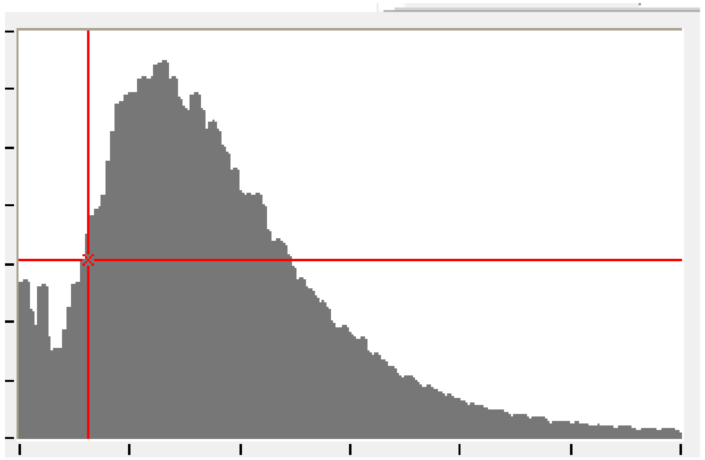
Quad working point



Fred Hartjes

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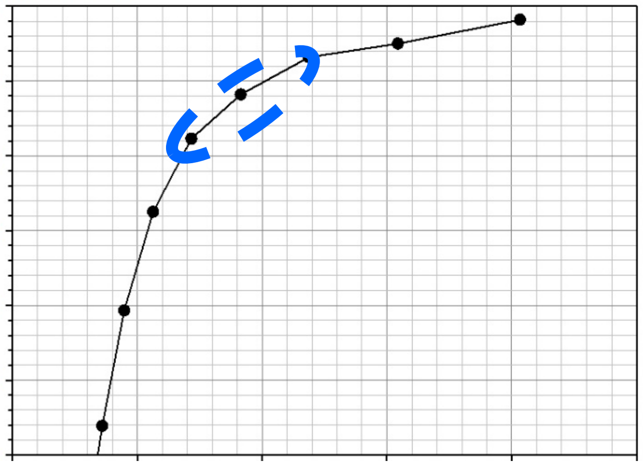


1. **False hits** when using T2K gas

2. **Reduction** of the **gas gain** at high rate

Both solvable in the MEMS technology

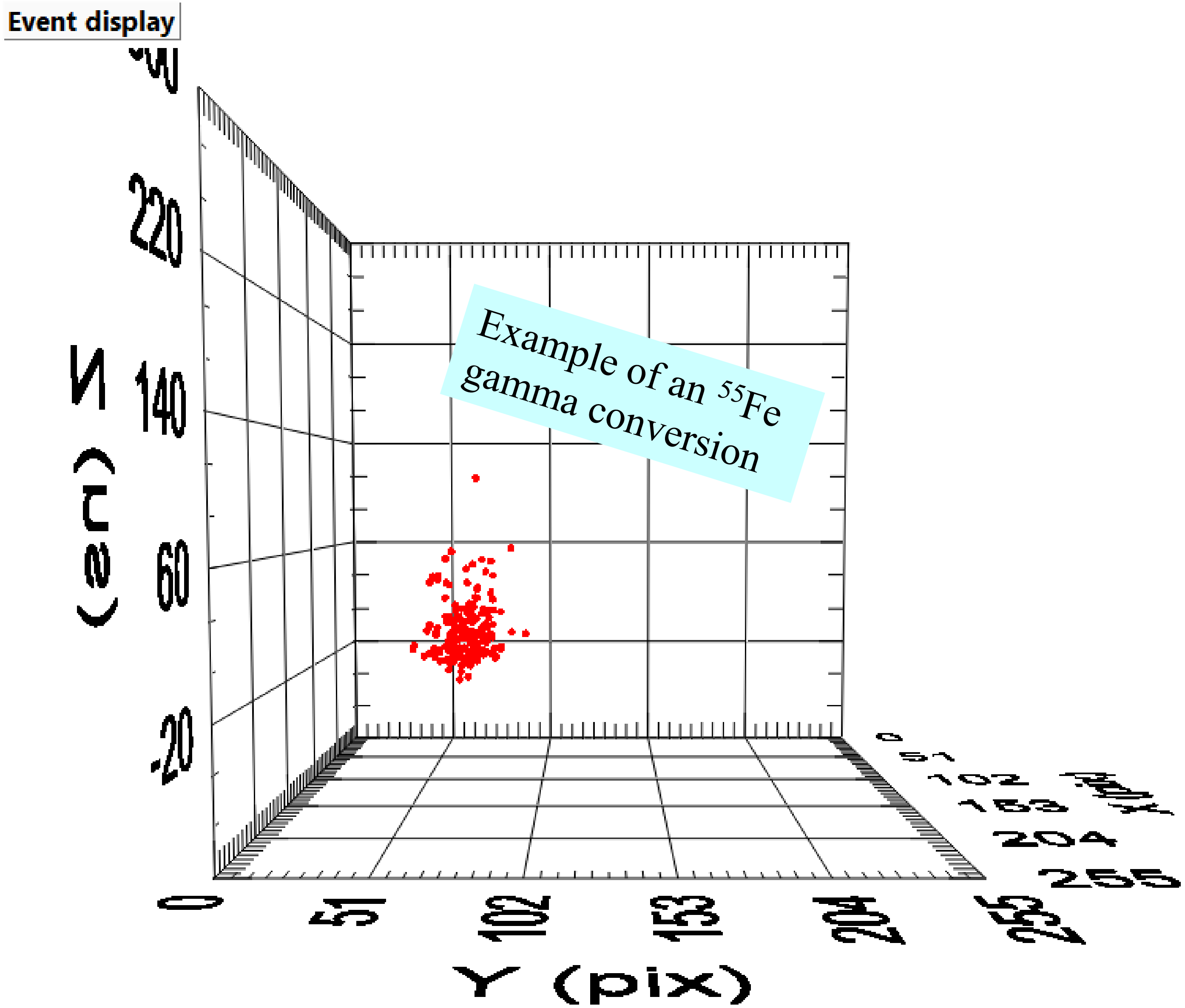
LC-TPC Collaboration Meeting

January 14, 2020

False hits when using T2K gas

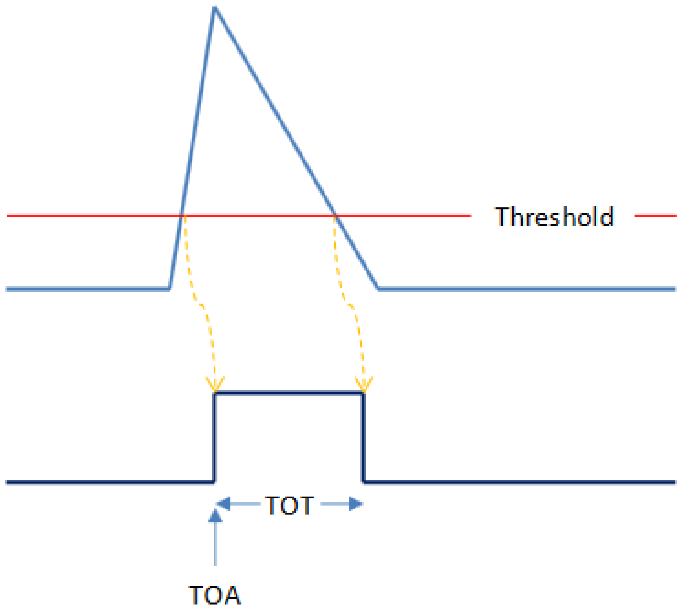
Efficiency measurements using ^{55}Fe irradiation

- The 5.9 keV quanta of the ^{55}Fe source liberate clusters of about 225 e^- in an argon based gas mixture
- The high granularity of the GridPix technology enables 3D reconstruction of all individual electrons
- So the single electron detection efficiency can be simply measured by counting the hits from the gamma conversion
  - In principle a minor correction should be made because of pileup

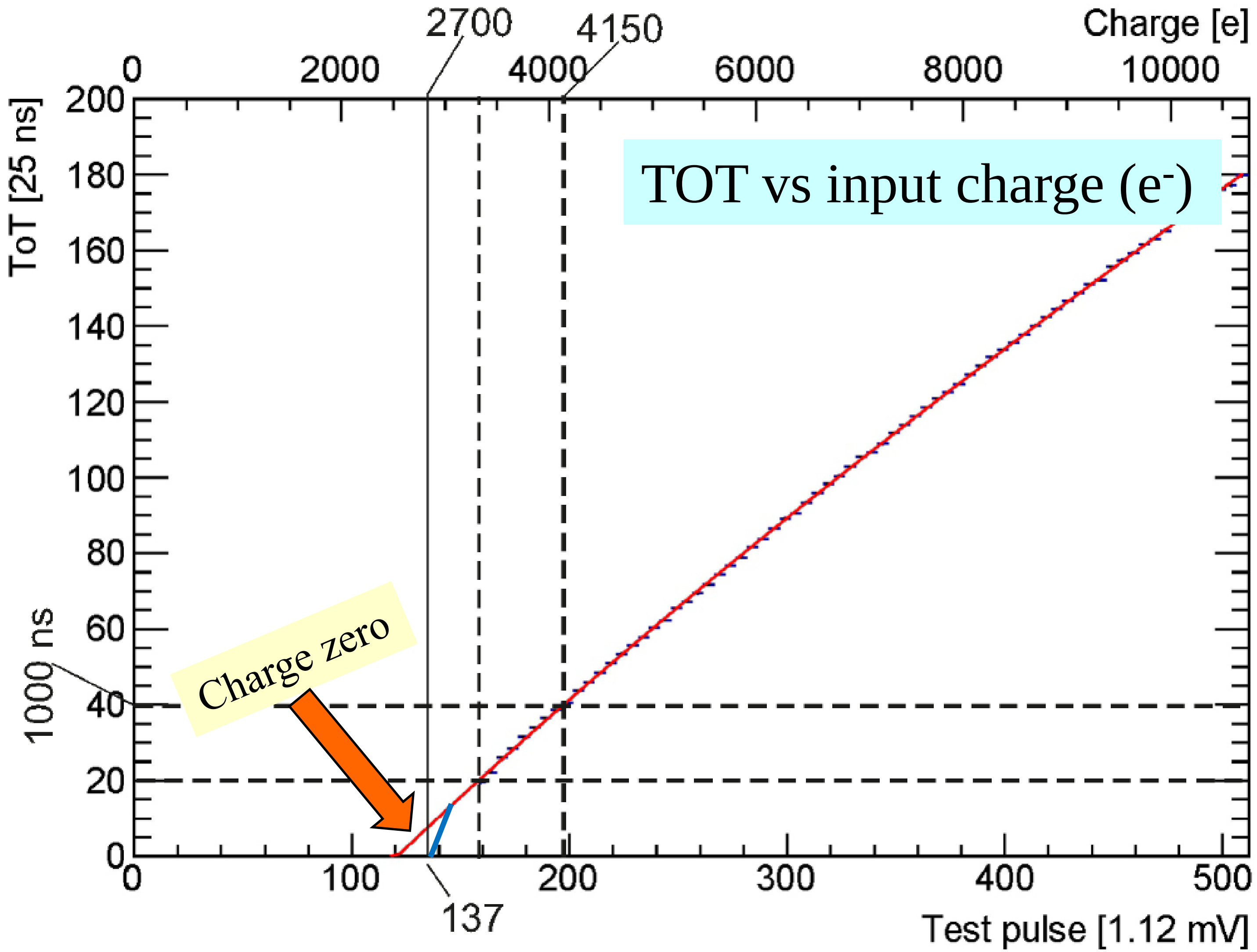


The two parameters measured by TimePix3

- **Time Of Arrival (TOA)**
- **Time Over Threshold (TOT)**
  - (Almost) linear relation between charge signal and TOT



- **TOT = 1000 ns ⇔ 1450 e$^-$**

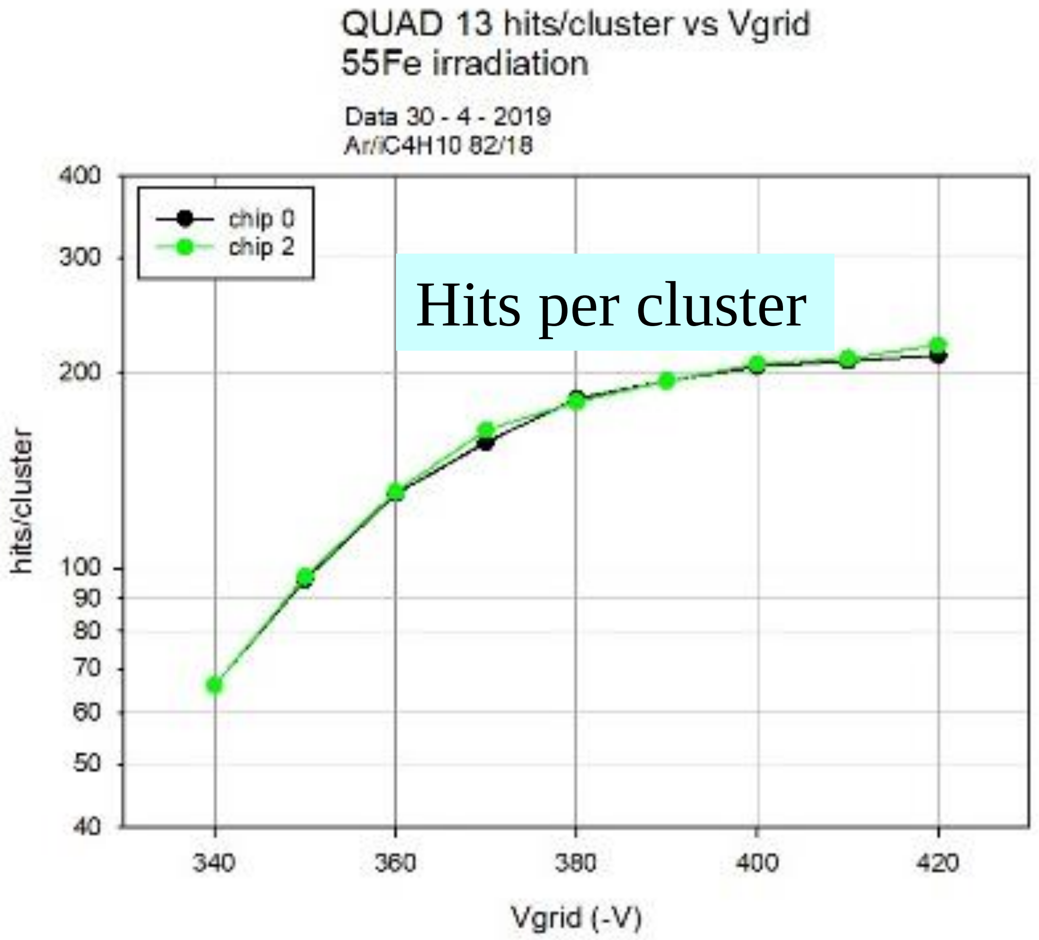


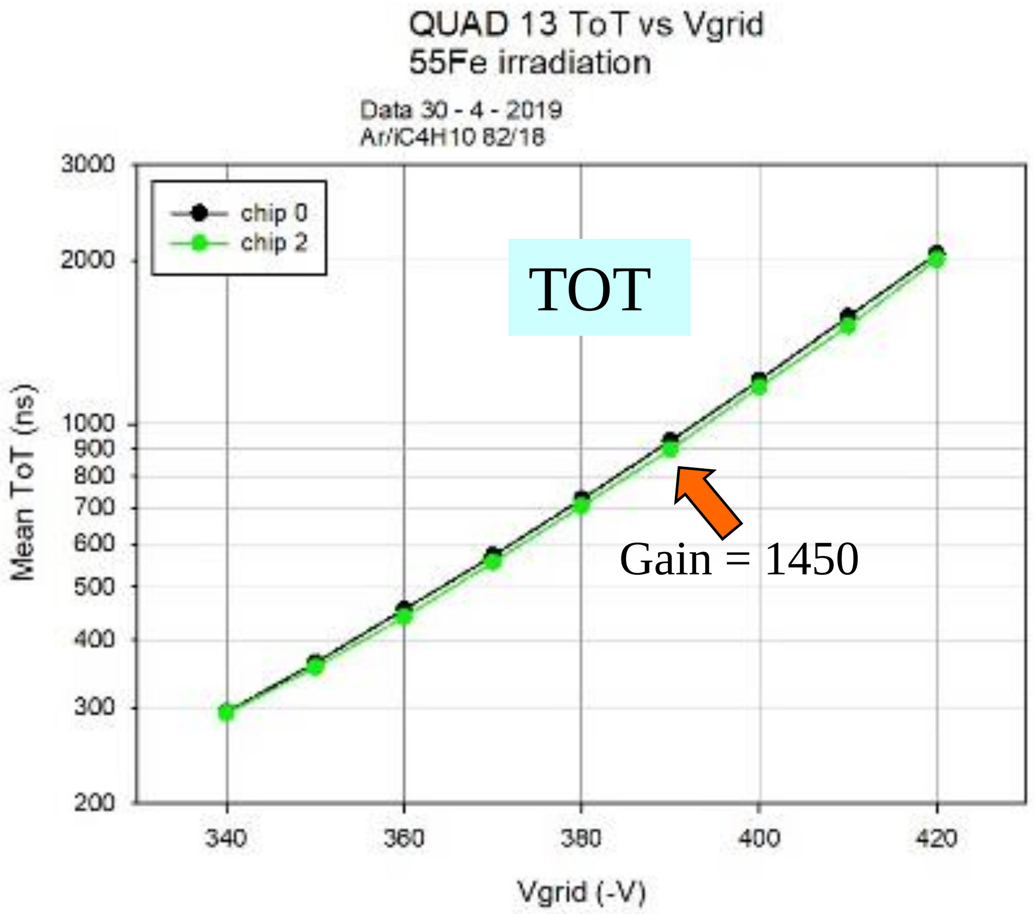
Efficiency calibration by ^{55}Fe irradiation

Ar/iC_4H_{10} 82/18

- Number of hits per cluster approaches a **plateau** at 220 – 230 hits for high gas gain

- The **continued rise of the TOT** (magnitude of the charge signal) curve shows the increasing gas gain
- Example: TOT = 1000 ns => gain = 1450





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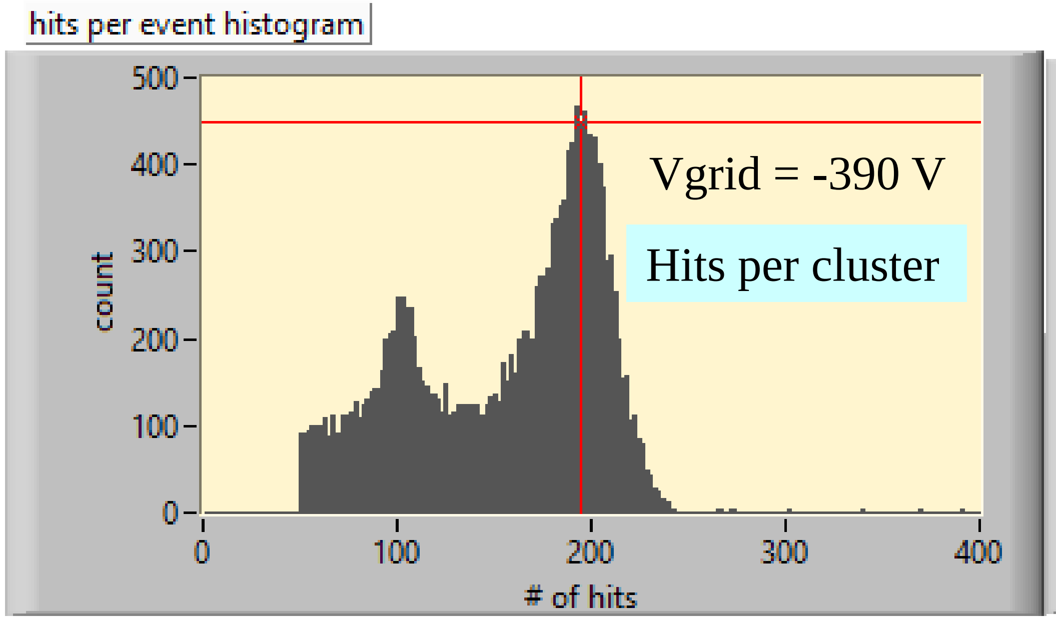
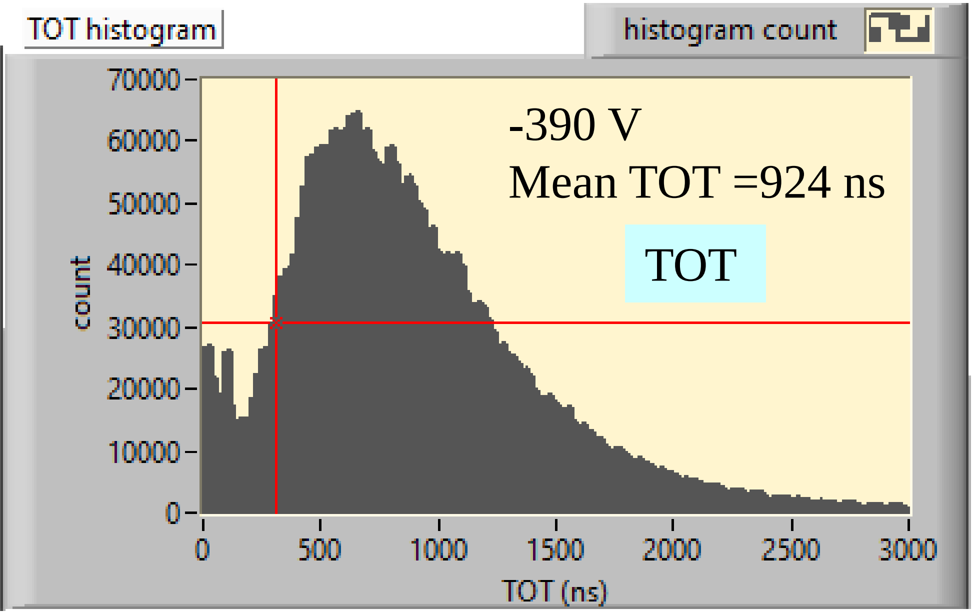
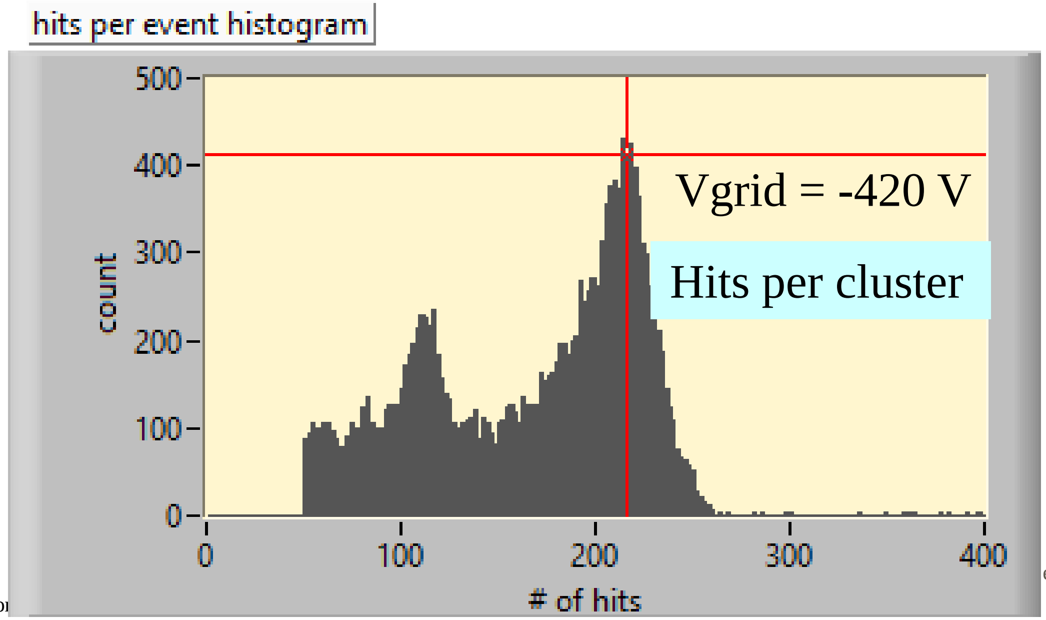
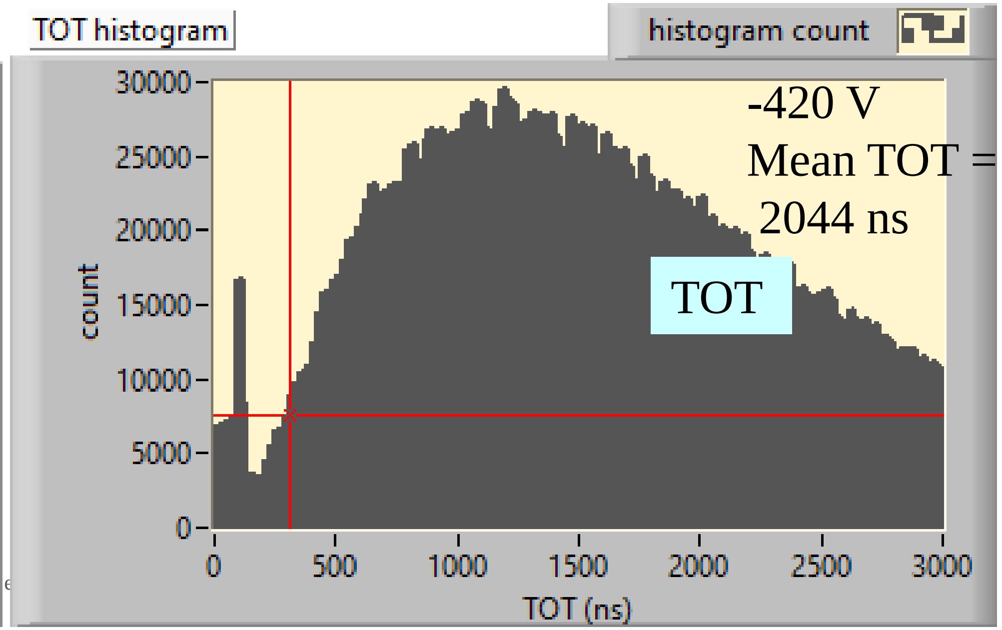
Saturation in ^{55}Fe spectra in hits/cluster, NOT in TOT

Ar/iC_4H_{10} 82/18





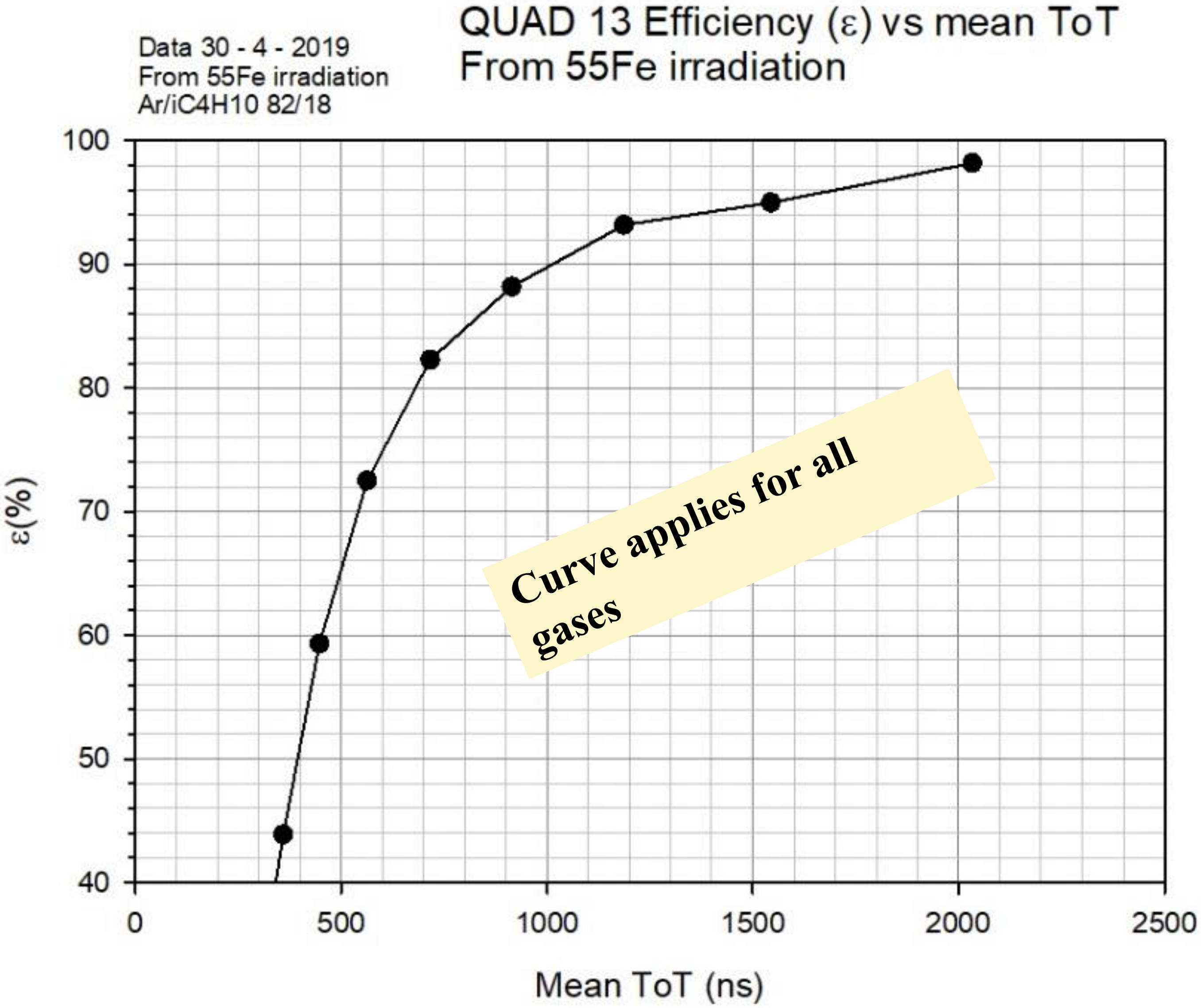




Single electron efficiency vs mean TOT

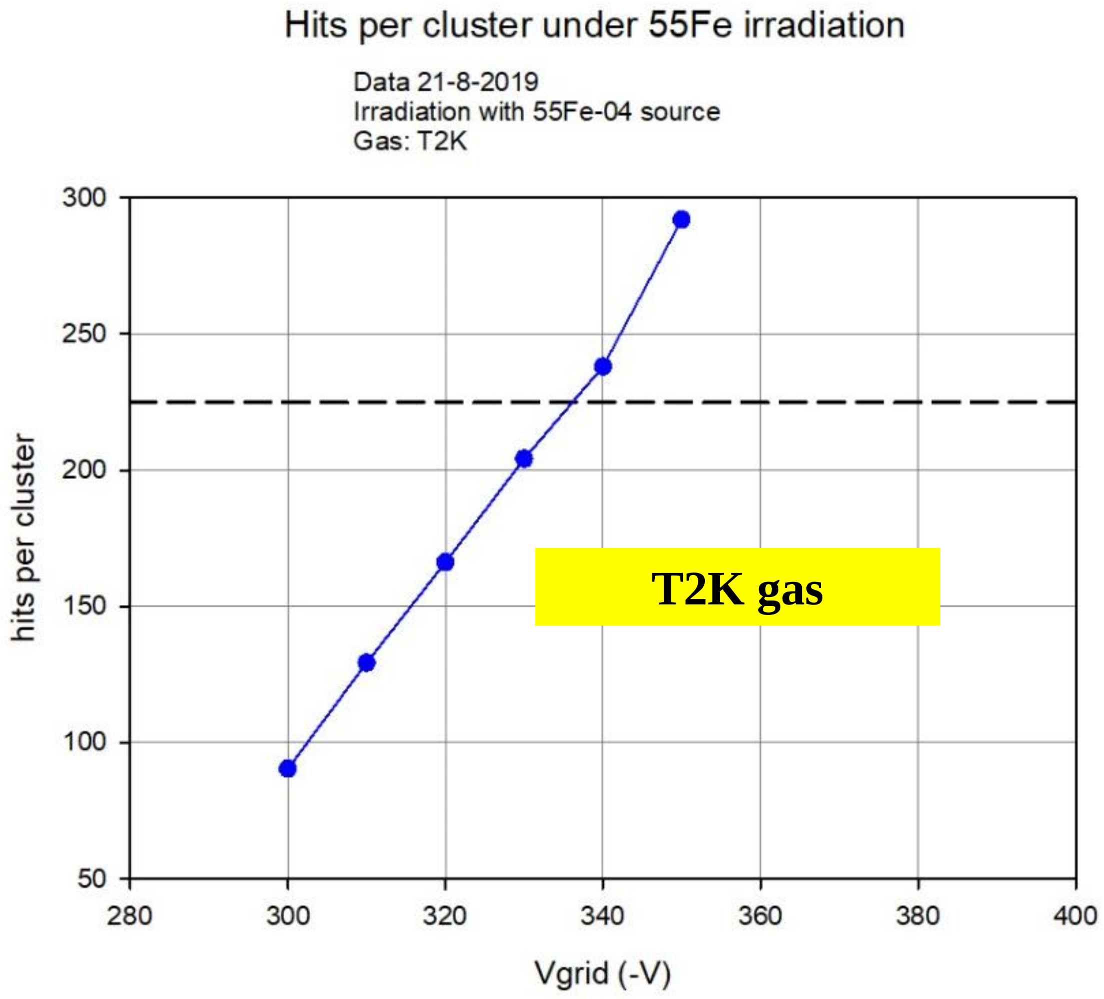
- Assuming 100% SE efficiency ⇔ 225 hits for ^{55}Fe in Ar
  - There may be bit of pileup

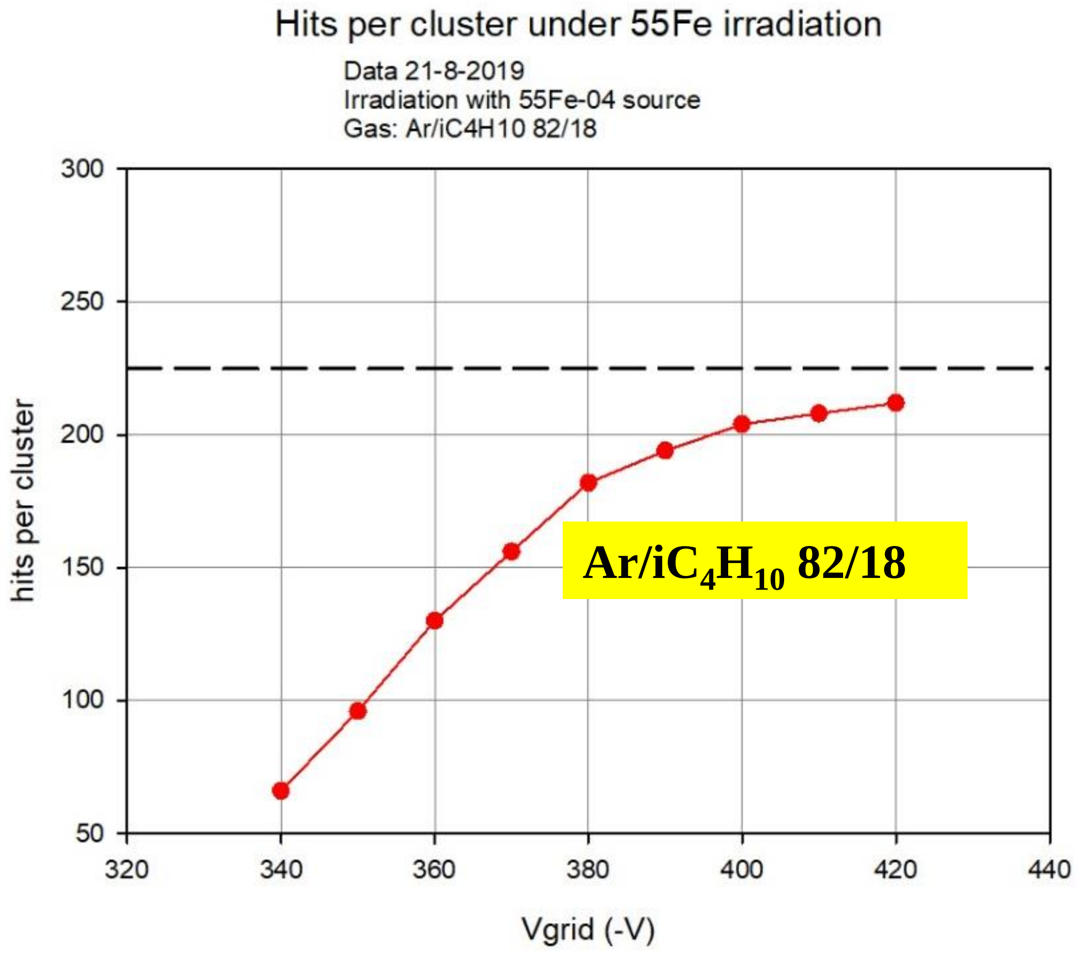
- By looking at the TOT spectrum we have a powerful tool to **predict the SE efficiency**



SE efficiency for T2K

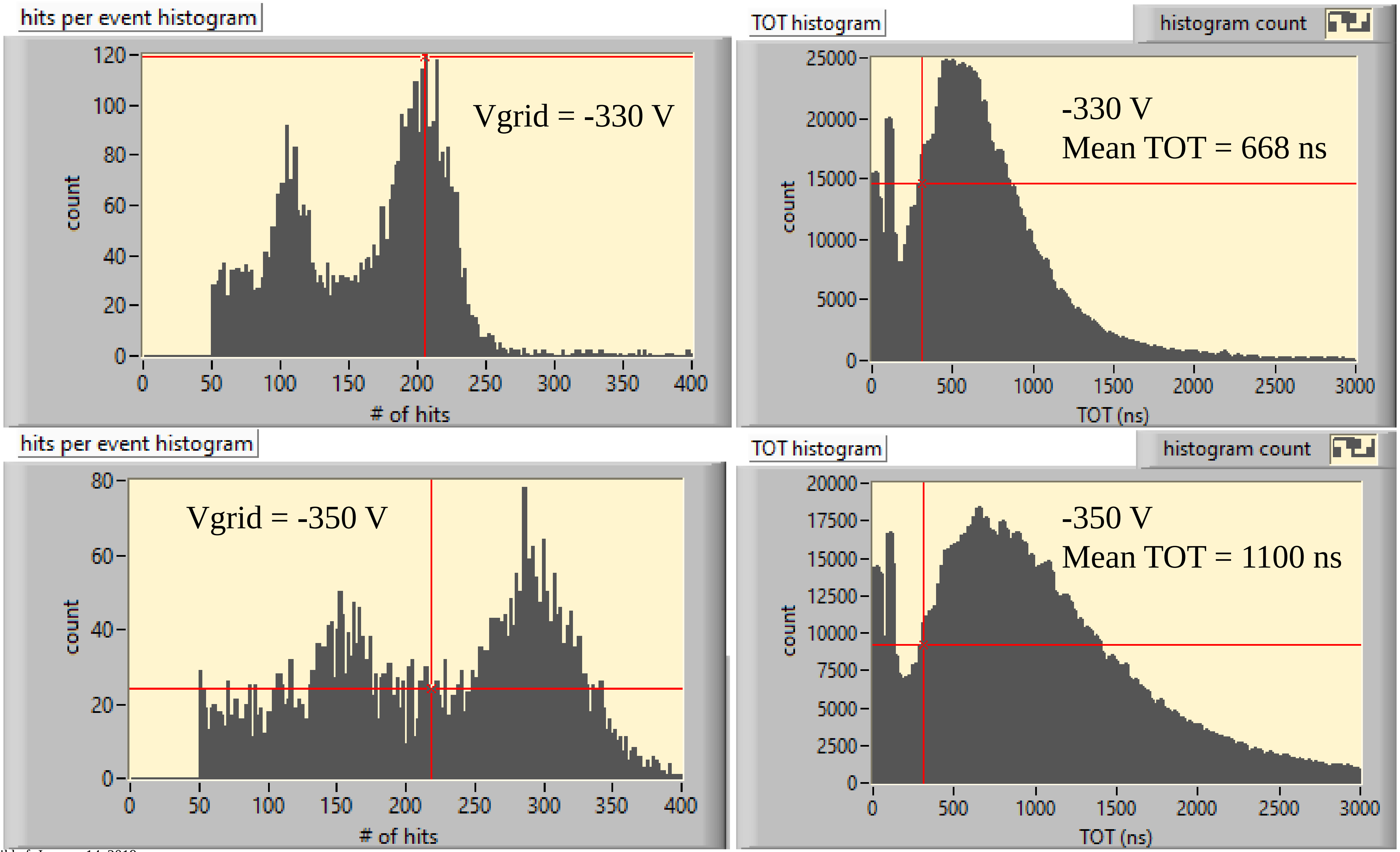
- **NO plateau for T2K gas**
  - Here the number of hits exceeds the number of primary ionization electrons





T2K gas

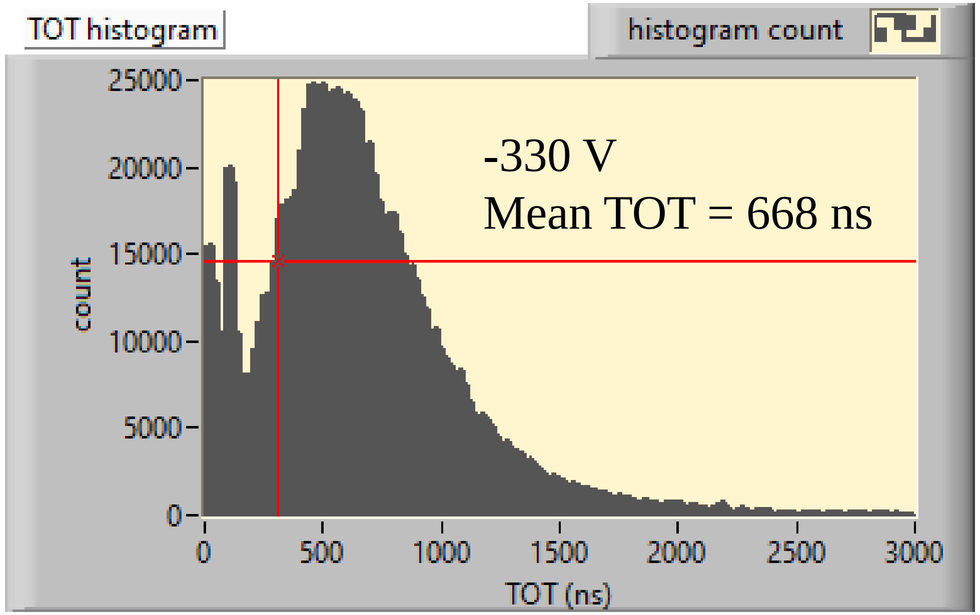
NO saturation in hits/cluster

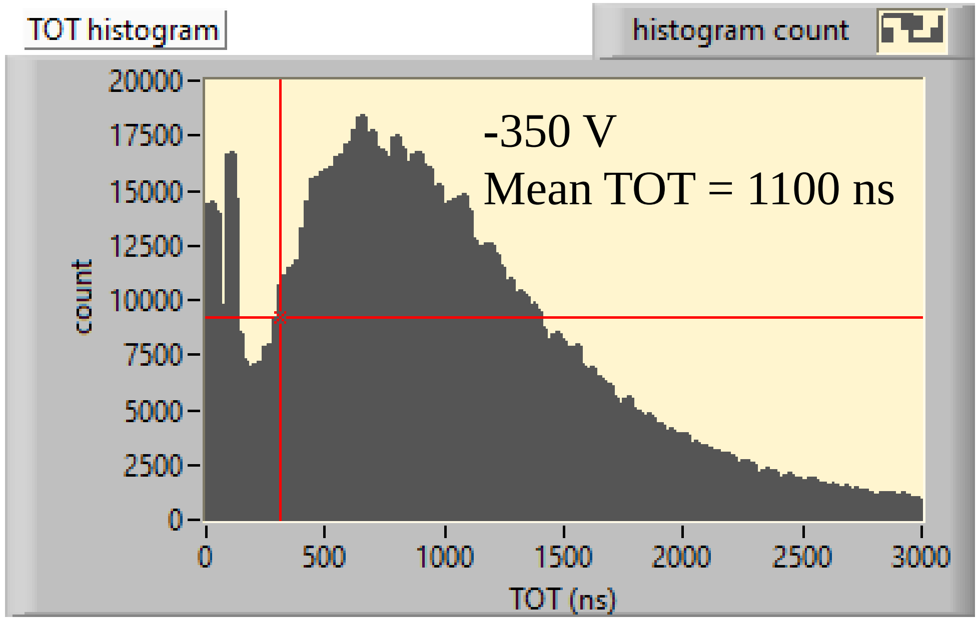


Where do the false hits come from?

T2K gas

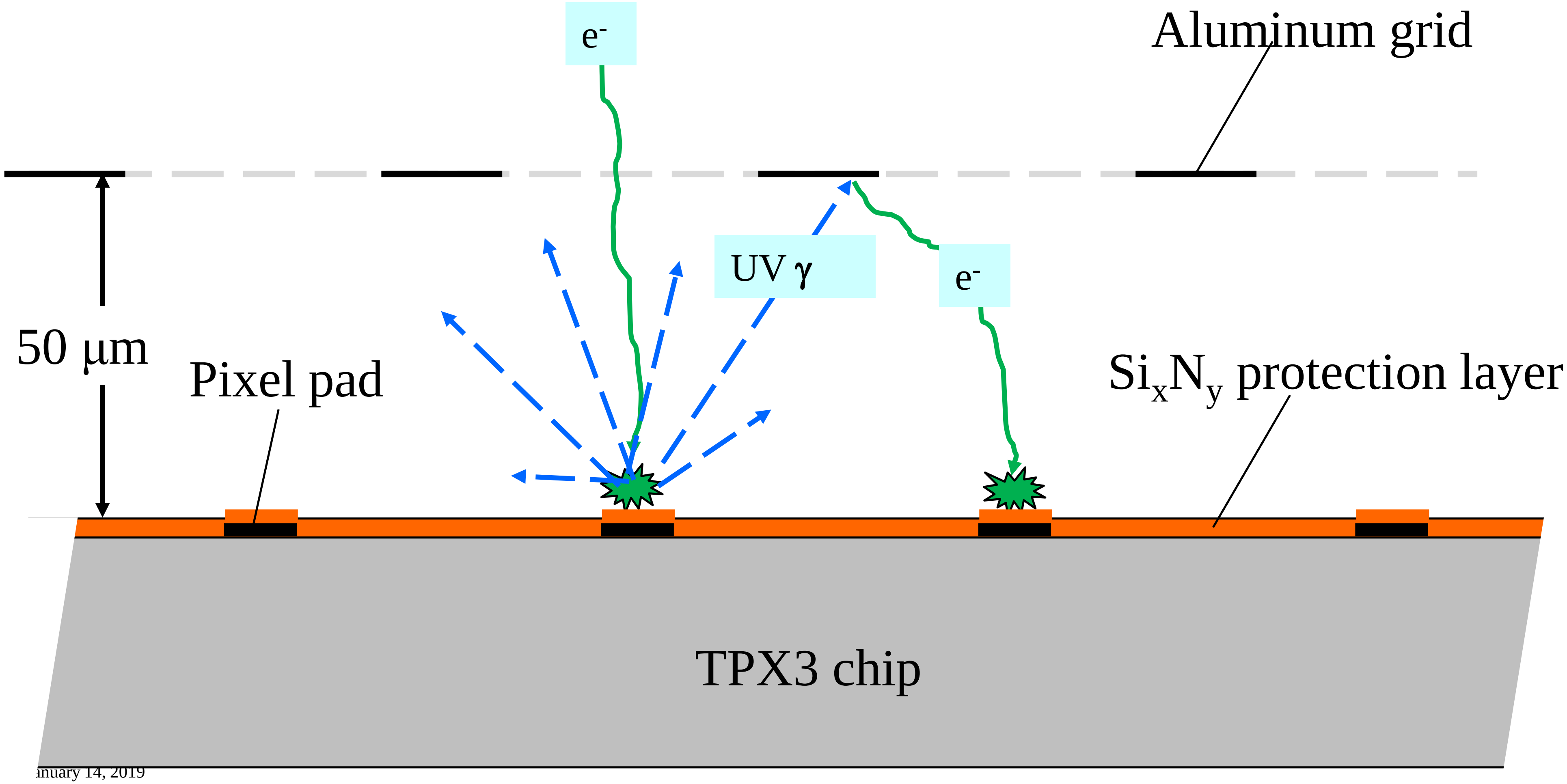
- **Electronic cross talk excluded**
  - We do not see a large increase of small signals in the TOT spectrum at elevated gas gain, the shape remains the same
  - We do not have false hits with the 18% iC_4H_{10} mixture
- Most likely: **secondary emission,** provoked by UV quanta from the avalanche
  - Test with good quenching gases (> 10% iC_4H_{10}) does NOT show false hits
  - T3K gas (3% instead of 2% iC_4H_{10}) reduces the amount of false hits by a factor of 2





Secondary emission

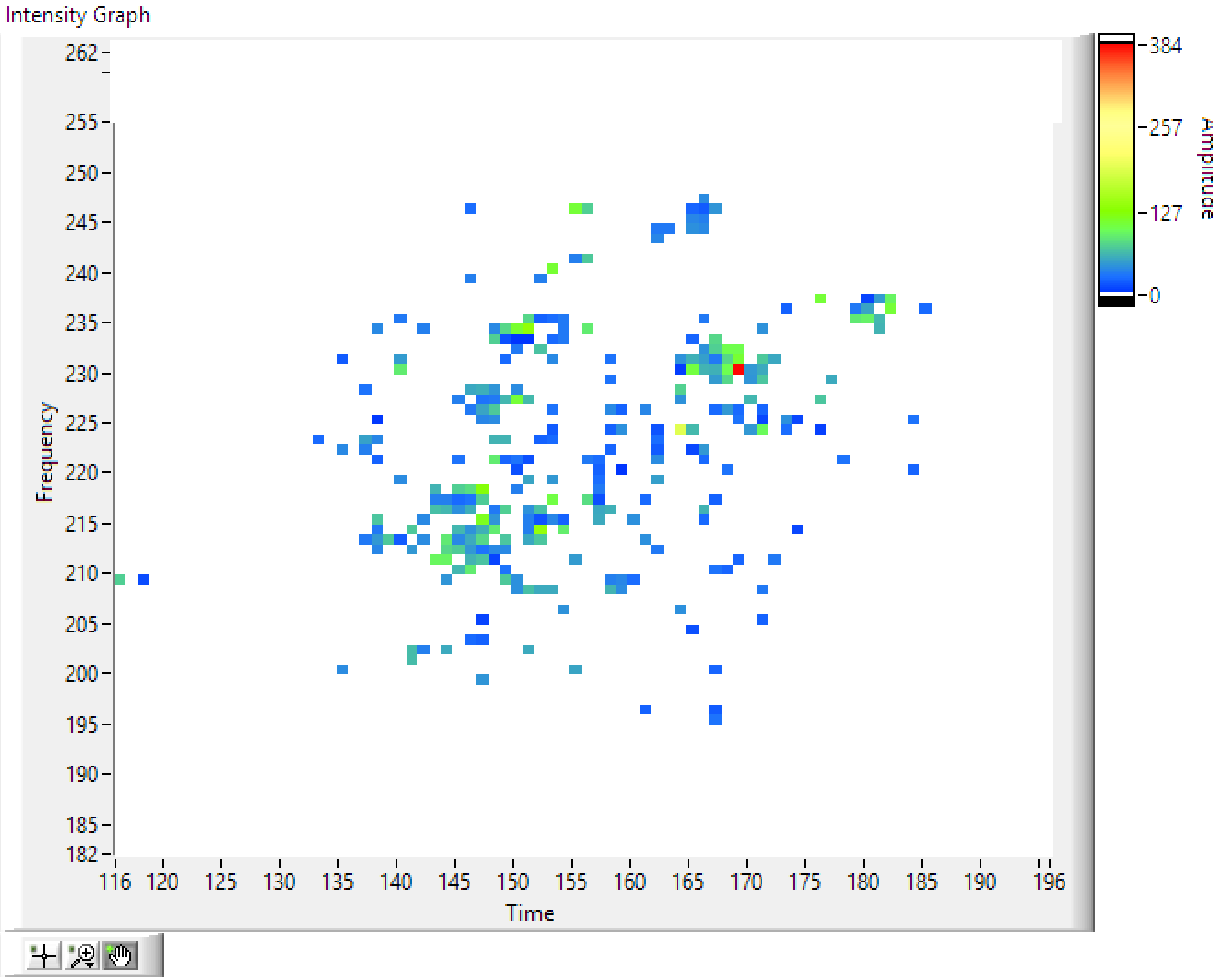
- UV photons are emitted by the avalanche
- They may occasionally liberate an electron from the negatively charged aluminum grid
- Higher quencher concentration reduces the effect



Example of an event with much secondary emission

- False hits are not randomly distributed but have a tendency of clustering around the primary hits

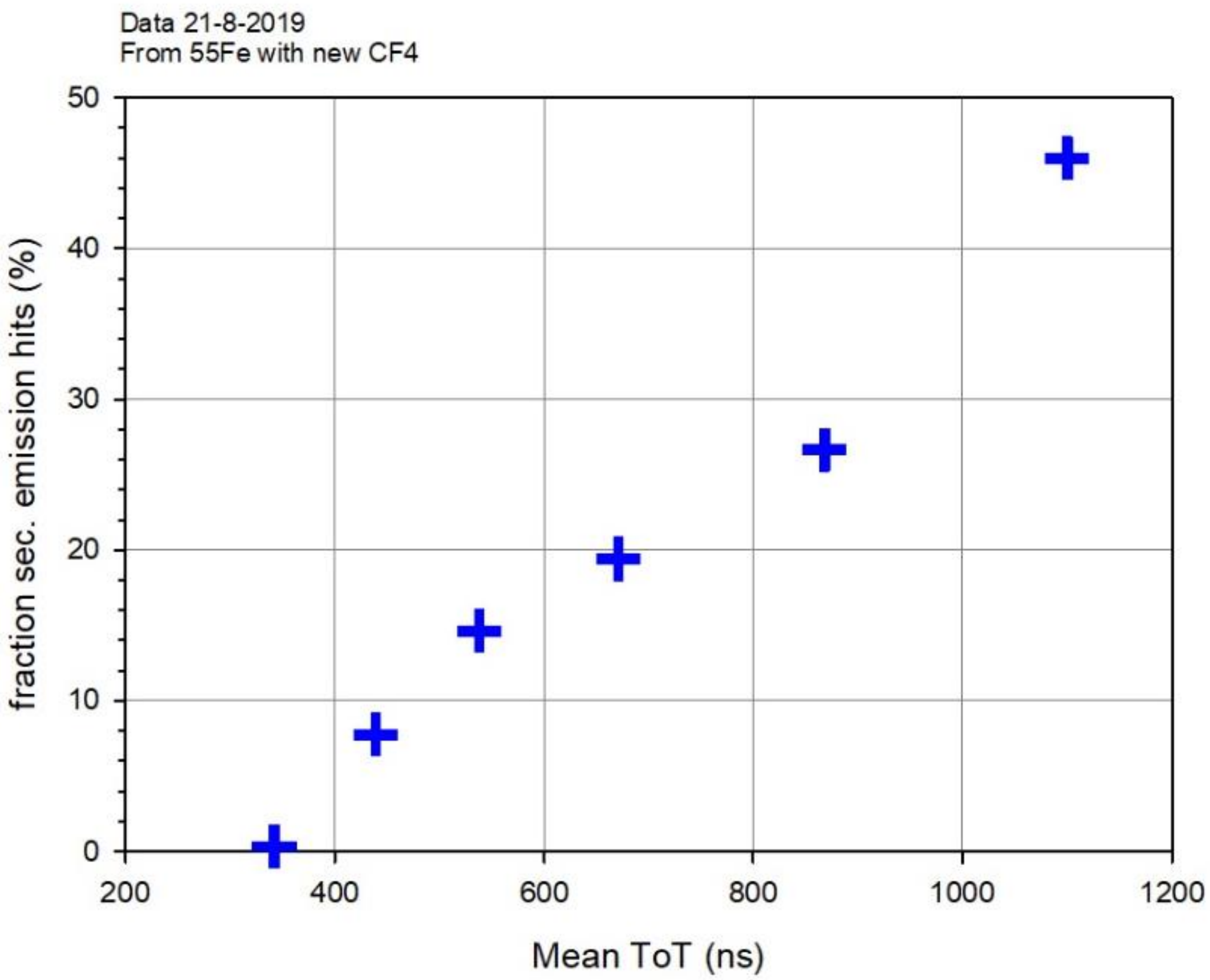
- => they have a small effect or not at all on the position resolution



Secondary emission

- Calculated by subtracting for each TOT value the number of expected hits from the measured number of hits
- Expected to be more or less proportional to the size of the avalanche
- But for higher grid voltages the work function of the aluminum grid is reduced => more false hits

Secondary emission fraction vs mean ToT for T2K gas
From 55Fe irradiation

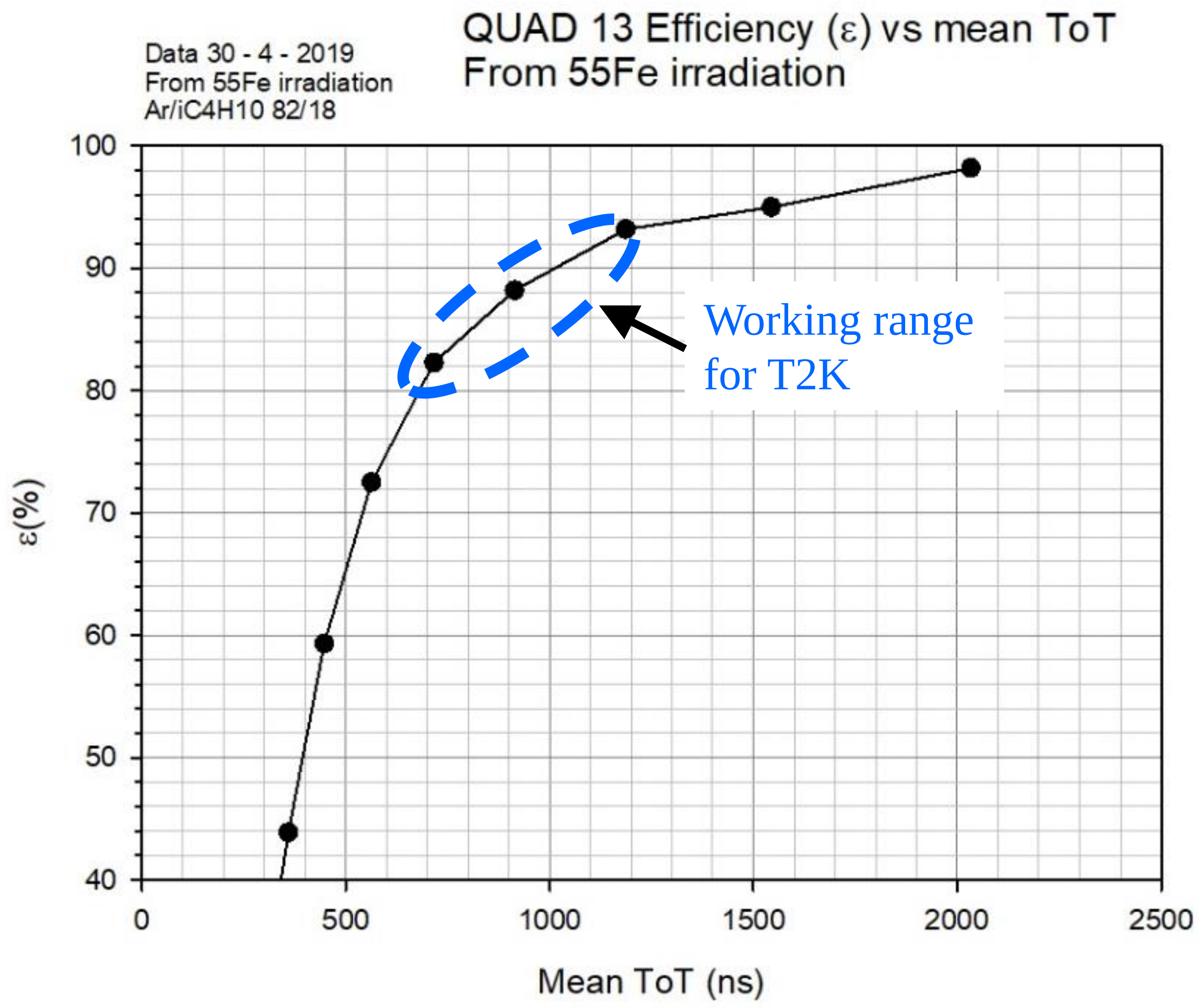


Working range for T2K gas

- We use two constraints:
  - Keep **SE efficiency ≥ 80%**
  - Keep **Secondary emission ≤ 50%**

- The secondary emission limits the working range to **700 ≤ TOT ≤ 1200 ns**

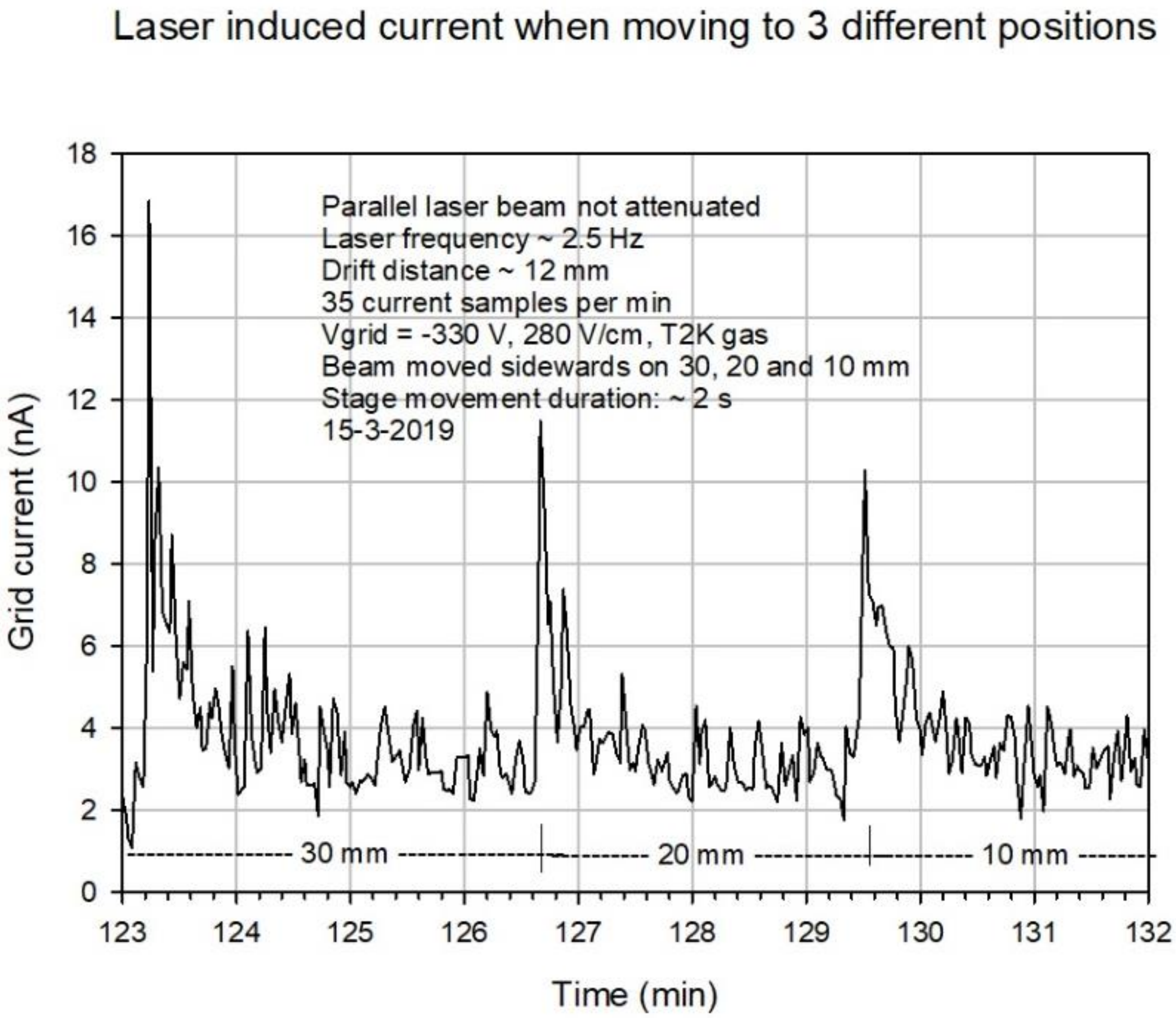
- **So for the gas gain we have a range of only +/- 25%**



Loss of gain due to potential difference across protection layer

Rapid decay of gain after high rate irradiation

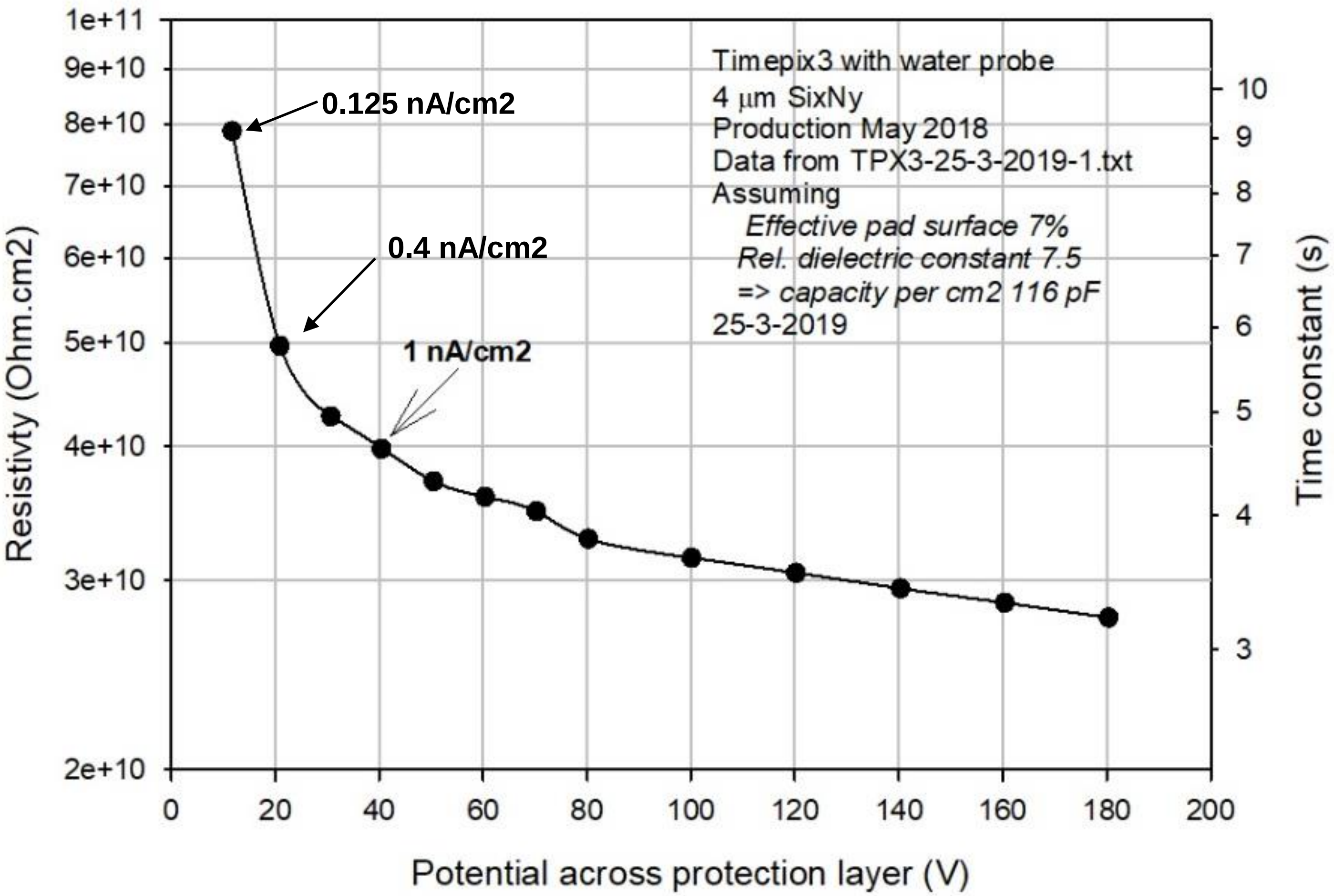
- Test with beam of a pulsed UV nitrogen laser at 337 nm
  - Not attenuated => **high ionization level**
- Three different beam positions, 10 mm apart
- Detection area covered by beam ionization cloud: ~ 1 cm^2
- Every time we move the laser beam to a new position above the grid, the initial induced grid current is 10-15 nA
- But within 1 min the current falls down to 3 nA



Caused by buildup of static potential across the protection layer

- Potential difference across the **4 µm thick** protection layer causes a reduction of the amplification field => drop of gain
  - 10V => gain drop of 1.36
  - 20V => gain drop of 1.8
  - 40V => gain drop of 3
- Resistivity **dependent on the potential** (Poole-Frenkel effect)
- Resistivity very high for potentials < 20 V
- Converting to physical units
  - Volume resistivity: 1 $Ohm.cm^2$ ⇔ ~200 Ohm.cm
  - Electric field: 1V ⇔ 2500 V/cm

Measured resistivity THROUGH the protection layer of the TPX3 chip



Summary

- **False hits** have been observed using T2K gas ($Ar/CF_4/iC_4H_{10}$ 95/3/2), strongly depending on the gas gain
- Presently we define the acceptable operating region as
  - A minimum **SE efficiency of 80%**
  - A maximum fraction of **false hits of 50%**
  - **=> 700 < TOT <1200 ns => gain tolerance +/- 25%**
- Experiments suggest the source of the false hits being **secondary emission**, an indication that the T2K gas is not sufficiently quenched for the present GridPix technology

- The false hit phenomenon can be reduced/cancelled by
  - Choosing another grid metal than aluminum or covering it with another metal (copper, chrome, titanium, gold…)
  - Using a better quenching gas mixture
  - (Increasing the amplification gap)

- **Decrease of gain** has been observed at a high ionization rate due to potential drop across the Si_xN_y protection layer
  - Acceptable grid current (potential drop between 10 and 20V) $\leq$ 0.2 nA/cm^2 => **6.6 kHz/cm^2 for mips**
- The effect can be reduced to a low value by decreasing the resistivity of the Si_xN_y layer
  - Factor of 25 lower resistivity has been demonstrated (Violeta Prodanovic, EKL Delft University, 2016)
  - Investigation by Yevgen Bilevic (IZM, Bonn) ongoing

Running constraints for present TPX3 chips in T2K gas

- SE efficiency >80%
- Secondary emission < 50%

- **=> 700 < TOT <1200 ns**

- Potential drop across protection layer < 20 V

- => Grid current < 0.2 nA/cm^2

- **=> particle rate for mips < 6.6 kHz/cm^2 across the chip surface**

END

Calculation maximum rate

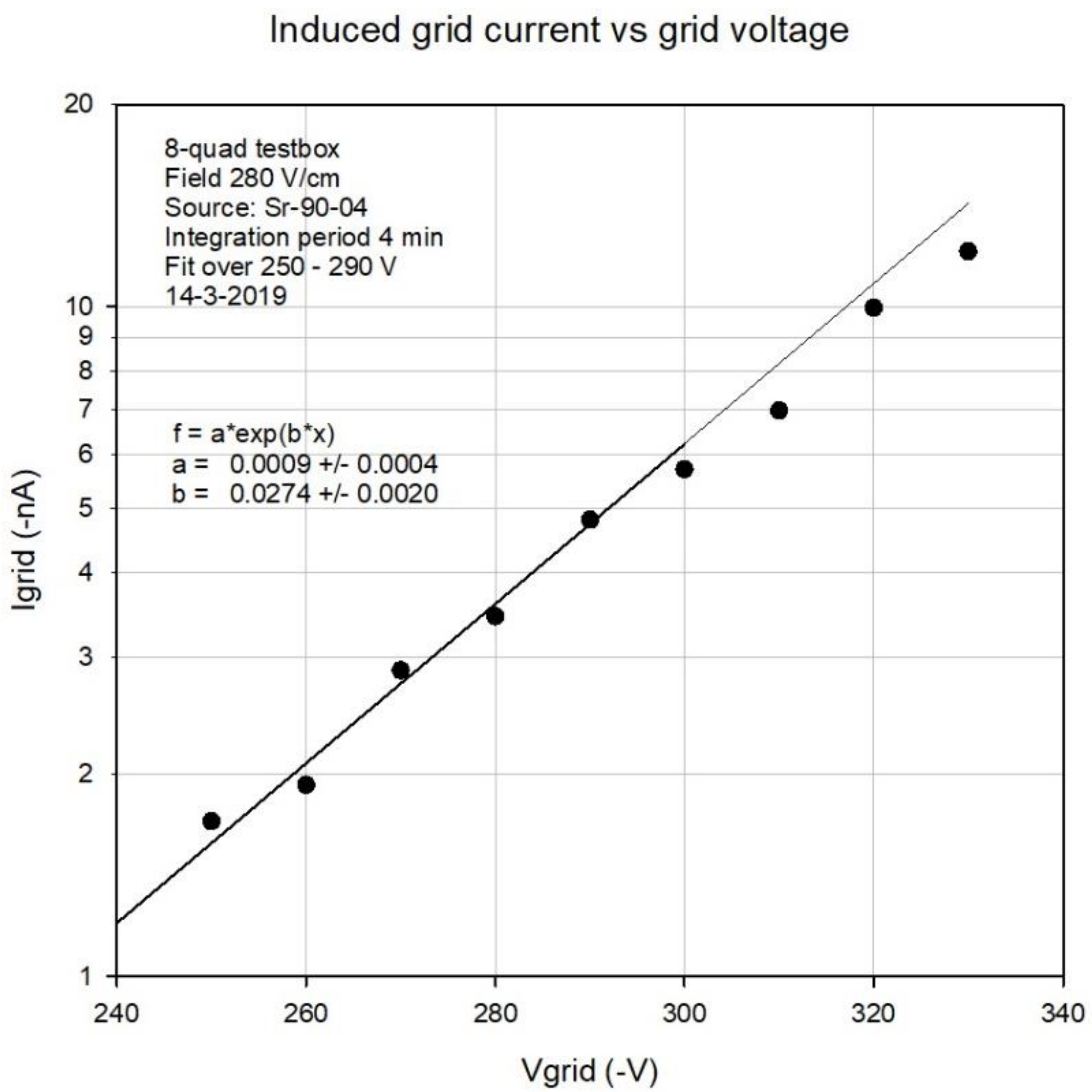
- Take working point at TOT = 1000 ns => gain = 2000
- T2K gas => 0.95 x 94 + 0.03 x 100 + 0.02 x 195 = 96.2 e-/cm

- => 192.4k e-/cm per mip
- => 30 x 10-15 C per cm per mip
- => 1 nA/cm2 => 34 kHz

- Acceptable current: 0.2 nA/cm2 => rate of 6.6 kHz/cm2 for mips

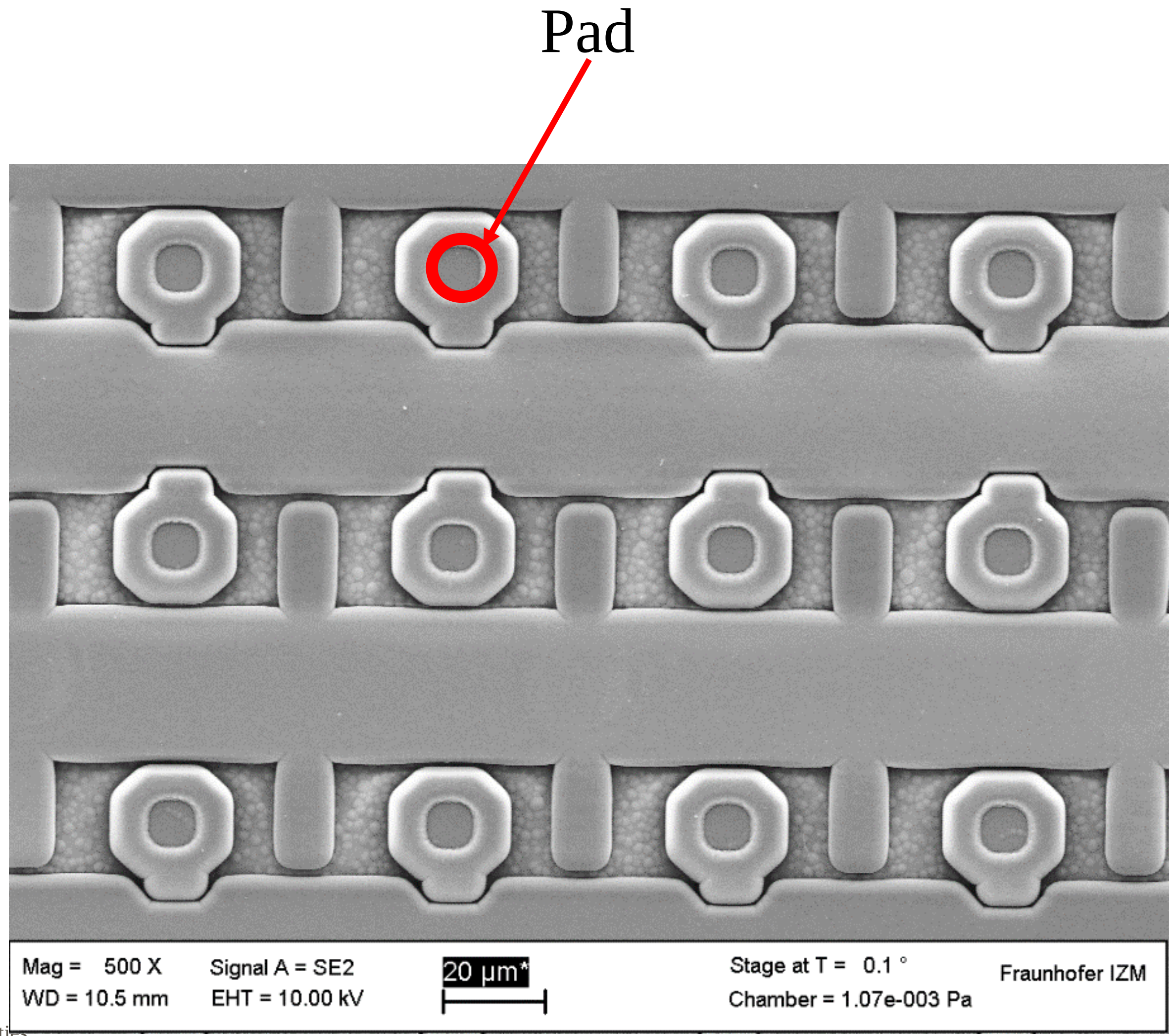
IV curve with source

- Quite small saturation effect
- Some 20 – 40 cm2 covered by source
- 25 V => factor 2 in gain



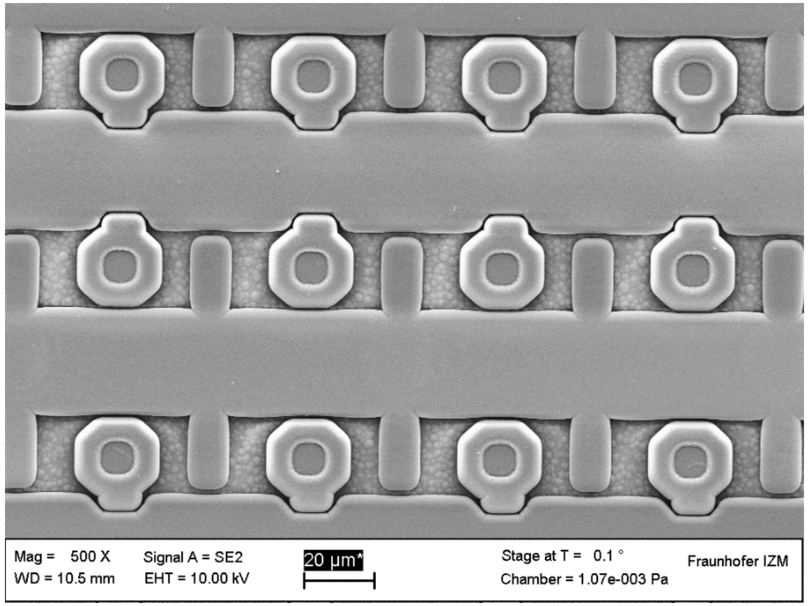
Measured resistivity also affected by small pad size of the TPX3 chip

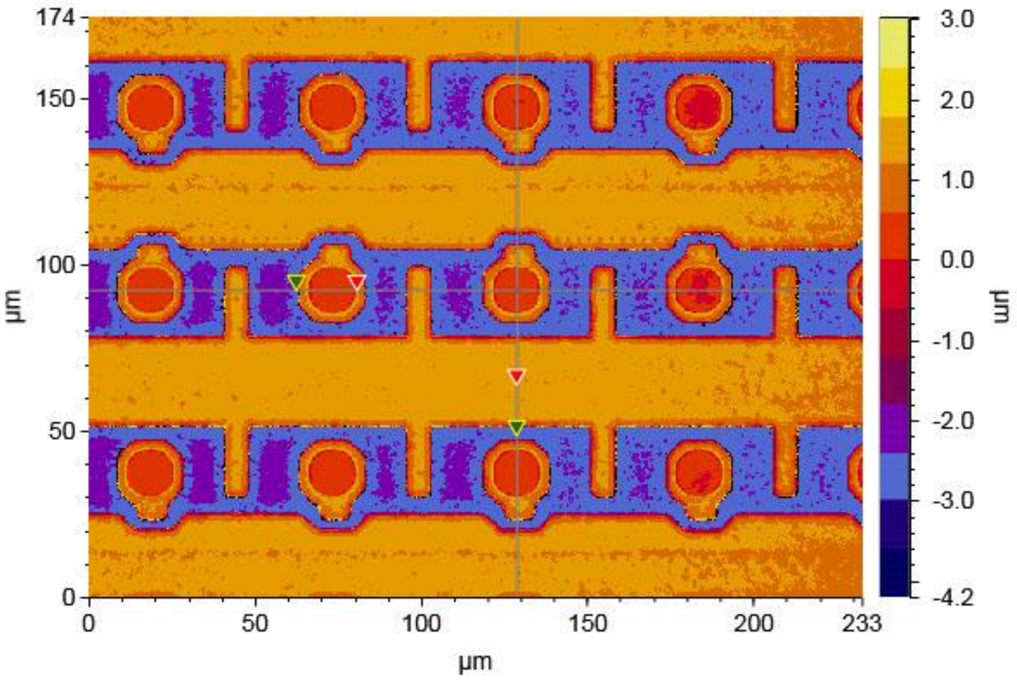
- Pads cover only 5% of the chip surface, the rest is covered by insulator (SiO2?)
- Taking into account the boundary effect => 8% effective pad surface
- Resistance of 4 um thick protection layer ⇔ volume resistivity
  - **1 Ohm.cm2** ⇔ 2500*0.08 = **200 Ohm.cm**



Geometry

- Pads lay in well ~ 3 um under surrounding material
- Pads diam 14 um + ~ 3 um edge => cover ~ 8% of the surface
- Time constants of charging up vary
  - Above pad surface: ~ 120 pF capacity
    - ~ 1 min for ΔV = 10 – 20 V (low rate)
    - 15 s for ΔV = 50 V
    - 4 s for ΔV = 100 V (very high rate)
  - Outside pad surface: ~ 800 pF capacity
    - 5 – 20 min, for less high rates much longer





Test with 90Sr source

- **Vgrid = -330V**

- Saturation value almost doubled (1.91x)
- Time constant ~ 1.9 min

- Potential build up over protection layer
  - Lower field in amplification gap
  - => lower gain