Data Acquisition with Fast Electronics

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CHEP/KNU

- **Basic Introduction**
- **Detection efficiency and Accidental Coincidence**
- **How to get the charge value with VME ADC?**
  - Energy Measurement, Calibration, and Resolution
- **How to get the time value with VME TDC?**
  - Time Measurement, Calibration, and resolution

2024.01.17

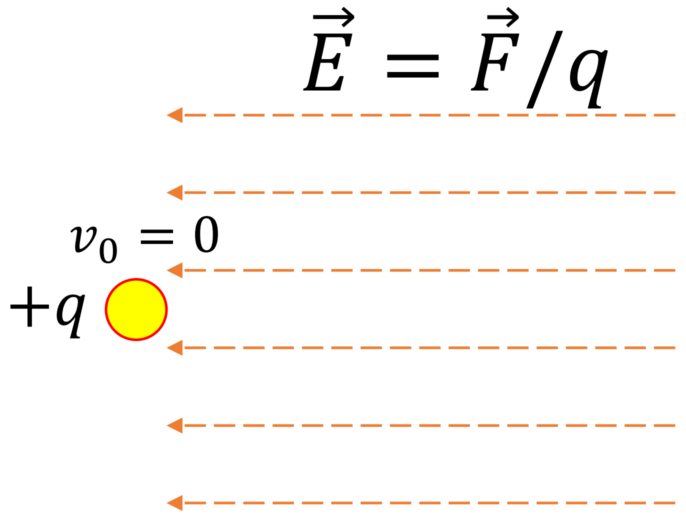
SPDAK 2024 (Daegu)

Radiation Science Research Institute
Kyungpook National University

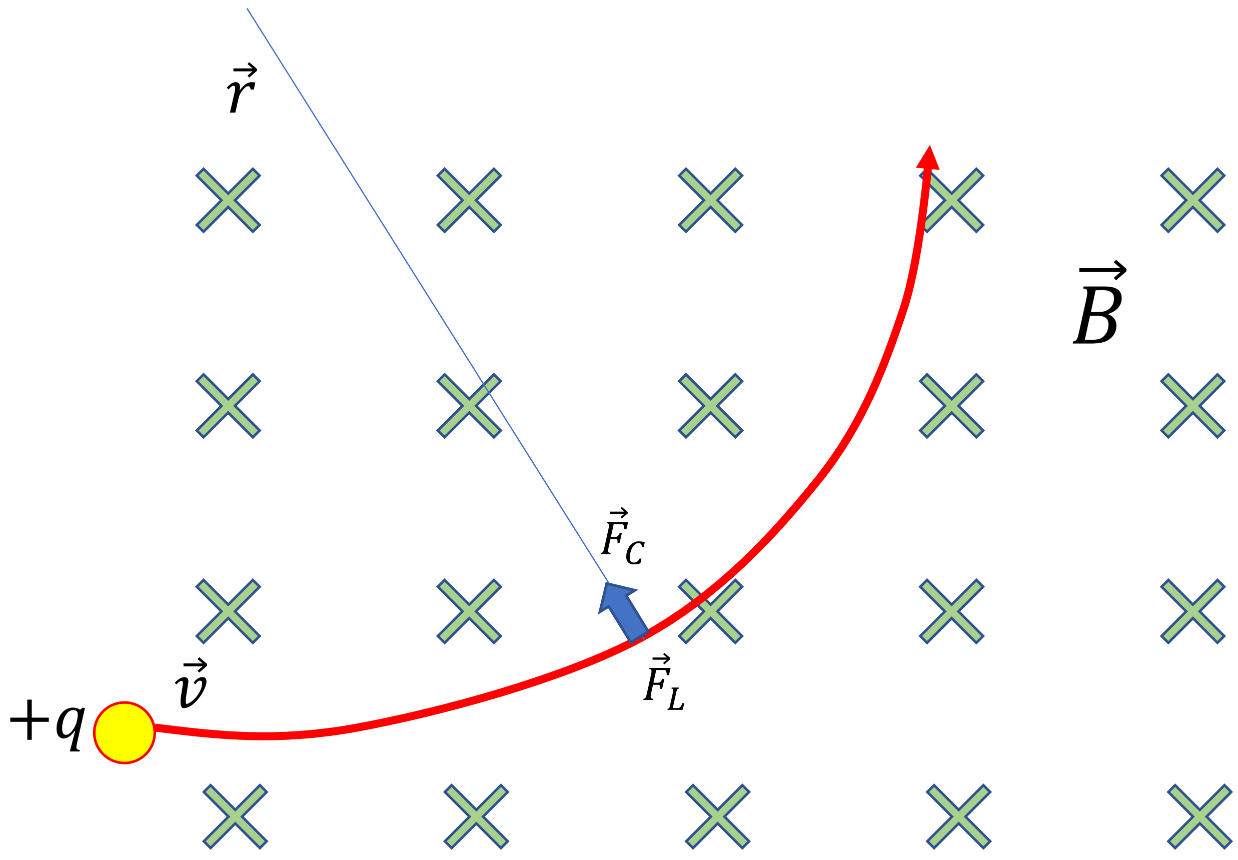
FOUR BK21 Education Research Center for Quantum Nature of Particles and Matter

KYUNGPOOK NATIONAL UNIVERSITY
DEPARTMENT of PHYSICS

Motion of Charged Particles in E & B fields



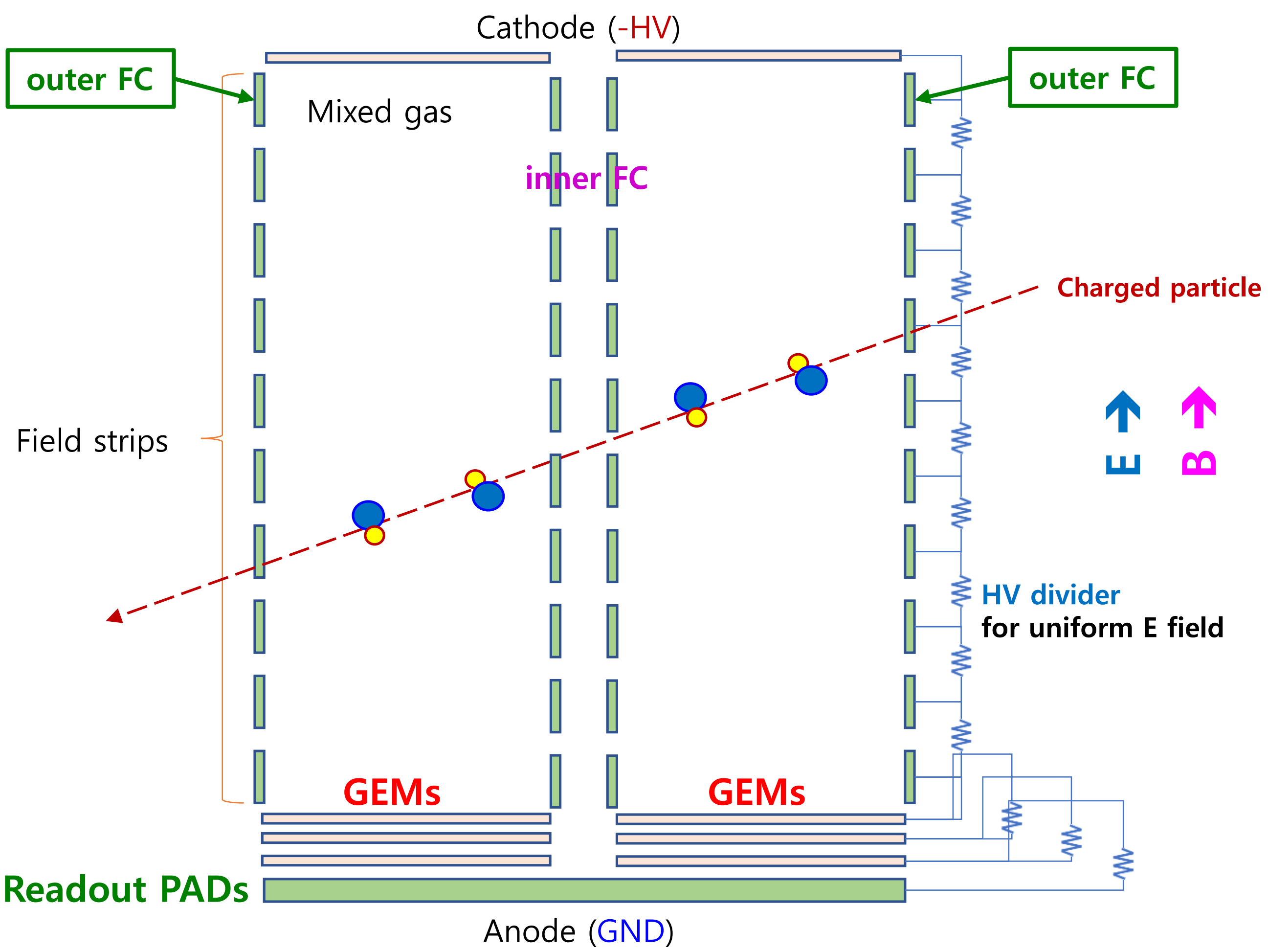
$$\vec{E} = \vec{F}/q$$



$$\underbrace{\vec{F}_L = q\vec{v}\times\vec{B} \qquad \vec{F}_C = \frac{m\gamma v^2}{r}}_{\therefore\ p = m\gamma v = qrB}$$

Particle Track in Time Projection Chamber (TPC)

TPC in xz-plane view



FC in xy-plane view

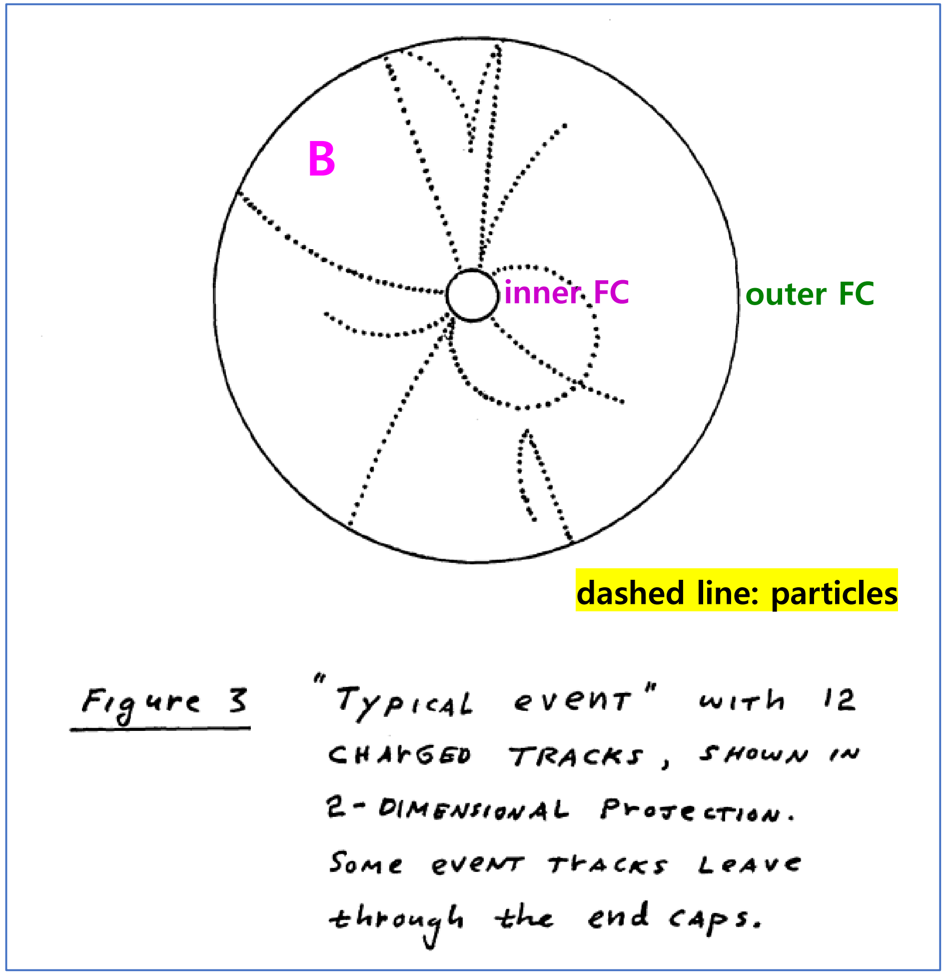
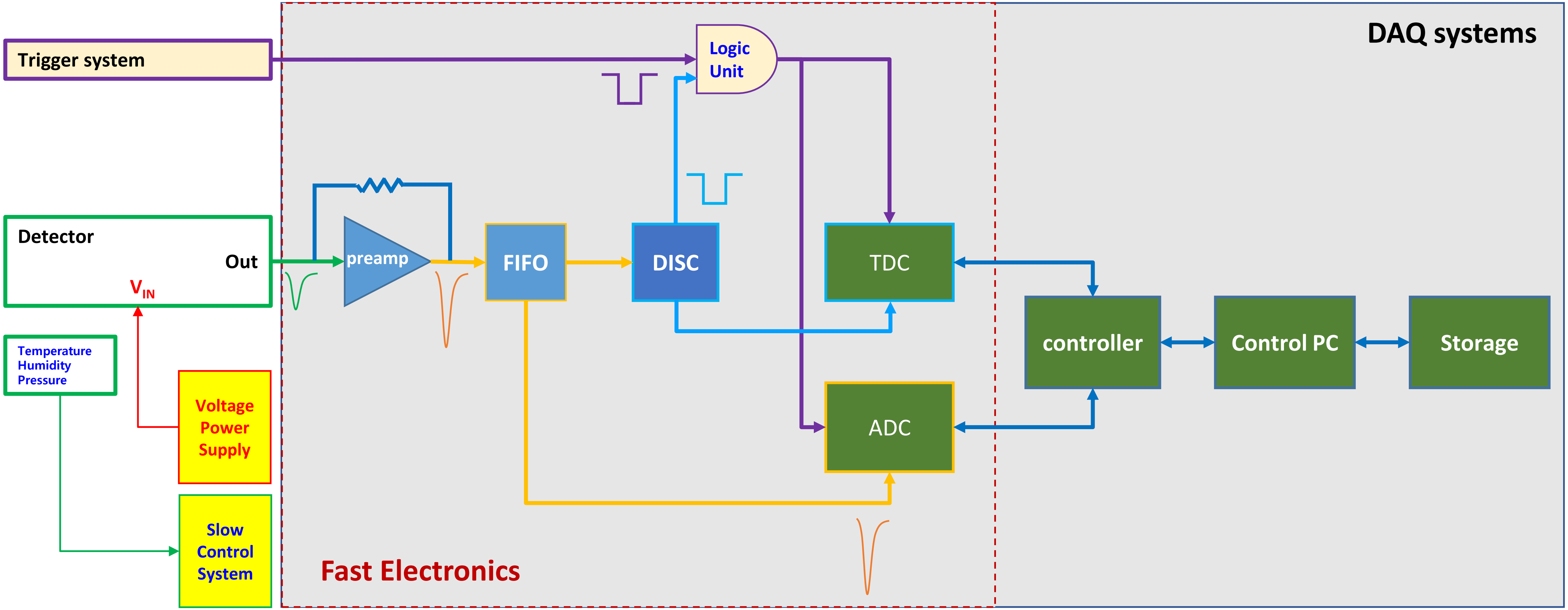


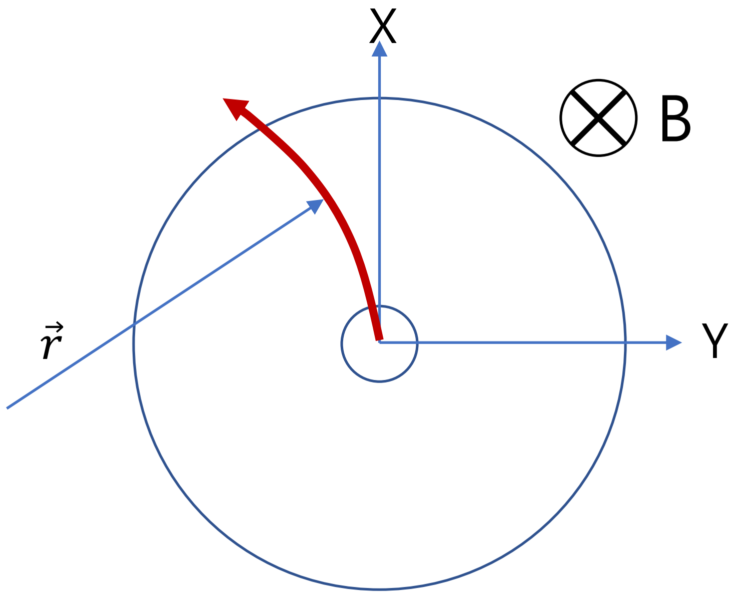
Figure 3 "Typical event" with 12 charged tracks, shown in 2-dimensional projection. Some event tracks leave through the end caps.

D.R. Nygren in 1974 PEP summer study
eConf C740805 (1974) 58
The Time Projection Chamber: A New 4 pi Detector for Charged Particles

Readout scheme for data acquisition (DAQ)



Track reconstruction from detector hit information



$$\mathbf{F}_{\mathbf{centripetal}} = \mathbf{F}_{\mathbf{B}} \rightarrow \frac{mv^2}{r} = qBv \rightarrow r = \frac{mv}{qB}$$

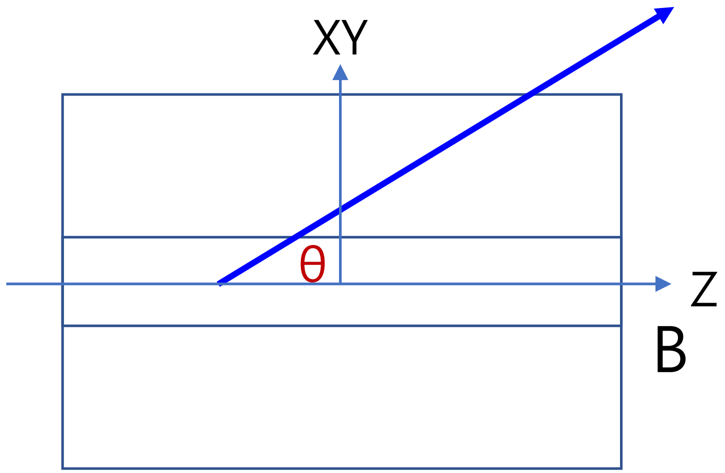
Transverse momentum

$$p_T = mv_T = m\left(\frac{qB}{m}\right)r = qBr = Br$$

where $v_T = \omega r$ and angular velocity $\omega = \frac{v}{r} = \frac{qB}{m}$

According to $1\,\mathrm{GeV} = 1.6 \times 10^{-10}\,\mathrm{J}$, and $\boldsymbol{B}(T),\ r(m)$

$$\boldsymbol{p_T[GeV/c]} = 10^{-9}Br\left(\frac{GeV}{m/s}\right) = 10^{-9}Br\left(\frac{GeV}{c}\right)3 \times 10^8 = \mathbf{0.3Br}$$



Longitudinal momentum

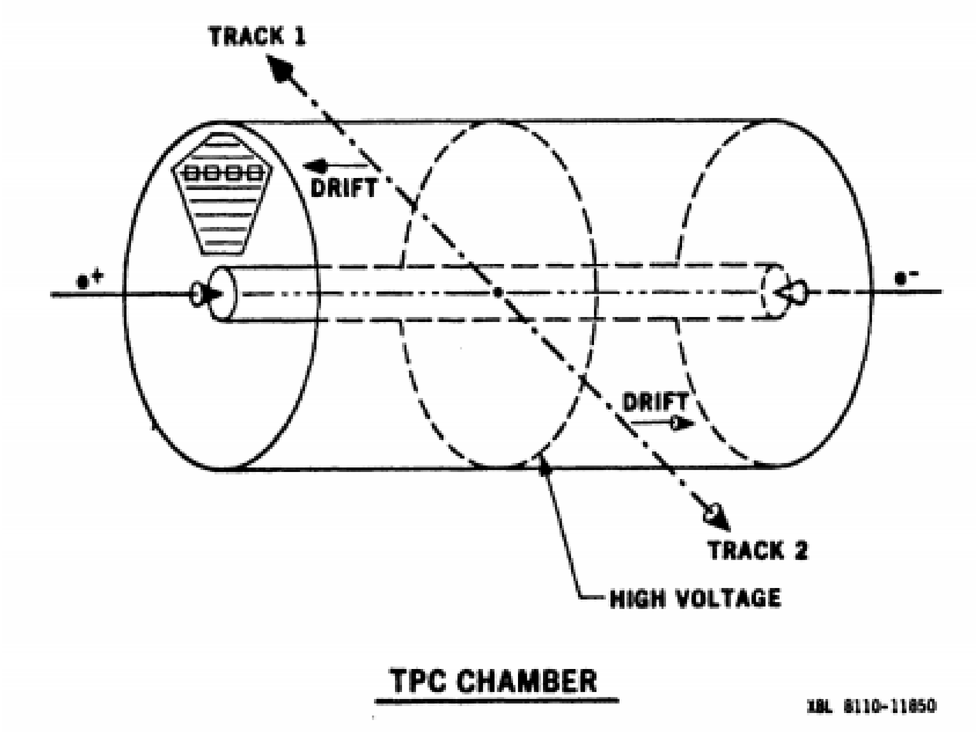
$$p_Z = \frac{p_T}{\tan\theta}$$

First TPC: PEP-4 TPC

Spatial resolution of the PEP-4 Time Projection Chamber
H. Aihara, et al.
IEEE Transactions on Nuclear Science, Vol. NS-30, No.1, Feb 1983

Recent results from the PEP-4 TPC
Ronald J. Madaras
LBL—17806

PEP-4 TPC detector at SLAC



$$\sigma_{XY} = 160 \pm 2\ \mu m$$

$$\sigma_Z = 340 \pm 5\ \mu m \text{ with } v_d = 5\ \text{cm}/\mu s$$

Gas: Ar/CH_4 = 80/20 at 8.5 atm

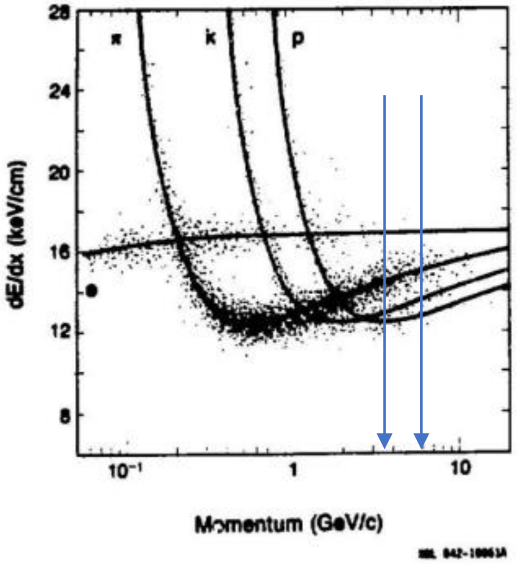
HV: -75 kV at a central membrane for 150 kV/m E field in the drift volume

Direction: Parallel in between E & B (4 kG)

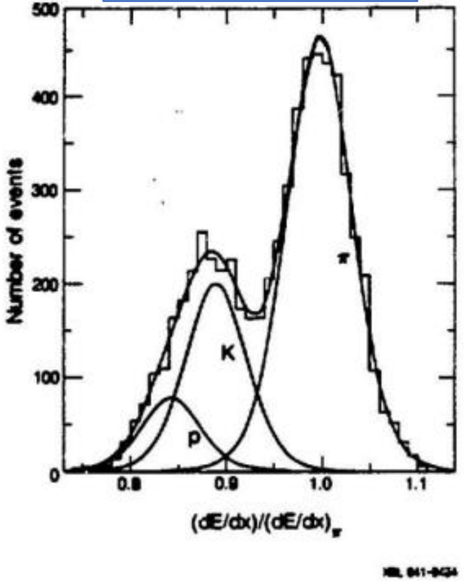
Readout method:
Y: 183 **sense wires** with 4 mm spacing (80 cm length) in each sector
➔ total 2,196 wires are used to measure the ionization energy loss (dE/dx)

X: **segmented cathode** (7x7.5 mm^2 pads) 4 mm under the wires
➔ total 13,823 pads are connected analog shift register (CCD), which records pulse height in 100 ns intervals

Z: **electron drift time**



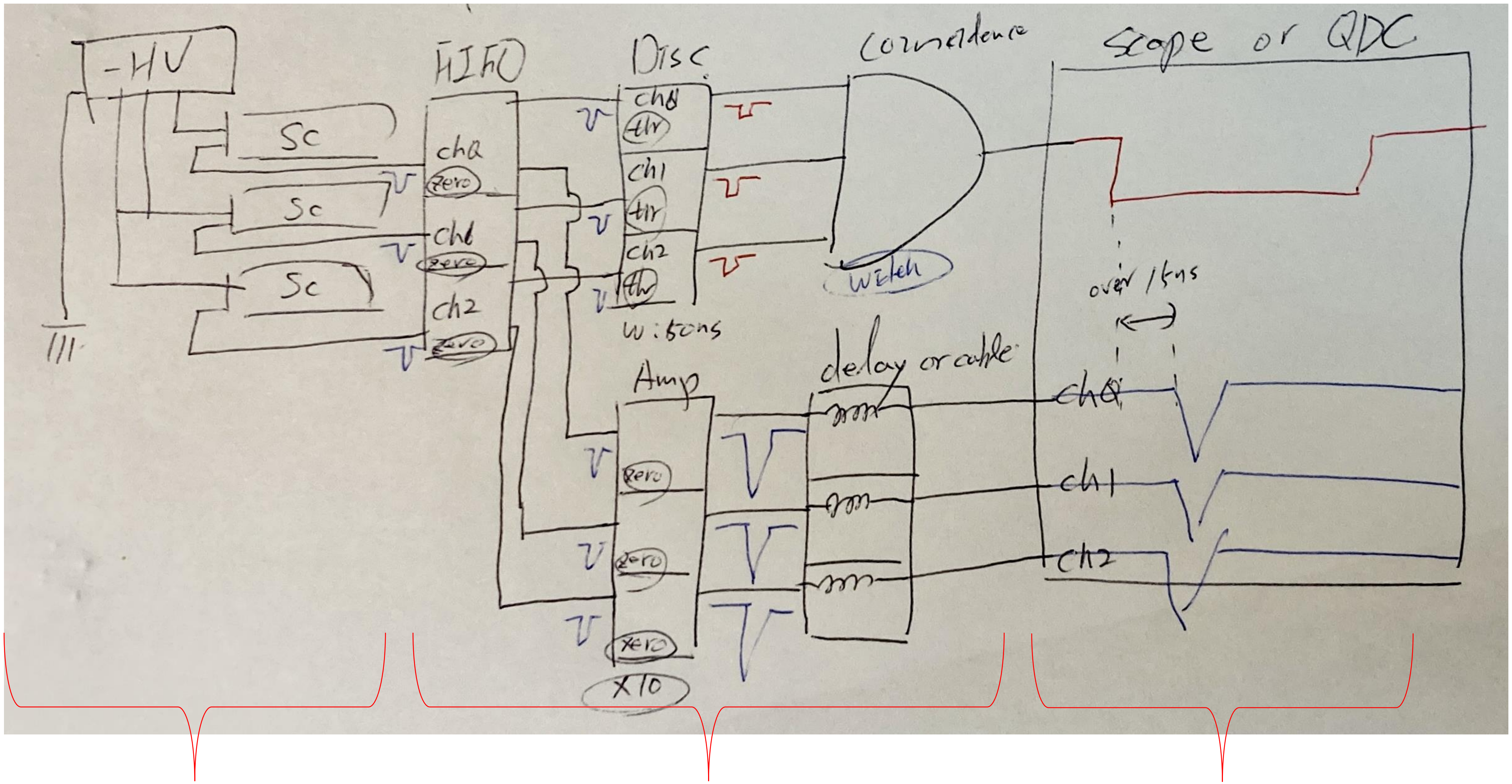
$3.5 < p < 6\ GeV/c$



PEP-4: Positron Electron Project-4

Data Acquisition (DAQ)

From Detectors to Data Storage



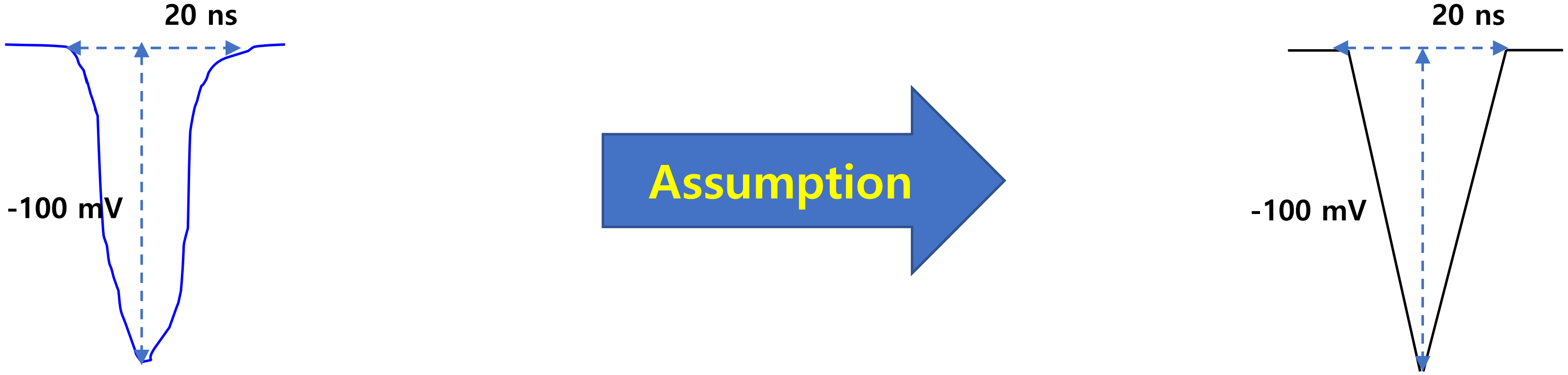
1) FIFO
2) Discriminator
3) Coin. Logic Un
4) Amplifier
5) Delay (or Cabl
6) Scope

Detector with HVPS

Fast Electronics (NIM or VME)

VME system

Charge of signal (analog and digital)

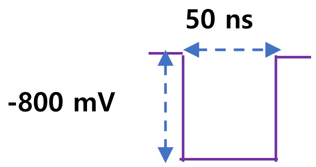


Electric charge of analog signal with assumption:

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

Charge of signal (analog and digital)

Logic signal (ex, NIM signal)

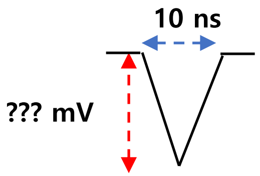


Electric charge of logic signal:

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

Expected pulse height from charge (1 pC)

Assumption



Pulse height of analog signal (1 pC):

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

Analog Pulse Processing on Fast Electronics

Fan-In Fan-Out (FIFO)
Preamplifier (Preamp)

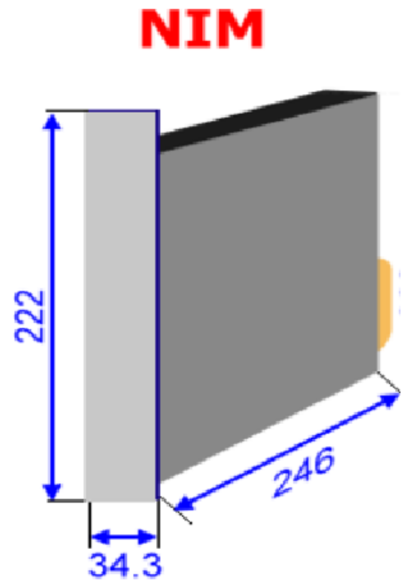
NIM bin/crate

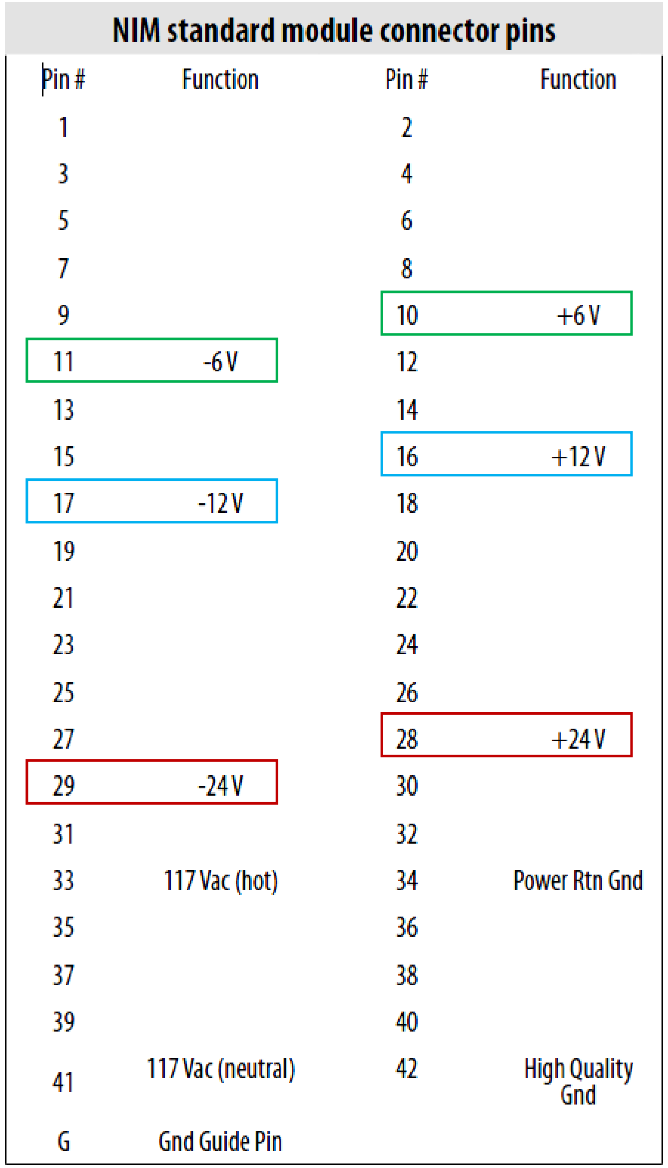
Nuclear Instrumentation Module (NIM): mechanical and electrical specifications for electronics modules used in experimental particle and nuclear physics.

First defined by the U.S. Atomic Energy Commission's report TID-20893 in 1968-1969, **NIM was most recently revised in 1990 (DOE/ER-0457T)**.

Output voltage: ±6V, ±12V, and ±24V DC

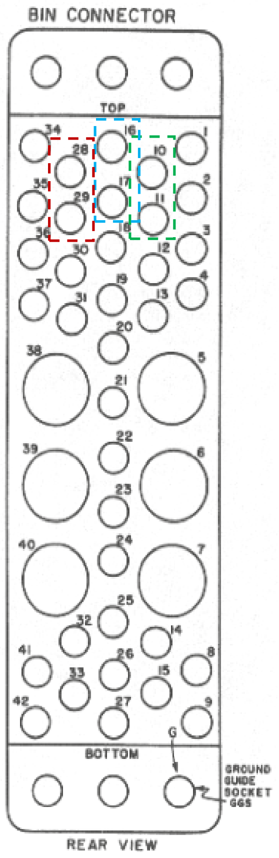
Size: H222xW34.3xD246 mm (except backplane power connector)





NIM standard module connector pins

Pin #	Function	Pin #	Function
1		2	
3		4	
5		6	
7		8	
9		10	+6 V
11	-6 V	12	
13		14	
15		16	+12 V
17	-12 V	18	
19		20	
21		22	
23		24	
25		26	
27		28	+24 V
29	-24 V	30	
31		32	
33	117 Vac (hot)	34	Power Rtn Gnd
35		36	
37		38	
39		40	
41	117 Vac (neutral)	42	High Quality Gnd
G	Gnd Guide Pin		

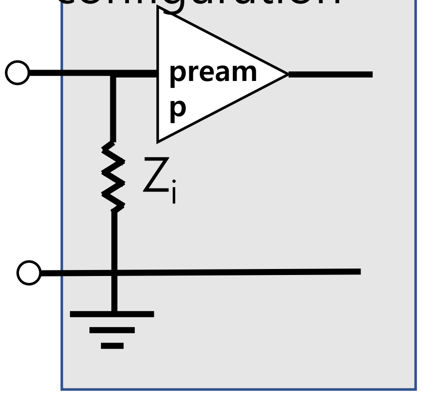


Device impedances

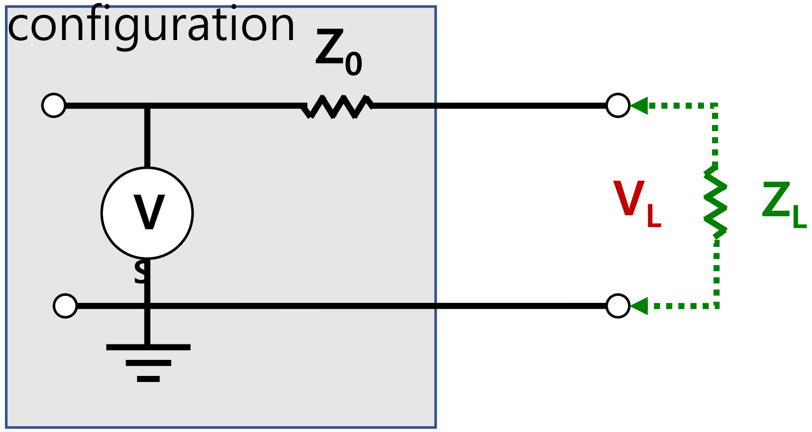
Radiation Detection and Measurement, Glenn F. Knoll

A basic concept in the processing of pulses from radiation detectors is the impedance of the devices that comprise the signal-processing chain.

Input configuration



output configuration



Voltage (V_L) appearing across a loading (Z_L) by voltage-divider relation

$$V_L = V_S \frac{Z_L}{Z_0 + Z_L}$$

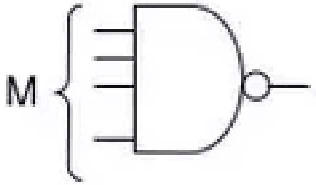
For the open-circuit or unloaded ($Z_L = \infty$), voltage is $V_L = V_S$. ➔ not for the real experiment

To preserve maximum signal level, one normally wants V_L to be as large a fraction of V_S as possible.
For $Z_L \gg Z_0$ then $V_L \cong V_S$ ➔ Fan-In & Fan-Out, Discriminator, ADC, etc

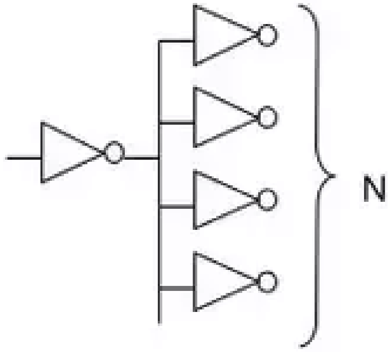
For $Z_L = Z_0$ then $V_L = V_S/2$ ➔ Divider or Splitter

Fan-In and Fan-Out (FIFO)

Fan-in: maximum number of input signals feeding into the input of a logic system

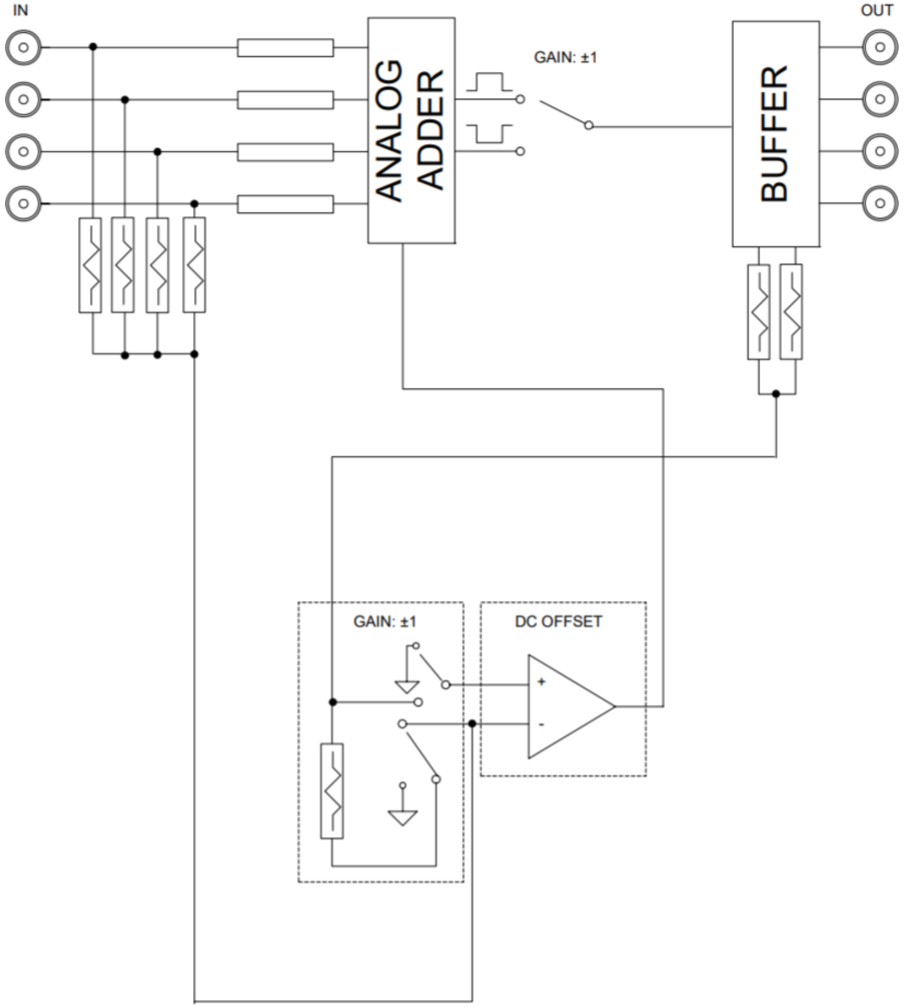


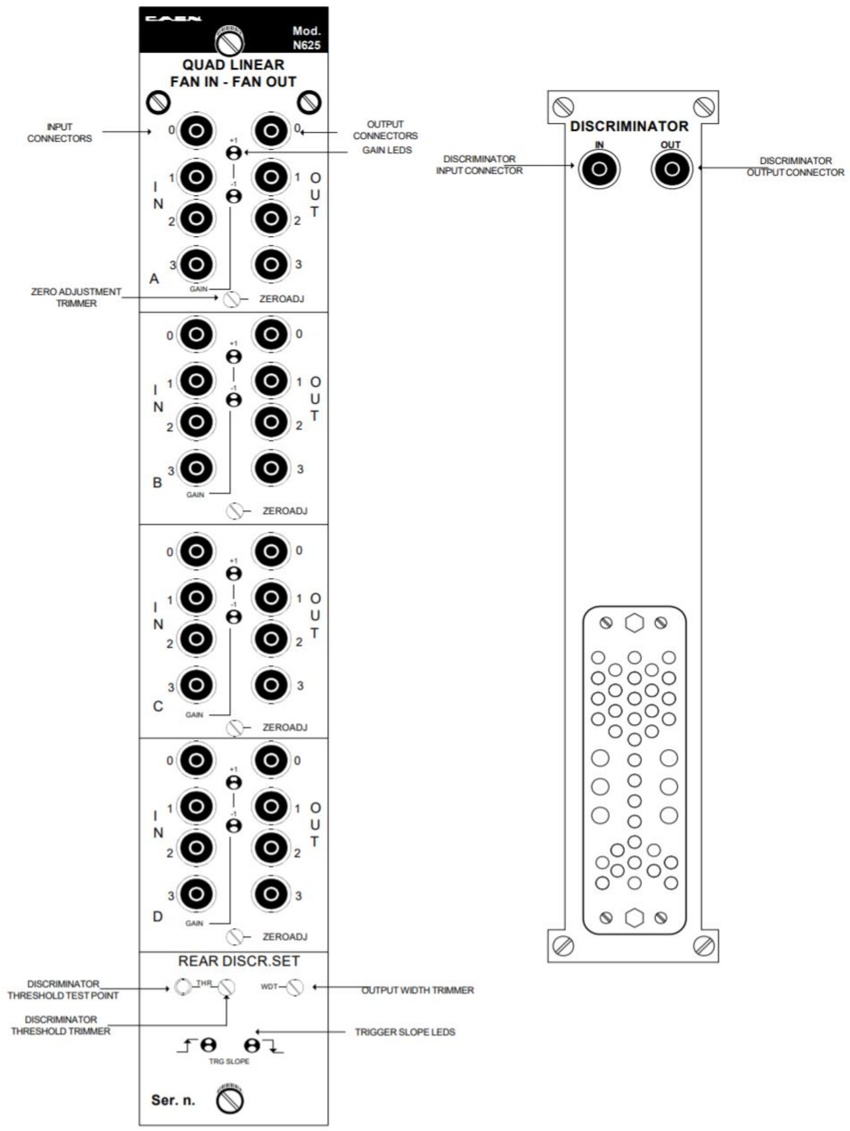
Fan-out: maximum number of output signals from the output of a logic system



Fan-In and Fan-Out (FIFO)

https://www.caen.it





CAEN N625 Quad Linear Fan In / Fan Out

Preamplifier

Role	**converting a raw signal from the detector into output signal with gain**
Location	**placing close to the detector to reduce the noise and avoid the signal loss**

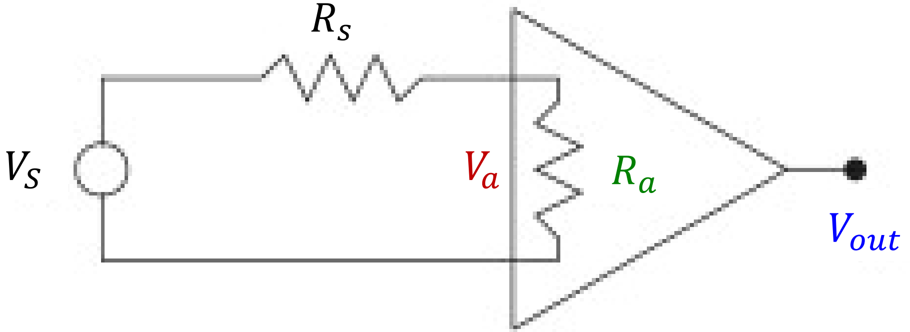
✓ **Specification for design**
- Dynamic range
- Size of input signal
- Pulse pileup
- Signal-to-noise ratio
- Power consumption

✓ **Configuration**
- Voltage-sensitive preamplifiers
- Current-sensitive preamplifiers
- Charge-sensitive preamplifiers

Radiation Detection and Measurement, Glenn F. Knoll
https://www.sciencedirect.com/topics/physics-and-astronomy/preamplifiers

Voltage-sensitive preamplifiers

https://www.sciencedirect.com/topics/physics-and-astronomy/preamplifiers



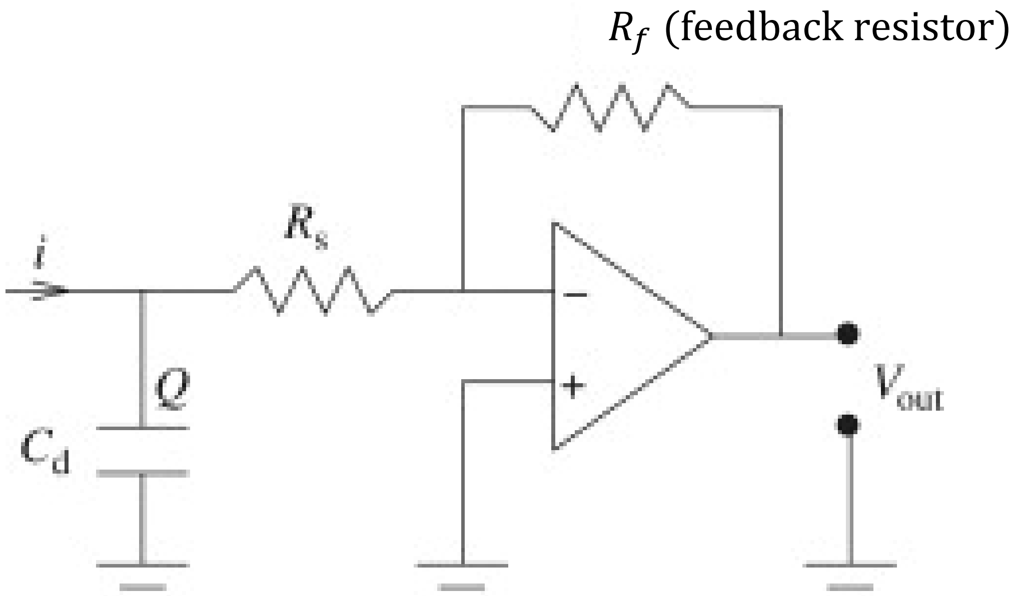
Design principle of V-sensitive preamp

Signal voltage V_S
Voltage at the input stage of the amplifier V_a
Output voltage V_{out}

$$V_a = V_S \frac{R_a}{R_s + R_a}$$

Any current drawn would decrease the potential drop across R_s.
Ideally, its input resistance have to be infinite.
But it can only be achieved up to a good approximation.

For $R_a \gg R_S$ then $V_a \cong V_S$
then $V_{out} = Gain \times V_a \approx Gain \times V_S$



Simplified realistic V-sensitive preamp

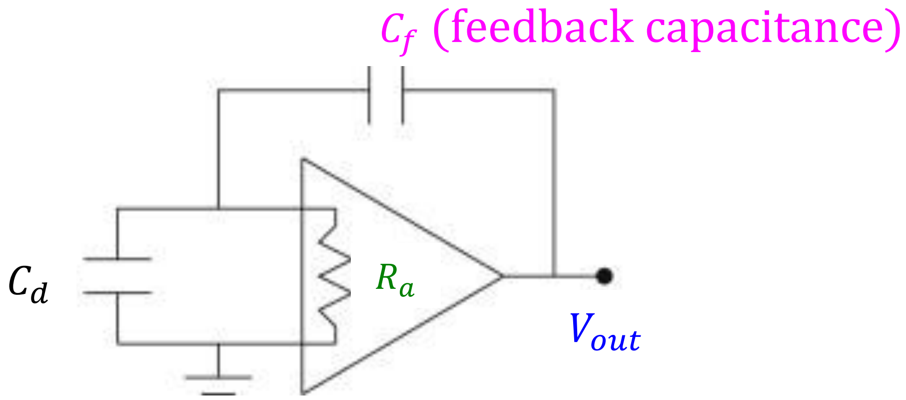
Signal voltage V_S = Q/C_d
Q: collected charge on the readout electrode ($Q = \int_0^{t_0} i_s(t)\,dt$)
C_d: combined detector and stray capacitance

then $V_{out} \approx Gain \times \frac{Q}{C_d}$

Since we are integrating the current to convert it into voltage, **C_d should discharge slower than the charge collection time** $t_d << R_aC_d$.

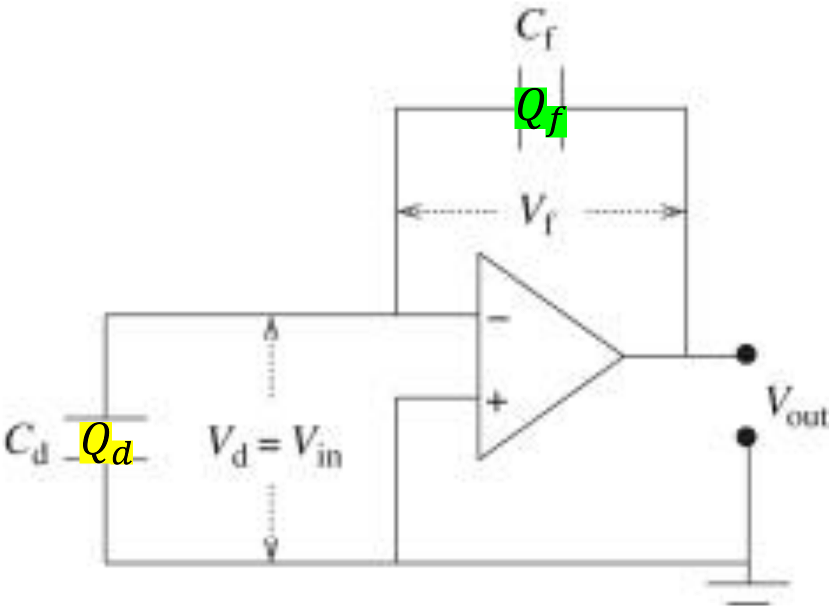
Charge-sensitive preamplifiers

https://www.sciencedirect.com/topics/physics-and-astronomy/preamplifiers



Basic principle of Q-sensitive preamp

The **dependence of a voltage-sensitive preamplifier on the** **input capacitance (C_f)** is a serious problem for many detection systems.
➔ to develop Q-sensitive preamplifiers



Simplified realistic Q-sensitive preamp

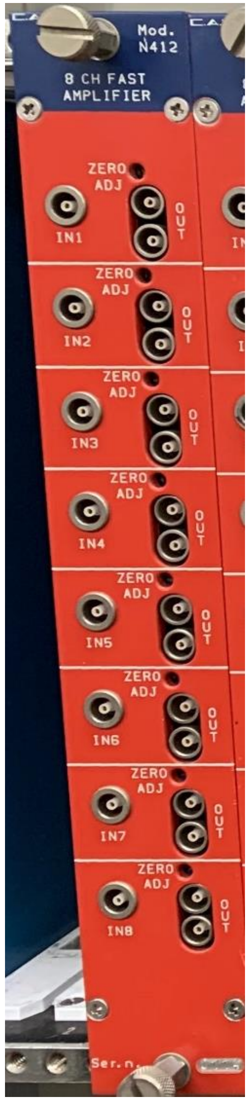
The charge (Q_d) accumulated on the electrode (C_d) is integrated on feedback capacitor (C_f).
Then the potential (V_f) on that capacitor is then directly proportional to the original charge (Q_d) on the detector.

$$V_{out} \propto \frac{Q_f}{C_f} \propto \frac{Q_d}{C_f}$$

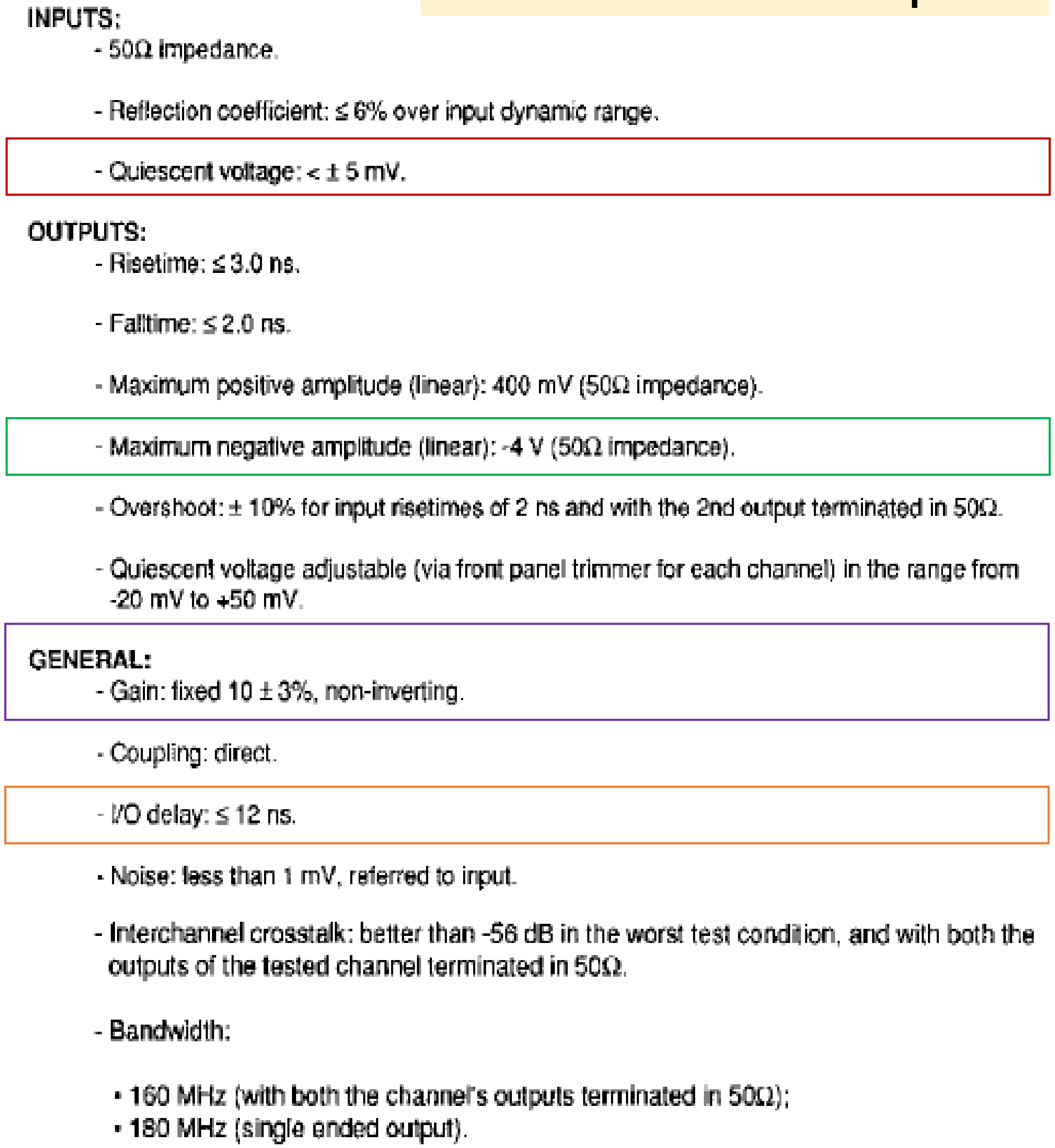
The condition that $Q_f \approx Q_d$ can only be achieved if no current flows into the preamplifier's input with $R_a \rightarrow \infty$.

Preamplifiers

CAEN N412 8ch Fast Amplifier



https://www.caen.it



INPUTS:

- 50Ω impedance.
- Reflection coefficient: ≤ 6% over input dynamic range.
- Quiescent voltage: < ± 5 mV.

OUTPUTS:

- Risetime: ≤ 3.0 ns.
- Falltime: ≤ 2.0 ns.
- Maximum positive amplitude (linear): 400 mV (50Ω impedance).
- Maximum negative amplitude (linear): -4 V (50Ω impedance).
- Overshoot: ± 10% for input risetimes of 2 ns and with the 2nd output terminated in 50Ω.
- Quiescent voltage adjustable (via front panel trimmer for each channel) in the range from -20 mV to +50 mV.

GENERAL:

- Gain: fixed 10 ± 3%, non-inverting.
- Coupling: direct.
- I/O delay: ≤ 12 ns.
- Noise: less than 1 mV, referred to input.
- Interchannel crosstalk: better than -56 dB in the worst test condition, and with both the outputs of the tested channel terminated in 50Ω.
- Bandwidth:
  - 160 MHz (with both the channel's outputs terminated in 50Ω);
  - 180 MHz (single ended output).

Digital Pulse Processing on Fast Electronics

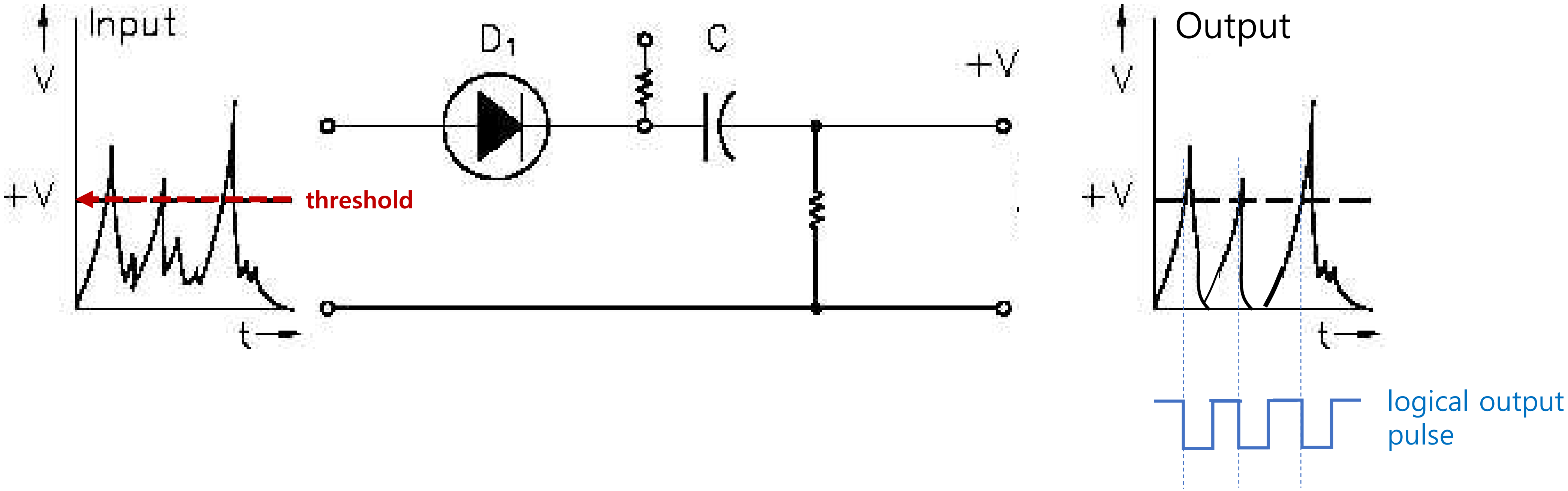
Discriminator (Disc.)
Coincidence Logic Unit (Coin.)

Discriminator (DISC)

http://nuclearpowertraining.tpub.com/h1013v2/css/Discriminator-Circuit-83.htm

Role: generating the logical output pulse when the input pulse exceeds the discriminator preset level

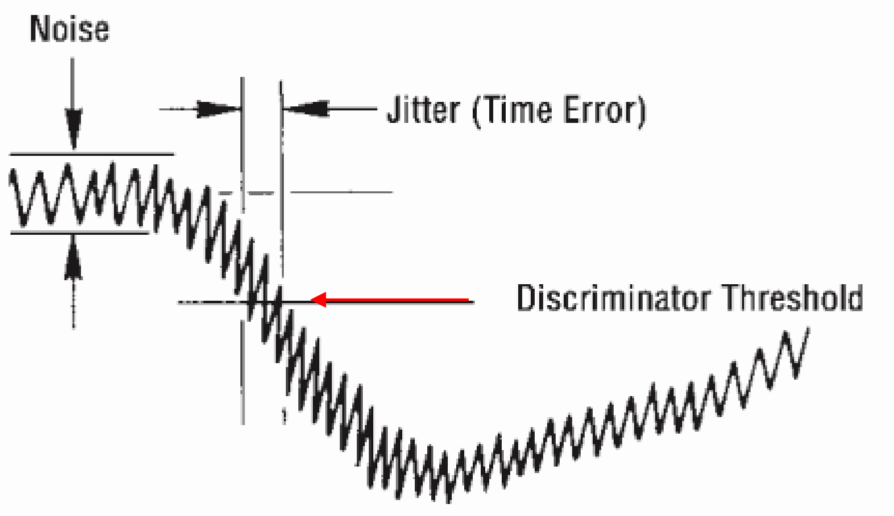
➔ If input voltages **exceeds the threshold value +V** then diode D_1 conducts and **DISC generates the logical output pulses**.



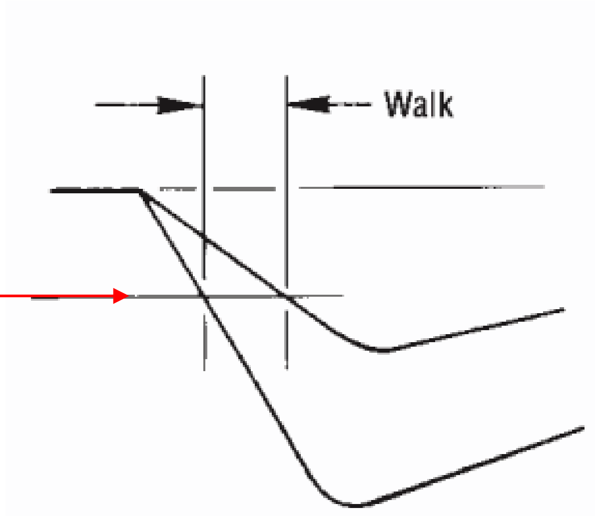
Timing jitter and walk

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

Timing jitter in a pulse



Timing walk among pulses



The contribution of noise to the (Timing) Jitter

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

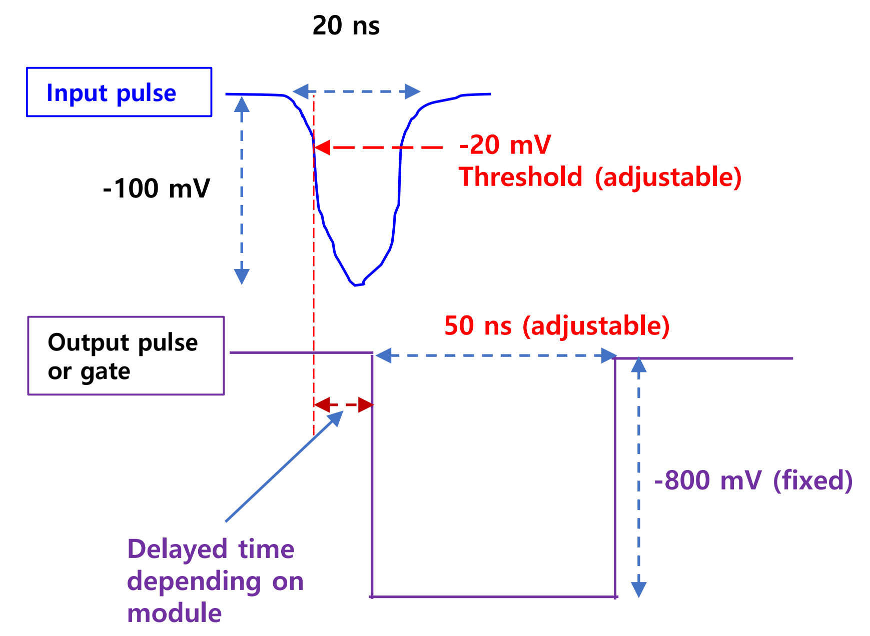
e$_{noise}$: voltage amplitude of the noise superimposed on the analog pulse

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.**

LED and CFD

Leading Edge Discrimination (LED)



20 ns

Input pulse

-100 mV

-20 mV
Threshold (adjustable)

Output pulse or gate

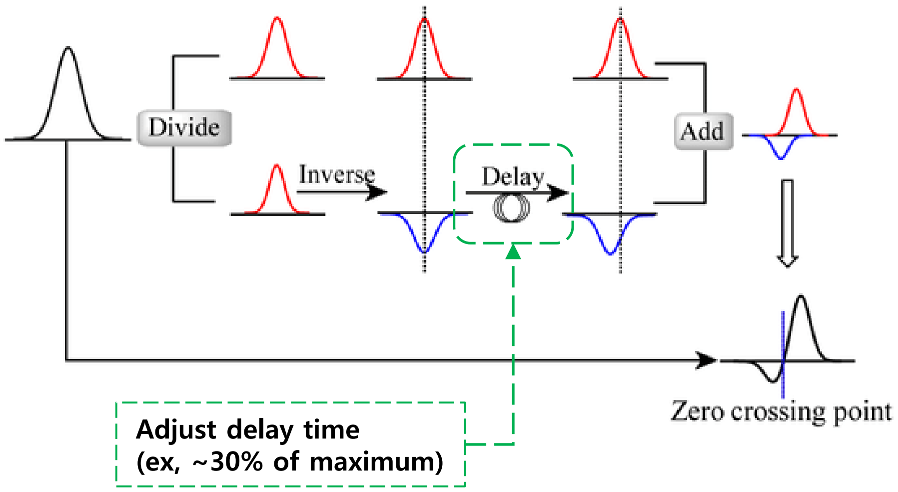
50 ns (adjustable)

-800 mV (fixed)

Delayed time depending on module

Constant Fraction Discrimination (CFD)

Tuhin Khan's Ph. D. thesis



Divide

Inverse

Delay

Add

Zero crossing point

Adjust delay time
(ex, ~30% of maximum)

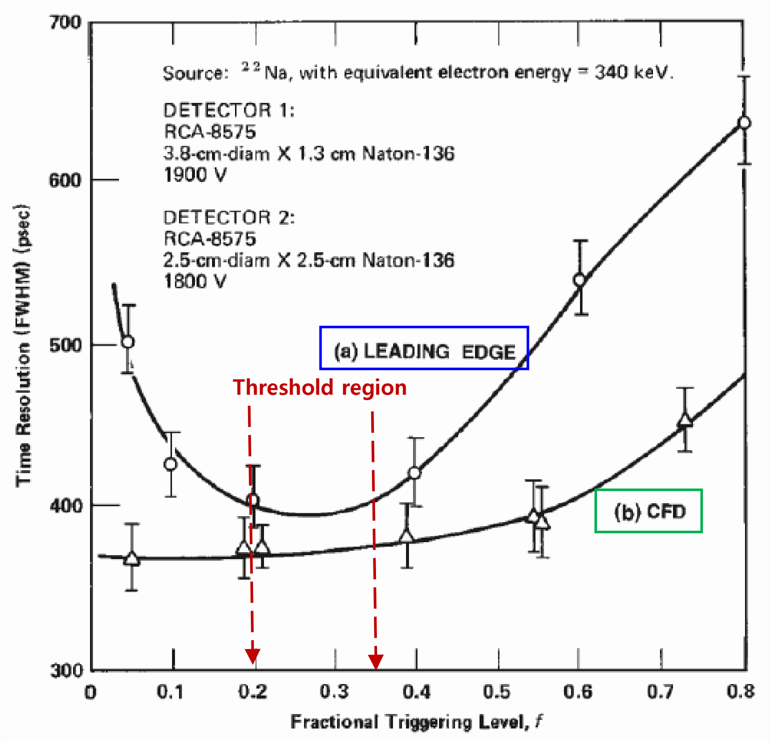


Fig. 2. A Comparison of Leading-Edge Timing with Constant-Fraction Timing for a Narrow Pulse-Height Range. The source was ^{22}Na, with the selected equivalent electron energy in the scintillator = 340 keV. The time resolution (FWHM) is Δ t.

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

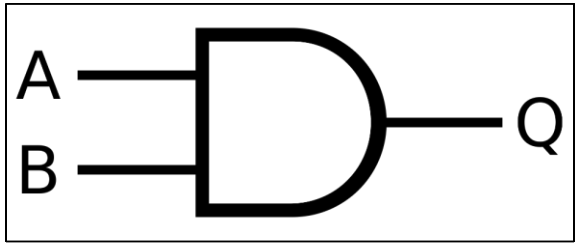
Time resolution: $\sigma_{CFD} < \sigma_{LED}$

Role of Logic Unit

https://www.wekipedia.com

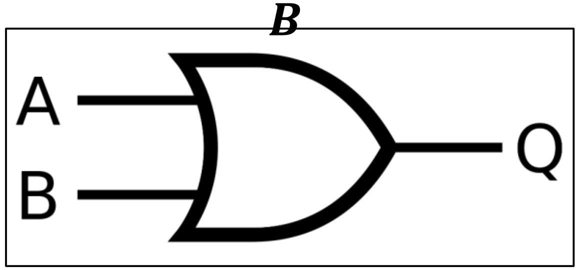
Role: generating the gating pulse when the preset of logical algorism against with inputs is true

AND logic: $\boldsymbol{A \cdot B}$ **or** $\boldsymbol{A \wedge B}$



INPUT		OUTPUT
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

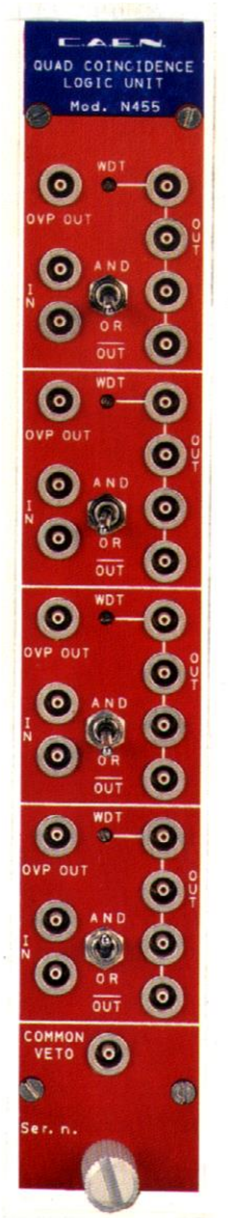
OR logic: $\boldsymbol{A + B}$ **or** $\boldsymbol{A \vee B}$

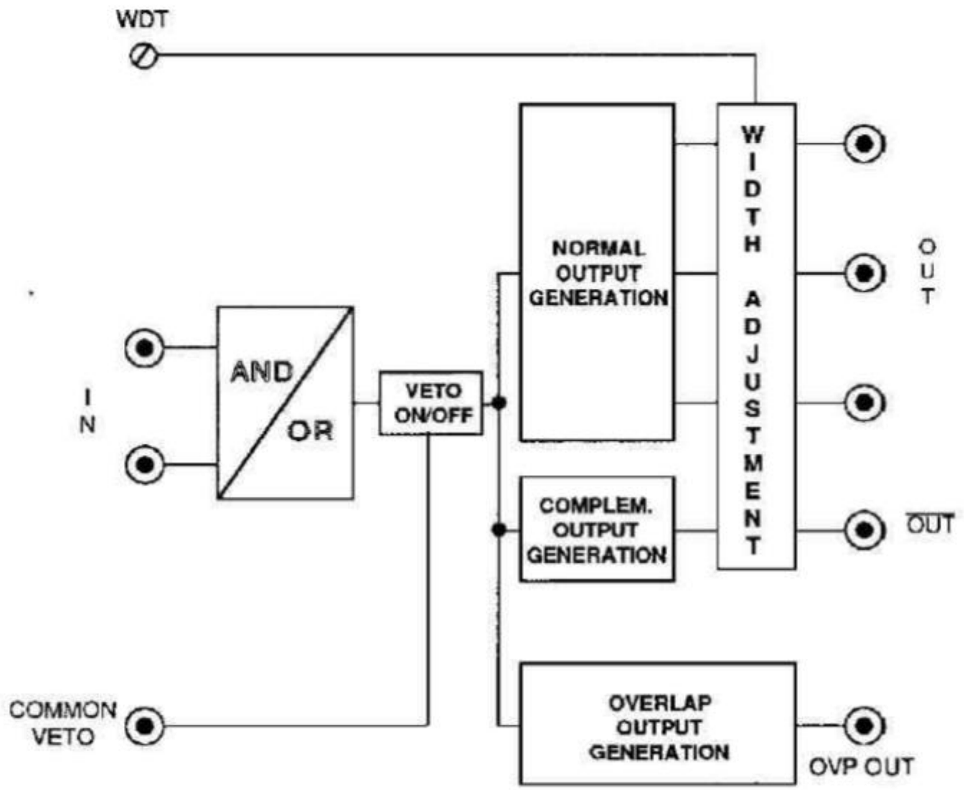


INPUT		OUTPUT
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

Logic Unit

https://www.caen.it



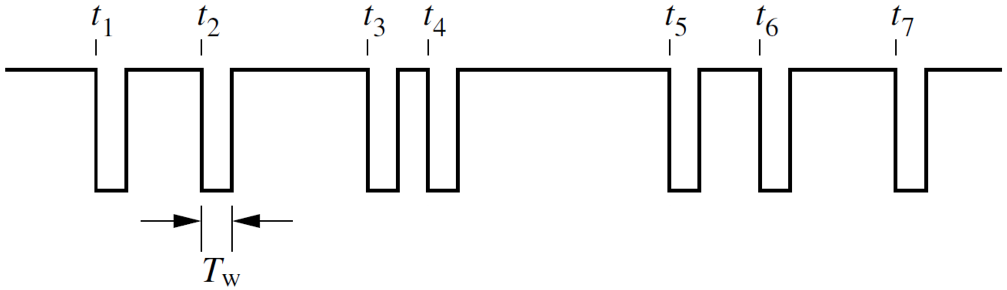


IMPORTANT NOTE:
Unused Outputs require a 50 Ω termination

CAEN N455 Quad Coincidence Logic Unit

How many accidental events will occur?

Single random pulse trains



Counting statistics of random events

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,

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

Oscilloscope

Oscilloscope

Components of waveform

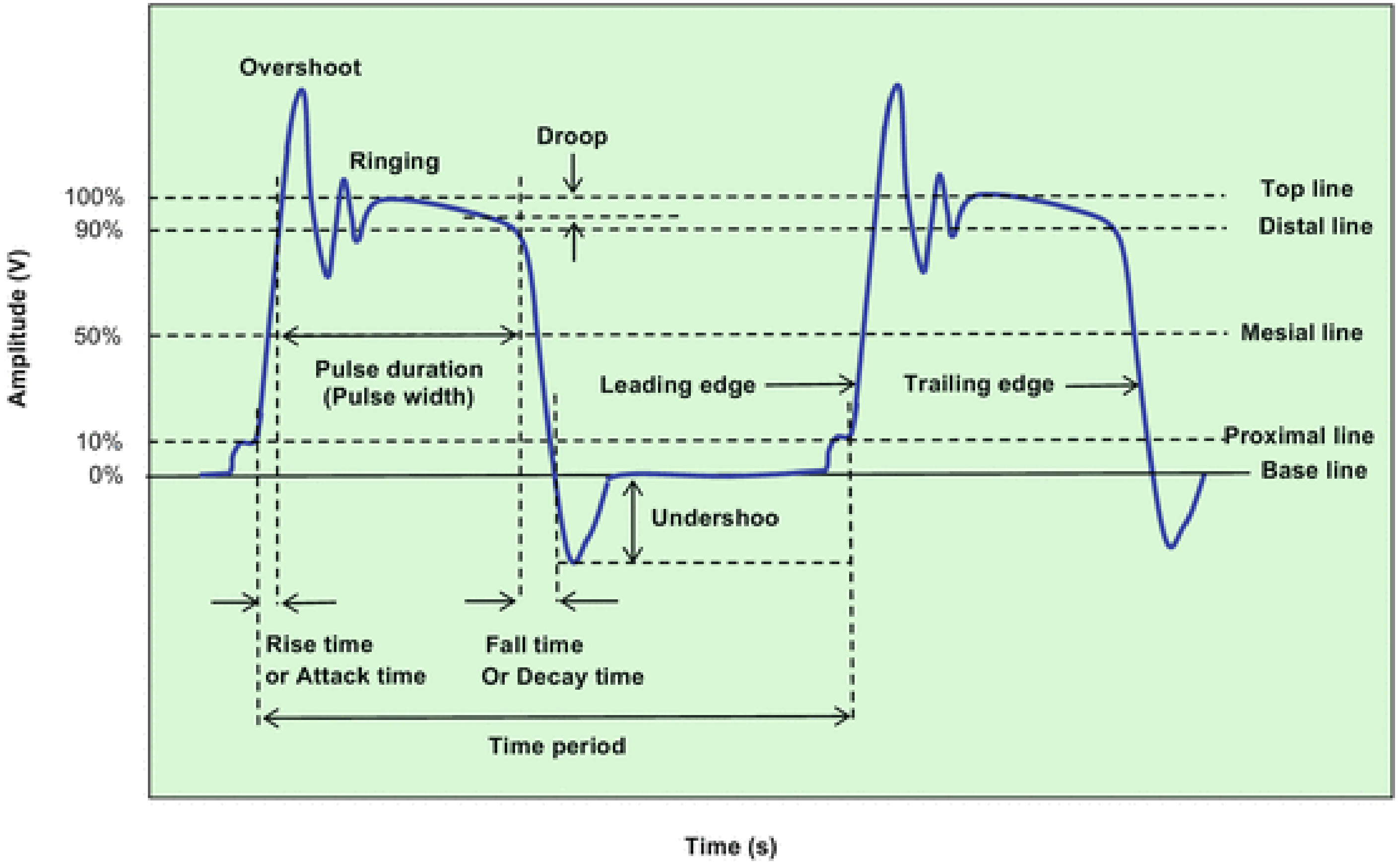
Base line
Pulse height
Pulse width

Proximal line: 10% of pulse height
Mesial line: 50% of pulse height
Distal line: 90% of pulse height

Rise time (or attack time) **at leading edge**
Fall time (or decay time) **at trailing edge**
➔ These depend on the polarity of waveform.

Overshoot
Undershoot
Ringing

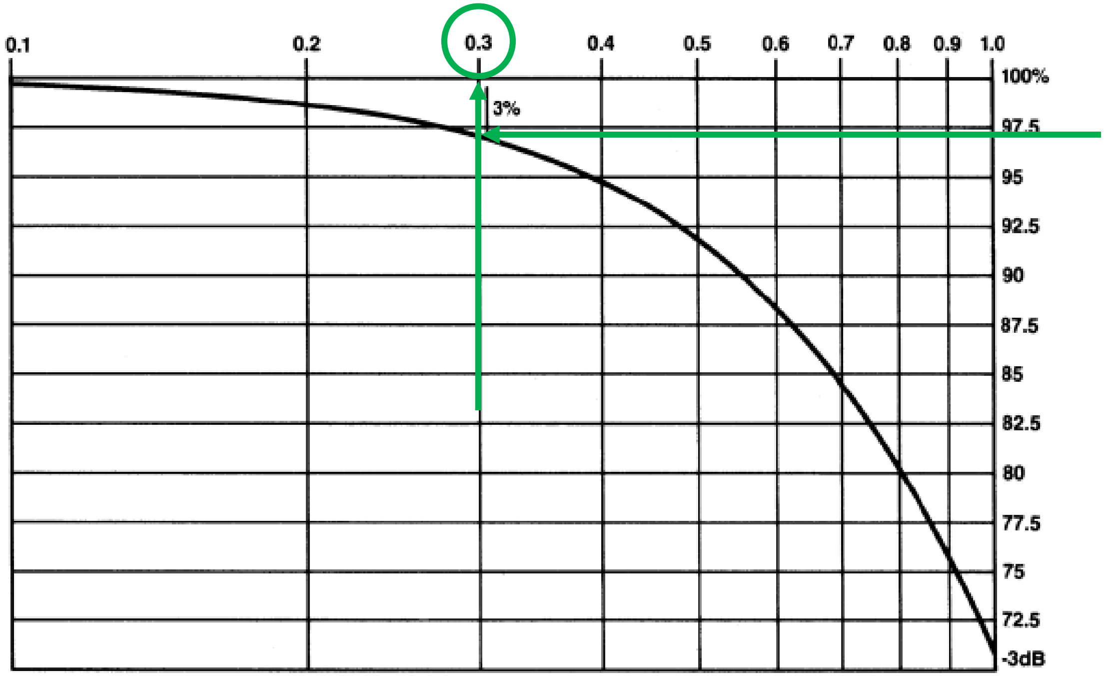
Time period



Amplitude Ambiguity of Pulse Shape

Bandwidth:
오실로스코프 회로를 거치면서 최소 진폭 감쇠가 나타나는 최대 주파수 값
Maximum frequency of an input signal which can pass through the analog front end of the scope **with minimal amplitude loss**

Bandwidth derating curve

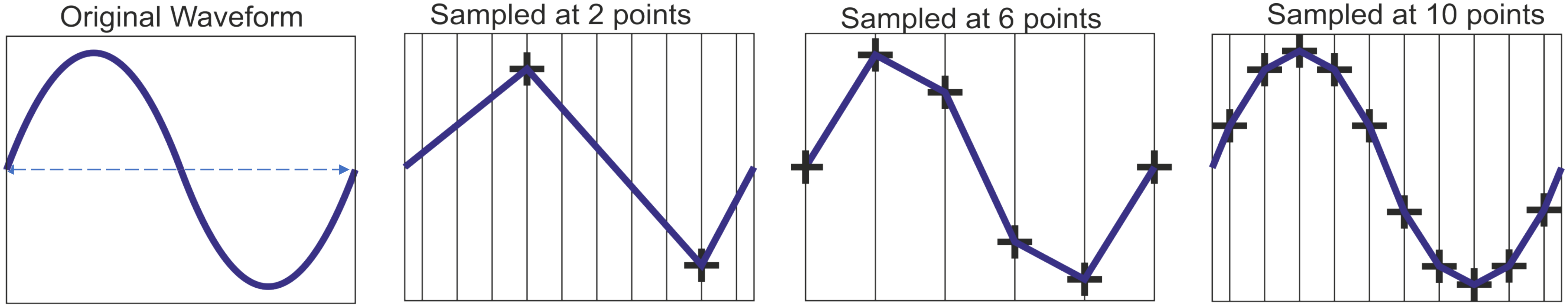


If you require **3% accuracy** of sine wave, you need to derate it by a factor of ~0.3 x (Bandwidth of scope).
➔ A **350 MHz scope** can **accurately measure 105 MHz within 3% accuracy**.

Time Ambiguity of Pulse Shape

Sampling rate:
1초당 최대 샘플수
Maximum number of samples per second

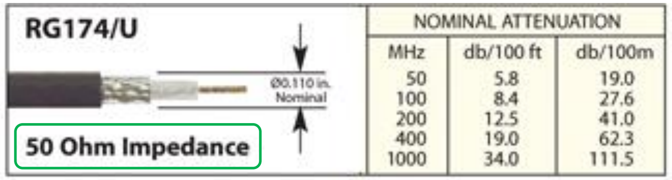
T = 1 sec



Cables & Connectors

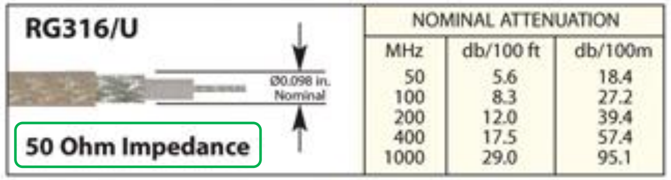
Radio Guide (RG) Cables

Signal transmission


RG174/U

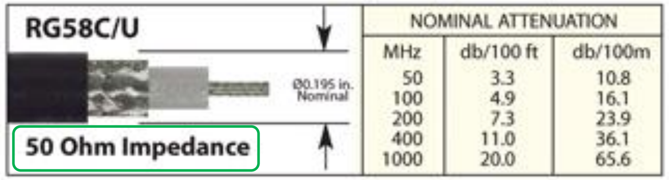
50 Ohm Impedance

NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	5.8	19.0
100	8.4	27.6
200	12.5	41.0
400	19.0	62.3
1000	34.0	111.5


RG316/U

50 Ohm Impedance

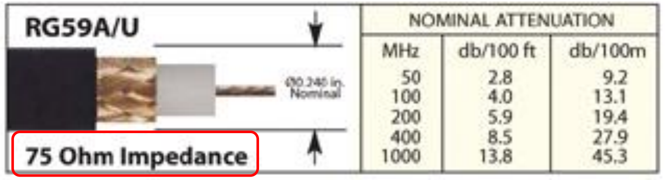
NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	5.6	18.4
100	8.3	27.2
200	12.0	39.4
400	17.5	57.4
1000	29.0	95.1


RG58C/U

50 Ohm Impedance

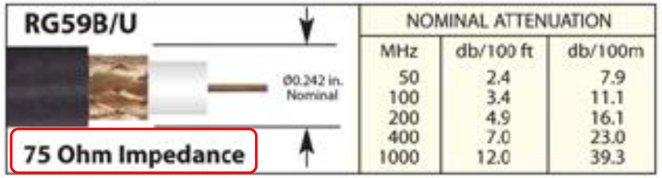
NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	3.3	10.8
100	4.9	16.1
200	7.3	23.9
400	11.0	36.1
1000	20.0	65.6

HV transmission


RG59A/U

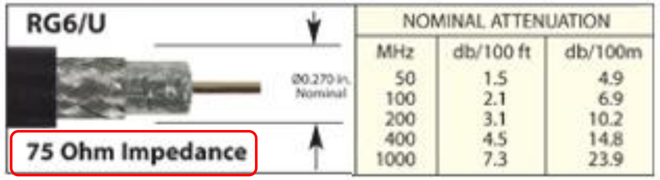
75 Ohm Impedance

NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	2.8	9.2
100	4.0	13.1
200	5.9	19.4
400	8.5	27.9
1000	13.8	45.3


RG59B/U

75 Ohm Impedance

NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	2.4	7.9
100	3.4	11.1
200	4.9	16.1
400	7.0	23.0
1000	12.0	39.3


RG6/U

75 Ohm Impedance

NOMINAL ATTENUATION		
MHz	db/100 ft	db/100m
50	1.5	4.9
100	2.1	6.9
200	3.1	10.2
400	4.5	14.8
1000	7.3	23.9

http://www.l-com.com/content/Article.aspx?Type=N&ID=10336

How fast signals move in cables? v_{signal} = ~5 ns/m

	c (m/s)	Velocity Fraction (%)	v (m/s)	v (m/ns)	v (cm/ns)	Connector type
Vacuum	3.00E+08	1	3.00E+08	0.300	30.0	
RG174	3.00E+08	0.66	1.98E+08	0.198	19.8	**LEMO**
RG316	3.00E+08	0.79	2.37E+08	0.237	23.7	**LEMO**
RG58	3.00E+08	0.66	1.98E+08	0.198	19.8	**BNC**

Power loss $\alpha_P(dB/km) = \frac{10}{L} log_{10}^{(P_1/P_2)}$

α_P = power attenuation, or loss between source and destination, unit (dB/km)
P_1 = power at the beginning (Source), unit (W)
P_2 = power at the end (Destination), unit (W)
L = distance between P_1 and P_2, unit (km)

If P_1 = 1 W, P_2 = 0.5 W, and L = 0.1 km, $\alpha_P = \frac{10}{0.1} log_{10}^{(1/0.5)}$ = 3.01 dB/100m

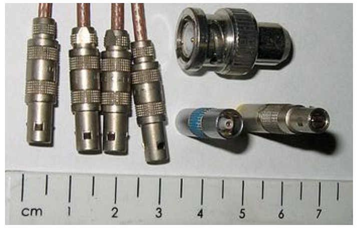
Power at the distance (L) : $P_2 = P_1 \cdot \exp(-\alpha_P L)$

RG58/U: 20 AWG (Φ0.812 mm) bare copper (28.5 pF/ft)
RG58A/U: 20 AWG standard thin copper (30.8 pF/ft)
RG58C/U: same as RG58A/U but not same outer jacket material

RG59A/U: 22 AWG (Φ0.644 mm) bare compacted copper
RG59B/U: 22 AWG solid bare copper covered steel

U: Universal
AWG: American Wire Gauge

Connectors for signal pulse and high voltage



Signal connection

LEMO (company founder, engineer **Lé**on **Mo**uttet)
name of an electronic and fibre optic connector manufacturer
push-pull connectors
NIM, CAMAC, VME, detector, and etc

BNC (Bayonet Neill-concelman) connector: miniature quick connect/disconnect
50 or 75 ohm impedance
frequencies below 4 GHz
voltage below 500 V
NIM, audio, video, detector and etc

SMA (Sub Miniature version A): semi-precision coaxial RF connectors
screw-type coupling mechanism
male Φ0.312 in (Φ7.9 mm)
0-18 GHz passband (some up to 26.5 GHz)
detector and etc

High voltage connection

MHV (miniature high voltage): type of RF connector used for terminating a coaxial cable

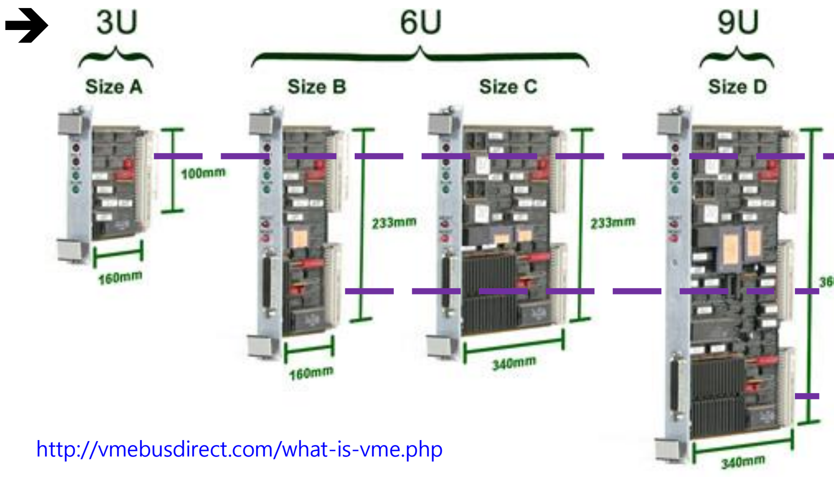
SHV (**safe high voltage**) **connector:** safer handling HV than other connectors
standard: up to5 kV (5 A)
higher-version: 20 kV or more
NIM, detector, and etc

VME (ADC and TDC)

VersaModular Eurocard (VME)

1 U rack size = 4.445 cm

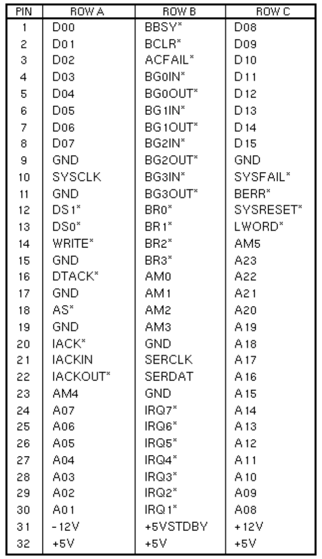
Height ➔



http://vmebusdirect.com/what-is-vme.php

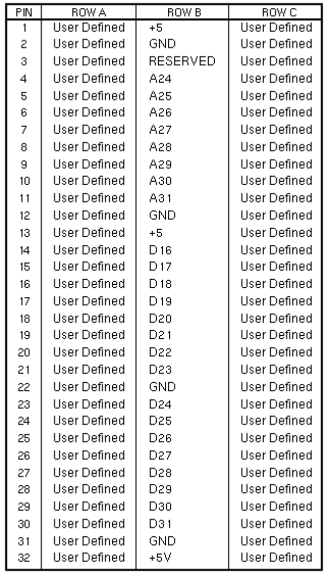
Width of VME modules: 20.3 mm

VME bus J1/P1 Pinouts



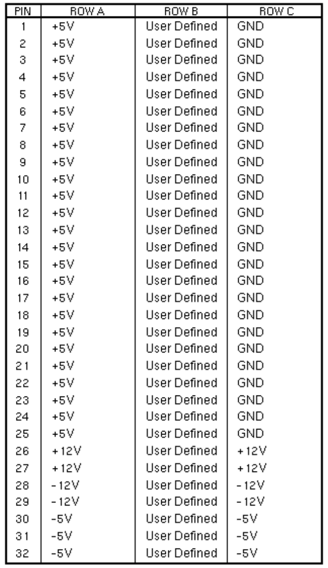
PIN	ROW A	ROW B	ROW C
1	D00	BBSY*	D08
2	D01	BCLR*	D09
3	D02	ACFAIL*	D10
4	D03	BG0IN*	D11
5	D04	BG0OUT*	D12
6	D05	BG1IN*	D13
7	D06	BG1OUT*	D14
8	D07	BG2IN*	D15
9	GND	BG2OUT*	GND
10	SYSCLK	BG3IN*	SYSFAIL*
11	GND	BG3OUT*	BERR*
12	DS1*	BR0*	SYSRESET*
13	DS0*	BR1*	LWORD*
14	WRITE*	BR2*	AM5
15	GND	BR3*	A23
16	DTACK*	AM0	A22
17	GND	AM1	A21
18	AS*	AM2	A20
19	GND	AM3	A19
20	IACK*	GND	A18
21	IACKIN	SERCLK	A17
22	IACKOUT*	SERDAT	A16
23	AM4	GND	A15
24	A07	IRQ7*	A14
25	A06	IRQ6*	A13
26	A05	IRQ5*	A12
27	A04	IRQ4*	A11
28	A03	IRQ3*	A10
29	A02	IRQ2*	A09
30	A01	IRQ1*	A08
31	-12V	+5VSTDBY	+12V
32	+5V	+5V	+5V

VME bus J2/P2 Pinouts



PIN	ROW A	ROW B	ROW C
1	User Defined	+5	User Defined
2	User Defined	GND	User Defined
3	User Defined	RESERVED	User Defined
4	User Defined	A24	User Defined
5	User Defined	A25	User Defined
6	User Defined	A26	User Defined
7	User Defined	A27	User Defined
8	User Defined	A28	User Defined
9	User Defined	A29	User Defined
10	User Defined	A30	User Defined
11	User Defined	A31	User Defined
12	User Defined	GND	User Defined
13	User Defined	+5	User Defined
14	User Defined	D16	User Defined
15	User Defined	D17	User Defined
16	User Defined	D18	User Defined
17	User Defined	D19	User Defined
18	User Defined	D20	User Defined
19	User Defined	D21	User Defined
20	User Defined	D22	User Defined
21	User Defined	D23	User Defined
22	User Defined	GND	User Defined
23	User Defined	D24	User Defined
24	User Defined	D25	User Defined
25	User Defined	D26	User Defined
26	User Defined	D27	User Defined
27	User Defined	D28	User Defined
28	User Defined	D29	User Defined
29	User Defined	D30	User Defined
30	User Defined	D31	User Defined
31	User Defined	GND	User Defined
32	User Defined	+5V	User Defined

VME bus J3/P3 Pinouts



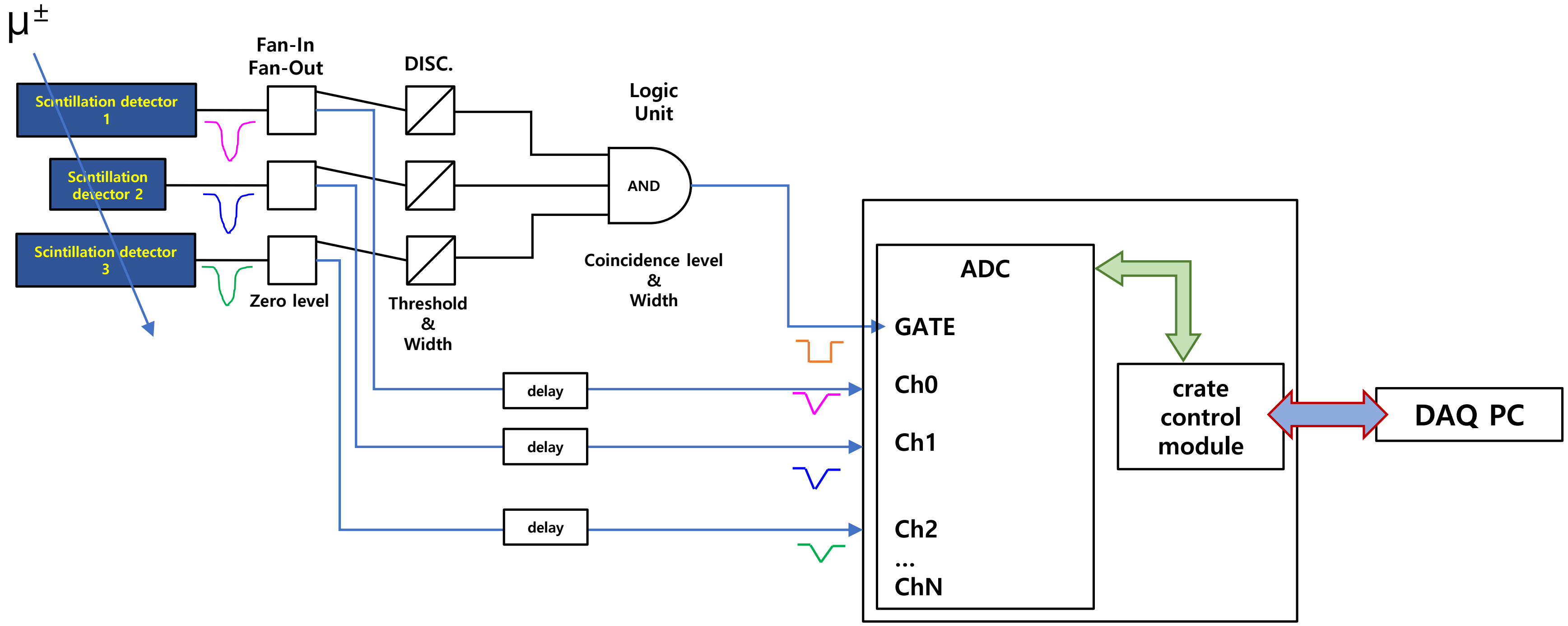
PIN	ROW A	ROW B	ROW C
1	+5V	User Defined	GND
2	+5V	User Defined	GND
3	+5V	User Defined	GND
4	+5V	User Defined	GND
5	+5V	User Defined	GND
6	+5V	User Defined	GND
7	+5V	User Defined	GND
8	+5V	User Defined	GND
9	+5V	User Defined	GND
10	+5V	User Defined	GND
11	+5V	User Defined	GND
12	+5V	User Defined	GND
13	+5V	User Defined	GND
14	+5V	User Defined	GND
15	+5V	User Defined	GND
16	+5V	User Defined	GND
17	+5V	User Defined	GND
18	+5V	User Defined	GND
19	+5V	User Defined	GND
20	+5V	User Defined	GND
21	+5V	User Defined	GND
22	+5V	User Defined	GND
23	+5V	User Defined	GND
24	+5V	User Defined	GND
25	+5V	User Defined	GND
26	+12V	User Defined	+12V
27	+12V	User Defined	+12V
28	-12V	User Defined	-12V
29	-12V	User Defined	-12V
30	-5V	User Defined	-5V
31	-5V	User Defined	-5V
32	-5V	User Defined	-5V

Analog-to-Digital Converter (ADC)

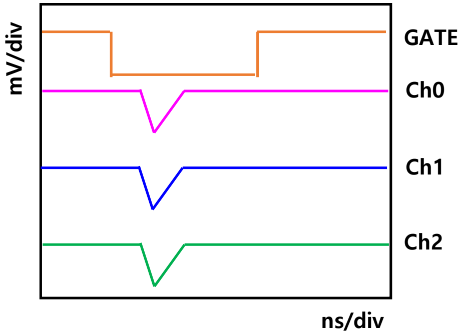
Charge-to-Digital Converter (QDC)

Charge measurements with ADC

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

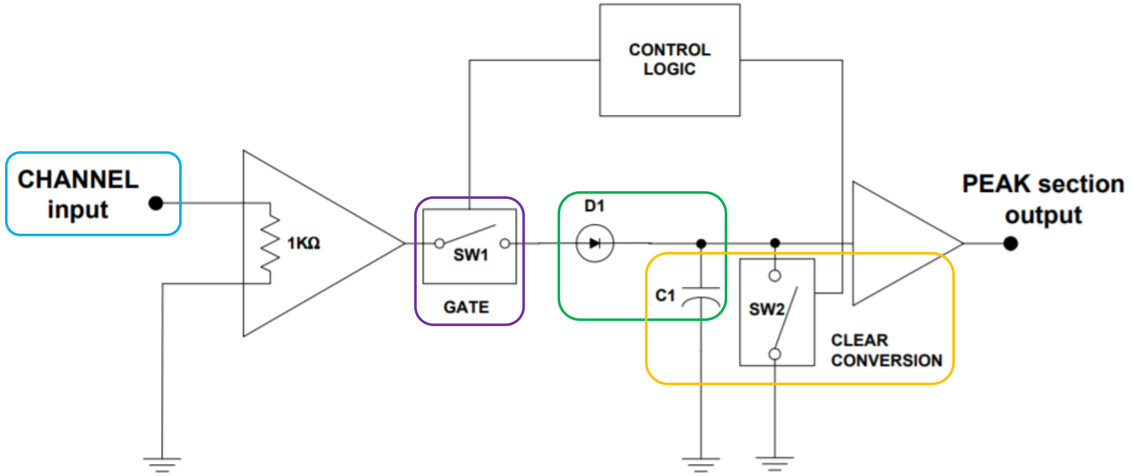


Time domain of signals for ADC



How to record charge in ADC?

https://www.caen.it



Block diagram of PEAK section in CAEN V1785 8ch Dual Range Peak ADC

COMMON STOP mode

The **GATE signal** closes the **switch SW1** thus allowing the **capacitor C1** to be charged as the **diode D1** is forward-biased by the signal.

⬇

As the **SW1** is open again, the signal is digitized by the 12-bit ADCs.

⬇

After digitization the **SW2 switch** is closed by the CLEAR signal which allows the discharge of the **capacitor C1**.

Both the GATE and CLEAR signals are controlled by the CONTROL LOGIC section.

ADC and signal conversion timing

https://www.caen.it

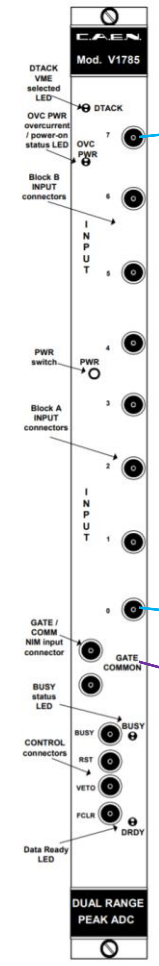


Fig. 3.1: Model V1785 front panel

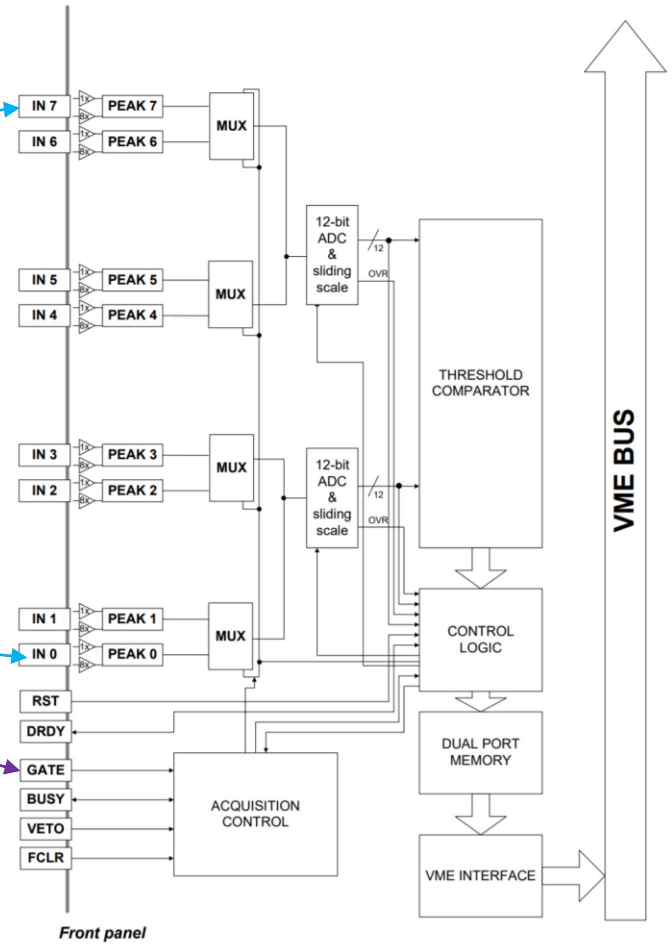


Fig. 1.1: Model V1785 Block Diagram

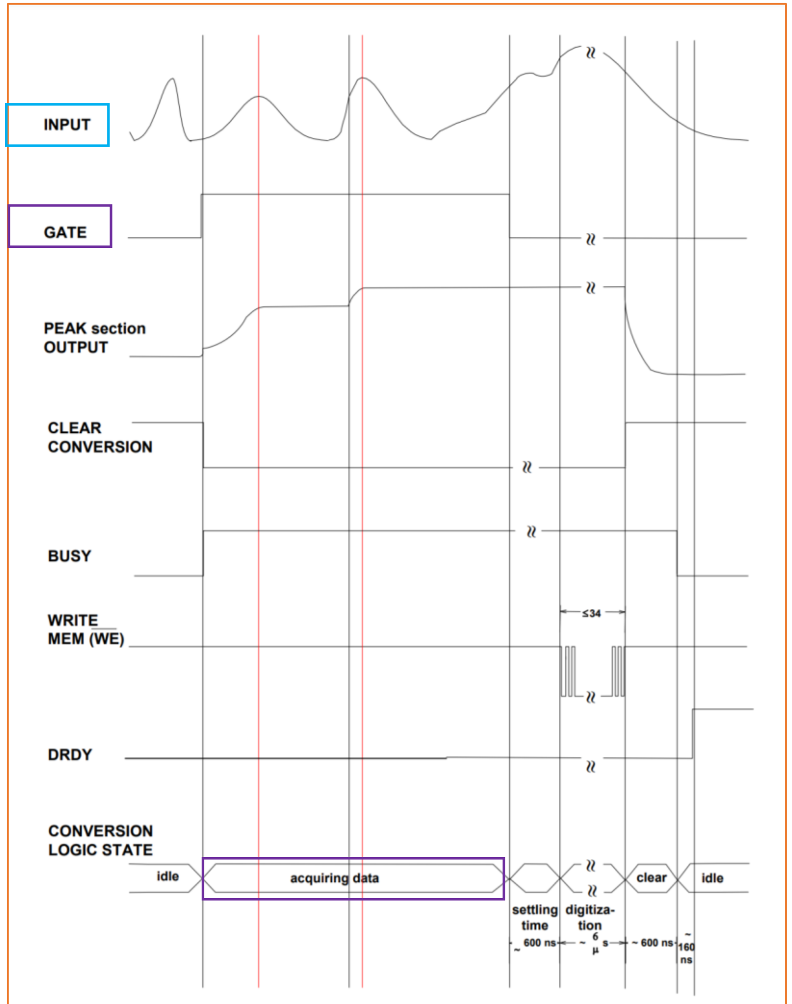


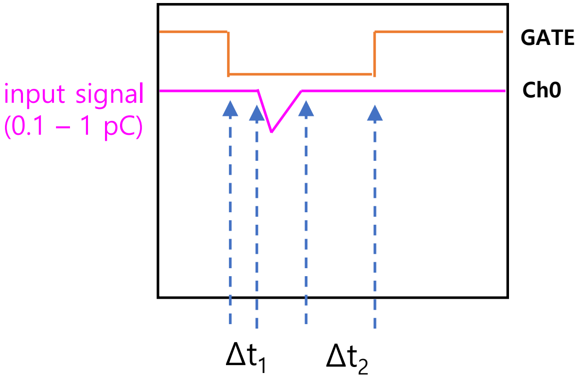
Fig. 2.2: Signal conversion timing

CAEN V1785 8ch Dual Range Peak ADC

Dual input range: 0 ÷ 4 V / 0 ÷ 500 mV
Gain: 1 mV/count and 125 uV/count for High and Low ranges

ADC calibration

Time domain of signals for ADC calibration



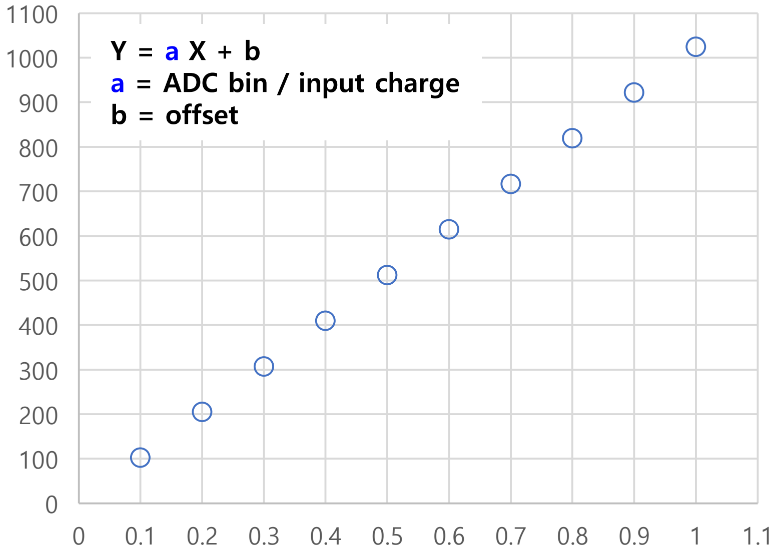
Δt_1 and Δt_2 depends on charge and shape of signal (ex, 10 ns or more).

Full Dynamic Range (FDR) = 1 pC with 10 bit

1	pC
1024	bin
0.00097656	pC/bin

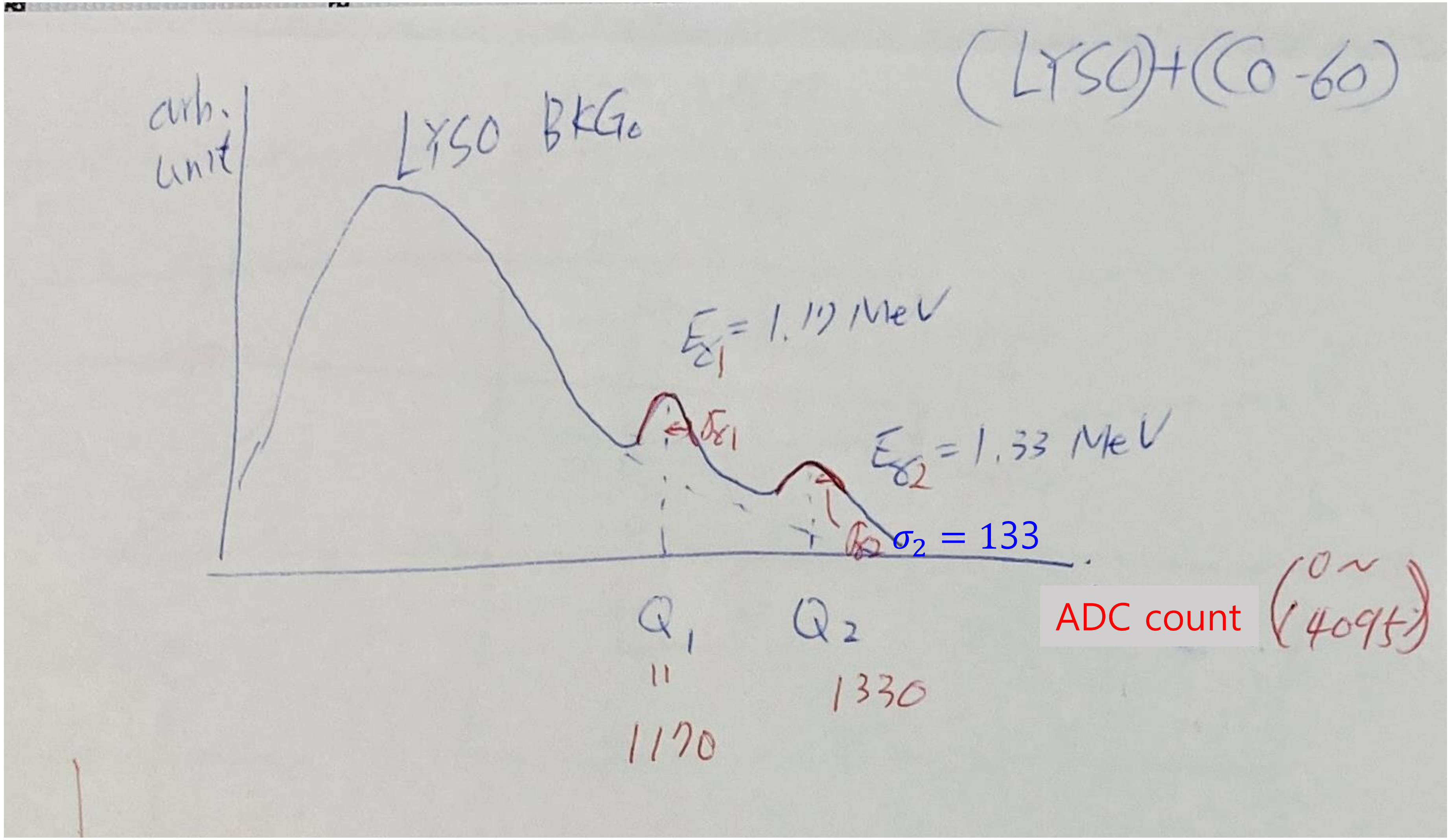
Input charge (pC)	unit charge (pC/bin)	Measured Charge (ADC bin)
0.1	0.000976563	102.4
0.2	0.000976563	204.8
0.3	0.000976563	307.2
0.4	0.000976563	409.6
0.5	0.000976563	512
0.6	0.000976563	614.4
0.7	0.000976563	716.8
0.8	0.000976563	819.2
0.9	0.000976563	921.6
1	0.000976563	1024

Measured Charge (ADC bin) vs input charge (pC)



Y = a X + b
a = ADC bin / input charge
b = offset

Energy Calibration and Resolution



1) Calibration Constant

$$= \frac{E_{in}\,(eV)}{<Q_1>(ADC\ count)}$$

$$= \frac{1.170\ MeV}{1170\ ADC\ counts}$$

$$= 1\,\frac{keV}{ADC\ count}$$

2) Energy Resolution (%)

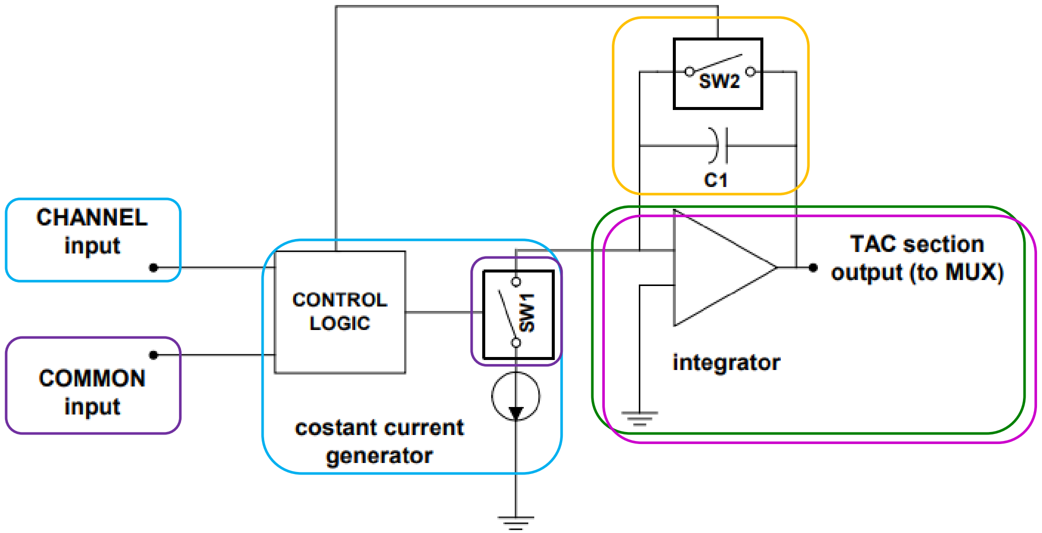
$$= \frac{\sigma_2}{<Q_1>} \times 100(\%)$$

$$= \frac{133}{1330} \times 100(\%) = 10\%$$

Time-to-Digital Converter (TDC)

How to record time in TDC?

https://www.caen.it



Block diagram of TAC section in CAEN V775N 16ch MultiEvent TDCs

A Start signal closes the **switch SW1** thus allowing a constant current to flow through an integrator; a Stop signal opens the **switch SW1** again.

⬇

The constant current generates a **linear ramp voltage which is stopped at an amplitude proportional to the time interval** between Start and Stop pulses. ➔ accumulation on C1

⬇

After digitization the **SW2 switch** is closed by the CLEAR signal which allows the discharge of the **capacitor C1**.

Both the COMMON and CLEAR signals are controlled by the CONTROL LOGIC section.

TDC and signal conversion timing

https://www.caen.it

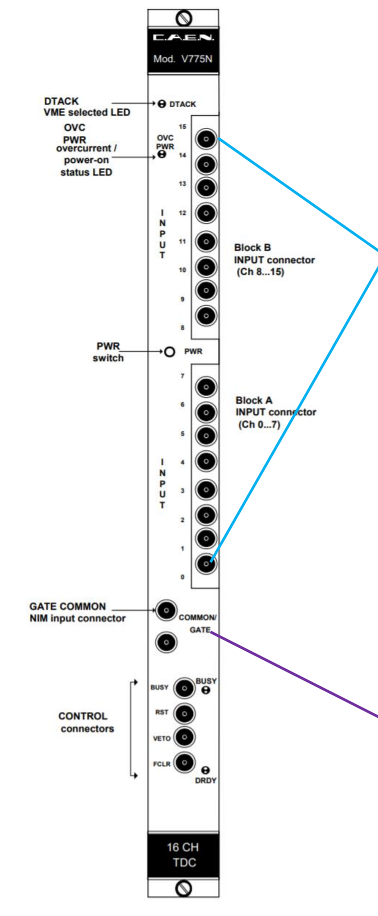
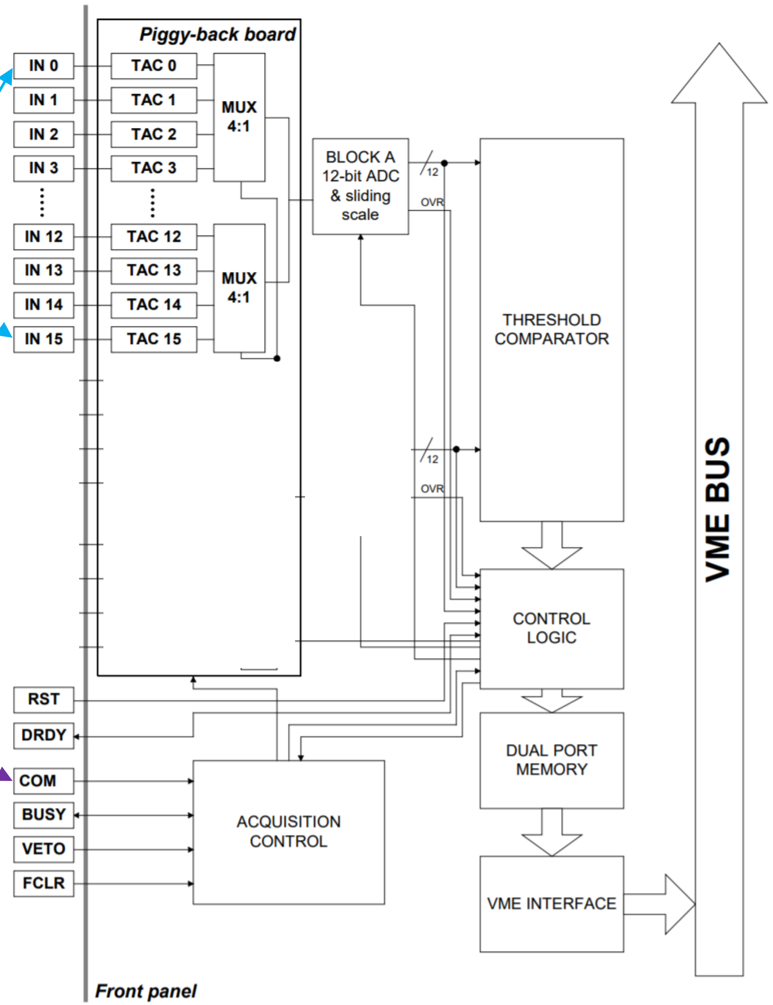


Fig. 3.2: Model V775 N front panel



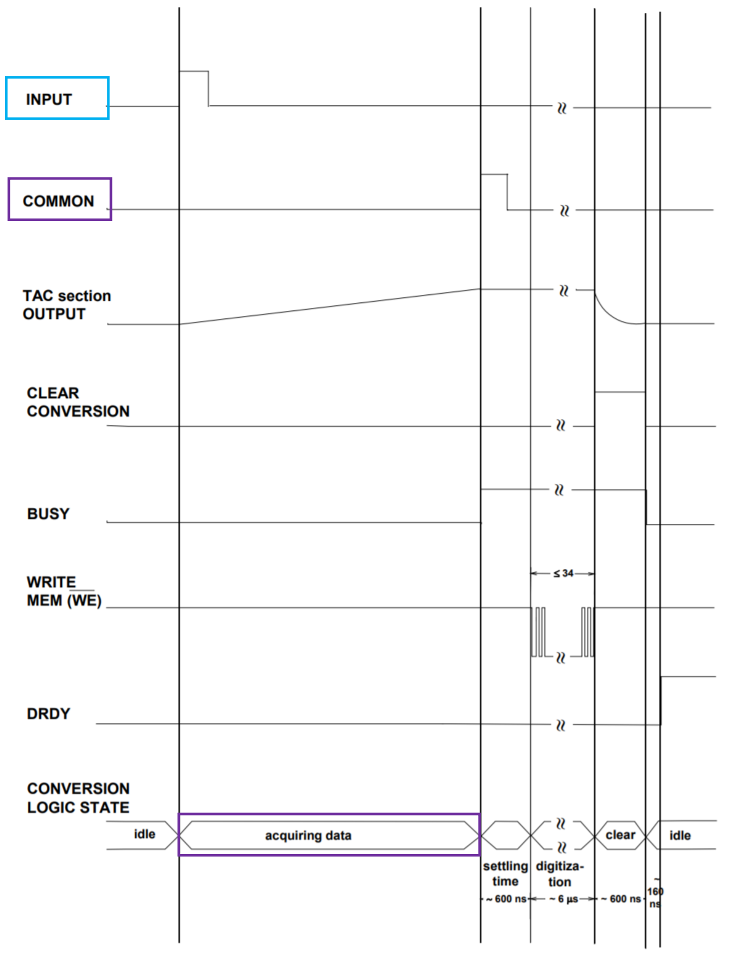


Fig. 2.2: Signal conversion timing in Common Stop mode

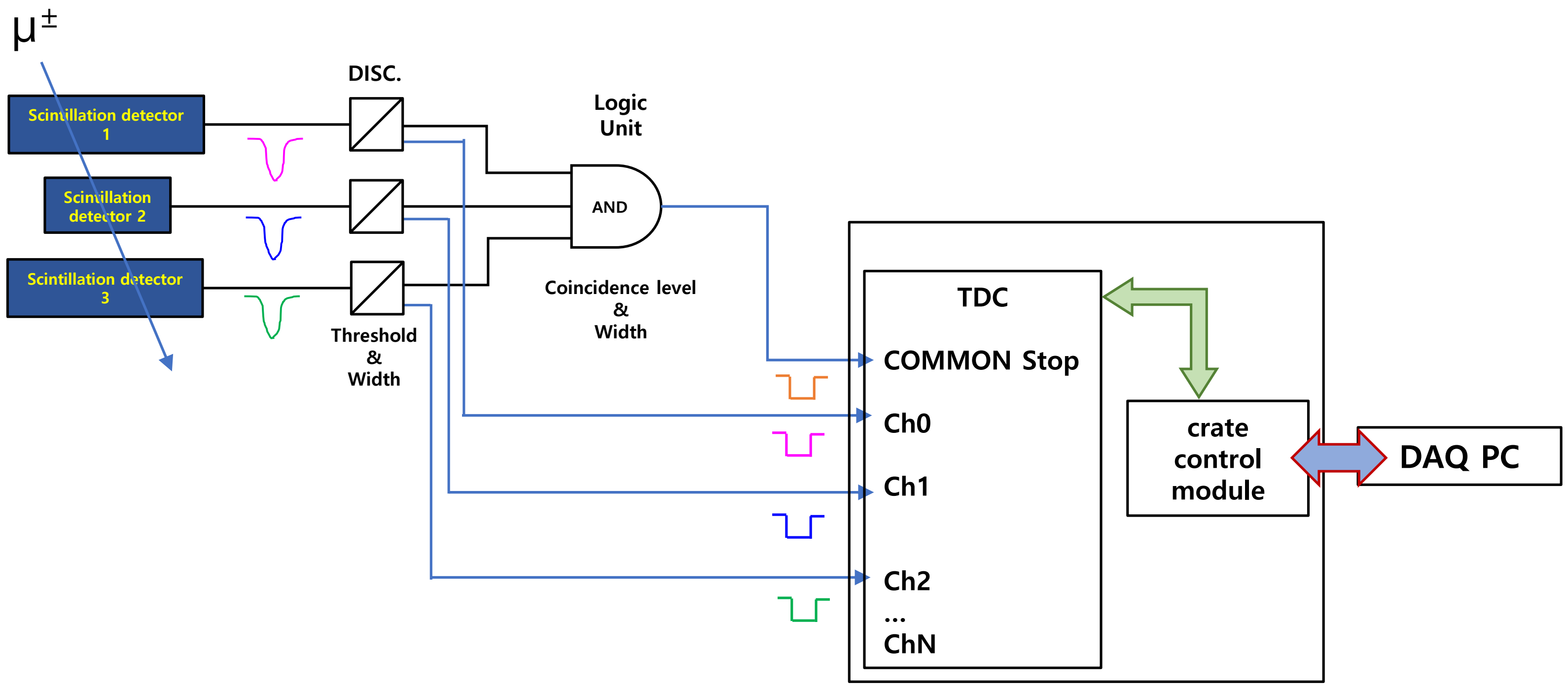
CAEN V775N 16ch MultiEvent TDCs

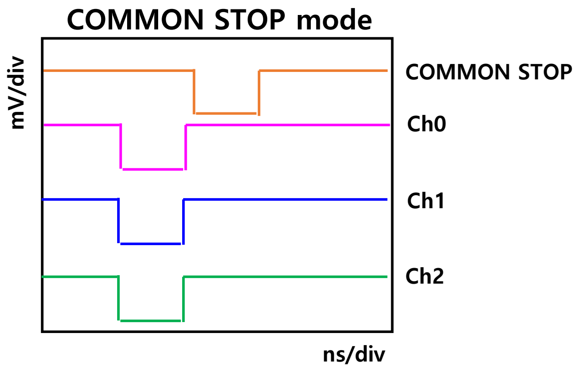
Time measurements with TDC

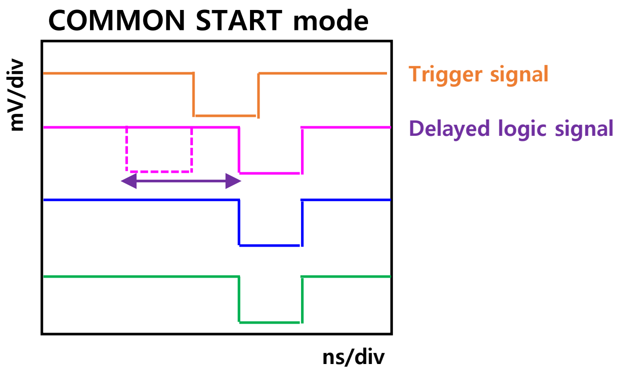
Time-to-Digital Converter (TDC)

Operation mode of TDC

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







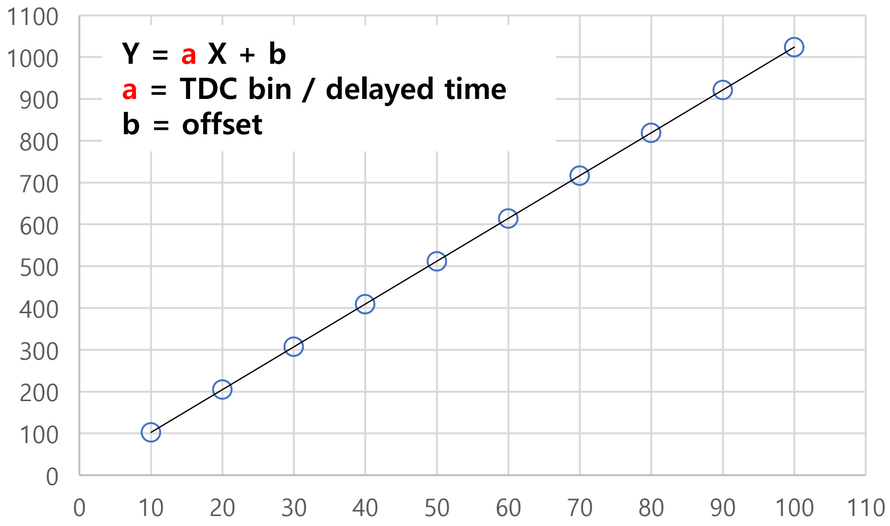
TDC Linearity Test for Calibration

T_full = 100 ns with 10 bit (1024) data set

100	ns
1024	bin
0.09765625	ns/bin

delay (ns)	unit time (ns/bin)	Measured Time (TDC bin)
10	0.09765625	102.4
20	0.09765625	204.8
30	0.09765625	307.2
40	0.09765625	409.6
50	0.09765625	512
60	0.09765625	614.4
70	0.09765625	716.8
80	0.09765625	819.2
90	0.09765625	921.6
100	0.09765625	1024

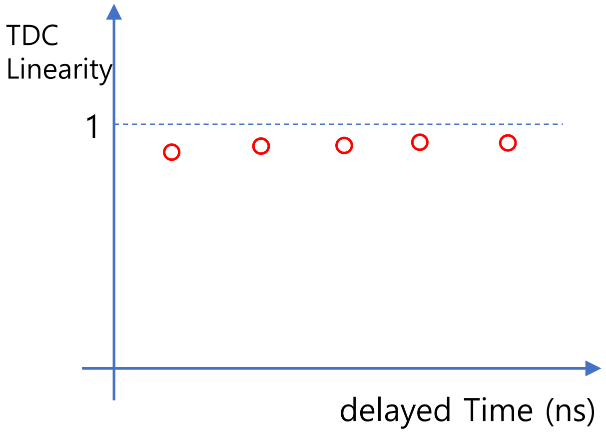
Measured Time (TDC bin) vs Delay time (ns)



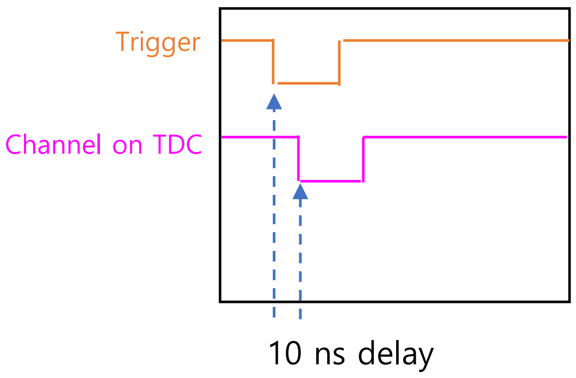
Y = a X + b
a = TDC bin / delayed time
b = offset

TDC Linearity

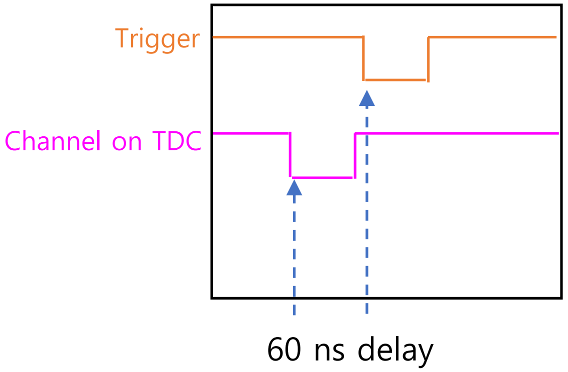
= measured Time (ns) / delayed Time (ns)



COMMON START MODE



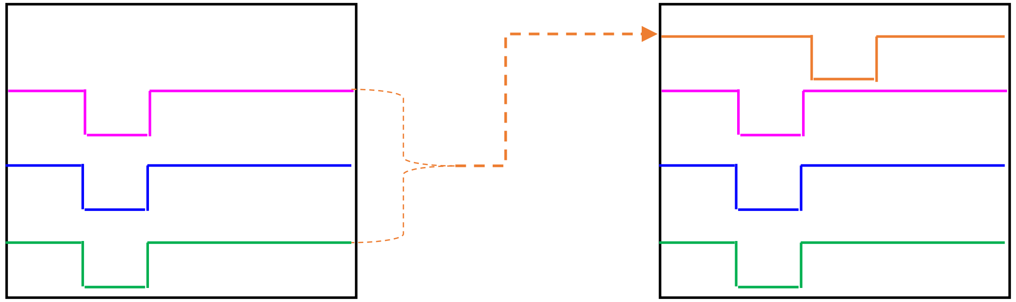
COMMON STOP MODE



TDC tips: Best Coincidence with 3 inputs

When events occur, **the input signals** from many detectors can be matched with Logic Unit.

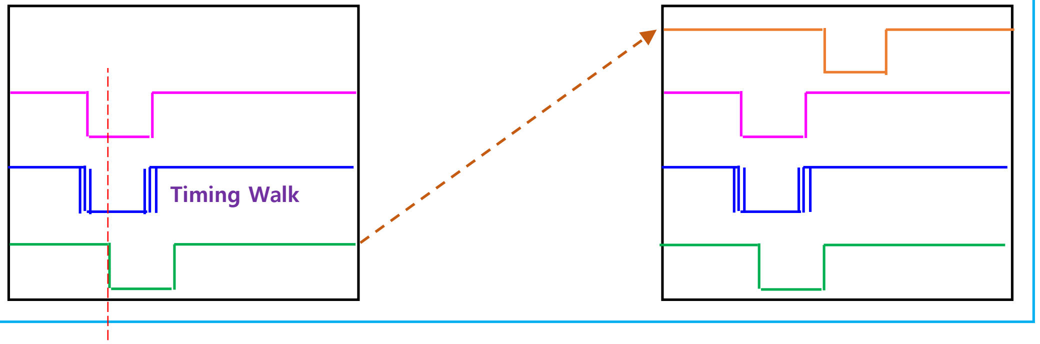
3 coincidence



Coincidence with timing walk

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

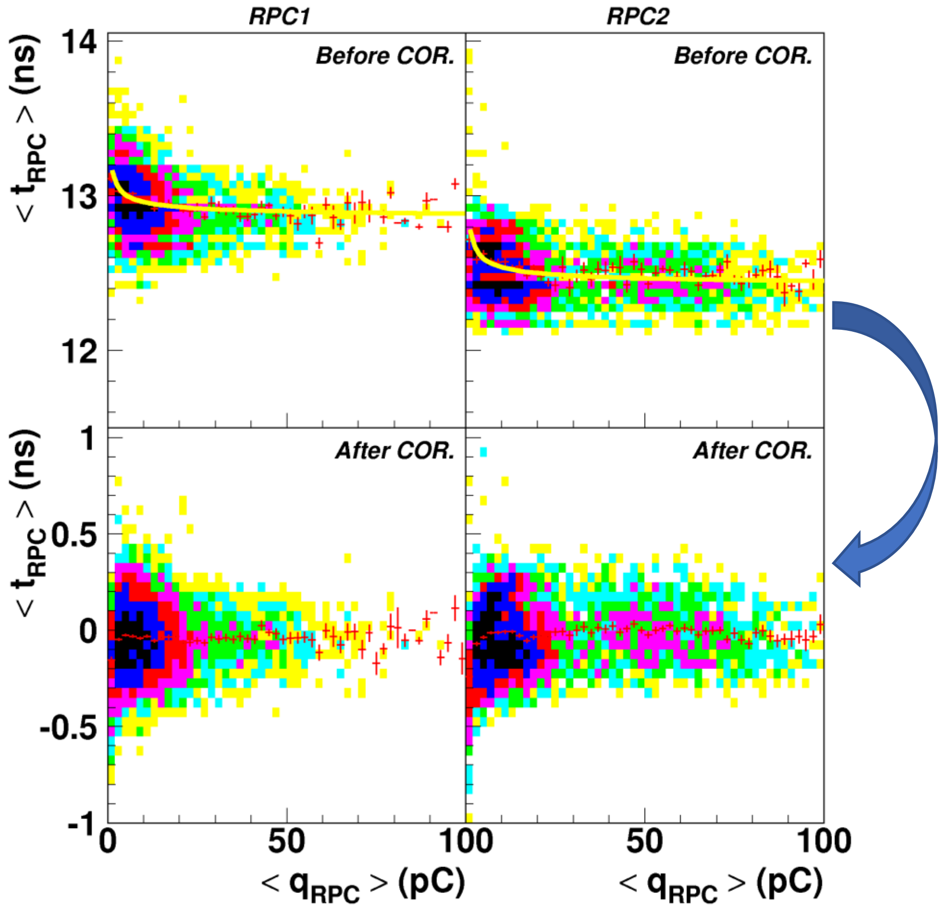
Gate (Ch3) delayed



Time resolution with slewing correction

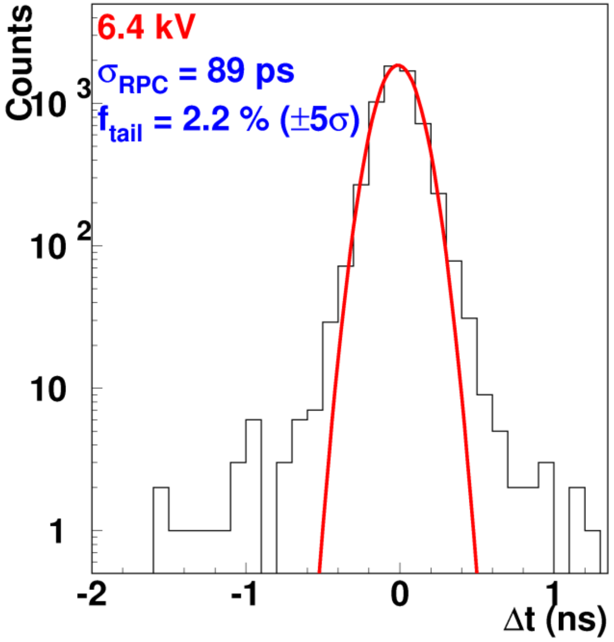
M. S. RYU et al, JKPS 52 (2008) 1748
Characteristics of Multigap timing RPC

At 6.4 kV with Gas 1

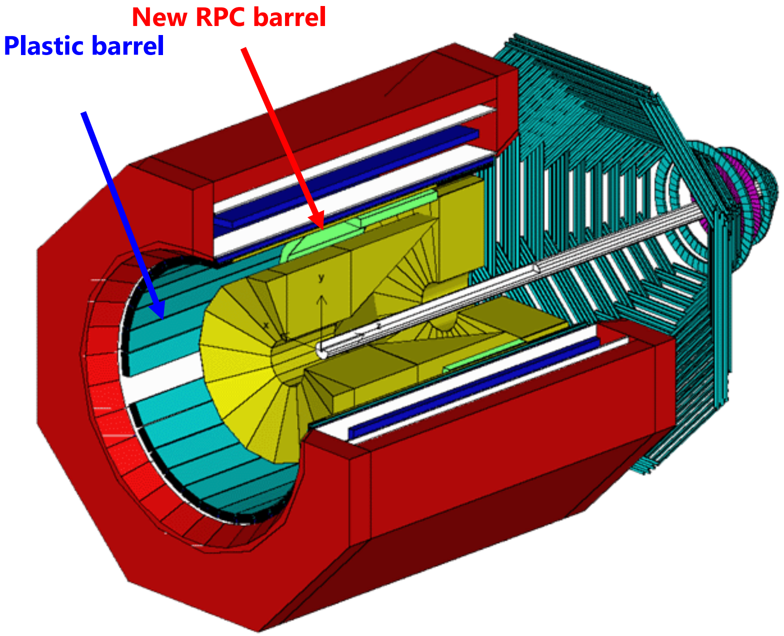


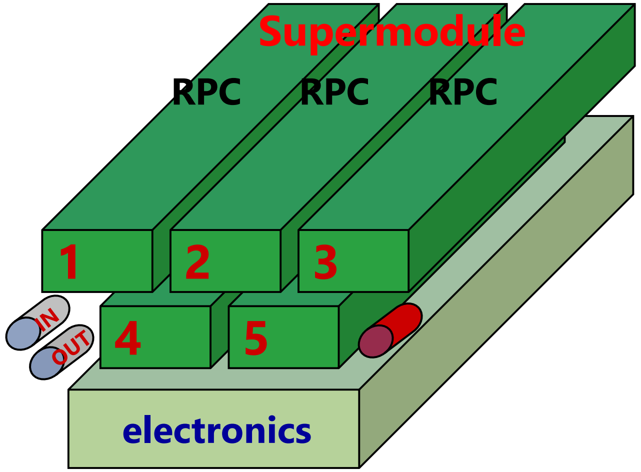
Slewing correction

$$\langle t_{RPC}\rangle = a\cdot\exp\frac{b}{\sqrt{\langle q_{RPC}\rangle}} + c$$

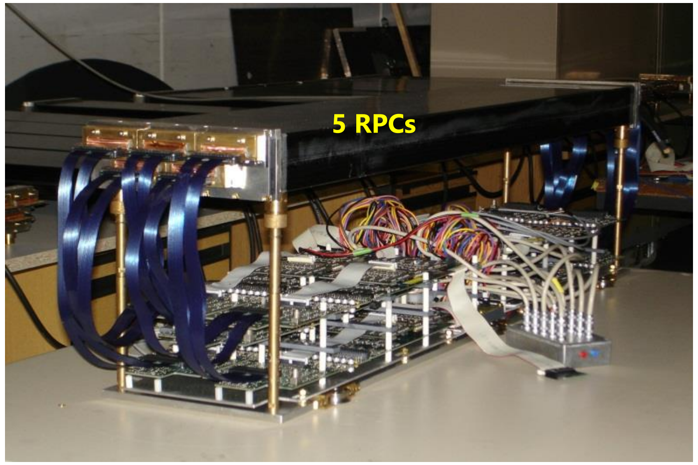


New Time-of-flight system of FOPI detector





Plastic barrel	**New MMRPC barrel**
180 scintillators for 30 sectors $39^\circ \leq \theta_{lab} \leq 130^\circ$ → $67^\circ \leq \theta_{lab} \leq 140^\circ$	**140 MMRPCs for 28 supermodules** $37^\circ \leq \theta_{lab} \leq 68^\circ$
$\sigma_t \leq 200\,\mathrm{ps}$	$\sigma_t \leq 100\,\mathrm{ps}$
$p_{lab} \leq 0.5\,\mathrm{GeV}$	$p_{lab} \leq 1\,\mathrm{GeV}$



M.S. Ryu, B. Hong, T. I. Kang, JKPS 59 1605 (2011)
M. Kis et al., NIM A 646 27 (2011)

Relation of momentum and time resolution

- The momentum p of the particle is related to its rest mass by the formula (1).

$$p = m_0 \gamma \beta c \qquad (1)$$

- Differentiating this leads to $\frac{\partial m_0}{m_0} = \frac{\partial p}{p} - \gamma^2 \frac{\partial \beta}{\beta}$.

- Since β is measured by measuring the time t taken to travel the length l, i.e. $\beta = \frac{l}{ct}$, this leads to $\boxed{\frac{\partial m_0}{m_0} = \frac{\partial p}{p} - \gamma^2 \left(\frac{\partial l}{l} - \frac{\partial t}{t} \right)}$. (2)

$$\boxed{\Delta t \approx \frac{lc}{2p^2}\left(m_1{}^2 - m_2{}^2\right)}$$

Time difference

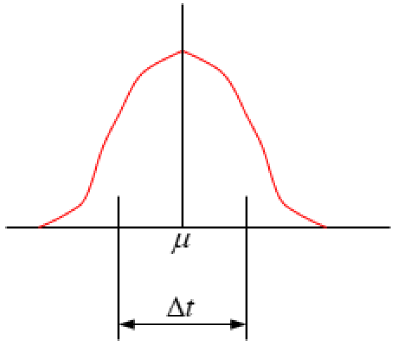
If m_1 and m_2 are $K^{\pm}(493.7MeV/c^2)$ and $\pi^{\pm}(139.6MeV/c^2)$ at $p=1\ GeV/c$, $(l=1m)$

$$\Delta t \approx \frac{lc}{2p^2}\left(m_1^2-m_2^2\right)=\frac{1(m)\cdot c}{2(1GeV/c)^2}\left(0.4937^2-0.1396^2\right)\left(GeV/c^2\right)^2$$

$$=\frac{\left(0.4937^2-0.1396^2\right)}{6\times10^8}s=373.8ps$$

$$\Delta t = FWHM$$

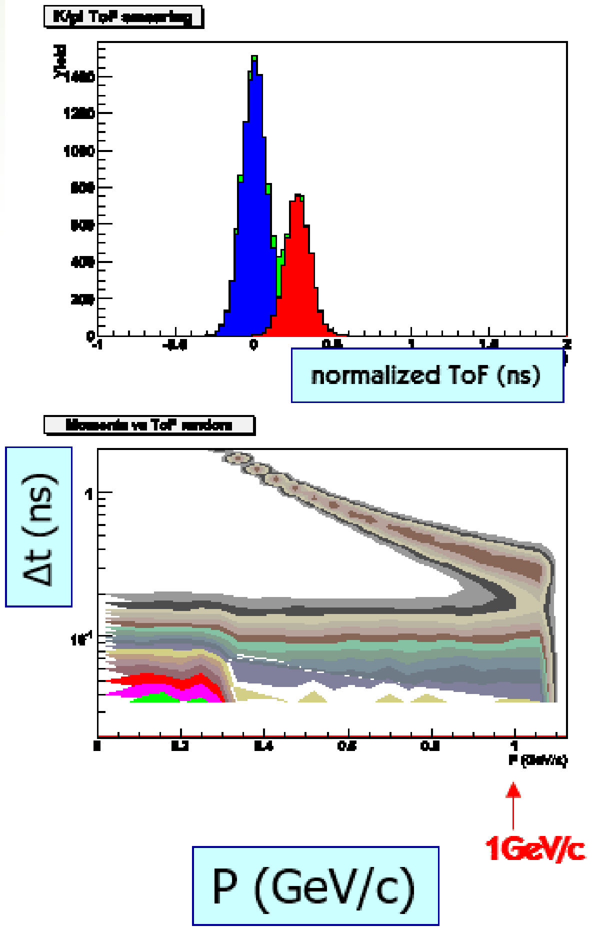
$$\sigma_{\Delta t} = FWHM/2.35$$



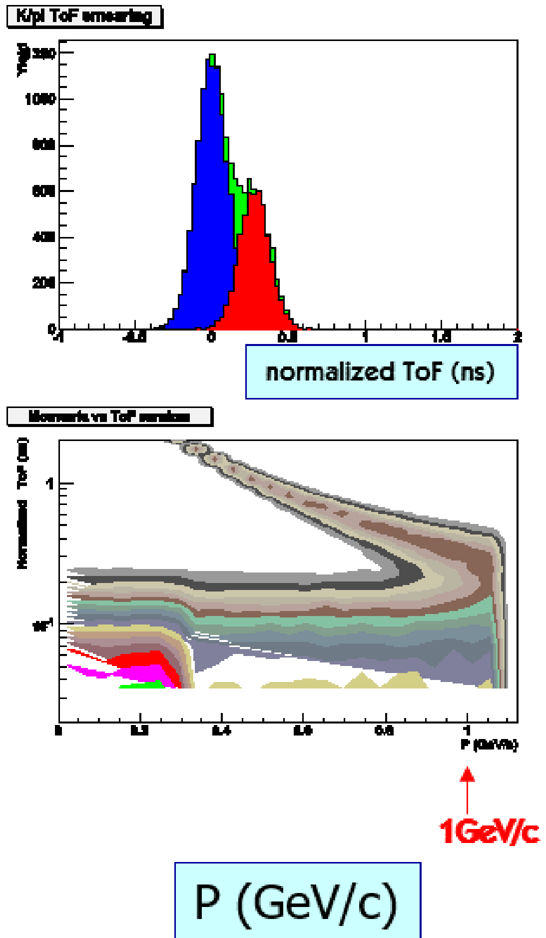
$$\text{if }\ \Delta t = 373.8ps,\quad \sigma_{\Delta t} = 159.1ps$$

Seperation of π /K for 1m flight path

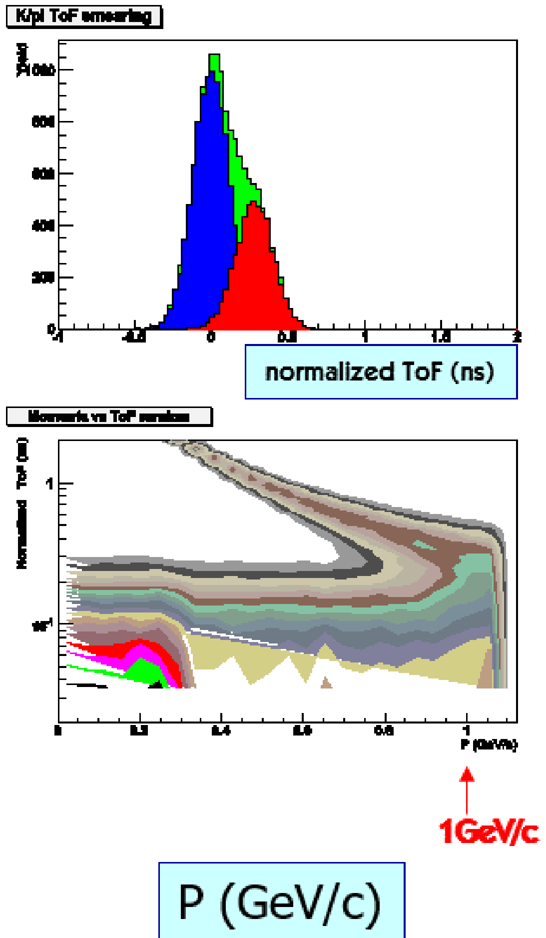
80 ps



100 ps



120 ps



Summary

"**DAQ with Fast Electronics**" are a main component of particle detection system to see what happens in the HEP experiments.