Characterisation of Micromegas+GEM amplification for HARPO

- The HARPO detector concept
- Test configuration
- Gain measurements
- Experimental results
- Conclusions

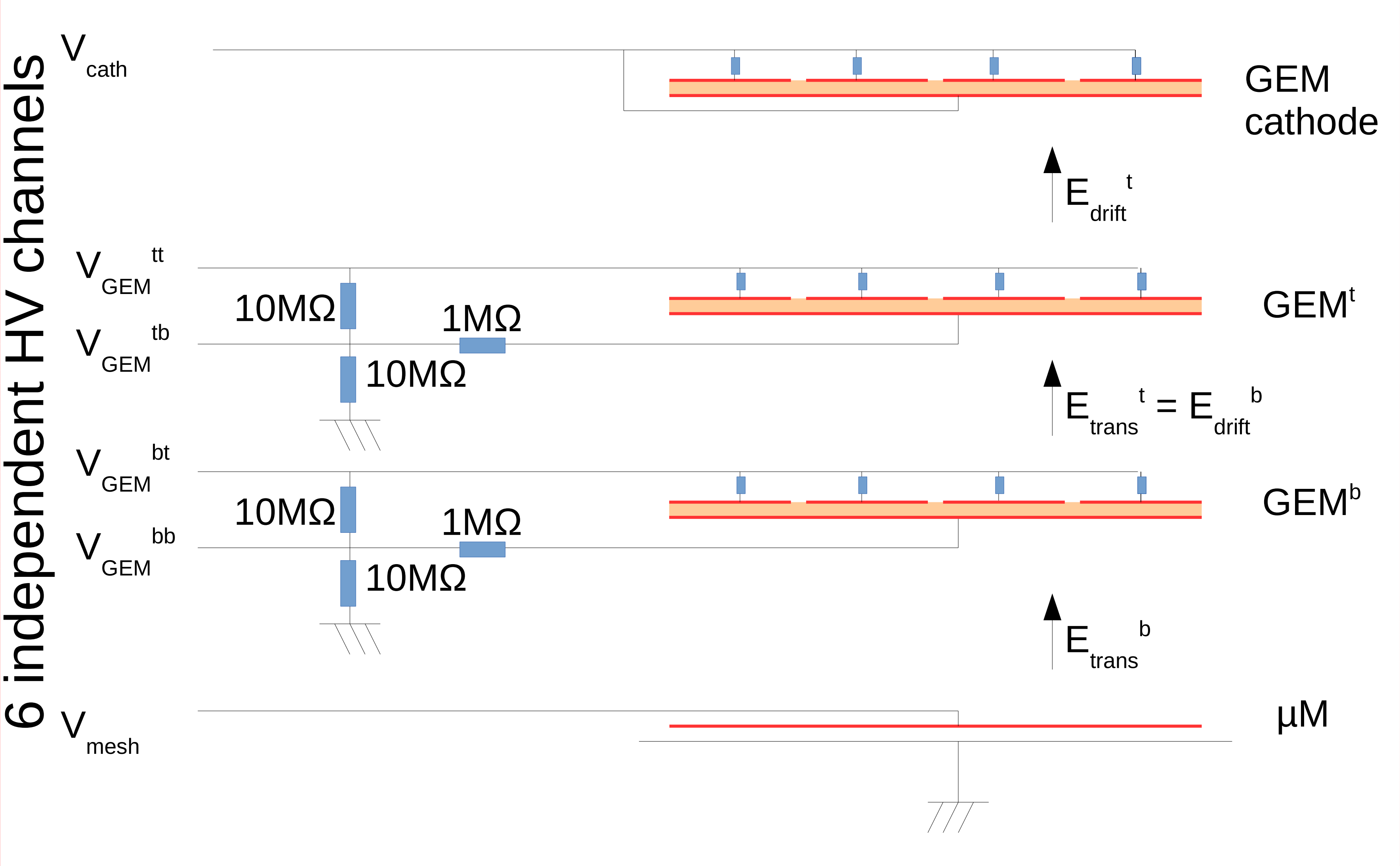
HARPO

- TPC for measurement of polarised gamma rays
  - e^+e^- conversion (MeV~GeV)
  - Various astrophysics applications (in space)
  - Low multiple scattering => high angular resolution
  - Sensitive to linear polarisation
  - High pressure gas for higher conversion probability
- Demonstrator
  - 30cm cubic TPC
  - μM+2GEM amplification (not enough gain at 2bar with μM only)
  - Up to 5bar argon based gas
- Project LLR+Irfu, funded by P2IO and ANR

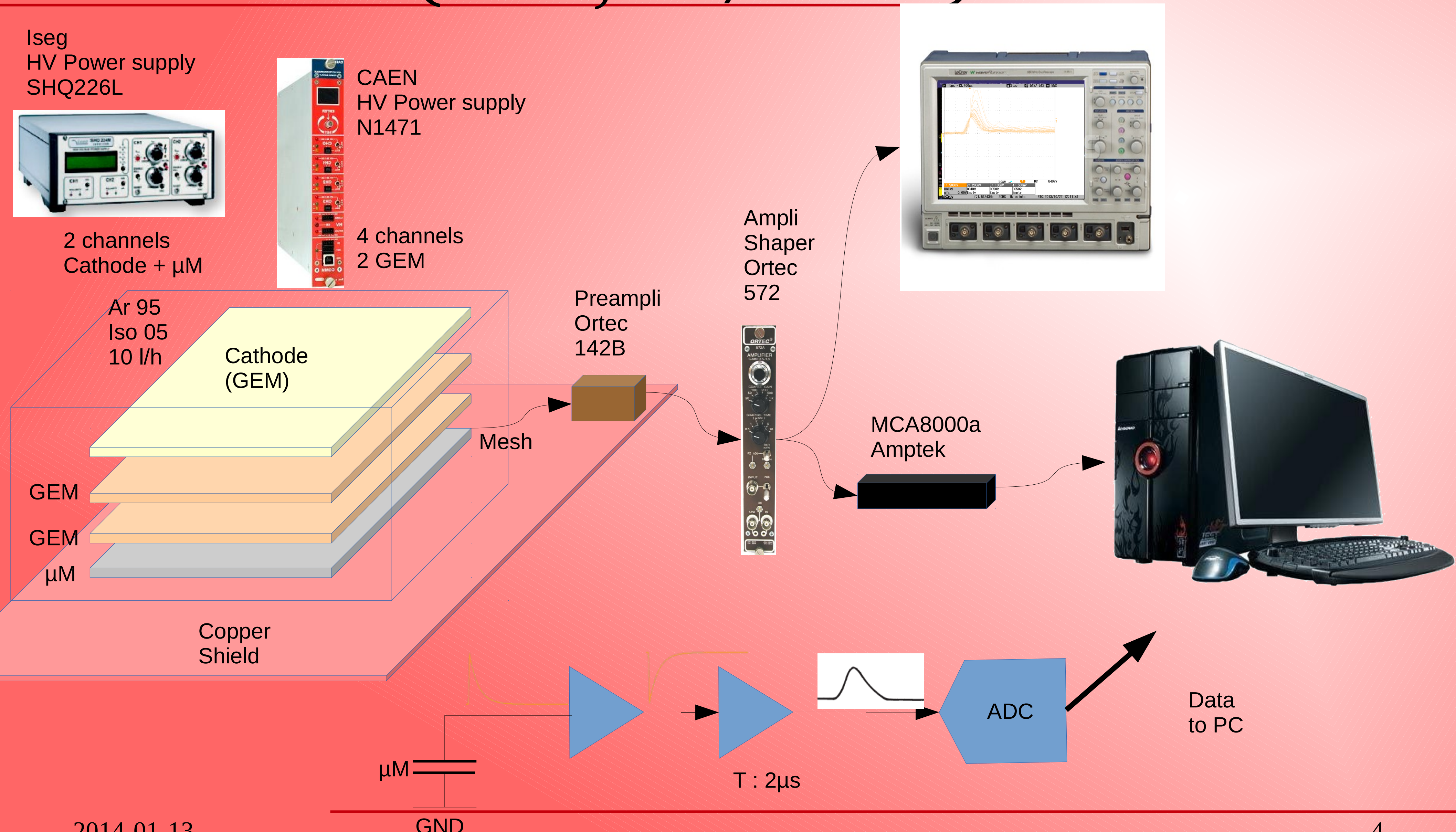
Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

IN2P3 Les deux infinis

Test configuration



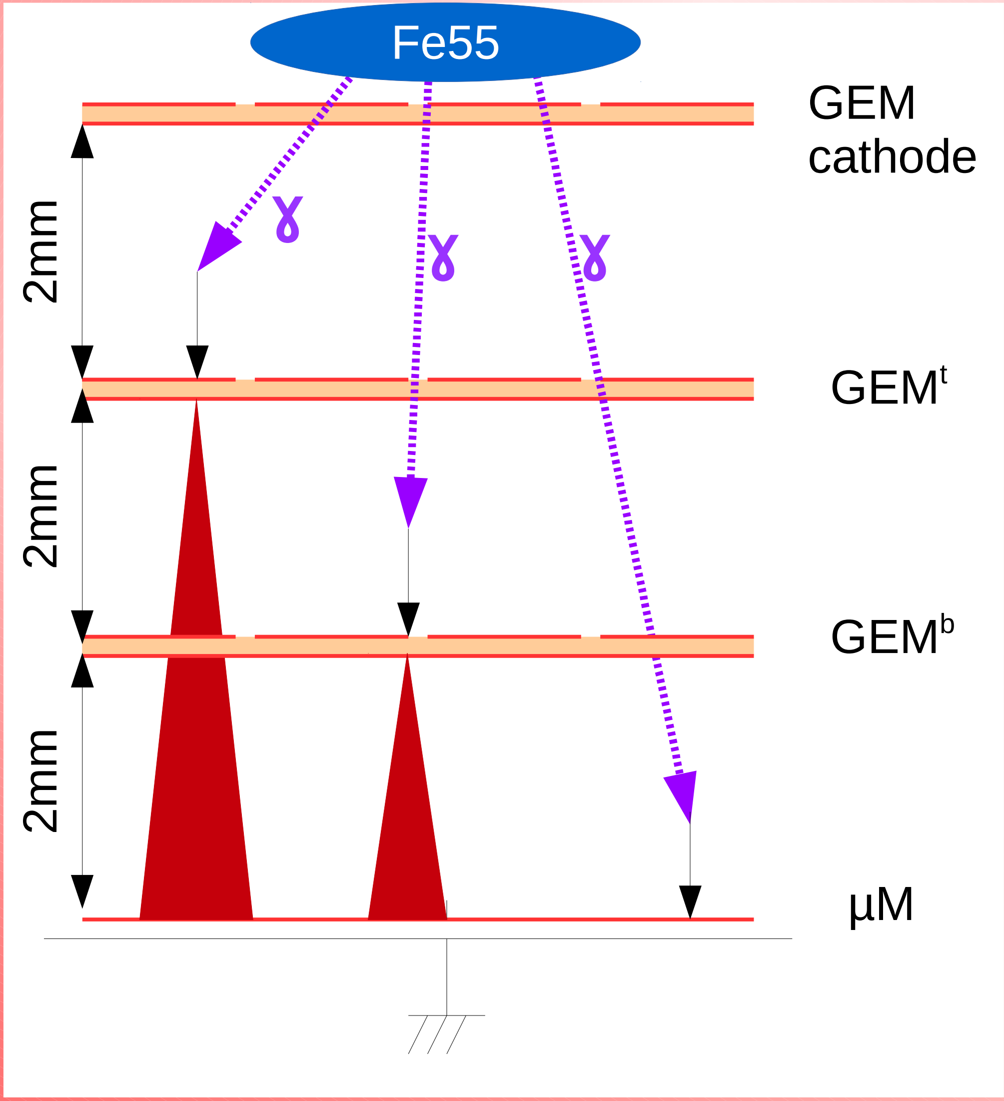
setup tests μM + 2GEM (CEA, 12/2013)

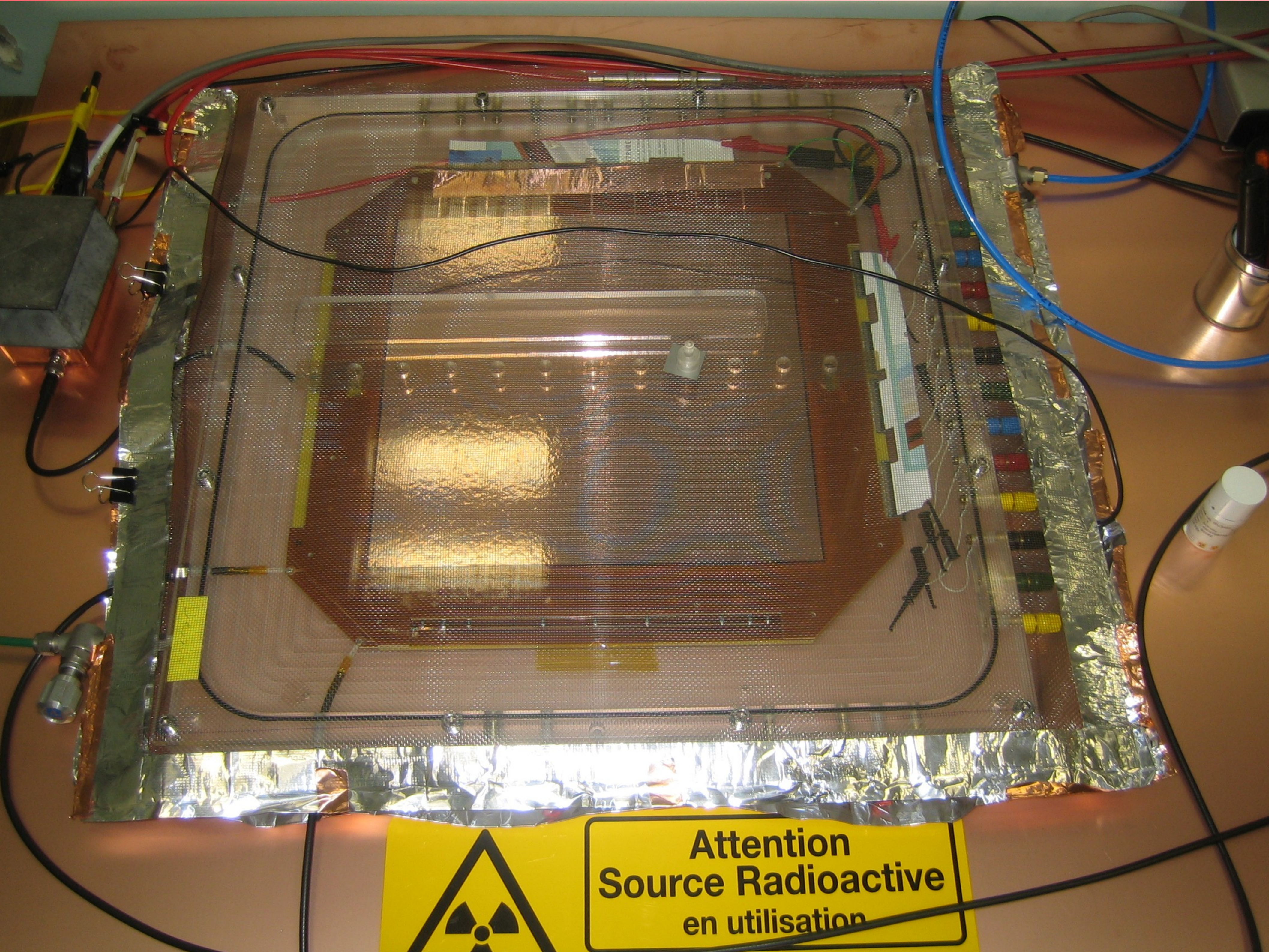


Test configuration

- Plexiglas test box
- 1bar Ar:isobutane (95:5)
- ^{55}Fe source
- 5.9 keV X ray can convert in one of 3 regions
- 2.7 keV escape peak

  => up to 6 peaks
- By setting the GEM voltages to zero, we can effectively remove the top regions




Attention
Source Radioactive
en utilisation

Effective gain

- Micromegas
  - intrinsic gain = $g_{\mu M}(V_{mesh}) \sim \exp(V_{mesh})$
  - transparency = $\mathcal{T}(E_{drift})$

$$g_{\mu M}^{eff} = g_{\mu M}(V_{mesh})\,\mathcal{T}_{\mu M}(E_{drift})$$

- GEM
  - intrinsic gain $g_{GEM}(V_{GEM}) \sim \exp(V_{GEM})$
  - collection efficiency = $\mathcal{C}(E_{drift})$
  - extraction efficiency = $\mathcal{E}(E_{trans})$

$$g_{GEM}^{eff} = \mathcal{E}_{GEM}(E_{trans})\,g_{GEM}(V_{GEM})\,\mathcal{C}_{GEM}(E_{drift})$$

Remarks

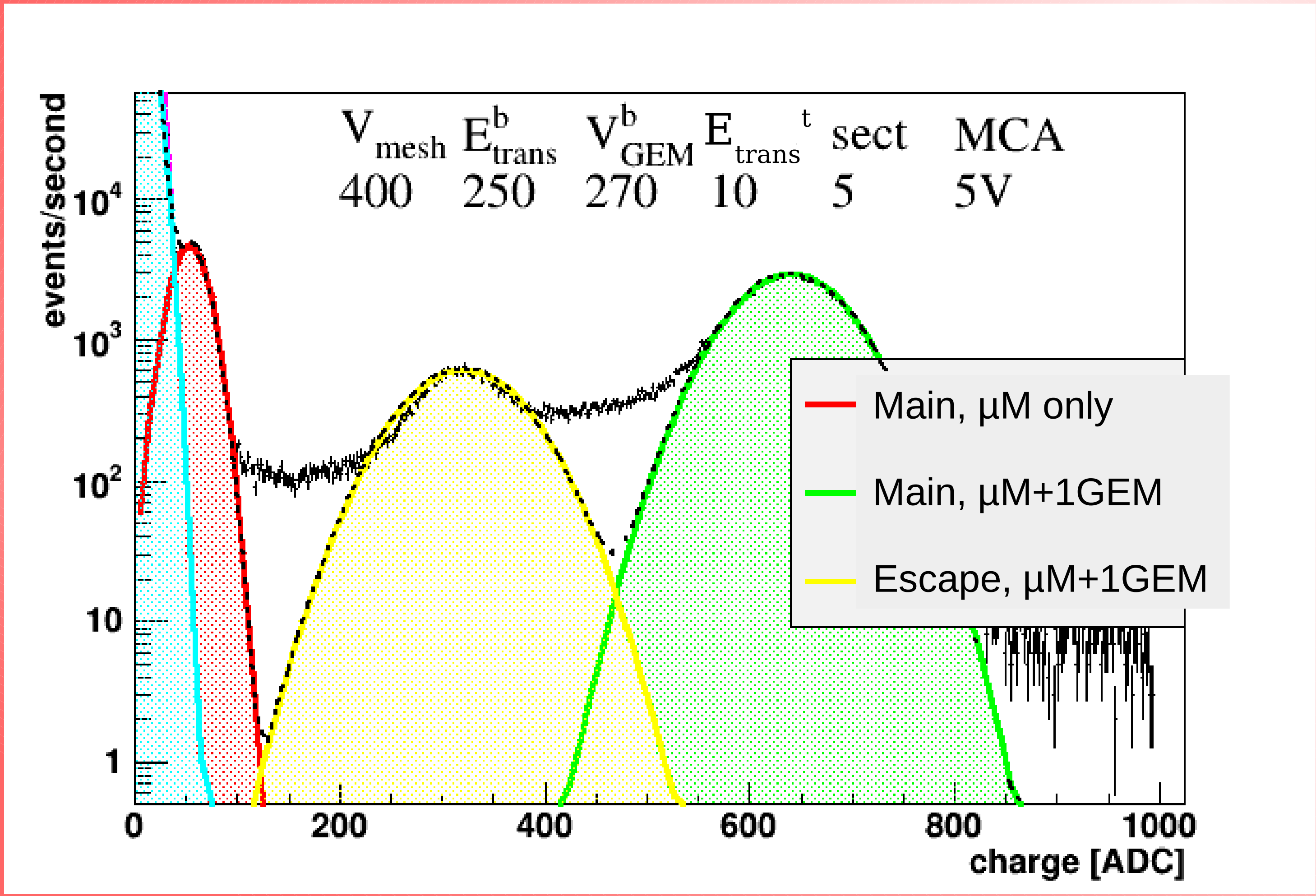
- E_{trans} and E_{drift} are the fields above and below the MPGD. They will be replaced by the corresponding value in our configuration
- $\mathcal{T}$, $\mathcal{E}$ and $\mathcal{C}$ should depend on E/V_{MPGD}, the relative variations of V_{MPGD} in our test is too small to have any effect on our measurements and will be ignored

Total effective gain

$$
\begin{aligned}
g^{eff}_{total} &= g^{eff}_{\mu M} \times g^{eff}_{GEM^b} \times g^{eff}_{GEM^t} \\
&= \left(g_{\mu M}\,\mathcal{T}_{\mu M}\right) \times \left(\mathcal{E}^b_{GEM}\, g^b_{GEM}\, \mathcal{C}^b_{GEM}\right) \times \left(\mathcal{E}^t_{GEM}\, g^t_{GEM}\, \mathcal{C}^t_{GEM}\right) \\
&= g_{\mu M}\left(V_{mesh}\right)\mathcal{T}_{\mu M}\left(E^b_{trans}\right) \\
&\times \mathcal{E}_{GEM}\left(E^b_{trans}\right) g^b_{GEM}\left(V^b_{GEM}\right) \mathcal{C}_{GEM}\left(E^t_{trans}\right) \\
&\times \mathcal{E}_{GEM}\left(E^t_{trans}\right) g^t_{GEM}\left(V^b_{GEM}\right) \mathcal{C}_{GEM}\left(E^t_{drift}\right)
\end{aligned}
$$

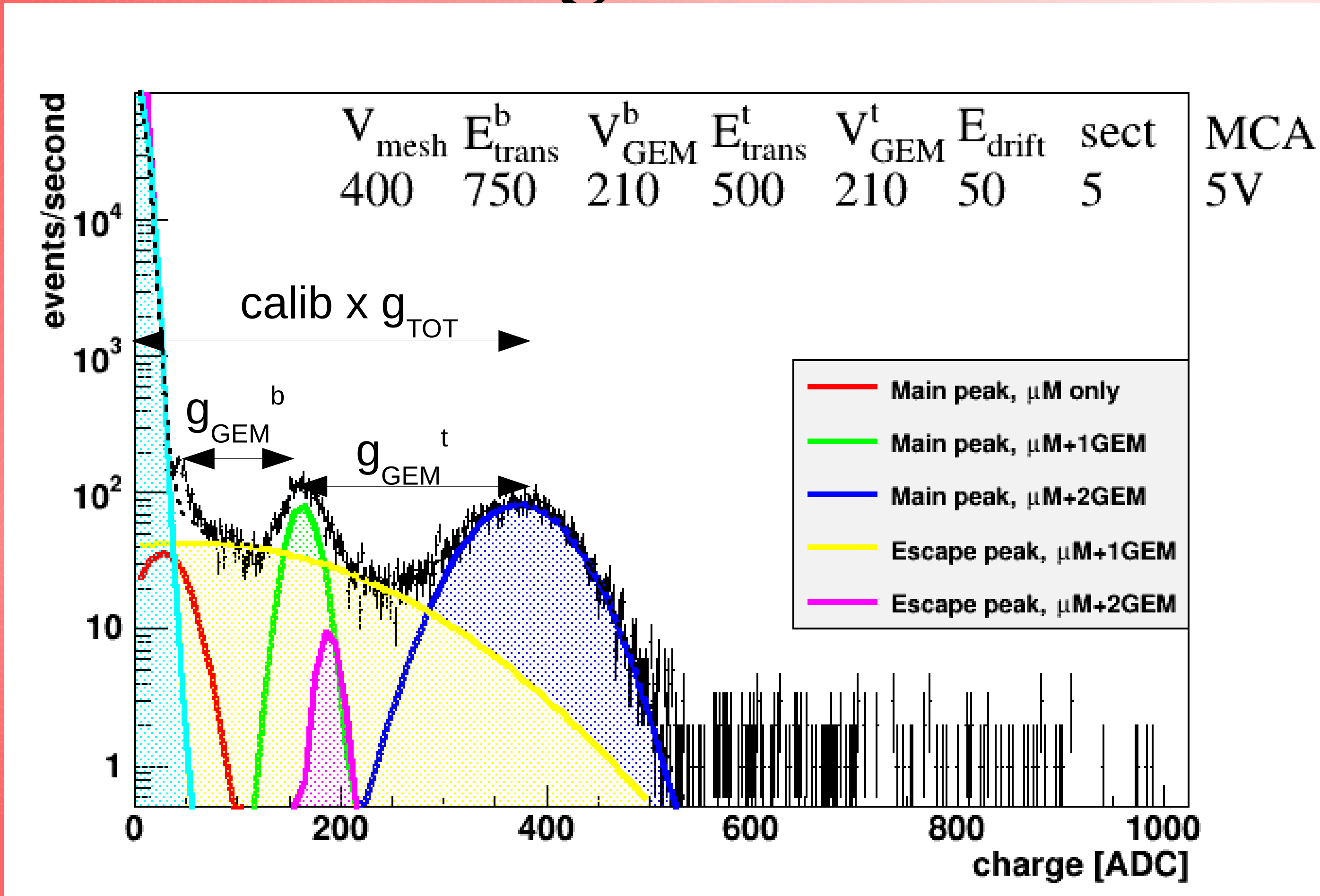
This factorisation formula is well confirmed by the experimental data

Measured spectrum Micromegas + 1GEM



Without gain on the top GEM, we only observe the peaks of the two lower regions

Measured spectrum Micromegas + 2GEM



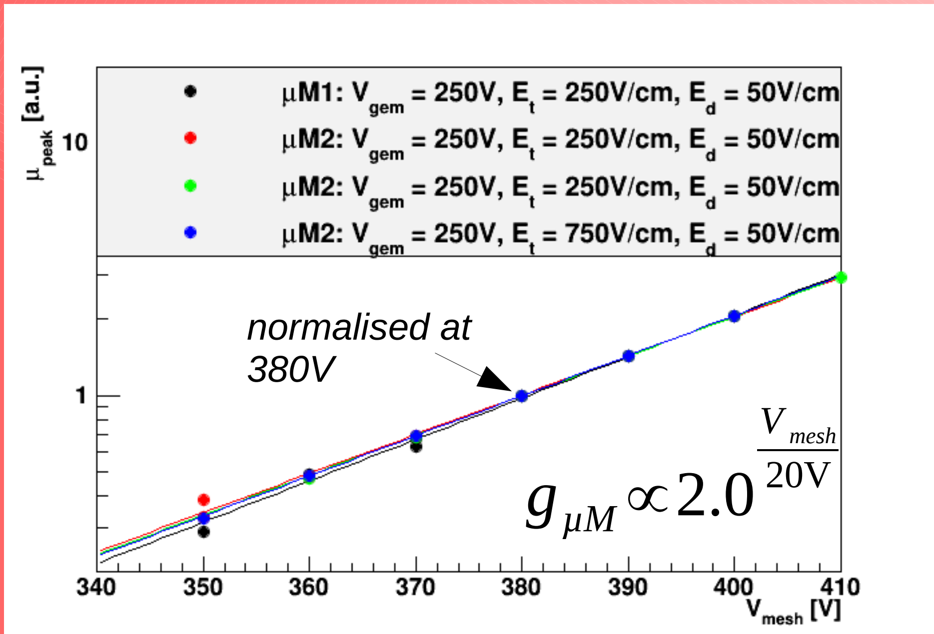
There can be up to 5 peaks, and cosmic and pileup backgrounds are impossible to describe. The following results only use the main peaks (best fitted), which were checked by eye.

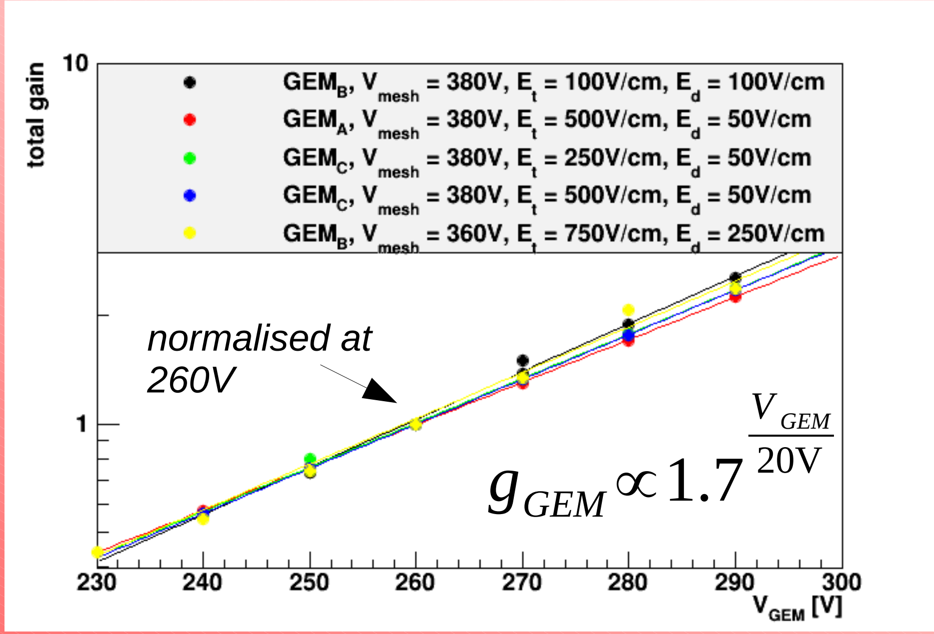
Effective gain measurements

- Measurements were done to check the dependency of the effective gain with the different fields
- Each run was done within 1 hour, varying only one field (V_{mesh}, E_{trans}^{b}, V_{GEM}^{b},E_{trans}^{t},V_{GEM}^{t} or E_{drift})
- Each run was normalised to cancel the effects of other parameters, as well as gas variations

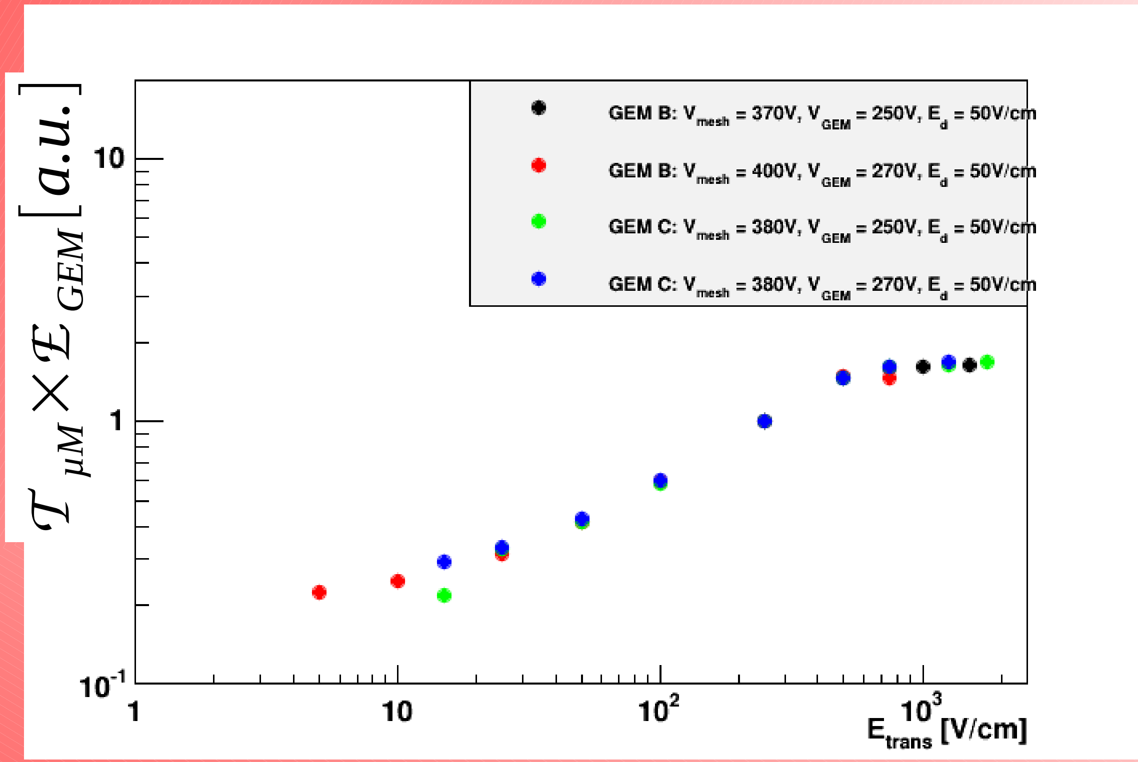
Variation with V_{MPGD} (intrinsic gain)

- The gain (position of the main peak) is shown for different values of V_{MPGD}
- Clear exponential dependency for both μM and GEM
- *The slope does not depend on other parameters*



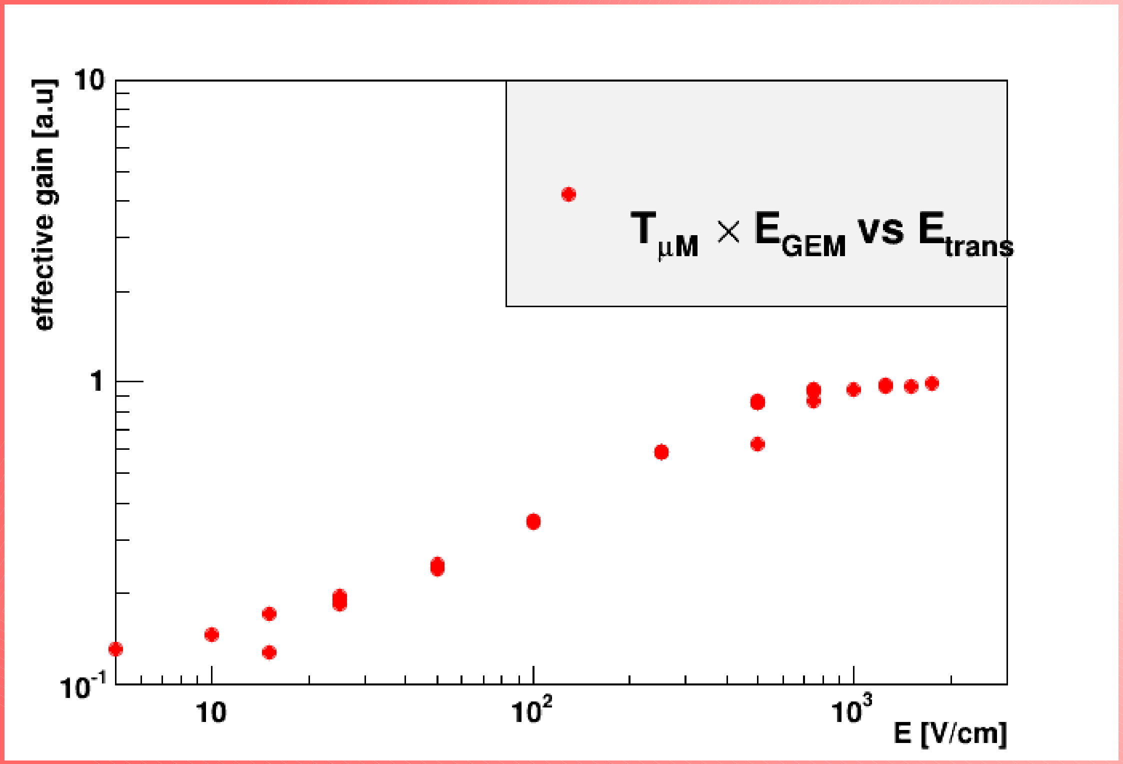


Variations with E_{trans}



- Measurement of total gain (main peak position), normalised for E_{trans}=250V/cm
- We observe the combined effect of μM transparency and GEM extraction efficiency
- *The behaviour is independent of the other fields and of the GEM used*

Variations with E fields



$$\times\ g_{\mu M}(V_{mesh})\,\mathcal{T}_{\mu M}(E^b_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^b_{trans})\,g^b_{GEM}(V^b_{GEM})\,\mathcal{C}_{GEM}(E^t_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^t_{trans})\,g^t_{GEM}(V^b_{GEM})\,\mathcal{C}_{GEM}(E^t_{drift})$$

- Measurement of total gain (main peak position), normalised for E_{trans}=250V/cm
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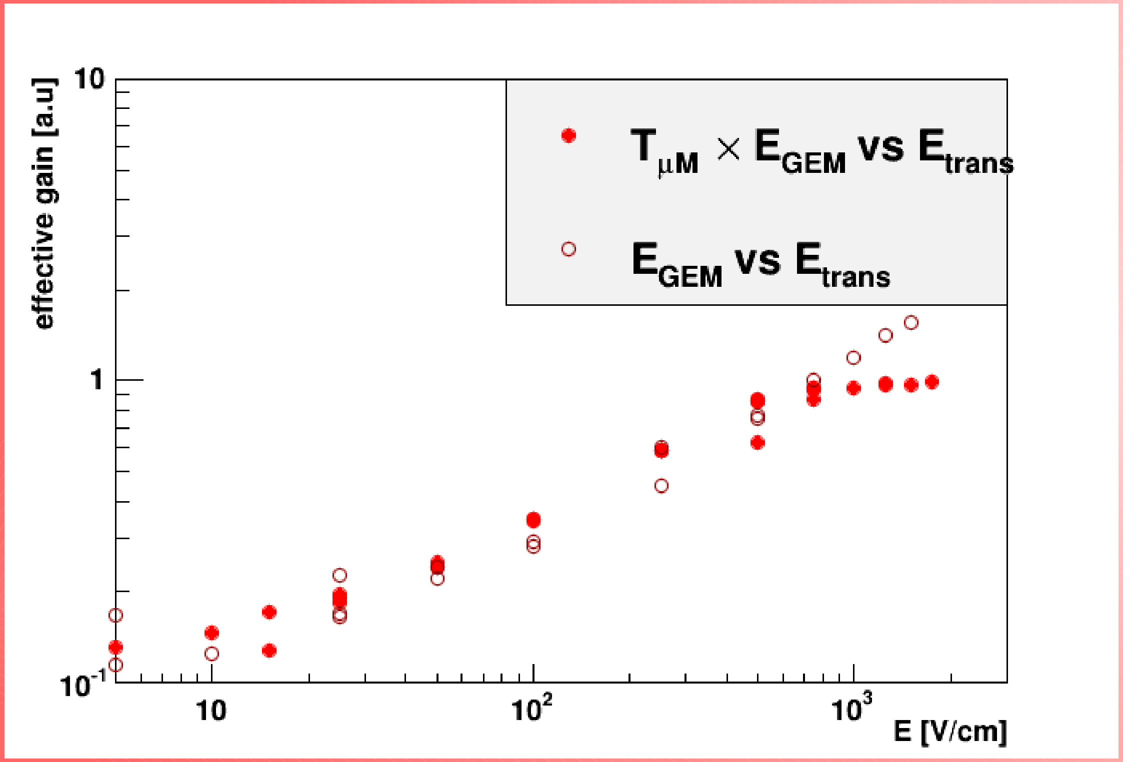
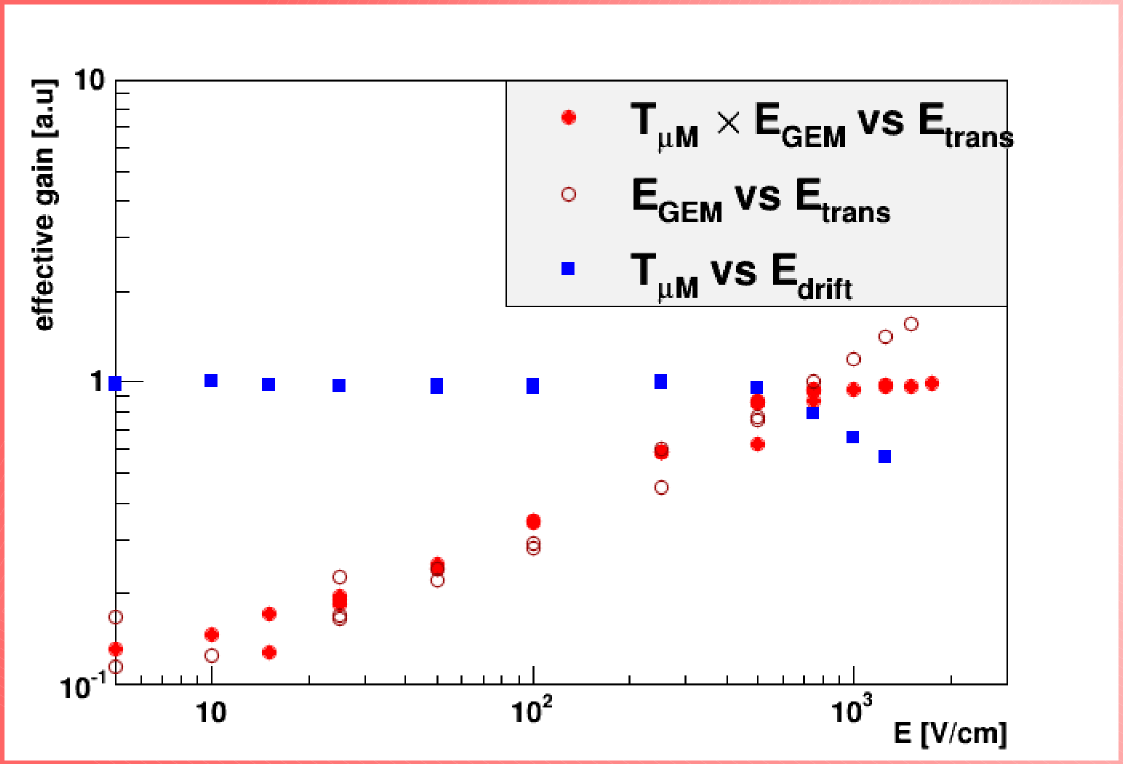
Variations with E fields



$$g_{\mu M}(V_{mesh})\,\mathcal{T}_{\mu M}(E^{b}_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^{b}_{trans})\,g^{b}_{GEM}(V^{b}_{GEM})\,\mathcal{C}_{GEM}(E^{t}_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^{t}_{trans})\,g^{t}_{GEM}(V^{b}_{GEM})\,\mathcal{C}_{GEM}(E^{t}_{drift})$$

- By taking the ratio of the peaks above and below the GEM, we cancel the effect of the other MPGD and get a measure of g^{eff}_{GEM}.
- We cannot maximize the GEM extraction efficiency in our voltage range (no plateau is reached)

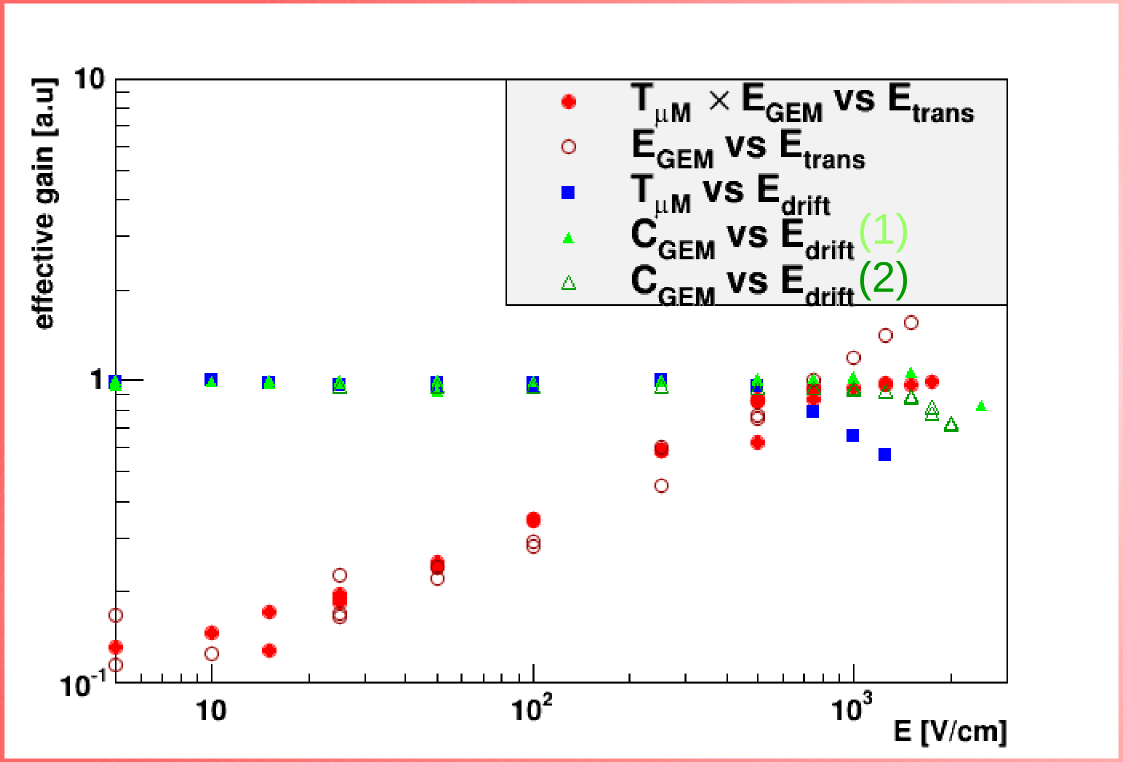
Variations with E fields



$$g_{\mu M}(V_{mesh})\mathcal{T}_{\mu M}(E^b_{trans})$$
$$\times \quad \mathcal{E}_{GEM}(E^b_{trans})\, g^b_{GEM}(V^b_{GEM})\, \mathcal{C}_{GEM}(E^t_{trans})$$
$$\times \quad \mathcal{E}_{GEM}(E^t_{trans})\, g^t_{GEM}(V^b_{GEM})\, \mathcal{C}_{GEM}(E^t_{drift})$$

- By powering only the micromegas, we can measure the micromegas transparency only
- We are limited by the low micromegas gain
- The factorisation of $\mathcal{T}_{\mu M}$ and $\mathcal{E}_{GEM}$ is confirmed
- GEM extraction and micromegas collection seem to cancel each other

Variations with E fields



$$g_{\mu M}(V_{mesh})\,\mathcal{T}_{\mu M}(E^b_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^b_{trans})\,g^b_{GEM}(V^b_{GEM})\,\mathcal{C}_{GEM}(E^t_{trans})$$
$$\times\ \mathcal{E}_{GEM}(E^t_{trans})\,g^t_{GEM}(V^b_{GEM})\,\mathcal{C}_{GEM}(E^t_{drift})$$

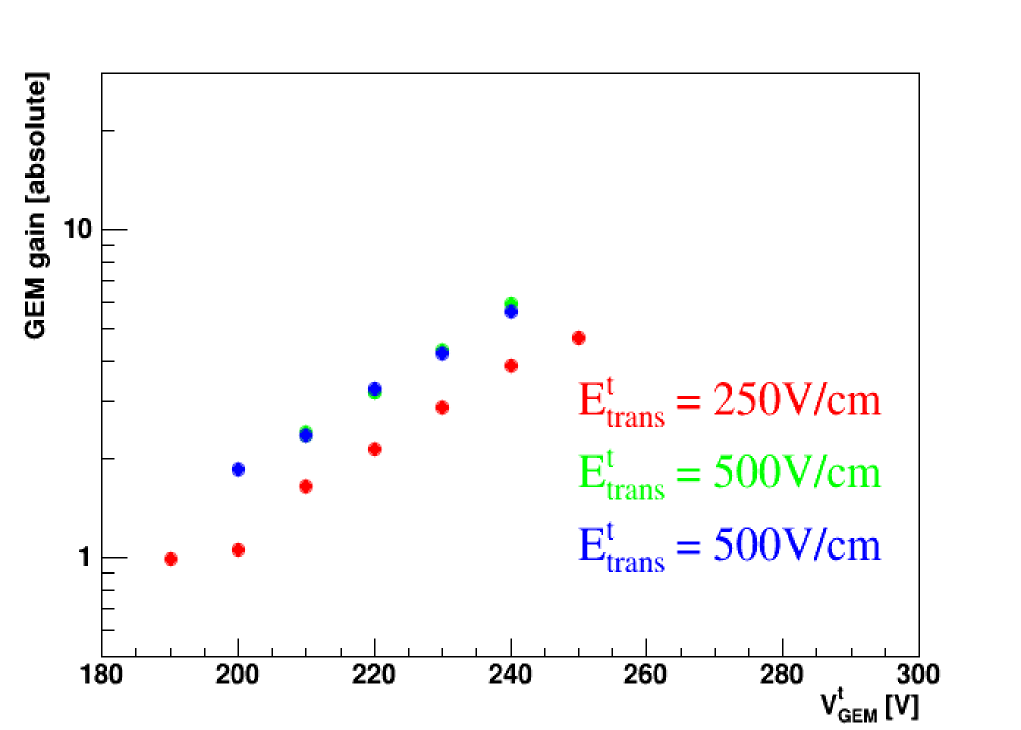
- We can easily measure the GEM collection efficiency from the main peak position (1) and the peak ratio (2) vs E_{drift}
- The collection efficiency is maximal on most of our voltage range

Variations with E fields

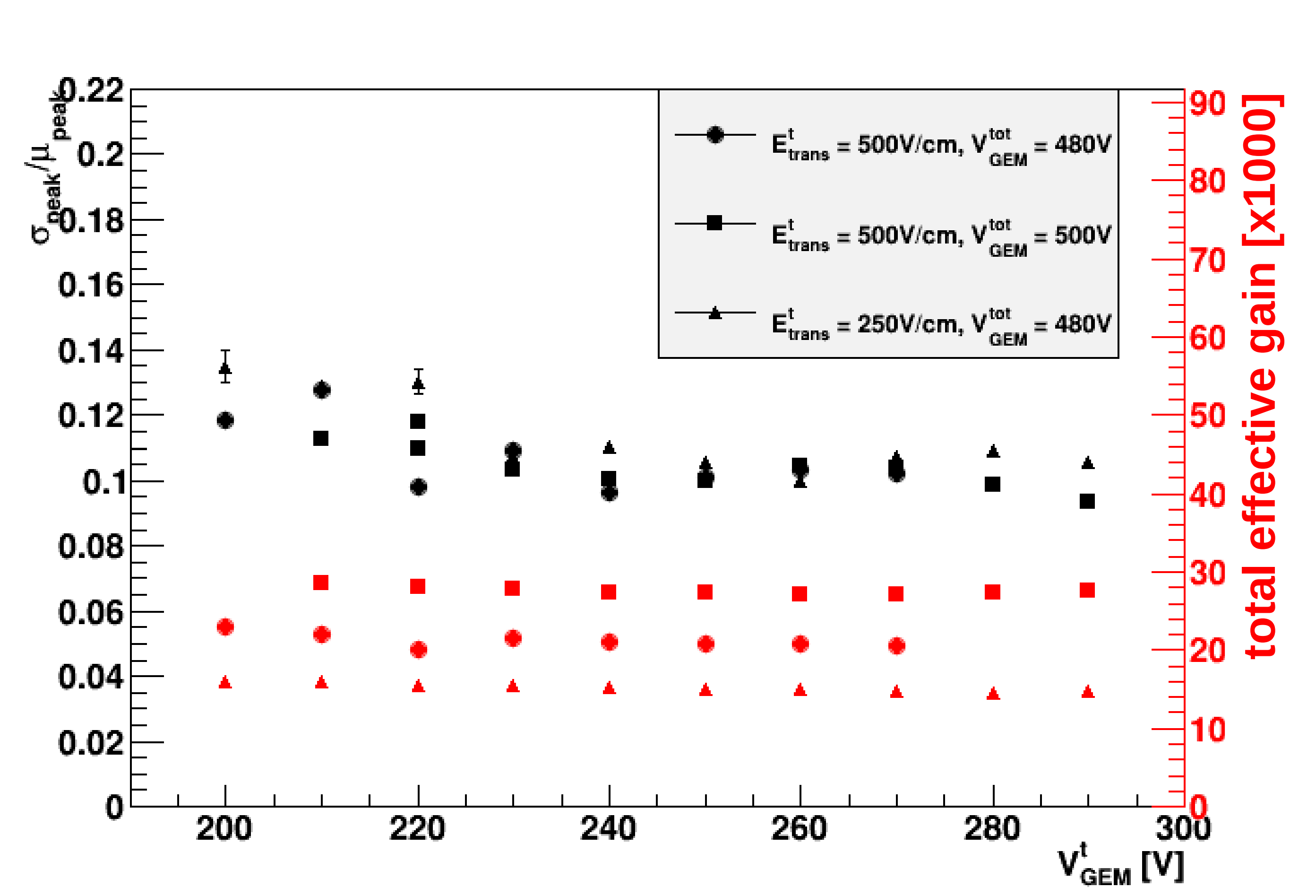
- Experimental measurements confirm the factorisation of the gain dependencies with the different fields
- The most stable field region is between 10 and 1000V/cm for all the fields
- The gain will also depend on the gas parameters (pressure, temperature, composition)

Absolute GEM gain

- From the ratio of the peaks of X-ray conversion above and below the GEM, we obtain an absolute measure of the gain
- More fitting errors
- Exponential dependency is still visible, even for gains close to 1
- The maximum measured GEM gain is ∼30, but cannot be seen with this method due to the dynamic range of the digital electronics (MCA)



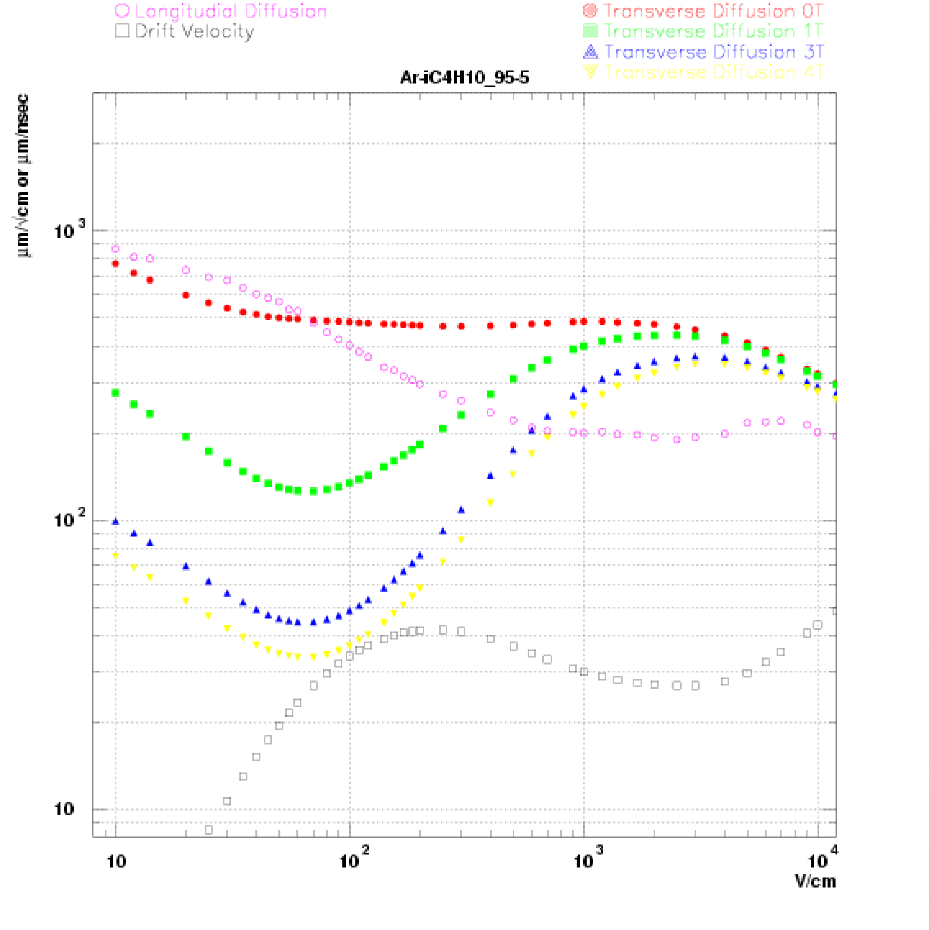
Other effects : charge resolution



- With fixed total voltage, the GEM gain is stable (as expected)
- the peak resolution gets slightly worse for low gain on the top GEM

Other effects : diffusion

- We want to maximise the transverse diffusion is the transfer regions
  - spread the charge
  - improve space resolution
- The transverse diffusion does not vary in our field range (50~1000V/cm)



Conclusions

- Amplification with micromegas and GEM for HARPO was succesfully tested. All the MPGD provided by CERN worked well
- The dependencies on the fields are well understood
  - factorisation of gain with transparency, extraction and collection efficiencies is valid in the field values considered
  - large freedom for the choice of fields

Conclusions

- We did not reach any gain limitation
  - GEM gain up to ~30
  - micromegas gain up to ~2000
  - total gain up to ~40,000

Outlook

- The MPGDs were installed in the TPC, tests with cosmic rays are starting
  - gain characterisation at P=1bar (comparison with test box results), P=2bar, P=5bar?
- Test in polarised photon beam scheduled for autumn 2014 at NewSubaru accelerator, Japan
  - performance study for polarisation measurement

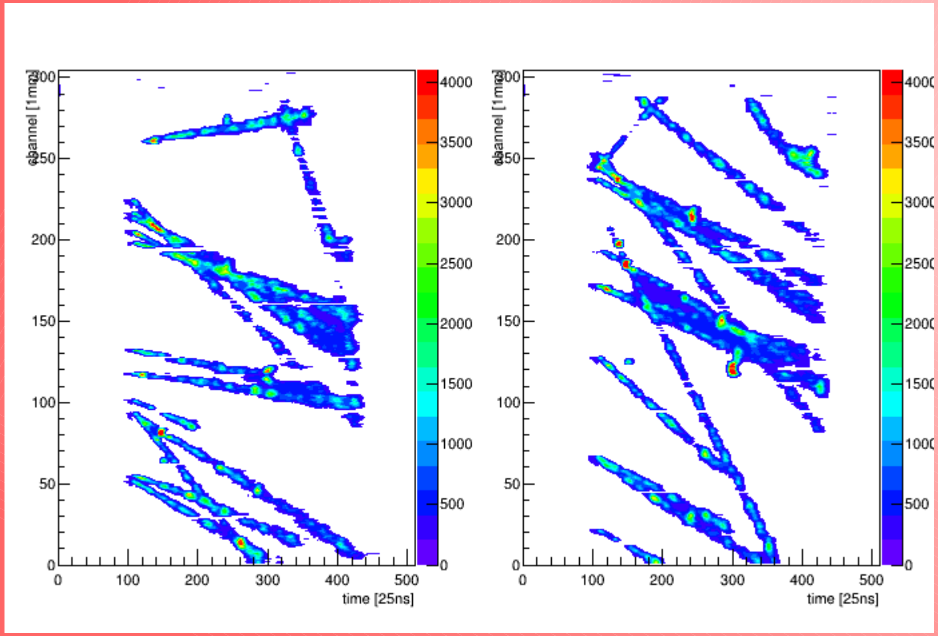
Thanks

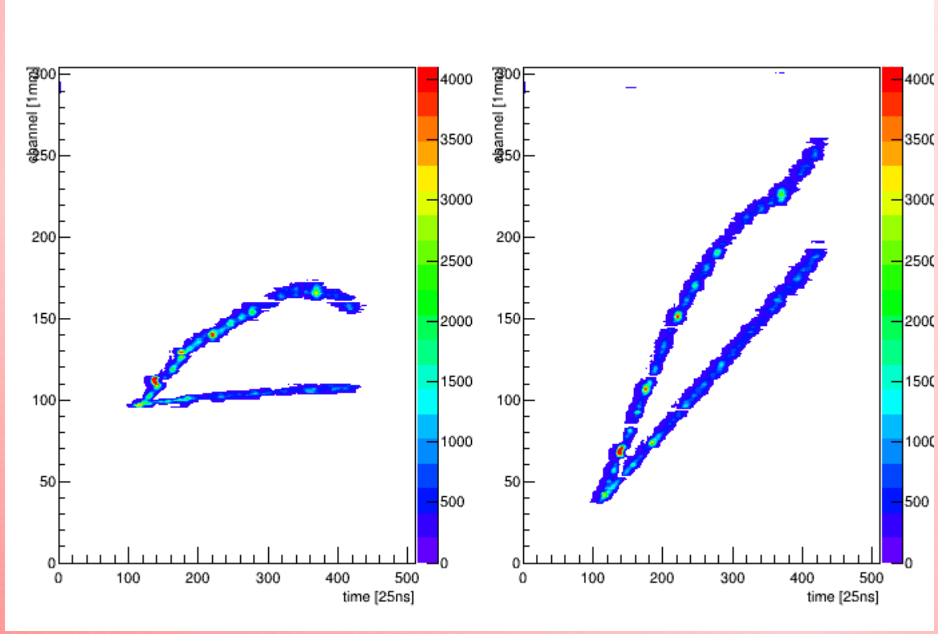
Many thanks to

R. de Oliveira et al. (CERN workshop),

L. Ropelewski et al. (RD51 lab @ CERN)

First cosmic ray events…





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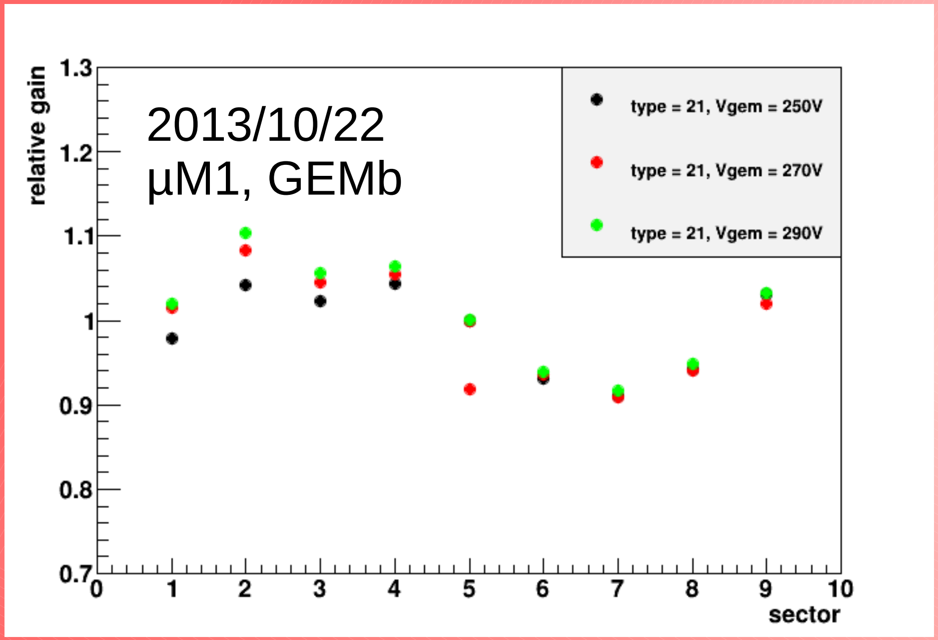
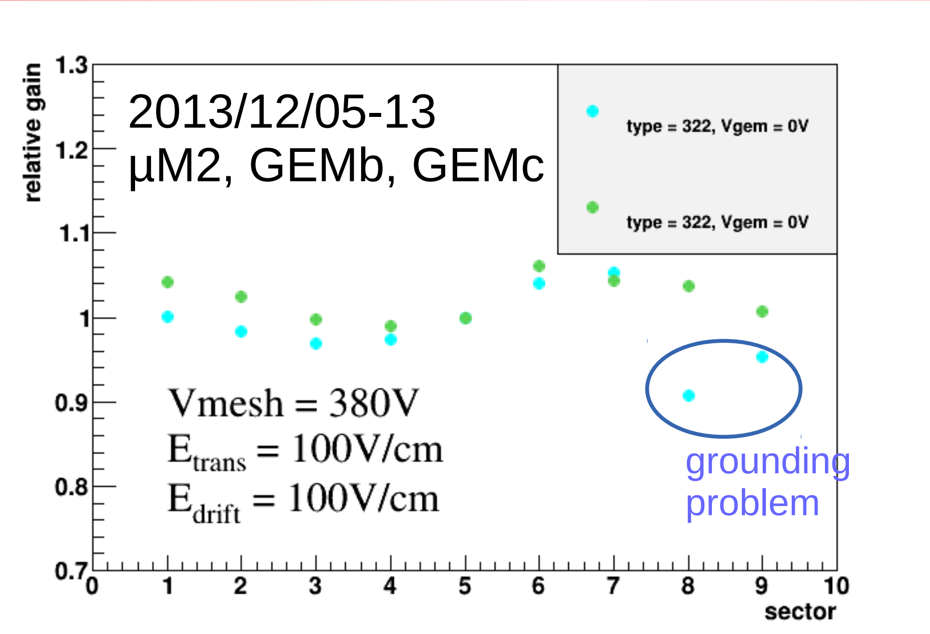
Extra result: Space dependency





Remarks about the electric setup

- GEM electrodes are coupled to limit the voltage in case of trip
  - current limitation will limit the voltage
- Each of the 9 GEM sectors is connected through a protection resistance of 10MΩ
  - the opposite electrode is connected through a 1MΩ (~10MΩ/9) resistance to get the two electrodes to discharge at a similar speed

Calibration

- The detector is replaced by a 2.2pF capacitance
- A square signal with fixed amplitude U is injected to simulate a charge Q :

$$n_e x q_e = Q = CU$$

$$n_e = C/q_e \text{ x } U$$

$$n_e = 13750 \text{ x } U \text{ [mV]}$$

Calibration ADC => n_e