A “Warm” MRPC for the high-rate charged-particle identification in proton-nucleus collisions at J-PARC

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2026/9/18, RPC2026, Rio de Janeiro

1. Overview of J-PARC E88
2. Design of the MRPC
3. Performance at the beam test
4. Performance at the cosmic-ray test
5. Summary and outlook

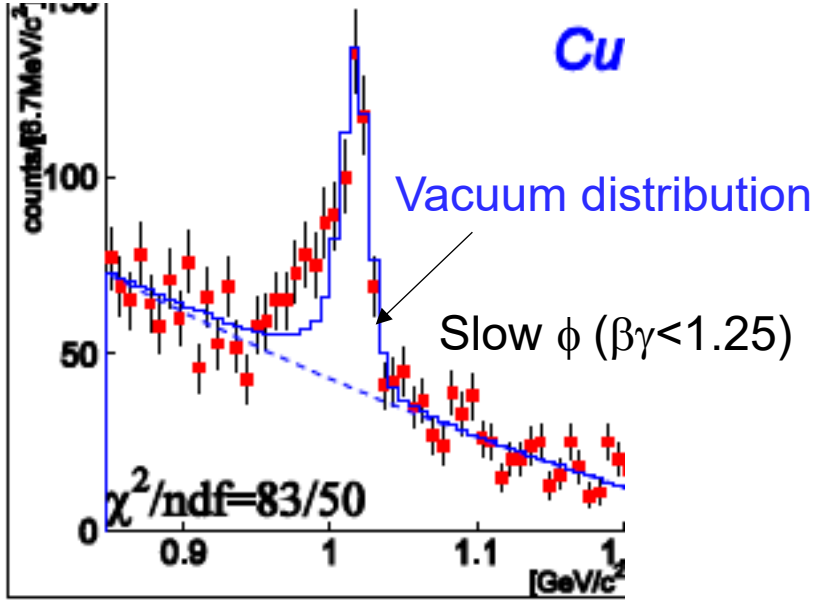
J-PARC E88/SAΦRE

- **J-PARC E88/SAΦRE**
  - High-statistics ϕ meson measurements in p+A
- **Goals**

  Studies of in-medium modification of ϕ mesons in nuclear matter to explore the chiral-symmetry restoration
  - The mass shift of ϕ meson is sensitive to $\langle s\bar{s} \rangle$ condensate in finite density

    (P. Gubler and K. Ohtani, PRD **90**, 094002 (2014))
- **Complementary measurements of $\phi \rightarrow K^+K^-$ (E88) and $\phi \rightarrow e^+e^-$ (E16)**
  - K^+K^-: Much higher statistics
  - On the other hand, $\phi \rightarrow K^+K^-$ invariant mass spectrum can be modified by the final-state interactions

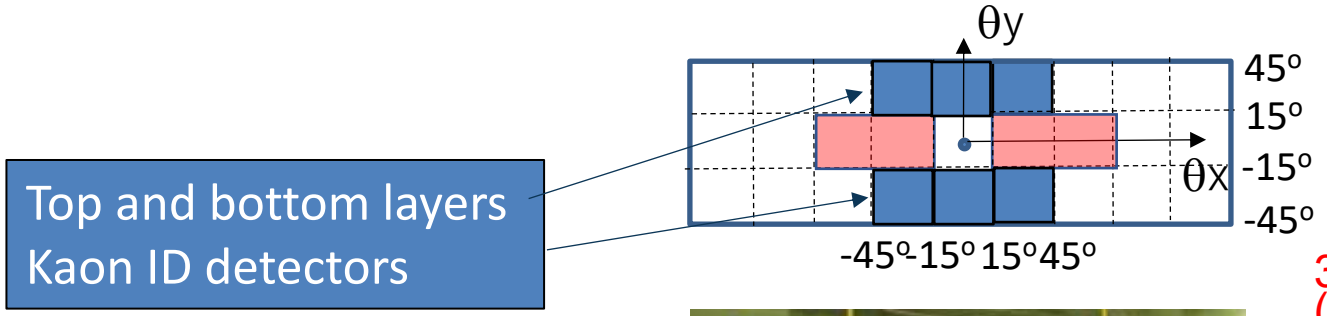
Previous KEK E325 observed low mass excess of $\phi \rightarrow e^+e^-$ invariant mass distribution

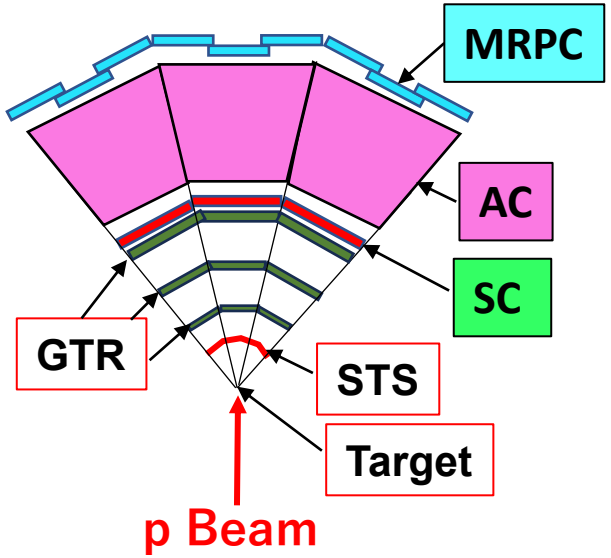


R. Muto et al, Phys. Rev. Lett. **98,** 042501 (2007)

J-PARC E88/SAΦRE Setup









30 GeV proton beam at the rate of 10^9 / spill (spill = 2s)

- C + Cu + Pb targets (0.1% interaction length)
- 1MHz interaction rate
- 1M events in total. The statistics increased by factor of 300 (p+C) and 500 (p+Cu) from E325

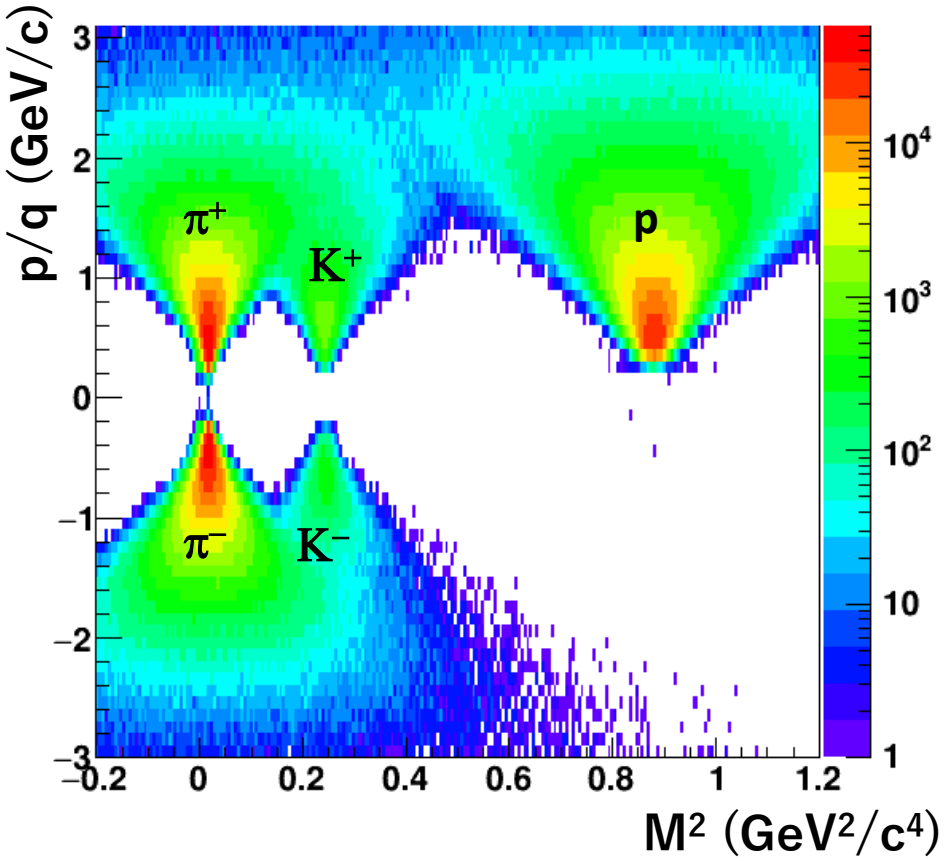
$\phi \rightarrow K^+K^-$ at E88			
	C	Cu	Pb
ϕ ($\beta\gamma<1.23$)	72k	113k	314k
ϕ ($1.23<\beta\gamma<1.72$)	79k	134k	313k
ϕ ($1.72<\beta\gamma<2.06$)	8k	15k	35k

- 6 forward modules for $K^{\pm}$ identification in top and bottom layers
- **MRPC** (Muliti-gap Resistive Plate Chamber) and **SC** (Start timing counter) for Time-of-Flight measurement
- **AC** (Aerogel Cherenkov counter) for pion rejection
- **STS** (Silicon Tracking System) and **GTR** (GEM Trackers) for track reconstruction

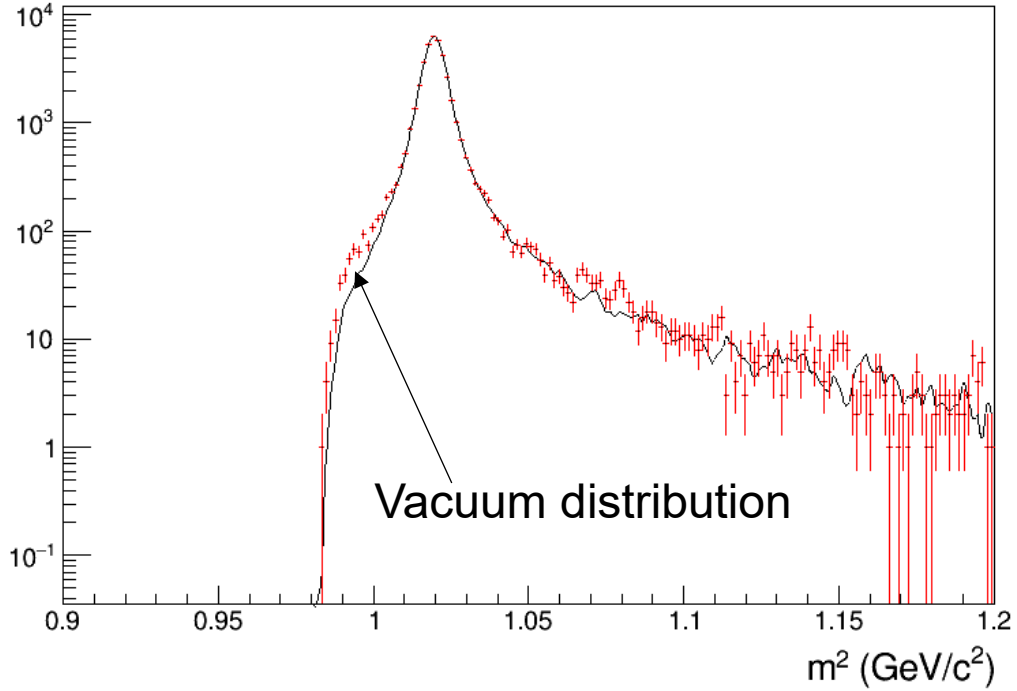
Particle ID and invariant mass spectrum

M^2: calculated with TOF between MRPC and SC
w/ timing resolution of 70 ps and 50 ps

M^2 vs rigidity (p+Cu Simulation)



Expected K^+K^- invariant mass distribution (longitudinal polarized ϕ (θ_K<30° or 150°<θ_K))



- Expected maximum hit rate on MRPC: ～1kHz/cm^2

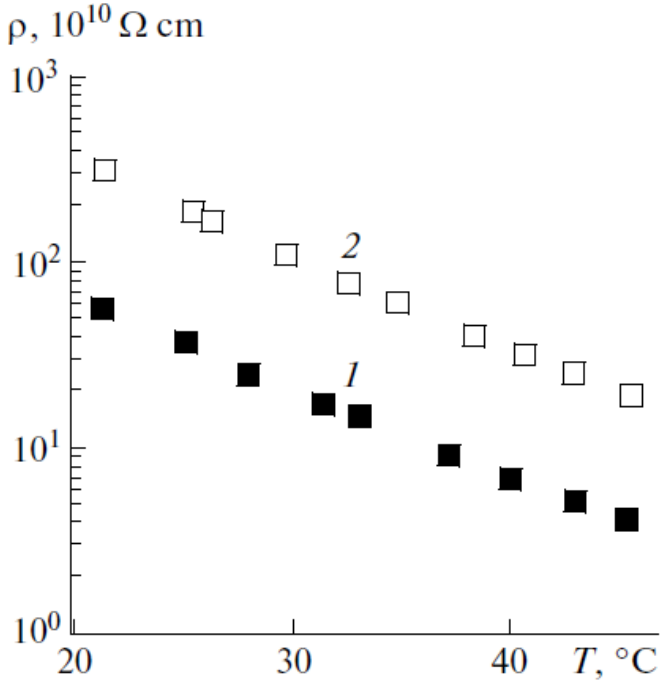
Previous study on warm MRPC

V.A. Gapienko et al, Inst. Exp. Tech. 56 265-270 (2013)

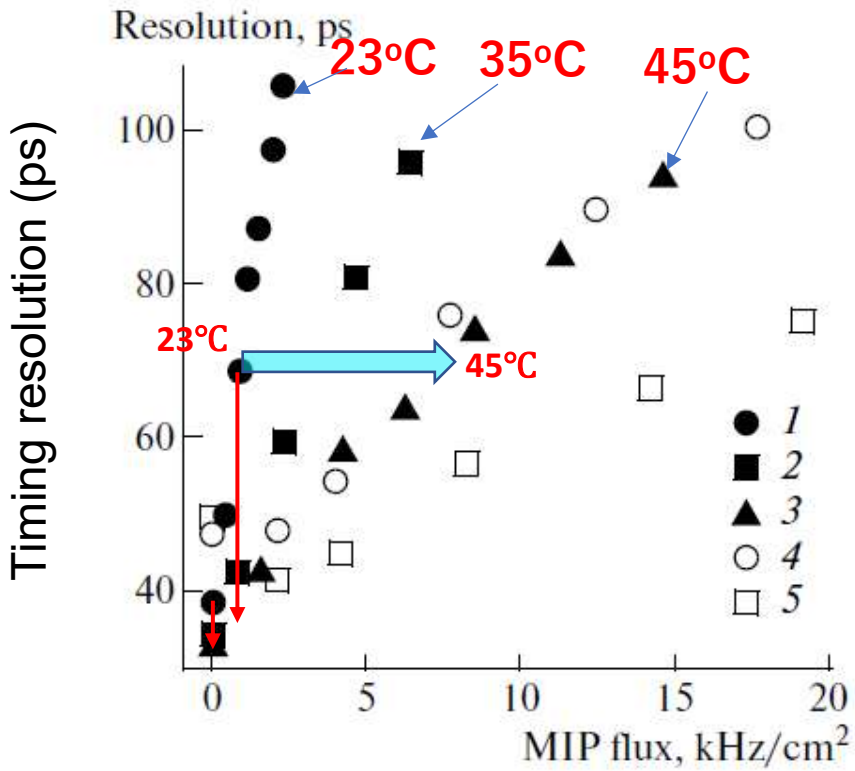
Small MRPCs (2.5cmx2.5cm) in the heat bath → R&D is required for a practical size MRPC
Gas: R134a (90%), SF6 (5%), isobutane (5%)

Enhanced high-rate capability
Warming glass sheets→lower resistivity
→shorter recovery time from avalanche

Temperature dependence of volume resistance of the float glass
Resistance: ~1/10 (20°C→45°C)



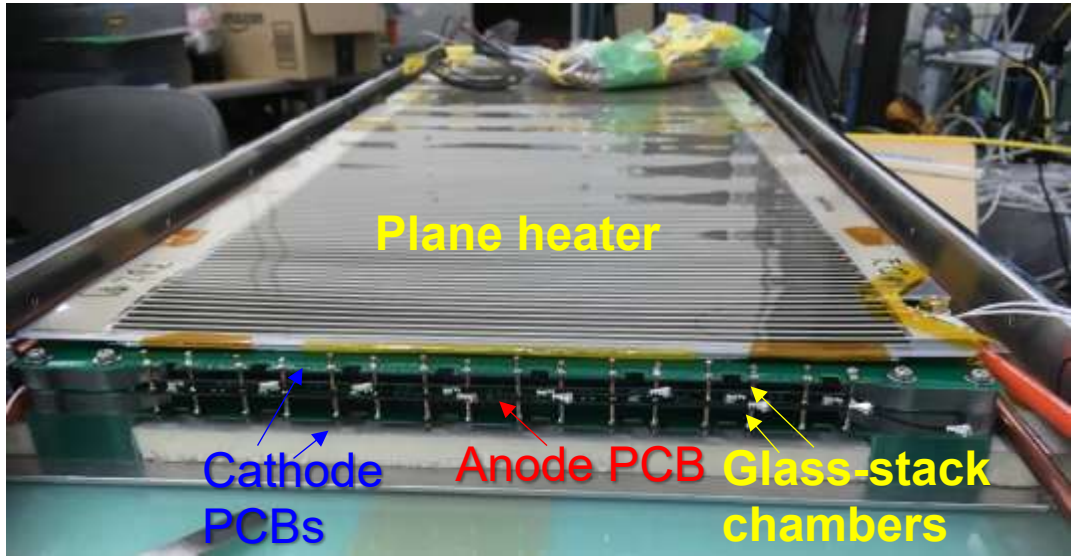
Rate dependence of the timing resolution of MRPC at different temperature



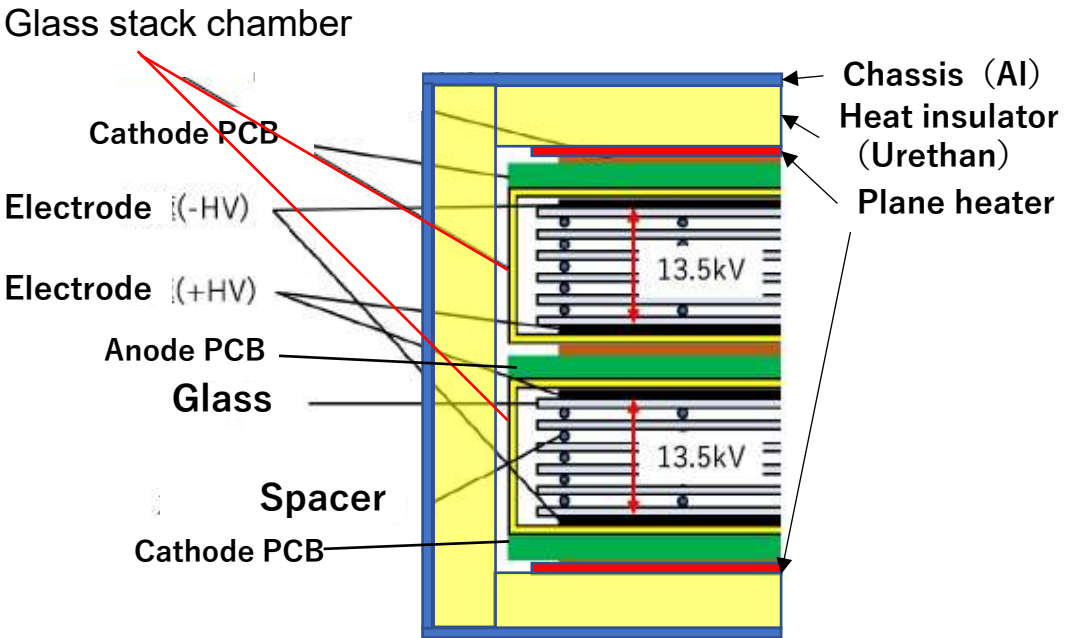
Factor ~5 increase of high-rate capability at 70 ps resolution

Timing resolution
- ~46% improvement at ~1kHz/cm2
- ~13% improvement at ~0.1kHz/cm2

E88 MRPC



- Gas: R134a (90%) : SF6 (10%)
- Double-glass-stack configuration
- Glass stack chamber: 5 gaps of 0.25 mm with 6 sheets of 0.4 mm-thick float glass, Chamber: Glass-Epoxy
- Glass sheet size: 230x750 mm^2
- Strip size 25x750mm^2
- Spacer: Fishing string
- HV electrodes: High-resistance (10MΩ/sq) carbon-based tape
- Readout: Amplifiers on both ends of the strip→Discriminator→TDC
- Heater and heat insulator

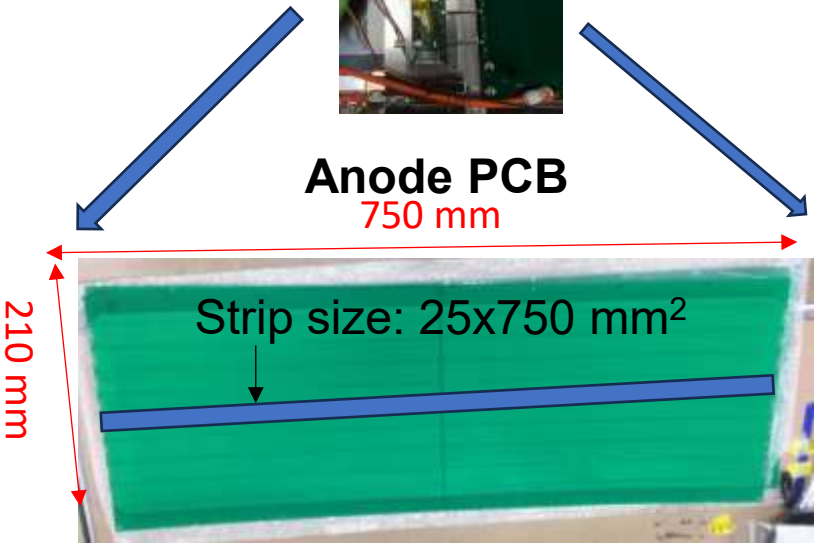


Glass stack chamber

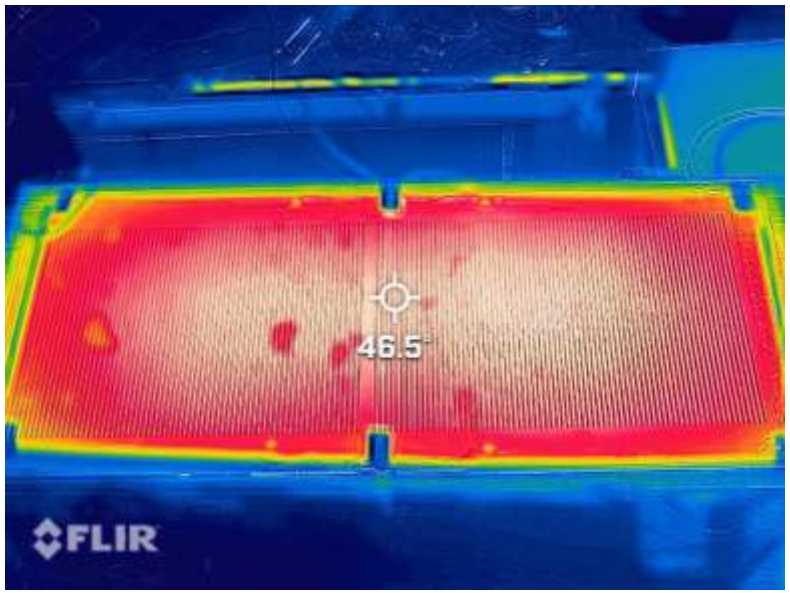


Amplifier



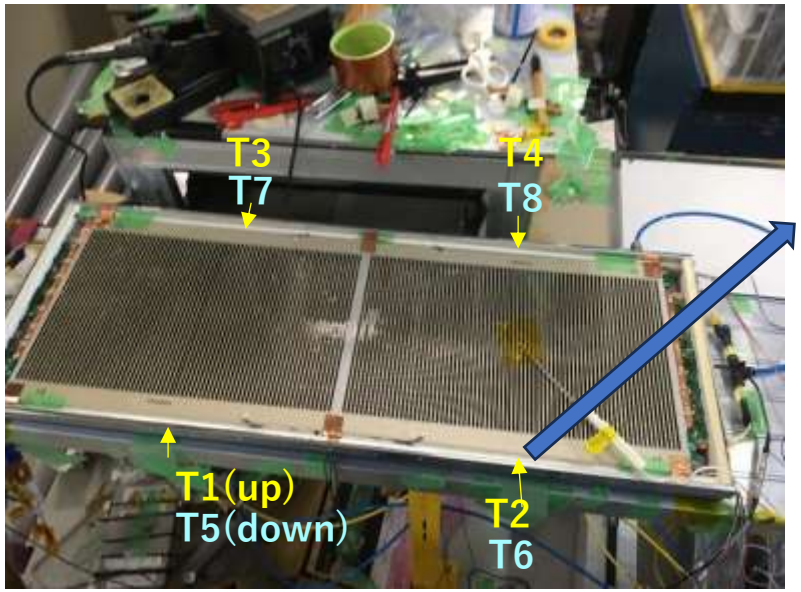


Glass heating test

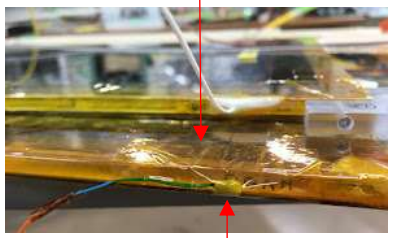


- Plane heaters with PTC (Positive Temperature Coefficient) on the top and bottom sides
- Easy to control the temperature with the constant voltage power supply.

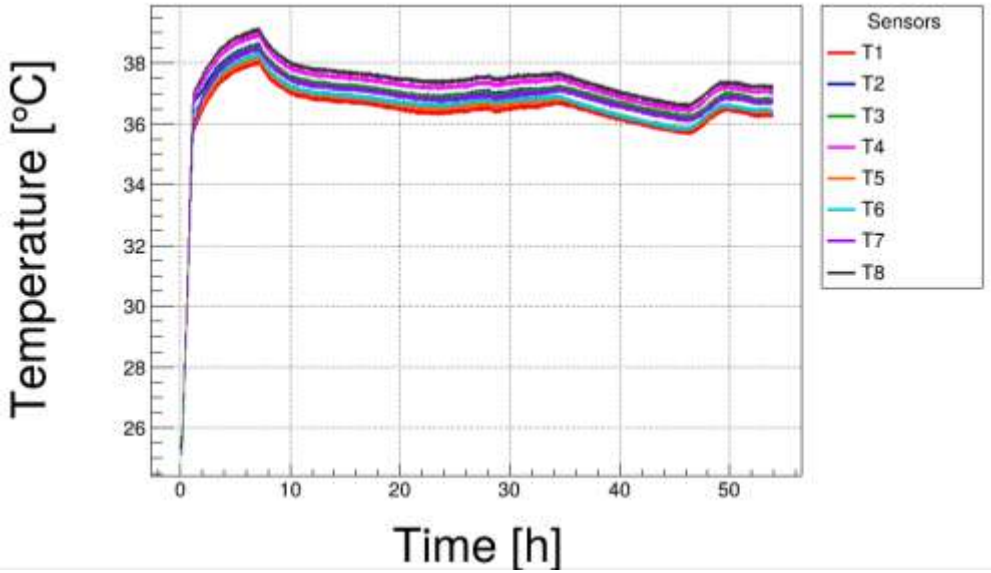
Temperature time evolution measured on the side walls of the glass-stack chambers (w/ thermistors).
Temperature difference among 8 sensors < 1.2 °C



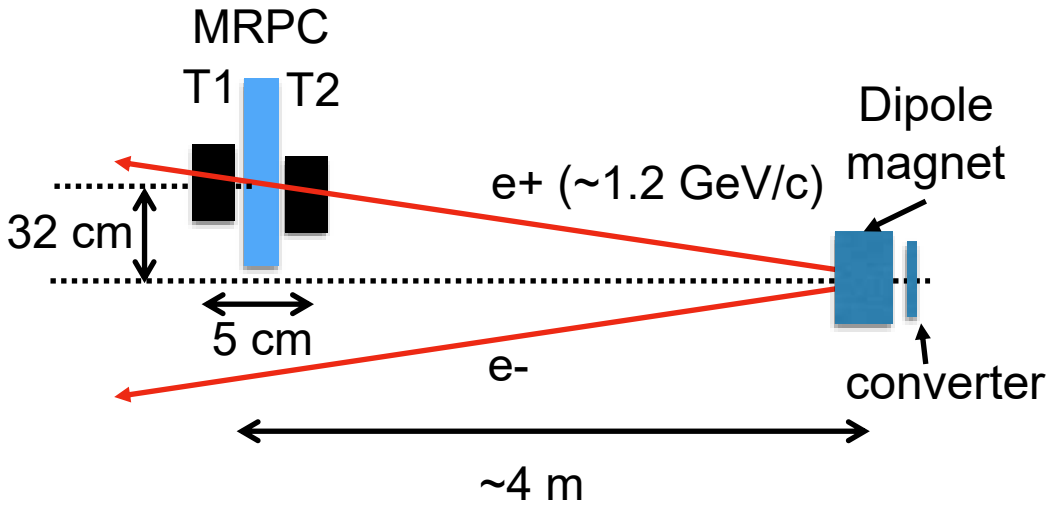
Glass stack chamber

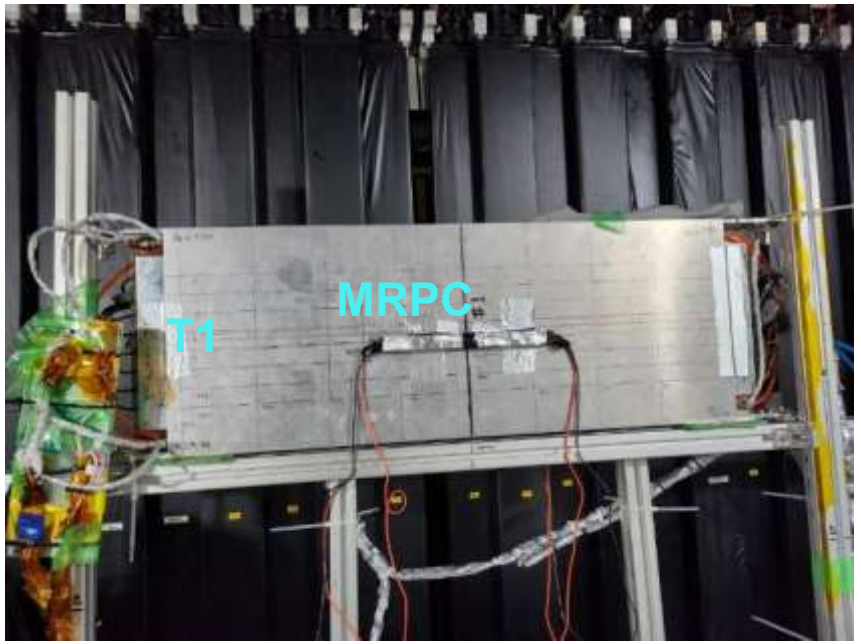


Thermistor



LEPS2 (SPring-8) beam test in July 2025



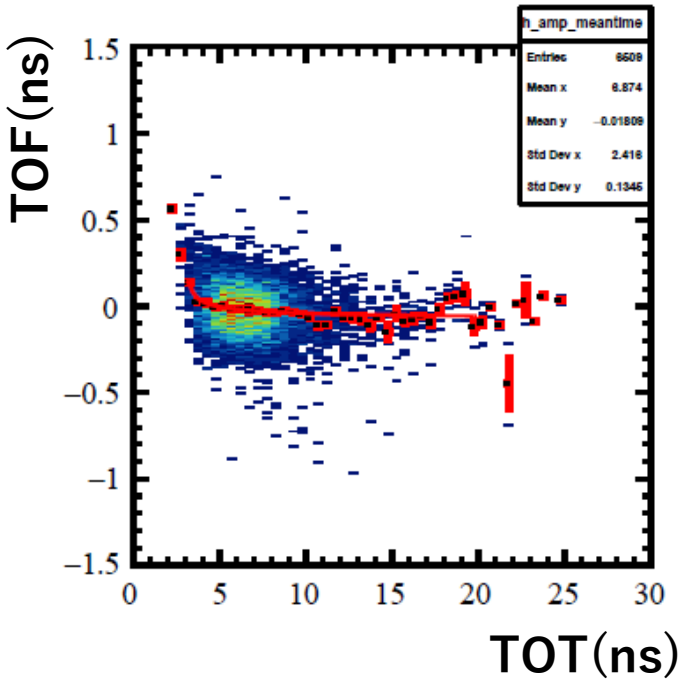


*T1&T2: Trigger counters
Sensitive area：8x20mm^2
Trigger：T1 ∩ T2→TDC common stop signal
Gas: R134a (90%), SF6 (5%), isobutane (5%)

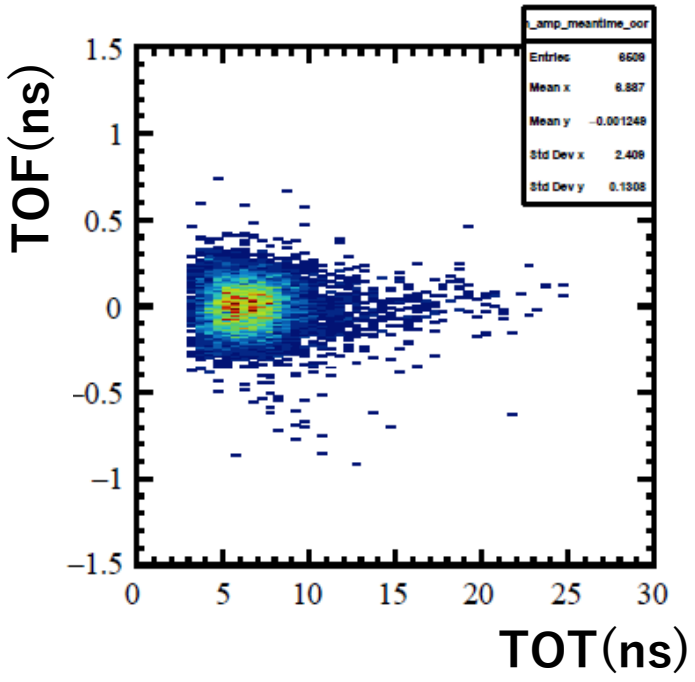
Slewing corrections

- TOF = Mean MRPC TDCs at both strip ends - RF TDC
  - Correction of TOF dependence on TOT（Slewing correction）

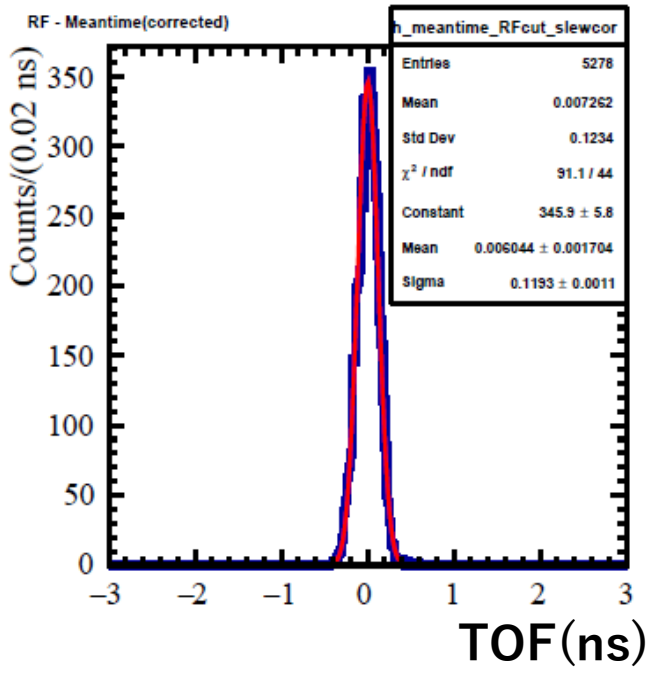
w/o correction



w/ correction



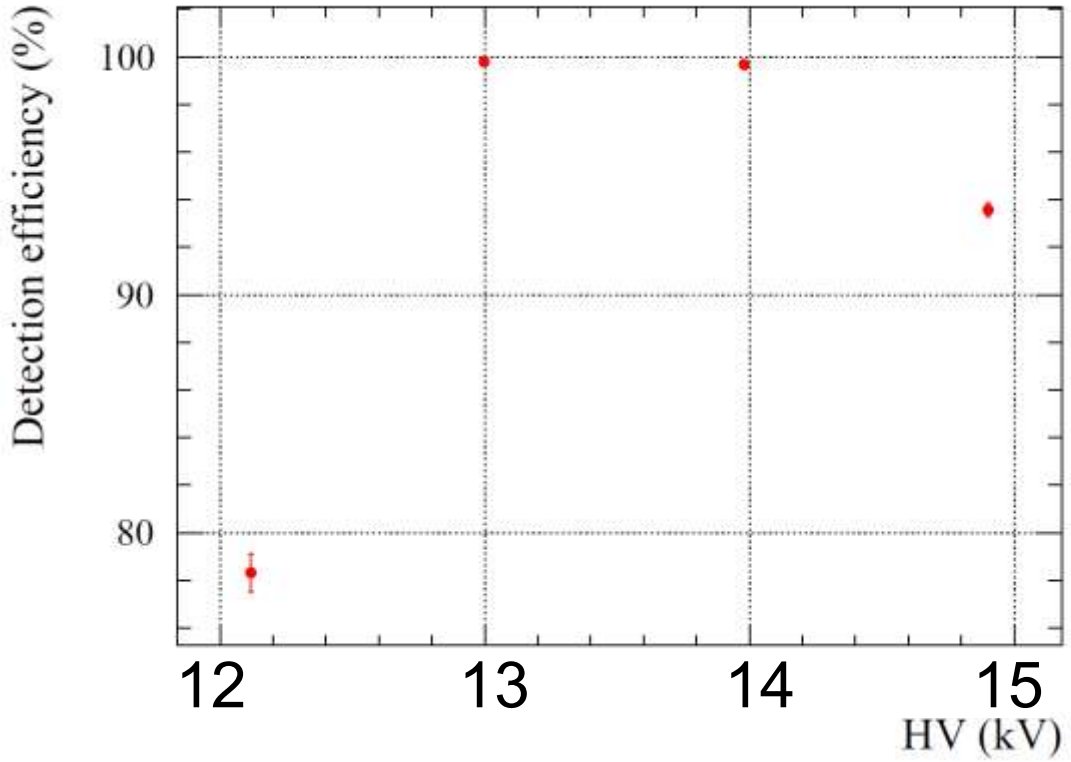
w/ correction



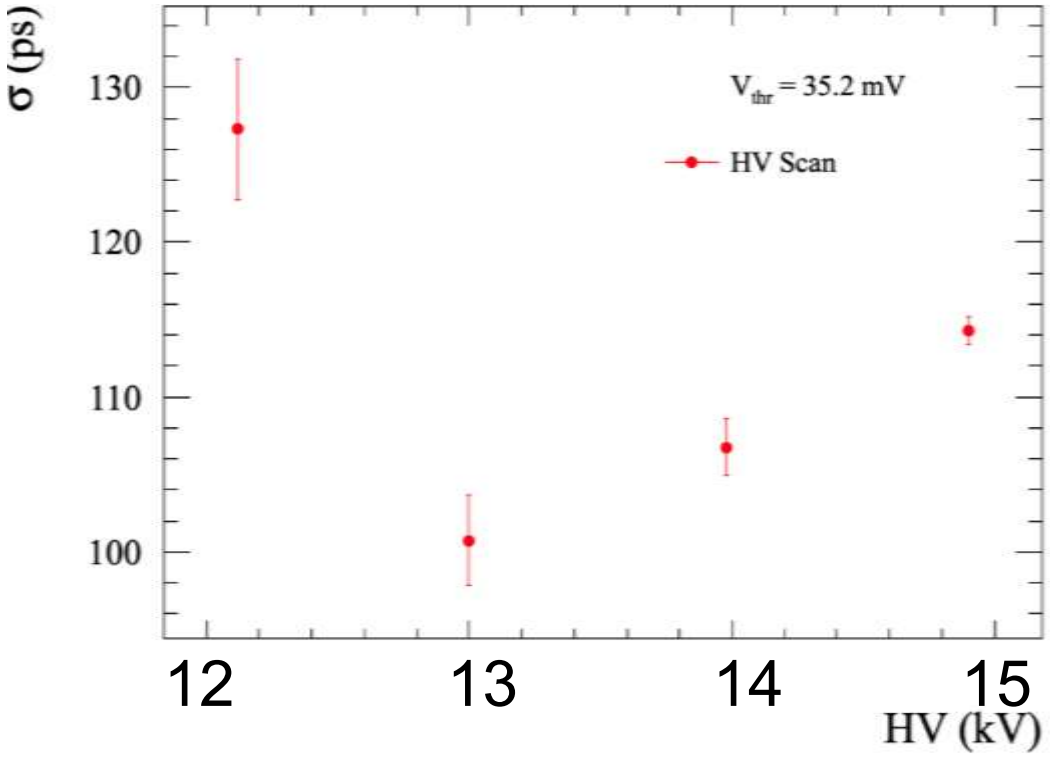
HV dependence of efficiency and timing resolution (LEPS2)

Operation HV: 13-14kV

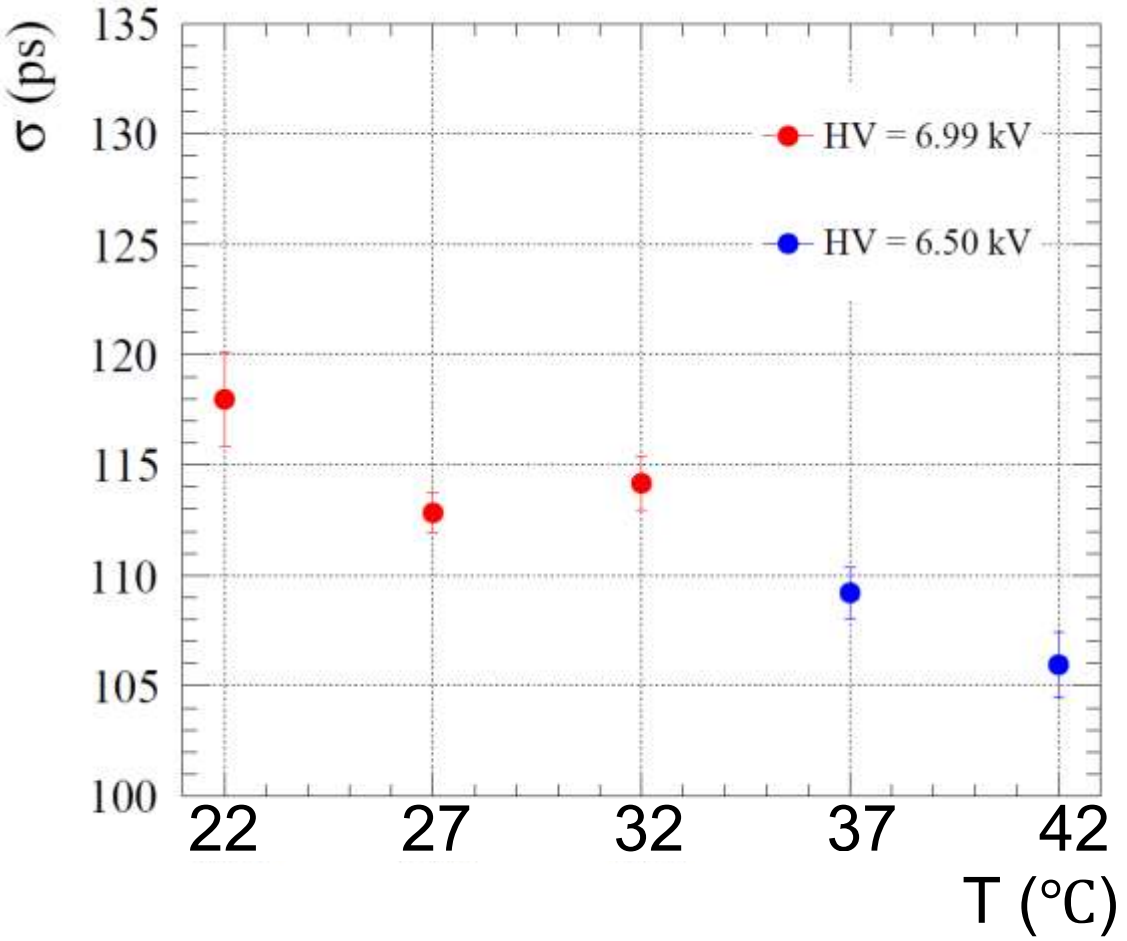
Efficiency vs HV



Timing resolution vs HV

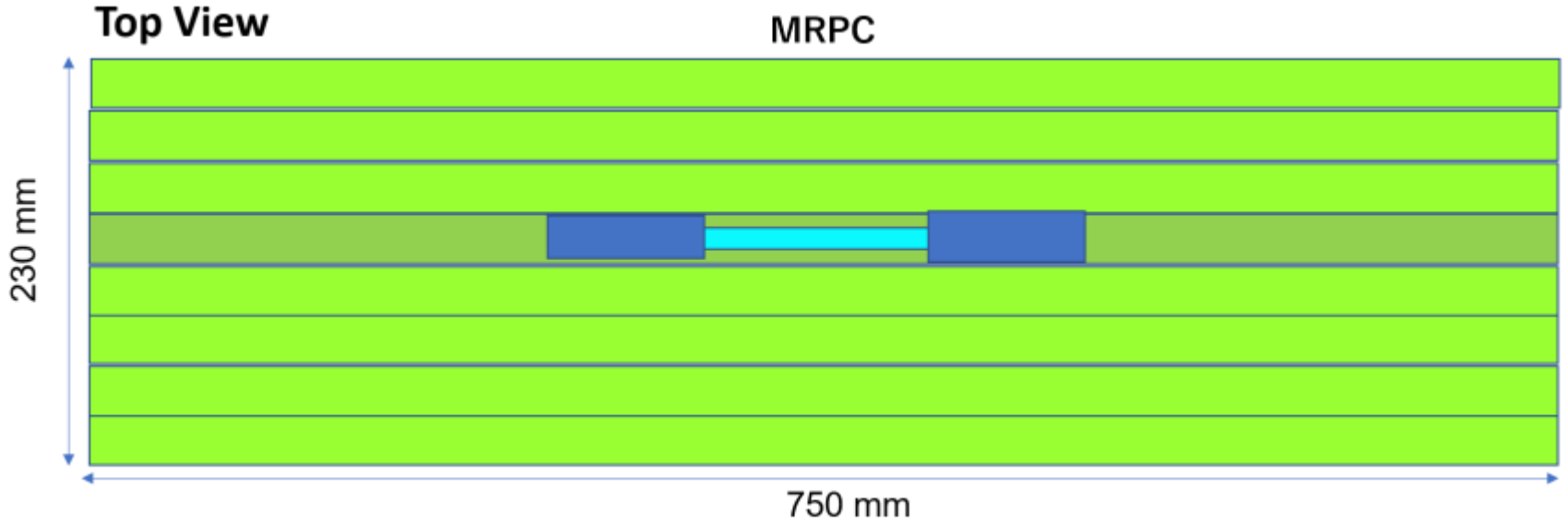


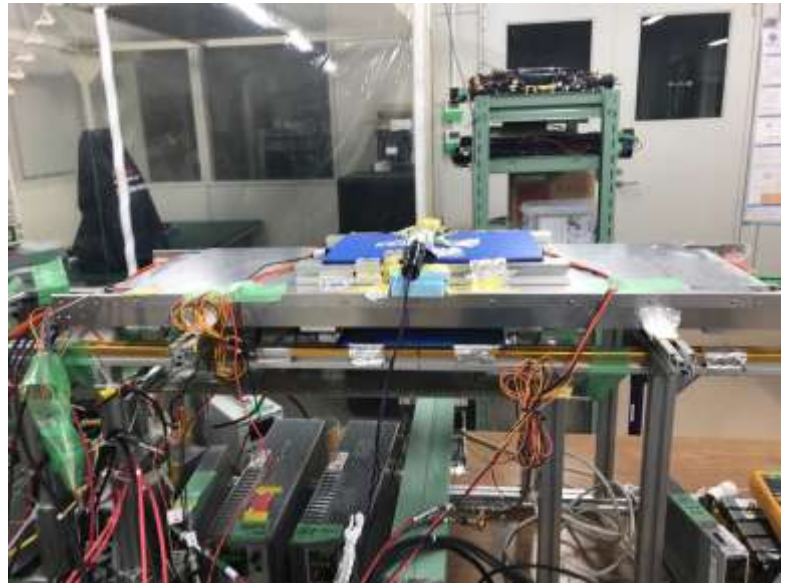
Temperature vs timing resolution (LEPS2)

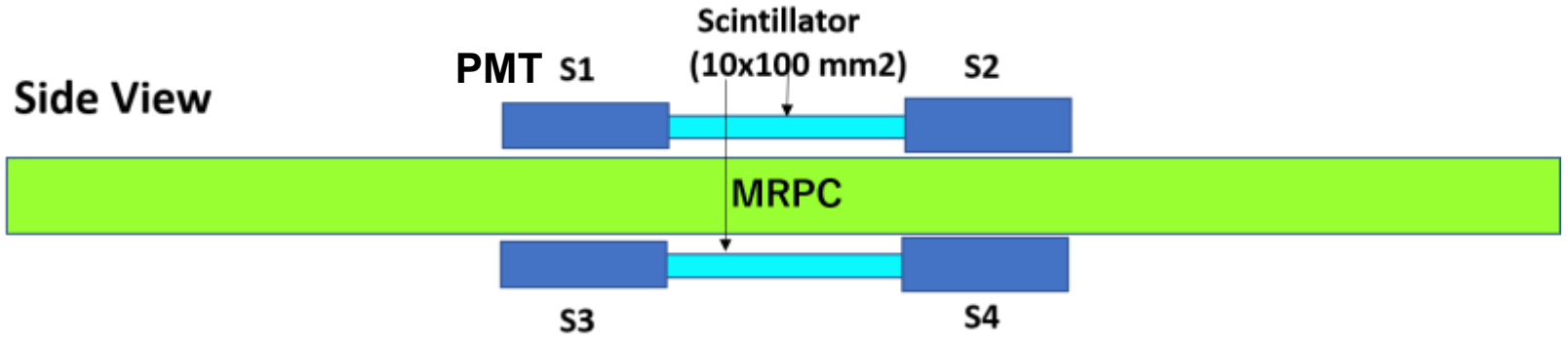


- Hit rate ~32Hz/cm^2
- Timing resolution improved 118→106 ps (T=22→42℃)
  - 10% improvement
- At ~0.1kHz/cm^2, ~13% improvement by Gapienko et al.

Cosmic ray test setup at Univ. of Tsukuba (June 2025)



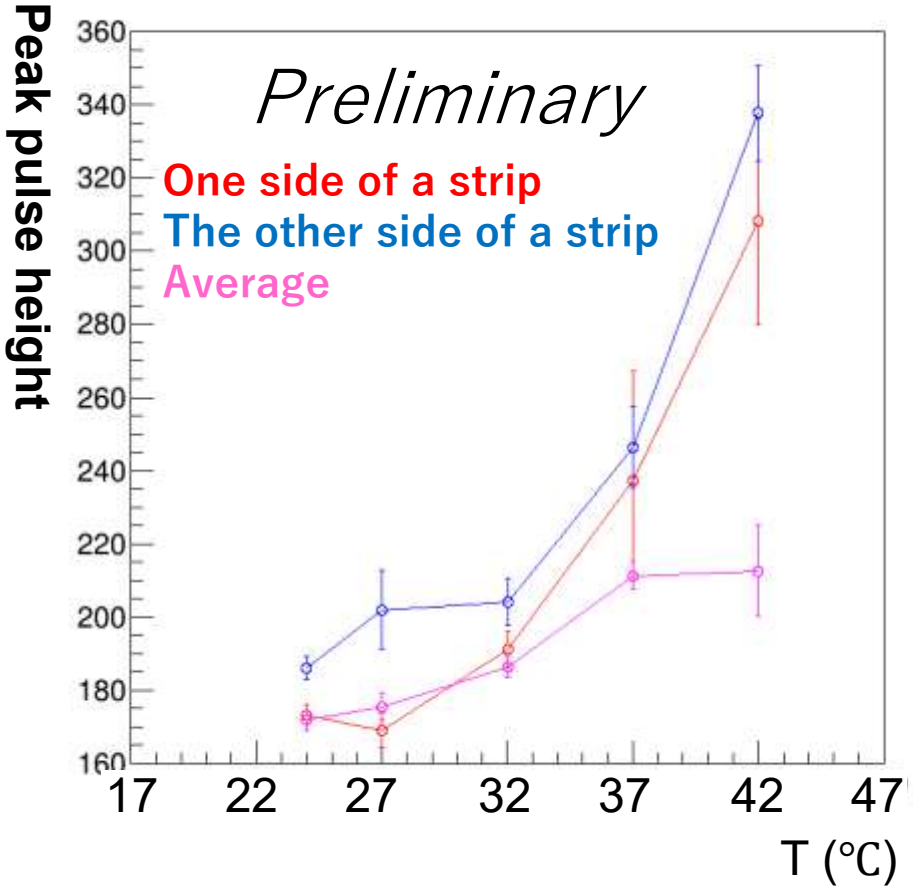




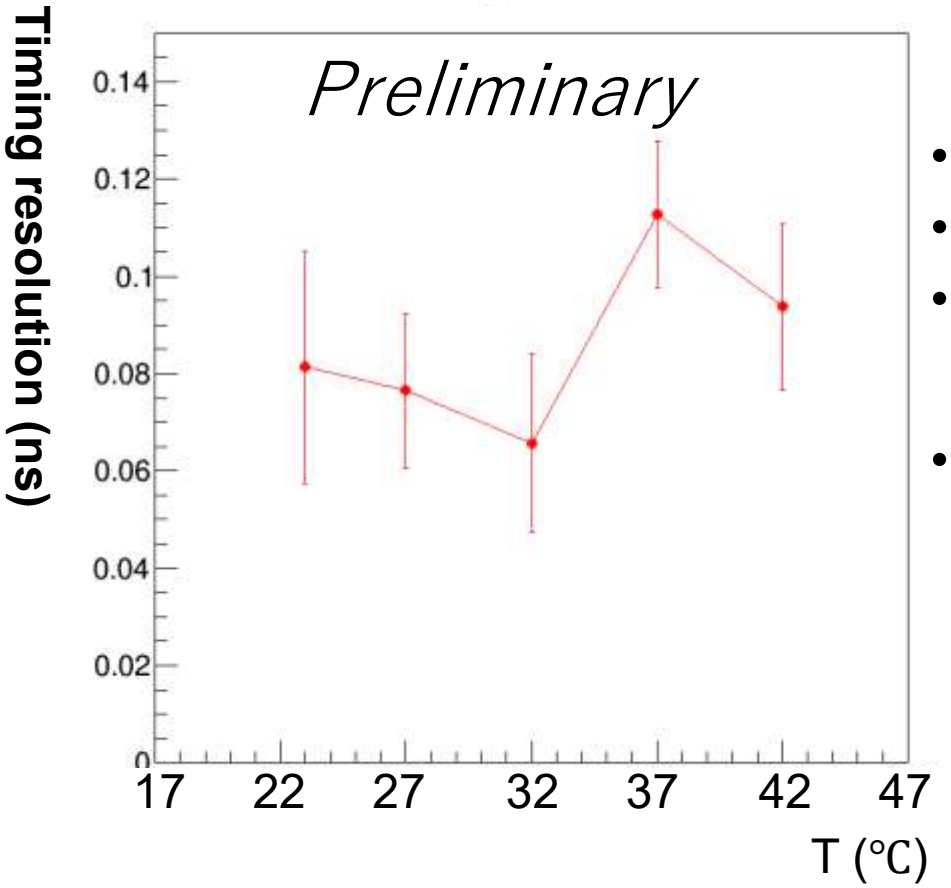
- Trigger
  - S1∩S2∩S3∩S4
- Gas mixture
  - R134a (90%), SF6 (10%)

T dependence of the pulse height and timing resolution (cosmic ray)

Peak pulse height with FADC



Timing resolution with TDC



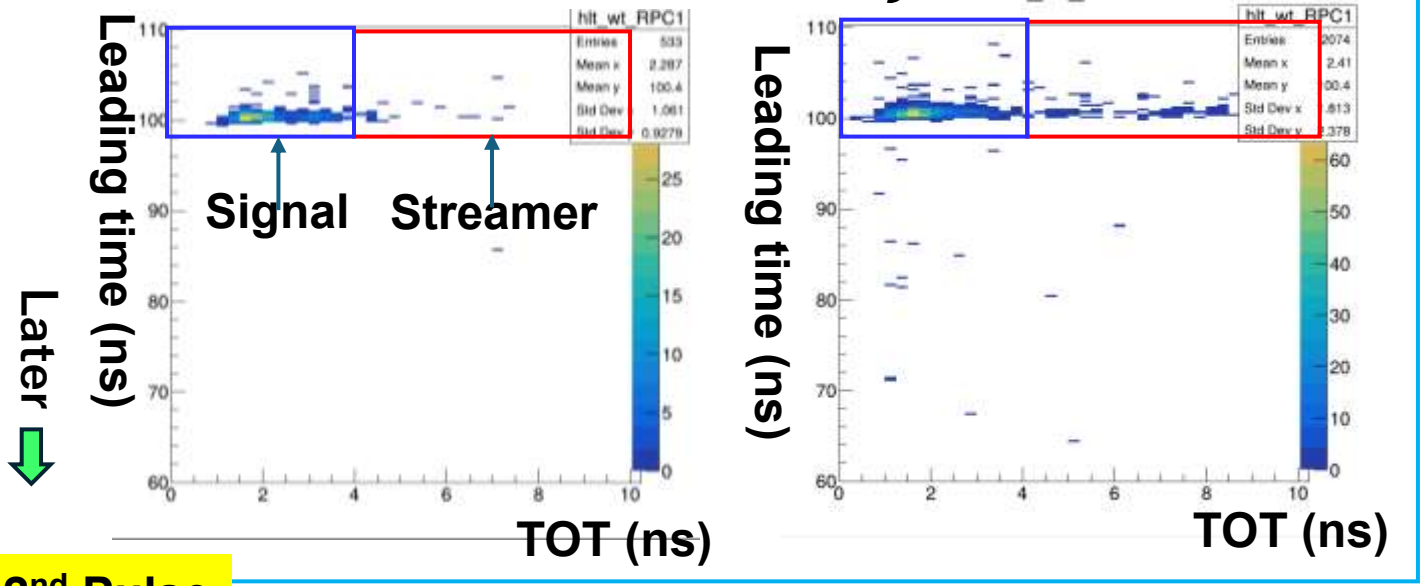
- Efficiency~95%
- Gain increases with T
- The timing resolution has almost no change with T
- At a very low rate, less than 13% improvement is expected according to Gapienko et al

Streamer study (w/ Multi-hit TDC)

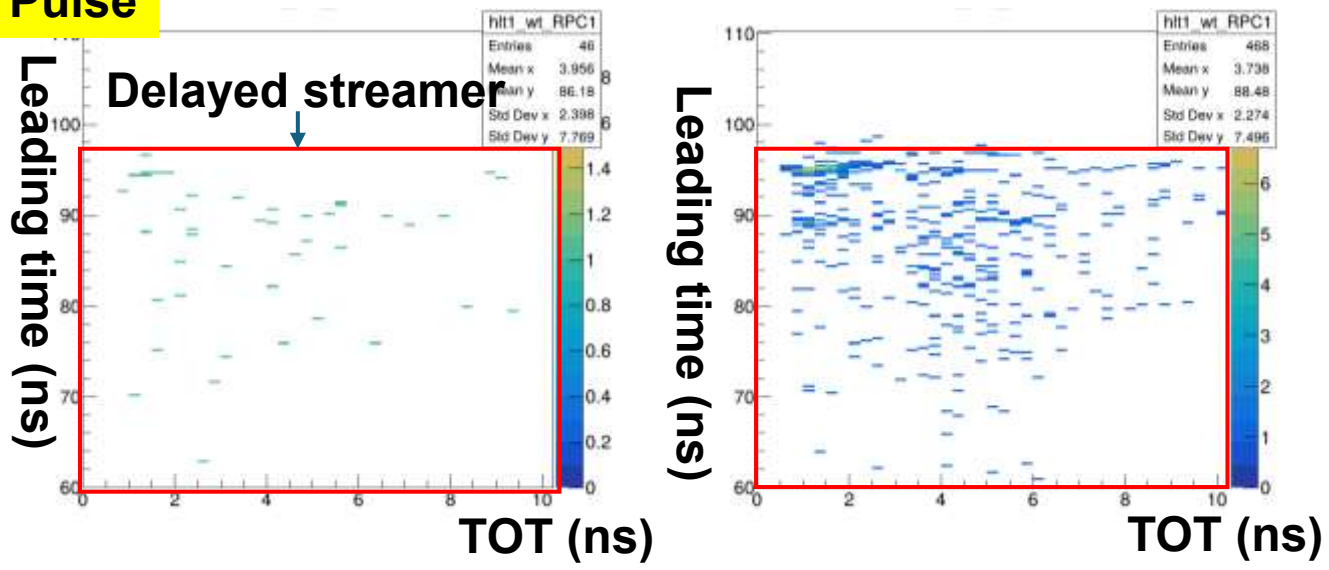
1st Pulse

T=28℃ T=37℃

Preliminary

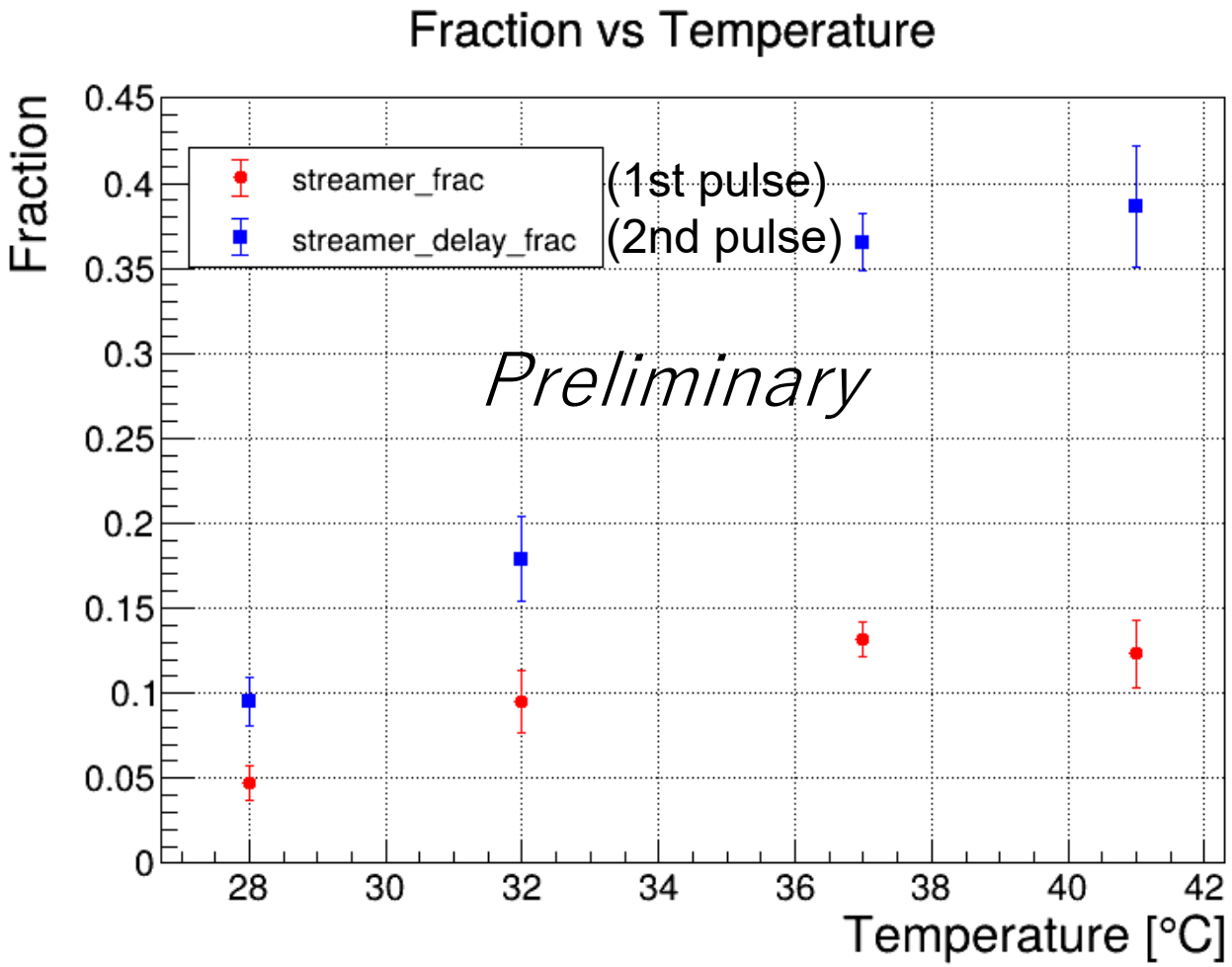


2nd Pulse



- Define “signal” as the 1st short-width pulse
- Define “streamer” as the first long-width pulse and the second delayed pulse
- Fractions of streamers to signals are estimated.

T dependence of the streamer fraction



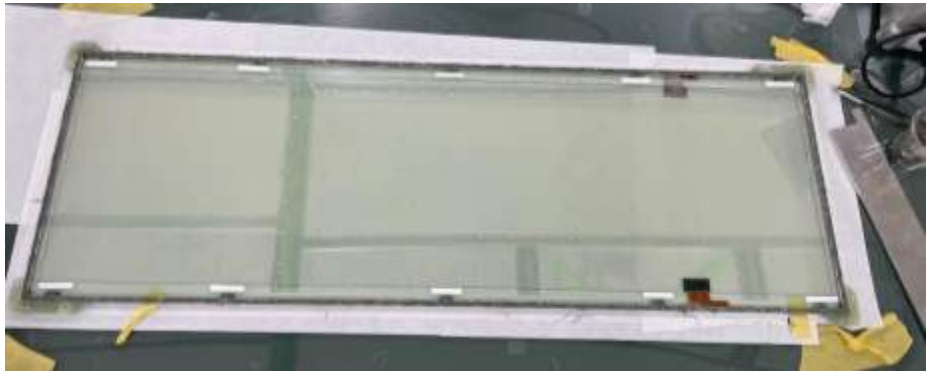
- Streamer fractions (both for 1st and 2nd pulses) increase with temperature significantly

Summary and Outlook

- MRPC with warming glass developed for J-PARC E88/SAΦRE
- Timing resolution improvement with T observed
- The increase of the streamer fraction with T observed
  - To reduce the streamer fraction, optimization of HV setting or gas mixture should be considered

Outlook

- R&D of MRPC with the new spacer (Mylar cylindrical seal) and the new electrode (in collaboration with MARQ)
- Production of ~10 MRPCs in 2028
- Physics beam time in ~2029



E88 Collaboration

- H. Sako (Spokesperson), W. S. Jung, G. Nukazuka, F. Oura, S. Sato (ASRC/J-PARC, JAEA)
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- W. C. Chang, M. L. Chu, C. Y. Hsieh, L. C. Huang, H. H. Yao (Academia Sinica, Taiwan)
- P. J. Lin, Y. L. Lin, M. S. Yeh (National Central Univ., Taiwan)
- T. Chujo, S. Esumi, Y. Miake, T. Niida, T. Nonaka, R. Sato (Univ. of Tsukuba)
- M. Inaba (Tsukuba Univ. of Technology)
- R. Koike, M. Naruki, S. Nagafusa, N. Tomida (Kyoto Univ.)
- T. Sakaguchi (BNL)
- S. Hayakawa, Y. Ichikawa, M. Kumekawa (Tohoku Univ.)
- T. Ishikawa, K. Mizutani, H. Noumi, S. Y. Ryu, K. Shirotori, K. Suzuki, T. N. Takahashi, (RCNP, Osaka Univ.)
- J. K. Ahn (Korea Univ.)
- S. H. Kim (Kyungpook National Univ.)
- T. Hachiya, M. Shimomura (Nara Women's Univ.)
- M. Ichikawa, T. Murakami, S. Nakasuga, S. Yokkaichi (RIKEN)

Main members working on MRPCs

