Measurement of gas gain fluctuations

M. Chefdeville, LAPP, Annecy

TPC Jamboree, Orsay, 12/05/2009

Overview

- Introduction
  - Motivations, questions and tools
- Measurements
  - Energy resolution & electron collection efficiency
    Micromegas-like mesh readout
  - Single electron detection efficiency and gas gain
    TimePix readout
- Conclusion

Gas gain fluctuations

- Final avalanche size obeys a probability distribution
  Signal fluctuations impact on detector performance
    - Spatial resolution in a TPC
    - Energy resolution in amplification-based gas detectors
    - Minimum gain and ion backflow
    - Detection of single electrons with a pixel chip

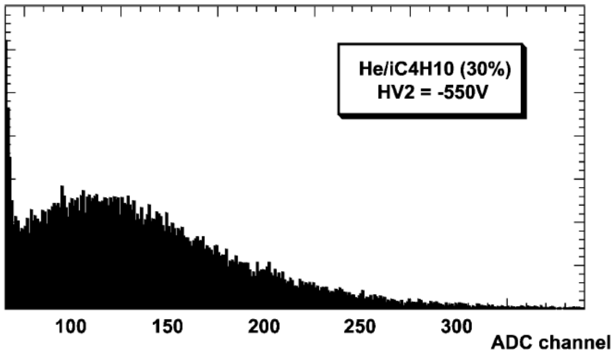
- What is the shape of the distribution?
  How does it vary with gas, field, geometry…?

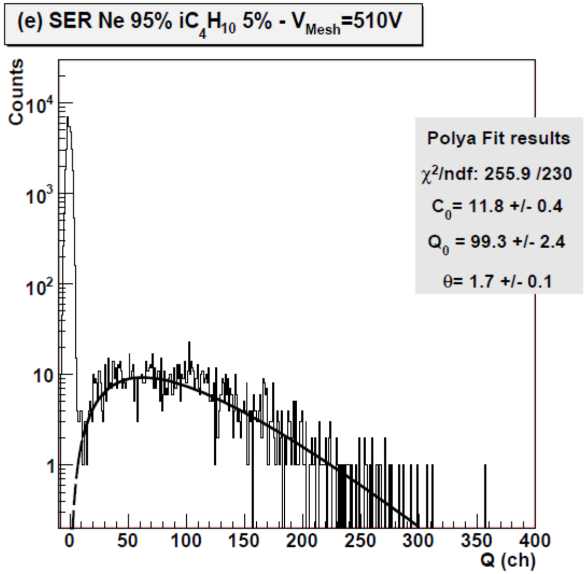
- The Polya distribution parametrized by
  gas gain *G* and parameter *m*
    - Works well with Micromegas/PPC/MCP/single GEM
    - With GEM stacks, distribution is more exponential

$$p_m(g) = \frac{m^m}{\Gamma(m)}\frac{1}{G}\left(\frac{g}{G}\right)^{m-1}\exp(-mg/G)$$

$\sigma^2 = 1/m$ *= b, relative gain variance*

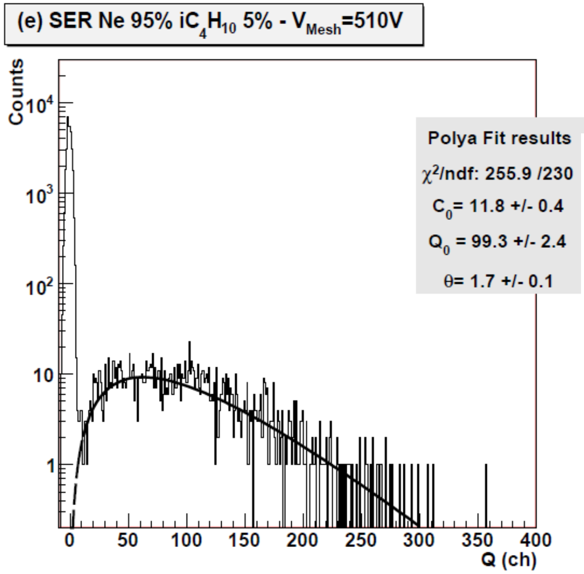
Micromegas, NIMA 461 (2001) 84





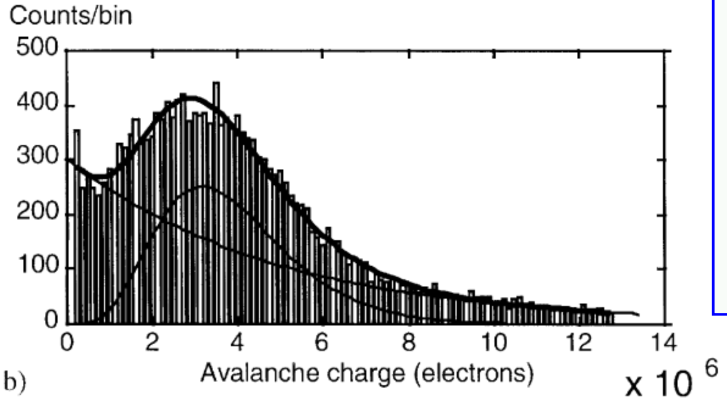
Micromegas
T. Zerguerras et al.
to be published in NIMA

Gain fluctuations in gas detectors

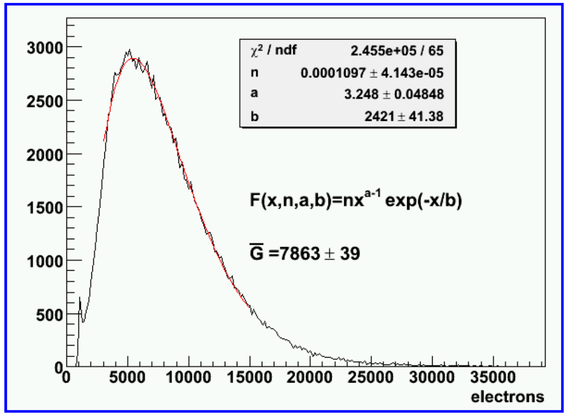


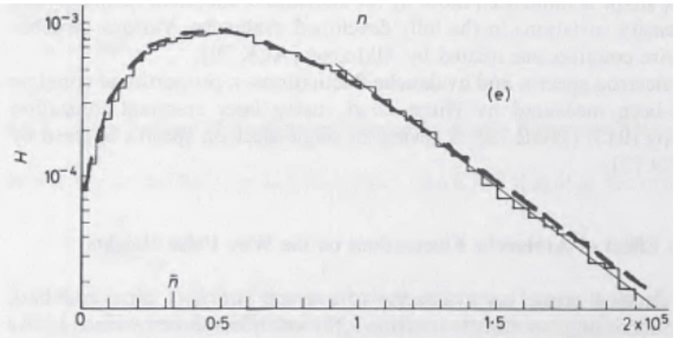
Micromegas

1 mm gap PPC
NIMA 433 (1999) 513

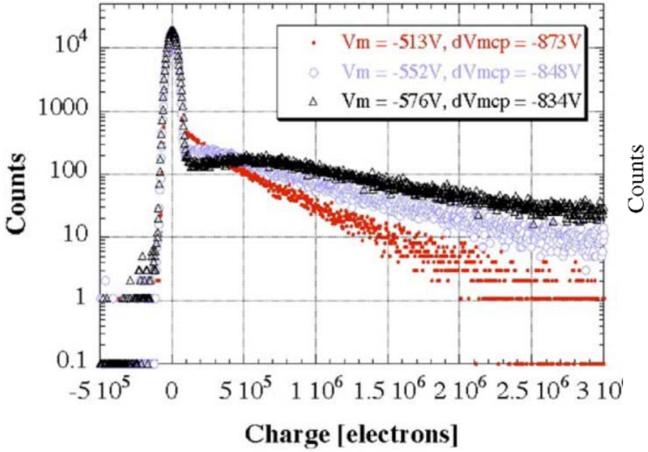


GEM, Bellazzini, IEEE 06, SanDiego



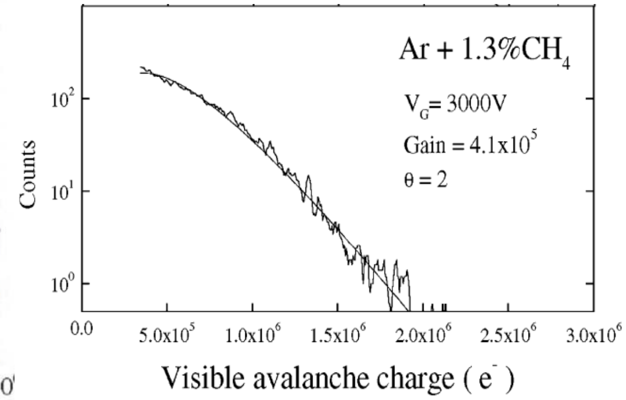


PPC, Z. Phys. 151 (1958) 563



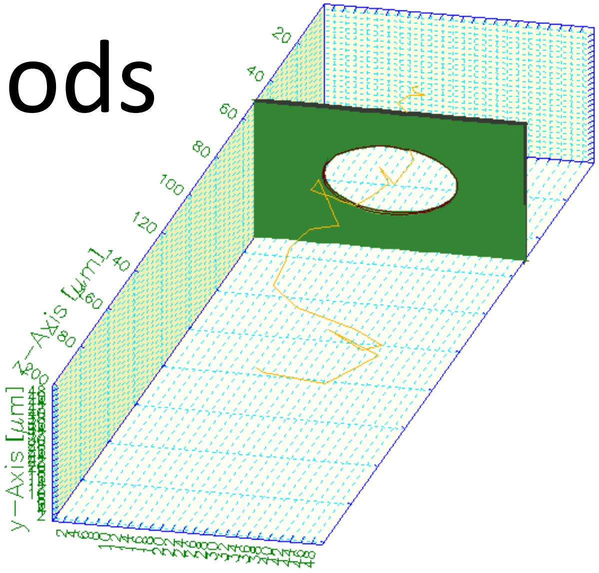
MCP+Micromegas, NIMA 535 (2004) 334

3 GEMs, NIMA 443 (2000) 164

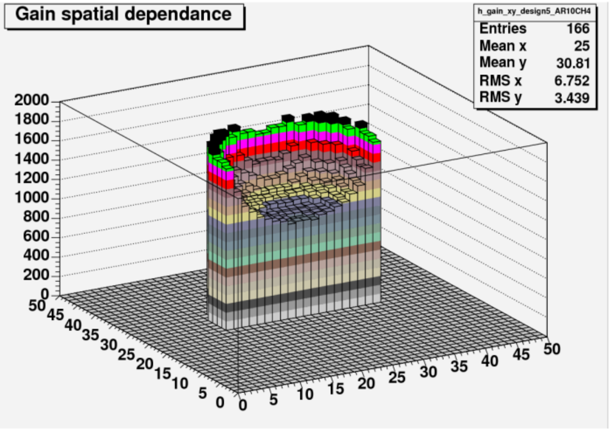


Investigation methods

- **Simulation, since recently within GARFIELD:**
  - Simulation of e- avalanche according to MAGBOLTZ cross-section database: ***study of gas & field***
  - Simulation of e- tracking at microscopic scale in field maps (3D): ***study of geometry***



- **On the experimental side:**
  - Direct measurement of the distribution:
    - High gains, low noise electronics, single electron source
  - Indirect measurements
    - Do not provide the shape but some moments (variance)
    - Assuming Polya-like fluctuations, one obtains the shape



- In this talk, only indirect methods are presented

  The Polya parameter *m* is deduced from:
  - Trend of energy resolution and collection efficiency
  - Trend of single electron detection efficiency and gas gain

Measurement of gain variance

- **Energy resolution *R* and electron collection efficiency *η***
  - R decreases with the efficiency according to
  - $R^2 = F/N + b/\eta N + (1-\eta)/\eta N$
  - $R^2 = p_0 + p_1/\eta$
    $p_0 = (F-1)/N$
    $p_1 = (b+1)/N$
  - **Measure *R(η)* at e.g. 5.9 keV, fix *F* and *N*, adjust *b* (i.e. *m*) on data**

- **Single electron detection efficiency *κ* and gas gain *G***
  - *κ* increases with *G* as more avalanches end up above the detection threshold *t*

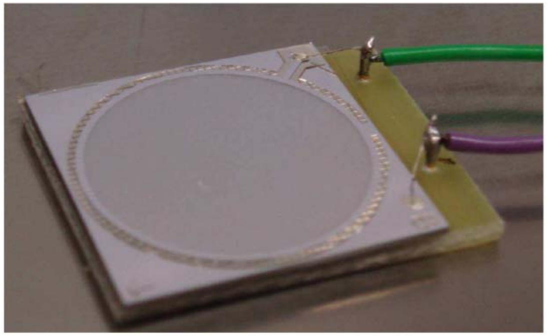
    $$\kappa_m = \int_t^\infty p_m(g)dg$$

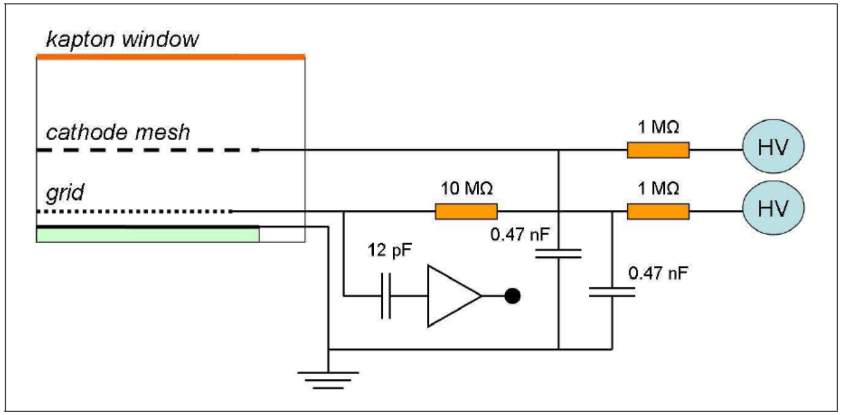
    Integral can be calculated for integer value of m
  - Count the number of e- from ^{55}Fe conversions (*N*) with TimePix
  - **Measure *N(G)*, adjust *κ(G,m)* on this trend, keep *m* for which the fit is best**

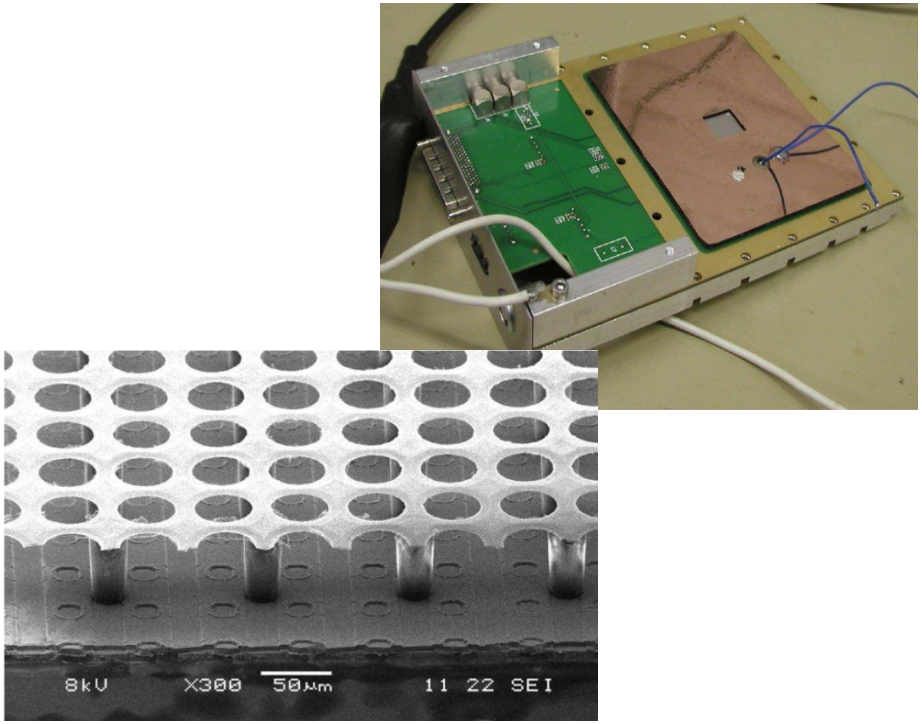
Experimental set-up(s)

- Measure 1: *R(η)*
  - InGrid on bare wafer
  - Preamp/shaper/ADC
  - ^{55}Fe 5.9 keV X-ray source
  - Ar-based gas mixtures with iC_4H_{10} and CO_2

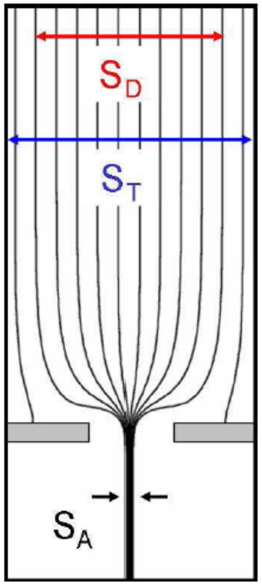
- Measure 2: *κ(G)*
  - InGrid on TimePix chip
  - Pixelman and ROOT
  - ^{55}Fe 5.9 keV X-ray source
  - Enough diffusion for counting
    - 10 cm drift gap
    - Ar 5% iC_4H_{10}



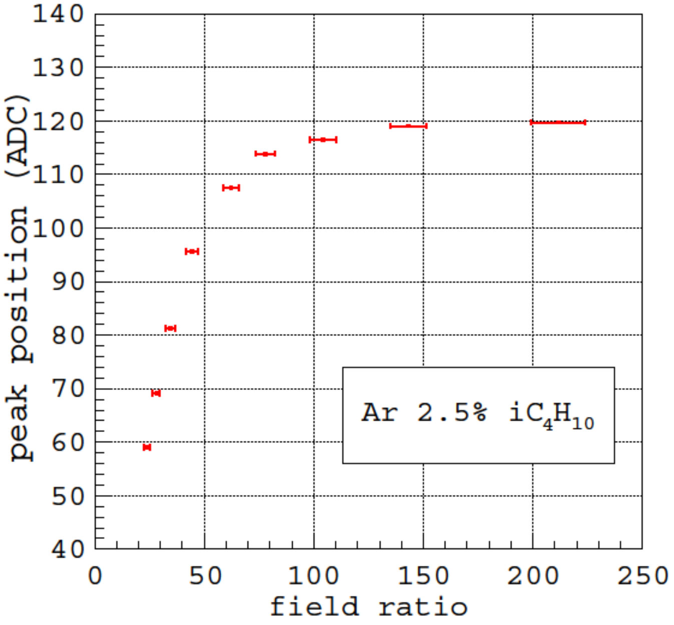


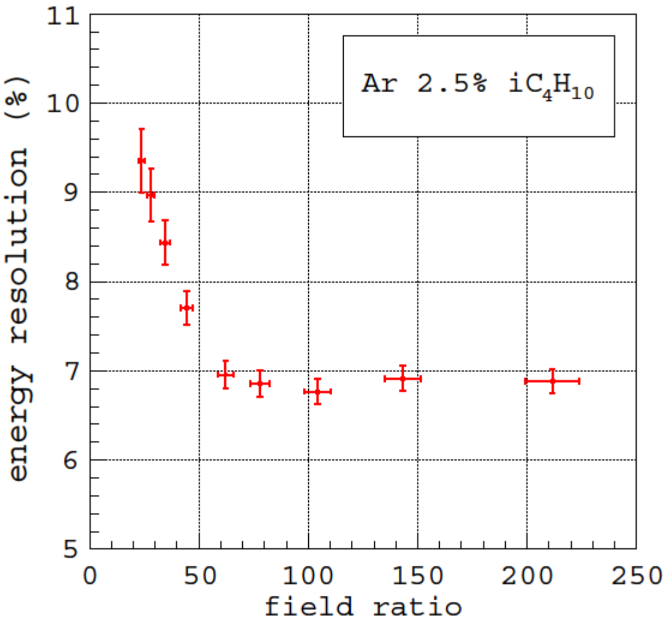


Energy resolution & collection



- Vary the collection efficiency with the field ratio
- Record ^{55}Fe spectra at various field ratios
  - Look at peak position VS field ratio define arbitrarily peak maximum as η = 1
  - Look at resolution VS collection
  - Adjust *b* on data points





Energy resolution & collection

- Record ^{55}Fe spectra at various field ratios
  - Look at peak position VS field ratio
define arbitrarily peak maximum as $\eta = 1$
  - Look at resolution VS collection
  - Fix *F* and *N*, adjust *b* on data points

Fit function:

$R = \sqrt{(p_0 + p_1/\eta)}$

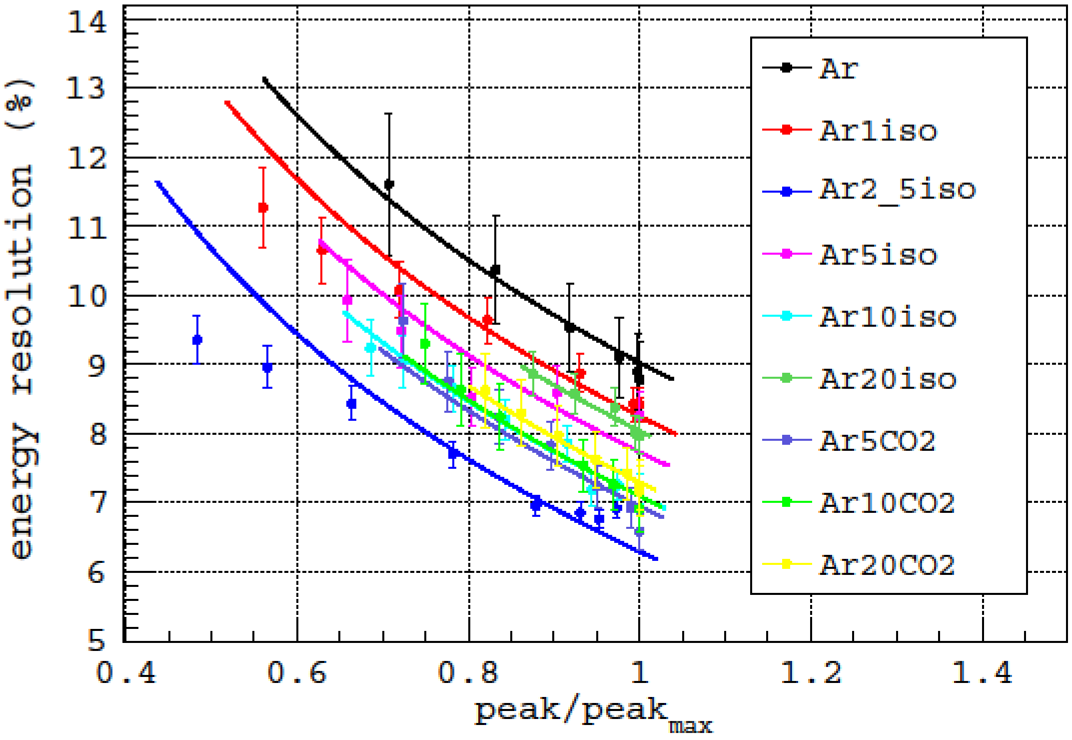
$p_0 = (F-1)/N$

$p_1 = (b+1)/N$

$F = 0.2$ in all mix.

$N = 230$ in Ar/iso

$N = 220$ in Ar/CO2



Gas	b	b_err	√b (%)	m=1/b
Ar	1,68	0,02	130	0,60
Ar1iso	1,37	0,01	117	0,73
Ar2_5iso	0,71	0,01	84	1,41
Ar5iso	1,18	0,02	109	0,85
Ar10iso	0,93	0,01	96	1,08
Ar20iso	1,29	0,01	114	0,78
Ar5CO2	0,86	0,02	93	1,16
Ar10CO2	0,91	0,02	95	1,10
Ar20CO2	0,97	0,02	98	1,03

- Rather low Polya parameter 0.6-1.4
May be due to a poor grid quality
- Curves do not fit very well points
Could let *F* or/and *N* free

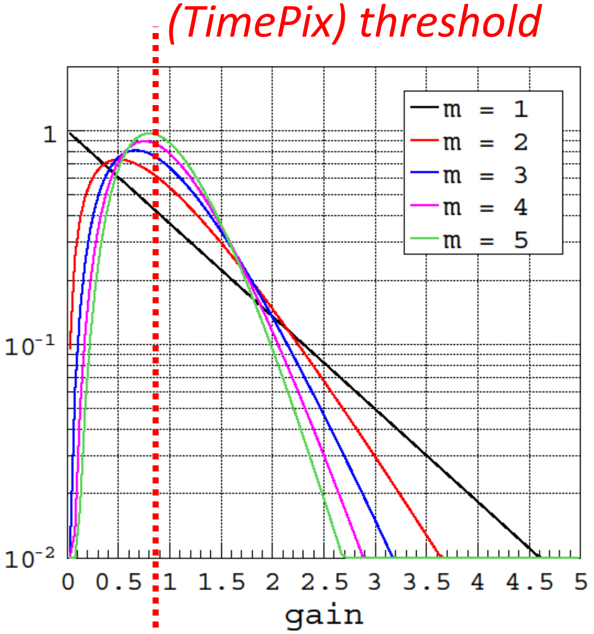
Single electron detection efficiency and gain

- Trend depends on:
  - the threshold *t*, the gas gain *G* and *m*

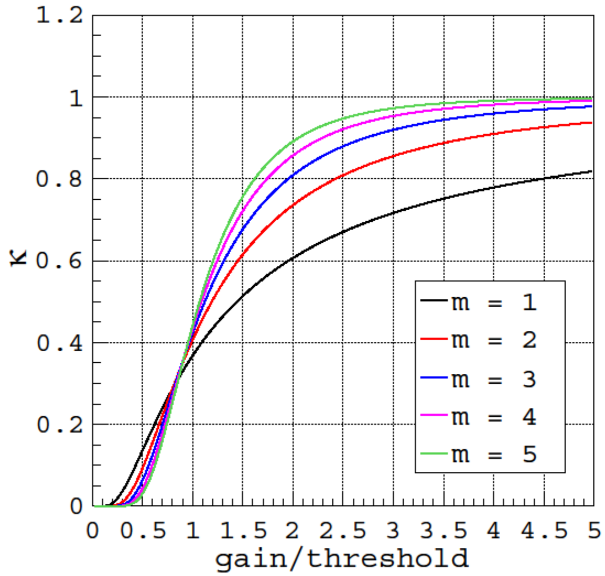
$$p_1(g) = \exp(-g/G)$$

$$p_2(g) = 4\frac{1}{G}\frac{g}{G}\exp(-2g/G)$$

$$p_5(g) = \frac{3125}{24}\frac{1}{G}\left(\frac{g}{G}\right)^4 \exp(-5g/G)$$



$$\kappa_m = \int_t^\infty p_m(g)dg$$



$$\kappa_1(t/G) = \exp(-t/G)$$

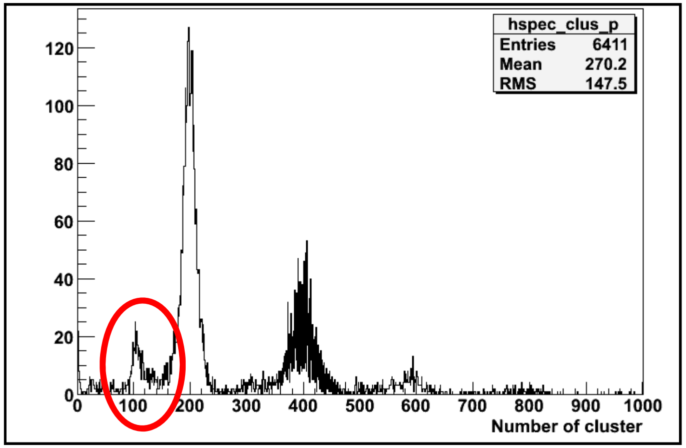
$$\kappa_2(t/G) = \exp(-2t/G)\left(1 + 2\frac{t}{G}\right)$$

$$\kappa_5(t/G) = \exp(-5t/G)\left(\frac{625}{24}\left(\frac{t}{G}\right)^4 + \frac{125}{6}\left(\frac{t}{G}\right)^3 + \frac{25}{2}\left(\frac{t}{G}\right)^2 + 5\left(\frac{t}{G}\right) + 1\right)$$

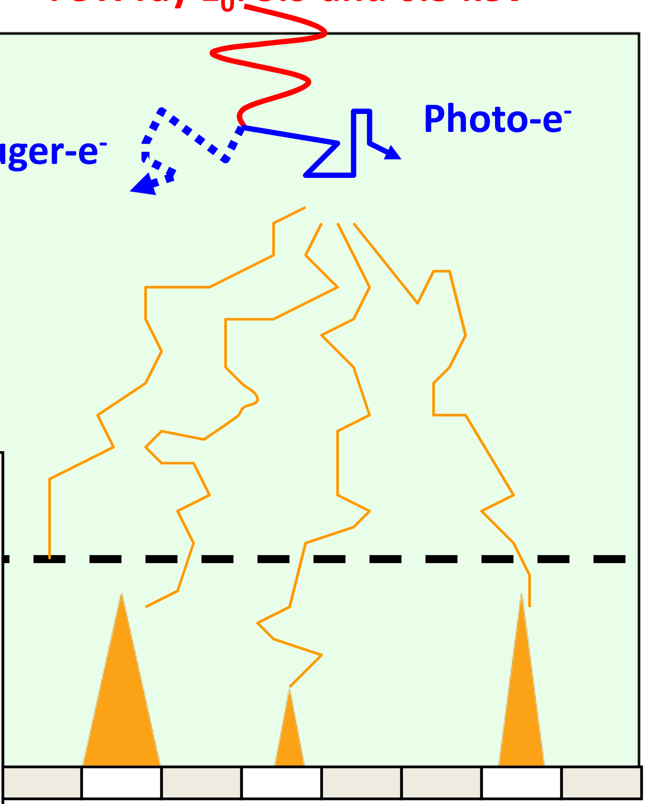
Single electron detection efficiency and gain

- Considering ^{55}Fe conversions:
  the efficiency is proportionnal to the number of detected electrons at the chip

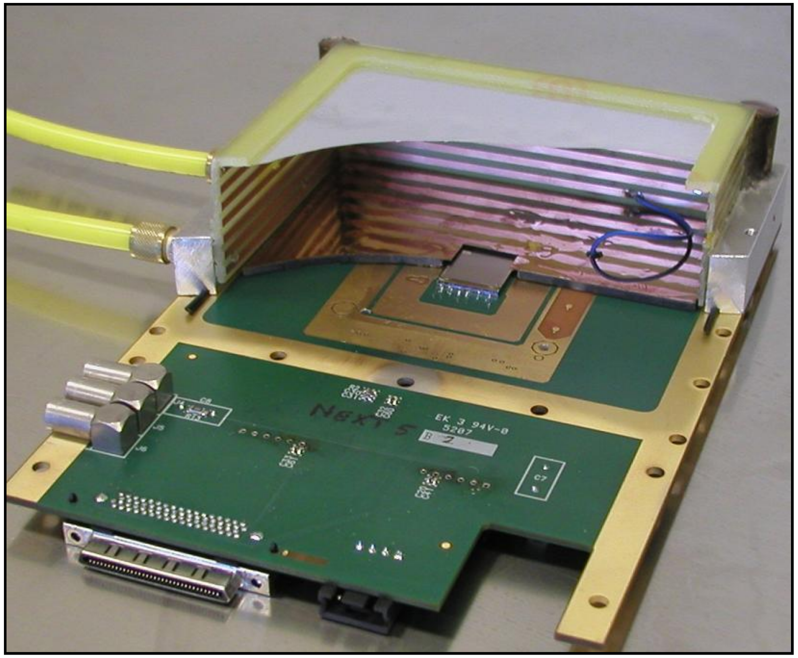
- Count the number of electrons at various gains
  - In the escape peak!
  - Apply cuts on the X and Y r.m.s. of the hits



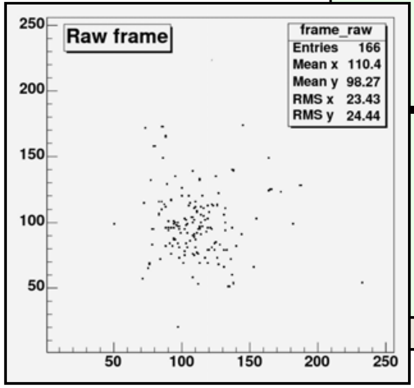
^{55}Fe X-ray E_0: 5.9 and 6.5 keV



TimePix chip

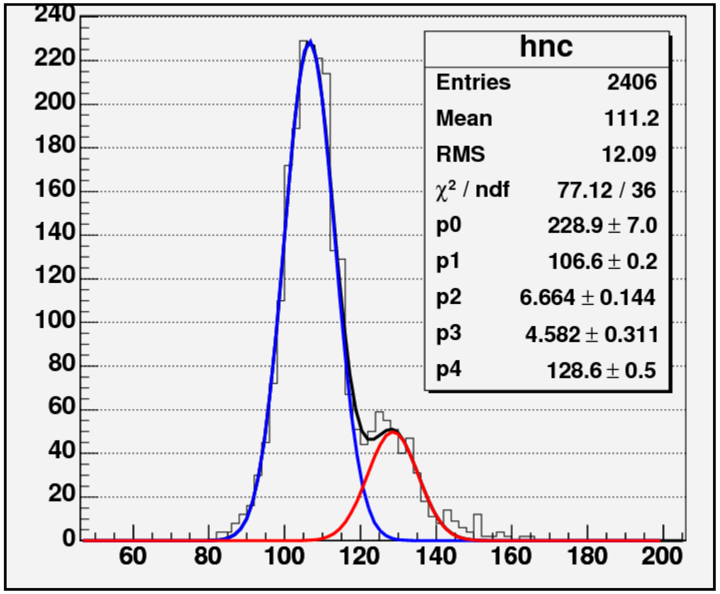


^{55}Fe cloud in Ar5iso after 10 cm drift



Single electron detection efficiency and gain

- Number of detected electrons at given voltage determined by
  - Adjusting 2 gaussians on escape peak
  - K_{beta} parameters constrained by K_{alpha} ones
  - 3 free parameters



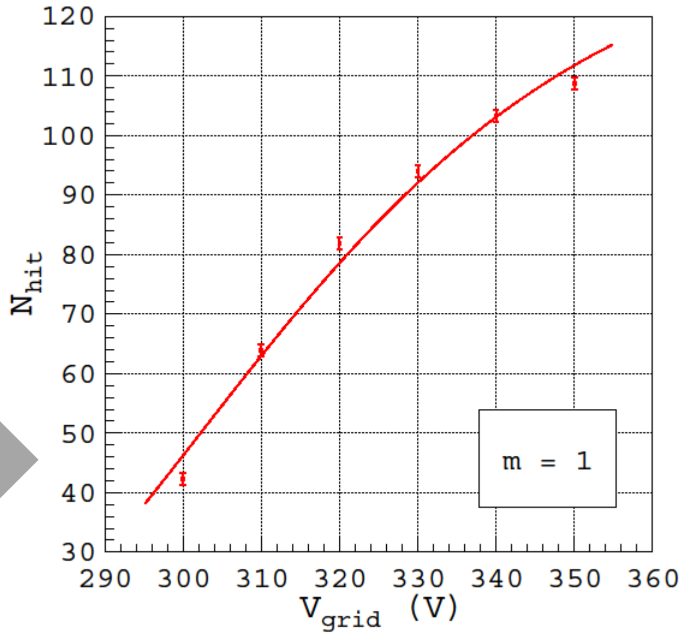
- Number of detected electrons and voltage
  - Use common gain parametrization
  - Fix p_2 (slope of the gain curve)
  - 2 free parameters: t/A and ηN

$$N_{\mathrm{d}} = \eta\kappa(m,t,G)N_{\mathrm{p}} = \eta\kappa(m,t,V_{\mathrm{g}})N_{\mathrm{p}}$$

$$G = A\exp(BV_{\mathrm{g}})$$

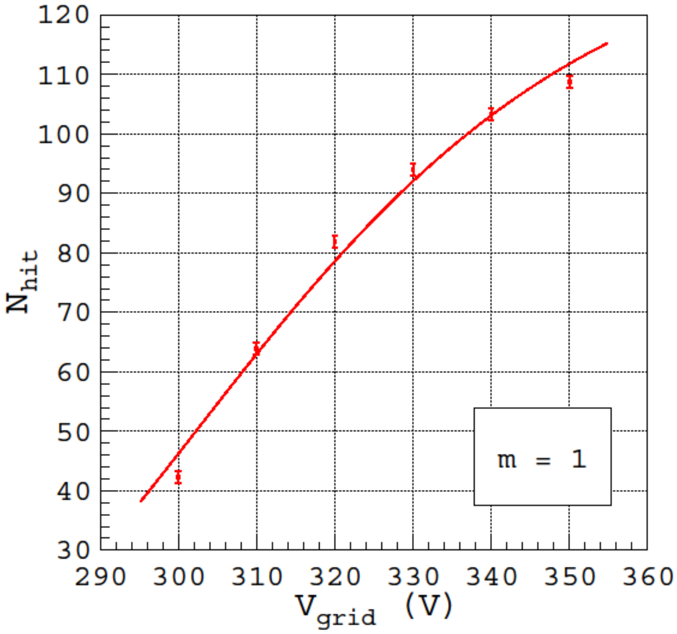
$$\boxed{N_{\mathrm{d}} = p_0 \cdot \exp\Big(-p_1 \exp(-p_2 V_{\mathrm{g}})\Big)}$$

$$p_0 = \eta N_{\mathrm{p}} \quad p_1 = t/A \quad p_2 = B$$

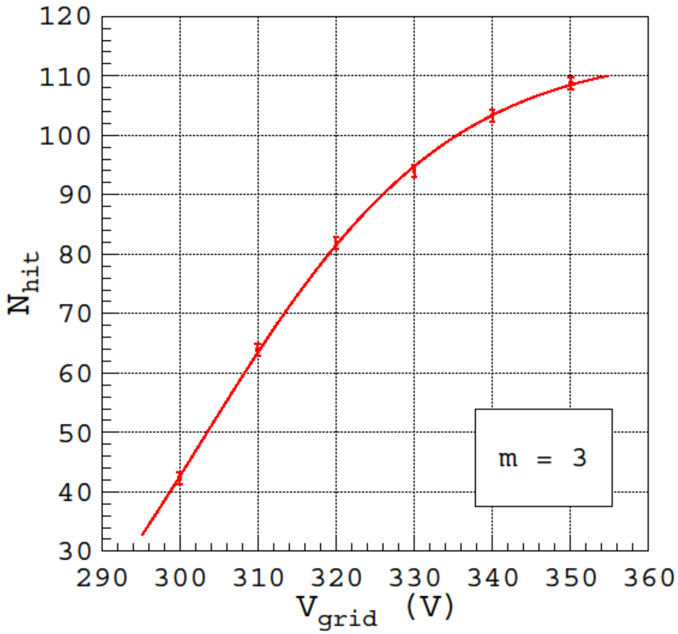


Single electron detection efficiency and gain

$$\kappa_1(t/G) = \exp(-t/G)$$



$$\kappa_3(t/G) = \exp(-3t/G)\left(\frac{27}{6}\left(\frac{t}{G}\right)^2 + 3\frac{t}{G} + 1\right)$$



m	*rms (%)*	*Chi²*
1	100	39.43
2	71	3.08
3	**58**	**1.16**
4	50	1.41
5	45	1.60

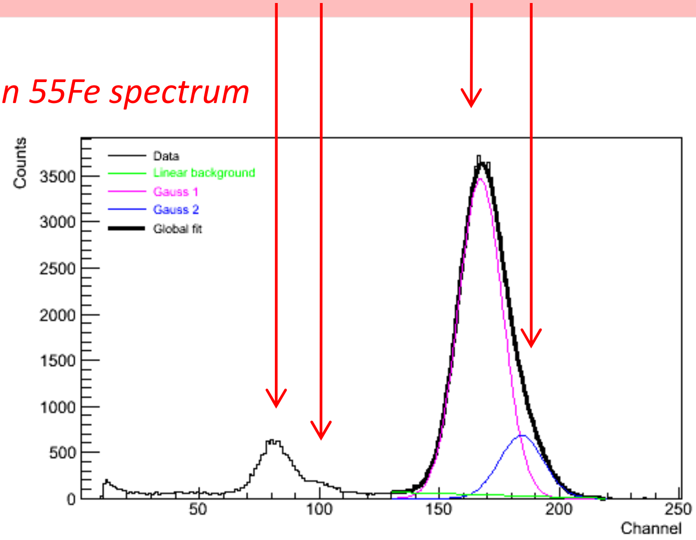
Best fit for $m = 3$
Yields $\sqrt{b} = 1/\sqrt{m} \sim 58\ \%$

- Also, ηN = 115 e-
  Upper limit on *W*(Ar5iso) < 25 eV
- Correcting for un-efficiency:
  Upper limit on *F*(Ar5iso) < 0.3

Conclusion

- Two methods to investigate gas gain variance
  - Assuming Polya fluctuation, shape available for detector simulation
  - Energy resolution and collection efficiency
    simple (mesh readout)
    but a certain number of primary e- and Fano factor have to be assumed
  - Single e- detection efficiency and gain
    powerful (provide not only *m* but *W* and *F*)
    but a InGrid-equipped pixel chip is needed

4 main lines in an 55Fe spectrum



- Another one not presented
  - Energy resolution and number of primary electrons

$$R^2 = p_0/N$$

$$p_0 = F+b$$