# MPPCとチェレンコフ光を利用した検出器
# - Cherenkov timing detector -

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**for the J-PARC E50 collaboration**

**Research Center for Nuclear Physics (RCNP), Osaka University**

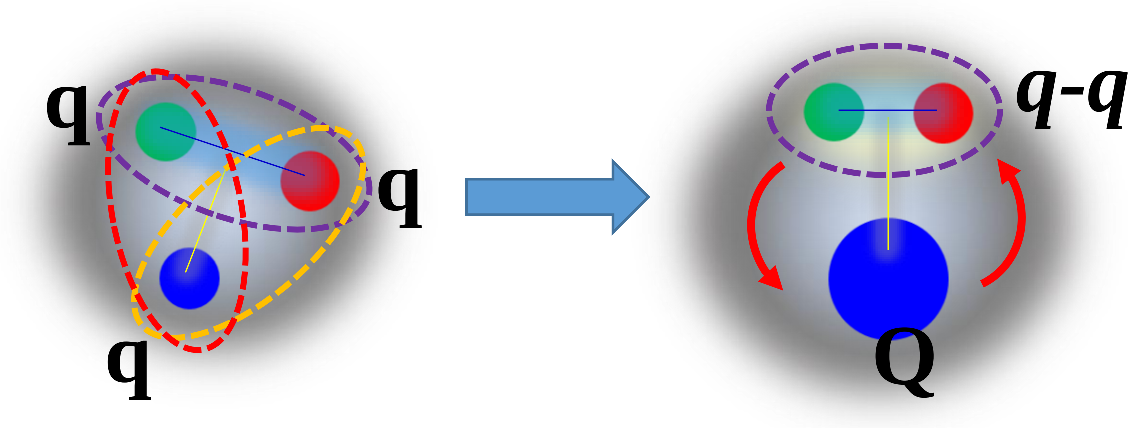
**計測システム研究会2022 @ J-PARC**

**17th Nov. 2022**

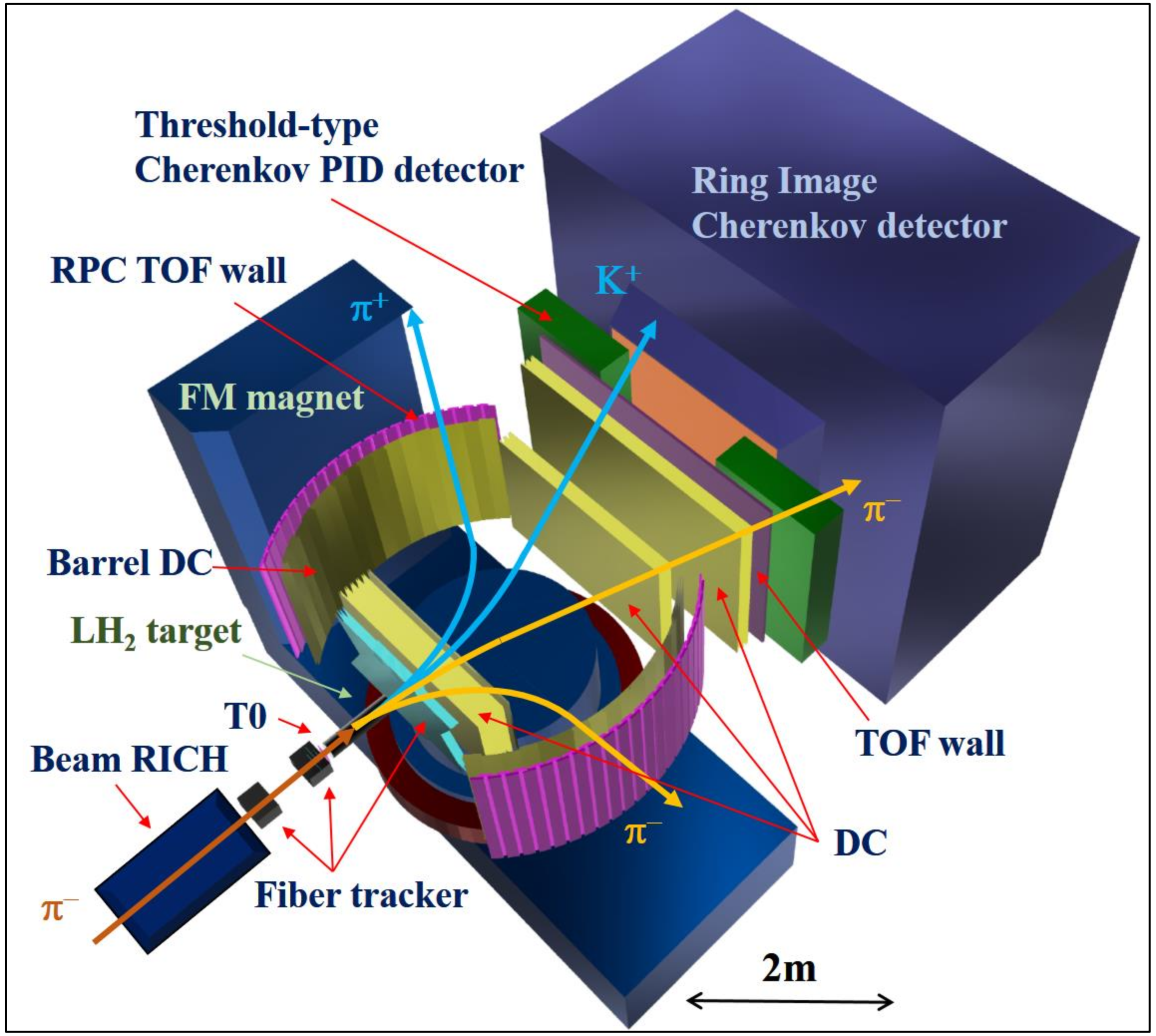
# Charmed baryon spectroscopy experiment: J-PARC E50

- Study of effective degrees of freedom of hadron: Diqaurk correlation

⇒ Charmed baryon spectroscopy: *q-q* + Q system




E50 spectrometer system




✱ Experiment: Production and decay

- Missing mass method: $\pi^- + p \rightarrow Y_c^{*+} + D^{*-}$
  - + Decay measurement $\rightarrow K^+ \pi^- \pi^-$

⇒ High-intensity 2ndary beam @ 20 GeV/c

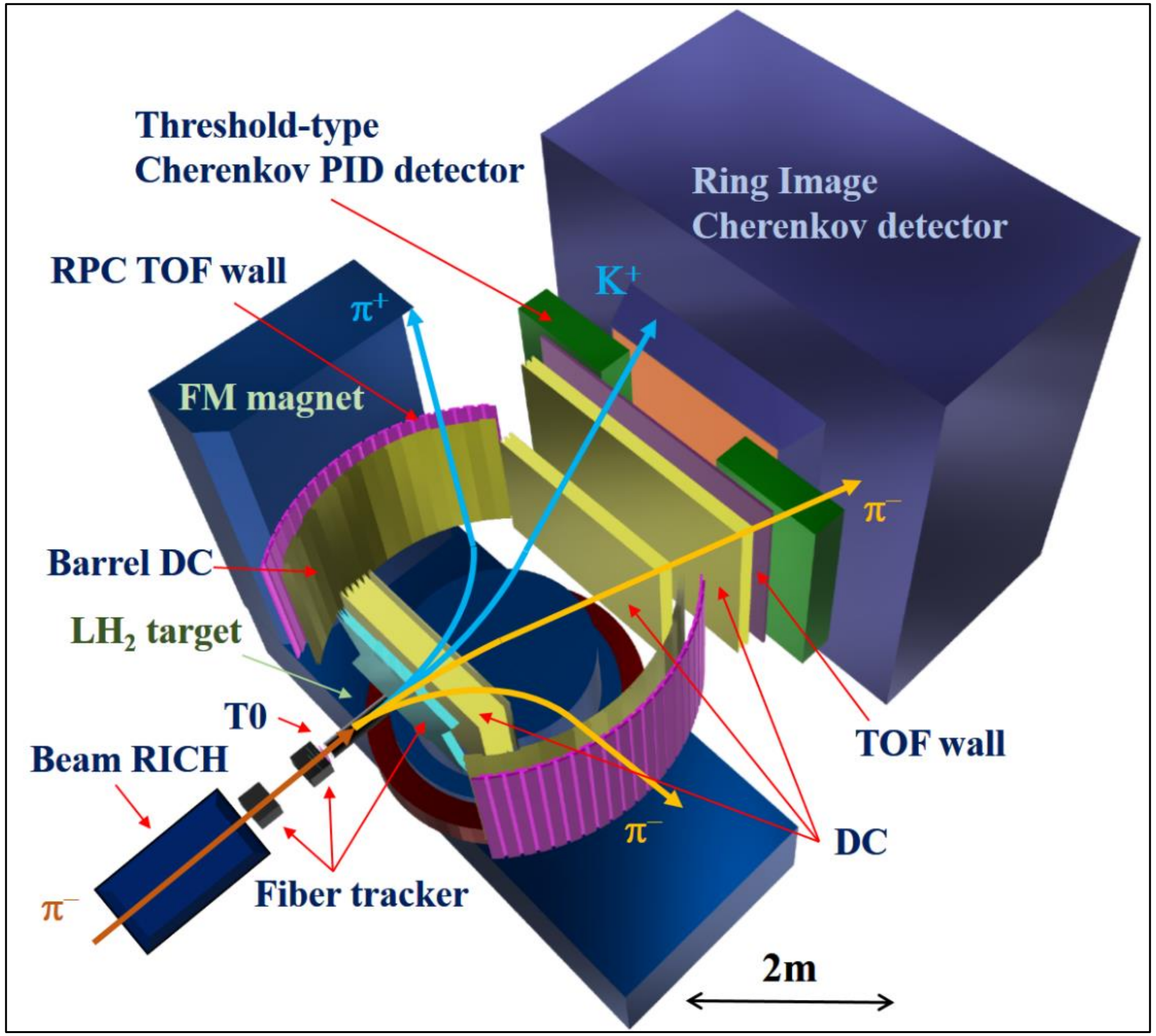
- 30 MHz ⇒ ~2 MHz reaction rate

# Overview of E50 spectrometer system

- High-rate beam detectors
  - Scintillation Fiber Tracker
  - Cherenkov Timing detector: T0
- High-performance PID detectors
  - High timing-resolution TOF wall: RPC
  - RICH & Beam RICH
  - Threshold-type Cherenkov detector
- Large size detectors
  - Large size drift chambers
  - Forward TOF wall
  - Muon detector: RPC

– Photon detector
– Gas detector

✱ Streaming-type trigger-less DAQ
  - Only timing (TDC) data taking



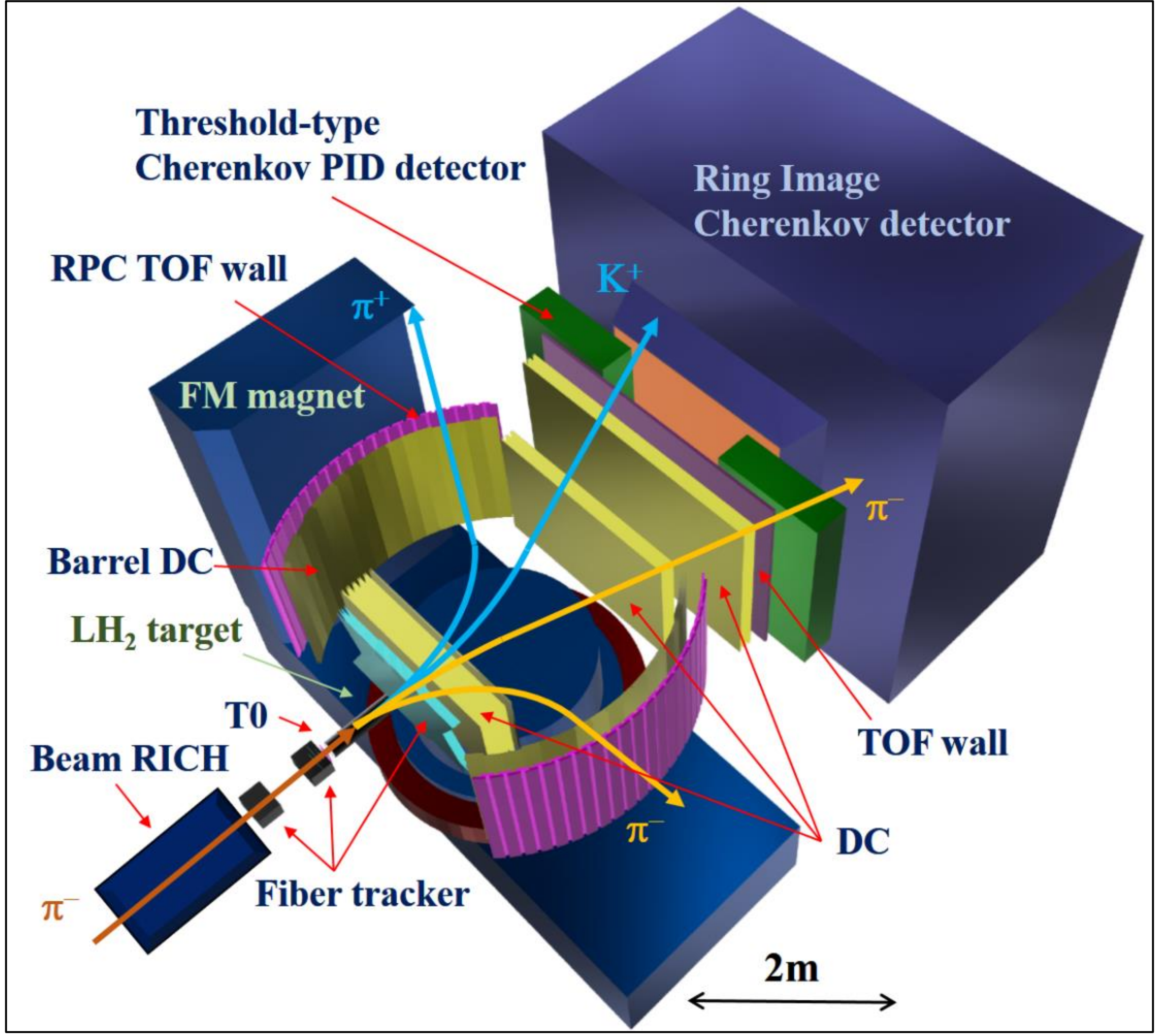
# Overview of E50 spectrometer system

- **High-rate beam detectors**
  - **Scintillation Fiber Tracker**
  - **Cherenkov Timing detector: T0**

    ∗*MPPC + Cherenkov: Timing w/ >3 P.E. detection*
- **High-performance PID detectors**
  - **High timing-resolution TOF wall: RPC**
  - **RICH & Beam RICH**
  - **Threshold-type Cherenkov detector**

    ∗*MPPC + Cherenkov: PID w/ 1 P.E. detection*
- **Large size detectors**
  - **Large size drift chambers: ASD card**
  - **Forward TOF wall**
  - **Muon detector: RPC**

**Yuji Yamamoto**




**∗Streaming-type trigger-less DAQ**
- **Only timing (TDC) data taking**

# Cherenkov Timing detector: T0

## Basic performance

# T0 detector overview

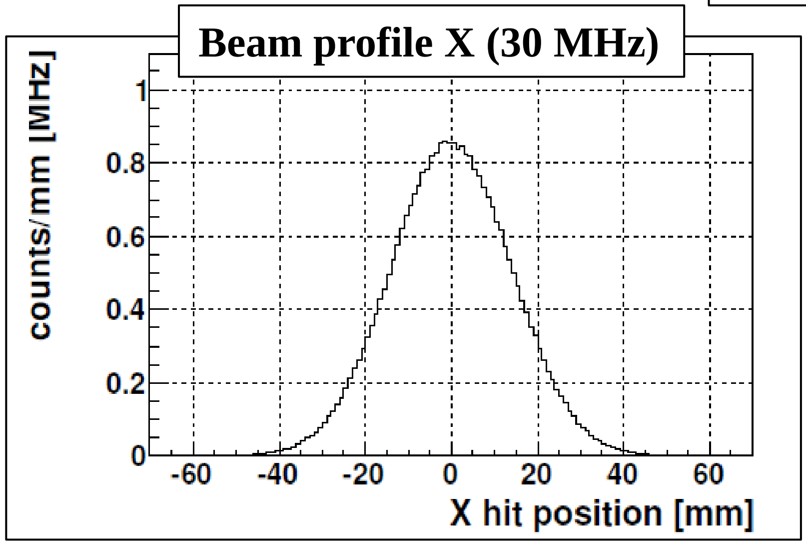
**＊Requirements**
- **ΔT < 70 ps(σ)**
- **~3 MHz/segment**
- **Time-walk correction w/o ADC**
  - **Discriminator(comparator) + TDC**

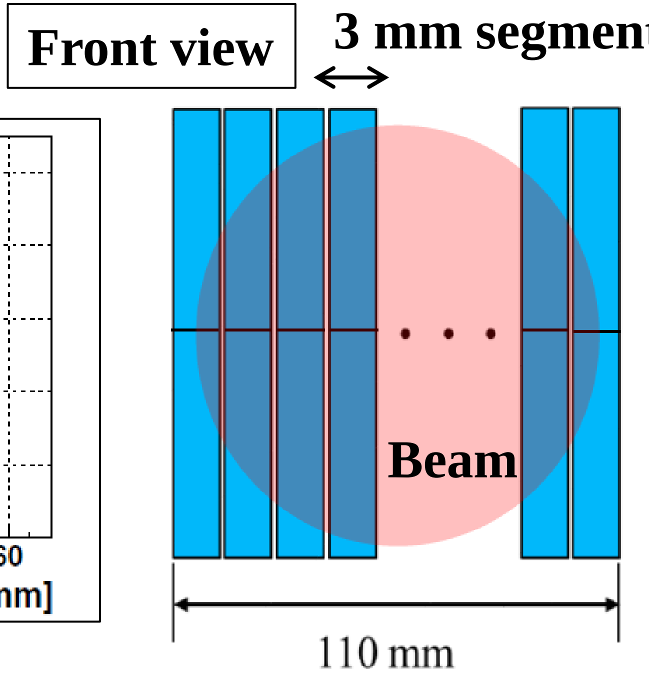
- **Segment by Acrylic (PMMA)**

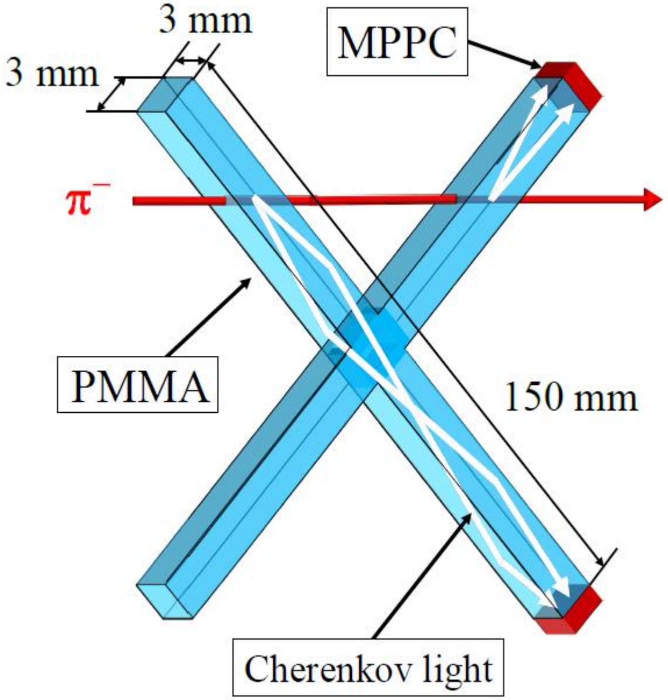
**⇒ Cross shape: X-type**
- **Cherenkov angle direction**
- **Both ends readout**

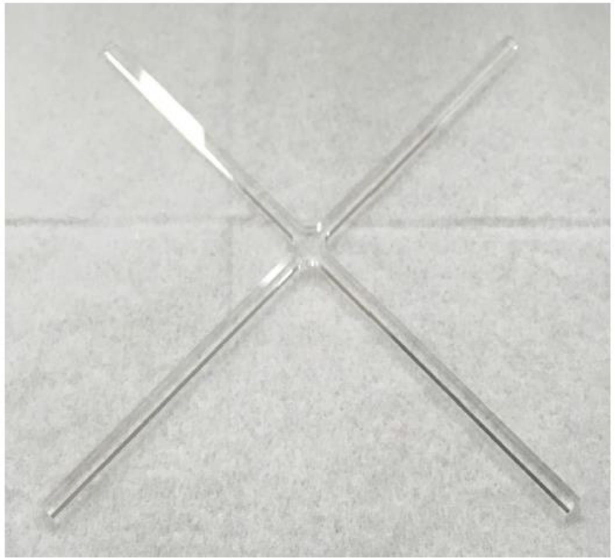
- **3-mm width segment + MPPC**
  - **S13360-3050PE (3 mm, 50 μm)**
  - **Amp: ~10 ns width**

**⇒ Time resolution: ΔT ~40 ps(σ)**
- **No position dependence**
- **$V_{ov}$ = +7V, Vth = 3.5 p.e.**



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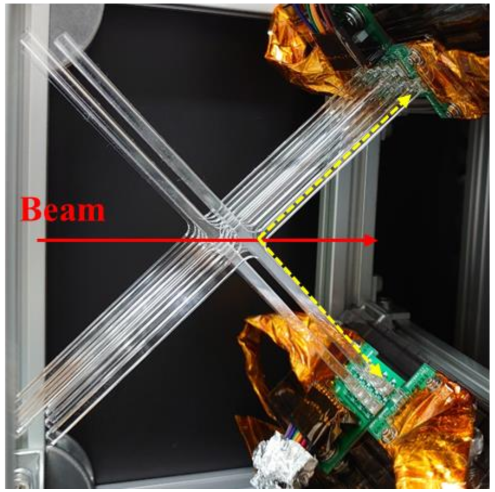
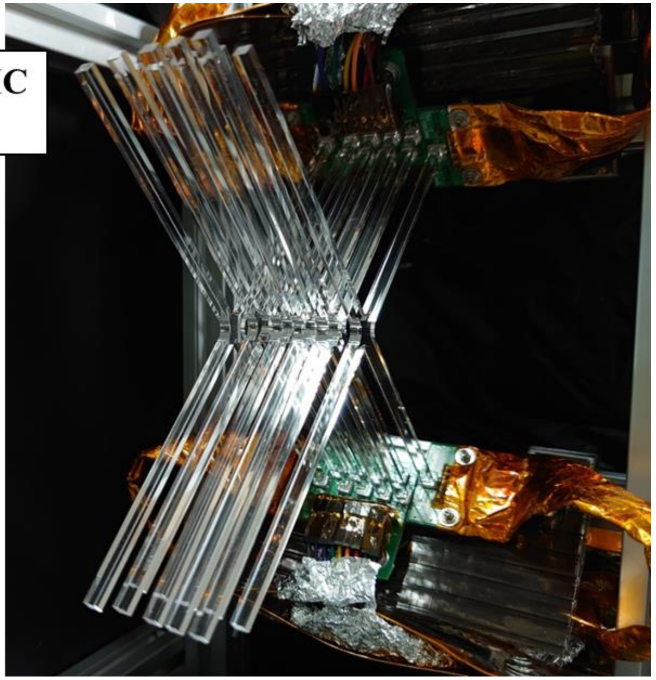
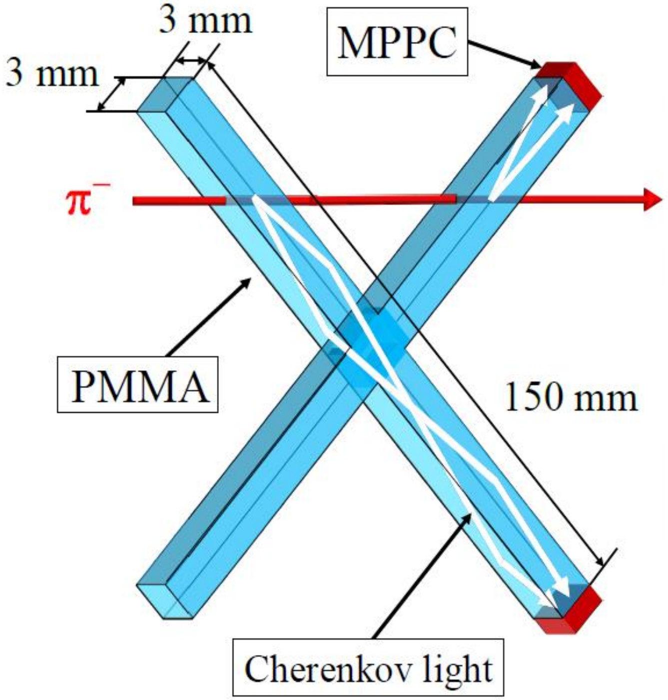
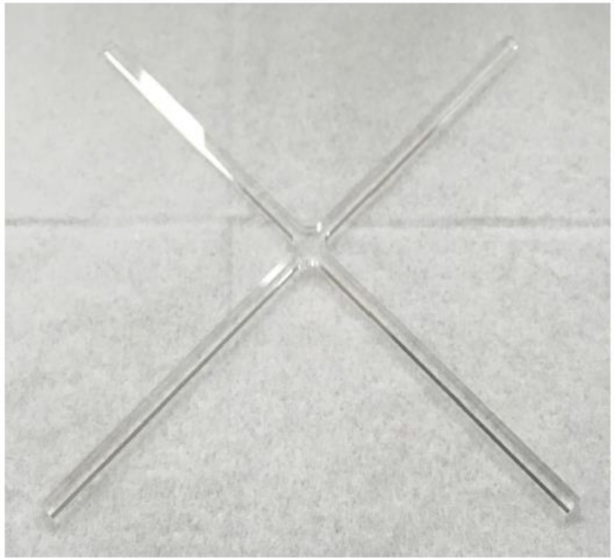
**T0 for EMPHATIC (10 segments)**





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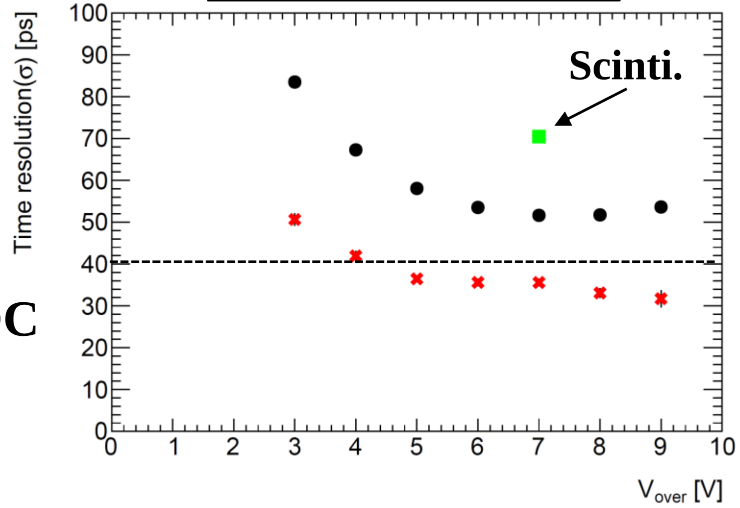
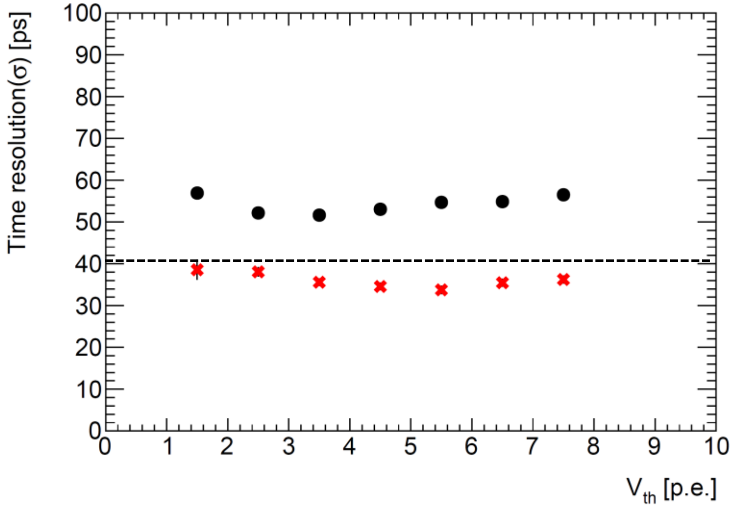
**$V_{ov}$ dependence: ΔT**

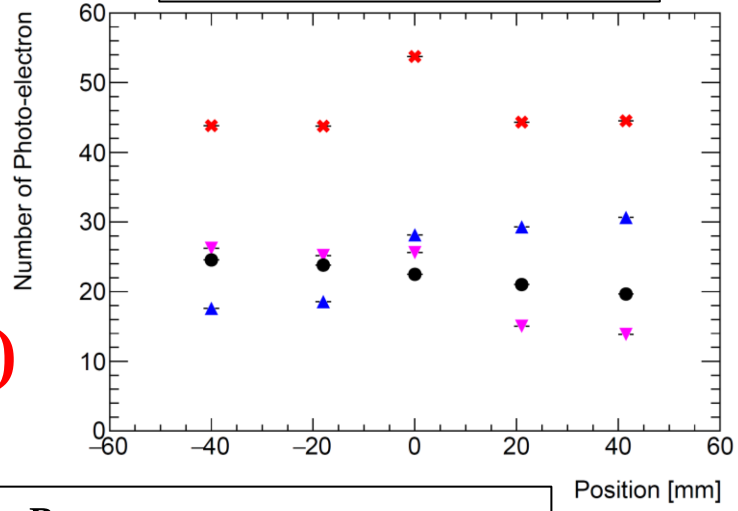



● Bar-type
× X-Type

**Vth dependence: ΔT**

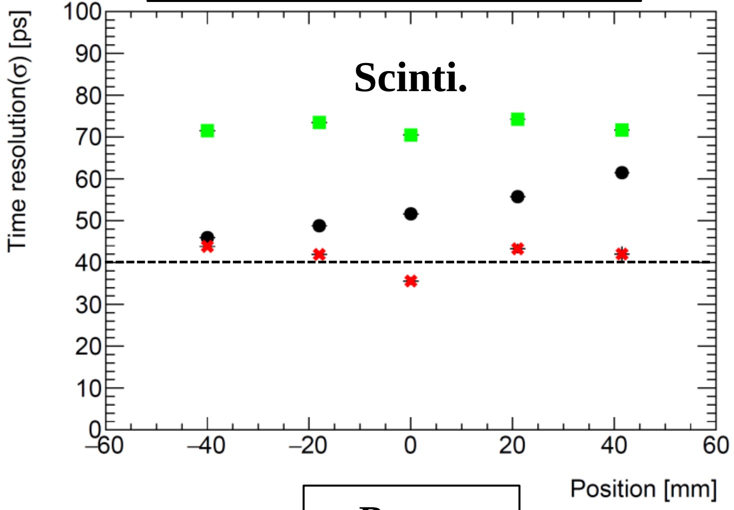



**Position dependence: P.E**




● Bar-type
×, ▲, ▼ X-Type (sum, top, bottom)

**Position dependence: ΔT**



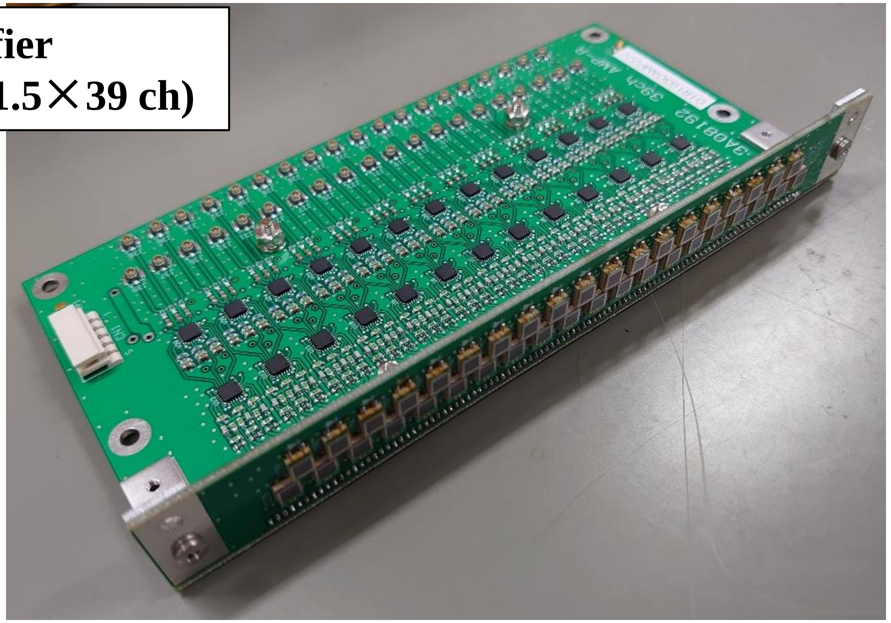

● Bar-type
× X-Type

# MPPC amplifier

- High speed operational amp: AD8000
- Damping resistance: 22Ω
- Overshoot suppression by pole-zero cancelation resistance: 390Ω

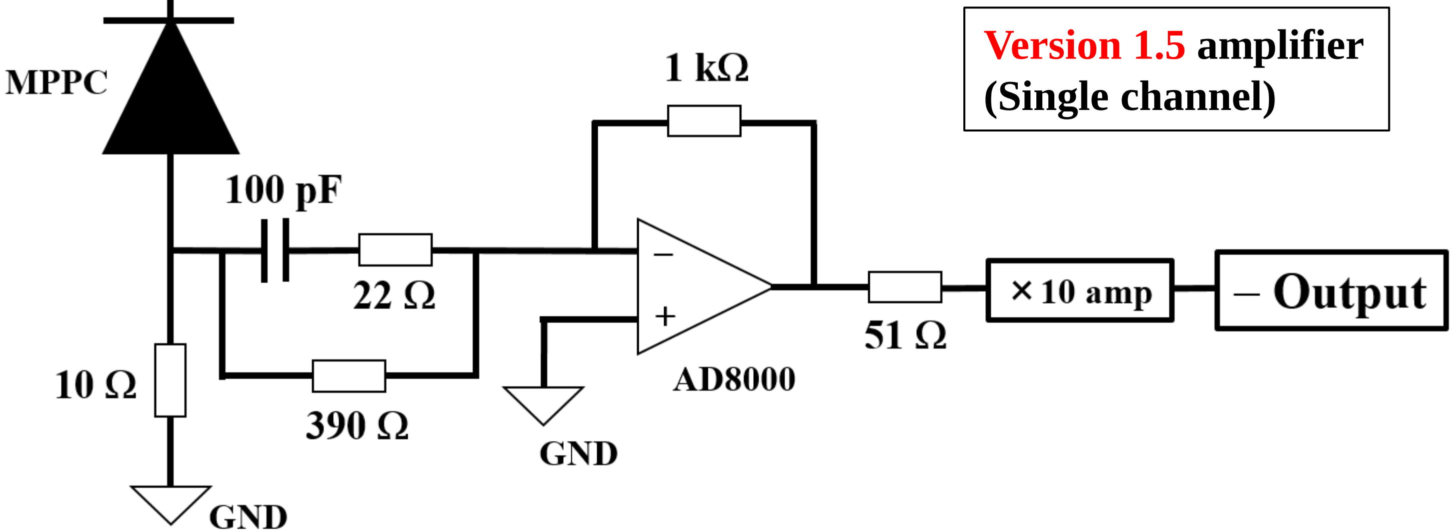
Based on T. Nishizawa et al., IEEE TNS 61 (2014) 1278.

×18.8: Higher gain for Cherenkov detector

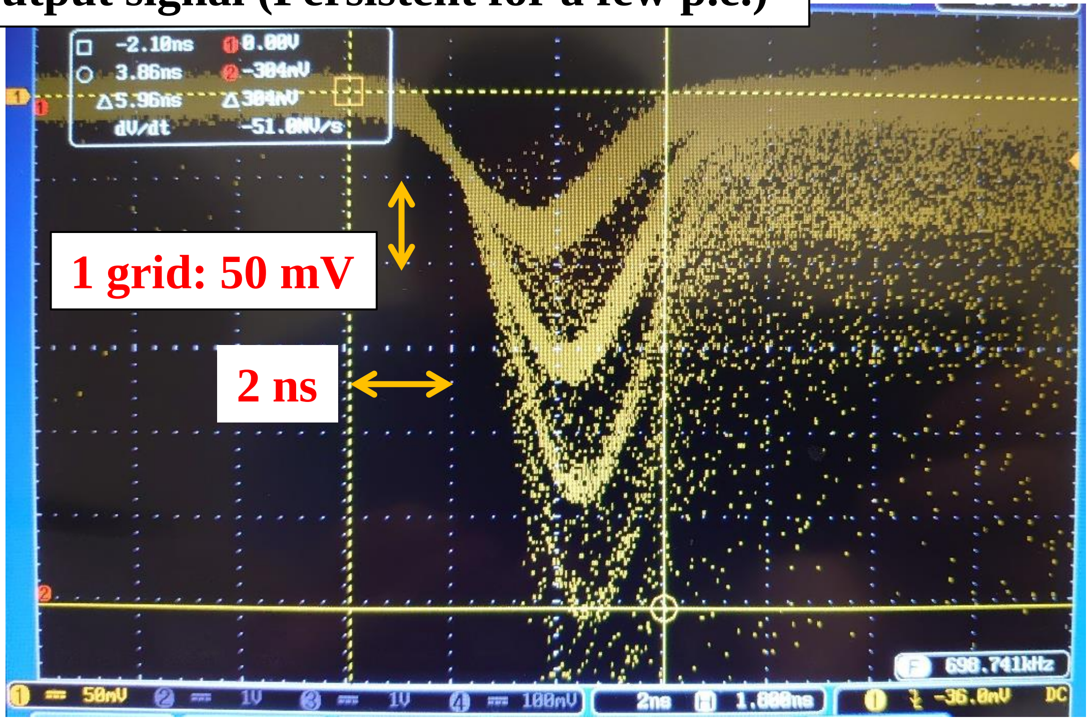


T0 amplifier
(Version 1.5×39 ch)

Version 1.5 amplifier
(Single channel)




Output signal (Persistent for a few p.e.)



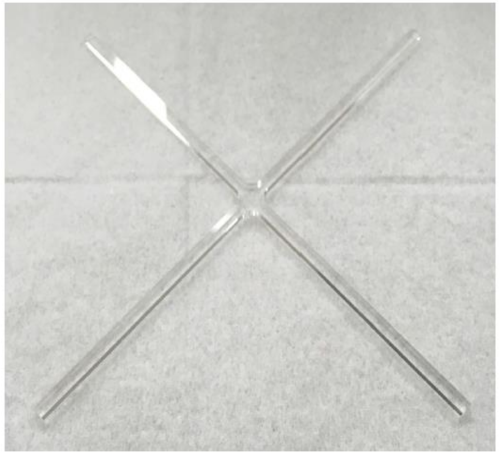
# R&D of Cherenkov Timing detector

- Convectional detector: Plastic scintillator + MPPC/PMT ⇒ ~100 ps(σ)

⇒ How can we get better resolution ?
- High-momentum: Good TOF measurement
- High rate: Fast response and discarding accidental coincidence


⇒ Previous study: Quartz + MCP-PMT ⇒ ~10 ps(σ) resolution
- A. Ronzhin *et al*., NIM A 623 (2010) 931, 10.1016/j.nima.2010.08.025
- Expensive radiator and not suitable PMT for fine segment

⇒ Acrylic(Cheap) + MPPC(fine segment)
- X-chape: No position dependence by mean time



∗R&D items
1. Fine-segment study: 3 mm ⇒ 0.5 mm
   - No thickness dependence of time resolution
2. High-rate study: Up to several MHz
   - Signal processing for suppressing pile-up effect: Schottky Barrier Diode (SBD)

# Fine-segment study

**3 mm $\Rightarrow$ 0.5 mm width**

# Simulation: Radiator width dependence

- Simulation by Geant4 Optical photon
  - Realistic parameters: PMMA, MPPC and so on

- 3-mm radiator light yield data: 25 p.e. @ 3 mm
  - Single-end P.E. data
  - Normalization of # of p.e.

  ⇒ Reflection probability of PMMA: 99.5%

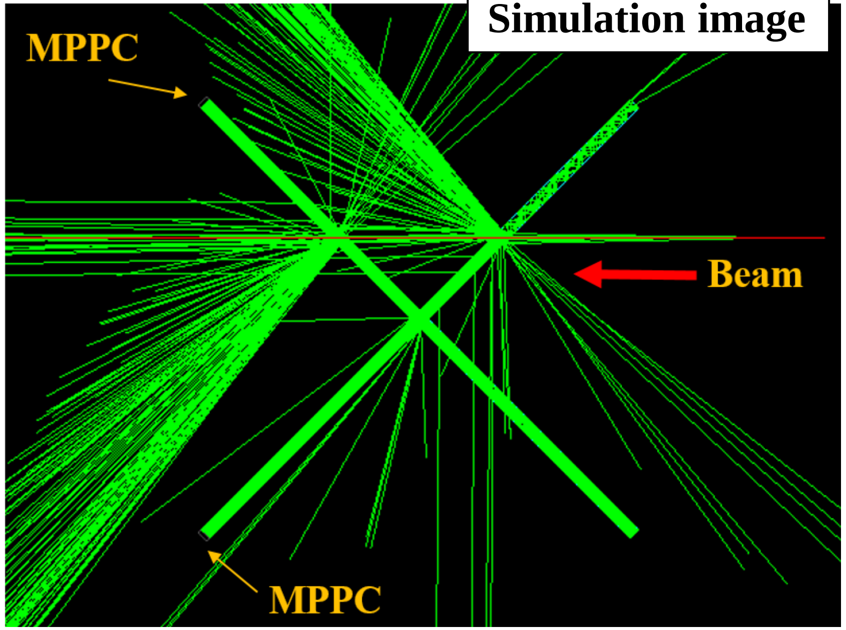
- Light yield is decreased.
  - ~16 p.e. @ 0.5 mm

⇒ Small loss of fast component
  - Small number of reflections

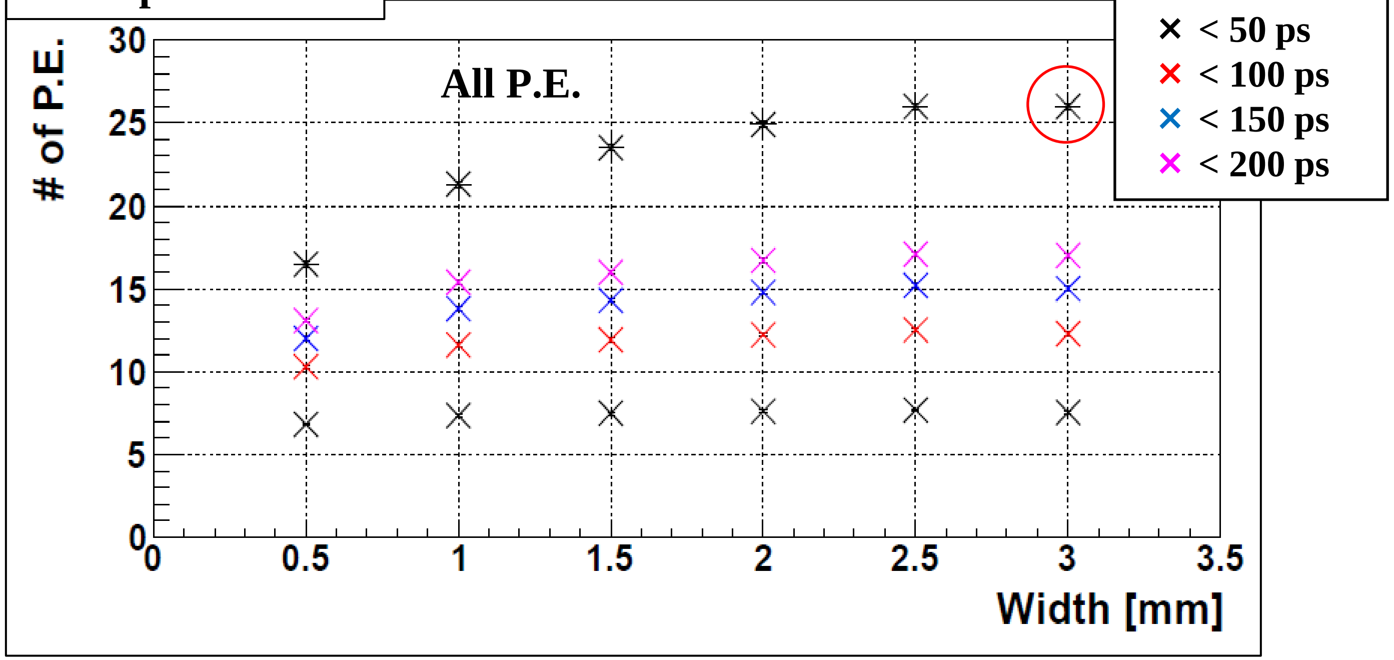
∗ Production by company
  - Cut from one PMMA board

⇒ Actual fine segment test

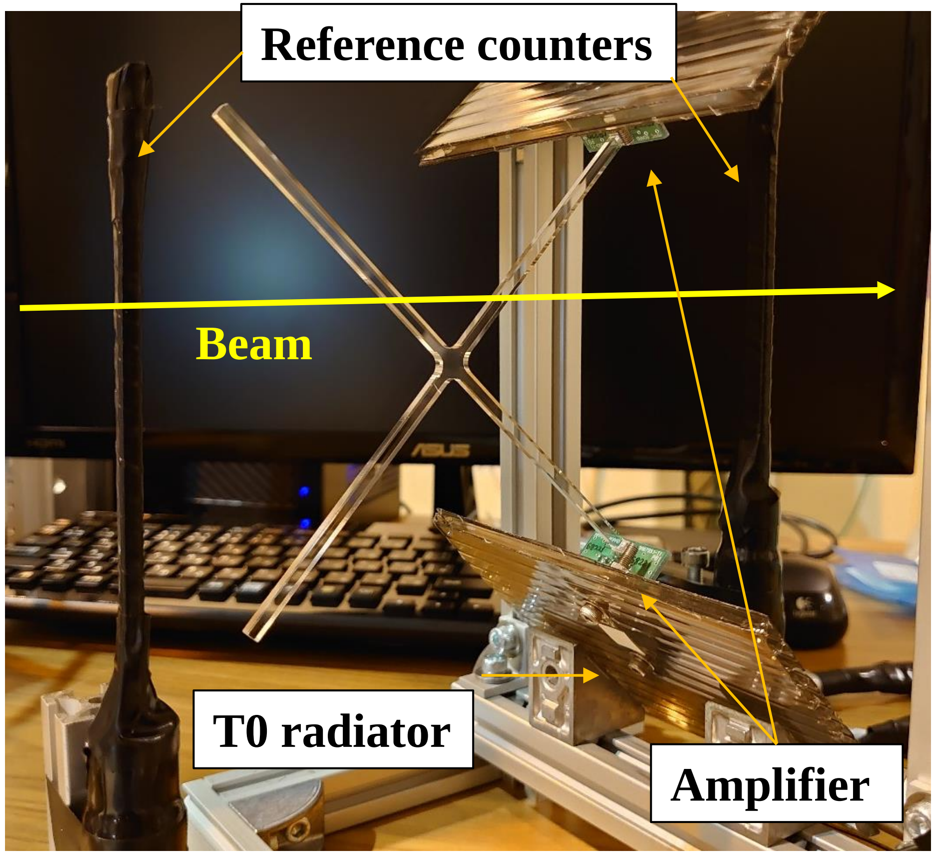
Simulation image



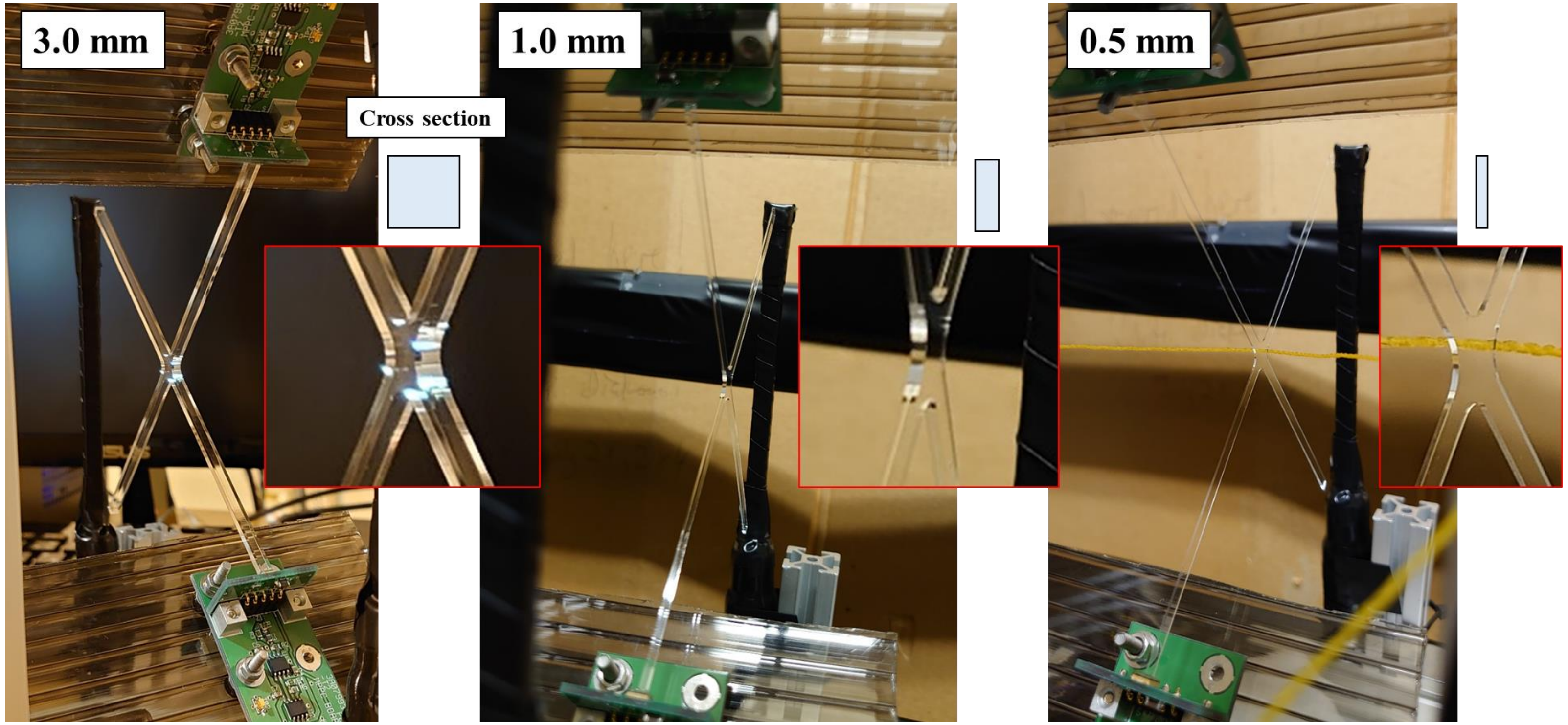

∗ Simple-end P.E.



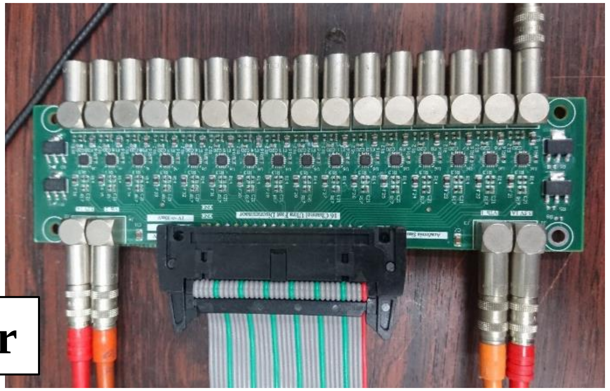
# Test experiment @ LEPS




**Fine segments: Radiators can be fixed by Silicone sheet with glue.**

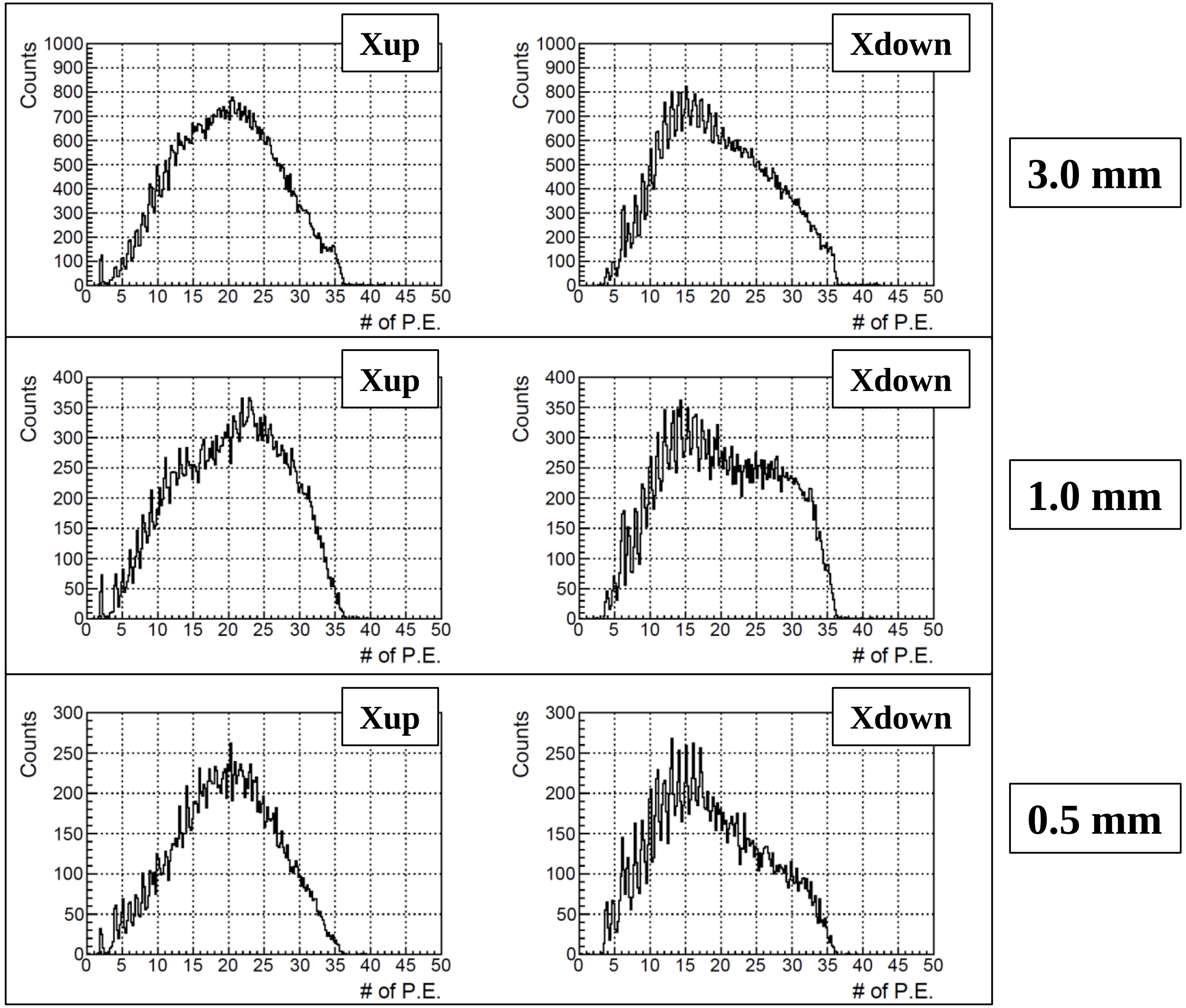


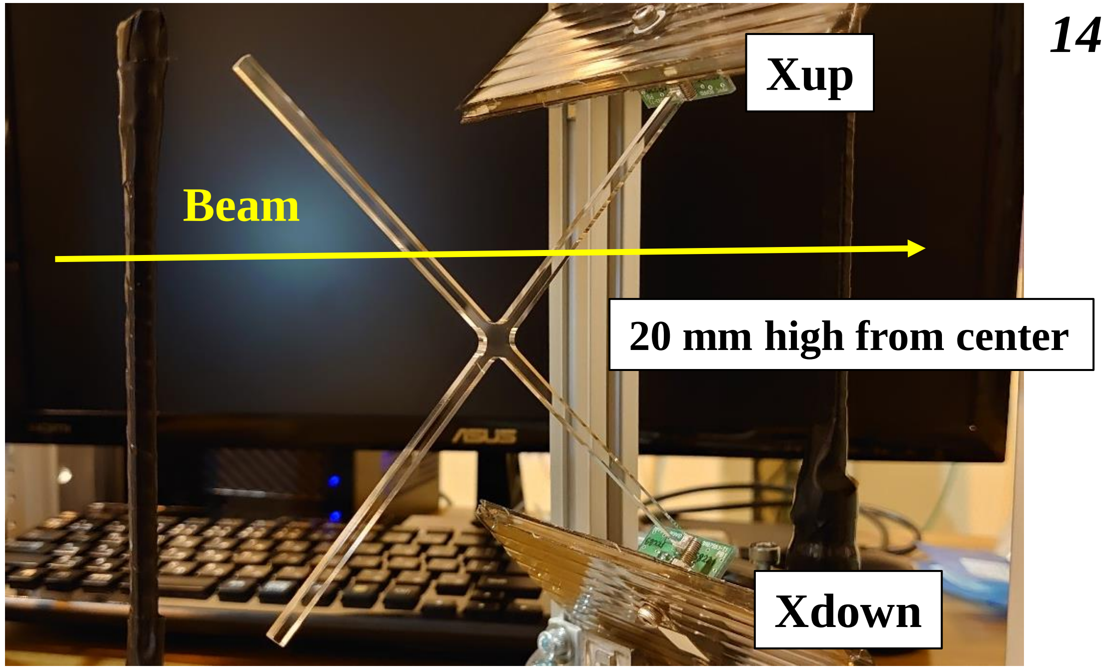

- **Time resolution evaluation by β~1 condition**
  - **$e^{\pm}$ from γ-ray conversion**
  - **Time walk correction by pulse height: DRS4 and HUL HR-TDC**
  - **LEPS2 discriminator for RPC**
    - **Comparator output: Both leading and trailing edge**
    - **N.Tomida *et al.*, JINST 9 C10008 2014**



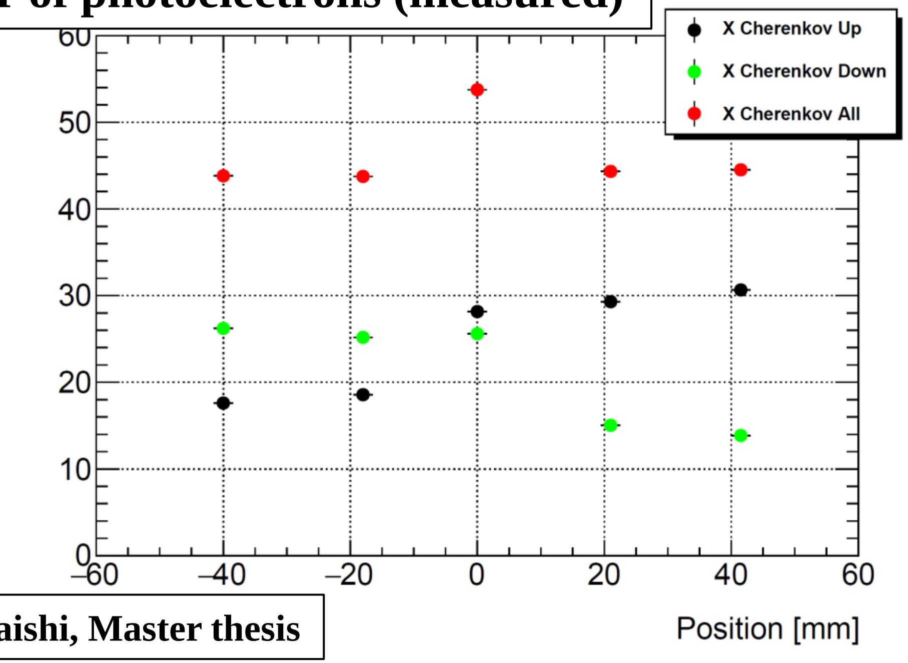
LEPS2 discriminator

# Number of photoelectrons @ +20 mm



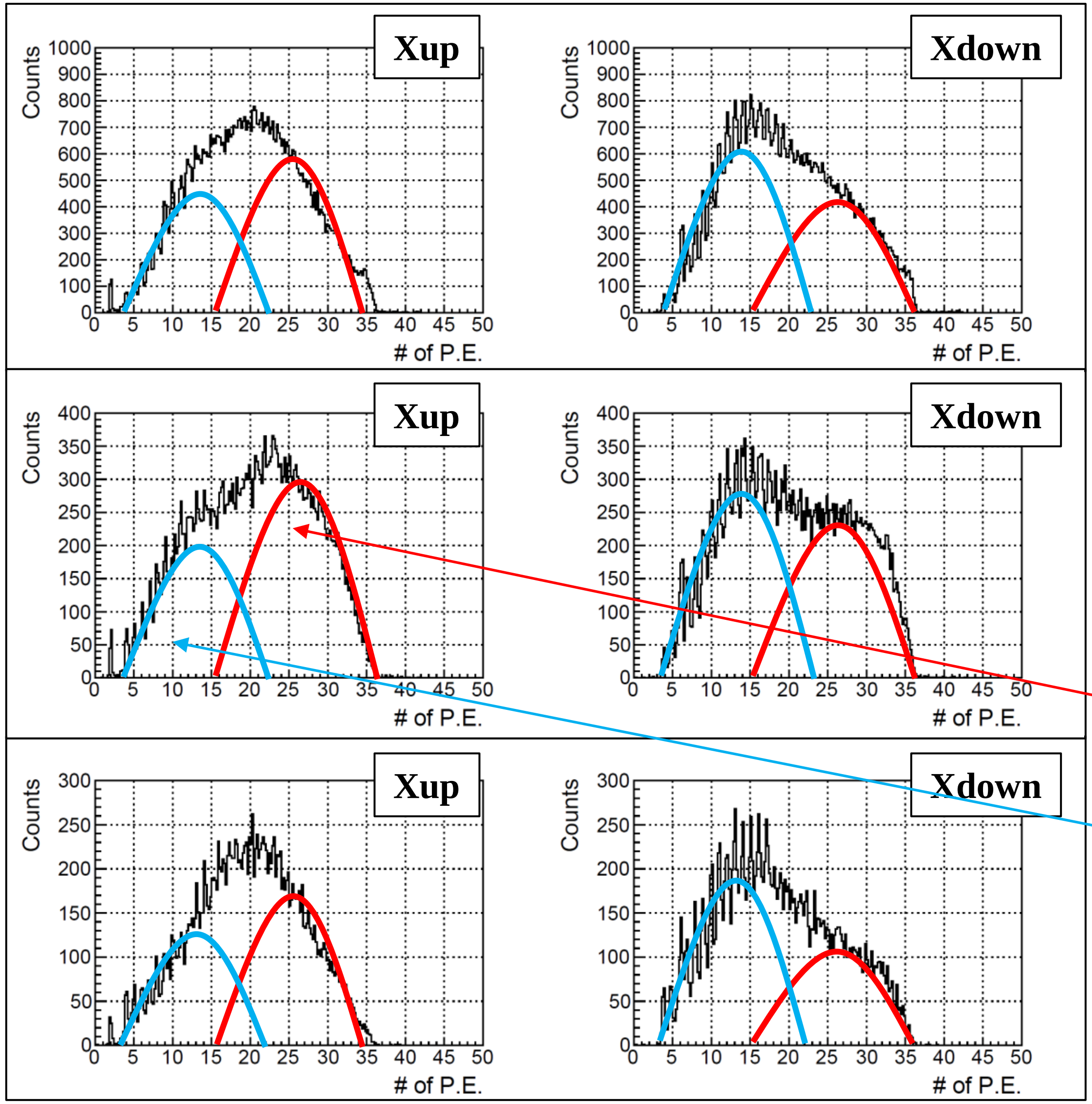

Number of photoelectrons (measured)




T. Akaishi, Master thesis

- **Average: ~20 p.e.**
- **Light yield tendency of both ends is consistent.**

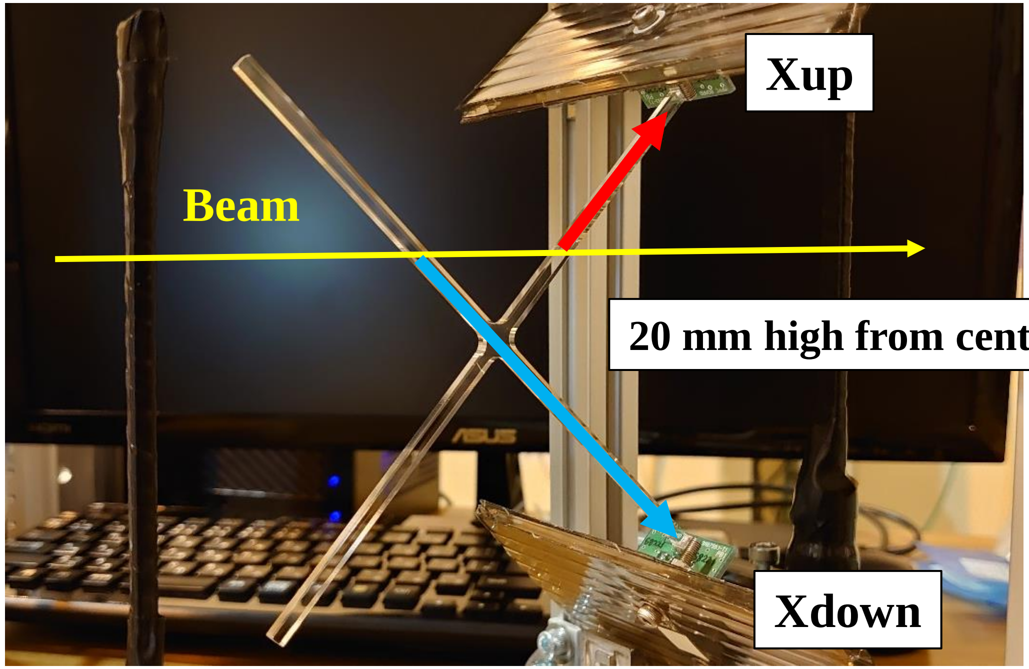
# Number of photoelectrons @ +20 mm

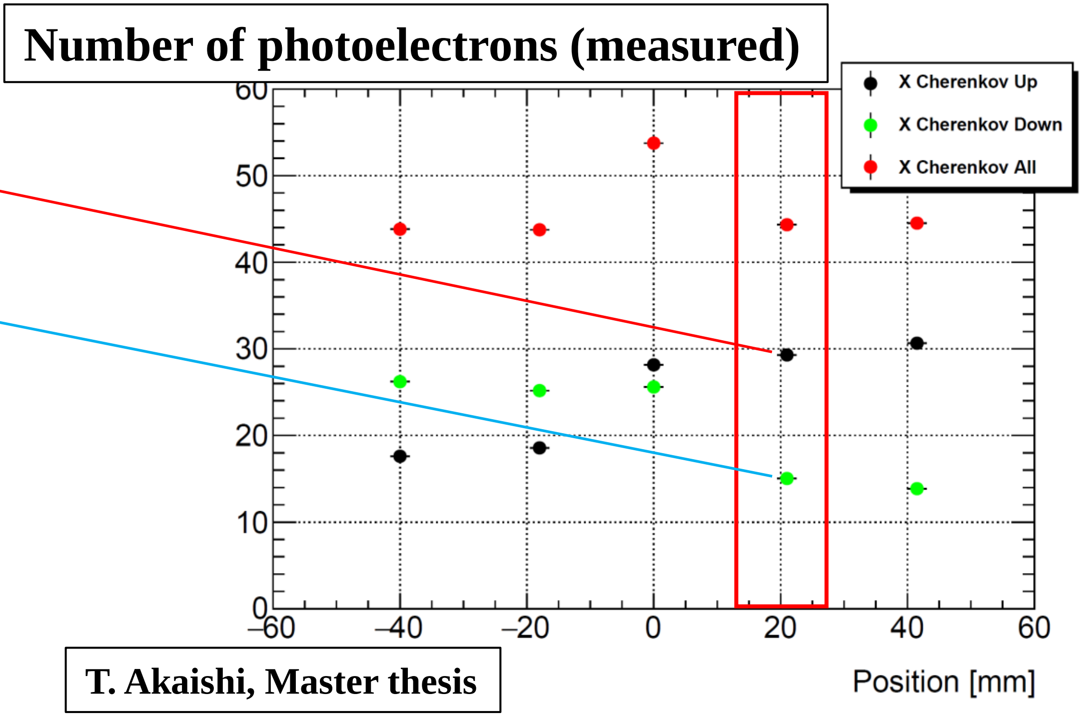



3.0 mm

1.0 mm

0.5 mm

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＊Handwriting curbs

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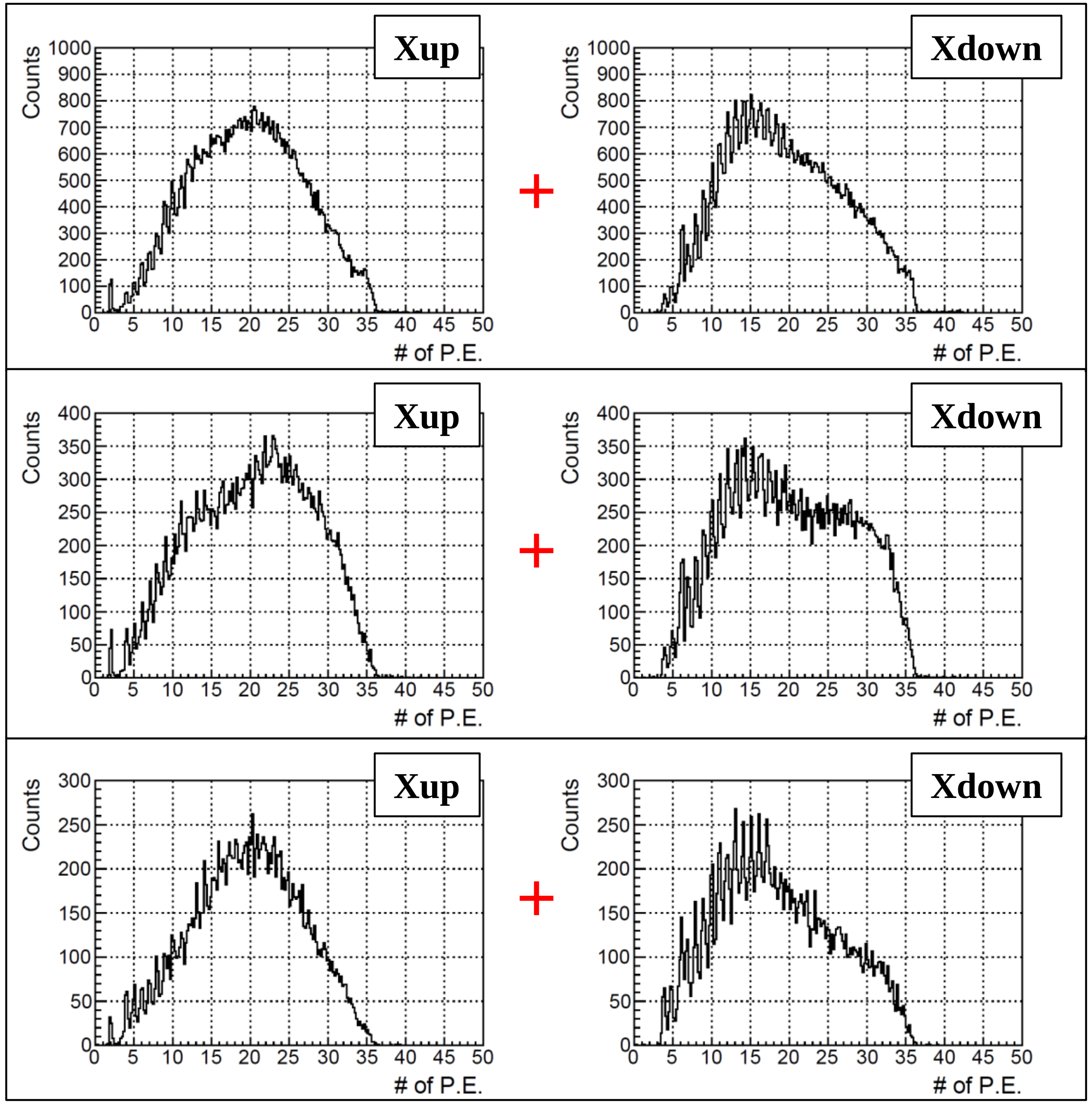


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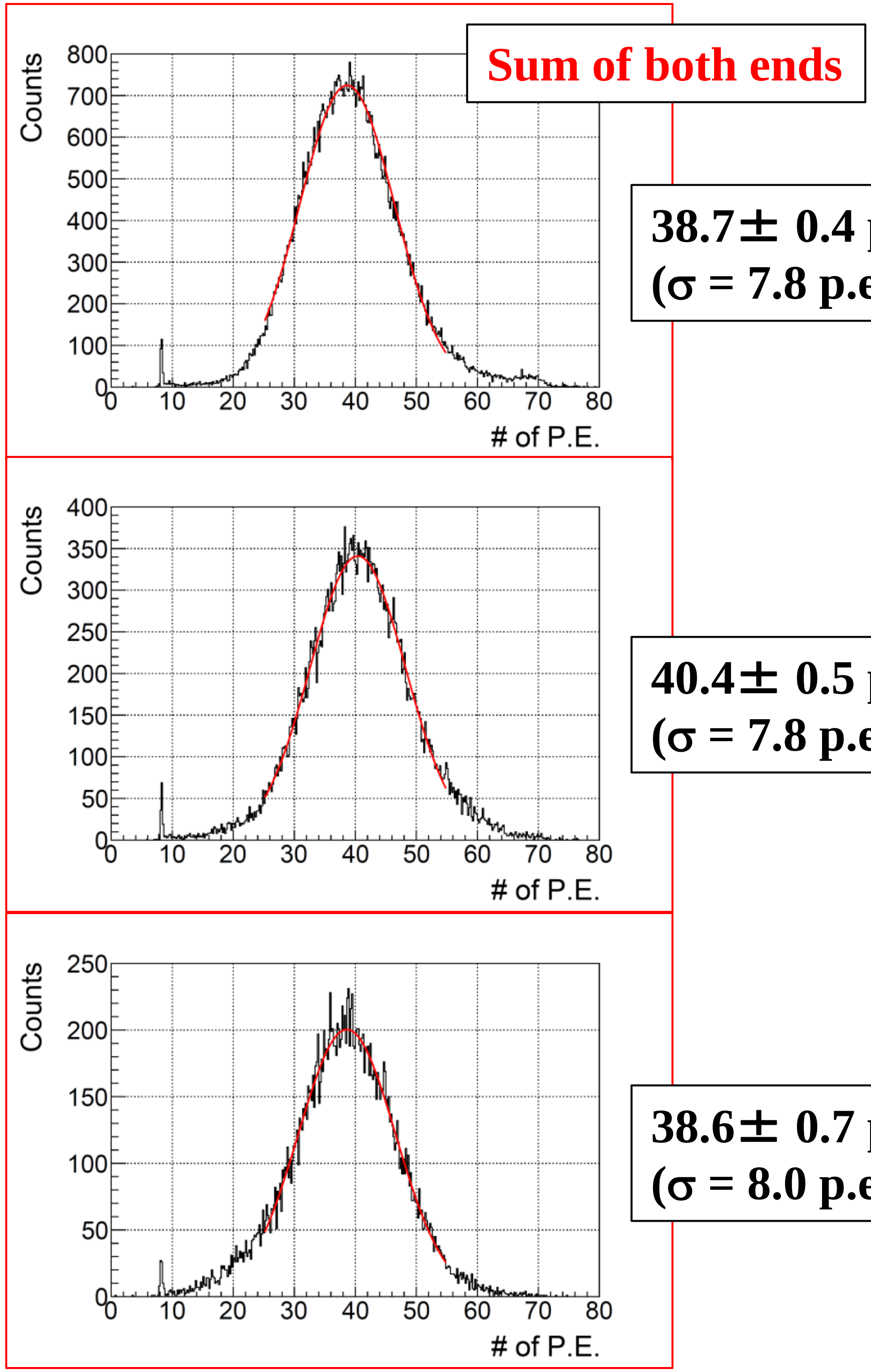



38.7± 0.4 p.e.
(σ = 7.8 p.e.)

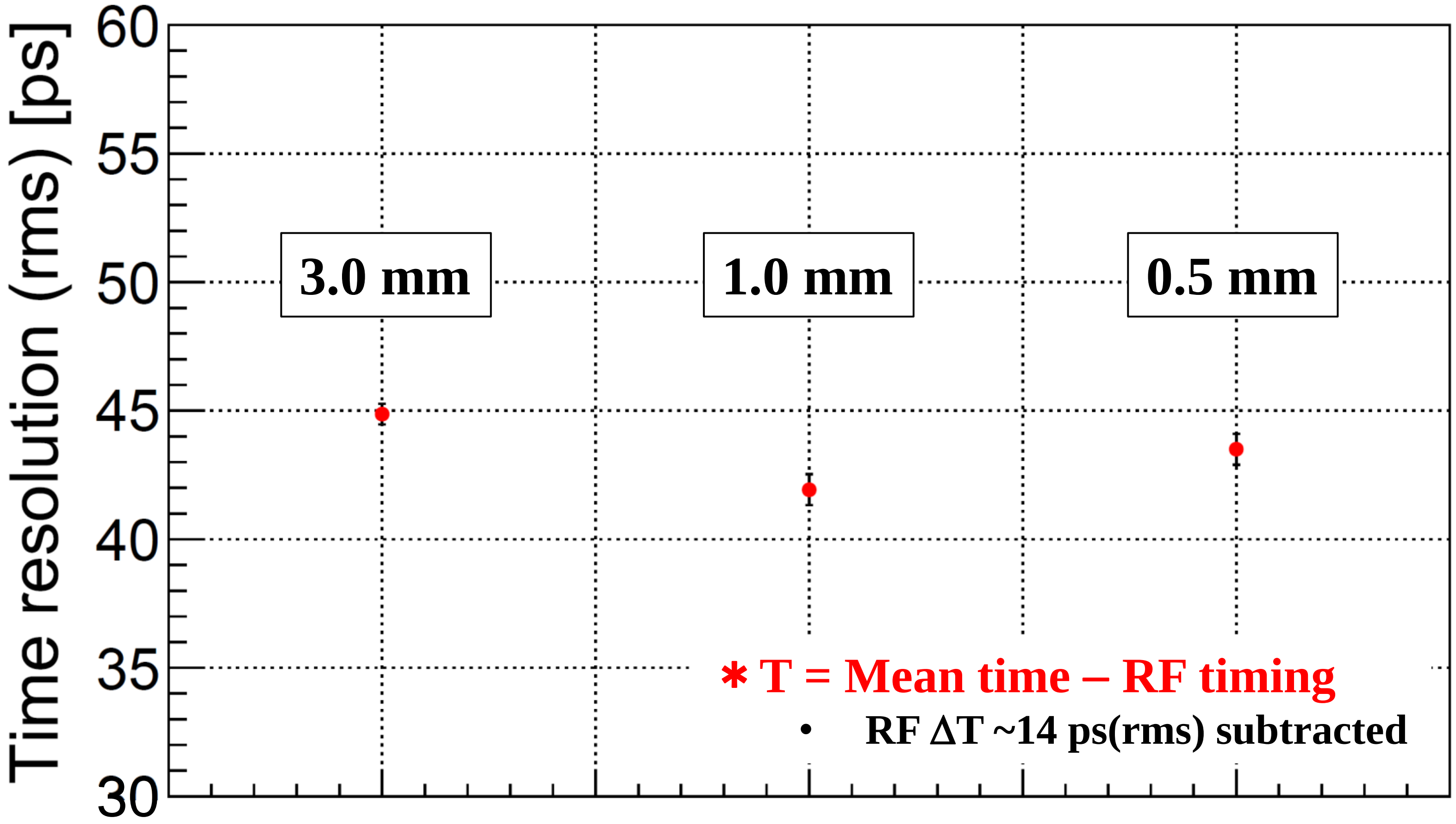
40.4± 0.5 p.e.
(σ = 7.8 p.e.)

38.6± 0.7 p.e.
(σ = 8.0 p.e.)

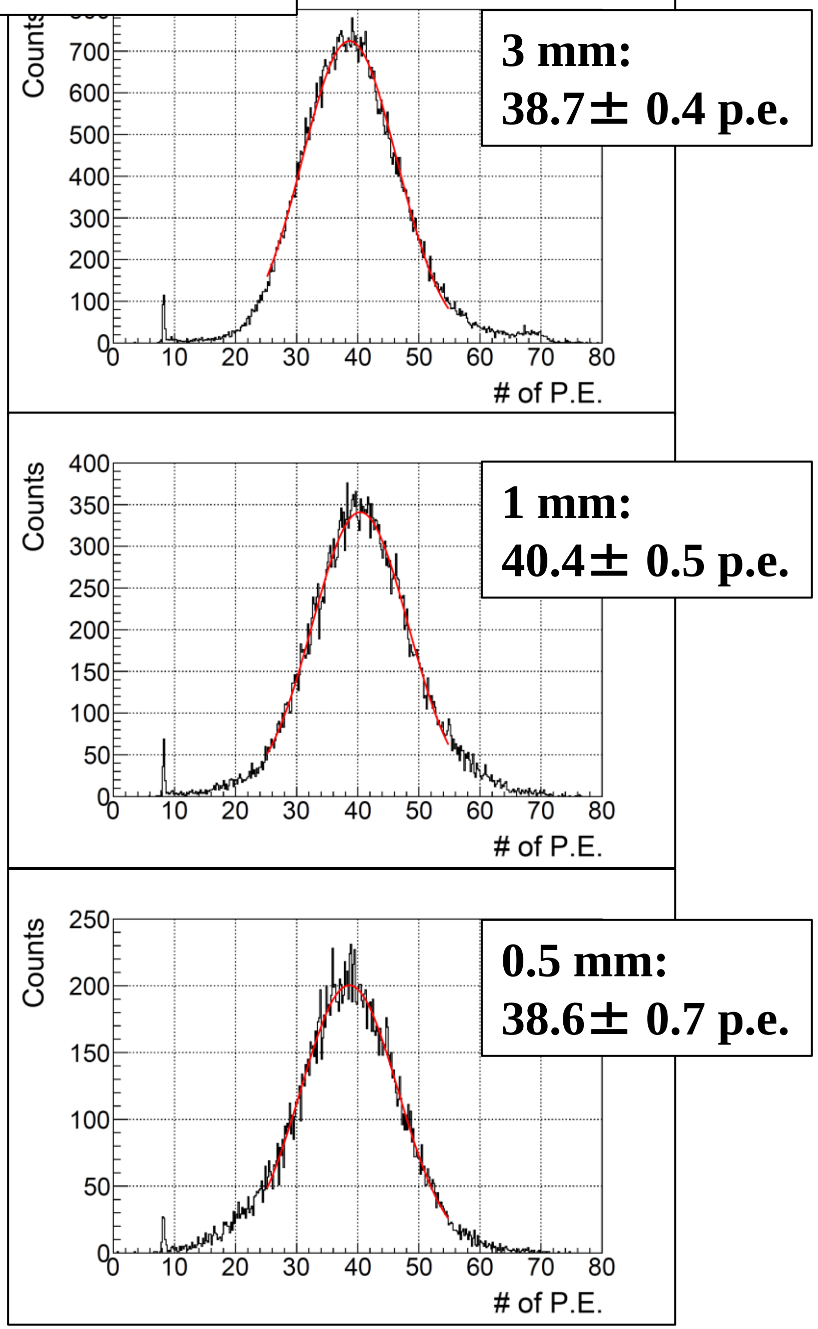
- **Sum of both ends and its distribution are same.**

⇒ **Collection of Cherenkov lights w/o surface loss**

# Time resolution: @ Vth = 3.5 p.e.




Sum of both ends




- **All data: Similar time resolution of ~45 ps(σ).**
  - **Time resolution is kept. = Same light yield**

*** 3.0 mm ⇒ 0.5 mm: ×6 higher counting rate**

- **3 MHz/3 mm @ 30 MHz ⇒ 3 MHz/0.5 mm @ 180 MHz**

*** 0.3 mm also tested ⇒ Time resolution of ~45 ps(σ)**

# High-rate study

## Signal processing for suppressing pile-up effect:

## Schottky Barrier Diode (SBD)

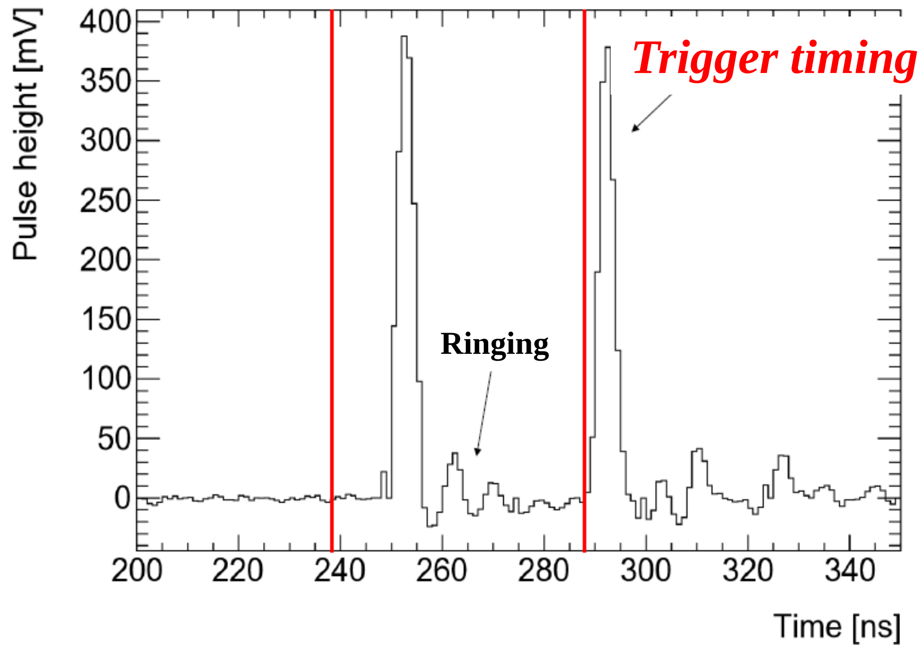
# R&D of signal processing

## 1. Ringing suppression

- Pile-up effects to time resolution
  - Time resolution: 43 ps ⇒ 54 ps @ High-rate condition

**⇒ Schottky Barrier Diode (SBD) was used as kind of filtering methods.**

**Pileup event**

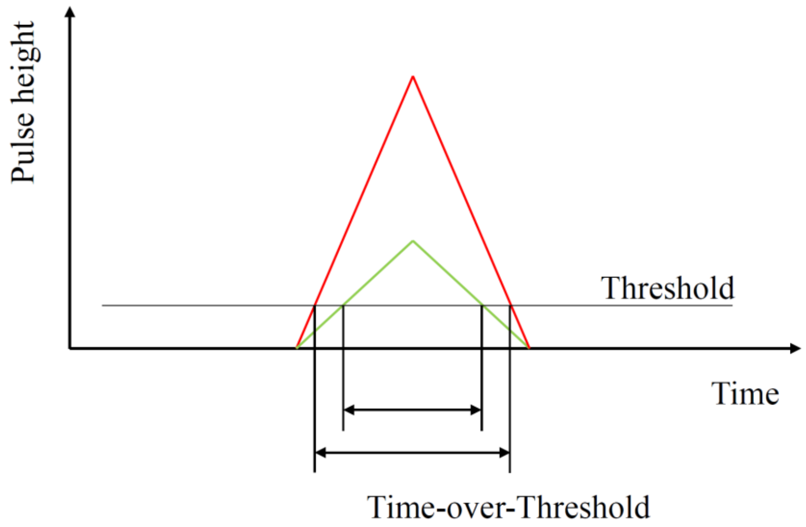



## 2. TOT measurement

- Only TDC measurement without ADC
  - Discriminator(comparator) + TDC
- Time-walk correction by Time-Over-Threshold (TOT) method
  - Width = (Leading edge – Trailing edge)
- Straight forward method doesn't well work.
  - ΔT ~ 70 ps(σ) ⇔ ΔT ~ 40 ps(σ)

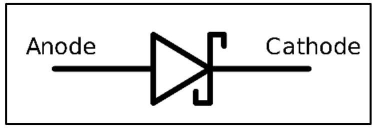
**⇒ SBD + slow shaping**

**Time-Over-Threshold (TOT) method**



# Schottky barrier diode: SBD

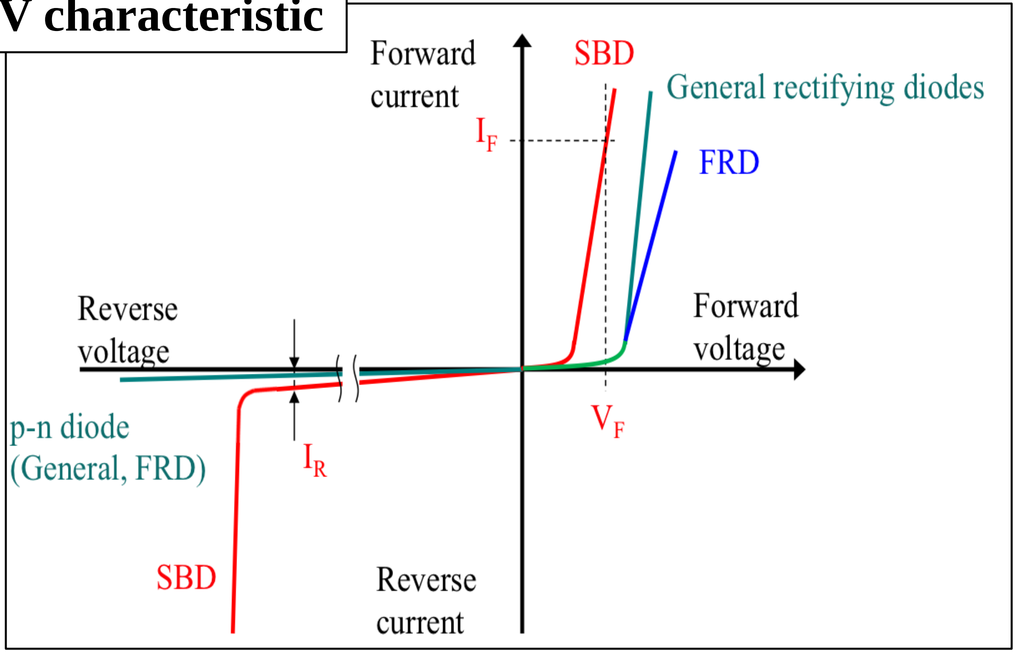
- Kind of rectifier diode
  - Quick responses
  - Smaller forward voltage: 100–200 mV level




＊Revered pulses and smaller pulses are suppressed.

⇒ Ringing suppression (+ dark current suppression)

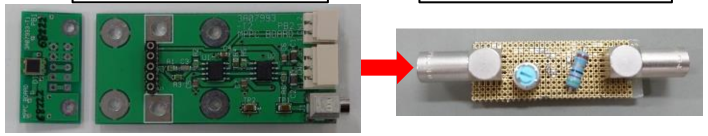
I-V characteristic




- BAT63: Series connection to amplifier
  - Signals width and leading slope: Same
  - $V_{out} = 0.62 \times (V_{in}) - 70.0$ (Minimum input: ~120 mV)

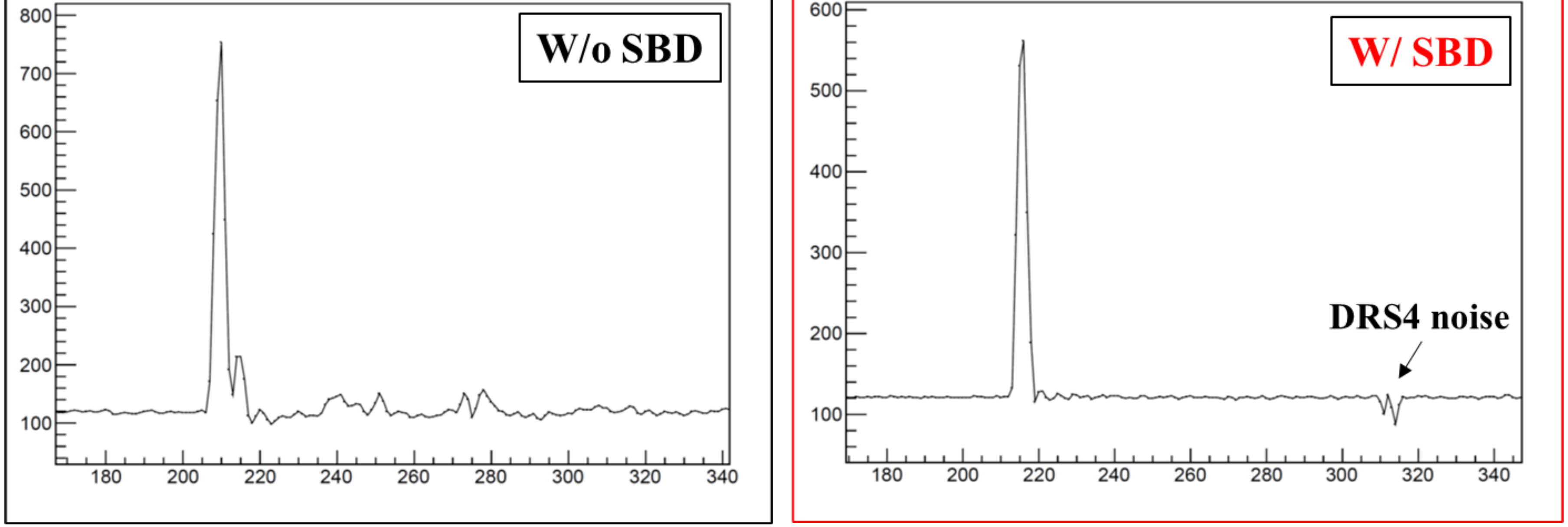
MPPC amp

SBD circuit



Series connection


Waveform by DRS4: 1 GHz sampling



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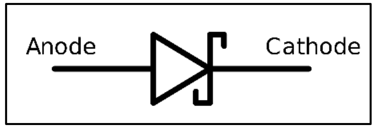


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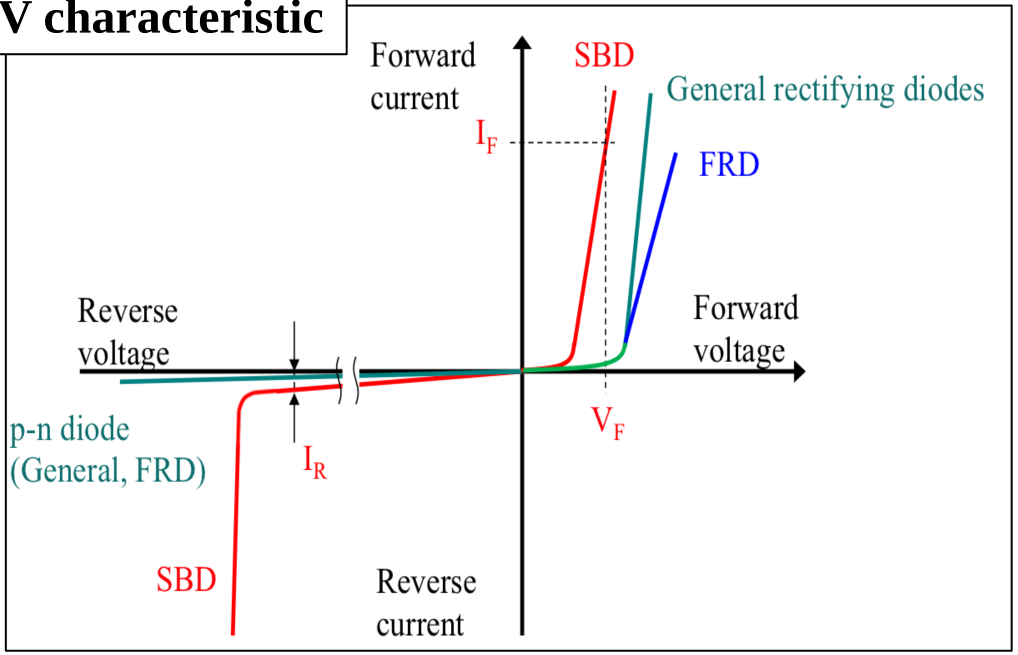
**I-V characteristic**

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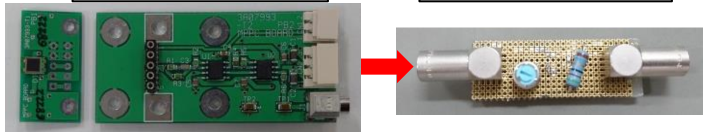
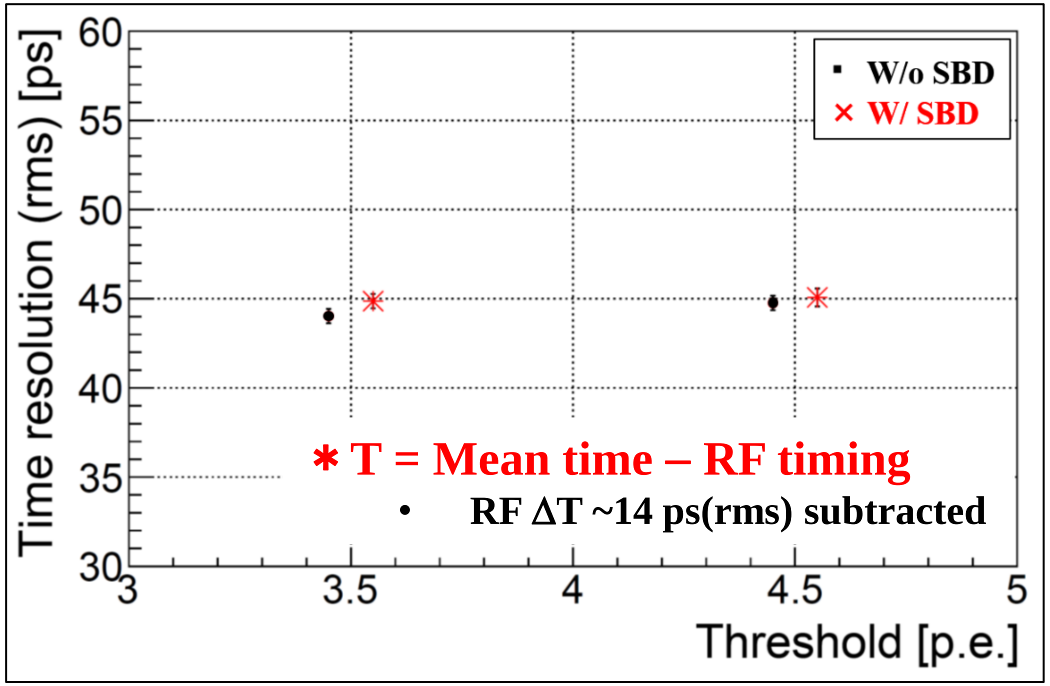
**MPPC amp** **SBD circuit**



**Series connection**


**＊Low-rate data @ LEPS**
**⇒ ΔT ~45 ps(σ)**
**⇒ SBD can be used as filter circuit.**



# SBD: BAT series, RB series

| Name | $V_F$ [mV] | $I_F$ [μA] | $I_R$ [nA] | Test | Comments |
|---|---|---|---|---|---|
| BAT17 | 220 | 10 | 5 | ○ | It can be used by adjusting amp gain. |
| BAT15 | 110 | 10 | – | ○ | Suitable responses |
| BAT63 | 120 | 100 | – | ○ | Suitable responses |
| BAT165 | 150 | 10 | 80 | × | Large overshoot signal |
| RB168MM-30TF | 300 | 100.0 | 2 | × | Large overshoot signal |
| RB510SM-30FH | 100 | 1.0 | 6 | △ | Small overshoot signal |
| RB510VM-30FH | 100 | 1.0 | 6 | △ | Small overshoot signal |
| RB520SM-30T2R-J | 80 | 1.0 | 40 | × | Large overshoot signal |
| RB530SM-30T2R-J | 90 | 1.0 | 25 | × | Large overshoot signal |
| RB540VM-30FHTE-17-J | 90 | 1.0 | 25 | × | Large overshoot signal |

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|---|---|---|---|
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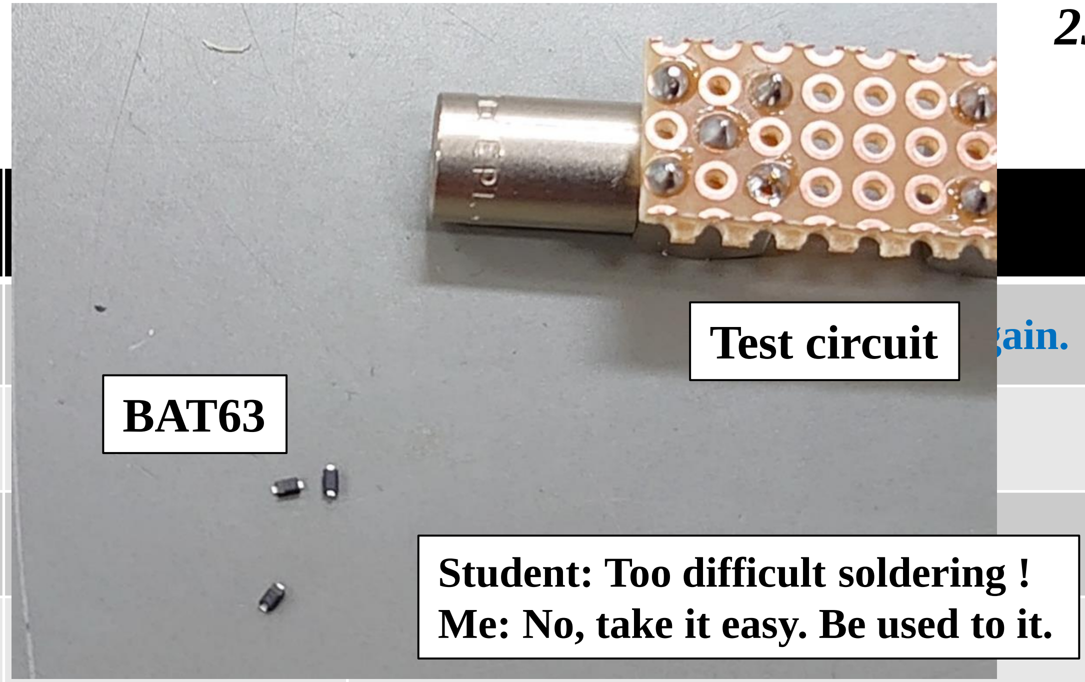
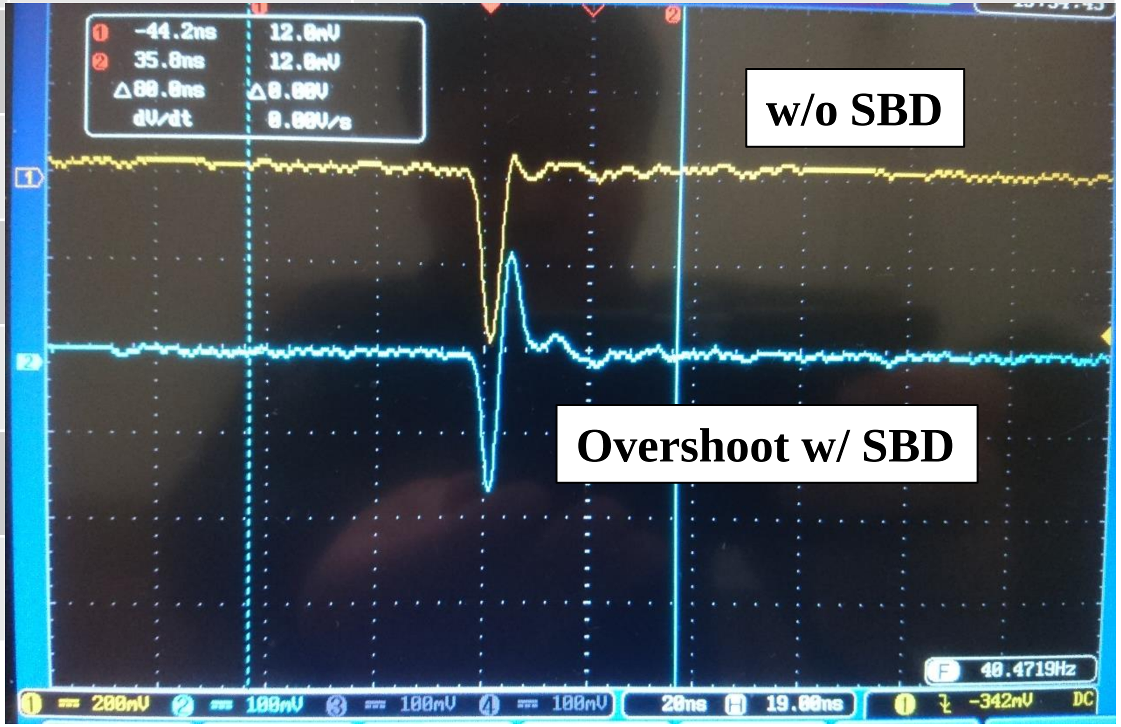
| BAT15 | 110 | 10 | – |
| BAT63 | 120 | 100 | – |
| BAT165 | 150 | 10 | 80 |
| RB168MM-30TF | 300 | 100.0 | 2 |
| RB510SM-30FH | 100 | 1.0 | 6 |
| RB510VM-30FH | 100 | 1.0 | 6 |
| RB520SM-30T2R-J | 80 | 1.0 | 40 |
| RB530SM-30T2R-J | 90 | 1.0 | 25 |
| RB540VM-30FHTE-17-J | 90 | 1.0 | 25 |



# Time-Over-Threshold method

- **Signal width is not sensitive to pulse height by our MPPC amp.**
  - **Width is saturated in higher pulse height.**
  - **Ringing signal affects TOT measuring.**

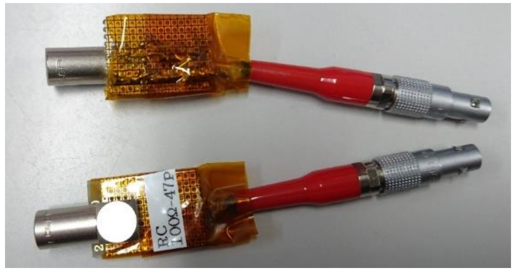
**⇒ Straight forward method doesn't well work.**

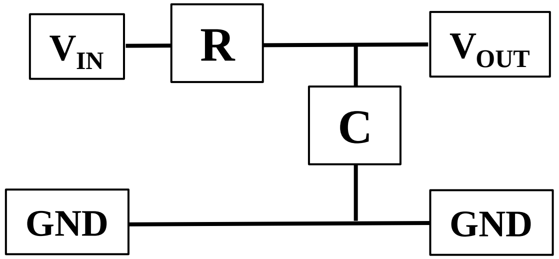
- **ΔT ~ 70 ps(σ) ⇔ ΔT ~ 40 ps(σ)**

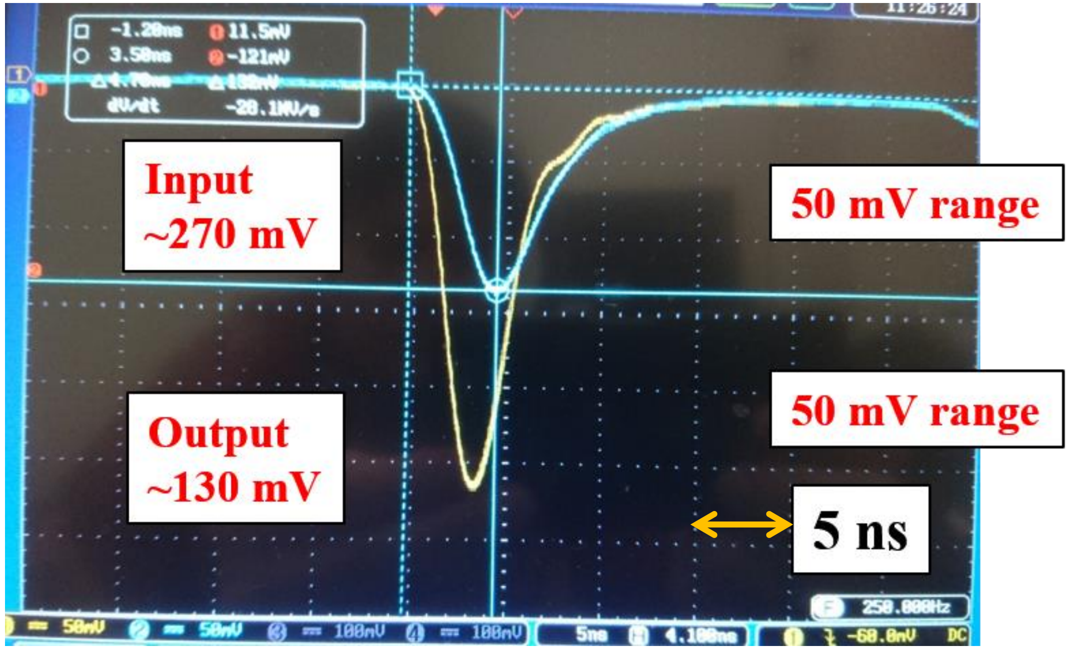
**＊Extract pulse height information from width**

**⇒ "SBD + Integrator circuit"**

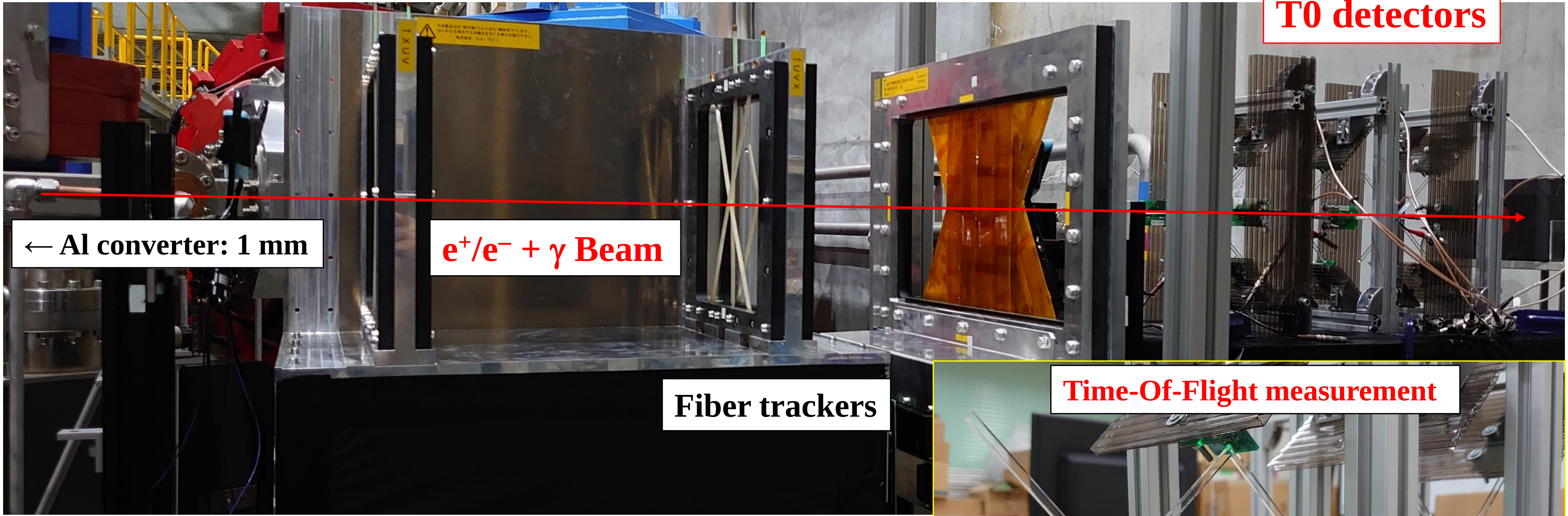
- **Test RC integrator circuit**
  - **τ = 2.4 ns**
    - **R = 51 Ω, C = 47 pF**
  - **Signal width: ~15 ns**
    - **Original: ~10 ns**
  - **Pulse height: ×1/2**

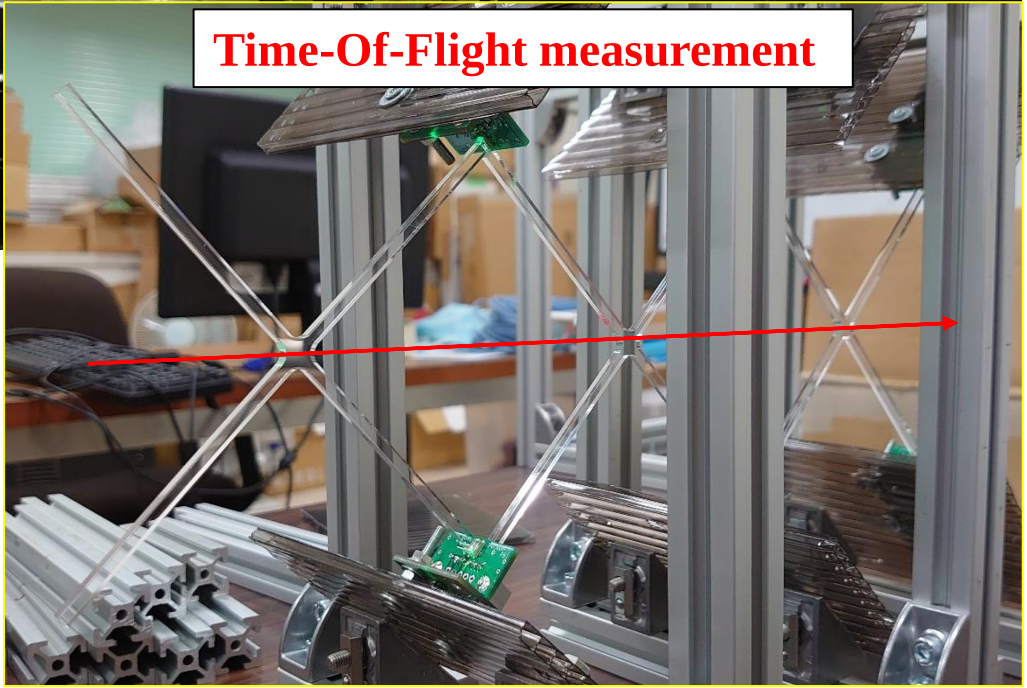




# High-rate test @ ELPH



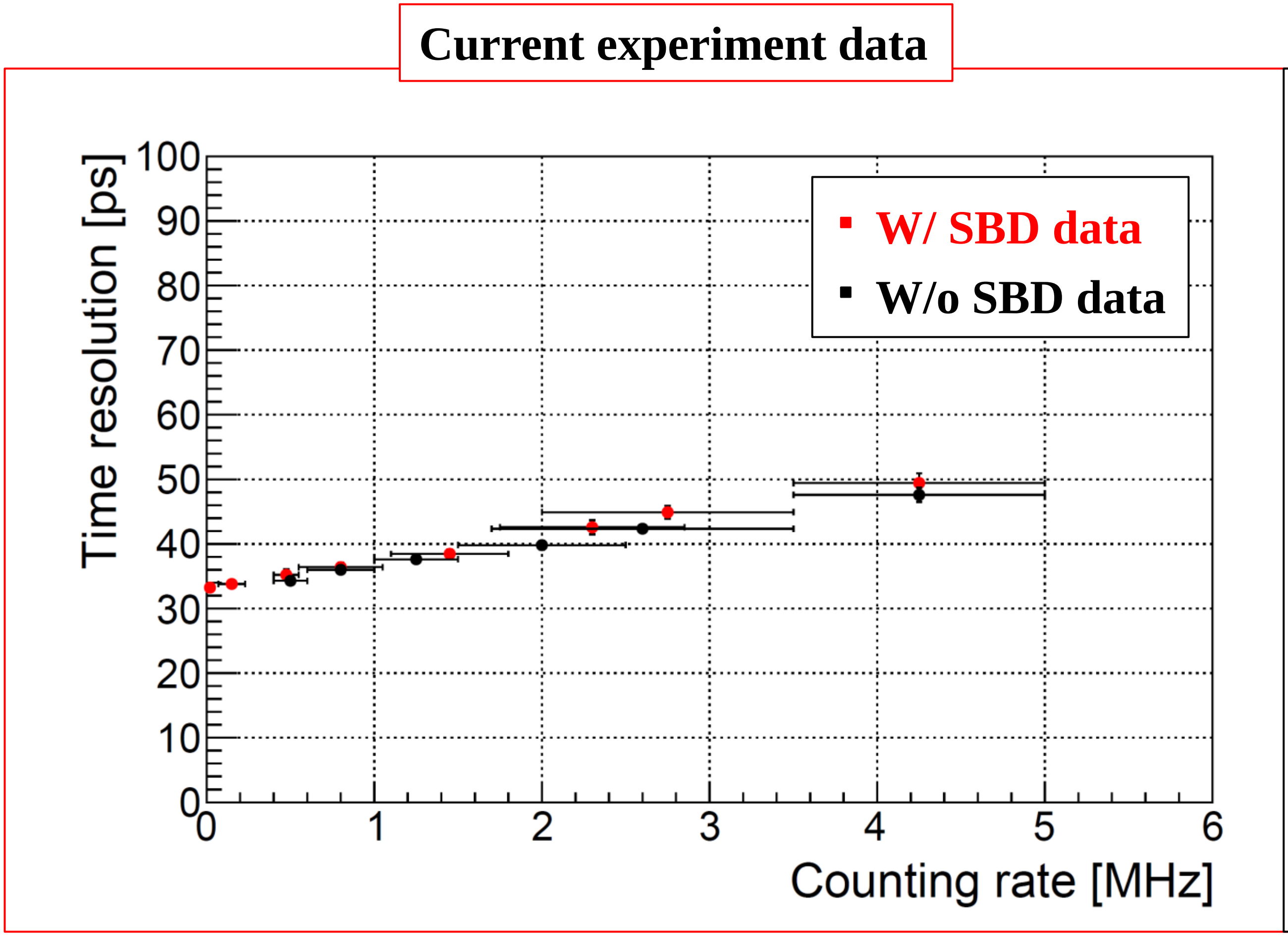



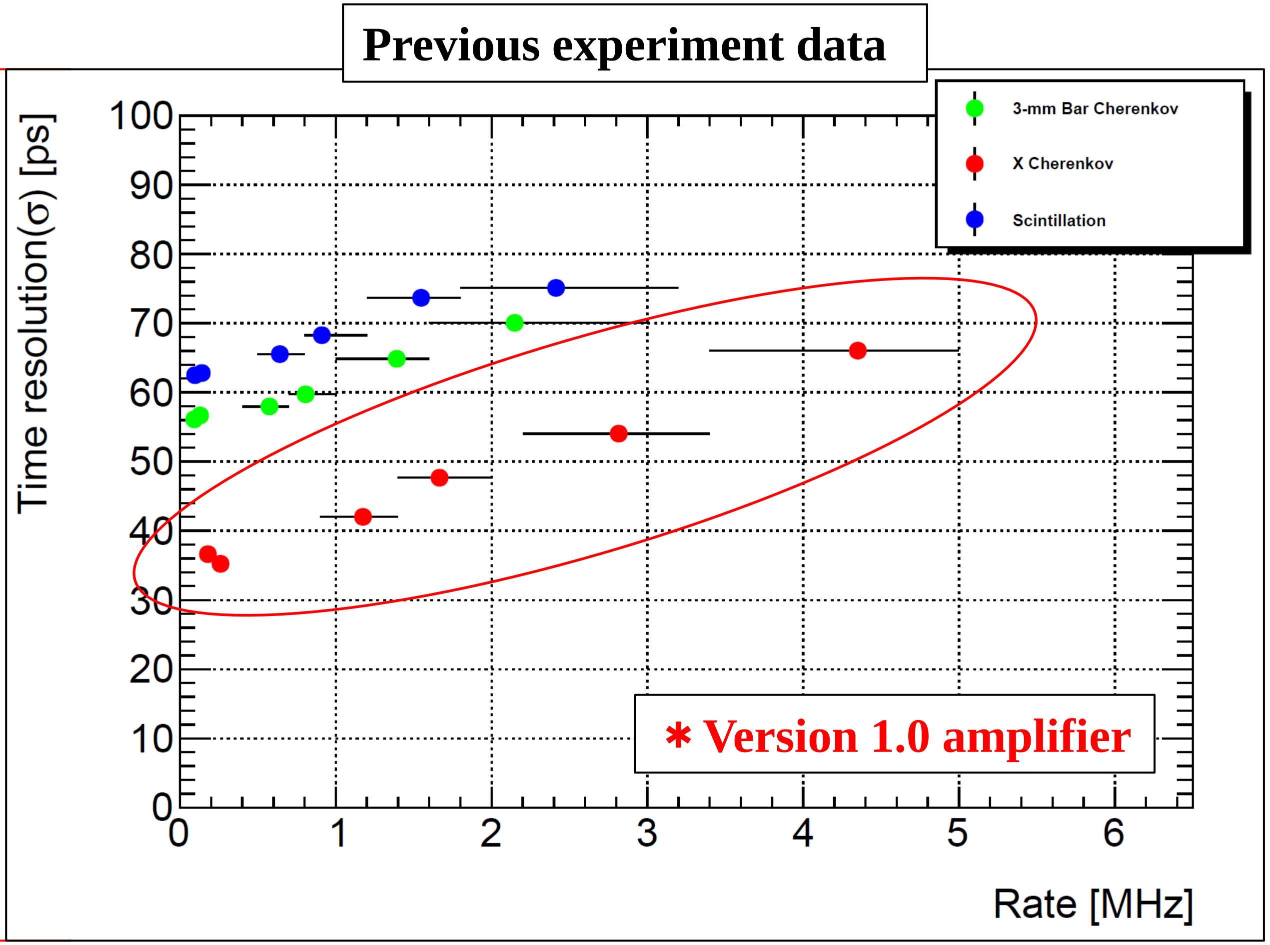

- **Time resolution evolution**

**⇒ Time-Of-Flight by mean times of 3 detectors**

- **Counting rate (event by event): 10 kHz – 5 MHz**
- **Modules: HUL HR-TDC & DRS4 (Waveform: ADC)**
  - **LEPS2 discriminator for RPC**

# Rate dependence: SBD filter



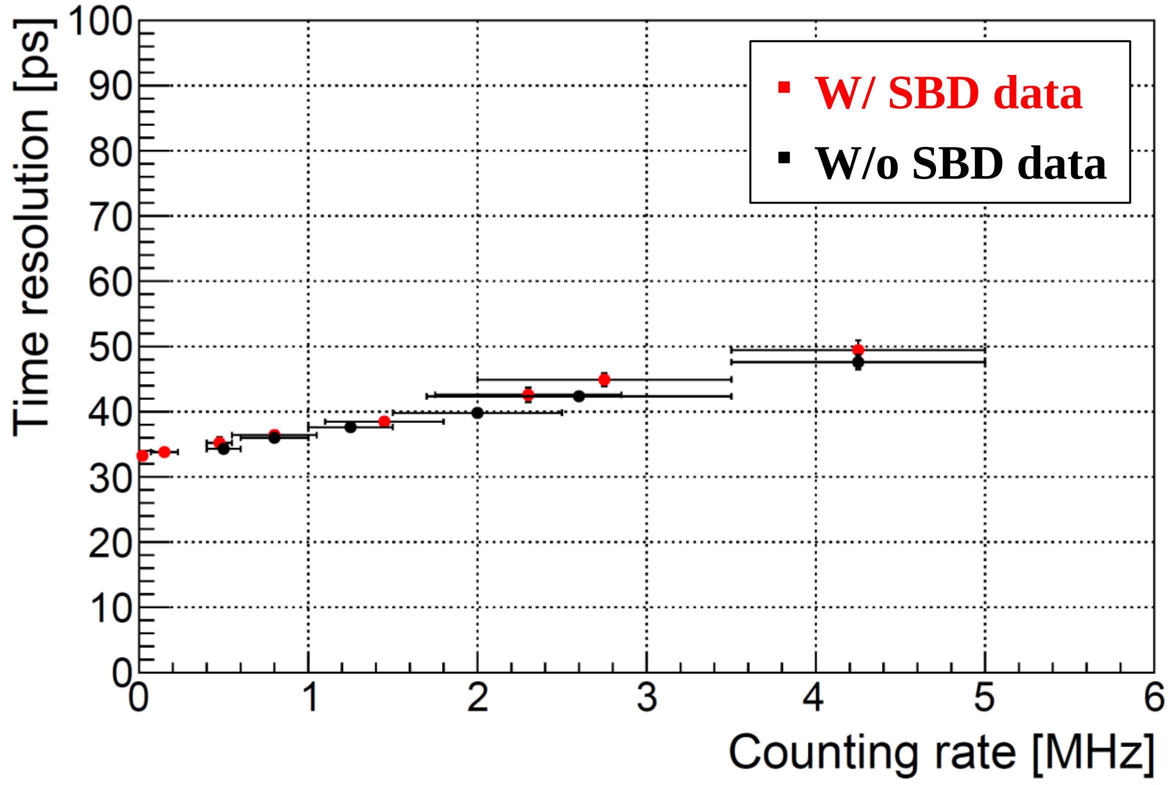

- **No improvement between data w/ SBD and w/o SBD**
  - **Improvement from previous study**

**⇒ Base line fluctuation on waveform (No SBD due to unexpected PH reduction with DRS4)**

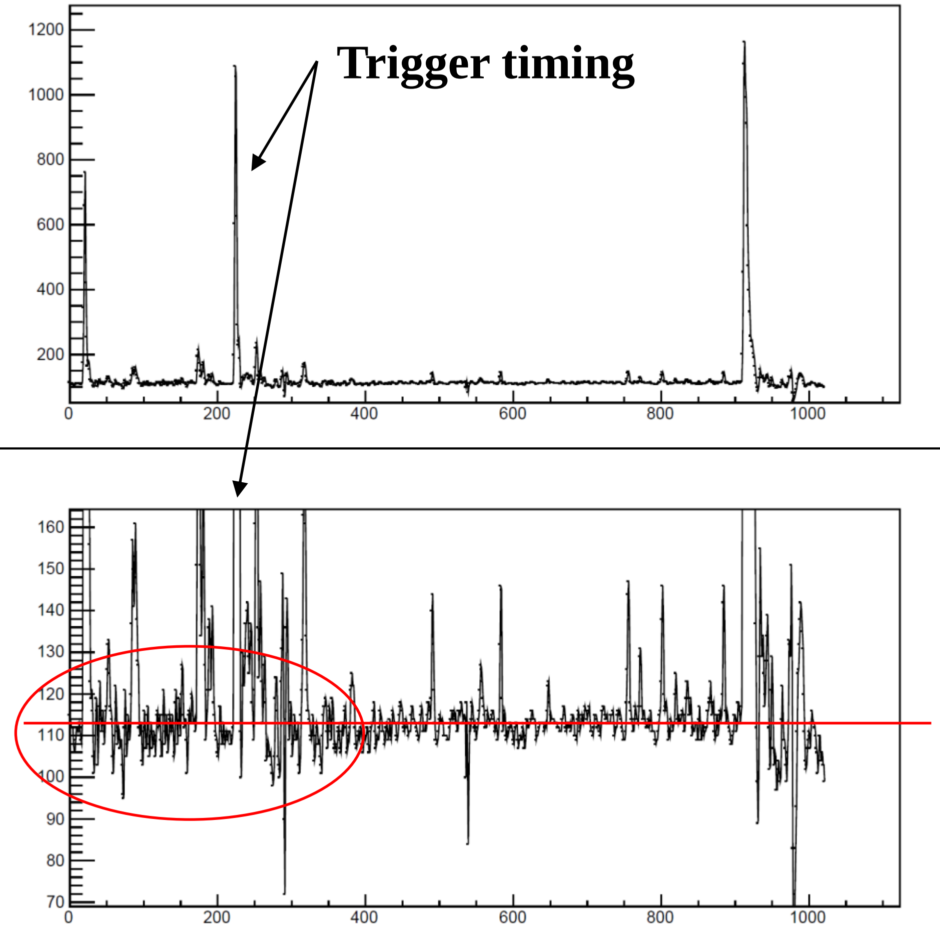
**⇒ It affected to time-walk correction. ($\Delta T_{BL}$~30 ps contribution)**

# Rate dependence: SBD filter

Current experiment data




Counting rate: 2.0–5.0 MHz



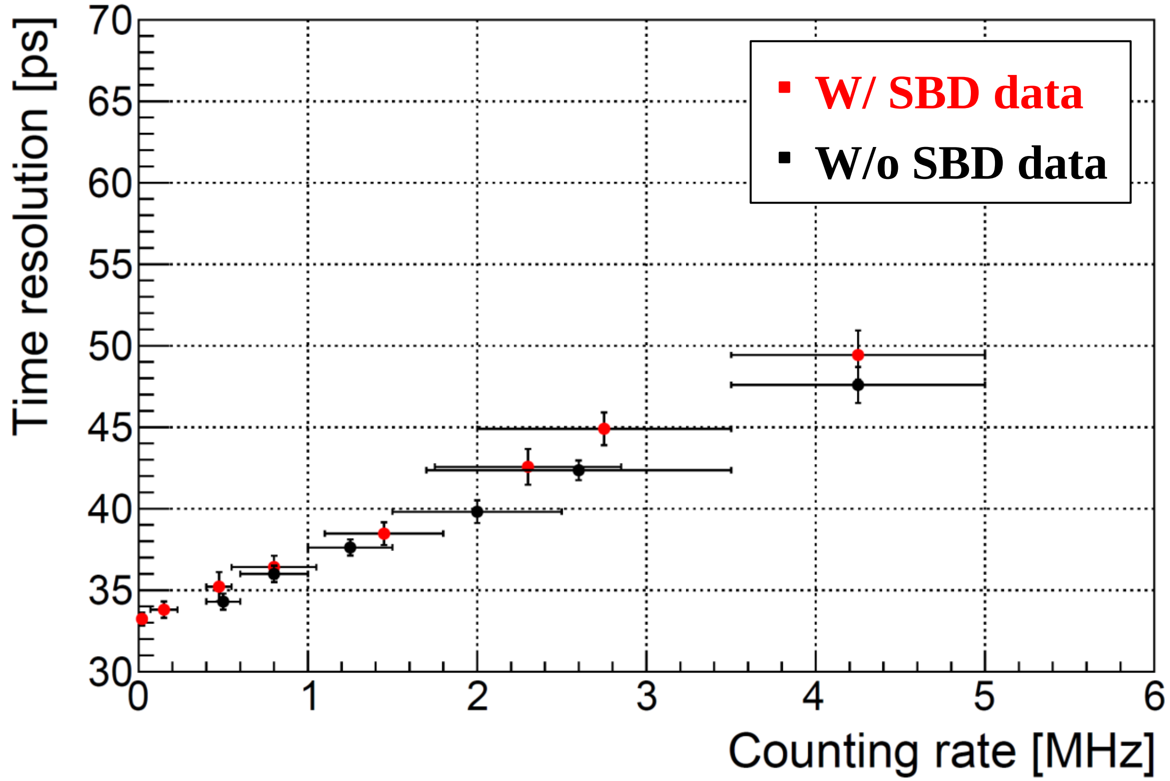

- **No improvement between data w/ SBD and w/o SBD**
  - **Improvement from previous study**

**⇒ Base line fluctuation on waveform (No SBD due to unexpected PH reduction with DRS4)**

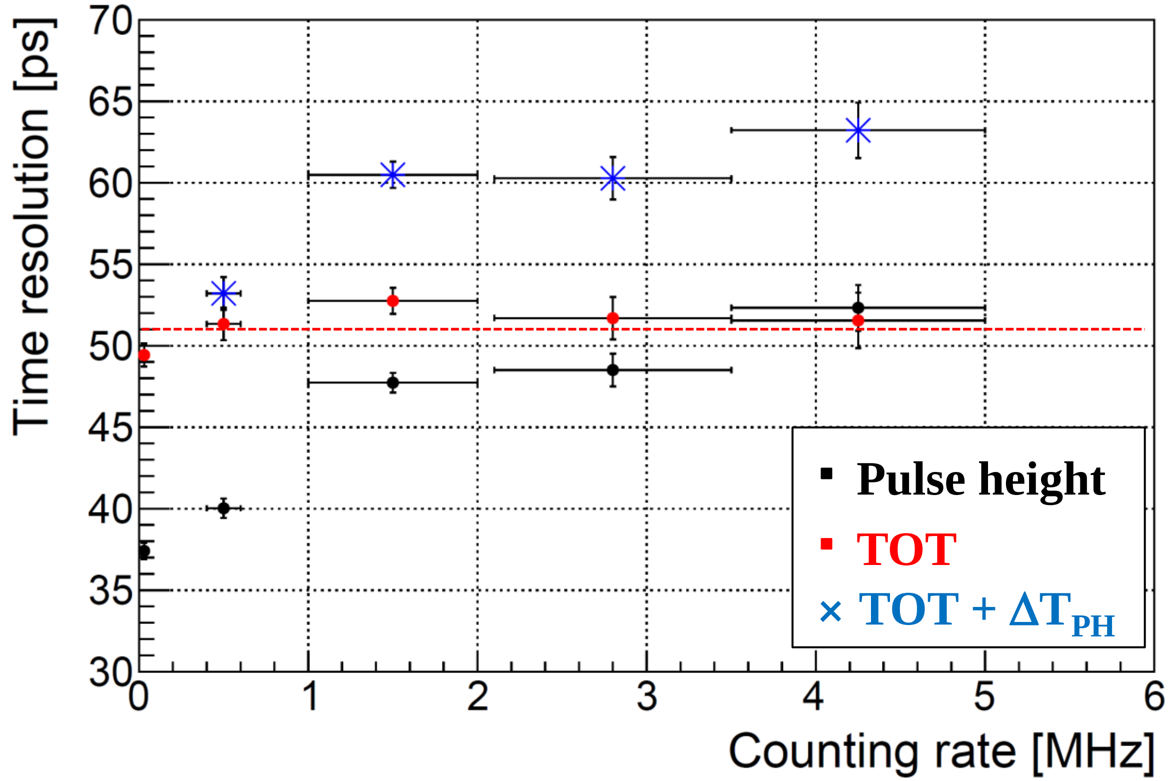
**⇒ It affected to time-walk correction. ($\Delta T_{BL}$~30 ps contribution)**

# Rate dependence: TOT (Just try)

Pulse height data W/ and W/o SBD




Pulse height and TOT data

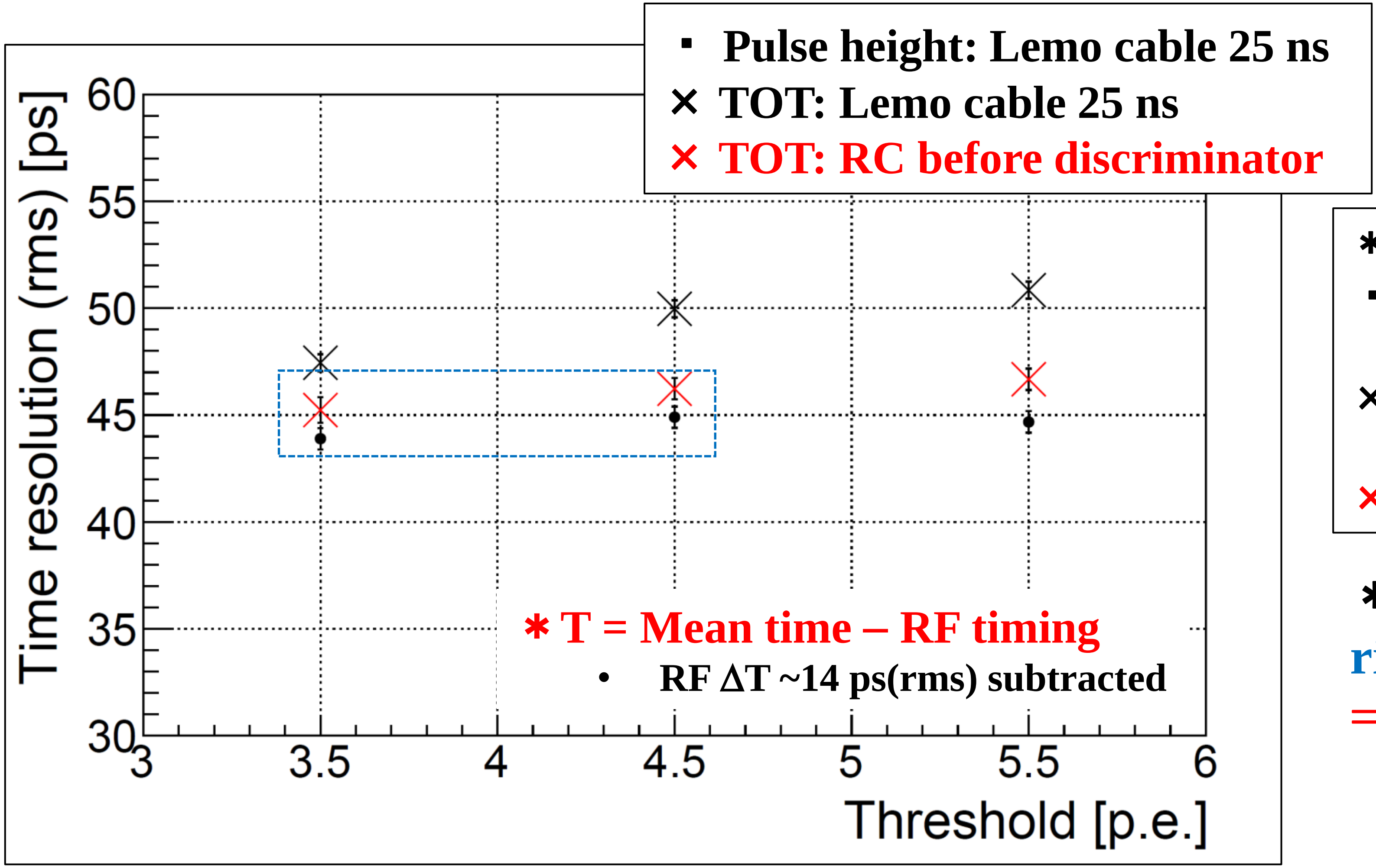



- **No rate dependence by TOT method**
  - **If there were dependences as of PH, resolution became worse. (× in Fig(R))**

**＊However, not best resolution (Divider×1/2, SBD×2/3, RC×1/2 & Both ADC and TDC)**

**⇒ Too low pulse height (low Vth ~7 mV) & long Lemo cable (attenuation)**

# Controlled condition data: Low-rate @ LEPS




* Cable connection
- ▪ Amp → SBD → Cable → ADC/Discri
- × Amp → SBD + RC → Cable → Discri.
- × Amp → SBD → Cable → RC → Discri.

* Cable length effect due to slower rinsing time by RC circuit ?
⇒ On-detector in actual T0

- Almost same resolution by time-walk correction using Pulse height and TOT

⇒ To optimize RC circuit and Revenge of High-rate test

- To design optimum amplifier circuit…?

# Other applications

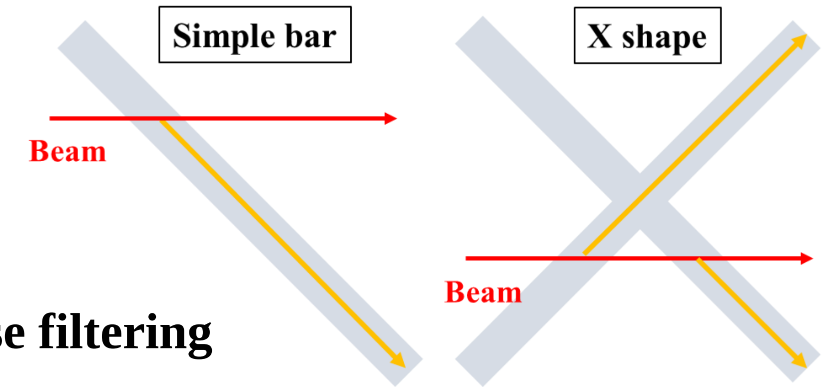
＊New ASIC for MPPC: High-rate capability and high-timing resolution

- SPADI Alliance TaskForce (R&D TF to be formed)

- Fine-segment property of Cherenkov radiator
  - sub mm segment with good time resolution

⇒ High time-resolution and good position-resolution detector

  - Timing detector + tracker
  - X shape ⇒ Simple bar




- Signal processing by Schottky Barrier Diode (SBD)
  - Applied to shaping circuit
    - Overshoot suppression, tail cutting, ringing suppression and noise filtering
  - Filtering for dark current of MPPC
    - Suppression of baseline fluctuation and screening out radiation damage

- Other detectors
  - Poor man’s TOP detector: Acrylic + MPPC
  - Phoswich detector: Cherenkov fast comment + scintillation light

# Summary

- **Charmed baryon spectroscopy experiment: J-PARC E50**

**⇒ Multi-purpose spectrometer system with trigger-less streaming DAQ**
  - **Various detectors using MPPC + Cherenkov radiation**

- **Cherenkov timing detector for high-rate beam measurement: Requirement: 3 MHz/3-mm segment**
  - **Acrylic X-shape Cherenkov radiator + MPPC readout with fast shaping amplifier**
    - **Timing resolution of ~40 ps(σ) @ Low rate**

- **Fine-segment study**
  - **X-shape Acrylic radiator with thin width: 0.5 mm, 1.0 mm, 3.0 mm**
  - **Light yield and time resolutions were kept by using fine segment radiators.**

- **Signal processing study for high-counting rate measurement**
  - **Suppression of pile-up effect by filtering with Schottky Barrier Diode (SBD): BAT63**
  - **TOT method: Time-walk correction by signal width with SBD + Integrator circuit**

  **⇒ No rate dependence by TOT method**
    - **Similar resolution between time-walk correction by Pulse height and TOT**

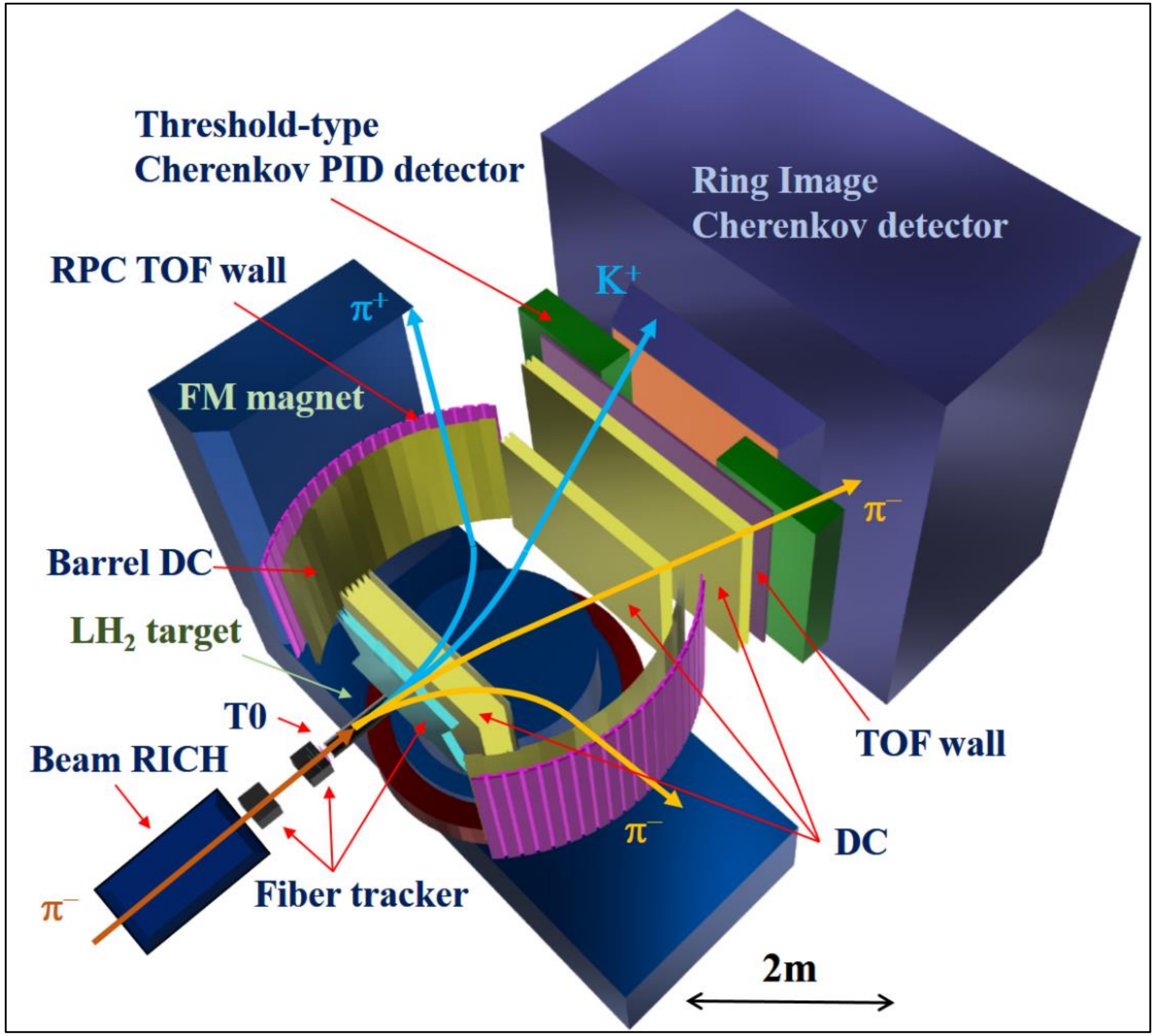
- **Other applications**
  - **High time-resolution and good position-resolution detector**
  - **Application using signal processing by Schottky Barrier Diode (SBD)**
  - **Poor man's TOP, Phoswich type detector for particle identification**

# Backup slides

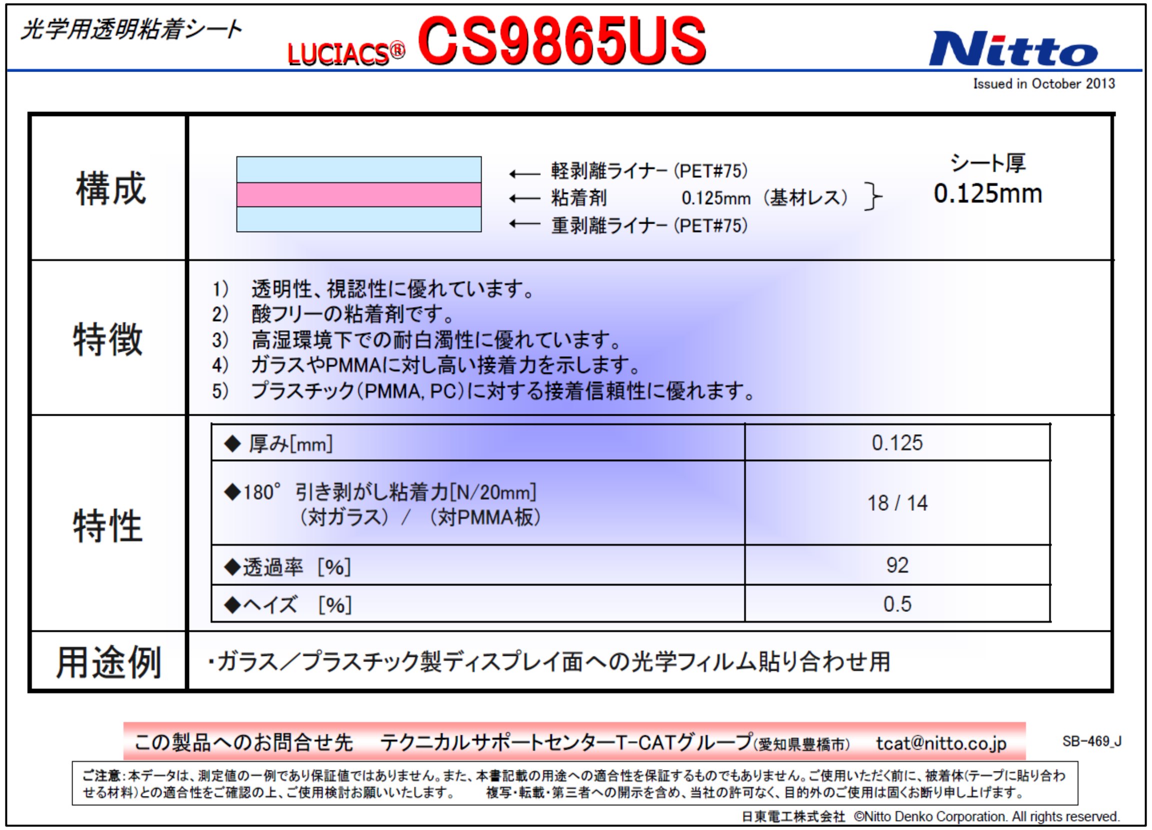
# Overview of E50 spectrometer system

– Photon detector
– Gas detector

- High-rate beam detectors
  - Scintillation Fiber Tracker
    - Fiber + MPPC array
  - Cherenkov Timing detector: T0
    - Acrylic(PMMA) + MPPC + amplifier
- High-performance PID detectors
  - High timing-resolution TOF wall: RPC
    - Gas detector + amplifier
  - RICH & Beam RICH
    - Aerogel & Gas + MPPC/MPPC array
  - Threshold-type Cherenkov detector: Vth AC
    - Low-index Aerogel + MPPC array
- Large size detectors for scattered particles
  - Large size drift chambers
    - Gas detector + amplifier
  - Forward TOF wall
    - Plastic scintillator + PMT (+RPC)
  - Muon detector
    - Tracker-RPC (+Plastic scintillator + PMT)



# Silicorn sheet for contact between radiator and MPPC



光学用透明粘着シート LUCIACS® CS9865US Nitto

Issued in October 2013

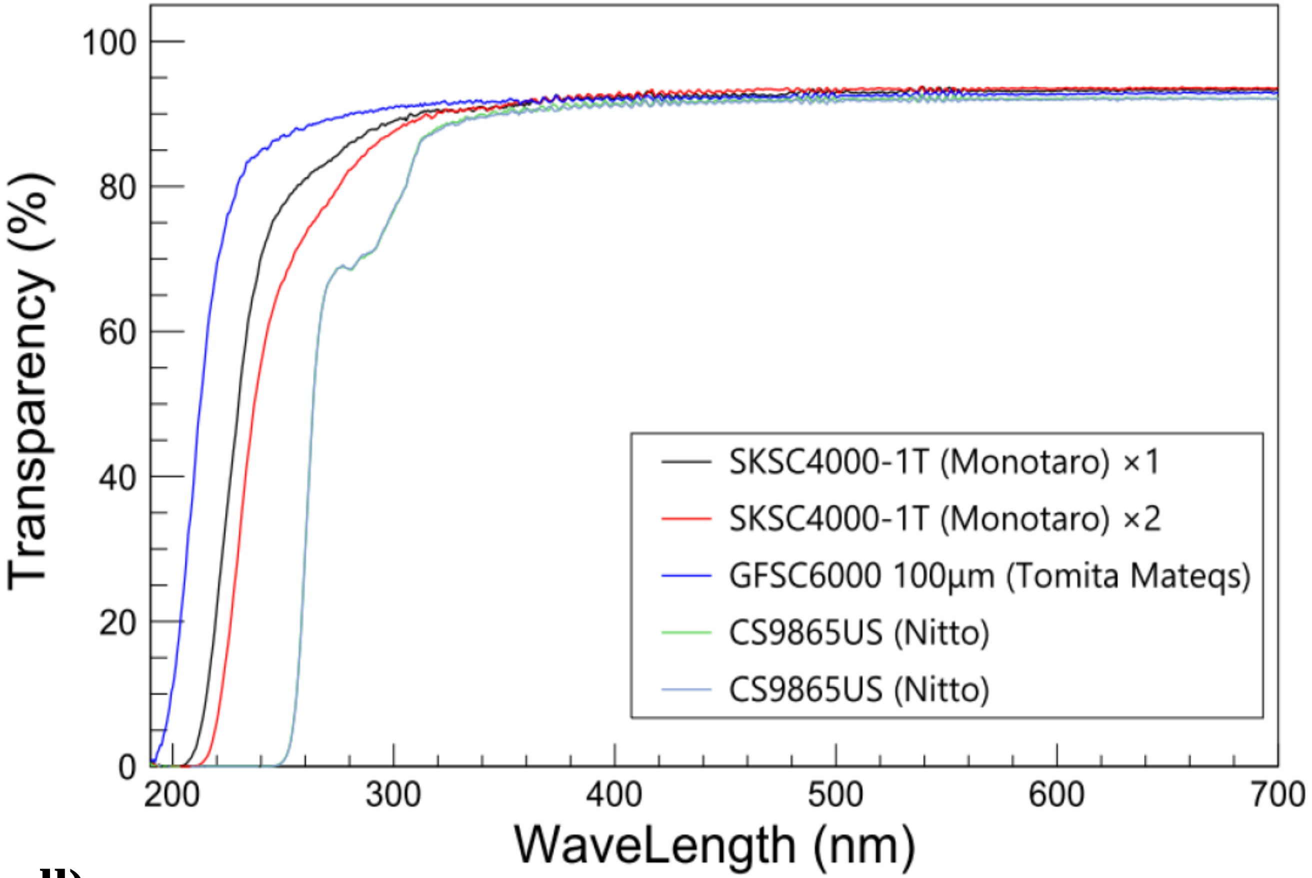
| | |
|---|---|
| 構成 | 軽剥離ライナー (PET#75)<br>粘着剤 0.125mm（基材レス）<br>重剥離ライナー (PET#75)<br>シート厚 0.125mm |
| 特徴 | 1) 透明性、視認性に優れています。<br>2) 酸フリーの粘着剤です。<br>3) 高湿環境下での耐白濁性に優れています。<br>4) ガラスやPMMAに対し高い接着力を示します。<br>5) プラスチック(PMMA, PC)に対する接着信頼性に優れます。 |
| 特性 | ◆厚み[mm]: 0.125<br>◆180° 引き剥がし粘着力[N/20mm]（対ガラス）/（対PMMA板）: 18 / 14<br>◆透過率 [%]: 92<br>◆ヘイズ [%]: 0.5 |
| 用途例 | ・ガラス／プラスチック製ディスプレイ面への光学フィルム貼り合わせ用 |

この製品へのお問合せ先 テクニカルサポートセンターT-CATグループ(愛知県豊橋市) tcat@nitto.co.jp SB-469_J

ご注意：本データは、測定値の一例であり保証値ではありません。また、本書記載の用途への適合性を保証するものでもありません。ご使用いただく前に、被着体(テープに貼り合わせる材料)との適合性をご確認の上、ご使用検討お願いいたします。 複写・転載・第三者への開示を含め、当社の許可なく、目的外のご使用は固くお断り申し上げます。



**Transparent Silicorn w/ glue: Nitto Denko**

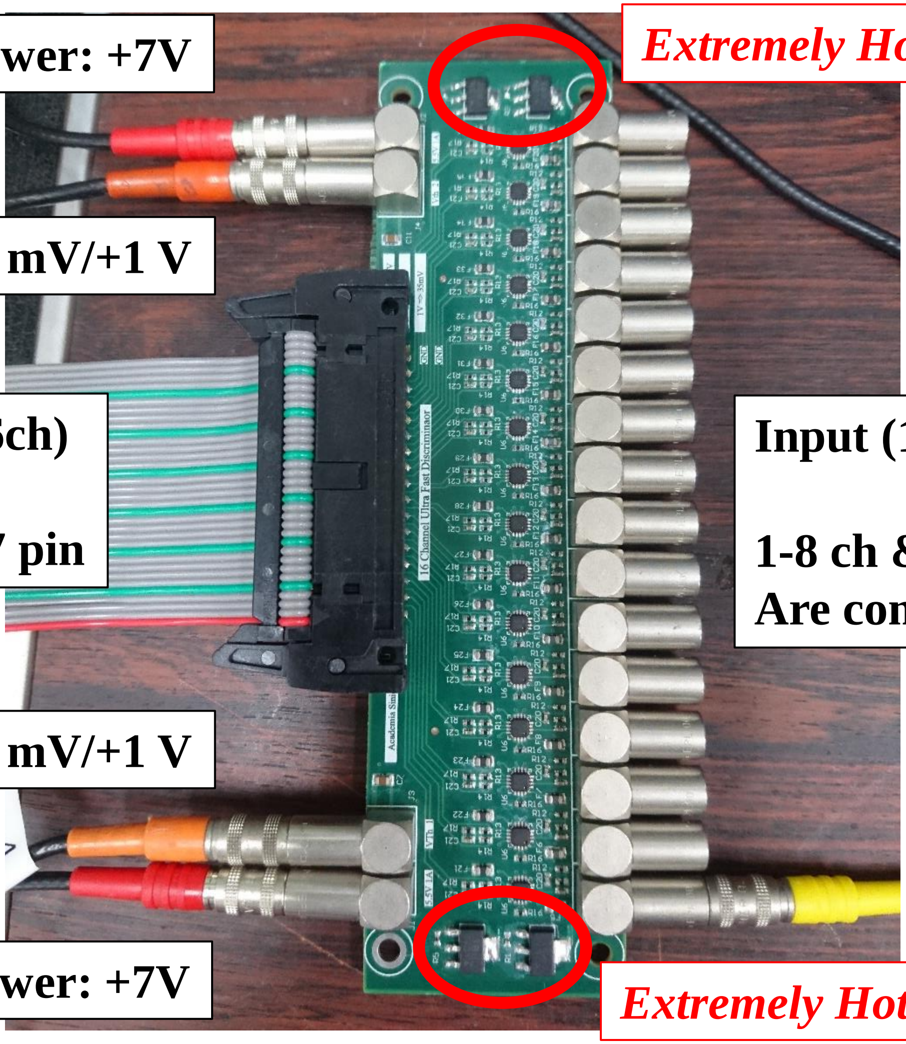


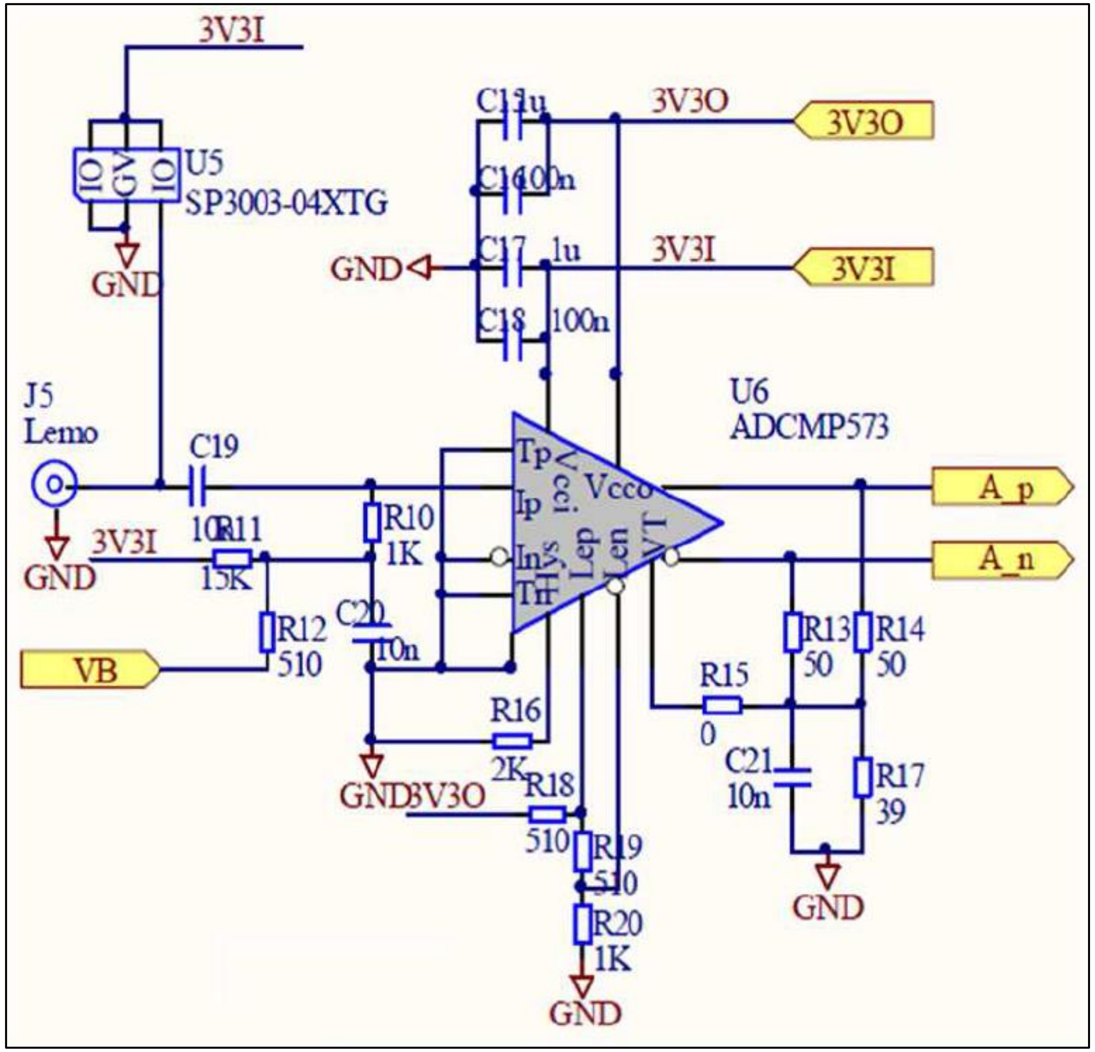

- **Good transparency: ~320 nm**
- **~0.1 mm thickness with glue for fixing tightly**
- **We can buy MISUMI (25 μm or 50 μm sheet as roll).**
- **Reflection index: n~1.405**

**⇒ Light yield ×1.3**

- **3 mm MPPC and 3 mm×3 mm ×150 mm scintillator and PMMA**

# LEPS discriminator




- 16 ch discriminator: Reading & Trailing
  - Narrow width signal can output.
- RSPELC ⇒ LVDS: Direct connection to HUL HR-TDC
  - Ground pin positions  are changed.

N. Tomida et al., 2014 JINST 9 C10008

# Narrow signal readout of MPPC

- **By using Schottky barrier diode (SBD)**
  - **Kind of rectifier diode: Quick response**

J. M. Yebras, P. Antoranz, J.M.Miranda
Optical Engineering 51(7),
074004 (July 2012)

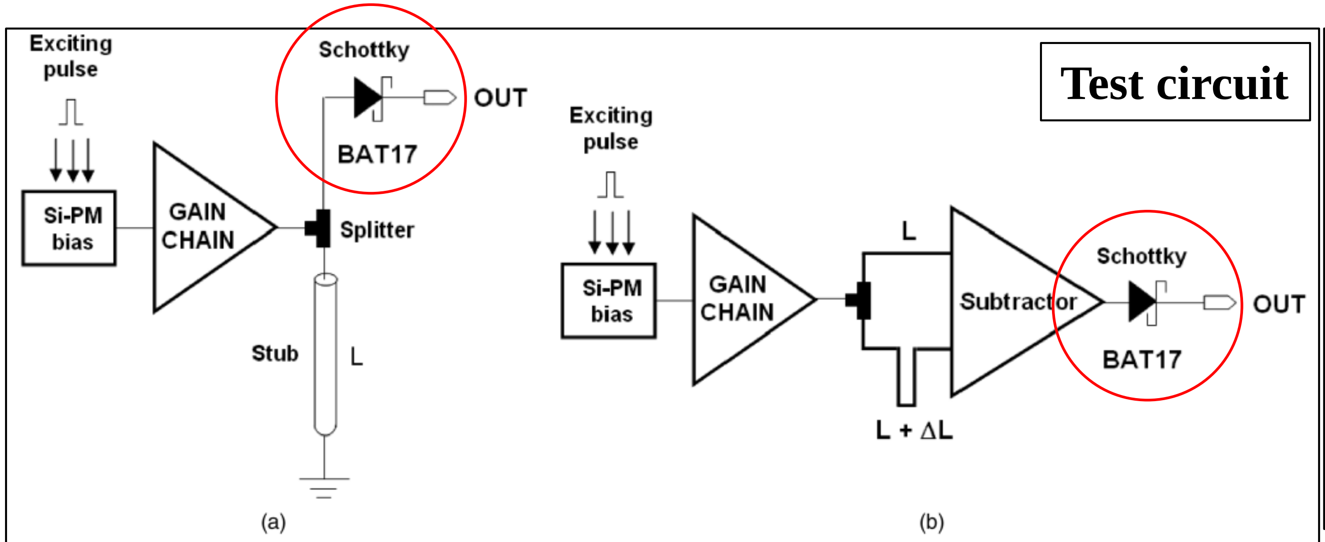
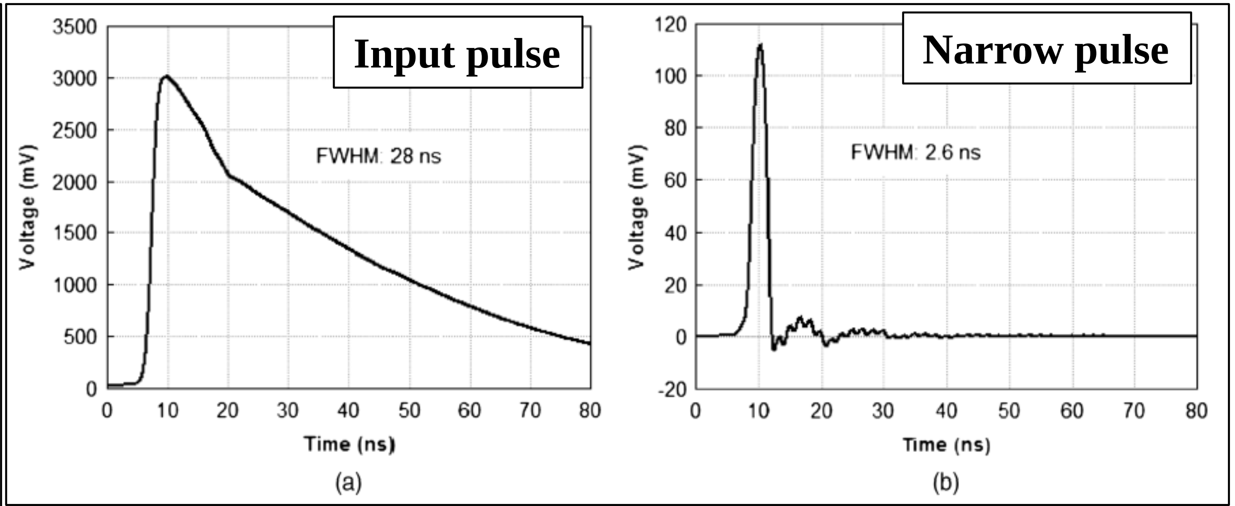
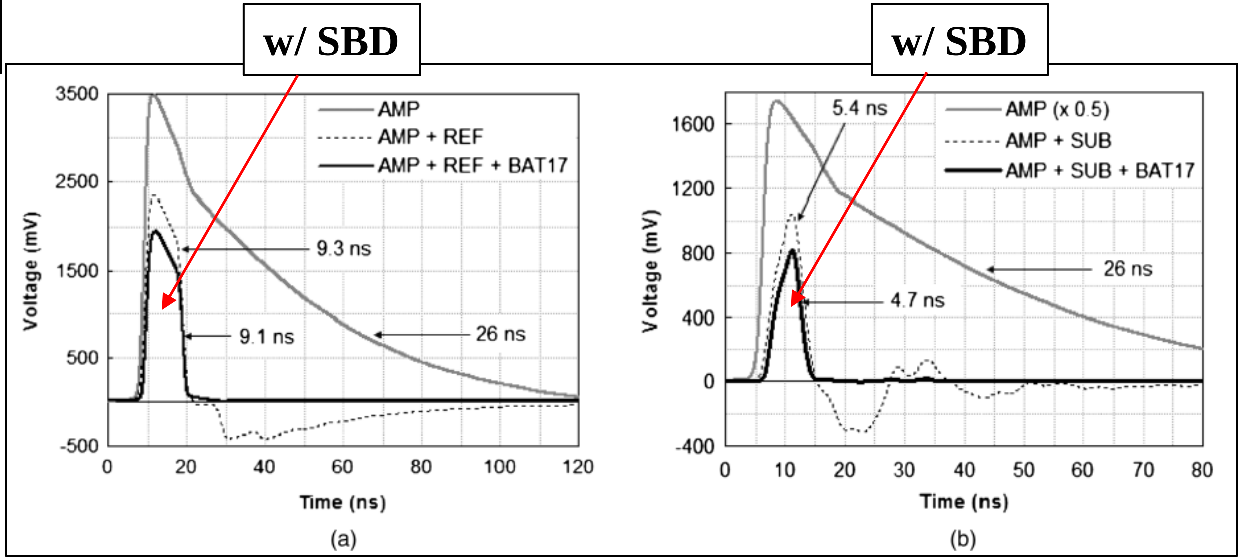



Fig. 4 Pulse shortening system based on reflectometry (a) and on subtractor fed with stubs of different lengths (b).




- **Test circuit: BAT17**
  - **It makes input pulse narrower one by using a subtraction circuit.**
  - **Schottky barrier diode is series connection at the end of circuit.**