Study of avalanche fluctuations and energy resolution with an InGrid-TimePix detector

D. ATTIÉ[1)], M. CAMPBELL[2)], M. CHEFDEVILLE[3)], P. COLAS[1)], E. DELAGNES[1)], K. FUJII[4)], I.GIOMATARIS[1)], H. VAN DER GRAAF[5)], X. LLOPART[2)], M. LUPBERGER[1)], H. SCHINDLER[2)], J. SCHMITZ[6)], M. TITOV[1)]

1) CEA/Irfu Saclay, 2) CERN, 3)LAPP Annecy, 4)KEK, 5)Nikhef, 6)Twente U.

Avalanche fluctuations are an old problem, motivated by recent applications in MPGDs, which can be addressed with new tools.

Avalanche statistics, an old problem…

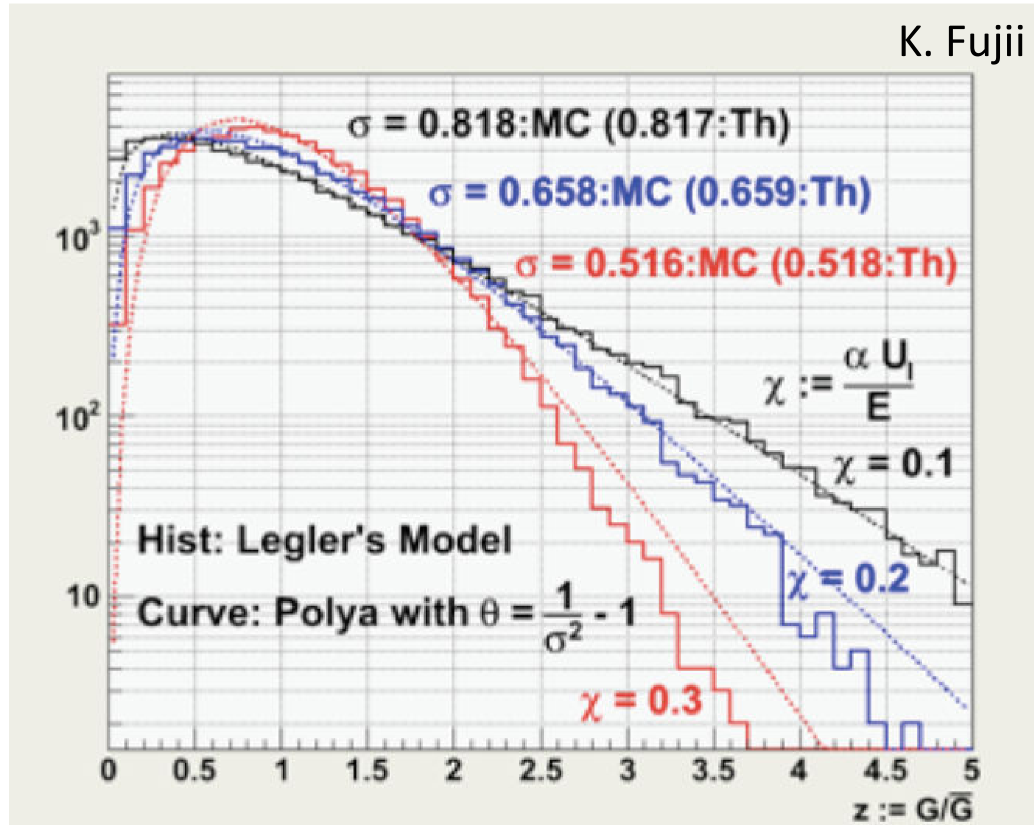
Wijsman 1949,

Yule-Furry : exponential

Legler 1955, 1961: it takes a distance U_I/E to get ionization energy from the E field

Alkhazov 1970 : avalanche process is iterative, moments of the size distribution can be calculated, turnover at low Z

Approx. solution for wires: Polya



$$P_G(G/G;\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)} \left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$$

$$\sigma^2_{G/\bar{G}} = 1/(1+\theta)$$

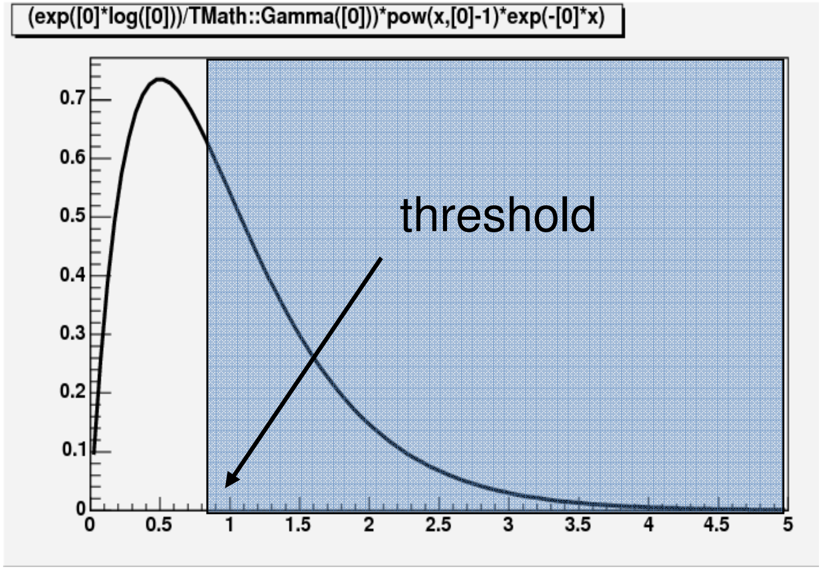
θ = 0 : exponential distribution

…with new motivations

Motivated by practical consequences:

- energy resolution of MPGD, contributes $1/\sqrt{(1+\theta)N}$
- spatial resolution of a Micromegas TPC, avalanche fluctuations lower by a factor $(1+\theta)/(2+\theta)$ the number of effective electrons, D. Arrogancia et al., NIM A 602 (2009) 403
- efficiency for single electron

detection



New tool : TimePix chip + InGrid

CERN-Nikhef-Saclay Collaboration within EUDET

Idea : take a medical imaging chip (Medipix 2), add a clock to each pixel, replace 'grey levels' by 'clock ticks'

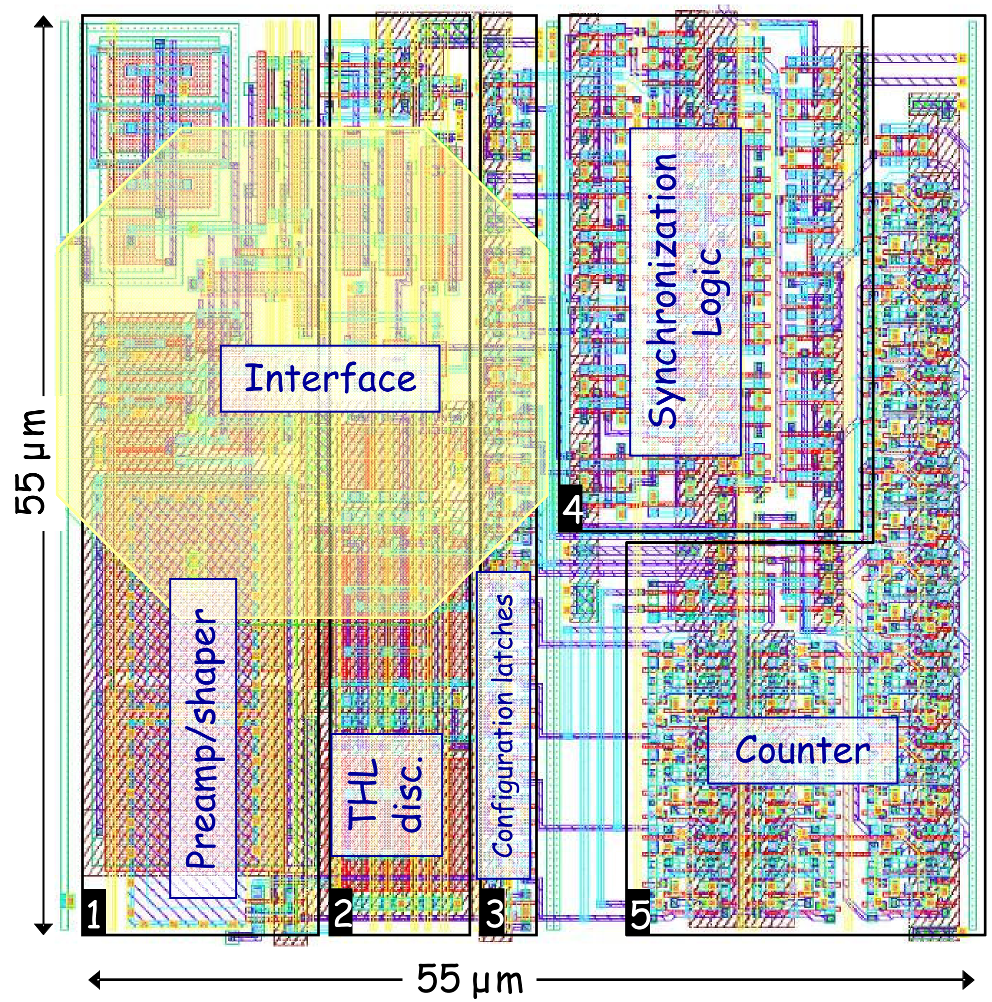
(Michael Campbell, Xavi Lloppart, CERN)

65000 pixels, 14-bit counter, 100 MHz tunable clock frequency -> more voxels than the ALEPH TPC, but tiny!

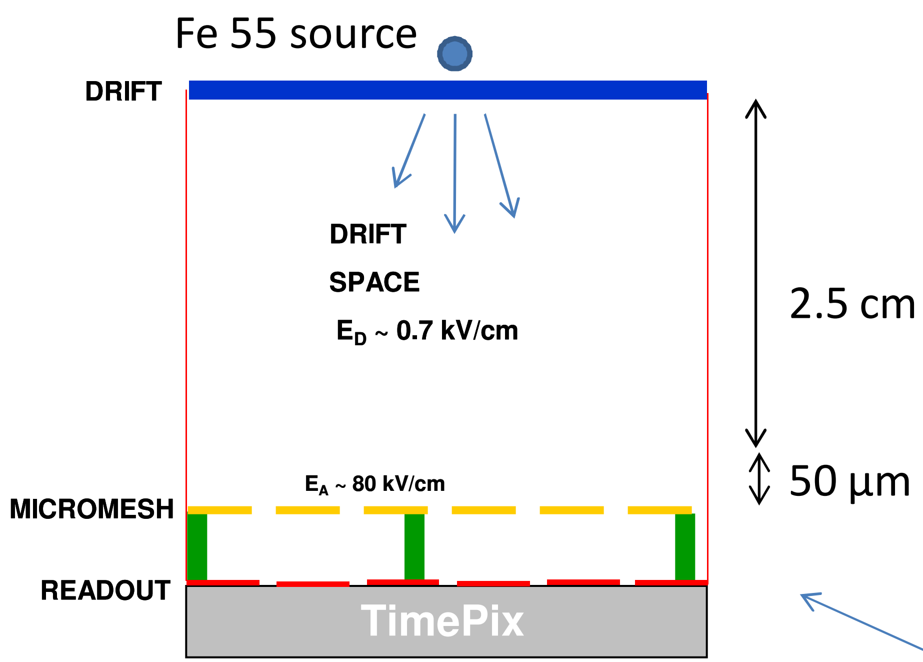
Cover the chip with a deposited grid over SU8 pillars 50 µ high to obtain gas amplification

The chip is protected by 7 µ SiN to avoid destruction by sparks.

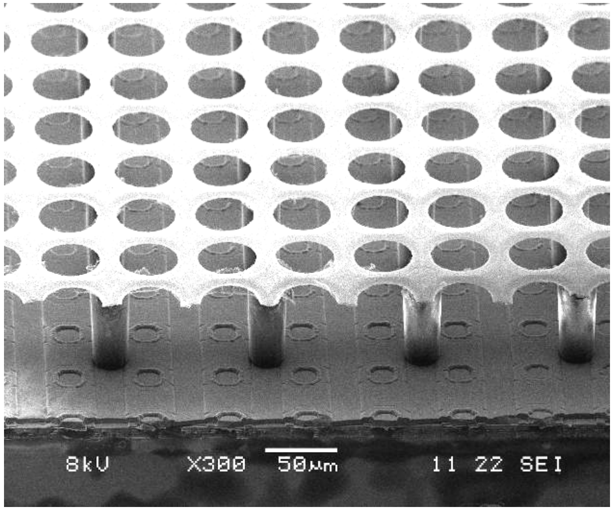
Pixel



Micromegas + TimePix



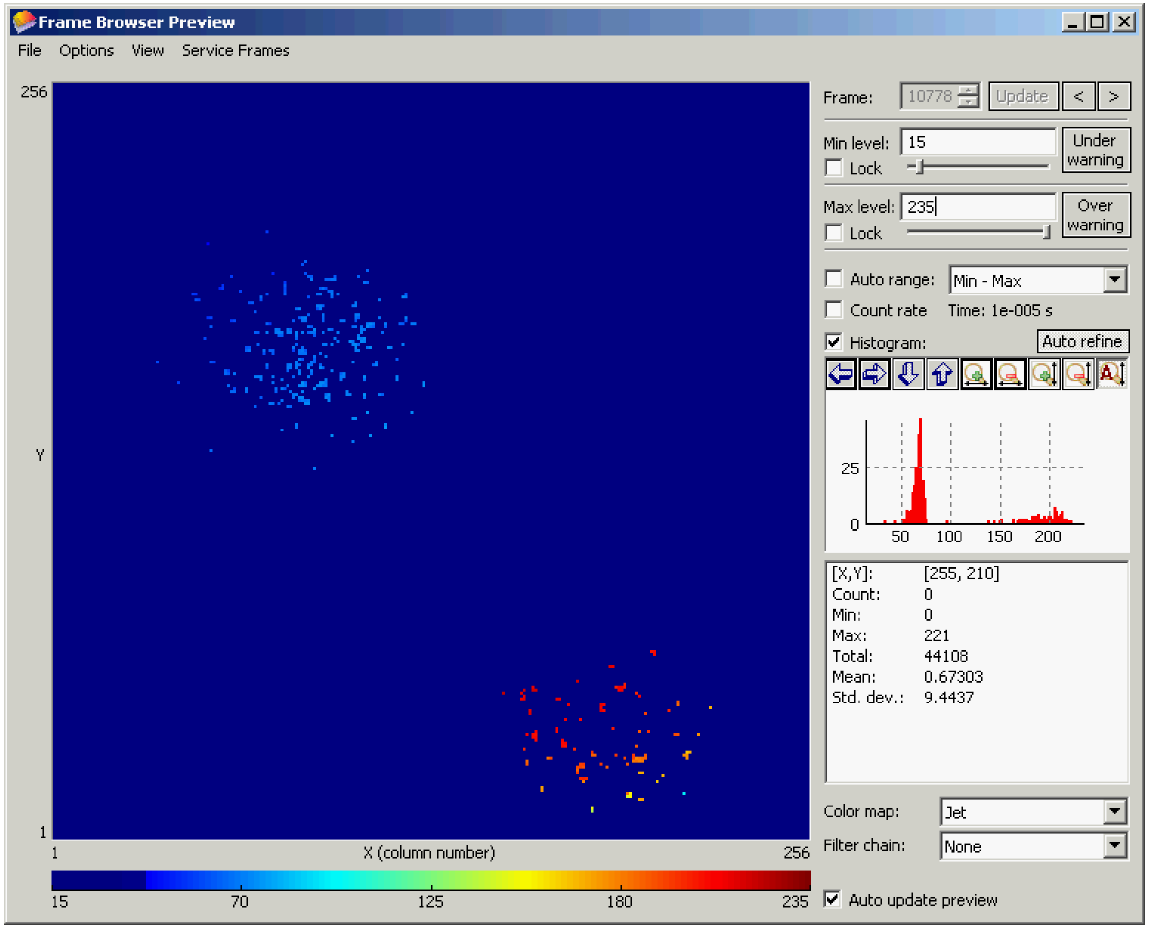
Chamber operated with an Ar+5% isobutane mixture



InGrid (Nikhef-Twente)

See electrons from an X-ray conversion one by one (^{55}Fe) and count them, study their fluctuations.

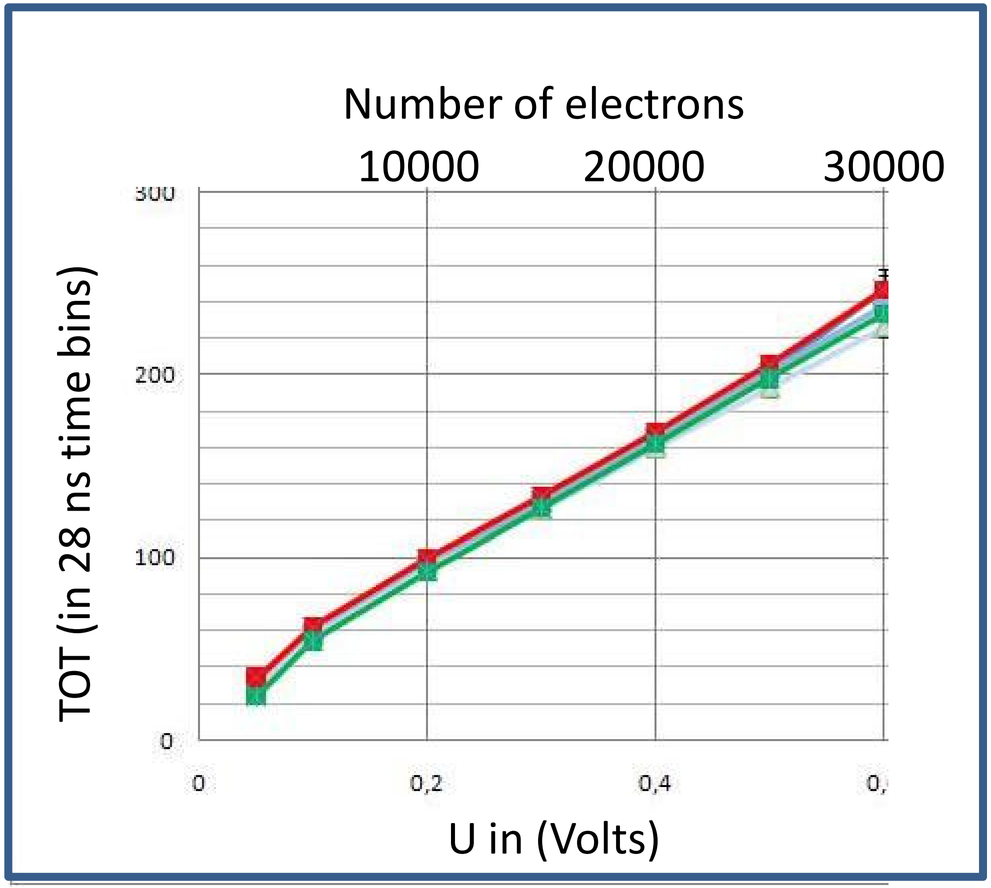
Measure Time Over Threshold (linear with charge above 5 ke-) for single isolated pixels : direct access to avalanche charge distribution.



Gain fluctuations from Time Over Threshold

Select isolated clusters with only 1 pixel. These are single electron avalanches (~10 µ rms radius).
TOT is linear with number of electrons seen by the amplifier above 5 ke- : **Ne = 167 TOT – 6700** (red curve, corresponding to the threshold setting of our data taking)
Valid up to 30 000 electrons.

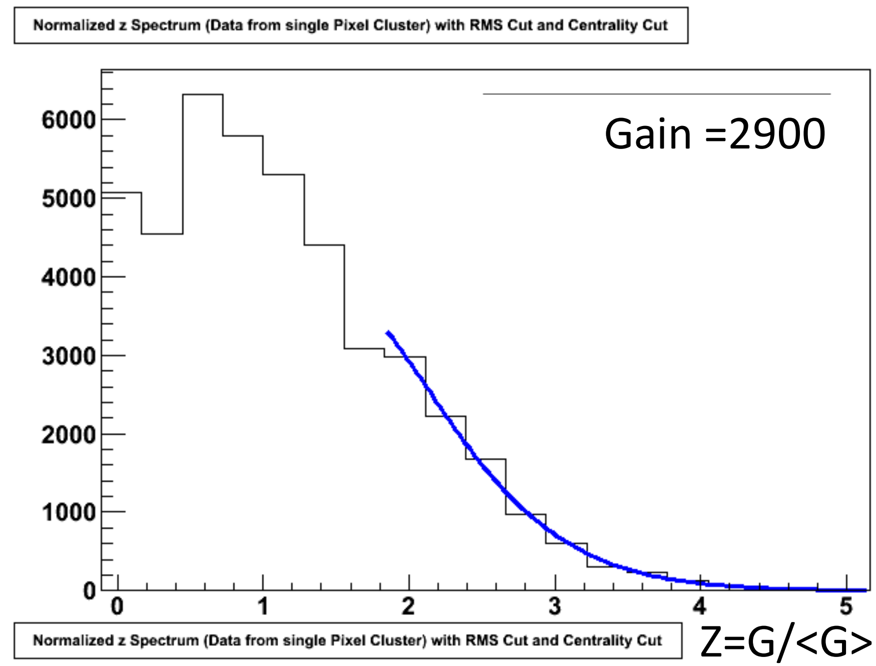
This gives a direct access to avalanche size.

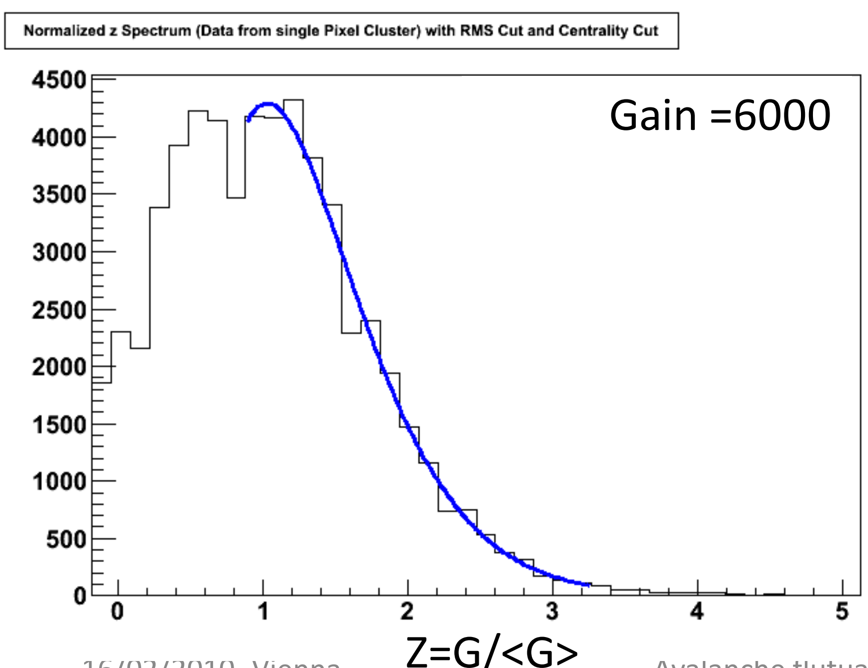


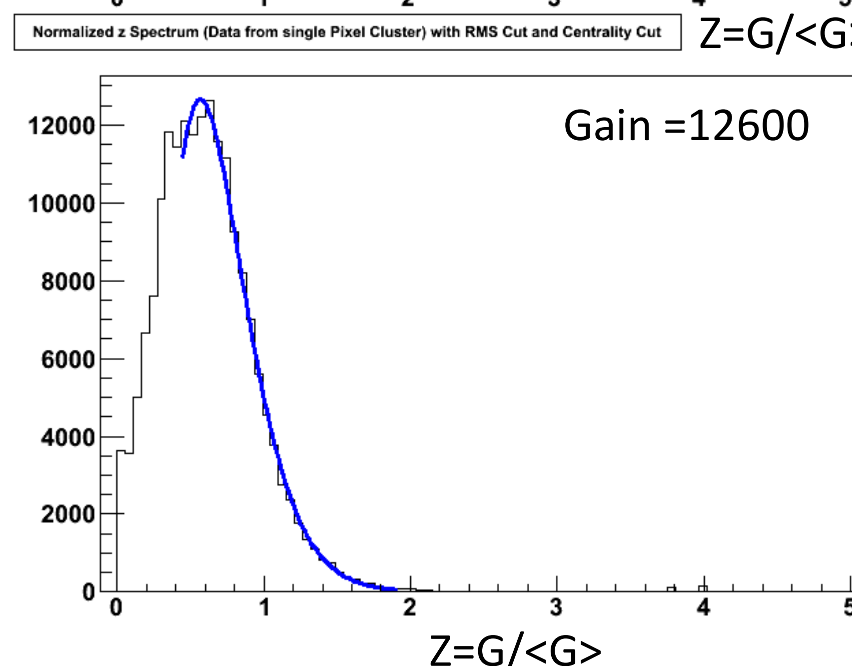
Distributions of avalanche size from TOT at different gains

$Z = G/<G> = (167*TOT-6700)/G(V)$

G(V) from a measurement using a source.

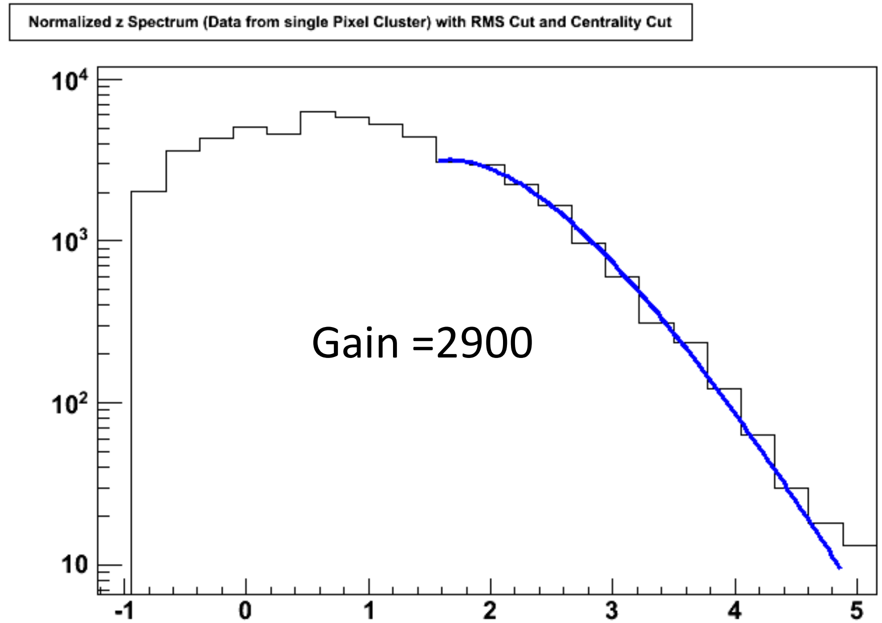




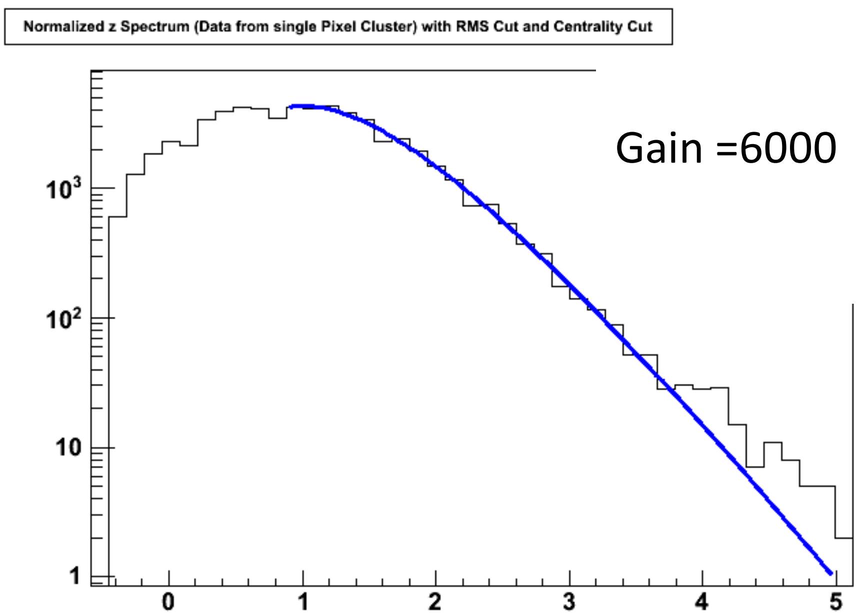


Same Z from TOT distributions but log scale to see the tails

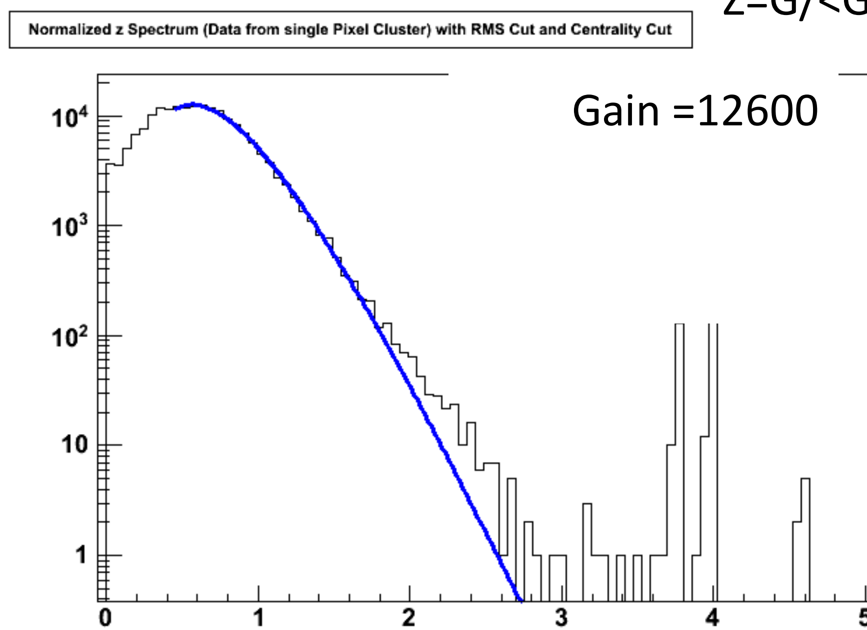
Unfortunately, the tails are dominated by TOT resolution effects.



Z=G/<G>



Z=G/<G>



Z=G/<G>

Avalanche size distribution from TOT

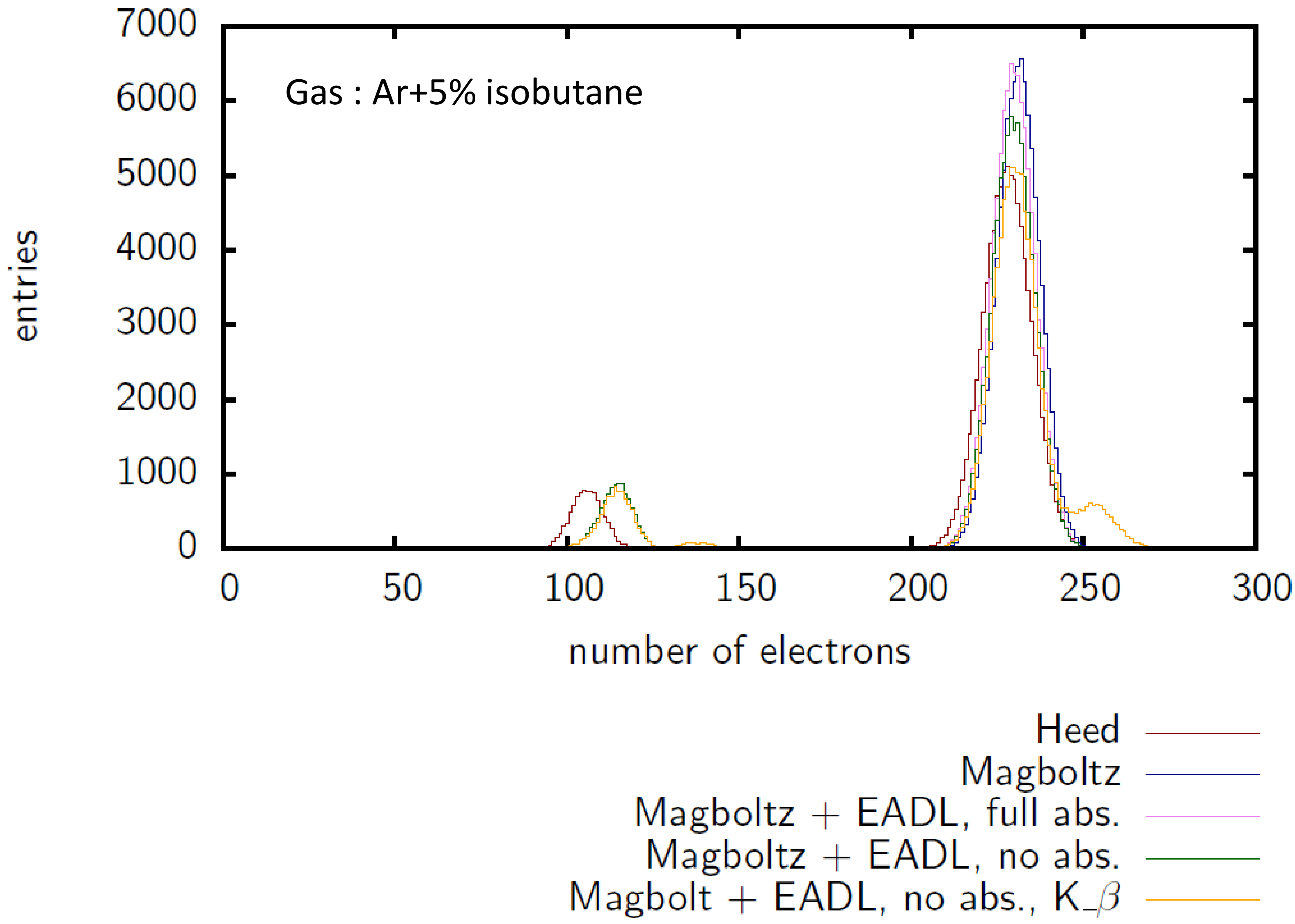
Polya fits above Zmin = 5000/<G> (region of linearity of TOT) are good
However theta values are not reliable (very correlated with the gain measurement and the TOT scale.
There is a discrepancy between the average number of electrons and the gain: this is a possible effect from the protection layer and from the shaping by electronics.

HV mesh	Gain	fitted θ
310 V	2900	5.3±1.3
330 V	6000	3.8±0.1
350 V	12600	4.7

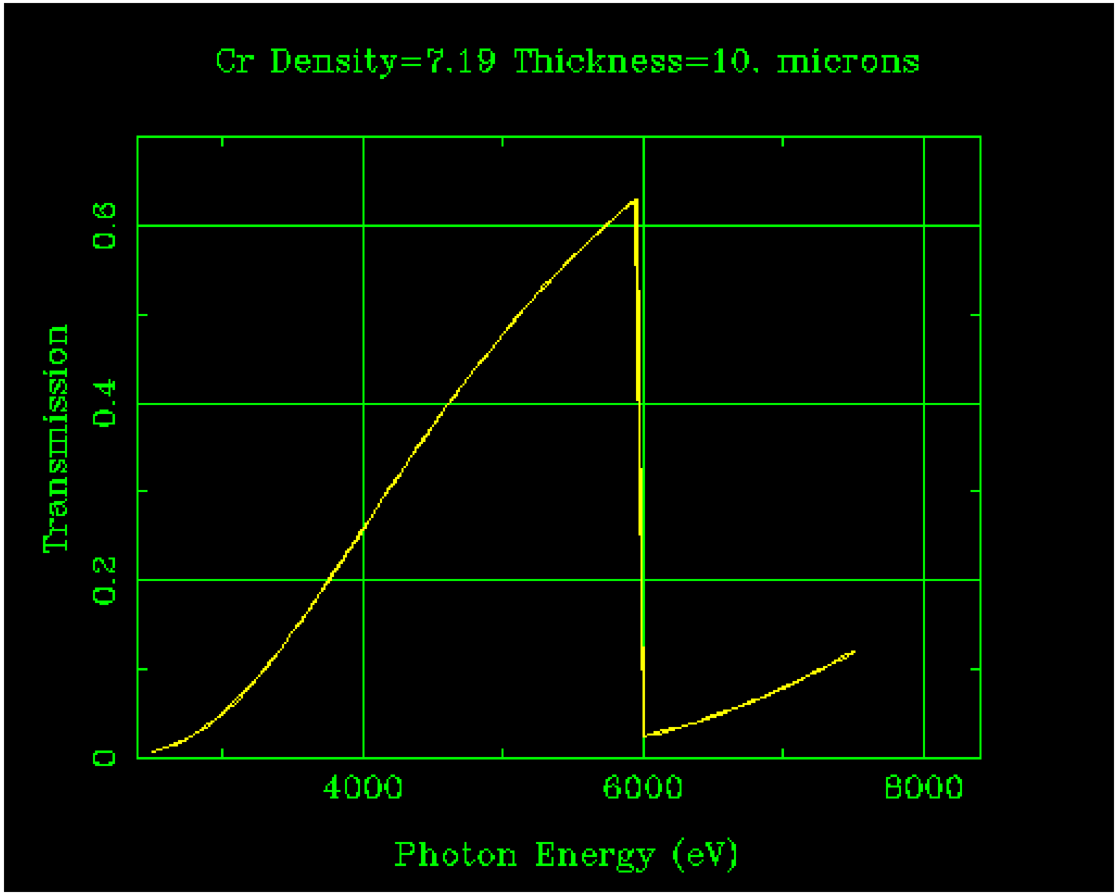
We do not regard these fitted values as measurements of theta.
They point to a value of 4.3 but with very large systematic errors (factor of 2?)

ELECTRON COUNTING

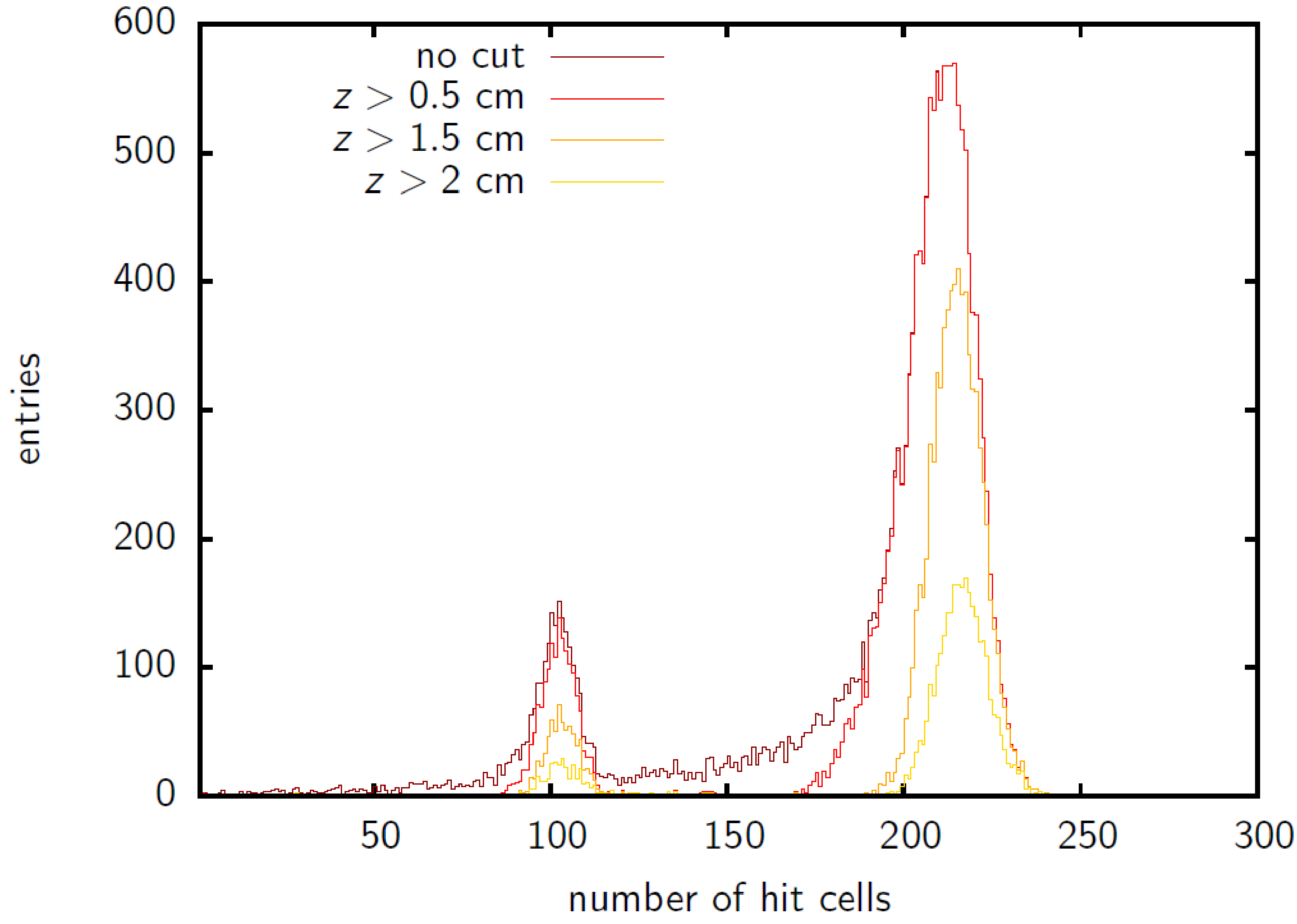
Monte Carlo simulation



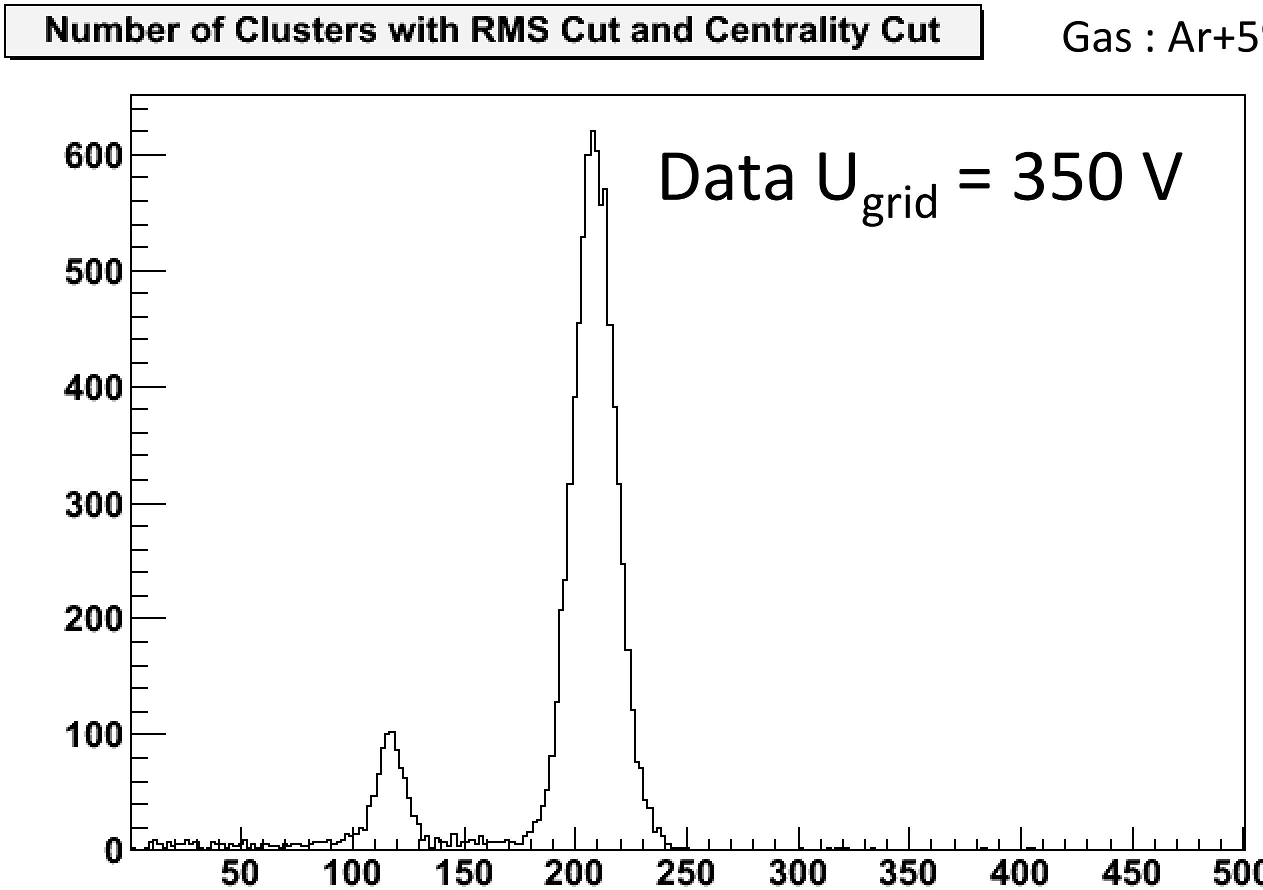
In our setup, we use the Chromium K-edge to cut the K_β line (Center for X-Ray Optics)



Monte Carlo simulation. Shows that we need enough drift distance to separate the clusters. Also shows that the escape peak is better contained than the photopeak.



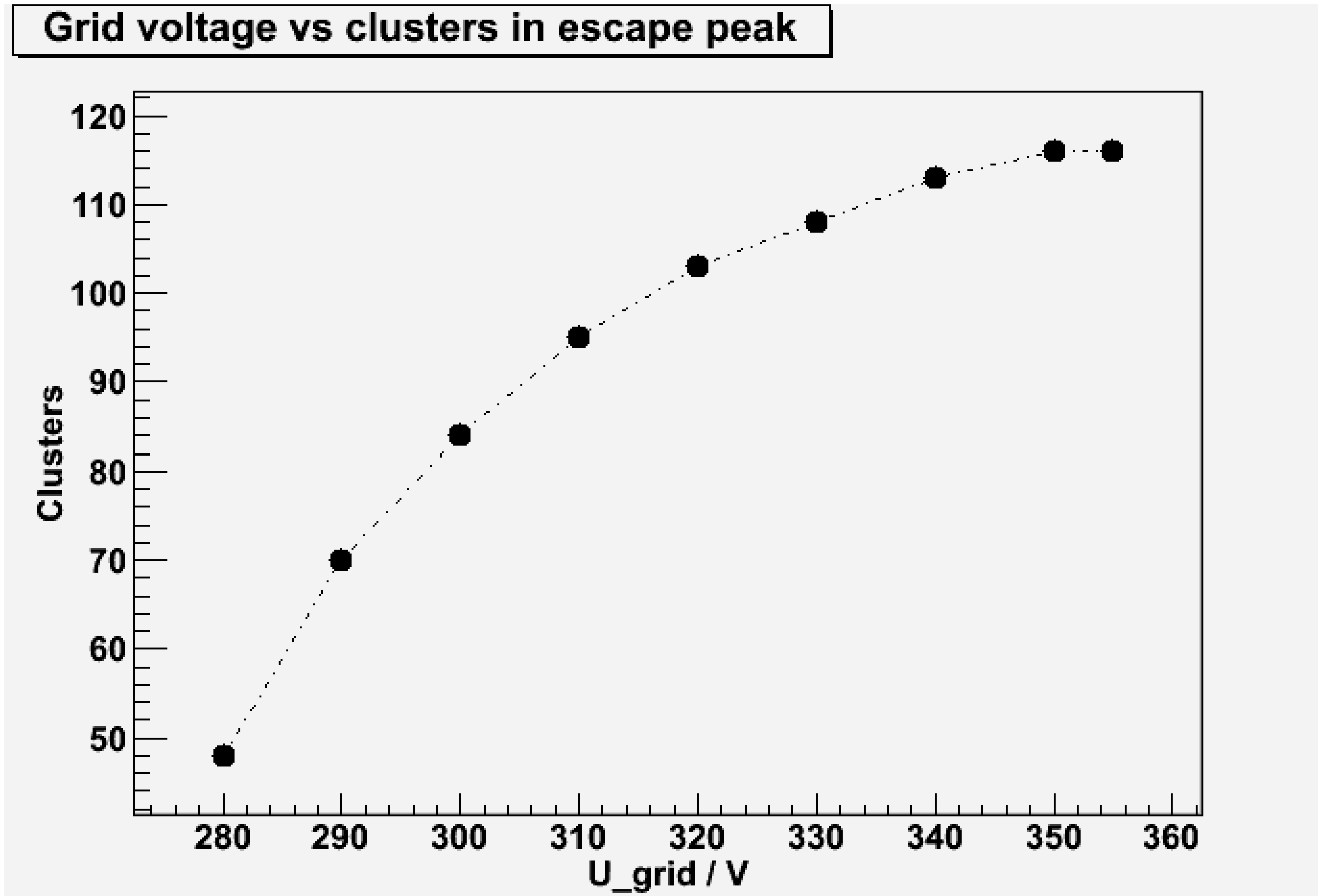
Drift distance (z) cut performed using the diffusion : sqrt(rmsx ^{2} + rmsy ^{2}) > 28 pixels (cluster separation)
Cloud center within a window around the chip center (containment)



Gas : Ar+5% isobutane

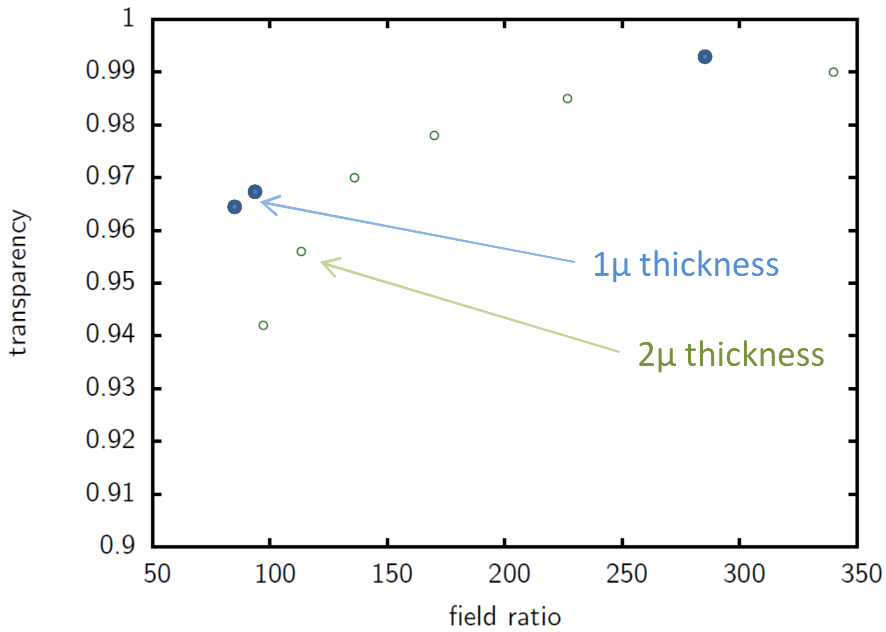
NUMBER OF CLUSTERS

Use escape peak (only one line, better contained)

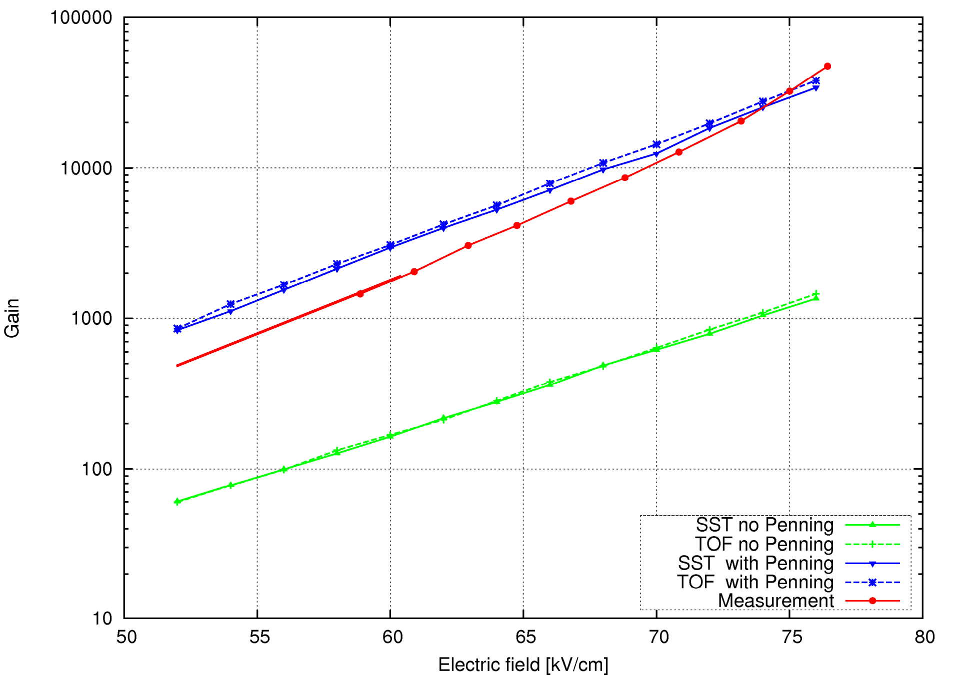


Then correct for collection efficiency (96.5 +- 1 % from MC, in this range of field ratios : 80-90)
Convert U_grid into gain/threshold (threshold = 1150 e-)

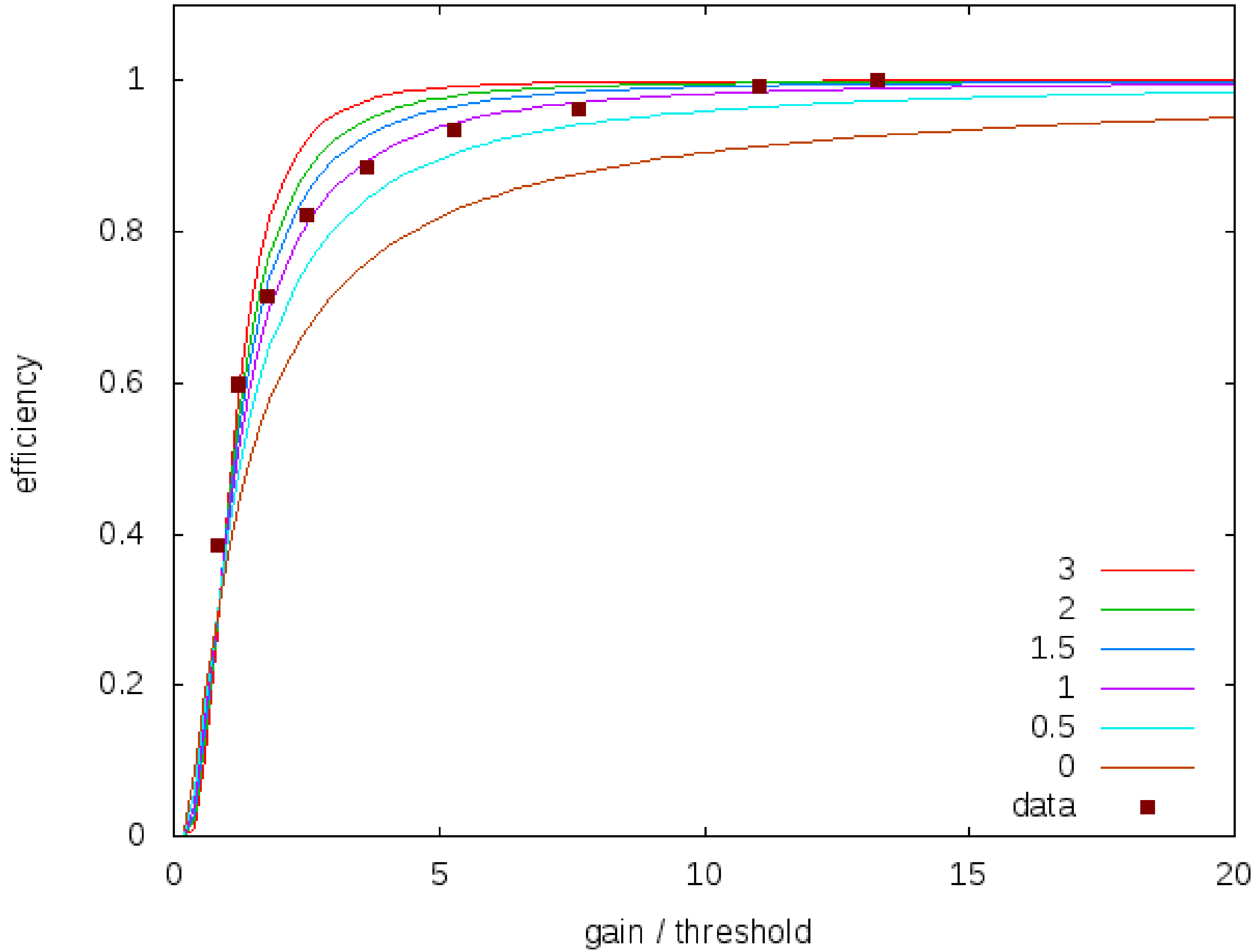
Collection efficiency from simulation : 96.5±1 %



Gain measurements (from a 80x80 mm2 copper mesh with the same gap 50 μm, gas : Ar+5% isobutane



Prediction from R. Veenhof et al., Data (in red) from D. Attié et al. (see also D. Arrogancia et al. 2009)



θ~1 at moderate gain (few 1000). Maybe higher at gains above 5000
Exponential behaviour (θ=0) strongly excluded, as well as $\theta>2$

Determination of W and F

The background is totally negligible (time cut taking 30 time buckets around the electron cloud among 11000)
The probability for merging two clusters is small, with the rms cuts. The probability for loosing electrons by the containment cuts is small. Attachment also is negligible.
The main inefficiency comes from collection : 96.5+-1 % from simulation.

Using the escape peak:

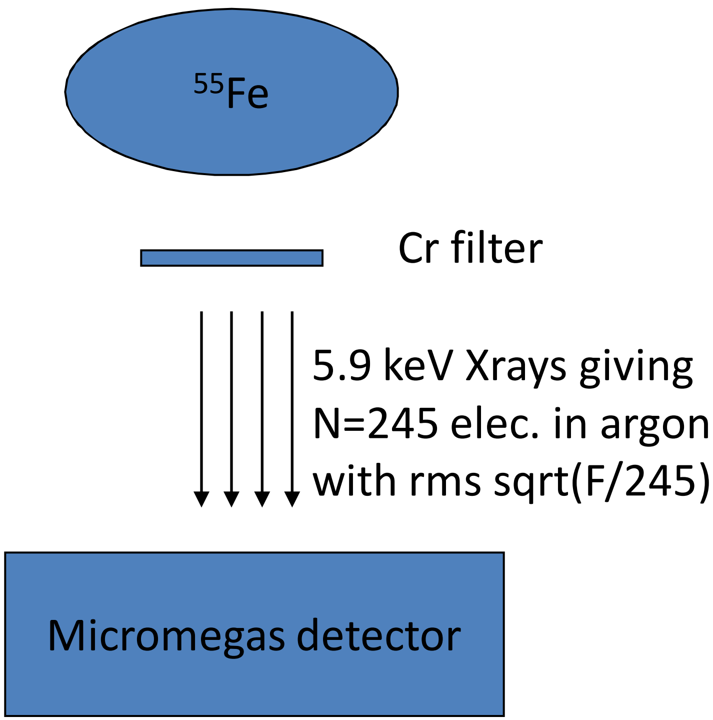
W= 2897 eV / 120.4 = 24.06 +- 0.25 eV

Gas : Ar+5% isobutane

This translates to 245+-3 electrons for the 5.9 keV line, larger than what is usually admitted for pure Ar (227). Photoelectric effect on the mesh is not excluded. This could also be a Penning effect in the conversion region.

The Fano factor could be derived from the rms of the escape line (6.8 e-) but needs large corrections from inefficiencies.

Energy resolution

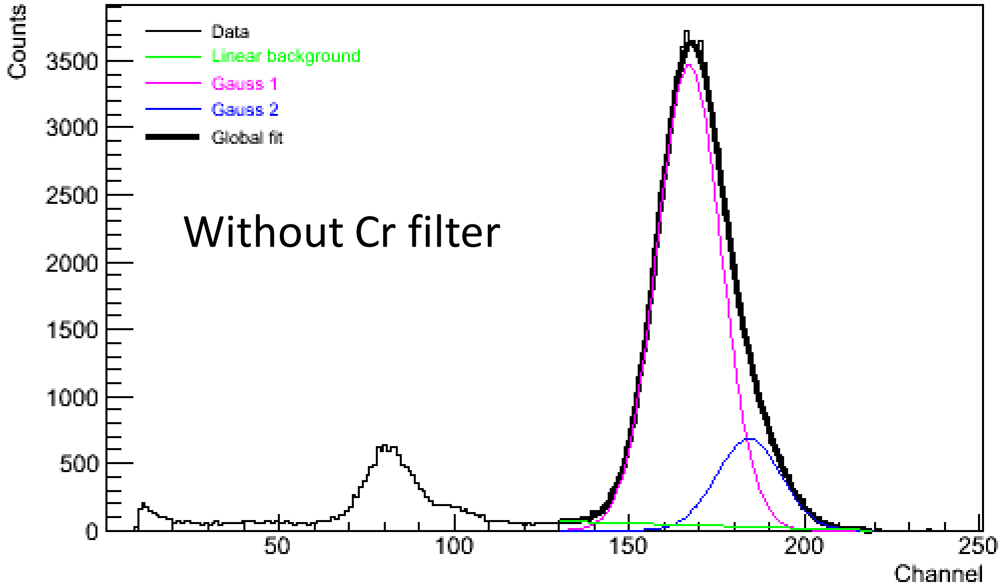


Peak width: contribution from primary (Fano) fluctuations and gain fluctuations (assuming high detection efficiency)

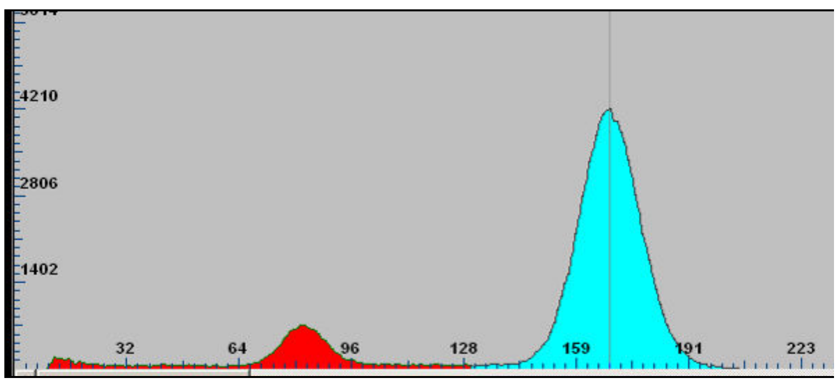
$$\text{Width} = \sqrt{(F+B)/N}$$

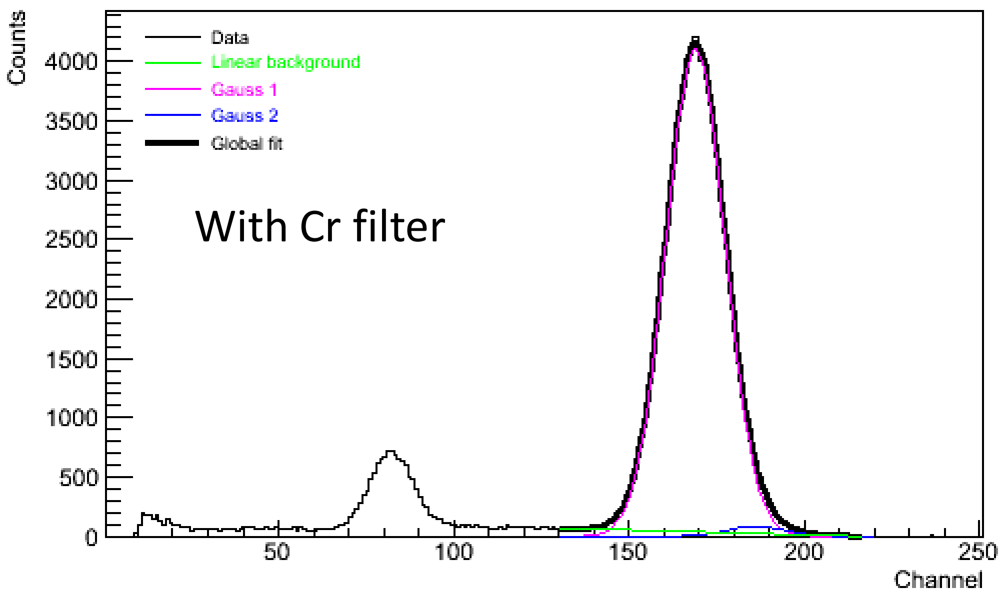
Resolution measurements with InGrid

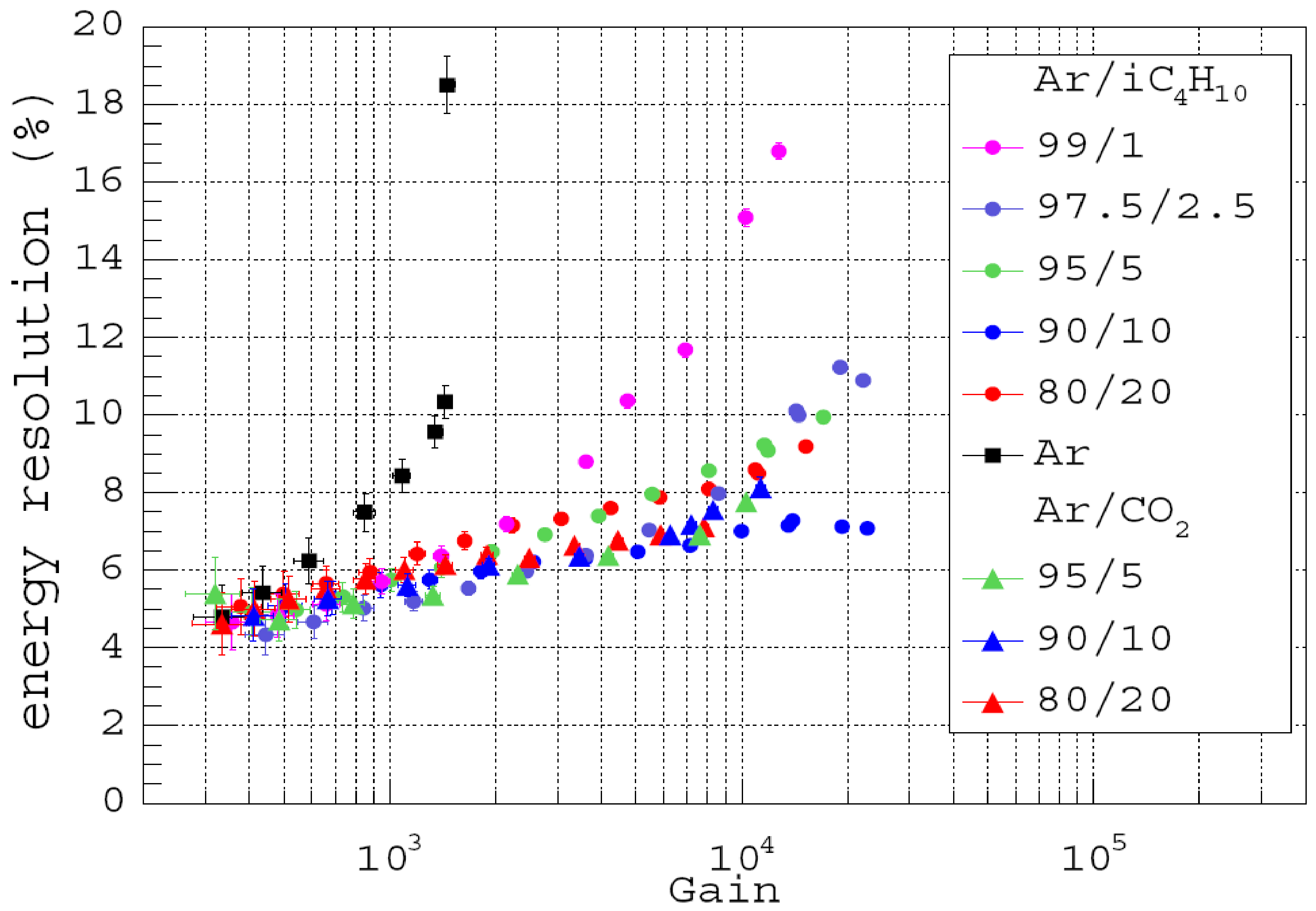
(Grid integrated on a Si wafer by post-processing technique)



5% rms resolution






energy resolution (%)
20
18
16
14
12
10
8
6
4
2
0
10^3
10^4
10^5
Gain
Ar/iC_4H_{10}
99/1
97.5/2.5
95/5
90/10
80/20
Ar
Ar/CO_2
95/5
90/10
80/20

$$Width=\sqrt{(F+B)/N}$$

With a measured relative width of 0.05 and assuming F=0.2, taking the measurement of N=245, we obtain B=0.41, thus θ =1.4
This is roughly consistent with the results from single electron counting efficiency.

CONCLUSIONS

InGrid, Microbulk, and TimePix are new detectors which allow to study the conversion and avalanche processes with unprecedented accuracy.

Time Over Threshold measurements give access to direct measurement of the fluctuations, provided absolute gain and TOT calibration can be better controlled.

The onset of single electron efficiency with Micromegas gain allows the exponential fluctuations to be excluded and favours Polya fluctuations with θ **close to 1 at moderate gain** and reaching a few units at gains of 10 000.

To measure Fano fluctuations will require an improved setup with a longer drift and better controled field. Energy resolution measurements assuming F=0.20 favour a value of $\theta \sim 1.4$.

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