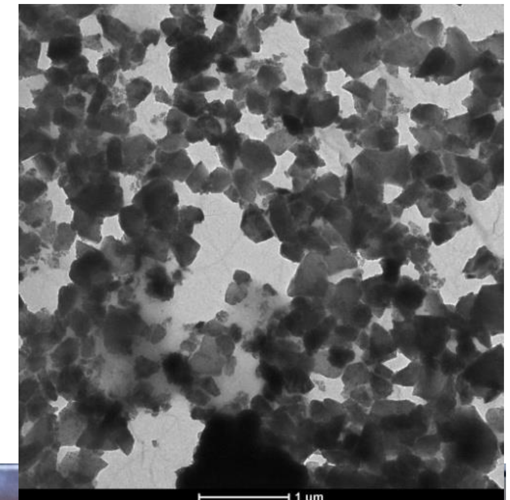
Progress on coupling MPGD-based PDs with nanodiamond photocathodes

Fulvio Tessarotto

On behalf of the nanodiamond-THGEM group
(Trieste-Bari-CERN)



Motivation for the R&D

H-ND: production and spray coating

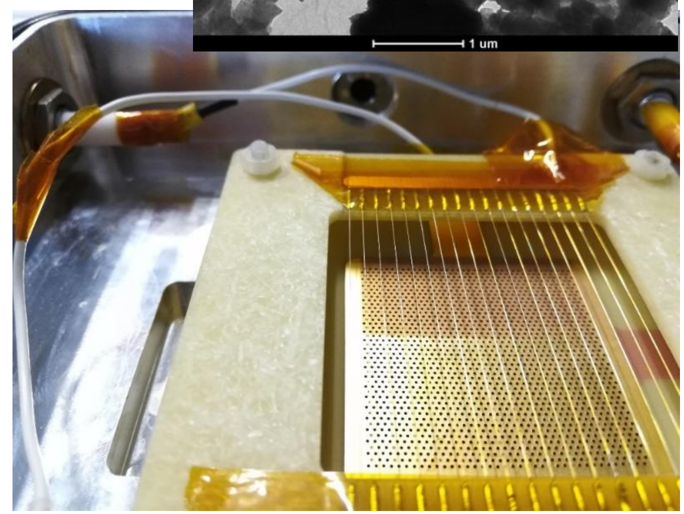
Photoemission measurements

THGEMs with nanodiamond coating

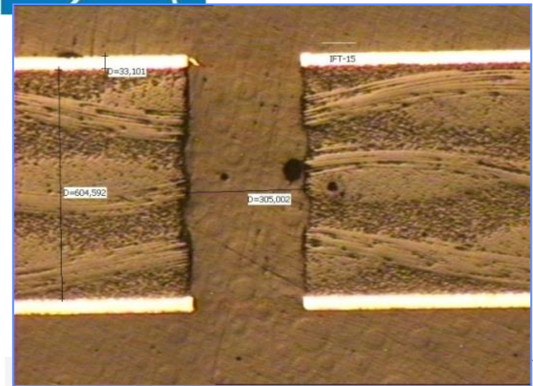
Measurements in different gas mixtures

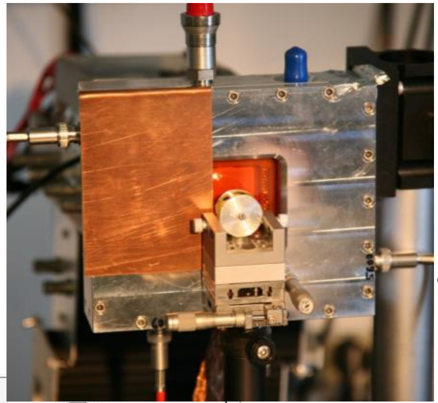
Aging studies

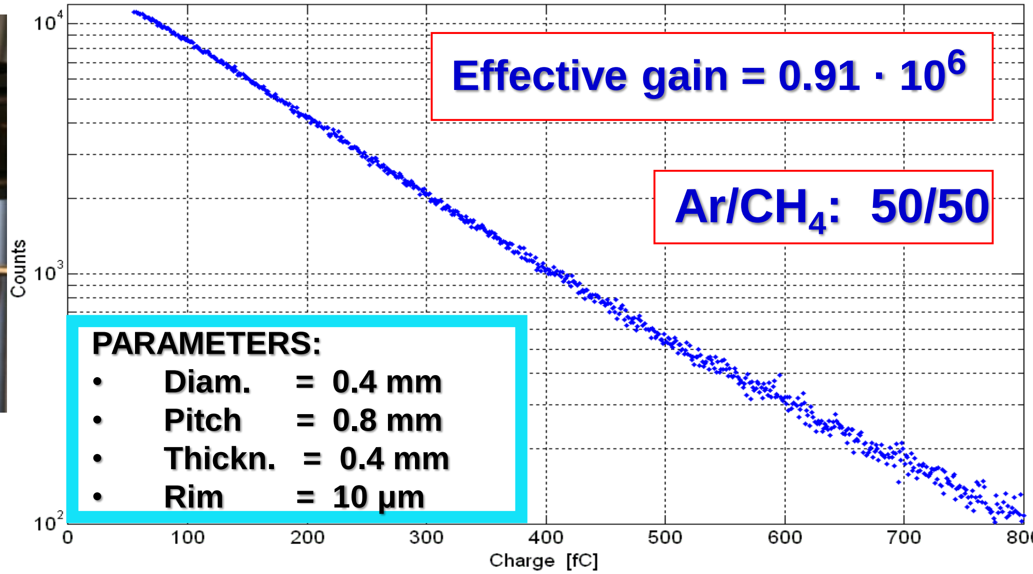
Conclusions

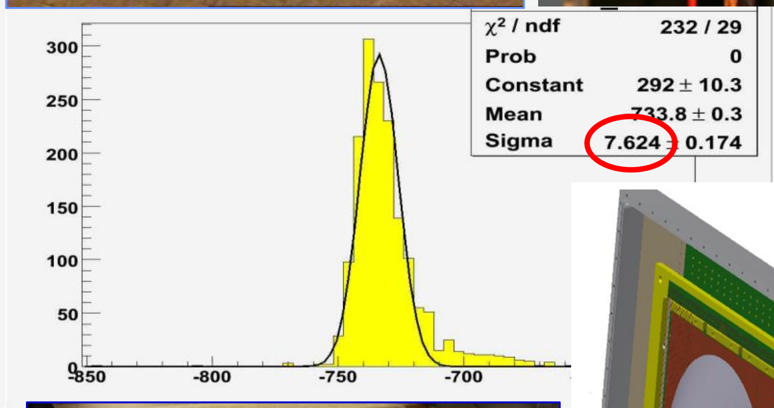


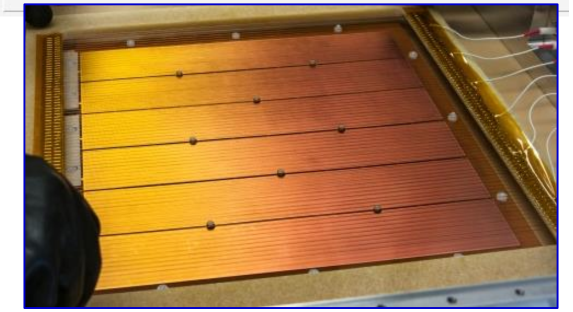
THGEM+CsI: 8 years of dedicated R&D

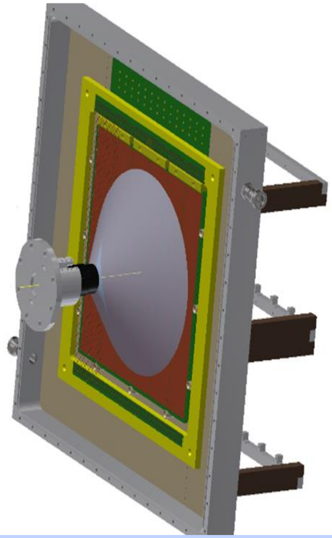


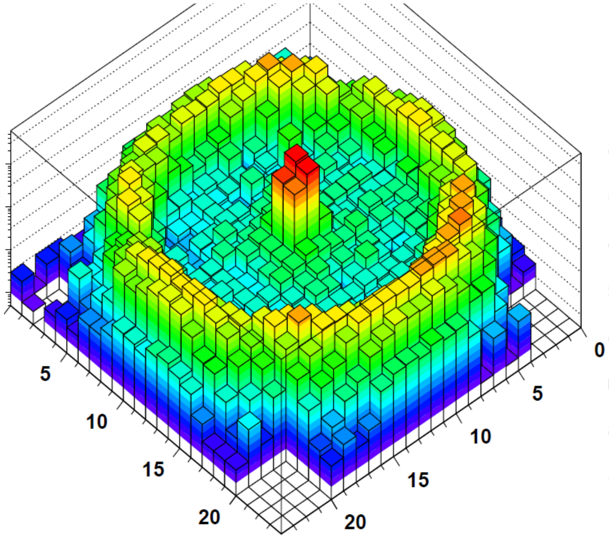




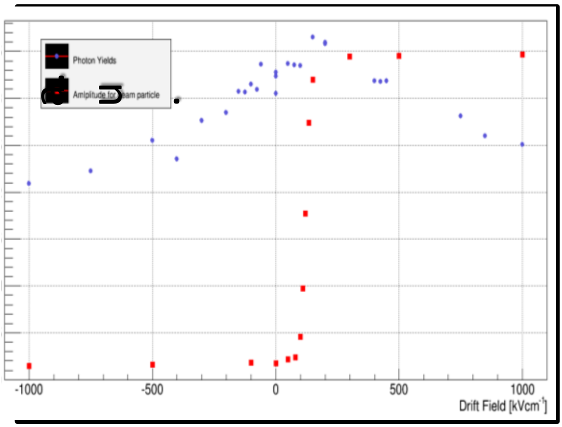








Photon yield & Charged Particles vs Drift Field

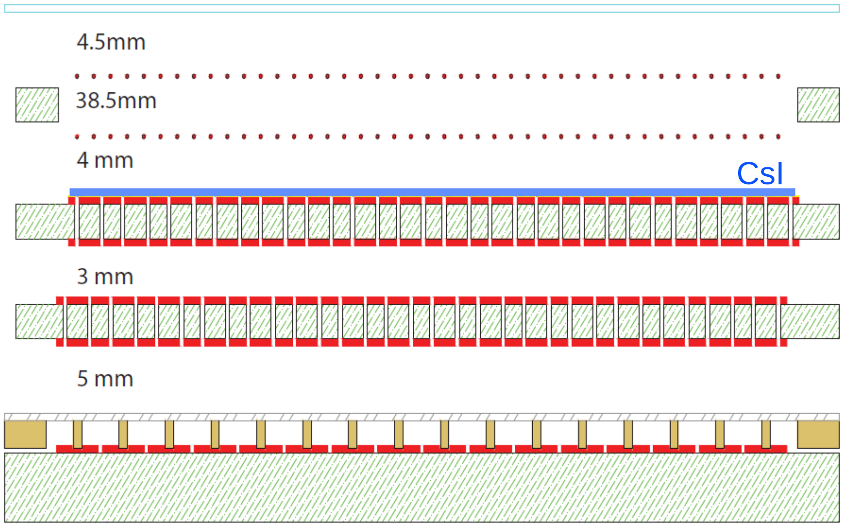


Difficult mastering of the technology to cover very large area: el. stability and reproducibility issues

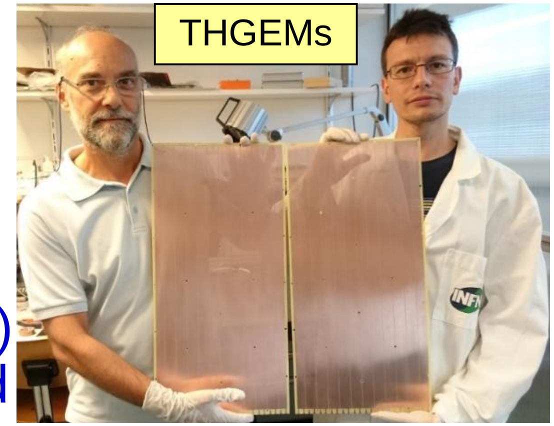
COMPASS Hybrid THGEM+MM PDs

Hybrid PD scheme

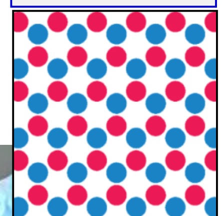
IBF = 3%

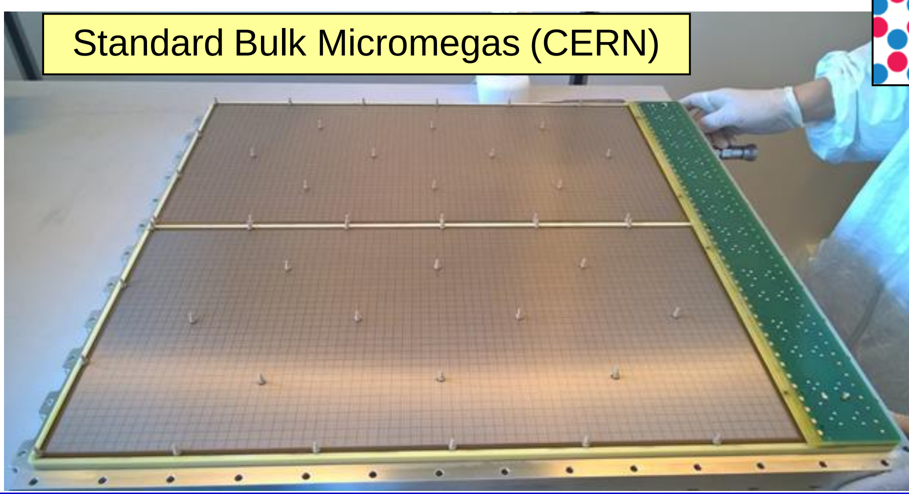


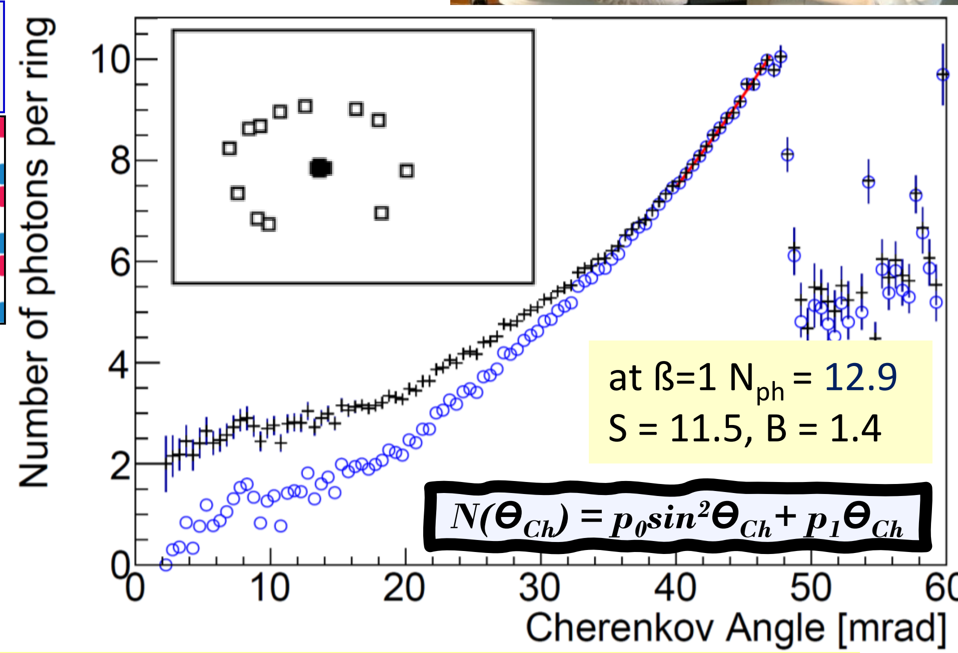
successfully implemented in 2016 on COMPASS RICH-1
active area = 1.4 m^2
eff. gain ~ 15000,
gain stability 5% (p/T corr.)
single γ ang. res. 1.8 mrad



staggered THGEMs





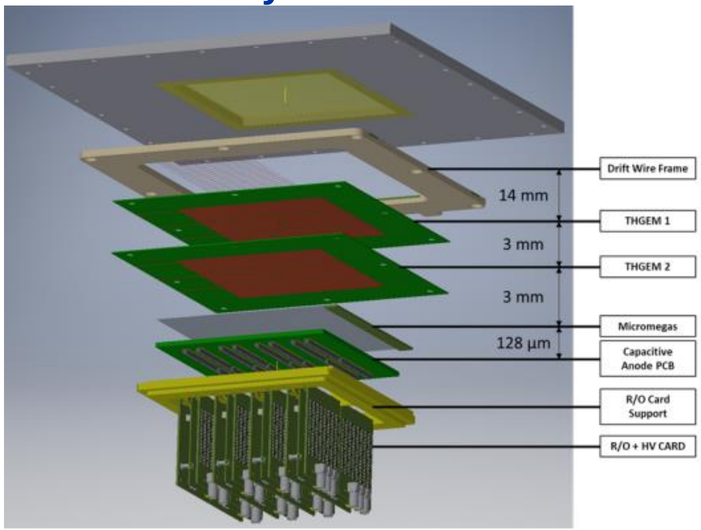


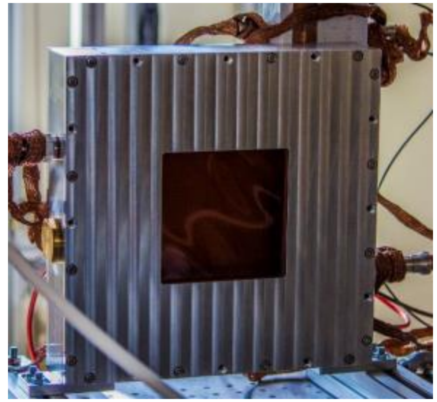
$$N(\Theta_{Ch}) = p_0 \sin^2\Theta_{Ch} + p_1\Theta_{Ch}$$

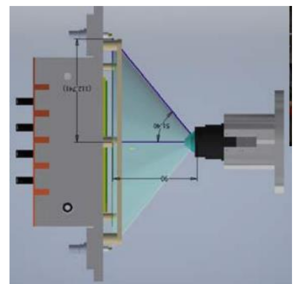
S. Dalla Torre, NIM A 970 (2020) 163768

Minipad Hybrid THGEM+MM PDs

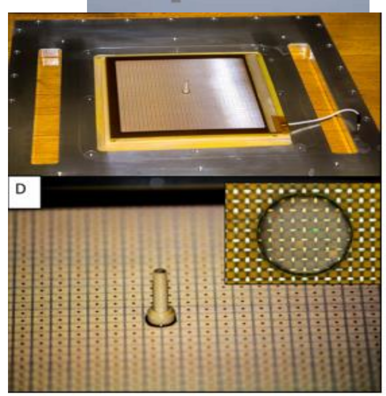
Modular Hybrid THGEMs + Micromegas Minipad prototype



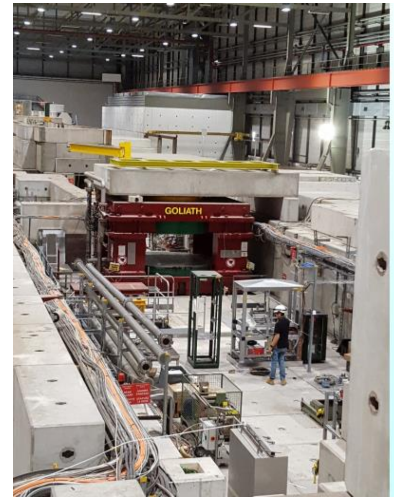


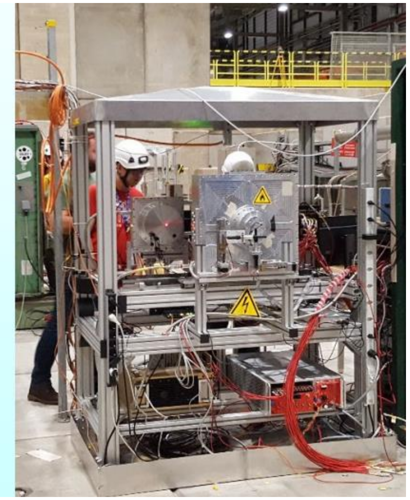


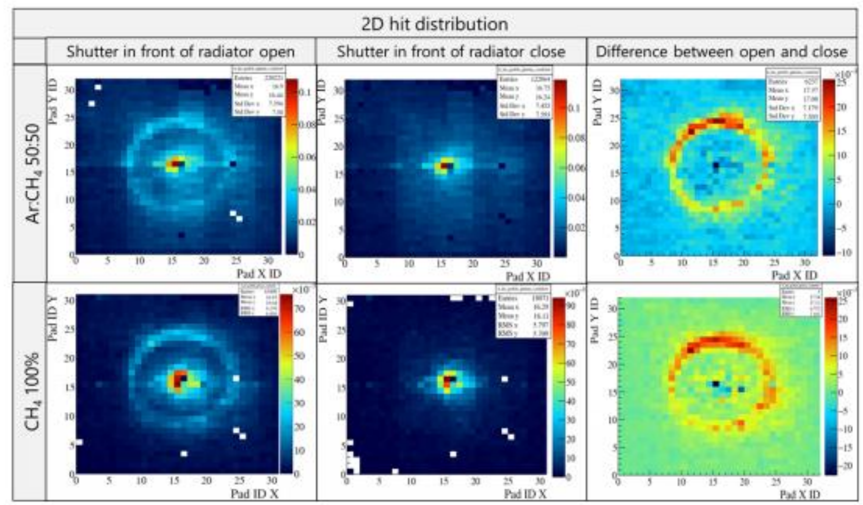
Prototype with 10x10 cm^2 active area. 1024 square pads of 3x3 mm^2 with 0.5 mm inter-pad space



"after the positive experience with COMPASS RICH"



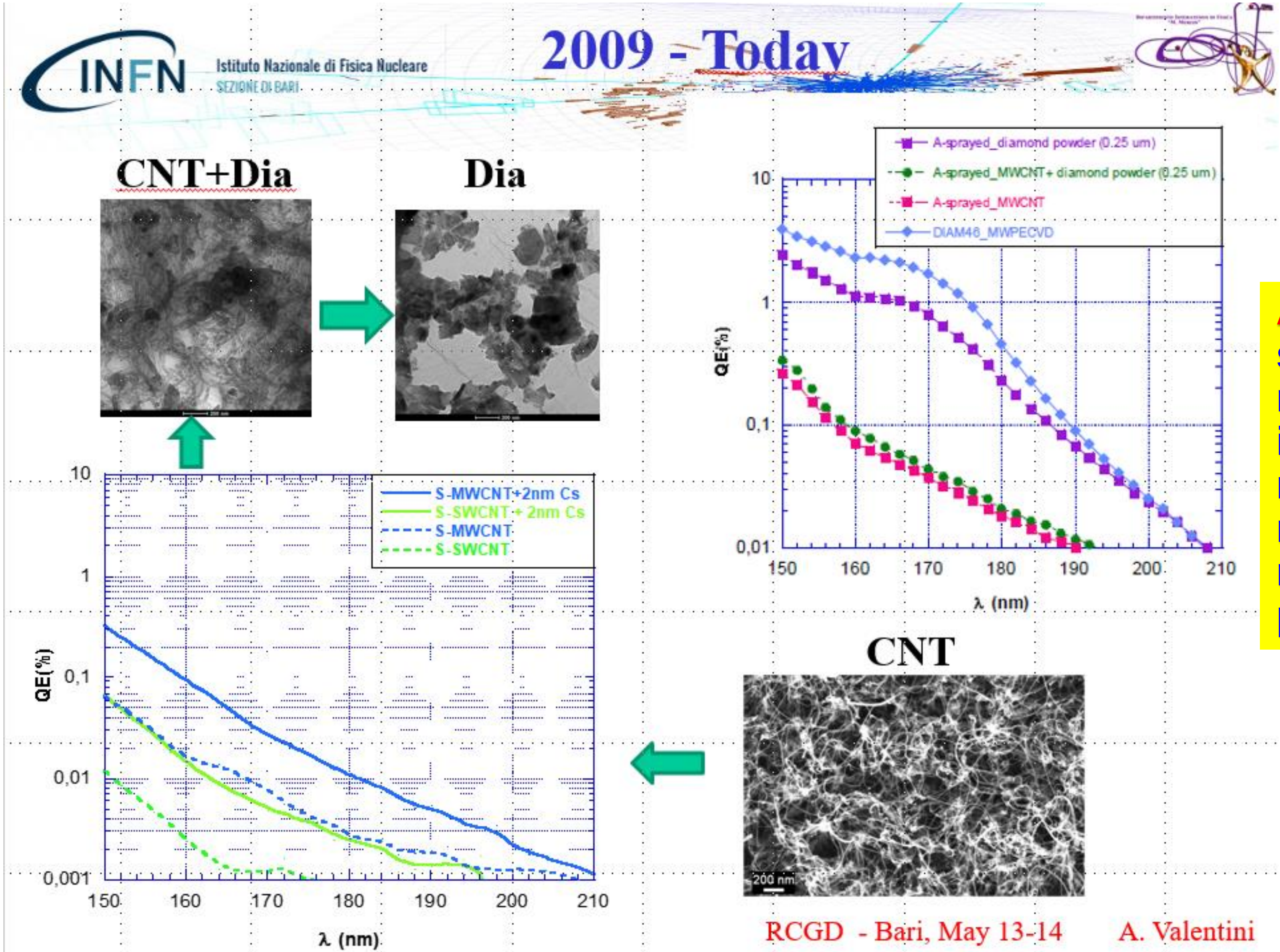




AIDA-2020-NOTE-2020-006

JINST 15 (2020) C09052

Nanodiamonds: the beginning in Bari



Antonio Valentini studies on carbon nanotubes led to identify diamond nano-grains as the most promising robust and efficient photoconverter

Rich-graphite Nano-Diamond film

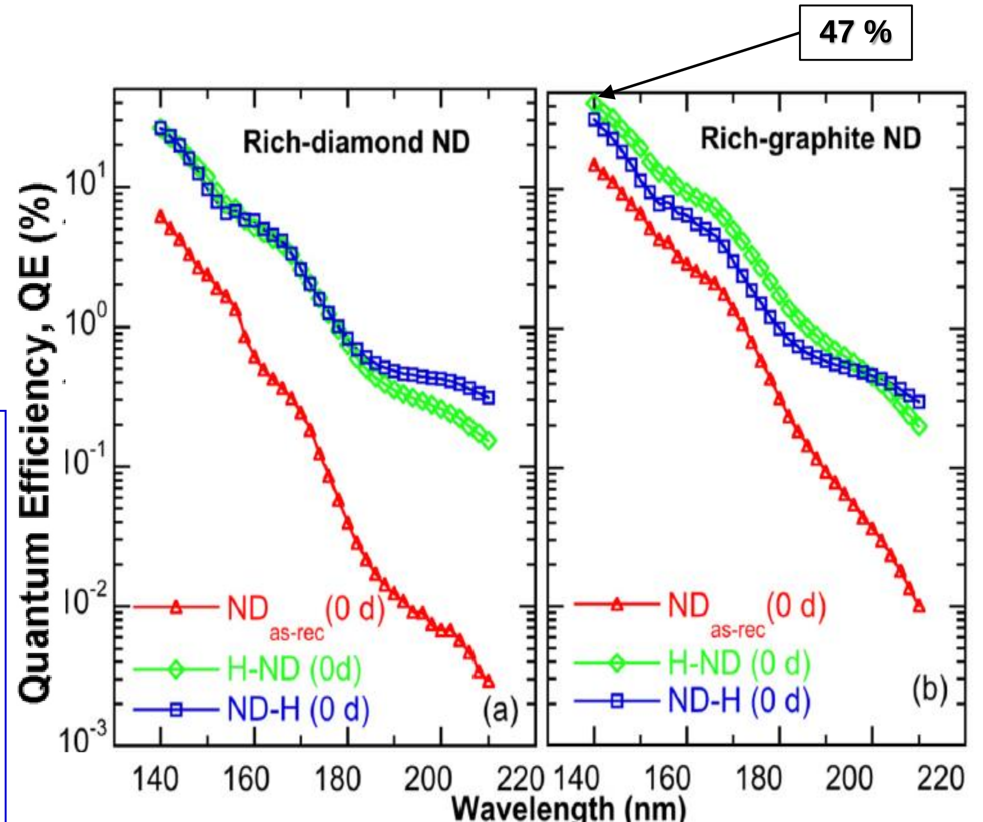
CsI bandgap: 6.2 eV; electron affinity: 0.1 eV; hygroscopic; ages by ion bombardment (~mC/cm^2)

Diamond bandgap: 5.5 eV; chemically inert and robust; if hydrogenated: electron affinity -1.27 eV

Hydrogenated chemical vapor deposited diamond films (4-6 μm) known to have QE ~15% @ 140 nm.

Heterogranular-structured diamond-gold nanohybrids proposed as stable field emission cathode material

Nano-Diamond grains (size: ~250 nm), with variable sp^2 (graphite phase) and sp^3 (diamond phase) hybridized carbon contents treated in H2 microwave plasma show large QE: >40% @ 140 nm



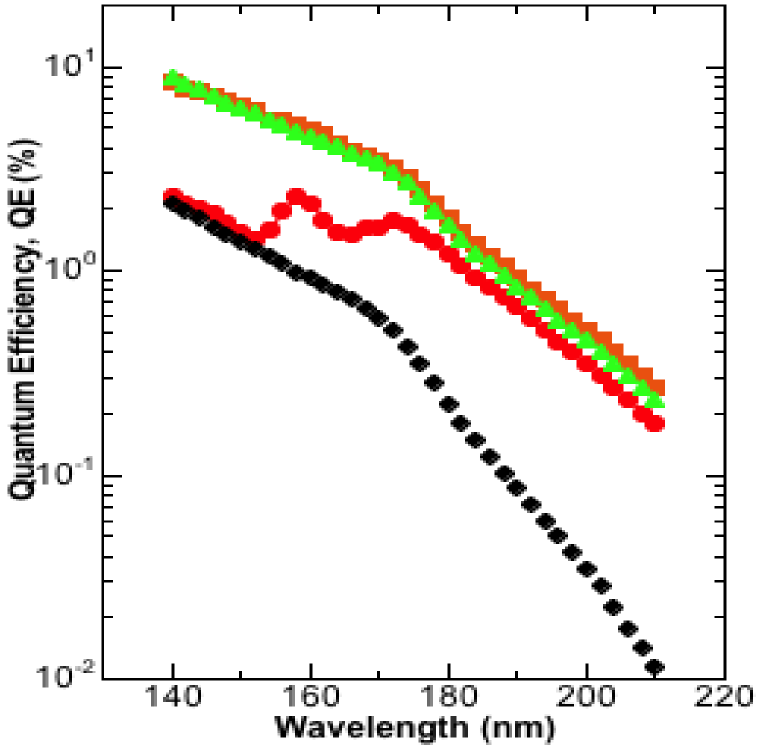
L.Velardi, A.Valentini, G.Cicala, Diamond & Related Materials 76 (2017) 1

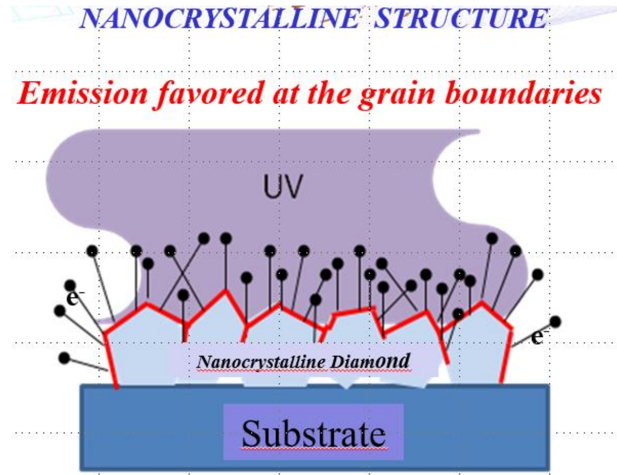
Photocatodes: diamond film obtained with Spray Technique

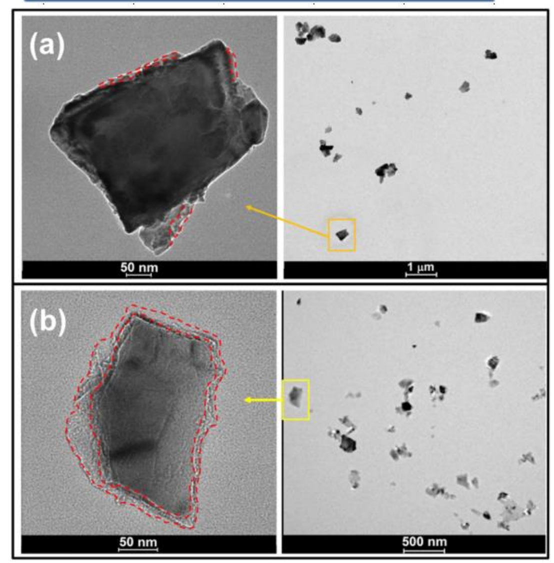
Spray technique: T ~ 120° (instead of ~800° as in standard techniques)

Nano-Diamond Q.E.

Phototube Hamamatsu







PCD_MgF2

Photocathode area ϕ 6 mm

Spectral response 110÷220 nm

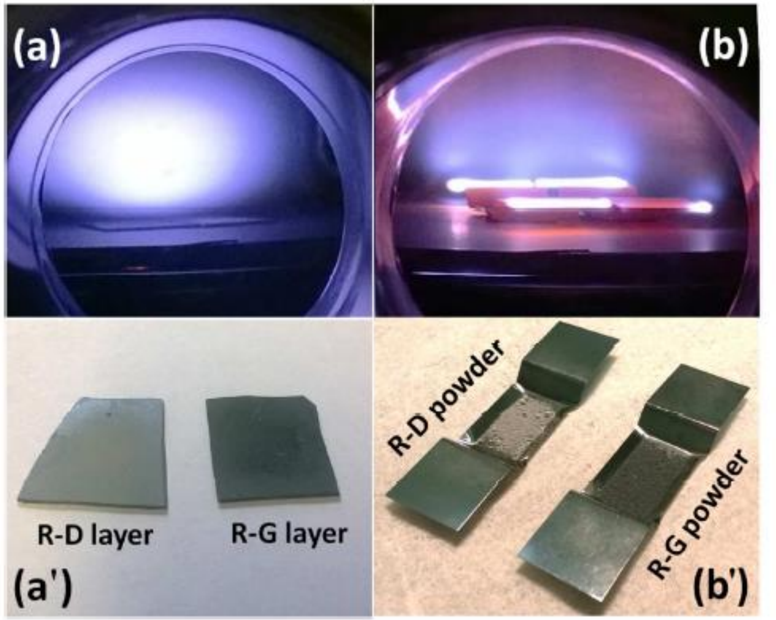
Hydrogenated powder
Hydrogenated powder

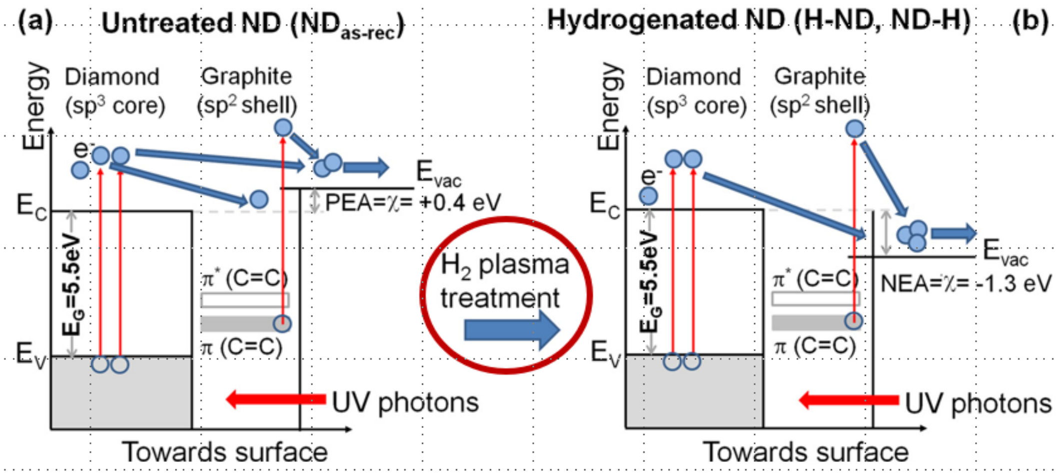
Phototube Hamamatsu

As received ND powder

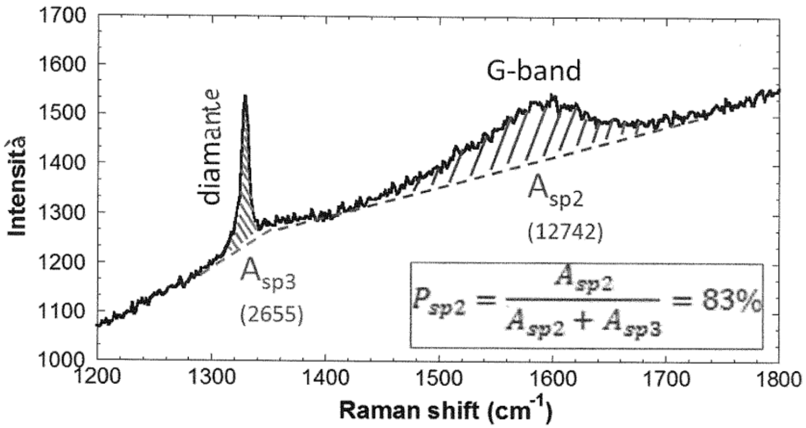
L. Velardi, et al
Diamond & Related Materials 76 (2017) 1–8

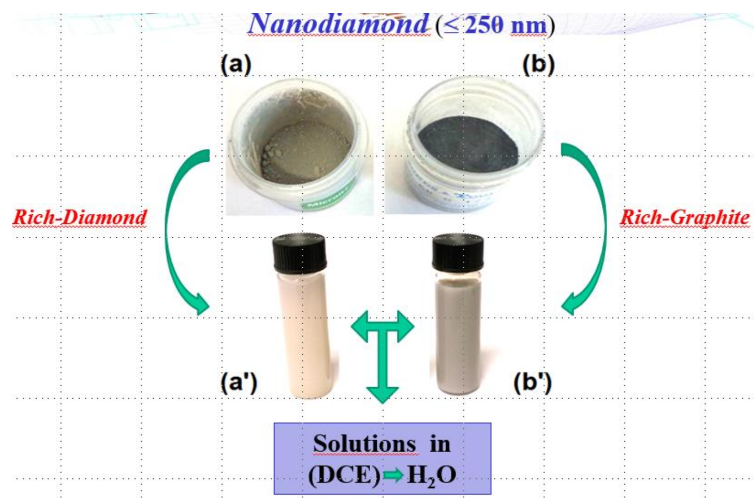
Hydrogenated Nano-Diamond



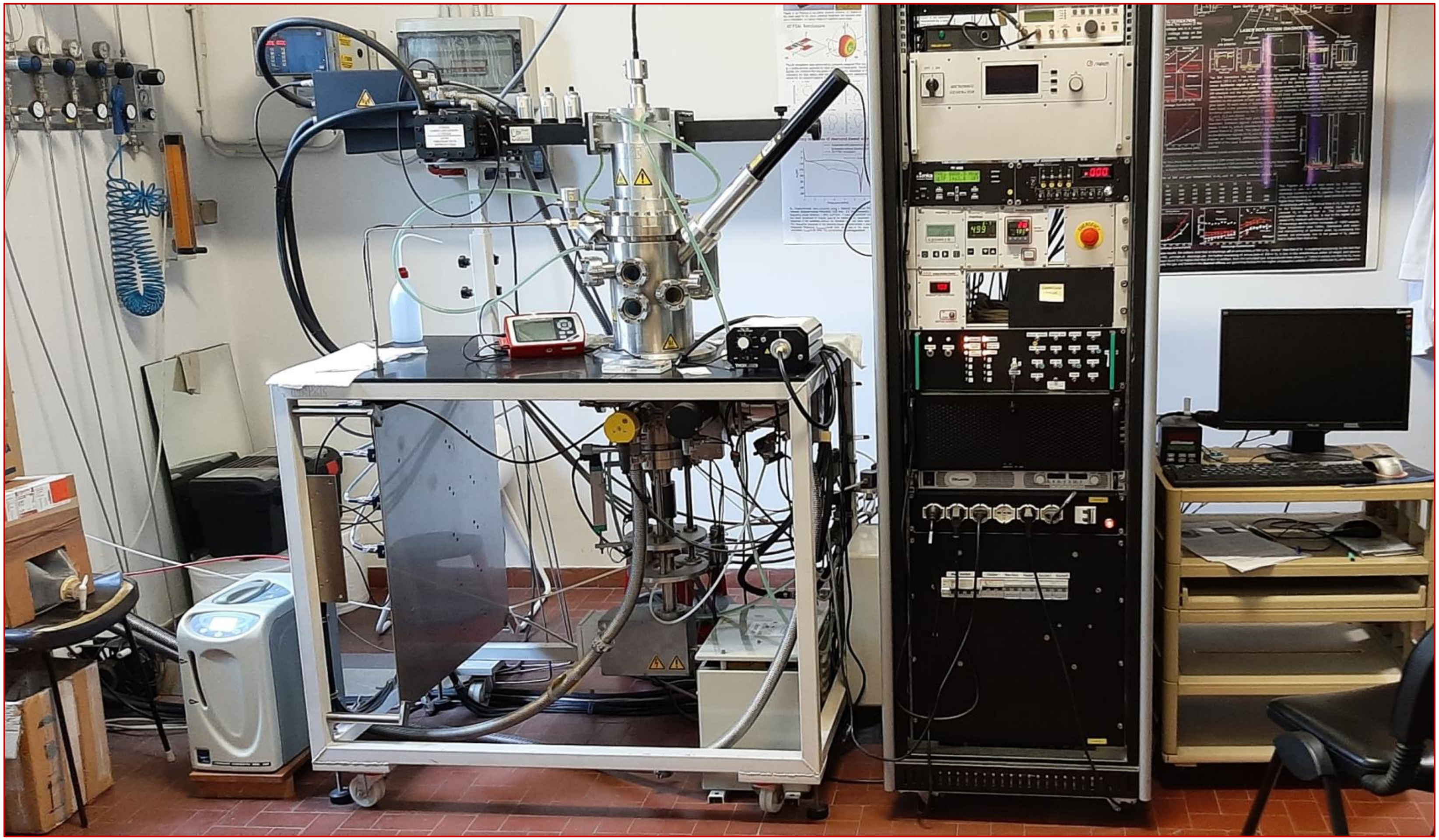


Schematic representation of the process of photoemission components **sp^3** e **sp^2** for **PEA** (a) and for **NEA** (b)





Hydrogenation: MWPECVD setup in Bari



Hydrogenation details:

Vacuum: ~6.5x10^{-6} mbar.

70 mm between H_2 source and ND powder.

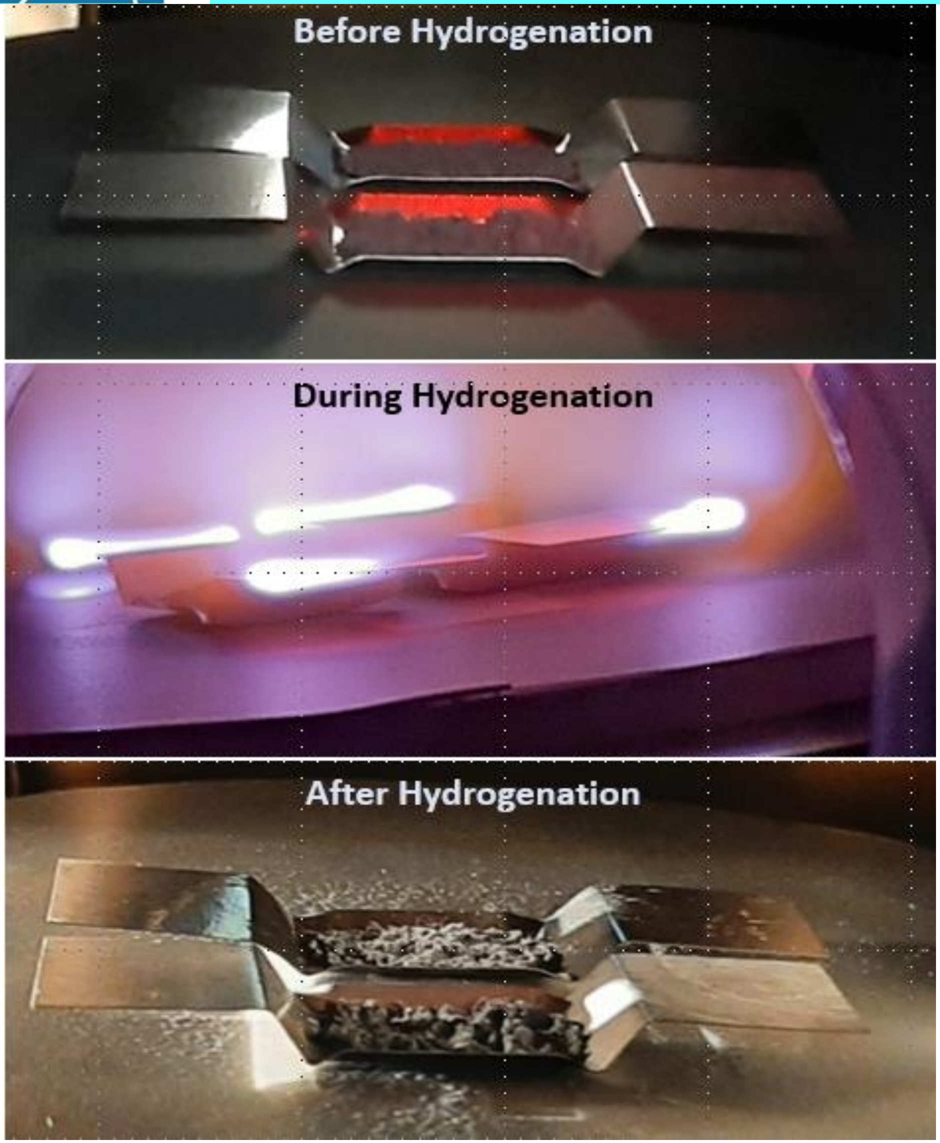
H_2 gas generated by electrolysis from distilled water. H_2 gas flow rate controlled to 200 sccm.

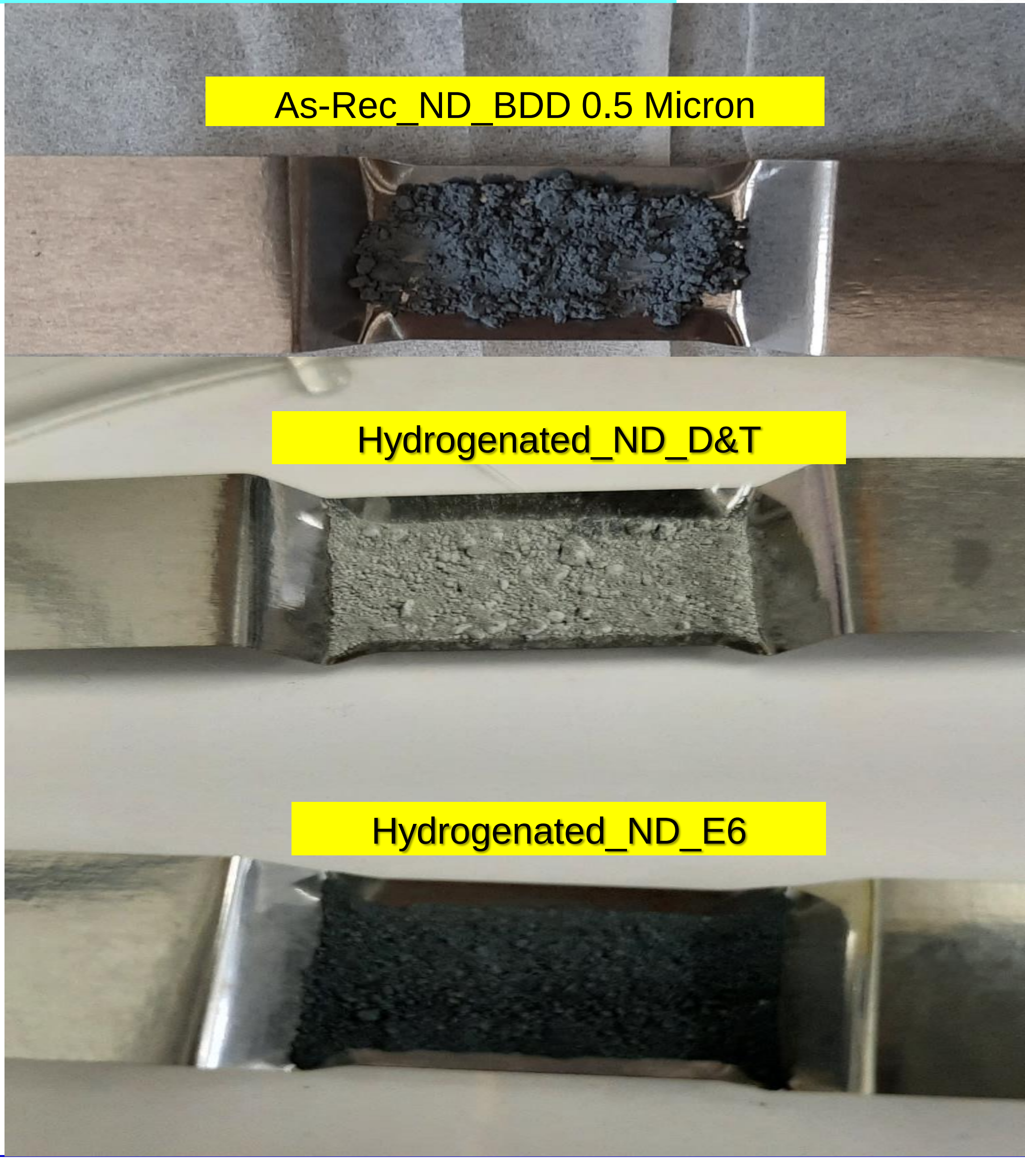
Hydrogenation of ND powder: 1 hour at 43 mbar.

1380 W microwave power → 1000 ^{0}C temperature with 830 ^{0}C substrate holder temperature.

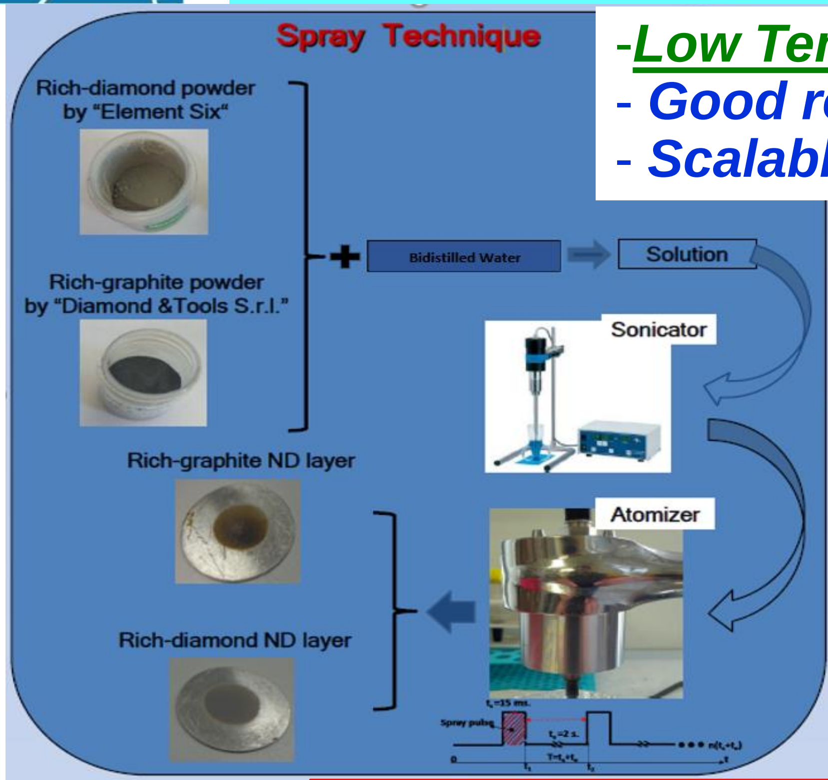
1250 W microwave power → 810 ^{0}C temperature with 650 ^{0}C substrate holder temperature.

Different ND and H-ND

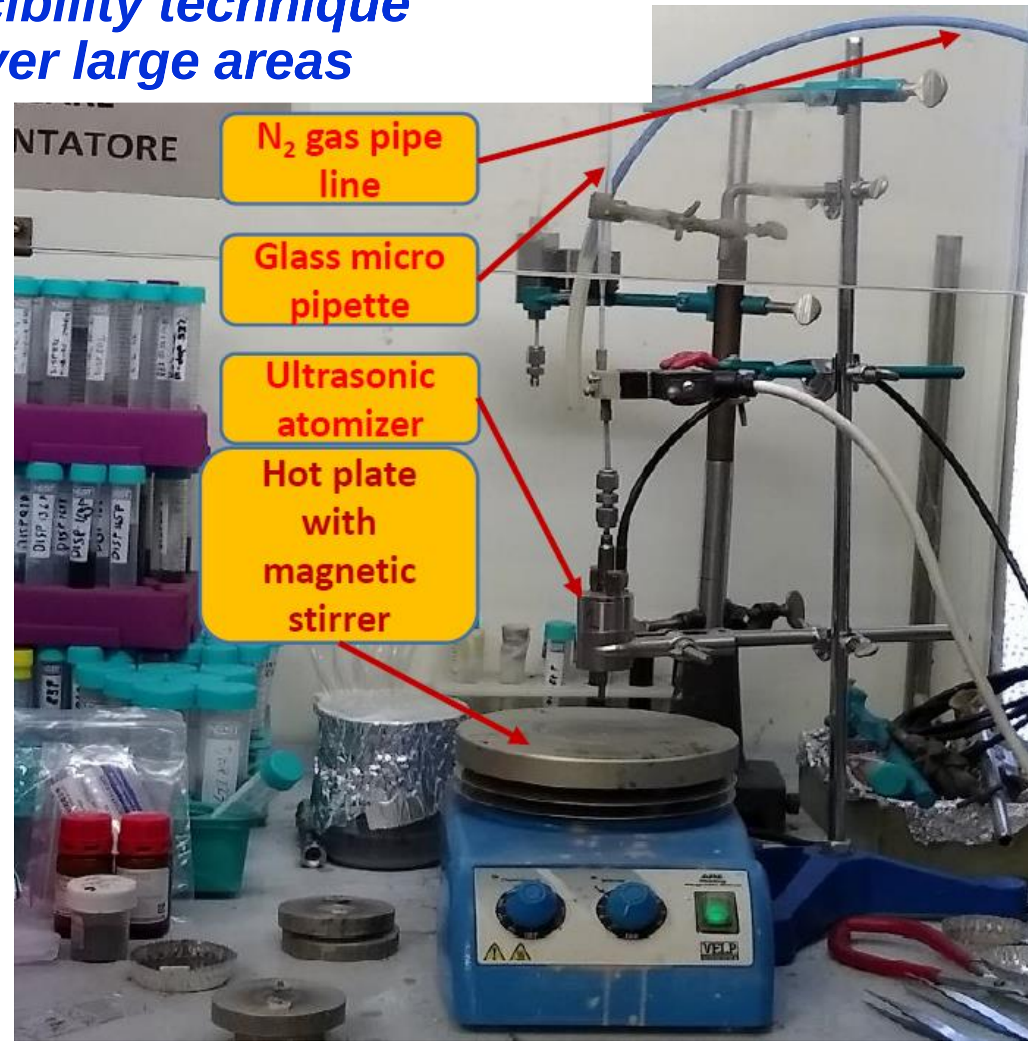




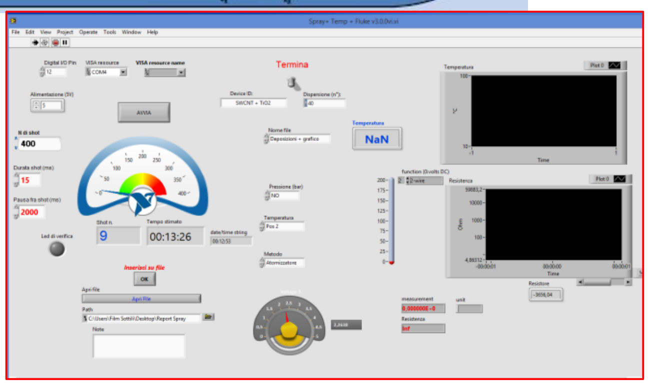
Pulsed spray coating in Bari



- *Low Temperature Deposition (≤120 °C)*
- ***Good reproducibility technique***
- ***Scalable to cover large areas***

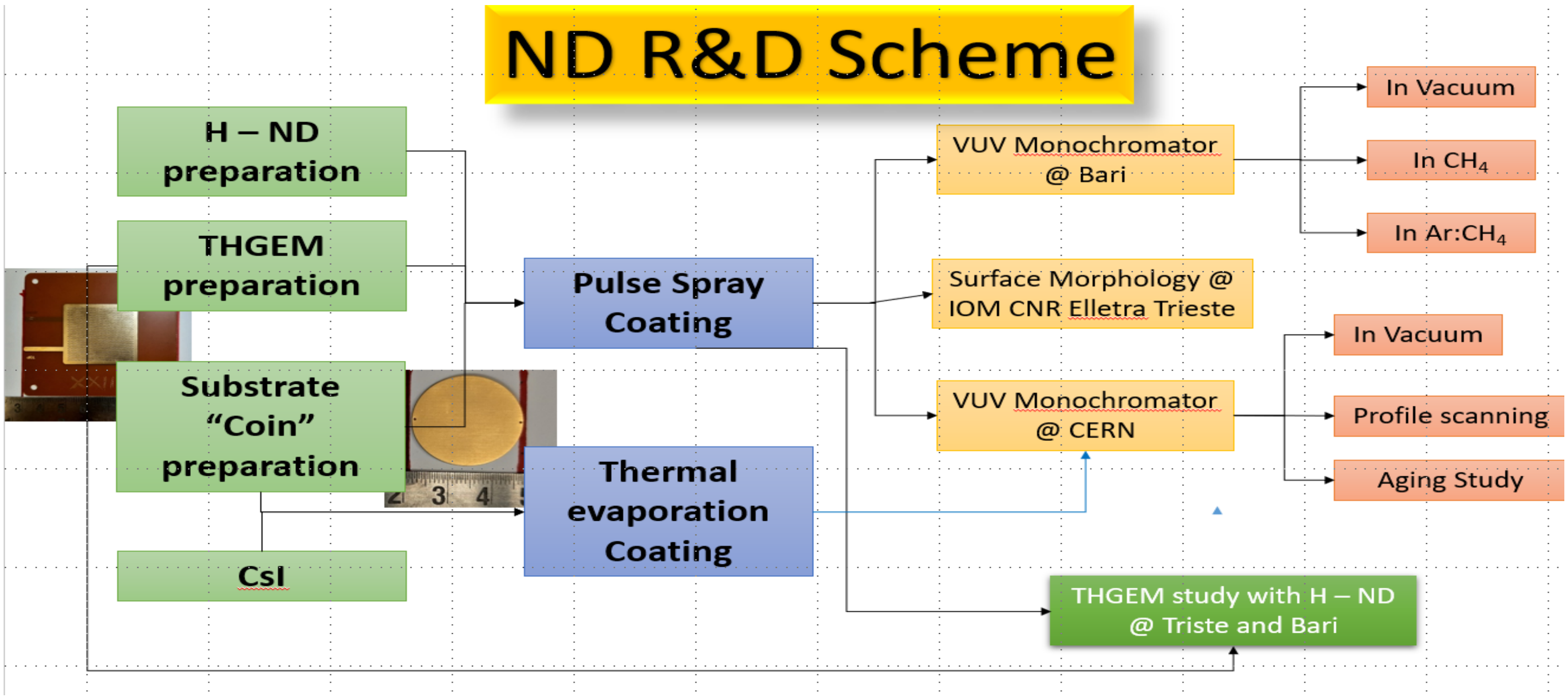


Spray Control Interface

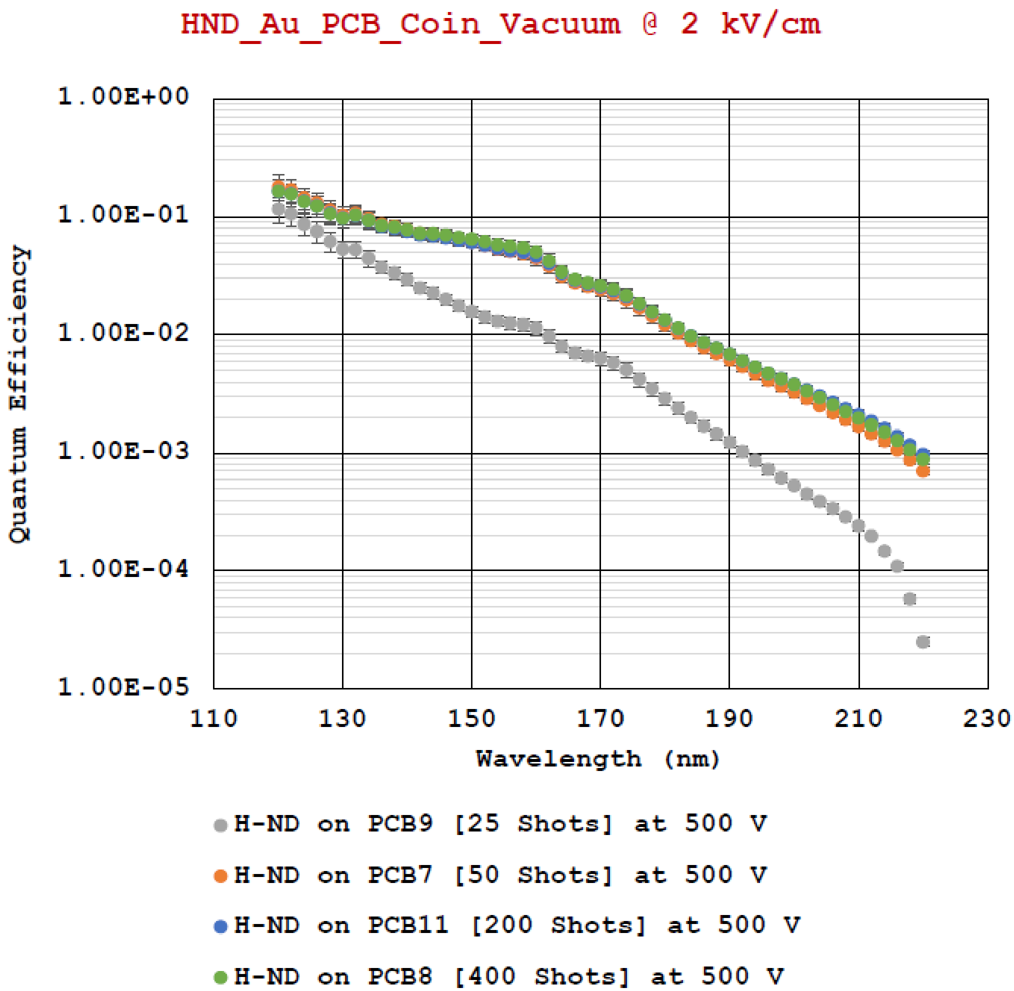


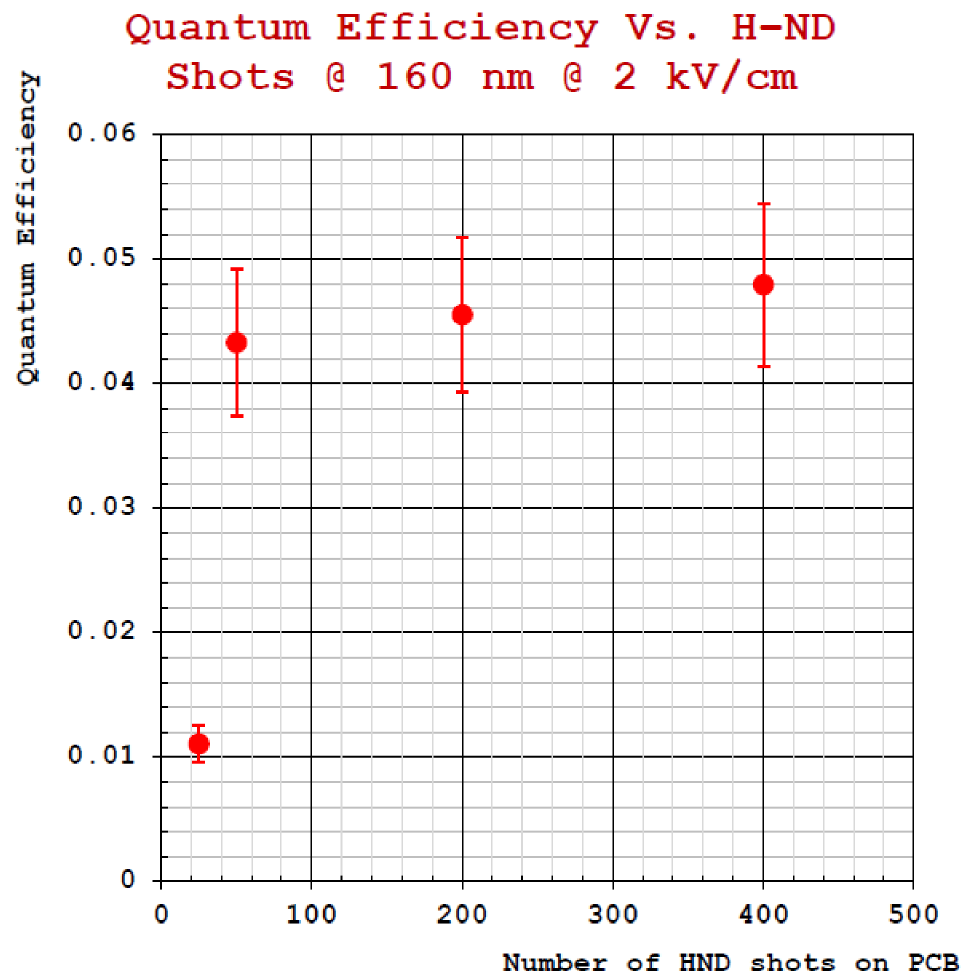
Basic questions about H-ND and TGEM coupling

Is the H-ND layer on the THGEM:
- Reducing the electrical stability?
- Changing the gain response?
- Providing the same PDE as on PCBs?
- Uniform and stable?
- More robust with respect to CsI?



"Thickness" study



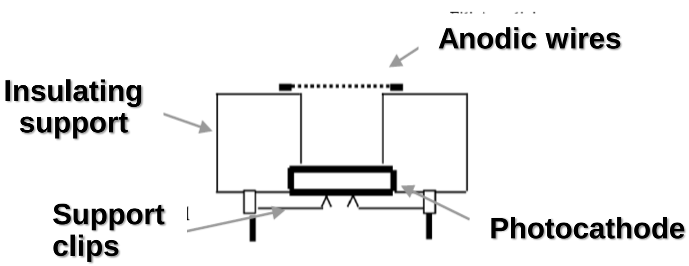


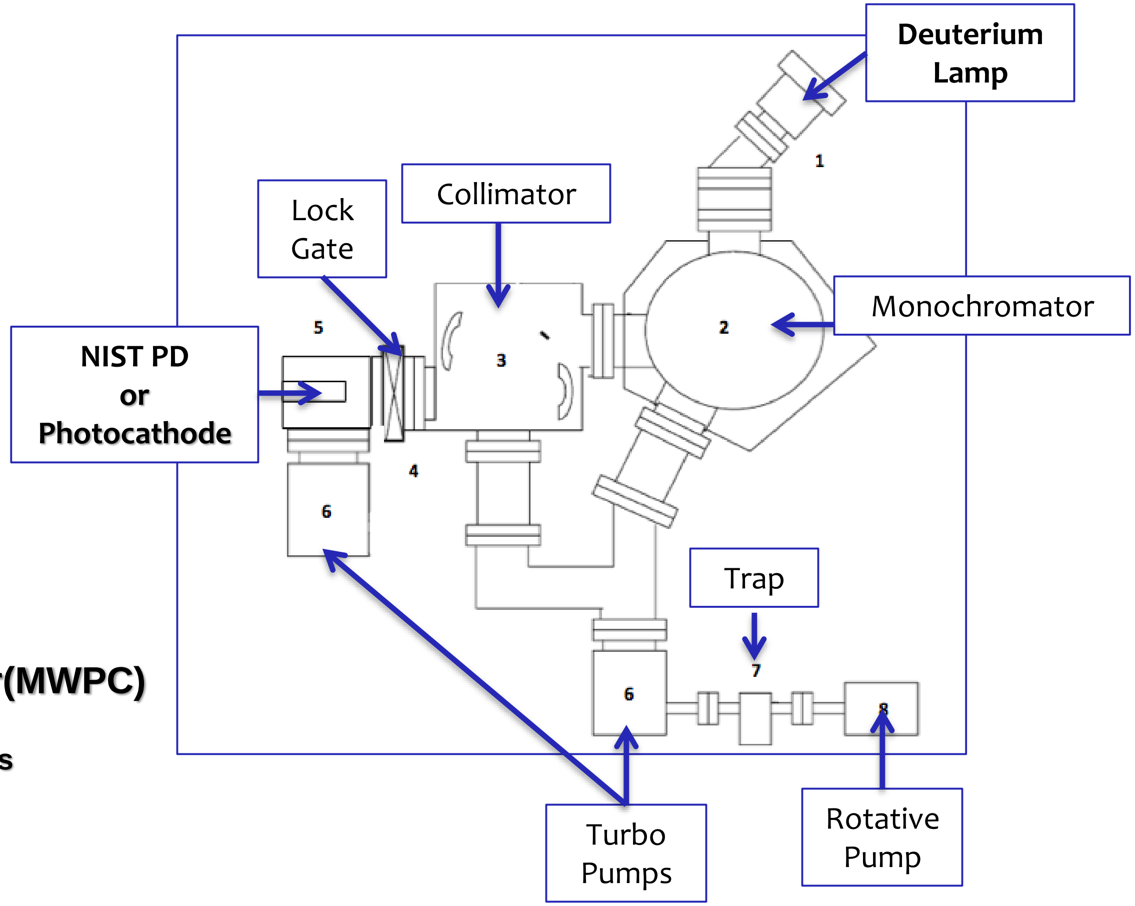
Sufficient surface coverage is reached with "100 shots" thickness

Q.E. measurement setup in Bari

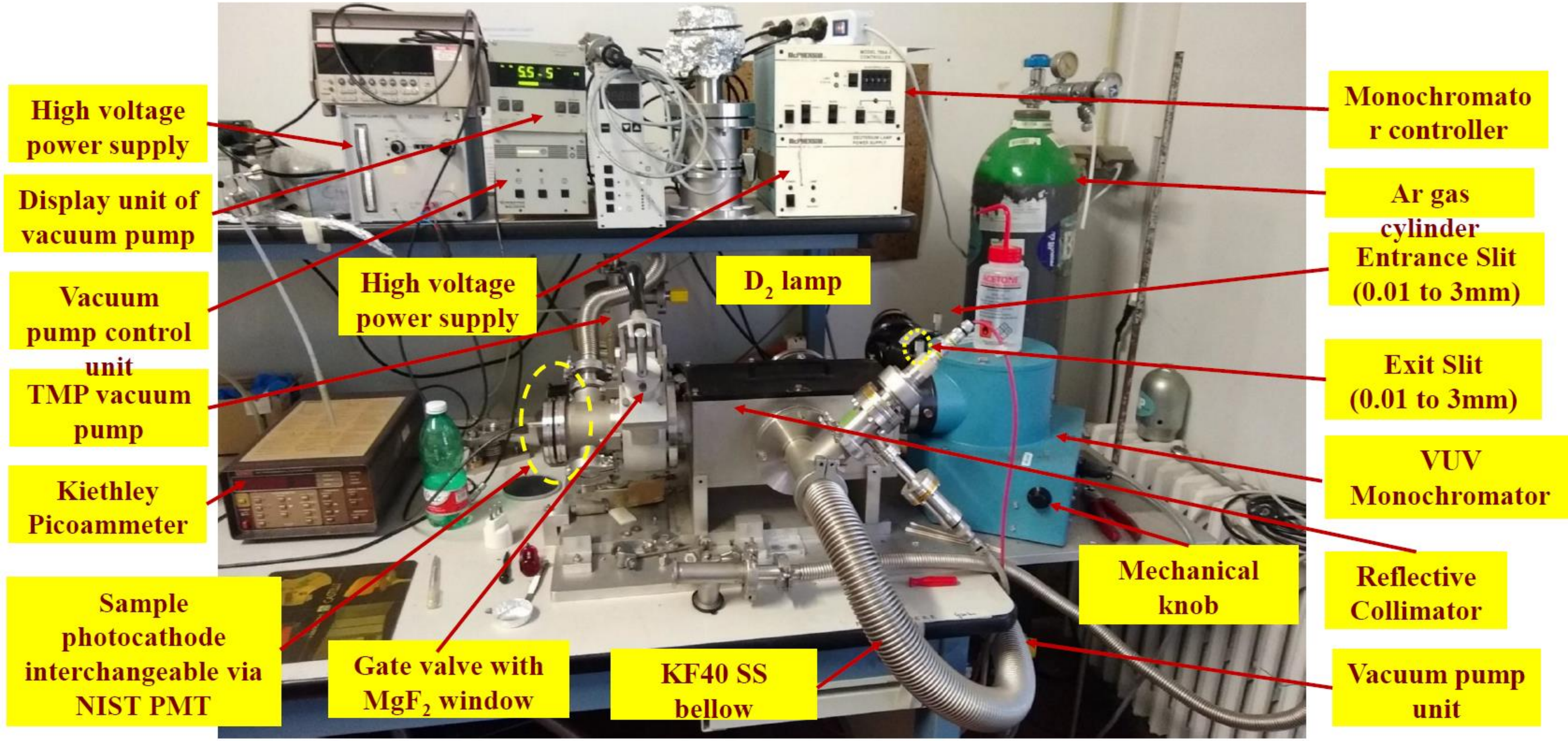
NIST Photodiode

Multiwire Proportional Chamber(MWPC)



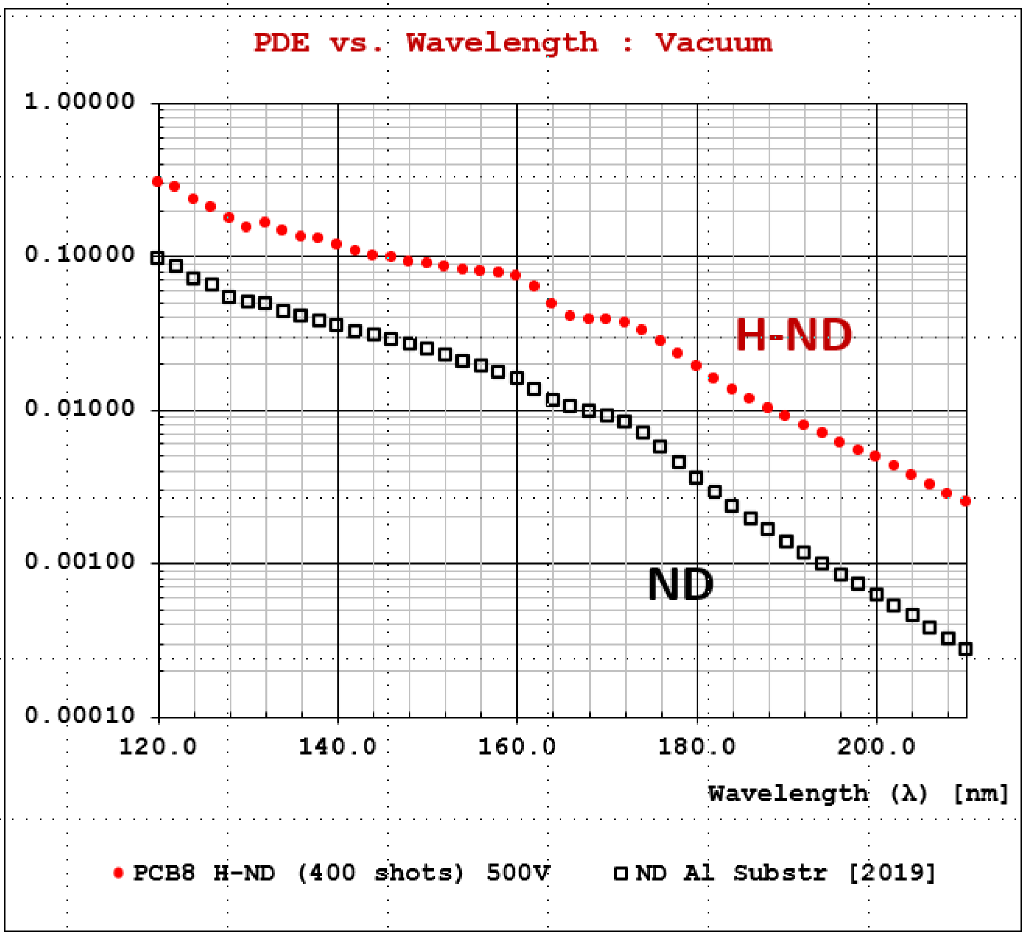


Q.E. measurement setup in Bari

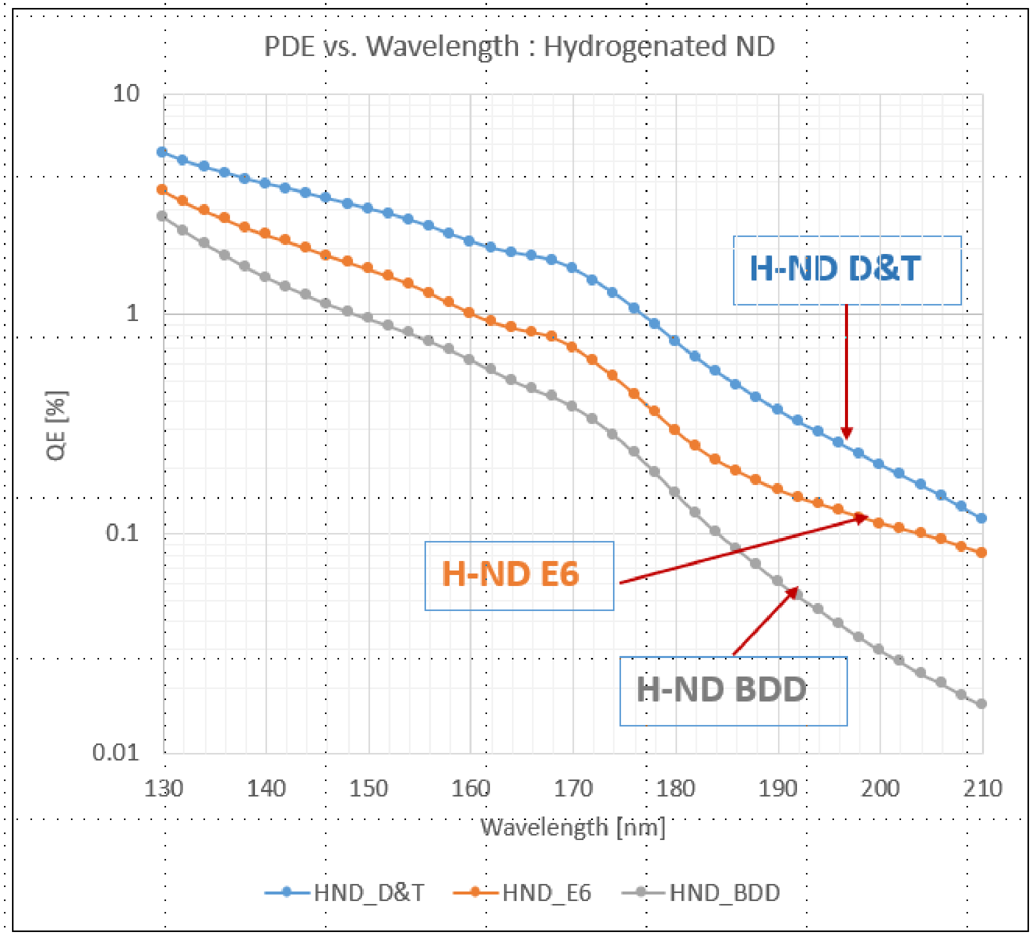


Photoemission of different NDs and H-NDs

OLD ND, H-ND [D&T]- 2019

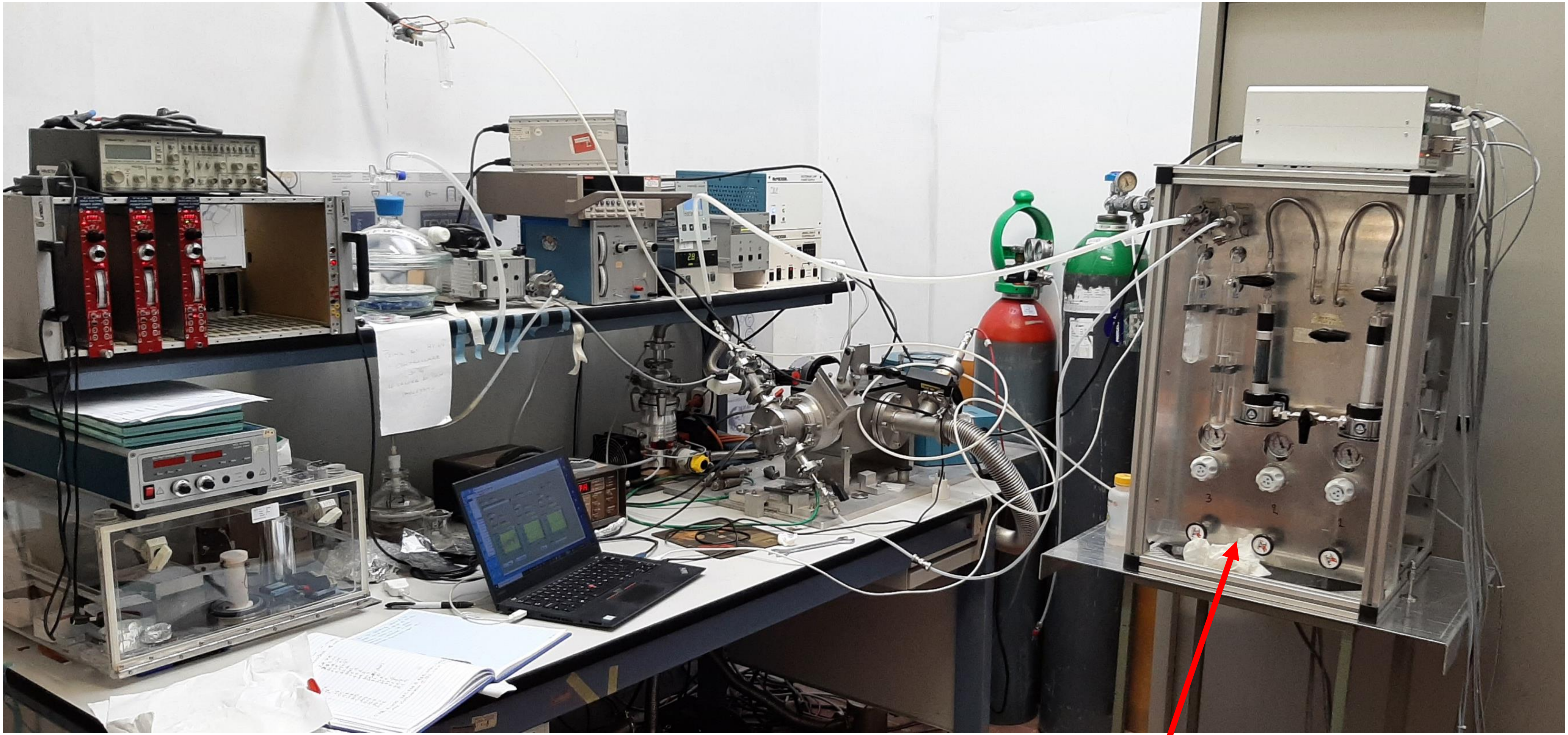


New H-ND [D&T, E6, and BDD]- 2021



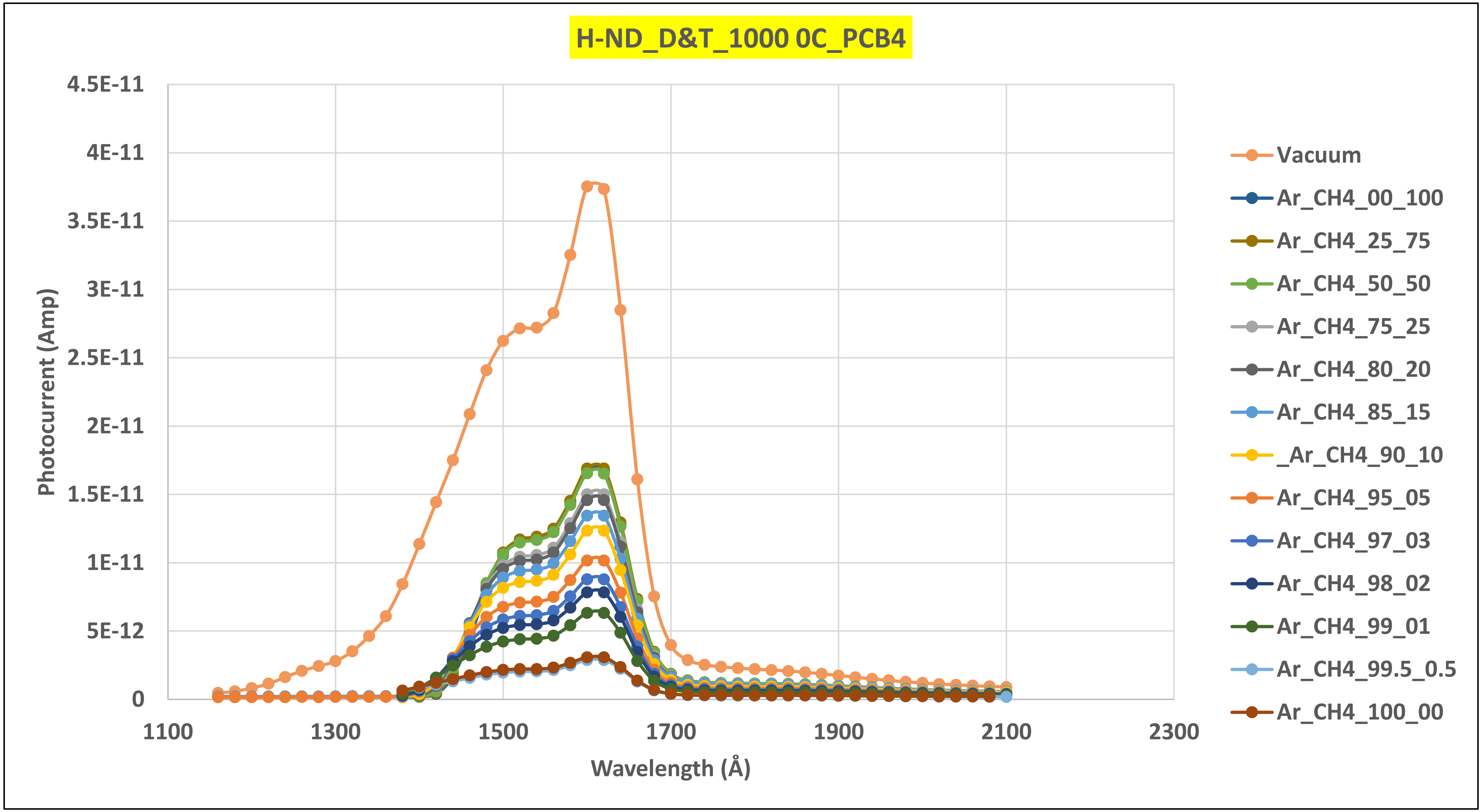
*Photocurrent values : H-ND Old/H-ND new factor ~3 for Vacuum @160 nm

Q.E. measurement setup with gas



ATEX compliant gas mixing unit

Photocurrent vs λ in Ar/CH_4 gases

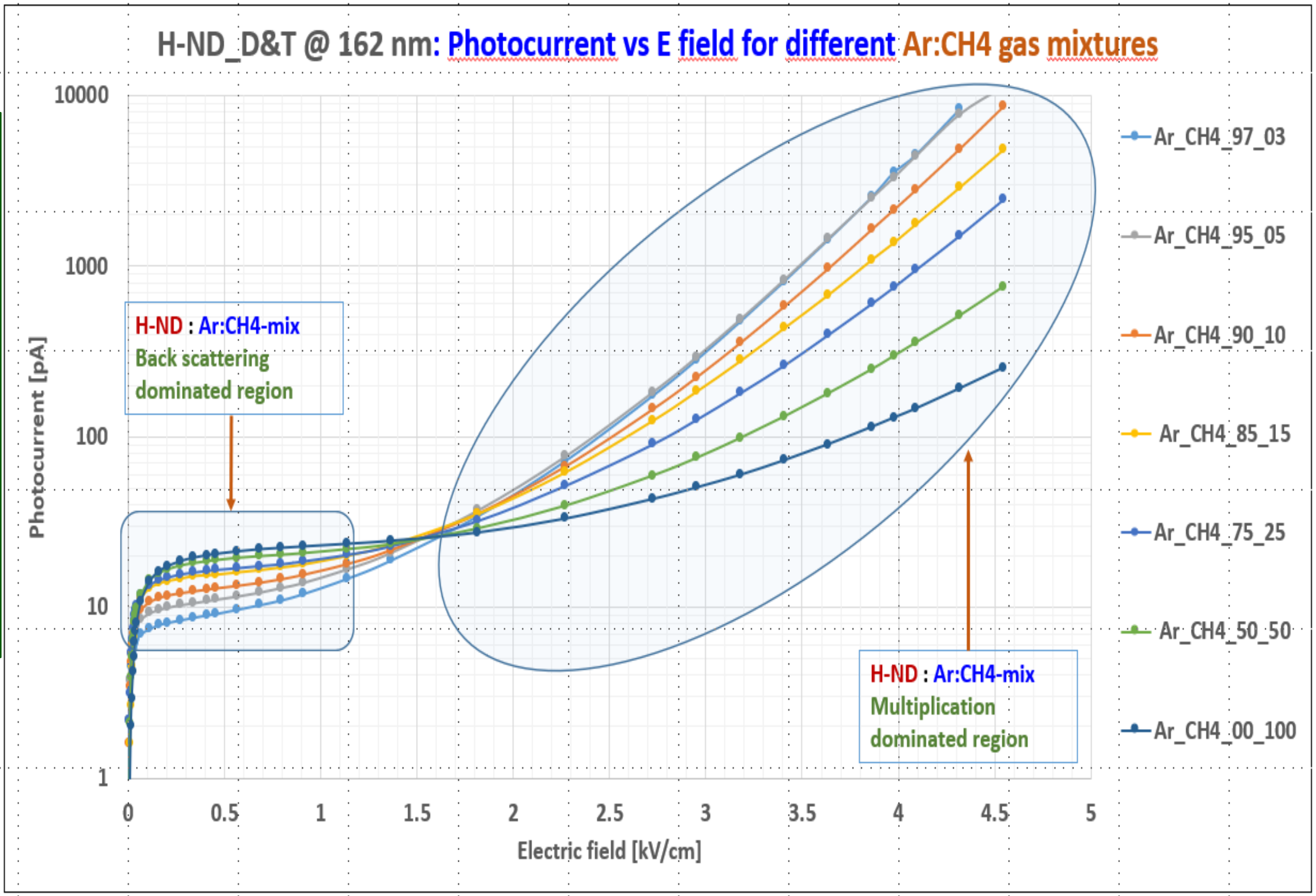


Photocurrent vs electric field

Substrate holder for photocurrent measurement

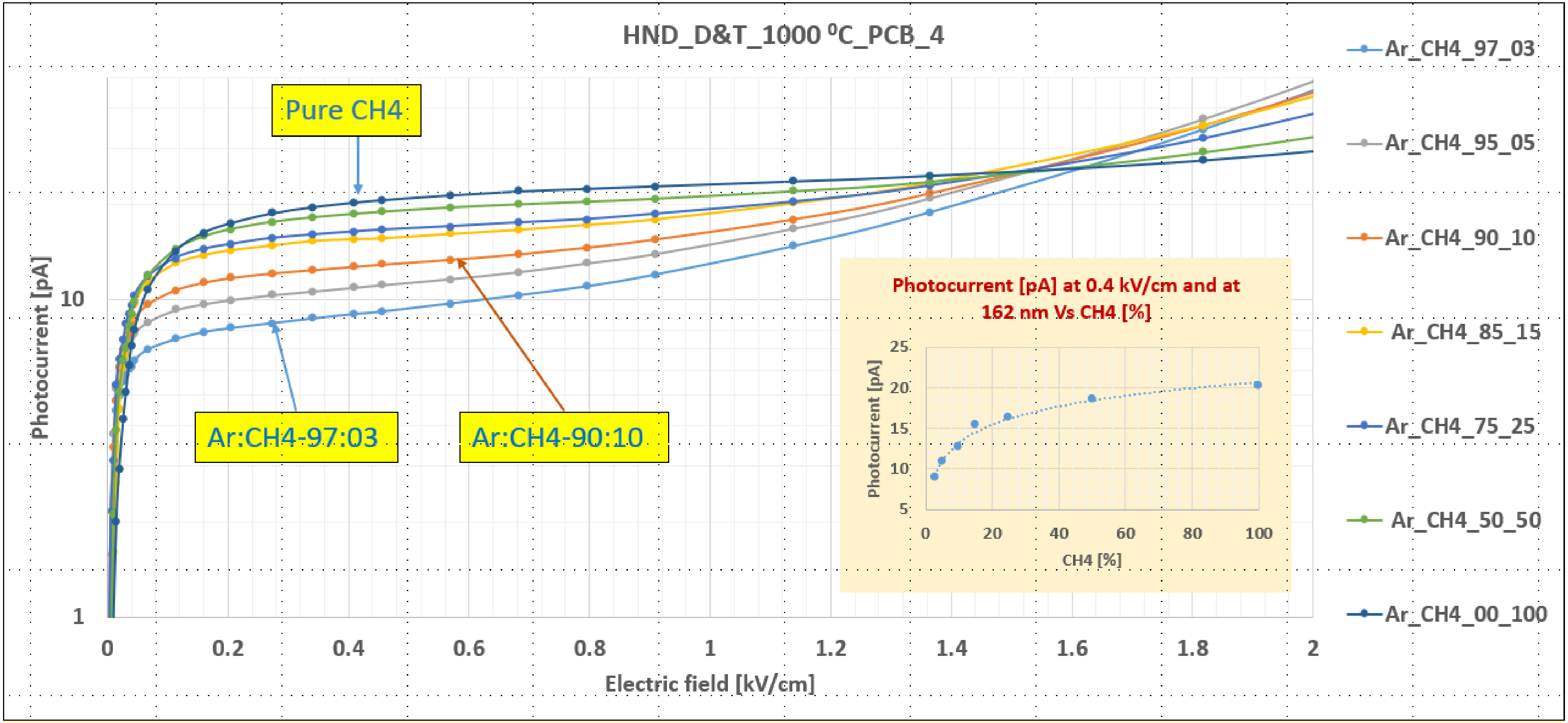
λ = 162 nm

H-ND D&T



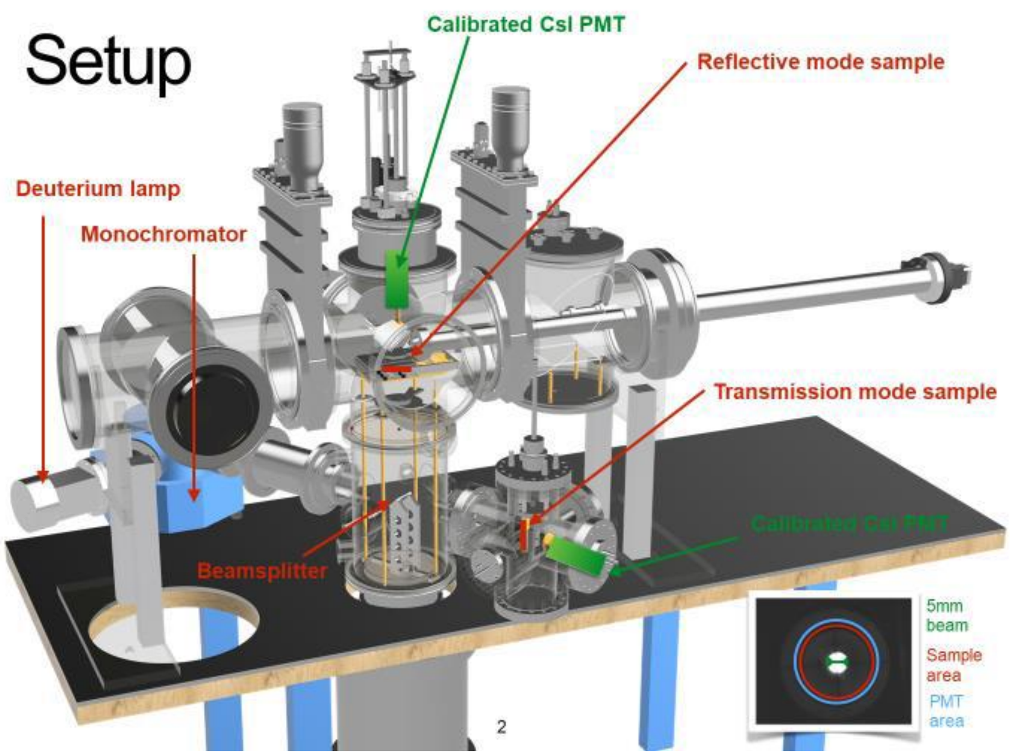
Gap between substrate and electric wire: 4.4 mm.
Scan performed with MgF2 window in vacuum and various Ar:CH_4 gas mixtures

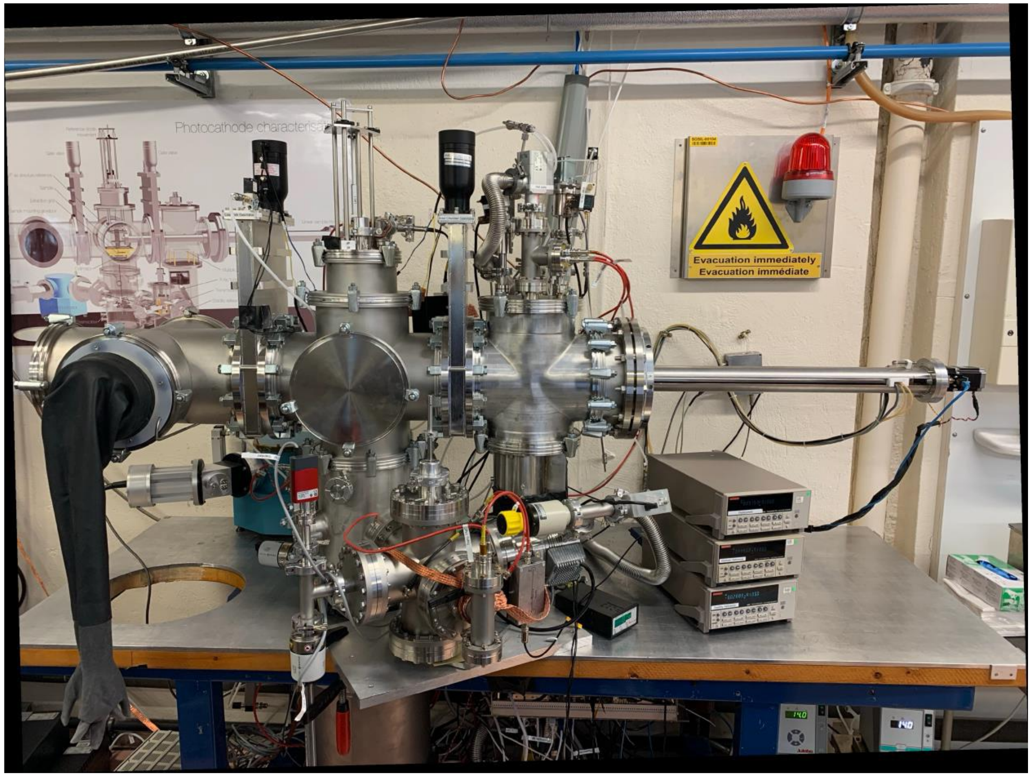
Photocurrent vs E in Ar/CH_4 gases



- ❑ 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

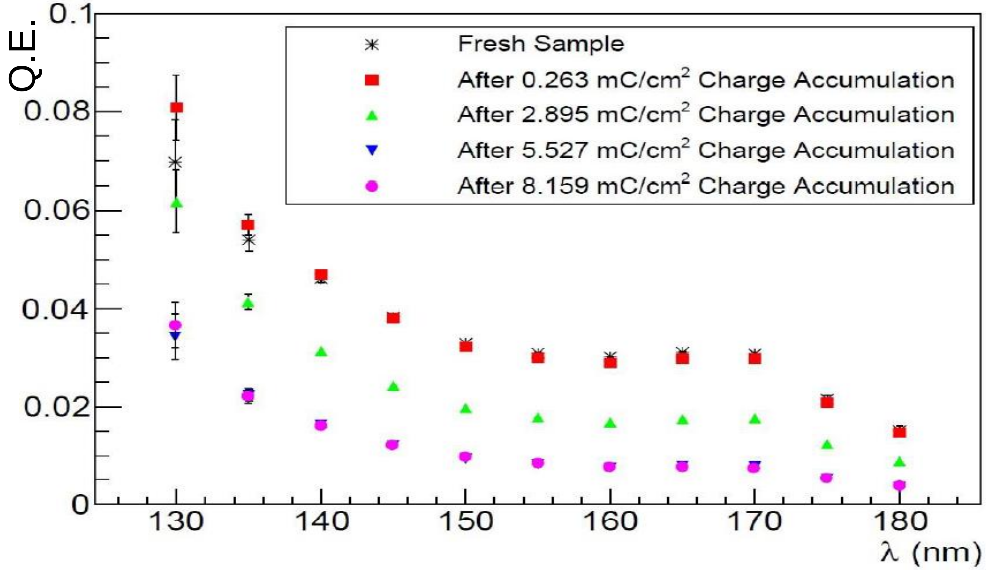
ASSET at CERN RD51 Lab

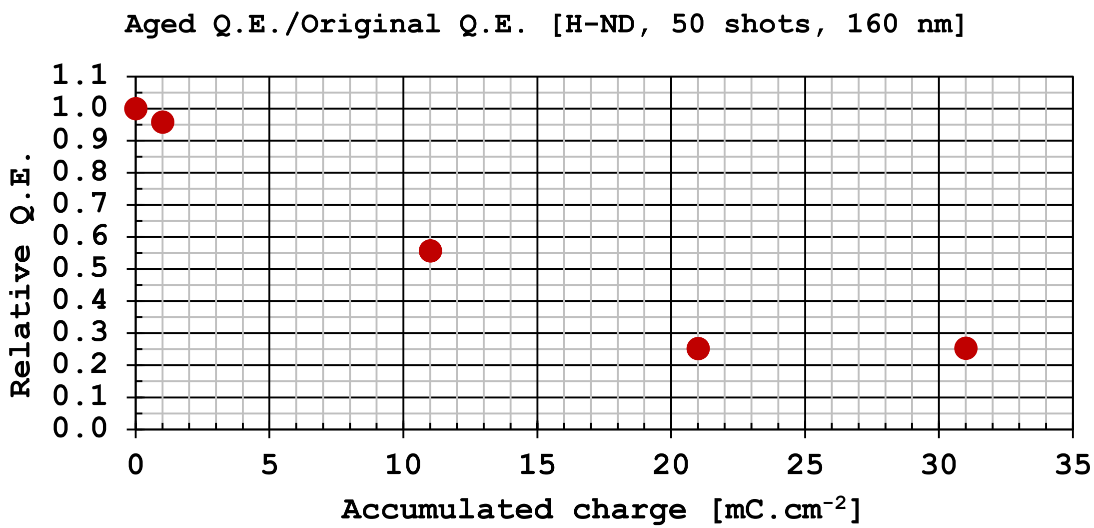




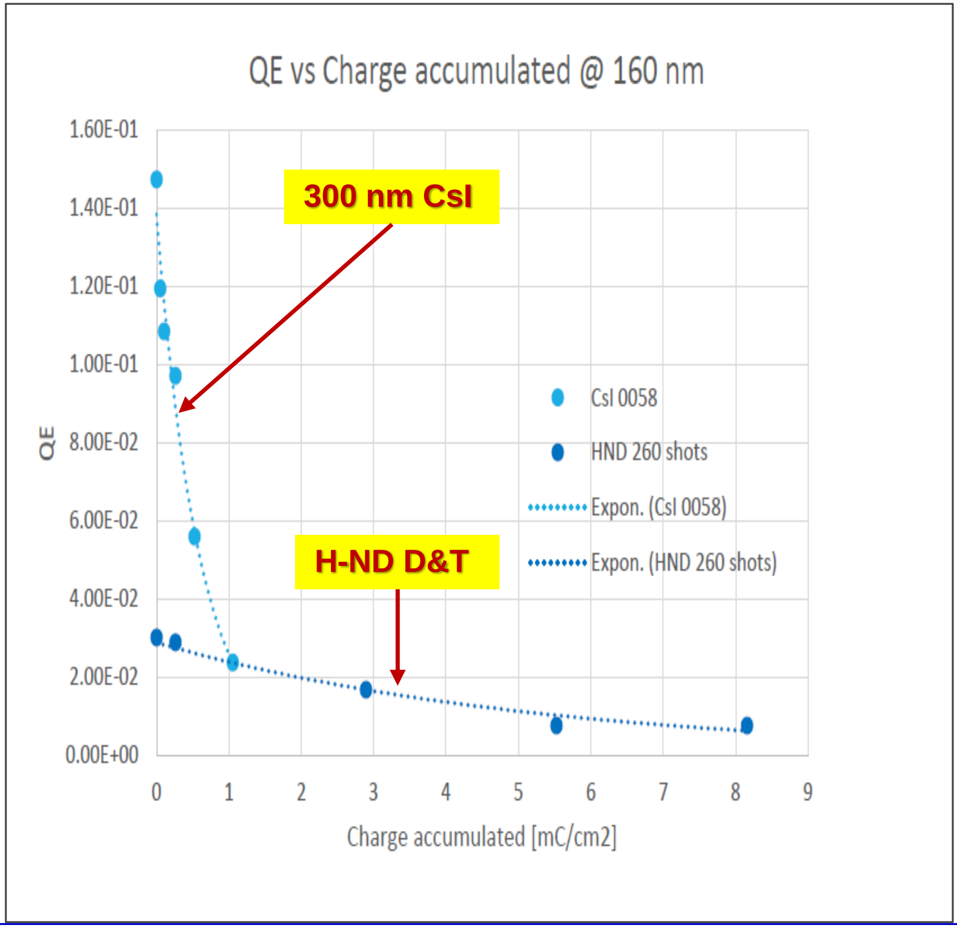
Aging tests performed thanks to the possibility to irradiate the sample inside the setup

First aging measurements





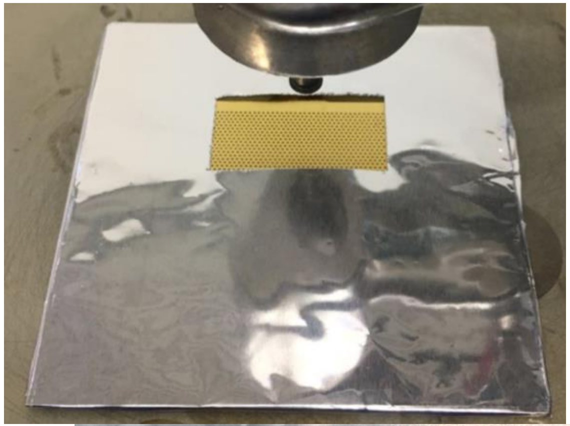
preliminary indication:
H-ND is at least ten times more robust than CsI against irradiation and ion bambardment

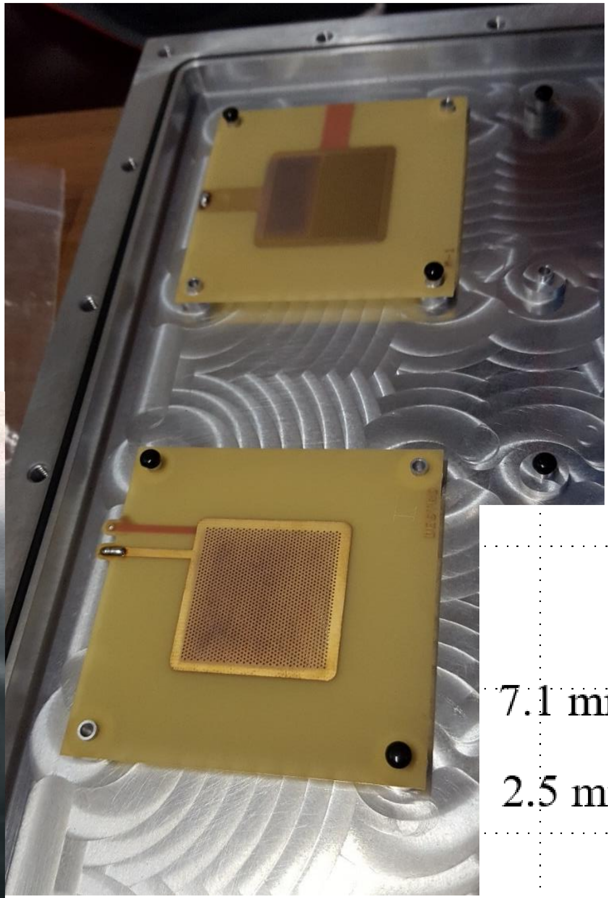


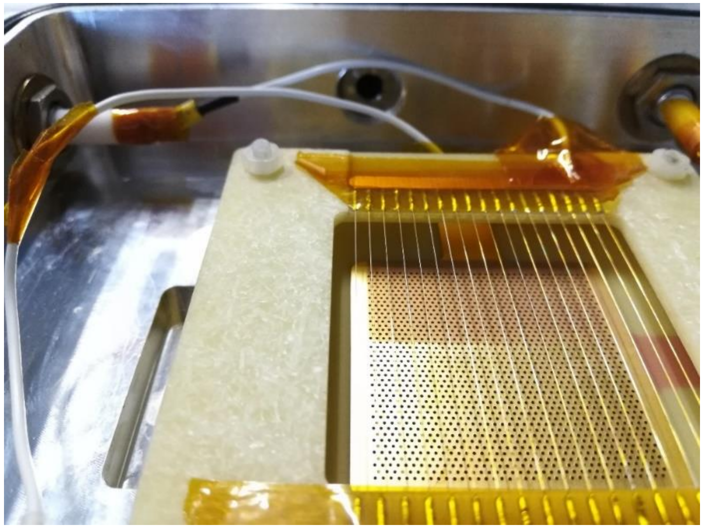
THGEMs + H-ND

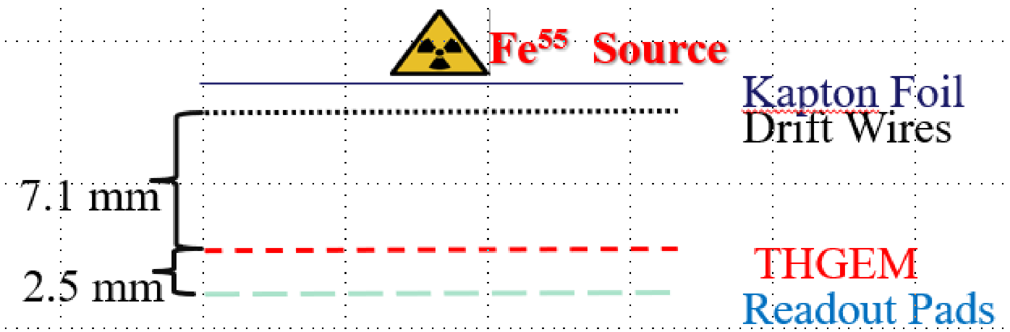
First trial of THGEM + H-ND not successful: coated THGEMs lost electrical strength.

Second trial: both full and half-coated THGEMs







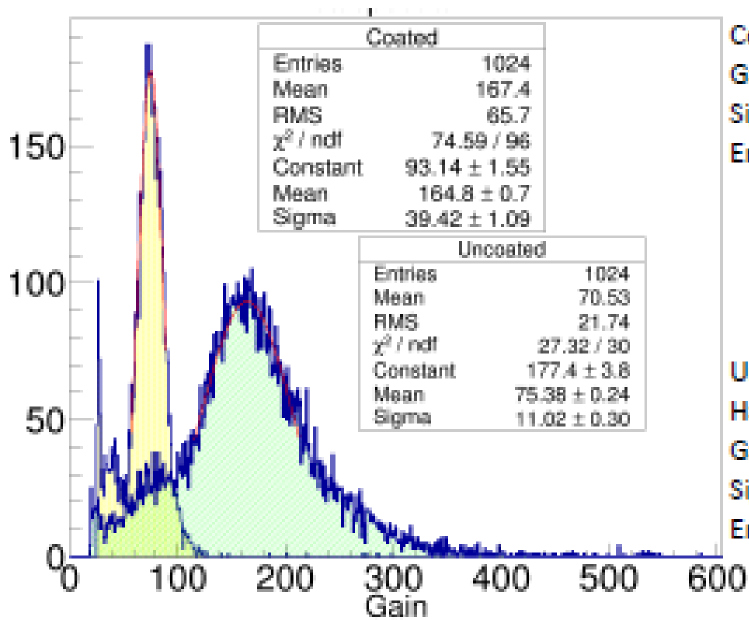


Schematic Diagram of the Chamber

THGEMs H-ND

First results were puzzling:

J. Agarwala, et al.
Nuclear Inst. and Methods in Physics Research, A 952 (2020) 161967



Coated Half:
Gain164.8
Sigma 39.42
En. Res. 0.24

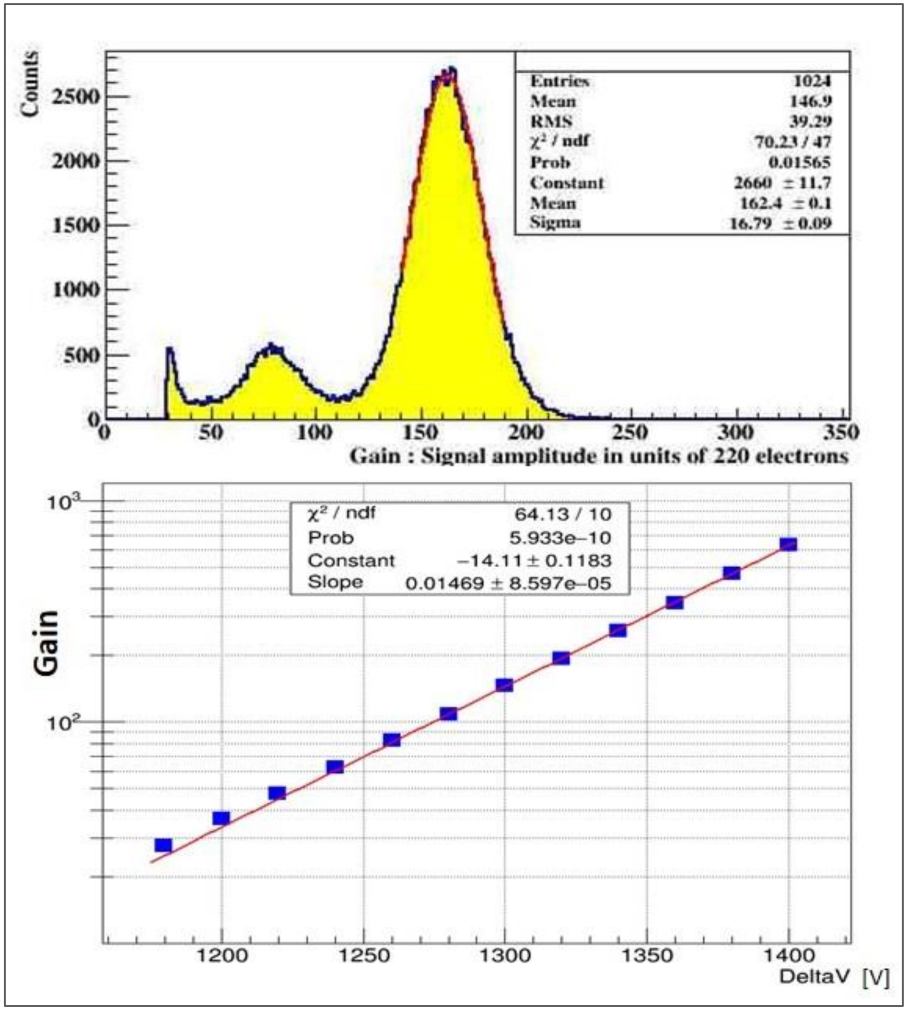
Uncoated Half:
Gain 75.48
Sigma 11.12
En. Res. 0.15

Figure 4: Gain behavior of THGEM with 20 μm rim, half-coated with nanodiamond. It is clearly shown that the gain in the coated part is almost two times higher than that in the the uncoated part.

Systematic studies: 15 THGEM samples characterized

THGEM characterization

Full characterization including charging up measurements before and after H-ND coating



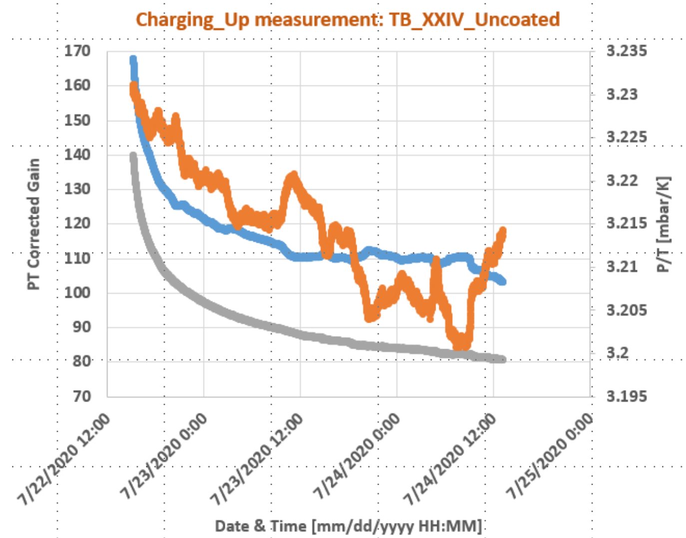
Voltage Applied:
Drift = 2250 V
T_top = 1750 V
T_bot = 500 V
Anode = 0 V

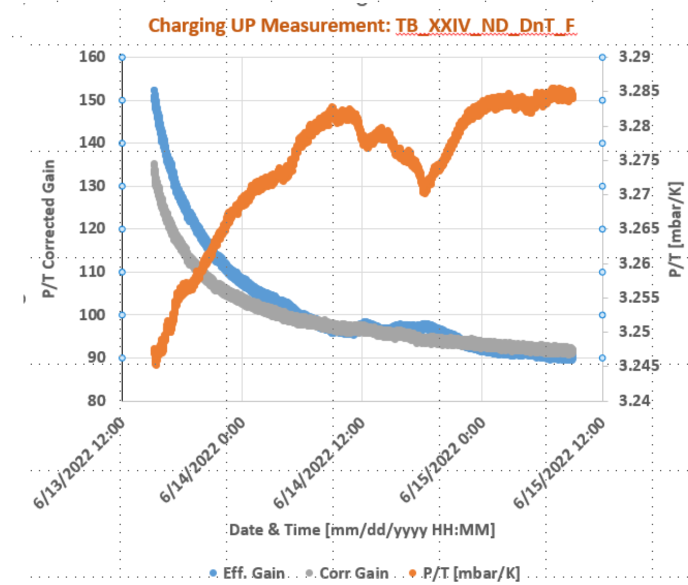
Gas Mixture:
Ar = 70 %
CO_2 = 30 %
@ 10 l/h flow rate

X-ray Source:
Fe-55

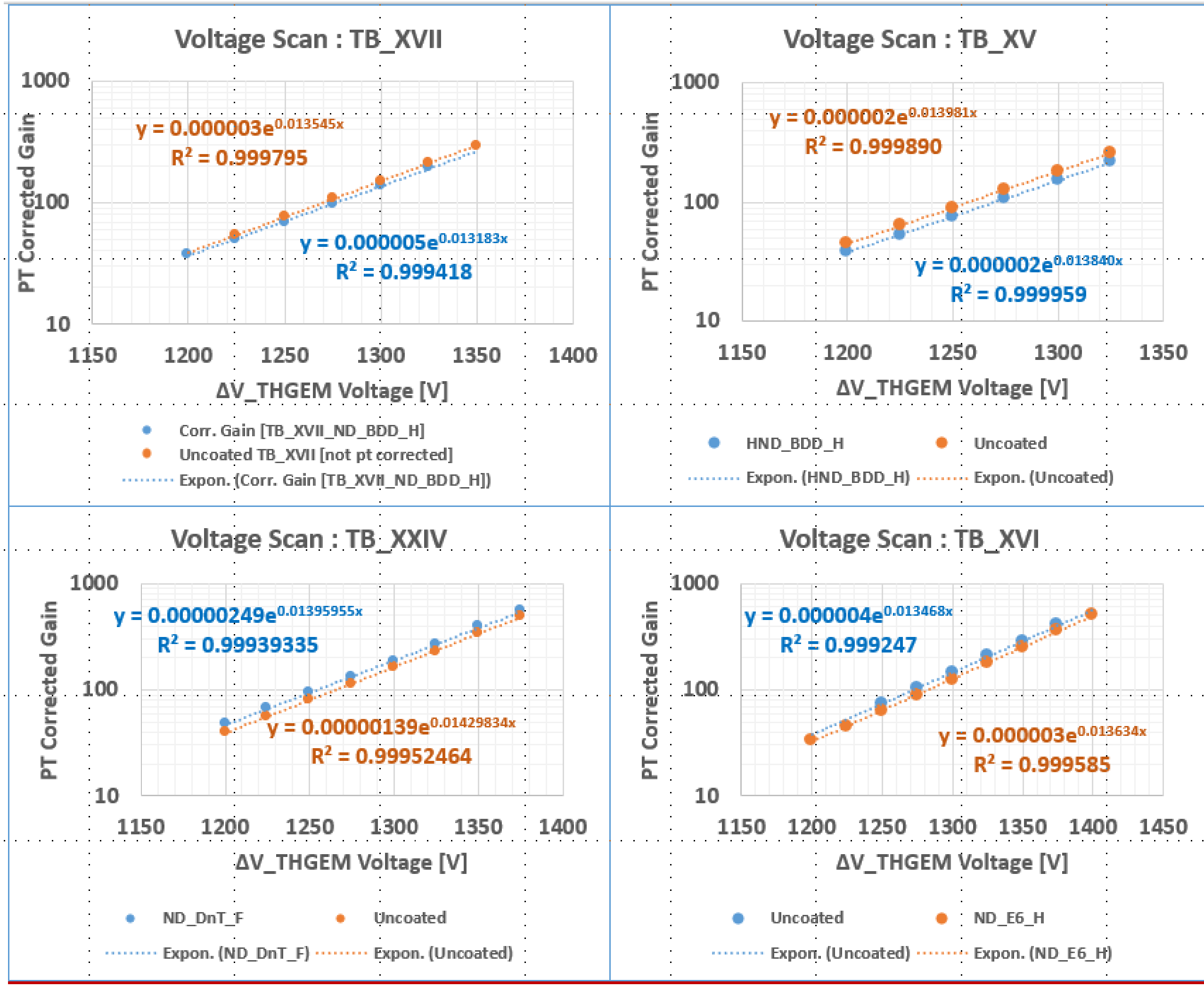
THGEM active area:
30 mm x 30 mm

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





THGEMs are H-ND compatible



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 H-ND coating

CONCLUSIONS

- Exploratory investigation on H-ND photocathodes
  - Promising values of Q.E. in the far UV but no clear reproducibility.
  - High robustness against moisture, light irradiation, ion bombardment
- Perspective of coupling H-ND with THGEM-based PDs
  - Full compatibility (same electron multiplication response if correctly coated)
  - Systematic study for gas, HV config. and detector geometry started
- Potentially interesting for windowless gaseous PDs, Picosec, fire detection, …