Thin Target Gas tracker

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I am a hardware person!

This is a list of detectors/ equipment's to which I made significant contribution. Many are collaborative work, but only those where my contribution is significant are listed.

scintillating fiber D, emulsion, Cherenkov D,

mechanical design/construction of SciBar/MUMON,

conceptual design of J-PARC ν facility, primary beamline optics,

design/construction of target-horn system,

concept of INGRID,

CdTe, electron-multiplier for MUMON,

HPXeTPC w/ structure, MPPC, electronics etc., ….

Contents

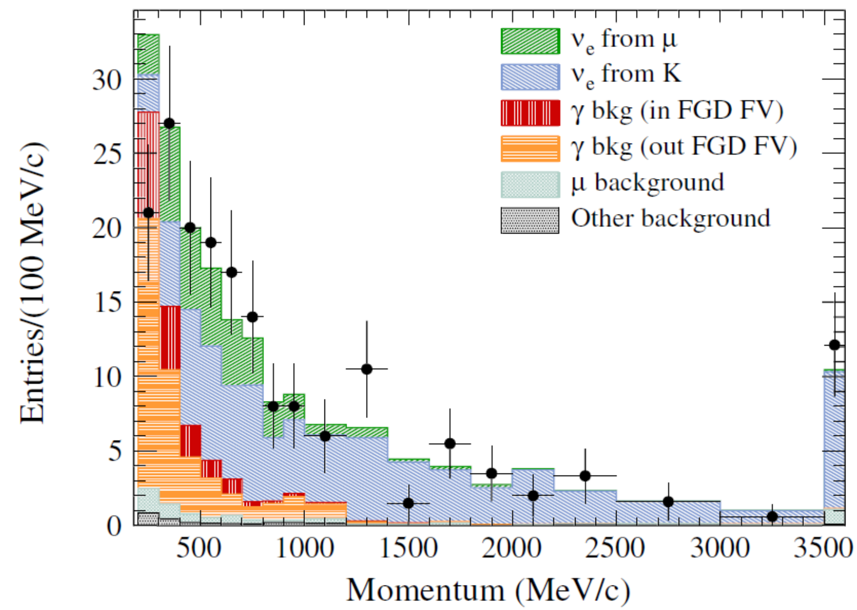
- reminder of issues with the current near detector
- New target tracker idea
- toy simulation study
- cost
- summary

Issues with current near detector

ND280 has shown excellent performance, but we want more.

- higher efficiency for high angle → side TPC
- higher efficiency for low momentum, especially for protons and pions → empty Wagaschi may improve, but PID may be difficult(I could be wrong).

- low energy γ background rejection for nue measurement
  - one calculation says radiation correction is as much as 10%, but not taken into account in T2K, now.

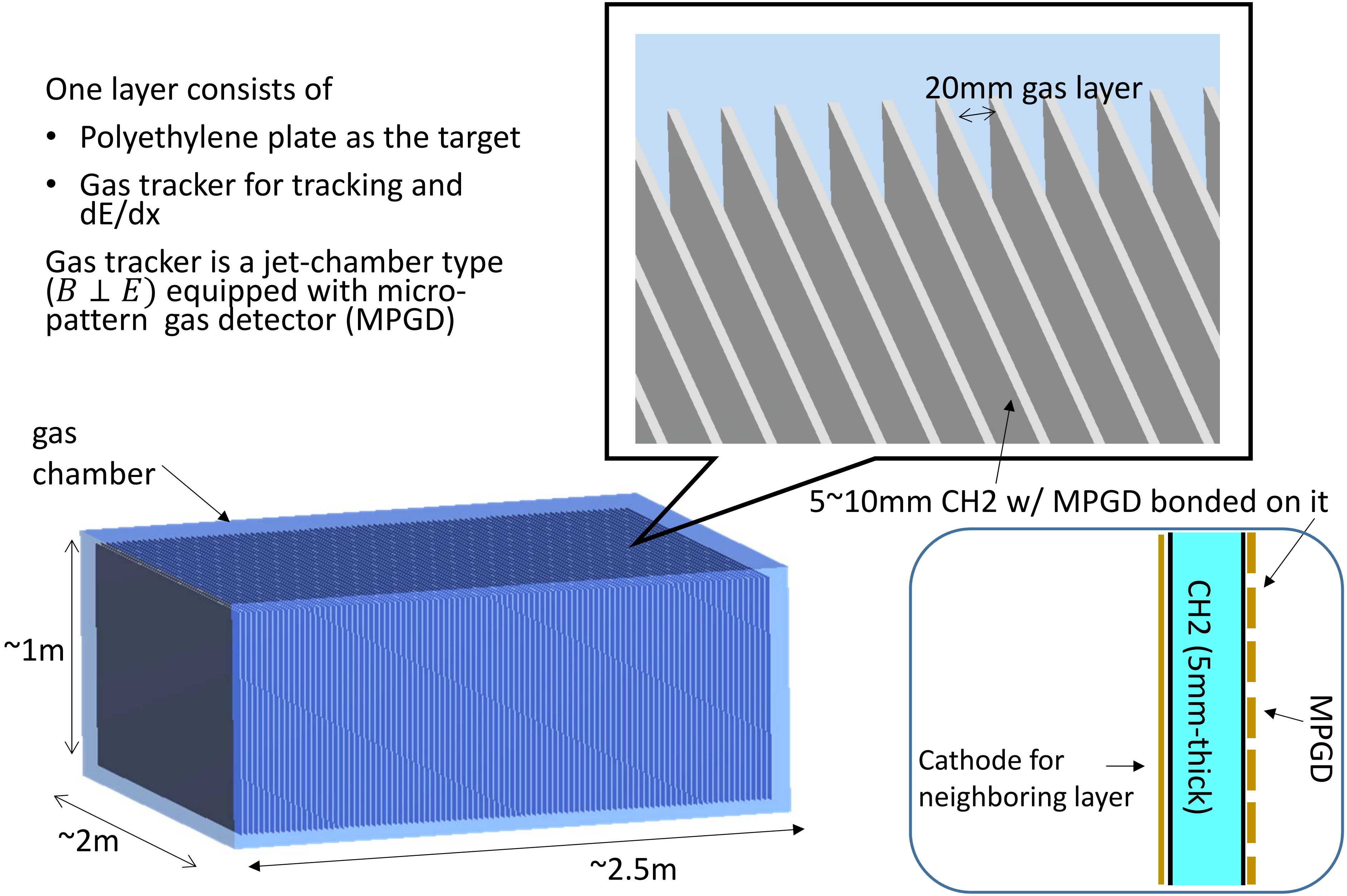


Thin target+gas-tracker concept

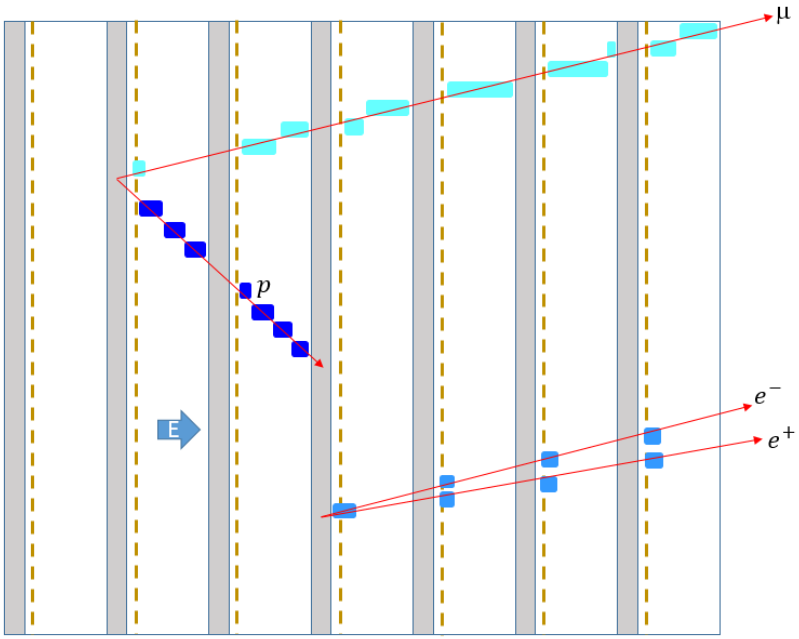
One layer consists of

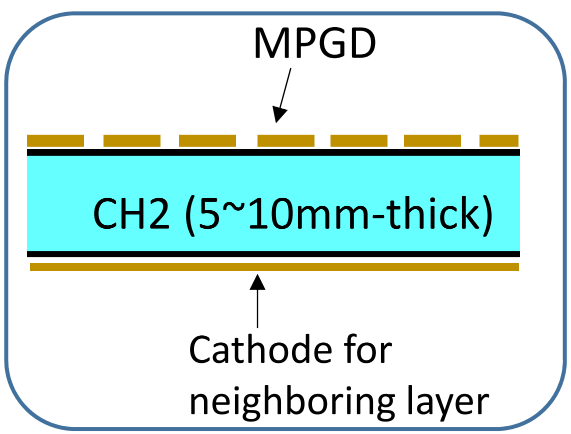
- Polyethylene plate as the target
- Gas tracker for tracking and dE/dx

Gas tracker is a jet-chamber type ($B \perp E$) equipped with micro-pattern gas detector (MPGD)



More explanation on gas-tracker part





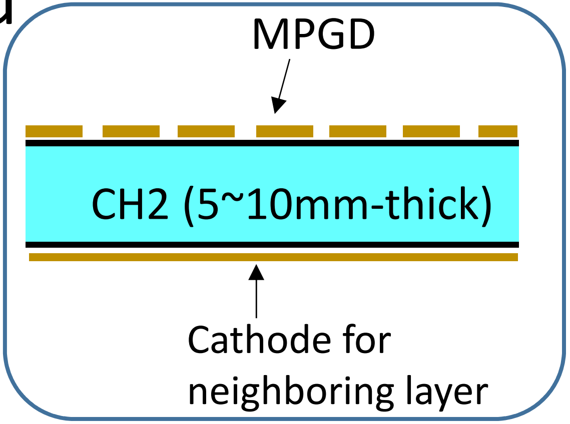
- Gas tracker signal will be readout by MPGD.
  - CH2 target is the structural base
- Waveform sampling enables tracking even with one layer.
  - Typical drift time for 20mm is $1\mu s$
  - No worry for pileup(*)
  - Number of electron-ion pair is ~200/cm for m.i.p. (or more with Penning effect)
  - Diffusion is negligible and deflection by B-field is small(~1mm) (*)
- Pad readout is not feasible because of huge number of channels.→ ~3mm pitch strip readout.

* explanations in backup

More on target part

- rigid part (= target and base of MPGD)
  - Polyethylene (out gas is comparable to PTFE)
  - If we also have PTFE($(C_2F_4)_{n}$) layers, can measure A-scaling of nuclear effects?? Graphite???
- MPGD part, very thin (~100μm)
  - Polyimide=$(C_{37}H_{24}O_6N_2)_n$
  - Electrode is Cupper, as thin as 5μm
- Ochi-san kindly suggested a few method

  to build Micromegas on CH2.



(potential) advantage

- tracking and PID by TPC starting just after the interaction point.

↓

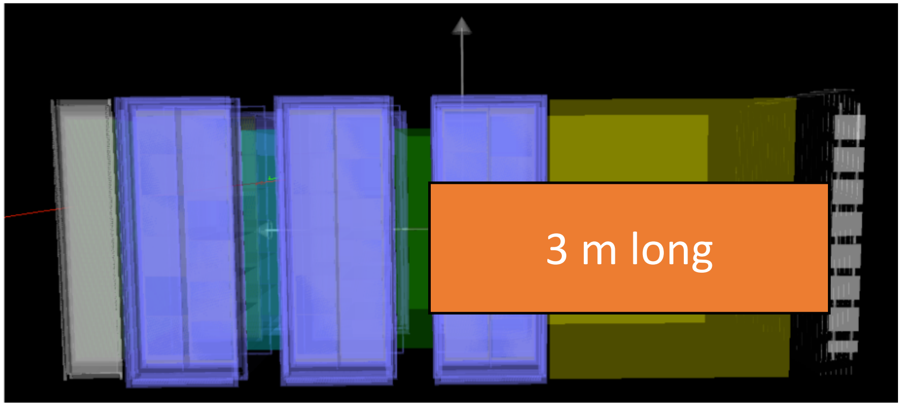
- wide angular acceptance
- very low threshold even for proton
  - $0.5 g/cm^2$ range = 23 MeV(=209MeV/c)
  - $1.0 g/cm^2$ range = 35 MeV(=259MeV/c)
  - only one layer if 2D strip readout is realized, two layers in case alternate x and y layers. (cf. FGD requires 6 layersx10mm.)
- nue interaction can be separated from gamma conversion.
- direction of muon can be identified by Bragg curve? (dEdX~ MIPx2)
- segmentation can be finer than < 1mm if necessary and if there's money

- support from side is possible → Top/bottom wall can be thin
- Low cost

Dimension and number of channels

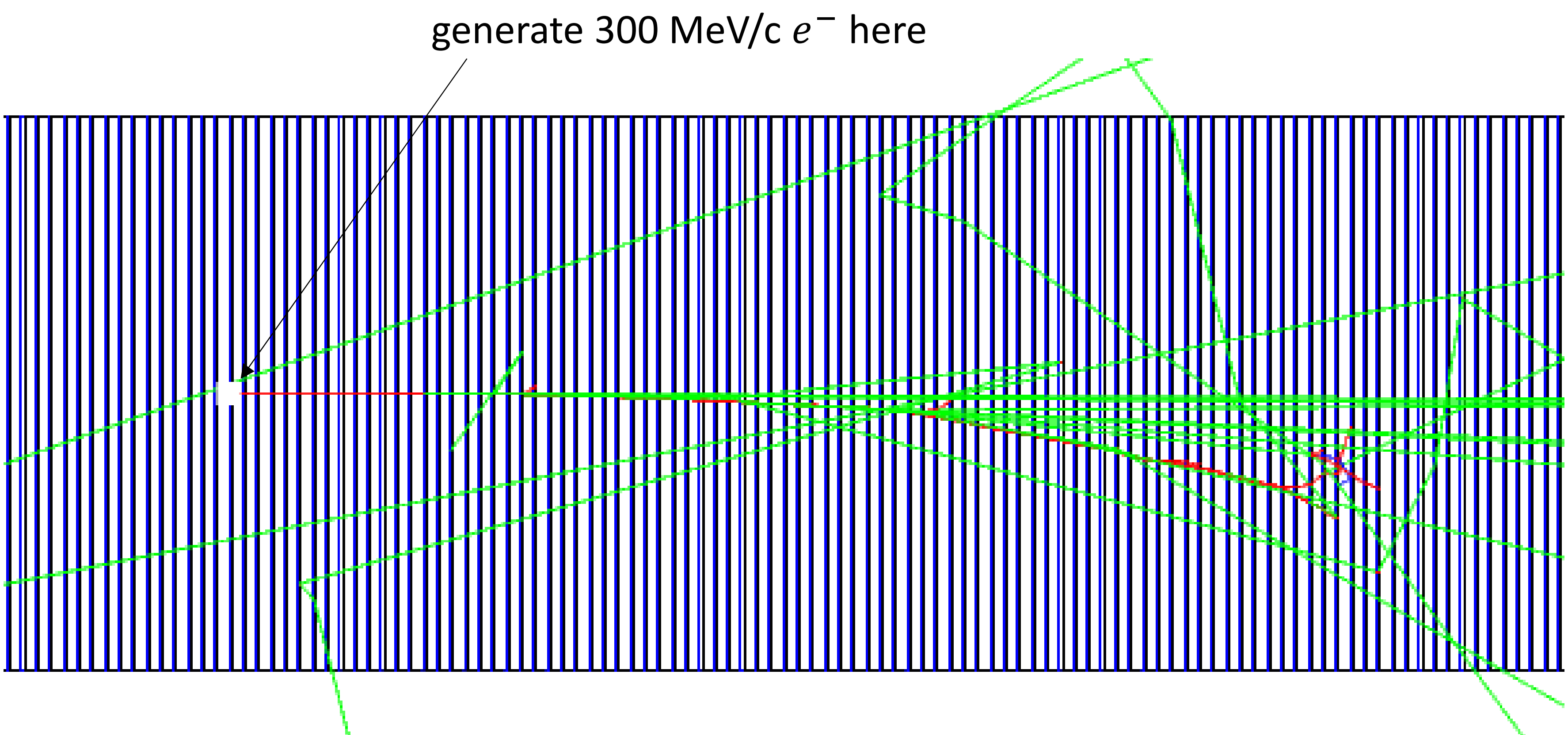
- All numbers are preliminary, subject to optimization
- Possible dimensions (all 1.2~1.3 ton)
  - Case 1 : 2m (H) x 1m (V) x 3 m (D), 120 layers of 5mm thick target
  - Case 2 : 2m (H) x 1m (V) x 2.5 m (D), 40 layers of 5mm thick target and 50 layers of 10 mm thick target
  - Case 3 : 2 m (H) x 1 m (V) x 2.4 m(D), 120 layers of 5mm thick target and 15mm thick gas layer

  * 1.7E4 $\nu_e CC$ interaction/ton/10×10^{21} POT
- 3mm pitch, 1m long strip, alternate x-layer, y-layer
  - assuming that horizontal strip is divided into two 1m long strip
  - 60k channels for Case 1 and Case 3
  - 45k channels for Case 2
  - cf. 124k for T2K TPC



*Polyethylene density $\rho = 0.91{\sim}0.965$ g/cm^3
Here, assume$\rho = 0.94$ g/cm^3

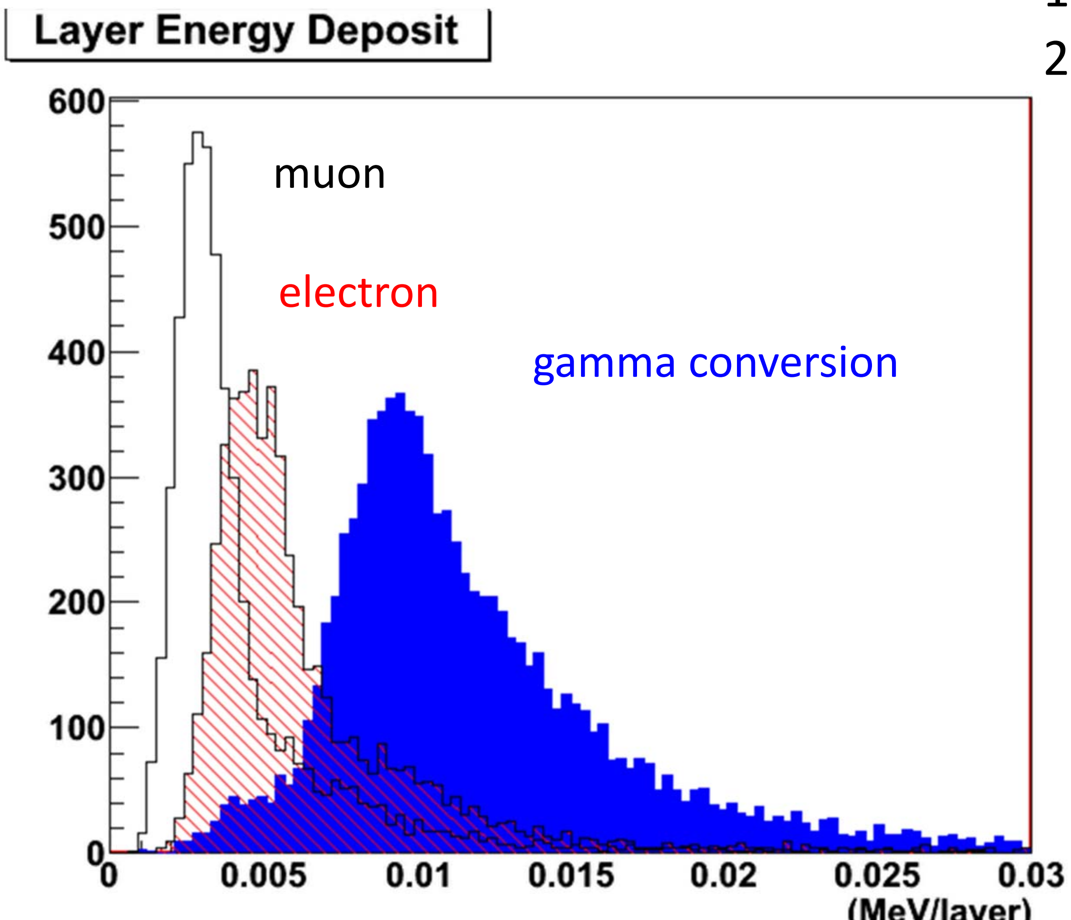
simple Geant4 simulation study for PID demonstration (by true information, yet)



Layer-by-Layer energy deposit

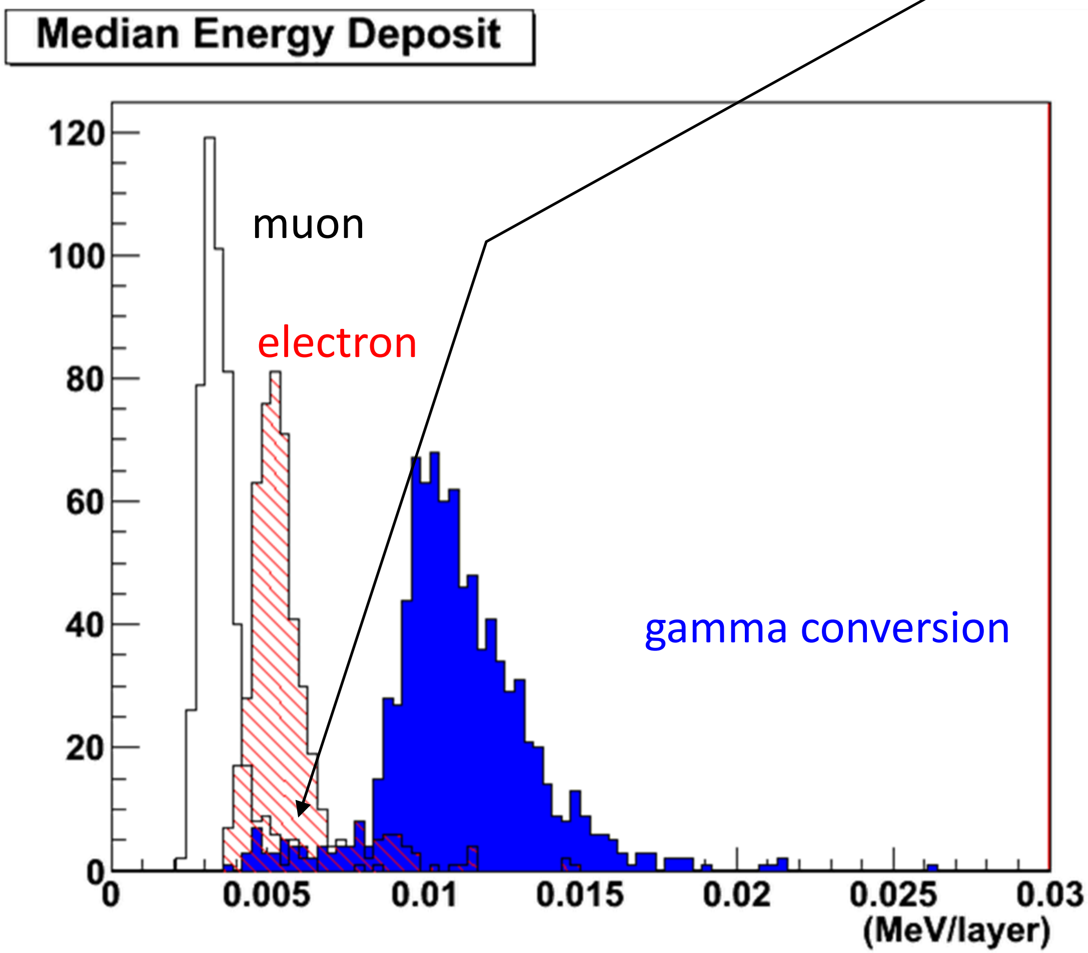
5mm(CH2)+20mm(gas)
$\vec{p} = (0,0,300\ \mathrm{MeV}/c)$
For γ,
1. generate 0.3 GeV/c < p_γ<0.6 GeV/c
2. fill only when p_e~0.3 GeV/c

Using 1st to 11th layer



Median energy deposit for 1st to 11th layer

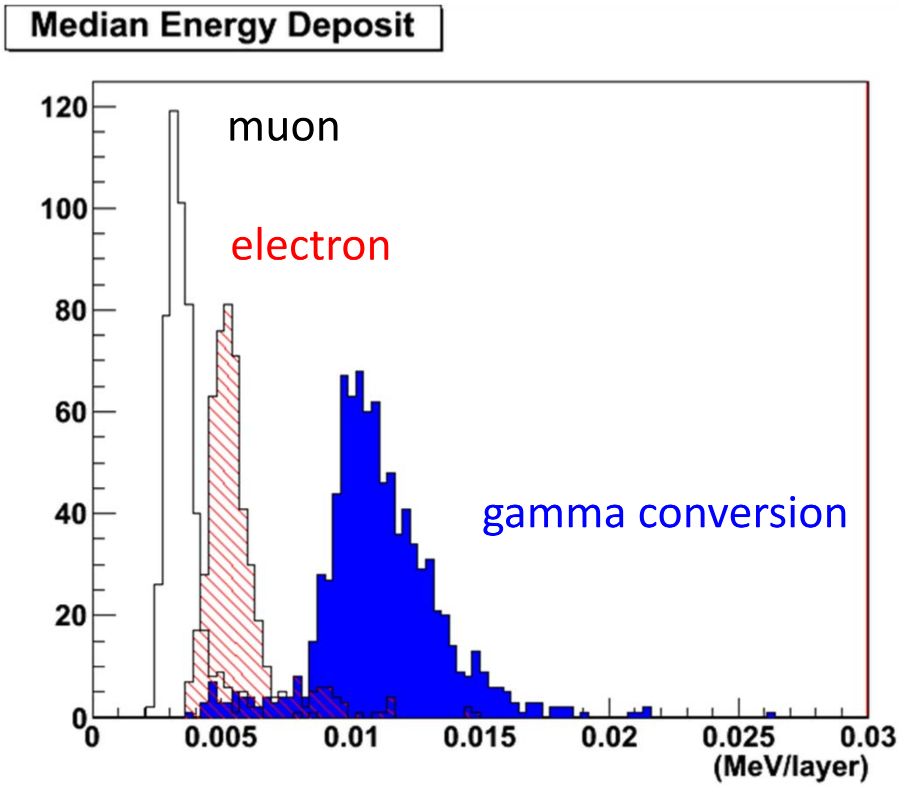
5mm(CH2)+20mm(gas)
$\vec{p} = (0,0,300\ \mathrm{MeV}/c)$



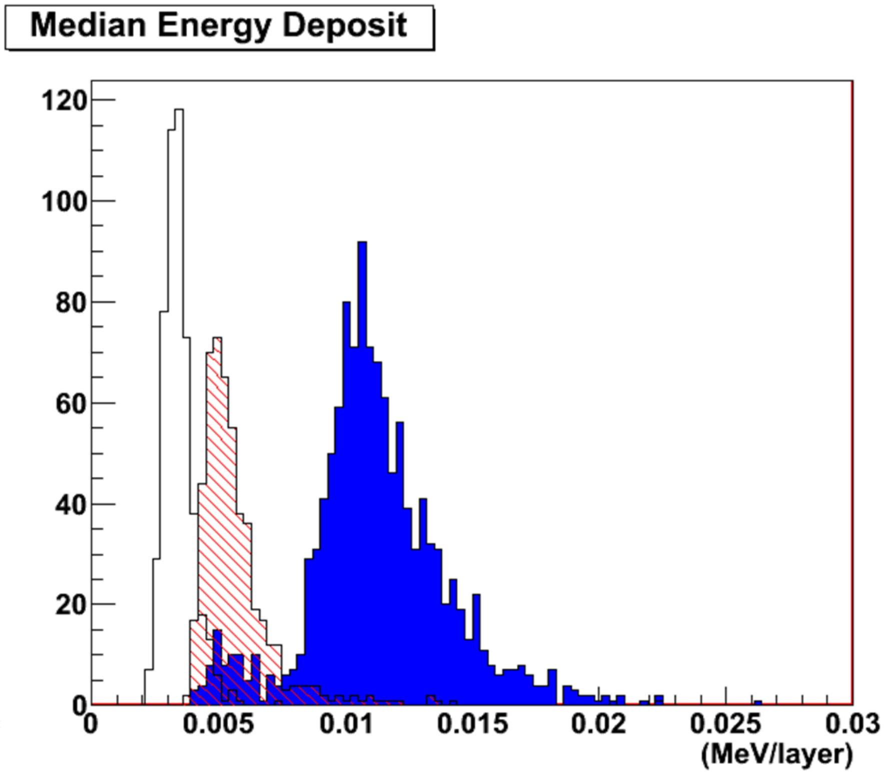
- Take median for quick check
- counter particle has very low energy for lower side tail of γ
- More sophisticated method (Likehood etc.) would give better performance.
- Note that p and e can be further separated using other information (#layers etc.)

5mm thickness vs 10mm thickness

5mm thick target



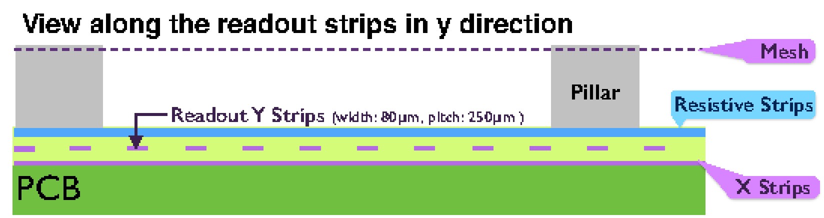
10mm thick target



Read-out

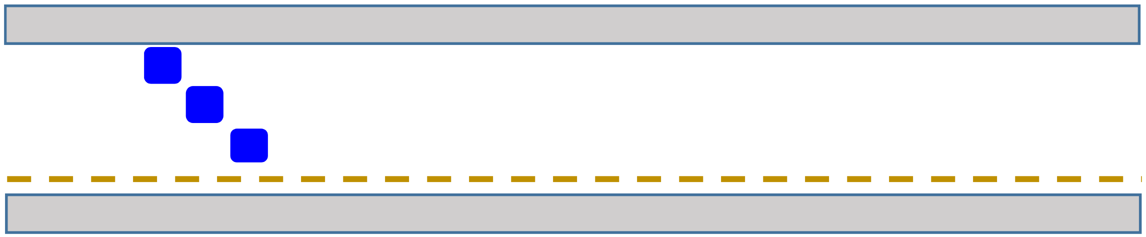
- 2D readout for each layer is ideal
  - lower threshold for p (209MeV/c vs. 259 MeV)
  - but not critical for other
  - need R&D to realize
- 2m long strip w/ Micromegas was realized by ATLAS
- Electronics similar to T2K

  TPC fits
  - 10~20 MHz sampling, <511 sampling for each spill

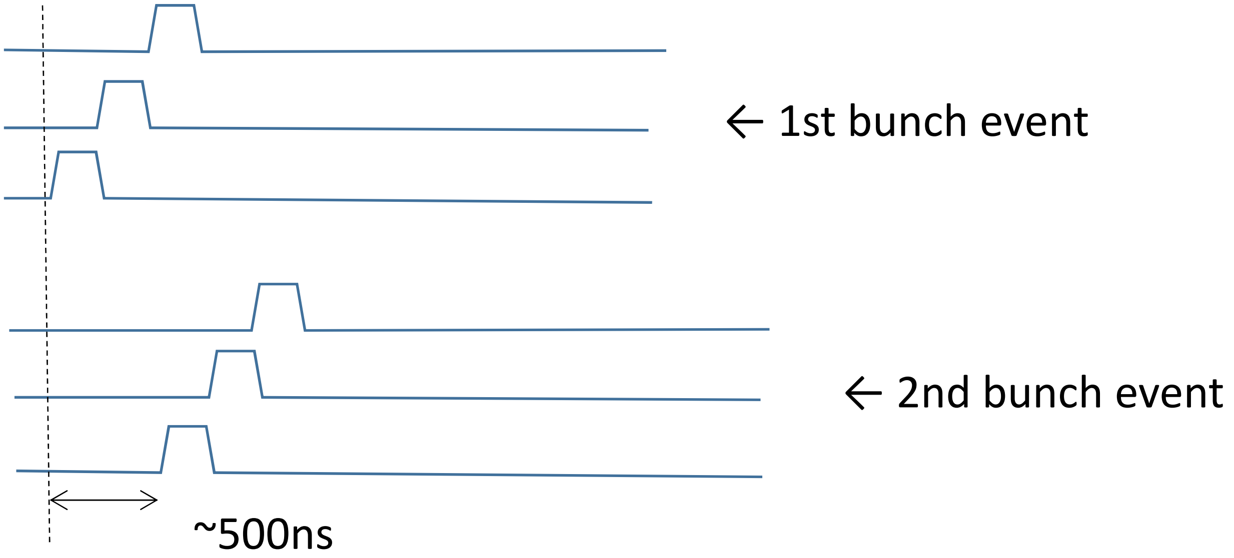


T.Lin et al., Nucl. Instrum.Meth. A767 (2014) 281

T_0



- It can be assumed that track will penetrate whole gas layer.
- T_0 can be determined by TPC signal itself.



Very very rough cost estimate

- MPGD : 20,000~50,000 Yen/m2 → ~0.1 M$ in total or ~<200 Yen/channel (!?)

  cf Scinti+fiber+MPPC ~ O(10,000)/ch

- Electronics similar to T2K TPC
  - Maybe 1 ADC chip for 256ch w/ AFTER-like chip

Summary

- It can be an ideal detector (except for neutron)
  - wide angler coverage
  - very low momentum threshold even for proton
  - PID and γ/e separation
- More quantitative evaluation is necessary to judge if it is really ideal or not.
  - Simulation
    - detector response
    - neutrino interaction
    - 15mm gas layer instead of 20 mm layer to fit to the space?
  - feasibility of large area MPGD+Polyethylene layer
- Then, test w/ prototype
- someone work together?

Back Up

effect of magnetic field

PDG2016

the Larmor frequency $\omega = eB/m_e$, and of the mean collision time τ:

$$\boldsymbol{v} = \frac{e}{m_e}\frac{\tau}{1+\omega^2\tau^2}\left(\boldsymbol{E} + \frac{\omega\tau}{B}(\boldsymbol{E}\times\boldsymbol{B}) + \frac{\omega^2\tau^2}{B^2}(\boldsymbol{E}\cdot\boldsymbol{B})\boldsymbol{B}\right) \quad (34.13)$$

To a good approximation, and for moderate fields, one can assume that the energy of the electrons is not affected by B, and use for τ the values deduced from the drift velocity at $B = 0$ (the Townsend expression). For $\boldsymbol{E}$ perpendicular to $\boldsymbol{B}$, the drift angle to the relative to the electric field vector is $\tan\theta_B = \omega\tau$ and $v = (E/B)(\omega\tau/\sqrt{1+\omega^2\tau^2})$. For parallel

For $B = 0$,

$$v = -\frac{e}{m}\tau E$$

$$\therefore \omega\tau = -\frac{B}{E}v$$

For E = 1kV/cm, B =0.2T,
v~2.5cm/us → $\omega\tau = 0.05$
$\therefore \theta_B = 2.9°$, 1mm shift for 20mm drift length if $B \perp E$, maybe acceptable

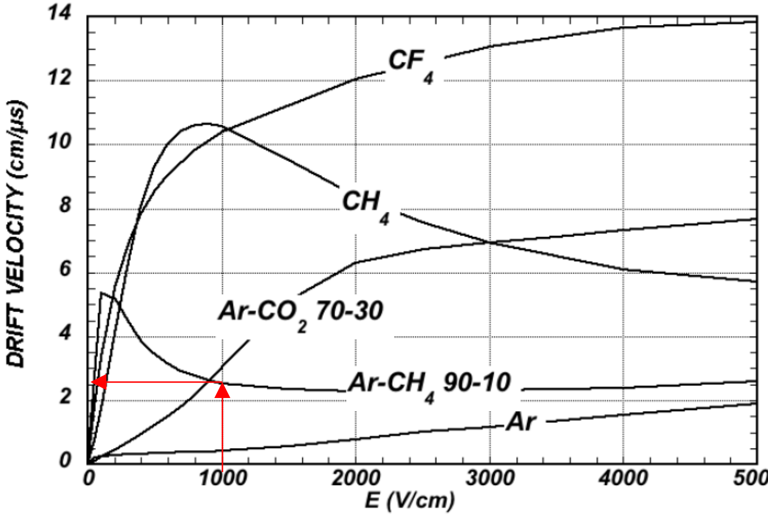


Figure 34.4: Computed electron drift velocity as a function of electric field in several gases at NTP and $B = 0$ [71].

Effect of Multiple Coulomb scattering on momentum measurement

Polyethylene : $X_0 = 44.77\ \mathrm{g/cm^2}, \rho = 0.89\ \mathrm{g/cm^3}$
assumption
target thickness = 6mm, muon, p=1 GeV/c ,$L_B =$ 1m
multiple scattering 1.2 mrad for 6mm, 7.6mrad for 40 layers

$$B = 0.2\mathrm{T} \rightarrow \rho = \frac{p}{0.3B} = 16.7m$$

$$\theta_{kick} = \sin^{-1}\frac{L}{\rho} = 61\mathrm{mrad}$$

$$\Delta x = \rho(1 - \cos\theta_{kick}) = 31mm$$

momentum resolution ~12%, almost independent from absolute momentum.
Not so bad if muon penetrate the target at right angle.
If target is placed horizontally, effective thickness would be larger, but the number of layers would be small.
For lower momentum, it is worse compared to the current configuration.

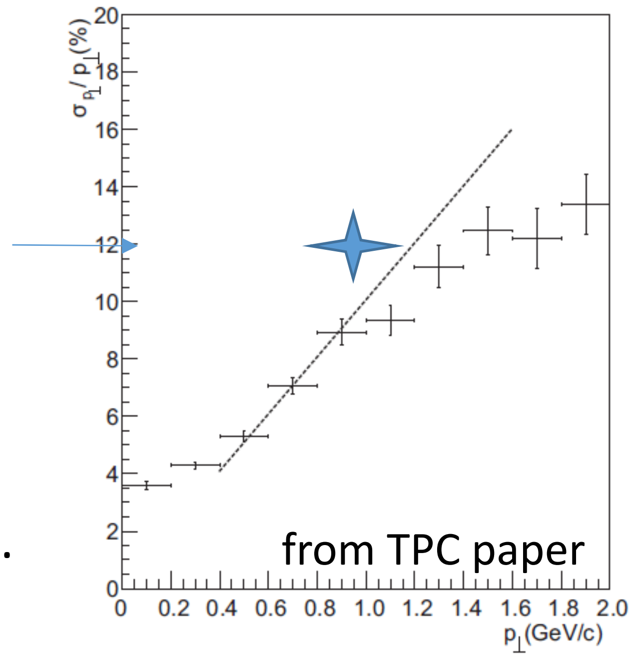


Figure 27: Momentum resolution for a single TPC is shown as a function of momentum perpendicular to the magnetic field as predicted by the Monte Carlo simulation of muons generated with the standard neutrino event generator of T2K. The tracks are selected to cross at least 50 out of the 72 pad columns of the TPC volume. The dashed lines represents the momentum resolution goal.

diffusion

- From “Time projection chambers for the T2K near detector”, N.Abgrall et al.,Nucl.Instrum.Meth. A637 (2001) 25, diffusion constant ~ 270 $\mu m/\sqrt{cm}$ @ 1.8 T
- 2.7 mm for 1 m
- 1.2 mm for 20cm
- 0.19mm for 20mm

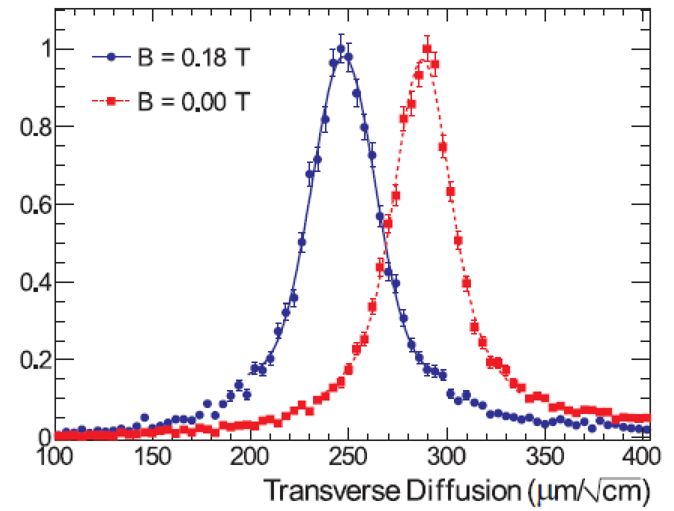


Figure 23: As part of the maximum likelihood track fit, the diffusion constant for the mean drift distance of the track is allowed to vary. The change in diffusion along the length of the track, due to differences in drift distance, is fixed in the fit. This plot shows the distributions of diffusion constant estimates from samples of cosmic rays with mean drift distance of more than 30 cm with magnetic field on and off. The distributions are fit to Gaussians and the means are found to be 247 and 288 $\mu m/\sqrt{cm}$ respectively. This method is known to underestimate the diffusion constant by approximately 10%.[17]

principal dEdX resolution

PDG2016

Table 34.5: Properties of noble and molecular gases at normal temperature and pressure (NTP: 20° C, one atm). E_X, E_I: first excitation, ionization energy; W_I: average energy per ion pair; $dE/dx|_{\mathrm{min}}$, N_P, N_T: differential energy loss, primary and total number of electron-ion pairs per cm, for unit charge minimum ionizing particles.

Gas	Density, $\mathrm{mg\,cm^{-3}}$	E_x eV	E_I eV	W_I eV	$dE/dx\|_{\mathrm{min}}$ $\mathrm{keV\,cm^{-1}}$	N_P $\mathrm{cm^{-1}}$	N_T $\mathrm{cm^{-1}}$
He	0.179	19.8	24.6	41.3	0.32	3.5	8
Ne	0.839	16.7	21.6	37	1.45	13	40
Ar	1.66	11.6	15.7	26	2.53	25	97
Xe	5.495	8.4	12.1	22	6.87	41	312
CH_4	0.667	8.8	12.6	30	1.61	28	54
C_2H_6	1.26	8.2	11.5	26	2.91	48	112
iC_4H_{10}	2.49	6.5	10.6	26	5.67	90	220
CO_2	1.84	7.0	13.8	34	3.35	35	100
CF_4	3.78	10.0	16.0	54	6.38	63	120

2017/5/2

pile-up

- FGD event rate
  - http://www.t2k.org/nd280/runco/data/rates/meetings/2013-may-10/FGD%20event%20rate
  - low level cut selection (all events including sand muons) : 3 events/1E15POT
  - FGD cross section is 184cm x 184 cm
- 1E-19 events/cm^2/POT → 3E-5events/cm^2/3E14POT(~1MW)
- Conclusion : Don't need to worry on pile-up in one gas cell.

2017/4/13

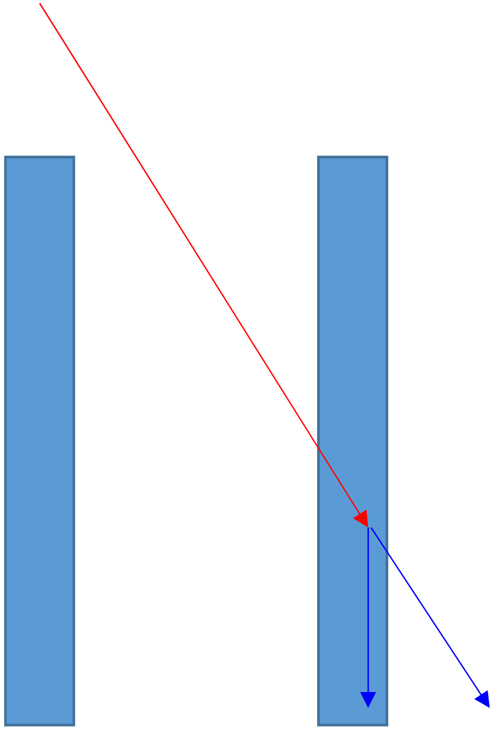
number of ν_e interaction

- From "Measurement of the Inclusive Electron Neutrino Charged Current Cross Section on Carbon with the T2K Near Detector", PRL 113 241803
  - flux-averaged charged current cross-section : $1.2 \times 10^{-38}\mathrm{cm}^2$/nucleon
  - Total flux $1.35 \times 10^{11}/\mathrm{cm}^2$ for 5.9×10^{20}POT.
- 1.65E4 interaction/ton/10×10^{21} POT

2017/4/13

comments by Nakaya-san

- influence of many particle from vertex
- gammas from outside may leak into the detector deep inside and become background



T2K ND280 TPCの読み出し

Nucl.Instr.Meth. A637 (2011) 25

- total 124,416 channel

A FEC has 4 AFTER chips and a ADC and process 288 channels.

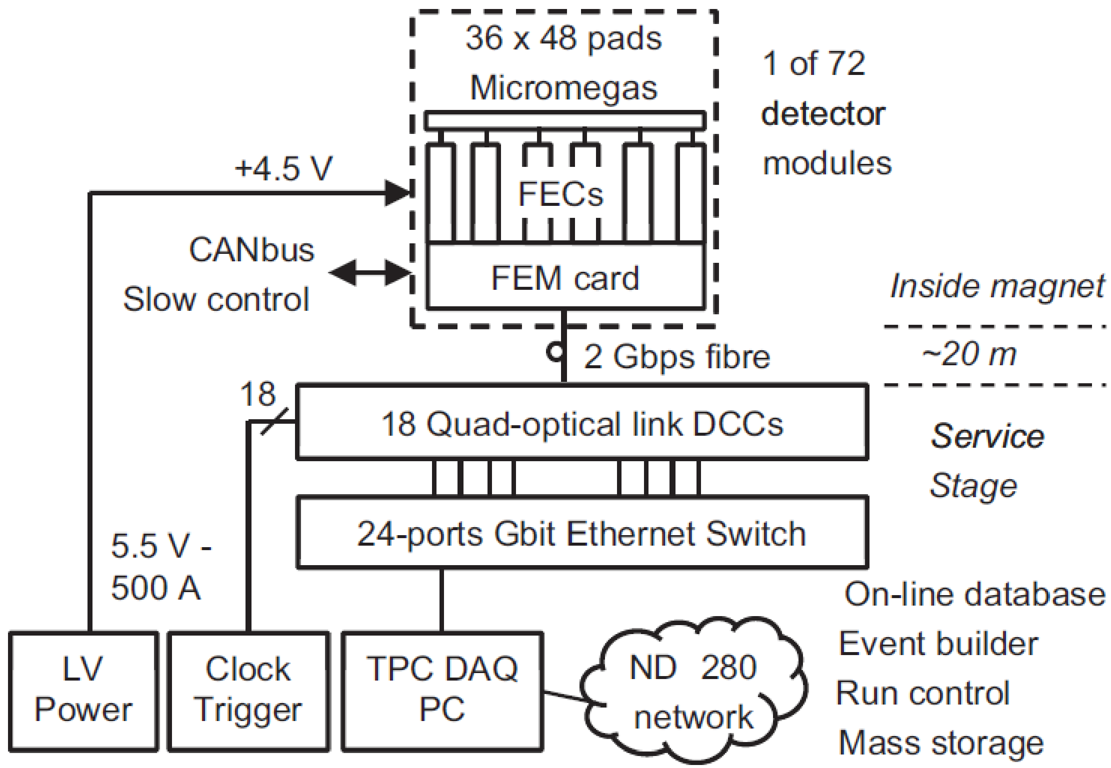


Fig. 14. Architecture of the TPC readout electronics.

NOMAD detector

2017/3/24

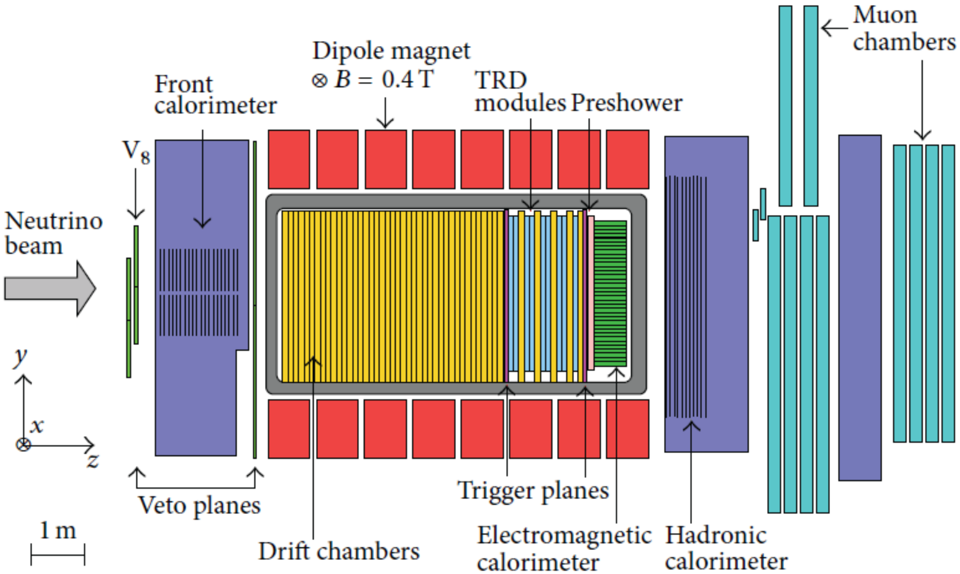


FIGURE 2: A schematic sideview of the detector.

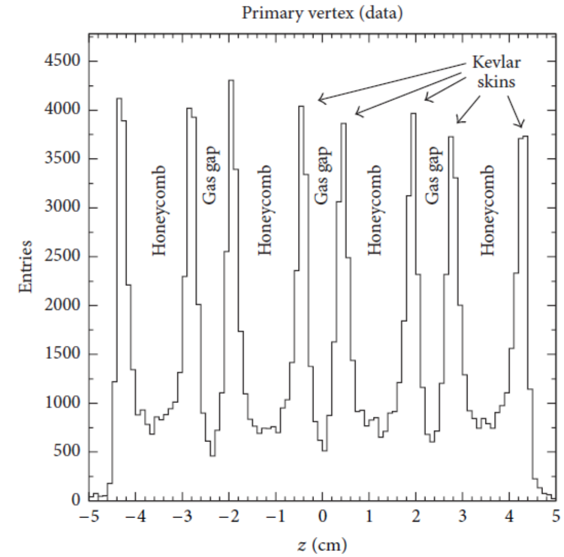


FIGURE 3: Distribution of vertices through one drift chamber along the beam direction (from [3]).

"The NOMAD Experiment at CERN", F. Vannucci, Adv.High Energy Phys. 2014 (2014) 129694

- 2.9 ton, 2.6x2.6m^2
- Drift chamber
  - panels made of aramid fibers in a honeycomb structure
  - 8mm gap, +5^o, -5^o respect to the magnetic field, 3.2 cm spacing
- Kevlar-epoxy resin skin (= target) sandwiches drift chambers.
- It seems it was used for tracking only

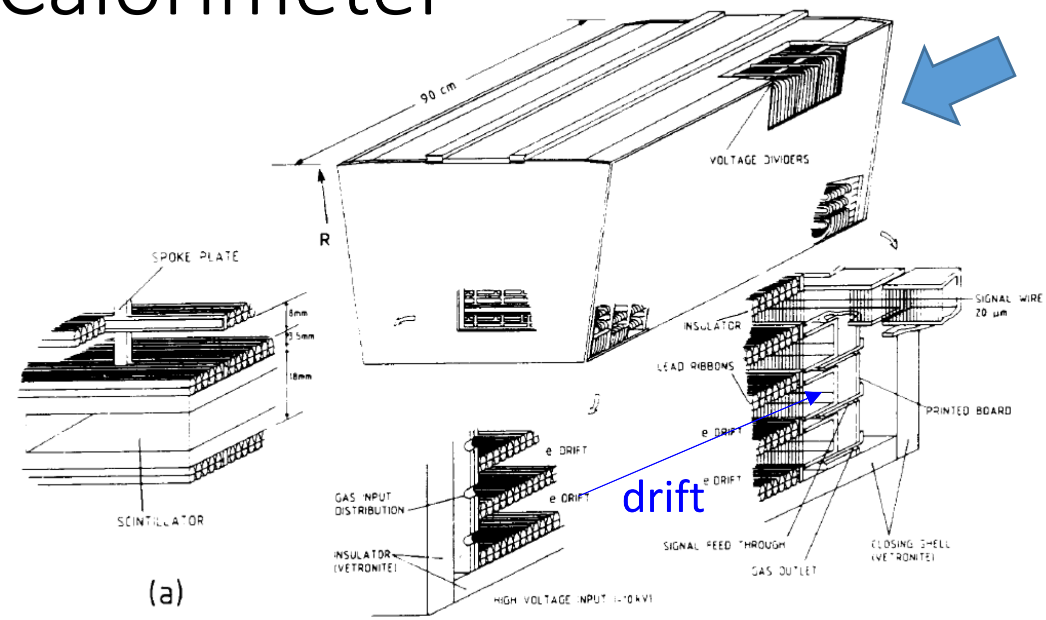
2017/3/24

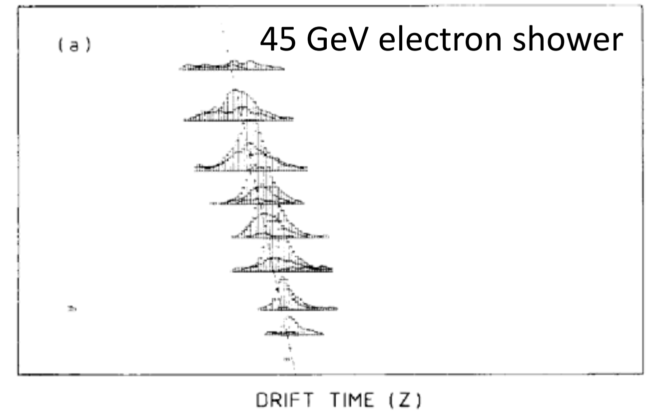
3.3. The Drift Chambers (DC). The drift chambers [2] were a crucial part of the detector. They provided the target material and the tracking device for the particles. They were designed with the conflicting requirements that their walls should be as heavy as possible in order to maximize the number of neutrino interactions and as light as possible in order to minimize multiple scattering of particles, secondary particle interactions, and photon conversions. To minimize the total number of radiation lengths (X_0) for a given target mass, the chambers were made of low density and low atomic number materials. The complete target consisted of 145 drift chambers, with a total mass of 2.9 tons over a fiducial area of $2.6 \times 2.6\,\mathrm{m}^2$. Each chamber contributed $0.02X_0$. Overall, the target had a density of $0.1\,\mathrm{g/cm}^3$ and a total length of $1.0X_0$; there was less than $0.01X_0$ between two consecutive hit measurements in the chamber planes.

The chambers were built on panels made of aramid fibres in a honeycomb structure. These panels were sandwiched between two Kevlar-epoxy resin skins. These skins gave the mechanical rigidity and flatness necessary over the large $3 \times 3\,\mathrm{m}^2$ surface area. Each drift chamber consisted of four panels. The three 8 mm gaps between the panels were filled with an argon-ethane (40%–60%) mixture at atmospheric pressure. The gas was circulating permanently in a closed circuit with a purifier section that removed oxygen and water vapor.

The central gap was equipped with sense wires at $+5^\circ$ and -5° with respect to the magnetic field direction. These sense wires were 20 μm in diameter and were made of gold-plated tungsten. They were interleaved with 100 μm potential wires made of Cu-Be. These wires were equally spaced vertically to

DELPHI HPC(High-density Projection chamber) Calorimeter

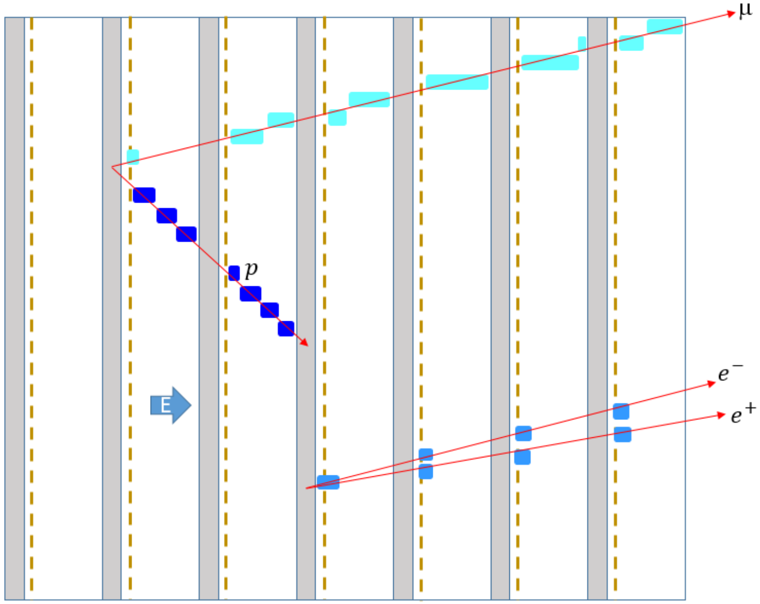




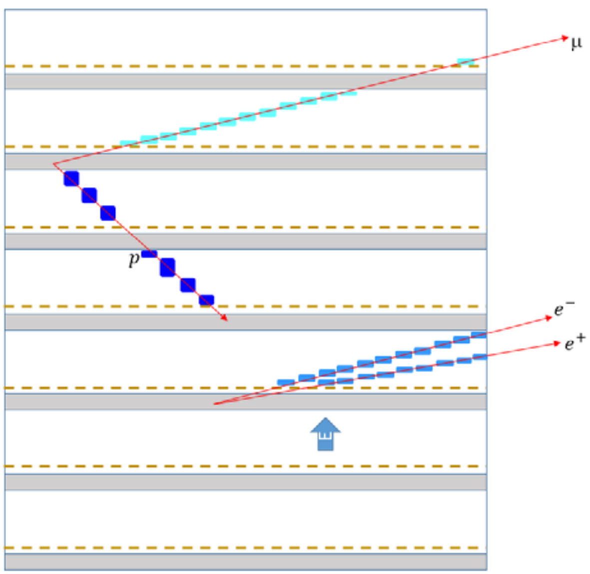
The DELPHI detector at LEP, DELPHI Collaboration, Nucl.Instrum.Meth. A303 (1991) 233-276

- Lead ribbons = converter & field-cage
- one wire at the end of each 8mm gap
- "In these narrow drift channels, charge transmission is limited by transverse diffusion,...Charge attenuation length in excess of 350 cm have been obtained in the HPC, for a maximum drift length of 85cm."
- 1.2 T magnetic field

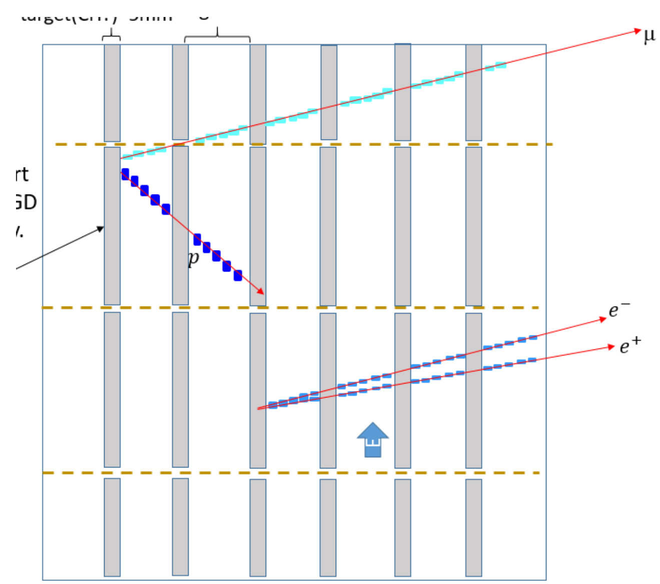
2017/3/28



元案



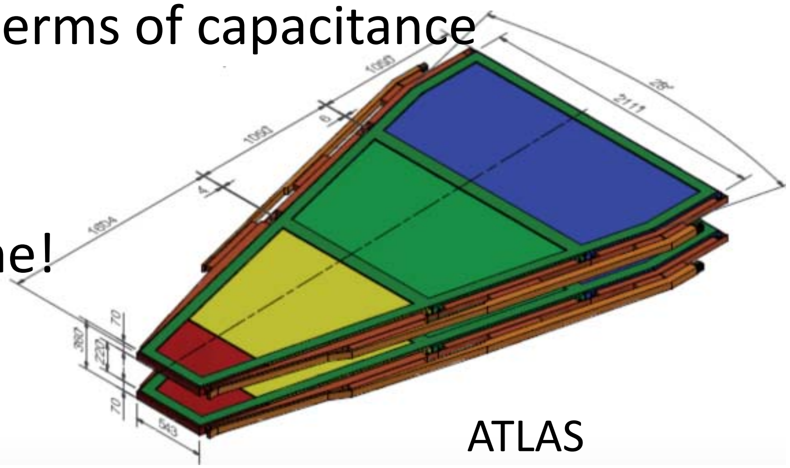
回転バージョン 1
前方に飛んだ時に、かなり長く物質中を飛ぶ場合がある。



回転バージョン 2
t0が必要になる。ドリフト方向に沿って物質がすぐ近くにあるのがいやな感じ。

possible issues
(See later slides for possible solutions)

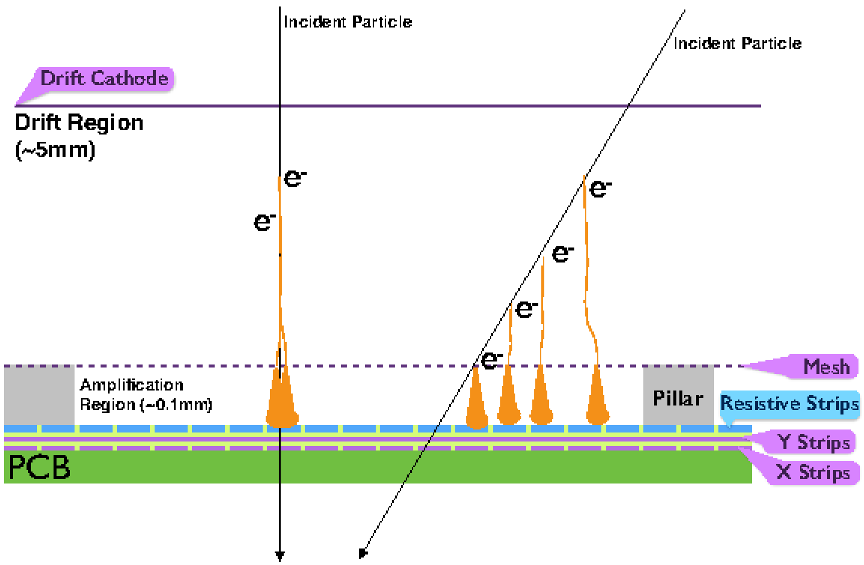
- Electric field and magnet field is not parallel in case of ND280
  - rotate 90degree?
- Need T_0 ? may not be necessary.
- multiple scattering worsen momentum resolution in case of ND280 unless it is measured by another bulk TPC ?
- xy stripline readout needs some investigation
  - if not possible, alternate x-layer, y-layer structure
- Need to be large (2mx2mx1.5m) for nue measurement
  - ATLAS developed 2m micromegas detector already
- 3mm pitch(x 2m) may be too wide in terms of capacitance
- Target has to be low out gas material
  - PE? PTFE?
- Are there any? Comments are welcome!

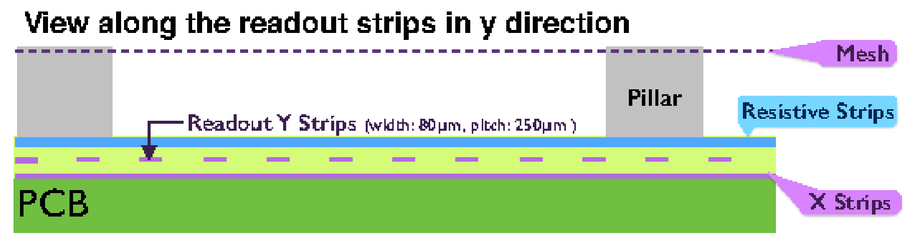


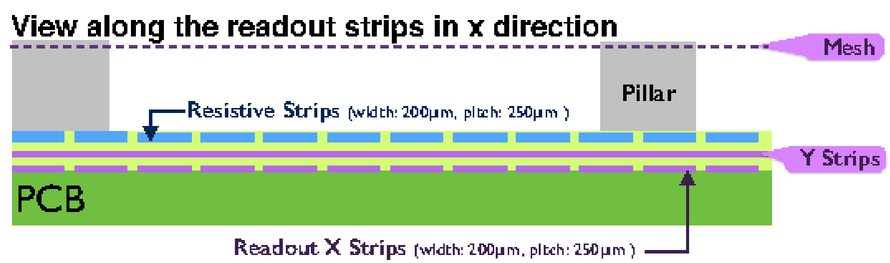
ATLAS

2D readout case 1

"Signal Characteristics of a Resistive-Strip Micromegas Detector with an Integrated Two-Dimensional Readout",
T.Lin et al., Nucl. Instrum.Meth. A767 (2014) 281



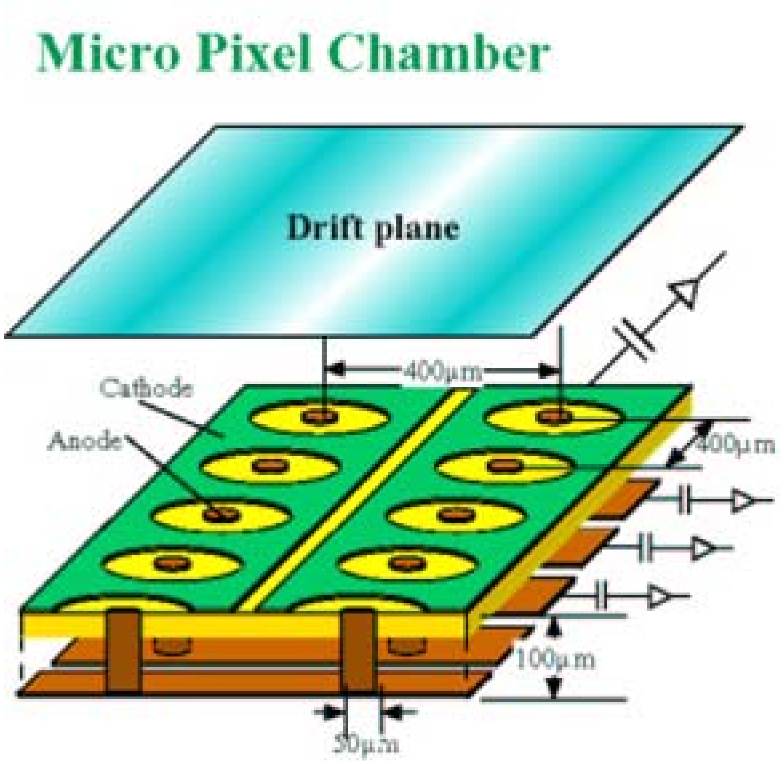




X-strip width is narrow compared to pitch in order to induce charge in y-strip placed downstream

PCB would be CH target in our case

2D read out case 2 μ-pic

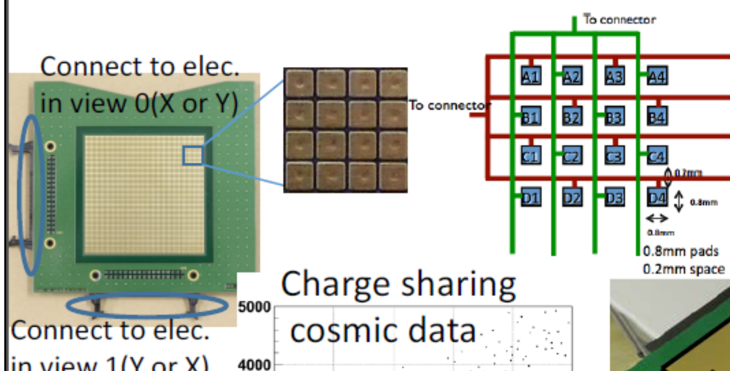


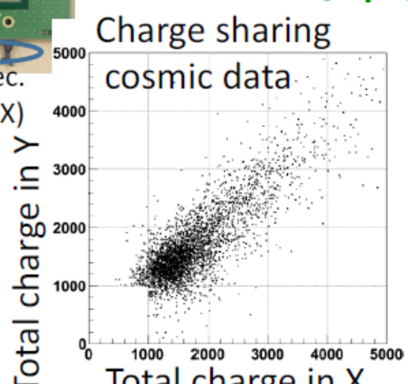
used with GEM to obtain sufficient gain

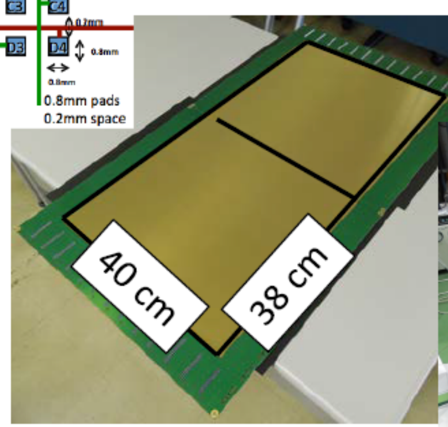
2D PAD readout being developed by Liq.Ar people

2D readout pad anode

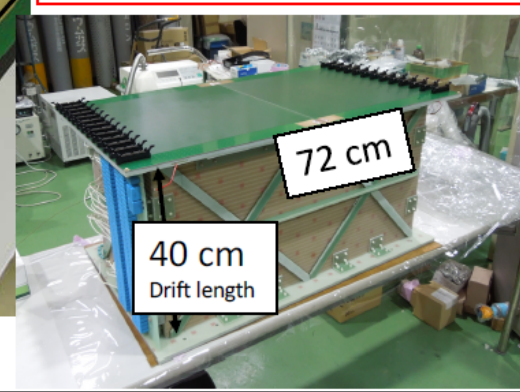
- 4 mm pitch readout
  (small pads are connected along X or Y direction independently)
- Charge is collected by pads and shared equally in X and Y channel.
- Large readout anode pad is developed (40 cm × 38 cm), based on largest multilayer PCB in commercially product.







Realize large area by connecting several boards.



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