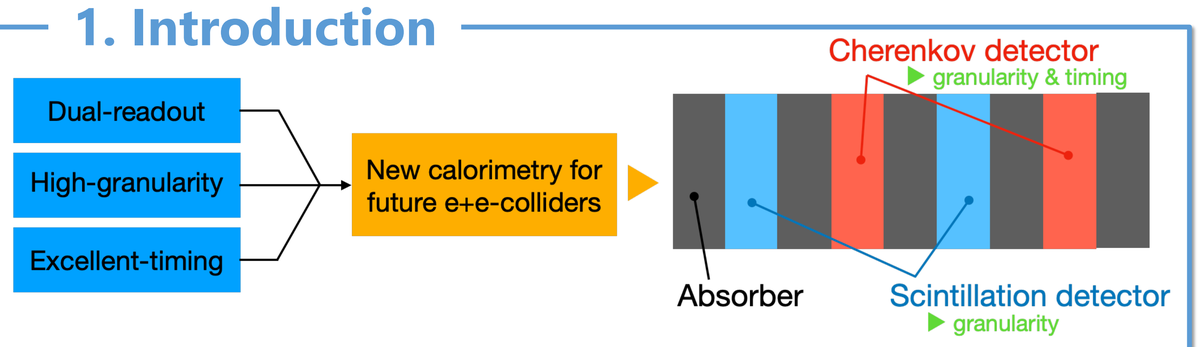
Excellent Timing Cherenkov Light Detection for Dual-readout High-granularity Calorimetry

Weiyuan Li[a], James Freeman[b], Corrado Gatto[c], Daniel Jeans[e], Taiki Kamiyama[a], Kodai Matsuoka[d], Hiroyasu Ogawa[a], Wataru Ootani[a], Taikan Suehara[a], Tohru Takeshita[e]

[a]ICEPP, The Univ. of Tokyo, [b]FNAL, [c]NIU, [d]KEK, [e]Dept. of Phys., Shinshu Univ.

1. Introduction



- Fusion of three features to achieve unprecedented energy resolution
- Opens access to 5D calorimetry and being driver of future experiments!

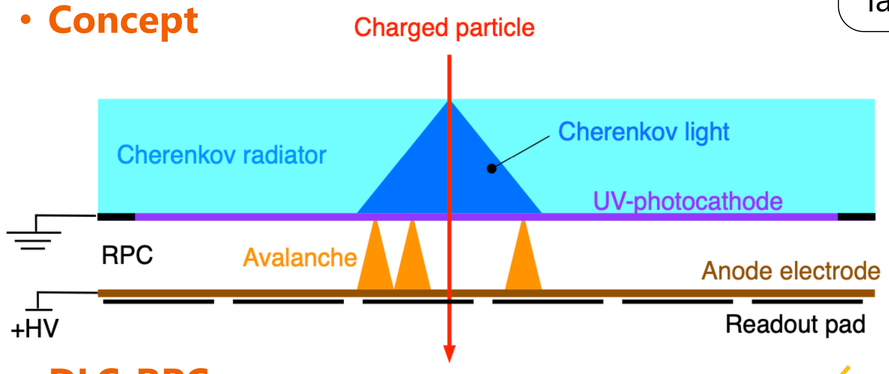
2. Cherenkov Detector Layer

• Requirements

- Highly segmented readout system ~ 1 cm
- Excellent time resolution ~ 20 ps

With a reasonable cost to cover the large area

• Concept



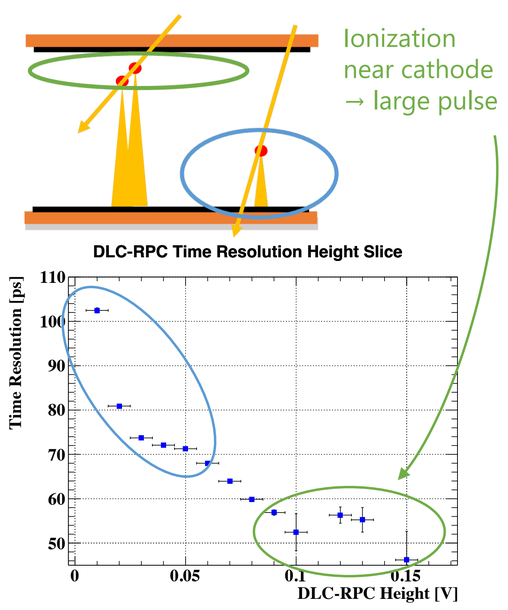
Cherenkov photon converts to electron

Amplification

Granularity realized by segmentation

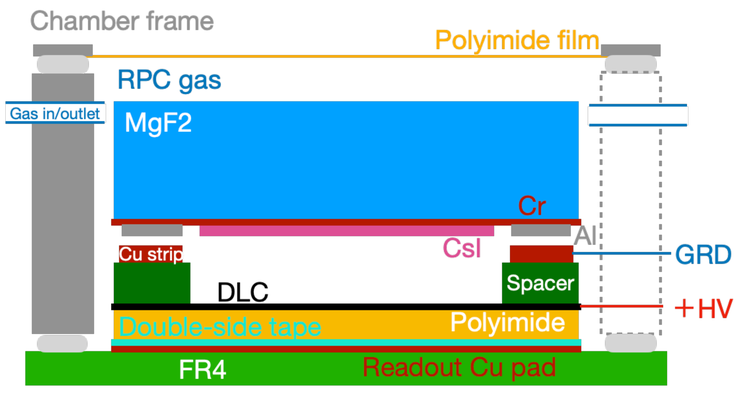
• DLC-RPC

- Diamond-Like Carbon (DLC) as resistive electrode
- Keep simple structure of Resistive Plate Chamber (RPC)
- Significantly improve rate capability $> 1\ \mathrm{MHz/cm^2}$ [1]
- 50 – 60 ps for large pulses (Depends on the gap thickness, 200 μm for this result)
- Estimated resolution for Cherenkov detector is 20 – 30 ps (average 10 p.e. is assumed)



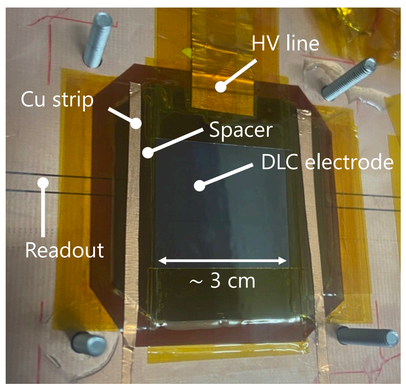
3. Prototype Detector

• Design of prototype detector

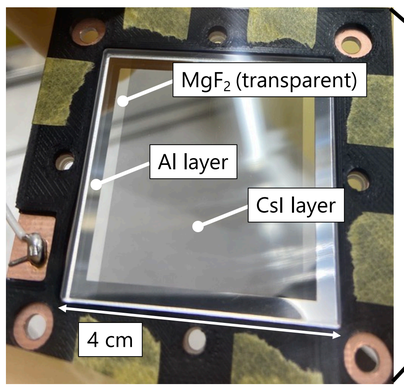


Radiator	MgF_2	2.4 mm
Photocathode	CsI	18 nm
Conductive layer	Cr	3 nm
Contact layer	Al	100 nm
Resistive layer	DLC	100 nm
Active area	-	2x1 cm^2
RPC gap	Kapton Plastic Cu	200 or 350 μm total
RPC gas	R134a SF_6 C_4H_{10}	93% 1% 6%

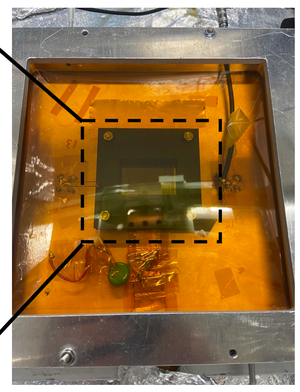
DLC (anode) electrode



Photocathode electrode



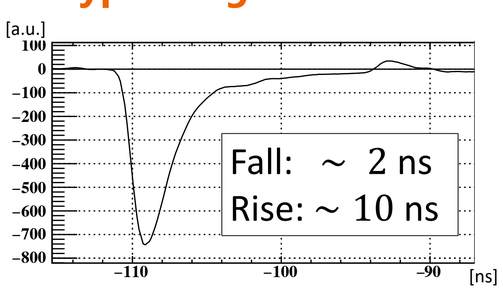
Detector Chamber



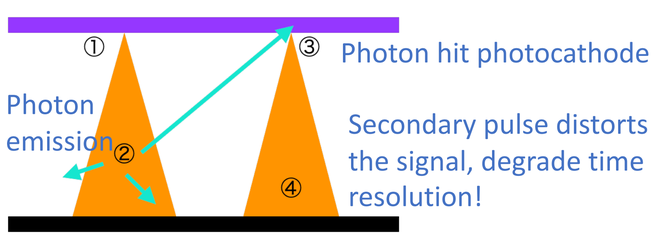
▶ Signal recorded by 5 GSPS Waveform digitizer

4. Operation Test

• Typical signal

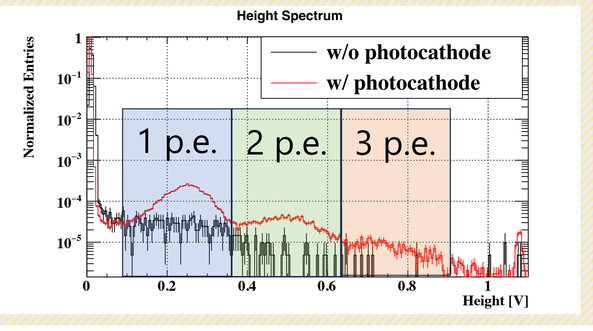


• Known issue: photon-feedback [2]



• Height spectrum of beta-ray data

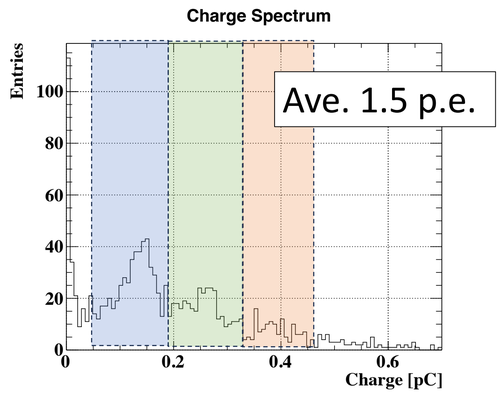
86 kV/cm E field applied, started with 350 μm gap-thickness for simplicity

	w/o photocathode	w/ photocathode
Hit rate	~ 200 Hz	~ 20 kHz
Height spectrum	The signals of "w/o photocathode" are generated by beta-ray ionization of gas molecules in DLC-RPC	

✓ Clear signs of signals from Cherenkov light!

▶ Discrete peaks of #p.e. observed in the height spectrum which indicates the photon counting capability

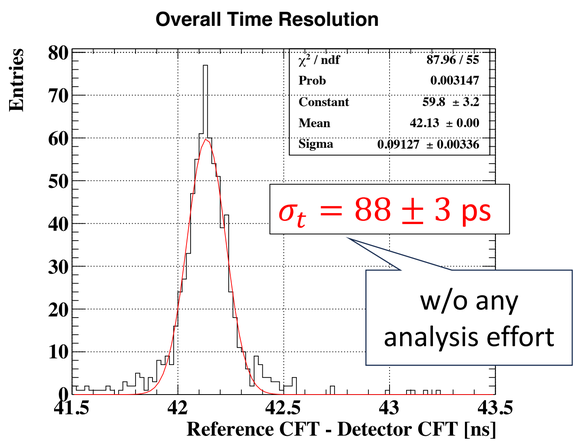
• Charge spectrum of cosmic-ray data

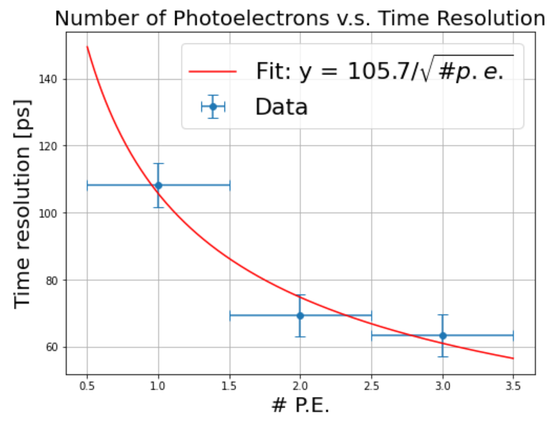


- ○ Confirms the response to MIP
- ○ Entries for #p.e. follows Poisson distribution whose average is 1.5
- ○ The thickness of the radiator and photocathode to be optimized to get more photoelectrons

5. Time Resolution

Cosmic data of 200 um gap-thickness prototype detector





125 kV/cm E field applied, gap thickness narrowed for better time resolution

▶ Operation successful, with time resolution $\sigma_t = 88 \pm 3$ ps

✓ Improves its performance by #p.e. with approximately 1/sqrt

▶ If average 10 p.e. is achieved, it will be ~ 33 ps

- Still the first result of prototype >> plenty of room for improvement
  - ❑ DLC-RPC gap thickness even narrower
  - ❑ Optimize the thickness of the photocathode and radiator
  - ❑ Investigation of the effect of photon-feedback and RPC signal overlapping, etc. …

6. Summary and Prospect

✓ Development of next-generation calorimetry, which is the fusion of dual-readout, high-granularity, and excellent-timing is ongoing

✓ The concept of the Cherenkov light detection layer has been presented and demonstrated

✓ Optimization of the hardware parameters such as the thickness of the materials and gap, the gas mixture, etc., will be investigated

References

1) K. Ieki, W. Li, A. Ochi, R. Onda, W. Ootani, A. Oya, M. Takahashi, K. Yamamoto, "Prototype study of 0.1%X_0 and MHz/cm^2 tolerant Resistive Plate Chamber with Diamond-Like Carbon electrodes", Nucl. Instrum. Methods Phys. Res. A, 1064 (2024), 169375, https://doi.org/10.1016/j.nima.2024.169375.

2) K. Matsuoka, R. Okubo, Y. Adachi, "Demonstration of a 25-picosecond single-photon time resolution with gaseous photomultiplication", Nucl. Instrum. Methods Phys. Res. A, 1053 (2023), 168378, https://doi.org/10.1016/j.nima.2023.168378

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Contact: weiyuan@icepp.s.u-tokyo.ac.jp