Study of GEM-TPC for ILC in Japan

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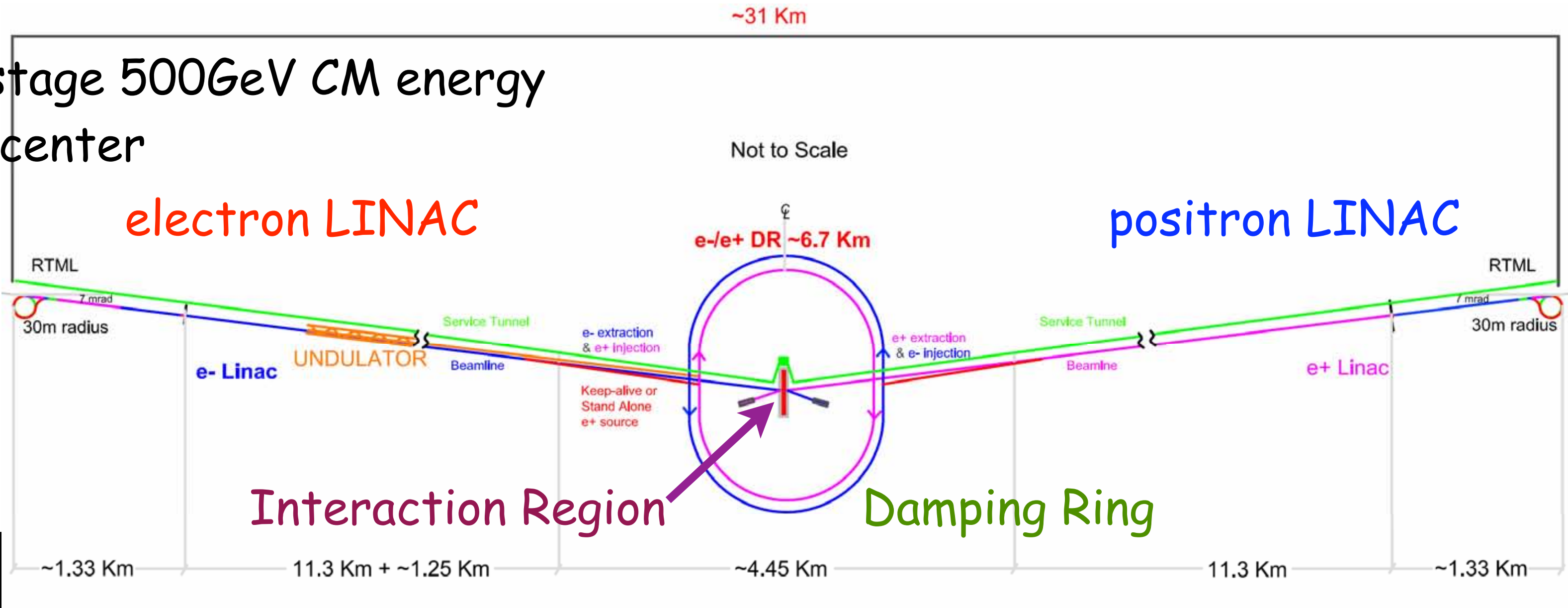
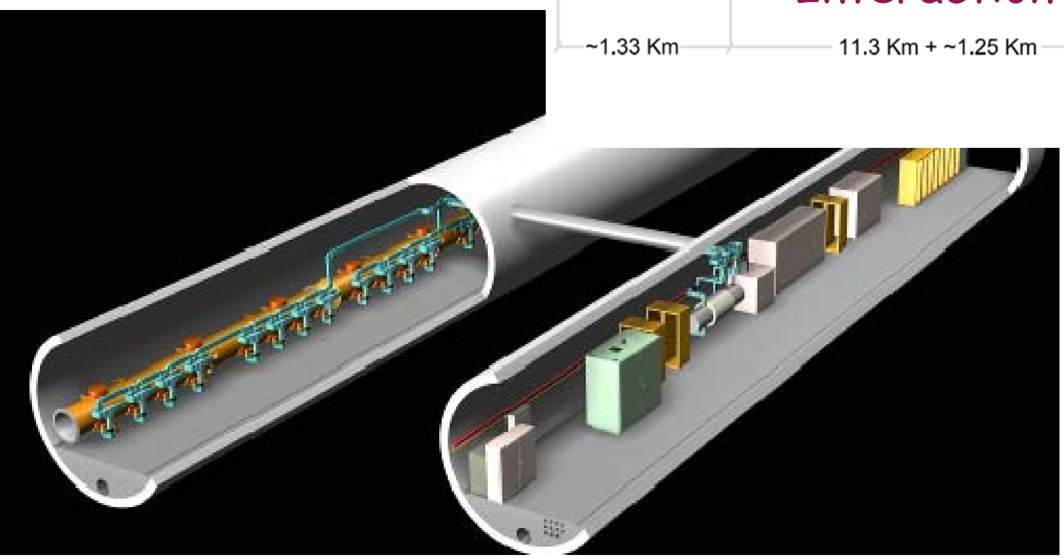
Requirements @ILC
ILC-TPC
results of small prototype test
GEM endplate for Large Prototype
Gating(simulation)

Brief review of ILC 1st Stage: 500 GeV

Total ~31 km at 1st stage 500GeV CM energy
Single dumping ring @center



Schematic Layout of the 500 GeV Machine



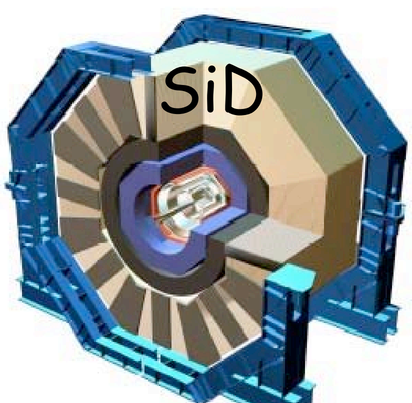
Two tunnels for Linac

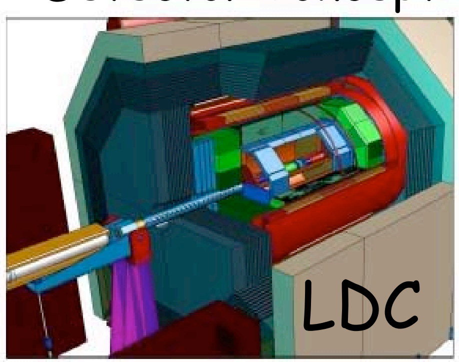
9-cell cavities will provide 31.5MV/m

Expected Cost

4.87 B$
1.78 B$ site specific

Detector Concept



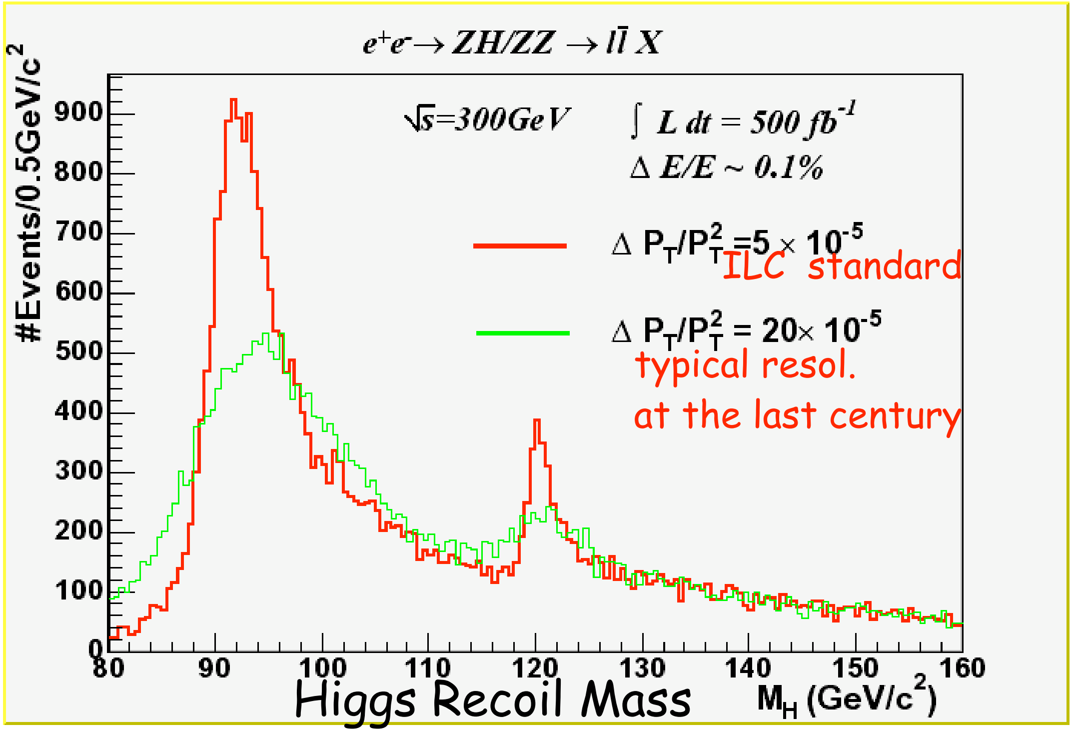


TPC is a main tracker for GLD/LDC

Requirements from ILC

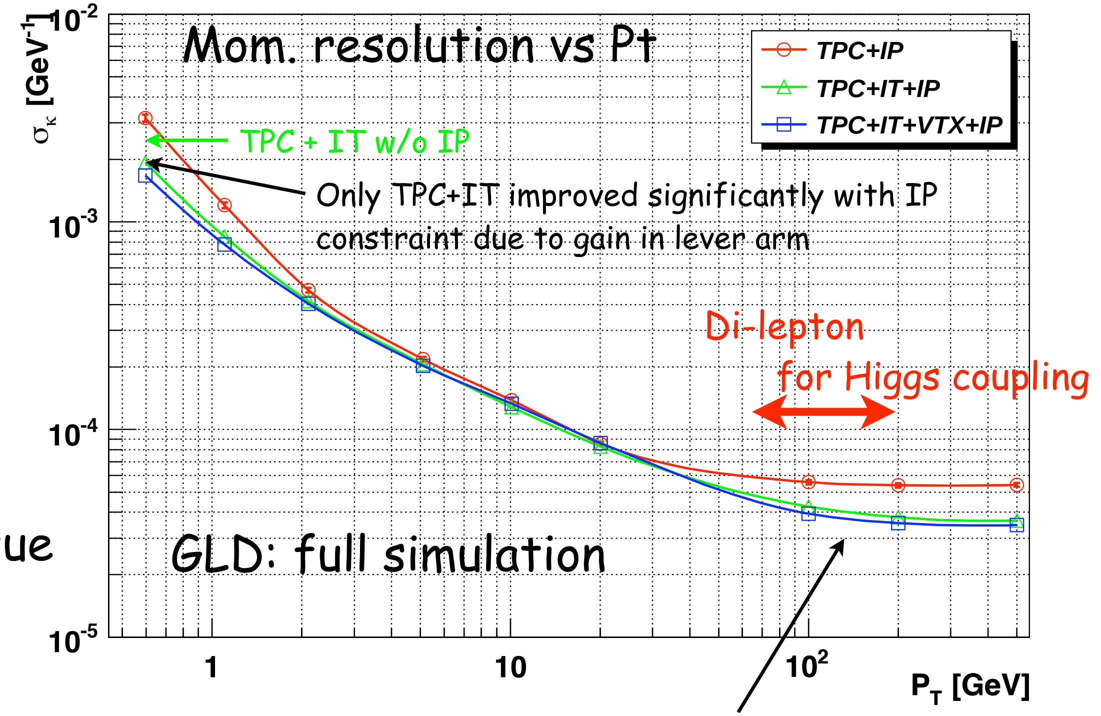
LC TPC has to provide
good momentum resolution
(high mom. tracks
$ee \to ZH$
$\quad \hookrightarrow \ell\ell$

for Higgs coupling measurement



Expected momentum resolution
can be obtained
with 150um (GLD : 100um for LDC)
local position resolution
for TPC
together with IT + VXD

How can we get 100/150um resolution
even for 2m drift



Tracking efficiency is another important issue
for Jet Energy resolution
(ie. Particle Flow Algorithm)

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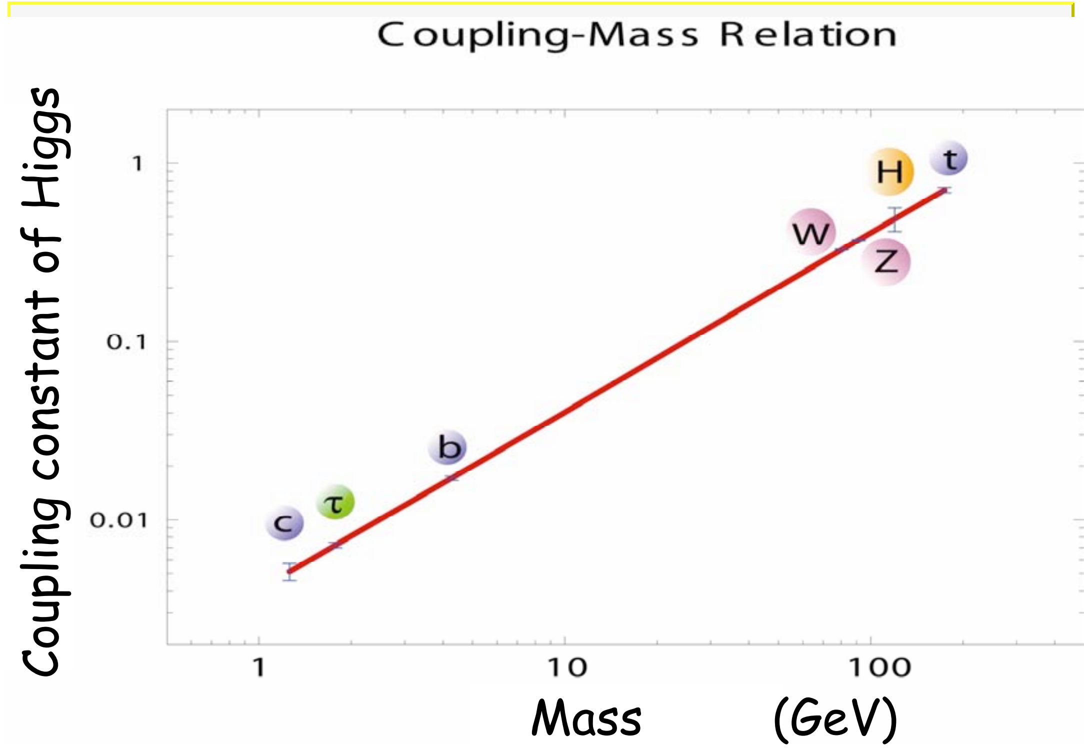

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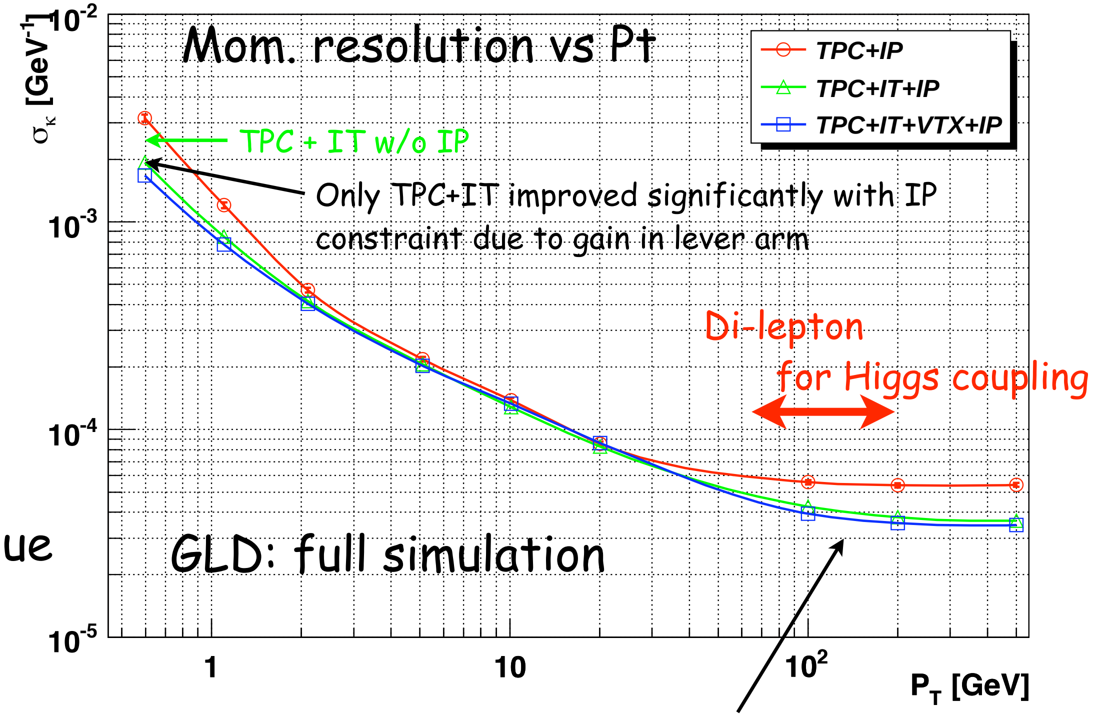
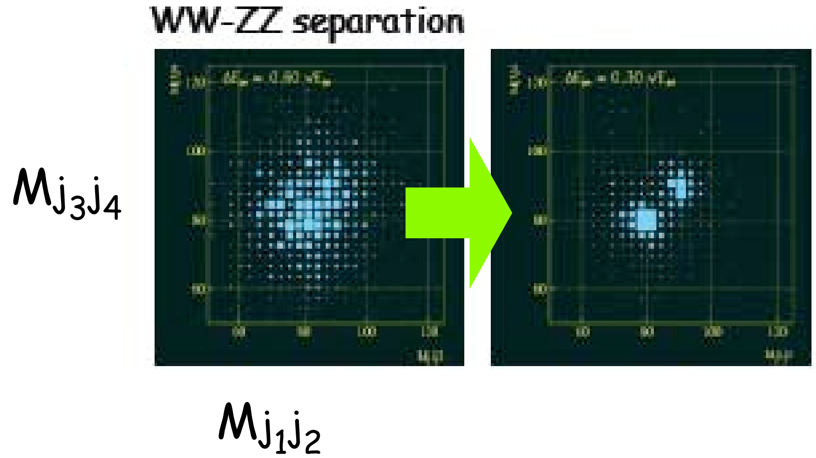


Tracking efficiency is another important issue
for Jet Energy resolution
(ie. Particle Flow Algorithm)

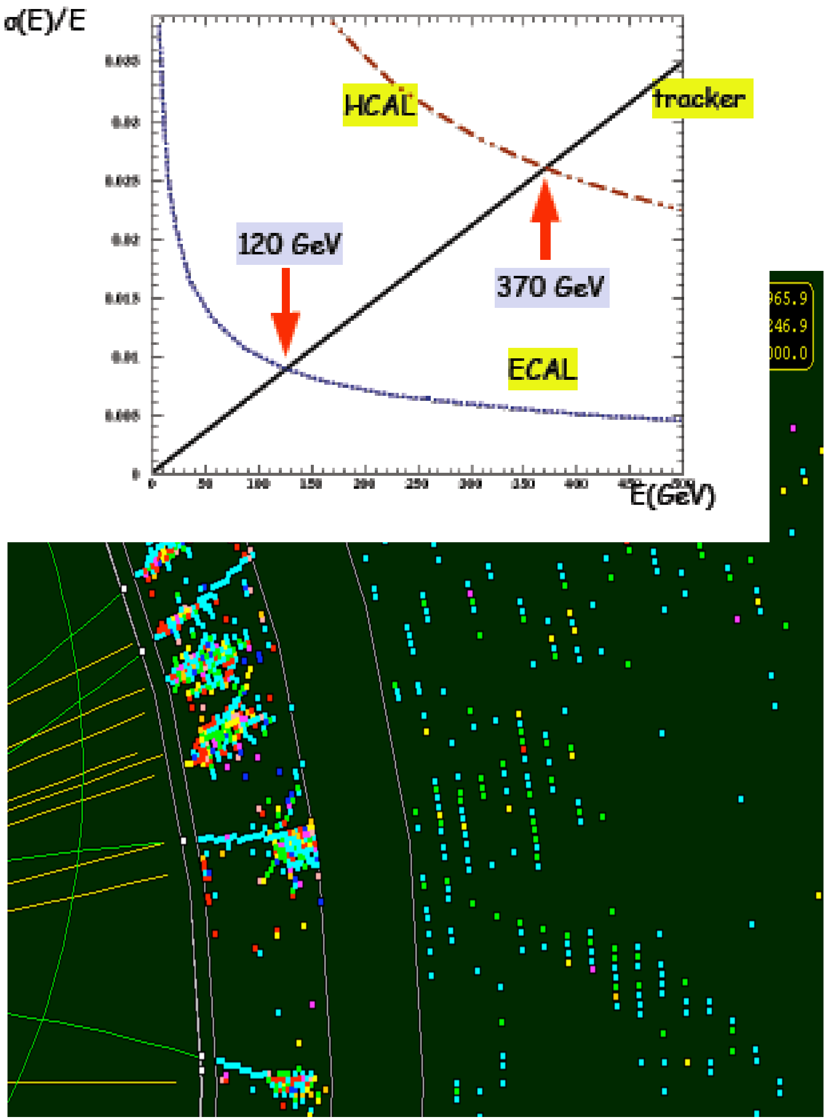
Jet energy resolution using PFA(Particle Flow Algorithm)

dE/E ~ 30%

discrimination of Z/W



Resolution tracker - Calorimeter



HCAL dominate a resolution

Tracker must provide high efficiency

(powerful pattern recognition capability)

rather than high mom. resolution

@ 1 TeV ILC

Detection efficiency

robust tracking

2 track separation

boundary effect

Background @ ILC

mini-jets

2x10^4 tracks/train ~ 10 tracks/bunch

~O(0.3%) occupancy @ innermost raw(r=45cm)

naive estimation

low Pt tracks contribute more(curling)

these rates are dep. on BDS/IR design

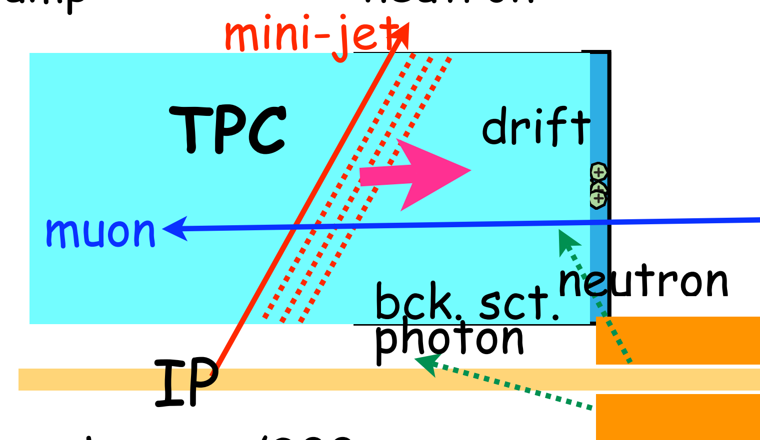
GAS in TPC (H less gas ?)

Physics background

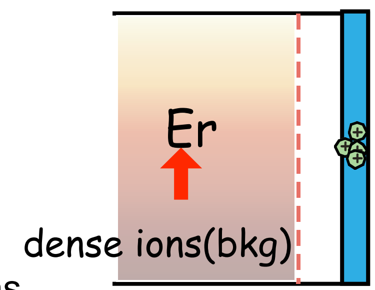
2 photon process - mini jets

Beam background

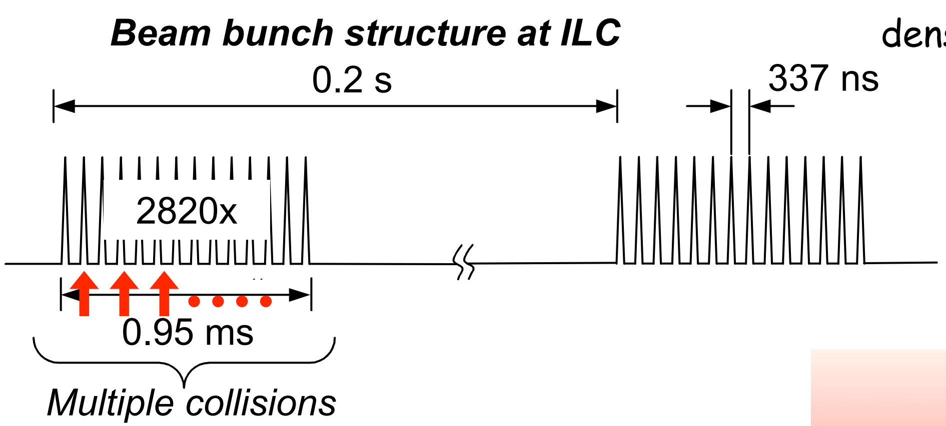
pair background	photon, electrons
disrupted beam	muon
beam dump	neutron



bunch cross/300nsec

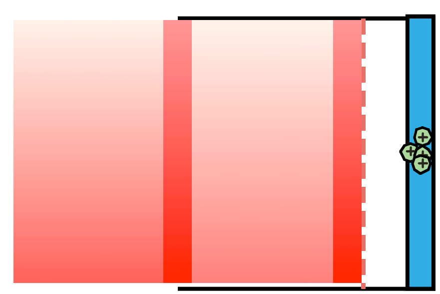


Beam Structure @ ILC



train produce back-drift ions' disk

without "Gate mechanism" for ions



MPGD has a natural ability of gating ions, but it's not perfect.

We need "GATE"ing GRID

Concept of ILC-TPC

good position resolution
~ 100 um

good trk. efficinecy

under realistic bkg. condition &
non-uniform field

low material budget

high B field

Lorentz angle
reduce diffusion effect

maximize hit information
no dead space on endplate

MPGD sensor TPC

with Gate mechanism

micro structure
reduce ExB effect

direct signal
fine readout

MWPC : too large ExB effect

How to achieve 100um resolution

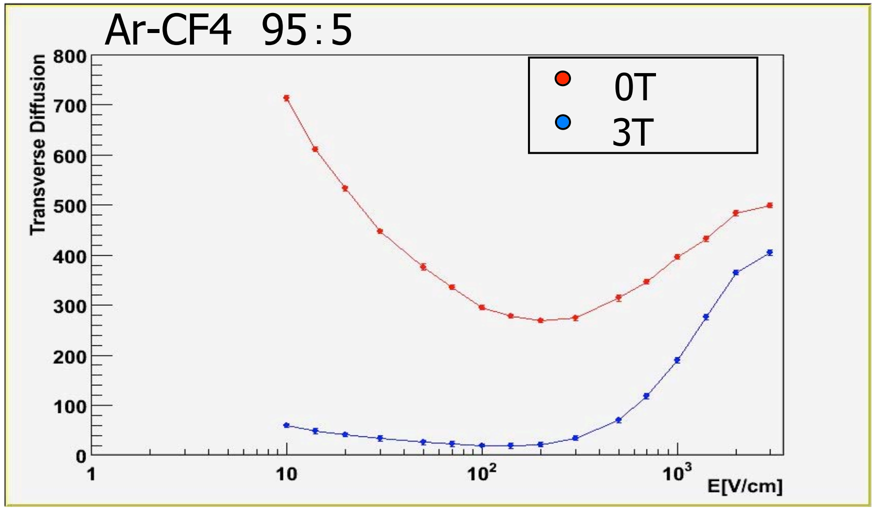
naive expectation of local resolution

$$\sigma_r = \sqrt{\sigma_0^2 + \frac{C_D^2 \cdot z}{N}}$$

this term dominate @ long drift

low diffusion gas @ B field

uncertainty @ MPGD



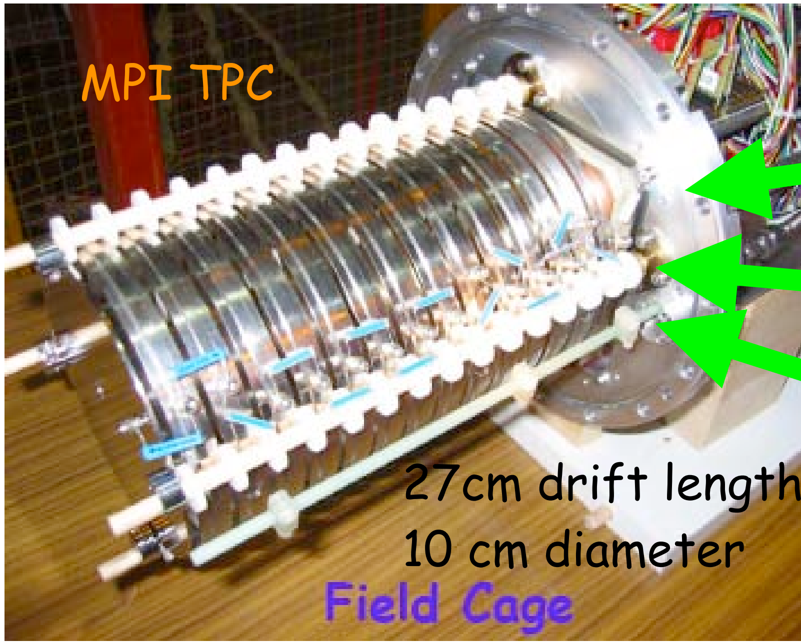
How really resolution behave ?

Issues of **Small Prototype test**

Clarify σ_0 and C_D and N

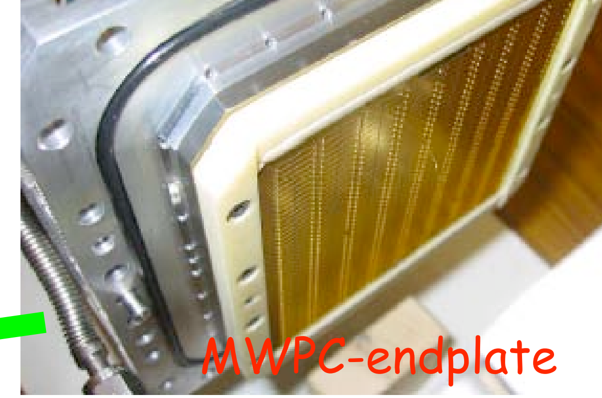
Small Prototype test

Series of prototype TPC tests in Japan



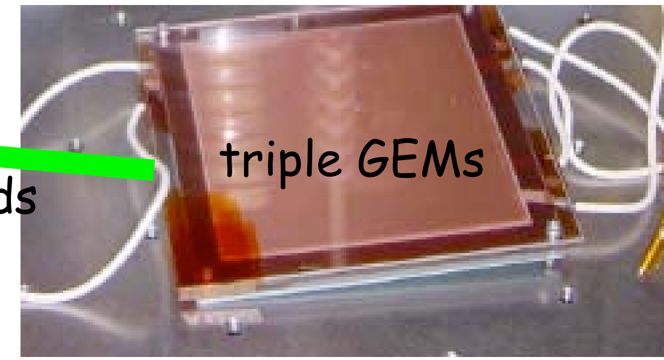
MWPC-TPC

2.3x6.3 mm2 pads
TDR gas



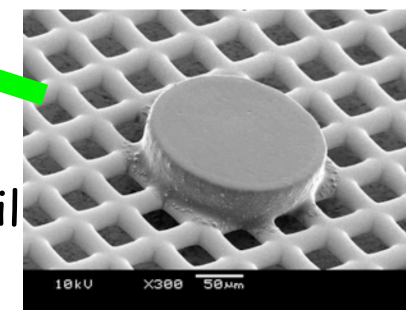
GEM-TPC

1.27x6.3 mm2 pads
TDR, P5 gas



Micromegas-TPC

2.3x6.3 mm2 pads
w/,w/o resistive foil
Ar+isoC4H10 gas



1 T B-field

measurement of diffusion(gas property)

$$\sigma_{SS} = \sqrt{\sigma_{PR}^2 + C_D^2 Z}$$

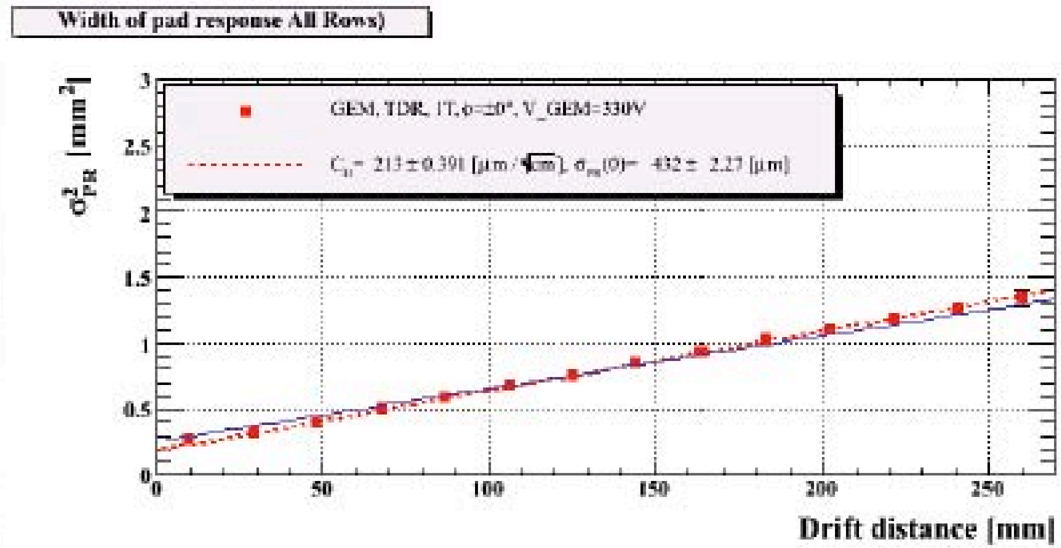
resolution $$\sigma = \sqrt{\sigma_0^2 + \frac{C_D^2 Z}{N_{eff}}}$$

diffusion plot (z dependence)

$$\sigma_{\mathrm{PR}}^2 = \sigma_{\mathrm{PR}_0}^2 + C_d^2 \cdot z$$

TDR gas

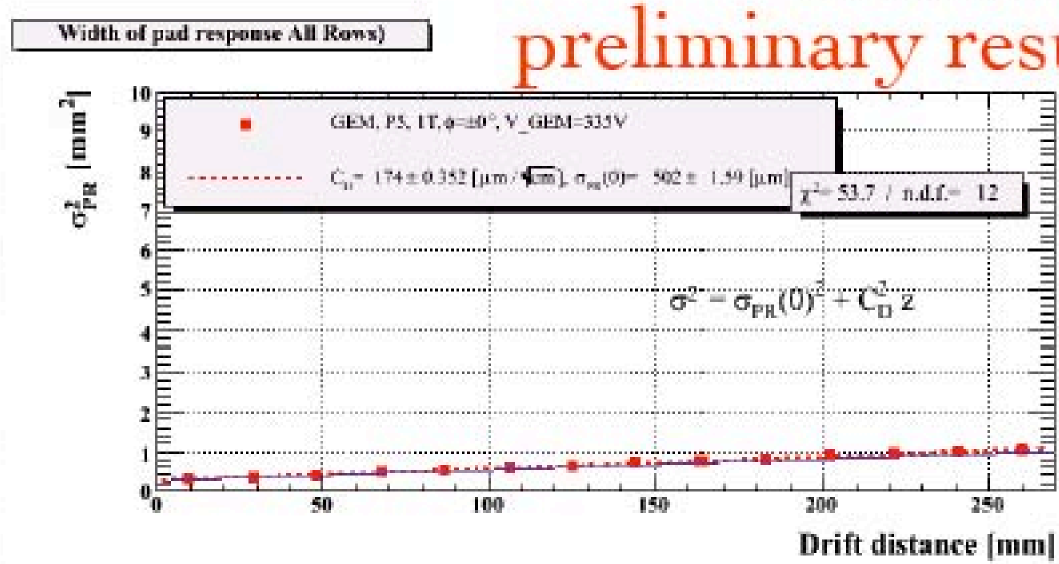
$$C_d = 213.0 \pm 0.4\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$$
$$= 200\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$$



P5

$$C_d = 174.0 \pm 0.4\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$$
$$= 166\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$$

preliminary results



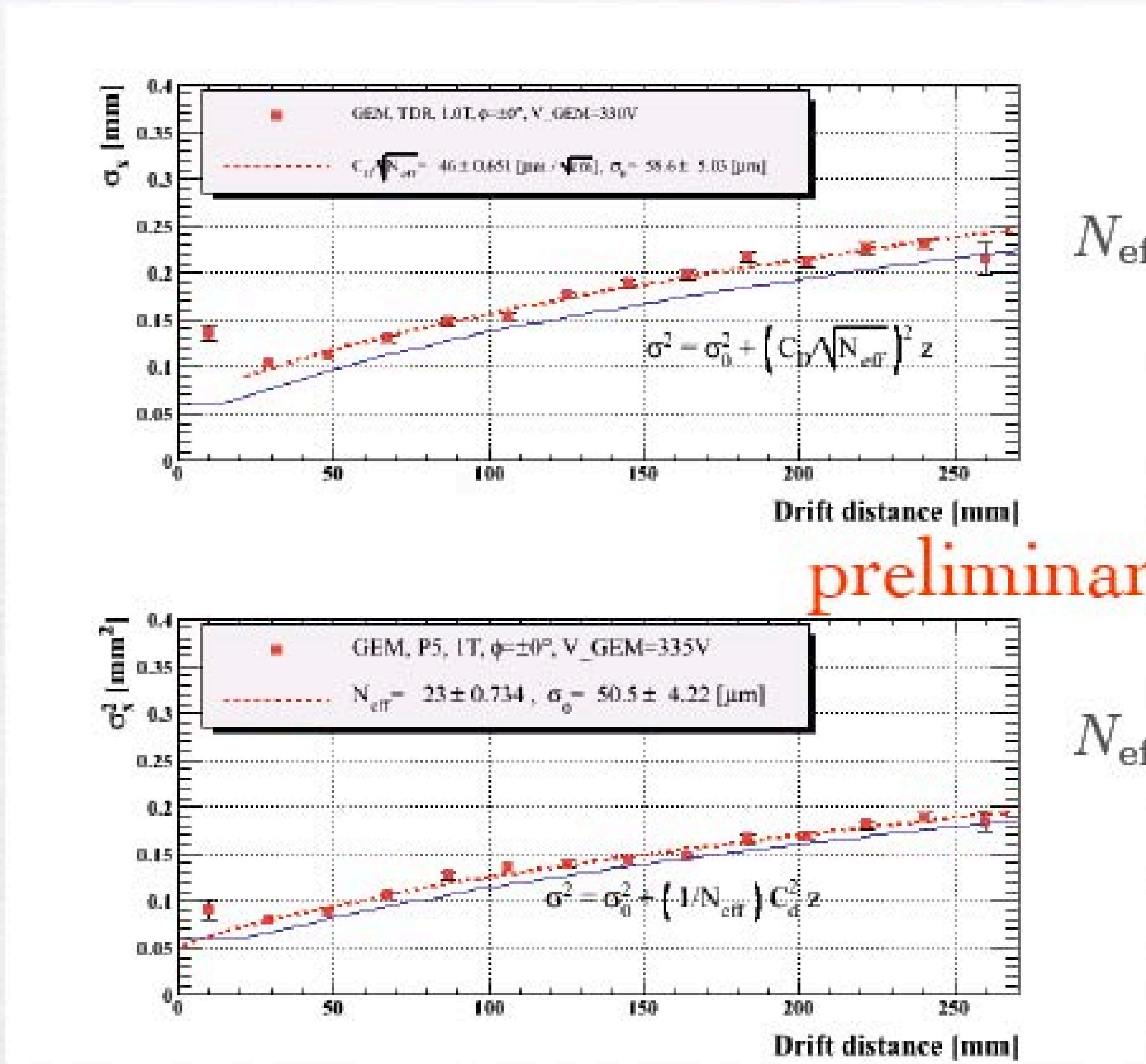
well understood by magboltz

x resolution (z dependence)

$$\sqrt{\sigma_0^2 + \frac{C_D^2 Z}{N_{eff}}}$$

TDR gas

P5



$N_{\mathrm{eff}} = 21.4 \pm 0.3$

preliminary results

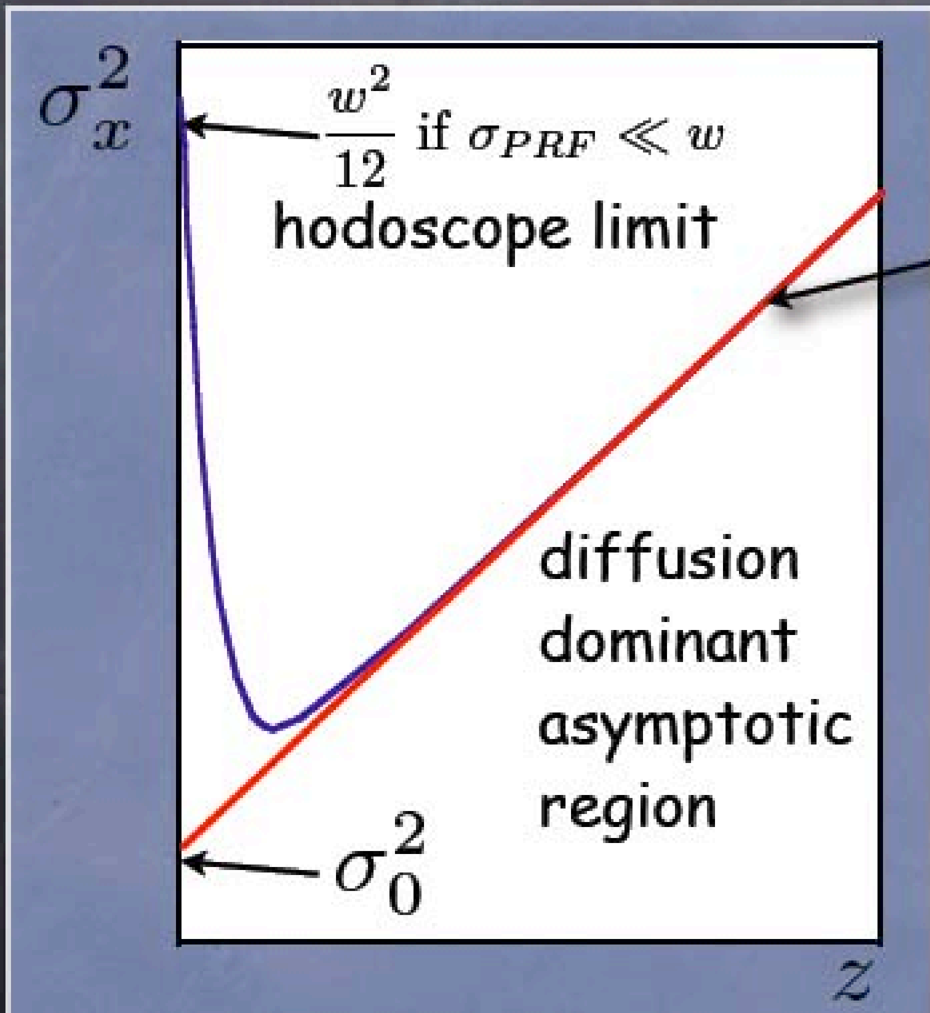
$N_{\mathrm{eff}} = 23.0 \pm 0.7$

$= 22$

Pad length ~ 6mm : we expect N ~ 60 but it was ~20

Two Mysteries

Generic behaviors of resolution with an MPGD endplate when the lateral avalanche spread is much smaller than the pad width



$$\sigma_x^2 = \sigma_0^2 + C_d^2 z / N_{eff}$$

- Why $N_{eff} < \langle N \rangle$?
- What is the origin of $\sigma_0 \equiv \sigma_x(z=0)$?

It's there even if electronic noise is negligible!

Ionization Statistics

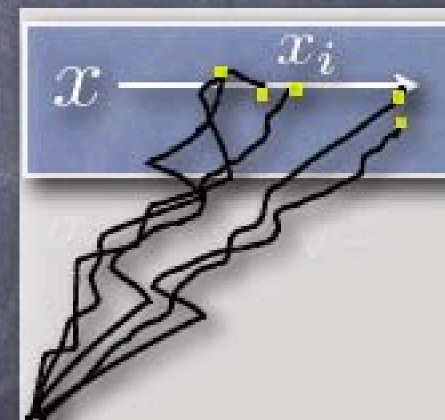
Ideal Readout Plane: Coordinate = Simple C.O.G.

PDF for Center of gravity of N electrons

$$P(\bar{x}) = \sum_{N=1}^{\infty} P_I(N;\bar{N}) \prod_{i=1}^{N} \left(\int dx_i P_D(x_i;\sigma_d) \right) \delta \left(\bar{x} - \frac{1}{N} \sum_{i=1}^{N} x_i \right)$$

Gaussian diffusion

Ideal readout plane



$$P_D(x_i;\sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d} \exp\left(-\frac{x_i^2}{2\sigma_d^2} \right)$$

$$\sigma_d = C_d\sqrt{z}$$

$$\sigma_{\bar{x}}^2 \equiv \int d\bar{x}\, P(\bar{x})\, \bar{x}^2 = \sigma_d^2 \left\langle \frac{1}{N} \right\rangle \equiv \sigma_d^2 \frac{1}{N_{eff}}$$

$$\boxed{N_{eff} \equiv 1/\left\langle 1/N \right\rangle < \left\langle N \right\rangle}$$

Gas Gain Fluctuation

Coordinate = Gain-Weighted Mean

PDF for Gain-Weighted Mean of N electrons

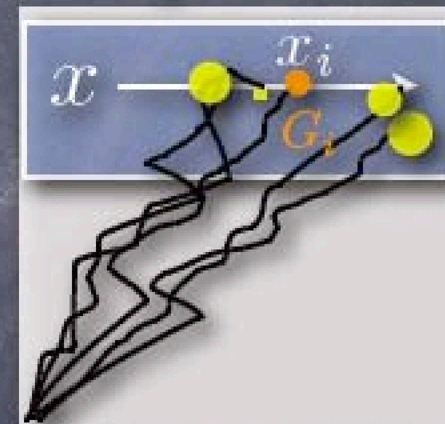
$$P(\bar{x}) = \sum_{N=1}^{\infty} P_I(N;\bar{N}) \prod_{i=1}^{N} \left(\int dx_i P_D(x_i;\sigma_d) \int d(G_i/\bar{G})\, P_G(G_i/\bar{G};\theta) \right) \delta\left(\bar{x} - \frac{\sum_{i=1}^{N} G_i x_i}{\sum_{i=1}^{N} G_i} \right)$$

Gaussian diffusion as before

Gas gain fluctuation (Polya)

Gain-weighted mean

$$\theta = \begin{cases} 0 & : \ \text{exp.} \\ \infty & : \ \delta\text{-fun} \end{cases}$$



$$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)} \left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left(-(\theta+1) \left(\frac{G}{\bar{G}}\right) \right)$$

$$\sigma_{\bar{x}}^2 \equiv \int d\bar{x}\, P(\bar{x})\, \bar{x}^2 = \sigma_d^2 \left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}}\right)^2 \right\rangle \equiv \sigma_d^2 \frac{1}{N_{eff}}$$

$$\boxed{N_{eff} = \left[\left\langle \frac{1}{N} \right\rangle \left\langle \left(\frac{G}{\bar{G}}\right)^2 \right\rangle \right]^{-1} = \frac{1}{\langle \frac{1}{N} \rangle} \left(\frac{1+\theta}{2+\theta} \right) < \langle N \rangle}$$

Finite Size Pads

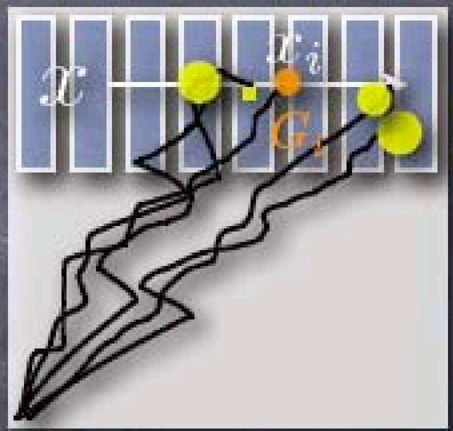
Coordinate = Charge Centroid

track position

$$x_i = \tilde{x} + \Delta x_i$$

diffusion

$$\langle \Delta x^2 \rangle = \sigma_d^2 = C_d^2 z$$



Charge on Pad j

Electronic noise

$$\langle \Delta Q^2 \rangle = \sigma_E^2$$

$$Q_j = \sum_{i=1}^{N} G_i \cdot f_j(\tilde{x} + \Delta x_i) + \Delta Q_j,$$

Normalized response fun. for pad j

$$\sum_j f_j(\tilde{x} + \Delta x_i) = 1$$

Charge Centroid

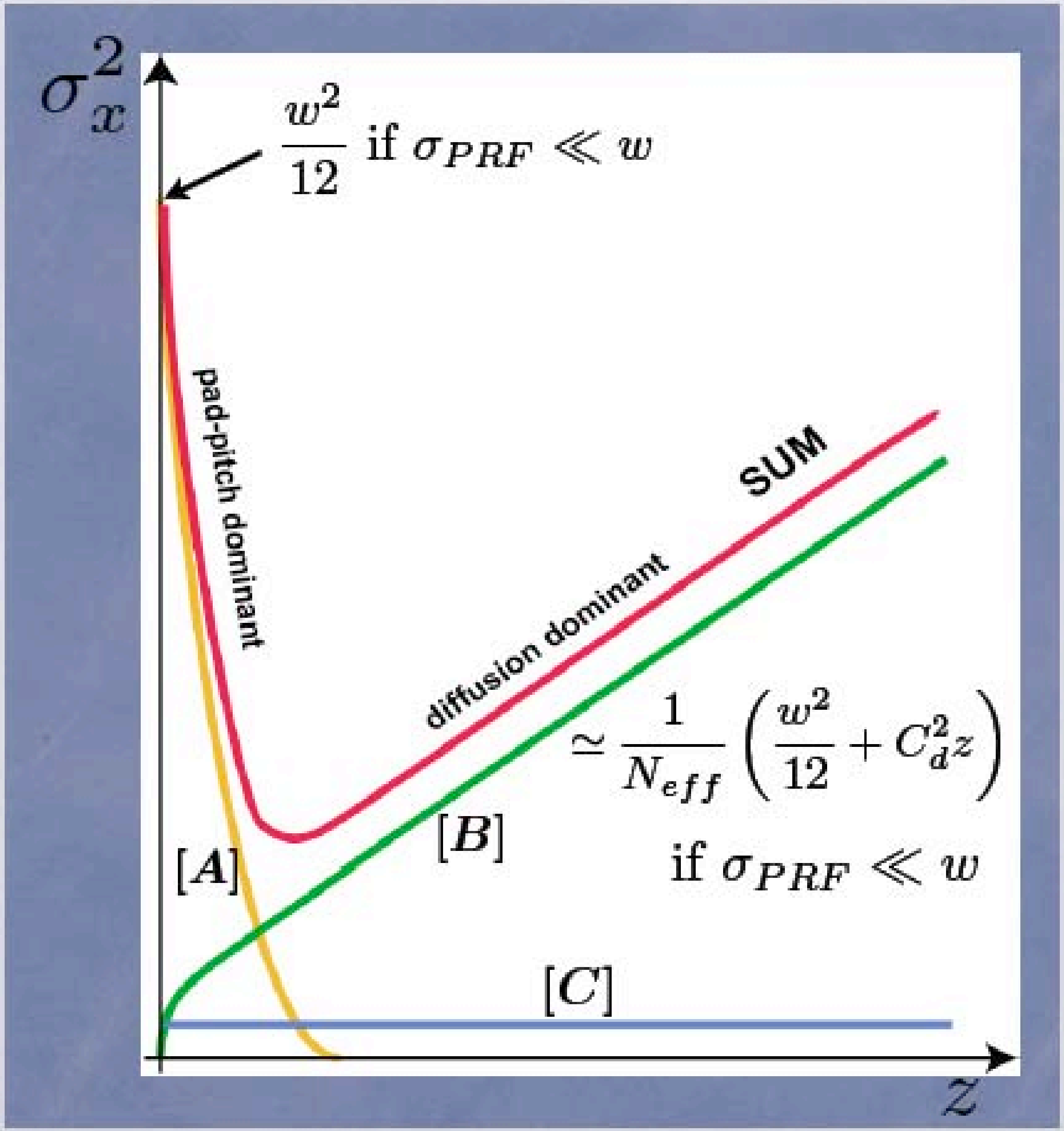
Pad pitch

$$\bar{x} = \sum_j Q_j \, (wj) / \sum_j Q_j$$

PDF for Charge Centroid

$$\begin{aligned} P(\bar{x}; \tilde{x}) \;\; = \;\; & \sum_{N=1}^{\infty} P_I(N; \bar{N}) \prod_{i=1}^{N} \left(\int d\Delta x_i P_D(\Delta x_i; \sigma_d) \int d(G_i/\bar{G}) \, P_G(G_i/\bar{G}; \theta) \right) \\ & \times \prod_j \left(\int d\Delta Q_j \; P_E(\Delta Q_j; \sigma_E) \; \int dQ_j \; \delta \left(Q_j - \sum_{i=1}^{N} G_i \cdot f_j(\tilde{x} + \Delta x_i) - \Delta Q_j \right) \right) \\ & \times \delta \left(\bar{x} - \frac{\sum_j Q_j \, (wj)}{\sum_j Q_j} \right) \end{aligned}$$

Interpretation



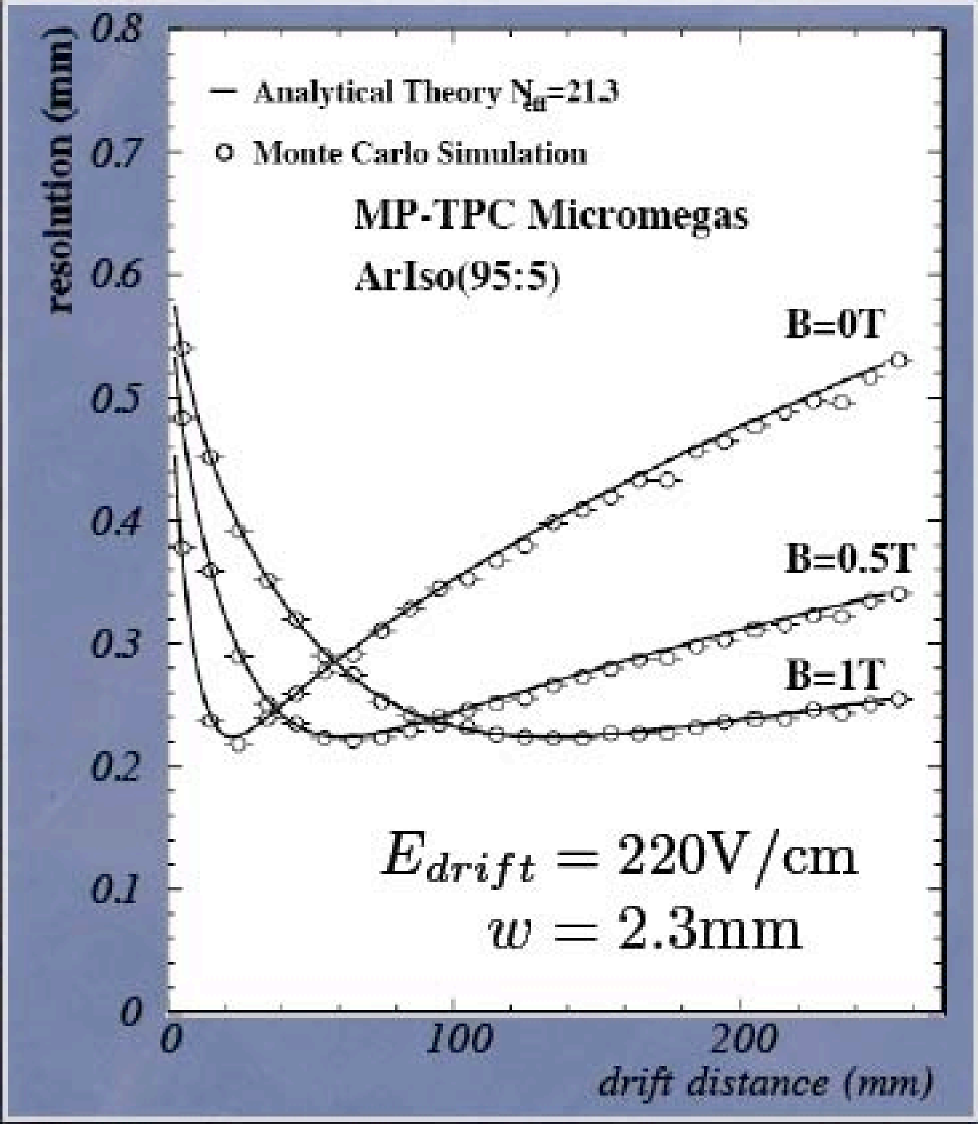
[A] Purely geometric term (S-shape systematics from finite pad pitch): rapidly disappears as Z increases

[B] Diffusion, gas gain fluctuation & finite pad pitch term: scales as $1/N_{eff}$, for delta-fun like PRF asymptotically:

$$\sigma_{\bar{x}}^2 \simeq \frac{1}{N_{eff}}\left(\frac{w^2}{12} + C_d^2 z\right)$$

[C] Electronic noise term: Z-independent, scales as $\langle 1/N^2 \rangle$

Comparison with MC



- Theory reproduces the Monte Carlo simulation very well !
- We can estimate the resolution analytically

drift distance

$$\sigma_x = \sigma_x(z; w, C_d, N_{eff}, [f_j])$$

pad pitch

diffusion const.

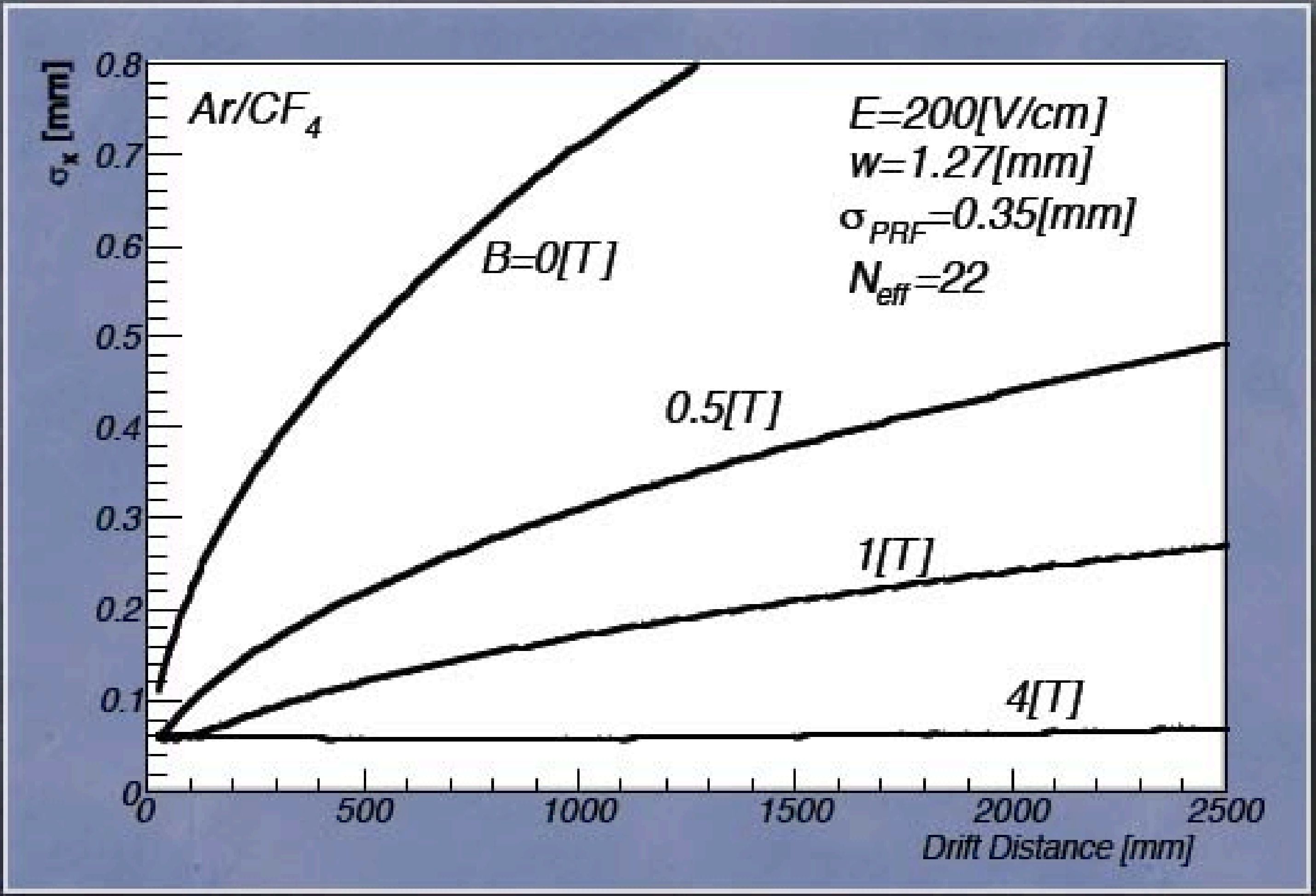
pad response function

δ-fun. for MM: $\sigma_{PRF} \simeq 12\mu\mathrm{m}$

gauss. for GEM: $\sigma_{PRF} \simeq 350\mu\mathrm{m}$

Extrapolation to LC TPC

Sample calculation for GEM with Ar/CF4



GEM in Ar/CF4: promising but needs R&D

We may achieve required resolution in principle.

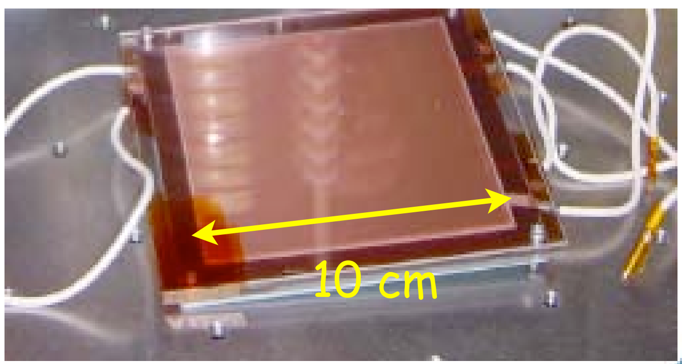
In order to avoid hod-scope effect

Diffusion @GEM must be larger than 0.3 x pad-pitch

Diffusion @ E~2-3kV/cm
transfer + induction gap ⟷ pad pitch ~ 1 mm

How do we achieve performance under realistic condition

Small Prototype



consideration of realistic GEM panel

How to reduce dead reagion

LargePrototype(LP1)

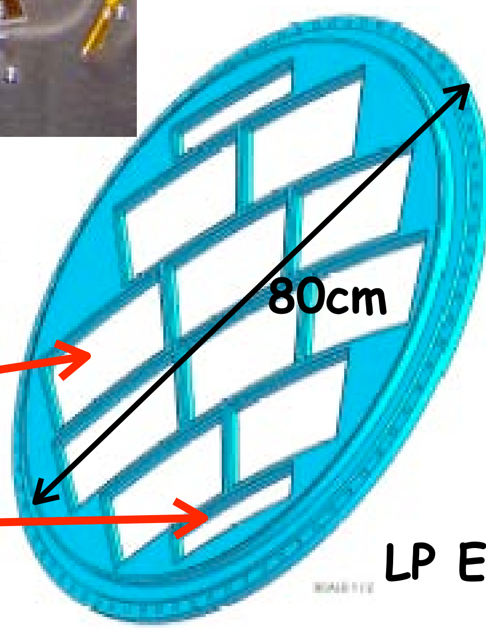
Size of panel

Panel boudary

mounting method of GEM

Gate

GEM/MM panel

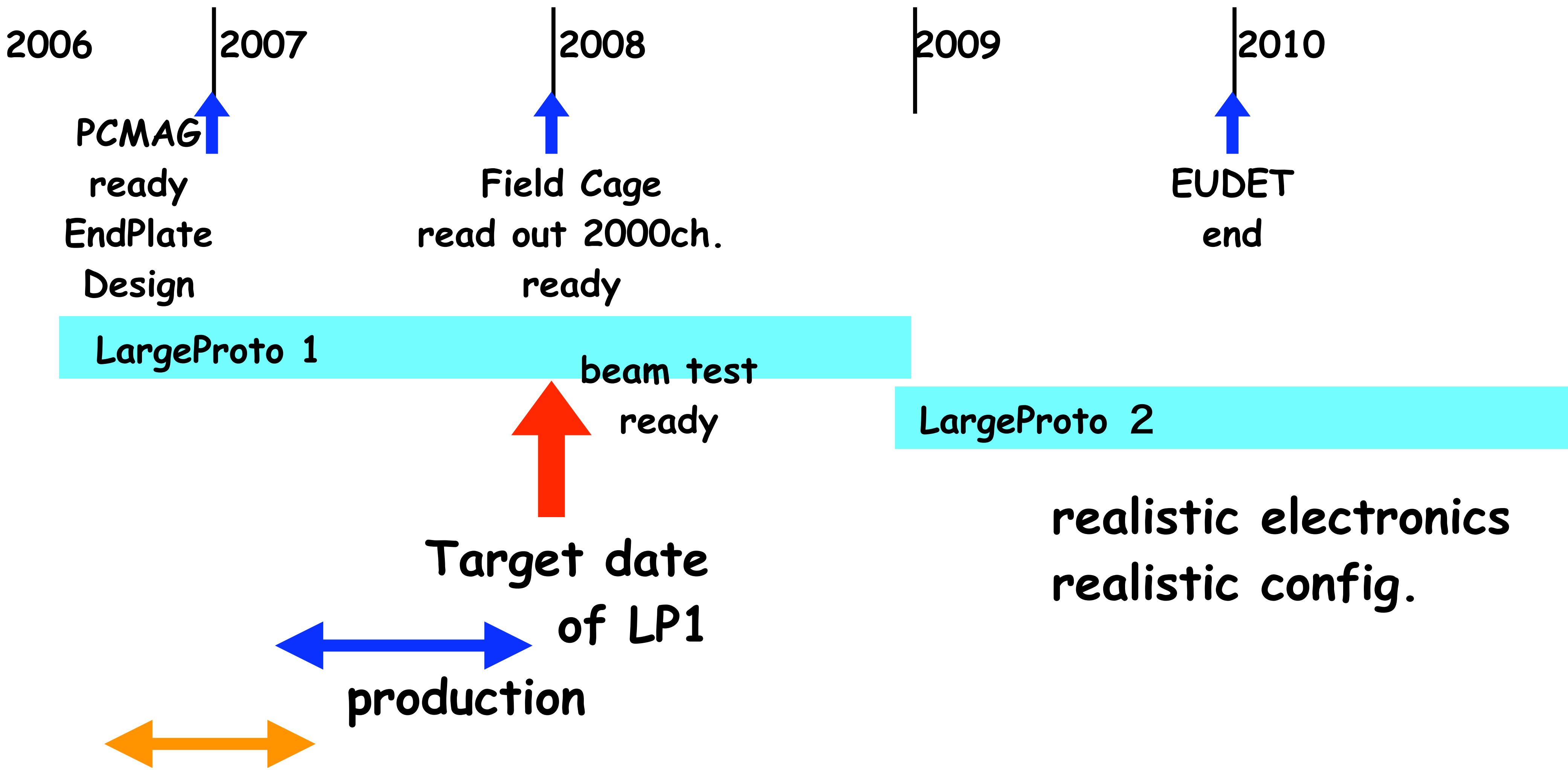


for Pixel

LP Endplate

LC-TPC prototype study schedule

EUDET



limited time for R&D !!

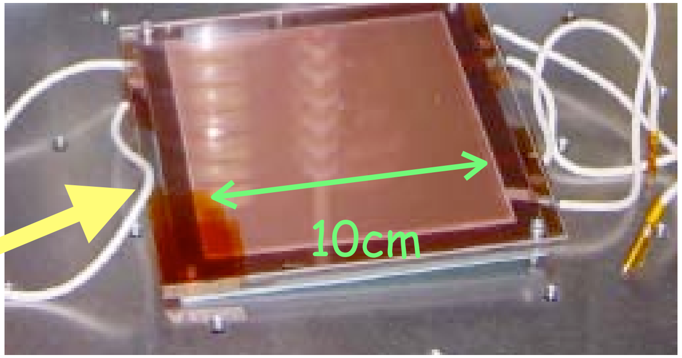
"Pre-PROTOTYPE"

though many issues are not fixed yet

What we want to do at Pre-prototype

Production of GEM panel

minimize dead area due to GEM support frame
specially in radial direction
we hope to remove radial frame
to avoid loss of series of hit info.
can we mount GEM properly ?
how do we stretch GEM?



GEM we used
@Small prototype test

we have competitor in LC-TPC group: team of Micromegas
who have experience to build large size detector for T2K

Readout Pad plane

Pad size
arrangement

readout connector

GEM structure on the pad plane

support structure
of GEM
HV supply

Larger
area GEM

mount structure to EP

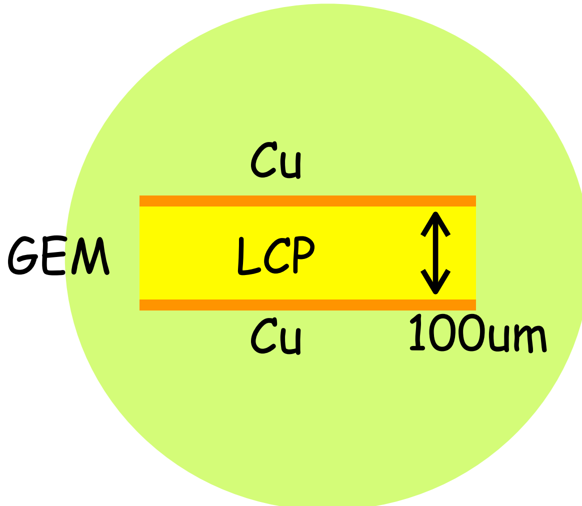
-> Dan Petersen
common system in LP

Gating structure

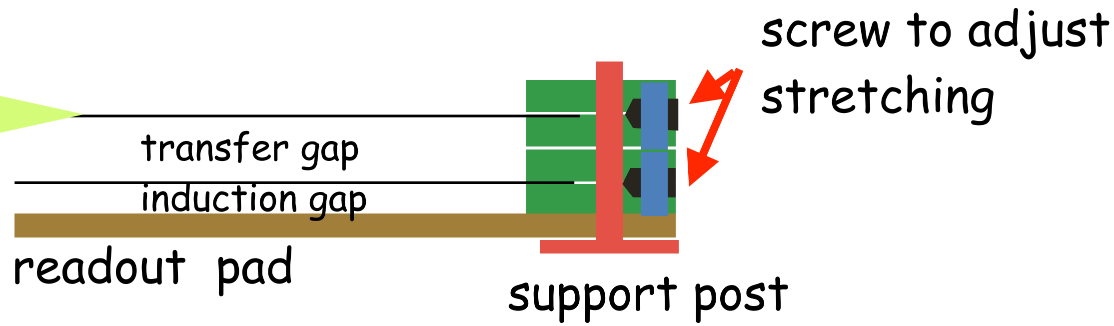
scheme

Conceptual design

Can we stretch GEM ?

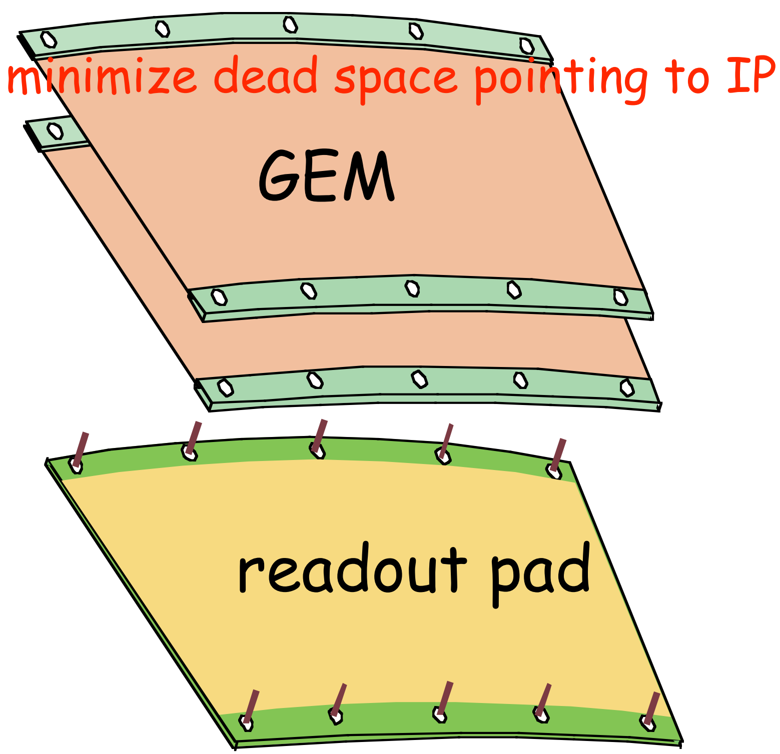


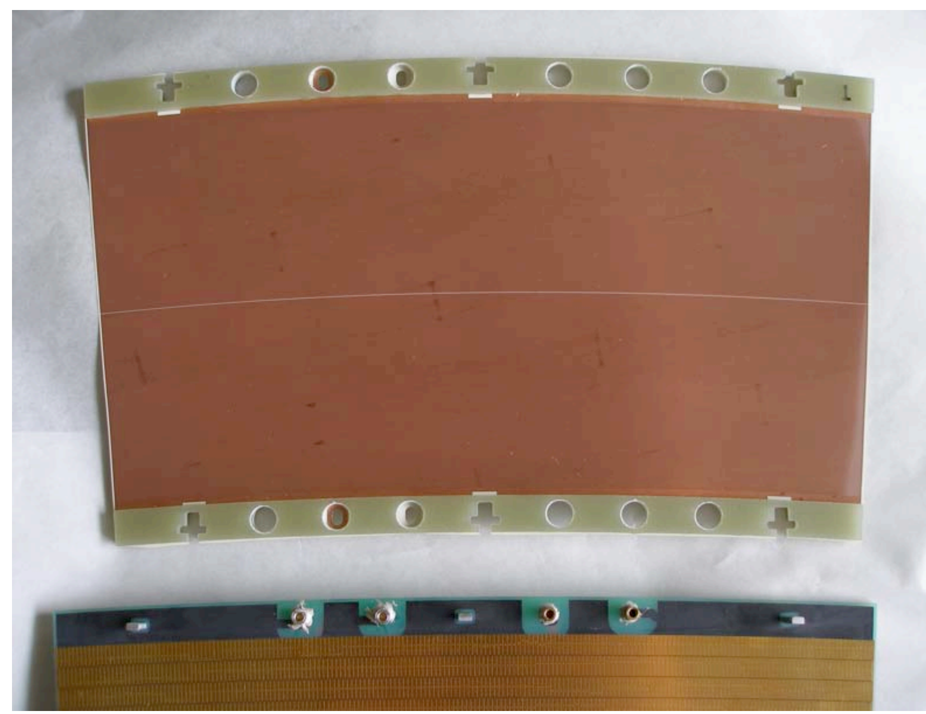
mounting(stretch) mechanism



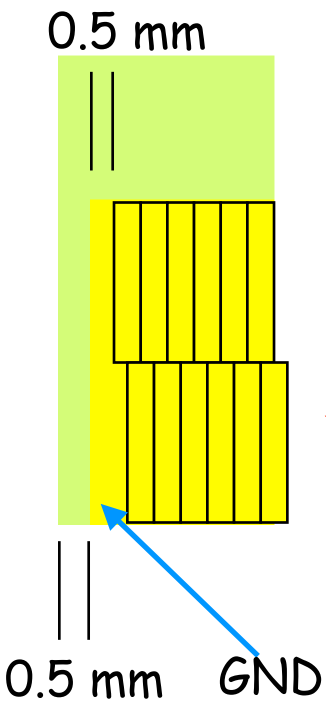
Transfer gap ~ 4mm (+2mm) : enlarge signal distribution width > 0.3* pad pitch

frame : top & bottom frame.
no side frame

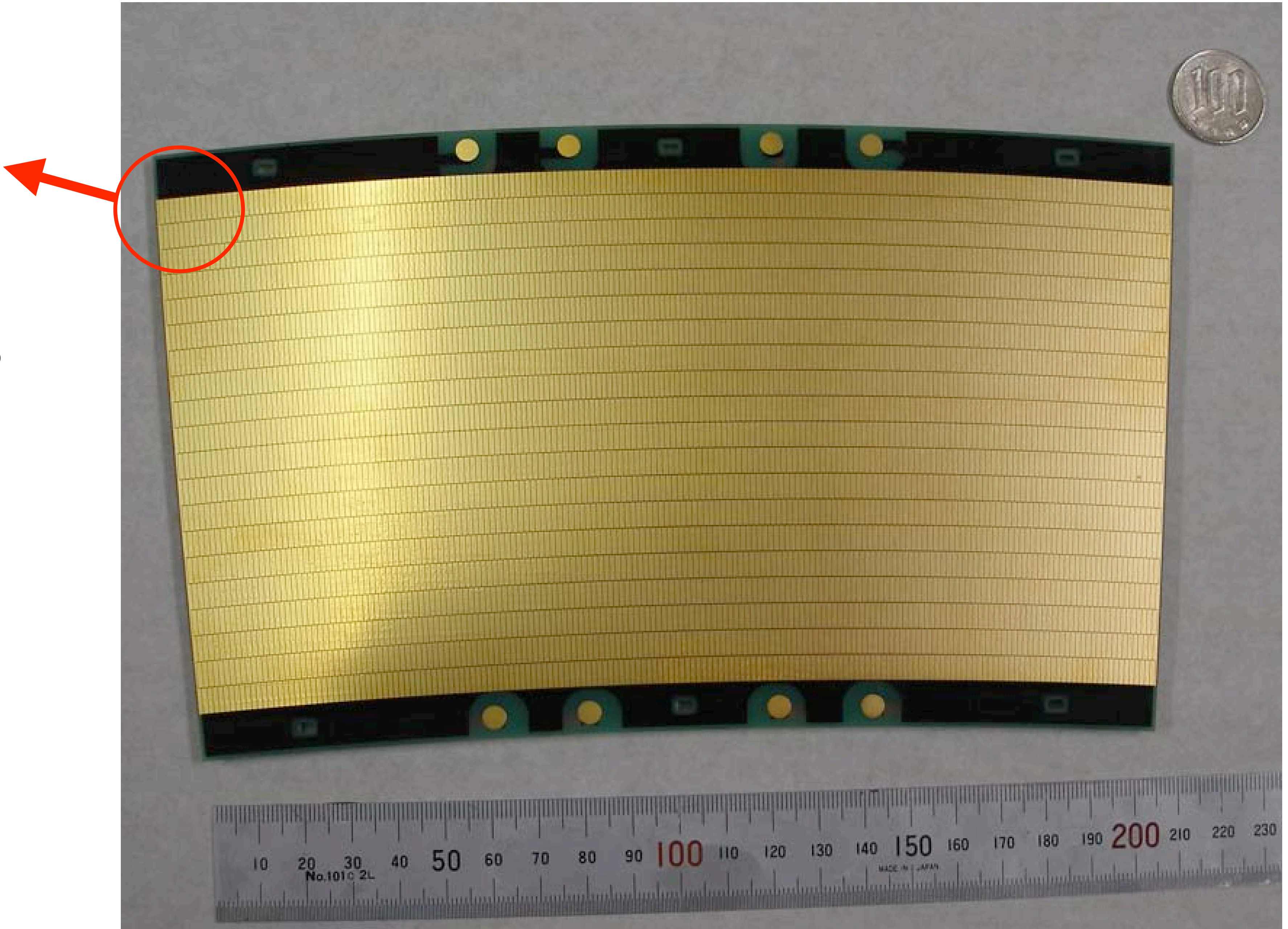




Pad plane

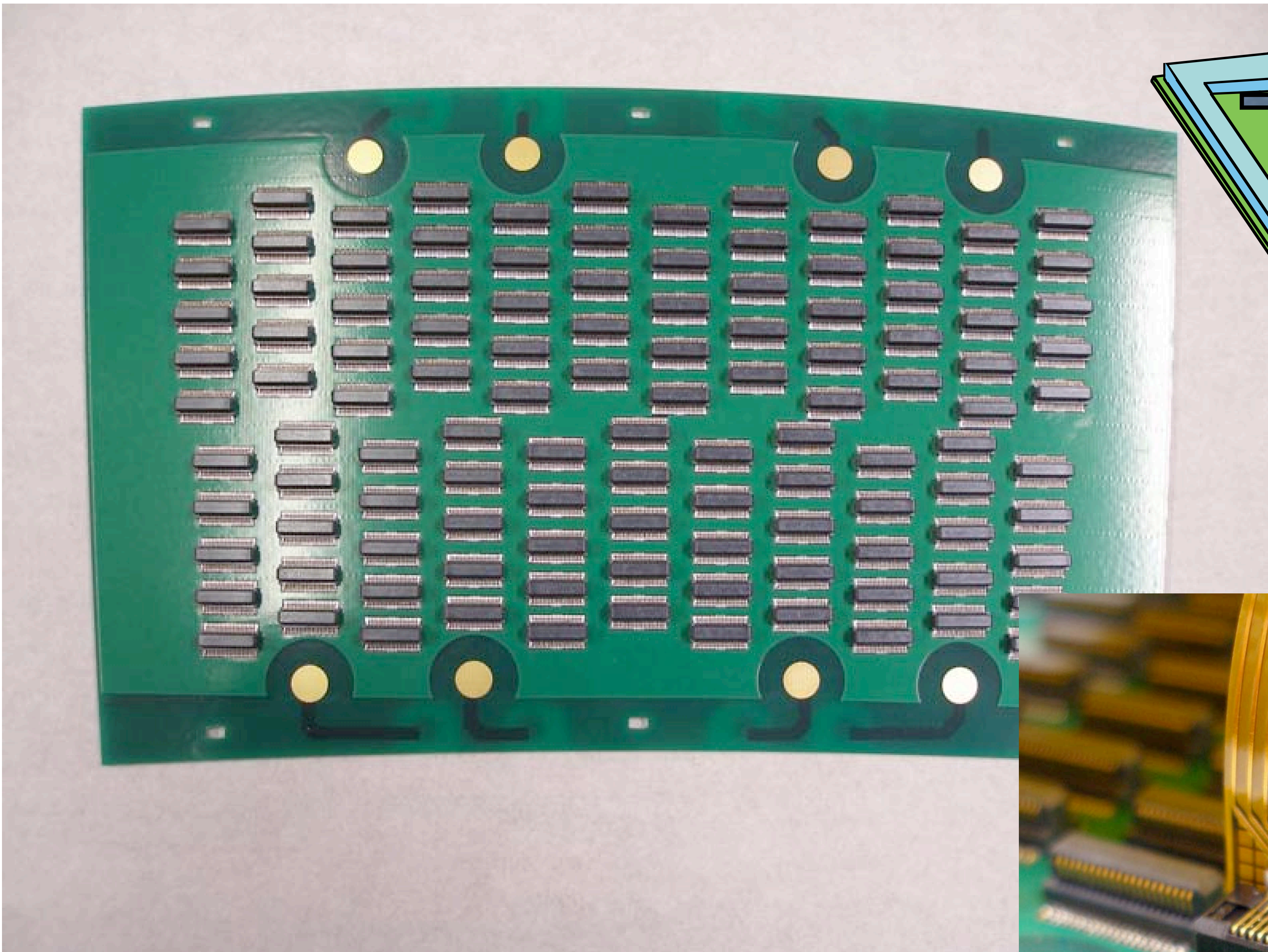


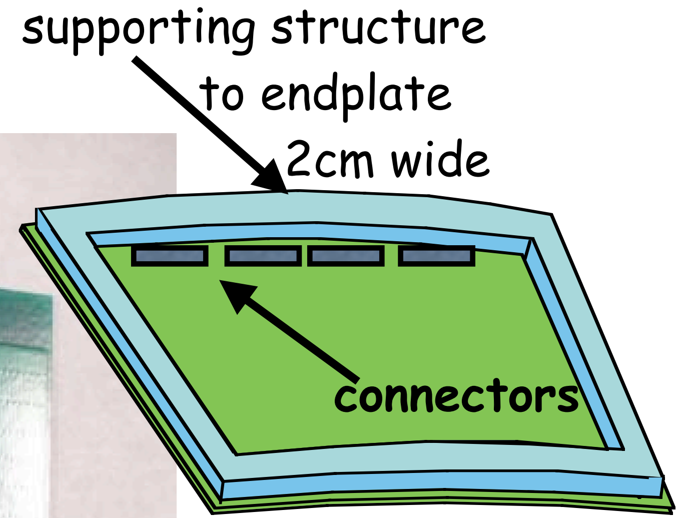
Pad size ~ 1.1 x 5.6 mm
20 pad rows
192 pads (outer half row)
176 pads (inner half row)

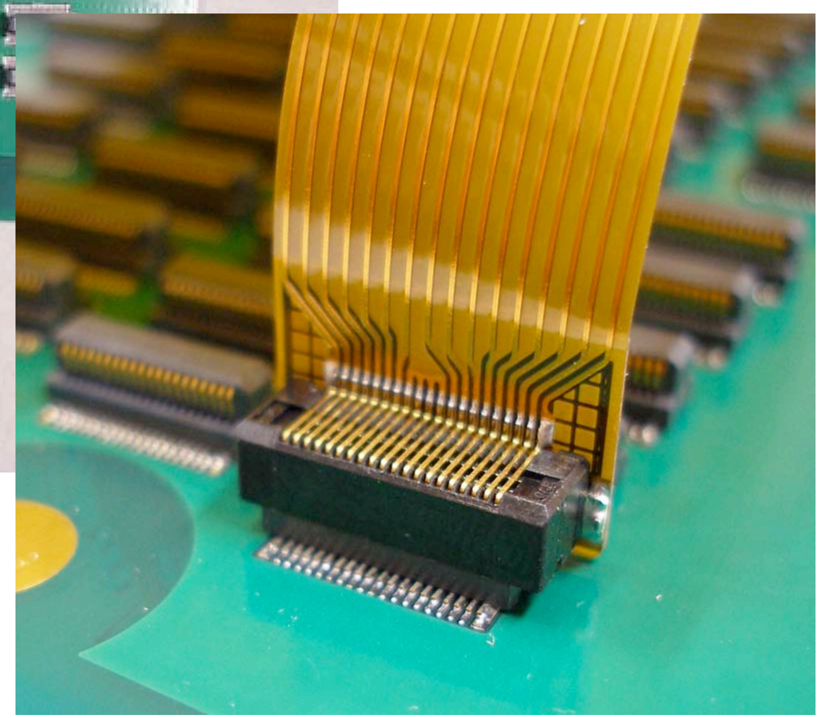


6 layered PCB

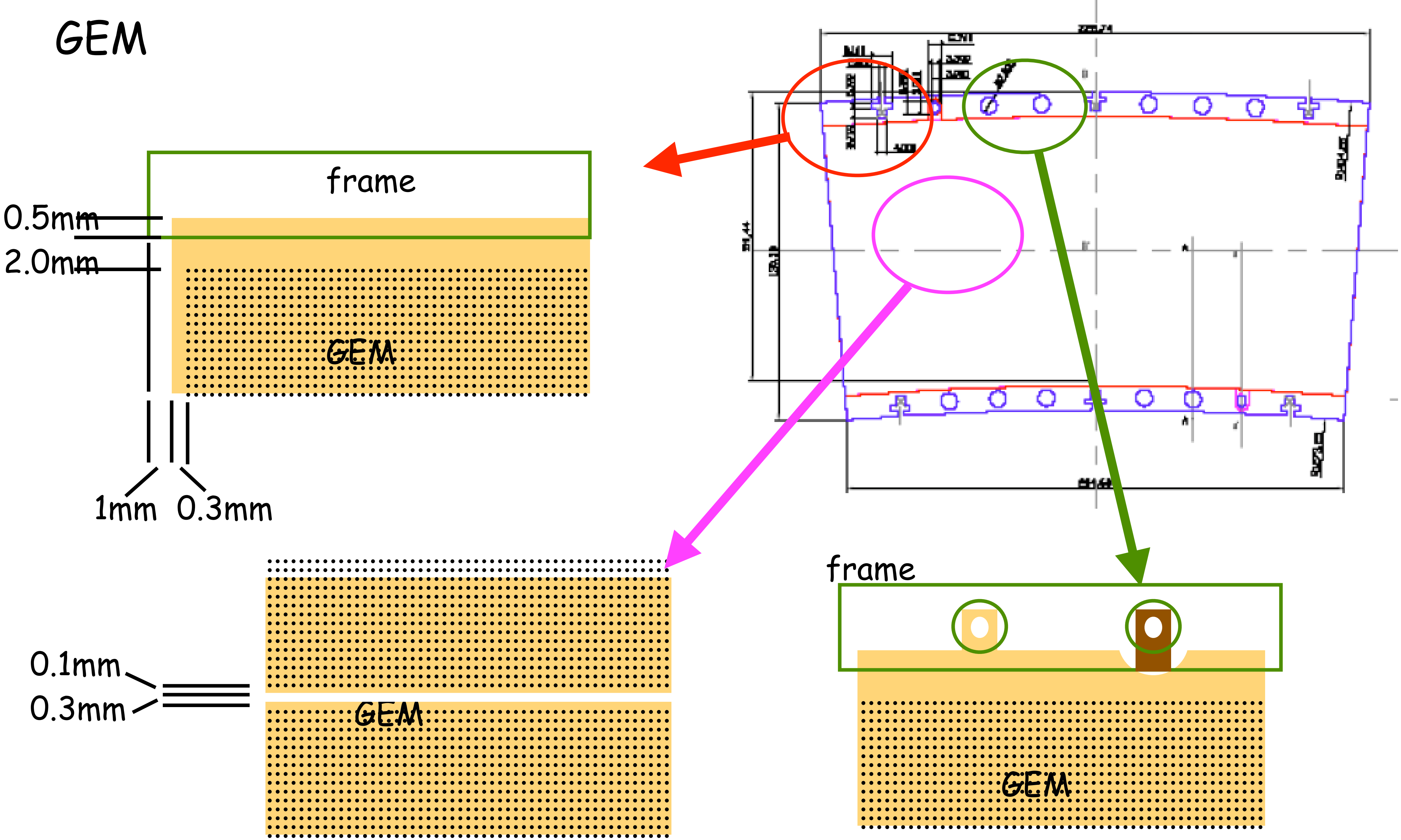
Pad plane - rear side

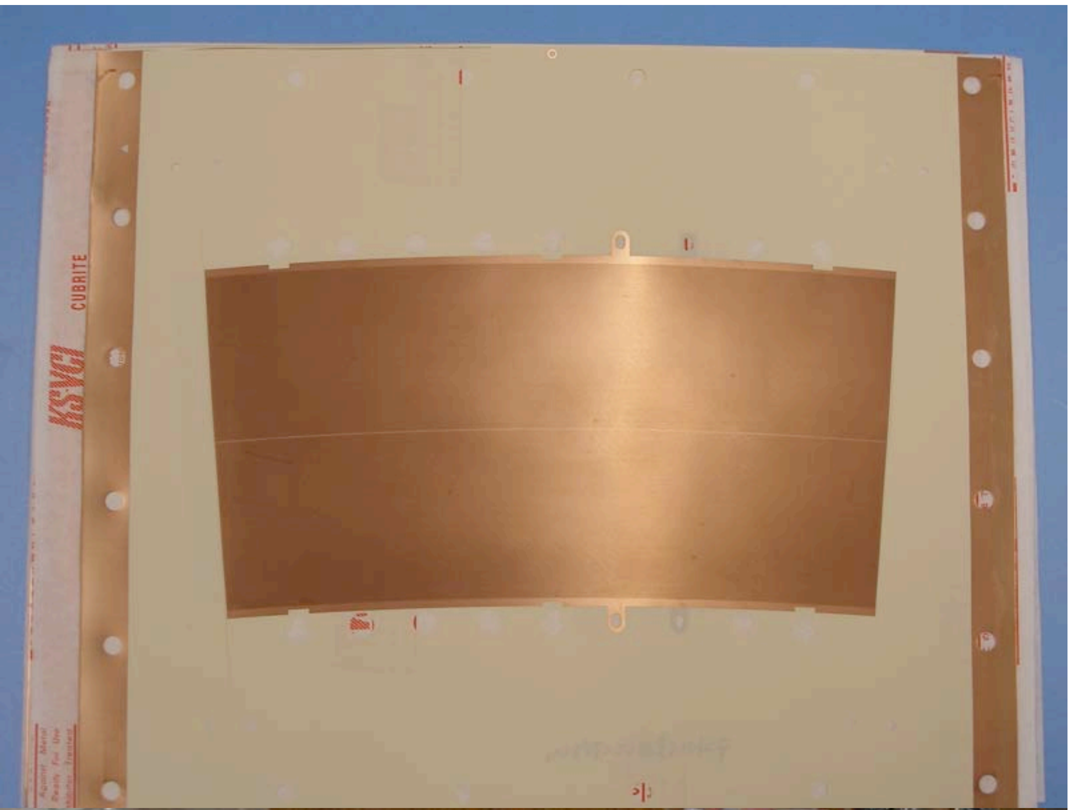


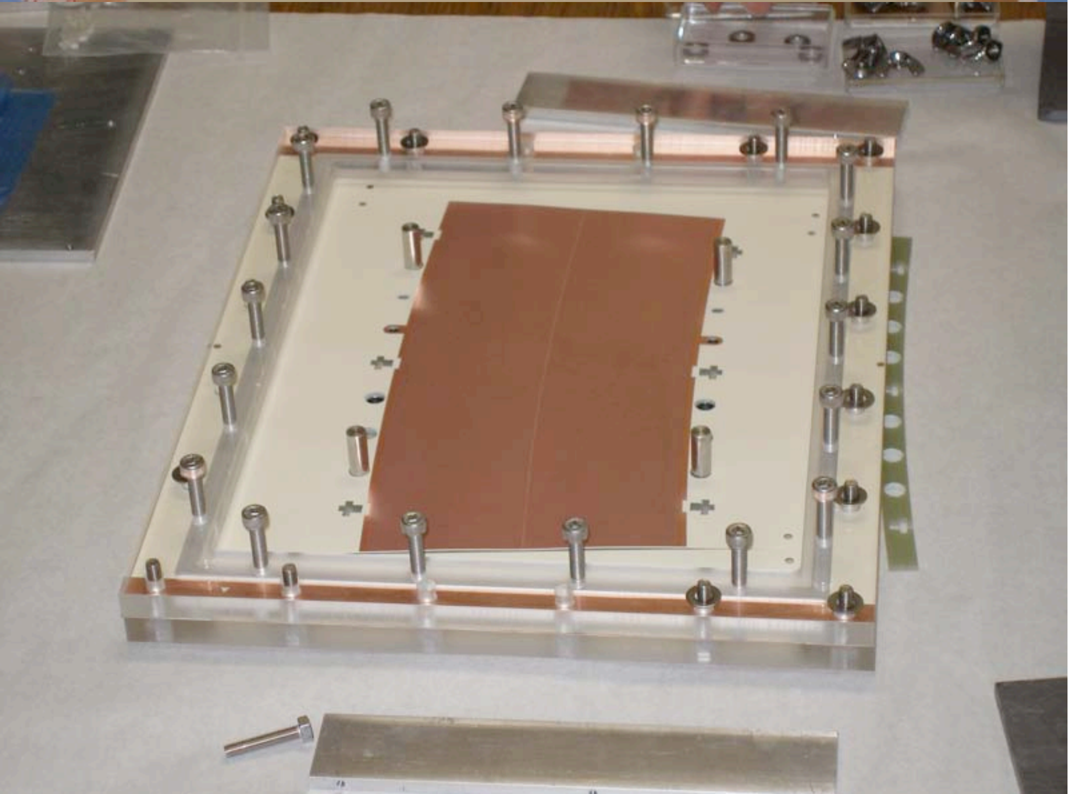


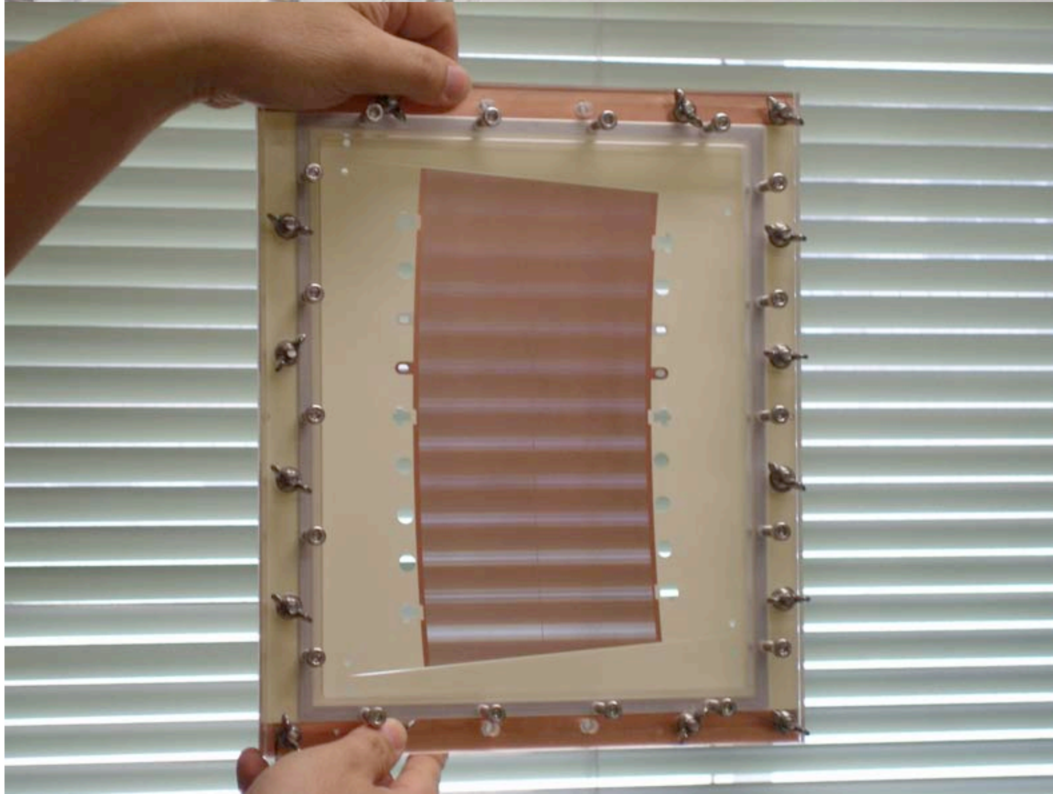


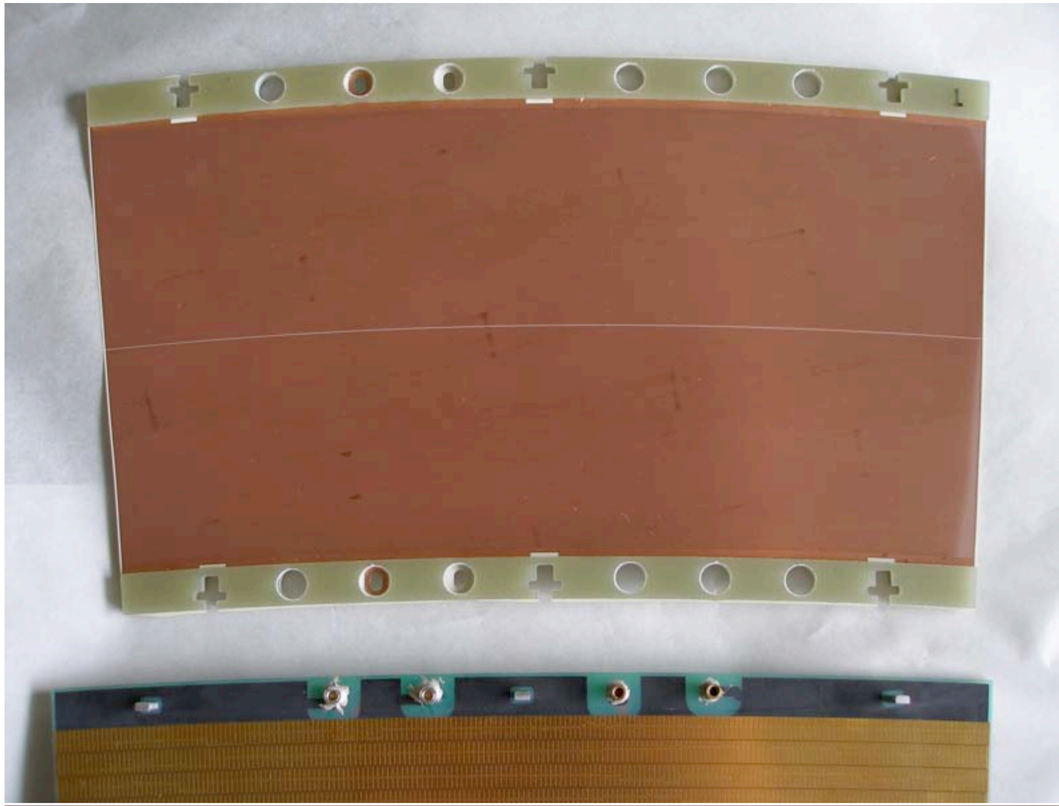
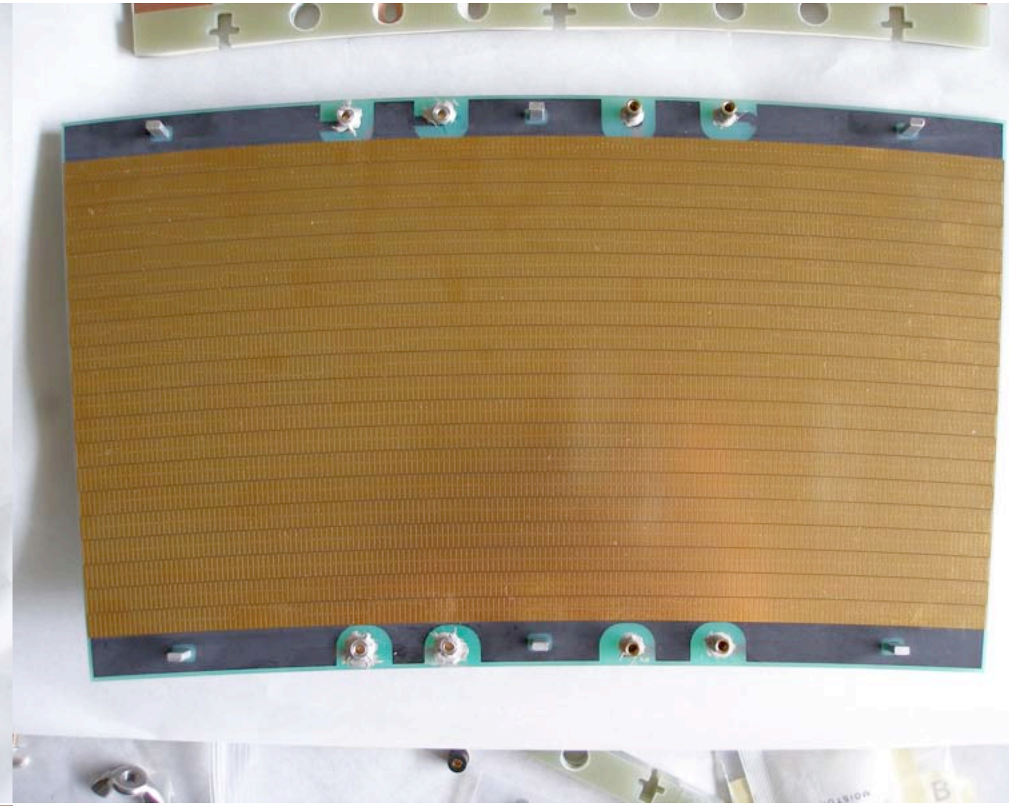
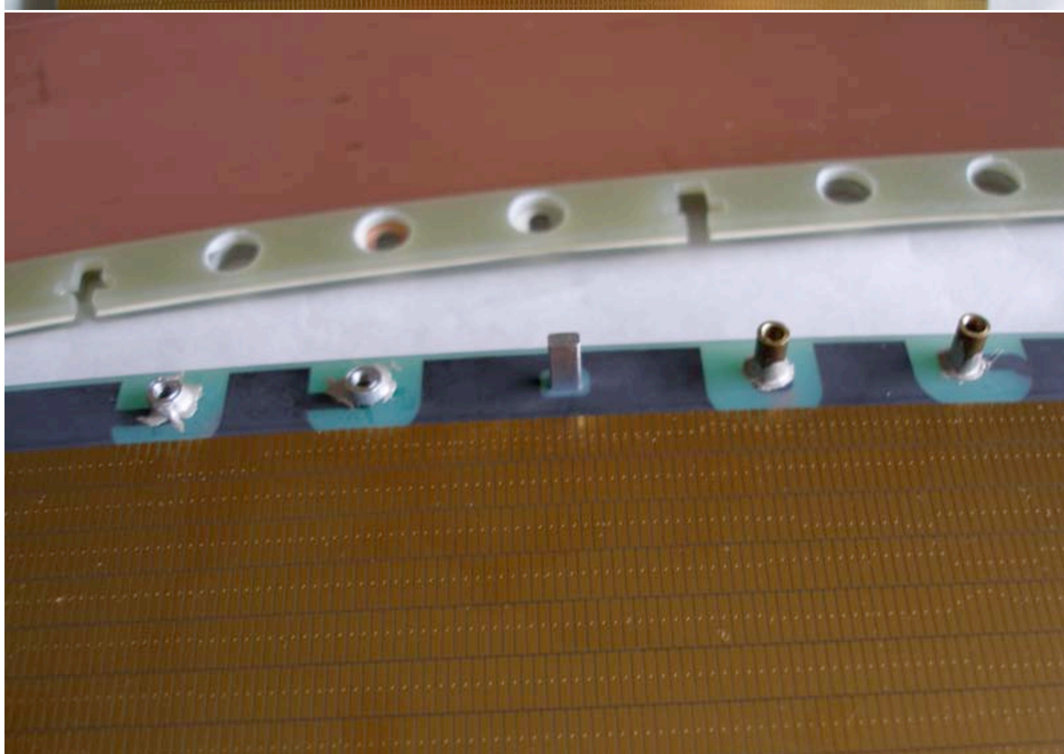
GEM









Plan of pre-prototype

gas container box will be ready soon.

check the mechanism of GEM mount under regular operation

gas gain uniformity over all panel by Fe source

long term stability

start design work for LP1(real prototype) GEM panel

start production LP1 panel from September

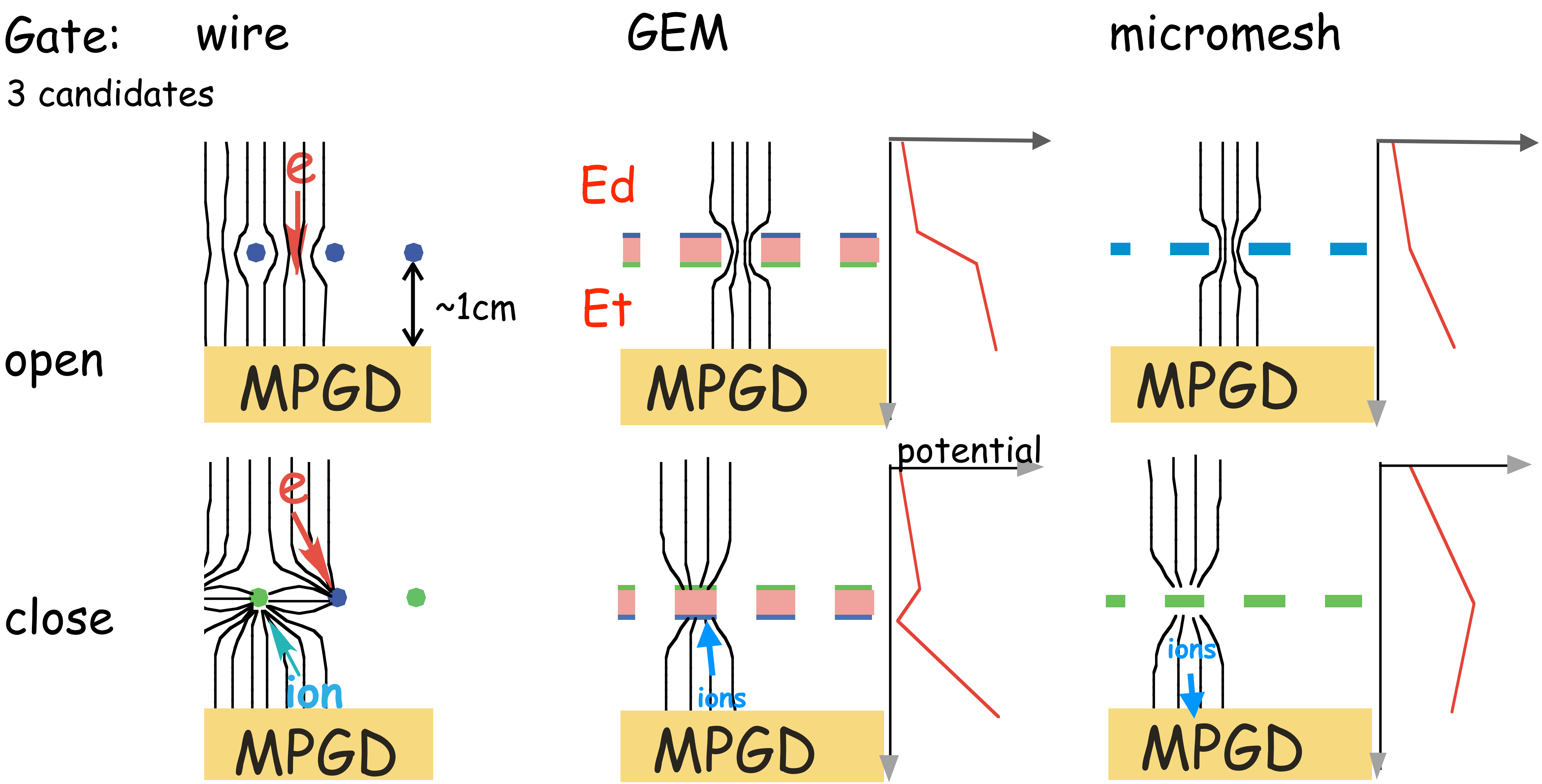
will be ready for beam test at the end of December

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 dirft < 1cm



local change of E — wire tension

local change of E — electron transmission

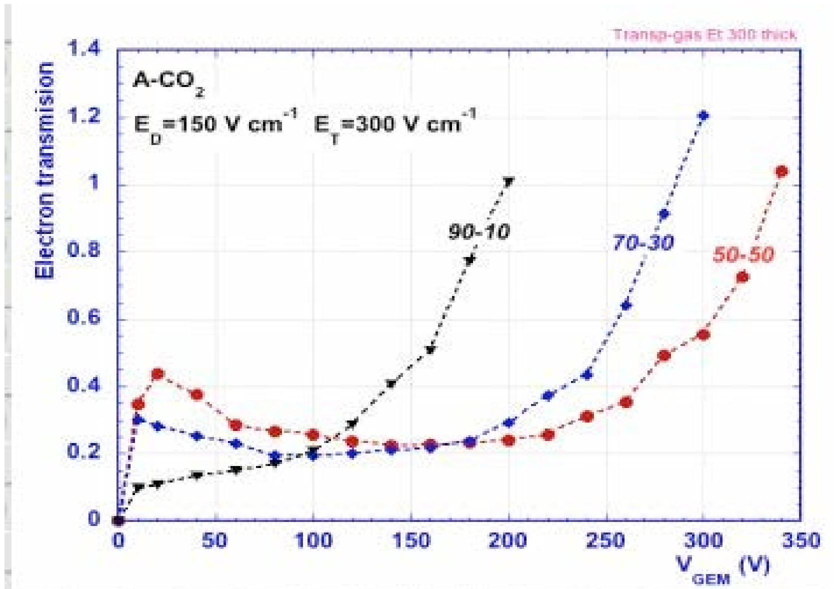
change of drift E — electron transmission

GEM gating

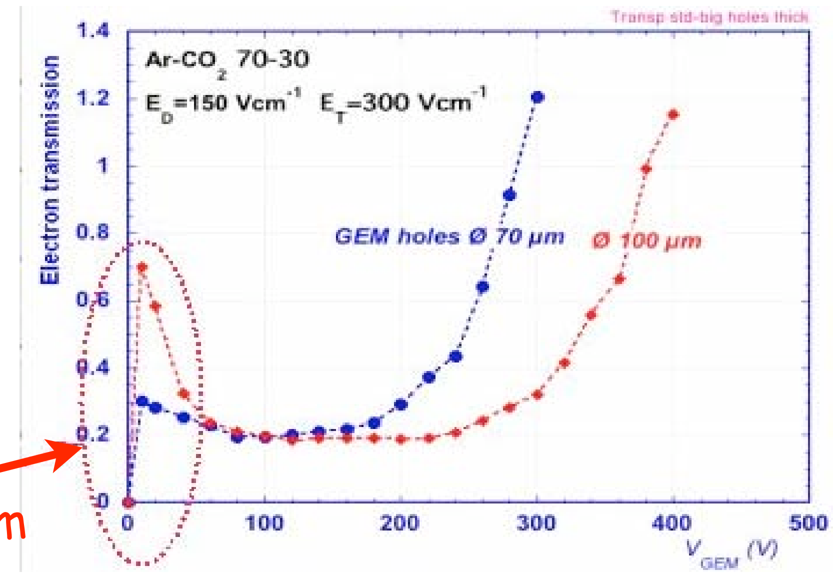
F. Sauli had proposed GEM as gating device @LBLTPC'06

Electron transmission had been measured as a function of V_{GEM}

for different Gas mixture



for different hole size



10V/50um

~ 2kV/cm

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

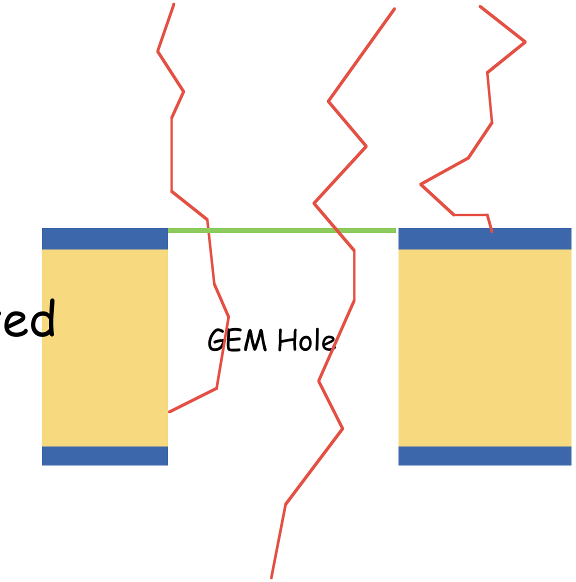
E field calculation and electron simulation in gas help us to do this.

Maxwell3D Garfield

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.

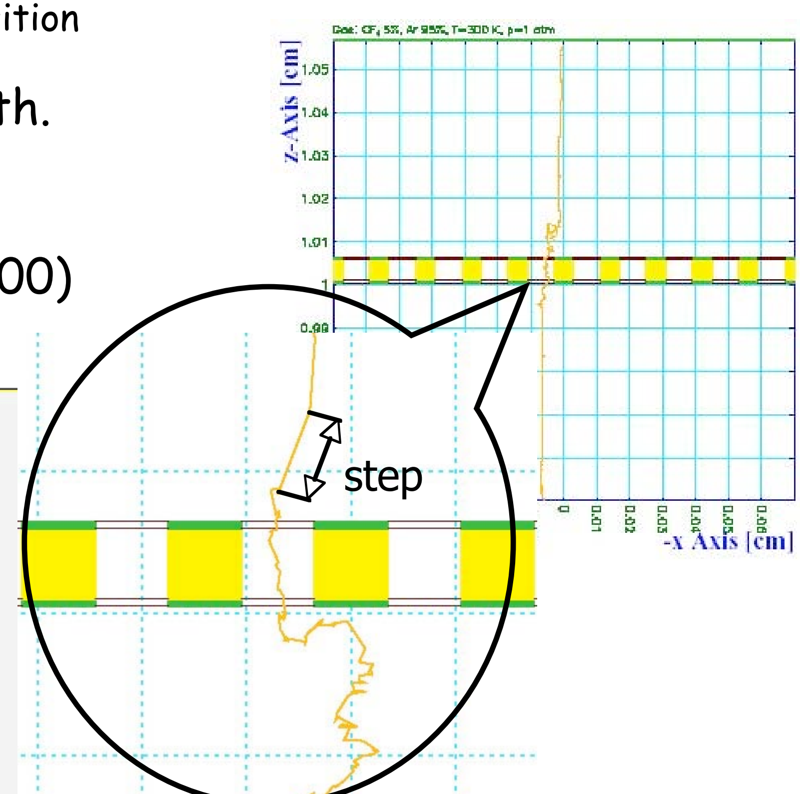
electrons are generated 500um above GEM surface uniformly.

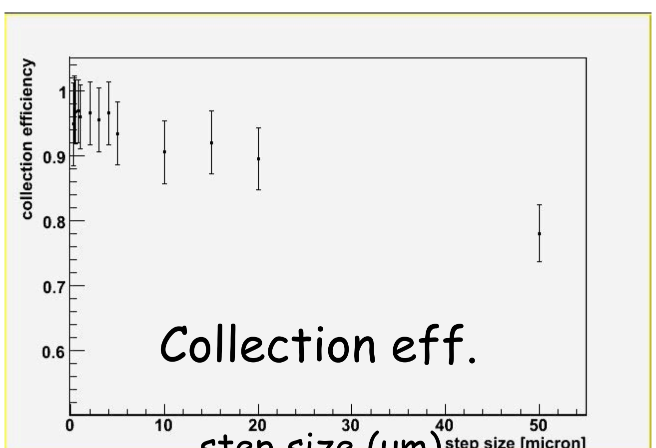
Important parameter of Garfield is STEP SIZE

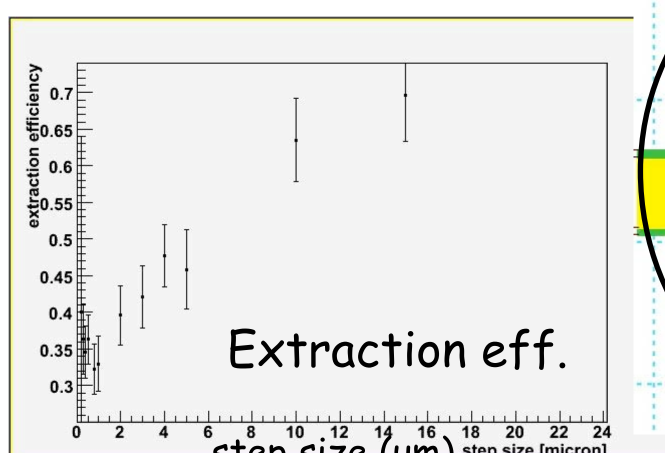
step size : interval to update electron position

step size is controlled by # of collisions OR length.

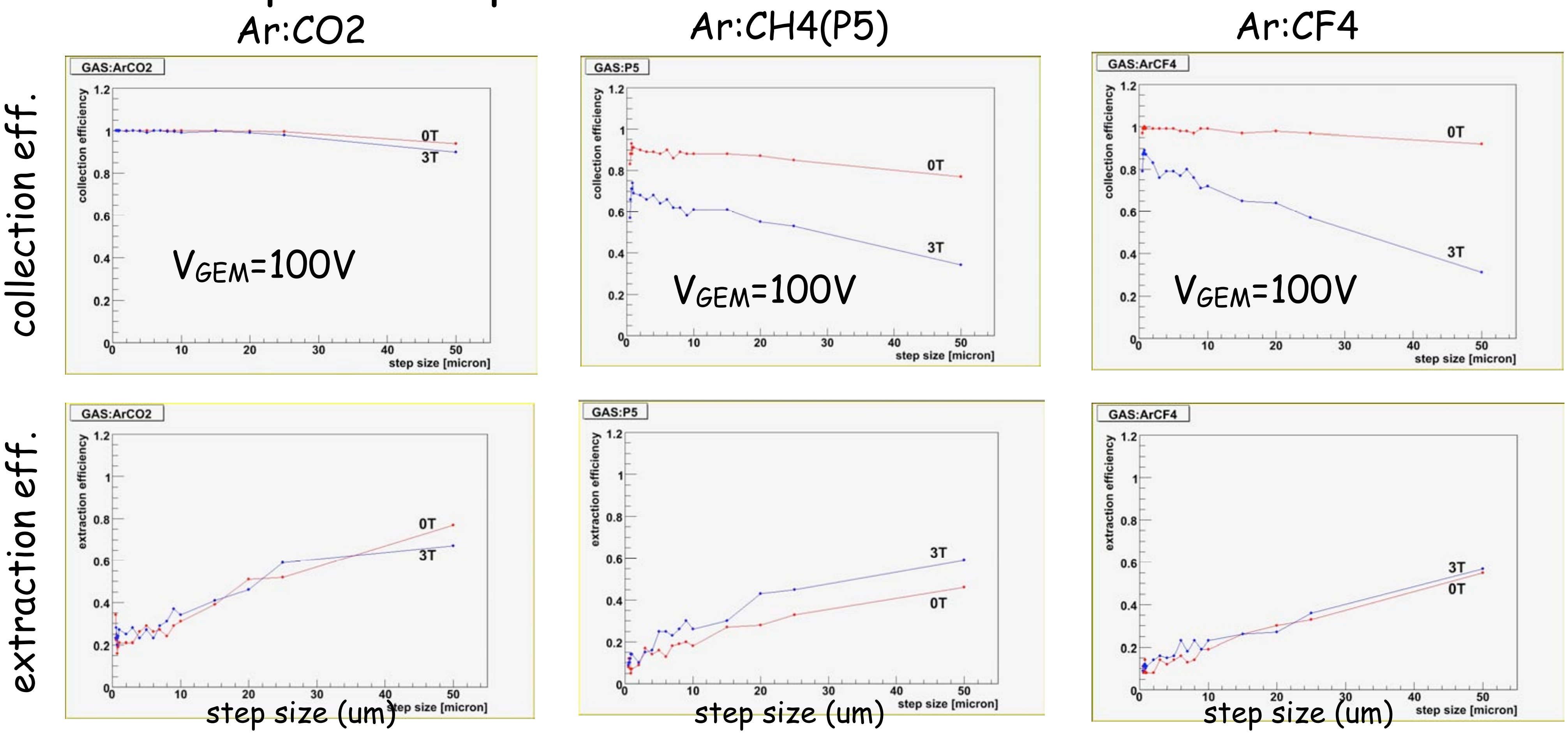
large step size -> incorrect result
too small step size -> cal. stopped by Max. number(1000)







More example of step size effect

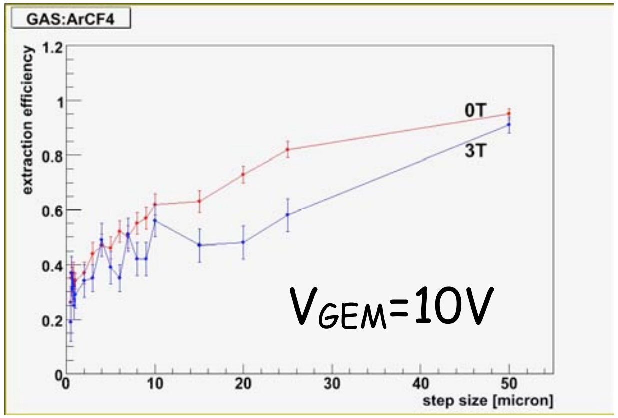


In any case, result change as step size

result @ 0 step size must be close to true value !

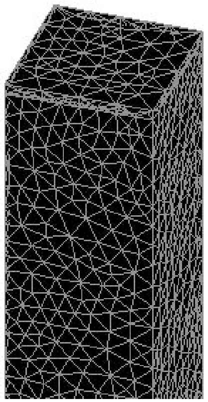
We chose 2 um step size

as the result may be close enough to true answer

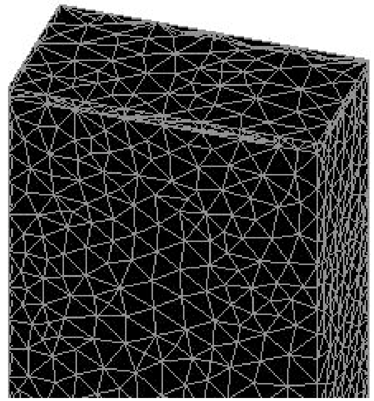


Size of Field map

Field map used in garfield can be provided from Maxwell3D.
but acceptable size is limited to ~ 10^5 elemtents



Blue line



Red line

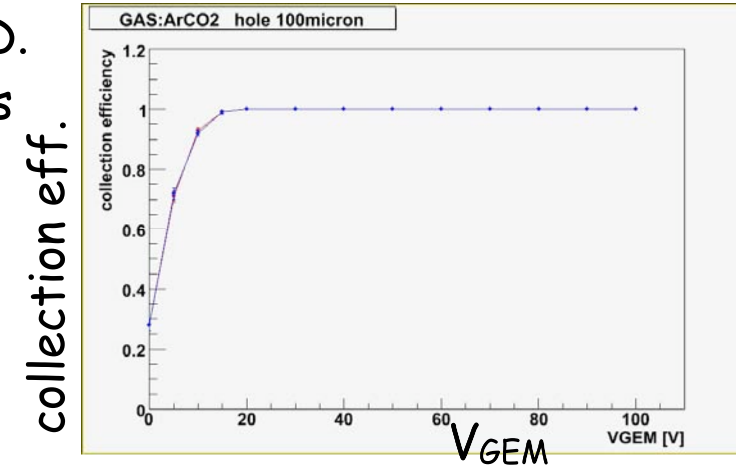
mesh size ~ 2x Blue

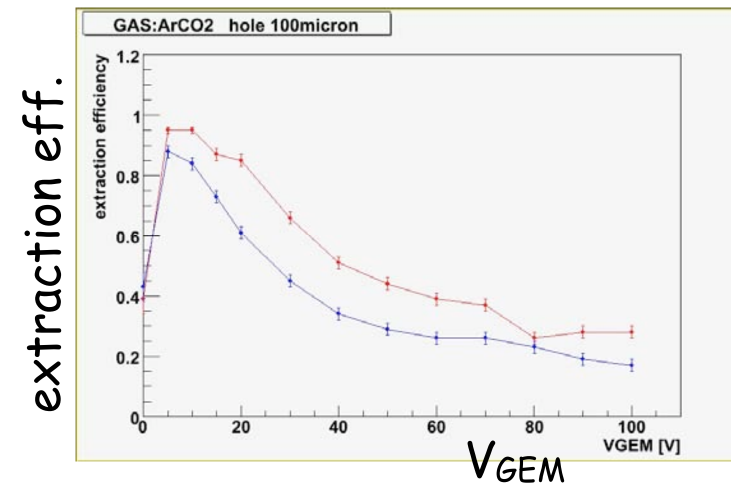
Collection eff. is same each other
ie. E filed @ collection seems to be precise enough
Extraction eff. provides ~10% diff.
ie. E field is not precisely calculated in hole
or interpolation of E field doesn't work in garfield

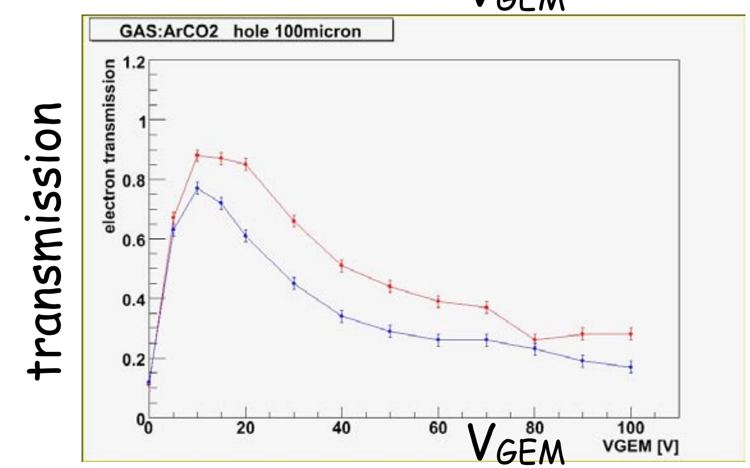
In Maxwell3D, mesh is automatically generated
we cannot quote exact volume of mesh

We have to remember accuracy of result
when we use garfield

ArCO2



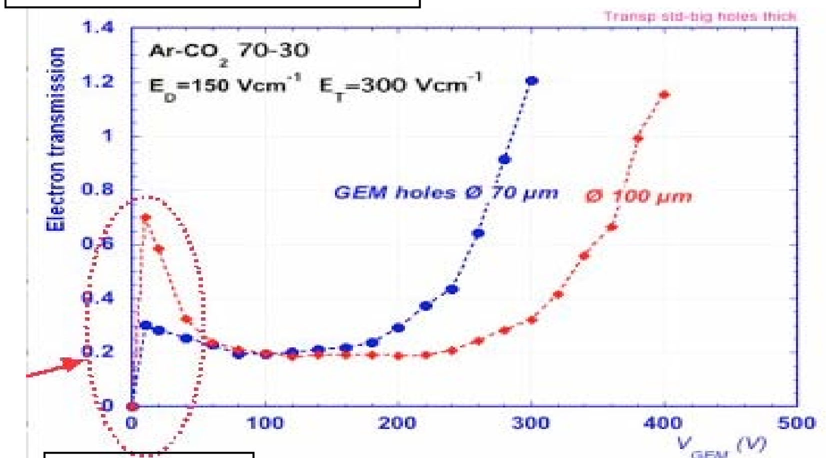




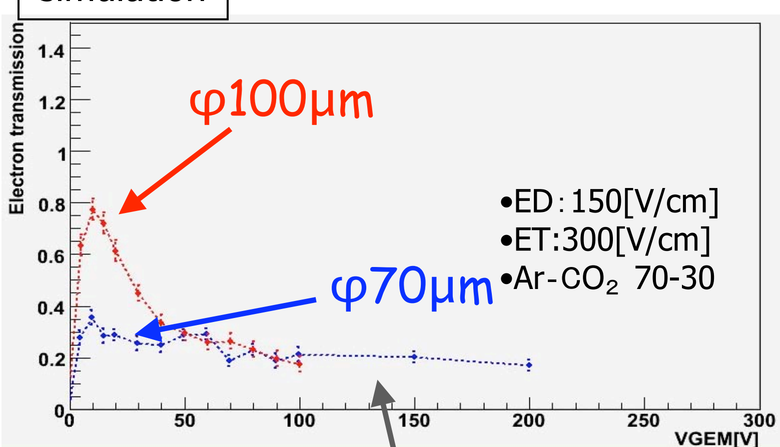
Comparison to exp. results

Electron transmission
Hole size dep.

Measurement by Sauli



simulation



Gas gain is not included

Simulation results are reproduced well !!

if we convert transmission into detail ....

Comparison to exp. results

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Hole size dep.

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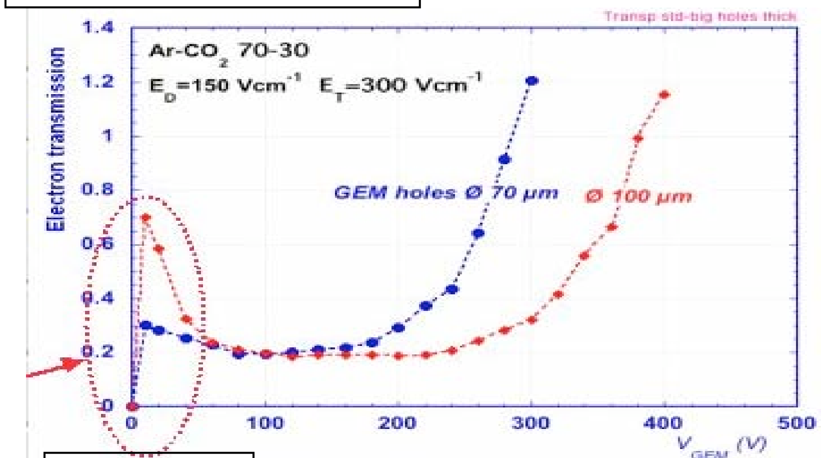
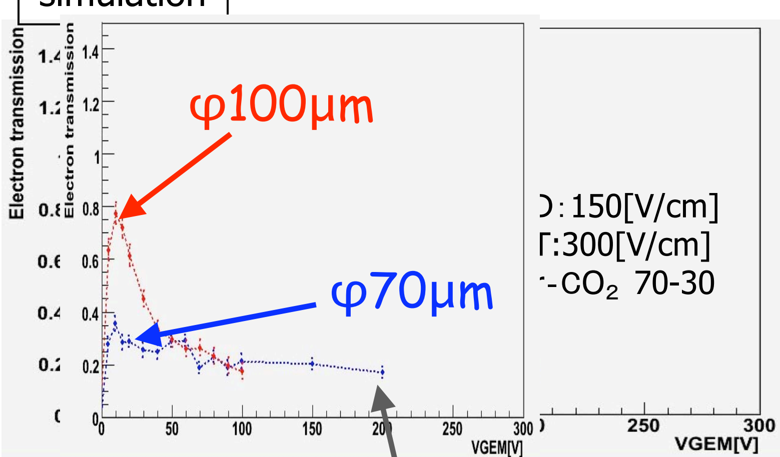


simulation



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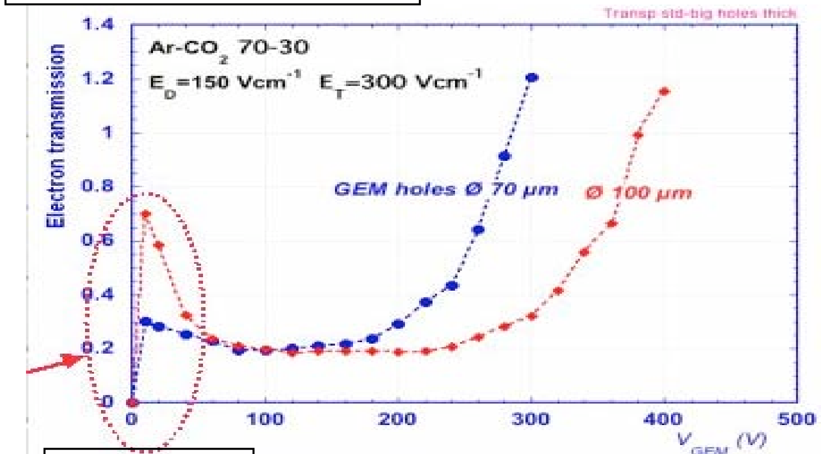
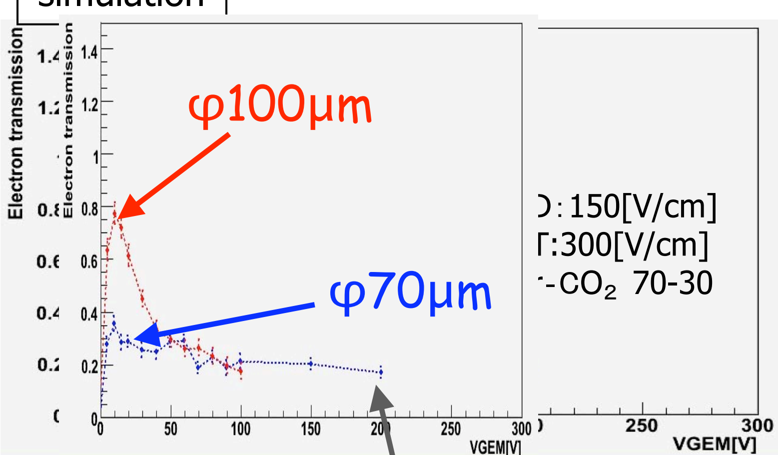
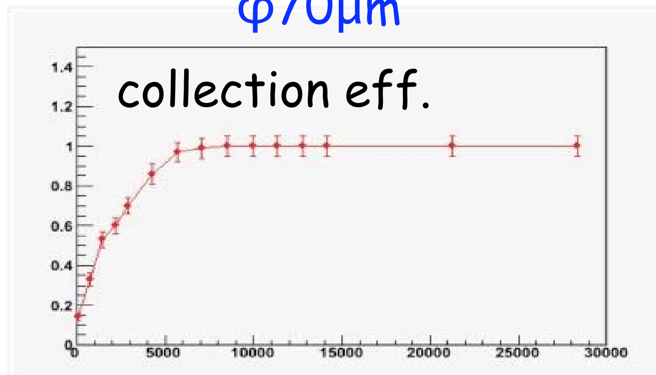


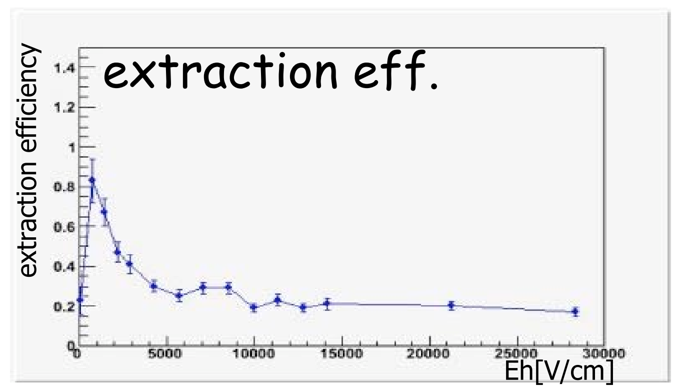
simulation

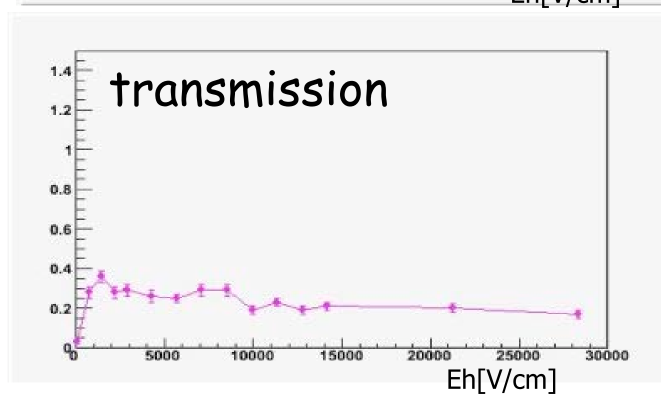


Gas gain is not included

φ70μm







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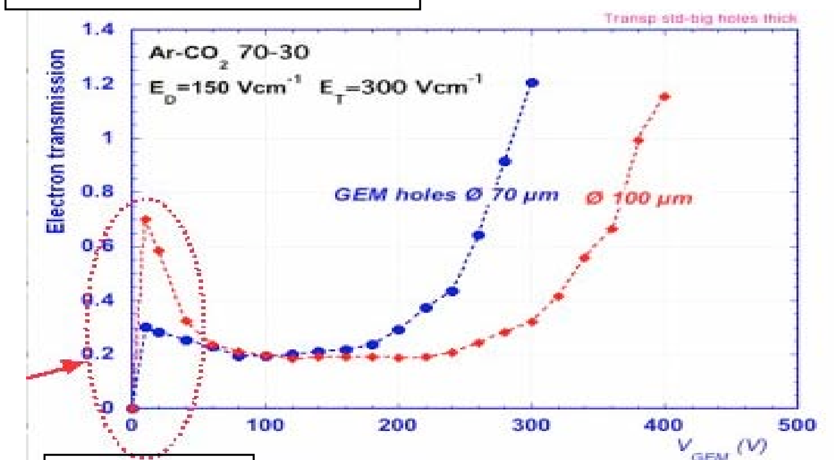
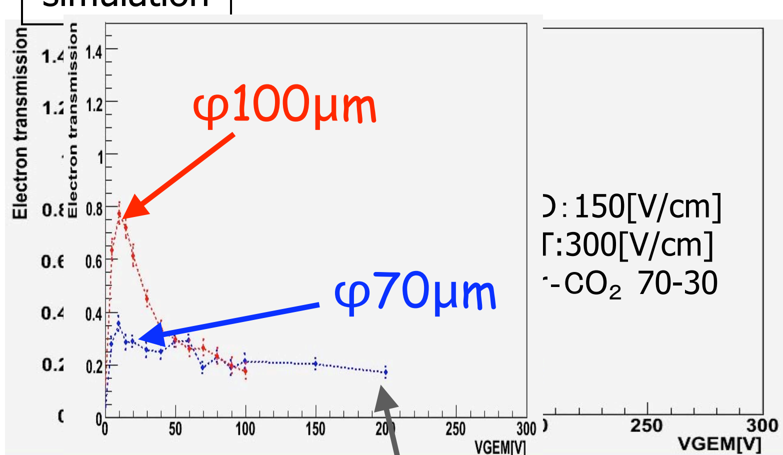
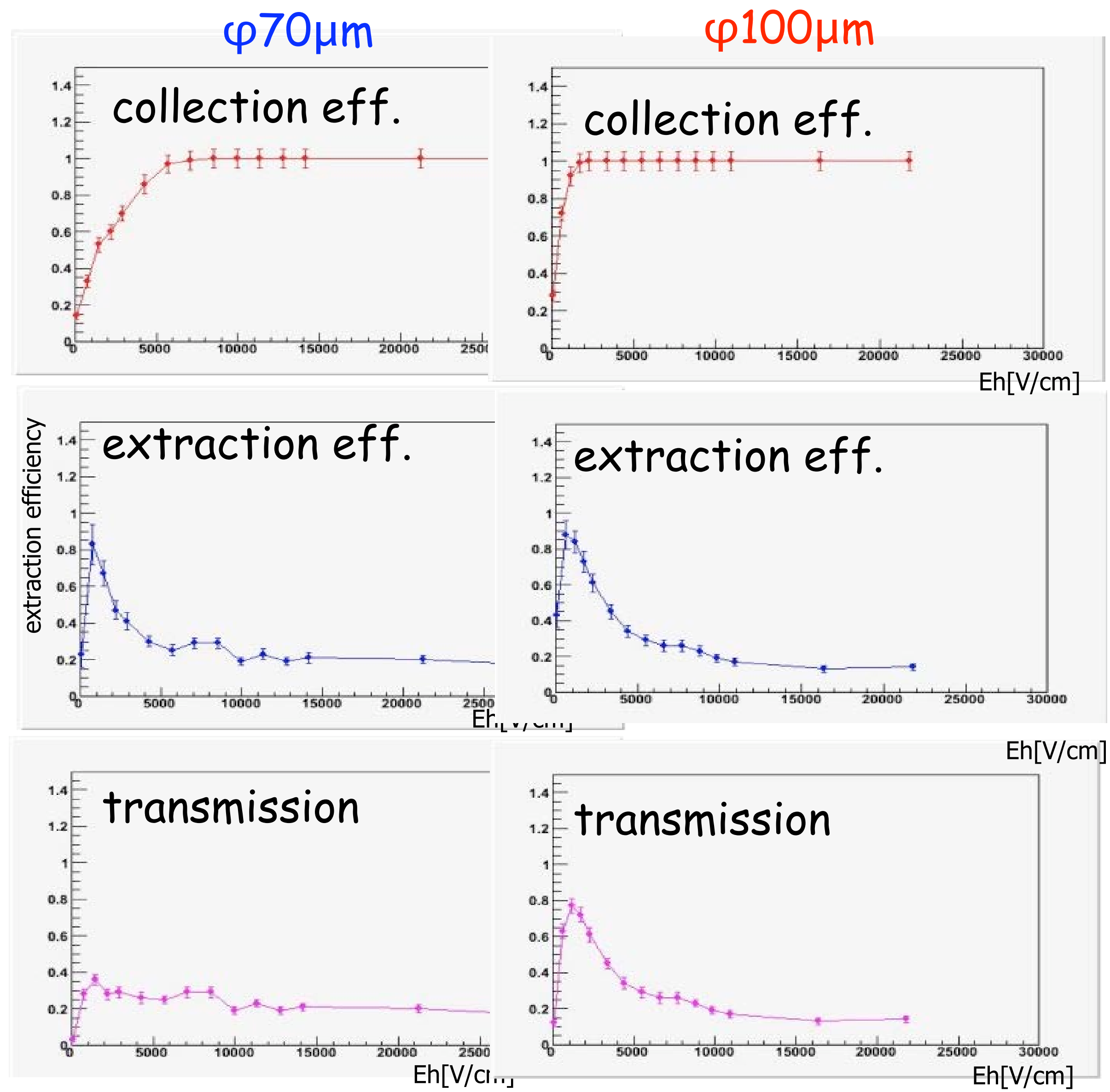


simulation



Gas gain is not included



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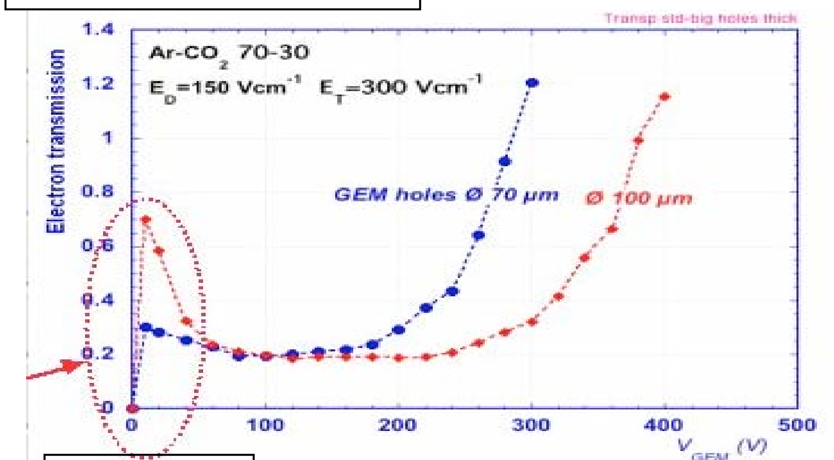

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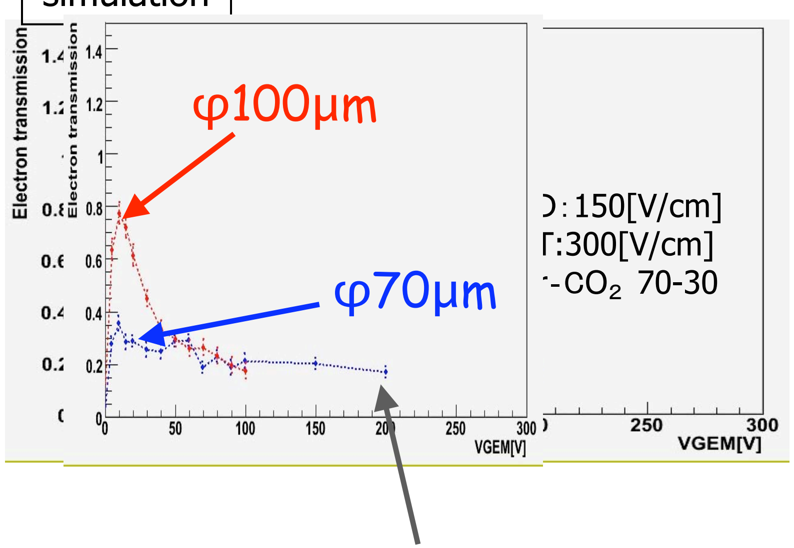

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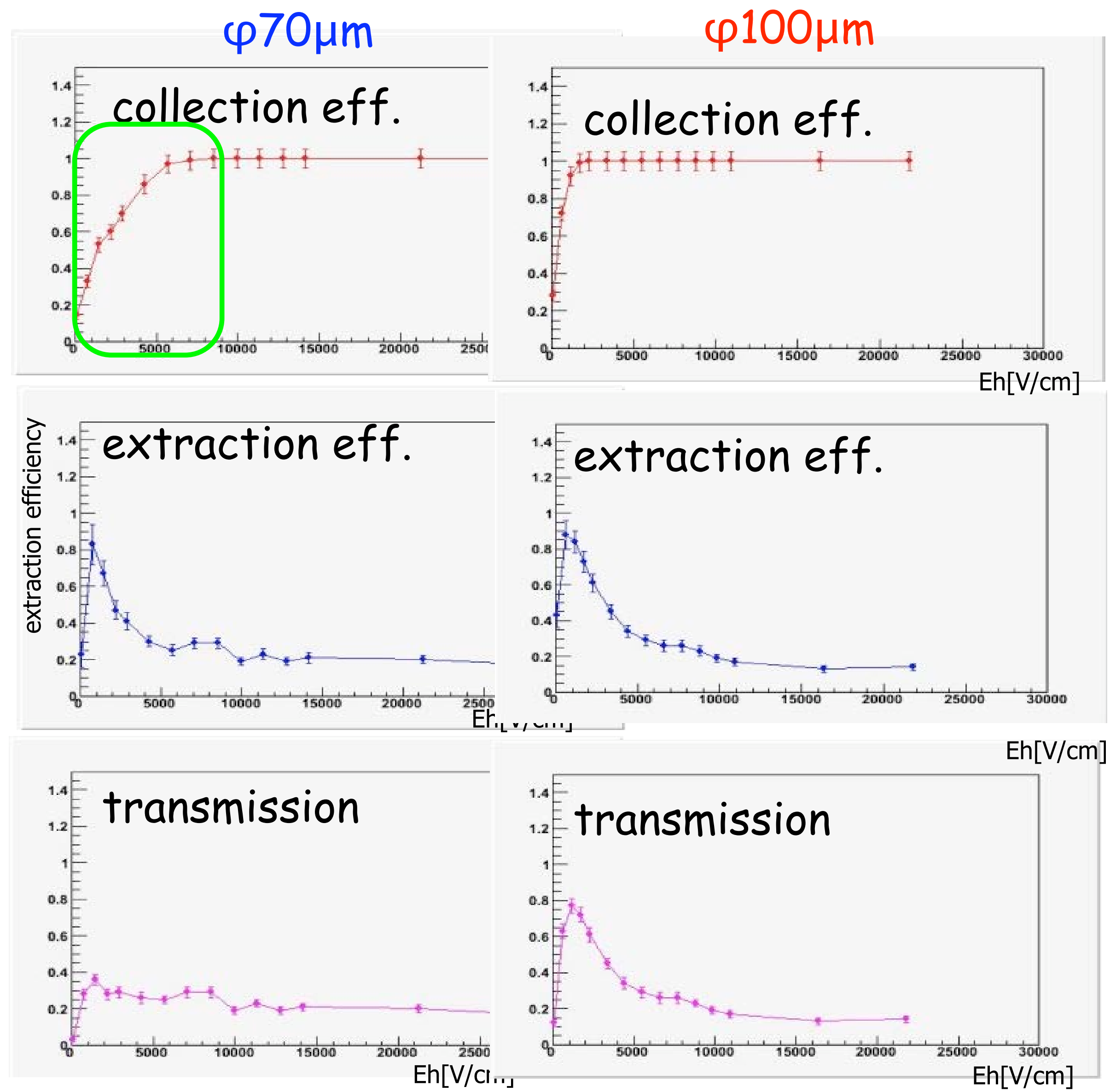

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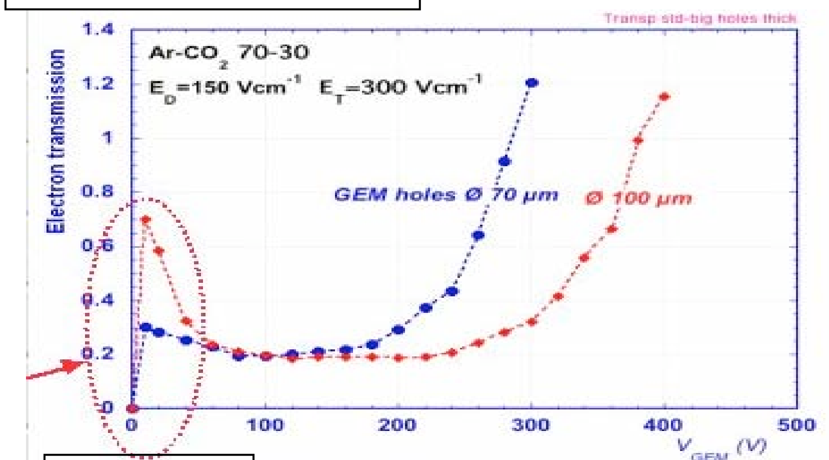
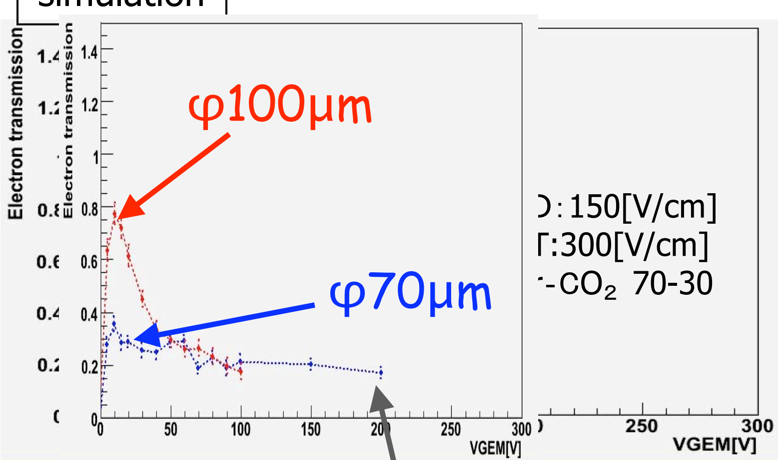
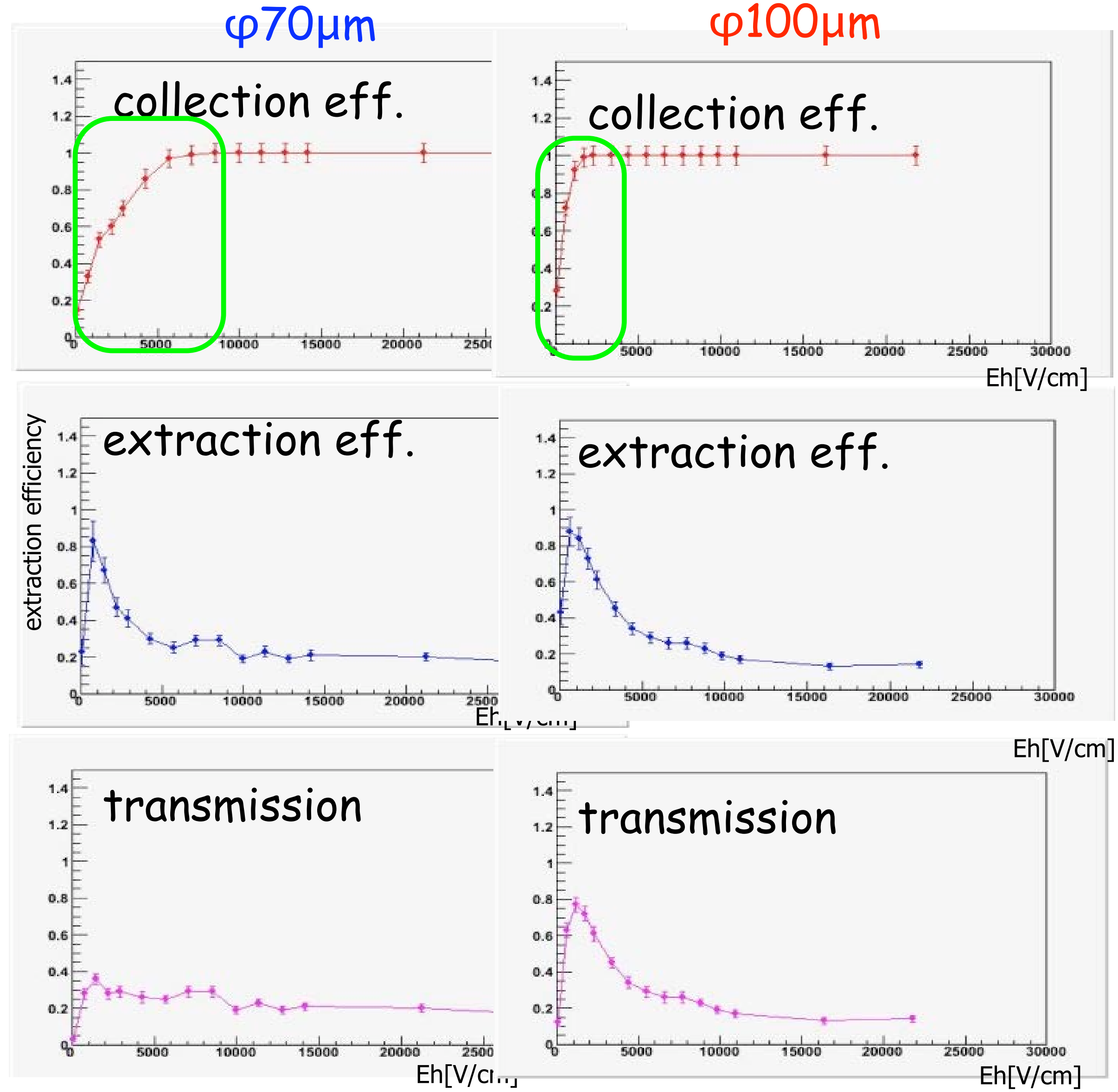


simulation





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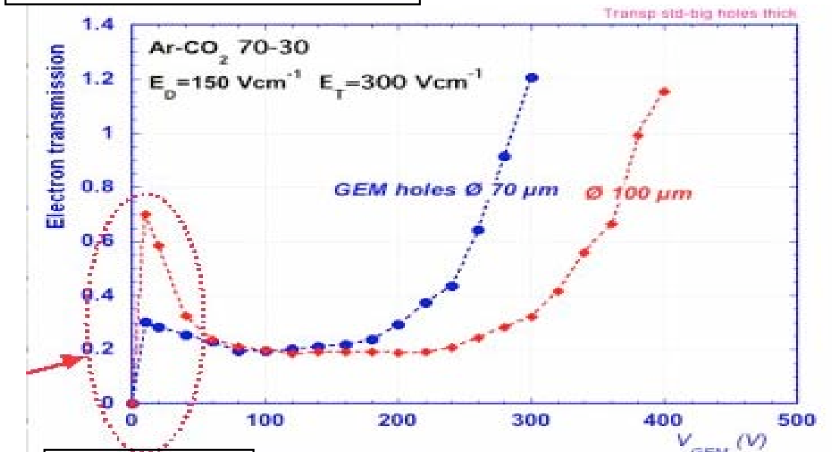
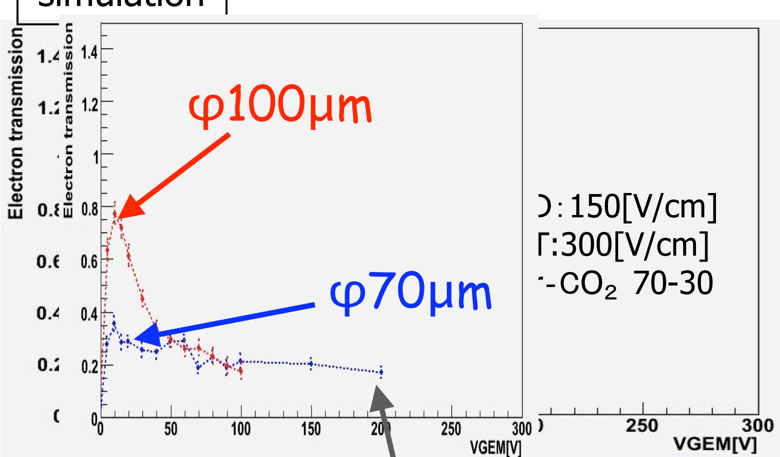
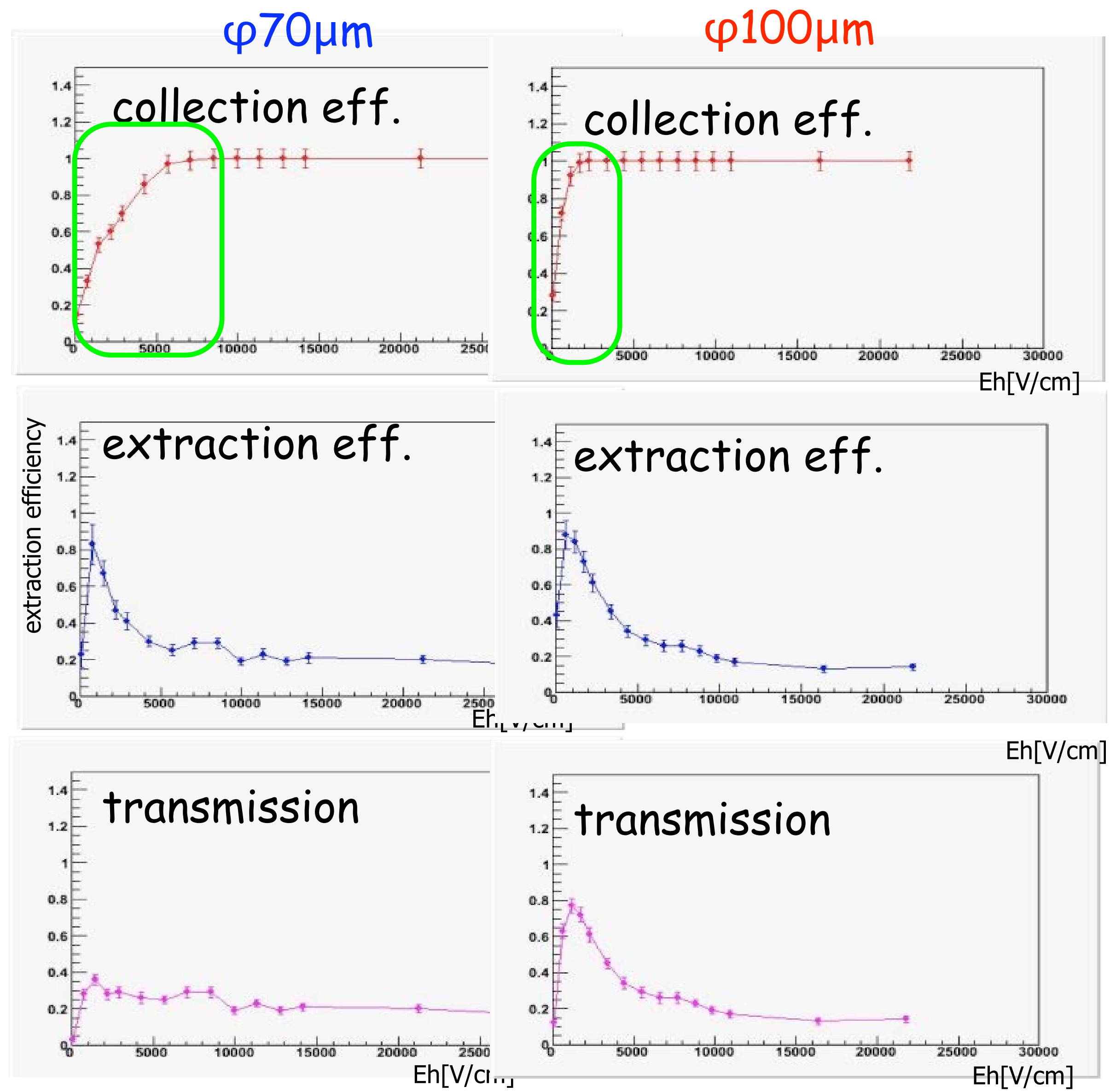


simulation

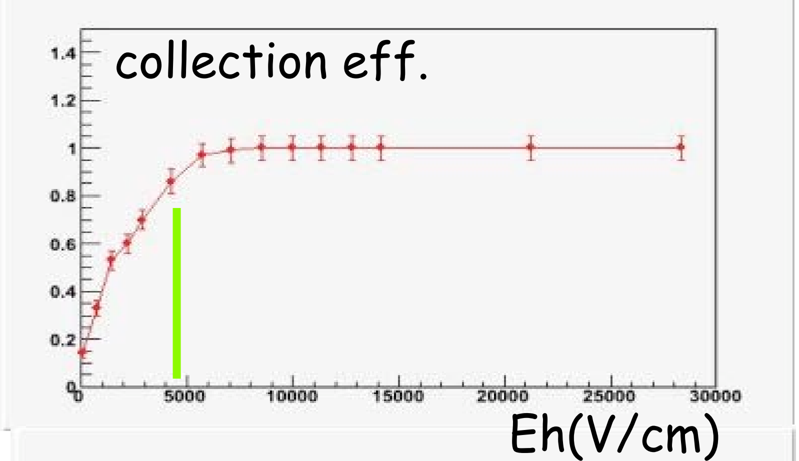


Gas gain is not included



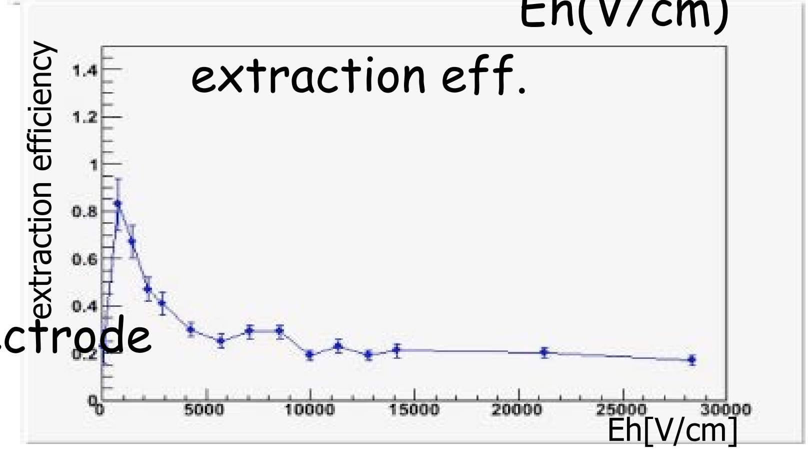
Collection eff. improve transmission
due to large aperture

Collection eff. has been studied by several groups as a func. of Ed/Eh and known to be ~1 @Ed/Eh < 0.03 (ie 4.5kV/cm here)



Extraction eff. behave more more complicatedly

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

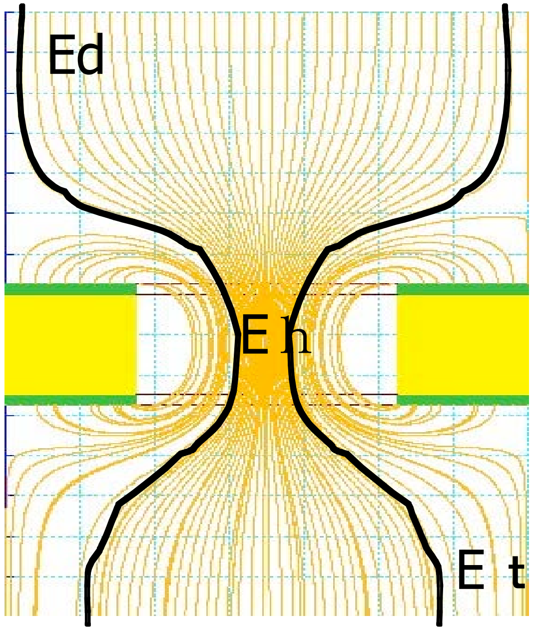


area of penetrating field line is larger @ low Eh
higher extraction

diffusion behavior is also important !

This means "transmission is largely depend on gas"

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



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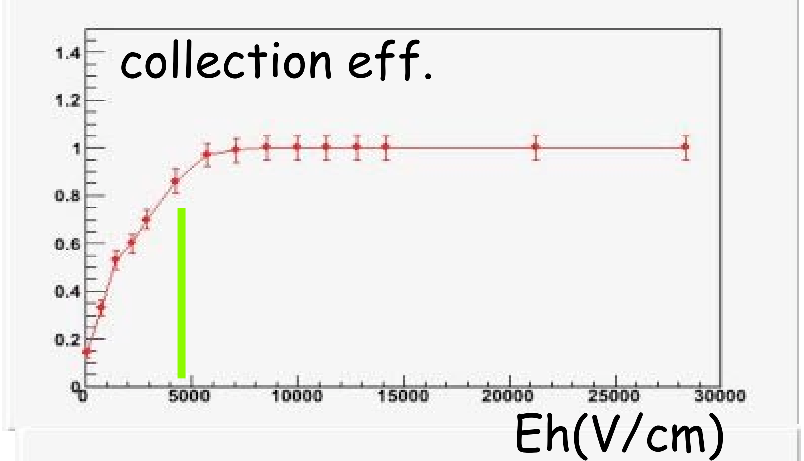

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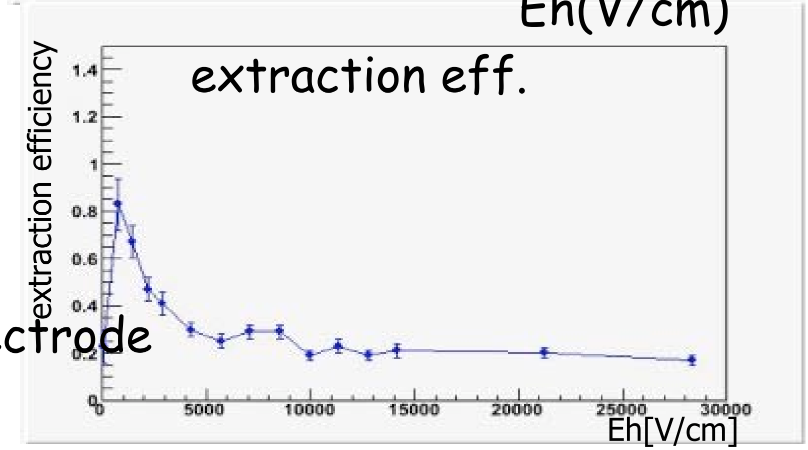

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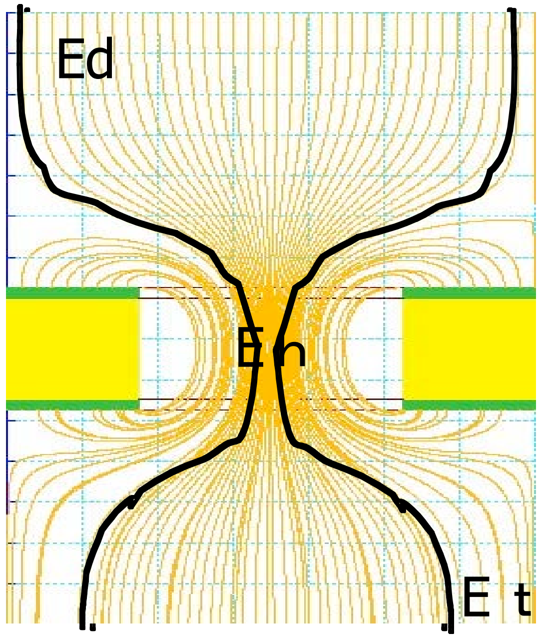

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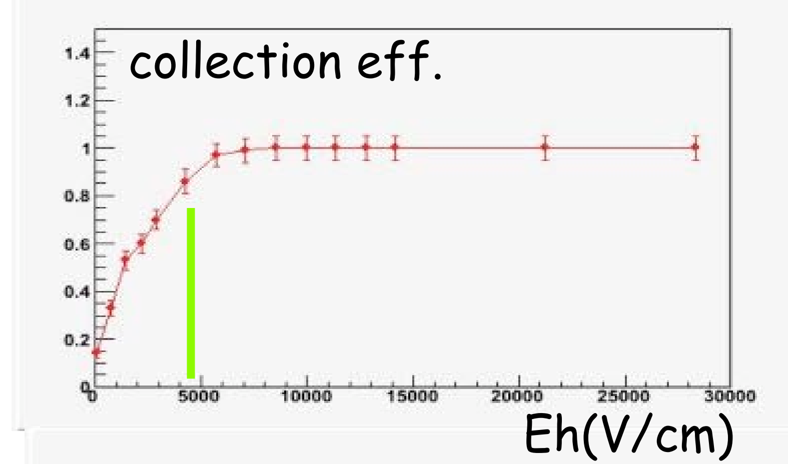

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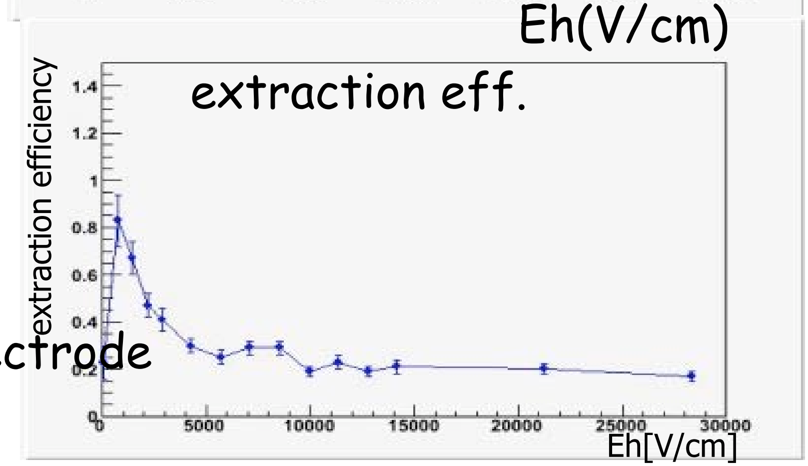

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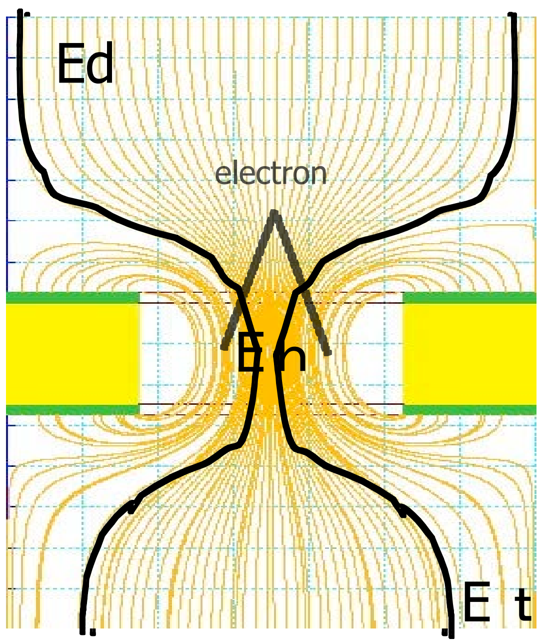

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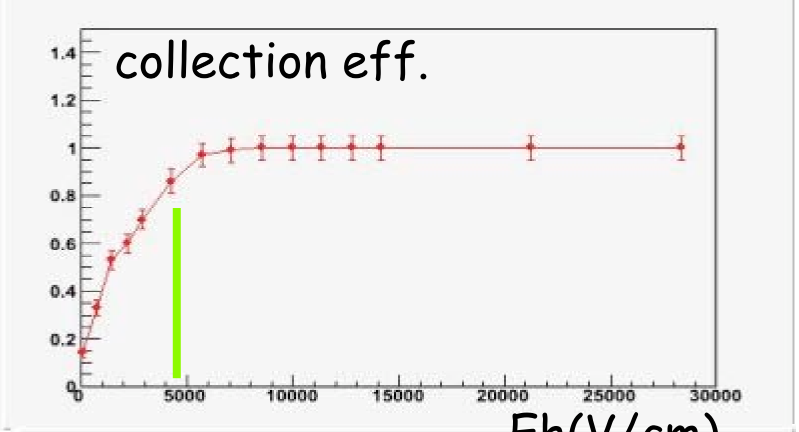

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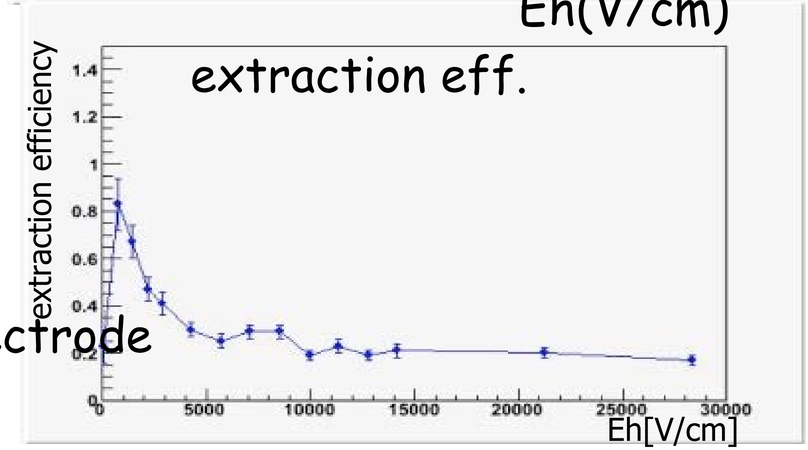

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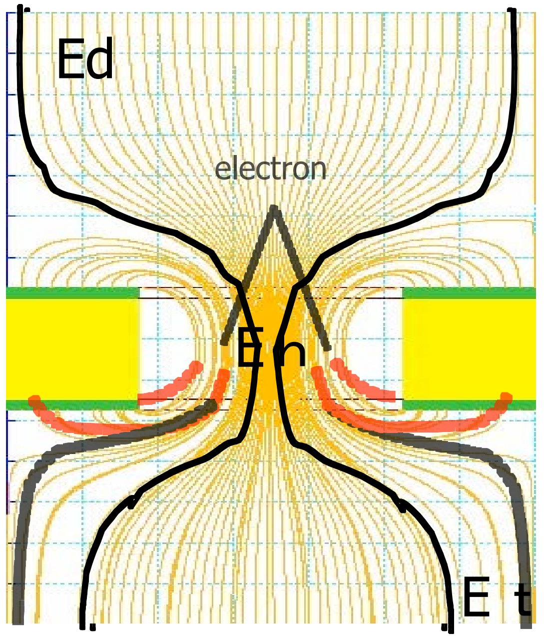
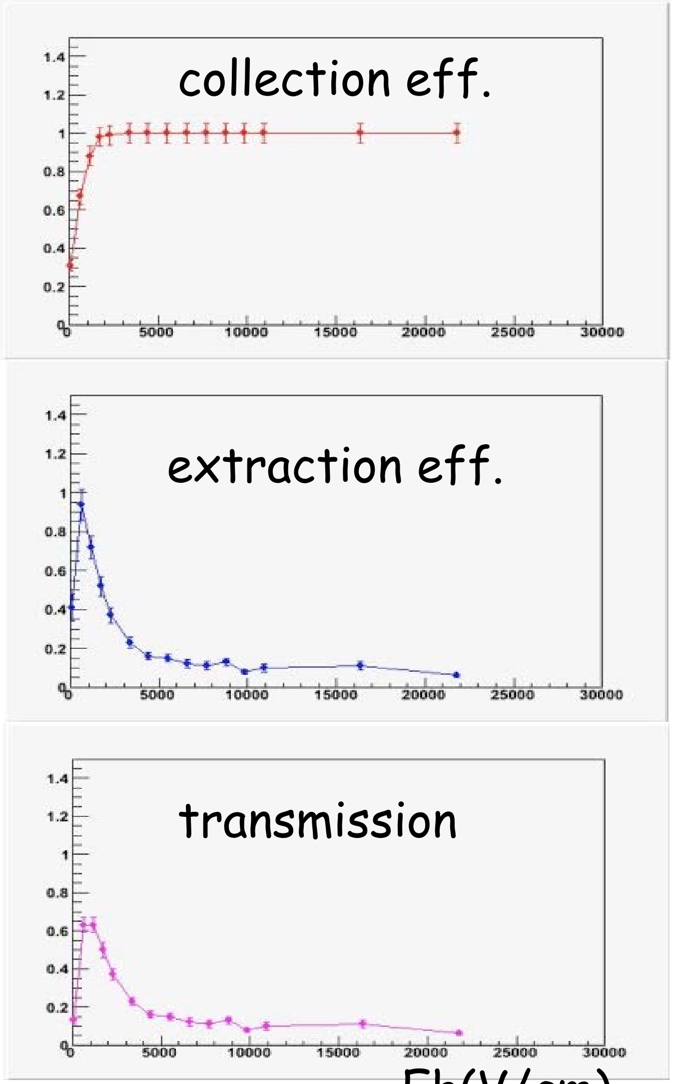


ArCF4 : candidate of LC-TPC Gas

Ed=150V/cm
Et=300V/cm
ϕ 100μm hole
B = 0 T



Eh(V/cm)

ArCF4 : candidate of LC-TPC Gas

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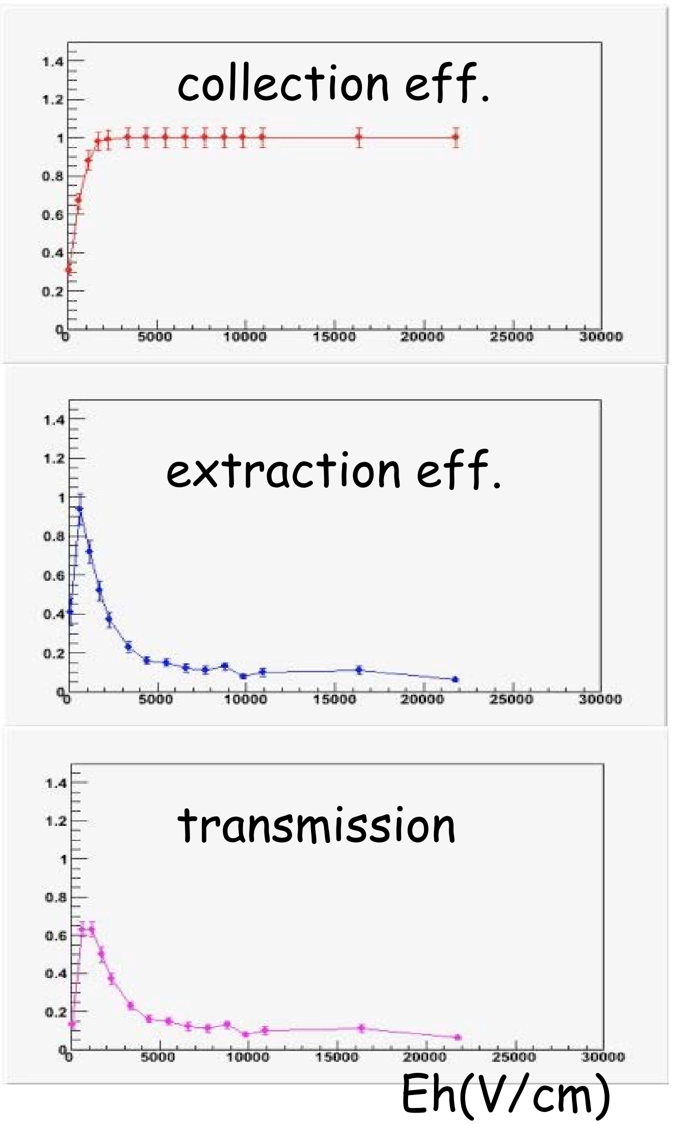
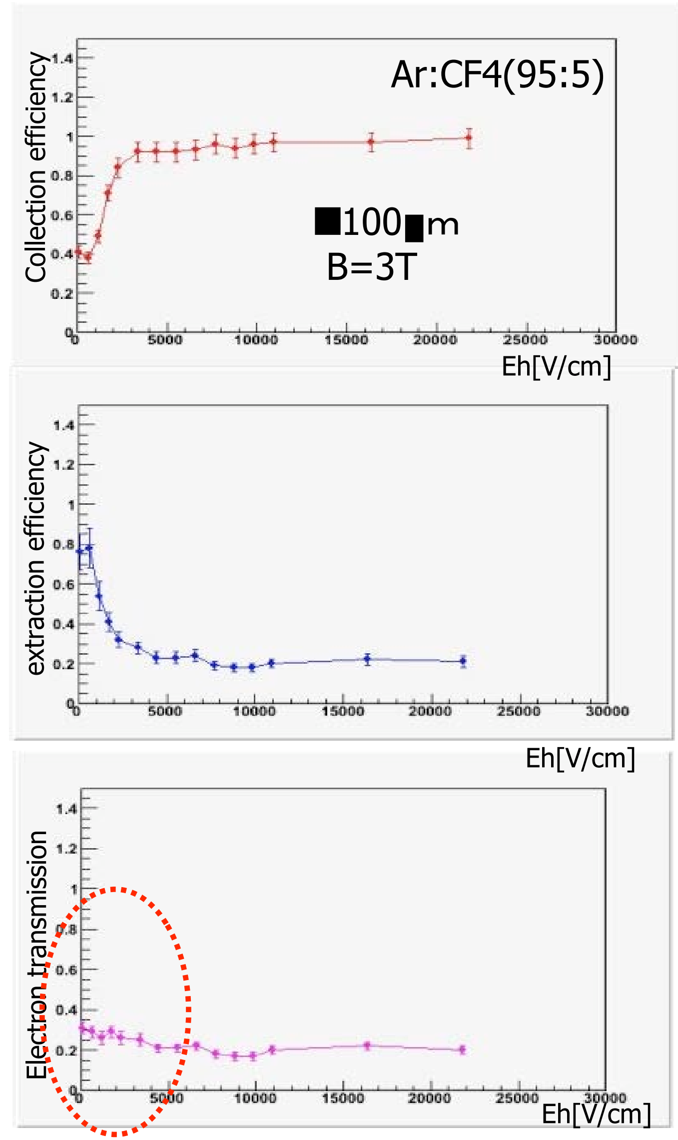


Effect of 3T magnetic field



Good region disappeared !

ArCF4 : candidate of LC-TPC Gas

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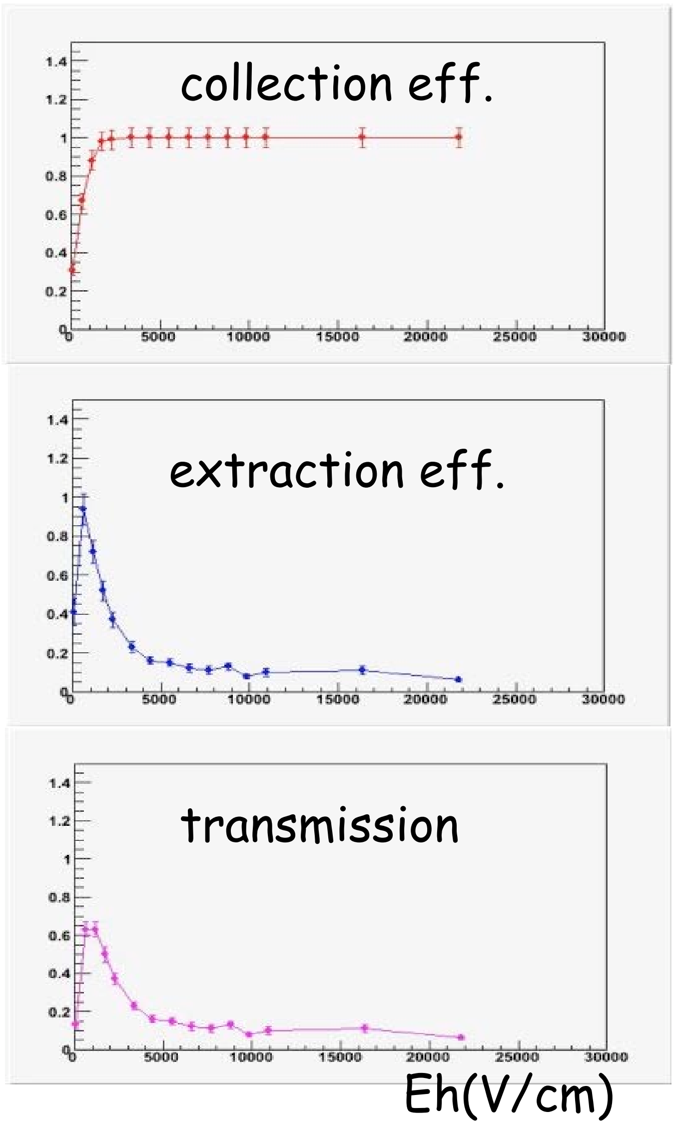
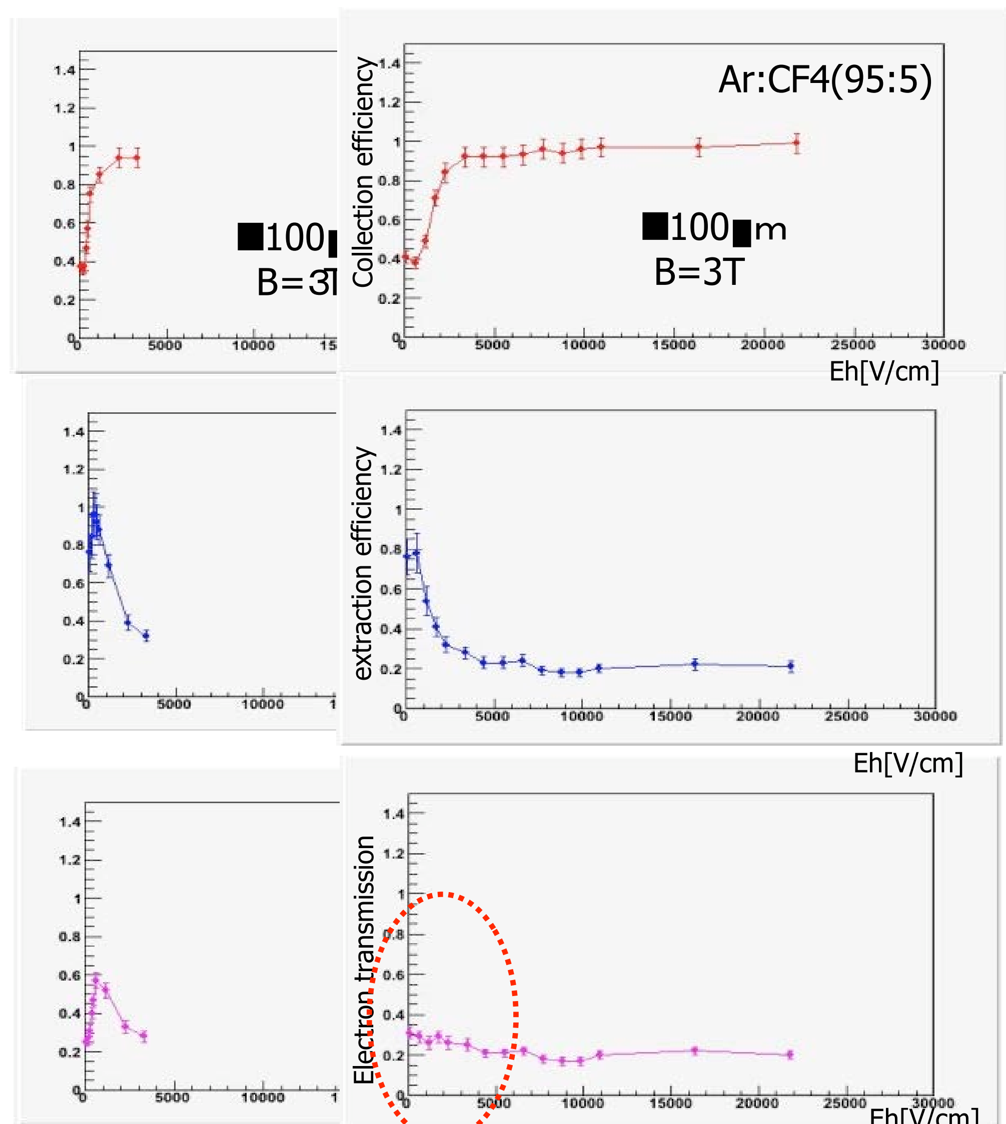


Effect of 3T magnetic field



Good region disappeared !

ArCF4 : candidate of LC-TPC Gas

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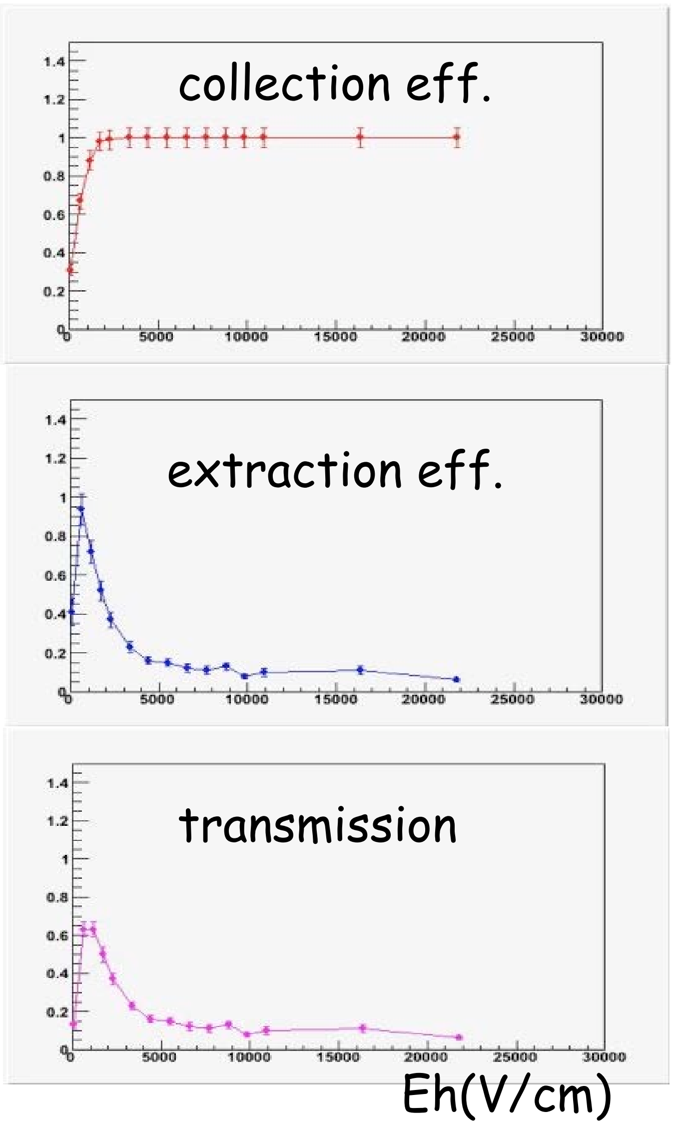
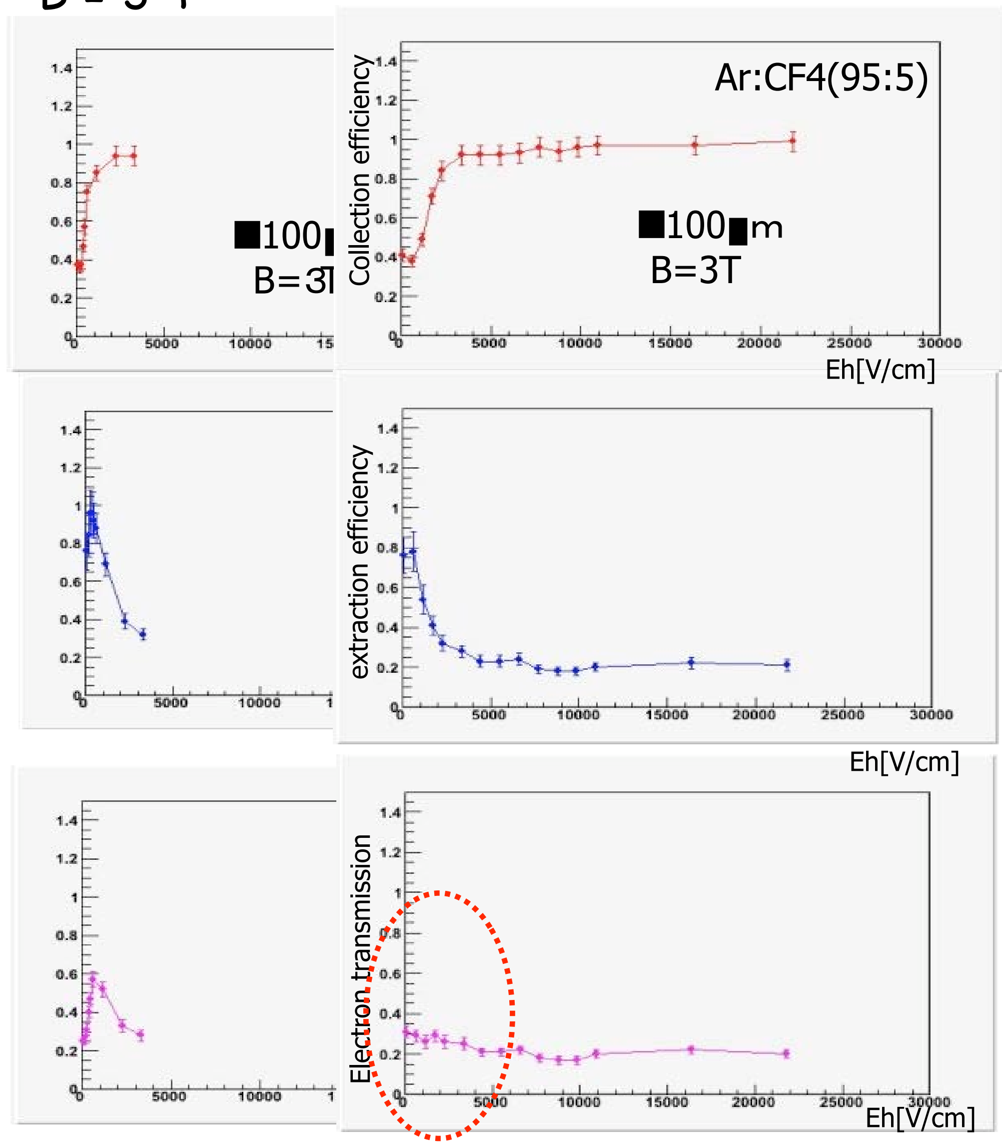
ϕ 100μm hole
B = 0 T



Ed= 50V/cm
Et=300V/cm
B = 3 T

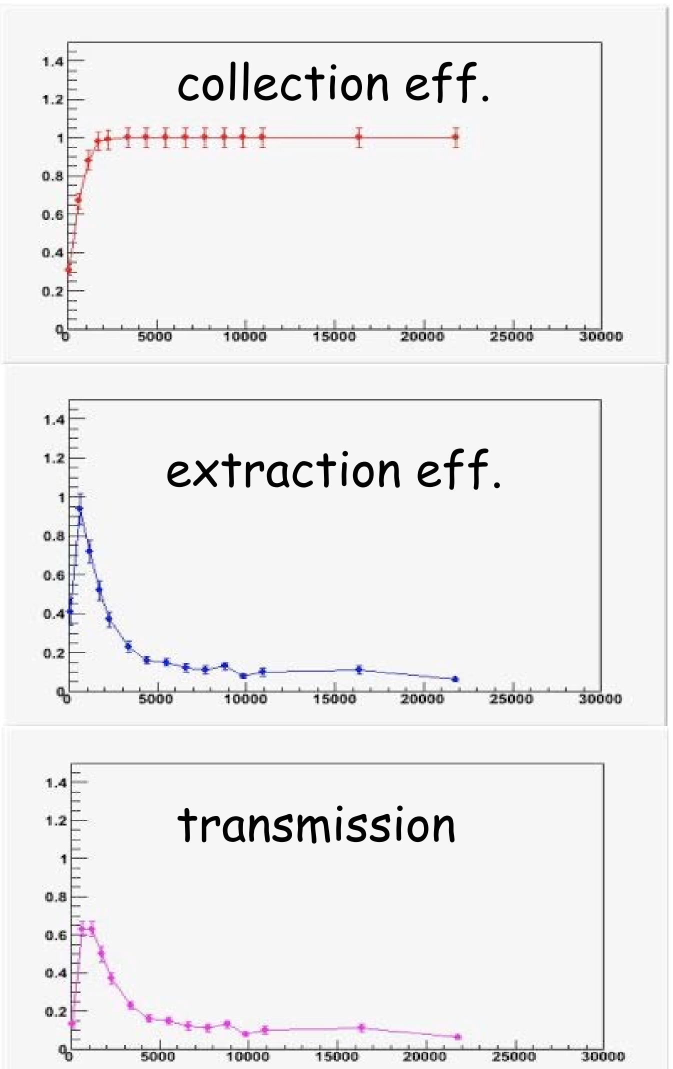
Effect of 3T magnetic field



Good region disappeared !

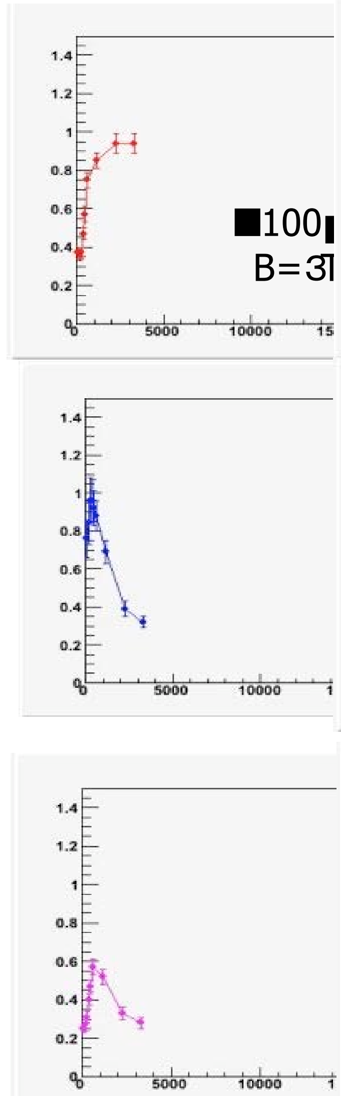
ArCF4 : candidate of LC-TPC Gas

Ed=150V/cm
Et=300V/cm
ϕ 100μm hole
B = 0 T

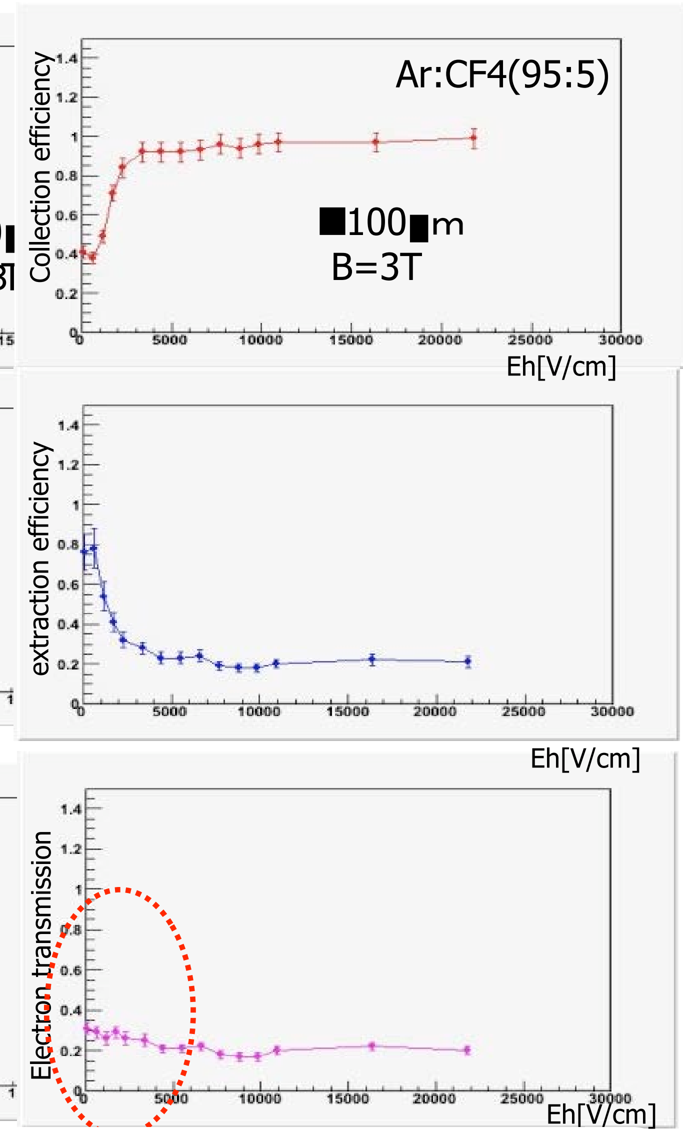


Eh(V/cm)

Ed= 50V/cm
Et=300V/cm
B = 3 T

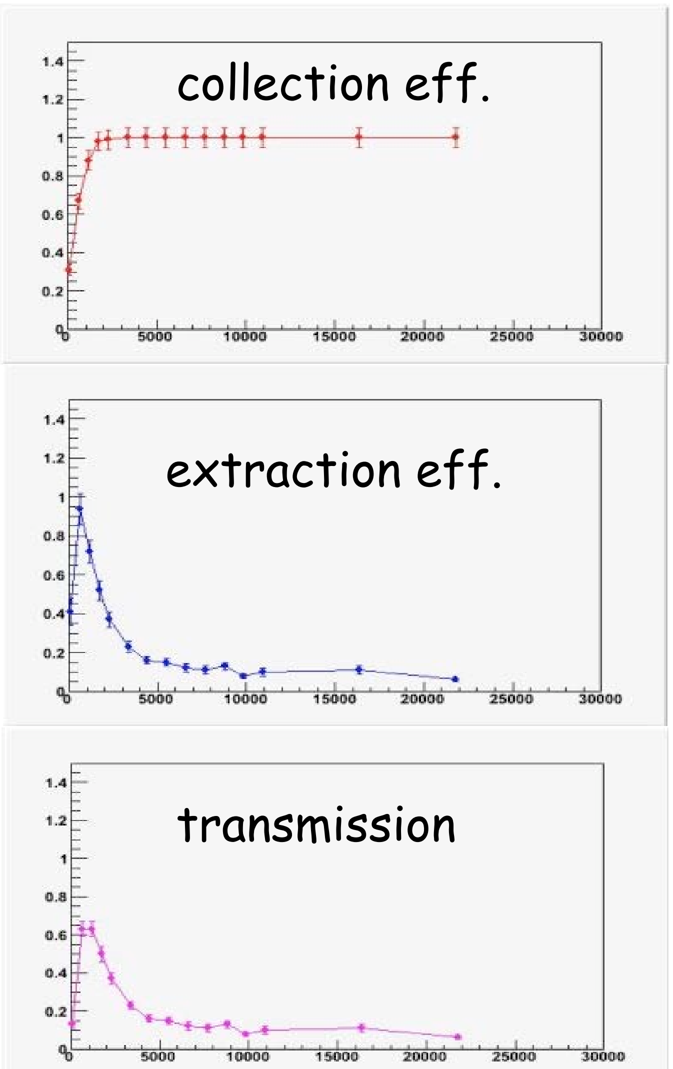


Effect of 3T magnetic field



ArCF4 : candidate of LC-TPC Gas

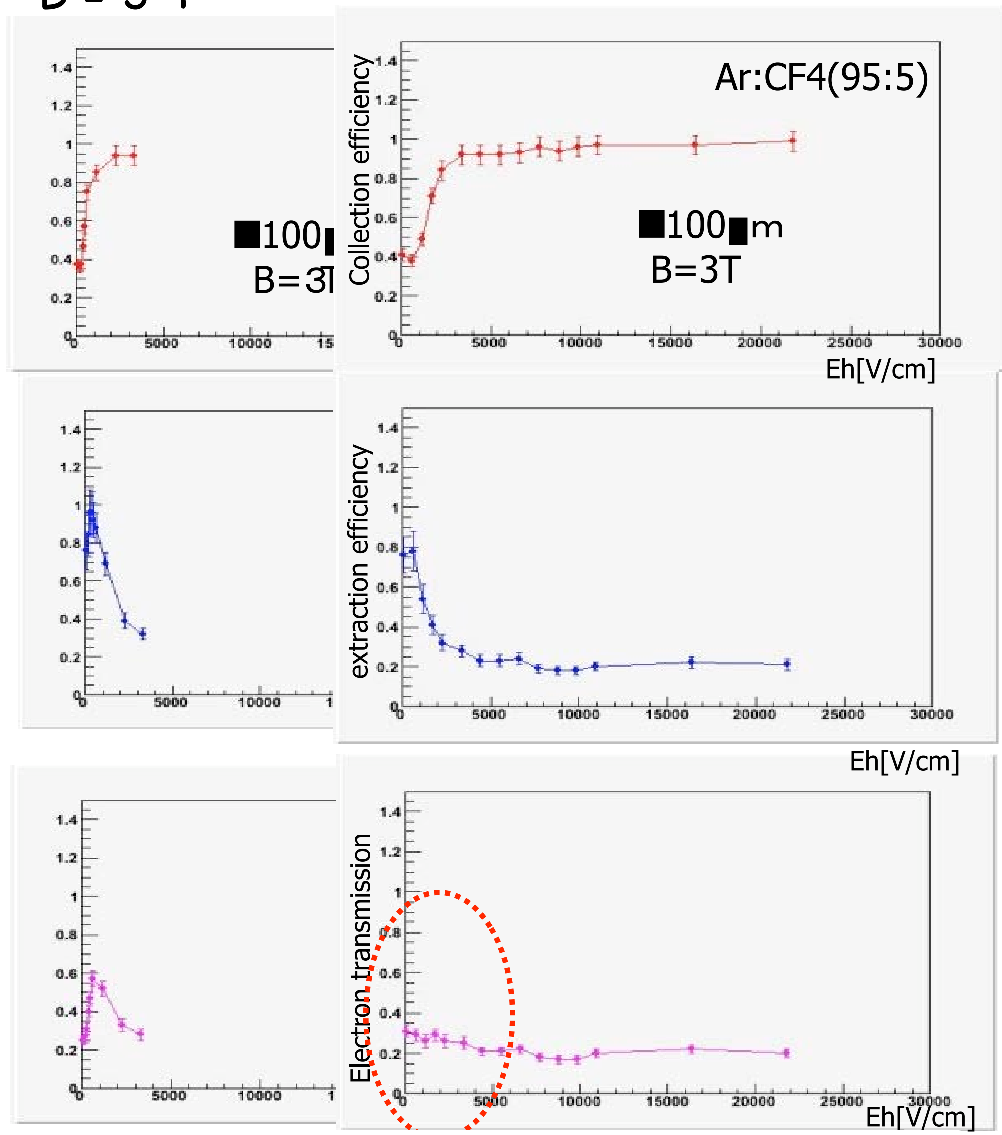
Ed=150V/cm
Et=300V/cm
ϕ 100μm hole
B = 0 T



Eh(V/cm)

Ed= 50V/cm
Et=300V/cm
B = 3 T

Effect of 3T magnetic field

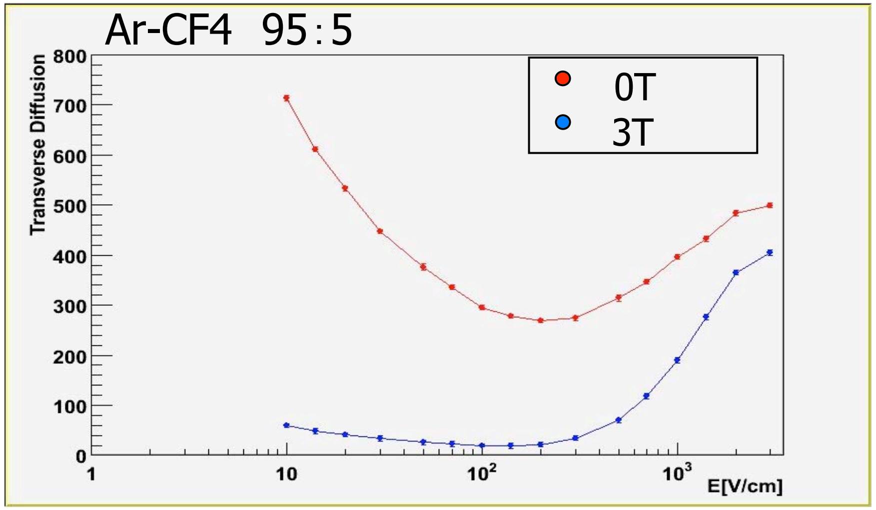


transmission is recovered by changing Ed

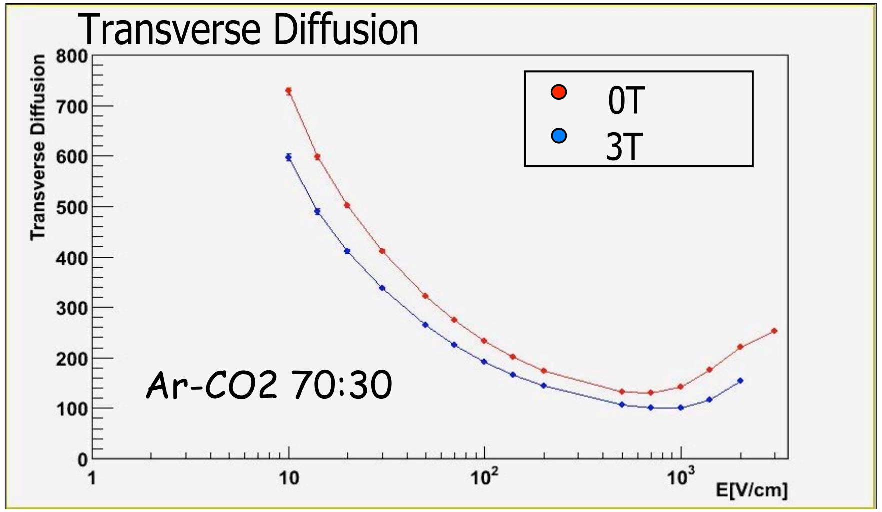
GEM Gating for ArCF4 gas

under this condition
is not good enough for LC-TPC
due to low transmission (~60%)

ArCO2 can provide better performance
these results are related to gas property



1.5kV/cm



We must find better geometry of
GEM(width, pitch, hole size)
or find better operation condition
or find better gas

Otherwise go to other gating method

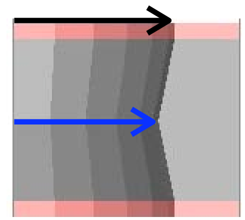
GEM optimization for Gating

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

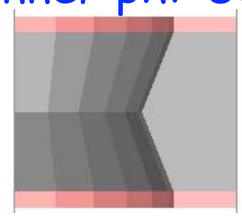
bi-conical shape
outer phi=100 um

We just begun !

inner phi=90 um



inner phi=80 um

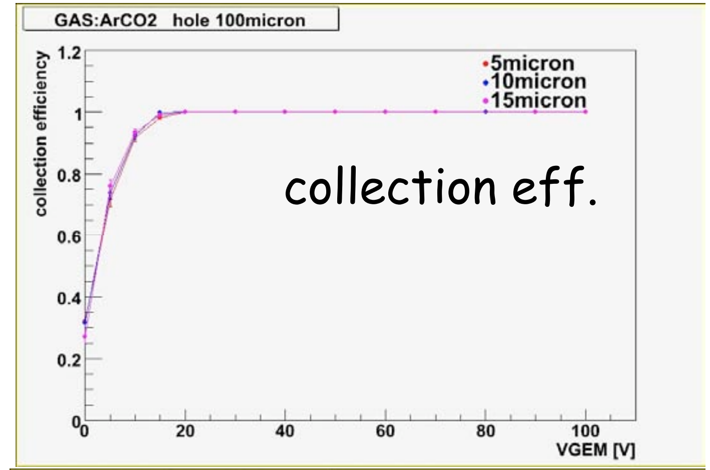


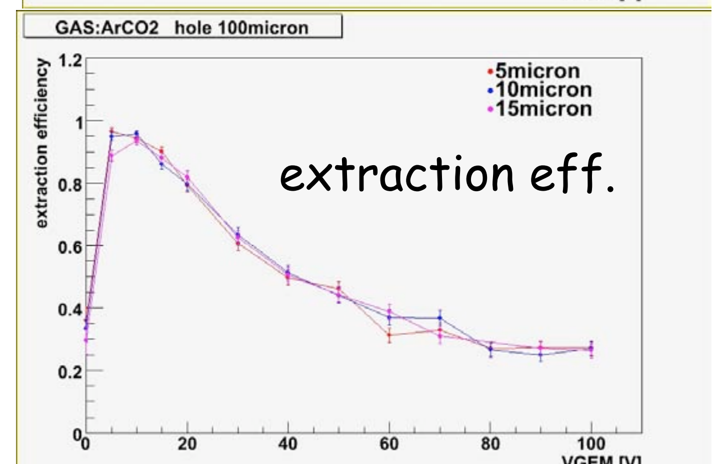
inner phi=70 um

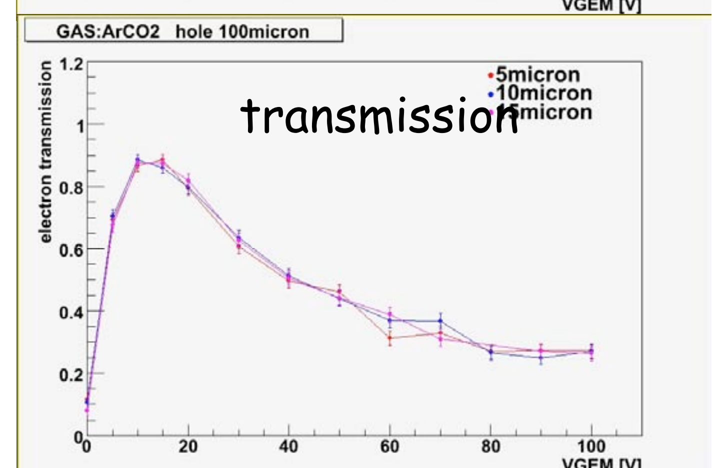
Hole shape is not a matter !
Over etching will be also not a matter
under low E field

We are going to study
hole size/pitch & GEM thickness

and
we have to measure it experimentally.







Summary

Serious studies for LC-TPC are on-going @ world-wide LC-TPC collaboration

"Proof of principle" has been studied with small prototype test.
Large Prototype project has started
Field Cage/Endplate/Electronics/Gas/Calibration/Monitor/DAQ/Software/.....

GEM is the alternative candidate for LC-TPC sensor
and also a candidate for ion-blocking gate
Japanese group is working for this now

We have to study many more basic things as well

dense ions effect in MPGD
(discharge/trip) recovery from unexpected local dense ionization hits
....