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# A high rate and high timing photoelectric detector prototype with RPC structure

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# Outline

# Background

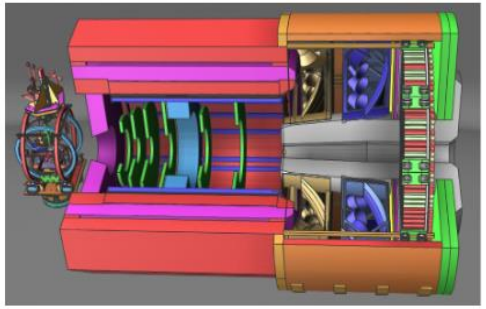
## Background

- Future high energy physics experiment:
  **high luminosity**
  high energy
- Challenges for (gas) detectors:
  high count rates, high time resolution, eco-friendly gases etc.

## Motivation

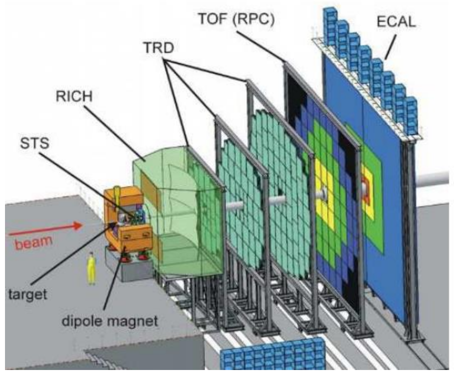
TOF (PID, trigger, background suppression, etc.)

- Working in such condition:
  requirements ($\sigma_t < \sim 30ps$ , higher rate > kHz/cm2) → develop a high rate and timing photoelectric gas detector
- Gas detector's limitation (greenhouse effect)→ new eco-friendly gases (low GWP value)



The SoLID apparatus in its first (semi-inclusive deep-inelastic scattering) configuration with the polarized 3He target on the left.

SoLID




CBM

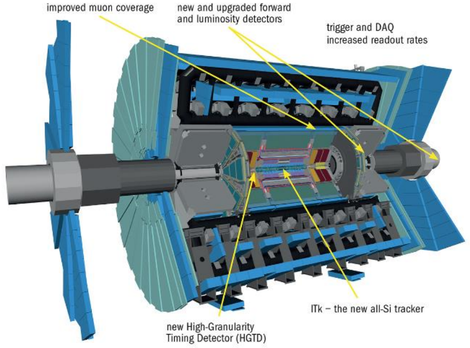


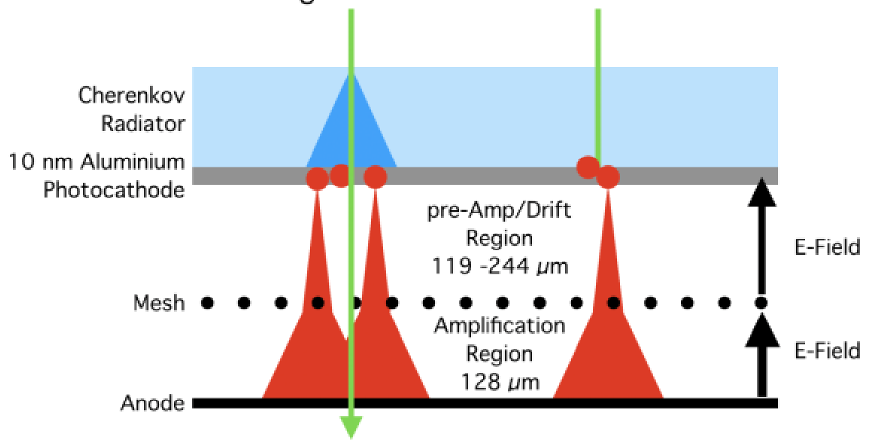

Figure 2: Schematic of the major upgrades to the ATLAS detector for the HL-LHC era. (Image: ATLAS Collaboration/CERN)

ATLAS upgrade (HL-LHC)

# Gaseous photodetector

## PICOSEC-Micromegas

- MPGD(micro patter gas detector)
- Single photoelectron: $\sigma_t \sim 44\mathrm{ps}$
- IBF~ $\sim\mathcal{O}(10^{-1})$



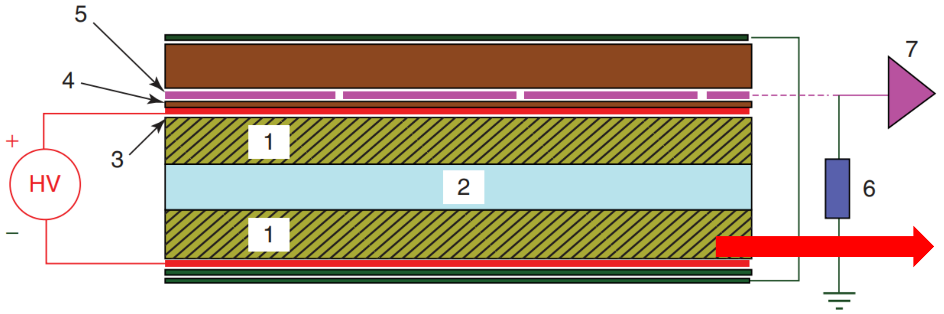

http://dx.doi.org/10.1088/1748-0221/15/04/C04053

## RPC-based photodetector

- One electrode → photocathode
  eliminating the position fluctuation of primary e-
- High and uniform electric field: enhances the quantum efficiency, large drift $v_{e^-}$
- Immediately avalanche of primary photoelectron

better time resolution than PICOSEC, but IBF=1

RPC ($\sigma_t$: $10^2$ps ~ ns)

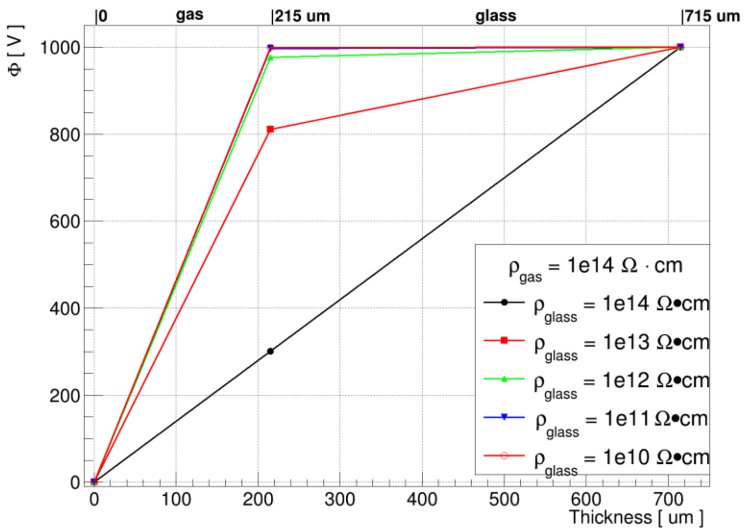



Replaced by photocathode

https://doi.org/10.1002/9783527698691.ch3 P.47

# Simulation – Comsol

## electric field

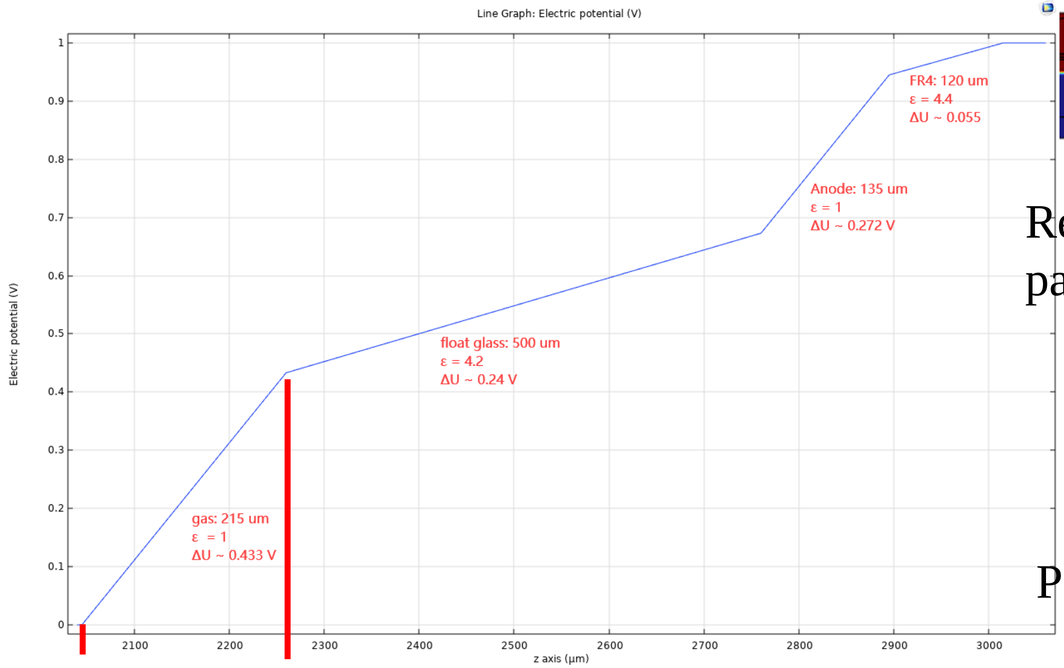


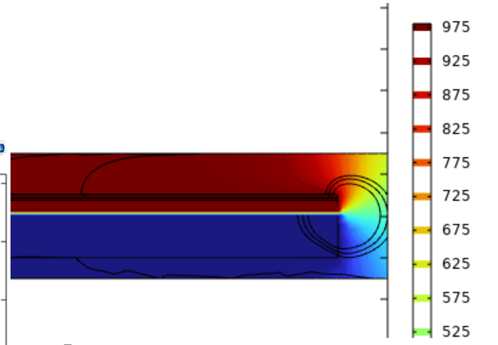

$$\Delta U_{gas} = HV * \frac{\rho_{gas} \cdot l_{gas}}{\rho_{gas} \cdot l_{gas} + \rho_{glass} \cdot l_{glass}}$$

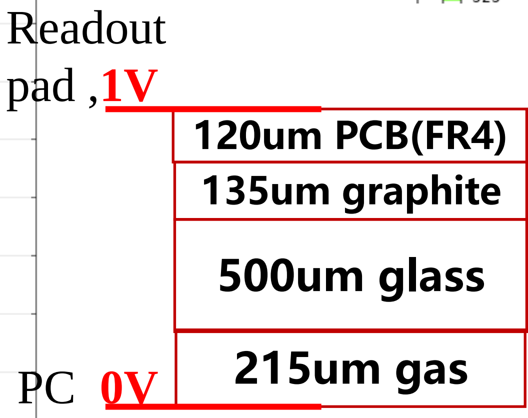
Small current in loop, not electrostatic

$\rho_{resistive\ plate}$↘, $\Phi_{gas}$ ↗, $E_{gas}$↗, Gain↗

## weighting field




Ramo's weighting field theorem

$\Delta U_{W-gas} \sim 0.43\ V$

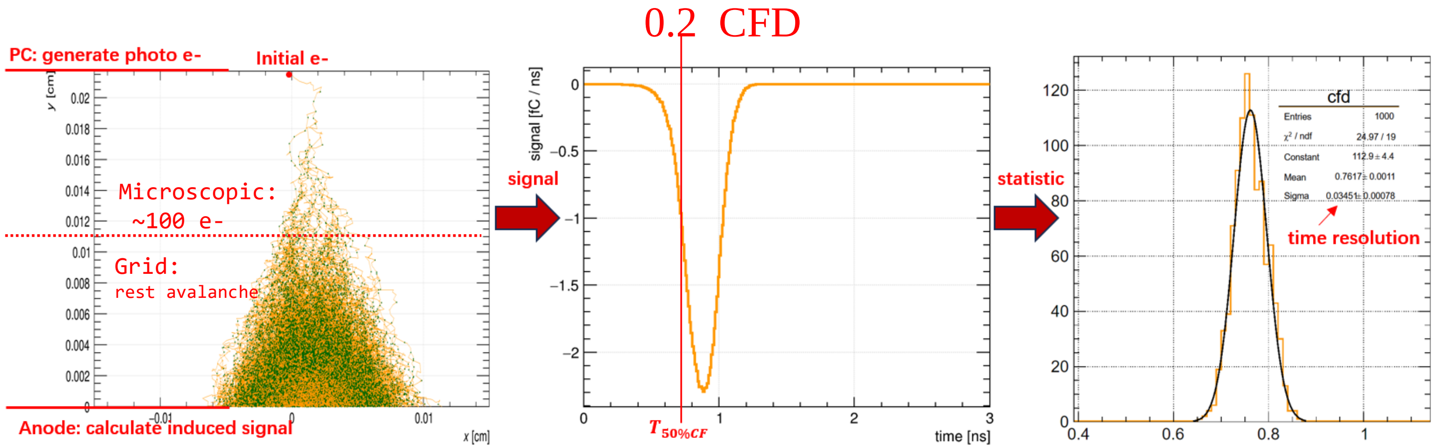
$T_{glass}$(Thicknees)↘, $T_{gas}$ ↗, $\Delta U_{W-gas}$↗, induce signal↗

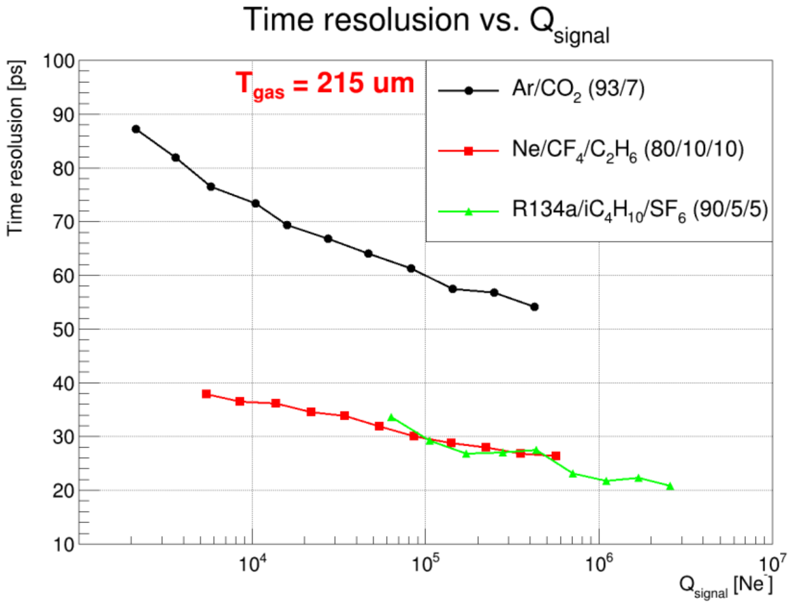
# Simulation

## Garfield++

avalanche → signal → gain, time resolution, etc.

Uniform filed inside gas, allows for a grid-based MC simulation for the avalanche dynamics (fast simulation)
[RPC | Garfield++ (cern.ch)](RPC | Garfield++ (cern.ch))




$$\sigma_{t-single\ e^-} < \sim \mathbf{30ps} \quad @(\text{RPC/Compass gas, 215um})$$

# Experiment

## Detector design and install

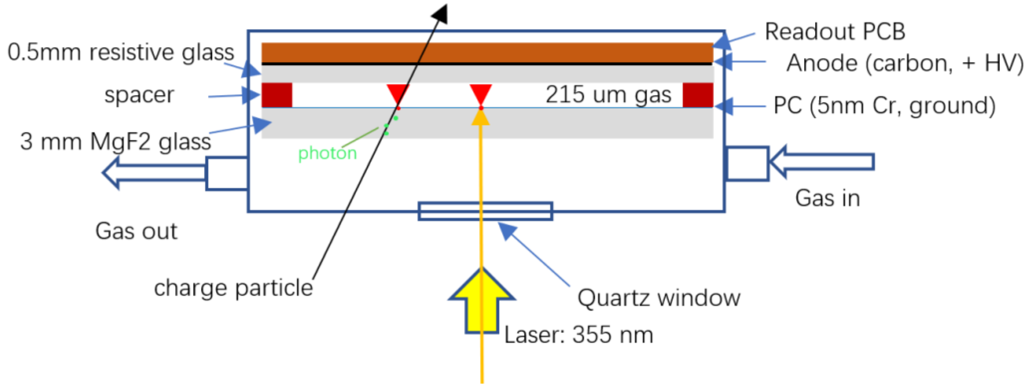



Figure 1: Schematic design of detector.

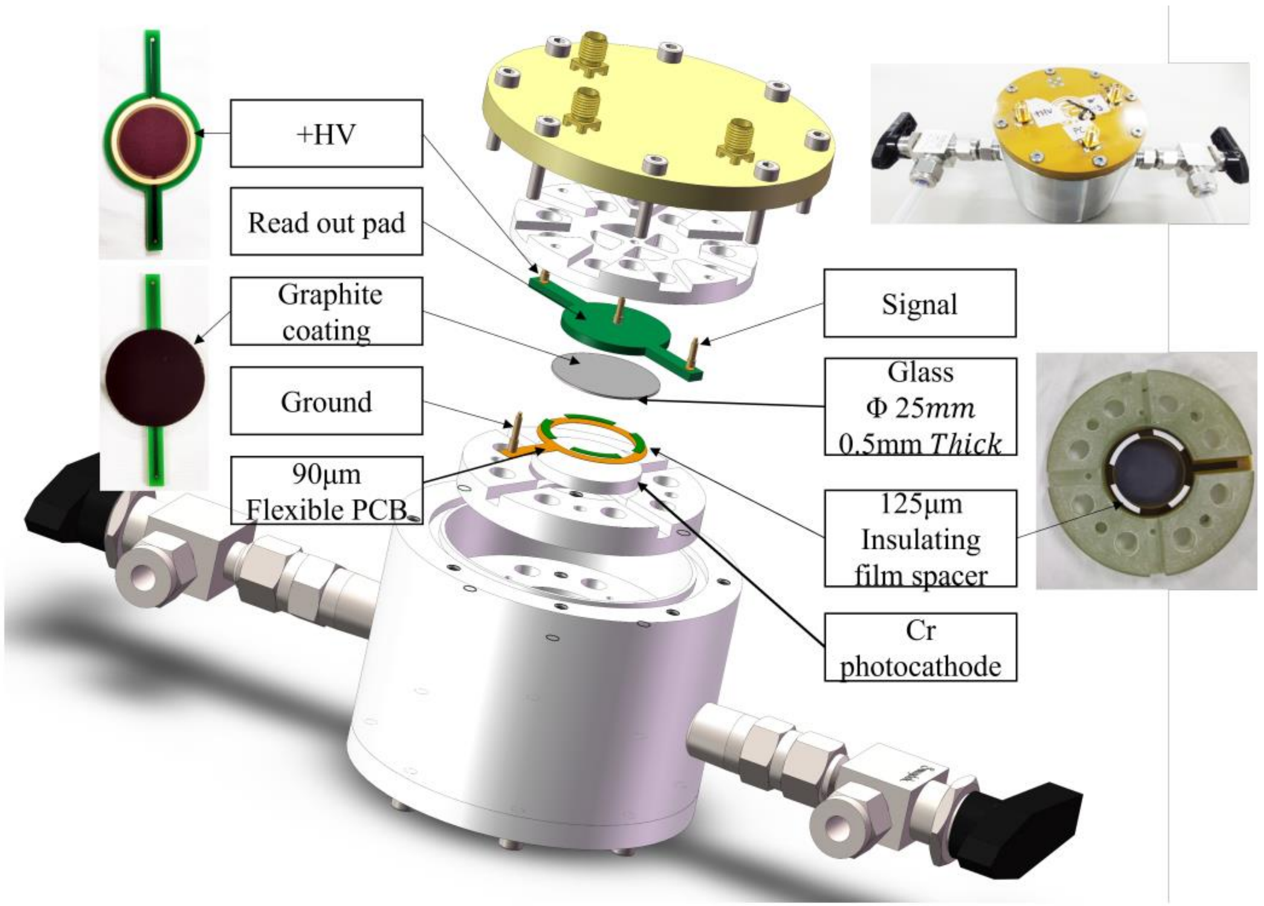


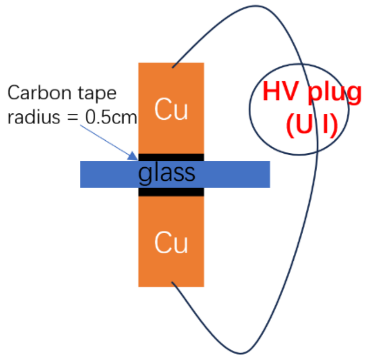

Figure 2: Exploded view and photographs of the detector.

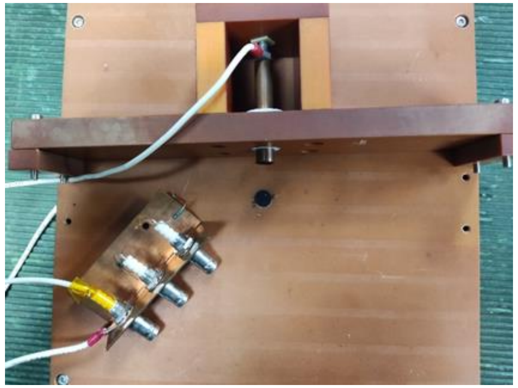
- Resistive glass: 0.5 mm
- Gas gap: 215 um
- Photocathode: 5nm Cr, in lab laser test, use ordinary quartz glass replace MgF2.

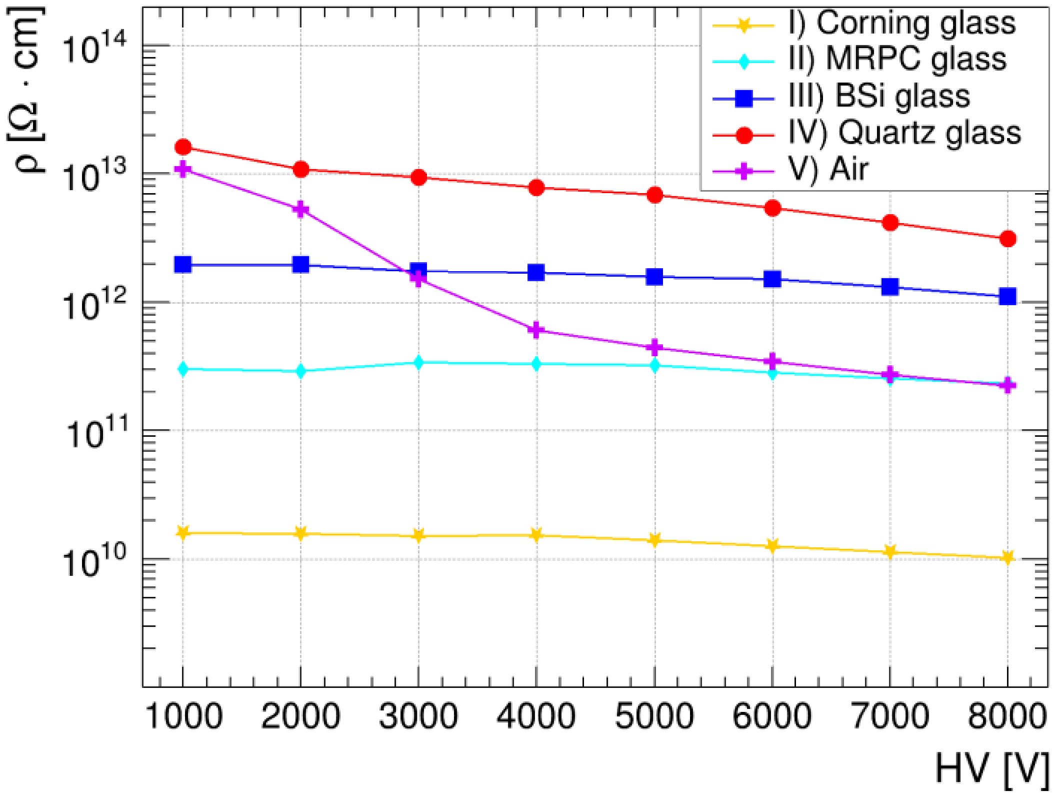
# Resistivity materials — float glass

## Resistivity test

Several types of float glass
Diameters = 25mm, thickness = 0.2mm, 0.3mm, 0.5mm





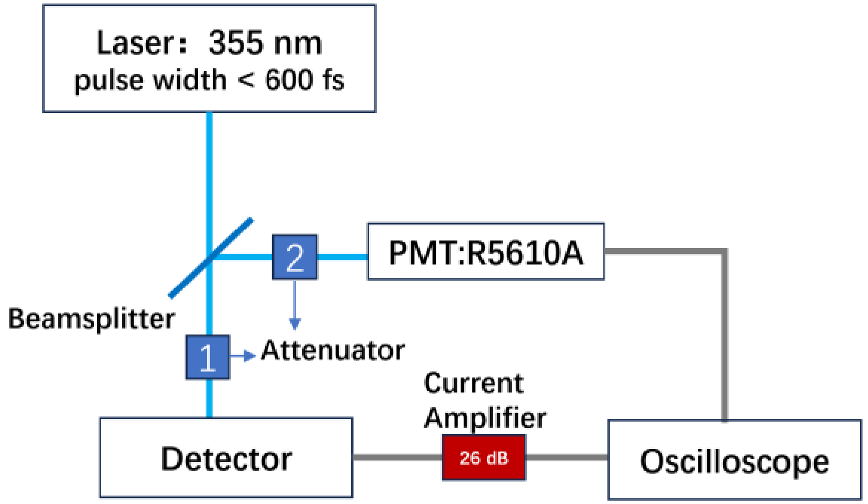

U=IR, $R = \frac{\rho l}{S}$ $\Rightarrow$ $\rho = \frac{U[voltage]}{I[current]}\frac{S[area]}{l[thickness]}$

HV↗, ρ↘

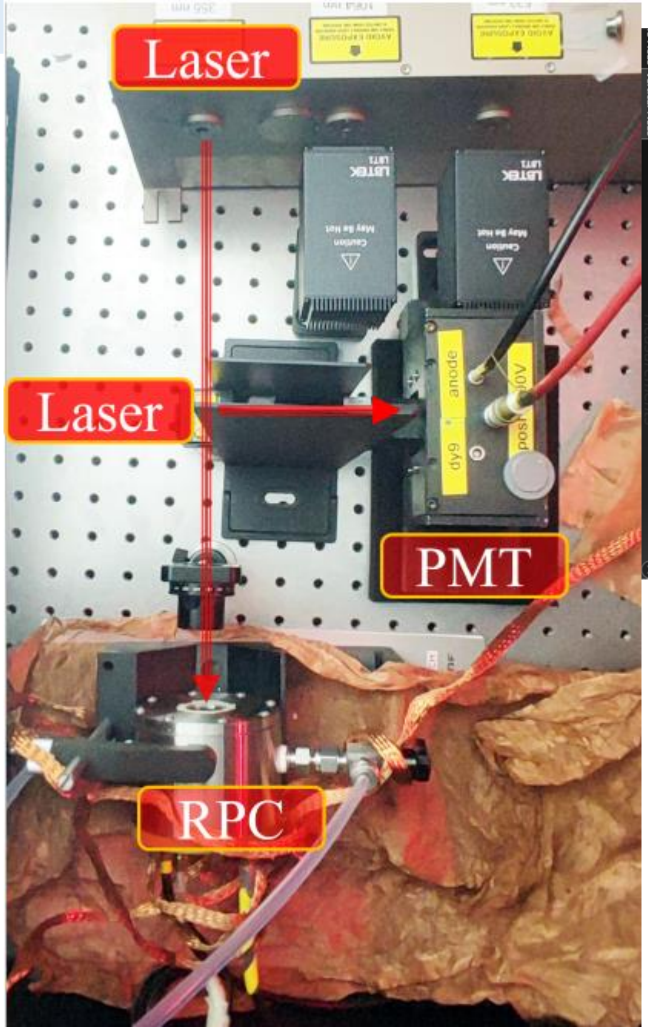
$\rho_{working\ gas} > \rho_{air} \sim 10^{13} \Omega \cdot cm$

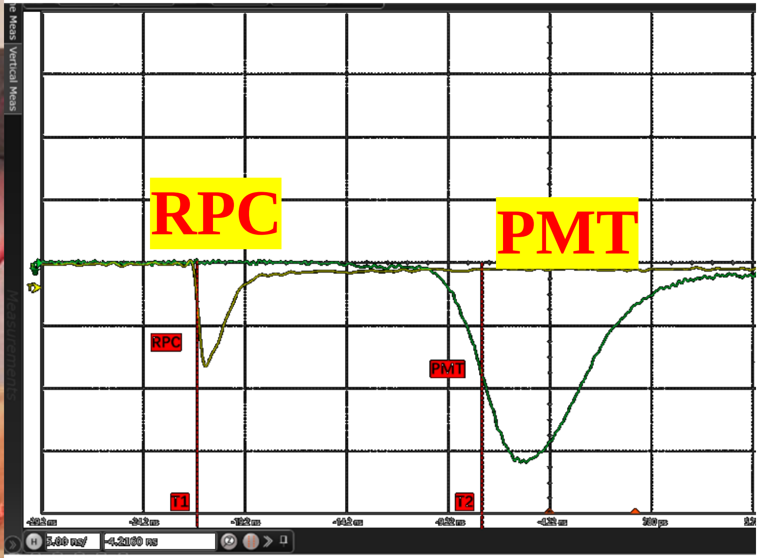
# Test system

## Setup in darkroom




$f_{laser}$: 1Hz~1000Hz
Change laser intensity by adjusting attenuator 1,2
Two signals are collected on the oscilloscope.



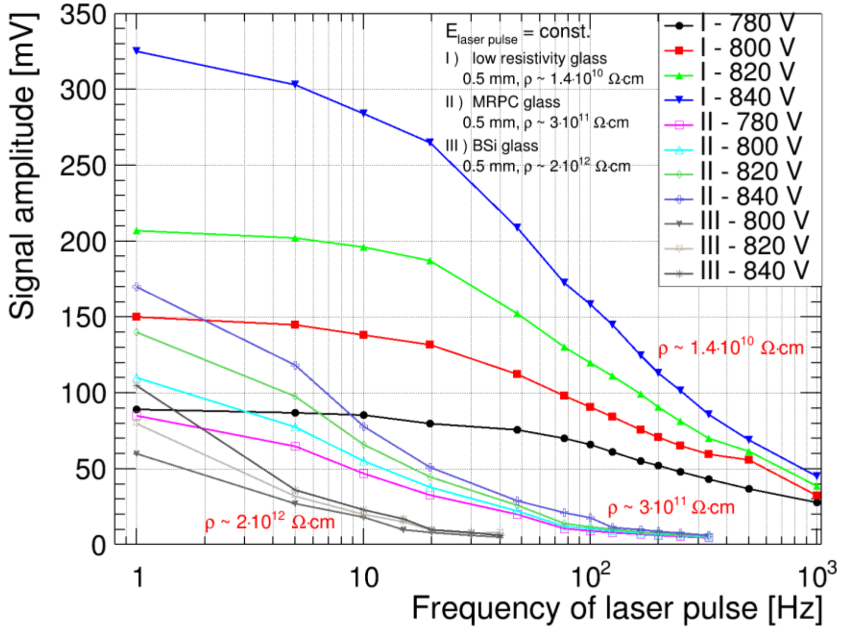

**System's time uncertainty:**

$\sigma_{system} \sim \sigma_{PMT} \sim 10ps$

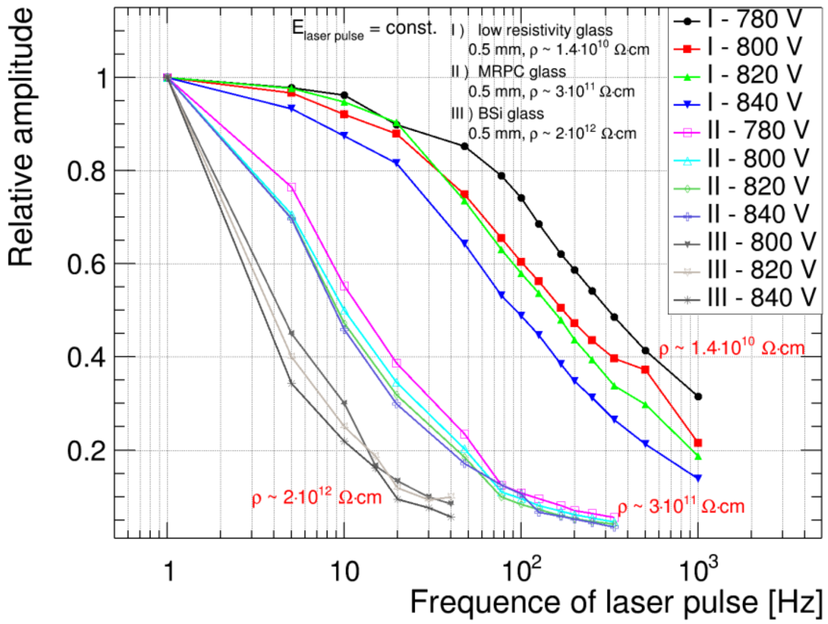
# Rate capability of different $\rho_{glass}$

## Test amplitude of RPC signal

Fix $E_{laser}$, so the number of primary photoelectrons stays the same.
Test $A_{RPC}$ with different glass in Ar/CO2(93/7) as a function of pulse frequency.




Real amplitude




Max amplitude = 1

- At same HV:
  $\rho_{glass}$ ↗, A↘, means smaller $E_{gas}$
- For a same glass
  $f_{laser}$ ↗, A↘, and
  the smaller $\rho_{glass}$, the slower A decreases.

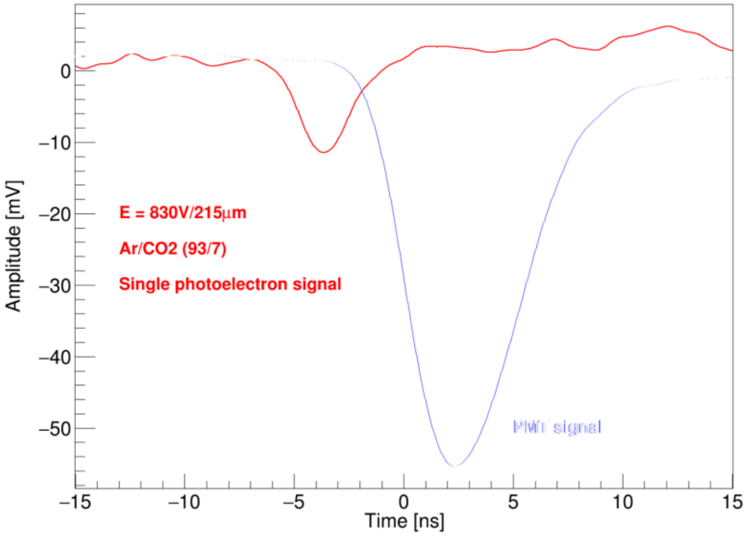
In the later tests, the low resistivity float glass ($1.4 \cdot 10^{10}\ \Omega \cdot cm$, thickness = 0.5 mm) was used.

# Single-photoelectron test

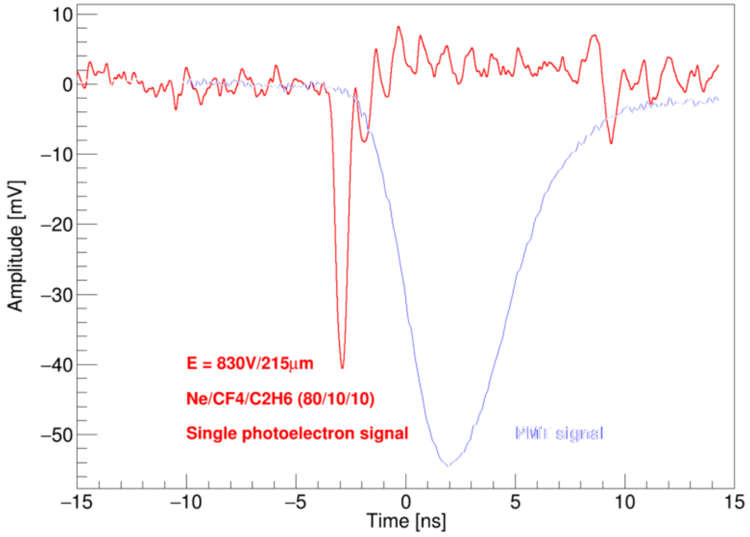
## Single-PE signal when $\frac{f_{RPC}}{f_{laser\ pulse}} < 0.1$

Typical signal of single-photoelectron collected by oscilloscope.
Signal amplitude, width, rise time are obviously different in  different gas.

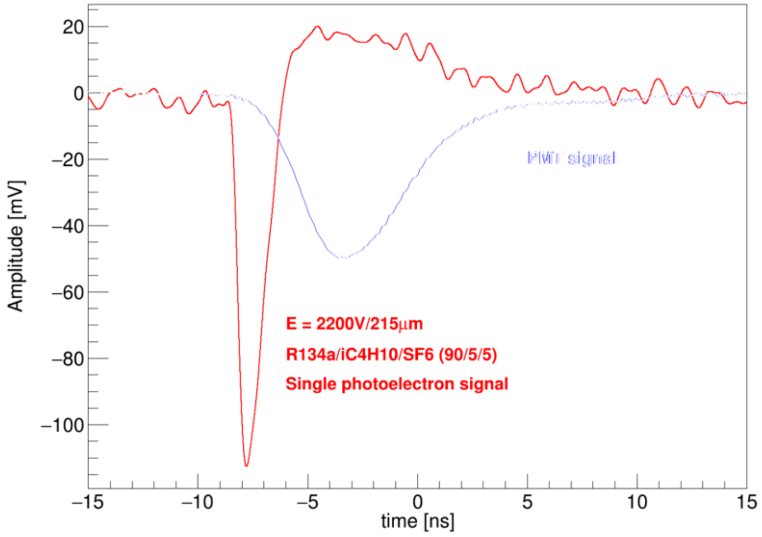
Ar/CO2(93/7)
2 GHz BW due to big S/N




COMPASS gas
Ne/C2H6/CF4(80/10/10)




MRPC gas
R134a/iC4H10/SF6(90/5/5)

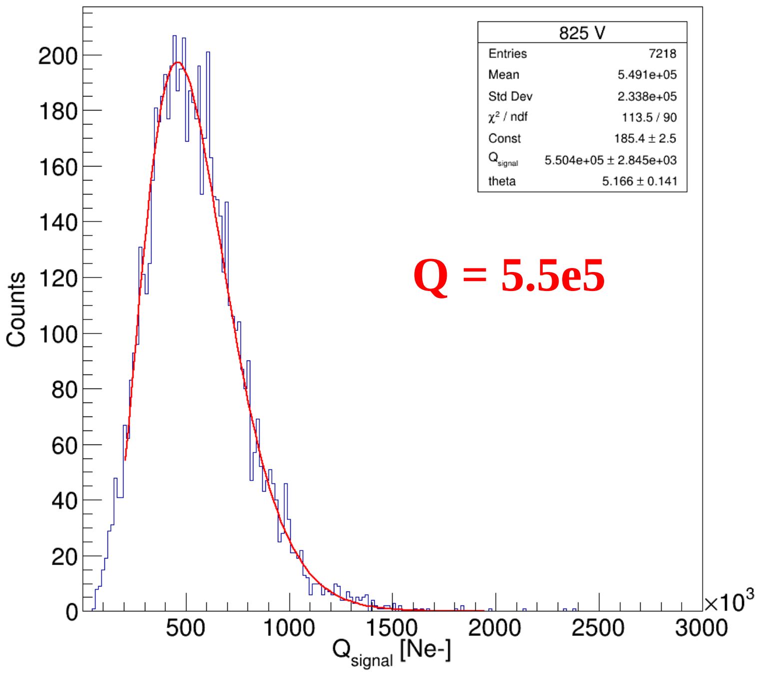


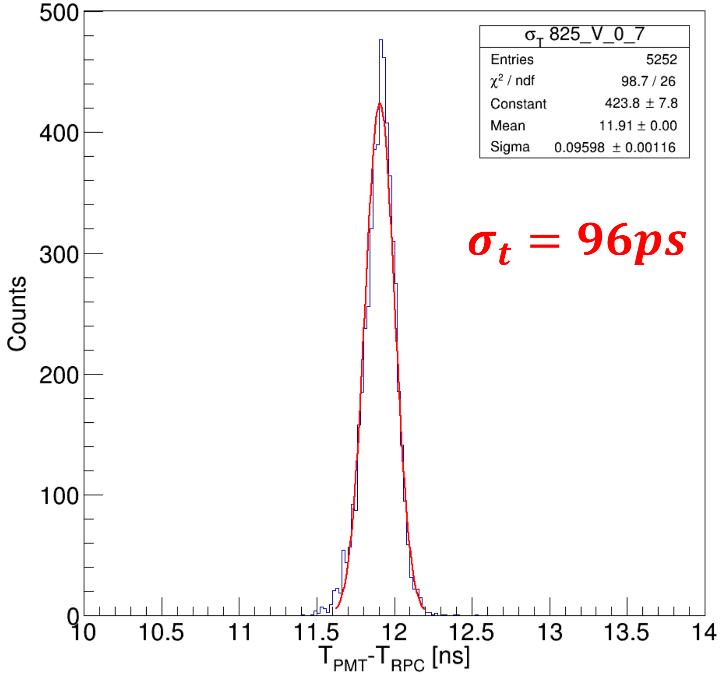
# Time resolution – Ar/CO2(93/7)

$CFD$: constant-fraction discrimination

$$\sigma_{RPC} = \sqrt{\sigma_{total}^2 - \sigma_{system}^2(10ps)}$$

**825 V**



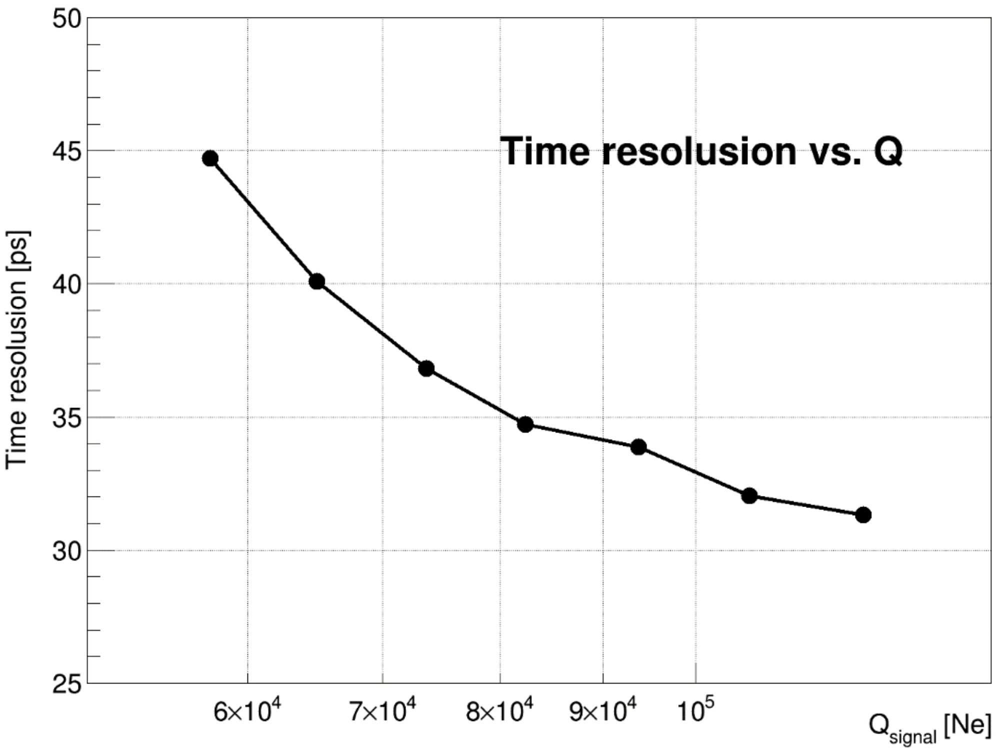

| $CF_{RPC}$ = 0.55, A>6mV | | |
|---|---|---|
| HV[V] | $A_{signal}$[Ne] | Time resolution[ps] |
| 775 | 2.3e5 | 121.9 |
| 800 | 4.4e5 | 100.0 |
| 825 | 5.5e5 | 96.0 |
| 850 | 4.8e5 | 100.9 |

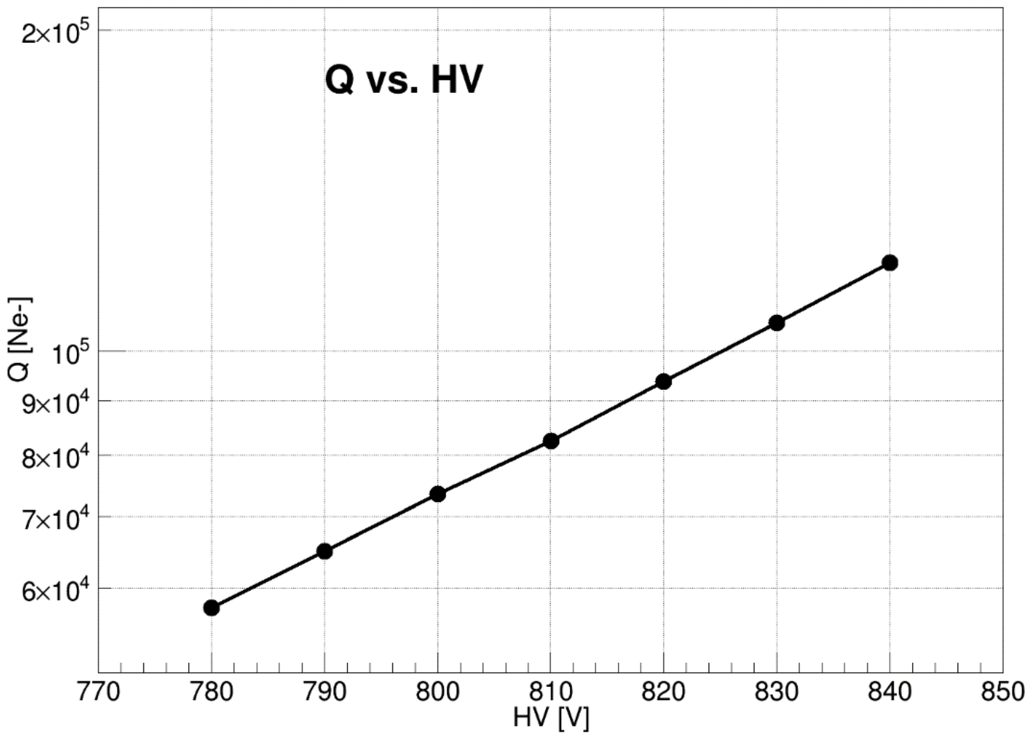
$\sigma_t$ best to 96ps at a gas gain of 5e5.
Ar is not a good working gas, $A_{signal}$ is too small, noise has a big influence, damages time resolution.

# Time resolution – COMPASS gas

**Ne/C2H6/CF4(80/10/10)**

$CF_{RPC} = 0.55$

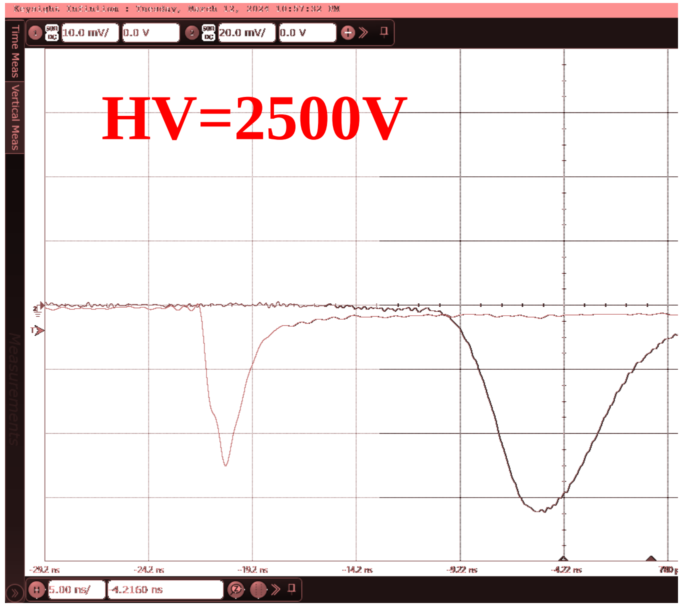


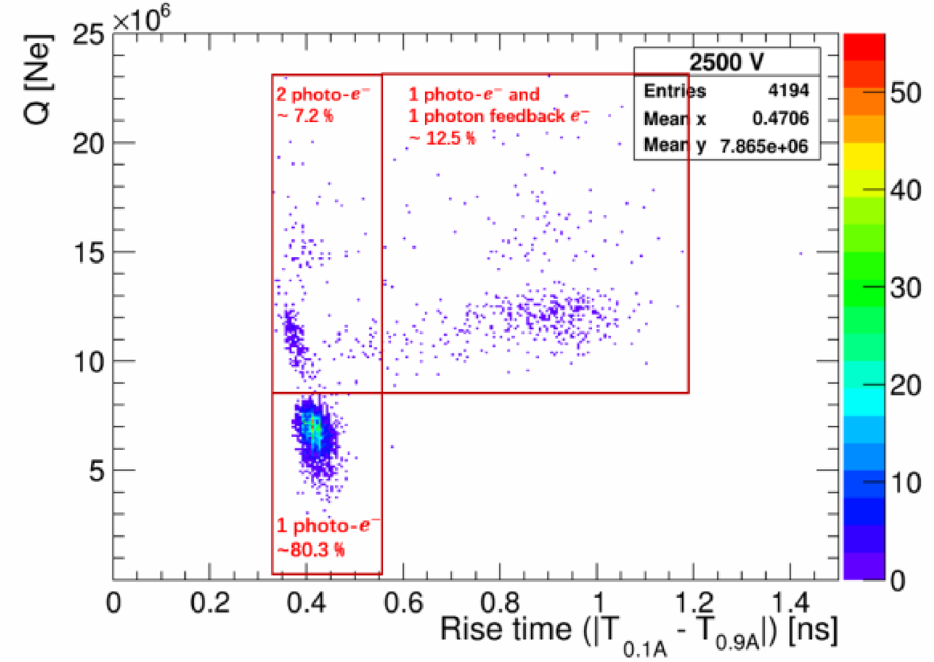



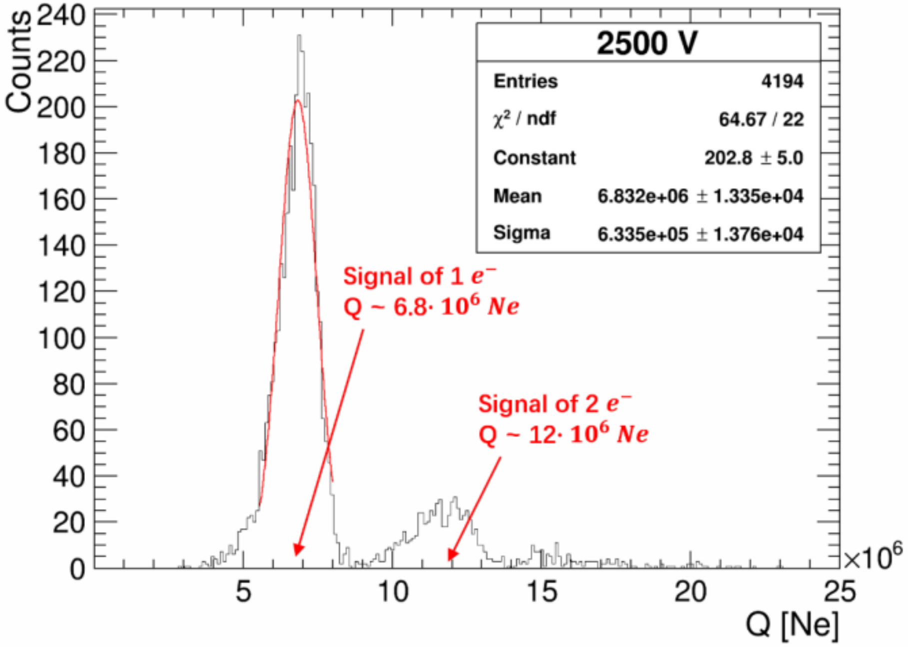

$\sigma_{\mathrm{NPE}=1}$ = 45~31ps at a gas gain of 6e4 ~ 2e5.

# MRPC gas: photons feedback

R134a/iC4H10/SF6(90/5/5)



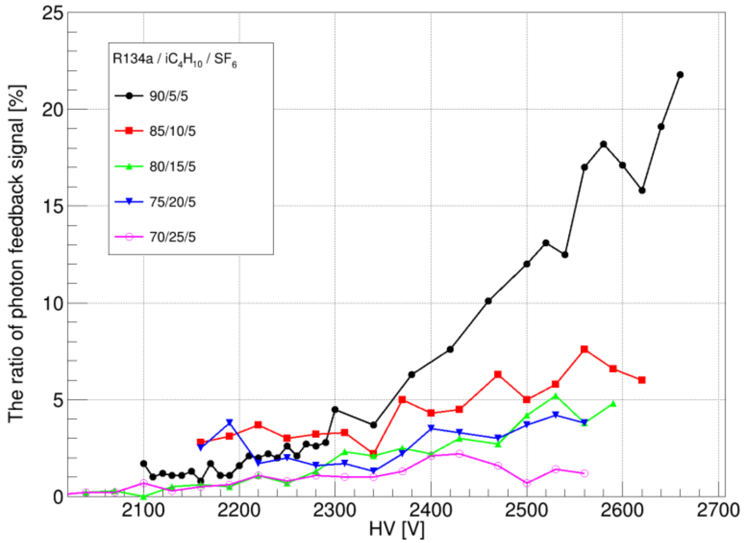

"Double peak", caused by photon feedback: at high HV, UV photons are produced and excited PC or gas to generated a new photoelectron, create a new avalanche.

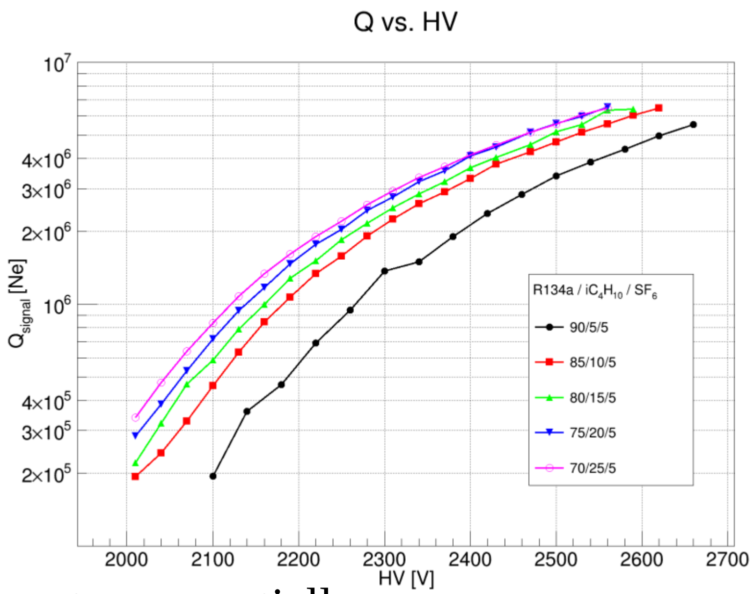
This will make the width and rise time of the signal larger, which is bad for time resolution.

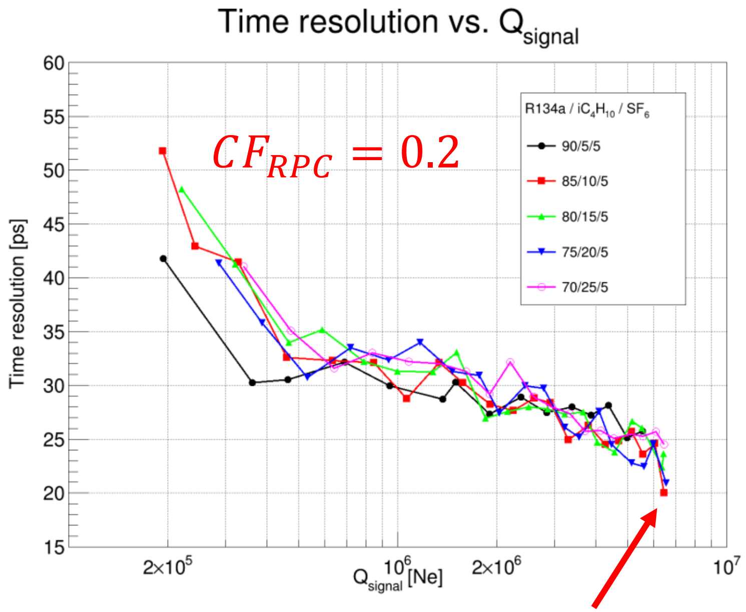
# Reduce photon feedback

Fix SF6 = 5%

Select signals of only one primary PE.




not exponentially, space charge effect

~20.3ps

Increase the proportion of iso-butane can effectively reduce photon feedback.

- Increase iso-butane(decrease R134a):
  1 Greater gain at same HV
  2 The max working voltage became small
  3 No significant change in the time resolution
  $\sigma_{NPE=1}$ best to ~20.3ps (85/10/5)

$\sigma_{\mathrm{NPE=1}}$ = 50 ~ 20 ps at a gas gain of 2e5 ~ 7e6.

# IV Eco-friendly gas test

## Test the single-PE performance

gain, time resolution, working voltage

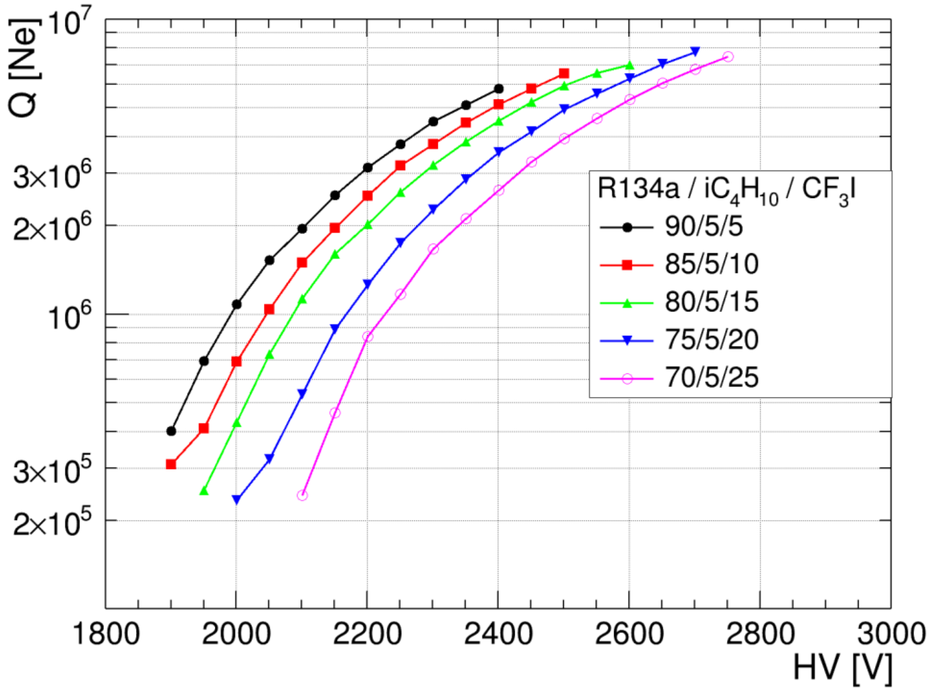
| Gas | formula | GWP |
|---|---|---|
| R134a | CF3-CFH2 | 1430 |
| **R1234ze** | CF3-CH=CHF | <1 |
| **R1233zd** | CF3-CH=CHCl | 1 |
| **R1234yf** | CF3-CF==CH2 | <1 |
| Iso-butane | iC4H10 | 3.3 |
| | SF6 | 22800 |
| | **CF3I** | <5 |

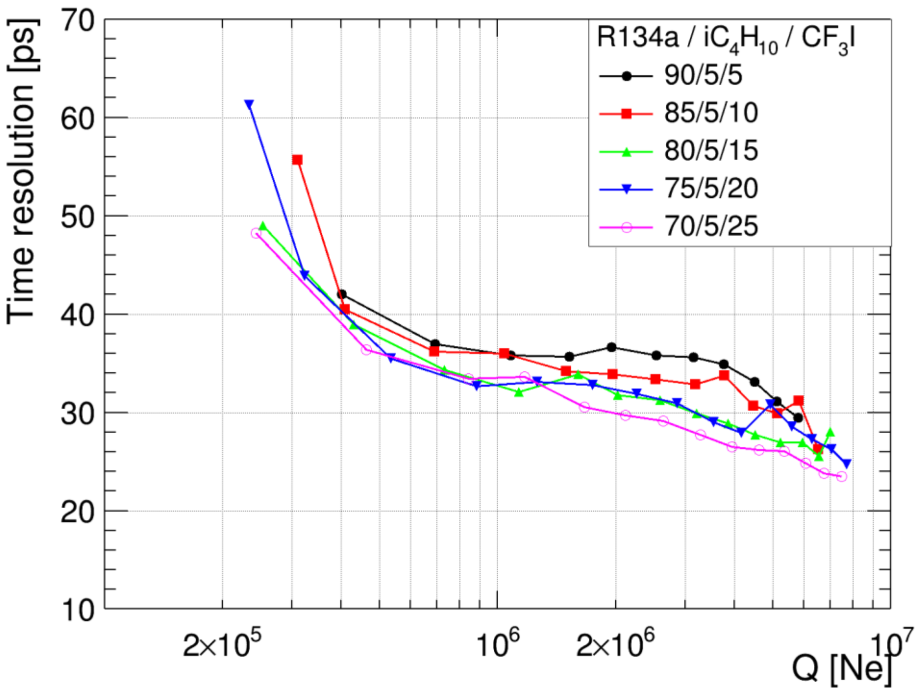
| test schedule | |
|---|---|
| 1 | R134a/iso/SF6 |
| 2 | SF6->CF3I |
| 3 | R134a->R123ze |
| 4 | R134a->R1233zd |
| 5 | R134a->R1234yf |
| 6 | R134a->R123ze<br>SF6->CF3I |

only change the working gas

# SF6 → CF3I

Fix iC4H10 = 5%, CF3I = (5,10,15,20,25)%

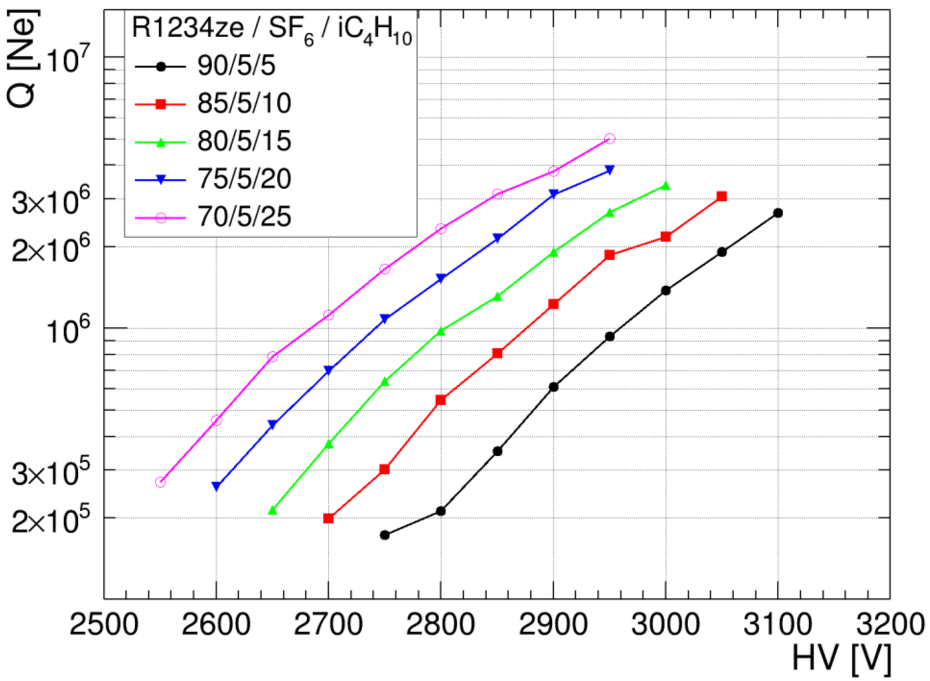


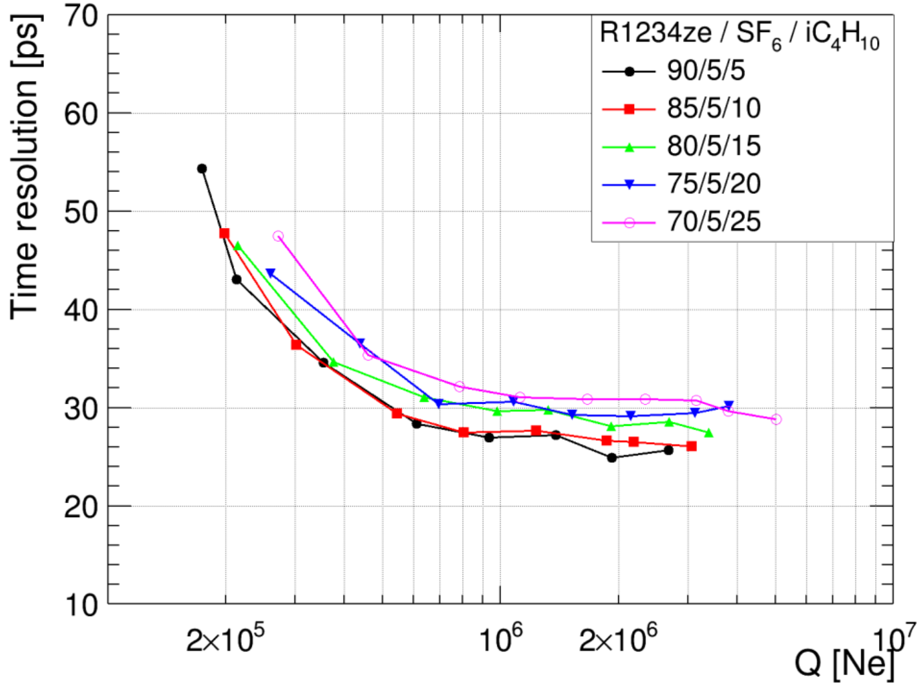




- Increase CF3I: Gain ↘, HV↗, TR↘

# R134a → R1234ze

Fix SF6 = 5%, R1234ze = (90,85,80,75,70)%

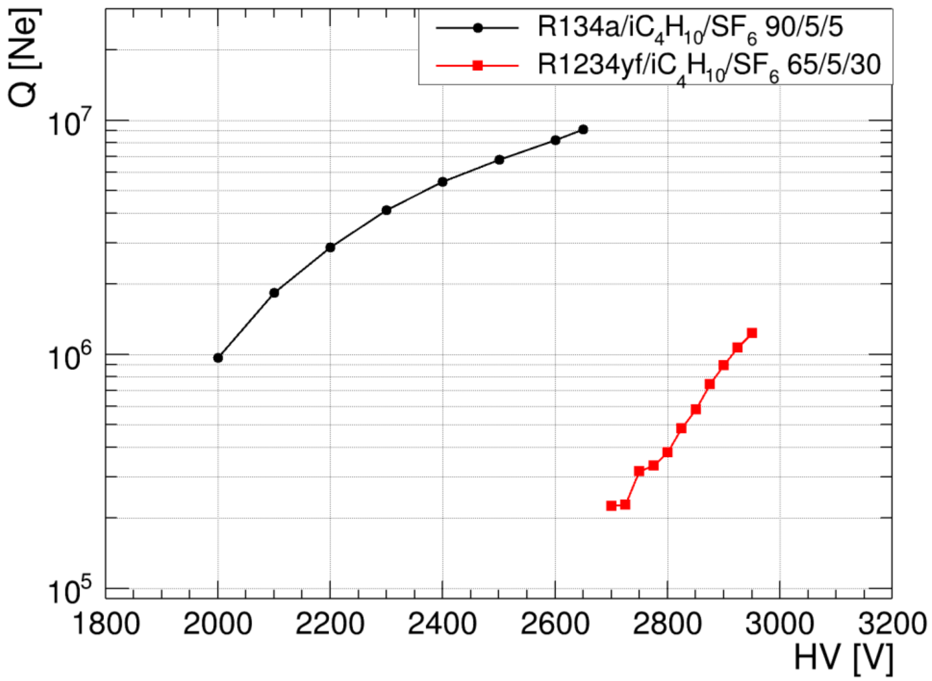


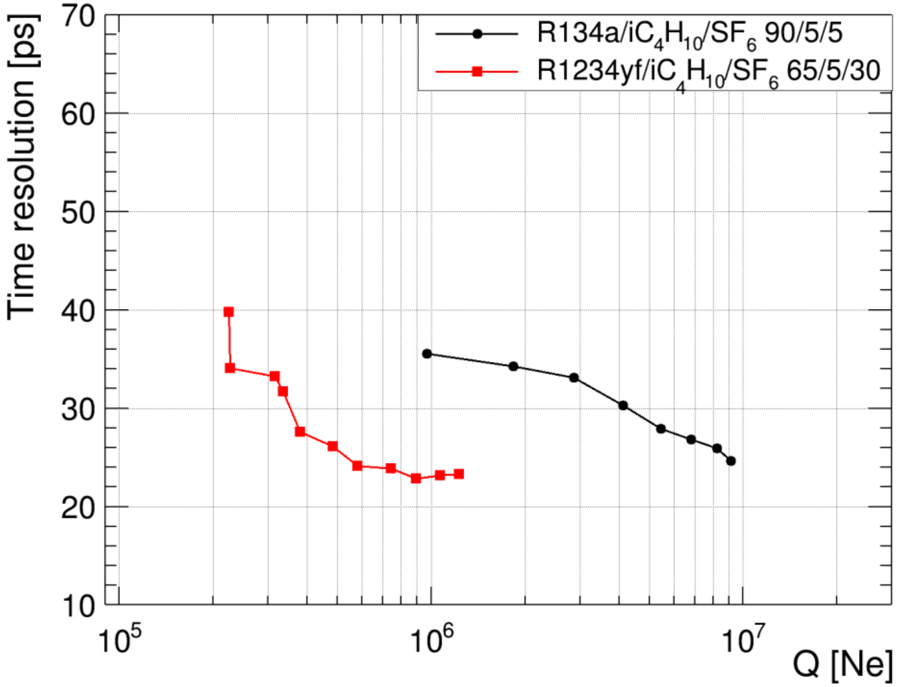




- Increase iC4H10 : Gain ↗, HV↘, TR↗

# R134a → R1234yf

iC4H10 = 5%, R1234yf = 65%, SF6 = 30%




| R1234yf ratio [%] | discharge HV [V] |
|---|---|
| 90 | 2300 |
| 80 | 2600 |
| 65 | 3000 |

- R1234yf: easy discharge.

R134a → **R1233zd** (<3100V)

No signal at all, can't work.

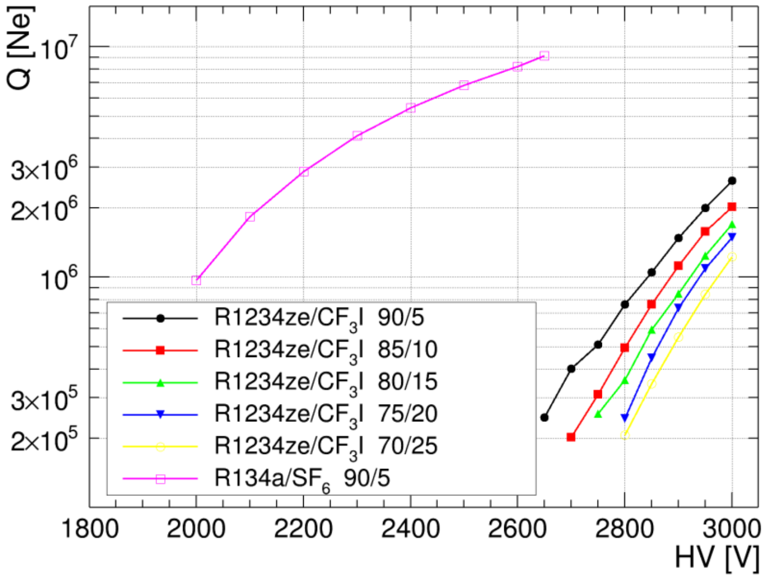
(A flat and peaceful curve on oscilloscope until a big discharge at >~3000V)

HV power supply turn off (rated I~3 mA),
Normal $I_{loop}$ ~ 10 nA
material breakdown.

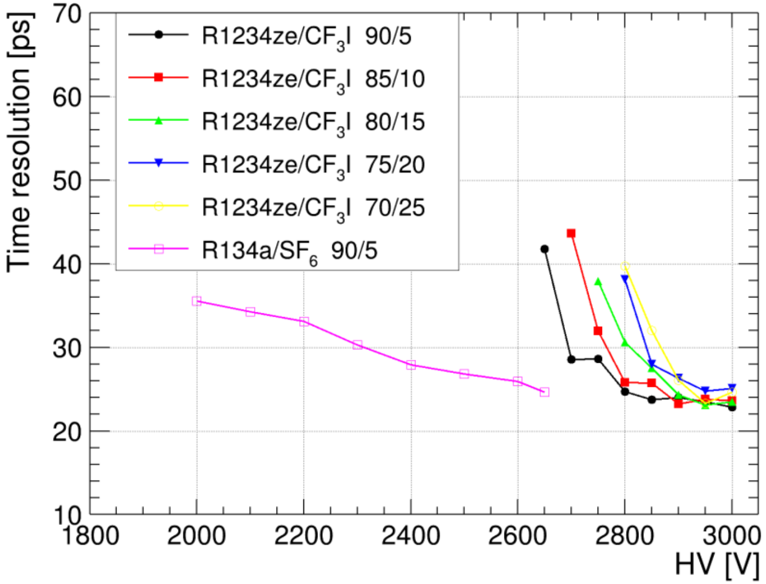
# R134a → R1234ze, SF6 → CF3I

Fix SF6 = 5%, R1234ze = (90,85,80,75,70)%

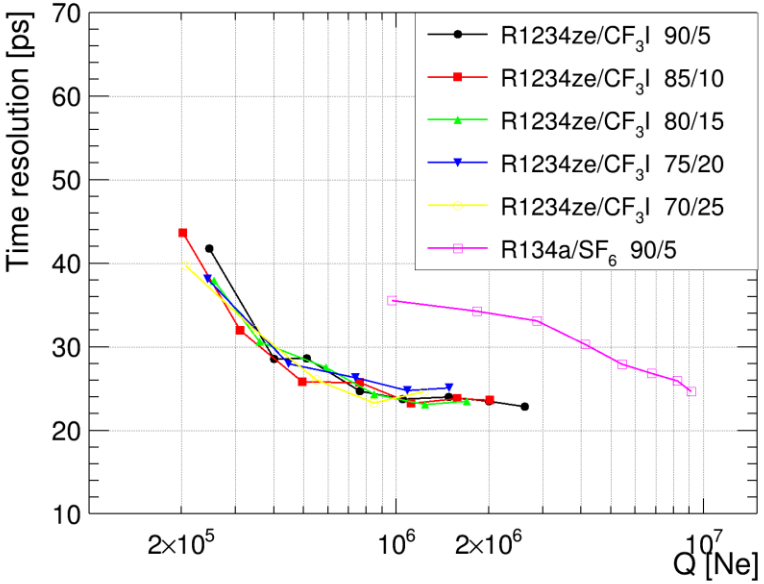
Q(Gain) vs. HV




Time resolution vs. HV



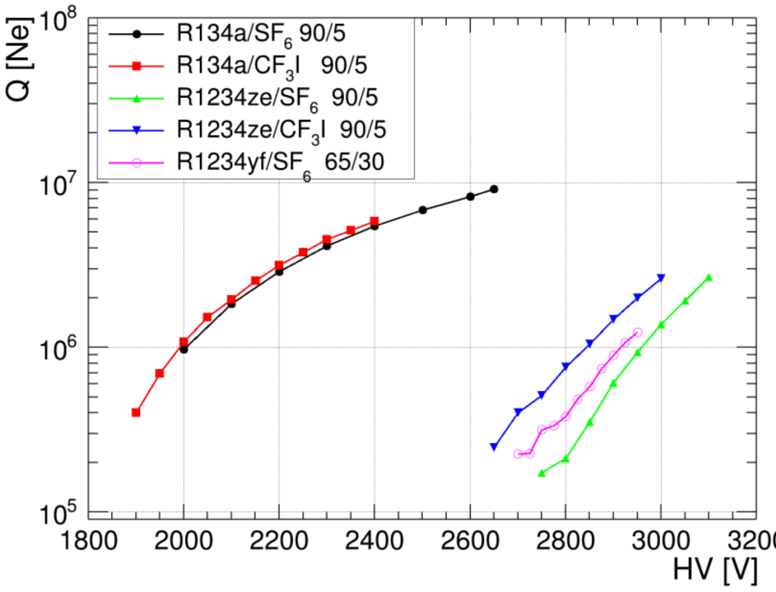

Time resolution vs. Q



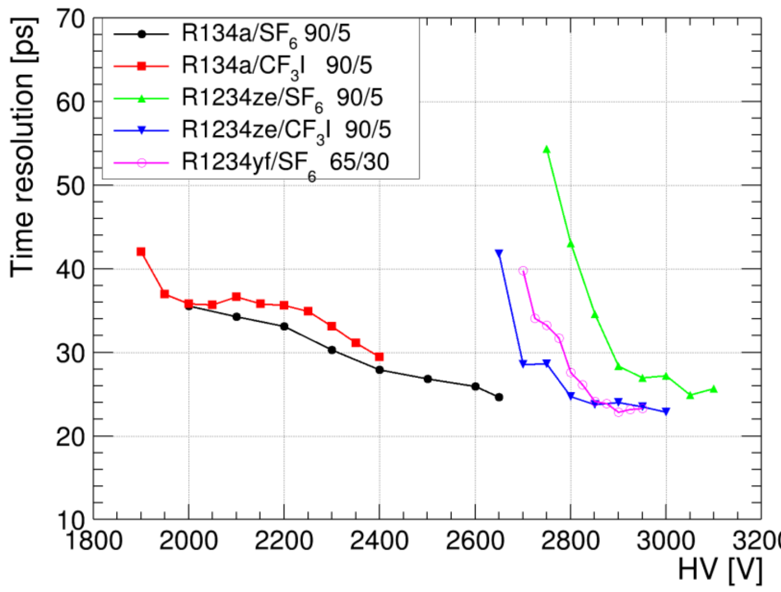

- Increase CF3I : Gain ↘, HV ↗, TR ~unchanged

# Result of all gas, fix iC4H10 = 5%

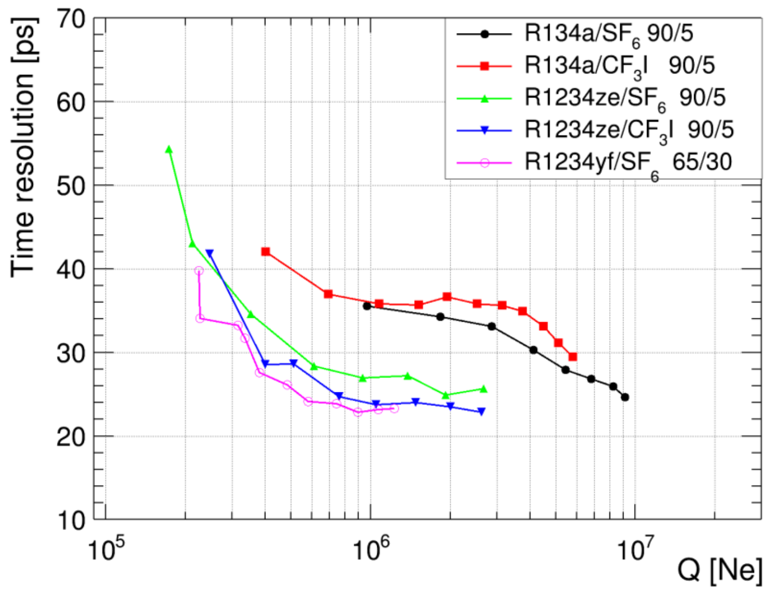
Q(Gain) vs. HV




Time resolution vs. HV




Time resolution vs. Q




R1234ze/iC4H10/CF3I(90/5/5) perform best:
low GWP, good TRvsQ, moderate working voltage

# Summary

1. Develop a photoelectric gas detector protype with RPC structure

2. Rate capability improved $10^1 \sim 10^2$ $times$ than typical
   Cheap low $\rho$ float glass: $\rho \sim 1.4 \cdot 10^{10} \Omega \cdot cm$ (typical: $10^{12} \sim 10^{14} \Omega \cdot cm, < kHz/cm^2$ )
   (very hopefully for mass production)

3. $\sigma_{t_{NPE=1}}$ = 52~20 ps (Q: 2e5 ~ 7e6) in standard RPC gas
   $\sigma_{t_{NPE=1}}$ = 45~31ps (Q: 6e4 ~ 2e5) in COMPASS gas

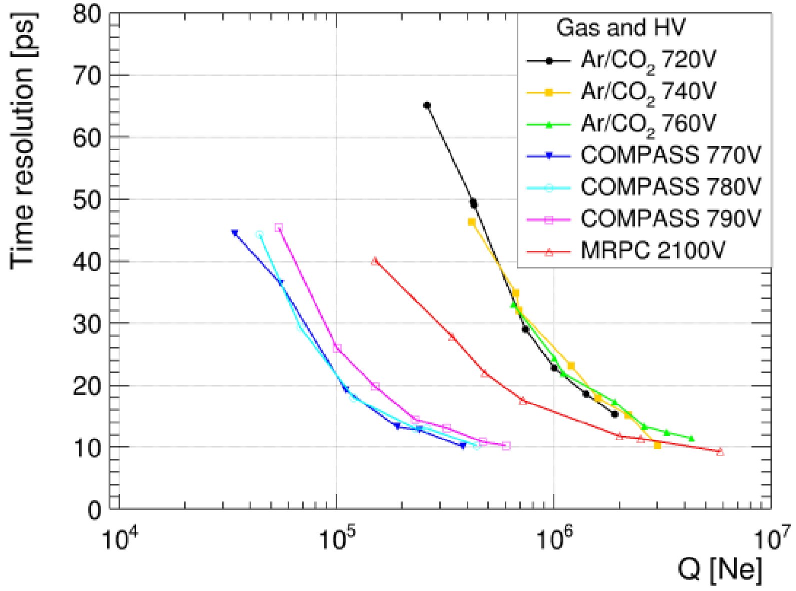
4. Eco-friendly gas test:
   R1234ze/iC4H10/CF3I(90/5/5) perform best

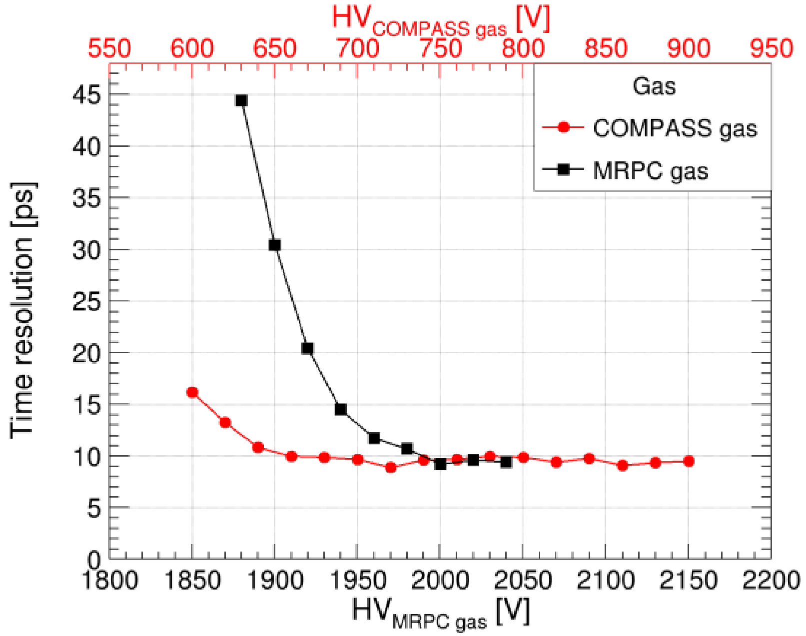
# Backup: more gas test

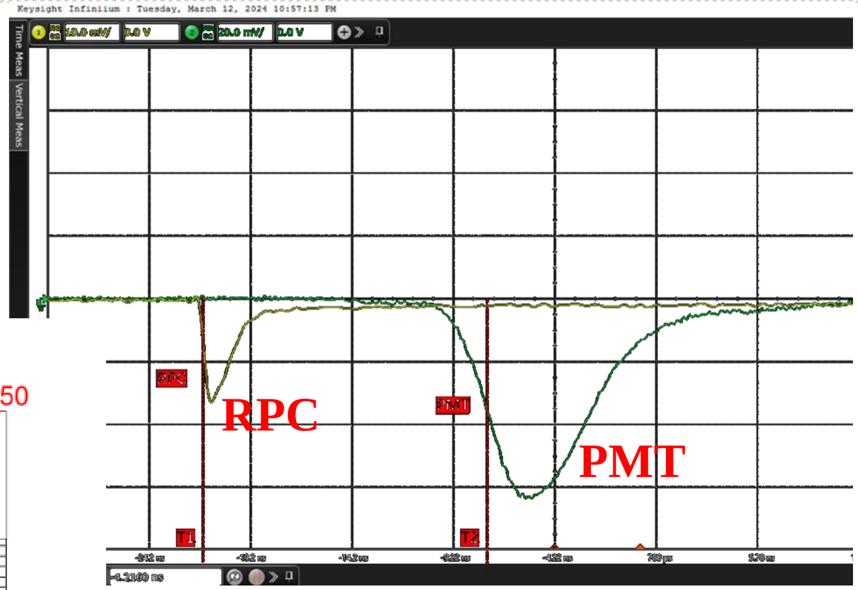
| Num | Gas | ratio | Working HV | Time resolution |
|---|---|---|---|---|
| 1 | Ar/CO2 | 93/7 | 790 ~850 | ~90 |
| 2 | Ne/C2H6/CF4 | 80/10/10 | 780~840 | ~30 |
| 3 | MRPC gas R134a(C2H2F4)/SF6/iC4H10 | 90/5/5 | 2100~2750 | ~29 |
| 4 | | 85/5/10 | 2100~2620 | ~27 |
| 5 | | 80/5/15 | 2100~2590 | ~26 |
| | | 75/5/20 | 2100~2560 | ~26 |
| 6<br>7 | | 70/5/25 | 2100 ~ 2530 | ~25 |
| 8 | R134a/SF6/iC4H10/CF4 | 70/5/20/5 | 2100 ~ 2530 | ~29 |
| 9 | R134a/SF6/iC4H10/C2H6 | 70/5/20/5 | 2100 ~ 2530 | ~26 |

# System's time uncertainty

$PMT$ : Voltage = 280V, amplitude ~50 mV without amplifier(many photoelectrons) (keep constant)
Fix $HV_{RPC}$, increase $E_{laser}$, or fix $E_{laser}$, increase $HV_{RPC}$.



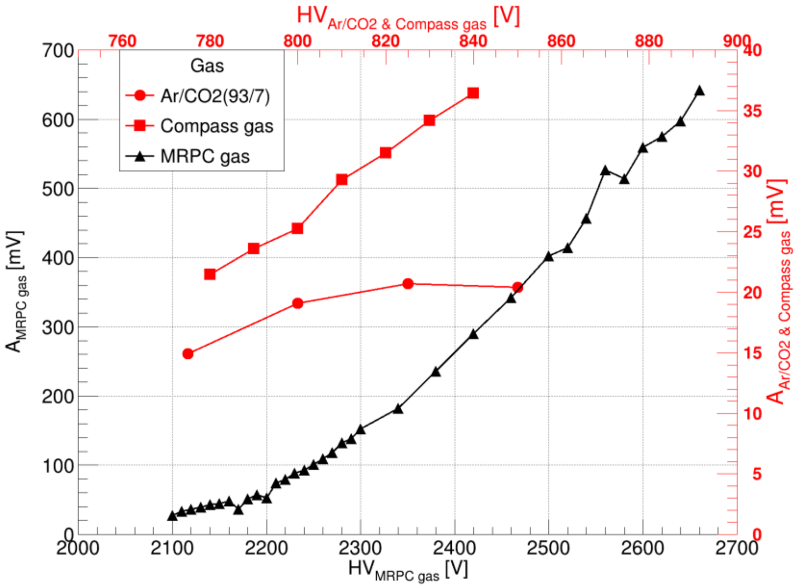



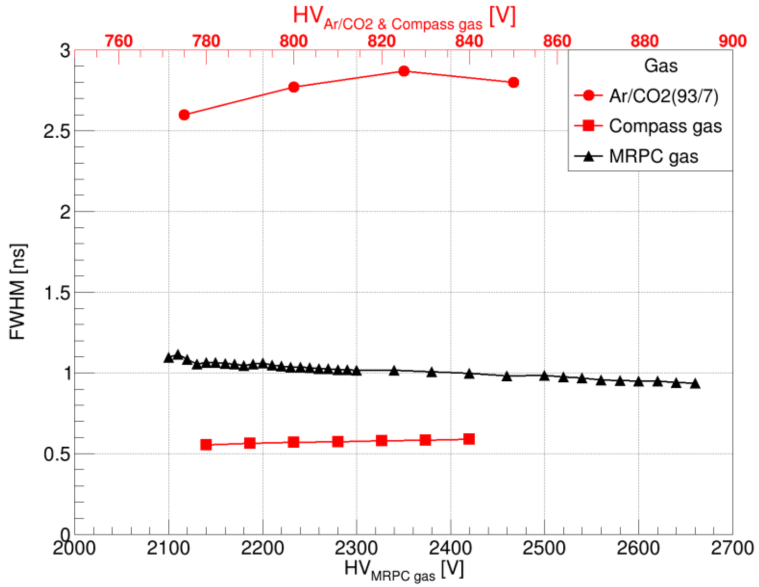



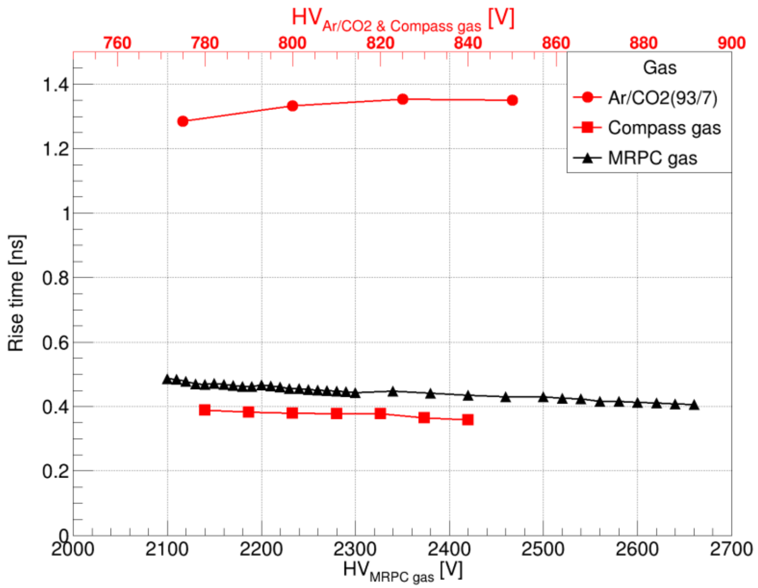

$$\sigma_{system} \sim \sigma_{PMT} \sim 10ps$$

# Signal’s characters

| Gas | Amplitude(mV) x20 | Width[ns] | Risetime[ns] |
|---|---|---|---|
| Ar\CO2 | 15 ~ 20 | 2.6 ~ 2.9 | 1.28 ~ 1.35 |
| Compass gas | 25 ~ 38 | 0.55 ~ 0.59 | 0.36 ~ 0.39 |
| Compass gas | 30 ~ 650 | 0.94 ~ 0.1.1 | 0.41 ~ 0.49 |



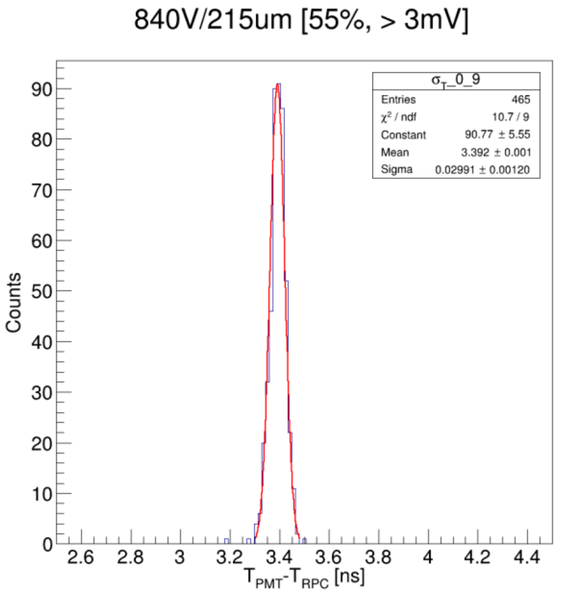



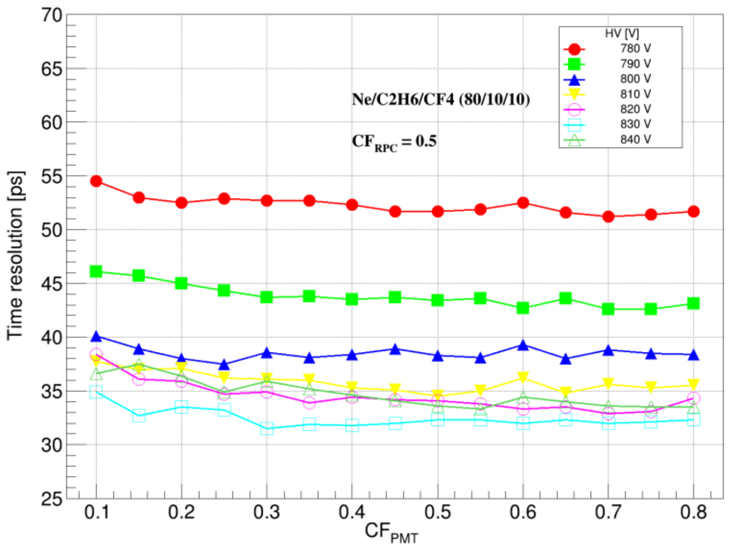
# Time resolution of single-photoelectron

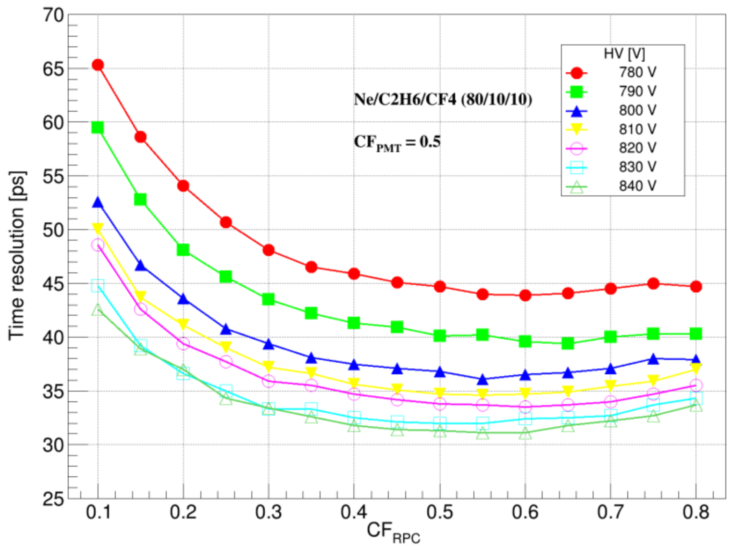
## Constant Fraction Timing (CFD)

$\sigma_{RPC} = \sqrt{\sigma_{total}^2 - \sigma_{system}^2(10ps)}$ How to decide CF coefficients? eg: Compass gas

So in Compass gas,
$CF_{RPC} \sim 0.55, CF_{PMT} = 0.5$




Fix $CF_{RPC} = 0.5, change\ CF_{PMT}$

Fix $CF_{PMT} = 0.5, change\ CF_{RPC}$

$CF_{PMT}$ has no significant influence.

$CF_{RPC} \sim 0.55, \sigma_{totla}$ is best.

# Eco-friendly gas test – fix iC4H10 = 5%

| test schedule | |
|---|---|
| 1 | R134a/iso/SF6 |
| 2 | SF6->CF3I |
| 3 | R134a->R123ze |
| 4 | R134a->R1233zd |
| 5 | R134a->R1234yf |
| 6 | R134a->R123ze<br>SF6->CF3I |

1 reference
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