中国科学技术大学
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A fast simulation method for THGEM charging-up study

Based on the G. Song *et al* 2020 *JINST* **15** P04015

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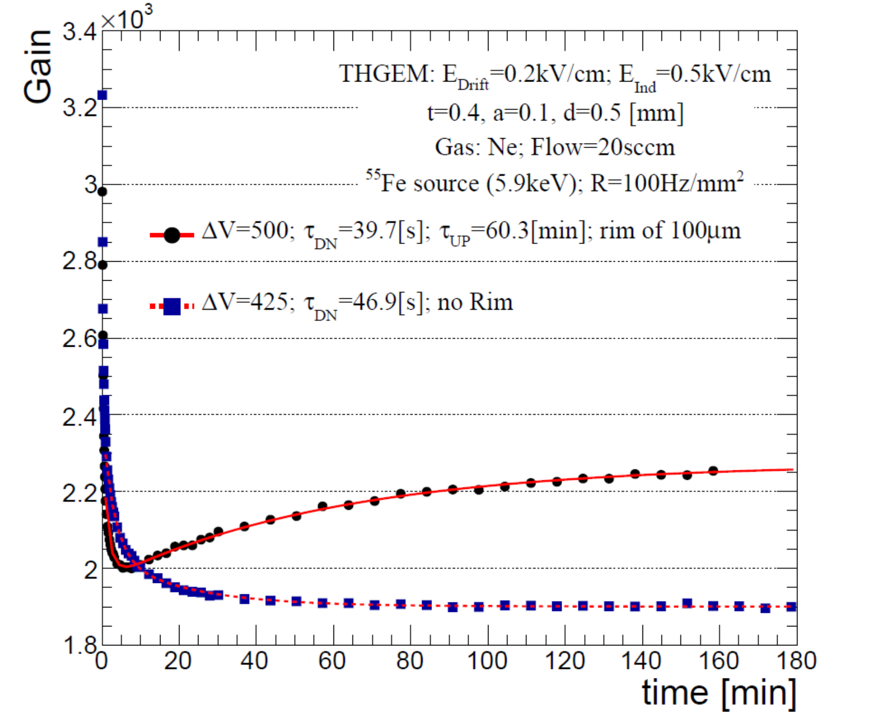
RD51 Mini-Week

CONTENTS

Gain evolution in Thick-GEM

2 different phenomena:

- Fast gain decrease: few minutes to few tens of minutes
- Long gain rise: hours to days, only in THGEM with large rims.

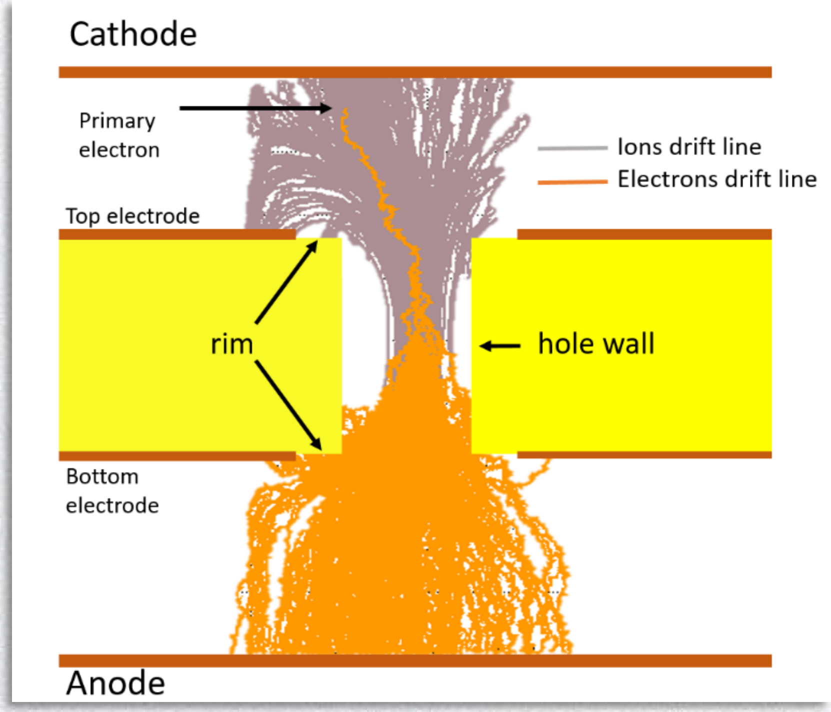


Measured gain stabilization over time

M. Pitt *et al* 2018 *JINST* **13** P03009

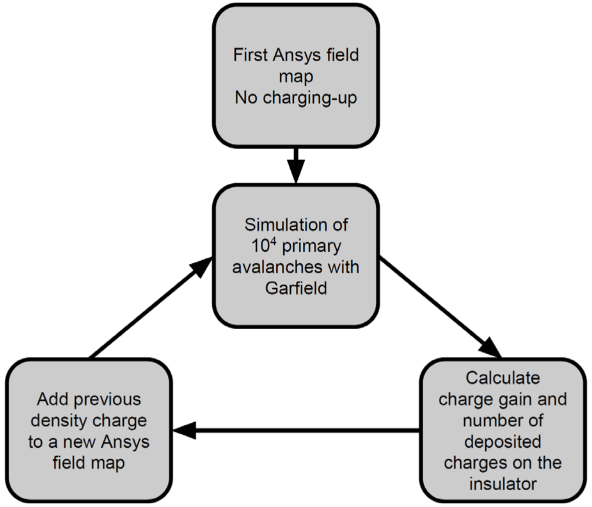
A qualitative understanding of the gain evolution

- Charging-up effect: the electrons and ions stop on the dielectric surface of THGEM.
- The field inside a THGEM hole is modified by the net charge accumulation.
  - Gain decreases vs. time: the net charge on hole wall generates an electric field opposite to bias one.
  - Gain increases vs. time: the net charge at the rim surface reinforces the bias electric field.

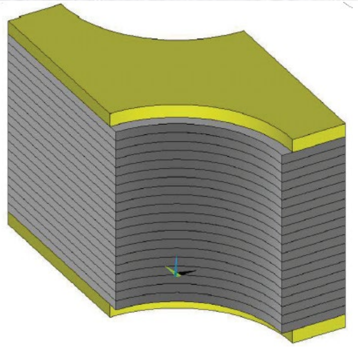


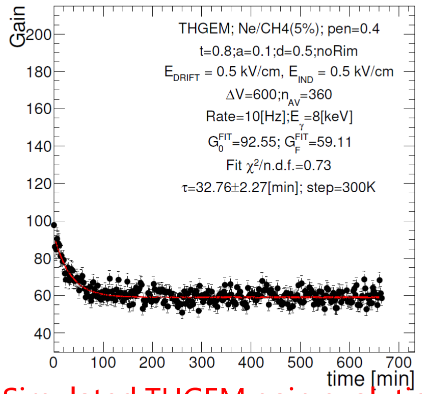
Schematic drawing of the THGEM charging-up

Previous method for Charging-up simulation



Simulation flow-chart


THGEM cell employed in simulations



Simulated THGEM gain evolution

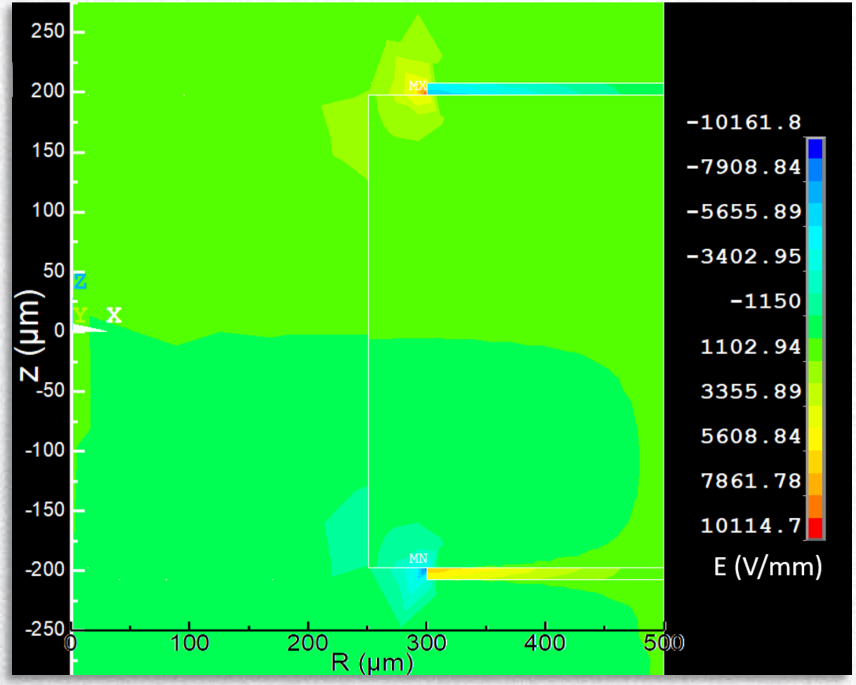
- *P.M.M. Correia et al., 2014 JINST 9 P07025 [arXiv:1401.4009].*
- *Correia, P.M.M. et al. JINST 13 (2018)*

- Iterative transition between the FEM software and Garfield++ after each iteration
- The step size affects the simulation efficiency and accuracy.
- CPU and time consuming.

Fast simulation method-- Charge deposition calculation

2 assumptions for Charge deposition calculation：

- The accumulation of avalanche charges on dielectric surfaces is driven by the electric field component perpendicular to the surface (E_r).
- The condition of equilibrium is that the electric field of the accumulated surface charge fully compensates the initially E_r, so that no more charges accumulate further.



Map of electric field component perpendicular to the THGEM hole wall.

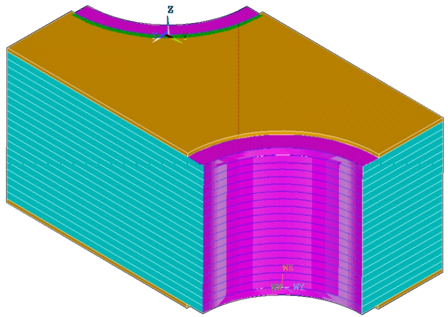
Fast simulation method-- Charge deposition calculation

- The electric field generated by the surface charge on the at its own location：

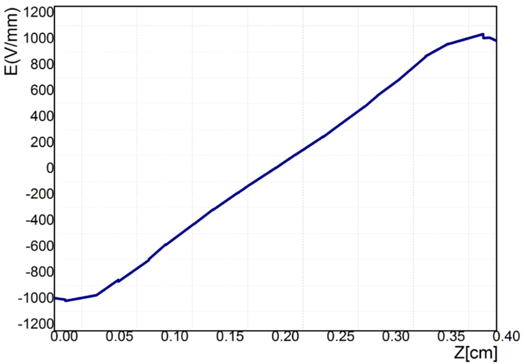
$$E = \frac{\sigma}{\varepsilon + \varepsilon_0}$$

ε and ε_0 are the dieletric constant of FR4 and gas.

- Divide the insulator surface into 20 small slices. Use the E_r on each slice of FR4 to calculate charge density σ_i on each slice.
- Add σ_i on each slice, the newly added charge will modify the field map of the THGEM, leading to non-zero E_r again. Thus, we recalculate σ_i until the field map gradually reaches convergence



Unitary cell for the THGEM



E_r along the THGEM hole wall

Superposition calculations for field update

Superposition calculations reduce the use of FEM software.

Superposition theorem :

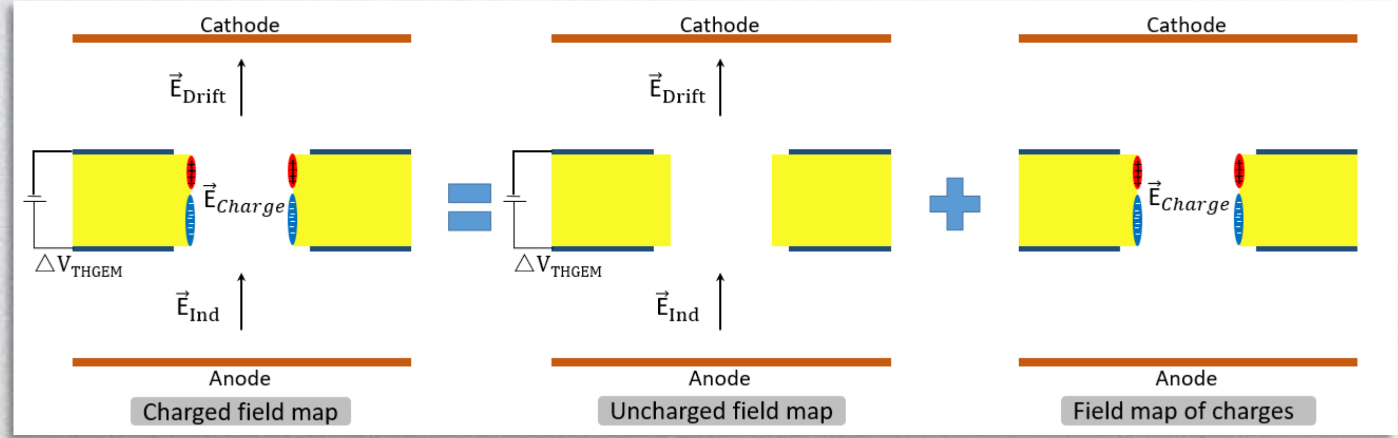
$$\vec{E}_{total} = \vec{E}_{uncharged} + \vec{E}_{charge}.$$

Potential and electric field at each node:

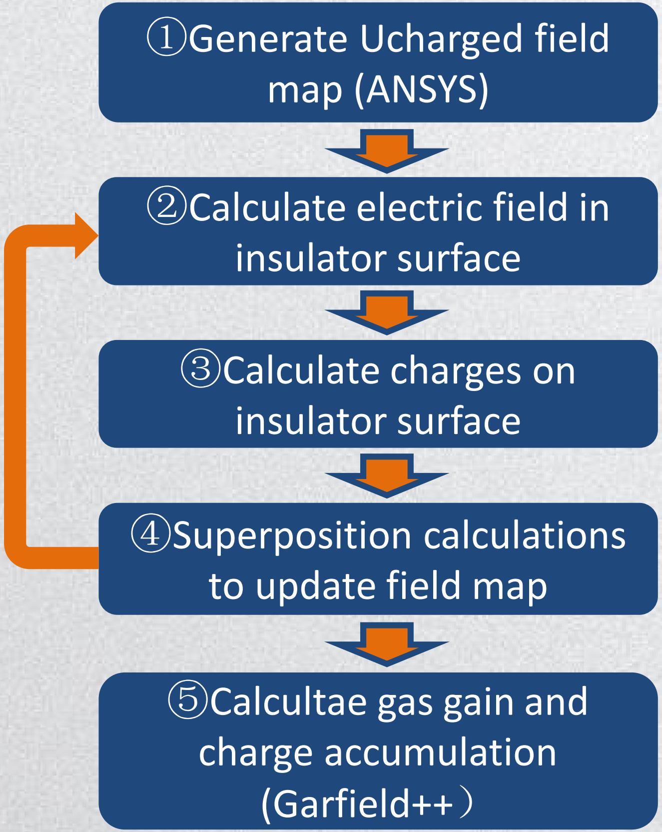
$$\vec{E}_{total}(j) = \vec{E}_{uncharged}(j) + \sum_{i=1}^{20} \sigma_i \vec{E}_{charge}(i,j),$$

$$V_{total}(j) = V_{uncharged}(j) + \sum_{i=1}^{20} \sigma_i V_{charge}(i,j),$$

$\vec{E}_{charge}(i,j)$ and $V_{charge}(i,j)$ are generated by a unitary positive charge in the surface of slice i



Simulation procedure



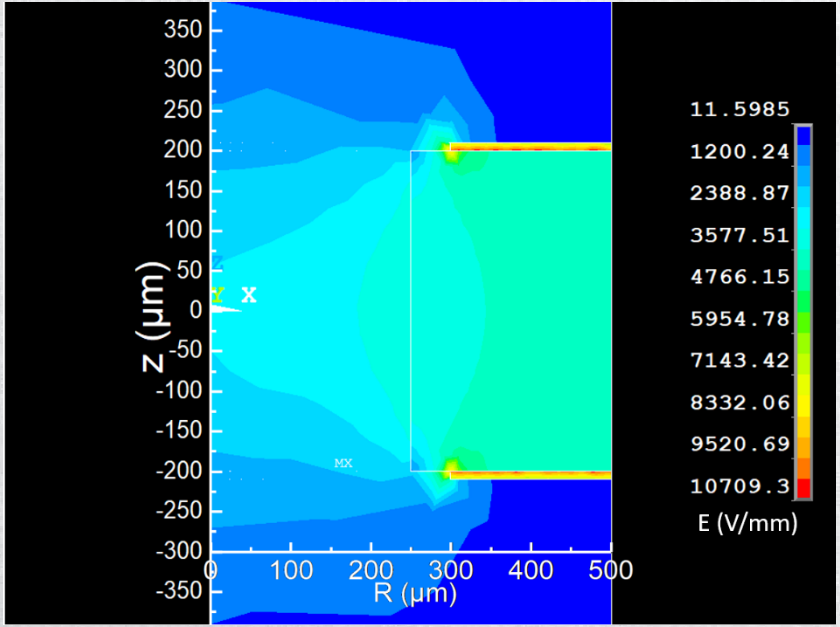
- Superposition theorem is used to update field map,FEM software is only used in the first iteration.
- In each iteration, gas gain and the charge accumulated on the dieletric surface ($Q_{ava,i}$) are calculated with Garfield++
- The time needed to accumulate charge Q_i for the i-th iteration:

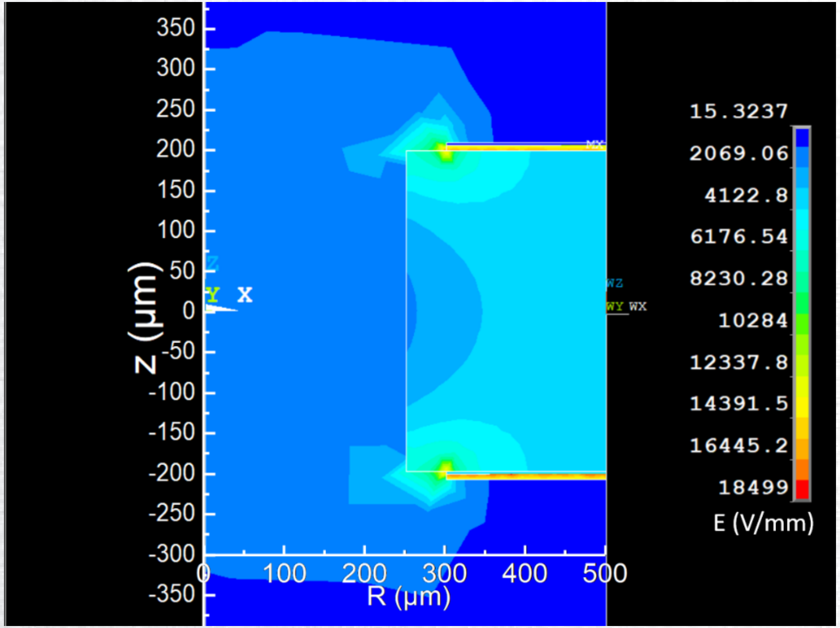
$$\Delta t_i = \frac{Q_i}{Q_{ava,i}} \frac{1}{n_p R}$$

R is irradiation rate, n_p is the number of primary charges.

Simulation process and results

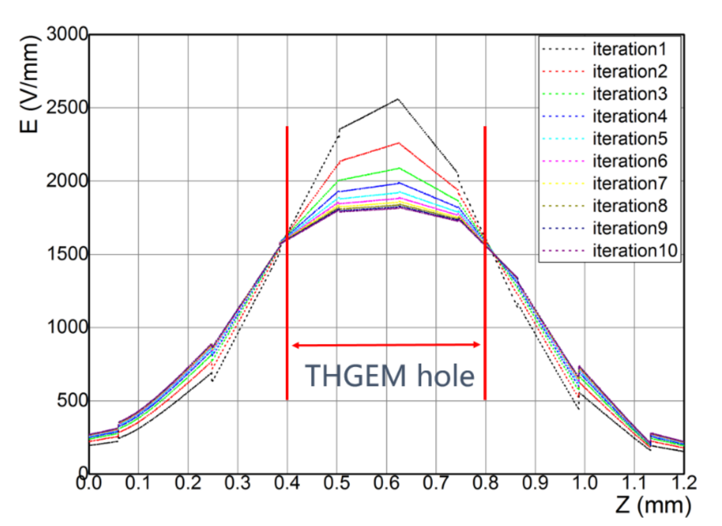
Field map in first iteration(left) and 10^{th} iteration(right)



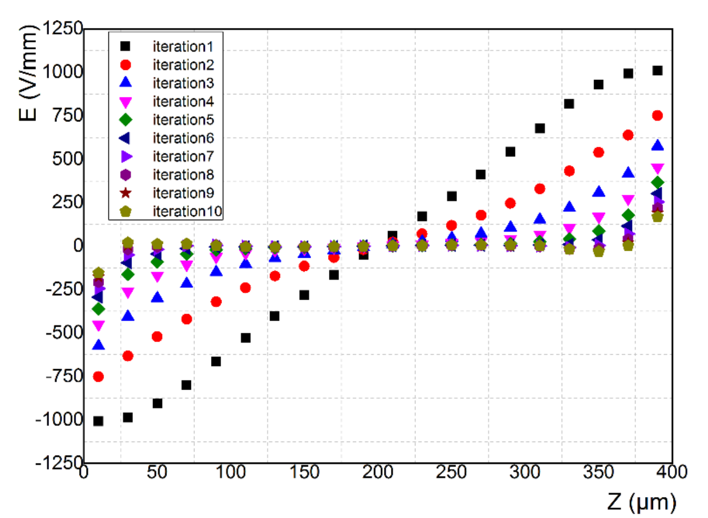


Simulation process and results

THGEM: E_{drift}=0.2kV/cm, E_{ind}=0.5kV/cm, pitch 1mm
thickness 0.4mm, diameter 0.5mm, rim 0.1mm, △V=1500V



Total electric field strength along the central axis of the THGEM cylindrical hole at each iteration.

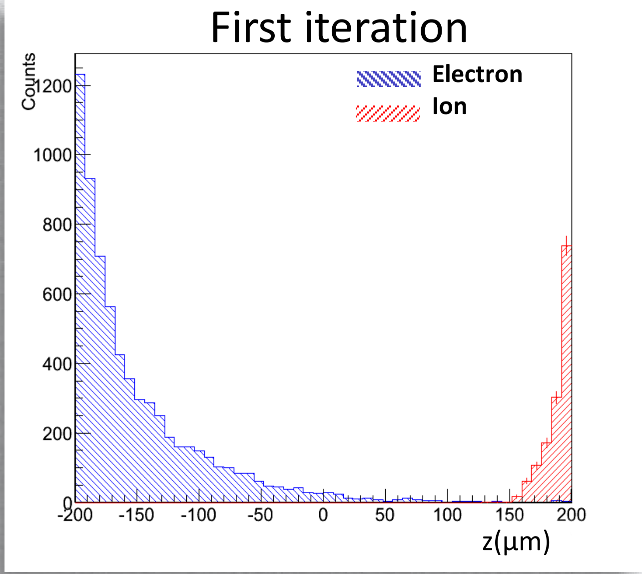


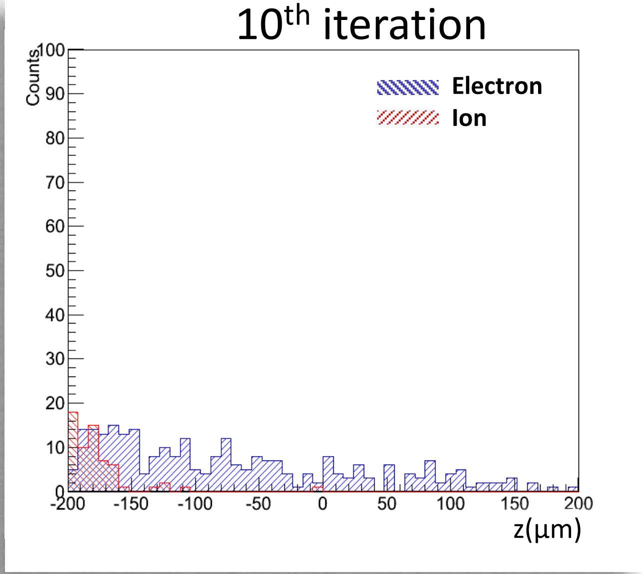
The electric field component perpendicular to the dielectric surface

- The electric field in the multiplication region decreased.
- We use these field components to estimate the charge accumulation in next iteration

Simulation process and results

Charge accumulation

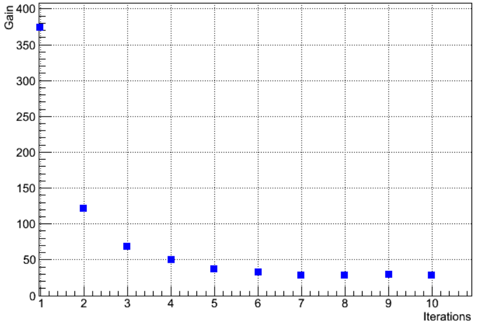




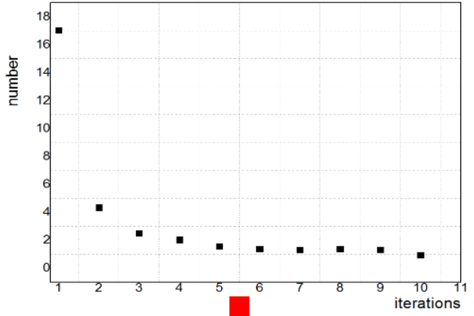
Charge accumulation along the hole wall in 500 avalanches
Calculated with Garfield++

Simulation process and results

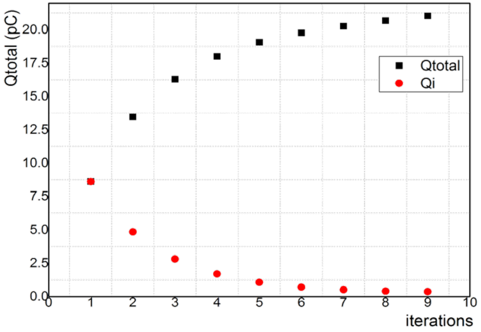
①Gain vs. iterations



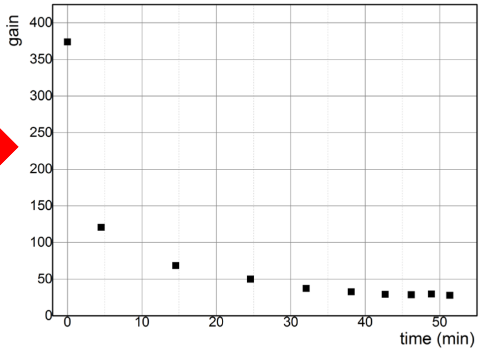
②Average number of electrons accumulated in one avalanche



③Charge vs. iteration(red), total charge（dark)



④Gain vs. time

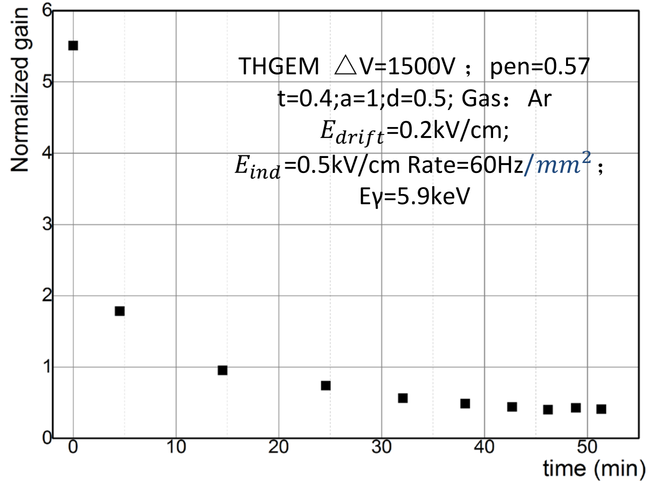


- Gain decreases significantly with increasing iteration
- Charge accumulation rate decrease with increasing iteration, because the accumulated charge prevents further charge accumulation
- With charge and it's accumulation speed, the time evolution of the gain can therefore be obtained.

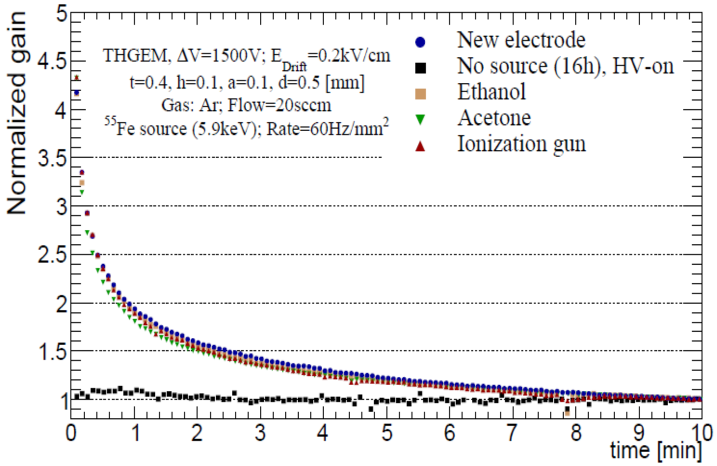
◆ 5.9keV X-ray Rate： 60Hz/mm^2

Simulation results

Compare the simulation results with measured data



- **Gain variation simulated by Fast Simulaiton Method,normalized by iteration3.**

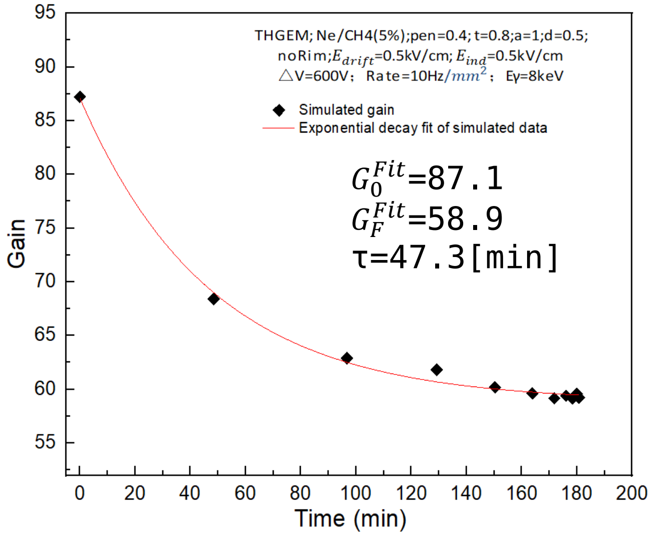


- **Measured relative gain variation due to charging up of a THGEM electrode**

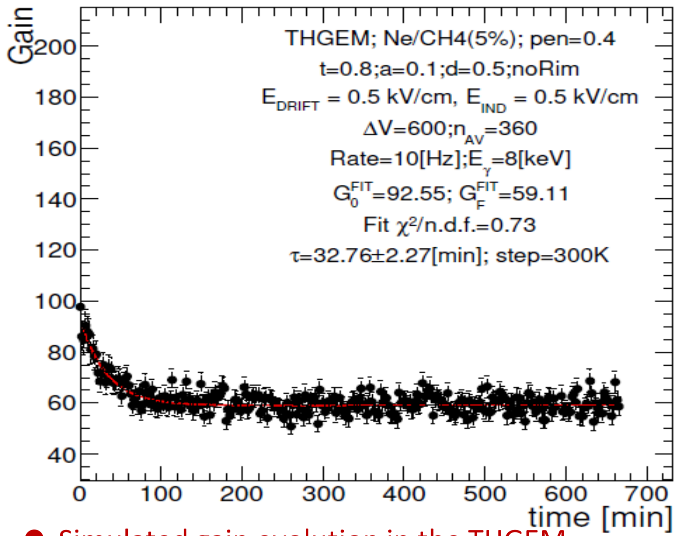
M. Pitt *et al* 2018 *JINST* **13** P03009

Simulation results

Compare the simulation results with previous simulation method



- Gain variation simulated by Fast Simulation Method



- Simulated gain evolution in the THGEM
Correia, P.M.M. et al. JINST 13 (2018)

◆ Fit the simulation result with fuction G(t)=G_0-△G（1-$e^{-t/\tau}$）, The fitting results are consistent with precious simulation method.

Conclusions and future work

Conclusions

- We developed a fast iterative method to simulate the charging-up effect of THGEM
- This method only requires a few iterations before reaching gain stabilization.
- The results are in agreement with experimental observations.

Future work

- We neglected the rim effect, we will consider the accumulation of charges on THGEM rims in the future.
- A small amount of avalanche charge still absorbed by the hole wall at last iteration, we may consider the charge migration from the dieletric toward the metallized area.