Orientation for Hardware Training

Son Cao (IFIRSE)

8th Vietnam School on Neutrinos, July 18, 2024

Timetable for hardware training

- We prepare **two independent setups** for hardware training. *They are not identical but same concept*
- Schedule for July 18th (Thu.)
  - 14:10 - 14: 25(15 mins.) Hardware orientation
  - 14:25 - 14:45 coffee break
  - 14:45 - 16:00 (1.5 hours) **Groups** ν_e, ν_μ **go for hands-on activities while groups** ν_τ, ν_s **work on mini-projects**
  - 16:15 - 17: 30 (1.5 hours) **Swap groups**
- Schedule for July 19th (Fri.)
  - 14:10 - 14: 25(15 mins.) Hardware orientation
  - 14:25 - 14:45 coffee break
  - 14:45 - 16:00 (1.5 hours) **Groups** ν_e, ν_μ **go for hands-on activities while groups** ν_τ, ν_s **work on mini-projects**
  - 16:15 - 17: 30 (1.5 hours) **Swap groups**
- Schedule for July 22nd (Mon.)
  - 13:20 - 13: 35(15 mins.) Hardware orientation
  - 13:40 - 15:40: (2 hours) **Groups** ν_e, ν_μ **go for hands-on activities while groups** ν_τ, ν_s **work on mini-projects**
  - 15:40 - 17: 40 (2 hours) **Swap groups**


Hardware training
Study place
for mini-project

Purpose:

Provide some hands-on experience w/ hardwares used in real Neutrino Detector

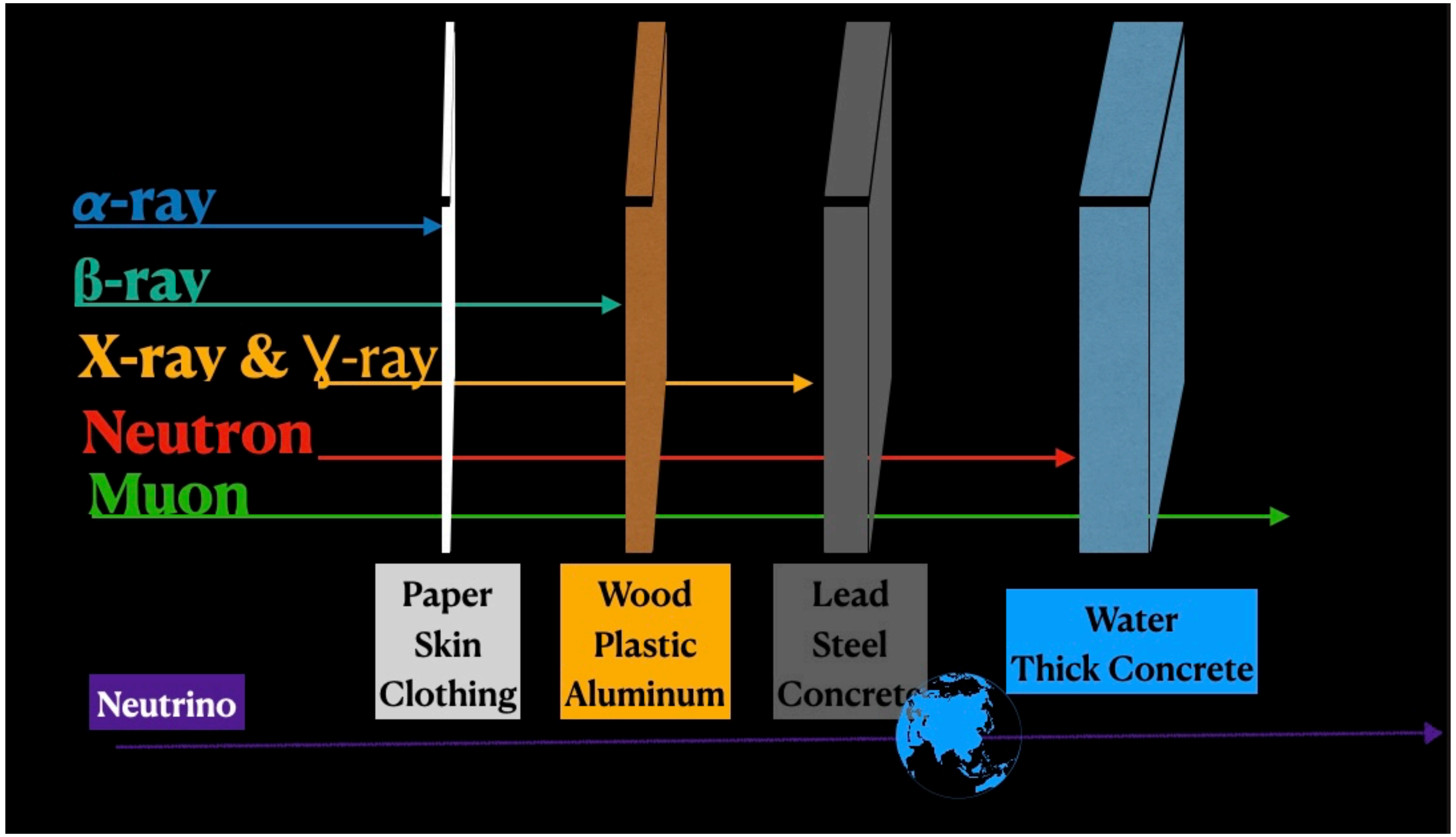
Vietnamese students lack skills with hardware, especially in particle and nuclear physics

- Did you use multimeter before?
- Did you use oscilloscope before?
- Did you use NIM modules before?
- Did you use photosensor (*not including smartphone’s camera*) before?
- ....

Purpose:

Provide some hands-on experience w/ hardwares used in real Neutrino Detector

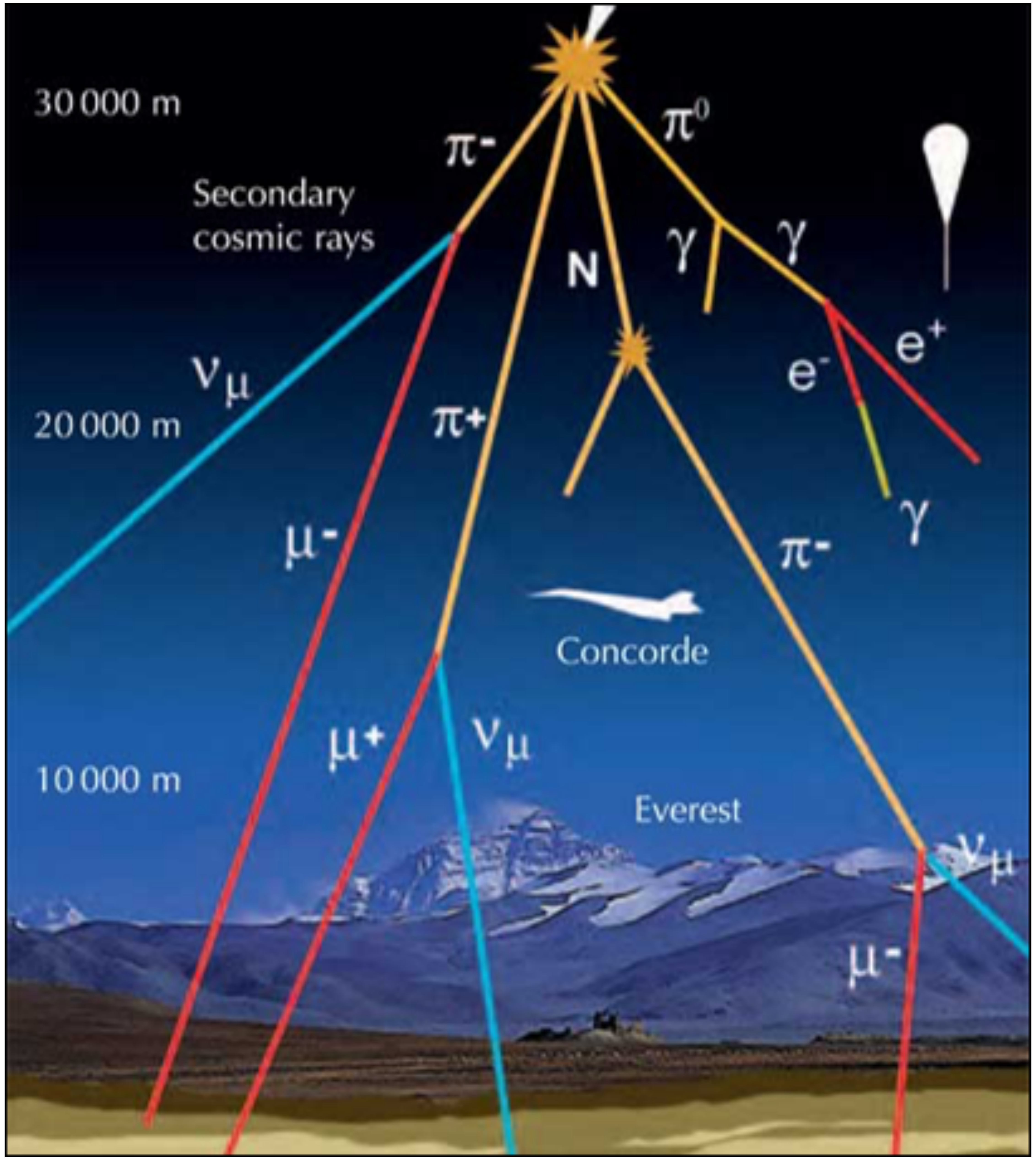
- But ...We won't see the neutrino interaction in the lab. *You will need big detector and place near the huge source of neutrino for this. Also real-time identification of neutrino interaction is quite challenging*
- What we can see is with the ***cosmic ray* muon (big** *brother/sister of neutrinos***)**



High energy astrophysical particles (eg. hydrogen & helium from the Sun) interact with the Earth's atmosphere →produce vast amount of muons

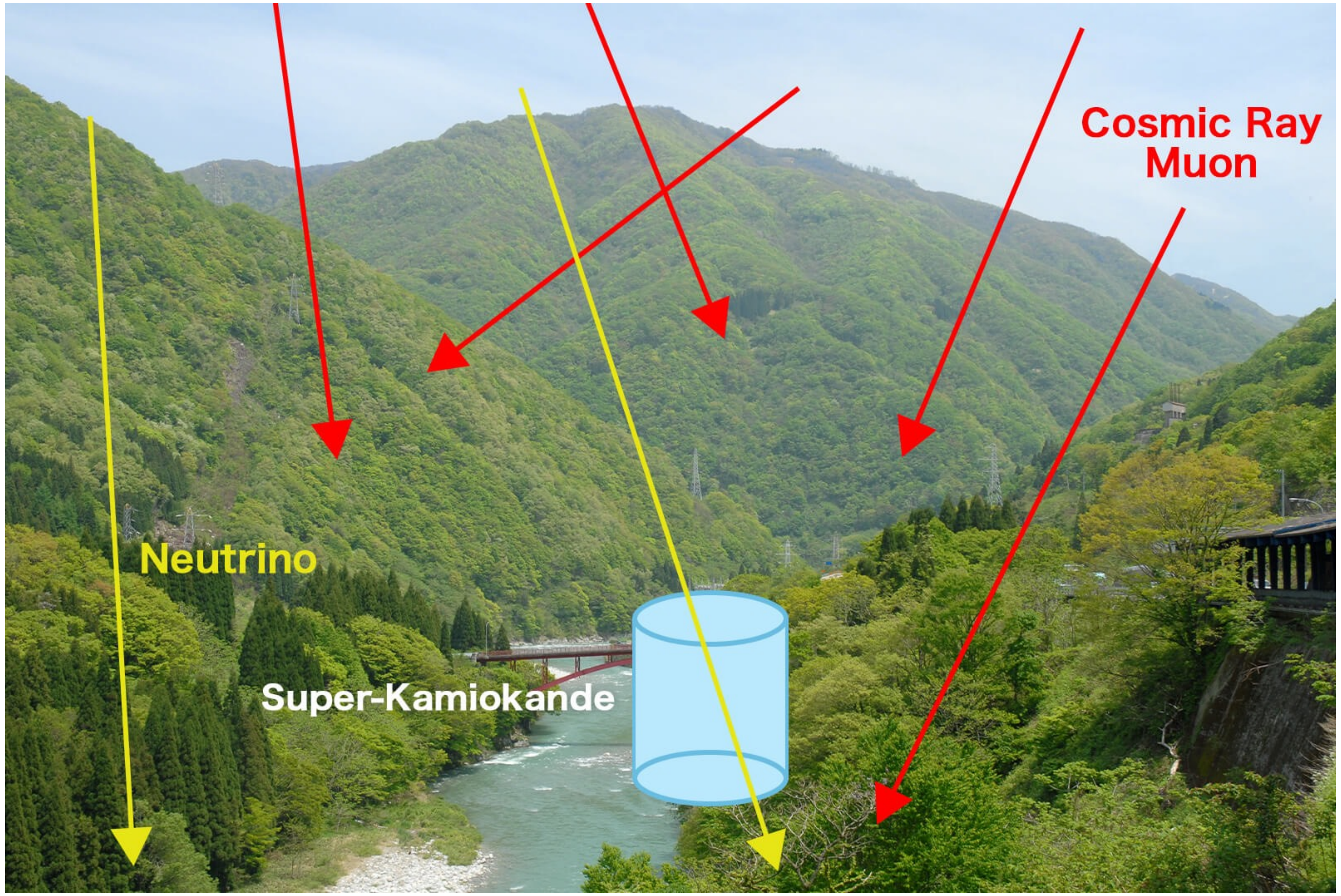
~ 1 muon/cm²/minute

This number is important for particle detection



Eg. What if Super-K places on the surface?

$A = 2.\pi . R . (R + h) \approx 2.3.40.80 = 9600\ m^2$



Note: flux of cosmic-ray muons depends on energy and the zenith angle

Simple calculation:

Cosmic ray rate ~ 10^6 Hz

Neutrino rate is in Hz-level rate.

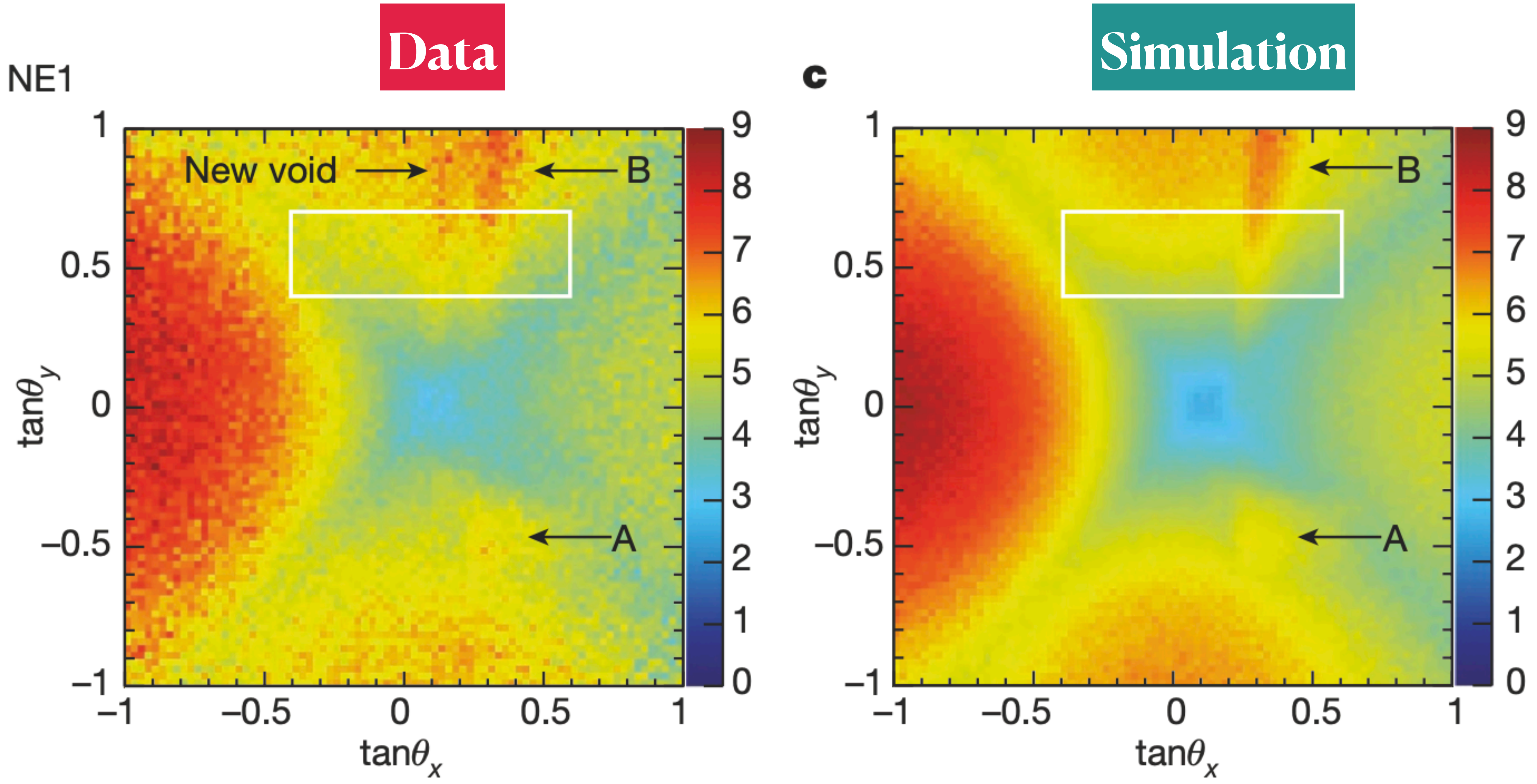
→ your detector is bombarded by cosmic ray muons (background) not neutrino (signal)

By putting detector 1000m underground, this cosmic ray rate is suppressed by factor of about 10^5 and what we have actually observed in Super-K is about 2Hz of cosmic ray

Muon can be used for a practical application

https://www.nature.com/articles/nature24647

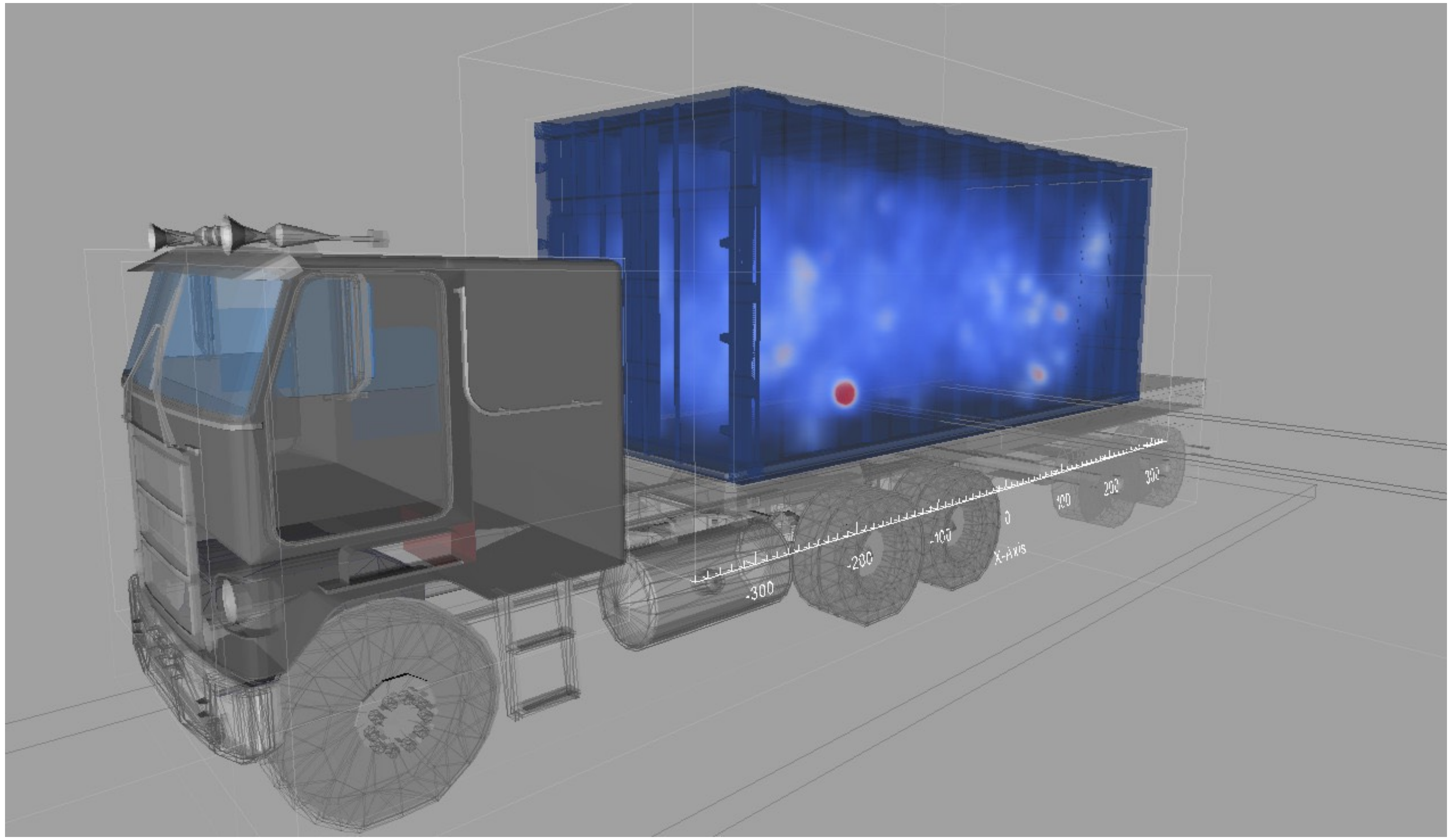
called: muon radiography technique



Color is corresponding to intensity of muons.
Red is with more muons detected

Muon can be used for a practical application

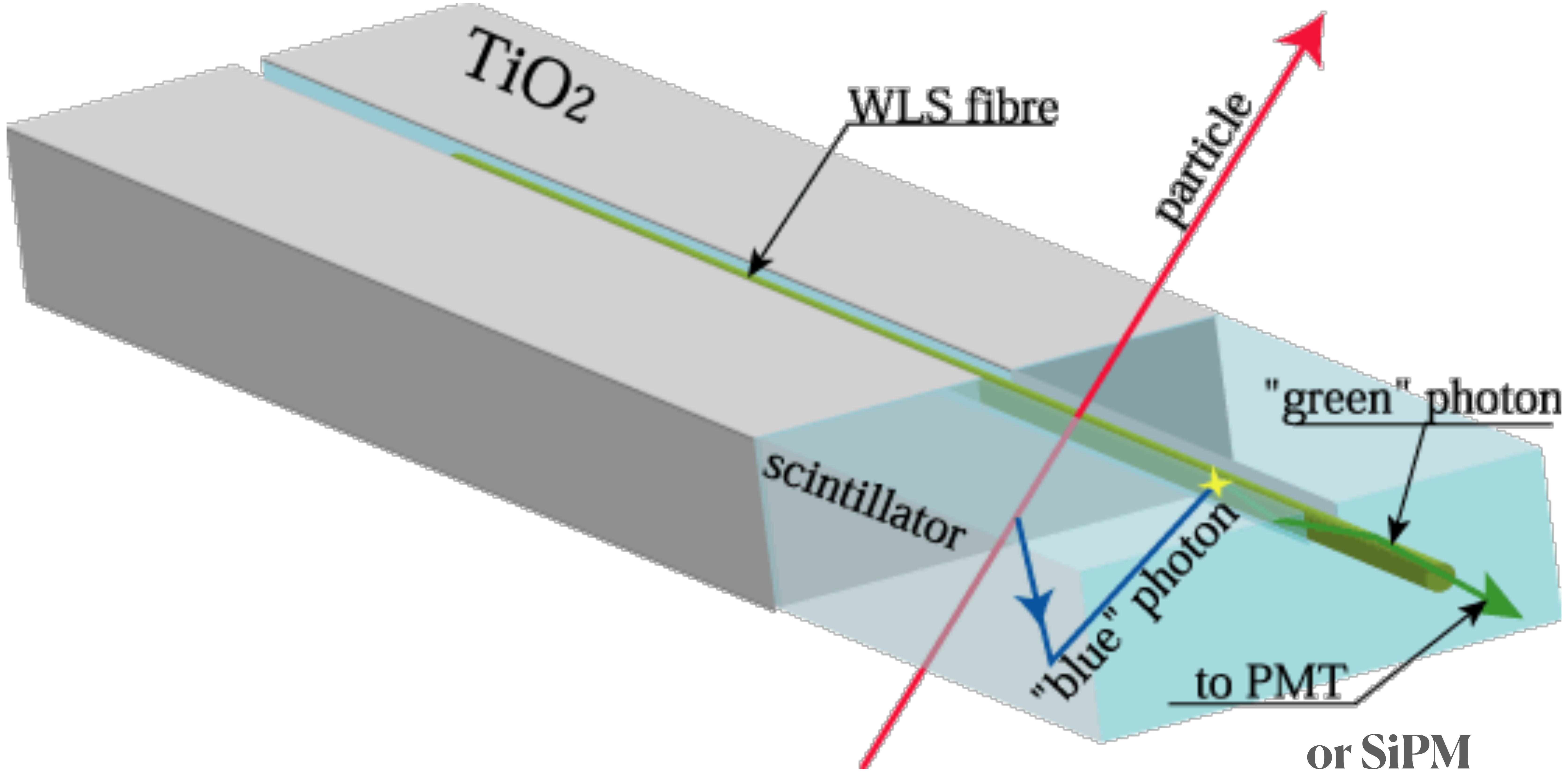
For cross-bolder security



https://cds.cern.ch/record/2281058

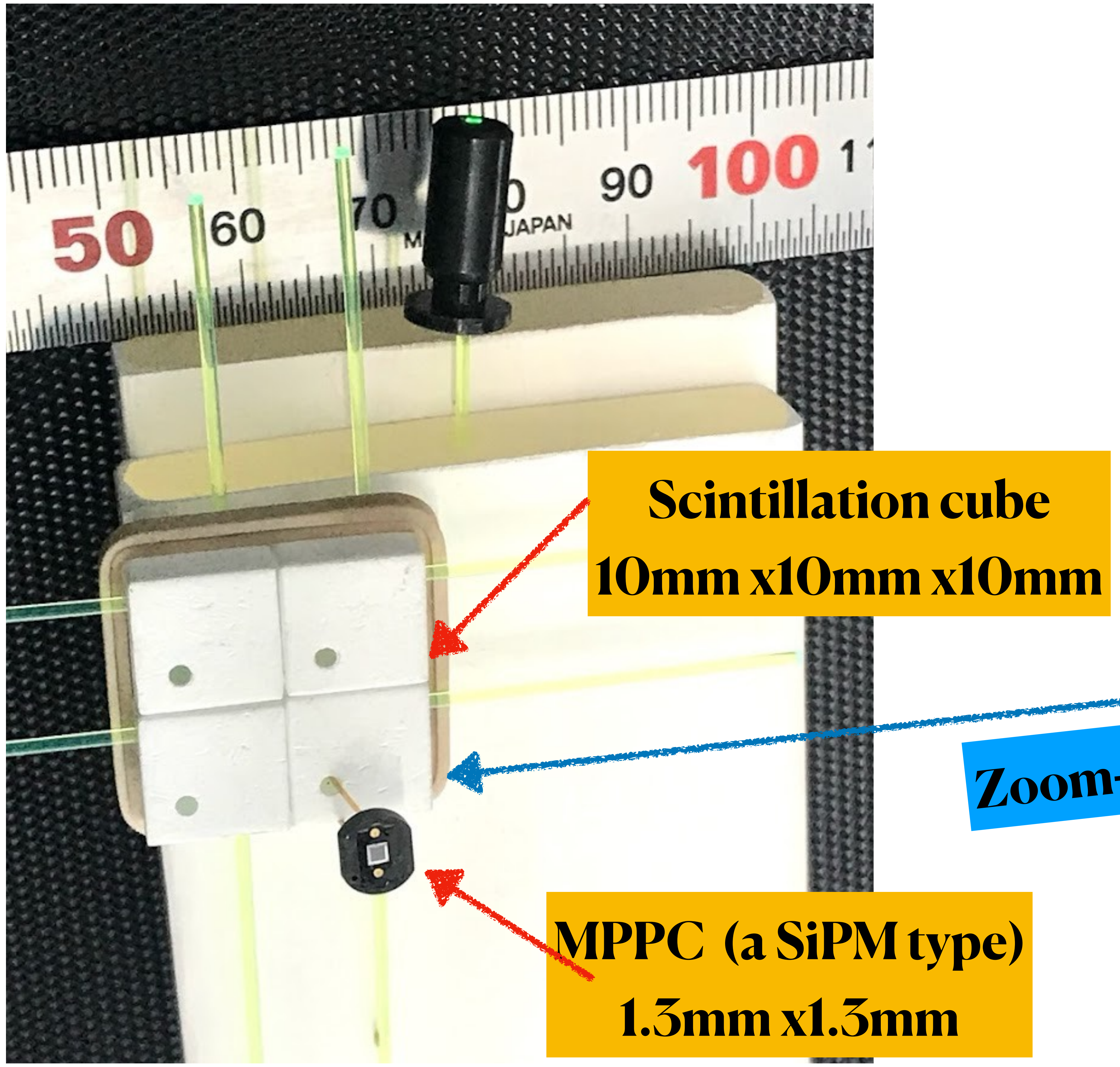
How can we see muons and measure their characteristics with *what we have in the lab?*

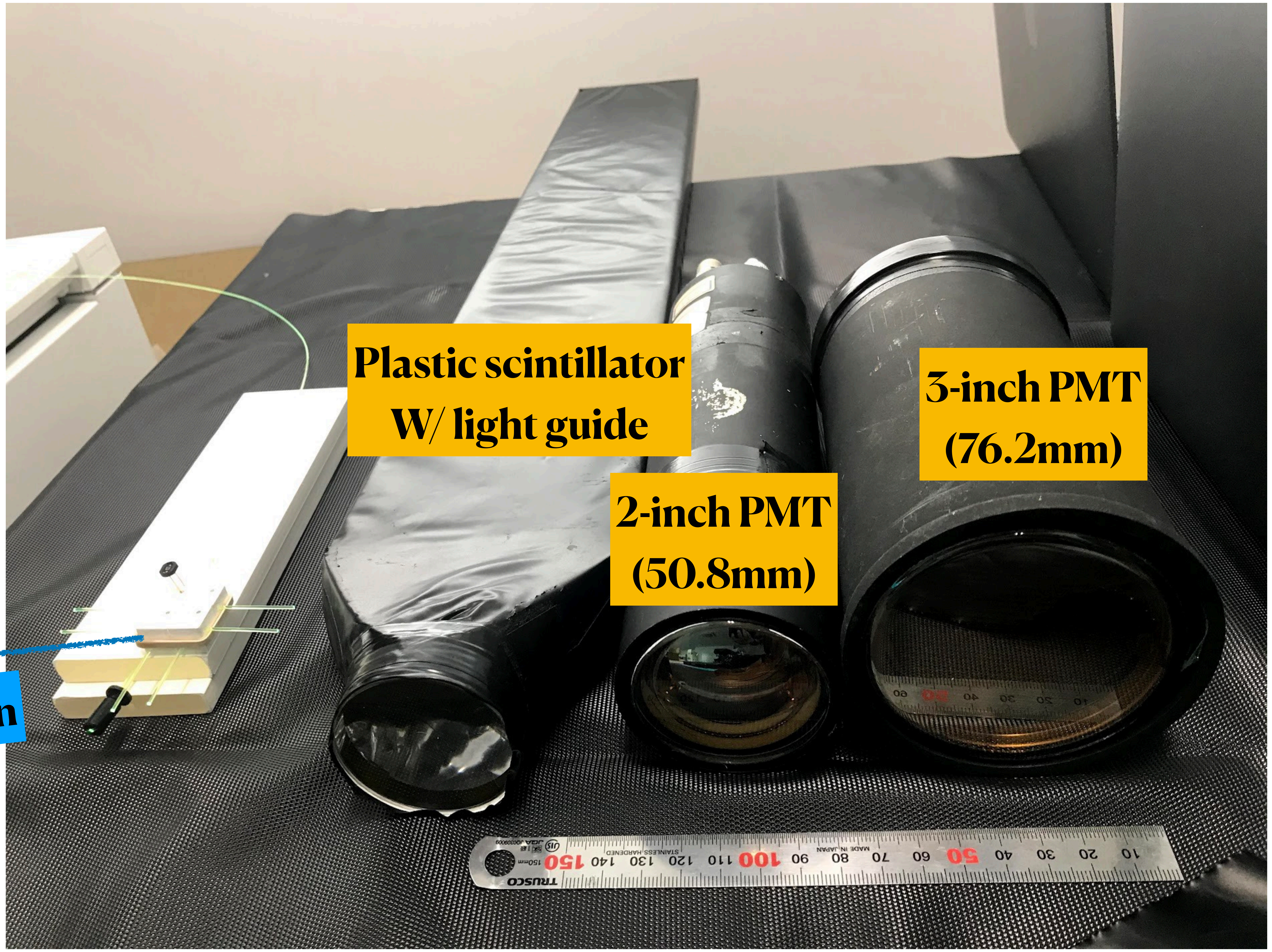
Tracking the charged particle w/ scintillator



When passing through the scintillator, charged particles (μ, π, e,...) deposits energy and excite the scintillation photons, which are collected and guided to the photosensor for converting to the electrical signals (*more convenient to manipulate*) for data recording.

Tracking the charged particle w/ scintillator





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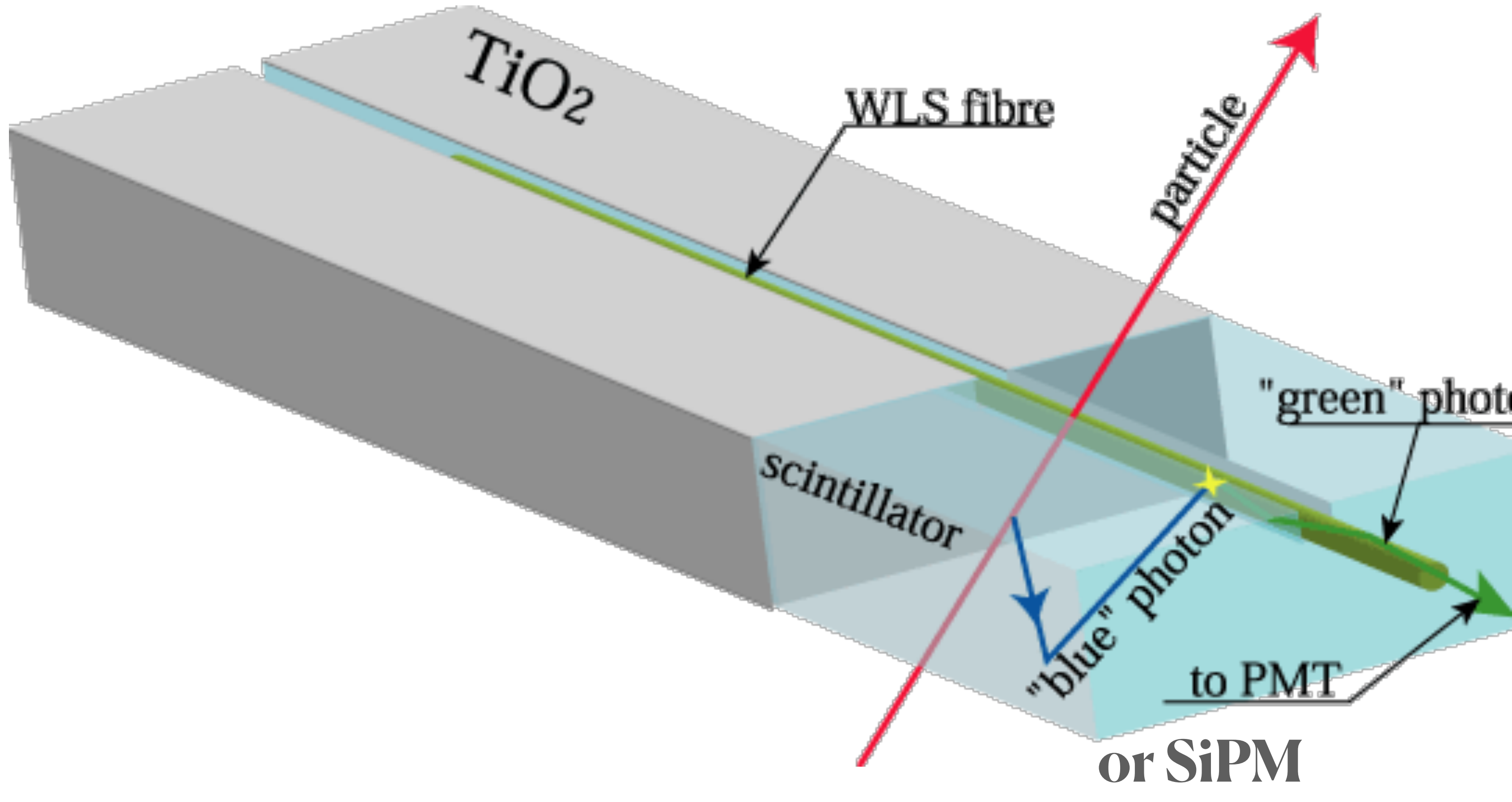
Tracking the charged particle w/ scintillator

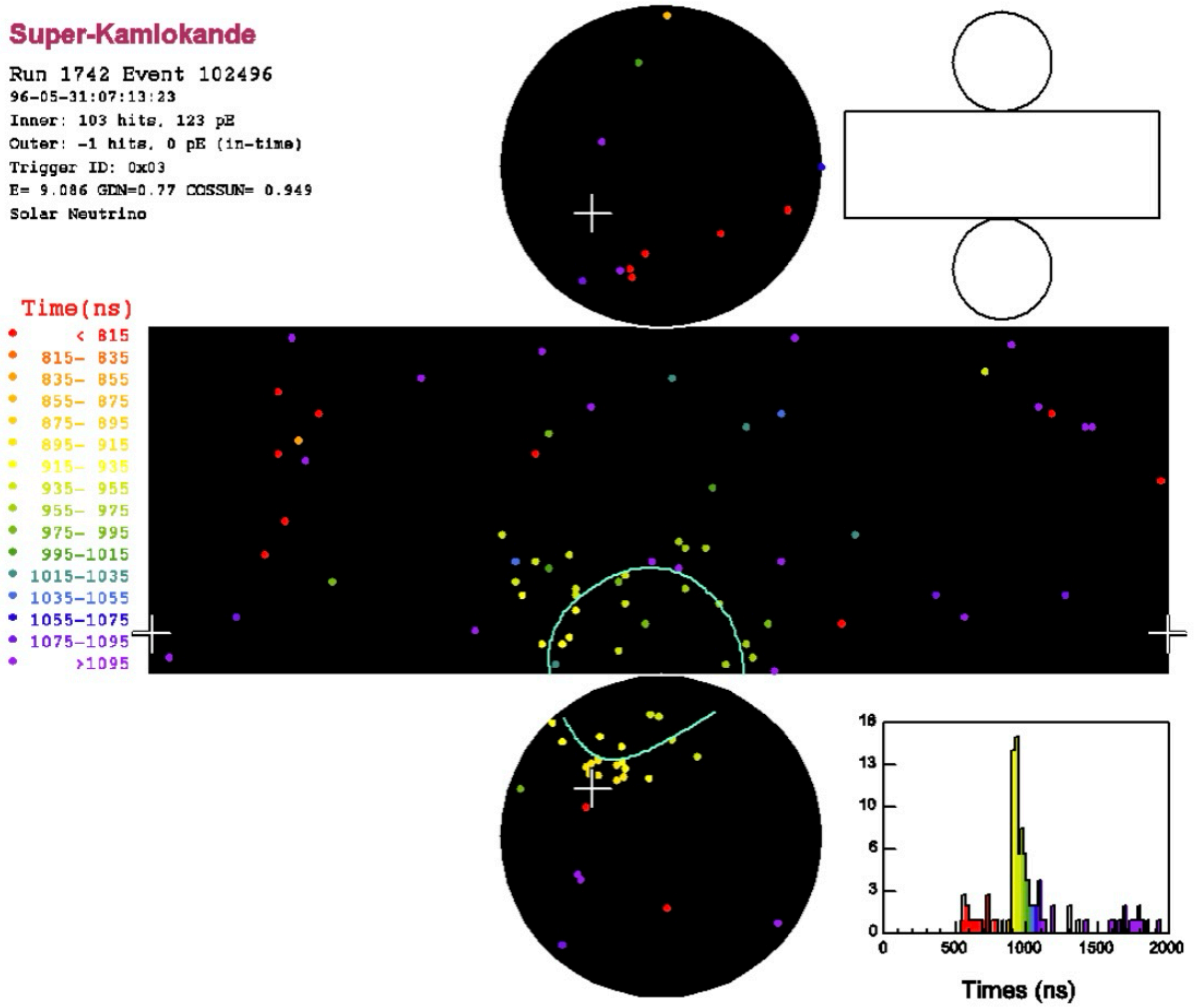
- Muon deposits ~ **2 MeV per 1cm-length** path in the plastic scintillator
- 2 MeV deposit energy will produce ~ **10,000 photons**
- Assume the probability for WLS catching the photons is about 1%, then ~ 100 photons are capture and change to green photons
- Detection of photosensor is about 20-40%, so will have about **20-40 photoelectrons observed**
  - Sometime you can get lower due to the aging of scintillator, attenuation in the WLS or light loss from imperfect coupling between the WLS and photosensor



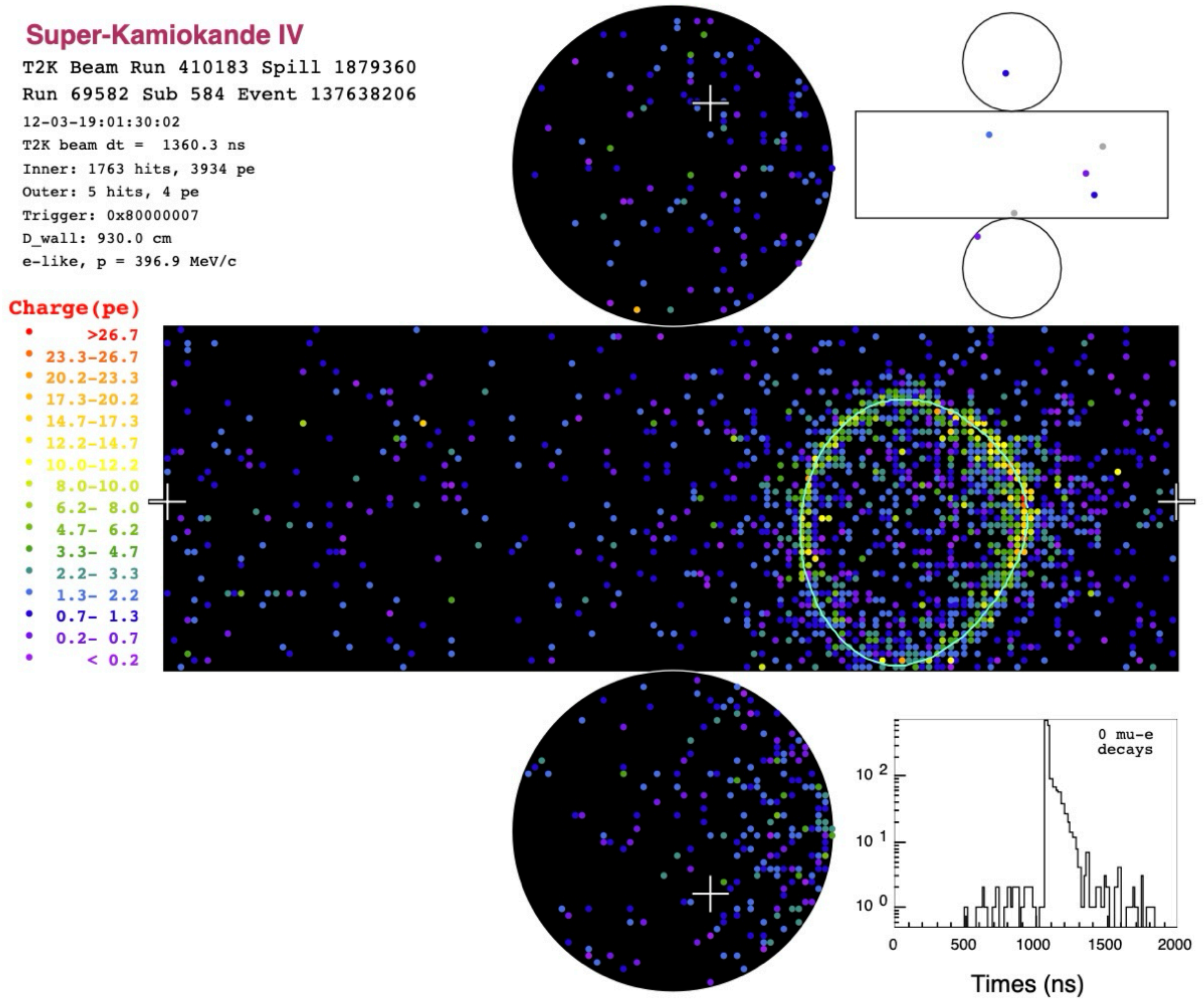
Why is light yield of scintillator important?

Trace of neutrinos: (typically) very faint flash of light

"Experimental neutrino experiment in the nutshell"



A ~ 9MeV solar neutrino candidate
123 p.e. counted in 103 PMT in few 100ns;
~ 1 p.e. per hit PMT



A ~400MeV ν_e candidate from T2K beam
3934 p.e. counted in 1763 hit PMT in few 100ns
~3-4 p.e. per hit PMT

In a blinking of LED

....~10^{15} photons are generated

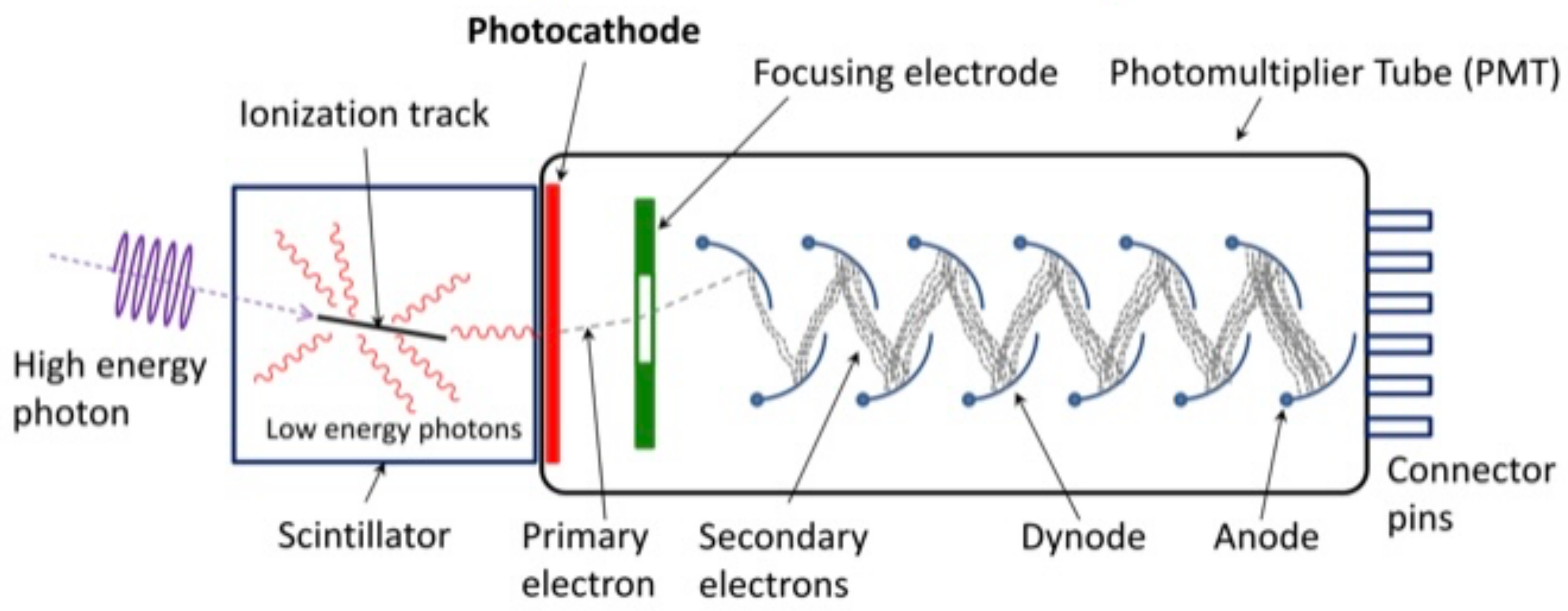
Typically, signature of the comic ray muons passing through detector is fast (ns or sub-ns) and faint (few 10s to 1000s photons)

↓

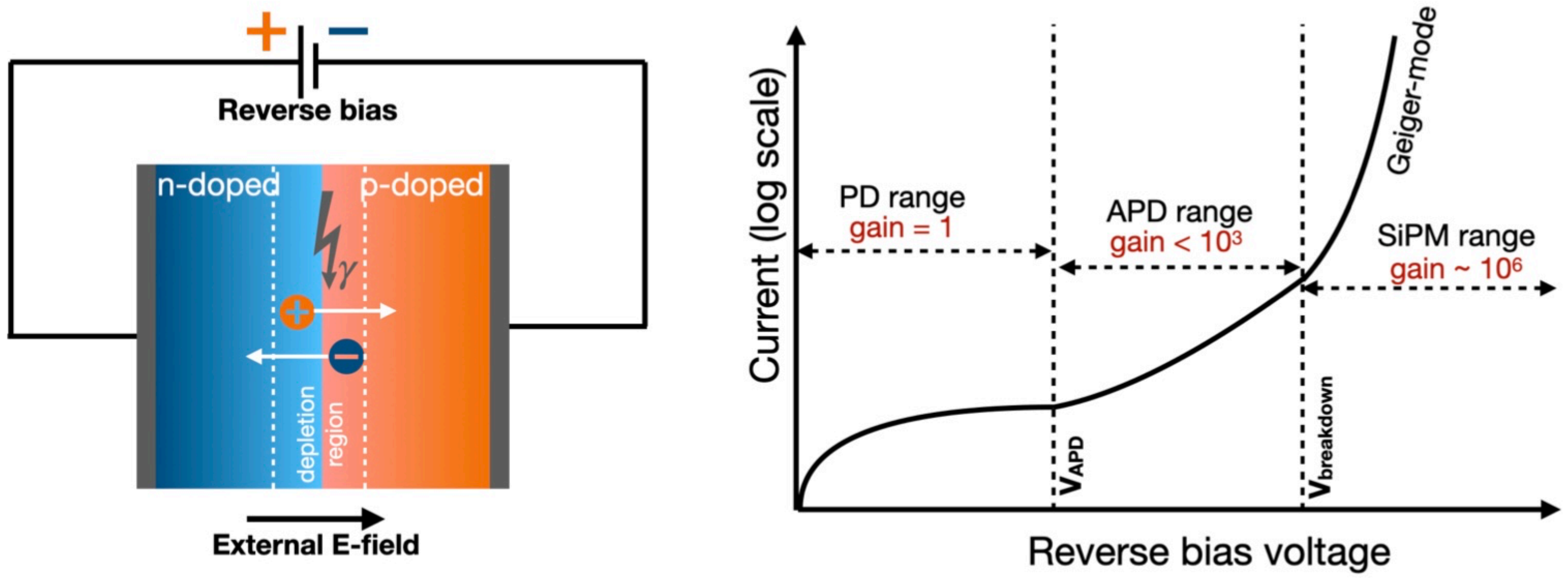
We need a very good "Eyes"

Great "eyes" in the market

Characteristic	PMT	PD	APD	SiPM
Spectral coverage [nm]	115-1,700	190-13,000	190-1,700	320-900
Peak QE (η) [%]	< 40	< 90	< 90	< 40 (*PDE*)
Active area [mm^2]	< 12,000	< 100	< 100	< 10
Gain (μ)	10^5-10^6	1	< 100	10^5-10^6
NEP [W/√Hz]	> $2x10^{-17}$	> $6x10^{-16}$	> $1x10^{-15}$	> $6x10^{-16}$
Rise time [ns]	> 0.15	> 0.23	> 0.35	> 1
Bandwidth [Hz]	< $2x10^9$	< $1.5x10^9$	< $1x10^9$	NA
Time jitter [ns]	> 0.05	NA	> 0.2	> 0.2

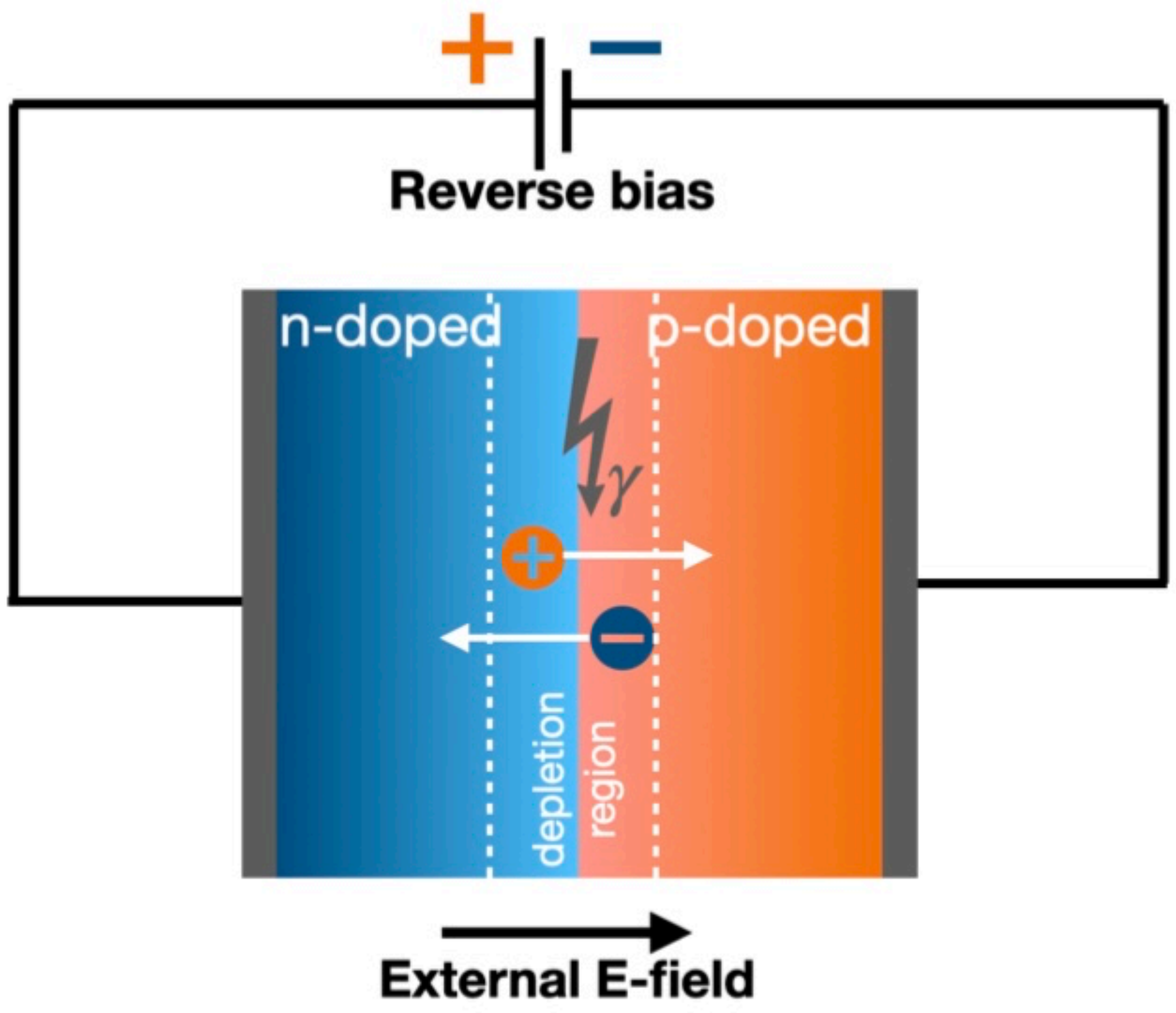


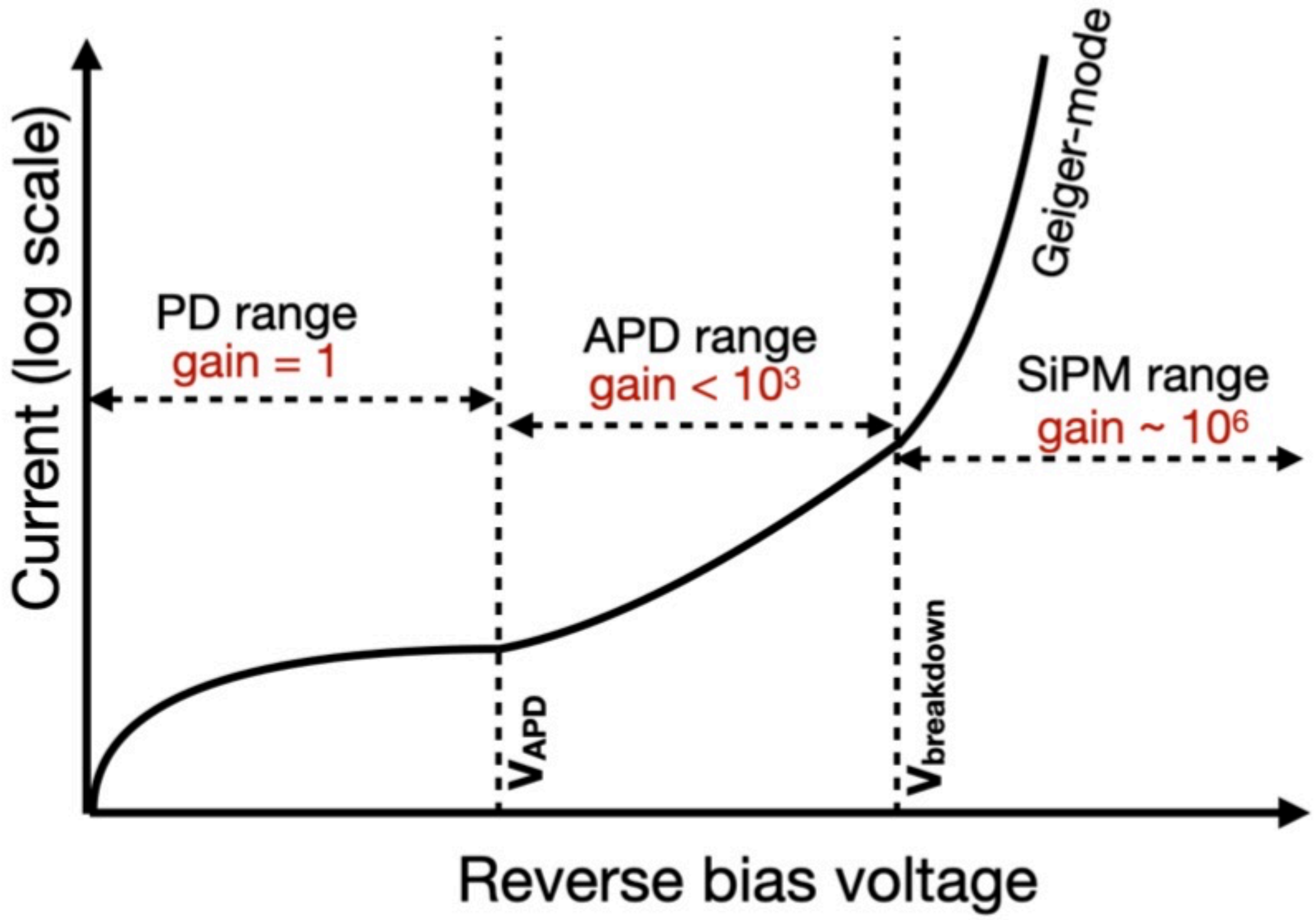
Based on "External" photoelectric effect



Based on "Internal" photoelectric effect

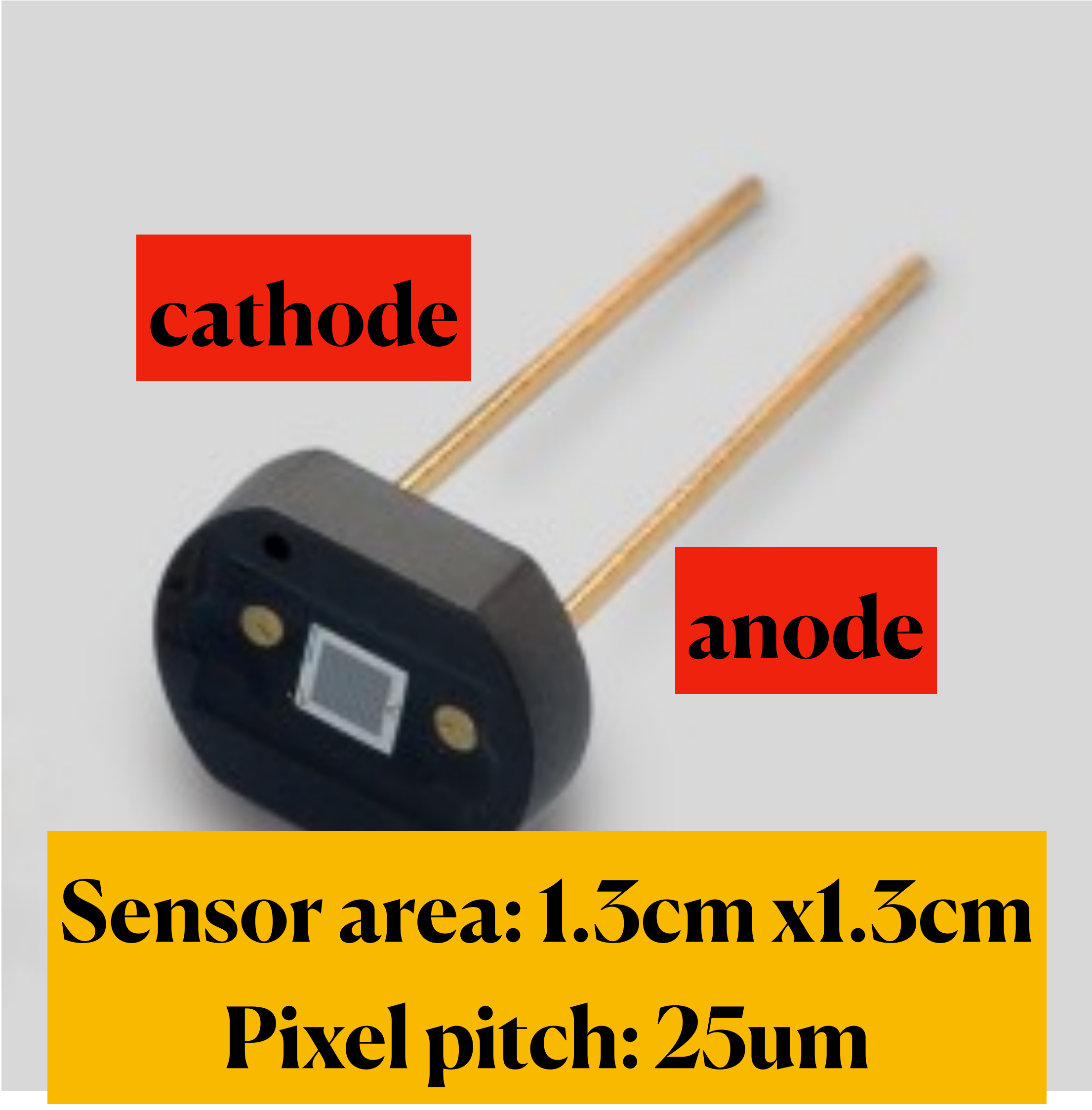
Photon detection principle w/ Silicon photomultiplier (SiPM)



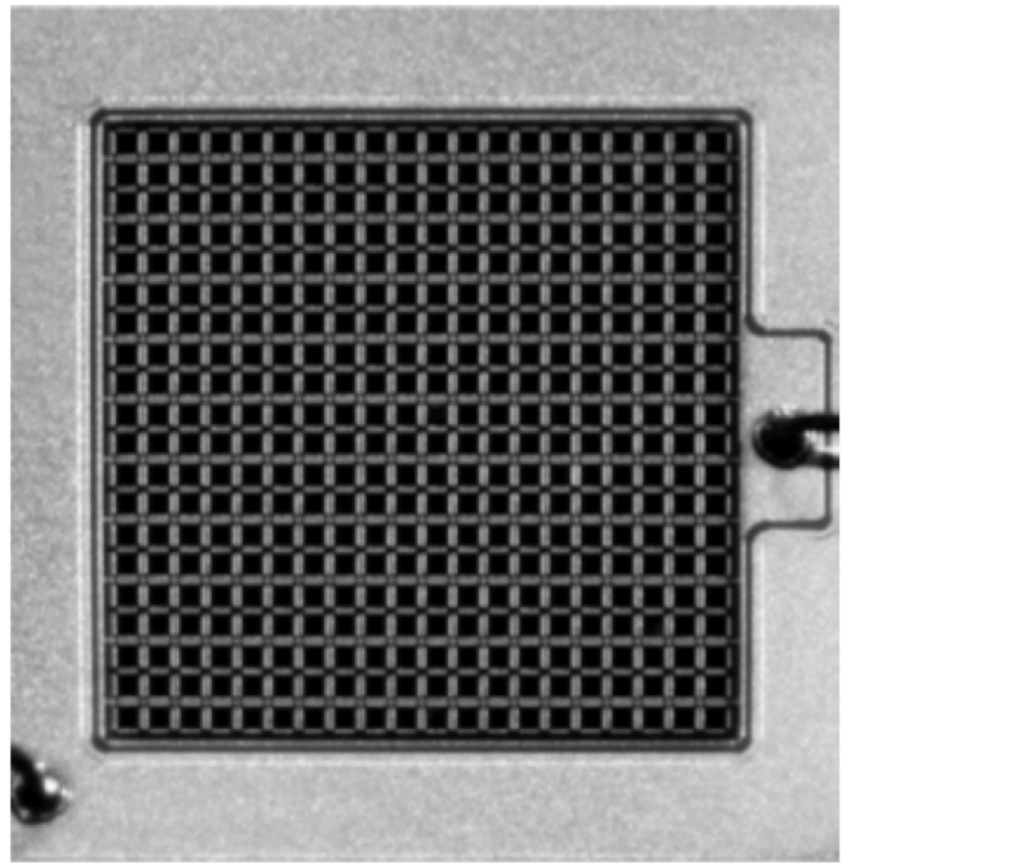


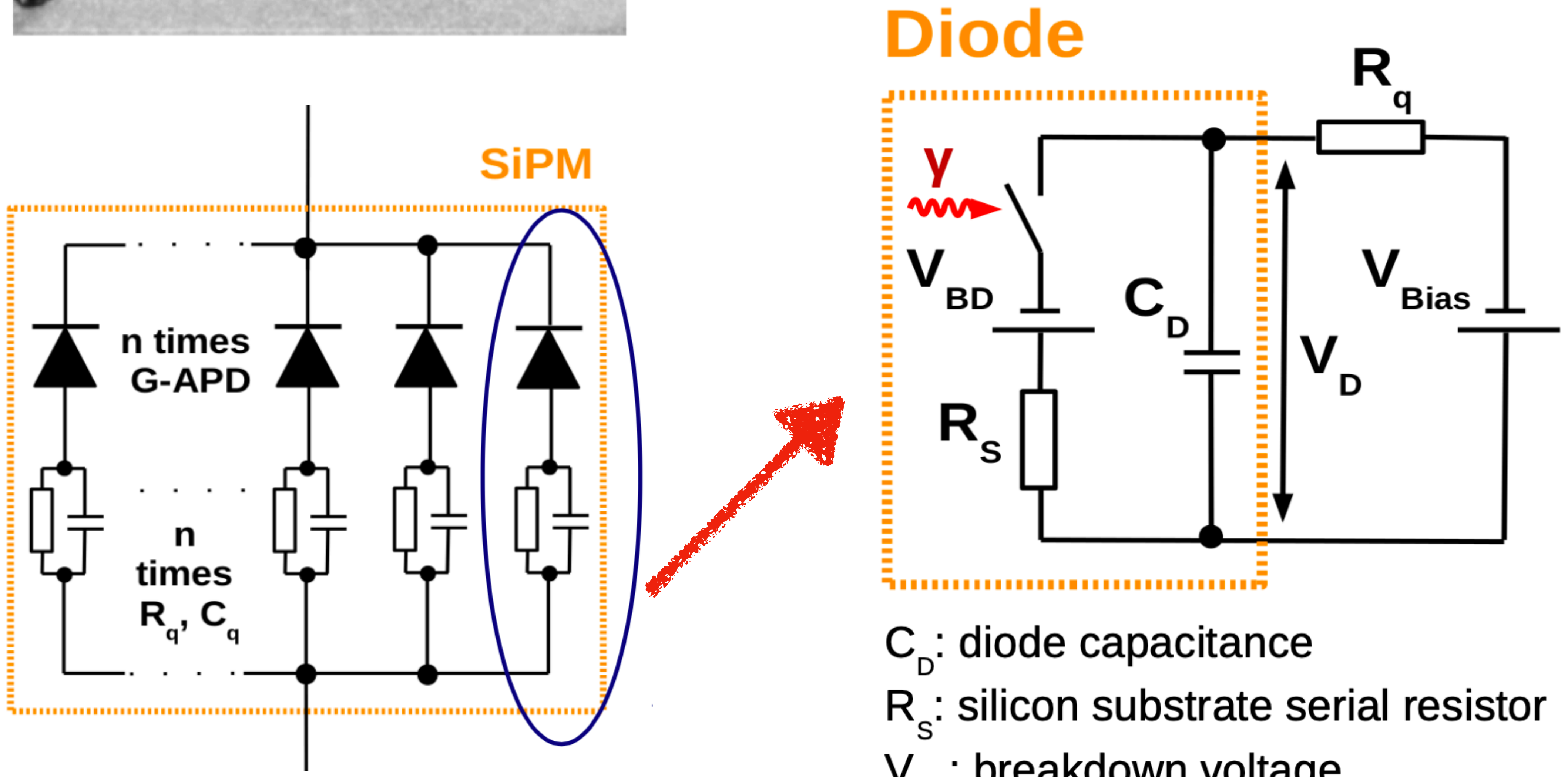
- Based on photoelectric effect: photon strikes and produce a pair of electron/hole
- Various types, selection depending on the measurement
- "Breakdown" here mean both hole and electron play roles in avalanche process

MPPC: a type of SiPM, developed by Hamamatsu



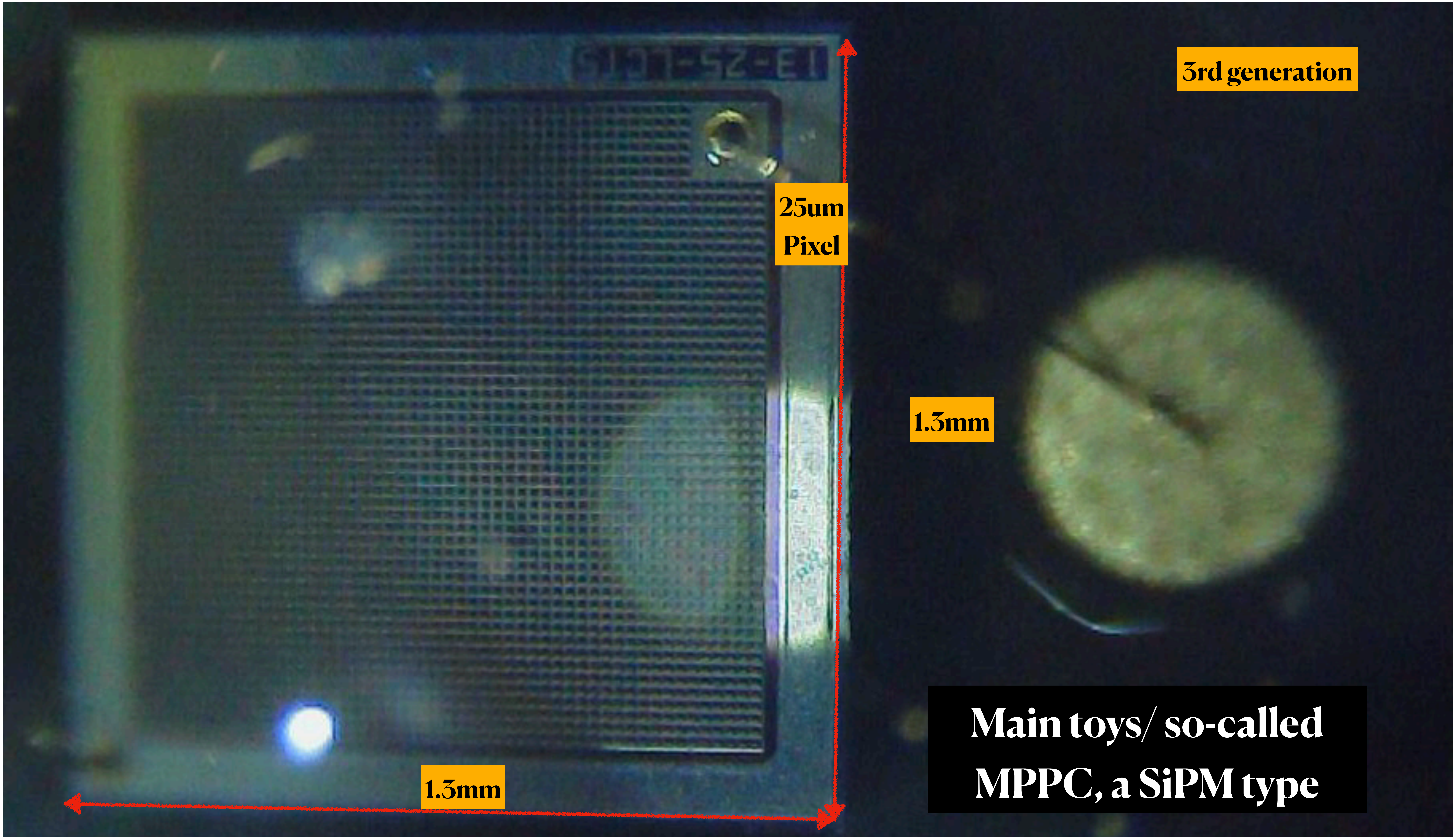
Hamamatsu S13360-1325CS





C_D: diode capacitance
R_S: silicon substrate serial resistor
V_{BD}: breakdown voltage

https://www.hamamatsu.com/jp/en/product/optical-sensors/mppc/mppc_mppc-array.html

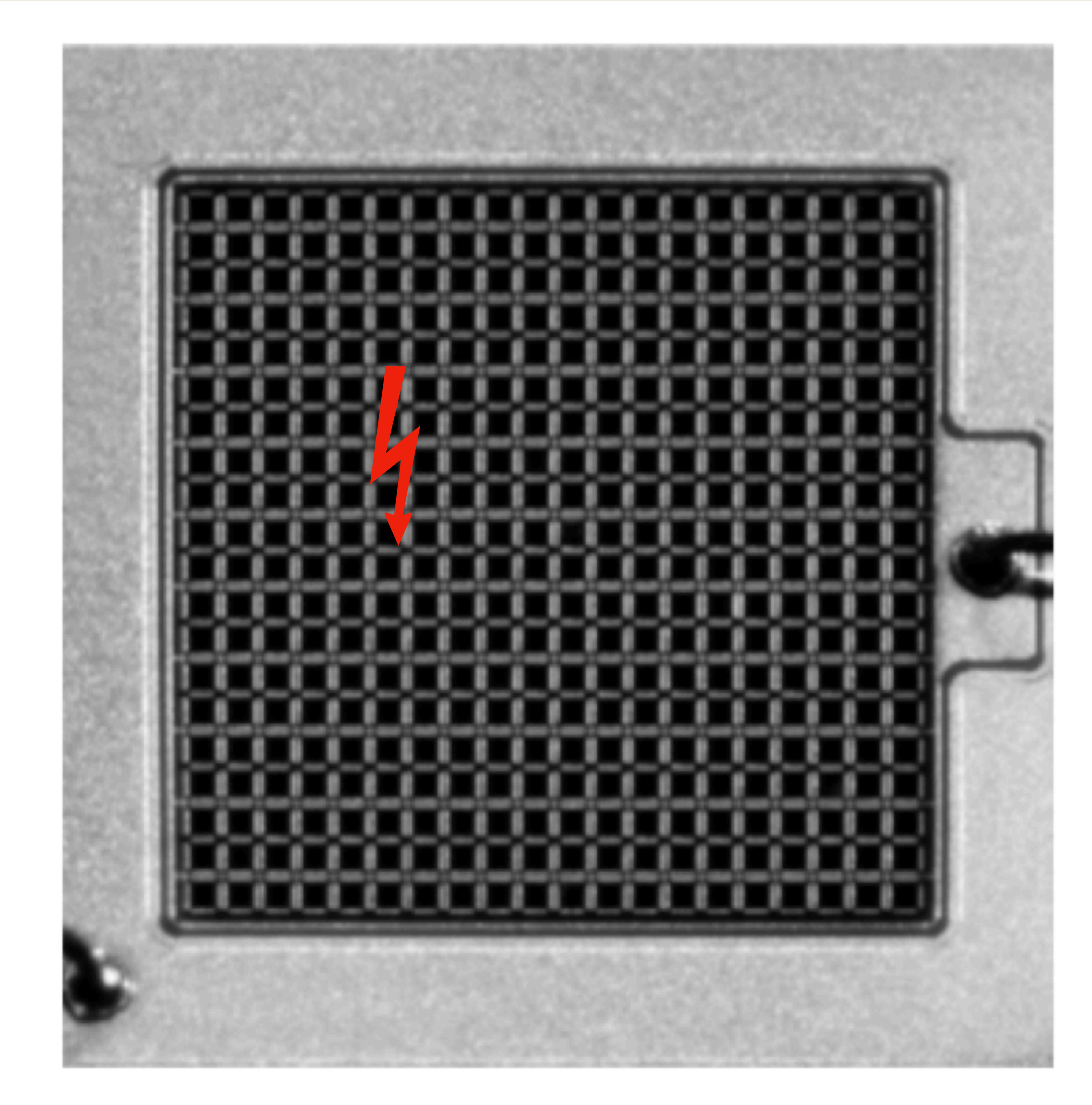

3rd generation
25um
Pixel
1.3mm
1.3mm
Main toys/ so-called
MPPC, a SiPM type

MPPC offers excellent capability of photon counting with high electric gain

Ref: *Hamamatsu's MPPC technical note* https://hub.hamamatsu.com/content/dam/hamamatsu-photonics/sites/static/hc/resources/TN0014/mppc_kapd9005e.pdf

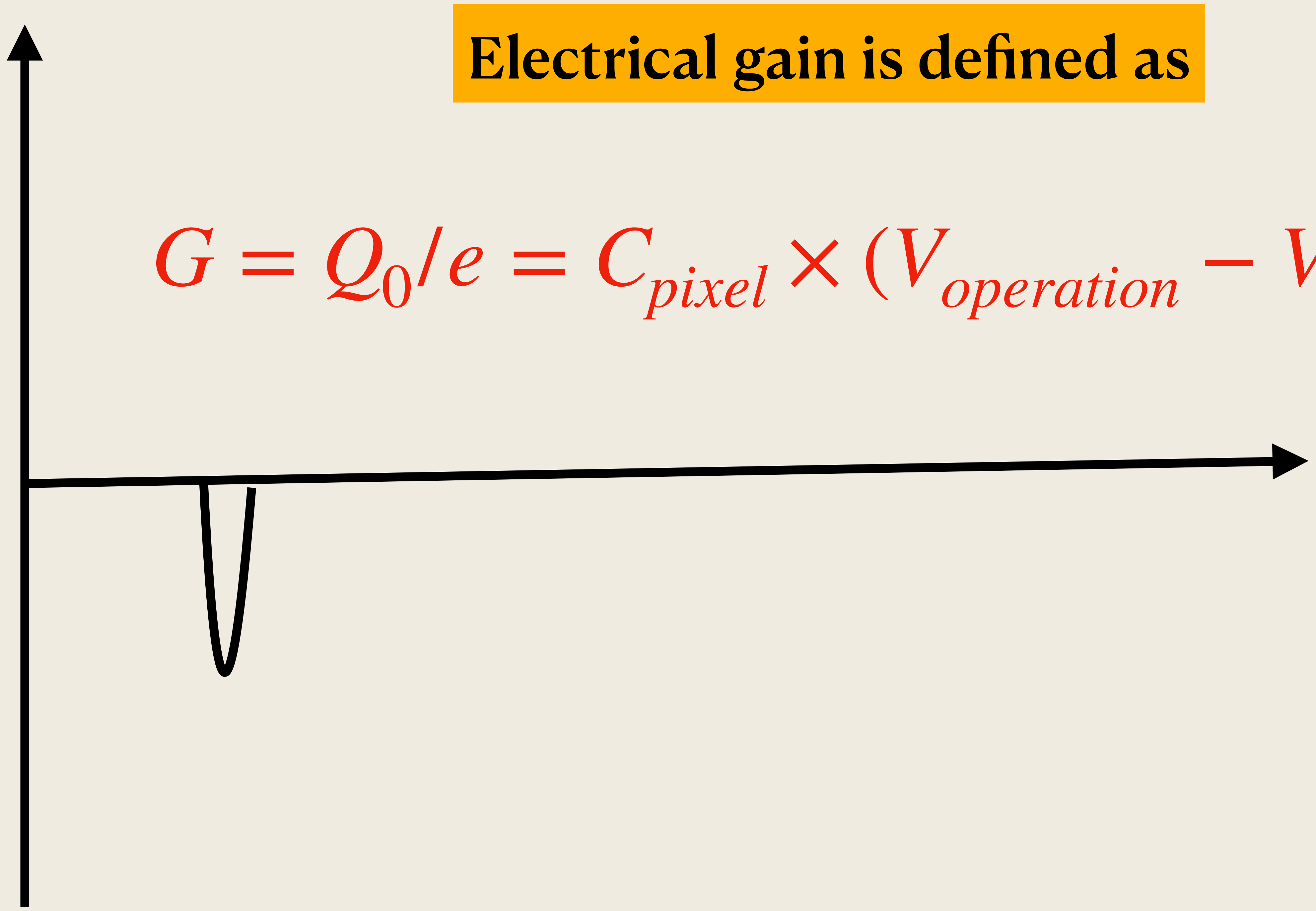
Basic principle of photon counting

When a photon fires a pixel, a signal with charge Q_0 is generated and observed in macroscopic scale



Electrical gain is defined as

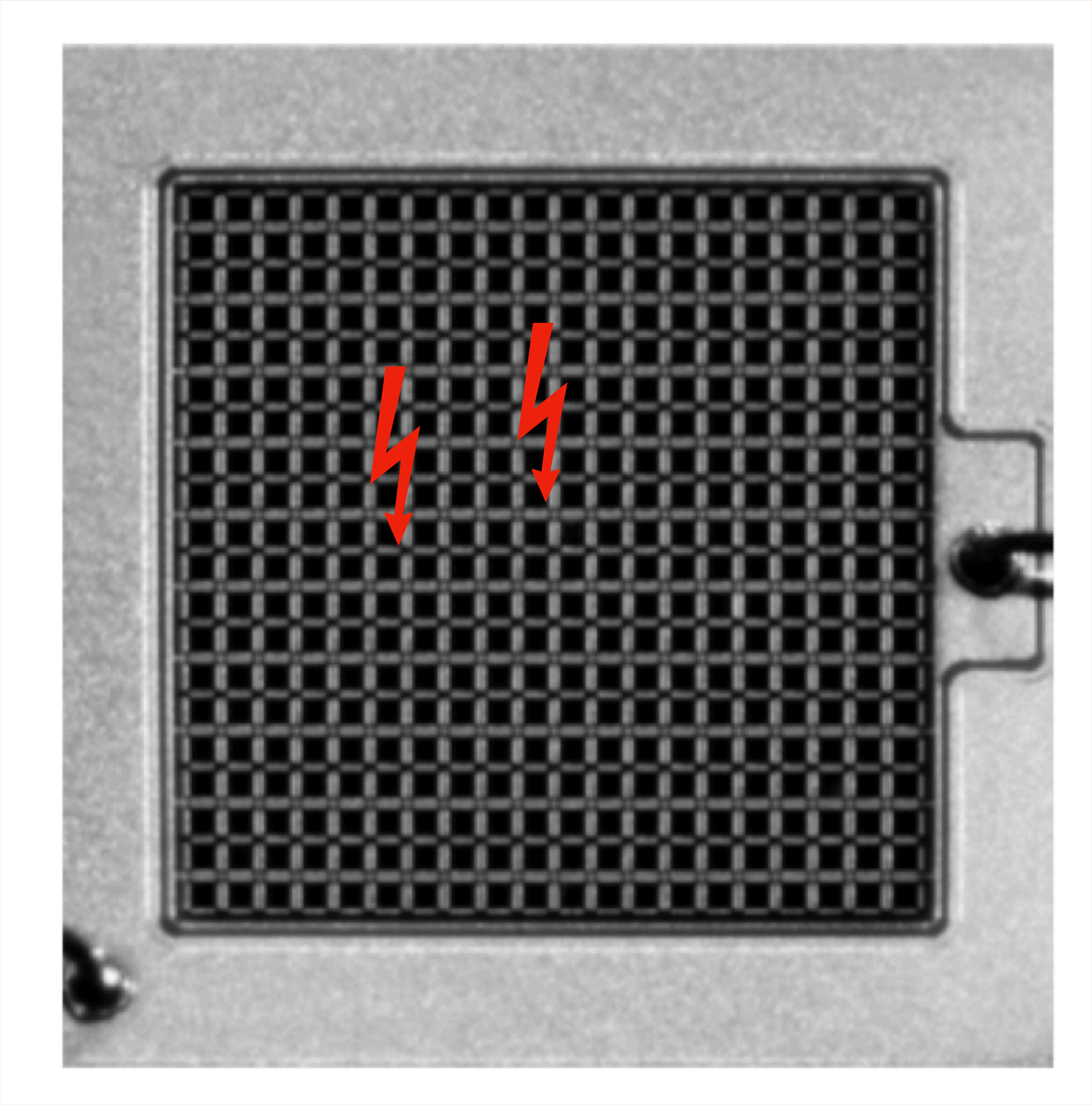
$$G = Q_0/e = C_{pixel} \times (V_{operation} - V_{breakdown.})$$

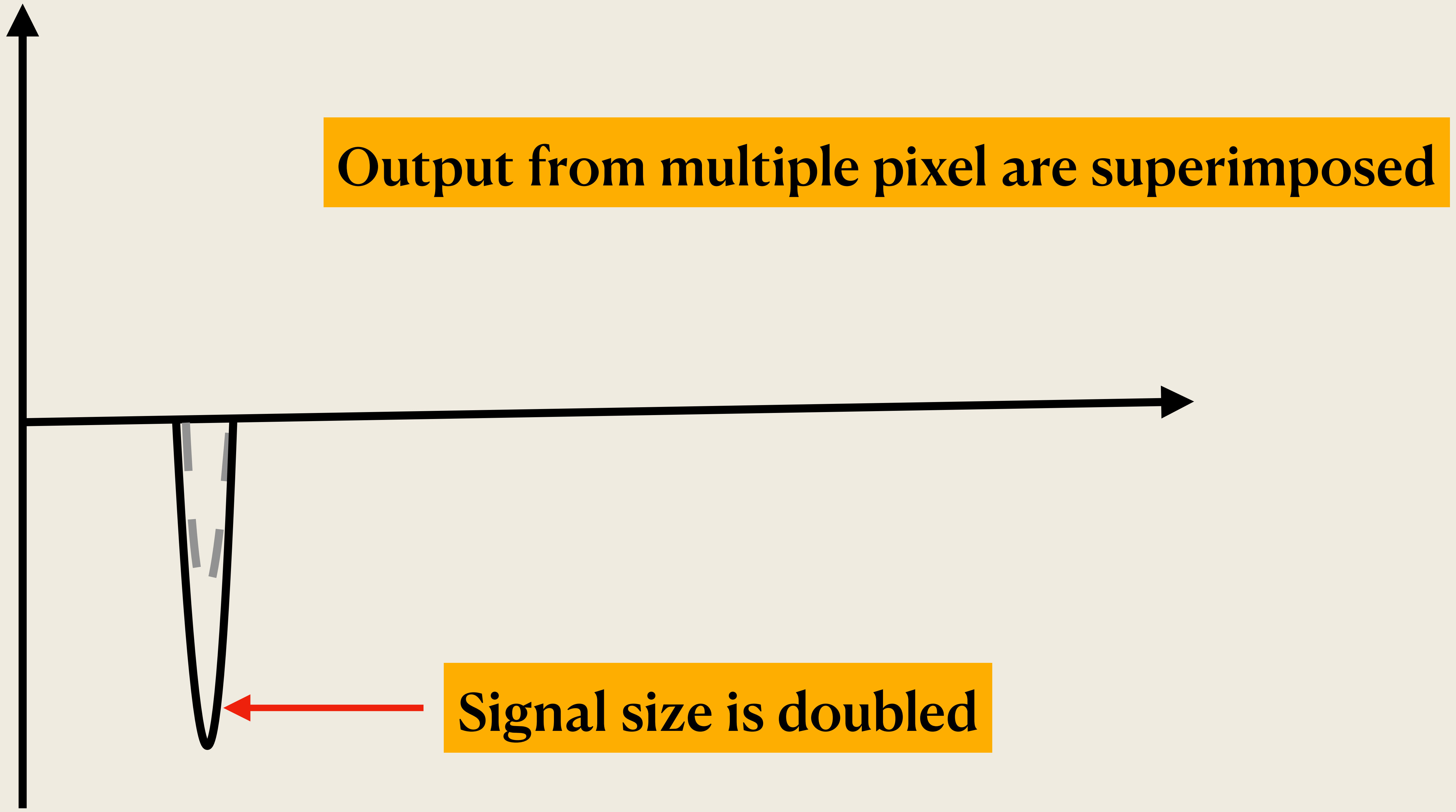


Pixel works independently but give out pulses with the same amplitude

Basic principle of photon counting

When a photon fires a pixel, a signal with charge Q_0 is generated and observed in macroscopic scale

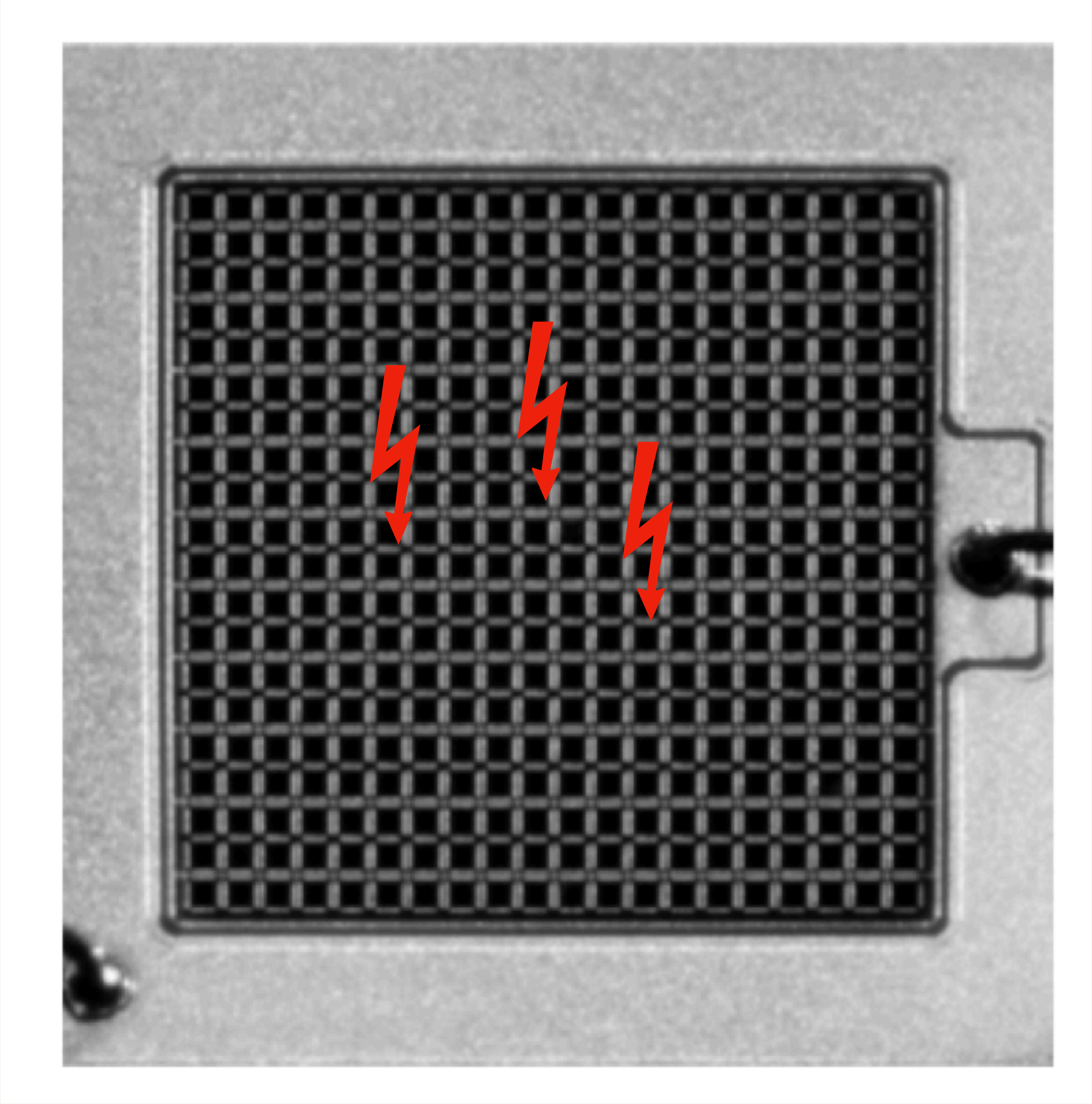


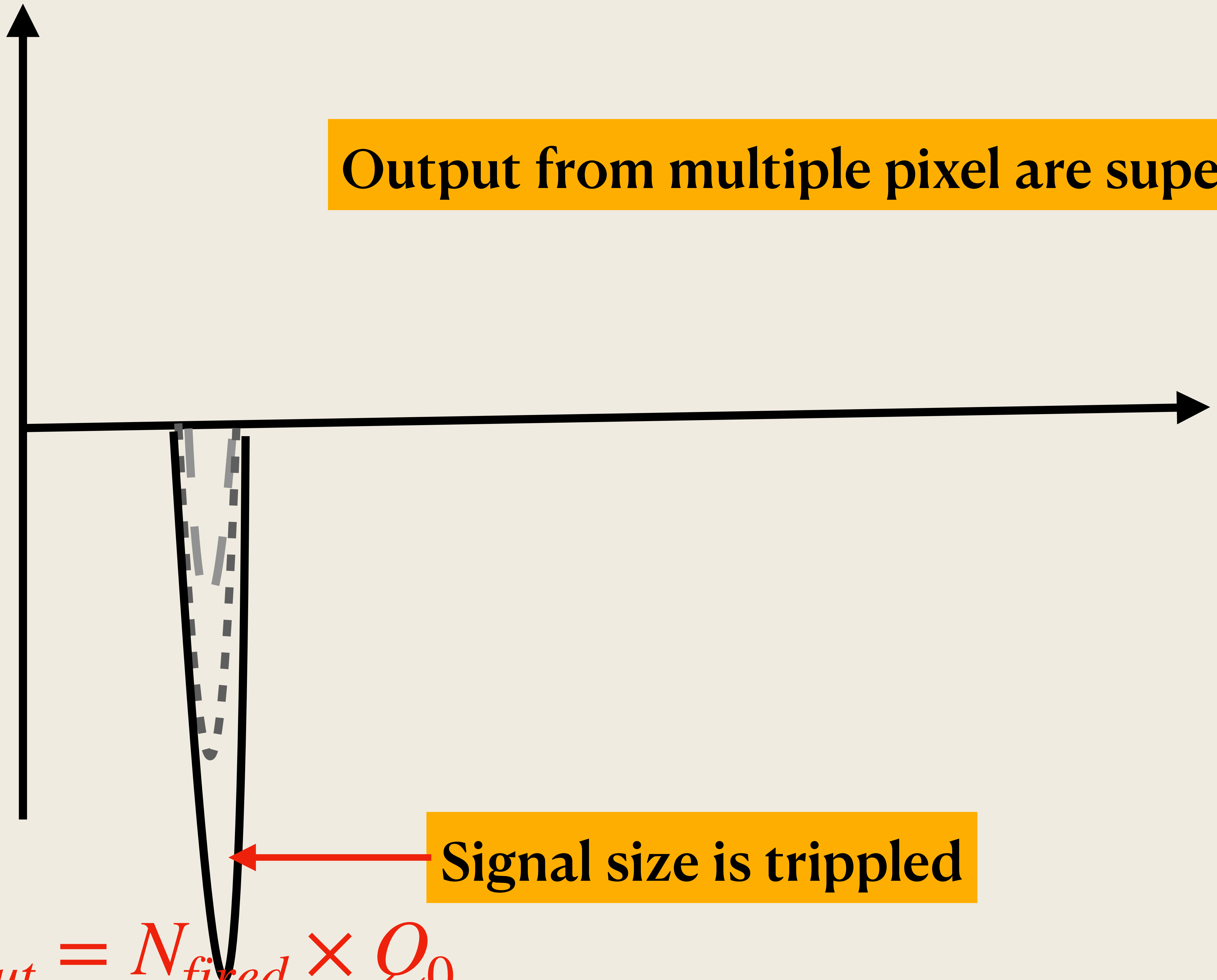


$$Q_{out} = N_{fired} \times Q_0$$
$$= N_{fired} \times C_{pixel} \times (V_{operation} - V_{breakdown.})$$

Basic principle of photon counting

When a photon fires a pixel, a signal with charge Q_0 is generated and observed in macroscopic scale



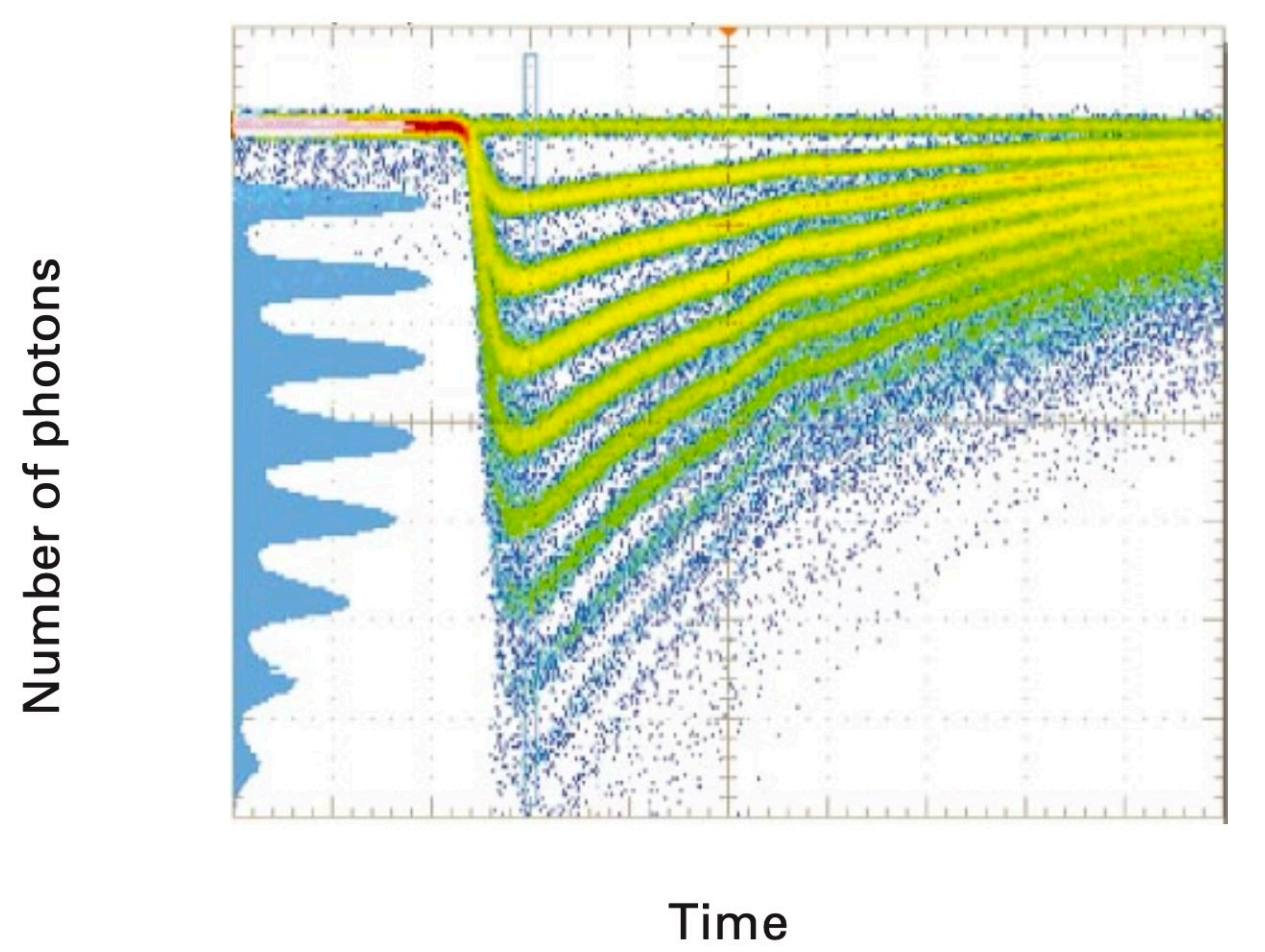


$$Q_{out} = N_{fired} \times Q_0$$
$$= N_{fired} \times C_{pixel} \times (V_{operation} - V_{breakdown.})$$

MPPC overlayed signals

Let enjoy the light quanta with your observation

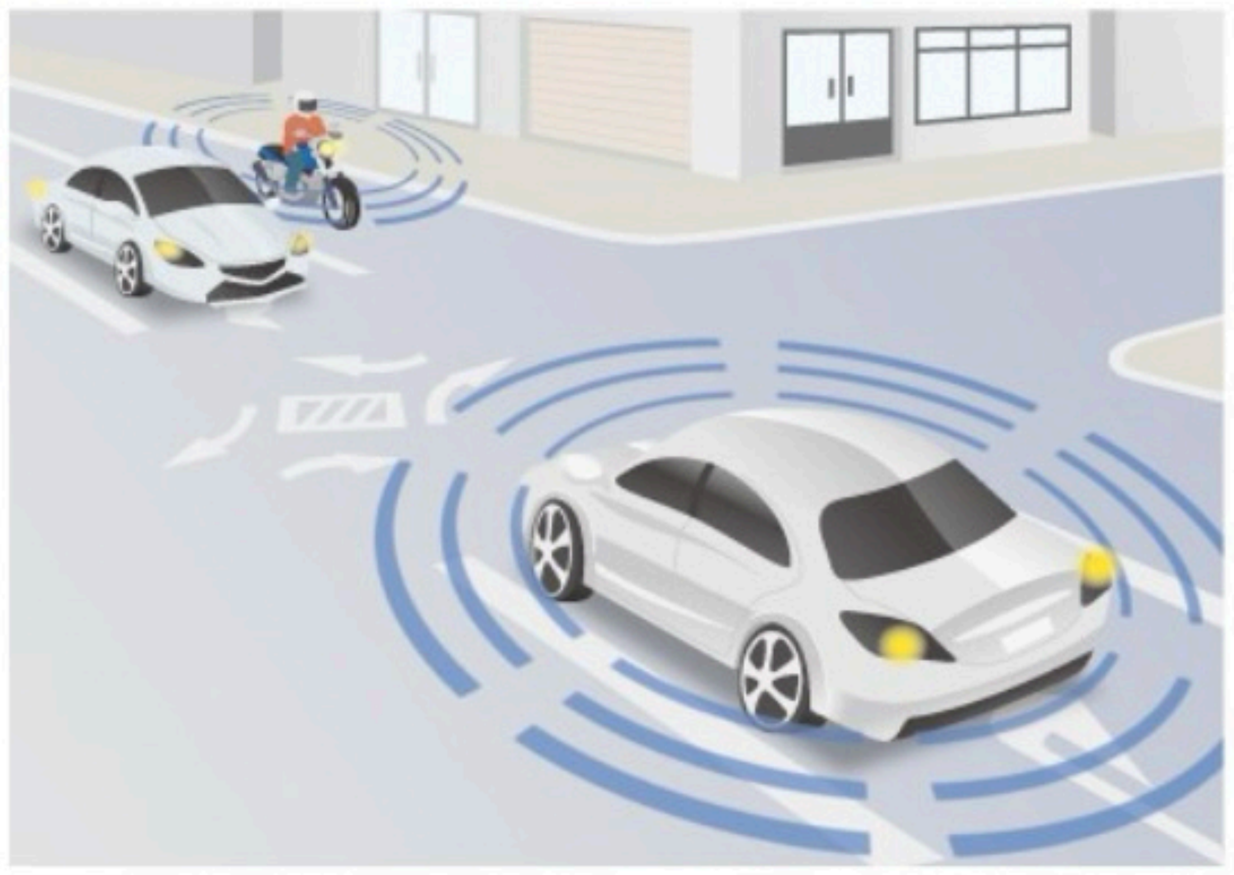
Lot of ambient in the lab, optical shielding (eg. Black sheet) is needed → give some ideas of low-light detection



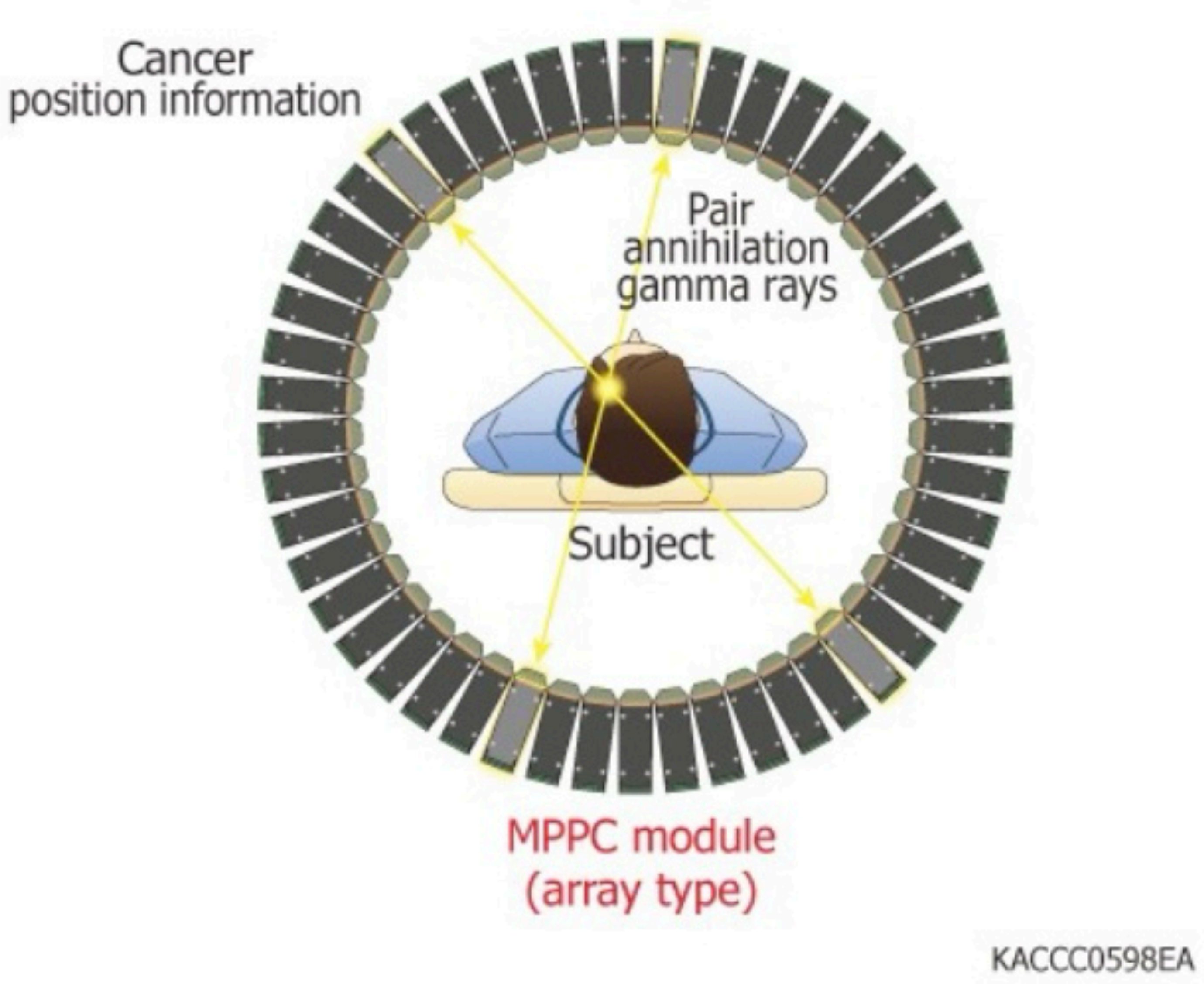
MPPC has wide-range of applications

https://www.hamamatsu.com/jp/en/product/optical-sensors/mppc/application.html

Distance Measurement (LiDAR)

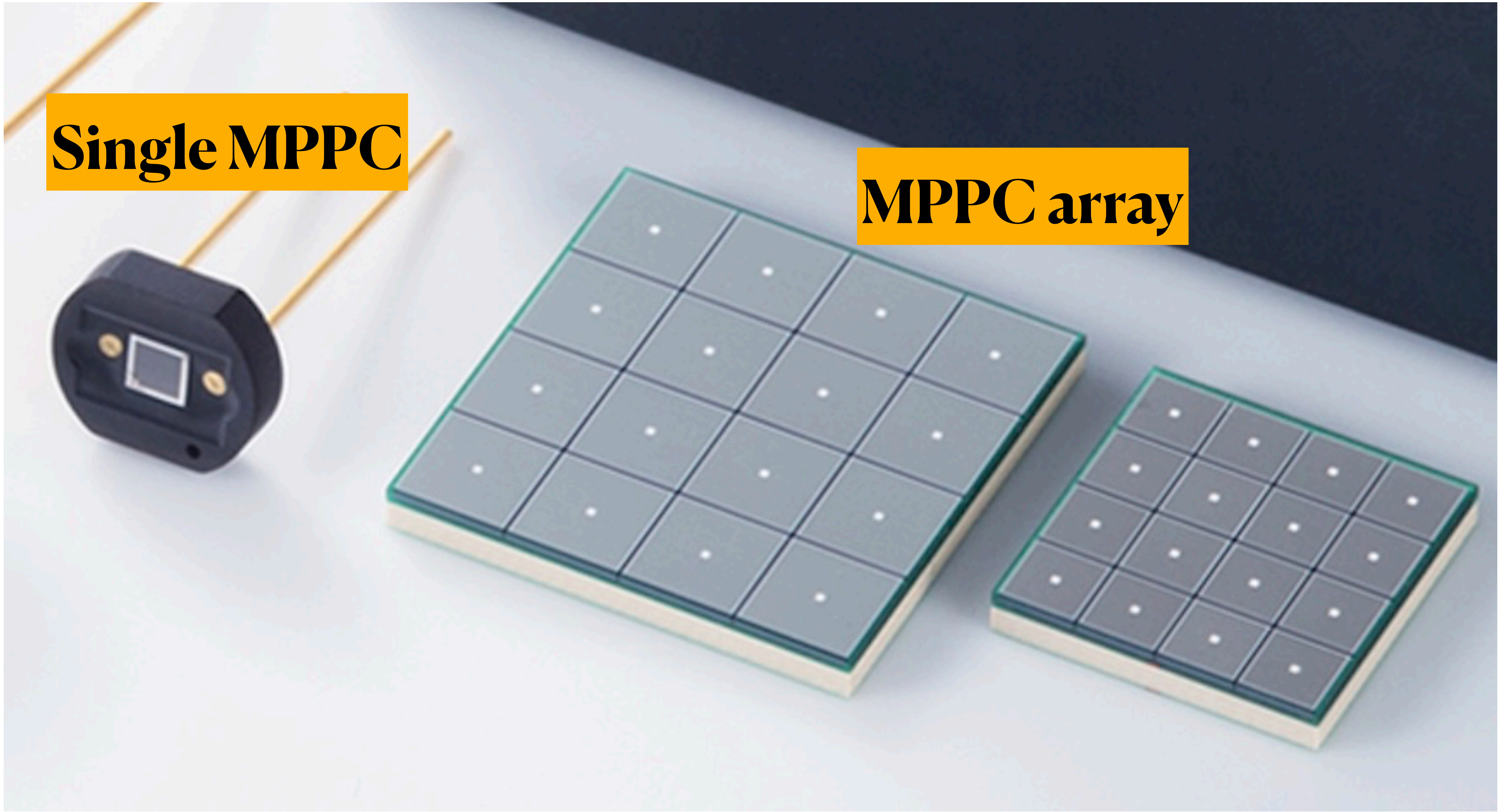


PET (Positron Emission Tomography)

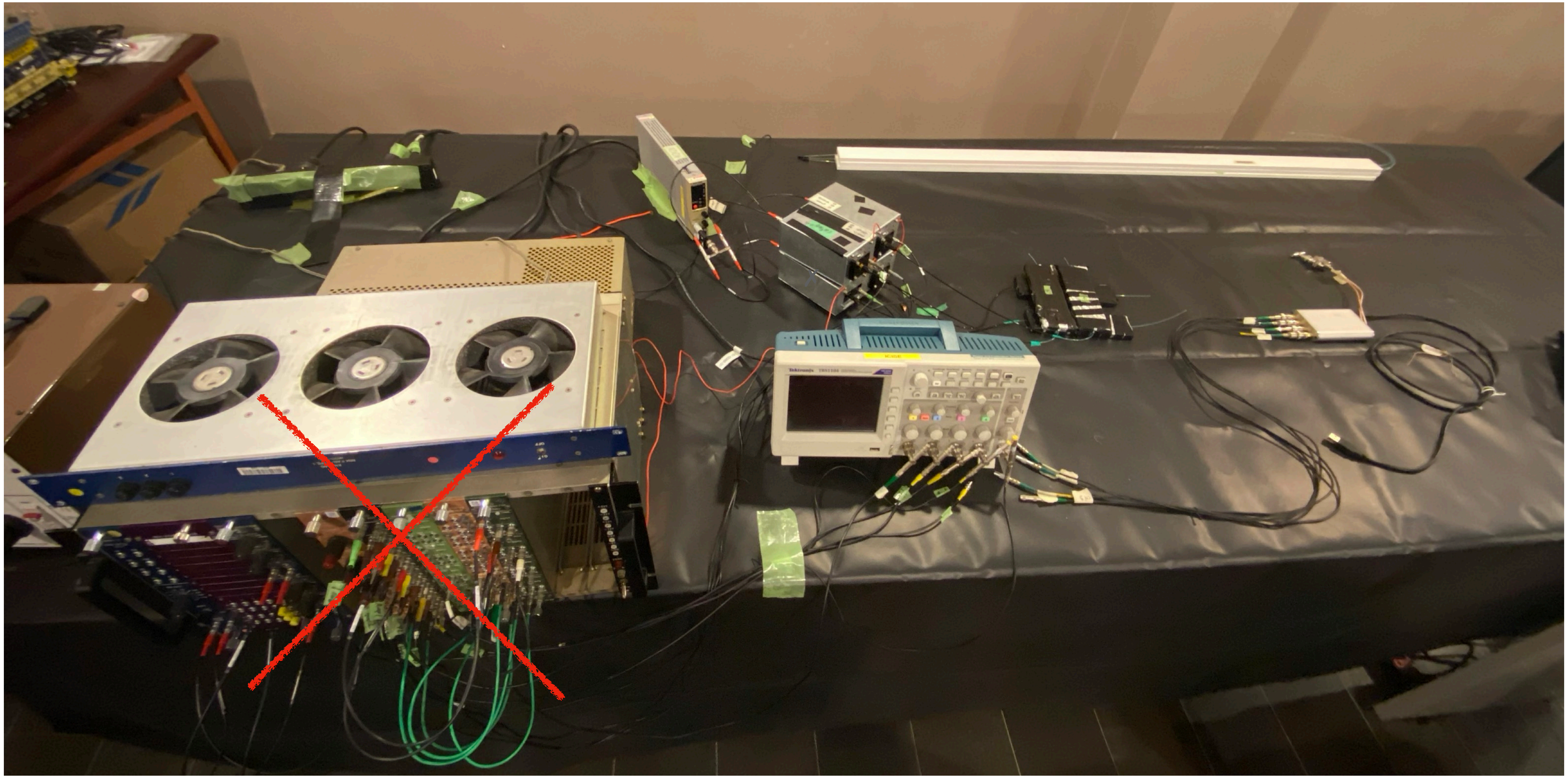


And many other applications

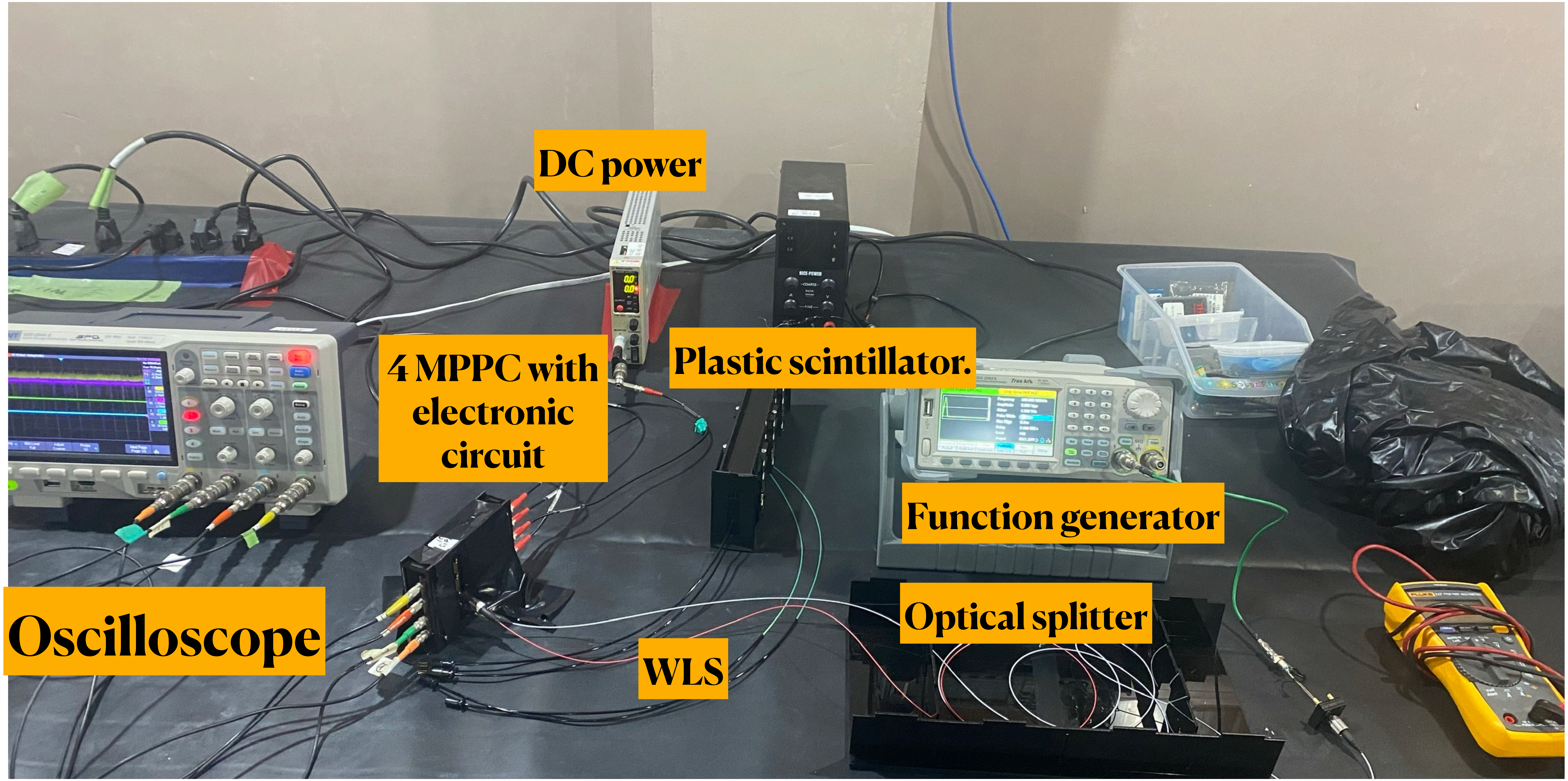
We basically have both single MPPC and MPPC arrays



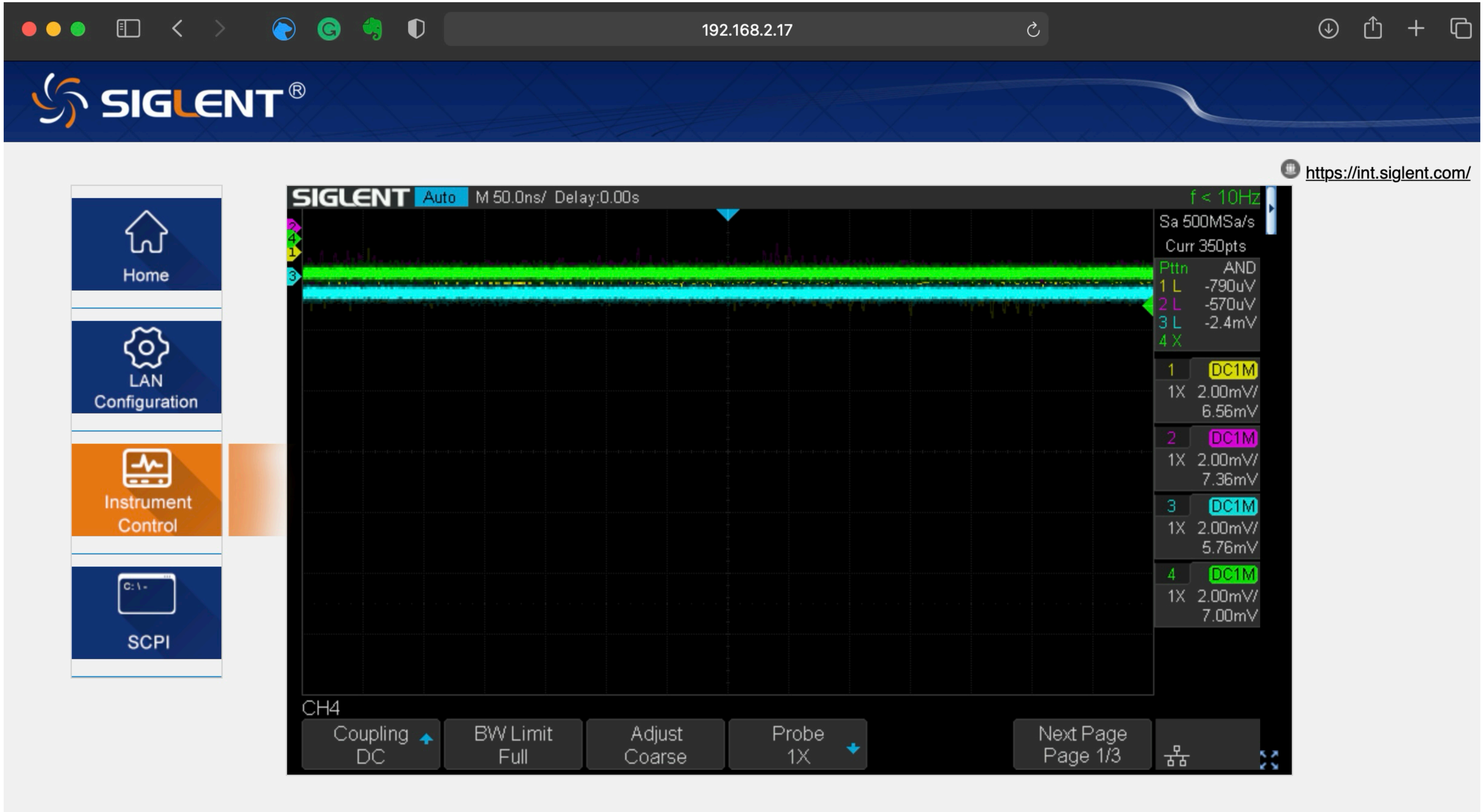
We get rid of the complicated setup with NIM modules



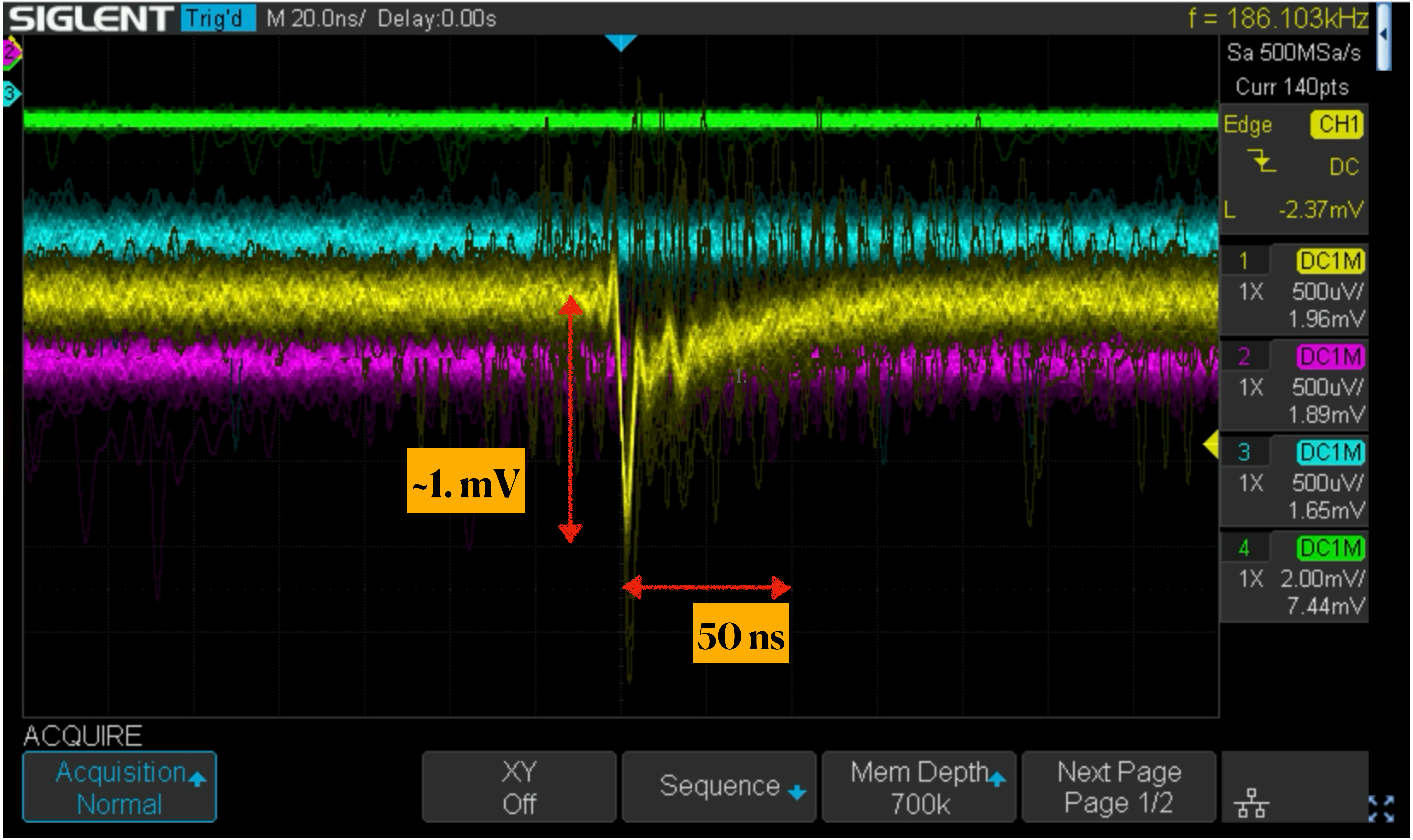
Setup-01 with single MPPCs for group ν_e, ν_τ



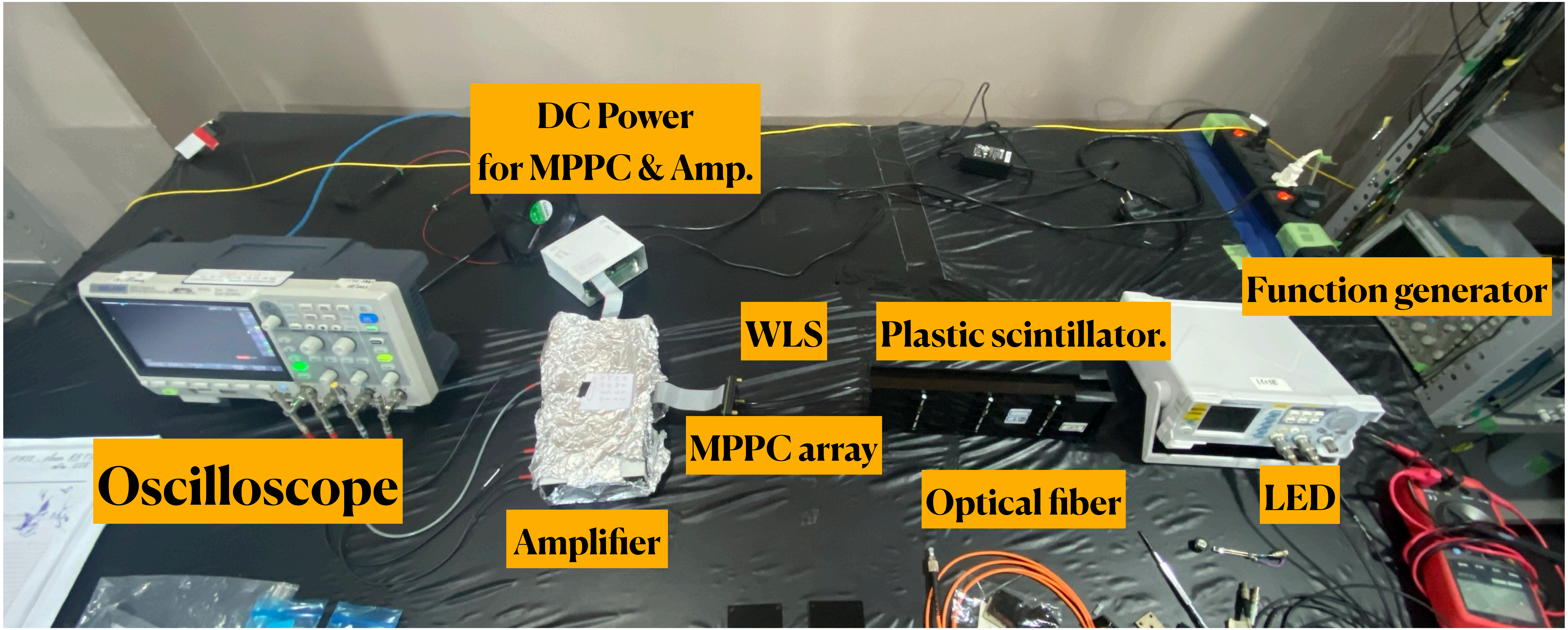
The oscilloscope has web interface and can acquire data remotely via ethernet (and VXI)



The signal is very small, 1 pe ~ 1.0 mV



Setup-02 with MPPC array for group ν_μ, ν_s



Signal size is higher than the previous setups (~ 5 mV / p.e.)

What we will explore (*detail will be explained on whiteboard during the training*)

Day #1, July 18th (Thu.)

- Familiar with hardwares
- Explore MPPC properties (no scintillator/WLS)
  - Observe single photoelectrons w/ oscilloscope
  - Observe the optical crosstalk
  - *(Extra: Charge integration and electric gain calculation)*
- Signal observe and measure with oscilloscope
  - Threshold setting
  - Trigger
  - Measure noise frequency with oscilloscope counter for single channel and coincidence of multiple channels with different threshold

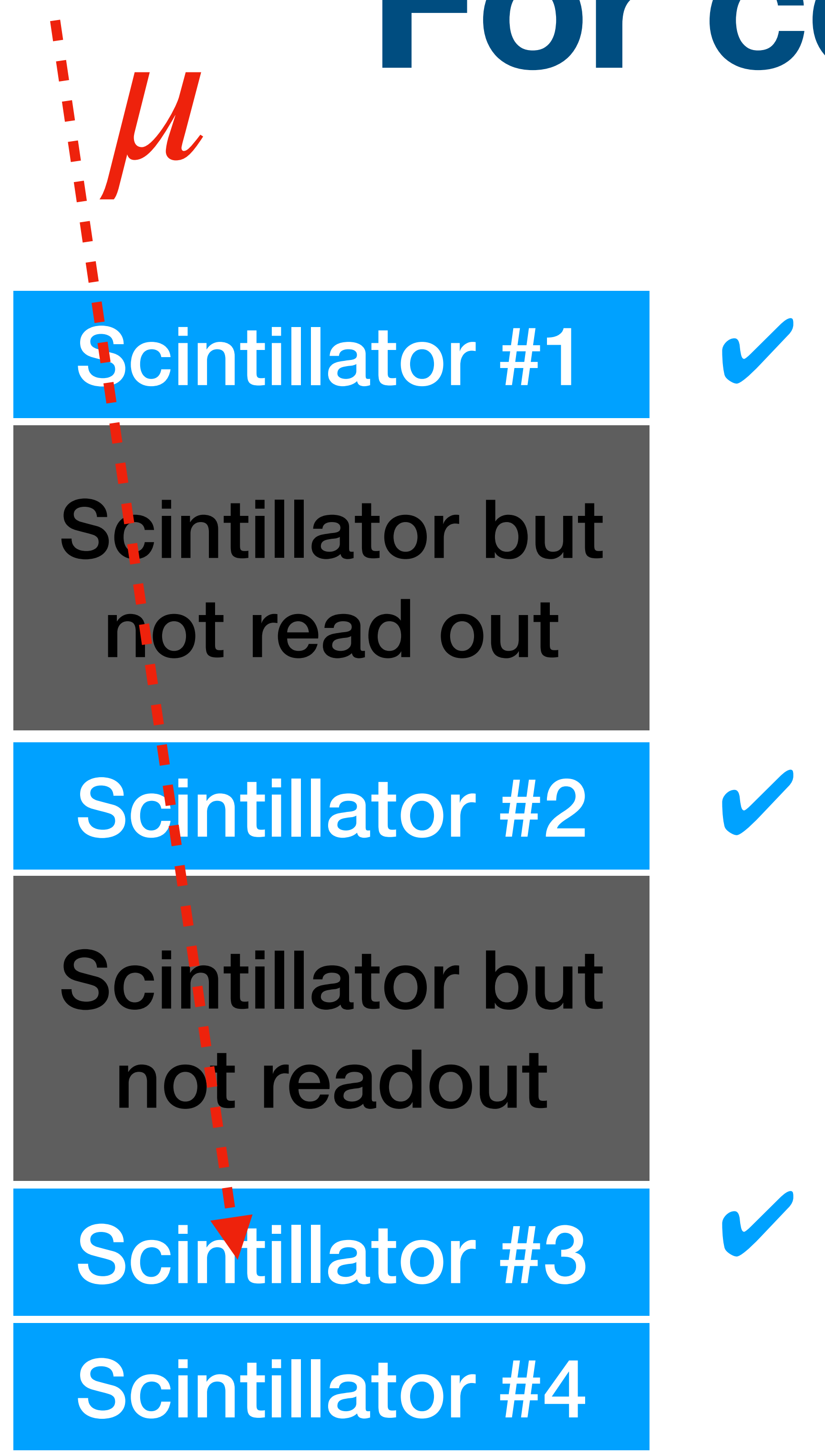
Day #2, July 19th (Fri.)

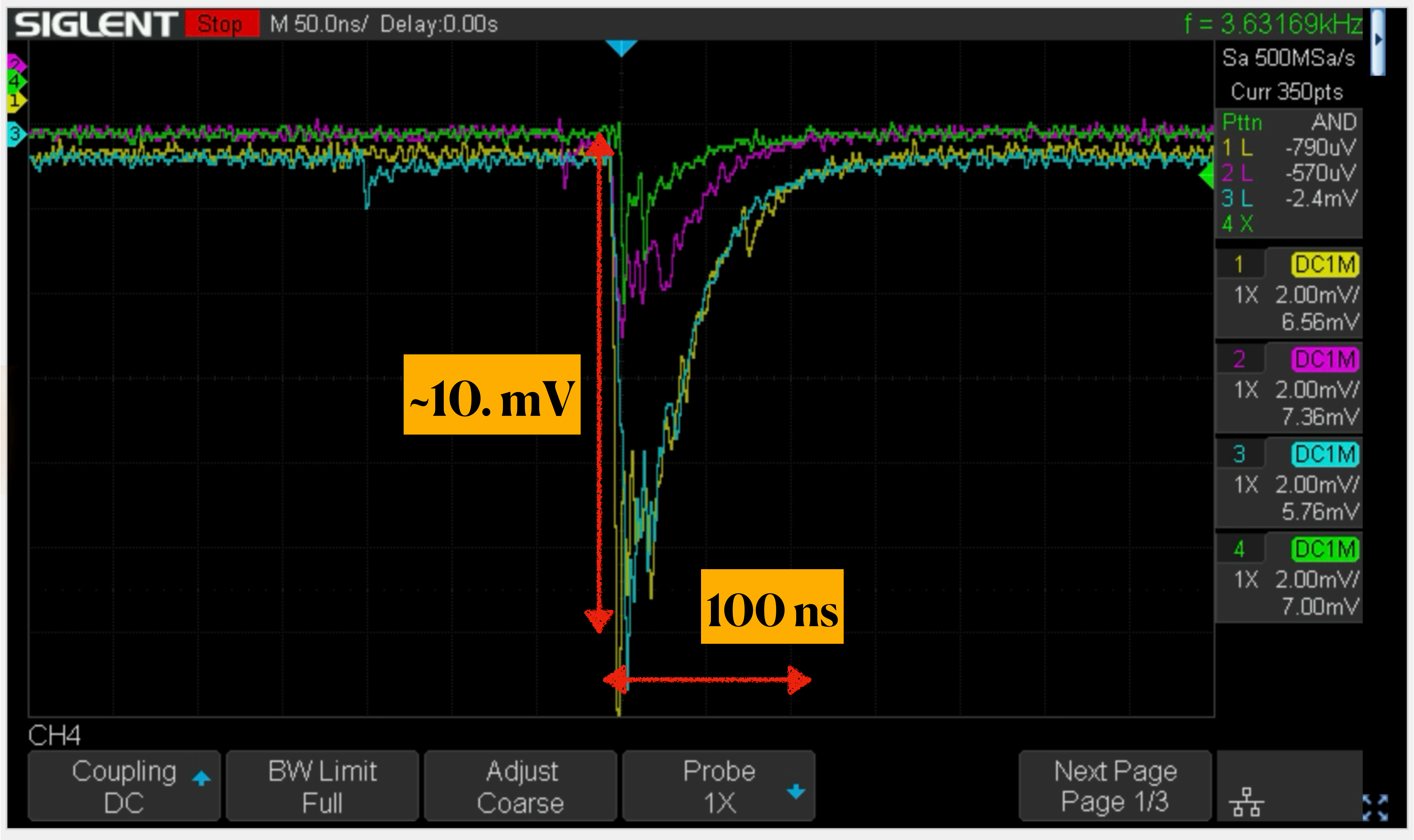
- Setup with LED and optical splitter (for single MPPC setup) or optical fiber (for MPPC array setup)
- Observe signal directly from pulsed LED with function generator
- Adjust the intensity and adjust the LED pulse width
- Ext: measure speed of light in the optical fiber for MPPC setup; optical cross talk for MPPC array setup

Day #3, July 22th (Mon.)

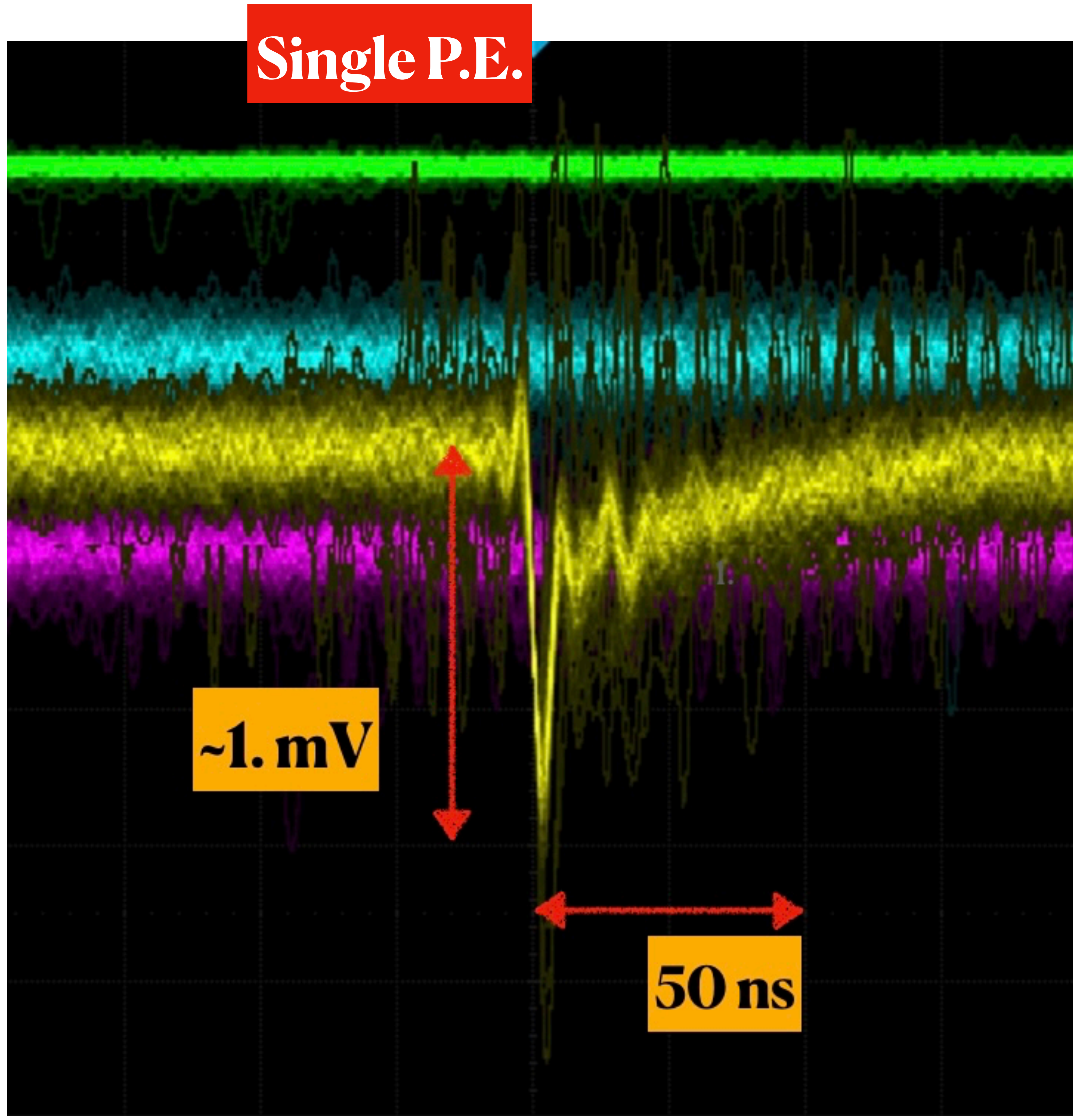
- Setup with scintillator and wavelength shifting fiber
- Observe cosmic ray muons
- Calculate the rate of muon (*how many trigged muon-like events per cm^2 of scintillator per second*)
- Compute the light yield of muons (h*ow many photons captured when a muon pass through 1cm thickness of plastic scintillator*)

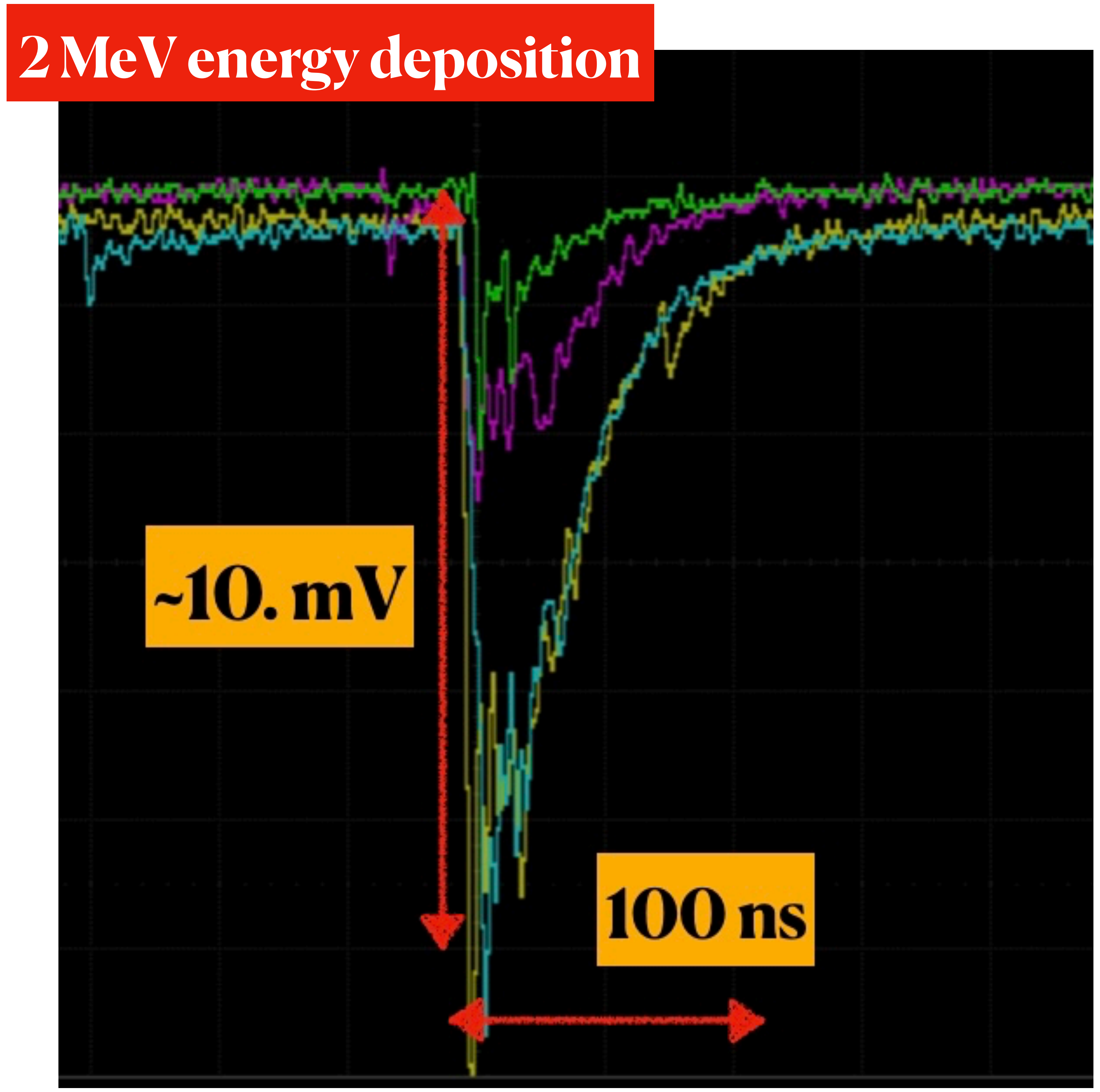
For cosmic ray muon detection





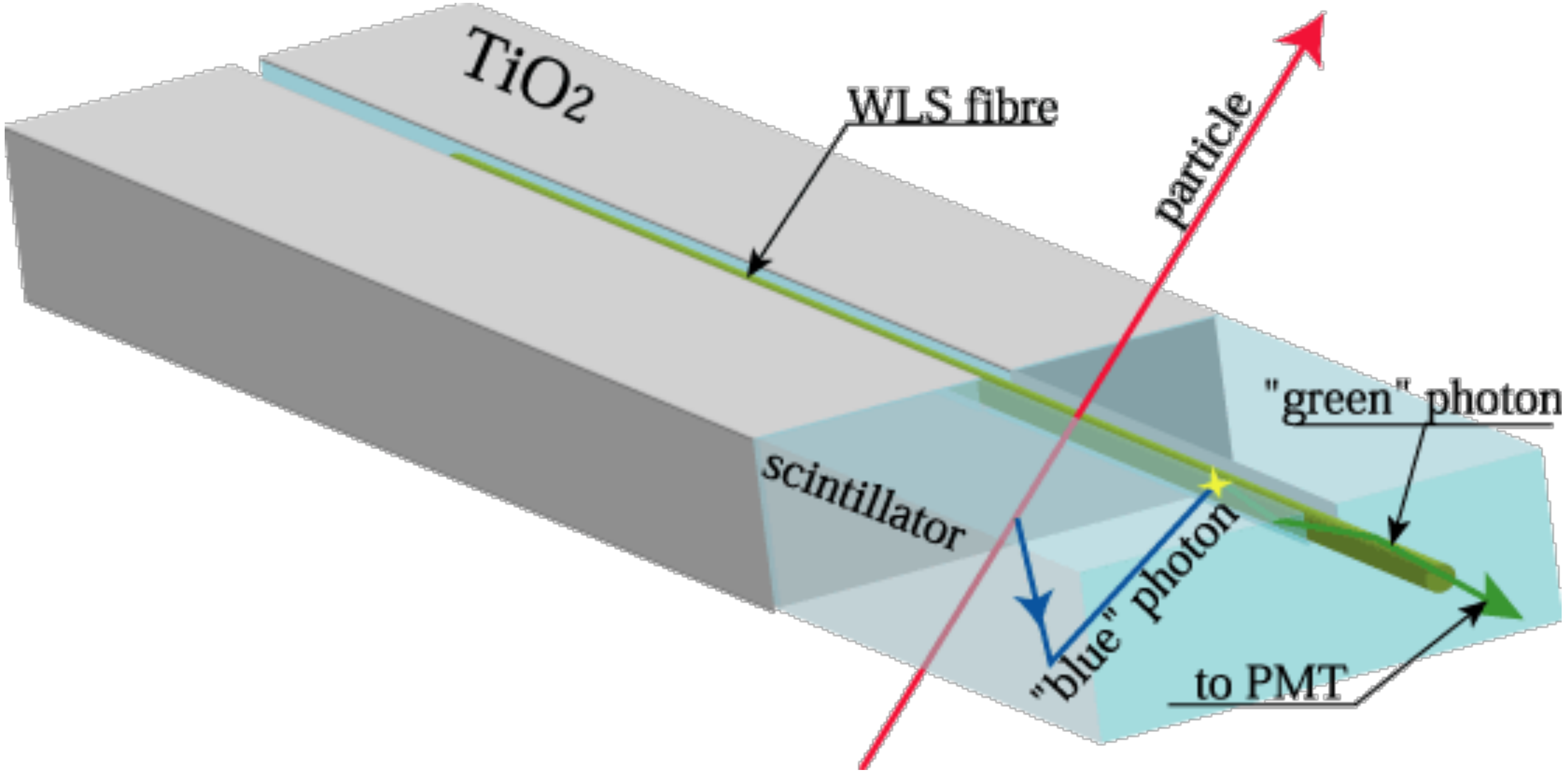
Light yield of scintillator to MIP deposition





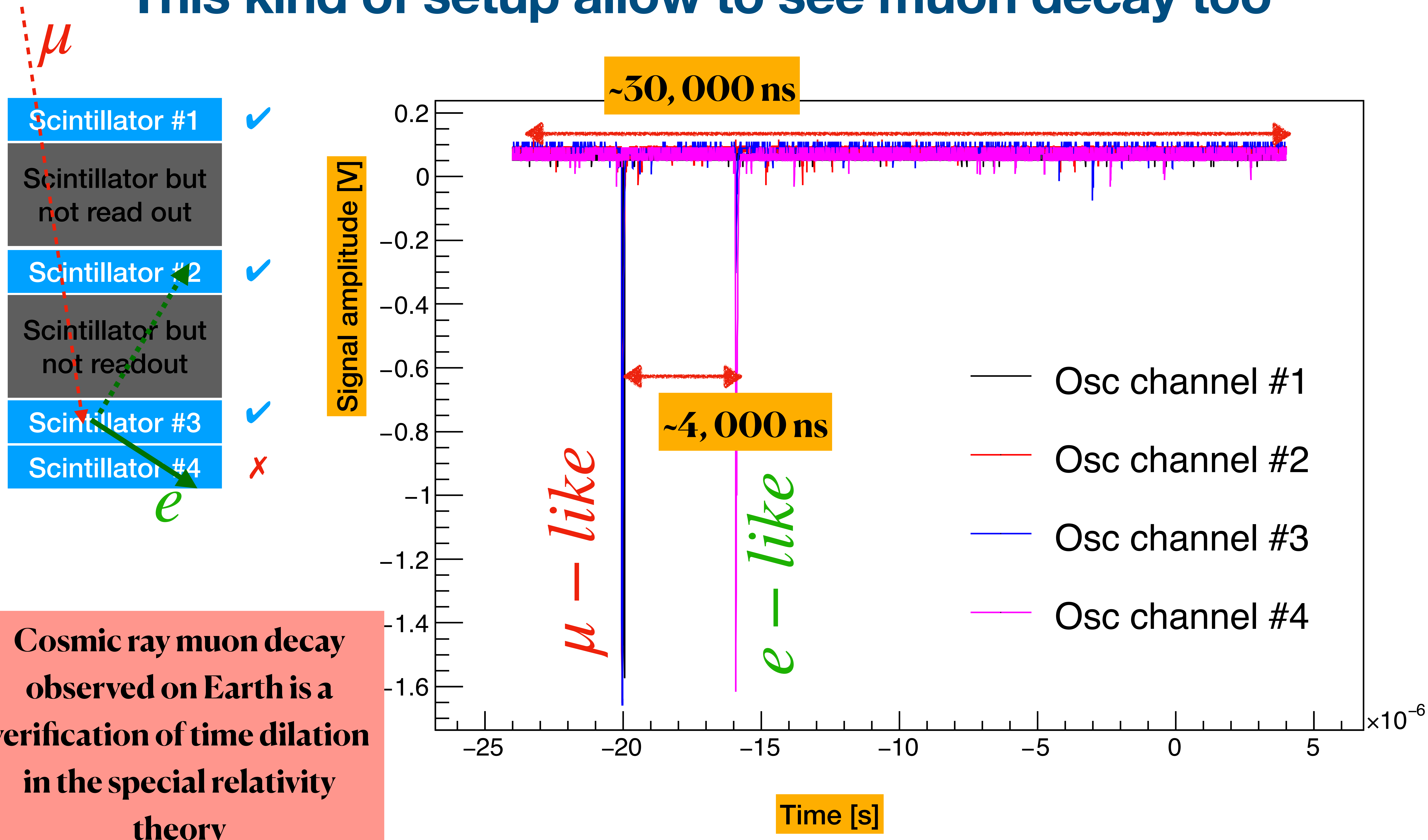
By getting the ratio between these two signals, it allows to get the light yield of scintillator to MIP deposition , which is a basics for particle energy measurement.

To keep in mind: converting photons to energy depostion is a short cut



Charged particle deposit and just few percents (~10%) are converted to scintillation light which needs to be captured by WLS and total reflection inside to guide to photosensor before experience the photoelectric effect and turn to the electric signal.

This kind of setup allow to see muon decay too



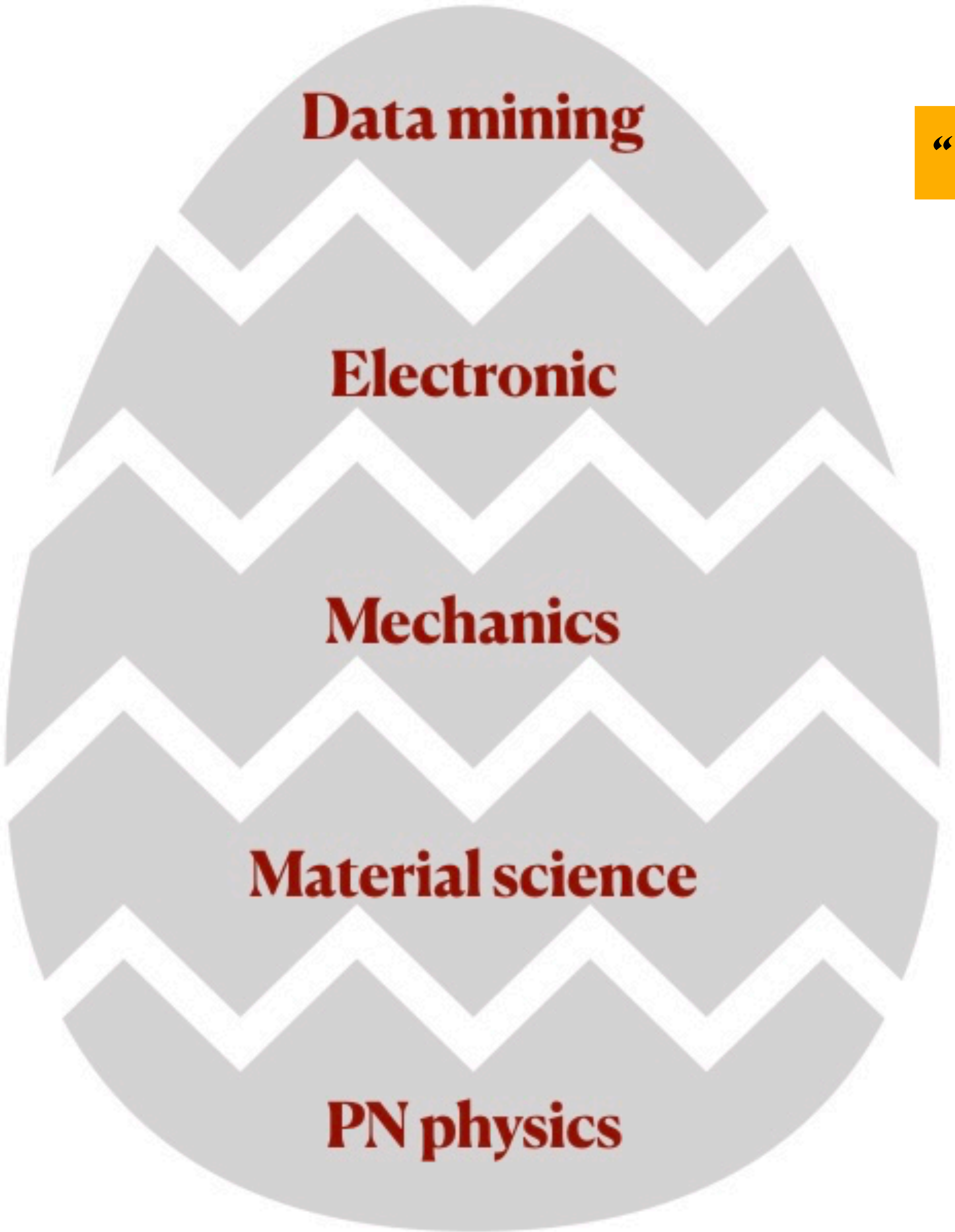
Cosmic ray muon decay observed on Earth is a verification of time dilation in the special relativity theory

Safety note for handling the equipments

- Please be **gentle**! They are **fragile**
- **Don't bend the WLS** too much.
- It use relatively high DC supply (50 - 80V). Please **use the slipper, no bare foot**, to avoid the electrostatic shock.
- Don't try to adjust the HV larger the allowed (~56V for single MPPC and ~ 58V for MPPC array)
- Single MPPC has two legs, be aware of positive and negative. **Identify the right leg position before plug in.**
- **Ambient light**: Why the MPPC is not likely damaged if exposure to so much light in short time but it's good practice to make sure the light tightening enough
- **Turn on and off DC HV properly**: no touching the electronics when HV on. If you want to check MPPC, HV must be turned off

There are many practical things to follow for better use of the electronics. Please consult with me or other mentors. Don't try to do some weird things. We appreciate your cooperation.

“Experimental neutrino experiment in the nutshell”



We will touch very small part of it.

Neutrino detection is a complicate, interdisciplinary field

Mentors

- Dr. Son Cao (overall in charge & take care of group ν_e, ν_τ)
- M.Sc. Sang Truong and Ph.D student Quyen Phan for group ν_μ, ν_s
- Some students (eg. Japanese students) may be familiar with the setup. Please help members in your group

Time is very limited to play with hardware. You won't satisfy, I'm sure. If you want to play more, please work with us or apply internship or hardware camp (typically happen in Feb.-Mar.)

https://ifirse.icise.vn/nugroup/internship/index.html

https://ifirse.icise.vn/nugroup/hardwarecamp/index.html

We thank for your donation

KEK

YOKOHAMA National University

Without their generosity, this hardware training is impossible.

Day1: (*detail will be explained on whiteboard during the training*)

Day #1, July 18th (Thu.)

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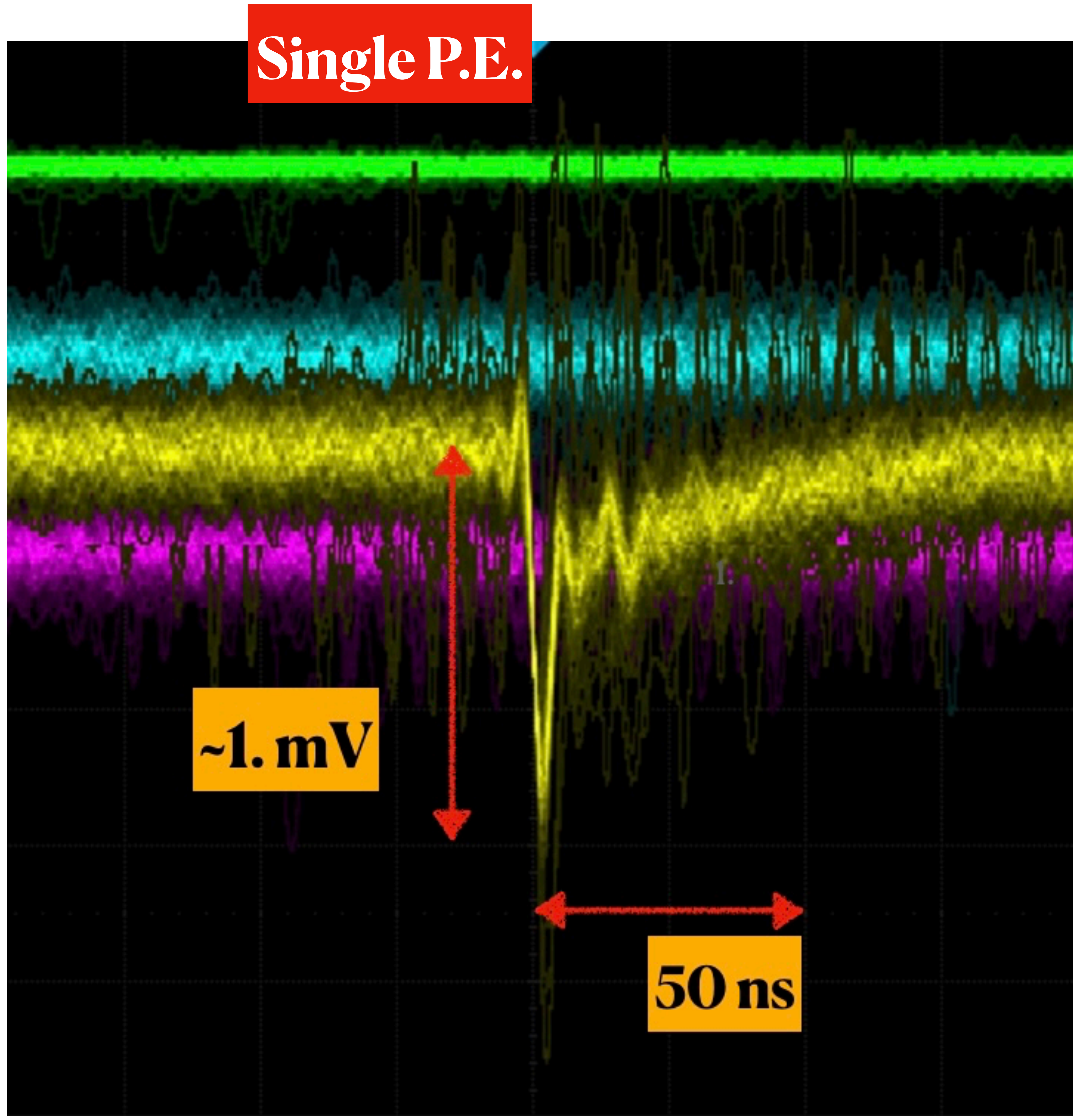
- Explore MPPC properties (no scintillator/WLS)
    - Observe **single photoelectrons w/ oscilloscope**
    - Measure the **optical crosstalk**
    - *(Extra: Charge integration and electric gain calculation)*
- Signal observe and measure with oscilloscope
    - **Threshold** setting
    - Over-threshold **Triggering**
    - Measure noise frequency with oscilloscope counter for single channel and **coincidence** of multiple channels with different threshold



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"Coincidence" Analogy : Assume you and your friend wish to meet at the park without setting a specific timing.

- Each come the park randomly 20 times per day and each time stay for 10 minutes to way
- What is the probability for them to meet?