Simulation Study of GEM Gating for LC TPC

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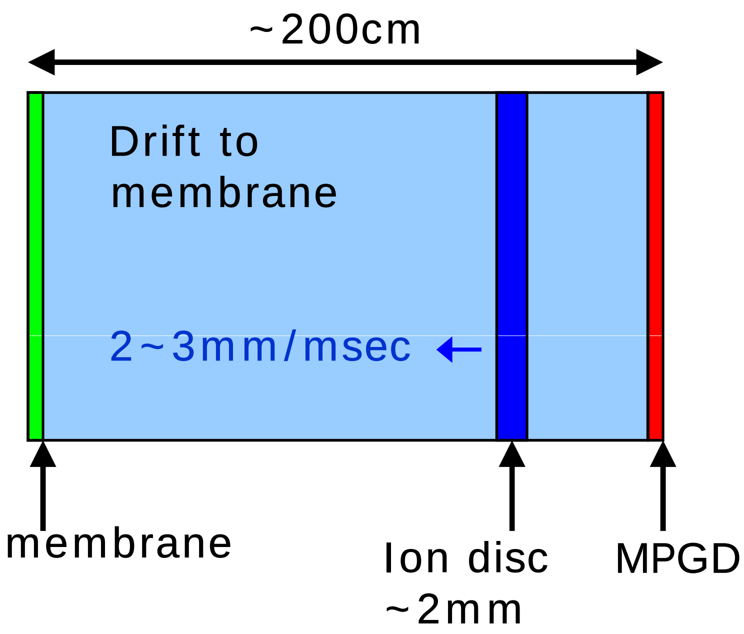
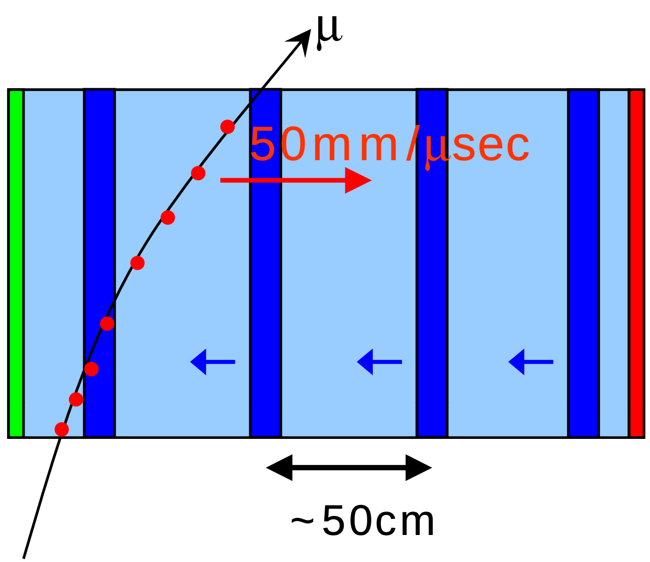
2007 Oct 24

Why do we need Gate?

- Ions are generated at MPGD by gas multiplications.
  - Gain ~ several x 10^3
  - Self ion suppression of MPGD $O(10^{-2})\sim O(10^{-3})$
- One bunch train (1msec) produces 2~3mm thick ion-dense disc.
  - cf. mobility of isoC_4H_{10} ion in Ar is 1.56 x 10^{-3} cm^2/Vmsec
  - Charge density of the disc assuming 1% occupancy is O(0.1)~O(1) fC/mm^3
- Ion discs drift only ~50cm and never reach central membrane between two trains (200msec)
- Primary electrons produced by charged tracks go through a few ion discs and the position information is deteriorated.

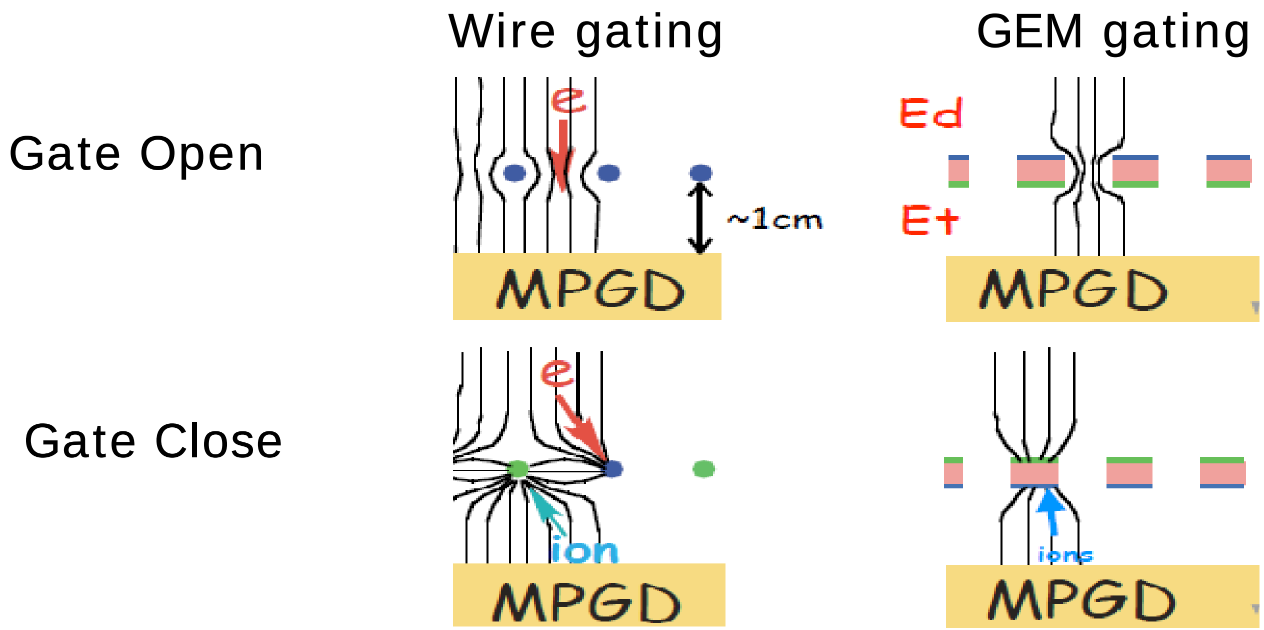
- Ions must be shut off by gate.
  - Ion feedback probability should be less than a few x 10^{-4}





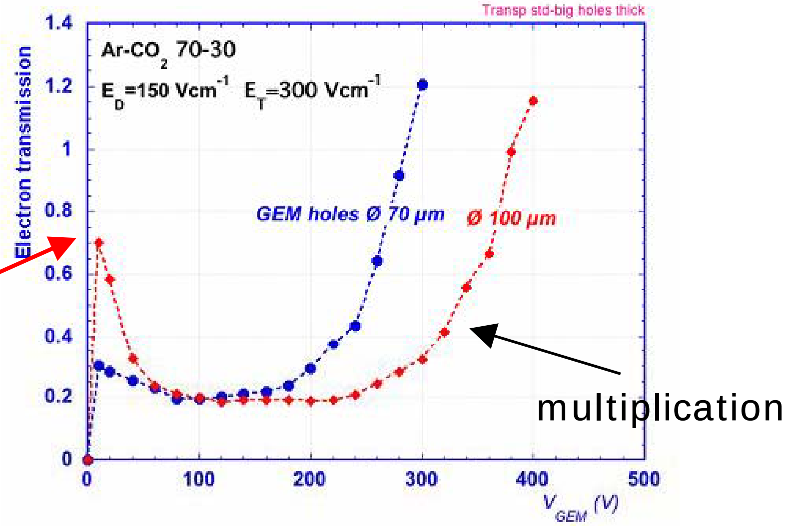
Gating Method

- Conventional Wire gating
  - Well understood
  - High electron transmission >90%
  - Large ExB effect under high B field
    - ~10% electron has deteriorated information
  - Should be designed to avoid wire vibration due to HV pulsing
  - Mechanical issue to string wires above MPGD
- GEM gating
  - Small ExB effect due to small structure
  - No vibration due to low voltage pulsing
  - Easy to mound on the multiplication GEM
  - Not well understood

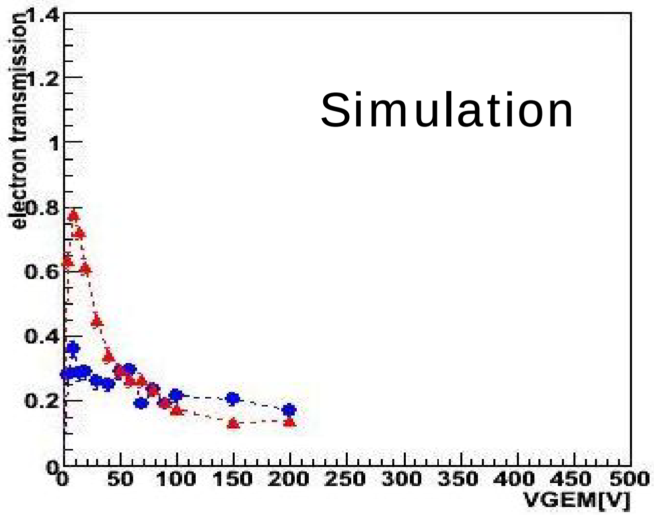


GEM Gating

- F.Sauli Proposed GEM as gating device.
  - Electron transmission is the key.
  - Low voltage operation with wider GEM holes gives good transmission.
  - 70% transmission with 10V/50um $Ar\text{-}CO_2=70:30$ under B=0T
- We can reproduce Sauli's result with Maxwell3D and Garfield for E-field calculation and electron/ion drift simulation.
- We try to optimize the GEM gating for LC TPC.
  - $Ar\text{-}CF_4\text{-}isoC_4H_{10}$
  - B=3T



F.Sauli et al. NIM A560, 269-277 (2006)



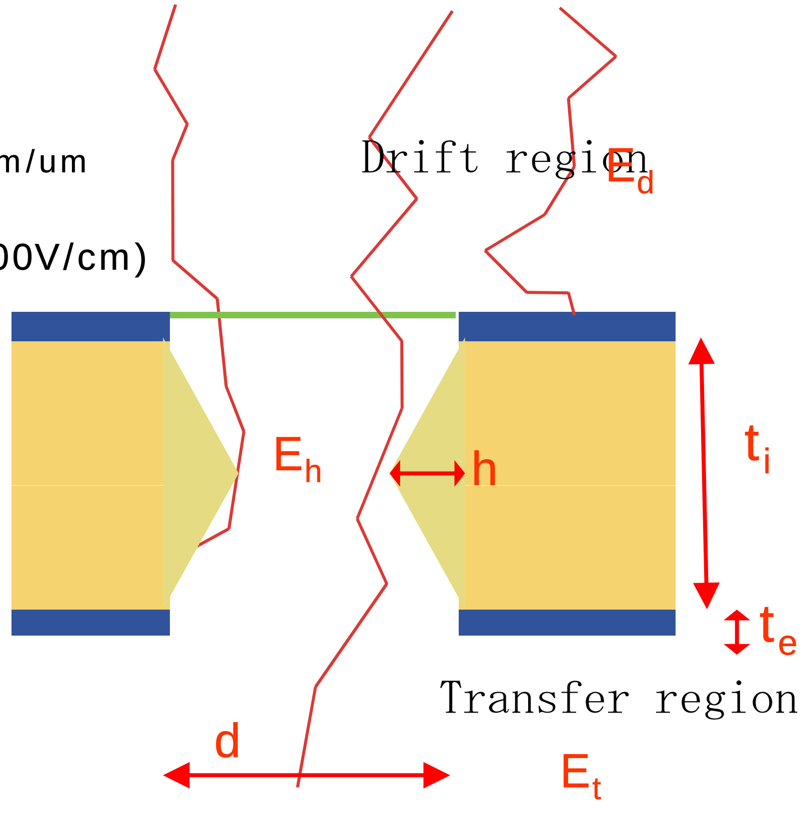
How to Understand the Electron Transmission

- Transmission is factorized in two part
  - Transmission = Collection eff. x Extraction eff.

$$\text{Collection eff.} = \frac{\#\text{electrons arrived at Hole entrance}}{\#\text{ produced electron}}$$

$$\text{Extraction eff.} = \frac{\#\text{electrons coming out from GEM hole}}{\#\text{electrons arrived at Hole entrance}}$$

- Parameters to be optimized.
  - E field
    - E_d : E field at drift region
      - Restricted to have the drift velocity > 5cm/um
    - E_h : E field at hole center (as x axis)
    - E_t : E field at transfer region (fixed to 300V/cm)
      - not sensitive to transmission in B field
  - GEM structure
    - p : hole pitch (fixed to 140um)
    - d : Hole diameter (fixed to 100um)
    - h : Hole shape
      - h=0: cylindrical
      - h>0:biconical
    - T_i : Insulator thickness
    - T_e : Electrode thickness
  - Gas
    - Concentration of Ar, CF_4, $isoC_4H_{10}$

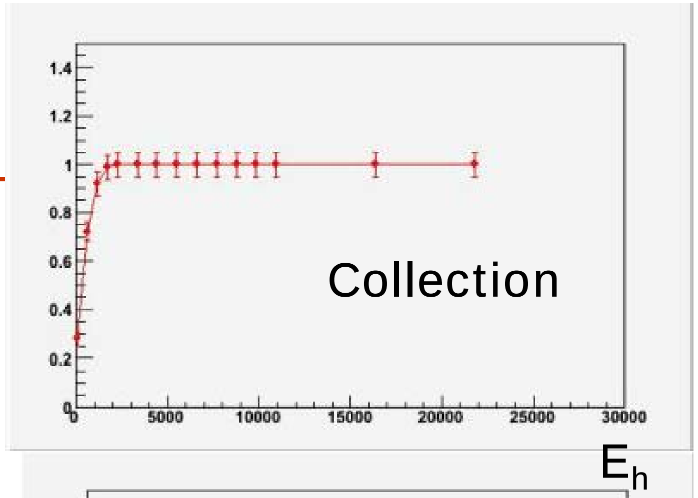


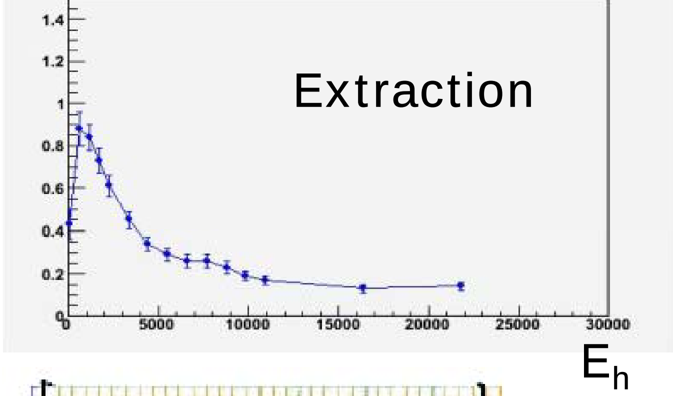
Collection and Extraction

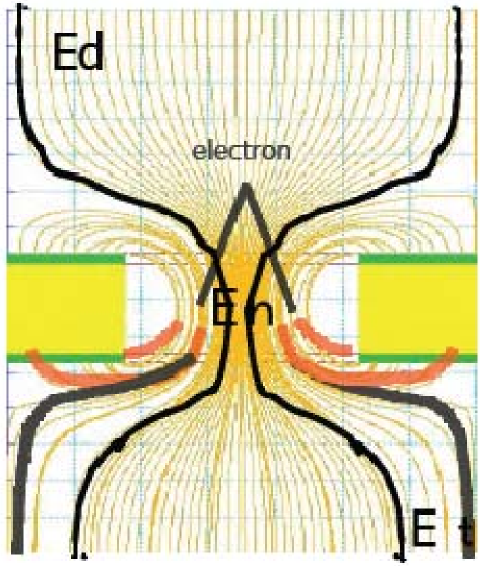
- Collection efficiency is known to be a function of Ed/Eh.
  - Collection efficiency is 100% when Ed/Eh<0.03 for 70um hole diameter.
  - This is relaxed when hole becomes larger.
  - Slightly worse in B field due to Lorentz angle than no B field.

- Extraction efficiency in B field is more complicated.
  - Entering position can be close to wall due to Lorentz angle
  - Area of penetrating field line becomes small as Eh increases.
  - Electron can spread due to diffusion
    - Absorption by wall
    - Follow field lines returning to GEM electrode

Transmission largely depends on gas.

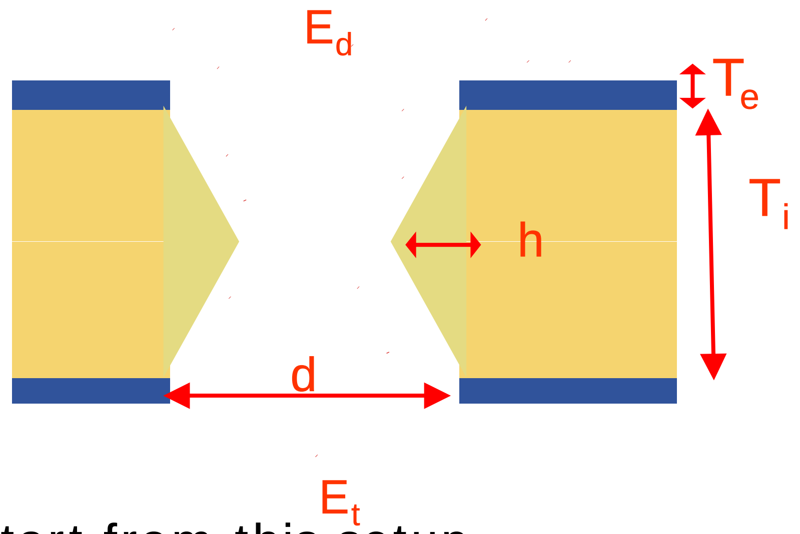




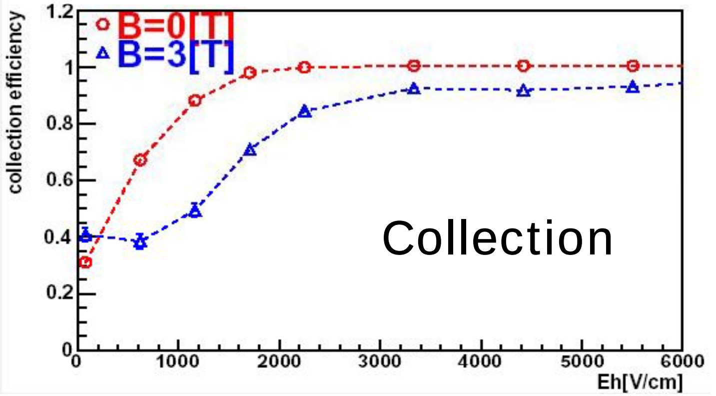


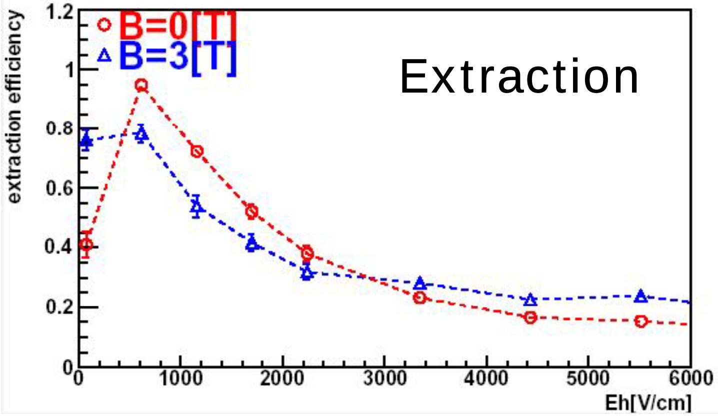
Setup

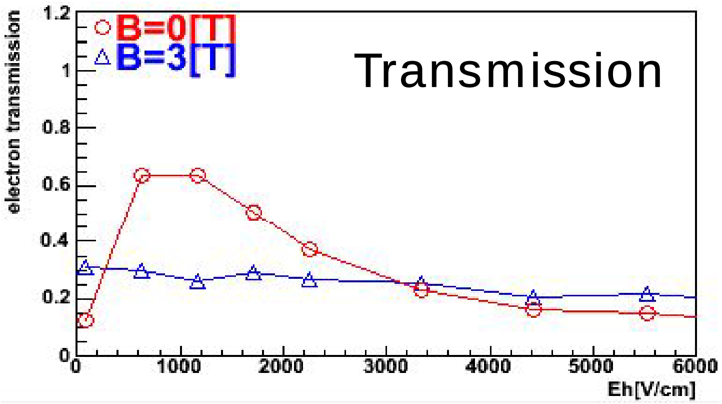
- Same setup as Sauli's except hole shape, gas and B field.
  - Electron transmission is ~30% in B=3T
    E_D=150 [V/cm]
    E_T=300 [V/cm] (fixed)
    Hole pitch p=140[um] (fixed)
    hole diameter d=100[um] (fixed)
    Insulator thickness T_i=50[um]
    Electrode thickness T_e=5[um]
    Hole shape h=0[um], cylindrical
    GAS Ar-CF4-isoC4H10(96:3:1)
    B= 3[T]



- Start from this setup





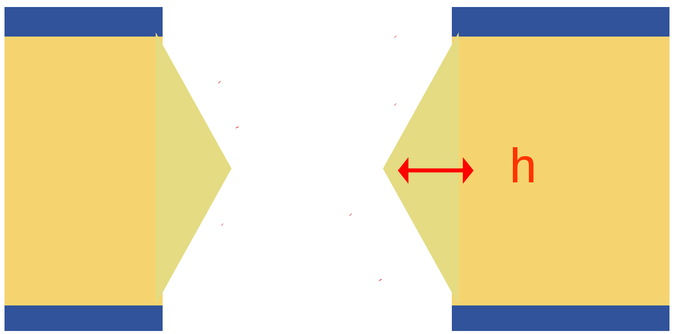


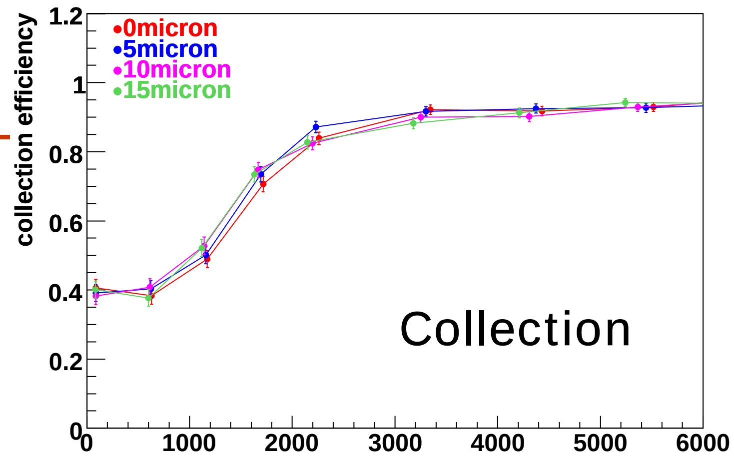
Hole shape

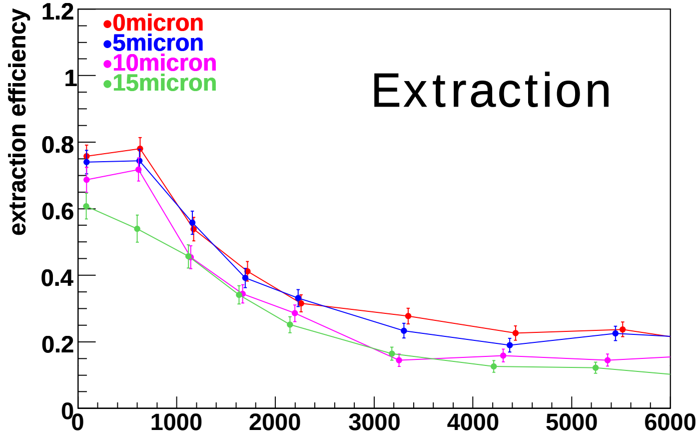
h=0, 5, 10, 15 [um]

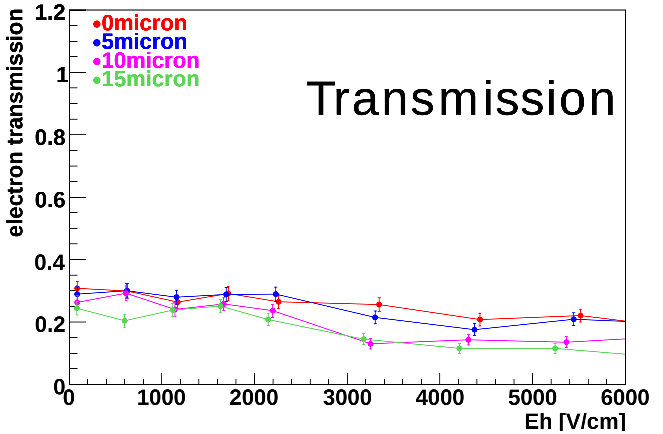
- Under non-B field, hole shape does not affect the transmission.
  - Electron follows field lines
- But under 3T B field, extraction efficiency is worse as h increases
  - entering position of electron can be close to GEM wall due to Lorentz angle
  - Electrons can not follow the field line due to Lorentz angle and are absorbed

Best parameter
h=0 [um]









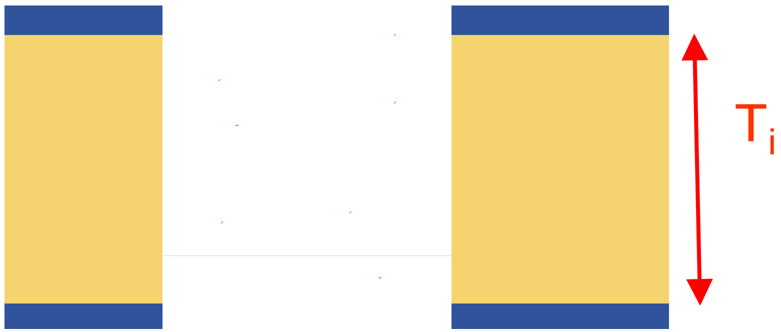
Insulator Thickness

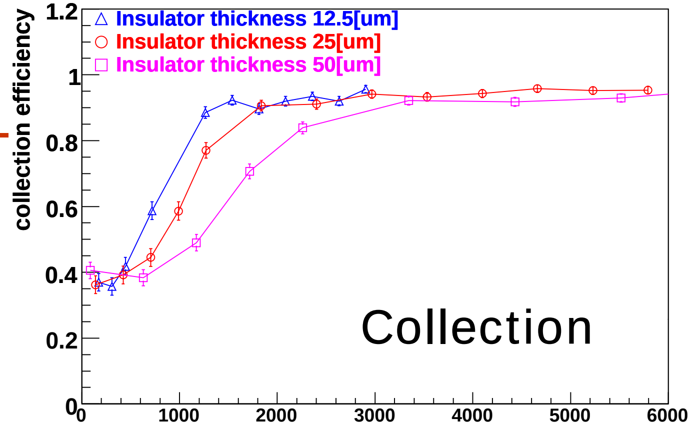
T_i = 12.5, 25, 50 [um]

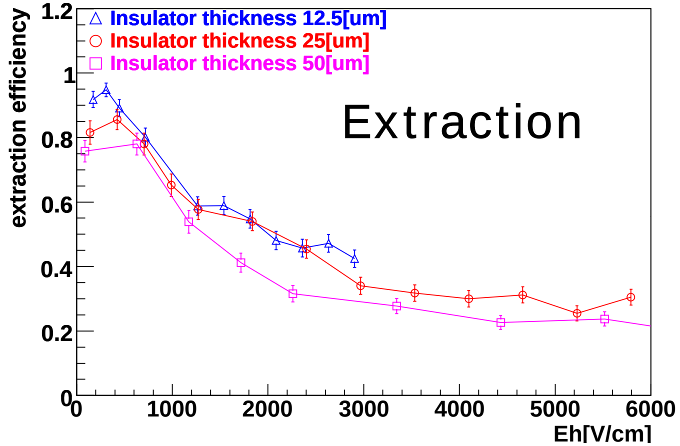
- Both collection and extraction becomes better as T_i decreases
  - E field at edge of hole becomes larger → field line can be easy to penetrate center of hole
  - E_h becomes lower
    - Small diffusion → better extraction

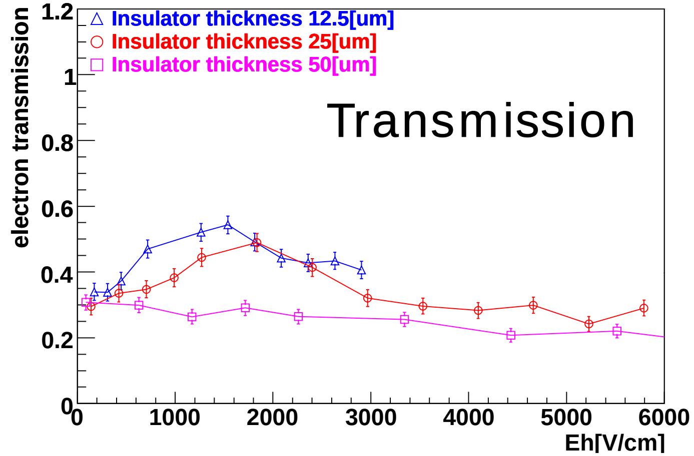
Best parameter

T_i = 12.5 [um]







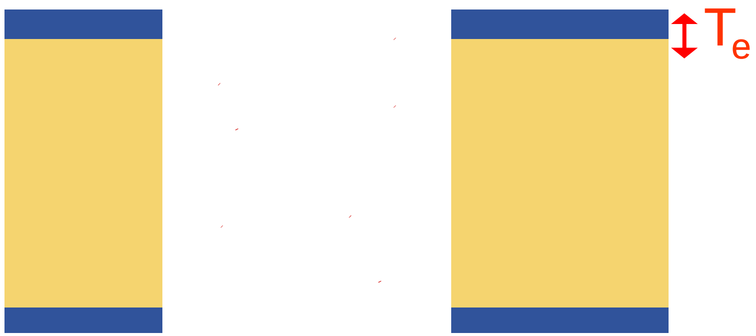


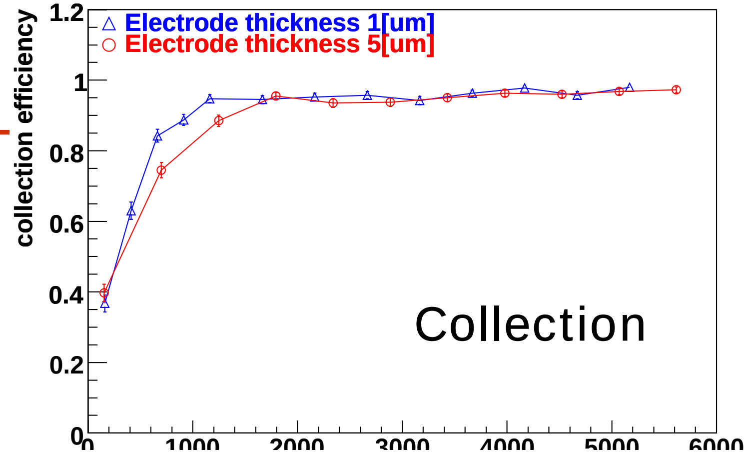
Electrode Thickness

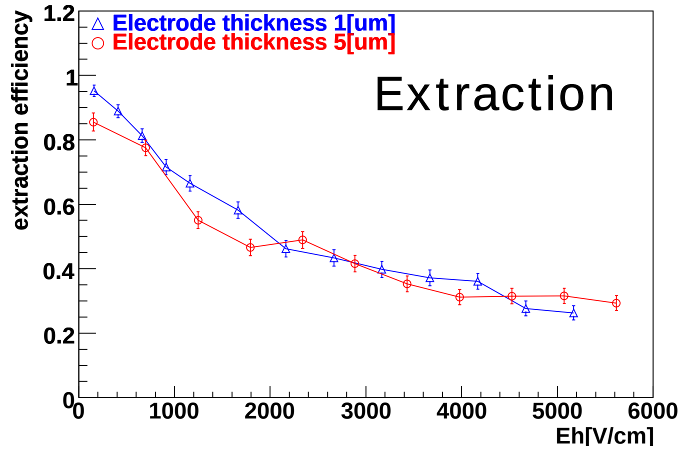
T_e=1, 5 [um]

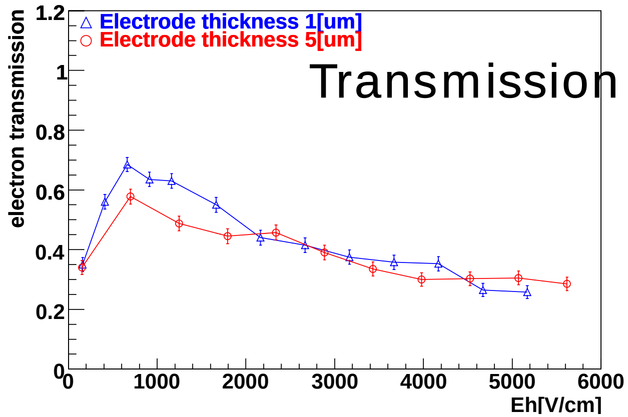
- Both collection and extraction becomes better as T_e decreases
  - Same reason as insulator thickness

Best parameter
T_e = 1 [um]







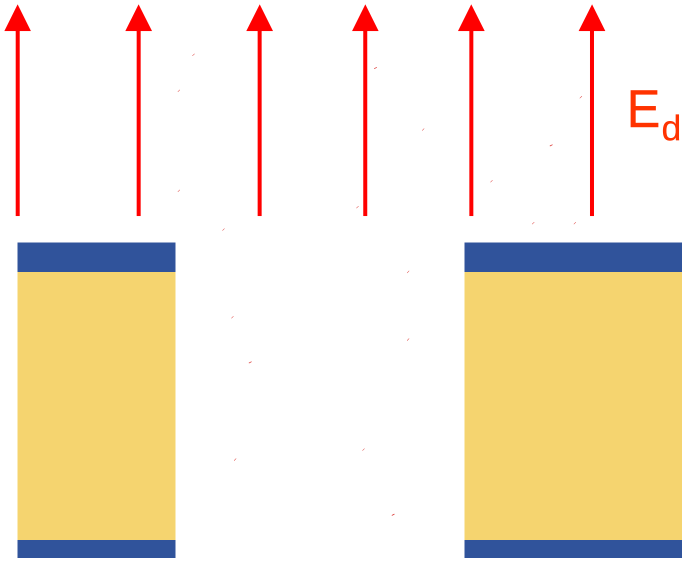


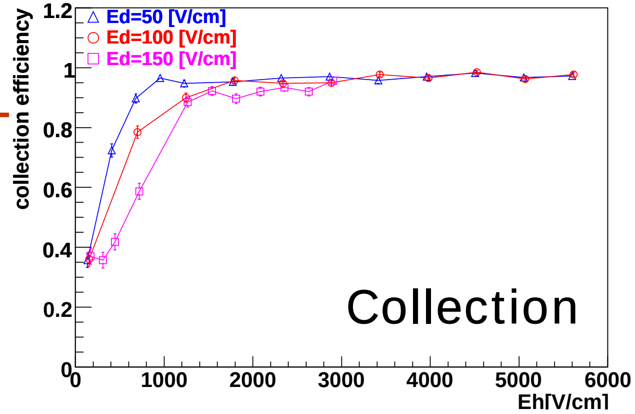
Ed dependence

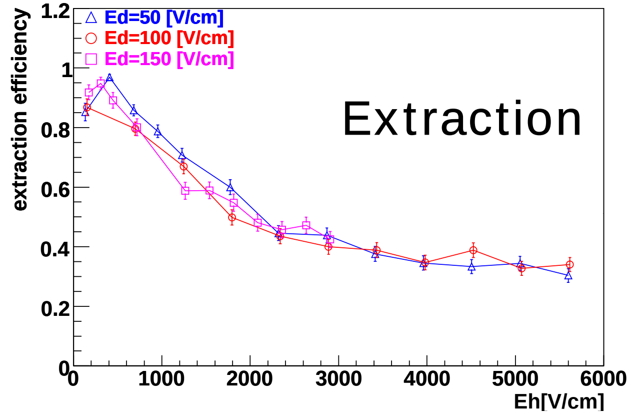
E_d=50, 100, 150 [V/cm]

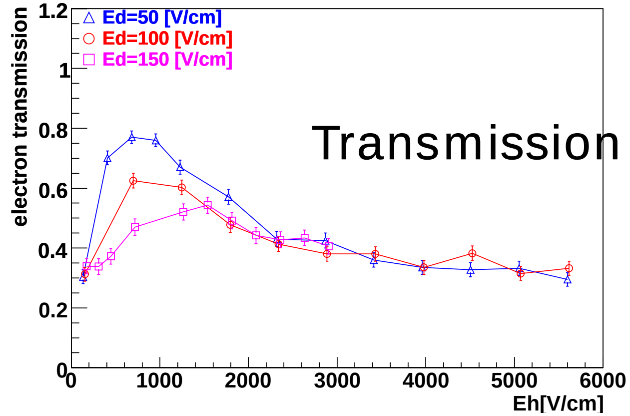
- Collection becomes better as E_d decreases.
  - E_d/E_h dependence
- Ed=50 [V/cm] gives best transmission but drift velocity is smaller than our requirement, 5 [cm/um].

- So we choose Ed= 100 [V/cm]





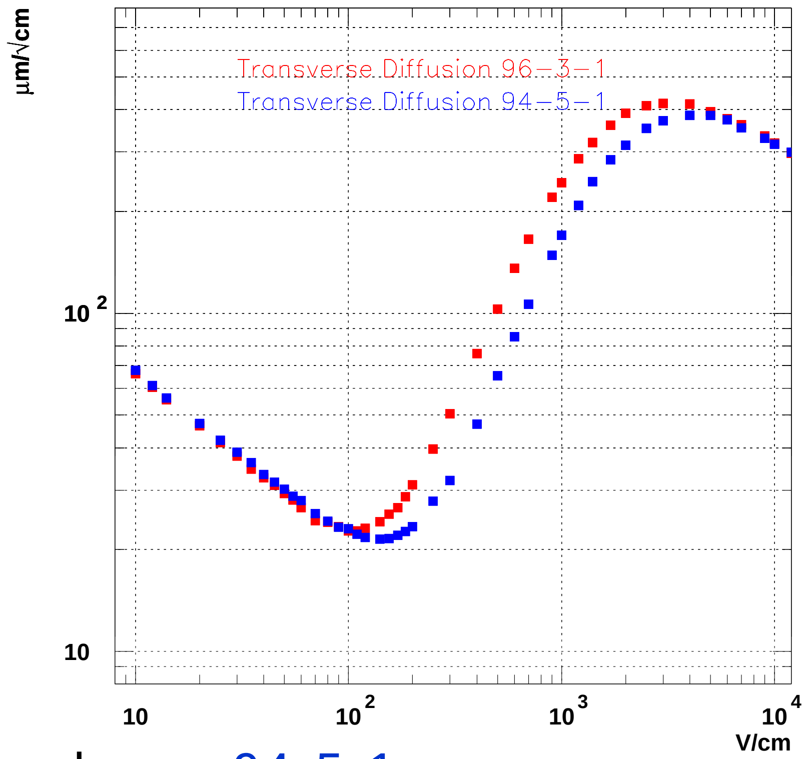




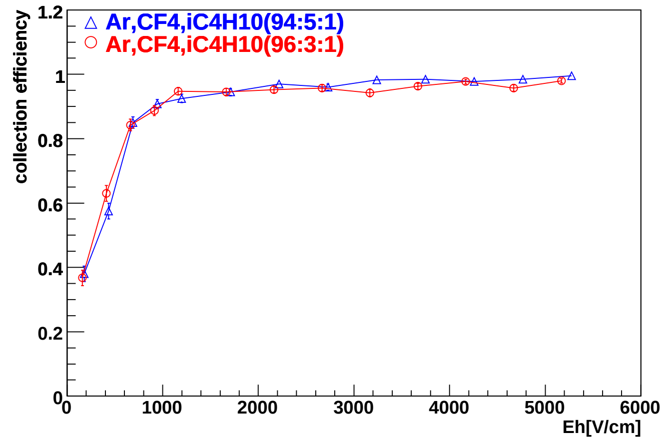
Gas Concentration

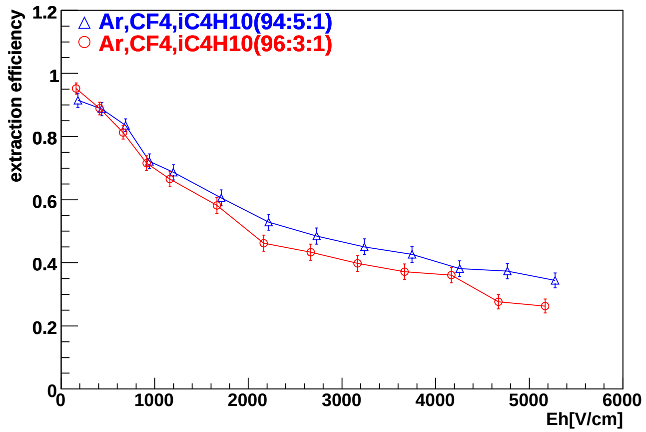
Ar-CF_4-isoC_4H_{10}= 94:5:1, 96:3:1

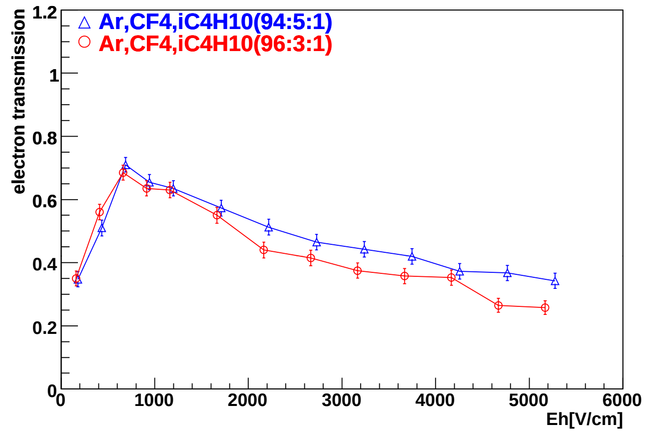
- For 94:5:1, we increase Ed to 120 [V/cm] to meet the requirement, drift velocity > 5 [cm/um]
- 94:5:1 gives better extraction due to small diffusion around 1000 [V/cm]



- we choose 94:5:1.

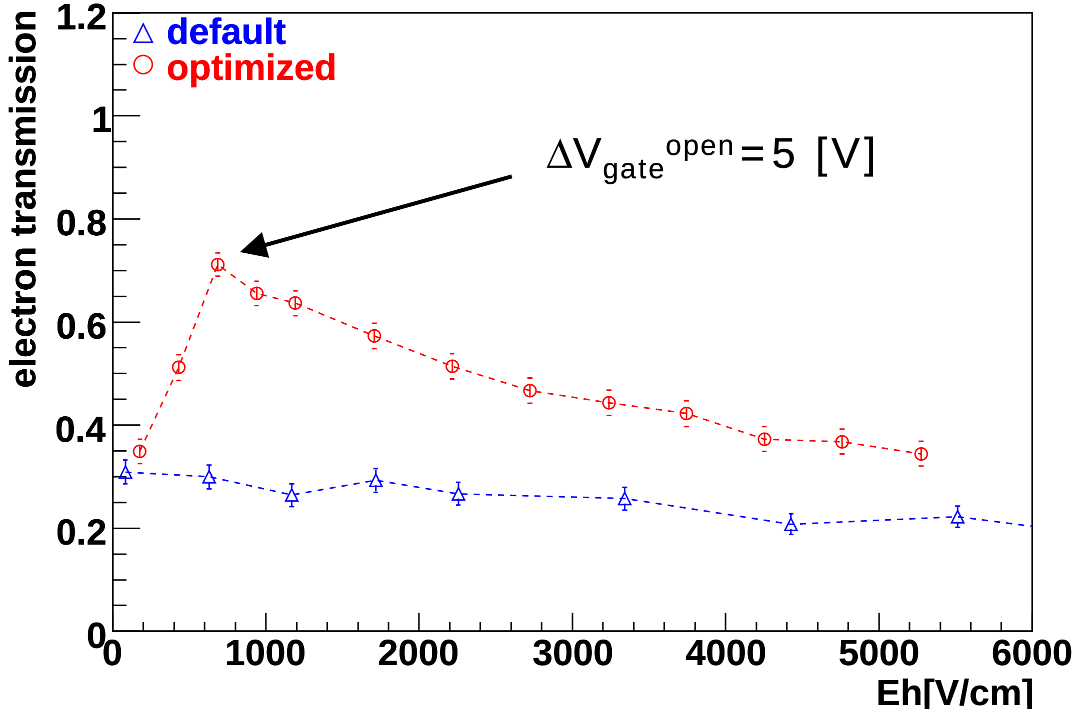






Optimized Setup

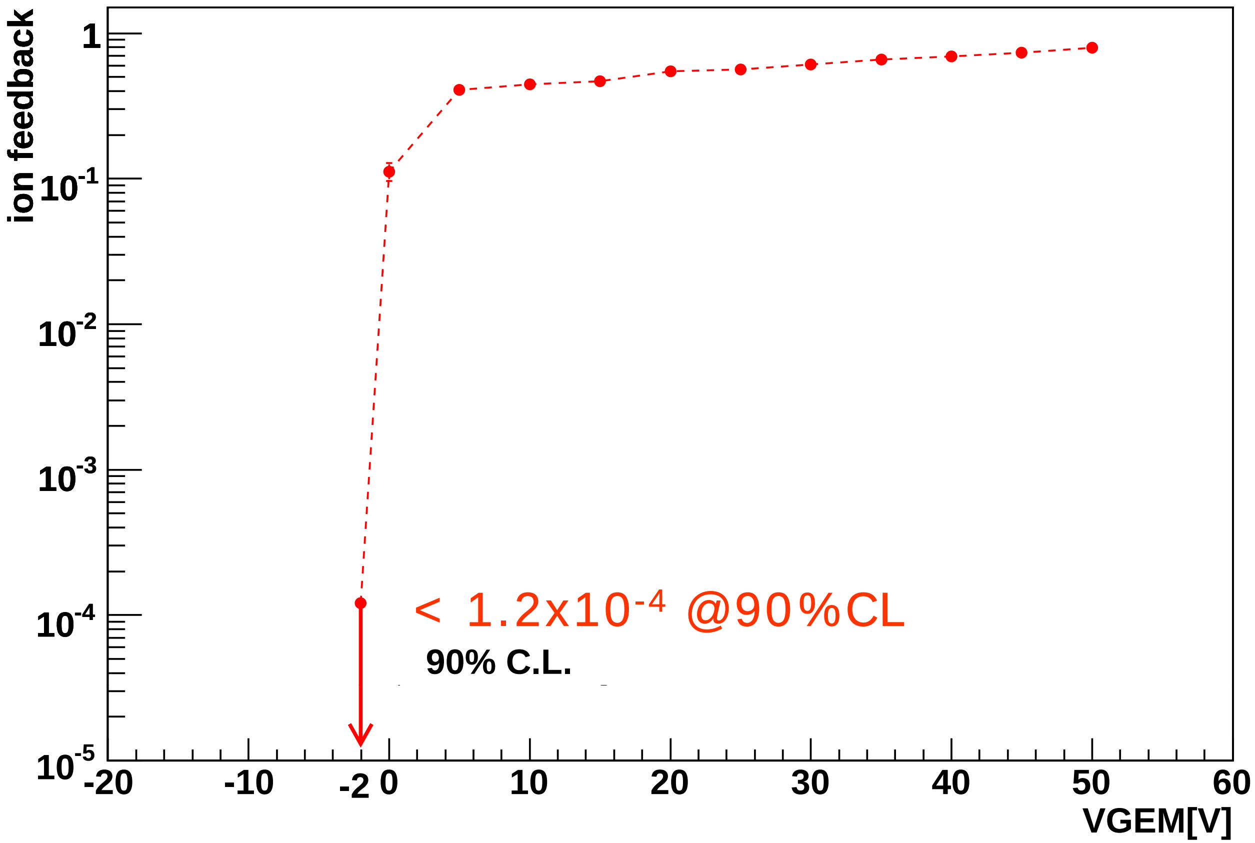
- 135% improvement from **default** setup
- 71% efficiency are achieved with optimized GEM and $\Delta V_{gate}^{open}=5$ [V]



	default	optimized	improvement
Hole shape	Cylindrical	Cylindrical	0%
Insulator Thickness	50[um]	12.5[um]	55%
Electrode Thickness	5[um]	1[um]	15%
E_d	150[V/cm]	120[V/cm]	25%
Gas	$Ar\text{-}CF_4\text{-}isoC_4H_{10}$ 96:3:1	$Ar\text{-}CF_4\text{-}isoC_4H_{10}$ 94:5:1	5%
Transmission	**30%**	**71%**	**135%**

Ion Transmission

- ΔV_{gate}^{close} = -2V is enough for ion transmission of less than a few $\times 10^{-4}$
  - We simulate 20k ion events with the optimized setup for electron transmission but no ions pass the GEM gate.
  - 90% C.L. upper limit on ion transmission by Gate is 1.2×10^{-4}
  - If ion suppression by multiplication GEM is included, ion transmission is less than a few $\times 10^{-6}$ for double GEM.



Towards Measurement

- We are preparing to measure the electron transmission with 25um thick and ϕ=90um GEM
  - 0T at Saga : Ar-isoC_4H_{10}
  - 1T at KEK : Ar-CF_4-isoC_4H_{10}
- Discussion to Scienergy on the production of optimized GEM
  - Plan to purchase 12.5um thick polyimide
  - Wet etching may be better to make larger hole.

Summary

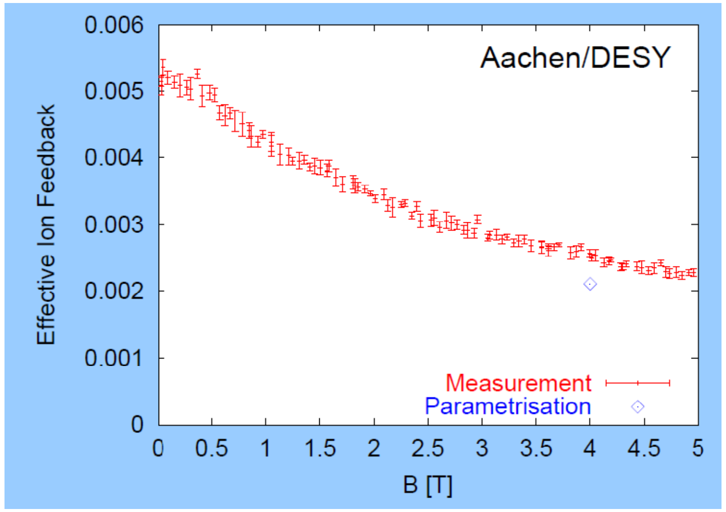
- We studied simulation of GEM gating
- E fields, GEM structure and gas mixture are optimized
  - Lower E_d, thinner GEM and lower diffusion gas
  - Electron transmission 71%
  - → about 15% degradation on position and dE/dx resolutions
  - Ion transmission less than 1.2×10^{-4}
    - < a few $\times 10^{-6}$ including self ion suppression capability
- Low voltage operation is enough for gating
  - $\Delta V_{gate}^{open} = 5$ [V]
  - $\Delta V_{gate}^{close} = -2$ [V]

- We are preparing to measure the electron transmission under 1T
  - Need to measure it under 3~4T, of course.

Backup

Self-Suppression Capability of Ion feed back

- MicroMEGAS
  - A few x 10^{-3}
- GEM
  - Triple GEM optimized case : a few x 10^{-3}
  - Double GEM non-optimized case : a few x 10^{-2}



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