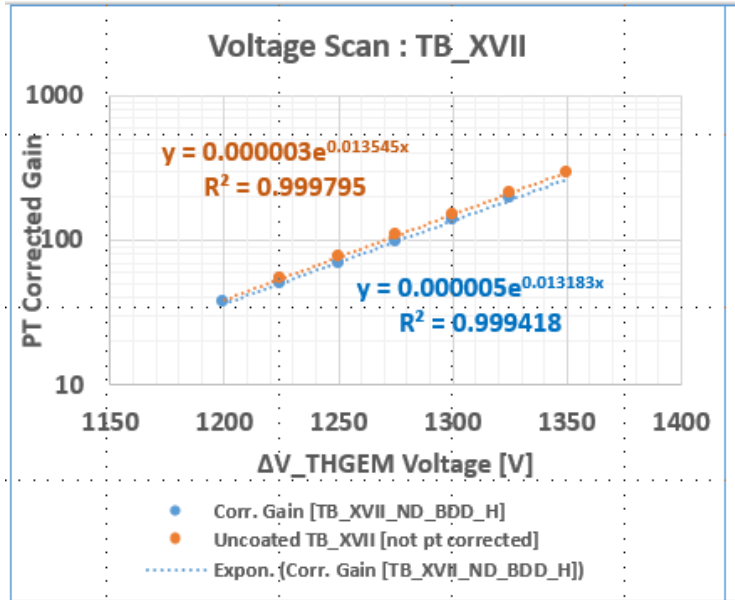
Voltage Applied:
Drift = 2250 V
T_top = 1750 V
T_bot = 500 V
Anode = 0 V

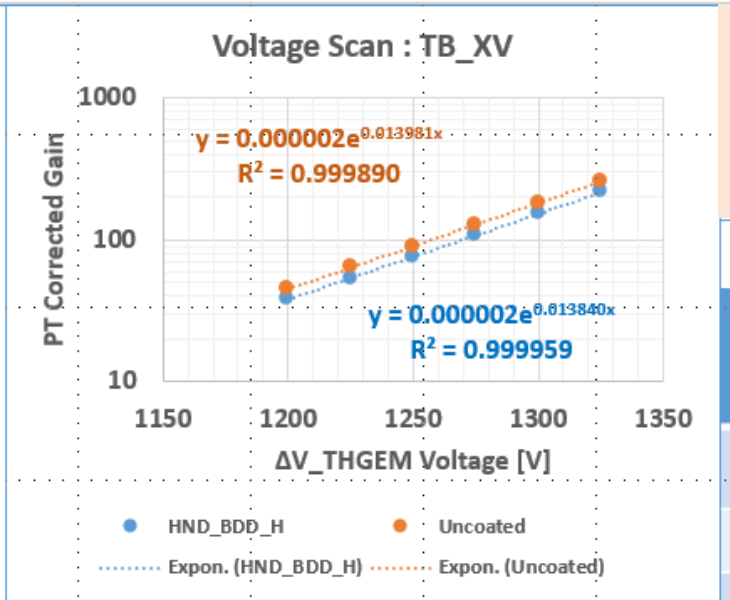
Gas Mixture:
Ar = 70 %
CO2 = 30 %
@ 10 l/h flow rate

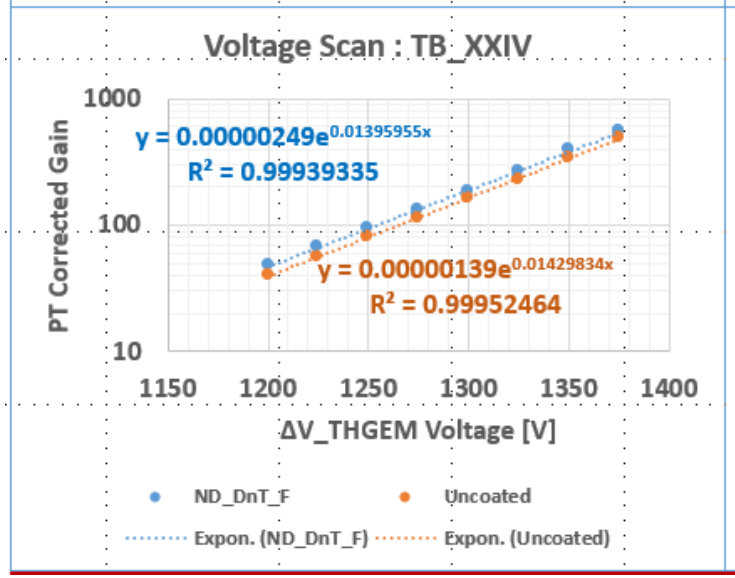
X-ray Source:
Fe-55

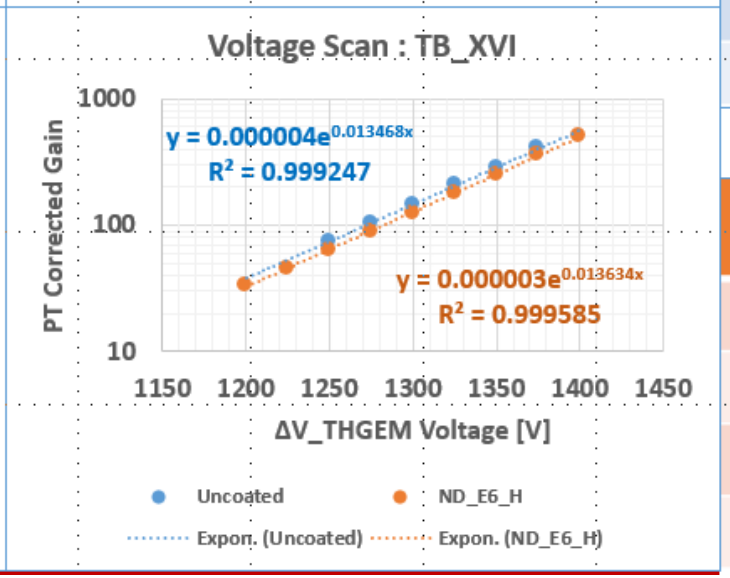
THGEM active area:
30 mm x 30 mm

Electronics used:
CAEN N1471H HV PS
CREMAT CR-110 Pre Amp
ORTEC 672 Amp
CREMAT CR-150 Eva Board
AMPTEK MCA 8000A









heat treatment after coating and p/T corrections + charging-up are essential

PT corrected Effective Gain in saturation part

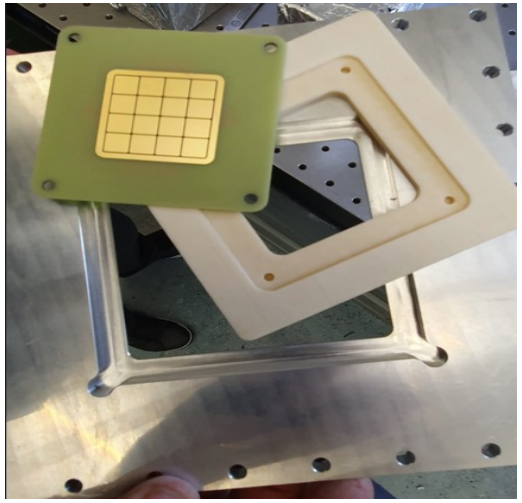
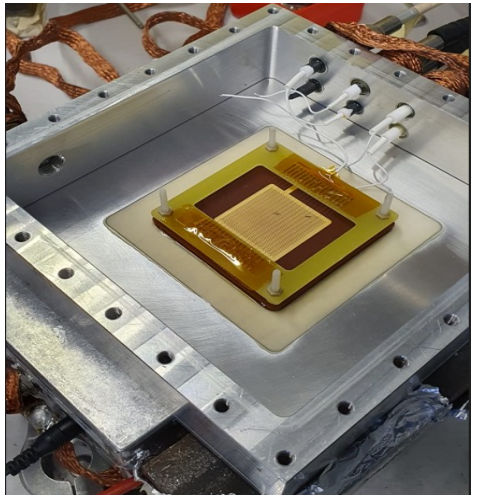
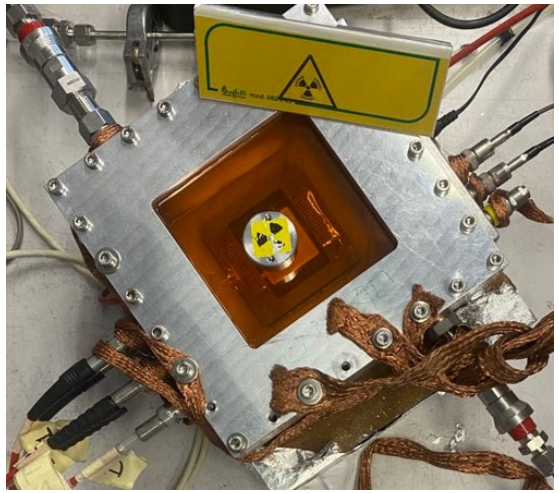
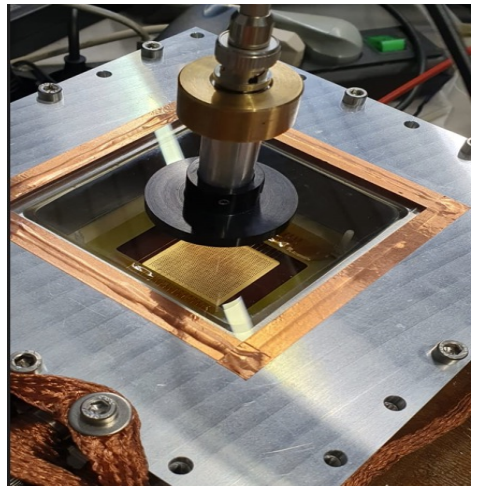
Uncoated THGEMs	Eff. Gain	Coated THGEMs	Eff. Gain	Eff. Gain
TB_XV	82	H-ND_BDD_H	87	+ 6
TB_XVI	75	ND_E6_H	63	- 16
TB_XVII	84	ND_BDD_H	69	-- 18
TB_XXIV	82	ND_D&T_F	91	+ 10

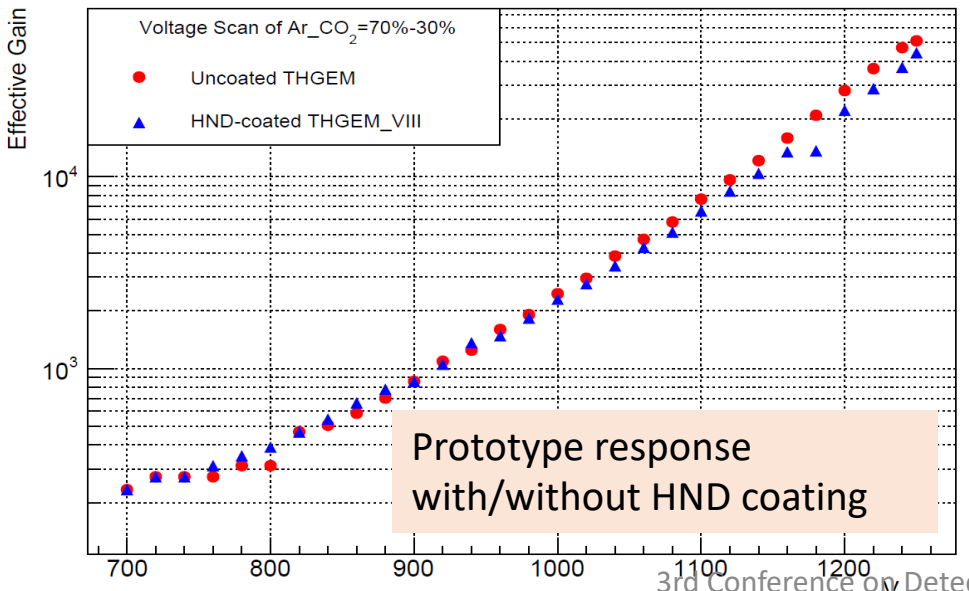
Max ΔV_THGEM voltage sustainability

Uncoated THGEMs	Max ΔV THGEM	Coated THGEMs	Max ΔV THGEM
TB_XV	1325	H-ND_BDD_H	1325
TB_XVI	1375	ND_E6_H	1400
TB_XVII	1350	ND_BDD_H	1325
TB_XXIV	1375	ND_D&T_F	1325

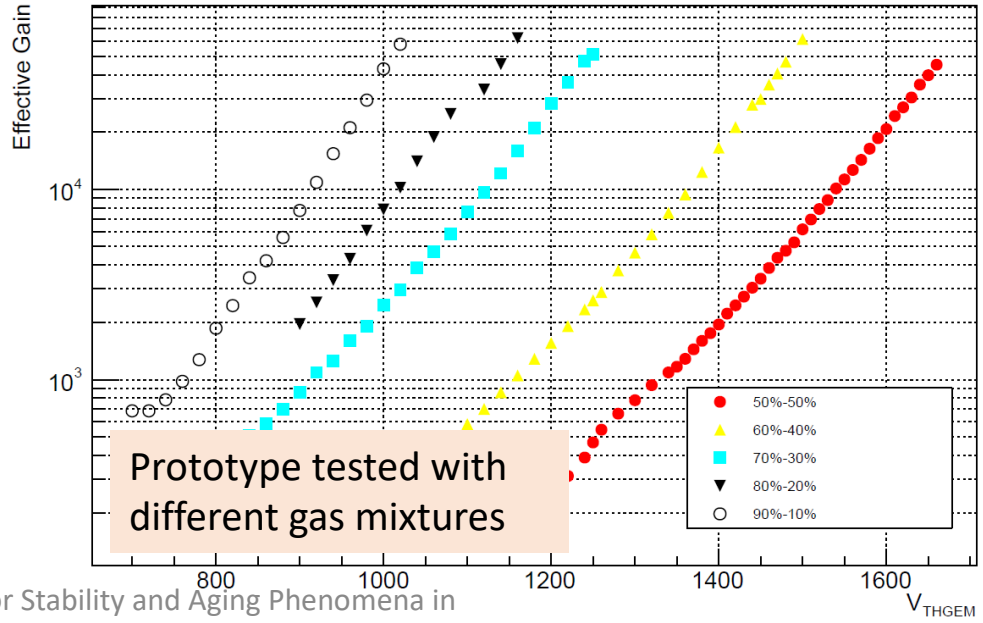
The response of THGEMs as electron multipliers is unaffected by HND coating

HND based prototype of photon detector



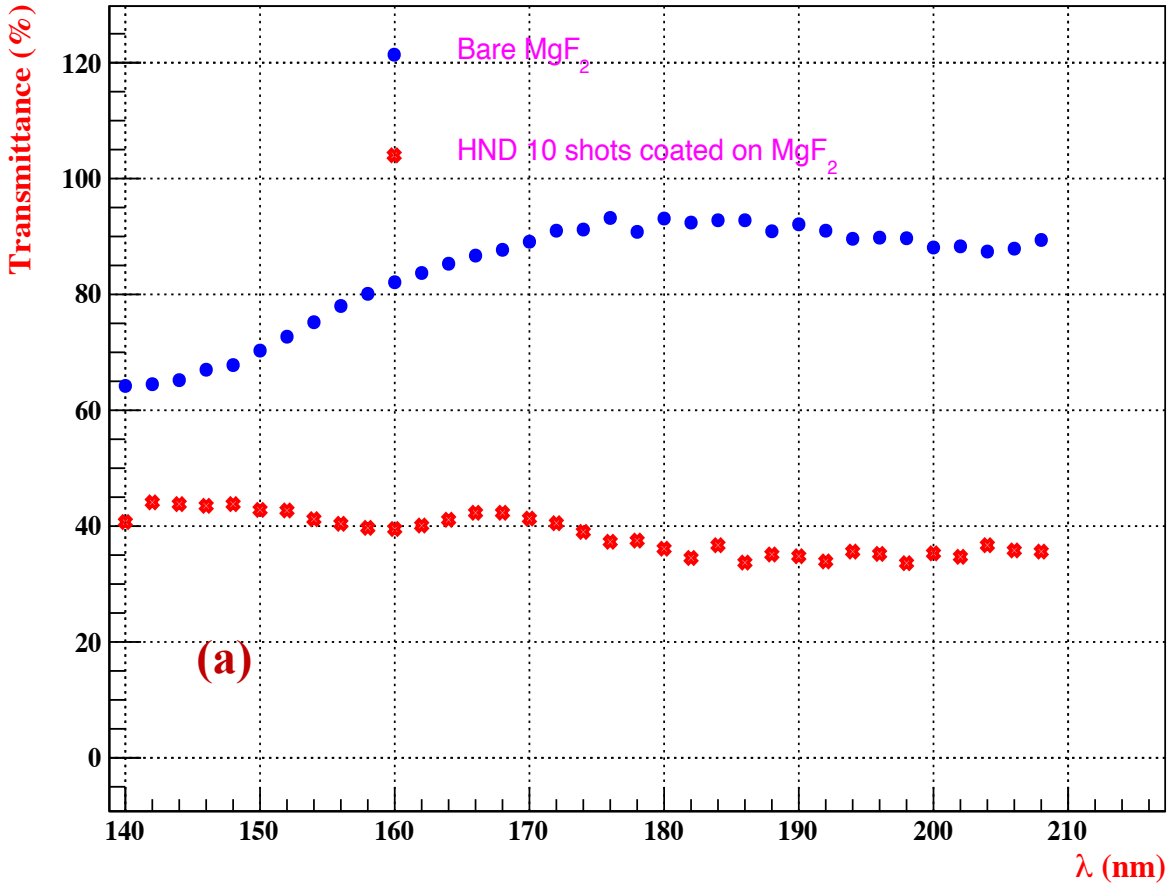
Prototype response with/without HND coating

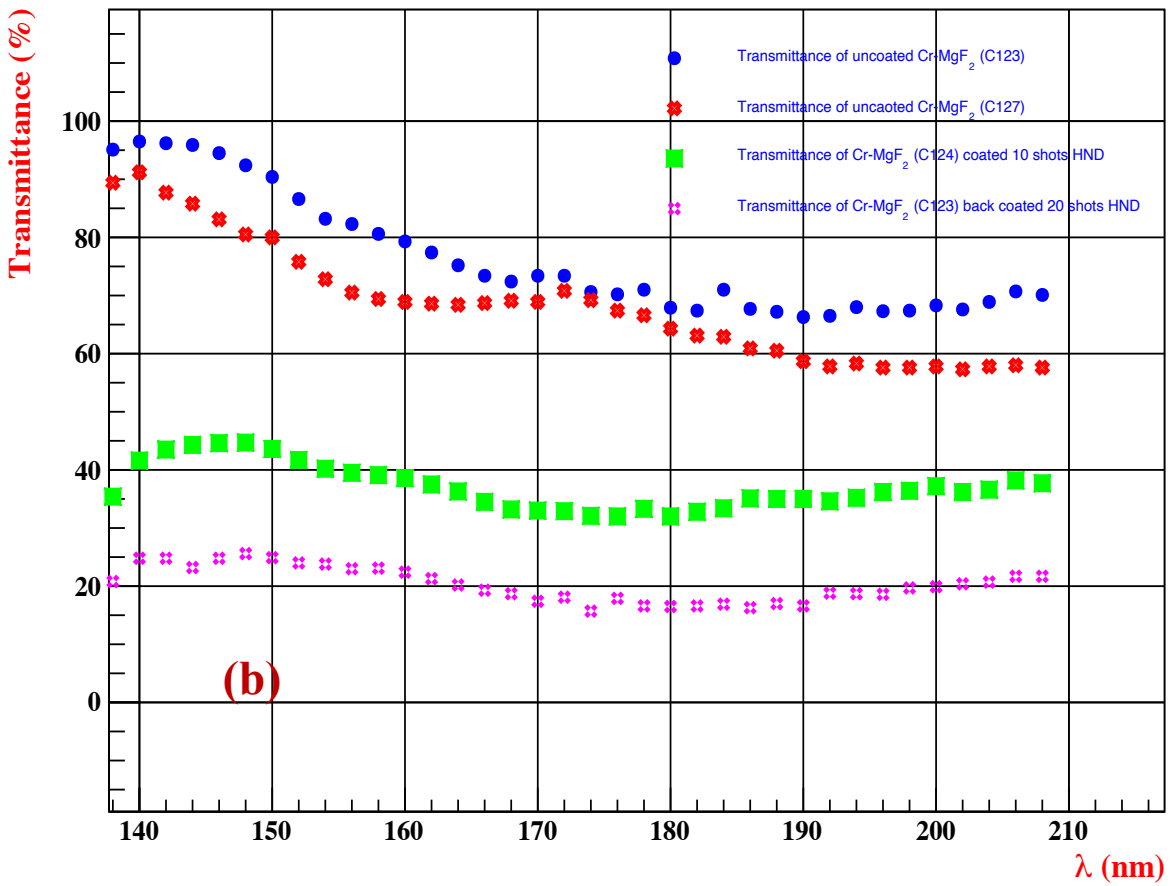


Prototype tested with different gas mixtures

Transmittance of HND coated on MgF_2 and MgF_2-Cr

Transmittance of HND

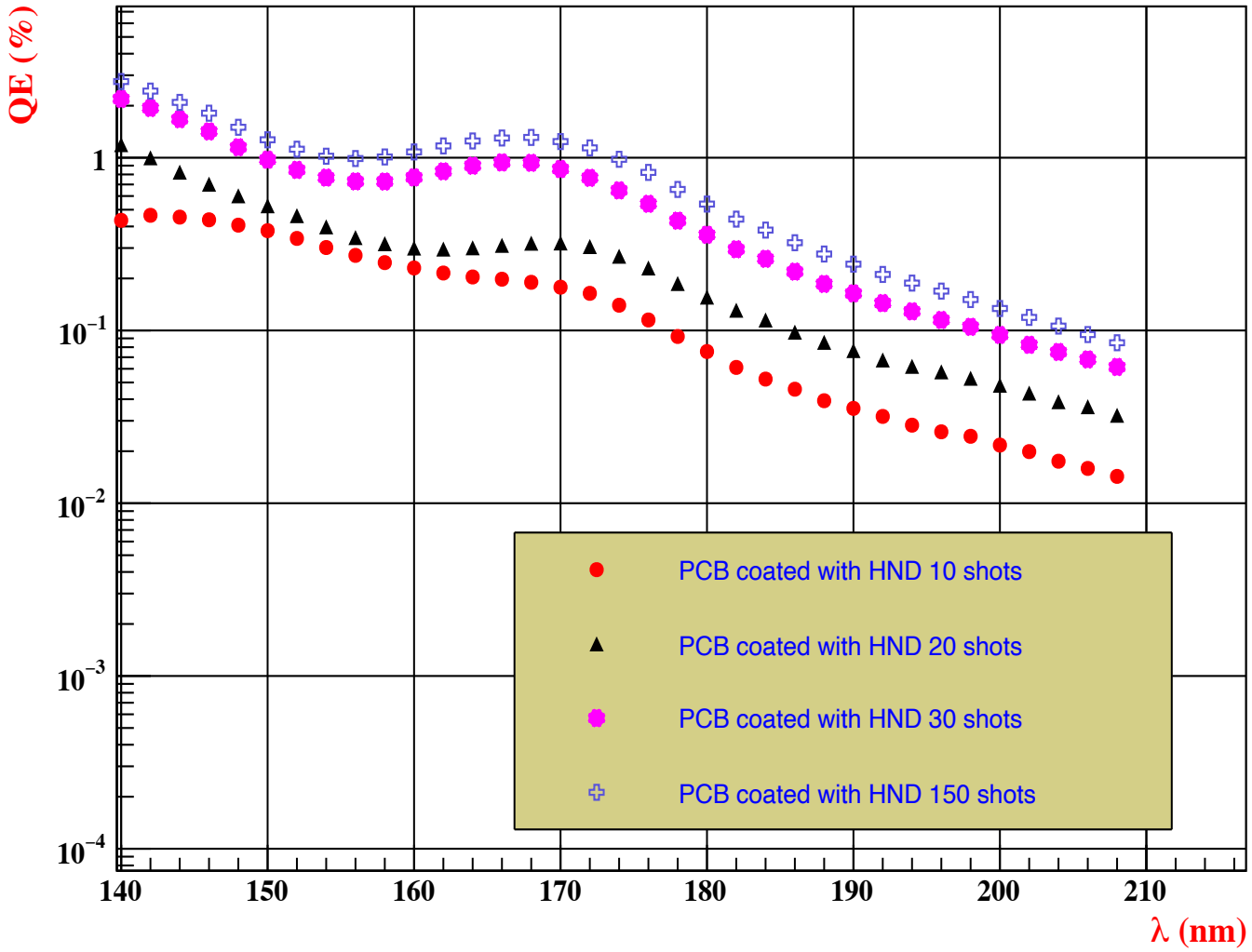




(a) Transmittance of bare and 10 shots HND coated MgF_2 and it is found to be about 40% for HND MgF_2.

(a) Transmittance of uncoated and HND coated Cr-MgF_2 window and similar as HND coated on MgF_2.

Quantum Efficiency of HND

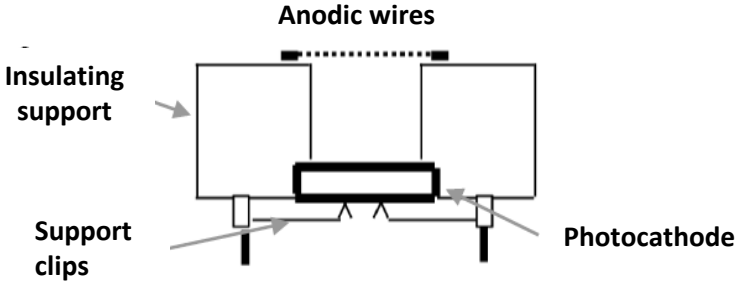


Quantum Efficiency of HND has been determined by using following relation

$$QE_{HND} = \frac{I_{HND}}{I_{NIST}} QE_{NIST}$$

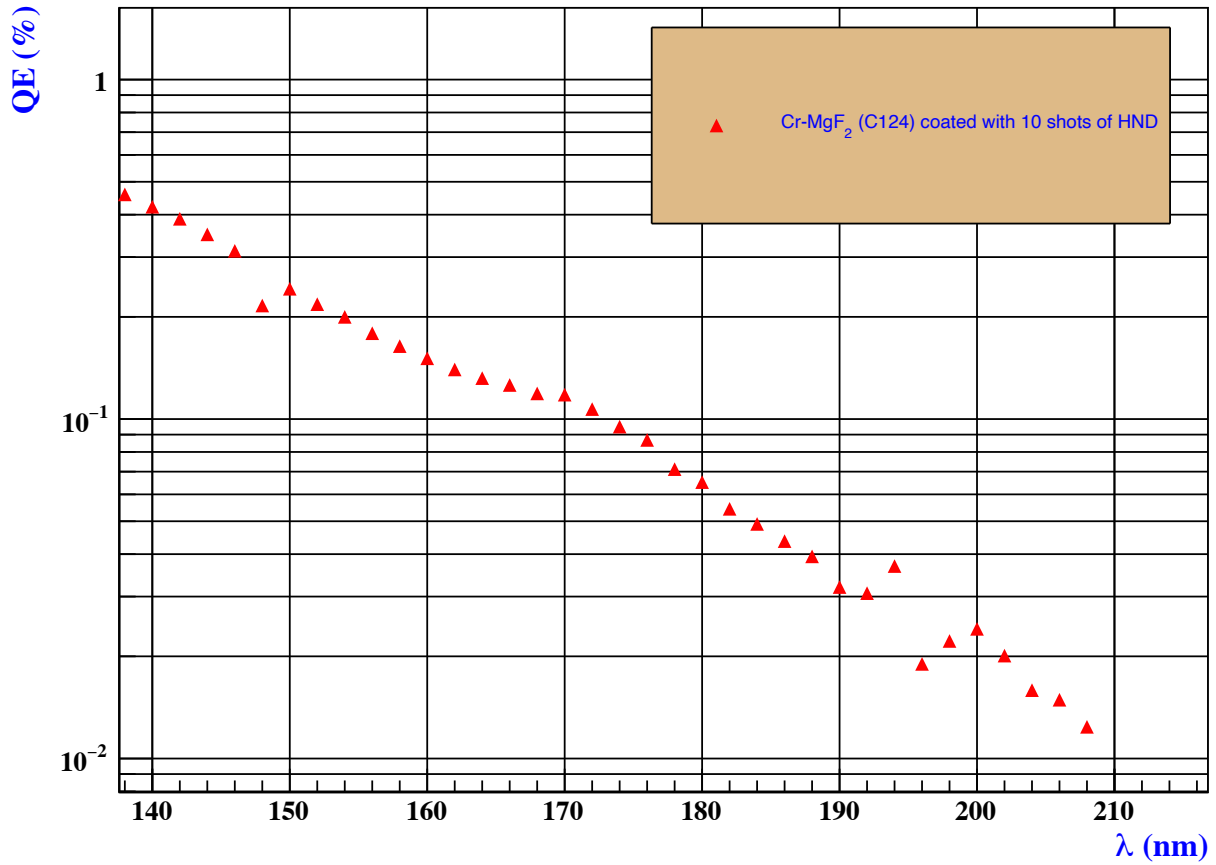
NIST Photodiode

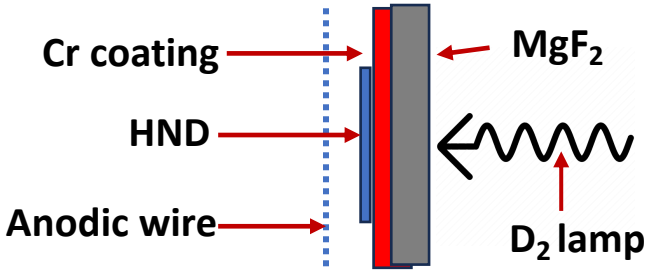
MWPC



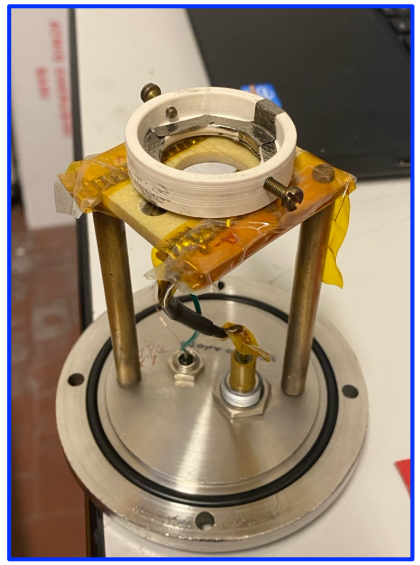
QE of HND in semitransparent mode

By coating HND on Cr-MgF_2





Semitransparent mode



Sample Holder

QE value increases for 10 shot is about ~0.4% at 140 nm wavelength.

Summary

- High robustness against moisture, light irradiation, ion bombardment.
- H-ND has been applied on THGEMs and a R&D towards a detector of single photon based on hybrid (THGEM + MM) MPGD technology with H-ND photocathode has been started.
- Photoemission measurements are performed in a vacuum as in different gas mixtures.
- Transmission and QE of HND in semitransparent mode have been measured.
- A systematic study of gas, HV configuration, and detector geometry has been done.
- ***Initial study suggests that; Hydrogenated Nano Diamond can be a potential candidate for future MPGD technology.***

Thank You