Status of gating device R&D

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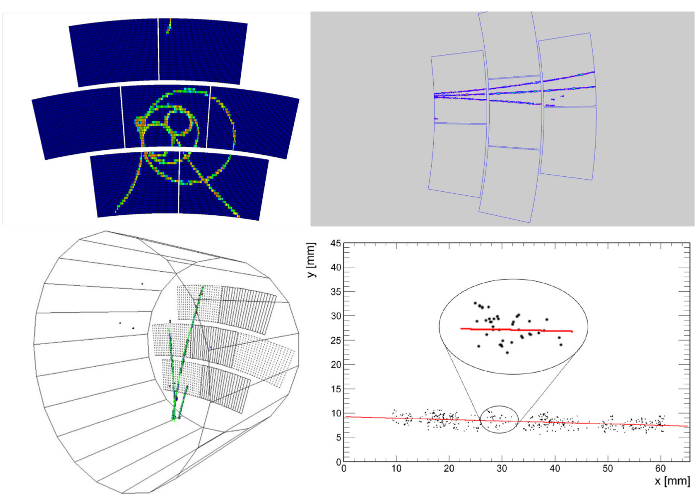
LCTPC Collaboration Meeting 2015

20 April, 2015 @KEK

ECFA Detector R&D Panel LCTPC Review Report by the LCTPC collaboration (November 3, 2013)

LC-DET-2014-001

Tracks recorded during test of different modules with the Large Prototype TPC



ECFA Detector R&D Panel
LCTPC
Review Report

LCTPC Collaboration

November 3, 2013

Contents

Some excerpts from The European R&D Committee Report: 2013 Report No. 3

European R&D Committee report
2013 Report No. 3
(Received in March 2014)


European R&D Committee report
Hamburg, November 5th, 2013 Report # 003

- **Ion back flow**
  - The committee recommends that in view that the ion back flow only affects the position resolution (due to the higher occupancy) in a limited radial region (385 to 550 mm) the collaboration should look into the possibility of limiting the gating arrangements to the affected region. Since **determination of the gating grid structure is most urgent** for LC- TPC, **it should be concluded as early as possible with detailed design and prototype tests.**

Remaining Issues

Ion Gate: The most urgent issue

***We need a ion gate*:**	To prevent the backflow of positive ions from the gas amplification region of the MPGD modules to the drift space of TPC. Distortions by the primary ions at ILC are still negligible.
***Options of ion gate*:**	
GEM gate: Mechanically most friendly to the current MPGD modules	A simulation has shown that the ion stopping power is sufficiently high → < 10**-4 at around 10V reversed biases Need to confirm by measurements ; who can do this? Electron transmission: Can be high with large optical opening Under study; How far need to go; >80%? Distortion due to the large GEM holes? To be studied with a laser beam (and then in beam test)
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Wire mesh or grid:	A solution never have been tested. High ion suppression with a accessible reverse voltage? Mechanical issues to mount on the MPGD module.

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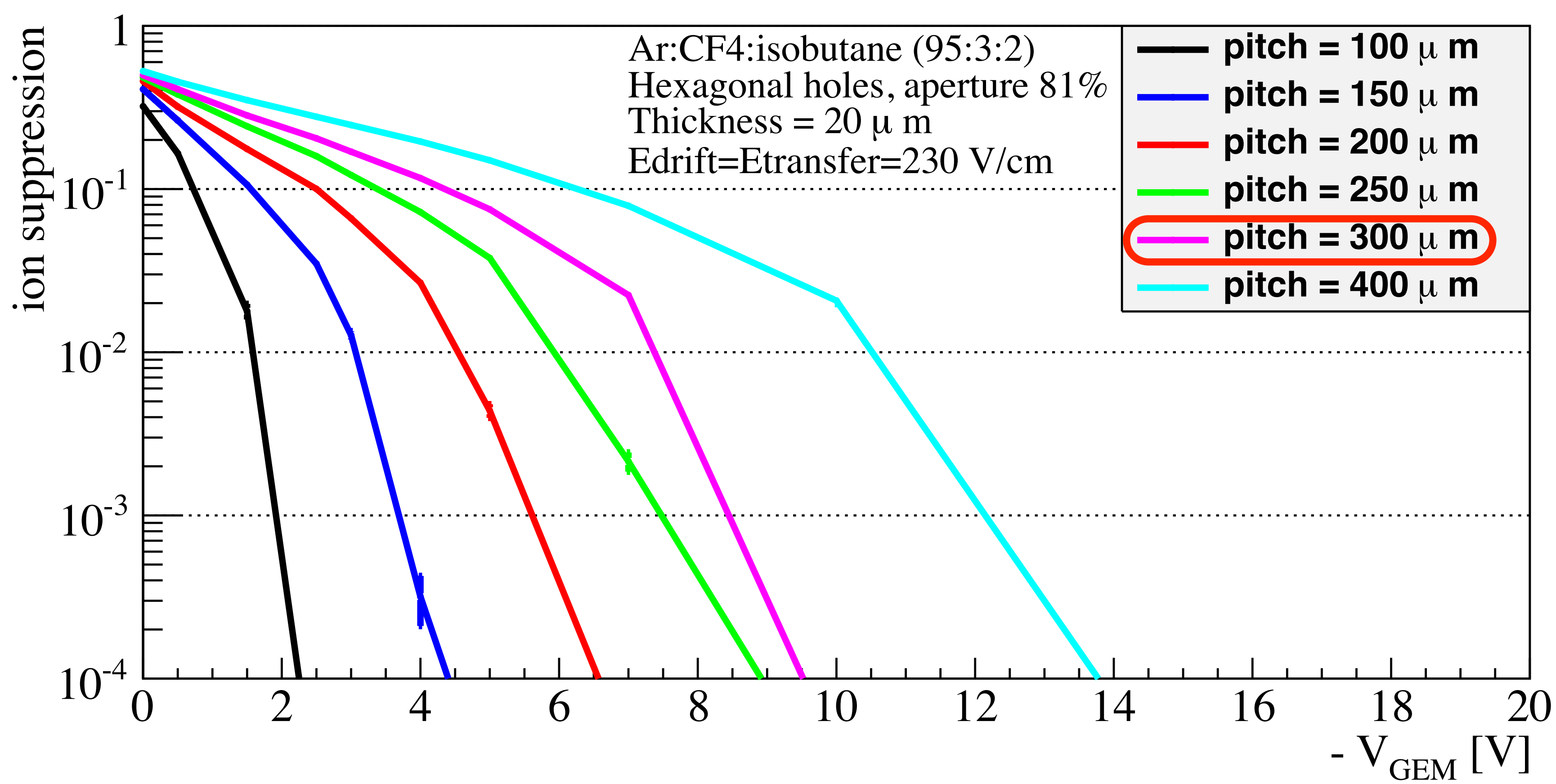

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In preparation for a LP1 module equipped with Fujikura Gate-GEM Type 4!

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Prom… …mple!

In pr… …Type 4!

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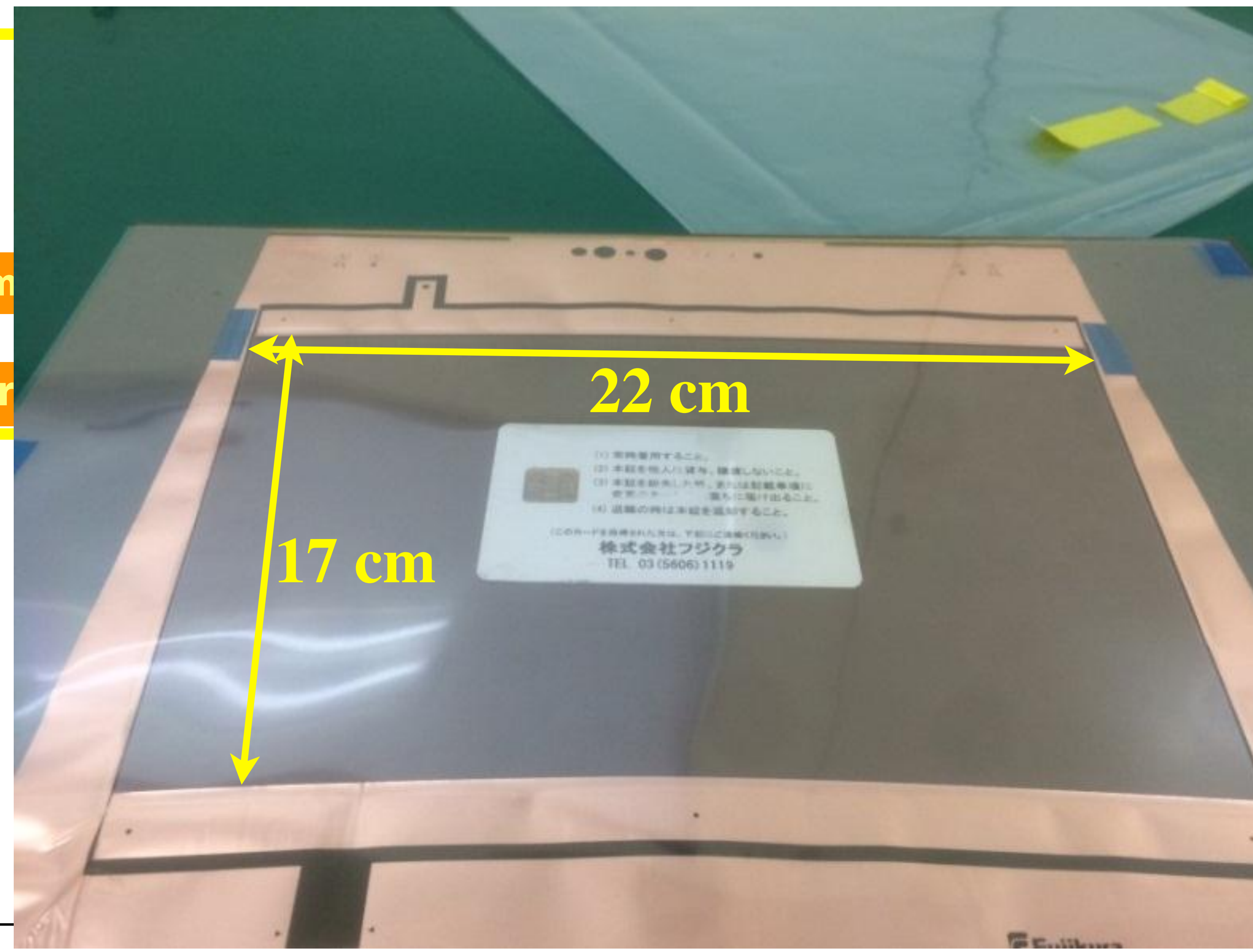

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Positive ion feedback in ILD-TPC

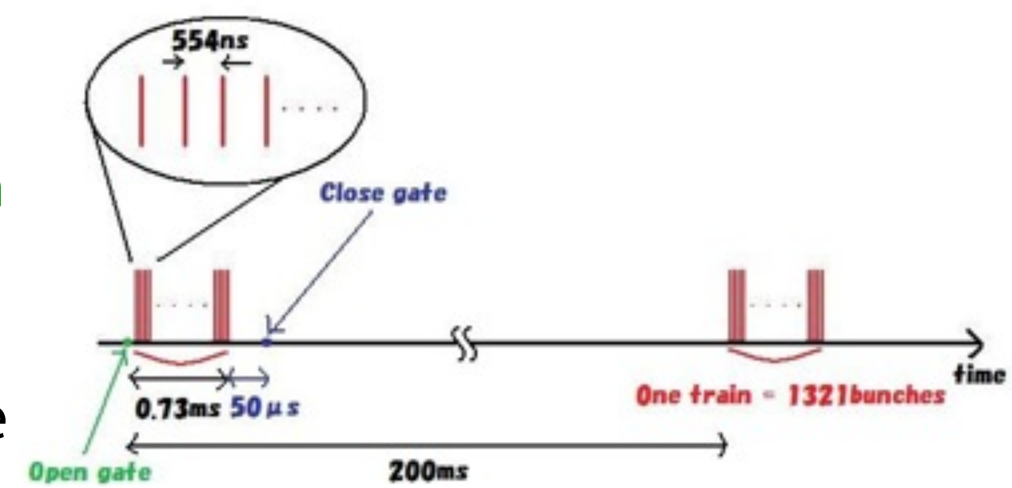
High performance of tracking by the TPC relies strongly on the quality of the electric field in the drift volume!

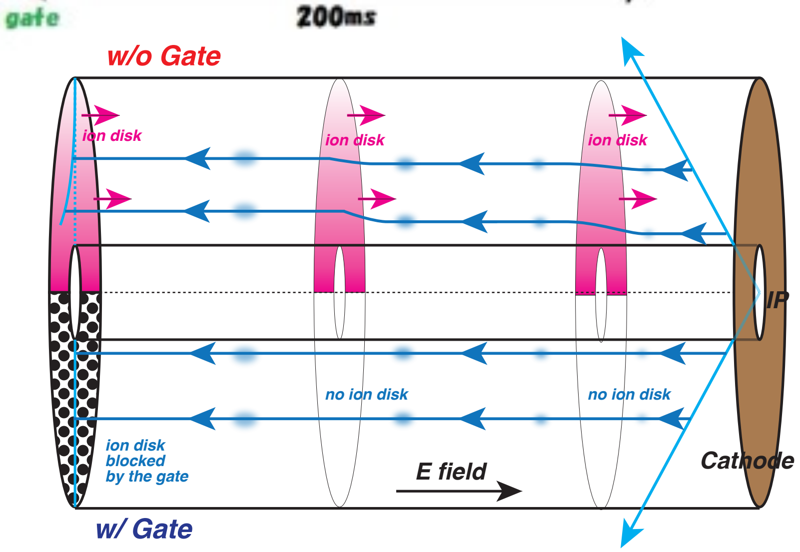
• Positive ions drifting back into the gas volume

- Well known issue for wire chambers based TPCs (traditional MWPCs)
- Even though the amount of back drift ions is much smaller for MPGD amplification, still be significant with a high track density like ILC background conditions (e.g. ILC beam expected to produce large amount of beamstrahlung = e^+e^- pair background)

• In the case of ILD-TPC

- Bunch-train structure of the ILC beam (one 1 ms train every 200 ms) => Ions from the amplification will be concentrated in discs of about 1 cm thickness near the readout, and then drift back into the drift volume
- 3 discs co-exist and distorted the path of seed e^-
- Simulations: a **gating system is required** to reach the tight momentum resolution requirements in the nominal running conditions of ILC
  - ‣ The ions have to be neutralised during the 200 ms period between the crossings





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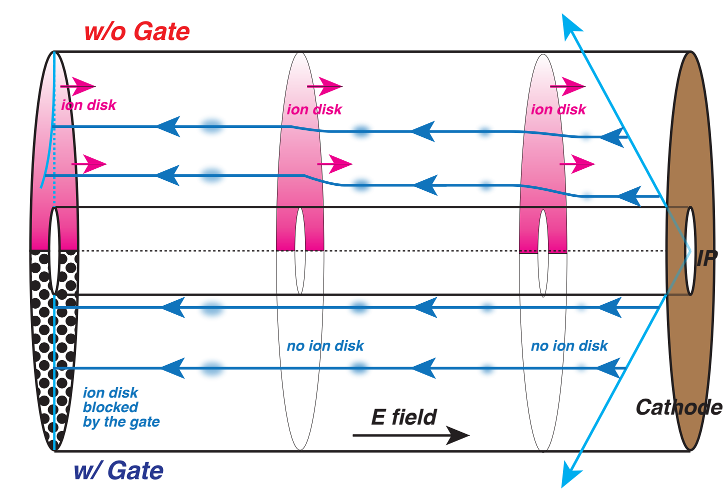
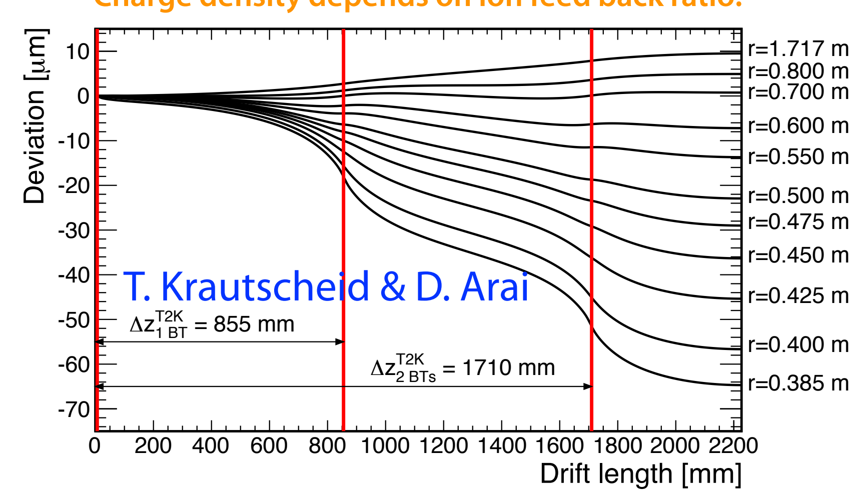


Charge density depends on ion feed back ratio!

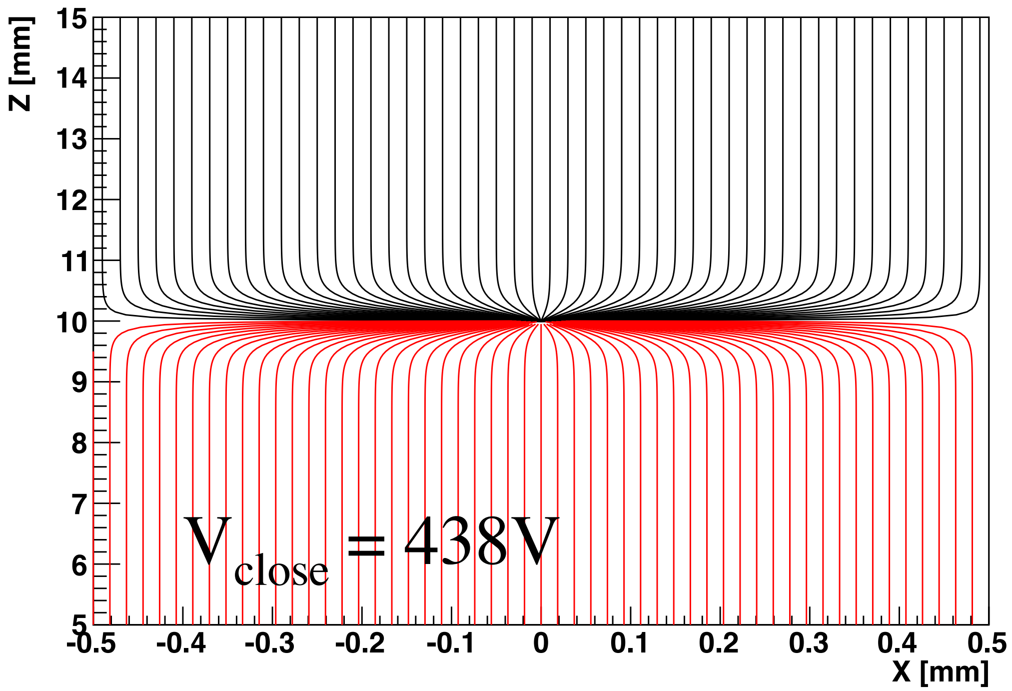


Conventional wire-grid as a gating device

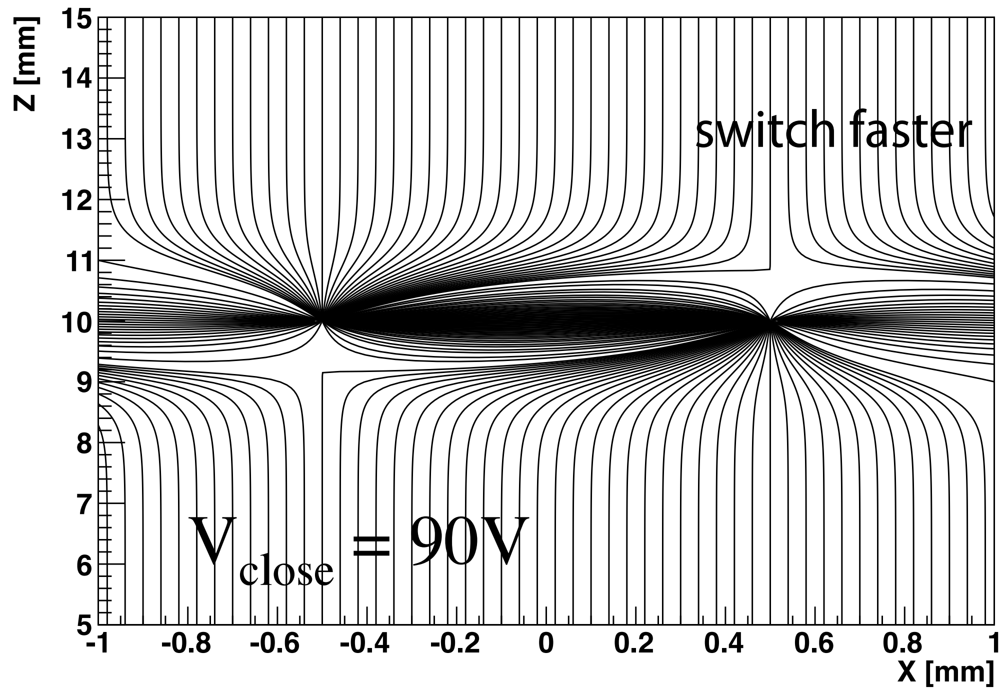
- **Wire-gating system is an option**
  - Traditional gating system
  - Two possible voltage schemes for the “closed” configuration of the wire-gate: mono-potential and alternate-potential

- fairly high voltage in the gate
- voltage depends strongly on the distance of the gate from the MPGD

- voltages required are relatively small and strongly dependent on the wire spacing
- more sophisticated structure to have two electrically isolated grids



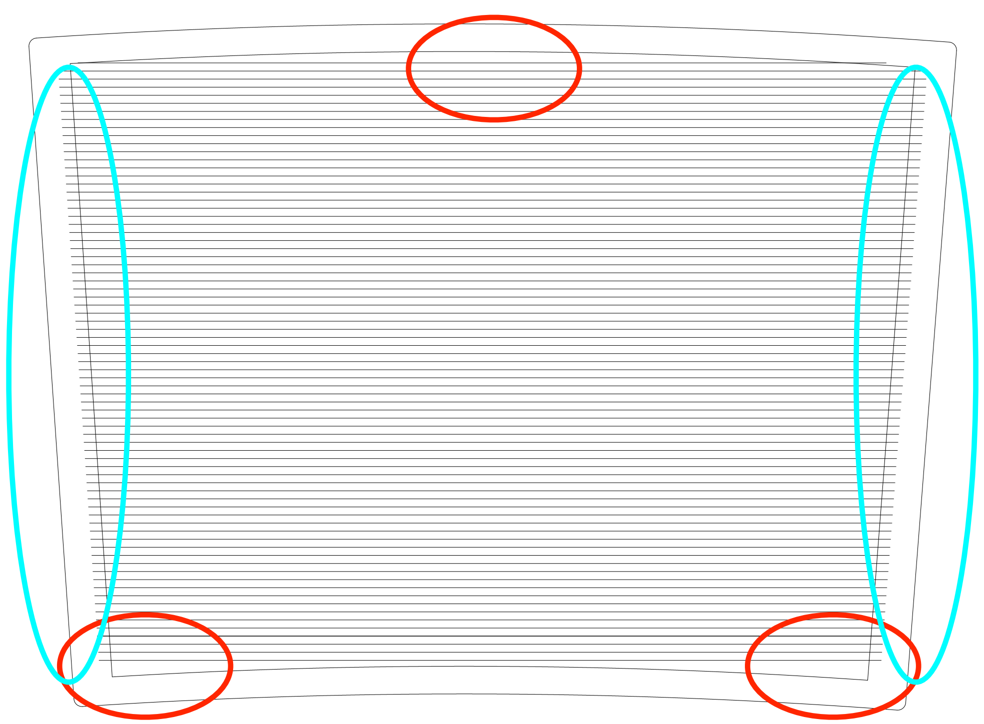
By increasing the potential on all the wires, the drift field between the gate and the amplification is reversed. The positive ions will then drift back and be neutralised on the MPGD.

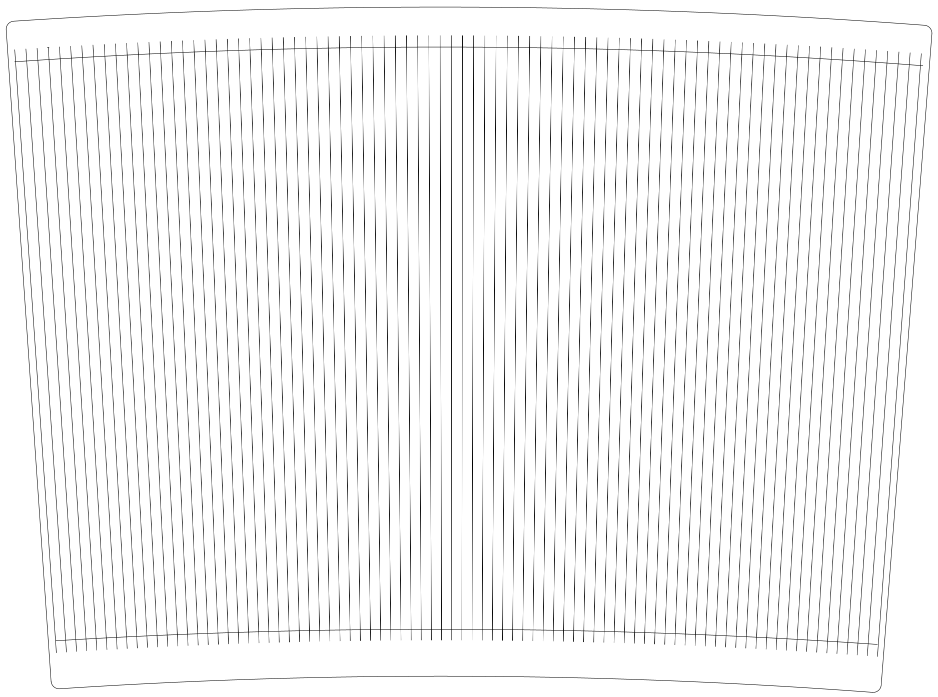


By shifting the voltage alternately on every second wire, we can create an electric field that will make the ions drift towards the wires, where they will be neutralised.

Conventional wire-grid as a gating device

- **Wire-gating system is an option**
  - Traditional gating system
  - Conventional transverse wires would require a structure creating dead angular regions => would put the wires radially
  - Wires can create field distortions, and in particular ExB effects...





Conventional wire-grid as a gating device?

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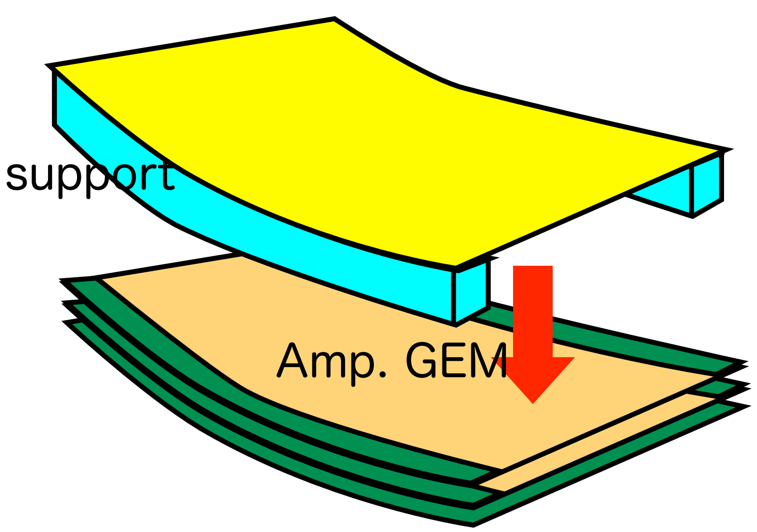
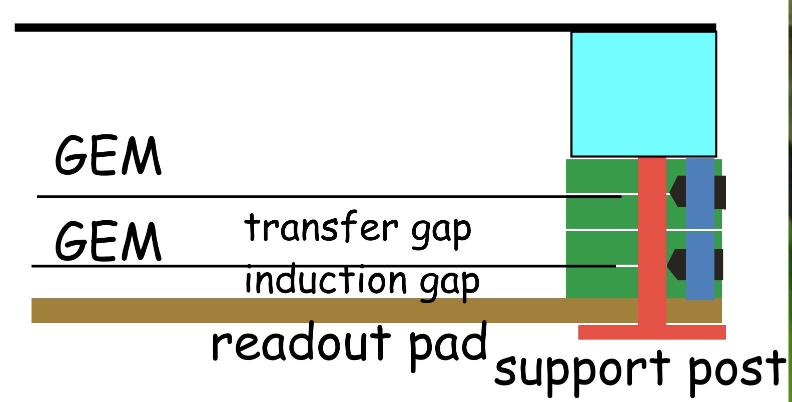
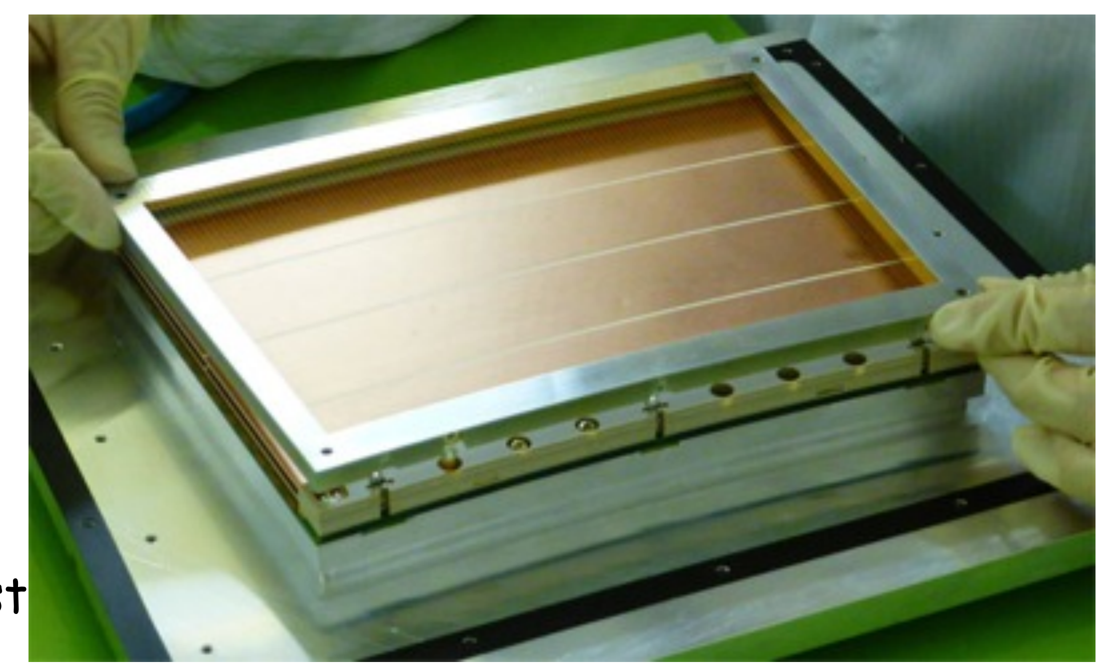
  - Traditional gating system
  - Conventional transverse wires would require a structure creating dead angular regions => would put the wires radially
  - Wires can create field distortions, and in particular ExB effects...
  - **Our 1st prototype**:
    - 30μm wires, 2mm pitch, radial => spot welded on stainless steel frame => frame still too big!
    - **performance tests of the 1st prototype by using UV-laser tracks has been finished!!**
- **Its implementation above the amplification GEMs or Micromegas would not be elegant!**

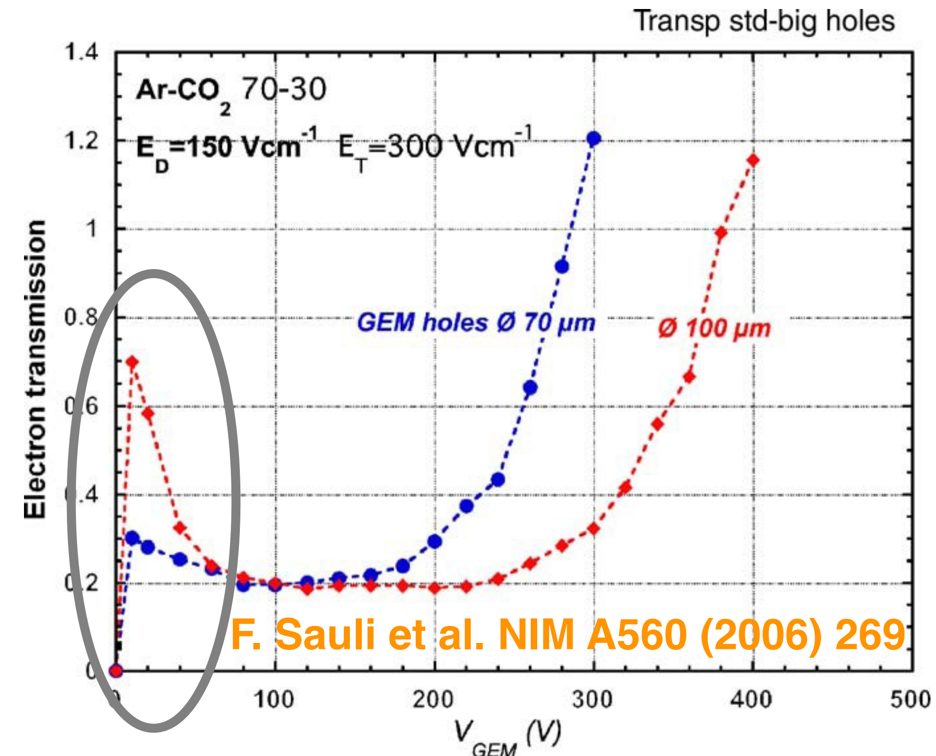


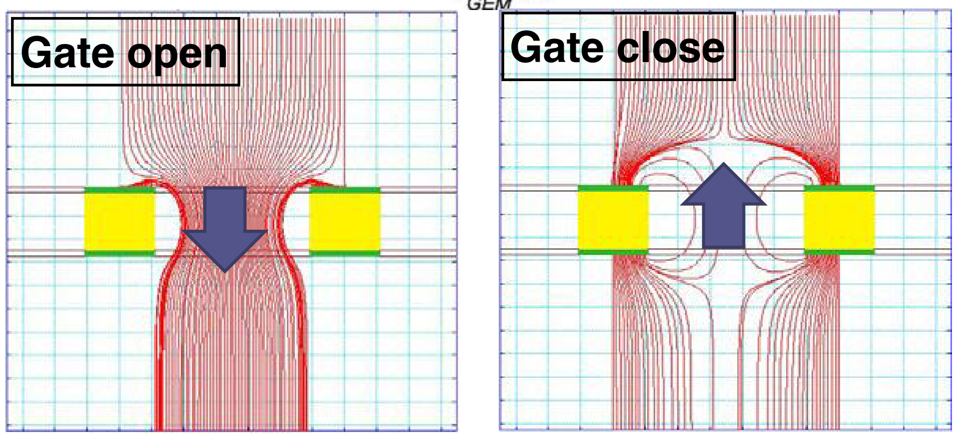




GEM as a gating device

- **GEM operated in low voltage mode**
  - Electron transmission film = without a function of gas amplification
  - Gate having a GEM-like structure (initially proposed by F. Sauli in 2006)
    - Gate-GEM can easily be used as a closed gate by reversing the electric field in GEM hole
  - GEM-gating device would be most adapted for the module structure of ILD-TPC!



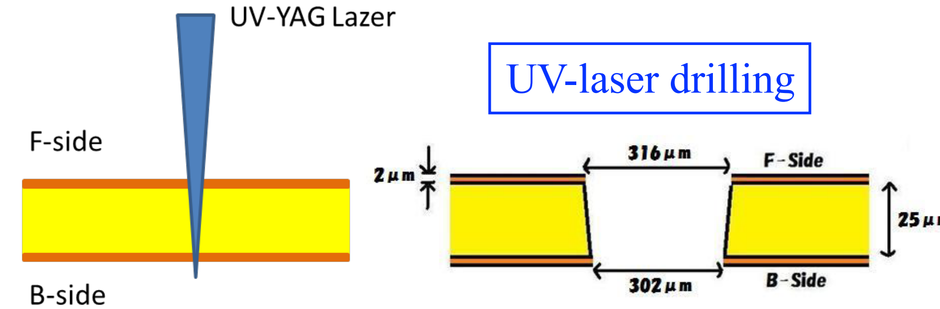


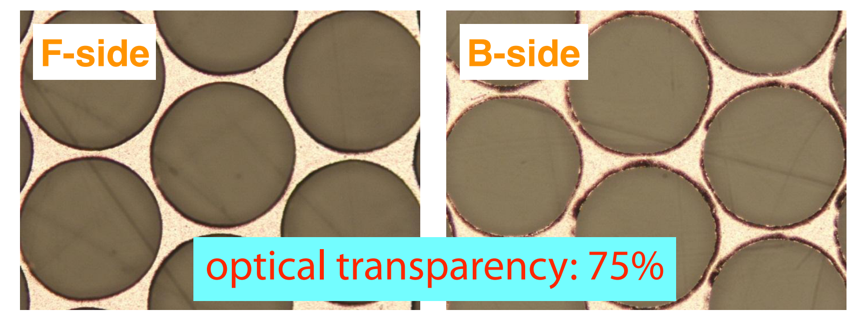
- **Requirement for Gate GEMs of ILD-TPC**
  - **Goal: 80% electron transmission** = corresponding the **deterioration in the spatial resolution ~O(10%)** for the ILD-TPC nominal electric field configuration
  - Operated in a 3.5 T axial magnetic field, and in a gas with a high mean free time (τ) of drift electrons between collisions with gas molecules => Motion of electrons is strongly restricted to the direction of the magnetic field => **high optical transparency of the gate is required** to ensure its high transmission rate of the electrons in the open state

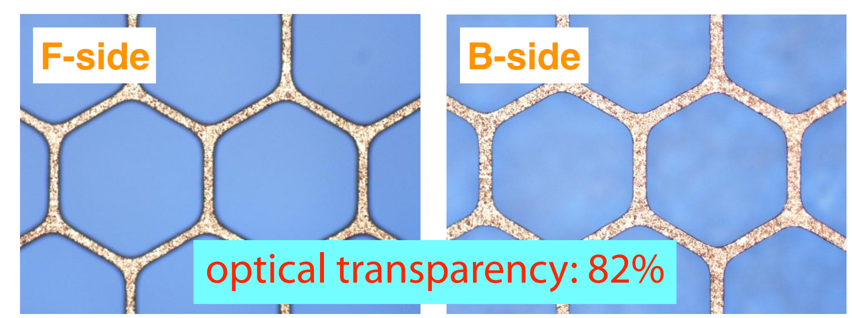
ordinary amplifying GEMs (e.g. CERN standard): not suitable because of their poor optical transparency

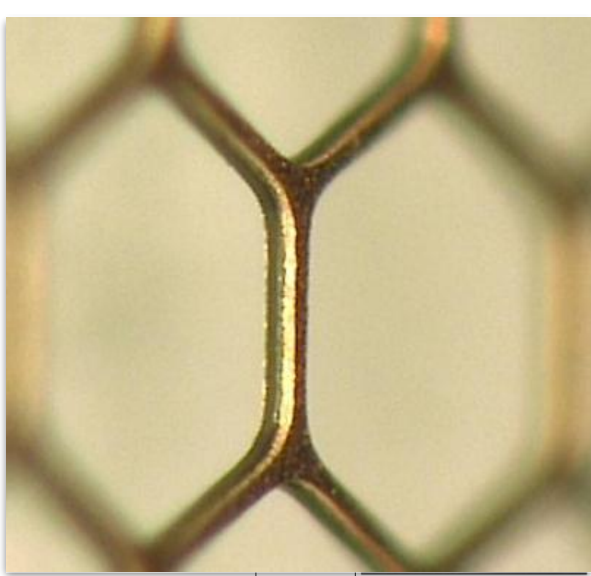
Large-aperture Gate-GEM samples

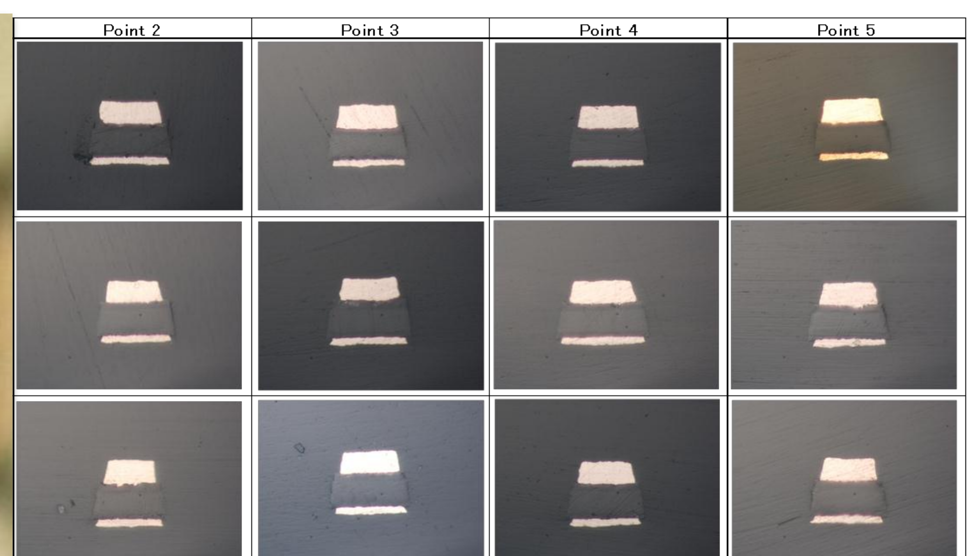
- **High optical transparency = Minimize rim width of GEM holes**
  - To achieve high electron transmission: 30 μm rim width & 330 μm pitch in honeycomb structure (= 80~85% optical transparency) required
- **Fujikura Gate-GEM Type 0 sample**
  - Round holes / Direct UV-laser drilling (1 x 1 cm²)
  - 14 μm (F-side) - 28 μm (B-side) rim width & 330 μm pitch with PI thickness 25 μm
- **Fujikura Gate-GEM Type 3 sample**
  - Hexagonal holes / UV-laser ablation (10 x 10 cm²)
  - 27 μm (F-side) - 31 μm (B-side) rim width & 335 μm pitch with PI thickness 12.5 μm





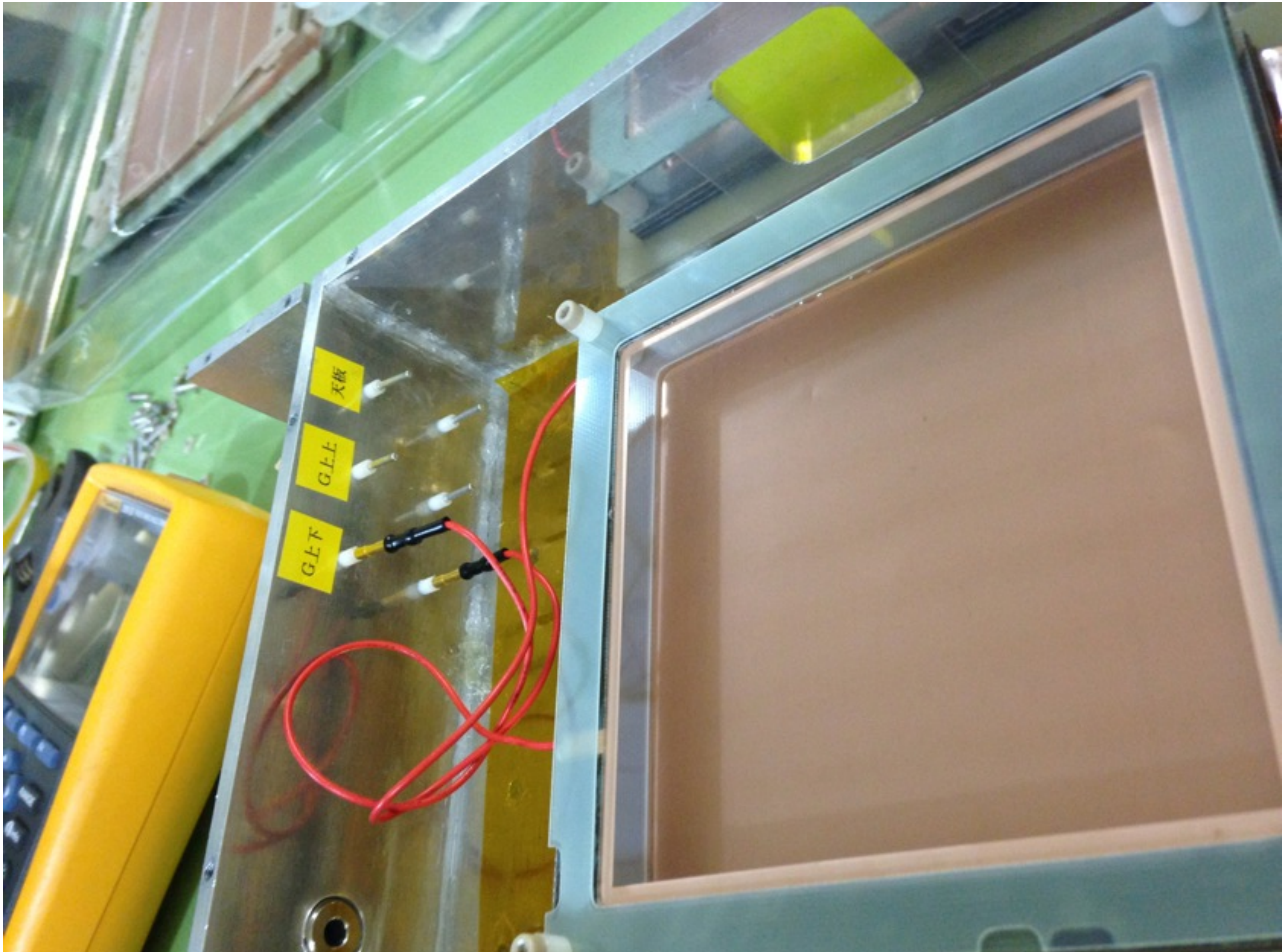






These 2 different samples: tested with a test chamber installed in a 1 Tesla solenoid magnet at KEK cryo center

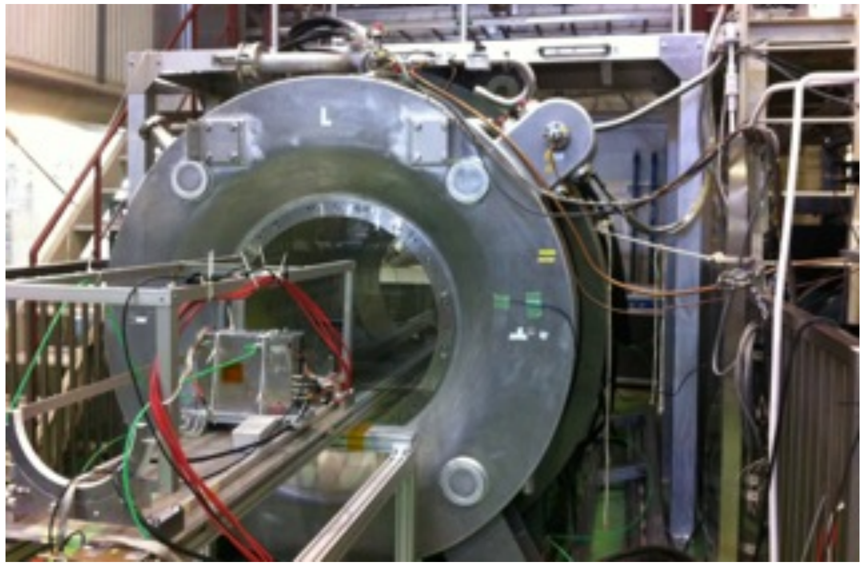
Fujikura Gate-GEM sample in test-chamber

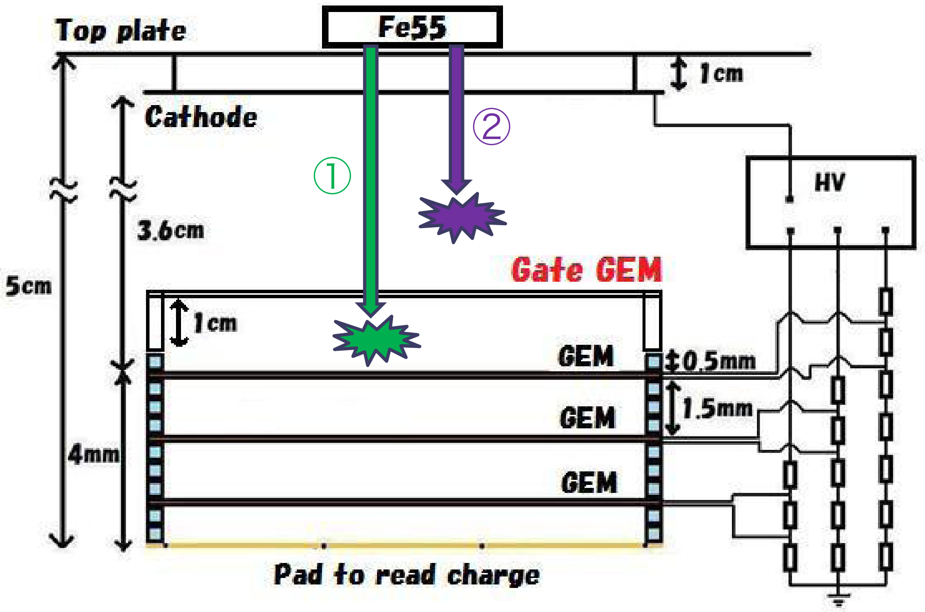


Electron transmission measurement

Motion of electrons is strongly restricted to the direction of the magnetic field => need measurements under high magnetic field!

- **Measurement method**
  - by comparing **signal charge passing through the Gate-GEM** to **signal without Gate-GEM** using a small test chamber irradiated with an ^{55}Fe source, which is installed in a 1 T MRI type super-conducting solenoid at KEK cryo center

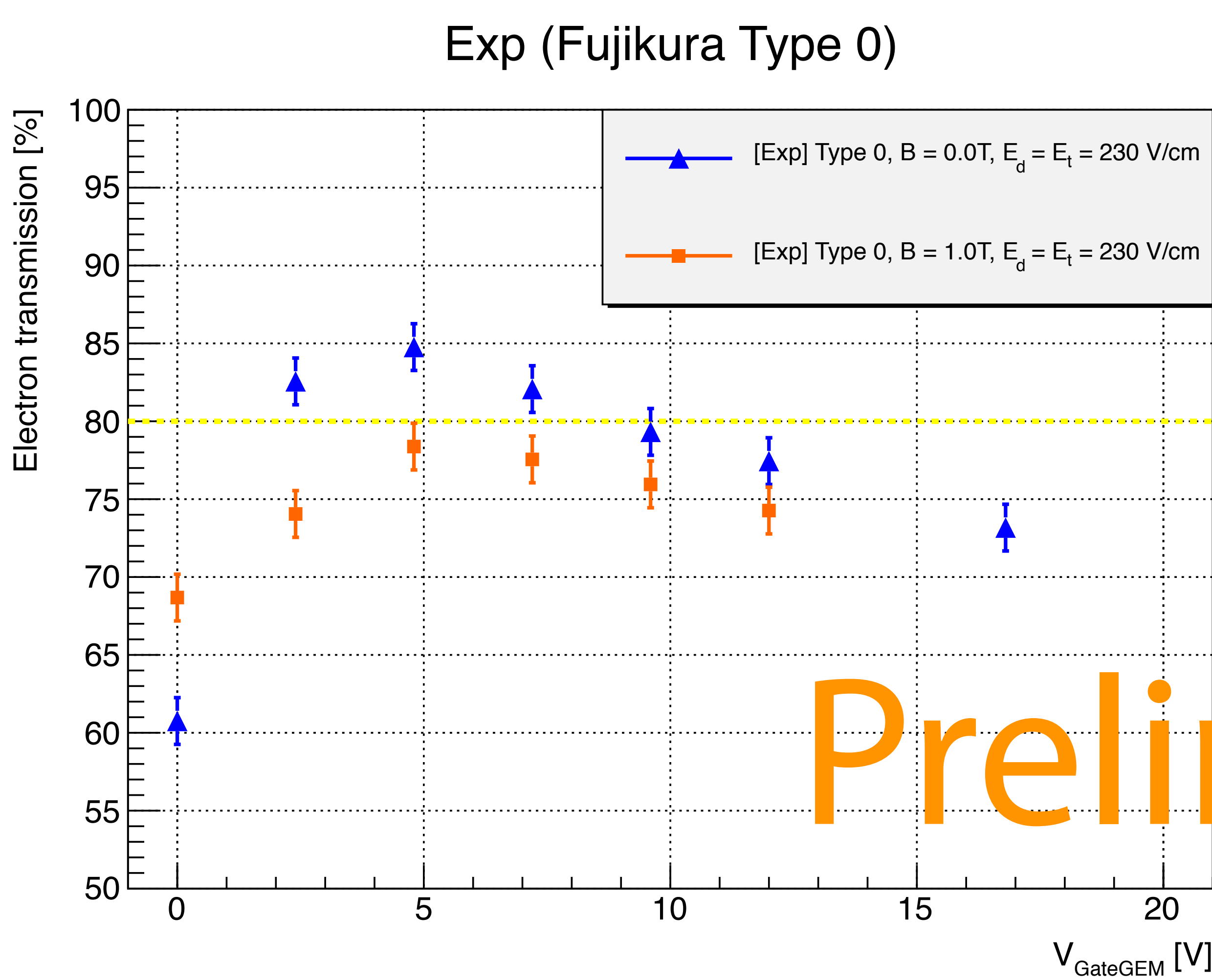


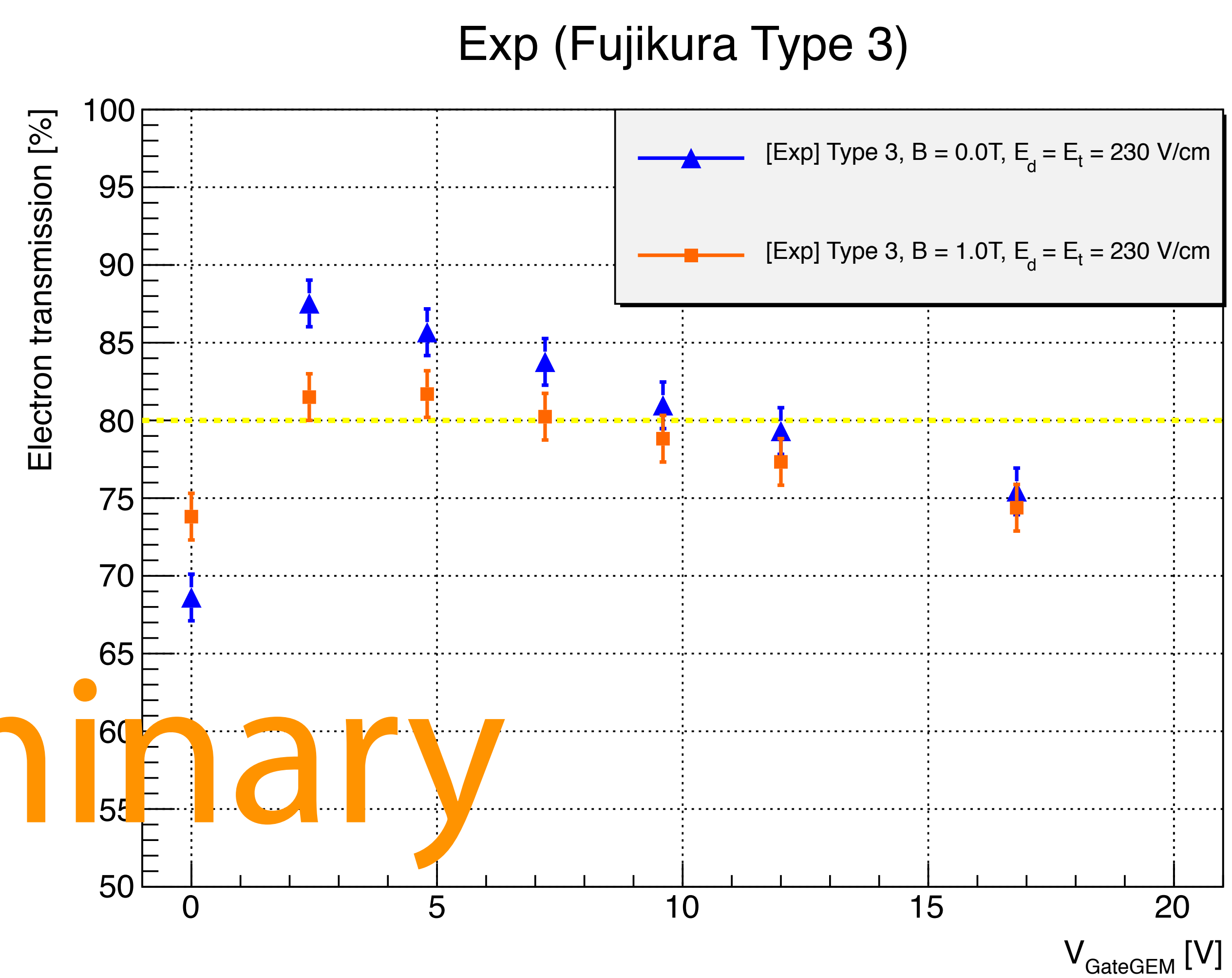


using a CERN standard GEM readout (triple stack) and one of Fujikura Gate-GEM samples placed 10 mm above

  - **Case (2)**: the conversion happens in the drift region, so that the produced electrons have to pass the gate and the signal is affected by the gate transmission
  - **Case (1)**: a small portion of the X-rays are converted in the region between the gate and the amplification GEM, which produces signal without any effect of the gate
  - **Electron transmission**: calculated as the ratio of the two signals

Results for electron transmission meas.

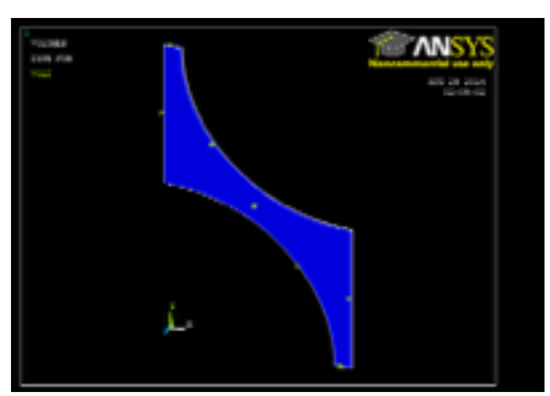




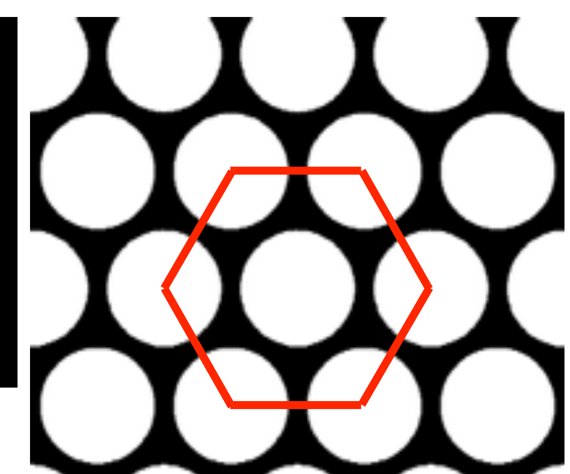
Preliminary

Evaluation of the measurement results and extrapolation to 3.5 T can be also discussed by a simulation

Combination of ANSYS and Garfield++ (microscopic tracking), has been used to understand quantitatively the data from the electron transmission measurements



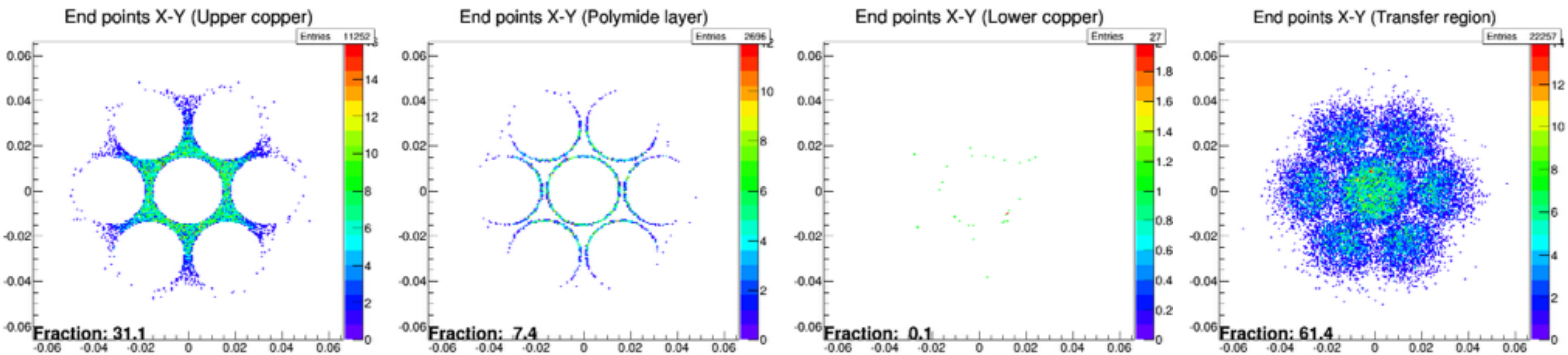
field calculations were done using finite element calculations with ANSYS



simply generate individual electrons above the GEM hole in the drift region

See whether electrons arrive below the Gate-GEM (in the transfer region) or somewhere on the Gate-GEM

ANSYS-Garfield++ simulation (0 T, V_{gate} = 0 V)



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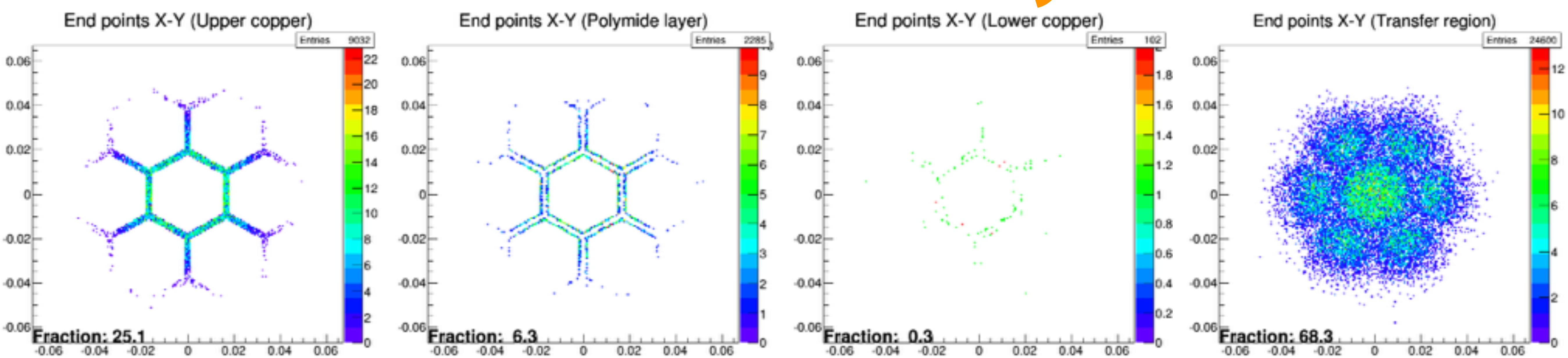

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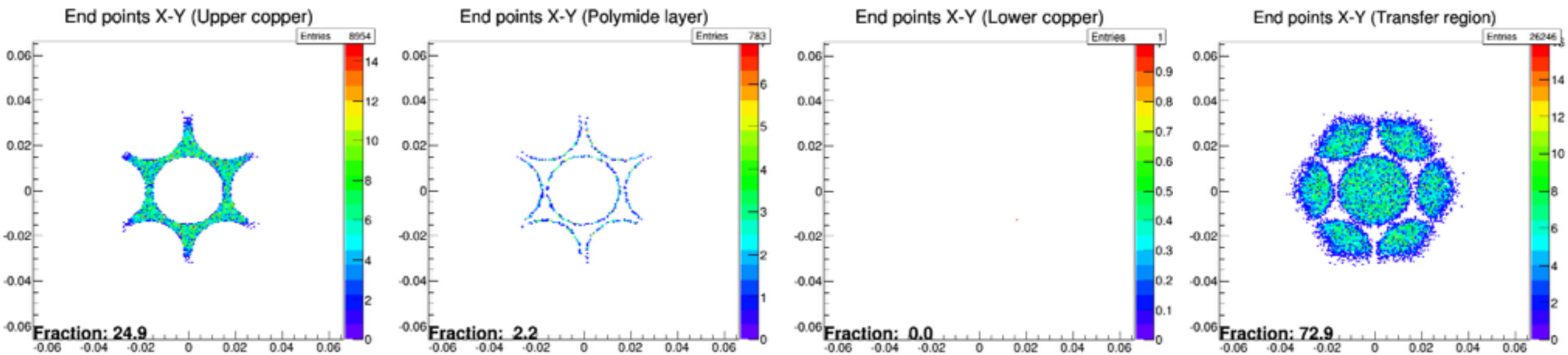
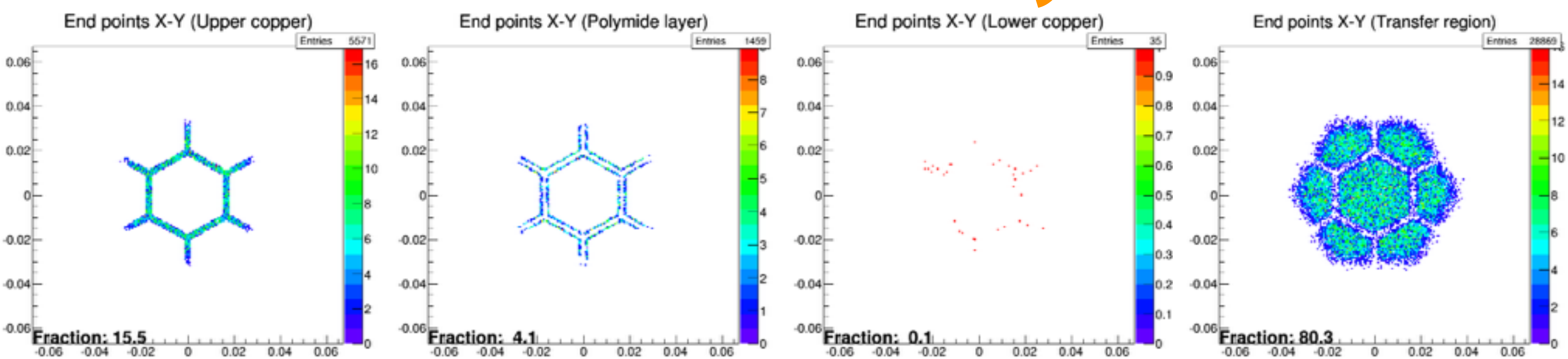
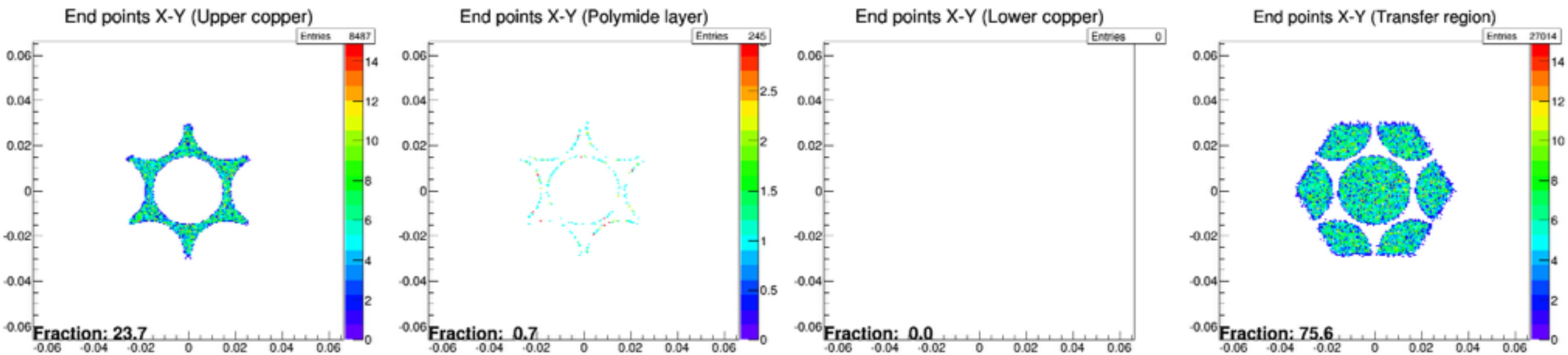


Preliminary



ANSYS-Garfield++ simulation (3.5 T, V_{gate} = 0 V)



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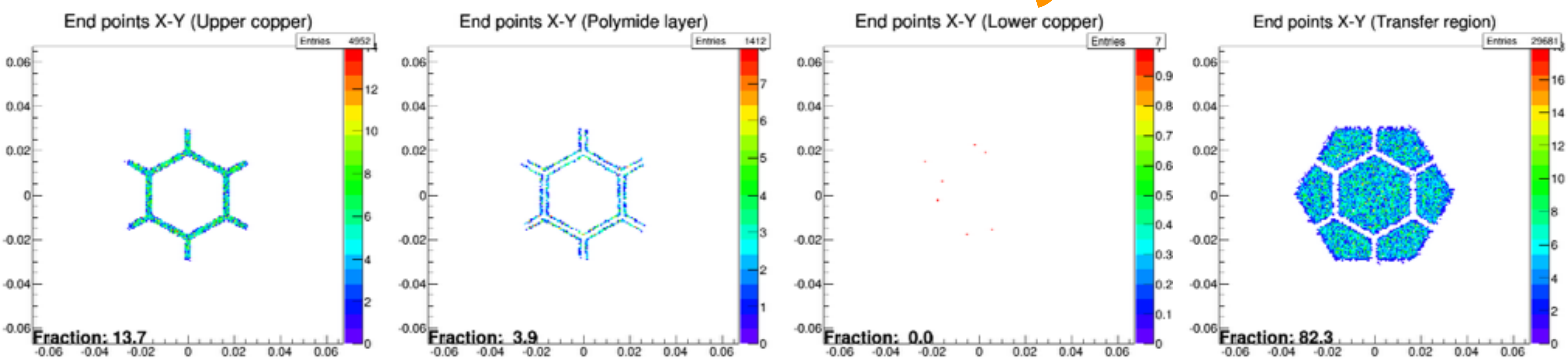
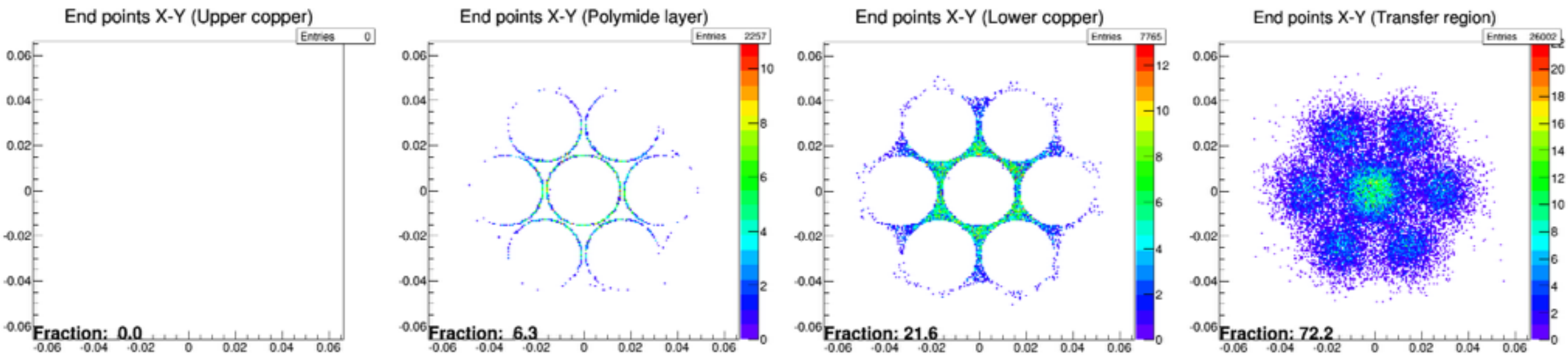
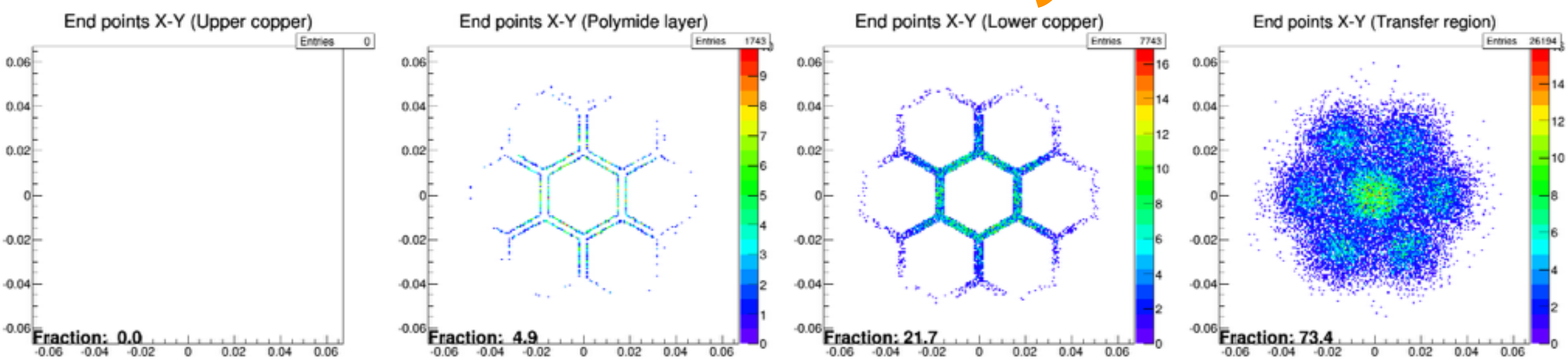


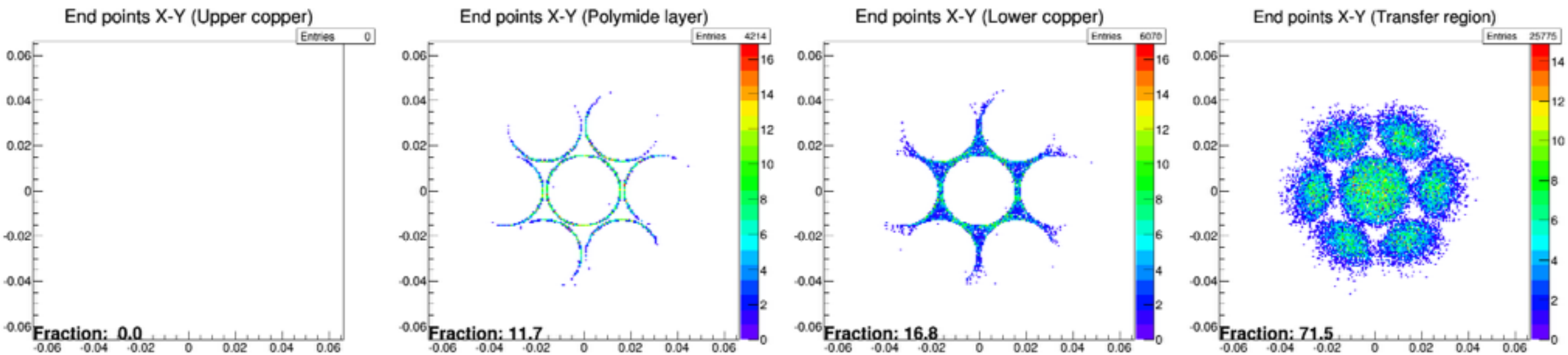
ANSYS-Garfield++ simulation (0 T, V_{gate} = 20 V)



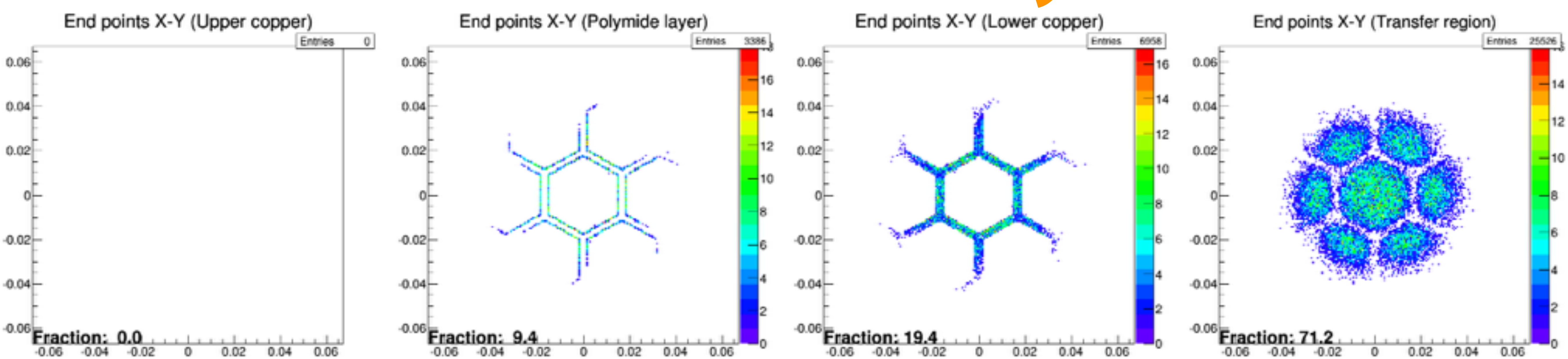
Preliminary



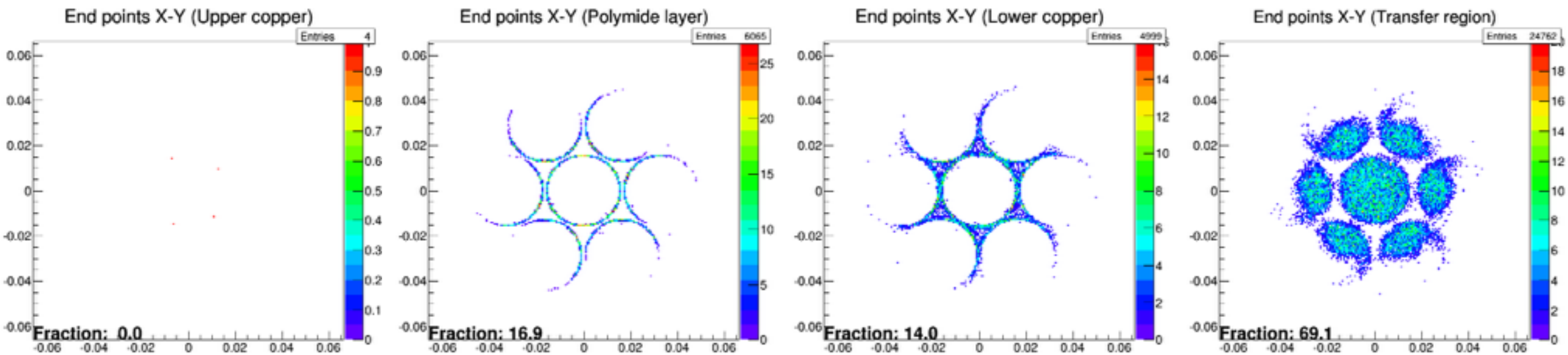
ANSYS-Garfield++ simulation (1 T, V_{gate} = 20 V)



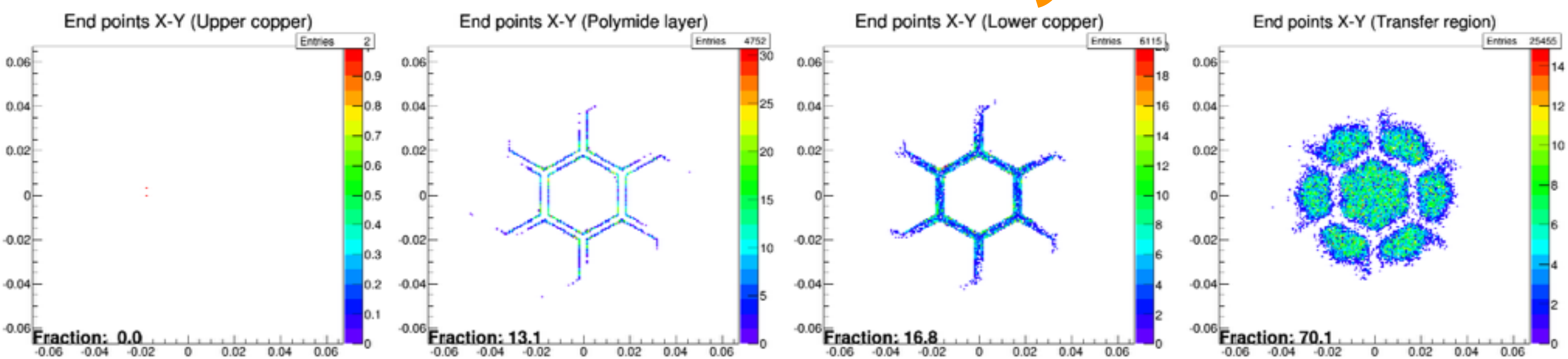
Preliminary



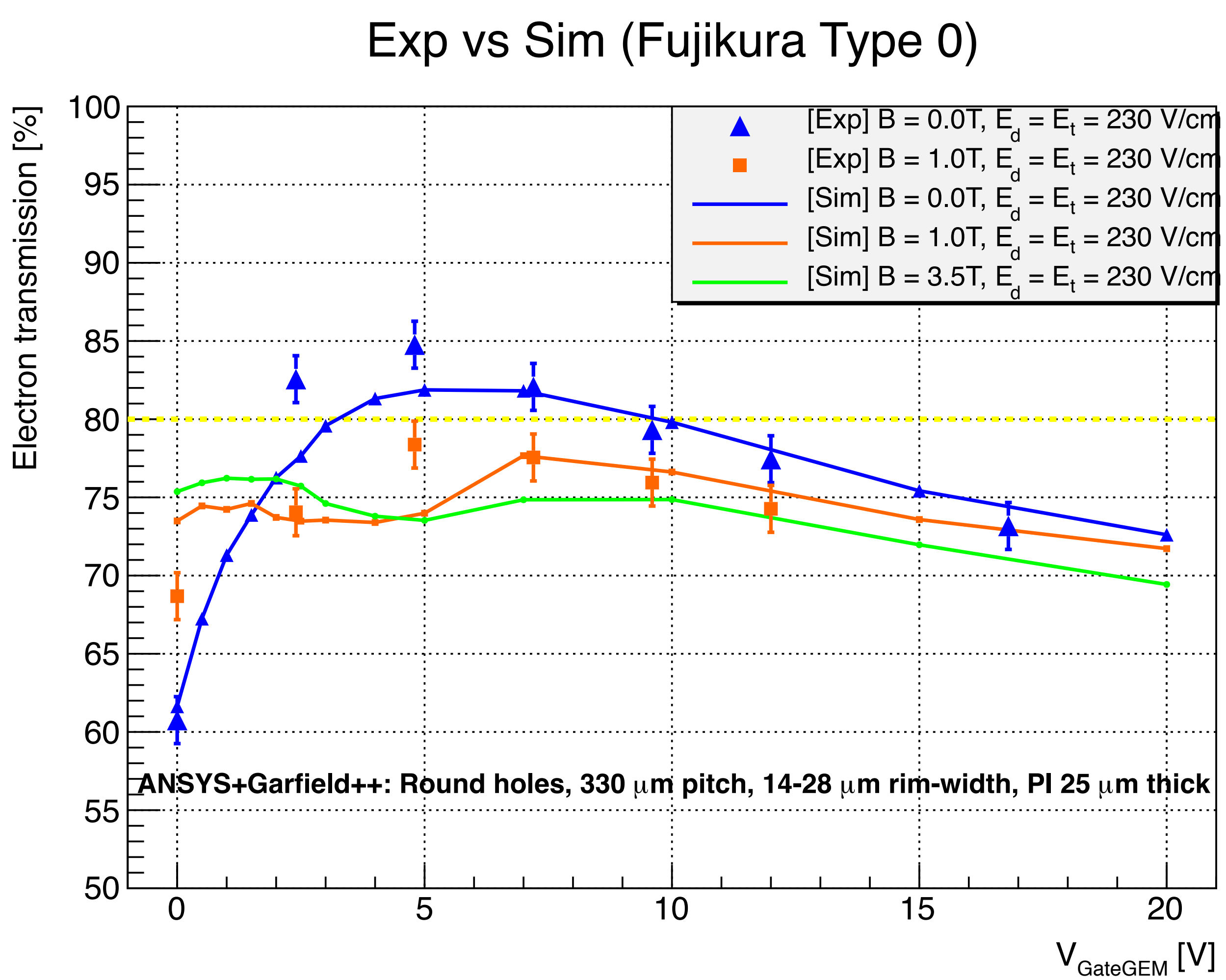
ANSYS-Garfield++ simulation (3.5 T, V_{gate} = 20 V)

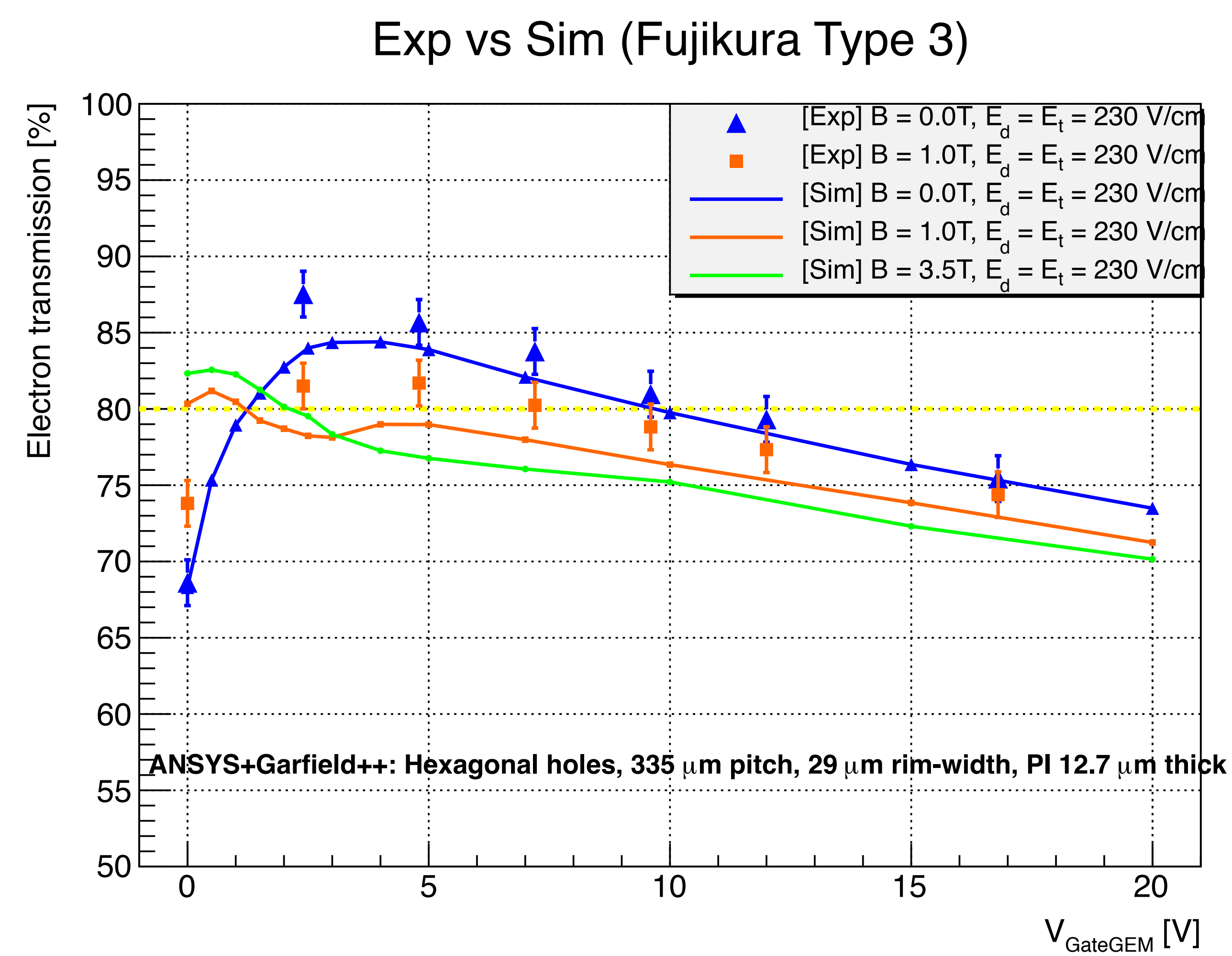


Preliminary



Comparison btw measurements and sim



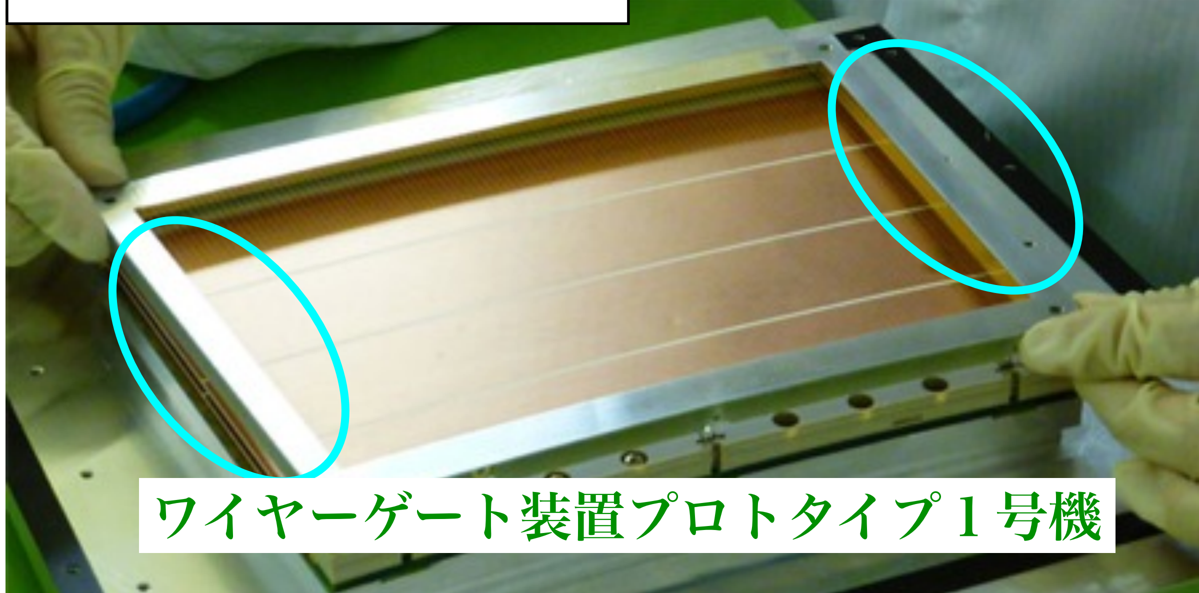


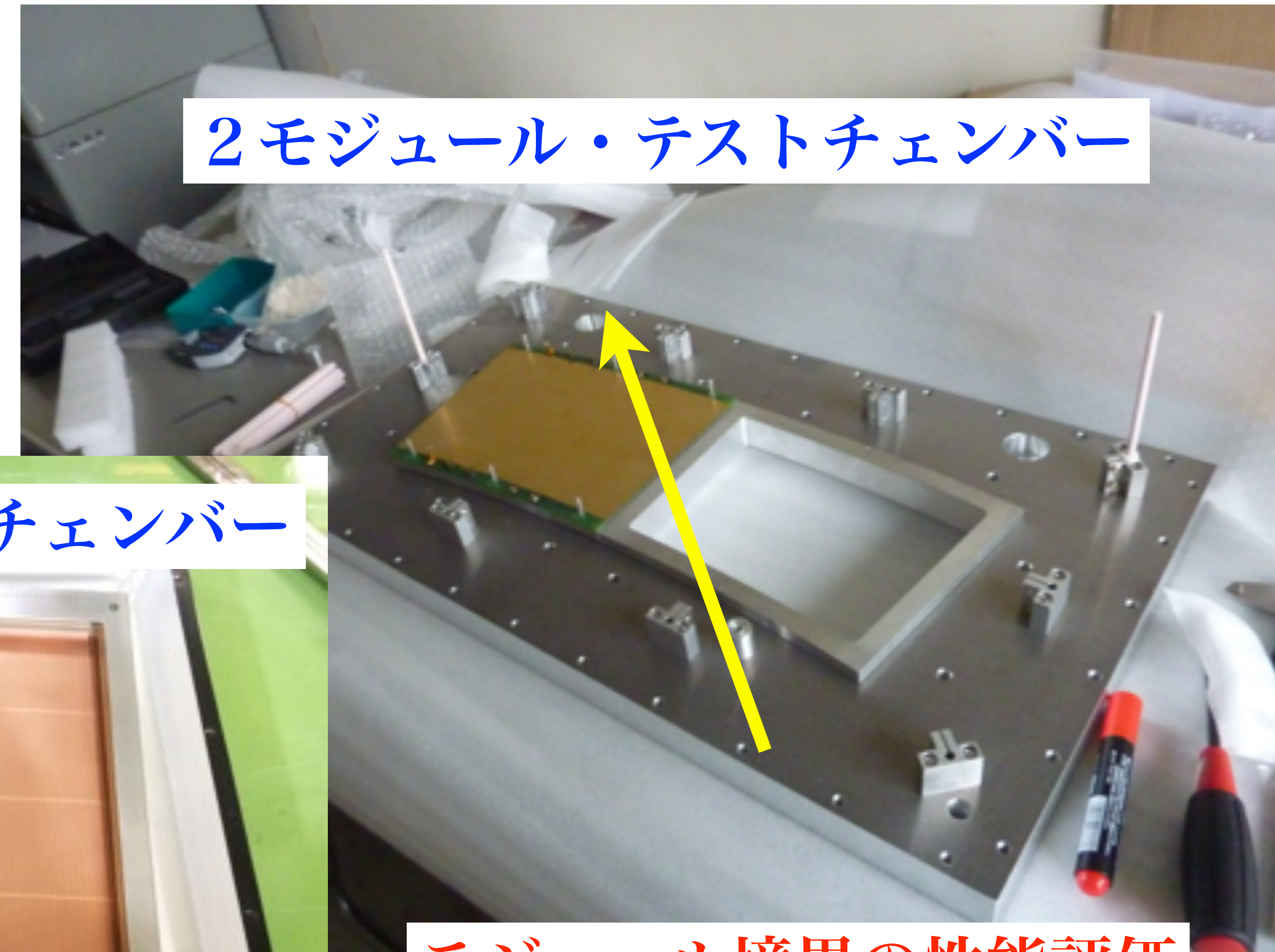
Preliminary

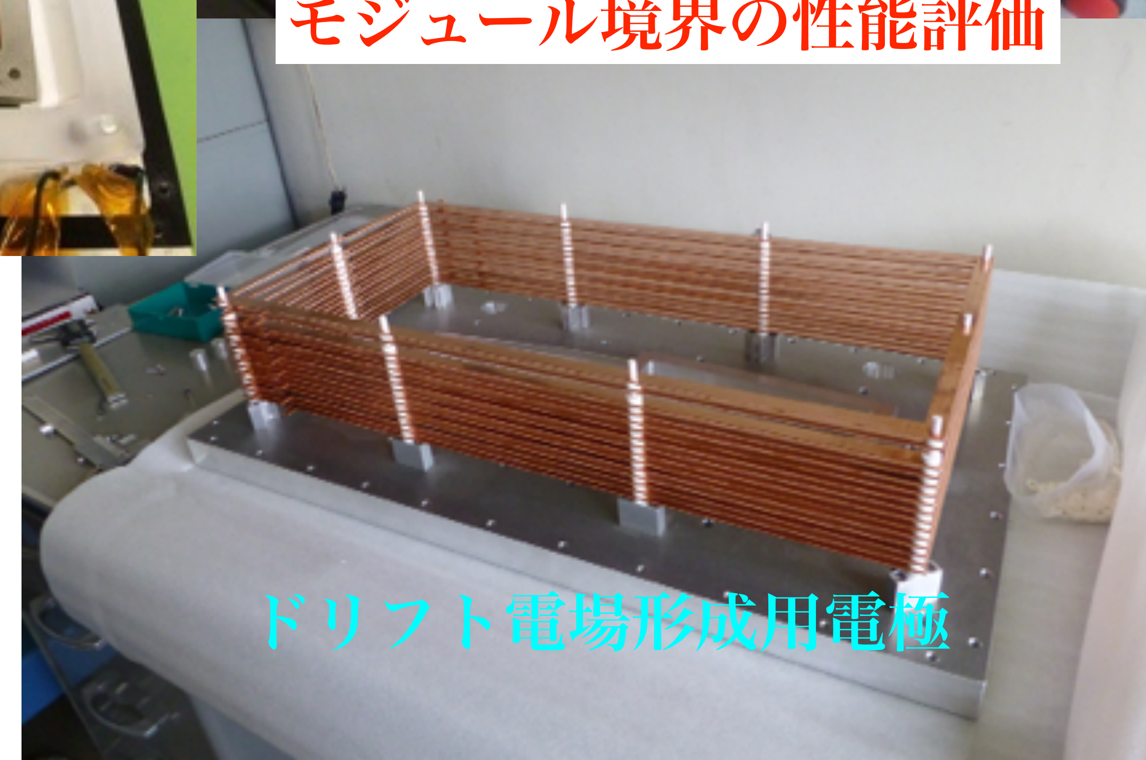
Evaluation of the measurement results by using the ANSYS-Garfield++ simulation has been performed, and **extrapolation to 3.5 T shows acceptable 80% electron transmission** for the resolution requirement of ILD-TPC

ゲート装置を搭載したモジュール試験

放射状ワイヤーグリッド (30 µm 径ワイヤー，2 mm ピッチ)
ステンレス鋼フレームにスポット溶接
単一ポテンシャルによるゲート閉







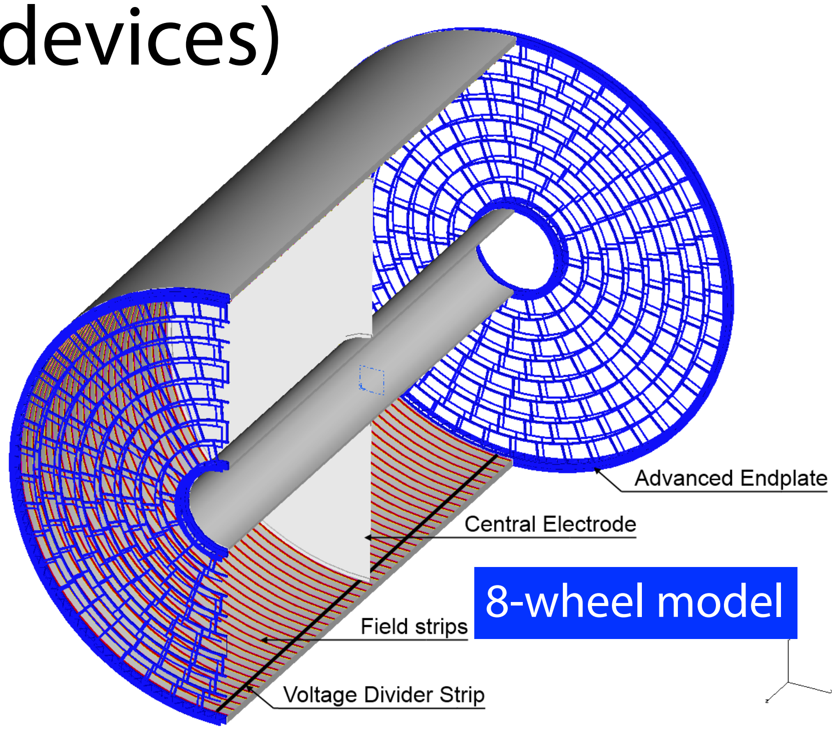
Summary and prospects

- ILD-TPC is planned to be equipped with a gating device located between the drift volume and the gas amplification device to prevent positive ions
- There are 3 options (wire-grid, Gate-GEM & wire-mesh) for a gating device: GEM-gating device would be most adapted for the module structure of ILD-TPC
  - The gate is required to block the positive ions when it is closed, and Gate-GEMs can offer a high ion suppression for a small applied voltage (~10V)
- To achieve high electron transmission, large-aperture Gate-GEM samples which have 75~85% optical transparency were produced by Fujikura Ltd.
- Fujikura Gate-GEM samples have been tested with a test chamber installed in the KEK MRI type 1 T solenoid, and the **electron transmission of the samples is reached about 80% under 1 T**
- Evaluation of the Gate-GEM electron transmission measurement results by using the ANSYS-Garfield++ simulation has been performed, and **extrapolation to 3.5 T shows acceptable 80% electron transmission** for the resolution requirement of ILD-TPC
- First sample of LP1 module sized Gate-GEM (17 x 22 cm^2) has been already delivered, and it will be integrated with current LP1 Asian GEM module and will be tested by using our UV-laser system

Backup

Introduction

- **Time projection chamber (TPC) for ILD**
  - The ILD concept for ILC: have a GEM- or Micromegas-based TPC as a main tracker
    - use of Micropattern gaseous detectors (MPGD) to replace the MWPCs (not possible to reach the required spatial resolution with a wire-based readout because the strong magnetic field of B = 3.5 T and the wide gap of 1-2 mm between wires leads to **strong E×B-effects**)
  - Another advantage of MPGDs: a large fraction of positive ions created in the gas amplification are guided to an electrode and are neutralized there
    - the number of ions potentially reaching the drift volume is greatly reduced (**Ion feedback suppression**)
    - do we really need a gating device located between the drift volume and the gas amplification device to prevent positive ions from entering the drift region?? => **next slide**
- **Features of ILD-TPC** (for a discussion of gating devices)
  - Point resolution of better than 100 μm for long drift (~2.3 m) => need a gas mixture in which D(B = 0) is small (cool) and τ (mean free time of drift electrons between collisions with gas molecules) is fairly large (fast) under a moderate drift field (E)!
    - use of $Ar:CF_4:iC_4H_{10}$ (95:3:2), so called **T2K gas**
  - Modular endplate detectors: concentric assembly of modules (current design: 240 modules of approximately 17 × 22 cm^2)

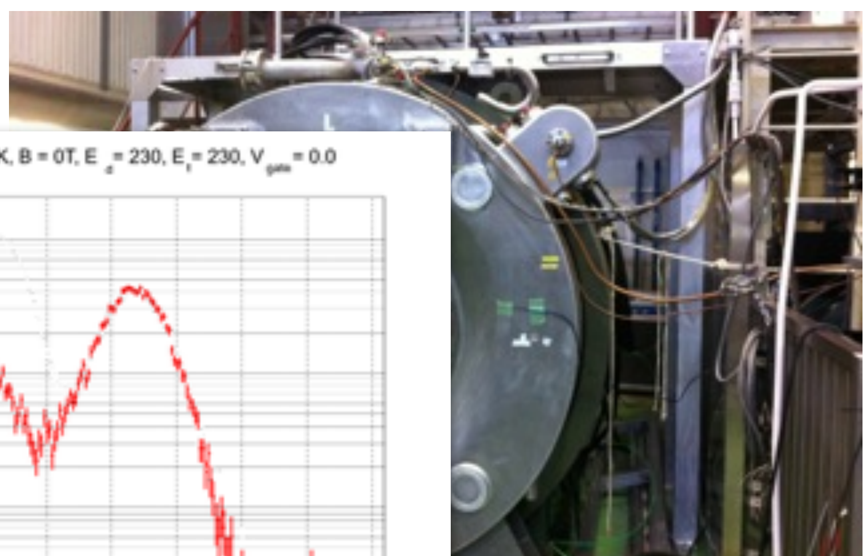


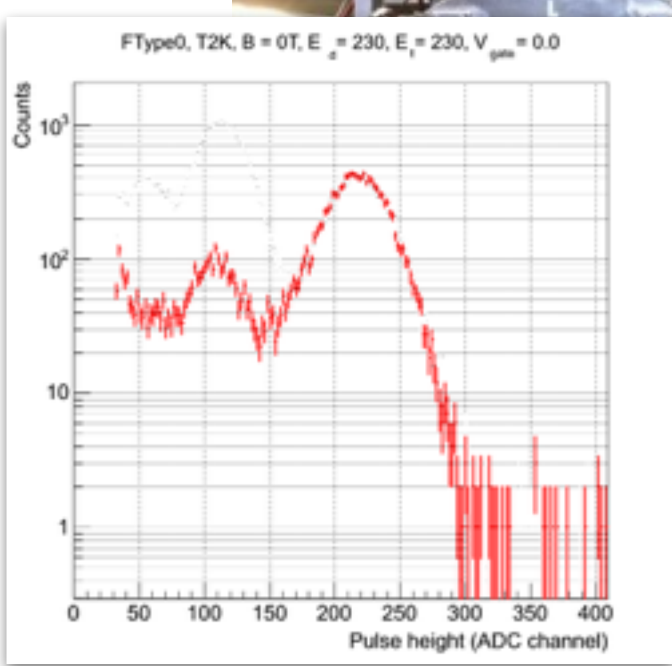
Electron transmission measurement

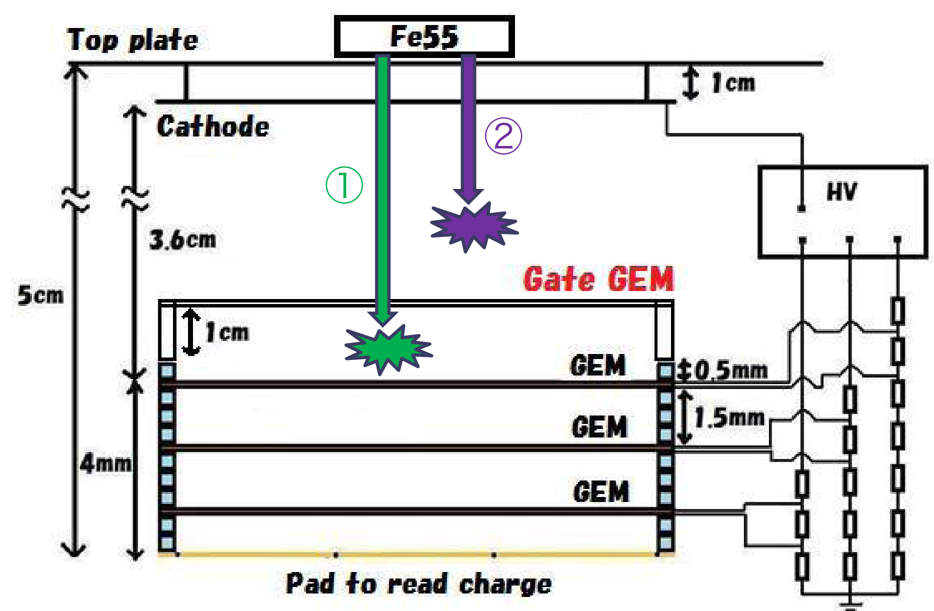
Motion of electrons is strongly restricted to the direction of the magnetic field => need measurements under high magnetic field!

• Measurement method

- by comparing **signal charge passing through the Gate-GEM** to **signal without Gate-GEM** using a small test chamber irradiated with an ^{55}Fe source, which is installed in a 1 T MRI type super-conducting solenoid at KEK cryo center







using a CERN standard GEM readout (triple stack) and one of Fujikura Gate-GEM samples placed 10 mm above

first to measure the charge without gate, switched off drift field -> only electrons from conversion at (1) can reach amplification GEM and be collected

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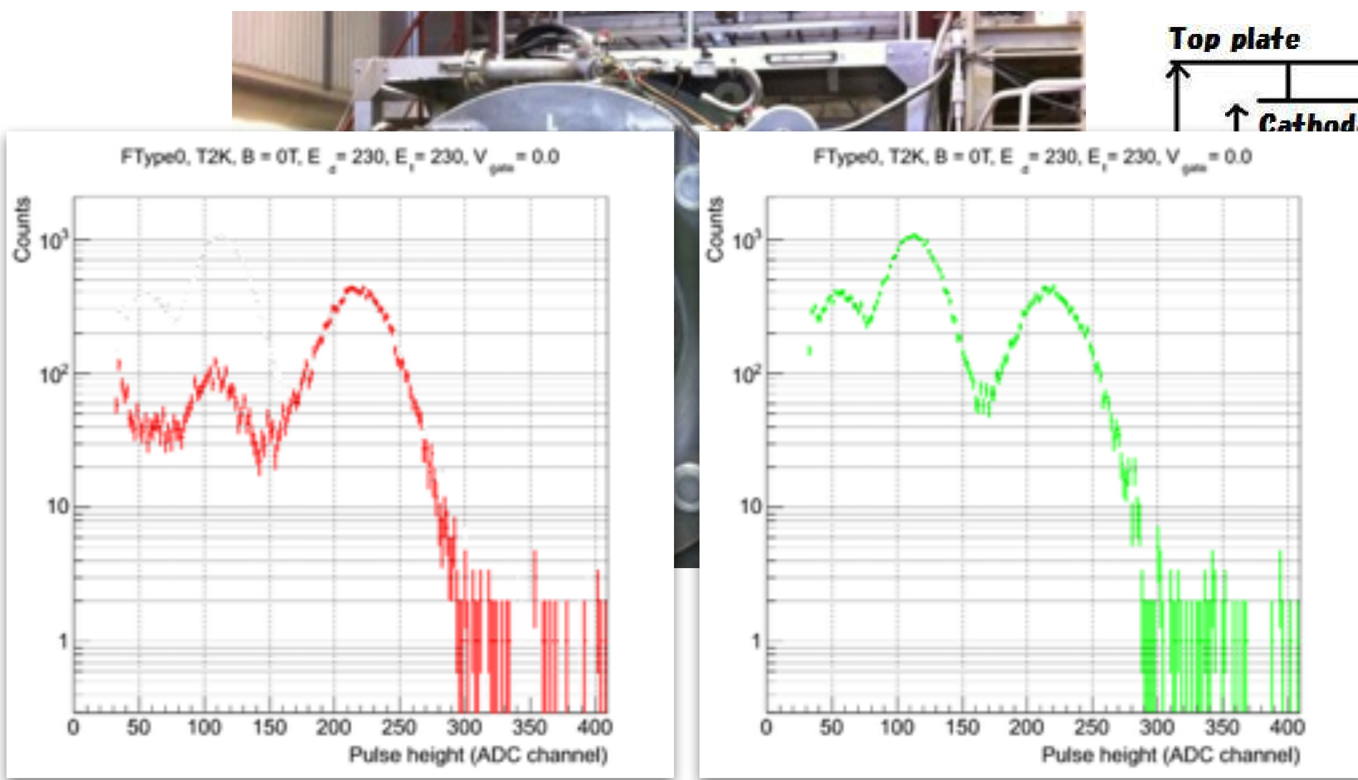
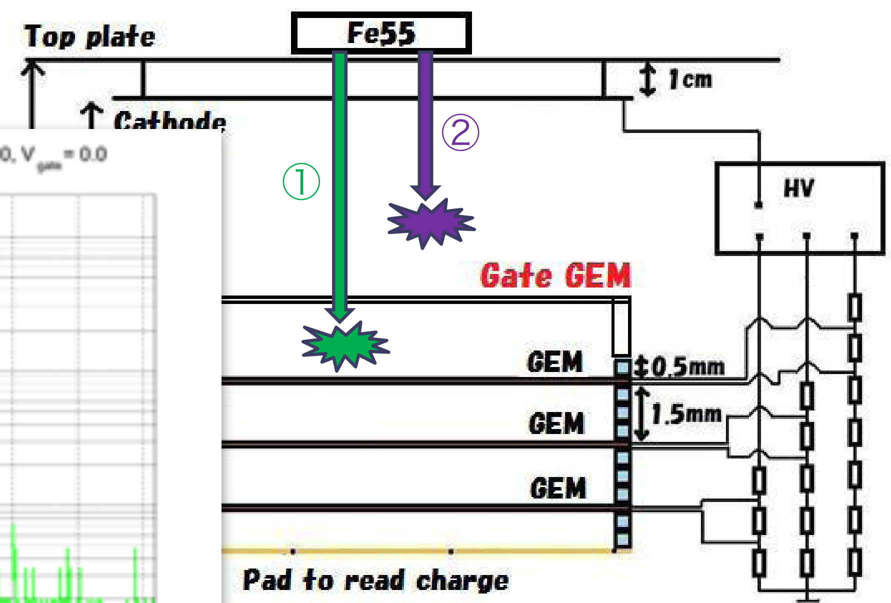


first to measure the charge without gate, switched off drift field -> only electrons from conversion at (1) can reach amplification GEM and be collected

then drift field is switched on -> electrons at both (1) and (2) can be collected



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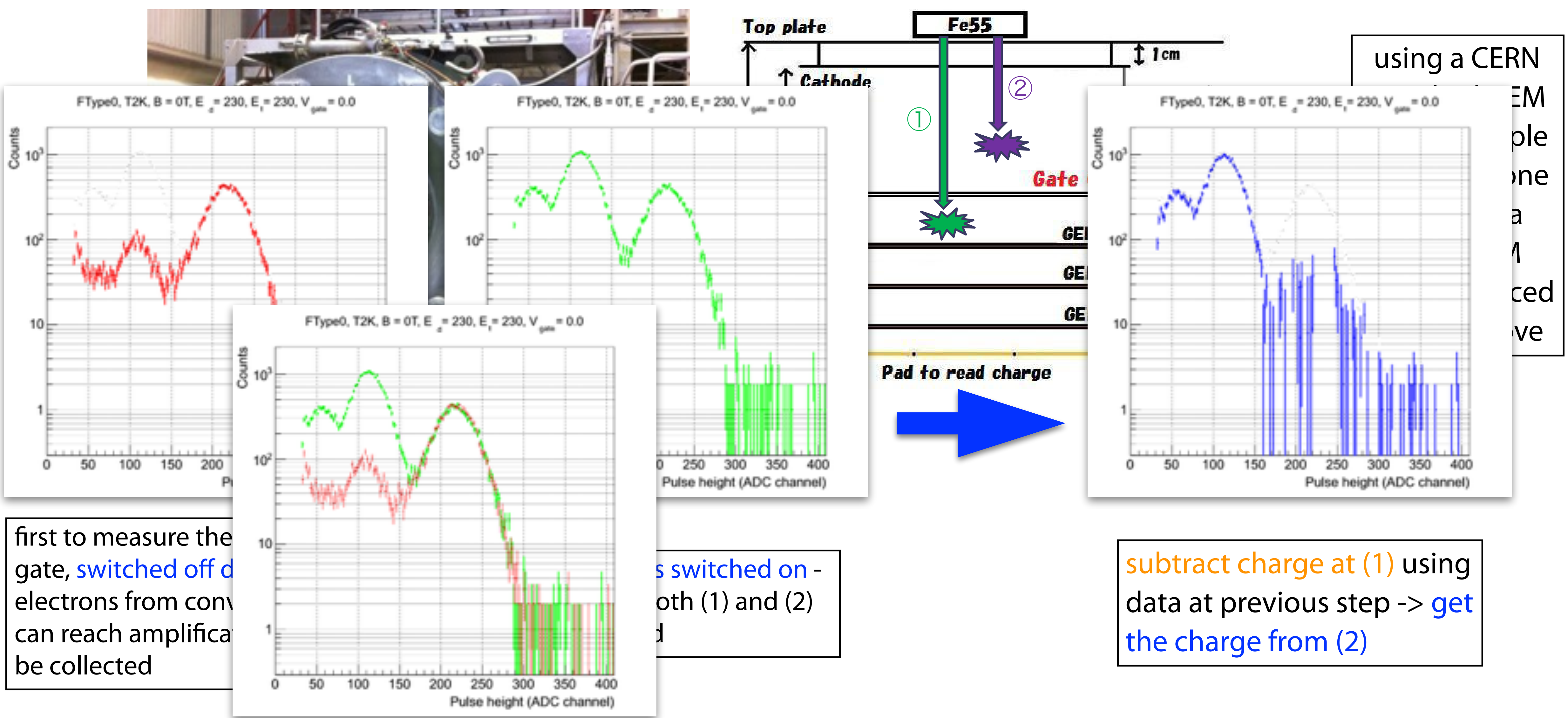
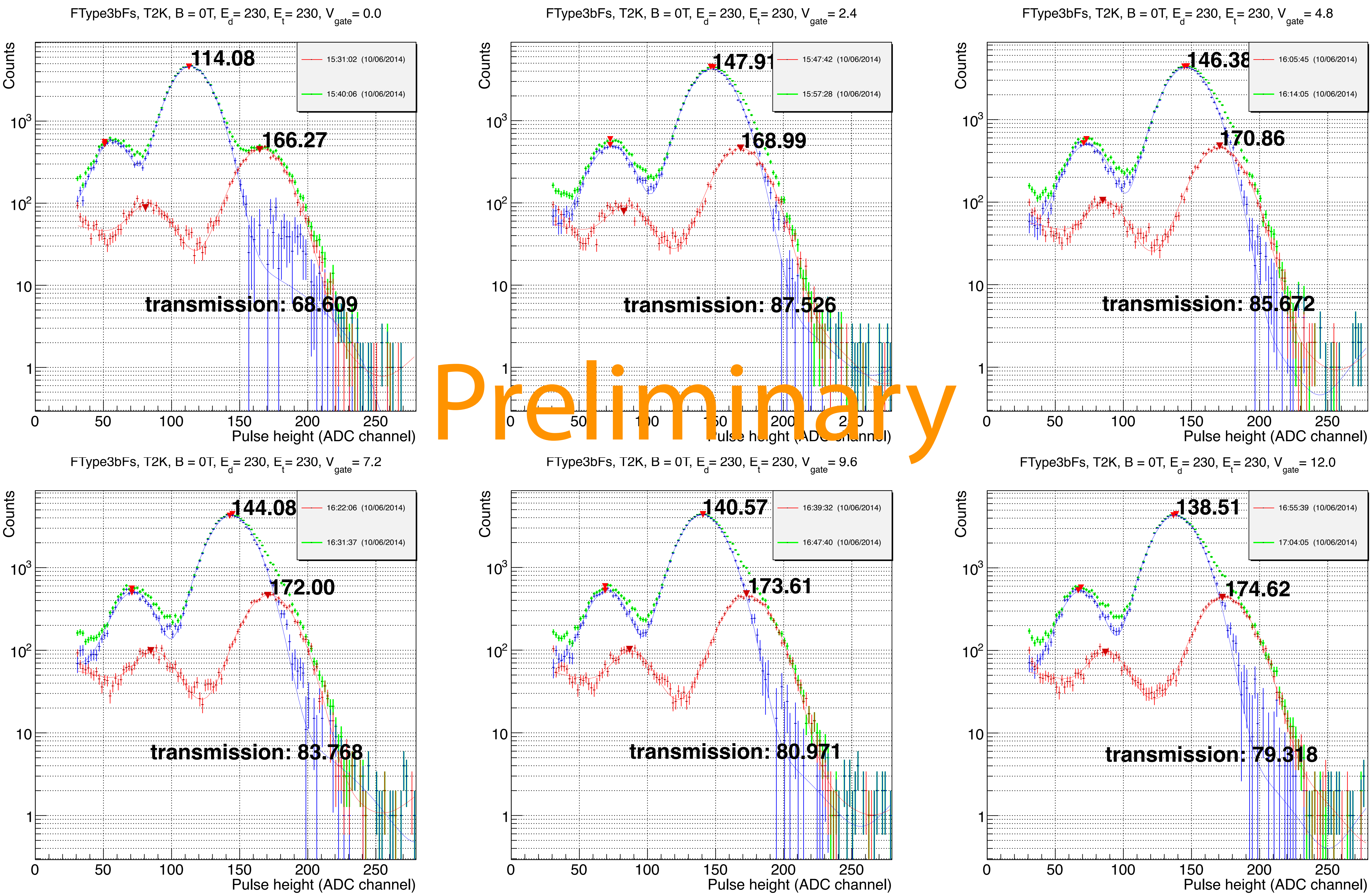
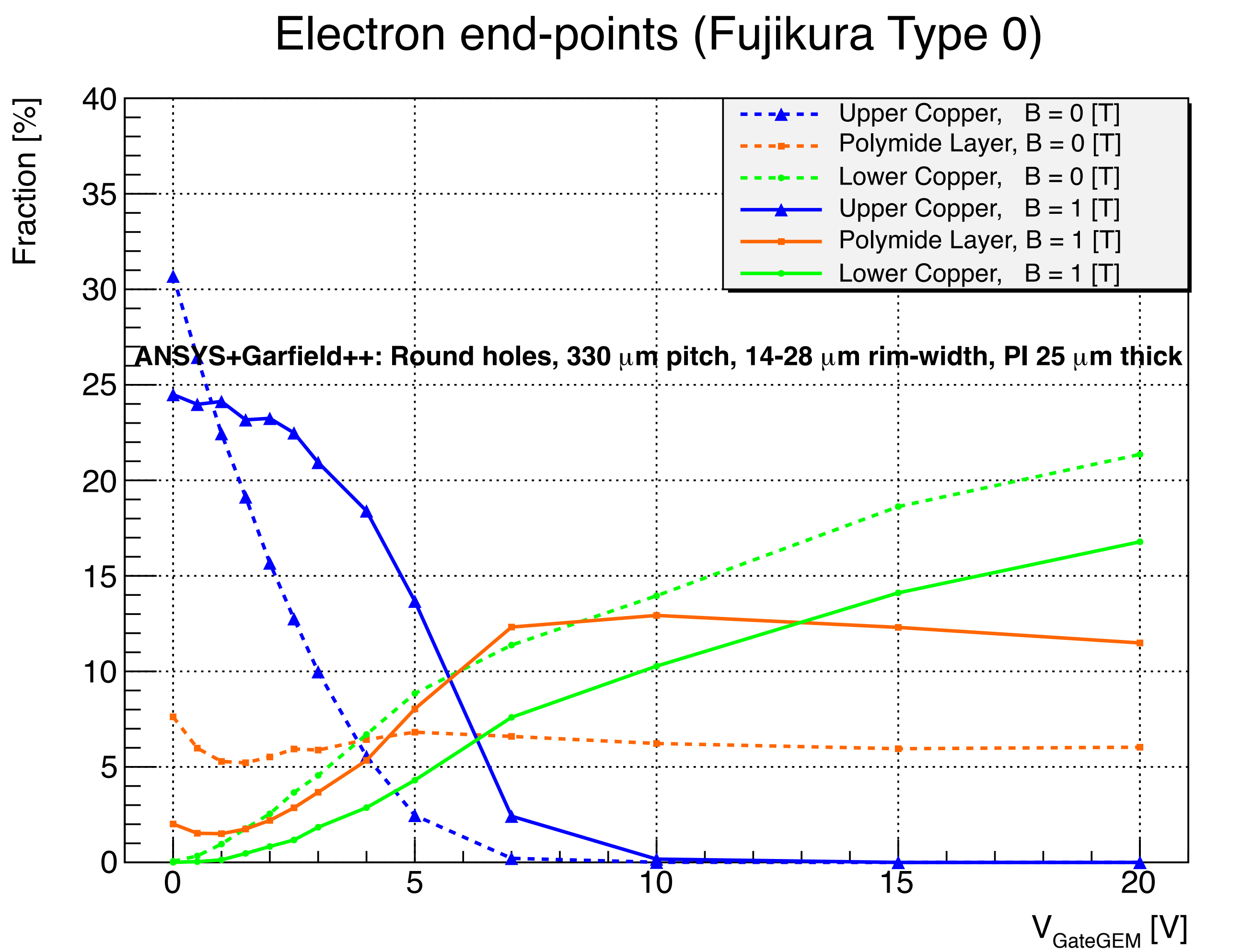
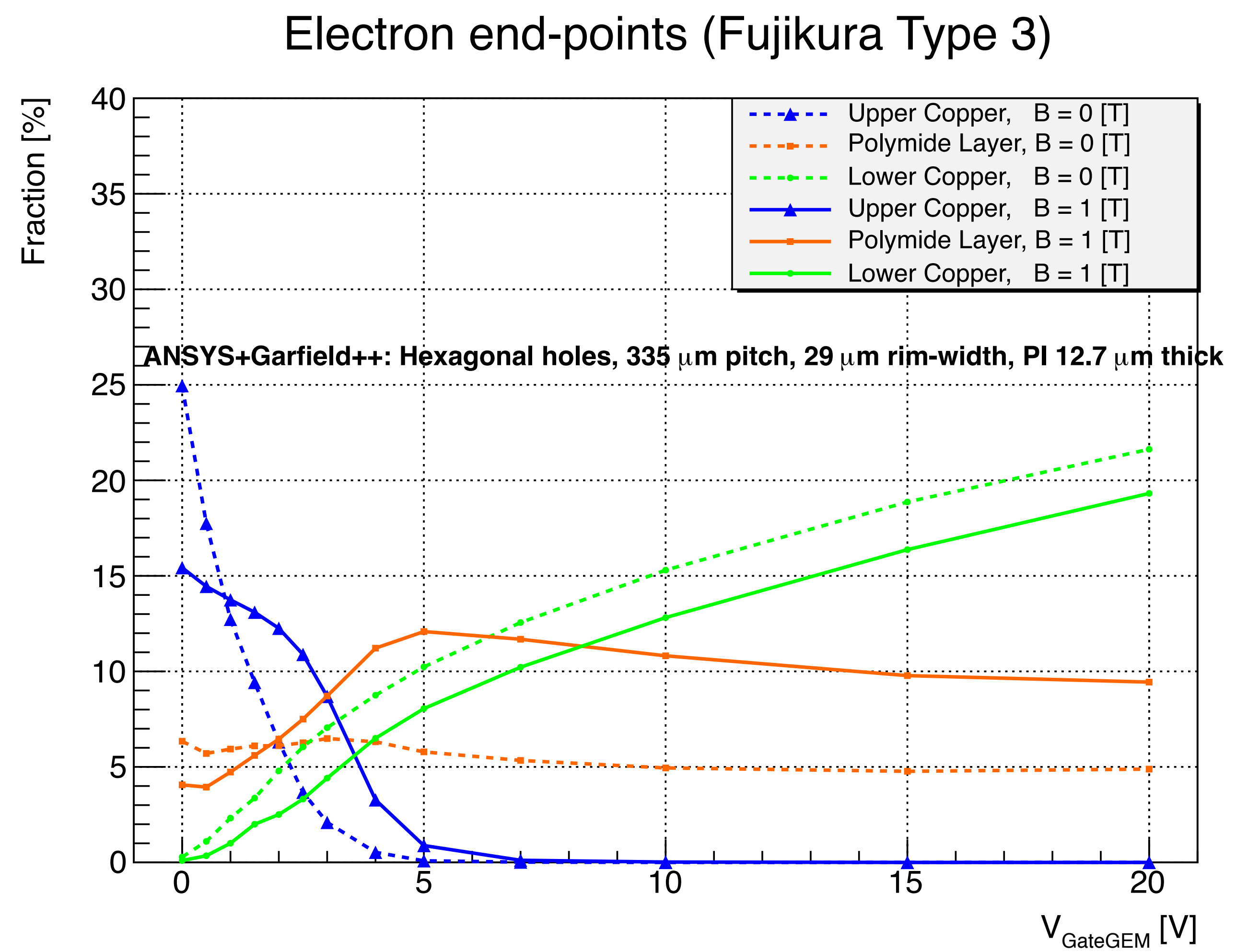


Type 3, B = 0, Ed = 230 V/cm, Et = 230 V/cm



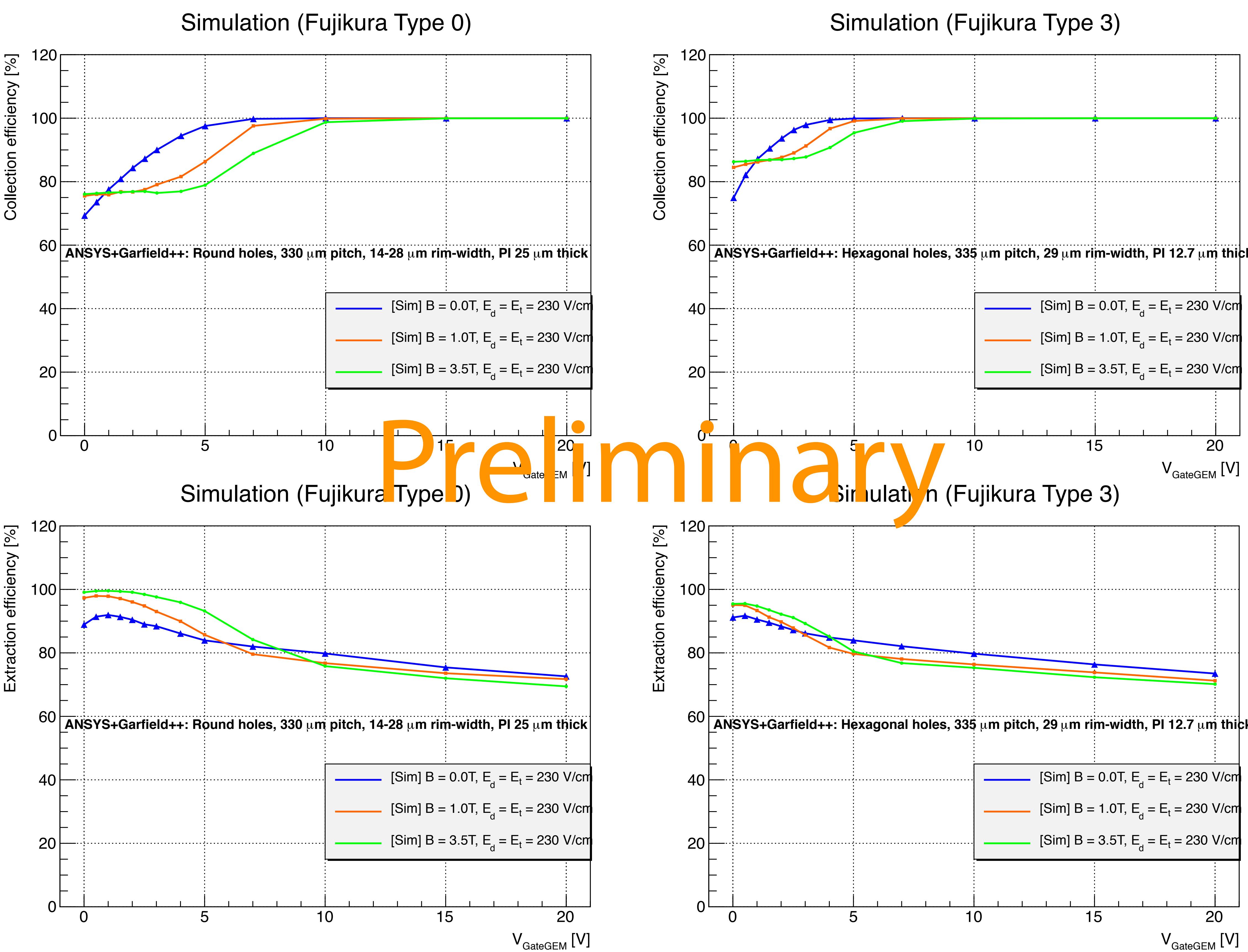
Electron end-points

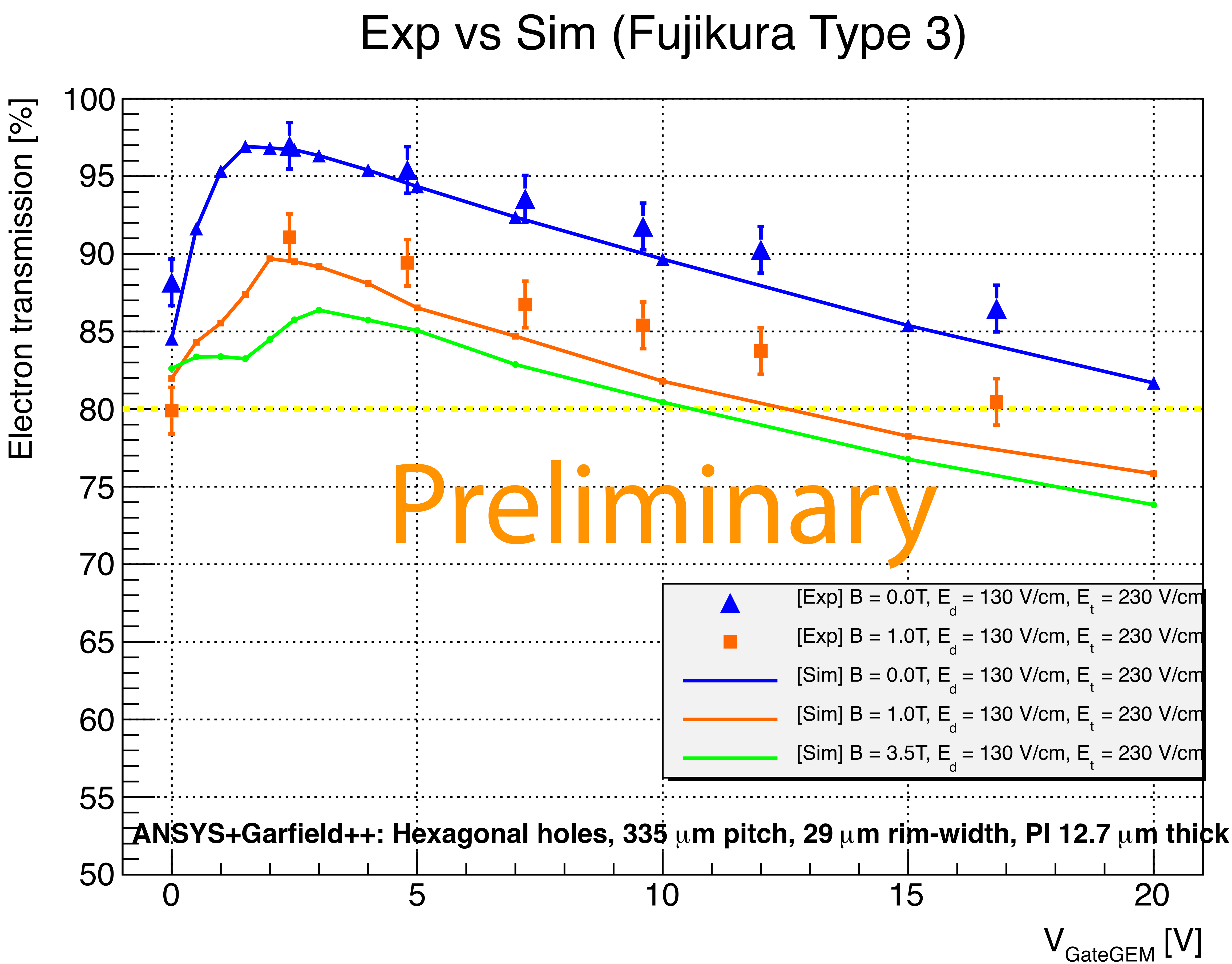




Preliminary

Collection efficiency × Extraction efficiency





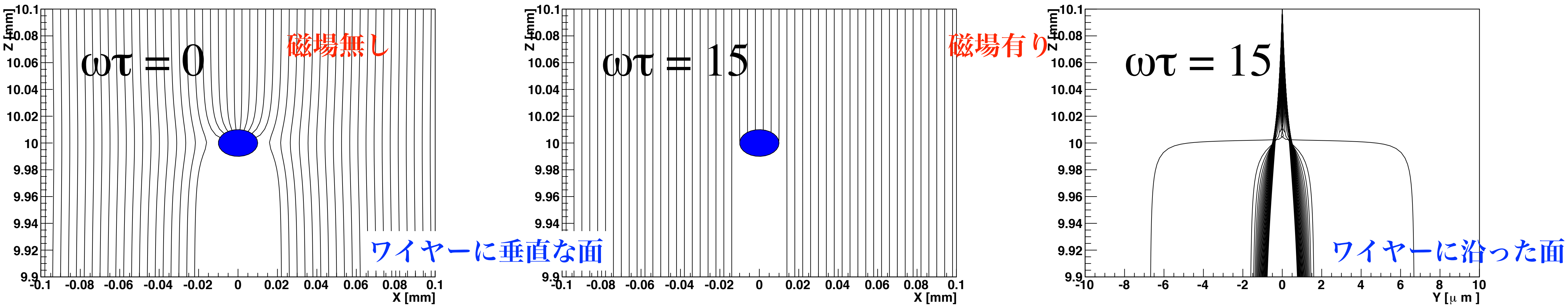
Exp vs Sim (Fujikura Type 3)
Electron transmission [%]
100
95
90
85
80
75
70
65
60
55
50
0
5
10
15
20
$V_{GateGEM}$ [V]
Preliminary
[Exp] B = 0.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Exp] B = 1.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Sim] B = 0.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Sim] B = 1.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Sim] B = 3.5T, E_d = 130 V/cm, E_t = 230 V/cm
ANSYS+Garfield++: Hexagonal holes, 335 μm pitch, 29 μm rim-width, PI 12.7 μm thick

ワイヤーを用いた陽イオンゲート装置

陽イオンゲートの開状態における位置分解能への影響

ＩＬＤ−ＴＰＣに要求される優れた運動量分解能を実現するには，ドリフト電子の変位を最小限にする必要がある
→ 1~2 mm ピッチで張られたワイヤーのグリッド電圧をドリフト電場の電位に合わせることにより，可能な限り均一なドリフト電場を保ちながらゲート開状態を作る → ワイヤーの電位が完璧にドリフト電場と一致する理想的な場合でも，ワイヤーにおける表面電荷分布はワイヤーに対して垂直なダイポール電場を作る (x z 平面)

ワイヤー近傍の電子ドリフトライン (拡散がない場合)



電場の乱れはワイヤー近傍にのみ現れる (ワイヤーからのダイポール電場はワイヤーの半径の数倍にしか広がらない)

十分に細いワイヤー (~20 μm) であれば，ワイヤー近傍のE×B効果によるドリフト電子の変位は十分に小さい

有限半径の影響と不完全な電圧調整はドリフト電場の歪みの原因となり，観測される飛跡の歪みとなり得る → プロトタイプによる実証試験が必要！