Activities at KEK

Keita Yumino

National University
SOKENDAI
The Graduate University for Advanced Studies

KEK
High Energy Accelerator Research Organization

Seasonal ILC detector meeting 10/12/2020

Introduction

The aim of study

To develop a high-performance GEM as a detector for LCTPC

Our Asian-GEM has some problems

- discharge,
- need for support structure, and
- **gas gain non-uniformity**

GEM optimisation study

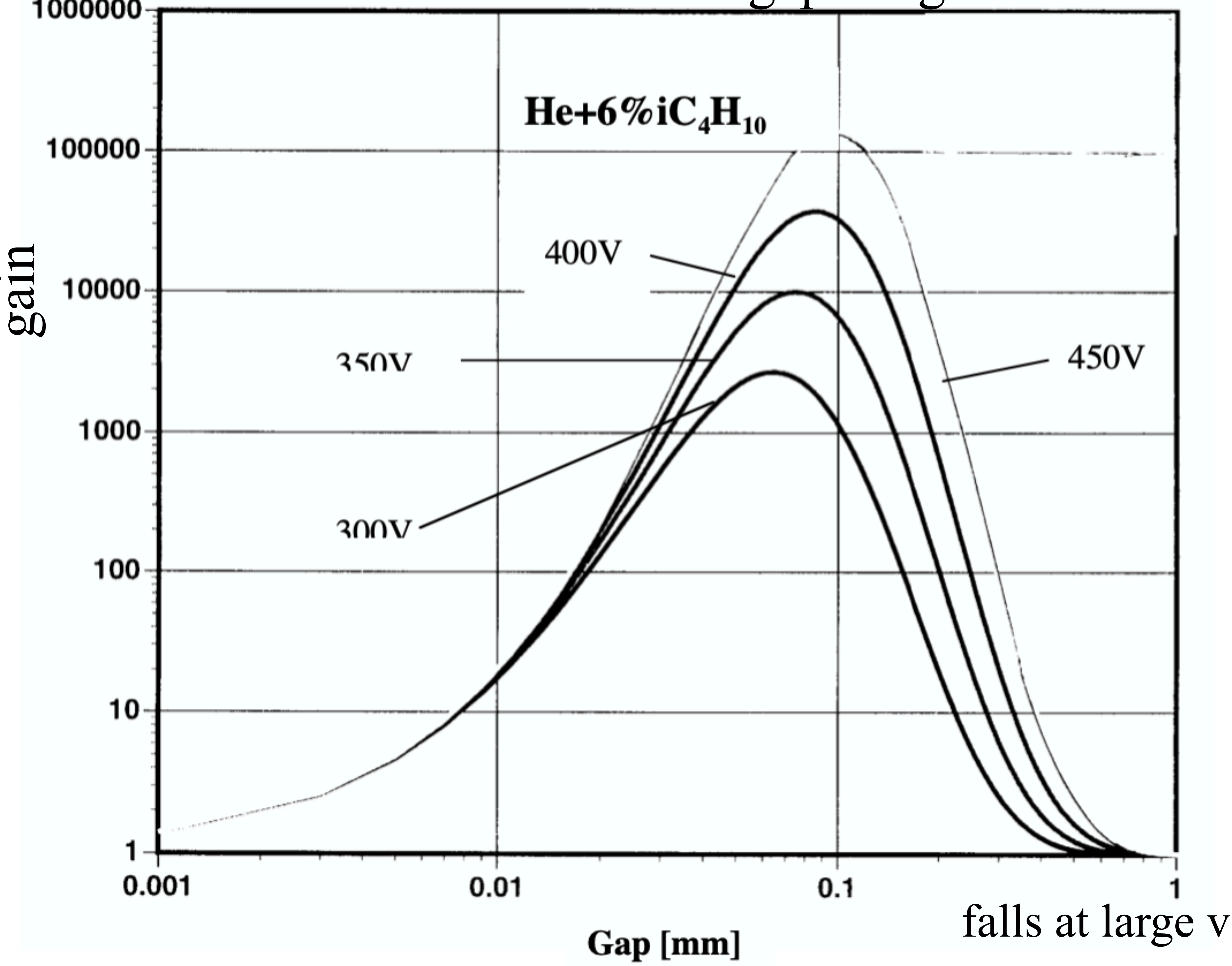
Theoretical approach	K.Yumino
Thickness measurement	All students of KEK-ILC group Y.Aoki, T.Mizuno, J.Nakajima, K.Yumino

GEM optimisation study

Motivation

thickness dependence of gas gain
in the case of MICROMEGAS

$M = e^{\alpha d}$ as a function of the gap d gas: He + iC4H10 = 94:6



falls at large values of d

MICROMEGAS: results and prospects : **I. Giomataris**

M increases as *d* increases,
reaches a maximum

M is at maximum in the range of gaps
between 30-100 μm.

This is the range currently used
by the MICROMEGAS detectors

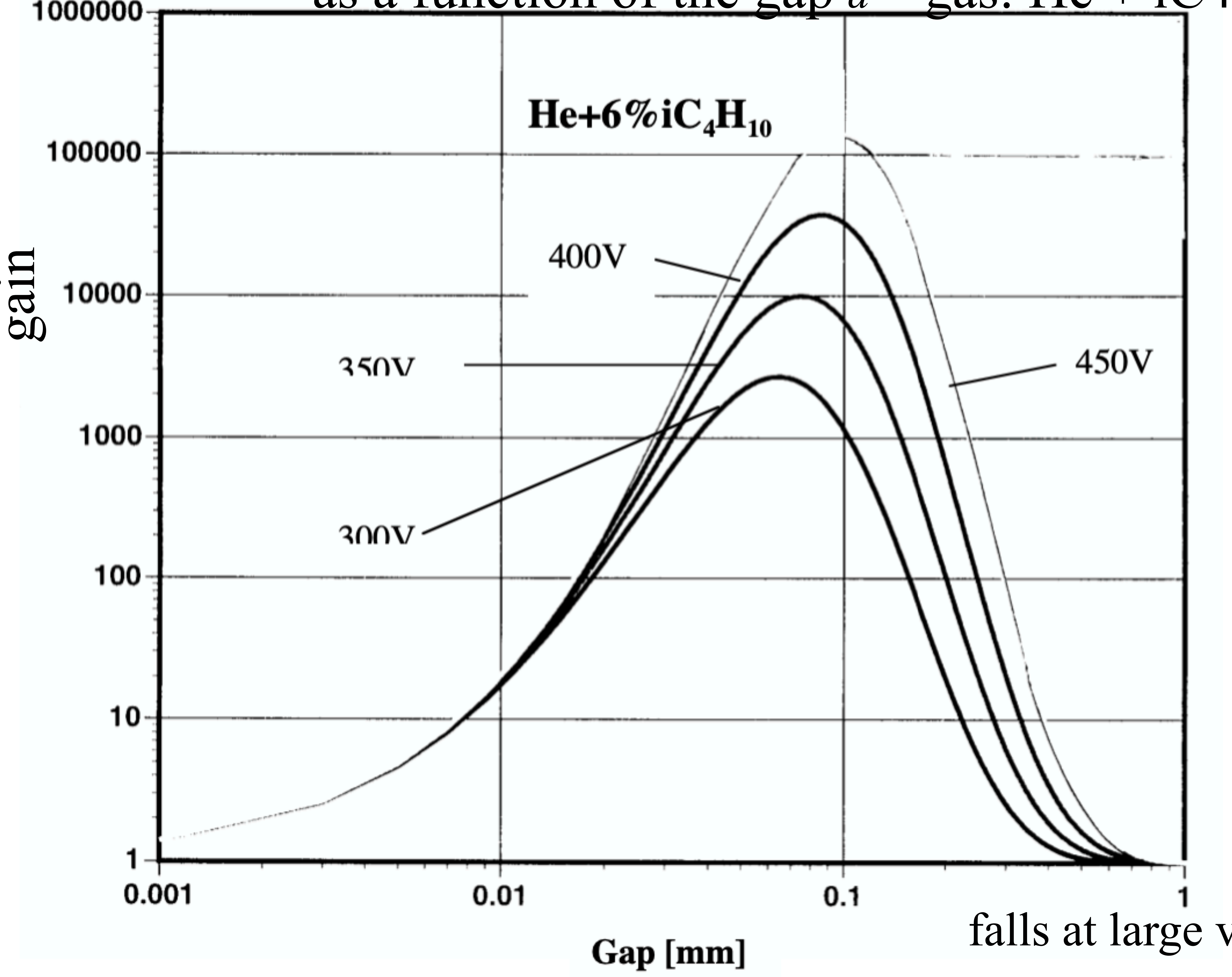
In this range, gas gain *M* is maximum and its fluctuations due to defects of flatness of the two parallel electrodes are canceled

Stability condition!!

Motivation

thickness dependence of gas gain
in the case of MICROMEGAS

$M = e^{\alpha d}$ as a function of the gap d gas: He + iC4H10 = 94:6



falls at large values of d

MICROMEGAS: results and prospects : **I. Giomataris**

Is there a “Stability condition"
in the case of GEM?

In this range, gas gain M is maximum and its fluctuations due to defects of flatness of the two parallel electrodes are canceled

Stability condition!!

current study

I’m now working on investigation of the conditions under which the thickness dependence of the gas gain is constant.

- Find plateau using Asian GEM geometry.
- Theoretically derive the “Stability conditions” under which the gas gain is stable.
- Verify the theory using Asian GEM geometry.

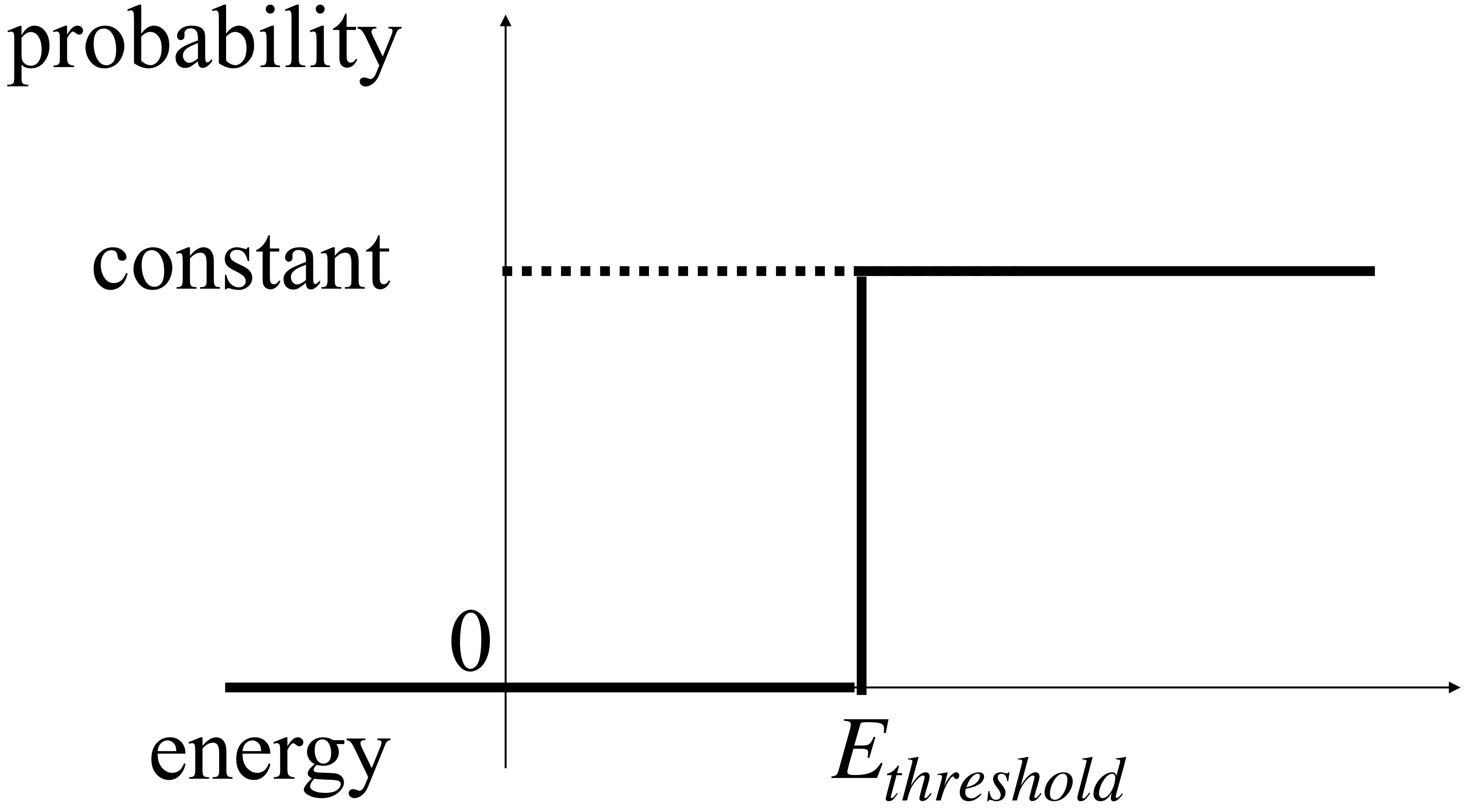
Theory

First, we assume that Legler's model[1] is correct

Legler's model have 2 assumptions

1. ionising collisions may occur <u>only after the seed electron flying over a minimum distance</u> so as to gain enough energy for ionisation from the E-field.

2. <u>the probability of ionising collision being constant</u> after the seed electron having reached the threshold energy like a step function



[1] STATISTICS OF ELECTRON AVALANCHES AND ULTIMATE RESOLUTION OF PROPORTIONAL COUNTERS

Theory

We have equation of gas gain variation $\frac{dG}{G}$

$$\frac{dG}{G} = \left(\frac{1}{1+\chi+\eta} \right) \left[1 - \frac{\epsilon}{\sigma_0} \left(\frac{\partial \sigma_0}{\partial \epsilon} \right) \right] \chi \, \delta \left(\frac{d\Delta}{\Delta} \right)$$

where

$\epsilon = \frac{E}{n}$, $E = \frac{V/\Delta}{n}$, $\delta = \frac{V}{U_0}$, $\eta = n\Delta \frac{U_0}{V} \sigma_0(\epsilon)$, $\chi = \frac{\ln G}{\delta}$, and Δ : thickness of GEM

the coefficients can be deleted by choosing these parameters.

the details of these parameters are put on a backup slide, p22

for stable operation, $\frac{dG}{G} = 0$ is required

σ_0 :effective cross section

ϵ : scaling variable =E/n

Therefore, we have the "Stability condition"

$$\boxed{\frac{\partial \sigma_0}{\partial \epsilon} = \frac{\sigma_0}{\epsilon}}$$

Process

1. Find the “plateau region” in gas gain distribution
2. Look at free path distribution after each collision

→Mean free path l $$l = \frac{1}{n\sigma}$$ n : gas density

3. cross section $\sigma \sim \frac{1}{l}$

$$\epsilon = \frac{E}{n}$$ E : electric field [kV/cm]

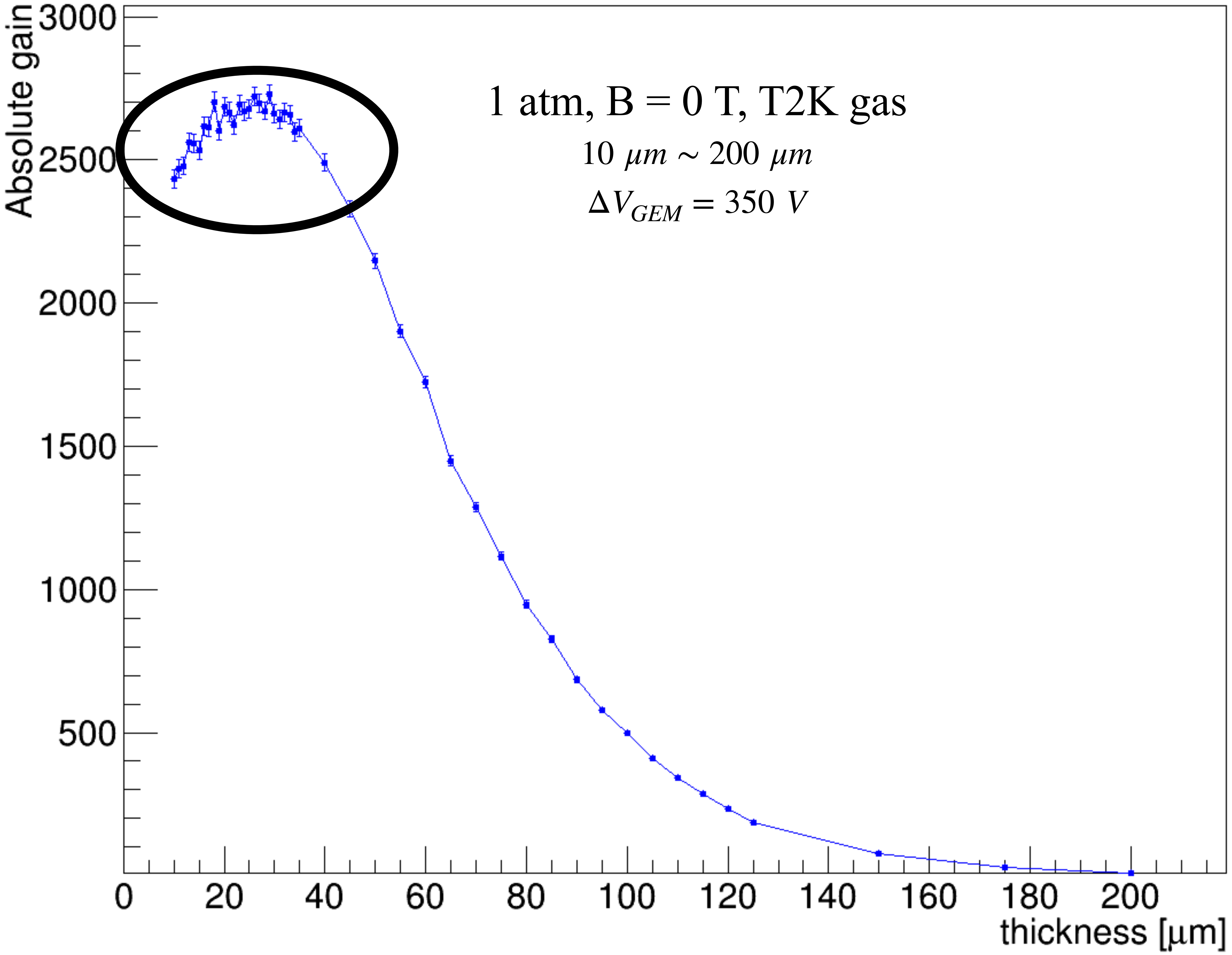
4. σ vs ϵ

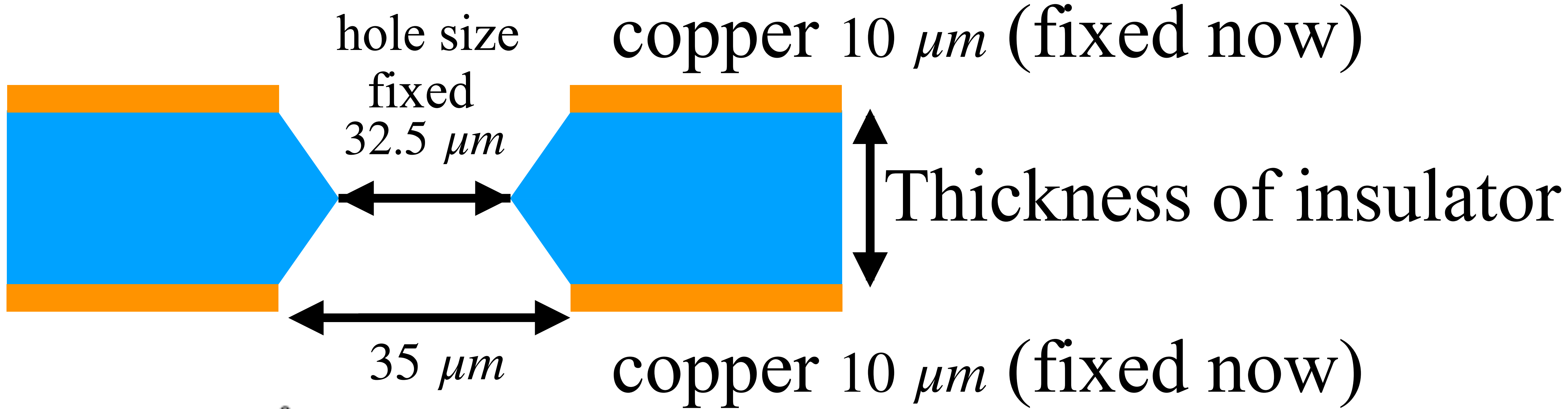
→Find stability condition

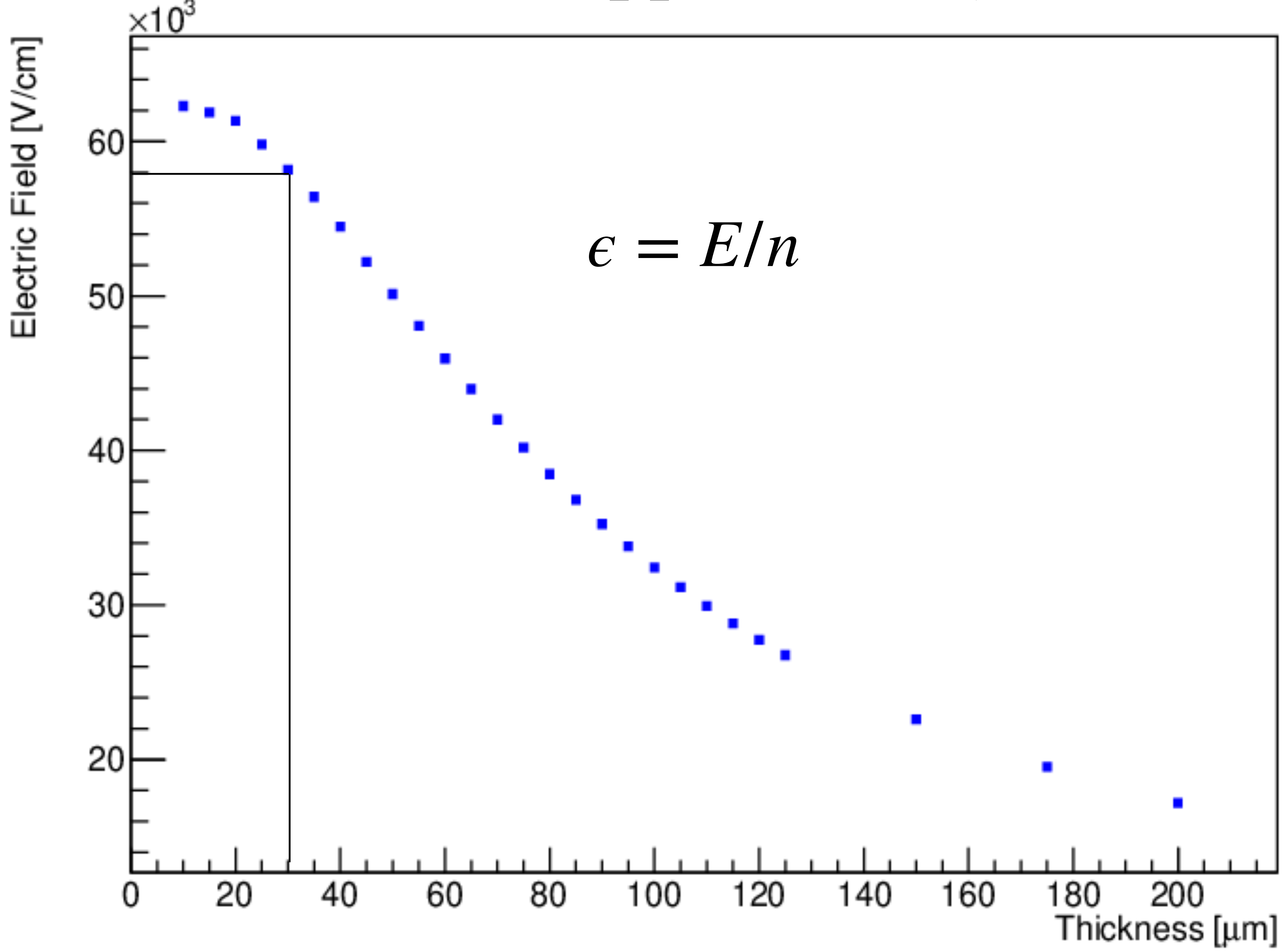
$$\frac{\partial \sigma_0}{\partial \epsilon} = \frac{\sigma_0}{\epsilon}$$

4. Compare the result

Thickness dependence of gain:Asian GEM







The plateau area was found in the range of $10\ \mu m \sim 40\ \mu m$

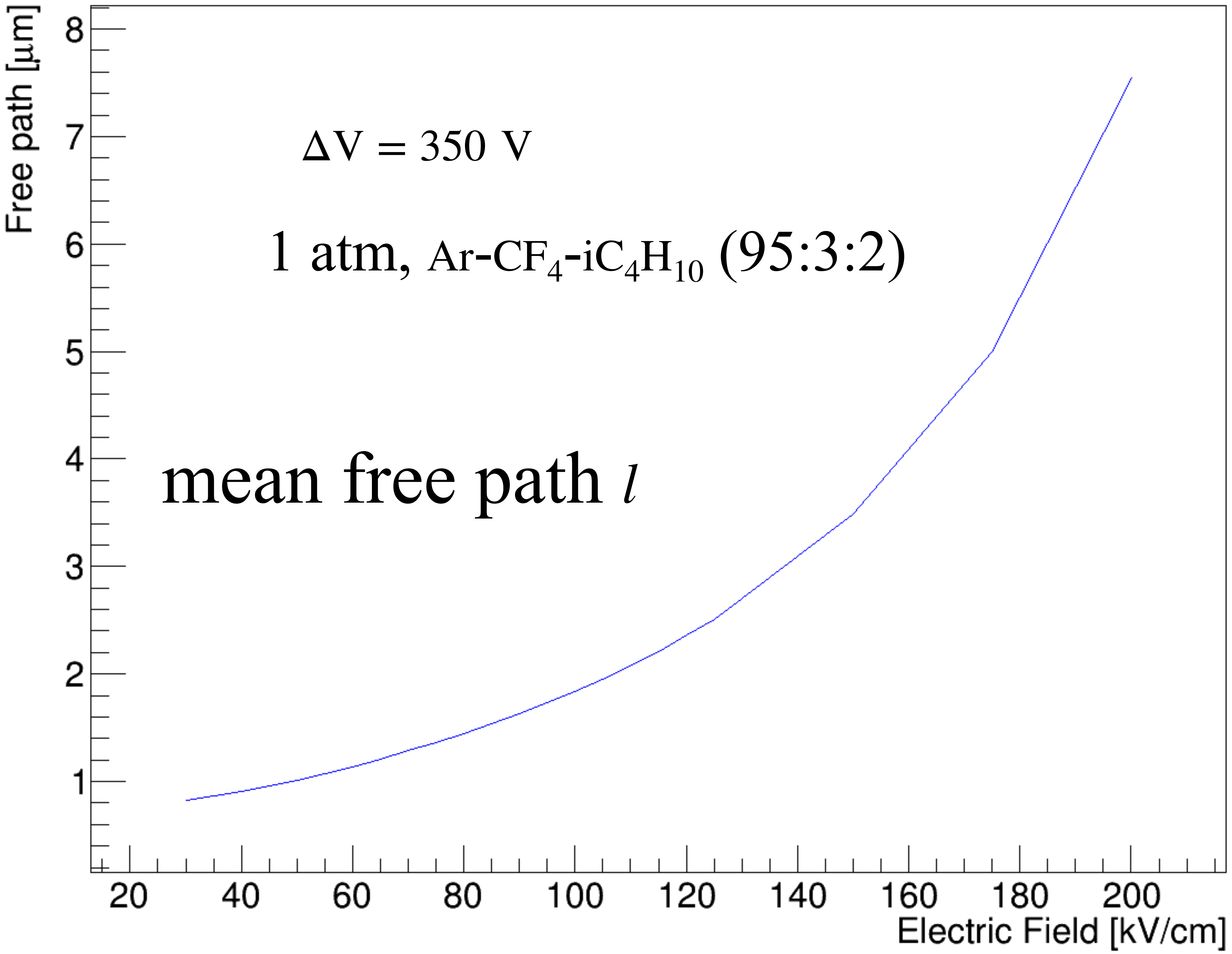
cf. CERN GEM:thickness $50\ \mu m$

If our theory is correct, the stability condition $\dfrac{\partial\sigma_0}{\partial\epsilon} = \dfrac{\sigma_0}{\epsilon}$ should be satisfied in this range

Free path distribution after each collision

To determine the cross section for each electric field value

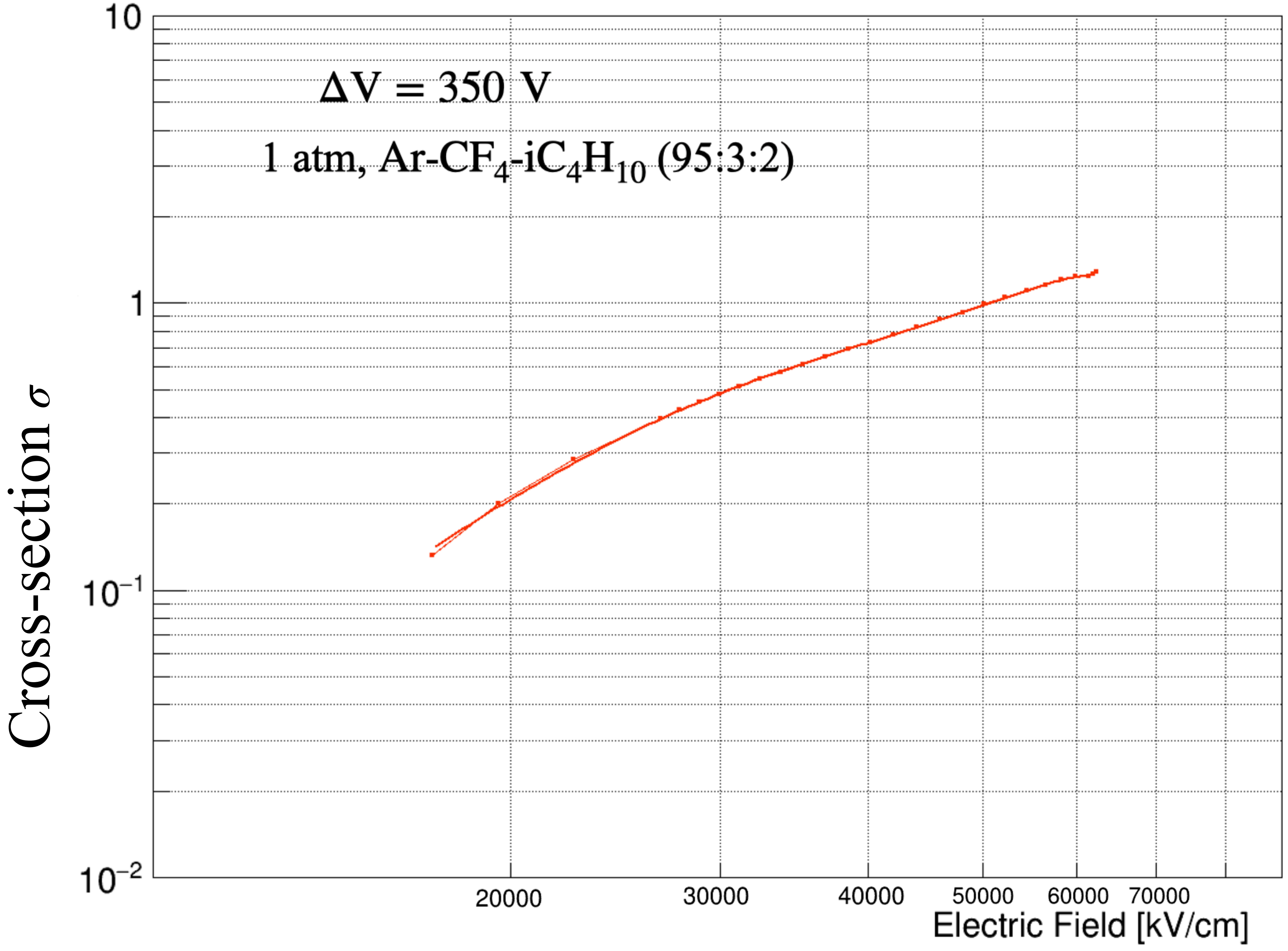
Mean free path of avalanche electrons l was used $\rightarrow$cross section $\sigma \propto \frac{1}{l}$



$\Delta V = 350$ V

1 atm, Ar-CF_4-iC_4H_{10} (95:3:2)

mean free path l



$\Delta V = 350$ V

1 atm, Ar-CF_4-iC_4H_{10} (95:3:2)

“Stability condition”

$$\frac{dG}{G} = \left(\frac{1}{1+\chi+\eta}\right)\left[1 - \frac{\epsilon}{\sigma_0}\left(\frac{\partial\sigma_0}{\partial\epsilon}\right)\right]\chi\,\delta\left(\frac{d\Delta}{\Delta}\right) \longrightarrow$$

Simulation result

$$\boxed{\frac{\partial\sigma_0}{\partial\epsilon} = \frac{\sigma_0}{\epsilon}}$$

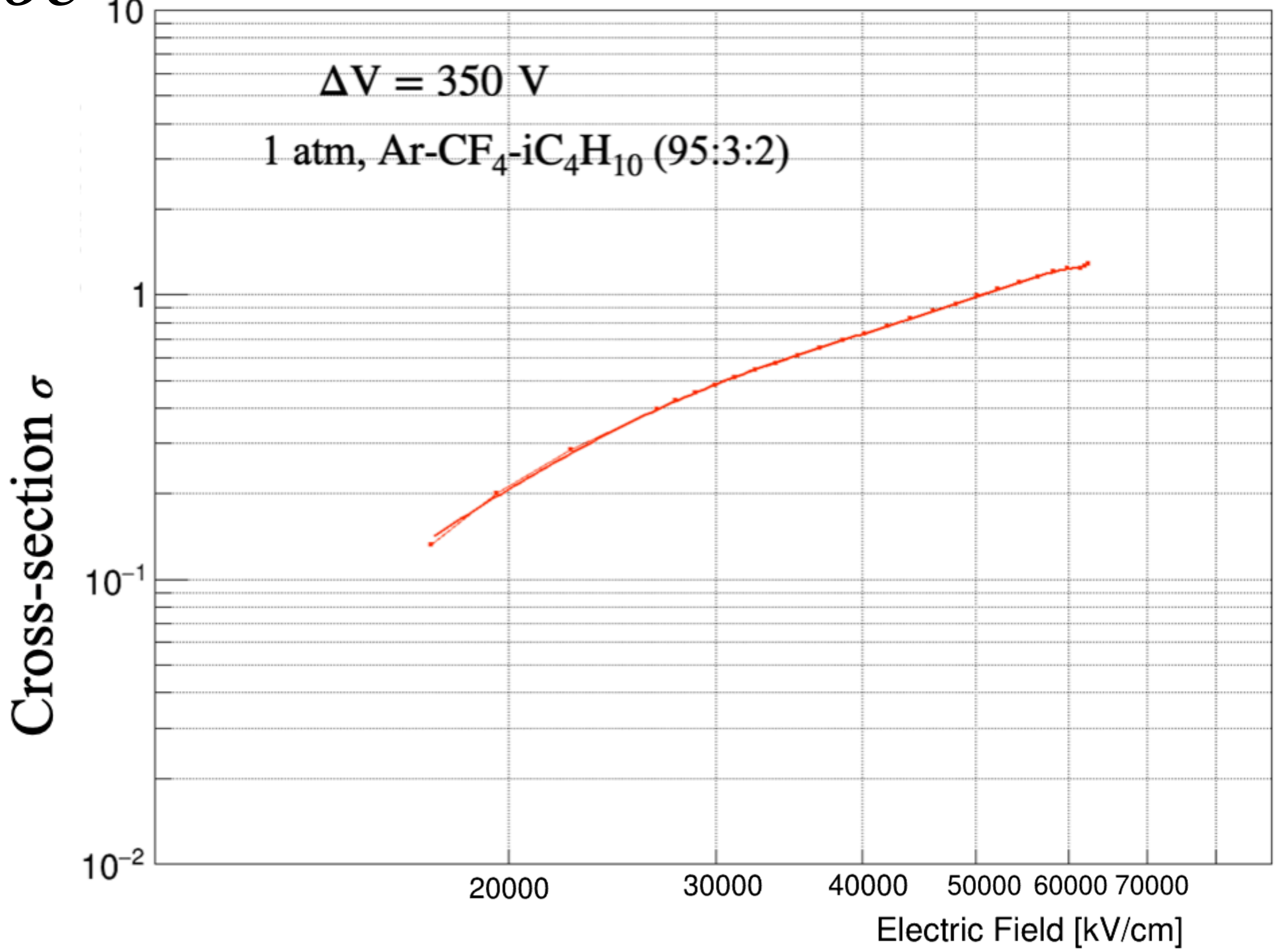
indicates

at the intersection point of

$\frac{\partial\sigma_0}{\partial\epsilon}$: Differentiation of

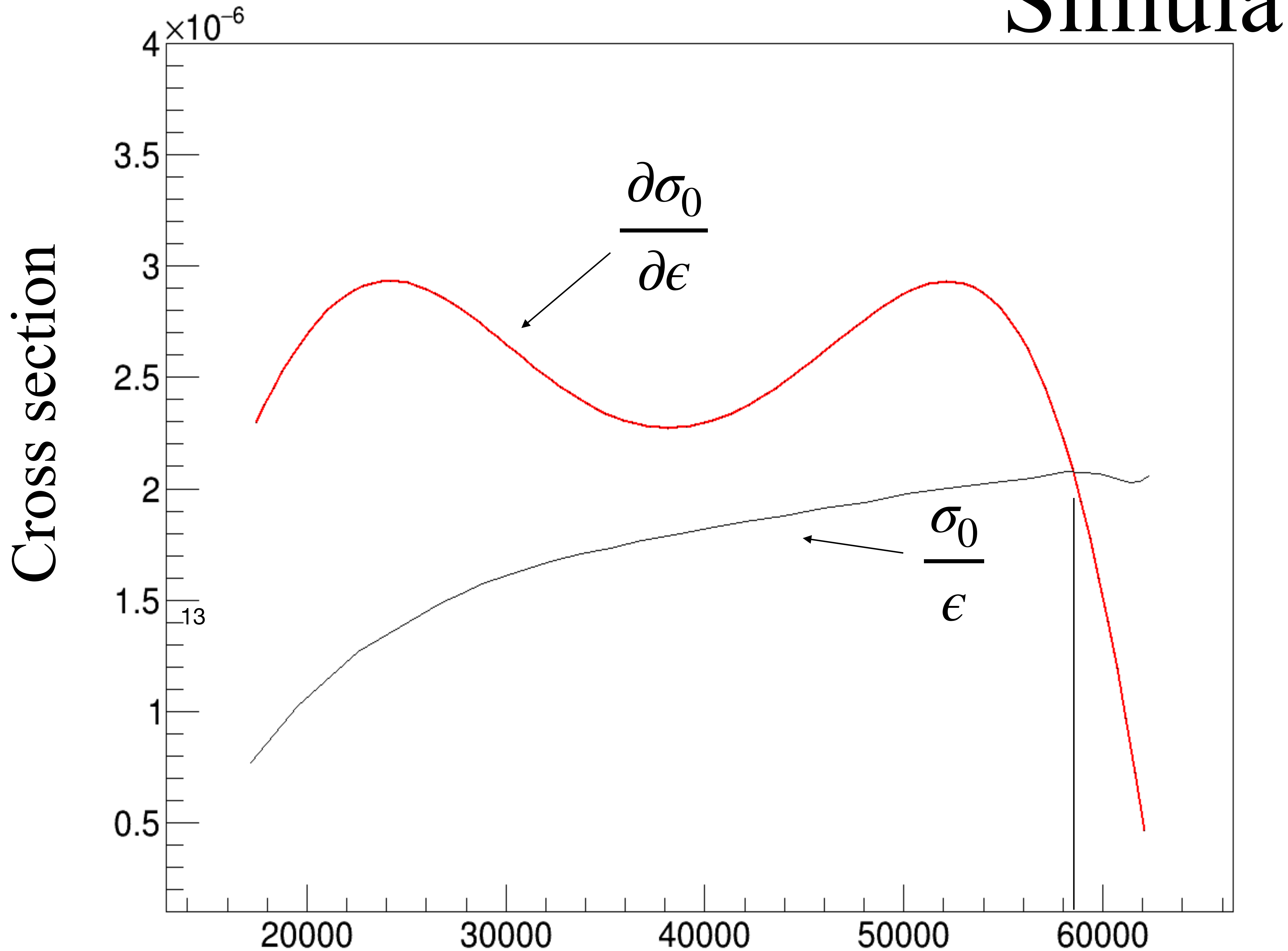
and

$\frac{\sigma_0}{\epsilon}$:cross section σ_0 divided by $\epsilon = E/n$



“Stability condition” is satisfied!!

Simulation result



~58 kV/cm

$\Delta V = 350$ V

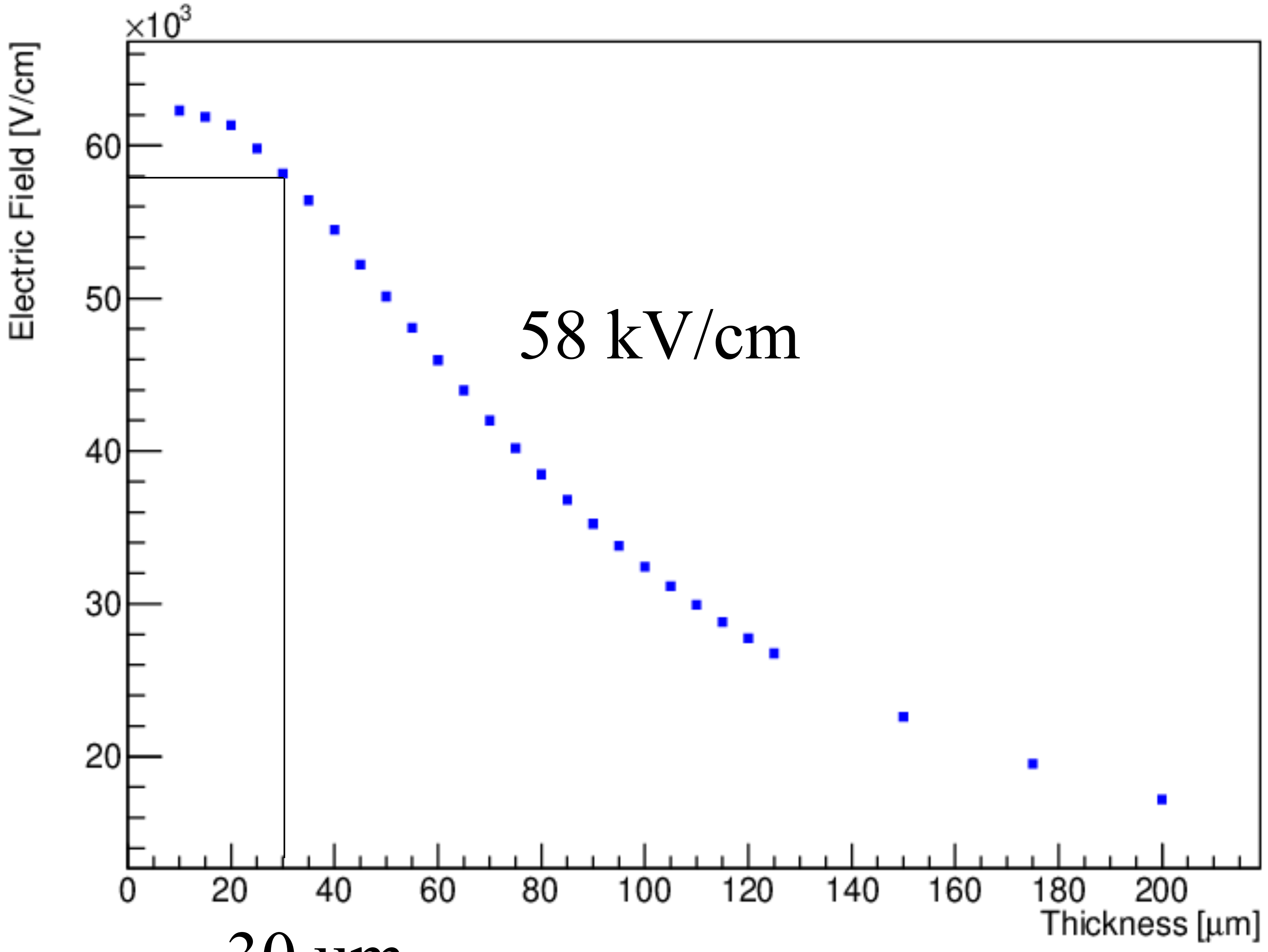
1 atm, Ar-CF_4-iC_4H_{10} (95:3:2)

this intersection point correspond to the electric field of $\sim 58\ kV/cm$

the thickness of GEM@58 kV/cm is

$\sim 30\ \mu m$ (+20 μm copper thickness)

and this thickness is almost same as CERN GEM 50 μm



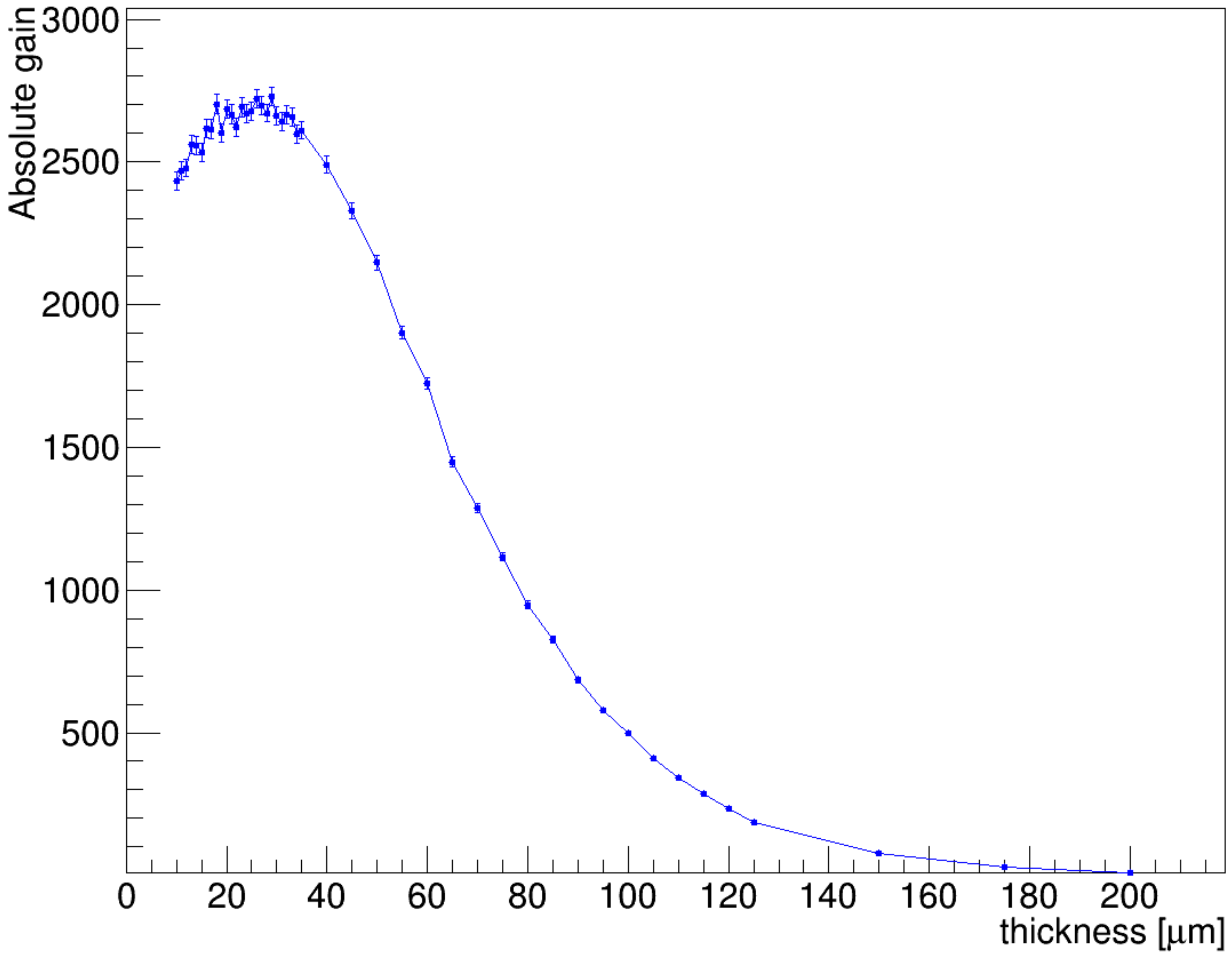
58 kV/cm

30 um

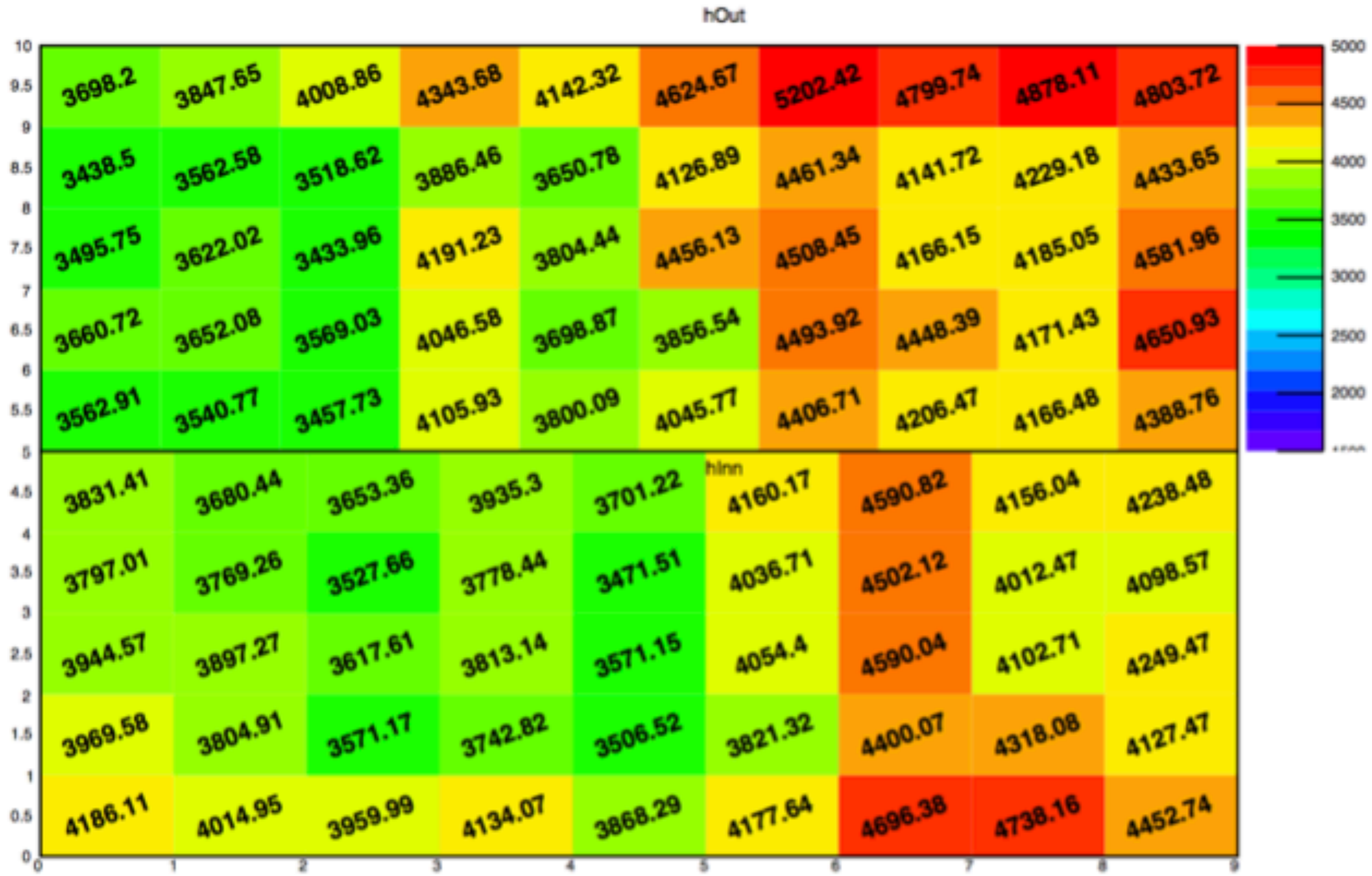
Thickness measurement

Thickness dependence of gain

From our simulation study, gas gain strongly depends on the thickness of GEM



measured gas gain over the pad



hOut

3698.2	3847.65	4008.86	4343.68	4142.32	4624.67	5202.42	4799.74	4878.11	4803.72
3438.5	3562.58	3518.62	3886.46	3650.78	4126.89	4461.34	4141.72	4229.18	4433.65
3495.75	3622.02	3433.96	4191.23	3804.44	4456.13	4508.45	4166.15	4185.05	4581.96
3660.72	3652.08	3569.03	4046.58	3698.87	3856.54	4493.92	4448.39	4171.43	4650.93
3562.91	3540.77	3457.73	4105.93	3800.09	4045.77	4406.71	4206.47	4166.48	4388.76

hInn

3831.41	3680.44	3653.36	3935.3	3701.22	4160.17	4590.82	4156.04	4238.48
3797.01	3769.26	3527.66	3778.44	3471.51	4036.71	4502.12	4012.47	4098.57
3944.57	3897.27	3617.61	3813.14	3571.15	4054.4	4590.04	4102.71	4249.47
3969.58	3804.91	3571.17	3742.82	3506.52	3821.32	4400.07	4318.08	4127.47
4186.11	4014.95	3959.99	4134.07	3868.29	4177.64	4696.38	4738.16	4452.74

arxiv:1701.05421

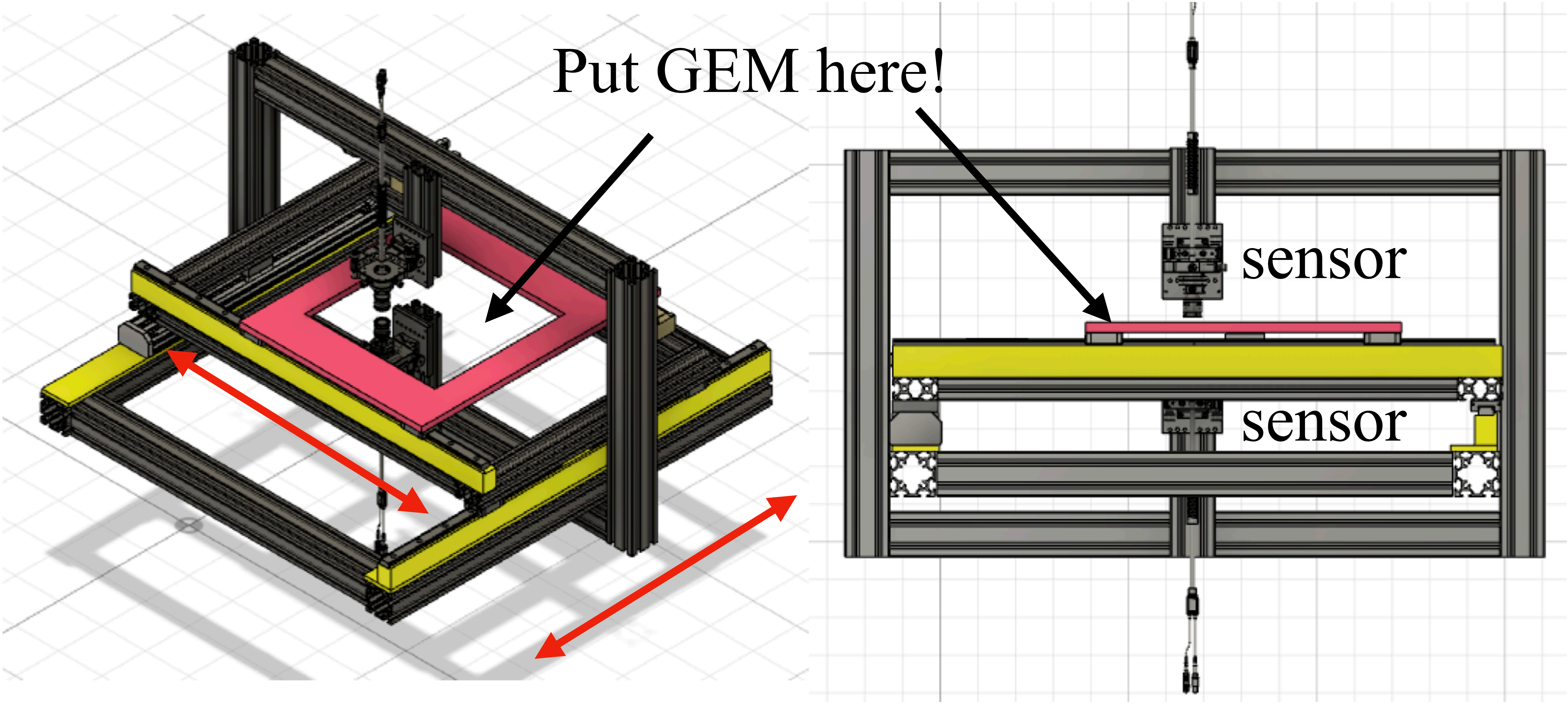
There is a gain variation of about 30% between the maximum and minimum values.

→due to thickness variation?

Need to investigate the cause of gain variation.

Thickness measurement system

3D Modelling

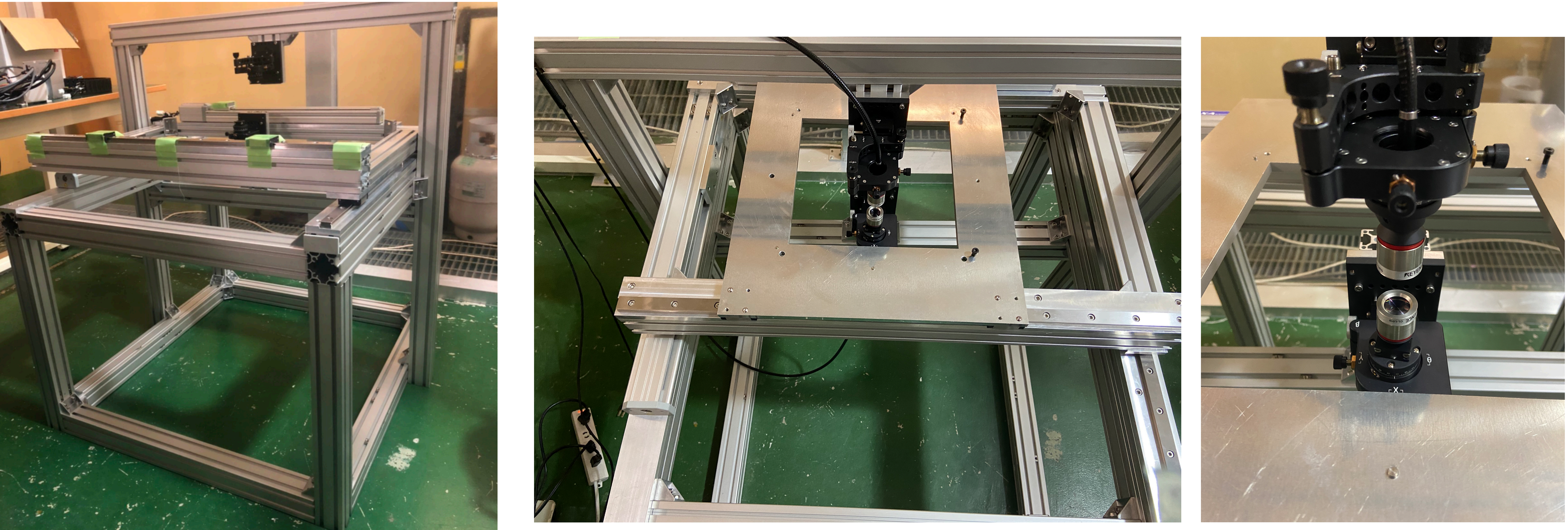


Put GEM here!

Our plan

Done! 1. 3D modelling of the measurement system

Done! 2. Setup (Assembly, Sensor calibration)



Our plan

1. 3D modelling of the measurement system Done!
2. Setup (Assembly, Sensor calibration) Done!
3. Software development
4. Thickness measurement

Not yet…
but on going!

5. Analysis

Compare the measurement result with simulation and investigate the cause of the large gain non-uniformity

will be finished by the end of March!

Summary

- To develop a high-performance GEM as a detector for LCTPC, we have worked on investigation of gas gain fluctuations.
- Theoretically derive the “Stability conditions” under which the gas gain fluctuations are cancelled.
- The gain plateau was found in the area corresponding to the stability condition.
- Therefore stability condition predicted by our theory is found consistent with the simulations so far.
- We have also been developing the thickness measurement system to investigate the cause of variation of measured gas gain.

Future Plan

Our simulation result indicates that we have to apply 350 V to 50 μm thick GEM.

we already have discharge problems with 100 μm thick GEM,

probably discharges will be a problem with 50 μm thick

This time, we applied a high voltage of 350 V such that sufficient gain was obtained for thicknesses of GEM in the range of 10 μm ~ 200 μm to verify our theory.

we need to investigate a geometry and a setup that satisfies "Stability Conditions" with

- sufficient collection efficiency $> 80\,\%$ and
- a high voltage that discharge does not happen much.

Also, we want to know

- how the intersecting points (p.13) that satisfies the stability condition changes by changing the applied high voltage and
- the effect of changing the hole size and copper thickness

Theory

We have equation of gas gain variation $\frac{dG}{G}$

$$\frac{dG}{G} = \left(\frac{1}{1+\chi+\eta}\right)\left[1 - \frac{\epsilon}{\sigma_0}\left(\frac{\partial\sigma_0}{\partial\epsilon}\right)\right]\chi\,\delta\left(\frac{d\Delta}{\Delta}\right)$$

where

G : gas gain
V : applied high voltage
$E = \frac{V/\Delta}{n}$, and Δ : thickness of GEM

scaling variable

$$\epsilon = \frac{E}{n},\ \delta = \frac{V}{U_0},\ \eta = n\Delta\frac{U_0}{V}\sigma_0(\epsilon),\ \chi = \frac{\ln G}{\delta}$$

Gas parameter

U_0 : ionisation potential
n : gas density
σ_0 : cross section

the coefficients can be deleted by tuning Δ, V depending on the gas parameters

Avalanche fluctuation

Avalanche fluctuation f

$$f \equiv \frac{\sigma_{N_e}^2}{< N_e >^2}$$

N_e :Gas gain

One of common empirical formula for avalanche fluctuations

Polya distribution

$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\overline{N_e}} \right)^{\theta} exp \left[-(1+\theta) \frac{N_e}{\overline{N_e}} \right]$$

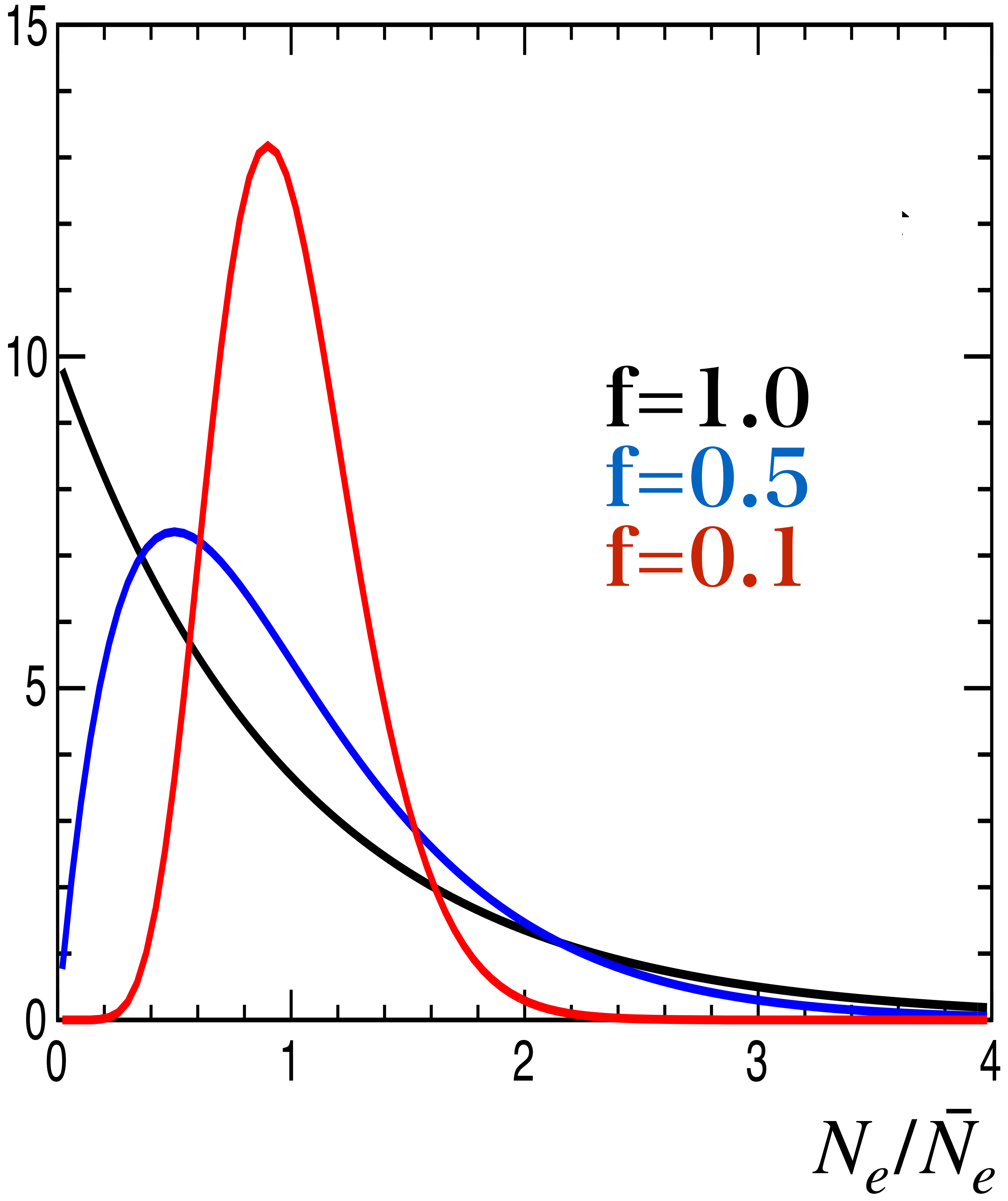
$\overline{N_e}$: mean of gain

θ : parameter of Polya distribution

$$\theta = \frac{1}{f} - 1$$

$$\theta = 0 \rightarrow f = 1.0$$

Exponential distribution



As f gets smaller, the fluctuations become more stable

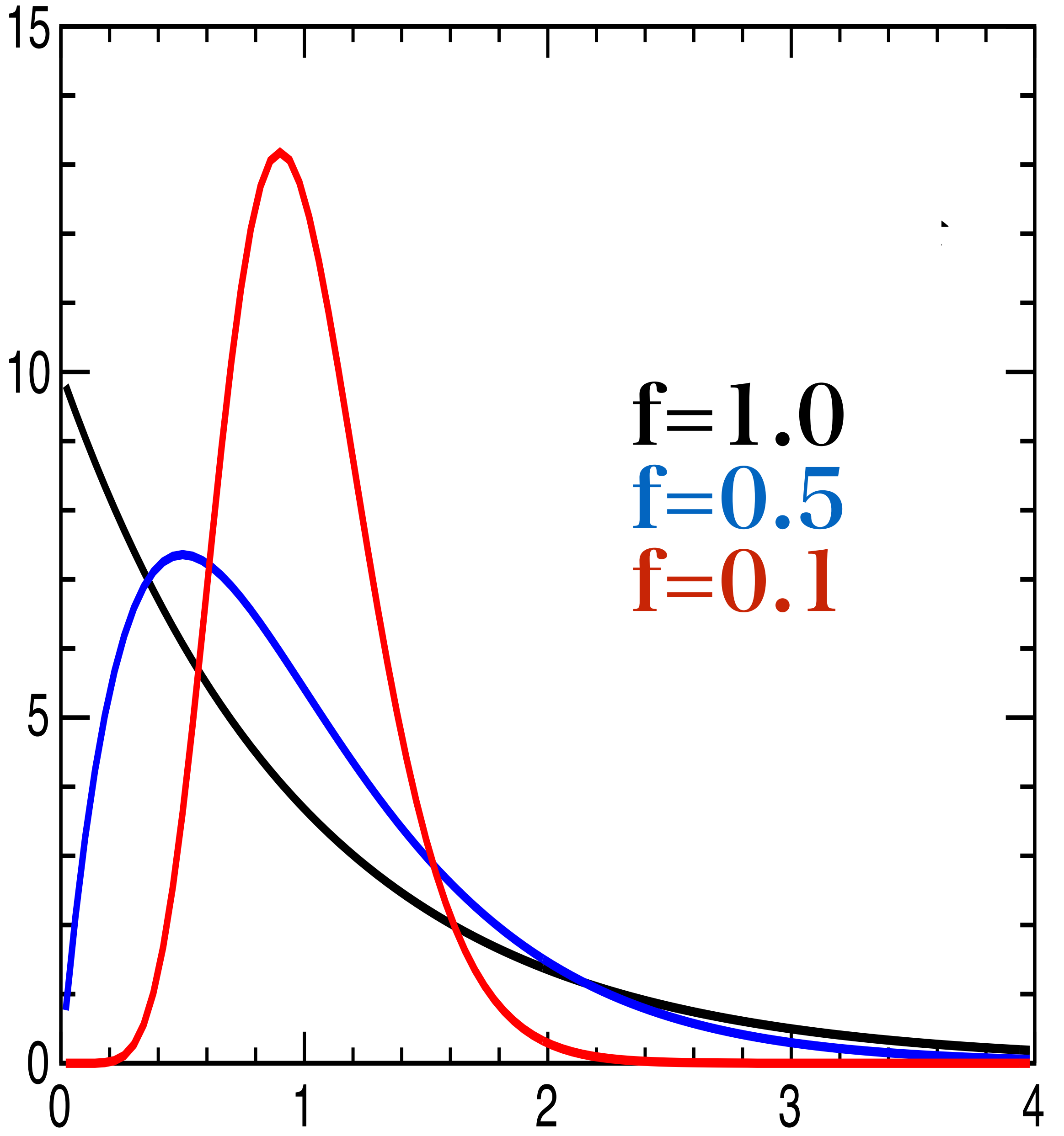
Avalanche fluctuation

Avalanche fluctuation f

$$f \equiv \frac{\sigma_{N_e}^2}{< N_e >^2}$$

Polya distribution

$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\overline{N_e}} \right)^{\theta} exp \left[-(1+\theta) \frac{N_e}{\overline{N_e}} \right]$$

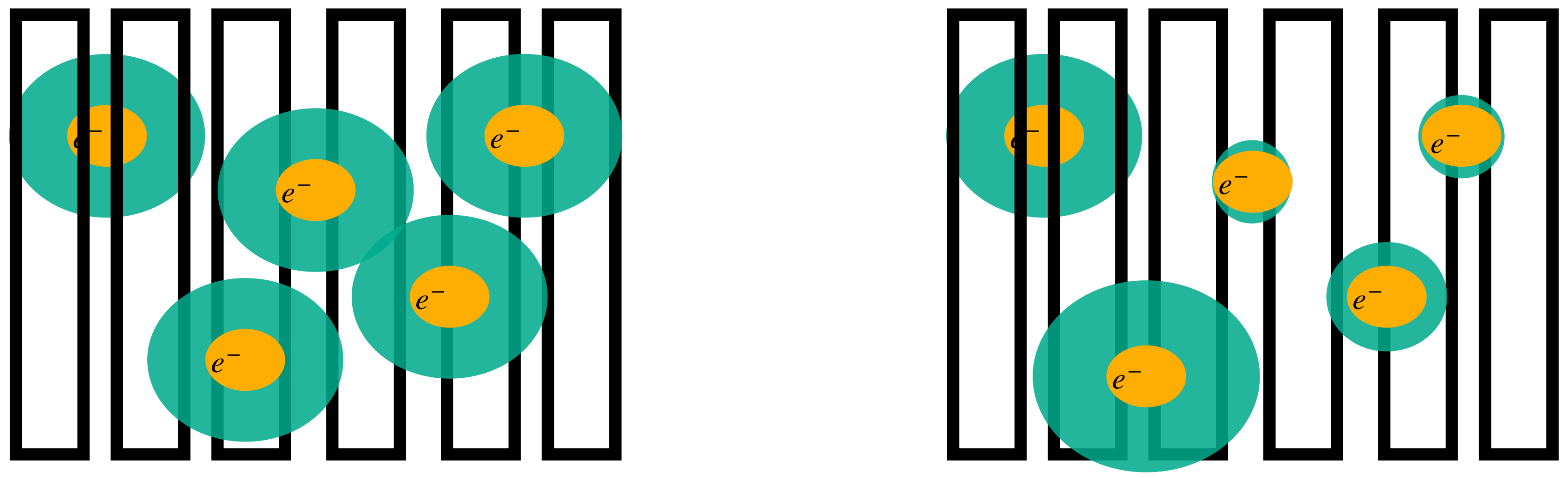


As f gets smaller, the fluctuations become more stable

fluctuation	small	large

● avalanche

e^- electron



f :small

f :large

charge center of gravity method	good	bad

Avalanche fluctuation

Avalanche fluctuation f

$$f \equiv \frac{\sigma_{N_e}^2}{< N_e >^2}$$

Larger values of f make the detector performance worse

Position resolution

$$\sigma_x = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot z}{\boxed{N_{eff}}}}$$

z: **drift length**

N_{eff}: **effective number of electron**

C_d: **diffusion constant of gas**

$$\frac{1}{N_{eff}} = \left\langle \frac{1}{N} \right\rangle * (1 + f)$$

N : number of primary electrons

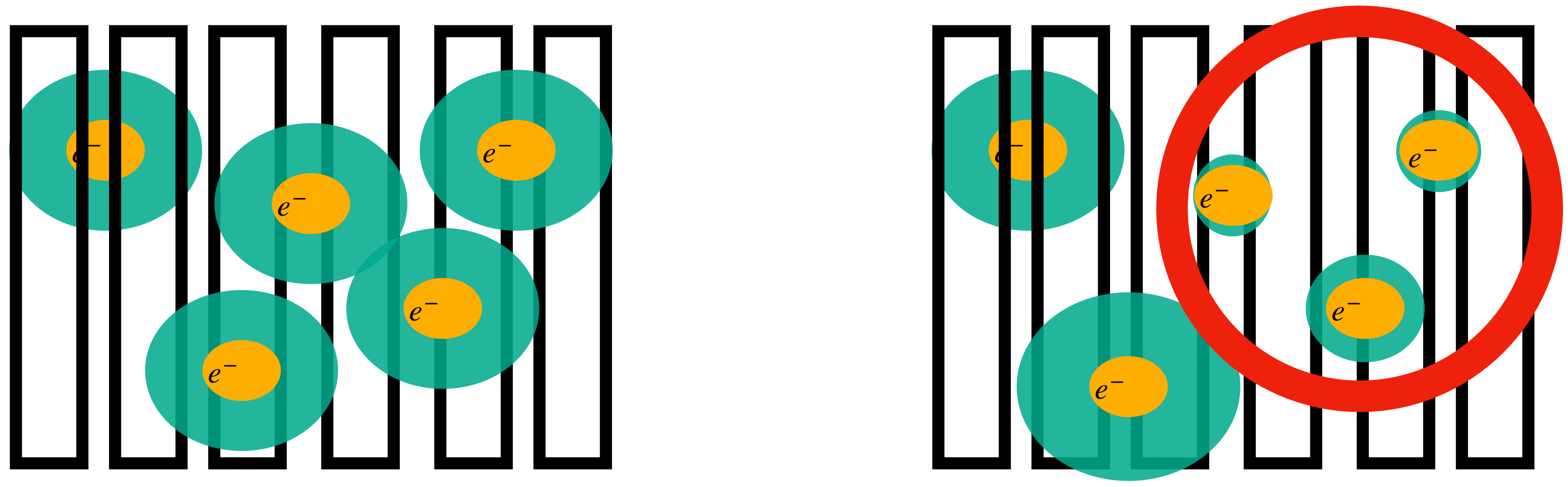
fluctuation

● avalanche

e^- electron

small

large



These electrons contribute little to the position measurement

f :small

f :large

N_{eff} :large

N_{eff} :small

$\rightarrow N_{eff}$ can be small

Avalanche fluctuation

Avalanche fluctuation f

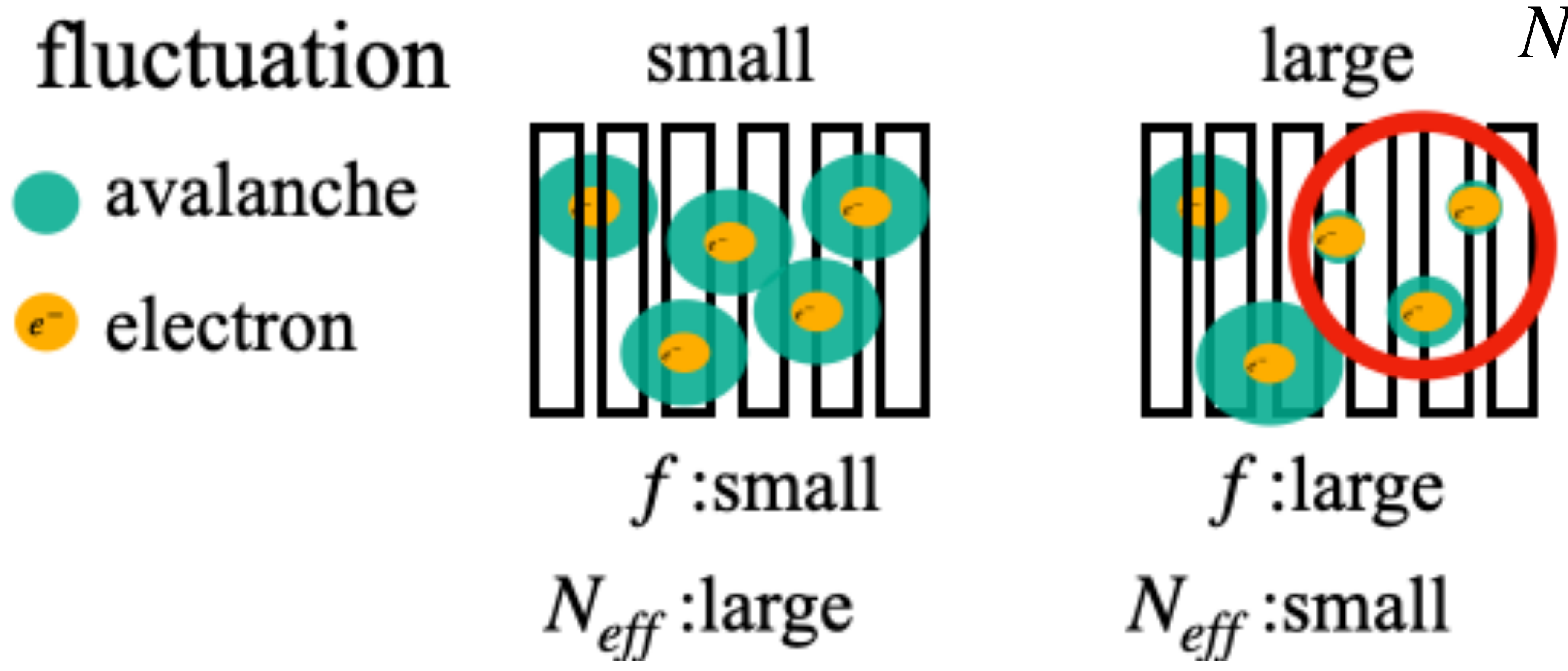
$$f \equiv \frac{\sigma_{N_e}^2}{< N_e >^2}$$

affects the detector performance

Position resolution

$$\sigma_x = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot z}{\boxed{N_{eff}}}}$$

$$\frac{1}{N_{eff}} = \left\langle \frac{1}{N} \right\rangle * (1 + f)$$



Make the position resolution better by increasing N_{eff}

To increase N_{eff}, we need to increase $< N >$ and decrease f

depends on the gas, density, pad row height and so on