Status of GEM gating studies
~ Electron transmission measurement ~

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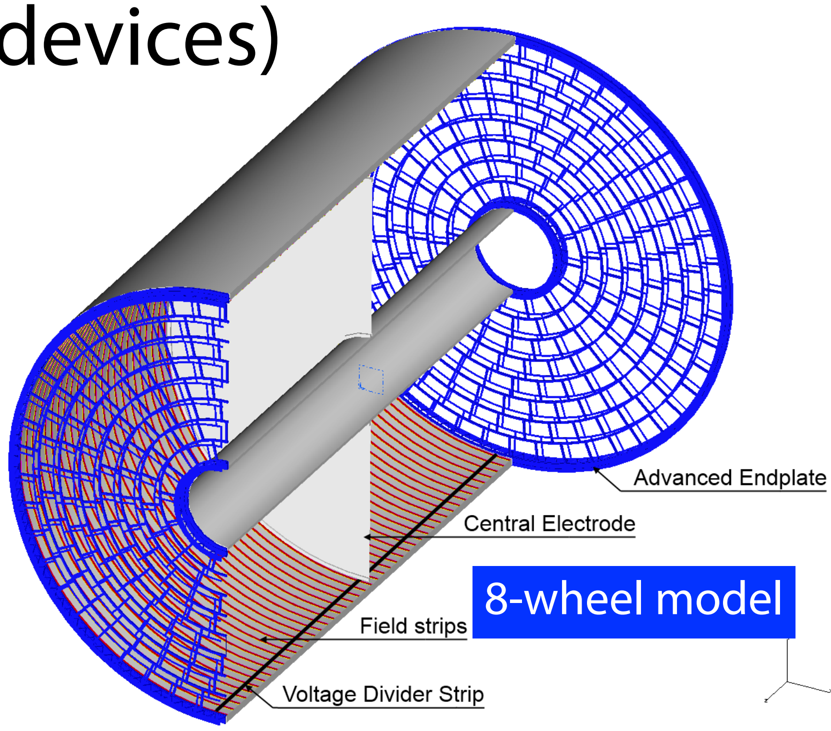
Introduction

- **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)

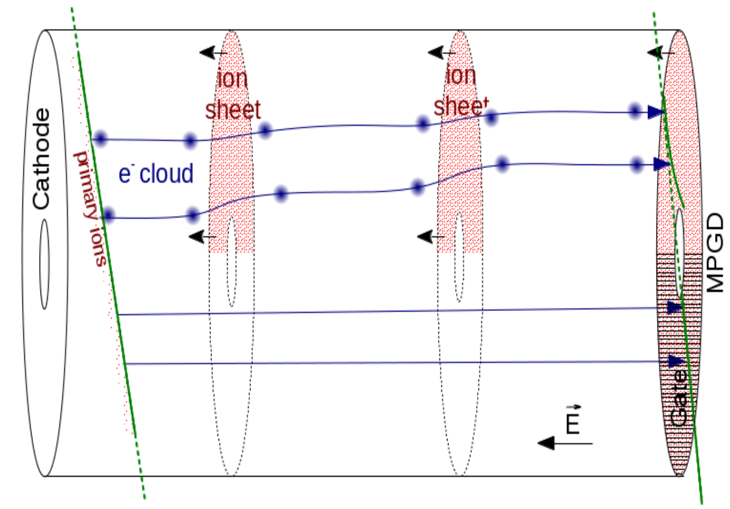


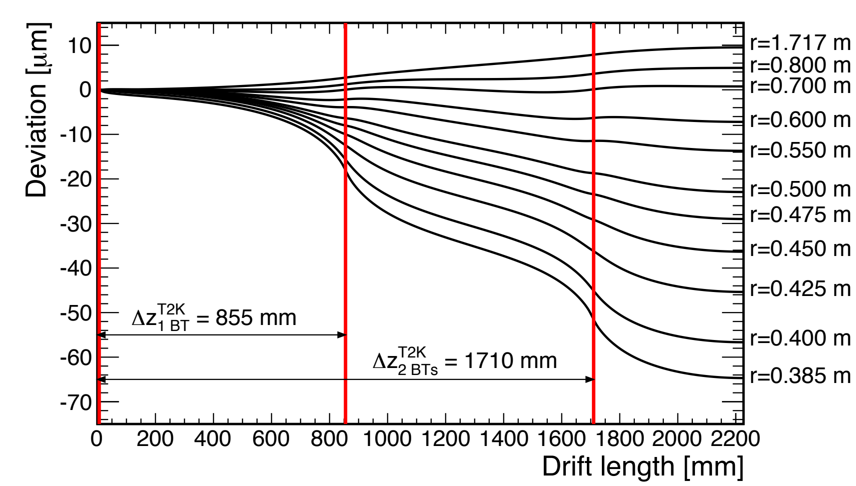
8-wheel model

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!

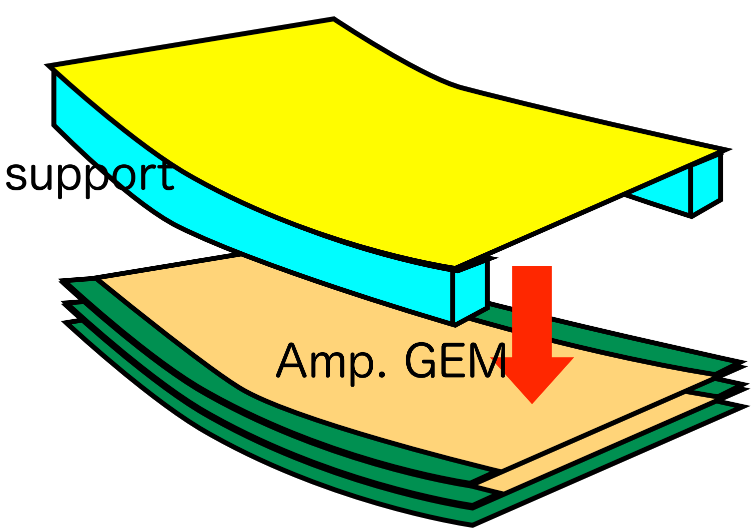
- **Positive ions drifting back into the gas volume**
  - Well known issue for wire chambers based TPCs (traditional MWPCs)
  - Even though the amount of back drift ions is much smaller for MPGD amplification, still be significant with a high track density like ILC background conditions (e.g. ILC beam 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

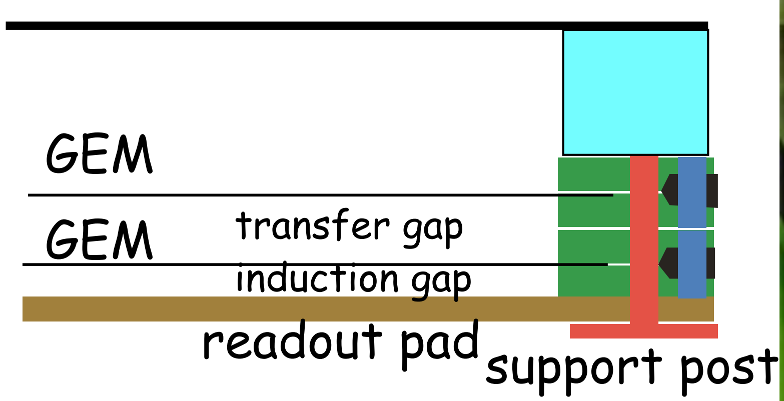


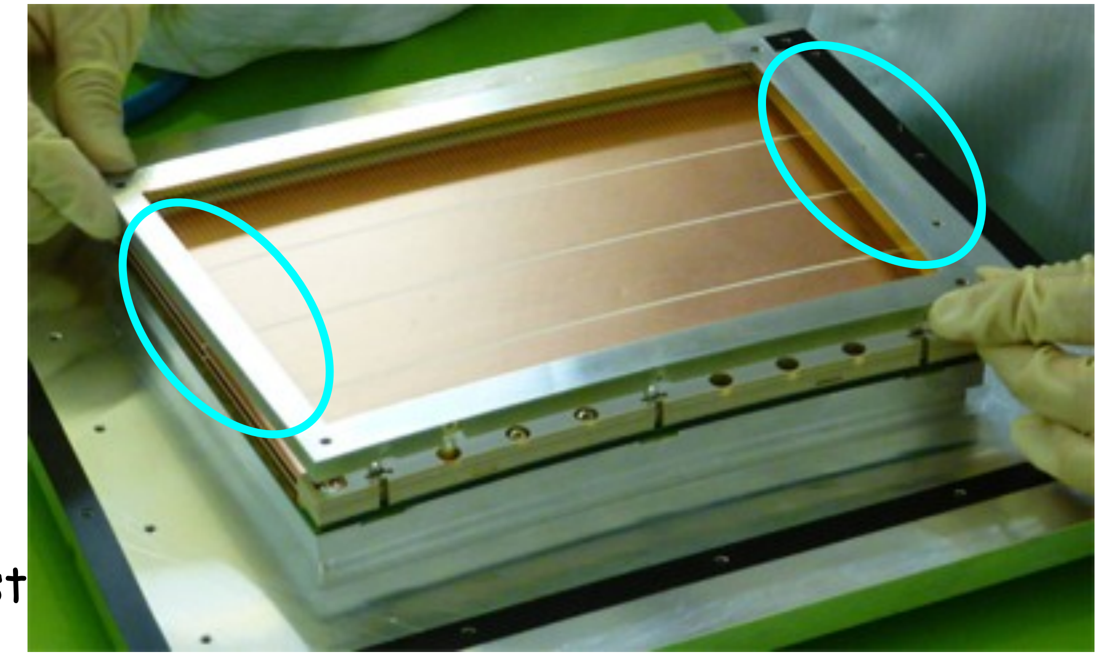


Conventional wire-grid as a gating device

- **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!!
    - to be tested with UV-laser tracks in the beginning of June by Saga-Hiroshima team
- **Its implementation above the amplification GEMs or Micromegas would not be elegant!**

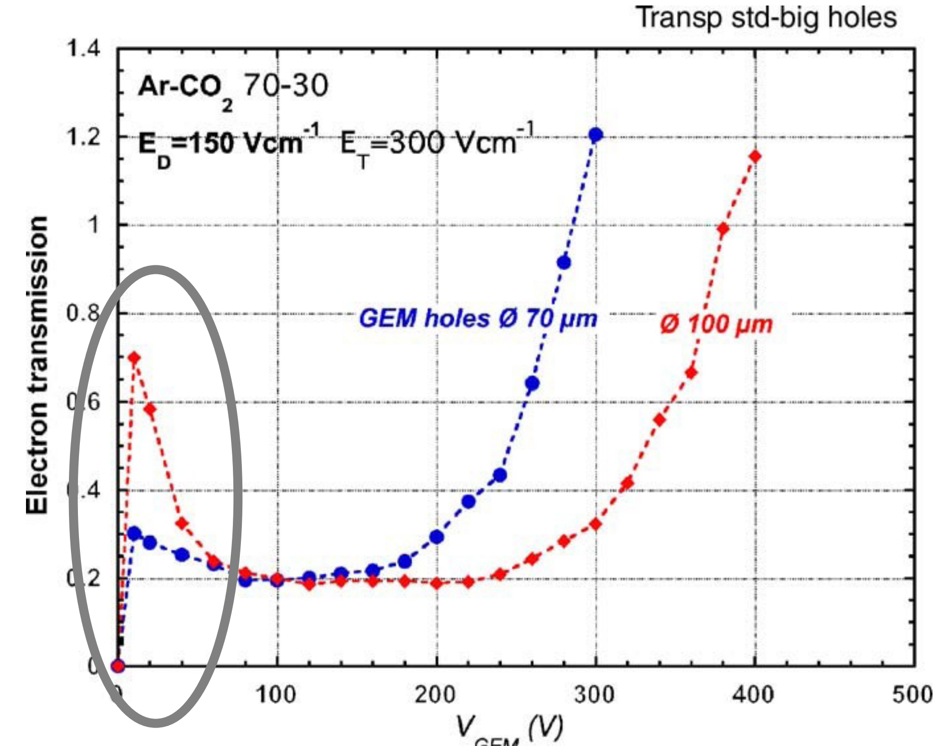


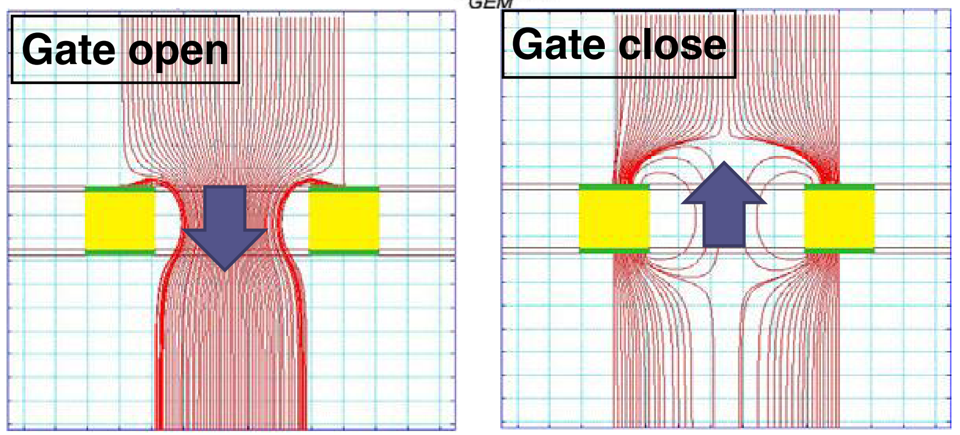




GEM as a gating device

- **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
    - 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!!

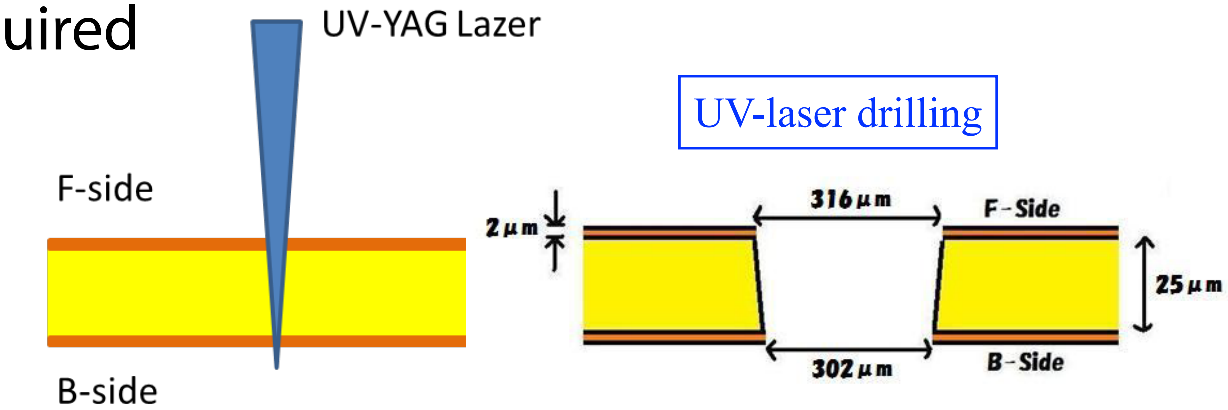




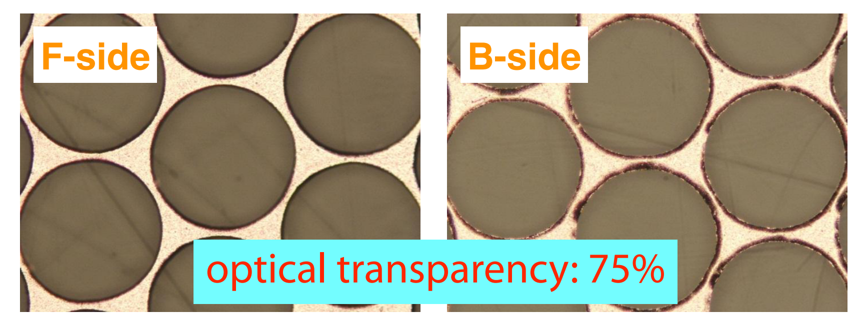
- **Requirement for Gate GEMs of ILD-TPC**
  - ILD-TPC: operated in a 3.5 T axial magnetic field, and in a gas with a high mean free time (τ) of drift electrons between collisions with gas molecules
  - Motion of electrons is strongly restricted to the direction of the magnetic field => **high optical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

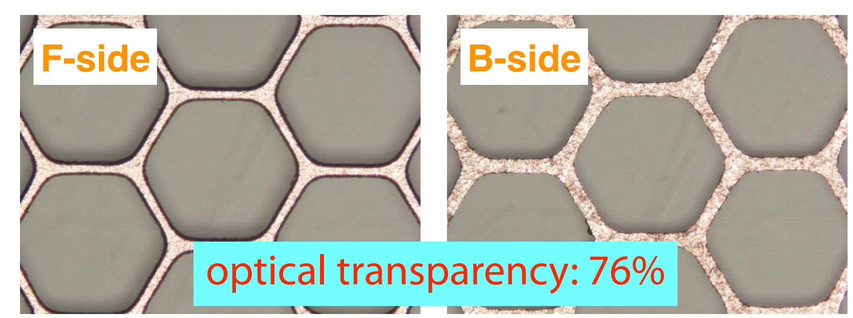
- **High optical transparency = Minimize rim width of GEM holes**
  - To achieve high electron transmission: 30 µm rim width & 330 µm pitch in honeycomb structure (= 85~90% optical transparency) required



- **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



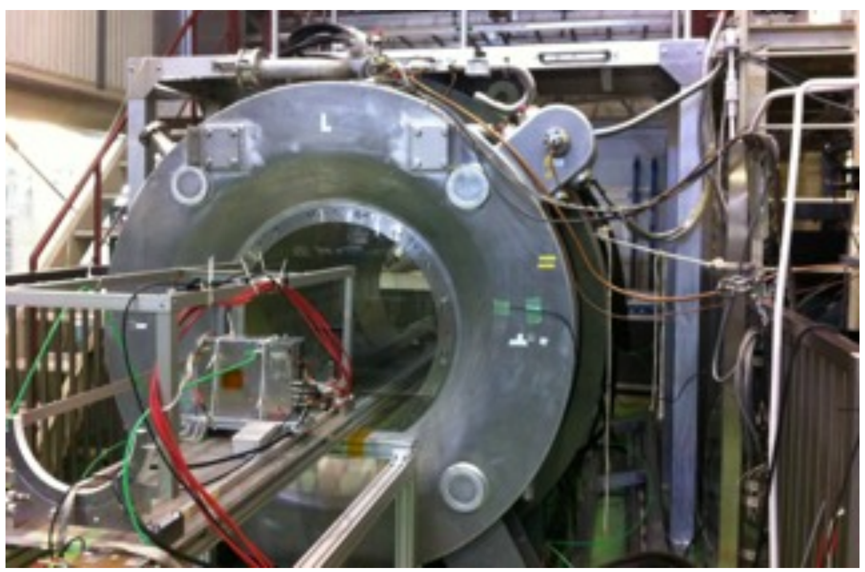
These 2 samples: tested with a test chamber installed in a 1 Tesla solenoid magnet at KEK cryo center

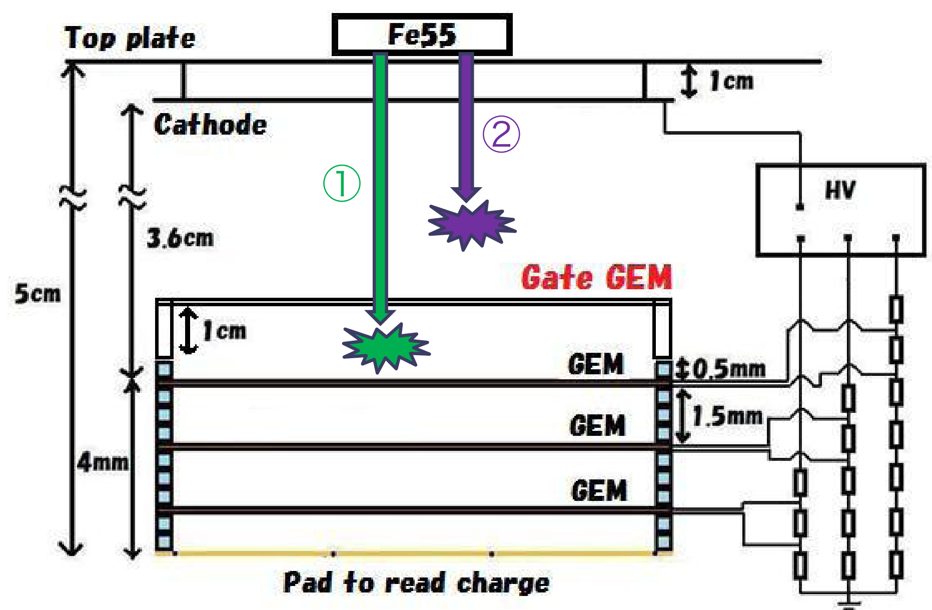
- Fujikura Gate-GEM Type 4 sample (Ni-less process & 20(F) µm rim width) and RAYTECH samples (by using precise chemical etching technique) will be tested from 7 July at KEK cryo center

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



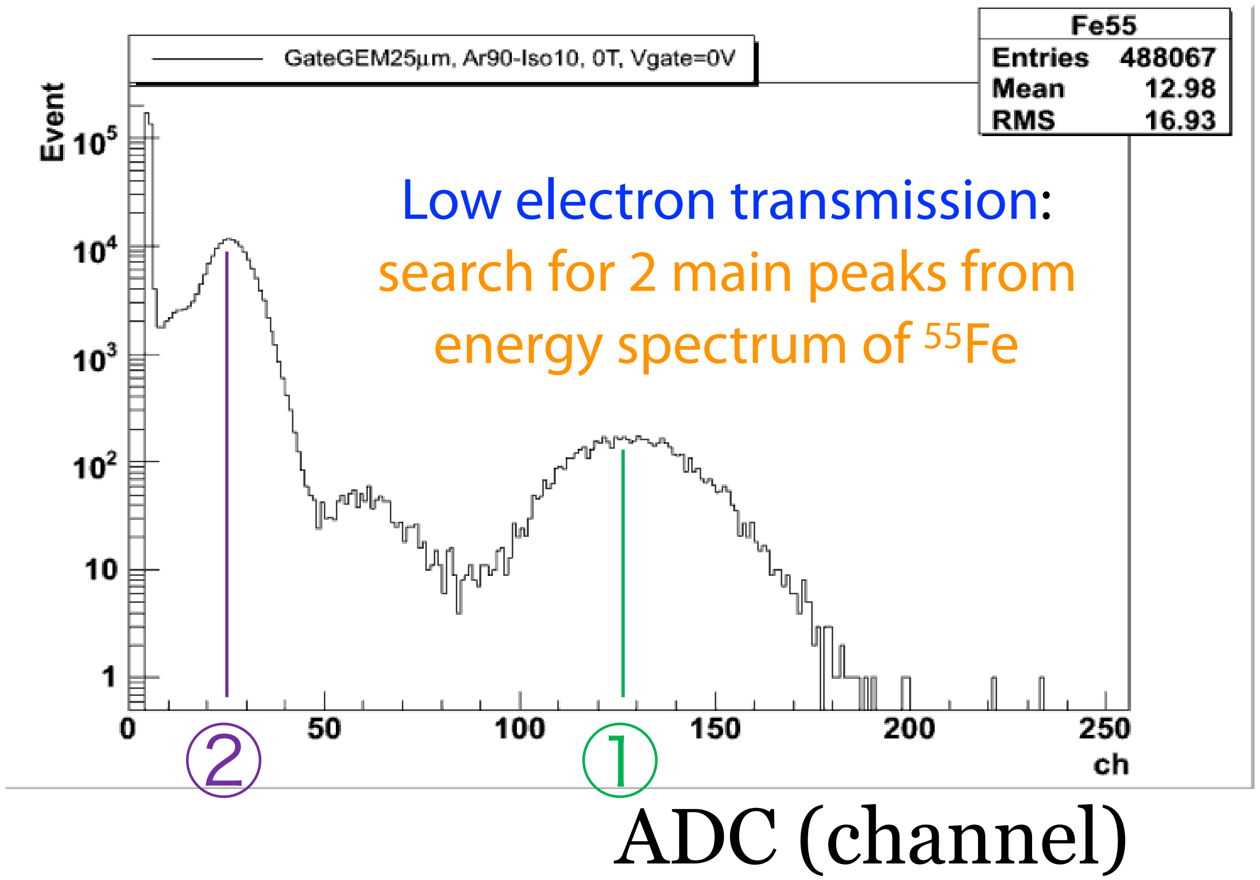


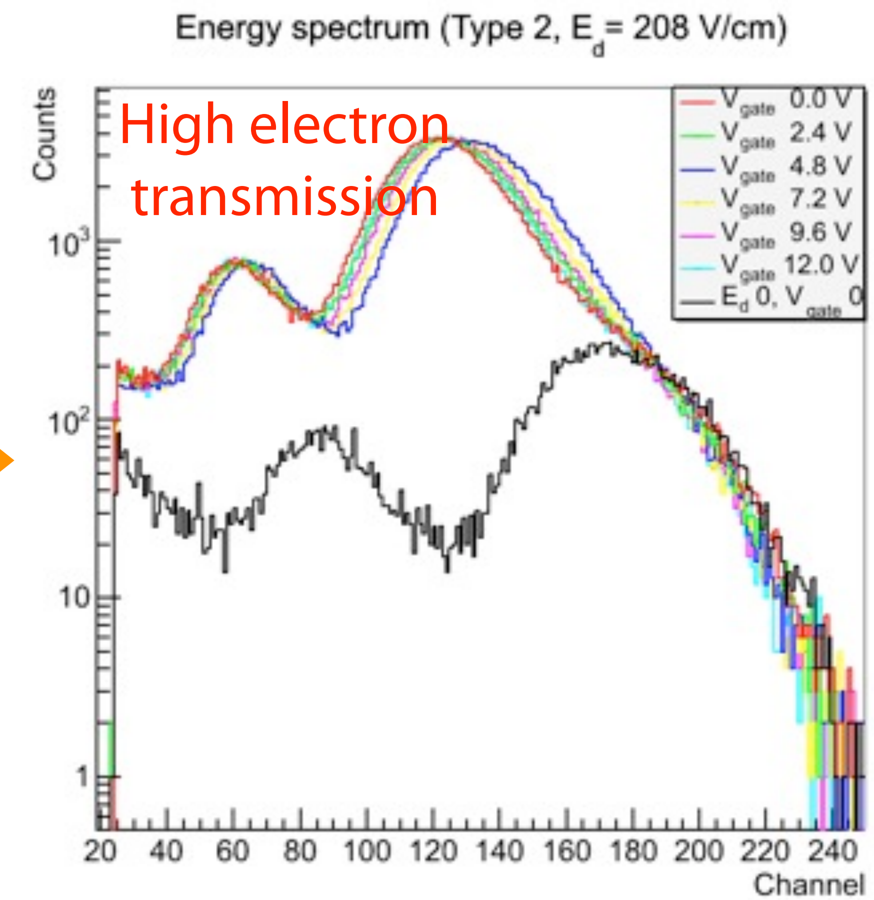
using a Fujikura 50 μm GEM readout (triple GEM stack) and one of Fujikura Gate-GEM samples placed 10 mm above

  - **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)

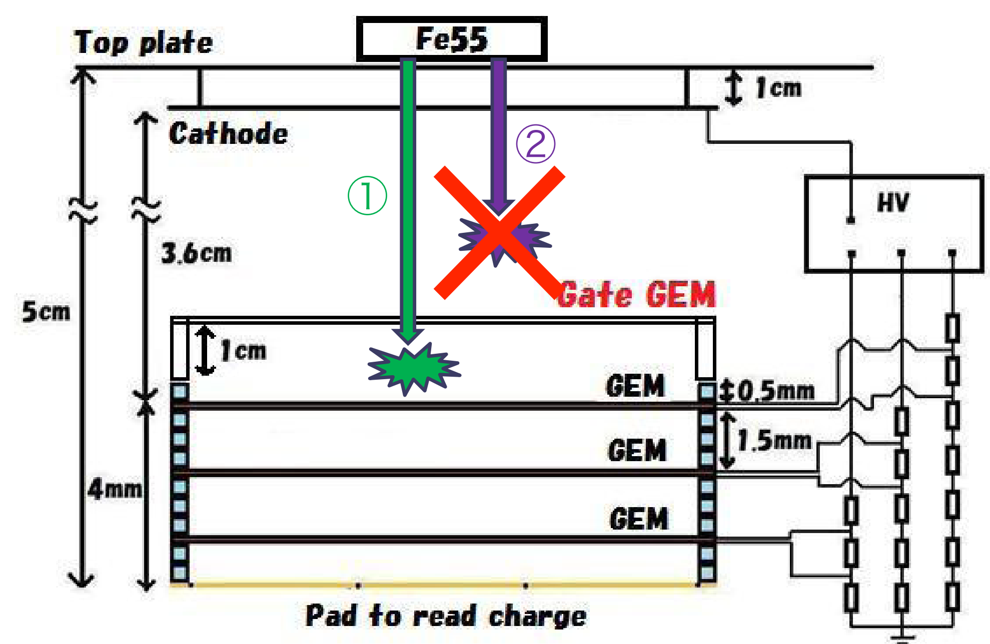
Electron transmission measurement (cont'd)

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

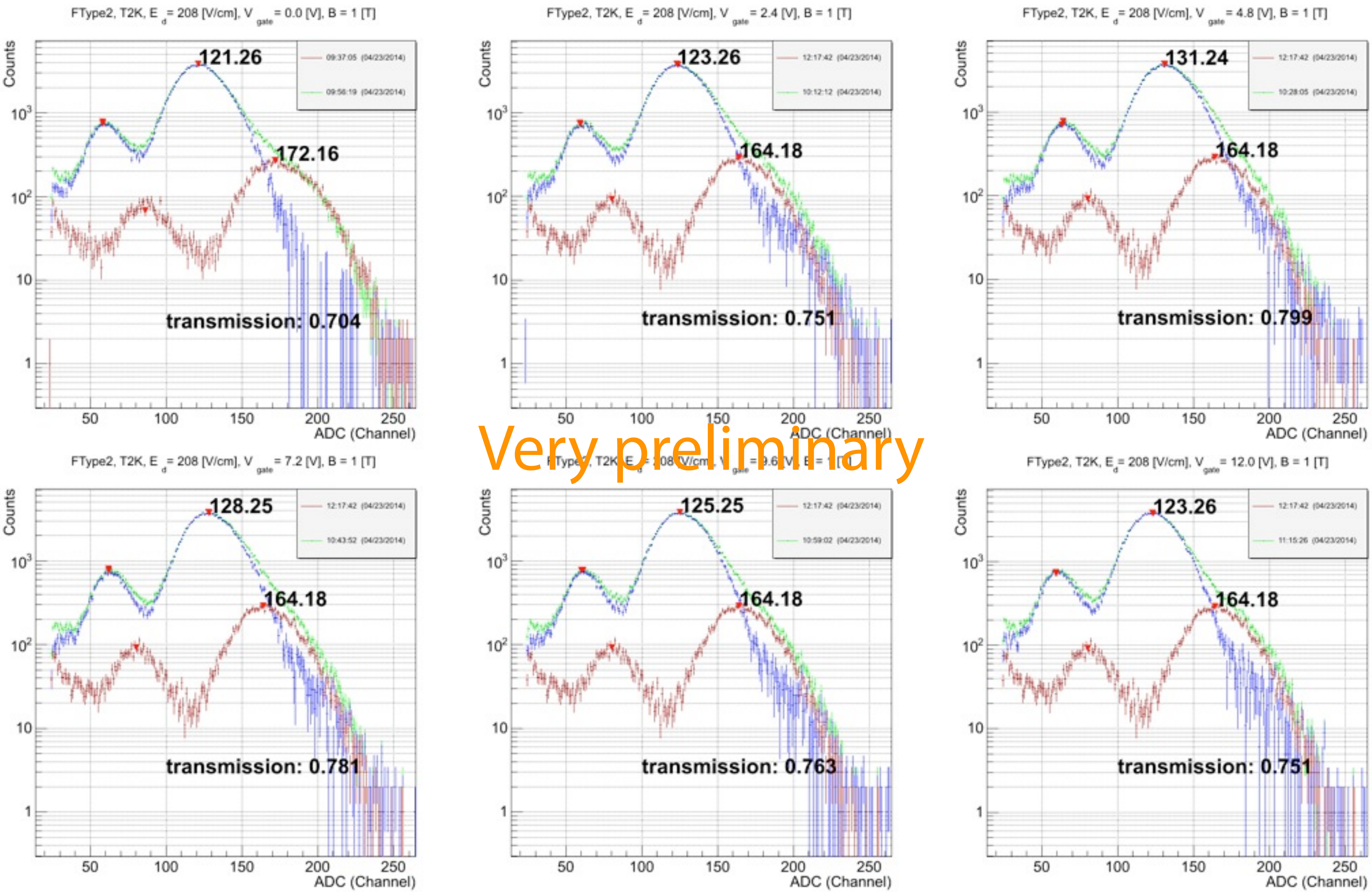




- Impossible to determine the two signals in the same measurement...
- Need to define 100% electron transmission from E_drift = 0 run
- Analysis: pick up proper E_drift = 0 run and apply corrections (e.g. correlation between gas gain and T/p)



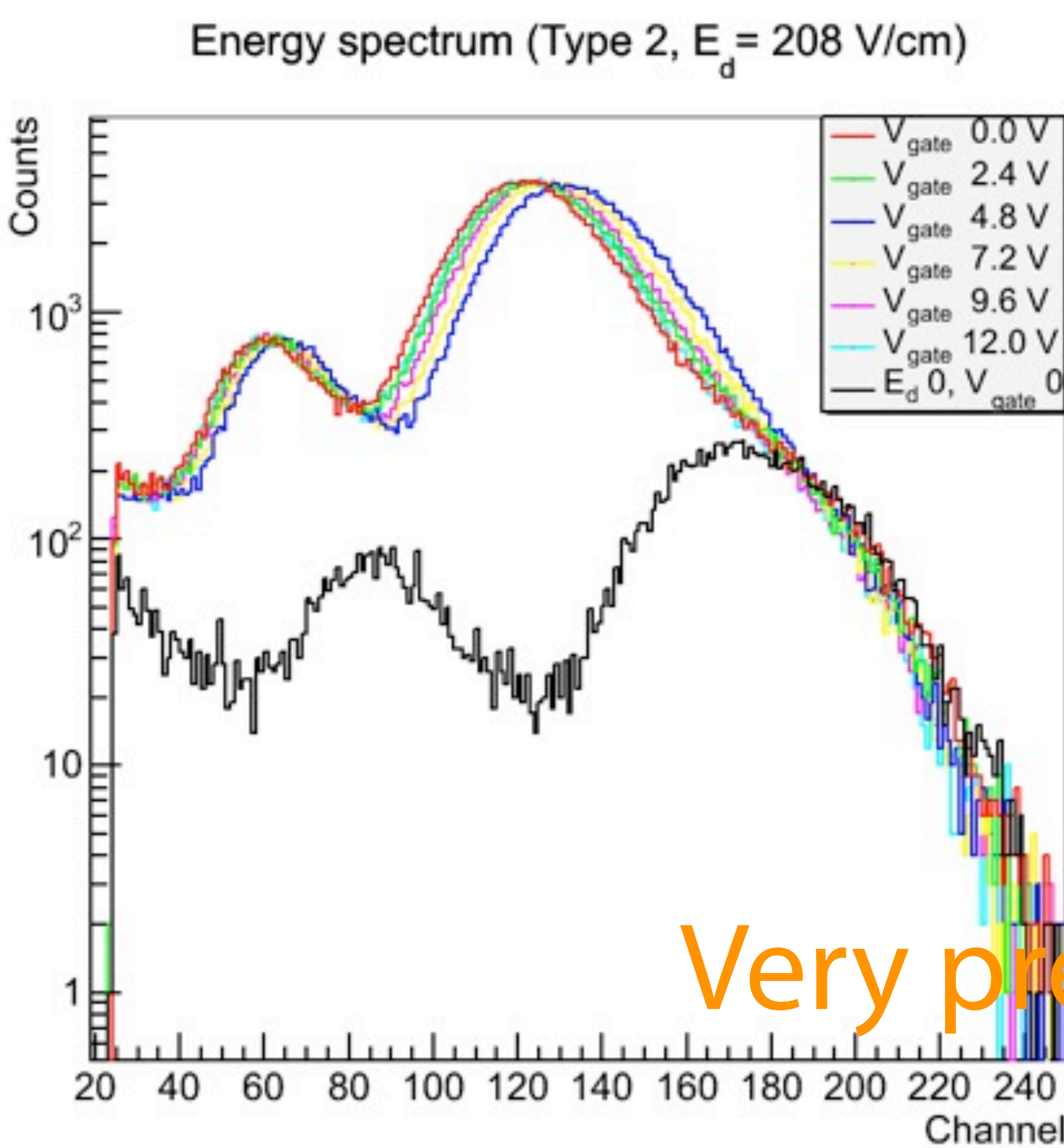
Type 2, T2K gas, B = 1, Ed = 208 V/cm

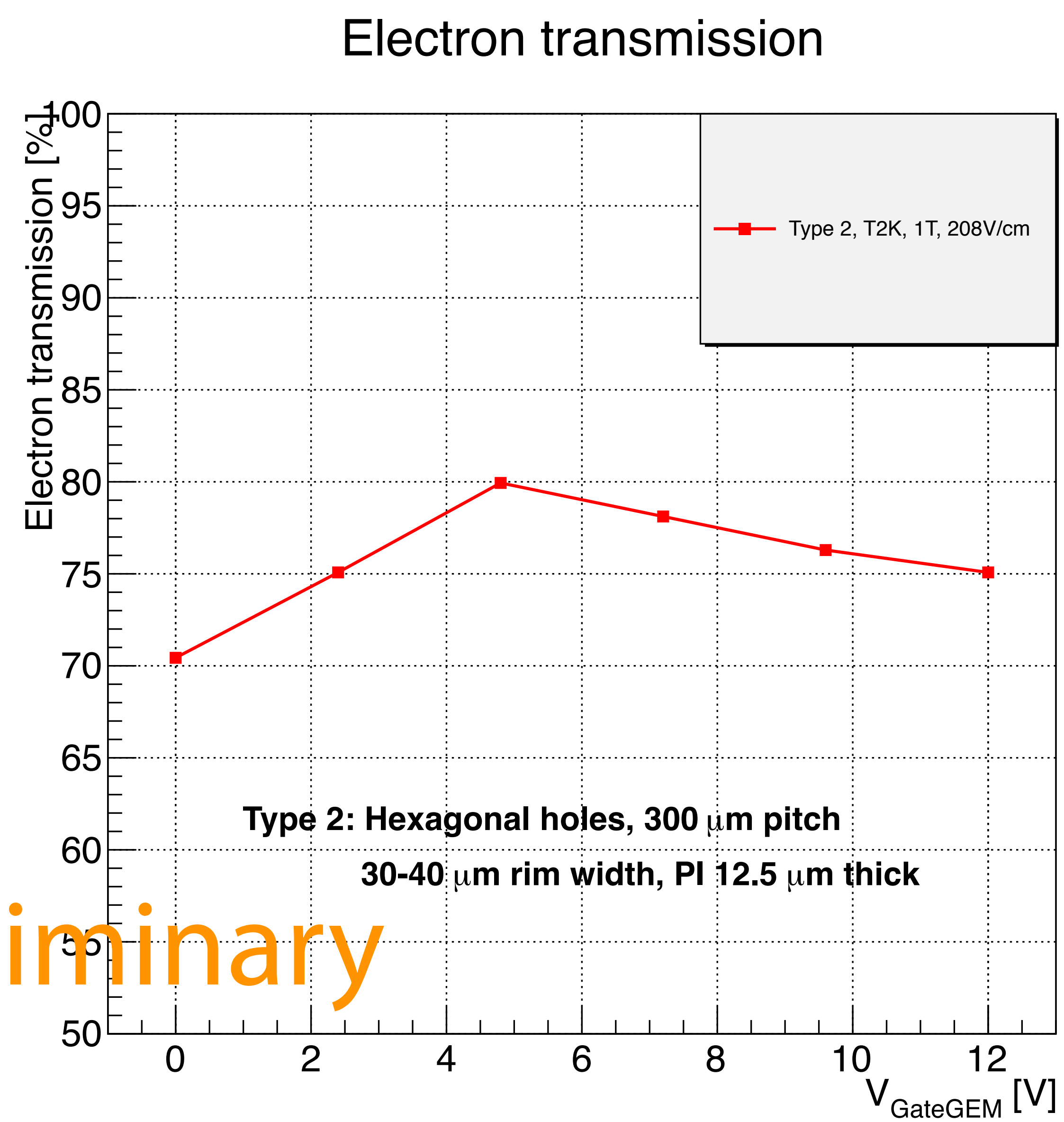


Very preliminary

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

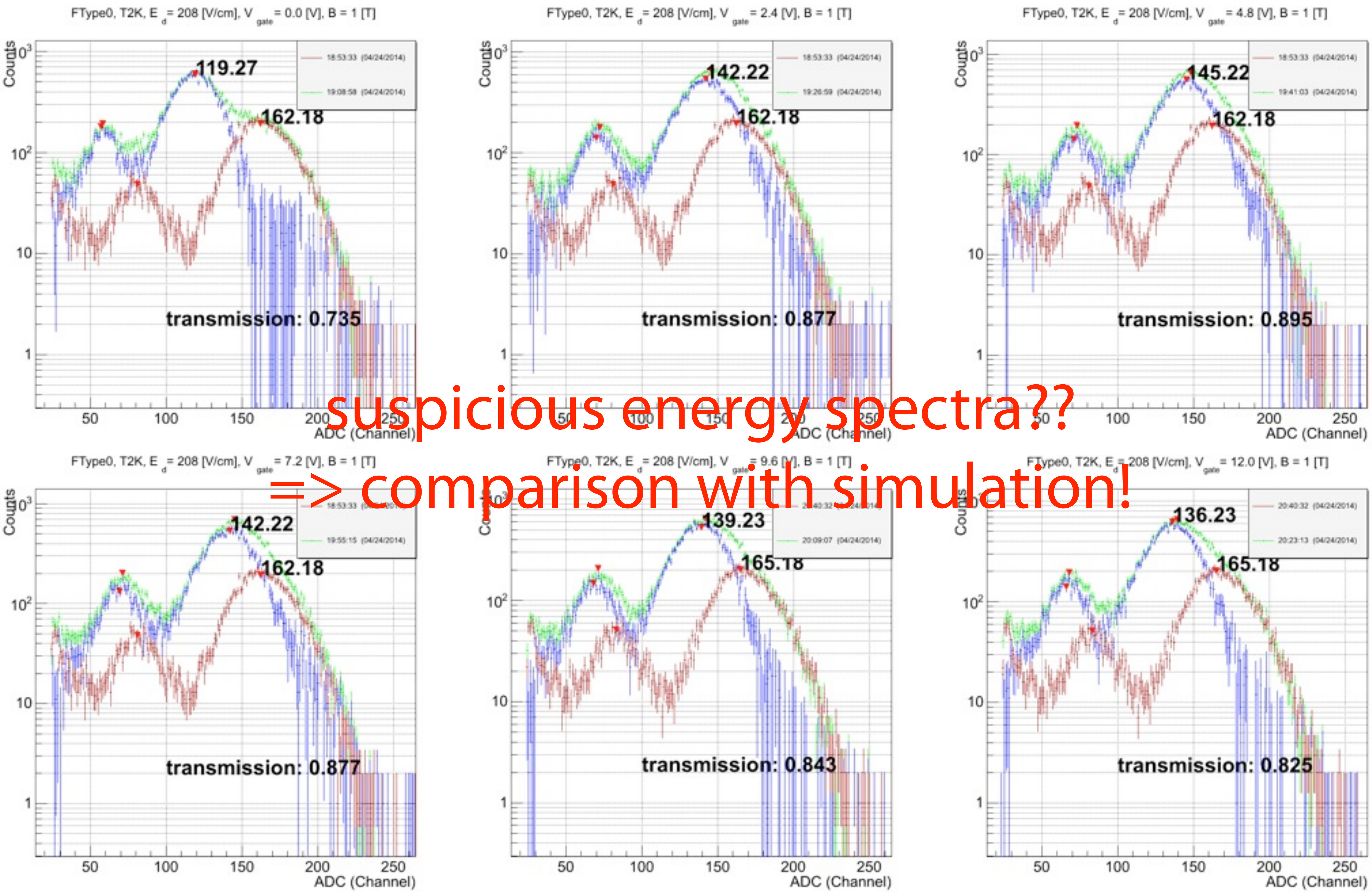
Measured energy spectrum, and electron transmission as a function of the voltage applied to gate GEM





- 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

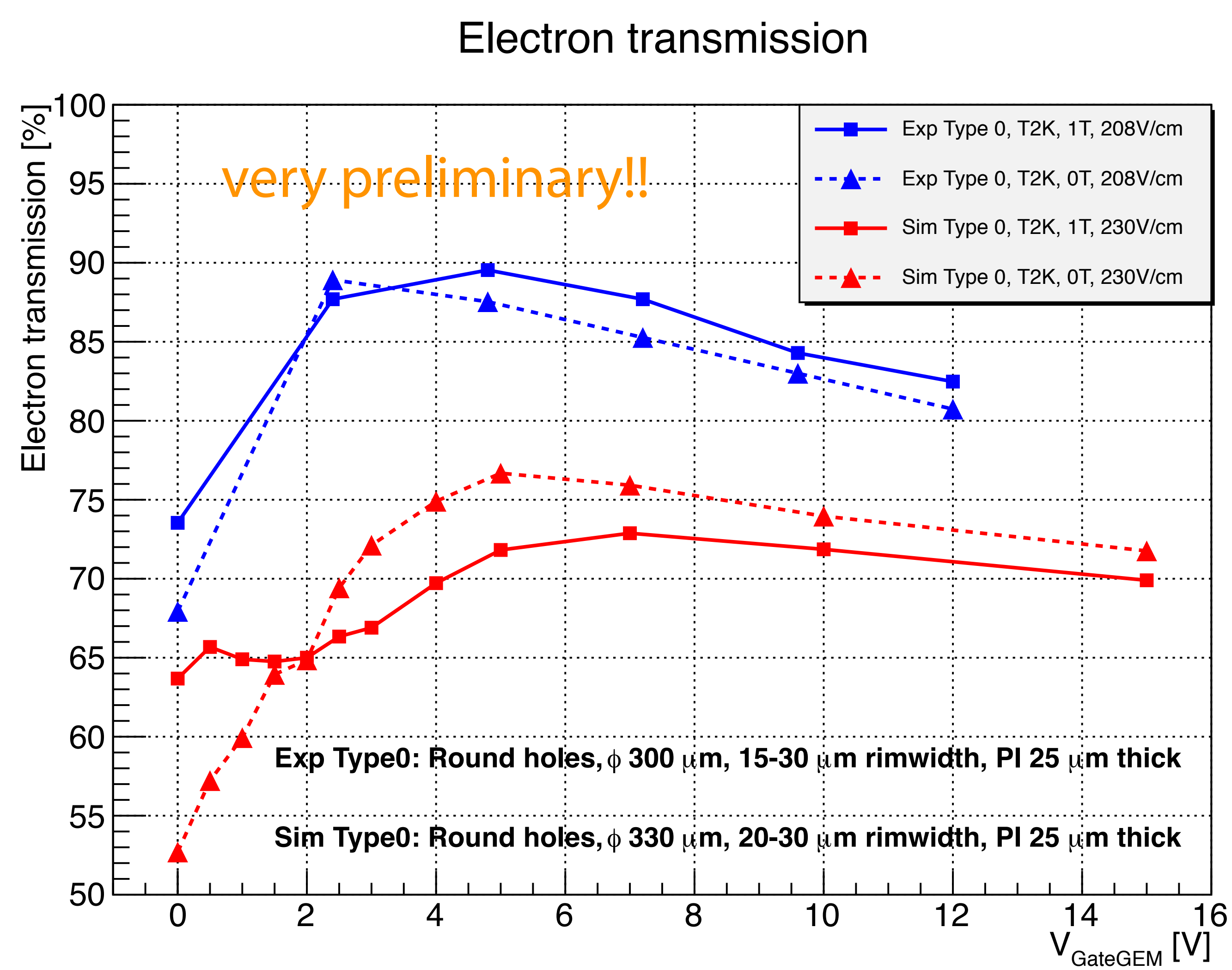


suspicious energy spectra??

=> 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)



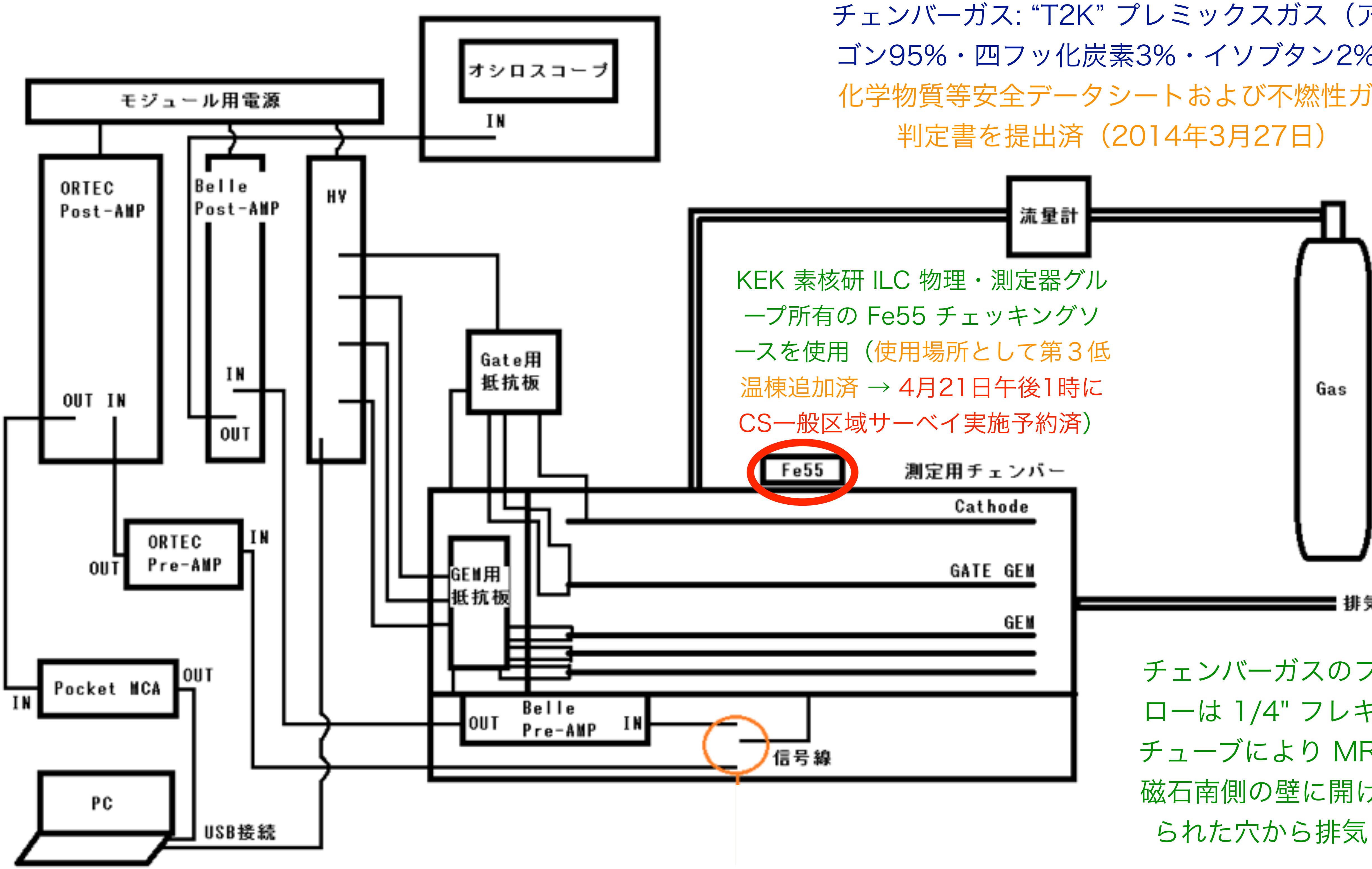
Summary and prospects

- 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

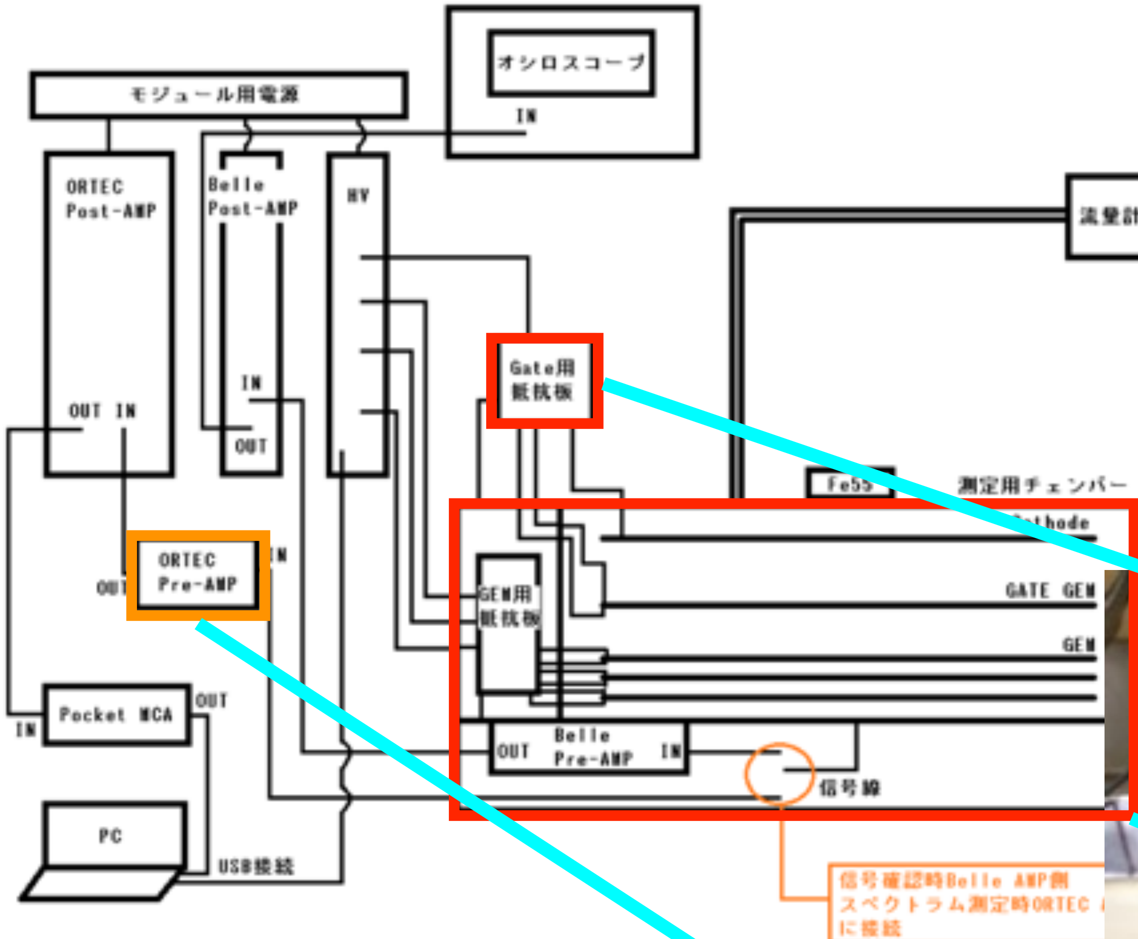
チェンバーガス: “T2K” プレミックスガス（アルゴン95%・四フッ化炭素3%・イソブタン2%）
化学物質等安全データシートおよび不燃性ガス判定書を提出済（2014年3月27日）

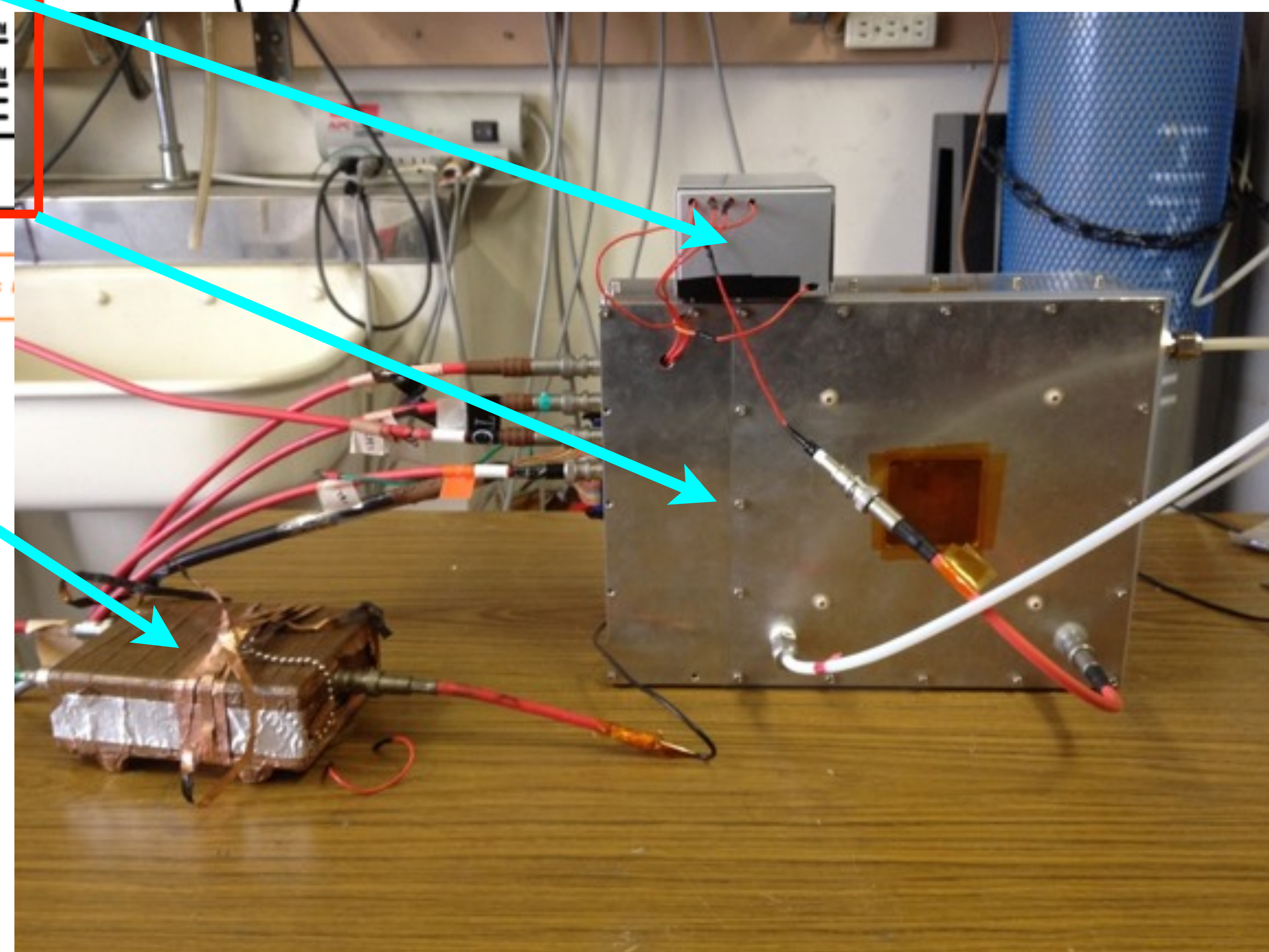


KEK 素核研 ILC 物理・測定器グループ所有の Fe55 チェッキングソースを使用（使用場所として第３低温棟追加済 → 4月21日午後1時にCS一般区域サーベイ実施予約済）

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





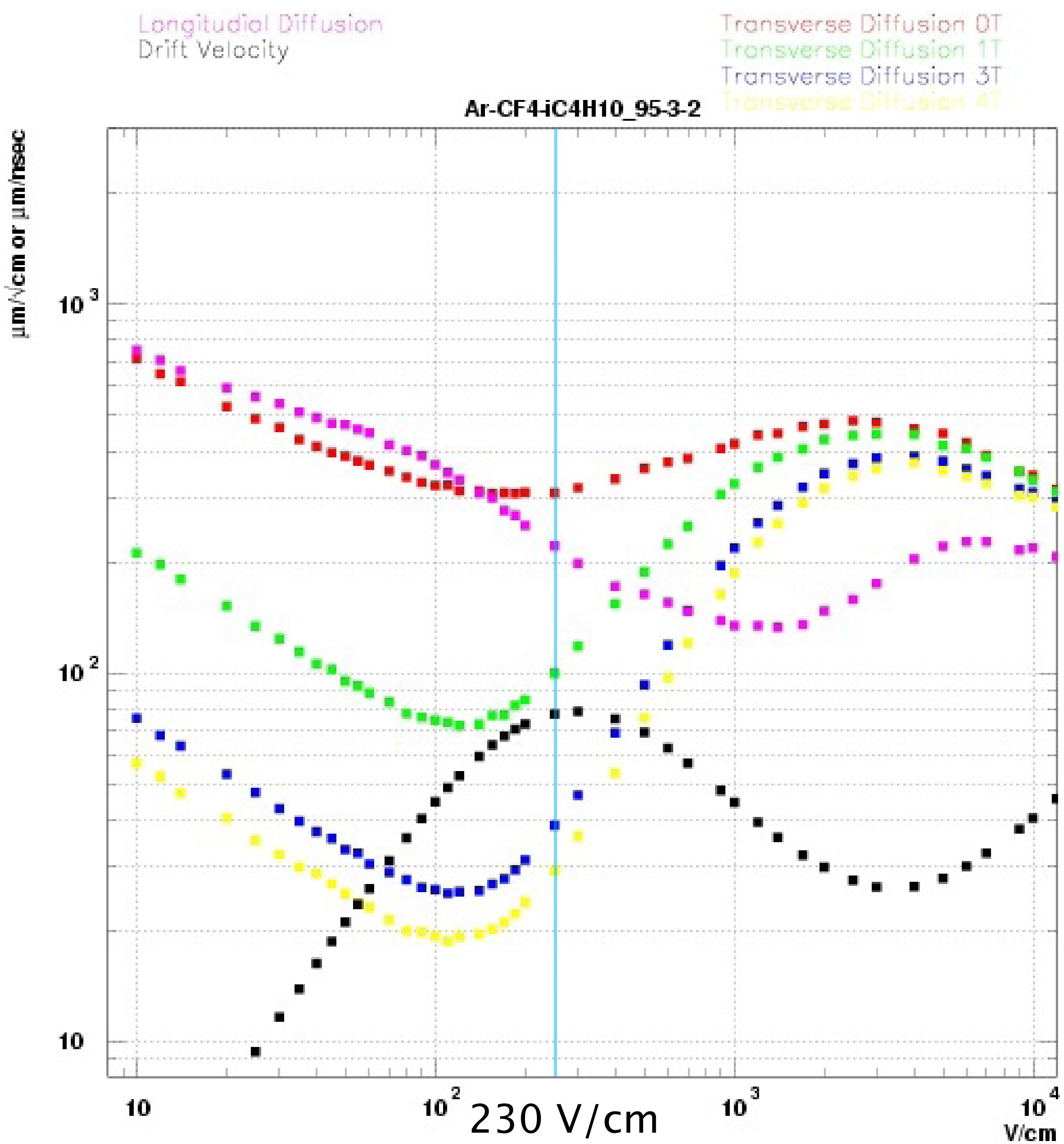
アルミニウムプレート上に
写真のように立てた状態
で据え付け

Performance and design parameters

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

Parameter			
Geometrical parameters	r_{in} 329 mm	r_{out} 1808 mm	z $\pm$ 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 $r\phi$	$\simeq 60\ \mu m$ 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)		

Drift velocity and diffusion (T2K gas)

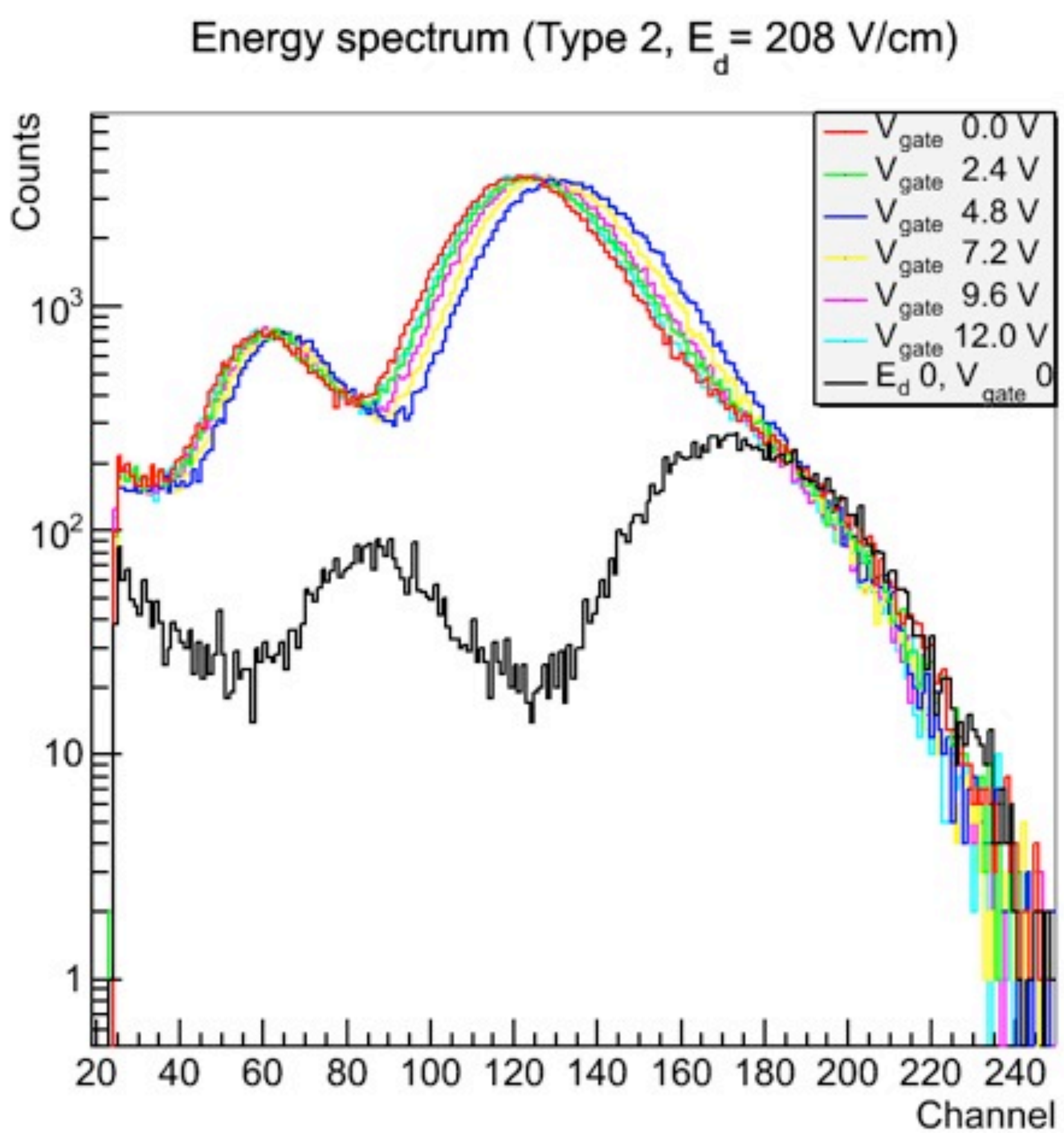


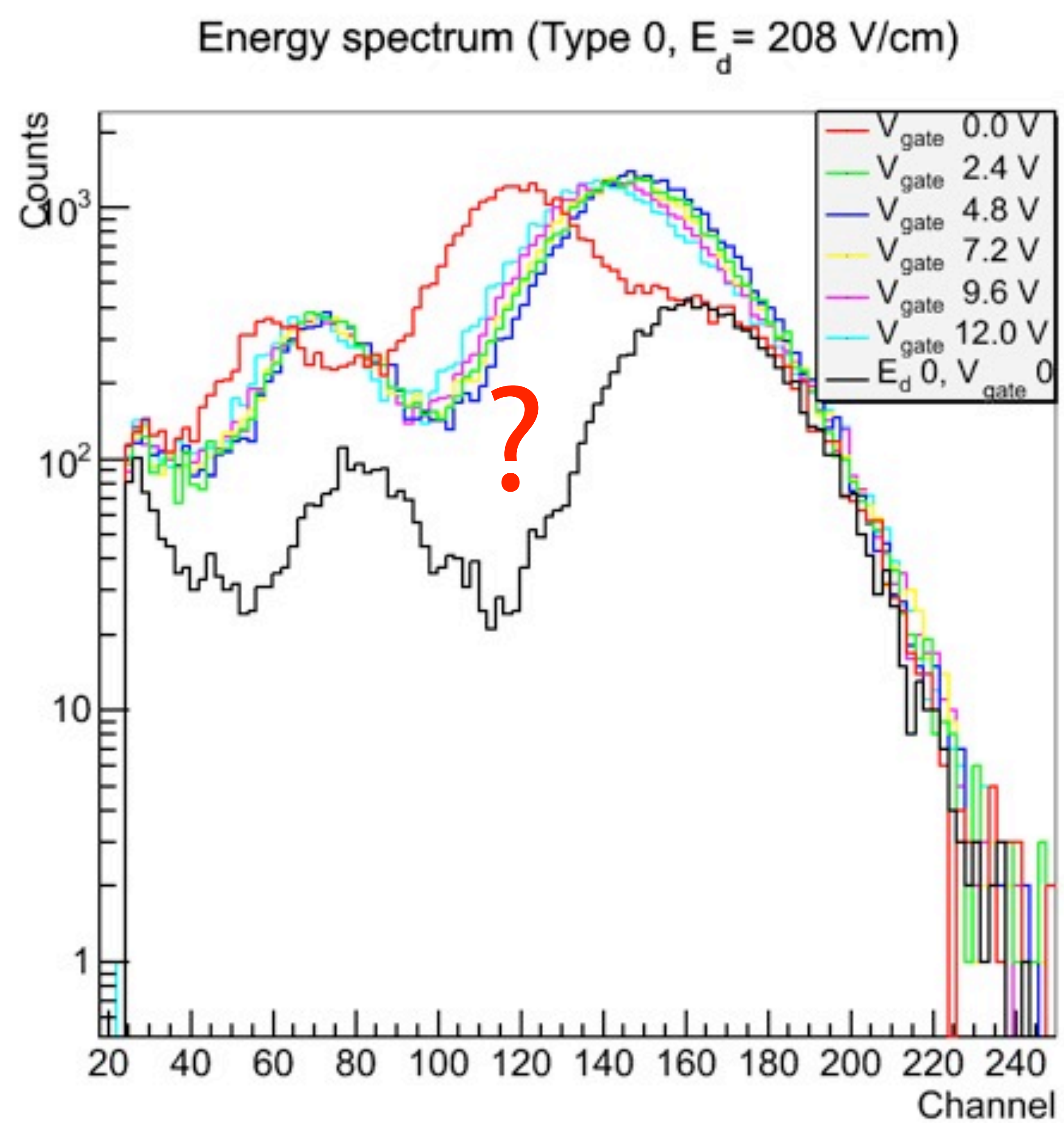
If we require the azimuthal resolution of 100 µm at z = 200 cm the diffusion constant (D), which is essentially the only free (controllable) parameter depending on the choice of gas mixture, needs to be smaller than 30 µm/√cm.

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)!

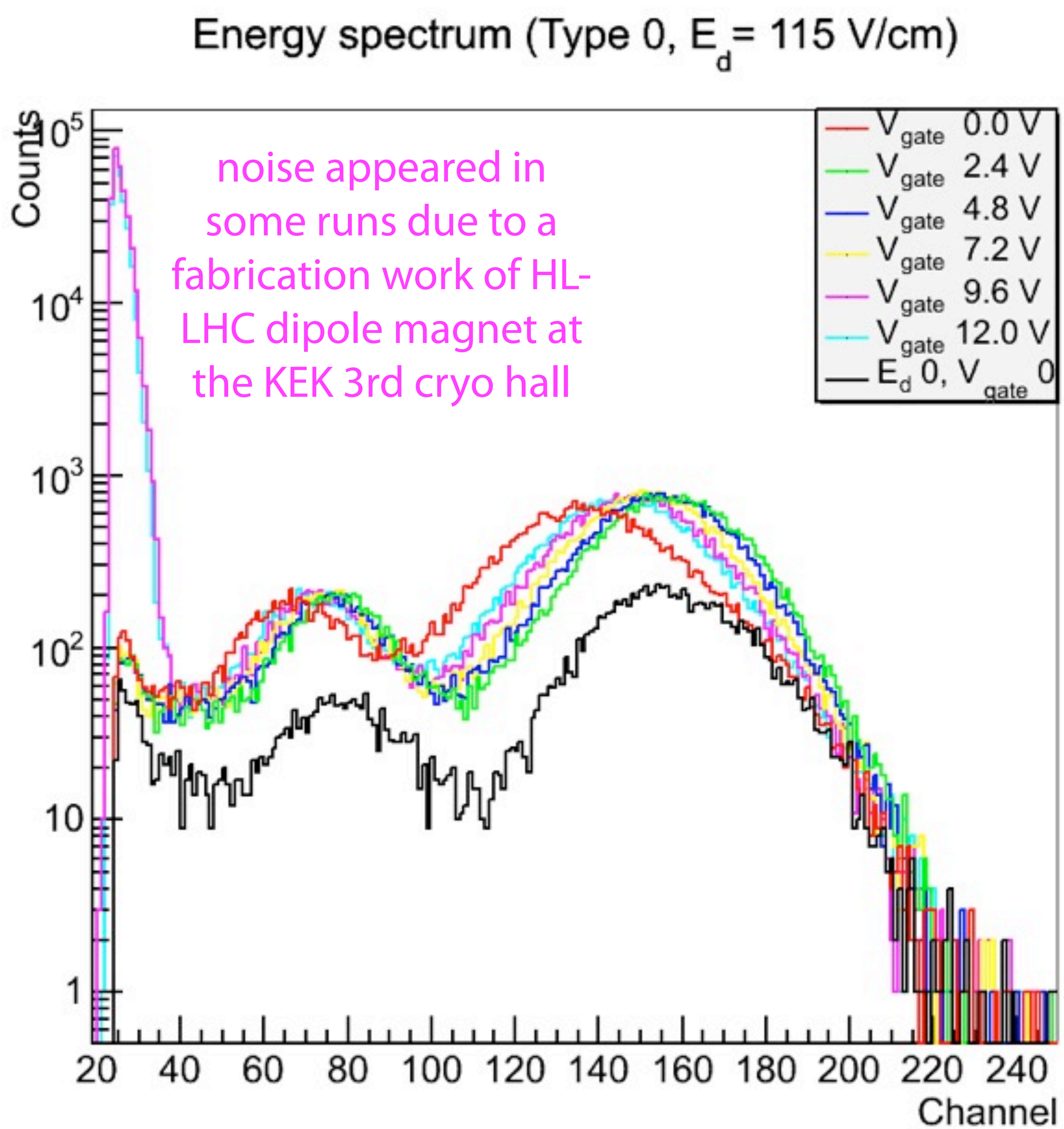
- The diffusion constant D is related to the diffusion coefficient (D^*) through $D2 = 2D^*/W$, where W is the electron drift velocity.
- The electron drift velocity is given by $W = e \cdot E/m \cdot \tau$ with e (m) being the electron charge (mass). A large value of τ, therefore, means a fast gas.

Raw energy spectrum

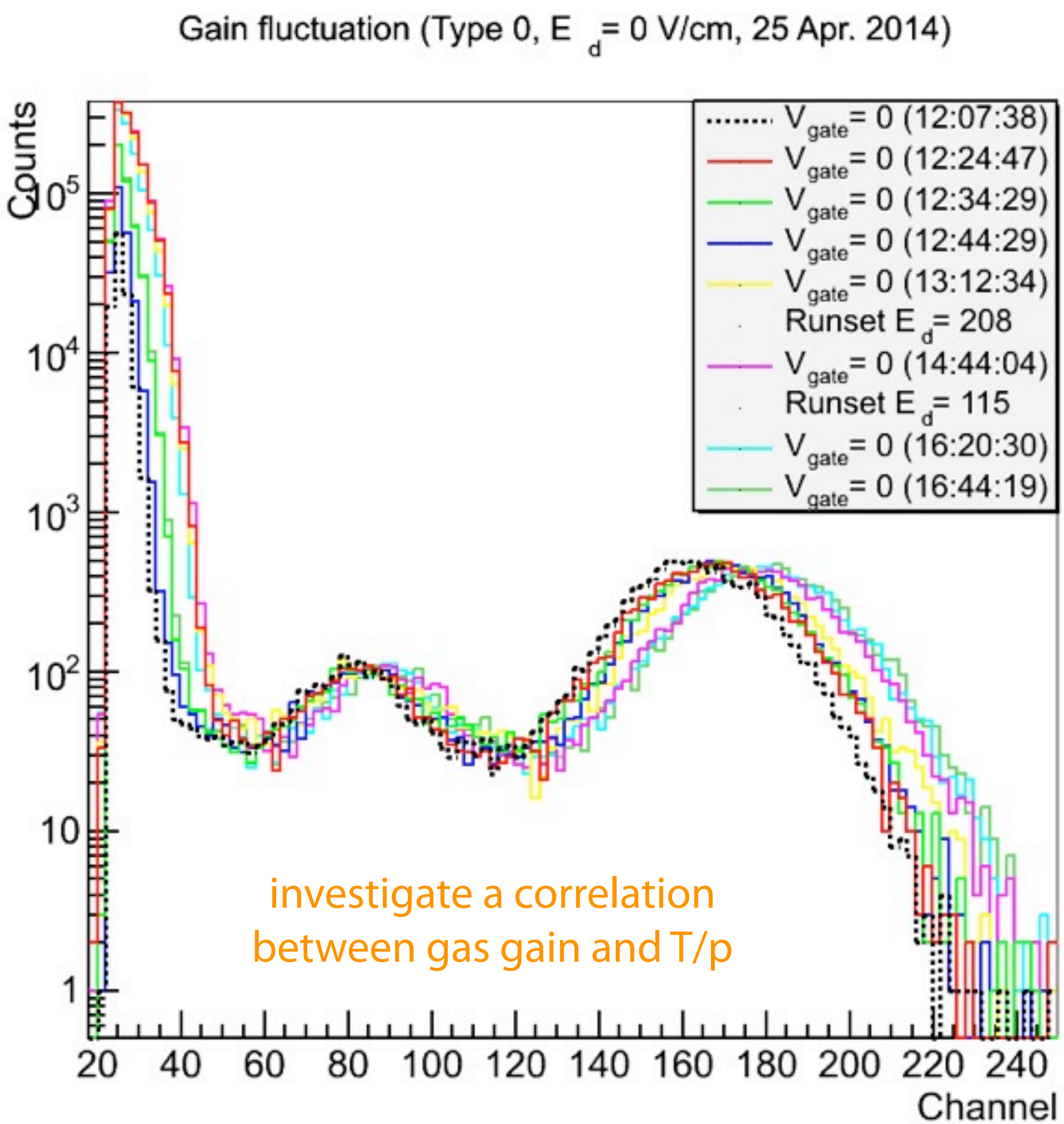




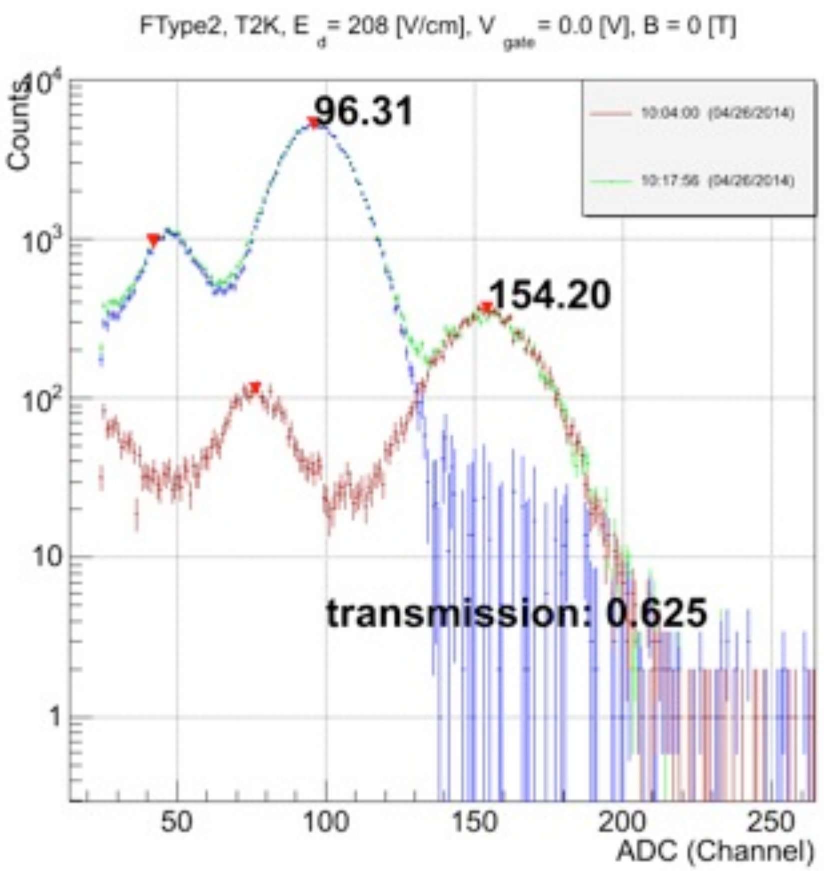
Raw energy spectrum w/ noise

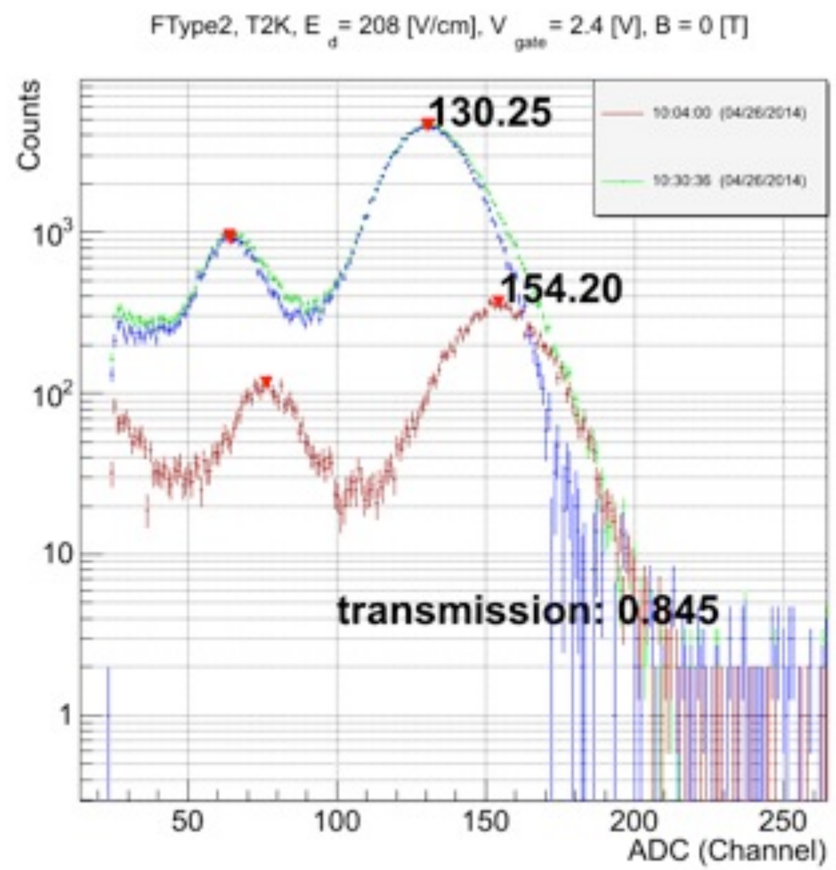


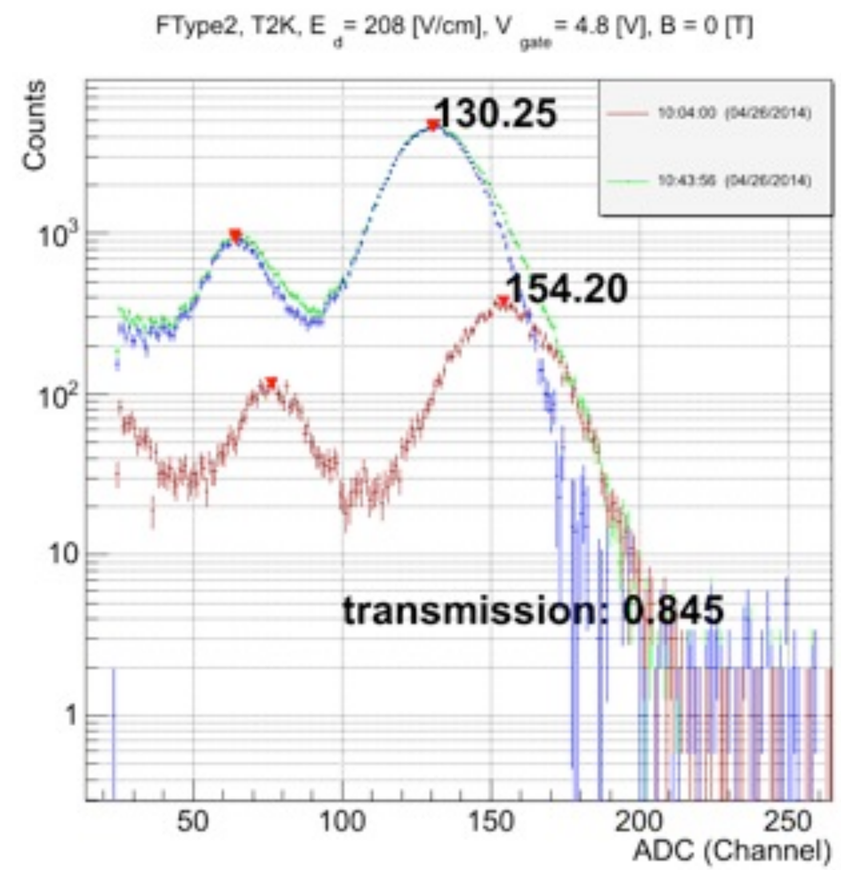
Gain stability (E_drift = 0 runs in a day)

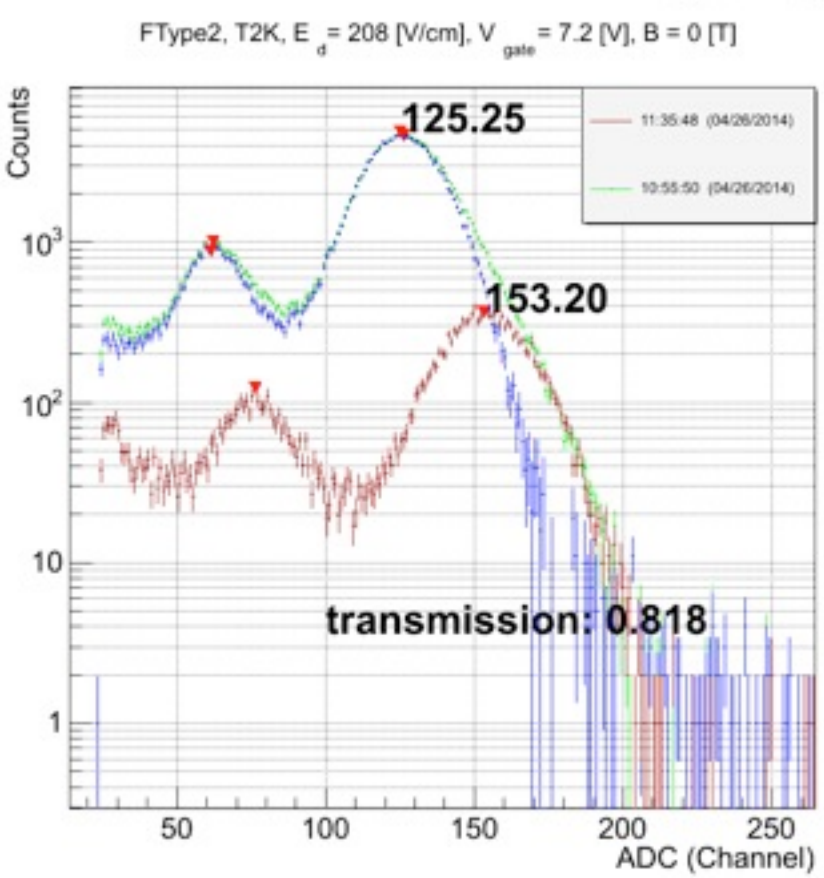


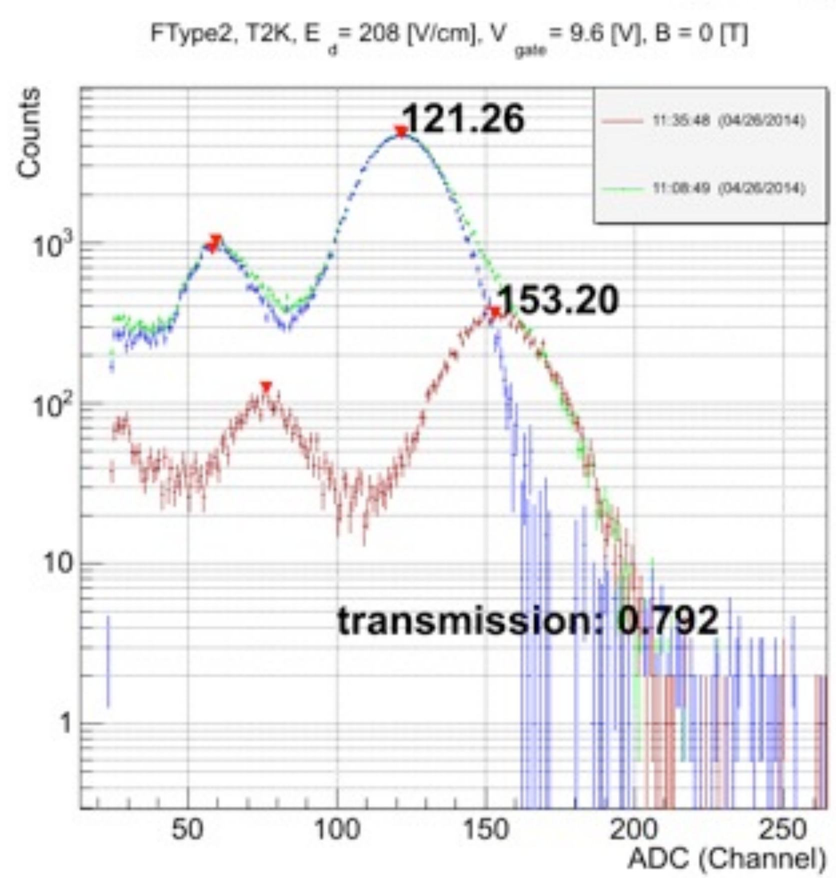
Type 2, T2K gas, B = 0, Ed = 208 V/cm

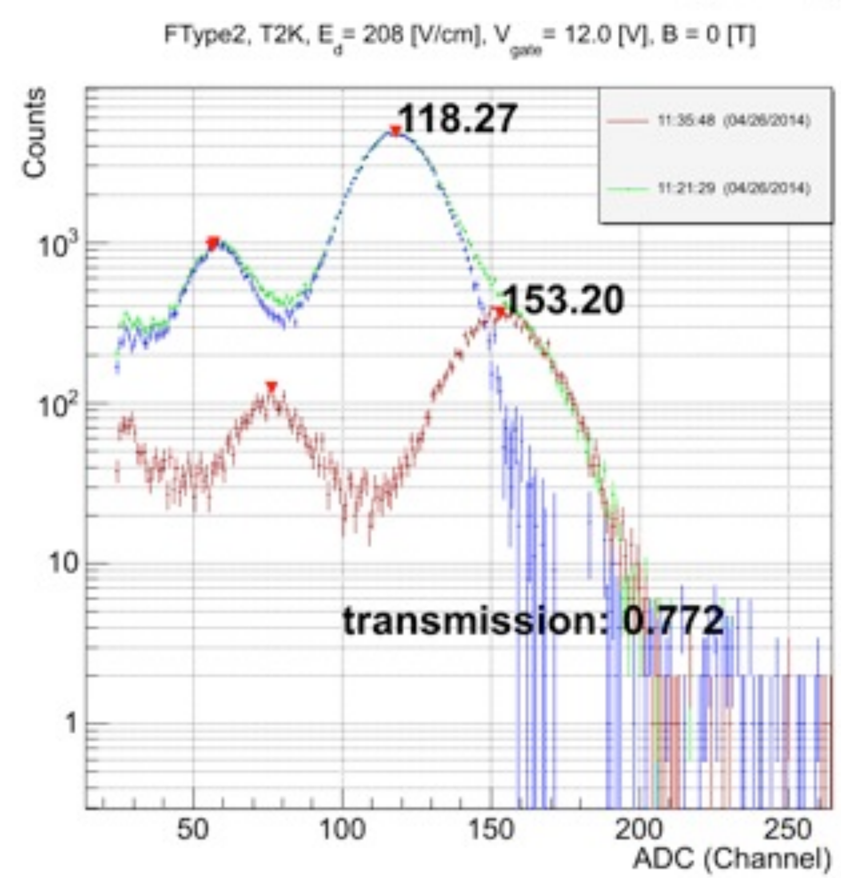




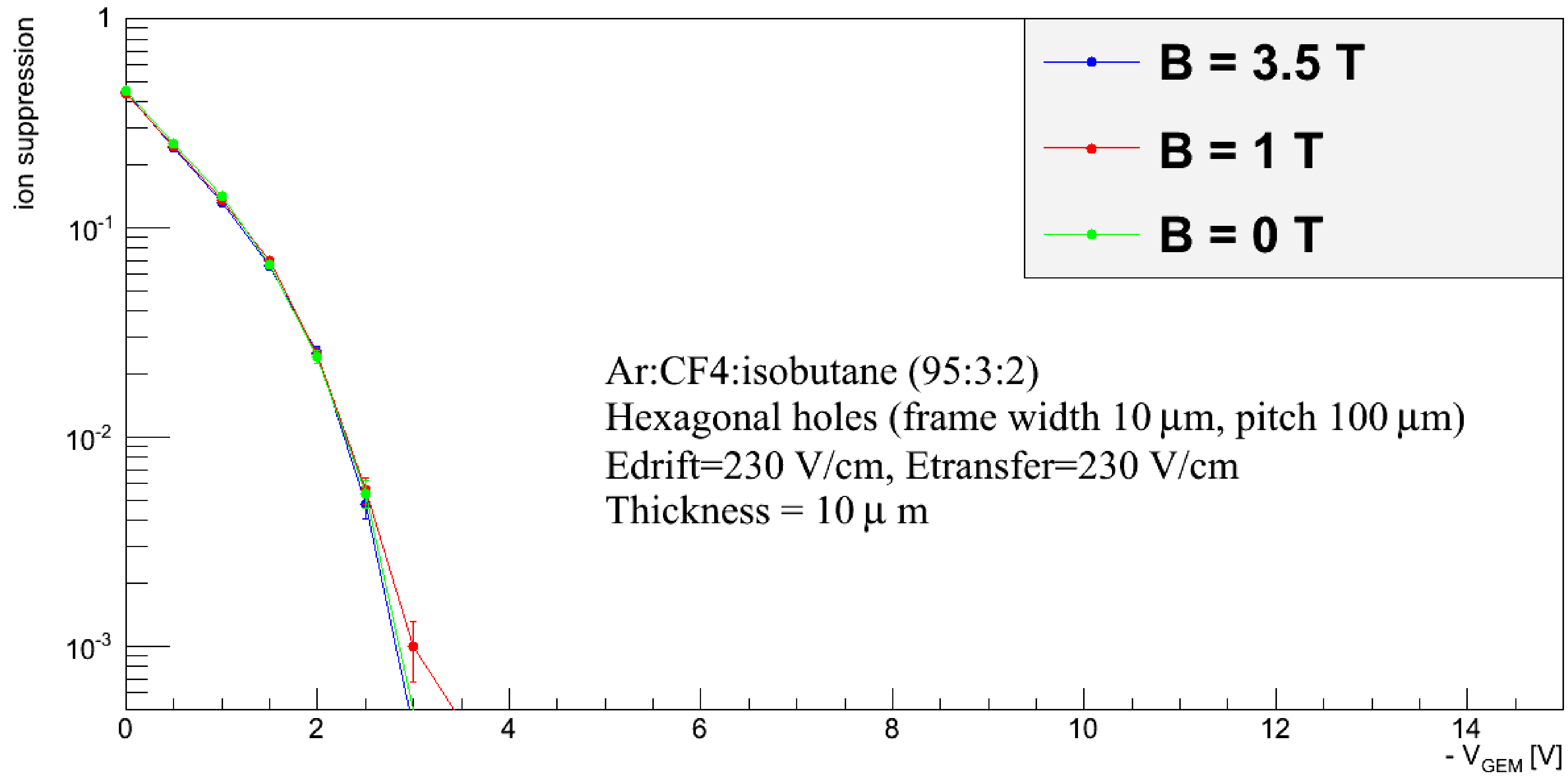








Closing the gate



As expected, the magnetic field has little influence on the ions

A GEM voltage above **3V** already gives enough ion suppression.