Development of a Cherenkov timing detector for measuring high-intensity secondary beams

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for the E50 collaboration

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  - **High-intensity beam measurement by fine-segmented detector**
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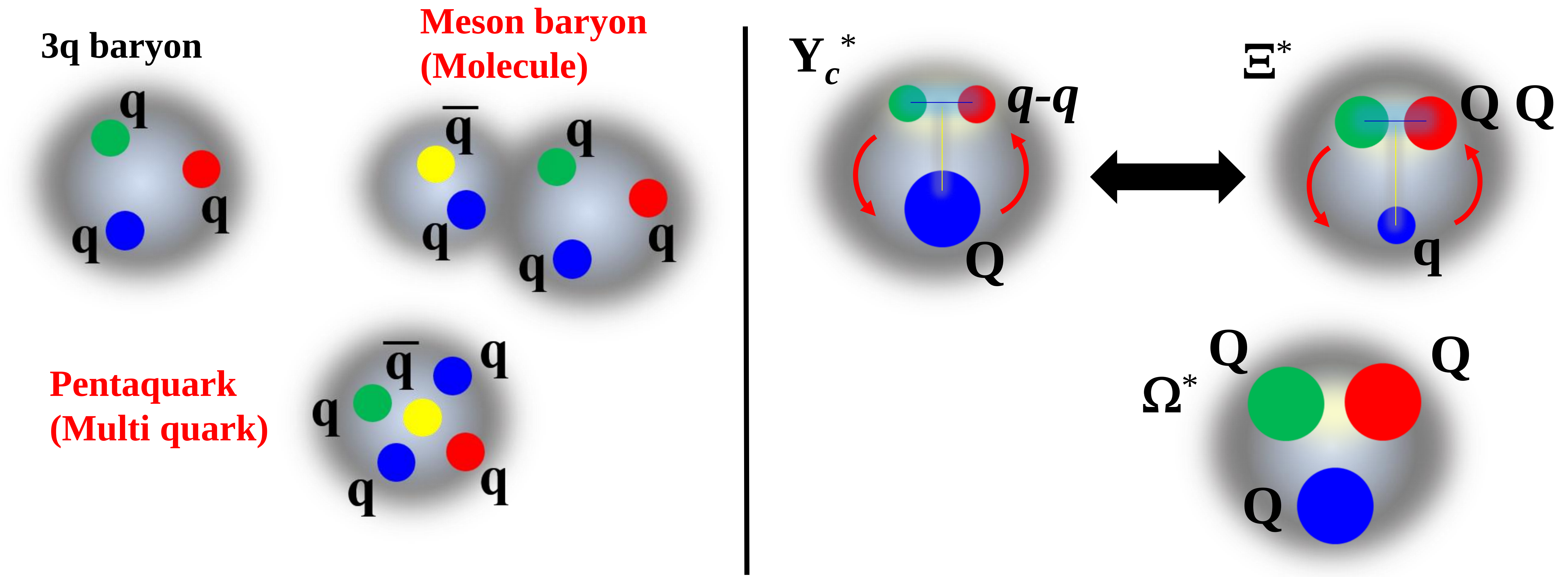
Introduction

Investigation of effective degree of freedoms



- **To understand role of effective degree of freedoms for hadrons**
  - **Diquark correlation, molecule states**
- **Systematic studies: Charmed baryon (q-q + Q) ⇔ Ξ^* (q + QQ) and Ω^* (QQQ) systems**
  - **Heavy (heavier) quarks are key.**

Experimental situations of Ξ^* and Ω^* baryons

- **Poor experimental data of Ξ^* and Ω^***
  - **Systematics studies are essential.**
- **Narrow decay width expected**

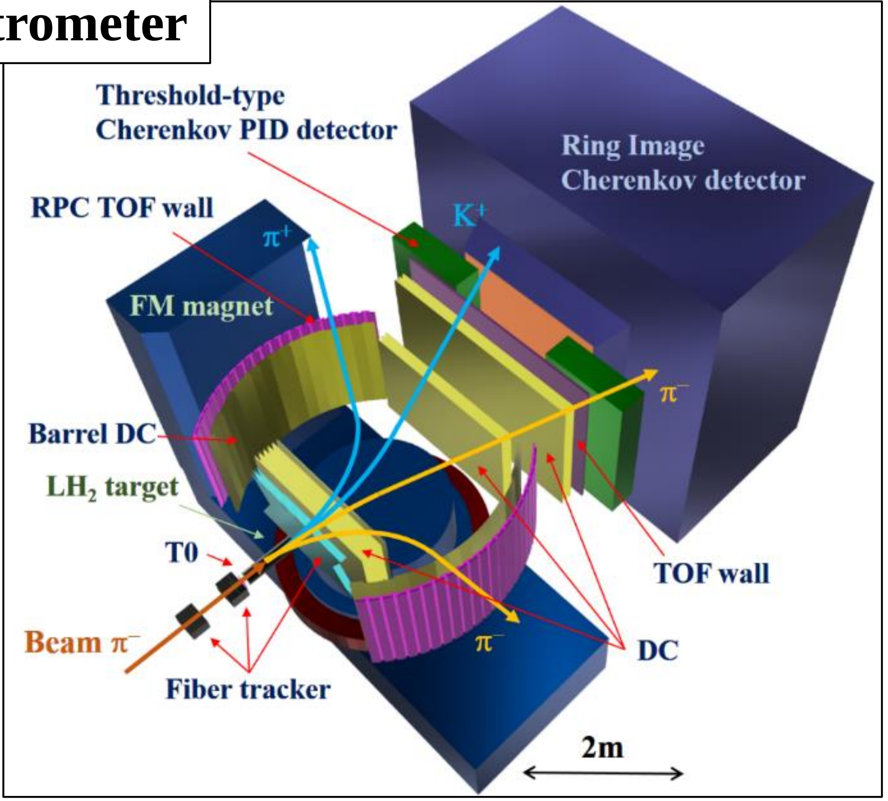
⇒ Chance to find and separate states

- **Γ ~ a few 10 MeV of Ξ^* < a few 100 MeV of Λ^*/Σ^***
- **Ω^* expects to have also narrow width.**

⇒ Systematics measurements

- **Production and decay**

E50 spectrometer



∗ K⁻ beam is effective tool to produce multi-strangeness baryons.

- **High-momentum beam: 5–10 GeV/c**
- **Large yield: σ = ~1 μb order and high-rate beam**

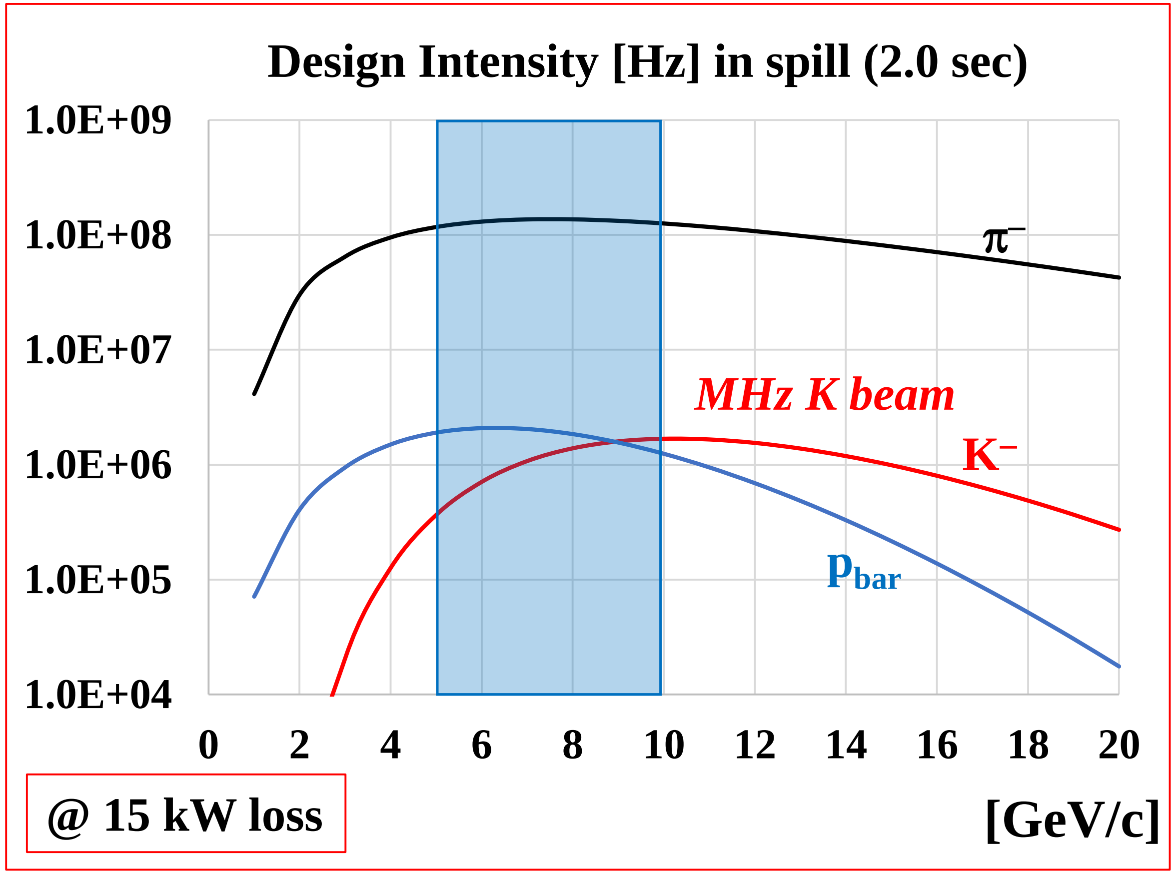
⇒ Systematic studies by E50 spectrometer

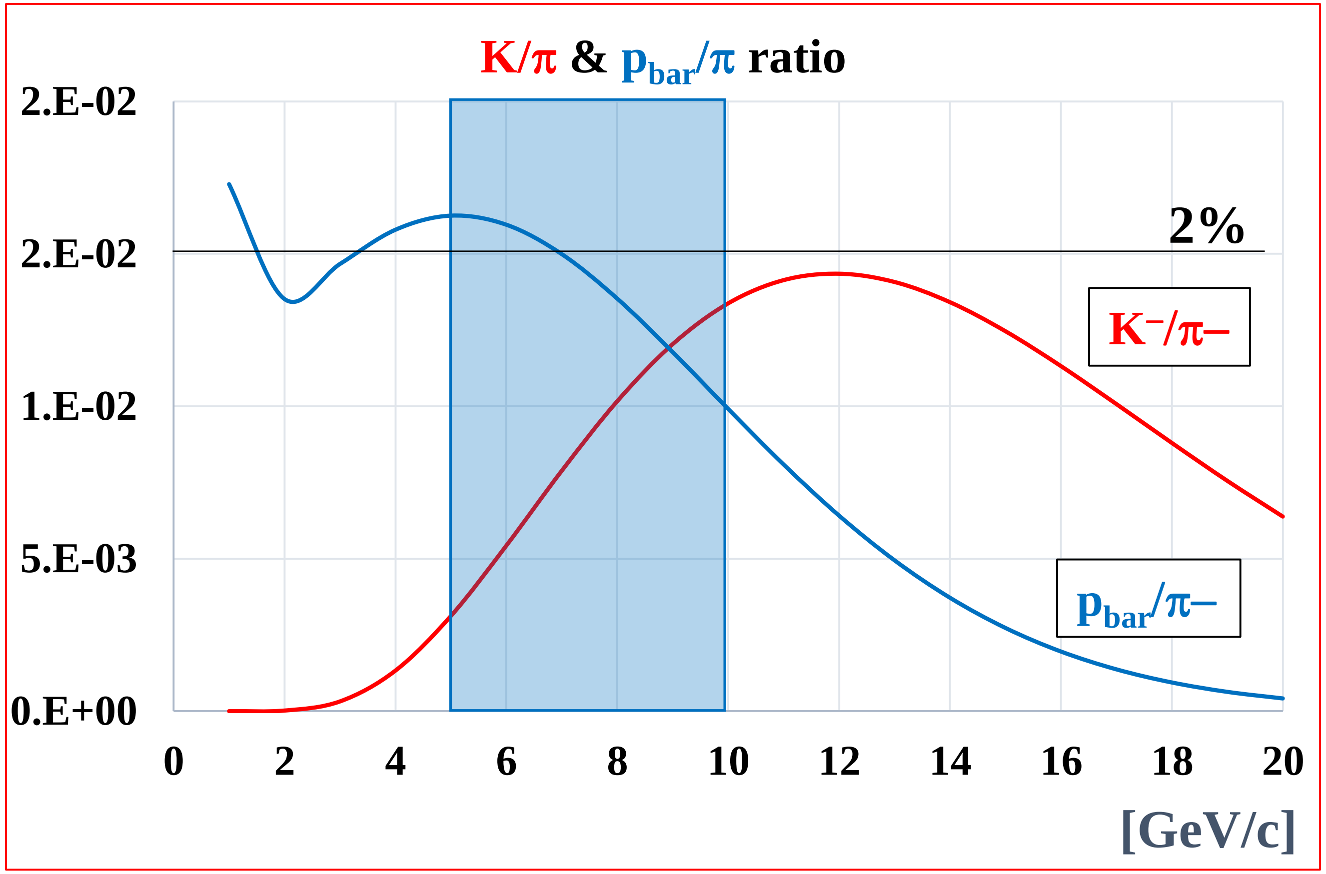
- **Beam measurement is essential for missing mass and decay measurement**

High-momentum beam line for 2^{ndary} beam

- High-intensity beam: > 1.0×10^7 Hz π (< 20 GeV/c)
  - Unseparated beam: π/K/p_{bar} : MHz K beam ⇔ 100 MHz π beam
- Beam timing measurement: Start timing

⇒ "*Bottleneck*" to increase beam intensity





High-momentum beam line for 2ndary beam

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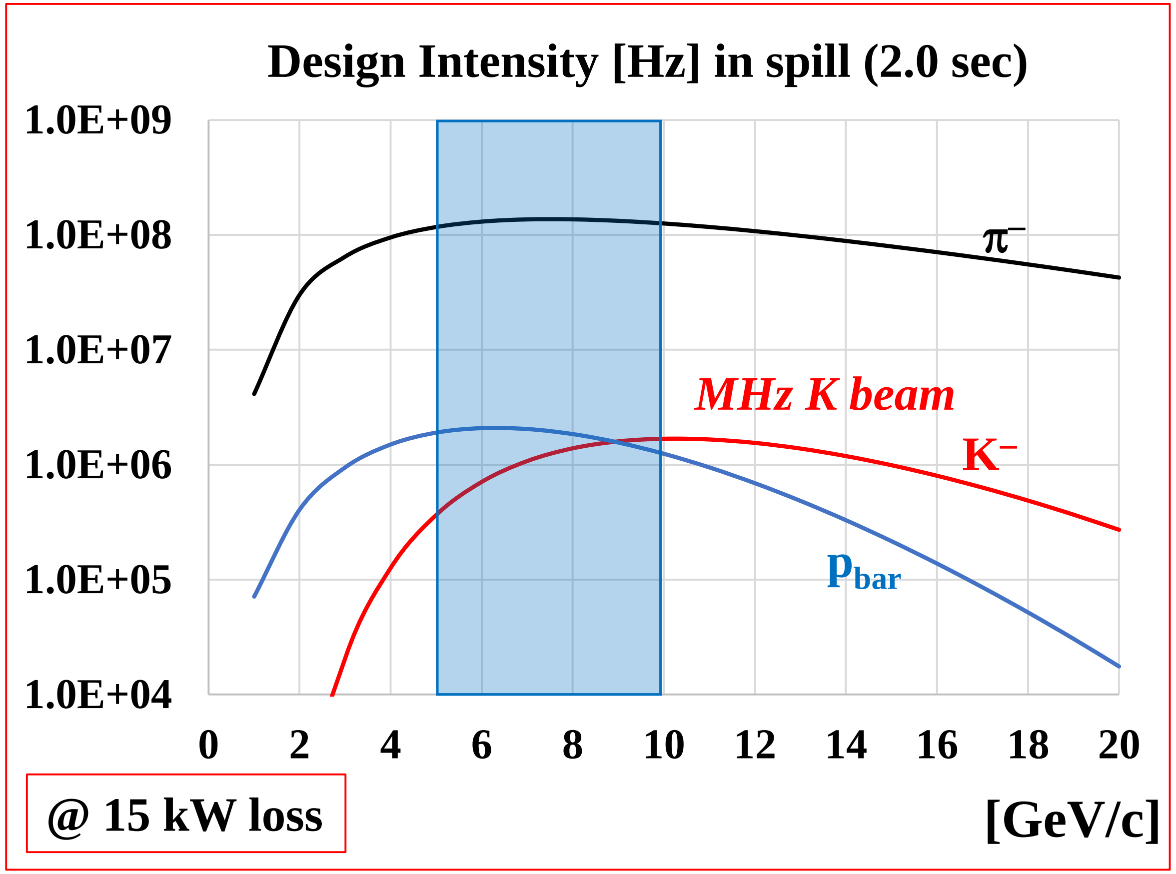
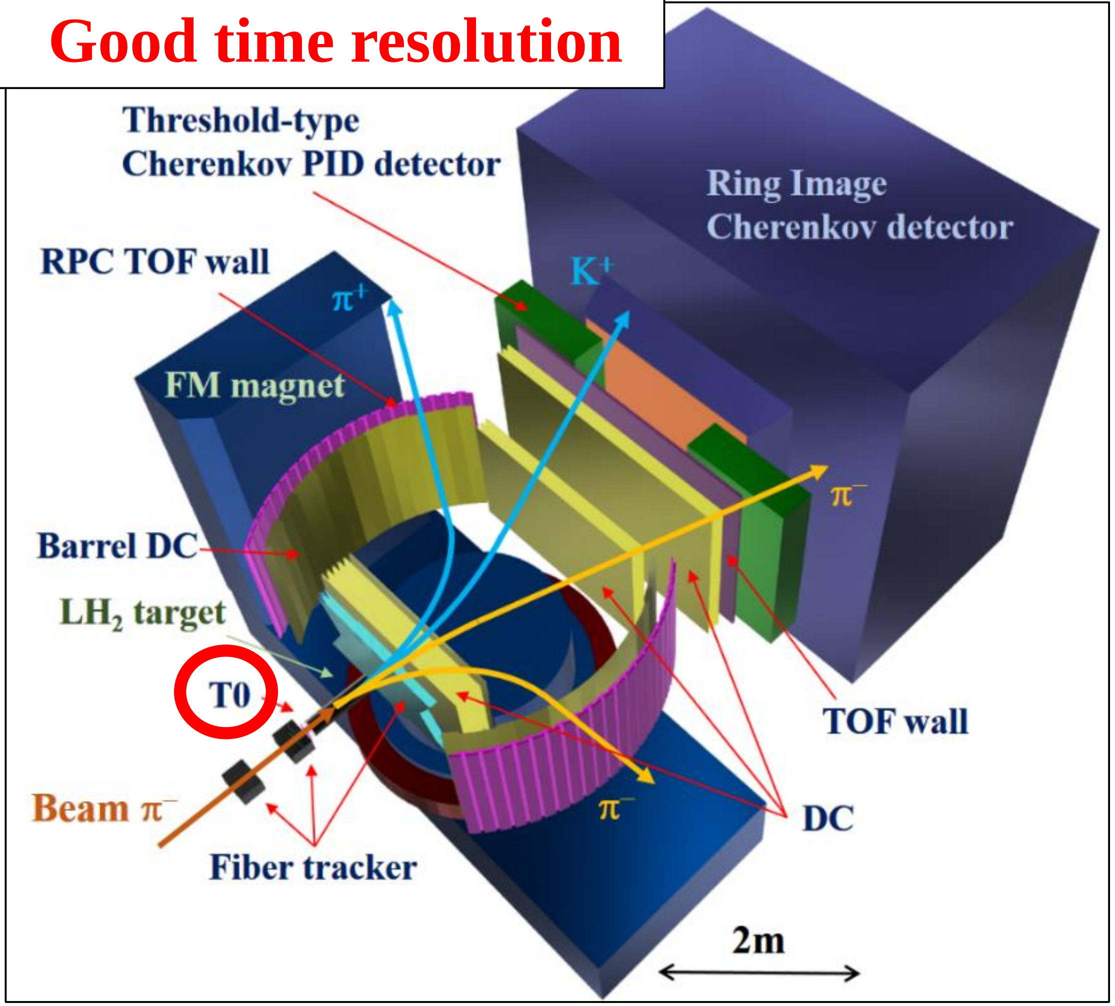
- High-rate capability
- Good time resolution





High-rate Cherenkov timing detector: R&D status

Fine segment test

Signal processing method test

T0 detector

- Segment by Acrylic (PMMA)

⇒ Cross shape: X-type
  - Cherenkov angle direction
    - Suppress time spread
  - Both edge readout
    - ×2 light yield

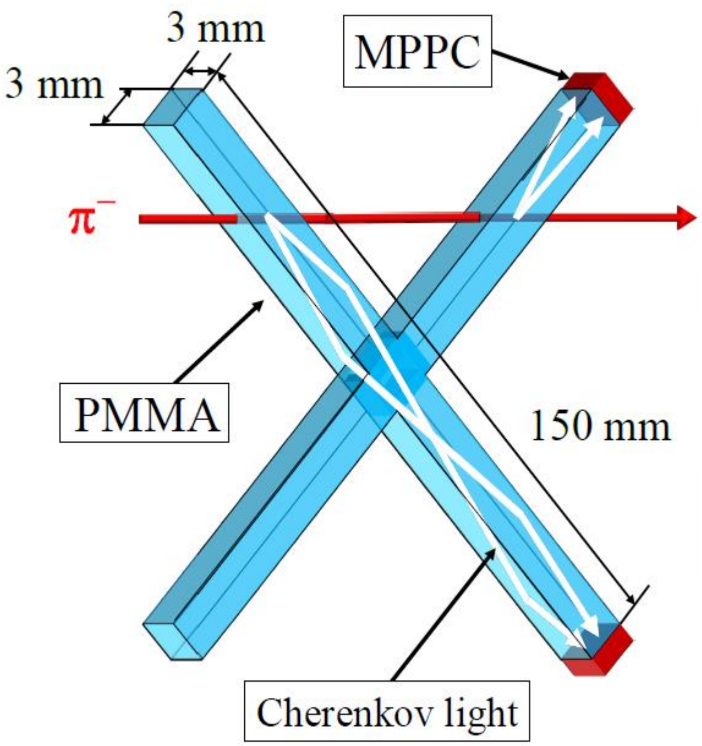
- 3-mm width segment + MPPC
  - MPPC amplifier: ~10 ns width

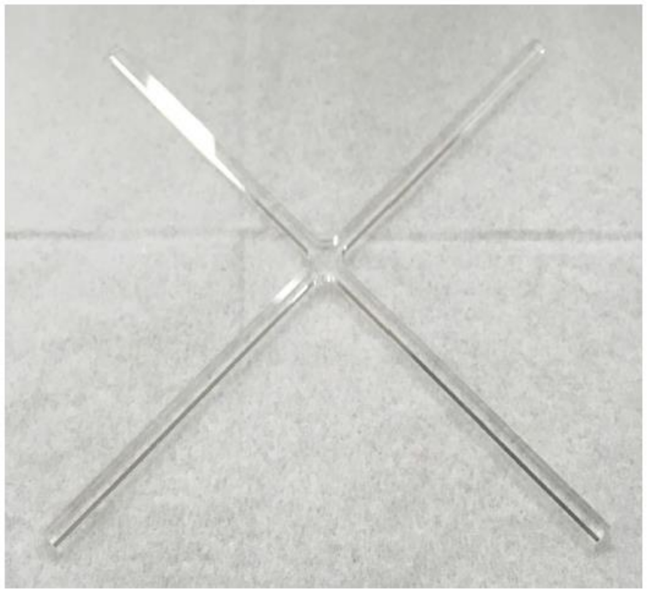
⇒ Time resolution: ΔT ~ 50 ps(rms)
  - 3 MHz/segment ⇒ Achieved
  - No position dependence

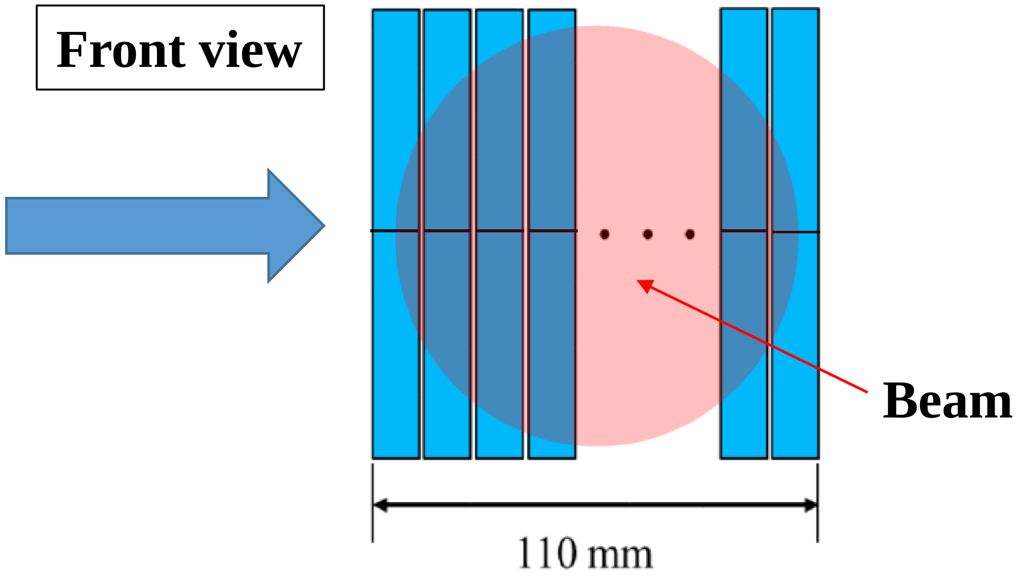
  ＊Akaishi master thesis

＊Limit: ~3 MHz/3-mm segment

⇒ < 1-mm width fine segment
  - Handle 100 MHz beam







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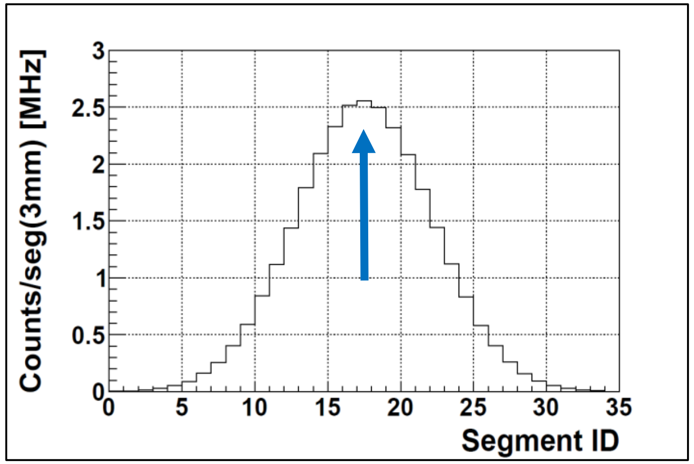
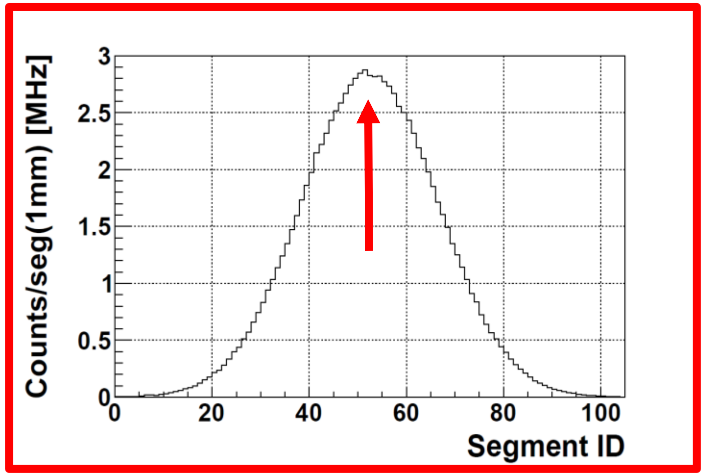
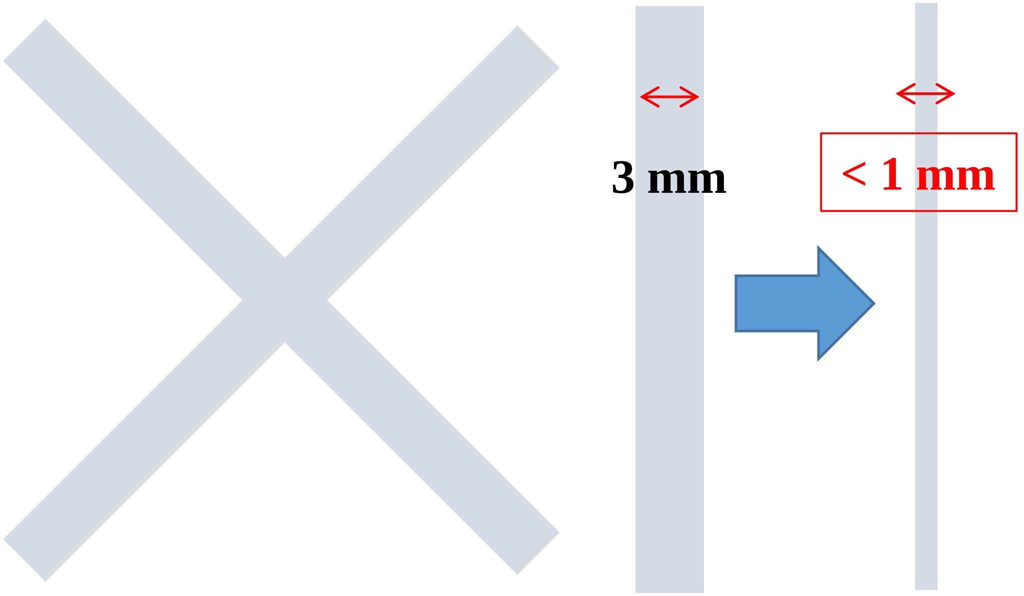
30 MHz by 3-mm segment



100 MHz by 1-mm segment



Front view



Simulation: Radiator width dependence

- Fine segment simulation
  - Geant4: Optical photon
    - Realistic parameters: PMMA, MPPC and so on

- Normalization of # of p.e.
  - 3-mm radiator light yield data

  ⇒ Reflection probability of PMMA: 99.5%

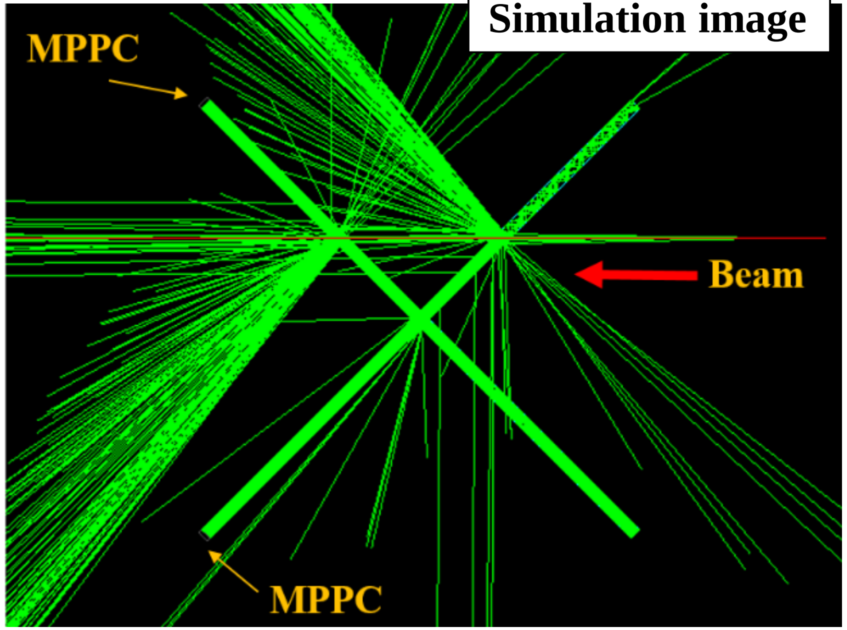
- Light yield is decreased by fine segments.
  - ~16 p.e. @ 0.5 mm

- Smaller loss of fast components
  - Small number of reflections
    - Resolution is expected to be kept.

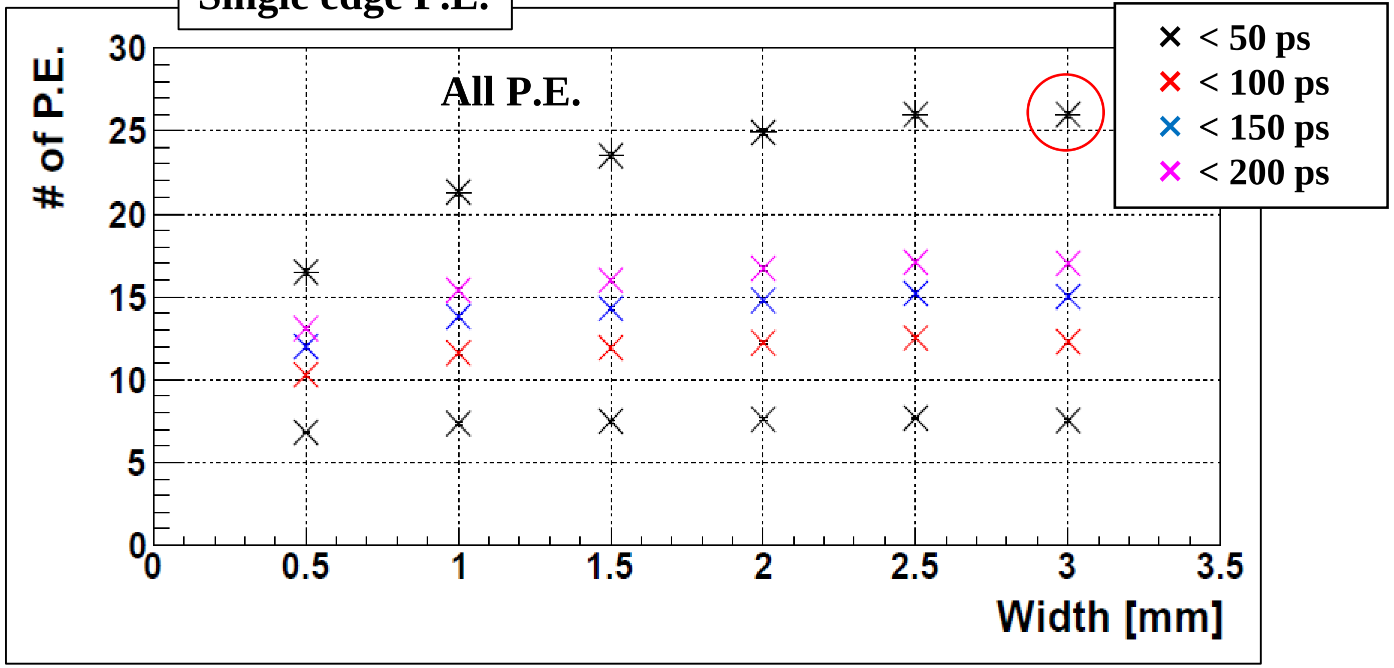
＊Production by company
  - Cut from one PMMA board

⇒ Actual fine segment test

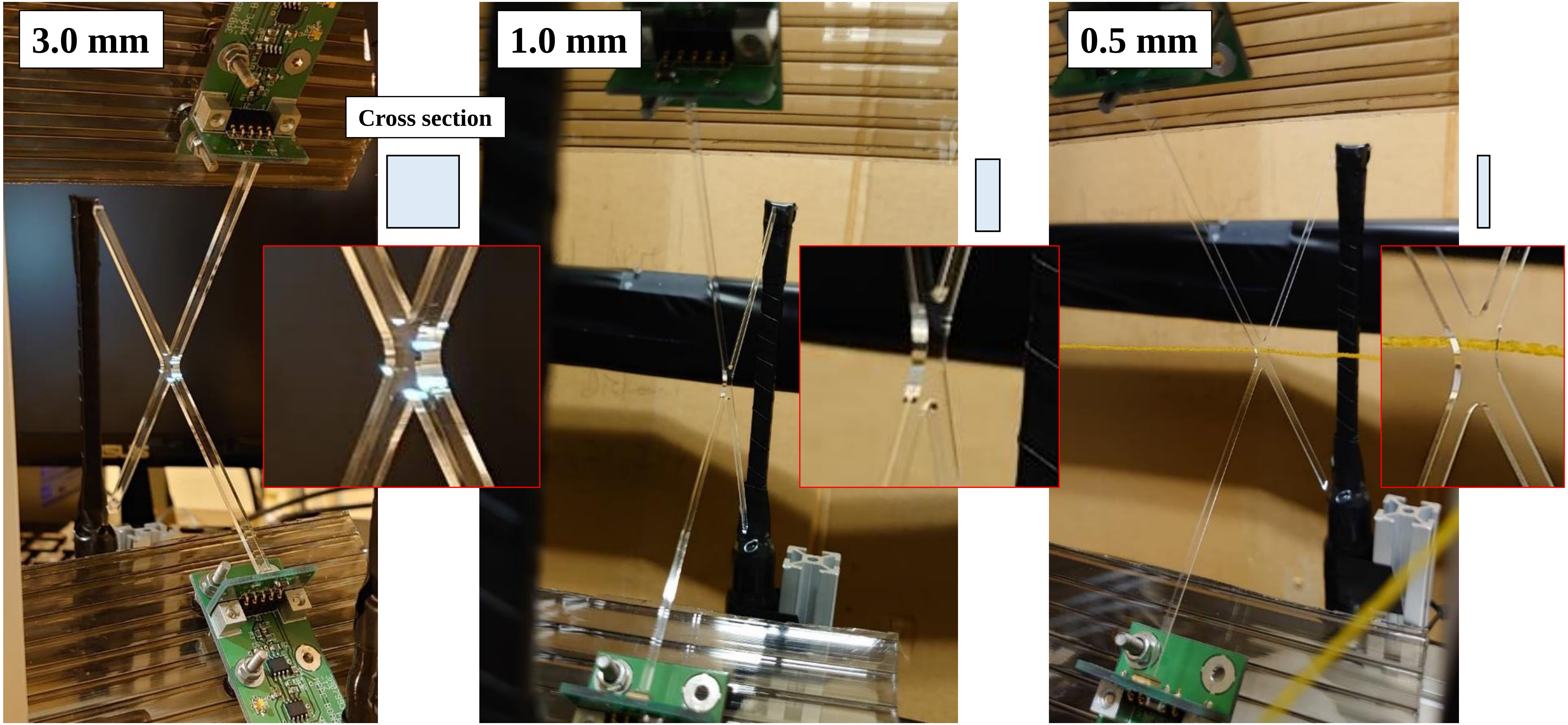
Simulation image



Single edge P.E.



Fine segments of Cherenkov radiator



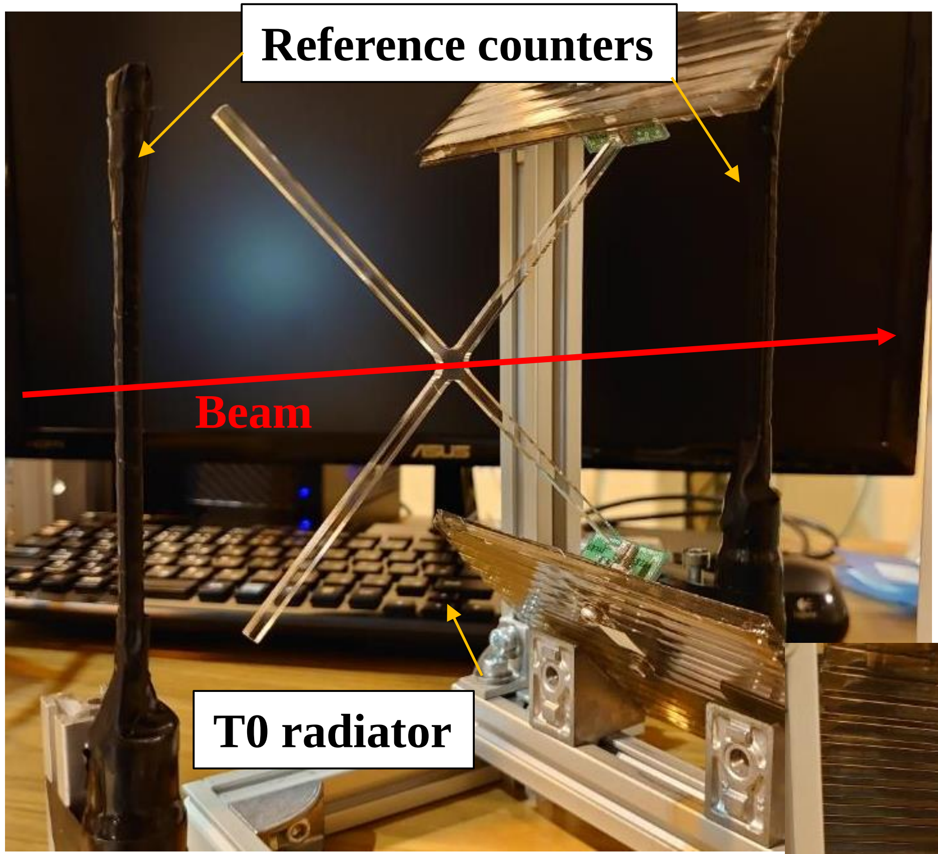
- Radiators can be fixed by Silicone sheet with glue and some wires.

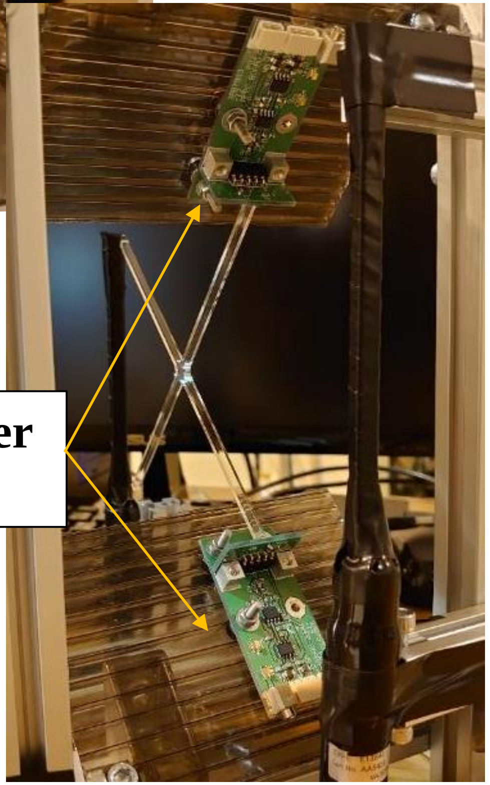
Test experiment @ LEPS

- Purposes
  - Fine segment test
    - 1.0 mm and 0.5 mm segments
  - New amplifier test
  - Signal processing test
    - Schottky Barrier Diode filter circuit
    - Integration circuit for TOT

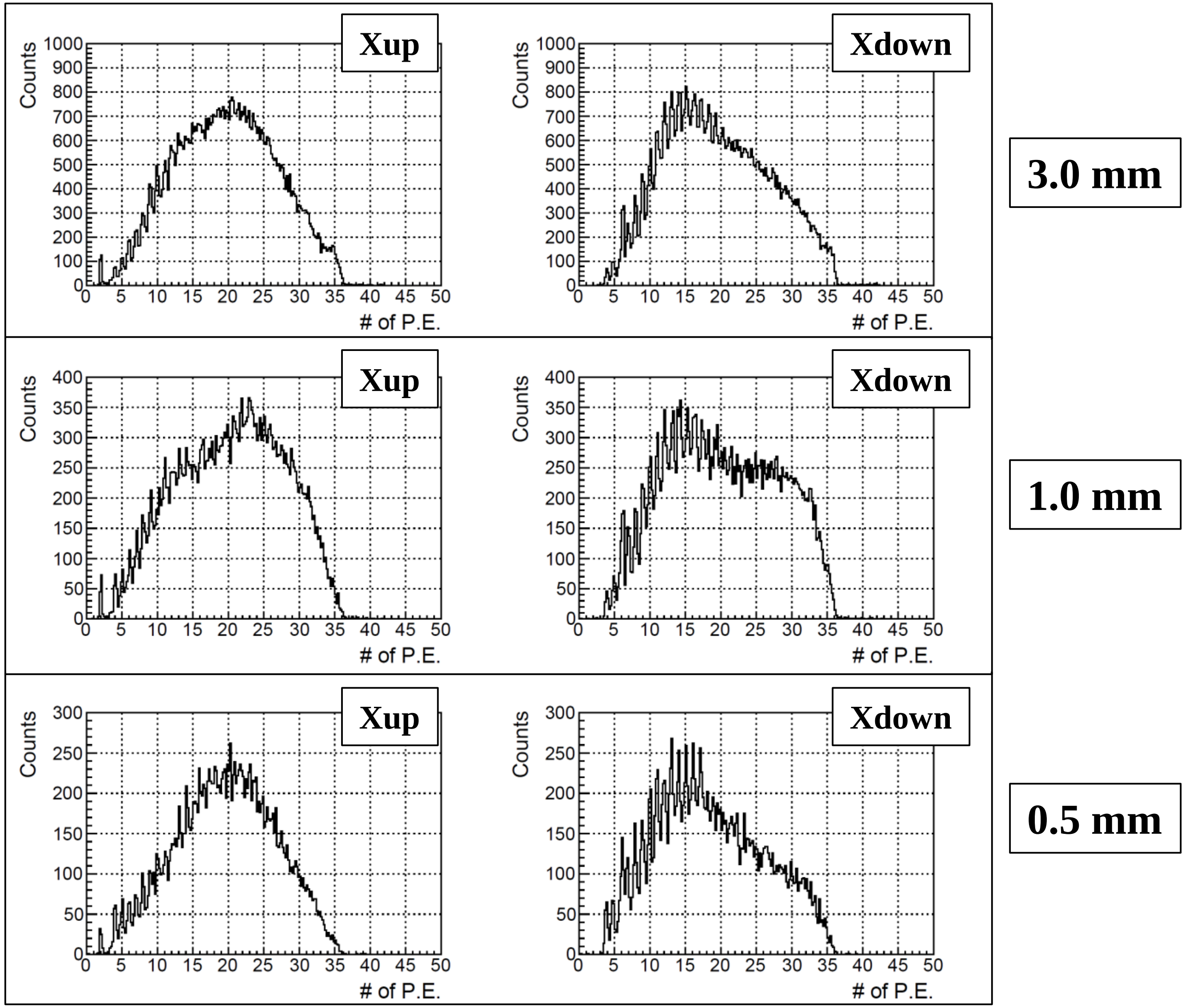
- Time resolution evaluation by MIP
  - $e^{\pm}$ from γ-ray conversion
  - RF timing reference: ΔT ~14 ps
  - Time walk correction by pulse height
    - Data taking: DRS4 and HUL HR-TDC

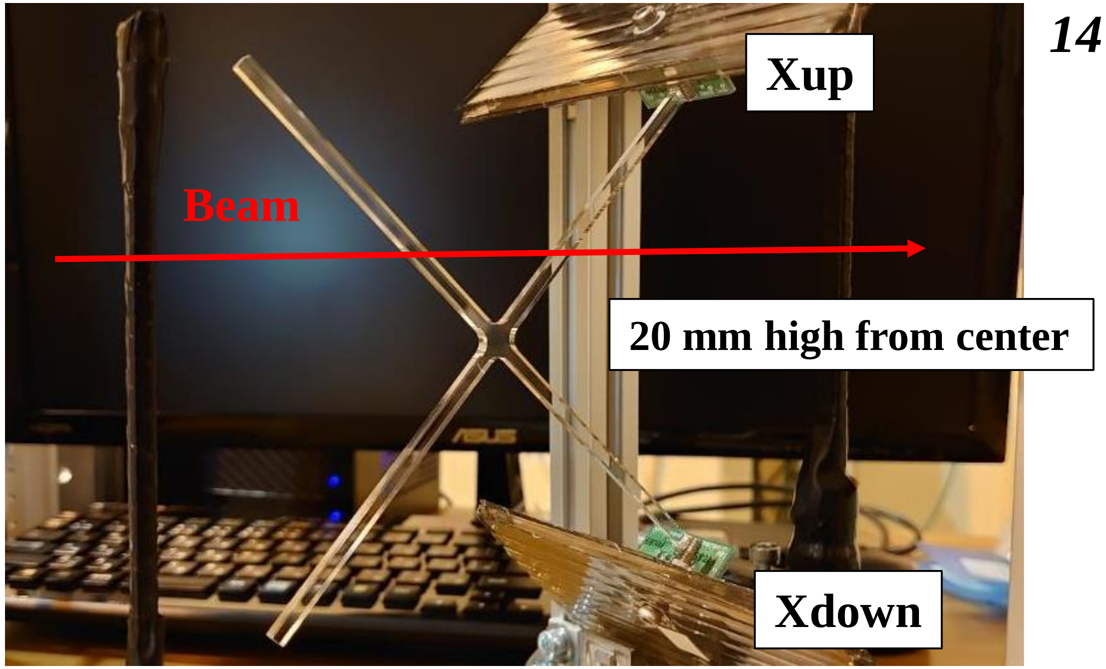
- MPPC (s13360-3050PE) conditions: V_{ov} = +7V
  - One p.e. pulse height: ~70 mV (amp gain: ×18.8)



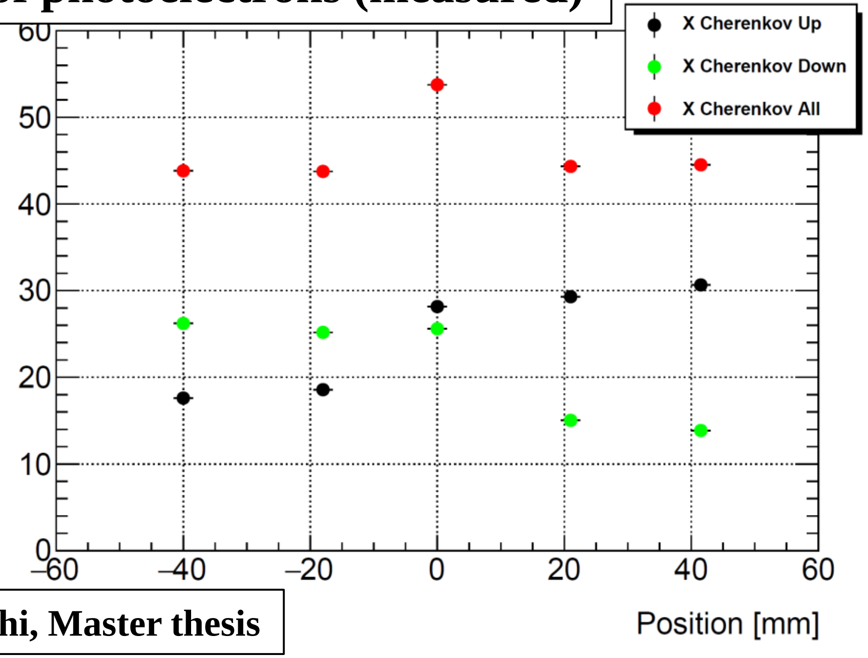


Number of photoelectrons





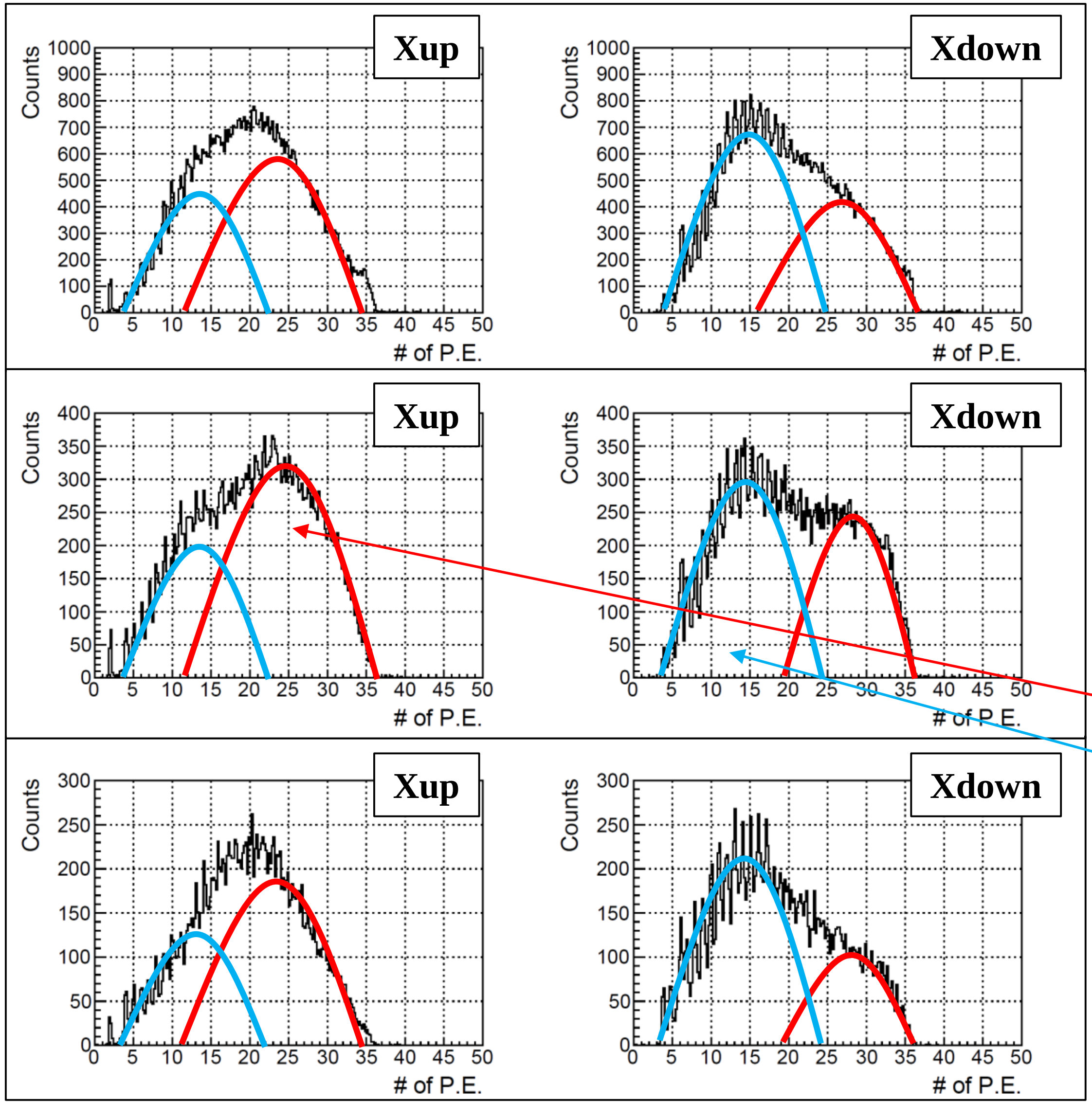
Number of photoelectrons (measured)



T. Akaishi, Master thesis

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

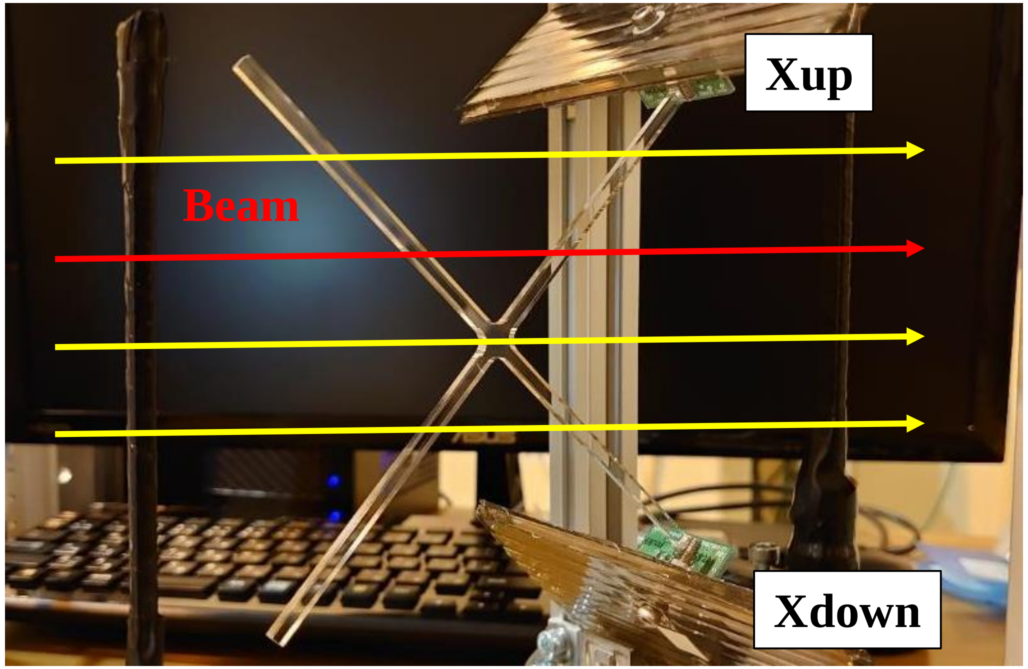
Number of photoelectrons



3.0 mm

1.0 mm

0.5 mm



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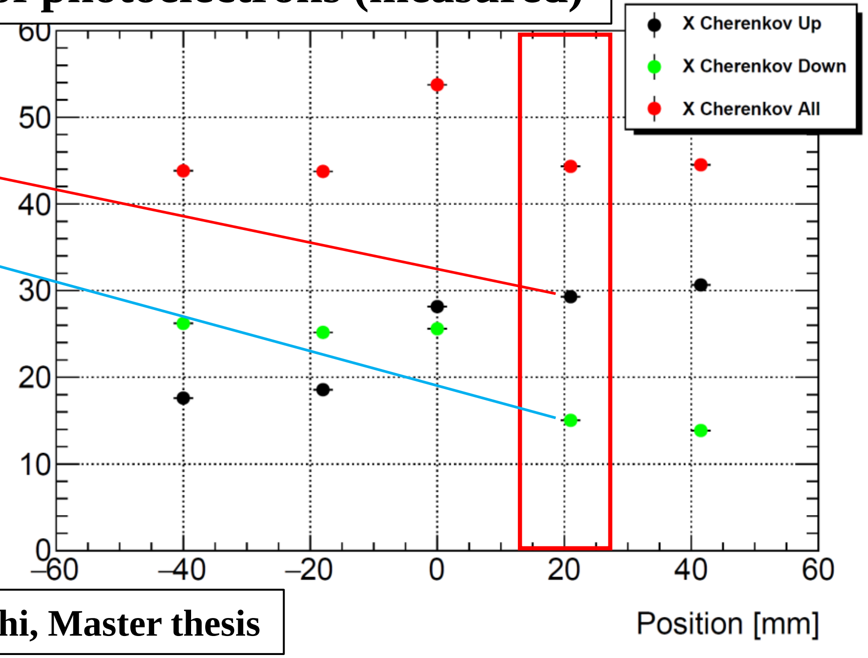

T. Akaishi, Master thesis

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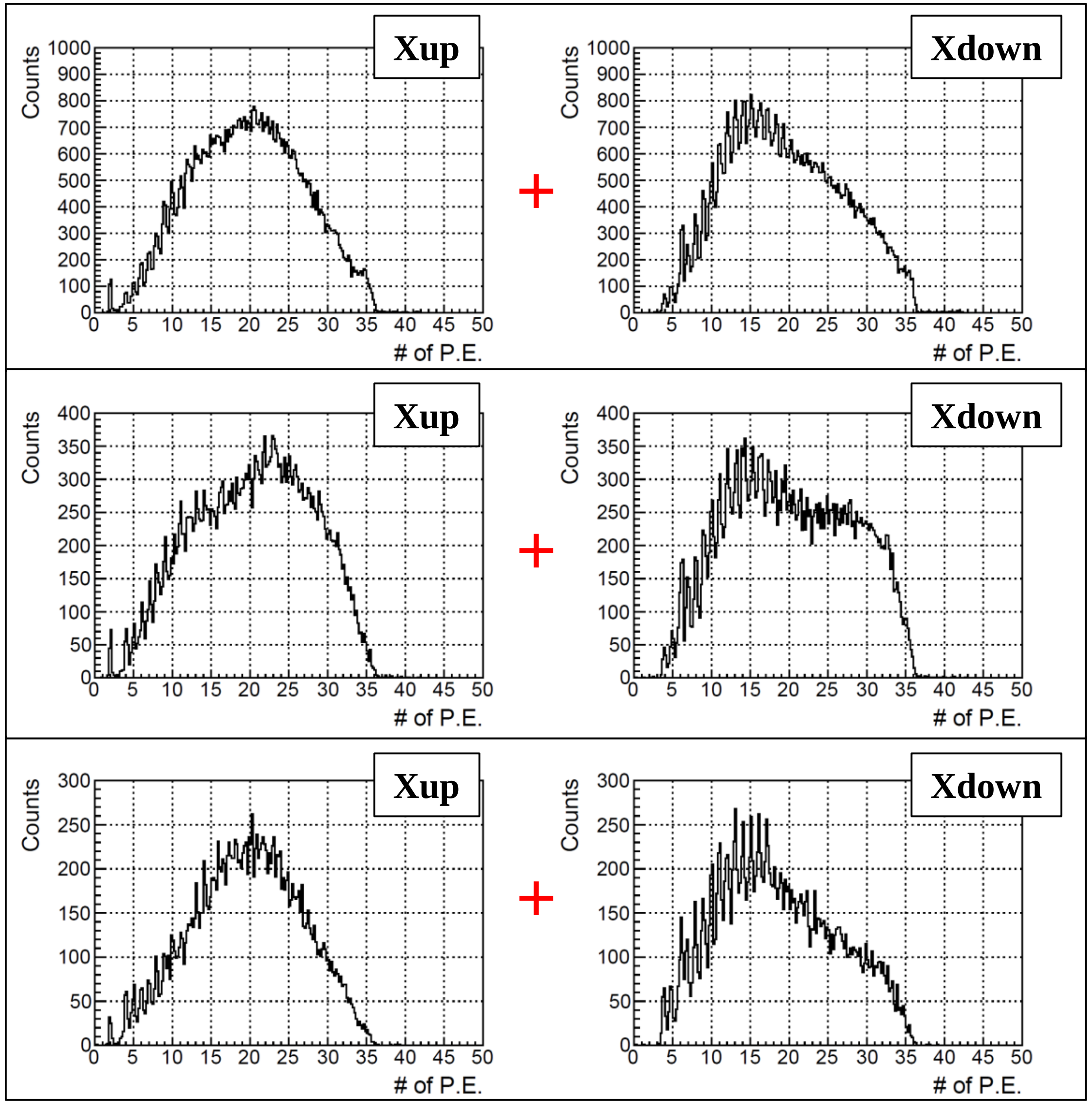
*Handwriting curbs

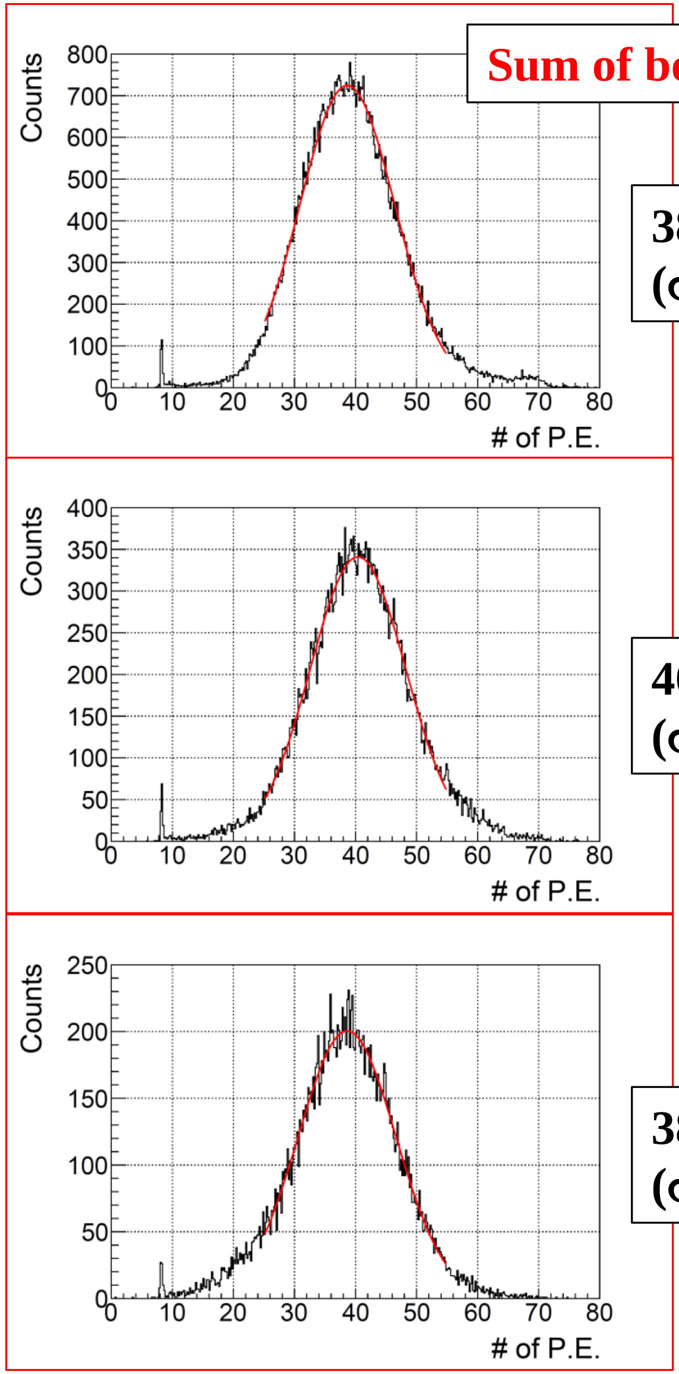
Number of p.e.: @ +20 mm



3.0 mm

1.0 mm

0.5 mm



38.7± 0.4 p.e. (σ = 7.8 p.e.)

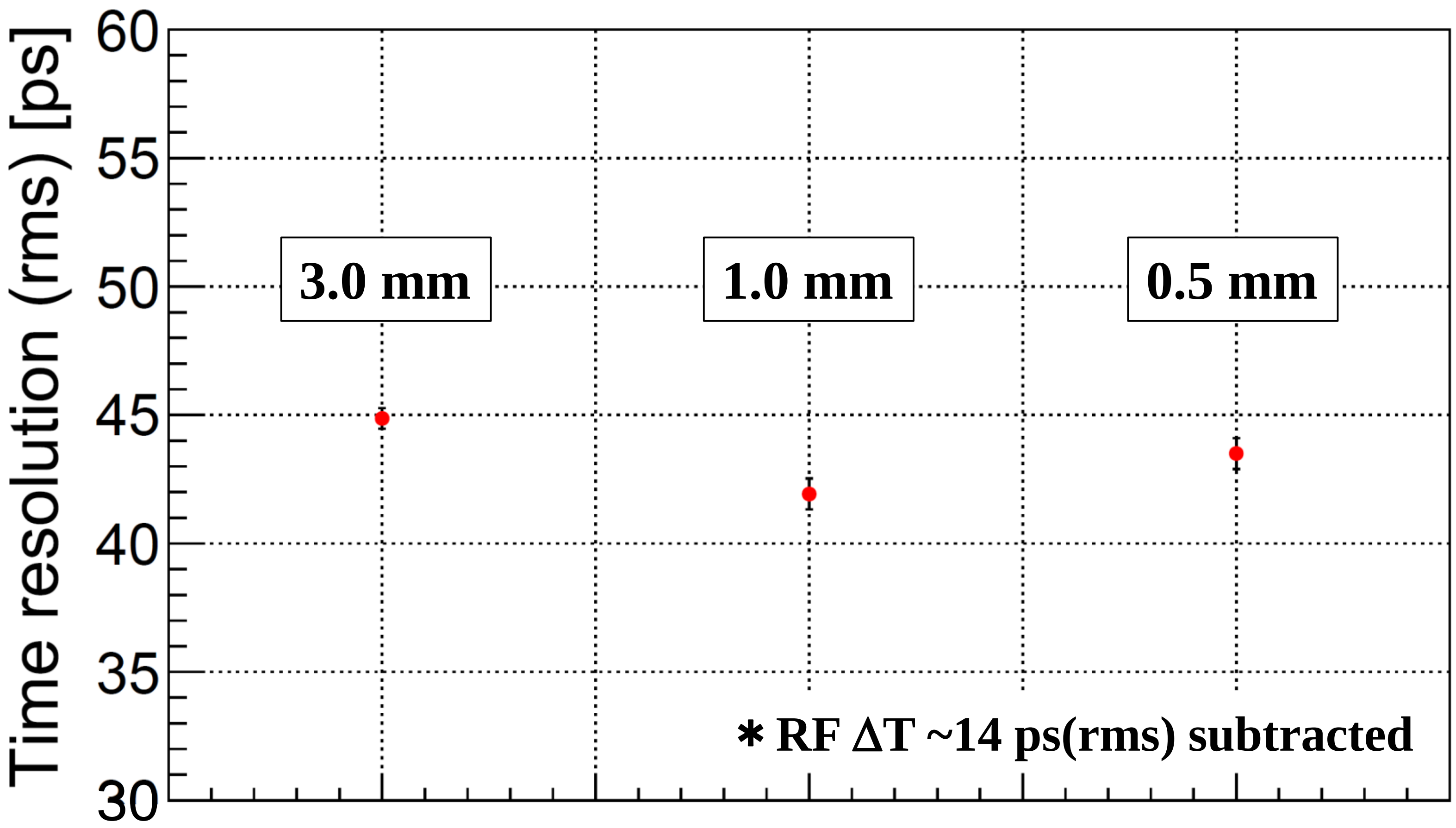
40.4± 0.5 p.e. (σ = 7.8 p.e.)

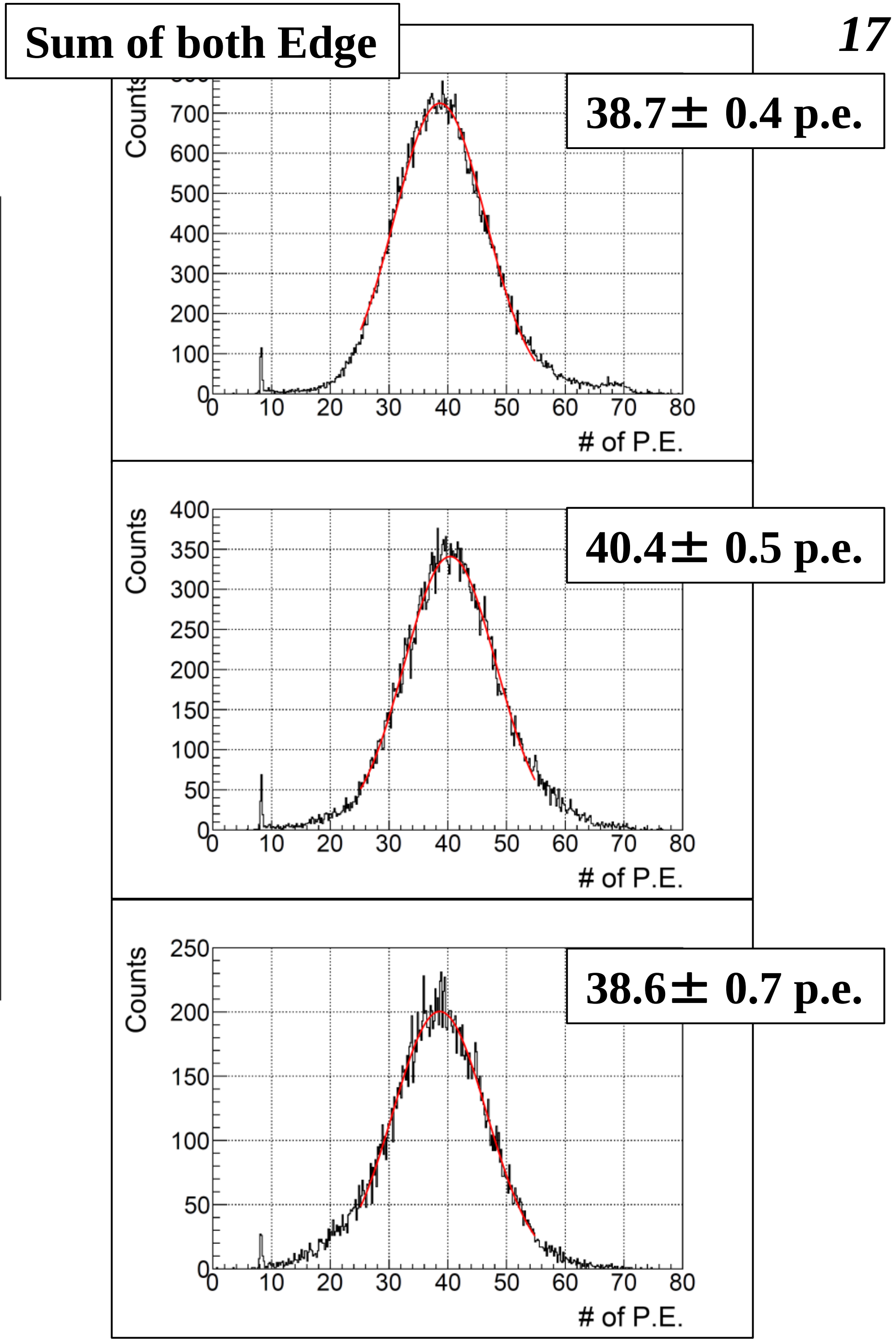
38.6± 0.7 p.e. (σ = 8.0 p.e.)

- Sum of both edge and its distribution are same.

⇒ Collection of Cherenkov lights w/o surface loss

Time resolution: @ Vth = 3.5 p.e.





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

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

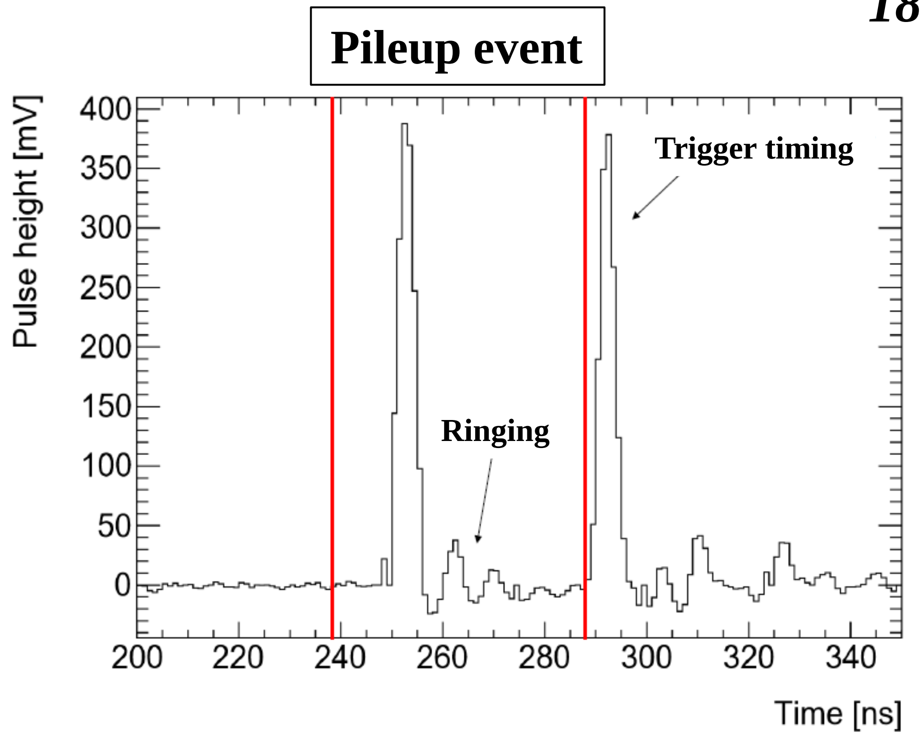
- **3 MHz/3 mm @ 30 MHz ⇒ 3 MHz/0.5 mm @ 180 MHz**

R&D issues of T0 detector

1. Ringing suppression

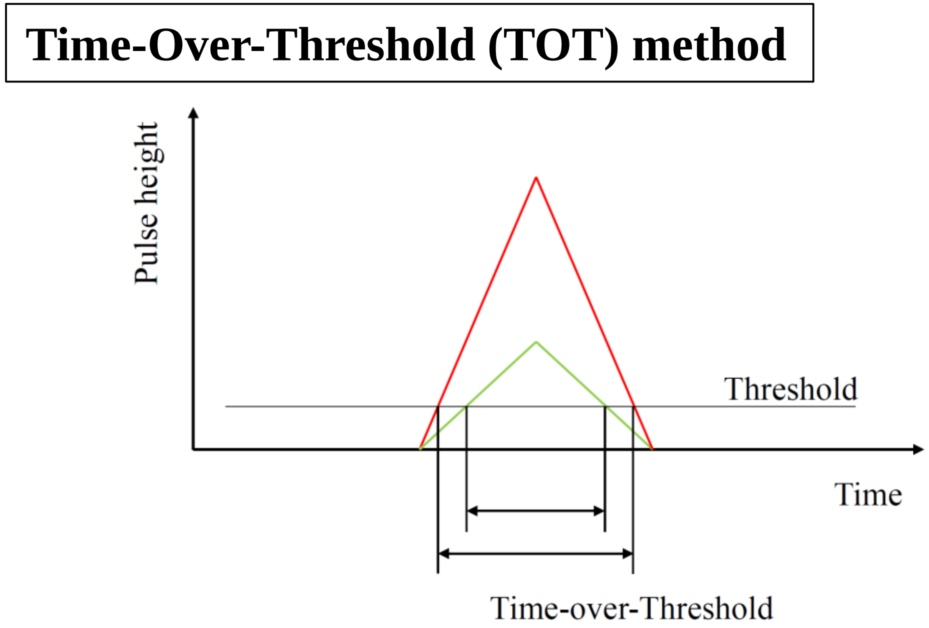
- Effects to time resolution by pile-up signal
  - Time resolution: 43 ps ⇒ 54 ps @ High-rate condition

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



2. TOT measurement

- Time-walk correction
  by Time-Over-Threshold (TOT) method
  - Width = (Leading edge – Trailing edge)
- **Only TDC measurement without ADC**
  - Dead-time less digitalization for streaming DAQ



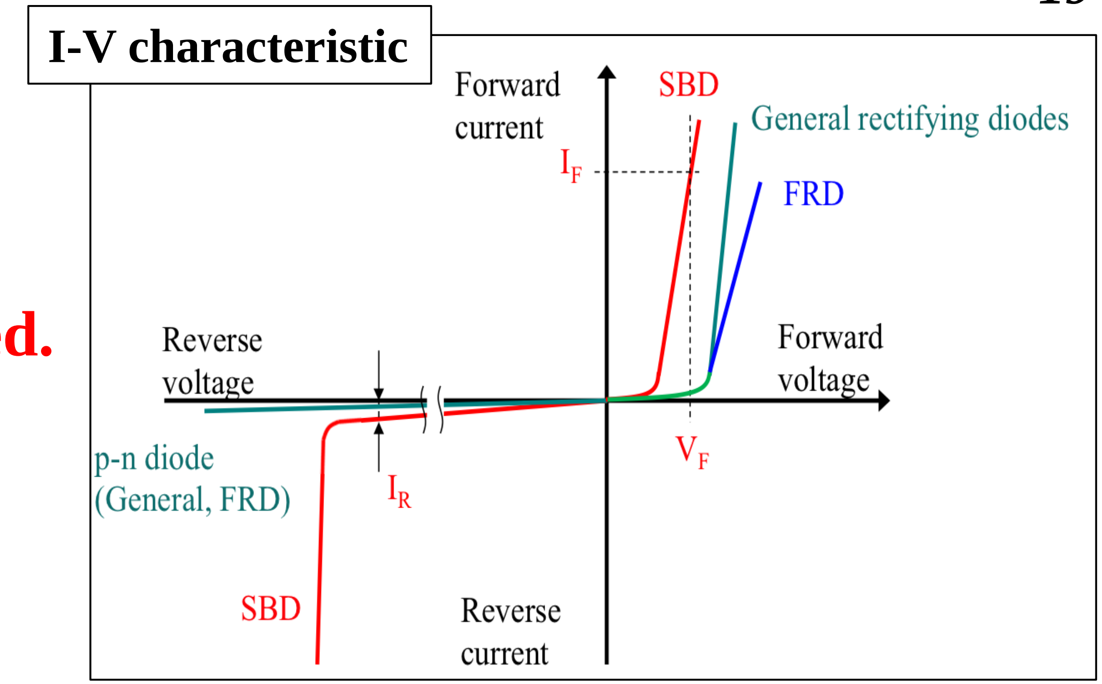
Schottky barrier diode: SBD

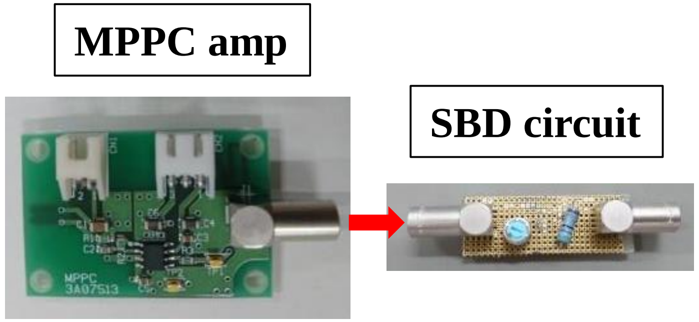
- Kind of rectifier diode
  - Quick responses
  - Smaller forward voltage: 100–200 mV level

＊Revered pulses and smaller pulses are suppressed.

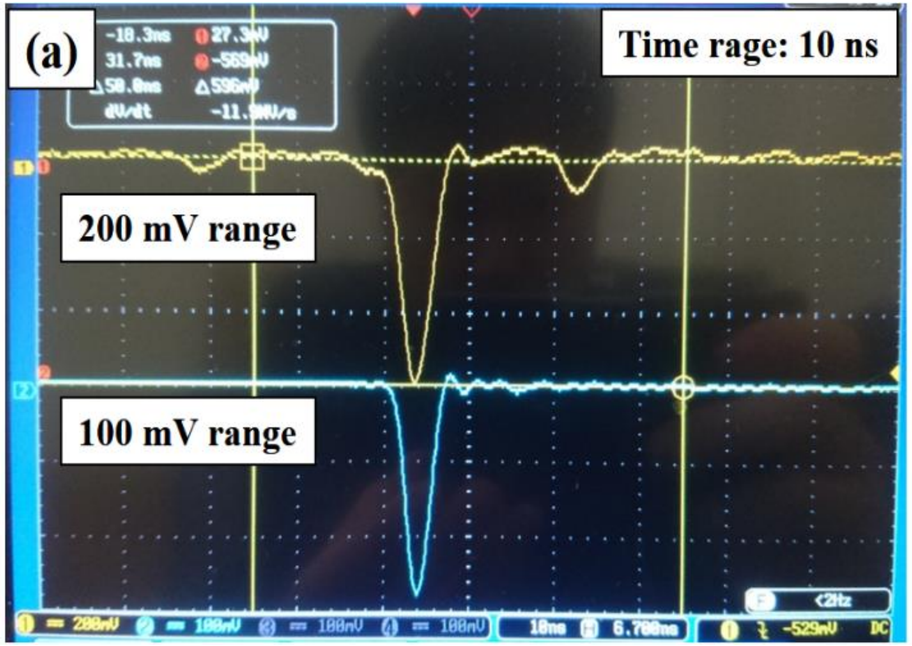
⇒ Ringing suppression

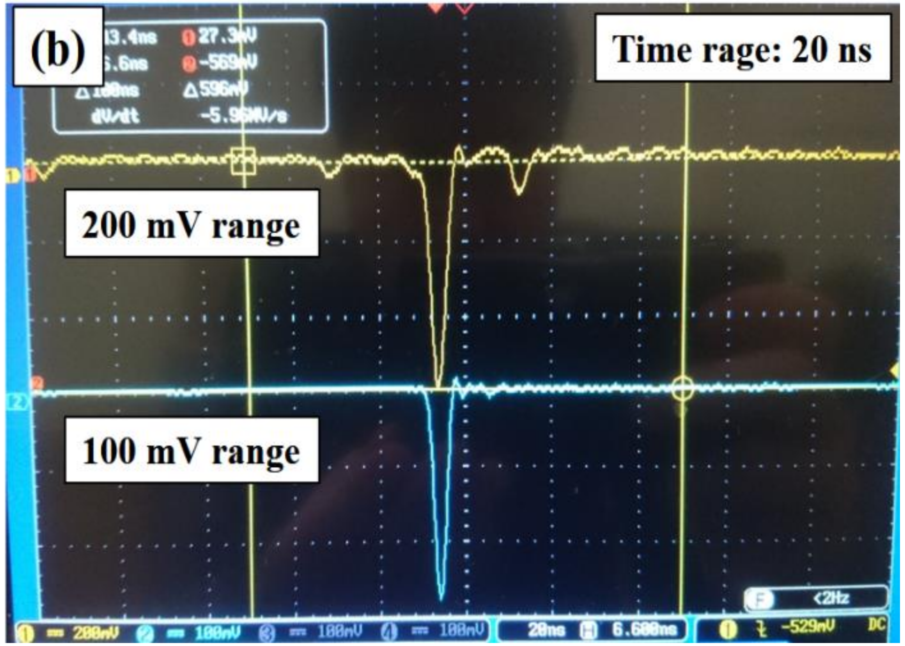
- BAT63: Series connection to amplifier
  - Signals width: Same
  - $V_{out} = 0.62 \times (V_{in}) - 70.0$ (Minimum input: ~120 mV)



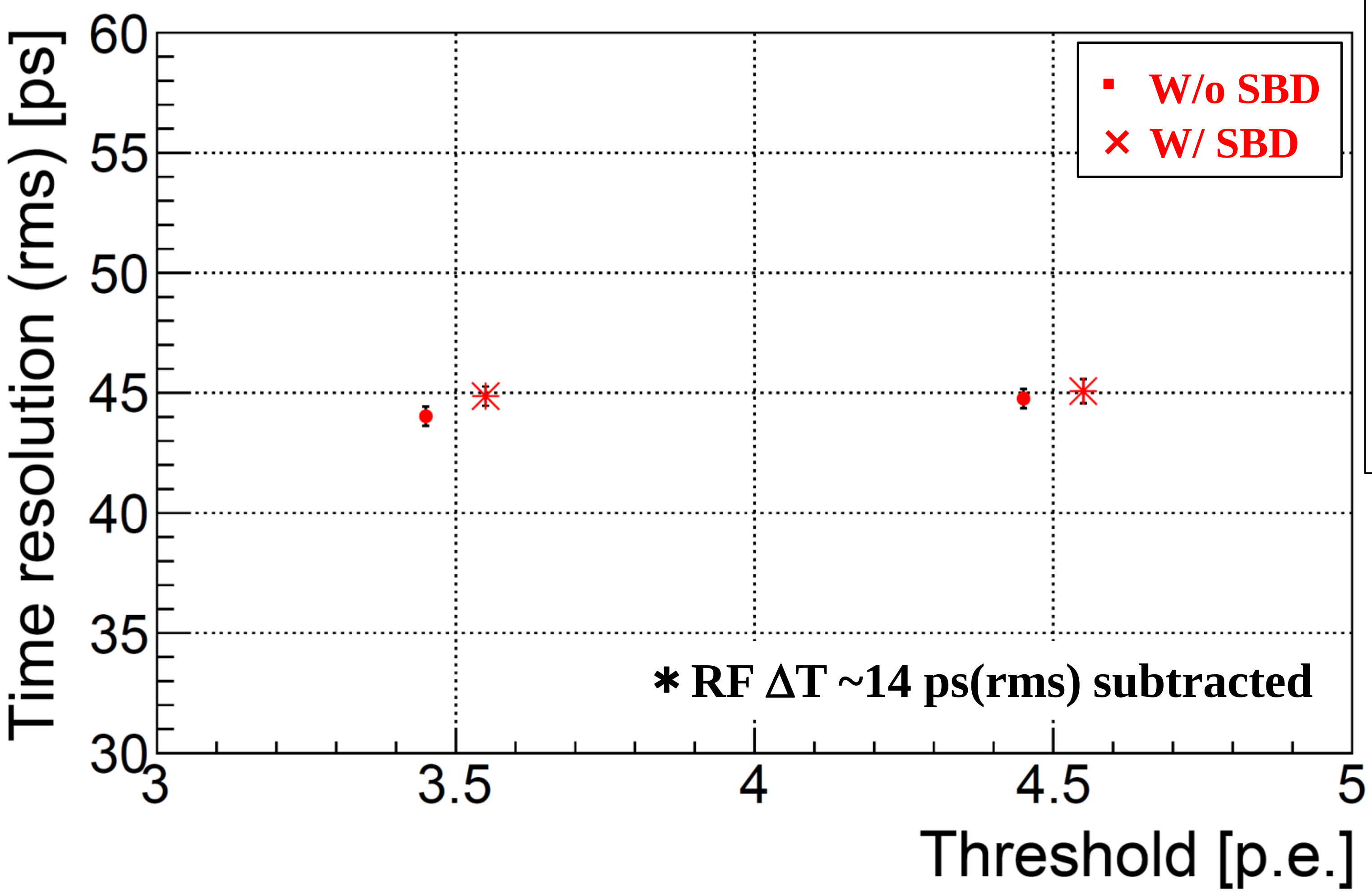


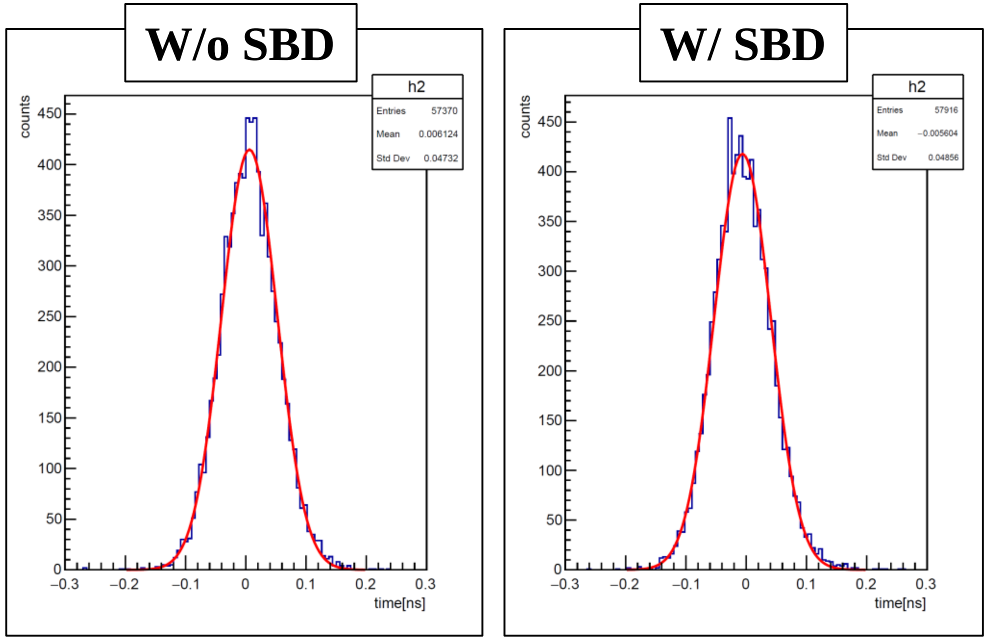
Series connection



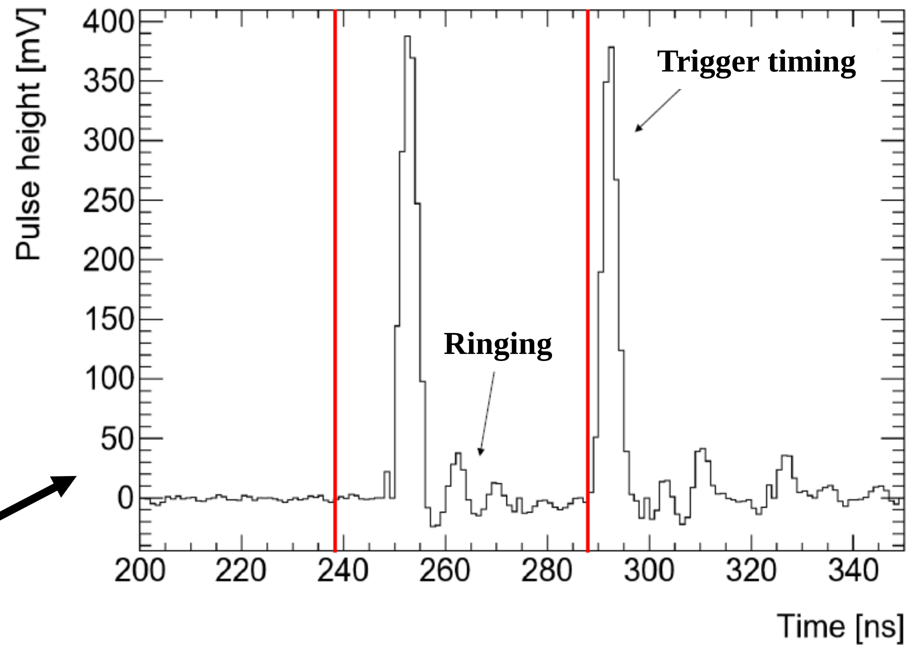


Time resolution: W/o and W/ SBD





∗ Horizontal axis: ±0.3 ns



- **Similar time resolution of ~45 ps(rms).**
  - **W/ SBD data showed little worse resolution.**
  - **Smaller pulse height affected by noise**
- **SBD can be used as filter circuit. ⇒ High-rate test**

Time-Over-Threshold method

- Straight forward method cannot correct time-walk of leading edge.
  - Differential circuit for narrow signal width

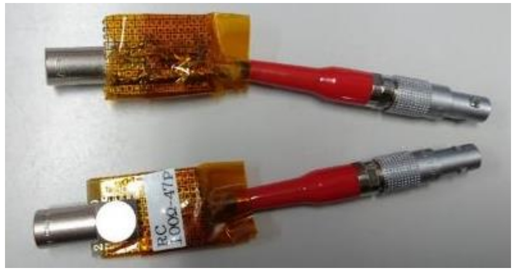
  ⇒ Width is saturated in the higher pulse height region.

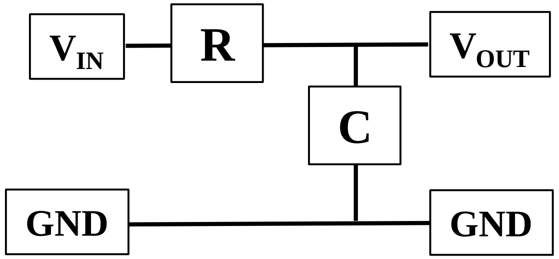
＊Extract pulse height information from width

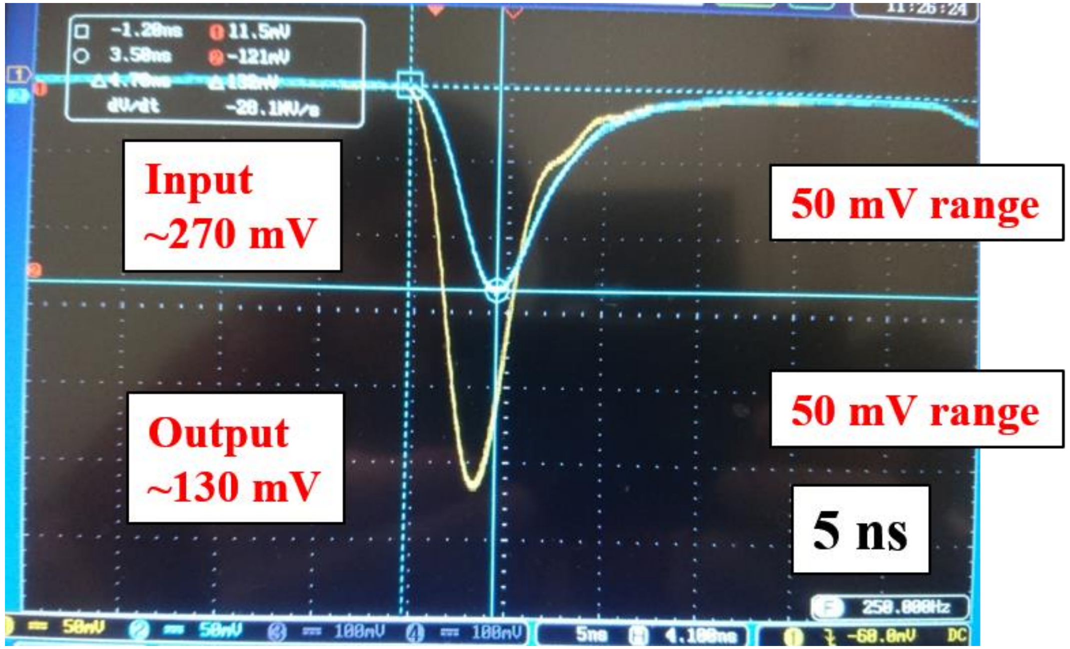
⇒ Integration by slow shaping

- **SBD + slow shaping is essential.**

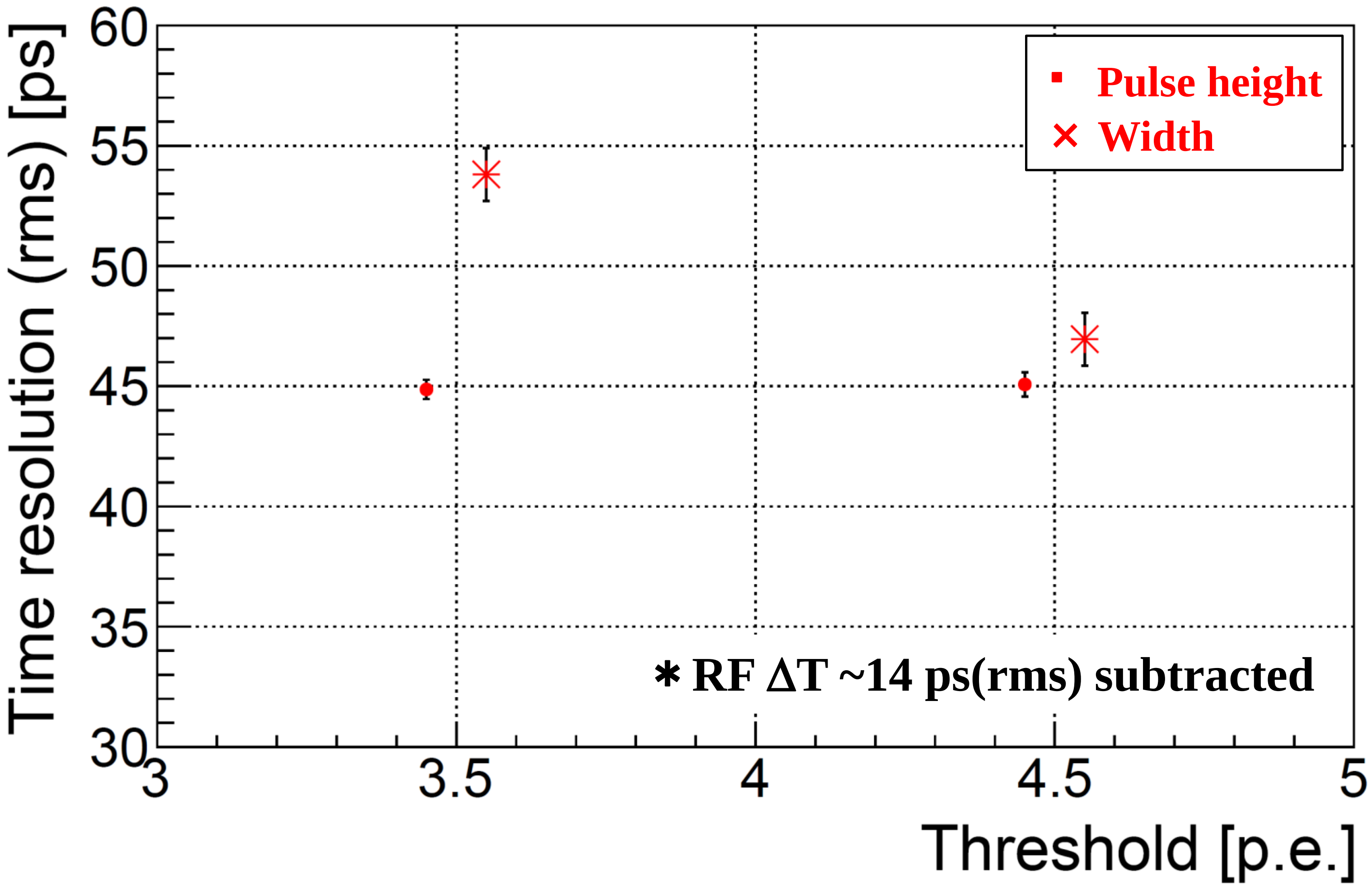
- RC integration circuit
  - τ = 2.4 ns
    - R = 51 Ω, C = 47 pF
  - Signal width: ~15 ns
    - Original: ~10 ns



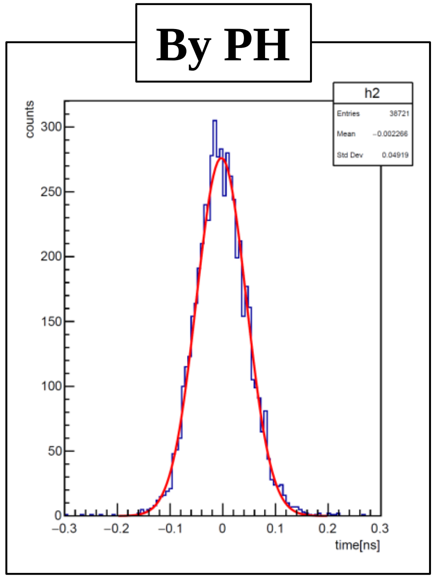


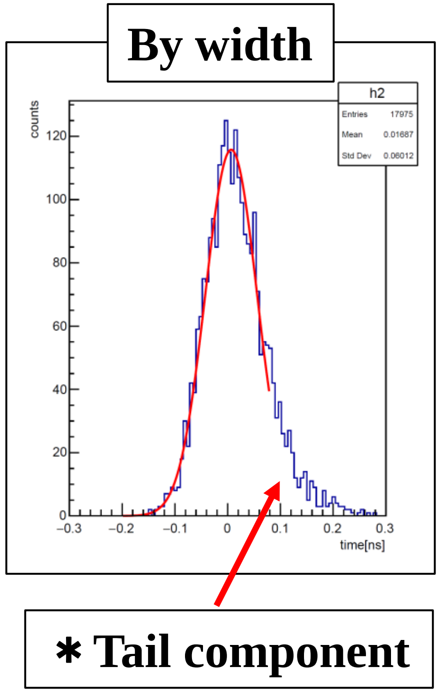


Time resolution: TOT method



* Vth = 3.5 p.e. data
⇒ Correlation is almost same as of Vth = 4.5 p.e. data.
⇒ It is necessary to investigate.





- **Width analysis showed similar resolution. @ Vth = 4.5 p.e.**
  - **Response is not completely understood by using amplifier w/ SBD and RC circuit.**

  ⇒ **Investigation of optimum time constant**

To do

＊To finalize R&D and production of Cherenkov beam timing detector

- **Tests in early 2020 are affected by COVID-19.**
  - **Segmented detector test by EMPHATIC @ Fermilab (Postponed by November)**

  ⇒ Test at other facilities (LEPS, ELPH ?)
  - **High-rate test @ ELPH ⇒ It will be performed in July(?) or October (?).**

  + Test by mixed signal: Emulate pile-up events

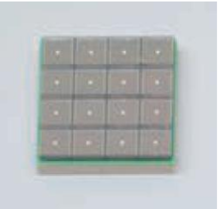
- **Investigate and optimization of filtering circuit**
  - **SBD and RC circuit**

- **Design of actual detector**
  - **Segment width size adjustment for beam profile**
  - **Simulation study for fixing radiators with good filling rate**
  - **MPPC array (TSV type) for assembling fine segments**

- **Publication plan**
  - **X-shape Cherenkov detector: 1st draft is under preparation.**
  - **High-rate measurement: Signal processing, TOT and so on**

8 ch MPPC board

TSV MPPC array (1 mm)



Summary

- **Investigation of effective degree of freedom for hadrons**
  - **Systematic study: Charmed baryon ⇔ Ξ and Ω**

- **K^- beam @ J-PARC High-p beam line**
  - **High-intensity K^- beam ⇒ Dominant π in unseparated beam**
  - **High-rate capability of beam timing detector: Fine segment beam detector**

- **R&D of Cherenkov timing detector**
  - **X-shape Acrylic radiator with thin width: 0.5 mm, 1.0 mm, 3.0 mm**
  - **Test experiment @ LEPS**

  ⇒ Time resolutions of ~45 ps(rms) were kept by using fine segment radiators.
    - **Availability of much higher counting rate beam: ×6 higher rate**
    - **3 MHz/3 mm @ 30 MHz ⇒ 3 MHz/0.5 mm @ 180 MHz**
  - **Filtering method test for suppressing ringing effects by SBD**
    - **High-rate test is necessary for finalizing R&D.**
  - **TOT method test: SBD + Integration circuit**
    - **It was found that measurement without ADC can be performed.**

＊To finalize R&D and production of Cherenkov beam timing detector
- **K^- beam intensity is as high intensity as possible at J-PARC high-momentum beam line.**

⇒ To drive investigation of multi-strangeness baryons