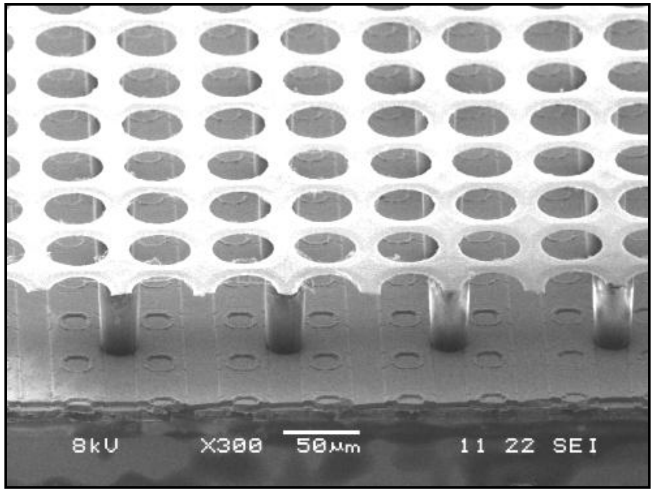
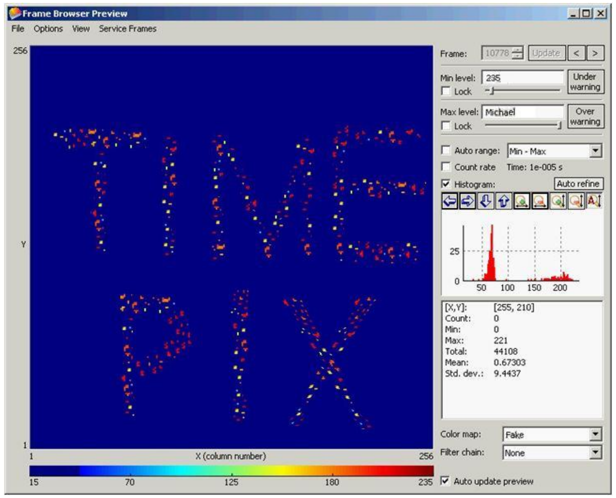



# Avalanche statistics and single electron counting with a Timepix-InGrid detector

**Michael Lupberger**

EUDET Annual Meeting

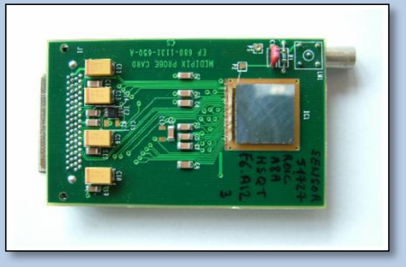
29.09-01.10.2010 DESY, Hamburg, Germany

# Outline

- Hardware
  - Timepix Chip + InGrid
  - Experimental setup and calibration
- Fe55 Spectra
  - Resolution and Fano factor
  - Efficiency: Electron counting
- TimeOverThreshold measurements
  - TOT spectra and Polya fits
  - Gain measurements
  - Influence of SiProt
  - Efficiency: Gain/Threshold
- LASER measurements

# Hardware
## The Timepix Chip

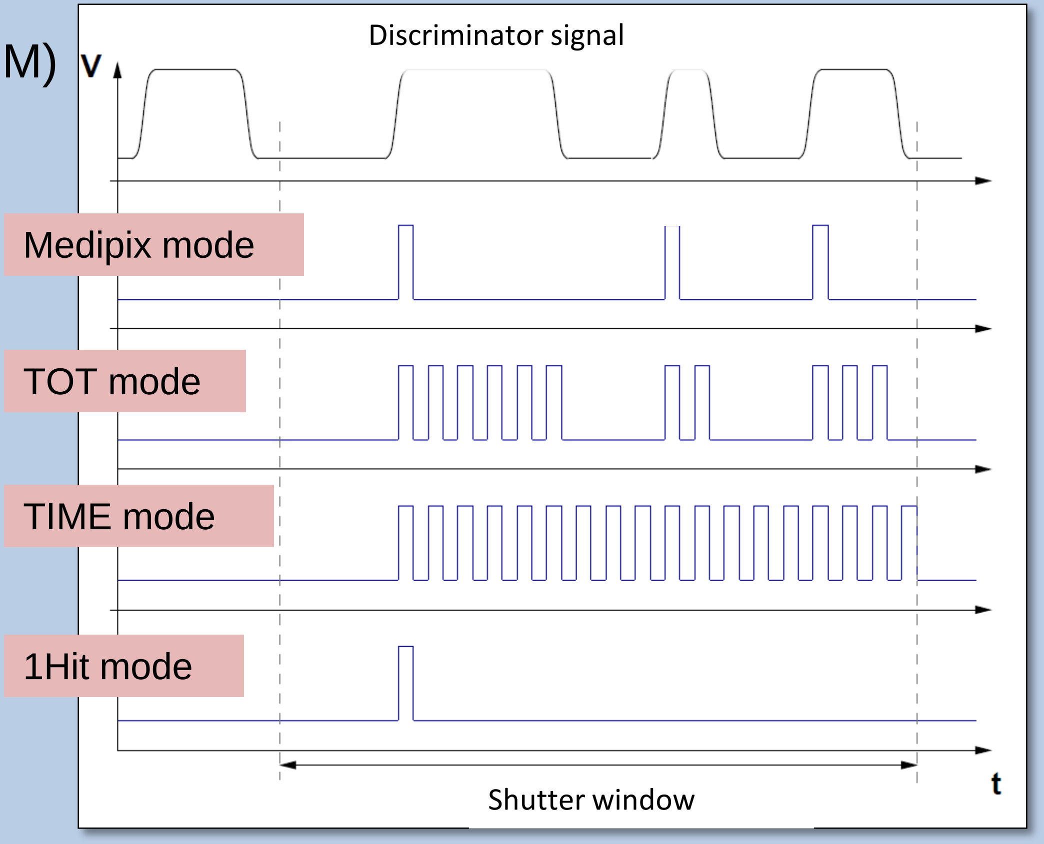
A modified MediPix2 Chip for TPC applications



Characteristics :
- 1,4 x 1,4 cm²
- matrix of 256 x 256 pixels (CMOS, IBM)
- 55 x 55 µm² per pixel
- Preamplifier/shaper ($t_{rise}$ ~150 ns)

Motivation: knowing the time of arrival of avalanches at pixels
⇒use 14bits for counting clock cycles

- lower threshold
- clock up to 100 MHz in each pixel
- noise threshold ~ 500 e-
- digital output signal
- 4 different modes possible



# Hardware

## Timepix + Ingrid = Pixelated Micromegas

<u>TimePix+Micromegas</u>:

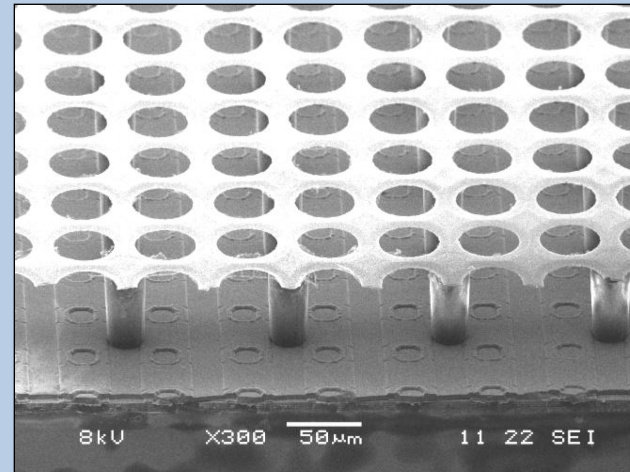
- No alignment between pixels and holes in grid
- pillars visible
- variation of distance between anode and grid
- irregular structure

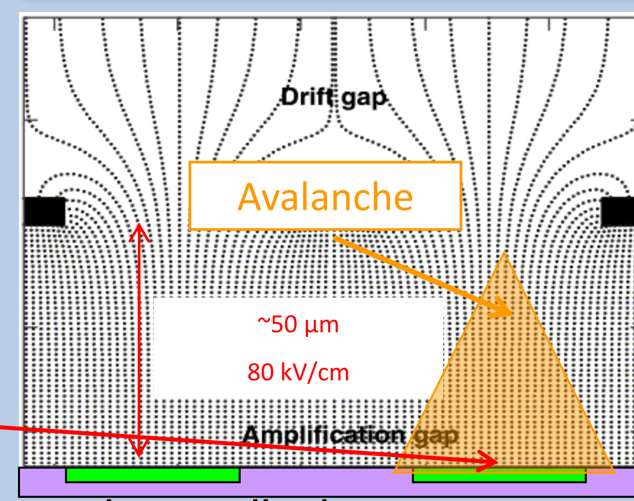
⇒ Gain inhomogeneities, Moiré effect

<u>Solution:</u>

GridPix: TimePix Chip with Micromegas structure in post-production (photolithography)

- alignment of grid
- flat surface
- regular structure
- possibility to vary grid parameters in post-process




!

Attention to discharges ⇒ place an additional layer: **SiProt**

# Hardware
## Setup

Gas box, volume: 1,5 l

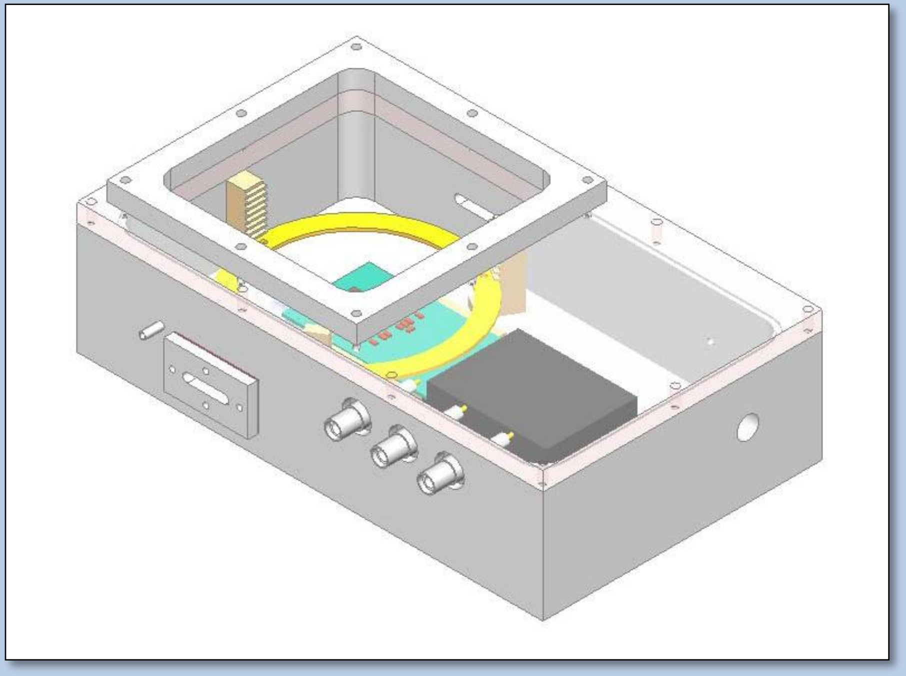
Source: Fe55, directly on cathode

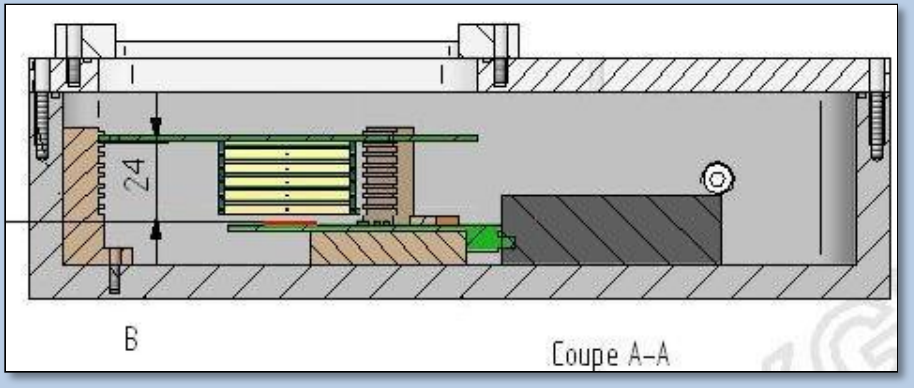
Gas: ArIso 95/5 (ArIso 80/20, P10, CF4)

Readout: MUROS, 36MHz, Pixelman
Filter: > 10 Pixel per Frame

Drift distance: max. 2,4 cm
Amplification gap: 50µm
SiProt: 7µm

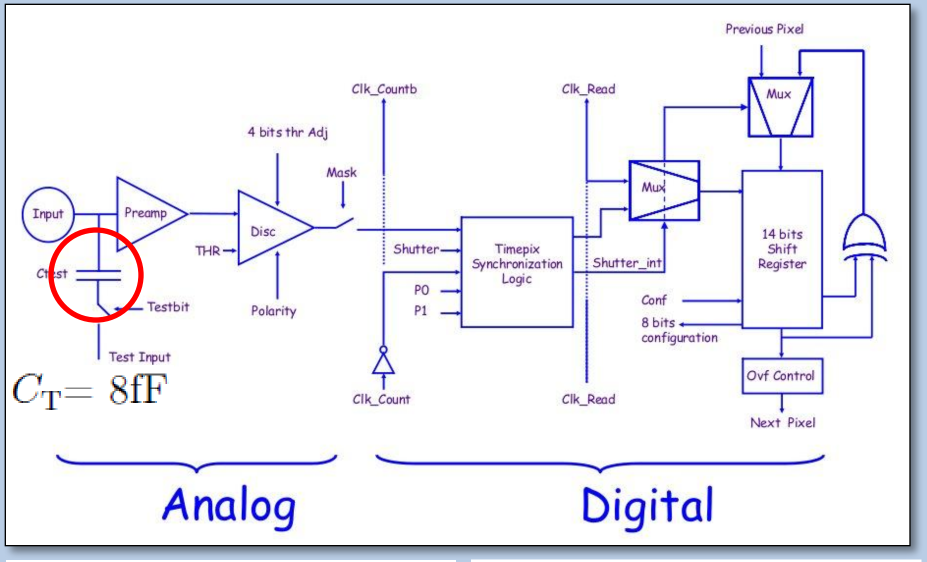
Field degrader
No anode plate around InGrid





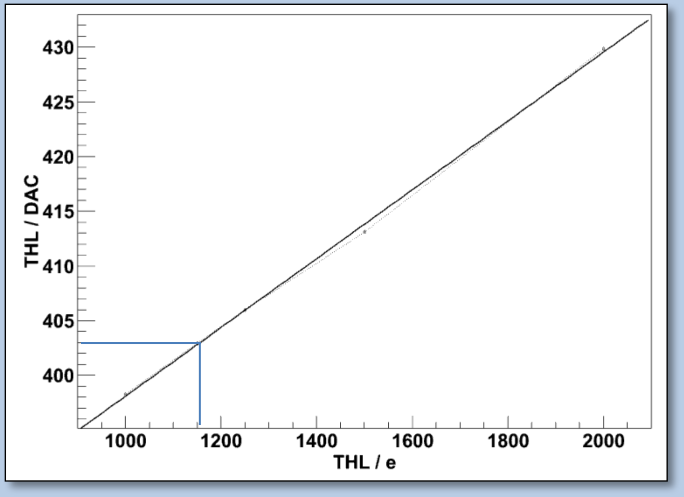
# Hardware

## Calibration

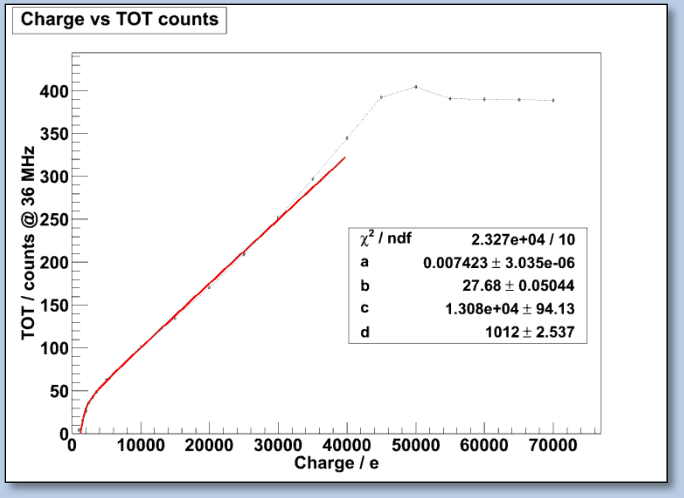



$Q_{inj}\,[e^-] = 50 \cdot \Delta U_{inj}[mV]$ $\quad Q_{inj} = C_T \cdot \Delta U_{inj}$

Threshold DAC → #e- calibration




TOT → #e- calibration




Internal test pulses applied to each pixel via MUROS

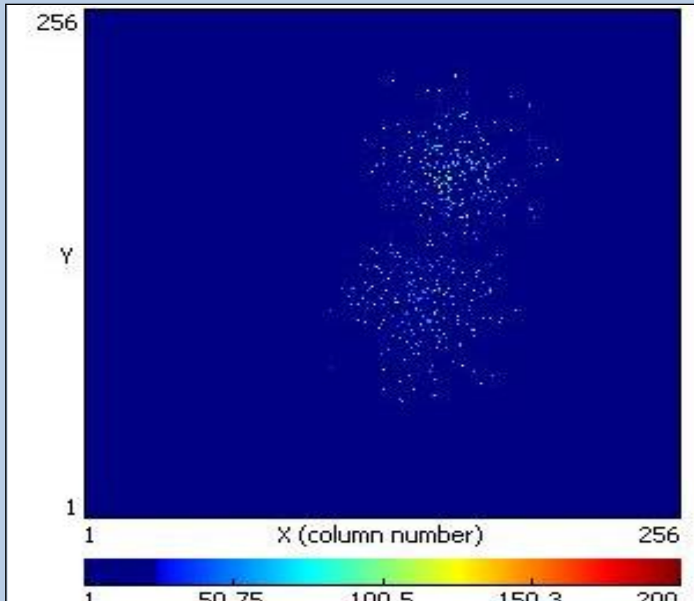
→ Known input charge into electronics

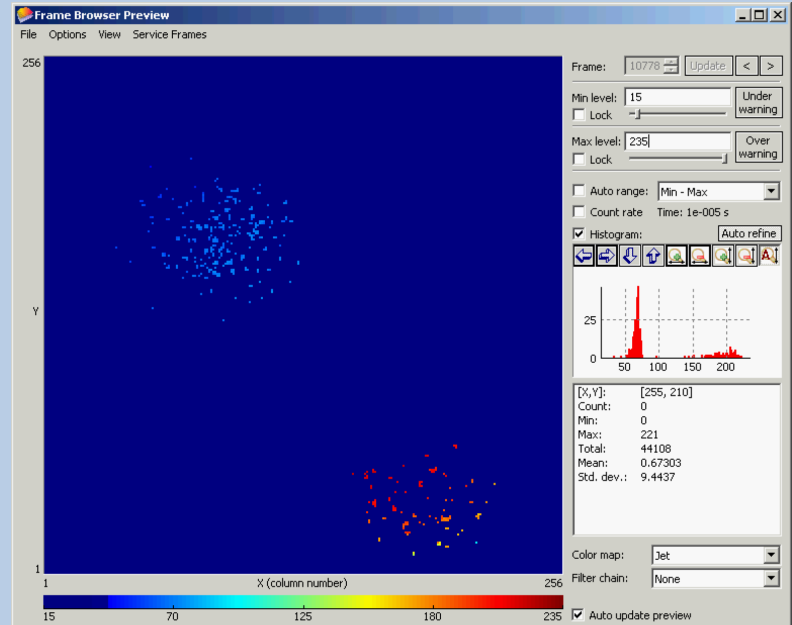
→ Threshold calibration

→ TOT calibration !Non linear for low charge

# Software

## Analysis code



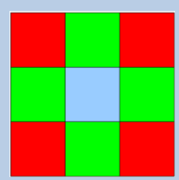

TOT Mode: 1. Check circularity of clouds

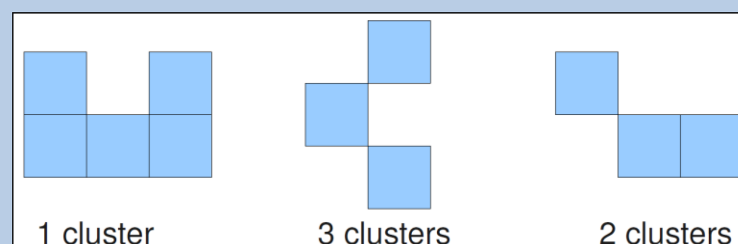
TIME Mode: 1. Separate clouds with time information

2. Check if cloud near centre
3. Check cloud size RMS

Find clusters (group attached pixels)

→ Histograms, Fits, TOT to electrons …

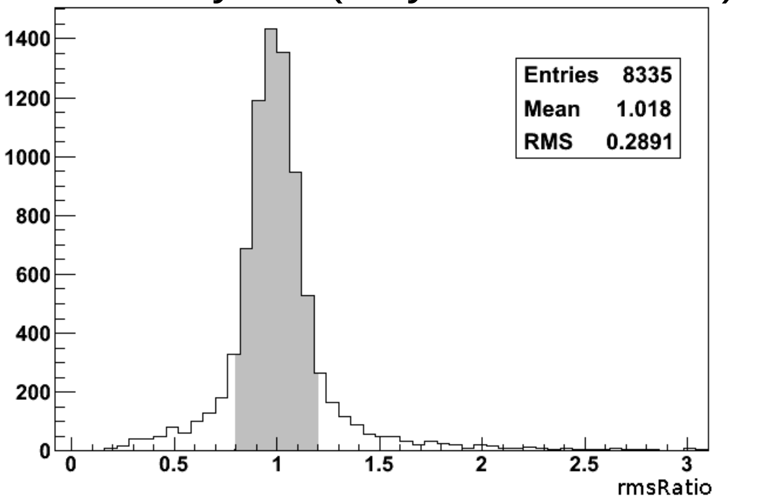




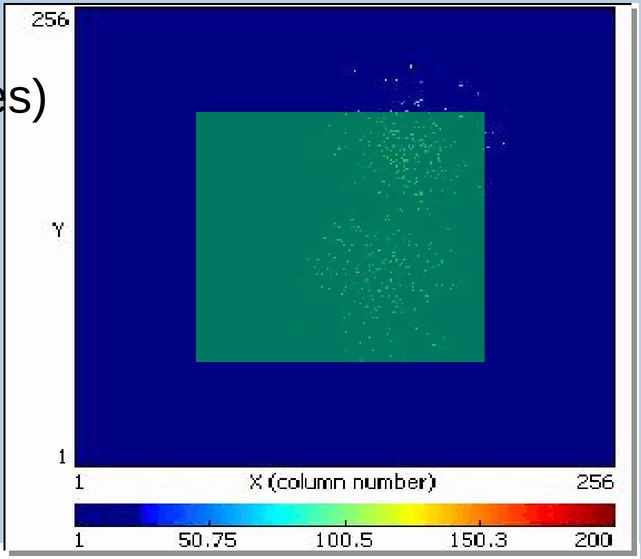
# Software

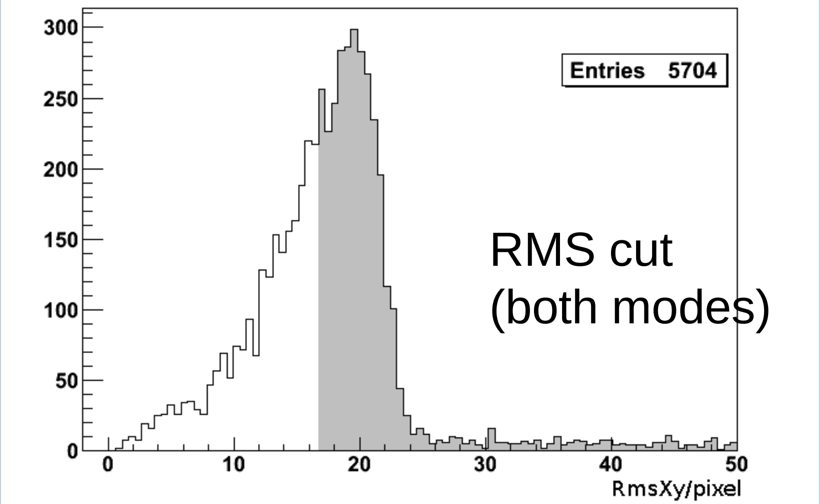
## Analysis code

Circularity cut (only in TOT mode)




Centre cut
(both modes)



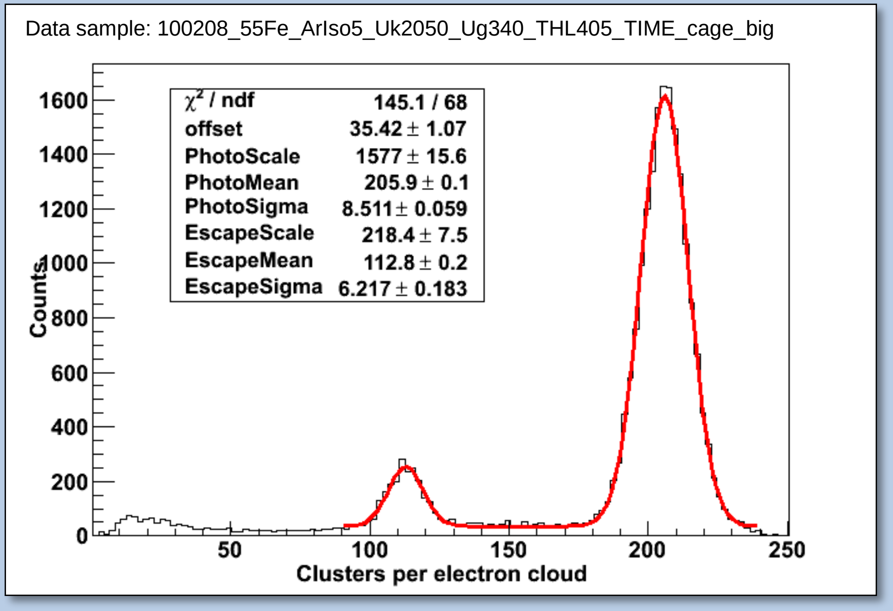

RMS cut
(both modes)

Physical interpretation of RMS cut:
Only take electron clouds, that have drifted a long distance:
⇒Primary electrons separated by diffusion
Cut: RMS of 16.4 pixels on chip

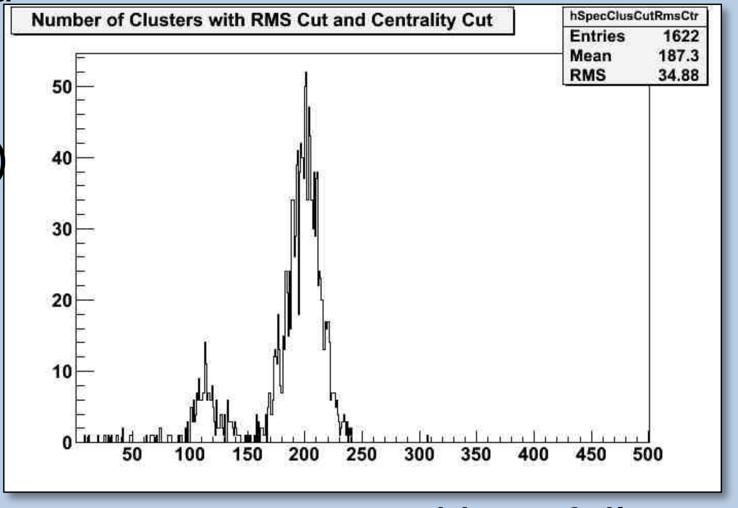
# Fe55 Spectra
## Resolution

- Count number of hit pixels/clusters per electron cloud
- Chromium foil to absorb $K_\beta$ photons
- long term measurement and hard cut on cloud size
- best resolution achieved: 9,73% FWHM (photo peak)

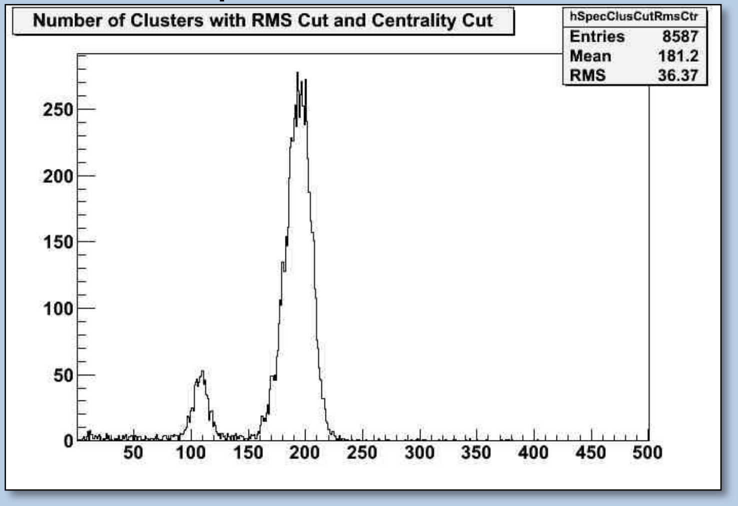
$$\left(\frac{\sigma_{N_d}}{N_d}\right)^2 = \frac{1}{N_p}\left(F + \frac{1-\frac{N_d}{N_p}}{\frac{N_d}{N_p}}\right)$$ [1] $\Rightarrow$ F = 0.26 (upper limit)




Fe55 spectrum without Cr foil




Fe55 spectrum with Cr foil





[1] Max Chefdeville, Development of Micromegas-like gaseous detectors using a pixel readout chip as collecting anode

# Fe55 Spectra

## Clusters in escape peak

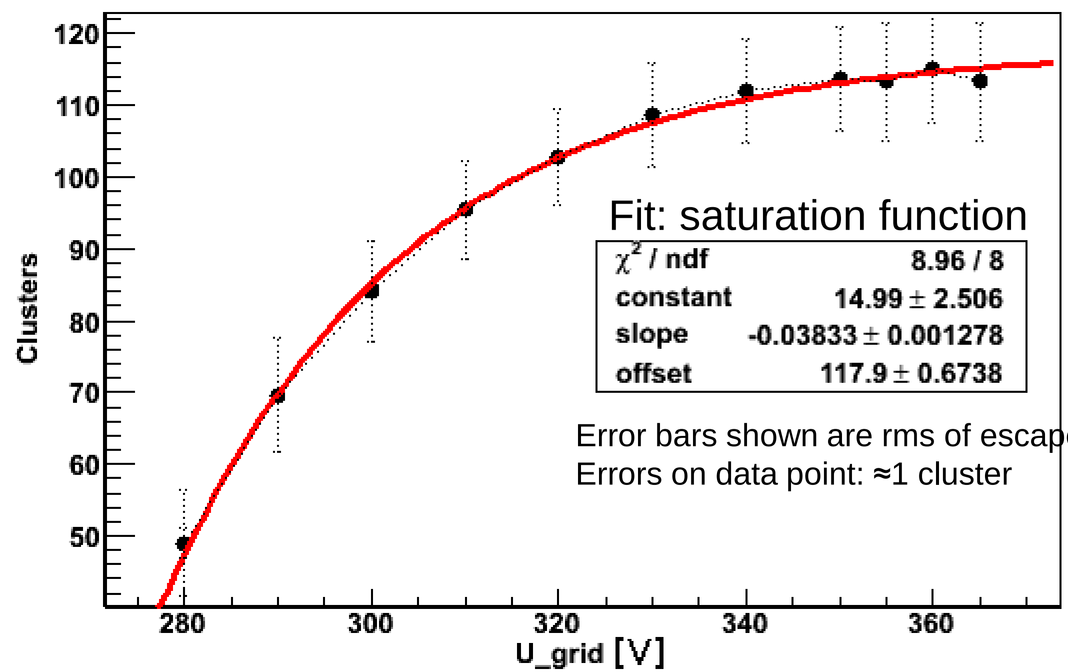
In ArIso 95/5:

- have a look on escape peak: less electrons, better separated by diffusion
- enough diffusion to arrive at plateau for escape peak: 117.9±0.7 cluster
- most clusters include just one pixel (also some charge sharing)
  $\Rightarrow$ 1 cluster $\cong$ 1 primary electron at plateau
- applying harder cuts on RMS of electron cloud does not effect number of clusters

- escape peak at: 2,9 keV
- photo peak at: 5,899 keV

- $\Rightarrow$ 236±1 electrons expected in photo peak (max counted: 215 cluster)

Simulations (H.Schindler):
233 electrons in photo peak
(MAGBOLTZ)

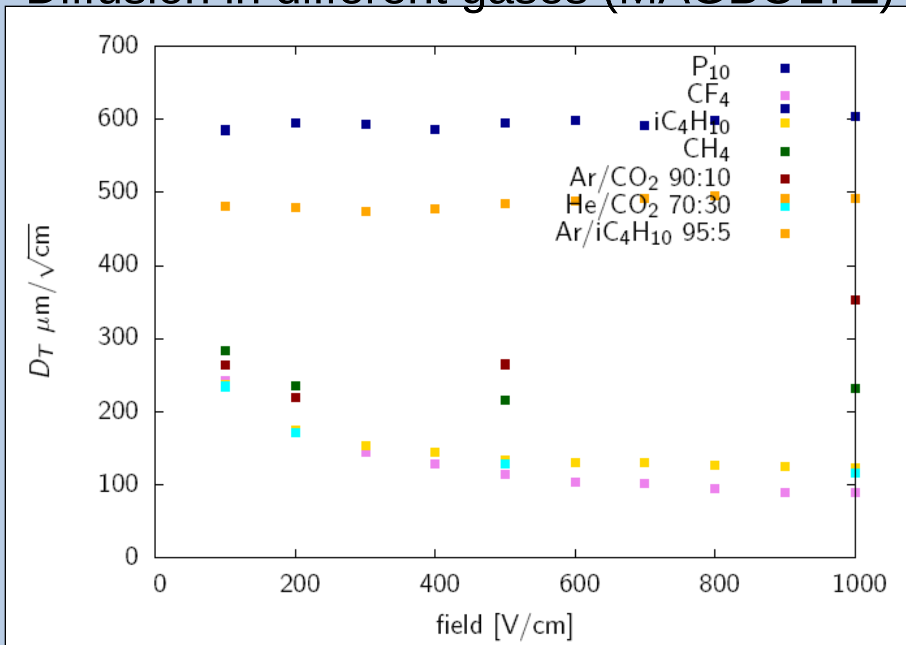


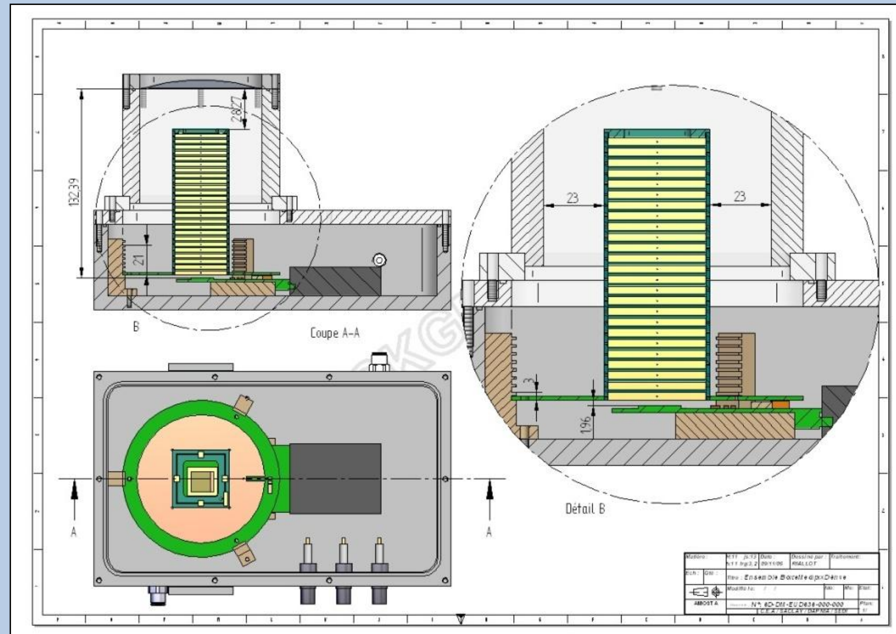

Error bars shown are rms of escape peak
Errors on data point: ≈1 cluster

# Fe55 Spectra

## Improvements to Setup

Diffusion in different gases (MAGBOLTZ)



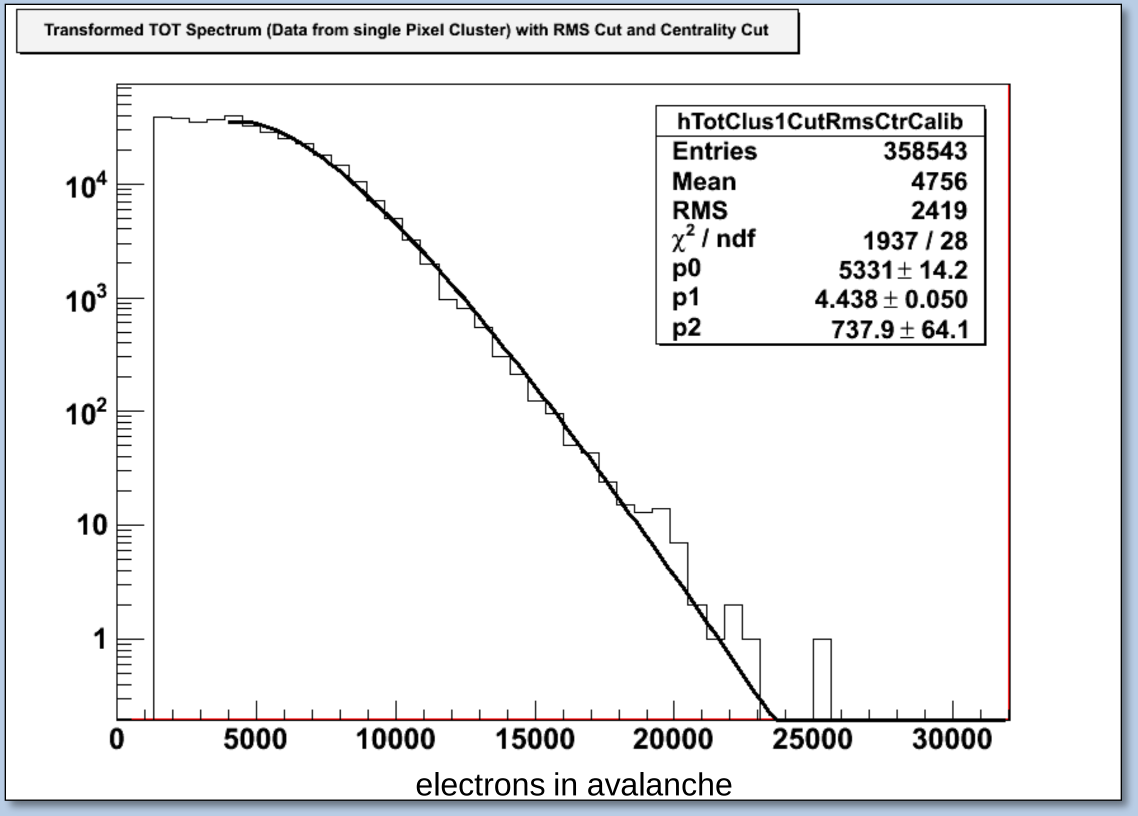

- ArIso95/5 is already gas with high diffusion
- P10 is dangerous for Chips
  - →Higher voltages needed
  - →Sparks more likely
- Diffusion for other gases to low
  - →Electron clouds to small
  - →Too low single electron det. Eff.

- Drift distance will be enlarged from 2,4 cm to ~ 10 cm
- Field degrader will be improved

# TimeOverThreshold
## TOT Spectra

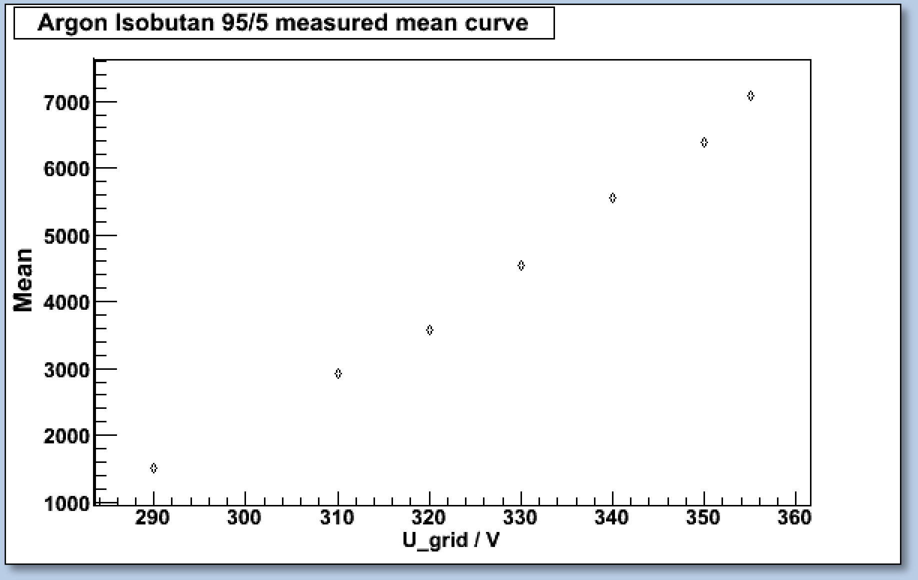
Data sample:
$U_{grid}$=330 V

Polya fit forced starting from 4000
Advantages:
•TOT → #e- calibration reliable
Disadvantages:
•few data points for low voltages
•just tail fit

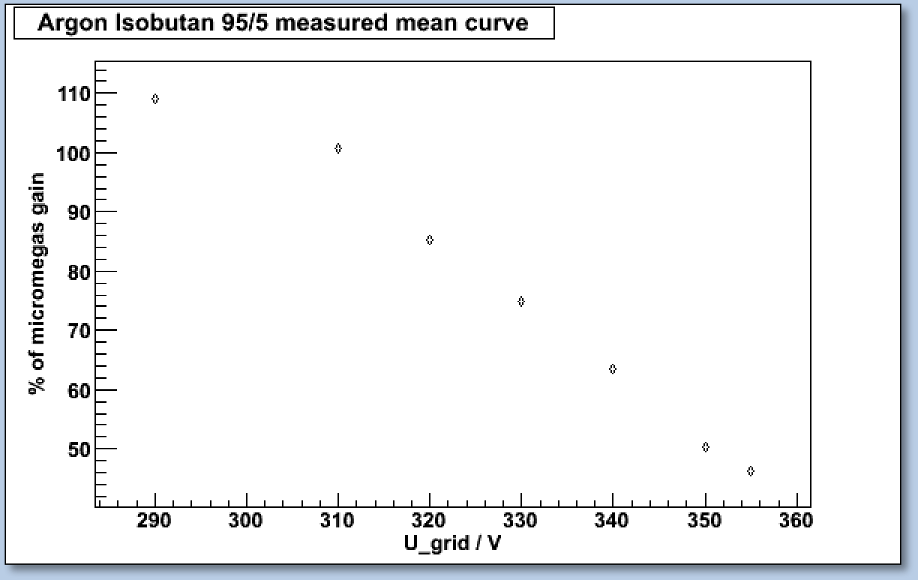


# TimeOverThreshold
## Gain Curve

Mean of Polya fit curve




Comparison to Micromegas results



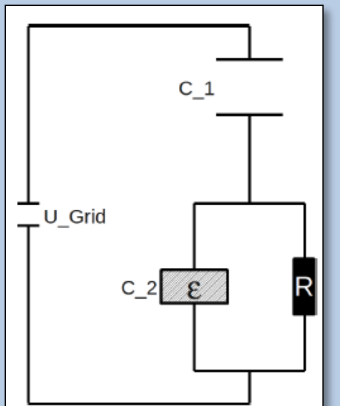

Use TOT → #e- calibration ⇒ gain curve
→ Not exponential at all
→ Very low gain at high voltages

→Higher gain at lower voltages?
→ lowest gain ≈ threshold
→ inaccurate calibration for low gains
→ Gain drop with voltage
→ difference to Micromegas:
SiProt

# TimeOverThreshold

## Influence of SiProt

Reason for lower gain: SiProt layer over anode. Look on single Pixel:
SiProt acts as capacitor that charges with avalanches and discharges over high resistance




$$\frac{dQ}{dt} = G\,f - \frac{Q}{R\,C}$$

$$G[C](U_{\mathrm{Si}}) = e\,\exp(A + B \times \Delta U)$$

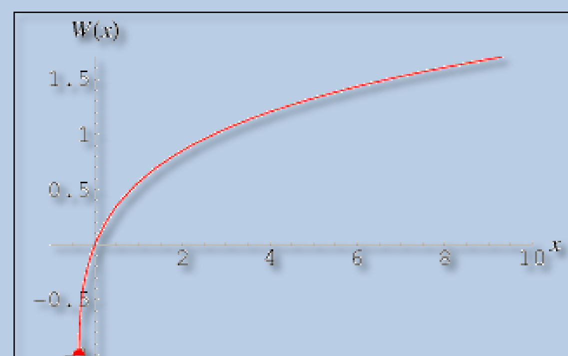
$$\Delta U = U_{\mathrm{grid}} - U_{\mathrm{Si}}$$

$$\frac{U_{\mathrm{Si}}(t\to\infty)}{R} = G(U_{\mathrm{Si}}(t\to\infty))\,f \Rightarrow \frac{U_{\mathrm{Si}}(t\to\infty)}{R\,f\,e} = \exp(A + B \times (U_{\mathrm{grid}} - U_{\mathrm{Si}}(t\to\infty)))$$

f = avalanche frequency, Q=C·U
G = number of electrons per avalanche
R = resistance of SiProt
C = capacitance of SiProt

$$U_{\mathrm{Si}}(t\to\infty) = \frac{W(B\,R\,f\,e\,\exp(A + B \times U_{\mathrm{grid}}))}{B}$$

W: Lambert W-function




$$\tau = R\,C = \varepsilon_0\,\rho\,\varepsilon$$

| | a-Si:H | $Si_3N_4$ |
|---|---|---|
| $\rho/[\Omega\,\mathrm{cm}]$ | $10^{11}$ [2] | $10^{14}$ [3] |
| $\varepsilon$ | 11.8 [1] | 7.5 [3] |

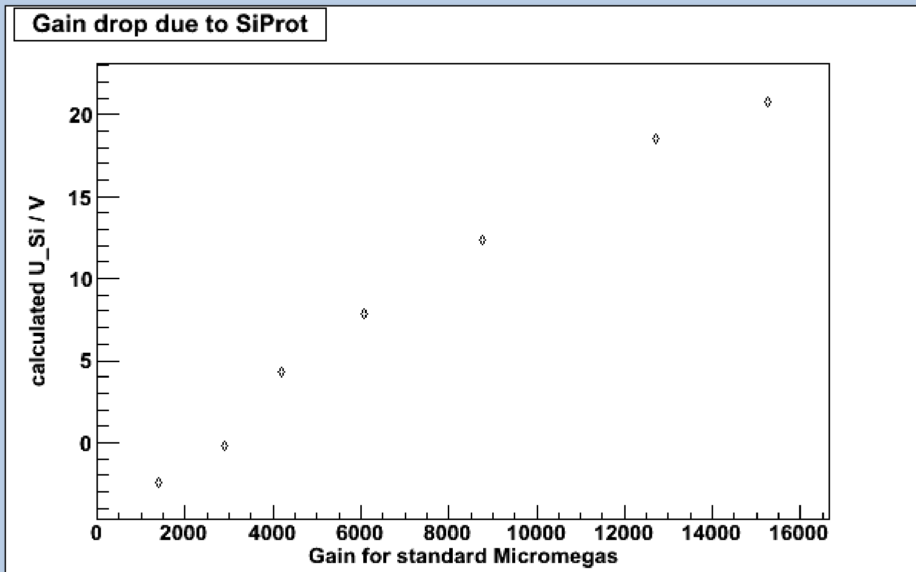
$\Rightarrow \tau \approx 1$ min


[1] S. C. Deane and M. J. Powell, Field-effect conductance in amorphous silicon thin-film transistors with a defect pool density of states, Journal of applied physics 1993, vol. 74, no11, pp. 6655-6666
[2] M.A. Chefdeville, Development of micromegas-like gaseous detectors using a pixel readout chip as collecting anode, Univ. of Twente, January 2009
[3] http://www.siliconfareast.com/sio2si3n4.htm

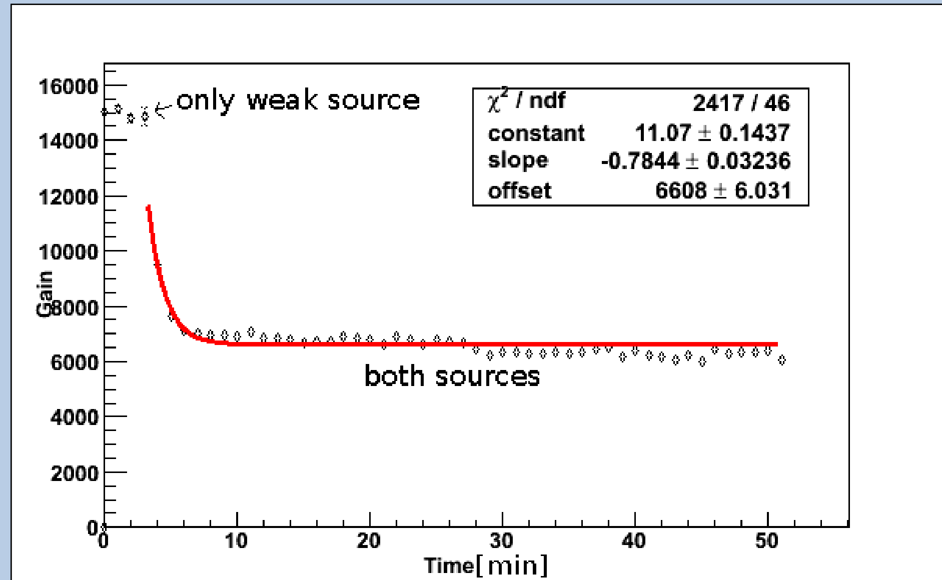
# TimeOverThreshold

## Influence of SiProt

Calculation of voltage on SiProt surface




Example for gain drop (charging of SiProt)




$$G = \exp(A + B \cdot U)$$

$$mean = G_{measured} = \exp(A + B \cdot \Delta U)$$

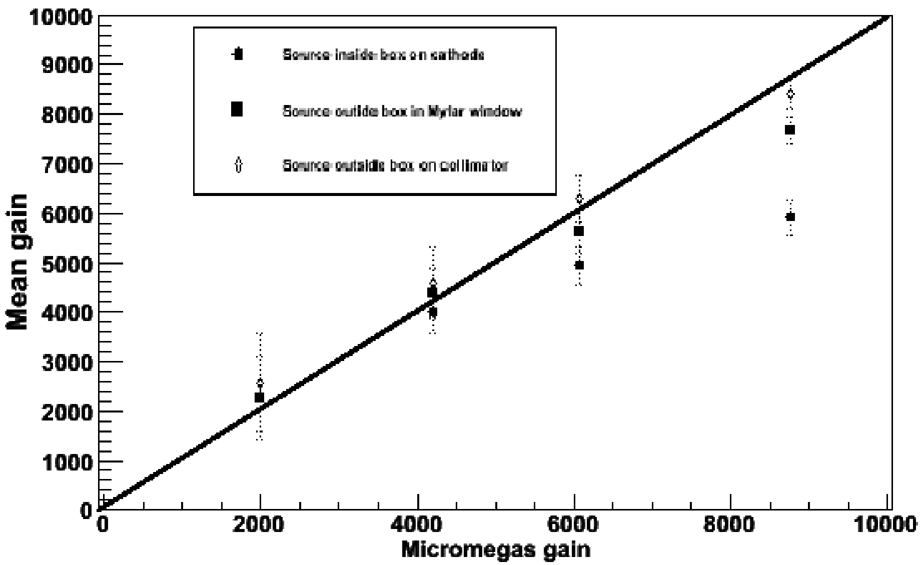
$$\Rightarrow \Delta U = \frac{\ln(mean) - A}{B}$$

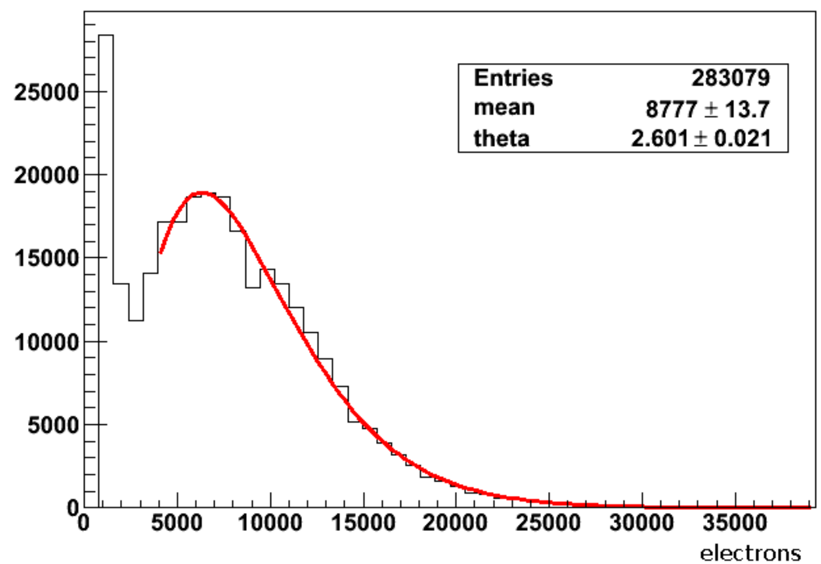
$$U_{Si} = U - \Delta U \qquad U_{Si} = \frac{W(B \cdot f \cdot R \cdot G)}{B}$$

Put on second, stronger source during measurements:
Gain drop from 15000 to 6600 with $\tau = 1.27 \pm 0.05$ min

# TimeOverThreshold

## Low rate measurements




Place source further away from detector
-> inside detector (high rate)
-> outside detector box (low rate)
-> outside detector box + collimator (highest rate)

InGrid gain approaches Micromegas gain

Measurement at lowest rate
→ high gain
→ noise visible, as acq. time needs to be longer
→ $\Theta$ = 2.6

# Combined Measurement
## Detection Efficiency

Comparison of theory and measurements assuming Polya distribution
Combine gain and primary electron measurements

From gain (TOT) measurements: Polya mean = gain

From primary electron (TIME) meas.:
number of prim. electrons,
117,9 electrons = 100 % det. Eff.

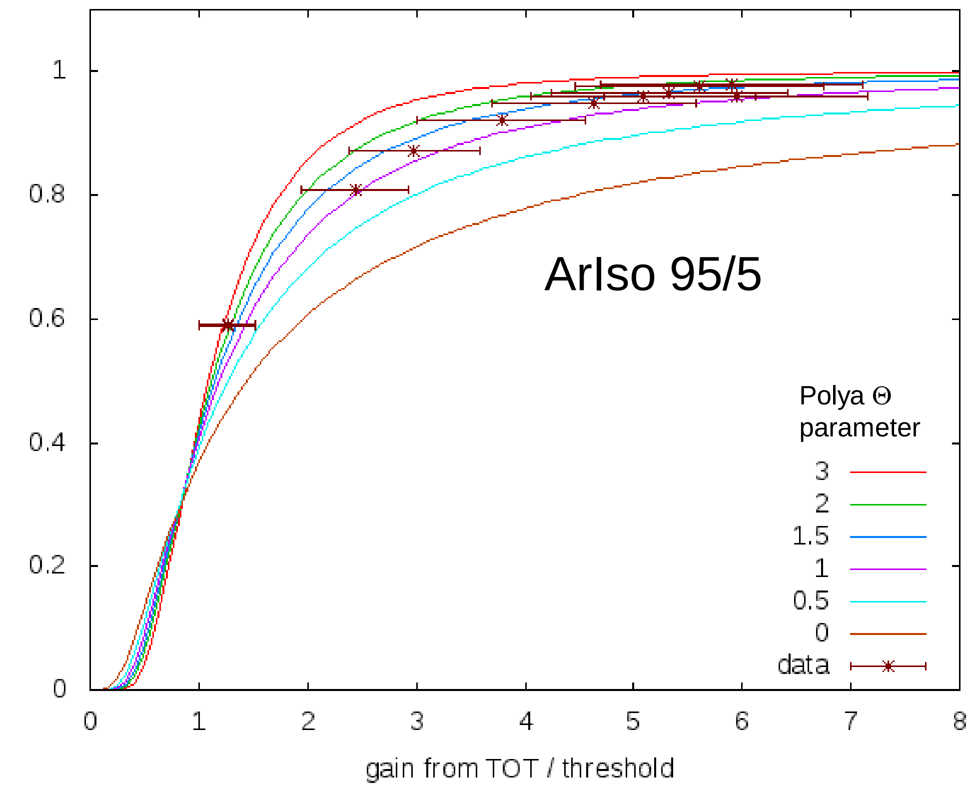
Detection efficiency:

$$\kappa(m,G,t) = \int_t^{\infty} \frac{m^m}{\Gamma(m)} \frac{1}{G} \left(\frac{g}{G}\right)^{m-1} \exp\left(-m\frac{g}{G}\right) dg$$

m=Θ+1
Threshold: t=1150 electrons

$\Rightarrow$ 0.5 < Θ < 2

[1]

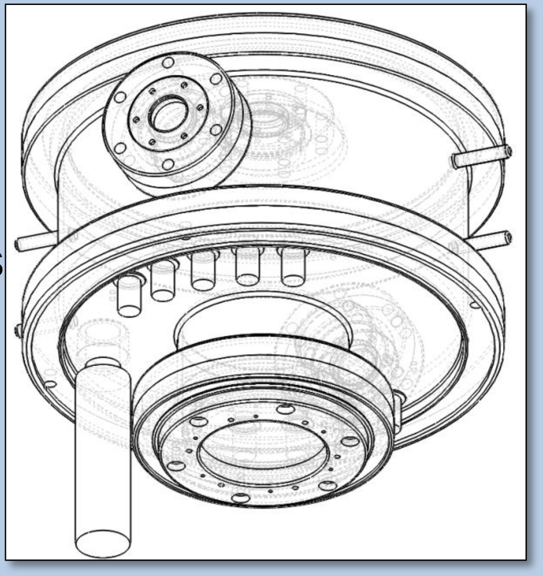


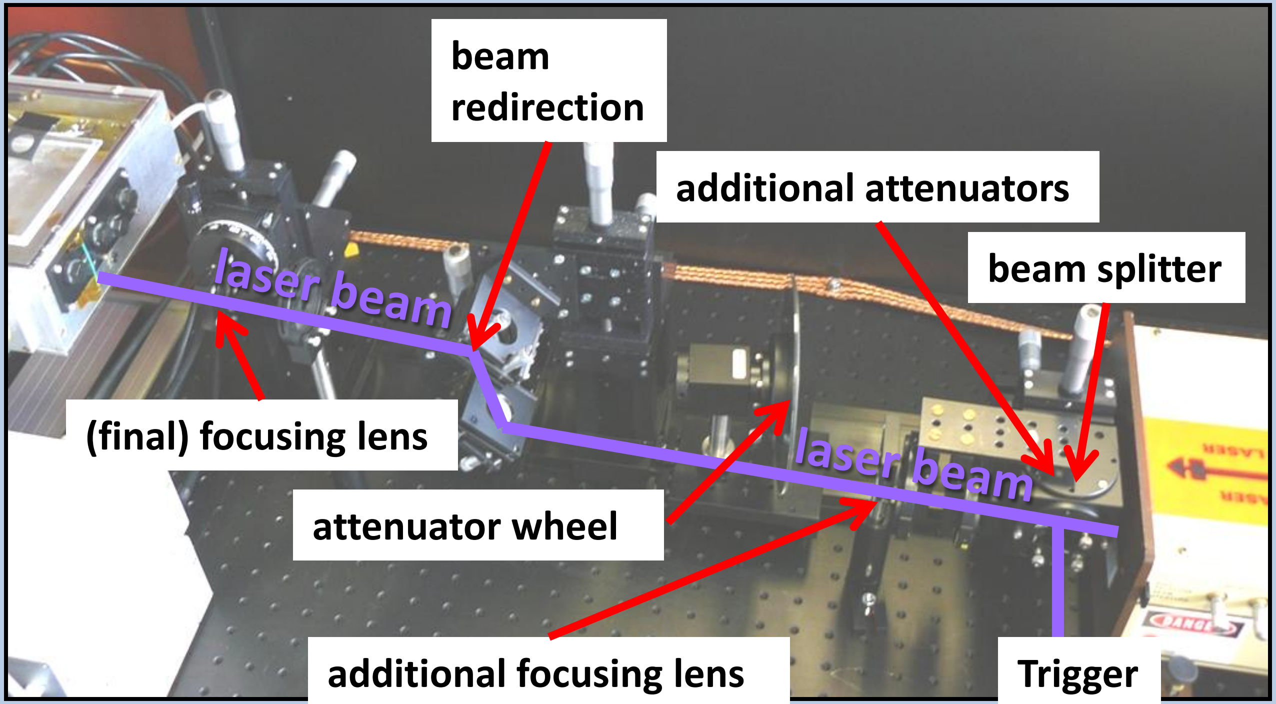

[1] Max Chefdeville, Development of Micromegas-like gaseous detectors using a pixel readout chip as collecting anode

# TimeOverThreshold
## Laser measurements

Quantitative measurements of gain – rate dependence

- Use (pulsed) LASER test bench and gas box in Freiburg
  - → photo effect on cathode, few electrons
  - → defined frequency and position of primary electrons
  - → temperature und pressure registration

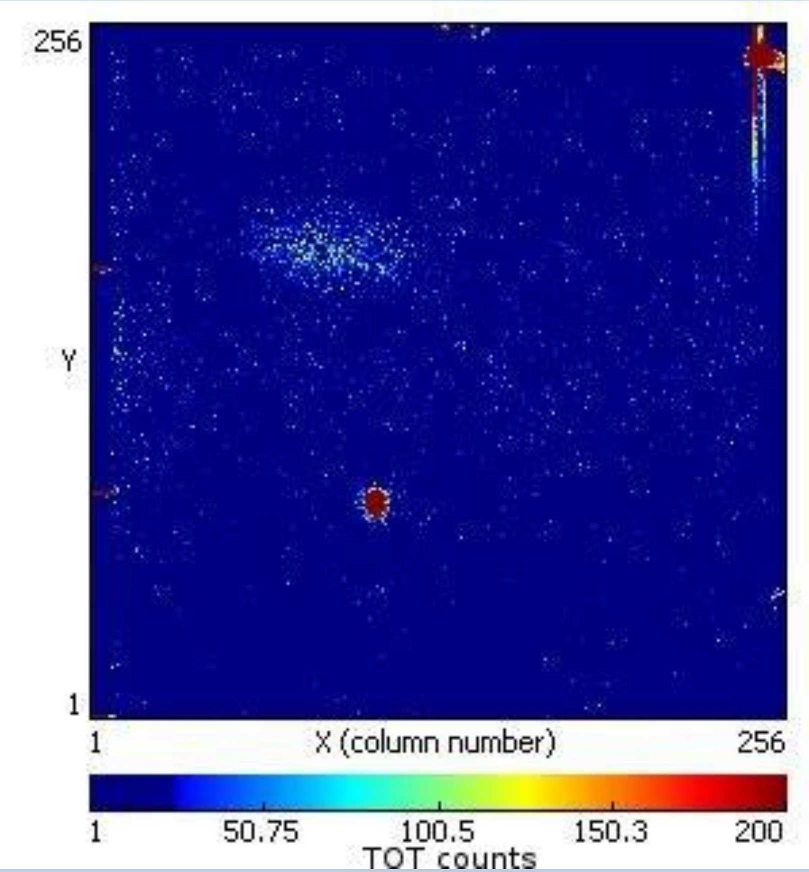


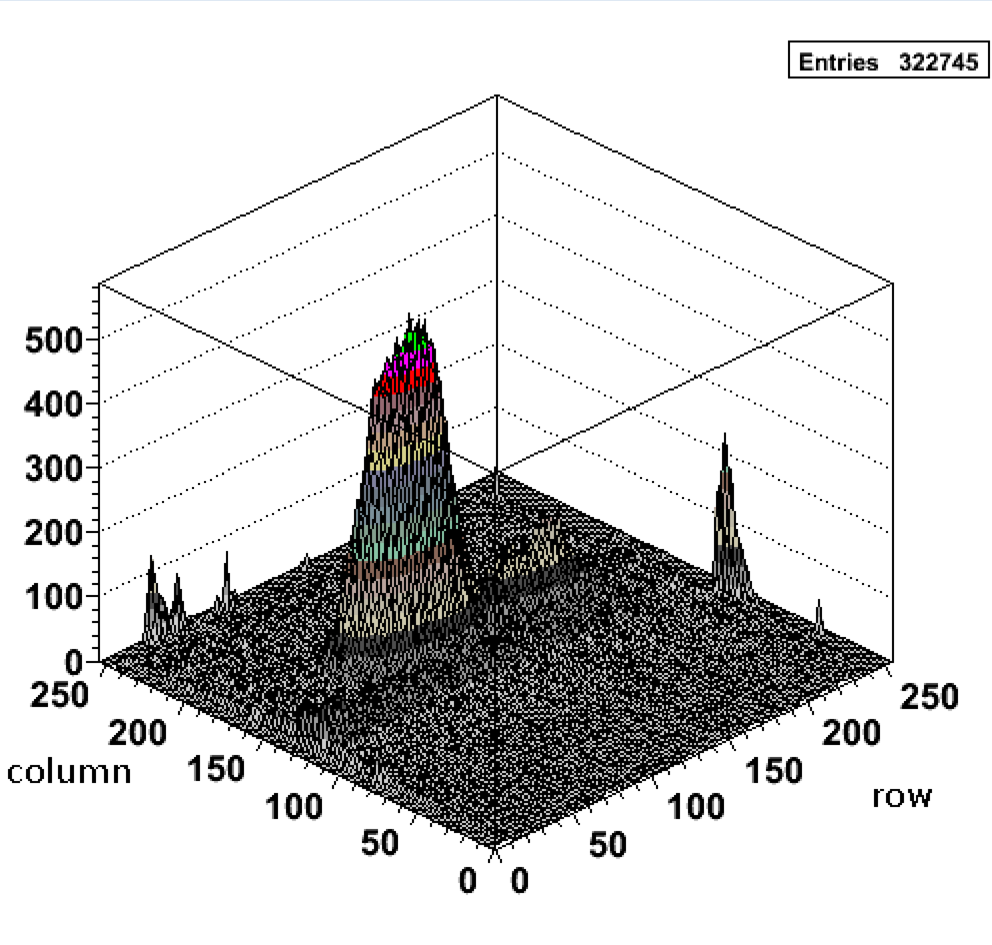



Measurement program:

- TIME mode:
  → drift velocity
  → electron counting
- TOT mode:
  → charging effect of SiProt
  → surface scan

# TimeOverThreshold
## Laser measurements



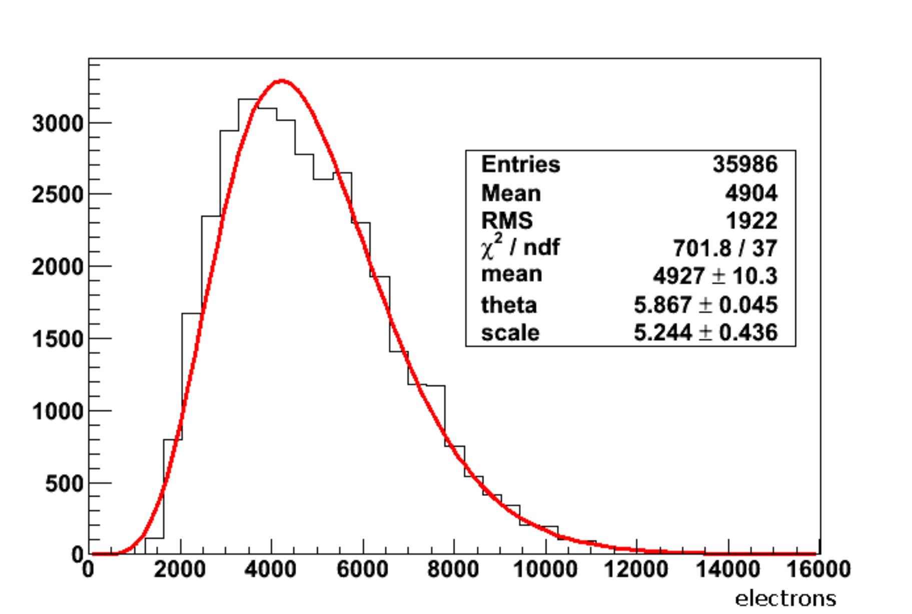

Problem: leakage current from grid to chip charges SiProt, reduces gain
⇒Quantitative G(f) measurements not possible, hot spots masked

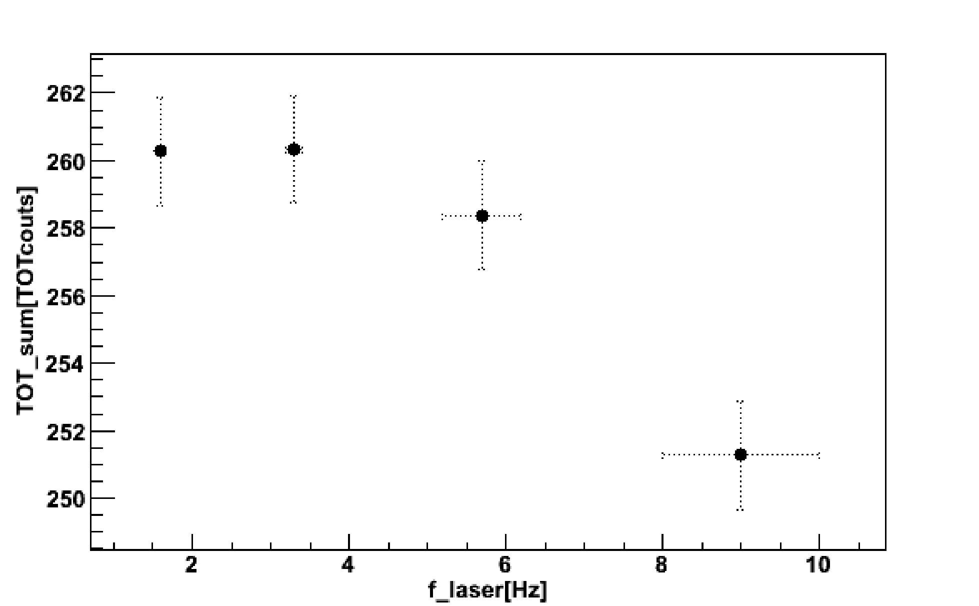
Hit pixels in one run: LASER focus on chip, discharges at grid border

# TimeOverThreshold

## Laser measurements

Photo electrons per LASER pulse:
Poisson distributed: mean ≈ 4




Gain spectrum:
→Mean ≈ 56 % of Micromegas gain
→Narrow distribution (high Θ)
Could be due to problems with recent TOT calibration (under study)

Data indicates gain drop for higher LASER repetition rates (not as clear as for 55Fe sources)

# Conclusion

**Fe55 spectra (primary electron counting):**

- 97.8% single electron detection efficiency was reached in ArIso 95/5 with 117.9±0.7 electrons in escape peak.
- A resolution of 9,73% FWHM was reached for the photo peak leading to a upper limit for the Fano factor of 0.26.

**TOT mode (gain measurements):**

- TOT mode can be used to measure the gain of a TimePix InGrid detector.
- Effects of the SiProt layer have to be taken into account:
    - reduces gain
    - SiProt layer can be modeled by a not perfect capacitor
    - measured time constant of capacitor ≈1 minute as predicted by model.
- $\Theta$ value between 0.5 and 2. for gains from 2000 to 5000.
- Pulsed LASER used to produce primary electrons by photo effect. Problems with Ingrid prevented gain measurement. Avalanche rate dependence of gain could not be analysed quantitatively.

# Thanks

David Attié, Paul Colas, Xavier Coppolani,
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Markus Köhli, Uwe Renz, Markus Schumacher

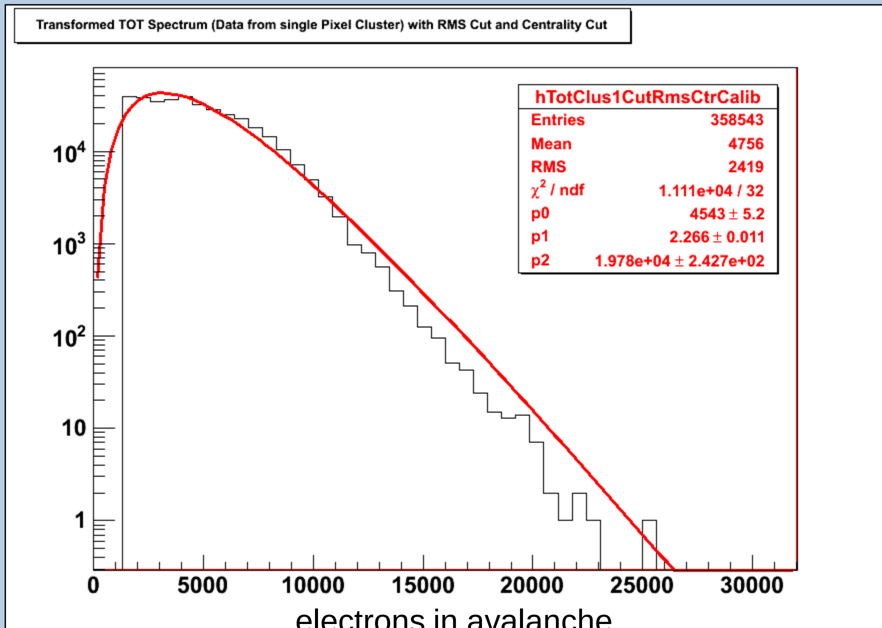
Maximilien Chefdeville

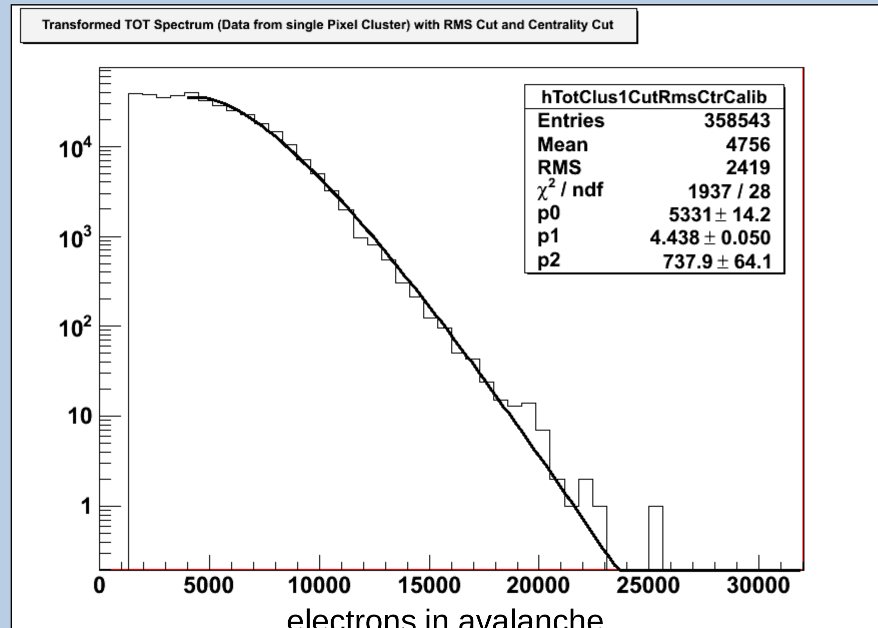
Yevgen Bilevych, Martin Fransen, Harry van der Graaf,
Joop Rövekamp, Jan Timmermans

# TimeOverThreshold

## TOT Spectra

Data sample: 100129_55Fe_ArIso5_Uk2040_Ug330_THL405_TOT_cage_Calib




Polya fit forced starting from 0

Advantages:

- curvature at low gain taken into account
- stable fit at low voltages

Disadvantages:

- gain calibration not accurate at low voltage

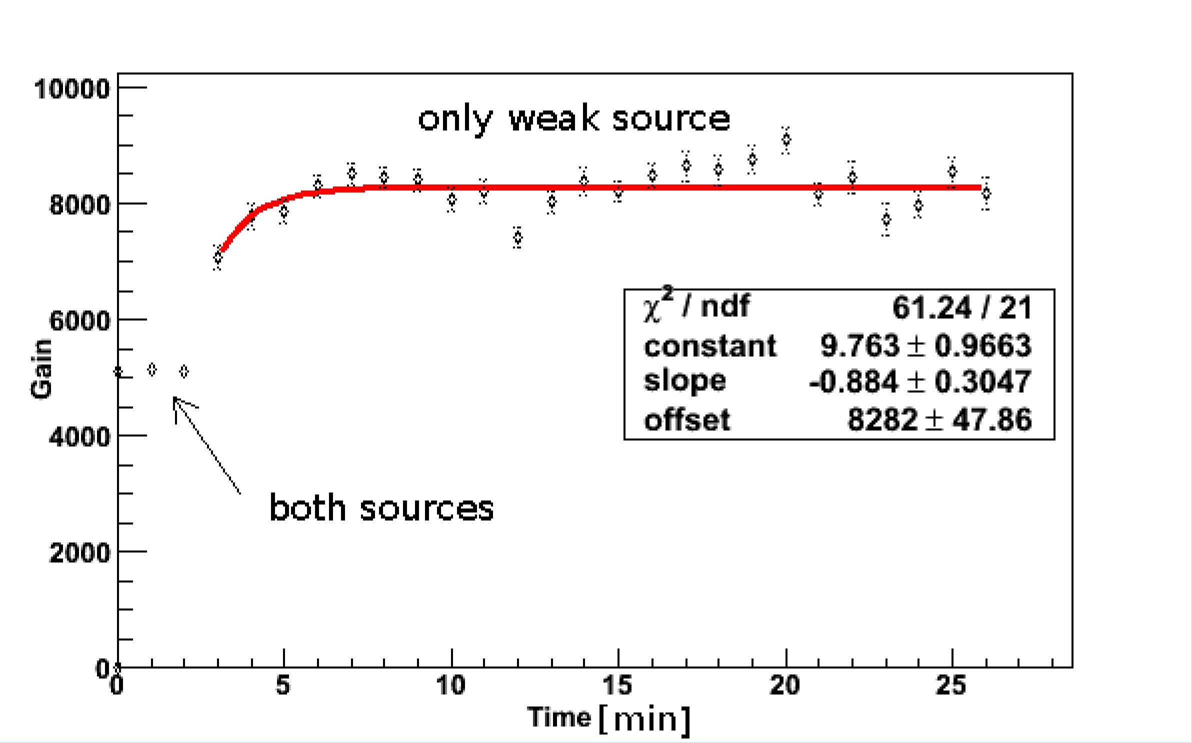
Polya fit forced starting from 4000

Advantages:

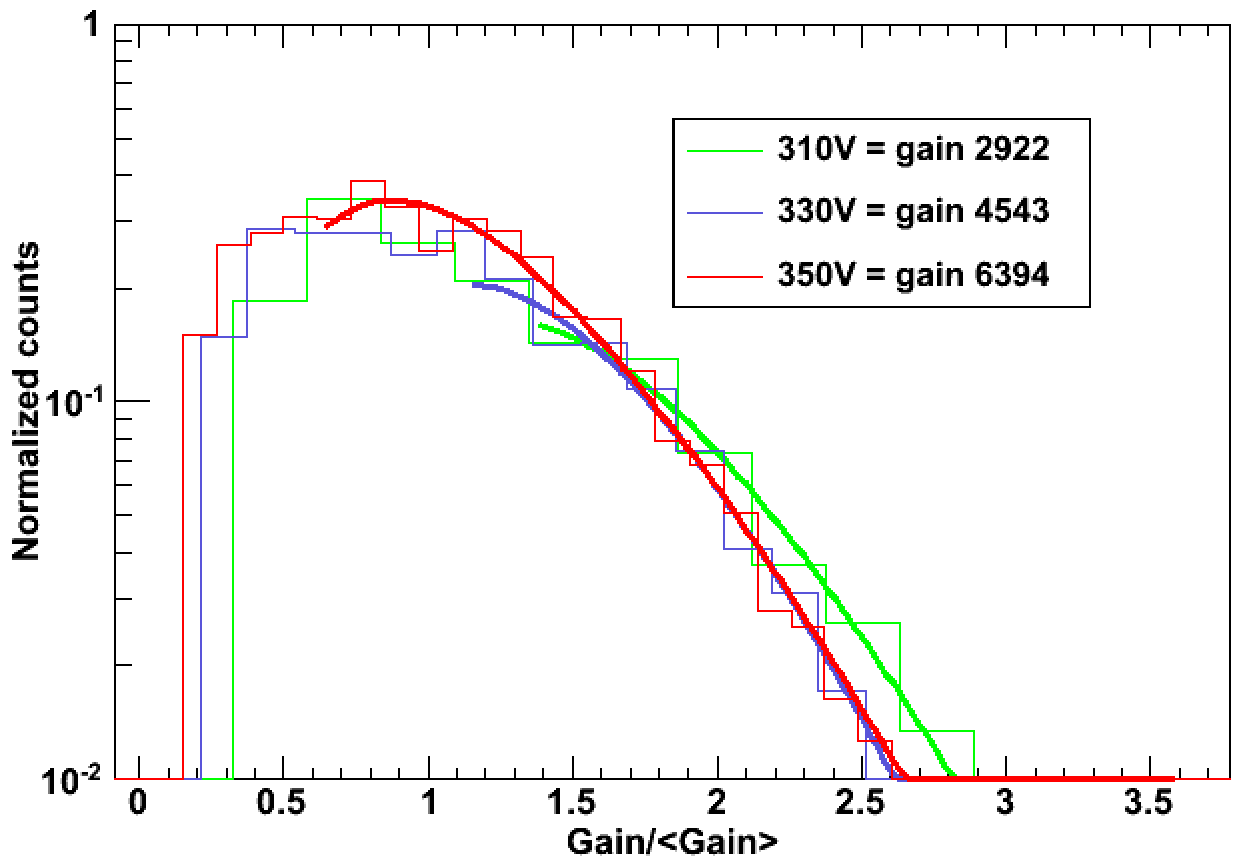
- TOT → #e- calibration reliable

Disadvantages:

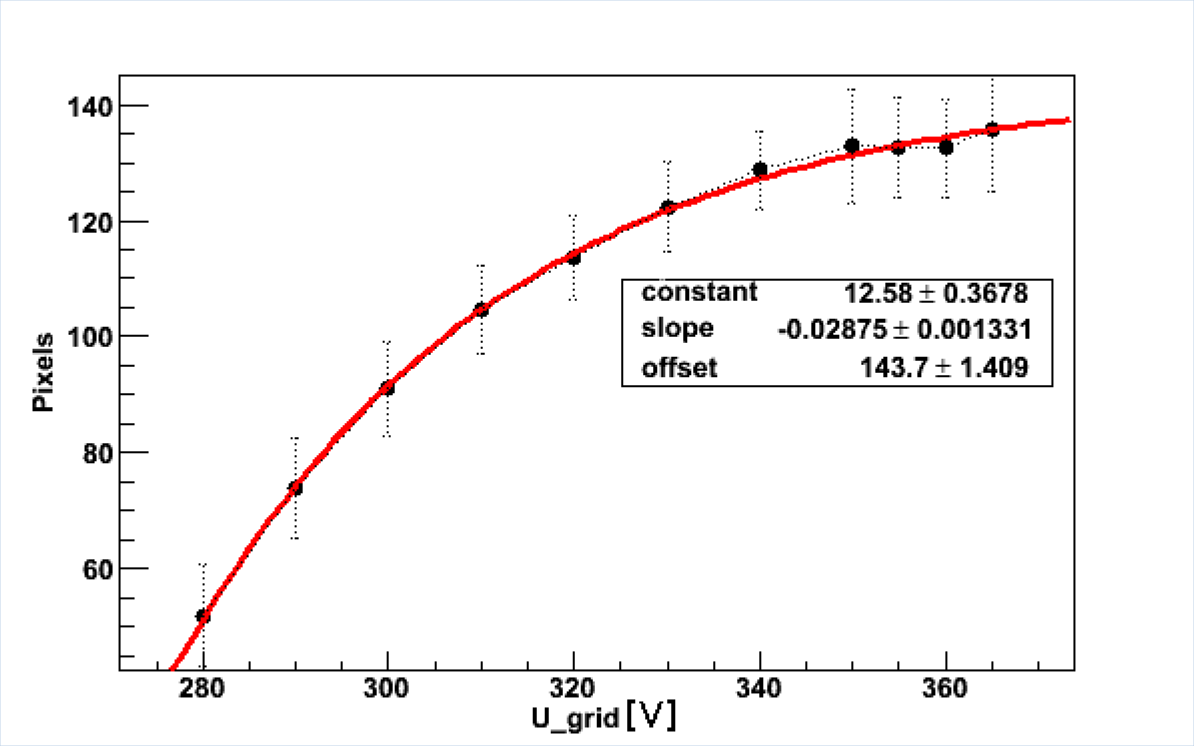
- few data points for low voltages
- just tail fit



only weak source
both sources
$\chi^2$ / ndf 61.24 / 21
constant 9.763 ± 0.9663
slope -0.884 ± 0.3047
offset 8282 ± 47.86
Gain
Time [min]
10000
8000
6000
4000
2000
0
5
10
15
20
25



Normalized counts
1
$10^{-1}$
$10^{-2}$
0
0.5
1
1.5
2
2.5
3
3.5
Gain/<Gain>
310V = gain 2922
330V = gain 4543
350V = gain 6394



140
120
100
80
60
Pixels
280
300
320
340
360
U_grid [V]
constant 12.58 ± 0.3678
slope -0.02875 ± 0.001331
offset 143.7 ± 1.409

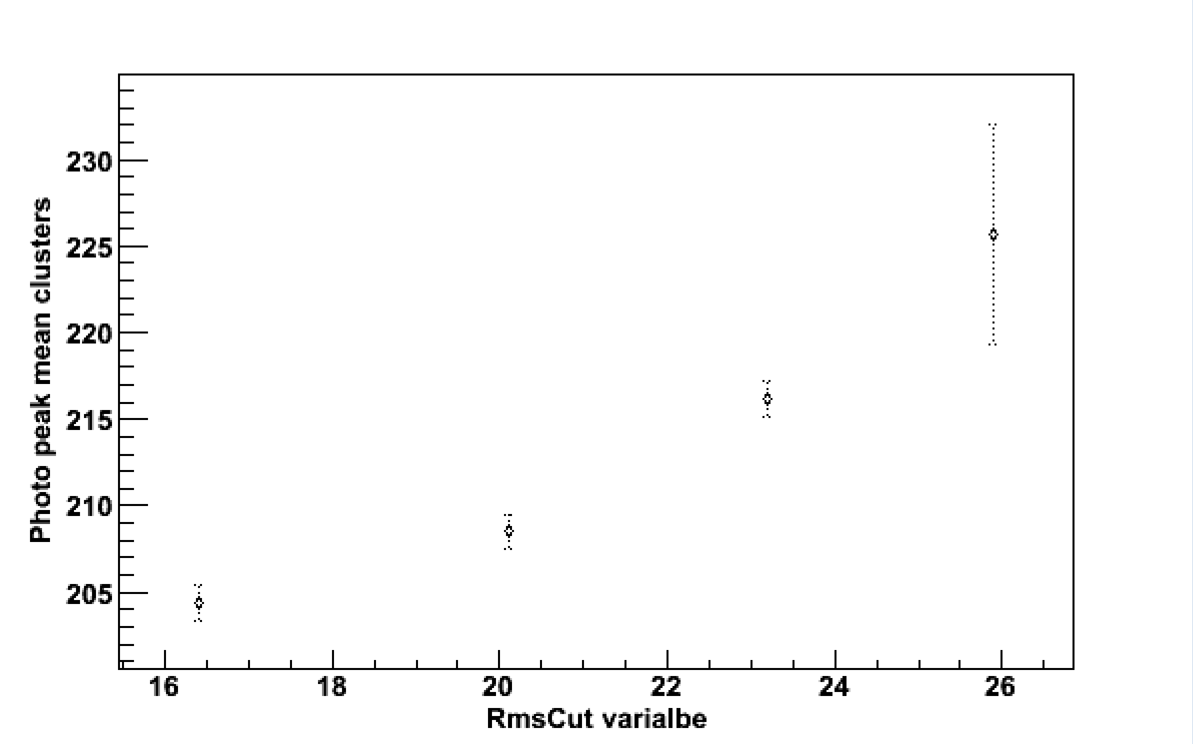


Photo peak mean clusters
230
225
220
215
210
205
16
18
20
22
24
26
RmsCut varialbe