Status of gating studies in Japan

~ GEM gate and wire gate tests progress ~

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LCTPC Collaboration Meeting (30 June, 2014)

Introduction

Charge for the CM: "Presentations should be overview style and meant to start the discussion"

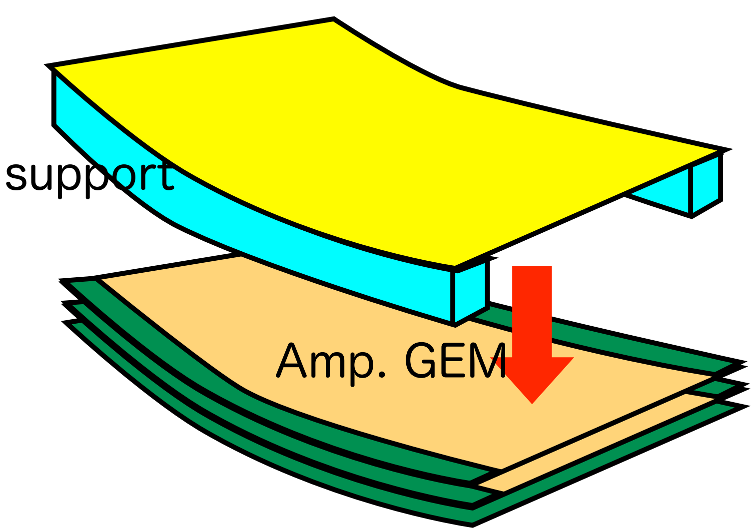
Initially I intended to bring some results to this CM for discussion, but for the last three months (April-June) it was a sort of training phase since we resumed all of our measurement activities by newcomers (including me)...

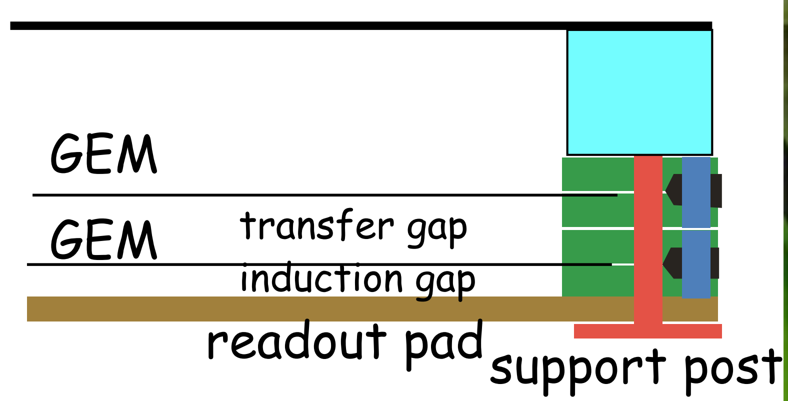
Once we obtain reliable results in July-August, should report in a WP meeting.

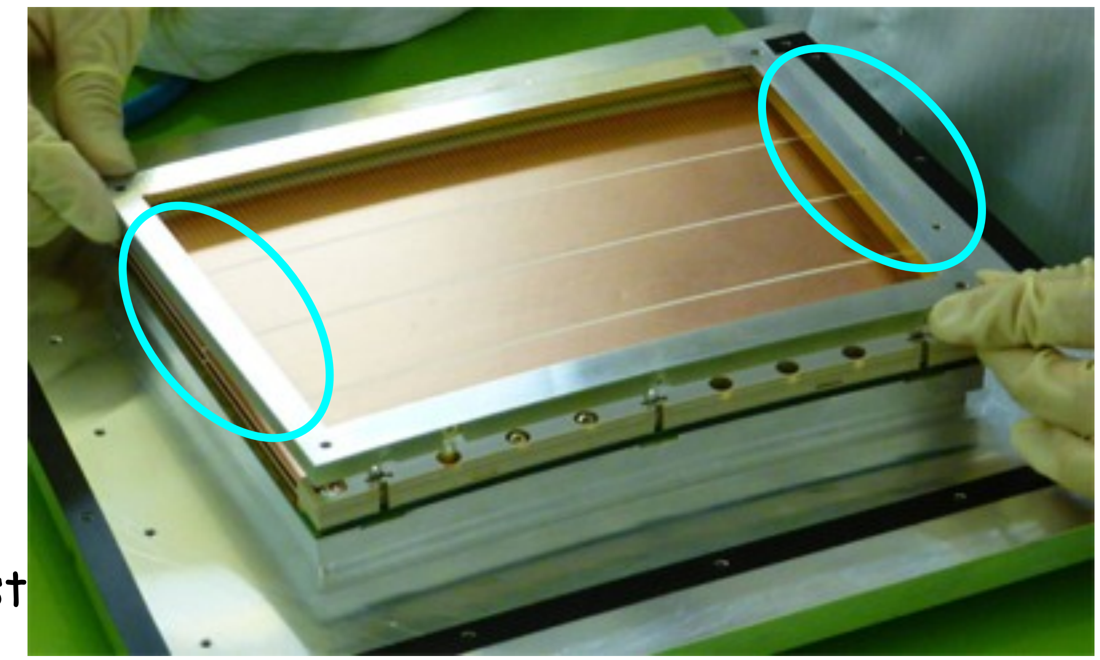
- **GEM gating tests**
  - Electron transmission measurement under high magnetic field is the key (urgent)
  - Large-aperture Gate-GEM samples (~ 10 x 10 cm^2 size): several samples in hand
  - Preliminary measurement was performed at KEK cryo center (1 T MRI magnet) in April
  - 2 weeks measurement will be conducted at KEK-CC from 7 July (w/ tools for quick analysis)
  - R&D effort is ongoing intensively by Fujikura Ltd. (minimize rim width & larger foil size for LP module)
- **Wire gating tests**
  - By using our UV-laser system at KEK the 1st prototype was ready to measure "some effect" in the presence of wire-grids above the GEM amplification, but had been interrupted due to ALTRO DAQ trouble... (our restoration work took longer than initially expected, and problematic boards will be tested at Lund from 2 July)
  - The 1st test measurement will be done from 10 July at KEK

Conventional wire-grid as a gating device

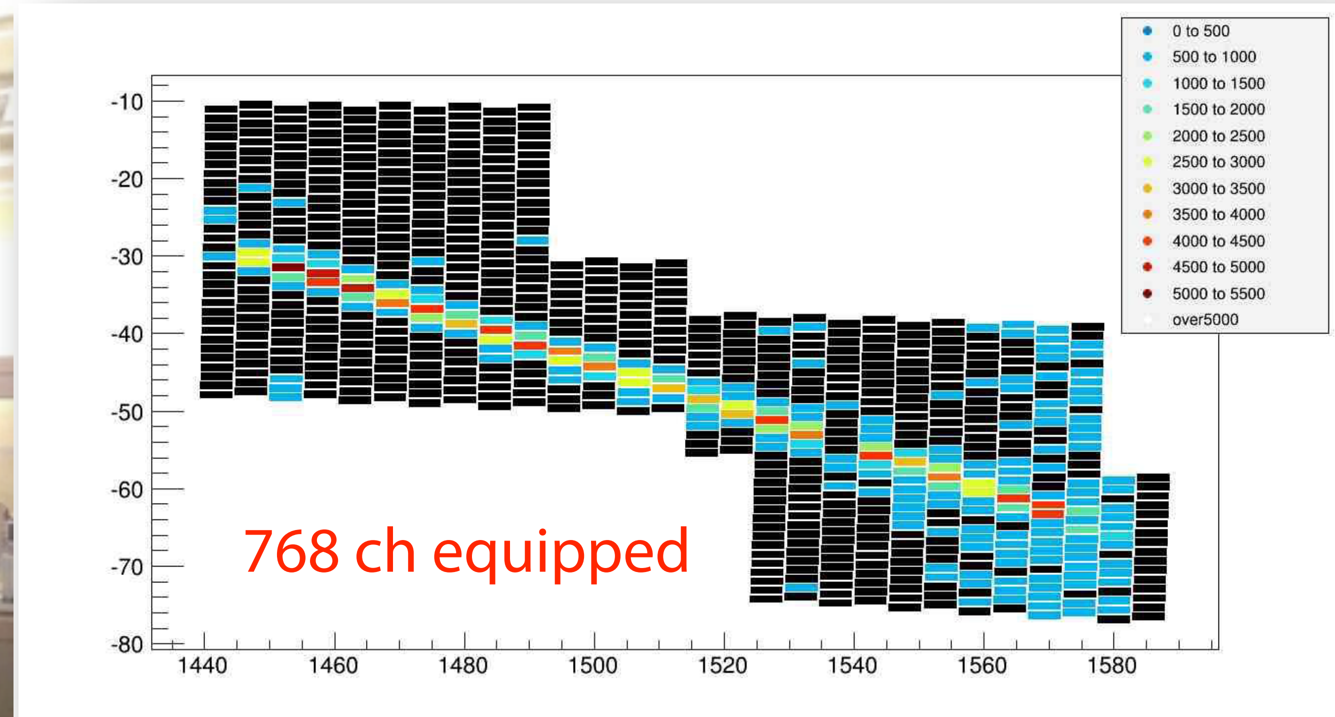
- **Wire gating grid is an option**
  - Traditional gating system
  - Conventional transverse wires would require a structure creating dead angular regions => would put the wires radially
  - Wires can create field distortions, and in particular ExB effects...
  - **Our 1st prototype**:
    - 30µm wires,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

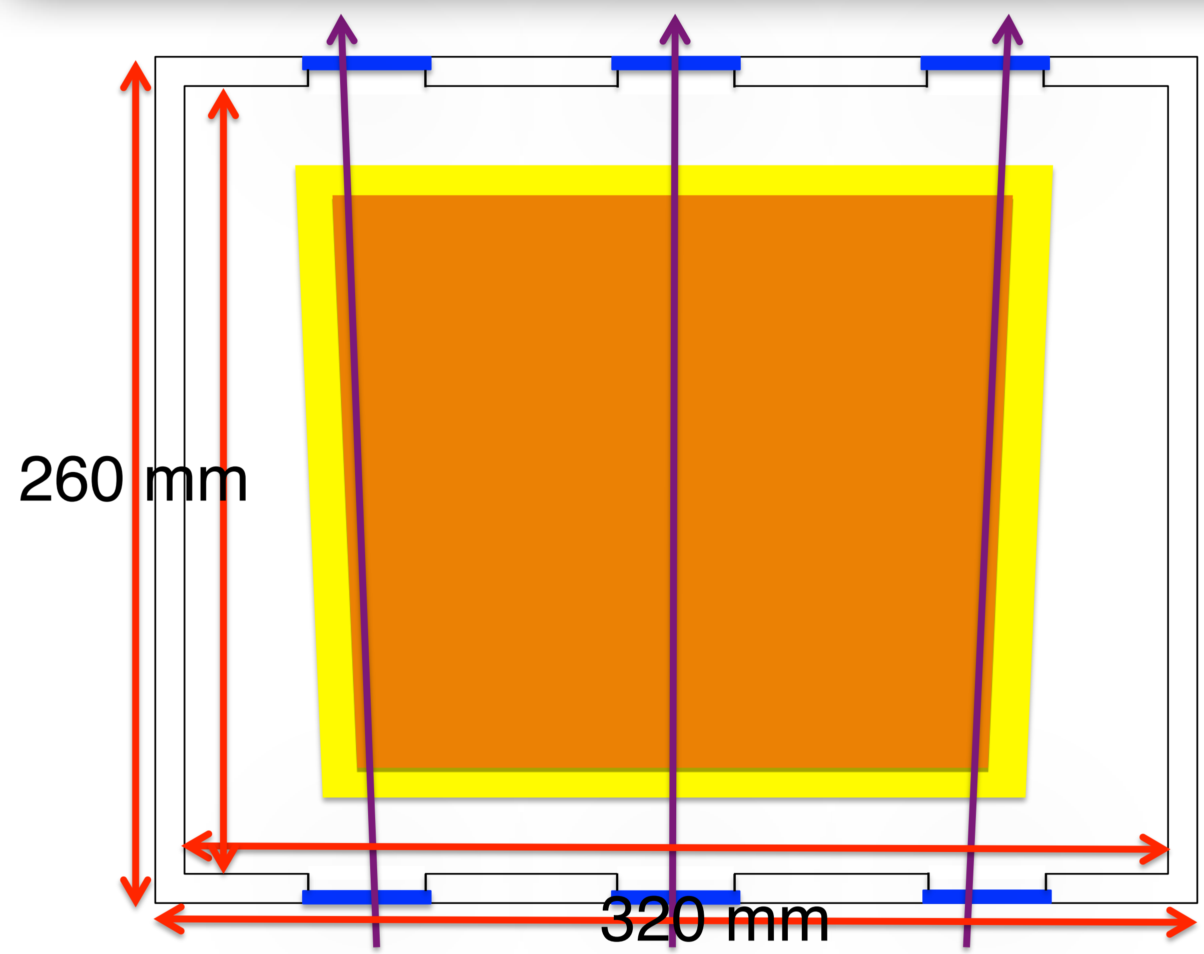






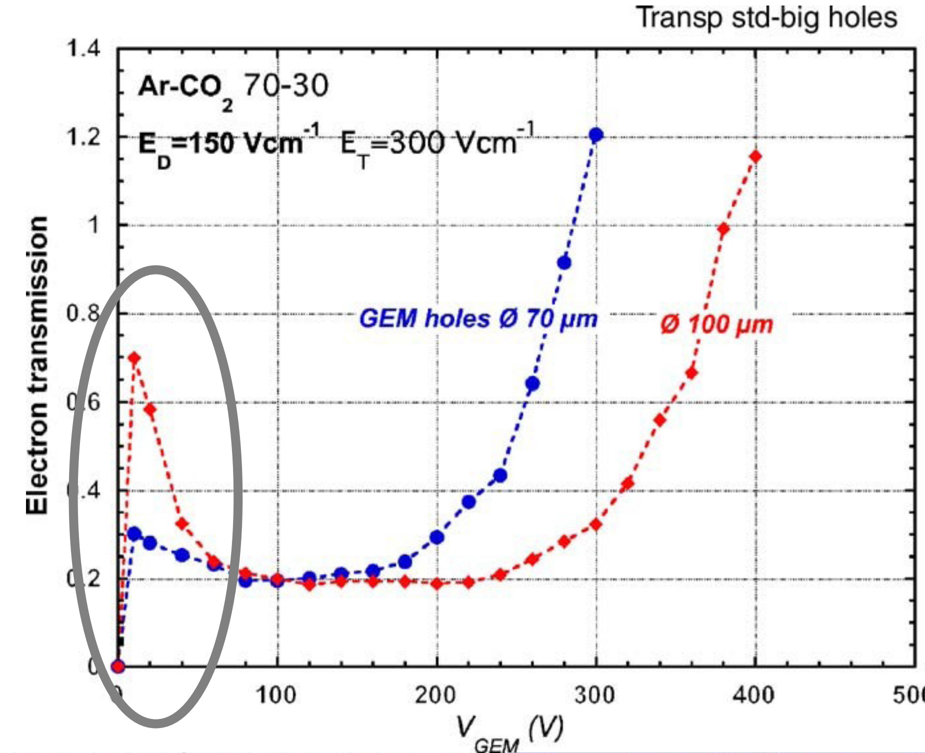
UV-Laser facility at KEK and wire-gate test

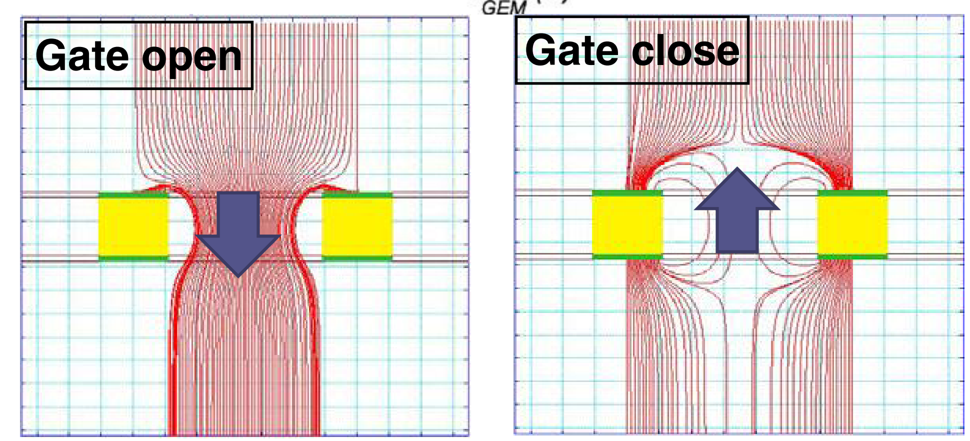




GEM as a gating device

- **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 ILD-TPC!!

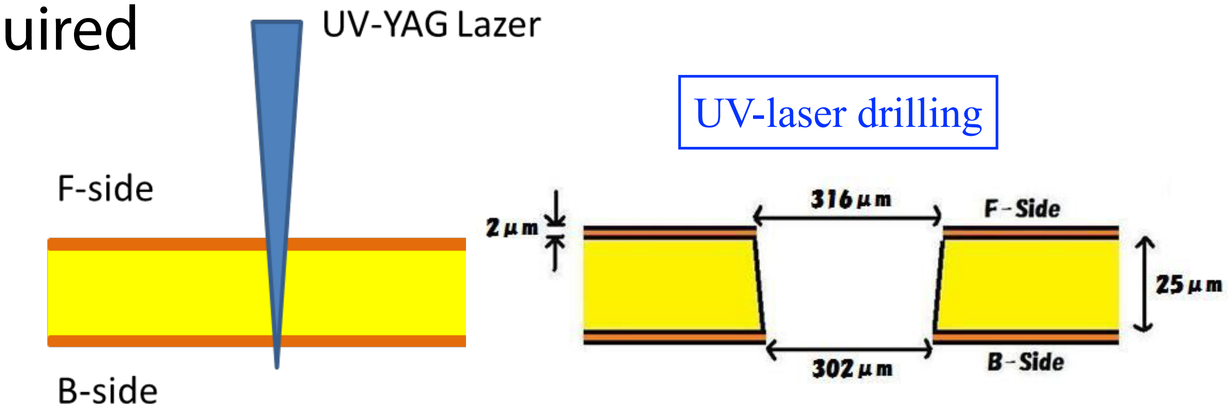




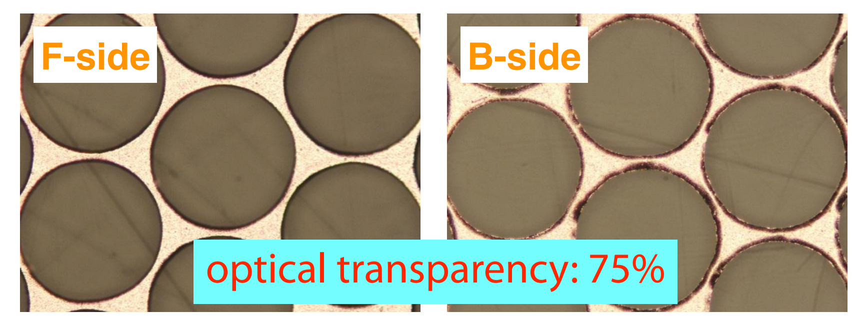
- **Requirement for Gate GEMs of ILD-TPC**
  - ILD-TPC: operated in a 3.5 T axial magnetic field, and in a gas with a high mean free time (τ) of drift electrons between collisions with gas molecules
  - Motion of electrons is strongly restricted to the direction of the magnetic field => **high optical 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

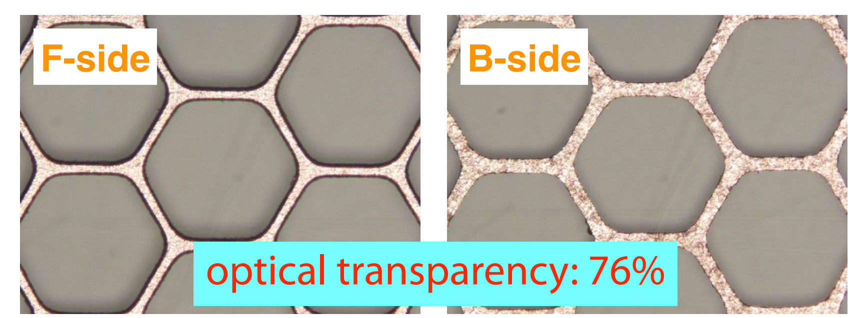
- **High optical transparency = Minimize rim width of GEM holes**
  - To achieve high electron transmission: 30 μm rim width & 330 μm pitch in honeycomb structure (= 85~90% optical transparency) required



- **R&D by D. Arai (Fujikura Ltd.)**
  - Thanks for his tremendous efforts!!!
- **Fujikura Gate-GEM Type 0 sample**
  - Round holes / UV- laser ablation technology (1 cm x 1 cm)
  - 15 μm (F-side) - 30 μm (B-side) rim width with PI thickness 25 μm: hard enough!



- **Fujikura Gate-GEM Type 2 sample**
  - Hexagonal holes / Ni-plating process (9 cm x 9 cm)
  - 30(F) - 40(B) μm rim width & 300 μm pitch with PI thickness 12.5 μm



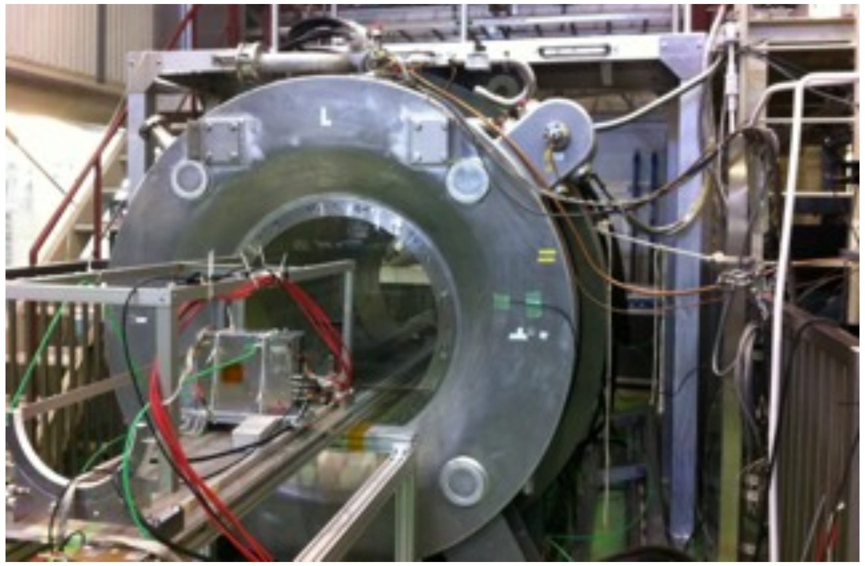
These 2 samples: tested with a test chamber installed in a 1 Tesla solenoid magnet at KEK cryo center

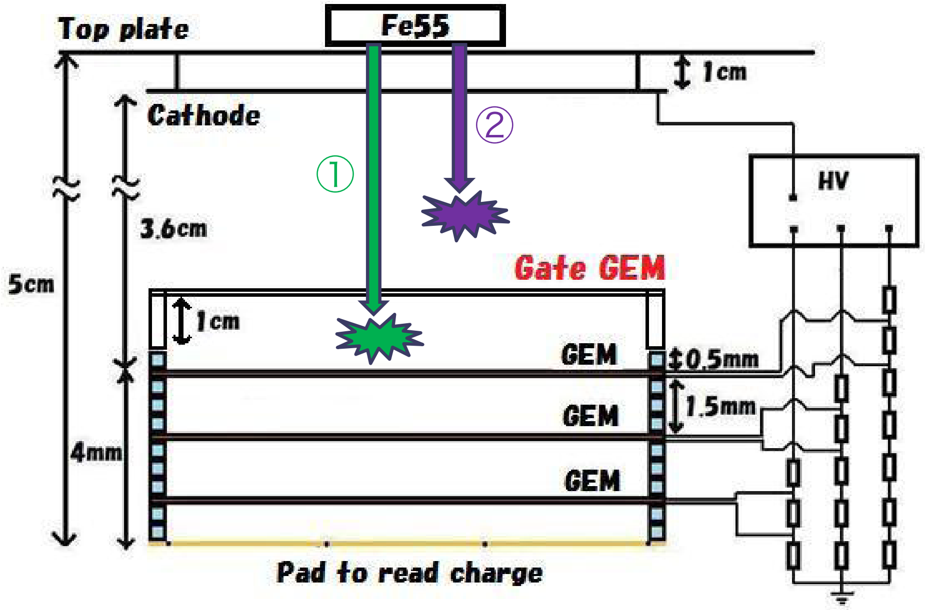
- Fujikura Gate-GEM Type 3 sample (Ni-less process & 20 μm rim width) and RAYTECH samples (by using precise chemical etching technique) will be tested from 7 July at KEK cryo center

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



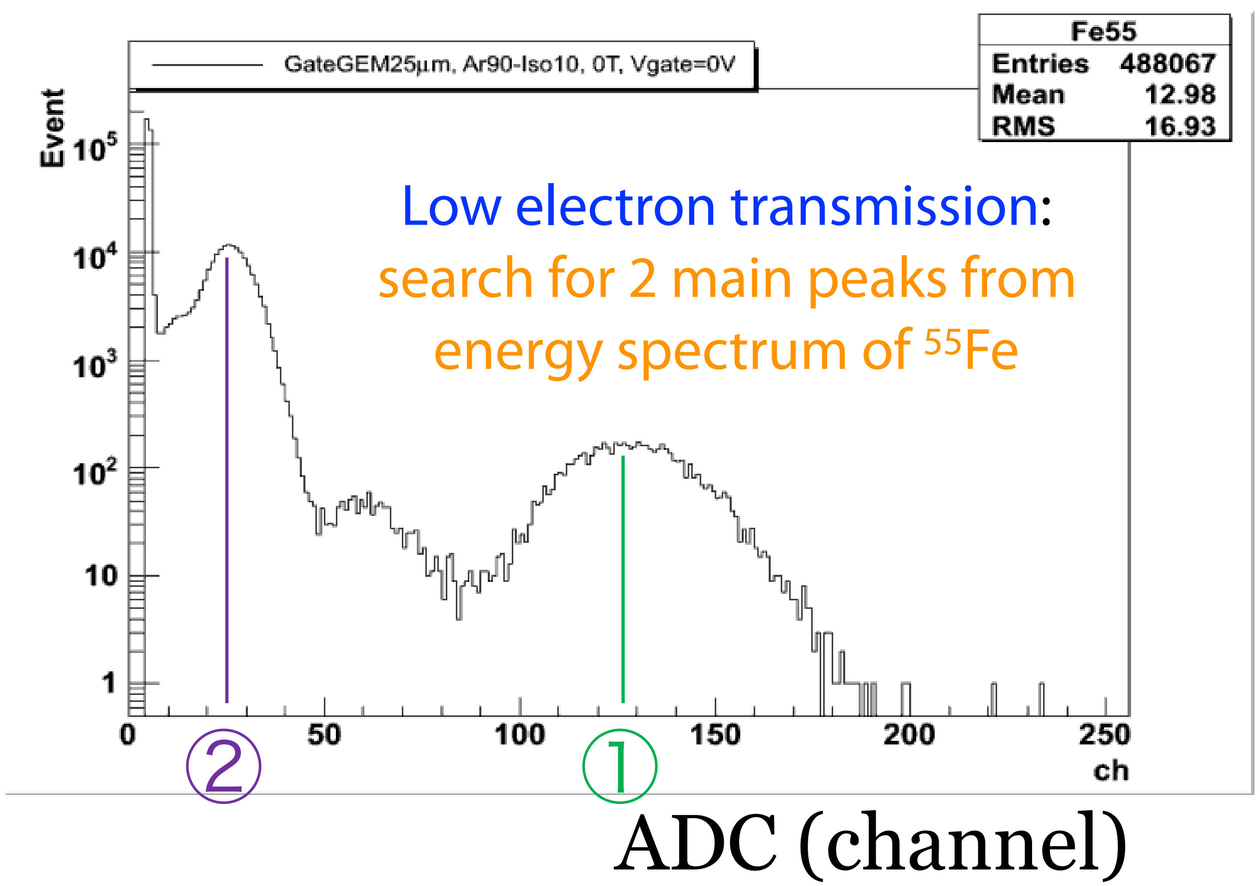


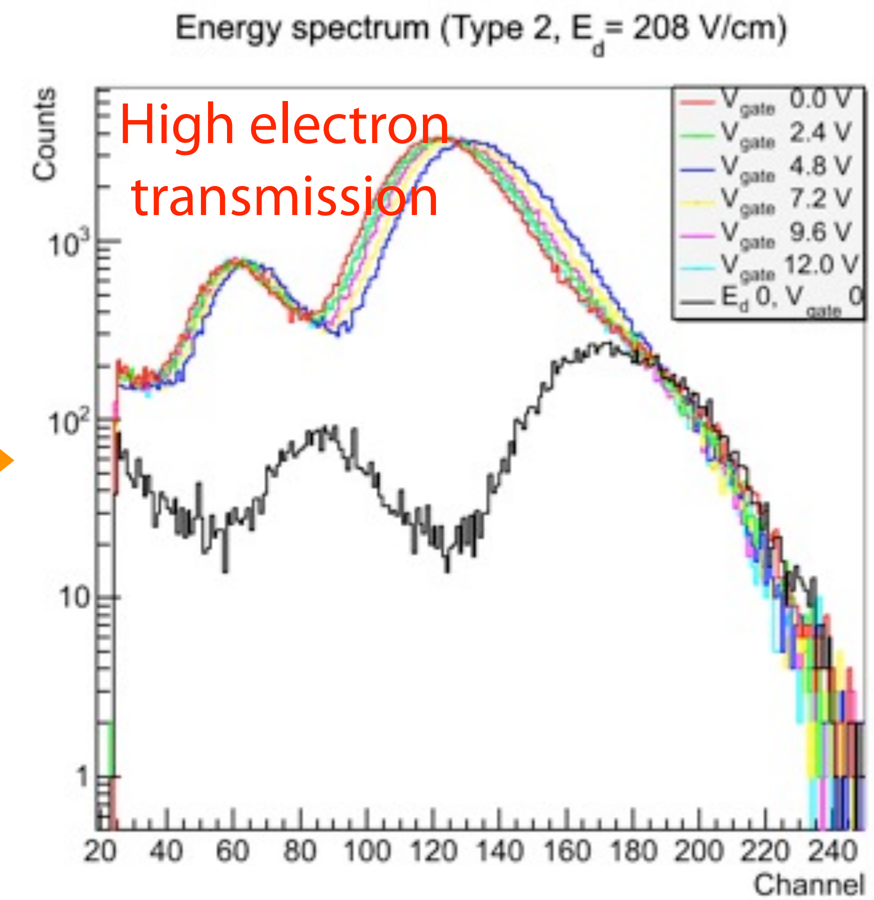
using a Fujikura 50 µm GEM readout (triple GEM stack) and one of Fujikura Gate-GEM samples placed 10 mm above

  - **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 in the same measurement (any systematics can be cancelled out in this method)

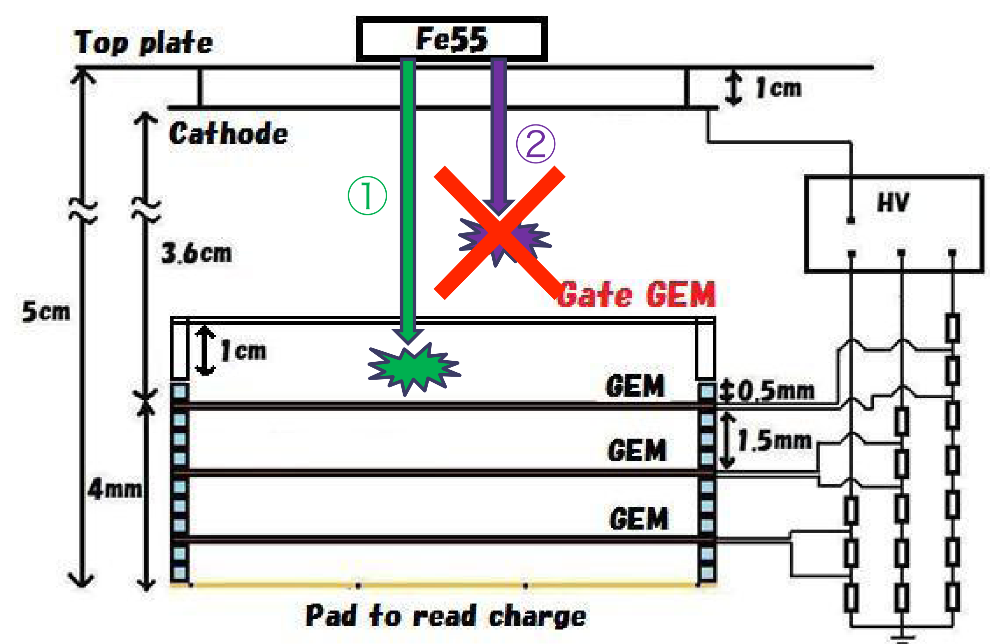
Electron transmission measurement (cont'd)

- **In the case of large-aperture Gate-GEM samples**

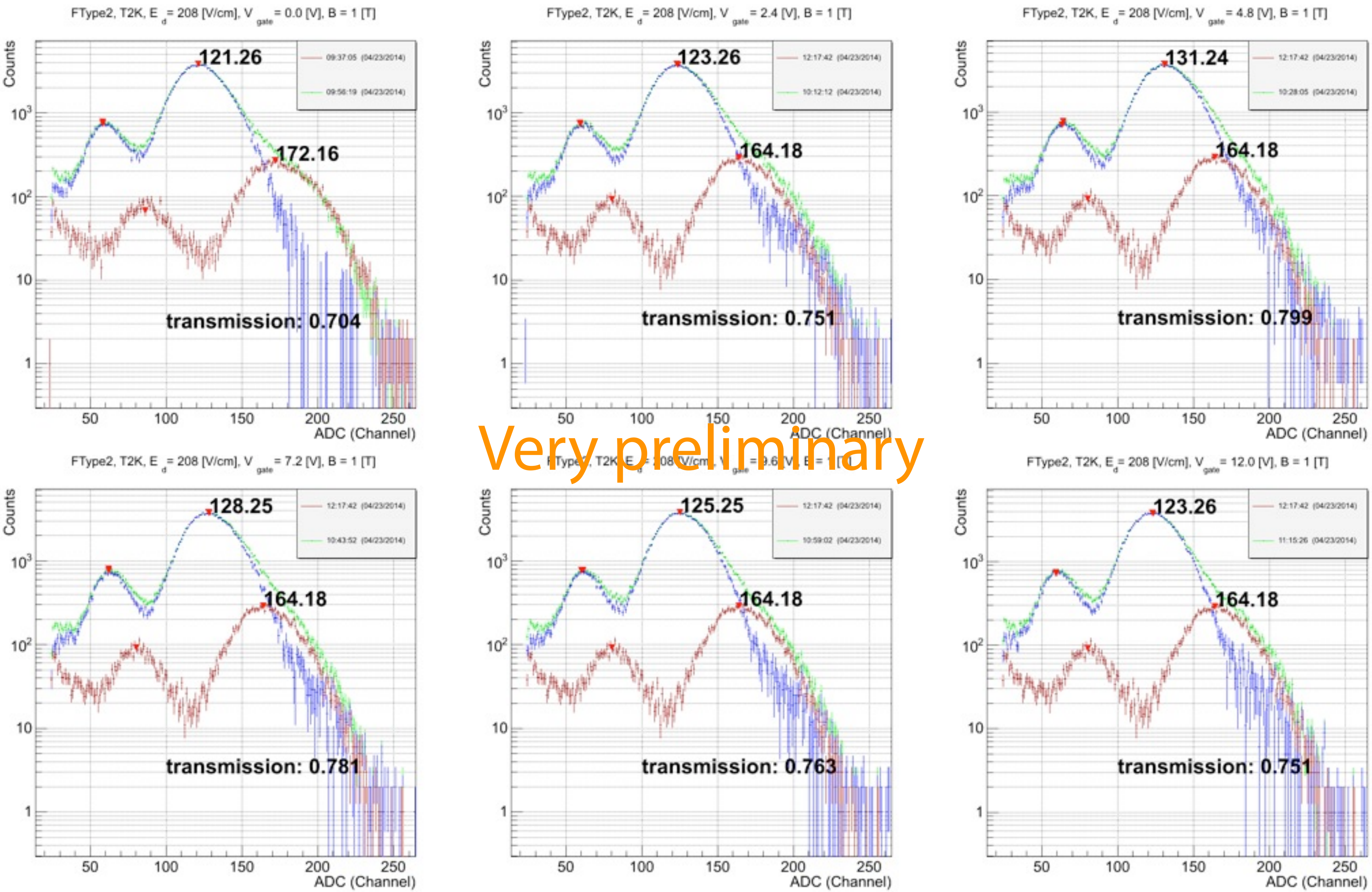




- Impossible to determine the two signals in the same measurement...
- Need to define 100% electron transmission from E_drift = 0 run
- Analysis: pick up proper E_drift = 0 run and apply corrections (e.g. correlation between gas gain and T/p)

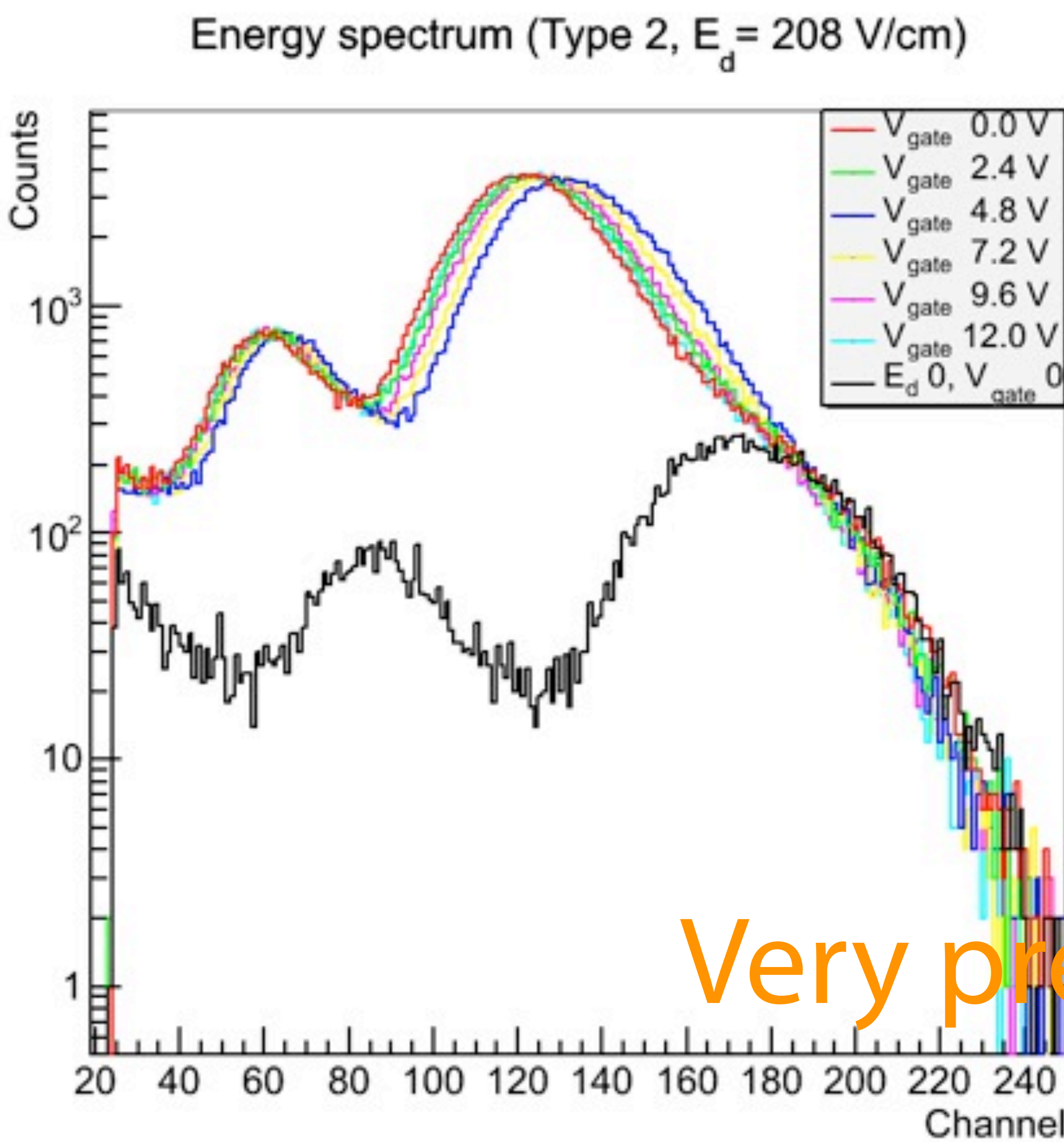


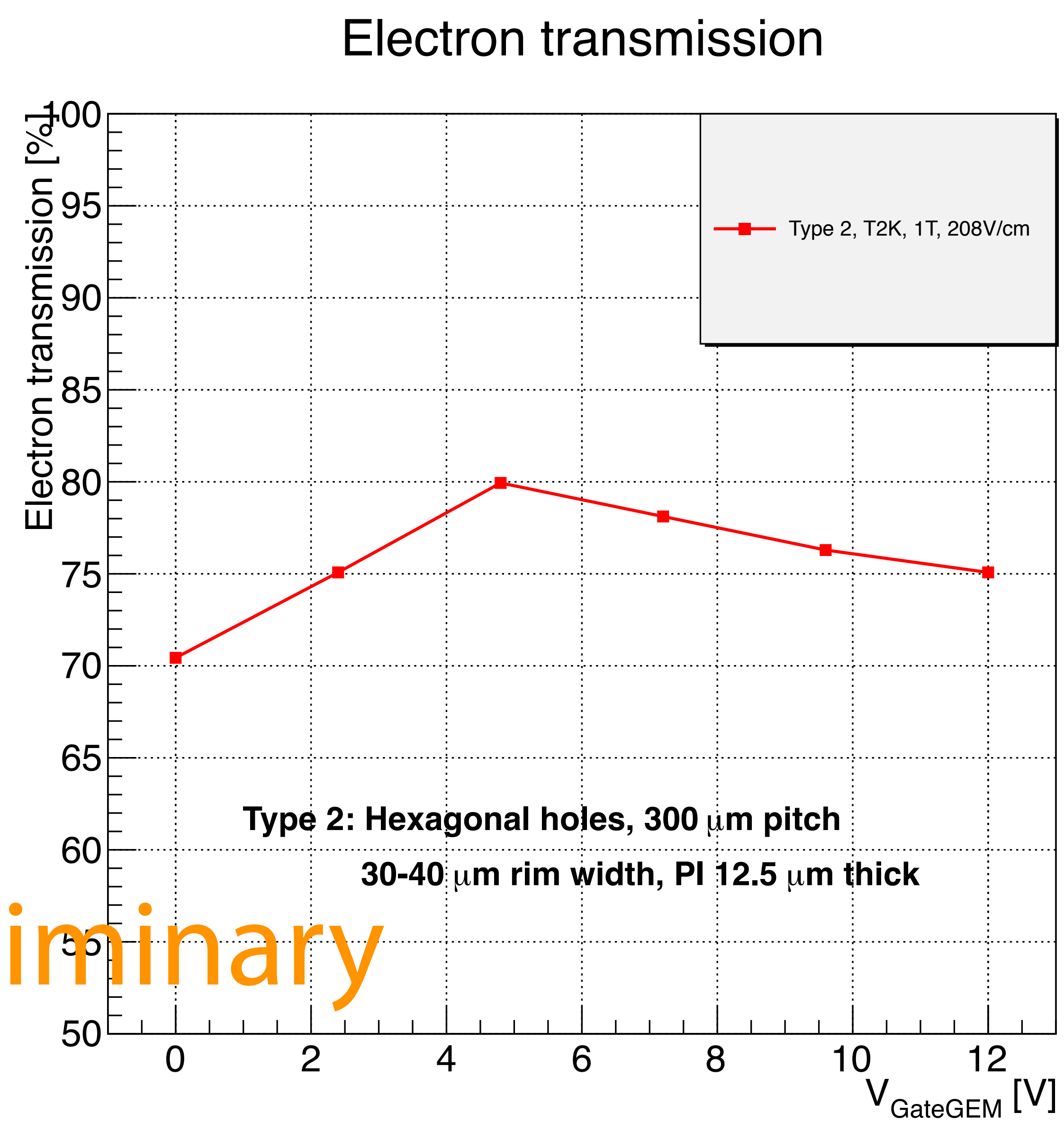
Type 2, T2K gas, B = 1, Ed = 208 V/cm



Type 2, T2K gas, B = 1, Ed = 208 V/cm

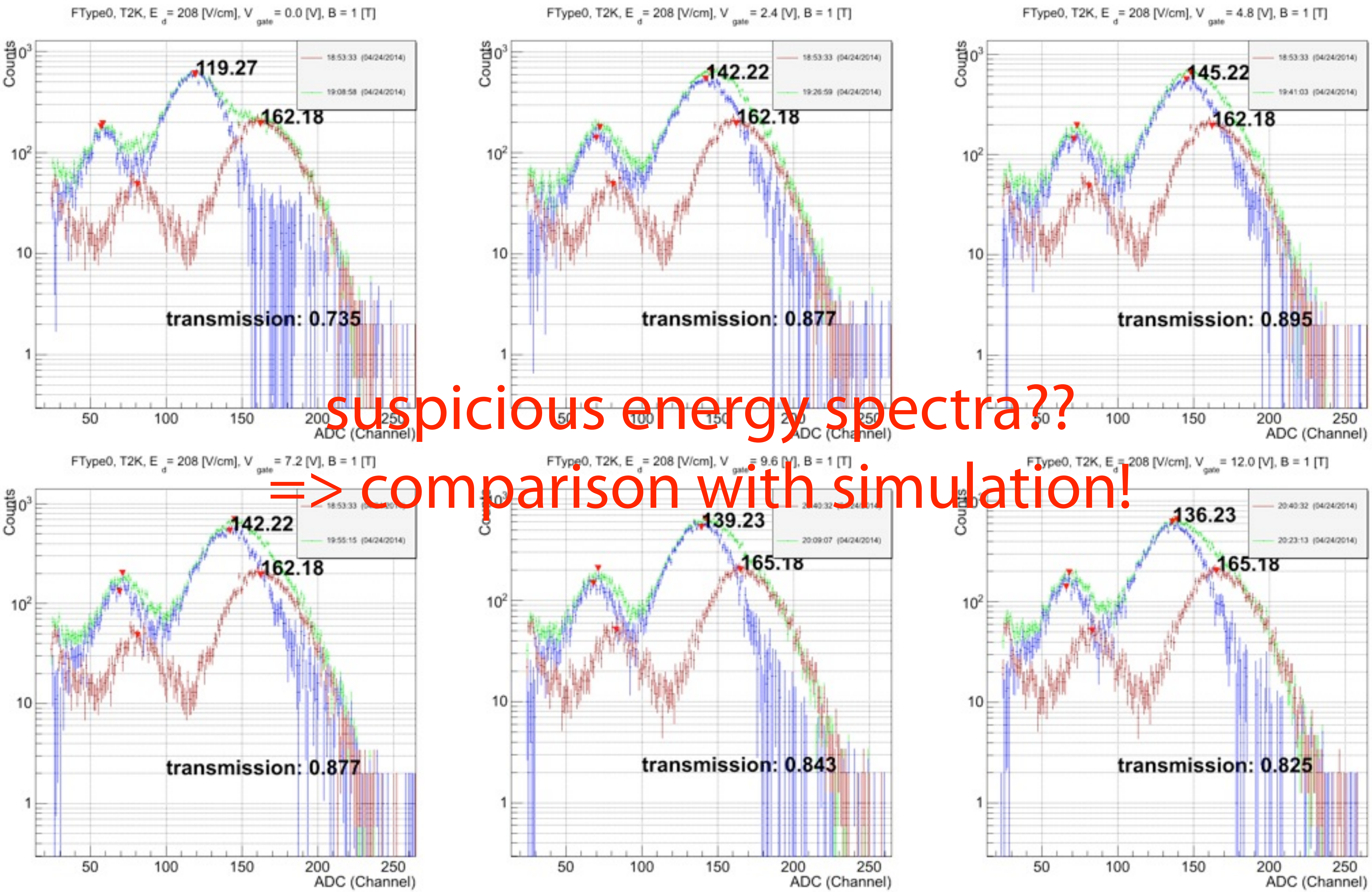
Measured energy spectrum, and electron transmission as a function of the voltage applied to gate GEM





- Electron transmission of Fujikura Type 2 sample: reached about 70-80% under 1 T
- Need comparison with simulation (ANSYS/Garfield++ framework)

Type 0, T2K gas, B = 1, Ed = 208 V/cm

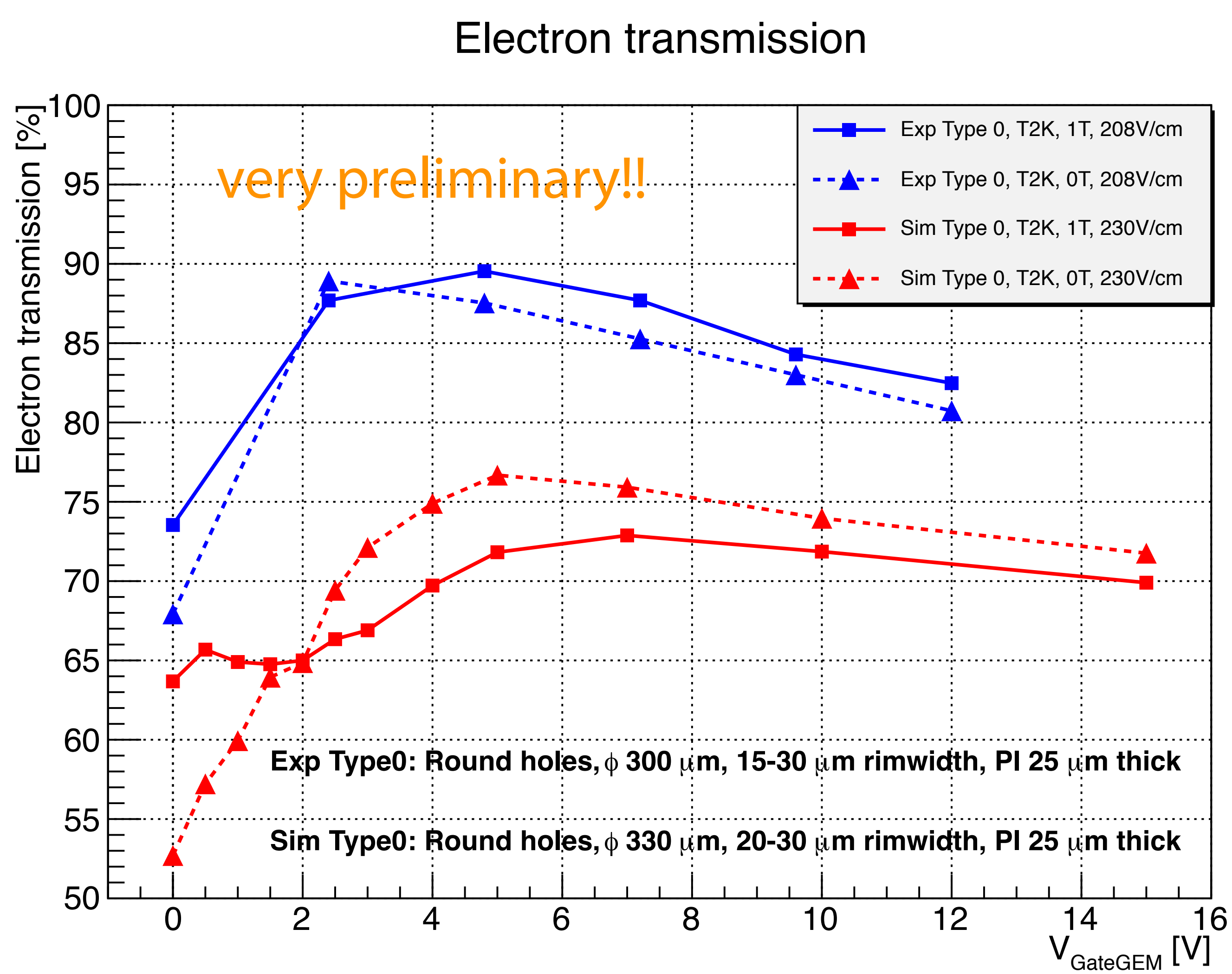


suspicious energy spectra??

=> comparison with simulation!

Status of comparison with simulation

- **Data analysis for Fujikura Gate-GEM Type 0 sample**
  - Suspicious energy spectra obtained (= too high electron transmission for 208 V/cm?)
  - Require careful comparison of experiment with simulation (ANSYS/Garfield++ based)
- **Simulation framework**
  - Nice self-learning materials: "RD51 Simulation School (Jan. 19-21, 2011)"
    - useful example codes to simulate the CERN standard GEM by using ANSYS and Garfield++
    - http://indico.cern.ch/event/110634/
  - Legacy codes from Philippe: started to hold frank exchanges from 2 May (just after I showed my preliminary results for data obtained in April)
  - Reproduced Type 0 simulation (coll. & extr. eff.) for 0, 1 and 3.5 T (T2K gas)
  - Integrate them and rewrite all by myself from scratch to avoid programs from unknown sources
  - Understand how to implement hexagonal holes (for Type 2)



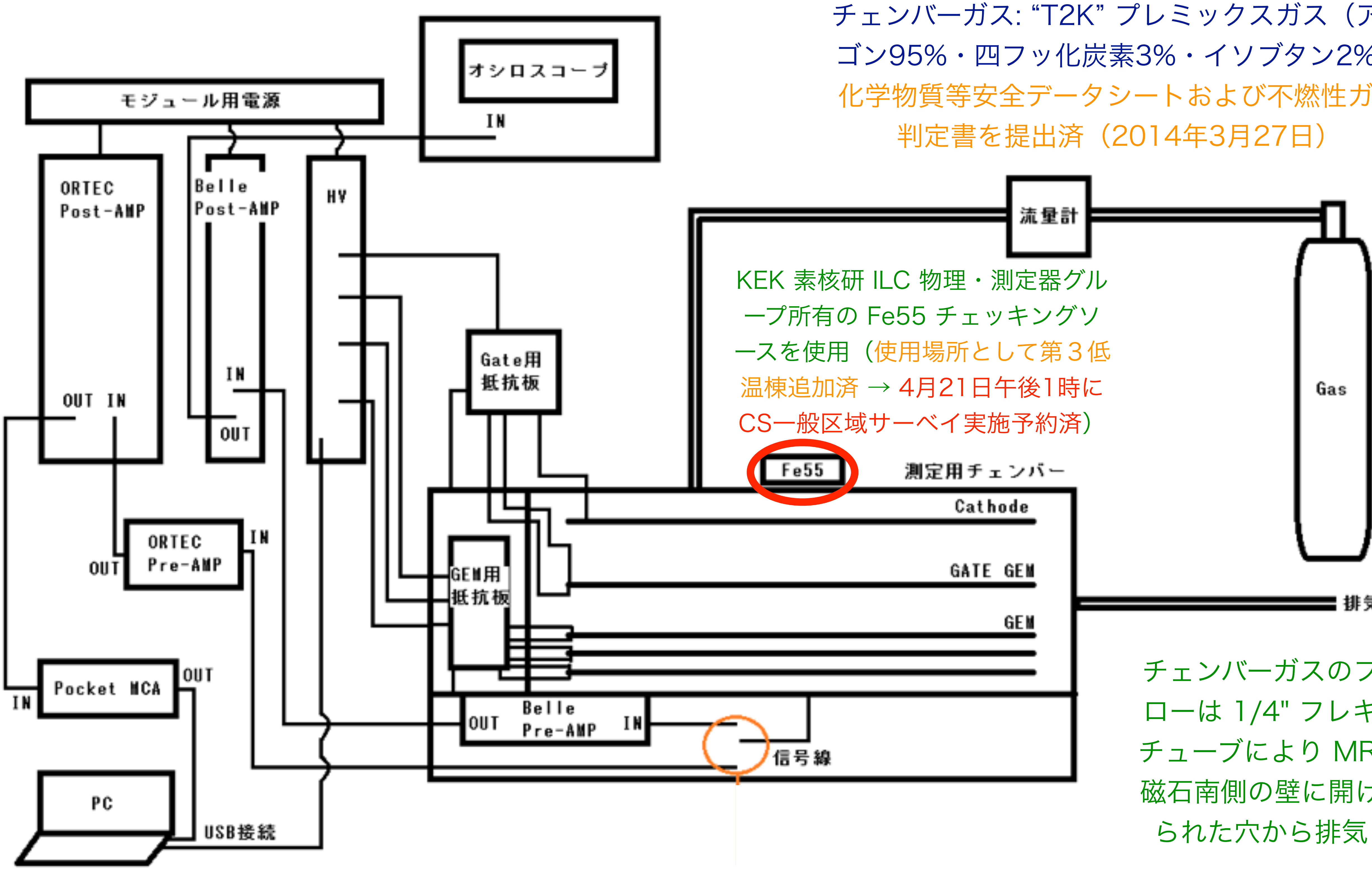
Summary and prospects

- 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
- The accumulated positive ions could cause serious distortion of the uniform drift field, thereby degrading the spatial resolution of the TPC
- The gate is required to block the positive ions when it is closed and to have high transparency to drift electrons when it is open
- High optical transparency of the gate is required to ensure its high transmission rate of electrons in the open state because the ILD-TPC is operated in 3.5 T, and in a gas with a high mean free time of drift electrons
- A Gate having a GEM-like structure would be most adapted for a module structure of ILC-TPC since it is easier to implement and allows a low switching voltage of a few tens of volts
- To achieve high electron transmission, 2 types of large-aperture GEMs which have ~75% optical transparency were produced by Fujikura
- These samples have been tested with a test chamber installed in the KEK MRI type 1 T solenoid, and the performance of high transmission has been observed (for Fujikura Gate-GEM Type 2)
- Evaluation of the measurement results by using the ANSYS-Garfield based simulation framework is ongoing
- Additional Fujikura Gate-GEM samples and RAYTECH samples will be tested from 7 July at KEK cryo center

Backup

実験セットアップ

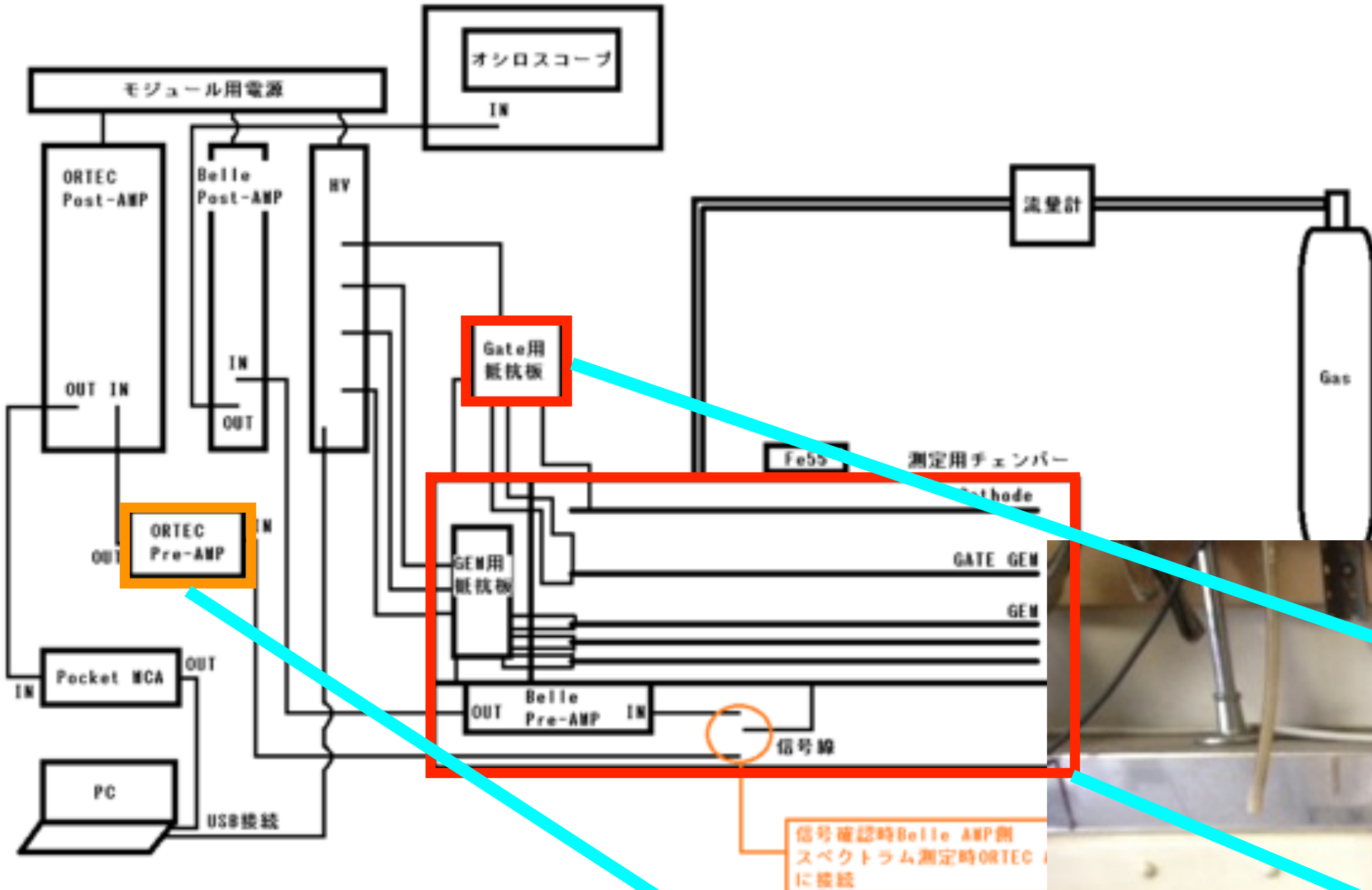
チェンバーガス: “T2K” プレミックスガス（アルゴン95%・四フッ化炭素3%・イソブタン2%）
化学物質等安全データシートおよび不燃性ガス判定書を提出済（2014年3月27日）

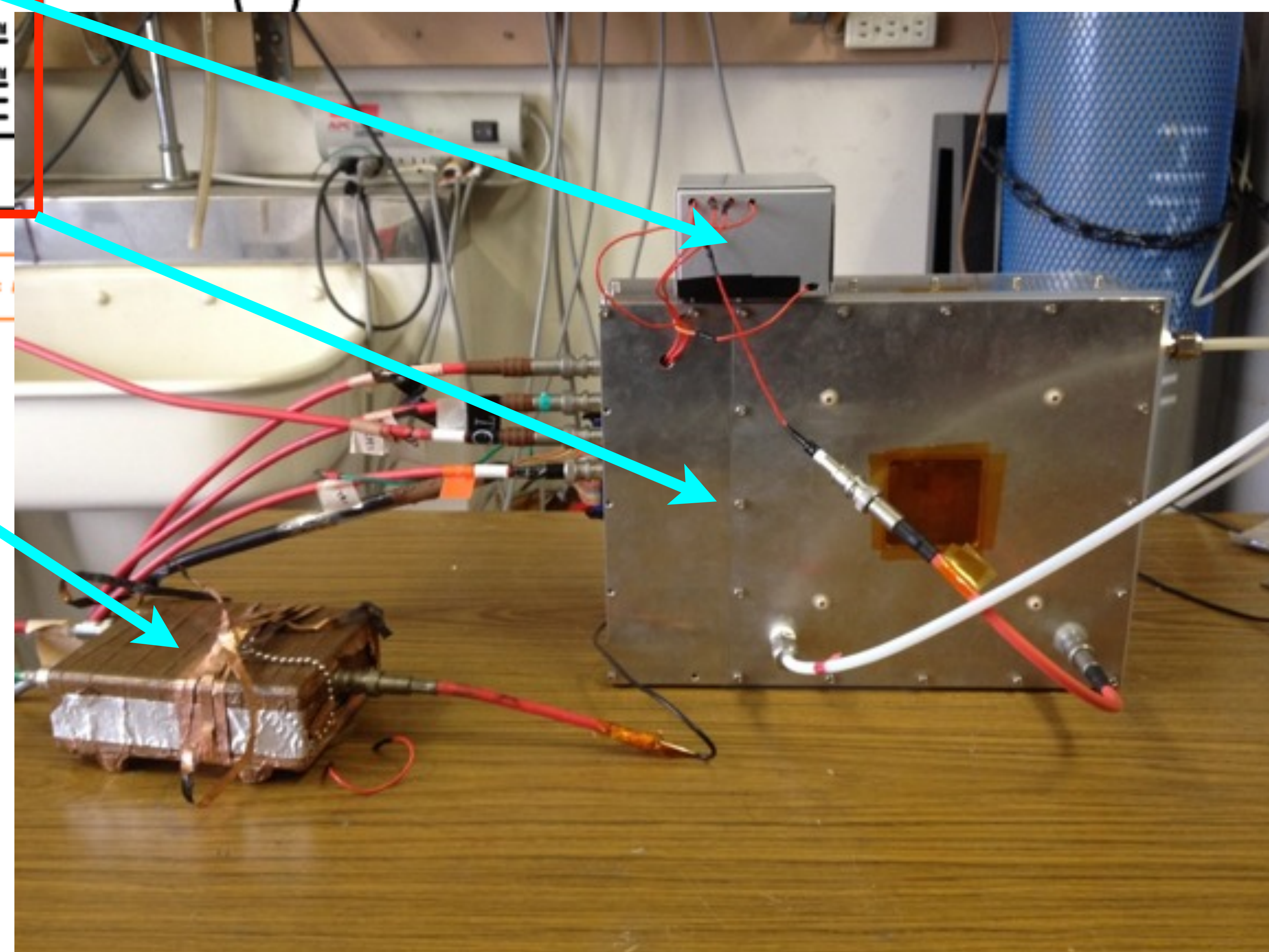


KEK 素核研 ILC 物理・測定器グループ所有の Fe55 チェッキングソースを使用（使用場所として第３低温棟追加済 → 4月21日午後1時にCS一般区域サーベイ実施予約済）

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

GEM 測定用チェンバー





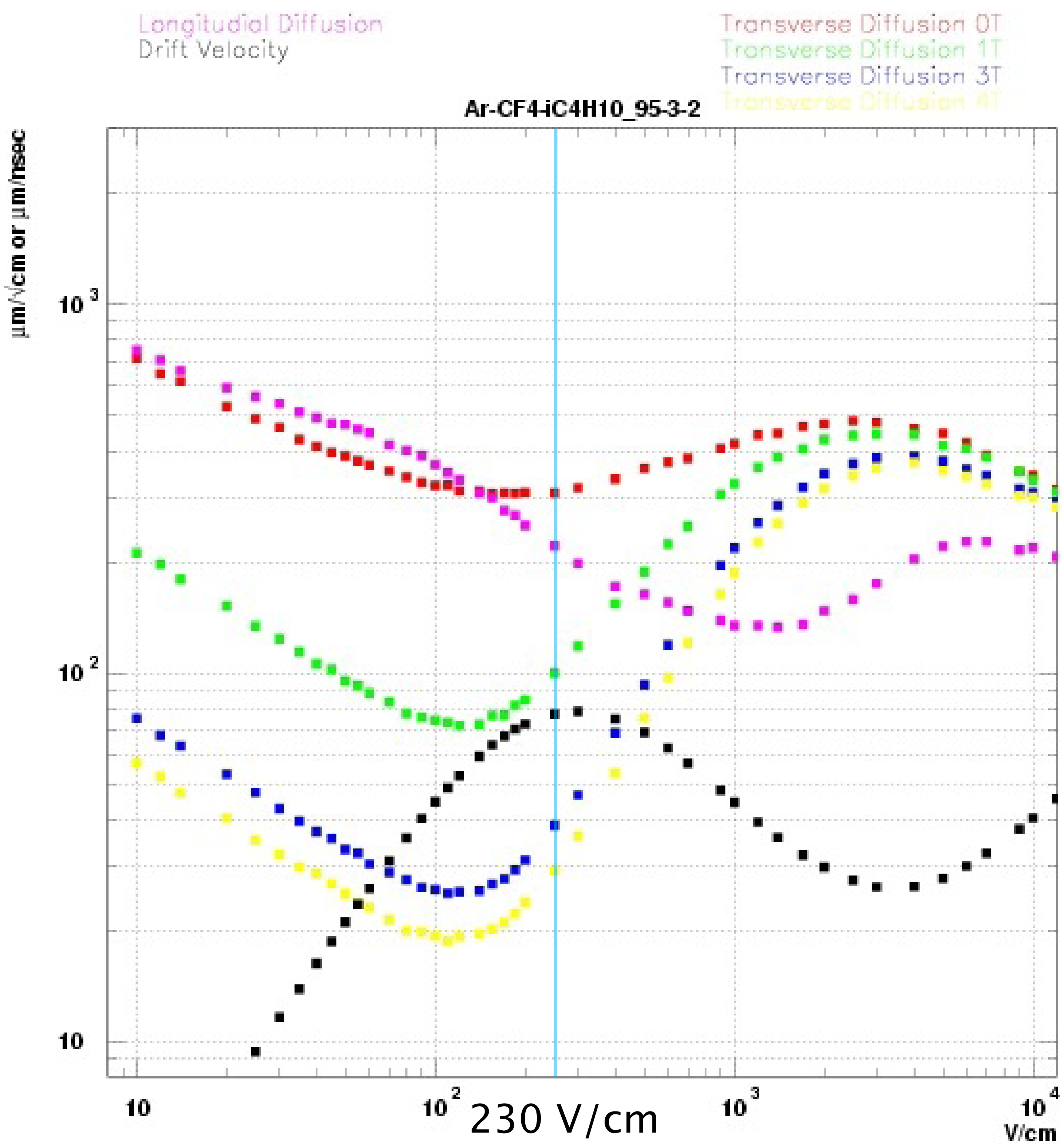
アルミニウムプレート上に
写真のように立てた状態
で据え付け

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	$\simeq 1\times 6$ mm^2 for 220 padrows		
σ_{point} in $r\phi$	$\simeq 60$ μm for zero drift, < 100 μm 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)		

Drift velocity and diffusion (T2K gas)

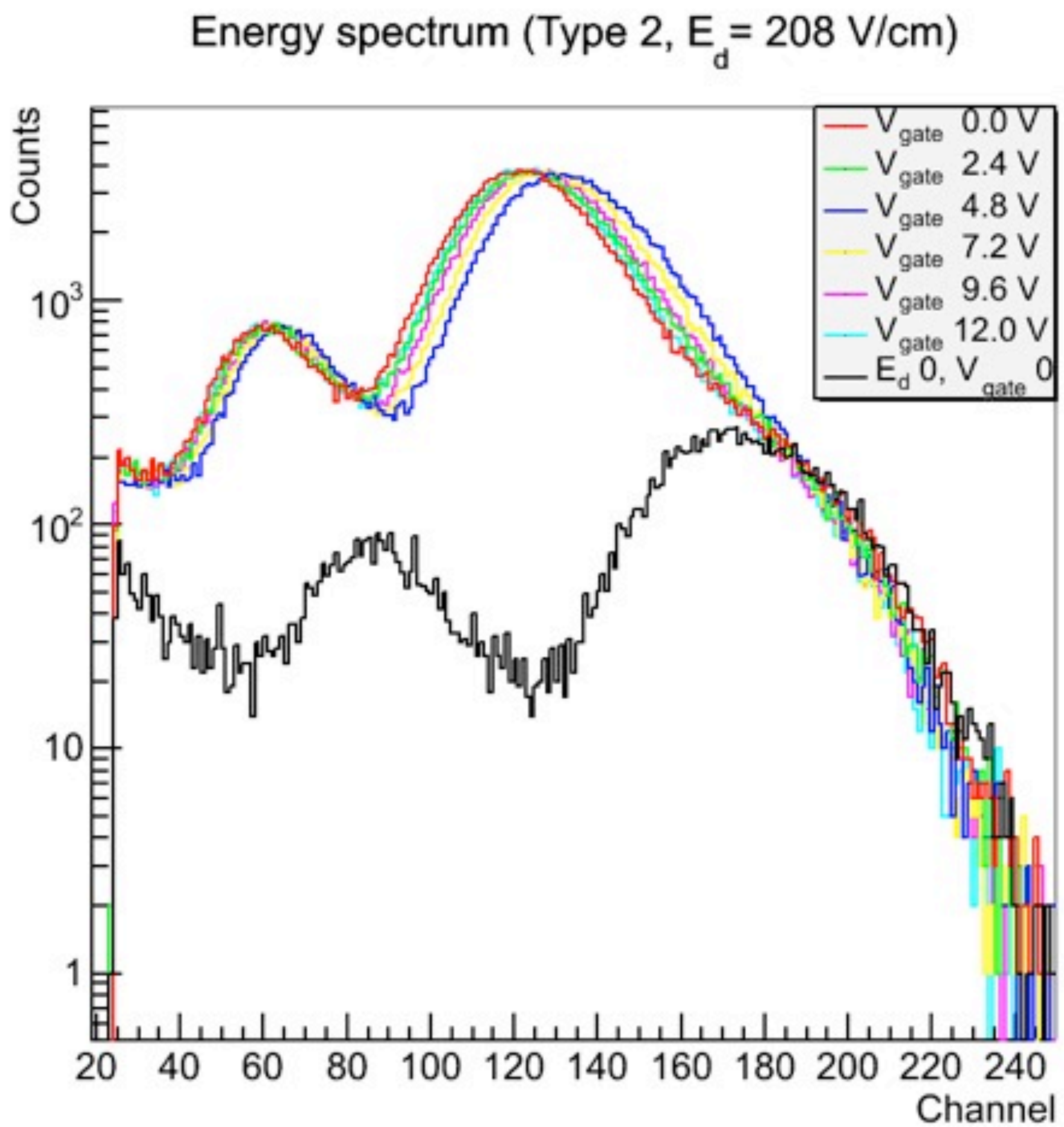


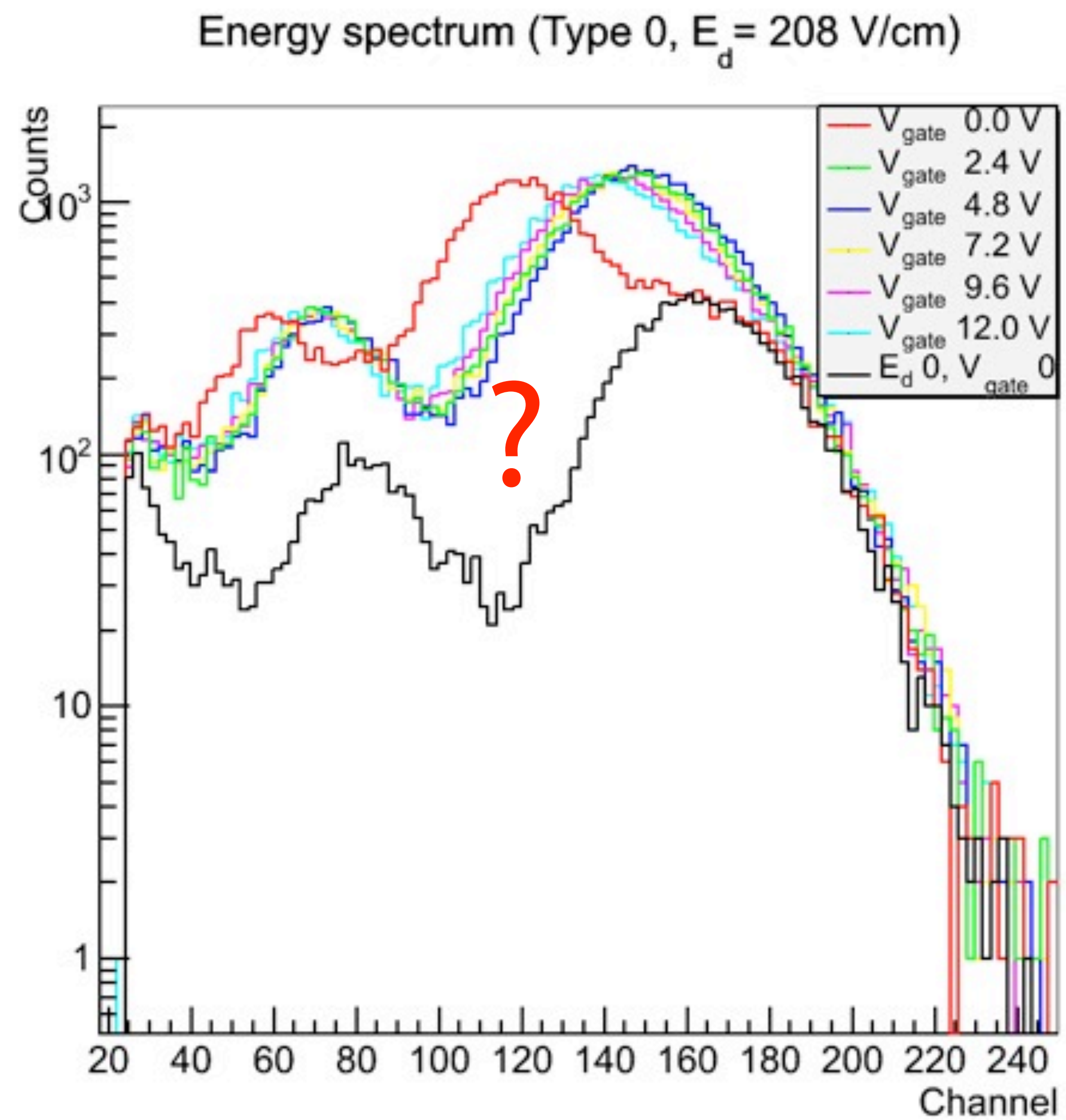
If we require the azimuthal resolution of 100 µm at z = 200 cm the diffusion constant (D), which is essentially the only free (controllable) parameter depending on the choice of gas mixture, needs to be smaller than 30 µm/√cm.

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)!

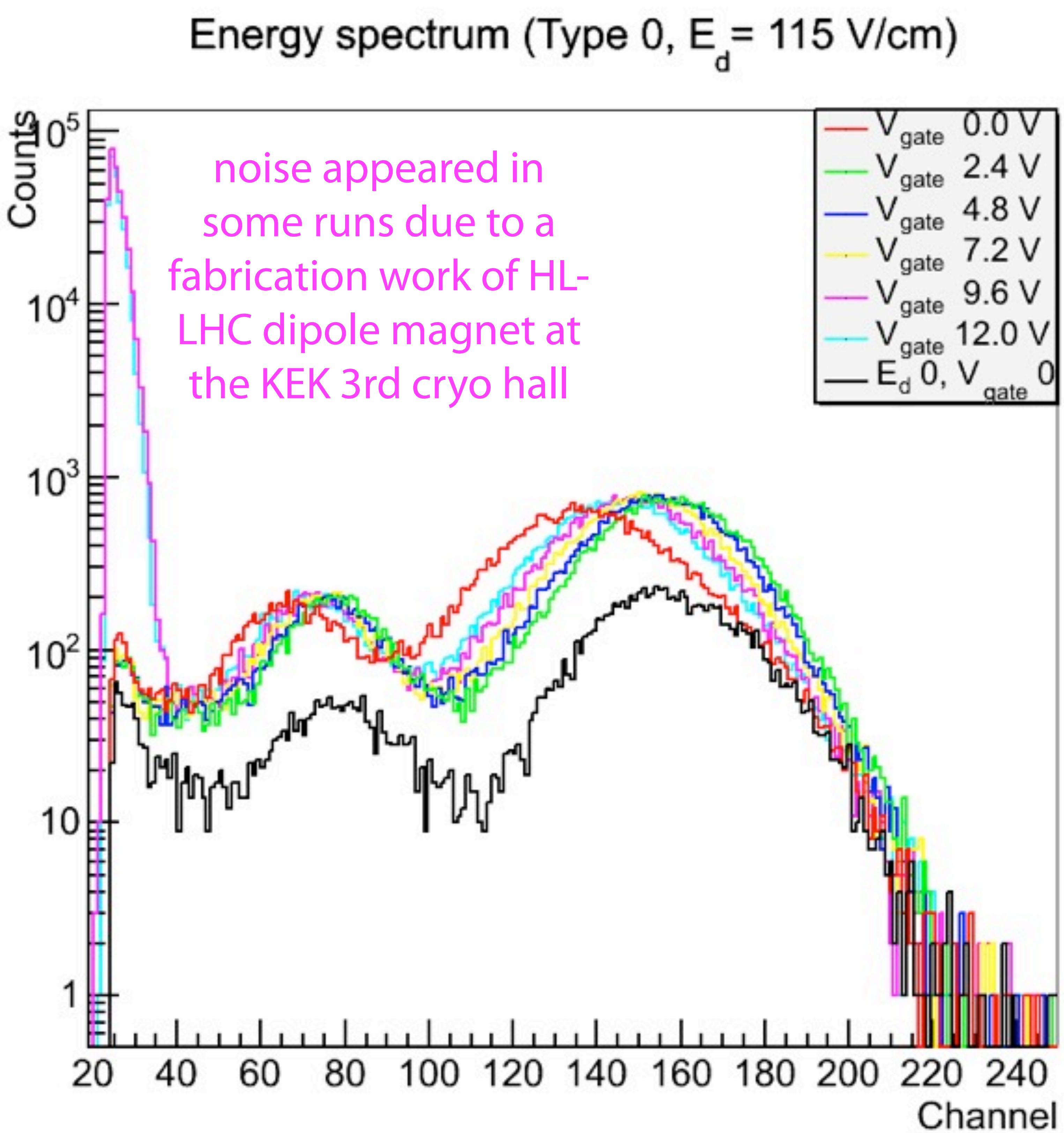
- The diffusion constant D is related to the diffusion coefficient (D^*) through $D2 = 2D^*/W$, where W is the electron drift velocity.
- The electron drift velocity is given by $W = e \cdot E/m \cdot \tau$ with e (m) being the electron charge (mass). A large value of τ, therefore, means a fast gas.

Raw energy spectrum

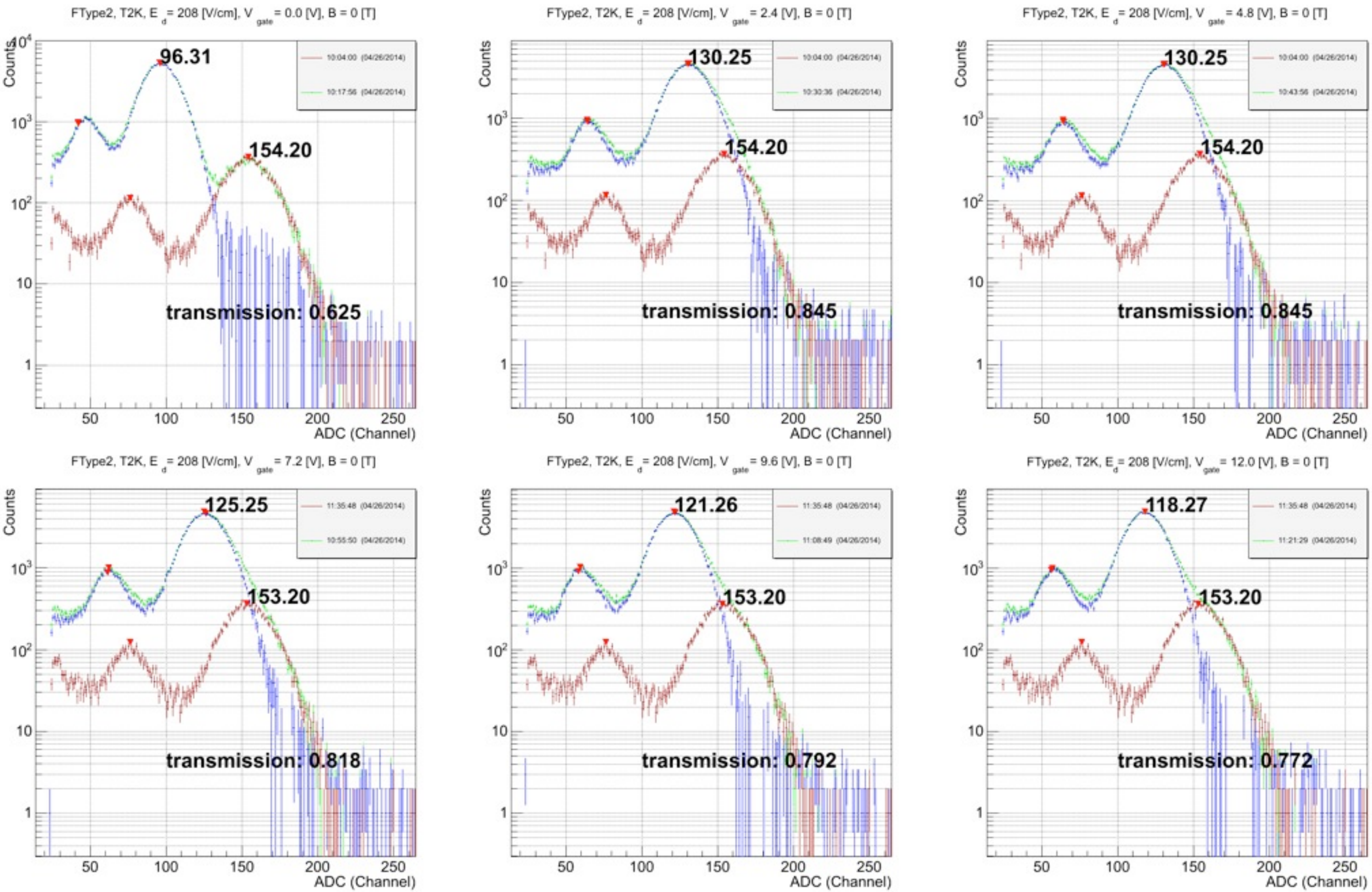




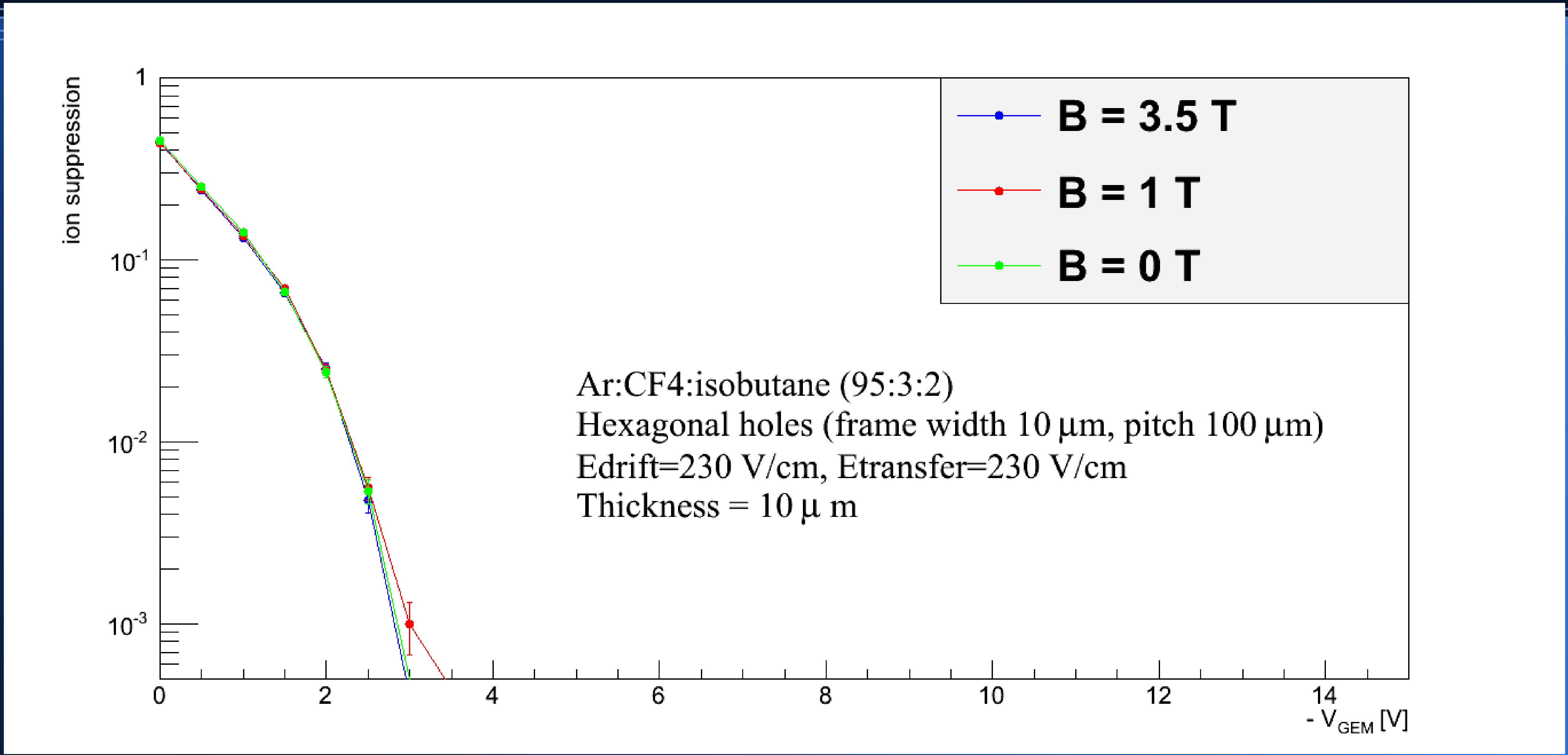
Raw energy spectrum w/ noise



Type 2, T2K gas, B = 0, Ed = 208 V/cm



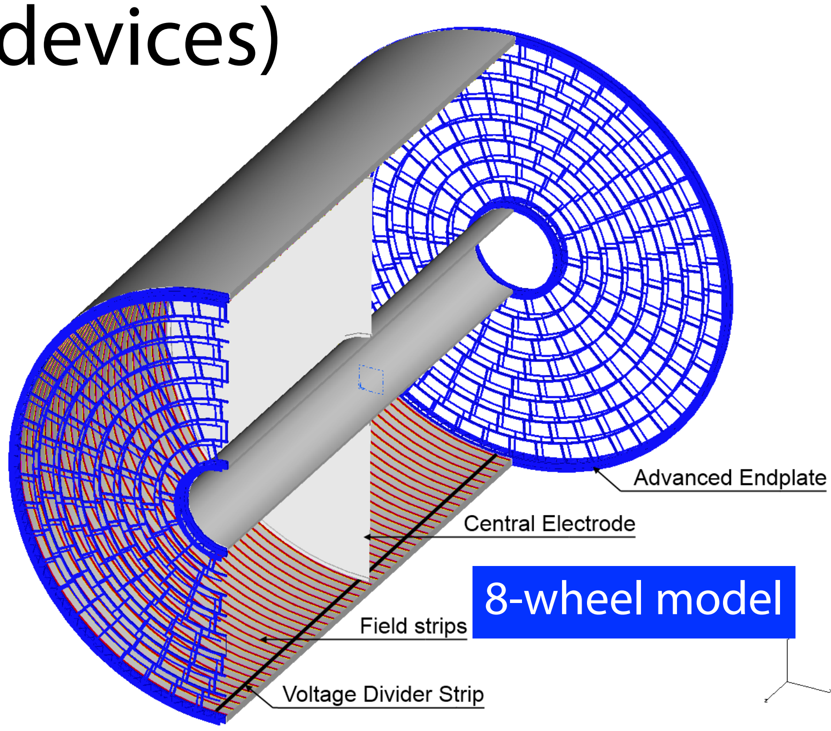
Closing the gate



As expected, the magnetic field has little influence on the ions
A GEM voltage above **3V** already gives enough ion suppression.

Introduction

- **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)



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
  - Three such discs in the chamber
  - 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