Introduction to Fast Electronics for Detectors

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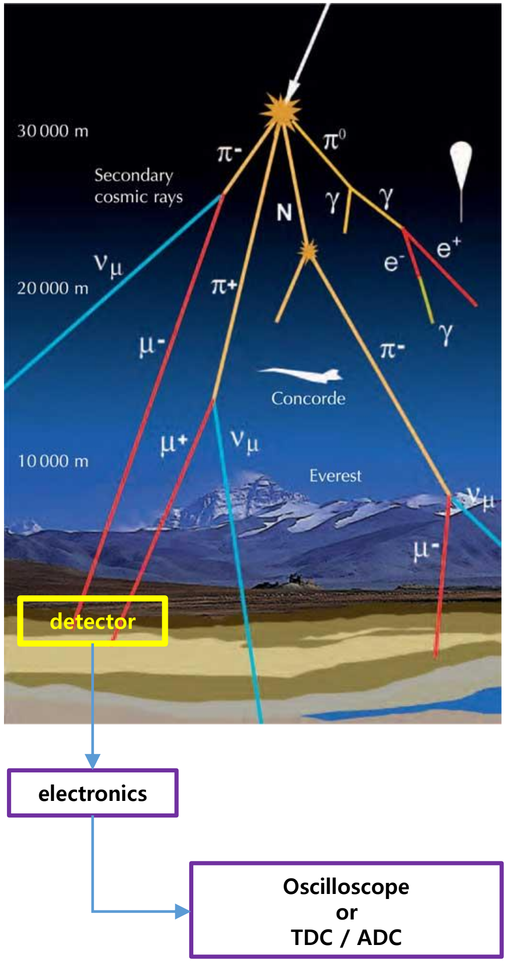
RISP/IBS

- **INTRODUCTION**
  - **Detection of cosmic ray muons**
  - **How to watch/take the information of signals?**
  - **Relation between signal and charge/voltage**
  - **Timing jitter and walk**
  - **Discrimination (analog to logic)**
  - **Coincidence**
  - **Accidental events**

- **TEST SETUP**
  - Scintillation counter
  - **NIM bin/crate**
  - **High voltage power supply**
  - Amplifier
  - **Fan-in Fan-out**
  - **Discriminator**
  - **Logic unit**
  - **Scaler and counter timer**
  - **Oscilloscope**
  - RG cables and connectors
  - **TDC and ADC**
  - **TDC calibration**
  - **ADC calibration**



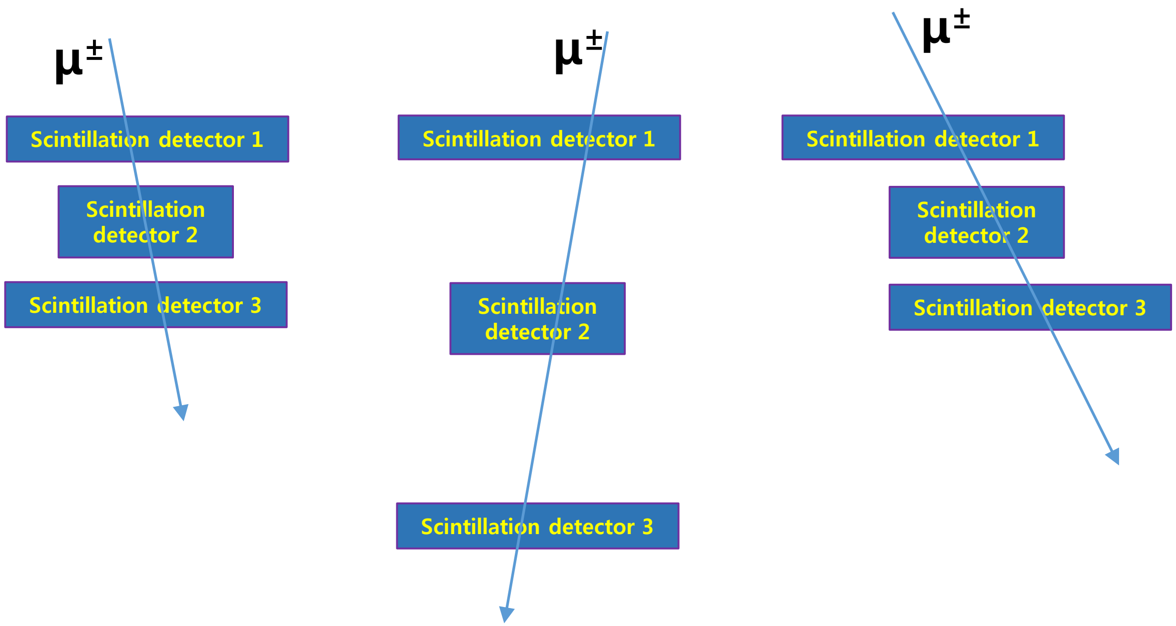
Goal: We can measure the cosmic-ray muons with fast electronics.

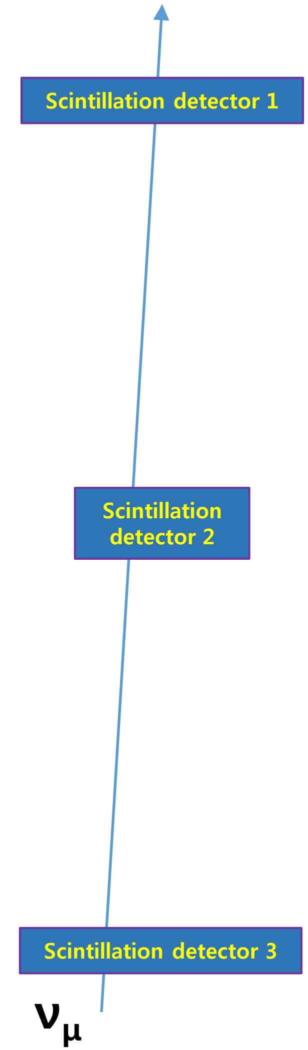
INTRODUCTION: Detection of Cosmic ray muons

Chapter 29. Cosmic rays in Particle Data Book (2018)

Incident angle dependence of cosmic ray muons

Overall angular distribution of muons at the ground:
At lower energy, I(Θ) increasingly steep, approaching a secΘ for $E_\mu >> E_\pi$ and $\Theta < 70°$
At E_{muons}=~3 GeV/c², I(Θ) ∝ cos²Θ
At higher energy, it flattens



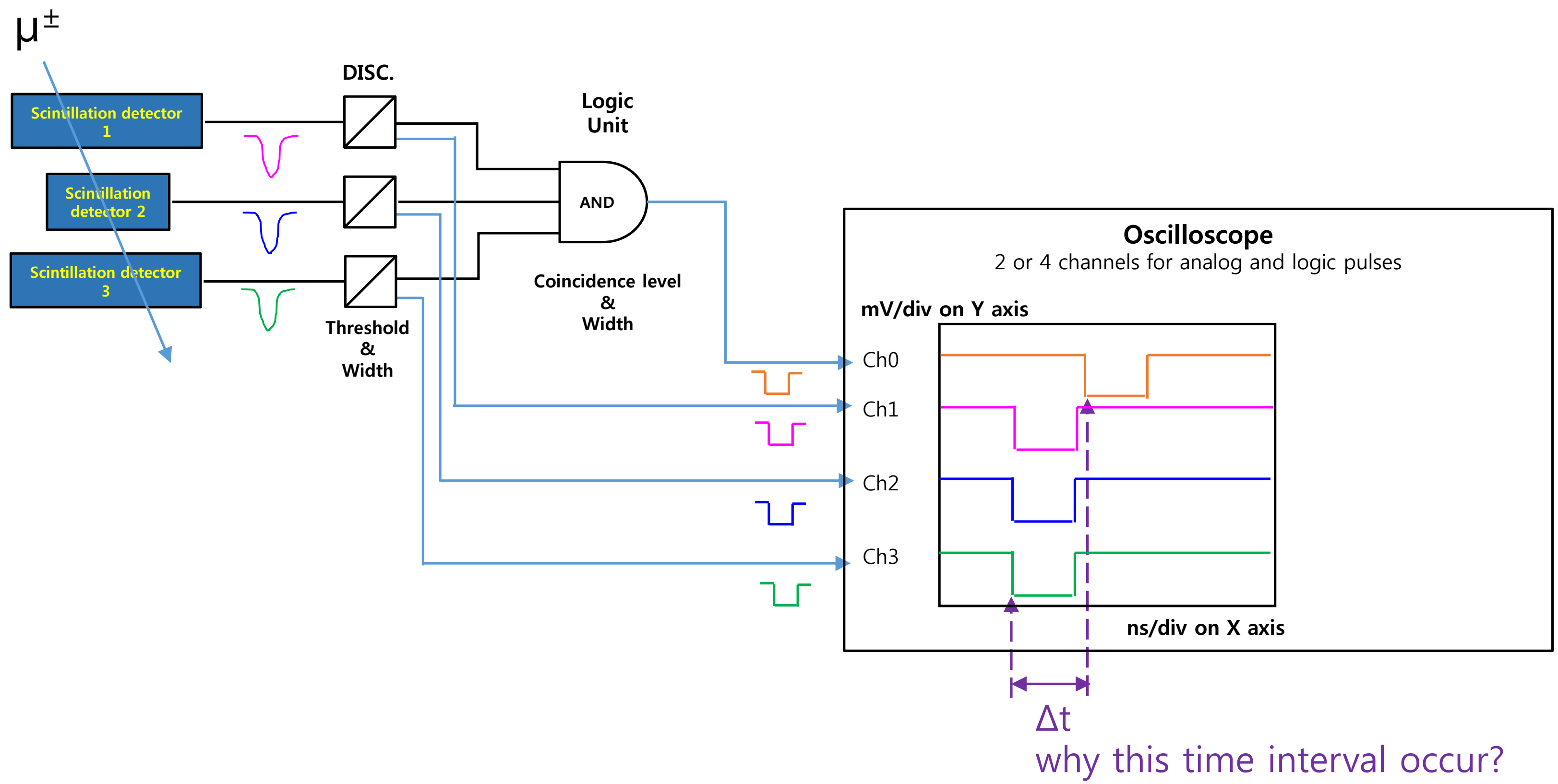


Geo-cosmic ray muons by muon neutrinos (ν_μ)

Flux of cosmic ray muons depands on: structure and shape of detectors
geometrical location

INTRODUCTION: Is it possible to watch the signal from detectors?

Scintillation counter/detector:
Scintillator + **P**hoto**M**ultiplier **T**ube (PMT)



Question> What is difference between scintillation counter and detector?

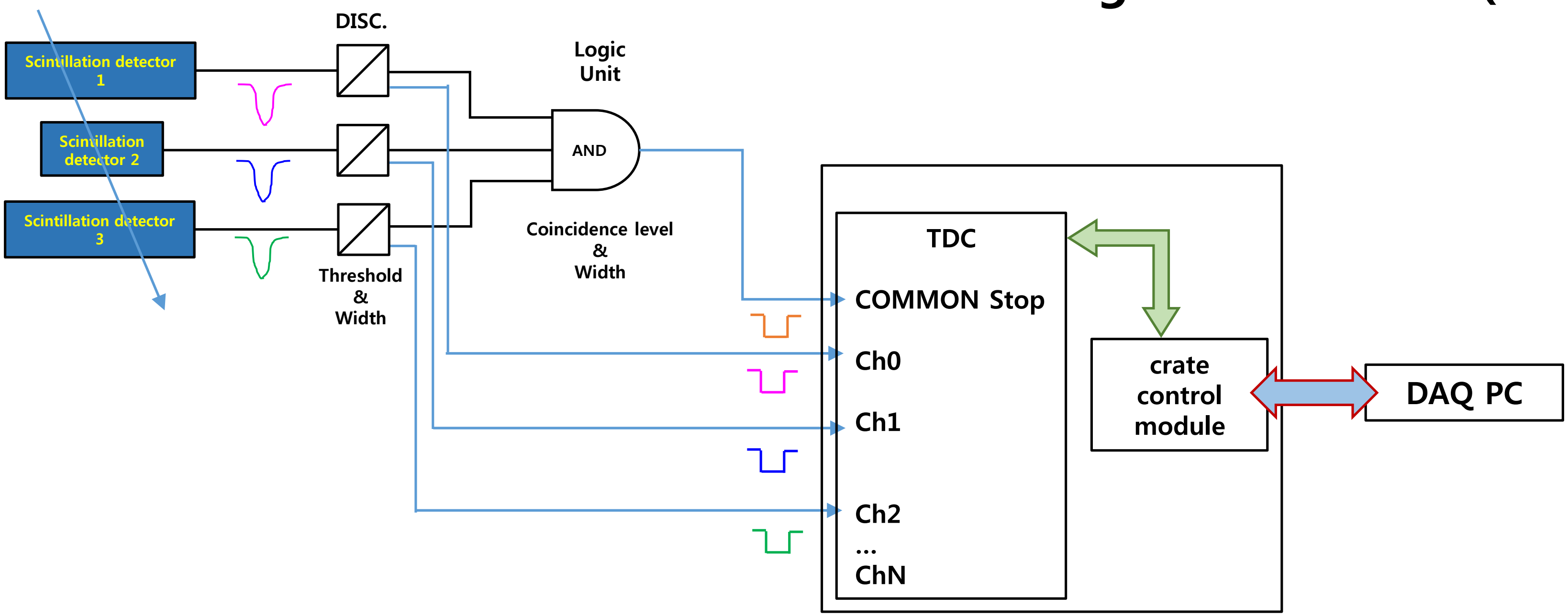
counter: just counting how many particles passed through it

detector: measure time and charge to get position, energy, dE/dx, and so on

INTRODUCTION: How to get the time information of signals?

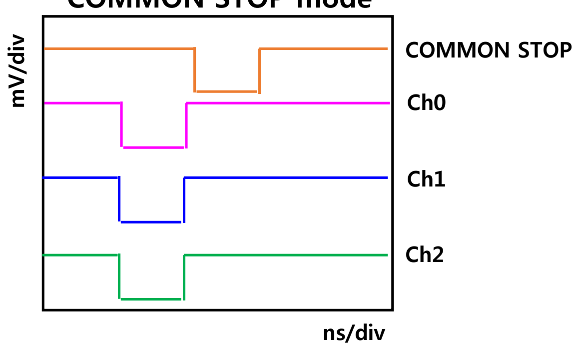
Scintillation counter/detector:
Scintillator + **P**hoto**M**ultiplier **T**ube
(PMT)

Time-to-Digital Converter (TDC)

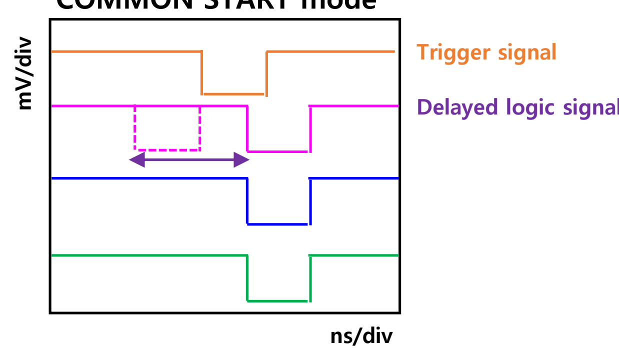


Question> Operation mode of TDC: COMMON STOP/START?

COMMON STOP mode

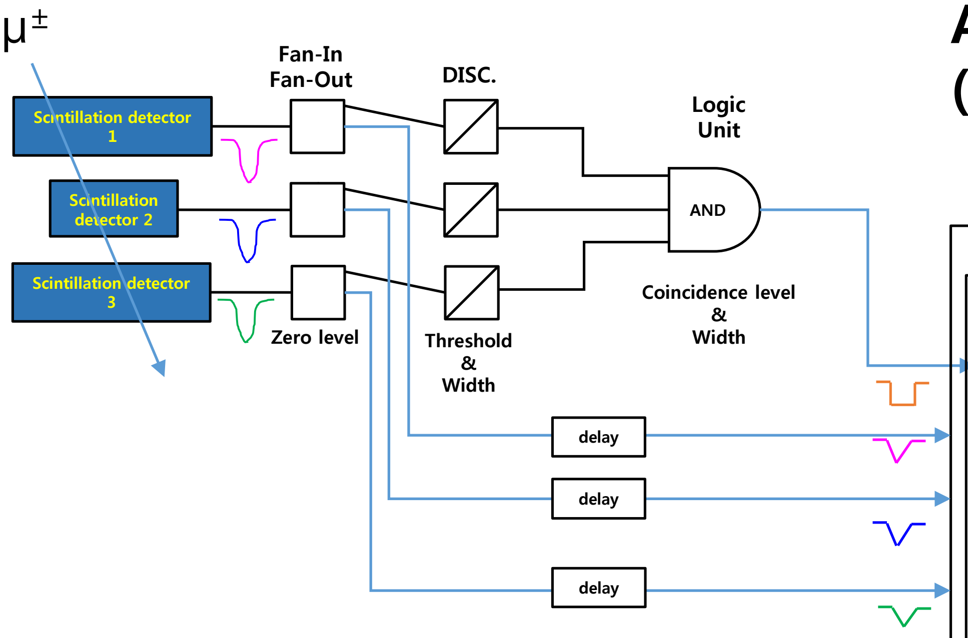


COMMON START mode

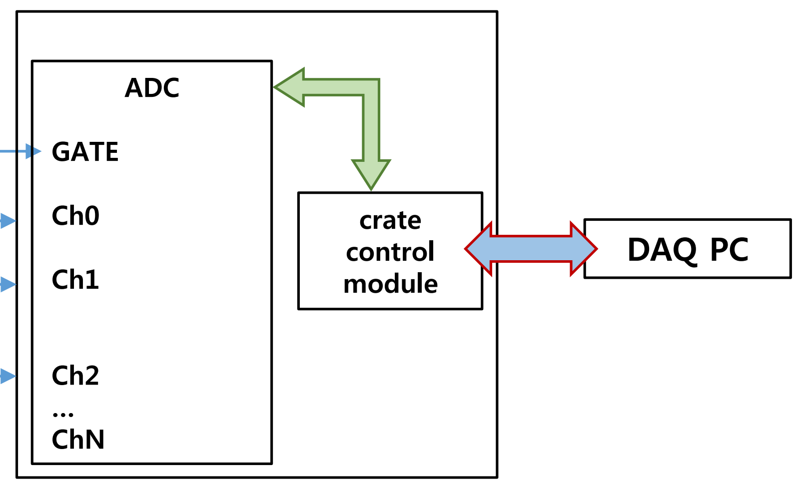


INTRODUCTION: How to get the charge information of signals?

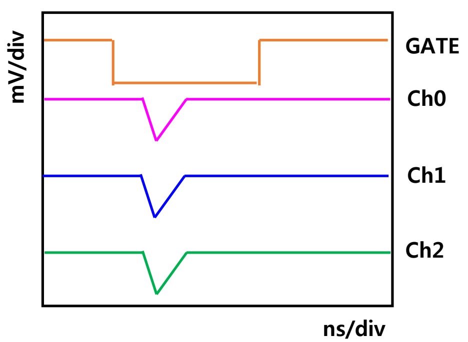
Scintillation counter/detector:
Scintillator + **P**hoto**M**ultiplier **T**ube (PMT)



Analog-to-Digital Converter (ADC)



Time domain of signals for ADC

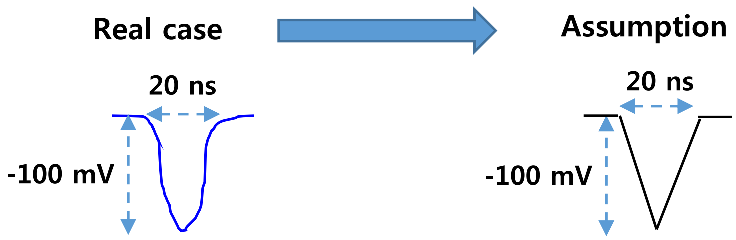


Question> if width of analog signal is 10 ns, which width of gate signal is proper one?

1) Just larger than analog signal
2) 100 ns
3) 1 μs
4) Case by case

INTRODUCTION: Relation between signals and charge/voltage

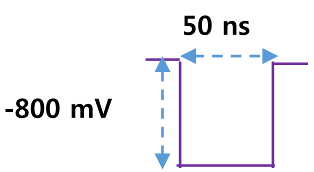
Analog signal



Electric charge of analog signal with assumption:

$$Q(C) = \frac{V(V) \cdot t(s)}{2 \cdot R(\Omega)} = \frac{0.1\,V \cdot 20\,ns}{2 \cdot 50\Omega} = 20\,pC$$

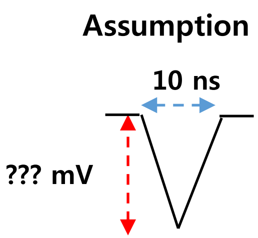
Logic signal (ex, NIM signal)



Electric charge of logic signal:

$$Q(C) = I(A) \cdot t(s) = \frac{V(V) \cdot t(s)}{R(\Omega)} = \frac{0.8\,V \cdot 50\,ns}{50\Omega} = 800\,pC$$

Expected pulse height from charge (1 pC)



Pulse height of analog signal (1 pC):

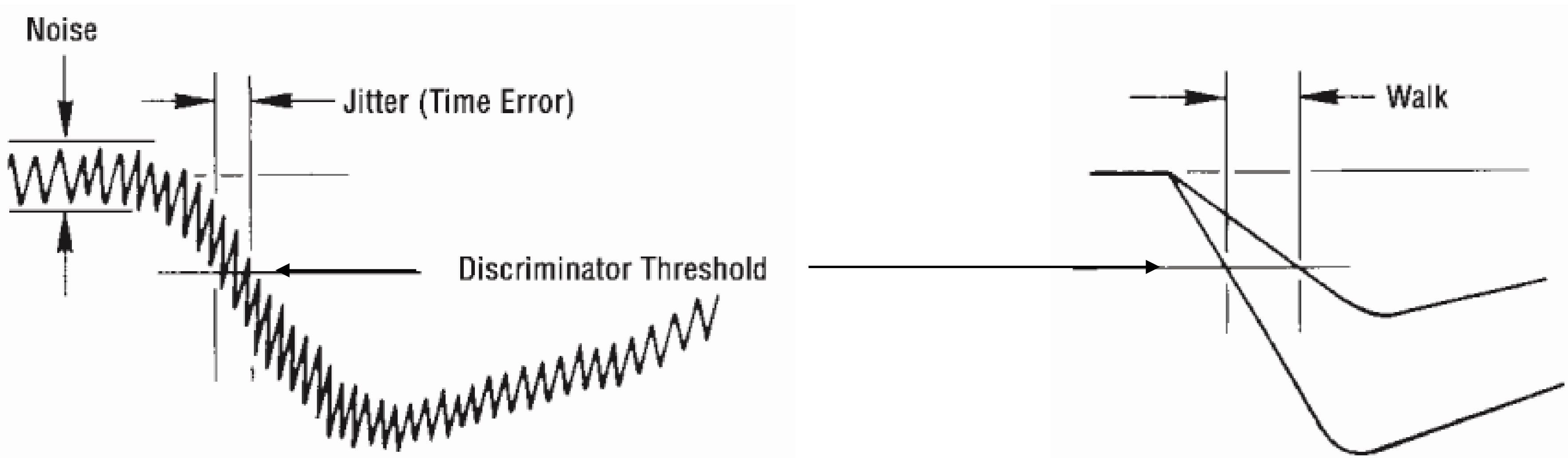
$$V(V) = \frac{2 \cdot R(\Omega) \cdot Q(C)}{t(s)} = \frac{2 \cdot 50\Omega \cdot 1\,pC}{10\,ns} = 20\,mV$$

INTRODUCTION: Timing jitter and Timing walk

Question> how much pulses are stable on the threshold?

Timing jitter in a pulse

Timing walk among pulses



http://www.peo-radiation-technology.com/wp-content/uploads/2015/09/ort_15_fast-timing-discriminators_datasheet_peo.pdf

The contribution of noise to the (Timing) Jitter

Timing Jitter = $e_{noise}/(dV/dt)$

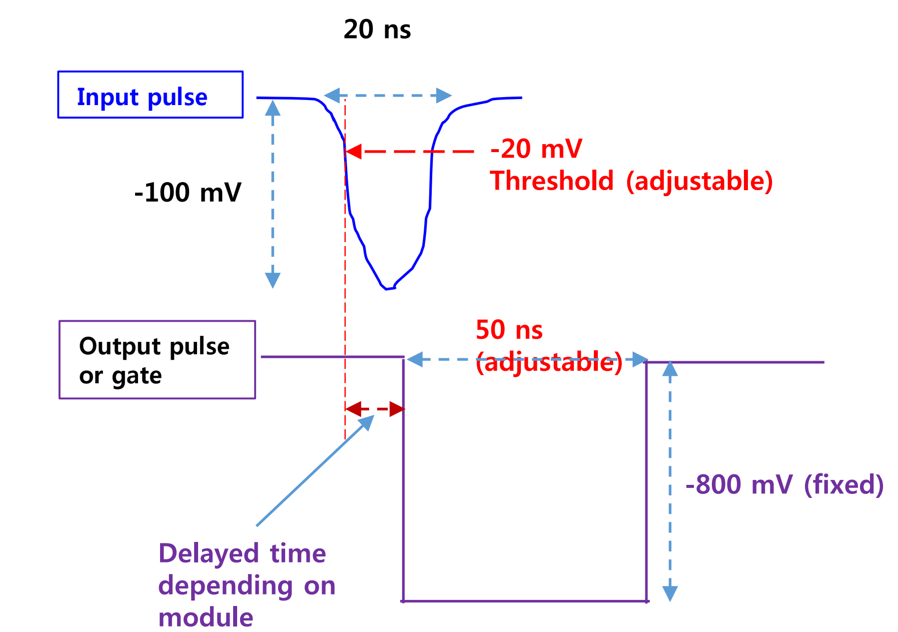
e_{noise}: voltage amplitude of the noise superimposed on the analog pulse

dV/dt: slope of the signal when its leading edge crosses the discriminator threshold

"**(Timing) Walk**" is the **systematic dependence** of the time marker **on the amplitude of the input pulse.**

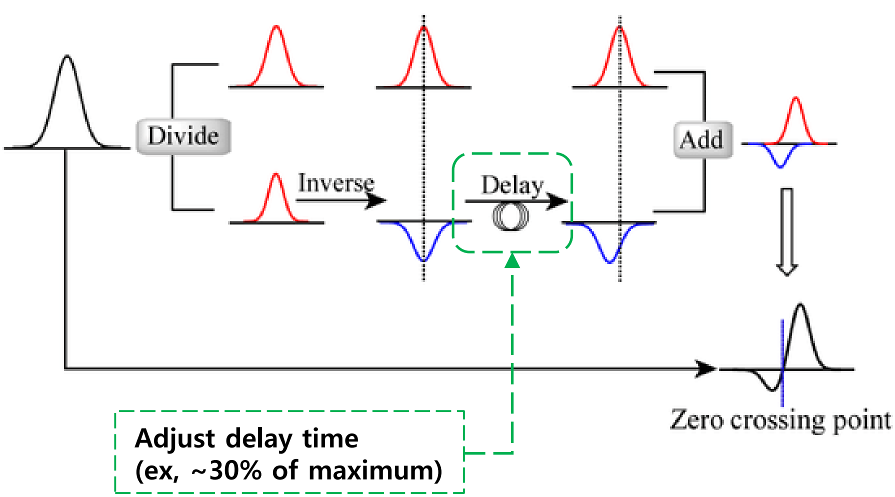
INTRODUCTION: Discrimination

Leading Edge Discrimination (LED)



Constant Fraction Discrimination (CFD)

Tuhin Khan's Ph. D. thesis



How to convert the information of analog signal?

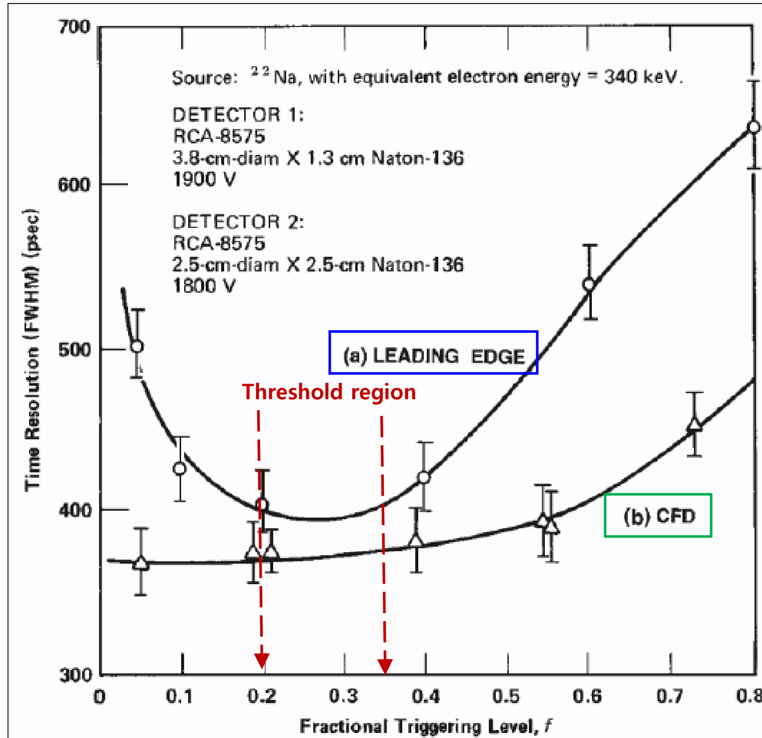


Fig. 2. A Comparison of Leading-Edge Timing with Constant-Fraction Timing for a Narrow Pulse-Height Range. The source was ^{22}Na, with the selected equivalent electron energy in the scintillator = 340 keV. The time resolution (FWHM) is Δ t.

http://www.peo-radiation-technology.com/wp-content/uploads/2015/09/ort_15_fast-timing-discriminators_datasheet_peo.pdf

Time resolution: $\sigma_{CFD} < \sigma_{LED}$

is it always correct?

INTRODUCTION: Coincidence

Question in concept> Do we know that the hits occur in many detectors **simultaneously**, as a event?

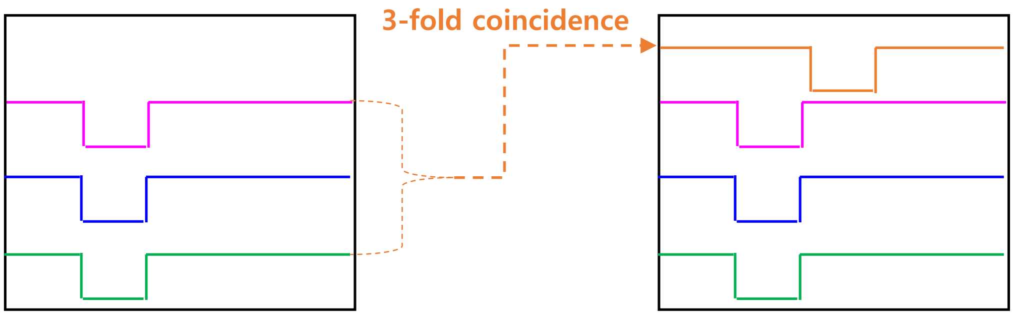
Question in real> How to define **simultaneous event**?
If origin of event source is same, we call it **single event**. (ex) particle, collision, or etc

Question in real> If events occur, **how to match the signals** from many detectors?

2-, 3-, 4-, and more fold coincidence

There are 3 independent logic pulses.

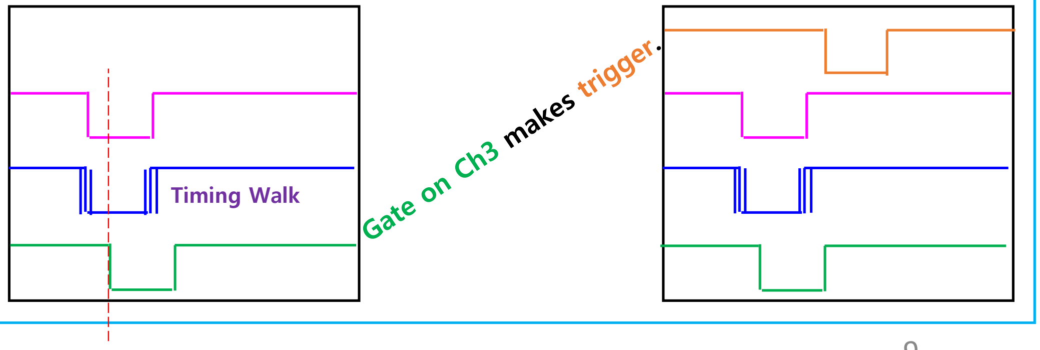
Question> Is it single event? **YES!**



Question in real> Is there a **good coincidence**?

Gate (Ch2) is shaking in time domain, called ***Timing Walk***.

Question> how to treat it? **Gate (Ch3) delayed**

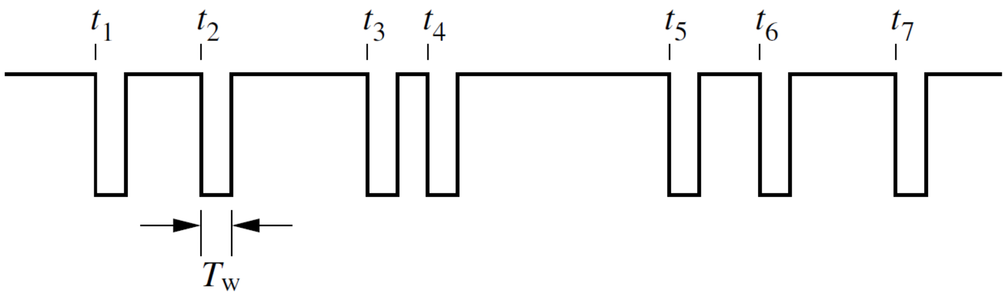


INTRODUCTION: How many accidental events will occur?

http://courses.washington.edu/phys433/muon_counting/counting_stats_tutorial_b.pdf

Counting statistics of random events

Single random pulse trains



Coincidence rate (R_2) of two random pulse trains

$$R = 2r_A r_B T_W$$

Rate of single random pulse train: r_A and r_B in Hz

Time width of each pulse: T_W in sec

If r_A = 10 Hz, r_B = 20 Hz, and T_W = 50 ns,

$$R = 2r_A r_B T_W = 2 \cdot 10 \cdot 20 \cdot 50 \cdot 10^{-9}\,(Hz) = 20\ \mu Hz = \frac{20}{10^6 s} = \frac{20}{\sim 278h} = \frac{20}{11.6 days}$$

Coincidence rate (R_3) of three random pulse trains (single rate: r_A, r_B, and r_C in Hz)

$$R = 3r_A r_B r_C T_W^2$$

If r_A = 10 Hz, r_B = 20 Hz, r_C = 20 Hz, and T_W = 50 ns,

$$R = 3r_A r_B r_C T_W^2 = 3 \cdot 10 \cdot 20 \cdot 20 \cdot (50 \times 10^{-9})^2 = 3 \times 10^{-11}(Hz) = 30\ pHz = \frac{30}{10^{12} s} = \frac{30}{31709 years}$$