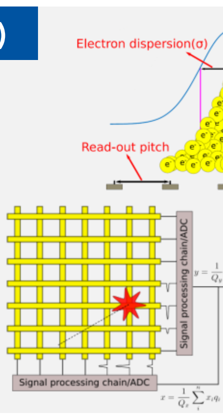
Position reconstruction studies with GEM detectors and the charge-sensitive VMM3a ASIC

Position reconstruction in Gas Electron Multipliers (GEMs)

Radiation deposits energy inside the detector by ionising the gas atoms. The liberated electrons drift towards the readout anode (here: 9 mm distance). The electron cloud diffuses (σ ~ 250 µm, Ar/CO_2 70/30%) while drifting. In addition, the electrons are multiplied inside the holes of the GEM (avalanche effect due to a high electric field). This leads to a spread of the electrons over the readout anode. With fine pitch granularity electrodes (here 400 µm pitch strips), spatial resolutions of about 100 µm are achieved (with MIPs, binary response). Better spatial resolutions (around 40–50 µm with MIPs) can be achieved by using position reconstruction algorithms, e.g. centre-of-gravity (COG). This requires electronics, which allows to access the analogue charge information.

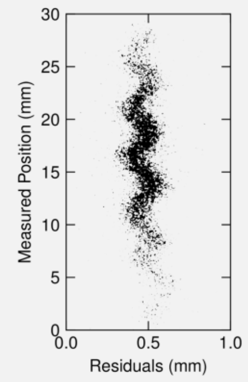


https://indico.cern.ch/event/889369/contributions/4039478

Bias in reconstructed positions

Despite the fine granularity, a bias can be introduced in the reconstructed position This is caused by the loss of charge and position information, due to the discrete readout electrodes in combination with a discriminator level of the readout electronics. A similar behaviour was already observed with Multi-Wire Proportional Chambers (MWPCs)[1]. This indicates that pure COG to reconstruct the position may not be ideal.

[1]: doi.org/10.1016/0029-554X(82)90113-6



Mitigation of the bias effect

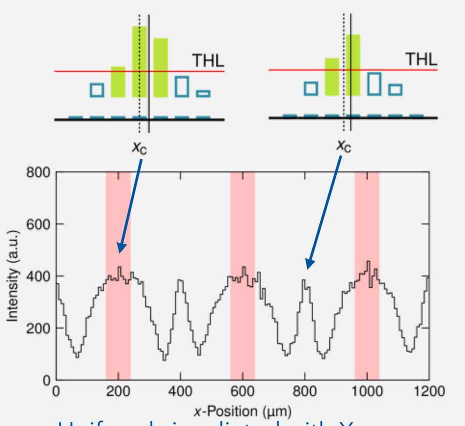
The loss of charge information can lead to inaccuracies in the position reconstruction, when using purely COG. Two different methods have been tested to mitigate the bias effect by improving the position reconstruction on the event-level without a correction algorithm.

a. Feature of the self-triggered VMM3a ASIC[2] to read out the signals on the neighbouring channels below threshold (neighbouring-logic/trigger)
b. Different weight for the charge in the COG formula. Give less weight to the tails that lead to the bias effect; more weight to the channels with higher charge (more 'correct' charge information).

[2]: doi.org/10.1088/1742-6596/1498/1/012051

Odd strip count: x_c forced to strip centre

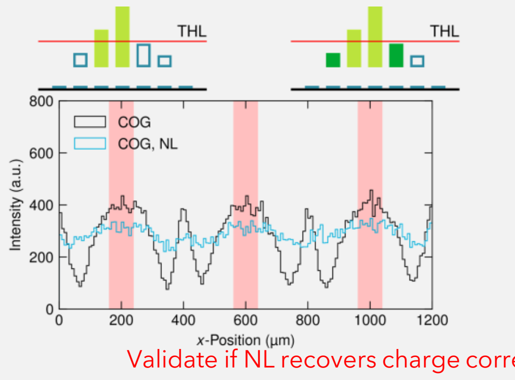
Even strip count: x_c in-between strips



Uniformly irradiated with X-rays

Method a: Neighbouring-Logic (NL)

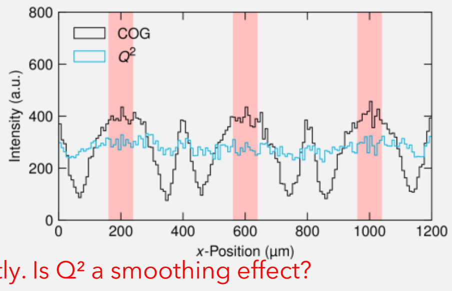
Signal above THL triggers readout of adjacent channel below THL. This recovers lost charge information; should automatically improve the position reconstruction



Method b: Q²

Change the weight of the charge in the COG formula, to give less impact to the tails and the charge the just passed the THL. Here n = 2 was tested.

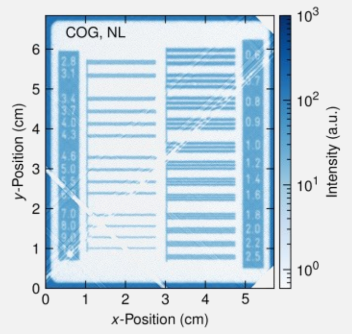
$$x_c = \frac{\sum_i Q_i^n x_i}{\sum_i Q_i^n}$$

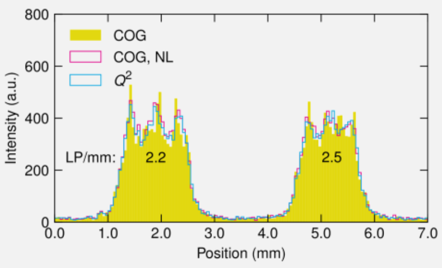


Validate if NL recovers charge correctly. Is Q² a smoothing effect?

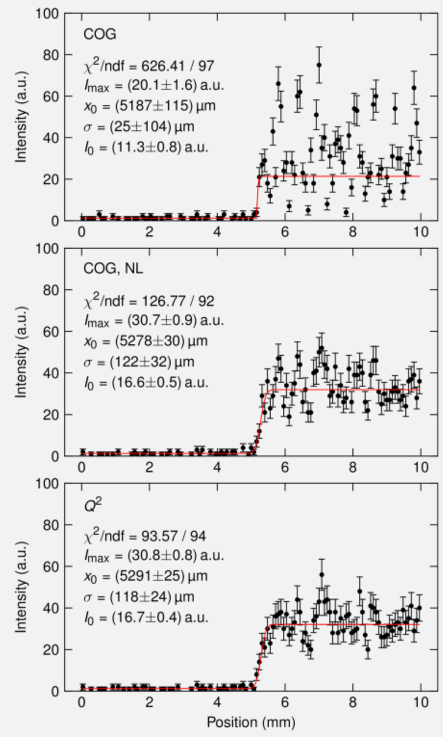
Measurements with X-rays

Measurements with soft X-rays (8 keV copper target X-ray tube) and line phantom (tilted by 45° with respect to the readout strips to give no preference to one readout direction due to Moiré patterns; the diagonal lines are dead strips/channels). Despite 3 slits in phantom, 4 peaks are observed in the transmission profile at 2.5 LP/mm, so one 'fake peak' is generated by the modulation effect. With NL and Q² this fake peak disappears, and all 3 slits are correctly reconstructed. The intensity response gets also more symmetric/less distorted (see especially central peak at 2.2 LP/mm).





Improvement observed also with Edge Spread Function (ESF). The events are integrated along 10x0.085 mm². This shows, that on a local level, NL and Q² improve significantly the position reconstruction, as the bias effect gets significantly reduced.

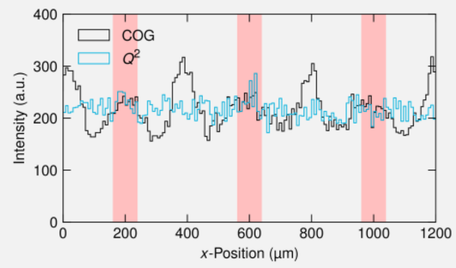


Both, NL and Q², improve the position reconstruction with X-rays, despite their different nature.

Measurements with MIPs

Measurement with MIPs in beam telescope (different readout electronics, without NL: APV25, still access to the analogue information of the signal).

σ_{COG} = (47 ± 1) µm
σ_{Q^2} = (42 ± 1) µm



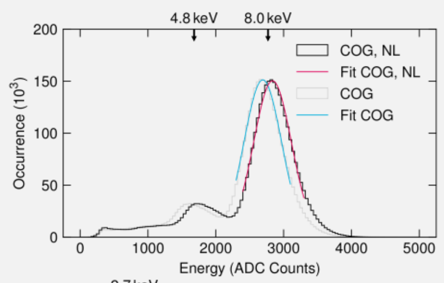
Q² improves the position resolution with MIPs in COMPASS-like triple-GEM detectors[3].

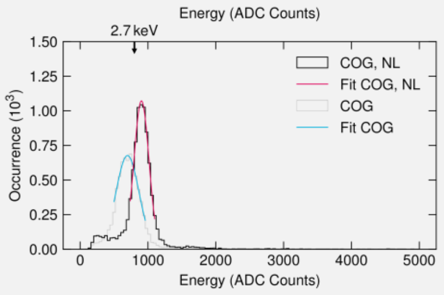
[3]: doi.org/10.1016/S0168-9002(02)00910-5

More on the VMM3a Neighbouring-Logic

To further ensure that the NL improves the detector response, the effect on the energy resolution is studied. In case of large energy deposition (8 keV X-rays), the fraction of charge which gets recovered is small, so the energy resolution improves only from (24.0 ± 0.3)% to (22.8 ± 0.3)%. For small energy depositions (2.7 keV), the energy resolution improves from (53.4 ± 0.7)% to (27.8 ± 0.8)%. This is not only because the peak position shifts towards larger values, but also because the fluctuations (width of the peak) get smaller[4]. NL helps to recover charge information

[4]: doi.org/10.1016/j.nima.2021.165576

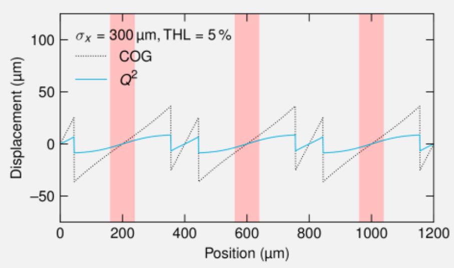


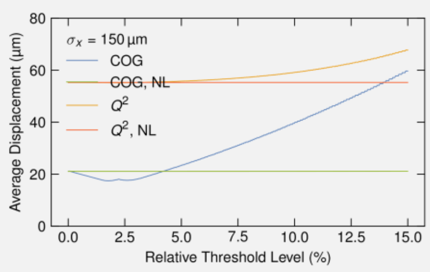


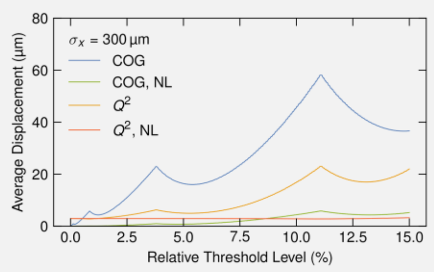
Numerical studies

Simplified calculations (1D, no noise, geometrical charge collection) were performed to understand limitations of Q². The strip pitch is 400 µm, the strip width w = 200 µm (50 % charge collection, as in the readout direction of the experimental set-up). The charge per strip s_i is given by $Q_i = \frac{1}{\sqrt{2\pi\sigma_x^2}} \int_{S_i-\frac{w}{2}}^{S_i+\frac{w}{2}} e^{-(x-\mu_x)^2/(2\sigma_x^2)}\,dx$ with σ_x the width of the charge cloud and μ_x the position. Knowing the initial position of the charge cloud, allows to calculate the displacement of the reconstructed position. The total charge in the charge cloud is normalised to 1. A THL is applied per readout strip. It is given as fraction of the total charge.

With this the average displacement for various charge cloud widths, THLs and reconstruction methods can be calculated. For σ_x = 300 µm (like the experimental conditions) Q² improves the position reconstruction. For smaller charge cloud widths (here σ_x = 150 µm), too much charge is acquired with one strip, enforcing the reconstruction to this strip, leading to an almost flat position response. The spikes, which are observed in the right plot, correspond to minimal cluster size variations.







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