# Tests of eco-friendly gas mixtures in GEM based detectors with optical readout

**D. Piccolo**
**(Laboratori Nazionali di Frascati)**
***for***
***the Cygno Collaboration***

# The Eco Gas issue

➢**The European Community has prohibited the production and use of gas mixtures with Global Warming Power > 150 (GWP($CO_2$) = 1)**

✓This is valid mainly for industrial (refrigerator plants) applications

✓Scientific laboratories would be excluded

➢ **Many GEM based applications uses or plan to use tetrafluoromethane ($CF_4$) in the mixture**

➢ LHCb (Ar-$CO_2$-$CF_4$)

➢ Cygno (He-$CF_4$)

➢ **GWP($CF_4$) = 6500**

➢ **Although scientific laboratories could still use $CF_4$**

➢ Recuperation systems are needed to not put $CF_4$ in the environment

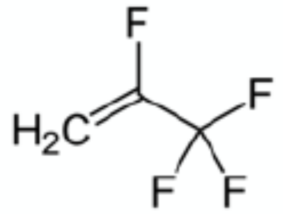
➢ Prices of banned gases could became more expansive in the next years

# Eco friendly gas candidate

- Studies ongoing since about 4 years mainly in the RPC community
  - Main gas used for RPCs working in avalanche mode (LHC experiments): tetrafluoroethane $C_2H_2F_4$ (commonly known as r134a)

**Possible replacement under study**

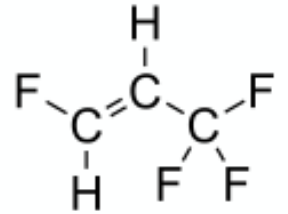
Hydro-Fluoro-Olefin (HFO)
- hydrogen-containing
- fluorine-containing
- C=C double bond




**HFO-1234yf (flam)**

($C_3H_2F_4$)

GWP 4




**HFO-1234ze**

($C_3H_2F_4$)

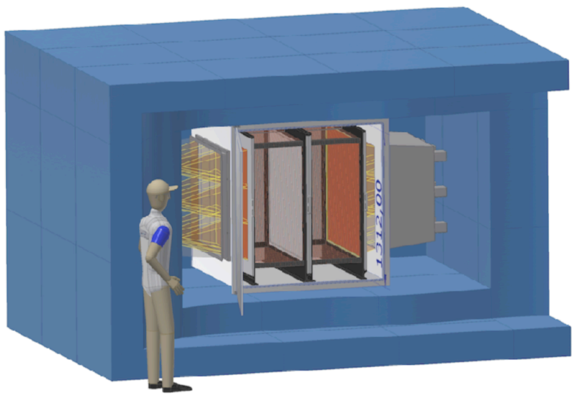
GWP 6

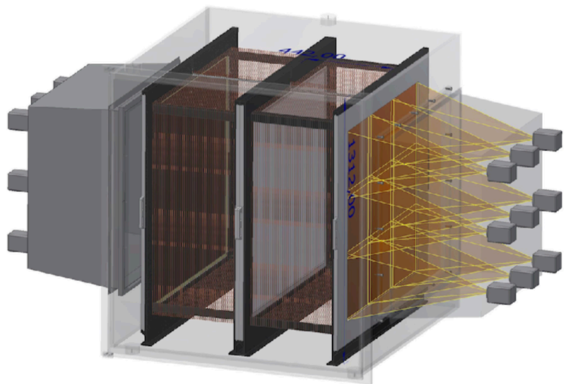
**HFO-1234ze under study in Frascati**

**References:**
- “Eco-friendly gas mixtures for Resistive Plate Chambers based on tetrafluoropropene and Helium”, D. Piccolo et al. Jinst Vol 11 August 2016
- “Preliminary results of Resistive Plate Chambers operated with eco-friendly gas mixtures for application in the CMS experiment” , D. Piccolo et al. *JINST* 11 C09018
- “Properties of potential eco-friendly gas replacements for particle detectors in high-energy physics”, D. Piccolo et al., Jinst Vol 13 March 2018

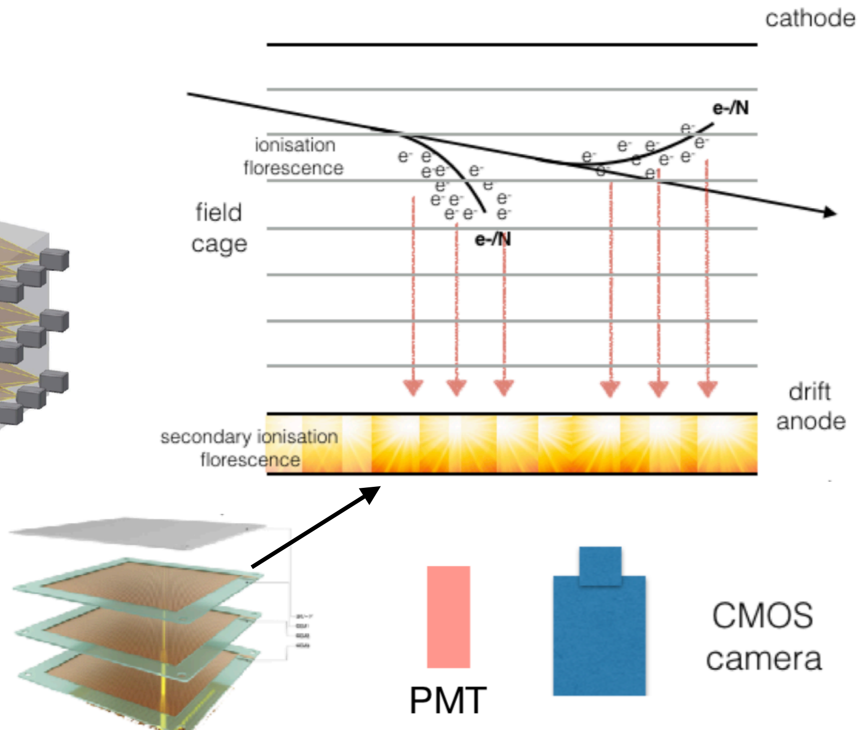
# The CYGNO project

CYGNO is a demonstrator exploiting large gas TPC, GEM based charge amplification, hight granularity and sensitivity of optically readout at atmospheric pressure in He-$CF_4$ based gas mixture





multiple GEM structures is used to obtain **gain** and **stable** detectors.



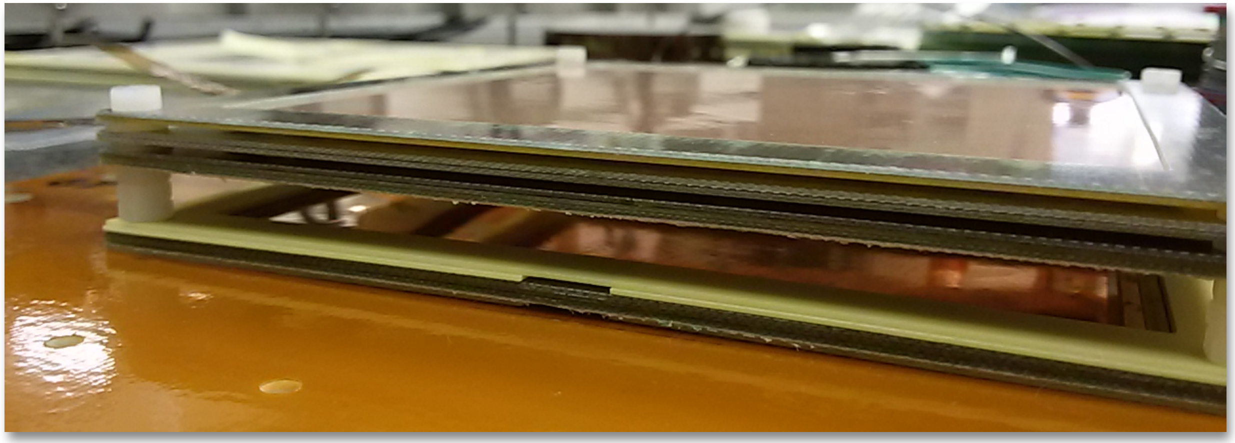

**Possible replacement of CF4 with HFO:**

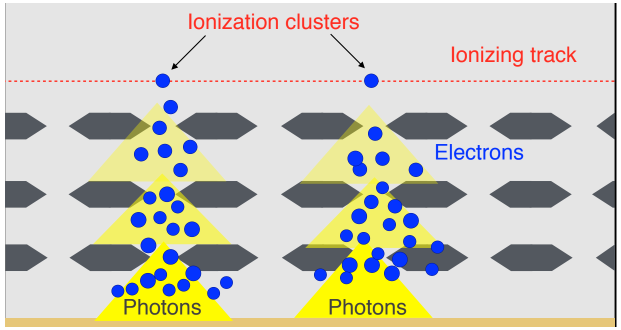
- **Ecological motivation**
- **Economic motivation (banned gas price could increase)**
- **Economical/pratical: recuperation system needed**
- **Presence of Hydrogen (going down with Wimp mass sensitivity)**

# Detector layout used for tests

## Optically ReAdout GEm

10x10 cm$^2$ standard GEMs





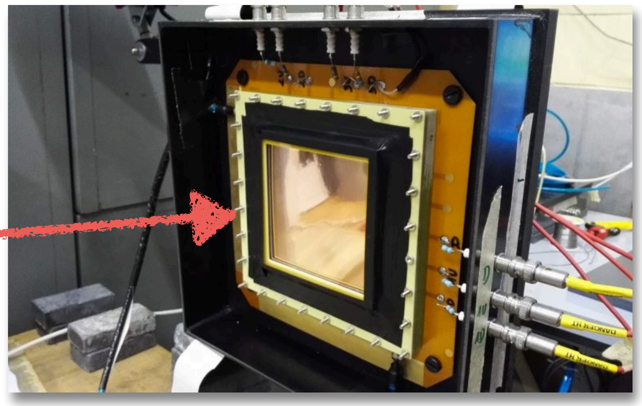

2 mm transfer gaps

**For the measurement of this talk a 4th GEM foil has been added**

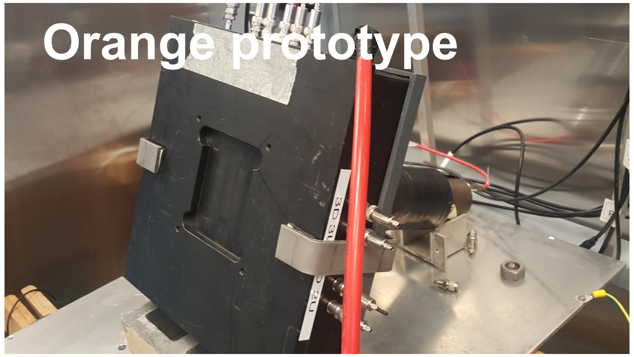
---

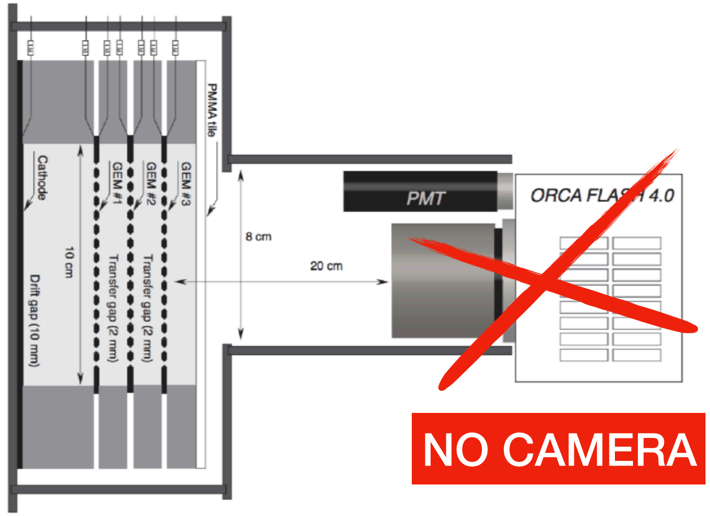
**1 cm drift region**
**2 mm distance between GEM foils**

transparent window is placed below the last GEM



# Measurement set-up

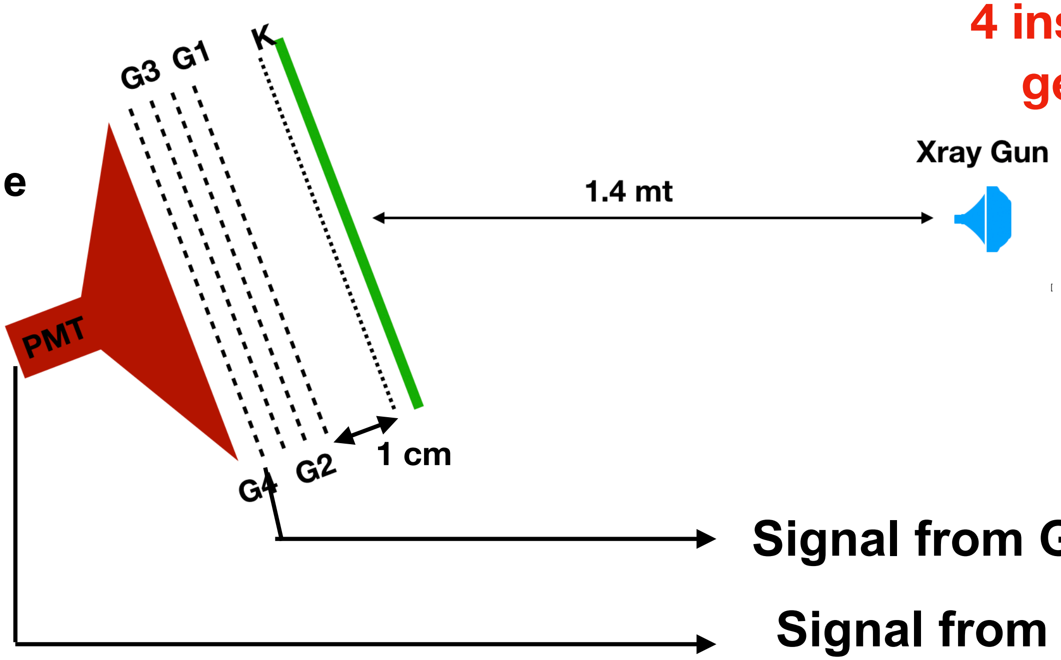




NO CAMERA

4 instead of 3 gem foils

Not in scale



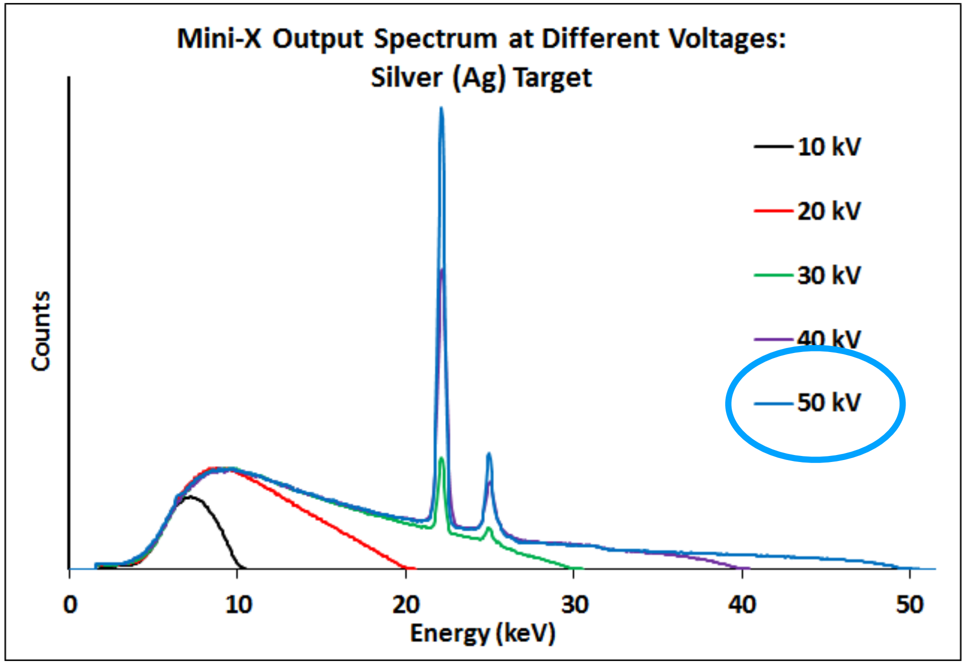

Signal from G4 foil

Signal from PMT

To scope
And ADC

# GEM gain estimation


**Xray Energy Peak at 22 KeV**
**Xray absorbed by copper atoms of cathode.**
**8 KeV Xray emitted by fluorescence**




**He-CF4 (60-40) $W_i$ = 46,6 eV**
**He-CF4 (70-30) $W_i$ = 45 eV**
**He-CF4-HFO (70-20-10) $W_i$ not available (assume 45 eV)**

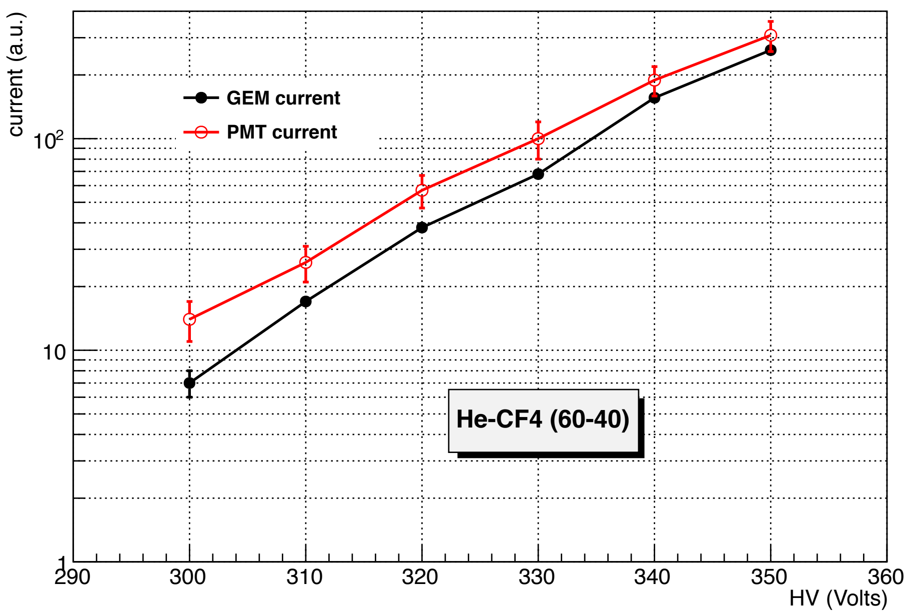
**$N_{e-}$ per Xray = 8000/$W_i$ $e^-$ = 172-178**

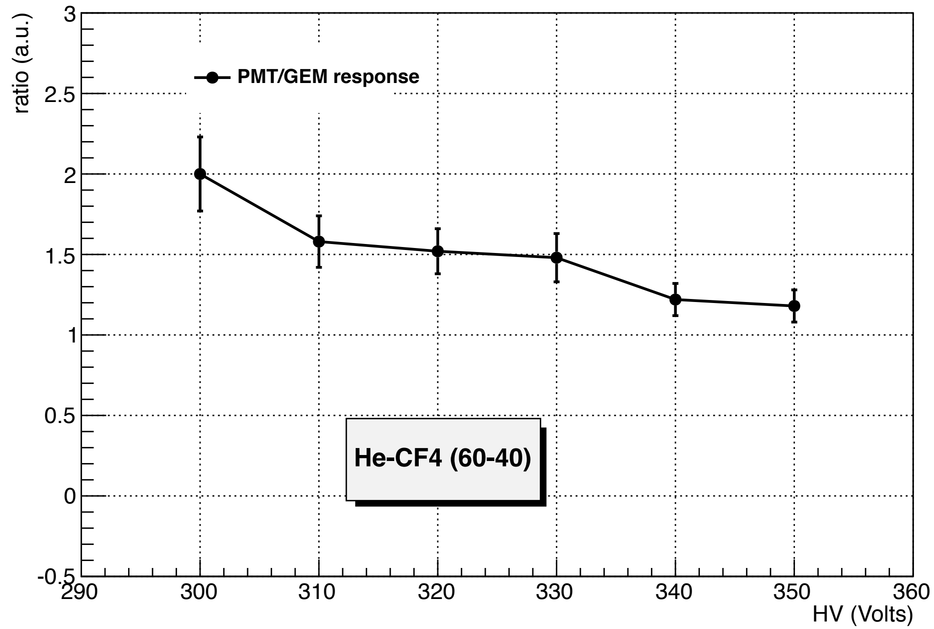
$G = \langle Q \rangle / (q_e \times N_{e-})$

<Q> from signal integral on the scope

# He-CF4 (60 %-40%)

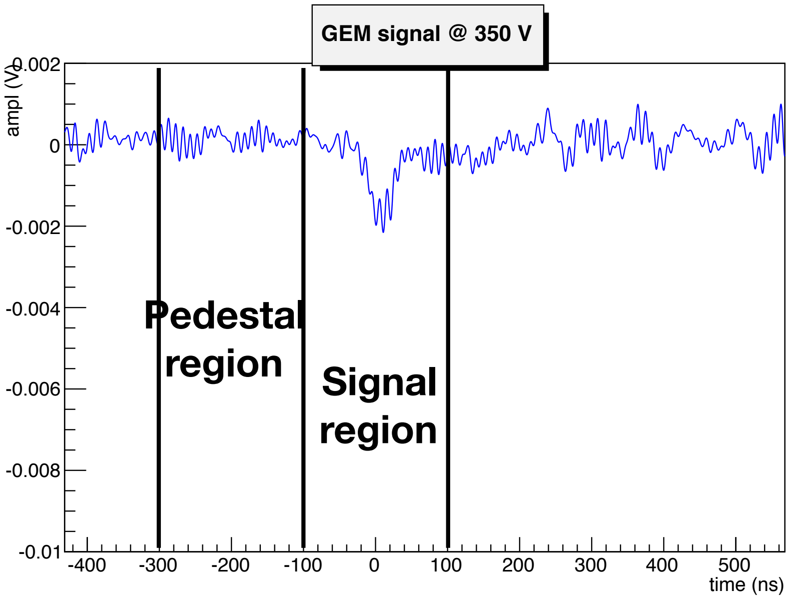
**X-ray Gun current: 5 uA**
PMT Voltage: 1400 V
GEM transfer field: 1.5 kV/cm
Drift field: 1 kV/cm



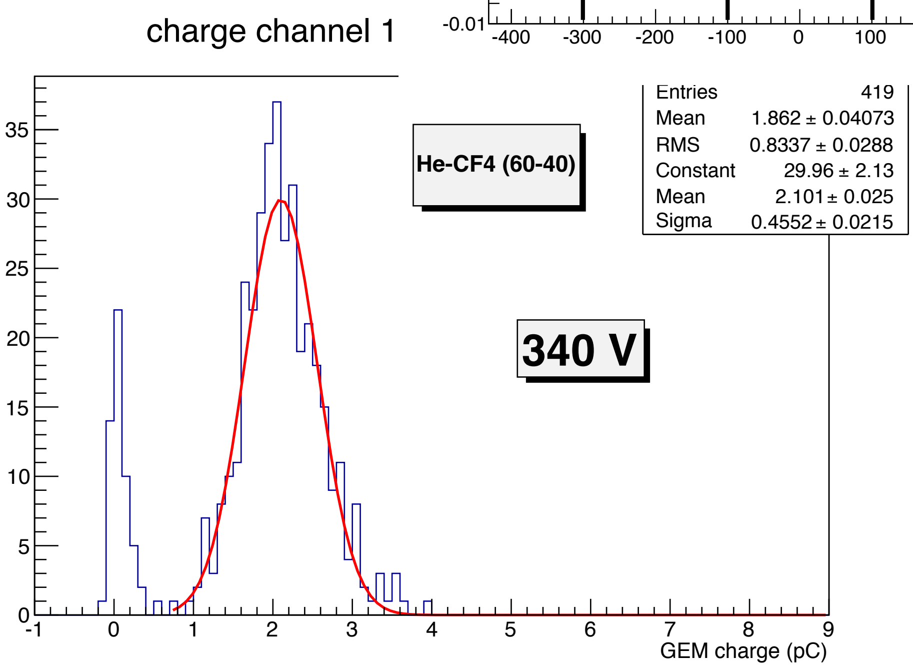
# He-CF4 (60%-40%)

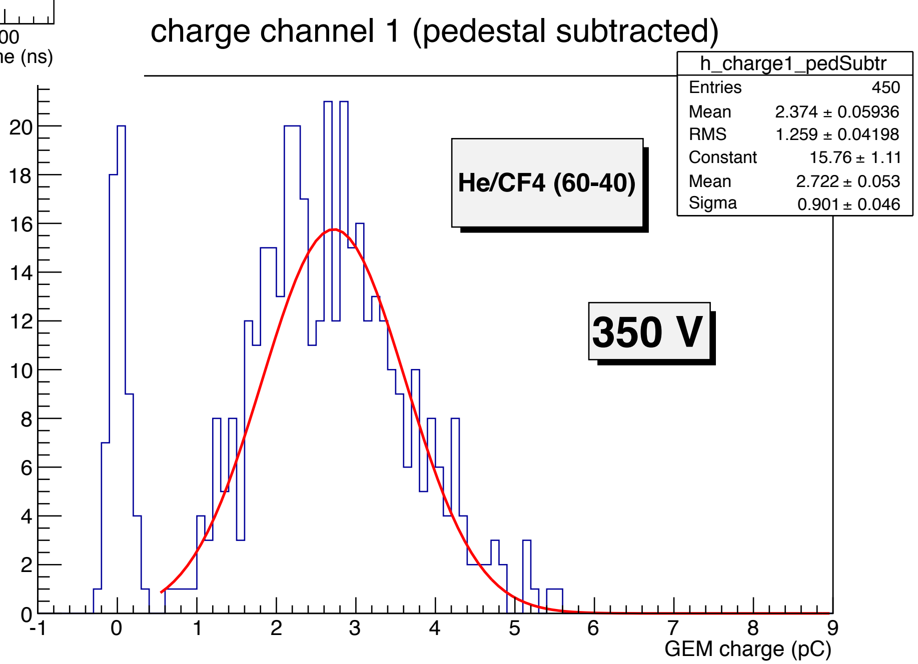
# WAVEFORMS analysis



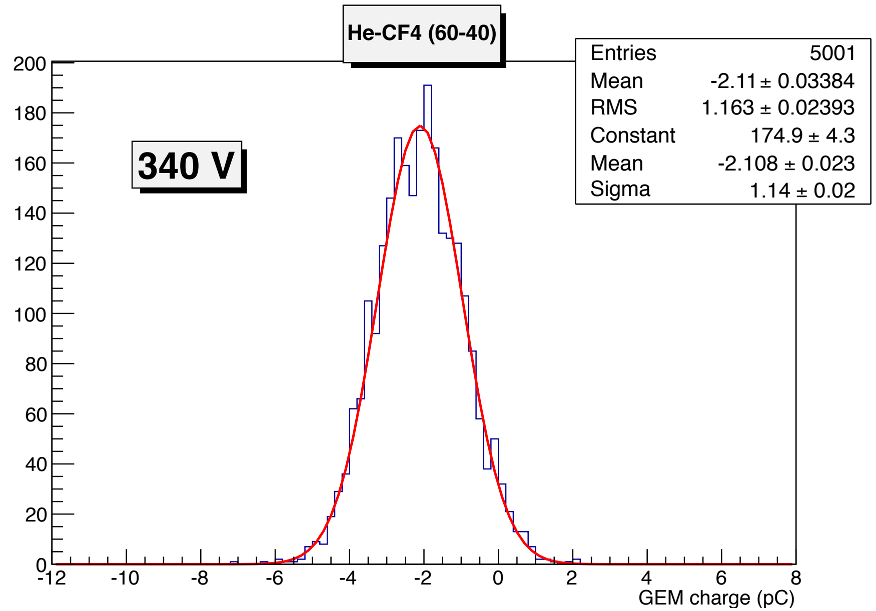

**Need to save several waveforms per measurement.**

**Measurements in the next slides done with scope integral.**



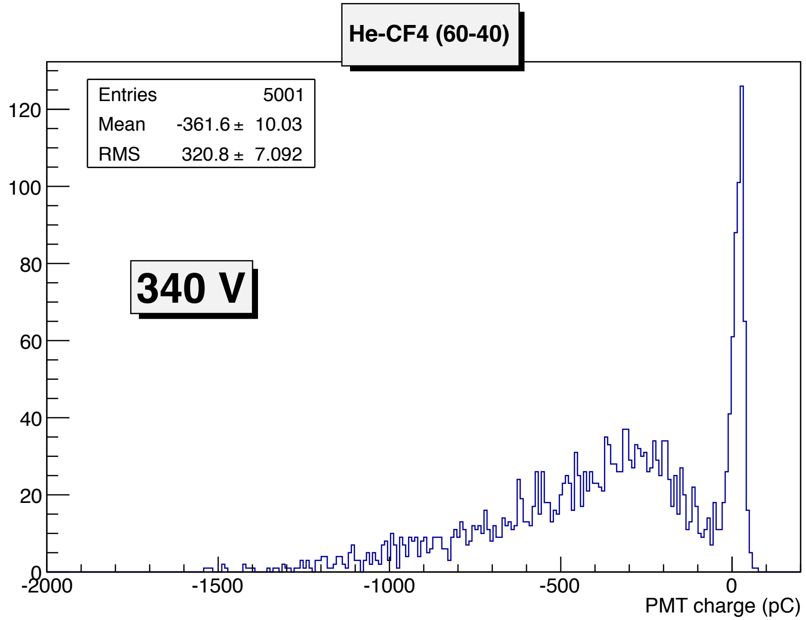



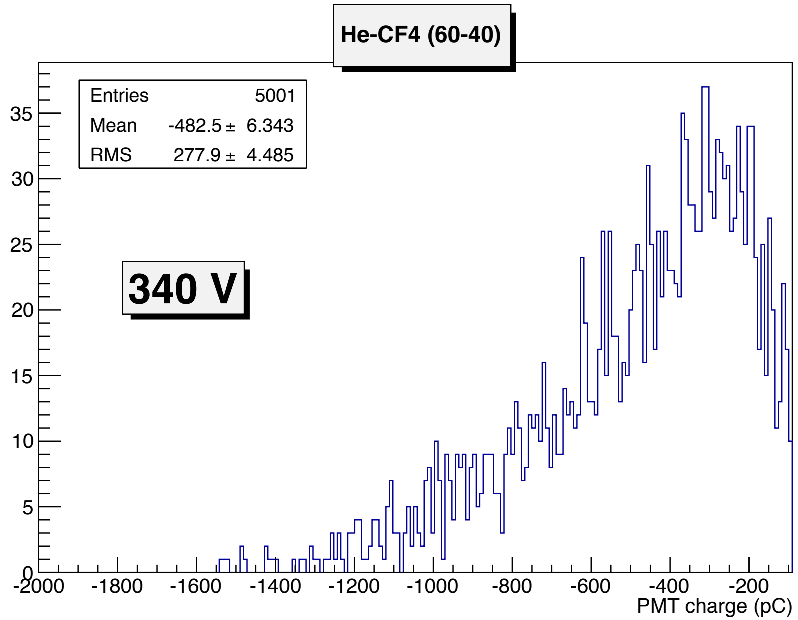
# He-CF4 (60 %-40%) @340 V



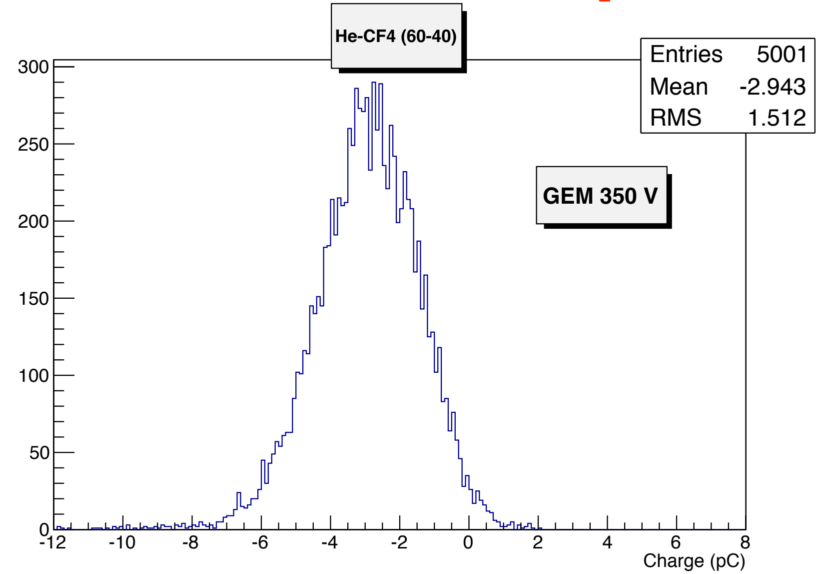

$G = \langle Q \rangle / (q_e \times N_{e-}) = \mathbf{8 \times 10^4}$

$Q_{PMT}/Q_{GEM} = \mathbf{230}$



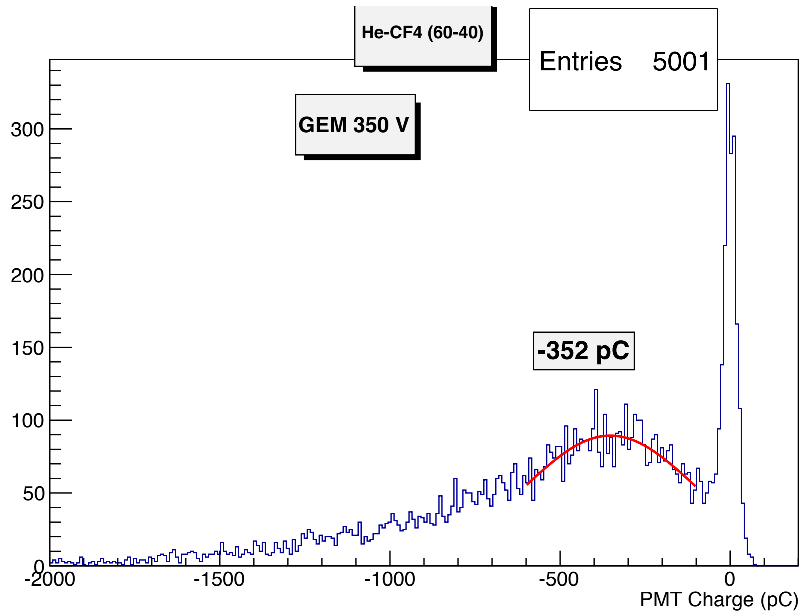



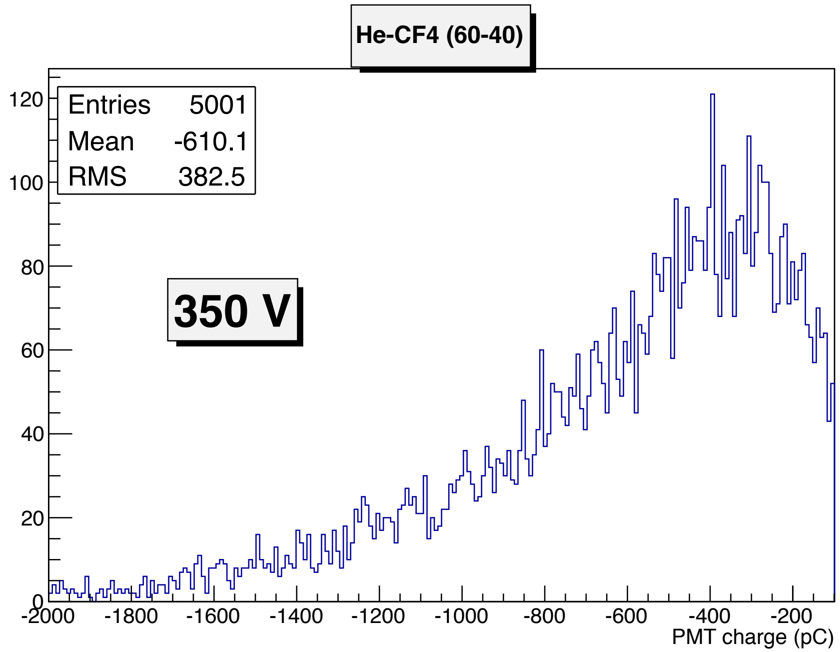
# He-CF4 (60 %-40%) @350 V




$$G = \langle Q \rangle / (q_e \times N_{e-}) = \mathbf{1 \times 10^5}$$

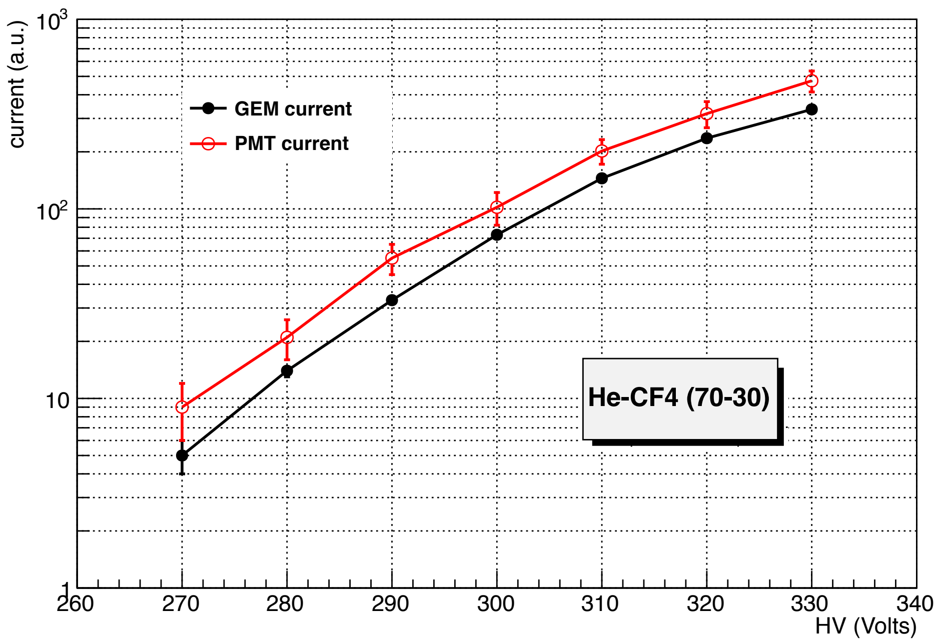
$$Q_{PMT}/Q_{GEM} = \mathbf{210}$$

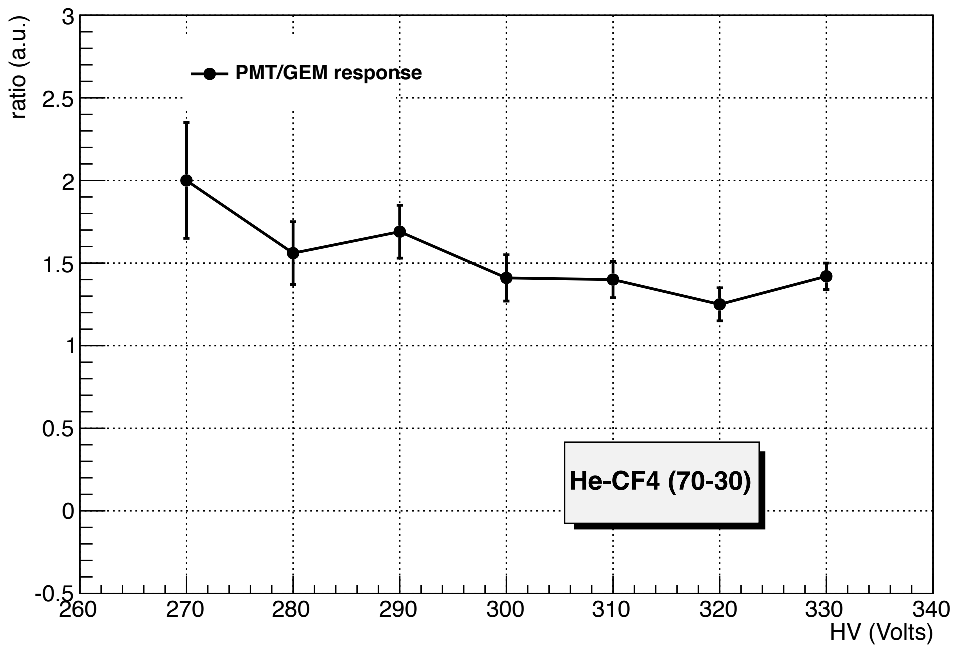


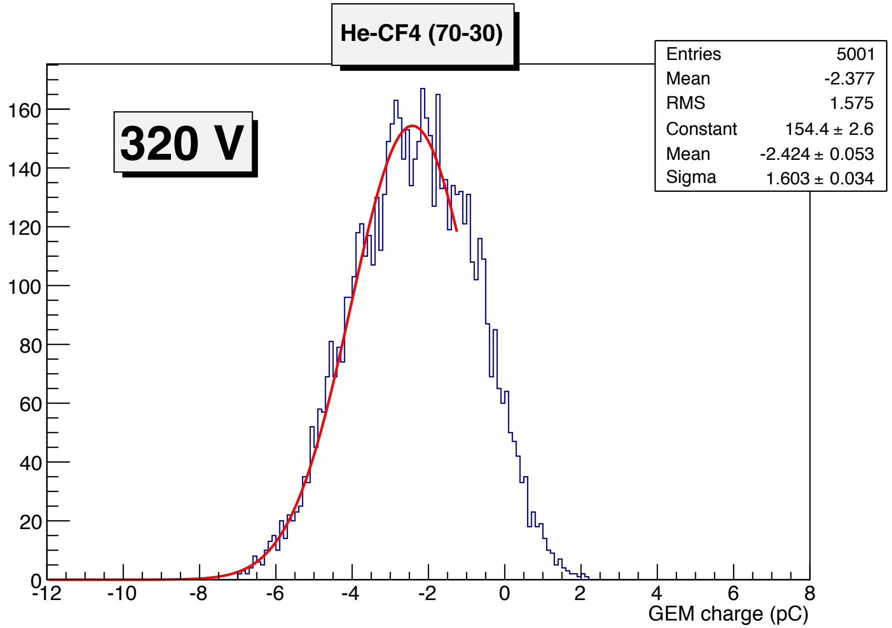
# He-CF4 (70%-30%)

**X-ray Gun current: 5 uA**
PMT Voltage: 1400 V
GEM transfer field: 1.5 kV/cm
Drift field: 1 kV/cm



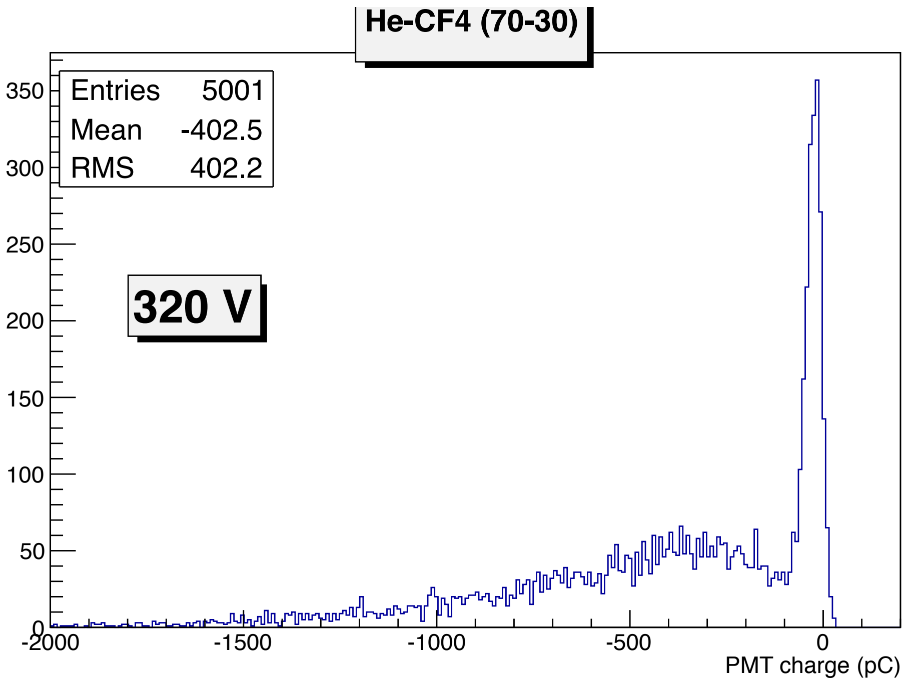



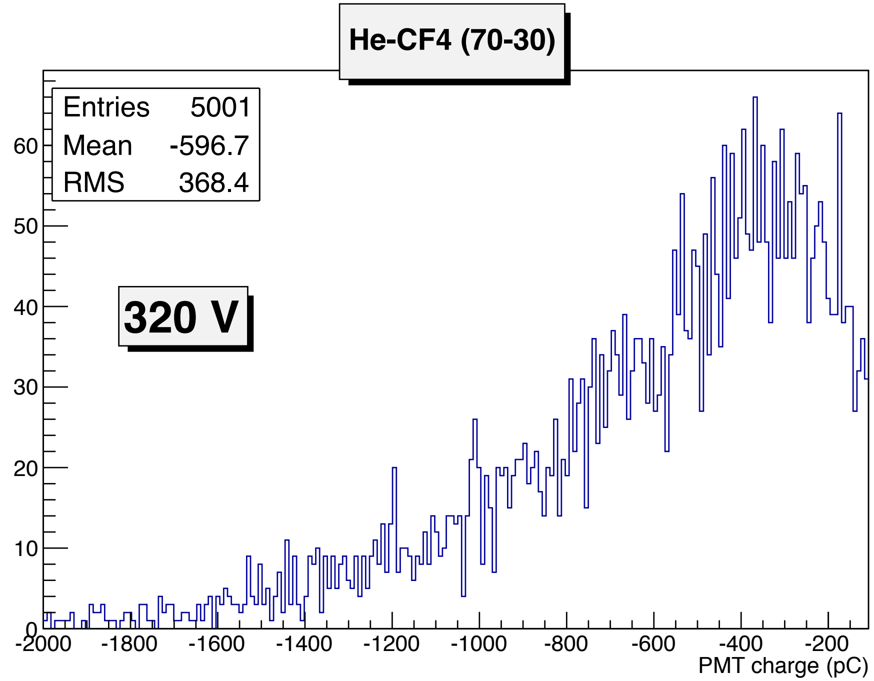
# He-CF4 (70-30) GEM @ 320 V



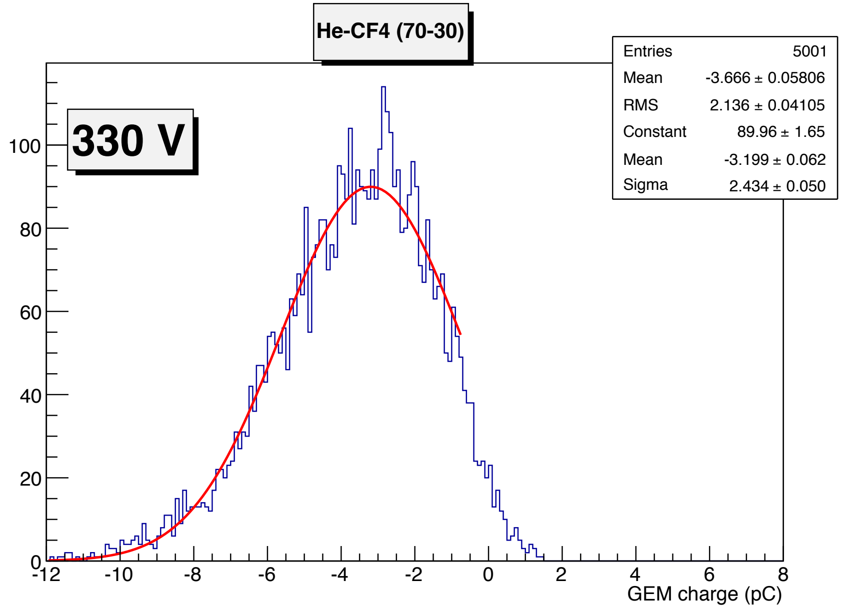

$$G = \langle Q \rangle / (q \times N_{e-}) = \mathbf{8.5 \times 10^4}$$

$$Q_{PMT}/Q_{GEM} = \mathbf{250}$$



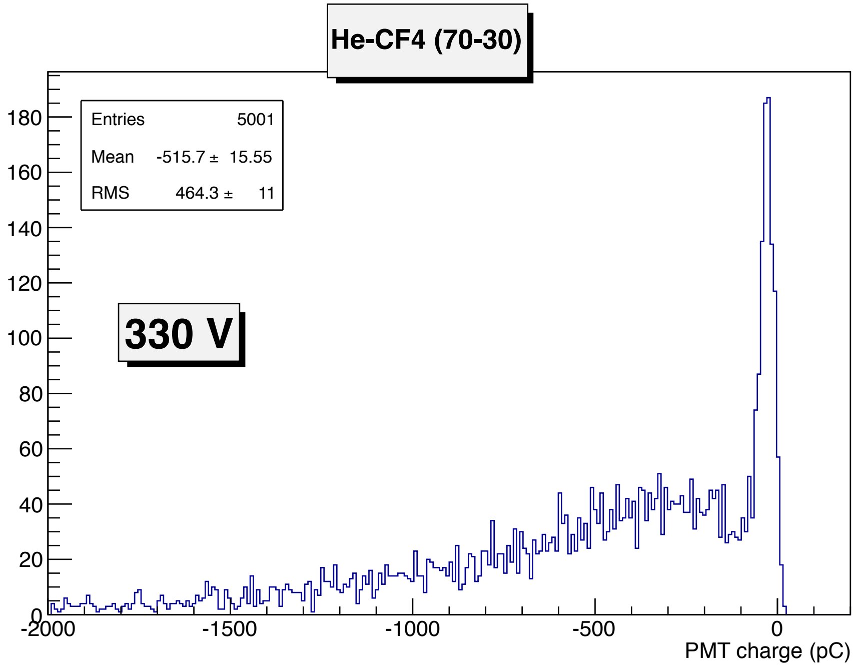



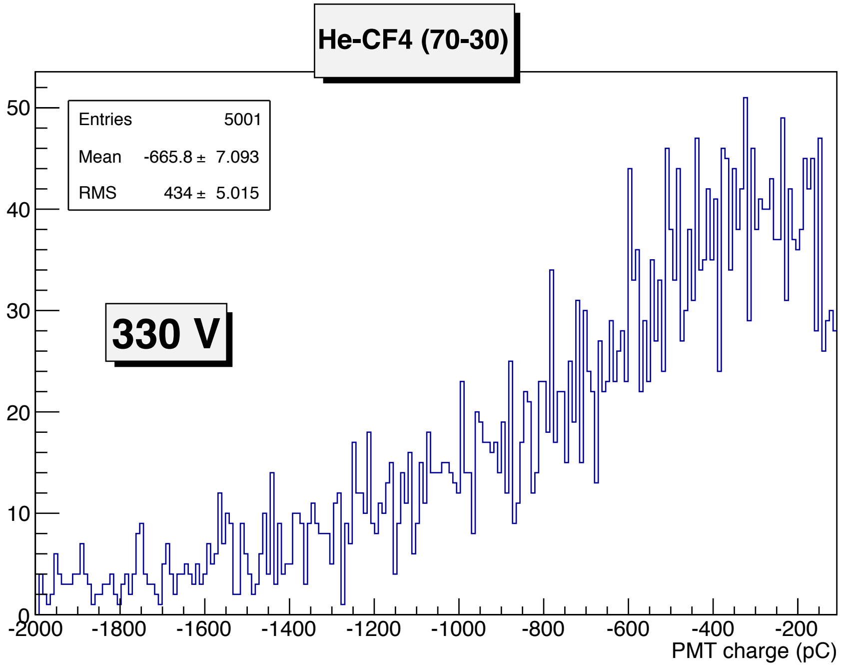
# He-CF4 (70-30) GEM @ 330 V




$$G = \langle Q \rangle / (q \times N_{e-}) = \mathbf{1.1 \times 10^5}$$

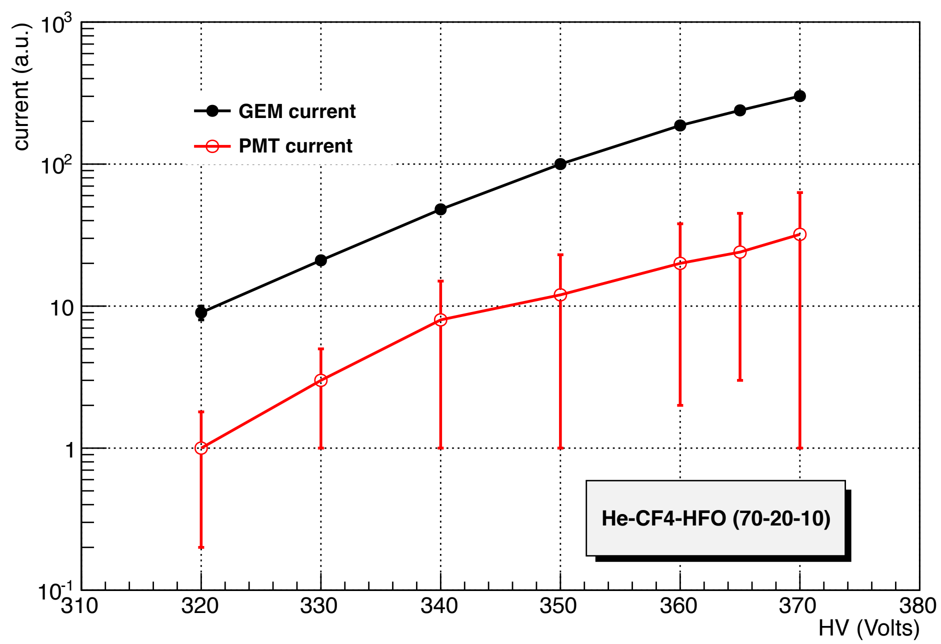
$$Q_{PMT}/Q_{GEM} = \mathbf{210}$$

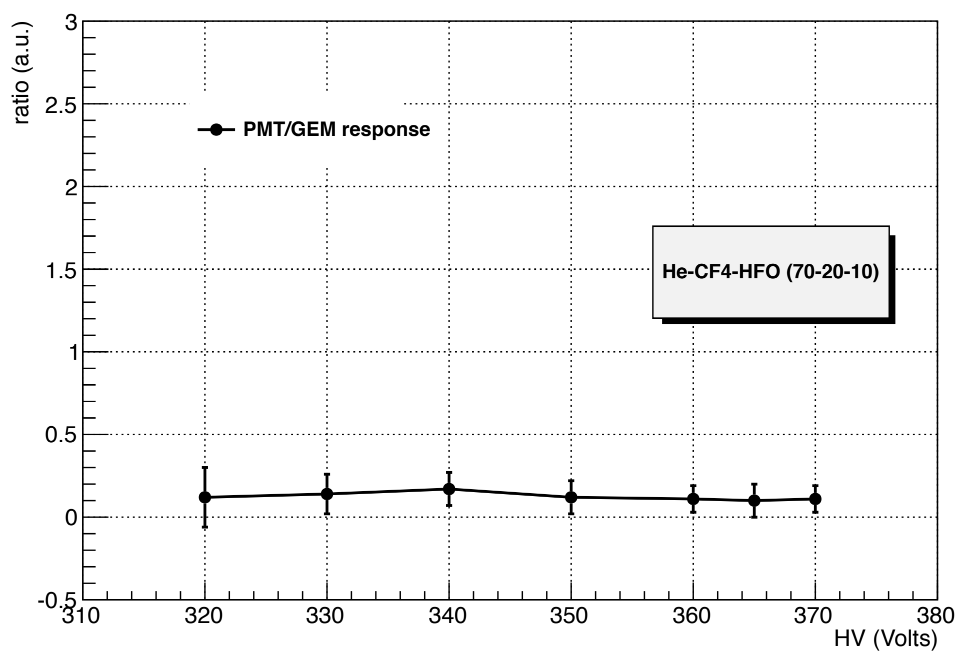


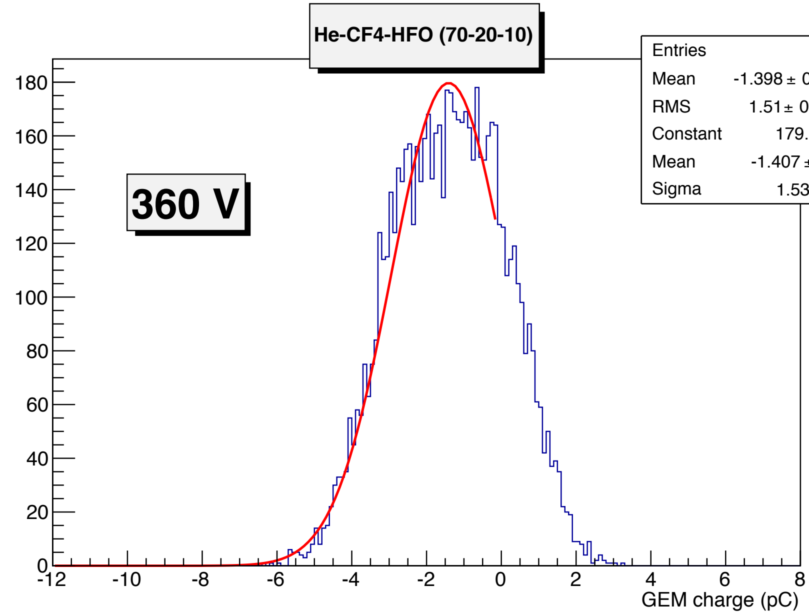
# He-CF4-HFO (70-20-10)

**X-ray Gun current: 5 uA**
PMT Voltage: 1400 V
GEM transfer field: 1.5 kV/cm
Drift field: 1 kV/cm



# He-$CF_4$-HFO (70-20-10)



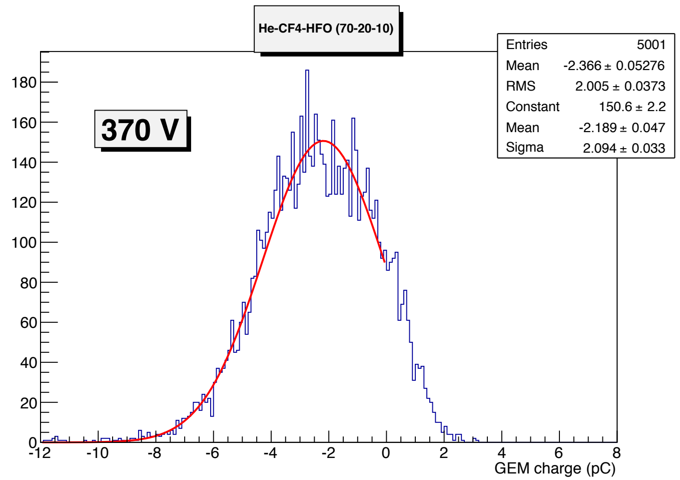

**360 V**

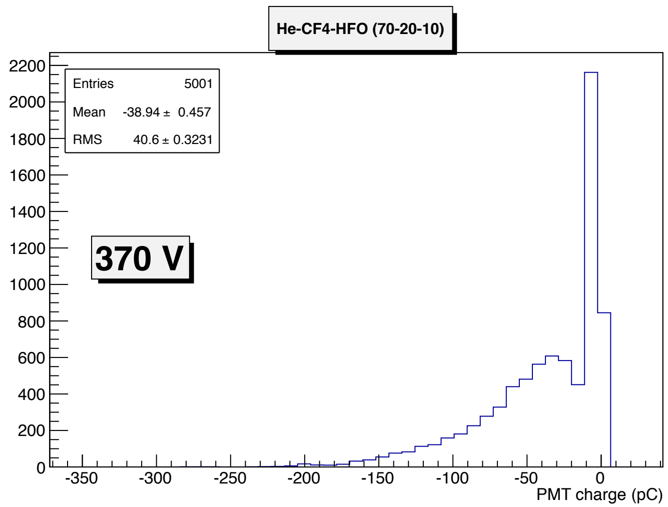
$G = \langle Q \rangle / (q \times N_{e-})$ = **5 x $10^4$**

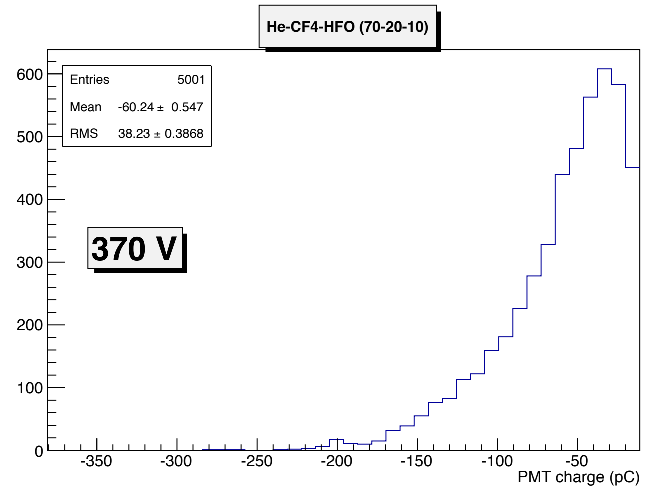
**370 V**

$G = \langle Q \rangle / (q \times N_{e-})$ = **7 x $10^4$**

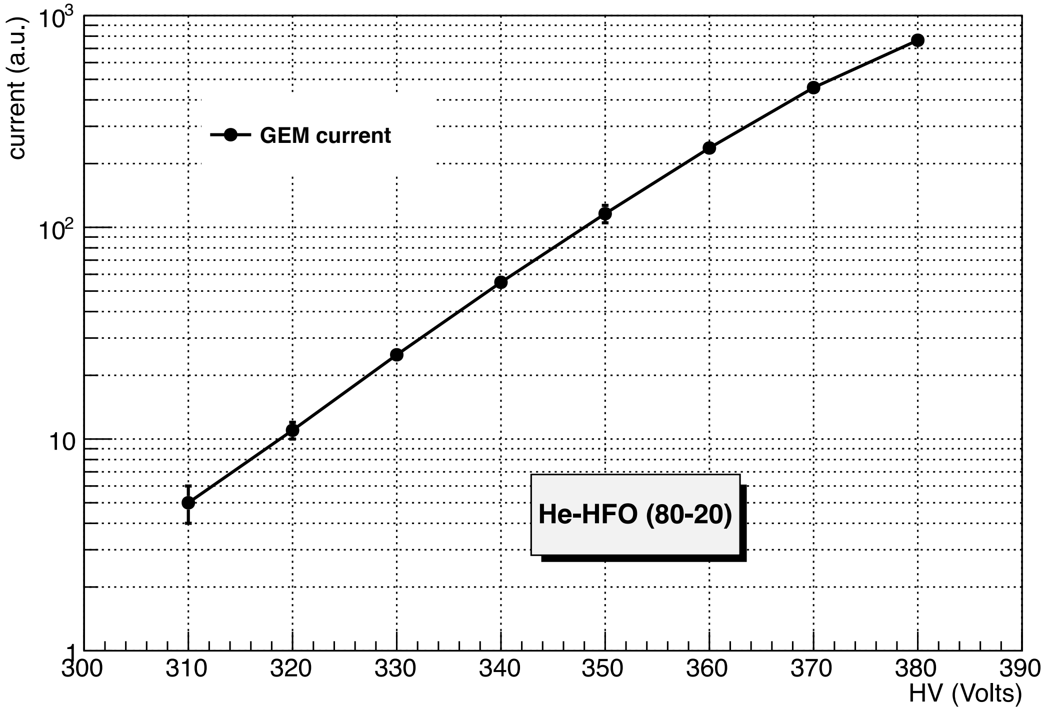
$Q_{PMT}/Q_{GEM}$ = **28**



# He-HFO (80-20)




**X-ray Gun current: 50 uA**
PMT Voltage: 1400 V
GEM transfer field: 1.5 kV/cm
Drift field: 1 kV/cm

**10x higher Xray gun current needed**

**No scope signal available**
**No detectable light**

Estimated Gain @ 380 V = **$1.8 \times 10^4$**

# Summary

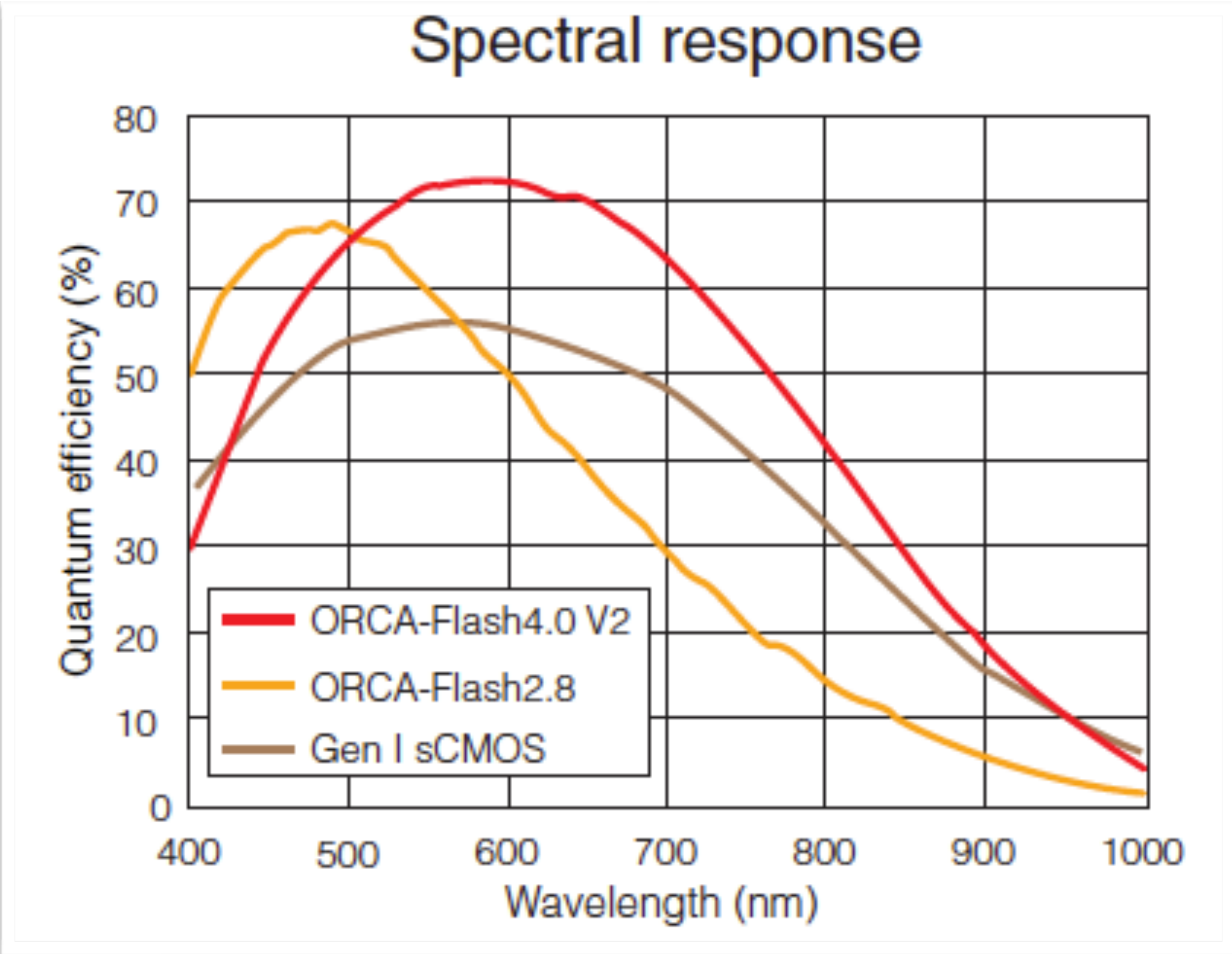
**PRELIMINARY**

| Mix | HV GEM | <Qgem> (pC) | G (10^4) | $\langle Q_{PMT} \rangle / \langle Q_{GEM} \rangle$ |
|---|---|---|---|---|
| He-CF4 (60-40) | 340 | -2.1 | 8 | 230 |
| He-CF4 (60-40) | 350 | -2.9 | 10 | 210 |
| He-CF4 (70-30) | 320 | -2.4 | 8.5 | 250 |
| He-CF4 (70-30) | 330 | -3.2 | 11 | 210 |
| He-CF4-HFO(70-30-10) | 360 | -1.4 | 5 | - |
| He-CF4-HFO(70-30-10) | 370 | -2.2 | 7 | 28 |
| He-CF4 (80-20) | 380 | ~0.6 | ~ 1.7 | - |

# Conclusions

- Fractions at level of 10 % of HFO:
  - Move the working voltage at higher values (about 40 V per GEM foil with respect to He-$CF_4$ 70-30.
  - reduce light emission of about a factor 10. (At least in the frequency range covered by PMT)
    - Note that frequency range covered by CMOS camera is different and could be better matched with HFO emission.
- Purely ecological mixtures have been tested up to lower gains:
  - Negligible light emission but a possibile choice for further investigation if no light is needed.
- To be studied the possible pollution generated during discharge.
  - From RPC experience: 5x more HF production with respect to r134a

# Backup


Spectral response
Quantum efficiency (%)
80
70
60
50
40
30
20
10
0
400
500
600
700
800
900
1000
Wavelength (nm)
ORCA-Flash4.0 V2
ORCA-Flash2.8
Gen I sCMOS