Nanodiamond photocathode for MPGD-based single photon detectors at future EIC

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1. EIC: The future QCD laboratory

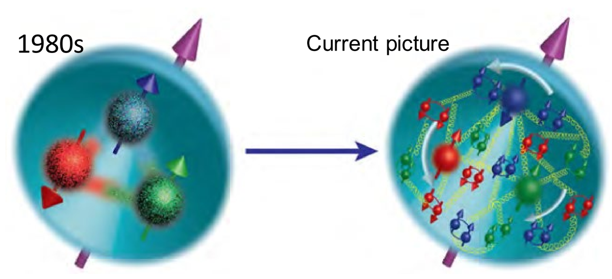
Quantum Chromodynamics (QCD) is the gauge field theory use to describe the nature of the fundamental strong interaction. Self interacting gluons contribute significantly to nuclear mass and leading to a little-explored regime of matter. An Electron ion collider (EIC) will be an ultimate laboratory to study QCD.

Examples:

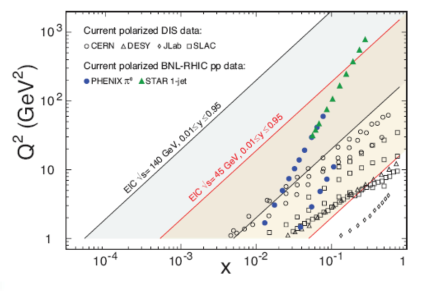
- ❑ HERA, RHIC and the LHC: gluon dominance in matter explored by electron-proton Deep Inelastic Scattering and high energy nucleon-nucleon collision. The precise study in this new regime requires an EIC facility.
- ❑ COMPASS at CERN, 12 GeV CEBAF at JLAB: studying tomographic images of valence quarks and gluons inside nucleons. EIC facility will explore sea quarks originating from gluons.

Frontier EIC environment capable to address the following questions:

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Where does the saturation of gluon densities set in?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?



Evolution of our understanding of nucleon spin structure.



Parton four momentum fraction x vs four momentum transferred by the electron to the proton Q^2. Current data and the future coverage of an EIC.

2. Hadron Identification

Semi Inclusive Deep Inelastic Scattering: one of the Physics goals of EIC, it requires efficient hadron identification, in order to study the transverse momentum dependent (TMD) quark distributions of nucleons, separation of high momentum final state hadrons (above 6-8 GeV/c) is essential. Gaseous RICH is an obvious choice.

Requirement of detecting photons in far Ultra Violet domain

- ❖ Number of produced photons per unit length is limited for reduced density of gas.
- ❖ **Increasing the radiator length recovers number of photons.** This approach is prohibitive in a collider set up.
- ❖ Frank and Tamm formula leads an alternative approach. Detecting photons in far UV (120 nm) gives more number of photons.

$$N = 2\pi L Z^2 \alpha \int_{\beta n>1} \left(1 - \left(\frac{\beta_t(\lambda)}{\beta}\right)^2\right) \frac{d\lambda}{\lambda^2}$$

- ❖ To control chromatic effect selection of defined wavelength bands is needed. Windowless photocathode directly facing the radiators are options.

Choice of CsI:

Low Electron affinity → 0.1 eV
Wide Band Gap → 6.2 eV
Typical Quantum Efficiency → 35-50% at 140 nm

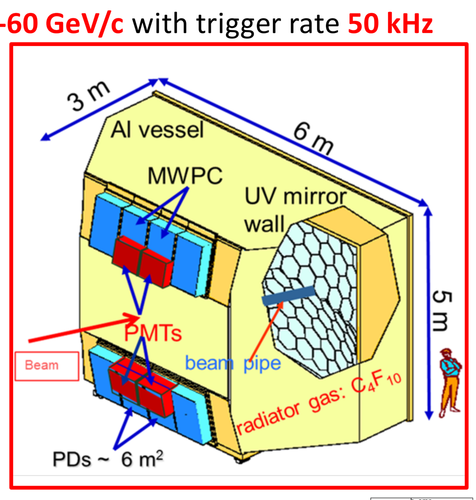
Makes CsI as mostly used photo-converter in the field of UV Photocathodes (PC).

Caveats:
CsI has hygroscopic nature→ Hydrolysis in presence of atmospheric moisture.
Decomposition under intense flux of photons and ions.
Degradation of QE of the PC.
CsI requires delicate handling! It cannot be exposed to air after coating!!

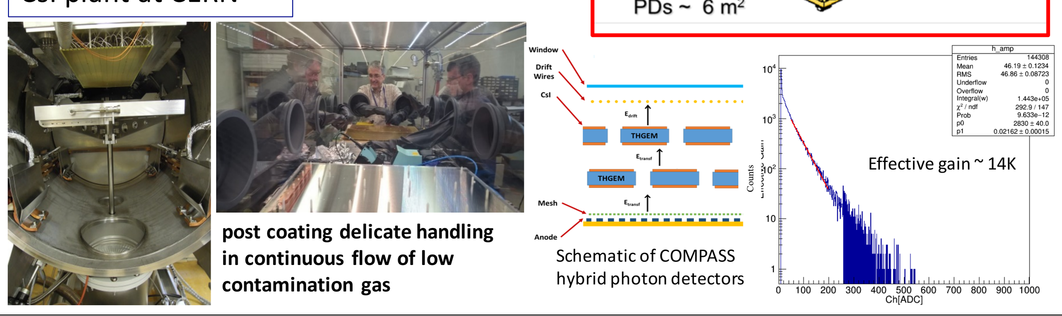
An Example: COMPASS RICH

COMPASS experiment at CERN SPS studies TMD quark distribution as one of its physics programs, it is equipped with a state of art gaseous RICH based on focusing technique with active detection area of 5.6 m² with 21 m² UV mirror wall capable of particle identification from 3-60 GeV/c with trigger rate 50 kHz and beam rate 10^8 Hz.

- ➢ 2016 Upgrade of COMPASS RICH-1:
- ➢ MPGD based Photon Detectors are in use.
- ➢ Composed of two layers of Thick GEMs (THGEM), the first THGEM is coated with CsI film acting as reflective PC, coupled to a MicroMegas(MM) on pad segmented anode.



CsI plant at CERN



post coating delicate handling in continuous flow of low contamination gas

Schematic of COMPASS hybrid photon detectors

3. Alternative Photocathode

R&D activity ongoing for the future EIC RICH foresees to use a less critical photocathode to work in the very far UV domain. Materials alternative to CsI are the highest priority to use in gaseous detectors.

Diamonds can be an alternative for the following properties:

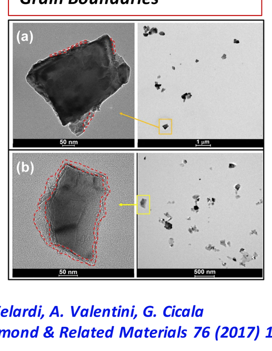
1. Band Gap of 5.5 eV
2. Low Electron Affinity 0.35-0.5 eV
3. Chemical inertness.
4. Radiation hardness.
5. Good Thermal conductivity.

Production of diamond films by MWPECVD technique at 800°C.
Peculiarity: hydrogenated surface!!

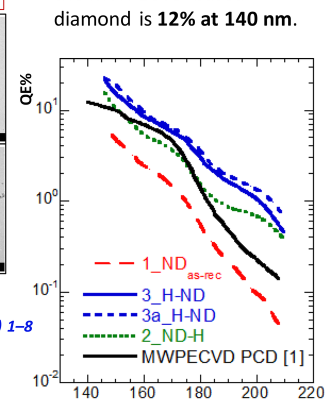
Moves down Negative Electron Affinity (N.E.A.) to -1.27 eV. A crucial parameter for electron photo and thermo emission.

Microwave Plasma Enhanced Chemical Vapor Deposited (MWPECVD) diamond films are used for thermionic current generation and for UV photocathodes, because they exhibit a better stability than CsI.

In **hatred** highlighted the ***sp²*** component present at ***the Grain Boundaries***



Maximum Q.E. achieved for the MWPECVD based diamond is **12% at 140 nm**.



Caveats for MWPECVD technique:

- ❑ High deposition temperature.
- ❑ Substrates resistant to high temperature
- ❑ Accessible to coat small area.
- ❑ Costly.

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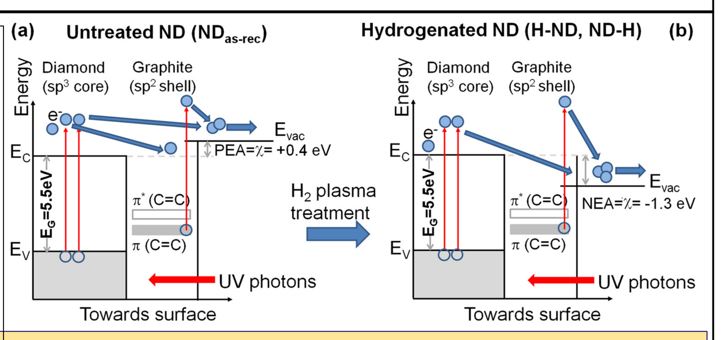
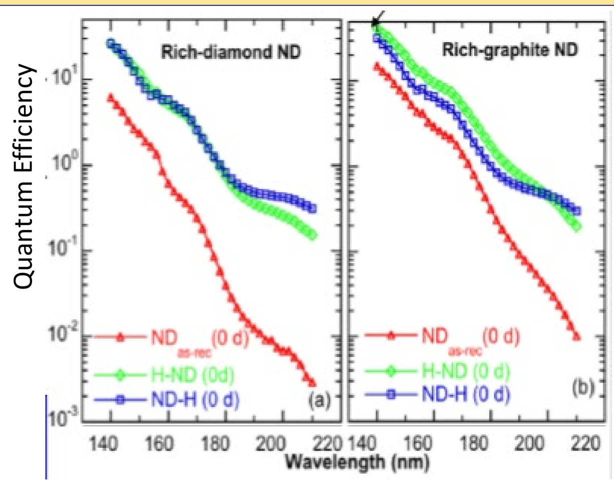
Presented by A. Valentini in Trieste, 06 December 2017

4. Hydrogenated Nanodiamond PCs

- New Technique developed in Bari, Italy to overcome the MWPECVD limitations has been set up (**international patent: Patent n. WO 2017/051318 A9 - INFN-CNR**) to deposit layers of hydrogenated nanodiamond powder.
- Powder filtering (grain size selection)
- Plasma Treatment (Hydrogenation)
- Water emulsion.
- Sprayed at T~120°C (instead of 800°C in standard technique).



Schematic representation of the photoemission process due to sp³ and sp² components for **PEA** (a) and for **NEA** (b)



Advantage of the newly developed technique:

- ❑ Higher stability upon exposure to air and to high photon and ionizing particle flux, compare to CsI PCs.
- ❑ Also, Negative Electron Affinity (NEA) of hydrogenated diamond enhances efficiency more markedly toward visible region.

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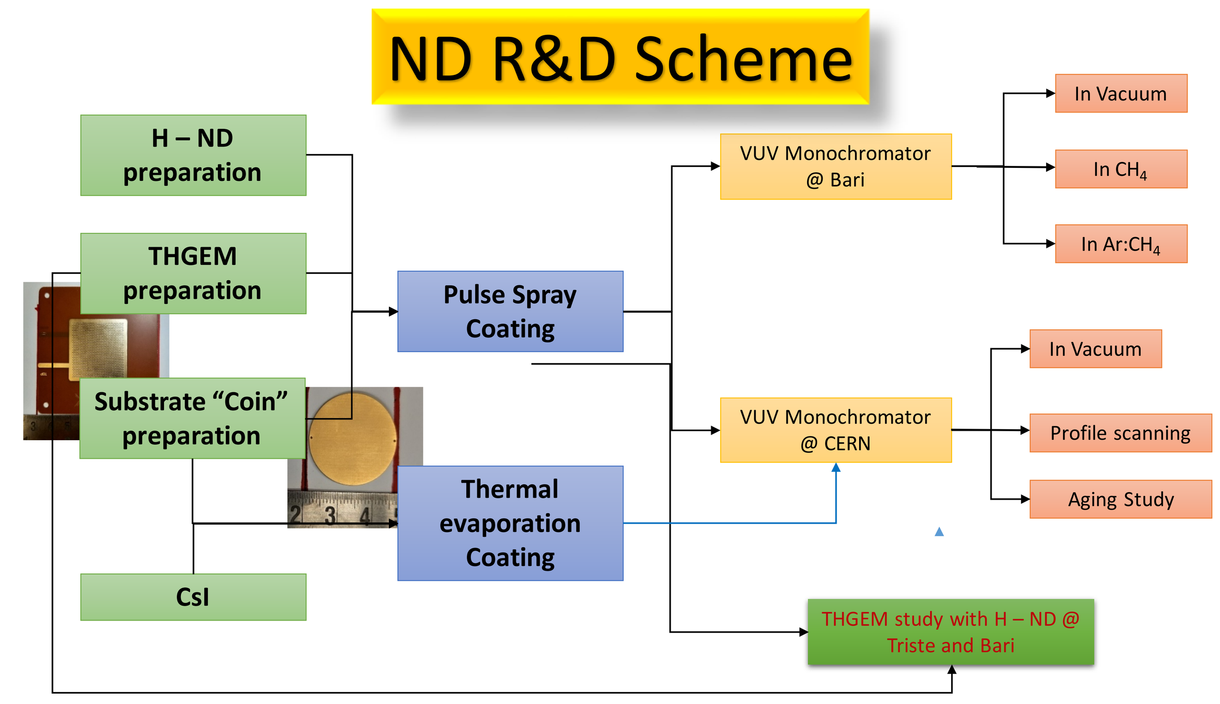
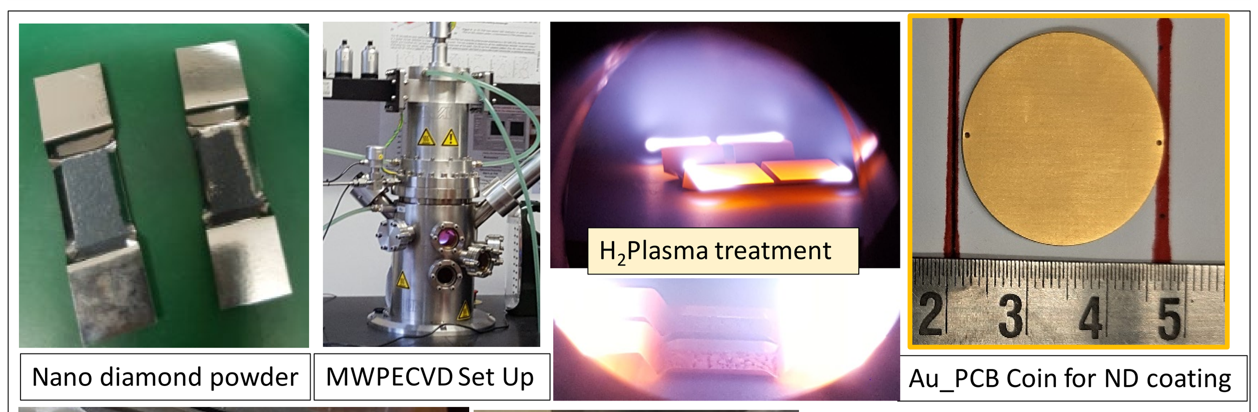
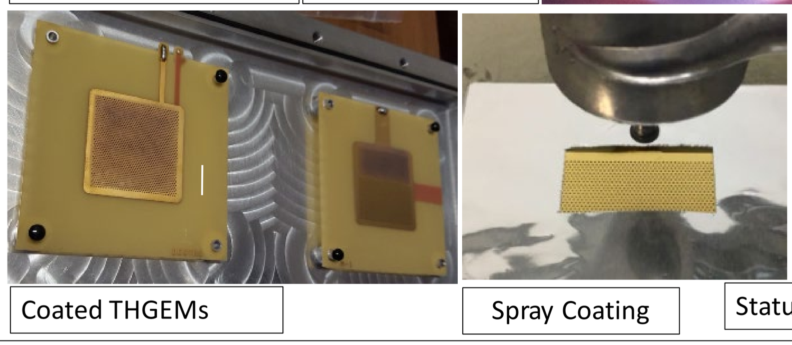
5. ND R&D Scheme @ INFN Trieste



6. ND coating in Bari



Nano diamond powder | MWPECVD Set Up | Au_PCB Coin for ND coating



Coated THGEMs | Spray Coating

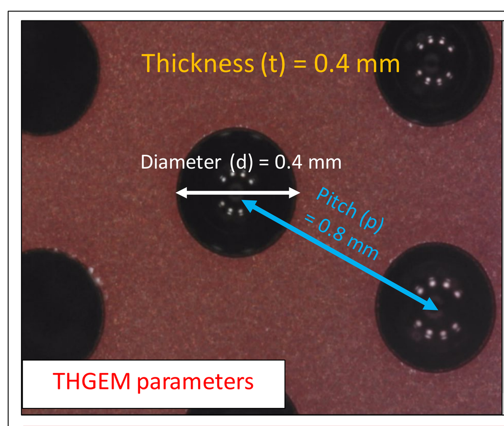
Coated THGEMs and PCB Coins:

2018:
- ❑ CsI full coating on THGEMs
- ❑ Non-hydrogenated ND half and full THGEMs
- ❑ Hydrogenated ND half and full THGEMs

2019:
- ❑ ND & H-ND coted on 14 PCB coins
- ❑ Non-hydrogenated ND full THGEMs (One)
- ❑ Hydrogenated ND full THGEMs (Five)

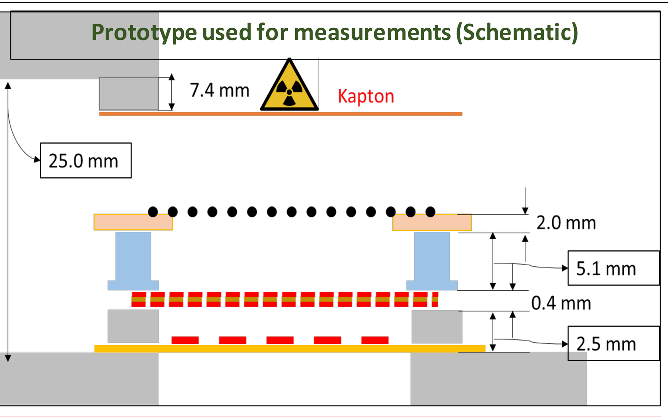
Status of Coated THGEMs and PCB Coins

7. Detector Assembly & QE Setup



THGEM parameters

Prototype used for measurements (Schematic)



- For measurements the gas mixture used is: Ar:CH₄-50:50 and Ar:CO₂-70:30 using a Bronkhorst HIGH-TECH mass flow meters
- 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.

VUV monochromator for the QE measurement at INFN Bari (left panel) and ASSET at RD-51 lab CERN (Right panel)

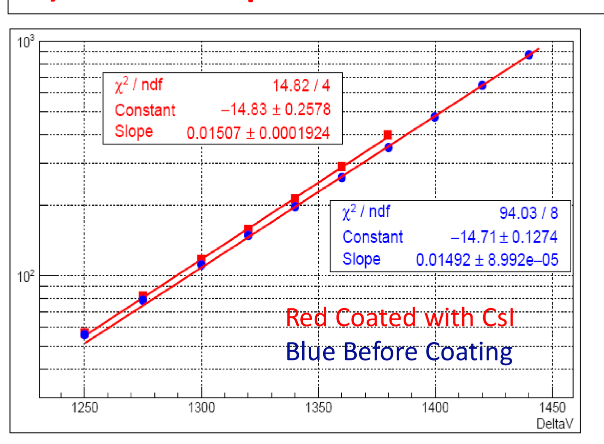
BARI: (H-)ND photocathodes can be produced, mature setup for absolute QE measurement

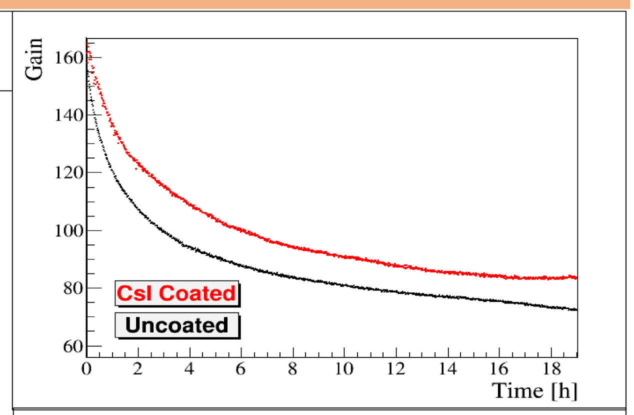
CERN: flexible setup where measurements like radiation damage profile scanning are possible

8. Effect of the Coating

Post coating characterization→ Same voltage configuration as before coating. Same setup → One to One comparison.

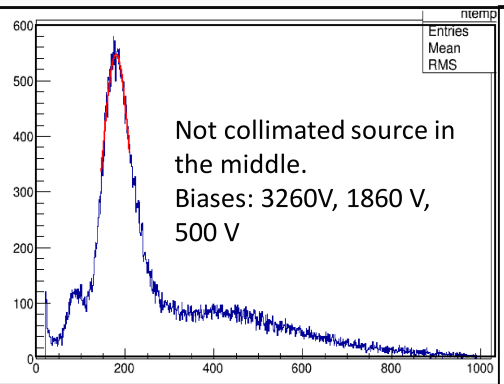
1) CsI: 10 µm rim ID2

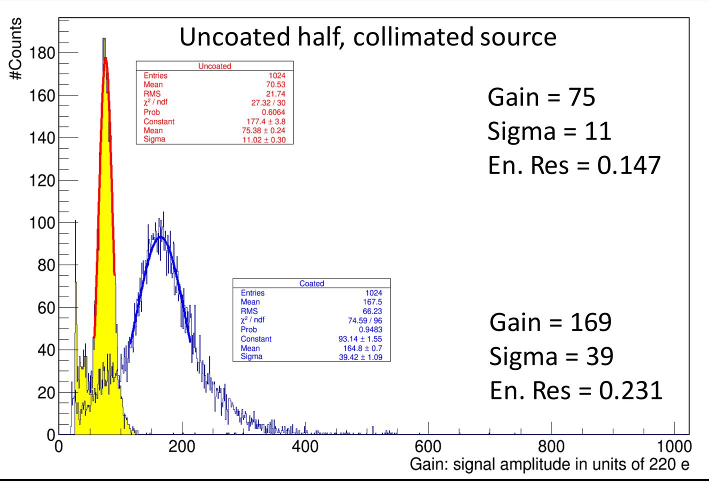




The responses of the THGEM before and after CsI coating are similar

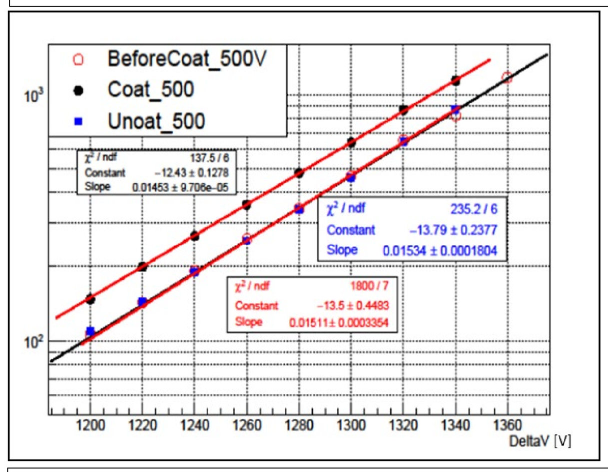
2) ND: 20 µm rim ID2 half coated (Non hydrogenated)

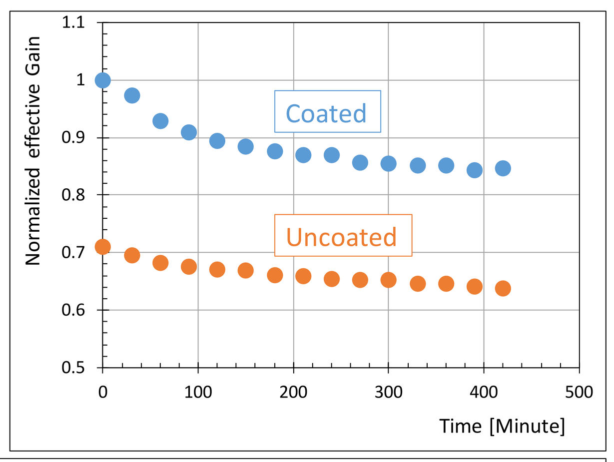


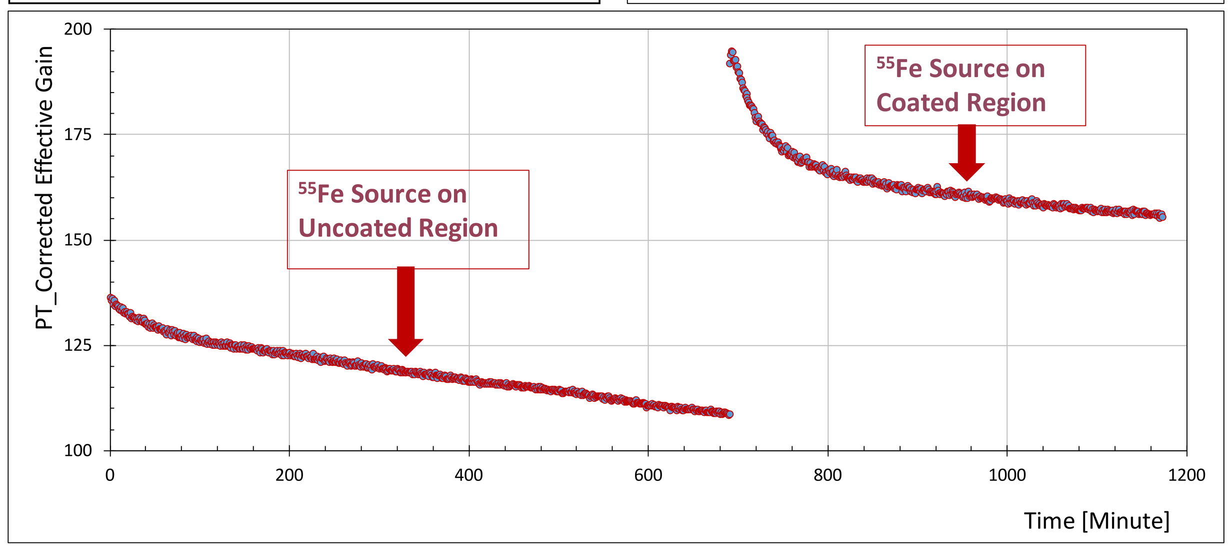


2.5 times larger amplification for the coated part.

3) ND: 0 µm rim ID2 half coated (Non hydrogenated)

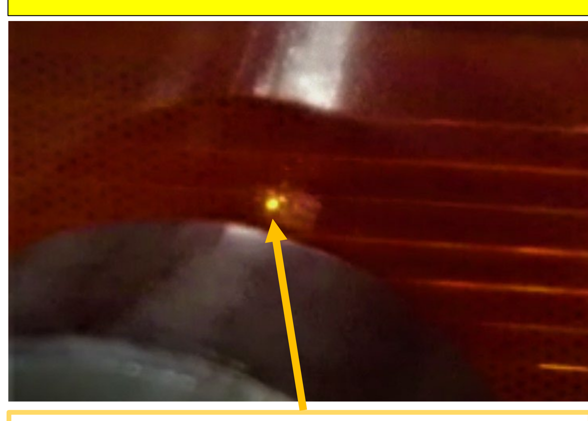






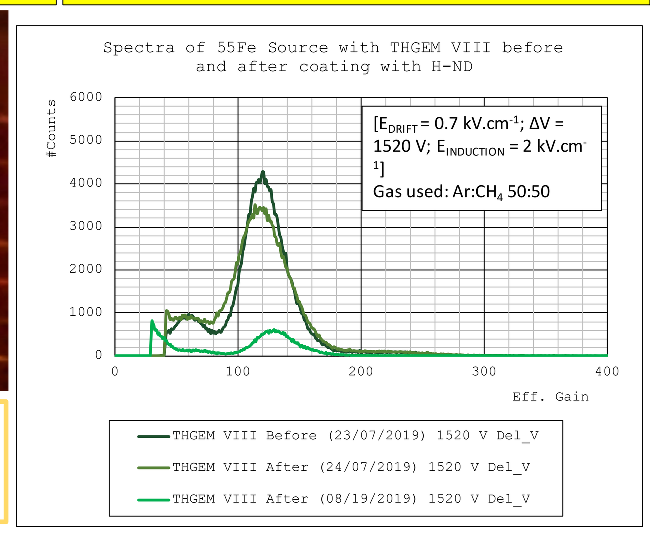
About 30% larger amplification for the coated part.

4) H-ND: Coated THGEMs — Before heat treatment

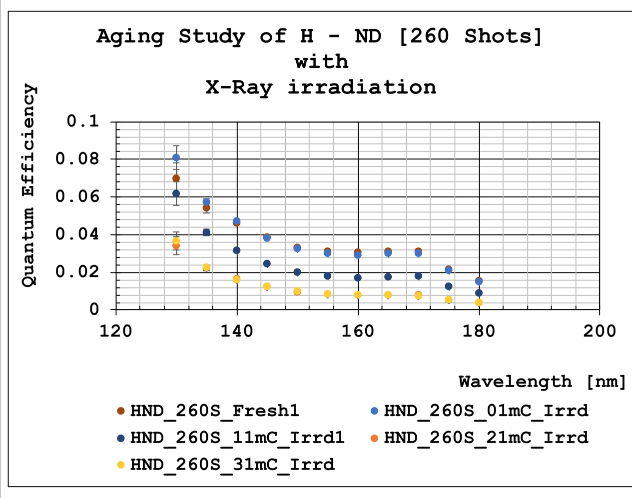


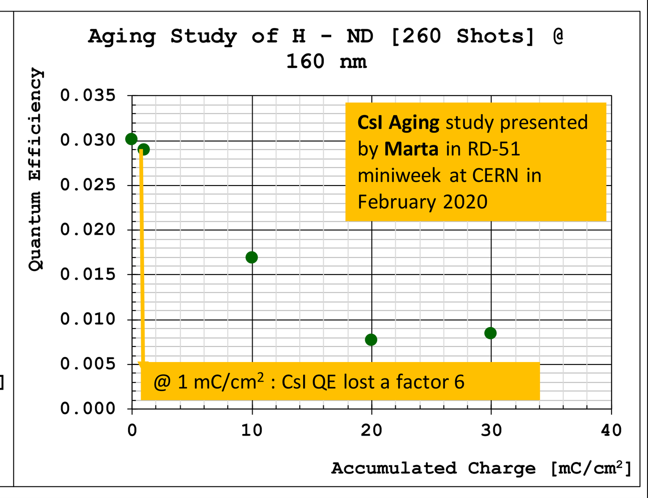
Fully coated with hydrogenated Nano Diamond.
After coating it did not stand voltage (sparks).

5) H-ND: Coated THGEMs — After heat treatment



9. Aging study with X-Ray irradiation





10. 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.
- ❑ Aging studies has been started.
- ❑ Preliminary results of QE shows that, H-ND photocathodes are quite stable in comparison with CsI
- ❑ 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.
- ❑ THGEMs, coated with non hydrogenated Nano Diamond show an increase of effective gain response with respect to the uncoated.
- ❑ The increase in effective gain is different for THGEMs with different rim size.
- ❑ Coated THGEMs show a decrease in electrical stability, in particular, for the hydrogenated Nano Diamonds case.
- ❑ Coated THGEM perform nicely thanks to heat treatment.
- ❑ Hydrogented Nano Diamond is a potential candidate as CsI substitute after overcoming the observed challenges.

Acknowledgement: We are very much thankful to RD-51 lab at CERN for the QE measurement and aging study of ND using ASSET system