

Simulation Study of GEM gating for LC-TPC

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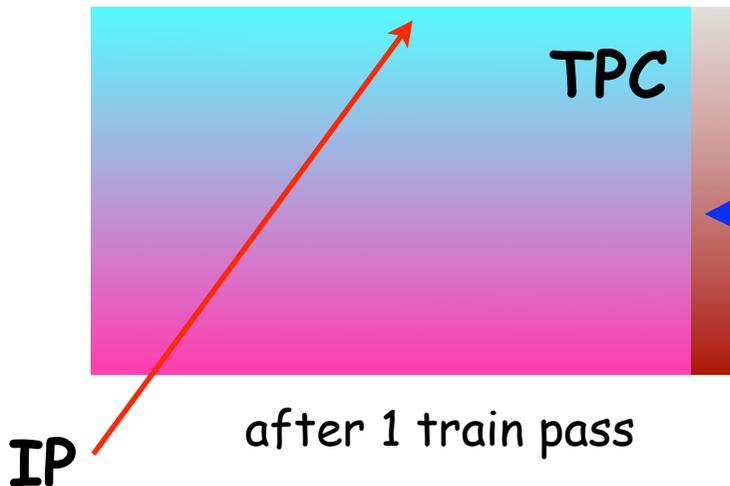
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Why do we need Gate for ions ?

Ions are produced at the Drift region as primary ionization
at MPGD region from gas multiplications (1000 times larger)

Ions @ drift may be accumulate for a few trains
as ions drift is slow

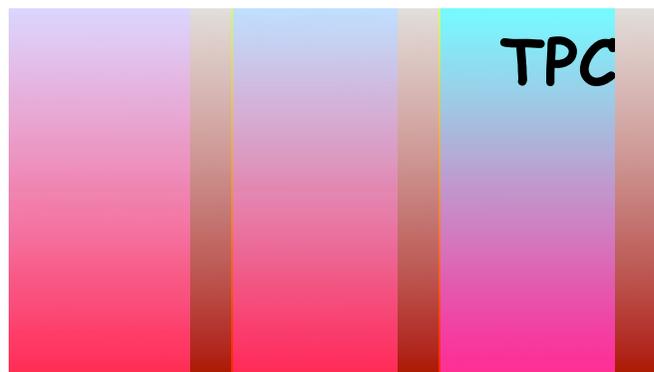


Ions produced at gas multiplications

Ions @ MPGD will form like a ion-dense disc
which travel in drift region slowly
if we don't have any gate mechanism to block ions

this disc may deteriorate drifting electron by E ,
 $E \times B$...
and these effects are not stable as ions are moving.

Ions produced at gas multiplications
must be shut off by **GATE**



after several trains

Gating for back-drift ions

ILC case : ions feedback must be smaller than 10^{-3} (ie. no ions from MPGD)

Gate can be open for 1 msec and be closed following 199 msec.

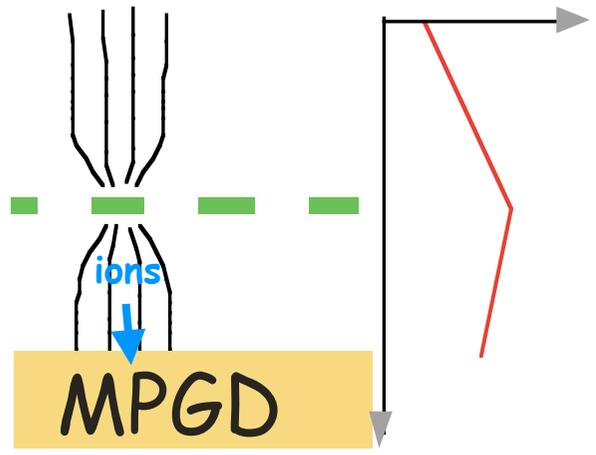
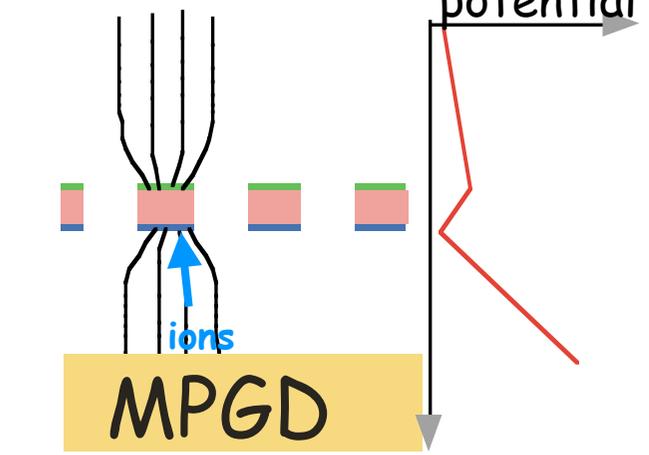
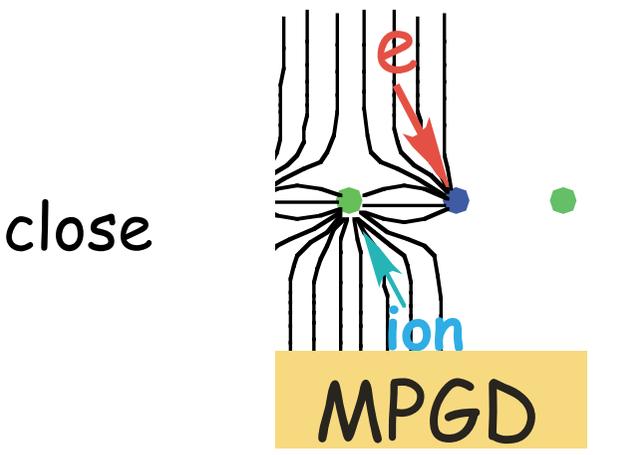
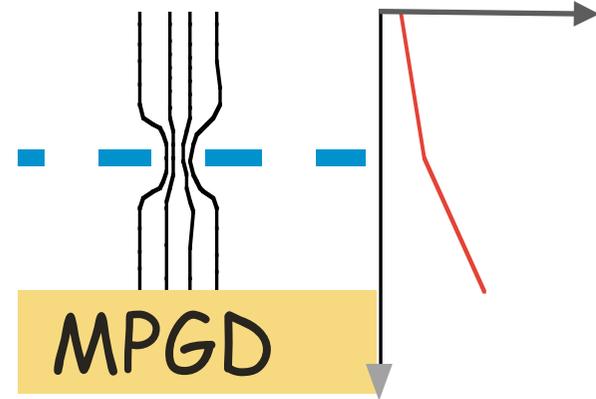
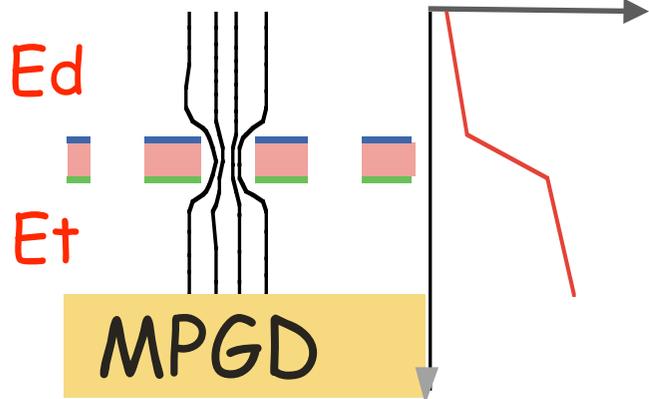
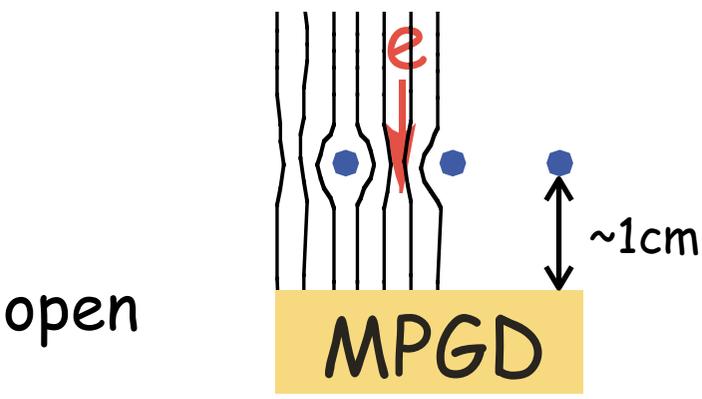
ion can drift < 1cm

Gate: wire

GEM

micromesh

3 candidates



local change of E
wire tension
 $E \times B$

local change of E
electron transmission

change of drift E
electron transmission

Before going to GEM gating

Is Wire a perfect gating method ?

Existing wires deteriorate electric field around a wire.
It introduces some ExB effect !!

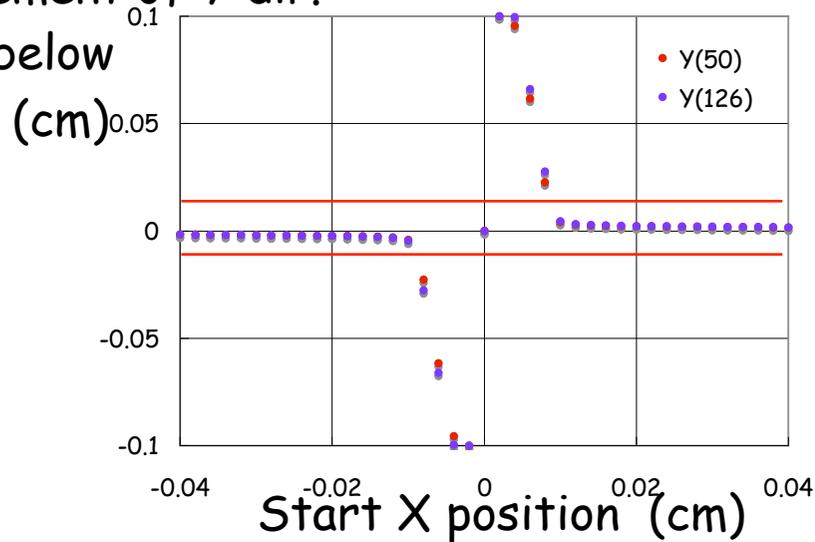
size of ExB effect and affected area are in question

Gas:	Ar:CF4 (95:5)
Magnetic Field	4T
drift/transfer E	100V/cm
	(gate:open)
gate wire diam.	126um/50um
spacing	2 mm
gate-pad gap	1cm

Electron transmission (@Gate Open)

Displacement of Y dir.

@2mm below

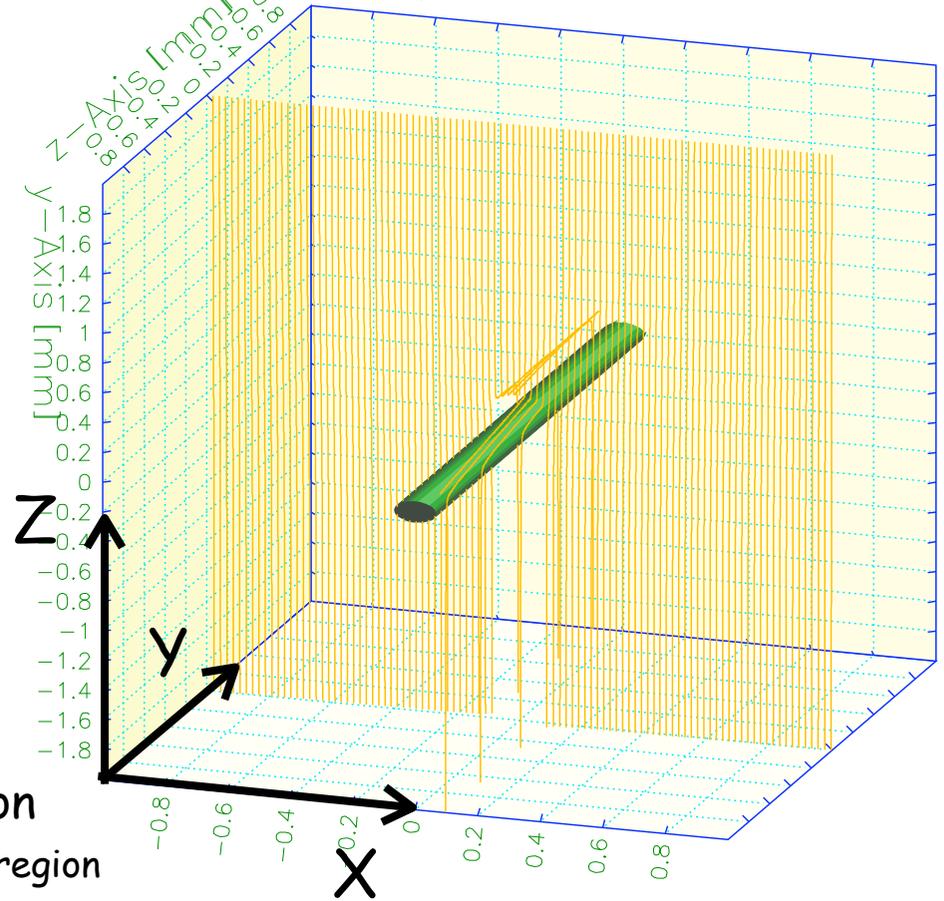


displacement > 100 um @ $|x - x_{wire}| < 100$ um
this result is not depend on wire diameter

10% of region provide deteriorated information
these electrons are also diffused @ transfer/MPGD region

Layout of the cell

Gas: CH₄ 5%, Ar 95%, T=300 K, p=1 atm

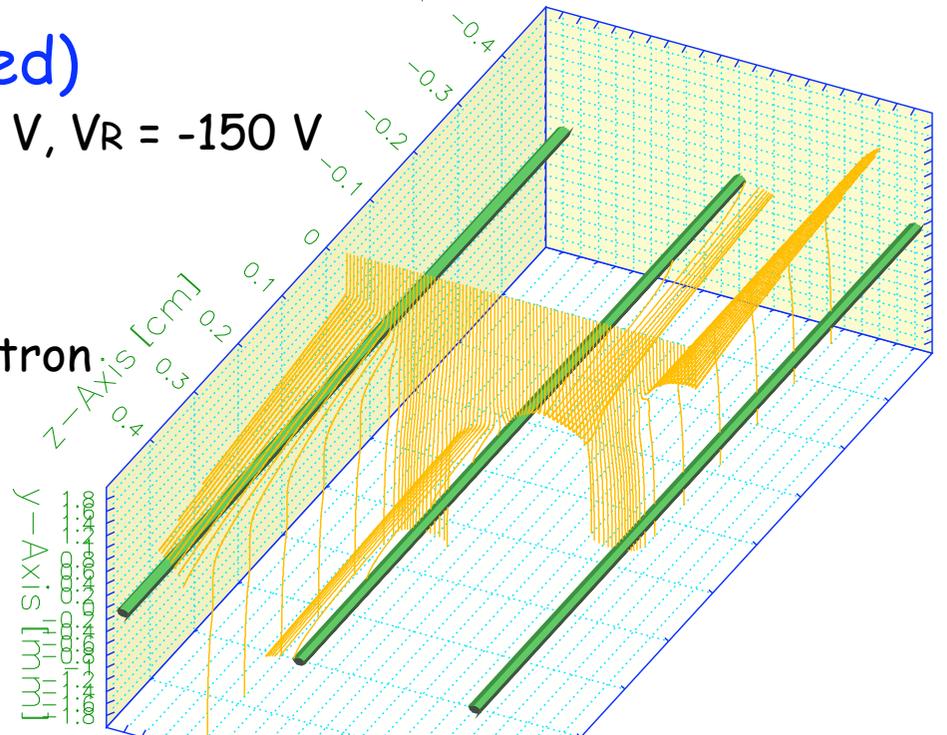


Electron transmission (@Gate Closed)

$V_L = -50\text{ V}, V_R = -150\text{ V}$

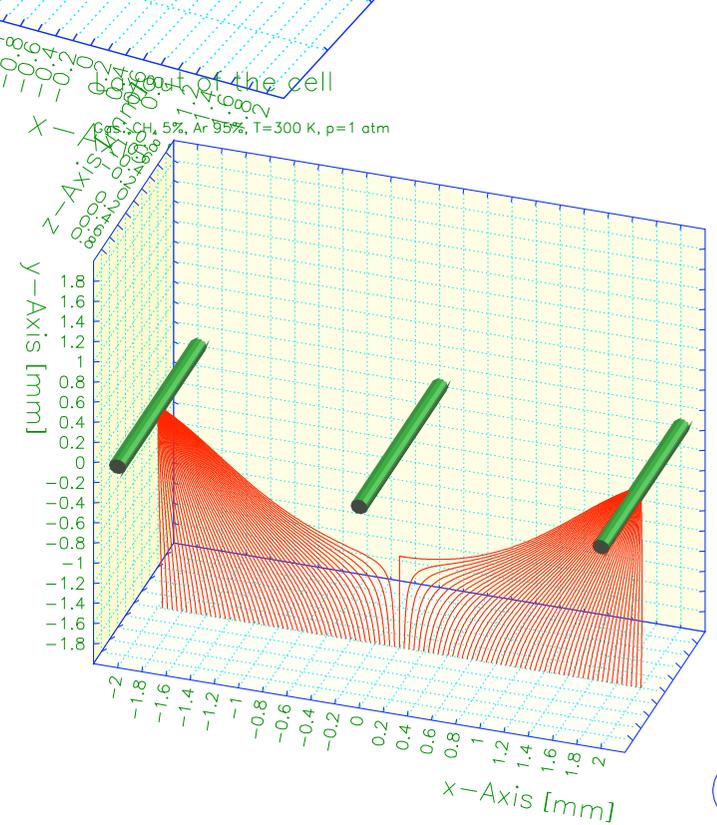
Even Gate is closed, a half of electrons can go through gate plane.

large difference of V_L and V_R may reduce electron transparency but.....



Ion blocking (@Gate Closed)

No problem about ions !!!



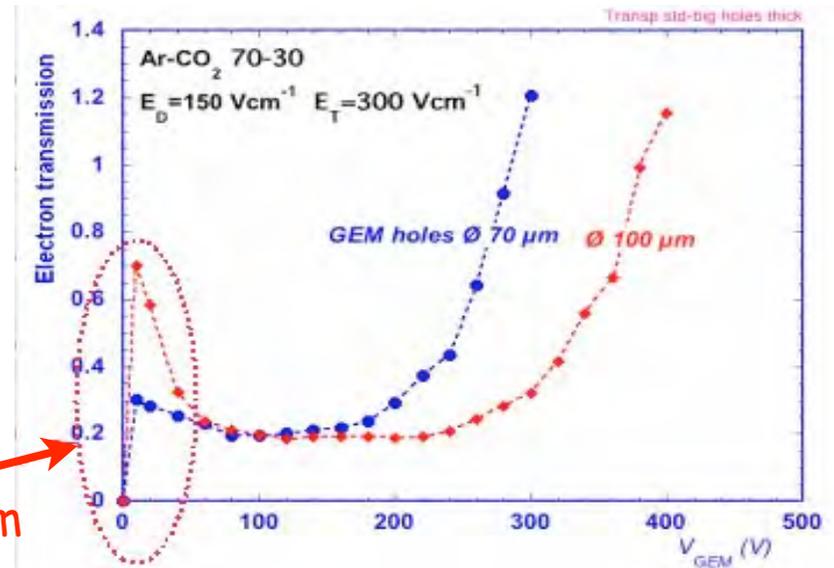
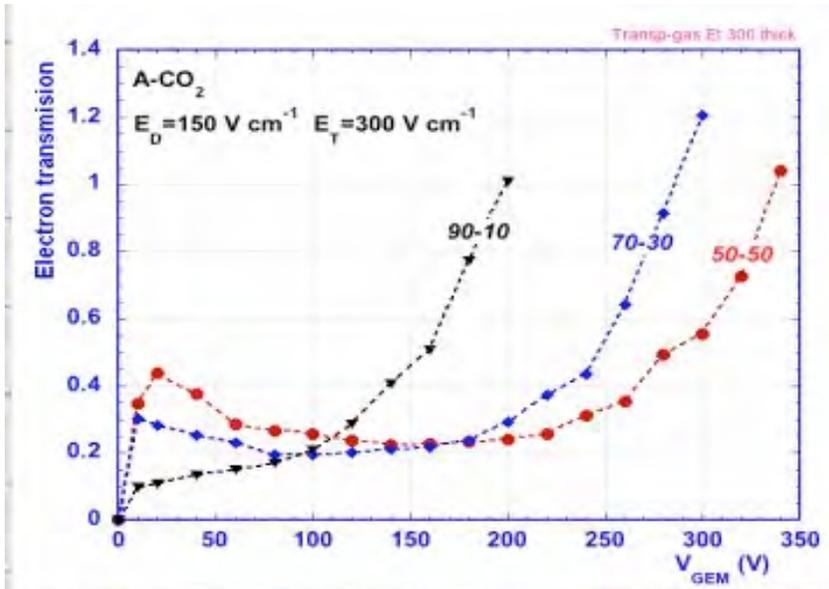
GEM gating

F. Sauli had proposed GEM as gating device @LBLTPC'06

electron transmission is the key issue here !!

Electron transmission had been measured as a function of V_{GEM}
for different Gas mixture

for different hole size



Low voltage operation may give us good electron transmission:
where no gas amplification happen.

We hope to understand this mechanism and optimize GEM for ILC gate
E field calculation and electron simulation in gas help us to do this.

Maxwell3D

Garfield

BUT We have to make sure these tools provide correct answer

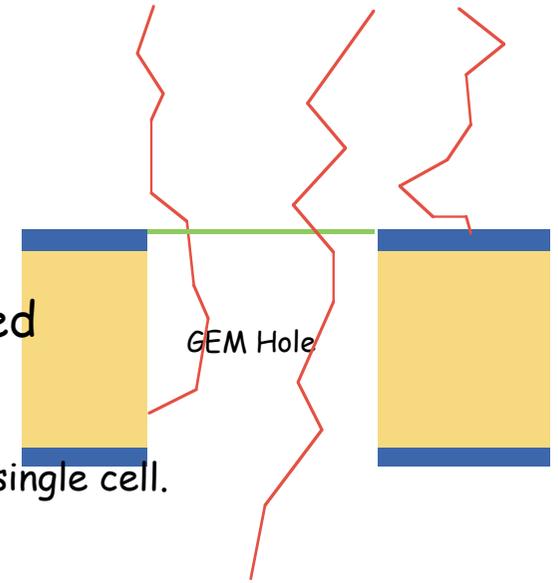
How do we understand electron transmission through simulation

Transmission = Collection eff. x Extraction eff.

Collection eff. = #e reached to entrance of hole/#e generated

Extraction eff. = #e extracted from hole/#e reached to ent.

electrons are generated 500um above GEM surface uniformly on a single cell.



Cautions 1

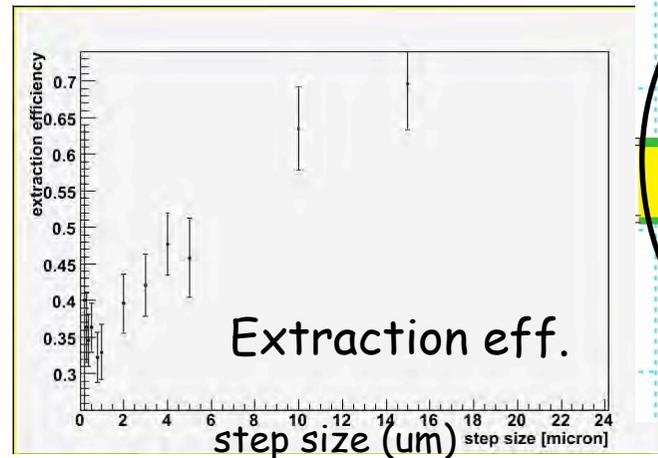
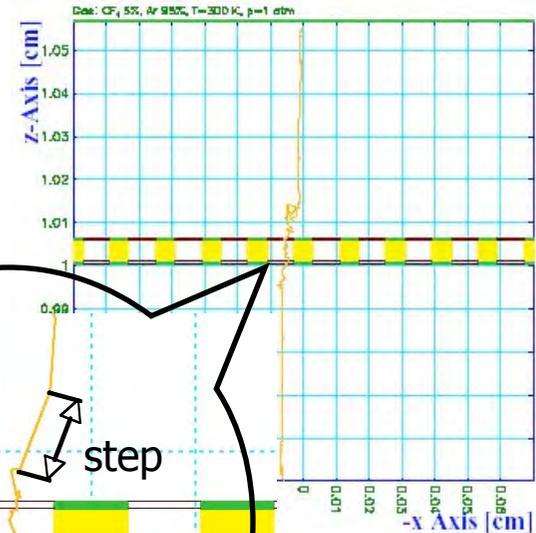
Important parameter of Garfield is **STEP SIZE**

step size : interval to update electron position

step size is controlled by # of collisions OR length.

large step size -> incorrect result

too small step size -> cal. stopped by Max. number(1000)



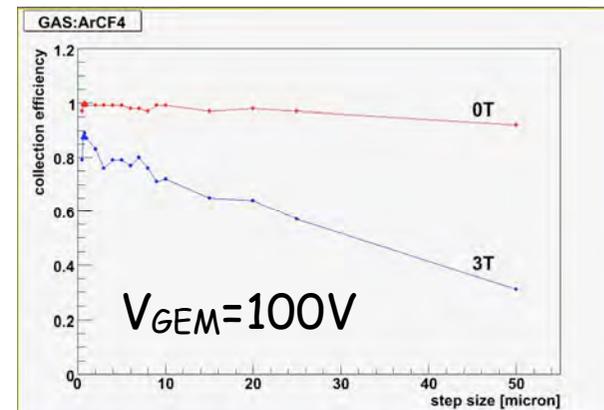
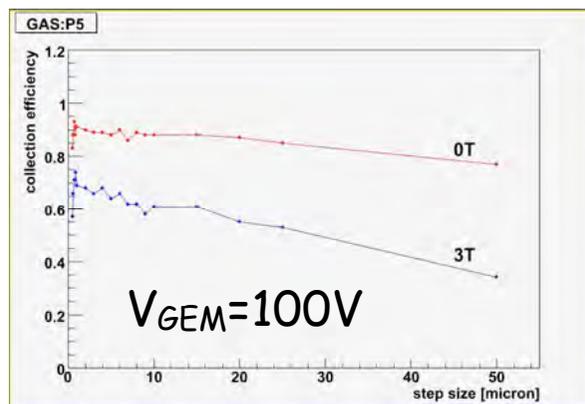
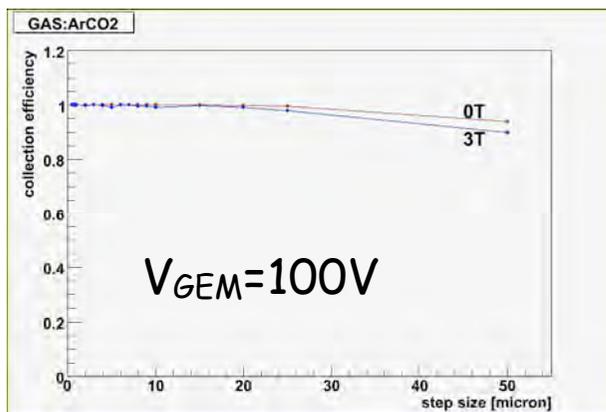
More example of step size effect **Cautions !**

Ar:CO₂

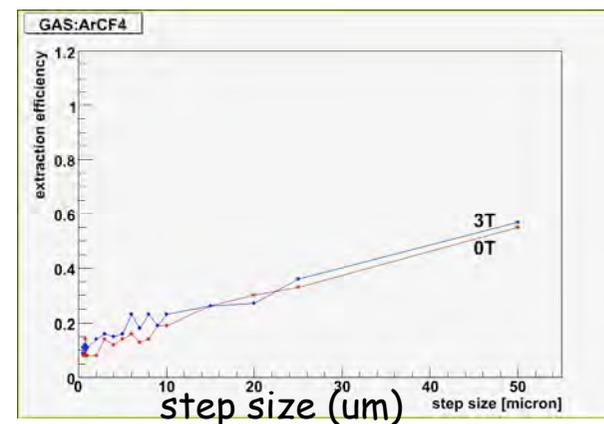
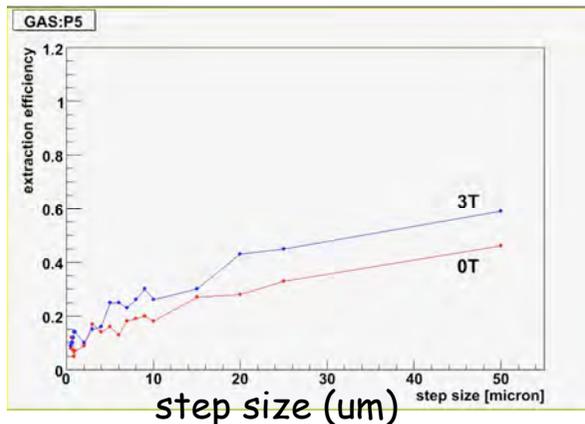
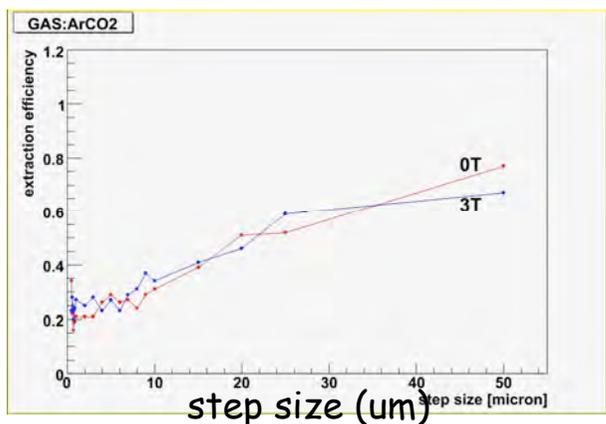
Ar:CH₄(P5)

Ar:CF₄

collection eff.

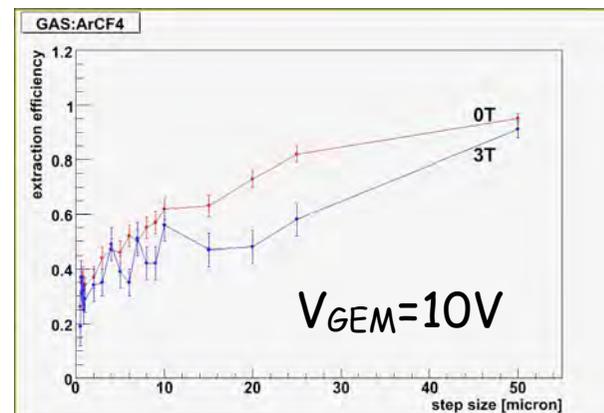


extraction eff.



In any case, result change as step size
result @ 0 step size must be close to true value !

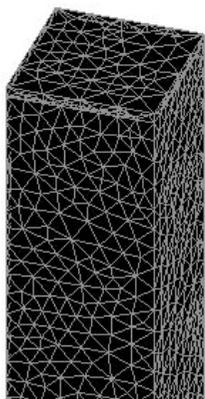
We chose 2 um step size
as the result may be close enough to true answer



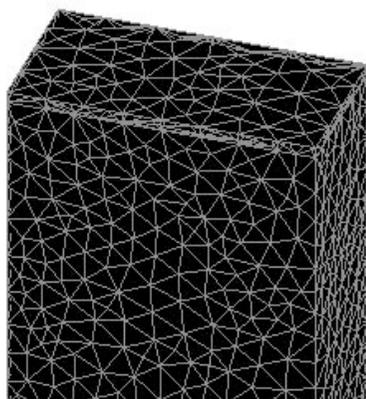
Size of Field map

Cautions 2

Field map used in garfield can be provided from Maxwell3D.
but acceptable size is limited to $\sim 10^5$ elements



Blue line



Red line

mesh size $\sim 2 \times$ Blue

Collection eff. is same each other

ie. E field @ collection seems to be precise enough

Extraction eff. provides $\sim 10\%$ diff.

ie. E field is not precisely calculated in hole

or interpolation of E field doesn't work in garfield

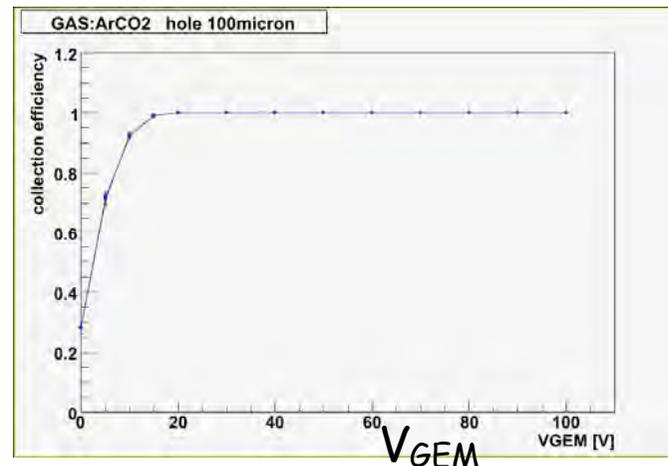
In Maxwell3D, mesh is automatically generated
we cannot quote exact volume of mesh

We have to remember accuracy of result

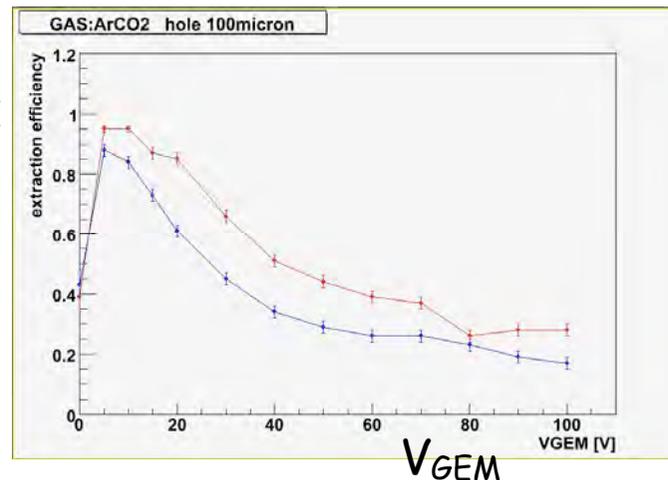
when we use garfield

ArCO2

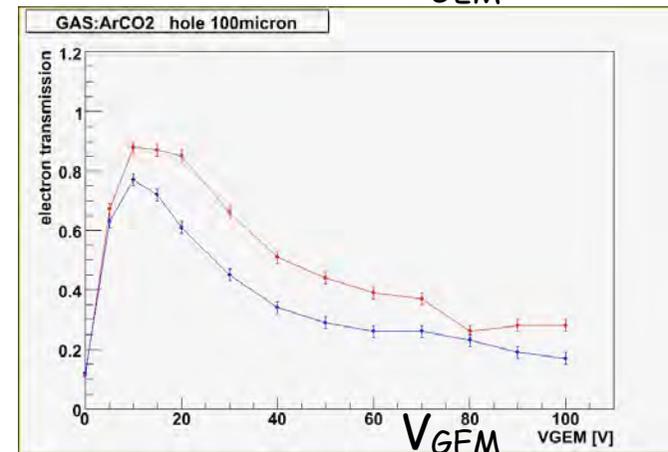
collection eff.



extraction eff.



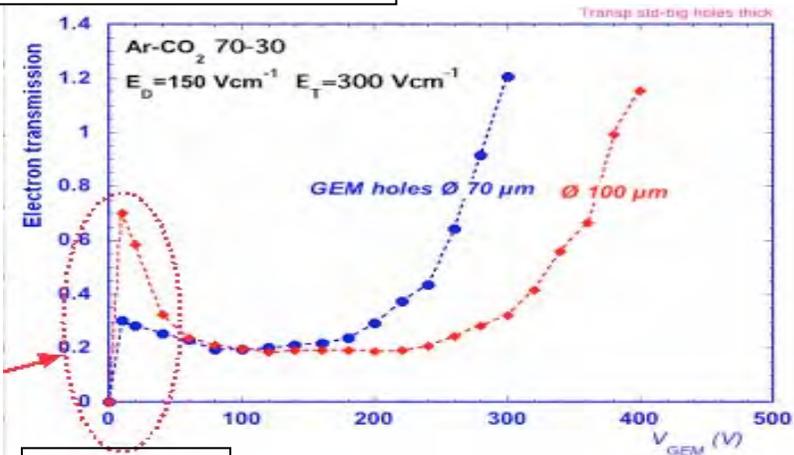
transmission



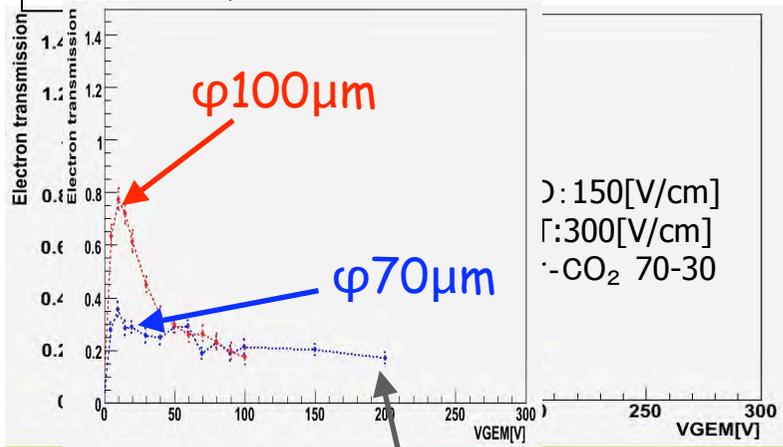
Comparison to exp. results

Electron transmission
Hole size dep.

Measurement by Sauli

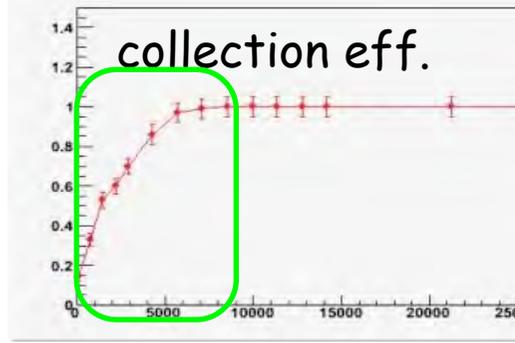


simulation

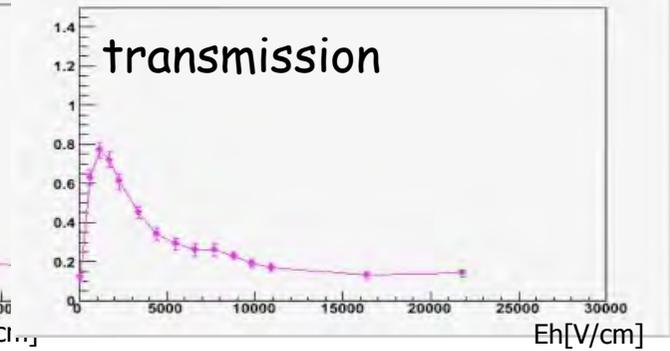
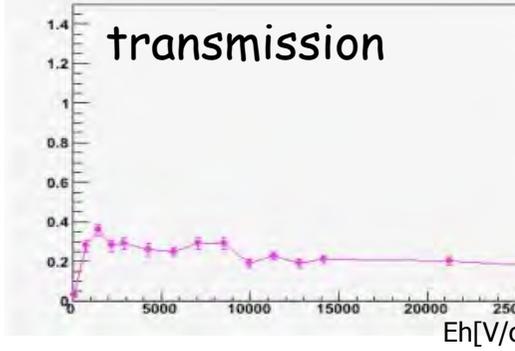
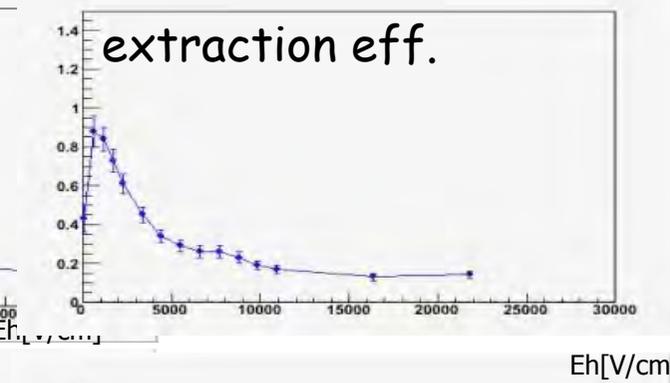
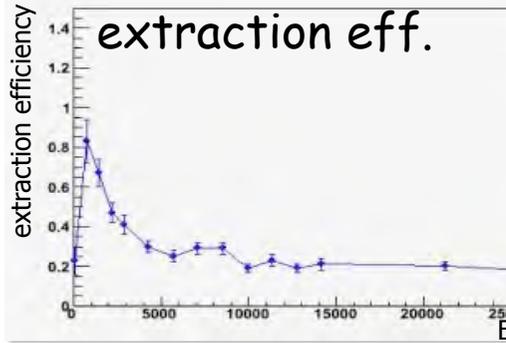
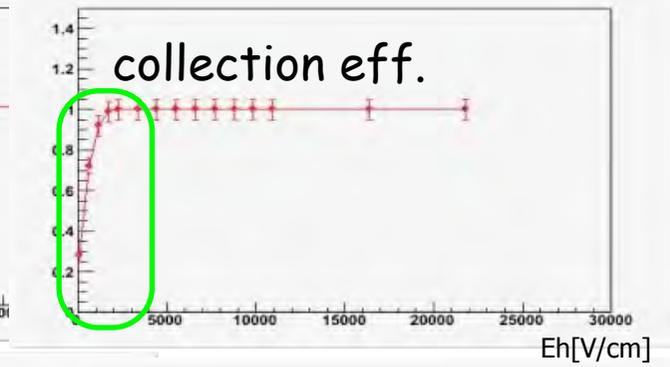


Gas gain is not included

$\phi 70\mu\text{m}$

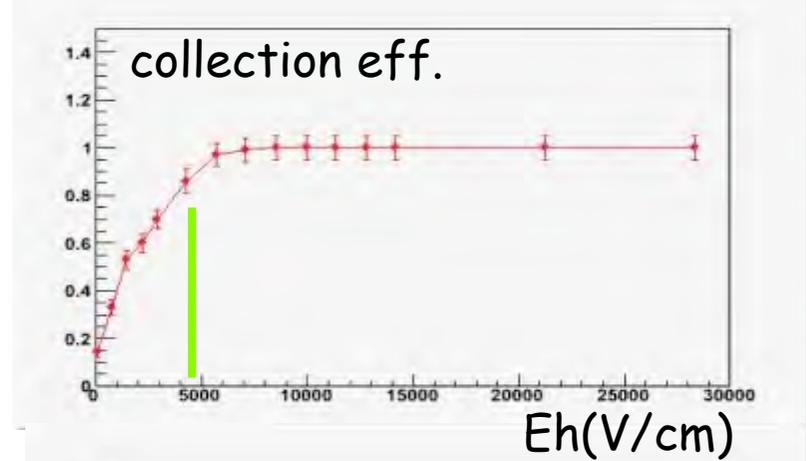


$\phi 100\mu\text{m}$



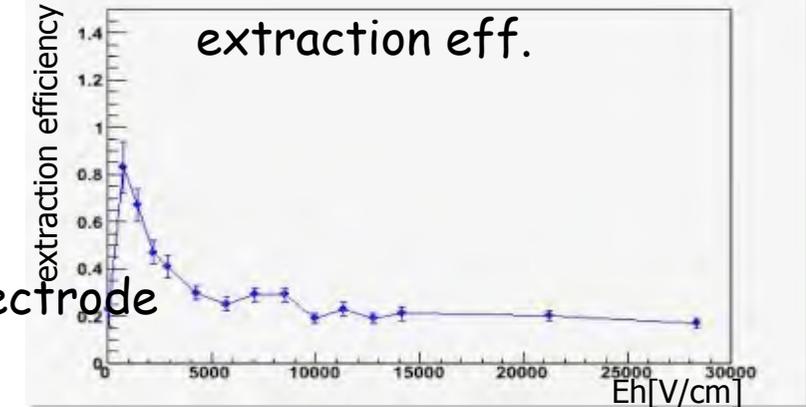
Collection eff. improve transmission
due to large aperture

Collection eff. has been studied by several groups
 as a func. of E_d/E_h
 and known to be ~ 1 @ $E_d/E_h < 0.03$ (ie 4.5kV/cm here)
 it is relaxed when hole become larger.



Extraction eff. behave more complicatedly

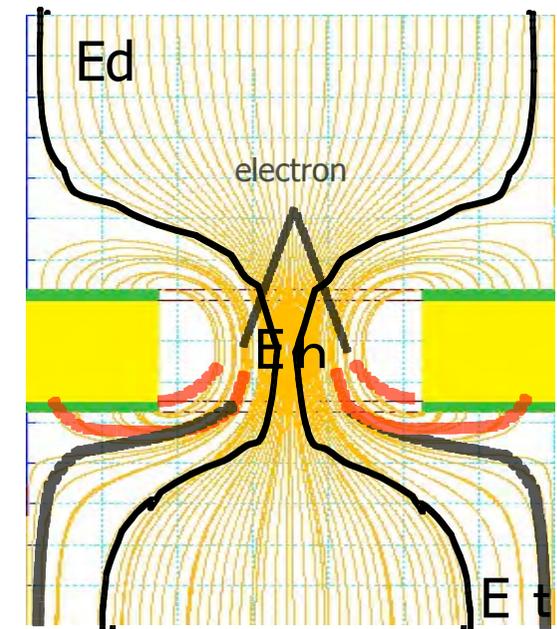
- area of penetrating field line become small as E_h
- electron can spread due to diffusion(E_h)
- some electron follow returned filed line to GEM electrode



area of penetrating field line is larger @ low E_h
 higher extraction
 diffusion behavior is also important !

This means "transmission is largely depend on gas"

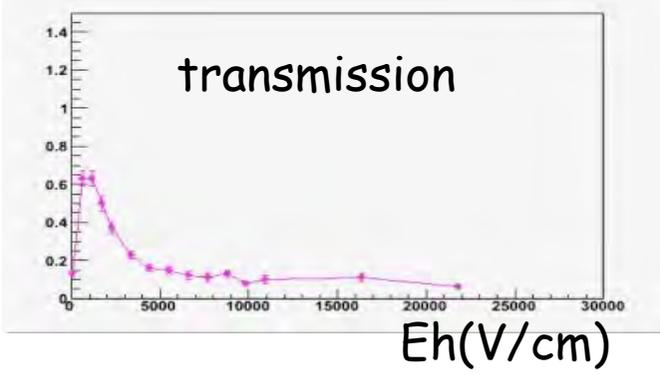
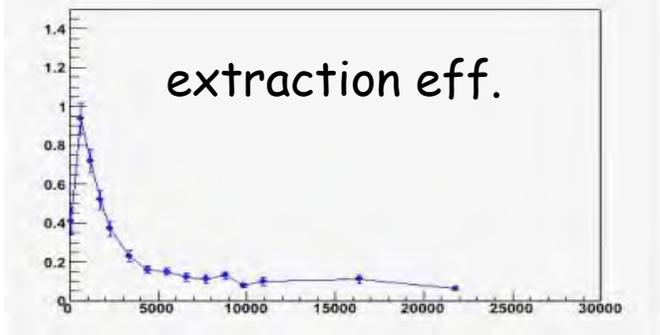
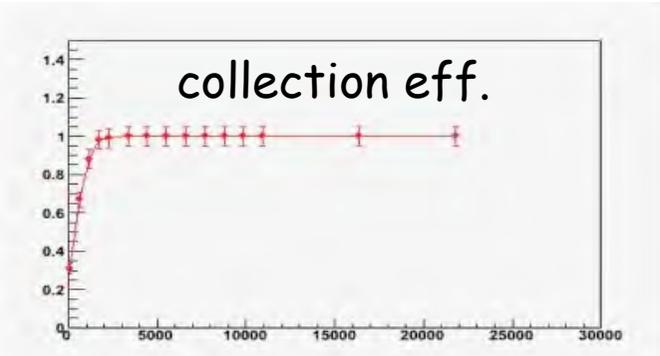
LC also requires High Magnetic Field (3~4 T)



Effect of Magnetic Field

$E_d = 150 \text{ V/cm}$
 $E_t = 300 \text{ V/cm}$
 $\phi = 100 \mu\text{m}$ hole
 $B = 0 \text{ T}$

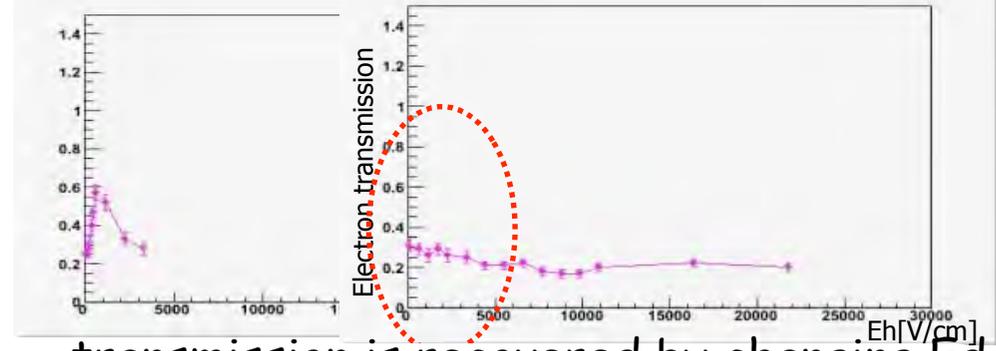
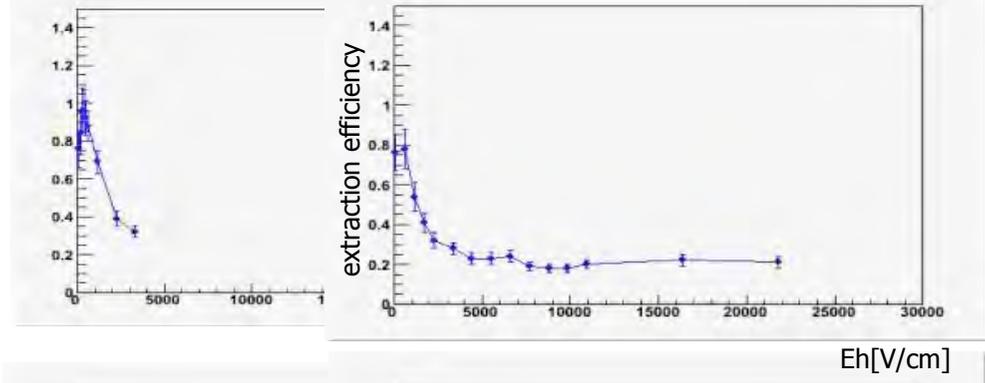
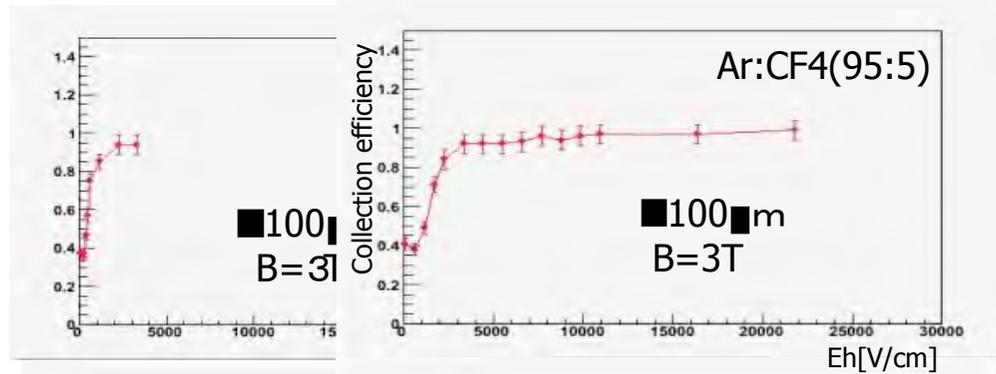
F.Sauli's choice



ArCF4 : candidate of LC-TPC Gas

$E_d = 50 \text{ V/cm}$
 $E_t = 300 \text{ V/cm}$
 $B = 3 \text{ T}$

Effect of 3T magnetic field



transmission is recovered by changing E_d
 But not enough yet

What's happening in B field ?

Collection

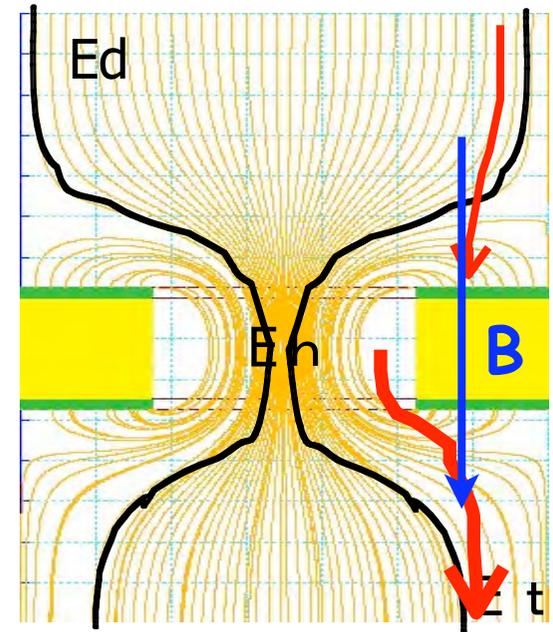
Once electron is attracted to the hole,

$E \times B$ effect make electron rotate around the hole

Reducing E_d change shape of lines around hole

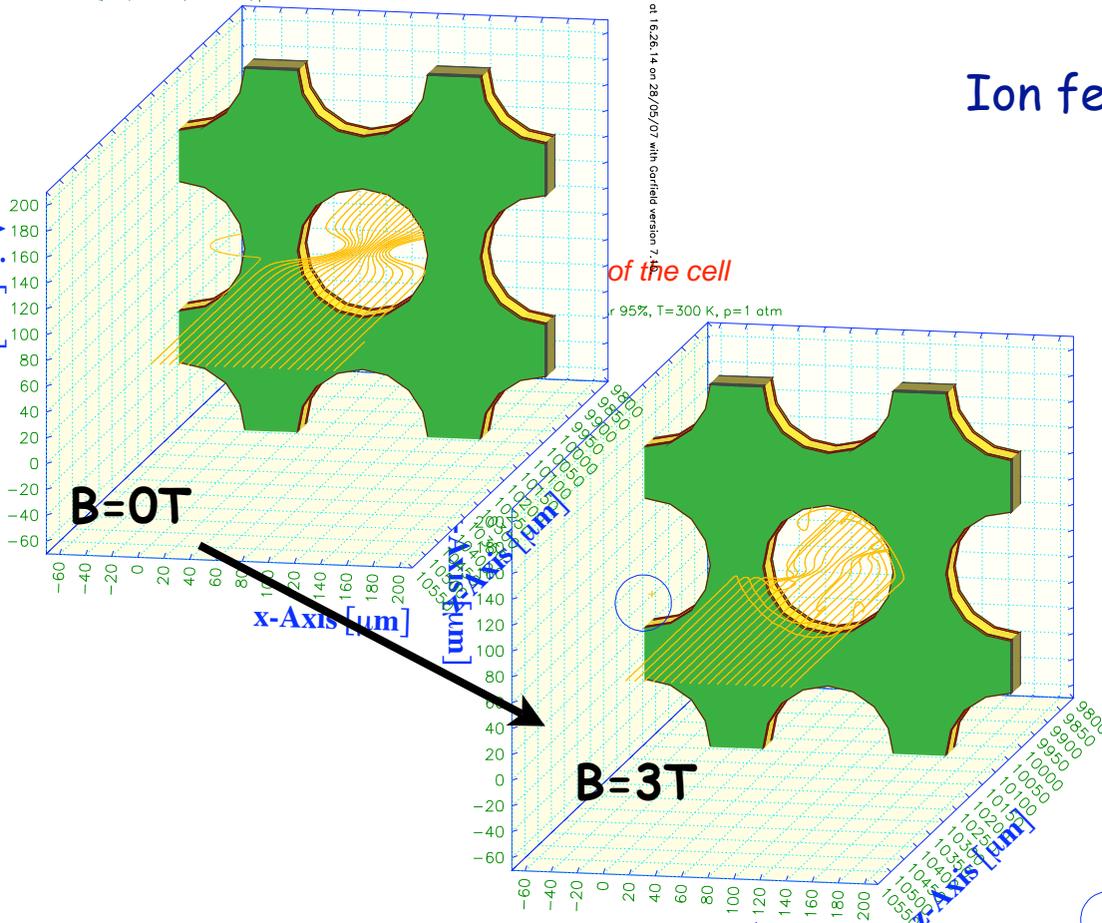
more line from upper GEM electrode and make this effect mild.

So, electrons are spread over whole hole under High B field



Layout of the cell

Gos: CF, 5%, Ar 95%, T=300 K, p=1 atm



Effect is similar to why anti-DID is useful for extraction

Ion feed back must be smaller under B field as ions follow e-filed line.

Extraction

Opposite things happen in extraction. Even electron exist on return field line, B field make electron go along the magnetic field line.

B field help to increase extraction eff.

Optimization of GEM Gating for LC-TPC

High Magnetic Field (3 ~ 4 Tesla)

High WT gas

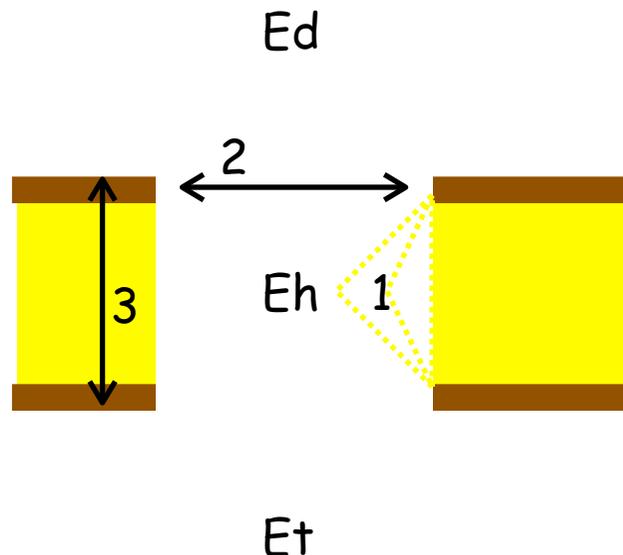
Ar:CF4 is the first candidate for this (w/ iso-C4H10)

Optimization of GEM itself

1. Hole shape
2. Hole Size/pitch
3. thickness

Optimization of operation condition

1. Drift E field : E_d
2. Hole E field (V_{GEM}) : E_h
3. transfer E field : E_t



Thickness of GEM Gate

Gas:

Ar:CF₄ (95:5)

drift Ed 150V/cm
trans. Et 300V/cm

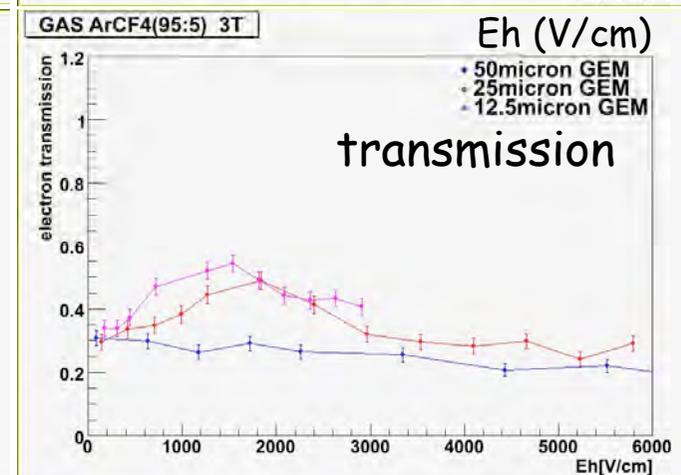
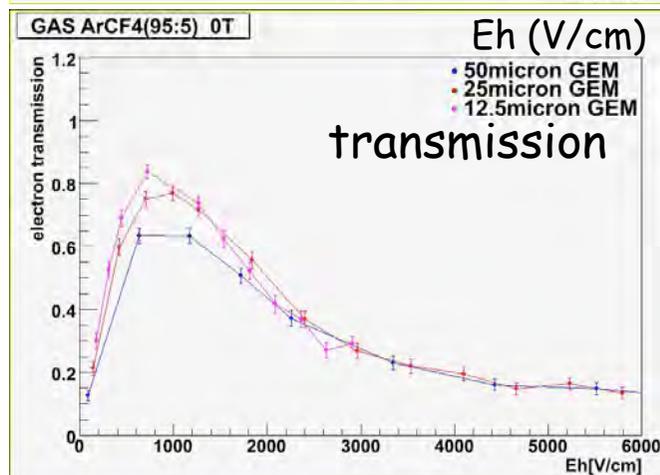
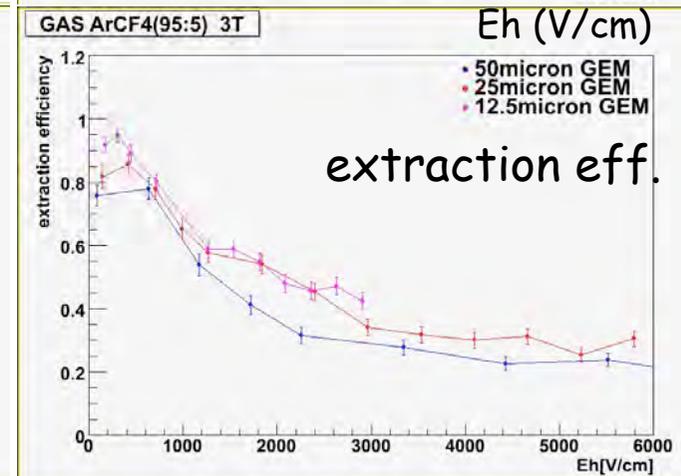
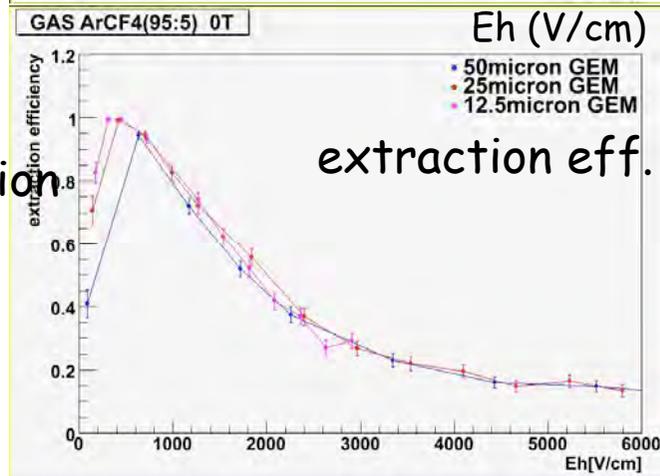
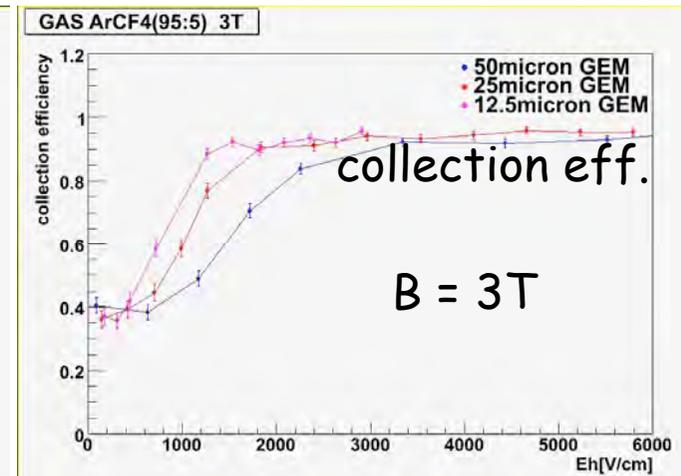
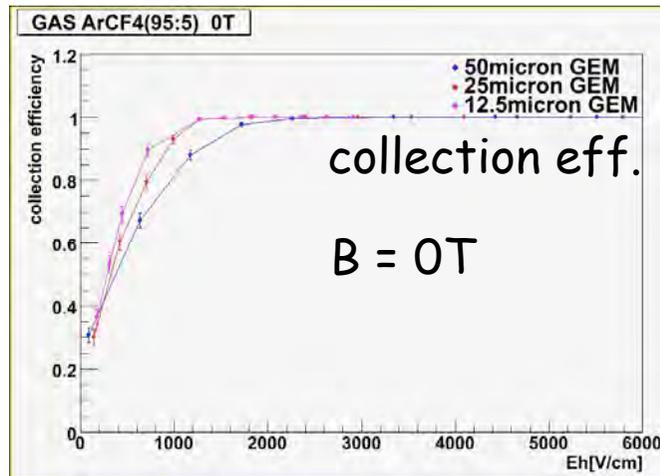
thickness

- + 50 μ m
- + 25 μ m
- + 12.5 μ m

some improvement @ collection

=>

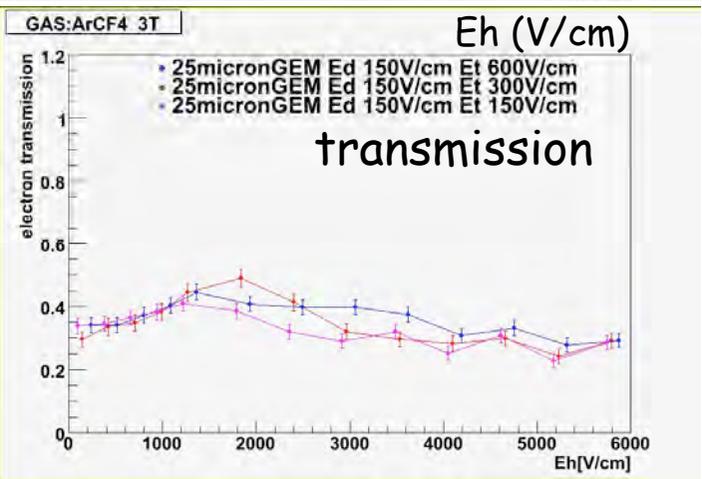
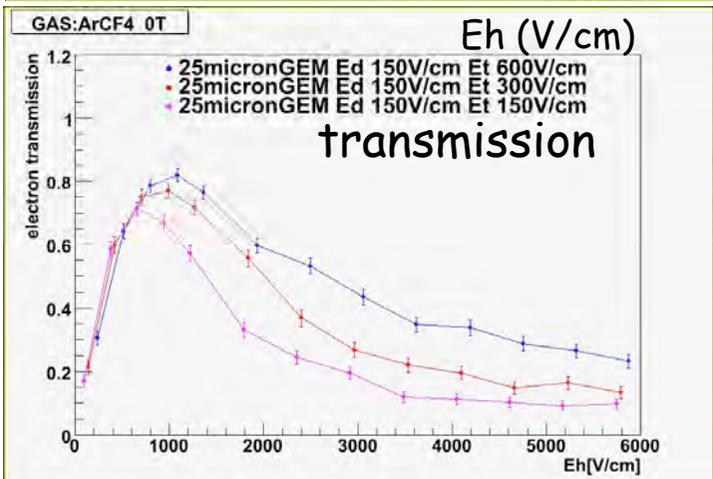
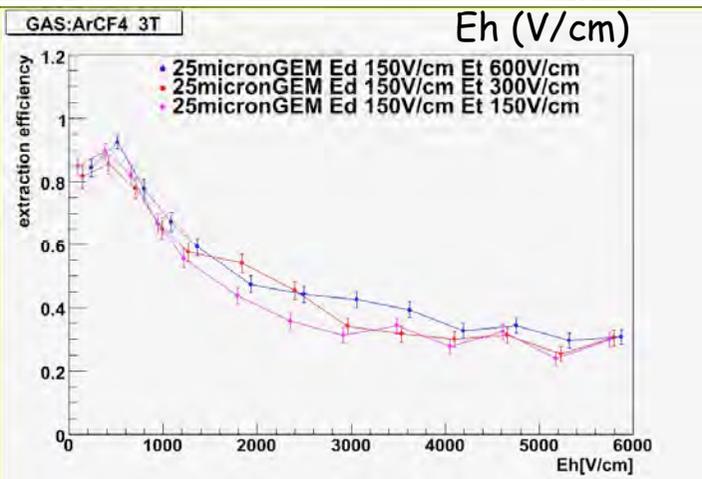
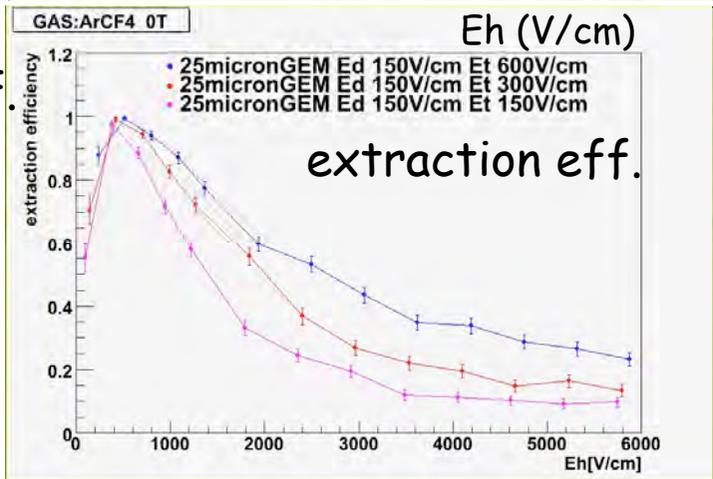
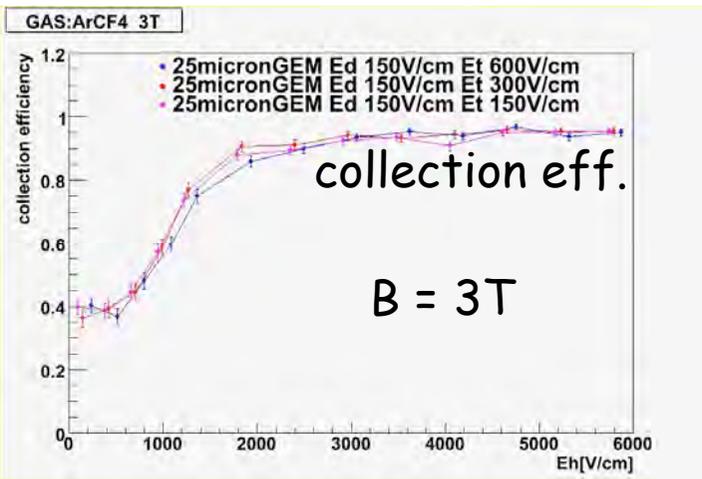
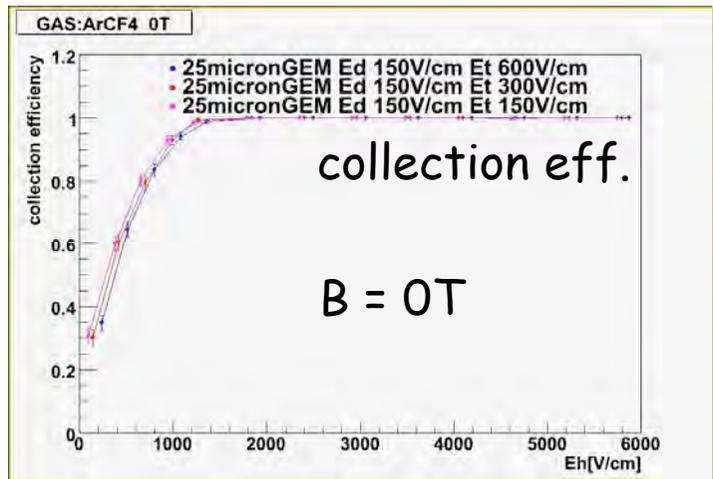
Eh becomes lower
due to thinner gap
(ratio of hole size to thickness)



Effect of Et @25 um thick GEM

drift Ed 150V/cm

trans. Et —+ 600 V/cm
—+ 300 V/cm
—+ 150V/cm



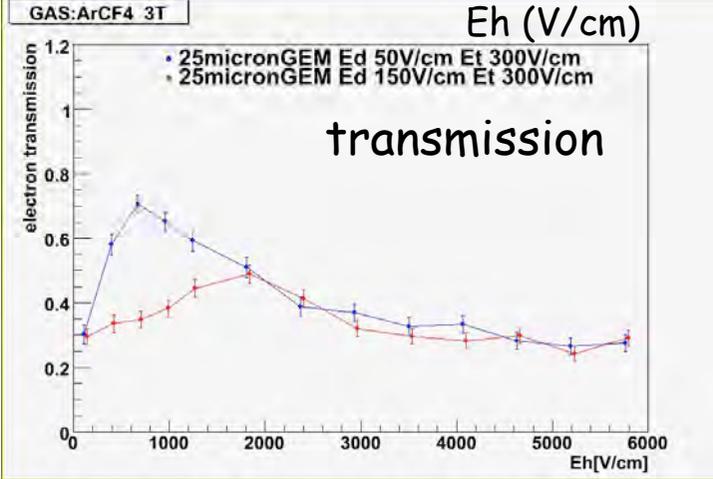
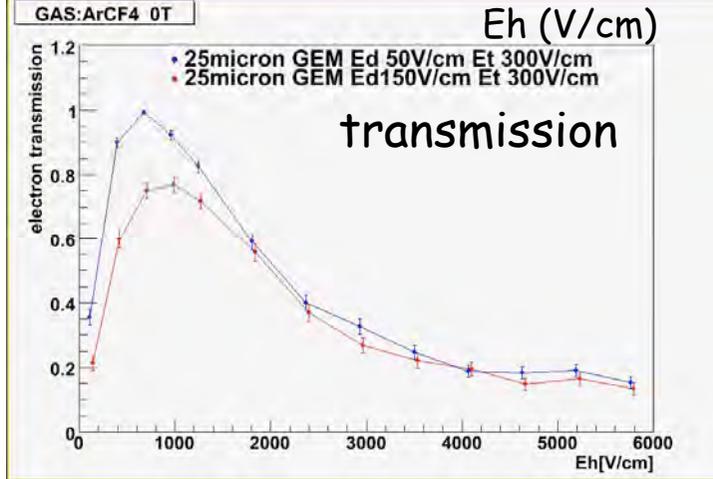
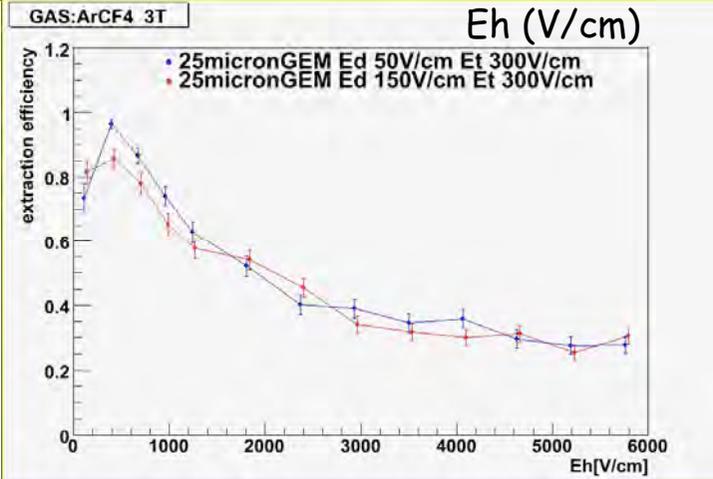
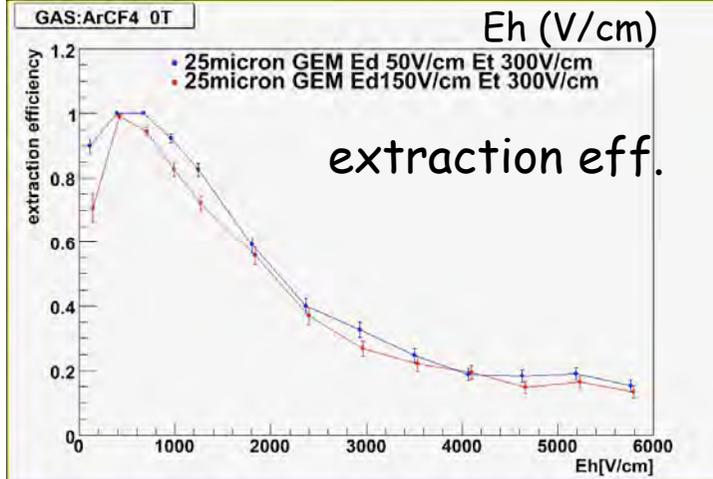
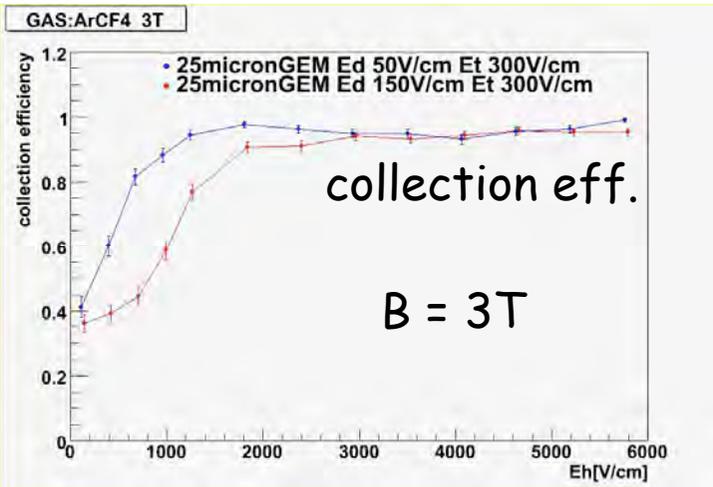
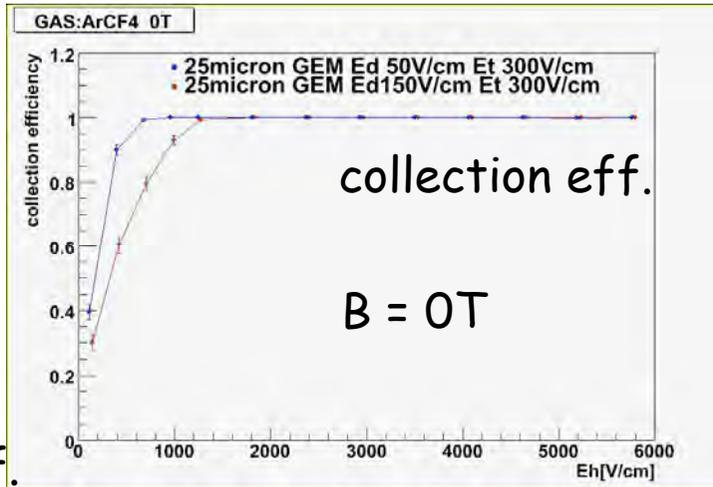
High Et improve extraction eff. very well @ B=0T
 No improvement is observable @B=3T, as extraction eff. is already good

Effect of Ed @25 um thick GEM

drift Et 300V/cm

trans. Ed —+ 50 V/cm
—+ 150 V/cm

Improvement in collection eff.
 comes from Ed/Eh ratio!



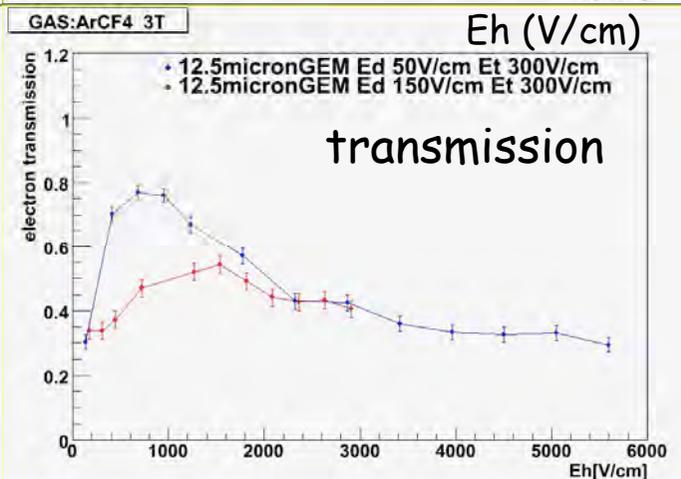
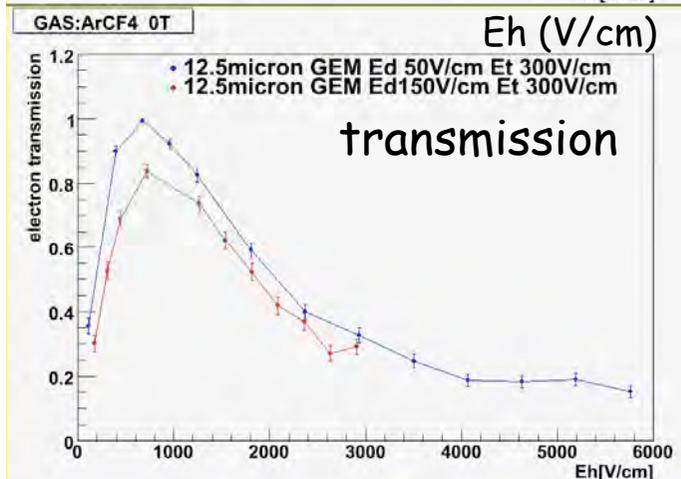
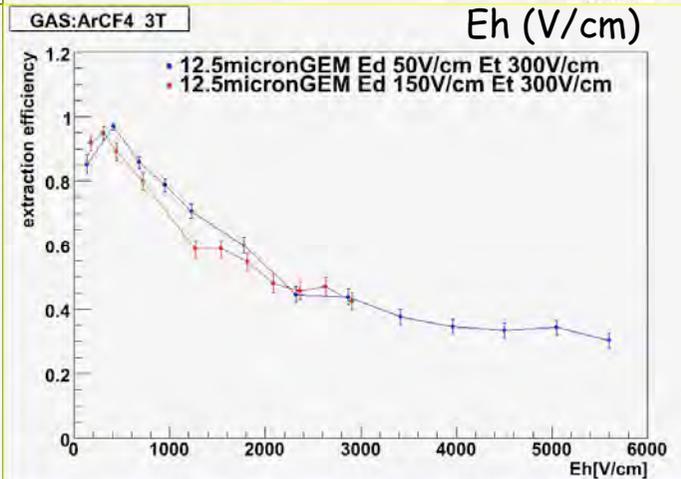
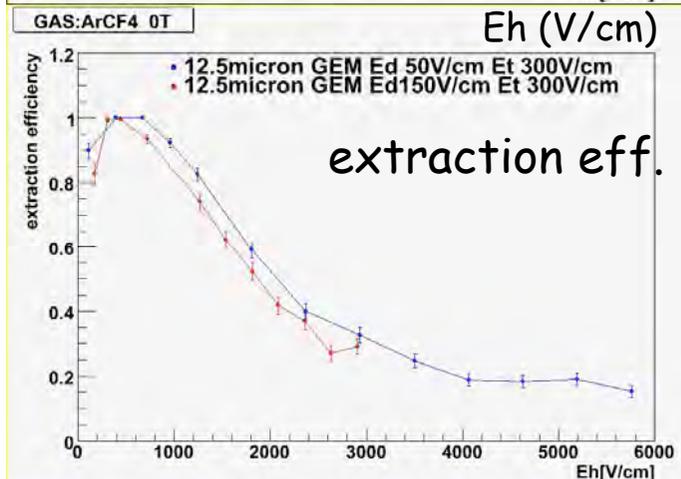
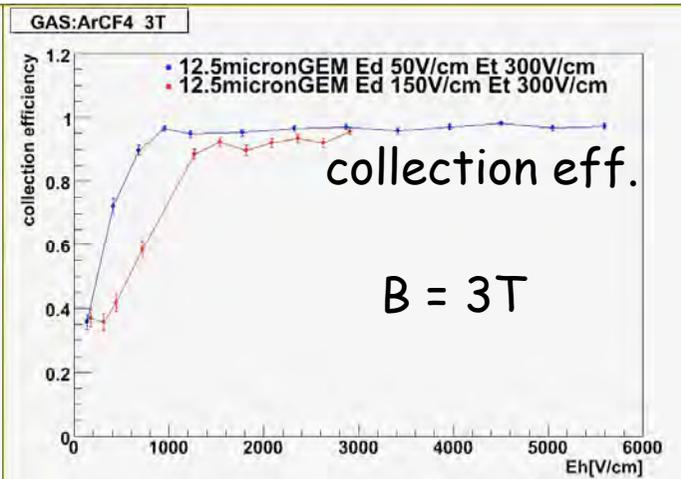
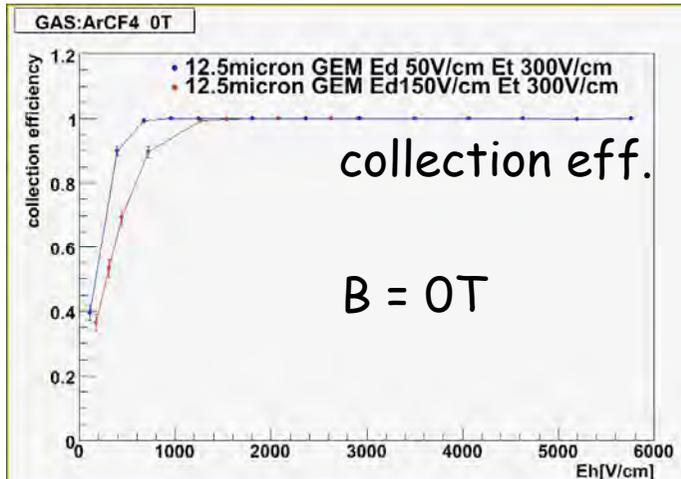
Effect of Ed @12.5 um thick GEM

drift Et 300V/cm

trans. Ed —+ 50 V/cm

—+ 150 V/cm

Improvement comes from Ed/Eh ratio !



Effect of hole size/pitch @25 um thick GEM

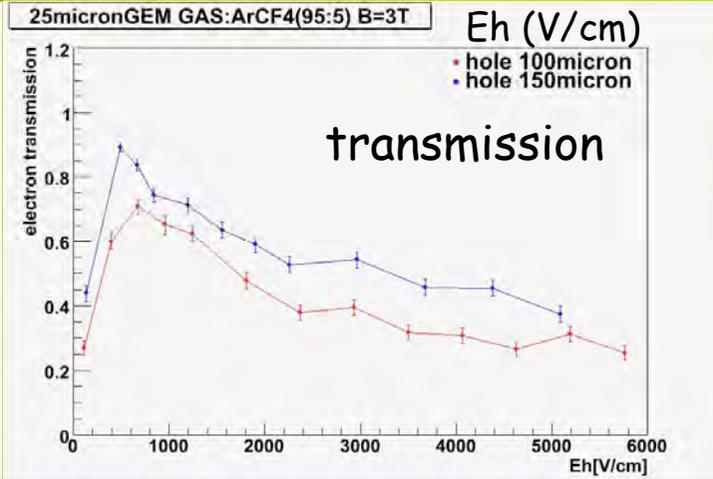
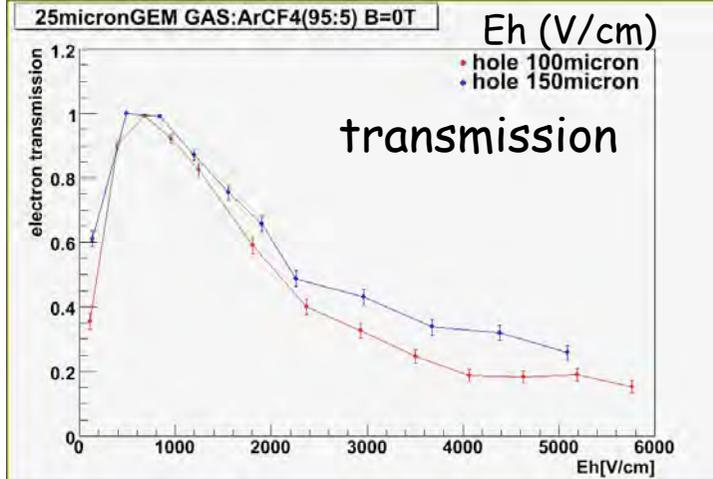
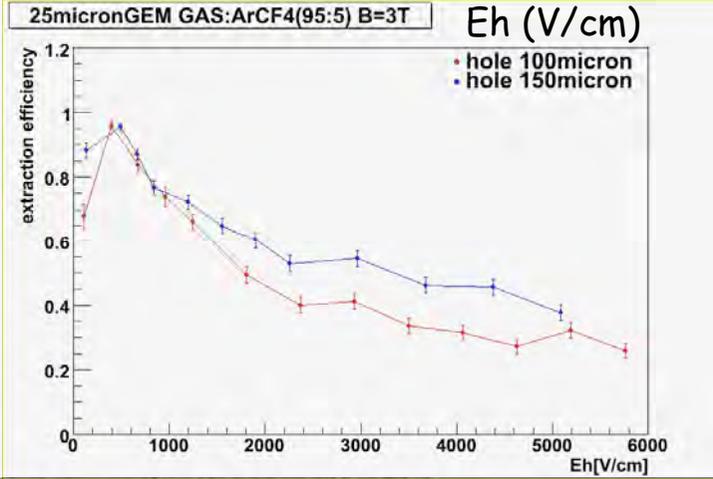
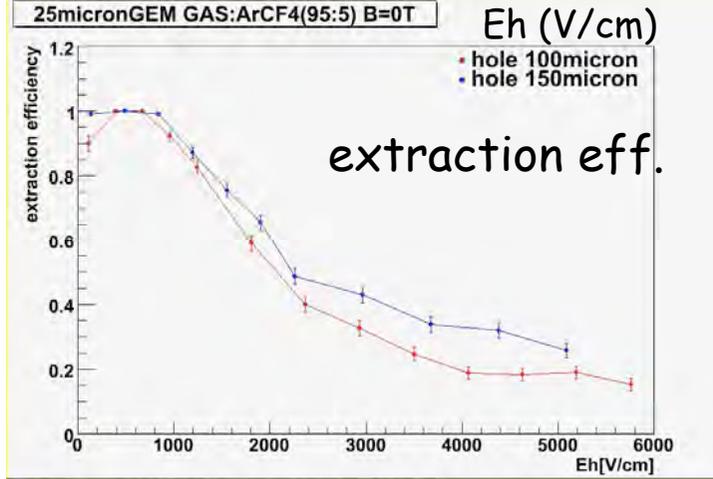
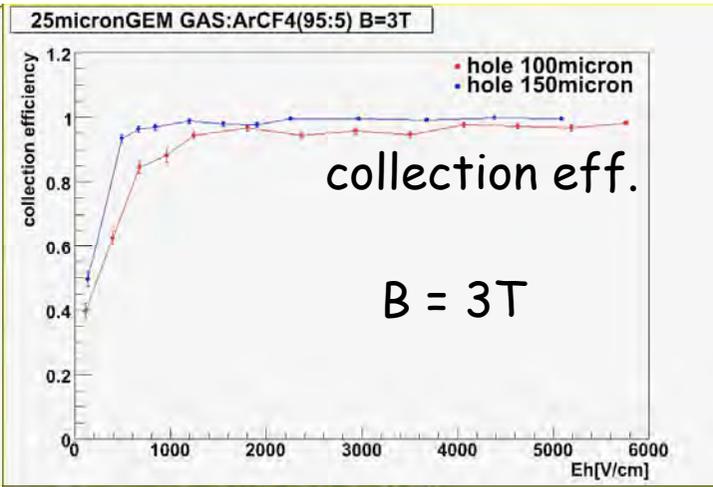
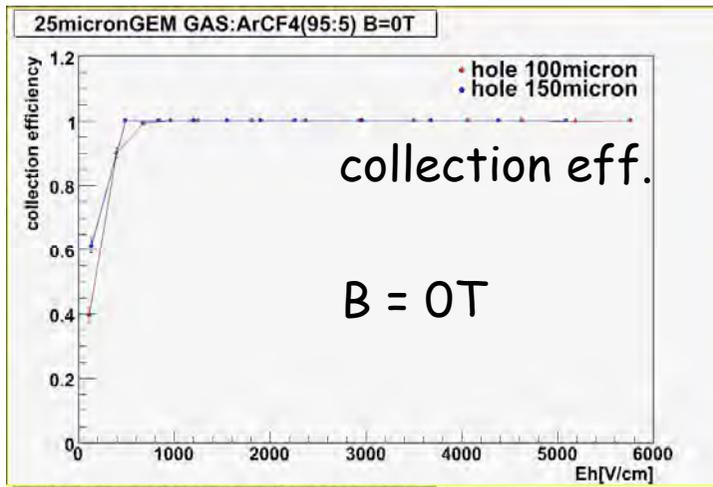
drift Ed 50V/cm
trans. Et 300V/cm

pitch/hole size

- + 190 um/ 150 um ϕ
- + 140 um/ 100 um ϕ

Cauton !

3T case some electrons go to neighbor holes (by $E \times B$...) which make resolution worse

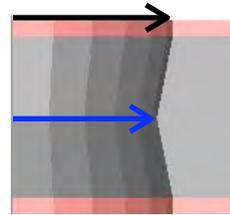


Effect of hole shape

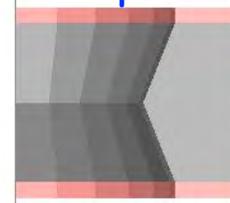
Hole shape

bi-conical shape
outer $\phi=100\ \mu\text{m}$

inner $\phi=90\ \mu\text{m}$



inner $\phi=80\ \mu\text{m}$



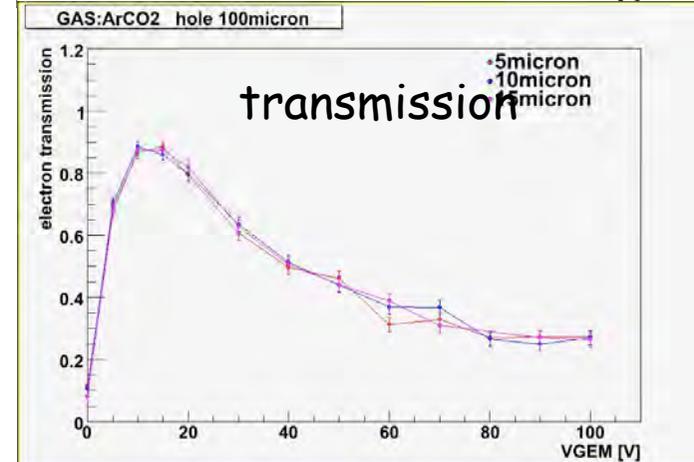
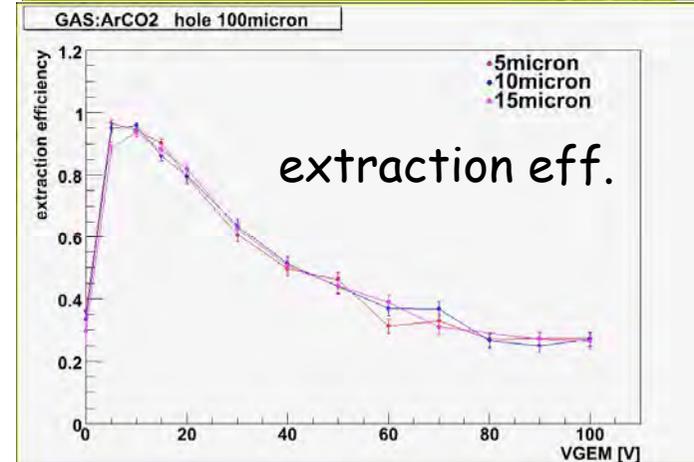
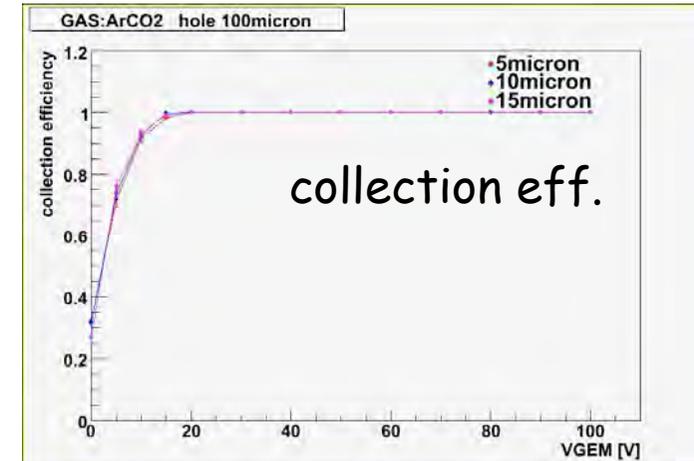
inner $\phi=70\ \mu\text{m}$



Hole shape is not a matter!
Over etching will be also not a matter
under low E field

BUT, under B field
the situation may be changed !?
as B change electron path
(not done yet,
but japanese GEM has straight hole would not be a problem)

$B = 0\text{T}$



Summary of simulation study

If GEM would be used for GATE, it must be

Aperture must be large (larger hole size)

Thinner GEM is better for Gating

Field shaping around hole

Eh need to be kept low (diffusion)

Ed must be low (50V/cm)

Et must be high (300V/cm) (but just below diffusion rise)

We may be able to achieve 70% transmission @25um thick GEM in simulation.

Do you accept this number ??

(10% error may exist)

Confirmation is necessary ! especially under High B field

Need to establish how to measure.

25um thick GEM is available (though hole diameter is 90 um)

Do we try 12.5um for 10% improvement ?

DESY 5T magnet is necessary for this

Let's do together