Progress of ILD-TPC Development in Japan

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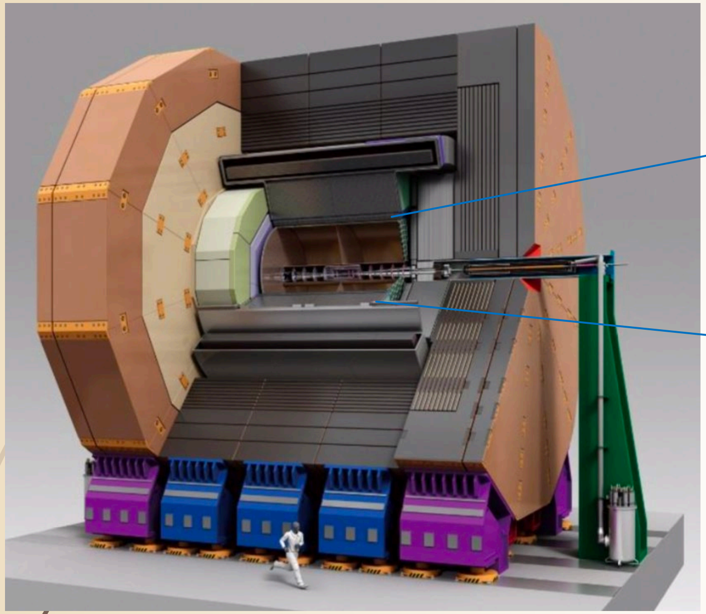
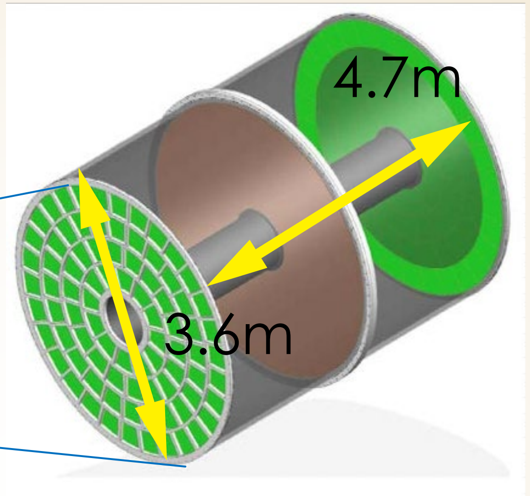
On behalf of ILD-TPC Japan group

ILD and ILD-TPC





ILD-TPC is a large volume Time Projection Chamber that reconstructs charged tracks in 3-dimension with up to 224 hit points in B=3.5T

ILD aims to reconstruct all particles (charged and neutral) in a event

Performance goal of ILD-TPC

✤ Momentum Resolution

$\sigma(1/p_T) < 2\times10^{-4}$ (GeV^{-1}) (TPC only) using > 200 sampling points along a track with a spatial resolution better than **$\sigma_{r\varphi}$~100 μm** over the full drift length of >2m in B=3.5T (recoil mass, $H\rightarrow\mu^+\mu^-$).

✤ High Efficiency

2-track separation better than **~2mm** to assure essentially 100% tracking efficiency for PFA in jetty events.High tracking efficiency also requires **minimization of dead spaces** near the boundaries of readout modules.

✤ Minimum material

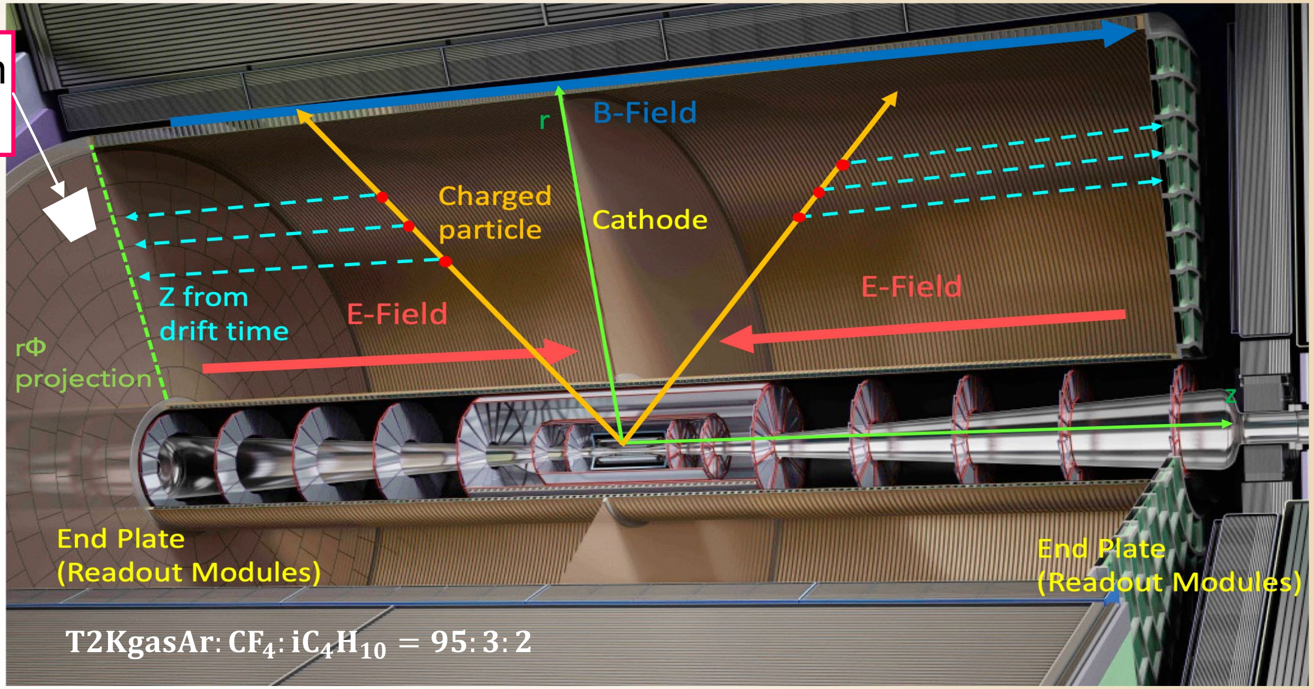
for PFA calorimeters behind, also to facilitate extrapolation to the inner Si tracker and the vertex detector

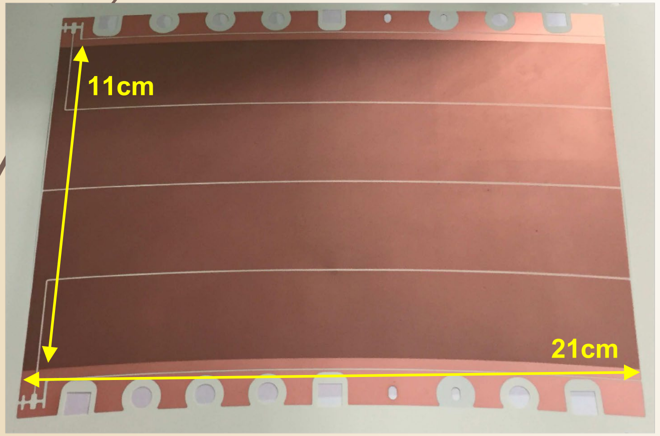
ILD-TPC gas amplifiers

Gas amplifier is placed in front of readout module

ILD-TPC has two options of gas amplifier
1. GEM (Gas Electron Multiplier)
2. Micromegas

ILD-TPC Asia group proposes Asian GEM module as gas amplifier for ILD-TPC





Asian GEM module

Characteristics of Asian GEM module

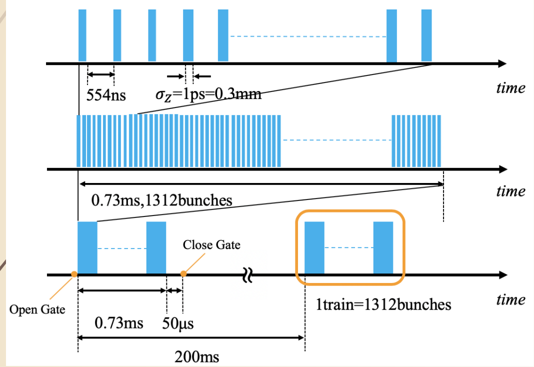
- ✓ Insulator: LCP (Liquid Crystal Polymer), *t*=100μm
- ✓ Electrode: *t*=5μm copper
  Electrodes are divided into four to prevent discharge
- ✓ Hole : 70μm hole diameter, 140μm pitch
- ✓ Size of active area: ～21x11 cm^2
  (Φ=9.3deg, r=128～139cm)
- ✓ Cylindrical hole shape

Positive ion back flow

Positive ions are produced in ionization process

- Ions produced in the GEM flow directly into the drift volume
- Drift velocity of ion is very slow (about O(10^{-4}) of electron)

→ **Making the distortion of E-field**

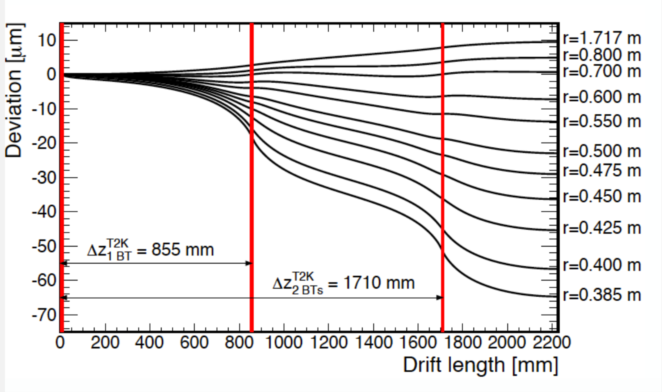


ILC beam operation

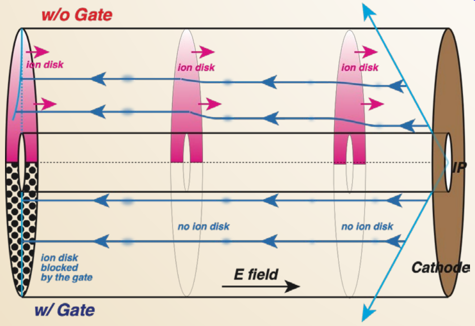
Drift path distortion in ILD-TPC

- ✓ Positive ions make ion disk (1cm) in 1 train
- ✓ Drift velocity (iso-C_4H_{10} ion) : 0.37cm/s
- ✓ Drift E-field : 230V/cm
- ✓ Interval between trains : 200ms
- ✓ Positive ions flow 74cm forward
- ✓ Max drift length : 2.2m

→ 3 disks are in drift volume



Maximum distortion is 60 μm !



Need gating device!

K. Fujii, "Positive Ion Effects (LCTPC collaboration meeting presentation)."

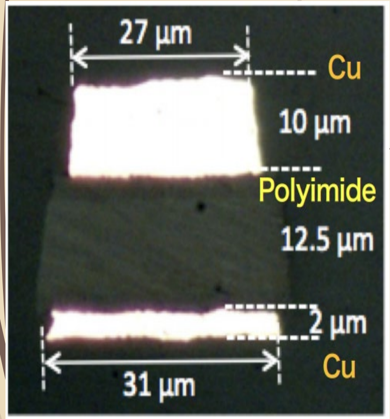
D. Arai, "Ion Problem Report (LCTPC Workpackage Meeting # 145)."

Gating device

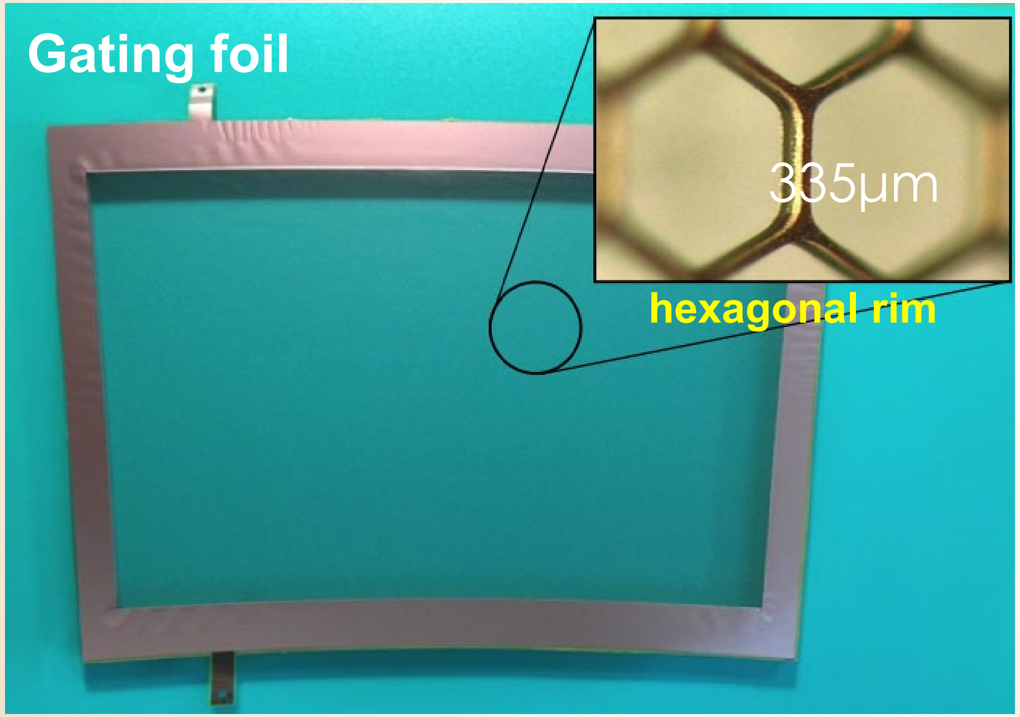
Requirements of gating device

- ✓ High electron transmission rate (>80%)
- ✓ Suppress ion transmission (>99.99%)

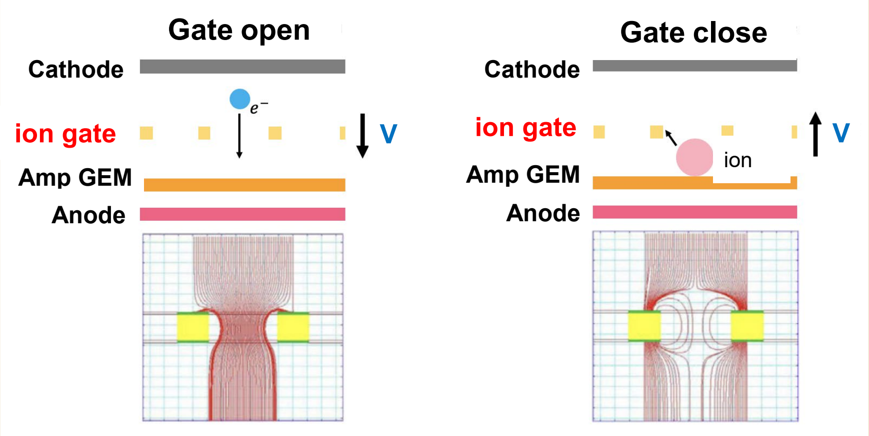
→ developed a GEM-like gating device in collaboration with Fujikura Co., Ltd



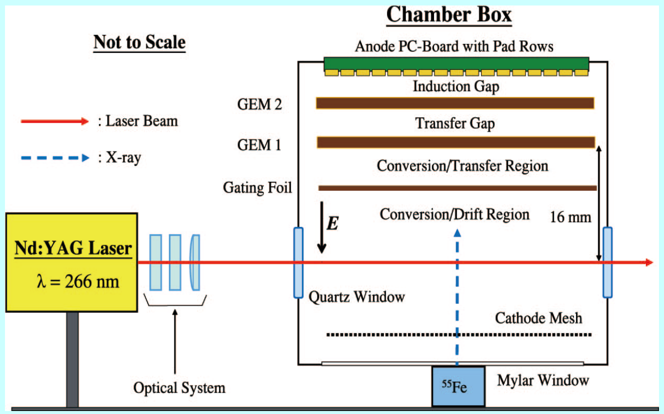
cross section of rim



- insulator thickness : 12.5 µm
- rim width : 27µm (F) and 31 µm (B)
- Hole : size 304 µm, pitch 335 µm
- optical aperture ratio : 82%
- low voltage operation : < 20V

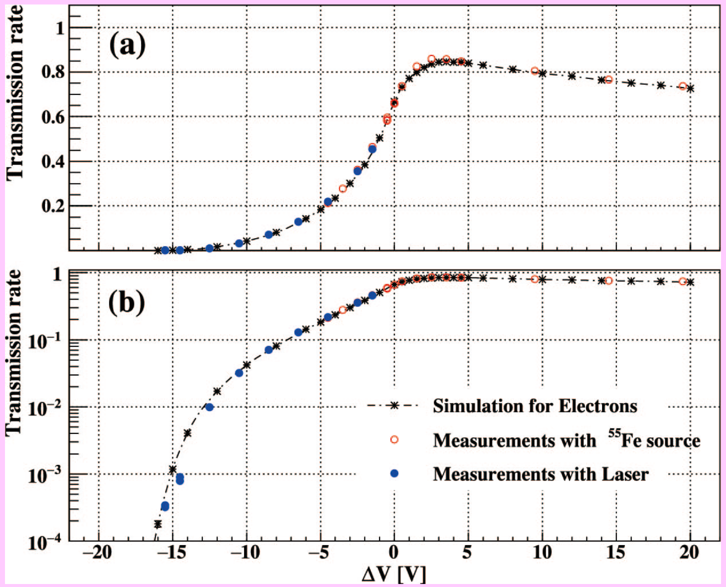


Gating device
(Measurement of electron Transmission)



Measurement setup

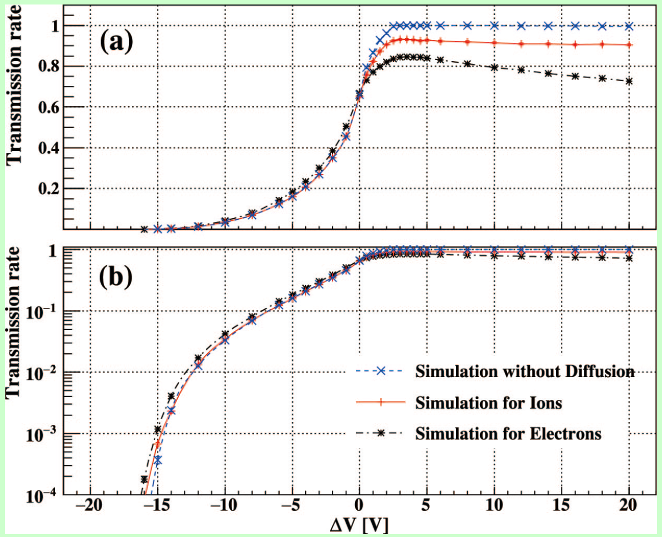
M. Kobayashi, et al., Nucl. Instrum. Methods Phys. Res. A 918 (2019) 41,



Results of measurement

M. Kobayashi, et al., Nucl. Instrum. Methods Phys. Res. A 918 (2019) 41,

Maximum electron transmission rate at B=0T : 86% (～+3V)



Results of simulation

M. Kobayashi, et al., Nucl. Instrum. Methods Phys. Res. A 918 (2019) 41,

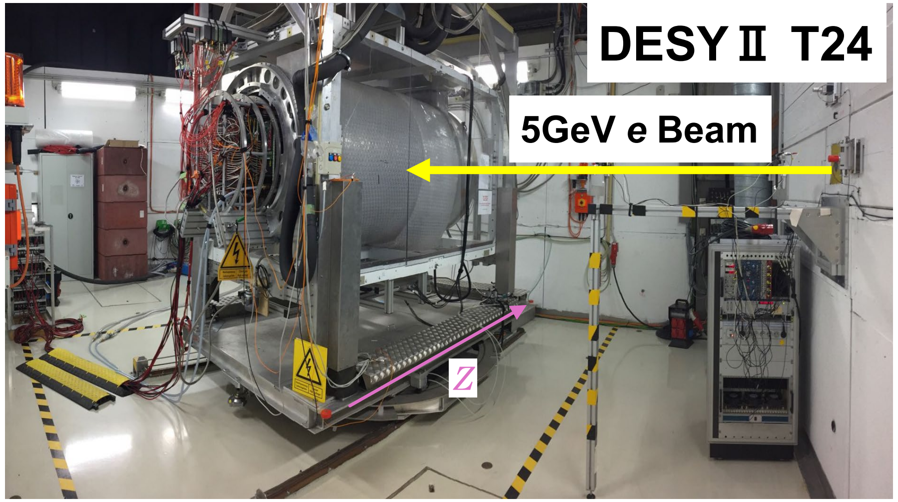
Simulation result at B=0T :
Upper limit of transmission rate for positive ions is (3.36±0.05)×10^{-4} at -15.5V

Our gating device has both good ion-blocking and electron-transmitting abilities

KINDAI UNIVERSITY

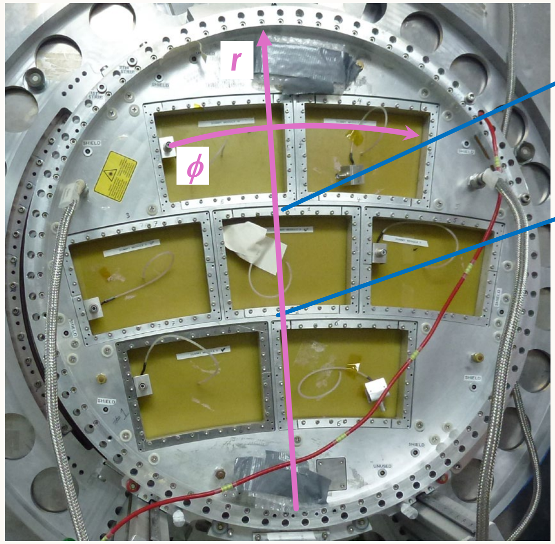
2016 Test beam in DESY

Performance comparison of Asian GEM modules with and without the gating foil

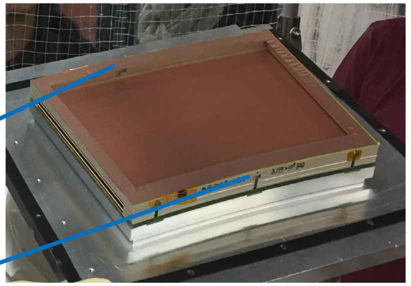


Large Prototype TPC (LP1)

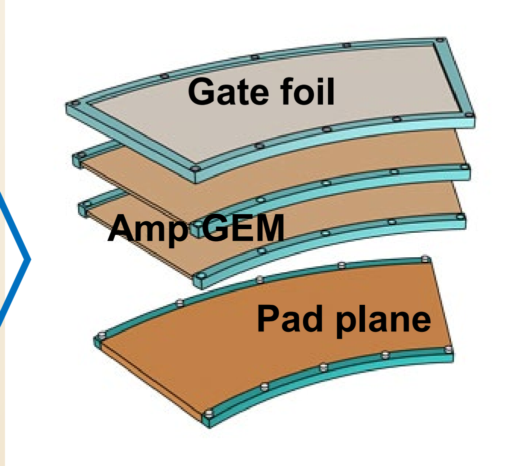
- ✓ B-Field : 1T (PCMAG)
- ✓ Length: 60cm
- ✓ Diameter: 70cm
- ✓ Gas: T2K (Ar 95%, CF_4 3%, iso-C_4H_{10} 2%)



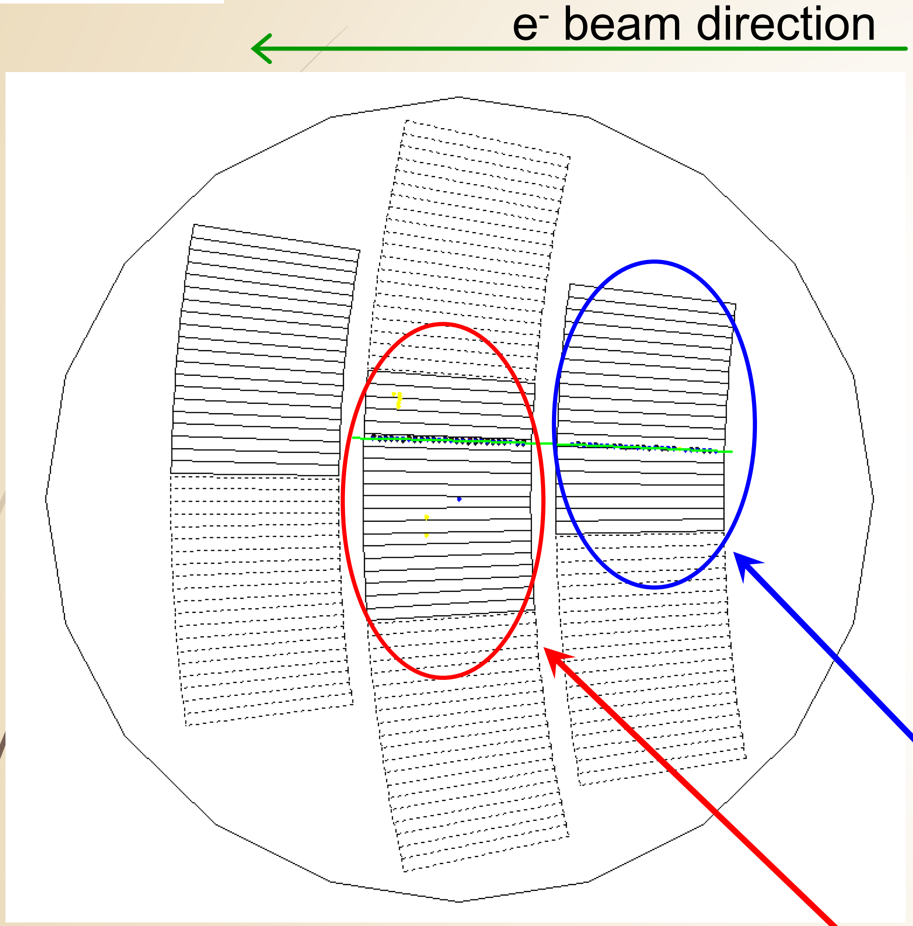
End Plate



Module

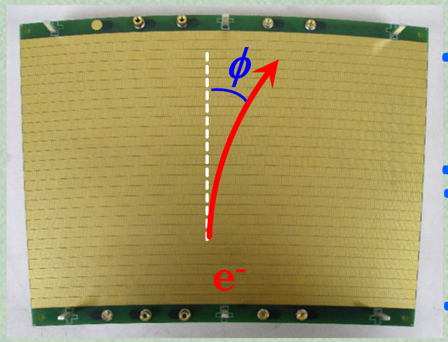


2016 Test beam in DESY
(Event display)



$r\phi$ plane view

Pad plane



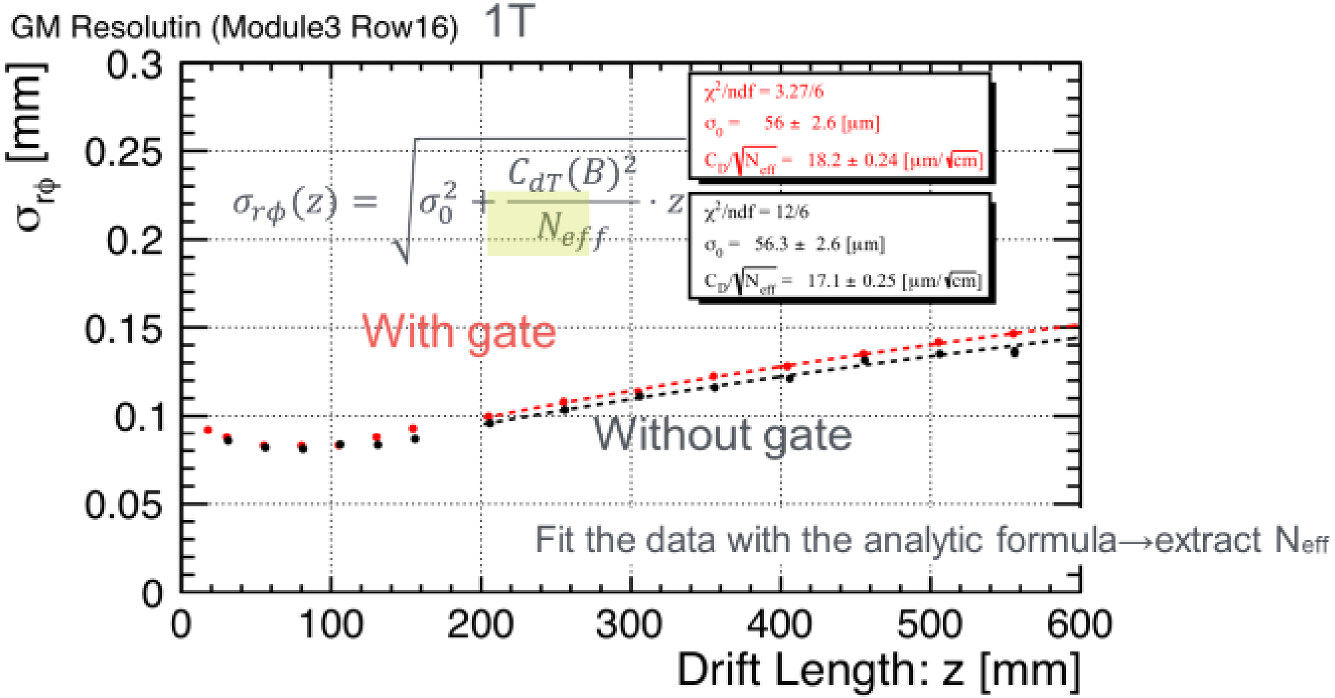
pad: (1.15～1.25) mm W X 5.26 mm H
0.1 mm gap, staggered layout

Without gate foil

With gate foil

Result of 2016 test beam

rφ Resolution Result



Validity of results

Estimated electron transmission rate of gating device from N_{eff}

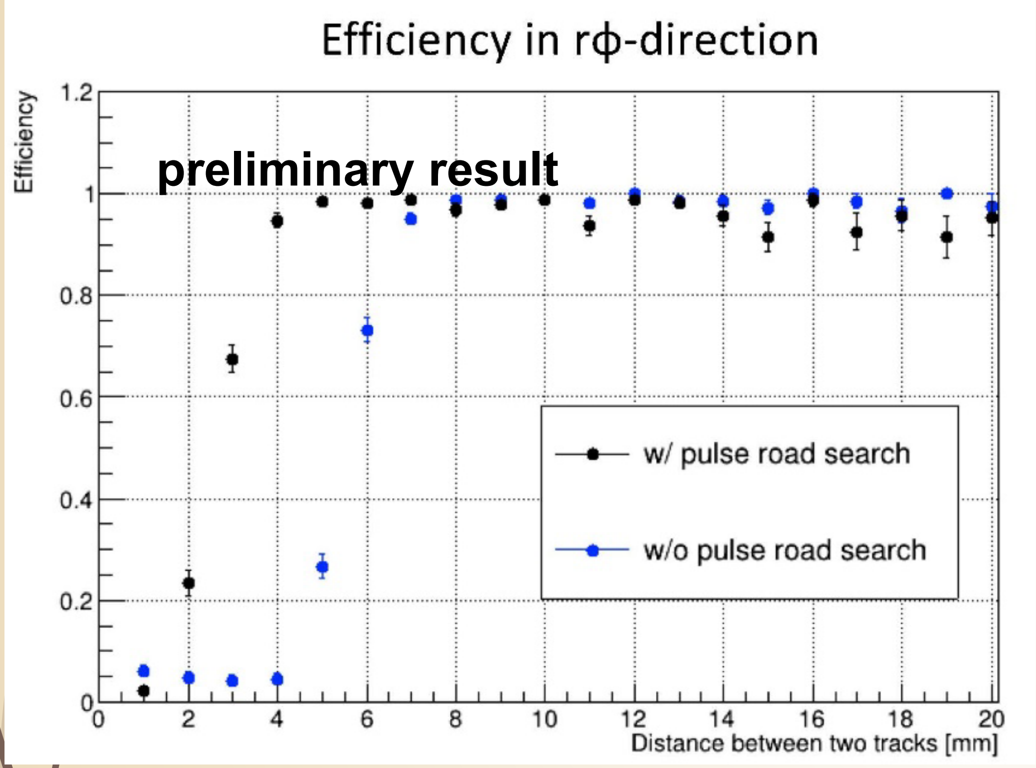
$$\frac{N_{eff}\text{ (With gate): } 24.5 \pm 0.7}{N_{eff}\text{ (Without gate): } 29.7 \pm 0.9} \sim 83\%$$

⟷ Electron transmission ~Optical aperture of gating device~80%

This result is reliable

Yumi Aoki, 2022 Annual meeting "The Spatial resolution result of the first beam test of a ILD-TPC end-plate readout module with a gating foil for the ILC"

two-track separation capability (analysis is in progress)



Aiko Shoji, LCWS2021"Study of 2-track separation for MPGD-base TPC"

Efficiency of two-track separation

There is only a few two-track event in the test beam data

two-track separation capability is examined overlaying 2 events

Using pulse road search method

cf. C.Kleinwort, DESY(2017), "A combined track and hit finding method for a TPC based on local road search with pad pulses"

When the track distance is 4mm in rϕ-direction, track separation is possible with higher efficiency

Further improve is needed for satisfying LC-TPC requirement (2mm)

New material for GEM insulators

The material of ordinary GEM Insulator is plastic (polyimide, LCP)

The problems are,

- ➢ **easily destroyed by discharge**
- ➢ **support flame is required for installation without bending**
- ➢ **need multi-layer structure to obtain the sufficient gain**

Solutions?

found and developed 2 insulator candidates in Japan

- **Glass GEM**
- **LTCC GEM**

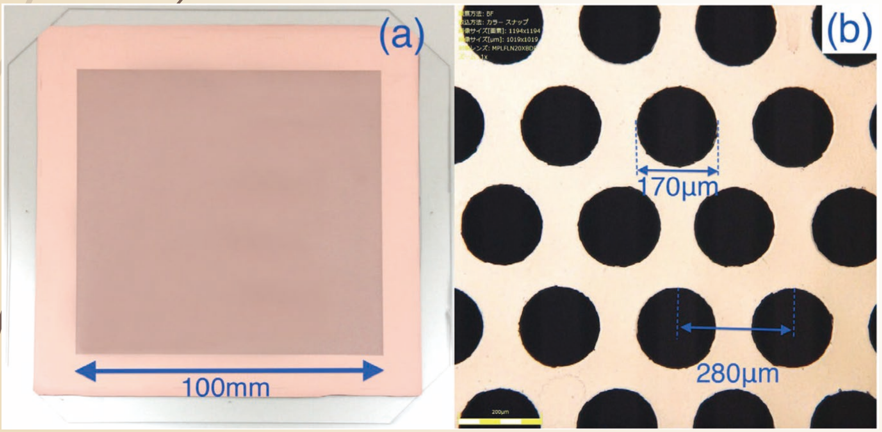
Considering whether new materials can be adopted for Asian GEM module

New material for GEM insulators (Glass GEM)

Glass GEM is developed by T.Fujiwara (AIST)

Features

- ✓ rigid enough to stand on its own
- ✓ good discharge resistant
- ✓ high gain over 9.0×10^4

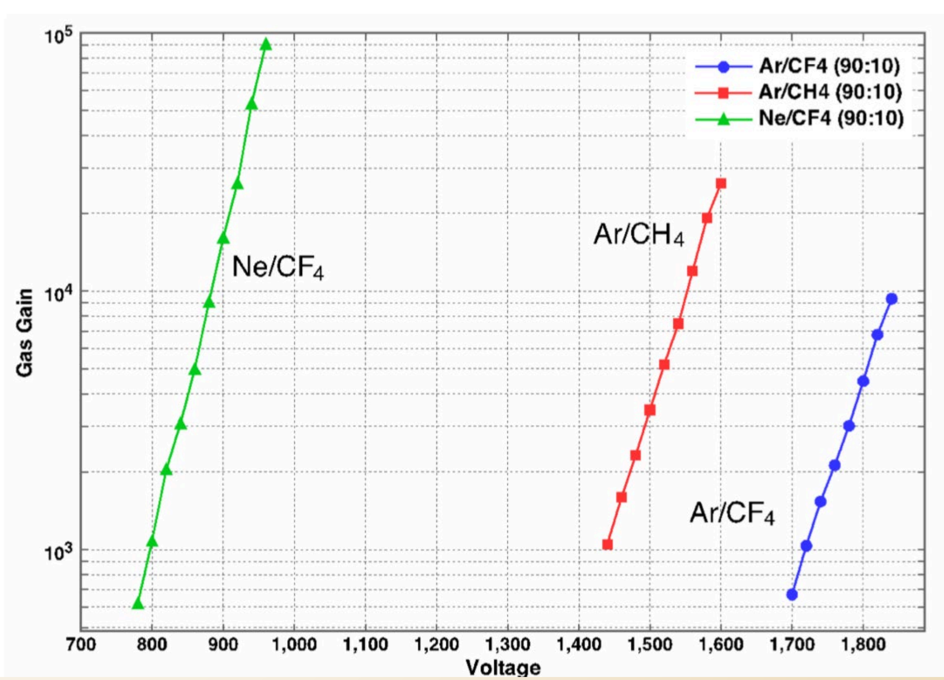


Picture of Glass GEM

T. Fujiwara, et al, NIM A878(2018)

Characteristics of Glass GEM

Type of GEM	*Glass GEM*	*CERN GEM*
Hole diameter	170 µm	50 µm
Pitch	280 µm	150 µm
Thickness	680 µm	50 µm
Insulator	Glass	Polyimide



T. Fujiwara, et al, 2014 JINST 9 P11007

New material for GEM insulators (LTCC GEM)

LTCC GEM is developed by K.Komiya (TIRI)

Features

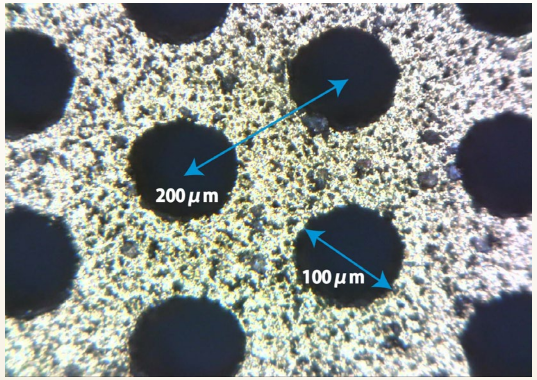
- ✓ **rigid enough to stand on its own**
- ✓ **good discharge resistant**
- ✓ **high gain over 2.0×10^4**
- ✓ **easy production and low cost (holes are made with a needle punch)**

Low Temperature Co-fired Ceramics (LTCC)

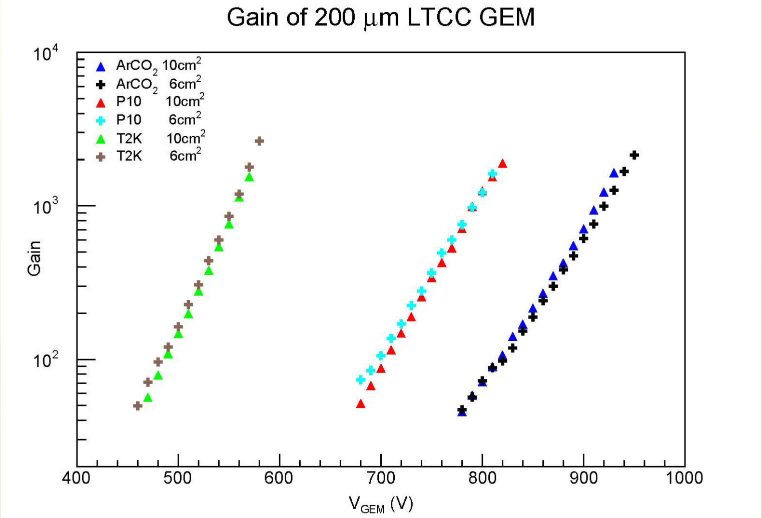
- ✓ ceramic substrate co-fired with a conductor at low temperatures below 900 degree
- ✓ used in electronic circuit board
- ✓ Substrate material : $CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}B_2O_3 + Al_2O_3$
- ✓ Conductor material : Au, Ag

Characteristics of LTCC GEM (manufacturing experience)

- ➢ hole diameter : 100μm, 200μm
- ➢ hole pitch : 200μm, 300μm
- ➢ hole area : 30cm X 30cm (max)
- ➢ thickness : 100μm, 200μm
- ➢ conductor : Au



photomicrograph

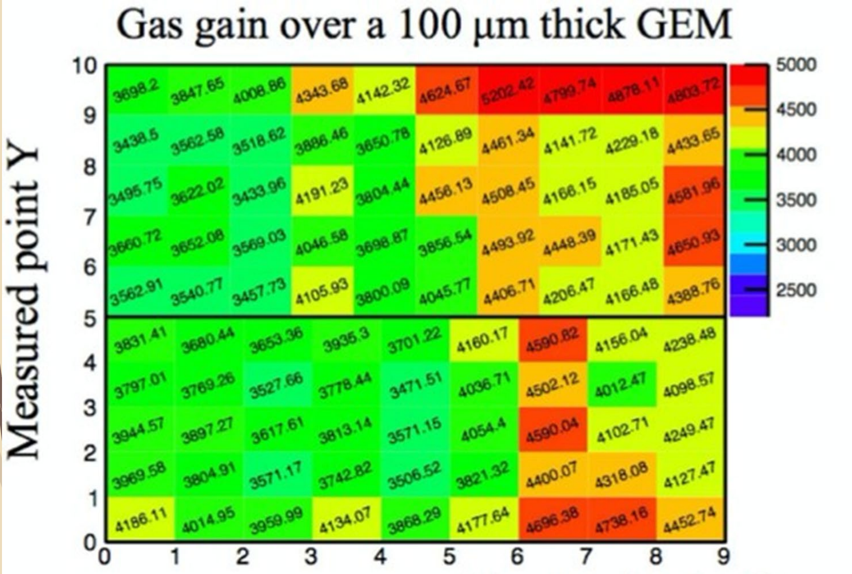


Gain measurement at Kindai Univ.

GEM gain stability

Gas gain non-uniformity measured in the Asian GEM (20x15cm^2) was more than 50%

The main cause is considered to be non-uniformity of the GEM thickness



arxiv:1701.05421

Study of "search for gain stable condition"

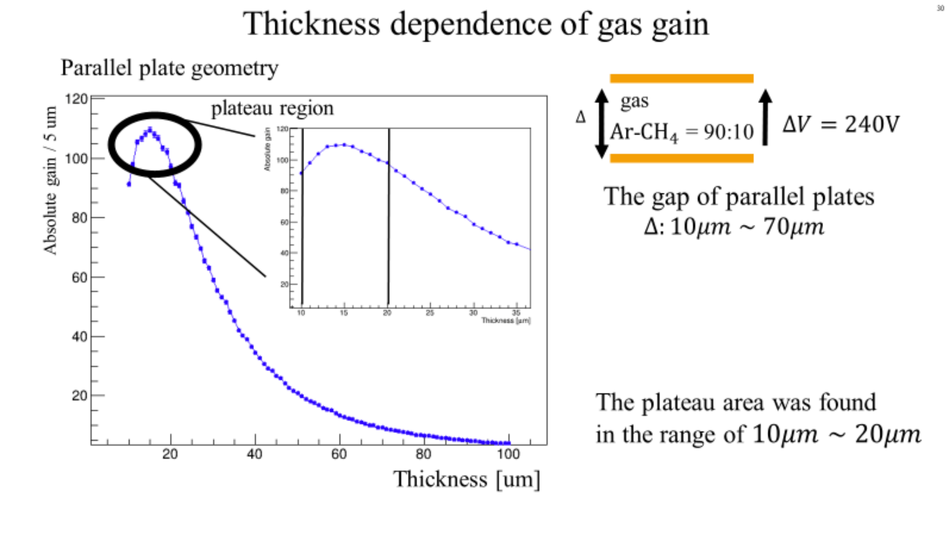
First step is,

- Looked at dependence of gain in the thickness of parallel plate (simple model)
- Found that there are conditions under which thickness variation has little effect on the gain.

next step

consider actual GEM model with gain stability

Measured actual GEM thickness and compared gain results to simulation



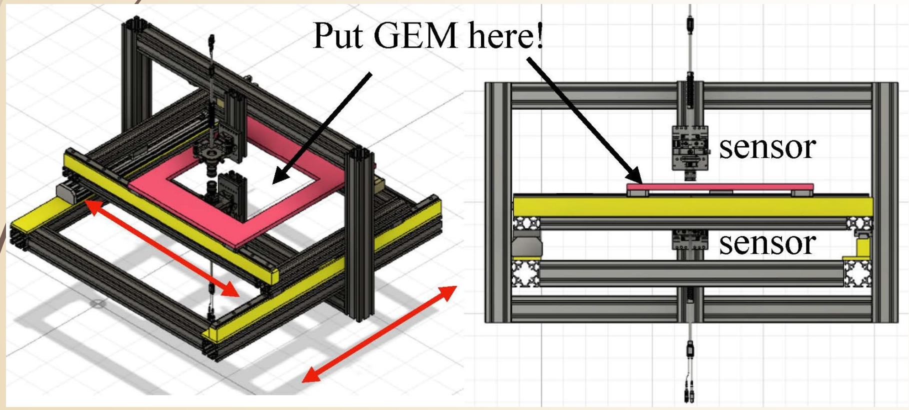
K.Yumino, 2022 Annual meeting, "Simulation study of for design optimization of GEM module"

GEM gain stability
(measurement of GEM thickness)

Gain depends on the magnitude of the electric field applied on both sides of GEM

Electric field depends on GEM thickness
→ Is gain fluctuation comes from thickness? ⇒ **want to know the accurate value of GEM thickness fluctuation**

- The automatic measurement system has been assembled and calibrated
- The measurement is in progress and the correlation between the thickness and the gain will be examined



Thickness measurement system

measurement of 100 μm thick GEM

Summary

- ILD-TPC Japan group is working on R&D of a GEM-based TPC
- R&D items for the realization of ILD-TPC are,
  - development of ion gating device for ILC beam condition
  - evaluation of ILD-TPC performance using test beam data
  - improve the Asian GEM module performance
- We can meet most of the requirements, but further study is needed for the realization of ILD-TPC including the use of new technical options being studied