Demonstration of the 25 ps single-photon time resolution of an RPC-based gaseous photodetector

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Introduction

High time resolution, large area are recent trends for Cherenkov and scintillation detectors in particle physics and nuclear experiments, for example, TOP counter at Belle II, RICH detector upgrade at LHCb, and future upgrade…

Performance of existing photodetectors

	Single-photon time resolution	**Sensitive area**	**Cost / area**
SiPM (FBK near ultra violet, NUV)[1]	$\sigma = 63.9$ ps	3 mm $\times$ 3 mm	Middle
1” MCP-PMT[2] (Hamamatsu, Channel diameter=10 μm)	$\sigma = 30$ ps	23 mm$\times$$23$mm	High
8” MCP-PMT(LAPPD)[3]	$\sigma = 60$ ps	$373\ \mathrm{cm}^2$	Middle (volume cost)

※SiPM: Silicon Photo Multiplier
※MCP-PMT: Micro Channel Plate Photo-Multiplier Tube
※ LAPPD: Large Area Picosecond Photo-Detectors

[1]https://doi.org/10.1088/1748-0221/11/10/P10016
[2]https://journals.jps.jp/doi/abs/10.7566/JPSCP.27.011020
[3]https://arxiv.org/abs/2212.03208

A photodetector with lower cost while keeping time resolution and area is necessary!
We aim to realize a photodetector with a better time resolution, larger area, and lower cost.

GasPM

<u>How to realize a photodetector with a high time resolution, large area, and low cost?</u>

<u>Gaseous detectors</u>

→ Have advantage in scale and cost

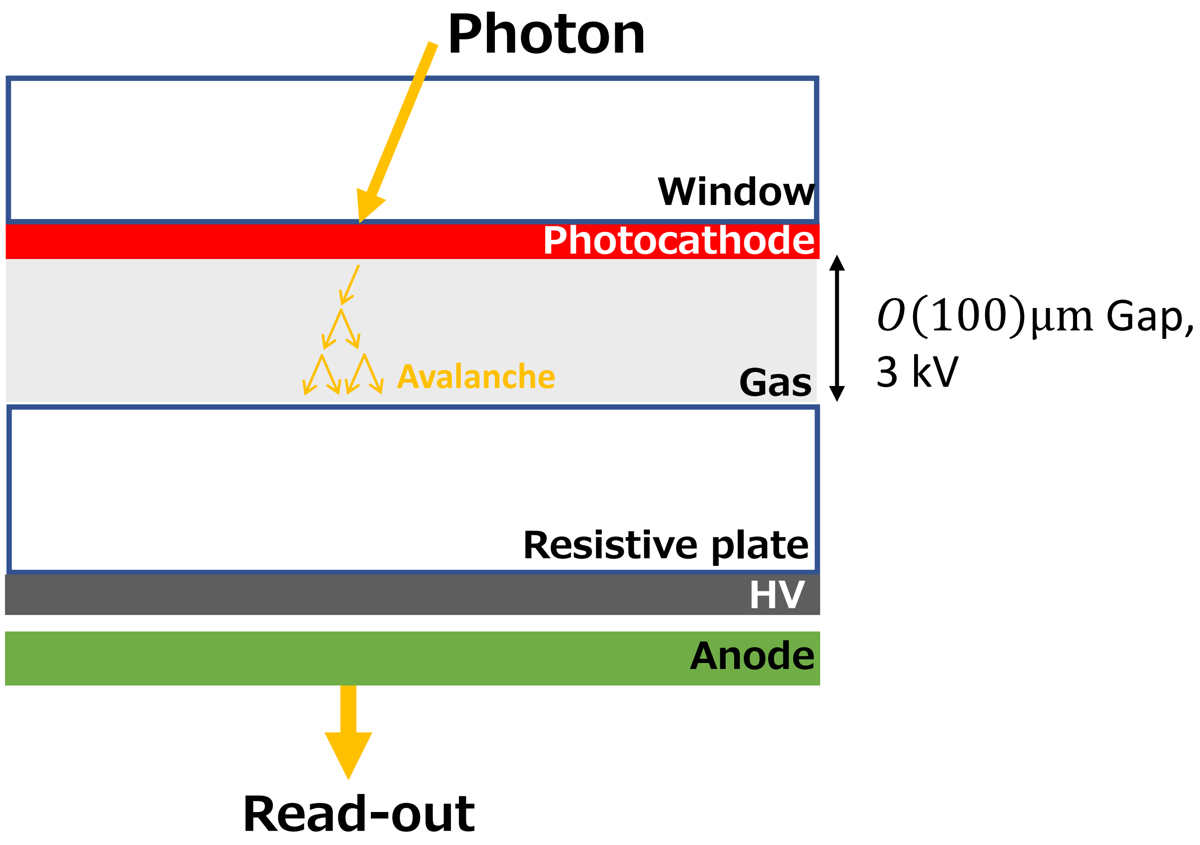
<u>How to achive high time resolution</u>

1.Uniform structure

2.High electric field and narrow gap

→ RPC–based photodetector with a narrow gap

Conceptual diagram of GasPM



1^{st} prototype of GasPM

Developed the first prototype targeting to demonstrate its high time resolution

LaB6 photocathode

Low QE , but stable performance in gas and the air.
→ Easy assembly

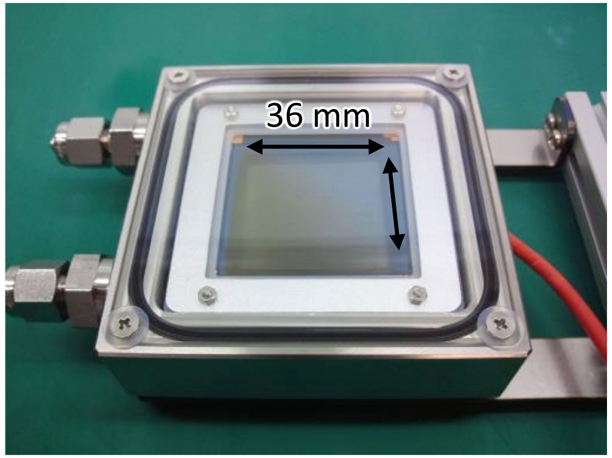
TEMPAX resistive plate

High resistivity ($10^{15}\Omega \cdot \mathrm{cm}$)
→ To concentrate on the timing performance without being disturbed by discharge in the gap at all.

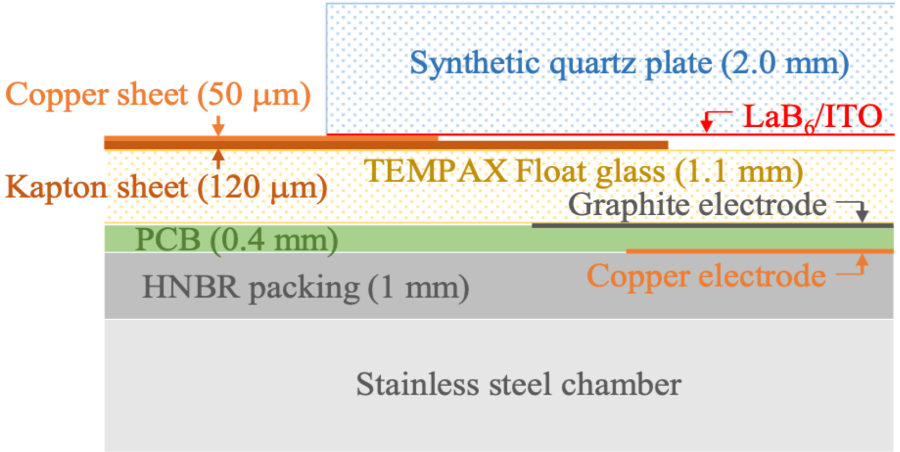
Prototype parameters

- Gap width 170 μm
- Gas: R134a 90%, SF_6 10%
- Applied voltage: 3 kV (176 kV/cm)
- Sensitive area: 36 mm×36 mm

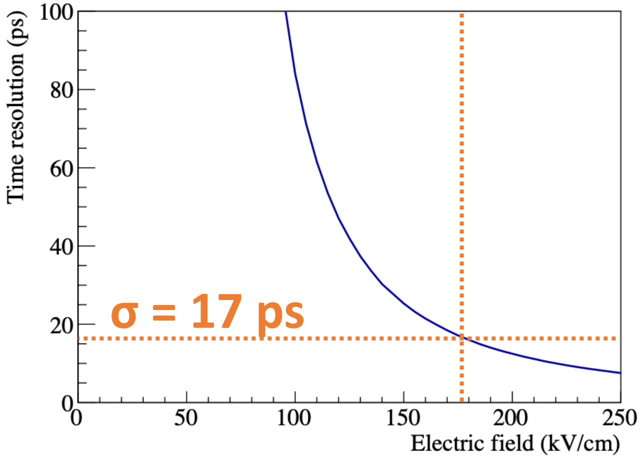
Prototype



Prototype design

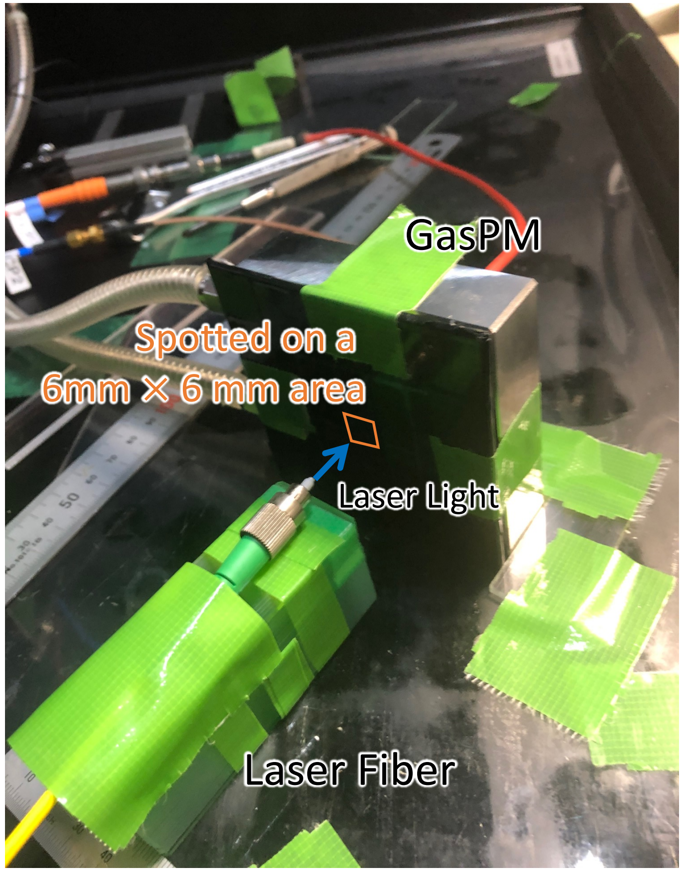


Expected time resolution



Time resolution measurement

Set up



Laser

Picosecond pulse laser with short wavelength and large intensity that is suitable for this measurement

- **Wavelength**: 375 nm
- **Average Power**: 1 mW
- **Pulse width**: 21.8 $\pm$0.5 ps

- **Repetition rate** : 100 MHz
  Laser signal detection rate: 0.02 Hz
  → Single photon
  Random noise rate : 0.3 – 1 Hz

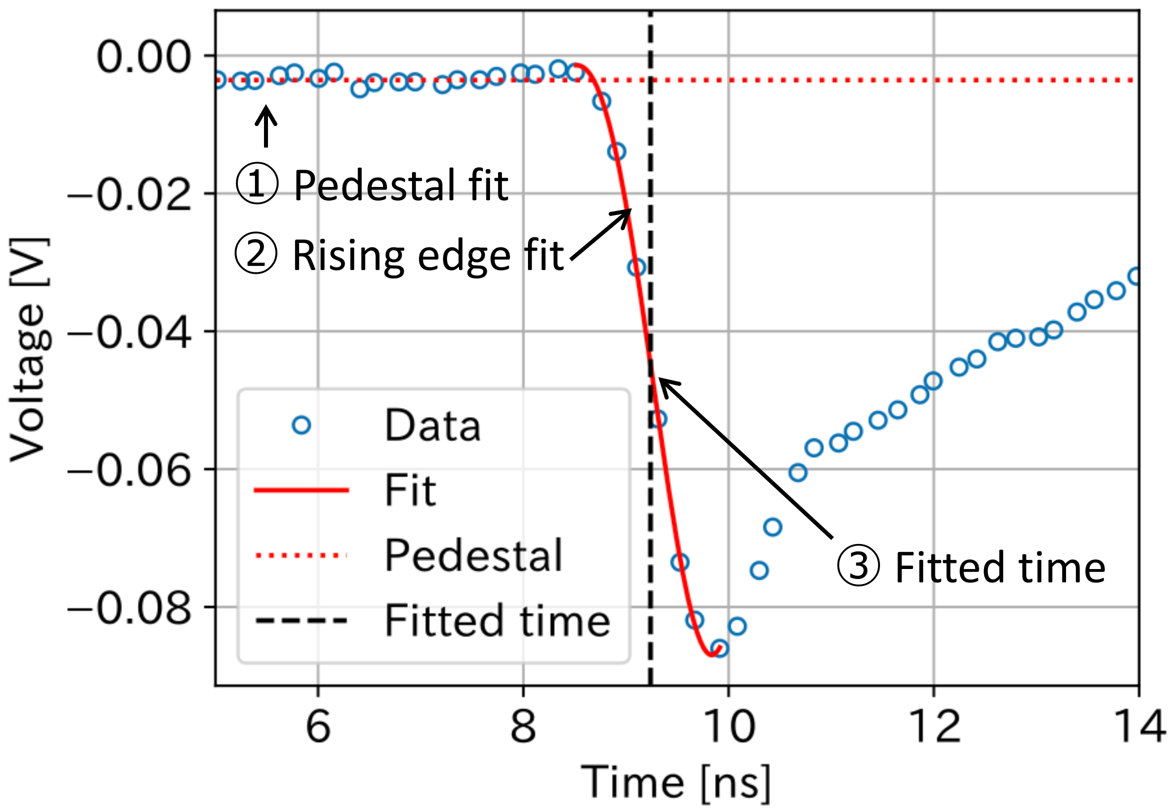
DRS4 evaluation board

Wave form readout with
a good time resolution.

- Sampling rate: 5 G samples / sec
- Analog bandwidth: 700 MHz
- Measured time resolution in this setup: 14.0 $\pm$ 0.3 ps

GasPM waveform

Typical waveform (amplified by 27dB)



Response to single photons

Gain	3.3×10^{6}
Rise time	1 ns

Signal timing determination by fitting

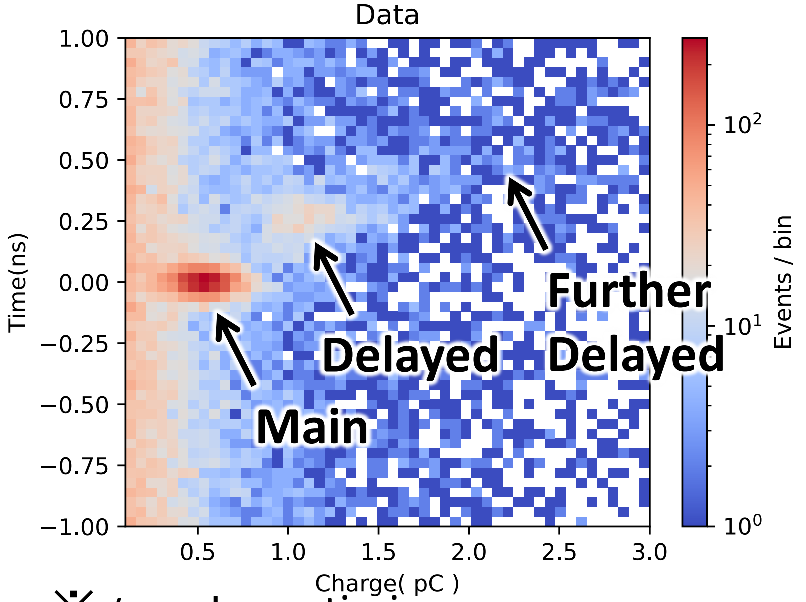
Determine the signal timing as the time when the rising edge reaches half of the maximum voltage

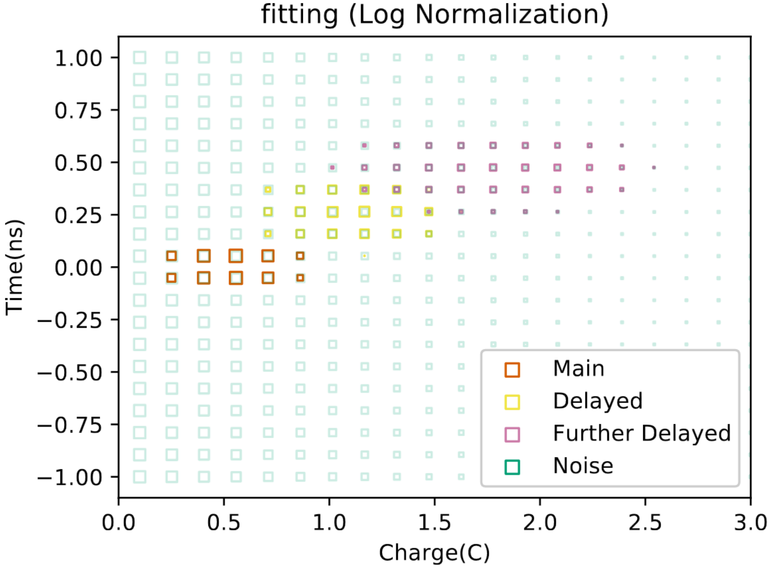
Output charge and timing distribution

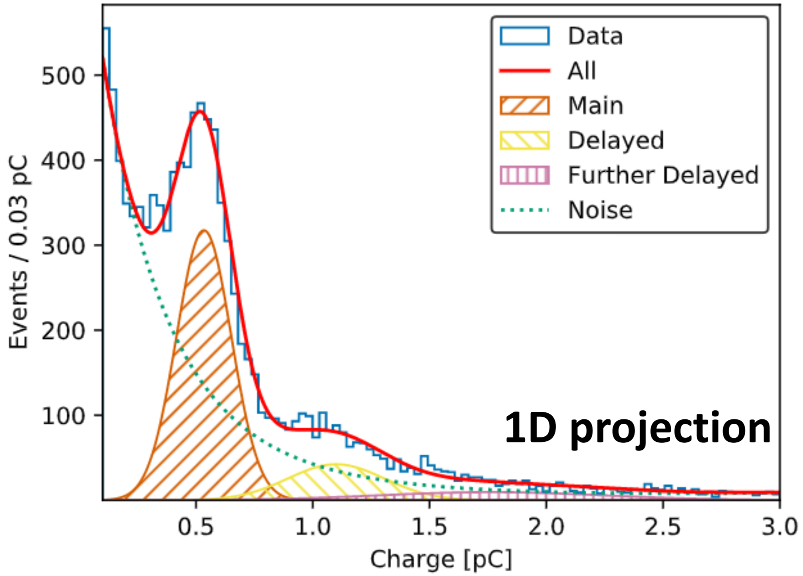
It was found that the signal timing shifts depending on the charge, and laser signals have three components, **Main, Delayed**, and **Further delayed.**

→ Performed the fitting and extracted the yield of each component.

	Yield	Ratio of the signal component
Main	3224 ± 64	**1**
delayed	752 ± 48	**0.23 ± 0.02**
Further-delayed	394 ± 47	**0.12 ± 0.01**

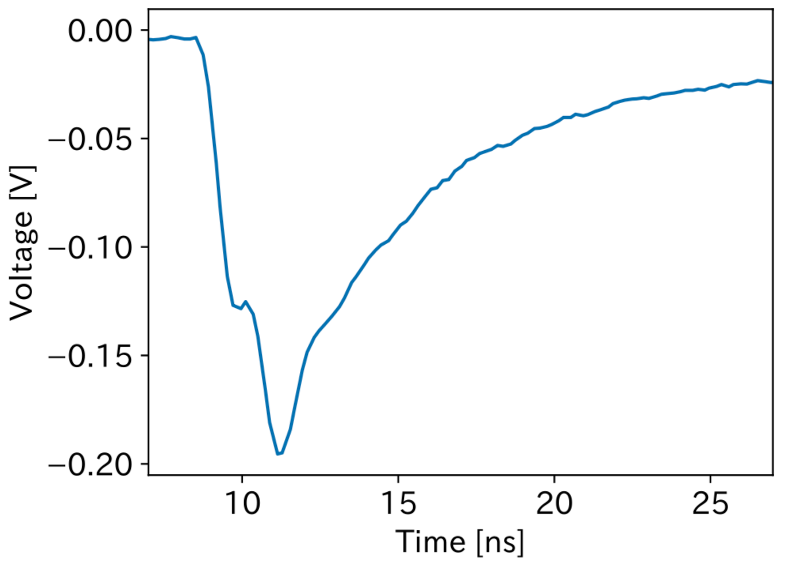






※ t_0 = Laser timing

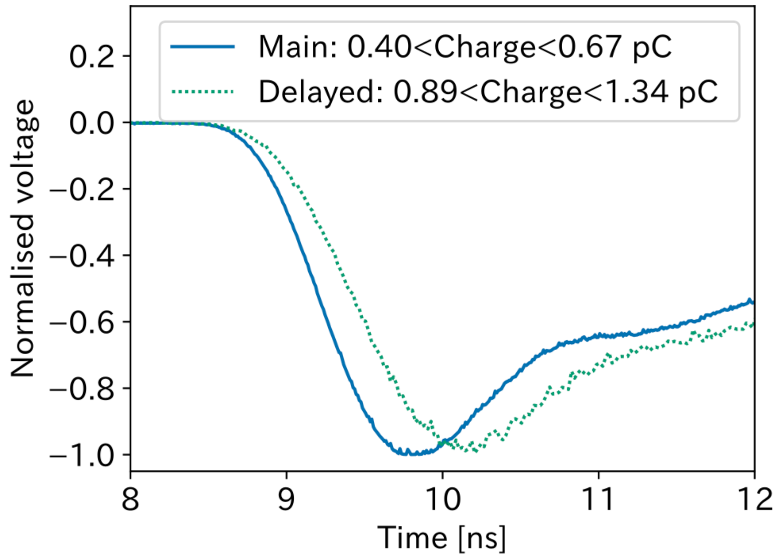
The cause of the "Delayed" signals



Multi-pulse signals

Observed multi-pulse signals when the pulse height is large.

→ Can be the cause of the timing delay.



Averaged waveform

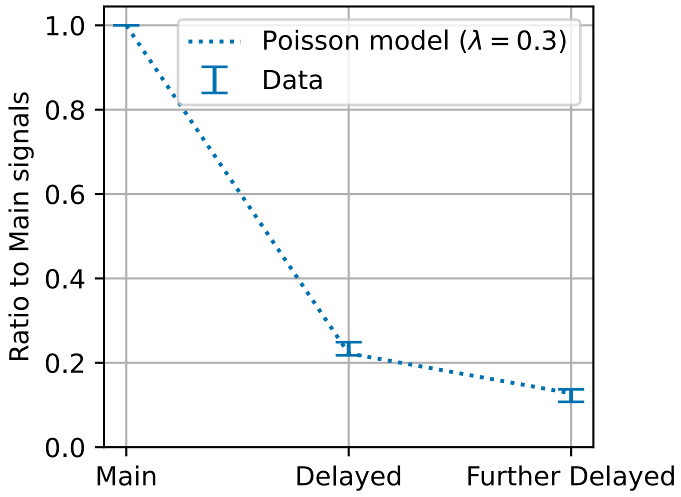
Because the timing of 2 pulses is as close as about 500 ps, many "Delayed" signals look as a single pulse.

However, on average, "Delayed" signals have a slower rising edge. It is because of the multi-pulse.

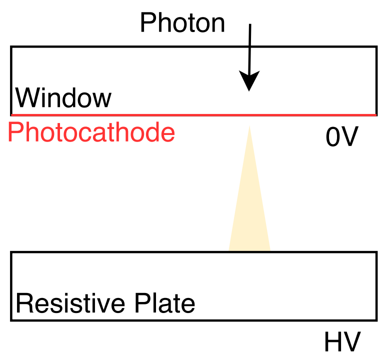
Photon feedback

Photon feedback

Secondary avalanche from UV light due to the gas excitation and deexcitation.
Photon feedback occurrence under the assumption of a Poisson model using the ratio of the signal component: **0.30 ± 0.02**.

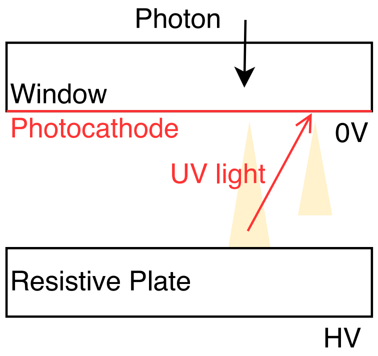


Main



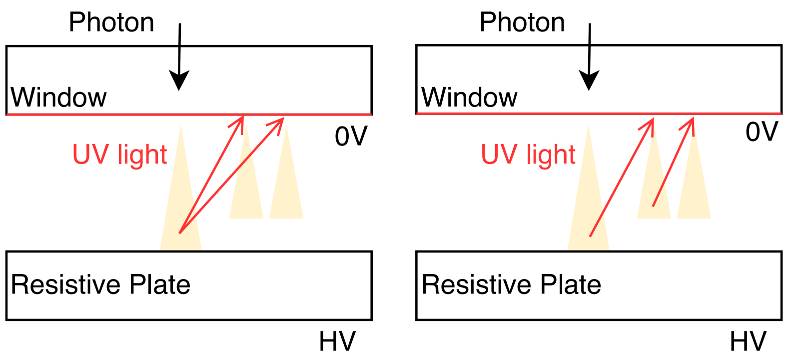
Delayed

1 photon feedback

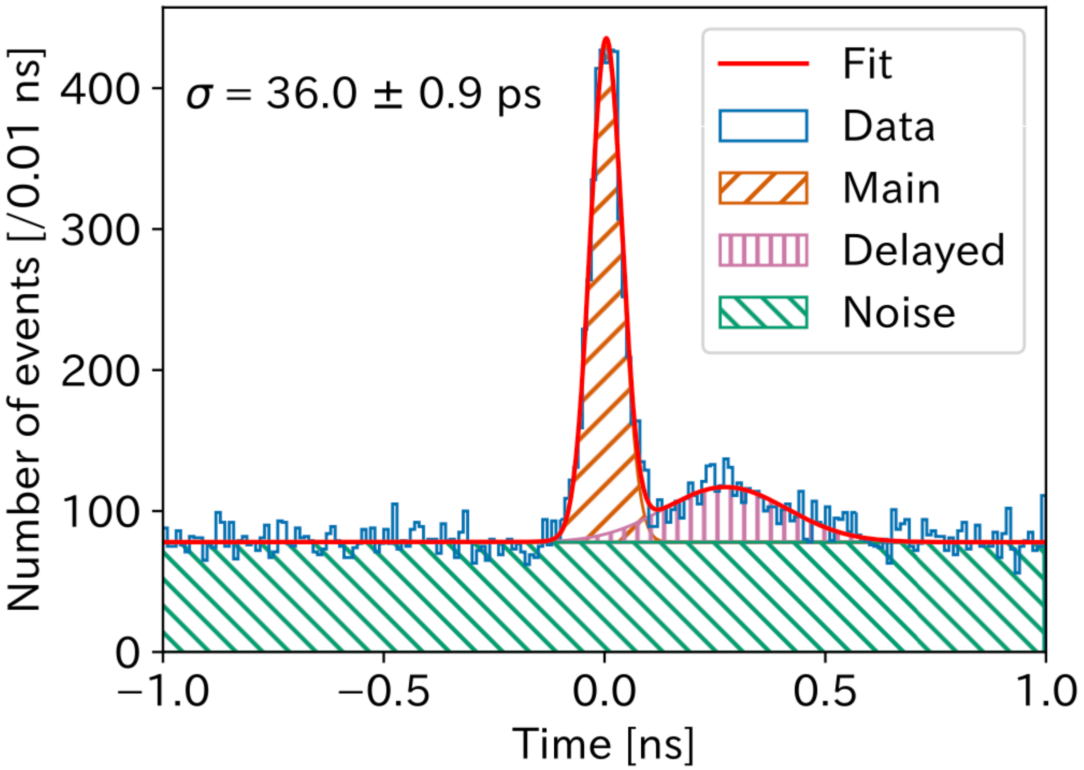


Further Delayed

2 photon feedback



Time resolution of GasPM



Time resolution

$\sigma = 36.0 \pm 0.9$ ps at the main peak.

Laser width: 21.8 ± 0.5 ps

(Measured by a streak camera)

Read out time resolution: 14.0 ± 0.3 ps

→**25.0 ± 1.1ps** w/o laser width and read-out resolution

Better than MCP-PMT

($\boldsymbol{\sigma = 30}$ **ps** (Channel diameter =10 μm))

Demonstrated the high time resolution of GasPM!

Future development plan

Practical photocathode sensitive to visible light

A new photocathode with high gas resistance and high quantum efficiency is necessary for GasPM.
If the photocathode is sensitive to visible light, GasPM can be used more widely for example, Cherenkov ring imaging detectors or scintillation counters.

Countermeasure to the photon feedback signals

1. Photon feedback occurrence depends on the gas mixtures

→ Test GasPM with various gas mixtures.

2. Readout with better sampling rate

→ The current readout system has 5GSPS (250 ps/step) of the sampling rate, but photon feedback signals can be identified from the main signals by using a readout with a higher sampling rate.

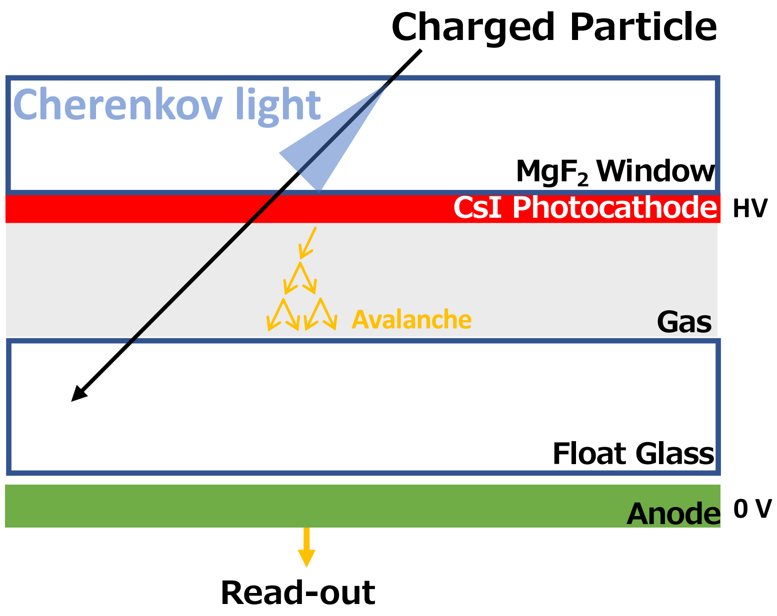
Application of GasPM as a Cherenkov timing detector

Detect Cherenkov light with <u>CsI photocathode</u>

Design of the protype

2 mm MgF_2 window

CsI photocathode: High gas resistance, Sensitive to UV light → Suitable for Cherenkov light detection.



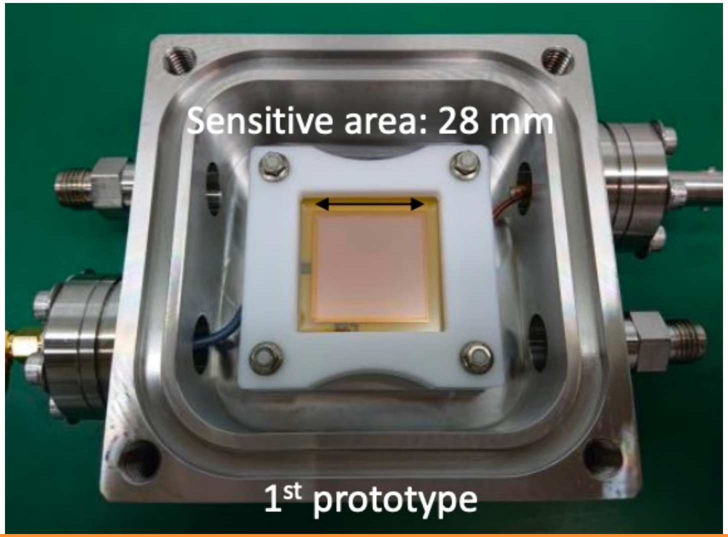
Expected performance

7 photons/ track (with 2 mm MgF_2, QE(CsI)=20% at 160 nm)

→

Detection efficiency : **100%**

Time resolution : $\sigma = \frac{25}{\sqrt{N}}$ ps (**9 ps** w/ 7 photon)



Developed the first prototype, and plan to perform a beam test in this year!

Summary

Gaseous photomultiplier is a photodetector that have three advantages, high time resolution, large-area, and low-cost.

Single photon response of GasPM

- Demonstrated that GasPM has an excellent single photon time resolution of **25.0 ± 1.1ps.**
- Some of the signals have a delayed timing and a large charge due to photon feedback.

Future development plan

- Developing a Cherenkov timing detector using GasPM.
- Developed the first prototype, and planning to test it.

GasPM has the potential to be a key technology in future particle physics experiments because of its time resolution, costs, and area!

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