東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo

KOBE UNIVERSITY

超低物質量・高レート耐性 DLC-RPCの時間分解能

李　維遠（東大理）

大谷航[A]、大矢淳史、越智敦彦[B]、高橋真斗[B]、
潘晟[A]、森俊則[A]、山本健介
（東大理、東大素セ[A]、神戸大理[B]）

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Outline

- **Review of DLC-RPC**
- **Motivation of this study:** Application to the new detectors
- **Strategy for better time resolution**
- **Setup at Lab test**
- **Results**
  - Efficiency
  - Time resolution
- **Performance estimation for the new detectors**
- **Summery**
- **Prospects**

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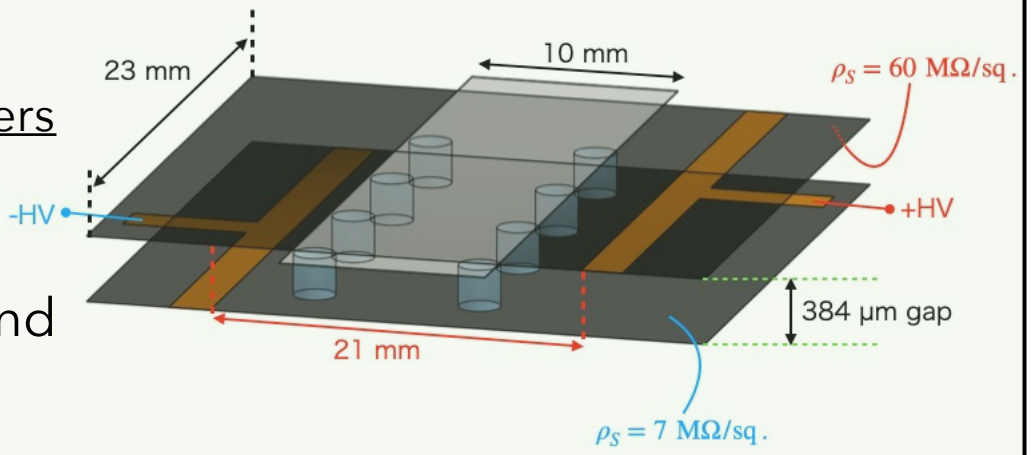
Review of DLC-RPC

- **Ultra-low Mass**
  - DLC based electrode

  <u>0.1 % radiation length with 4 layers</u>
- **High-rate Capability**
  - segmented HV supply and relatively low resistance

  <u>Over 1 MHz/cm^2</u>
- σ_t = 160 – 170 ps with single layer, 384 μm gap width

DLC-RPC with single layer



Related Talks :
6pA421-1(高橋)
6pA421-2(山本)

Optimization for timing

"Ultra-low mass × High-rate capability × Fast timing"

Why not use this technology for future detectors?

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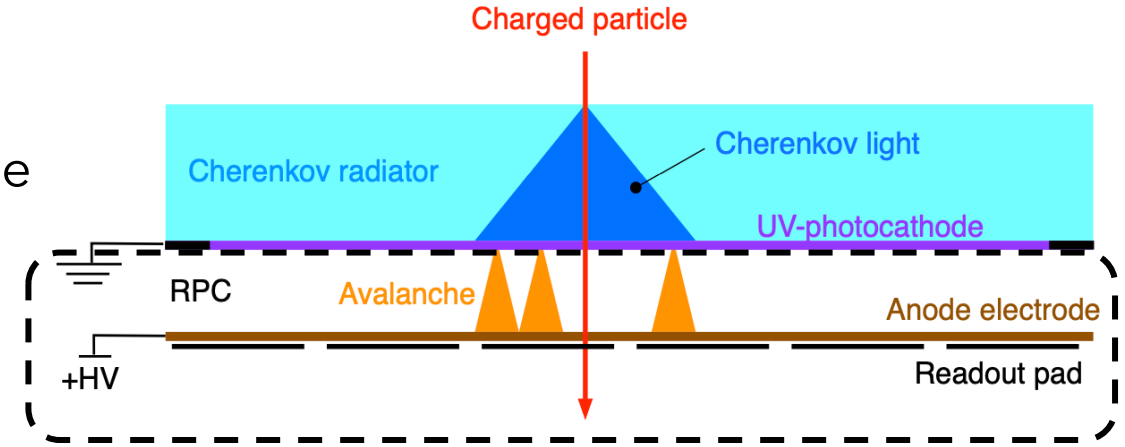
Application to New Detectors

- **Cherenkov Detector**
  - Electron multiplier usage
  - Aiming to achieve
    20 ~ 30 ps with
    ~10 photoelectron*



* : value of PICOSEC detector (https://doi.org/10.1016/j.nima.2021.165049)
similar concept detector using micromegas for the electron multiplier

- **Multigap-RPC (mRPC) consists of DLC-RPC**
  - Aiming for good time resolution (~ 40 ps) & efficiency (99 %)
    by stacking DLC-RPC
  - Motivation triggered by development of elemental technology
    for the successor to MEG II

Related Talks : 7pA442-1(横田), 7pA442-2(池田)

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Strategy

- **What is the main contribution of time resolution?**
  - $\sigma_t \approx \frac{1.28}{(\alpha - \eta) \cdot v_{\mathrm{drift}}}$ ref. https://doi.org/10.1016/S0168-9002(03)00337-1
    - $\alpha\ (E)$: Townsend coefficient, describes multiplication of #(electron)
    - $\eta\ (E)$: attachment coefficient, describes attenuation of #(electron)
    - $v_{\mathrm{drift}}\ (E)$: electron drift speed

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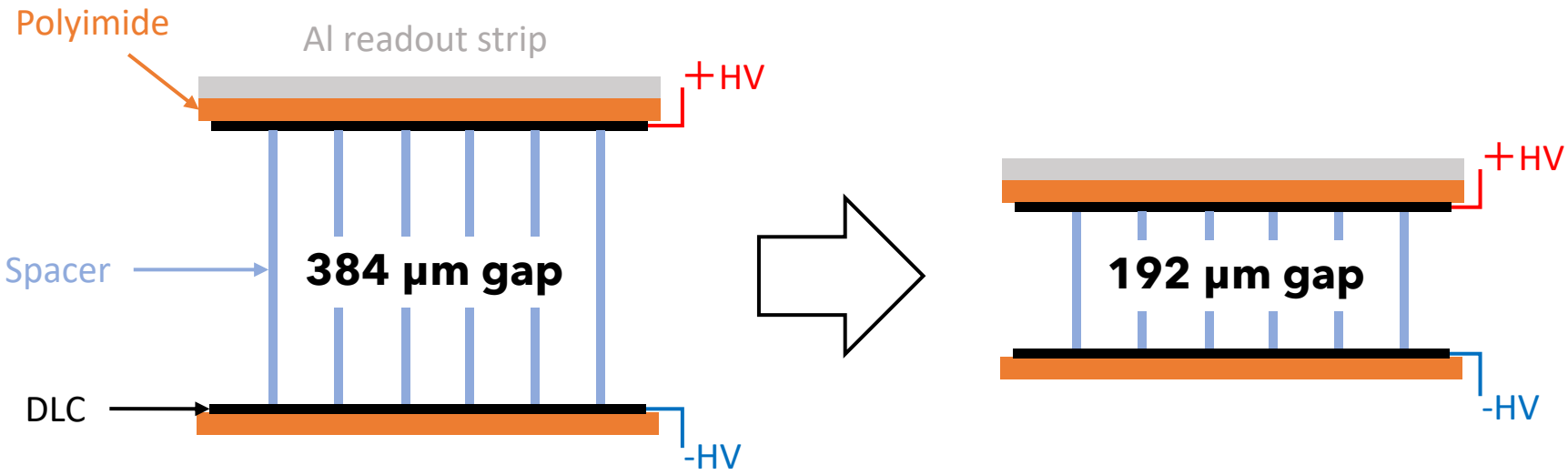
    - $\eta\ (E)$: attachment coefficient, describes attenuation of #(electron)
    - $v_{\text{drift}}\ (E)$: electron drift speed
  - Smaller gap → Larger E field → Better time resolution



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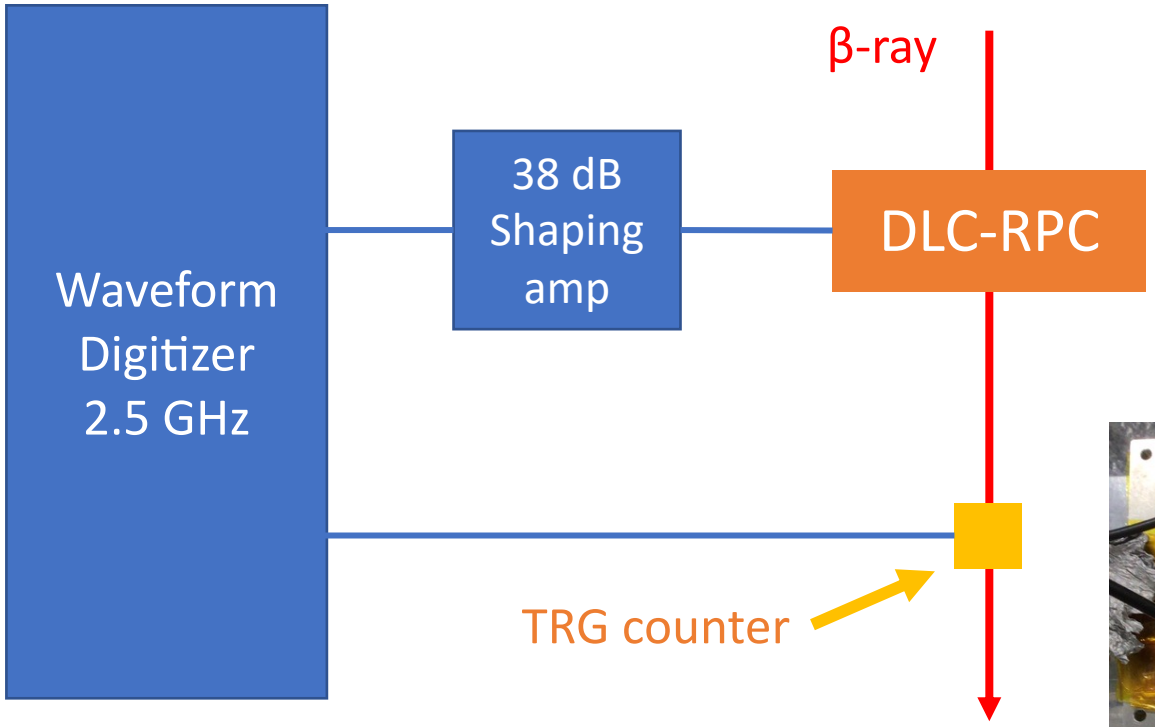
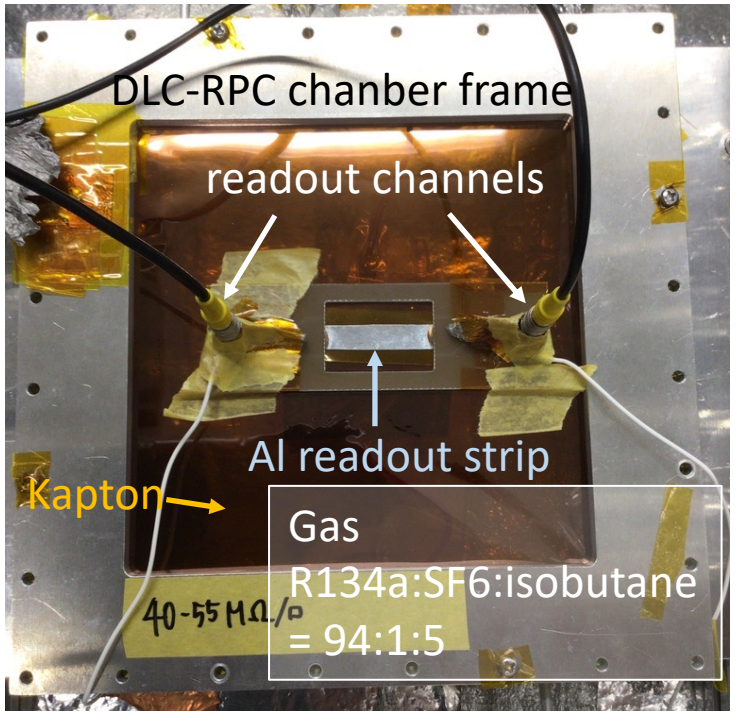
Setup



DLC-RPC from top side



- **HV scan**
  - From 1760 V to 1960 V by 50 V step

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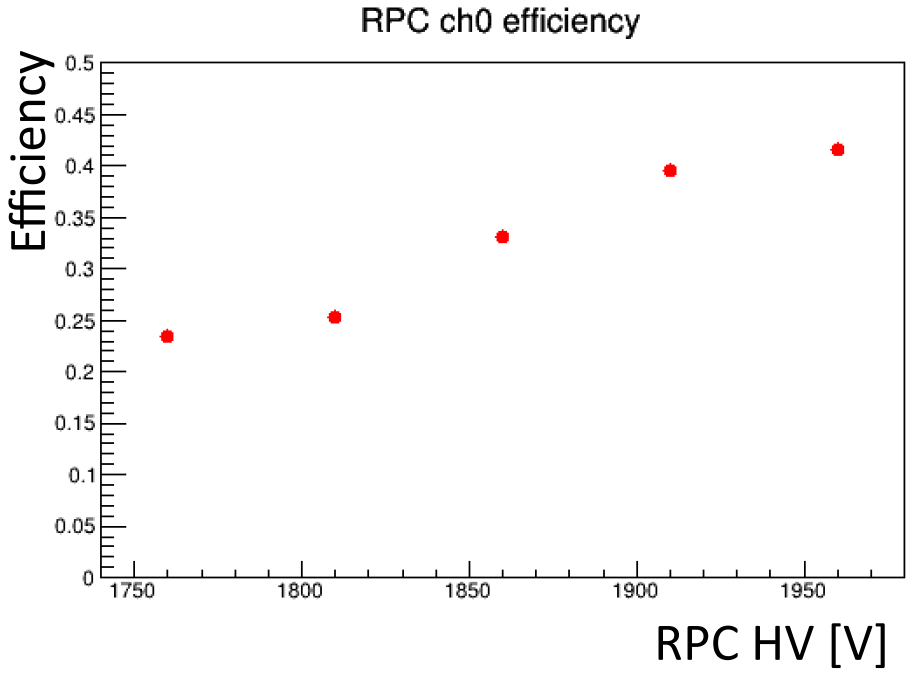
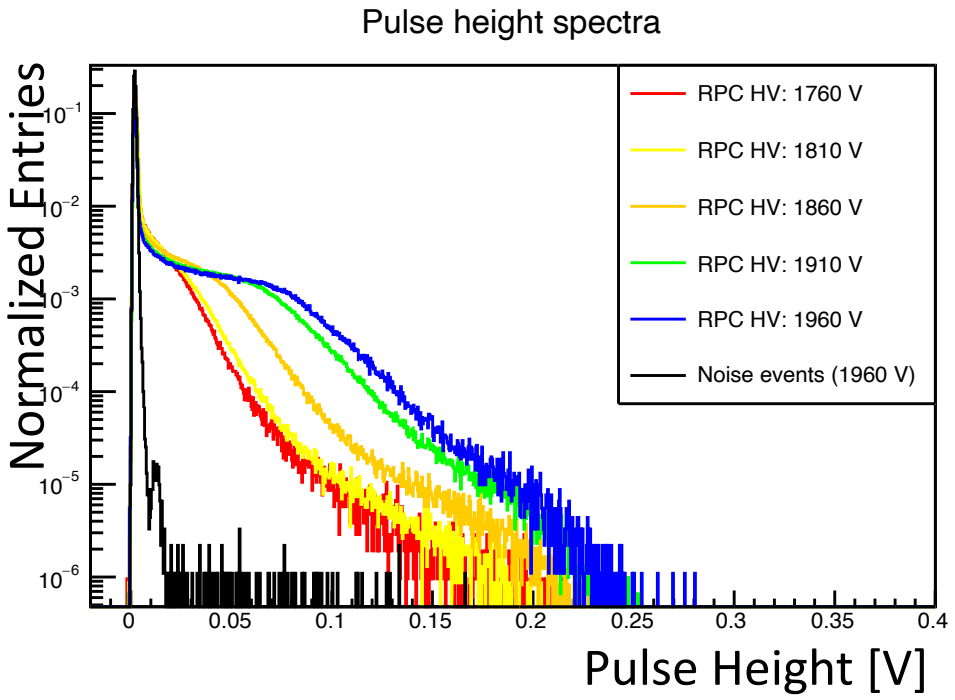
Efficiency

- **41.5 % signal efficiency was achieved at 1960 V**
  - Threshold was set to 5 mV considering noise level
  - 0.1 % noise contamination

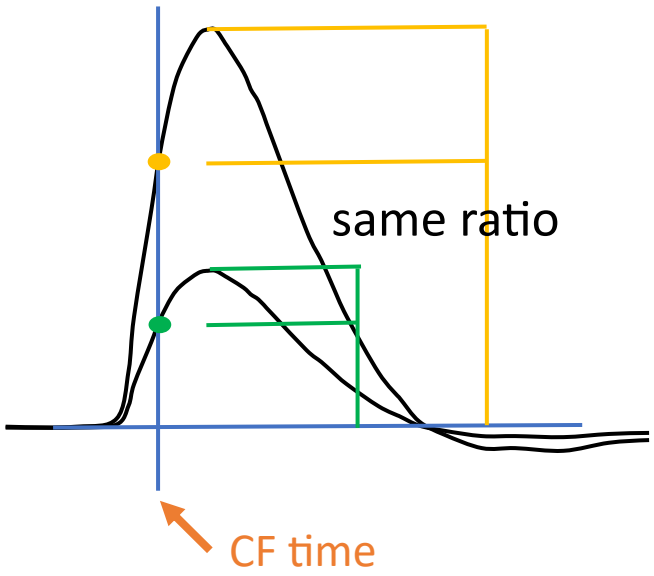


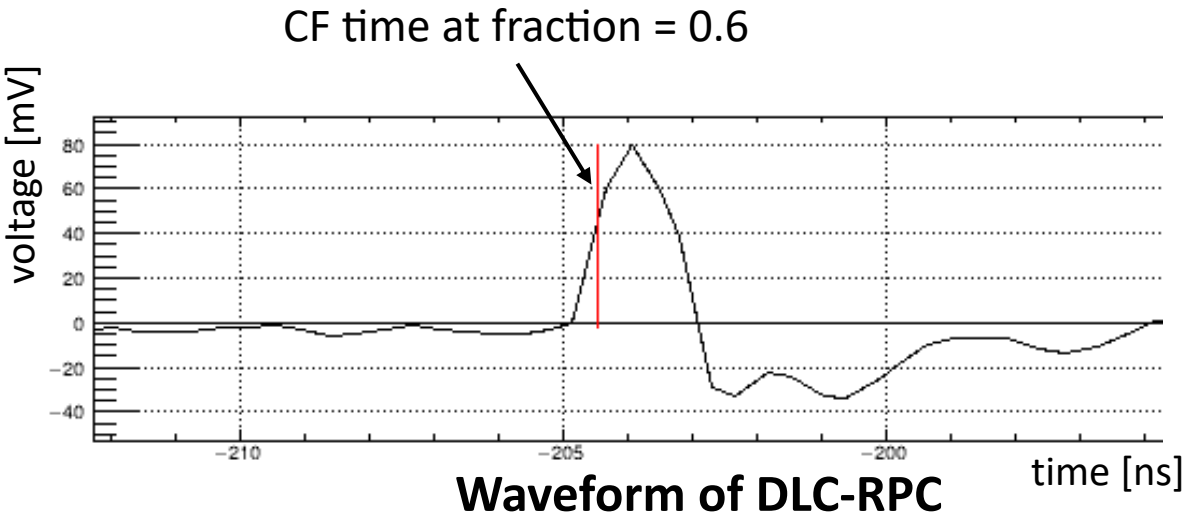


Time Resolution

- **Constant Fraction (CF) Method**
  - if pulse shape is similar in the height direction, constant fraction time will be the same

  → time walk can be suppressed

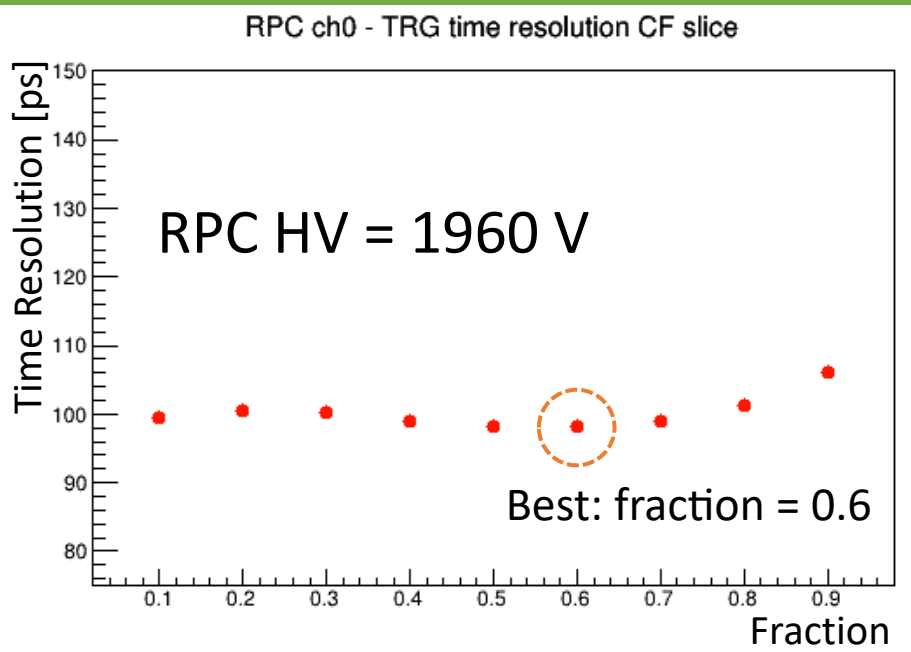




Waveform of DLC-RPC

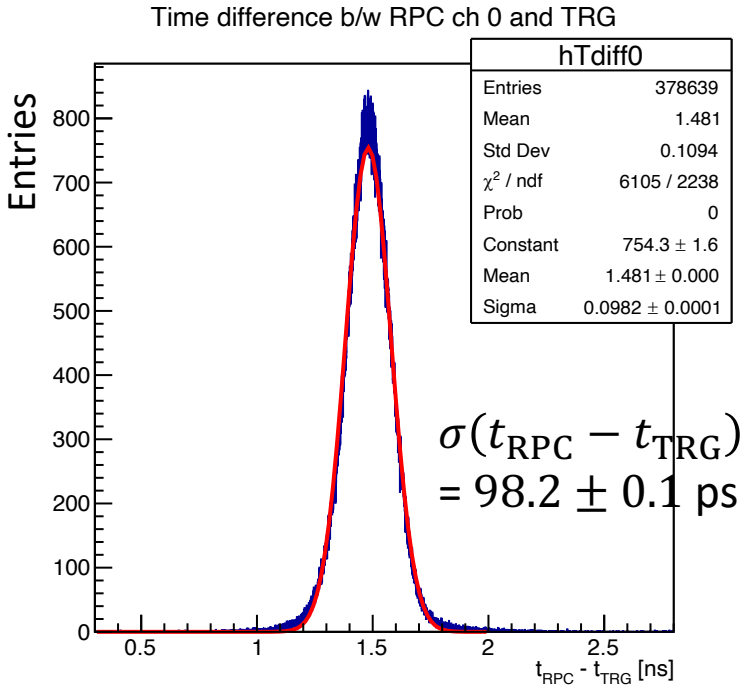
Time Resolution

- **Fraction choice**
  - Best time resolution achieved at fraction = 0.6



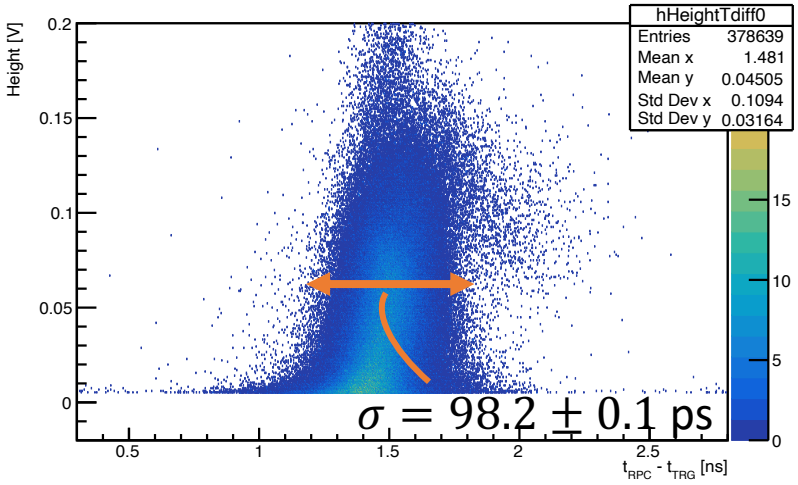
In the condition of
- HV = 1960 V
- Threshold = 5 mV
- Fraction = 0.6

$\sigma(t_{\mathrm{RPC}} - t_{\mathrm{TRG}})$ = 98.2 ± 0.1 ps was achieved

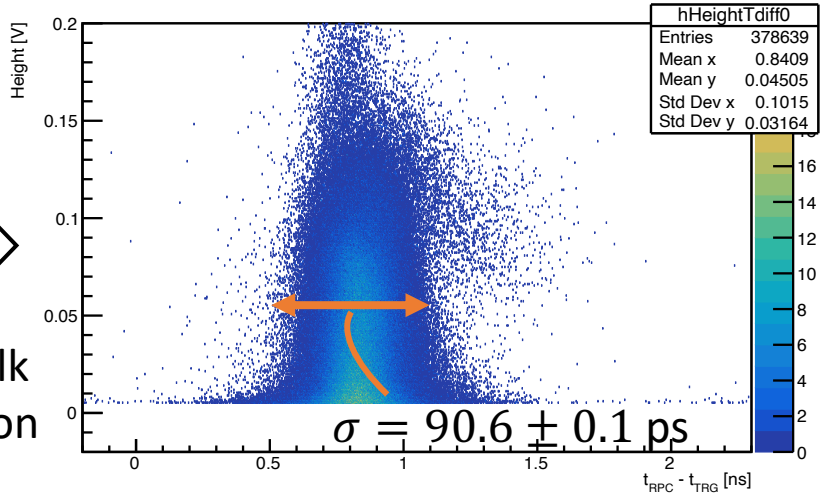


Time Resolution

- **Even after the CF method, time walk still exists…**
  - After time walk correction, $\sigma(t_{\mathrm{RPC}} - t_{\mathrm{TRG}}) = 90.6 \pm 0.1$ ps
    - Correction function = $\sigma(t_{\mathrm{RPC}} - t_{\mathrm{TRG}}) - (\text{pulse height} \times 0.042)^{0.068}$



time walk correction

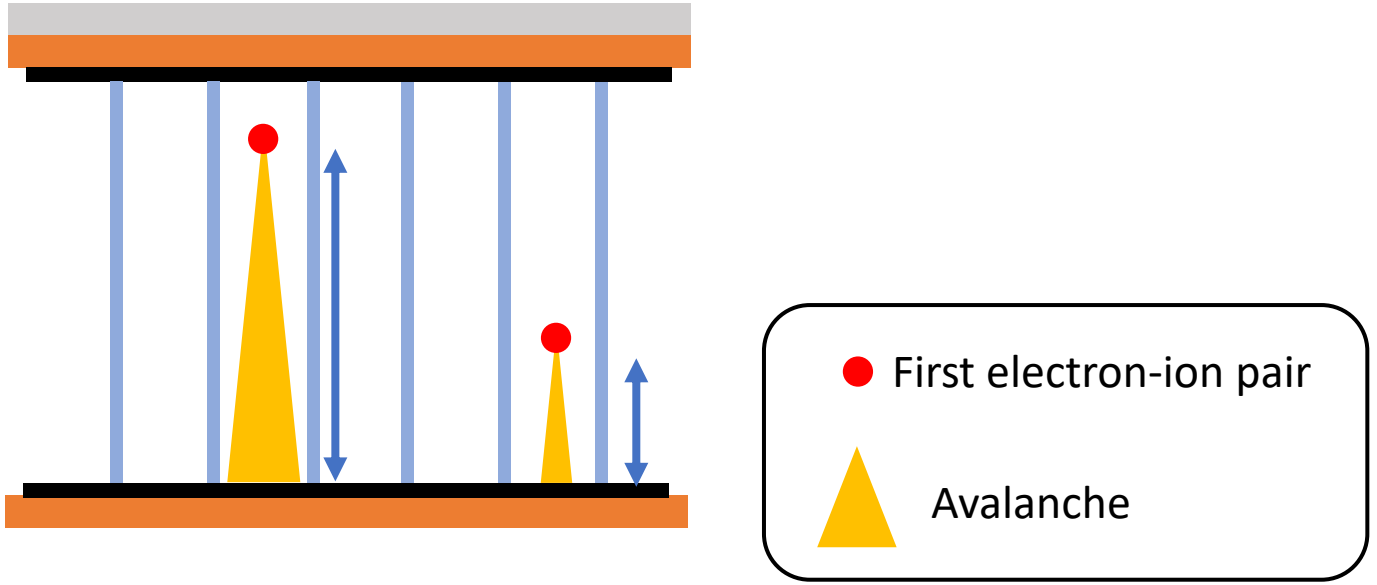


Time Resolution

- **Intrinsic time resolution**
  - $\sigma(t_{\mathrm{RPC}}) = \sigma(t_{\mathrm{RPC}} - t_{\mathrm{TRG}}) \ominus \sigma(t_{\mathrm{TRG}}) = 84.5 \pm 0.3$ ps
    - ✓ Time resolution of trigger counter was measured to be $\sigma(t_{\mathrm{TRG}}) = 32.7 \pm 0.7$ ps
- **Comparison with** $\sigma_t \approx \dfrac{1.28}{(\alpha - \eta) \cdot v_{\mathrm{drift}}}$
  - $\sigma_t \approx 70$ ps at $E = \dfrac{1960\ \mathrm{V}}{192\ \mu\mathrm{m}} \sim 1.0 \times 10^5$ V/cm
  - $\sigma_t \approx 190$ ps at $E = \dfrac{2750\ \mathrm{V}}{384\ \mu\mathrm{m}} \sim 7.2 \times 10^4$ V/cm
    - This estimation has factor level of deviation
    - Roughly showing comparable behavior

Time Resolution

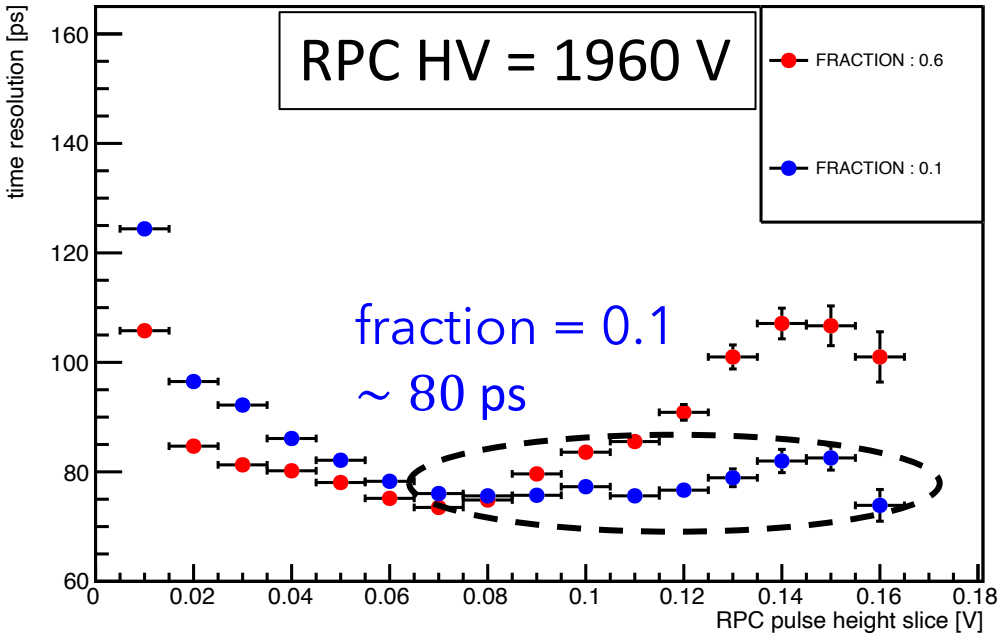
- **Height slice of $\sigma(t_{\mathrm{RPC}})$** : with application to CD
  - longer amplification distance ~ larger pulse height event



Time Resolution

- **Height slice of $\sigma(t_{\mathrm{RPC}})$**
  - longer amplification distance ~ larger pulse height event
  - Constant fraction = 0.1 gives the best time resolution

~ 80 ps is achieved at large pulse height region



Time Resolution

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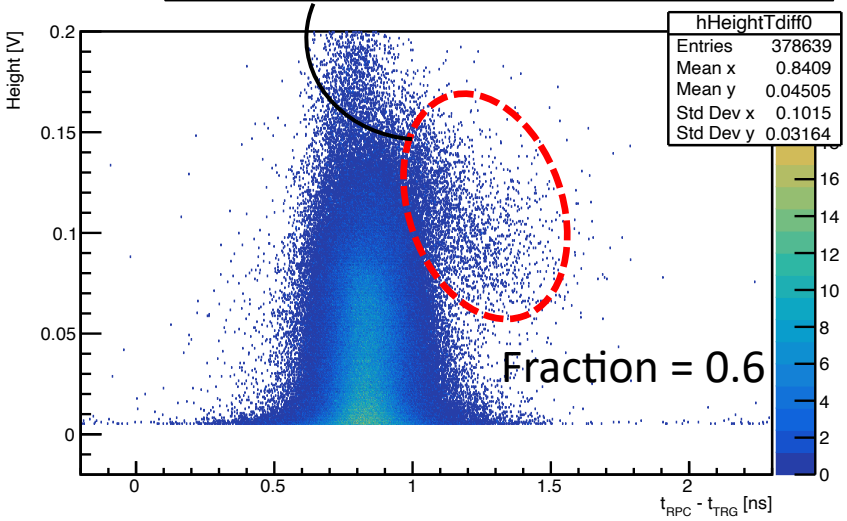
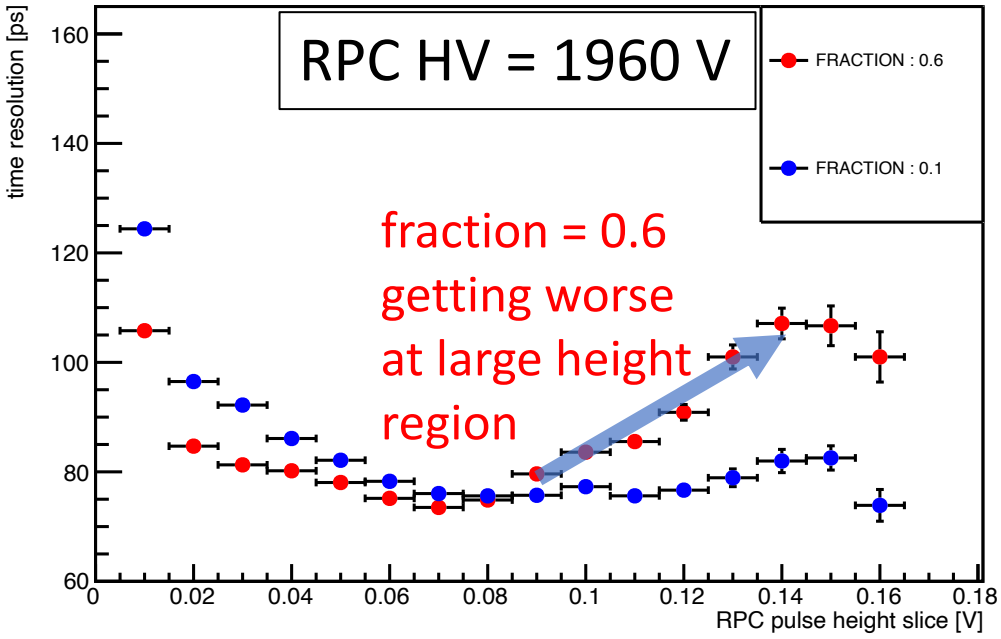
What is happening here?
▶ furthur study with simulation





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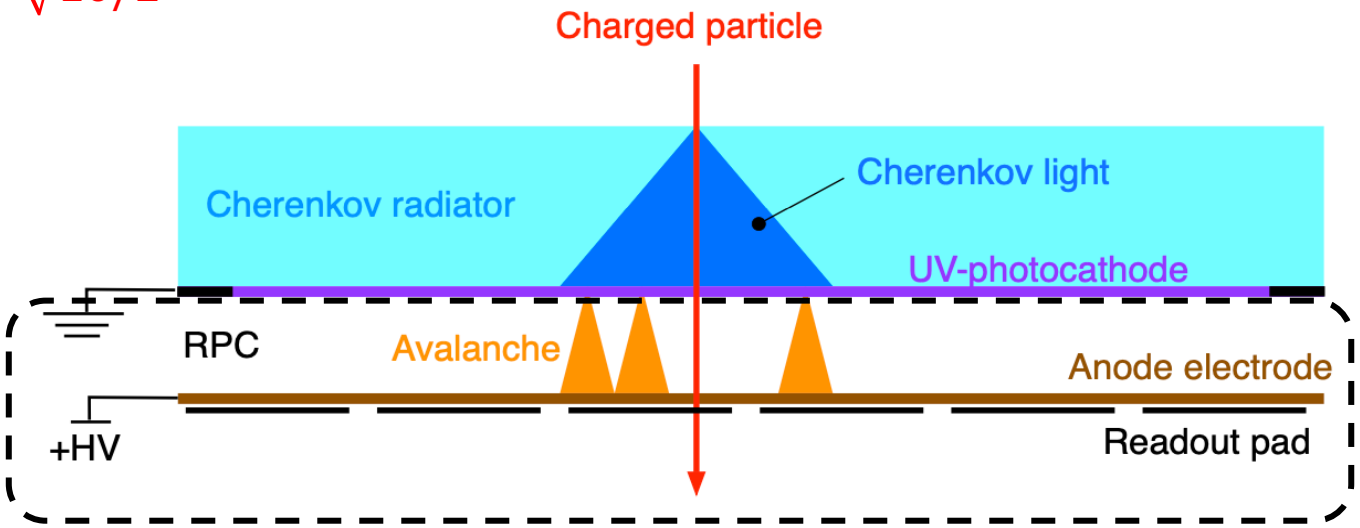
Performance Estimation

- **Chrenkov Detector (CD)**
  - $\sigma(t_{\mathrm{RPC}}) \sim 80$ ps at large pulse height events
    - Average ~ 2 primary electrons per cluster*
  - Assuming ~ 10 p.e. comes out of the photocathode

$$\sigma(t_{\mathrm{CD}}) \sim \frac{80}{\sqrt{10/2}} \sim 36 \text{ ps}$$

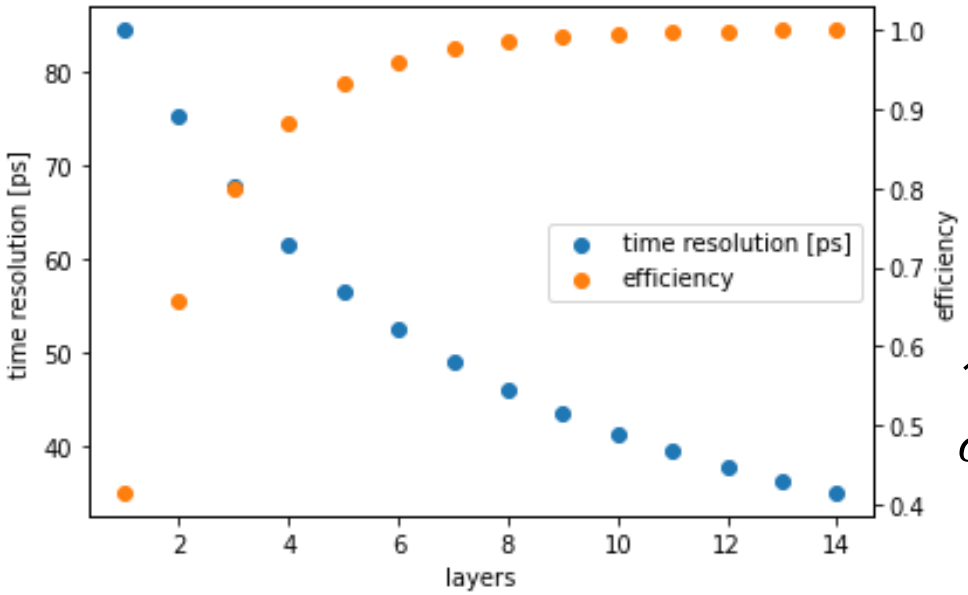
* : roughly calculated from
https://doi.org/10.1016/S0168-9002(03)00337-1



Performance Estimation

- **mRPC**
  - Assuming $\sigma_1 = 84.5$ ps, $\epsilon_1 = 41.5$ % as time resolution and efficency for single layer, ϵ_n and σ_n for n layers:

$$\epsilon_n = 1 - (1-\epsilon_1)^n, \qquad \sigma_n = \frac{\sigma_1}{\left(\sum_{k=1}^{n}\binom{n}{k}\frac{\epsilon_1^k(1-\epsilon_1)^{n-k}}{1-(1-\epsilon_1)^n}\right)^{1/2}}$$



11 layers will be needed to achieve $\sigma_t = 40$ ps and efficiency = 99%

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Summary

- **By shorten the gap width of DLC-RPC to 192 μm, better time resolution is achieved at HV = 1960 V**

	DLC-RPC Prototype for MEG II	This study
gap width [μm]	384	192
HV [V]	2750	1960
efficiency	~ 60 %	41.5 %
$\sigma(\mathrm{RPC})$ [ps]	160 ~ 170	$\mathbf{84.5 \pm 0.3}$

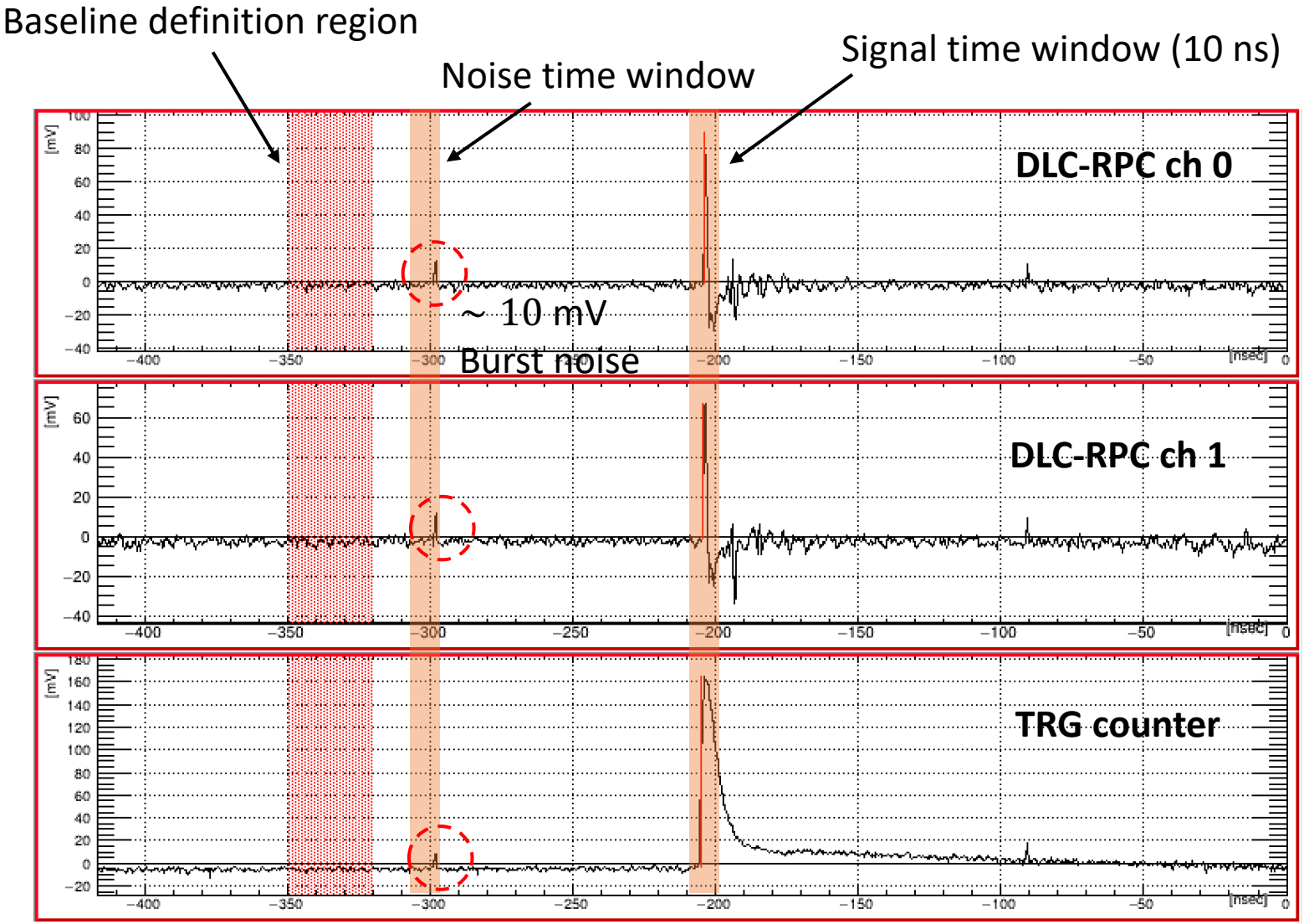
- **Application of DLC-RPC to future detectors were discussed**

Prospects

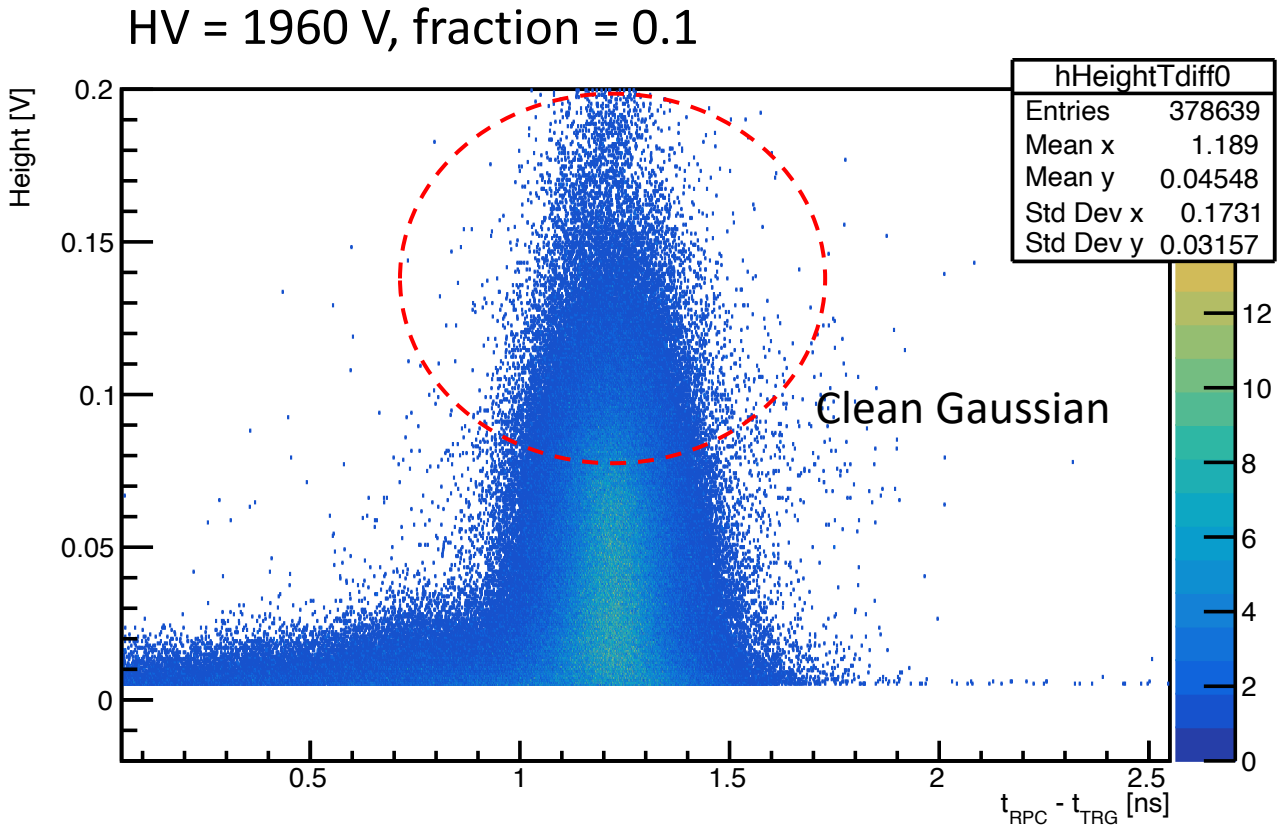
- **Further understanding of DLC-RPC**
  - Simulation study of DLC-RPC
  - Stack to multilayers
- **Application to Cherenkov Detector**
  - DLC-RPC operation using UV photo-cathode

Backups

10 mV peak at noise height distribution



$\sigma(t_{RPC} - t_{TRG})$ vs Pulse Height : CF = 0.1

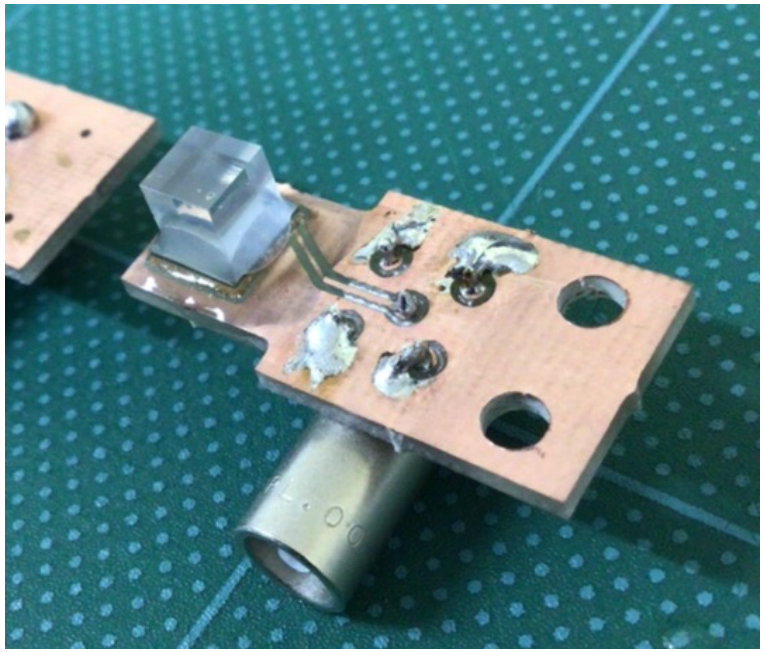


TRG counter

- **MPPC + plastic scintillator**
  - MPPC : S14160-6050HS

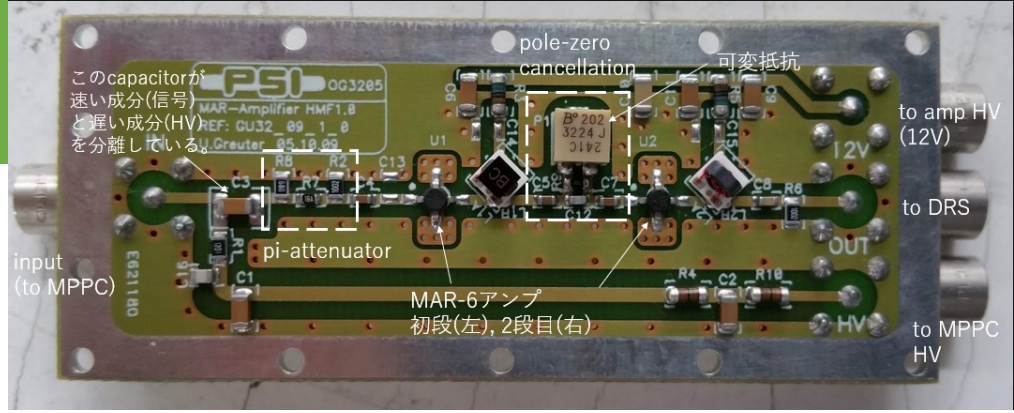
    ref: https://www.hamamatsu.com/jp/ja/product/optical-sensors/mppc/mppc_mppc-array/S14160-6050HS.html
    - OP voltage : 39.9 V
  - Scintillator : EJ-232 (FAST TIMING PLASTIC SCINTILLATOR)

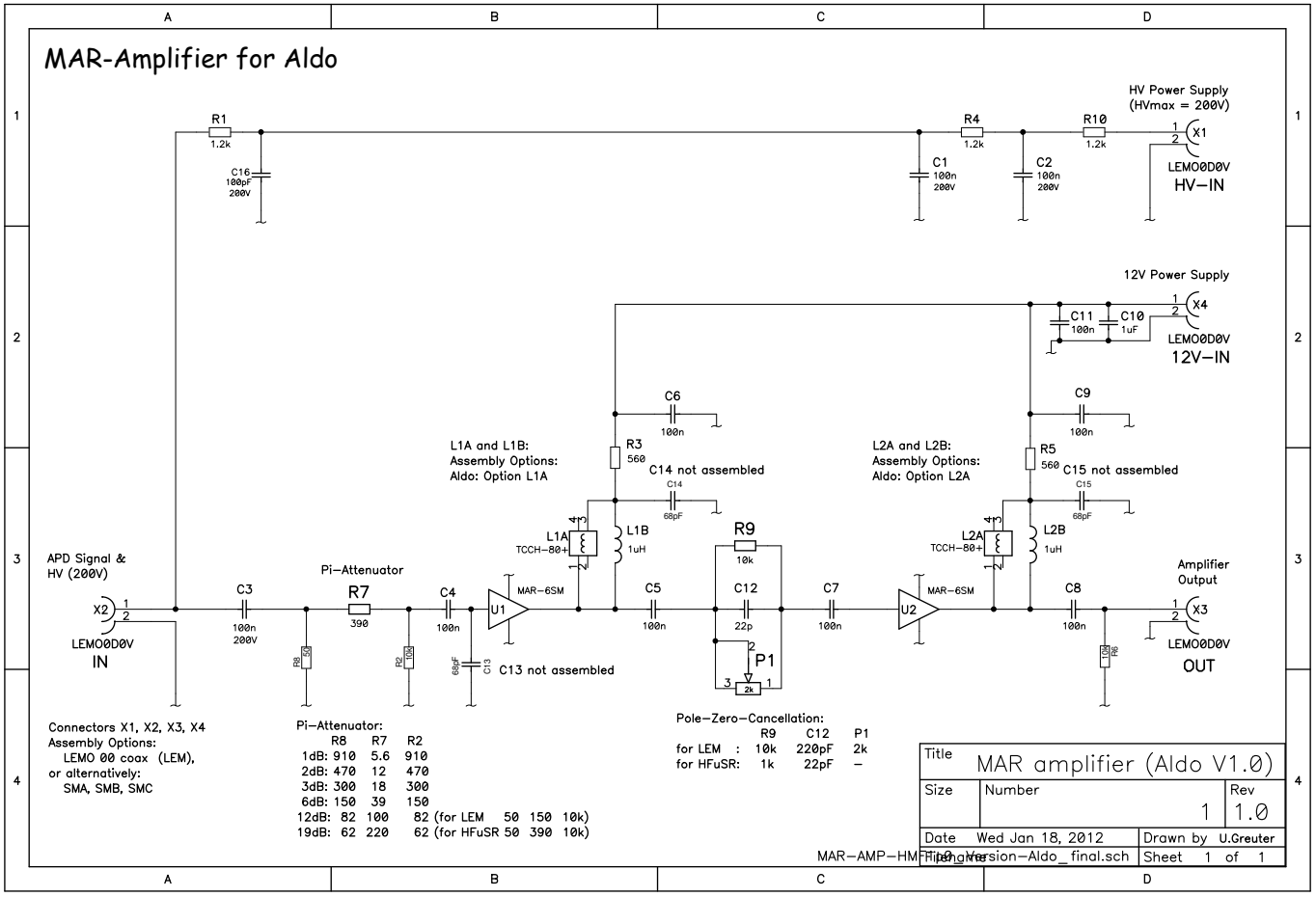
    ref: https://eljentechnology.com/products/plastic-scintillators/ej-232-ej-232q
  - $\sigma(\mathrm{TRG}) = 32.7 \pm 0.7$ ps



Amplifier

- **PSI amp**





Gain : 38 dB
PZC : 1.75 kΩ

Structure of DLC-RPC