Introduction of TPC for ILC experiment

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ILC Summer Camp2020 online

TPC talk @ILC summer camp 2019

Main topics: Overview of LCTPC

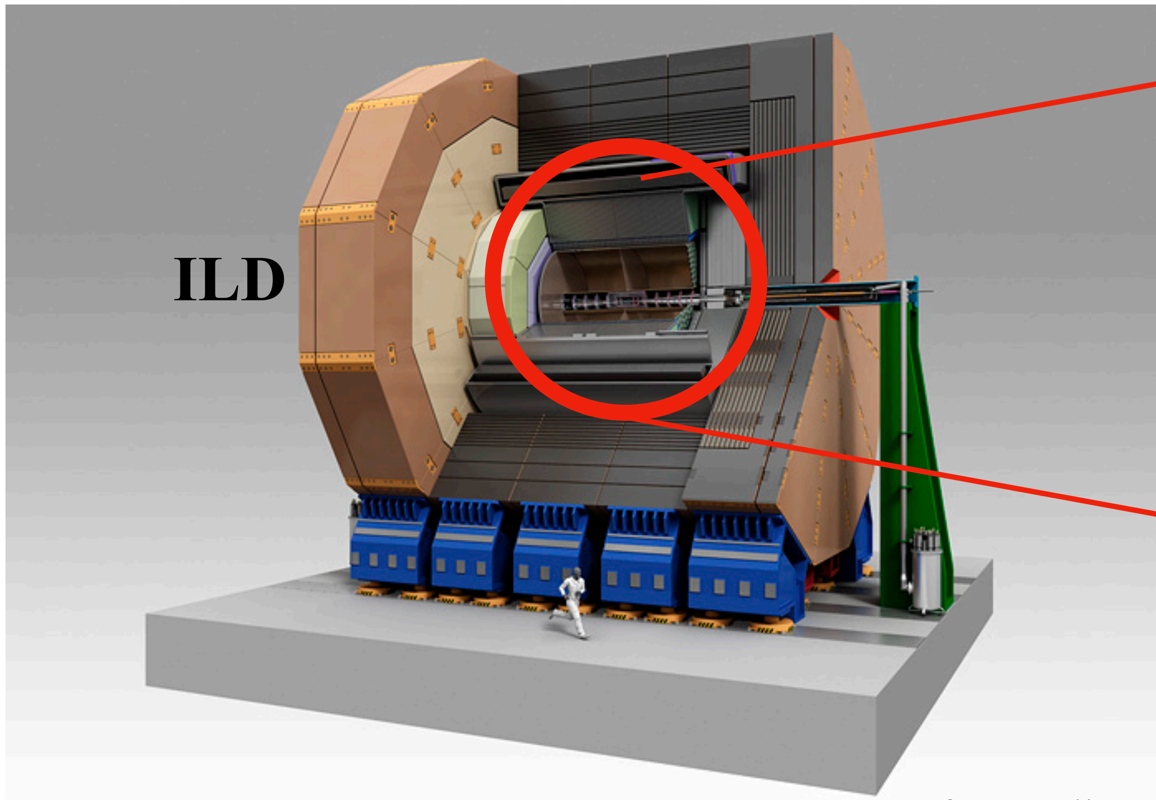
https://agenda.linearcollider.org/event/8237/contributions/44016/attachments/34697/53550/ILC_SummerCamp_Yumino2019ENG_0.pdf

This year Mainly focus on

- dE/dx
- Gas mixture
- Avalanche gas gain

Time Projection Chamber (TPC)

Central tracker of ILD



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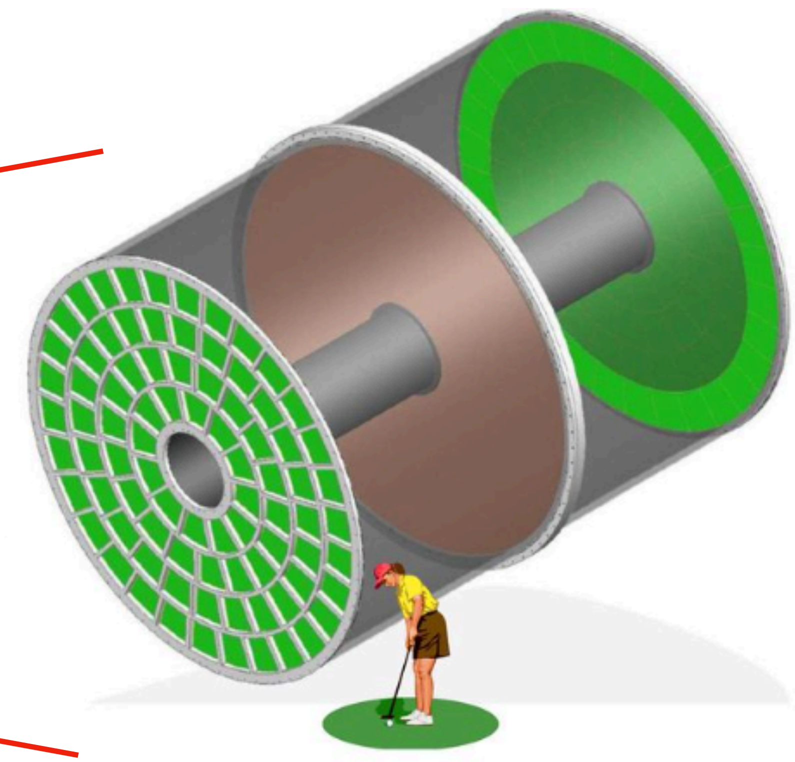


Detects reactions of charged particles in 3-dim as tracks

Role of TPC

charged particle

<u>Track measurement</u>

Measure passing points along trajectory

↪Directions of track

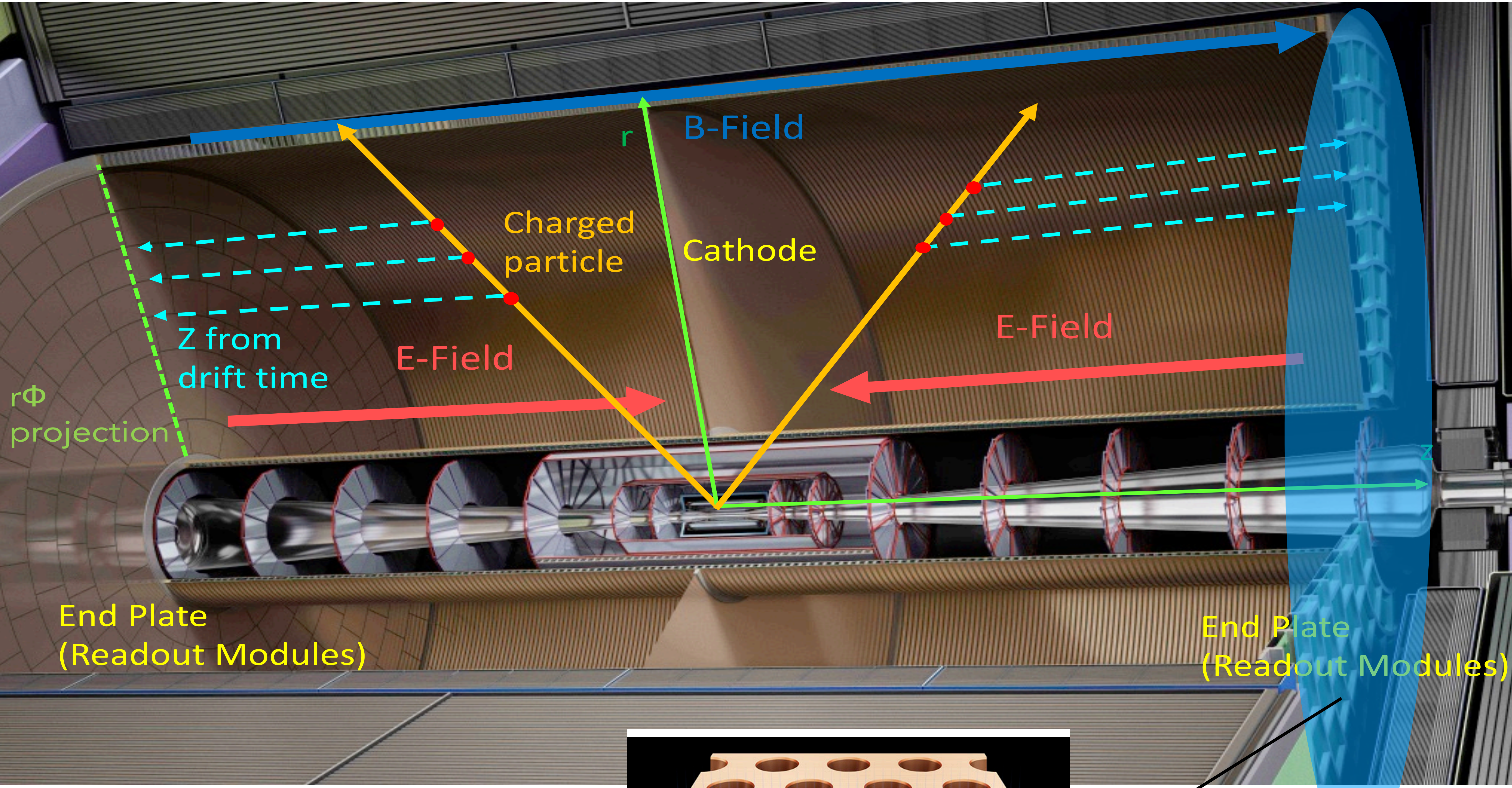
<u>Momentum measurement</u>

Measure the bend of tracks in B-Field

↪Momentum of charged particle

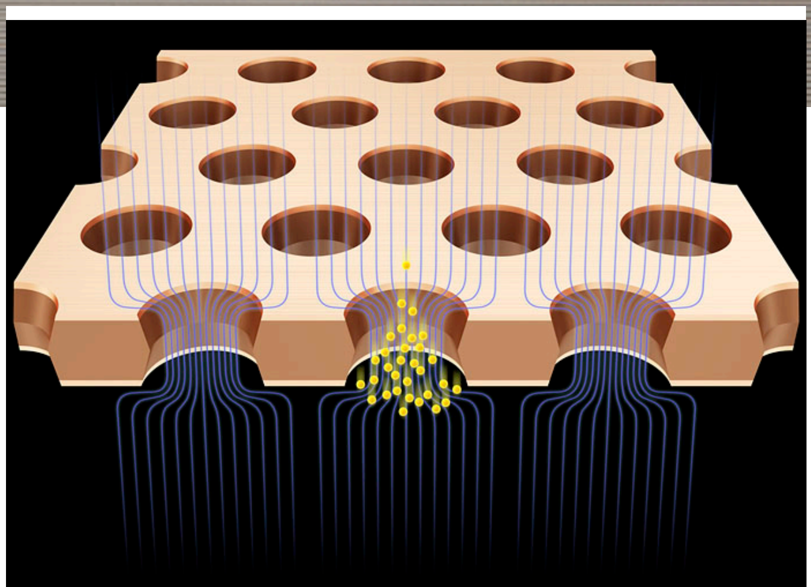
<u>Particle Identification (PID)</u>

Inside of ILD-TPC



T2K gas $Ar : CF_4 : iC_4H_{10} = 95 : 3 : 2$

Gas amplification of ionised electrons and read out as electrical signal

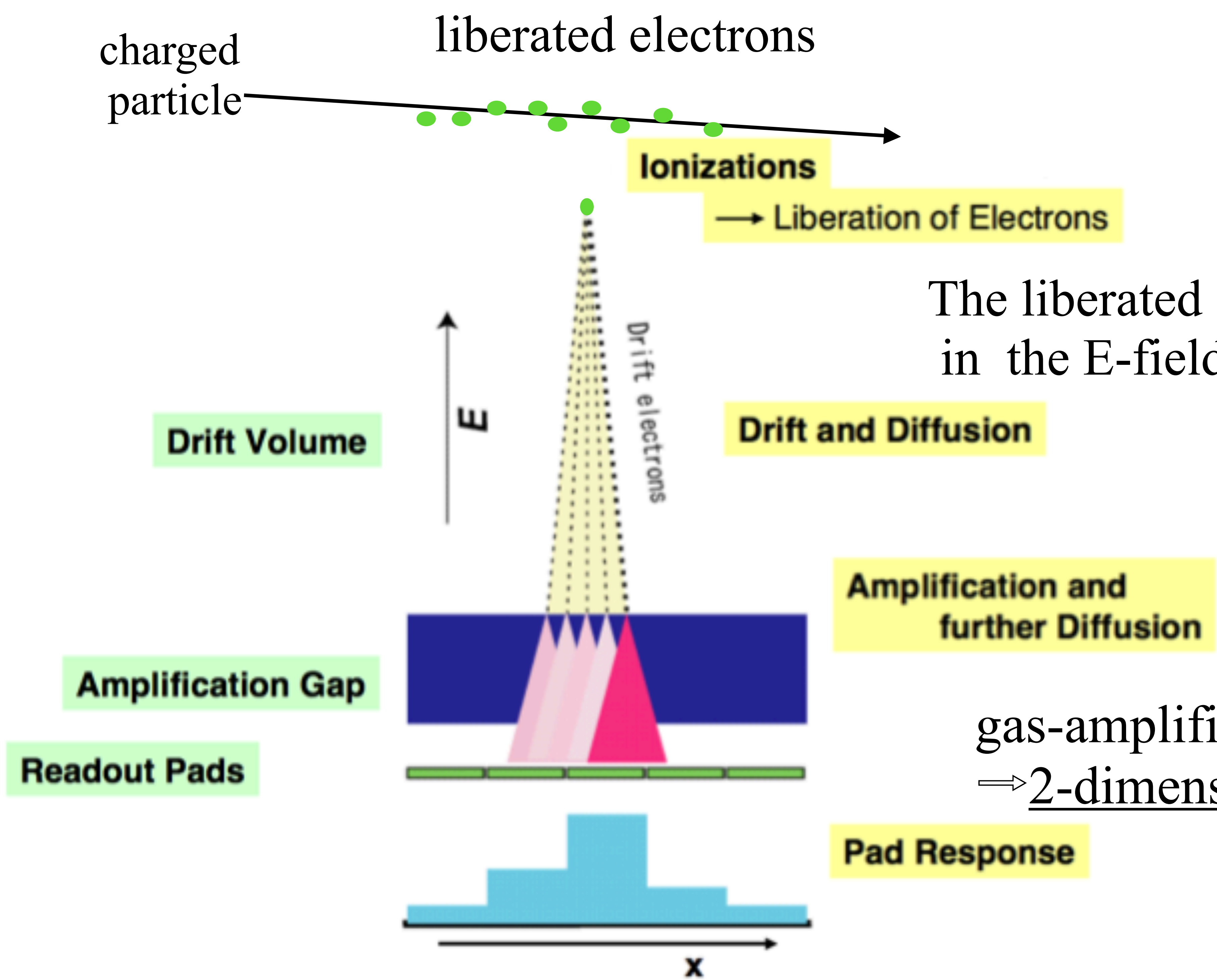


Example of gas-amplifier

GEM (Gas Electron Multiplier)

Operating principle of TPC

A charged particle ionizes the atoms of the gas mixture along its trajectory

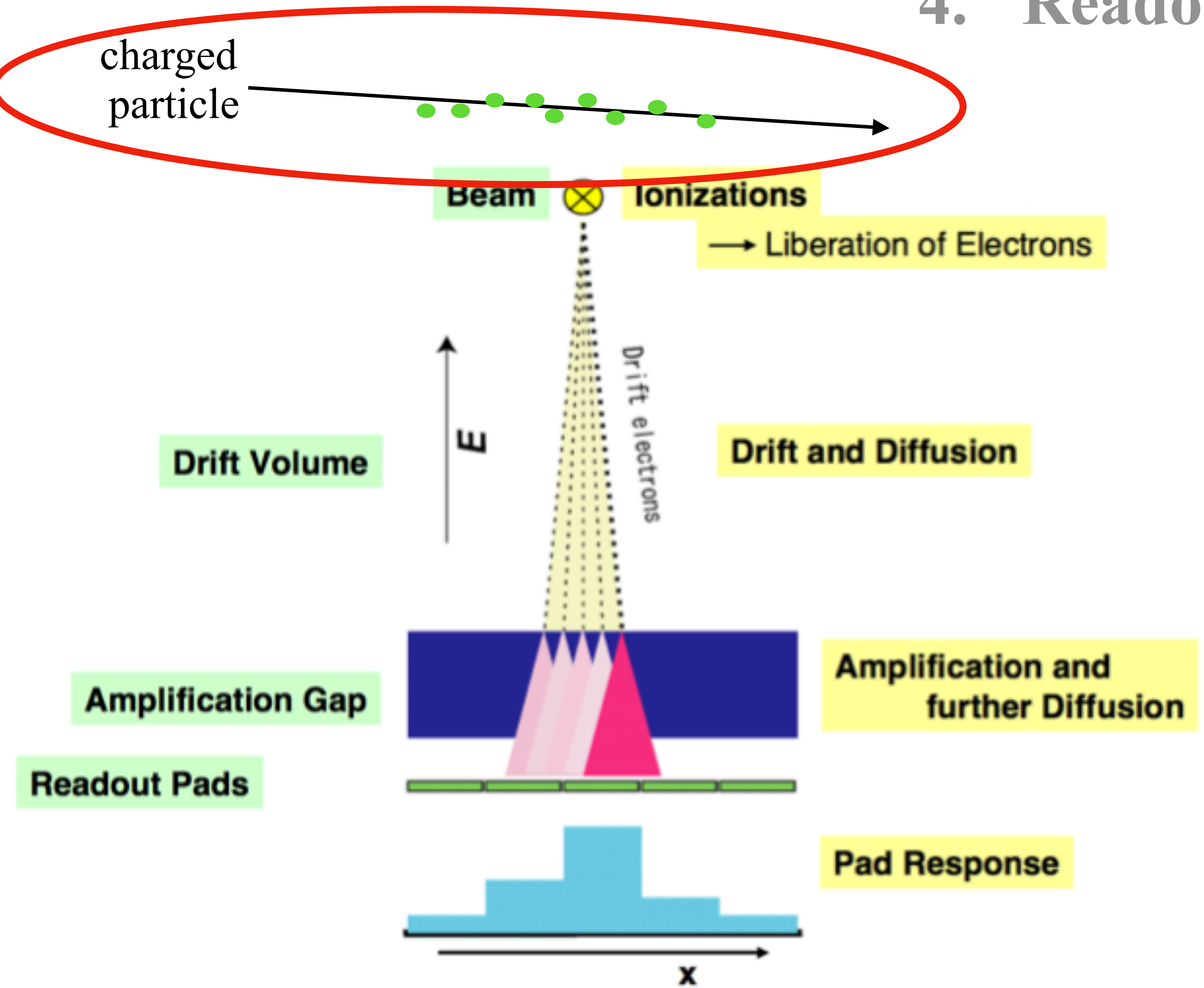


The liberated electrons drift in the E-field towards the readout pad

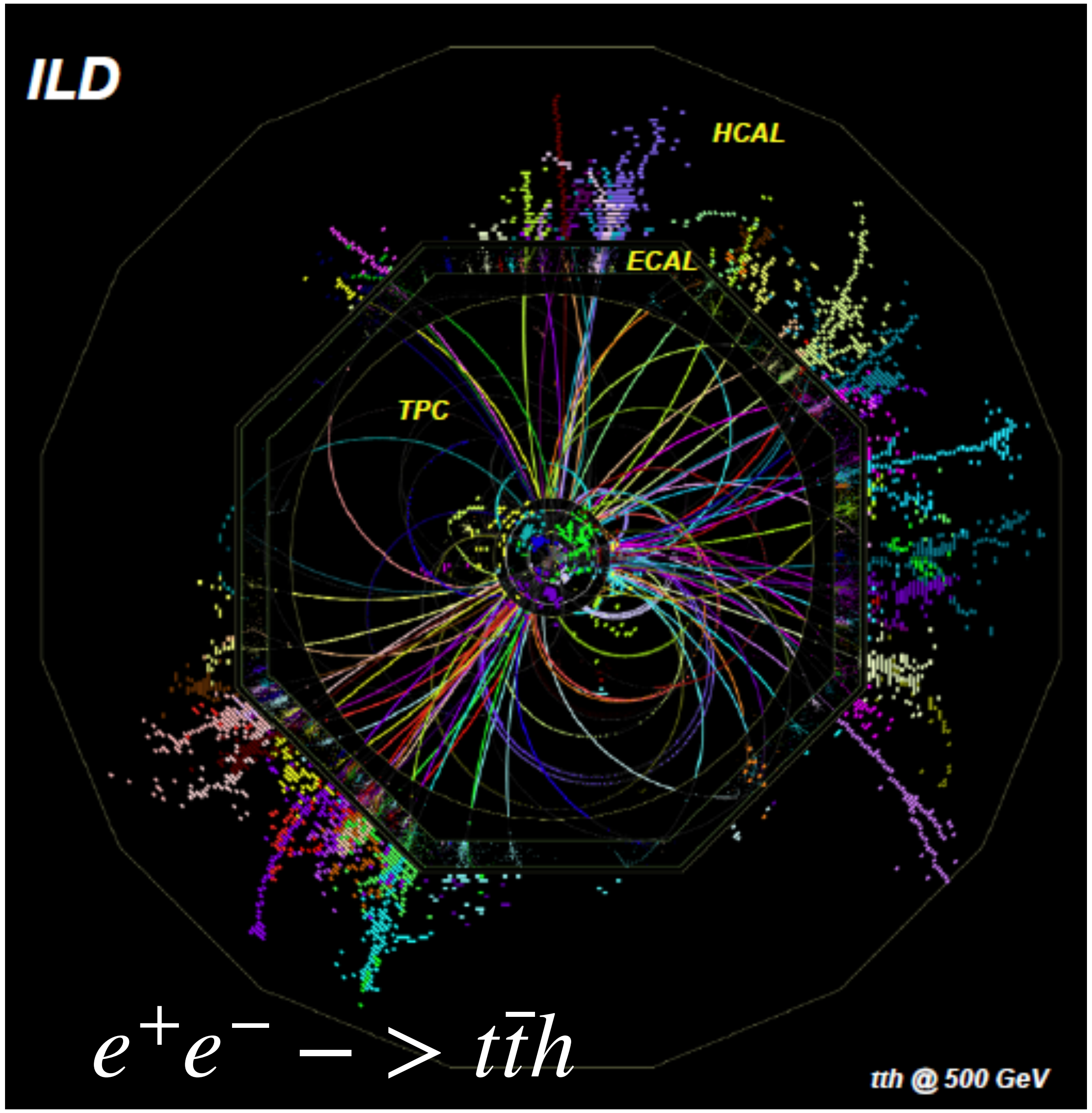
gas-amplified and read as signal
⇒ <u>2-dimensional (x,y) information</u>

z component is obtained from drift time ⇒ <u>3-dimensional (x, y, z) information</u>

1. **Momentum measurement**
2. Gas mixture
3. Particle ID and dE/dx
4. Readout module



Momentum measurement



track of particles(simulation) see from the side of TPC

Charged particle : circular motion in B-Field

$$p_\perp = 0.3\ BR\ [GeV/c]$$

B = 3.5 T @ILC

$p_\perp$: **vertical axis component**

p_z : **beam axis component**

R : **radius of curvature**

The ratio of p_z and $p_\perp$ is obtained from the emission angle

The radius of curvature $\underline{R}$ gives momentum $\underline{p}$

required momentum resolution of ILD-TPC

ILC: "Higgs factory"

Higgs precision measurement is a high-priority goal

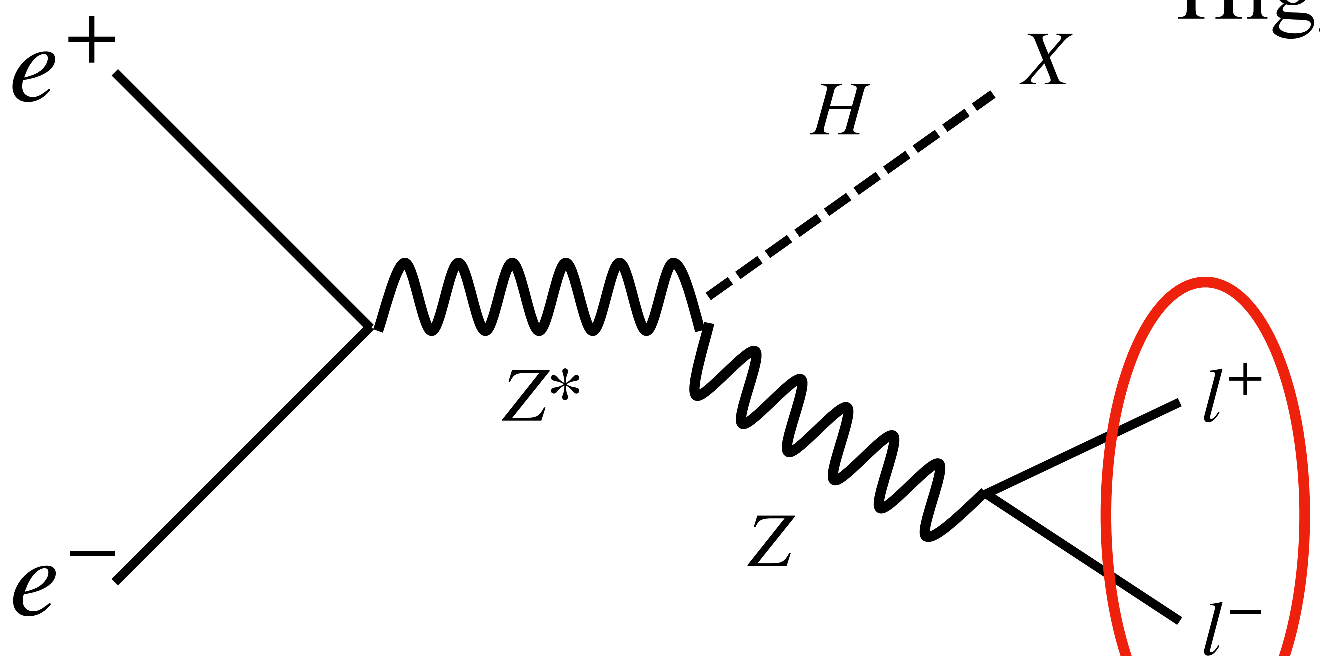
"Recoil"

Higgs can be reconstructed indirectly

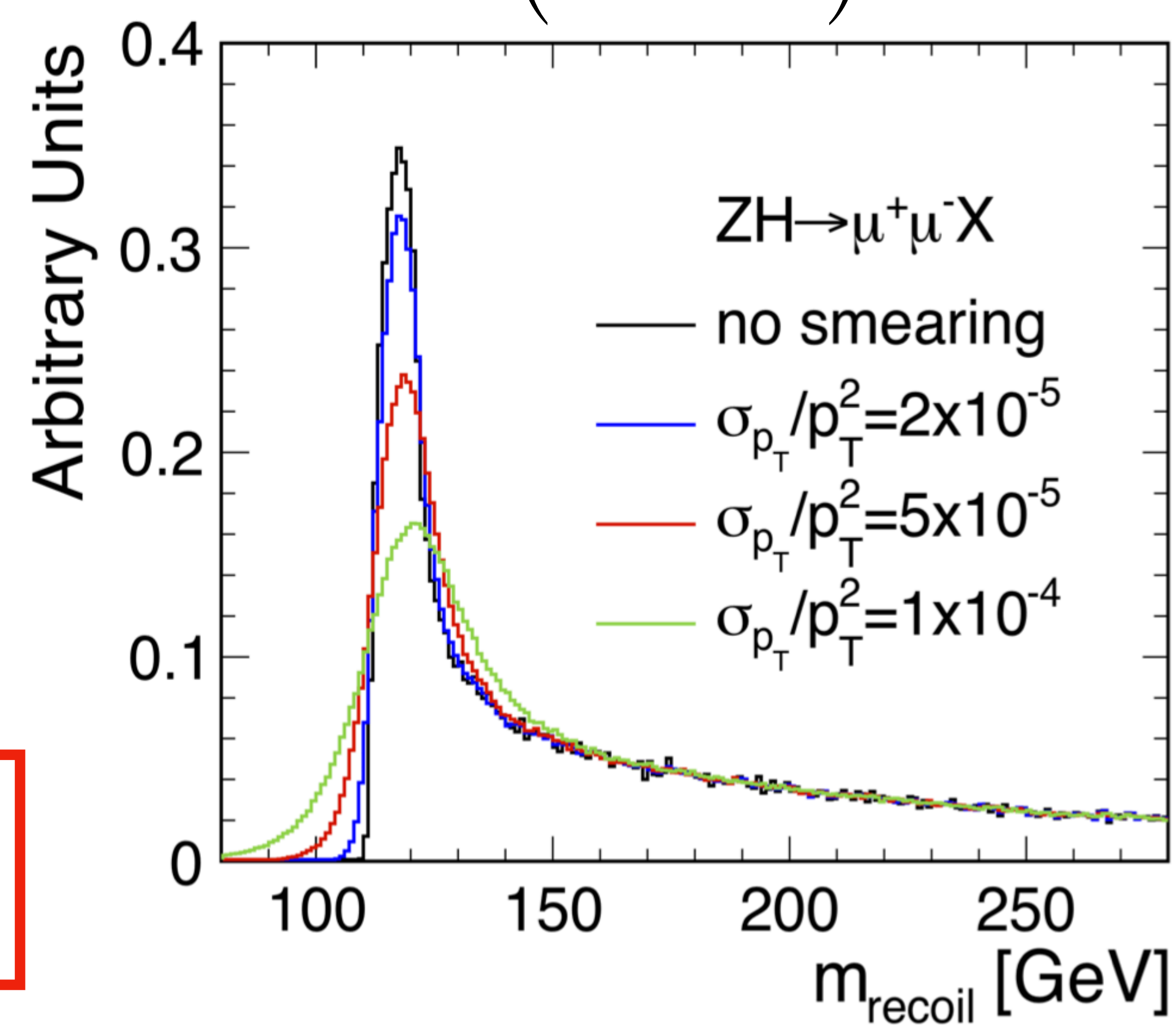
$$P_h = \underline{P_{e^-} + P_{e^+} - P_Z}$$

or

$$m^2_{recoil} = \left(\sqrt{s} - E_{ll}\right)^2 - |P_{ll}|^2$$



$e^+e^- \rightarrow ZH \rightarrow l^+l^-X$



Reconstruction of $Z \rightarrow ll$

momentum resolution is crucial

Momentum resolution

Momentum resolution

$$\frac{\sigma_{p_\perp}}{p_\perp} = \sqrt{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{N+4}\right) p_\perp^2 + \left(\frac{\alpha' C}{BL}\right)^2 \frac{10}{7}\left(\frac{X}{X_0}\right)}$$

measurements — multiple scattering

$p_\perp$: transverse momentum — B : strength of B-Field — L : track detection length — α', C : constant

σ_x : position resolution — N : # of measurement points — $\frac{X}{X_0}$: radiation length of gas

R.L. Gluckstern, NIM 24 (1963), 381

<u>required momentum resolution of ILD-TPC</u>

$$\frac{\sigma_{p_\perp}}{p_\perp} \approx 2 \times 10^{-5}\, p_\perp\ GeV/c$$ **(including information of silicon tracker)**

TPC only...

$$\frac{\sigma_{p_\perp}}{p_\perp} \approx 1 \times 10^{-4}\, p_\perp\ GeV/c$$

Momentum resolution

Momentum resolution

$$\frac{\sigma_{p_\perp}}{p_\perp} = \sqrt{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{N+4}\right) p_\perp^2 + \left(\frac{\alpha' C}{BL}\right)^2 \frac{10}{7}\left(\frac{X}{X_0}\right)}$$

measurements multiple scattering

$p_\perp$: transverse momentum
B : strength of B-Field
L : track detection length
α', C : constant
σ_x : position resolution
N : # of measurement points
$\frac{X}{X_0}$: radiation length of gas

R.L. Gluckstern, NIM 24 (1963), 381

to achieve required momentum resolution

$$\frac{\sigma_{p_\perp}}{p_\perp} \approx 1 \times 10^{-4}\, p_\perp\ GeV/c$$

ILCTPC: $B = 3.5\ T,\ N \simeq 200,\ L = 1.5\ m$

we need small position resolution σ_x $\qquad \sigma_x \approx 100\ \mu m$

Position resolution

$$\sigma_x = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot \boxed{z}}{N_{eff}}}$$

z: drift length
Neff: effective number of electron
Cd: diffusion constant of gas

depends on drift length

small position resolution σ_x

$$\sigma_x \approx 100\ \mu m$$

even at the large drift length of $2.2\ m$

- **Strong magnetic field** $B = 3.5\ T$
- **Gas mixture with small diffusion constant**

Position resolution

$$\sigma_x = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot \boxed{z}}{N_{eff}}}$$

depends on drift length

Transverse diffusion constant

$$C_d(B,E) = \frac{1}{\sqrt{1+(\omega\tau)^2}} C_d(0,E)$$

z: drift length
Neff: effective number of electron
Cd: diffusion constant of gas

ω:Cyclotron frequency
τ:mean free time

Signal electrons are affected by diffusion

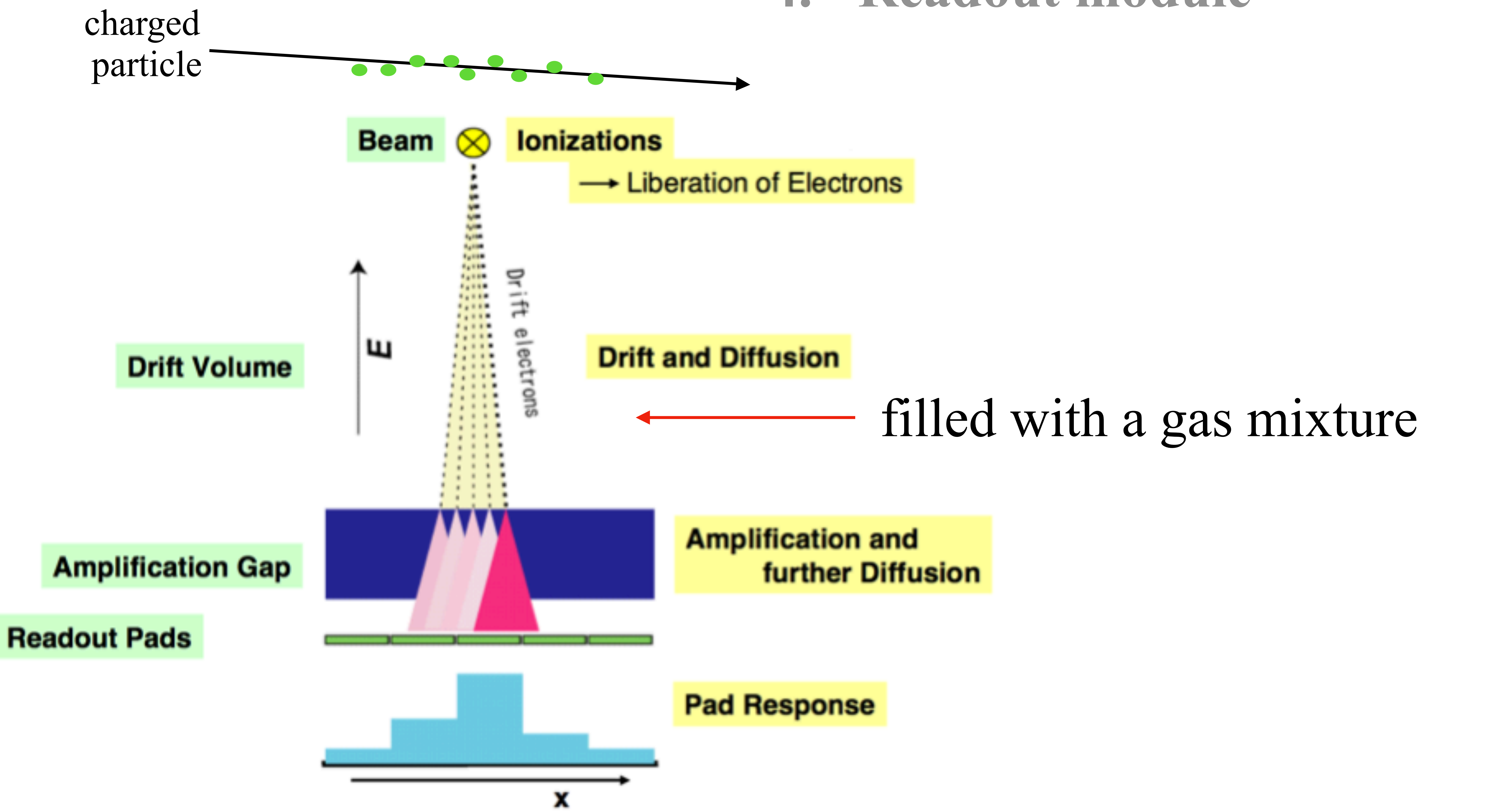
†transverse diffusion makes position resolution worse

In TPC : E // B

Lorentz force suppresses transverse diffusion of drift electrons by curling them around the B-Field

Gas: small transverse diffusion in the B-Field to achieve position resolution required by ILD-TPC

1. Momentum measurement
2. **Gas mixture**
3. Particle ID and dE/dx
4. Readout module



Gas mixture

to achieve the position resolution required by ILD-TPC

In order to reduce transverse diffusion

a gas mixture which has a <u>large $\omega\tau$</u> is needed

T2K gas **Ar : $\boxed{\text{CF4}}$: iC4H10 = 95 : 3 : 2**

$$C_d(B, E) = \frac{1}{\sqrt{1 + (\omega\tau)^2}} C_d(0,E)$$

<u>CF4</u>

- **Ar-CF4 is a relatively fast gas**

  ->Large ωτ **∵drift velocity $\propto \tau$**

- **The value of $\omega\tau$ is about 11.6 with E = 230 V/cm and B = 3.5 T**

(see the first paragraph of Section 5.3 in NIM A918 (2019) 41)

Gas mixture

T2K gas **Ar : CF4 : $\boxed{\text{iC4H10}}$ = 95 : 3 : 2**

The isobutane

act as a "quencher"

absorb ultraviolet photons from Ar molecules excited during avalanche process

→might cause discharge and destabilise chamber operation.

bonus

A small amount of isobutane is added to obtain a high gas gain at low voltages

⇒Penning effect

Penning effect

The Penning effect in our case:

additional ionisation of isobutane molecules by meta-stable argon atom (Ar*)

The Penning effect

isobutane(iC4H10) with a low-ionisation potential

$$I_{\mathrm{Isobutane}} = 10.67 \text{ eV} \qquad <$$

Ar: excited state energy higher than an ionisation energy of isobutane

Argon:
Excitations:

- 11.55 eV **(S)**
- 13.0 eV **(P)**
- 14.0 eV **(D)**

$$\mathrm{Ar}^{*}(\mathrm{S}, \mathrm{P}, \mathrm{D} \text{ level exc.}) \rightarrow \mathrm{iC4H10}$$

$$\mathrm{Ar}^{*} + (\mathrm{iC4H10}) \rightarrow \mathrm{Ar} + (\mathrm{iC4H10})^{+} + e^{-}$$

additional electron!!

high gas gain at low voltages

Transverse diffusion

$$D(B,E) = \frac{1}{\sqrt{1+(\omega\tau)^2}} D(0,E)$$

ω depends only on B

large τ gas is needed!

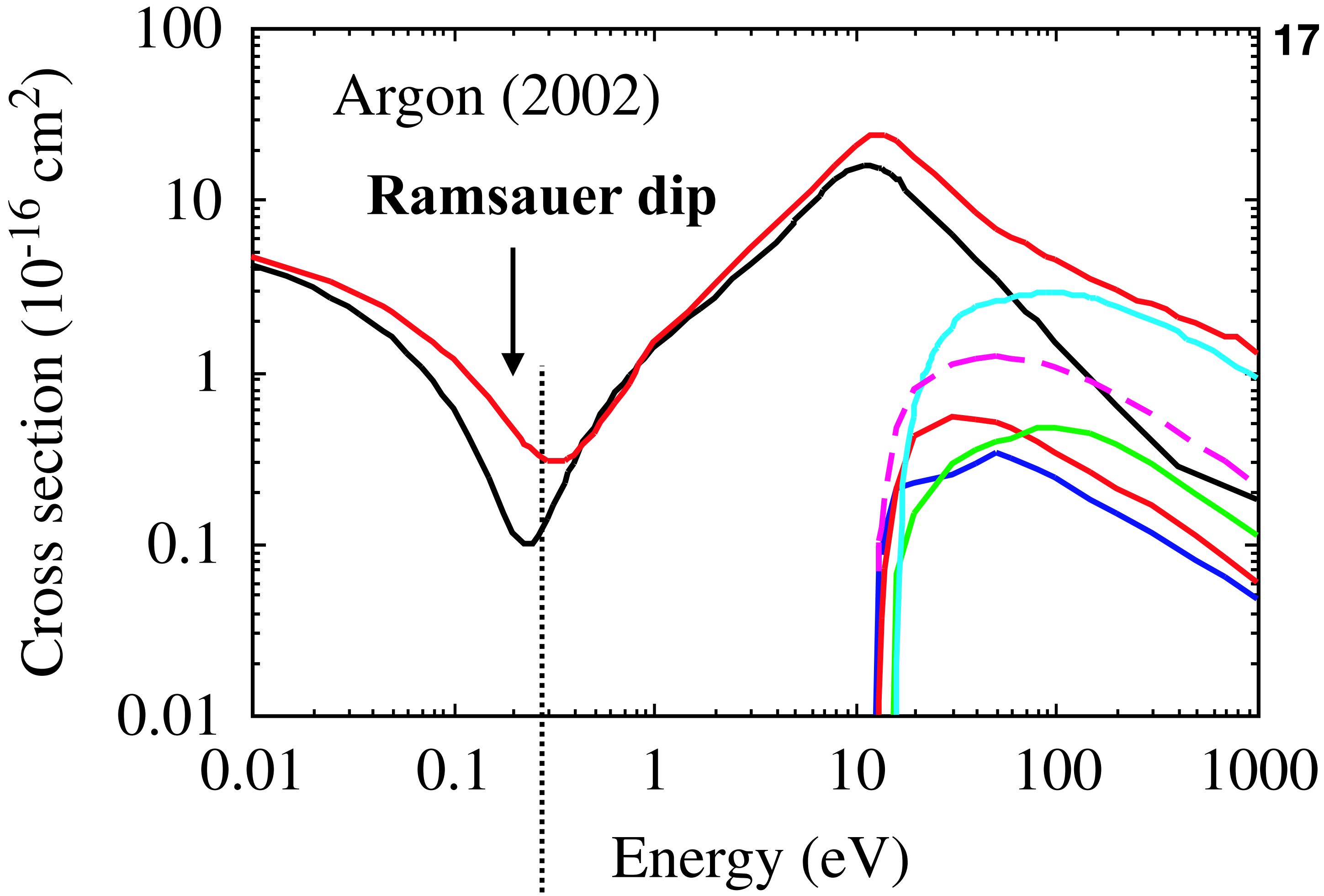
$$\tau \propto \sigma^{-1}$$

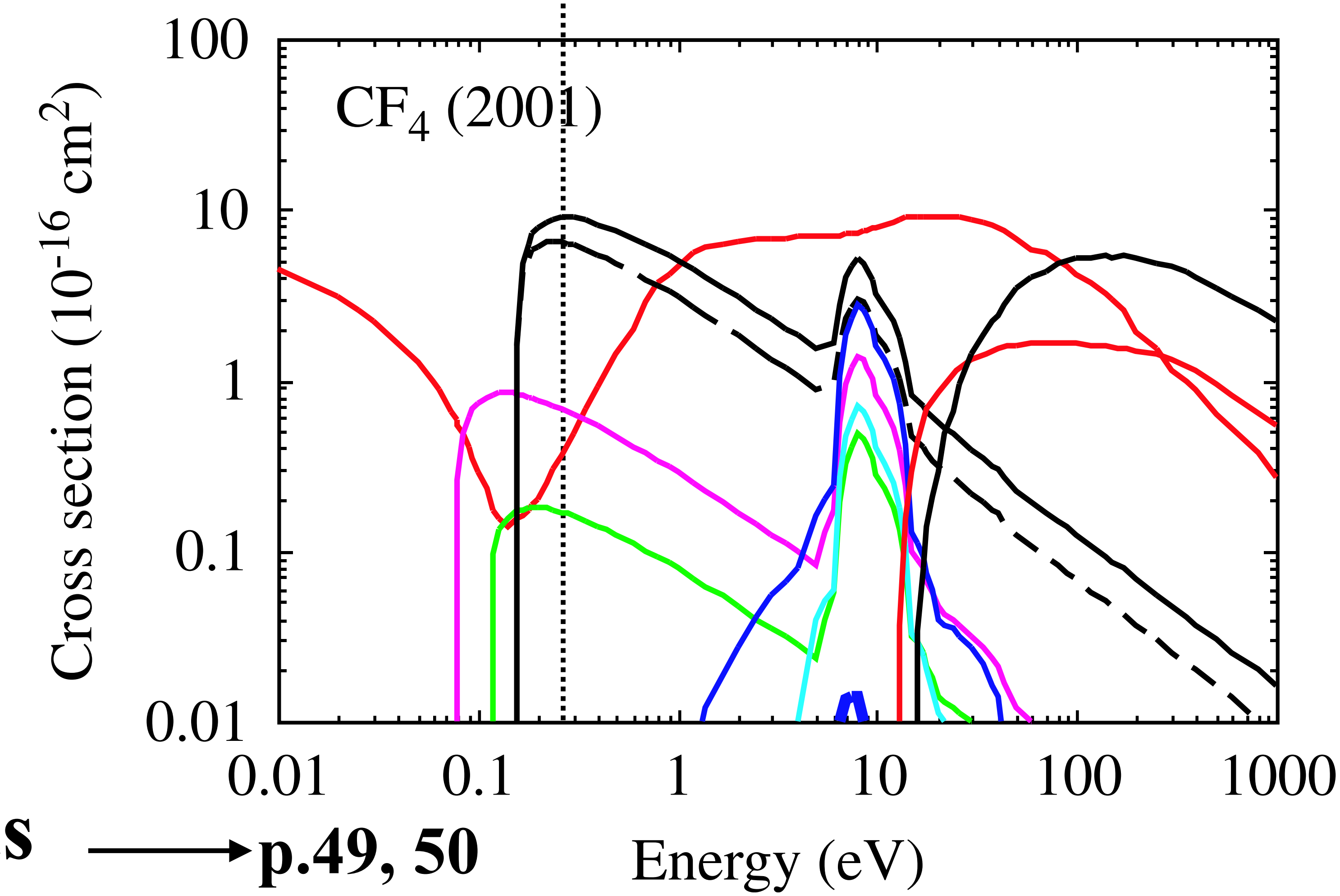
σ : cross-section

CF4 has a much larger cross-section to electrons with energies near the Ramsauer dip

we can obtain large τ gas by adding CF4 to Ar-based gas

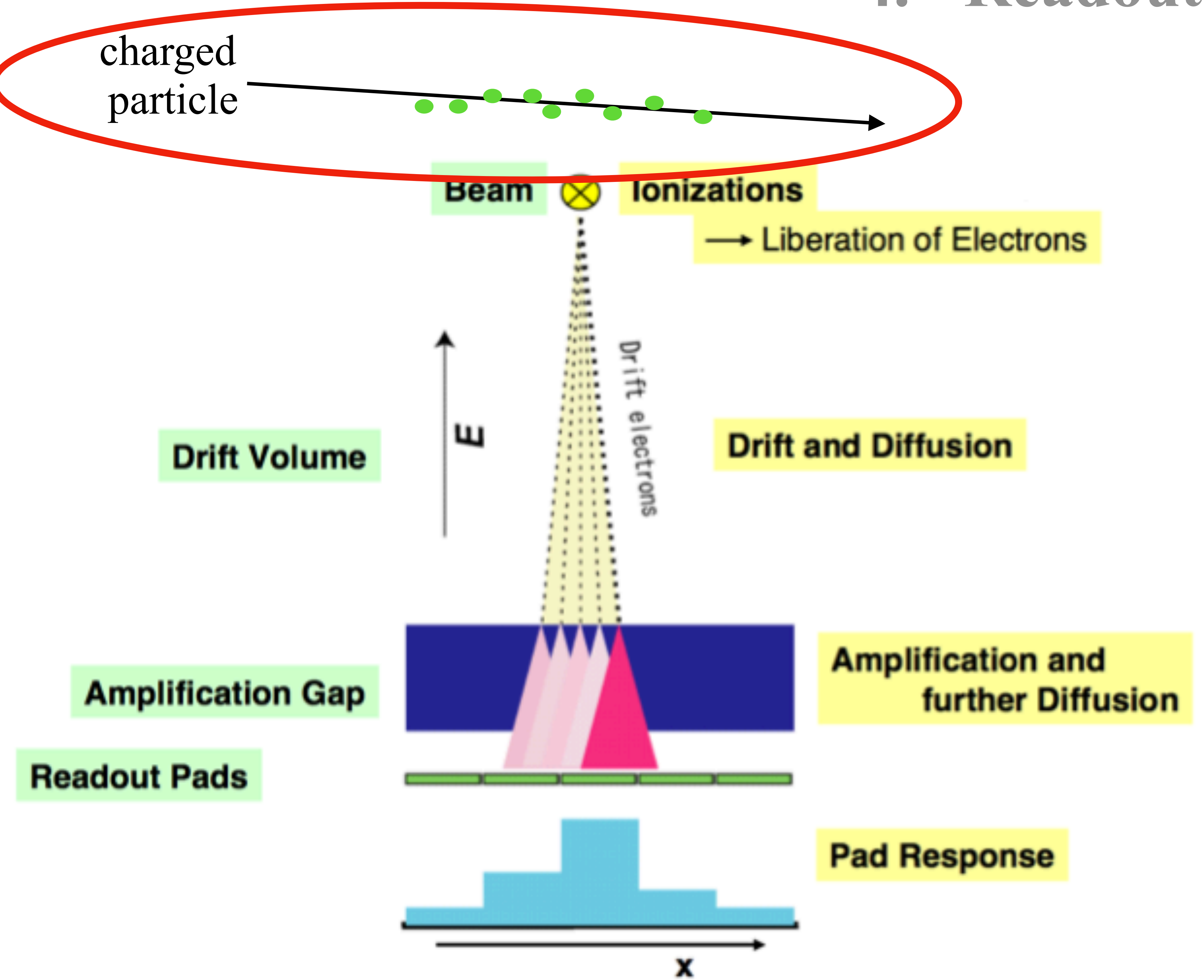
→ p.49, 50





Cosmic ray tests of a GEM-based TPC prototype operated in Ar–CF4 –isobutane gas mixtures

1. Momentum measurement
2. Gas mixture
3. **Particle ID and dE/dx**
4. Readout module



Particle identification

◎**charged particle pass ->detect as track**

main charged particle on the detector

- **π**
- **K**
- **e**
- **μ**

from the direction of bending by a B-Field

<u>charge</u> can be identified

particle <u>type</u>

dE/dx:Energy loss per unit length

Bethe-Bloch formula

$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

the value of <dE/dx> depends on particle species at a given momentum

→particle <u>type</u> can be identified

Bethe-Bloch formula

$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

material parameter

Z, A: atomic, mass number of material **I:ionization energy**

charged particle parameter

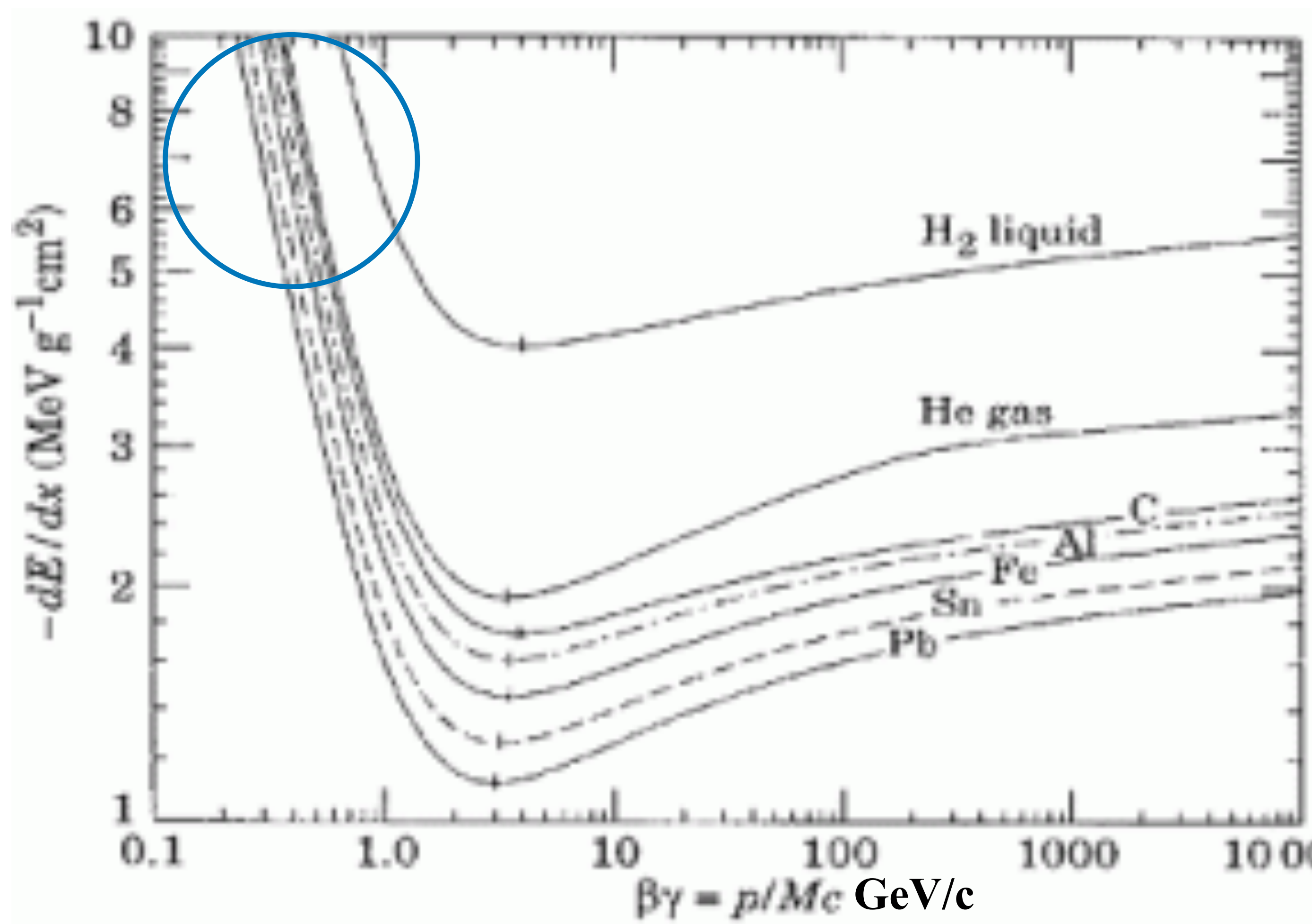
z : particle charge in units of *e* **β,γ : relativistic parameter**

non-relativistic region

$\beta\gamma < 4$

$$\left\langle -\frac{dE}{dx} \right\rangle \propto \frac{1}{\beta^2}$$

“kinematical term”



LARGE ionisation

slower particles receive an electric force from atomic electrons for a longer time

non-relativistic description of scattering of charged particles with electrons of gas molecules

Minimum ionisation particle (MIP)

$$\left\langle -\frac{dE}{dx}\right\rangle = K\boxed{z}^2 \boxed{\frac{Z}{A}}\frac{1}{\boxed{\beta^2}}\left[\frac{1}{2}\ln\frac{2m_ec^2\boxed{\beta^2\gamma^2}W_{max}}{\boxed{I}^2} - \boxed{\beta}^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

material parameter

Z, A: atomic, mass number of material **I:ionization energy**

charged particle parameter

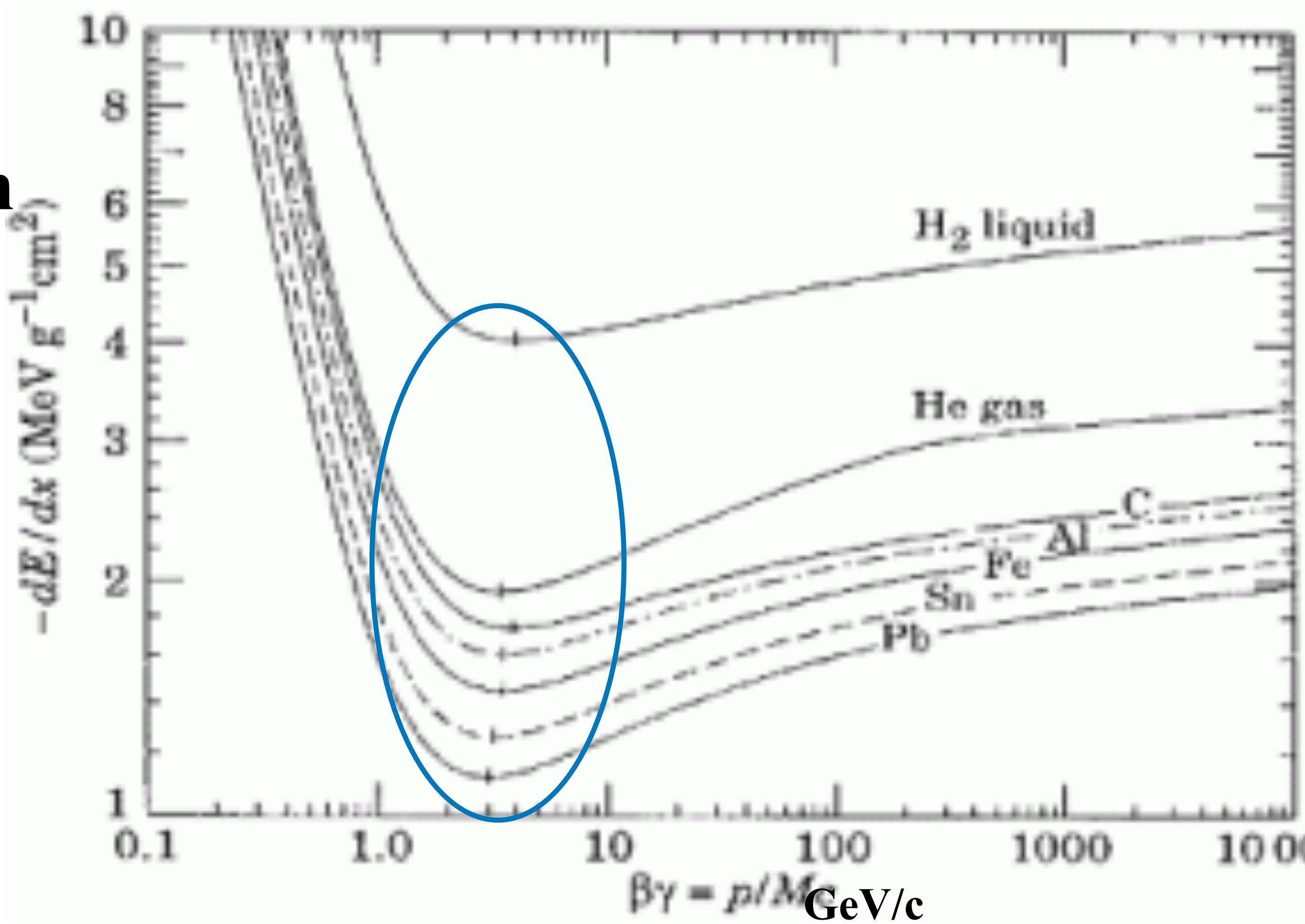
z : atomic number of charged particle **β,γ : relativistic parameter**

$$\beta\gamma \approx 4$$

Particles pass through a substance with a minimum ionisation loss

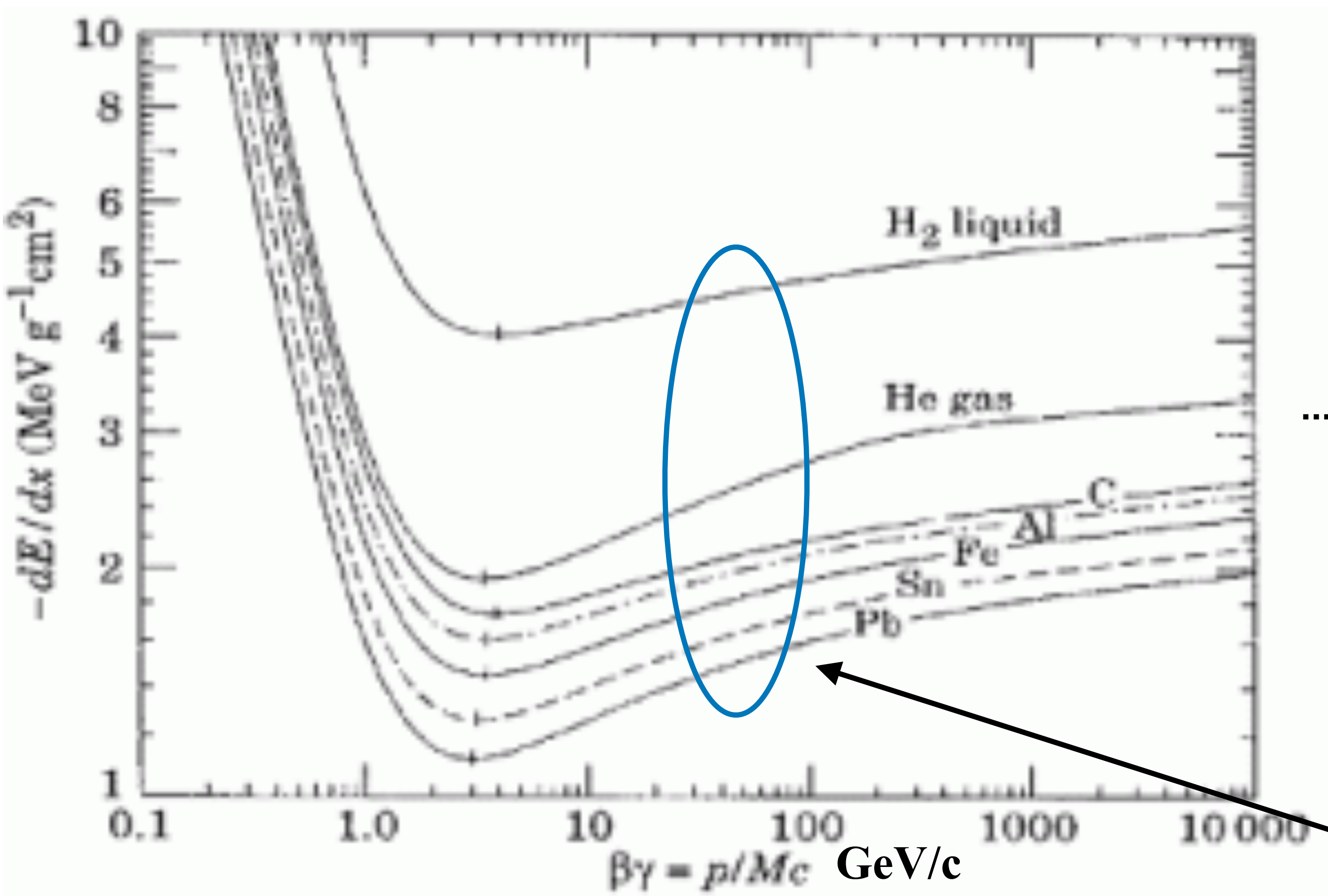
minimum ionizing particle (MIP)

e.g. cosmic-ray muon



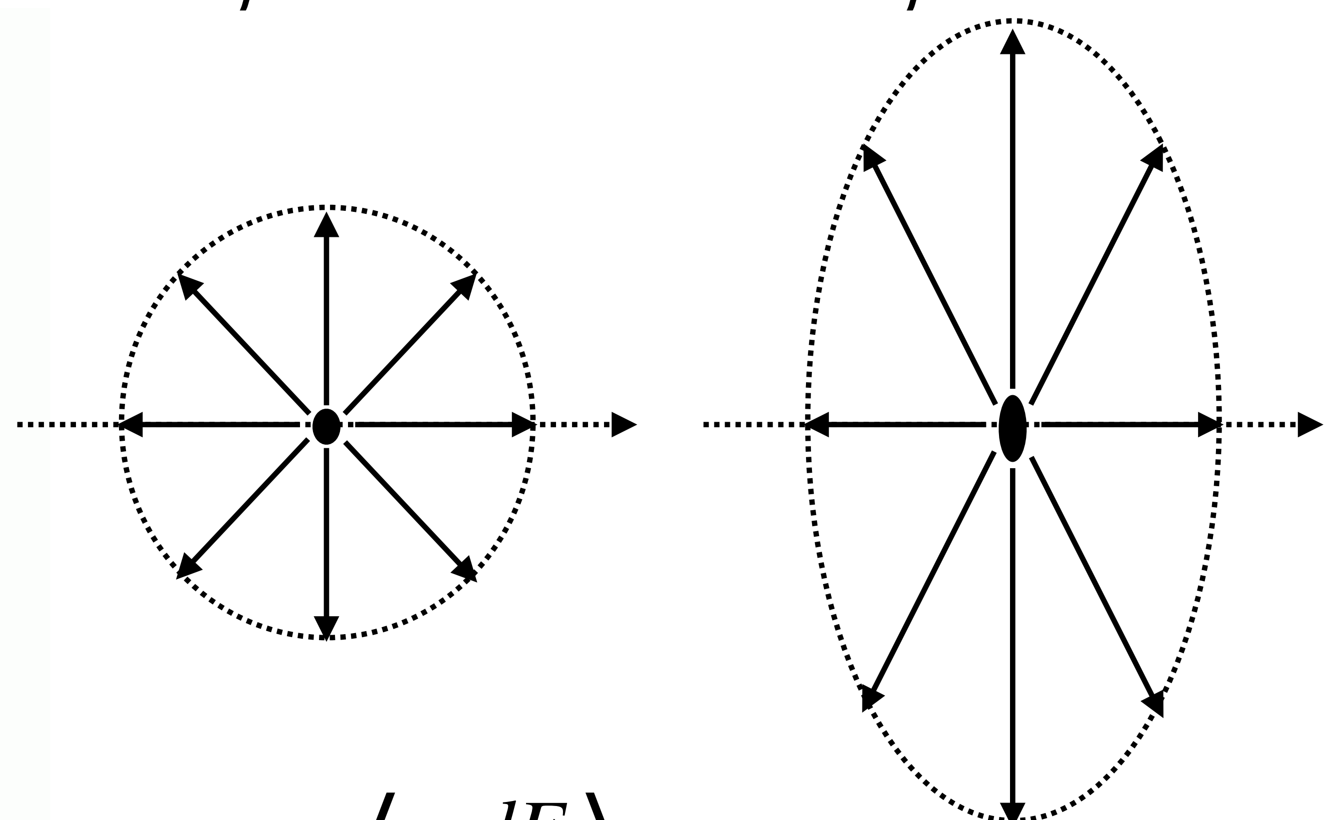
Relativistic effect

$$\left\langle -\frac{dE}{dx} \right\rangle = K\boxed{z}^2 \boxed{\frac{Z}{A}} \frac{1}{\boxed{\beta^2}} \left[\frac{1}{2} \ln \frac{2m_e c^2 \boxed{\beta^2\gamma^2} W_{max}}{\boxed{I}^2} - \boxed{\beta}^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



relativistic effect

$\beta \sim 0$ $\quad\quad$ $\beta \sim 1$



$$\left\langle -\frac{dE}{dx} \right\rangle \propto \ln \beta^2\gamma^2$$

"relativistic rise"

the energy loss of fast moving particles increases because the transverse electric field extends by relativistic effect

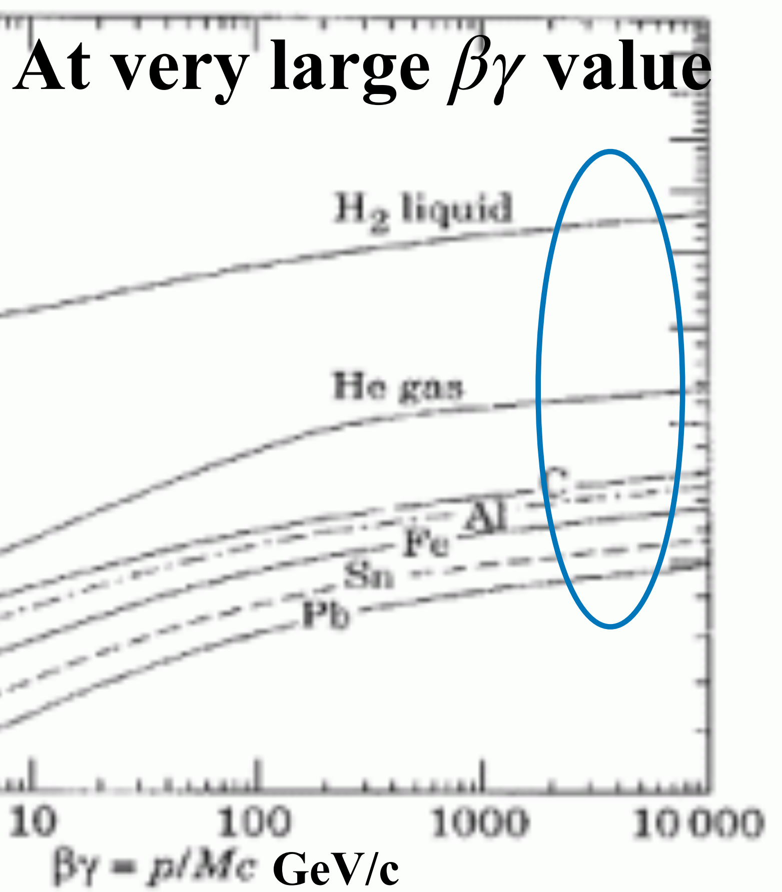
Density effect

$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\boxed{\delta(\beta\gamma)}}{2} \right]$$

relativistic rise stops   energy loss becomes independent of $\beta\gamma$

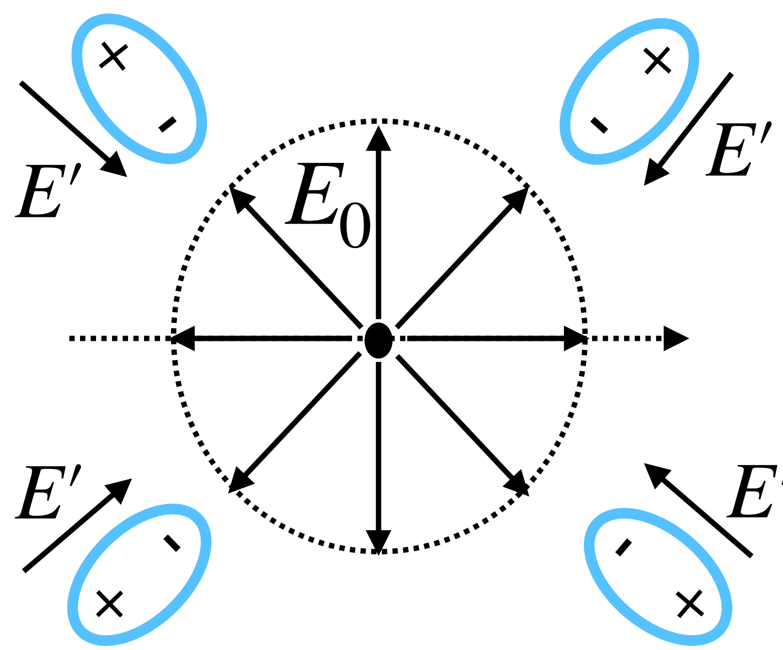
"Fermi plateau"

At very large $\beta\gamma$ value



electric field of the moving particles tends to polarise the atoms along its path

electrons far from this moving particles will be shielded



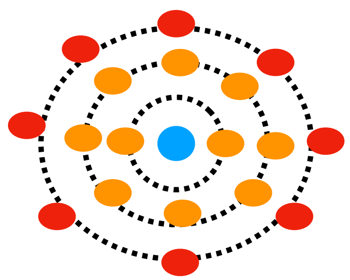
transverse size of the electric field are limited by polarisation of gas medium

this polarisation of gas medium depends on its "density"   "density effect"

Landau distribution

energy loss calculated by Bethe-Bloch formula is the "average" energy loss

In very <u>thick</u> materials, the number of scattering with electrons <u>increases</u>
→a symmetric Gaussian distribution

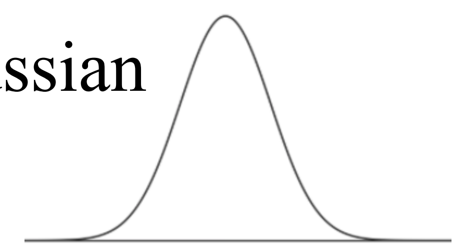


In very <u>thin</u> materials, the number of scattering with electrons <u>decreases</u>

electrons of the outermost shell

binding energy small
easily ionised

Gaussian



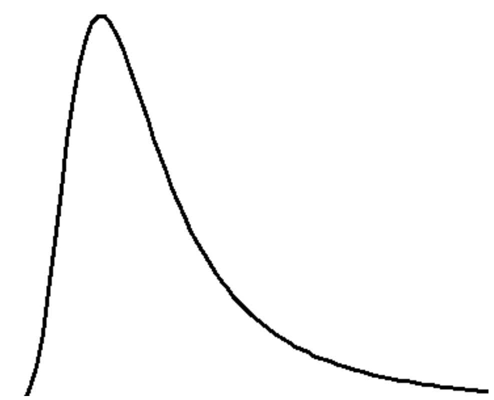
electrons of the inner shell

binding energy Large
rarely ionised

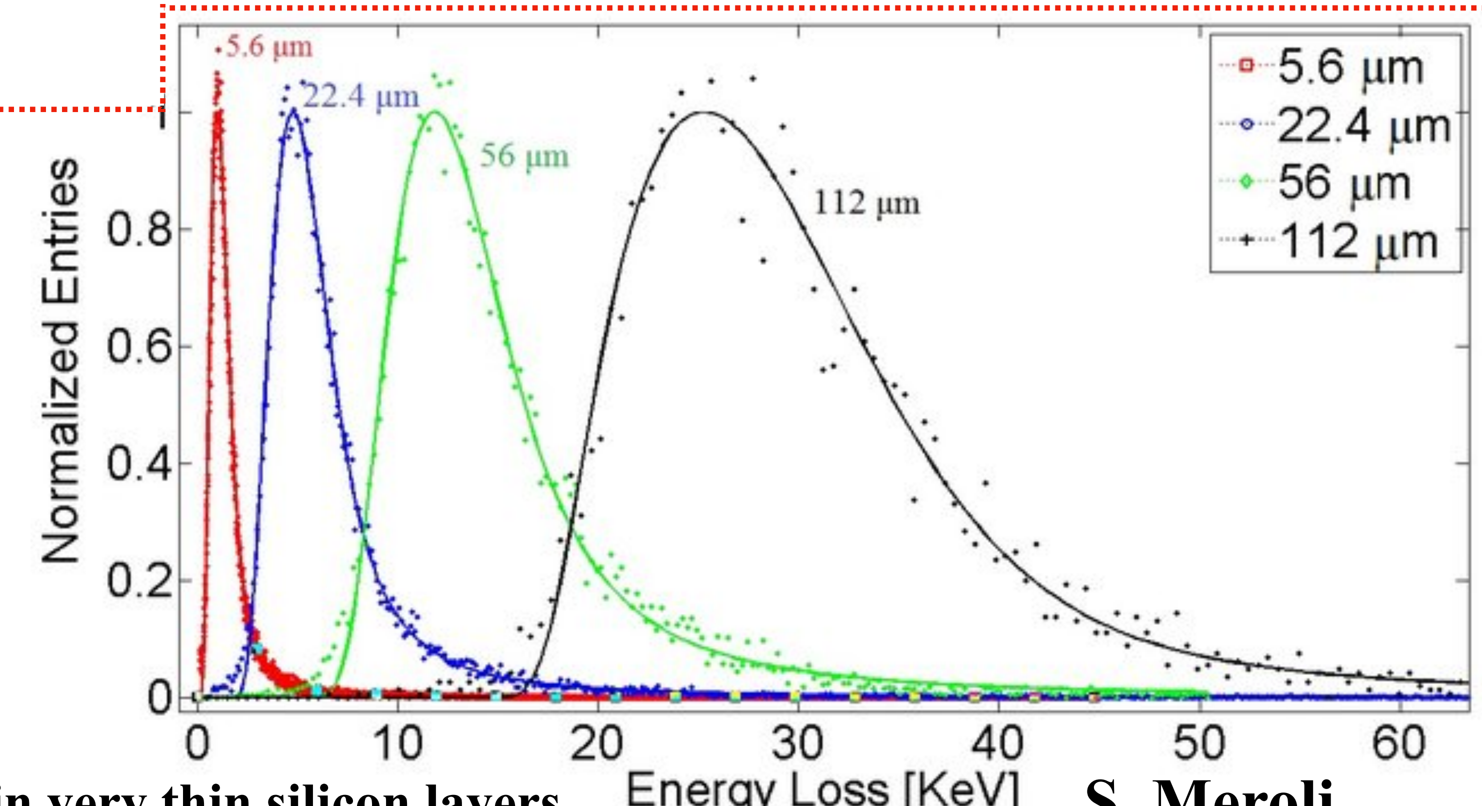
long tail distribution

Convolution

→



The distribution of energy loss will be
an asymmetric
<u>Landau distribution</u>
with a long tail

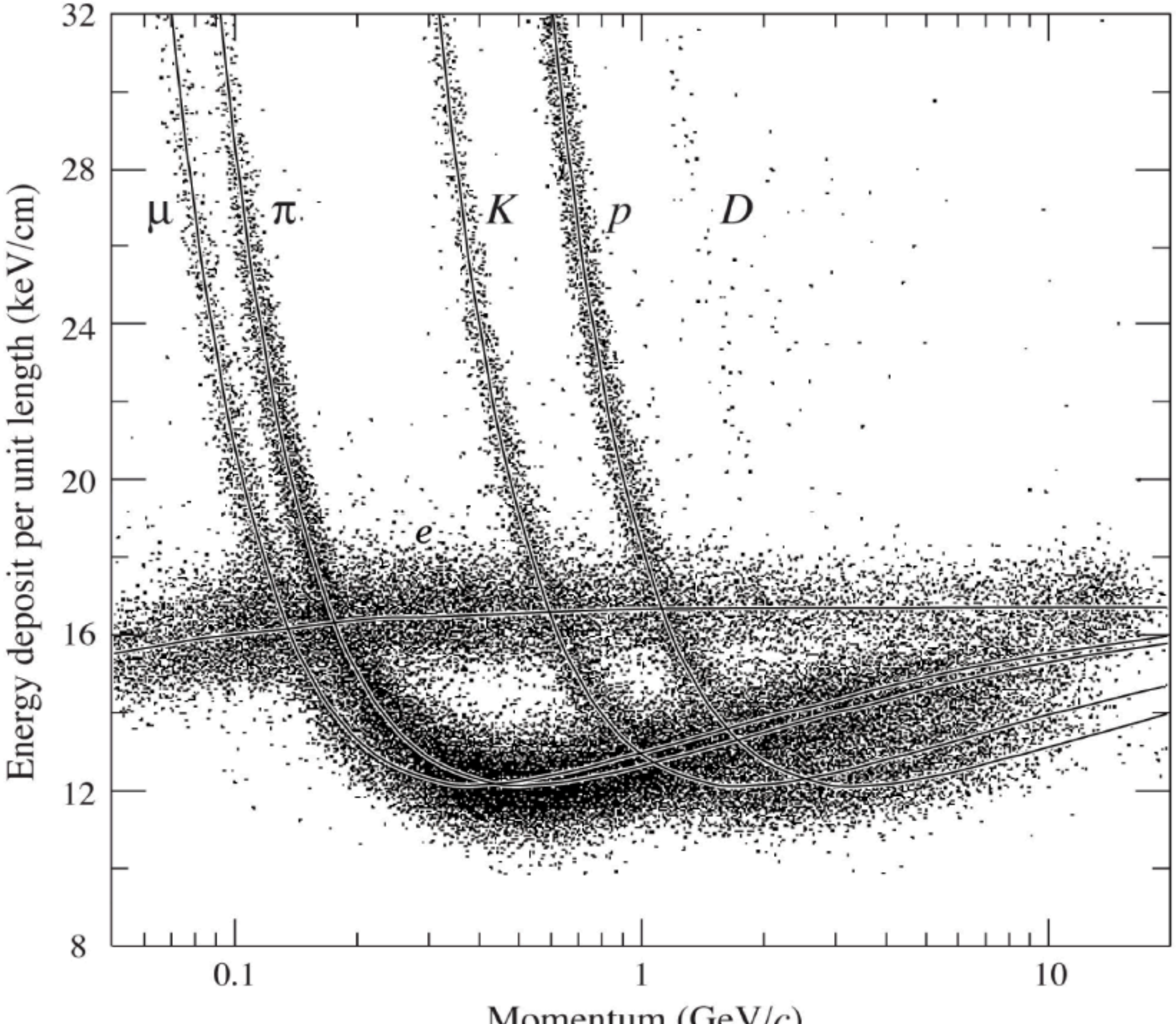


Energy loss measurement for charged particles in very thin silicon layers **S. Meroli**

Particle identification

function of $\beta\gamma = p/M$: **<u>same distribution</u>**
regardless of <u>particle type</u>

plot with function of $p = M\beta\gamma$

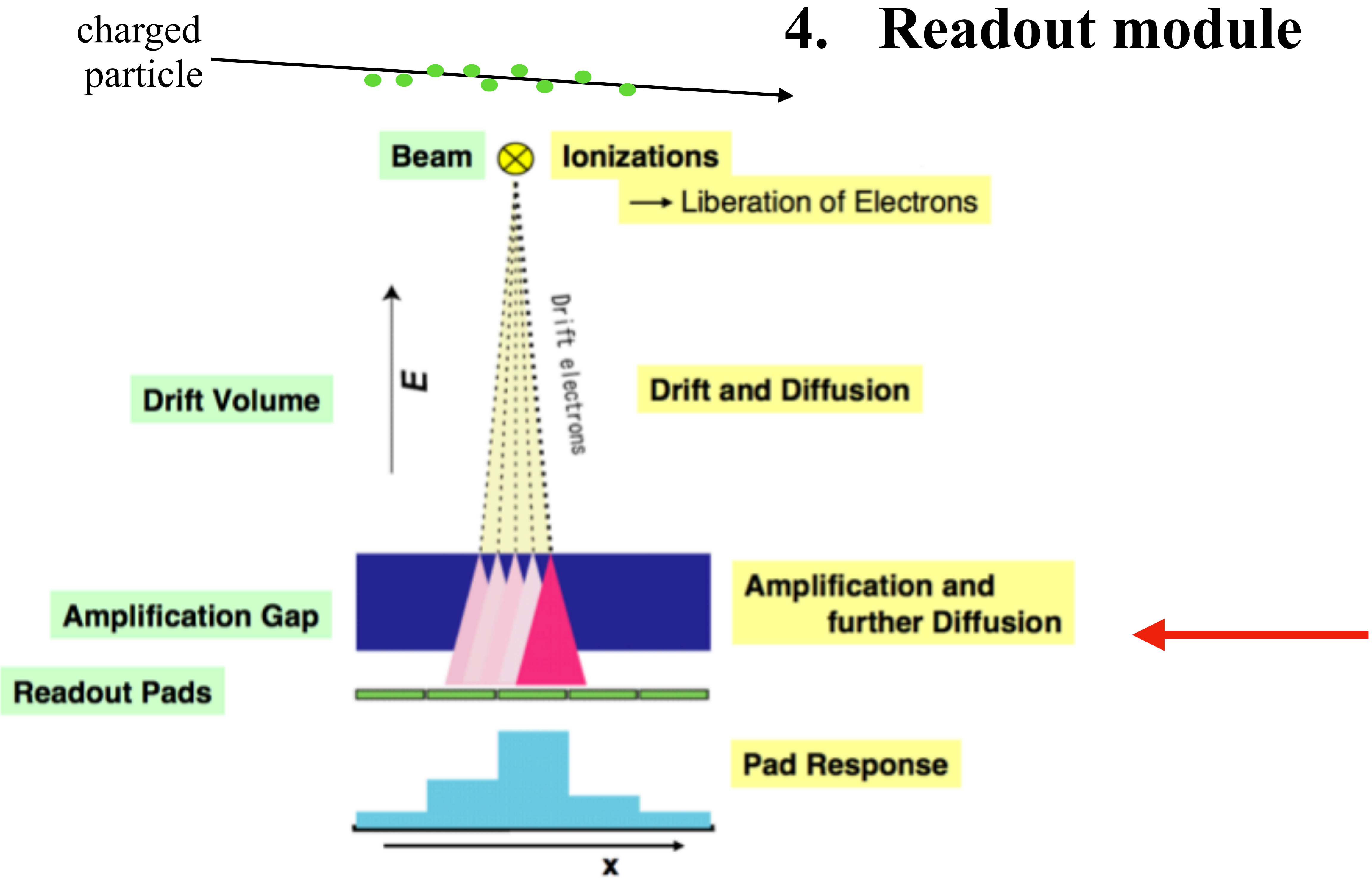


shift according to <u>particle type</u>

Particle ID **using the specific ionization loss is possible at LOW MOMENTA**

(PEP4/9-TPC energy deposit measurement)
Physics Letters B667 (2008) 1
available on the PDG WWW page

1. Momentum measurement
2. Gas mixture
3. Particle ID and dE/dx
4. **Readout module**

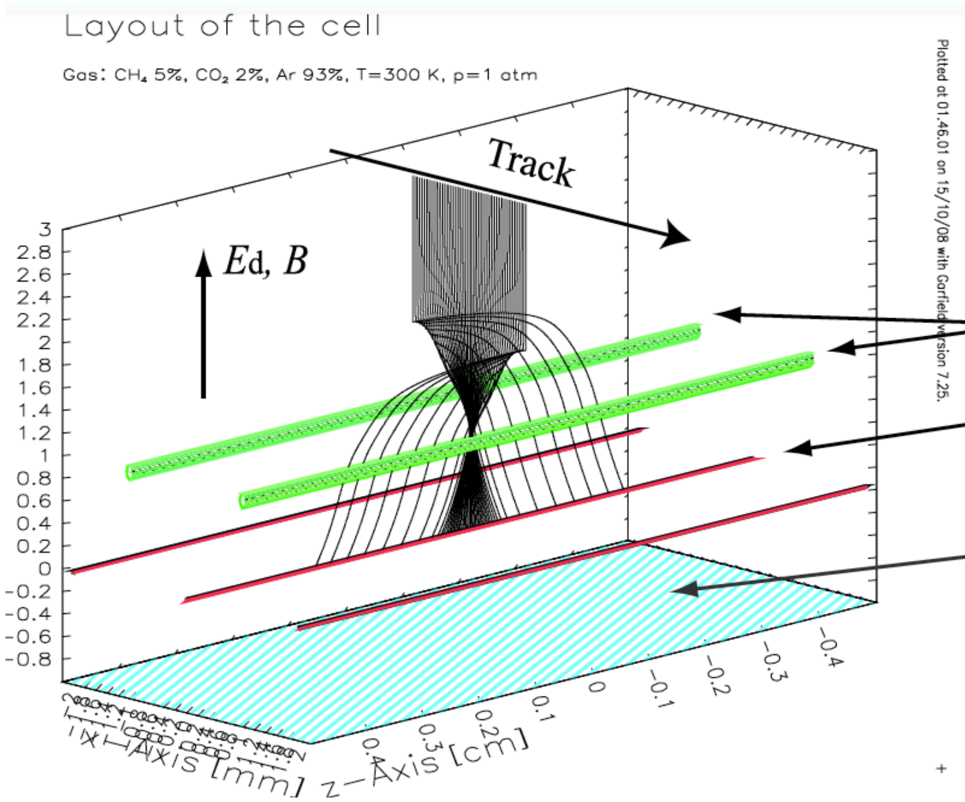


Readout module

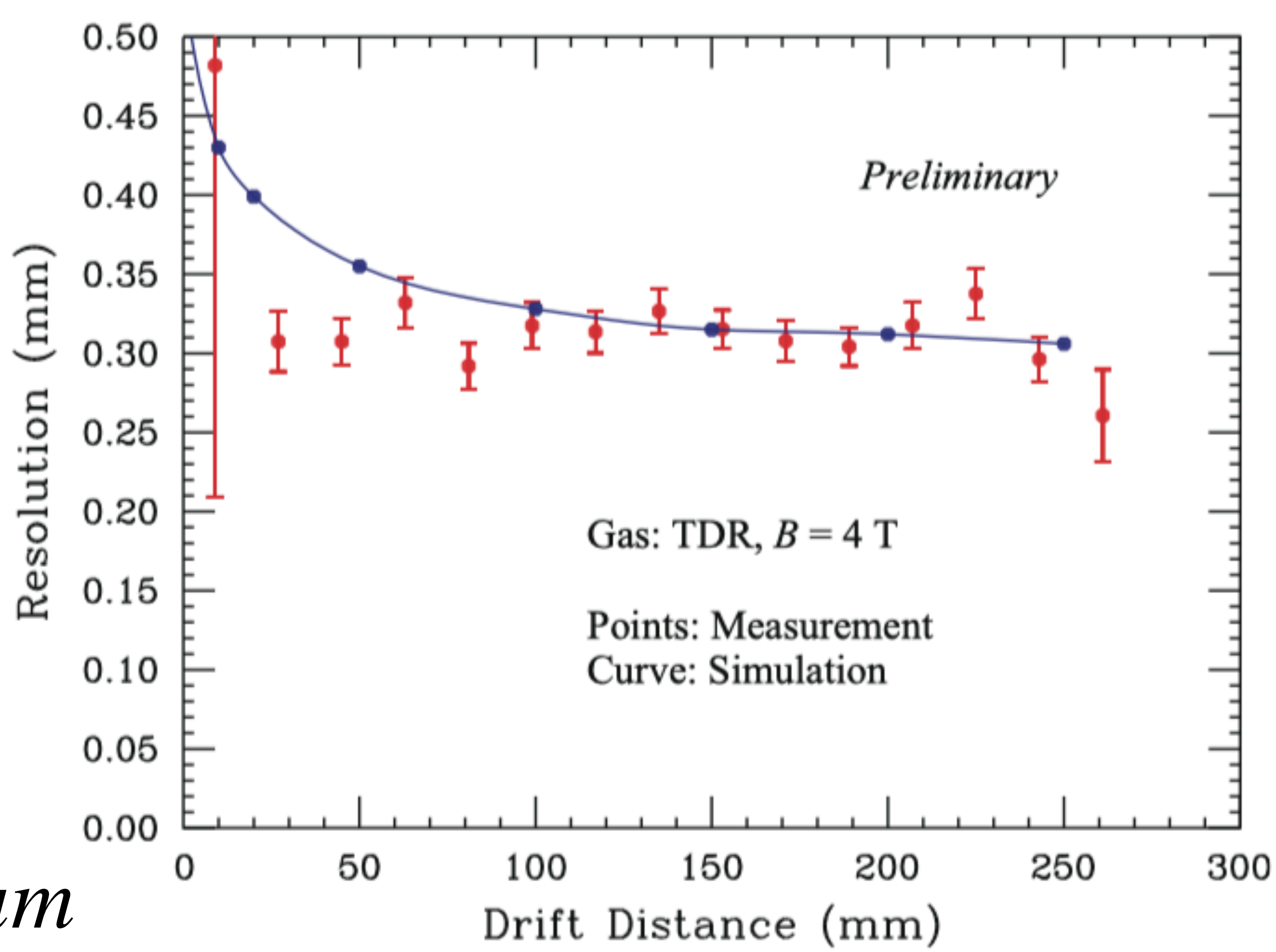
MWPC (Multi-Wire Proportional Chamber)
has been used in various experiments

ILD: B-field = 3.5T
→E×B effect: bend the electron drift path near the wire → **p.48**
the spread of drift electron is VERY LARGE under a strong axial B

TPC using MWPC



flat at position resolution of about $300\ \mu m$



A study with a small prototype TPC for the international linear collider experiment

MWPC cannot achieve

ILD requirement $\underline{\sigma_x \approx 100\ \mu m}$

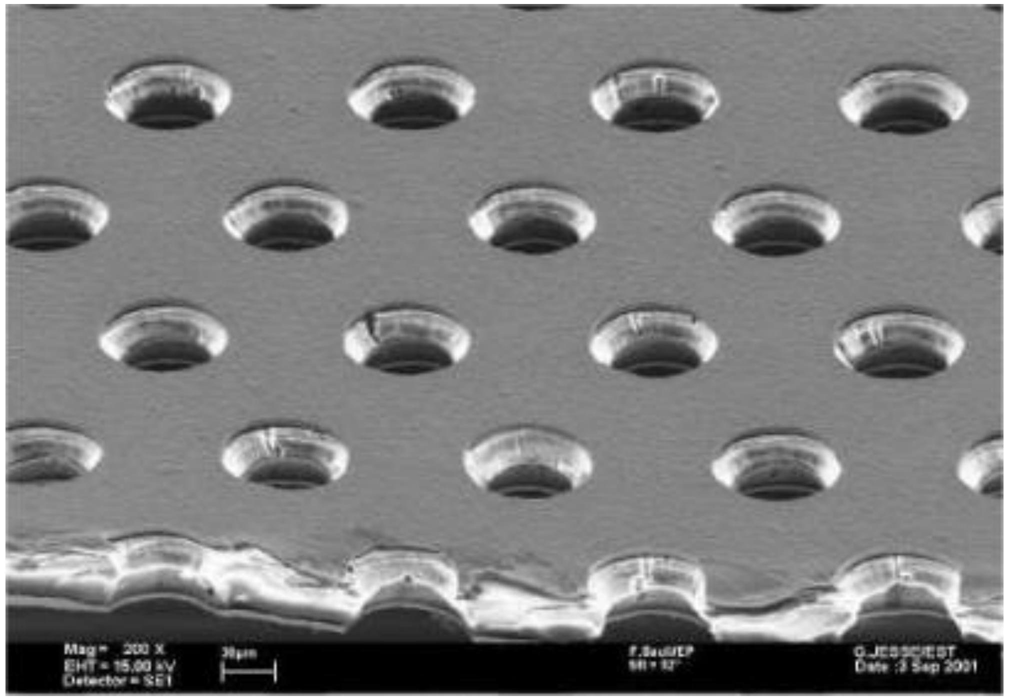
Readout module

MPGD (Micro-Pattern Gas Detector)

Gas detector using PCB(Printed Circuit board) etching technology

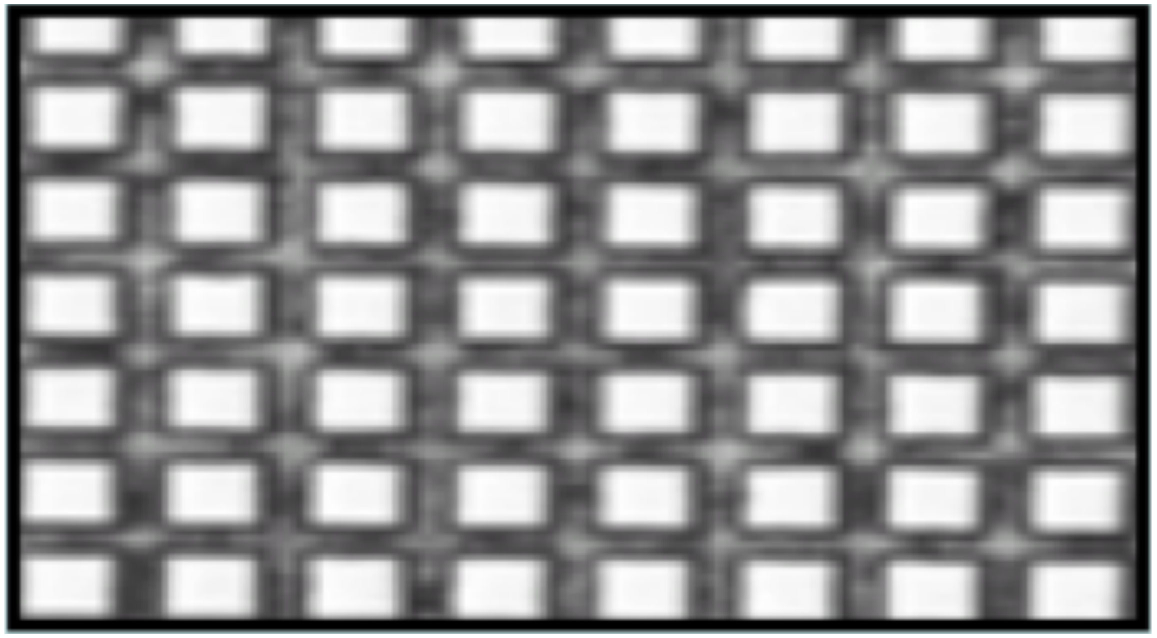
example of MPGD

GEM



F.Sauli, NIM A 386(1997)531

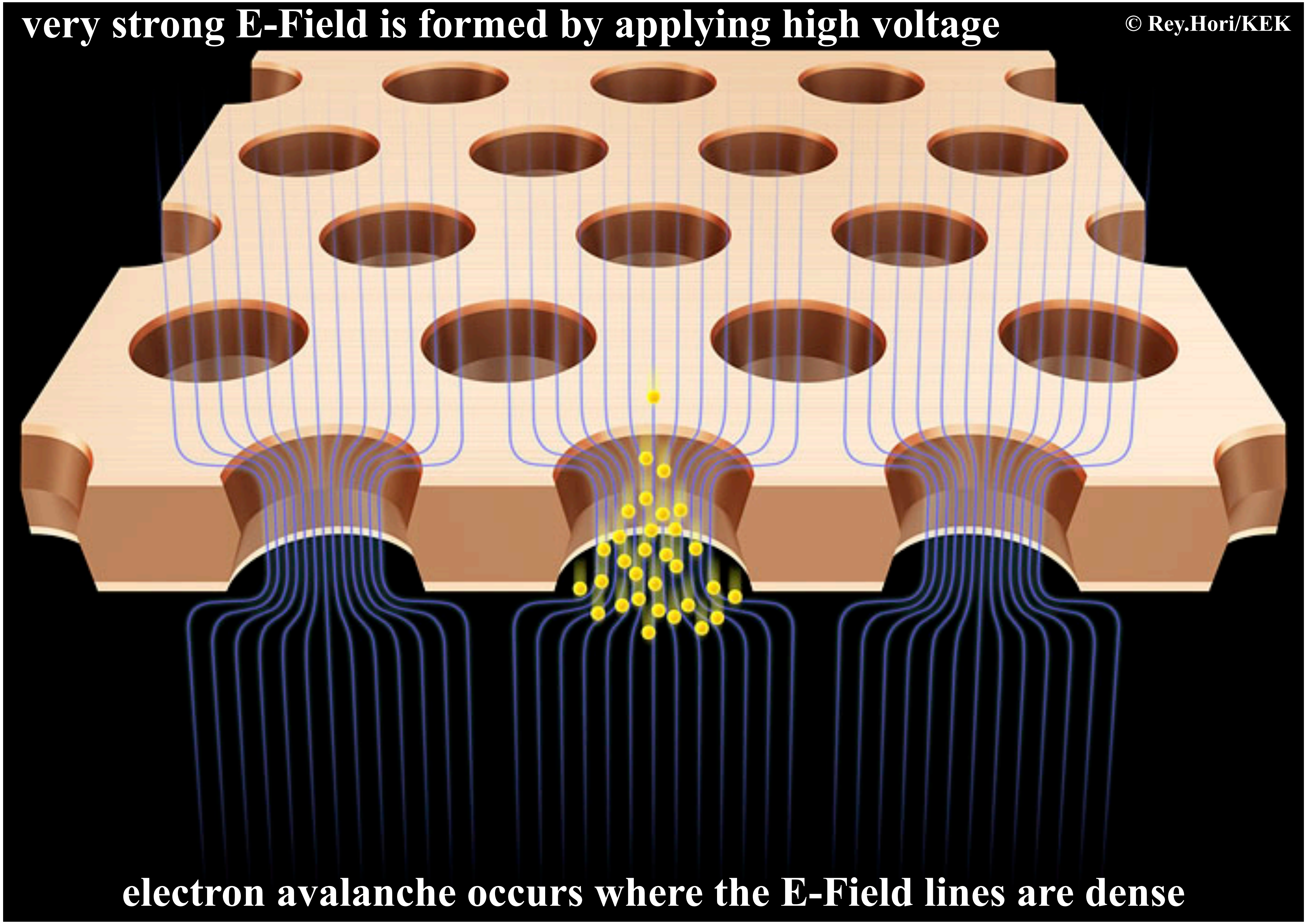
MICROMEGAS



<u>E×B effect</u> is suppressed even in a high B-Field

the position resolution is good!

Amplification



The avalanche gas gain depends on the high voltage

and generally increases with the high voltage

Positive ions are also produced

Gas gain

The dependence of the gas gain M in the electric field

$$\log M = \int \alpha(E(s))ds \quad \text{or} \quad M = e^{\int \alpha(E(s))ds}$$

s along field line

where $\alpha(s)$ is the first Townsend coefficient

mean free path of the electron between ionising collision

in the case of Penning gas

the first Townsend coefficient

$$\alpha(s) \to (1 + r)\ \alpha(s)$$ where r is the penning transfer rate

depends on gas mixture

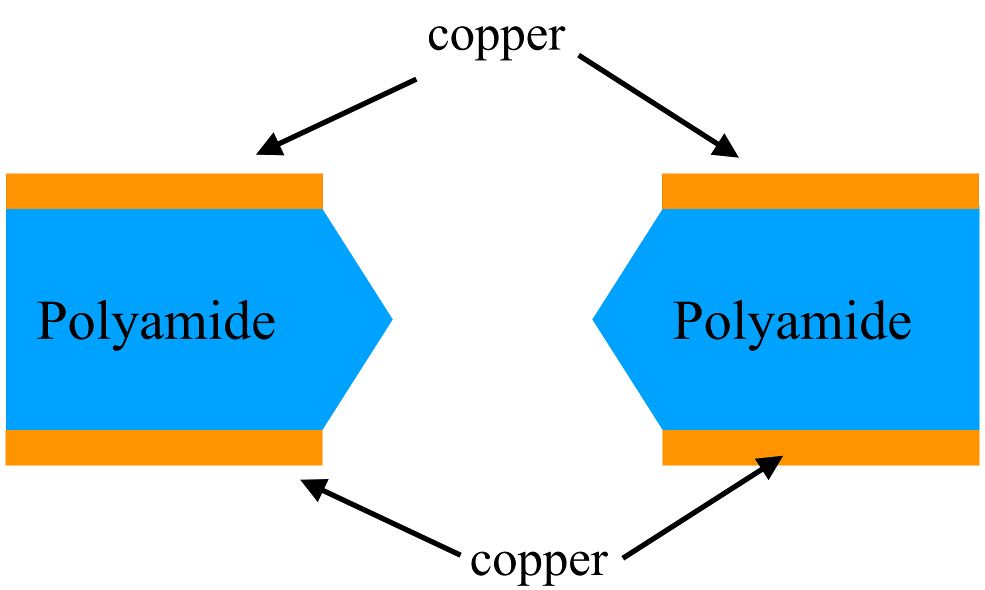
Gas gain for Penning Gas

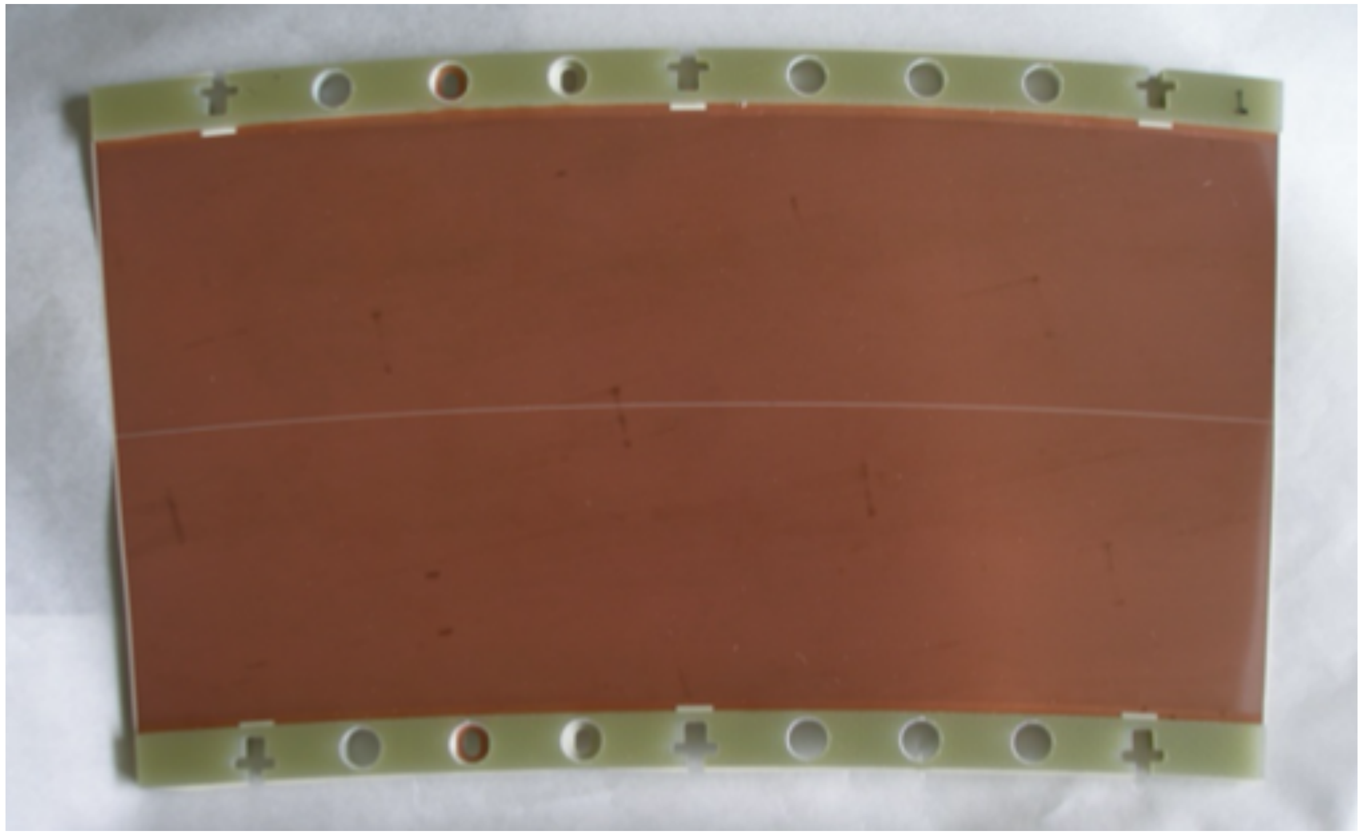
$$M = e^{\int (1+r)\ \alpha(E(s))ds}$$

ILC-TPC
R&D

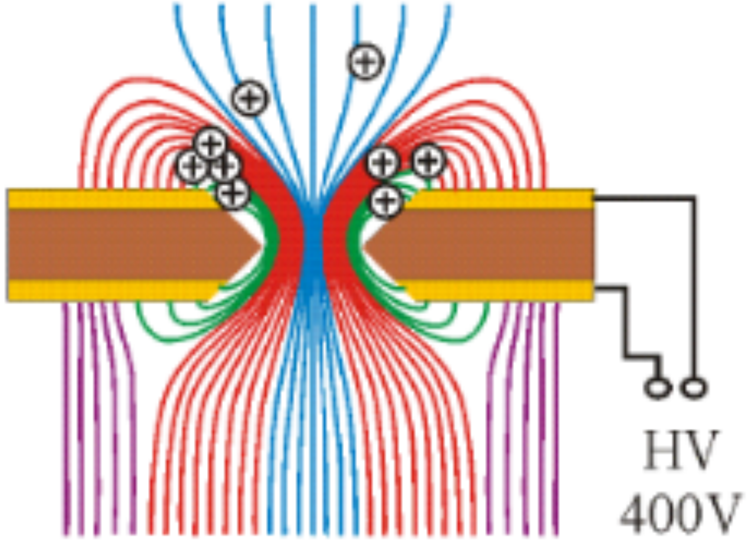
To develop a high-performance GEM as a detector for LCTPC

Asian-GEM





- fast signals ~$\mathcal{O}$(10 ns) → $\left\{ \begin{array}{l} \text{time resolution} \\ \text{2-track separation} \end{array} \right.$ good!
- Gas amp region is small → good position resolution
- prevent positive ions to go into drift region



To develop a high-performance GEM as a detector for LCTPC

Our Asian-GEM has still some problems

- discharge
- need for support structure
- gas gain fluctuations due to bending of GEM

One solution to solve these problems is to use GEM with stiff insulating material

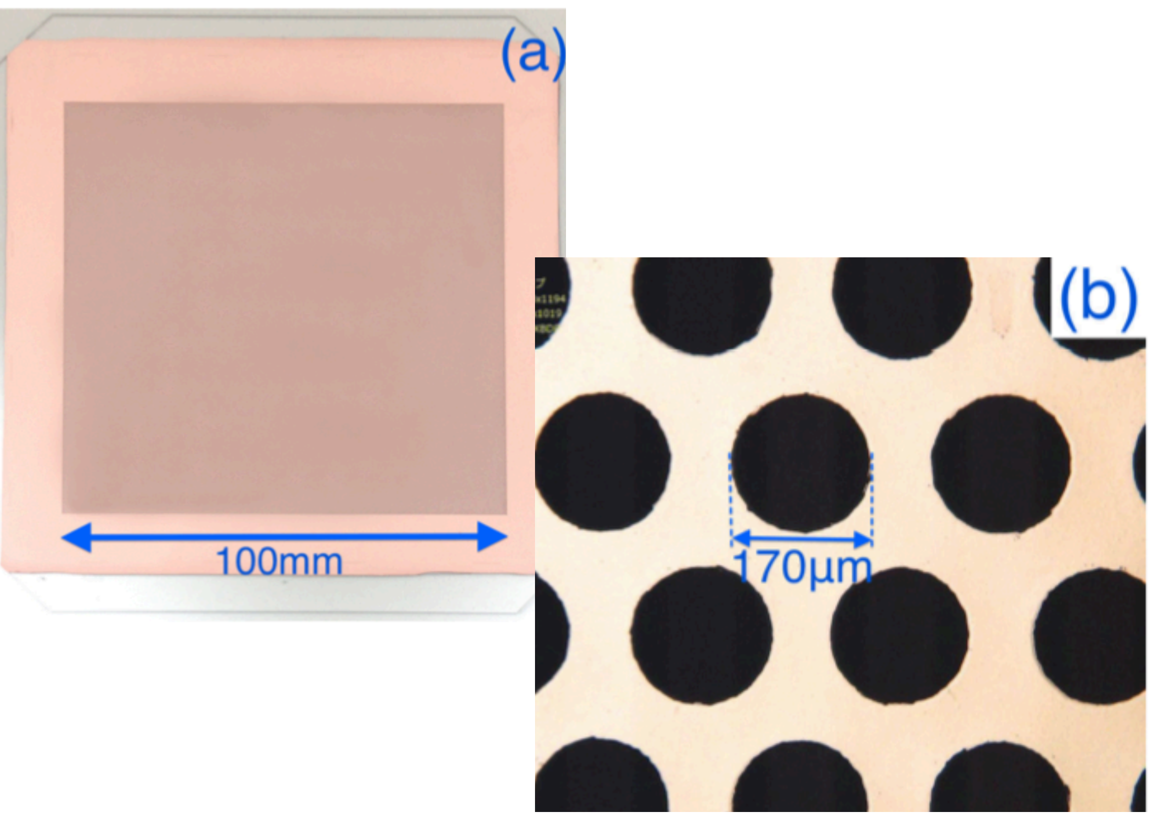
Insulation material of GEM

GEM is vulnerable to discharges: a single (large) discharge could be fatal

=> Looking for new insulator material

Glass GEM

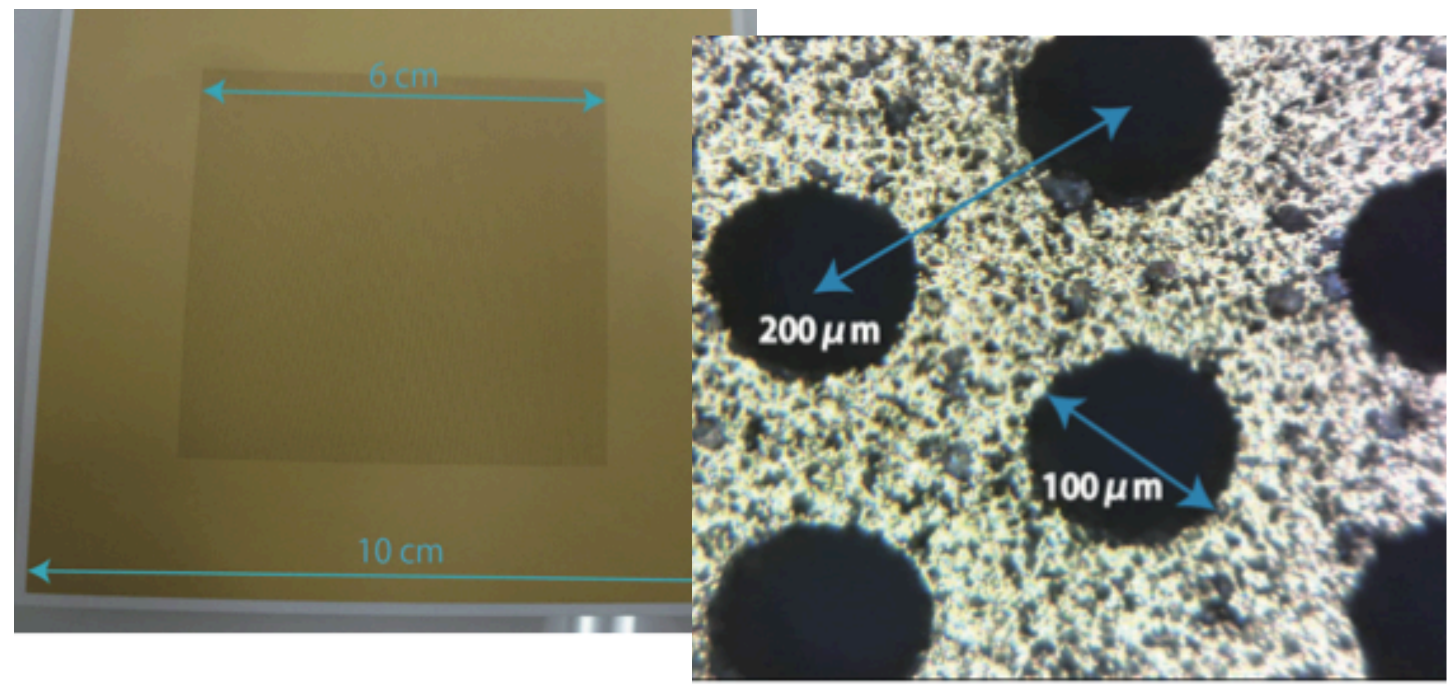
Using glass instead of polyimide



T. Fujiwara et al 2014 JINST 9 P11007

LTCC

Low Temperature Co-Fired Ceramics



Yukihiro Kato 2020 J. Phys.: Conf. Ser. 1498 012010

No outgassing

High gain with only one stage

LTCC or G-GEM is a thin but stiff "plate": self-supporting without tension applied

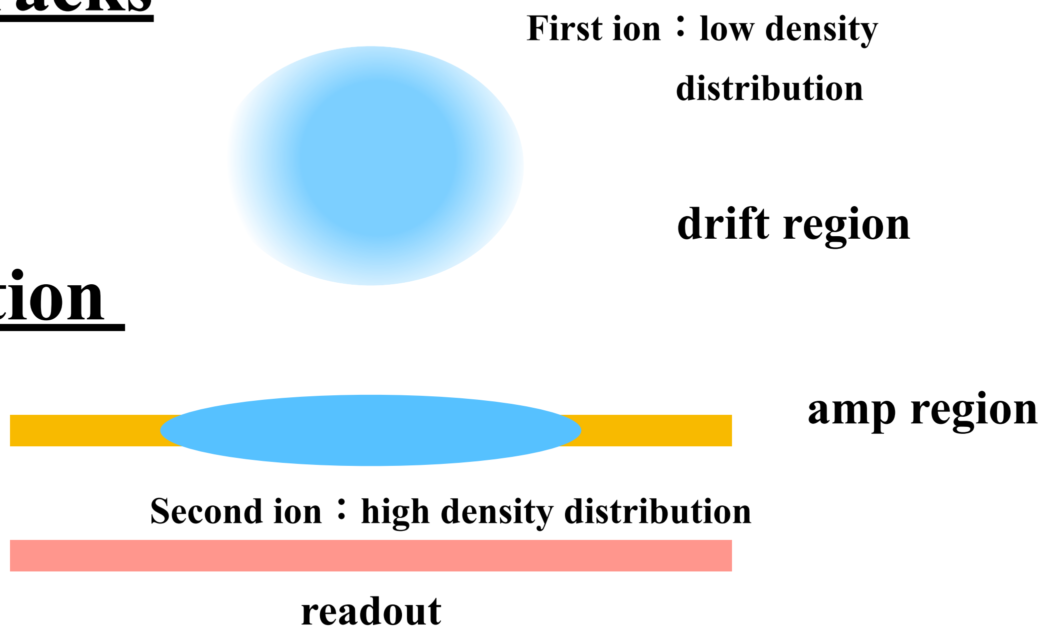
Ion Backflow

Primary ion **：Created <u>along charged particle tracks</u>**

distributed over the drift volume

Secondary ion : Created during <u>the gas-amplification</u>

form 2-3 high density thin disks



<u>Backward drift</u> region moves to cathode

drift velocity of ion is <u>VERY SLOW</u> (about $\mathcal{O}(10^{-4})$ of electron)

The ion disks create a radial component of the E-field, the drift electrons are <u>deflected</u> azimuthally due to the E x B effect.

effect on position resolution

effect of primary ion is negligible
secondary ion cannot be ignored　60 μm

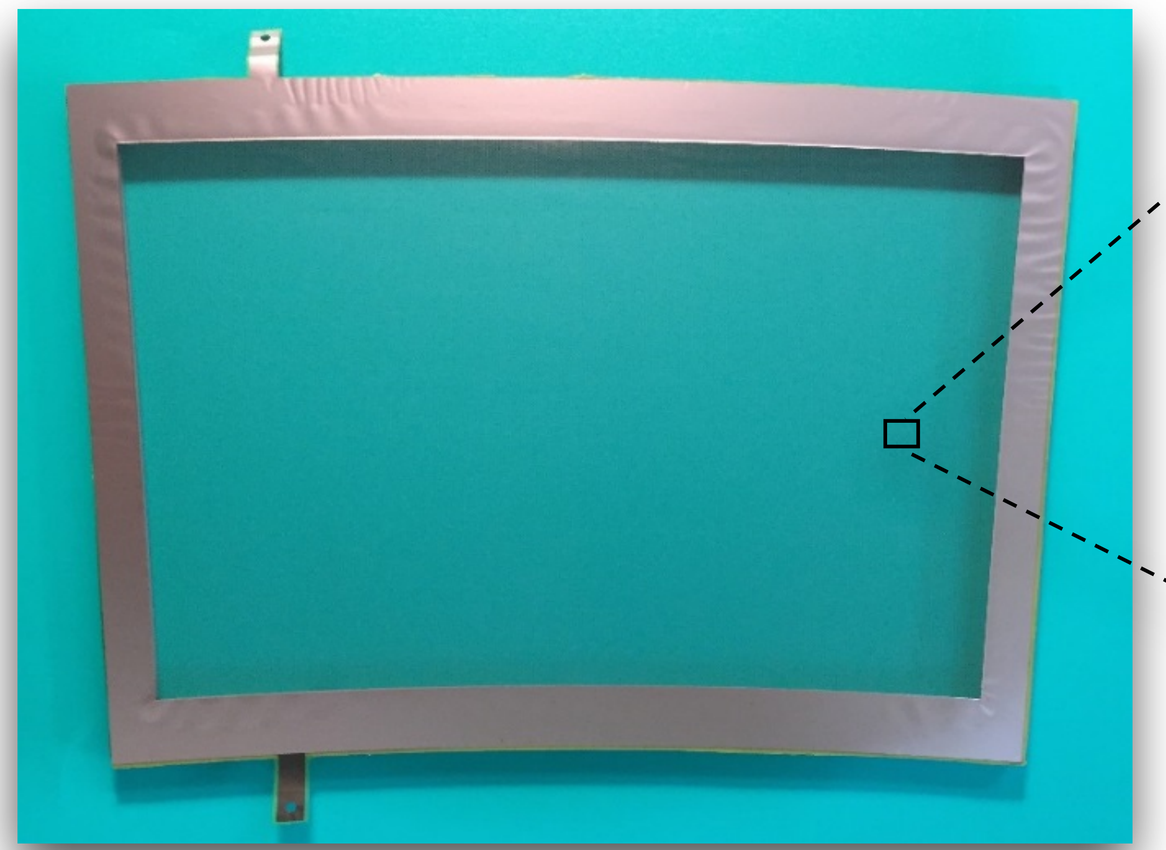
The positive ion back-flow needs to be blocked by a gating device since the deflection could be O (1 mm) in our case.

Gating foil

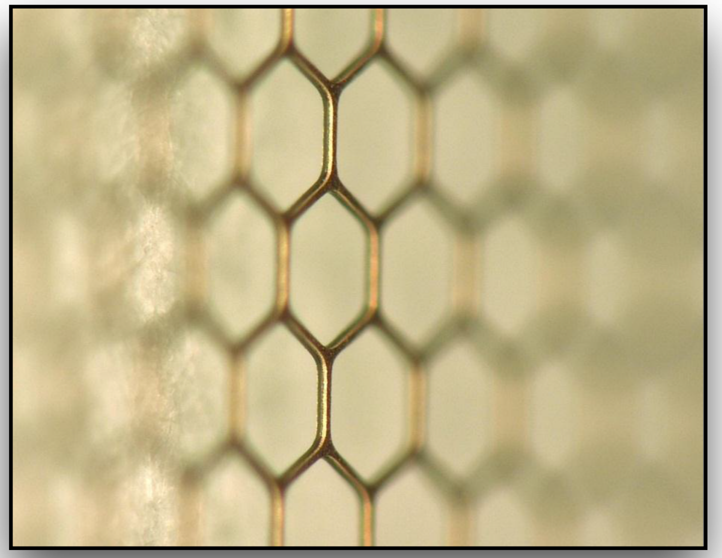
positive ions :

- much heavier than electrons
- moves along electrical flux line Low diffusion

using GEM under low voltage -> positive ion blocking membrane



co-developed with Fujikura Co., Ltd.

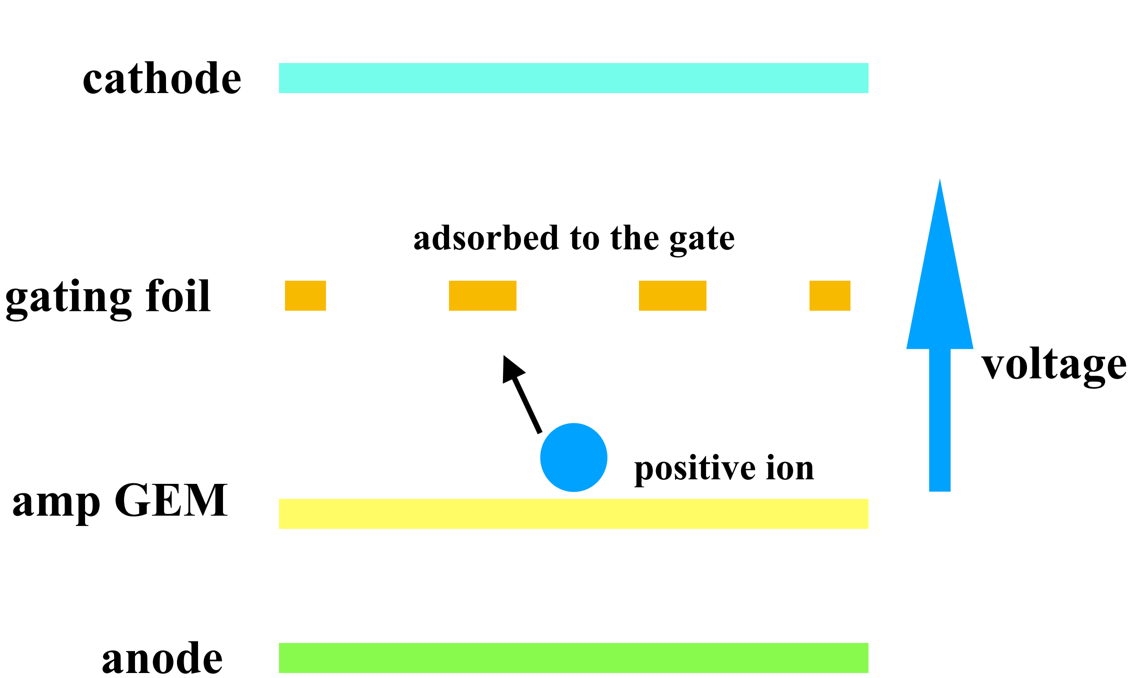


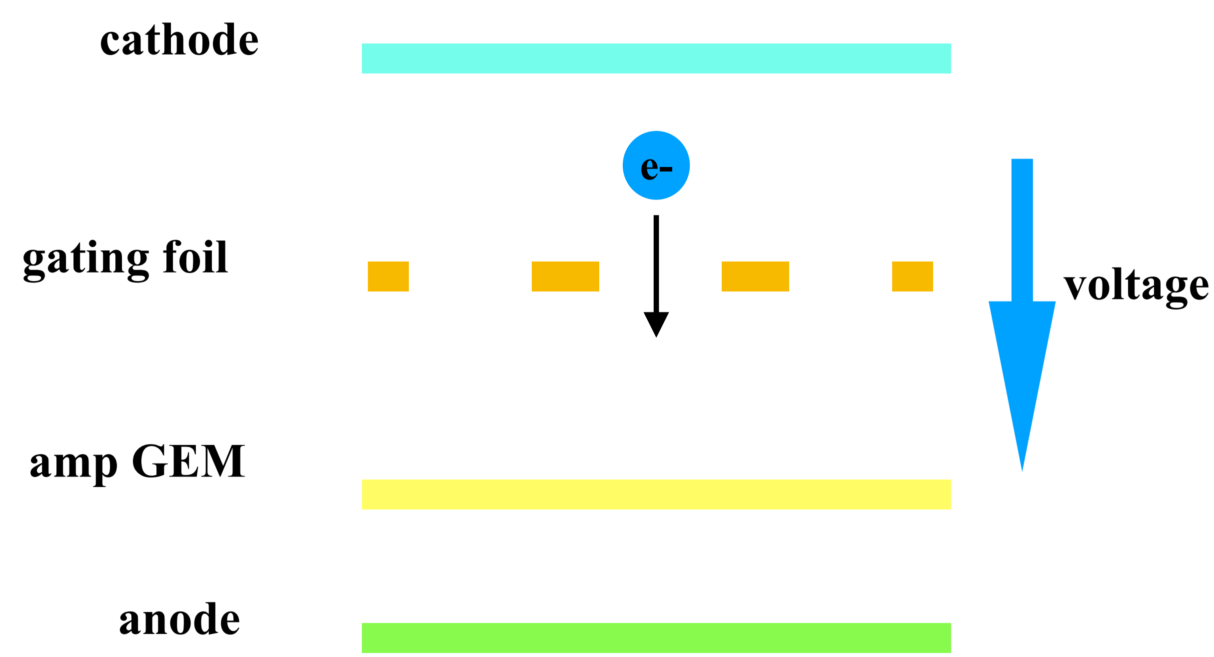
Gating foil・・・High electron transmission rate

suppress ion transmission gate device

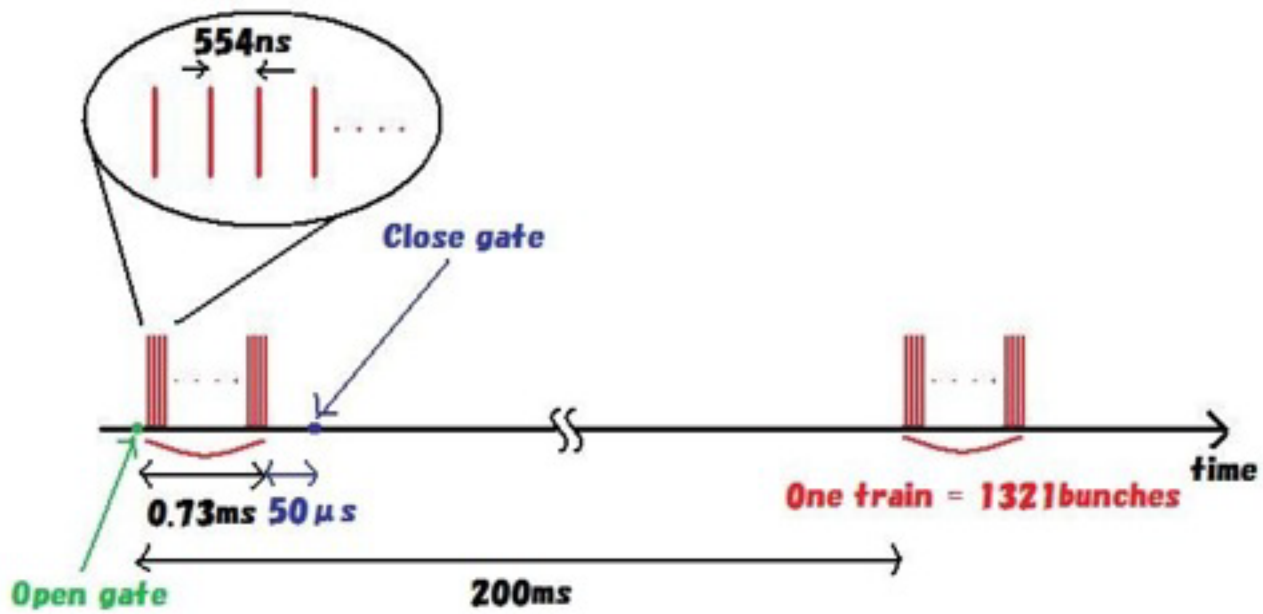
electron transmission rate in B-Field ≒ Optical aperture

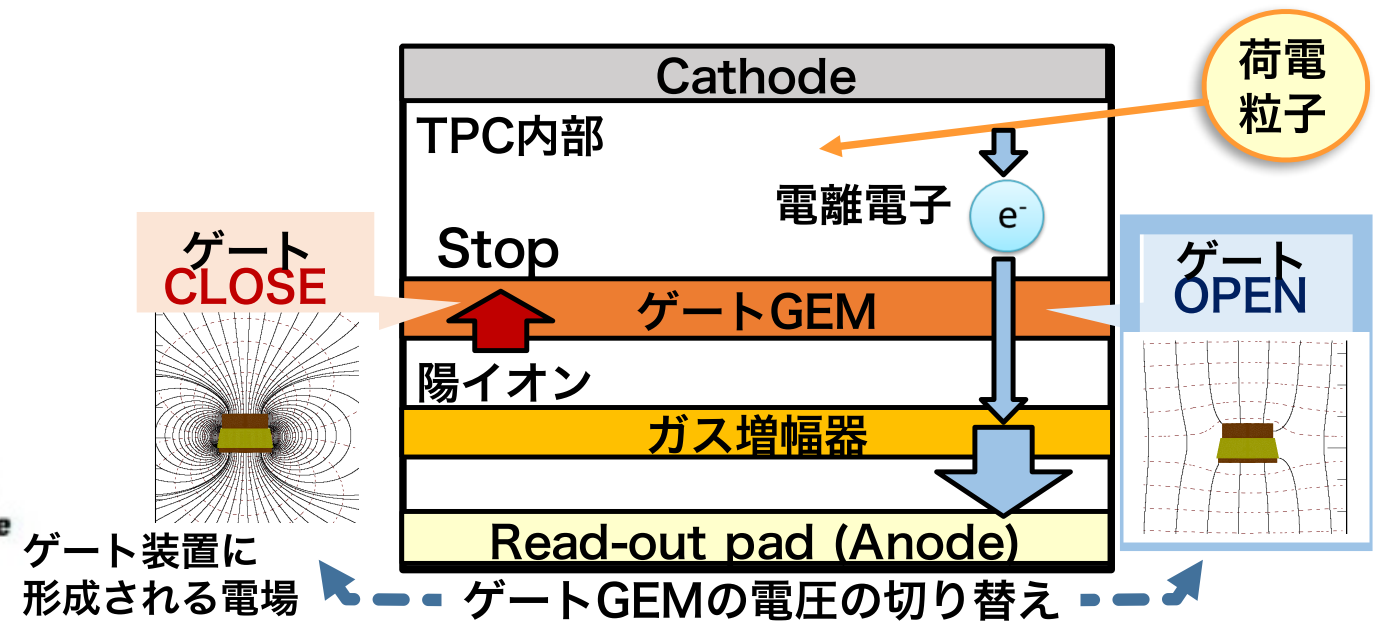
Gating foil





▼beam structure of ILC





By closing the gate between bunch trains
Ion Backflow can be prevented

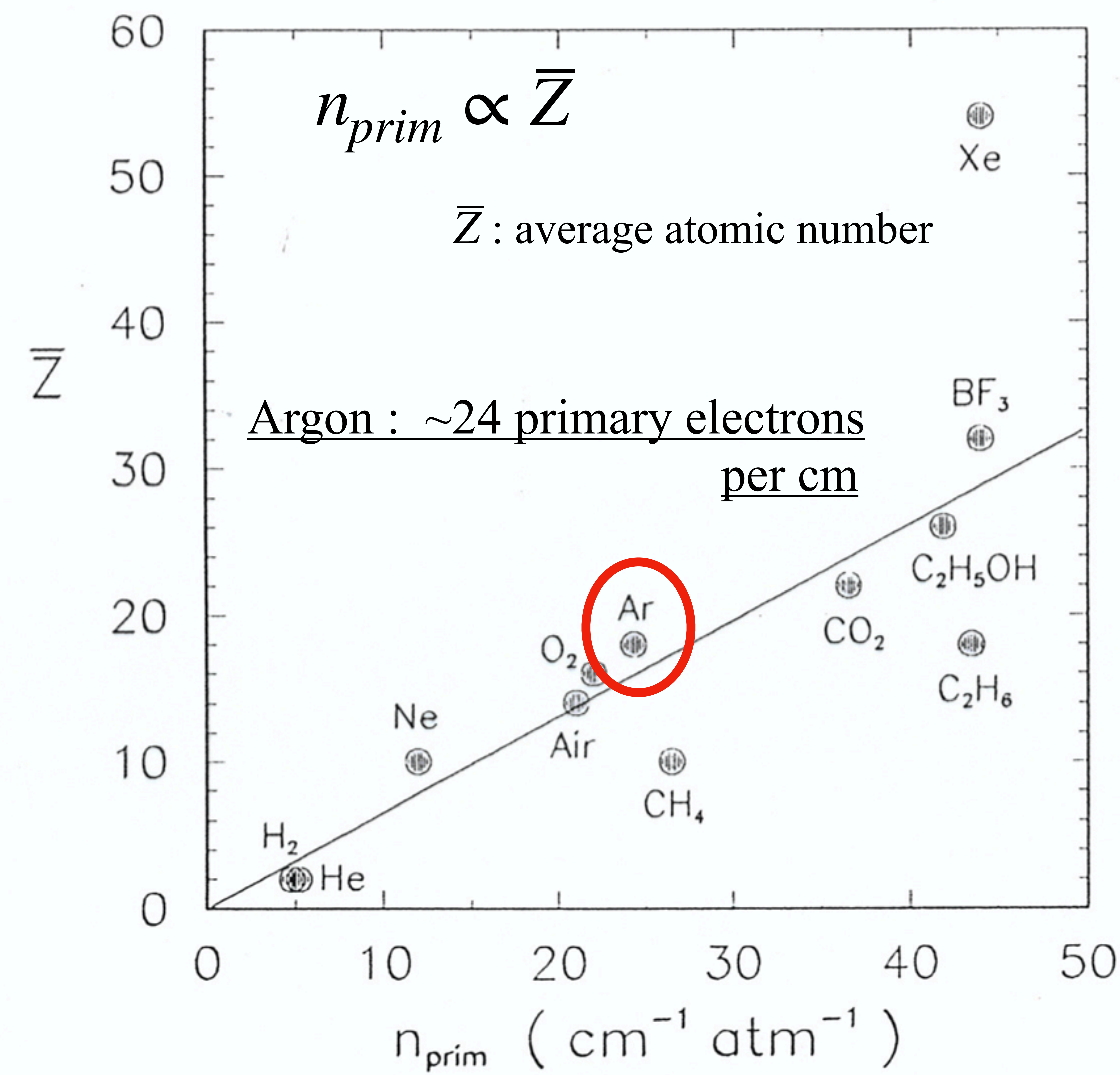
Summary

The ILD-TPC is a high-performance central tracker operated in a strong B-field, featuring MPGD readout modules.

The TPC provides excellent track pattern recognition capability with small 3-D voxels, along with good position, momentum, and dE/dx information of each track in jets, which are indispensable for the Particle Flow Analysis.

We have successfully developed a gating foil that meets the requirements, and are now working on the R&D of new GEM foils (plates) with new insulator materials in order to make the gas-amplification device simple and "die-hard".

Backup



Number of primary electrons versus the average atomic number of popular chamber gases

F.Sauli, Principles of Operation of Multiwire Proportional and Drift Chambers, CERN 77-09(1977)

Total number of ionisation electrons n_{tot}

$$n_{tot} = \frac{\Delta E}{W_I}$$

ΔE total energy loss in the gas volume

W_I effective energy loss for the production of one ionisation

Gas	Z	A	δ (g/cm^3)	E_{ex}	E_i (eV)	I_0	W_i	dE/dx ($MeV/g\ cm^{-2}$)	dE/dx (keV/cm)	n_p (i.p./cm) a)	n_T (i.p./cm) a)
H_2	2	2	8.38×10^{-5}	10.8	15.9	15.4	37	4.03	0.34	5.2	9.2
He	2	4	1.66×10^{-4}	19.8	24.5	24.6	41	1.94	0.32	5.9	7.8
N_2	14	28	1.17×10^{-3}	8.1	16.7	15.5	35	1.68	1.96	(10)	56
O_2	16	32	1.33×10^{-3}	7.9	12.8	12.2	31	1.69	2.26	22	73
Ne	10	20.2	8.39×10^{-4}	16.6	21.5	21.6	36	1.68	1.41	12	39
Ar	18	39.9	1.66×10^{-3}	11.6	15.7	15.8	26	1.47	2.44	29.4	94
Kr	36	83.8	3.49×10^{-3}	10.0	13.9	14.0	24	1.32	4.60	(22)	192
Xe	54	131.3	5.49×10^{-3}	8.4	12.1	12.1	22	1.23	6.76	44	307
CO_2	22	44	1.86×10^{-3}	5.2	13.7	13.7	33	1.62	3.01	(34)	91
CH_4	10	16	6.70×10^{-4}		15.2	13.1	28	2.21	1.48	16	53
C_4H_{10}	34	58	2.42×10^{-3}		10.6	10.8	23	1.86	4.50	(46)	195

a) i.p. = ion pairs

Important parameters for frequently used chamber gases.

Argon

Gas	Z	A	δ (g/cm³)	E_{ex}	E_i (eV)	I_0	W_i	dE/dx (MeV/g cm^{-2})	dE/dx (keV/cm)	n_p (i.p./cm) a)	n_T (i.p./cm) a)
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C_4H_{10}	34	58	2.42×10^{-3}		10.6	10.8	23	1.86	4.50	(46)	195

a) i.p. = ion pairs

Argon: total number of ionisation electrons is 94 /cm

24 **primary electrons produce about 2, 3 secondary electrons**

F.Sauli, Principles of Operation of Multiwire Proportional and Drift Chambers, CERN 77-09(1977)

Characteristic of electron transmission

aim of ILD-TPC

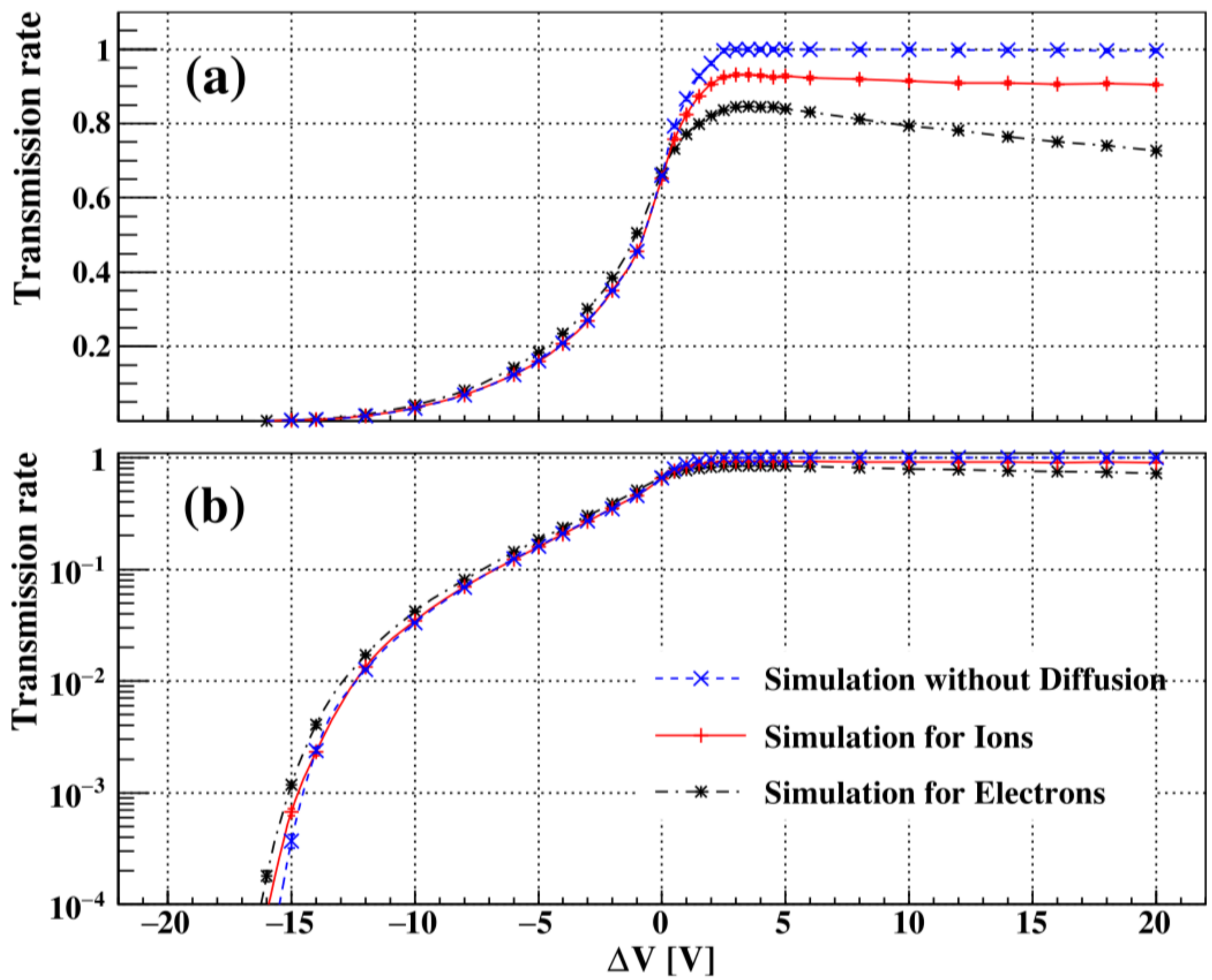
momentum resolution: $$\frac{\sigma_{p_\perp}}{p_\perp} \approx 1 \times 10^{-4}\ p_\perp\ GeV/c$$

-> position resolution: $$\sigma_x \approx 100\ \mu m$$

aim of gate device

electron transmission rate > 80 %

ion blocking rate ~ $\mathcal{O}(10^{-4})$

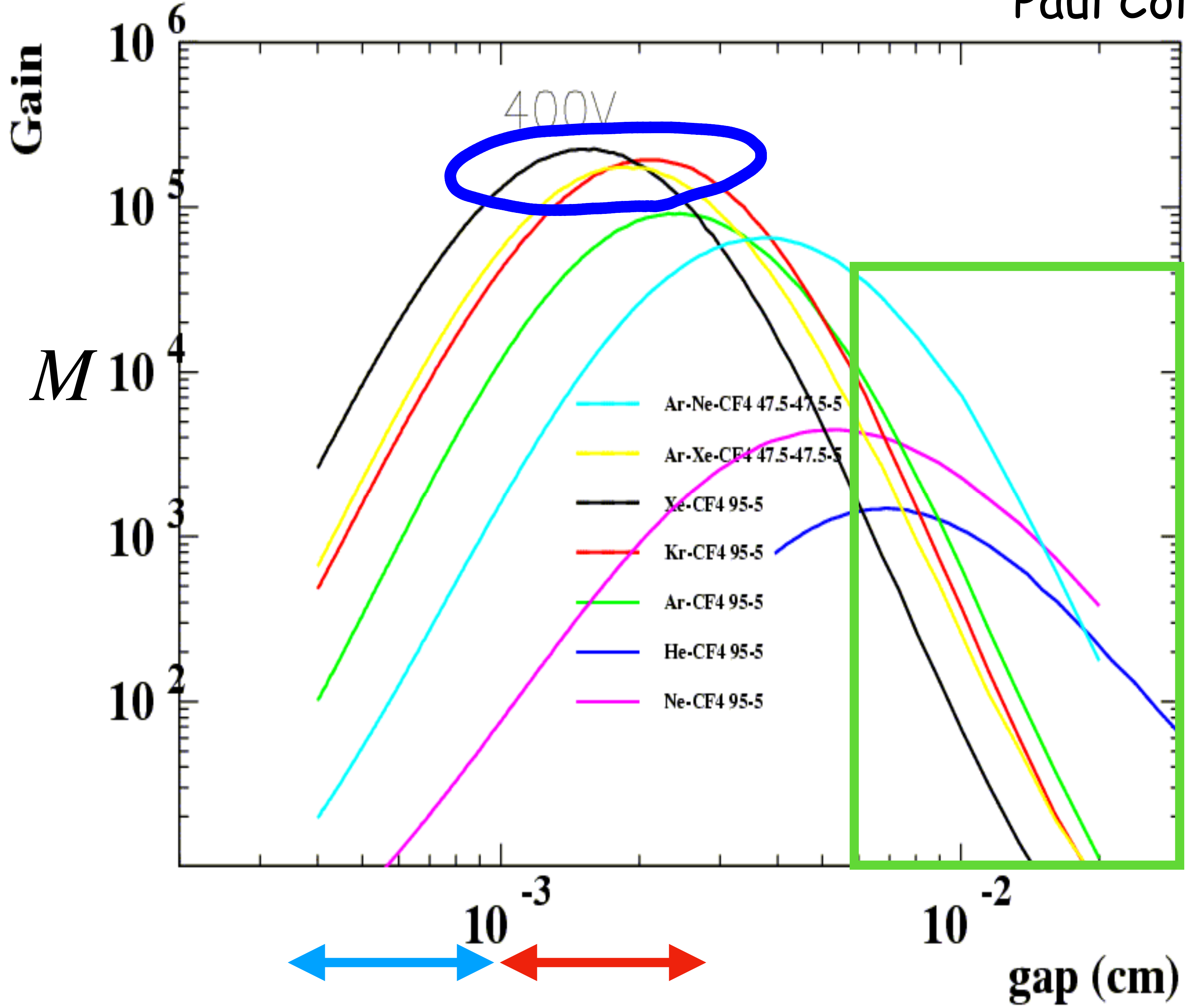


Measurement of the electron transmission rate of the gating foil for the TPC of the ILC experiment
M. Kobayashi et al.

in the case of a MicroMEGAS, there is a “plateau” in a gap dependence of gas gain

Paul Colas

$$M = e^{\alpha d}$$



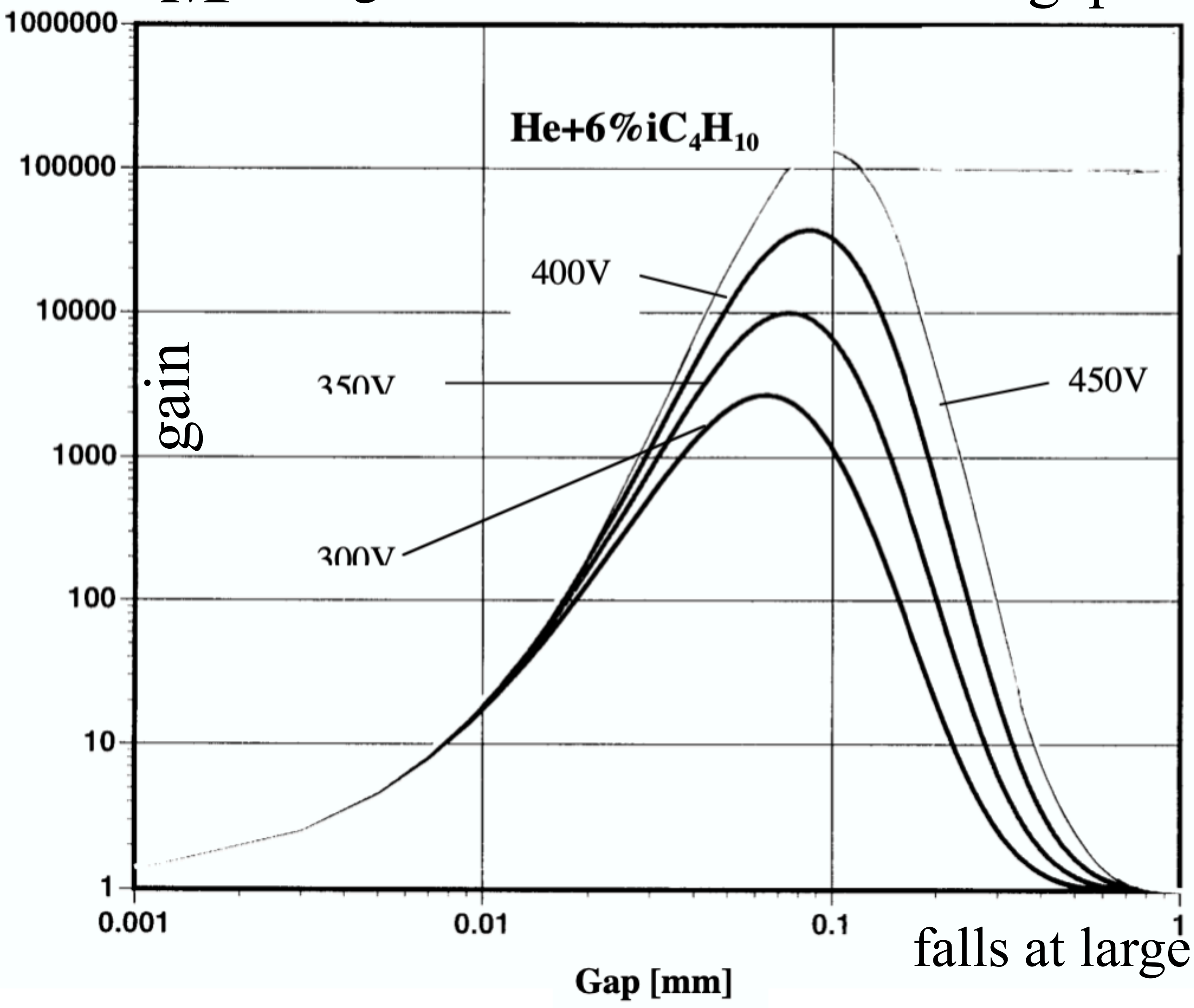
“plateau”

gap d : ↑↑
EField:↓
α: ↓ (depends on Efield)

gap d : ↑
EField:↓↓
α: ↓↓ (depends on Efield)

MICROMEGAS

$M = e^{\alpha d}$ as a function of the gap d gas: He + iC4H10 = 94:6



M rises as d increases, reaches a maximum

M is at maximum in the range of gaps between 30-100 μm.

This is the range currently used by the MICROMEGAS detectors

falls at large values of d

MICROMEGAS: results and prospects : **I. Giomataris**

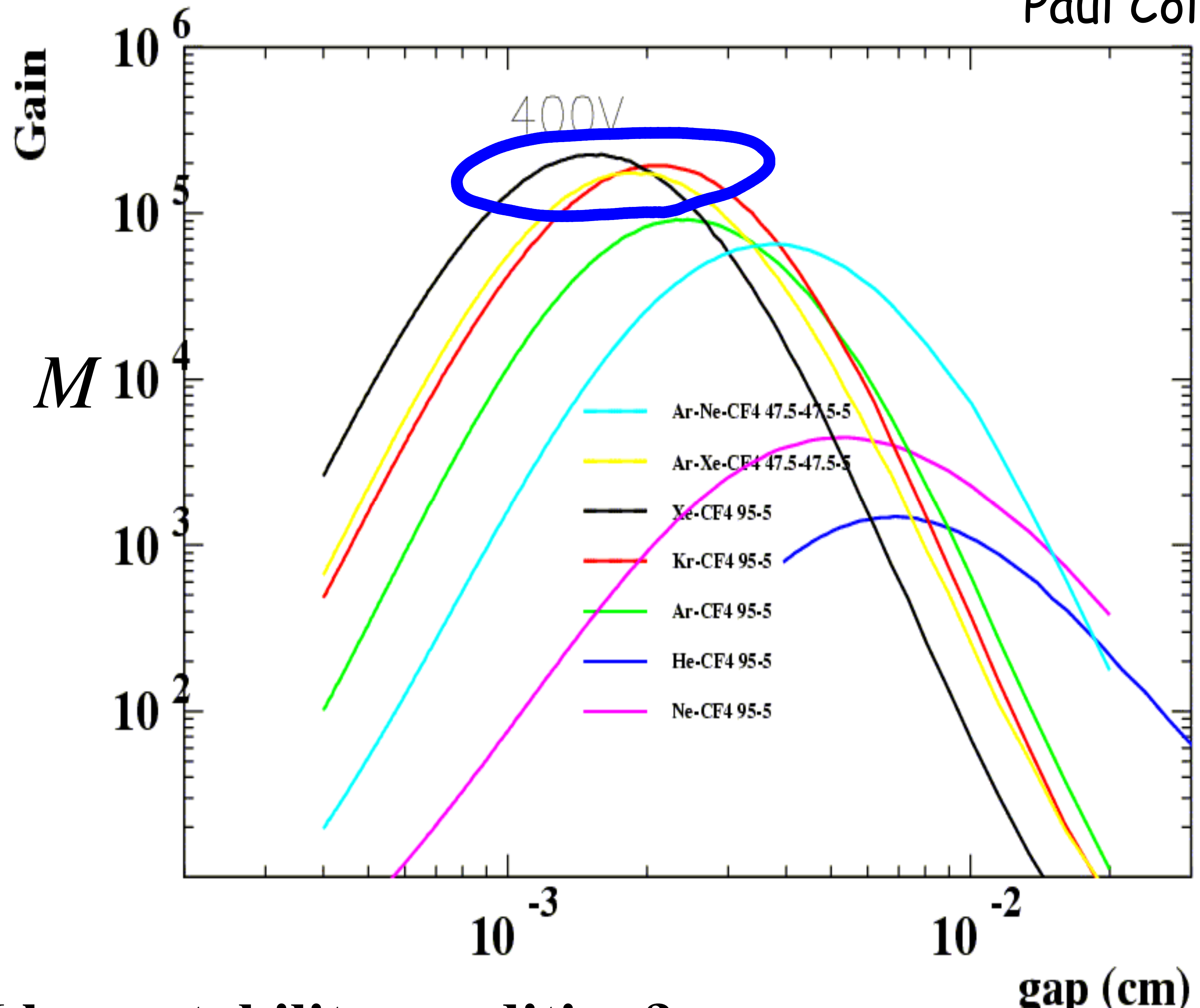
In this range, gas gain M is maximum and its fluctuations due to defects of flatness of the two parallel electrodes are canceled

Stability condition!!

in the case of a MicroMEGAS, there is a “plateau” in a gap dependence of gas gain

Paul Colas

$$M = e^{\alpha d}$$

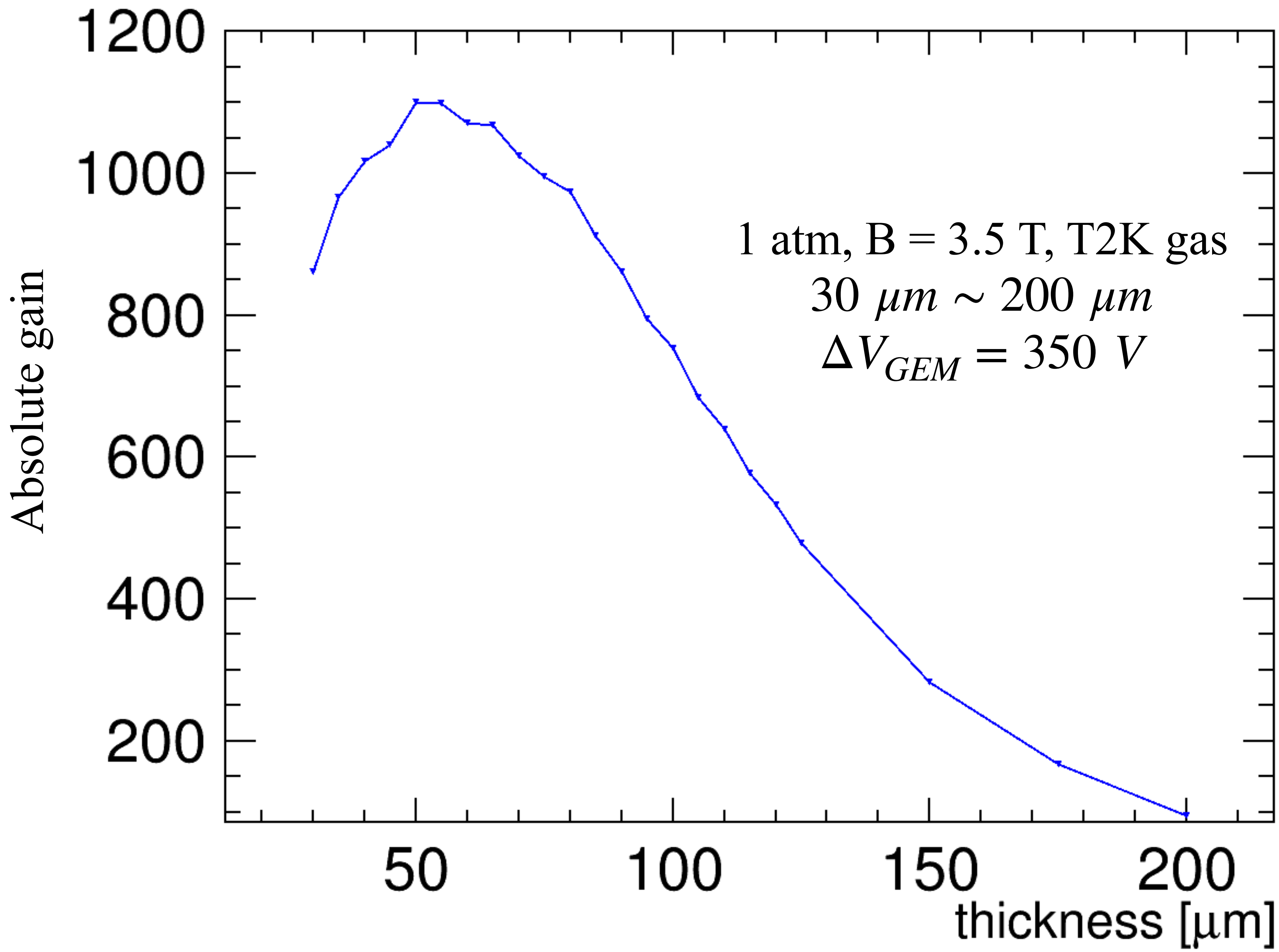


Does GEM have stability condition?

Theoretically, derive the stability conditions under which the gas gain is stable

I (KY) am working on this study $\boxed{\text{on going}}$

Thickness dependence of gain:Asian GEM



The plateau area was found in the range of 40 $\mu m \sim 80\ \mu m$

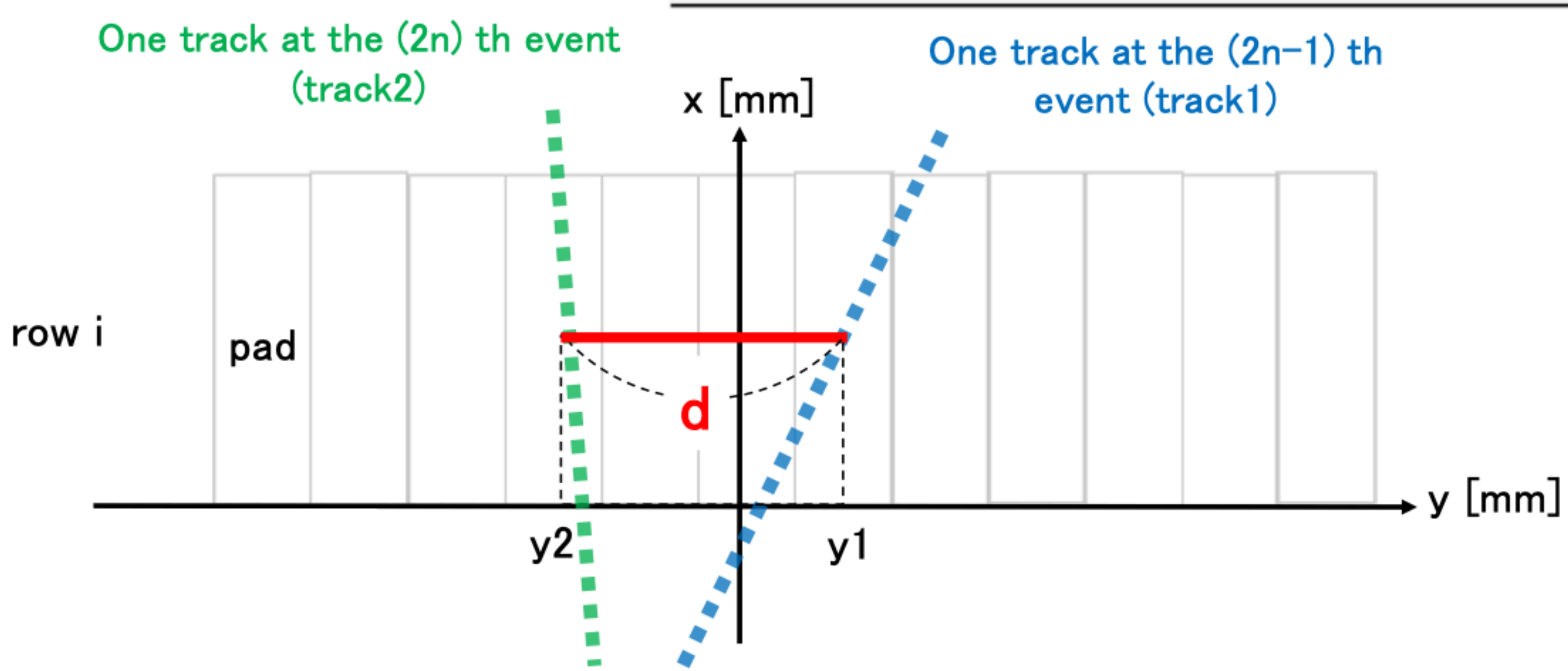
cf. CERN GEM:thickness 50 μm

If our theory is correct, the stability condition
should be satisfied in the range of 40 $\mu m \sim 80\ \mu m$

2-hit resolution (2-track separation)

- A MPGD–based TPC can provide clearly track separation thanks to its small ExB effect compared with MWPC.
- We're trying to investigate 2–track separation for a GEM–based TPC using electron beam.

σ_{point} in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm
2-hit resolution in rz	$\simeq 6$ mm
dE/dx resolution	$\simeq 5$ %
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)

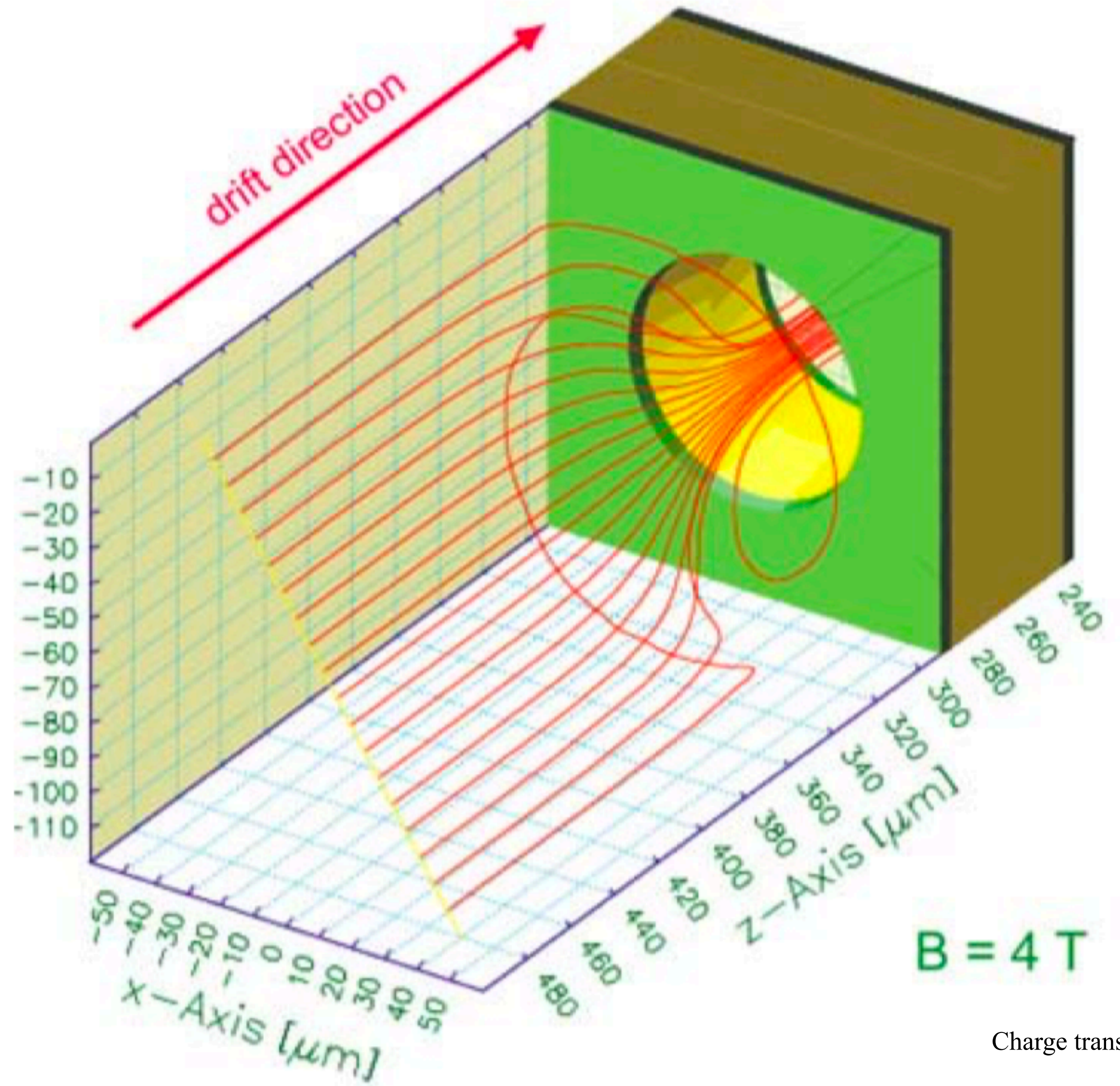


on going

Aiko shoji is working on this study

From Aiko Shoji (LCWS 2019) @ Sendai

Backup



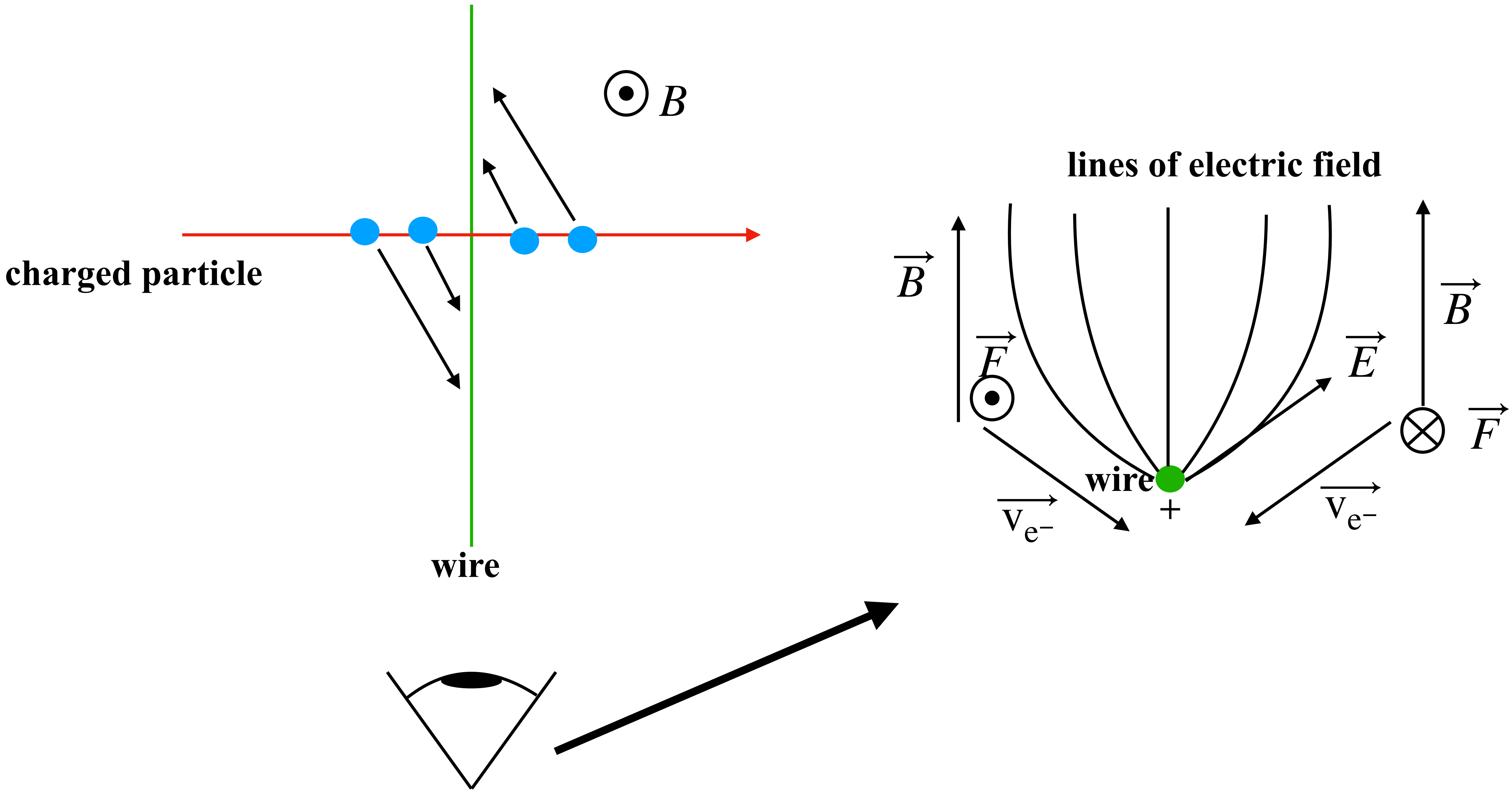
Charge transfer and charge broadening of GEM structures in high magnetic
M. Killenberg et al.

GARFIELD simulation of electron drift lines starting in front of a GEM (electric field 200 V=cm; GEM voltage 400 V); at 4 T

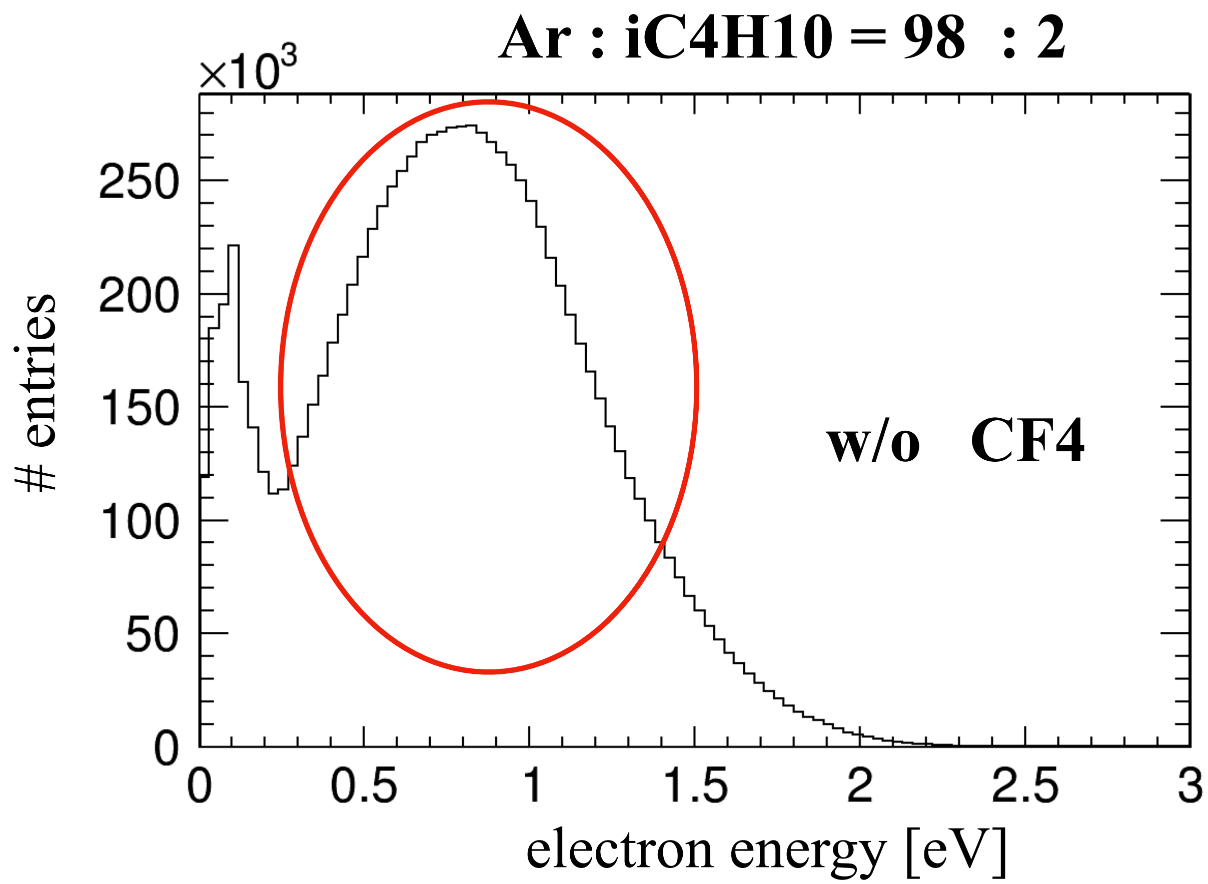
no electrons are lost during collection into the GEM holes.

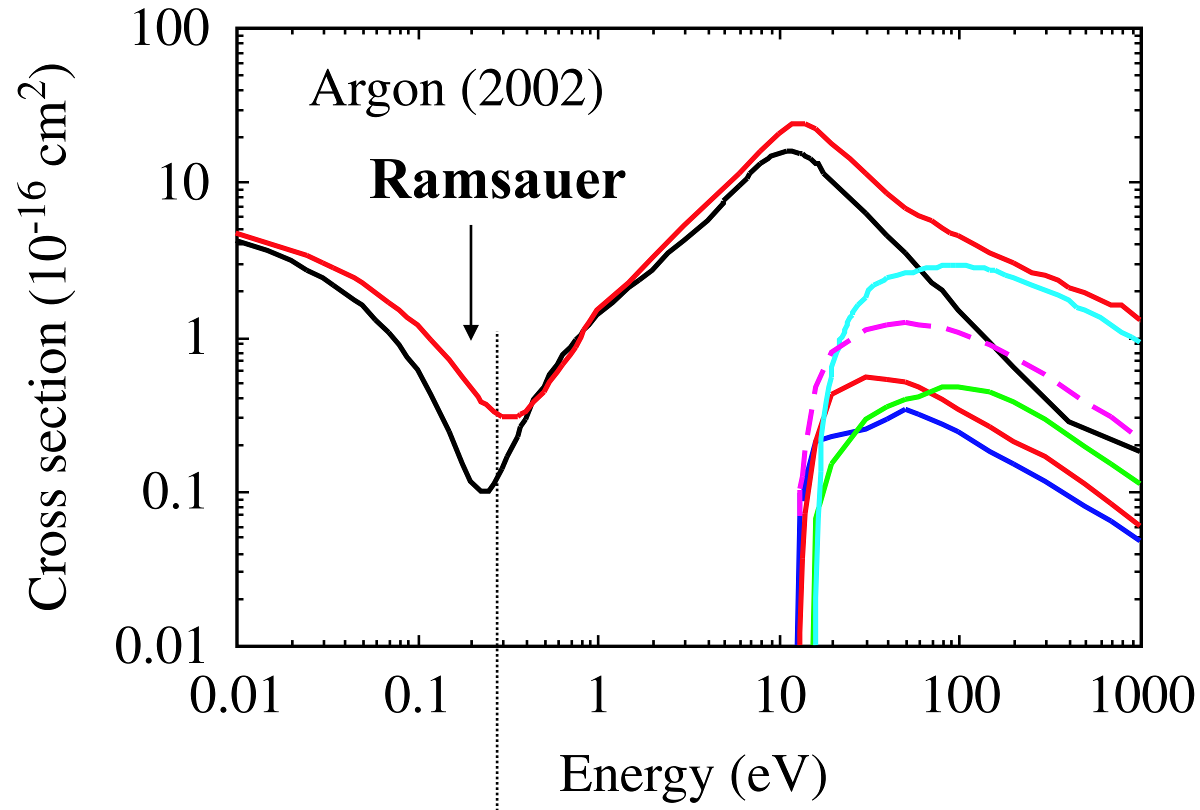
$E \times B$ effect

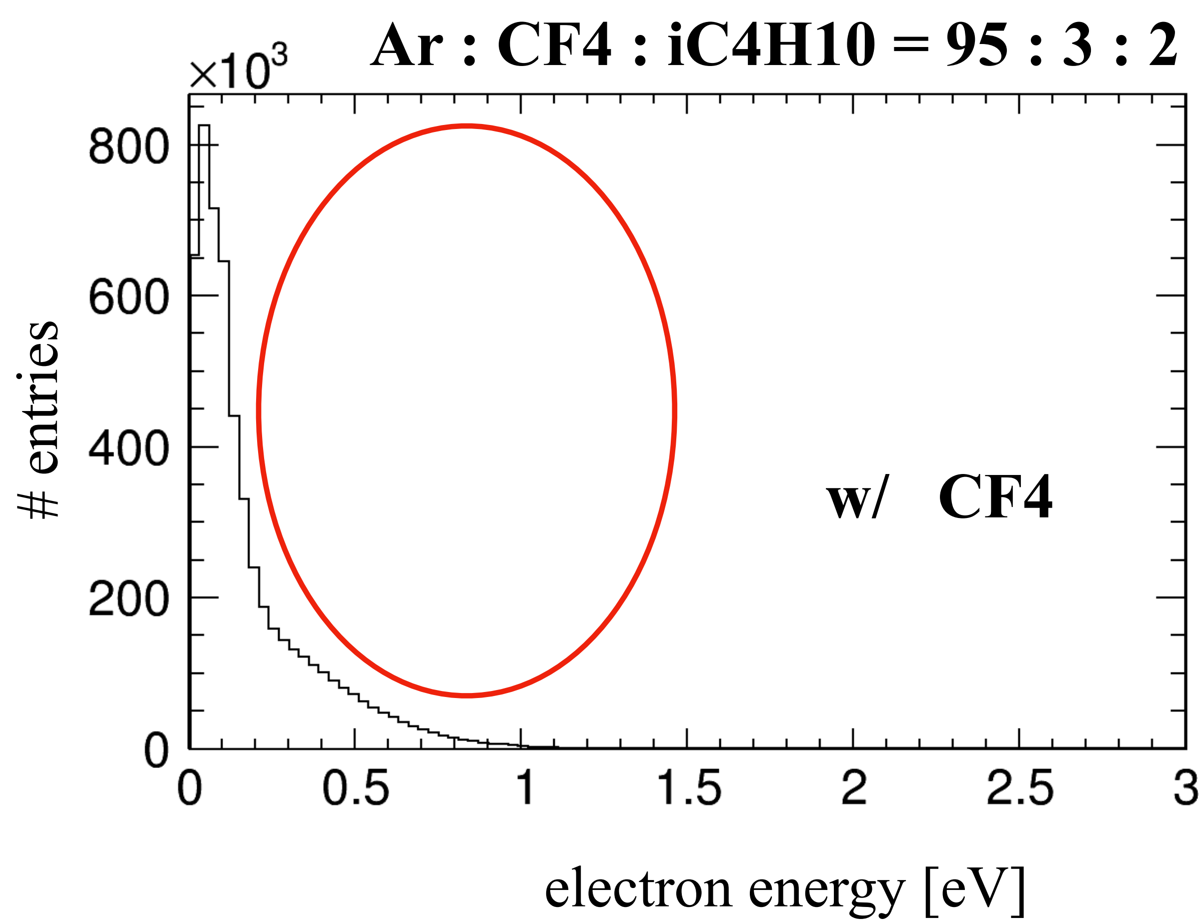
bend the electron drift path near the wire

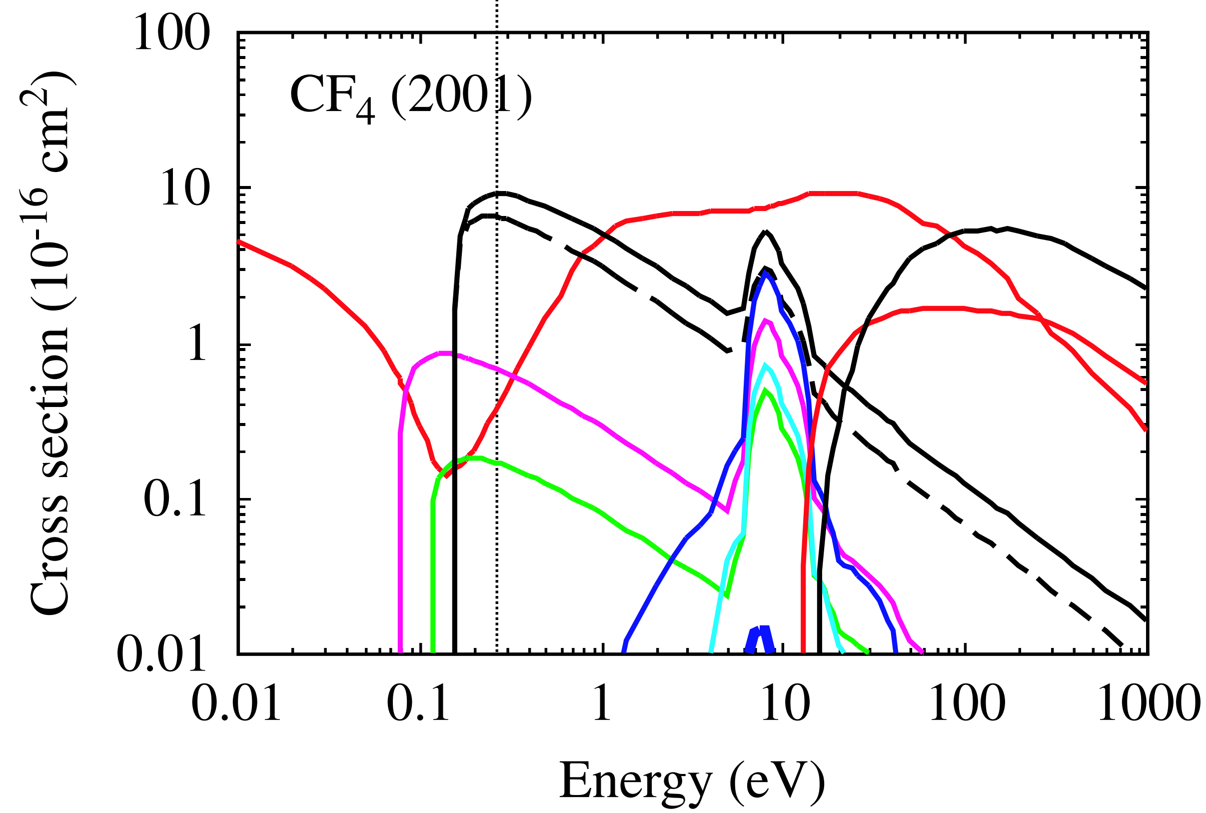


liberated electrons are bent along the wire (in the direction of wire)



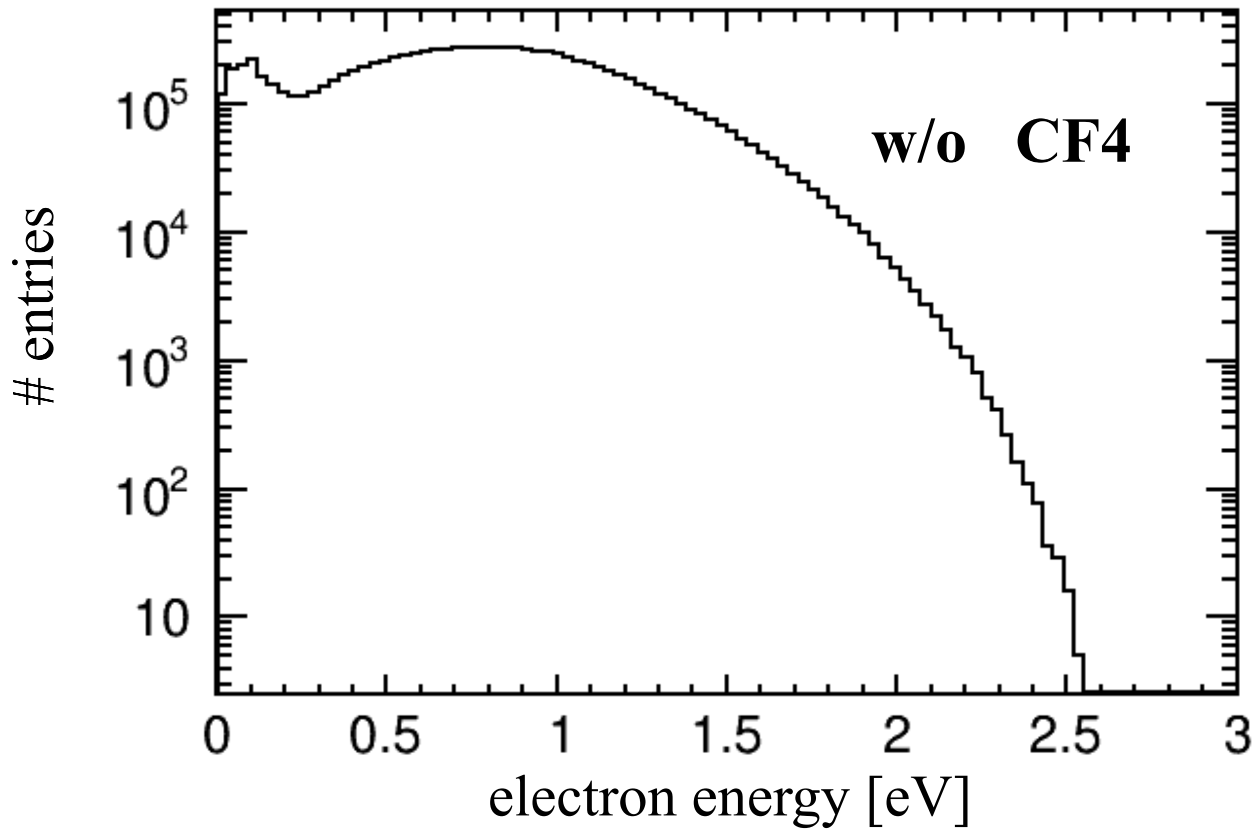




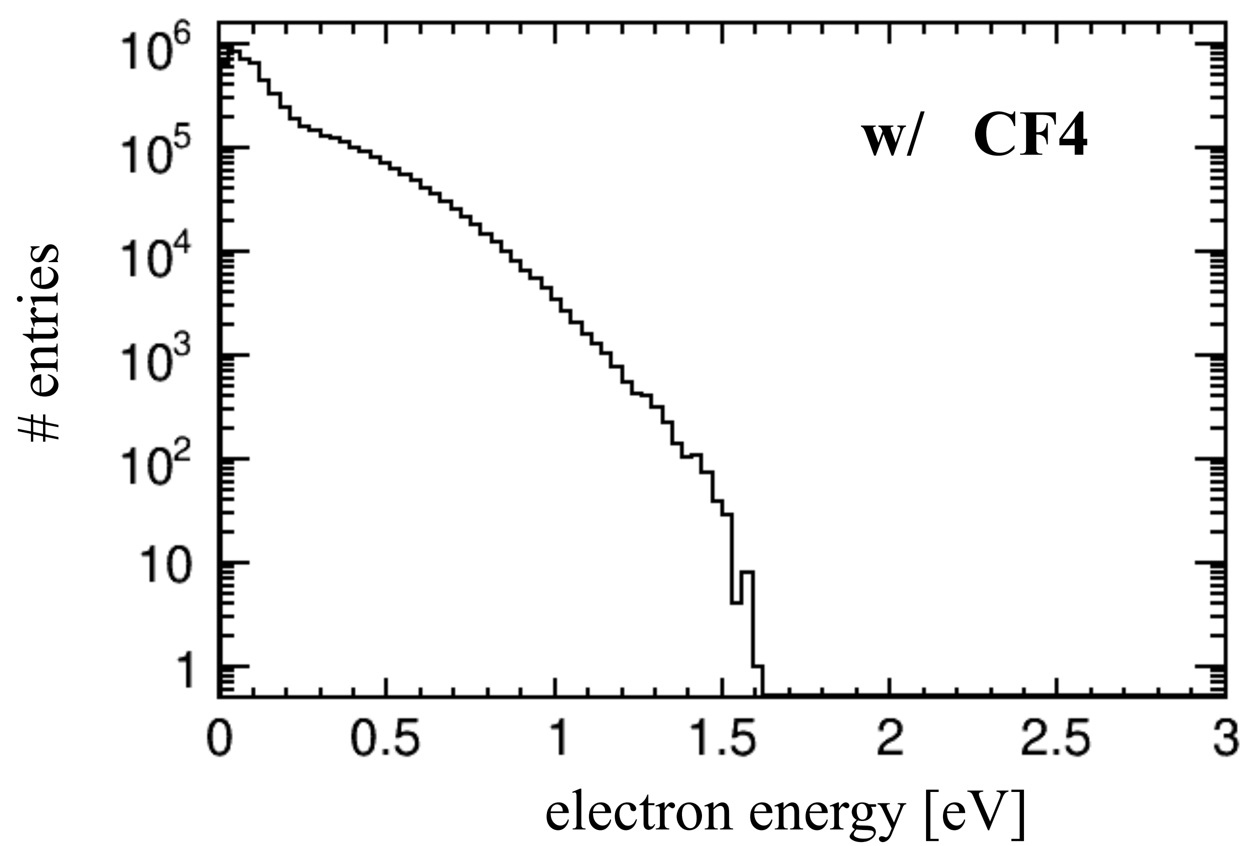


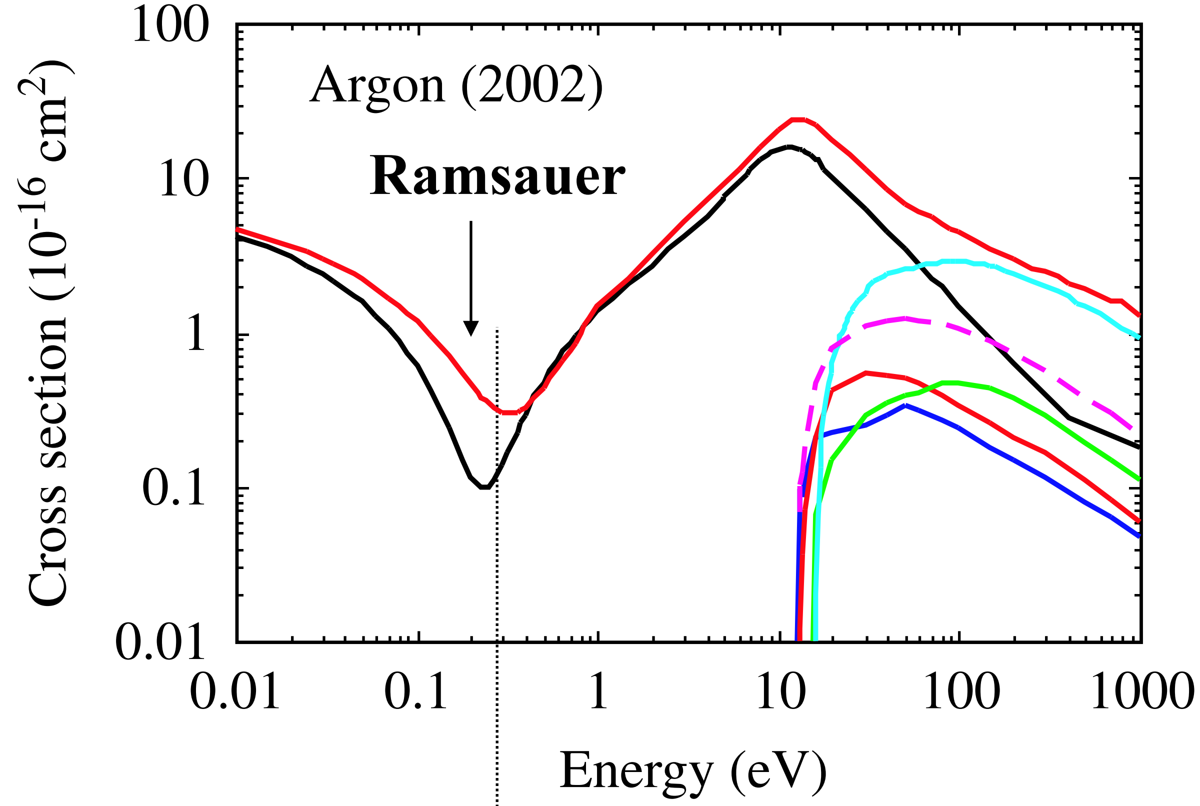
$E = 230\ \mathrm{V/cm}$

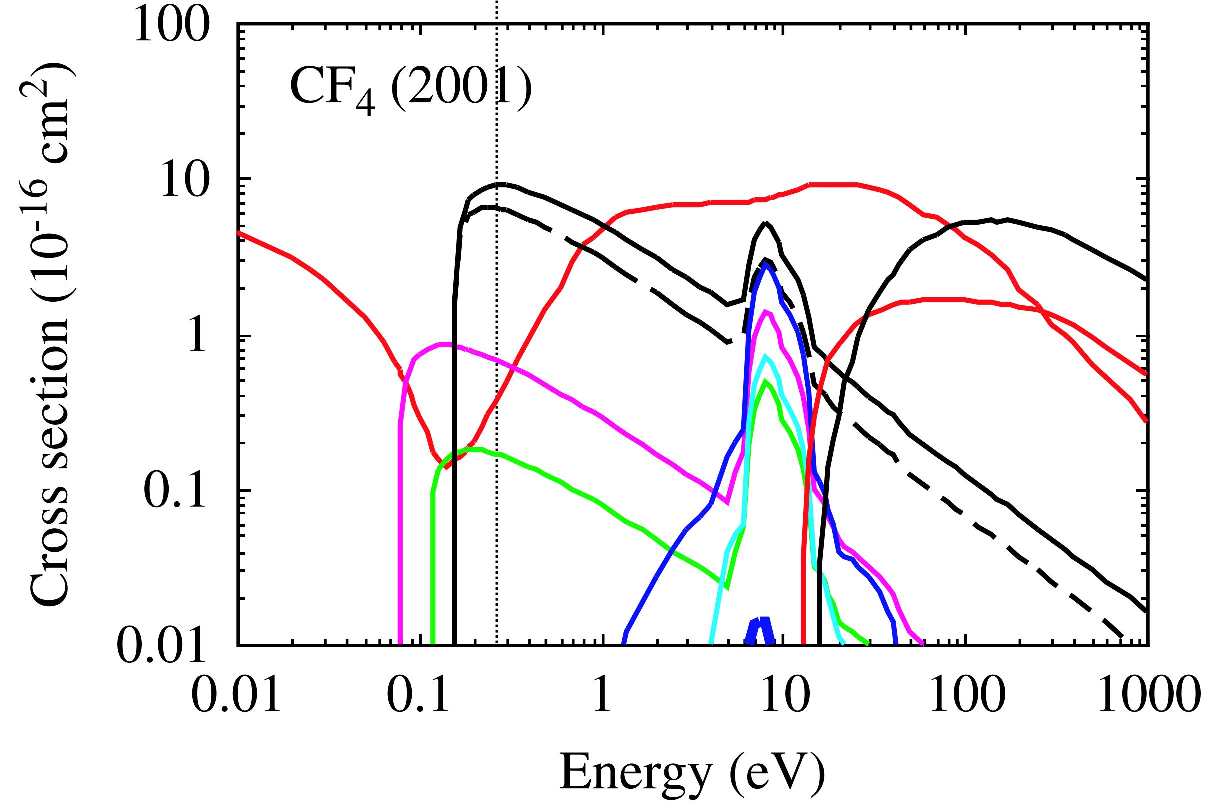
Ar : iC4H10 = 98 : 2



Ar : CF4 : iC4H10 = 95 : 3 : 2







$E = 230$ V/cm

Insulation material of GEM

GEM is vulnerable to discharges: a single (large) discharge could be fatal

= > Looking for new insulator material

Glass GEM

Using glass instead of polyimide as the substrate

No outgassing

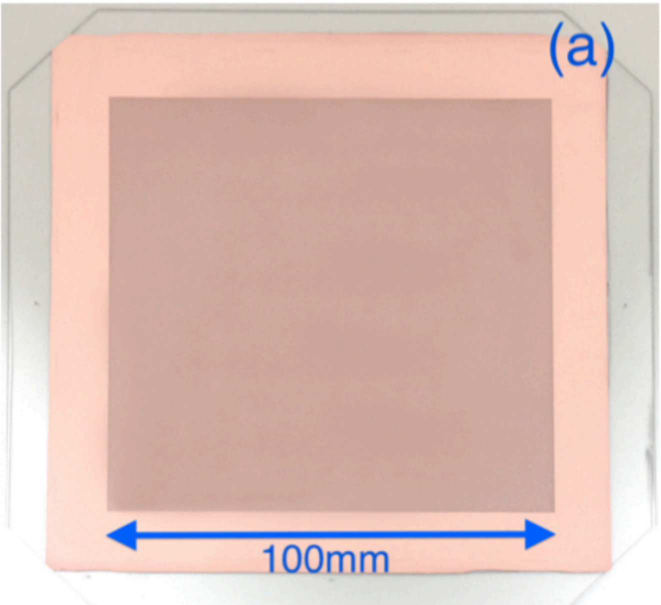
High gain with only one stage

LTCC or G-GEM is a thin but stiff "plate": self-supporting without tension applied

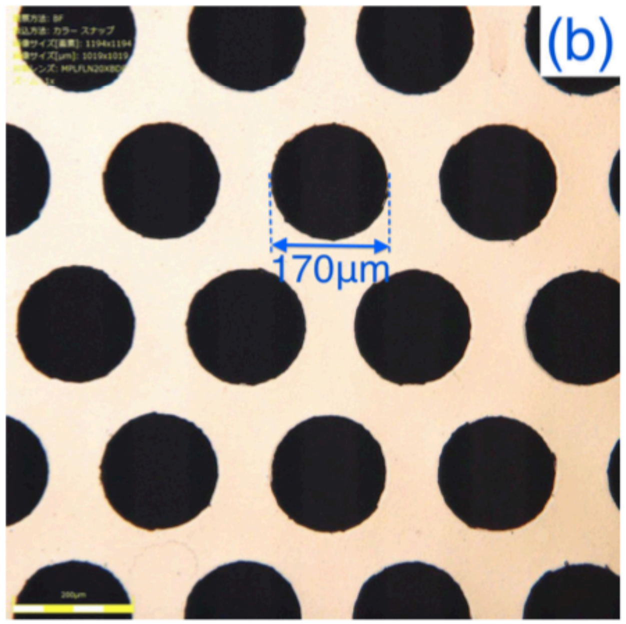
Characteristics of G-GEM & CERN GEM

Type of GEM	*Glass GEM*	*CERN GEM*
Hole diameter	170 μm	50 μm
Pitch	280 μm	150 μm
Thickness	$\boxed{680\ \mu\text{m}}$	50 μm
Insulator	Glass	Polyimide

T. Fujiwara et al 2014 JINST 9 P11007

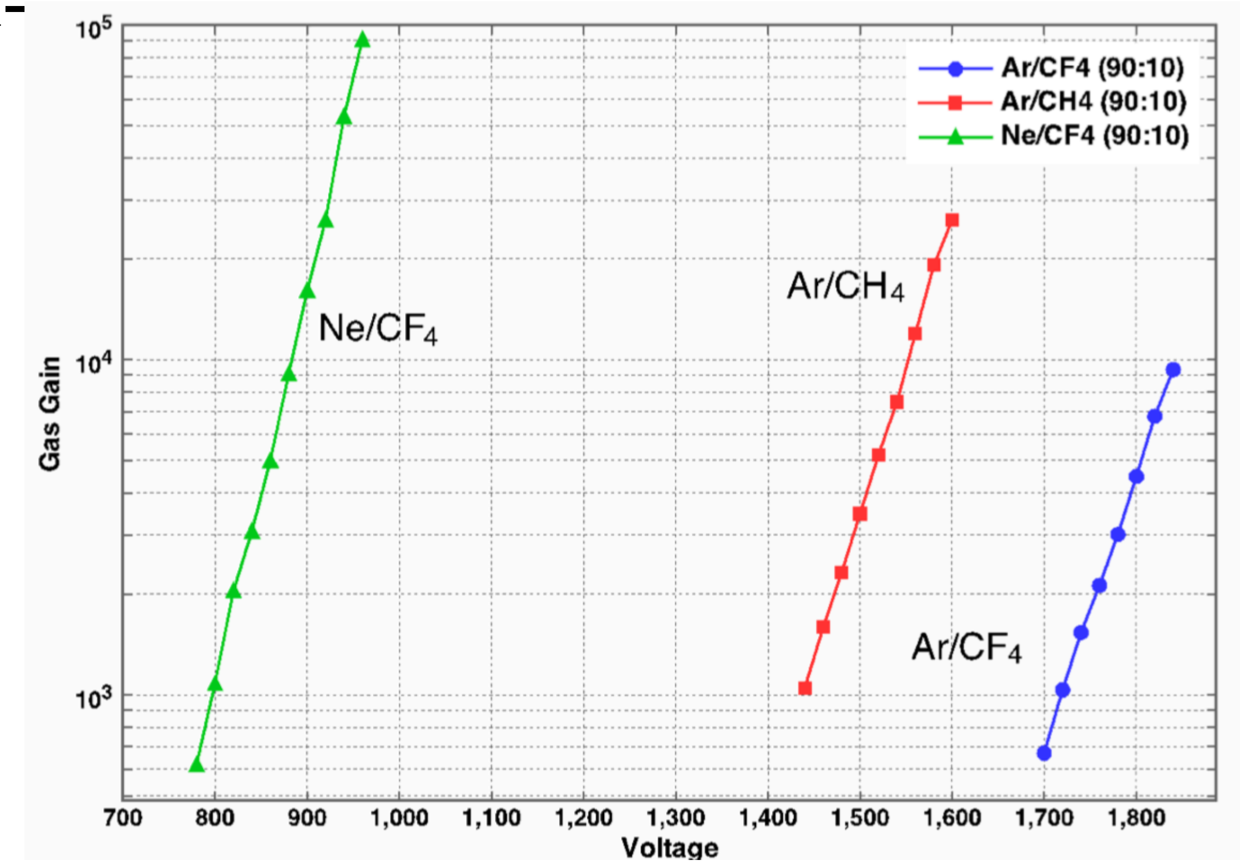


Photograph of the G-GEM



Microphotograph of the G-GEM

T. Fujiwara et al 2014 JINST 9 P11007



Gas gain curves of Glass GEM measured with 5.9-keV X-rays

T. Fujiwara et al 2014 JINST 9 P11007

Insulation material of GEM

LTCC: <u>Low Temperature</u> Co-Fired Ceramics

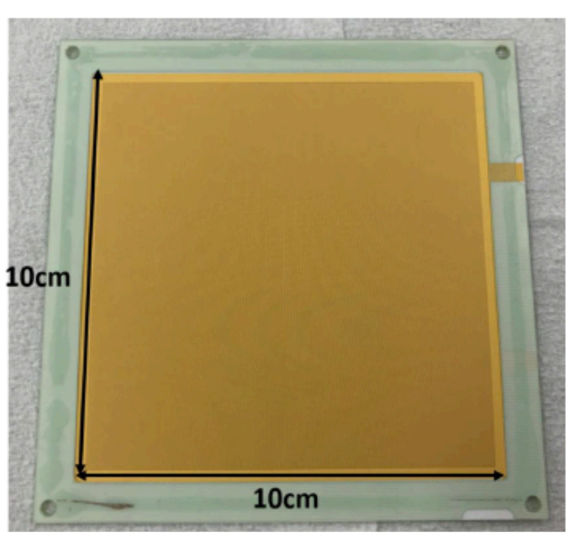
By mixing glass components with alumina ceramics annealing temperature ~ 900℃

Area
Substrate: 12.4 cm x 12.4 cm
Hole region: 10 cm x 10 cm
Thickness: 100 µm or 200 µm
Hole size: ϕ100 µm
Hole pitch: 200 µm

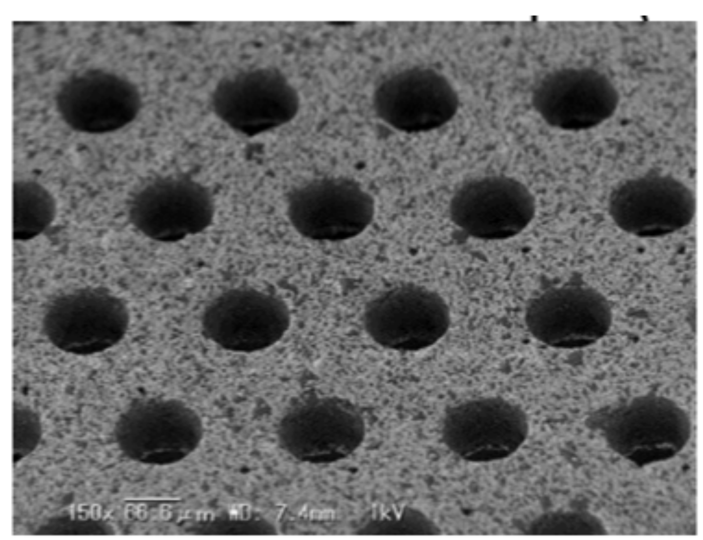
No outgassing

High gain with only one stage

LTCC or G-GEM is a thin but stiff "plate": self-supporting without tension applied



Photograph of the LTCC-GEM


Microphotograph of the LTCC-GEM

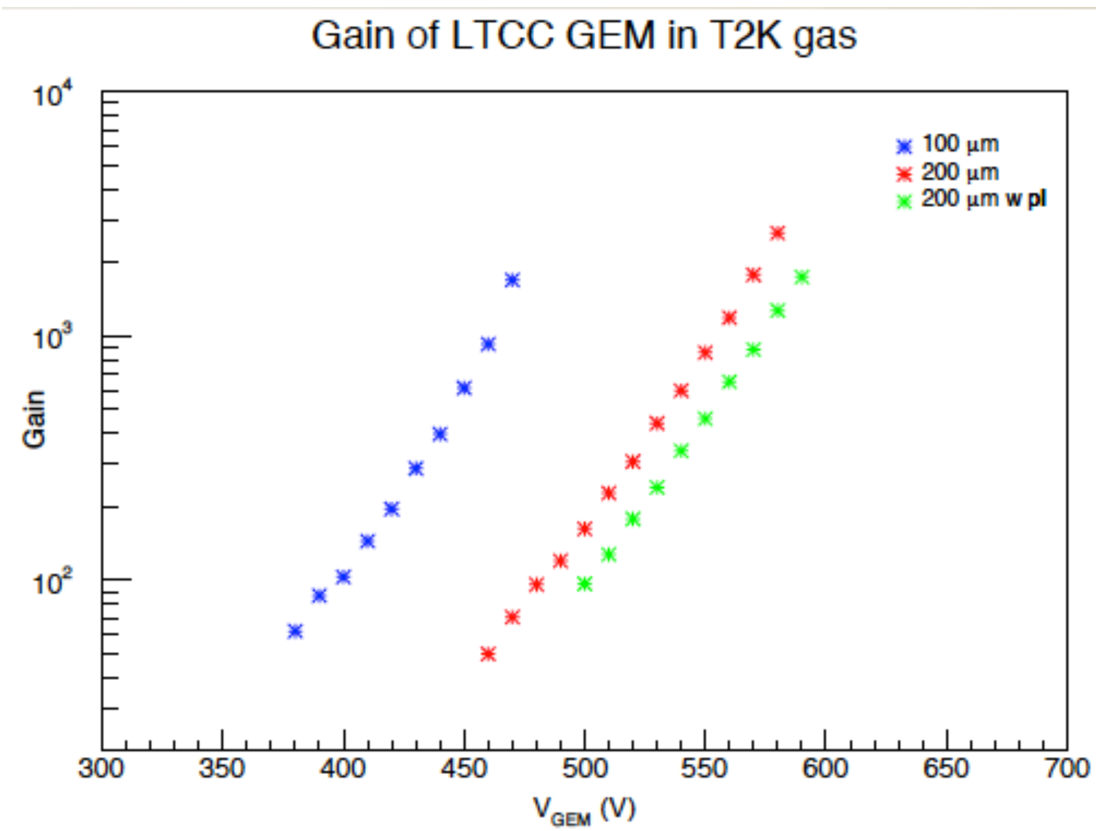
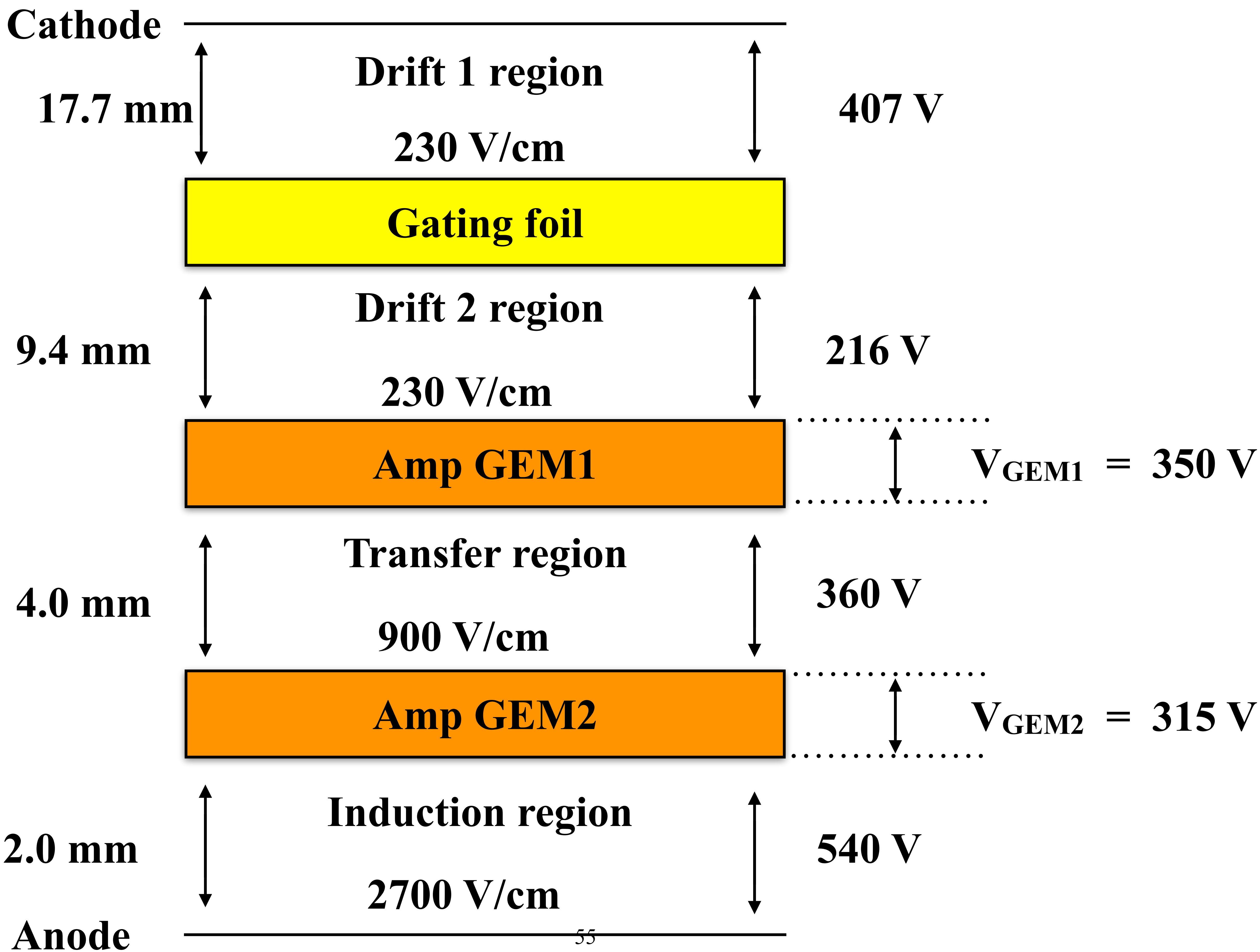


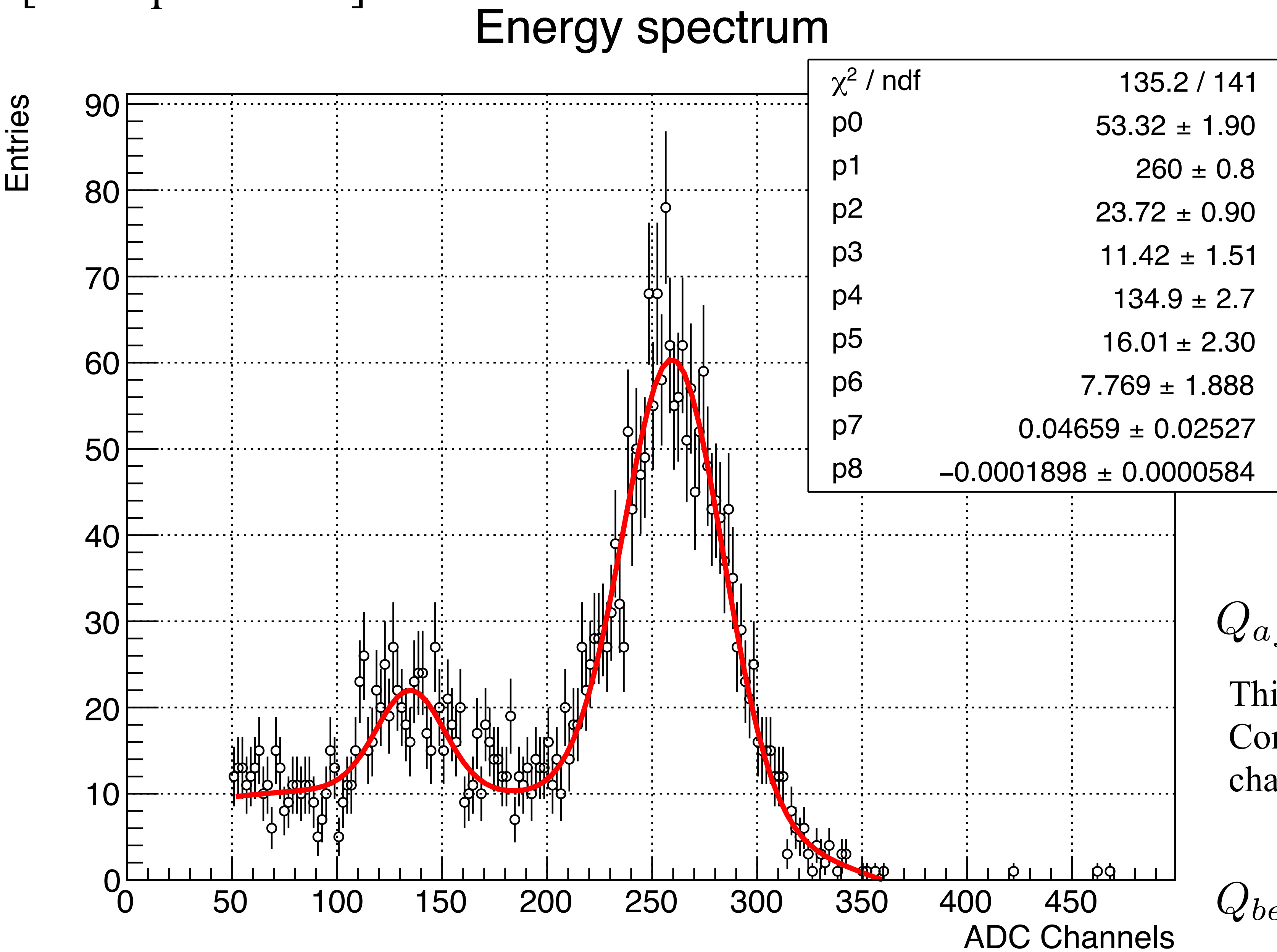
Figure by Y.Kato, Kindai Univ.

Electric field and voltage



Definition of Gain

[Example: run10]



Gain:

$$G = \frac{\text{Charge after amplification}}{\text{Charge before amplification}}$$

Q_{after}

Q_{before}

$$Q_{after} \sim 0.52 * p_1 - 0.78 \quad \text{[fC]}$$

This formula is obtained from ADC calibration.
Correlation between ADC channels and charge was examined using a pulse generator.

$$Q_{before} \sim n_0 * 1.6 * 10^{-19} \quad \text{[C]}$$

n_0: seed electrons ~ 227

Fitting function:

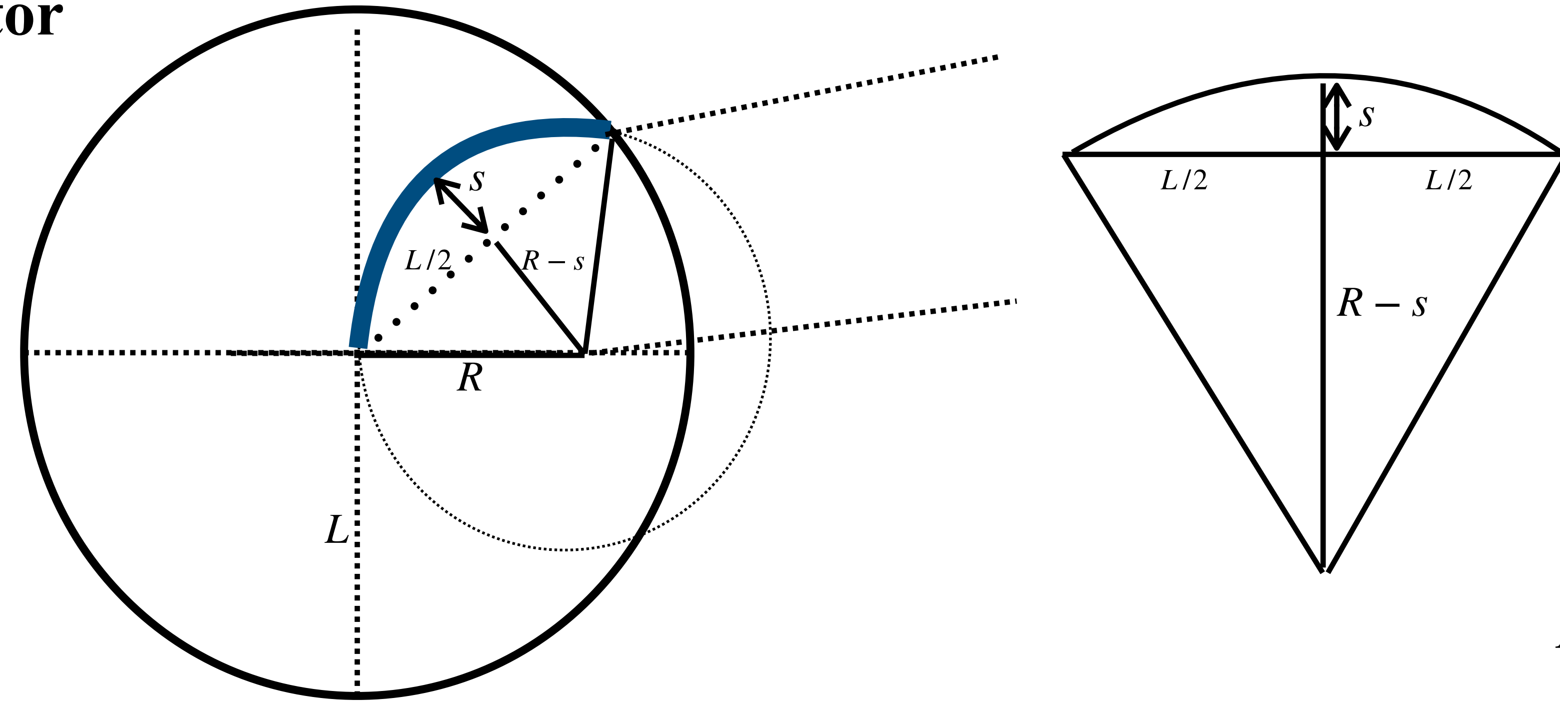
$$f(x) = p_0 \exp\left(-\frac{(x-p_1)^2}{2p_2^2}\right) + p_3 \exp\left(-\frac{(x-p_4)^2}{2p_5^2}\right) + p_6 + p_7 x + p_8 x^2$$

Main peak Escape peak Background

Momentum resolution

cross section of detector

using **sagitta** s



Let R be

$$R \gg s \qquad R \approx \frac{L^2}{8s}$$

$$p_\perp = 0.3\ BR \approx \frac{0.3BL^2}{8s}$$

$$\frac{\sigma_{p_\perp}}{p_\perp} \propto \frac{\sigma_x p_\perp}{BL^2}$$

by taking into account

- **Multiple measurements points**
- **Multiple scattering**

precisely,
Momentum resolution is

$$\frac{\sigma_{p_\perp}}{p_\perp} = \sqrt{\underbrace{\left(\frac{\alpha'\sigma_x}{BL^2}\right)^2 \left(\frac{720}{N+4}\right) p_\perp^2}_{\text{measurements}} + \underbrace{\left(\frac{\alpha' C}{BL}\right)^2 \frac{10}{7} \left(\frac{X}{X_0}\right)}_{\text{multiple scattering}}}$$

$p_\perp$: lateral momentum

σ_x : position resolution

B : strength of B-Field

N : # of measurement points

L : track detection length

$\frac{X}{X_0}$: radiation length of gas

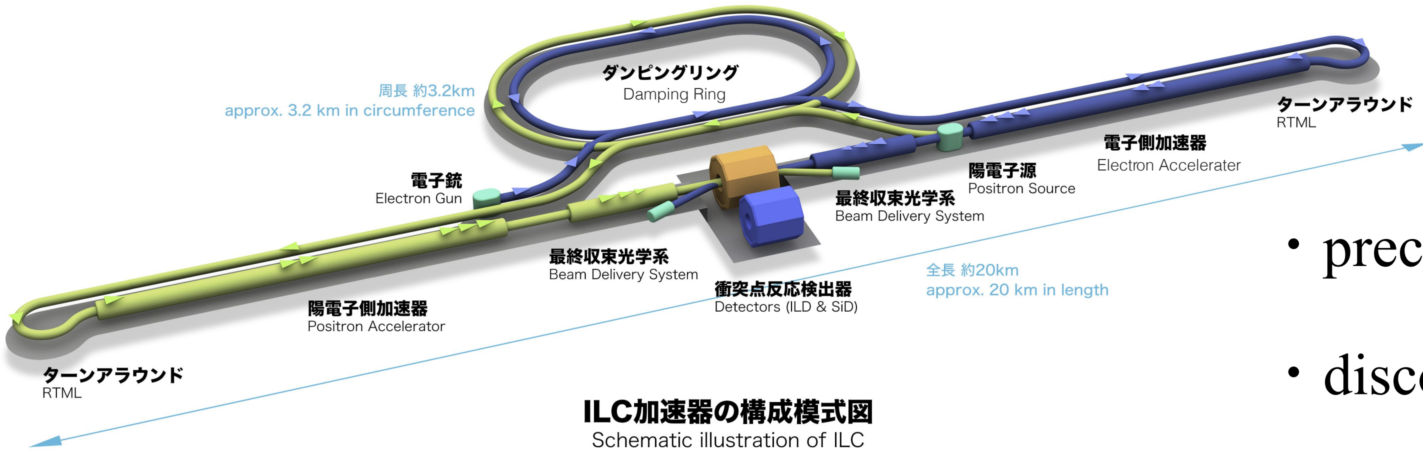
α', C : constant

R.L. Gluckstern, NIM 24 (1963), 381

Introduction

International Linear Collider (ILC)

linear electron-positron collider

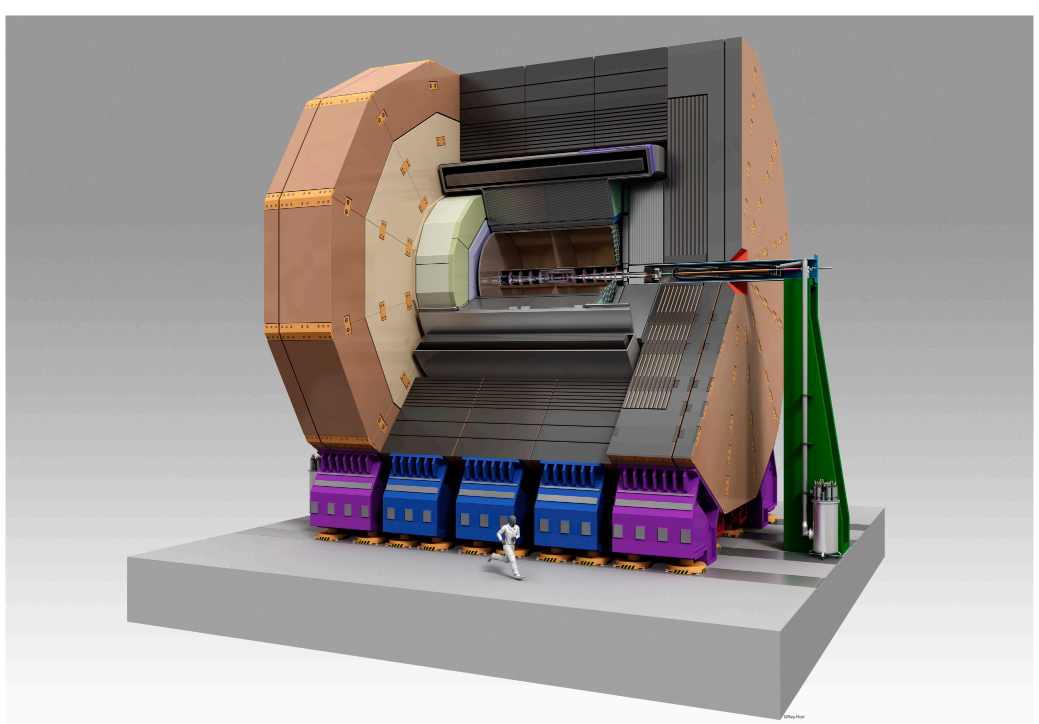


・precision measurement of the Higgs boson and top quark

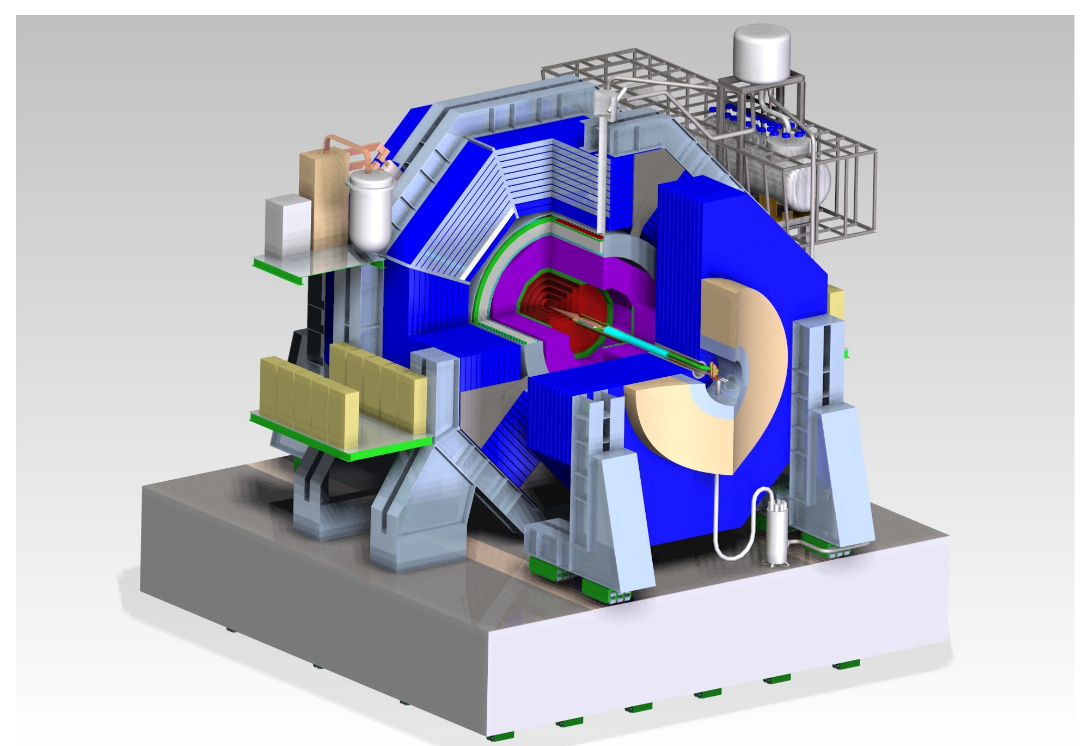
・discovery of physics beyond the Standard Model

-search for candidates for dark matter

ILC has two detectors



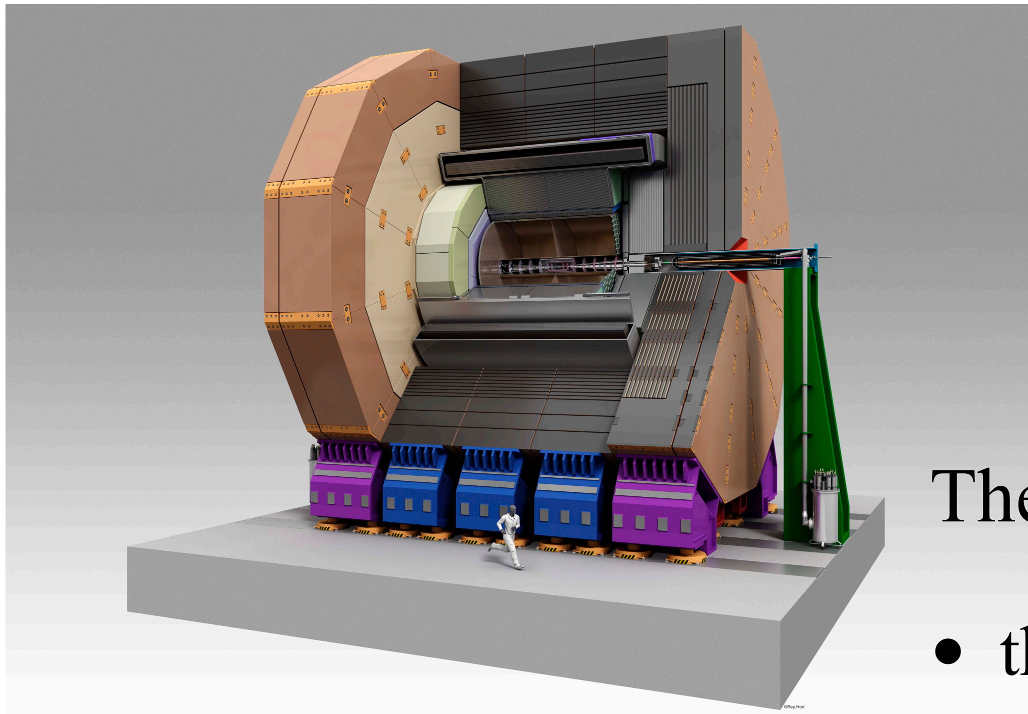
ILD



SiD

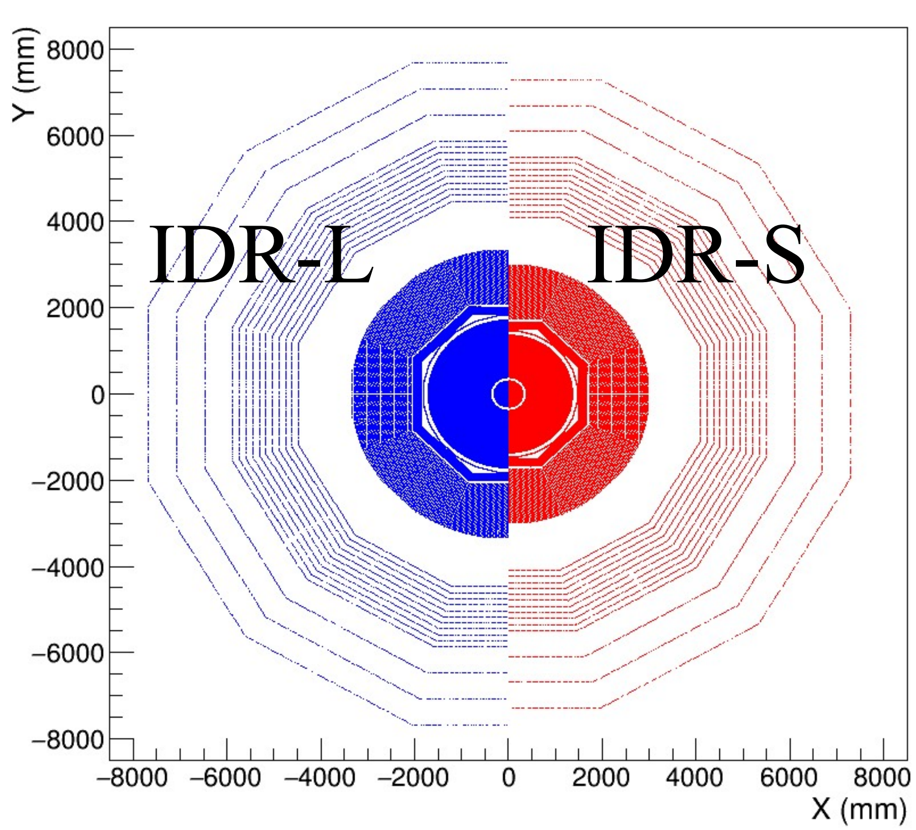
Introduction

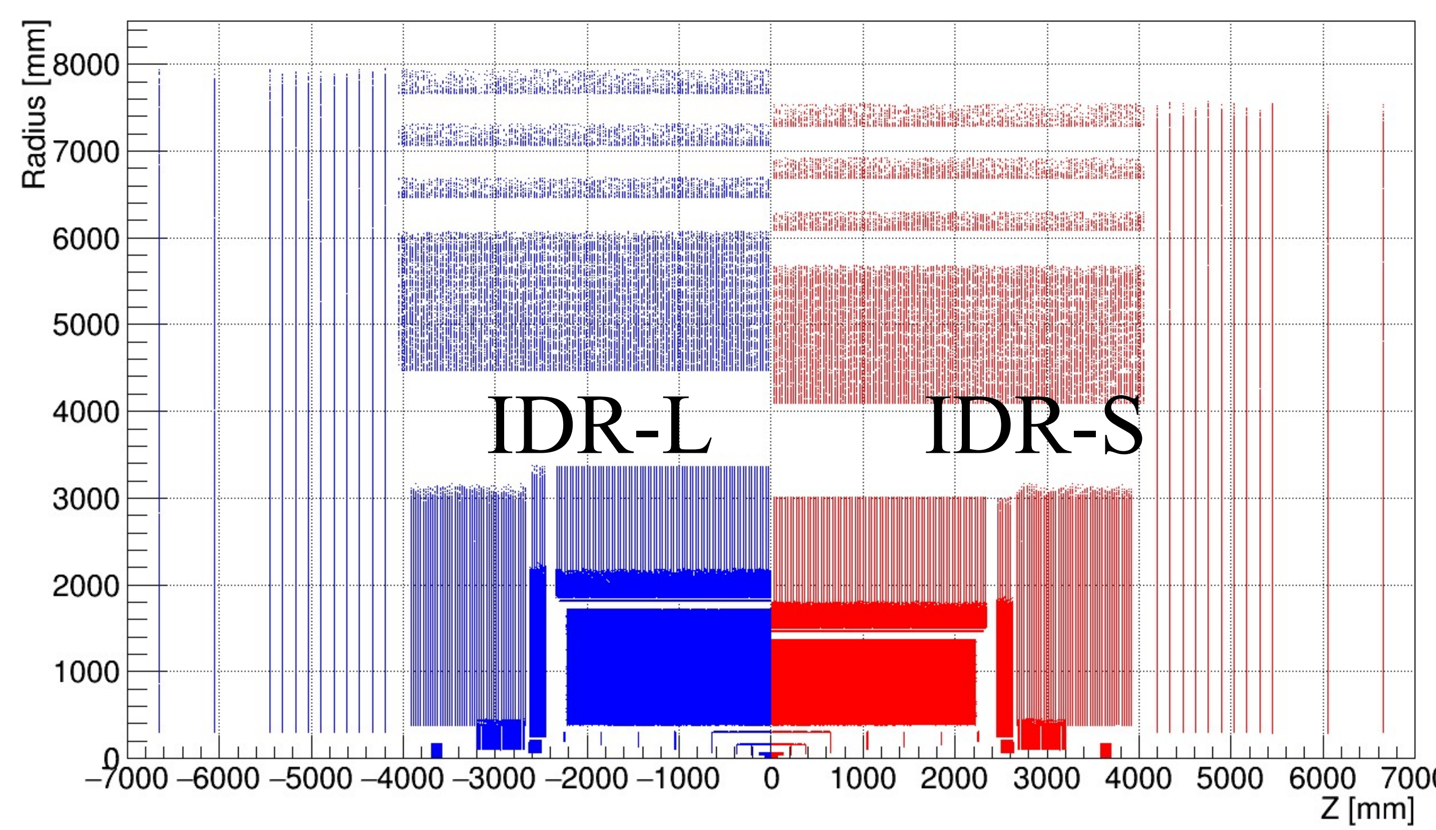
International Large Detector (ILD)



two models of the ILD detector

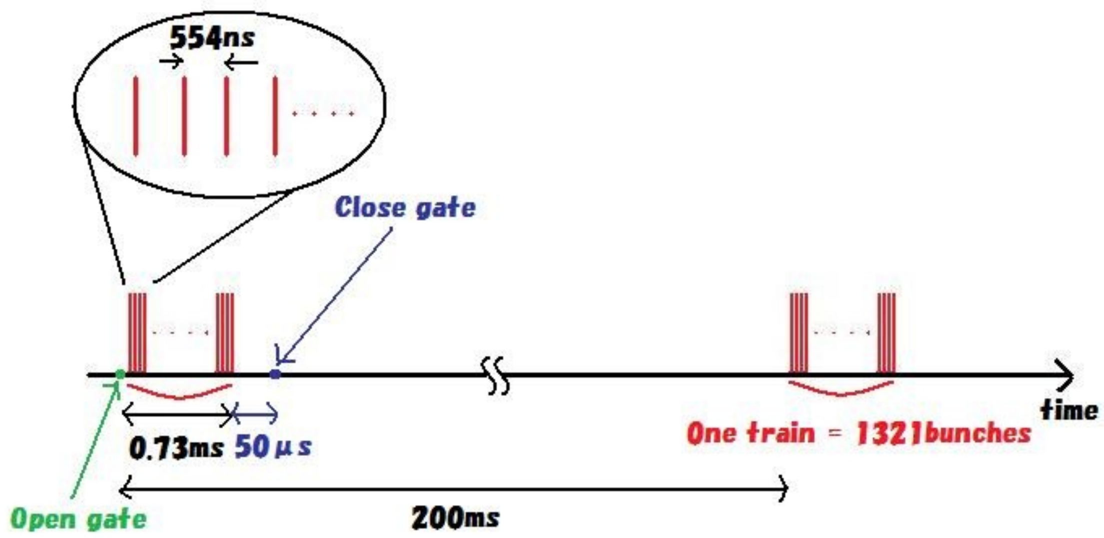
The difference	IDR-L	IDR-S
• the outer radius of TPC	1770 mm	1427 mm
• the strength of a magnetic field	3.5 T	4.0 T

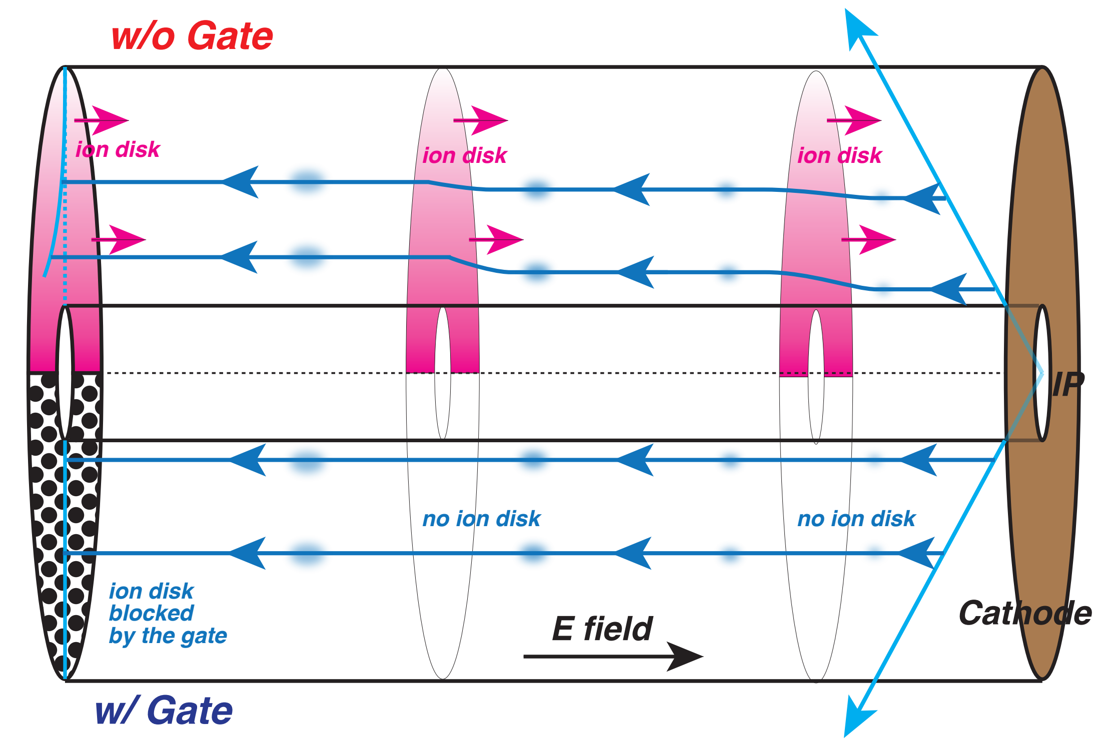




Effects of Positive Ions

ILC Beam Structure



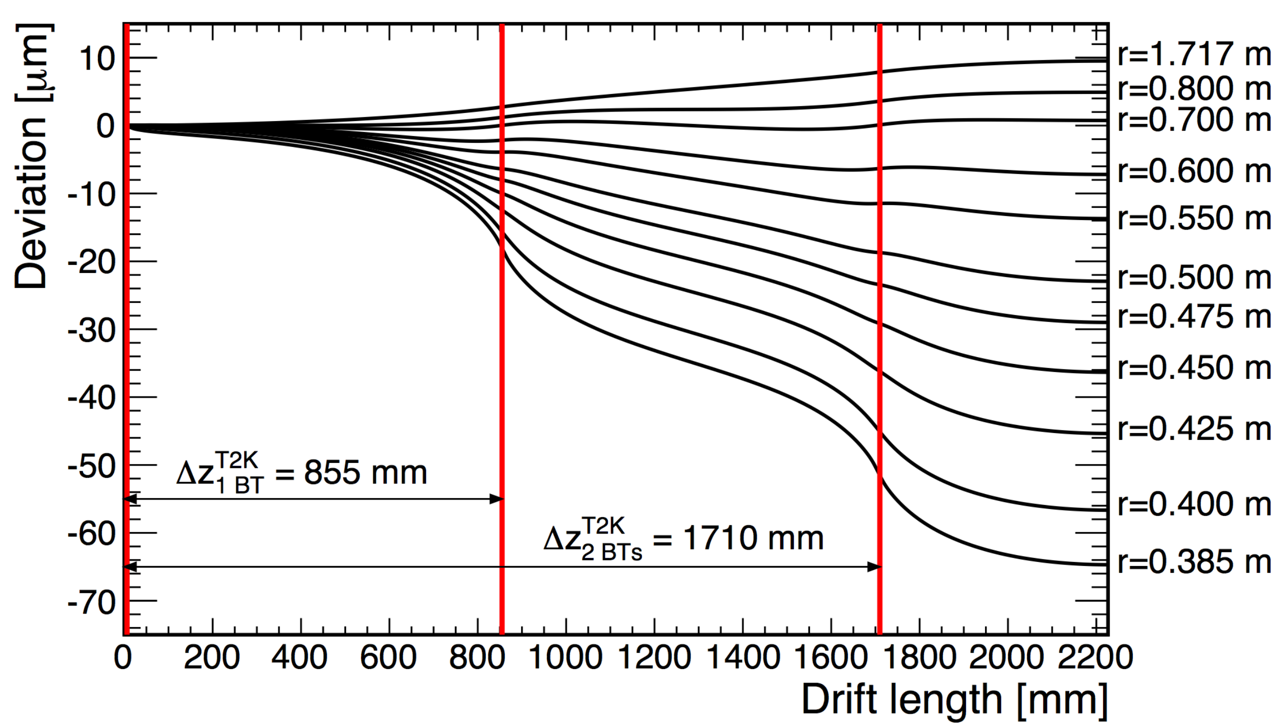


Positive Ion Disk

Positive ions created in the gas amplification region of readout MPGD modules drift slowly to the cathode.

Since they are slow, the positive ions created in a single bunch train form ***a thin (<1cm) sheet (ion disk)***.

There would be ***maximum three such ion disks*** drifting towards the cathode, which ***distort the drift paths of track electrons***, if there is no gating device.



σ of random walk

$$\sigma = \sqrt{2D^{*}t}$$

$D^{*}[\mu m/\sqrt{cm}]$: **Diffusion Coefficient**

σ of GEM

$D[\mu m/\sqrt{cm}]$: **Diffusion Constant**

$$\sigma^2 = D^2 L$$

参考

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