A feasibility study of the reflection readout method of RPC

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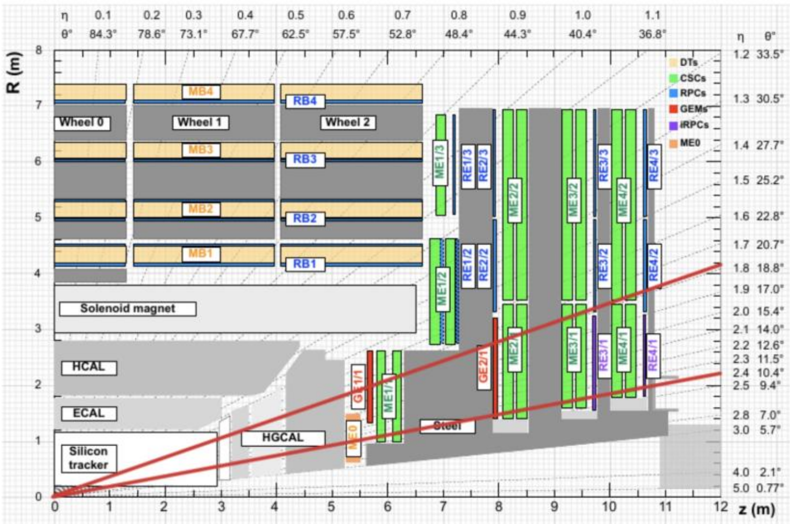
Outline

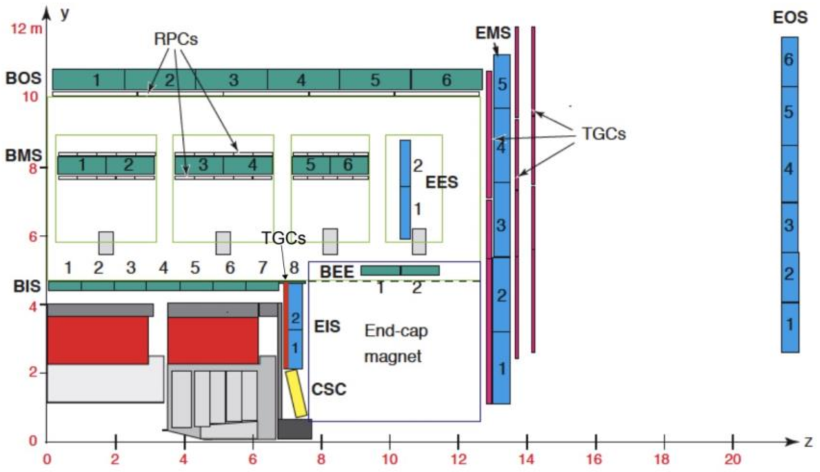
- Introduction
  - RPC in HEP experiment
  - three readout methods of RPC
  - feasibility study for reflection readout method
- Experimental setup
- Data analysis
  - waveform analysis
  - efficiency
  - transmission velocity
  - spatial Resolution
- Summary

RPC in HEP experiment

- RPC advantages
  - high trigger efficiency
  - affordable for large trigger areas
  - high geometrical acceptance
  - effective reconstruction of the 2D position
- RPC in LHC
  - used mainly as muon trigger detectors
  - CMS: total surface area of ~ 3500 m ^{2}
    - used in barrel region and end-caps region
    - nearly cover all the regions of the muon stations
  - ATLAS: total surface area of more than 4000 m ^{2}
    - 384 muon stations that contain RPCs
    - ~ 370k channels



A r-z cross section of a quadrant of the CMS detector (RBs and REs = RPCs)

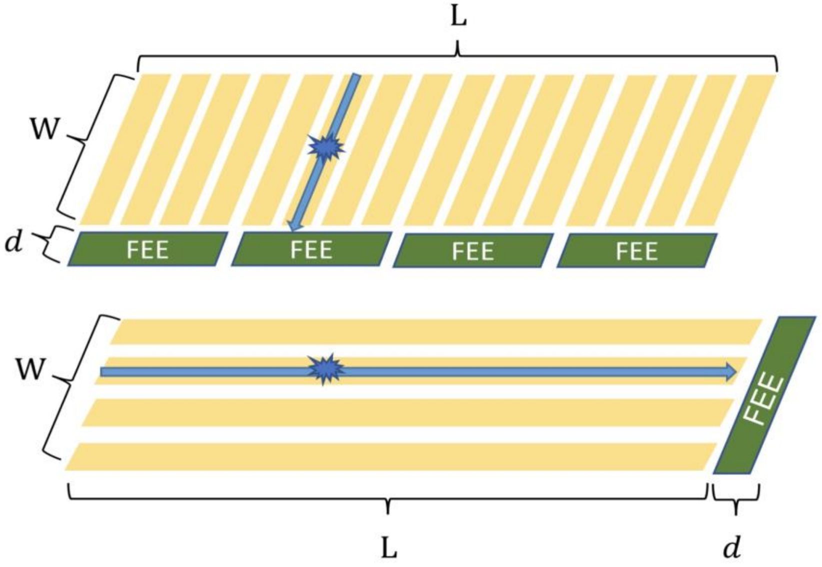


A z-y plane section of ATLAS MS layout

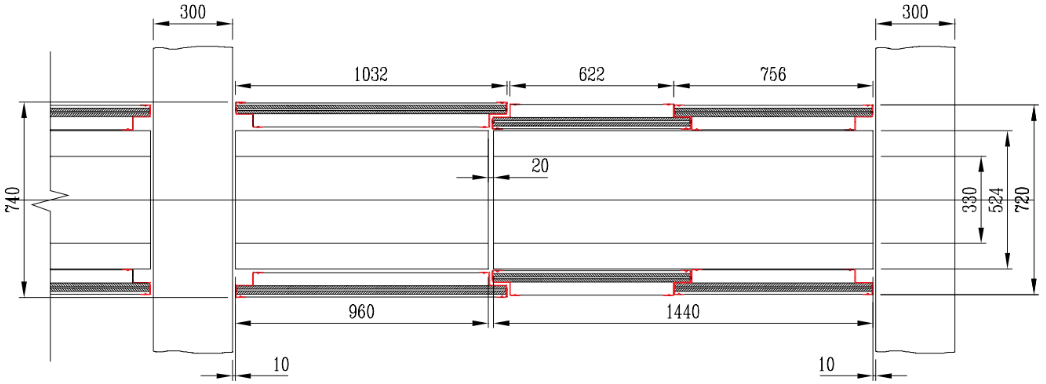
Traditional readout method

- Traditional readout method
  - two sets of orthogonal readout strips
    - find fired strips to reconstruct the 2D hit position
  - chamber geometrical acceptance r
    - $\mathrm{d, W, L} = 50, 500, 2000$ mm (typical RPC design)
    - $r = \frac{L}{L+d} \times \frac{W}{W+d} = 88.7\%$
- How to increase acceptance in experiments
  - overlapping can eliminate the factor $\frac{W}{W+d}$
    - $r = \frac{L}{L+d} = 97.5\%$
  - **in the case of insufficient space budget**
    - decrease FEE areas of one singlet

propose new readout schemes



scheme of the traditional RPC readout method

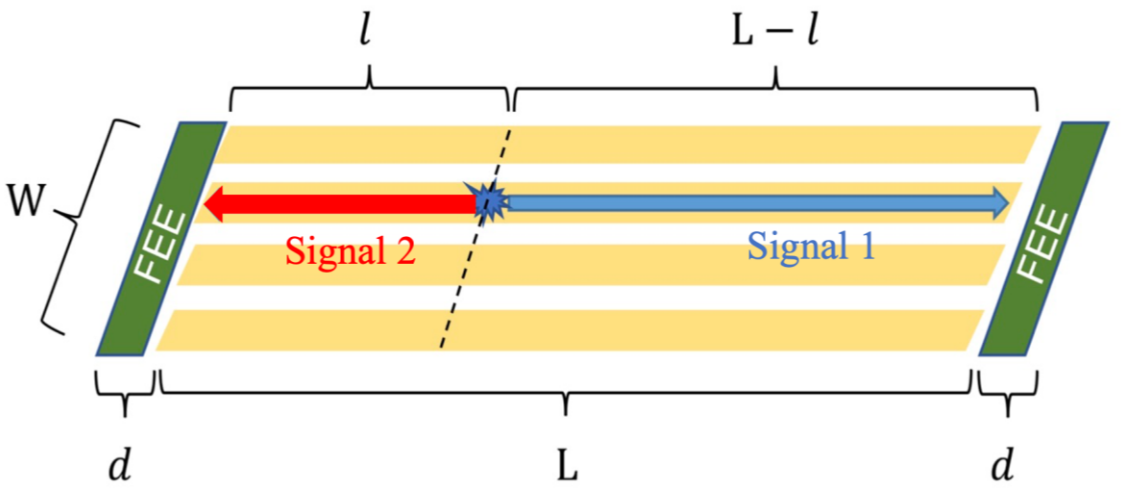


chambers partially overlapped along the z direction

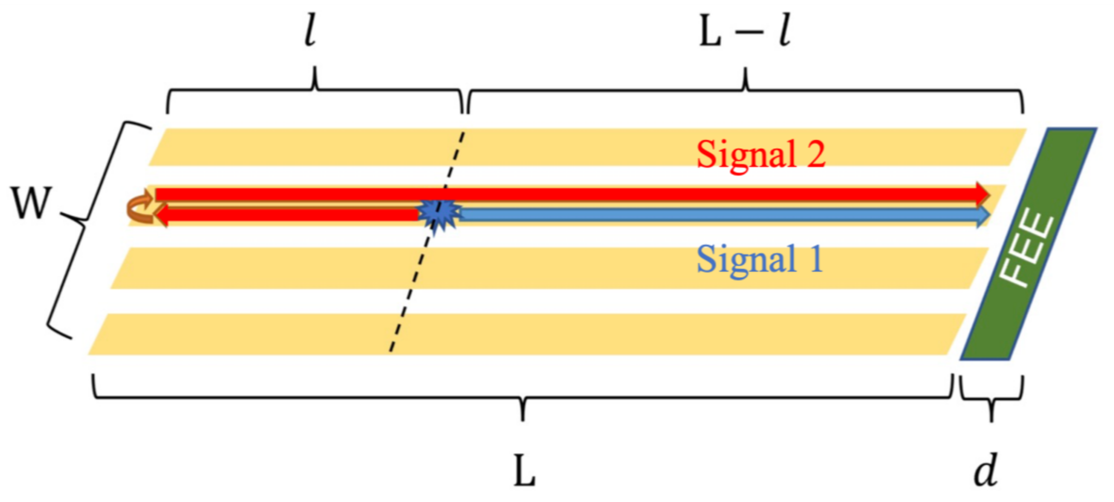
New Readout Methods for RPC detectors

- Double-end readout method
  - from time to position
    - time difference of two signals indicates the hit position
  - an increase in geometrical acceptance
    - $r = \frac{L}{L+2d} = \mathbf{95.2\%}$

- Reflection readout method
  - inspired by the double-end readout method
  - use the principle of signal reflection
  - a further increase in geometrical acceptance
    - $r = \frac{L}{L+d} = \mathbf{97.5\%}$



schematic diagram of double-end readout method



schematic diagram of reflection readout method

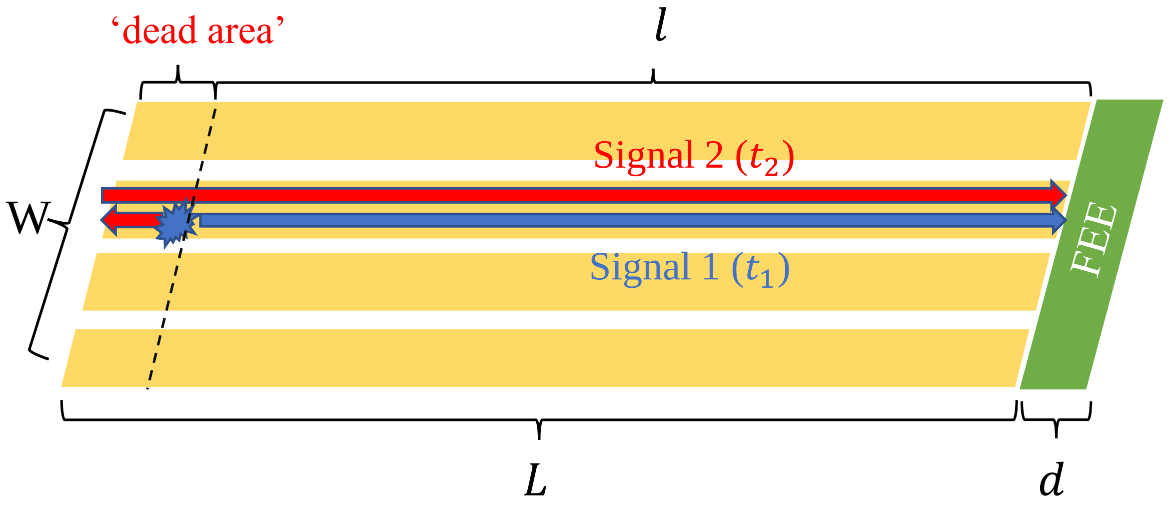
Feasibility study for reflection readout method

$$t_1 = \frac{l}{v},\ t_2 = \frac{2L - l}{v}$$

$$t_{diff} = t_2 - t_1 = \frac{2(L-l)}{v}$$

$$if\ l \rightarrow L,\ t_{diff} \rightarrow 0$$

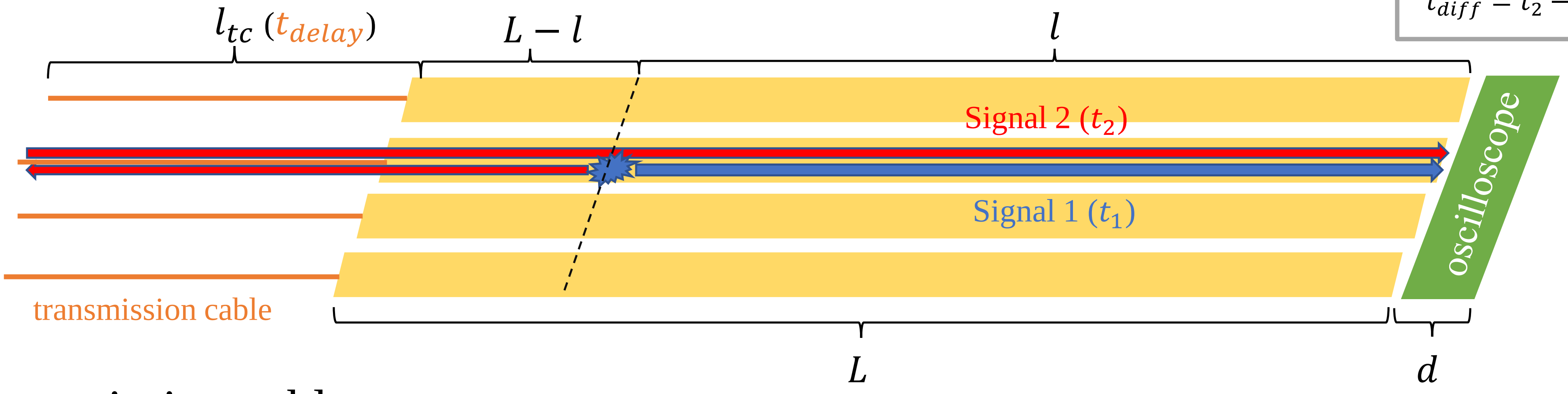
- Limitation
  - ‘dead area’
    - when a muon hits some area away from the FEE end, time difference of the two signals is too short to be distinguished.
  - theoretical length : $l_{dead} = \frac{v \times FWHM}{2} = \frac{210mm/ns \times 1.22\ ns}{2} = 128\ mm$
    - v, $FWHM$: typical propagation velocity and $FWHM$ of RPC signals
- A possible solution
  - introduce transmission cables
- Feasibility study content
  - signal quality
  - efficiency
  - spatial resolution



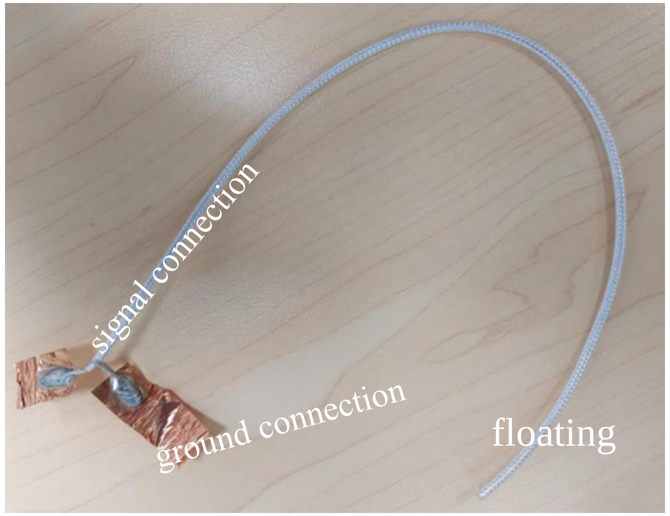
Reflection readout scheme

$$t_1 = \frac{l}{v},\ t_2 = \frac{2L-l}{v} + t_{delay}$$

$$t_{diff} = t_2 - t_1 = \frac{2(L-l)}{v} + t_{delay}$$



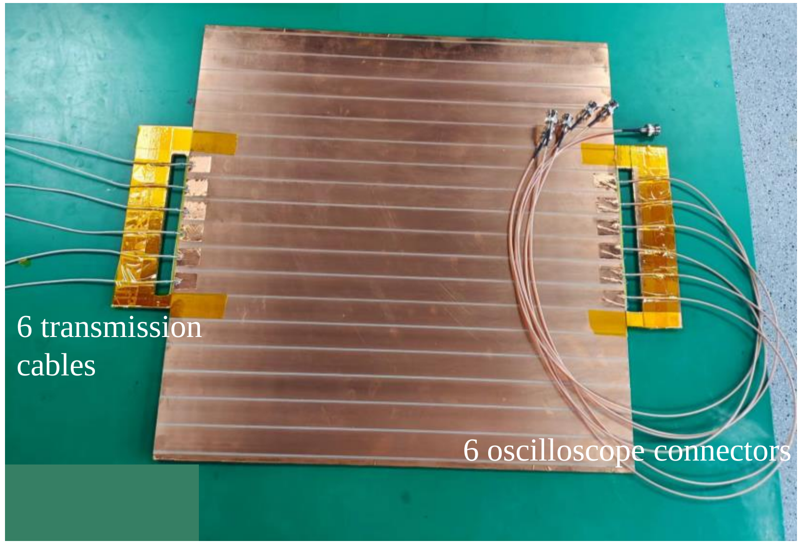
- Transmission cable
  - <u>**act as delay line**</u>
    - formation of delay time (t_{delay})
    - distinguish Signal 1 and Signal 2
  - floating, signal full reflected
  - flexible / little space occupation
  - <u>**customized with special characteristic impedance**</u>
    - to match the characteristic impedance of readout strips --- **20 Ω**
- From time to position
  - $(t_{diff} - t_{delay}) = 2(L-l)\ /\ v$ t_{diff}: time difference of two signals



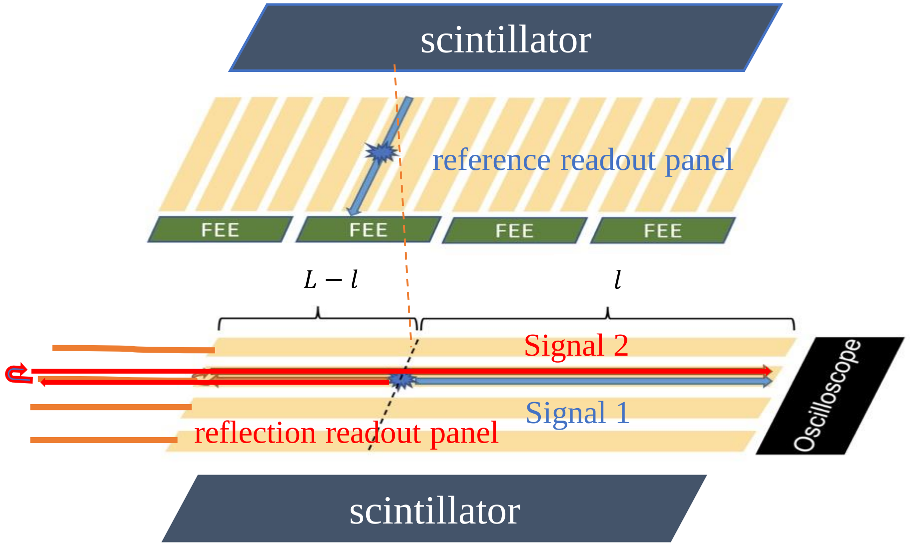
transmission cable

Experimental setup 1

- RPC : 0.5 m * 0.5 m
  - one gas gap (bakelite)
  - two orthogonal readout panels
    - top panel for reference position
    - bottom panel for reflection readout
- Six transmission cables
  - length: 40 cm
  - characteristic impedance : 20 Ω
- Two scintillators
  - provide trigger of the signal
- DAQ setup
  - sampling ADC
    - record signals on reference readout panel
  - an oscilloscope
    - record Signal 1 and Signal 2 on reflection readout panel
    - **probe on raw waveform directly**
    - **maintain signal integrity**

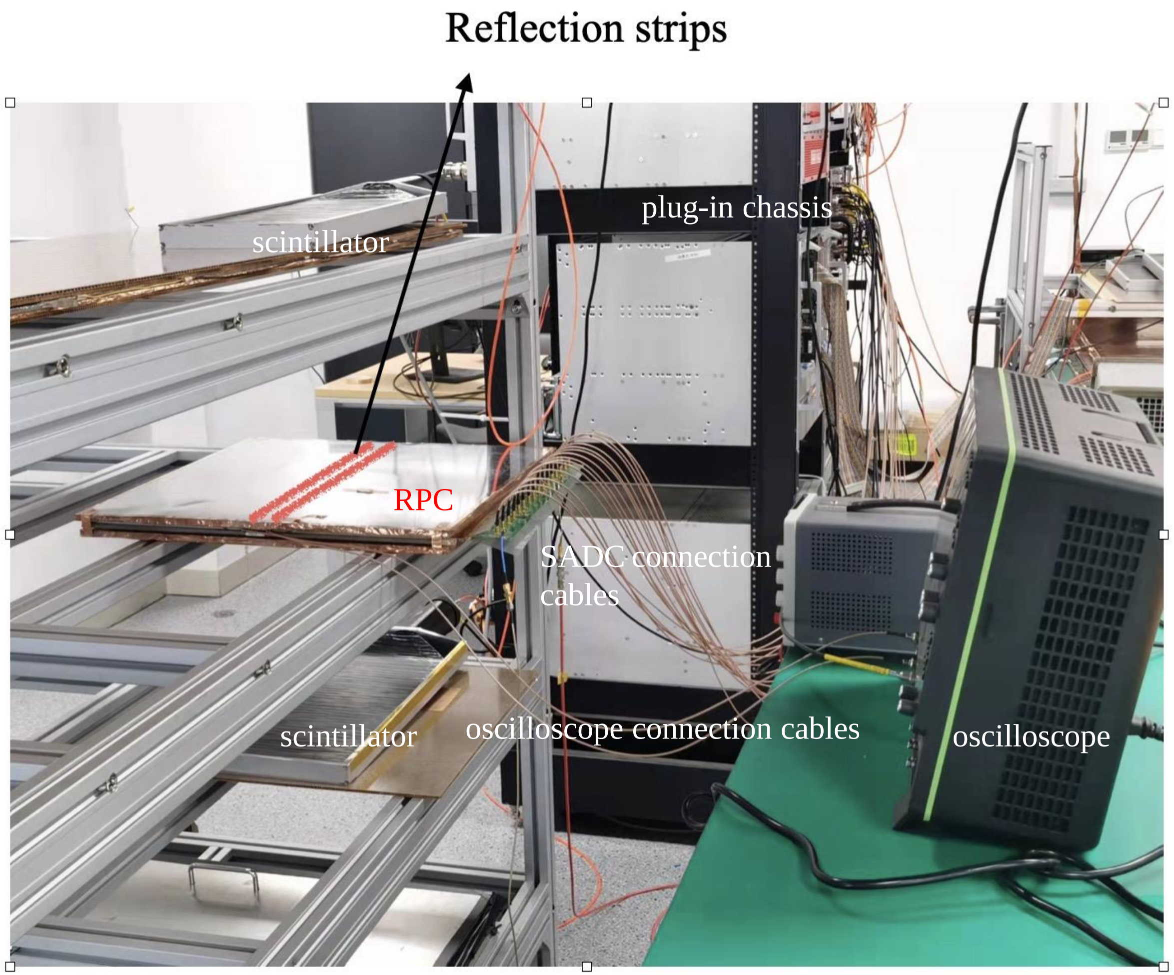


reflection readout panel

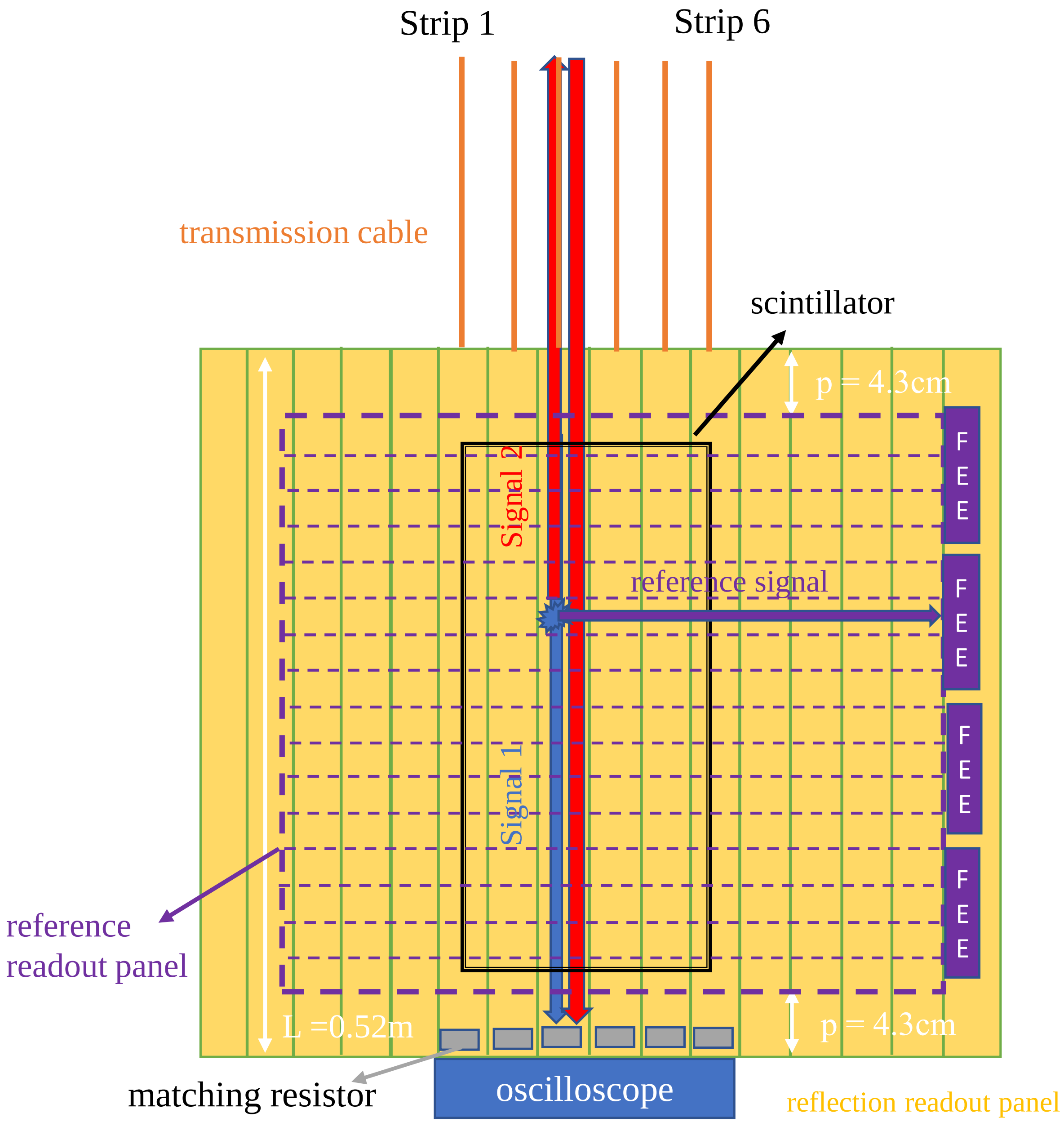


Scheme of reflection readout method

Experimental setup 2

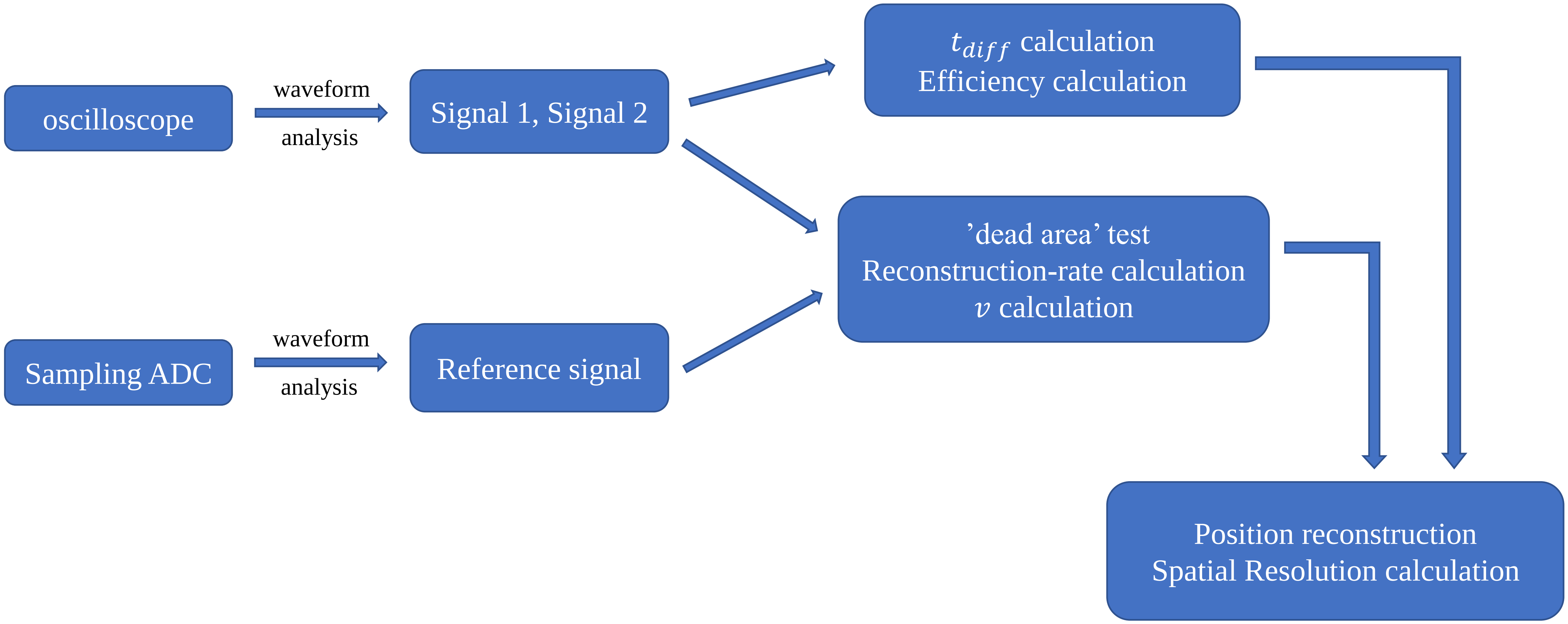


Experimental setup in laboratory



Top view of experimental setup

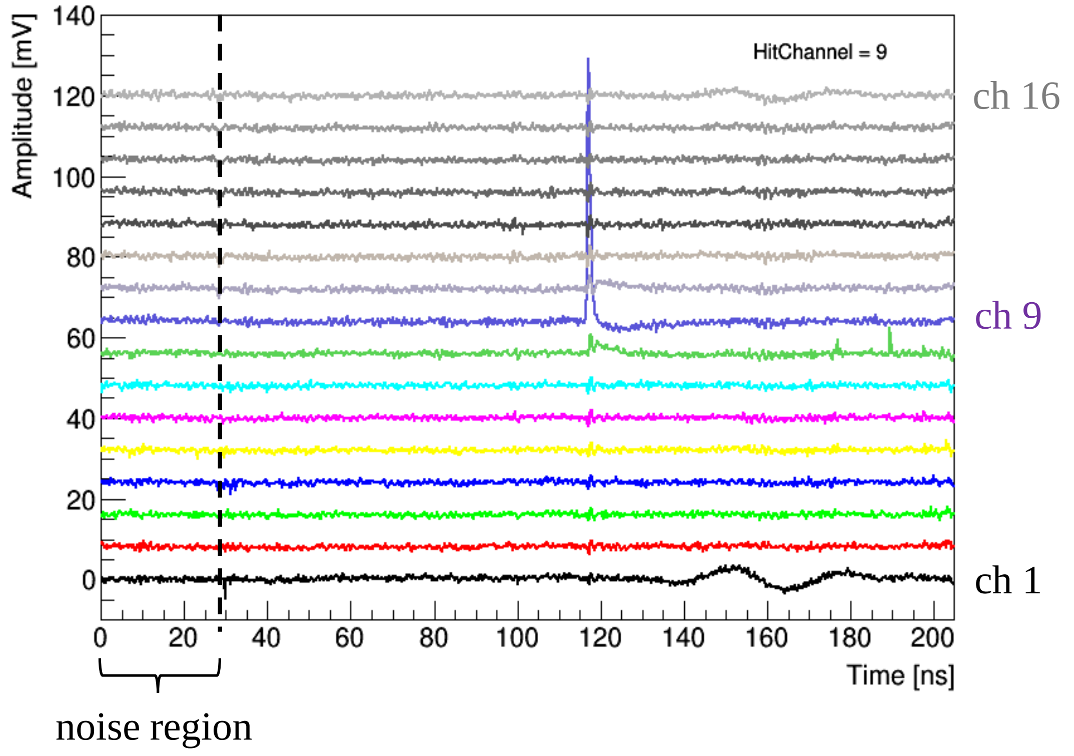
Data analysis process



Waveform analysis ---- reference panel

- Signal on reference panel
  - one positive signal
  - threshold : 5*RMS
    - RMS : RMS of noise (waveform in noise region)
- Reference hit channel selection
  - the channel which has the largest peak value
  - represents the reference position
    - expressed as center of hit channel

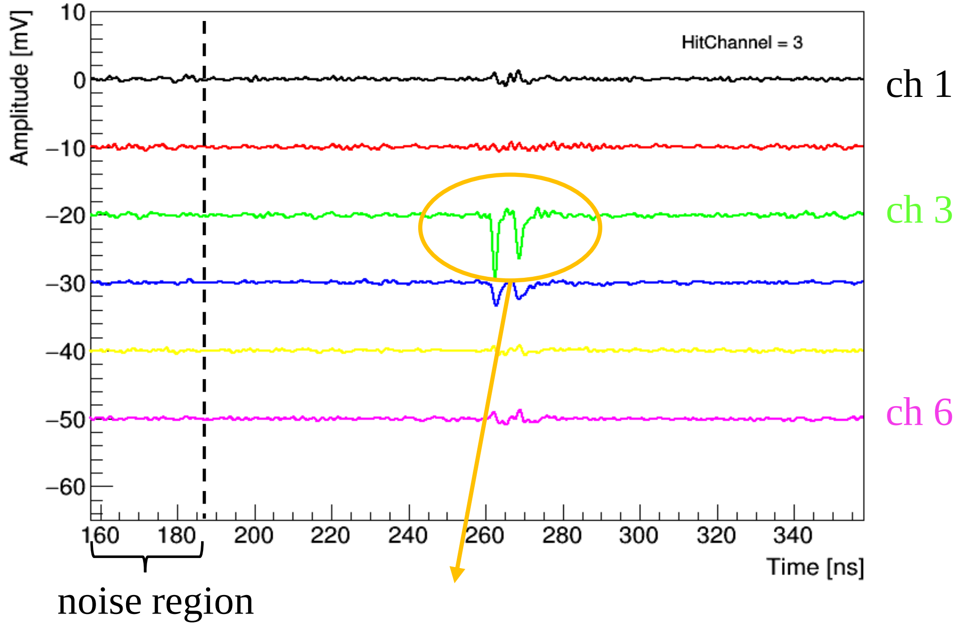
reference panel waveform

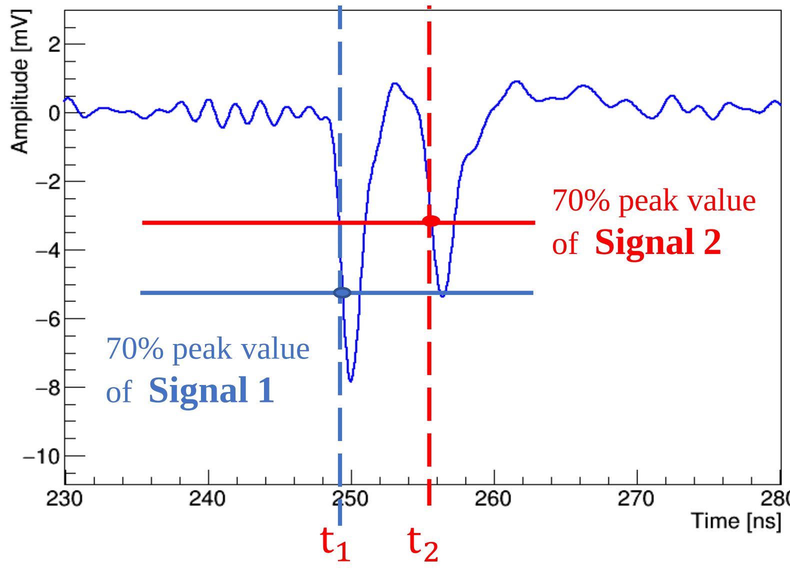


Waveform analysis ---- reflection panel

- Signal on reflection panel
  - two associated negative signals
    - clear, complete
    - no redundant signals
  - threshold : 5*RMS
- Time-difference selection
  - $t_{diff} = t_2 - t_1$
  - amplitude threshold : 70% of peak value
    - we also use other different amplitude thresholds to calculate and compare experimental result further
  - use t_{diff} to reconstruct hit position on readout strip

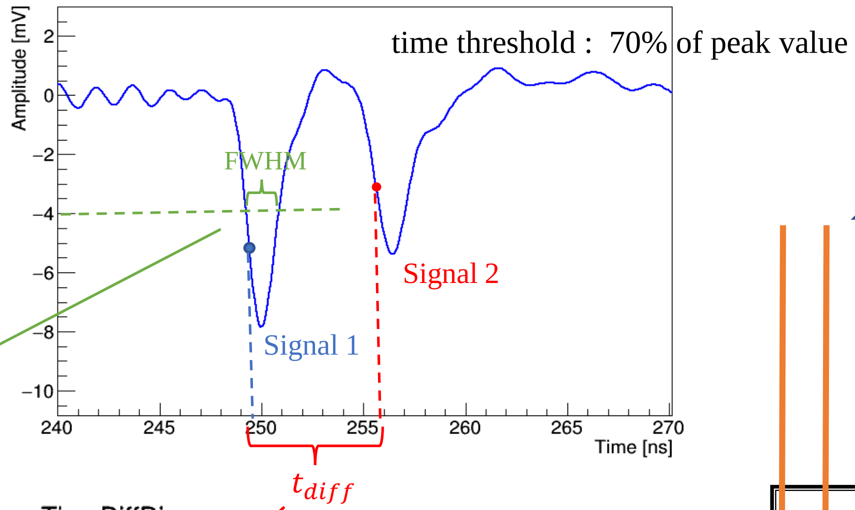
reflection panel waveform

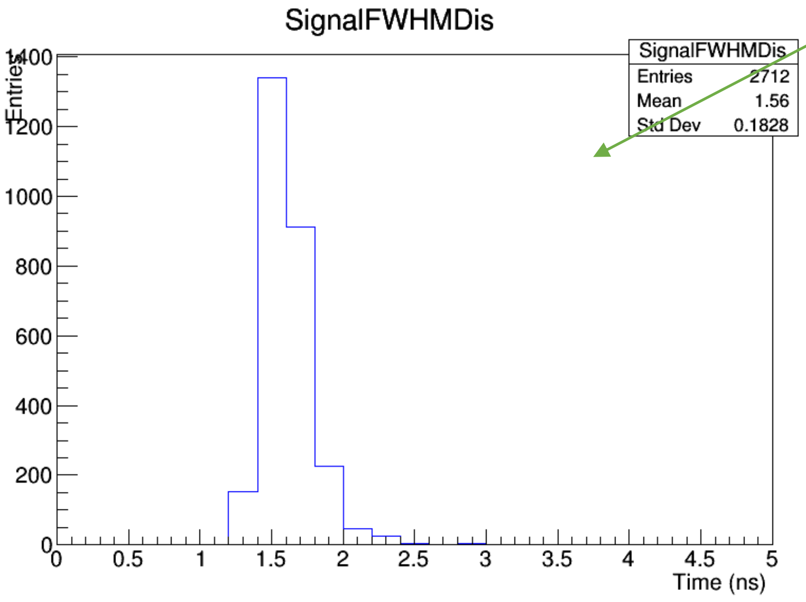




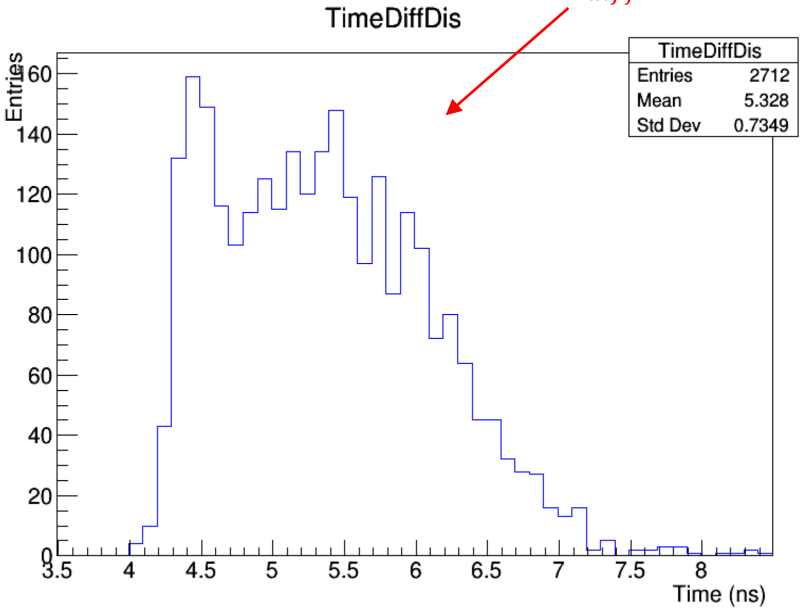
‘dead area’ test

- Test if ‘dead area’ still occurs
  - make scintillators cover the edge of reflection panel which hosts the transmission cable
  - compare the FWHM of Signal 1 and the time difference between the two signals

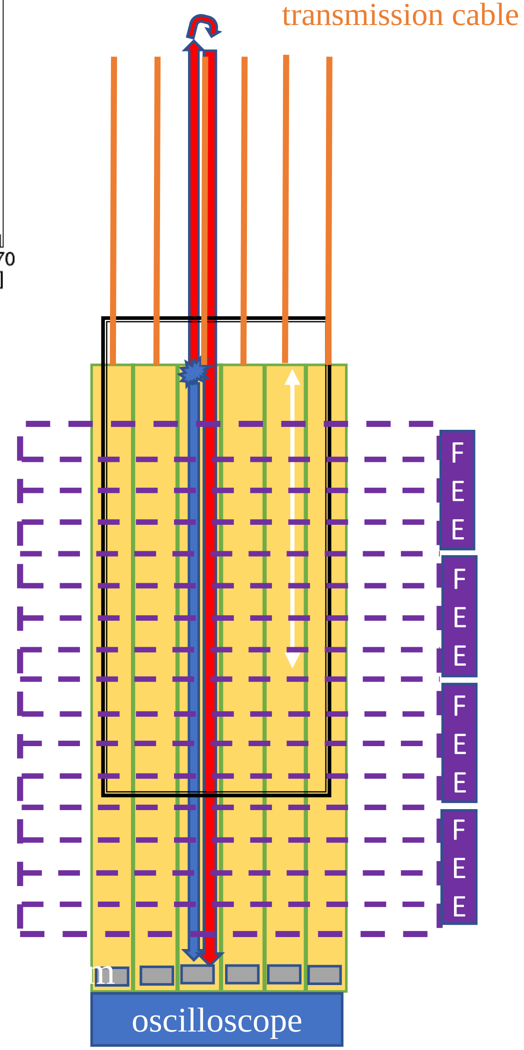




FWHM distribution of Signal 1



time difference distribution of two signals



simple schematic diagram of new setup

Time difference of two signals is much larger than FWHM of one signal, we can distinguish two signals by using transmission cable well.

Efficiency

$$Eff = \frac{N_{Signal\ 1\ \&\ Signal\ 2}}{N_{trigger}}$$

$$Recon\_Rate = \frac{N_{Signal\ 1\ \&\ Signal\ 2}}{N_{reference\ signal}}$$

- Efficiency calculation
  - denominator: number of trigger events
    - trigger: coincidence of scintillators
  - numerator : number of events with two signals on the same strip of the reflection readout panel
  - high voltage is corrected by pressure and temperature
    - $HV_{effective} = HV_{nominal} \cdot (1 + \alpha(\frac{p-P_0}{P_0}) \cdot (1 - \beta(\frac{T-T_0}{T_0}))$
    - $\alpha = 0.8, \beta = 0.5, P_0 = 970\ mBar, T_0 = 293.15\ K$
  - Efficiency of reflection readout method is about **92%**.
- Reconstruction rate calculation
  - denominator: number of events with one reference signal
  - numerator : consistent with efficiency calculation
  - with a reference signal, reconstruction rate of reflection readout method can be up to **97%**
    - **losses only from readout method**
- Choose 6000V as test high voltage
  - enter the HV plateau region

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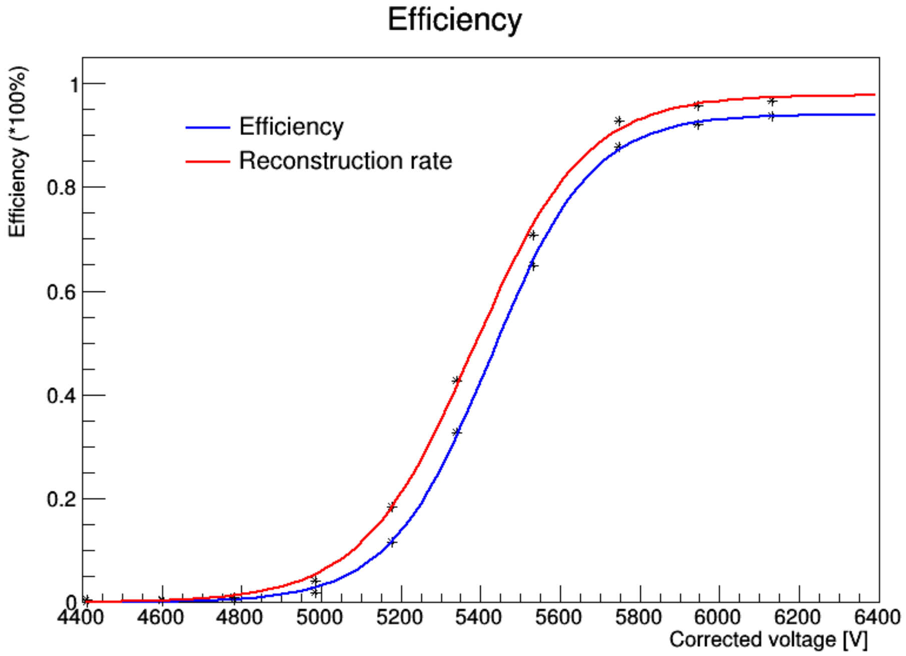
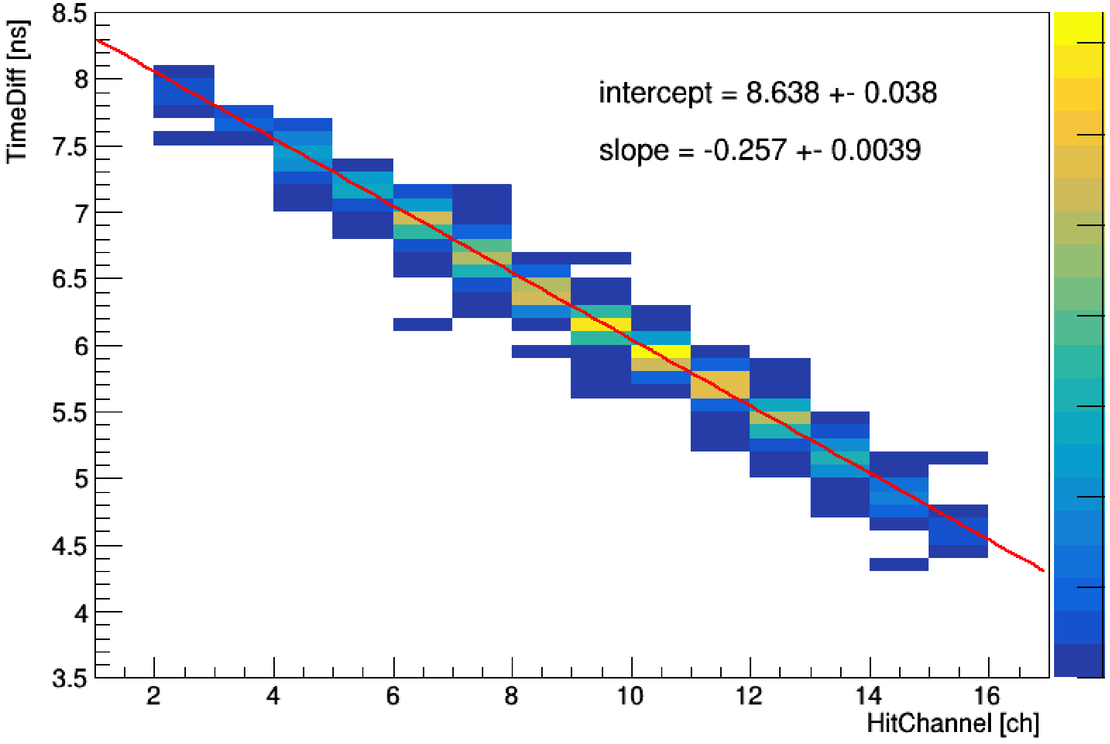
fitting empirical function: $f(V) = p_o[1 - \frac{1}{1+\exp(\frac{V-p_1}{p_2})}]$



Velocity calculation

$$(t_{diff} - t_{delay}) = 2(L - l) \,/\, v$$

t_{diff} VS reference hit channel



- t_{diff}: calculated by 70% amplitude points
- Slope $= \frac{2 \times l_{ch}}{v}$
  - ○ l_{ch} : strip pitch of reference panel (27 mm)
  - ○ v : signal propagation velocity on readout panel
- t_{diff}, v : used to reconstruct hit position
- t_{delay} (transmission cable caused) only affects intercept

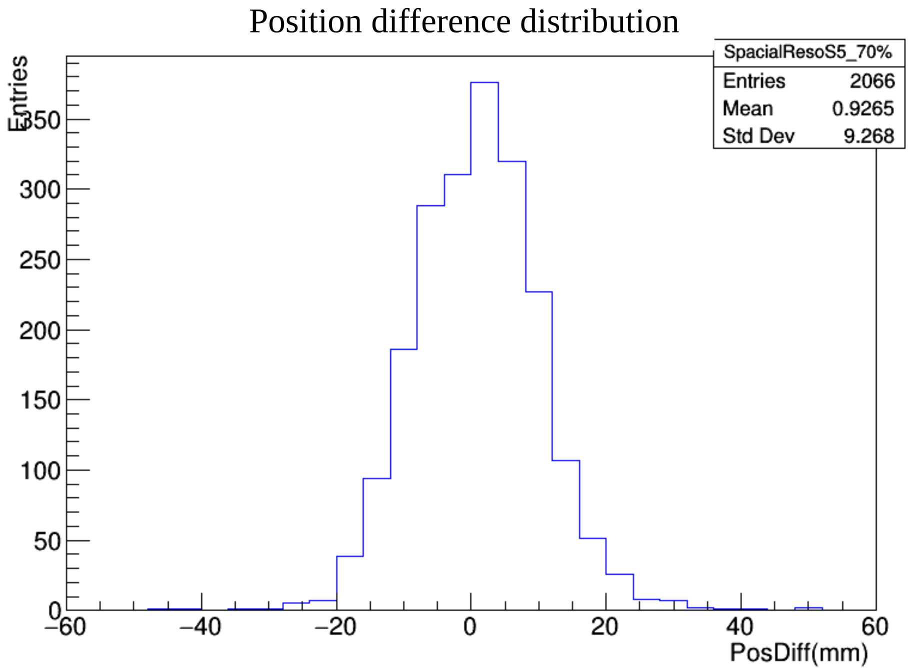
$$v = \ (2 * 27\ mm)\ /\ slope$$

$$v = 54\ mm\ /\ (0.257 \pm 0.0039) = 210.1 \pm 3.2\ mm/ns$$

Signal propagation velocity on readout panel is about 210 mm/ns.

Spatial resolution

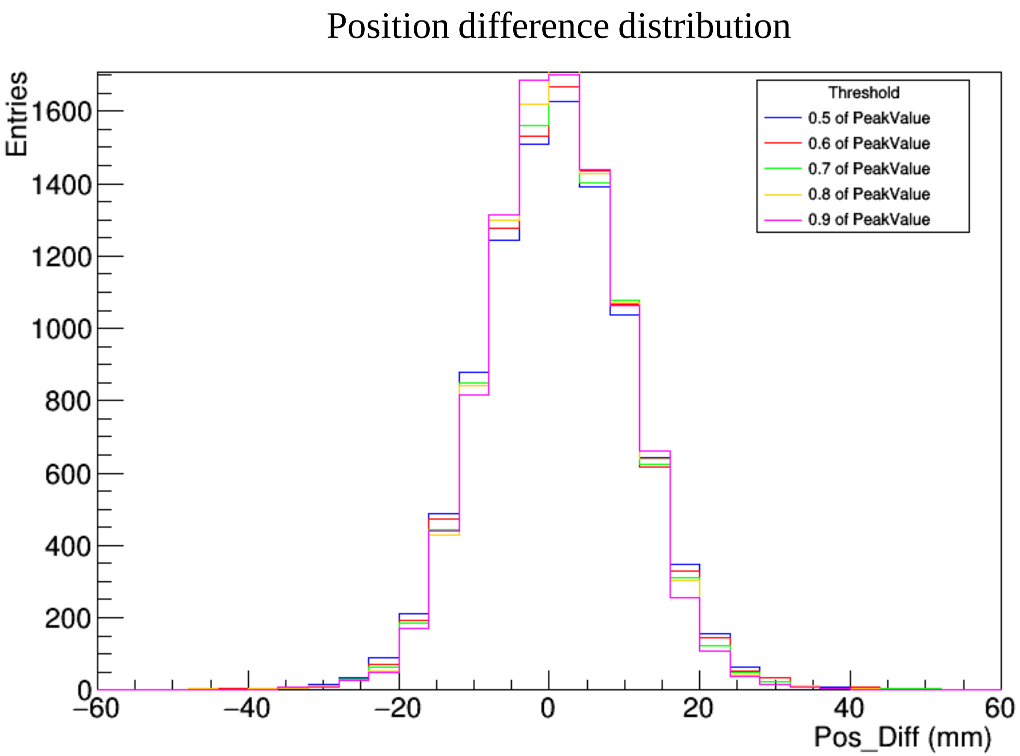
- Reference position point : p_{refer}
  - reference hit channel middle position
- Reconstructed position point : p_{recon}
  - use v , t_{diff} to calculate
- $p_{diff} = p_{recon} - p_{refer}$
  - $\sigma_{diff}^2 = \sigma_{recon}^2 + \sigma_{refer}^2$
  - calculate position difference distribution
  - σ_{diff} also contain the contributions from the granularity of the readout strip, 27/ √ 12 mm (**uniform distribution , strip pitch = 27 mm**)
  - $\sigma_{recon}^2 = \sigma_{diff}^2 - (\frac{27}{\sqrt{12}})^2$



position difference distribution

Spatial resolution ---- constant fraction discrimination

- t_{diff} calculation
  - use different amplitude thresholds
    - 50%, 60% ,70%, 80%, 90% of peak value
    - linear interpolation calculation
- v selection : 210 mm/ns
- HV : 6000V
- $\sigma_{recon}^2 = \sigma_{diff}^2 - (\frac{27}{\sqrt{12}})^2$



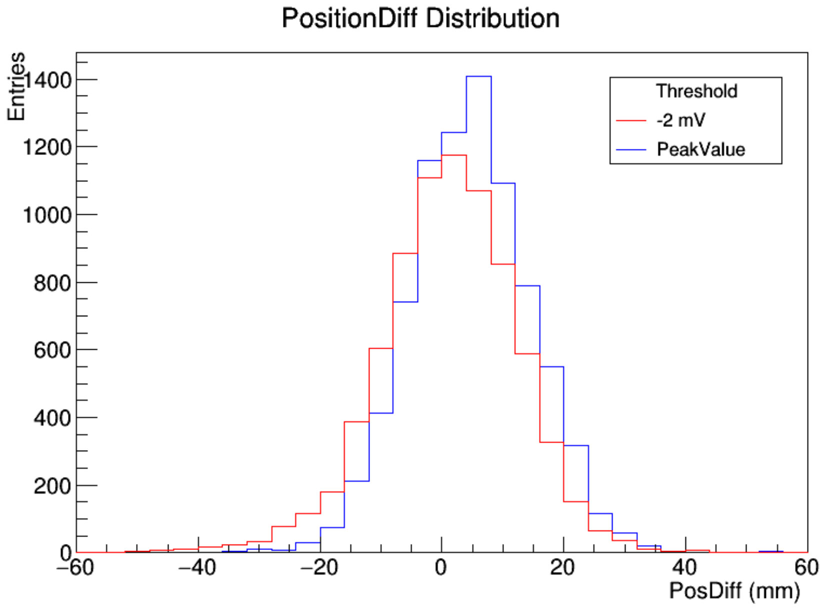
Different PCTs of peak value	50%	60%	70%	80%	90%
σ_{diff} (mm)	10.07 ± 0.14	9.75 ± 0.12	9.56 ± 0.13	9.36 ± 0.12	9.22 ± 0.11
σ_{recon} (mm)	$\mathbf{6.37 \pm 0.14}$	$\mathbf{5.86 \pm 0.12}$	$\mathbf{5.53 \pm 0.13}$	$\mathbf{5.18 \pm 0.12}$	$\mathbf{4.92 \pm 0.11}$

90% amplitude point is the best choice, spatial resolution can be up to 5 mm.

Spatial resolution ---- for electronics

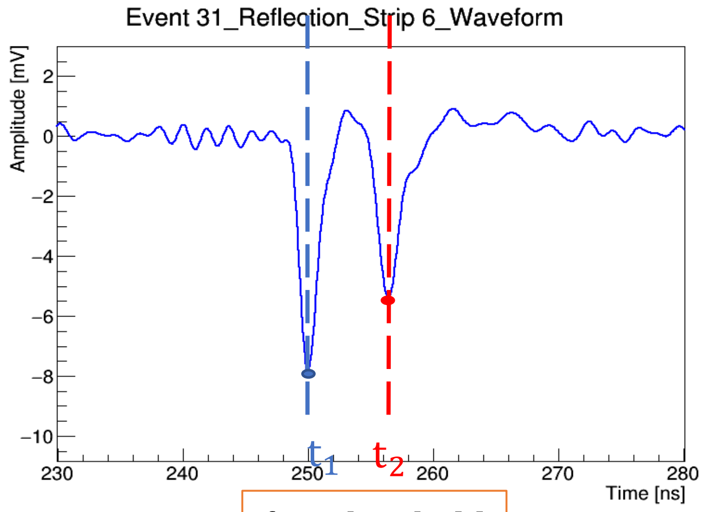
HV = 6000V

- Consider the application of electronics
  - first threshold : peak value point
  - second threshold : -2 mV (fixed threshold)

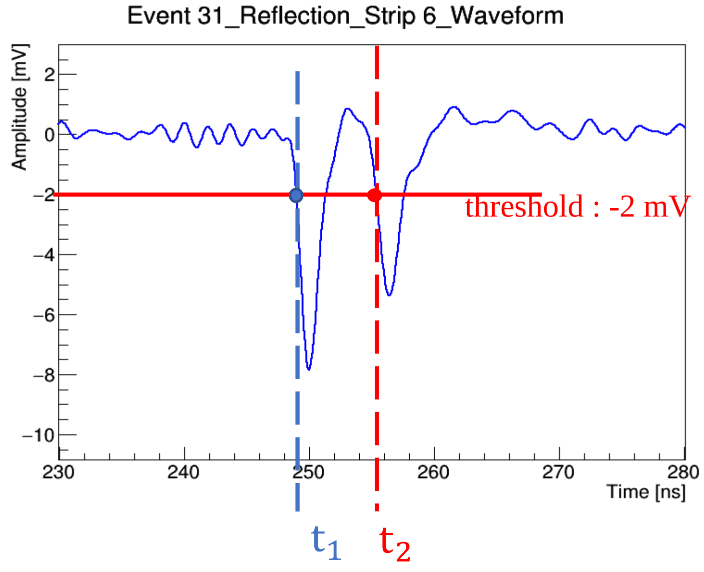


Threshold	peak value	-2 mV
σ_{diff} (mm)	9.89 ± 0.16	11.38 ± 0.22
σ_{recon} (mm)	**6.09 ± 0.16**	**8.58 ± 0.22**

Setting fixed threshold can also make spatial resolution less than 1 cm.



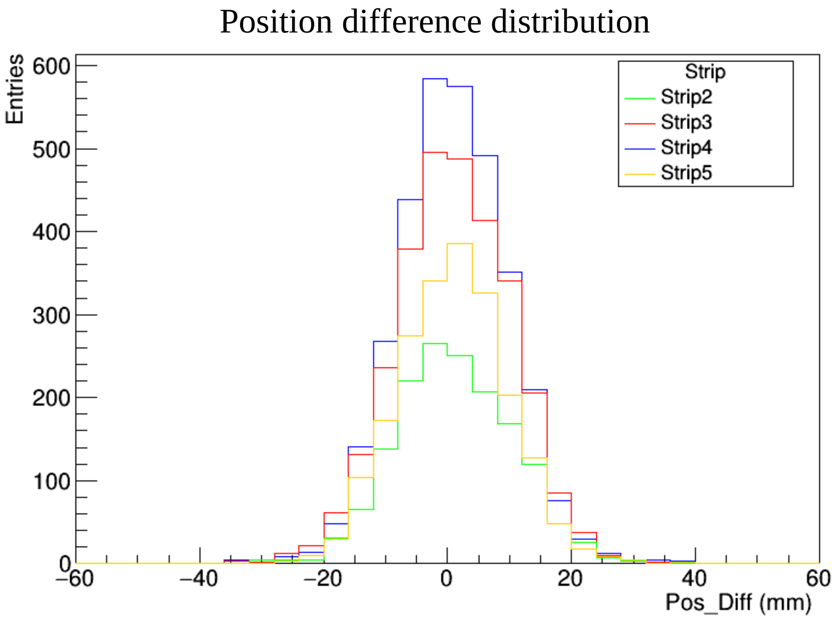
first threshold



second threshold

Spatial resolution ---- separate channel calculation

- t_{diff}: calculated by 90% amplitude threshold
- **v selection : also calculated by each strip**
- HV = 6000V
- Test strip1 and strip 6 are discarded
  - to ensure selection consistency



Velocity	Strip 2	Strip 3	Strip 4	Strip 5
v (mm/ns)	210.9 ± 2.9	211.2 ± 3.3	209.7 ± 3.1	209.3 ± 2.7

Spatial Resolution	Strip 2	Strip 3	Strip 4	Strip 5
σ_{diff} (mm)	9.26 ± 0.14	9.33 ± 0.19	9.22 ± 0.16	9.17 ± 0.11
σ_{recon} (mm)	$\mathbf{5.09 \pm 0.14}$	$\mathbf{5.12 \pm 0.19}$	$\mathbf{4.93 \pm 0.16}$	$\mathbf{4.84 \pm 0.11}$

The performance of each strip tends to be consistent.

Summary

- Reflection readout scheme is preliminarily verified
  - ~ 5 mm spatial resolution at the best case
  - < 1 cm spatial resolution by setting fixed threshold
  - reflection readout reconstruction rate ~ 97%
  - 'dead area' has been suppressed

Backup ----- Oscilloscope

- Key Features
  - Highest resolution – 12 bits all the time
  - More channels, flexibility – 8 analog and 16 digital channels
  - Longest Memory – 5 Gpt records with simple navigation – no compromise
  - View 16 channels on one display with OscilloSYNC™
  - Powerful, deep toolbox enables and simplifies complex analysis
  - MAUI with OneTouch user interface for intuitive and efficient operation

Wave-Runner 8000HD 8 Channel
High Definition Oscilloscopes

Backup ----- Error Analysis

- Error component
  - time-difference selection of different timestamps (main)
    - other selection timestamp : 50%, 60%, 80%, 90%, 100% of peak value
    - different timestamps selection will generate the error
  - fitting error in the velocity calculation
    - intercept and slope have their own fit error