Development of a Gaseous-Photomultiplication-Based Cherenkov Detector Targeting Picosecond Time Resolution

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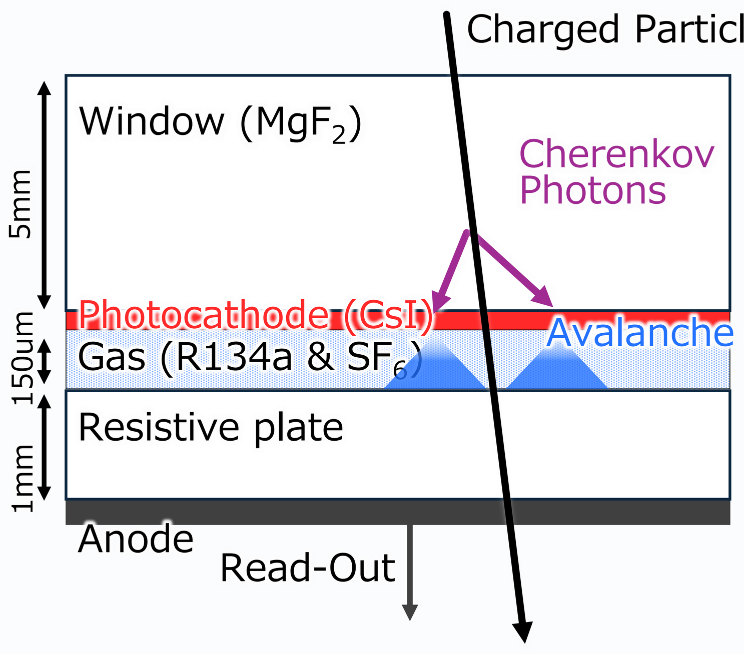
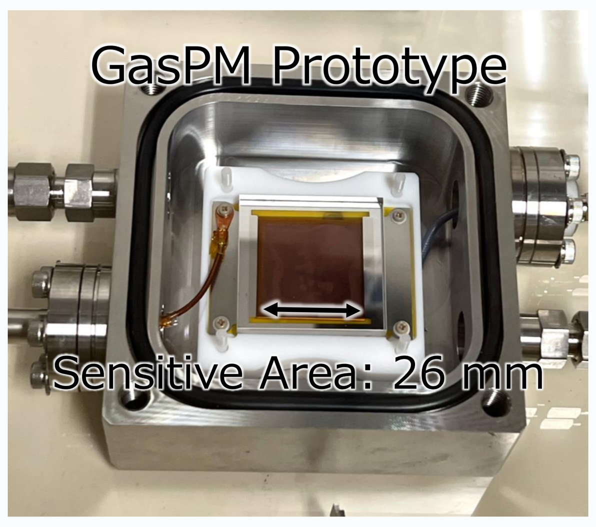
Introduction

- **Target:** To develop a Cherenkov detector with high time resolution, large area, and low cost for future large-scale experiments.
- **Our Approach: Gaseous photomultiplier (GasPM)**
  A photon detector that combines a Resistive Plate Chamber with a photocathode. It operates as a Cherenkov detector by detecting the Cherenkov light produced in its entrance window.



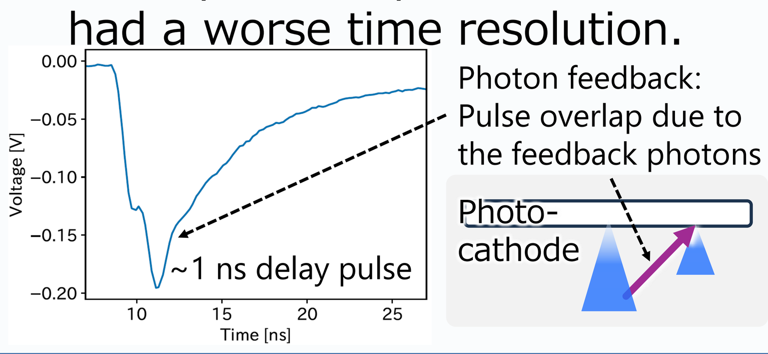


GasPM Advantages:

- **High Time Resolution**
  fast avalanche due to narrow $O(100um)$ gap & high voltage.
- **Large Photo Coverage**
  Can be enlarged without diminishing the time resolution because of the uniform structure. Easy to enlarge because of the atmospheric pressure gas.
- **Low Cost**
  Simple structure.

Previous Results:

- Pico-second pulse laser test: Achieved a single-photon time resolution of 58.9 ± 2.6 ps (FWHM) ($\sigma = 25.0 \pm 1.1$).
- e⁻ Beam Test: Measured a time resolution of 253.8 ps (FWHM) under a low electric field.
- In both tests, events with pulse overlap due to photon feedback had a worse time resolution.



Development plans:

- **Increase the gap electric field.**
- **Increase the number of detected photons with a thicker radiator** or by using a photocathode with higher quantum efficiency.
- Increase the read-out sampling rate from 5GSPS to 10GSPS for better separation of the photon feedback pulse from the main pulse.

→ **Aim to achieve ~20 ps (FWHM) resolution.**

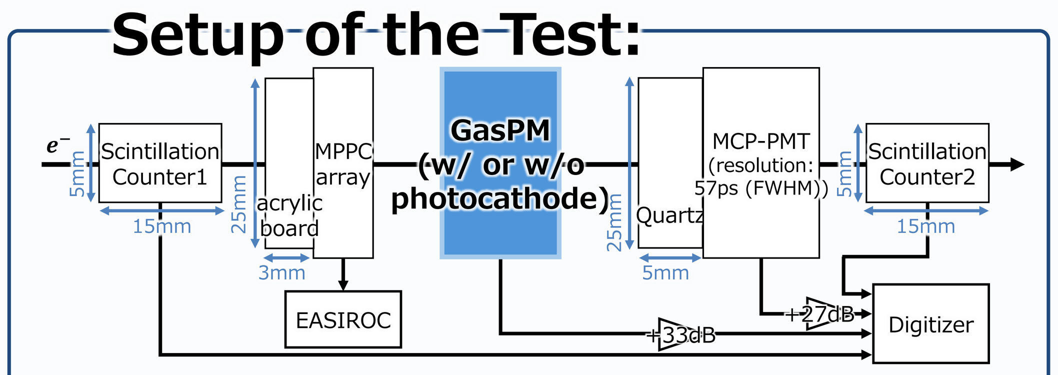
e⁻ Beam Test

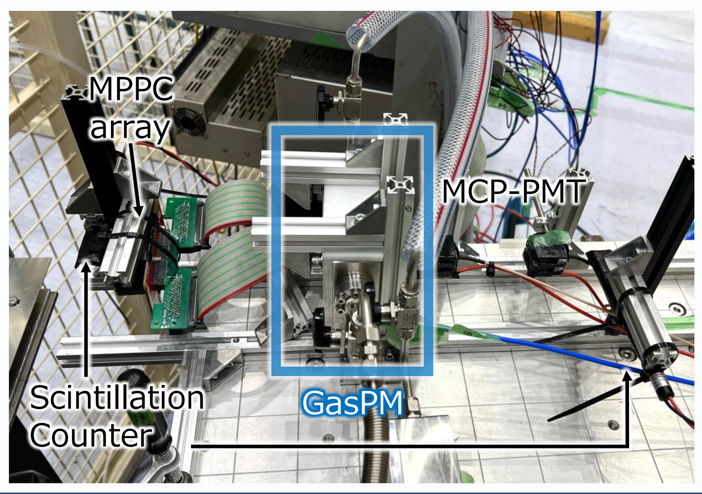
Aim: To demonstrate the GasPM time resolution for charged particles.

Expected Improvements:
- Higher Detection Efficiency
- Increased Gain
- Faster Rise-Time
- Improved Time Resolution

	2023 Test	2025 Test
Gas Gap	200 um	150 um
HV	-2.8 kV	-2.8 kV
Electric Field	**-140 kV/cm**	**-187 kV/cm**
Radiator Thickness	**2.4 mm**	**5.0 mm**

Setup of the Test:





Beam: KEK PF-AR Test Beam Line

Momentum	5 GeV / c
Trigger Rate	23 Hz

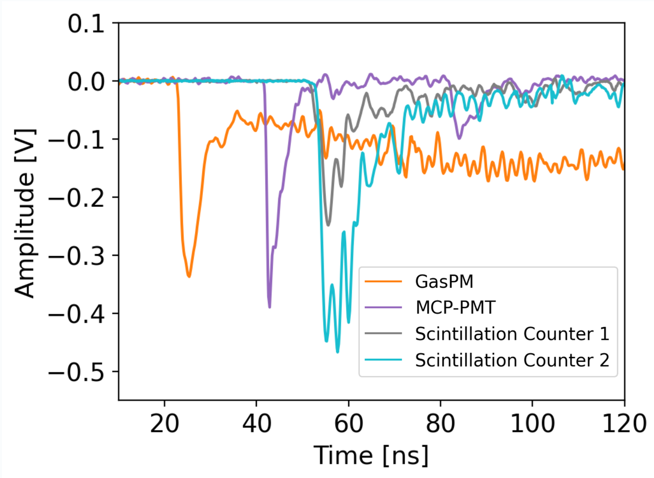
We reduced the beam rate due to readout limitation.

Digitizer: DRS4 Evaluation Board (PSI)

Sampling Rate	5 GSPS
Time Resolution	32.3 ± 0.2 ps (FWHM)

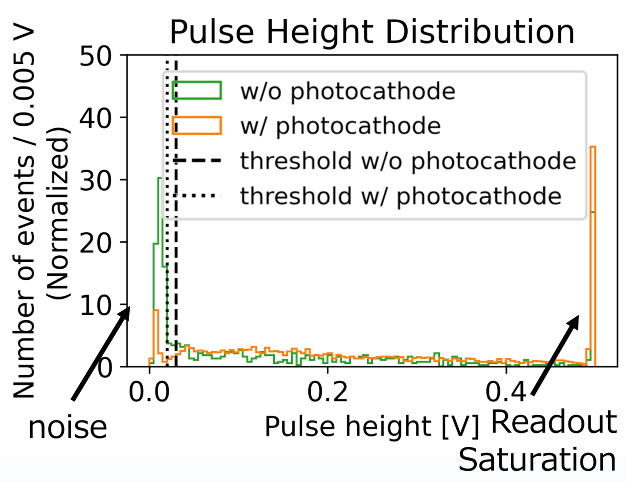
We also used another digitizer with a sampling rate of 10GSPS. In this presentation, we will only discuss the one with 5GSPS.

Results



1. Signal Pulse Shape

- Successfully observed signals.

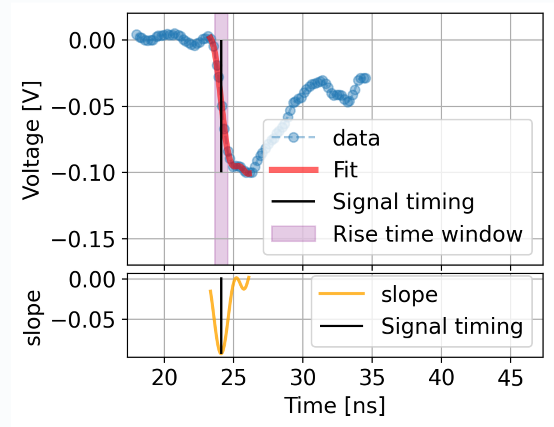


2. Detection Efficiency

Two types of signals:
- Ionization (w/ & w/o photocathode)
- Cherenkov photon (w/ photocathode)

Number of Cherenkov photons detected did not increase, despite the higher electric field and the thicker radiator.

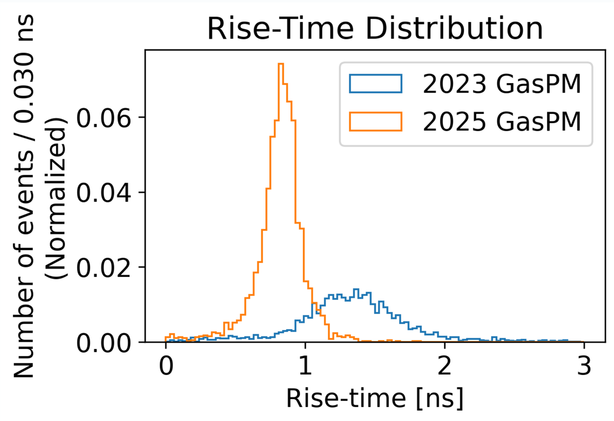
	w/o photocathode		w/ photocathode		
	beam detection efficiency (P)	$N_{avalanche}$ $(-\ln(1-P))$	P	$N_{avalanche}$ $(-\ln(1-P))$	Number of Cherenkov photons detected
2023	$77.2 \pm 0.5\%$	1.48 ± 0.03	$96.5 \pm 0.3\%$	3.34 ± 0.06	$\mathbf{1.86 \pm 0.07}$
2025	$63 \pm 2\%$	1.00 ± 0.05	$93.4 \pm 0.4\%$	2.71 ± 0.07	$\mathbf{1.71 \pm 0.09}$

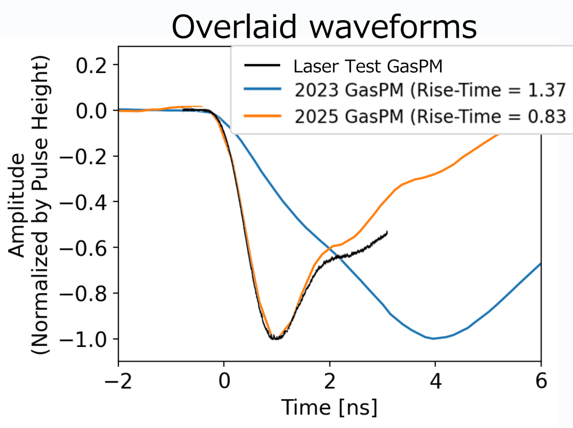


3. Timing Algorithm

To reduce effects of photon feedback, we performed waveform fitting and used specialized algorithm to determine the signal timing.

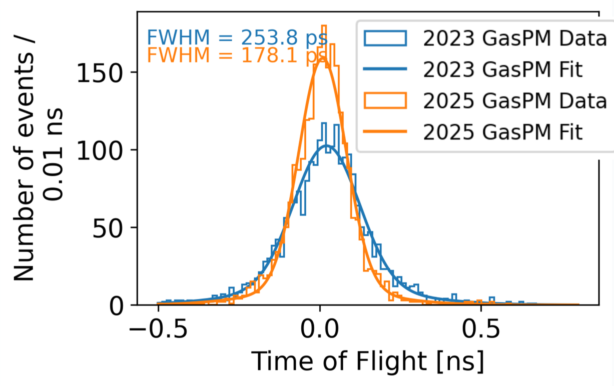
1. Polynomial fit to the rising edge
2. Measure the slope of the fitted curve
3. Define the signal timing (T) at the maximum slope
4. Define the rise time as $(\mathrm{T}-\mathrm{T}') \times 2$ T': time at 20% of the voltage at T





4. Rise Time

2025 GasPM has a sharp rising edge similar to the laser test.



5. Time Resolution

- Measured timing difference between GasPM and MCP-PMT.
- **Time resolution: 178.1 ps (FWHM).**

Discussion

- Number of Cherenkov photons detected was lower than our expectation. It can be attributed to a lower quantum efficiency.
- Although a stronger electric field improved the resolution, the resolution was worse than expected. A potential cause of the worse resolution could be the photon feedback.

Plans:
- Investigate the cause of the lower quantum efficiency.
- Analyze 10 GSPS digitizer's data to see if the higher sampling rate helps mitigate the photon feedback effect.

Conclusion

For future large experiments, we are developing GasPM. We conducted the beam tests, and found that the major issue in achieving high time resolution could be the photon feedback. We will address it using a digitizer with a higher sampling rate. We will also try to improve the time resolution by addressing the low quantum efficiency.

Acknowledgements

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