

Plan for ion back flow measurements with gating GEM @CERN

I plan to stay at CERN from October 8 to December 14
to conduct performance evaluations of Gating GEM.

Kanako Watanabe

Iwate University

In the ILD-TPC, ions generated during electron amplification using GEMs and other devices flow backward into the drift region and distort the electric field (IBF).

→ IBF is suppressed using the Gating GEM.

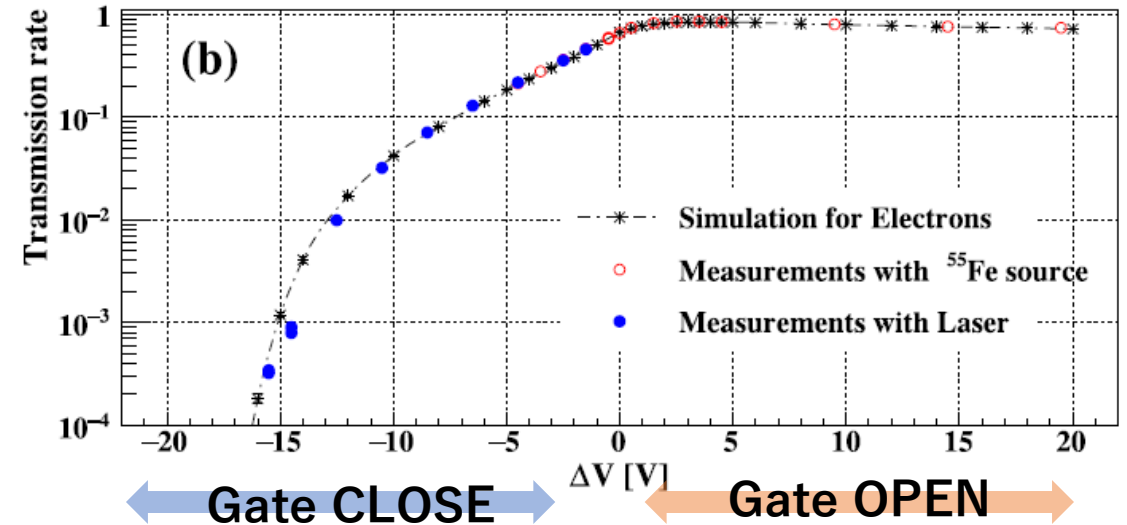
Measure the ion stopping power of the large-aperture GEM at reversed polarity under space-charge free effects.

Gate open ... high electron transparency

Gate close ... low ion transparency

➡ **Measure electron transparency & ion stopping power with changing ΔV**

- M. Kobayashi (2019)
 - Double Asian GEM, T2K
 - Estimating ion transparency from electron transparency
- P. Thuiner (2017)
 - Triple standard CERN GEM, ArCO₂
 - Direct Measurement of electron transparency and ion transparency



Gating GEM

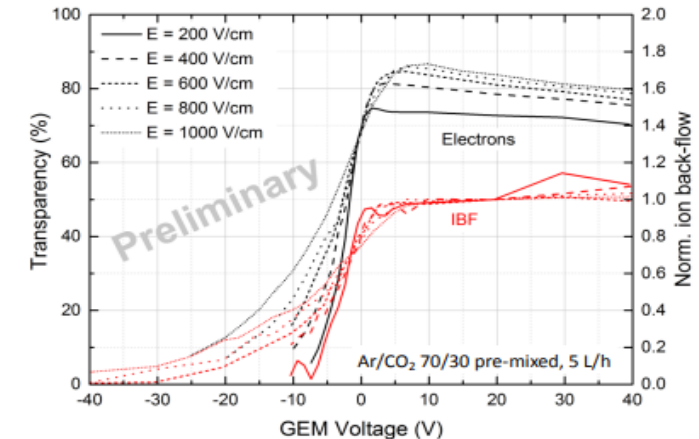
Ion back-flow at equal fields

Ion back-flow reaches **maximum** at approx. **same voltage** as for electron transparency

Higher voltages than for electrons to fully **close gate**

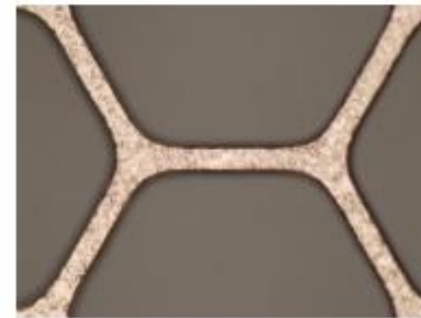
Very preliminary data with large error bars (not shown)!

IBF normalized to $\Delta V_{\text{GEM}} = 20 \text{ V}$

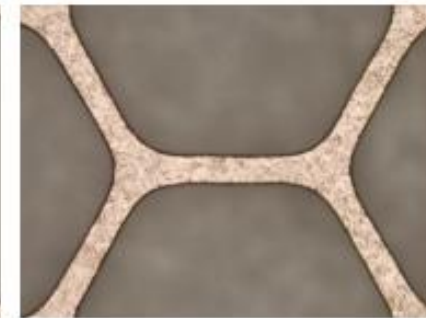


Gating GEM Setup

Hole size	303.4 μm
Hole pitch	335.0 μm
Optical transparency	82%
Cu thickness (front)	7.2 μm
Cu thickness (back)	1.2 μm
Insulator thickness	(?) 12 μm
Rim width (front side)	27.7 μm
Rim width (back side)	31.6 μm
Active area	10 cm x 10 cm



Top (detail)



Bottom (detail)



Top



Cross-section (detail)

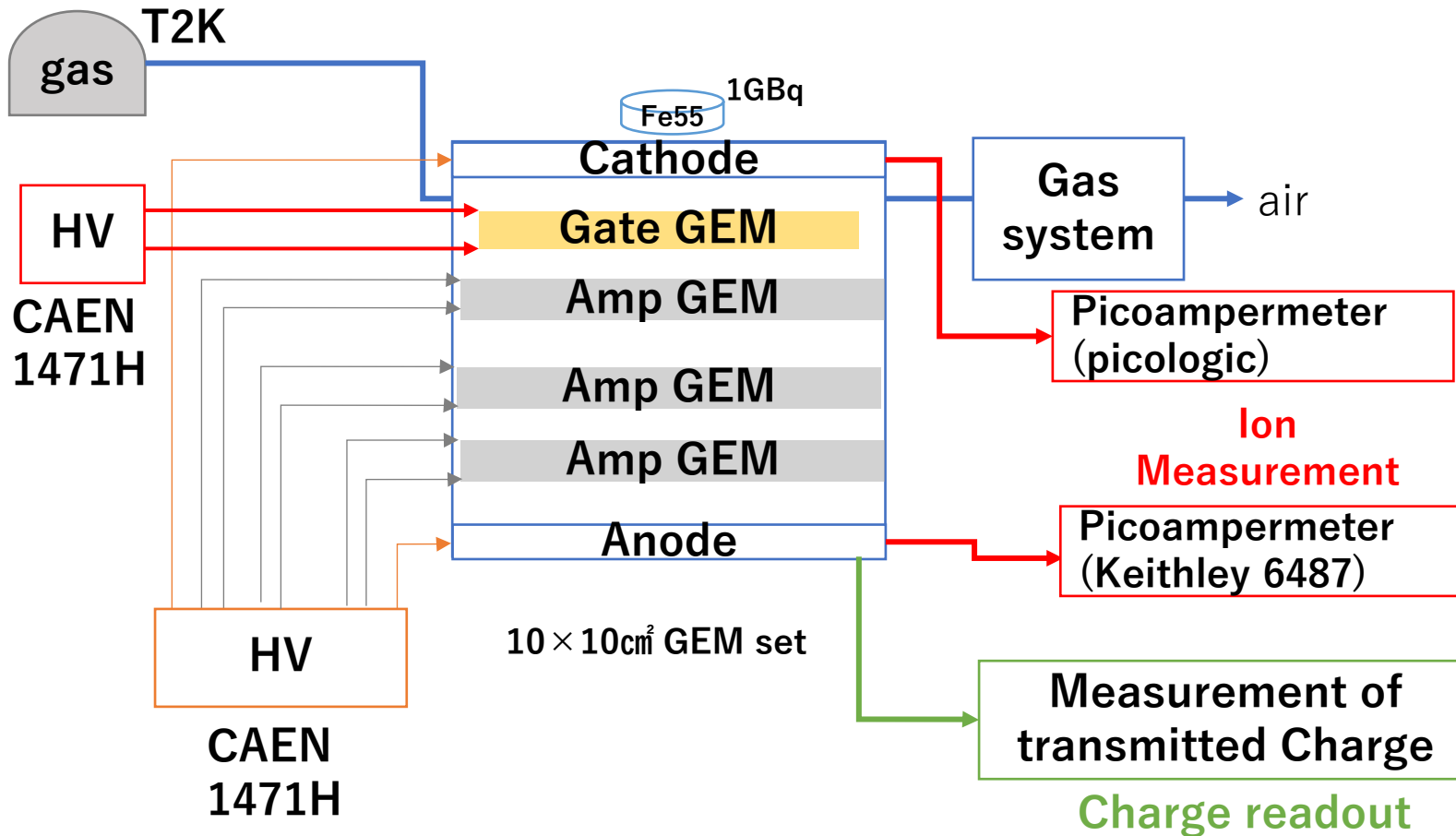
Reference

P. Colas, P. Thuiner, Latest measurements on gating GEMs

<https://indico.cern.ch/event/607147/contributions/2482621/attachments/1417119/2170091/20170223gatingGEM.pdf>

Experimental Setup

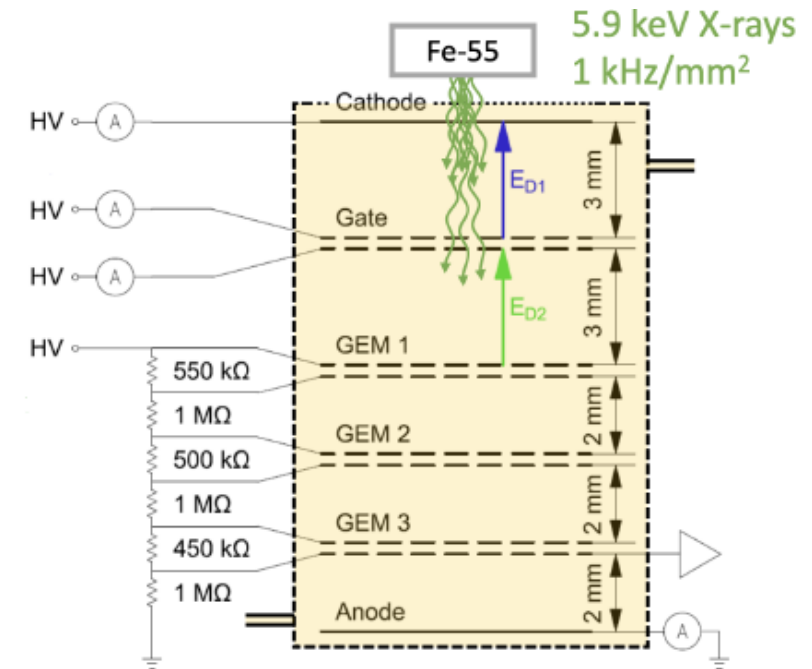
5



- T2K gas (Ar : CF₄ : iC₄H₁₀ = 95 : 3 : 2)
- Triple(or Double) standard CERN GEM
- HV : CAEN1471H
- Picoampmeter_Cathode : ALICE floating picoammeter(picologic)
- Picoampmeter_Anode : Keithley 6487

Reference setup

P. Colas, P. Thuiner, Latest measurements on gating GEMs



Picoampemeter

- shield everything well from external 50/60Hz fields
- the noise that comes from HV supply
→ maybe need HV filter ?

Measurement Parameters:

- Gain
- Electron transparency

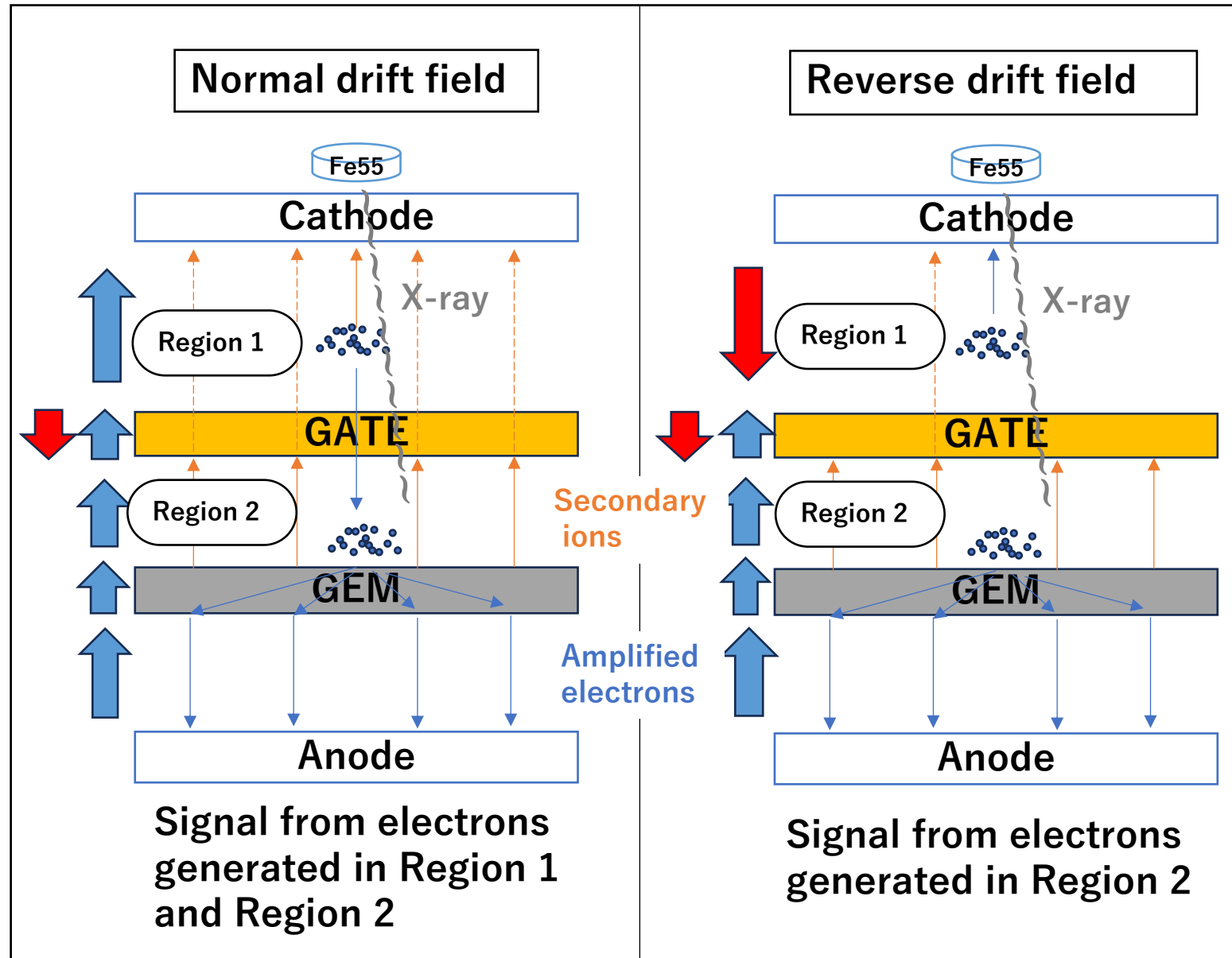
$$\text{Electron transparency} = \frac{\text{Peak1} - \text{pedestal}}{\text{Peak2} - \text{pedestal}}$$

- Cathode current I_C
- Anode current I_A
- IBF

$$\text{IBF} = \frac{I_{C_ON} - I_{C_OFF}}{I_{A_ON} - I_{A_OFF}}$$

- X-ray intensity dependence
 - Identify the space-charge-free region
 - Compare Gain, Electron transparency, and IBF as X-ray intensity is varied

➡ Evaluate electron transparency and IBF using gain $\times$ IBF as a performance metric



Expected Current by Fe55

7

- $N_{\text{amplified electron}} = N_{\text{initial electron}} \times \text{Gain}$
- $N_{\text{amplified ion}} \approx N_{\text{amplified electron}}$
- $N_{\text{back ion}} = N_{\text{amplified ion}} \times \text{IBF}$
- $I_{\text{cathode/event}} = N_{\text{back ion}} \times 1.602 \times 10^{-19}$

$$\begin{aligned} N_{\text{initial e}} &= 5.9\text{keV}/26 = 227 \\ \text{Gain} &= 3000 \\ \text{Fe55} &= 1\text{GBq} \end{aligned}$$

incident X-ray rate
= X-ray source intensity [Bq]
× effective transmission efficiency

$$I_{\text{cathode}} = N_{\text{initial electron}} \times \text{Gain} \times \text{IBF} \times 1.602 \times 10^{-19} \times \text{Incident X-ray rate}$$

(227) (3000)

Fe55 incident X-ray rate	IBF = 10-2	IBF = 10-3	IBF = 10-4
10kHz	10.9 pA	1.09 pA	0.109 pA
100kHz	109 pA	10.9 pA	1.09 pA
1MHz	1.09 nA	109 pA	10.9 pA
10MHz	10.9nA	1.09nA	109pA
	IBF × Gain=30	IBF × Gain=3	IBF × Gain=0.3

$$\text{Incident X-ray rate} \approx 1\text{GHz} \times 0.25 \times 0.1 \times 0.13 \approx 3.25\text{MHz}$$

- **25%:** Approximate fraction of Fe55 decays producing **Mn Kα X-rays (5.9 keV)**
- **10%:** Overall **transmission factor** accounting for attenuation in the source/Mylar window/gas/geometric acceptance up to the Cathode
- **13%:** **Absorption probability** of 5.9 keV X-rays in the 3 mm drift region between Cathode-Gate

If $\text{IBF} \times \text{Gain} < 1$,
picoammeter capable of
measuring currents
ranging from a few pA
to tens of fA is required.

Expected
range

Expected Current by X-ray tube

8

In the ALICE TPC, since the IBF current is too small at rates below 100 pA—resulting in a poor signal-to-noise ratio relative to the background current—an X-ray tube was used to increase the current. Ref. M. Ball, Ion backflow studies for the ALICE TPC upgrade with GEMs, MPGD2013

Based on this, I estimated what current values could be expected given certain injection rates and IBF values.

$$N_{initial\ electron} = \frac{22000}{26} \approx 846$$

$$N_{amplified\ electron} = N_{initial\ electron} \times Gain$$

$$I_{cathode} = \underset{(846)}{N_{initial\ electron}} \times \underset{(3000)}{Gain} \times IBF \times 1.602 \times 10^{-19} \times Rx$$

X-ray tube Mini-X (used at ALICE TPC)

Energy : 22 keV (Ag target)

Typical Flux

: 6×10^4 counts/s/mm² /uA
@30 cm, on-axis, 50 kV

Rx	IBF = 10 ⁻²	IBF = 10 ⁻³	IBF = 10 ⁻⁴
1 kHz	4.1 pA	0.41 pA	0.041 pA
10 kHz	41 pA	4.1 pA	0.41 pA
100kHz	410 pA	41 pA	4.1 pA
1MHz	4.1 nA	410 pA	41 pA
10MHz	41 nA	4.1 nA	410 pA
	IBF × Gain=30	IBF × Gain=3	IBF × Gain=0.3

Rx [Hz] = Incident X-ray rate

(I checked a wide range to find a range where the current would be several tens of pA or more, but it is unclear whether this rate can actually be achieved.)

Cathode side... picologic

- **Measuring range:** ± 125 nA. It can be changed to ± 62.5 nA.
- **Resolution (LSB):** 4 pA at the measuring range ± 125 nA.
- **Sampling frequency:** 1 kHz
- **HV:** It was tested up to ± 5 kV. The limitations were the SHV connectors and cables.

https://indico.cern.ch/event/365380/contributions/1780297/attachments/726497/996960/pmf_picoammeter.pdf

Anode side... Keithley 6487

- **Measuring range:** ± 2 nA $\sim$ ± 20 mA
- **Resolution :** 10 fA at the measuring range ± 2 nA.
- **Sampling frequency:** up to 1000 reading/s
- **HV:** ± 505 V DC

<https://www.tek.com/en/datasheet/series-6400-picoammeters/6487-picoammeter-voltage-source>

Noise check

■ X-ray OFF

■ HV scan = 0, -500, -1000, -1500, -2000 V ➡ Baseline current measurement

- Check whether the measured current/noise changes with cathode HV

■ HV ripple / cable noise / 50–60 Hz noise ➡ RMS / periodic noise characterization

- Check the current as a function of time at each HV setting.

➡ Establish the baseline current and noise before measuring the ion backflow signal.

Main goal:

Measure the ion stopping power of the large-aperture GEM at reversed polarity under space-charge free effects.

Intermediate steps:

(① Set up equipment)

① Measure electron transparency

- Study space-charge effects & Identify the optimal operating voltage by varying the intensity of the X-ray source.
- Optimize the applied voltage to maximize electron transmittance.

② Measure ion stopping power

- Measure ion stopping power at optimal ΔV under both nominal and optimized GEM stack voltages.
- Measure ion stopping power while varying the applied voltage (including reversed polarity) to determine the optimal working point.

➡ Measure electron transparency & ion stopping power with changing ΔV

----- How to Apply Bias Voltage to the Detector -----

- A proposal was made to apply high voltage to the anode side and connect the cathode side to GND.
- This may make the cathode-side handling/processing easier. Care must be taken during assembly to avoid discharges.
 - ➡ My opinion : I think bringing the cathode side to GND is a good option. One reason is that, if we want to use a picoammeter for the GATE current measurement as well, the GATE voltage may be lower than in the previous setup, which could reduce the required voltage range of the picoammeter. This may give us more flexibility in selecting a suitable picoammeter, although the required voltage may still be outside the instrument's range.

----- X-ray Irradiation Position -----

- Is the interior of the detector completely covered with metal? When X-rays enter through the window, there is a possibility that X-ray conversion may also occur outside the active region.
- In the past, to avoid unintended X-ray conversion in other regions, a small tube was used to direct the X-rays into the drift region, so that the X-ray conversion occurred in the drift region. However, this setup is mechanically quite challenging.
- -### Question:
Does “directly introducing the X-rays into the drift region” mean that there was a small window on the side of the detector through which the X-rays were introduced?

----- Current Correction -----

- A method can be used to measure the current generated in each region separately and correct for (subtract) the contribution from unintended X-ray conversions.
- If this correction is difficult, an alternative frame/setup may be considered.

----- GEM Charging-Up and Stabilization -----

- In previous measurements, the signal changed over time due to charging-up/polarization of the insulating parts, so it was necessary to wait until the signal reached a stable condition.
- A similar effect may occur this time. If so, we should wait for a sufficient amount of time until the detector reaches a stable condition before taking measurements.

----- IBF Measurement -----

- The anode current and cathode current are measured simultaneously, which allows us to monitor their relative changes.
- It was proposed to measure not only the ion backflow of the entire GEM stack, but also to distinguish the contribution of the gate GEM to the overall IBF.
- By simultaneously monitoring the anode current, cathode current, and gate current, we may be able to evaluate the relative changes in each component.

Question:

Is measuring the gate current similar to the approach used in P. Tüinuer's 2017 study?

----- X-ray Tube -----

- A proposal was made to irradiate a relatively wide area in order to reduce the local X-ray rate.
- The reason is that a high local rate may cause problems in the detector before reaching the desired operating conditions.

----- Measuring with the Gate GEM Flipped Upside Down -----

- Since the GEM is not perfectly symmetric and has conical holes, flipping it upside down may result in different performance.
- The effect may be small because the hole openings are relatively large, but this would be an interesting configuration to investigate since it has not been studied previously.

.

----- High-Speed Voltage ON/OFF Switching -----

- The possibility of performing measurements involving rapid switching of the electrode voltage was discussed.
- We will consider whether the high-speed switching device (on the nanosecond scale) introduced by Marco Cortese at MPGD could be used for this purpose. The device could not be transported from Japan.
- Since the required voltage change is only on the order of several tens of volts, it may be feasible.

----- Limited Availability of Gate GEMs -----

- The gate GEM (10 × 10 cm) currently available has a history of being shorted and has subsequently been cleaned and repaired.
- We also have a prototype-size gate GEM in Japan. However, it cannot be cut to the required size, and we need to confirm when it was last used (Probably the 2016 beam test ?).
- Having a new GEM of the same type produced by a Japanese manufacturer would be difficult and expensive.
- Therefore, we should also consider alternative plans in case the currently available gate GEM cannot be used

Back up

~ List of Items to Prepare ~

List of Items to Prepare 【CERN】 -1

16

【】 ... model numbers used during experiments at KEK

Gas system

- T2K gas
- Mass Flow Meter
- Gas bubbler(liquid Si)
- (H2O monitor)
- (O2 monitor)

GEM

- GATE (10×10cm)
- GEM (10×10cm)
- Chamber (for 10×10cm)

The only chamber in Iwate U. capable of laser irradiation is the one for Asian GEM.

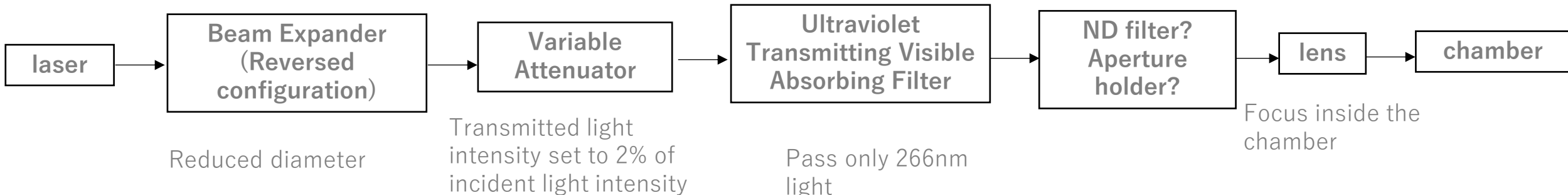
Source

- Fe55 source
- Laser (Nd:YAG)
【NEW WAVE RESEARCH POLARIS】

Optical System for guiding laser (p.9)

- Beam Expander 【SIGMA KOKI BE-3-266】
- Variable Attenuator 【SIGMA KOKI SVAB-266A-08】
- Ultraviolet Transmitting Visible Absorbing Filter SIGMA KOKI UTVAF-50S-33U
- (ND Filter)
- (Aperture holder 【SIGMA KOKI IH30】)
- (Convex-flat lens (focal length 600mm))

▼ Optical system setup at KEK as predicted from the above
(this is merely a past example, and whether the same setup is required remains to be discussed)



【】 ... model numbers used during experiments at KEK

Power supply

- Power supply for GEM & Cathode 【CAEN SY 2527LC Universal Multichannel Power Supply System】
- (HV Control PC (for CAEN HV))
- Voltage Divider Box (The voltage was applied via a protection circuit.)

Measurement system (for ion current)

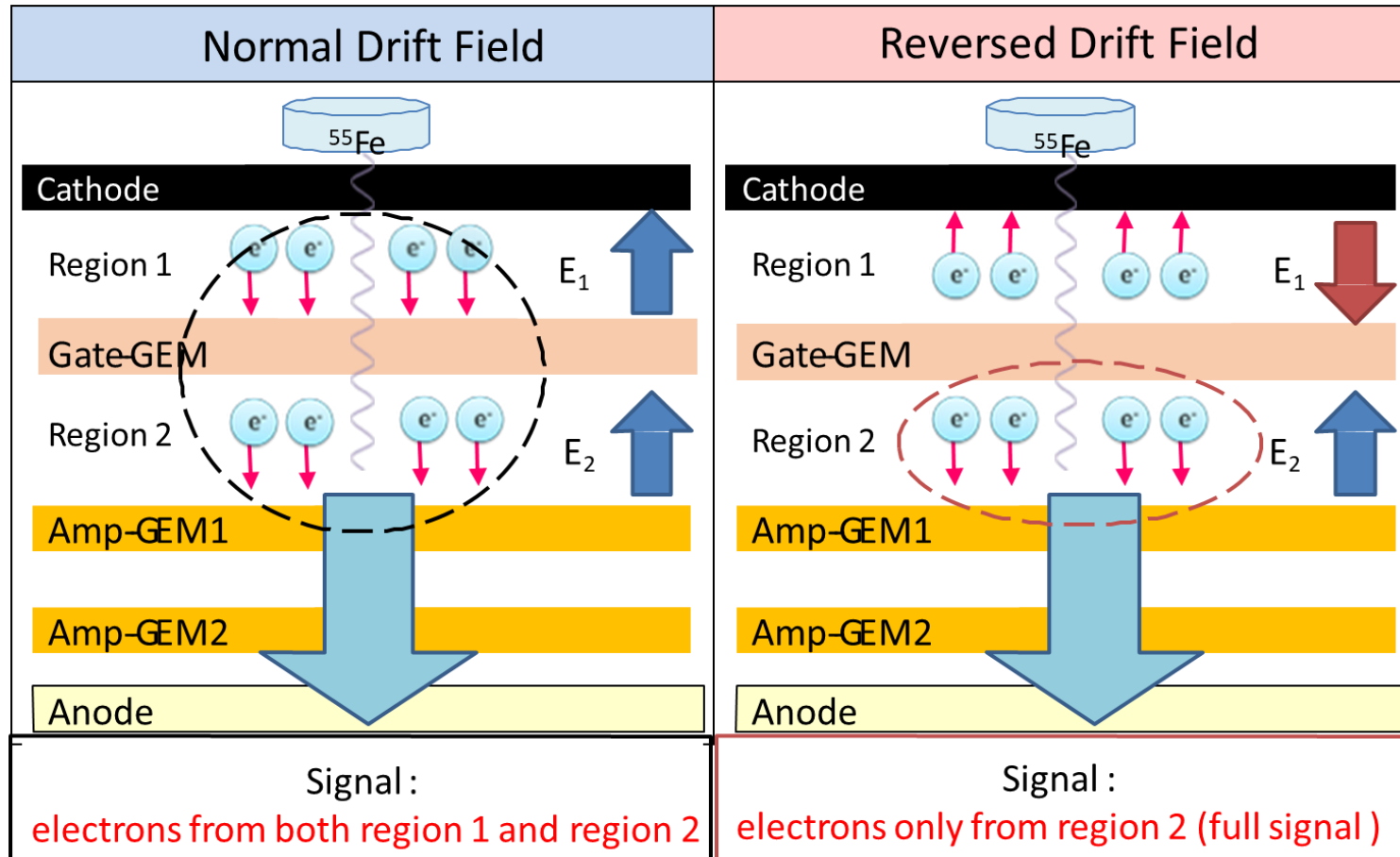
- Picoampermeter

Measurement system (for Gain measurement) (p.8)

- Charge-sensitive preamplifier 【ORTEC 142PC】
 - Shaper amplifier 【ORTEC 672】
- (The total gain of the amplifiers is 14V/pC and 10V/pC, respectively in the 55Fe runs and the laser runs.)
- converter 【 ORTEC MODEL LI380/NL 】
 - Inverter
 - Attenuator
 - Discriminator
 - Gate Generator
 - CAMAC ADC 【 Hoshin ADC C008, 12-bit resolution for 0–2.5 V input 】
 - CAMAC Crate controller 【TOYO CC/NET】
 - CAMAC Crate power supply 【TOYO MODEL PS-6000】

Back up

~Past Measurement Concepts~



[3] A,Shoji, Measurements of the electron transmission rate of a full-size gating GEM in the absence of magnetic field, LCWS2016, 2016

When using ^{55}Fe as the source, the low number of transmitted electrons during gate CLOSE makes lasers more suitable for low-transmittance measurements.

Using laser

The electron transmission rate when using the laser was determined from the ratio of the peak position to that in the corresponding normalization run using the ^{55}Fe source, for which the transmission rate had been measured to be $58.74 \pm 0.11\%$.

Using ^{55}Fe

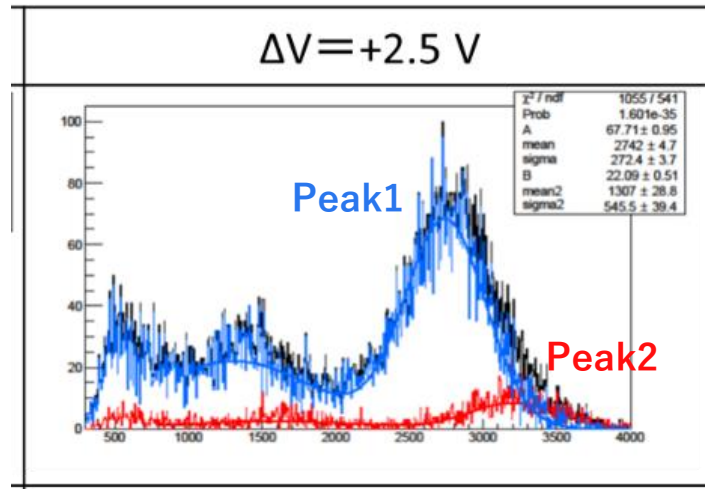
$$\text{Electron transmission rate} = \frac{\text{Peak1} - \text{pedestal}}{\text{Peak2} - \text{pedestal}} \times 100 \quad [\%]$$

Ref. [3]

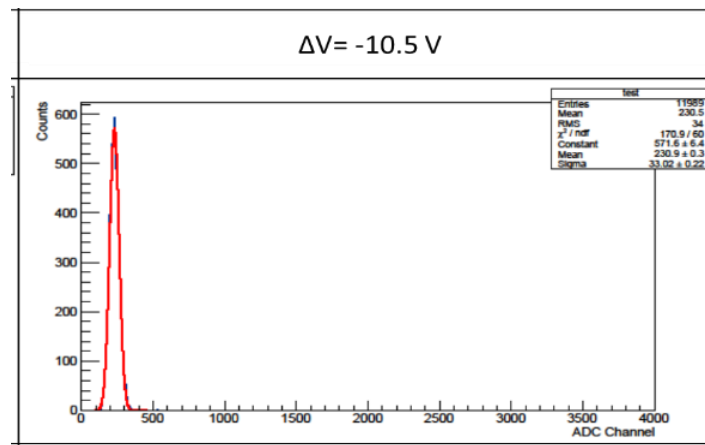
Electron transmission rate

$$= \frac{\text{Peak1} - \text{pedestal}}{\text{Peak2} - \text{pedestal}} \times 100 \quad [\%]$$

ADC spectra
@using Fe55



ADC spectra
@using laser



@using laser

When the gate applied voltage is large and negative (i.e., the gate transmittance is low), the signal is weak.

➔ Therefore, we performed the measurement by taking several hundred events, shuffling them, and then taking the average.

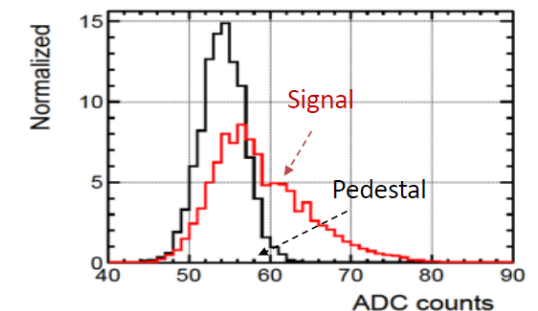
Measurement using a Laser (for Negatively High ΔV) 13

Example: $V_{\text{Gating-GEM}} = -14.5 \text{ V}$

Raw Pulse Height Distributions

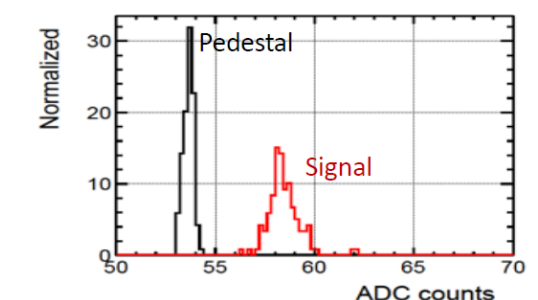
The signal is not well separated from the pedestal (noise) distribution.

The average laser signal can be obtained by taking the average of the distribution.

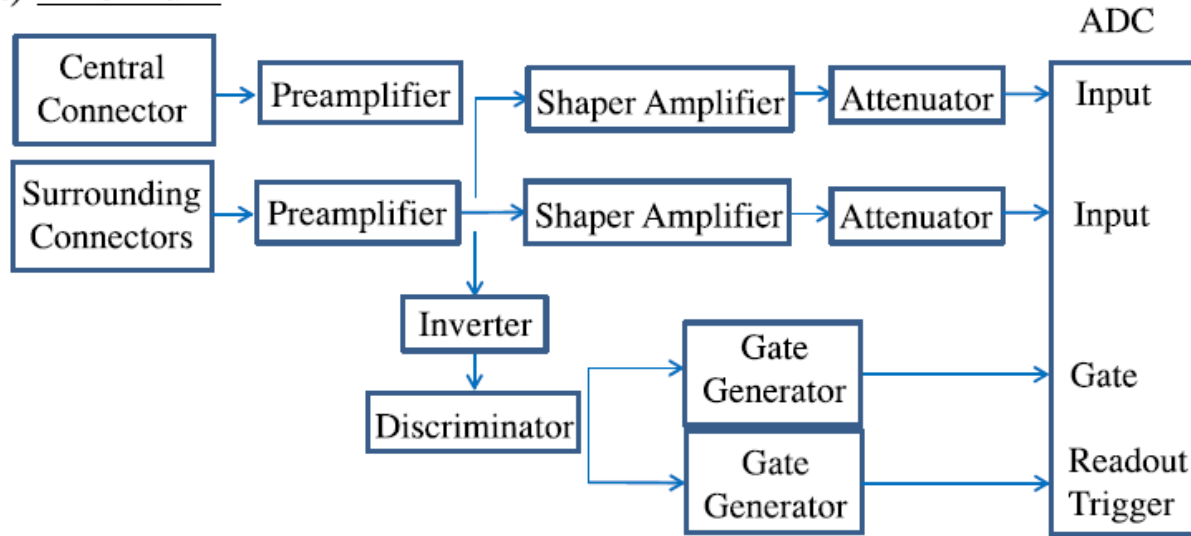


Distribution of the averages taken for several hundreds of signals (pedestals).

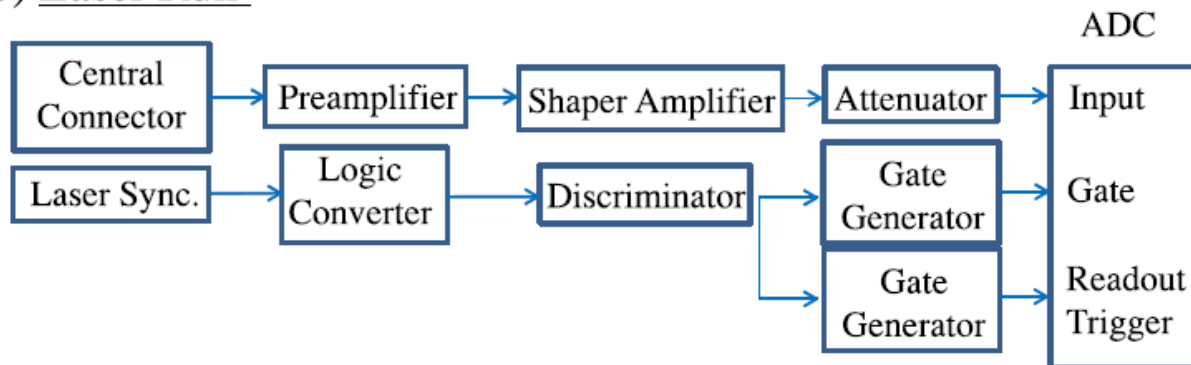
The existence of the laser signal is clear, and the average signal can be estimated by Gaussian fitting.



(a) ^{55}Fe Run



(b) Laser Run



The event trigger and the ADC gate

^{55}Fe runs ... these are generated by the output signal of the preamplifier for the central connector with a sufficiently low discriminator threshold (self-trigger)

Laser runs ...the external trigger is provided by the laser as a logic signal synchronized to its firing.

The width of the gate provided to the ADC is 500 ns with its center located at the signal-peak timing both in the ^{55}Fe runs and laser runs.

The relatively narrow gate as compared to the amplified signal width of $\approx 12 \mu\text{s}$ (FWHM) assures that the peaksensitive ADC output always contains the signal contribution (if any) along with the electronic noise component just below the signal peak.

Laser beam size & how to generate beam (KEK)

22

At the focal point, the 266 nm flat laser beam has a (2σ) size of $\sim 600 \mu\text{m} \times 300 \mu\text{m}$ (horizontal $\times$ vertical).

[1] M.Kobayashi, Measurement of the electron transmission rate of the gating foil for the TPC of the ILC experiment, Nuclear Inst. and Methods in Physics Research, A 918 (2019) 41–53, 2019

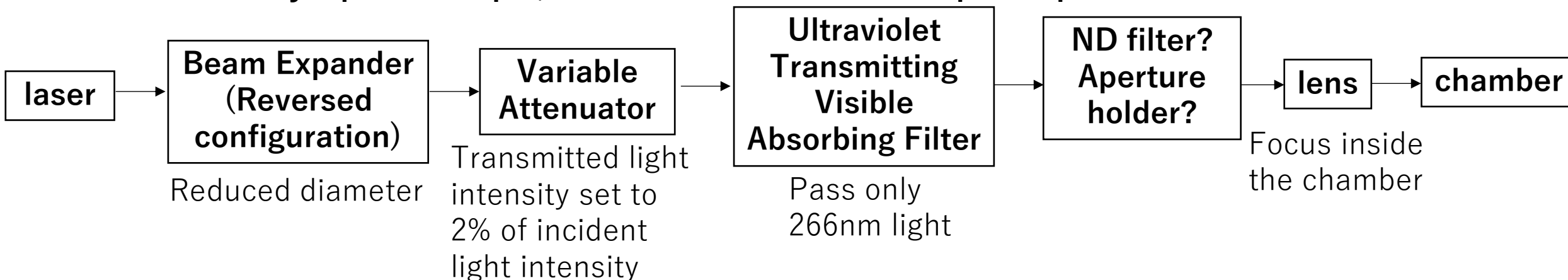
Optical System

- Beam Expander 【SIGMA KOKI BE-3-266】
- Variable Attenuator 【SIGMA KOKI SVAB-266A-08】
- Ultraviolet Transmitting Visible Absorbing Filter 【SIGMA KOKI UTVAF-50S-33U】
- (▪ ND Filter)
- (▪ Aperture holder 【SIGMA KOKI IH30】)
- (▪ Convex-flat lens (focal length 600mm))

[6] K.Tomohiko, Master thesis, 2015

[7] O.Miki, Master thesis, 2014

▼ Optical system setup at KEK as predicted from the above
(this is merely a past example, and whether the same setup is required remains to be discussed)



- ◆(Gate OPEN) When $\Delta V = +3\text{V}$, Electron transmission rate is 0.86 (from measurement using ^{55}Fe)
- ◆(Gate CLOSE) When $\Delta V = -15.5\text{V}$, Electron transmission rate is $(3.36) \times 10^{-4}$ (from measurement using laser)
 - ➡ ion blocking power is estimated to be $<10^{-4}$

