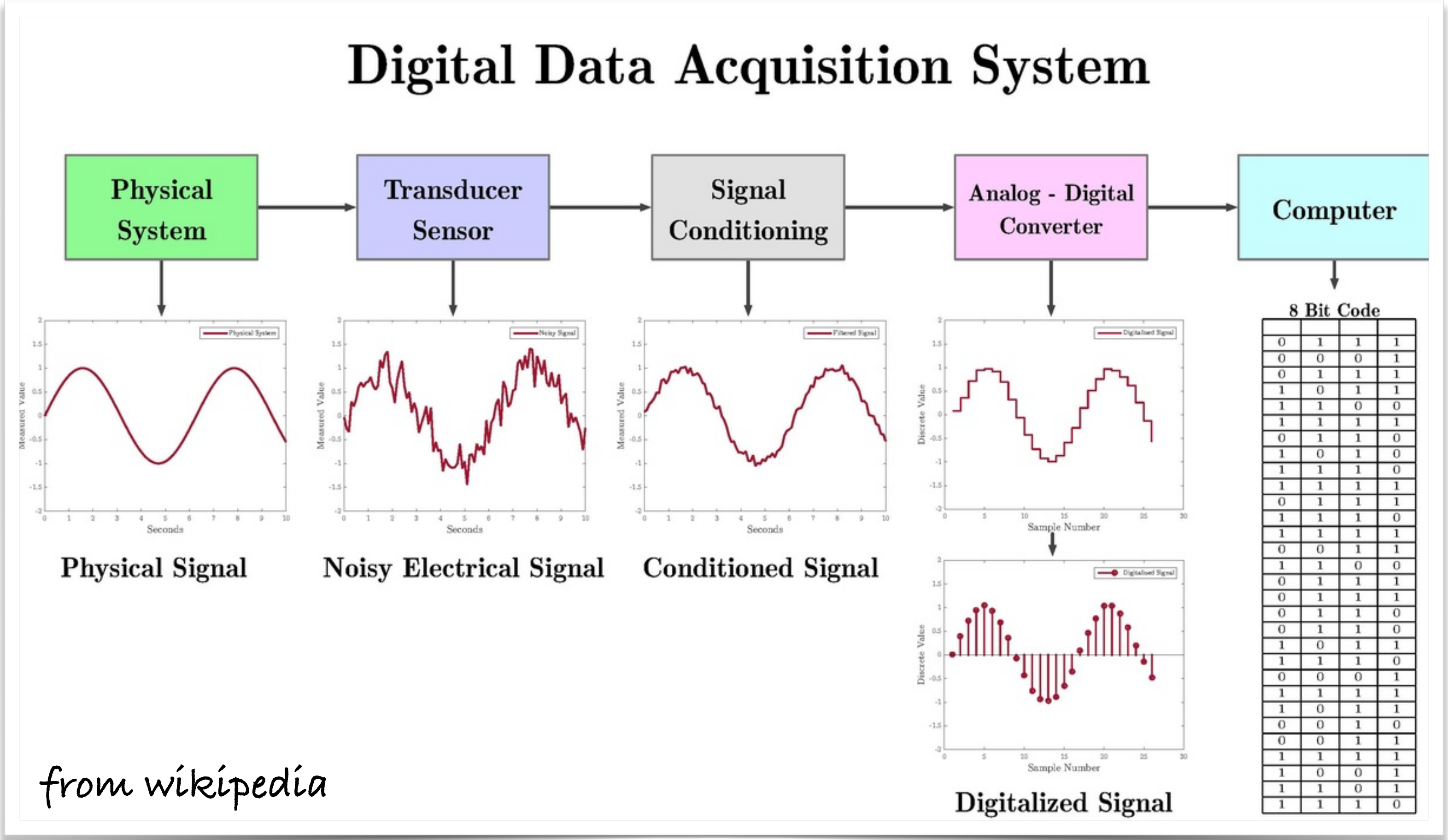
Data acquisition system for J-APRC neutrino beamline

March 6th, 2024, Hardware Camp 2024

Ken Sakashita(KEK/J-PARC neutrino group)

What is data acquisition system(DAQ) ?

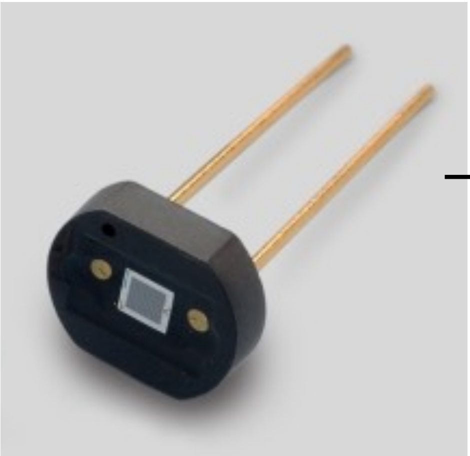
- process a **signal generated in a detector**
- and saving the interesting information on a storage



from wikipedia

Oscilloscope

sensor
(detector)



analog
signal

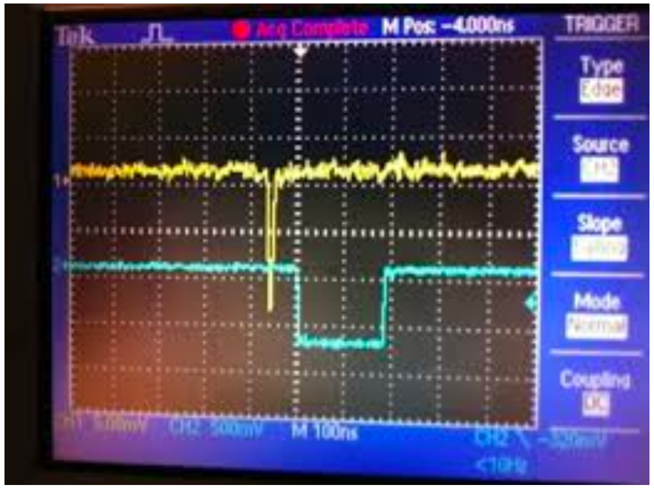
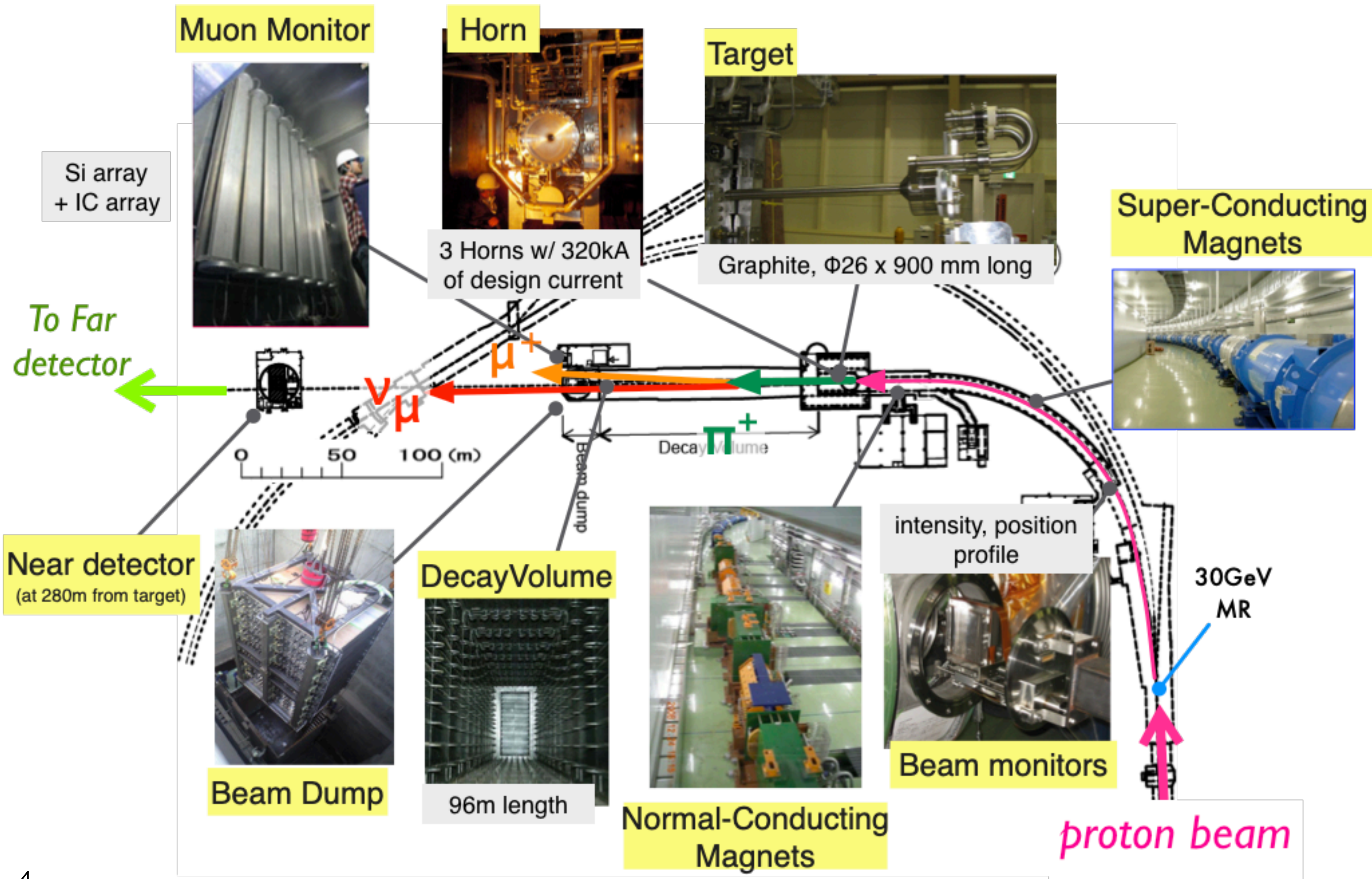


image file,
waveform data
(digital data)

USB

PC

A specific example (1): J-PARC neutrino beamline

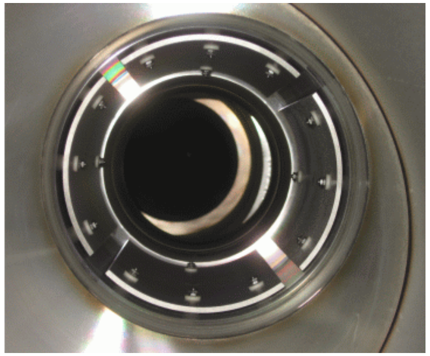


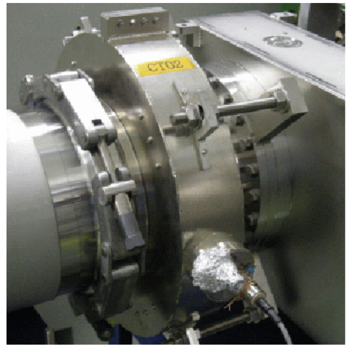
What kind of data is saving ?

save signal waveform from sensors

extracting various information from the waveform of the signal

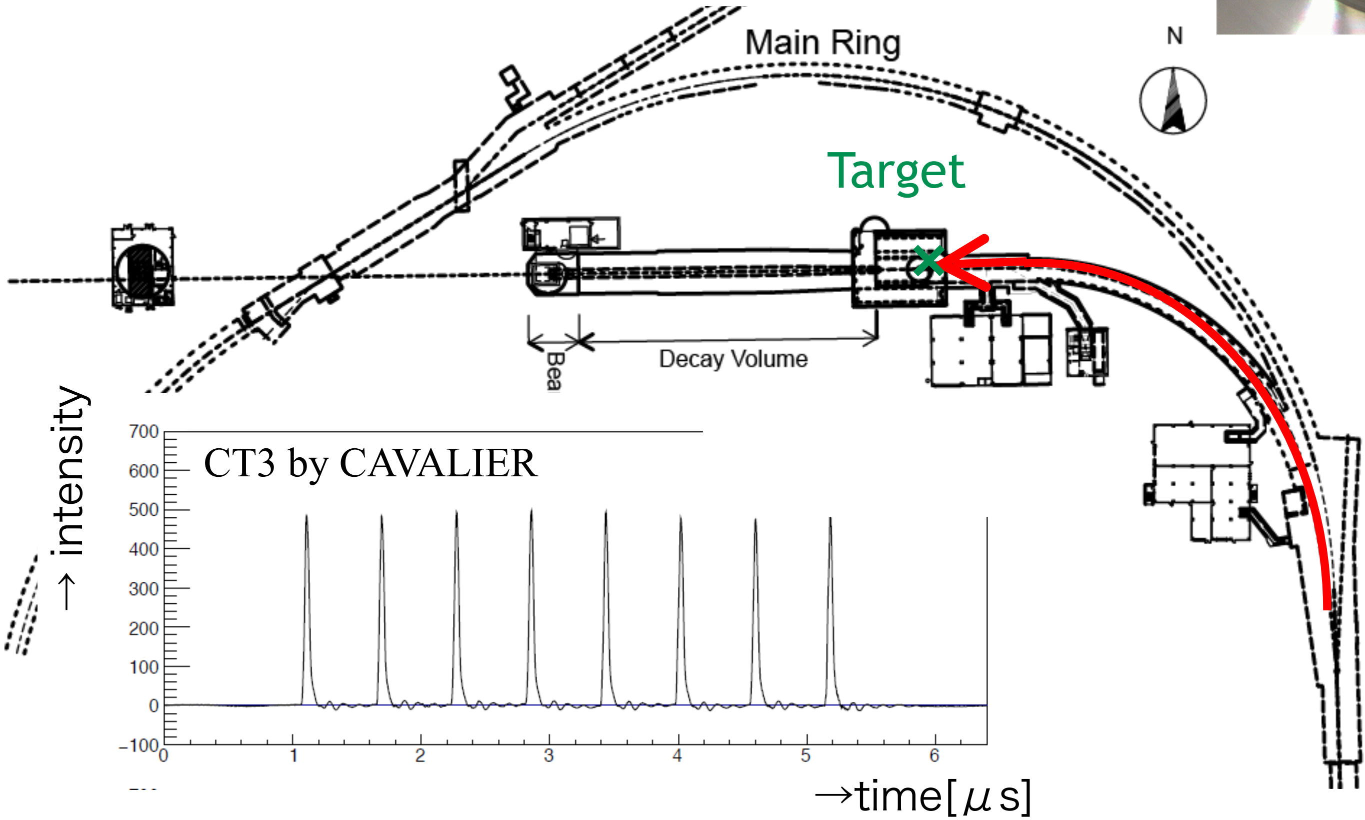
Beam monitors





Primary proton transport line

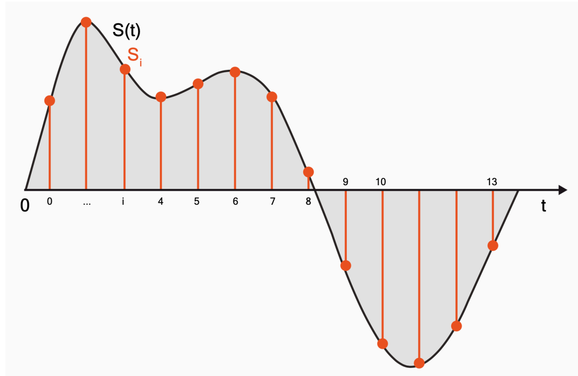
Super-conducting combined-function magnets



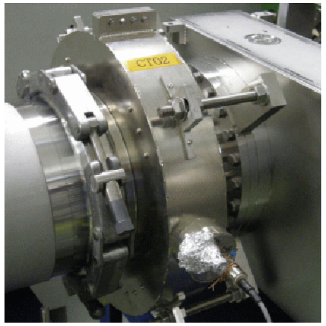
Time structure of J-PARC beam

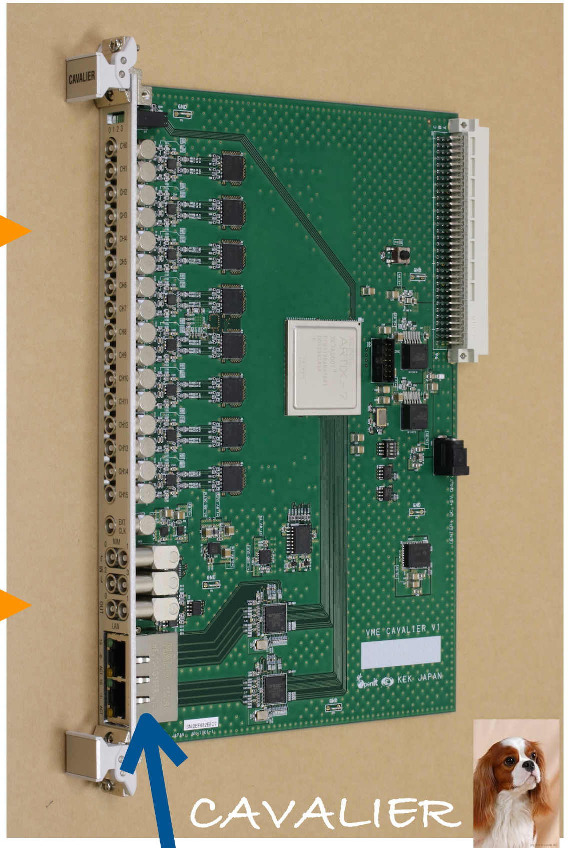
8 bunch in 5μsec is monitored

Waveform digitizer (sampling ADC)
(an example at J-PARC neutrino beamline)

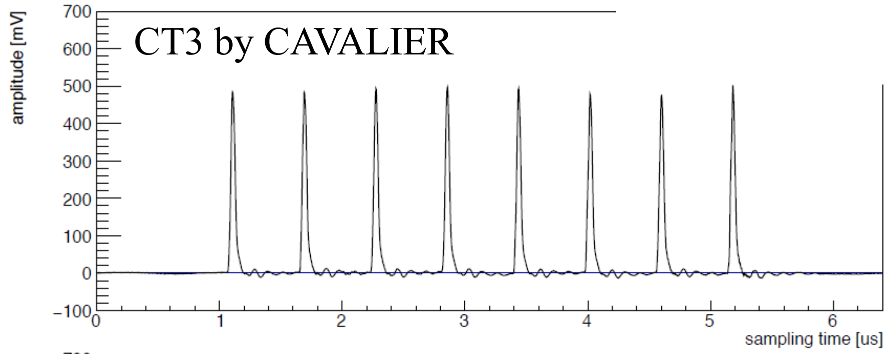


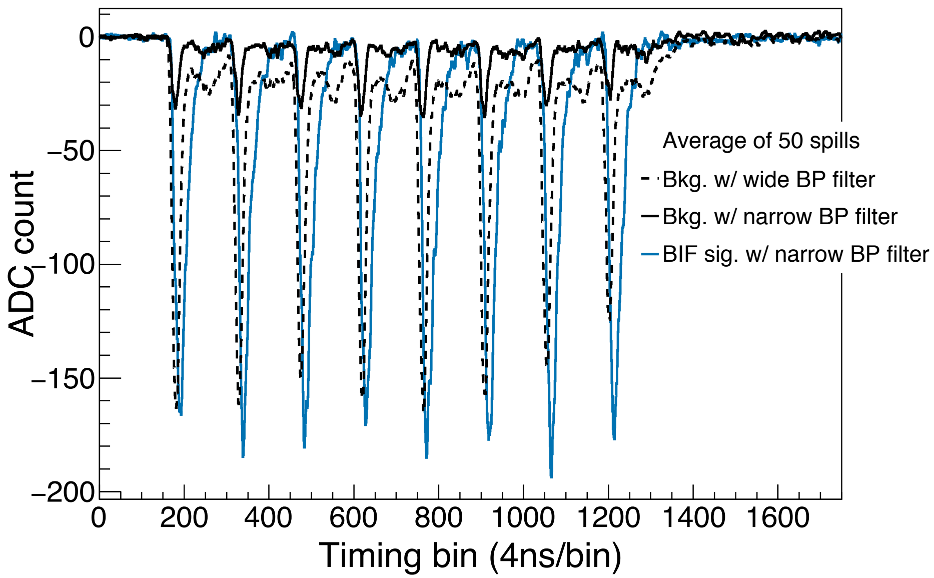
250Msample per sec.





data are read out via network(GbE)





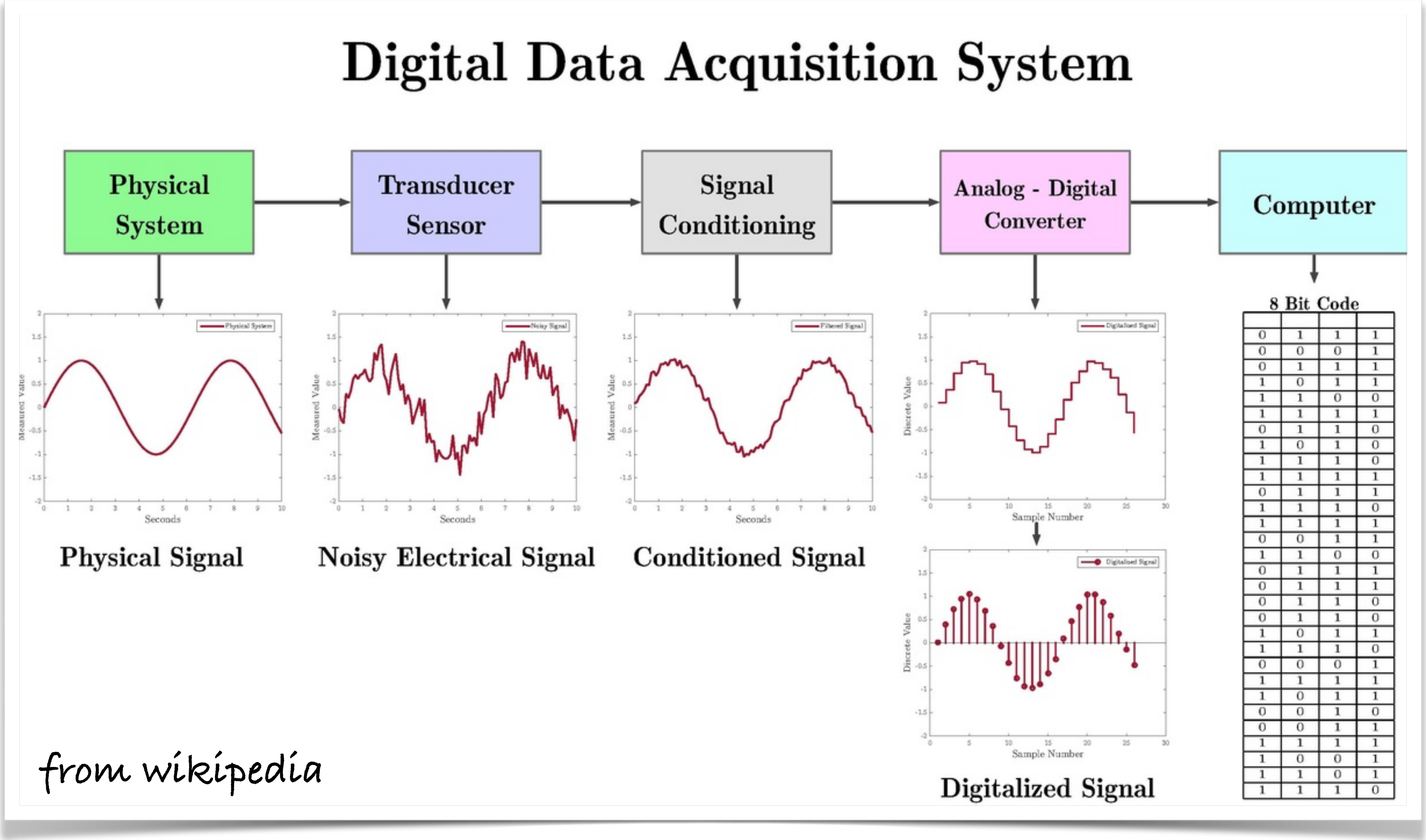
Open source consortium of Instrumentation

http://openit.kek.jp/project/fadc250

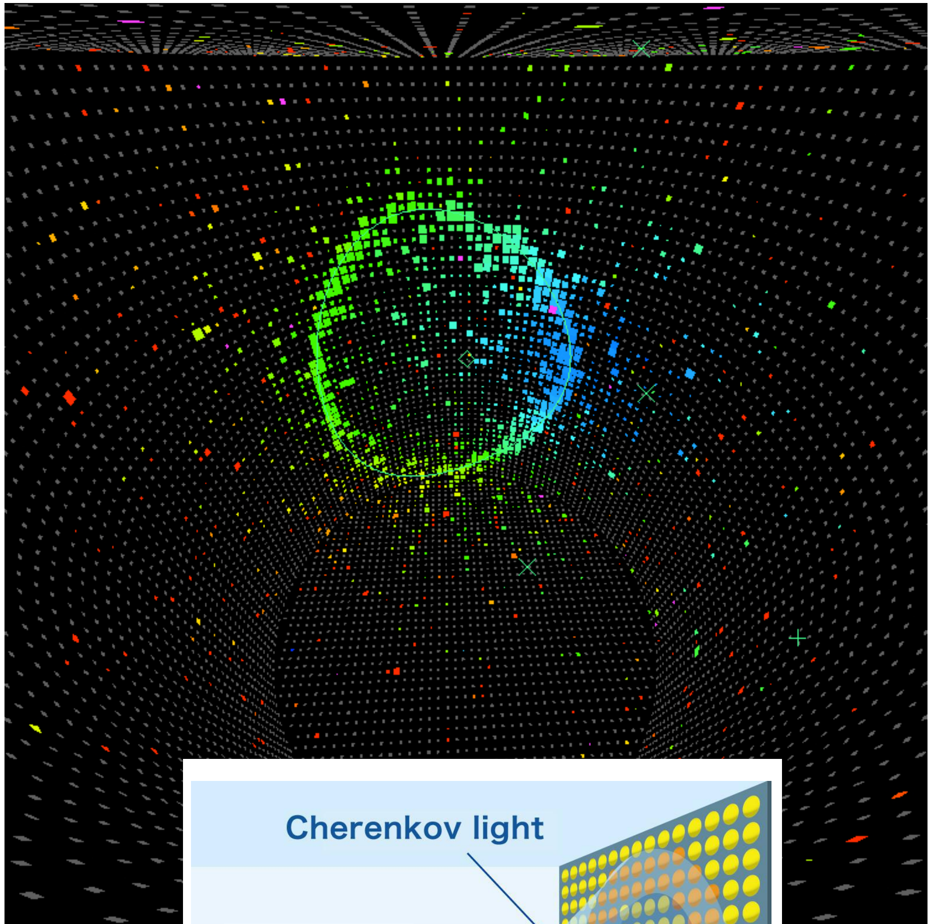
https://doi.org/10.18429/JACoW-IBIC2020-WEPP34

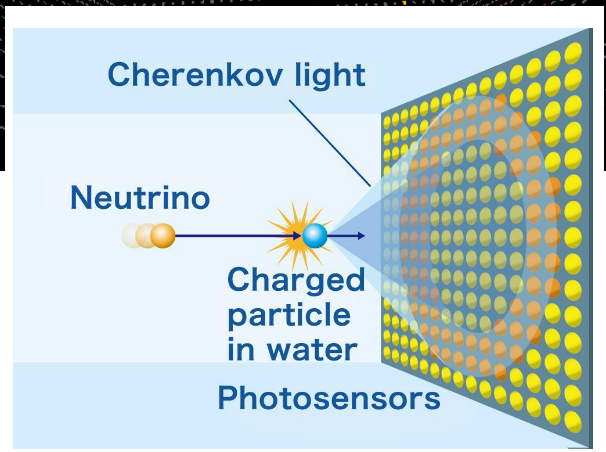
What is Data acquisition system(DAQ) ?

- process a **signal generated in a detector**
- and saving the **interesting** information on a storage

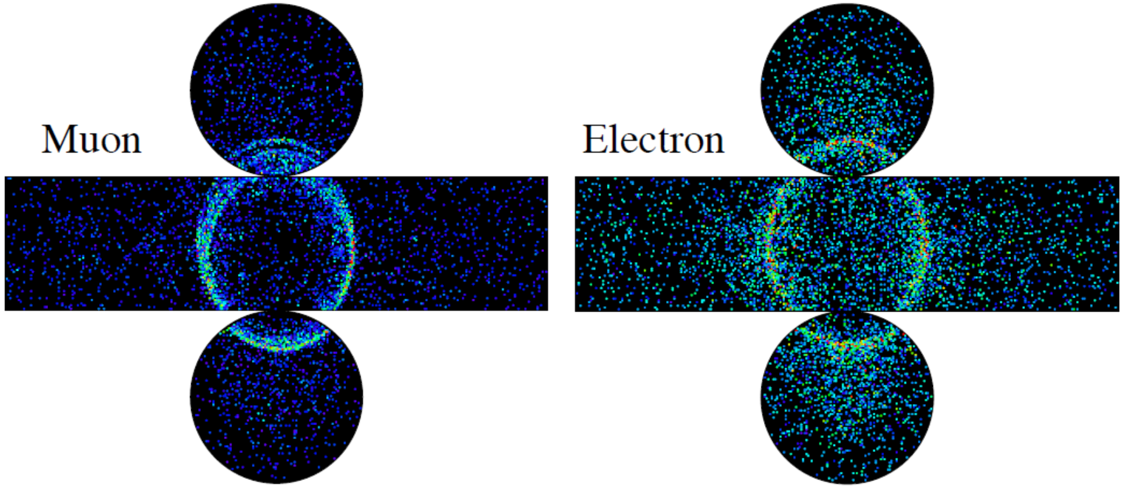


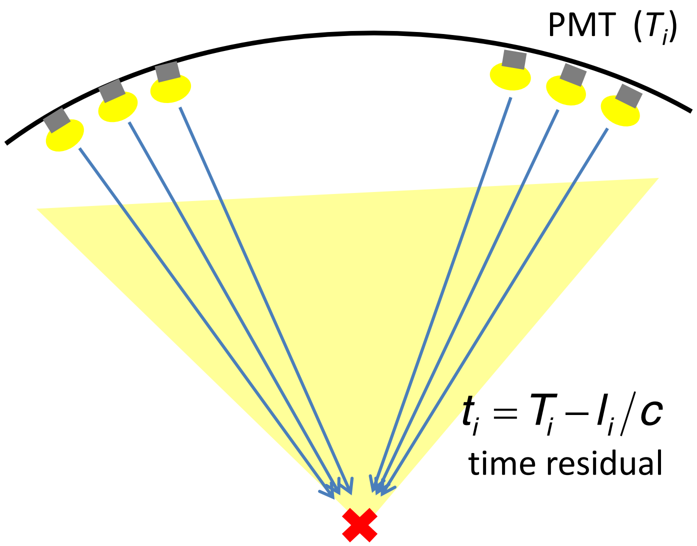
A specific example (2): SuperKamiokande (SK)





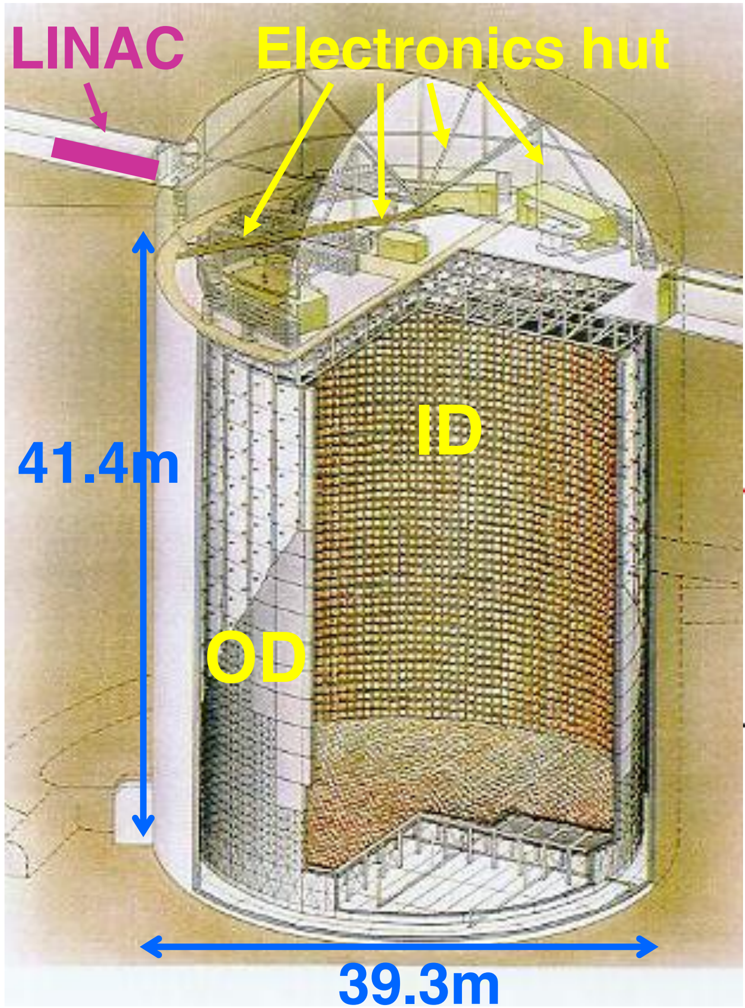
Event display of SK (water Cherenkov detector)

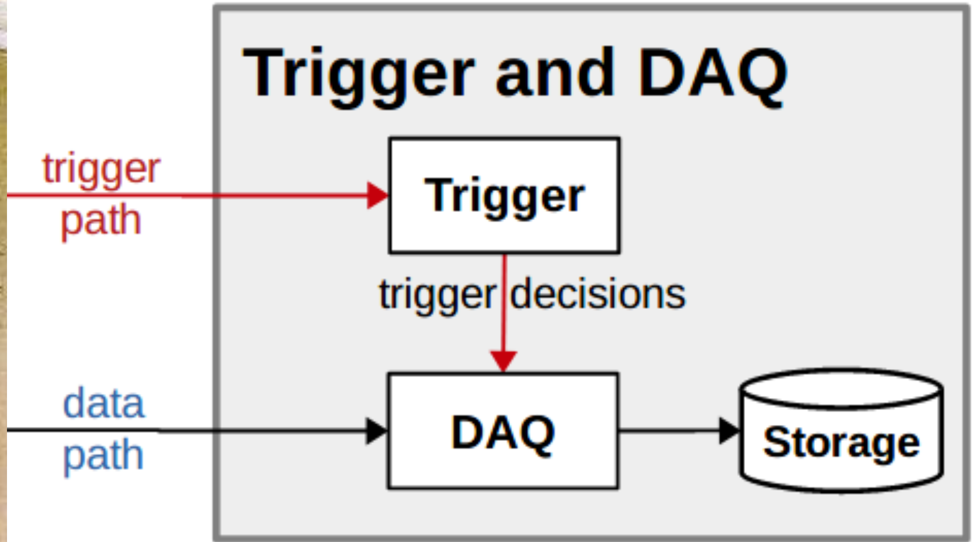




charge and hit timing of each PMT are recorded

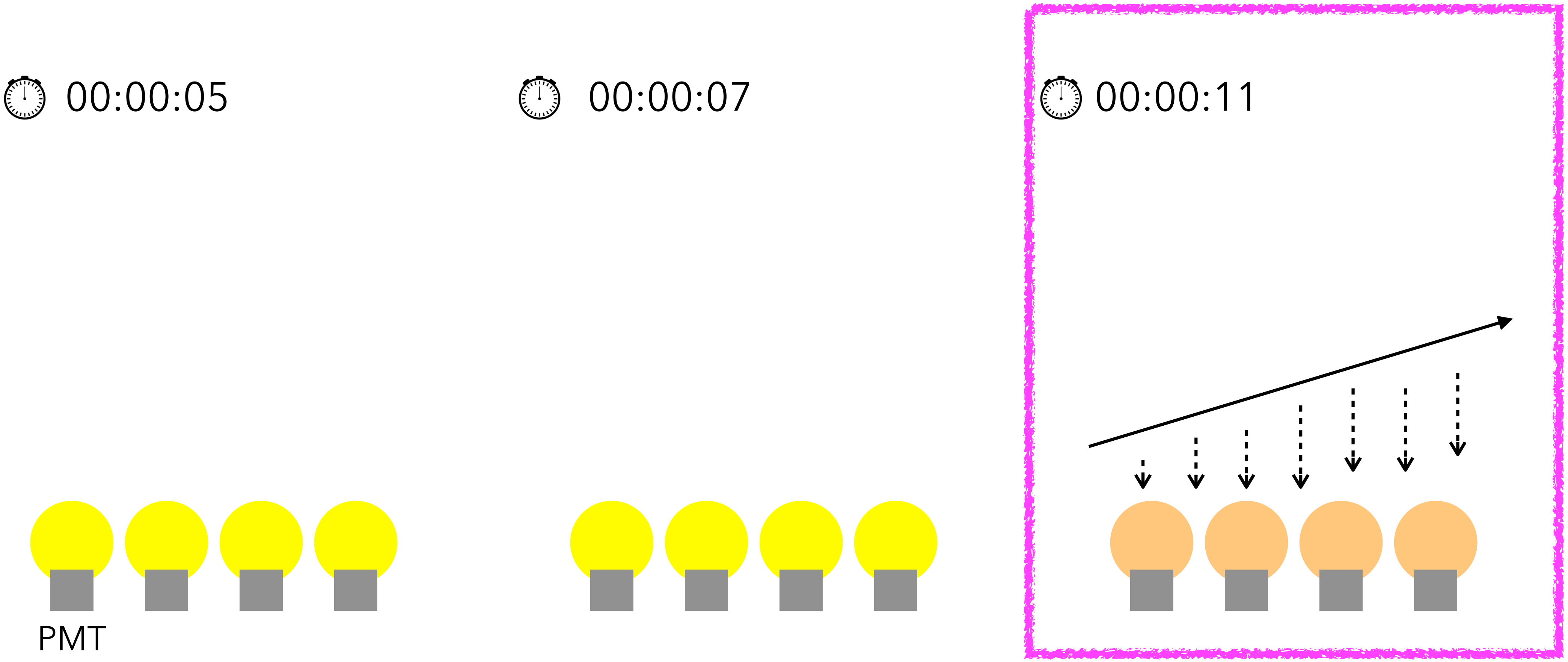
Trigger and DAQ





Trigger

- Trigger tells us when is the “right” moment to take data



Trigger

- Trigger tells us when is the “right” moment to take data

Two cases:

“periodic”

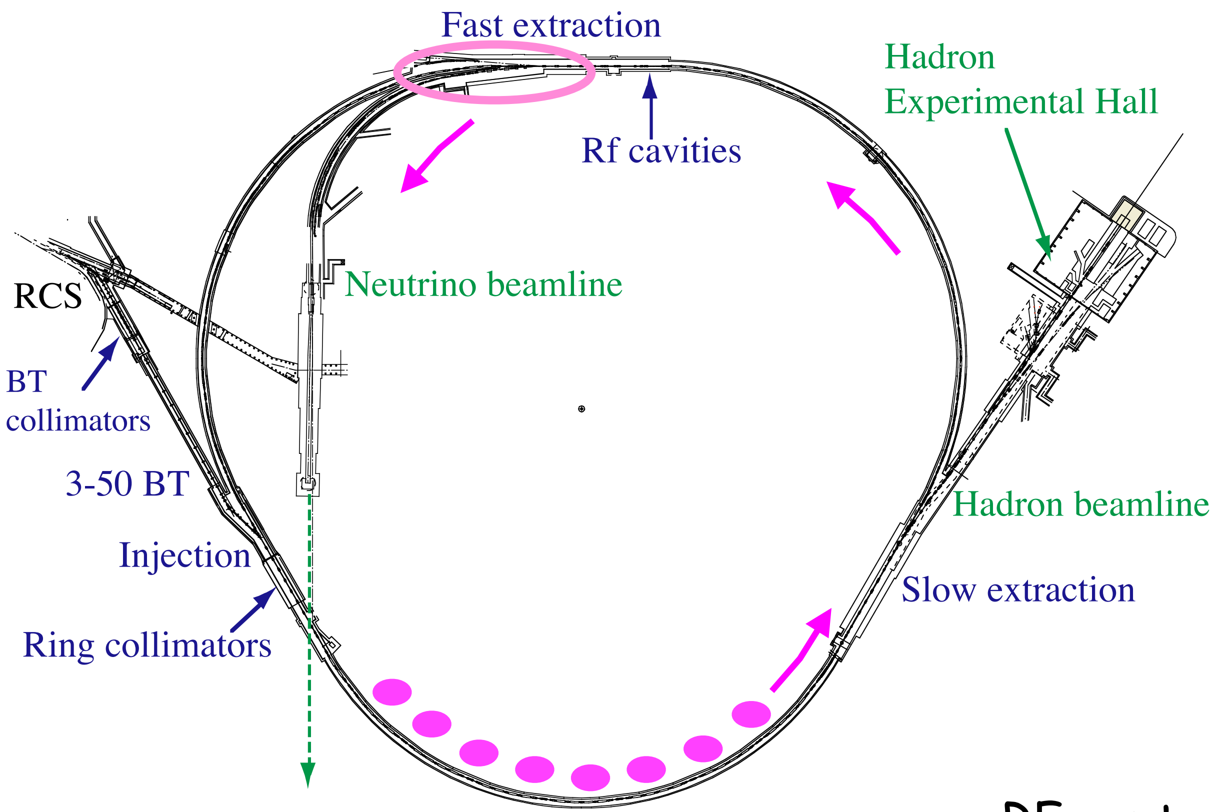
and

“physics process”

✳ Periodic trigger

e.g. J-PARC Main Ring extraction beam

Beam accelerated up to 30GeV is extracted every 1.36 seconds



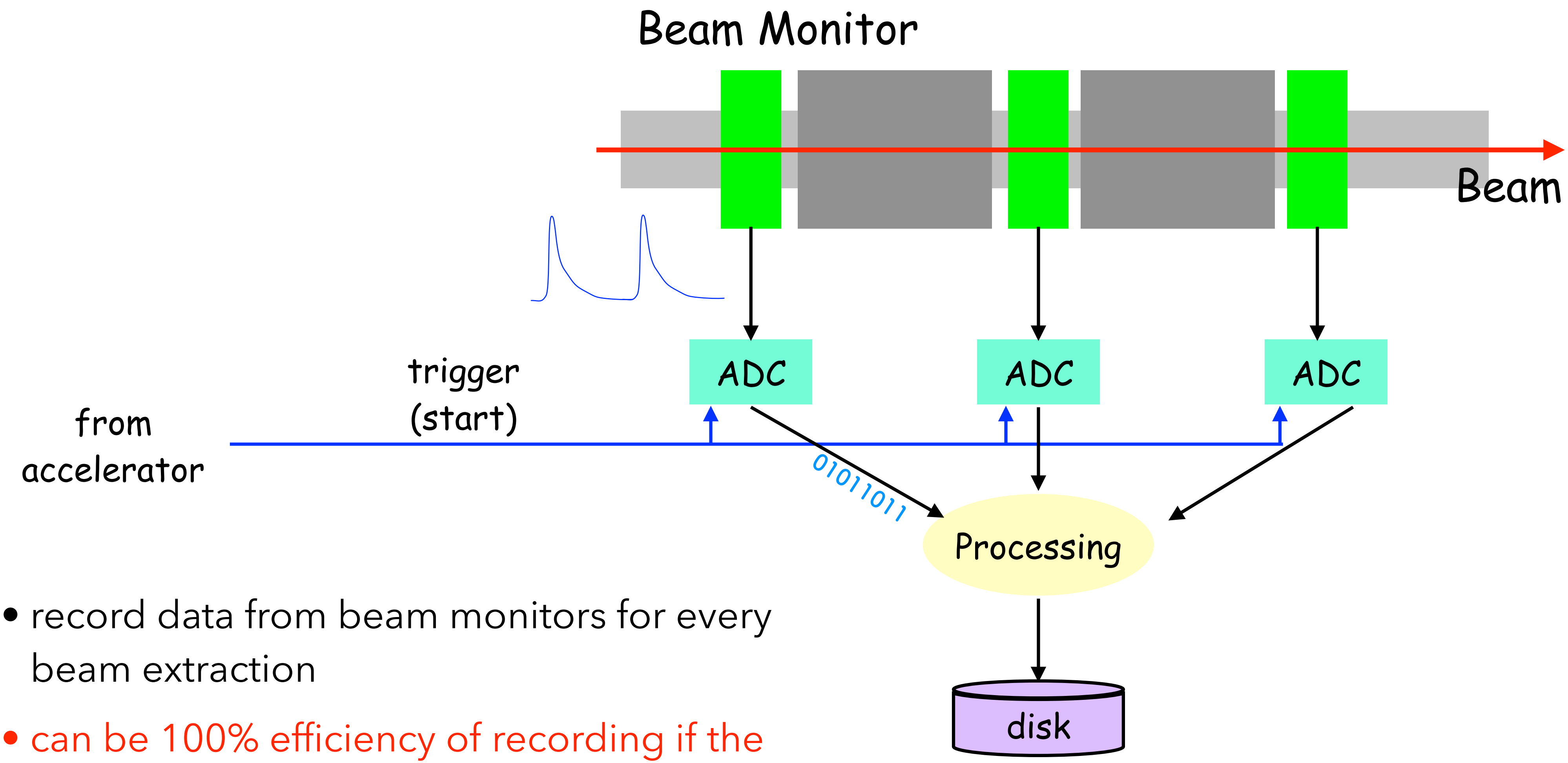
RF captured beam

→ synchronized with RF clock signal

✳ Periodic trigger

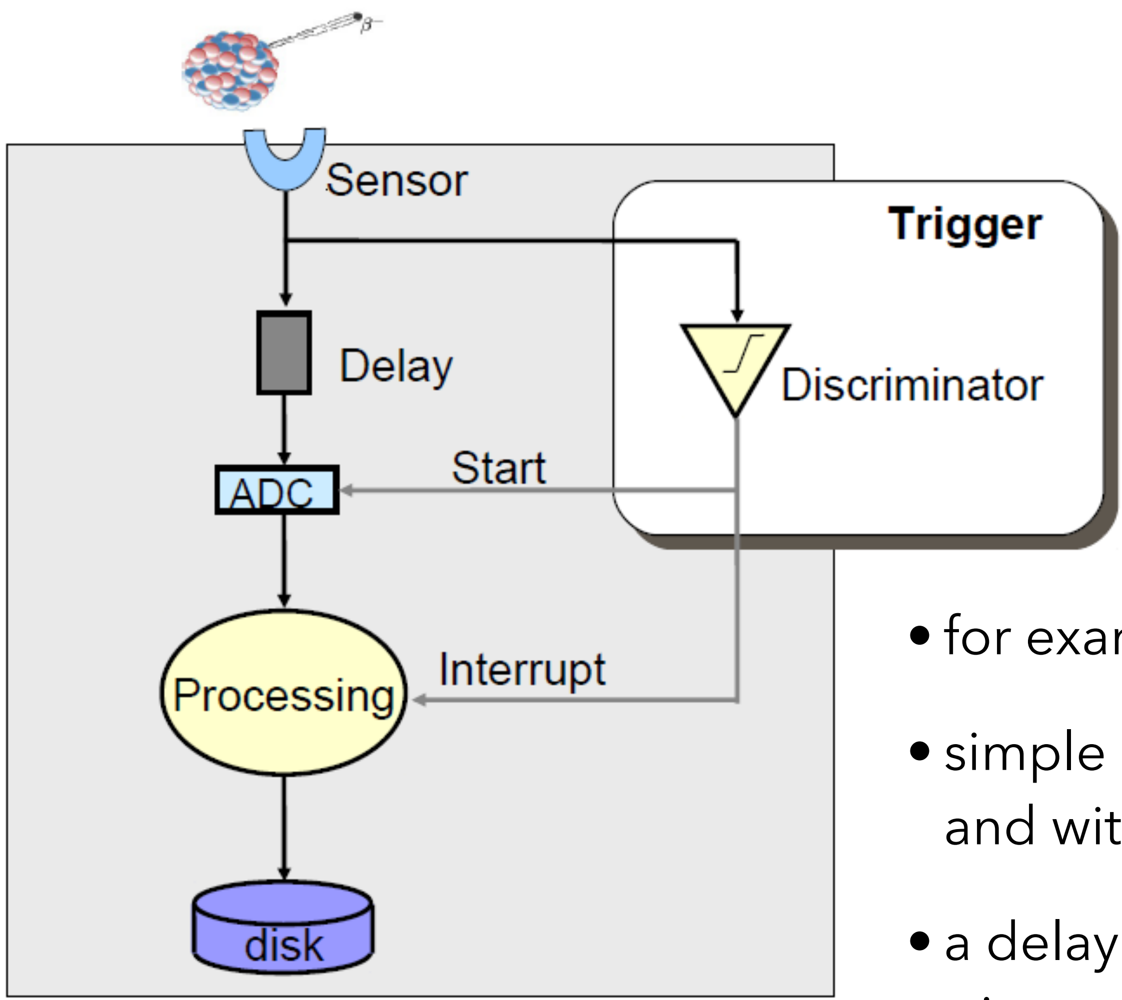
e.g. J-PARC Main Ring extraction beam

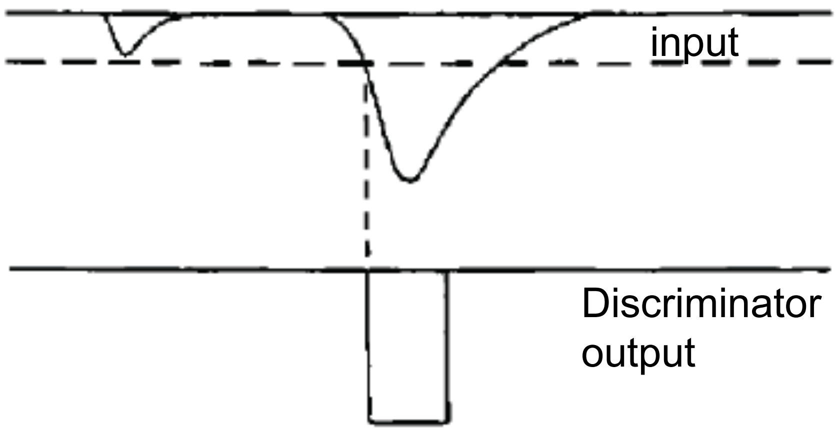
Beam accelerated up to 30GeV is extracted every 1.36 seconds



- record data from beam monitors for every beam extraction
- can be 100% efficiency of recording if the processing time is less the repetition interval

✳ Trigger based on a "physics" process

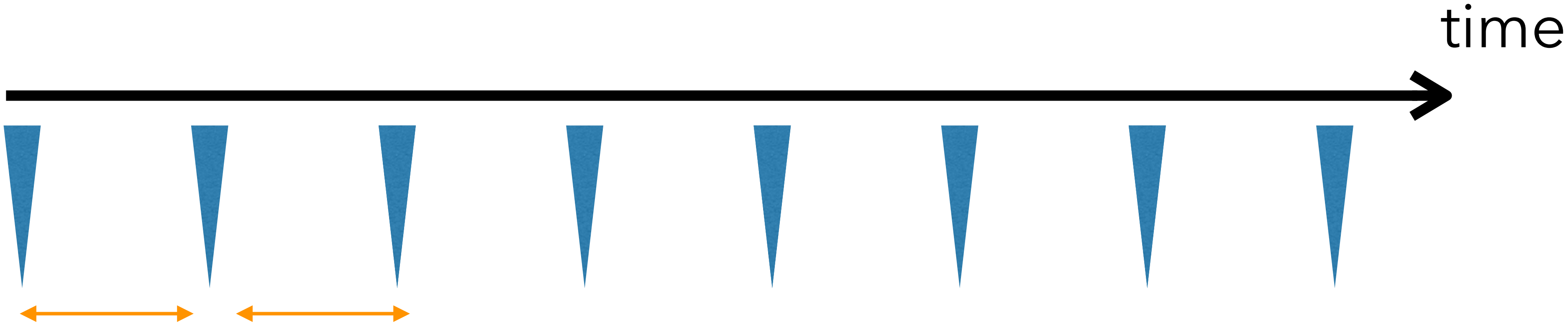




- for example, β decay signal
- simple case is a single sensor (e.g. MPPC) and with a "self-trigger"
- a delay is necessary to compensate the trigger decision time

ref. "Introduction to Trigger and DAQ", M.Wielers (RAL)

* Periodic

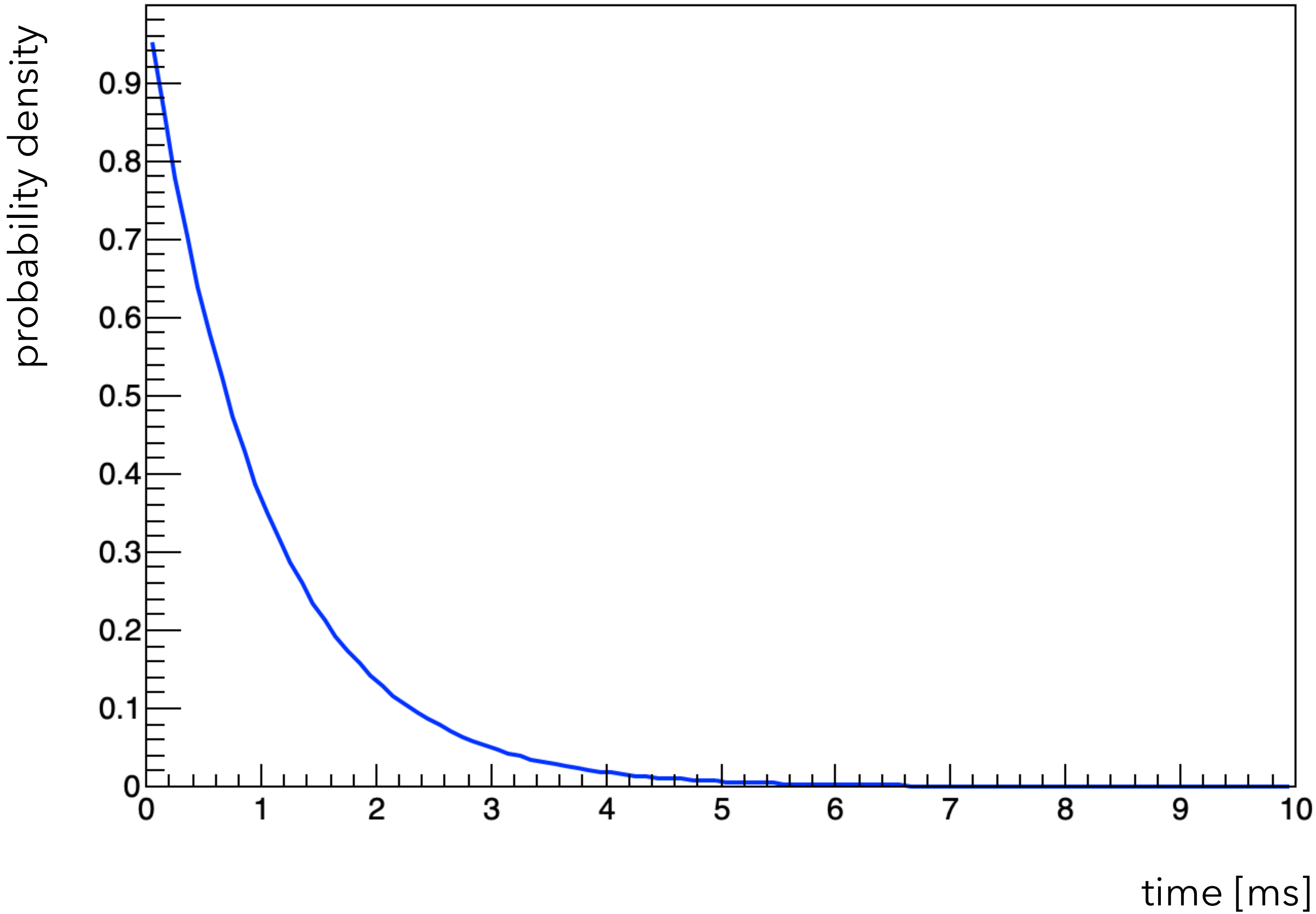


interval is a constant

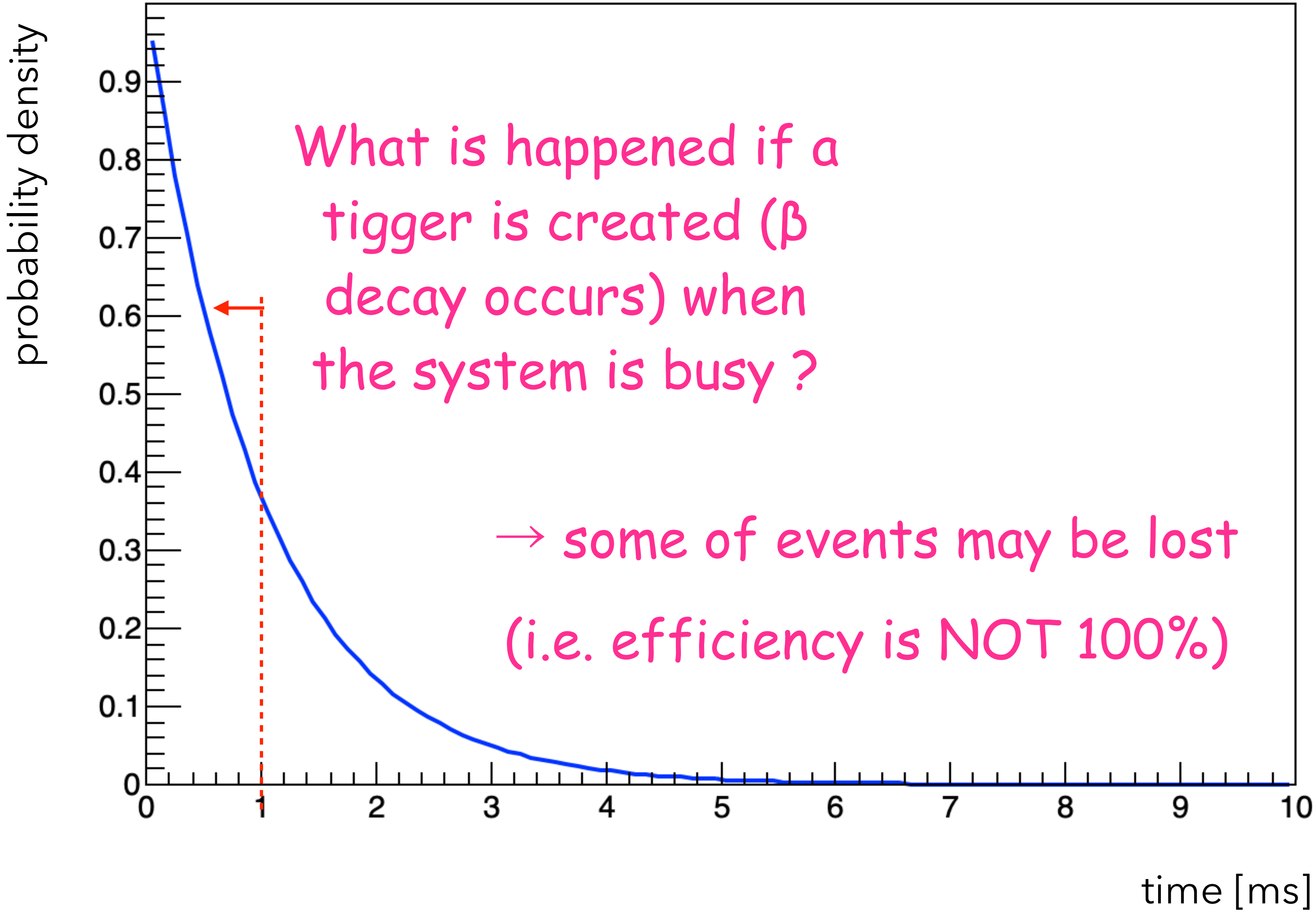
* “physics” process

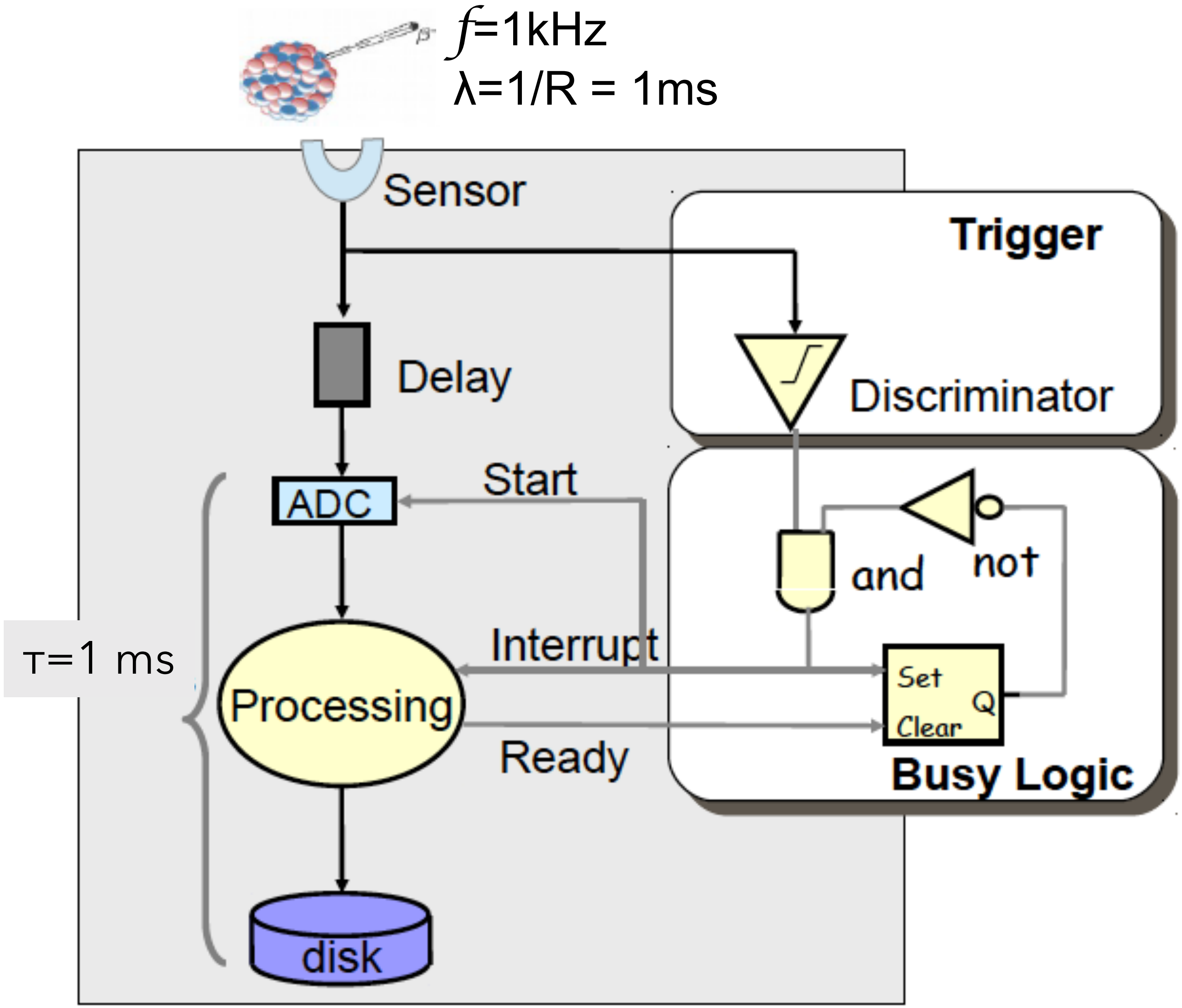
interval is NOT a constant

Probability of time (in ms) between events for average decay rate of τ=1ms



Probability of time (in ms) between events for average decay rate of τ=1ms





- to avoid trigger during the processing is busy, a veto logic (busy logic) is added

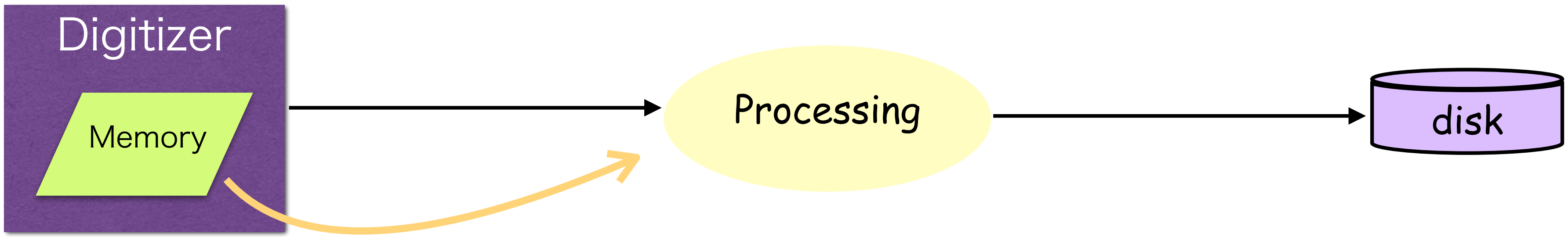
✳ Processing time

data size :

30 [bits/sample] * 100 [samples/ch/event] * 1000ch
= 0.4 Mbytes/event

1 byte = 8 bits

ex.) data size for charge, time information



data transfer

VME PIO : 1.5Mbytes/s → 267 ms

VME DMA : 14Mbytes/s → 29 ms

SDRAM : 1Gbytes/s → 0.4 ms

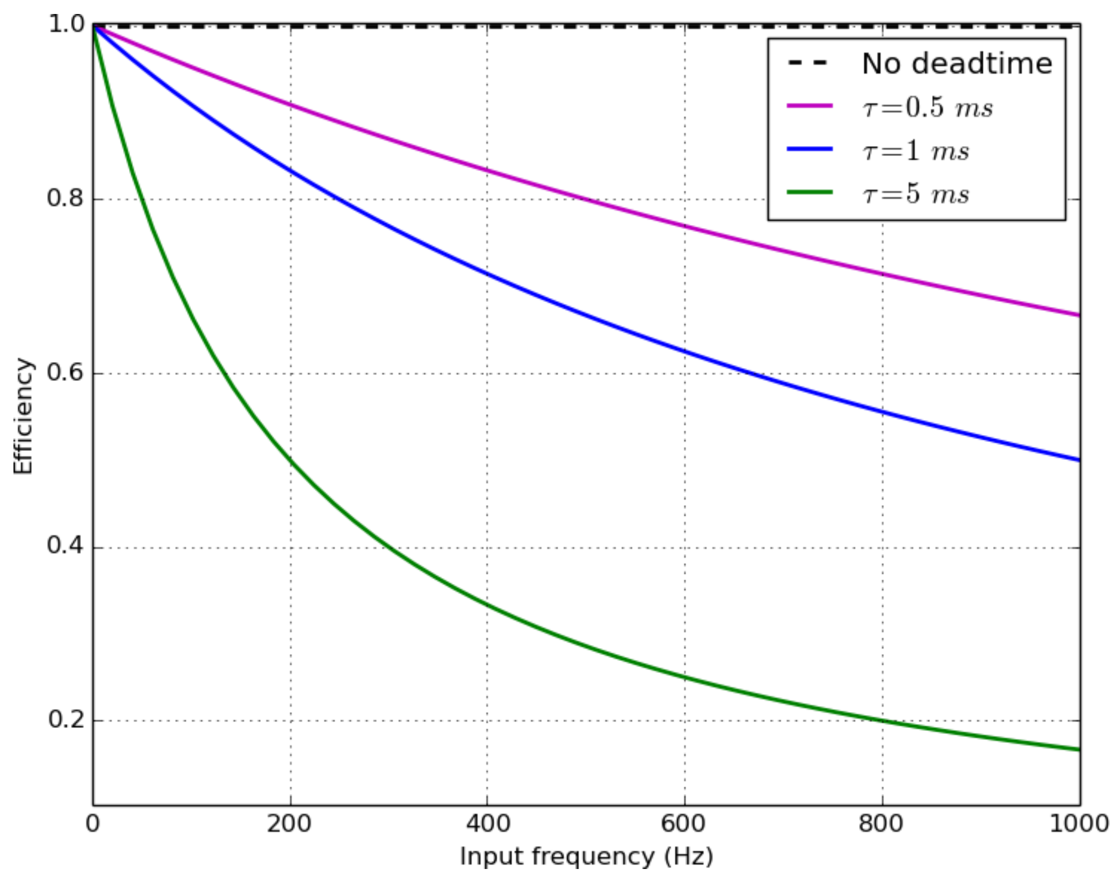
disk writing speed : ~500Mbyte/s

→ 0.8ms

this example shows the processing time of 0.4+0.8ms = 1.2ms

✳ Efficiency

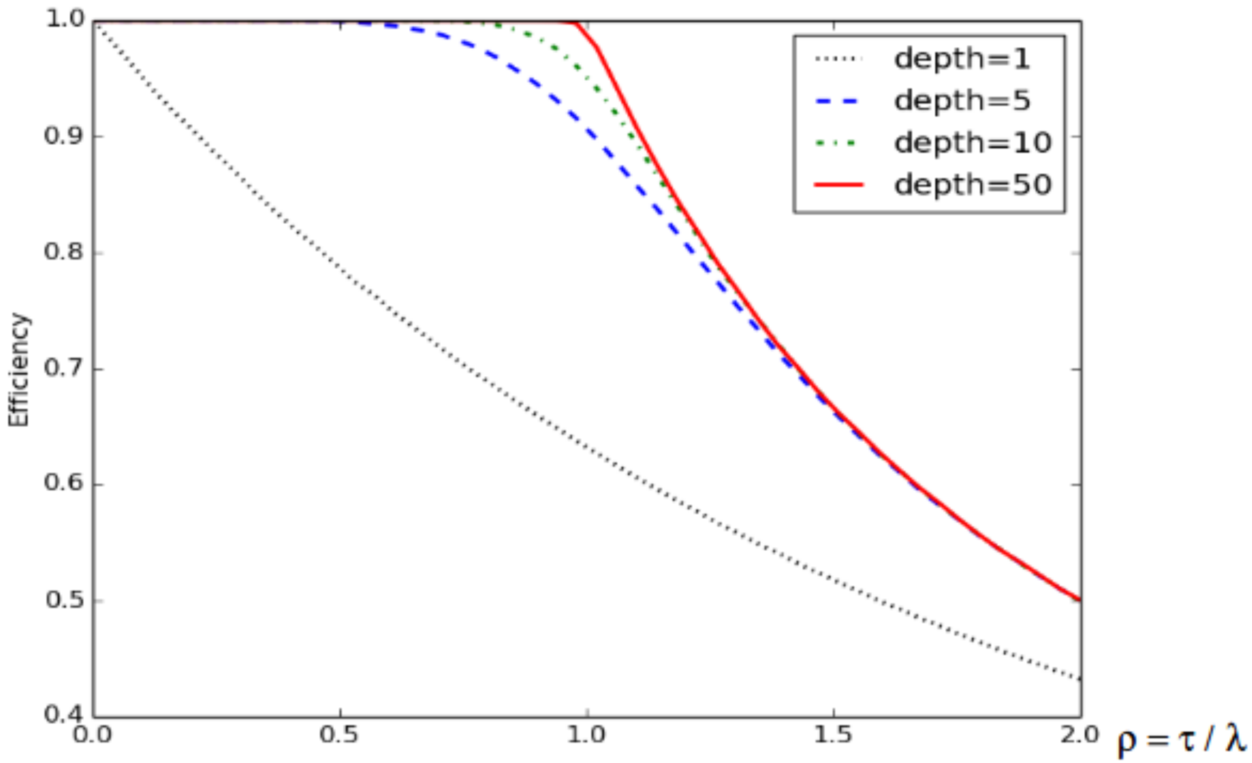
- Let us assume :
  - f : average rate of trigger (input)
  - w : average rate of accepted (output)
  - T : dead-time, i.e. necessary time to process an event
- Probability : P[busy] = wT, P[free] = 1- wT
- w = f*P[free] → w=f*(1-wT)
- DAQ efficiency is w/f = 1/(1-wT)

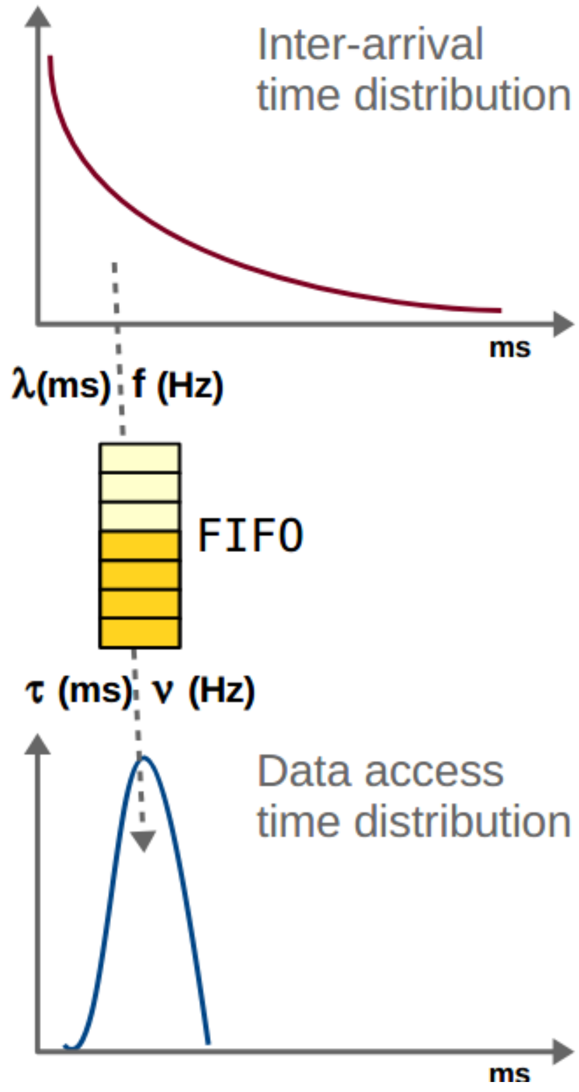


if T=1ms, f = 1000Hz
efficiency is 50%

✳ De-randomization

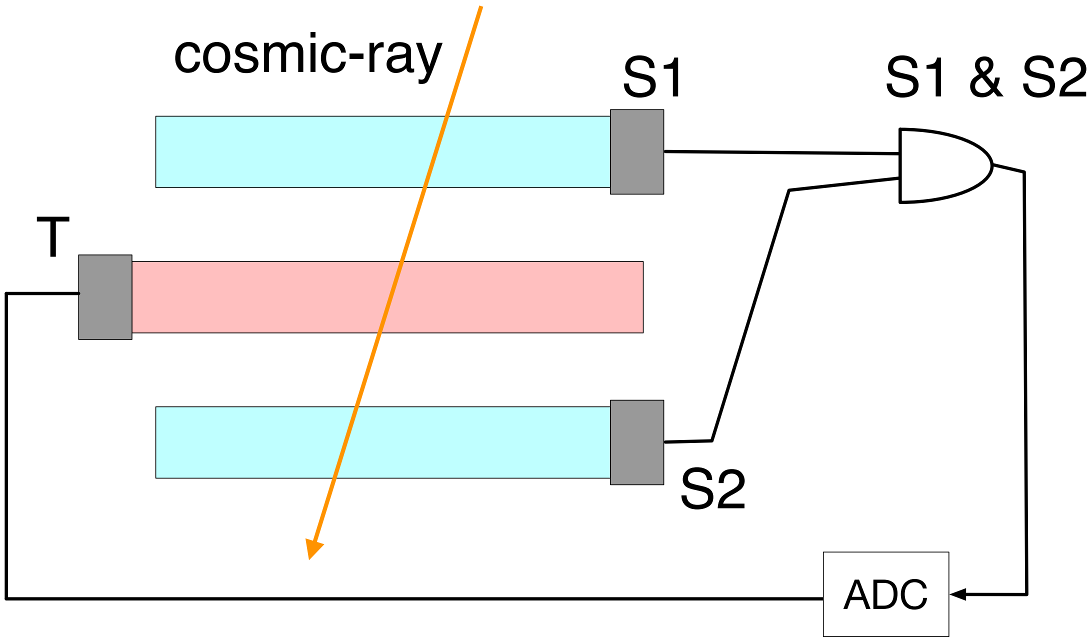
- What if we were able to make the system less dependent on the arrival time of our signals?
- Then we could ensure that events don't arrive when the system is busy – this is called de-randomization
- Can be achieved by buffering the data

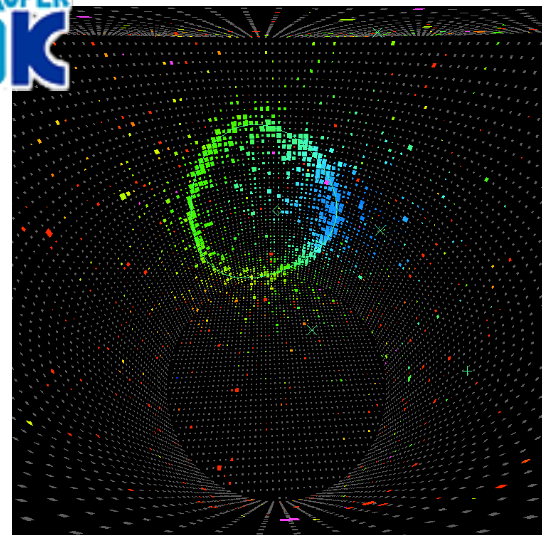




for example, oscilloscope has a memory to store some events

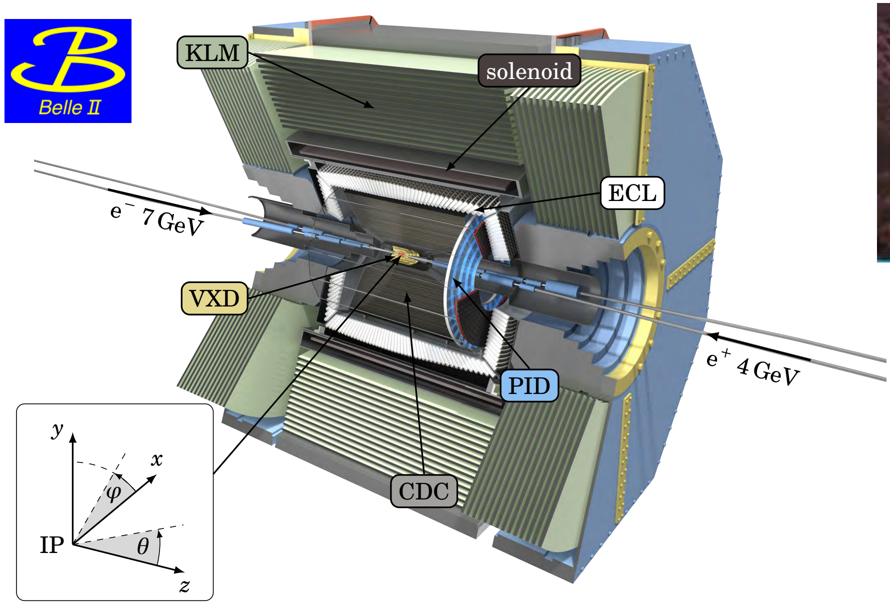
✳ Various trigger scheme



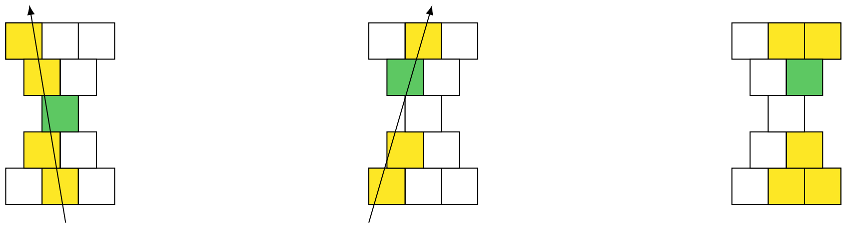


$$\sum_i Q_i \geq threshold$$

→ G. Pronost's talk for trigger system on Friday



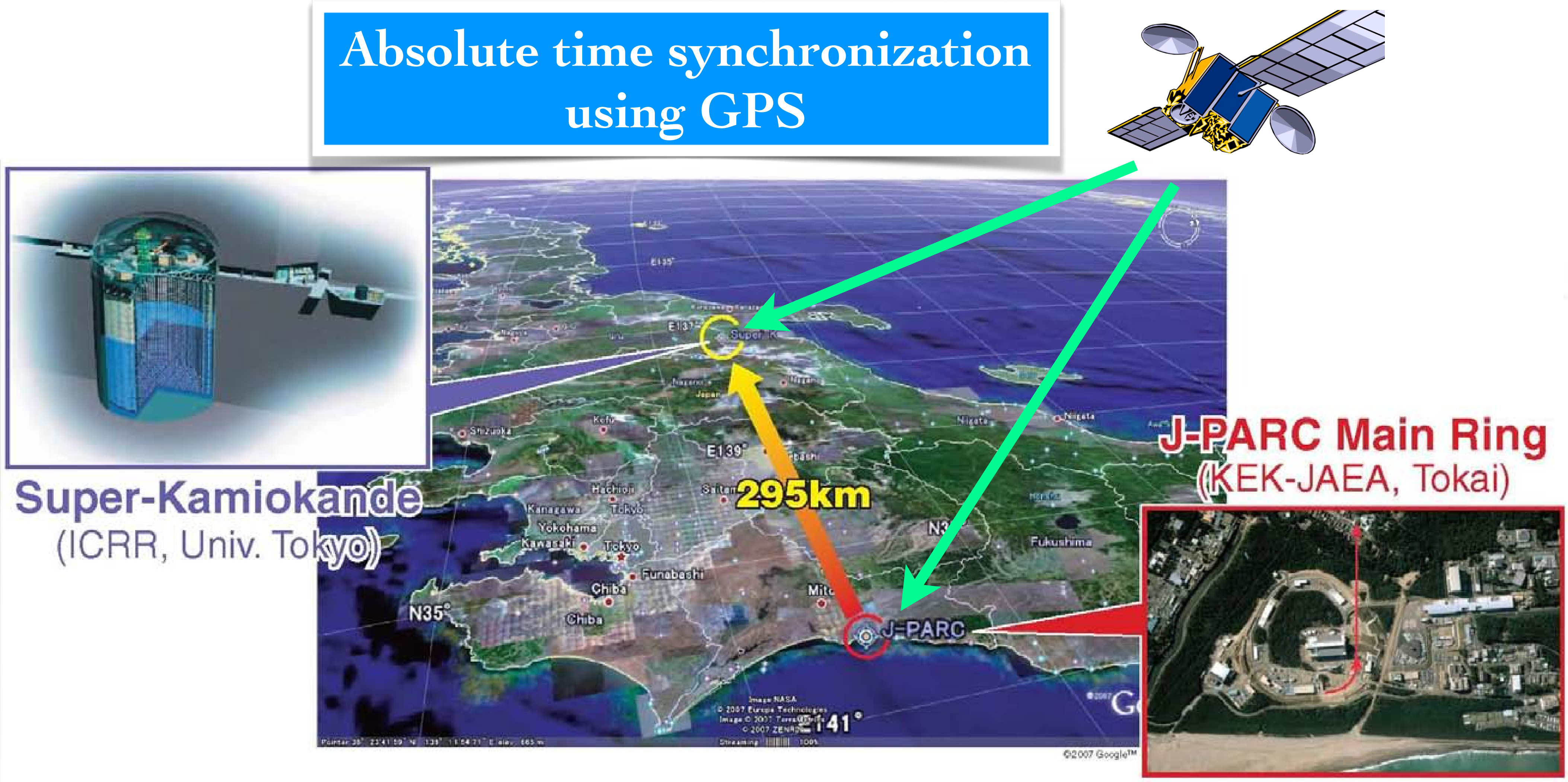
several smart trigger condition utilizing a FPGA etc. as well as a multi-level trigger scheme are adopted at a large scale experiment



need to consider : trigger eff., decision time etc.
(design of trigger scheme is important !)

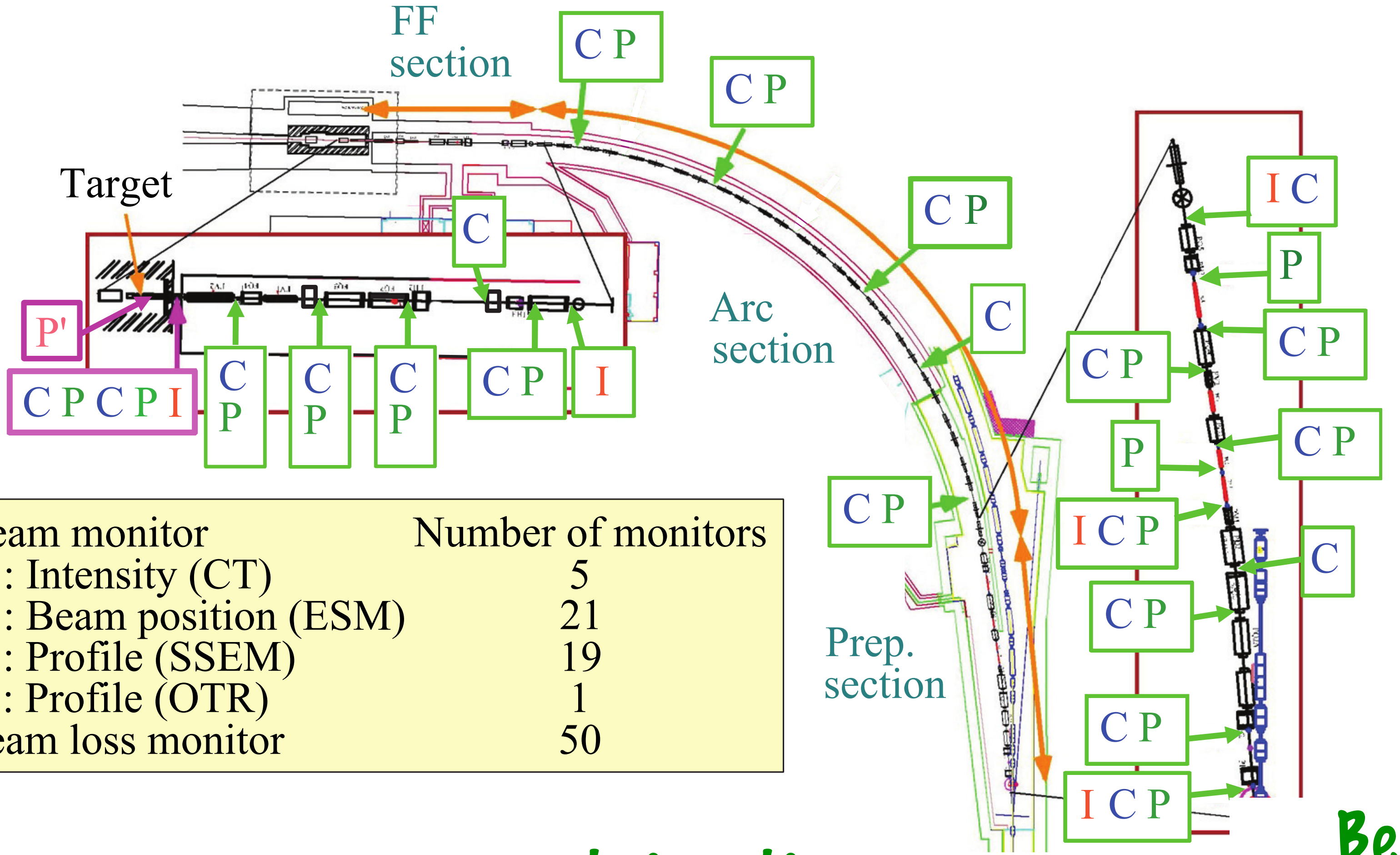
Introduction of neutrino beamline DAQ

Beam trigger & GPS



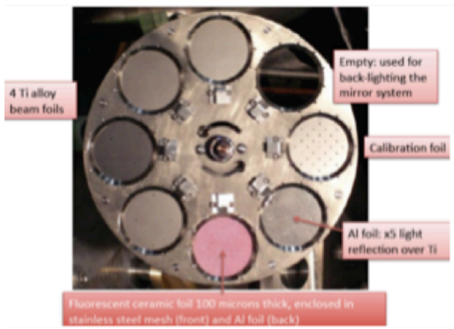
Beam extraction trigger is provided by accelerator.
This trigger is used to start DAQ and stored a absolute timestamp

Beam monitor



Beam monitor	Number of monitors
I : Intensity (CT)	5
C : Beam position (ESM)	21
P : Profile (SSEM)	19
P' : Profile (OTR)	1
Beam loss monitor	50

Beam profile



Optical Transition Radiation (OTR)

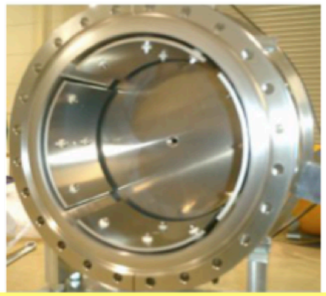
Beam loss

Beam Loss Monitor (BLM)

intensity

Current Transfomer (CT)

position

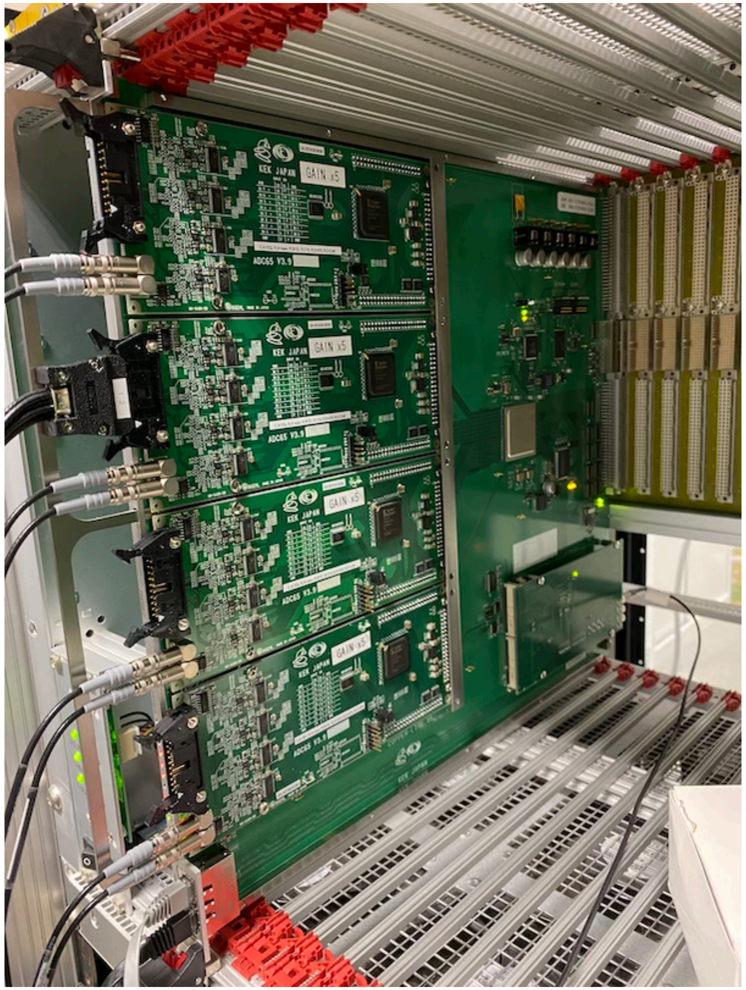


Electro Static Monitor (ESM)

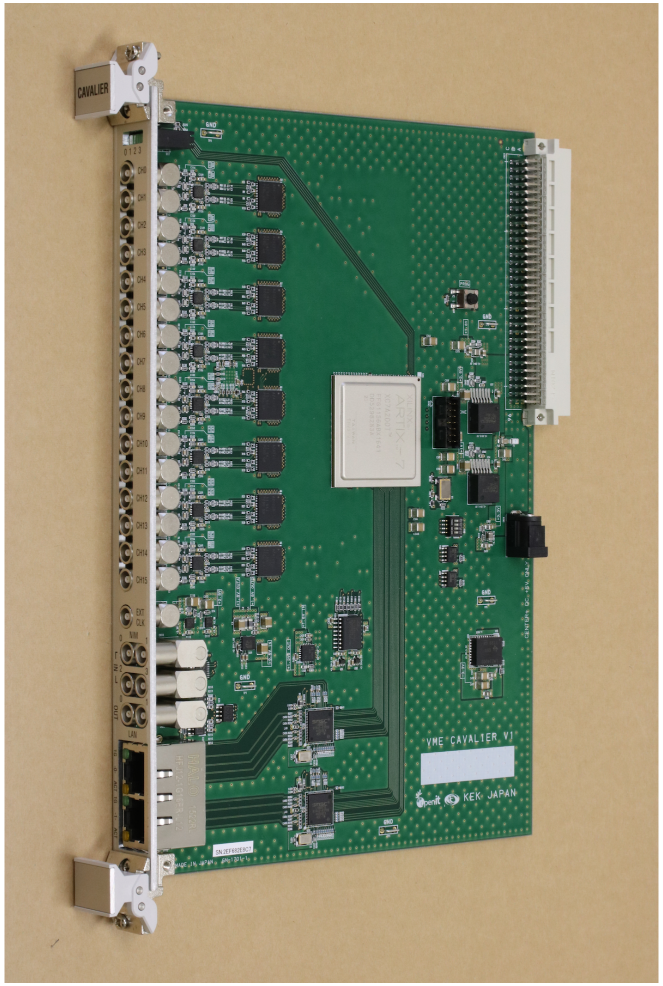
Beam profile

Segmented Secondary Emission Monitor (SSEM)

✳ Readout electronics



- COPPER-lite + FINESSE
- 65MHz sampling ADC(12bits/sample)
- Network readout



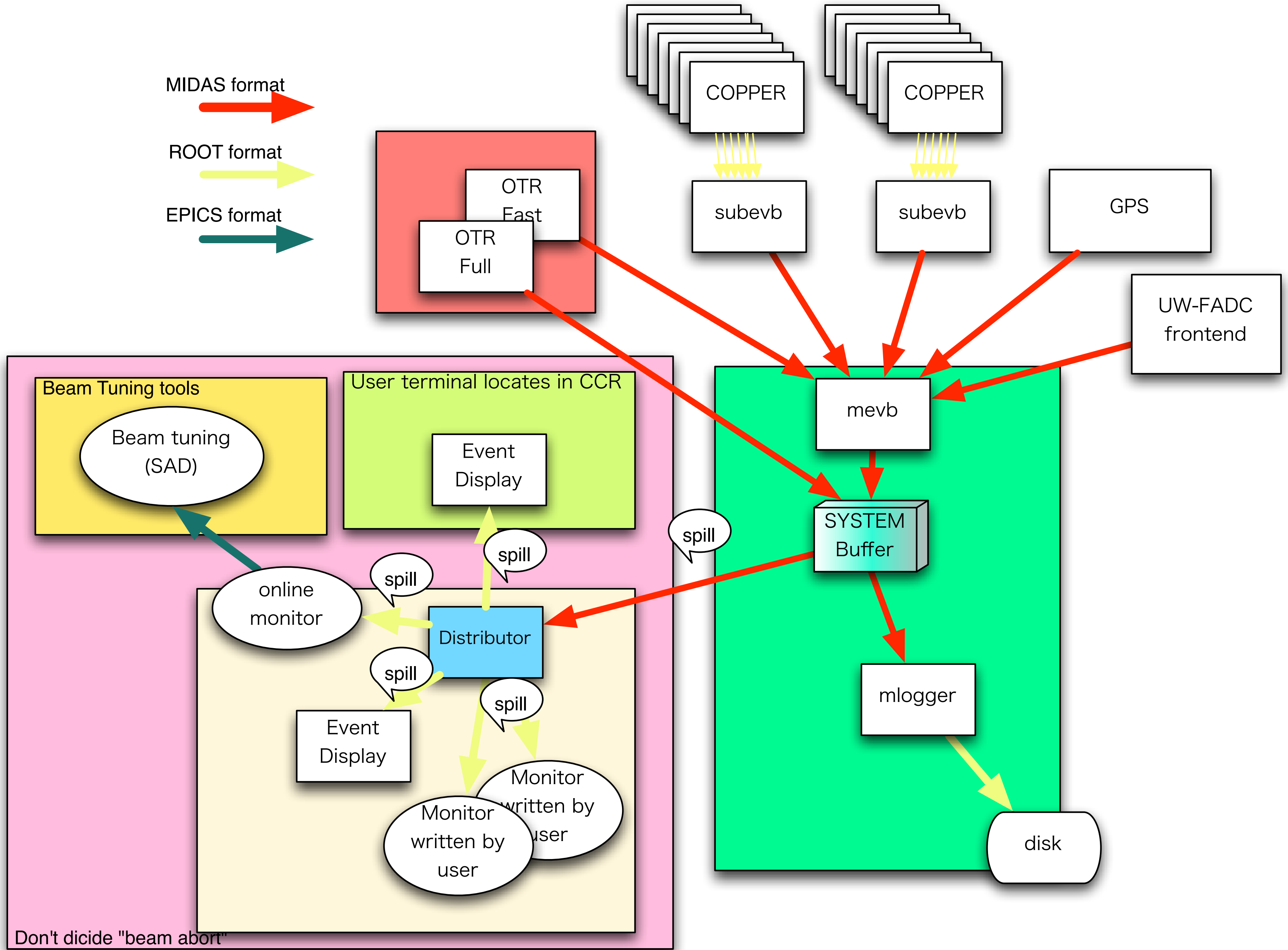
- CAVALIER
- 160MHz or 250MHz sampling ADC(12bits/sample)
- Network readout

Beam monitor readout

	# of channel (# of ch. x # of det.)	readout	frame	other necessary equipments
SSEM	(24ch+24ch) x 19 = 912 ch	Finesse 65MHz ADC	COPPER (KEK-9U-VME)	Attenuator(32ch, VME-9U) HV, moving structure control
ESM	4ch x 21 = 88 ch	CAVALIER 160MHz ADC	VME-6U(normal)	Attenuator(8 ch, VME-6U)
CT	1ch x 5 = 5 ch	CAVALIER 160MHz ADC	VME-6U(normal)	Attenuator(8 ch, VME-6U)
Loss	1ch x ~50 = ~50 ch	Finesse 65MHz ADC	COPPER (KEK-9U-VME)	HV, Interlock (Integrator,Comparator etc..)
OTR	1ch	TRIUMF-custom (w/ FPGA)	Intel SC5295UP Chassis	
Horn-CT	1ch x 18 = 18 ch	Finesse 65MHz ADC (w/ 1MHz clock)	COPPER (KEK-9U-VME)	Attenuator, Isolation
MUMON	49ch(IC)+26ch(SI) +~5ch(DIA) = ~80 ch	Finesse 65MHz ADC	COPPER (KEK-9U-VME)	Attenuator(8ch, VME-6U) HV
FxKm	~5ch	CAVALIER 160MHz ADC	VME-6U(normal)	Attenuator(8 ch, VME-6U)

Total # of ch =~1200 ch, Total expected data size = ~1.1Mbytes/spill

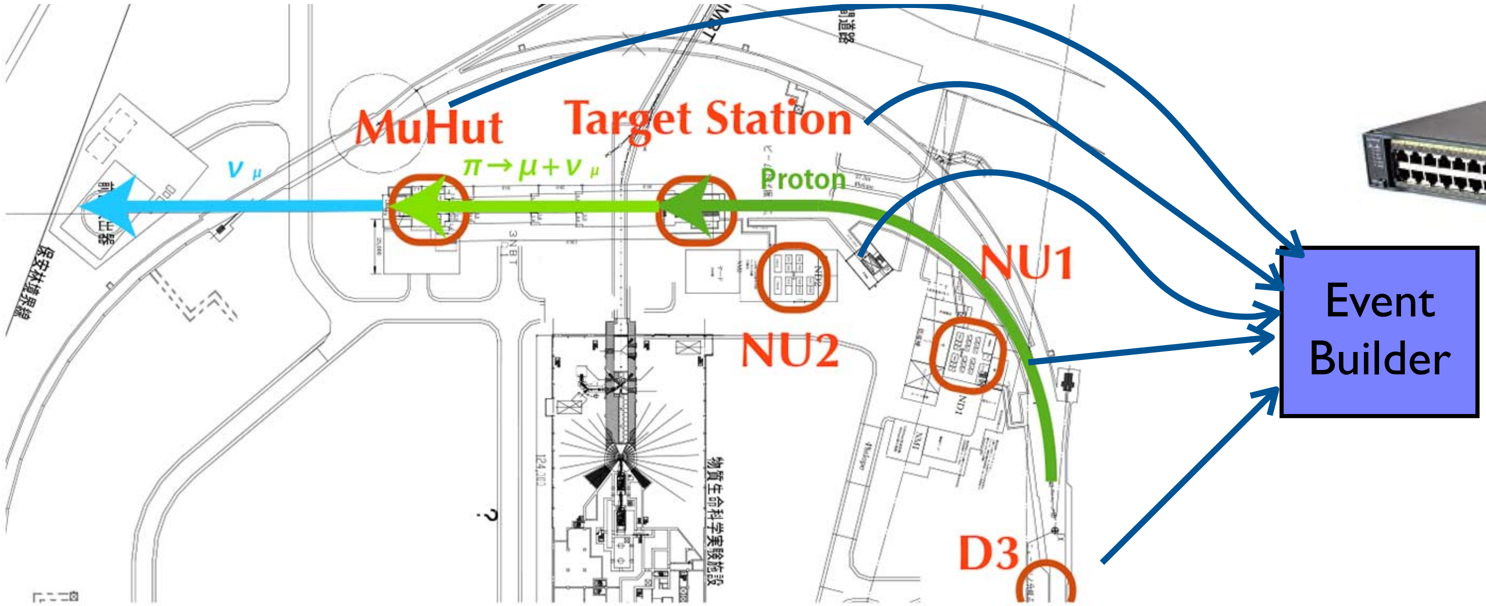
Beamline DAQ system

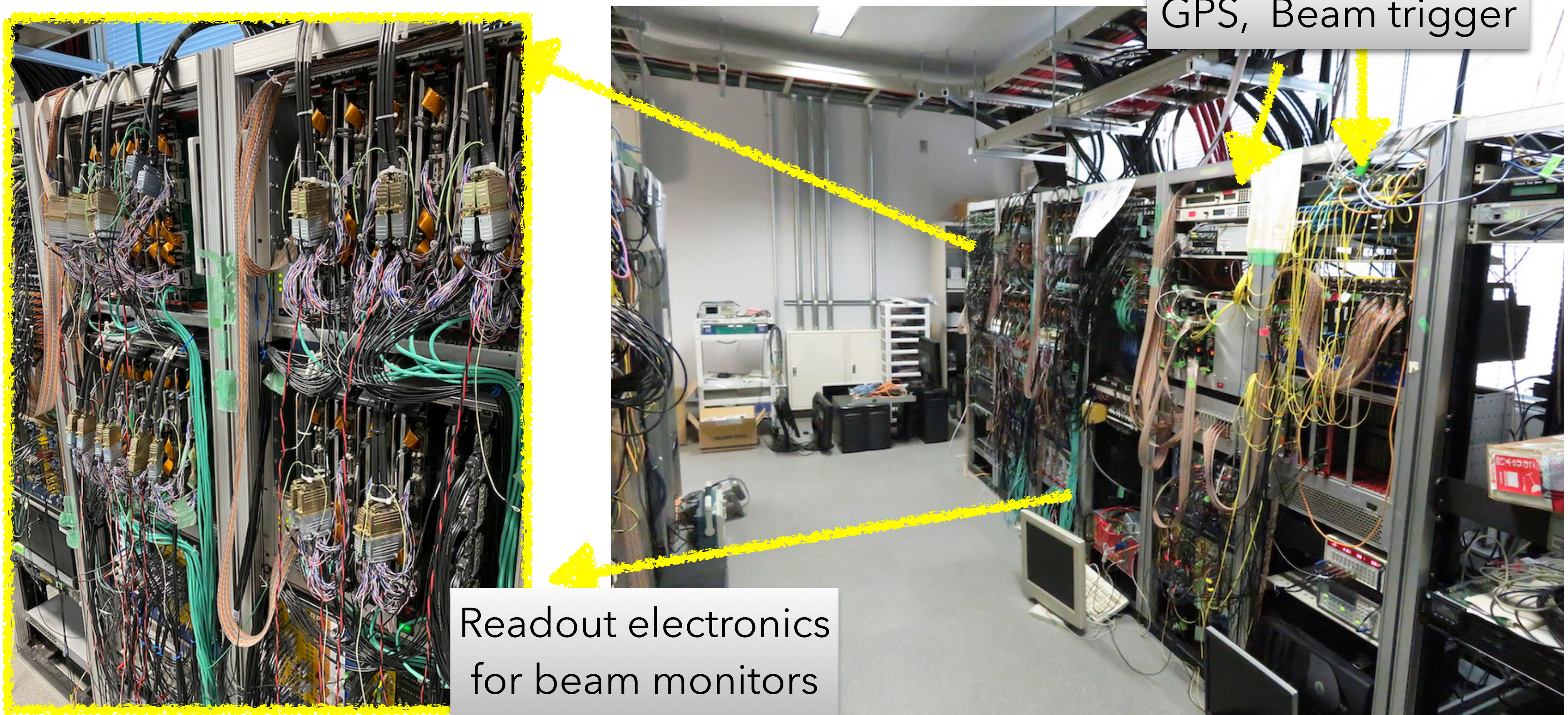


(based on MIDAS)

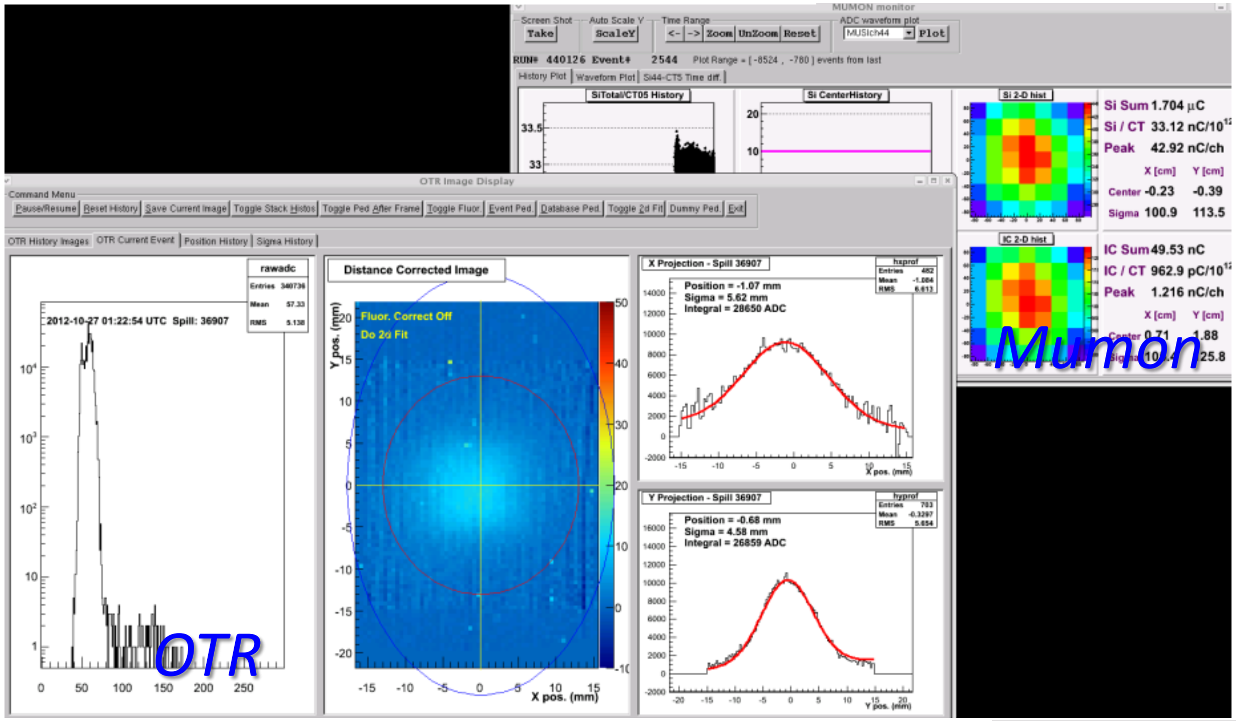
S.Suzuki(KEK)

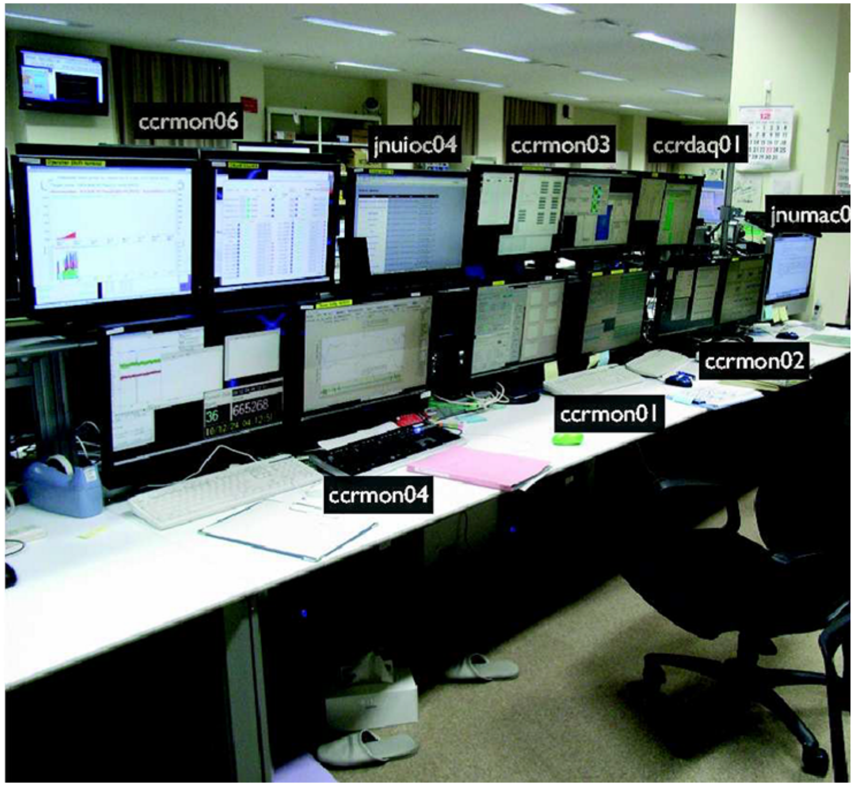
Data is collected over ethernet to an event builder PC



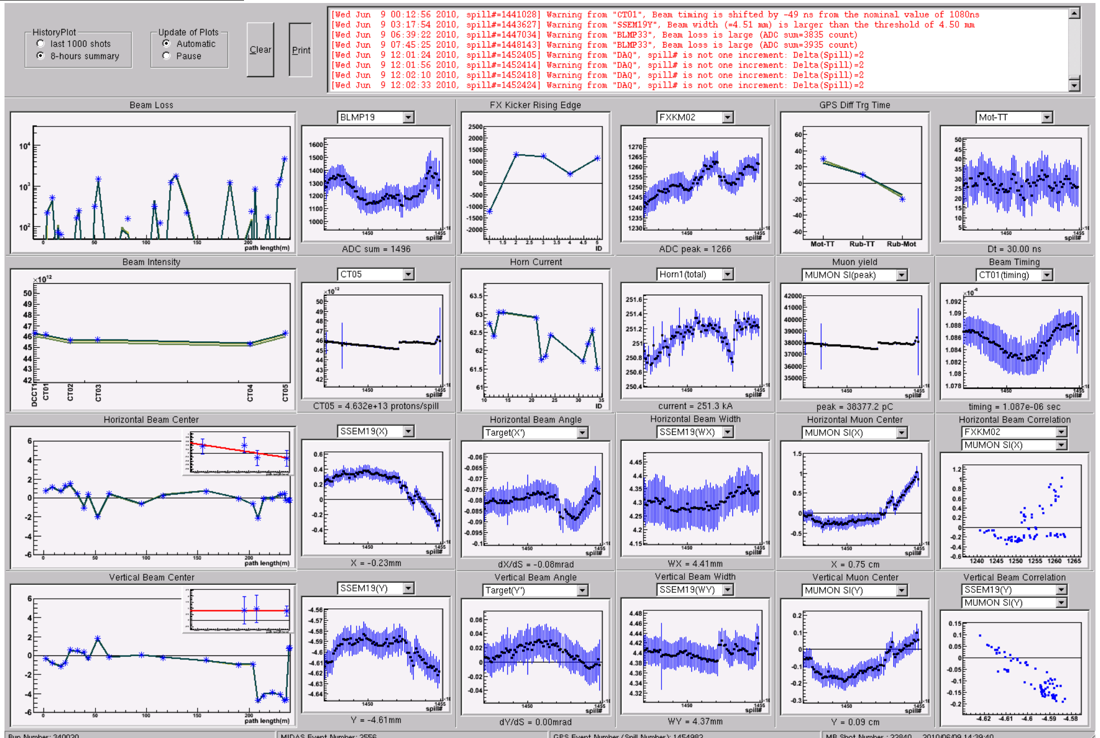


Online event displays





Data collected by DAQ is processed in realtime to check beam quality etc.



Summary

- Data acquisition system is briefly introduced
- J-PARC neutrino beamline DAQ system is shown as an specific example