GEM operation in Nitrogen based gas mixtures: opening new applications for X-Rays, UV-light and neutron detection with the use of environmental-friendly mixtures

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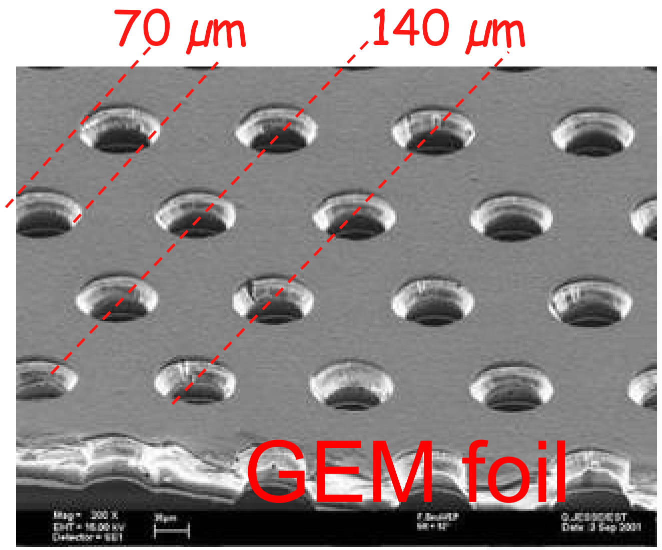
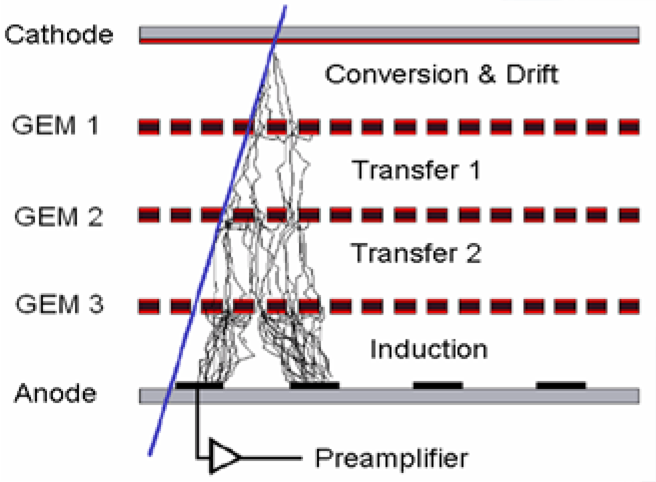
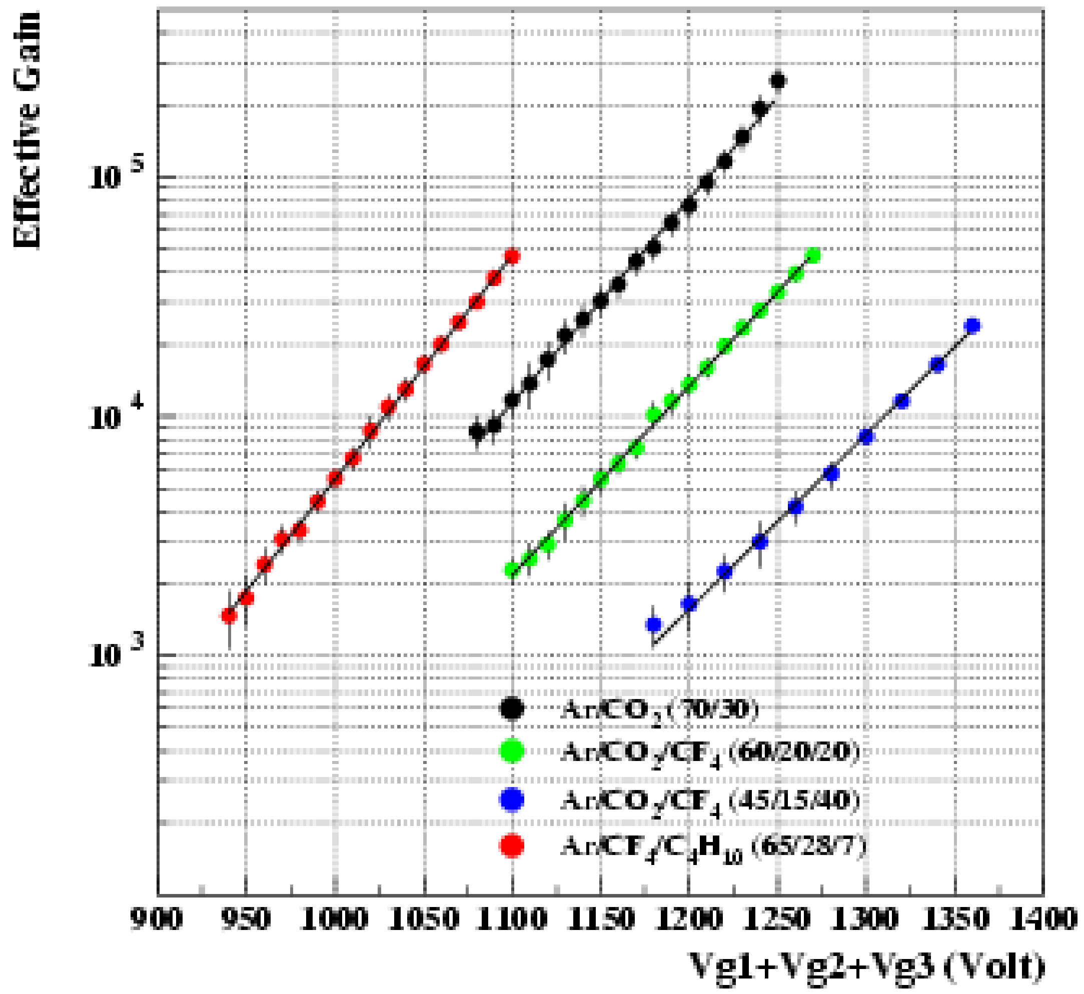
Outline

- Standard Gas used for GEM Operation
- Nitrogen based gas mixtures
  - Properties
- GEM based detectors operated with N_2 based gas mixtures
  - X-Rays
  - Thermal neutrons
  - UV light (an idea)
  - alpha particles

Gas mixtures commonly used with GEM detectors







CO_2 and CF_4 mainly used as quenching gas → **What about Nitrogen (N_2)?**

Gas Properties

Property	CO_2 (Carbon Dioxide)	CF_4 (Carbon Tetrafluoride)	N_2 (Nitrogen)
Molecular Weight	44.01 g/mol	88.00 g/mol	28.01 g/mol
Gaseous Density (g/cm^3 at STP)	0.00198 g/cm^3	0.00372 g/cm^3	0.00125 g/cm^3
Polarity	Nonpolar	Nonpolar	Nonpolar
Bond Type	Covalent (O=C=O)	Covalent (tetrahedral)	Covalent (triple bond)
Bond Angle	180° (linear)	109.5° (tetrahedral)	180° (linear)
Ionization Potential (1st)	13.77 eV	16.2 eV	15.58 eV
Ionization Potential (2nd)	21.16 eV	28.9 eV	29.60 eV
Lowest Electronic Energy Level	13.77 eV	~10 eV	14.53 eV
Wi	33 eV	54	35 eV
Excited State	~10.5 eV (for $\pi^* \leftarrow \pi$ transition in UV)	~12.5 eV (Rydberg-like states)	~12.1 eV
Greenhouse Effect	Moderate	High (strong GHG)	Minimal (neutral effect)
Electronic Structure	Linear (sp^2 hybridization)	Tetrahedral (sp^3 hybridization)	Triple bond (sp hybridization)

Why is N_2 not commonly used with GEM detectors?
Too slow drift velcity? Other reasons?
N_2 is extensively used in clean room as «drying gas».

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(Few) Literature examples of N_2 gas mixtures

- 24 -

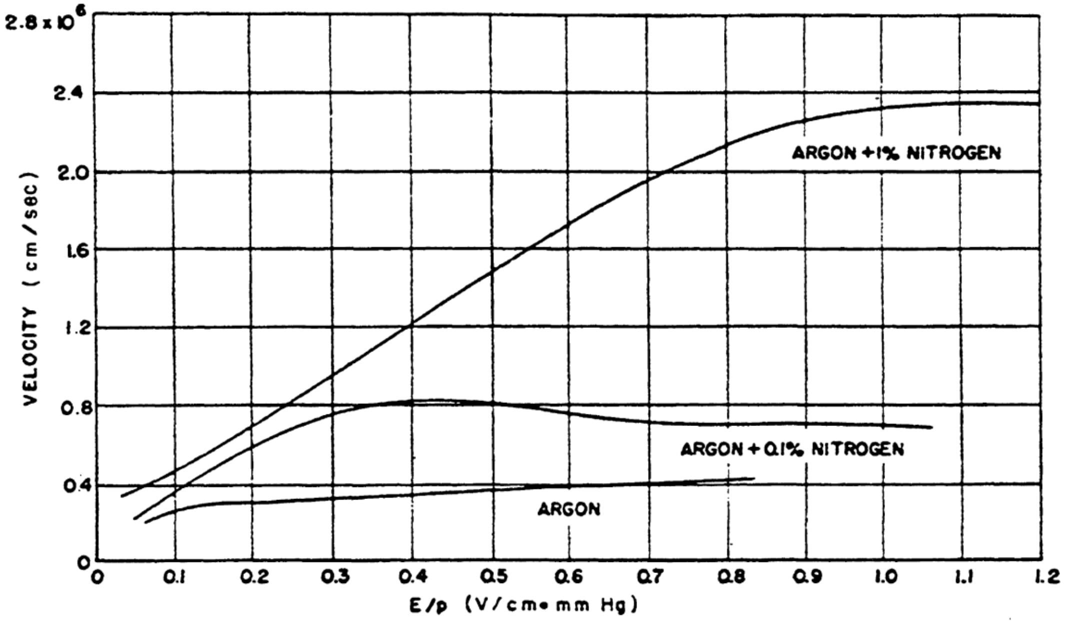

Fig. 25 Drift velocity of electrons in pure argon, and in argon with small added quantities of nitrogen. The very large effect on the velocity for small additions is apparent[22].

F. Sauli, CERN Yellow Paper 1977

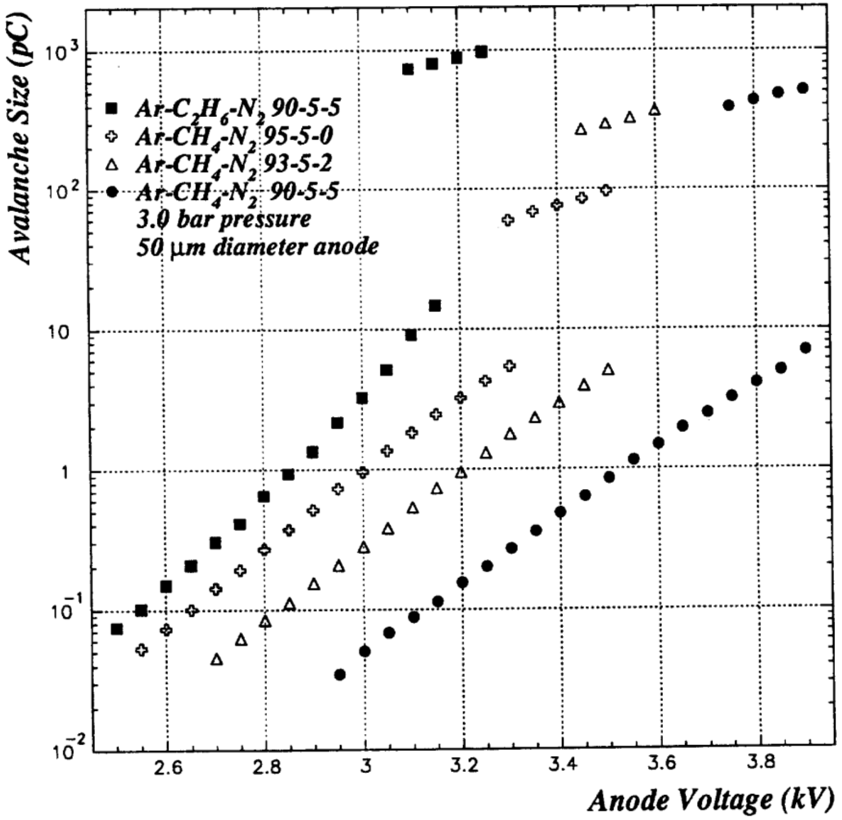

Figure 7: Avalanche size vs anode high voltage for four gas mixtures containing Ar, CH_4, C_2H_6 and N_2. The avalanche size of the SQS mode signals increases as the amount of nitrogen increases. Also, it is much larger in Ar-C_2H_6-N_2 90:5:5 than in Ar-CH_4-N_2 90:5:5.

T. Zhao, A study of gas mixtures for ATLAS MDT, Atlas internal note, 1995

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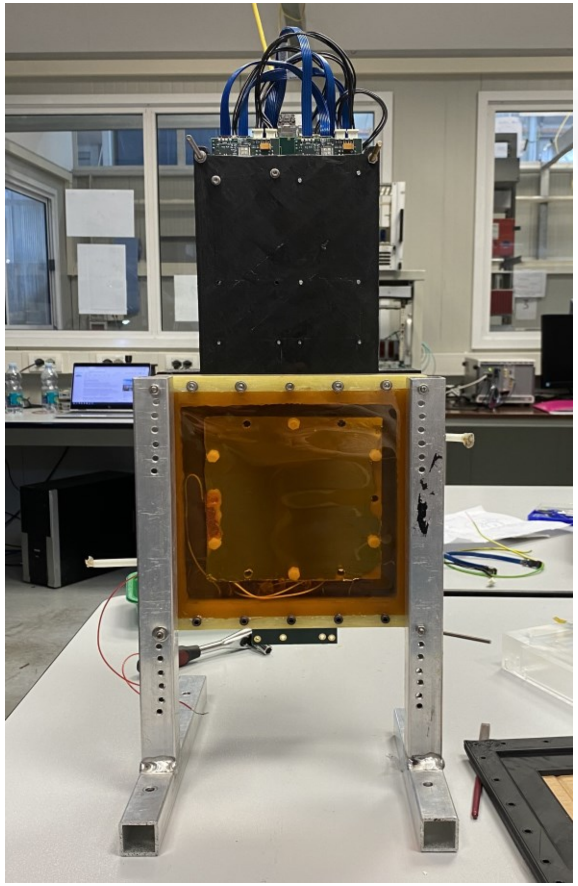
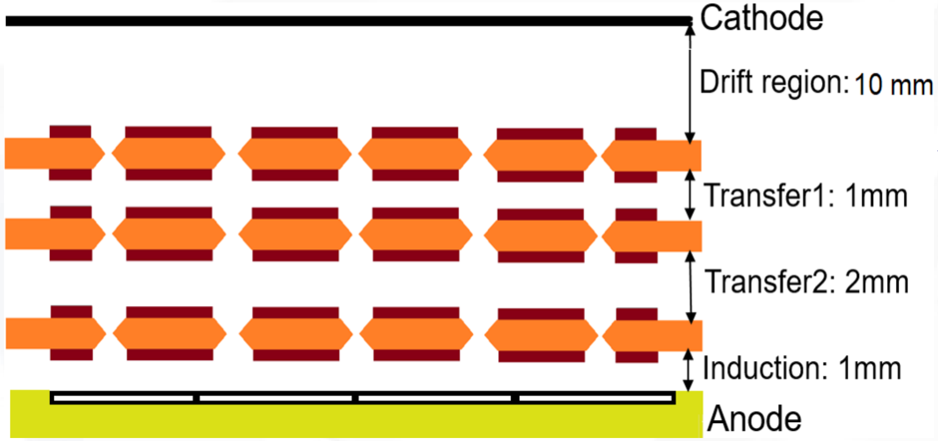
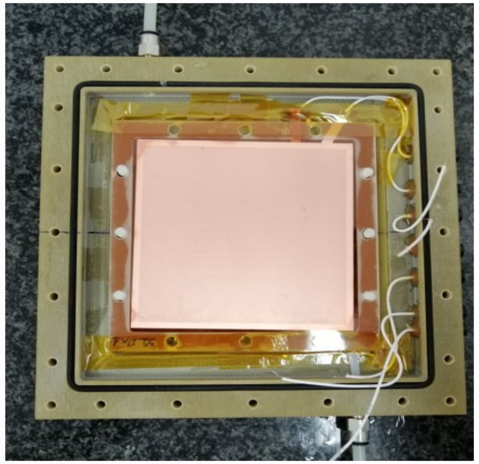
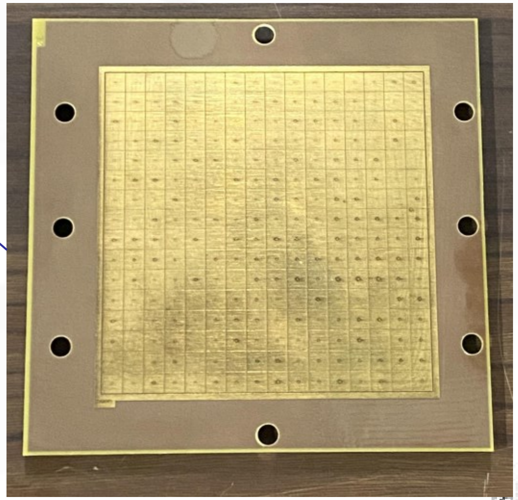
Detector Setup used for X-rays and neutrons







- Ar-Co2 mixture 70%-30%
- N2-based mixtures
- Copper GEM GEM.
- 16 x 16 Pads, 6mm x 6mm
- GEMINI electronics .

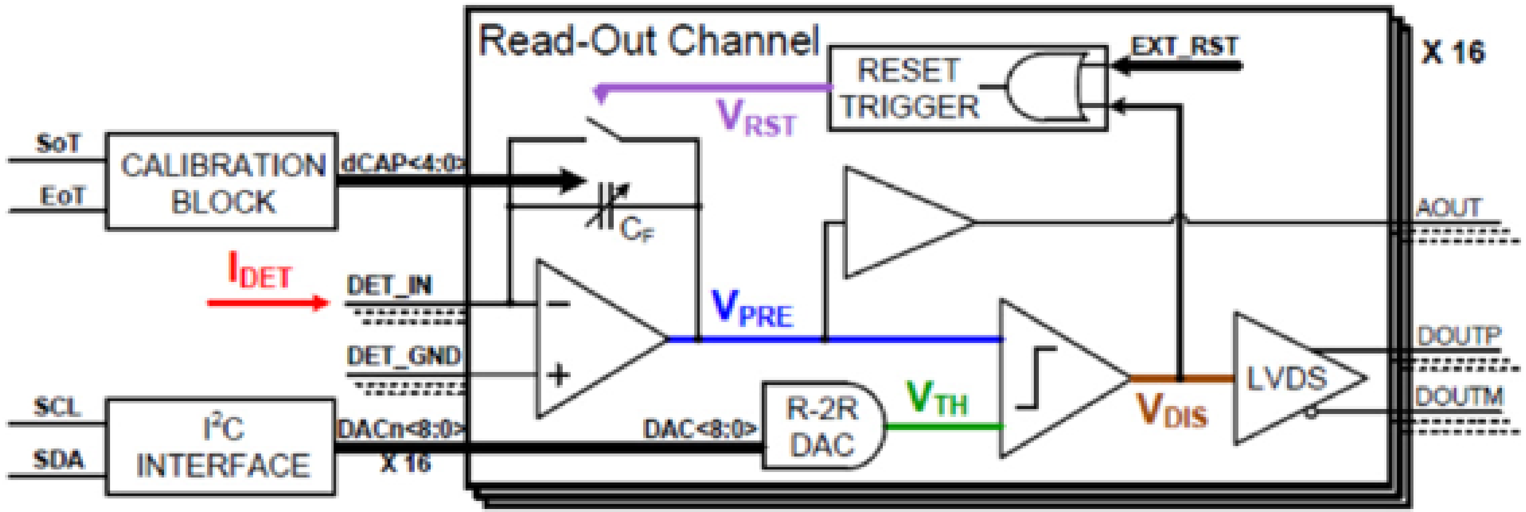


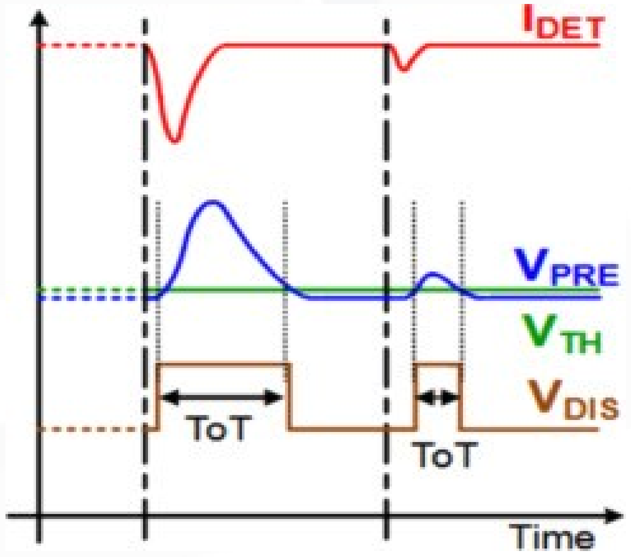
GEMINI Electronics

A compact Readout electronics composed by an Application Specific Integrated Circuit (ASIC) called GEMINI and a custom made FPGA.

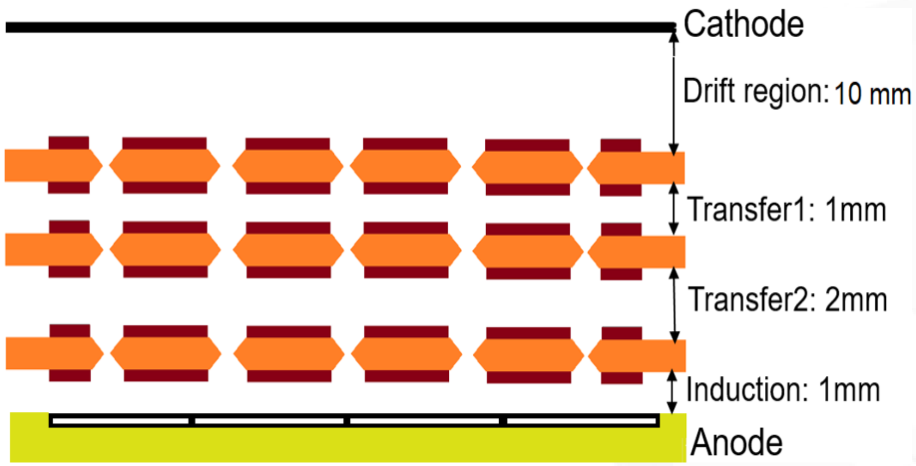
Each pixel is read by a single GEMINI channel, making the measure **asynchronous, in photon counting mode.** The energy information is retrieved by a **Time over Threshold** technique.

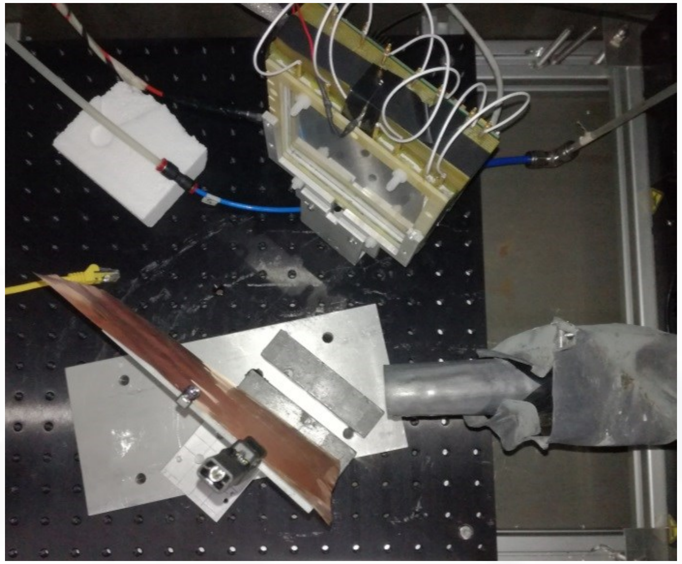
The time binning can be adapted to different event rates, the maximum event rate is **1 MHz per channel.**

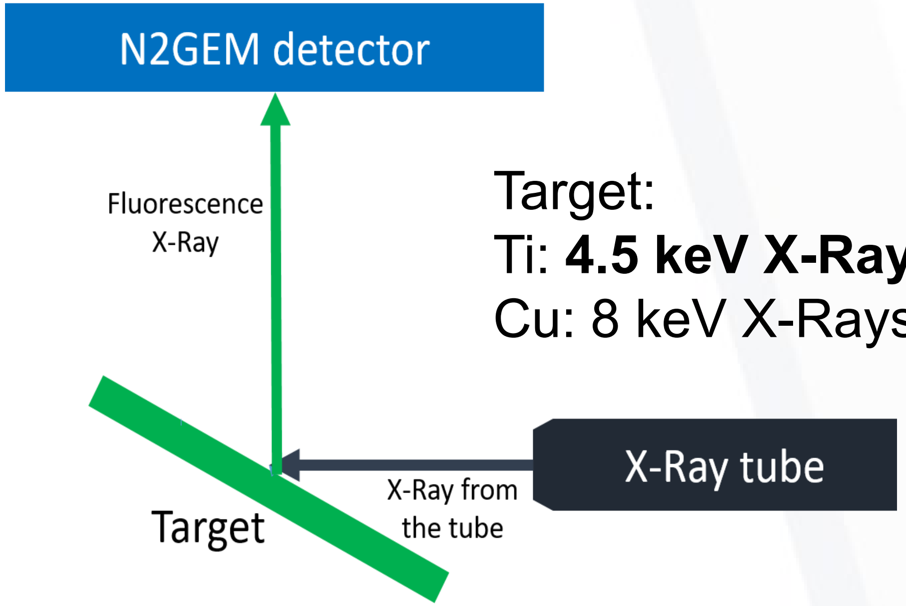




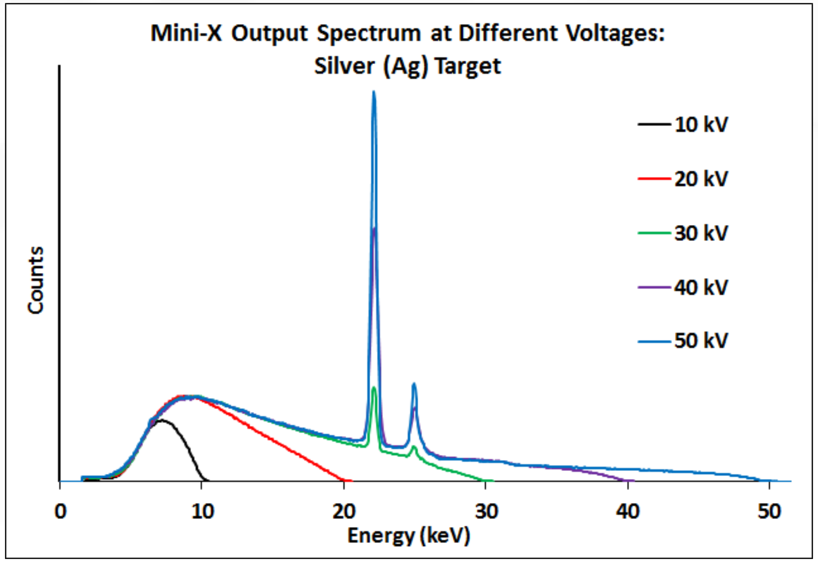
X-Rays Characterization - Setup



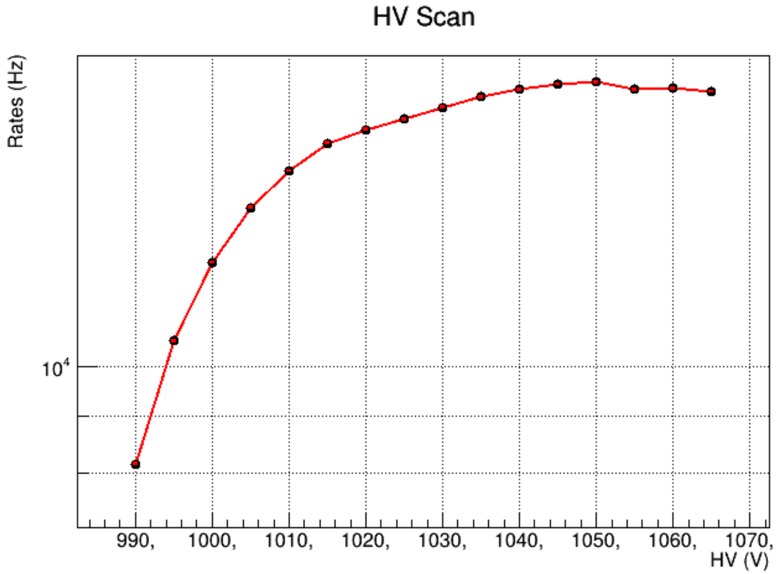


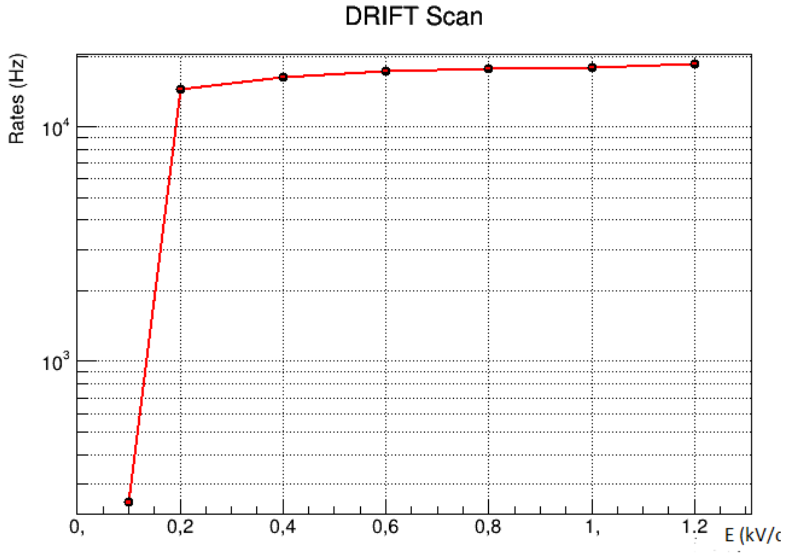


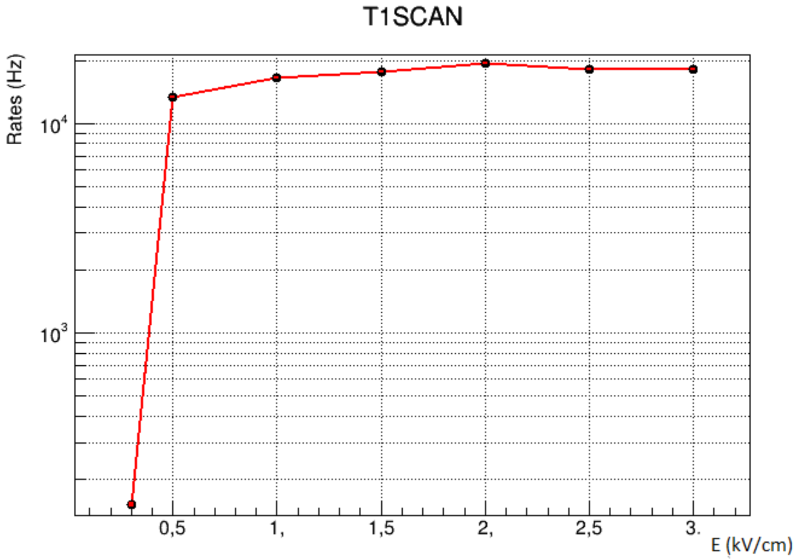
Target:
Ti: **4.5 keV X-Rays**
Cu: 8 keV X-Rays

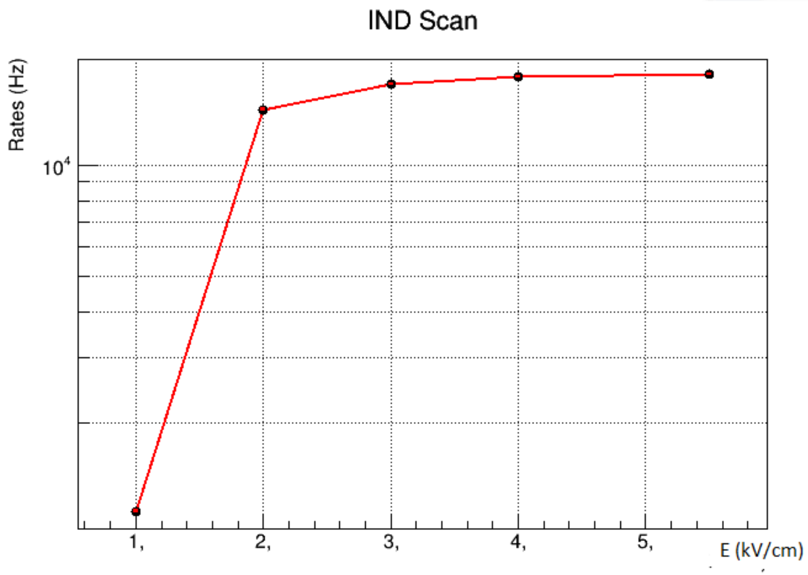


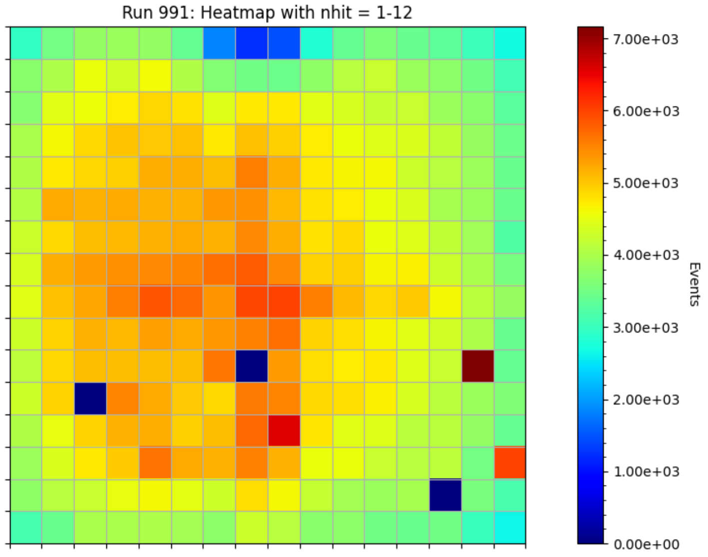
4.5 keV X-Rays Measurements – Ar/N_2 90%/10%

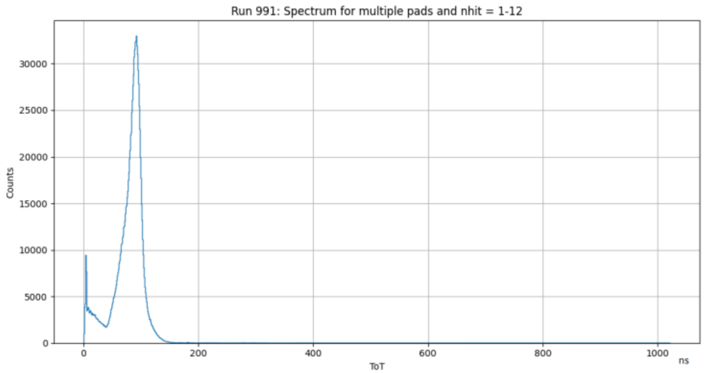












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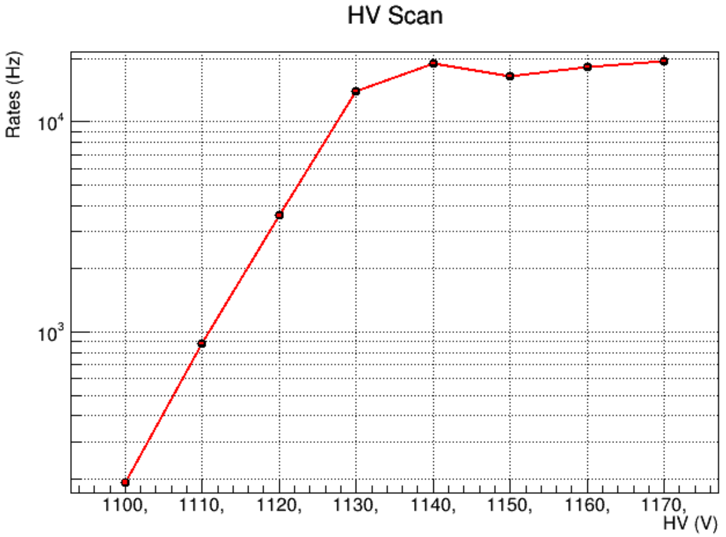
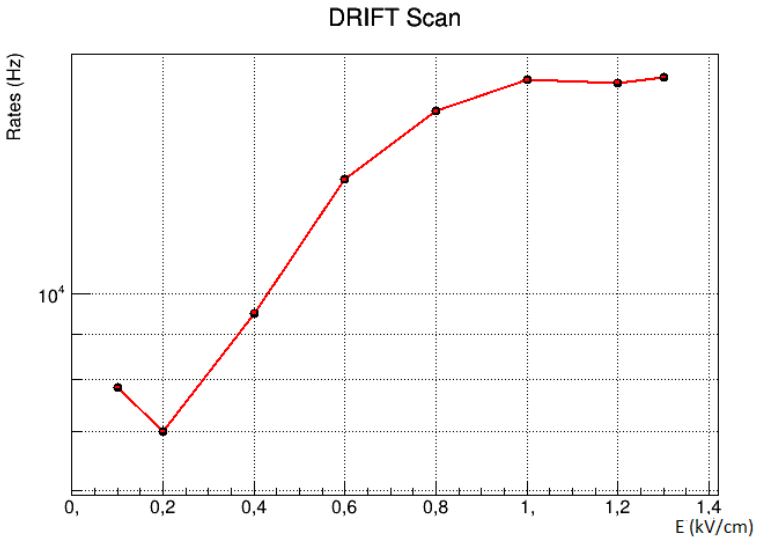
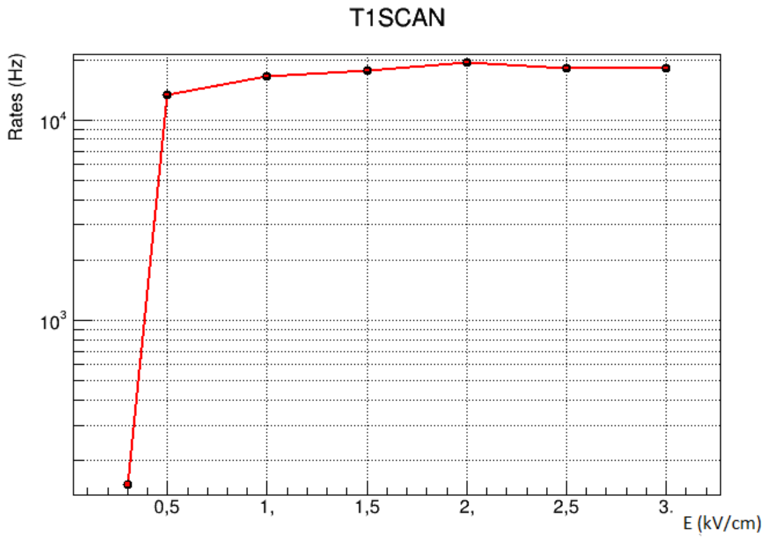
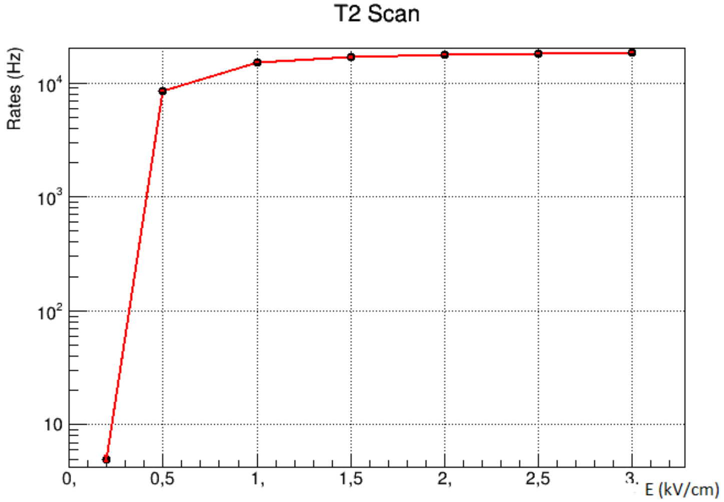
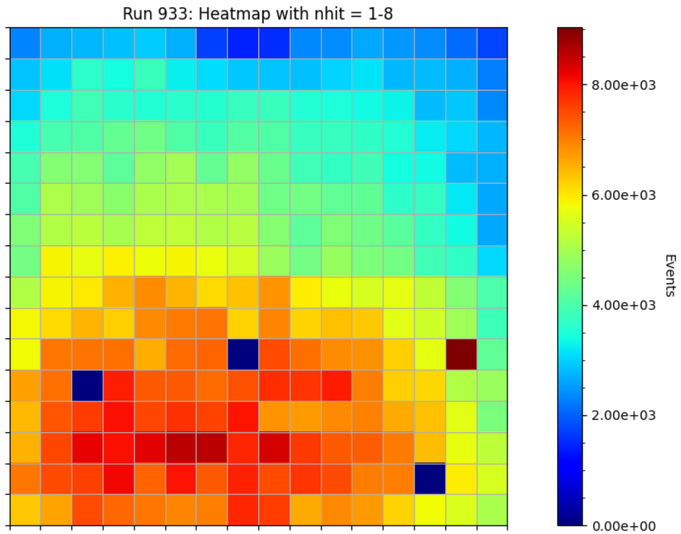
4.5 keV X-Rays Measurements – Ar/N_2 80%/20%

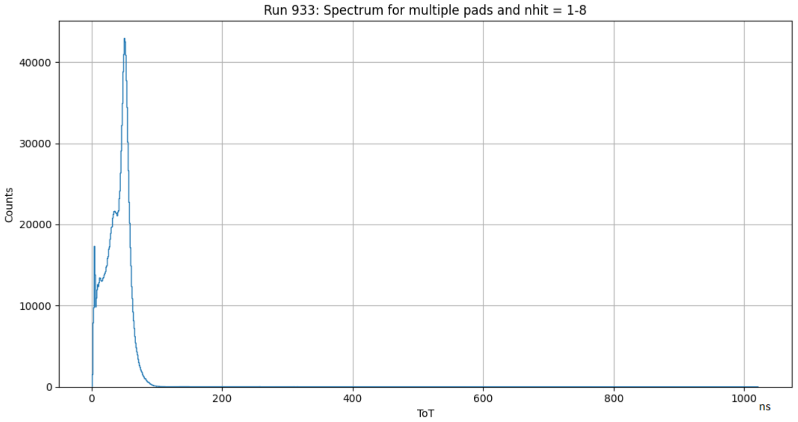




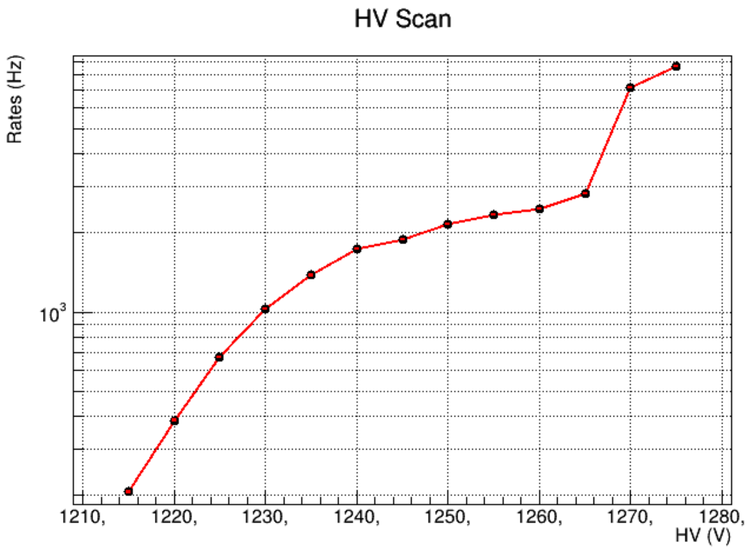


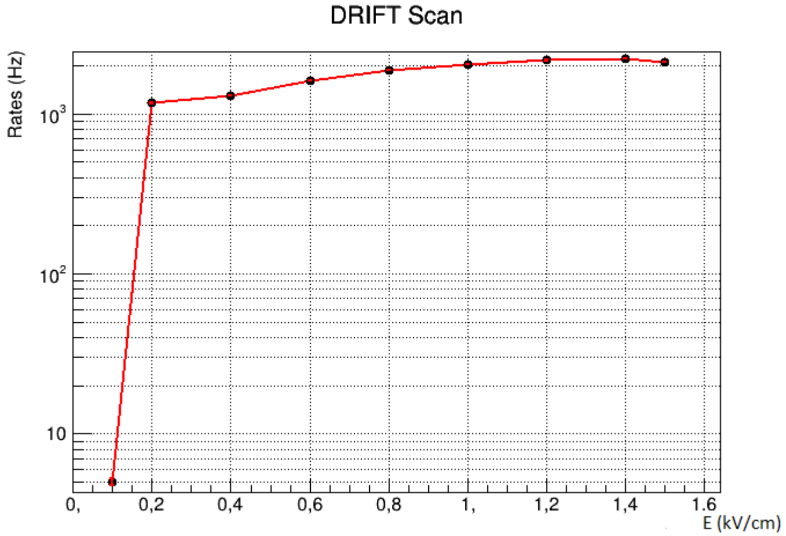


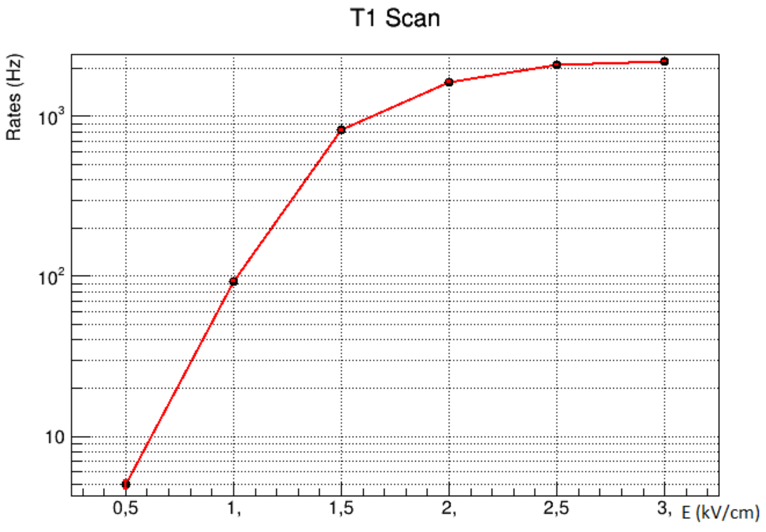


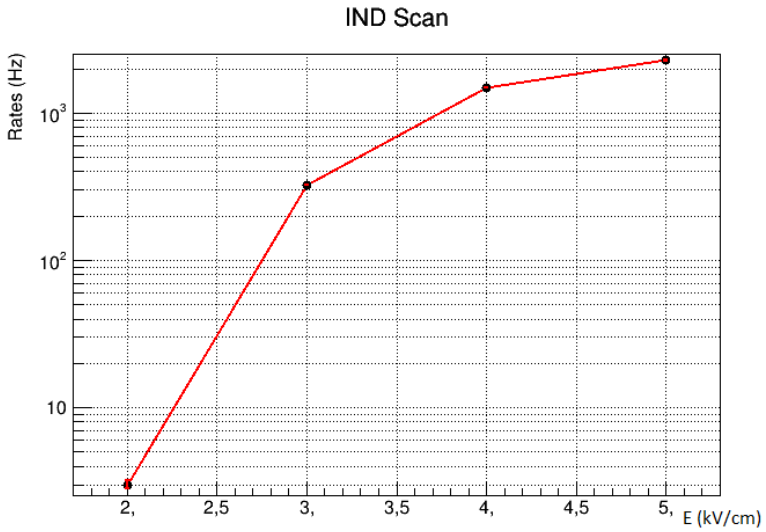


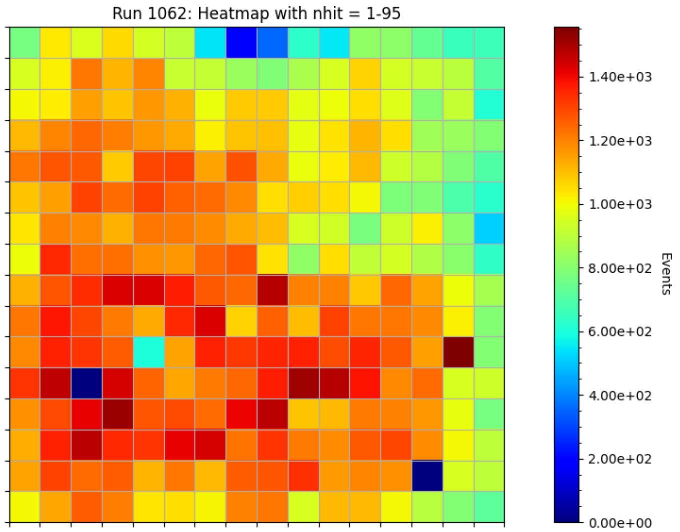
4.5 keV X-Rays Measurements – Ar/N_2 70%/30%

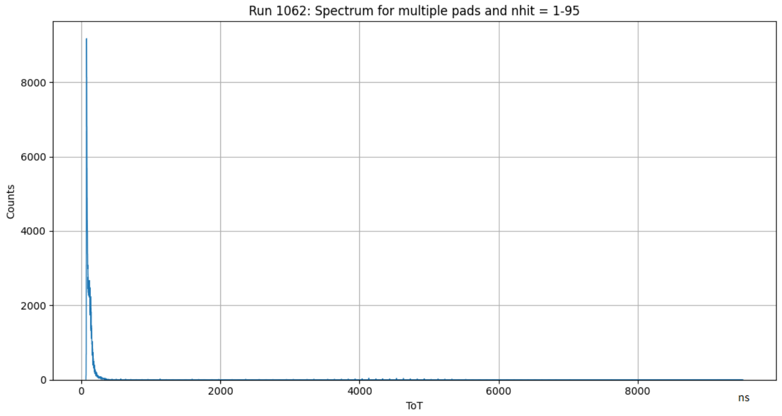




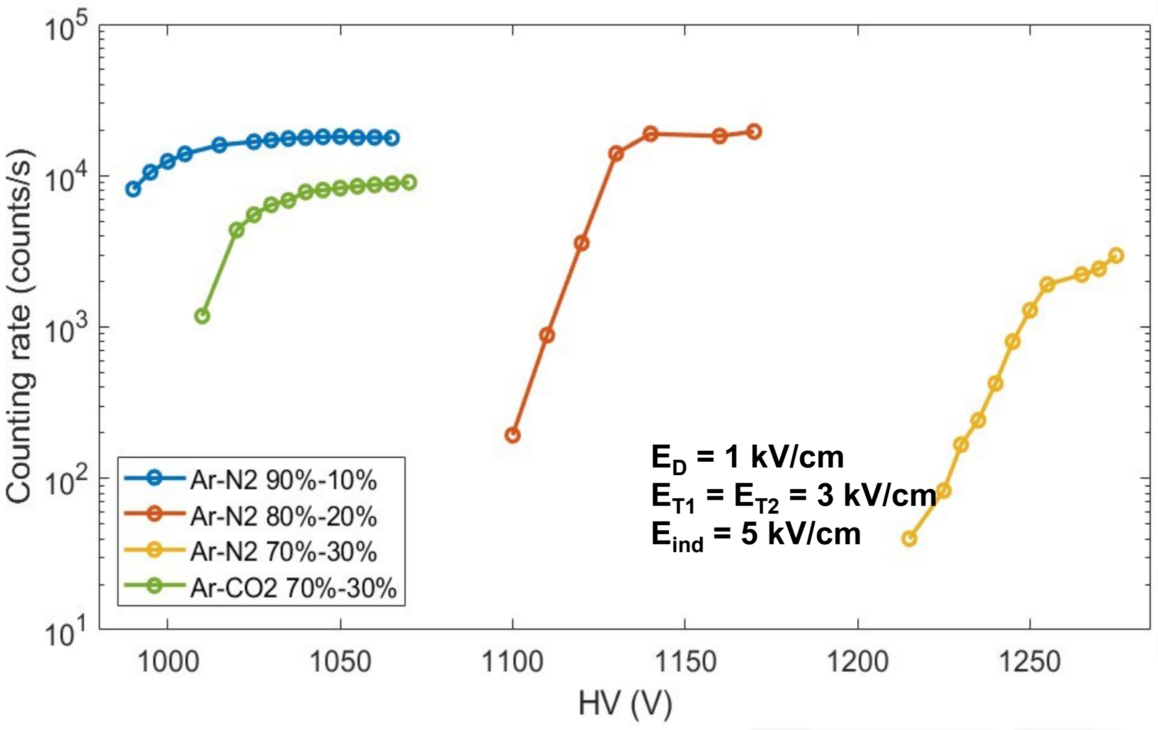


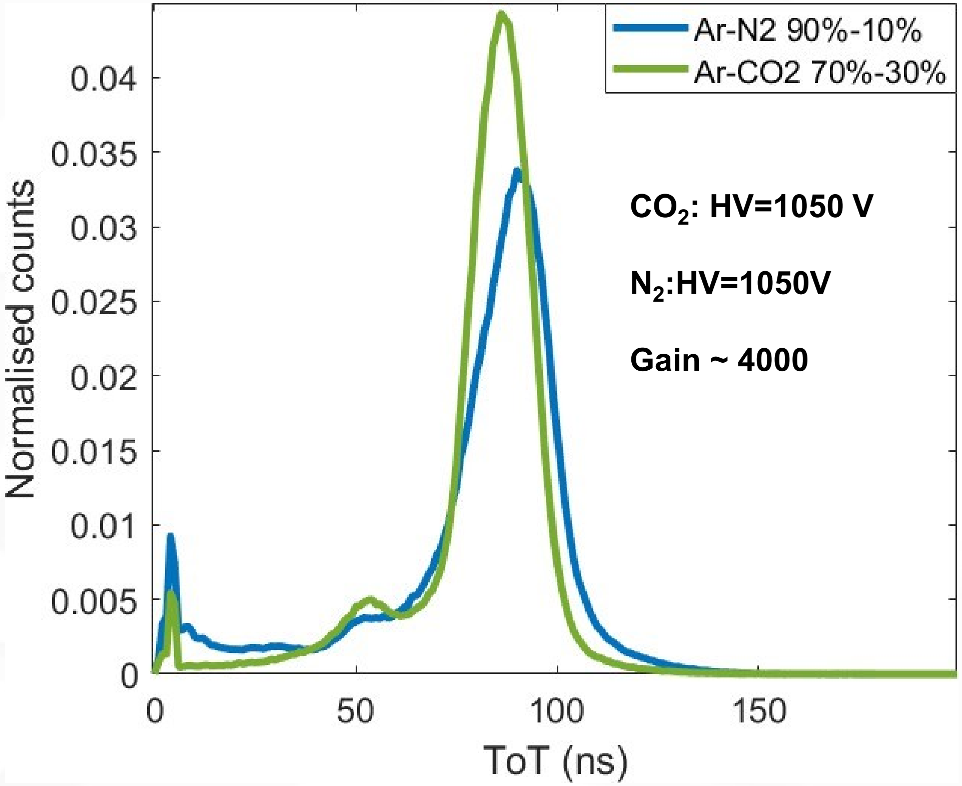






Comparison with Ar/CO_2 70%/30%





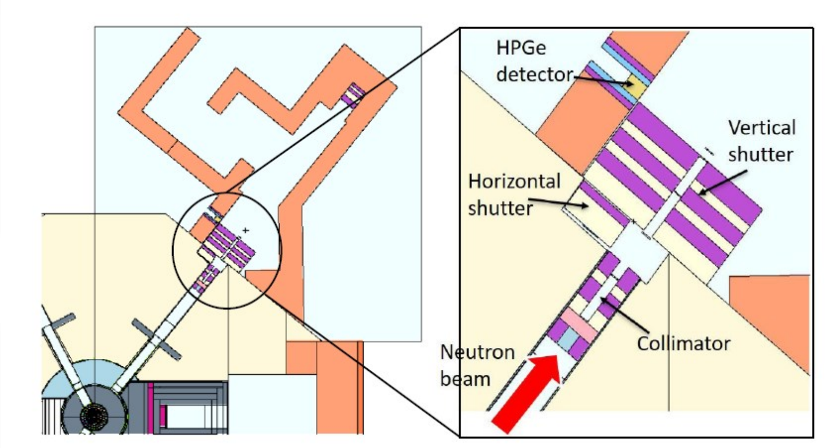
Gas Mixture	V_{G1} + V_{G2} + V_{G3} Working Range
Ar/CO_2 70%/30%	1010 -1080 V
Ar/N_2 90%/10%	1045–1070 V
Ar/N_2 80%/20%	1130–1170 V
Ar/N_2 70%/30%	1230–1250 V

Similar behaviuor among Ar/CO_2 70%/30% and Ar/N_2 90%/10%

Very promising for closed-recycle gas systems

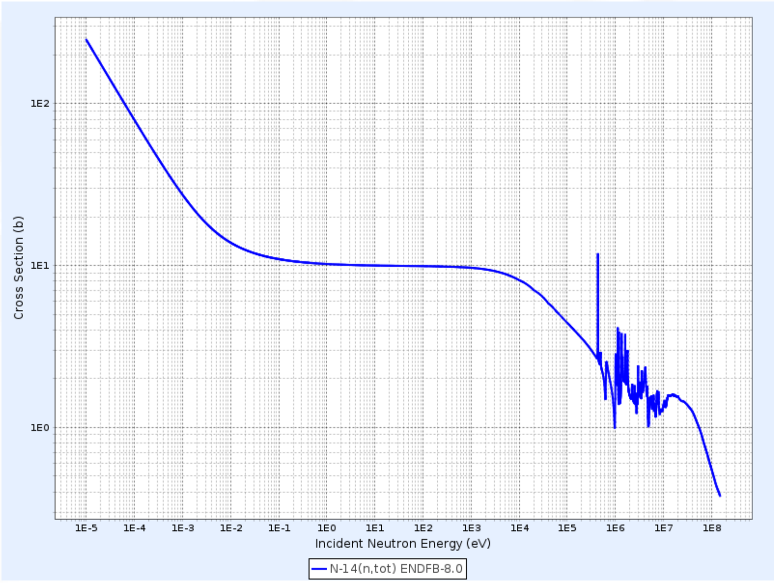
Test as Neutron detector: measurements at L.E.N.A. reactor (PAVIA)

- Study of three gas mixture:
  - ArN_2 90%-10%
  - ArN_2 80%-20%
  - ArN_2 70%-30%
- Almost thermal neutrons: large gaussian centred at 25 meV



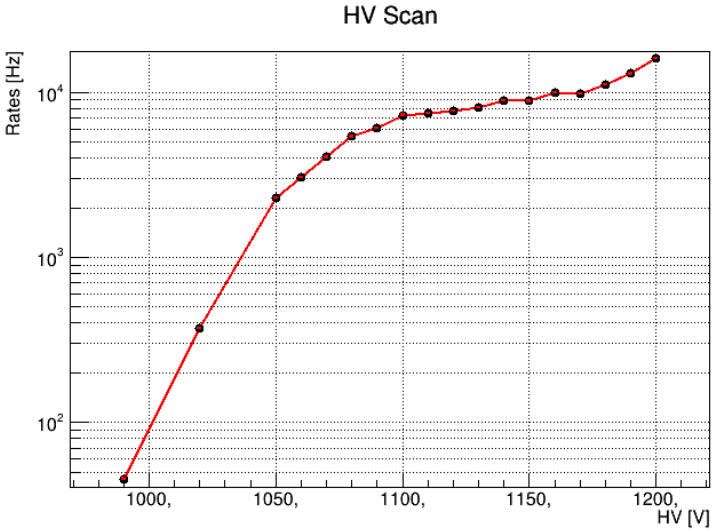
- Neutrons are detected via nuclear reaction:

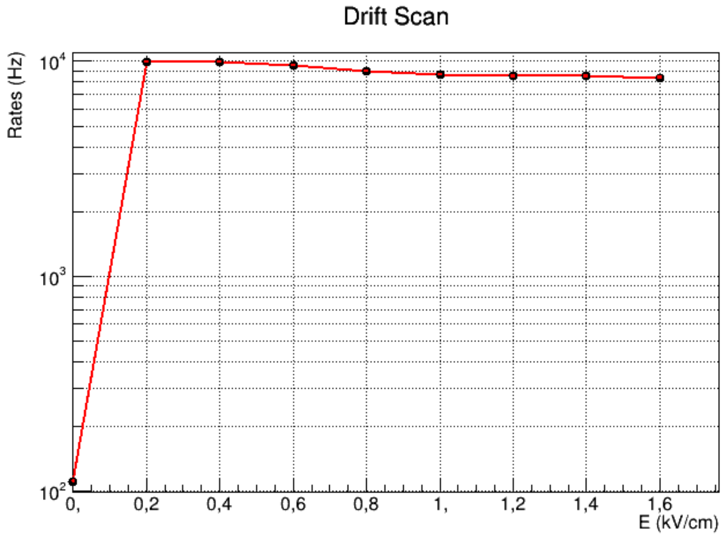
$$\mathbf{n} + {}^{14}\mathbf{N} \rightarrow \boldsymbol{p} + {}^{14}\mathbf{C}\ \boldsymbol{Q}_{\mathbf{val}} = \mathbf{0.626}\ \boldsymbol{MeV}$$

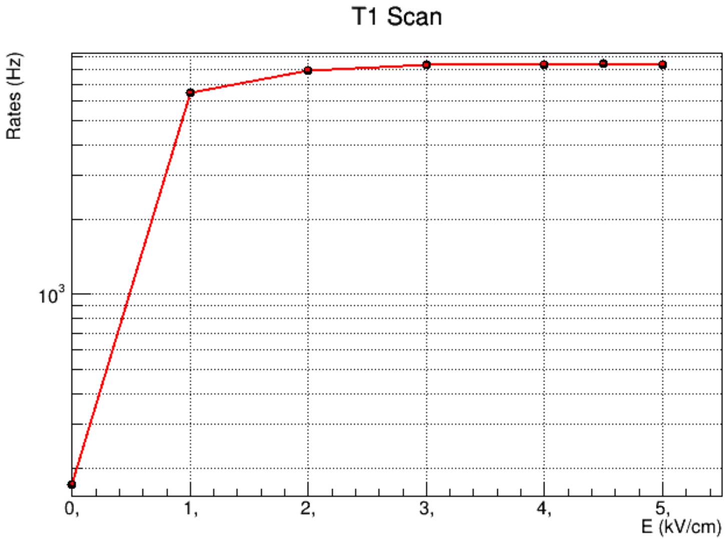


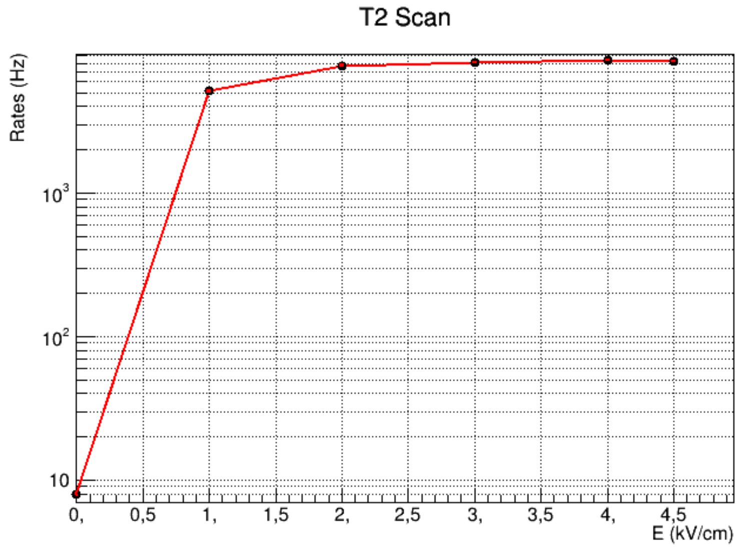
- Similar test performed also by D. Raspino at ISIS using the NitroGEM detector

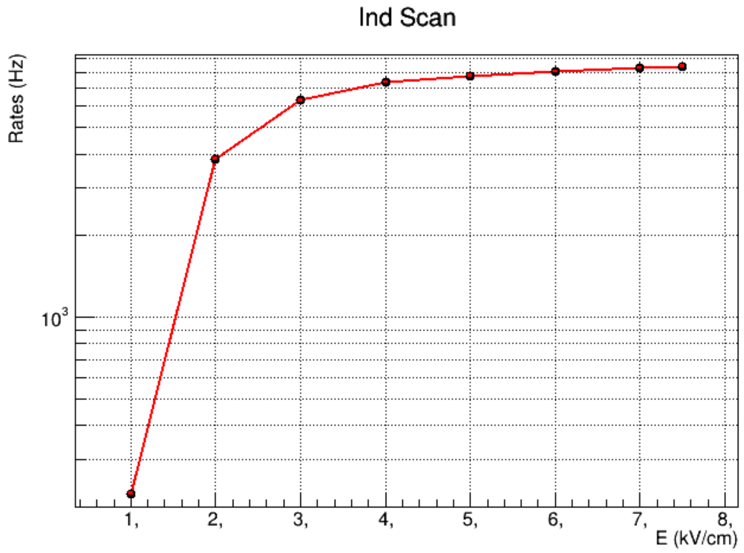
25 meV neutrons Measurements – Ar/N_2 70%/30%



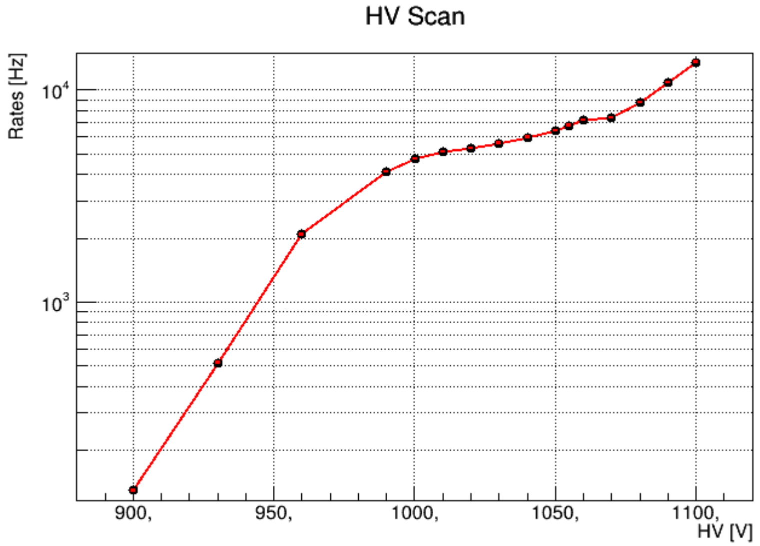


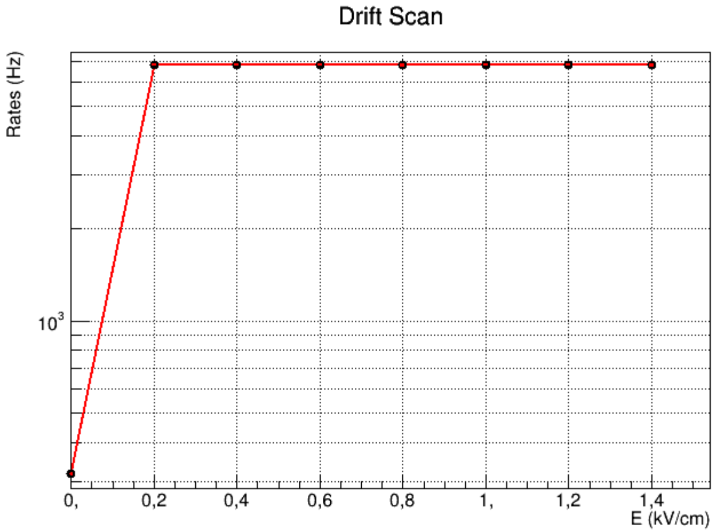


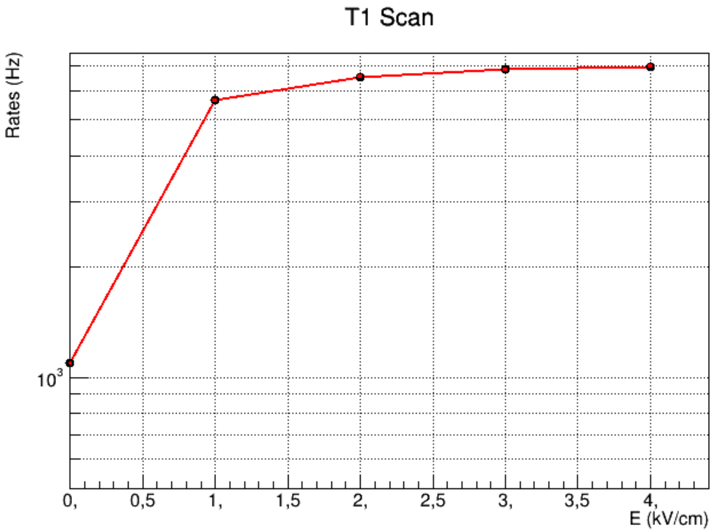


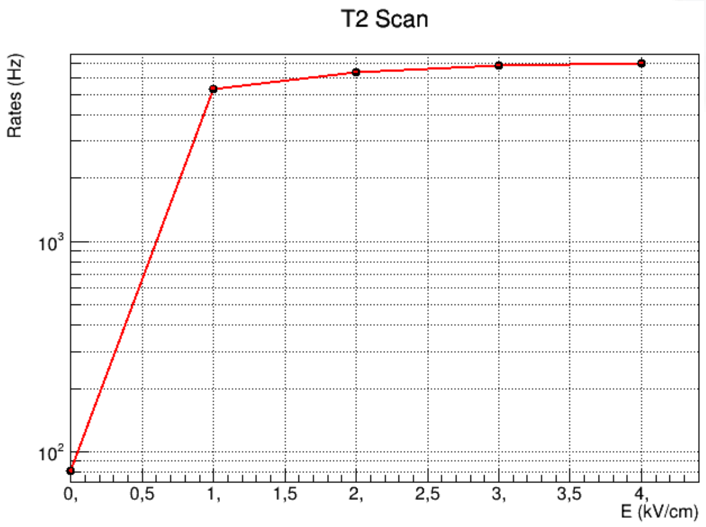


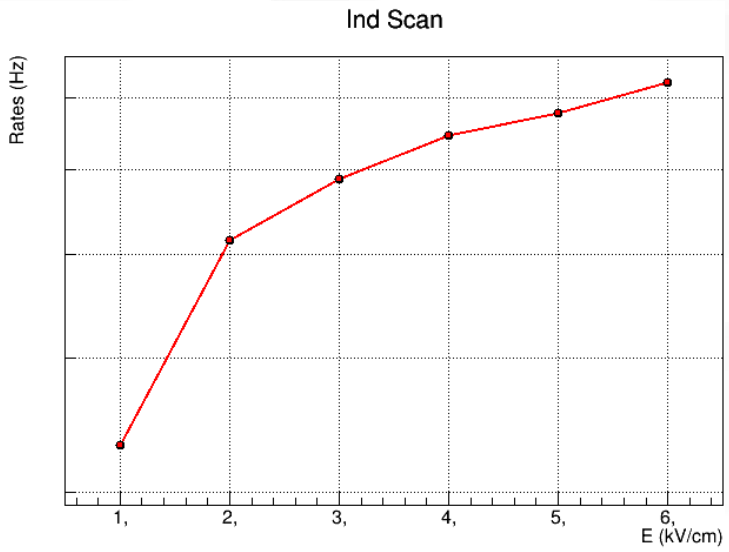
25 meV neutrons Measurements – Ar/N_2 80%/20%



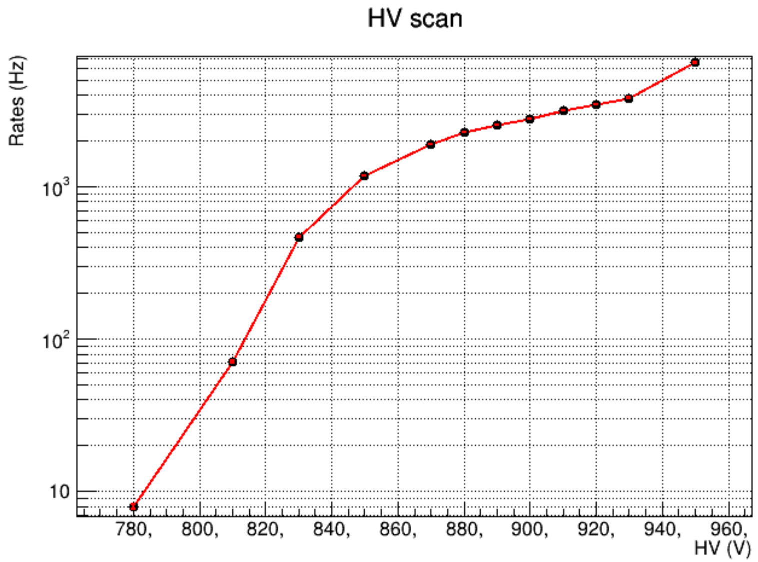


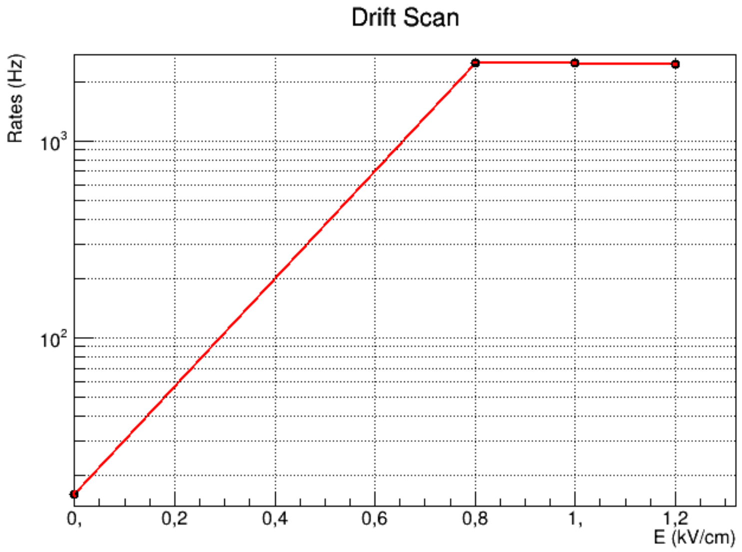


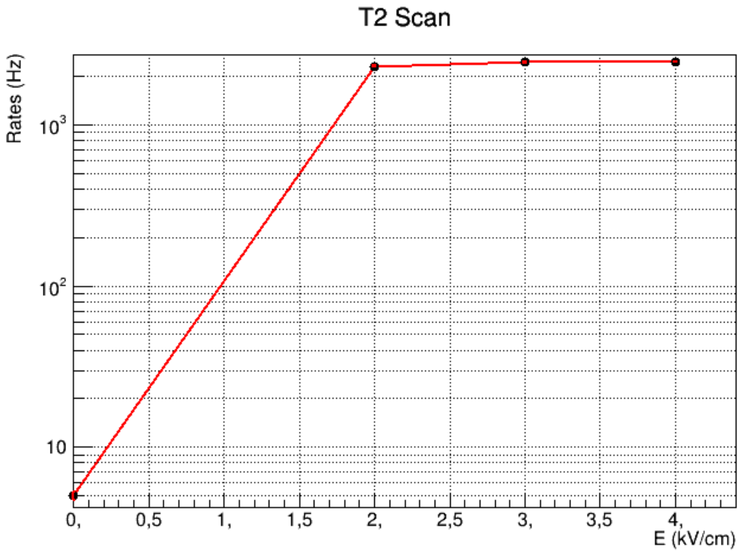


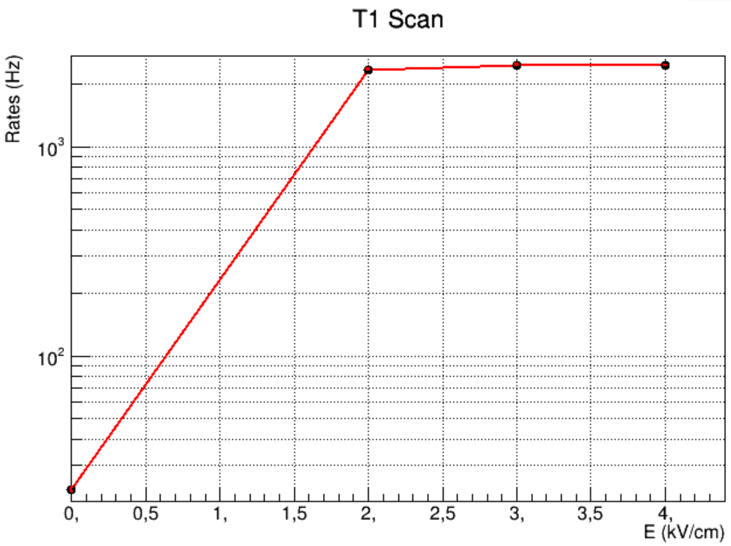


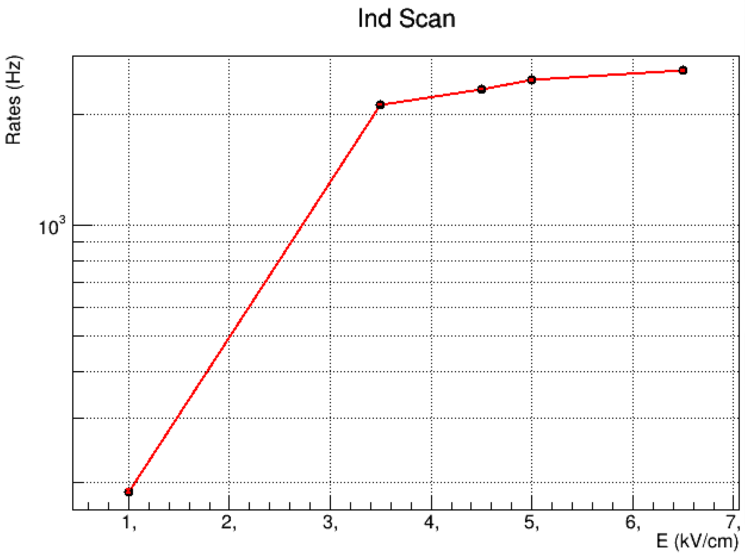
25 meV neutrons Measurements – Ar/N_2 90%/10%











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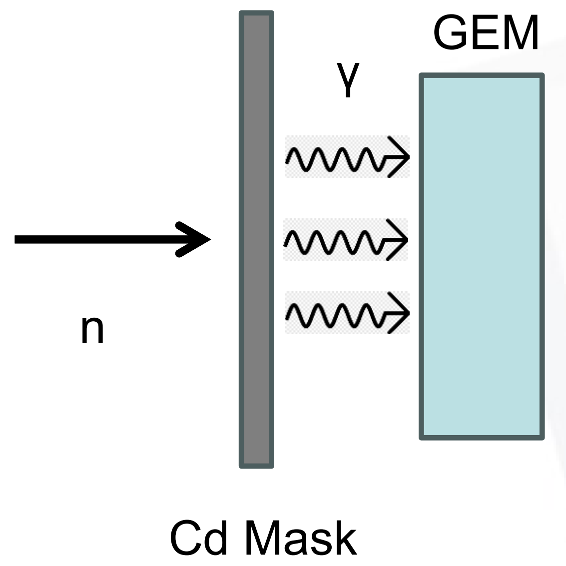
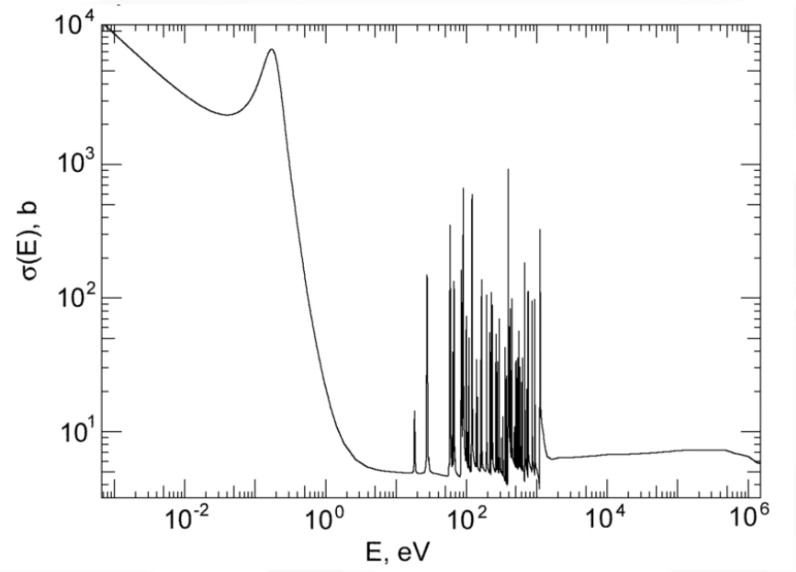
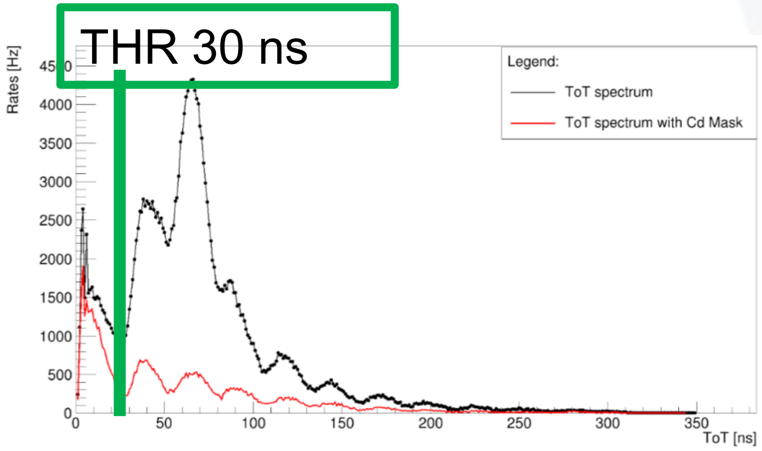
25 meV neutrons Measurements – Ar/N_2 70%/30% Using a Cadmium Mask to study gamma sensitivity

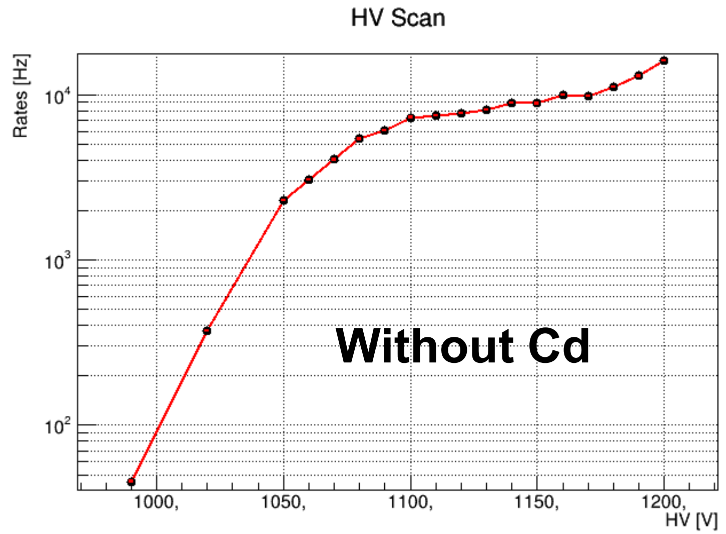


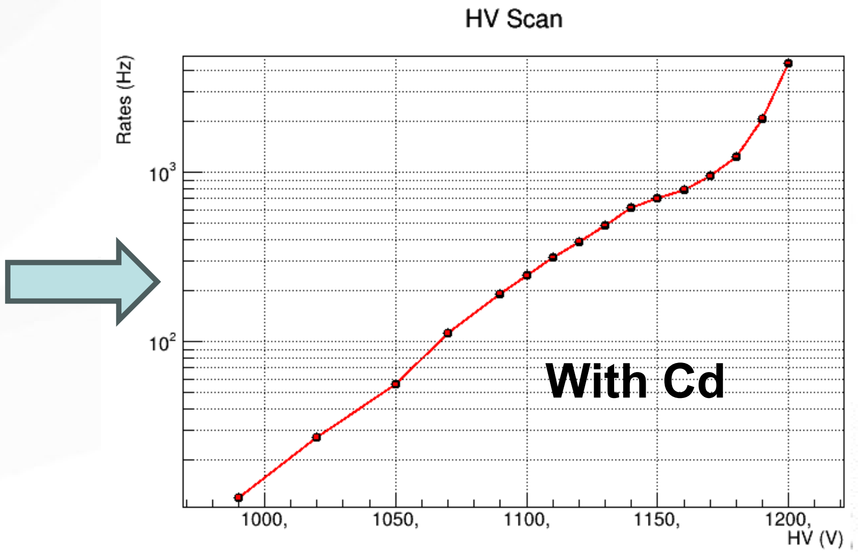


Cadmium Black Resonance at 0,5 eV.

"Trkov, Andrej. (2015). Nuclear Reactions and Physical Models for Neutron Activation Analysis. Journal of Radioanalytical and Nuclear Chemistry."

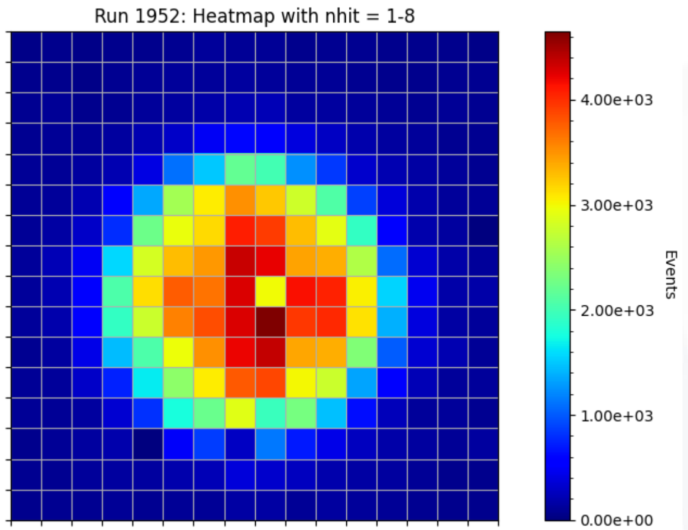




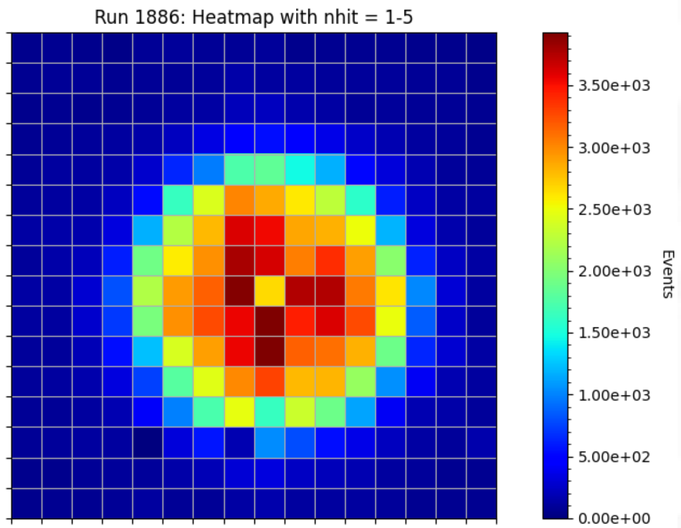


2D Beam profiles

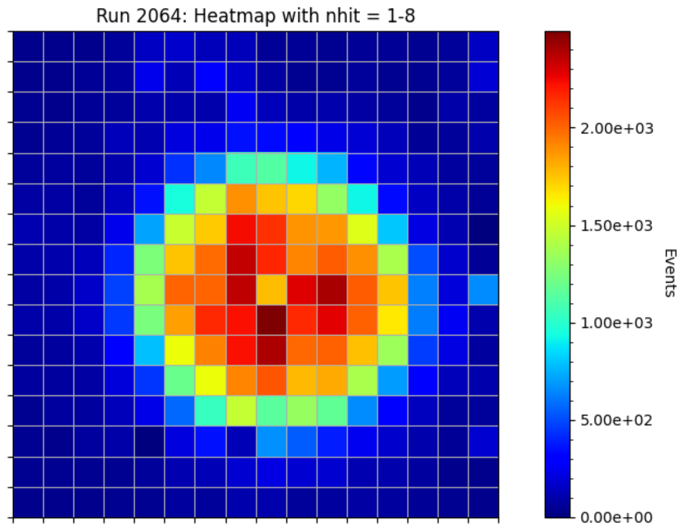
ArN_2 70%-30%



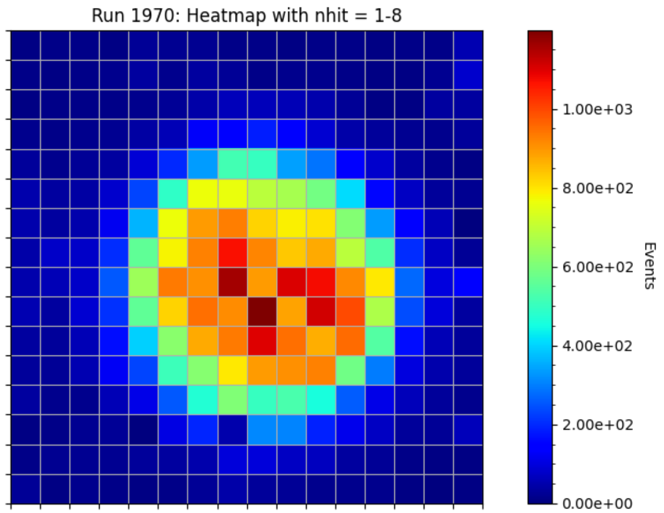
ArN_2 80%-20%



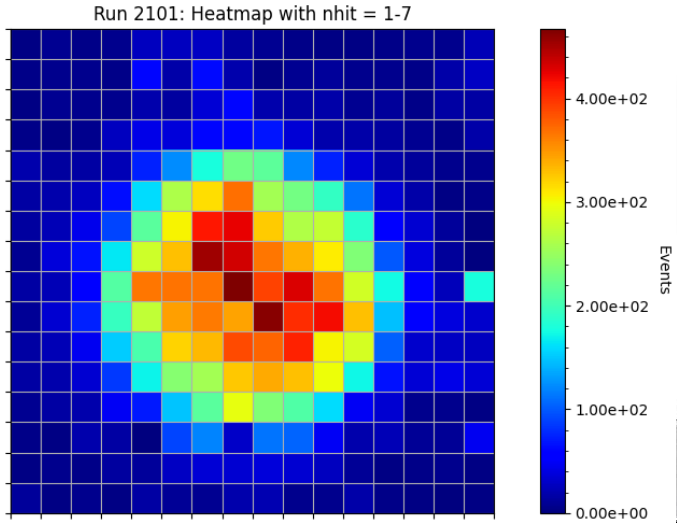
ArN_2 90%-10%



With Cd Mask



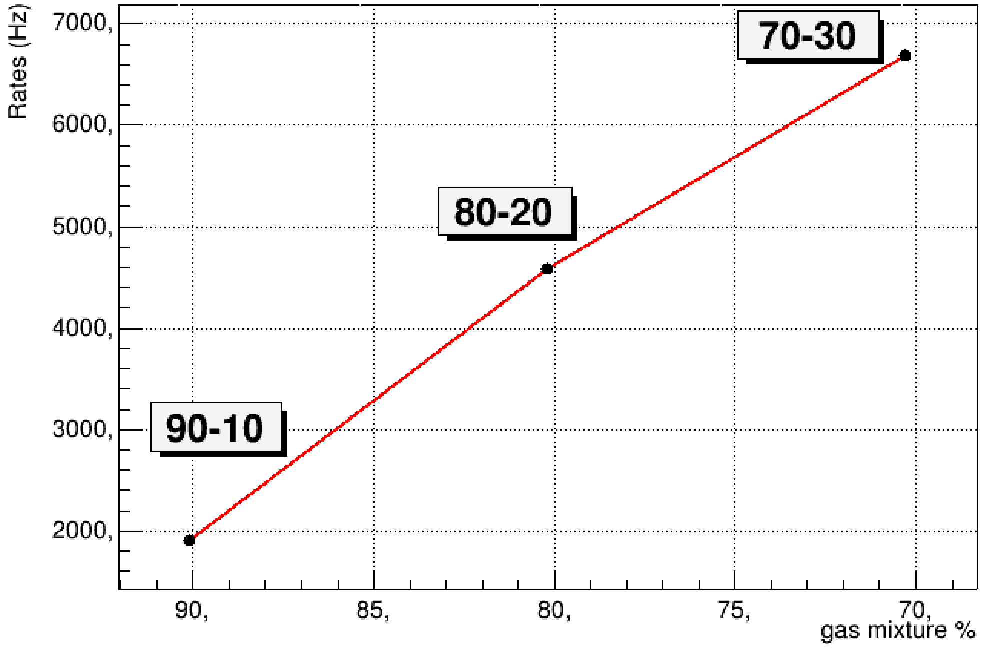
With Cd Mask

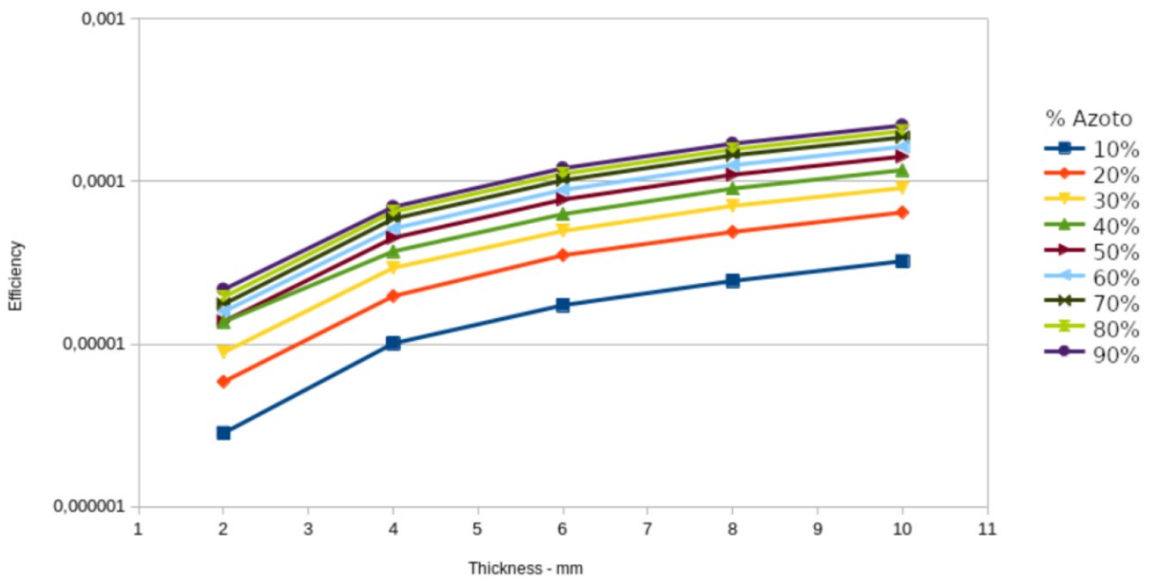


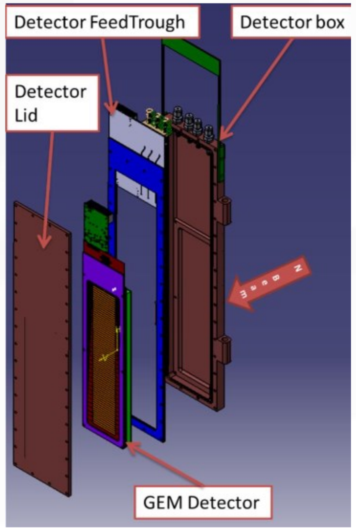
Detection efficiency and counting rate as a function of N_2 content

- Preliminary estimation of the detection efficiency

  – $\varepsilon_{GEM} = \frac{cps_{GEM}}{cps_{3He}} * \varepsilon_{3He} \sim 10^{-4} - 10^{-5}$



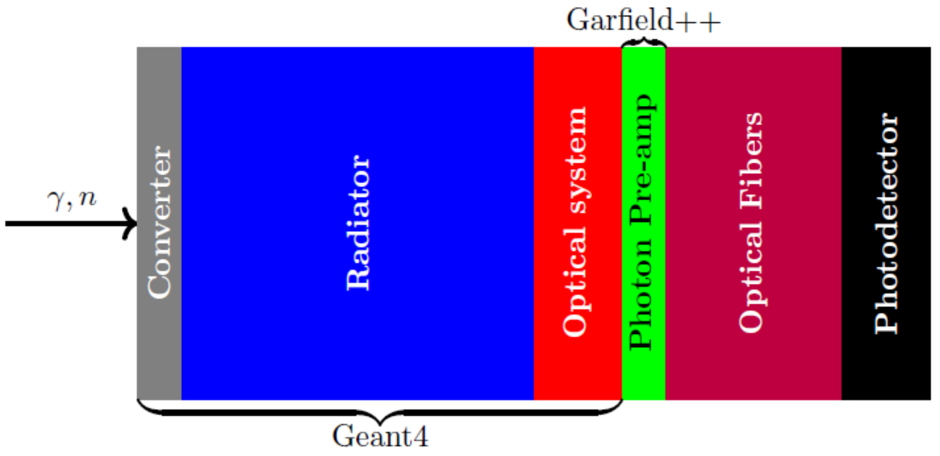


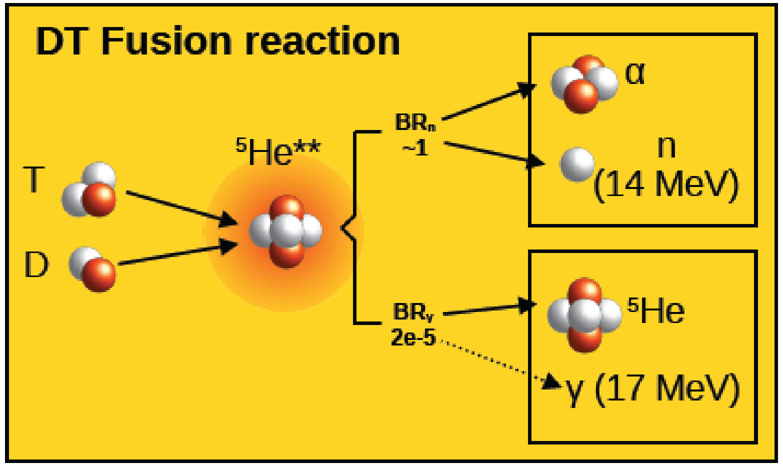


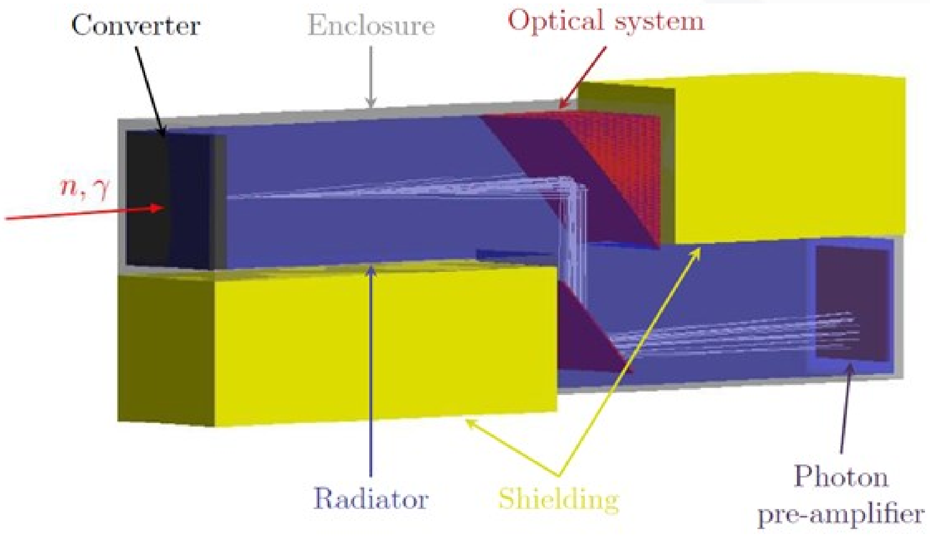
Very promising for construction of low material budget thermal neutron beam monitors

(TH)GEM photon preamplifier using pure N_2

- The project behind this R&D: development of a **Cherenkov light** detector for fusion power measurements for tokamak operating in DT







- Over threshold **γ efficiency** 10^{-3}.
- **Neutron efficiency** 10^{-6}.
- Efficiency ratio compensates for branching ratio
- **Photon pre-amplifier** boosts the Cherenkov..

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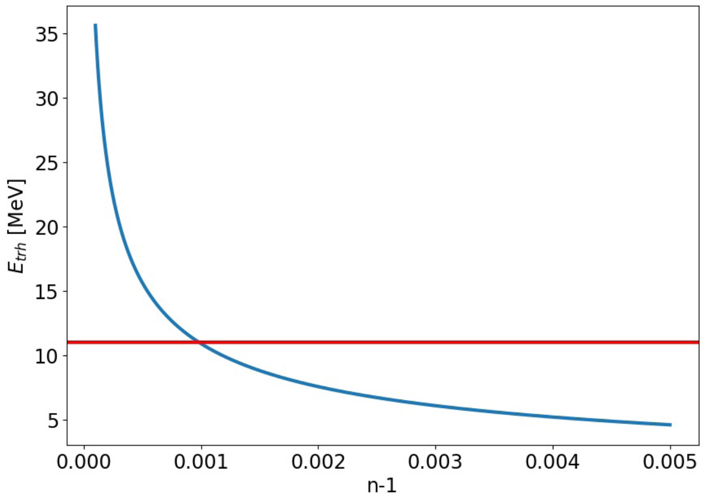
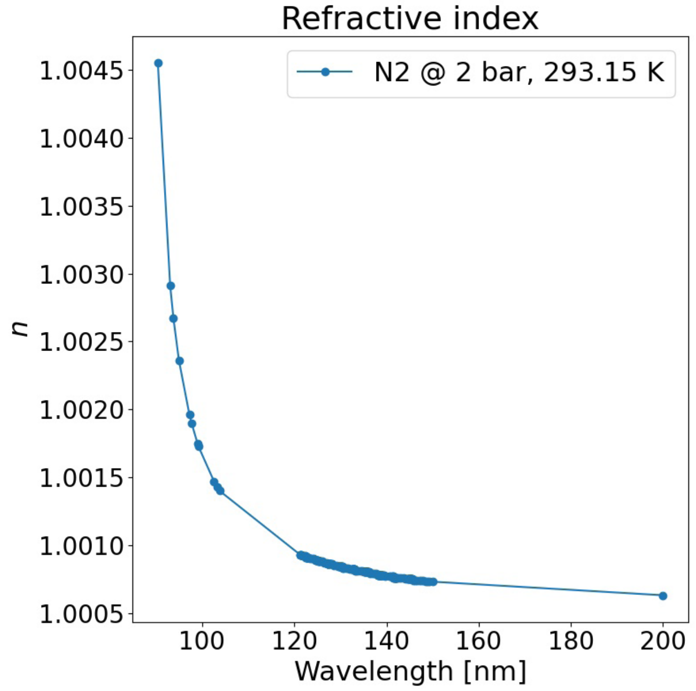
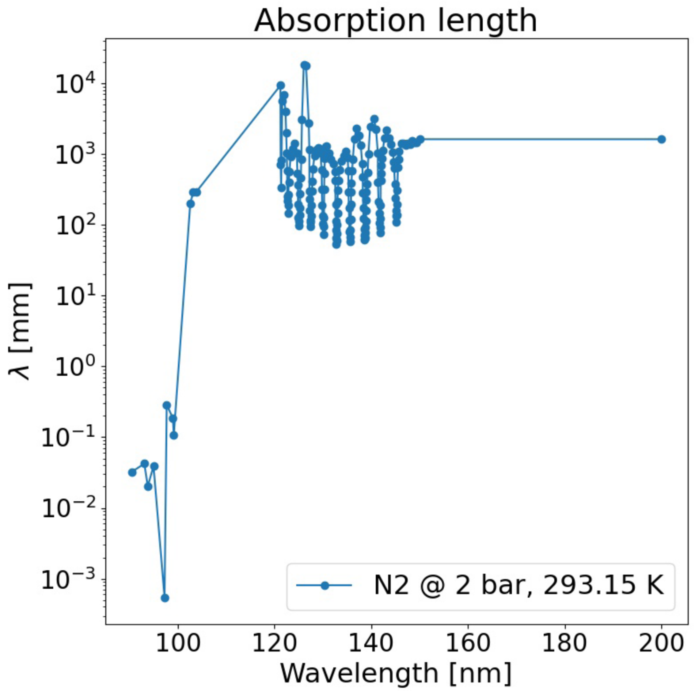
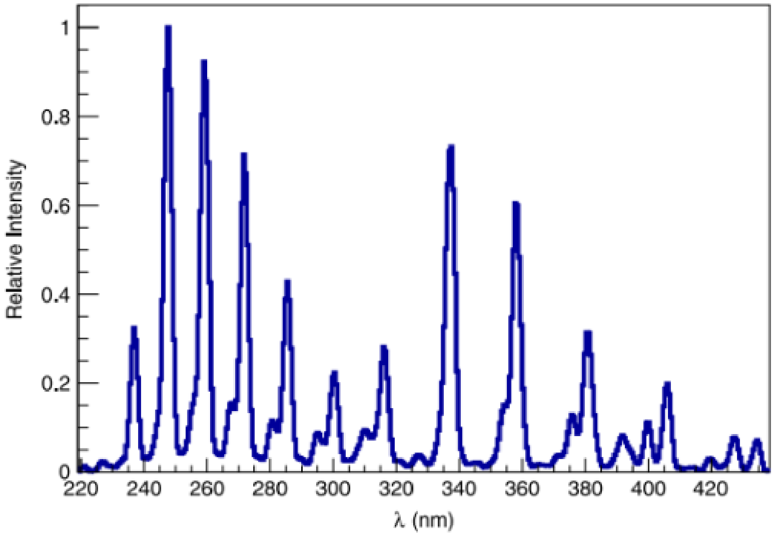
(TH)GEM photon preamplifier using pure N_2 – Why N_2?

Electron Cherenkov threshold as a function of medium refractive index.

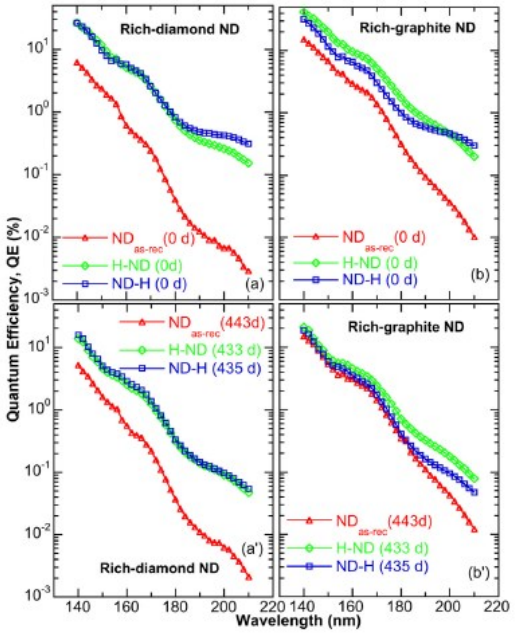


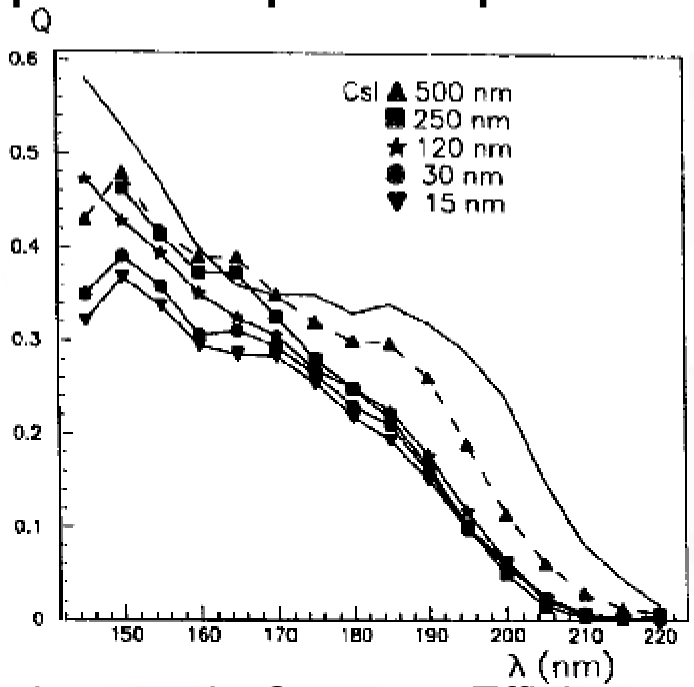






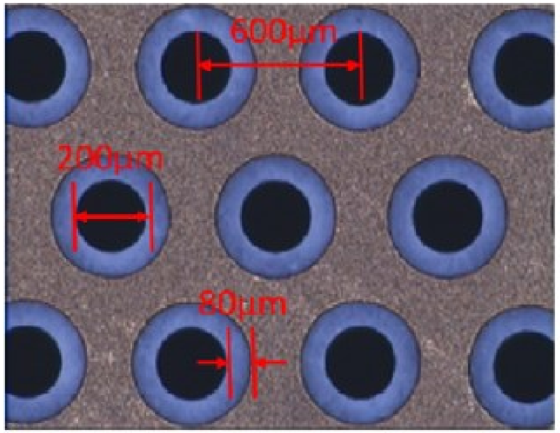
(TH)GEM photon preamplifier using pure N_2 – Why N2?

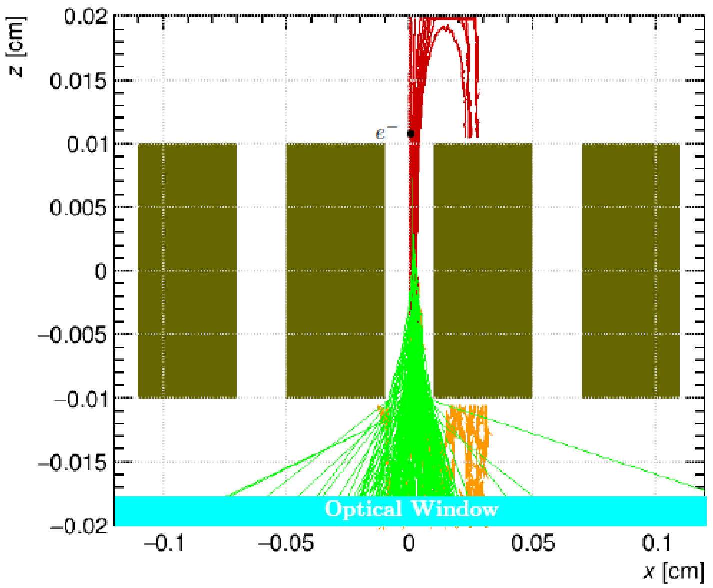


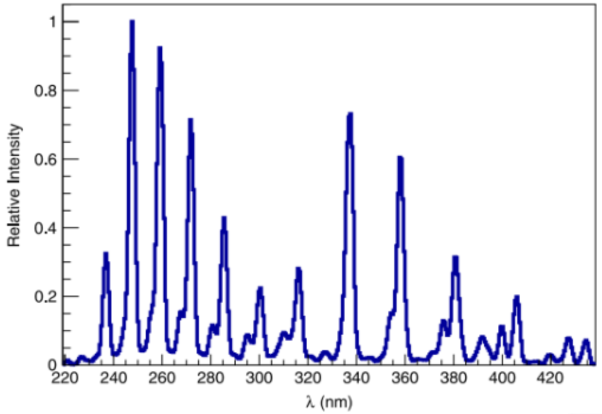


CsI and Nanodiamonds phrocatode Quantum Efficiency

CsI/ Nanodiamonds coated (TH)GEM as phtoon preamplifier.
THGEM comes from CSNS





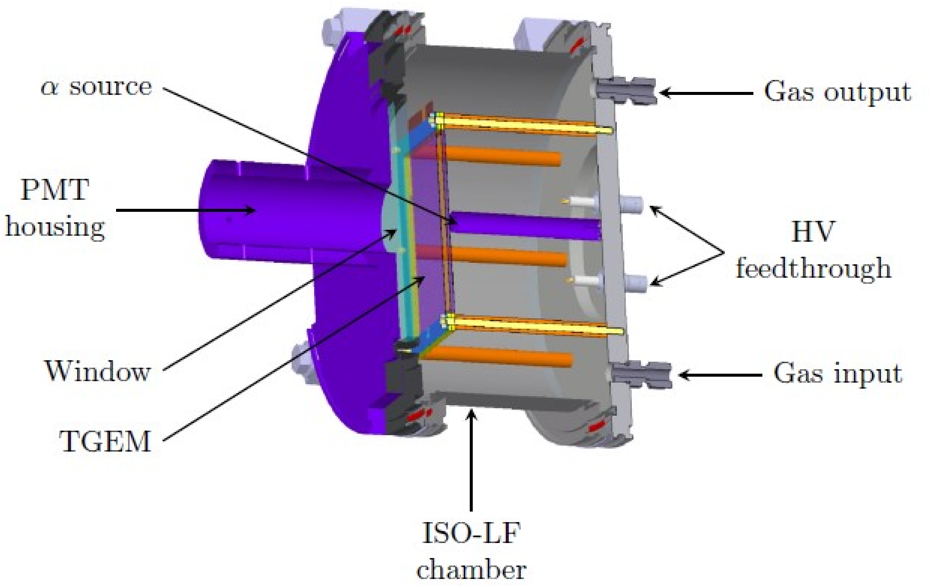


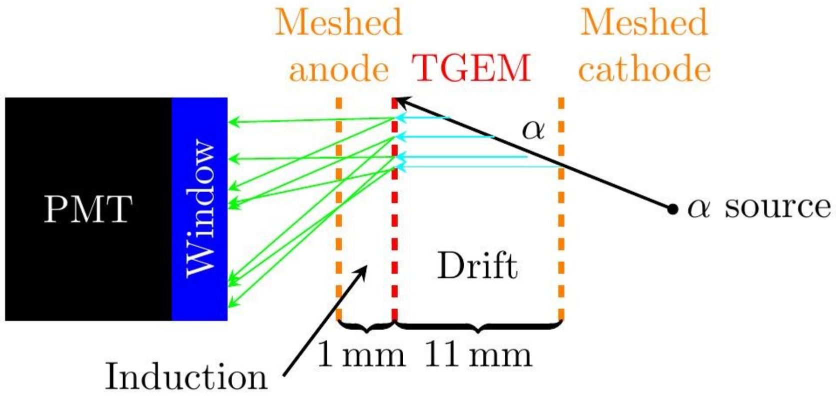
Fluorescence emission of N_2

- Cherenkov photons wavelength are < 200 nm
- If scintillation is only > 200 nm a suitable photocathode (CsI) can discriminate Cherenkov and scintillation photons

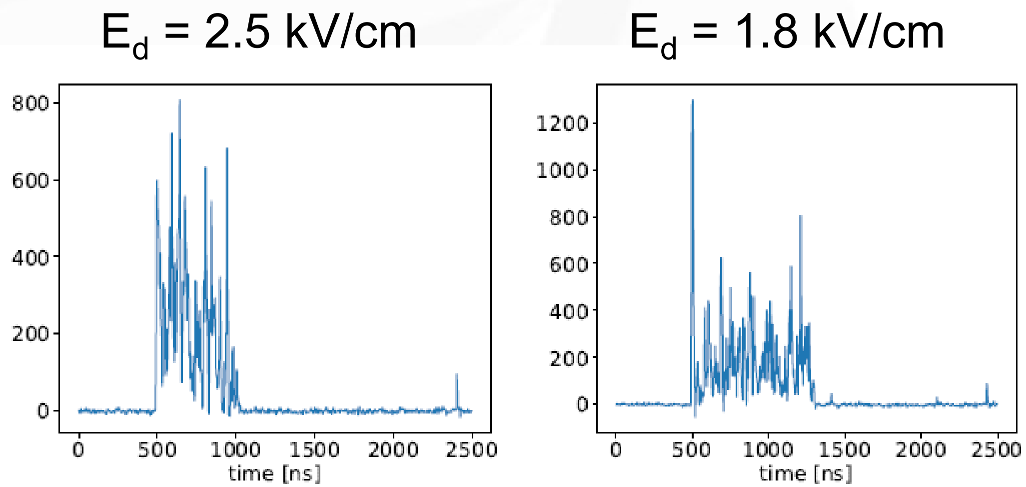
Preliminary test: experimental setup
Test of N_2 scintillation signals using PMT

Use ^{241}Am source (alpha emitter) as an electron source

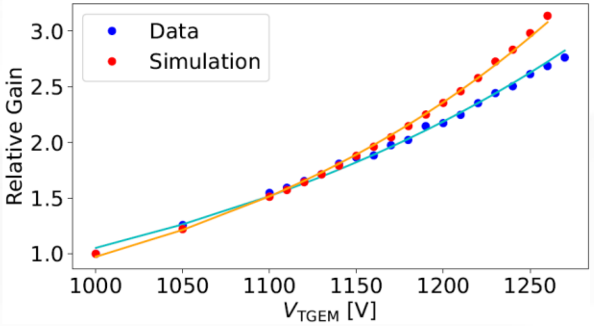


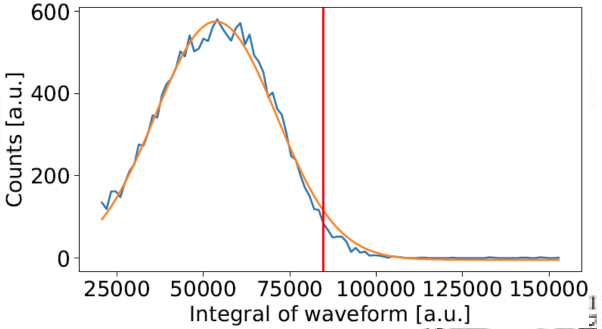


PMT: Hamamatsu R9420-100-10-mod



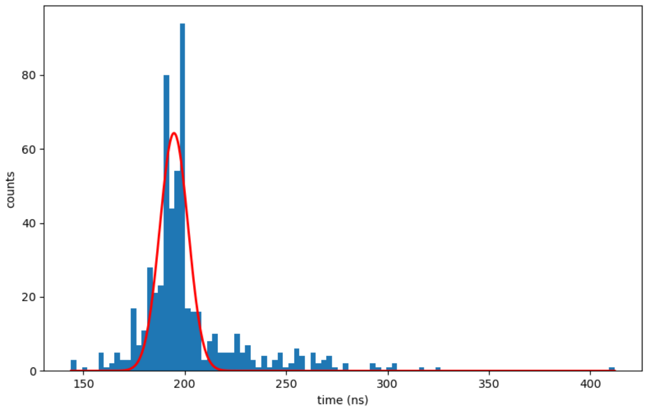
Waveforms of signals recorded by a PMT for two different drift electric fields in pure N2 at 1 Bar, 20 degC



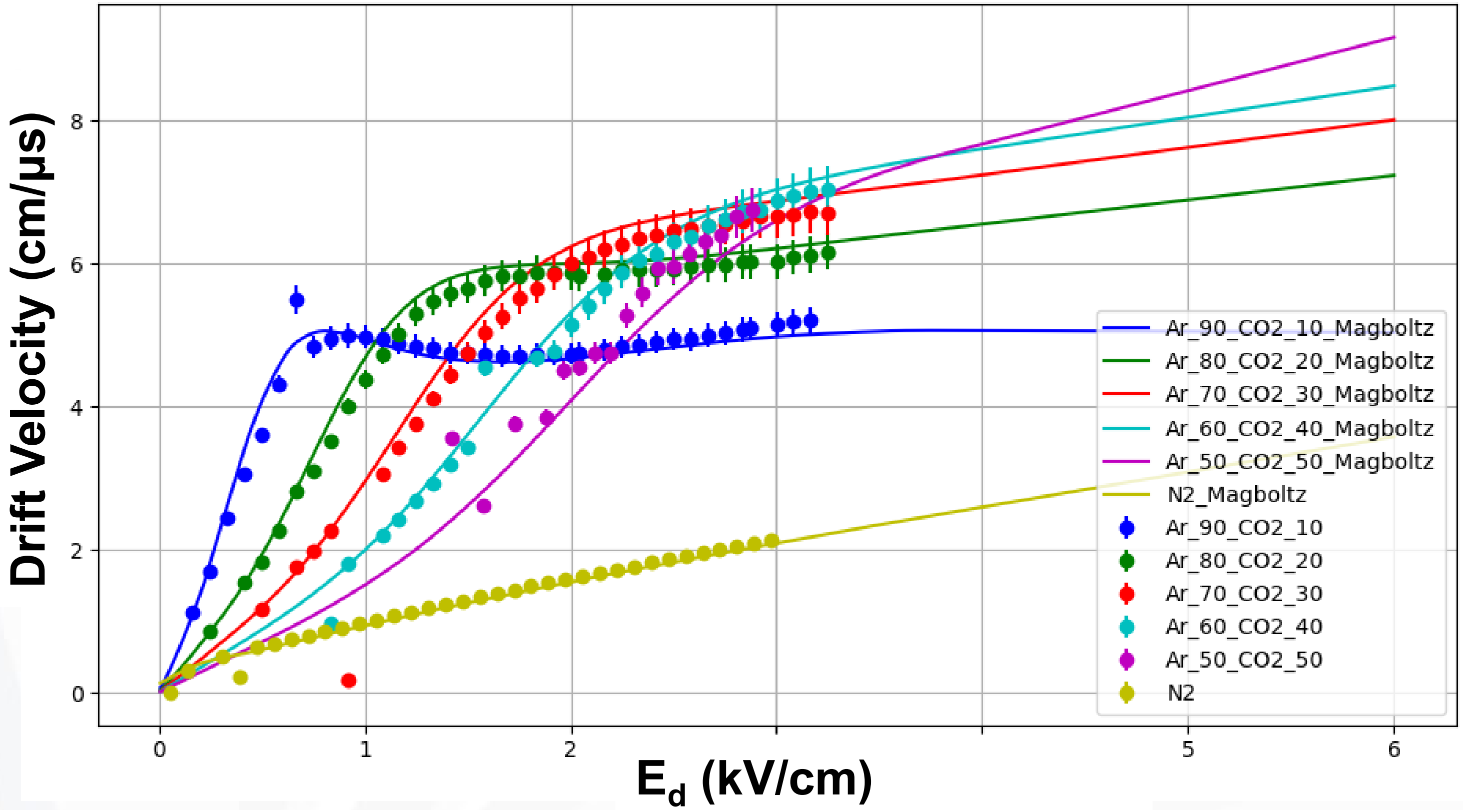


Amplification as a function of ΔV_{THGEM} and PH spectrum

Test of N_2 scintillation signals: Measurement of e^- drift velocity



Histogram of time duration of waveforms



Proof that we are really detecting N_2 scintillation light!
Experimental setup also tested with other gases

Next step: get a CsI or NanoDiamond coated (TH)GEM and measure photocurrent in pure N_2 at different pressures!

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Conclusions and Future Perspectives

- Different detectors have been operated using N_2 based gas mixtures
  - Possible development for X-Rays detector using closed-loop gas systems.
    - Most of the purifiers are not sensitive to N_2
  - N_2 GEM detectors based neutron beam monitors can be a solution for low material budget beam monitors for high flux sources (like ESS)
  - N2 can be used as a scinitillation gas for alpha particle detection and (maybe) UV-light
    - We are going to test CsI or nanodiamonds coated (TH)GEM using UV generator
    - We are trying to restore the nanodiamond UV photocathode activity (started by INFN Trieste) with ISTP-Bari.

- Maybe we need better description of N_2 cross section (ionization, excitation,…) for correct simulation

Spare Slides

Single GEM measurements

ArN2 70%-30%

ArN2 80%-20%

ArN2 90%-10%