Status of electron transmission measurements for a GEM gating device

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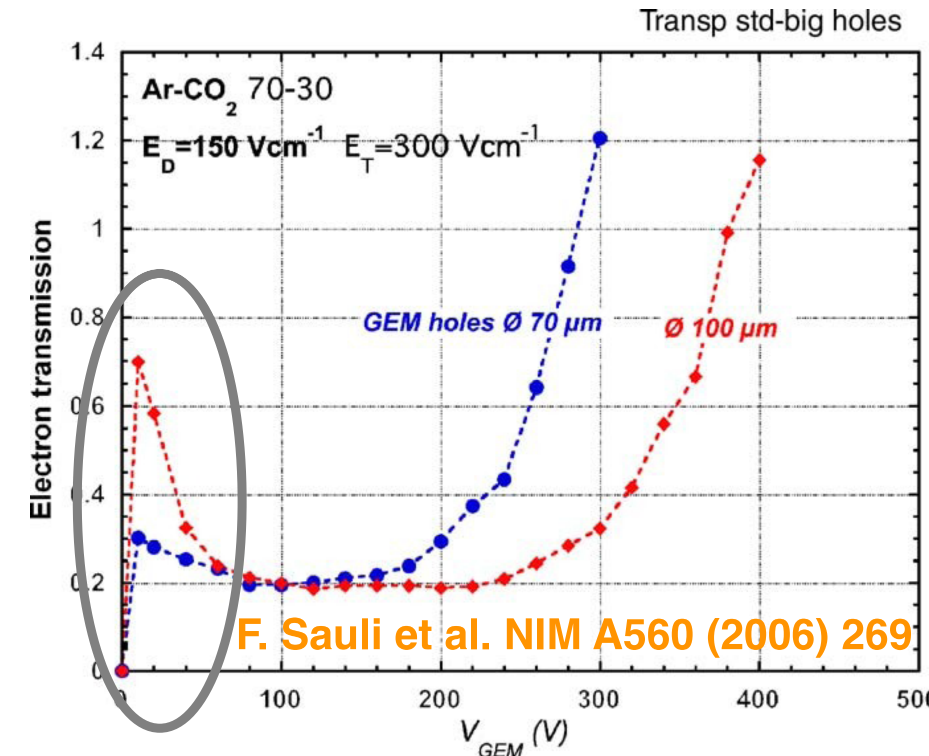
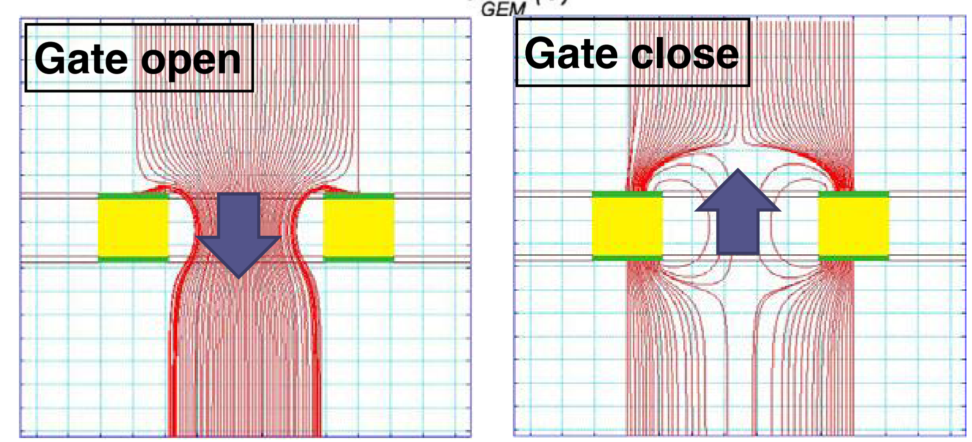
GEM as a gating device

- **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
    - can be achieved by changing only the potential of lower electrode of GEM, without affecting the field in drift region
  - GEM-gating device would be most adapted for the module structure of ILC-TPC!



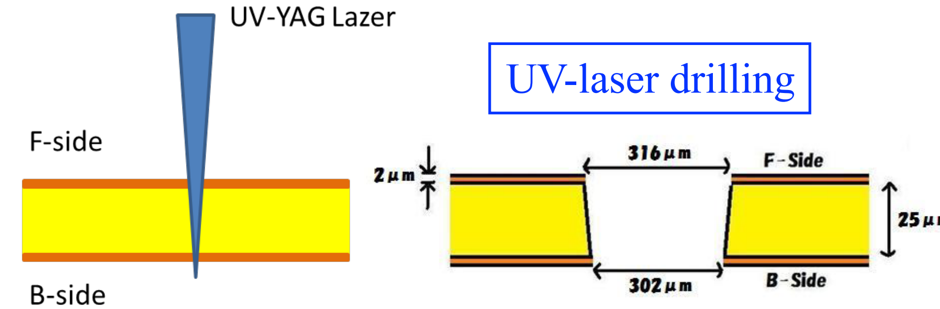


- **Requirement for Gate GEMs of ILC-TPC**
  - **Goal: 80% electron transmission** = corresponding the **deterioration in the spatial resolution ~O(10%)** for the ILC-TPC nominal electric field configuration
  - Operated in a 3.5 T axial magnetic field, and in a gas with a high mean free time (τ) of 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

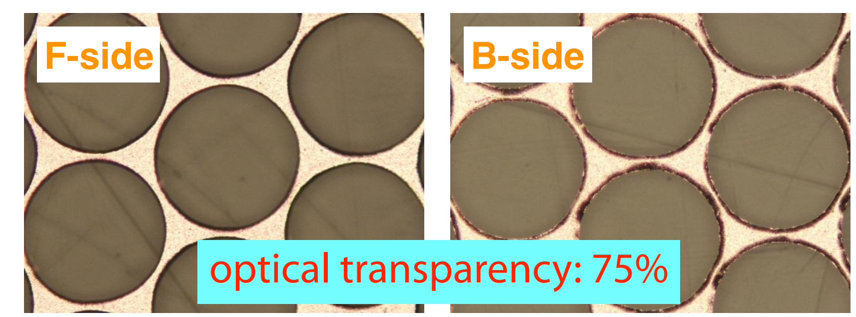
ordinary amplifying GEMs (e.g. CERN standard): not suitable because of their poor optical transparency

Large-aperture Gate-GEM samples

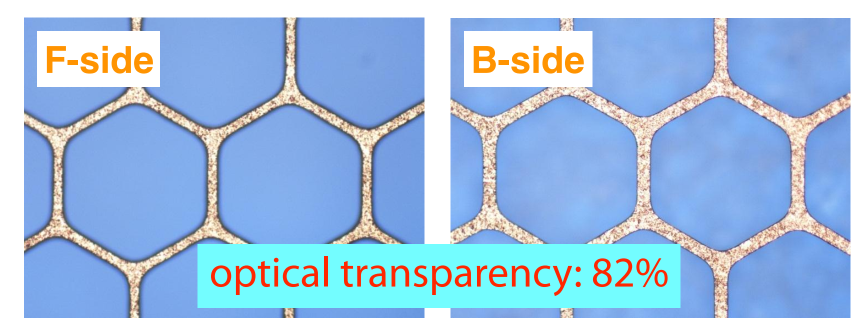
- **High optical transparency = Minimize rim width of GEM holes**
  - To achieve high electron transmission: 30 μm rim width & 330 μm pitch in honeycomb structure (= 80~85% optical transparency) required

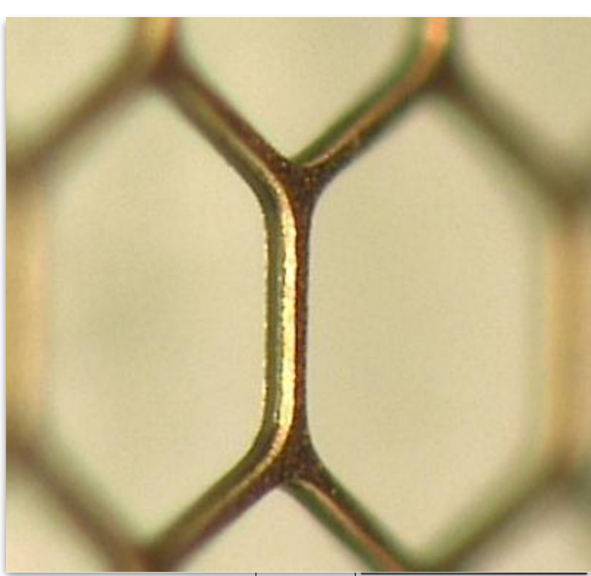


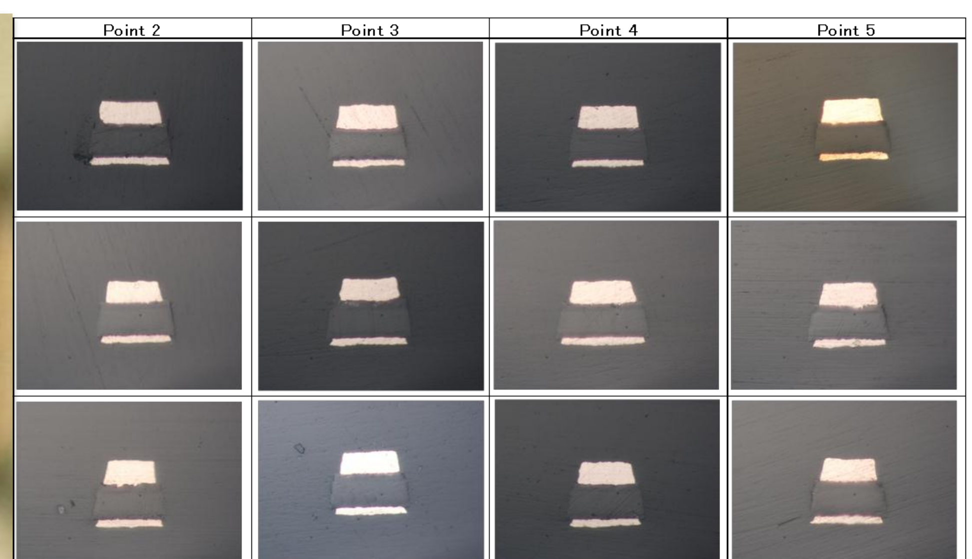
- **Fujikura Gate-GEM Type 0 sample**
  - Round holes / Direct UV-laser drilling (1 x 1 cm^2)
  - 14 μm (F-side) - 28 μm (B-side) rim width & 330 μm pitch with PI thickness 25 μm



- **Fujikura Gate-GEM Type 3 sample**
  - Hexagonal holes / UV-laser ablation (10 x 10 cm^2)
  - 27 μm (F-side) - 31 μm (B-side) rim width & 335 μm pitch with PI thickness 12.5 μm

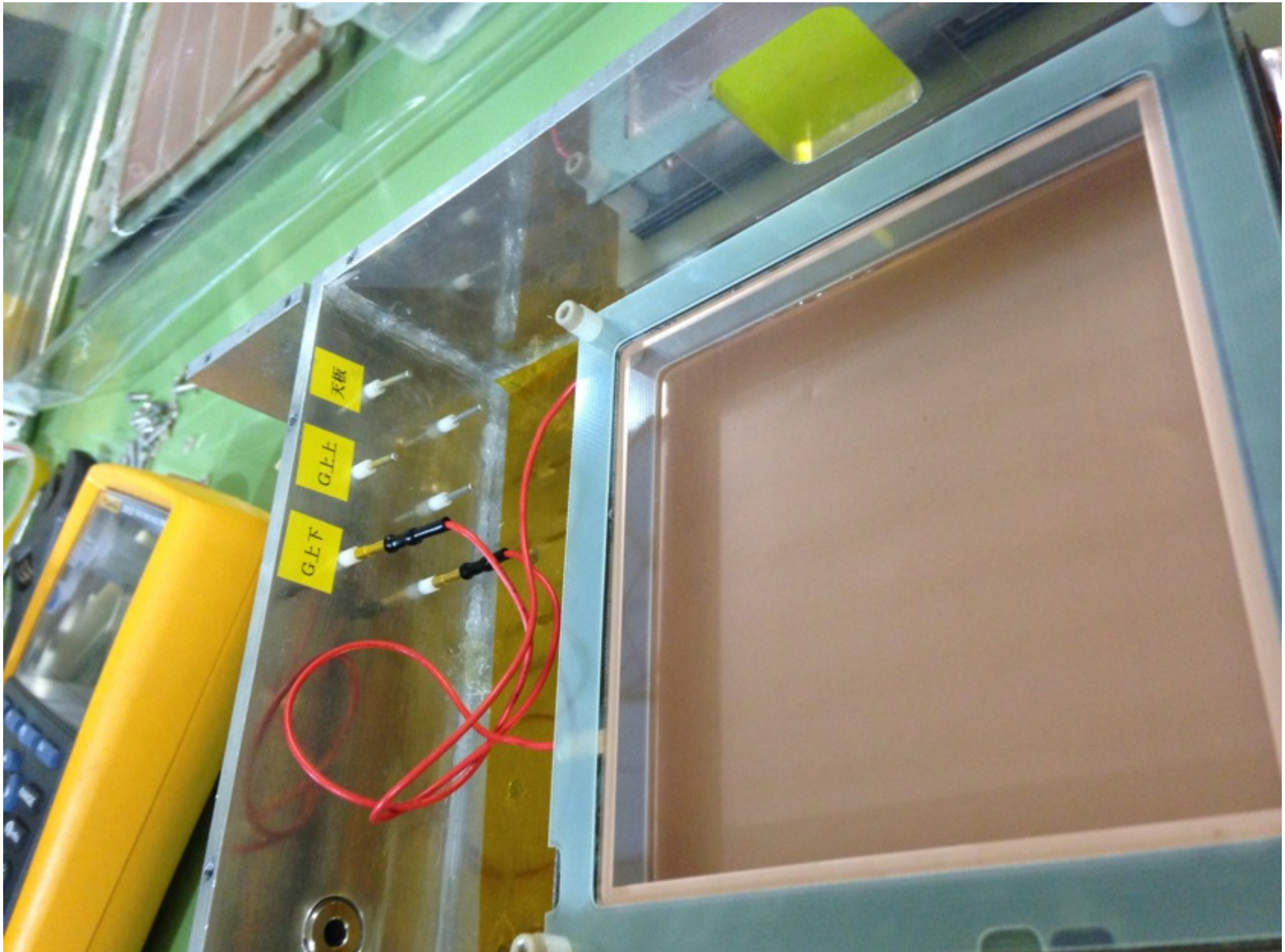






These 2 different samples: tested with a test chamber installed in a 1 Tesla solenoid magnet at KEK cryo center

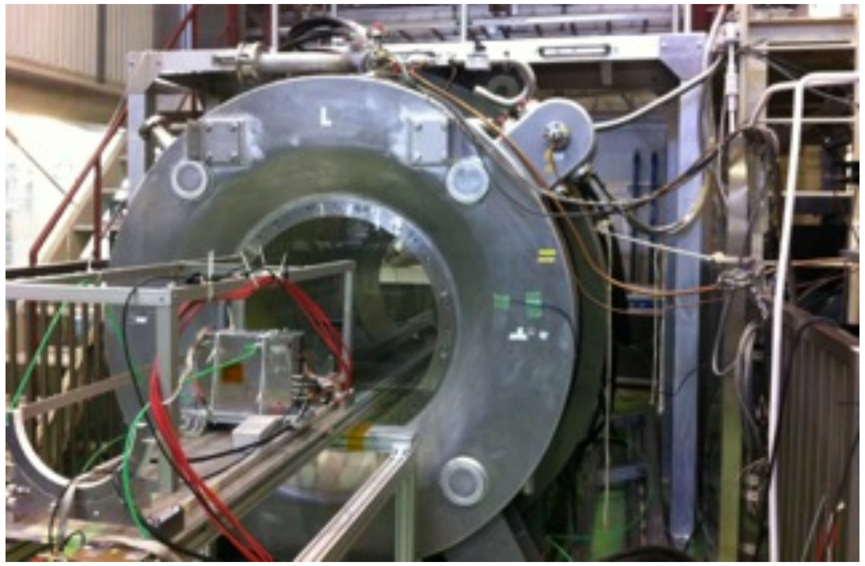
Fujikura Gate-GEM sample in test-chamber

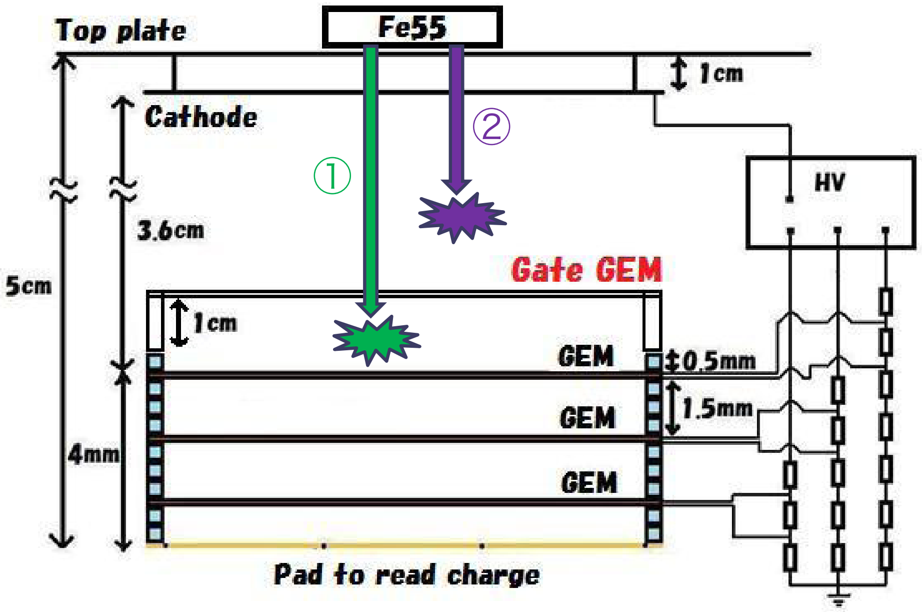


Electron transmission measurement

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

Electron transmission measurement

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

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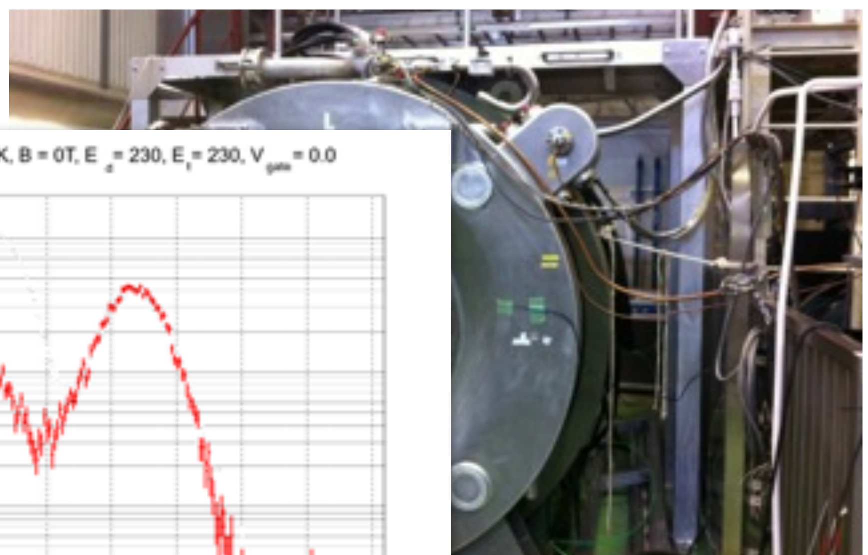
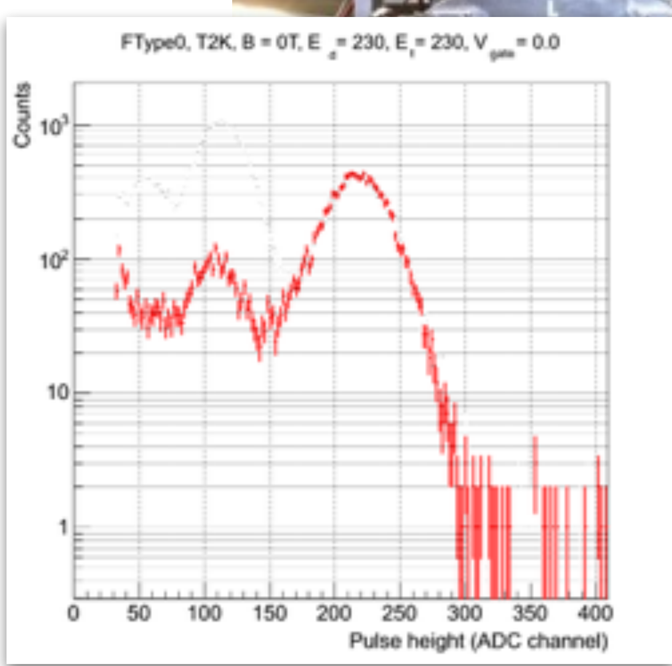
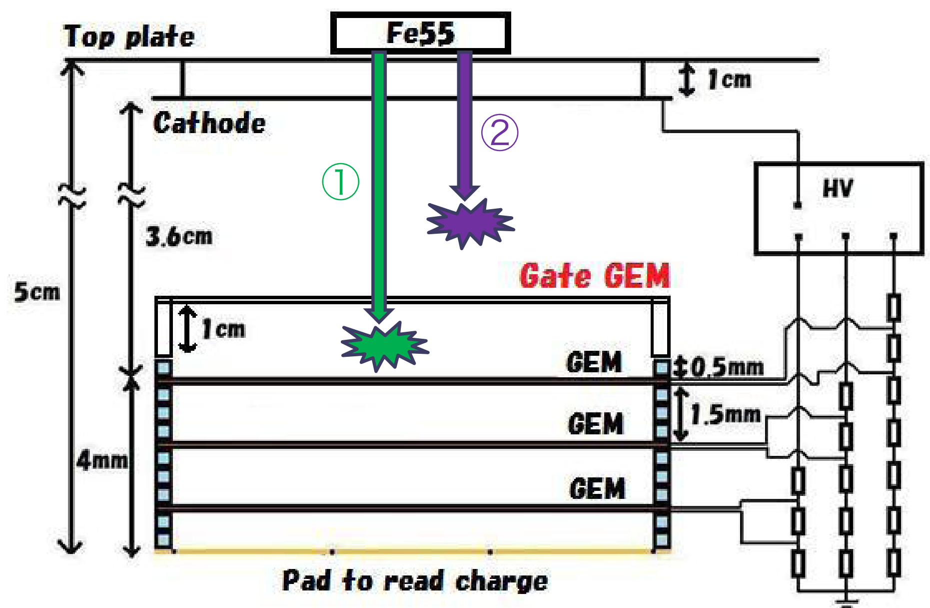




first to measure the charge without gate, switched off drift field -> only electrons from conversion at (1) can reach amplification GEM and be collected

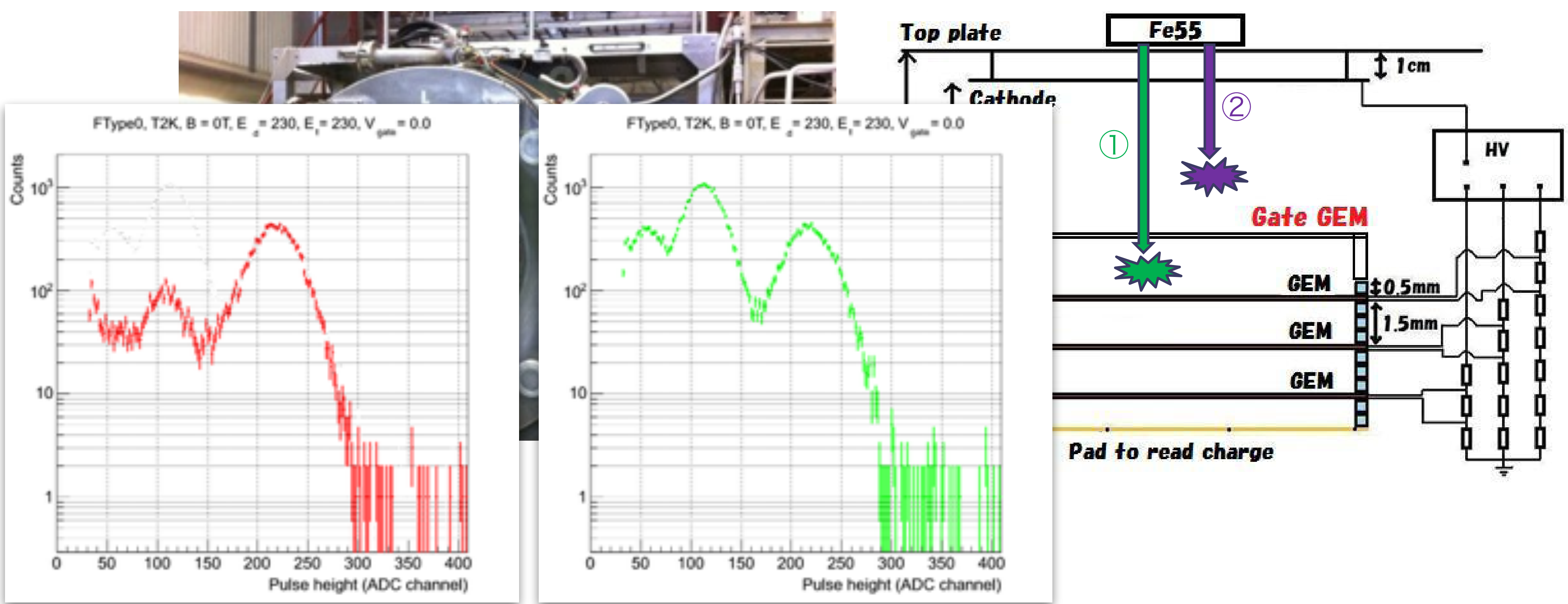


using a CERN standard GEM readout (triple stack) and one of Fujikura Gate-GEM samples placed 10 mm above

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

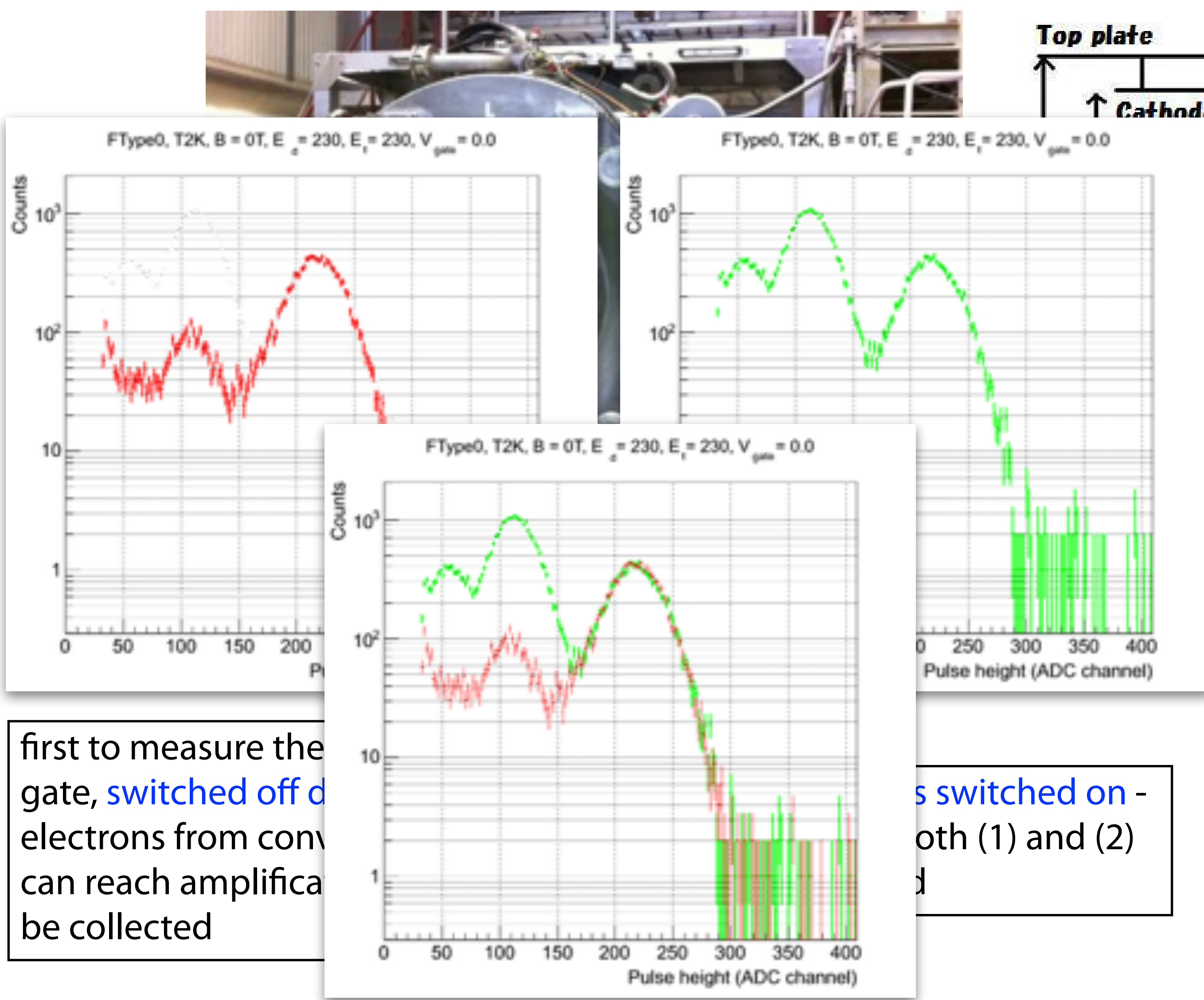
first to measure the charge without gate, switched off drift field -> only electrons from conversion at (1) can reach amplification GEM and be collected

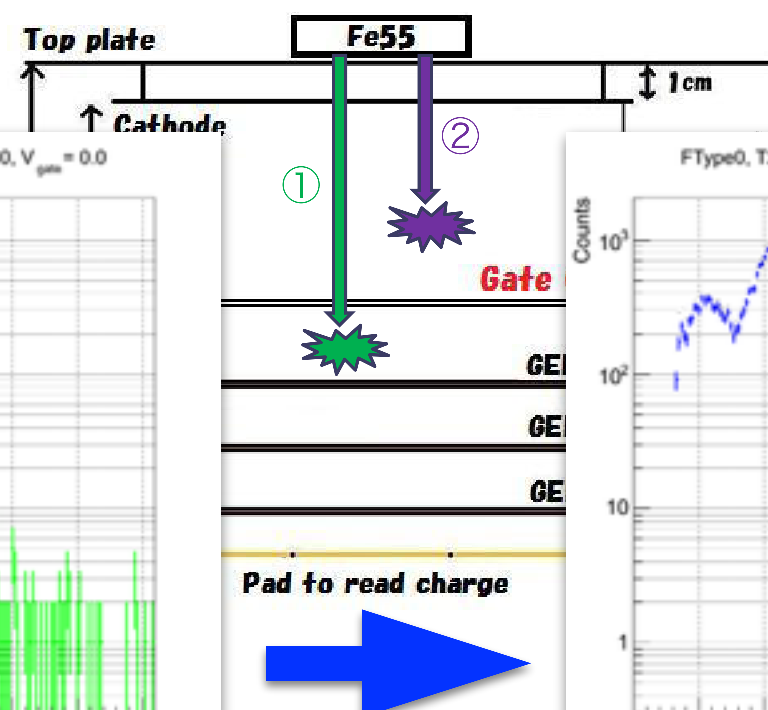
then drift field is switched on -> electrons at both (1) and (2) can be collected

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





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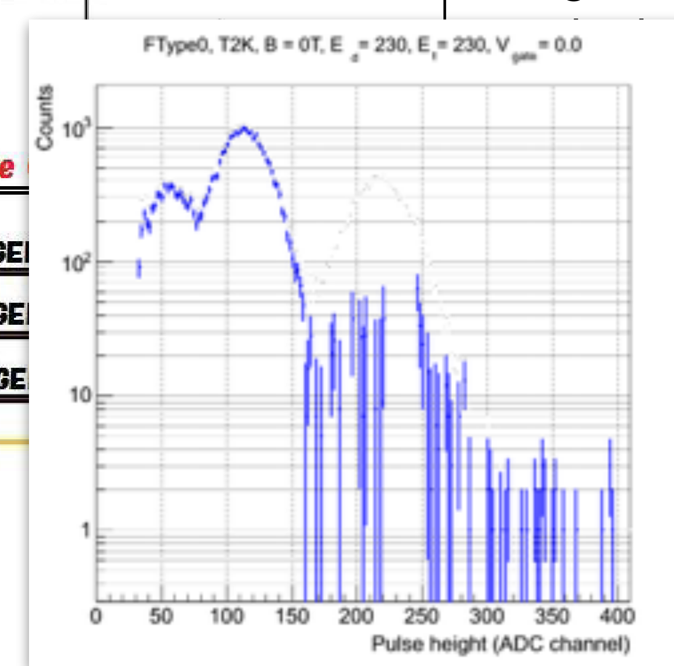

first to measure the
gate, switched off d
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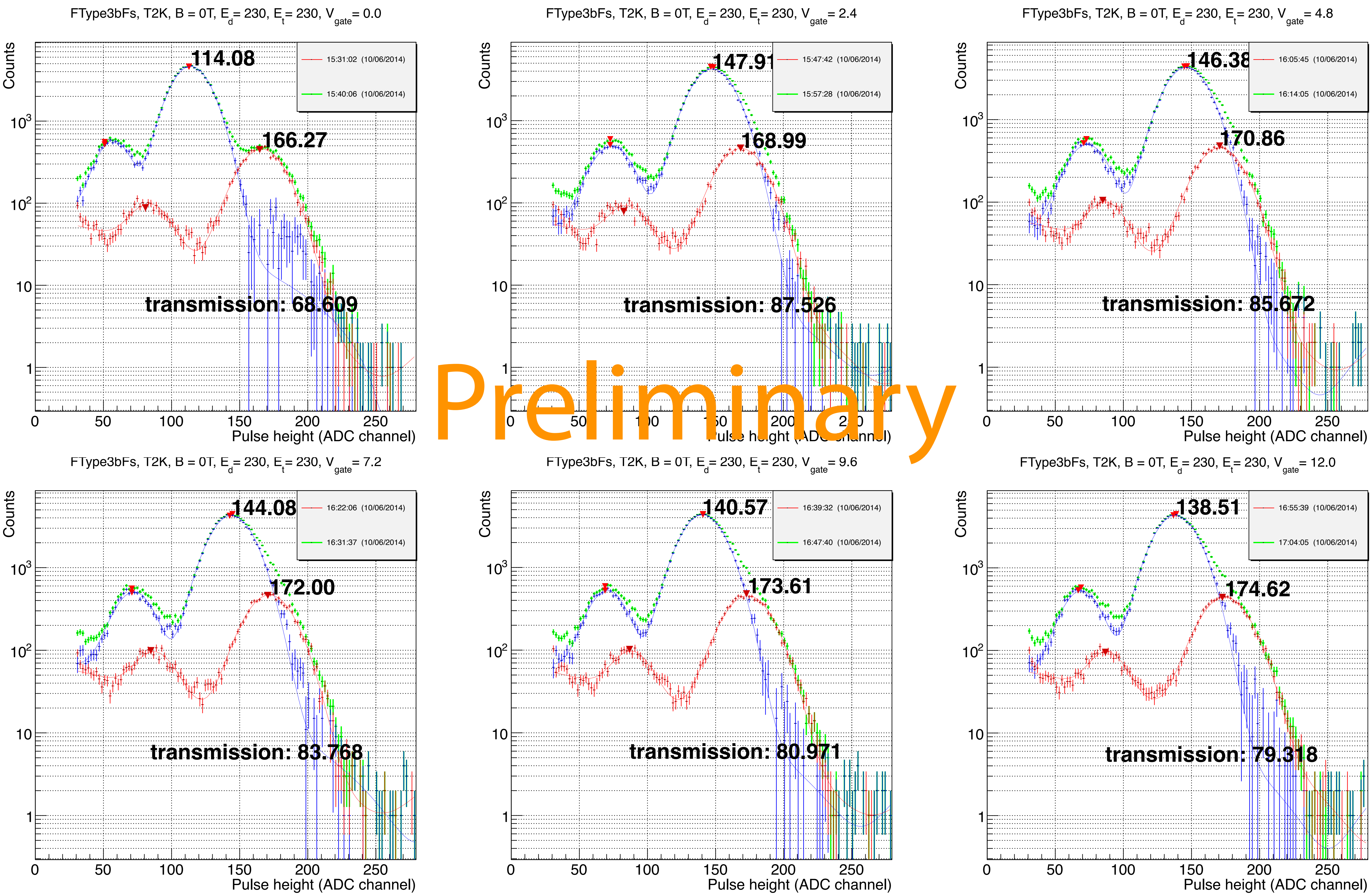
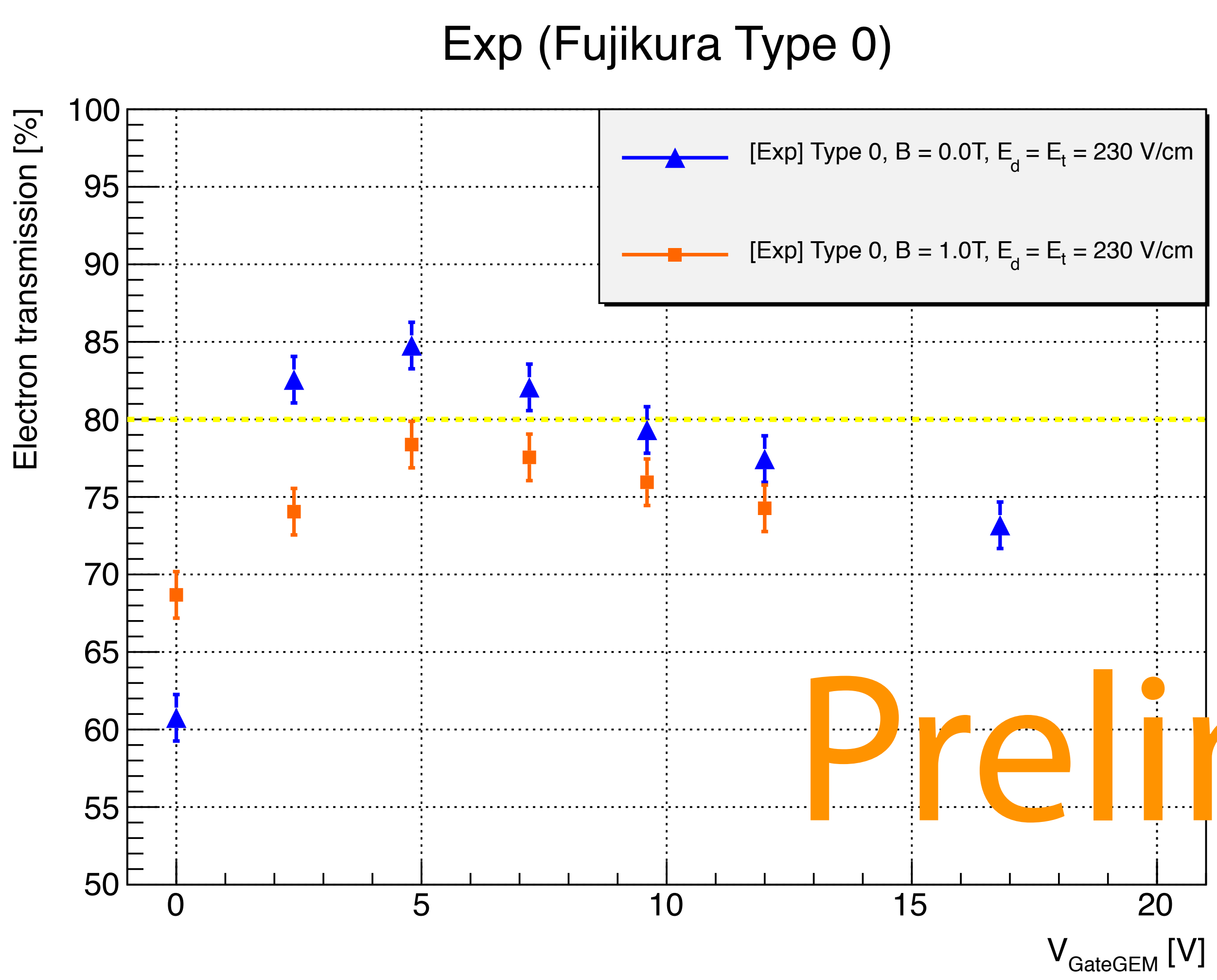
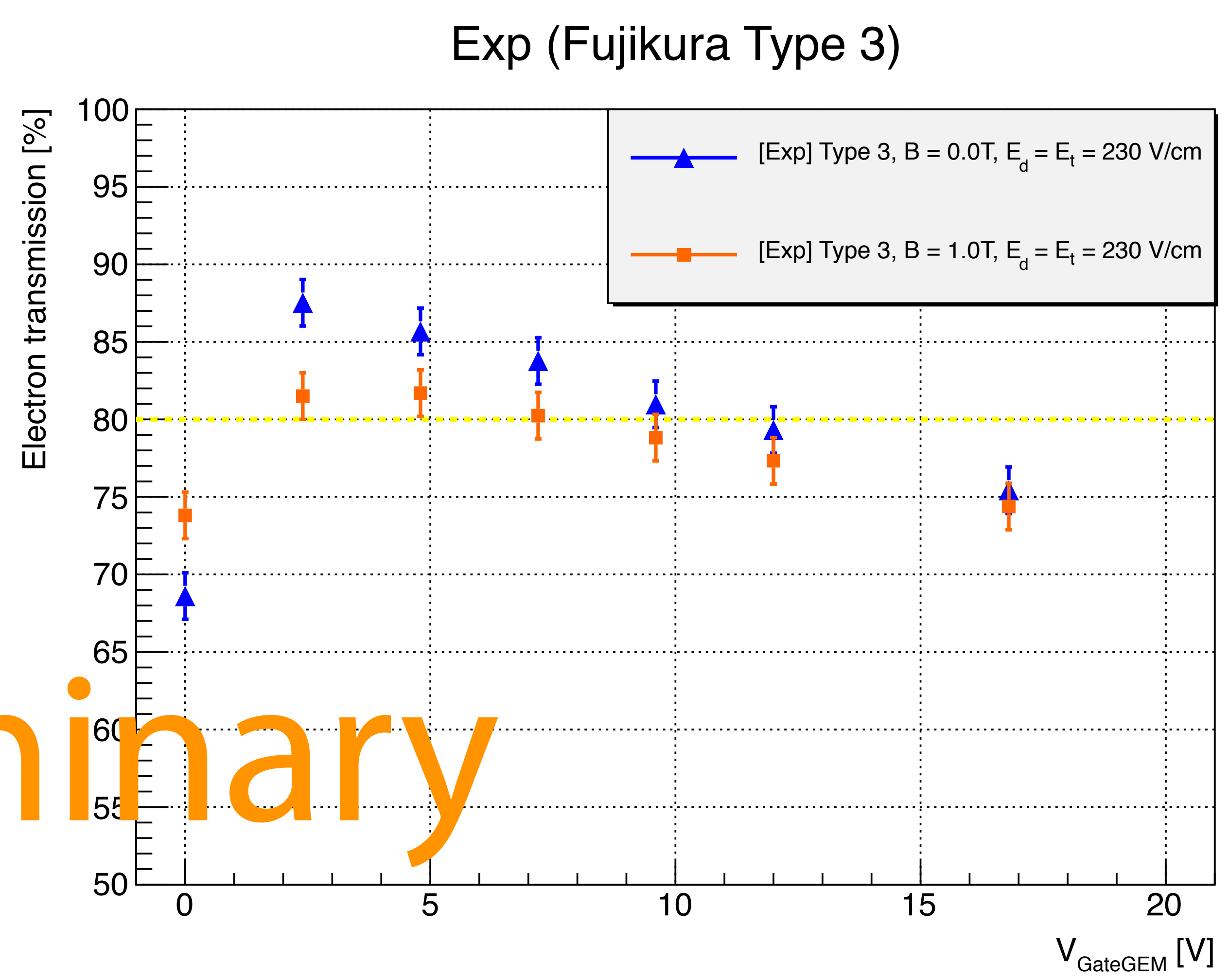
subtract charge at (1) using data at previous step -> get the charge from (2)

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



Results for electron transmission meas.

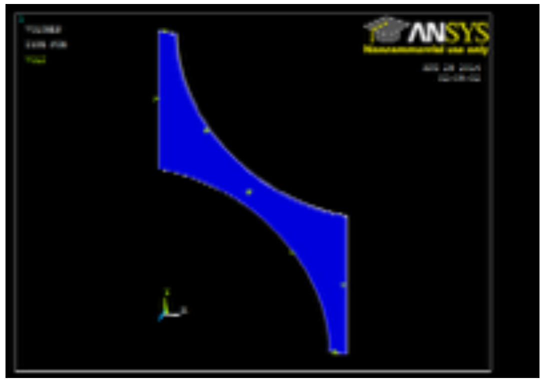




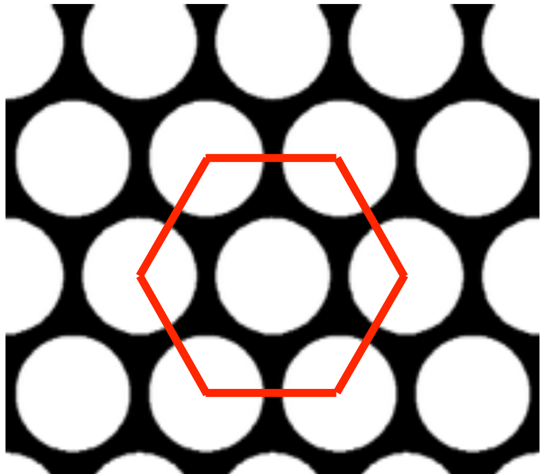
Preliminary

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



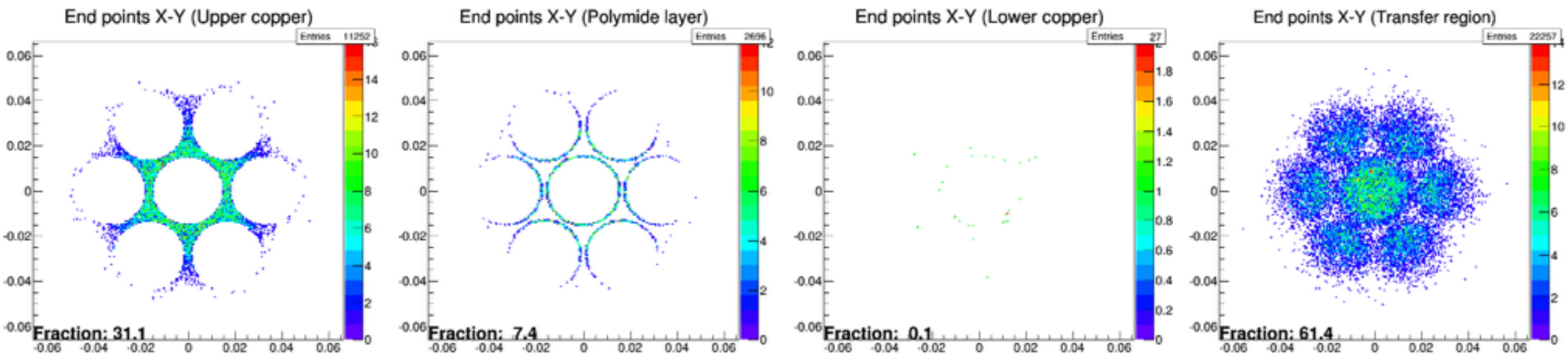
field calculations were done using finite element calculations with ANSYS



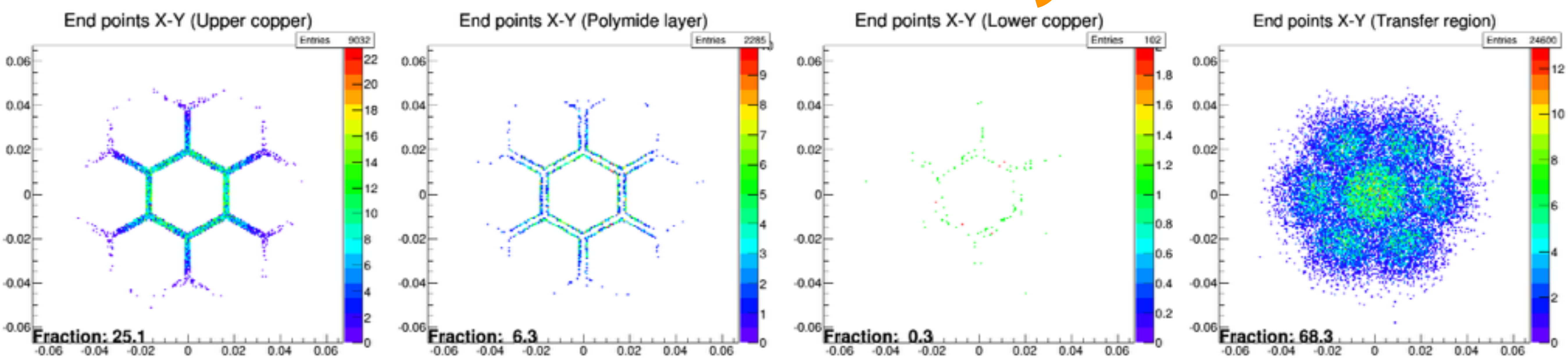
simply generate individual electrons above the GEM hole in the drift region

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

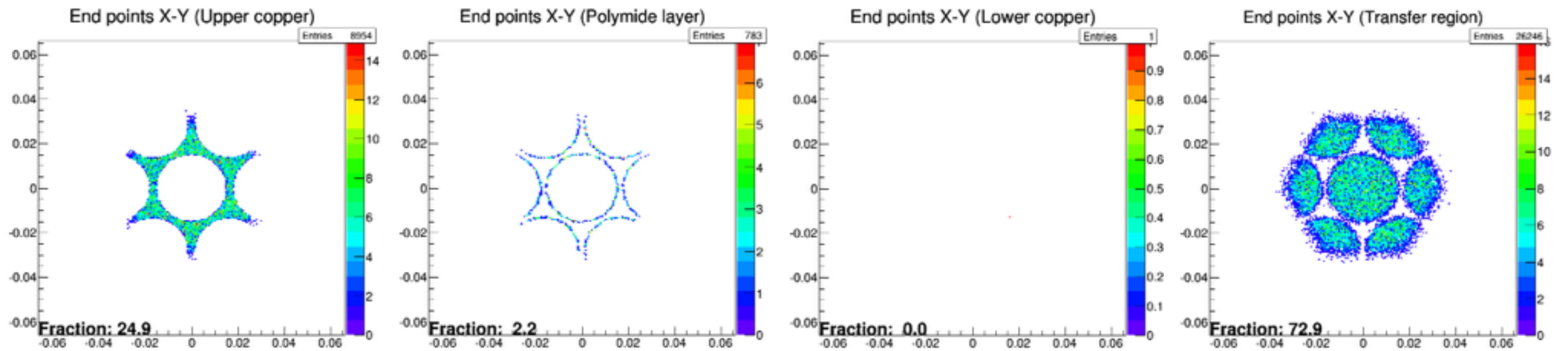
ANSYS-Garfield++ simulation (0 T, V_{gate} = 0 V)



Preliminary



ANSYS-Garfield++ simulation (1 T, $V_{gate} = 0$ V)



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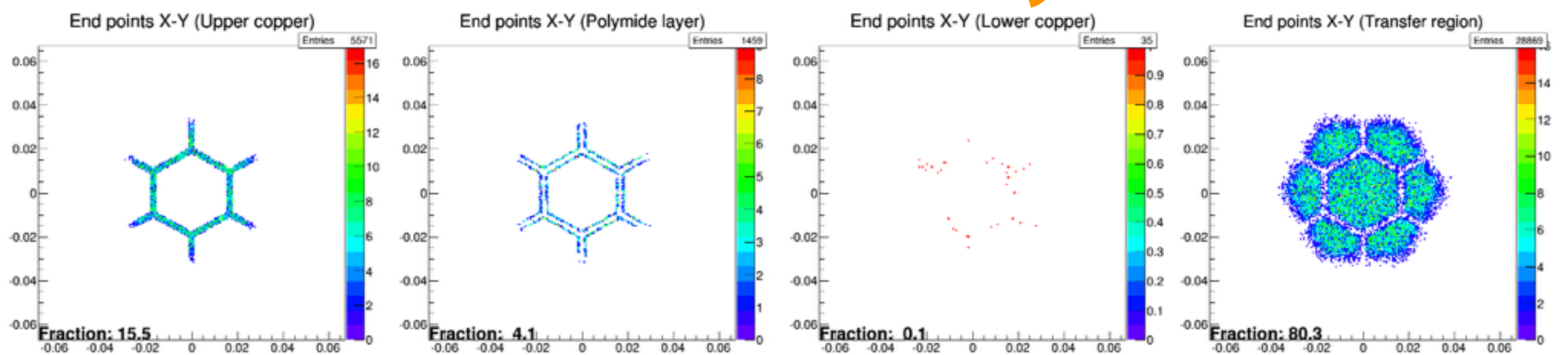

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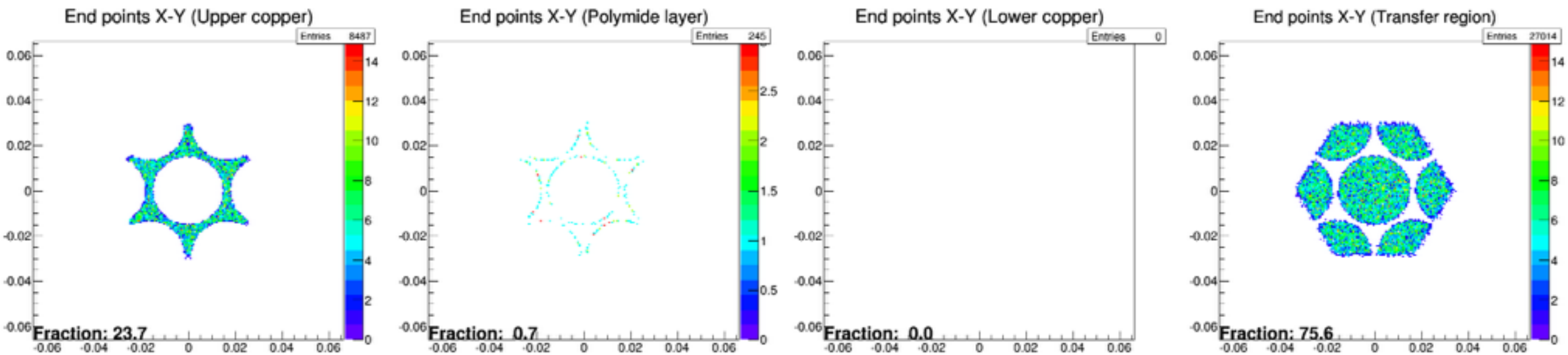

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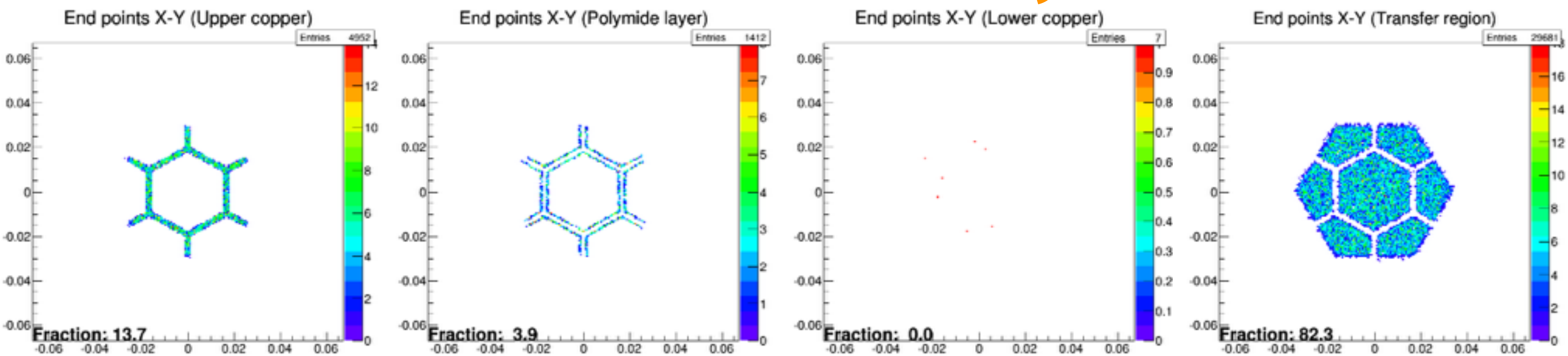
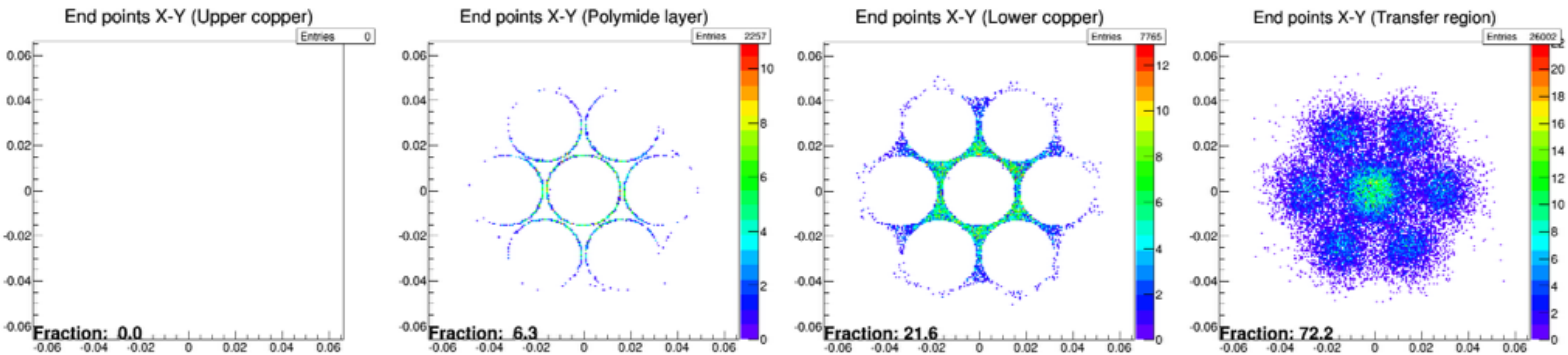
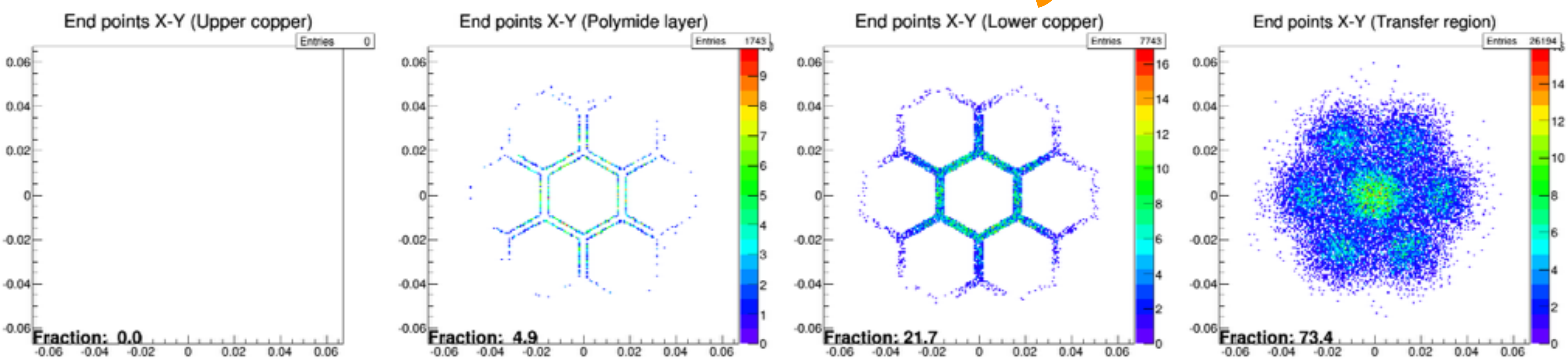


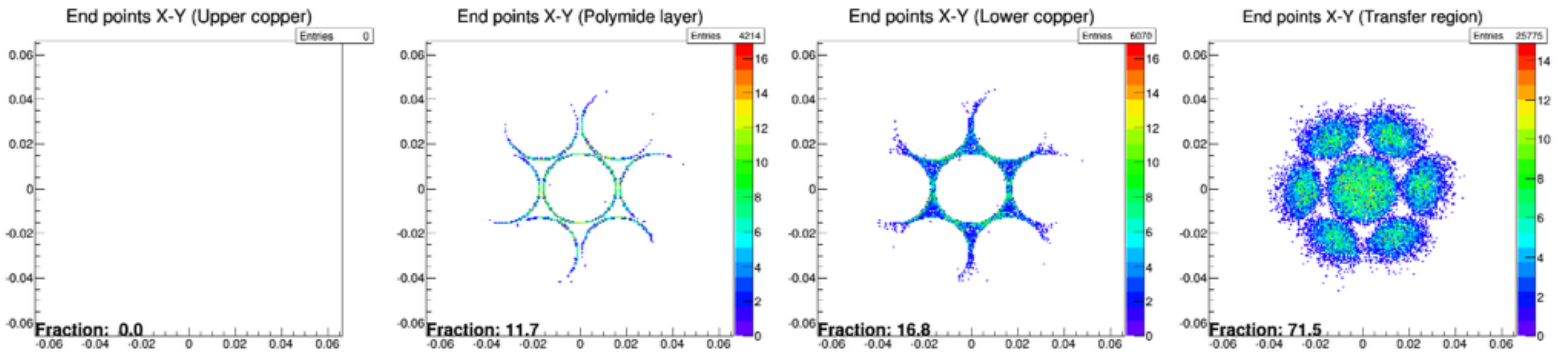
ANSYS-Garfield++ simulation (0 T, V_{gate} = 20 V)



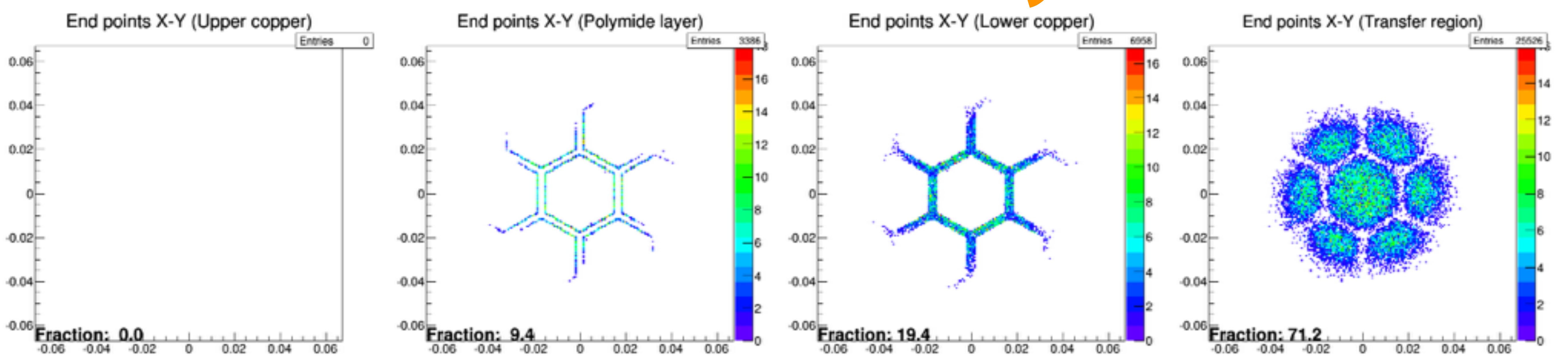
Preliminary



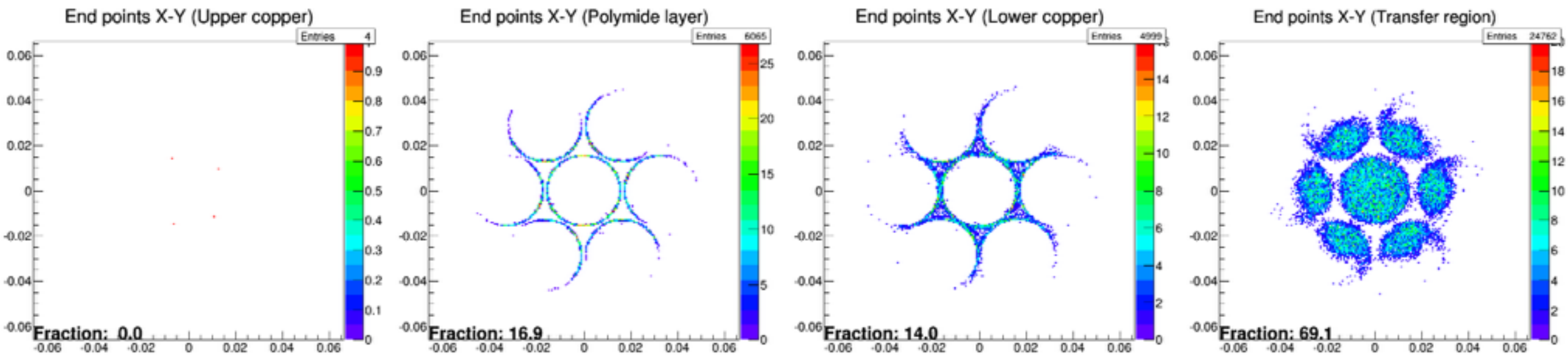
ANSYS-Garfield++ simulation (1 T, V_{gate} = 20 V)



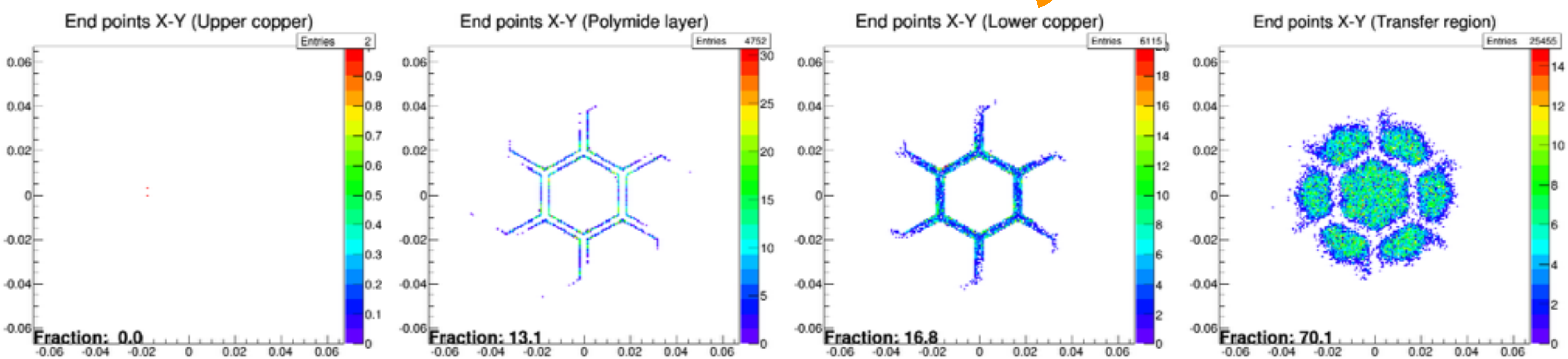
Preliminary



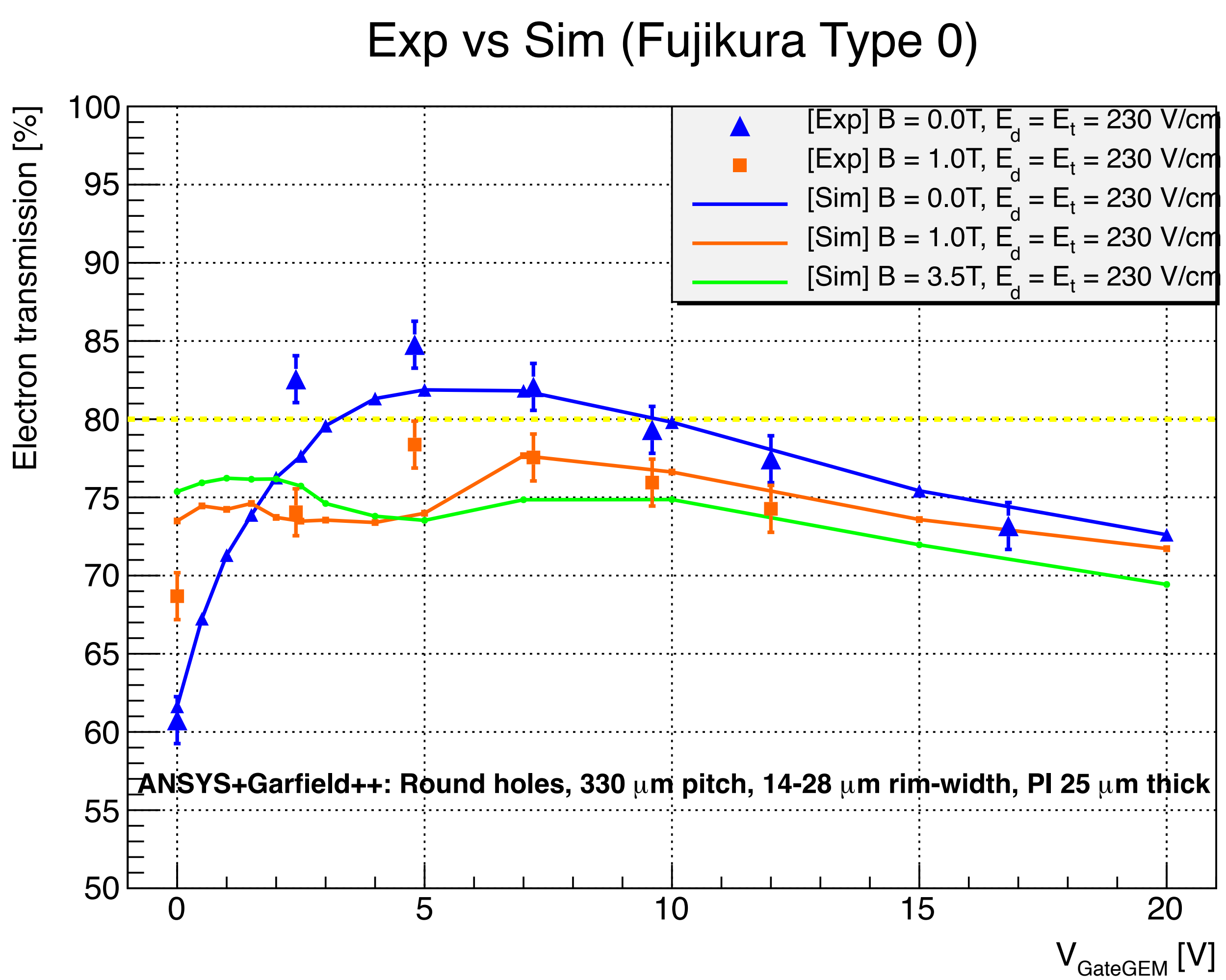
ANSYS-Garfield++ simulation (3.5 T, V_{gate} = 20 V)

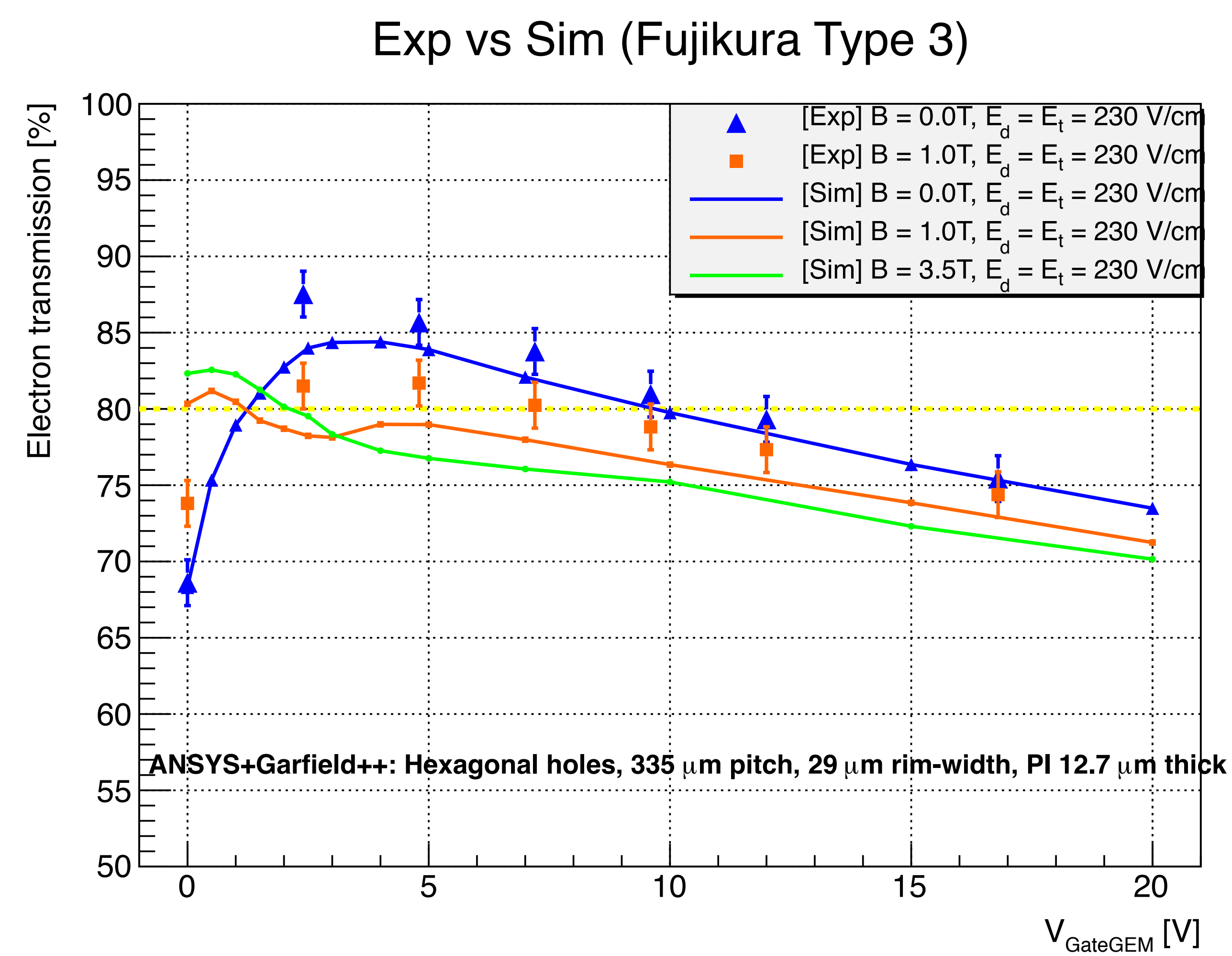


Preliminary



Comparison btw measurements and sim

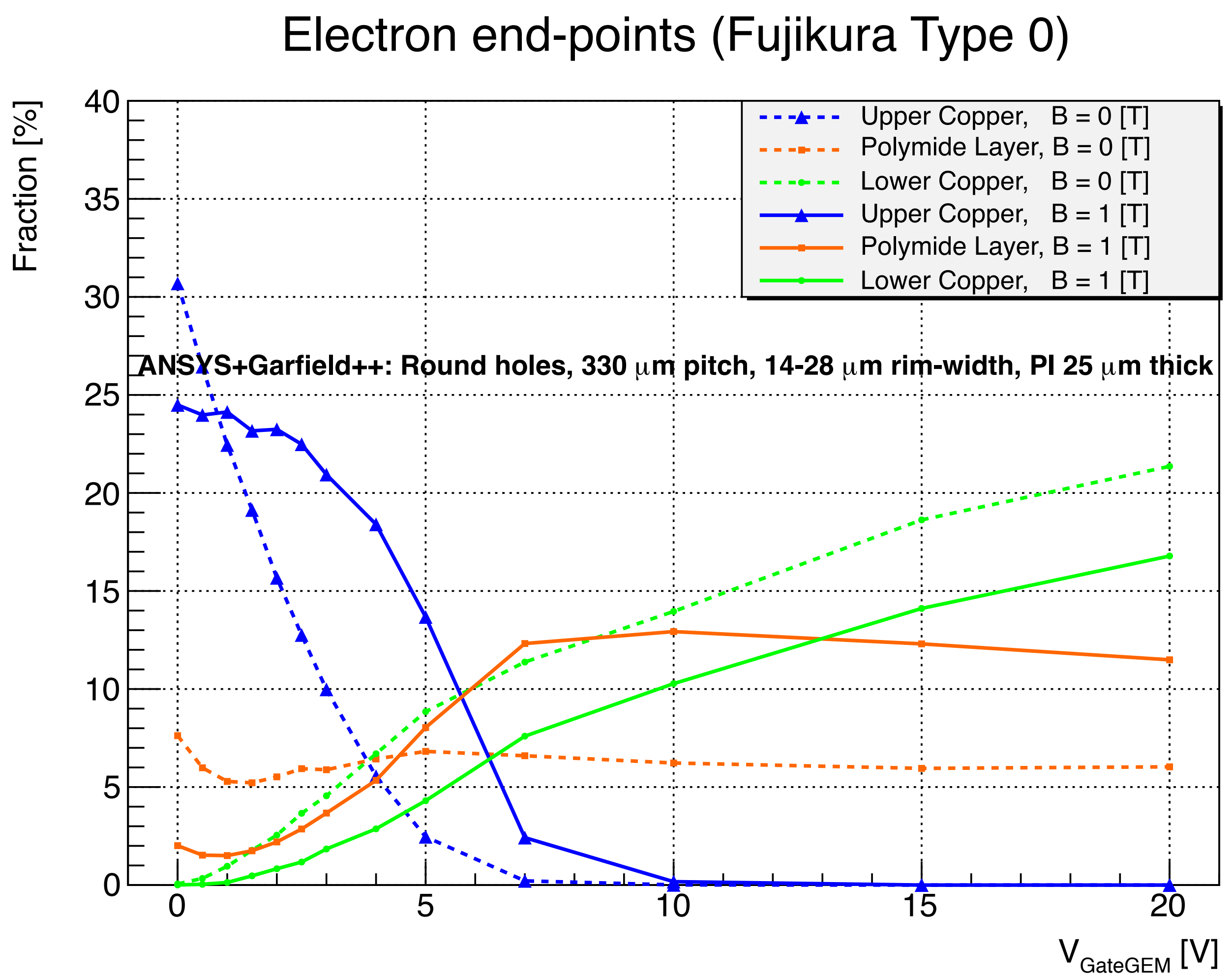


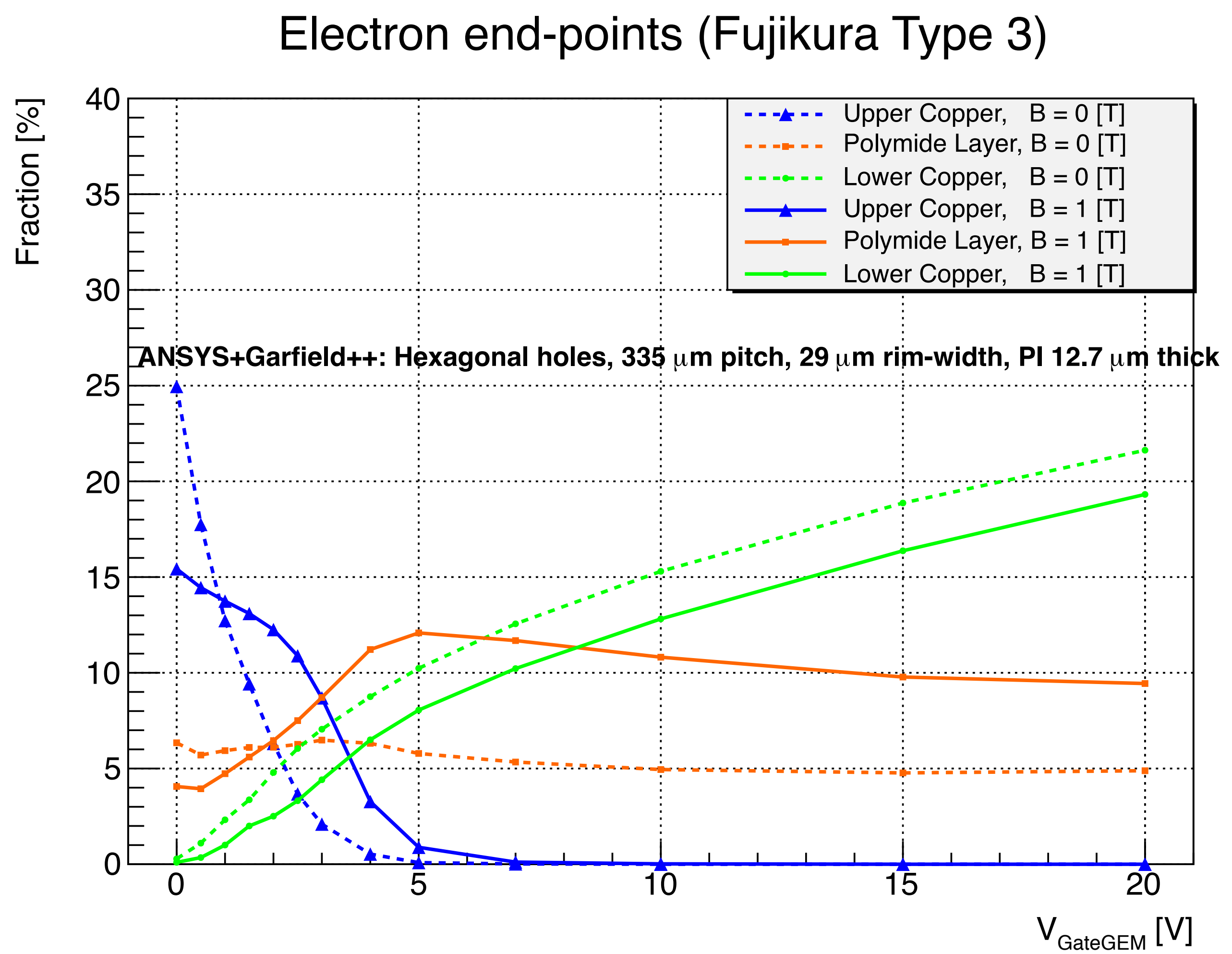


Preliminary

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 ILC-TPC

Electron end-points

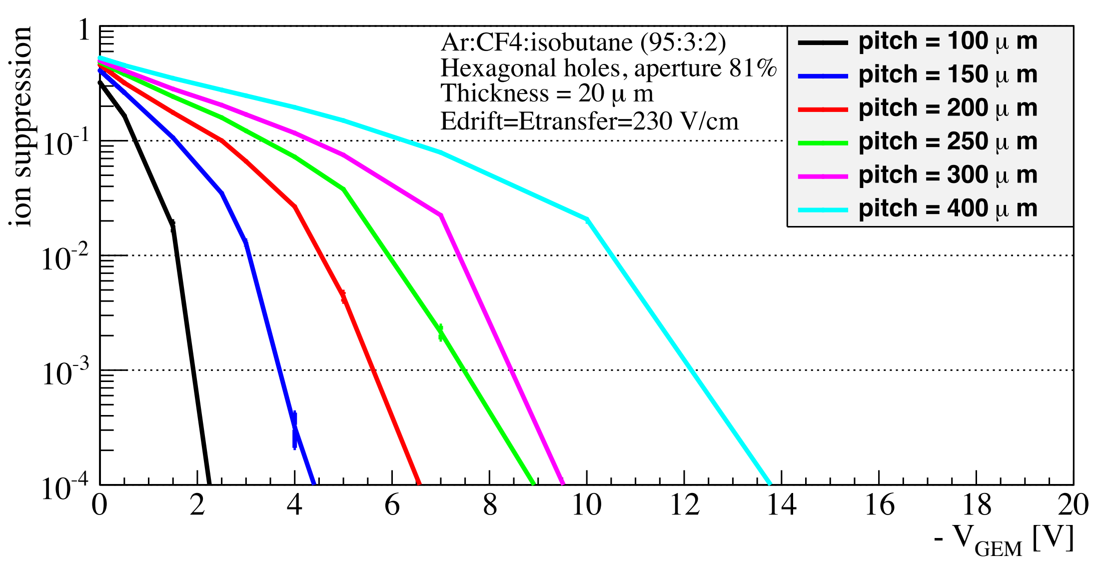




Preliminary

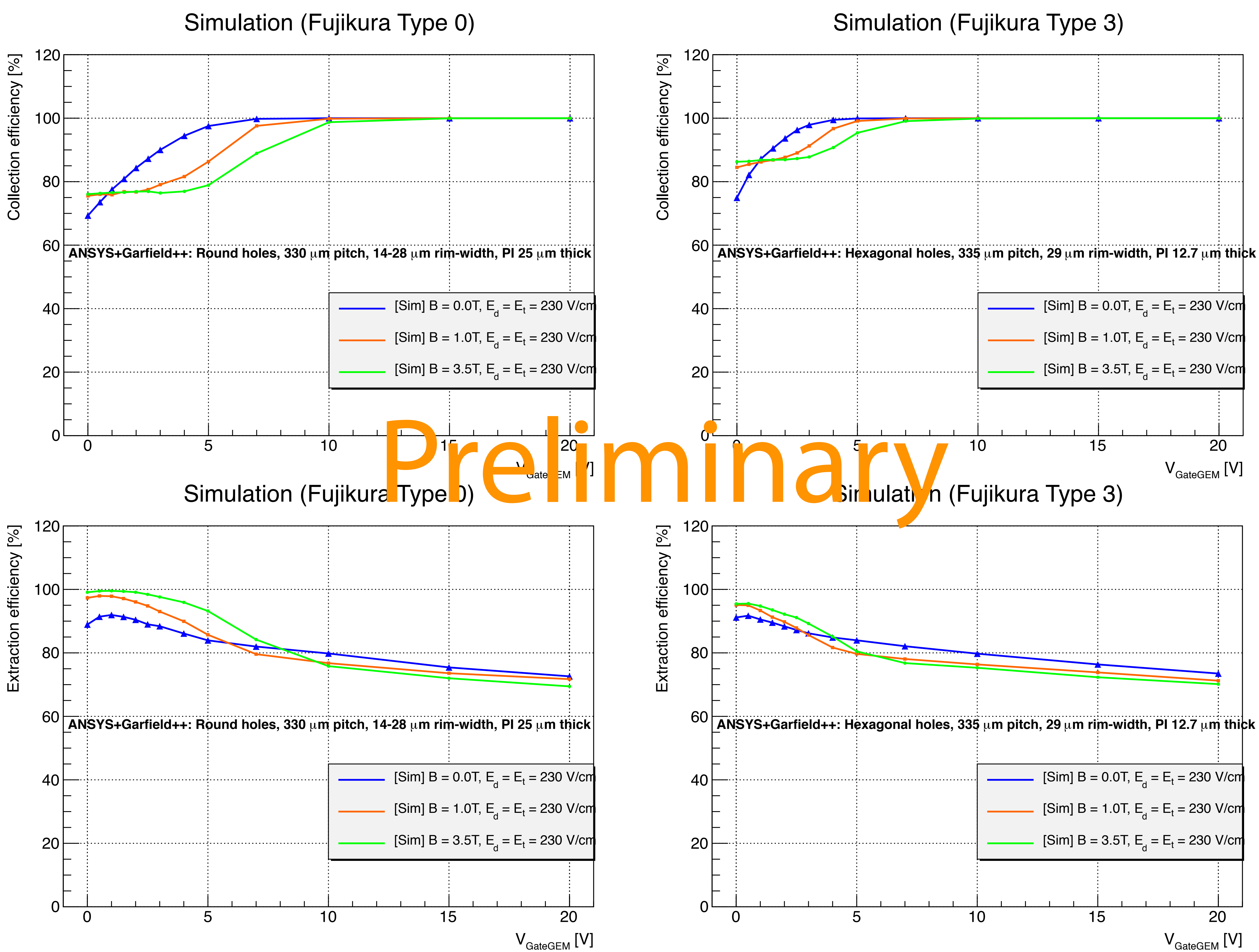
Summary and prospects

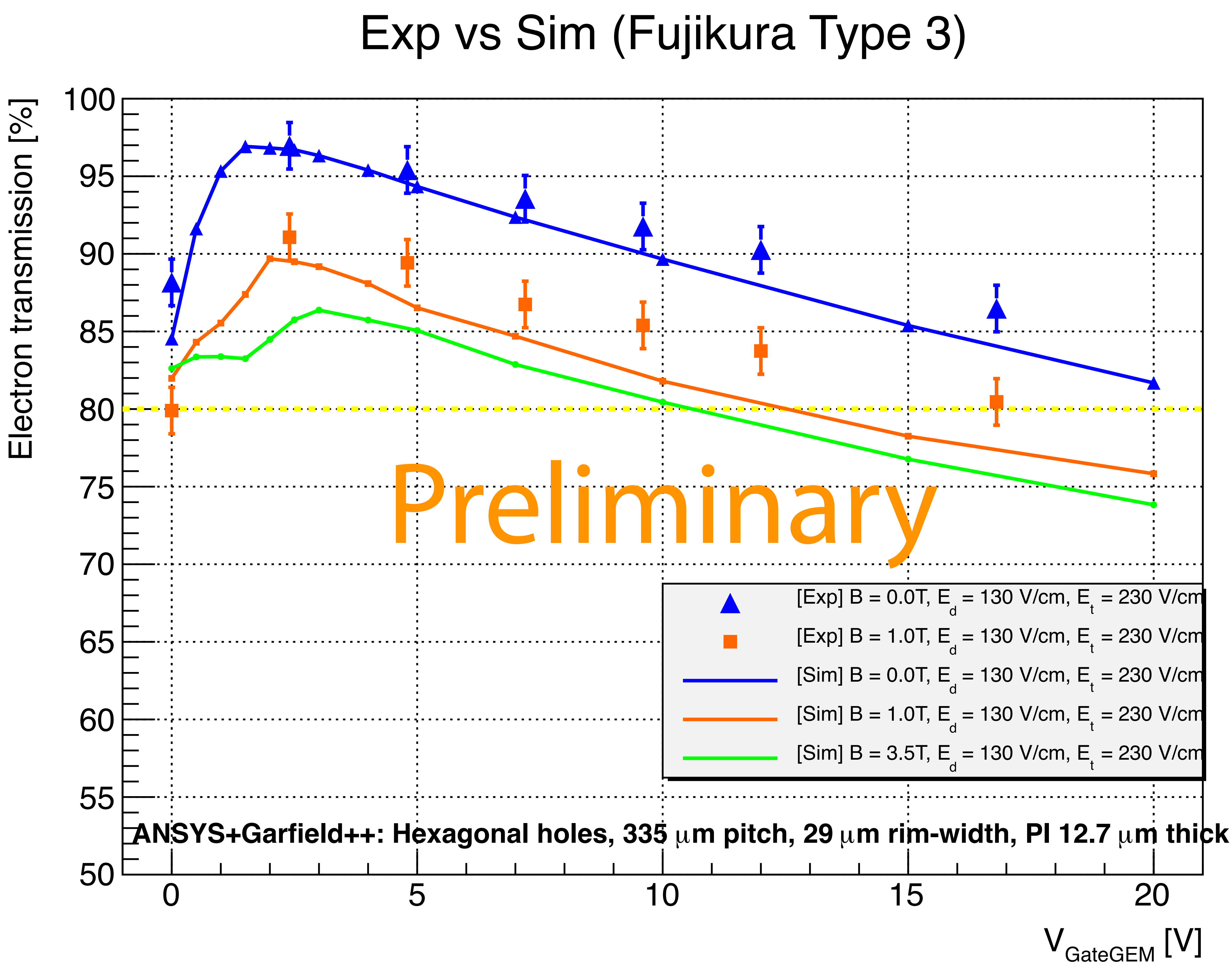
- ILC-TPC is planned to be equipped with a gating device located between the drift volume and the gas amplification device to prevent positive ions => GEM-gating device would be most adapted for the module structure of ILC-TPC
  - easier to integrate the system and allows a low switching voltage of a few tens of volts
- **High optical transparency of Gate GEM** is required to ensure its high transmission rate of electrons in the open state because ILC-TPC is operated in 3.5 T, and in a gas with a high mean free time of drift electrons
- To achieve high electron transmission, large-aperture Gate-GEM samples which have 75~85% optical transparency were produced by Fujikura Ltd.
- These 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 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 ILC-TPC
- Development of ILC-TPC module size Gate-GEM (17 x 22 cm^2) has been already started, and the 1st product is expected by the end of FY2014
- 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 (under 20V)



Backup

Collection efficiency × Extraction efficiency

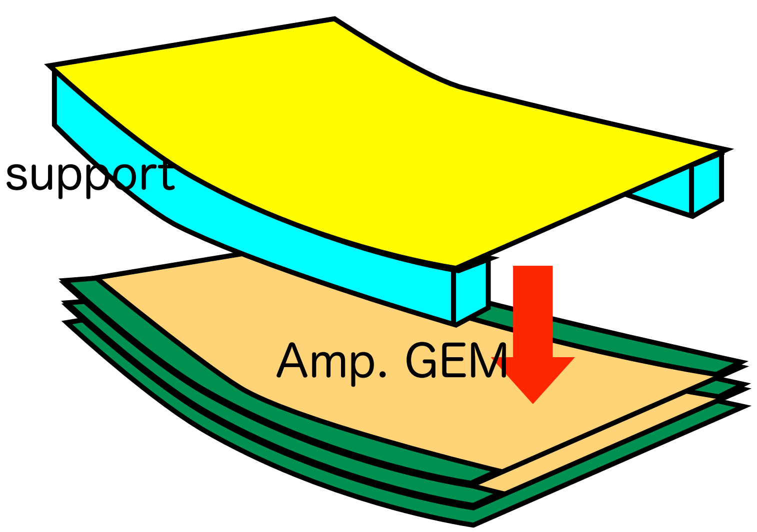


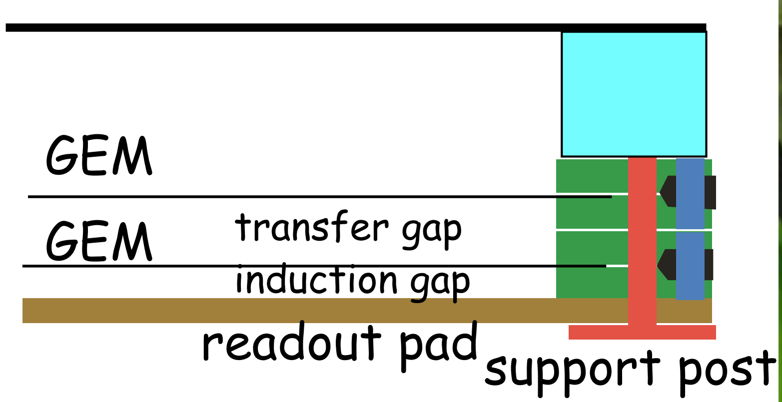


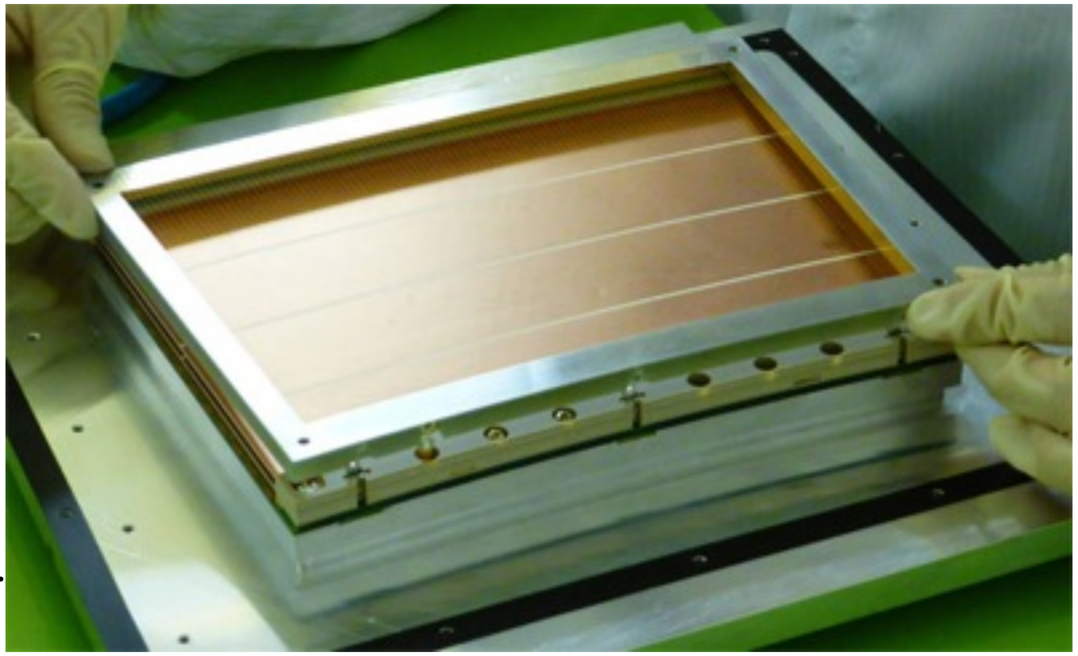
Exp vs Sim (Fujikura Type 3)
Electron transmission [%]
100
95
90
85
80
75
70
65
60
55
50
0
5
10
15
20
V_GateGEM [V]
Preliminary
[Exp] B = 0.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Exp] B = 1.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Sim] B = 0.0T, E_d = 130 V/cm, E_t = 230 V/cm
[Sim] B = 1.0T, E_d = 130 V/cm, 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

Conventional wire-grid as a gating device

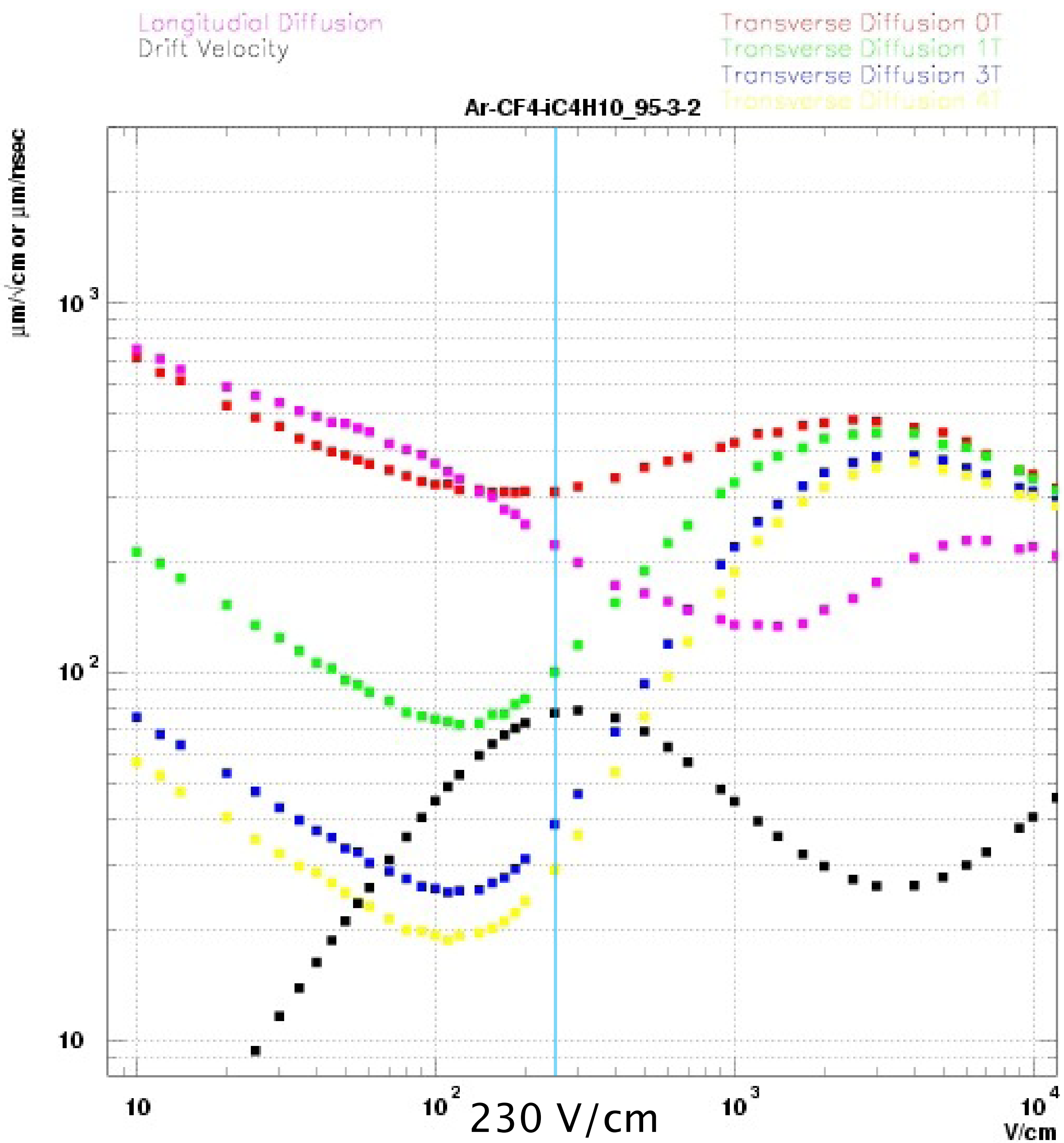
- **Wire gating grid is an option**
  - Traditional gating system
  - Conventional transverse wires would require a structure creating dead angular regions => would put the wires radially
  - Wires can create field distortions, and in particular ExB effects...
  - **Our 1st prototype**:
    - 30µm wires,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







Drift velocity and diffusion (T2K gas)



If we require the azimuthal resolution of 100 μm at $z = 200$ cm the diffusion constant (D), which is essentially the only free (controllable) parameter depending on the choice of gas mixture, needs to be smaller than 30 μm/√cm.

The diffusion constant of drift electrons under the influence of an axial magnetic field (B) is given by $D(B) = D(B = 0)/\sqrt{1 + (\omega\tau)^2}$, where $\omega \equiv e \cdot B/m$, the electron cyclotron frequency, and τ is the mean free time of drift electrons between collisions with gas molecules. Therefore we need a gas mixture in which $D(B = 0)$ is small (cool) and τ is fairly large (fast) under a moderate drift field (E)!

- The diffusion constant D is related to the diffusion coefficient (D^*) through $D2 = 2D^*/W$, where W is the electron drift velocity.
- The electron drift velocity is given by $W = e \cdot E/m \cdot \tau$ with e (m) being the electron charge (mass). A large value of τ, therefore, means a fast gas.

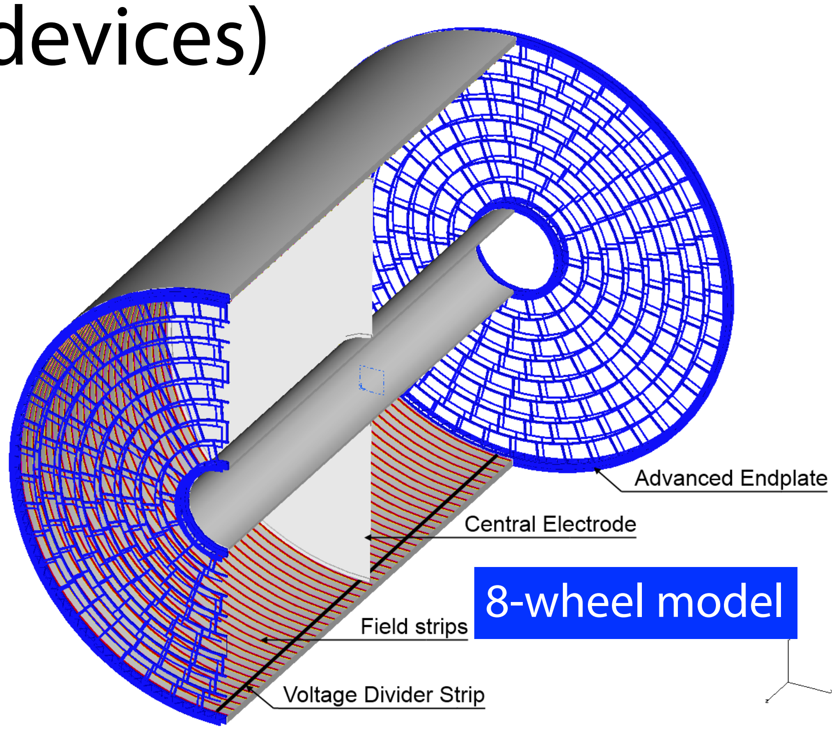
Performance and design parameters

- **Performance and design parameters for the ILD-TPC with standard electronics and pad readout**

Parameter	
Geometrical parameters	r_{in} r_{out} z 329 mm 1808 mm $\pm$ 2350 mm
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\ X_0$ including outer fieldcage in r
	$< 0.25\ X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2 $\times 10^6$/1000 per endcap
Pad pitch/ no.padrows	$\simeq 1\times 6\ \text{mm}^2$ for 220 padrows
σ_{point} in $r\phi$	$\simeq 60\ \mu$m for zero drift, $< 100\ \mu$m overall
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm
2-hit resolution in rz	$\simeq 6$ mm
dE/dx resolution	$\simeq 5$ %
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)

Introduction

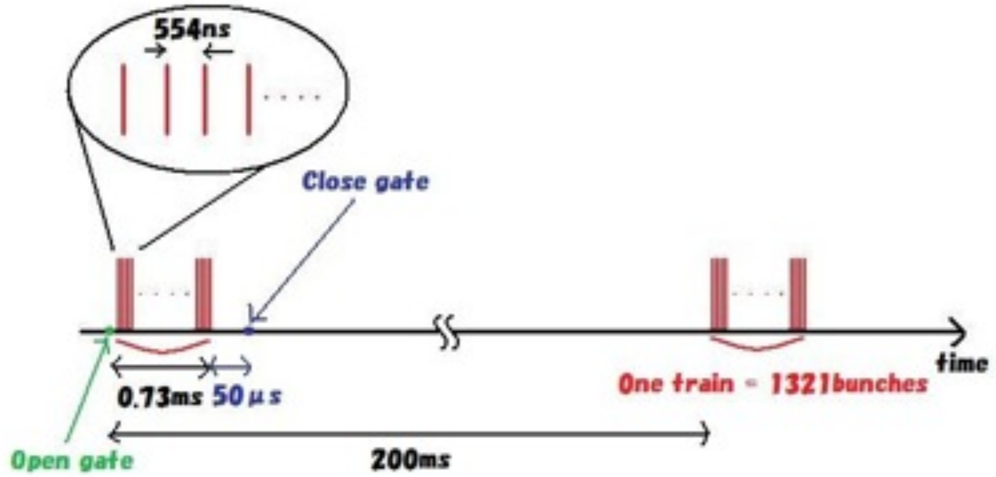
- **Time projection chamber (TPC) for ILC**
  - The ILD concept for ILC: have a GEM- or Micromegas-based TPC as a main tracker
    - use of Micropattern gaseous detectors (MPGD) to replace the MWPCs (not possible to reach the required spatial resolution with a wire-based readout because the strong magnetic 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 ILC-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)

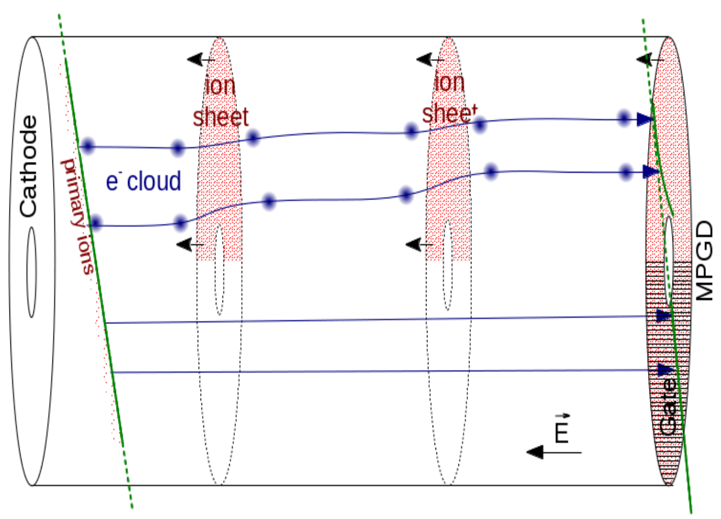


Positive ion feedback in ILC-TPC

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 ILC-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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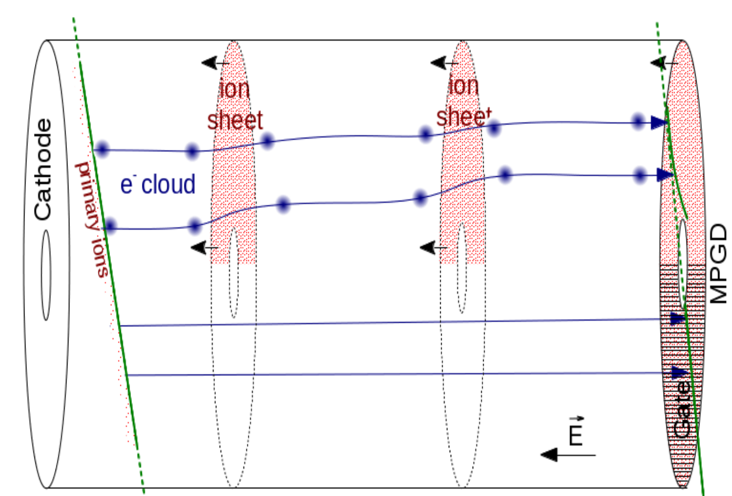
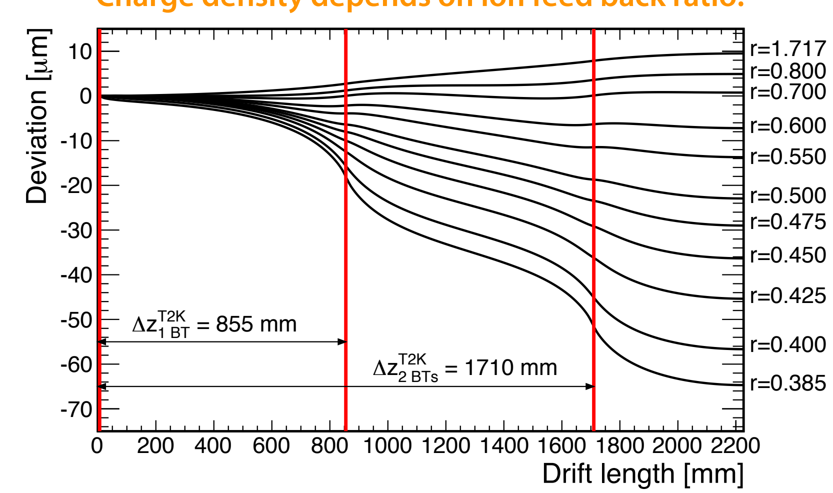
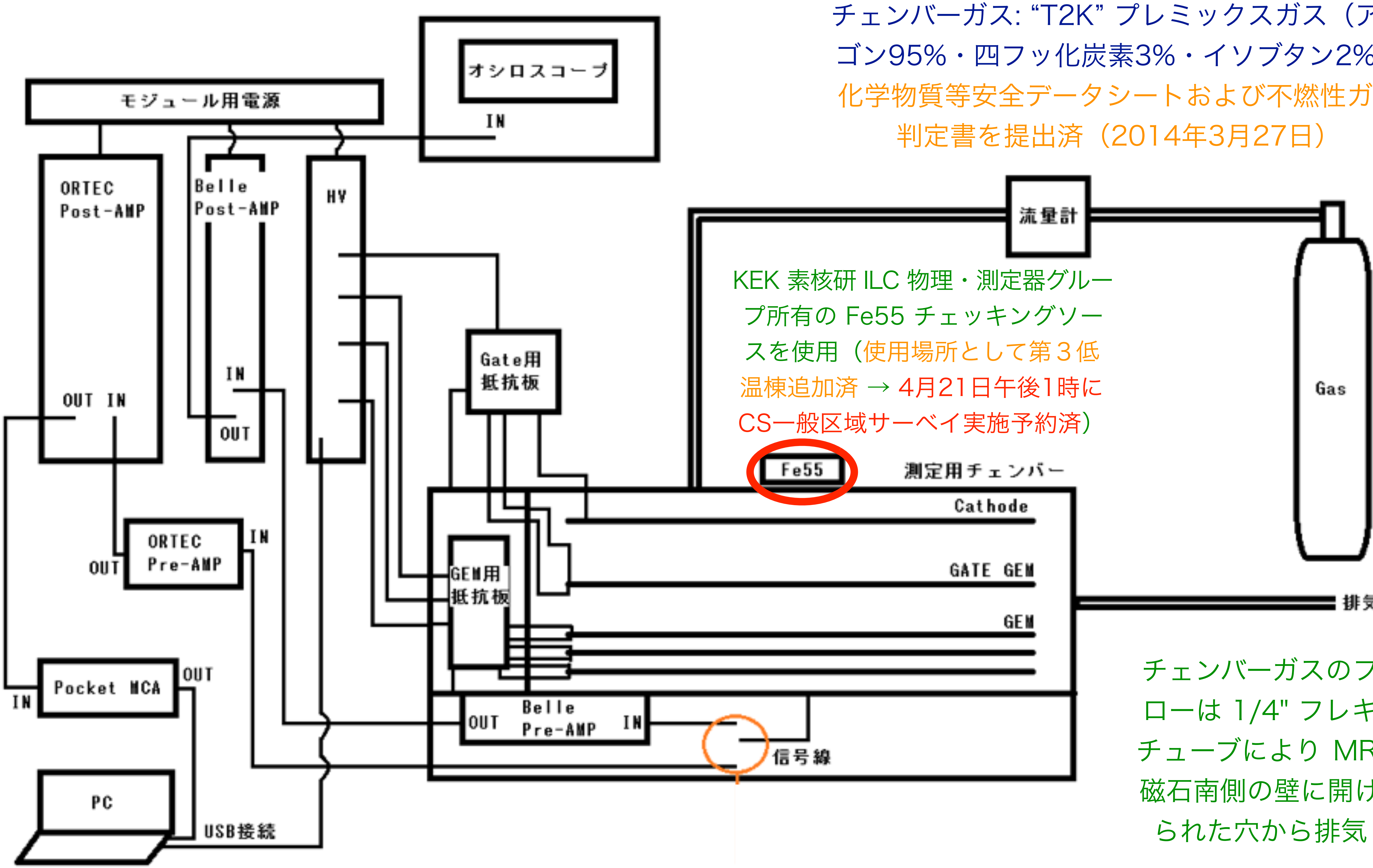


Charge density depends on ion feed back ratio!



実験セットアップ

チェンバーガス: “T2K” プレミックスガス（アルゴン95%・四フッ化炭素3%・イソブタン2%）
化学物質等安全データシートおよび不燃性ガス判定書を提出済（2014年3月27日）



KEK 素核研 ILC 物理・測定器グループ所有の Fe55 チェッキングソースを使用（使用場所として第３低温棟追加済 → 4月21日午後1時にCS一般区域サーベイ実施予約済）

チェンバーガスのフローは 1/4" フレキチューブにより MRI 磁石南側の壁に開けられた穴から排気