Single-avalanche response mesurement method for MPGD detectors

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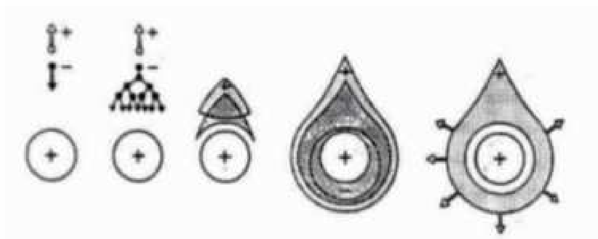
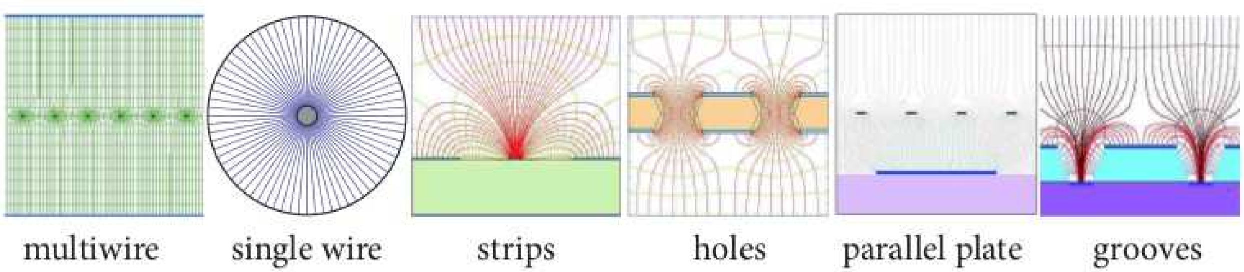
Gas based particle detectors

- Gas based particle detectors are widely used in HEP experiments.
- Relatively low price, very low material budget in the way of particles.
- Signal amplification based on electron multiplication by avalanche process.
- High field necessary for avalanche process obtained in various ways:
  - Classical solution: Multi-Wire Proportional Chamber, high field near wire.

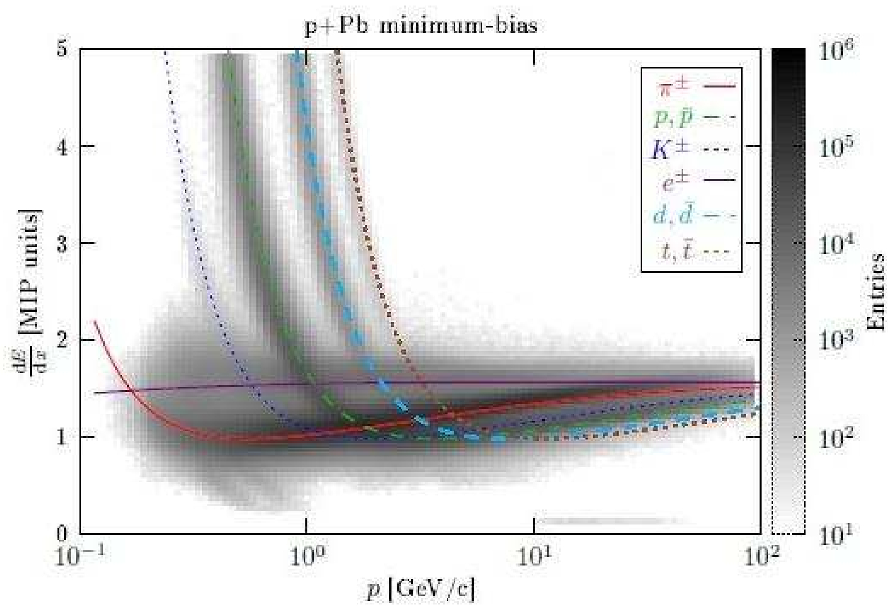


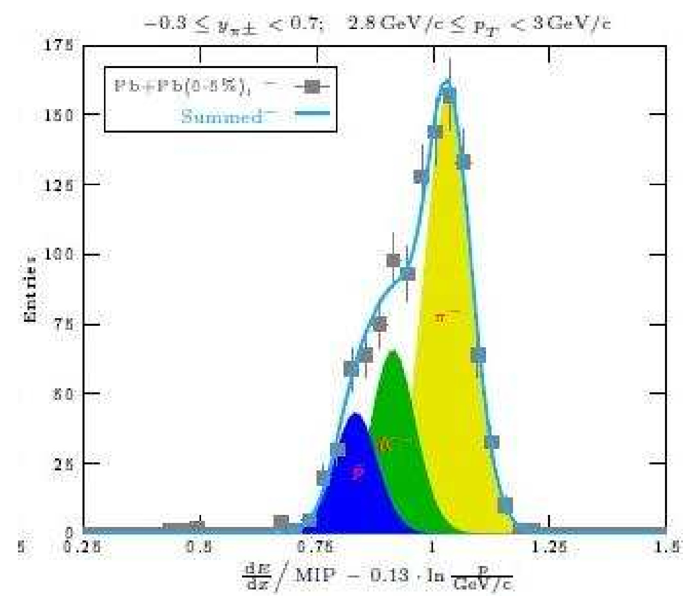
  - Newer solutions: Micro Pattern Gas Detectors (such as GEMs), high field by microstructures.



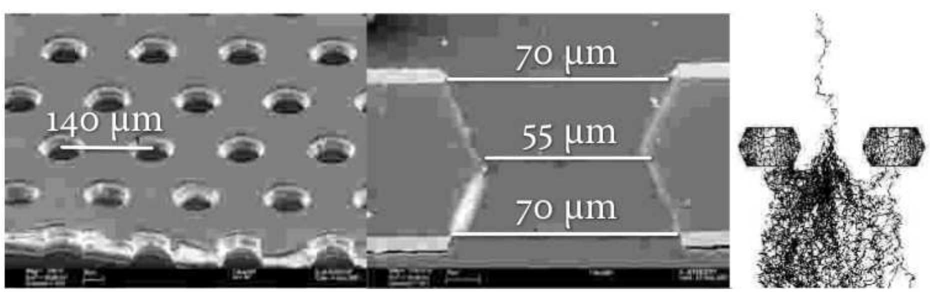
Intrinsic limits to energy deposit resolution

- When particles traverse the sensitive volume, they leave trace of ionization.
- Before electronic detection, large signal amplification ($\sim 10^4$) is needed.
- This amplification done by electron multiplication avalanche process in high electric field.
- Response to ionization energy deposit depends on the properties of avalanche process.
- Measurement of ionization energy deposit ($\mathrm{d}E/\mathrm{d}x$) used for particle identification
  $\Rightarrow$ good response resolution to $\mathrm{d}E/\mathrm{d}x$ is important.

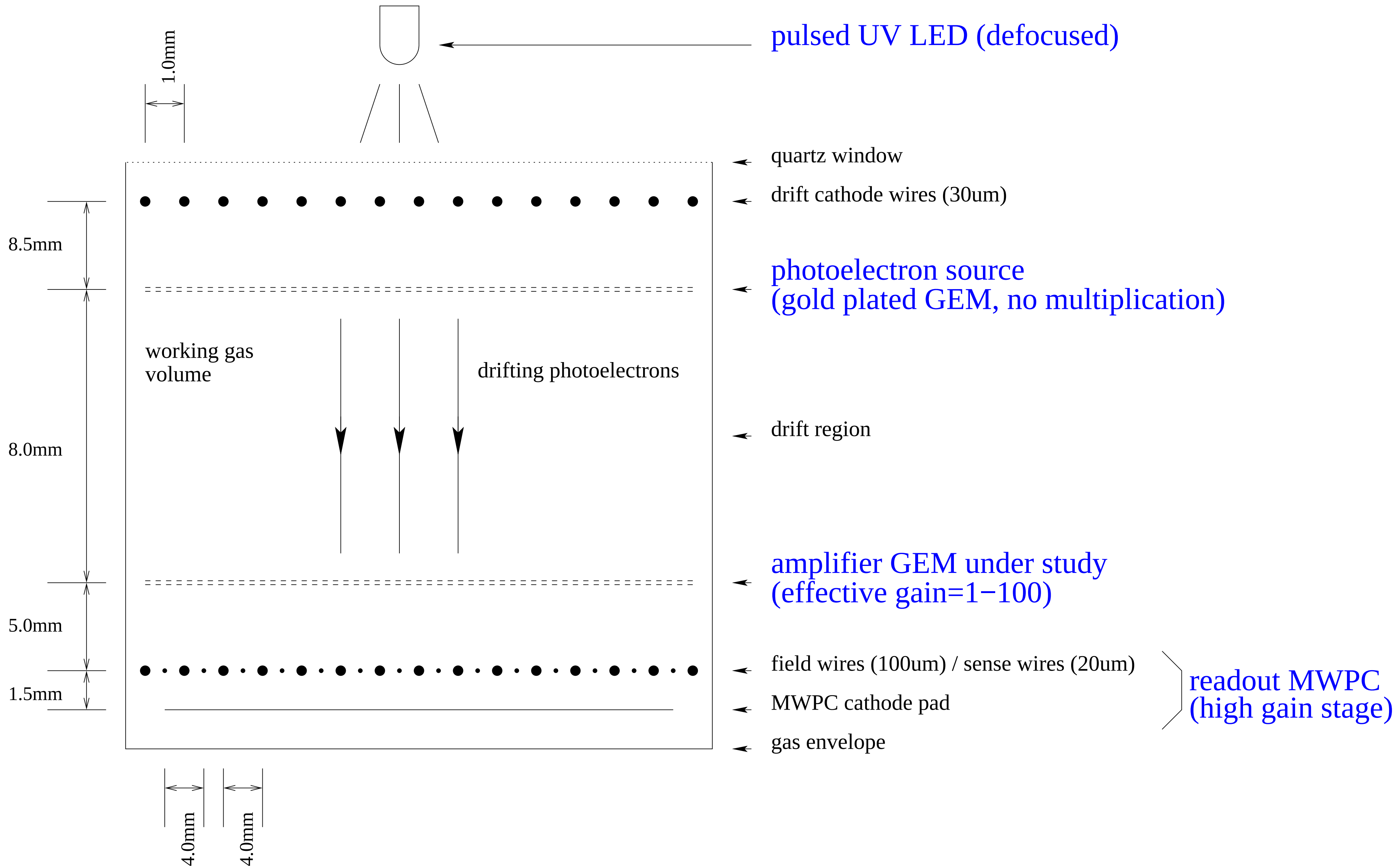




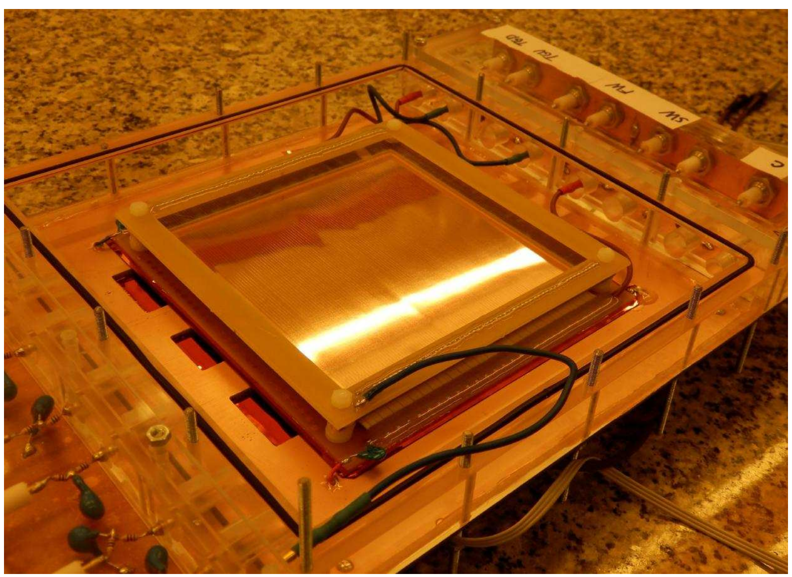
- Idealized large avalanches: system does not have memory, any intermediate electron in the avalanche generates the same response.
  $\Rightarrow$ Final population has exponential (geometric) distribution.
  $\Rightarrow$ $\sigma/\mathrm{mean} = 1$ for the response distribution.
  $\Rightarrow$ Intrinsic limit to $\mathrm{d}E/\mathrm{d}x$ resolution after amplification process.
- Lot is known on the behavior on classic MWPC avalanches (NIM **75** 161, NIM **89** 155): available space and time for avalanche development is large.
  $\Rightarrow$ Large, close-to-idelized avalanches with large number of generations.
  $\Rightarrow$ Approximately exponential single-avalanche response.
  $\Rightarrow$ $\sigma/\mathrm{mean} \approx 1$.
- For MPGD detectors? Micromegas: T.Zerguerras et al. NIM **A608** 397. Deviation from exponential due to limited space and time for avalanche development, $\sigma/\mathrm{mean} < 1$.
- What about GEMs? This talk is about that. Motivated also by ALICE TPC upgrade.



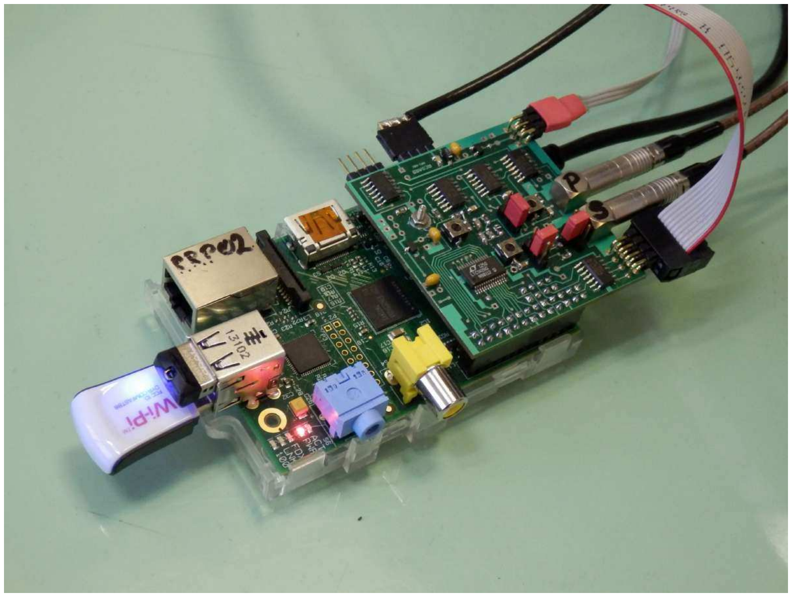
Exp. setup for multiplication response measurement



- Defocused pulsed UV LED used to extract photoelectrons (PEs) from surface of gold plated classic GEM.
- These PEs were transferred to the reverse side, providing a source of laminarly drifting PEs.
- Electron multiplication takes place in a subsequent classic GEM (effective gain 1-100).
- Multiplied electrons enter into an MWPC amplifier region to enhance their signal.
- Electronic FEE amplifier detects the MWPC-amplified signal from sense wires.

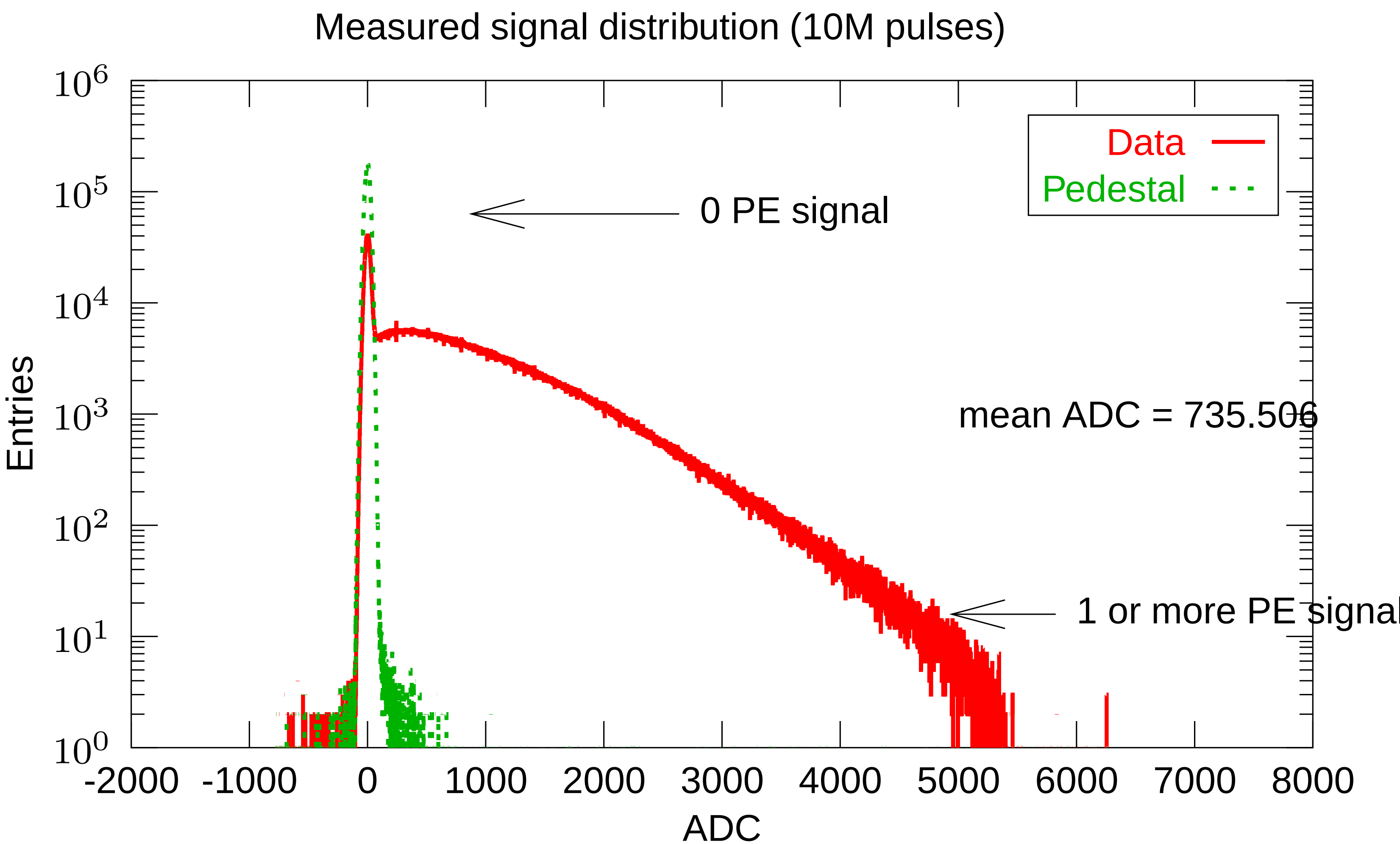


- Front-End Electronics and LED electronics from the Leopard project (NIM **A694** 16, POS **TIPP2014** 056).



- MWPC design based on CCC concept (NIM **A648** 163, NIM **A698** 11).
- Due to fast recording, statistics of 10M pulses were recorded for each setting. (Negligible statistical errors, systematics dominated measurement.)
- Various working gases: Ar(80)CO_2(20), CH_4, Ne(90)CO_2(10), Ne(90)CO_2(10)N_2(5).

Amplitude distribution from direct measurement for typical setting.



Single-avalanche response reconstruction

Signal formation:

- Photoelectron generation with Poisson distribution P_ν, here ν is the per pulse PE yield.
- Multiplication of each PE by GEM avalanche process, with distribution p each.
- Multiplication of each GEM-multiplied PE by MWPC avalanche process, with distribution e_γ each (γ: MWPC gain). Note: e_γ is approximately exponential with slope γ.
- An additive noise is mixed to the signal at the FEE amplifier input, with distribution g. Note: g is approximately Gaussian, and can be measured with zero-signal events.

GEM response distribution to an incoming single-photoelectron:

$$p.$$

GEM+MWPC response distribution to an incoming single-photoelectron:

$$f = \sum_{k=0}^{\infty} e_\gamma^{(k\text{-fold convolution})}\, p(k).$$

GEM+MWPC+FEE response distribution to an incoming LED pulse:

$$h \quad = \quad g \ \text{(convolution)} \ \sum_{n=0}^{\infty} f^{(n\text{-fold convolution})}\, P_\nu(n).$$

- Using convolution theorem, one has in Fourier space:

$$H = G\ \exp\left(-\nu\left(1-F\right)\right)$$

where F, G and H is the Fourier transform of f, g and h.
Here, F decays to zero because of Riemann-Lebesgue lemma.
$\Rightarrow\ H/G\Big|_{\text{high freq.limit}} = \mathrm{e}^{-\nu}$, i.e. the PE yield ν can be determined.
$\Rightarrow$ the single-PE GEM+MWPC response f can be reconstructed in mathematical way.

- Using an unfolding method (A.László JPCS **368** 012043, `arXiv:1404.2787`):

$$f = \sum_{k=0}^{\infty} e_{\gamma}^{(k\text{-fold convolution})}\ p(k)$$

can be solved for p.
$\Rightarrow$ the single-PE GEM response p can be reconstructed in mathematical way.

- Due to the additivity of mean μ and variance σ^2 of independent distributions:

$$\mu_p = \frac{\mu_h - \mu_g}{\nu\,\gamma} \qquad \text{(= GEM gain)},$$

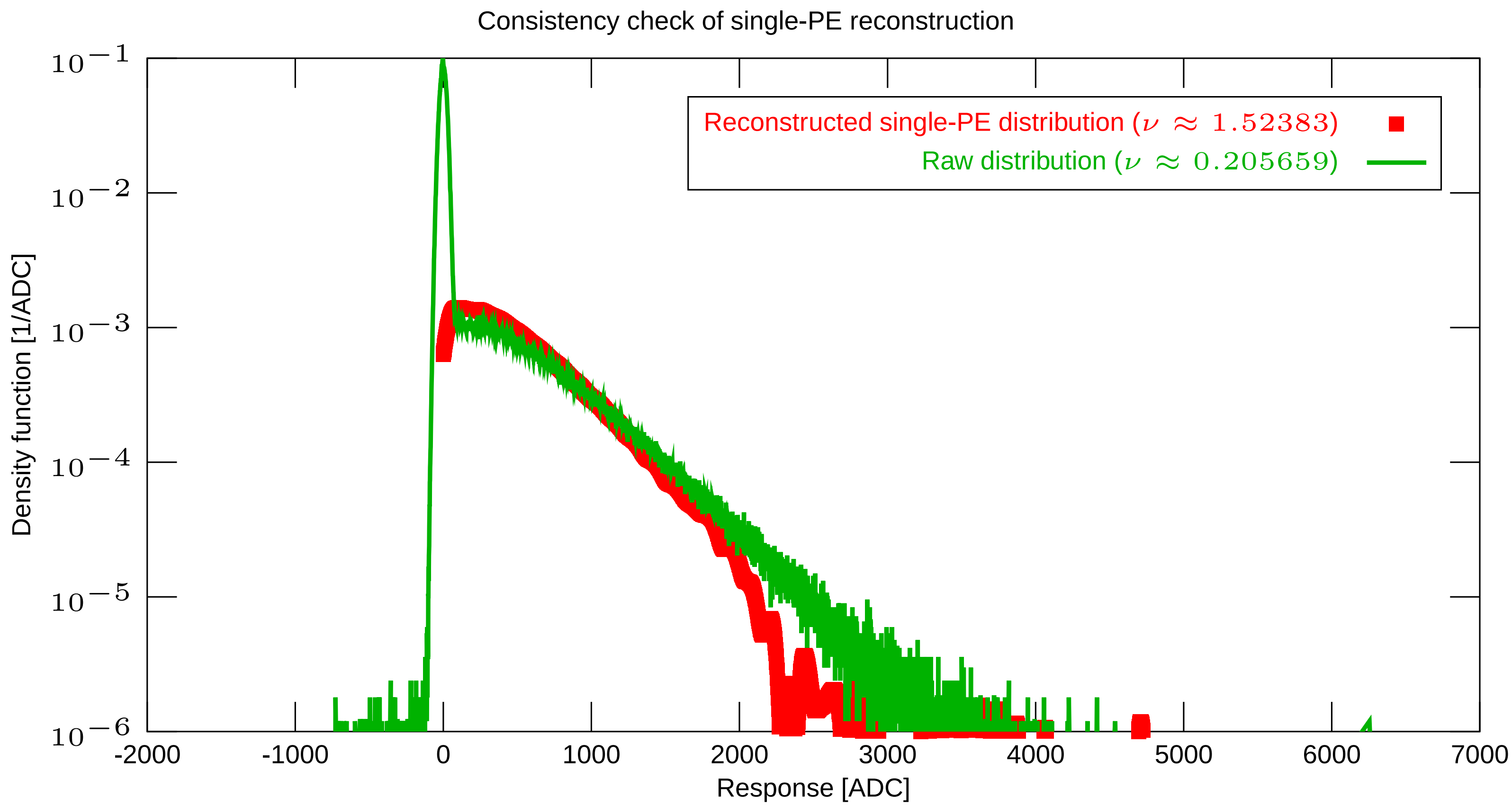
$$\frac{\sigma_p}{\mu_p} = \sqrt{\nu\,\frac{\sigma_h^2 - \sigma_g^2}{(\mu_h - \mu_g)^2} - \left(\frac{\sigma_{e_\gamma}}{\mu_{e_\gamma}}\right)^2 \frac{1}{\mu_p} - 1} \qquad \text{(= GEM intrinsic resolution)}$$

  is valid for the moments.
  $\Rightarrow$ the GEM gain μ_p and the GEM intrinsic resolution σ_p/μ_p can be recovered.

  Note: it is seen that systematic errors caused by possible small non-exponentiality of MWPC response is suppressed by 1 $/$ GEM gain.

Measurements can be performed in two extremes:

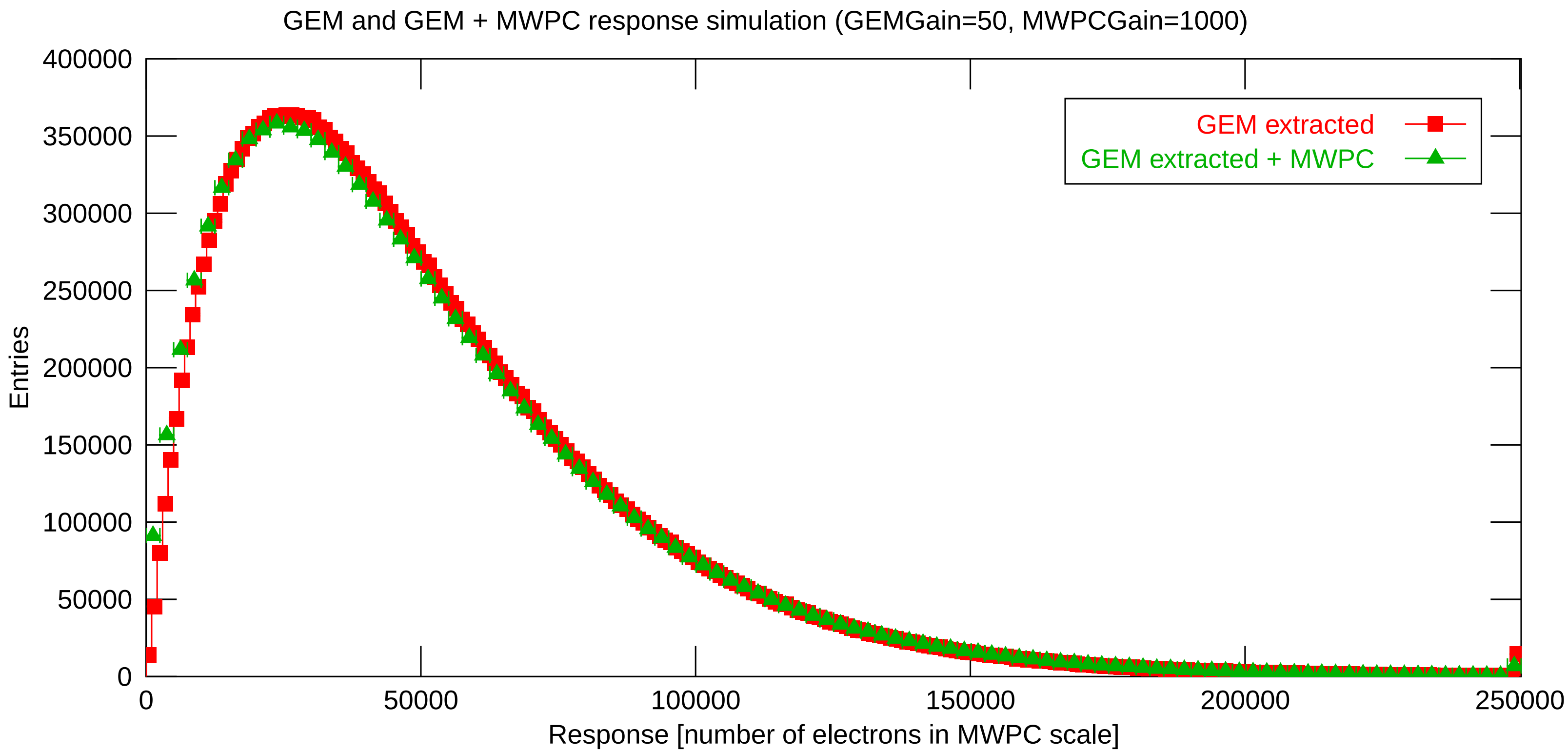
- small PE yield ($\nu \approx 0.01 - 0.1$) — direct measurement possible without reconstruction, but low amplitude region not directly visible on raw spectra,
- large PE yield ($\nu \approx 1 - 3$) — the discussed Fourier method is needed, and can also recover the small amplitude region.



Good consistency seen.

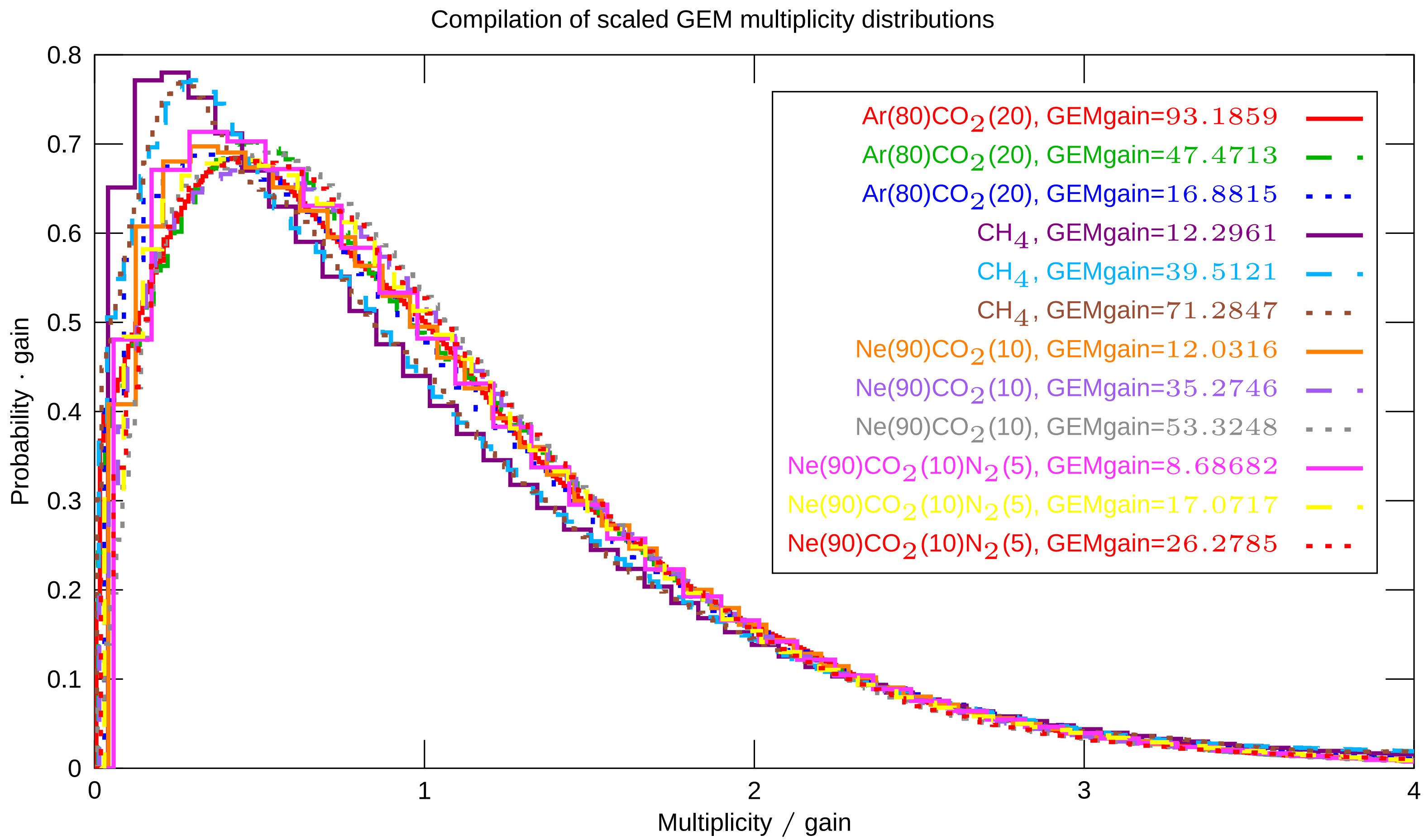
Shape bias by MWPC response is small, especially for not too small GEM gain settings.

Simulation example:



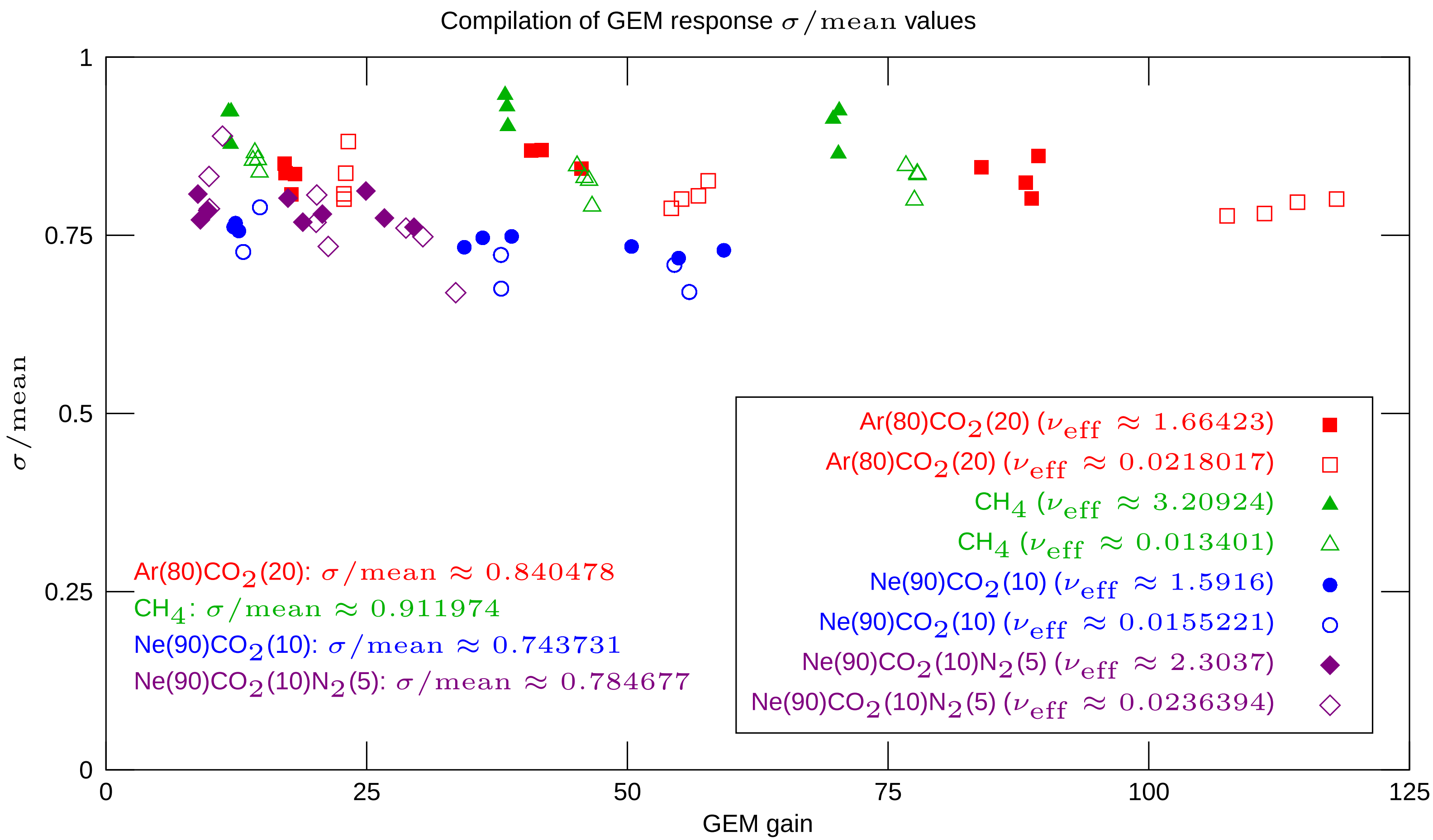
Can be corrected in an exact way by the discussed unfolding method, and shape correction is very small for GEM gain ≥ 10.

Preliminary results



Preliminary results show that shape of GEM avalanche response distribution is approximately independent of the effective gain, and slightly depends on the working gas (better for Neon based).

The same effect is seen on the σ/mean values: independent of the effective gain, and slightly depends on the working gas (better for Neon based).



(Systematic errors of large PE yield measurements are better – about 5%.)

Summary

- An experimental setup and methodology was developed for determination of the multiplication distribution of GEM electron avalanches.
- Apparatus and methodology was designed specially for the coverage of wide ranges of effective gain (1-100) as well as for measurement of the low multiplication region of the avalanche response.
- Experimentally measured avalanche multiplication distributions show deviation from exponential for GEMs: $\sigma/$mean down to 0.8 were seen.
- Preliminary results reveal universal properties of the shape of the single avalanche multiplication distribution.
- Best intrinsic resolution ($\sigma/$mean) seen for Neon based working gases around $0.8 \Rightarrow$ improved $\mathrm{d}E/\mathrm{d}x$ resolution.