Characterisation of protection layers in pixelised MPGDs

Harry van der Graaf and Fred Hartjes
NIKHEF

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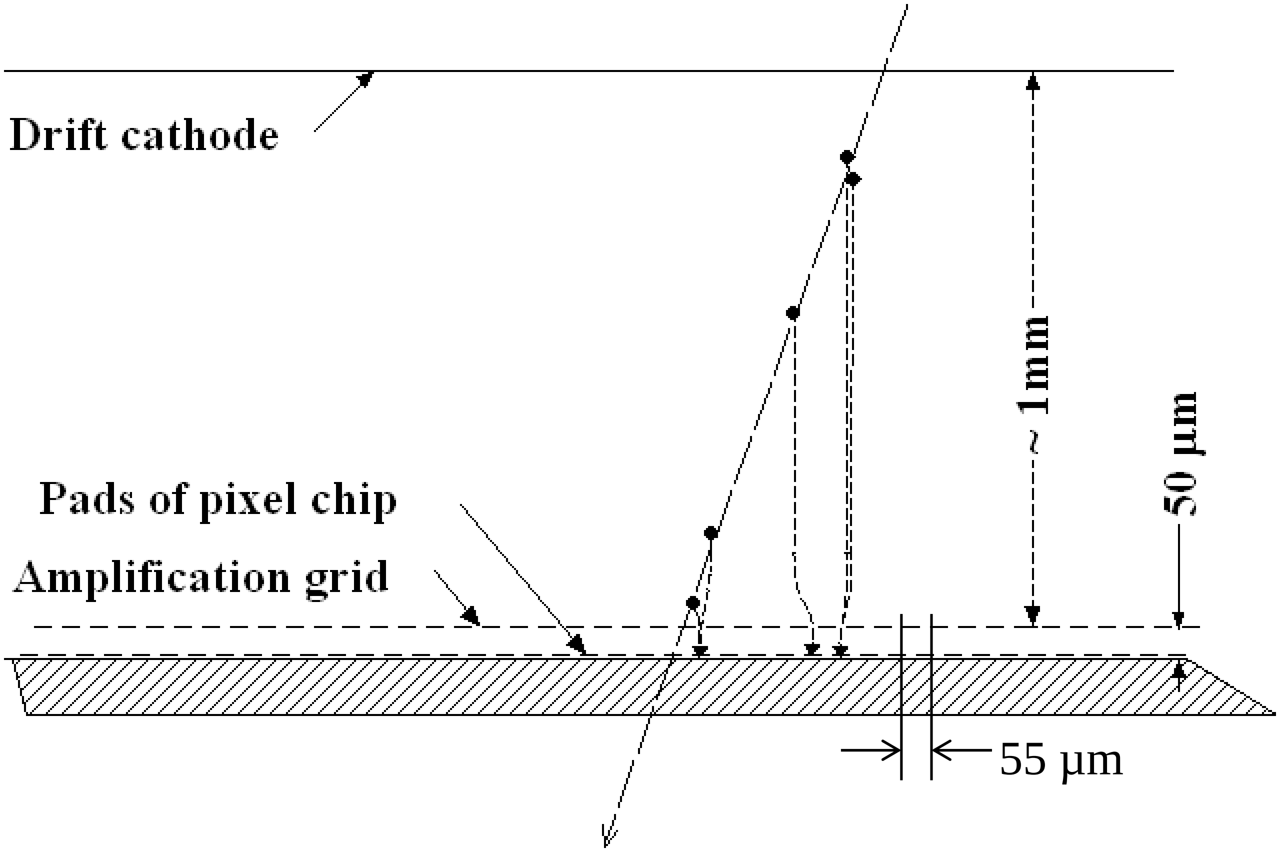
Principle GridPix detector

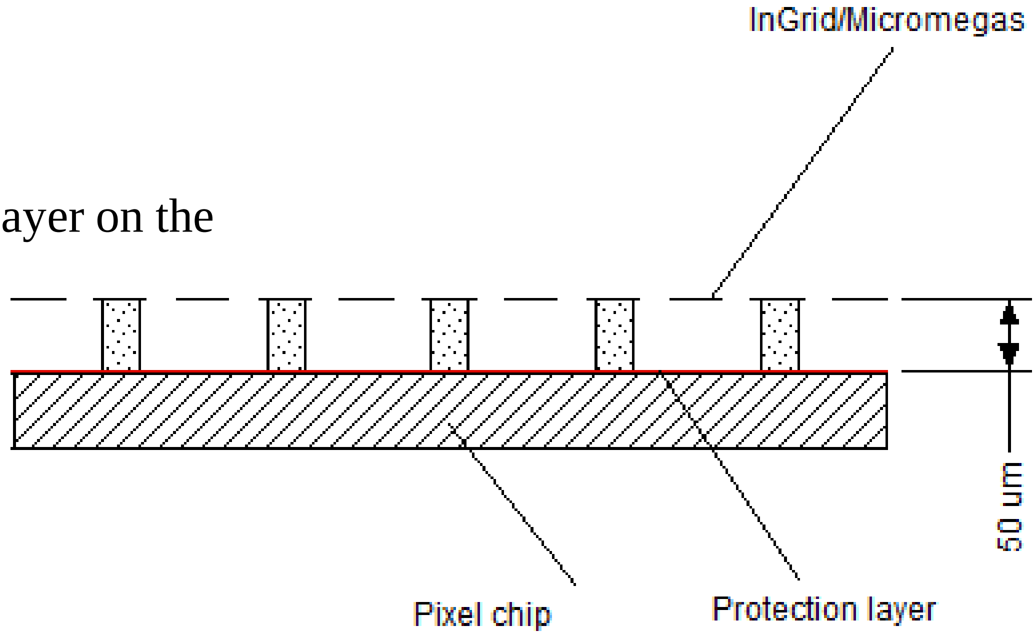
- Amplification grid on pixel chip
- Pixels 55 µm pitch
- Many electrons reconstructed individually



Protection layer in InGrid based pixel detectors

- Protection layer essential to avoid spark damage to the pixel chip
  - Raether limit ≤ 10^8 electrons
  - Reached for G = 5000 at 20k e^- primary ionization (from alfa)

- 4 – 8 um thick insulating layer on the anode (pads of the pixels)
  - Often resistive SixNy

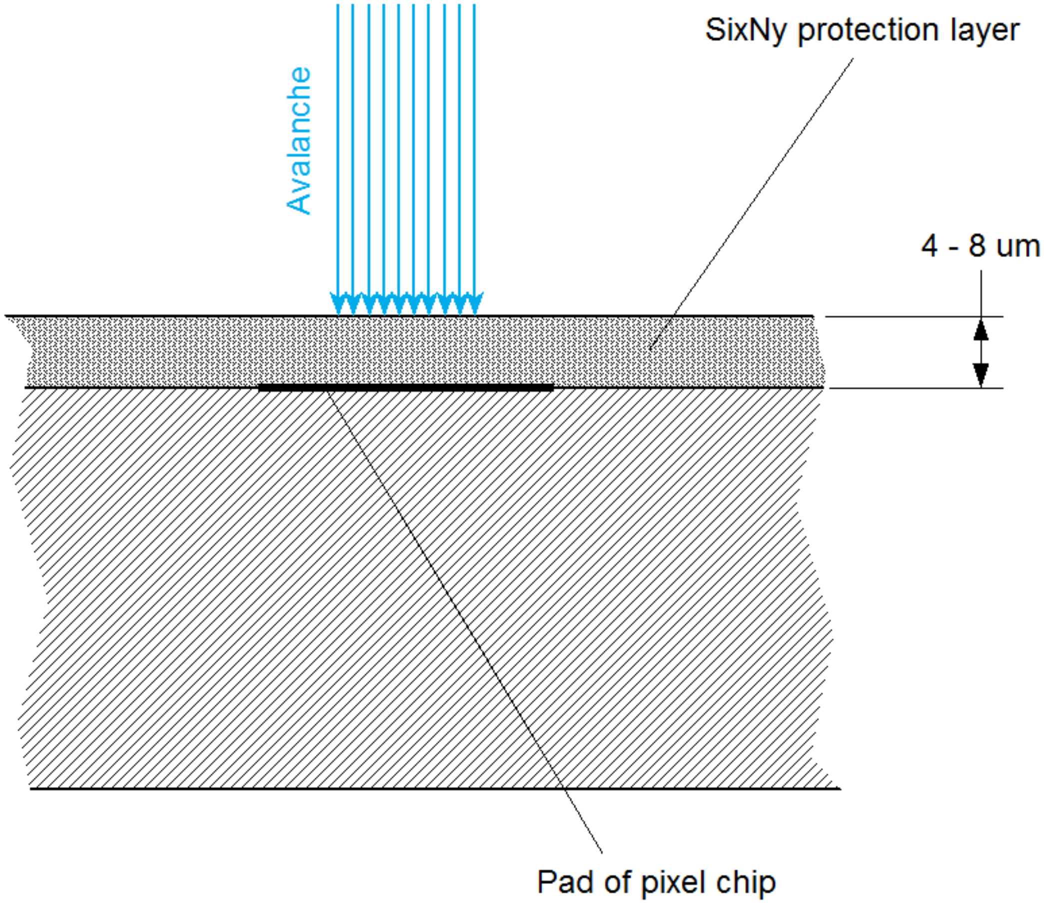


Calculations for 4 µm layer thickness

- For normal operation the charge signal (~1 fC) is induced via the layer capacity (6.6 fF) to the pixel

- At a spark discharge (300 – 600 V) we induce ≤ 2 – 4 pC in the pixel input
  - No damage on electronics
  - The charge of the grid may be distributed across a 2 mm wide surface
  - But mostly the discharge is much earlier quenched

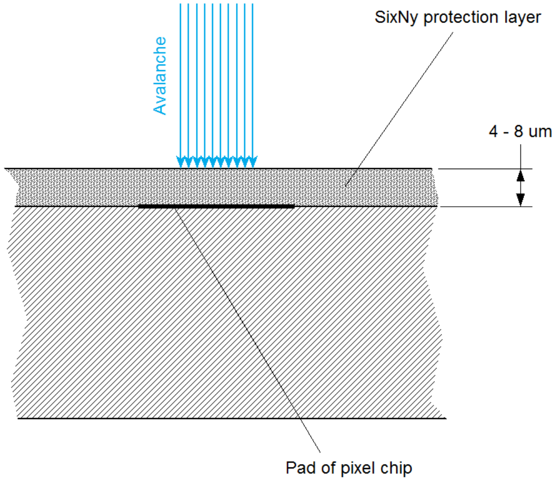
- Without protection layer we would inject 10 – 20 nC into a single pixel
  - => fatal damage



Requirements for the layer resistivity

- The integral of the signal currents creates voltage drop across the layer
  - Reducing the gas gain

- Maximum resistivity dependent on the particle rate and the gas gain



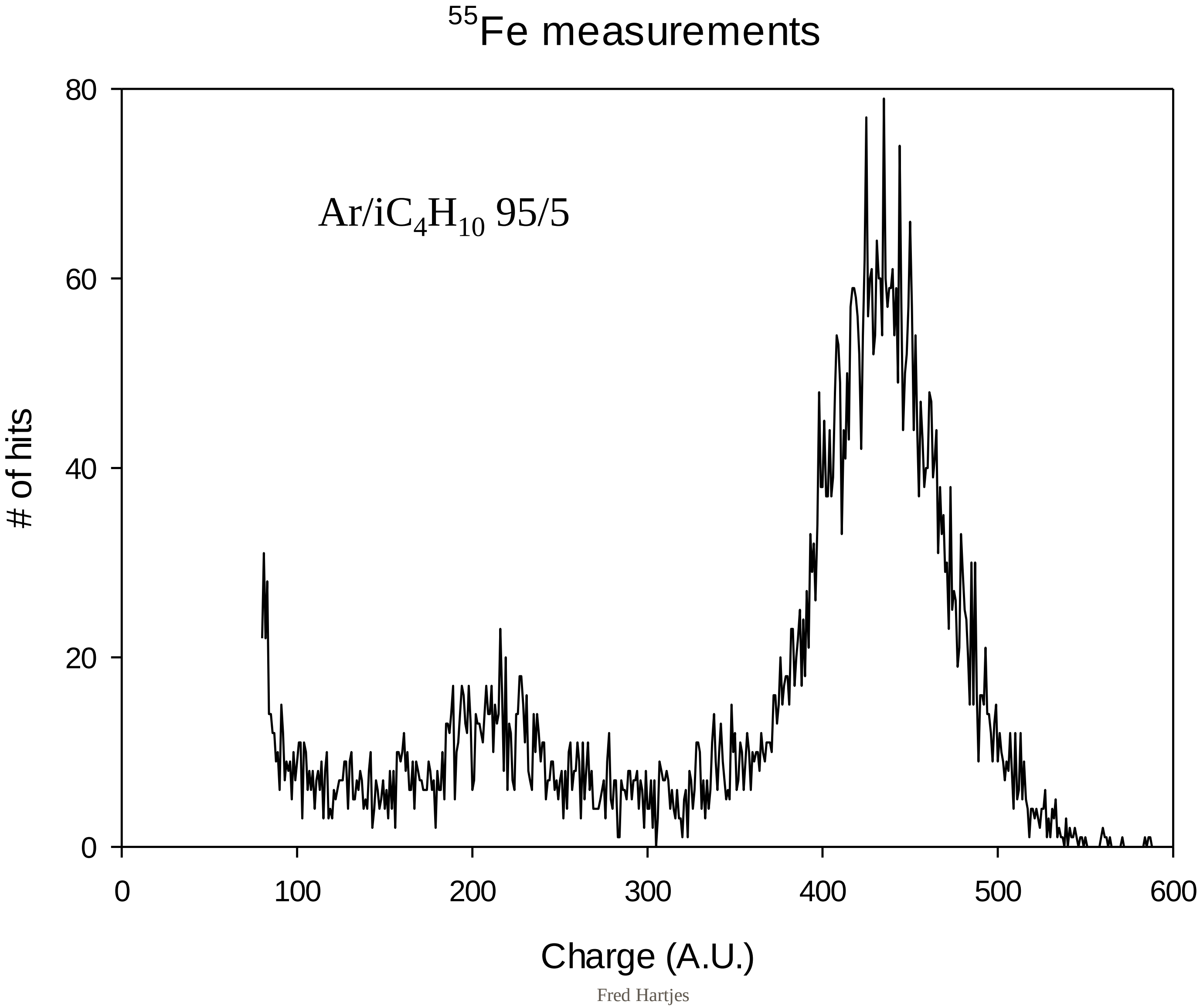
- Lower limit on resistivity is given by
  - Coupling fast signal to neighbouring pixels
  - Affecting the Krummenacher currents

- Example max resistivity
  - Mip rate 0.9 GHz/cm^2
  - Gas gain 5000
  - 126 electron/ion pairs per track
  - Voltage drop across layer: 10 V (gain reduced by 17% for DME/CO$_2$ 50/50)
  - **=> layer resistivity ≤ 1.6 * 10^7 Ω.m**

Maybe minimum value

Gain measurements

Measurements of gas gain using ^{55}Fe source



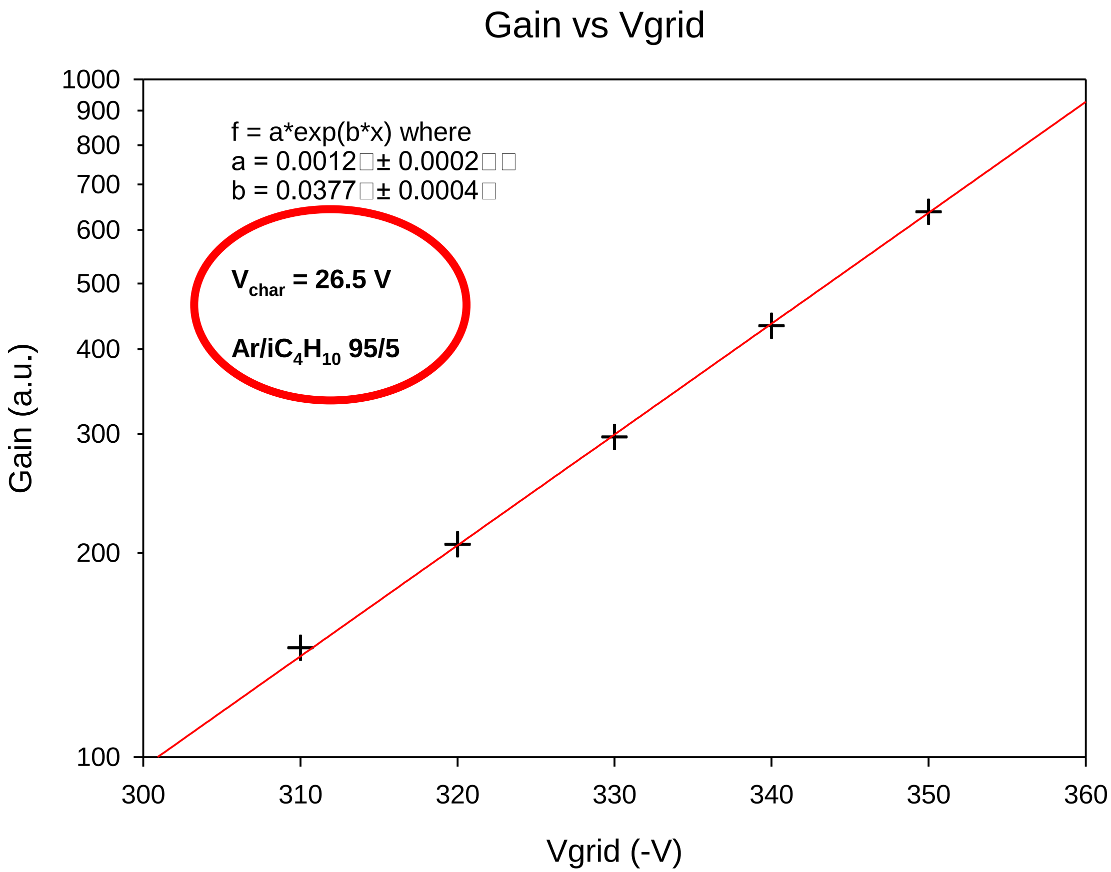
Example of dependence of gas gain on V_{grid}

- Exponential growth with V_{grid}
  - Gain multiplied by **factor e** by increase with $\mathbf{V_{char}}$

$$G = A.e^{\frac{V_{grid}}{V_{char}}}$$

- Where A is a constant

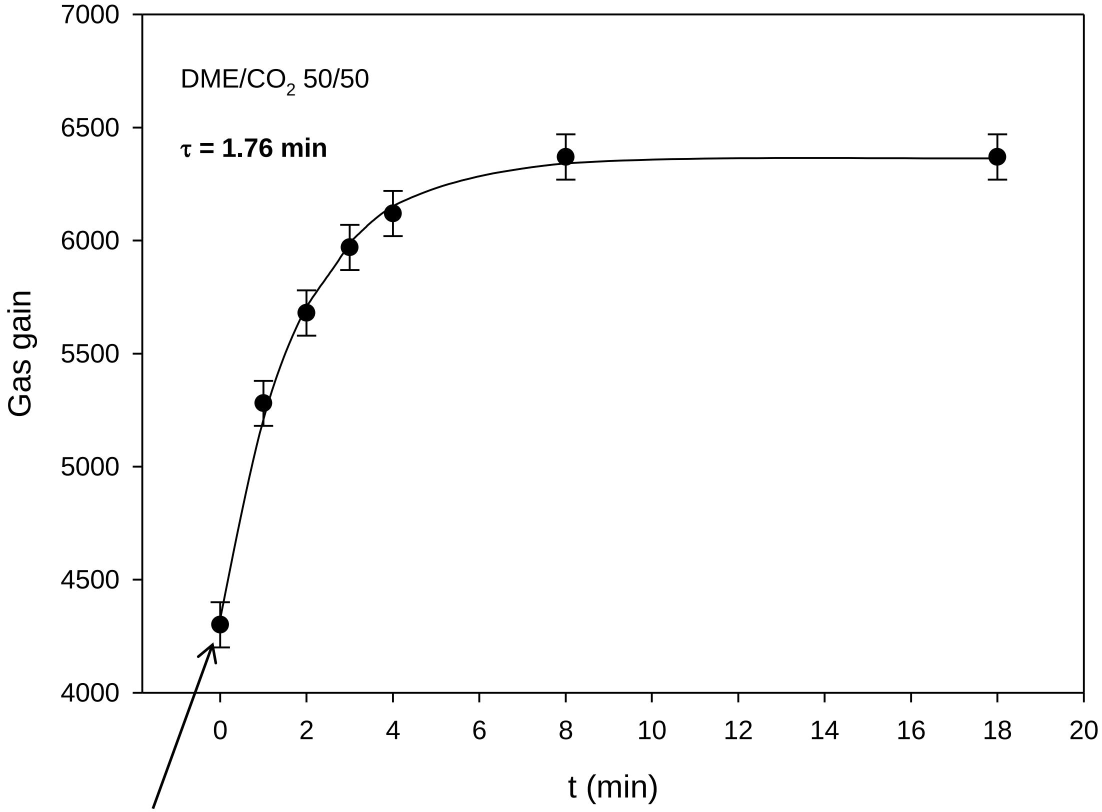
- $\mathbf{V_{char}}$ dependent on type of gas, width of amplification gap etc



Measurement of gain reduction by high irradiation rate

- TimePix3 based GridPix detector under irradiation by 5 MBq ^{90}Sr on 4 cm distance
  - Gas: DME/CO2 50/50
  - Grid voltage: -610 V
- Gain considerably decreased because of voltage drop across the protection layer
- Plot shows gain recovery after removal source

Gas gain recovery after irradiation



^{90}Sr source removed

Expressions

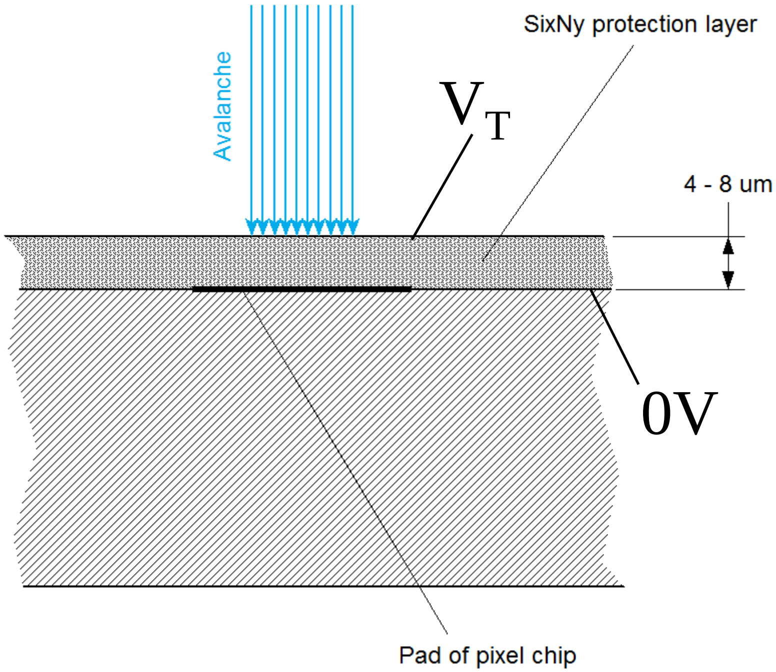
- **Potential V_T** is formed across the protection layer due to irradiation
- Gain G is reduced according to

$$G = G_u e^{-\frac{V_T}{V_{char}}}$$

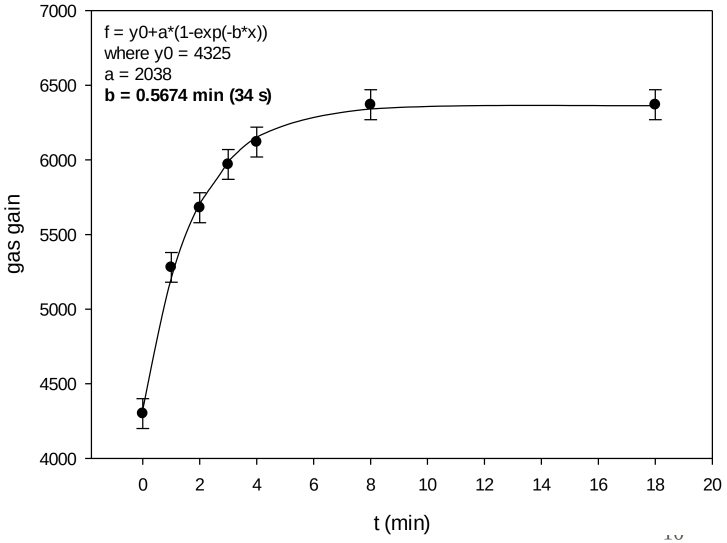
- But after removal of the source V_T falls back to zero with time t

$$V_T(t) = V_{T0} e^{-t/_{RC}}$$

- Where V_{T0} is the original potential and RC is the capacity and resistance of the investigated layer surface



Gas gain recovery after irradiation



The volume resistance of the layer

- The RC constant of the layer is independent of the geometry of the investigated layer surface and thickness and can be written as

$$RC = \varepsilon_0 . \varepsilon_r . \rho$$

- Where **ρ** is the **volume resistance** of the layer.

- Consequently we get for the time dependent expression of the gain after removal of the source

$$G(t) = G_u e^{-\frac{V_{T0} e^{-t/\varepsilon_0 . \varepsilon_r . \rho}}{V_{char}}}$$

- By fitting the double exponential expression to the measured curve, the volume resistance ρ can be determined from the time dependent behaviour

Deducing the value for ρ

- One may deduce ρ directly from the curve fit through the measured G(t) values

$$G(t) = G_u e^{-\frac{V_{T0} e^{-t/\varepsilon_0.\varepsilon_r.\rho}}{V_{char}}}$$

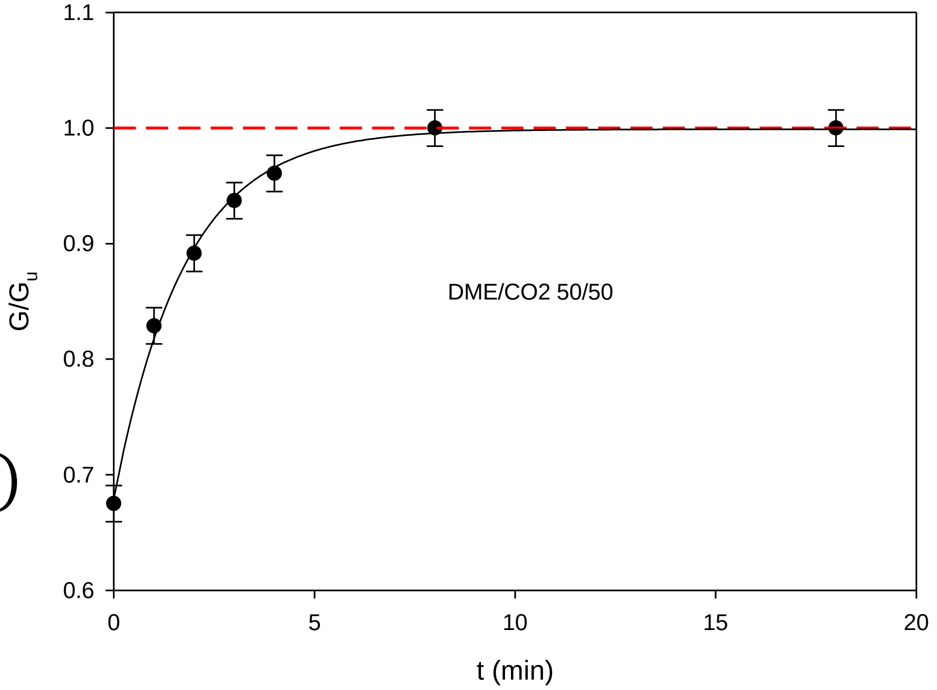
- But it is practical to convert $\boldsymbol{G(t)}/\boldsymbol{G_u}$ to the corresponding $V_T(t)$

$$V_T(t) = -V_{char}.\ln\left({G(t)}/{G_u}\right)$$

- Subsequently fit an exponential through the $V_T(t)$ points

$$V_T(t) = V_{T0} e^{-t/\varepsilon_0.\varepsilon_r.\rho}$$

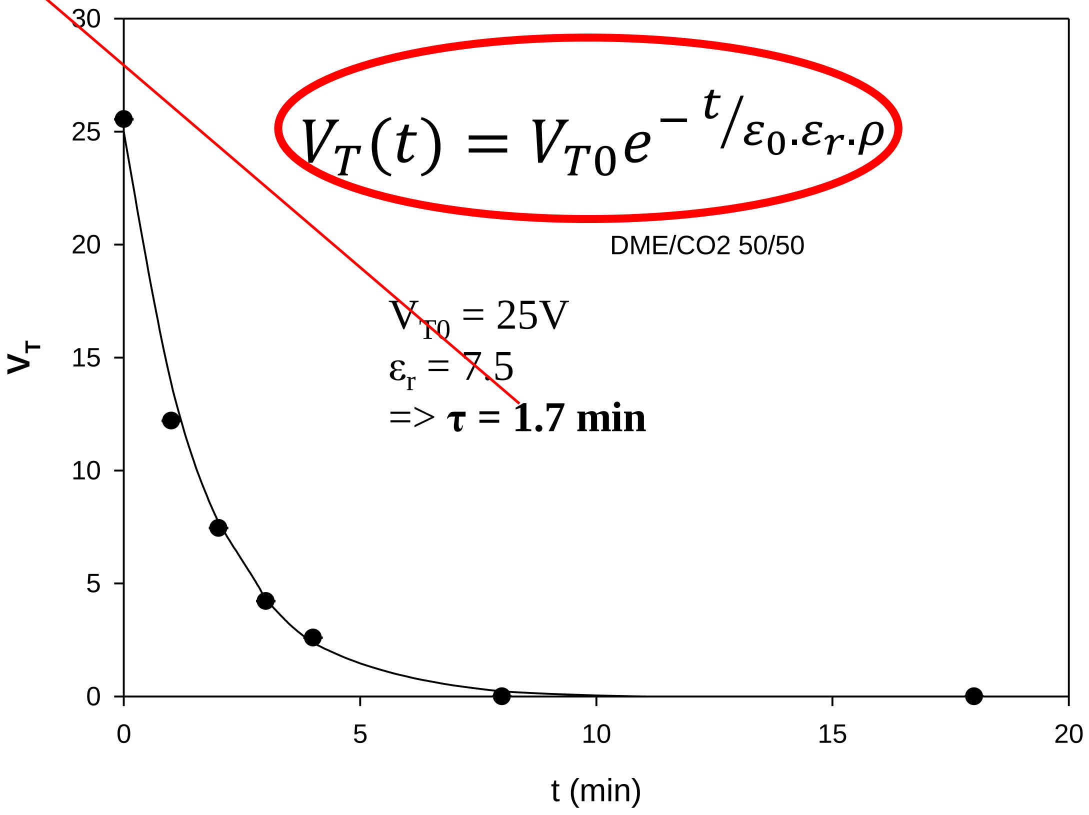
Example of the gas gain recovery after irradiation



Decay of the calculated voltage drop across the protection layer

- For the example we get
  - **$\varepsilon_0 * \varepsilon_r * \rho = 1.7$ min**
  - V_{char} estimated at 65V
- For ρ we get accordingly:
  - **$\rho = 1.5*10^{12}\ \Omega m$**
- The range in which ρ can be measured extends due to practical constraints from
  - **10^{11} to $10^{17}\ \Omega m$**
  - (10^{13} to $10^{19}\ \Omega cm$)
  - ($\tau = 10$ s to 117 days)
- *Note: a simple exponential fit through the original $G(t)/G_u$ curve gives about the same result*
  - ***$\tau = 1.76$ min***

Decay V_T after removal source (example)



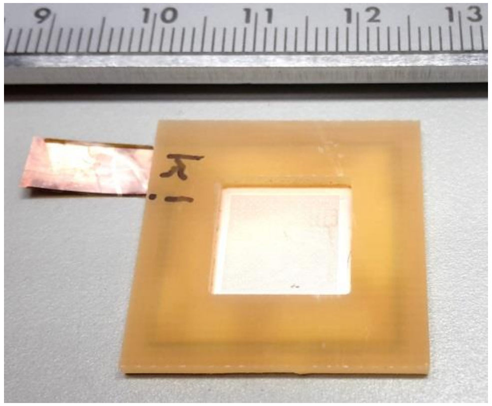
$$V_T(t) = V_{T0} e^{-t/\varepsilon_0.\varepsilon_r.\rho}$$

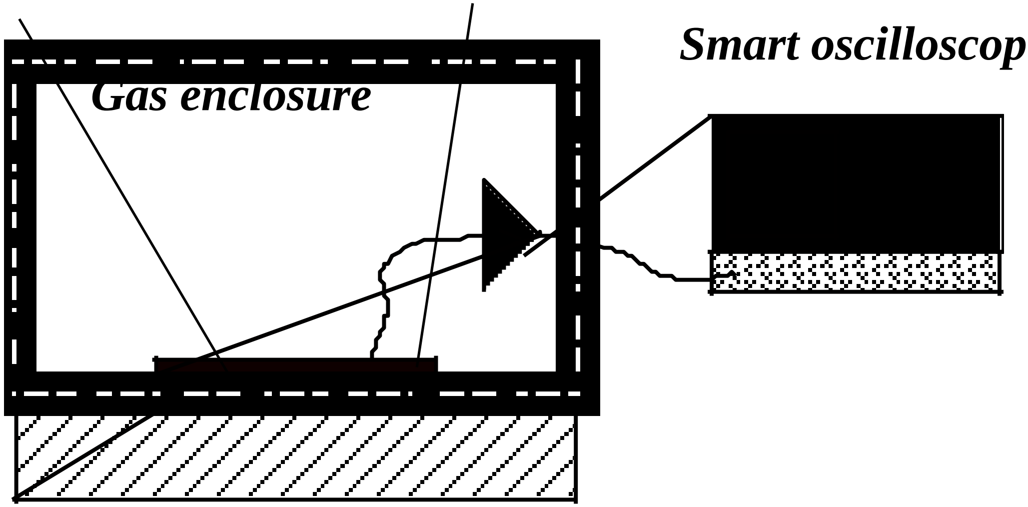
DME/CO2 50/50

$V_{T0} = 25$V
$\varepsilon_r = 7.5$
=> **$\tau = 1.7$ min**

Method to do the ρ measurement of a protection layer?

- No pixel chip is needed
  - can be done well with a dummy piece of silicon
- Just place a dedicated Micromegas on top and put it in gas enclosure
- Analyse the induced signals from the Micromegas grid created by the ^{55}Fe source





(Dummy) chip

Micromegas

Smart oscilloscope

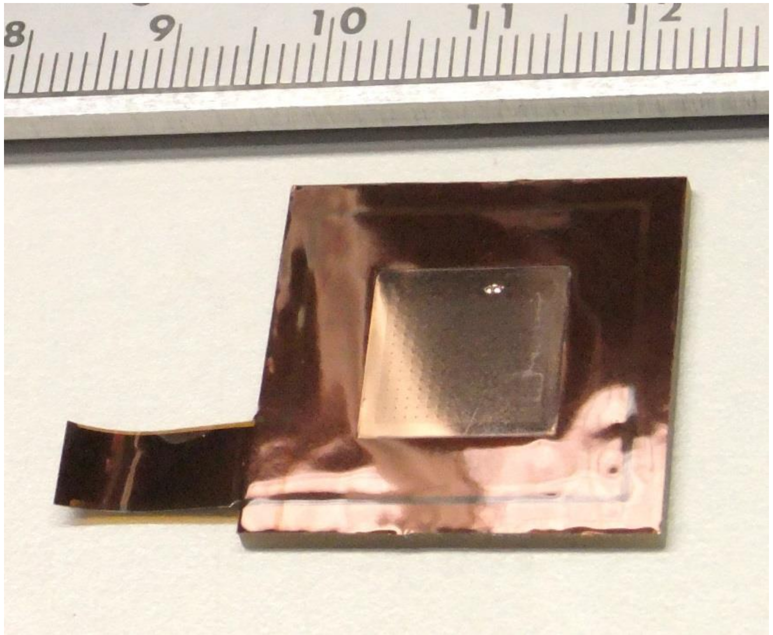
Gas enclosure

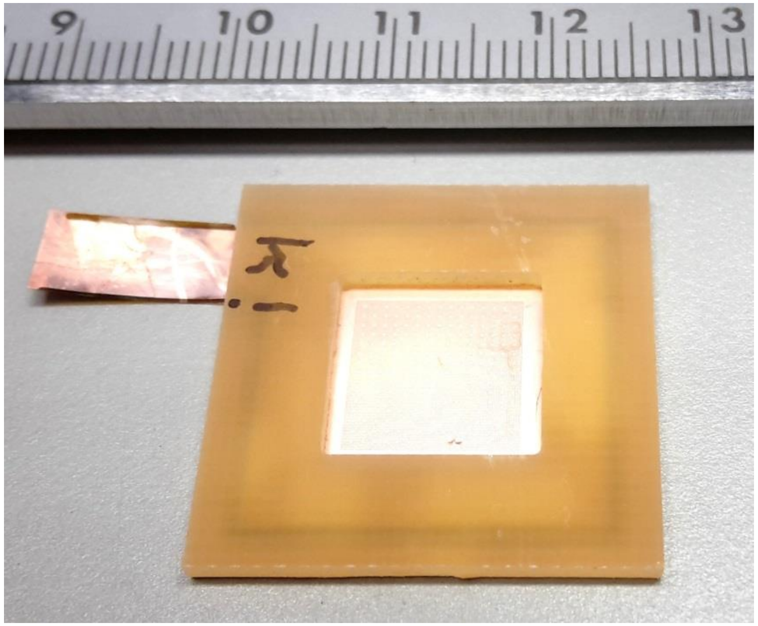
Dedicated Micromegas board

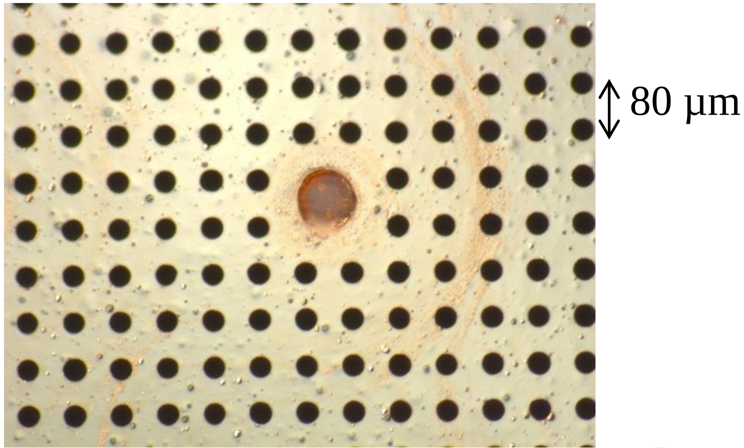
- Designed by Harry van der Graaf

- 5 µm copper on 50 µm Kapton
- 80 µm hole pitch
- Mounted on glass fibre epoxy frame
  - 25 x 25 mm

- Fabricated at CERN (Rui De Oliveira)

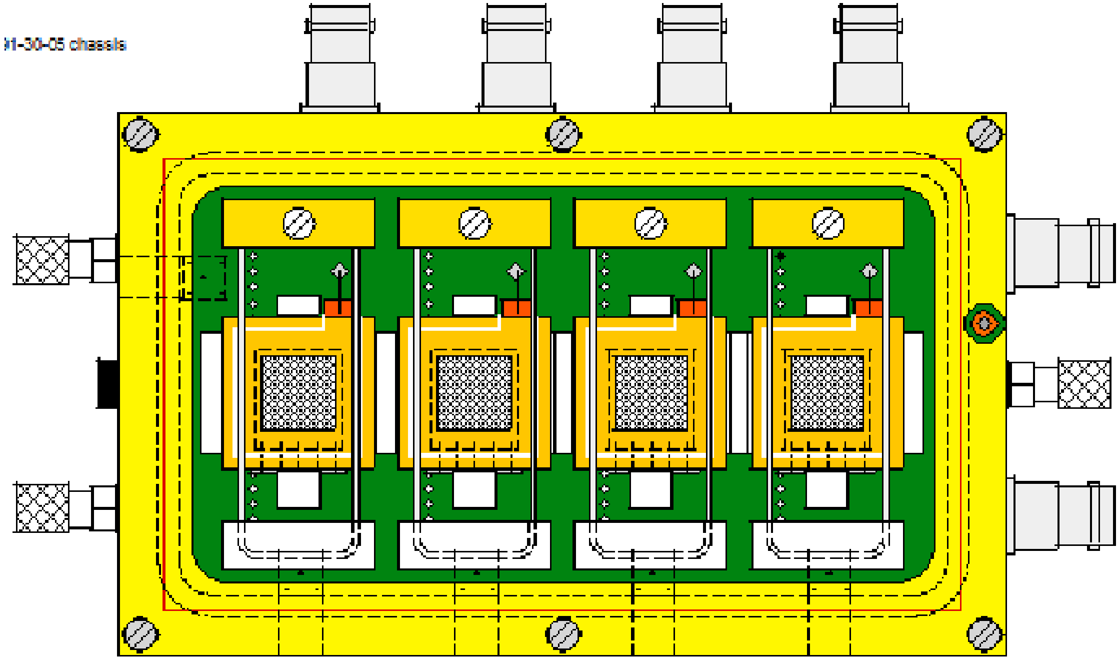


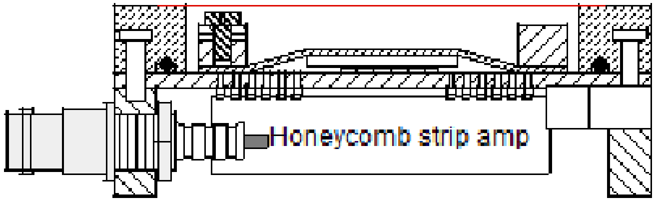


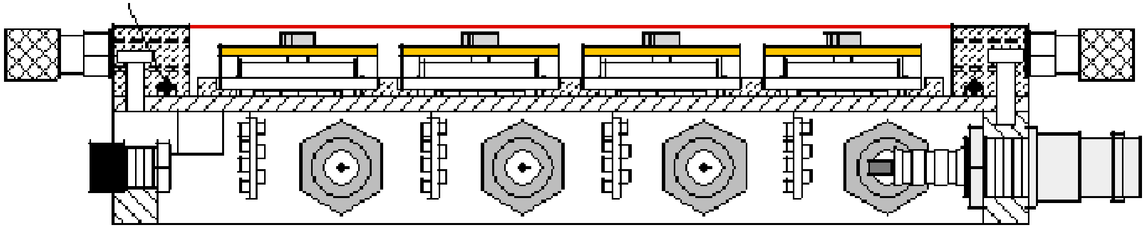


Protection layer test device

- Designed to measure systematically the long term HV tolerance of protection layers
  - Resistivity
  - Breakdown sensitivity under harsh conditions
- 4 channels
  - HV from Nikhef miniHV
  - nA resolution
  - Good detection of sparks





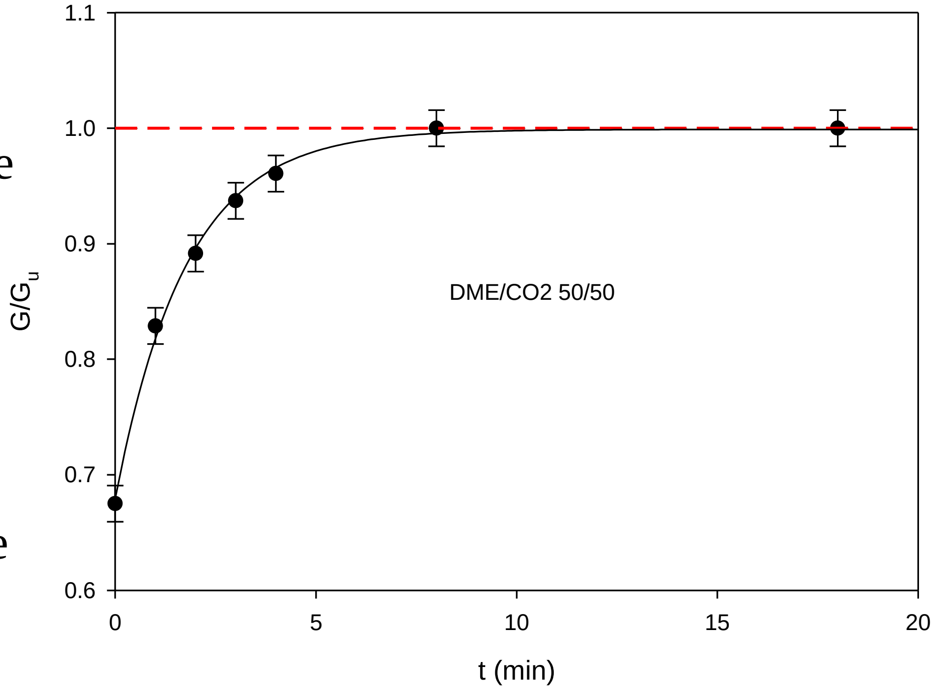


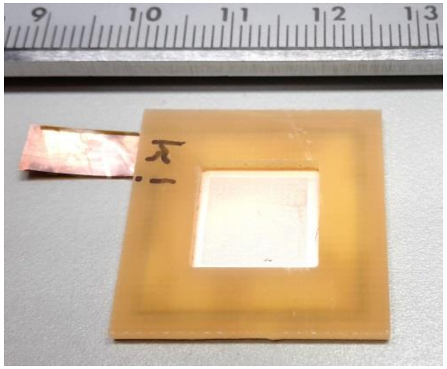
Summary

- A pixelized gaseous detector needs a protection layer on the anode to avoid spark damage
- But the detector may experience loss of gain at high counting rates because of voltage drop across the protection layer
- This effect can be reduced by lowering the resistivity of the layer

- We devised a method where from the dynamic response of the gain to external irradiation the volume resistance can be accurately deduced between 10^{11} and 10^{17} Ωm
- Can also be applied for all kinds of layers on a dummy substrate
  - Interesting for MEMS technology

Example of the gas gain recovery after irradiation





Fred Hartjes