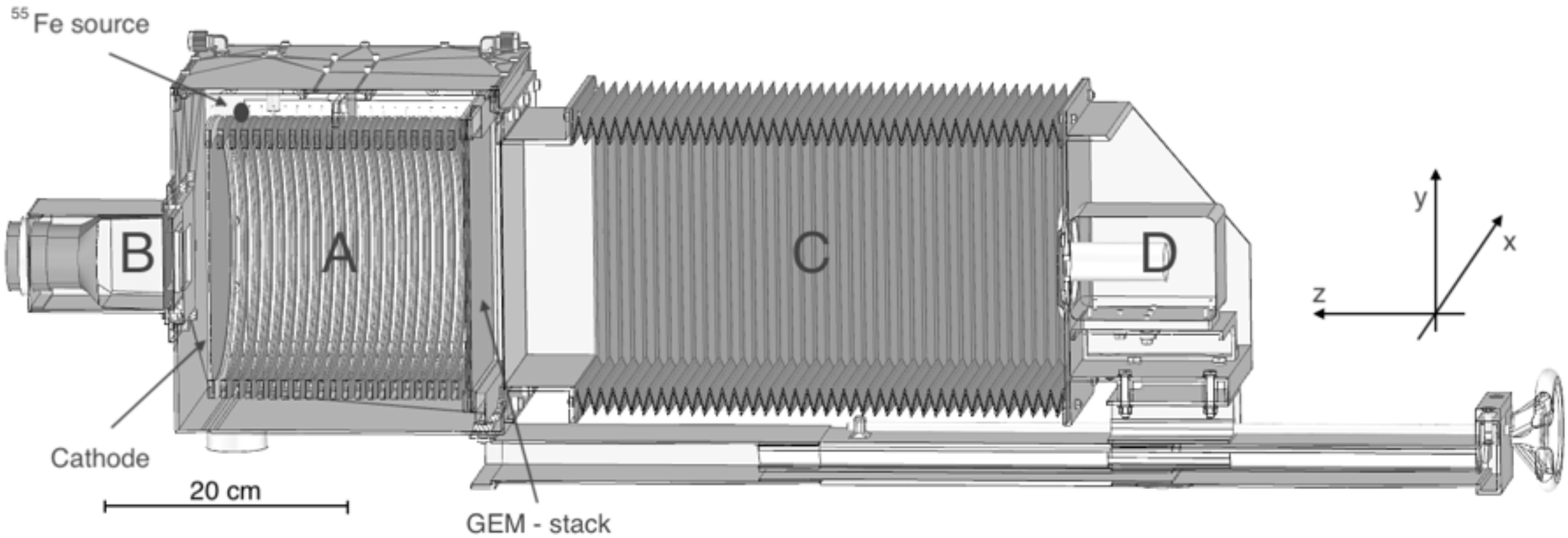

CYGNO COLLABORATION

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Studies of non-linearity in the response of an Optical Readout GEM-TPC

Part of this project has received fundings from the European Research Council (ERC) grant agreement No 818744

Introduction

- Optically readout GEM-TPCs are a suitable technology for *keV-scale* ionization cluster reconstruction (see CYGNO presentation by D. Pinci)

- The ionization density is large, but the optical readout is quite inefficient in energy to signal conversion (solid angle),

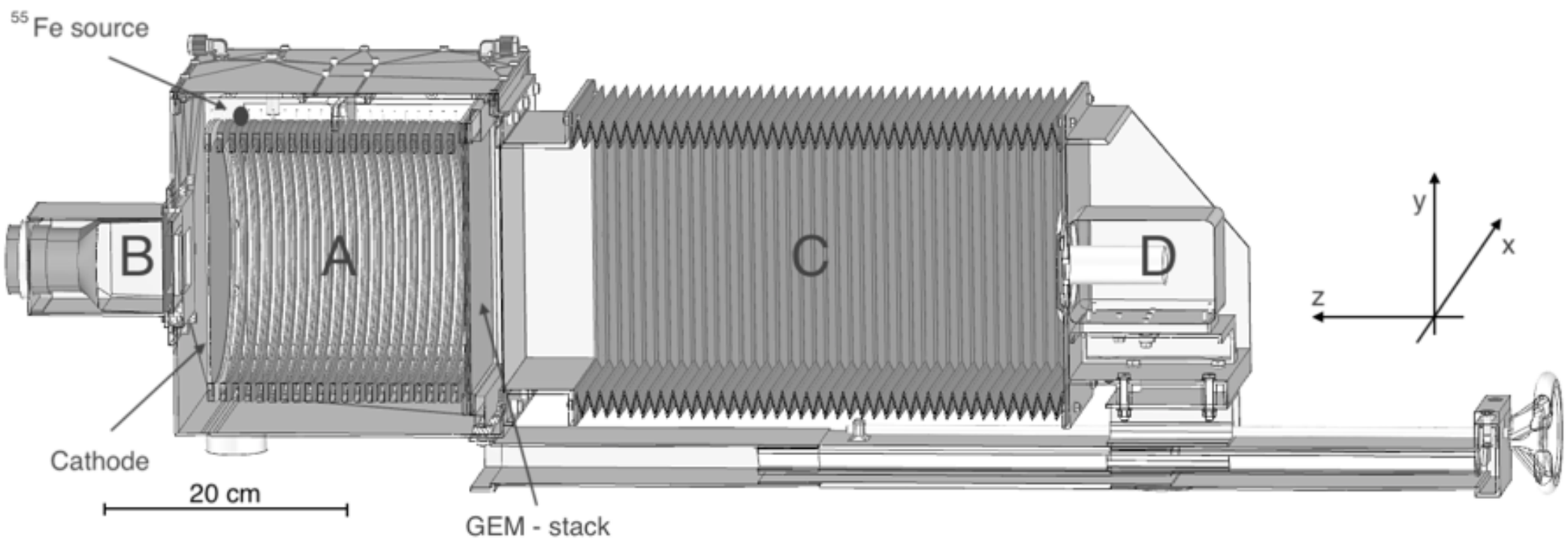
  - need a large gain to see the signal in the sCOMS with a good resolution

  - large density + large gain saturate the multiplication process in the GEMs and deteriorate the linearity

The LEMON prototype

- 3D printed gas box
- 3D printed field cage with metallic rings
- Semi-transparent cathode (wire mesh)

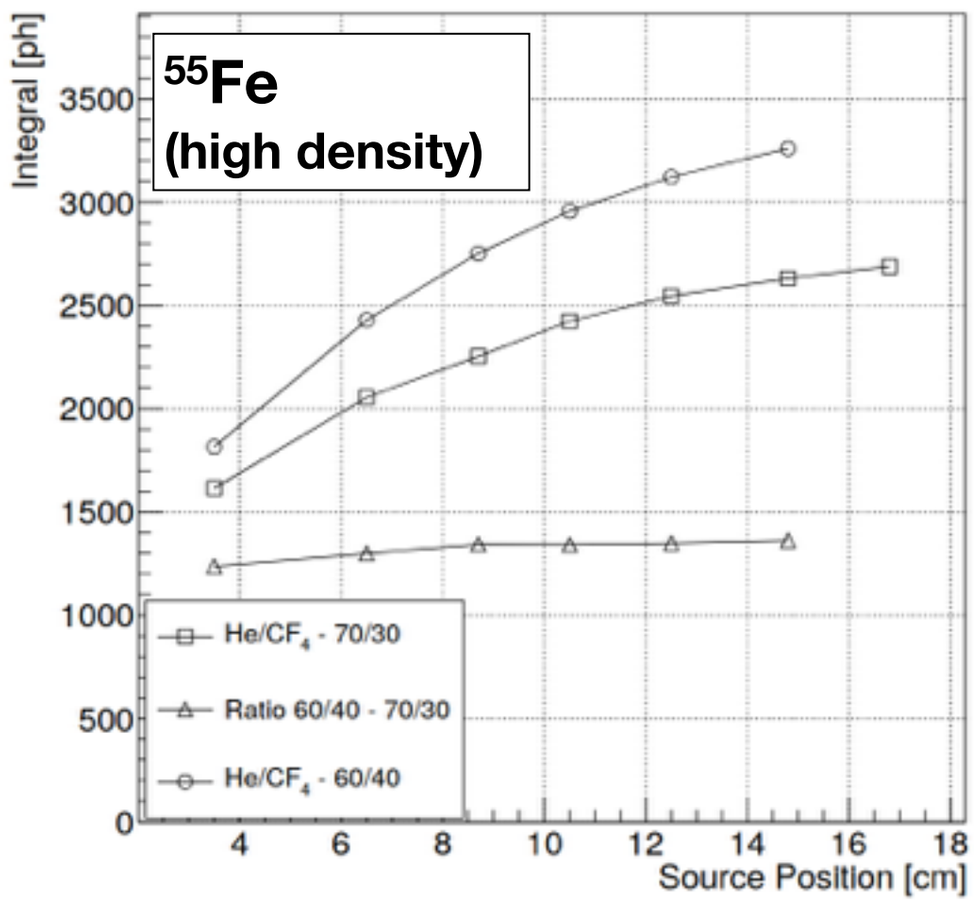
(A) Field Cage
(B) PMT
(C) Adaptable bellow
(D) CMOS camera

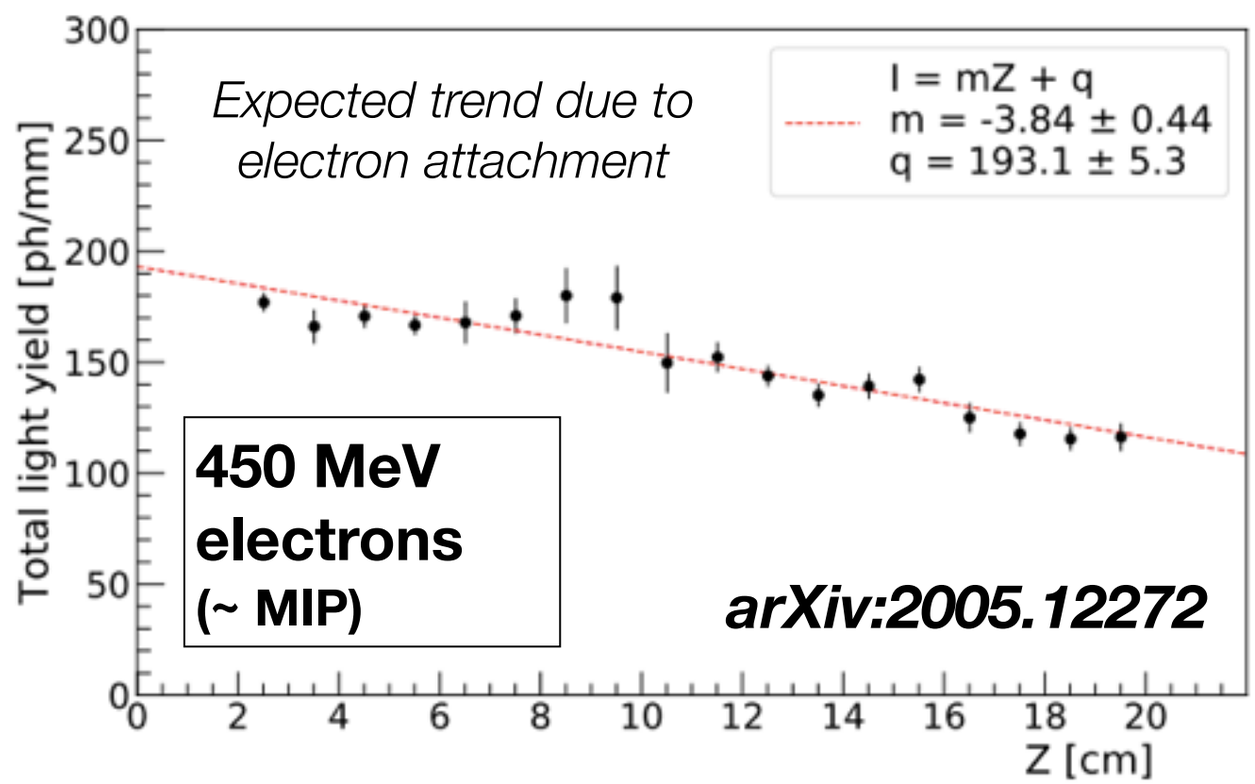


The 3-GEM stack is operated with He:CF_4 (60:40) at gain $O(10^6)$ to get $O(10^3)$ photons/MeV

Non-linearity in 3-GEM stacks (I)

- The saturation effect in GEMs is already well known
  - see e.g. S. Franchino et al., arXiv:1512.04968
- We have got a first evidence in our setup from the collected light as a function of the drift distance

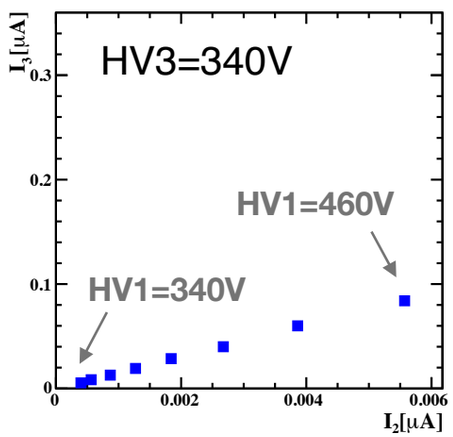


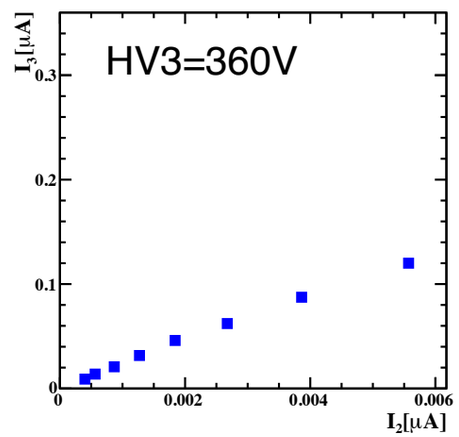


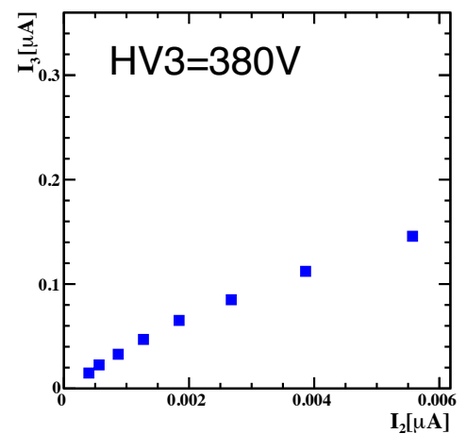
Non-linearity in 3-GEM stacks (II)

- A quantitative approach to estimate the effect effect of saturation on the detector energy scale has been developed
  - a monochromatic source (^{55}Fe) is used
  - different energies are mimicked by changing the gain of the first GEM
  - the mimicked energy is monitored from the current in the second GEM (low charge density -> linear)
  - the reconstructed energy is monitored from the current in the third GEM (higher charge density -> non-linear)

Non-linearity in 3-GEM stacks (III)

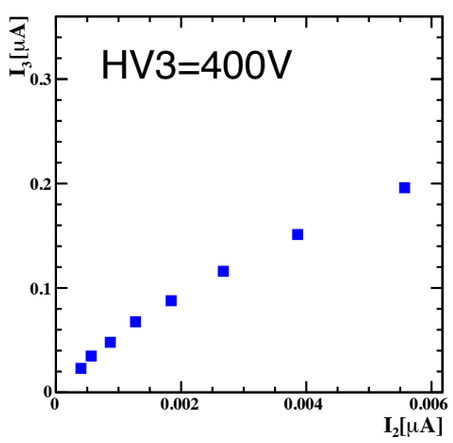


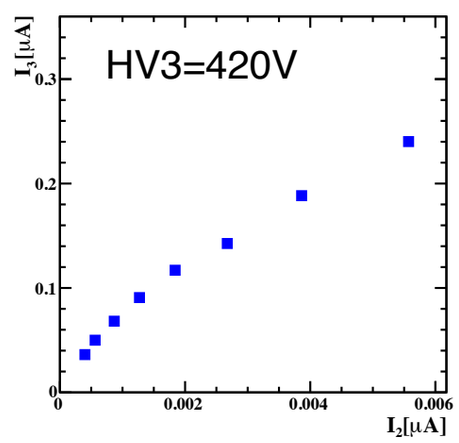


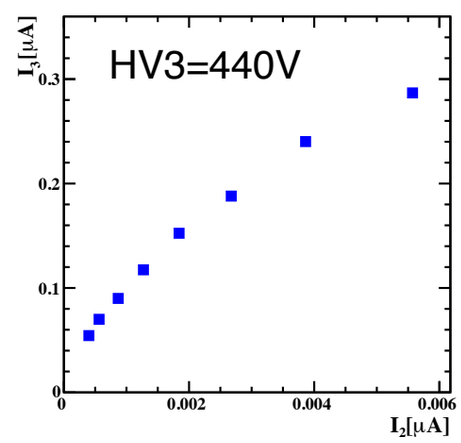


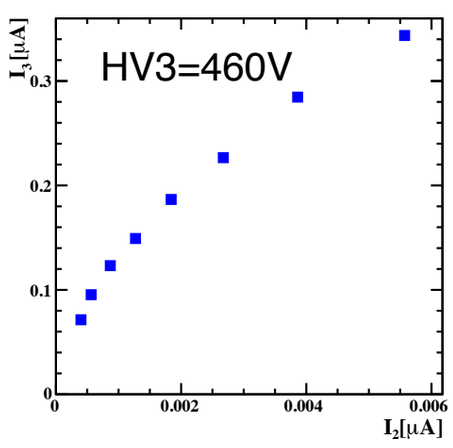
I_3 vs. I_2

HV_2 = 460 V



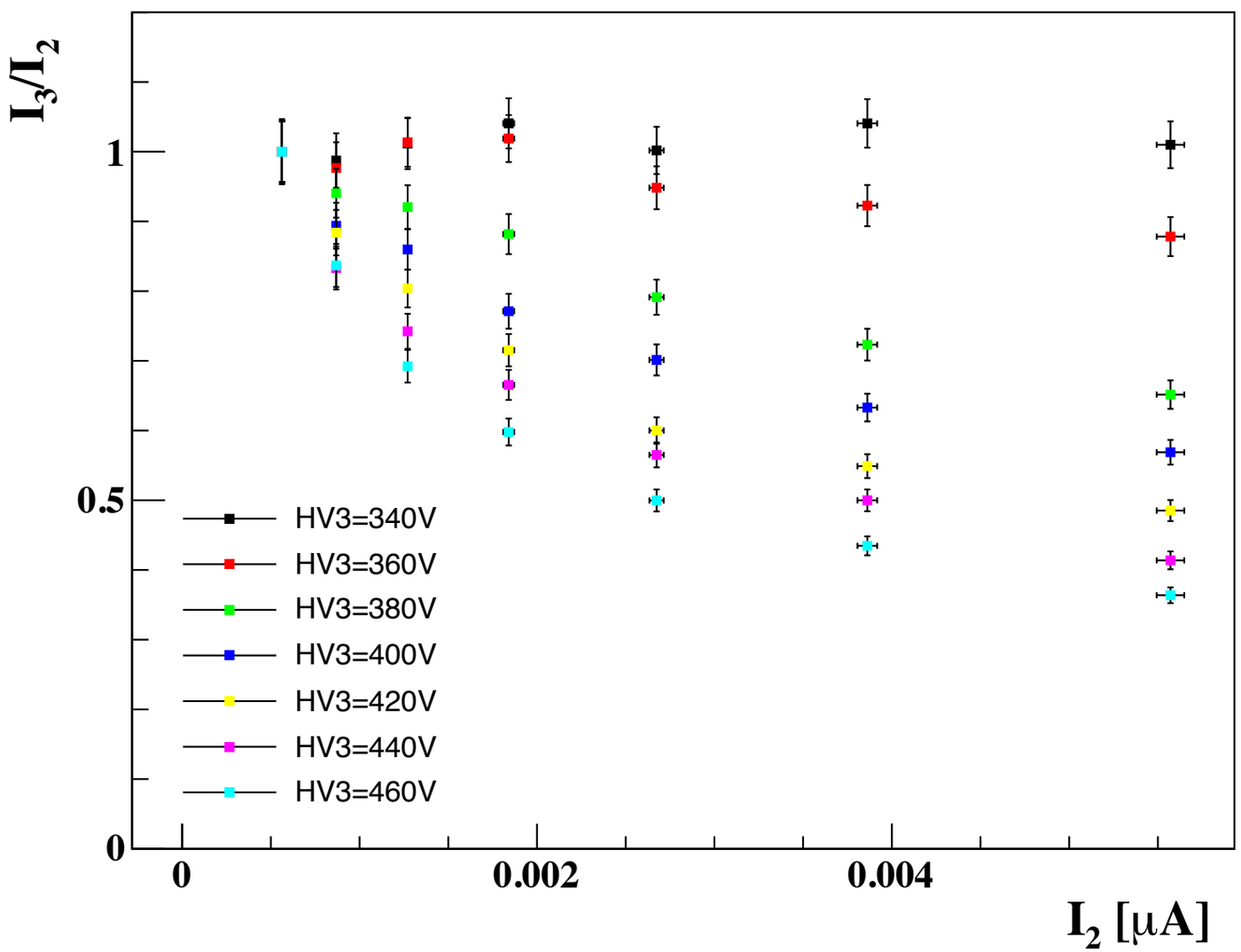






Good linearity only below
$HV_{1,2,3}$ = 460, 340, 460
(HV_1+HV_2+HV_3 = 1260V)

Non-linearity in 3-GEM stacks (IV)



I_3/I_2 vs. I_2

HV_2 = 460 V

Discussion

- Saturation effect for the typical density of ^{55}Fe spots emerges above $HV_1+HV_2+HV_3 > 1260V$

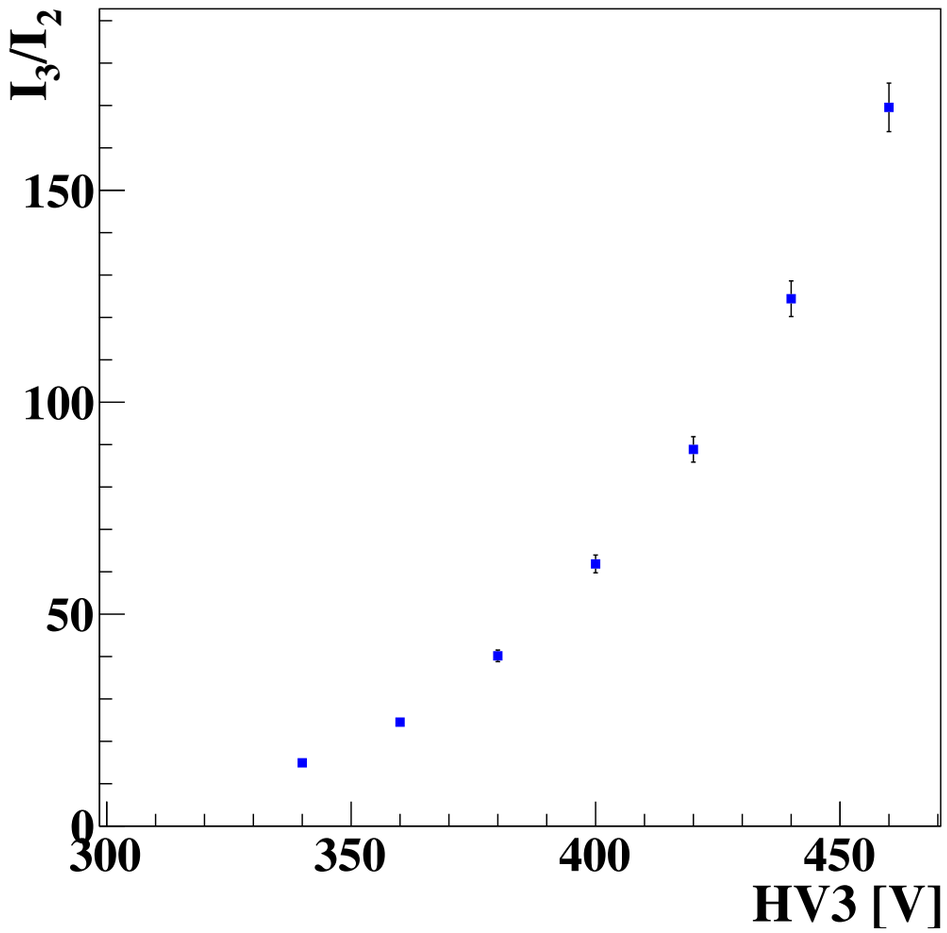
  - the corresponding gain is not enough to reach the required performances of sCMOS reconstruction

  - nuclear recoils are expected to have an even larger density (saturation at even smaller gain)

- We are trying to develop algorithms to correct for this effect and recover a good linearity

Correction approach

- From our measurements we can extract:
  - the gain of a generic GEM in linear regime as the ratio I_3 / I_2, as far as the total gain is below 1260 V



HV_1 = 340 V
HV_2 = 460 V

Correction approach

- From our measurements we can extract:

  - the average charge produced in the **second** GEM (linear regime) by one ^{55}Fe event

$$Q_2 = N_e \, e \, G(HV_1) \, G(HV_2)$$

  - the average charge we would **expect** in linear regime in the **third** GEM

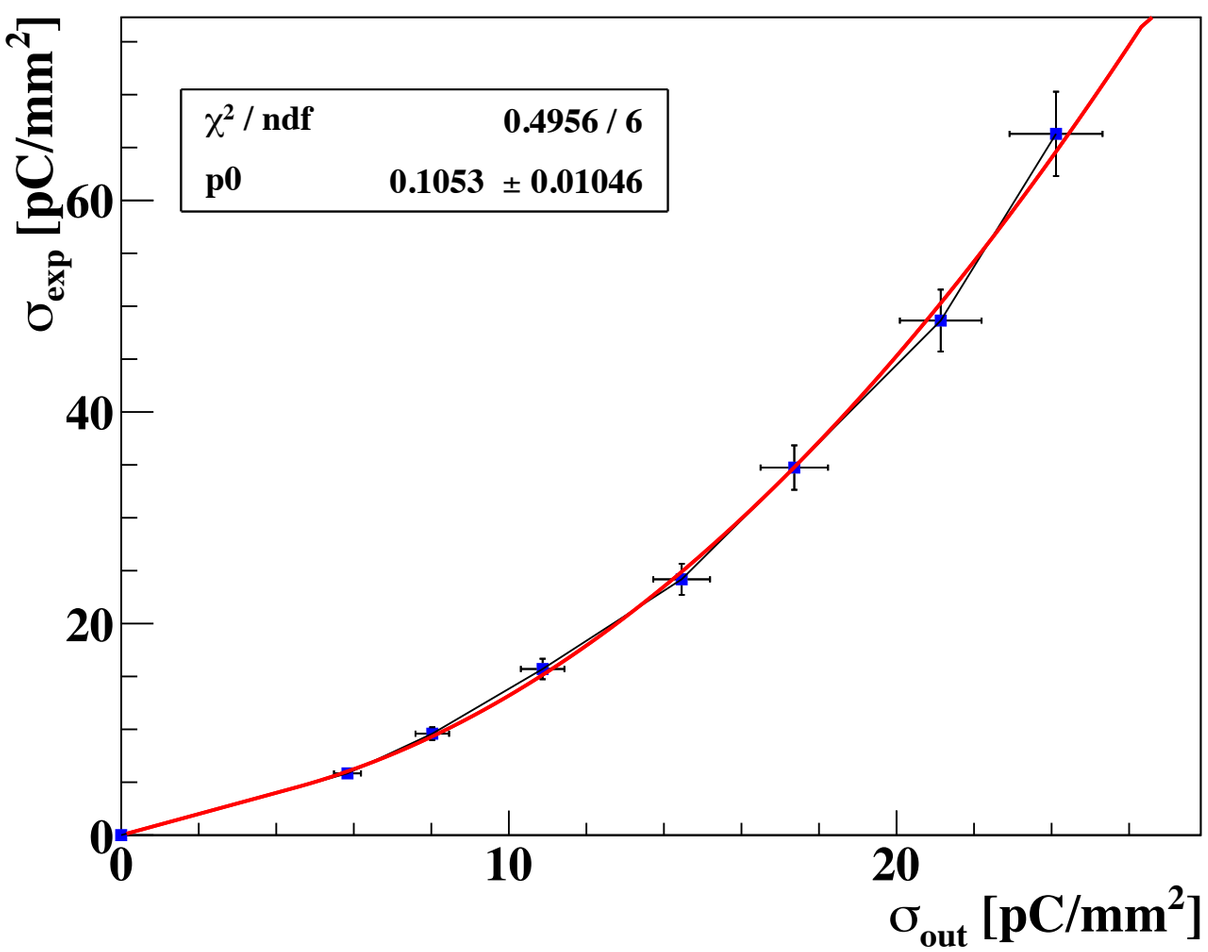
$$Q_{exp} = N_e \, e \, G(HV_1) \, G(HV_2) \, G(HV_3)$$

  - the average charge **really** produced in the **third** GEM

$$Q_3 = \frac{I_3}{I_2} Q_2$$

Correction approach

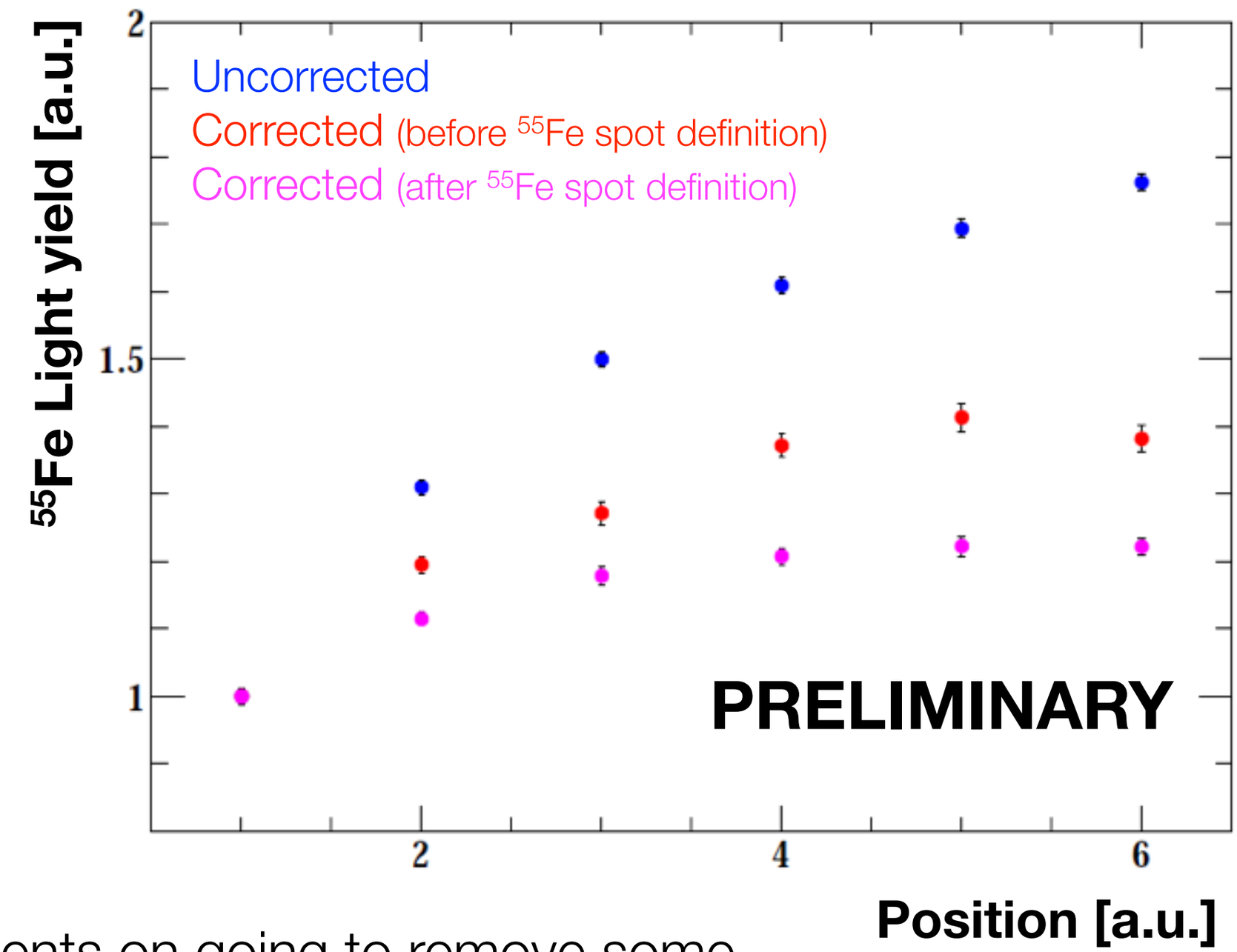
- Since we know the average size of one ^{55}Fe spot (from pictures with optical readout) we can convert the charges into charge densities



Since this is a *charge density effect (charge per hole)*, we can assume that this curve is **universal**

In our images we measure the charge density *(photons per pixel)* -> the curve can be used to **correct our images *pixel by pixel***

Pixel by pixel correction

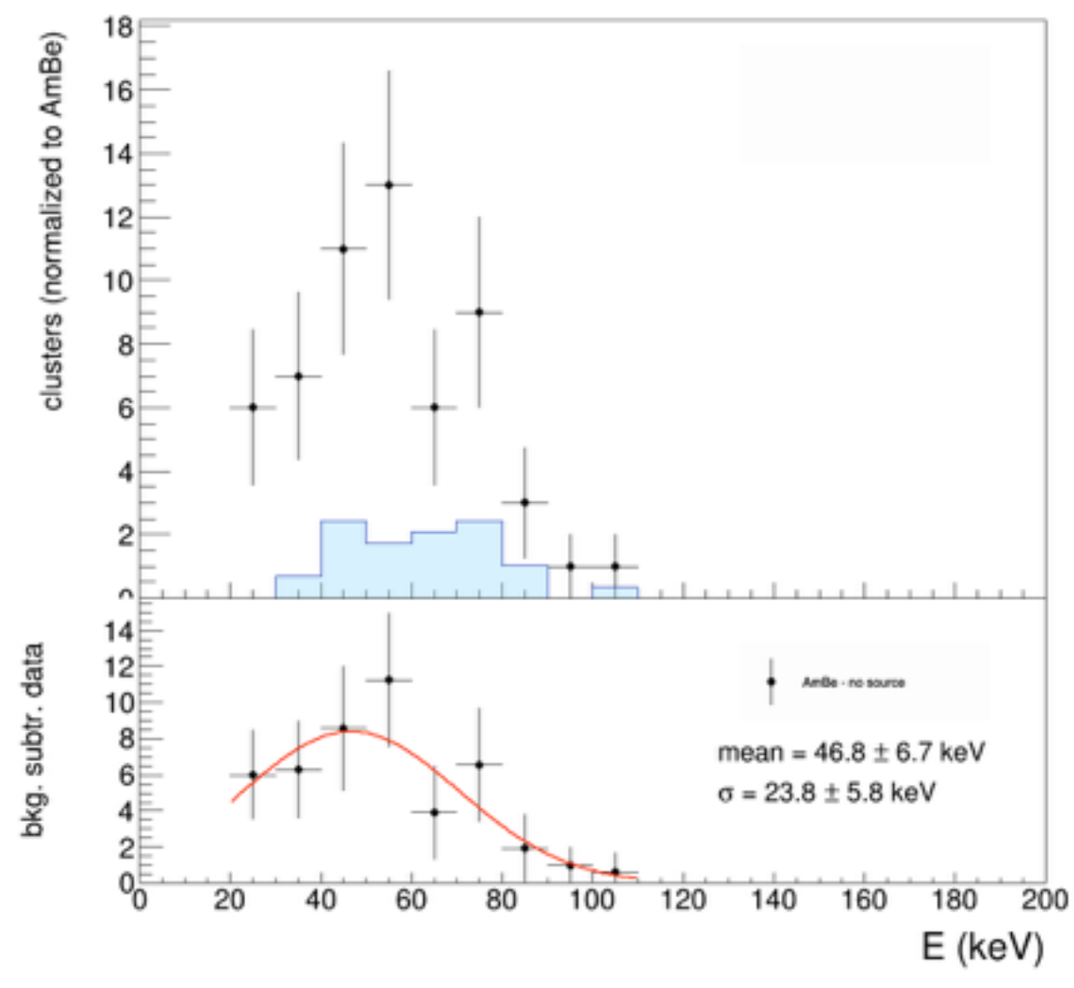


Refinements on going to remove some artifacts due to the definition of clusters

Alternative approaches

- As a first-order correction, we can assume that, given a cluster from a non-^{55}Fe source, the correction formula can be applied to portions of the cluster similar in size to ^{55}Fe clusters
  - avoid some systematics of the pixel-by-pixel correction
  - other systematics due to the different shape of the clusters
  - tested with 59 MeV photons from and AmBe source, it seems that it helps to recover the correct energy scale

Before correction
46.8 ± 6.7 keV



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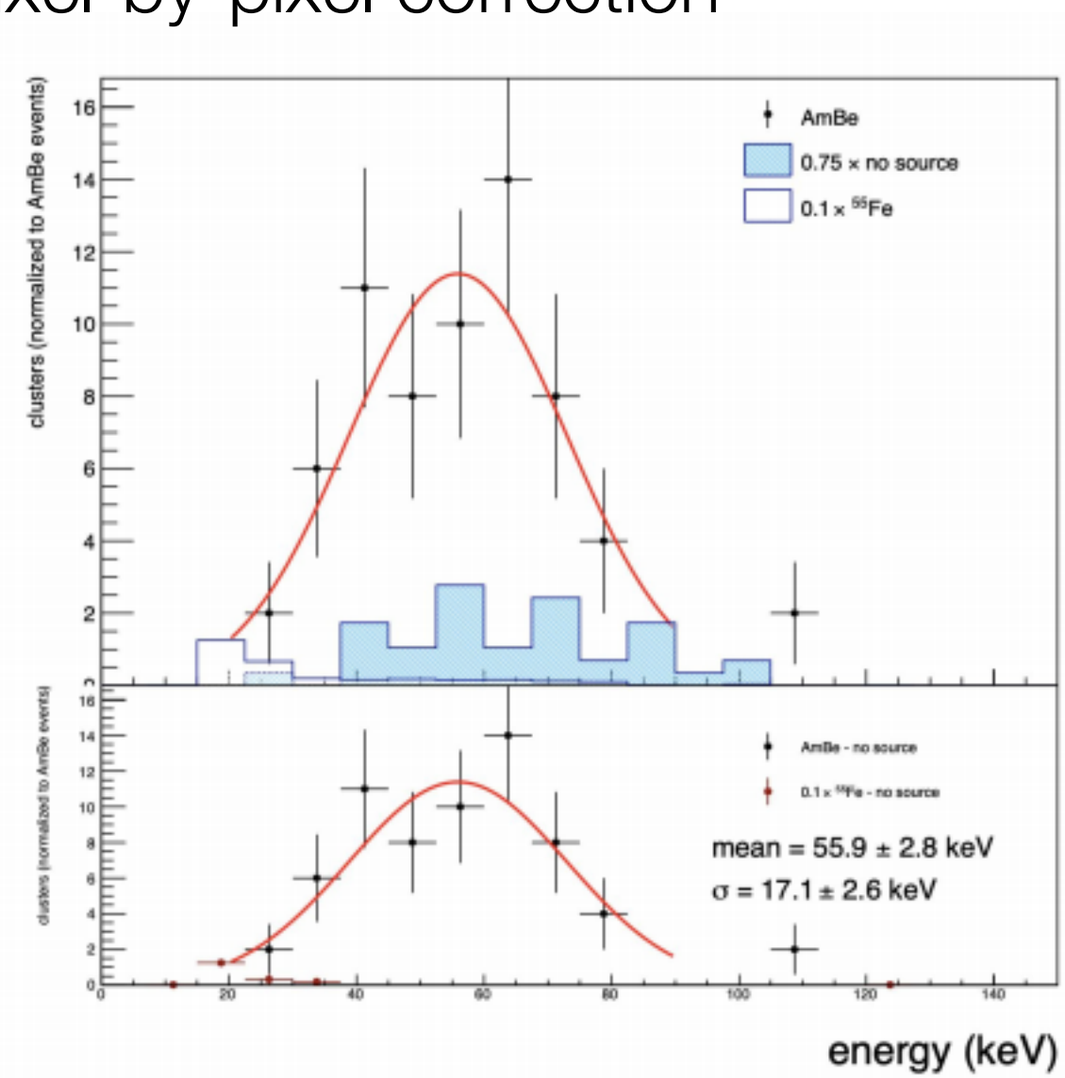
  - avoid some systematics of the pixel-by-pixel correction
  - other systematics due to the different shape of the clusters
  - tested with 59 MeV photons from and AmBe source, it seems that it helps to recover the correct energy scale

After correction
55.9 ± 2.8 keV



Alternative approaches

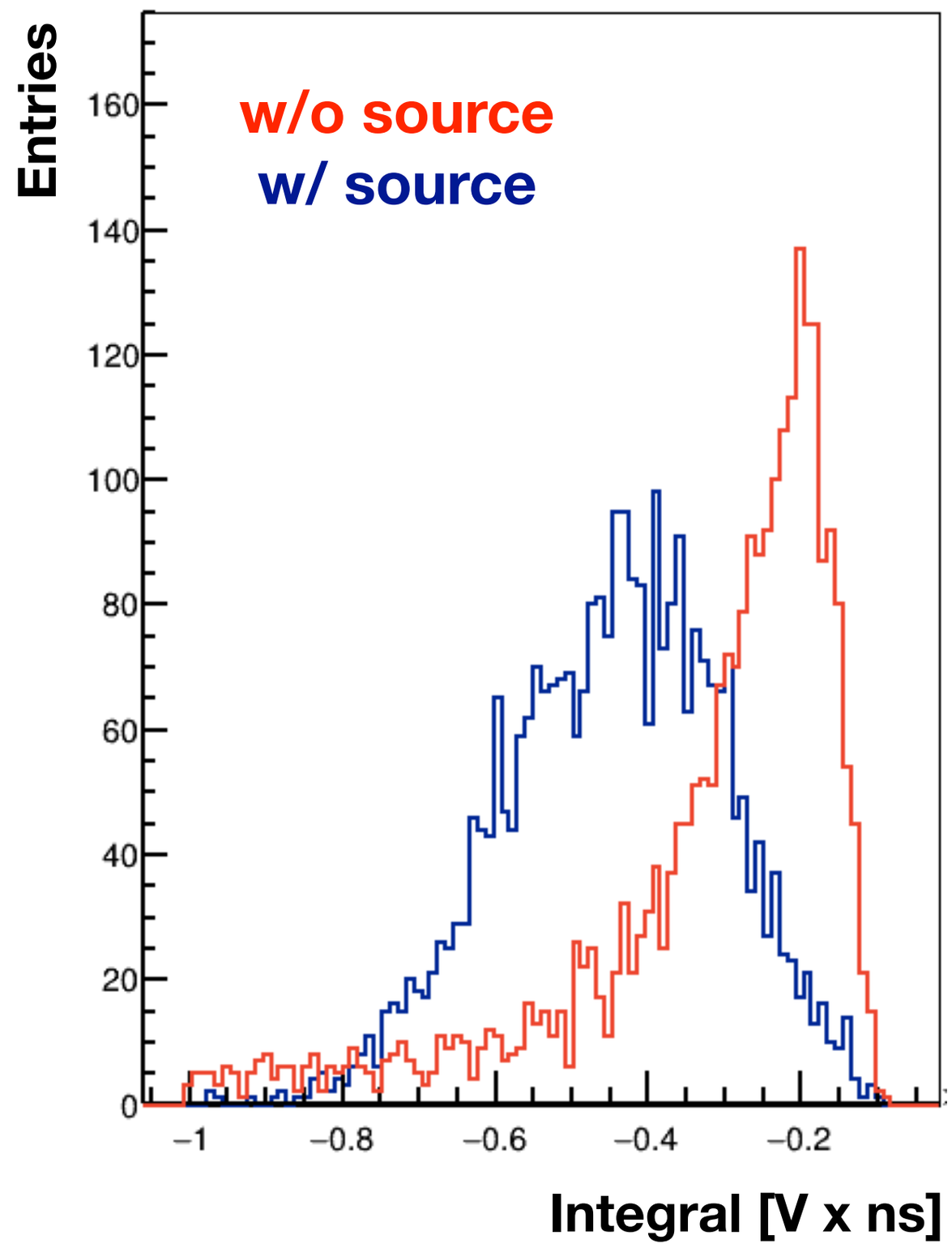
- Since we also have a PMT signal, we are trying to see if the light from the second GEM (non saturated) is visible right before the third GEM signal

  - we could use the PMT signal from GEM2 (linear regime) to estimate the energy and rely on the sCMOS picture only for the 2D cluster shape

  - work in progress…

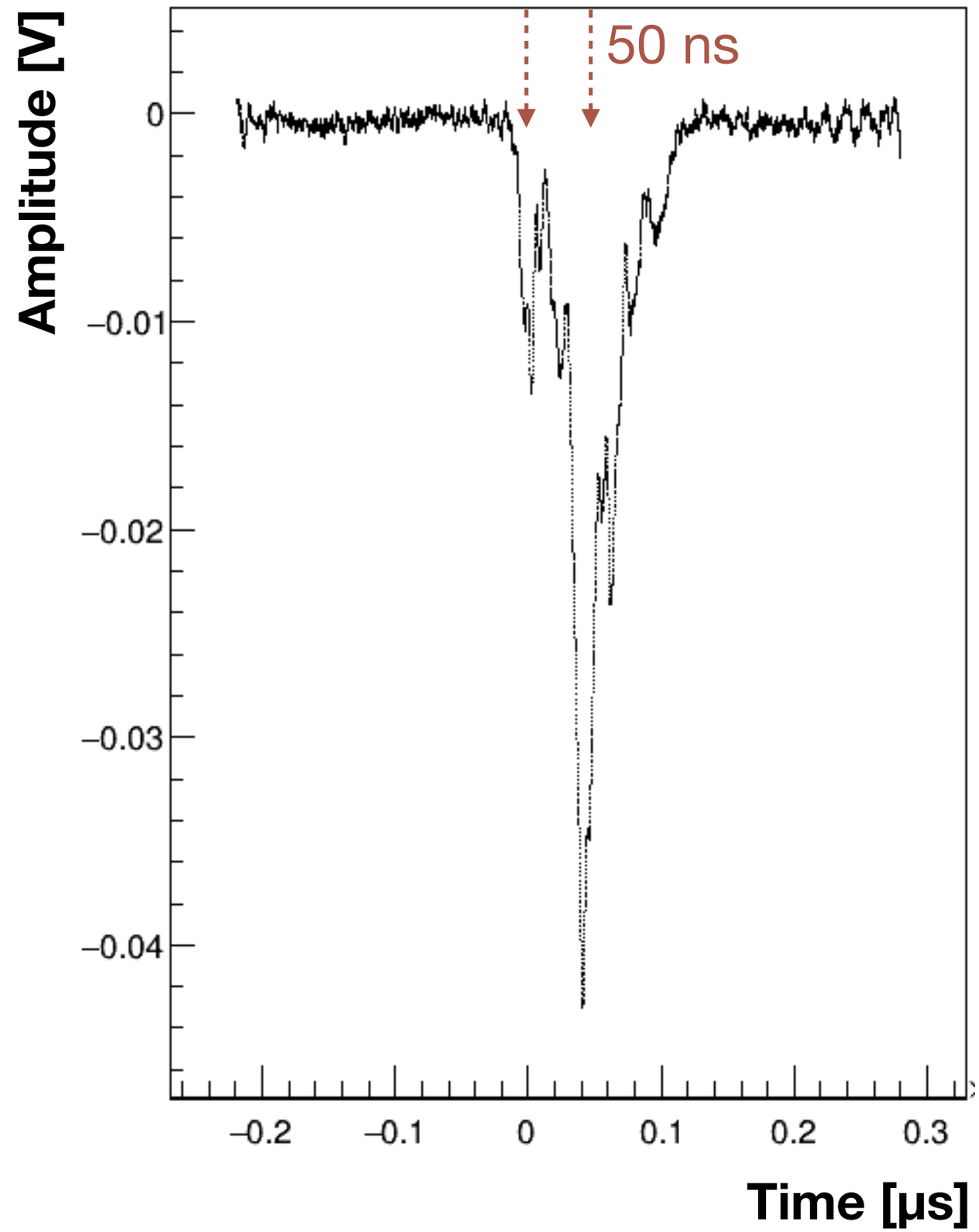
PMT signals

- We see light from GEM2 when GEM3 is off



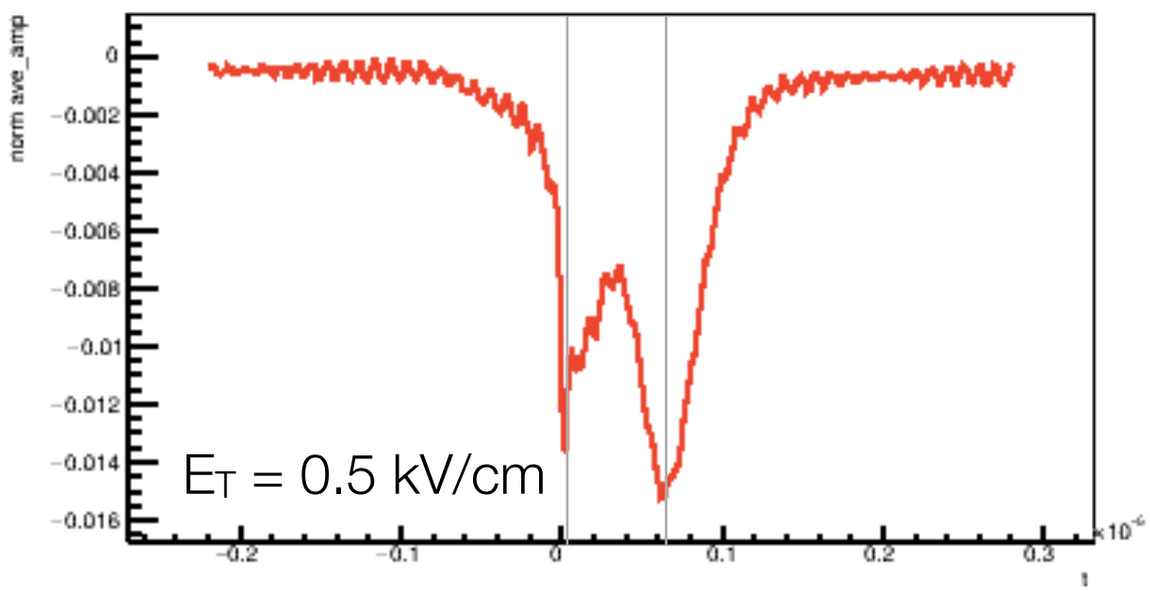
PMT signals

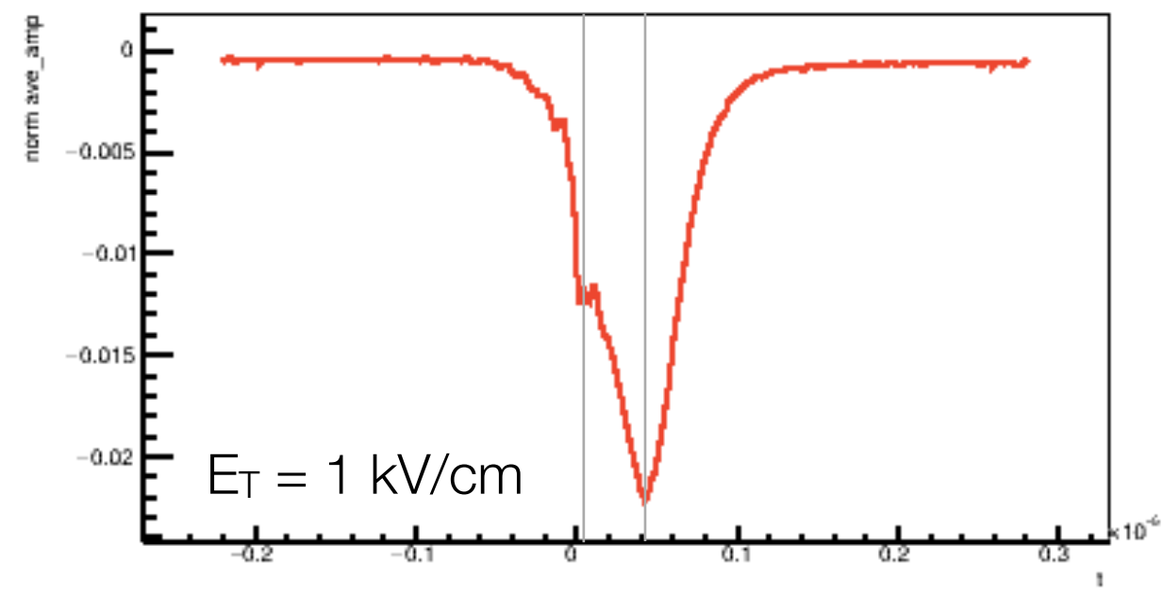
- We lowered the transfer field from GEM2 to GEM3 (-> lower drift velocity) to better separate in time the two signals
  - E_T = 0.5 kV/cm
- The size of the signals (integrals) look approximately consistent with (gain) x (extraction efficiency) x (collection efficiency) for such a low transfer field
- The time between peaks look approximately consistent with the drift velocity (2 mm at ~40 μm/ns)

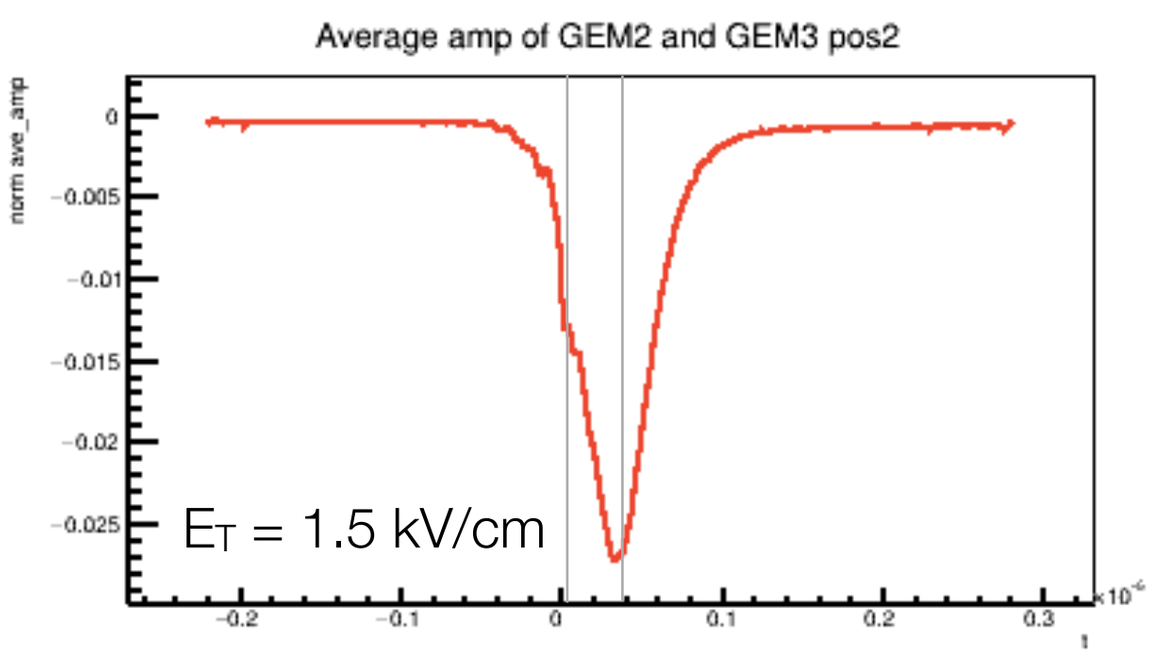


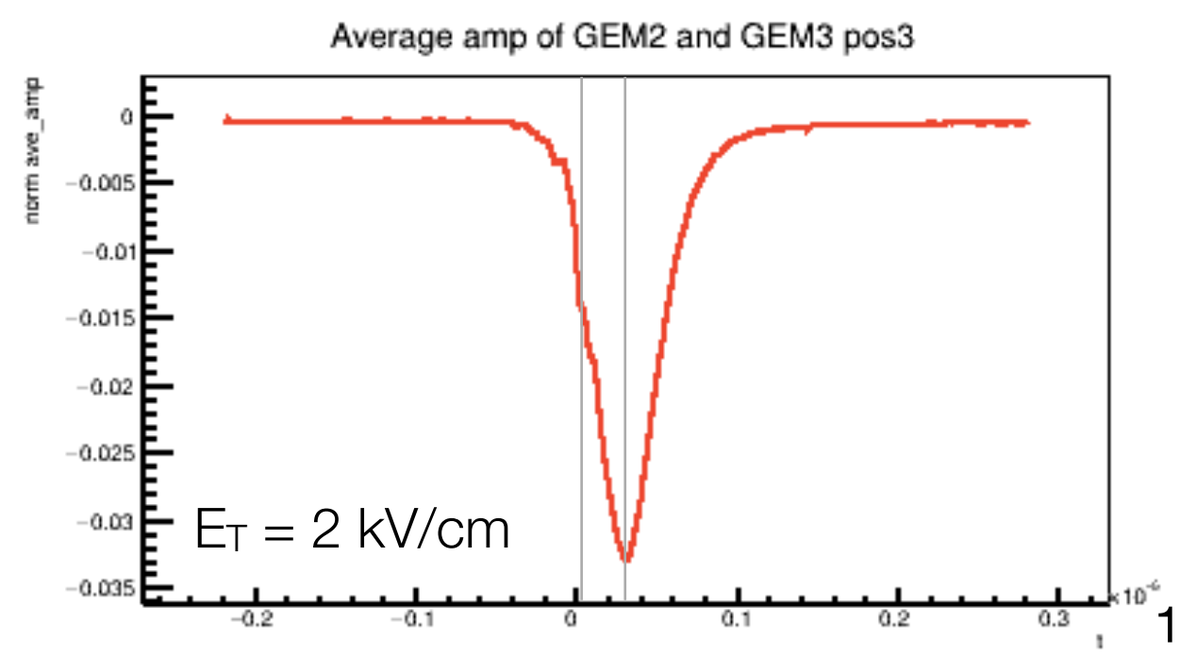
PMT Signals

Average waveforms [a.u.]









Conclusions

- A correction for non-linearity effects is needed for keV-scale energy deposit reconstruction in optically readout GEM-TPCs

- We developed a method to measure the non-linearity and find a universal correction function to be applied to the sCMOS pictures pixel-by-pixel or on average to portions of clusters

- Work on-going to develop alternative approaches, also on hardware (see electroluminescence approach in G. Dho talk)