Development of High-Rate Ionization Chamber

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Development of high-rate and high-resolution particle identification device for high-energy heavy ions

Required performance

High rate : ~ 1 Mcps
High resolution : $\Delta Z < 0.3$

Semiconductor Detector（SSD)

- Energy resolution, good
- Short life for high intensity heavy-ion beams
- Difficult to fabricate large area detectors

Gas ionization chamber

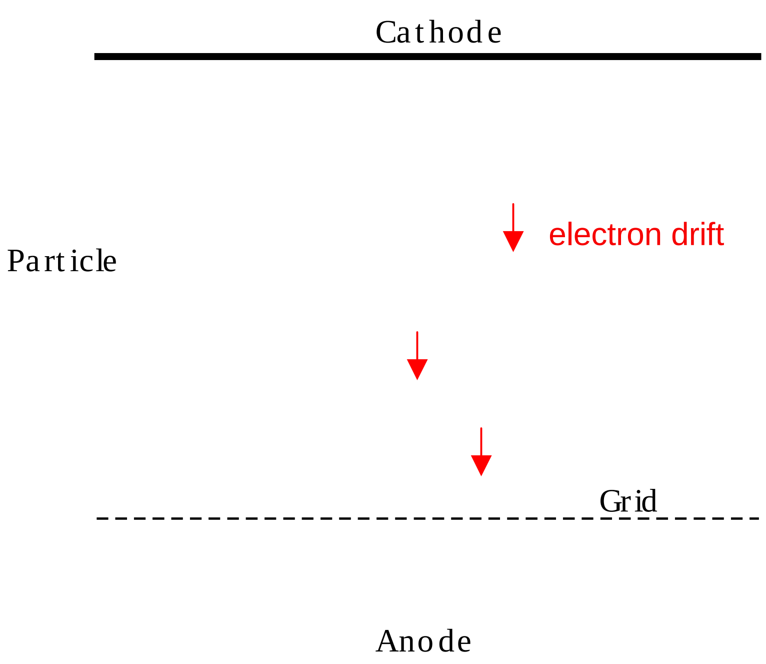
- Resolution comparable to SSD
- Long life and stable operation using gas flow system
- Easy to fabricate large area detectors
- Slow response, need to develop high-rate performance

Gas Ionization Chamber with Frish Grid

e.g., GSI ionization chamber

Ordinary usage:

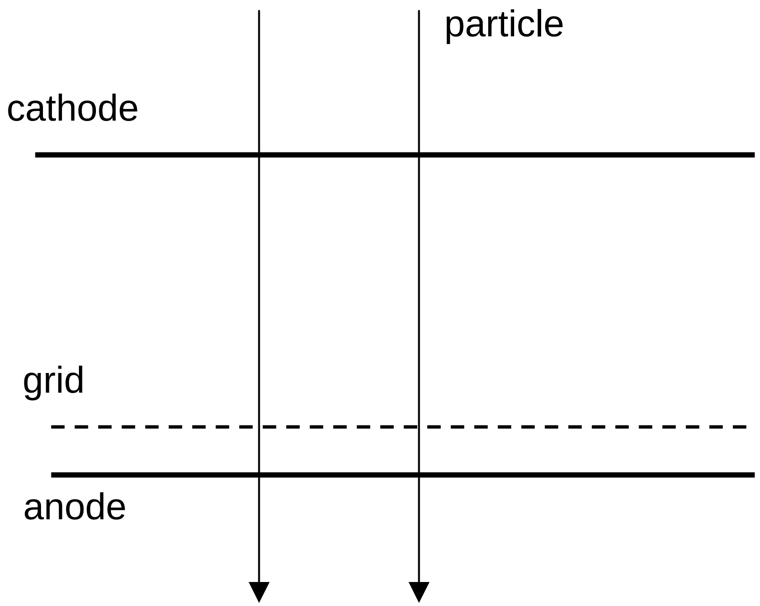
Particles are injected parallel to the electrodes.



- Time delay
  anode signal ←→ trigger time
  electron drift ∽ 5 cm/μsec
- Variable delays depending on the distances between particle tracks and the grid
- At high rates, late coming particles happen to produce anode signals prier to a tagged particle.

Signal delay can be avoided by vertically injecting particles.

Ionization chamber of vertical injection type



Required condition :

- Short anode-cathode distance, short rise time of anode pulse
- Multi-layer configuration for obtaining sufficient energy loss

Deficit :

- Non-uniformity of grid plane, non-uniform energy loss

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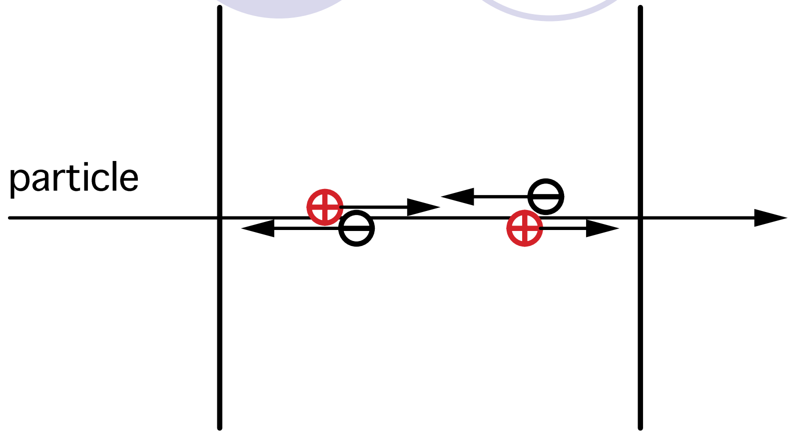
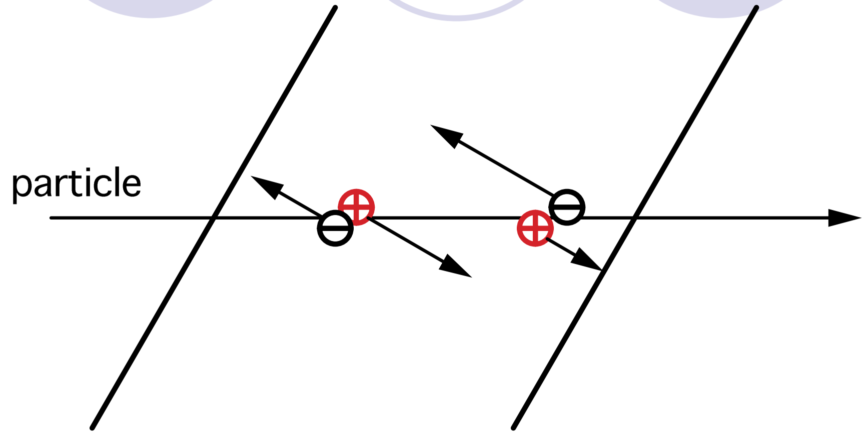
Grid-less gas ionization chamber

Grid-less gas ionization chamber





Operational characteristics :

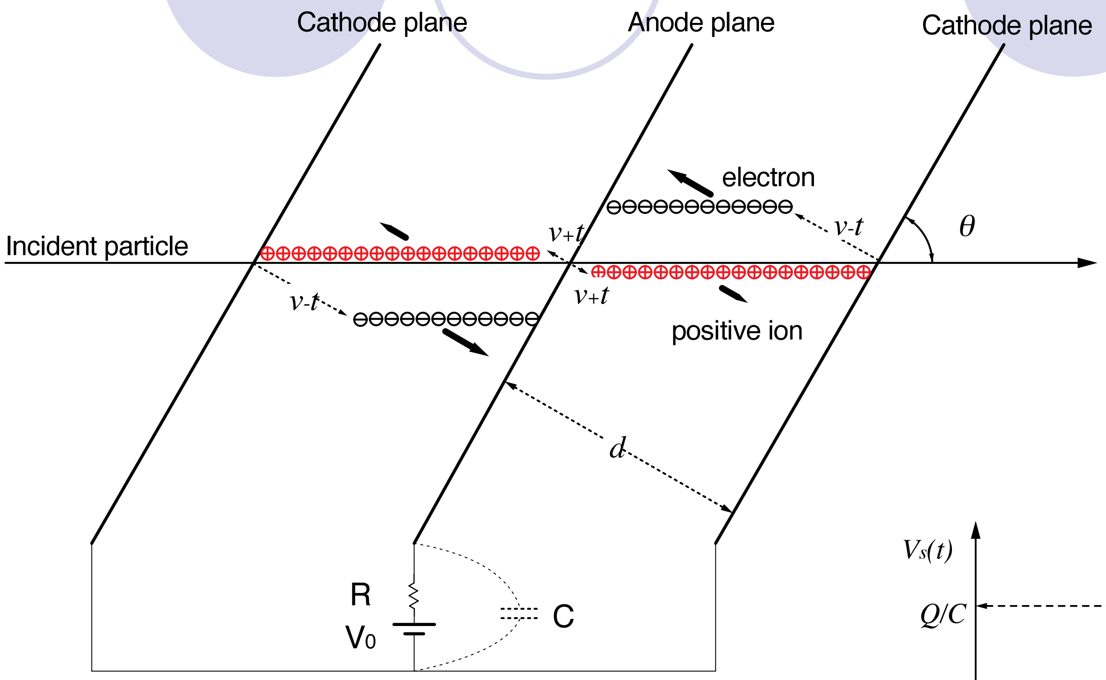
- Anode signal, composed of electron and positive ion parts
- Sum of the two parts ∝ energy loss
- Electron part = 1/2 of the total height
- Charge loss due to recombination of electrons and positive ions

Prescription :

- Rejection of positive ion pulse using electronics
- Avoid recombination by tilting electrodes

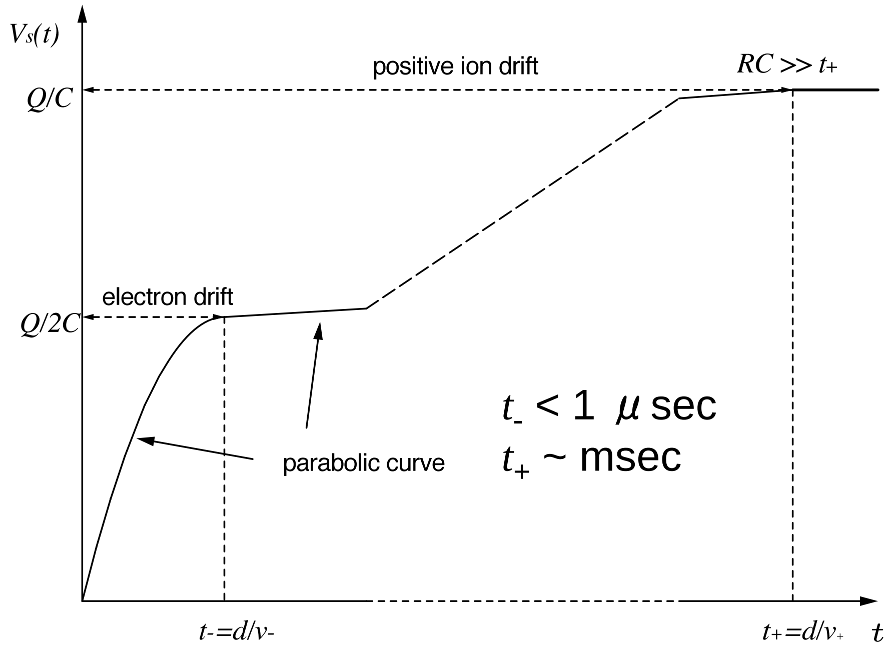
Tilted Electrode Gas Ionization Chamber (TEGIC)

Anode pulse shape of TEGIC



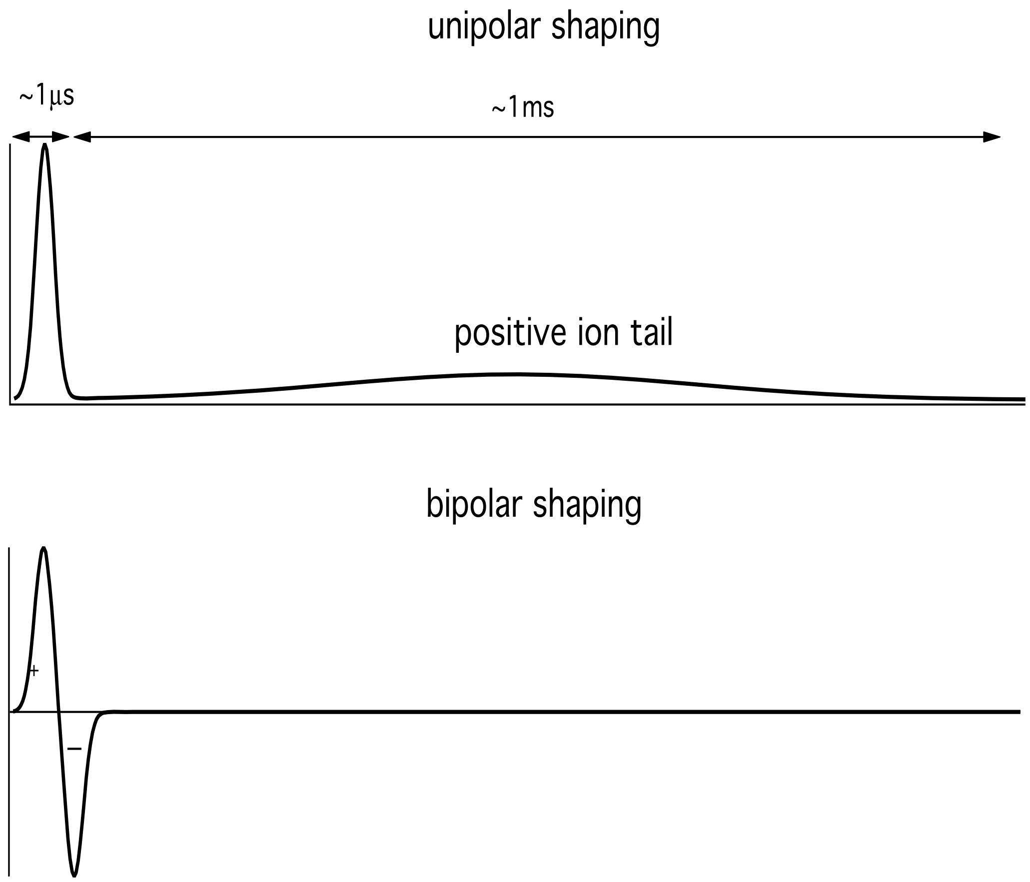
- v_- : electron drift velocity
- v_+ : ion drift velocity
- d : anode-cathode distance
- Q : total charge of electron or positive ion
- C : detector capacity

$$V_s(t) = \frac{Q}{2C}\left\{\frac{2(v_- + v_+)}{d}t - \frac{v_-^2 + v_+^2}{d^2}t^2\right\}$$



Rejection of positive ion pulse through pulse shaping

Pulse shaping using main amplifier



Unipolar shaping :
Difficult to filter out slow ion pulse using a shaping time for electron pulse.
Pileup of ion pulse occurs even at low counting rates.

Bipolar shaping :
Positive and negative pulses with equal area.
For low frequency signals, + and - components cancel with each other.

Noise level : bipolar shaping = $\sqrt{2} \times$ unipolar shaping

Construction of TEGIC

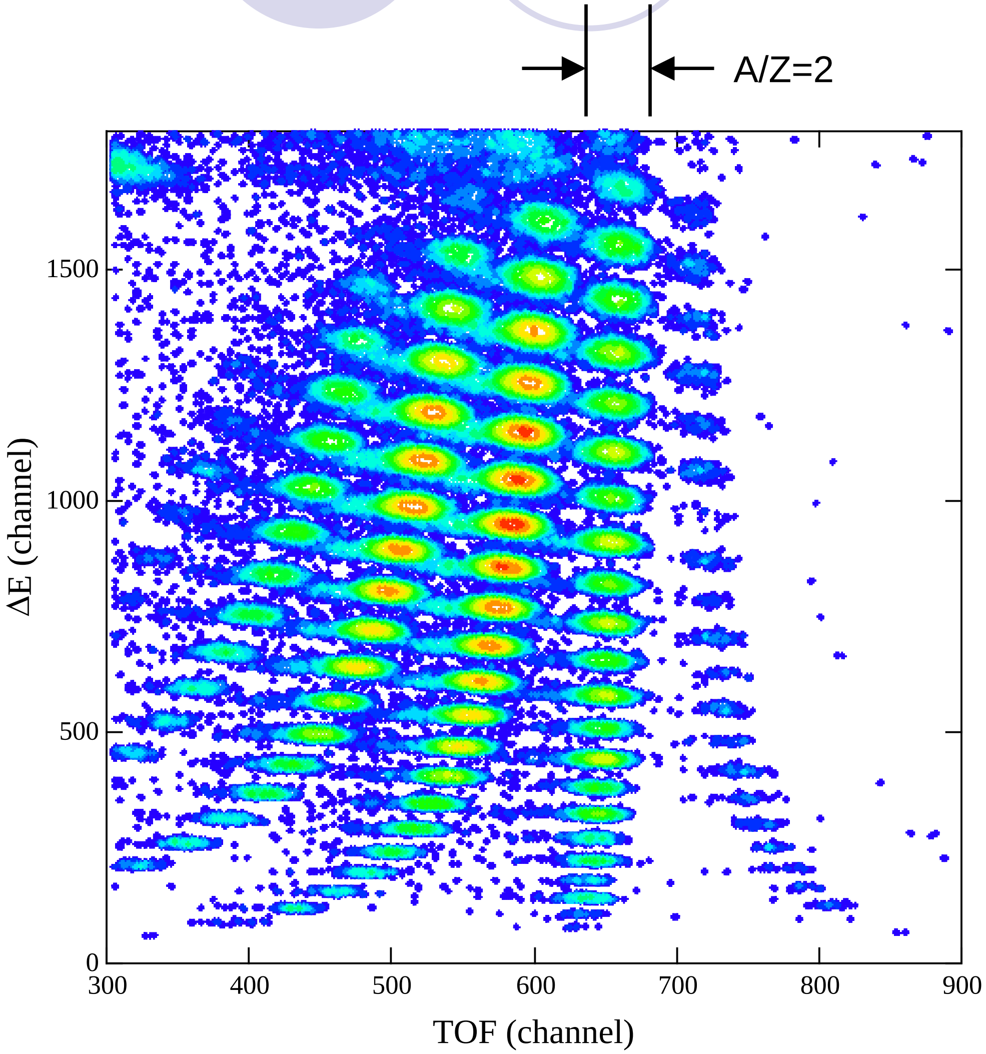
Anode & cathode electrode	:	aluminized mylar (thickness = 4 μm)
Anode-cathode gap	:	2 cm
Number of anode plane	:	12 (total gas length = 48 cm)
Inner diameter of electrode	:	12 cm
Inclination of electrode	:	30°

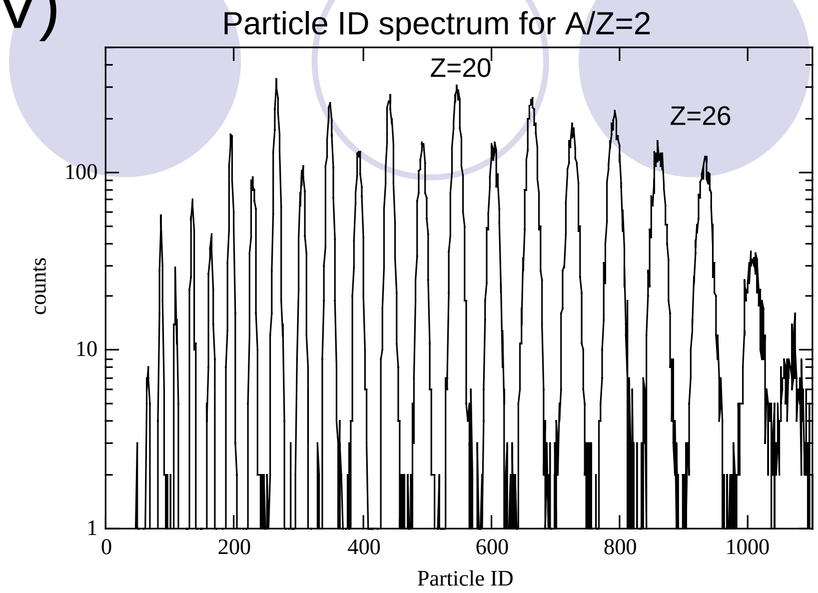
Test experiment at RIKEN

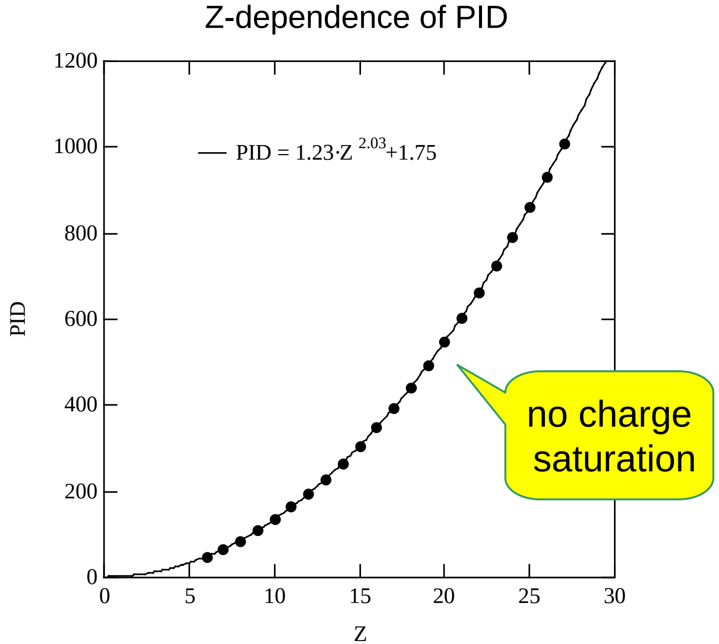
Experimental condition

Beam particle	: Secondary particles produced by fragmentation of ^{56}Fe(90AMeV)
Chamber gas	: P-10 (Ar+CH_4), 740 Torr gas flow
Anode voltage	: +500 V
Preamplifier	: Tennelec charge sensitive preamplifier
Main amplifier	: Canberra spectroscopy amplifier shaping time = 0.25 μs
TOF	: plastic scintillator timing & RF-signal

Nuclear fragments of ^{56}Fe(90AMeV)







Z-resolution

$$\Delta Z = \frac{2 \cdot \Delta PID(Z)}{PID(Z+1) - PID(Z-1)}$$

ΔPID : FWHM of a PID peak
$PID(Z)$: PID channel number

Consider only energy straggling, then

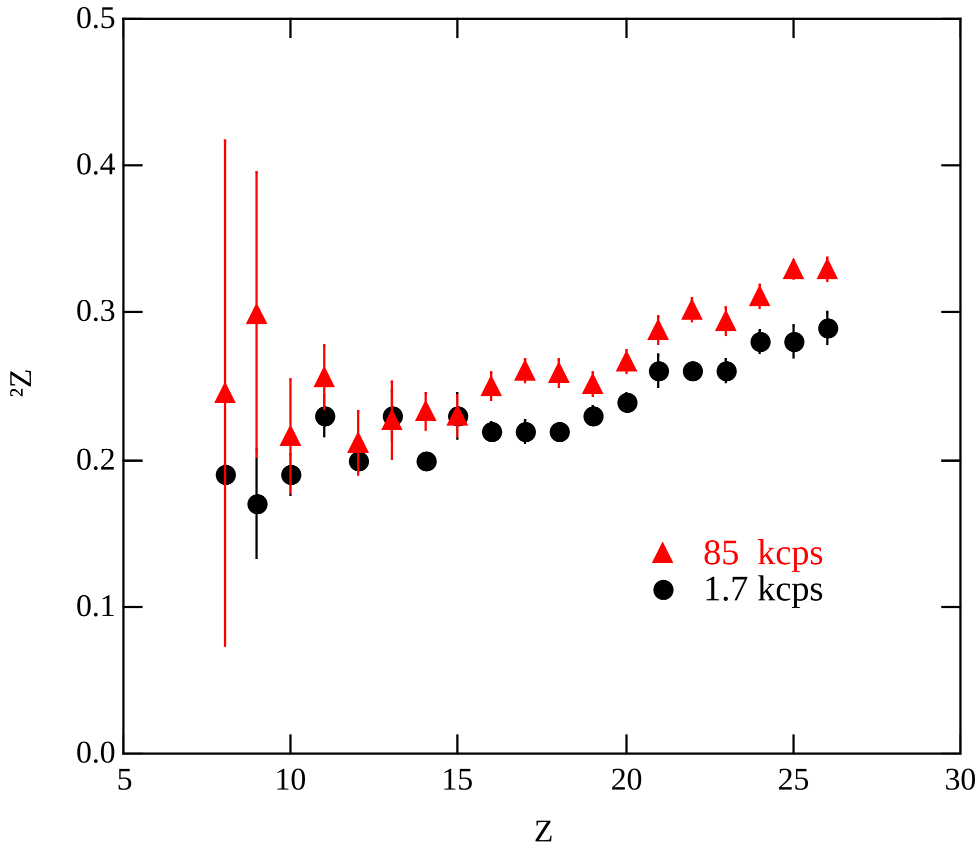
$\Delta PID \propto \delta(\Delta E) \propto (\Delta E)^{1/2} \propto Z$

and

$PID(Z+1) - PID(Z-1) \propto Z$

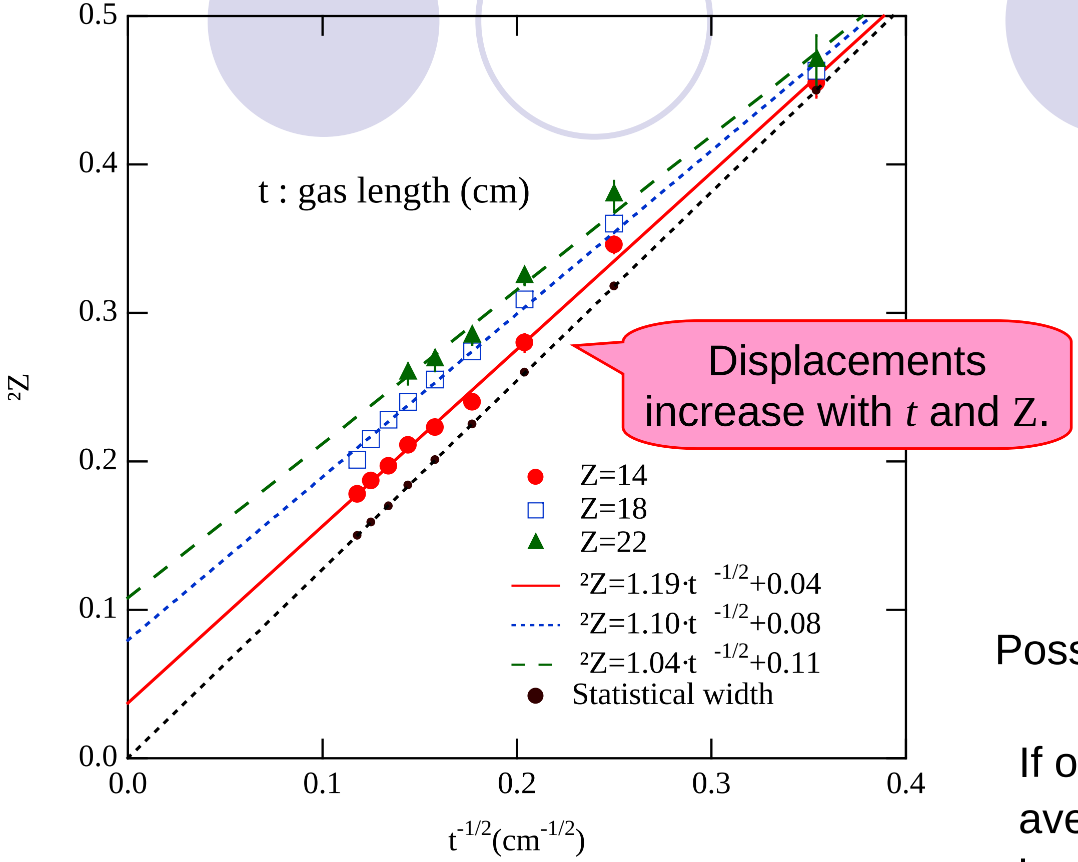
thus

ΔZ = constant .



Deterioration of ΔZ → large Z
Existence of non-statistical factor ?

Dependence of ΔZ on gas length



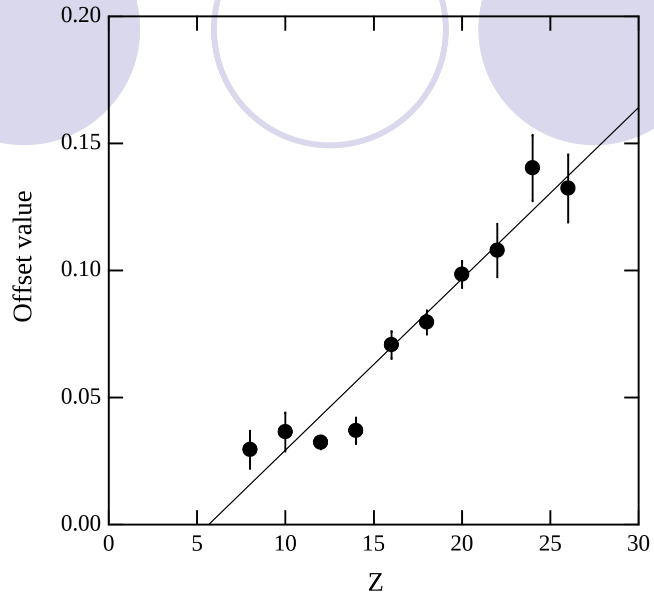
Consider only energy straggling then,

$$\Delta PID(Z) \propto \delta(\Delta E) \propto (\Delta E)^{1/2} \propto t^{1/2}$$

$$PID(Z+1)\text{-}PID(Z-1) \propto \Delta E \propto t$$

thus

$$\Delta Z \propto t^{-1/2} .$$



Possible non-statistical factor :

ΔE ∝ 1/E

If one particle loses larger energy than the average at the first section, it tends to lose larger energy than the average in the next section.

This effect increase with Z.

Improvement :

Remove unnecessary energy loss.

Use thinner electrode foils.

Rate dependence of Z-resolution

Secondary particles produced by fragmentation of ^{40}Ar(95AMeV)

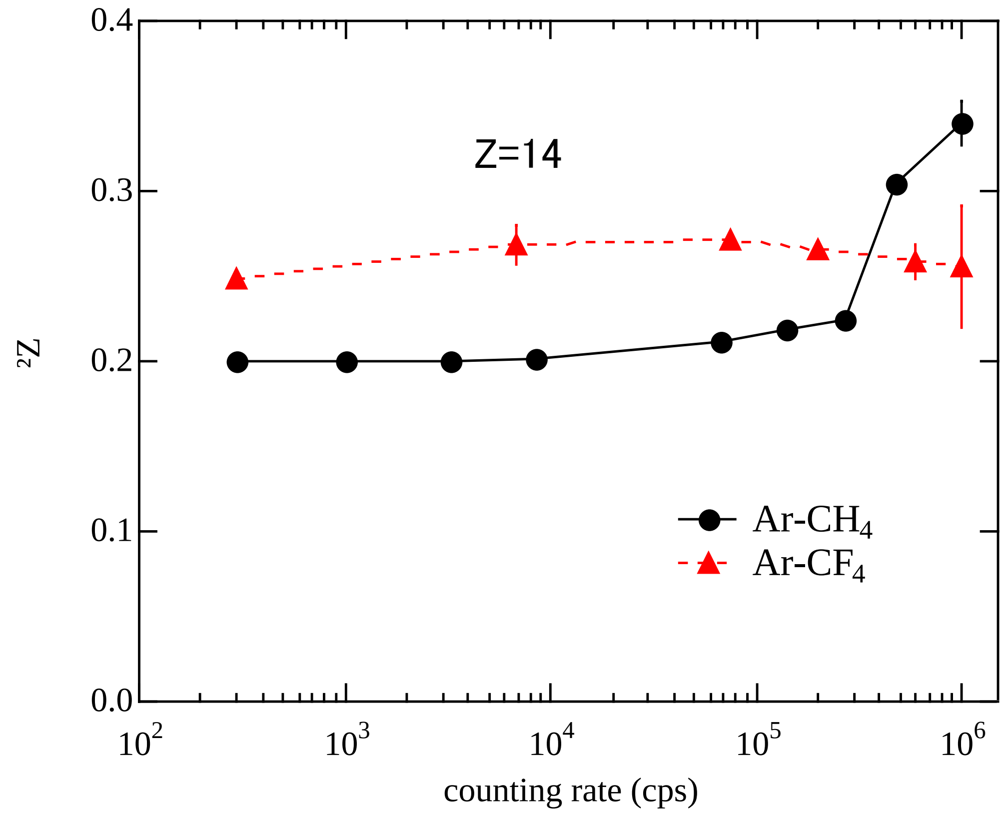
Gas performance is compared.

Gas mixture	v_e
Ar(90%)+CH_4(10%)	∽6cm/μs
Ar(90%)+CF_4(10%)	∽12cm/μs

- Up to 300kcps
  Resolutions are good for both gas mixtures.

- Above 300kcps
  Ar-CF_4 is better than Ar-CH_4.

  Existence of pile up events
  at 300kcps ~ 40%
  at 1Mcps ~ 75%



Reduction of pileup events : narrower electrode gaps & faster pulse shaping circuits

Conclusions

- The present TEGIC works well.
- Almost flat rate dependence of ΔZ up to 1 Mcps.
- $\Delta Z < 0.3$ attained for $Z < 30$.
- Above 300 kcps, reduction of pileup events necessary.
- For $Z > 30$, improvement of ΔZ necessary.

Necessary improvements

High-rate : Making anode-cathode gaps narrower.
Employing faster pulse shaping circuits.
ΔZ : Using thinner electrode foils.