# The preliminary results of MPGD-based TPC performance at KEK beam test

Yukihiro Kato
Kinki University
(ILC-TPC Collaboration)

# Motivation

**Understand the basic performance of MPGD-based TPC**

Comparison of several readout scheme (gas amplifiers) using same Field Cage, Electronics, analysis procedure,

- MWPC: beam test in Jun. 2004
- GEM: beam test in Apr. 2005, Oct. 2005
- MicroMEGAS: beam test in Jun. 2005, Oct 2005

**Results are updated from ACFA05**

# ILC-TPC collaboration

- Asia

Japan (KEK, Saga, TUAT, Tsukuba, Kogakuin,

Kinki, Hiroshima)

Philippines (MSU-Iligan)

- Europe

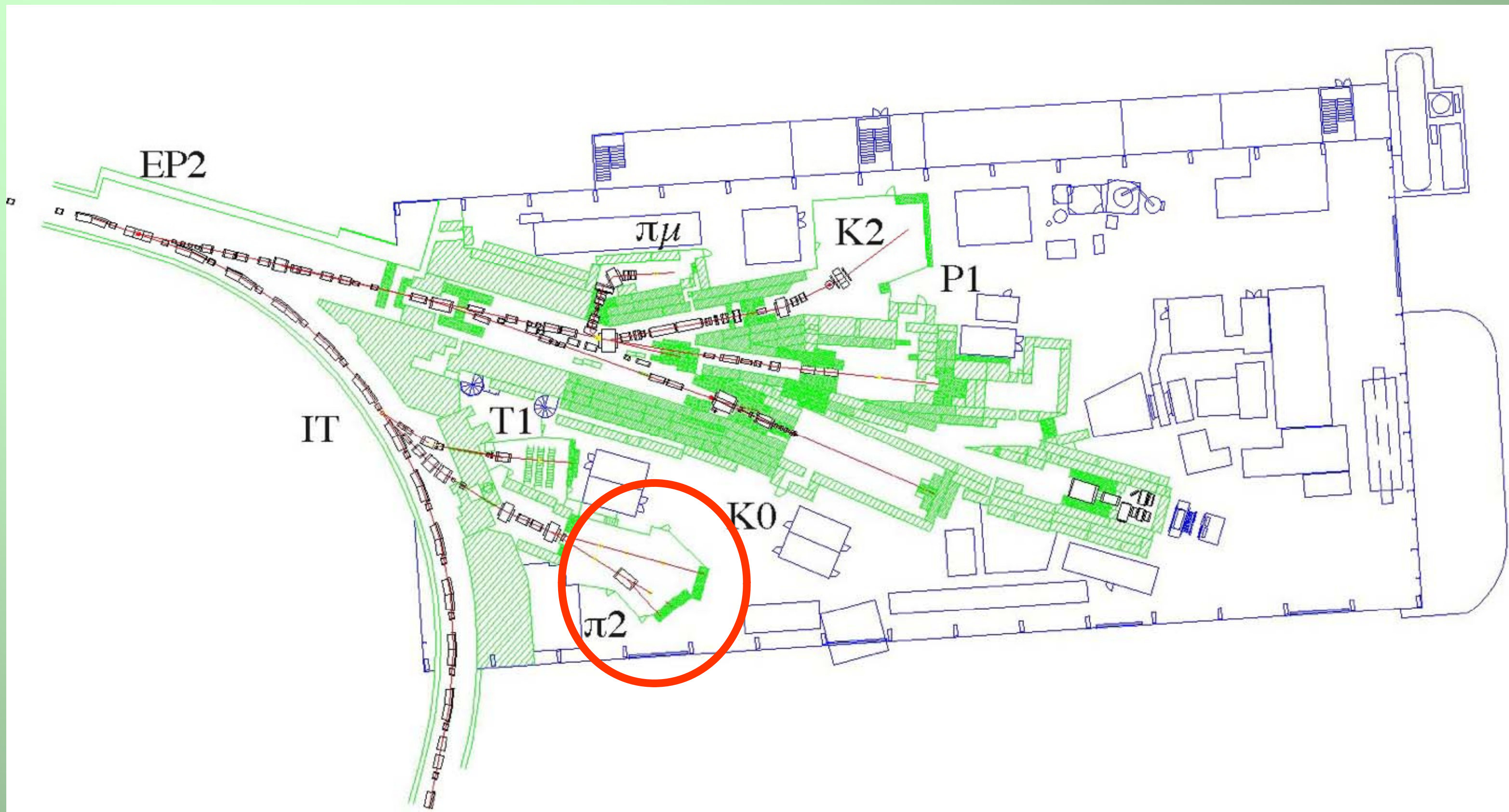
Germany (DESY, MPI)

France (CEA Saclay, LAL Orsay, IPN Orsay)

- North America

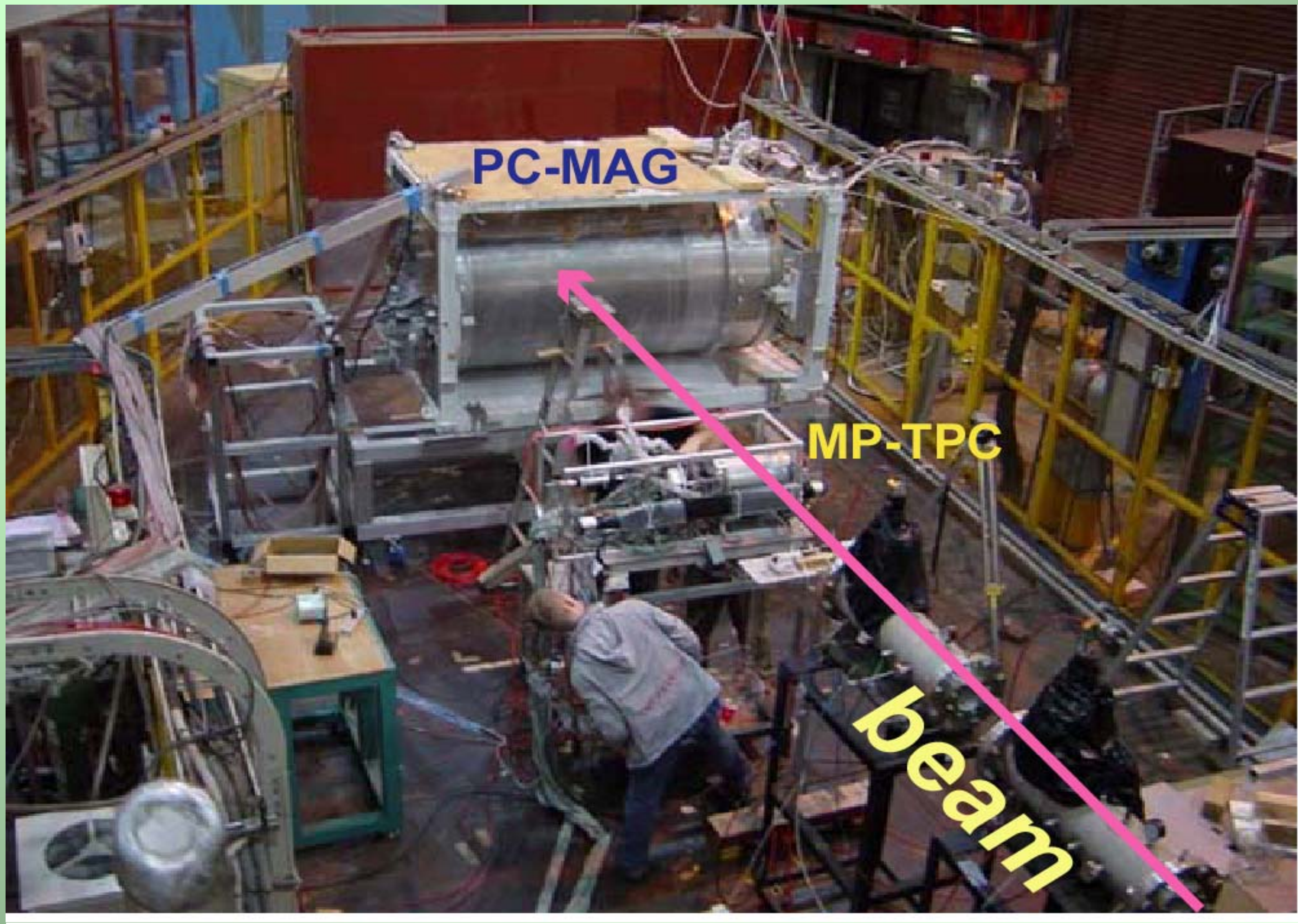
Canada (Carlton, Montreal)

# KEK PS beam line




**π2 beam line:** $\pi^{\pm}, e^{\pm}, p$ (P = 0.6 ~ 4 GeV/c)

# π2 beam line



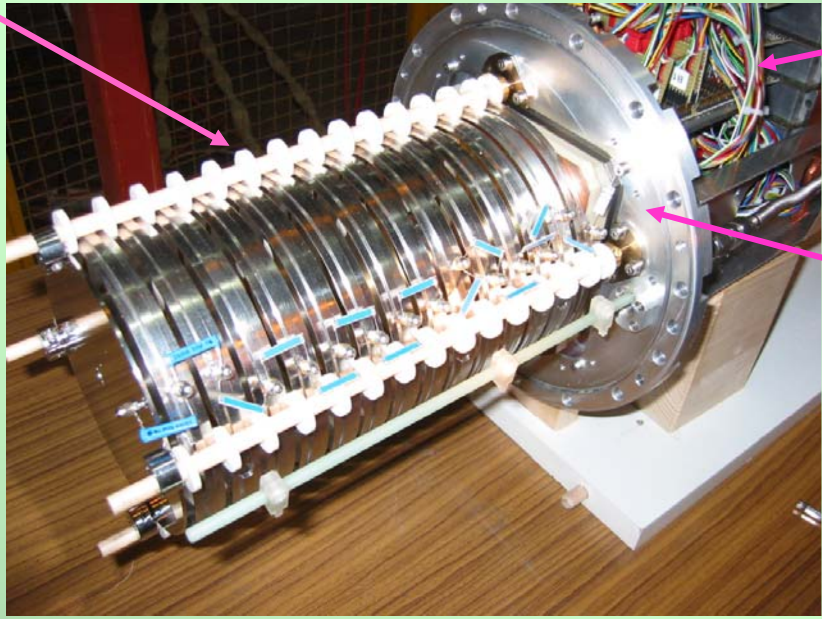
# PC-MAG

- known as JACEE magnet for BESS-II
- B field ： 1.0 ~ 1.2T@ center, No Return Yoke
  inner diameter: 850 mm, effective length: 1000 mm
- Transported to DESY for EUDET at Dec. 2006

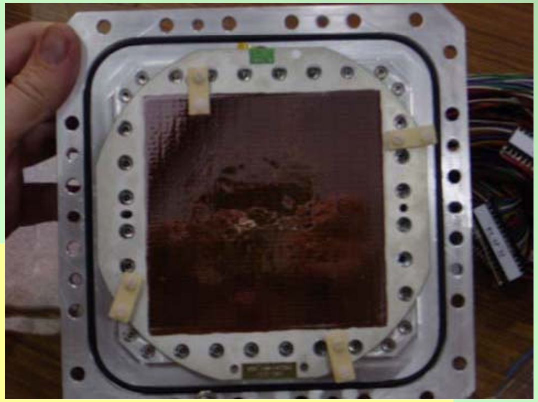
# MP-TPC

**Field Cage**

**Preamplifiers**



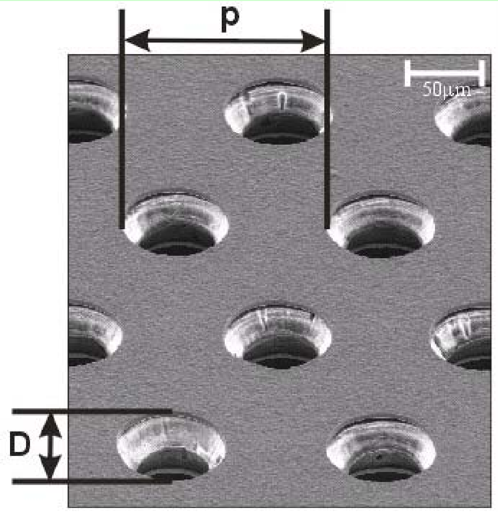
**Readout plane**



- ✓ **Pad plane: effective area 75×75 mm²**
- ✓ **Maximal drift length: 260 mm**
- ✓ **Detachable endplate**

**MWPC and MPGD (GEM, MicroMEGAS)**

# GEM (Gas Electron Multiplier)

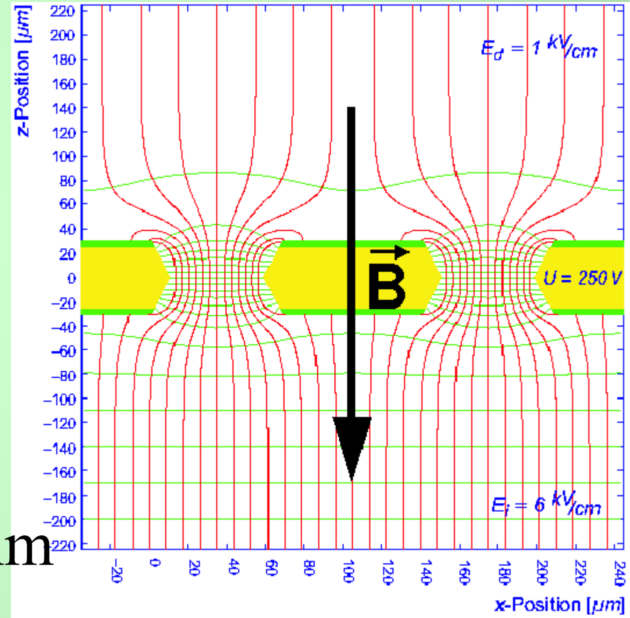



- Two copper foils separated by polyimide, uses 2 or more stages for safer operation.
- High electric field inside the holes, multiplication takes place in holes.

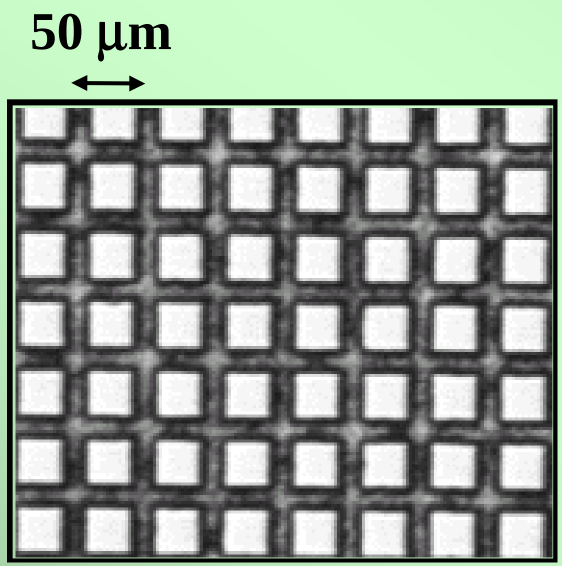
## CERN type GEM geometry

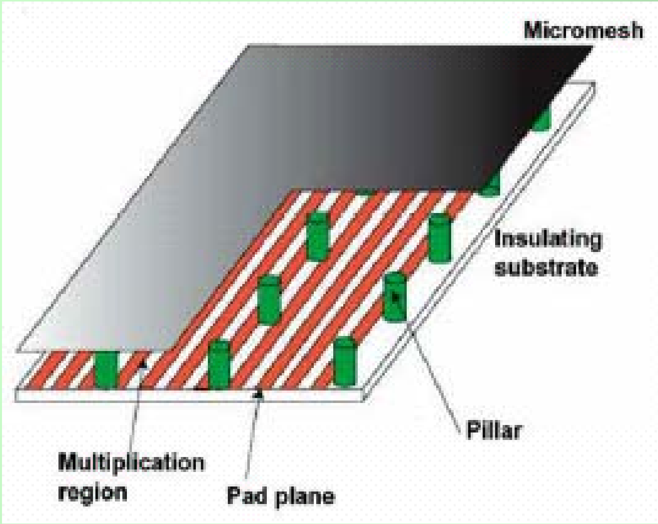
- Copper electrodes (5 μm thick)
- polyimide insulator (50 μm thick)
- Bi-conical holes due to chemical etching
- Hole size D ~ 60 μm, pitch p ~ 140 μm
- Using 3 stages

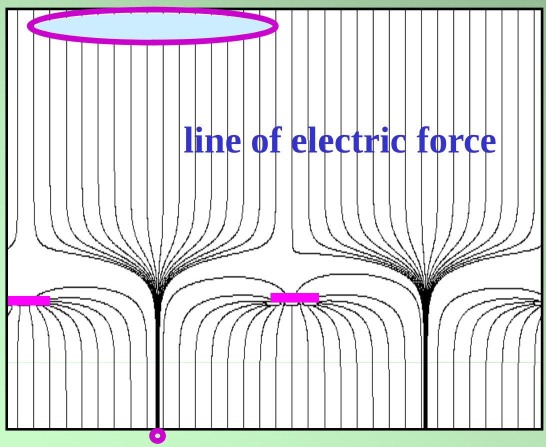
  induction gap: 1.0 mm, transfer gap: 1.5 mm

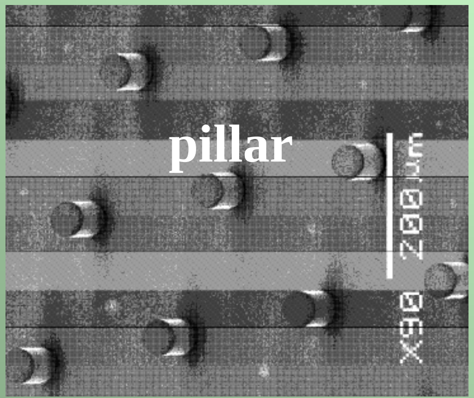


# MicroMEGAS




- Mesh size: 50 μm
- Micromesh sustained by 50 μm pillars, multiplication between anode and mesh, one stage
- Self-suppression of positive ion feedback

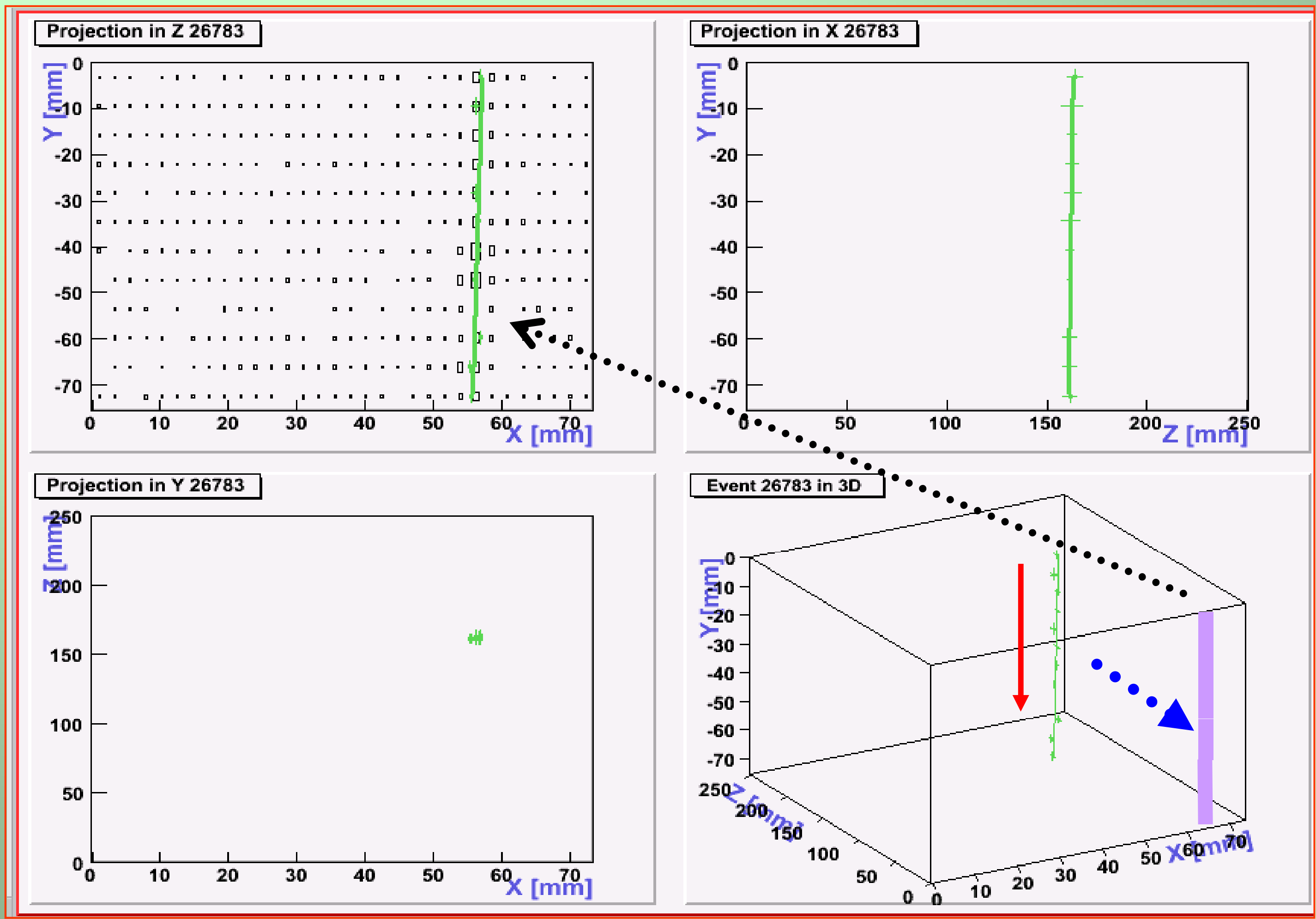
# Readout scheme and Gas

| Readout Device | Pad Size (pitch) | Gas | Drift field |
|---|---|---|---|
| **GEM**<br>(triple GEM) | 1.17 mm × 6 mm<br>(1.27 mm × 6.3 mm) | TDR:<br>(Ar:CH4:CO2 = 93:5:2)<br>P5: Ar-methane (5%) | 220 V/cm<br>100 V/cm |
| **MicroMEGAS** | 2 mm × 6 mm<br>(2.3 mm × 6.3 mm) | Ar-isobutane (5%) | 220 V/cm |
| **MWPC** | 2 mm × 6 mm<br>(2.3 mm × 6.3 mm) | TDR | 220 V/cm |

- DAQ electronics: ALEPH TPC electronics
  - Charge sensitive pre-amp+shaper amp (500ns)
  - 8-bit FADC with 12.5MHz sampling rate
- B field: 0, 0.5, 1.0 Tesla

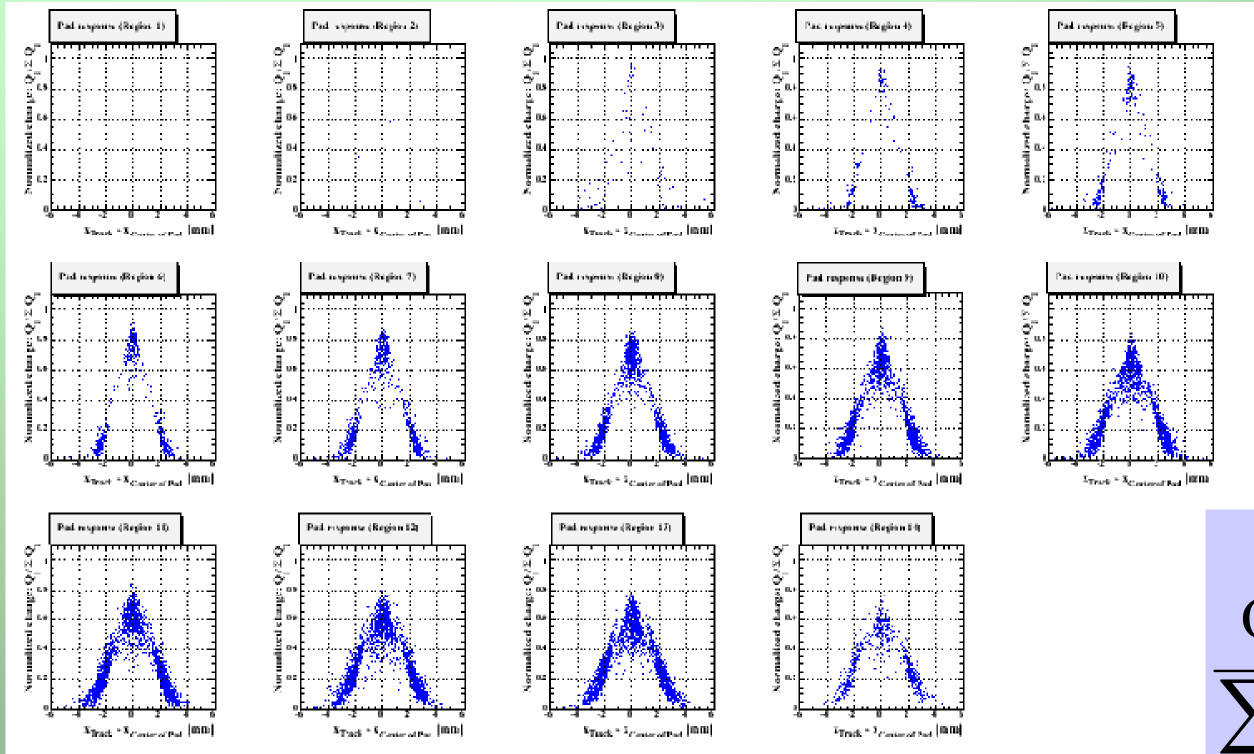
# Typical event

## (MicroMEGAS, B=0.5T)



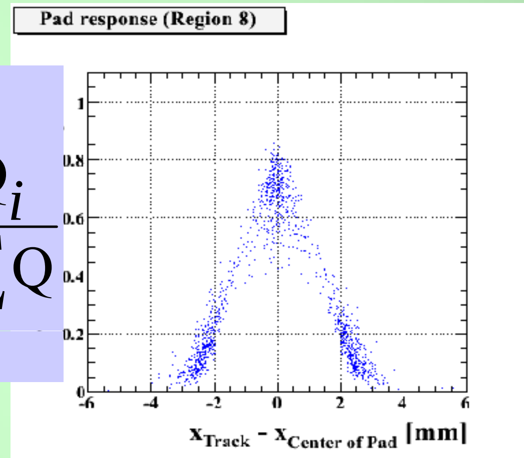
# Pad-response per region

z = 0 mm →



→ z = 260 mm

the avalanche charge spread for single electron




$$\frac{Q_i}{\sum Q}$$

$$x_{\text{track}} - x_{\text{pad}\,i}$$

**MicroMEGAS, Ar-isobutane (5%),**

**B=0.5 T, E = 220 V/cm**

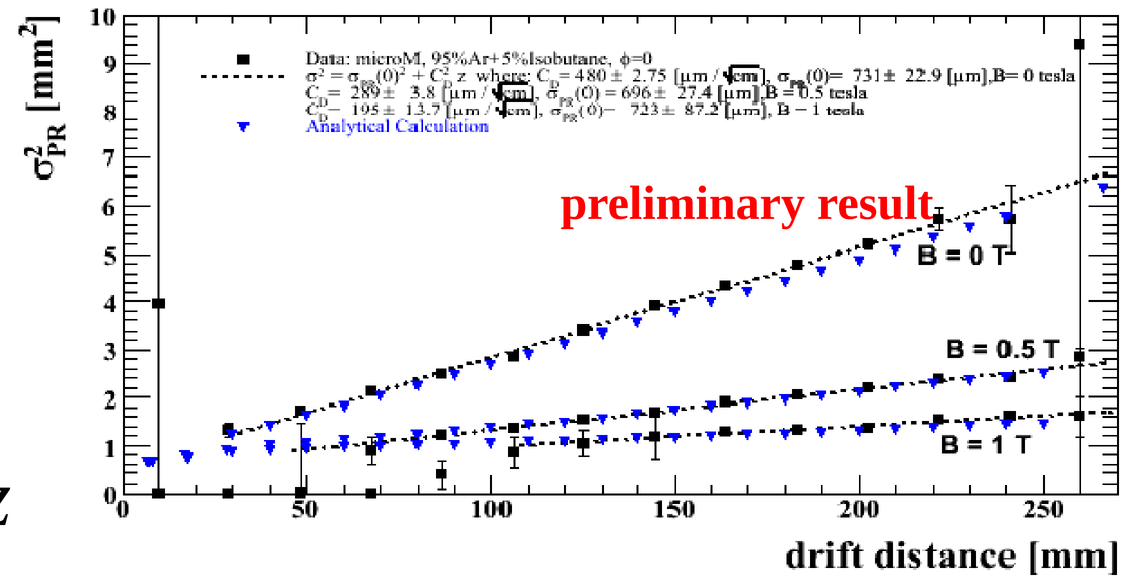
# Transverse diffusion properties

**MicroMEGAS**

$$\sigma_{\mathrm{PR}_0}^2 = \sigma_{\mathrm{PRF}}^2 + \frac{\omega^2}{12}$$

**diffusion in readout**

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

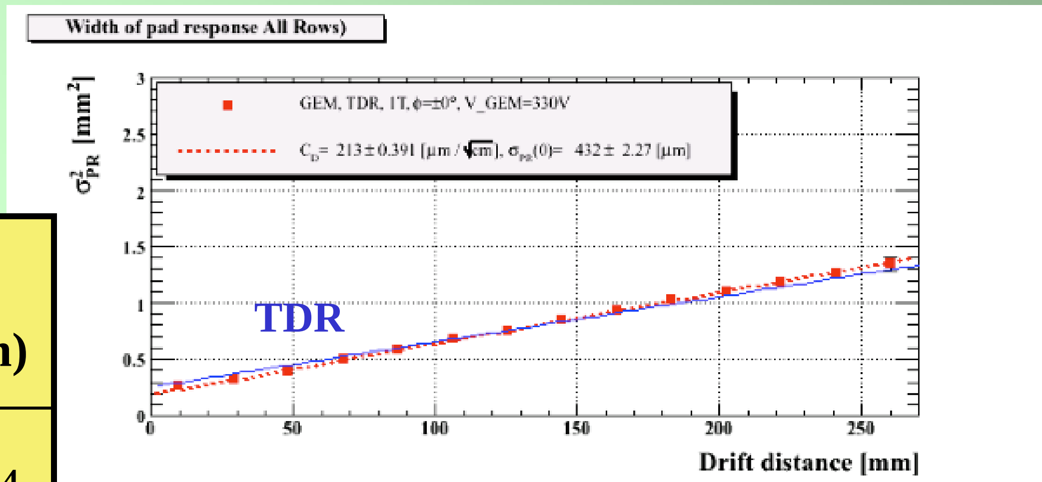



| B (Tesla) | Diffusion constant ($C_D$) ($\mu m/\sqrt{cm}$) | $C_D$ by Magboltz simulation ($\mu m/\sqrt{cm}$) | $\sigma_{\mathrm{PR}_0}$ ($\mu$m) |
|---|---|---|---|
| 0 | $480 \pm 3$ | 469 | $731 \pm 23$ |
| 0.5 | $289 \pm 4$ | 285 | $696 \pm 28$ |
| 1.0 | $195 \pm 14$ | 193 | $723 \pm 88$ |

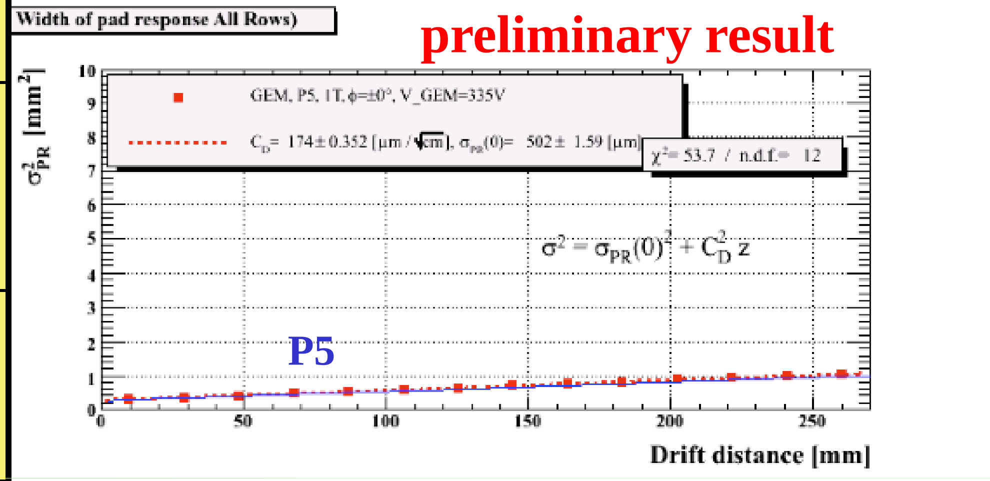
# Transverse diffusion properties

GEM B=1T

| Gas | TDR (E=220V/m) | P5 (E=100V/m) |
|---|---|---|
| $C_D$ $(\mu m/\sqrt{cm})$ | $213.0 \pm 0.4$ | $174.0 \pm 0.4$ |
| $C_D$ [Magbolz] $(\mu m/\sqrt{cm})$ | 200 | 166 |
| $\sigma_{PR_0}$ $(\mu m)$ | $432 \pm 3$ | $502 \pm 2$ |




preliminary result



# Spatial resolution vs. drift distance

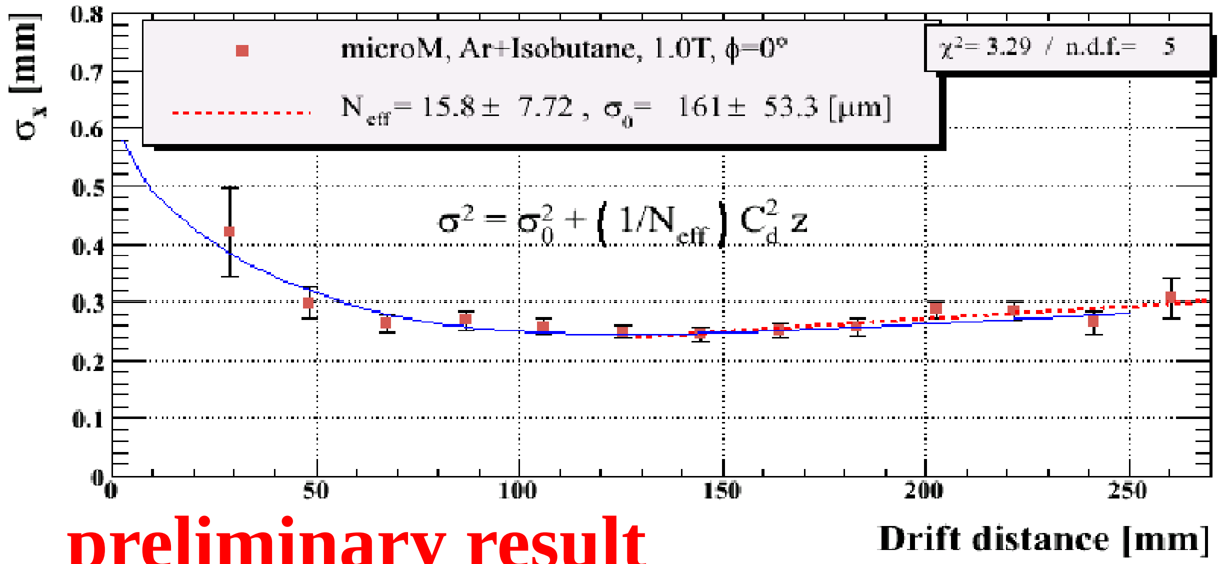
$$\sigma_x^2 = \sigma_0^2 + \frac{C_D^2 \cdot z}{N_{\mathrm{eff}}}$$

other effects  diffusion

- $\sigma_0$ : resolution without diffusion
- $C_{\mathrm{D}}$ : diffusion constant from data
- $N_{\mathrm{eff}}$ : effective number of electrons

# Spatial resolution

**MicroMEGAS**

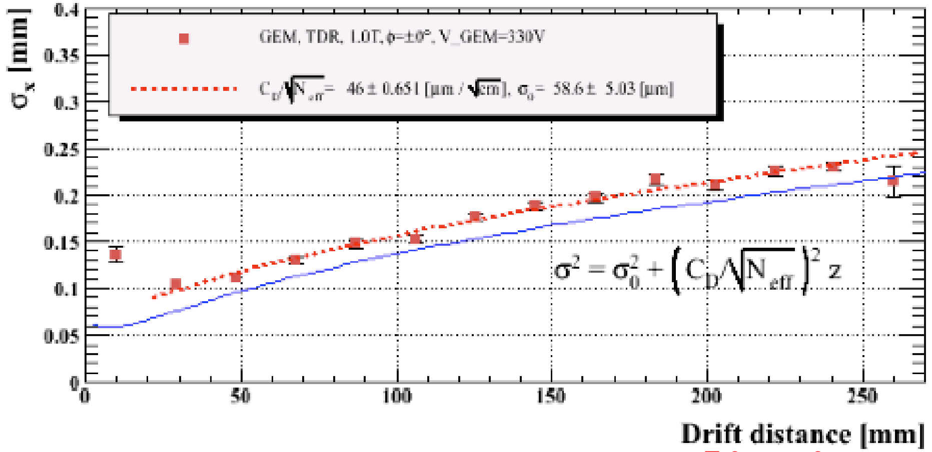



**preliminary result**

| B | 0 T | 0.5 T | 1.0 T |
|---|---|---|---|
| $N_{eff}$ | 15.1±1.2 | 18.7±2.6 | 15.8±7.7 |

# Spatial resolution

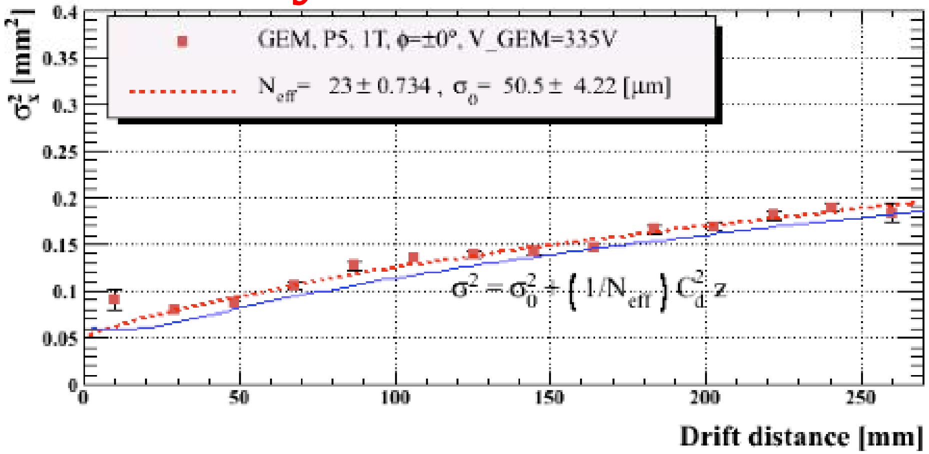
**GEM**




TDR

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

**preliminary result**

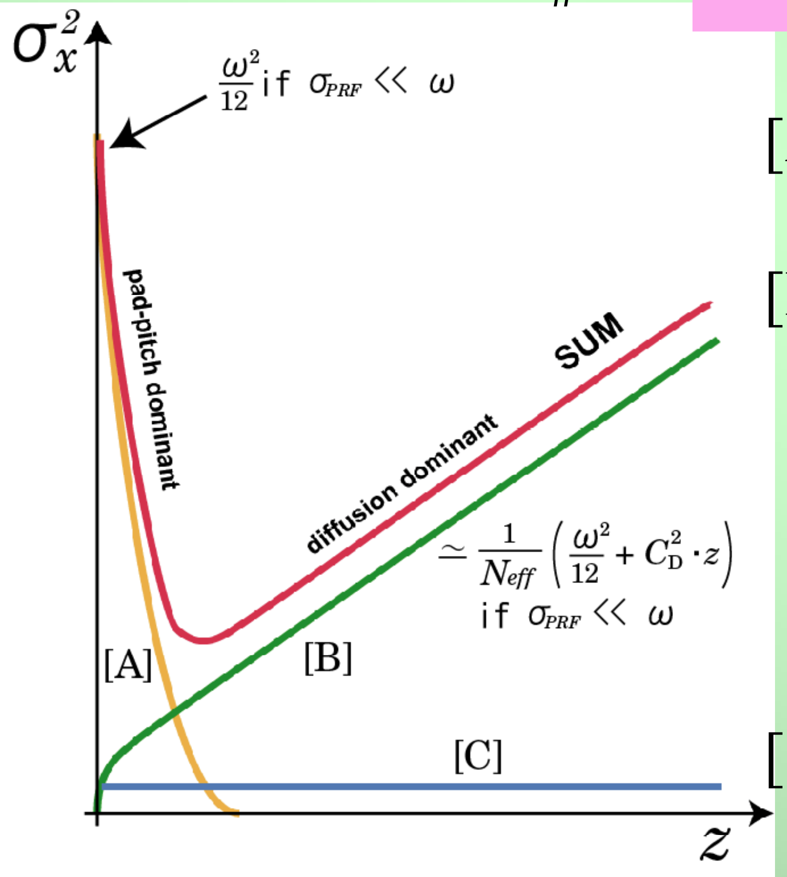



P5

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

# Analytic formula for spatial resolution

$$\sigma_x^2 = \sigma_0^2 + \frac{C_d^2 \cdot z}{N_{eff}} = \int_{-1/2}^{+1/2} d\left(\frac{x}{\omega}\right)\left[[A] + \frac{1}{N_{eff}}[B]\right] + [C]$$



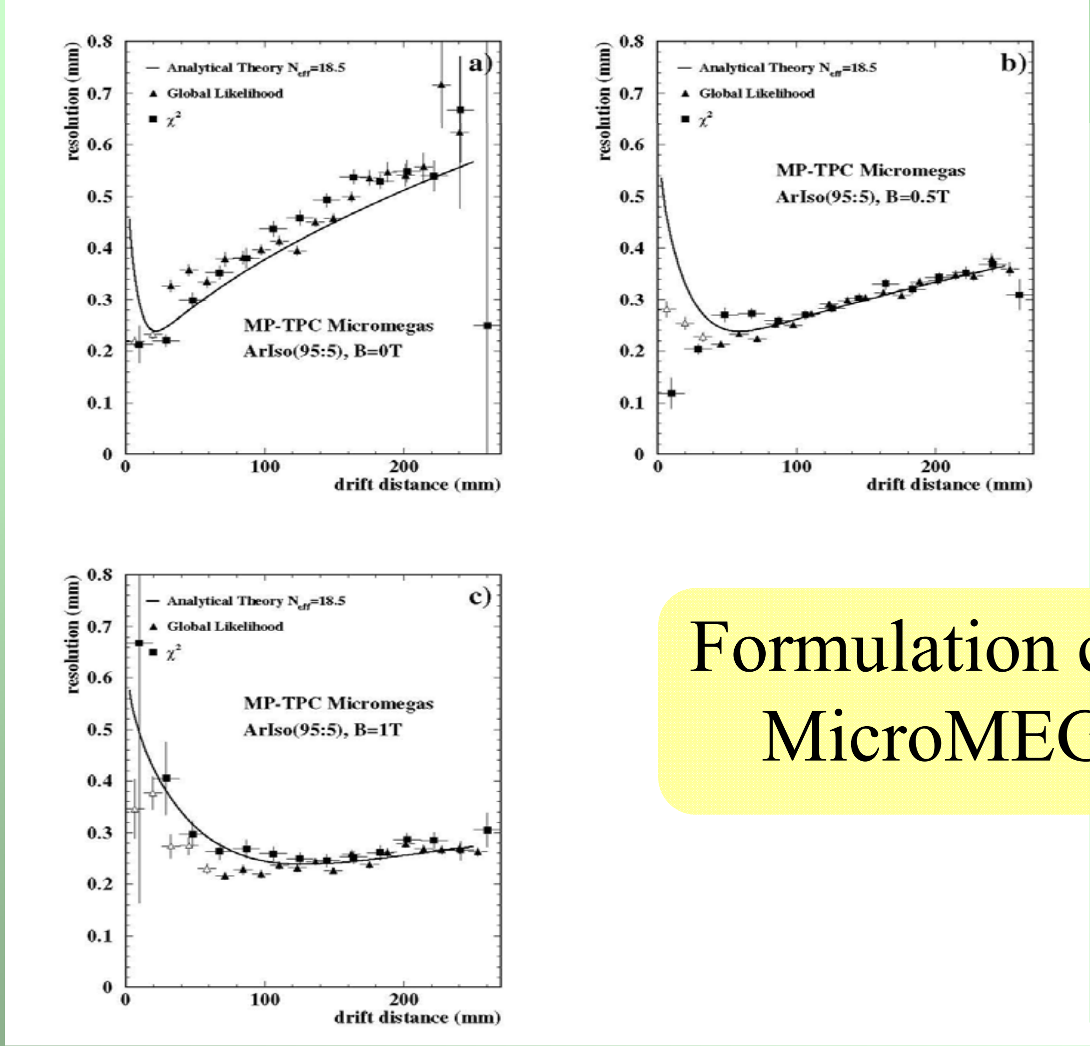

[A] Finite pad pitch: rapidly disappears as z increases. $N_{eff}$ independent.

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

$$\sigma_x^2 \approx \frac{1}{N_{eff}}\left(\frac{\omega^2}{12} + C_d^2 \cdot z\right)$$

[C] Electronic noise: z independent

# Comparison with measurements




Formulation can explain the MicroMEGAS data.

# diffusion and resolution

| | MicroMEGAS | GEM | | MWPC |
|---|---|---|---|---|
| Gas | Ar-isobutane (5%) | TDR | P5 | TDR |
| $\sigma_{PR_0}$ (μm) | 723±88 | 432±2 | 502±2 | 1270±4 |
| $C_D$ $(\mu m/\sqrt{cm})$ | 195±14 | 213.0±0.4 | 174.0±0.4 | 211±1 |
| $C_D$ [Magboltz] | 193 | 200 | 166 | 200 |
| $N_{eff}$ | 16±8 | 21 | 23 | 20 |

B = 1T data

**preliminary results**

$$\sigma_{PR_0}^2 = \sigma_{PRF}^2 + \frac{\omega^2}{12} \quad \sigma_x^2 = \sigma_0^2 + \frac{C_D \cdot z}{N_{eff}}$$

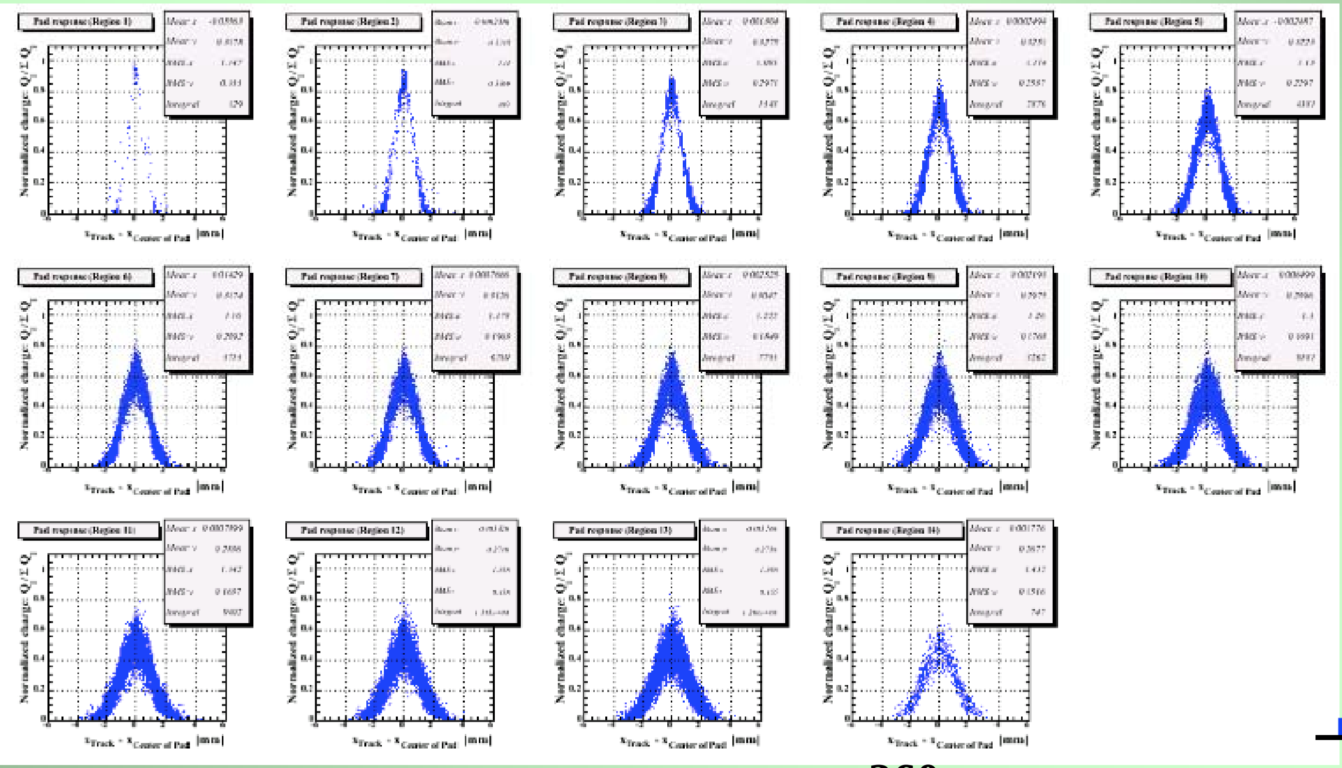
# Summary

- The values of diffusion constant ($C_D$) are consistent with Magboltz simulation.
- In the case of MicroMEGAS, $\sigma_0$ has a large. The avalanche size is much smaller than the pad pitch and $\sigma_0$ is determined by $\omega^2/12$. Need to spread the avalanche size by resistive foil, etc.
- Spatial resolution can be described with the simple analytic formula.

# Backup slide

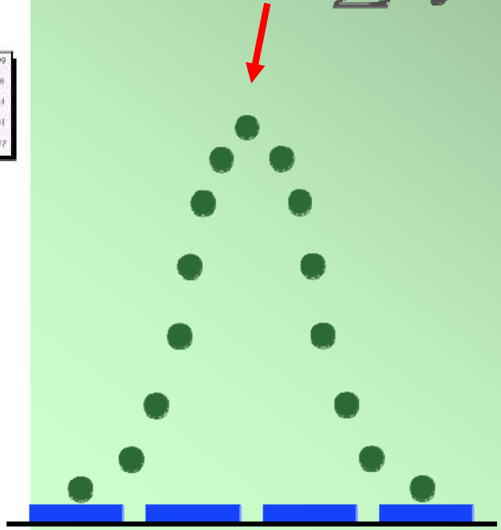
# Pad-response per region

z = 0 mm →



→ z = 260 mm

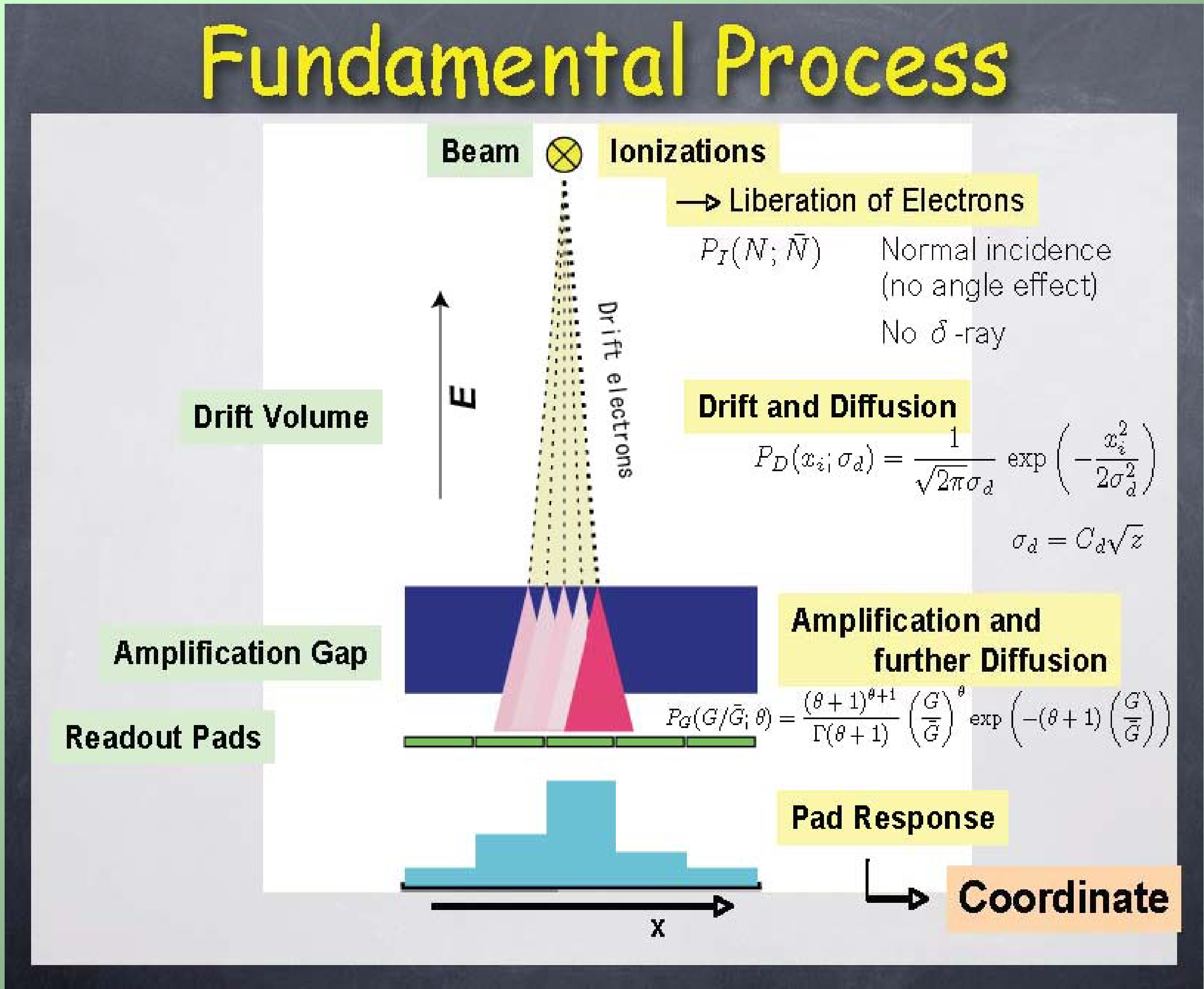
$$NQ_i = \frac{Q_i}{\sum Q}$$



$x_{\mathrm{pad}_i} - x_{\mathrm{track}}$

**GEM, TDR, B = 1T, E = 100V/cm**

K.Fujii


Fundamental Process
Beam
Ionizations
→ Liberation of Electrons
$P_I(N;\bar{N})$
Normal incidence
(no angle effect)
No $\delta$-ray
E
Drift electrons
Drift Volume
Drift and Diffusion
$P_D(x_i;\sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d} \exp\left(-\frac{x_i^2}{2\sigma_d^2}\right)$
$\sigma_d = C_d\sqrt{z}$
Amplification Gap
Amplification and
further Diffusion
Readout Pads
$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)} \left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$
Pad Response
Coordinate
X

# Full Analytic Formula

K.Fujii

$$\sigma_{\bar{x}}^2 \equiv \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \int d\bar{x}\, P(\bar{x};\tilde{x})\,(\bar{x}-\tilde{x})^2 = \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left[[A] + \frac{1}{N_{eff}}[B]\right] + [C]$$

- Purely geometric term

$$[A] = \left(\sum_j (jw)\,\langle f_j(\tilde{x}+\Delta x)\rangle - \tilde{x}\right)^2$$

- Diffusion, gas gain fluctuation & finite pad pitch term

$$[B] = \sum_{j,k} jkw^2\,\langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle - \left(\sum_j jw\,\langle f_j(\tilde{x}+\Delta x)\rangle\right)^2$$

$$\langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x\, P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)\, f_k(\tilde{x}+\Delta x)$$

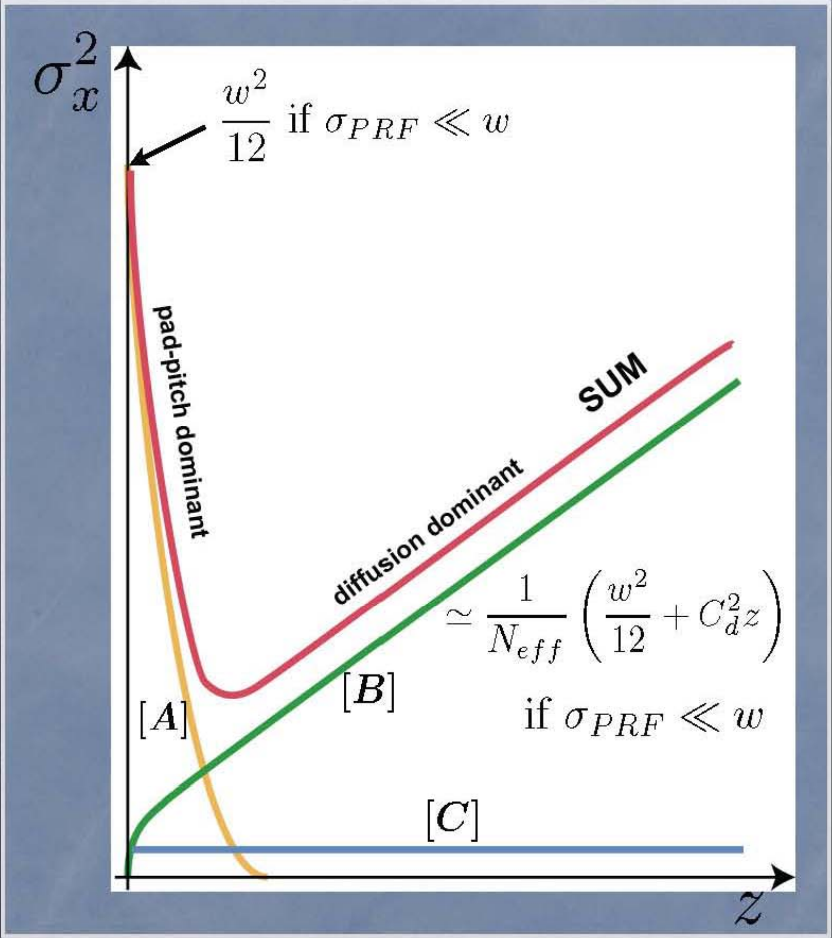
$$\langle f_j(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x\, P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)$$

- Electronic noise term

$$[C] = \left(\frac{\sigma_E}{\bar{G}}\right)^2 \left\langle \frac{1}{N^2} \right\rangle \sum_j (jw)^2$$

K.Fujii

# 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 $\langle 1/N^2 \rangle$