Novel Nano-Diamond based photocathodes for gaseous detectors

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on behalf of Bari and Trieste INFN-EIC Group
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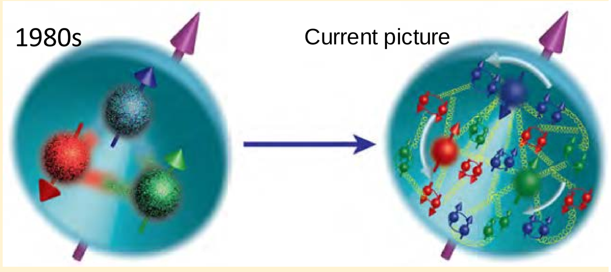
1. EIC: The future QCD laboratory

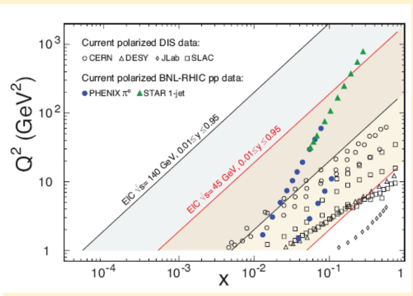
Quantum Chromodynamics (QCD) is the gauge field theory use to describe the nature of the fundamental strong interaction. Self interacting gluons contribute significantly to nuclear mass and leading to a little-explored regime of matter. An Electron ion collider (EIC) will be an ultimate laboratory to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

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

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

Choice of CsI:

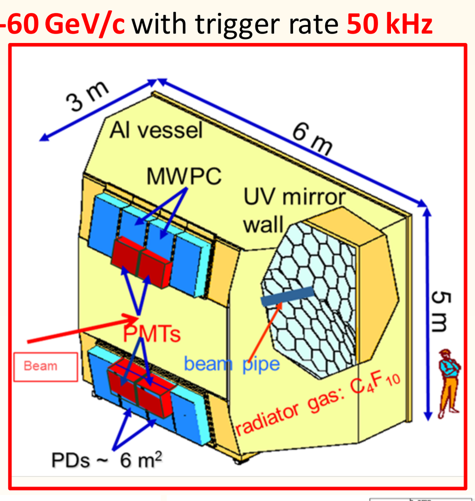
Low Electron affinity → 0.1 eV
Wide Band Gap → 6.2 eV
Typical Quantum Efficiency → 35-50% at 140 nm
Makes CsI as mostly used photo-converter in the field of UV Photocathodes (PC) .

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!!

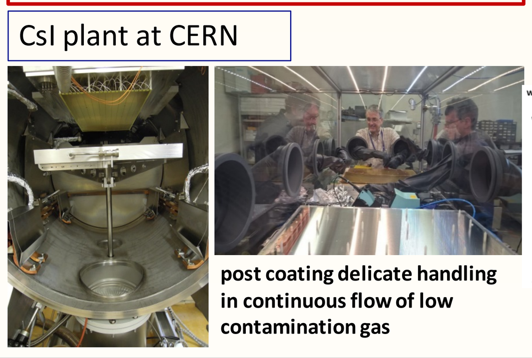
An Example: COMPASS RICH

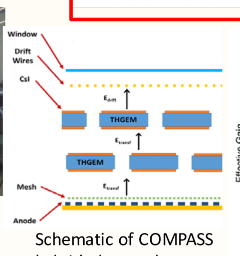
COMPASS experiment at CERN SPS studies TMD quark distribution as one of its physics programs, it is equipped with a state of art gaseous RICH based on focusing technique with active detection area of 5.6 m² with 21 m² UV mirror wall capable of particle identification from 3-60 GeV/c with trigger rate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

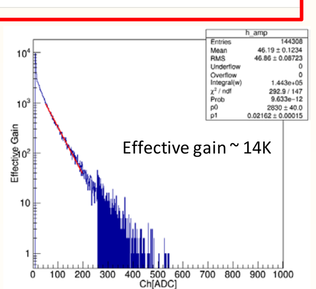
- ➢ 2016 Upgrade of COMPASS RICH-1:
- ➢ MPGD based Photon Detectors are in use.
- ➢ Composed of two layers of Thick GEMs (THGEM), the first THGEM is coated with CsI film acting as reflective PC, coupled to a MicroMegas(MM) on pad segmented anode.



CsI plant at CERN


post coating delicate handling in continuous flow of low contamination gas


Schematic of COMPASS hybrid photon detectors



3. Alternative Photocathode

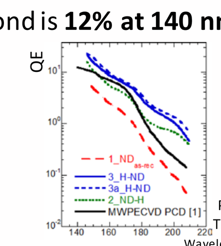
R&D activity ongoing for the future EIC RICH foresees to use a less critical photocathode to work in the very far UV domain. Materials alternative to CsI are the highest priority to use in gaseous detectors.

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.

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.

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

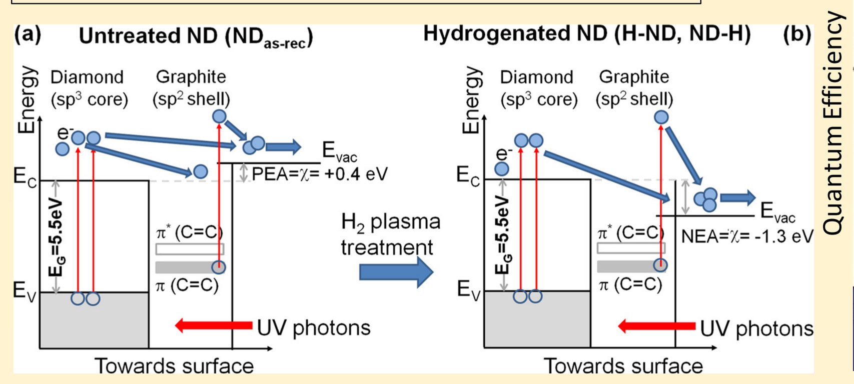
Caveats for MWPECVD technique:
- ❑ High deposition temperature.
- ❑ Substrates resistant to high temperature
- ❑ Accessible to coat small area.
- ❑ Costly.


Presented by A. Valentini Trieste, 06 December 2017

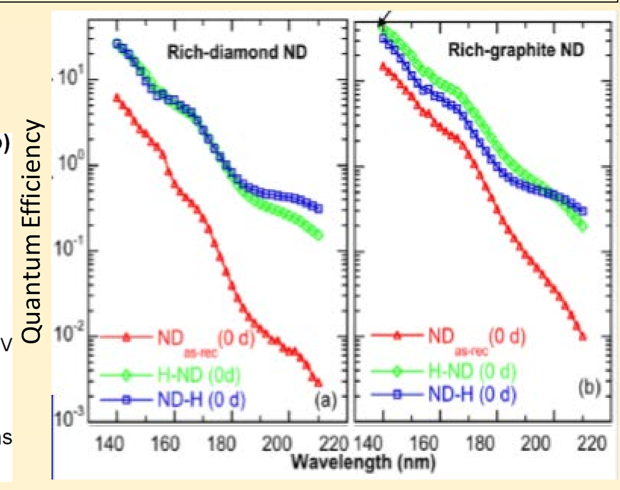
4. Hydrogenated Nanodiamond PCs

- **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).

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.



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



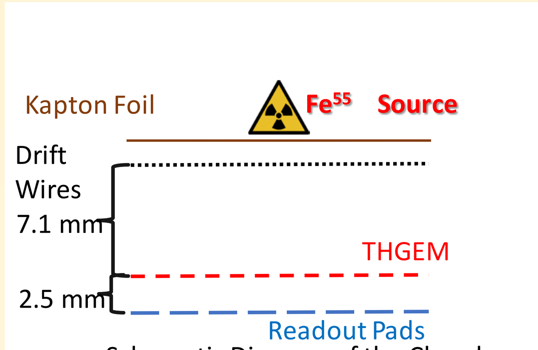
Ref: L. Velardi, A. Valentini, G. Cicala Diamond & Related Materials 76 (2017) 1–8

5. Characterization of THGEMs Before Coating

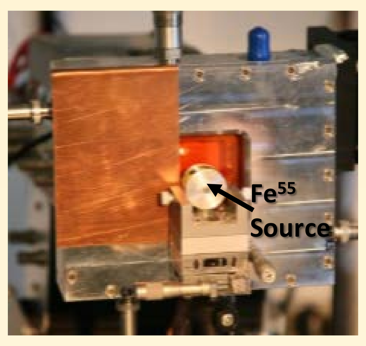
THGEMs are Gas Electron Multiplier with RIGID dielectrics in between the electrodes. With dense pattern of holes.

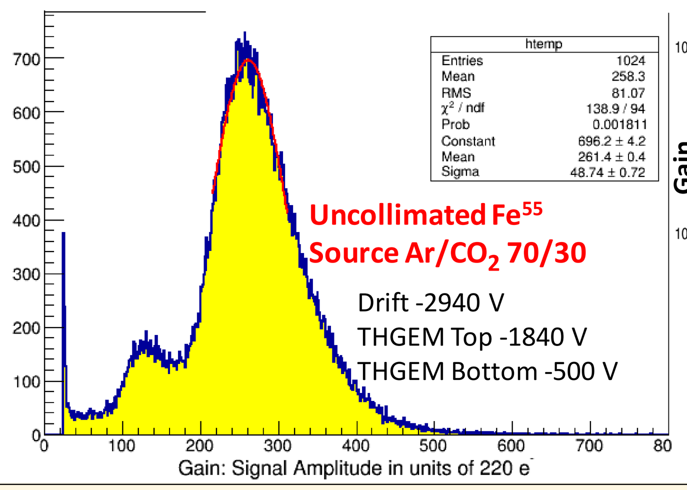
We characterized 5 standard PCB THGEMs of active area 30X30 mm²

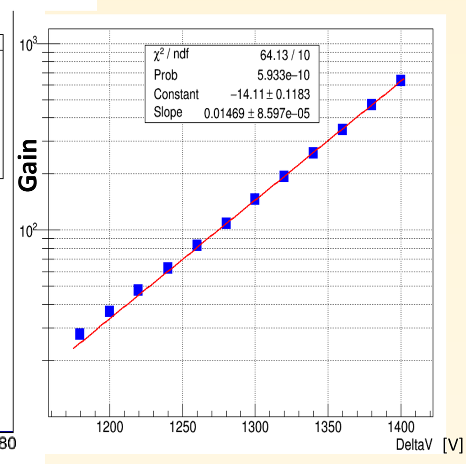
THGEMs:
1) 0 µm rim ID1
2) 0 µm rim ID2
3) 10µm rim ID1
4) 10µm rim ID2
5) 20µm rim ID1



Schematic Diagram of the Chamber

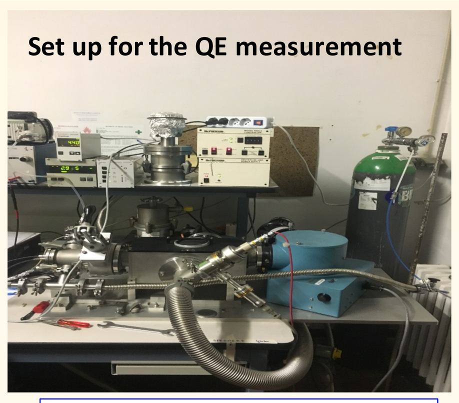




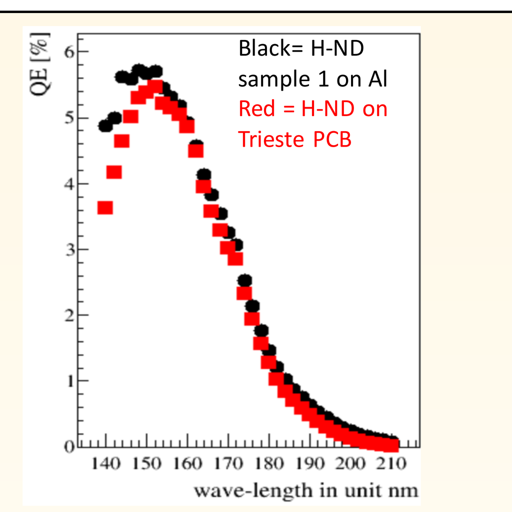


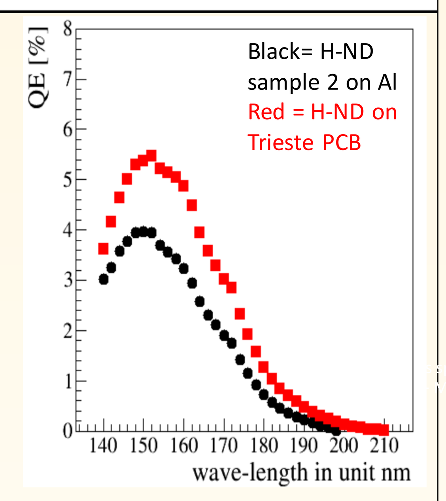
6. Measurement of QE in Bari

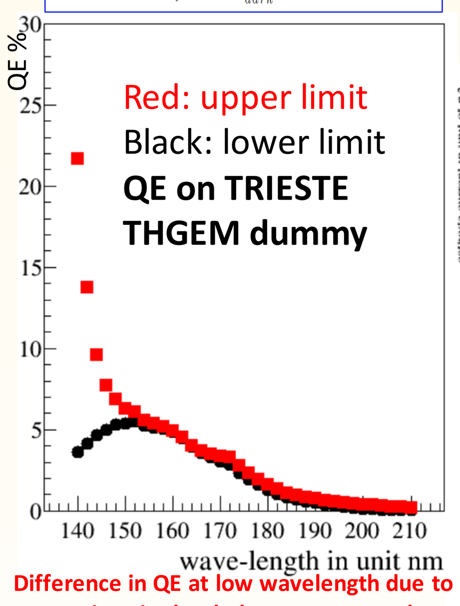
Set up for the QE measurement



$$QE_{sample} = \frac{I_{sample} - I_{dark}^{sample}}{I_{reference} - I_{dark}^{reference}} \times QE_{reference}$$

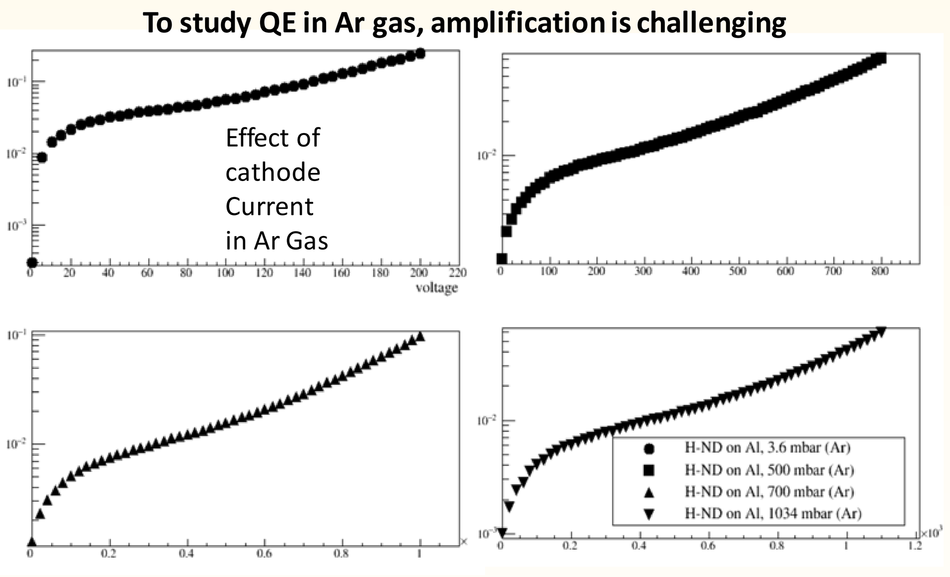




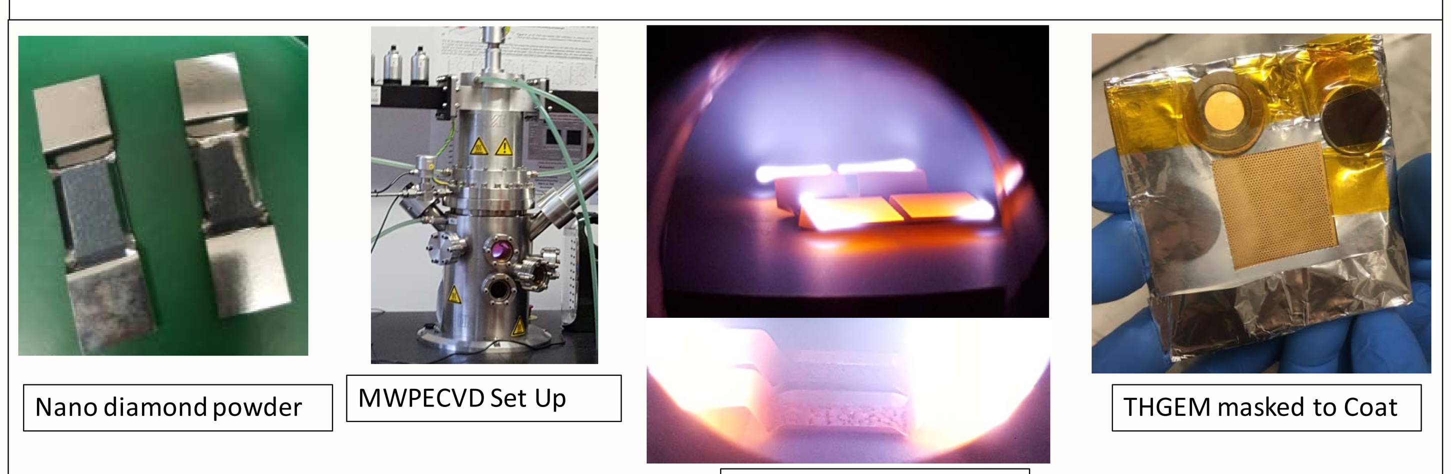


Difference in QE at low wavelength due to uncertainty in the dark current control

To study QE in Ar gas, amplification is challenging



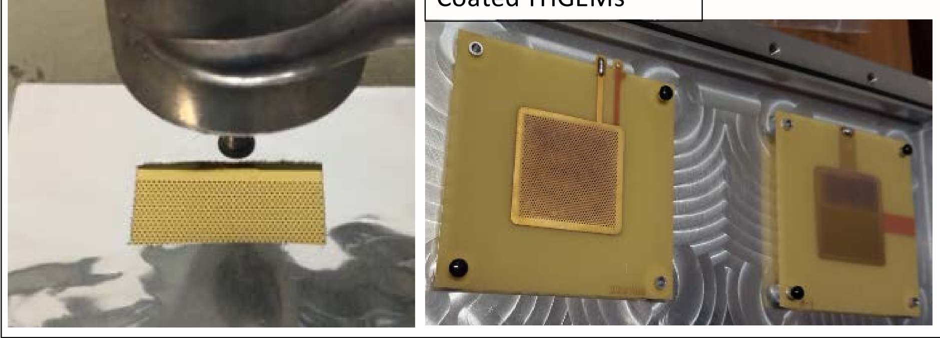
7. Coating in Bari


Nano diamond powder

MWPECVD Set Up

H_2Plasma treatment

THGEM masked to Coat


Spray Coating

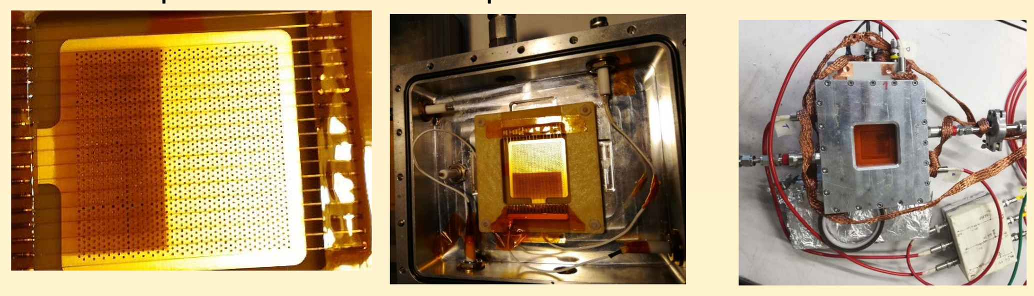
Coated THGEMs

Status of Coated THGEMs

Coated THGEMs:		
1) 0 µm rim ID1	H-ND	1/2 coating
2) 0 µm rim ID2	ND	1/2 coating
3) 10µm rim ID1	H-ND	full coating
4) 10µm rim ID2	CsI	full coating
5) 20µm rim ID1	ND	1/2 coating

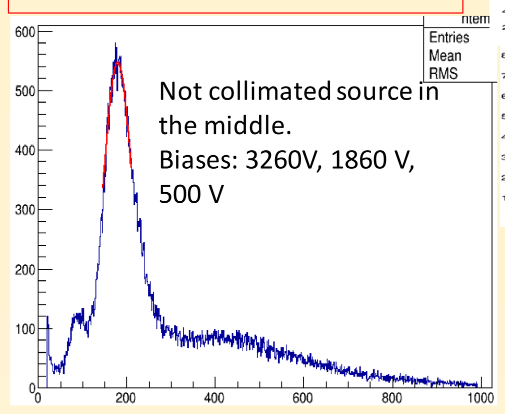
8. Effect of the Coating

Post coating characterization → Voltage configuration was used as before coating.
Same setup → One to One comparison.

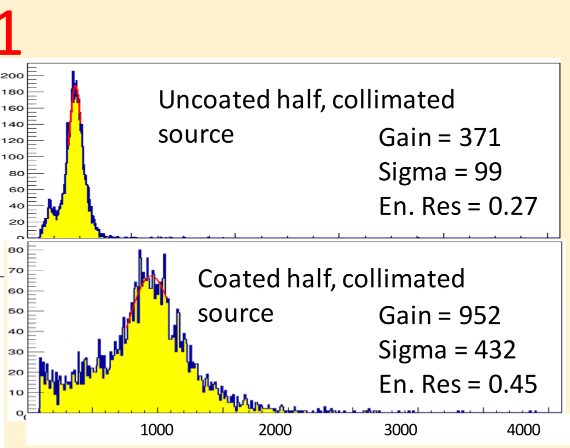


20 micron rim ID1

- ❑ Characterized before coating.
- ❑ Half coated with untreated Nano diamond.



2.5 times increase in amplification for the coated part

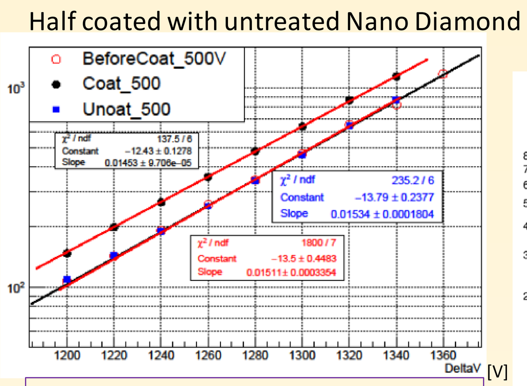


Drift 3510 THGEM Top 2110 Bottom 750 Source Fe^{55}

Further studies on gain effect were made with collimated source

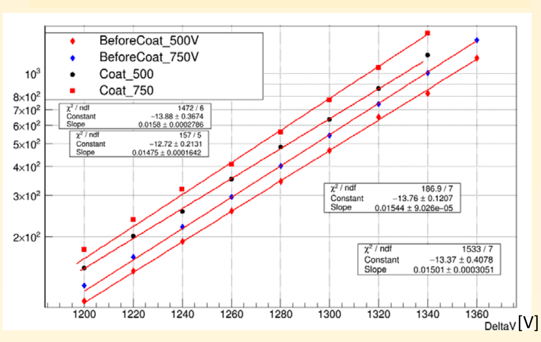
0 micron rim ID2

Half coated with untreated Nano Diamond



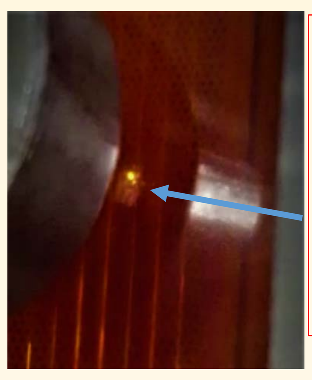
Gain of the uncoated part and gain before coating coincide. **30% increase in amplification for the coated part**

Gain vs Delta V for coated part and before coating : 2 values of E_{IND}

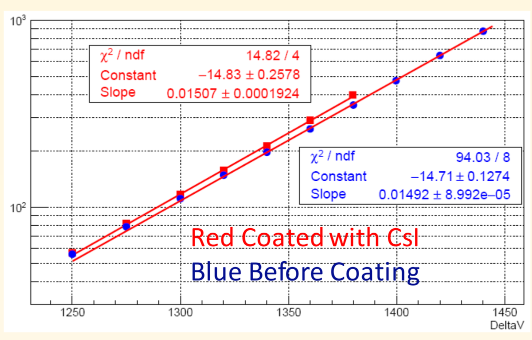


Different effect of coating in different rim pieces ? Yet to be understood!!

10 micron rim ID1


Fully coated with **hydrogenated Nano diamond.** After coating did not stand voltage (sparks).

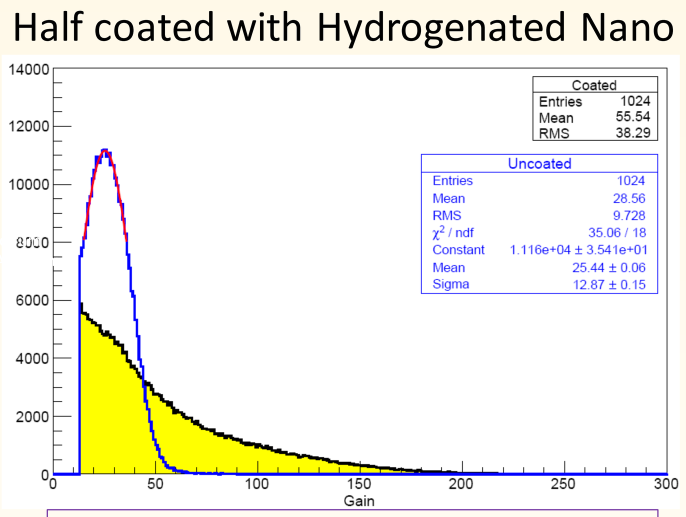
ID2



After coating Gain is compatible with gain obtained before coating. No gain increase was expected.

0 micron rim ID1

Half coated with Hydrogenated Nano Diamond



About factor of 2 increase in amplification for the coated part

Voltage Stability has decreased. Frequent sparks have been observed. Can not reach nominal voltage obtained before coating.

9. Conclusion

The Photocathode has shown promising outcome after the very first preliminary exercises, started few months ago.
Still the open questions are:
1. THGEMs, coated with a untreated nanodiamond showed different amount of increase in gain in coated and uncoated part. The amount of the gain rise has been observed to be different for THGEMs with different rim size.
   → The reasons are under investigation.
2. Electrical stability has decreased for THGEMs after coating, in particular for the hydrogenated ones. To understand the reason, further study is required.
   → Under investigation.
3. Understanding of the effect of substrates on quantum efficiency needs further study.
4. To estimate QE at very low wavelength control over dark current is crucial.
5. Measuring QE in pure Argon gas is challenging
   → Measurements in CH_4 is foreseen.

<u>HND is a potential candidate as CsI substitute</u>