Hardware Training

Son Cao (IFIRSE)

7th Vietnam School on Neutrinos, July 24, 2023

Protocol for hardware training

- We prepare **three independent setups** for hardware training. *They are not identical but same concept*
- Schedule for Mon. July 24th
  - 13:20 - 14: 00 (40 mins.) **General introduction to the hardware training**
  - 14:00 - 15:30 (1.5 hours) **Groups ν_1, ν_2, ν_3 go for hardware training while groups ν_e, ν_μ, ν_τ work on mini-projects**
  - 15:30 - 17: 00 (1.5 hours) **Change groups**
- Schedule for Tue. July 25th
  - 13:20 - 15:20: (2 hours) **Groups ν_1, ν_2, ν_3 go for hardware training while groups**
  - 15:20 - 17: 20 (2 hours) **Change groups**


Hardware training
Study place
for mini-project

Purpose:

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

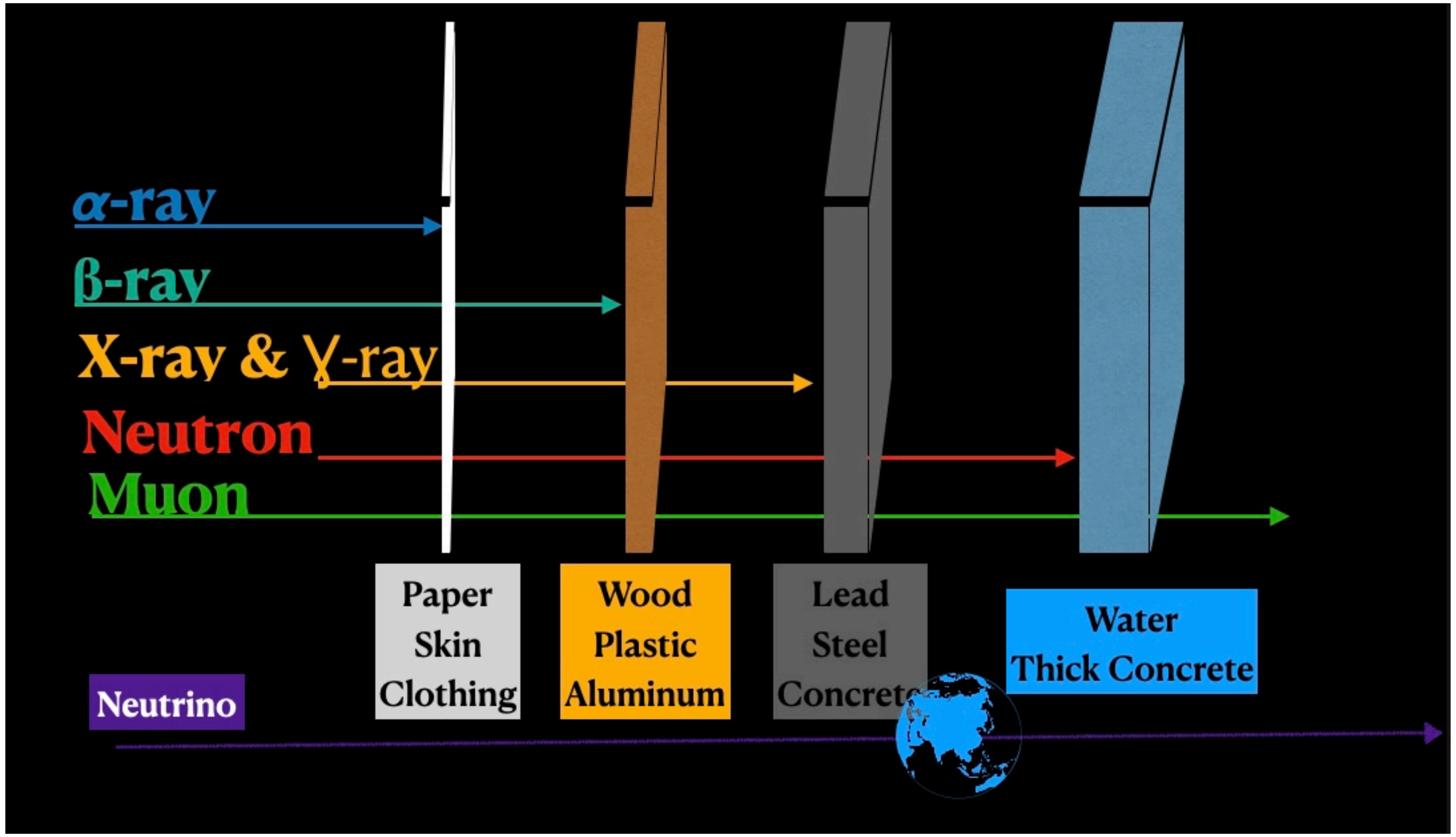
Vietnamese students lack skills with hardware, especially in particle and nuclear physics

- 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?
- ....

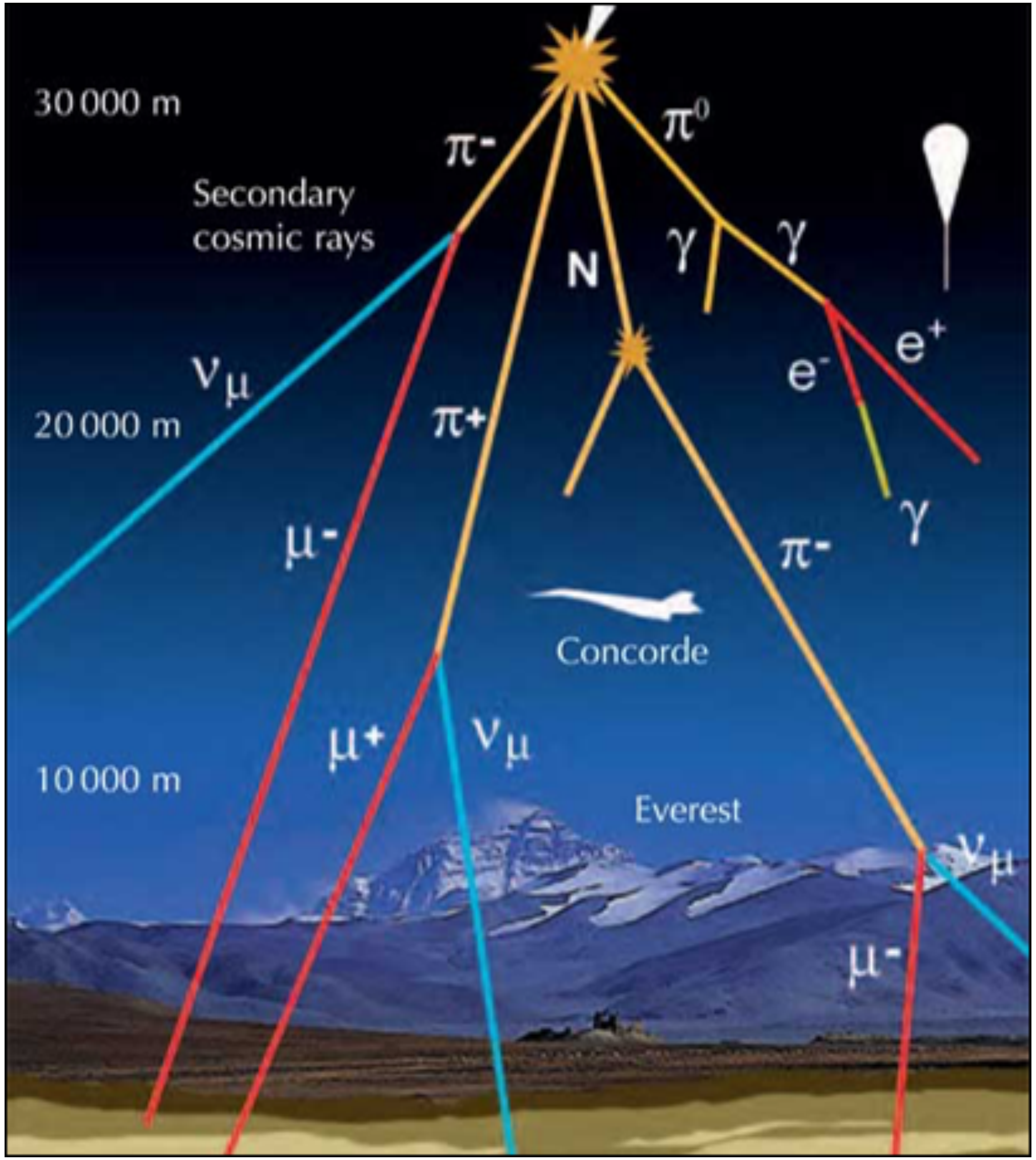
Purpose:

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***)**



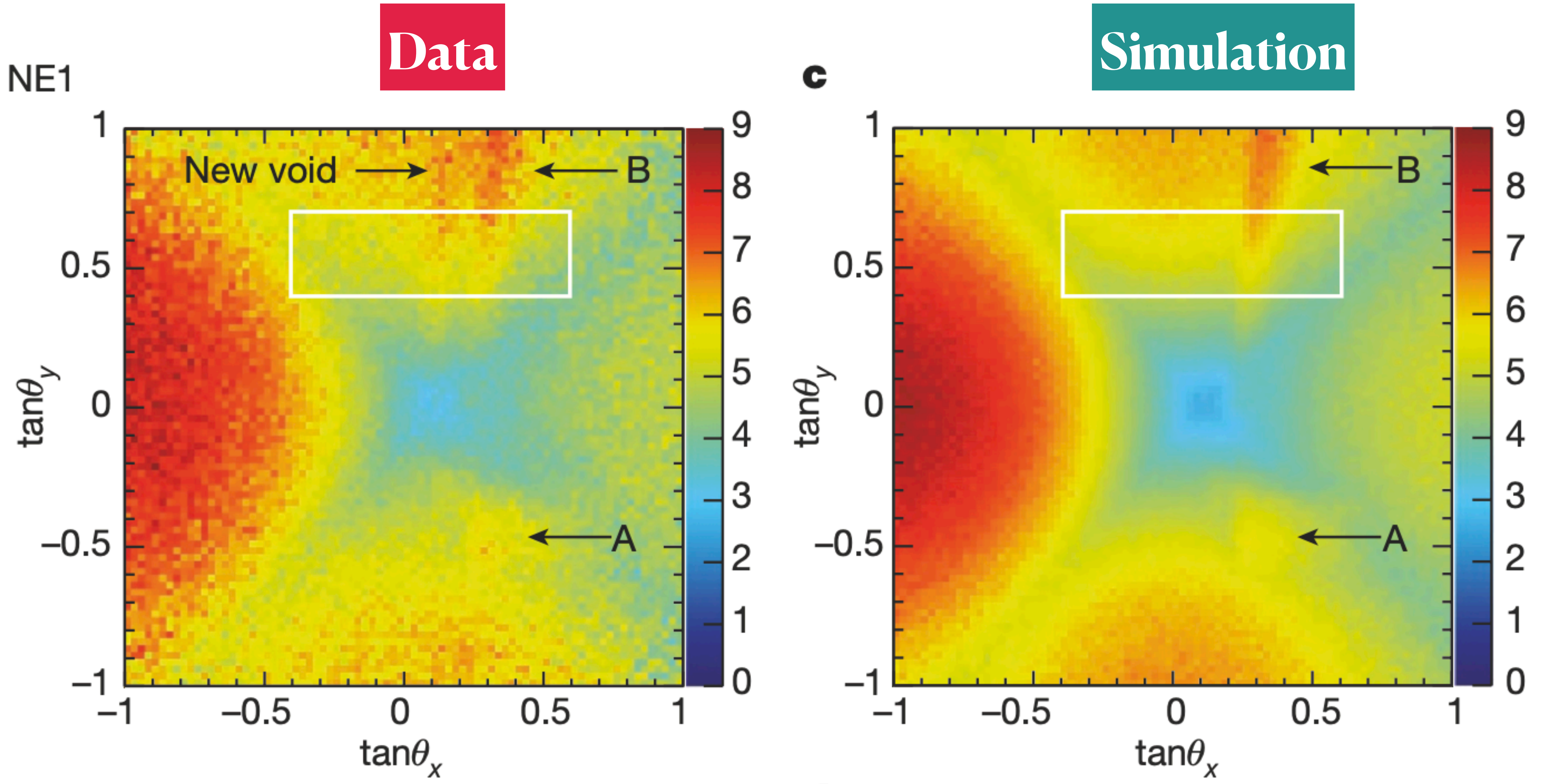
High energy astrophysical particles (eg. hydrogen & helium from the Sun) interact with the Earth's atmosphere
→produce vast amount of muons
~1 muon/cm²/s



Muon can be used for a practical application

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

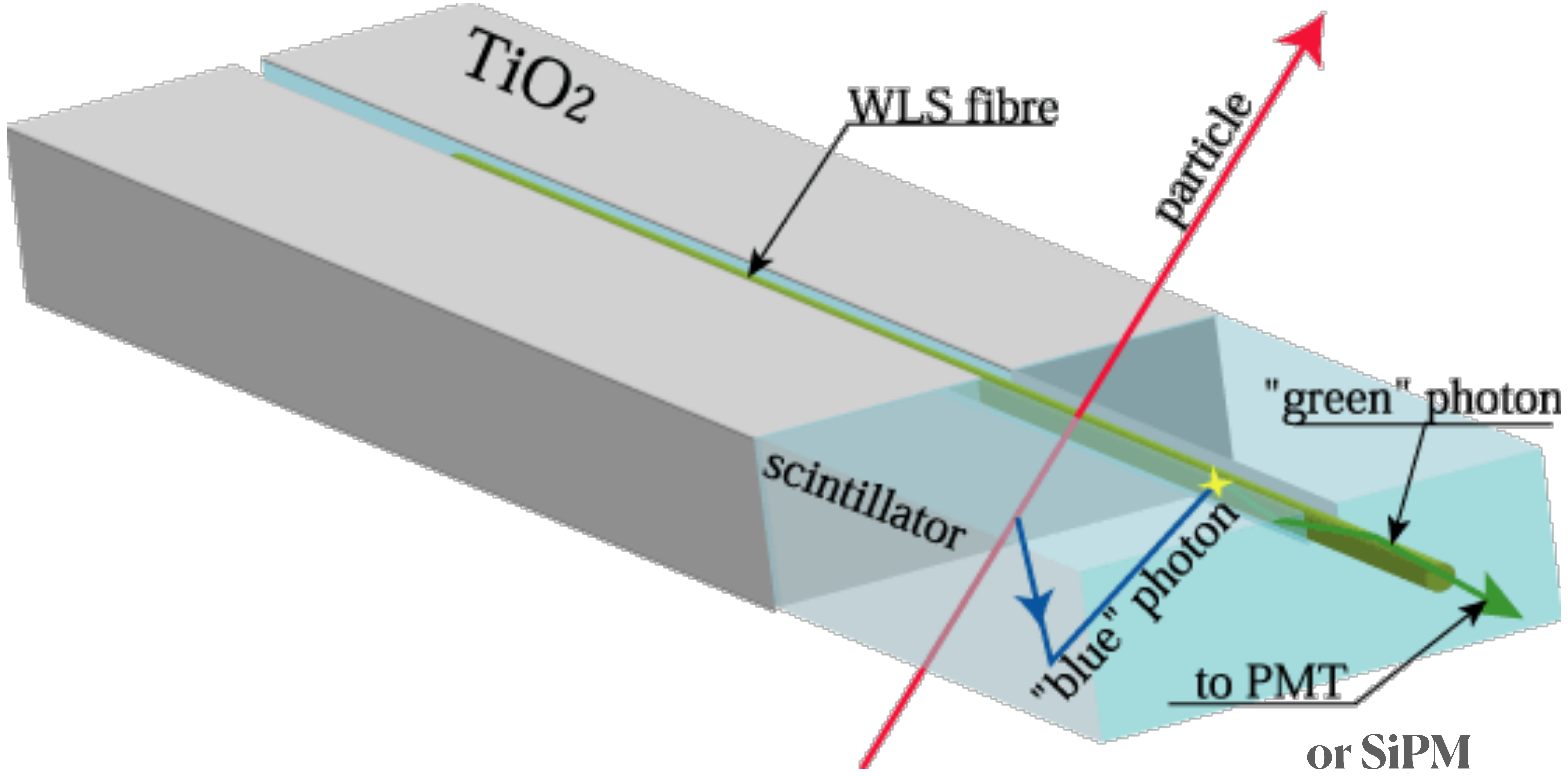
called: muon radiography technique



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

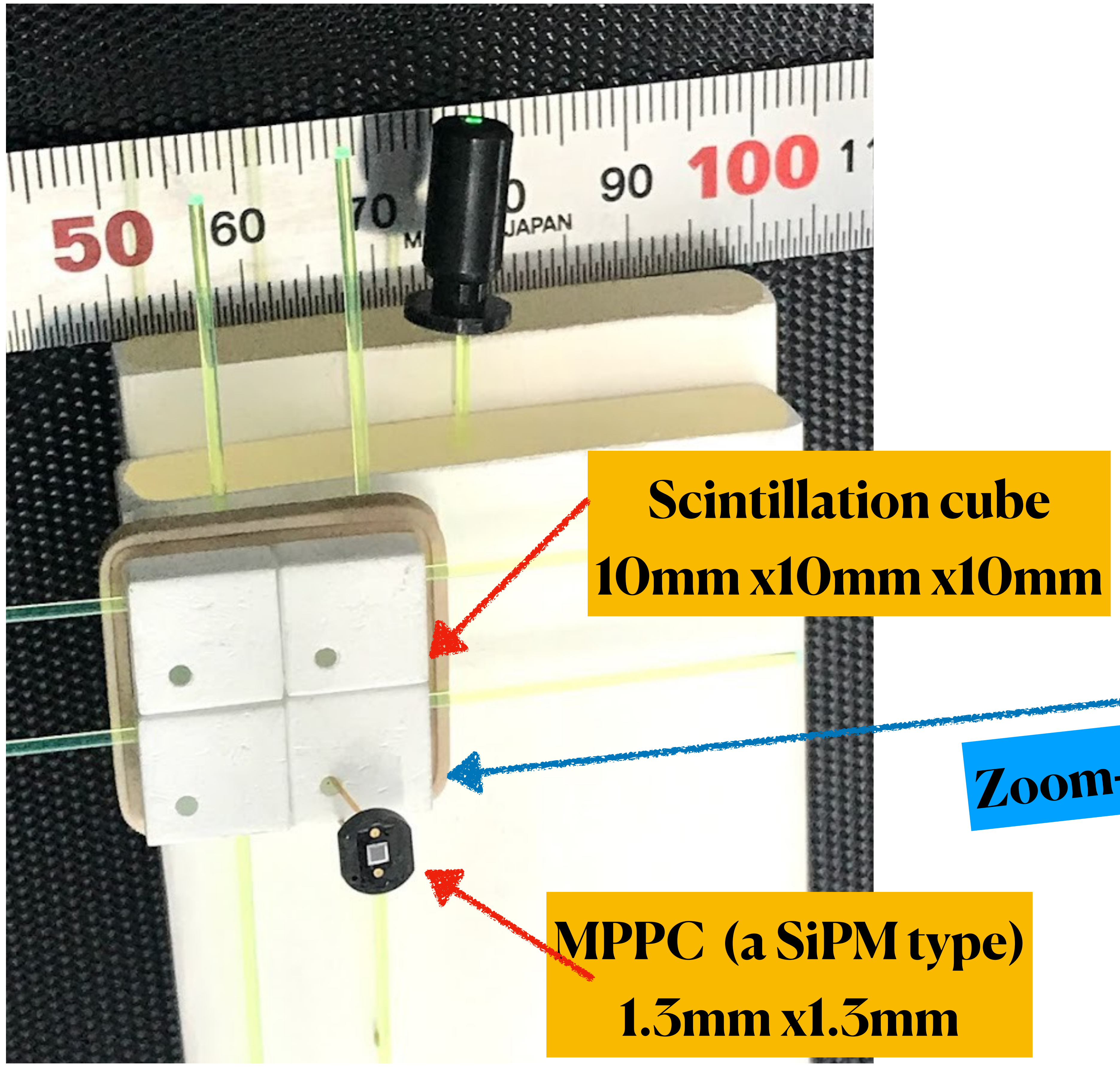
How can we see muons and measure their characteristics with *what we have in the lab?*

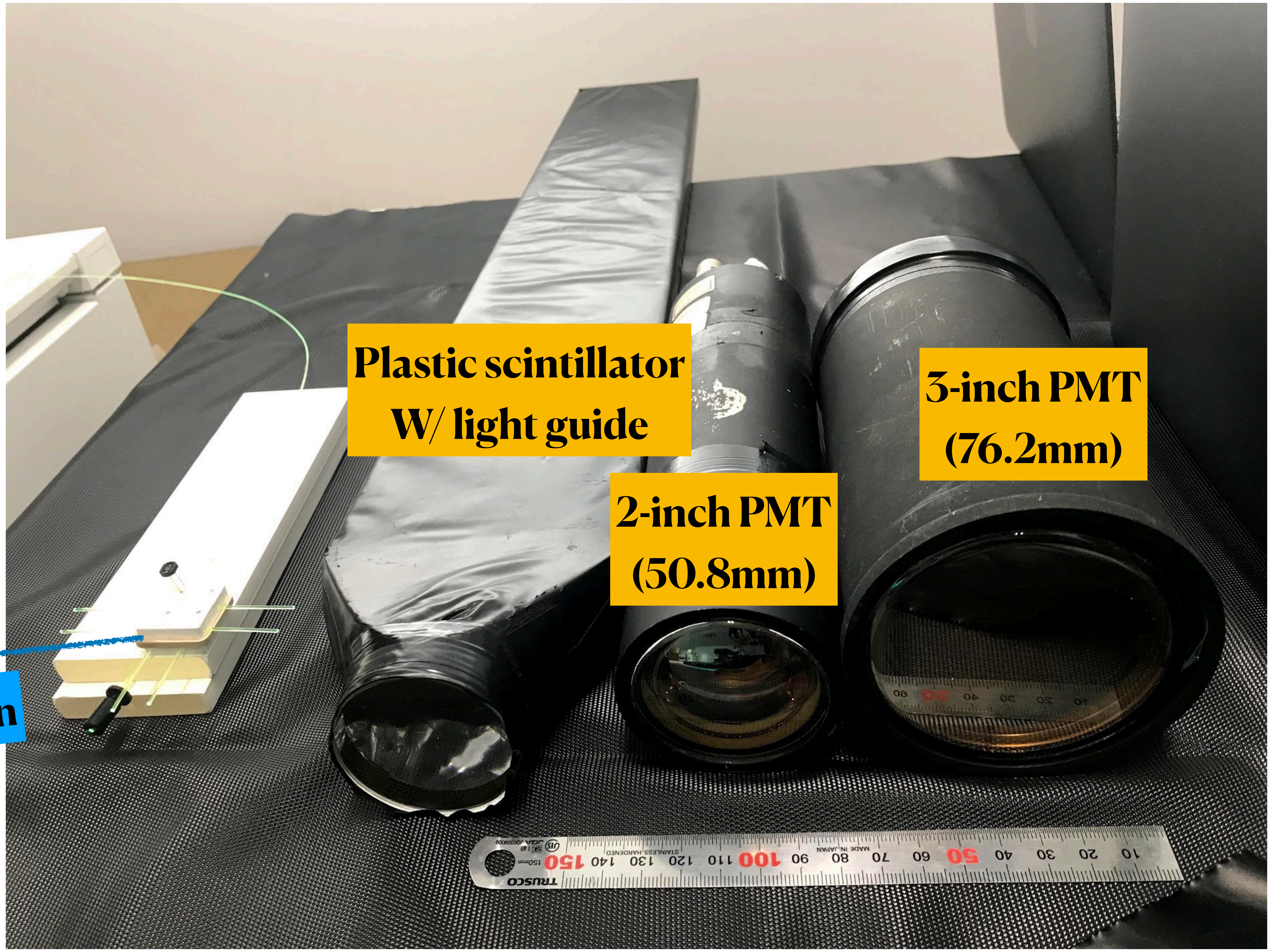
Tracking the charged particle w/ scintillator



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

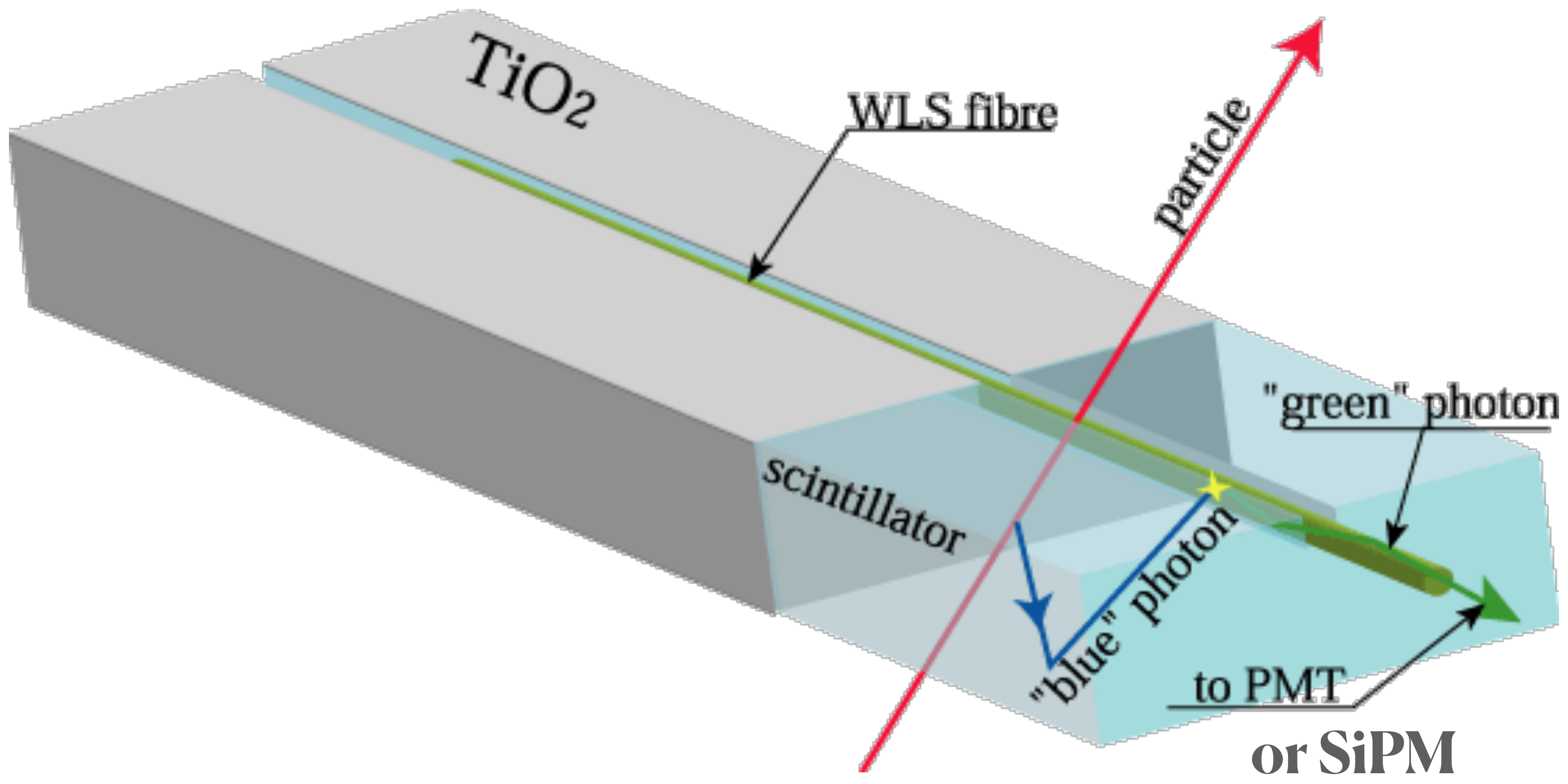




When passing through the scintillator, charged particles (μ, π, e,...) deposits energy and excite the scintillation photons, which are collected and guided to the photosensor for converting to the electrical signals (*more convenient to manipulate*) for data recording.

Tracking the charged particle w/ scintillator

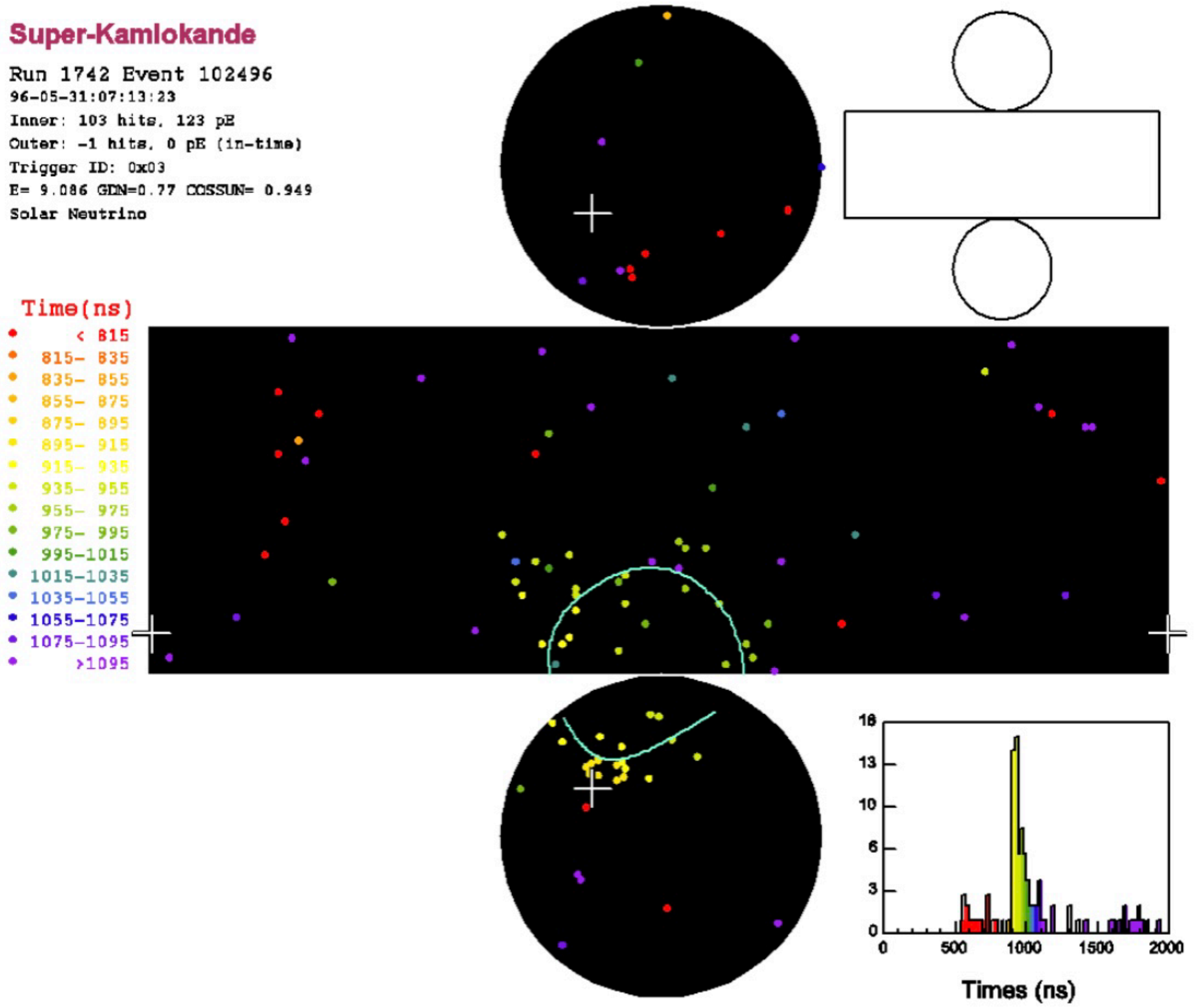
- Muon deposits **~ 2 MeV per 1cm** path in the plastic scintillator
- 2 MeV deposit energy will produce **~ 10,000 photons**
- Assume the probability for WLS catching the photons is about 1%, then ~ 100 photons are capture and change to green photons
- Detection of photosensor is about 20-40%, so will 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



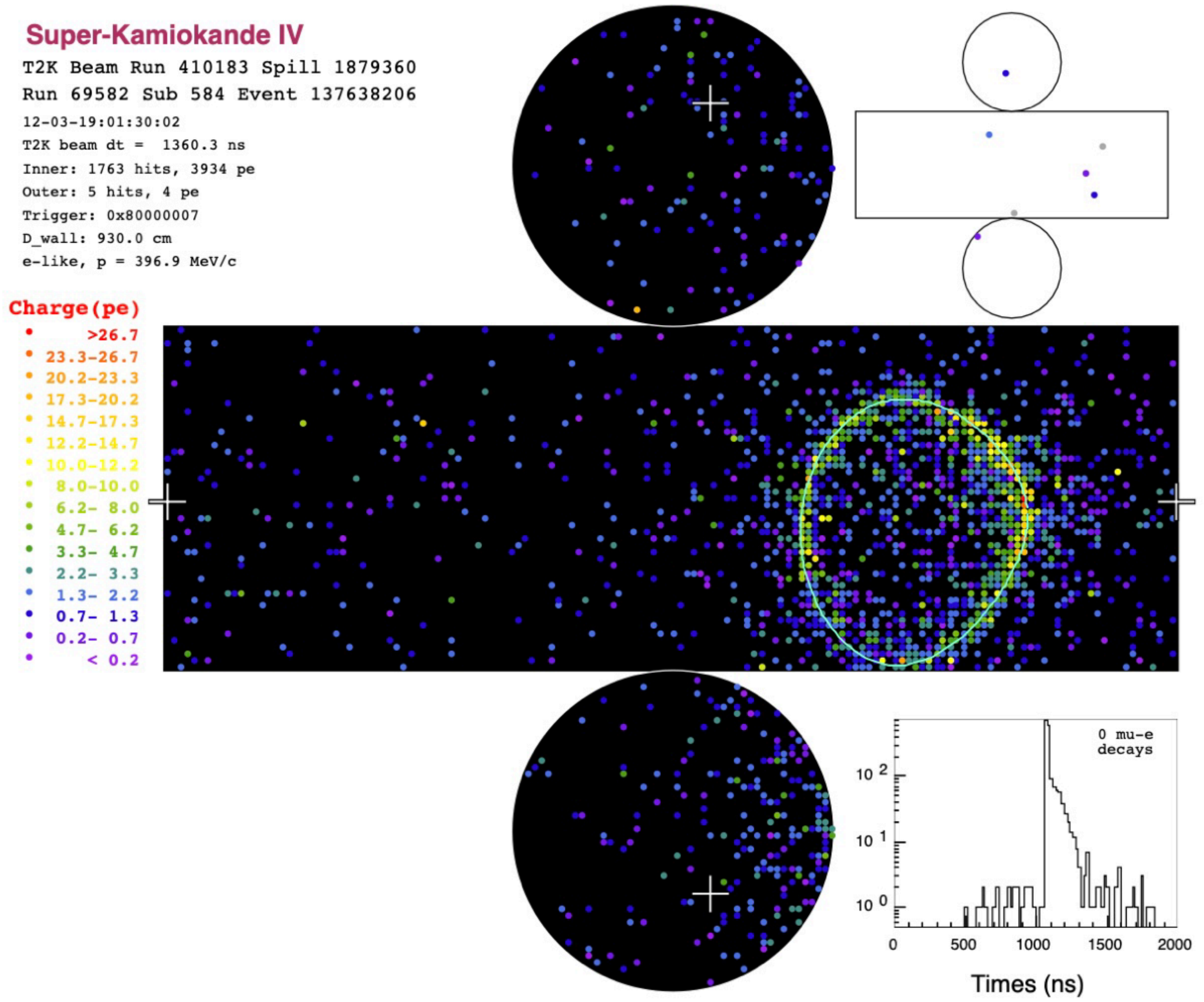
Why is light yield of scintillator super-important?

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

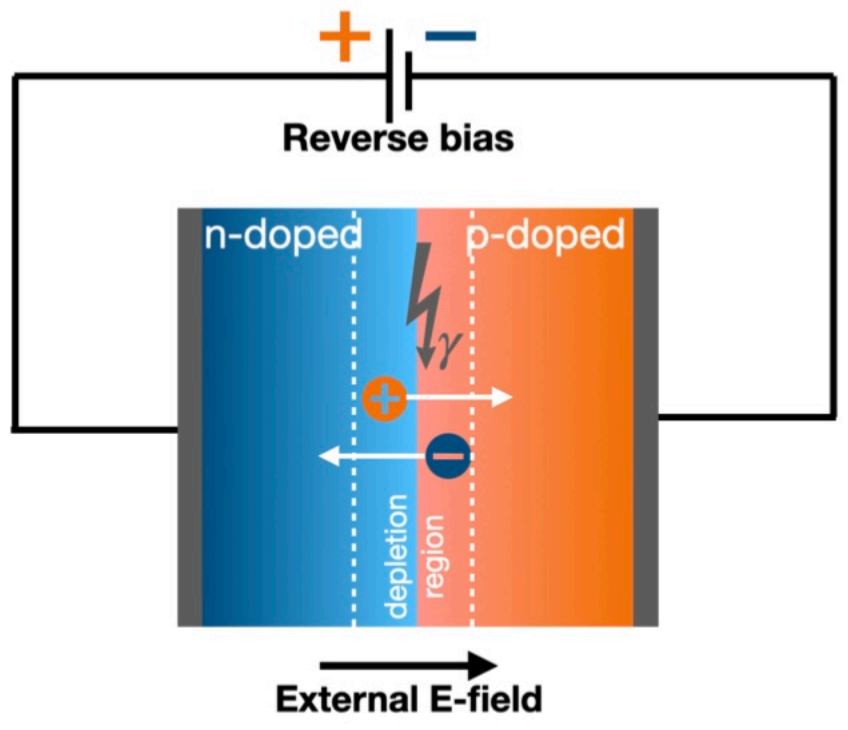
Typically, signature of the comic ray muons is also faint

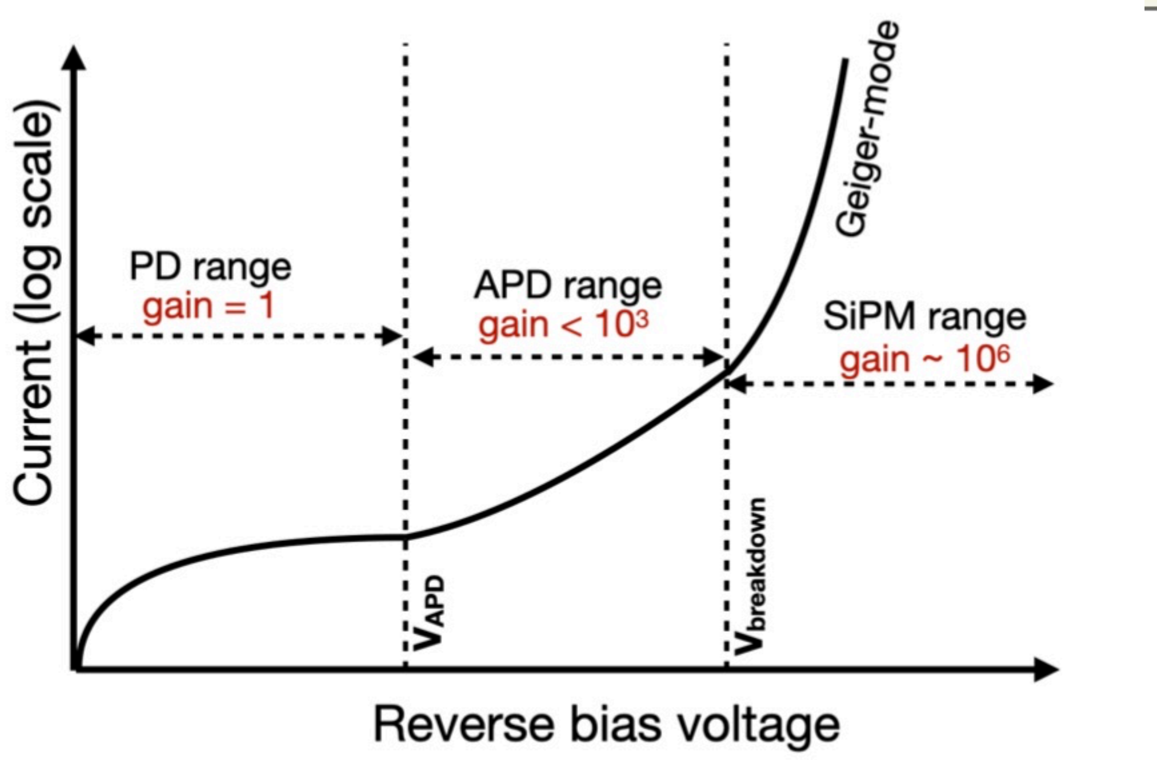
We need a very good "Eyes"

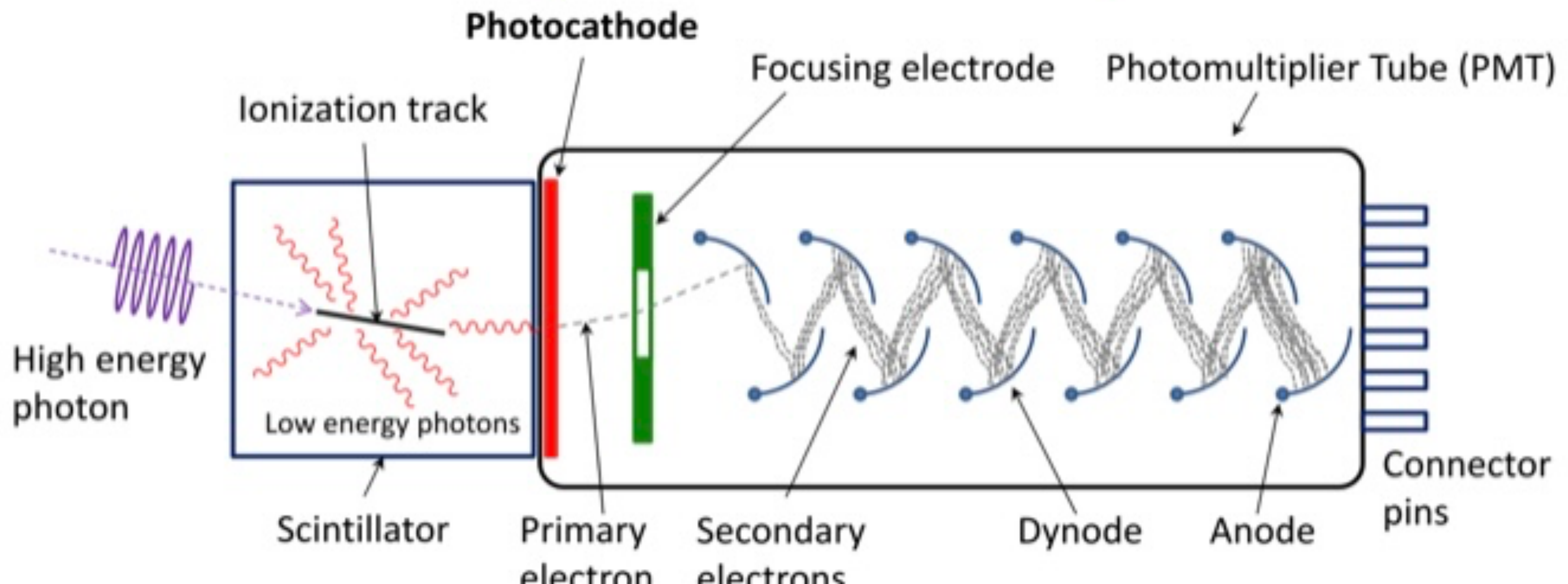
Photosensors: Extremely important to extend particle frontiers (precision, sensitivity, intensity…)

Ref: Prof. Nakaya's 2nd lectures

	PD	APD	MPPC	PMT
	Photo-diode	Avalanche photo-diode	Multi-channel Giger mode photo-diode	Photomultiplire tube
gain	1	10^2	$\sim 10^6$	$\sim 10^7$
sensitivity	low	medium	high	high
Voltage applied	5V	100~500 V	30~60 V	800~1000V
Sensitive area	small	small	small-medium	large
Electronics	complicated	complicated	simple	simple
Noise	low	medium	medium	low
Uniformity	◎	○	◎	○
Fast response	○	○	◎	○
Energy resolution	good	not bad	good	good
Temperature dep.	low	high	medium	high
Outer-light dep.	○	○	○	×
Magneticfield dep.	○	○	○	×
Compact & light	○	○	○	×



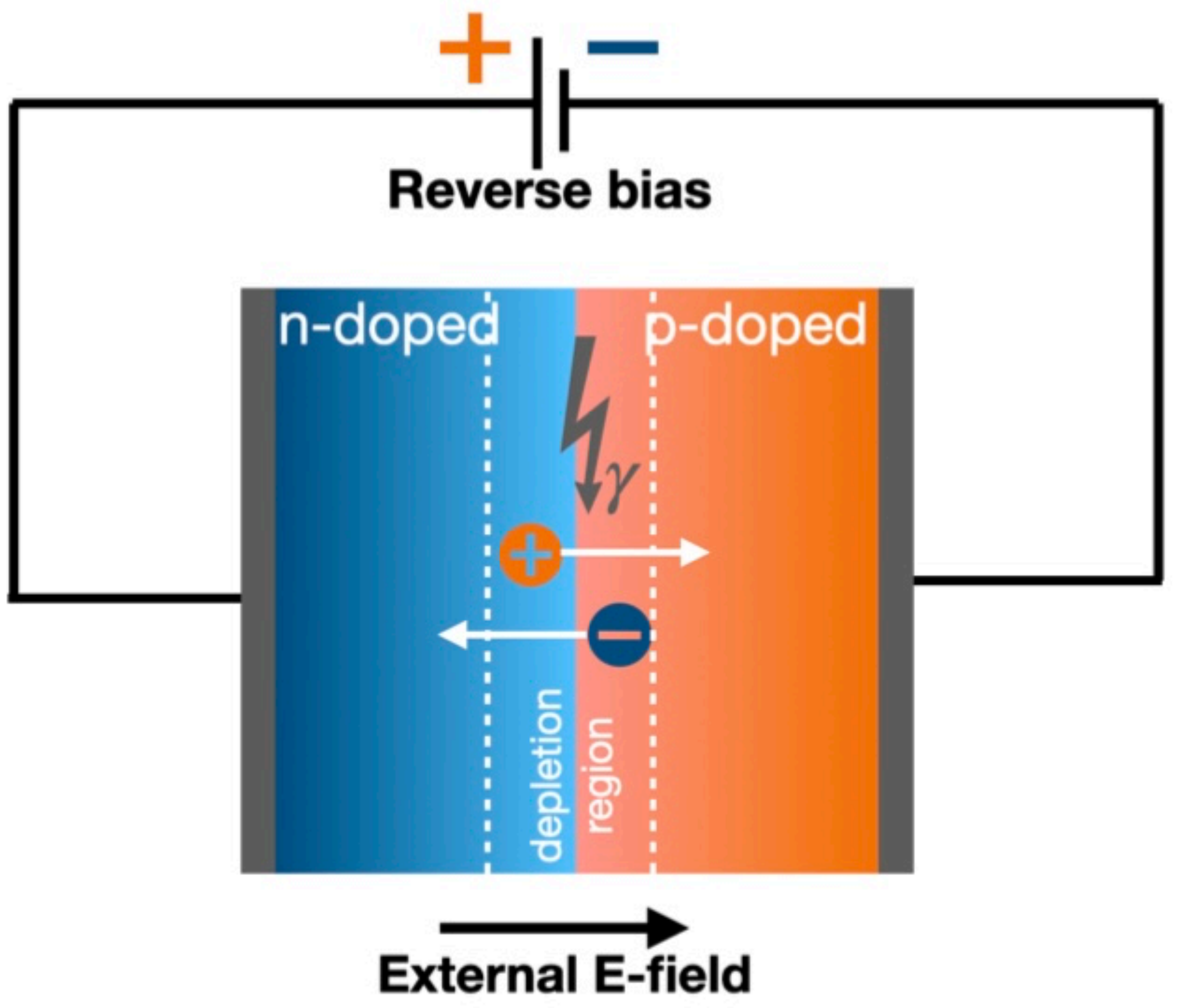


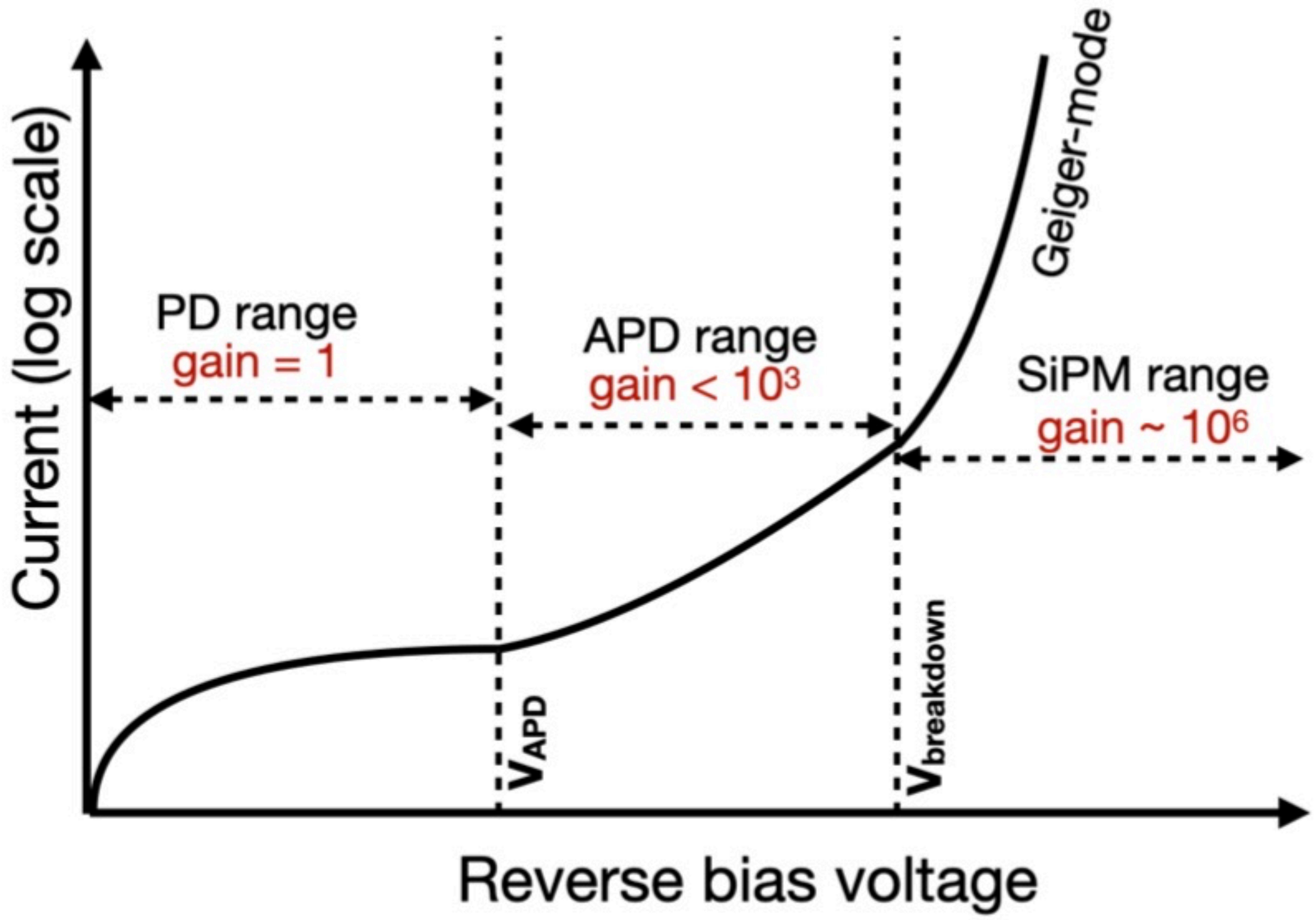


“The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes”

~Marcel Proust~

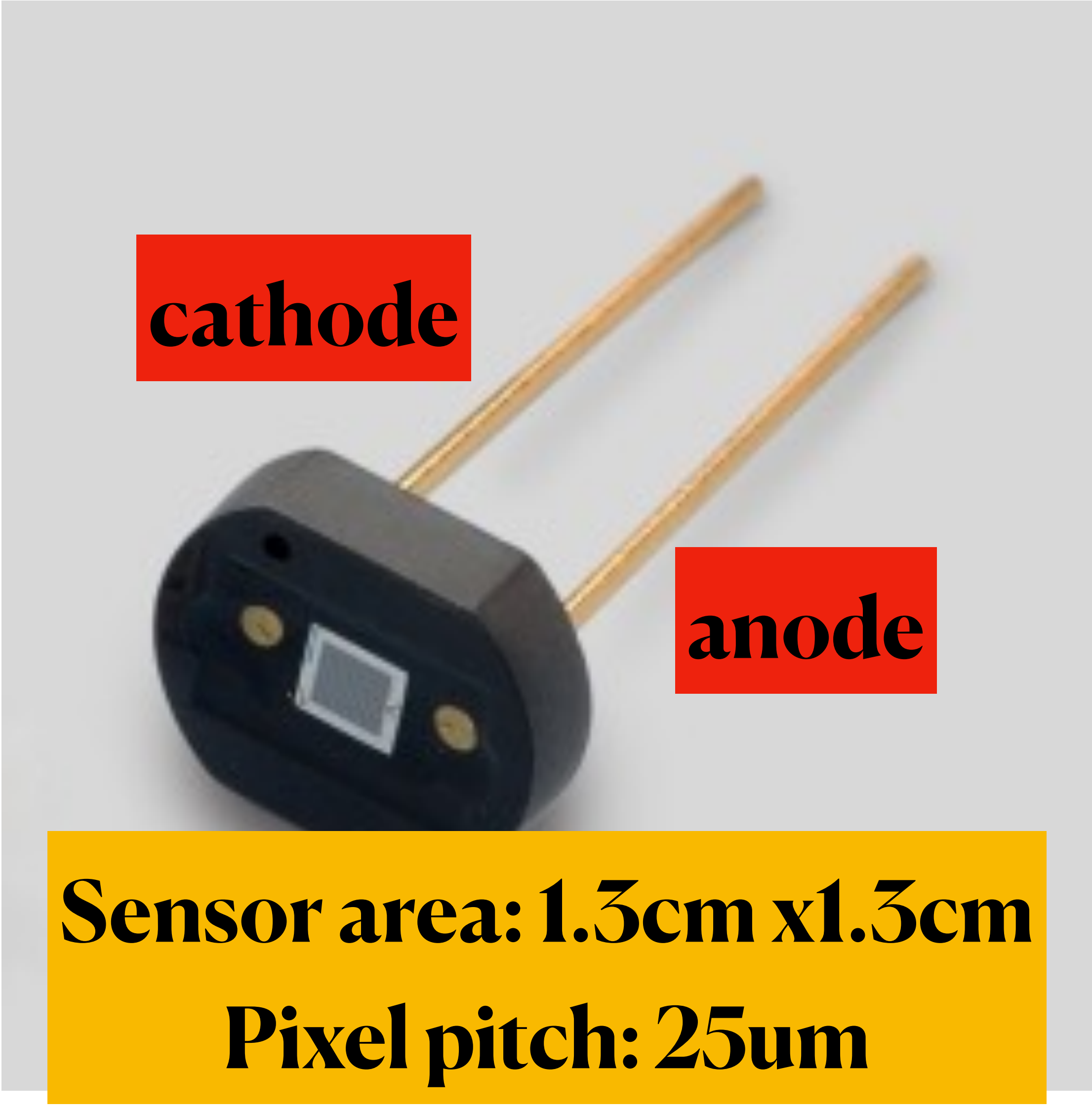
Photon detection principle w/ Silicon photomultiplier (SiPM)



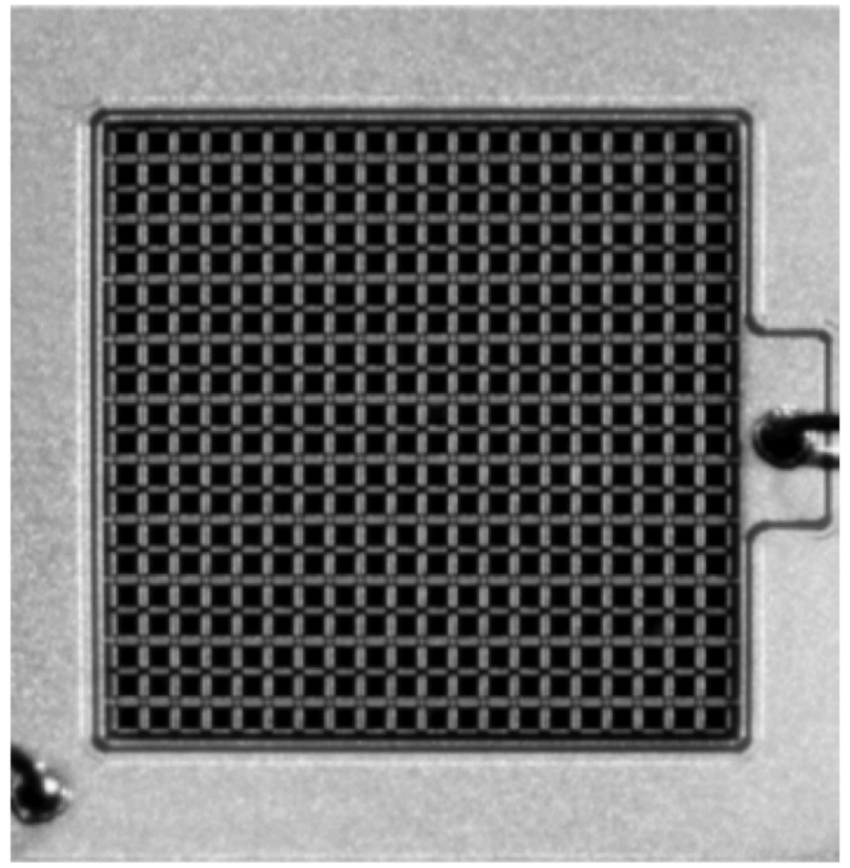


- Based on photoelectric effect: photon strikes and produce a pair of electron/hole
- Various types, selection depending on the measurement
- "Breakdown" here mean both hole and electron play roles in avalanche process

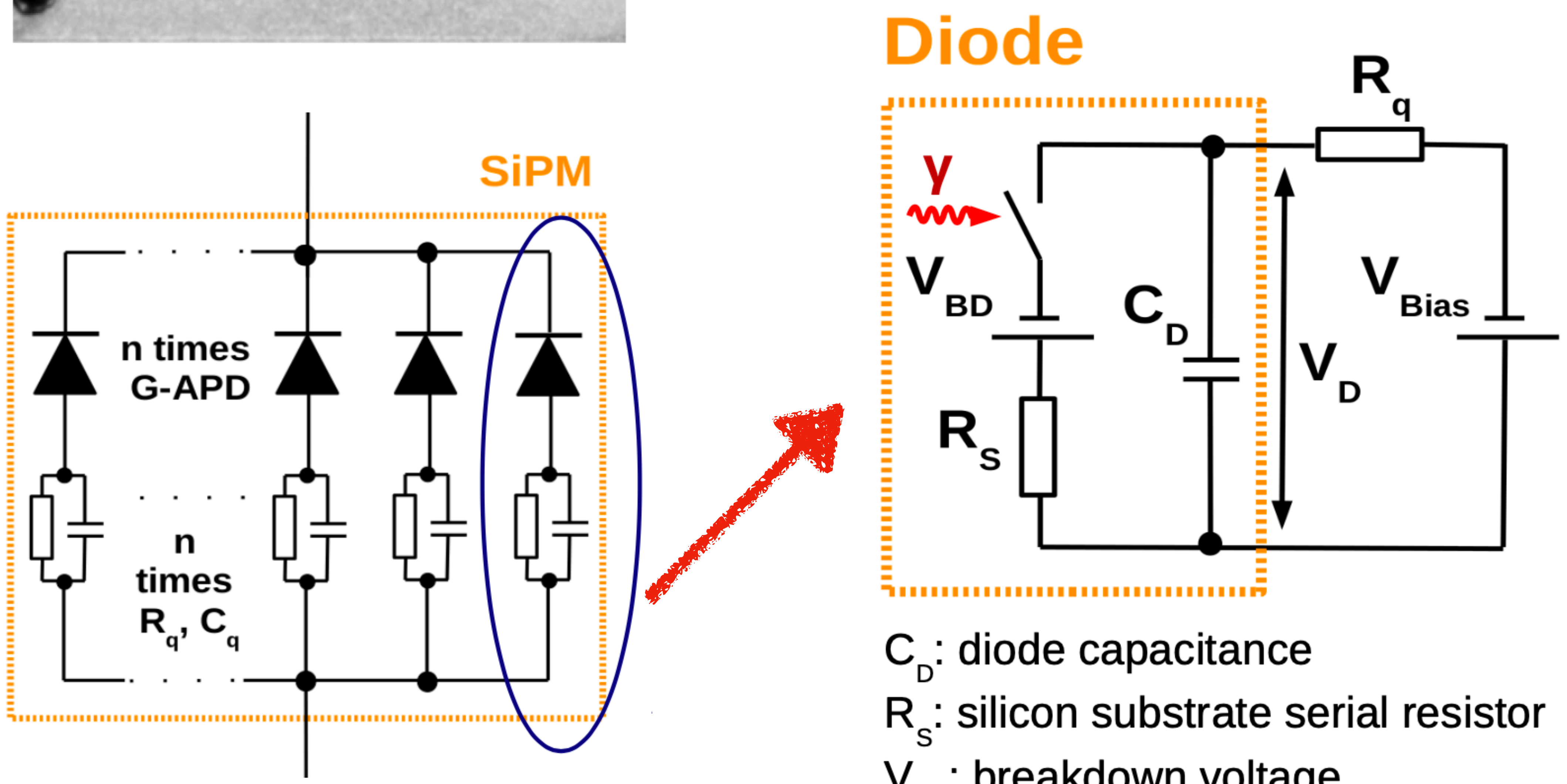
MPPC: a type of SiPM, developed by Hamamatsu



Hamamatsu S13360-1325CS



Array of pixels

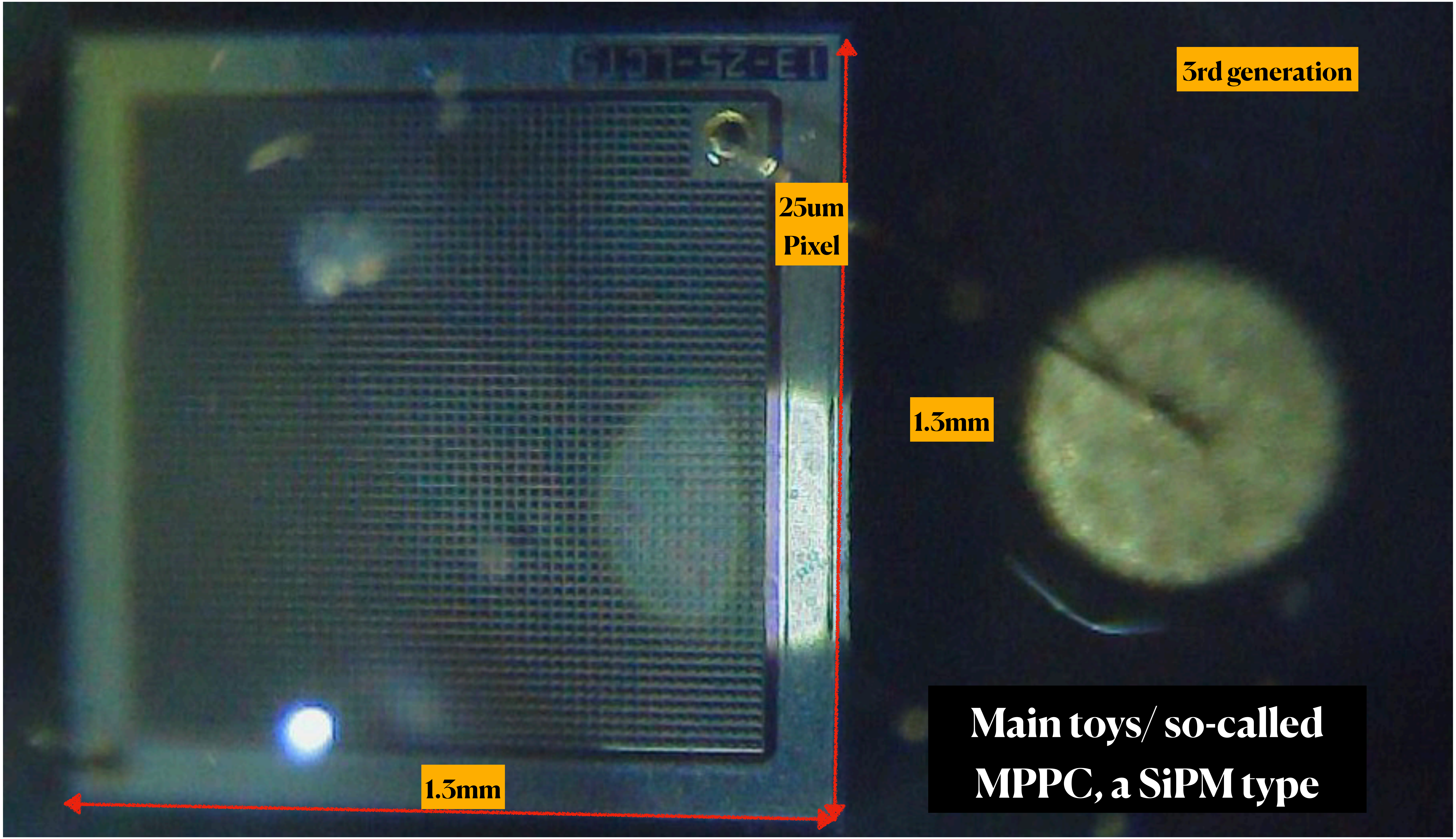


C_D: diode capacitance

R_S: silicon substrate serial resistor

V_{BD}: breakdown voltage

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

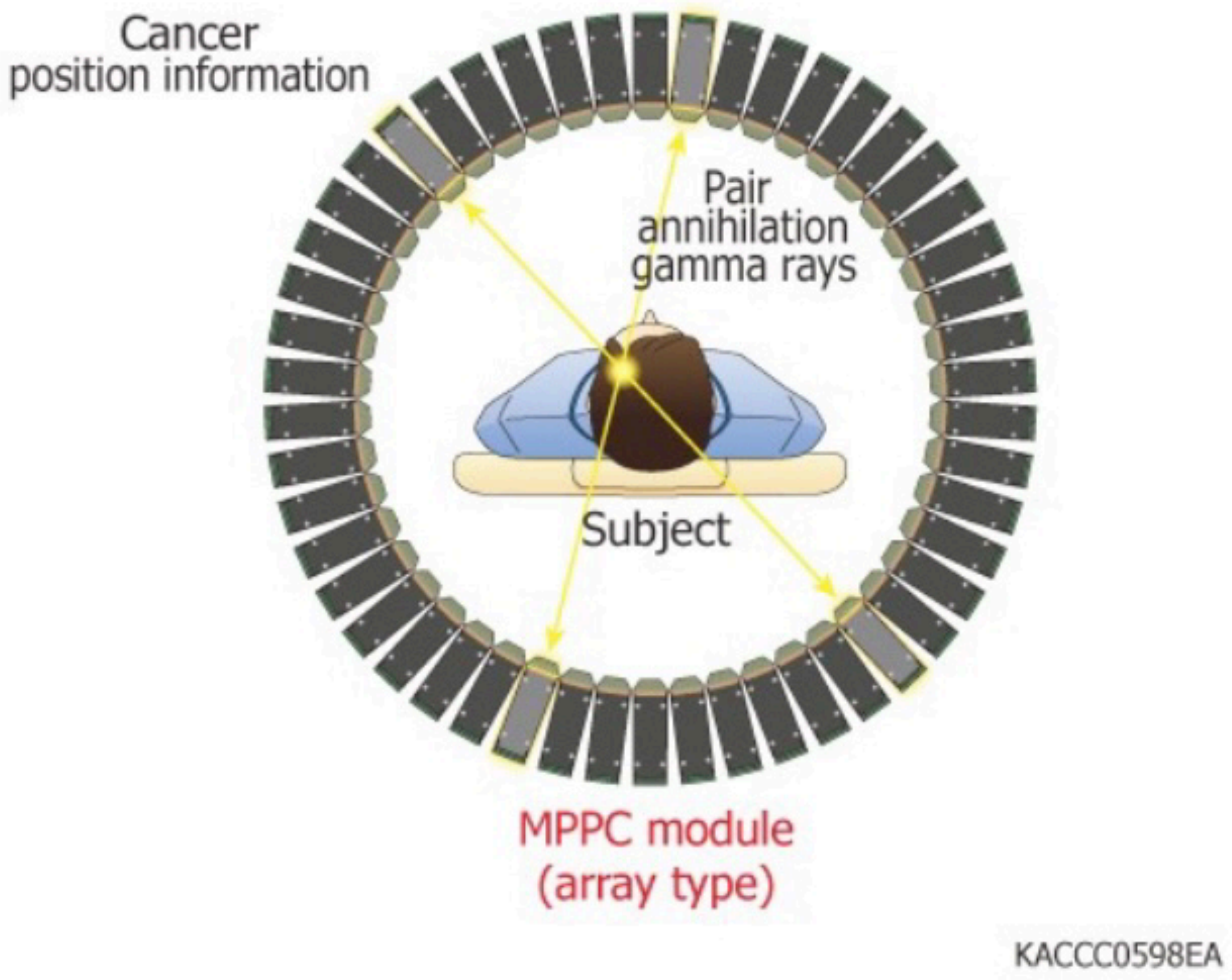

3rd generation
25um
Pixel
1.3mm
1.3mm
Main toys/ so-called
MPPC, a SiPM type

MPPC applications

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

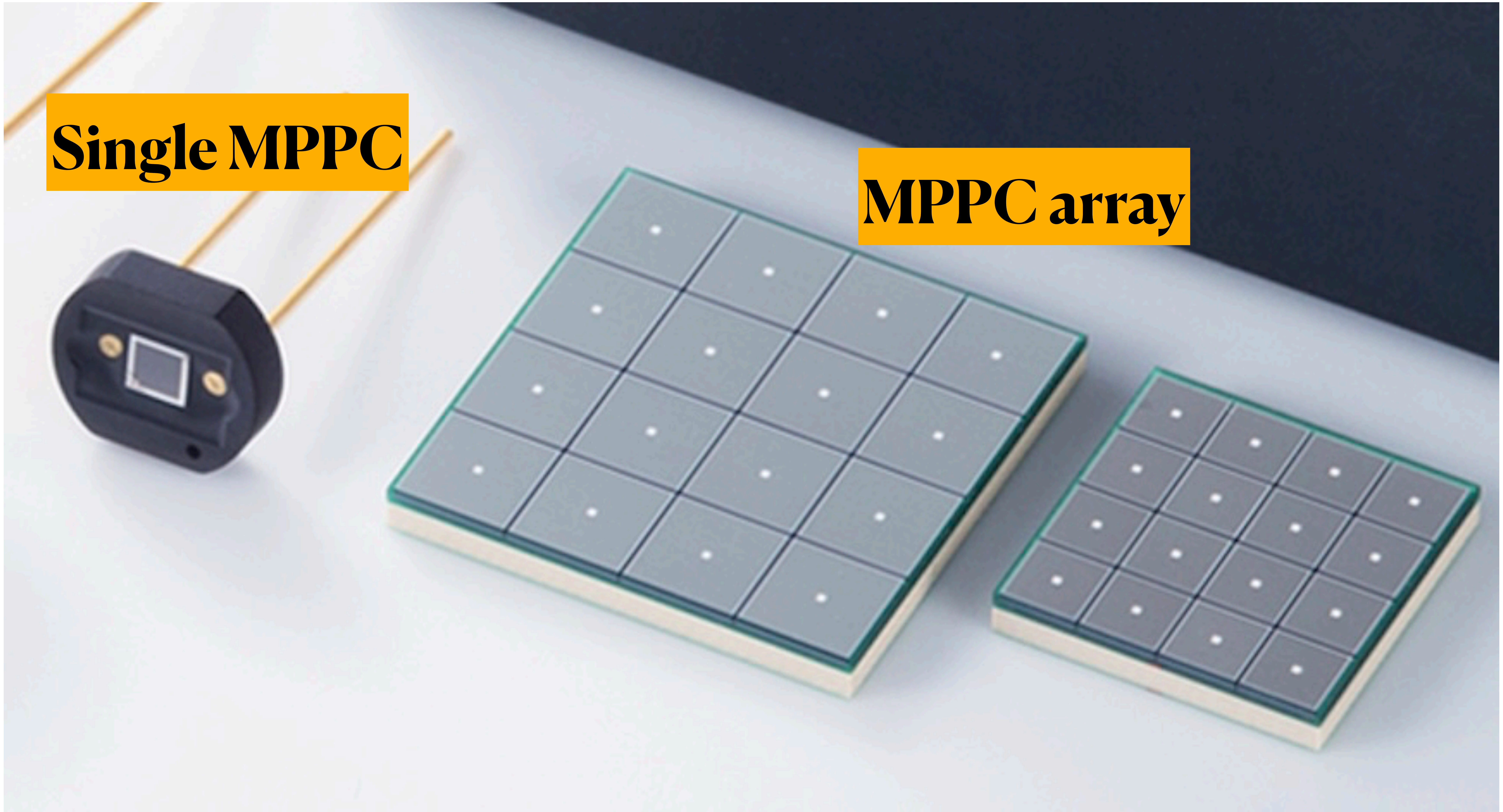
Distance Measurement (LiDAR)

PET (Positron Emission Tomography)

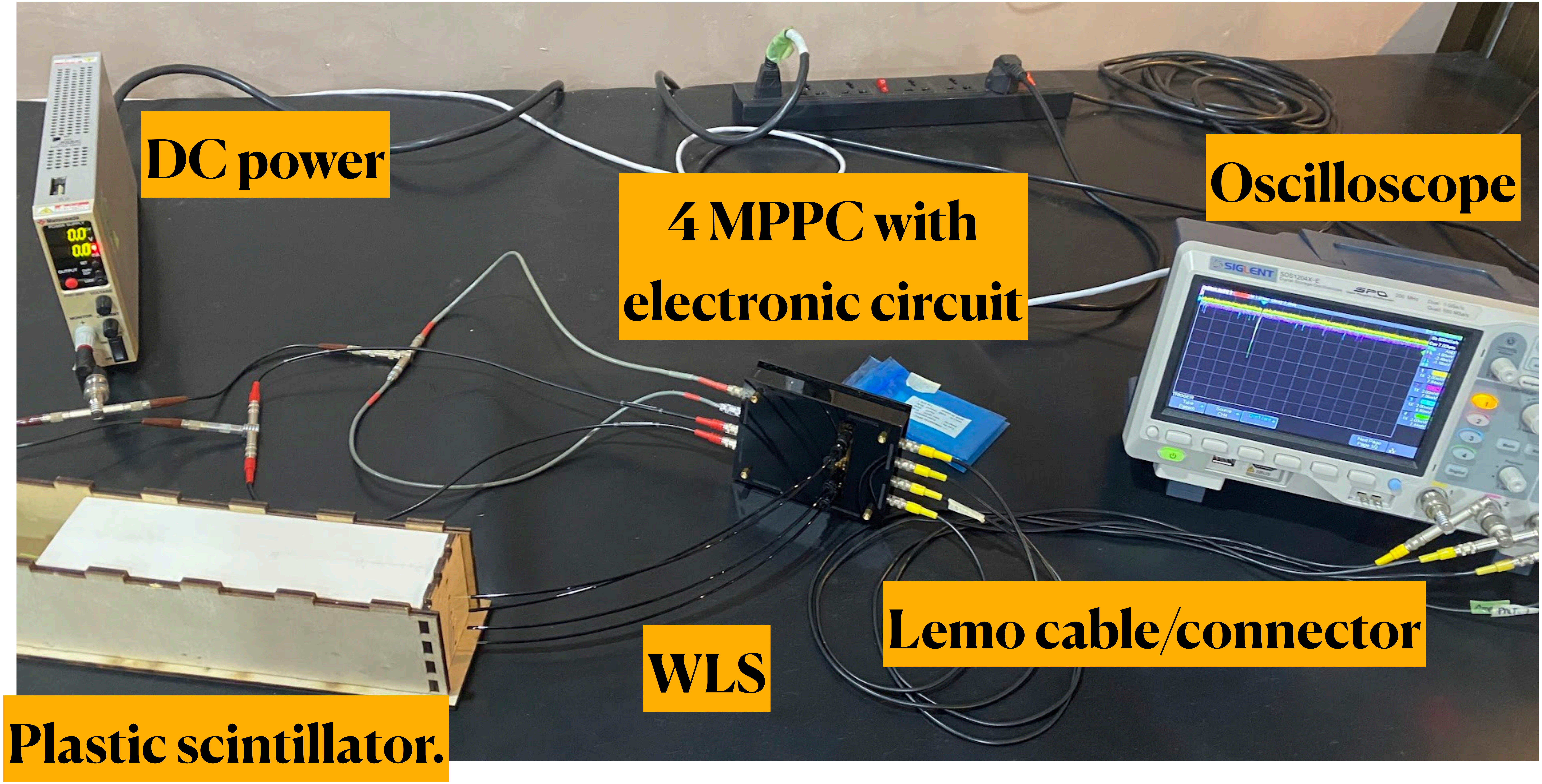


And many other applications

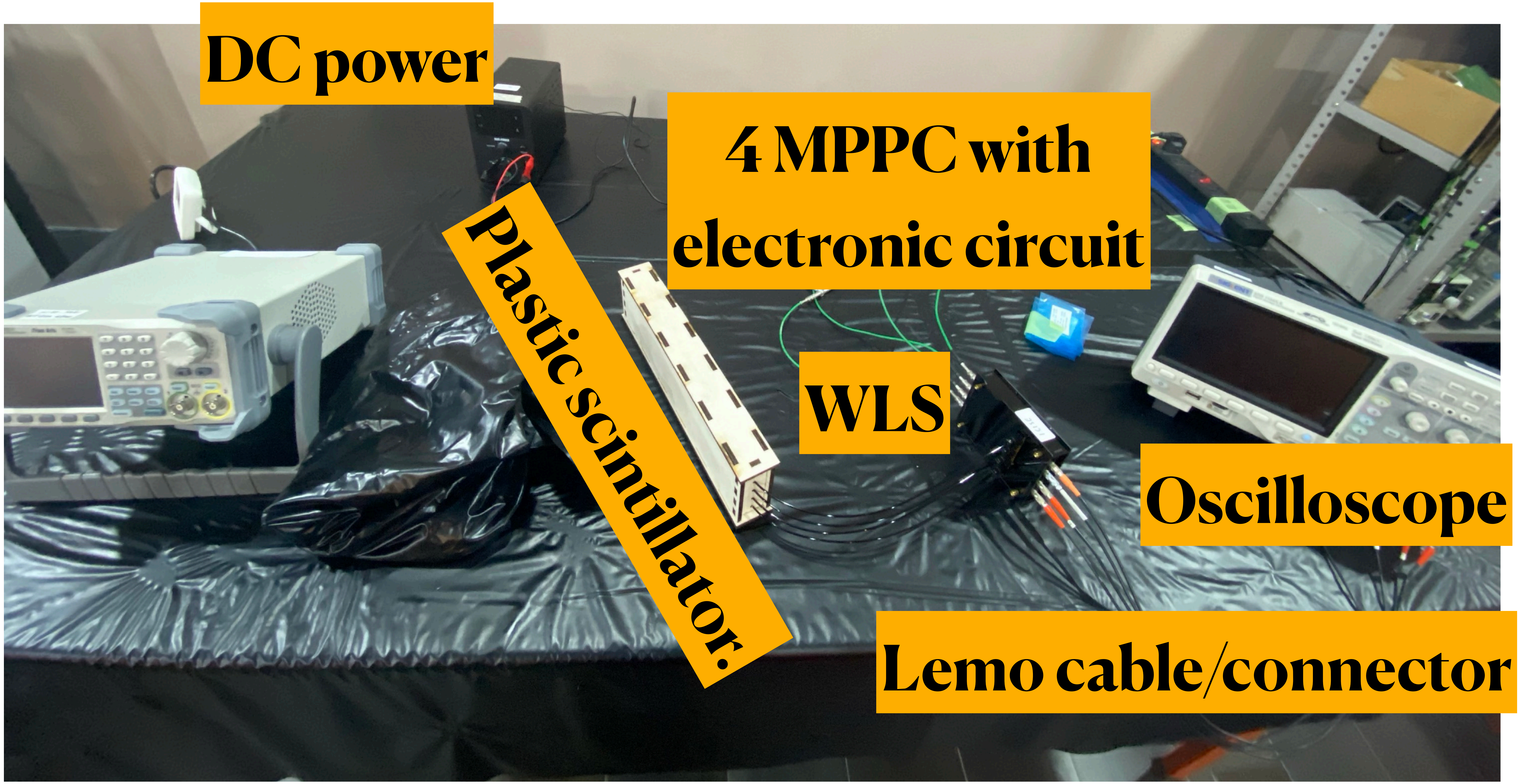
We basically have both single MPPC and MPPC arrays



Setup-01 with single MPPCs (for group $\nu_1,\ \nu_e$)



Setup-02 with single MPPCs (for group $\nu_2, \ \nu_\mu$))

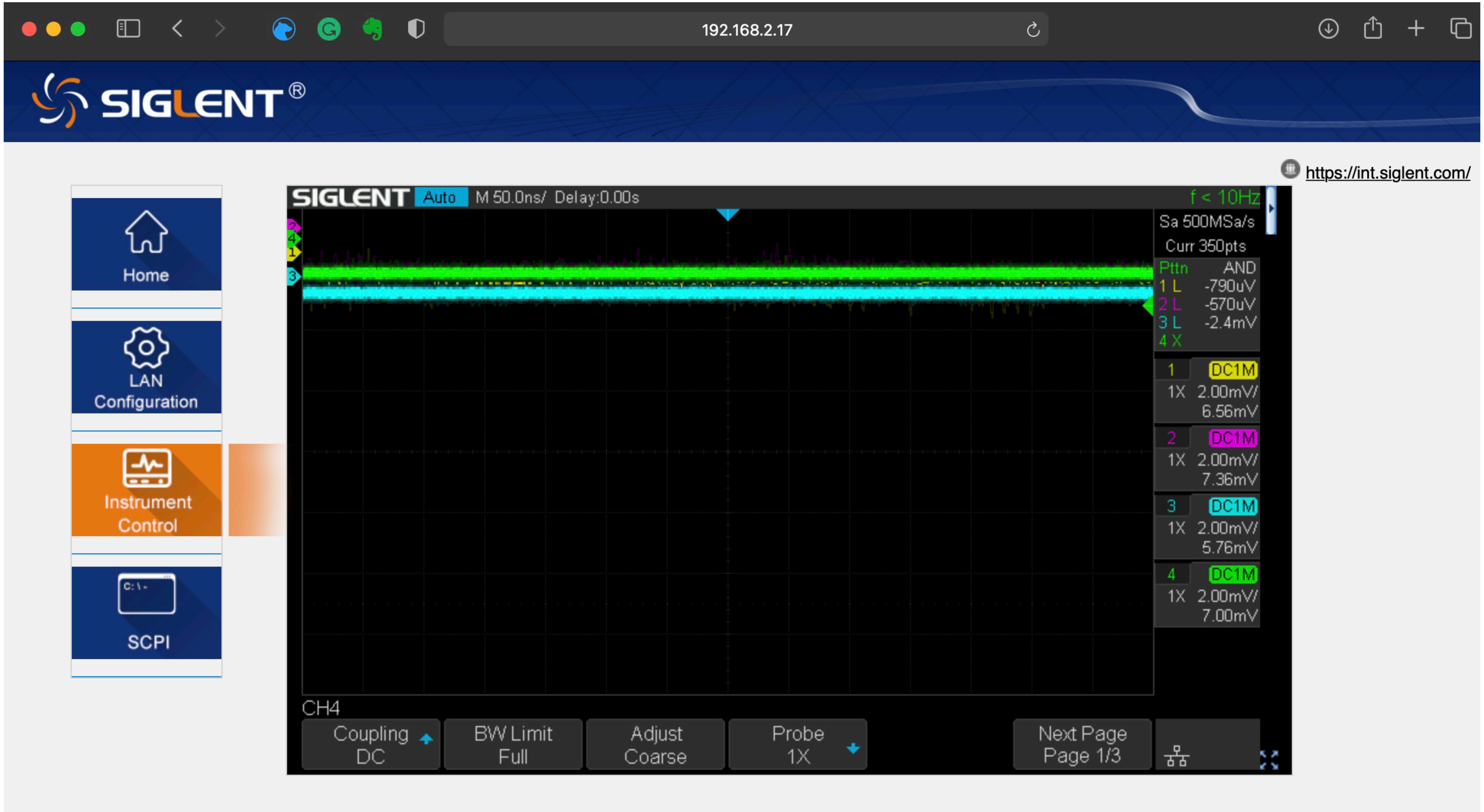


Important notes for the setup with single MPPC

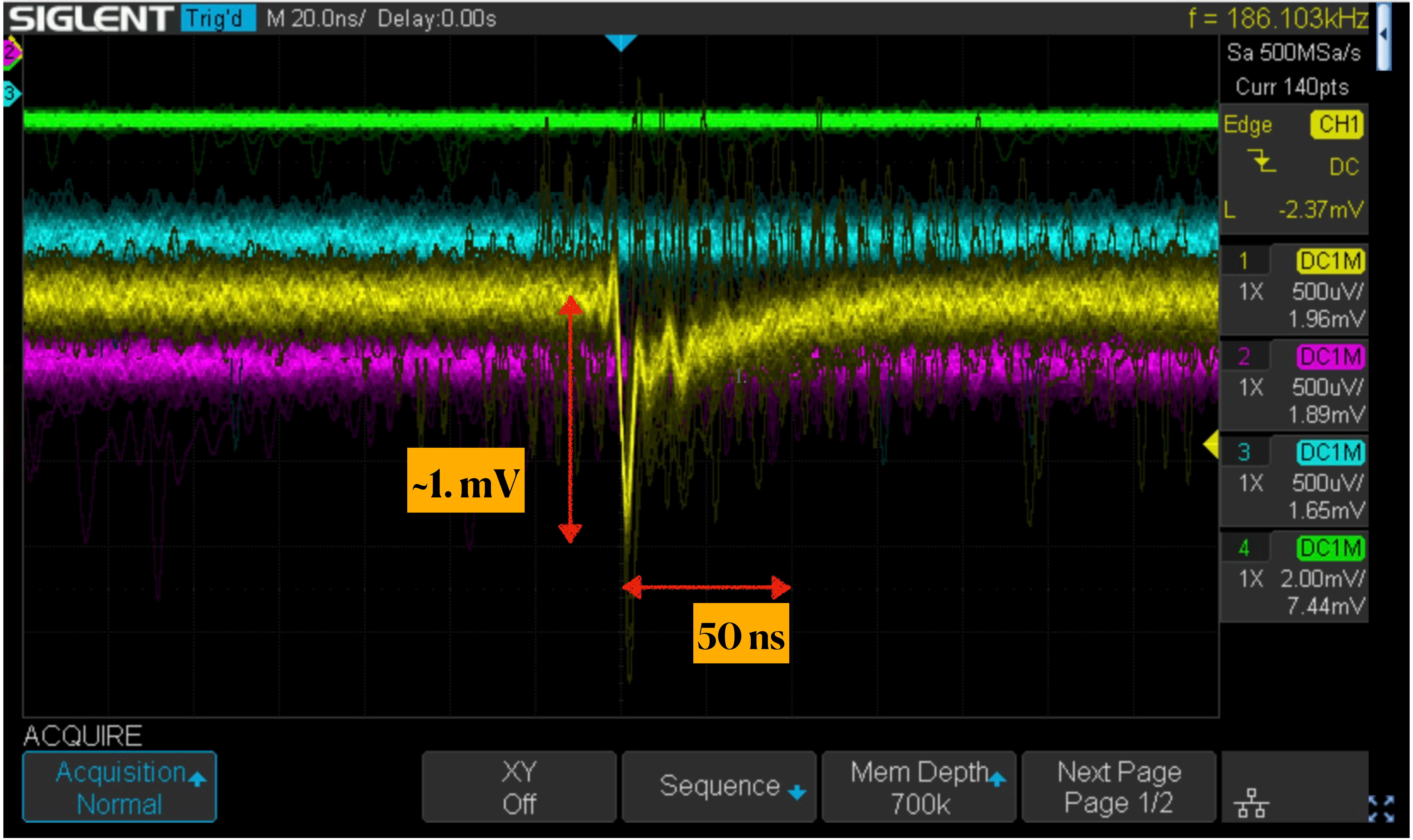
- Electronic readout for the MPPC is relatively simple and we can make the electronic circuits (to provide HV DC and to get signals) by our own.
- The electronic circuit is not so good yet, you can observe the noise (*due to not perfect grounding and RF shielding / we will improve in the future*)
- There is no NIM standard modules such as amplifier, coincidence, scaler but we ultilise the oscilloscope for these tasks

We simplify the setup for a short hardware training

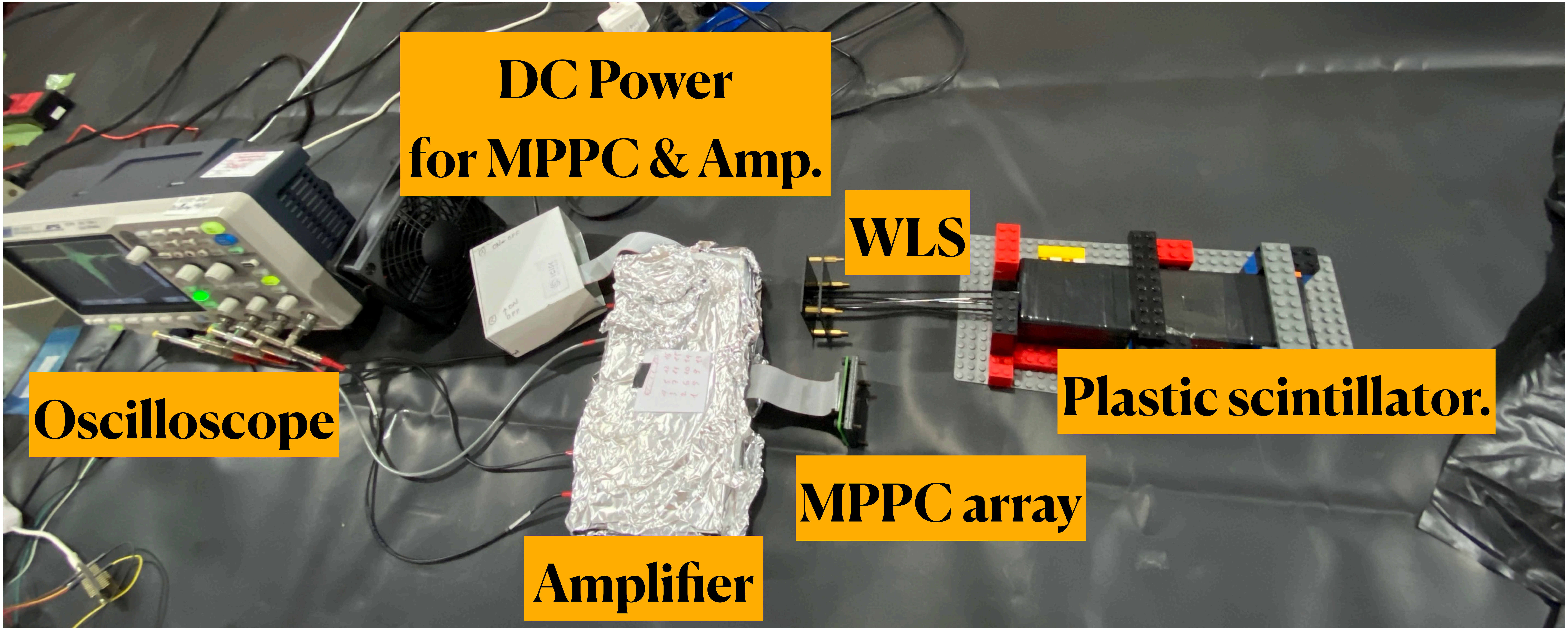
The oscilloscope has web interface and can acquire data remotely via ethernet (and VXI)



The signal is very small, 1 pe ~ 1.0 mV

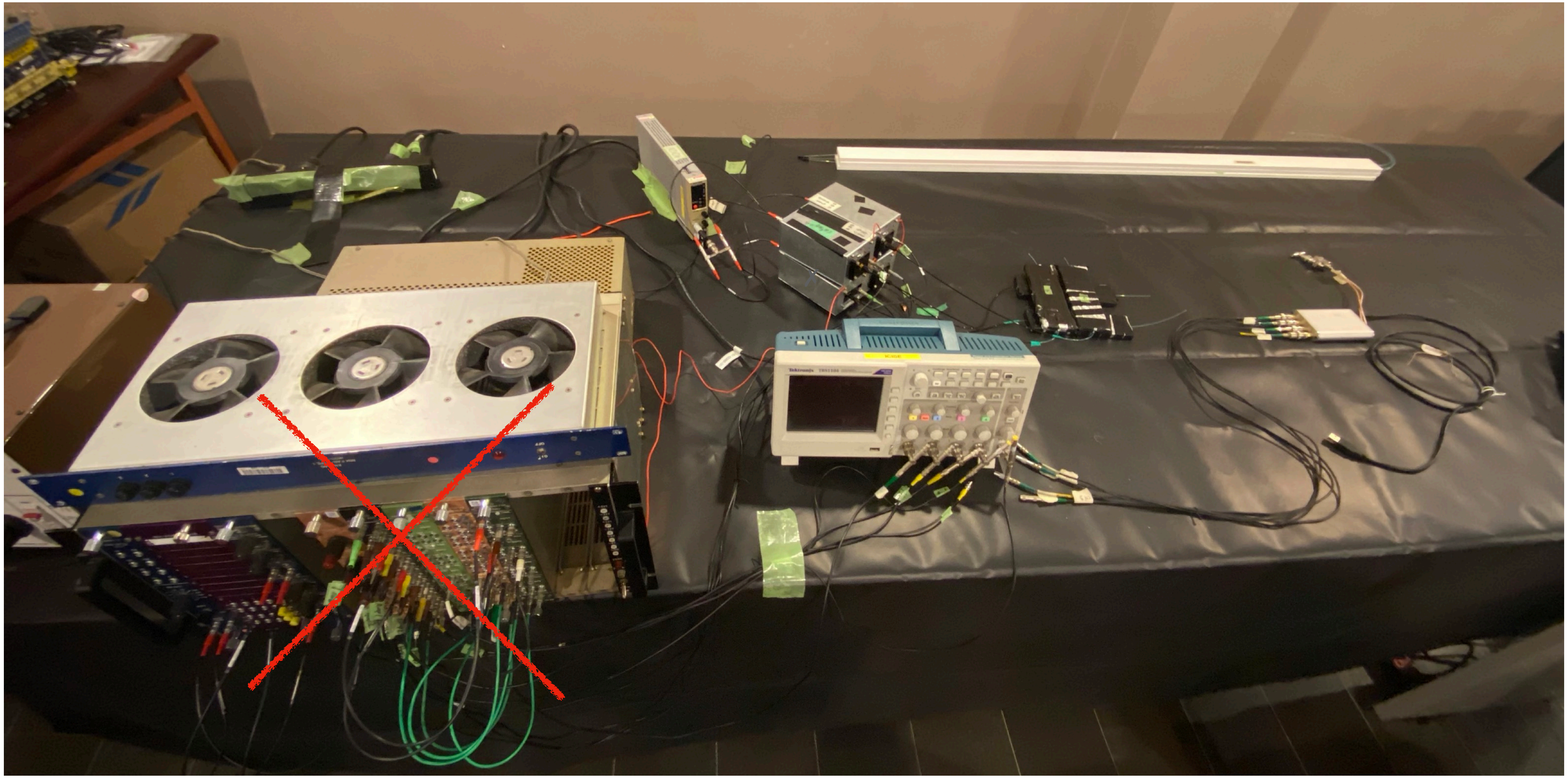


Setup-03 with MPPC array (for group ν_3, ν_τ))



Signal size is higher than the previous setups (~ 5 mV / p.e.) and better grounding and RF noise cancellation

We get rid of the complicated setup with NIM modules



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

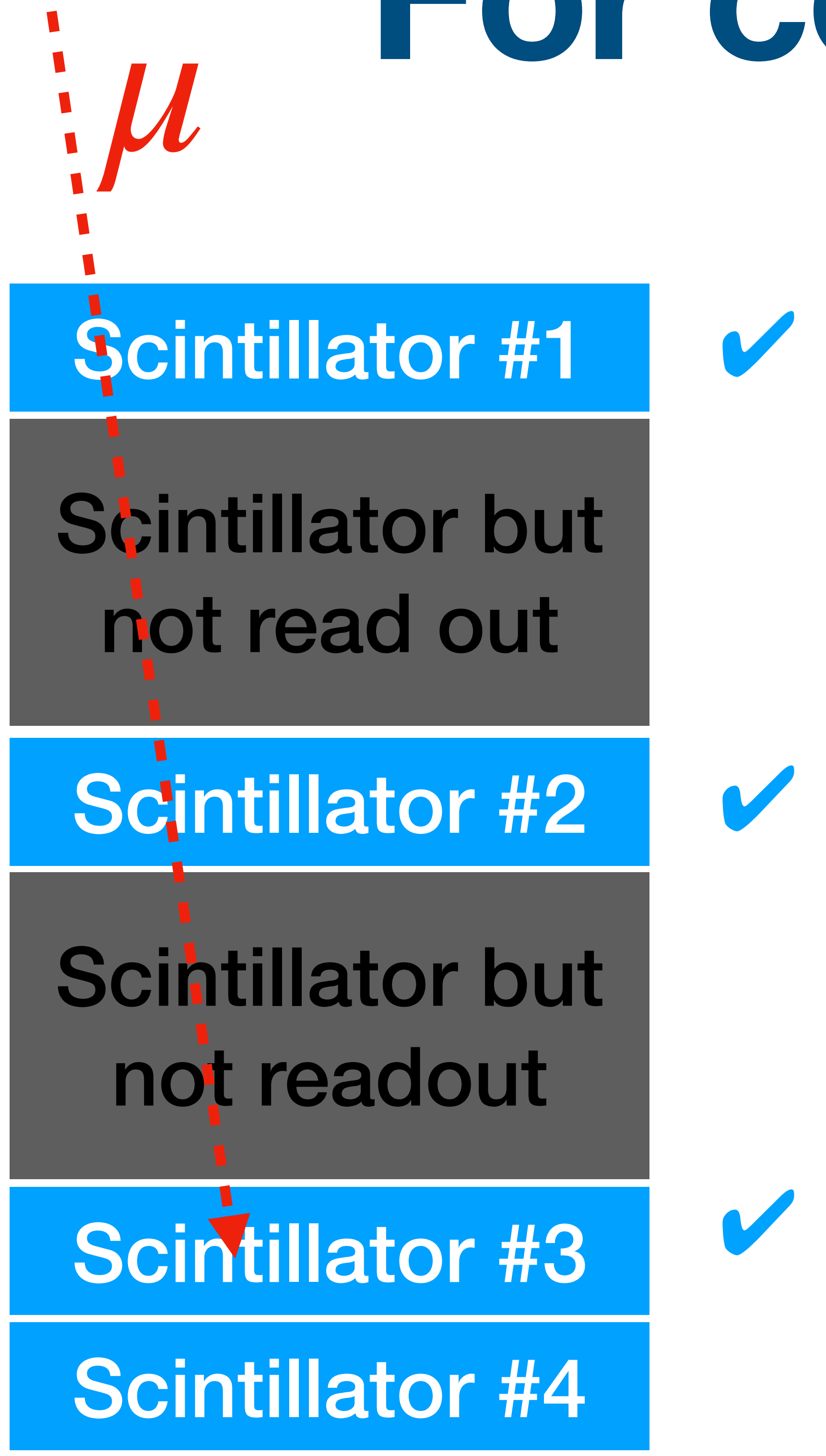
Day #1, July 24th (Mon.)

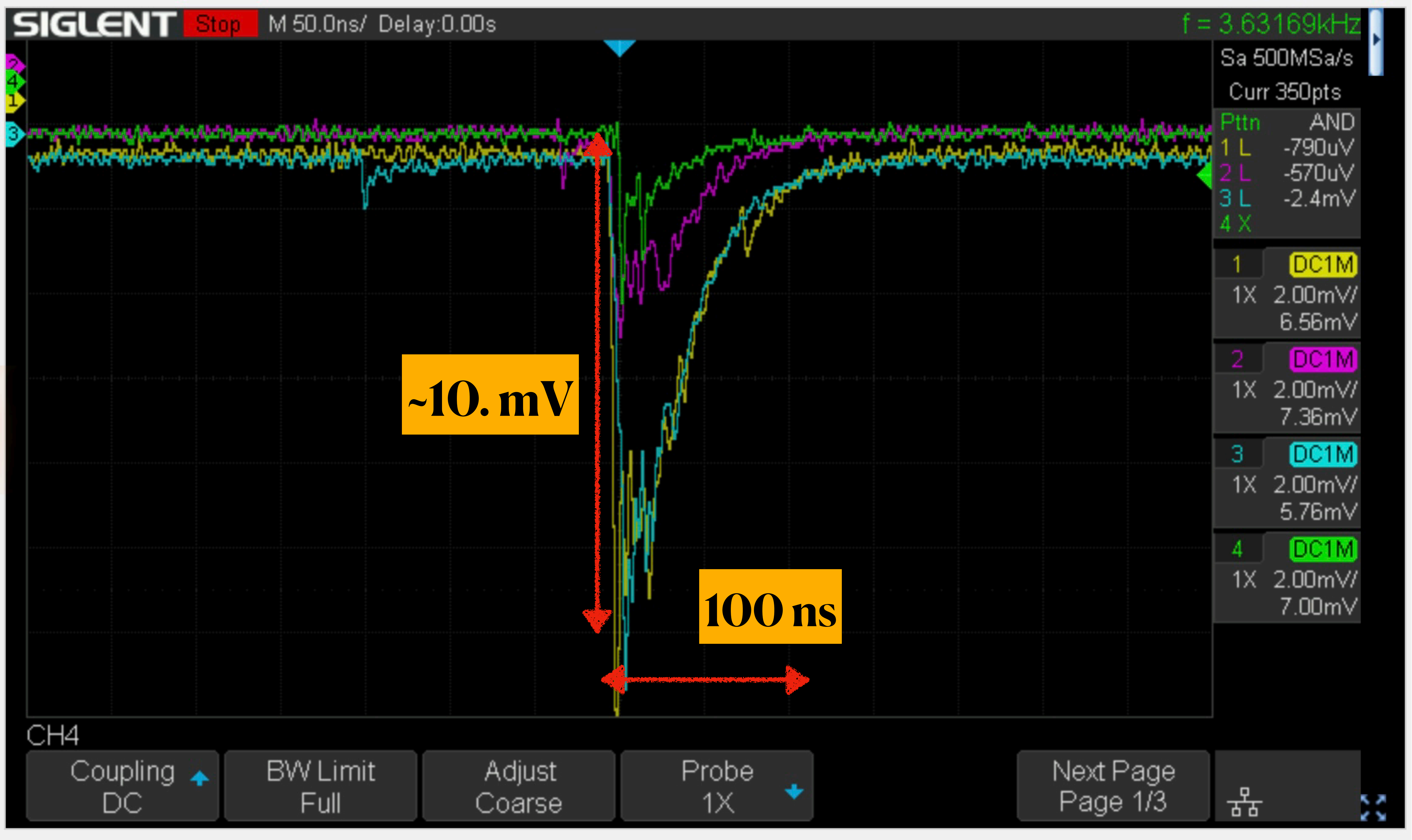
- Familiar with hardwares
- Explore MPPC properties (no scintillator/WLS)
  - Observe single photoelectrons w/ oscilloscope
  - Observe the optical crosstalk
  - (Extra: Charge integration and electric gain calculation)
- Signal observe and measure with oscilloscope
  - Threshold setting
  - Trigger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

Day #2, July 25th (Tue.)

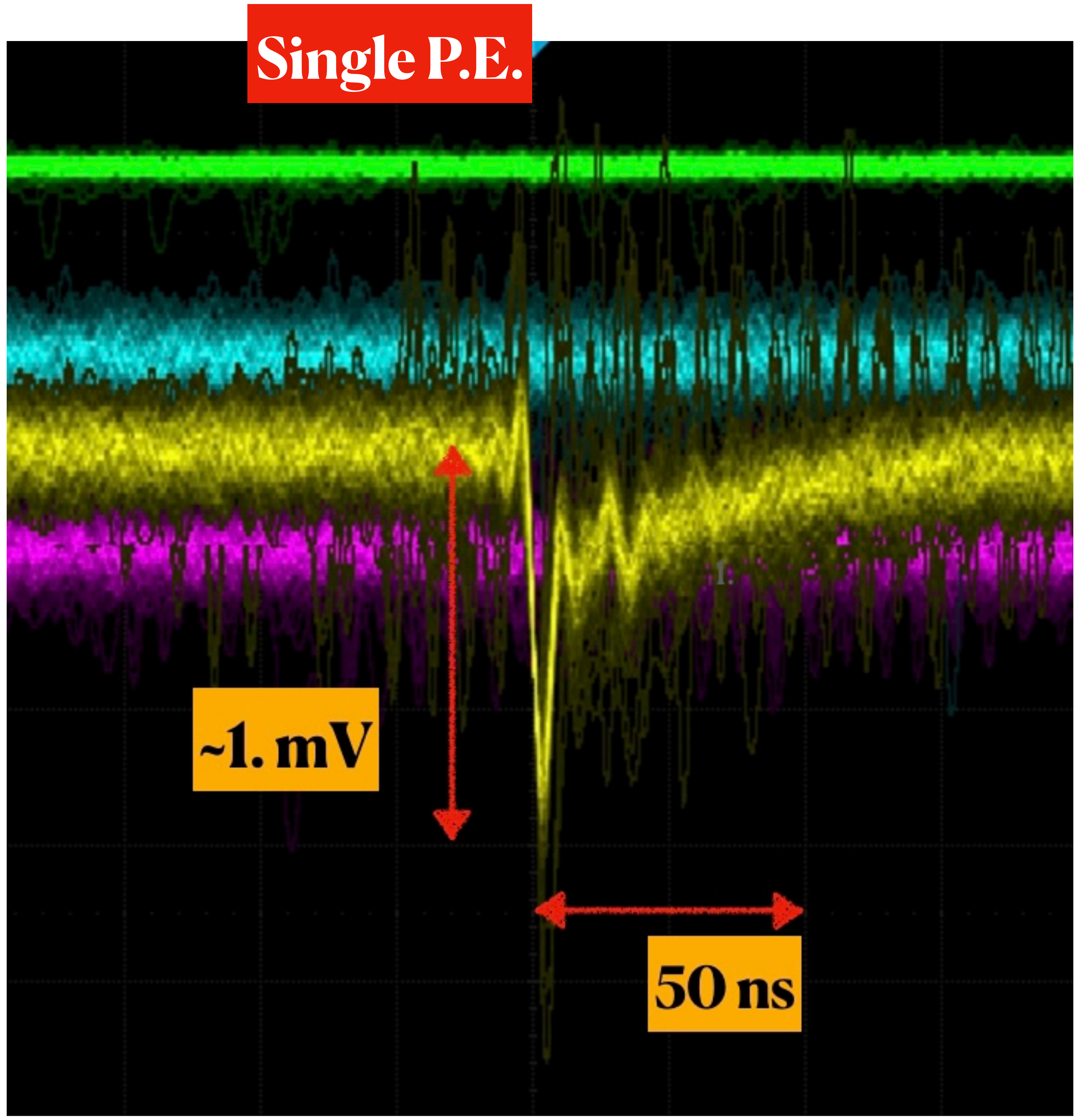
- Setup with scintillator and wavelength shifting fiber
- Observe cosmic ray muons
- Calculate the rate of muon (*how many trigged muon-like events per cm^2 of scintillator per second*)
- Compute the light yield of muons (h*ow many photons captured when a muon pass through 1cm thickness of plastic scintillator*)

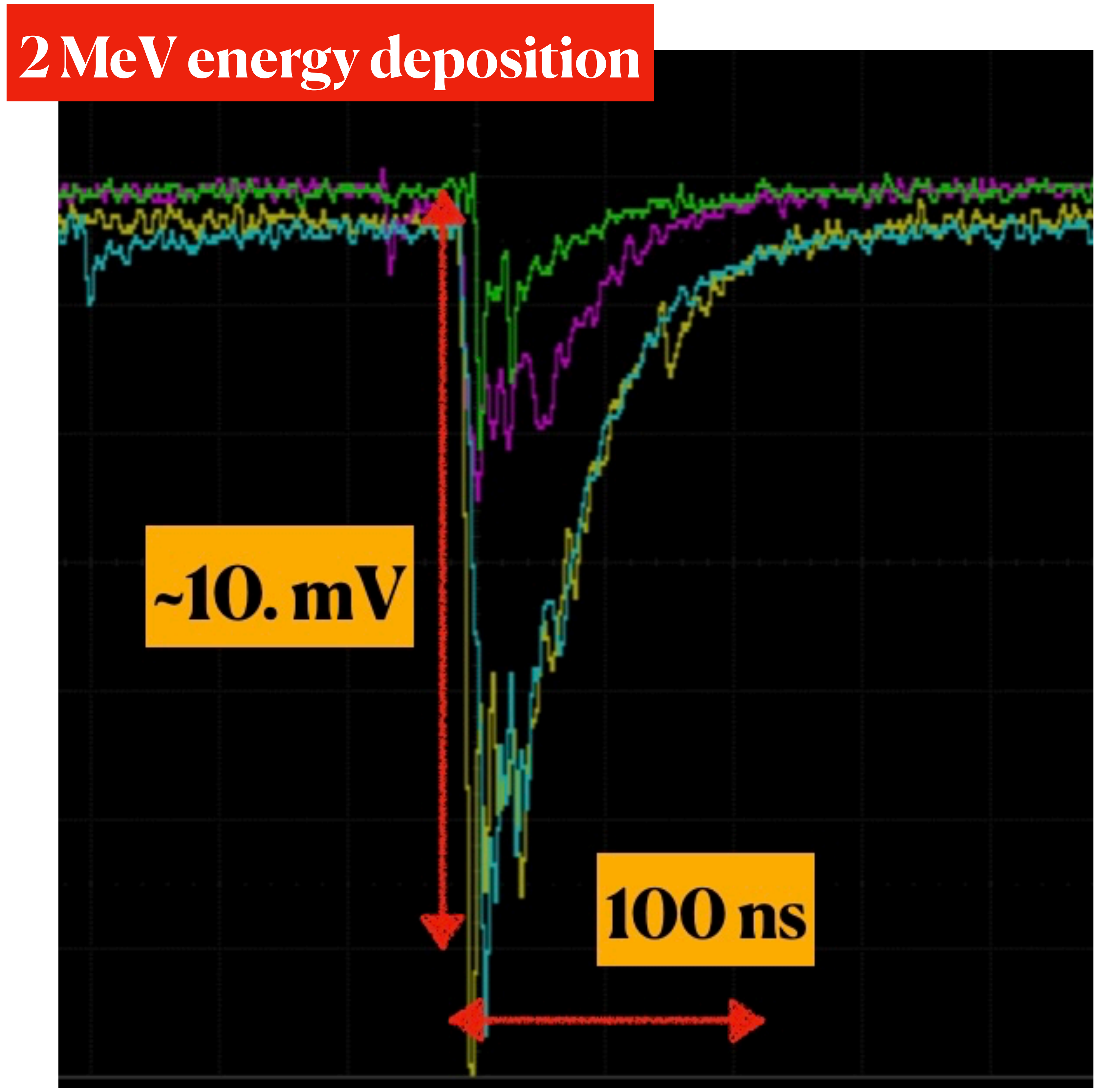
For cosmic ray muon detection





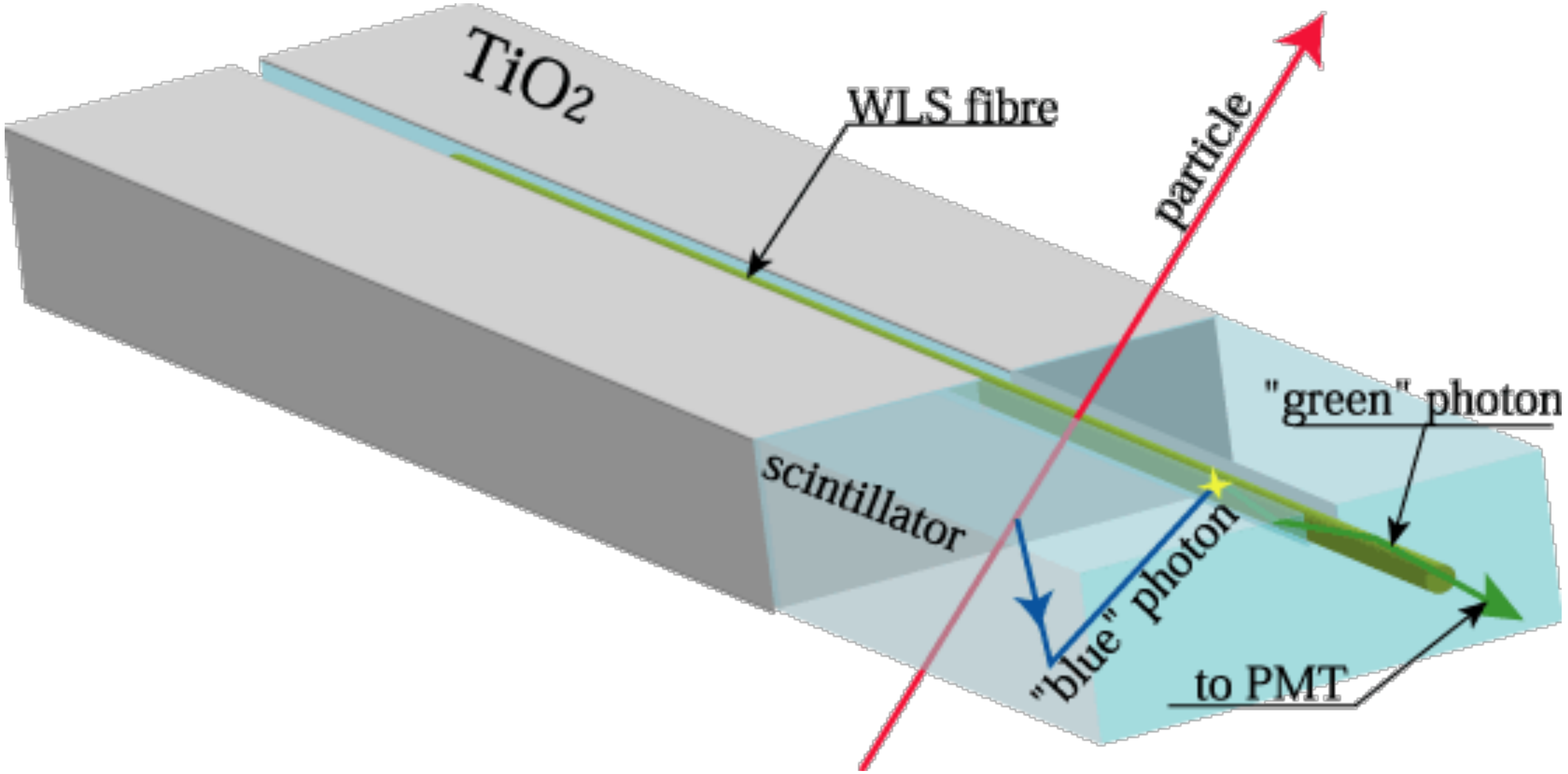
Light yield of scintillator to MIP deposition





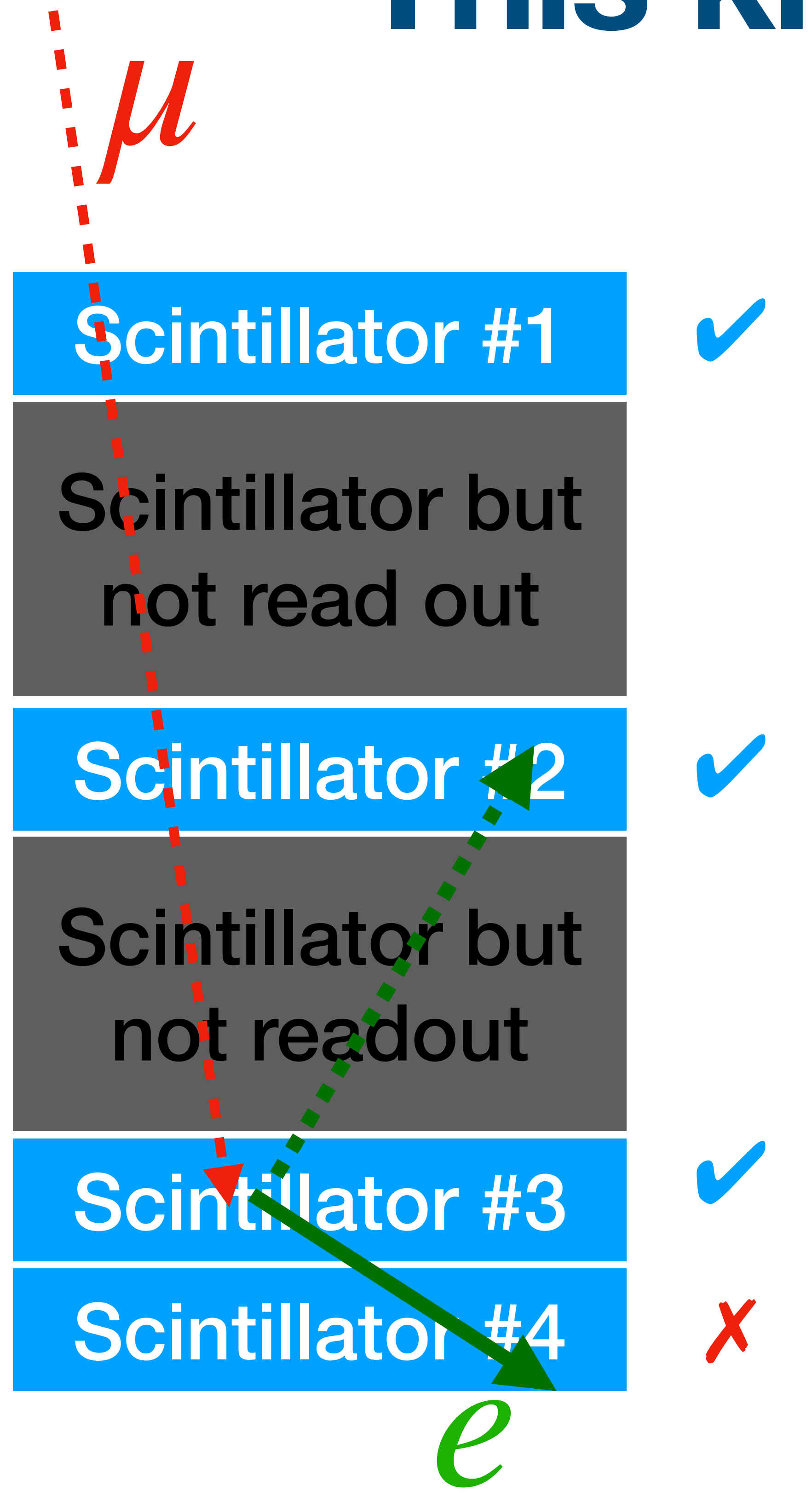
By getting the ratio between these two signals, it allows to get the light yield of scintillator to MIP deposition , which is a basics for particle energy measurement.

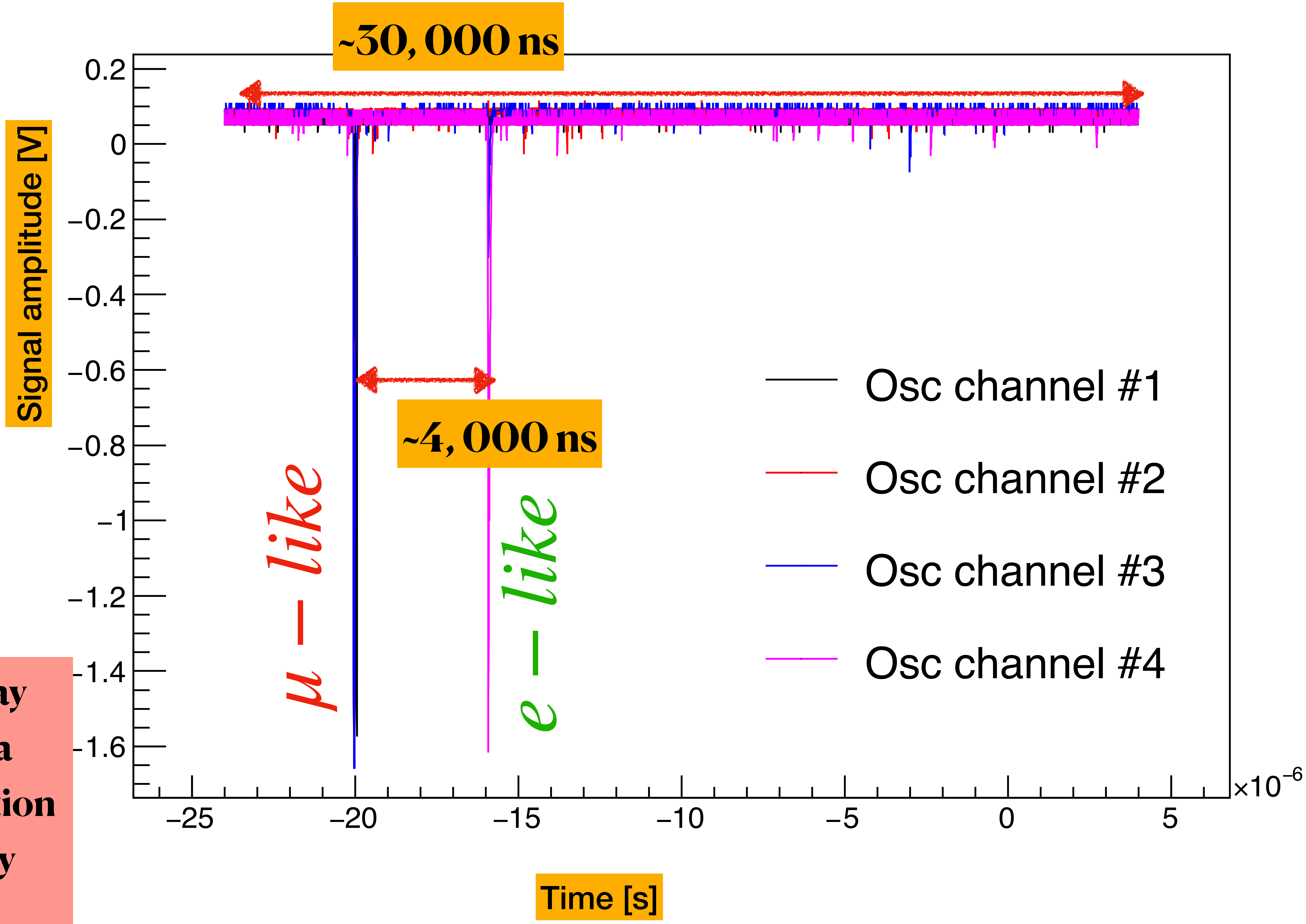
To keep in mind: converting photons to energy depostion is a short cut



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

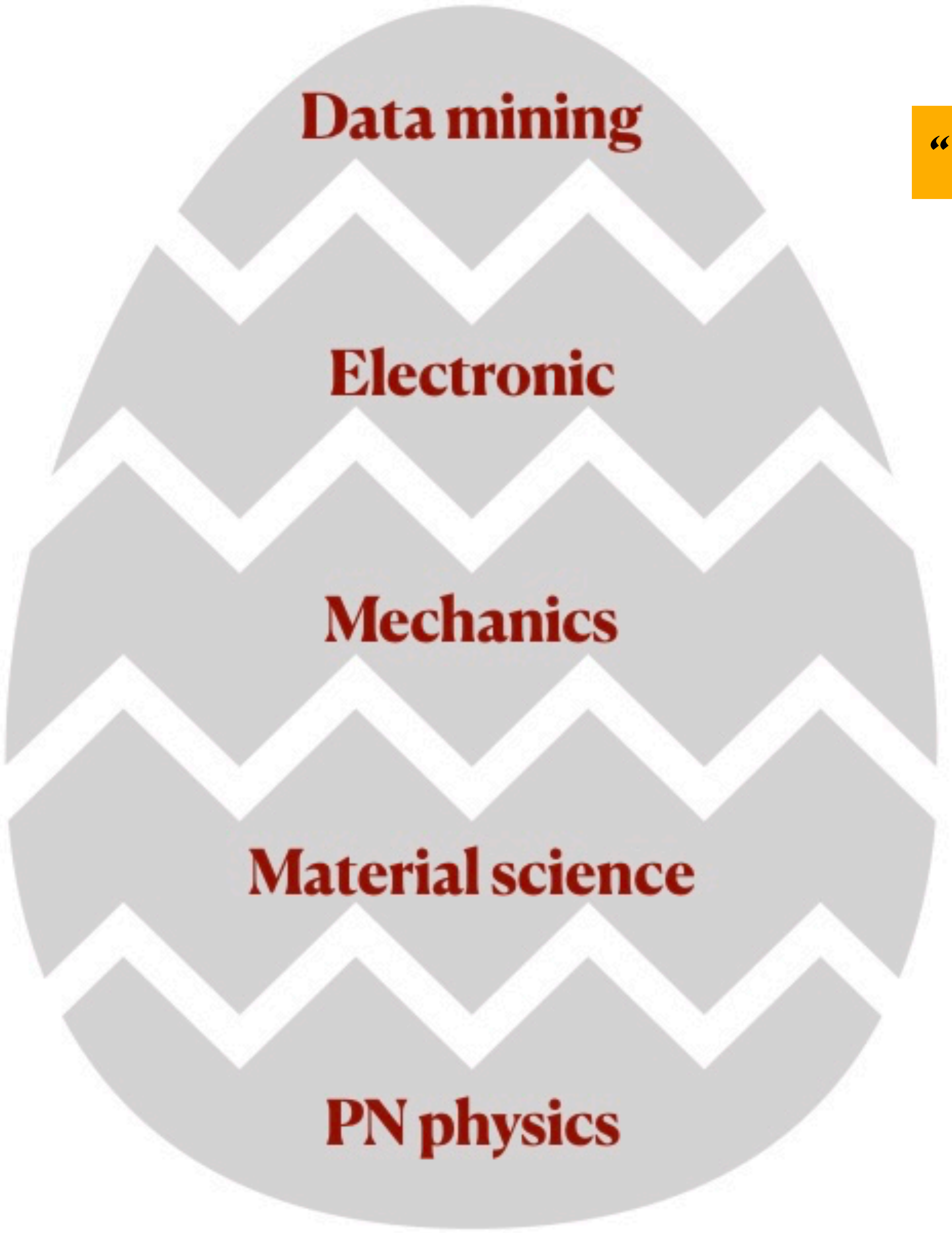
Safety note for handling the equipments

- 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_1, ν_e)
- Dr. Ngoc Tran (for group ν_2, ν_μ)
- M.Sc. Sang Truong (for group ν_3, ν_τ)
- 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

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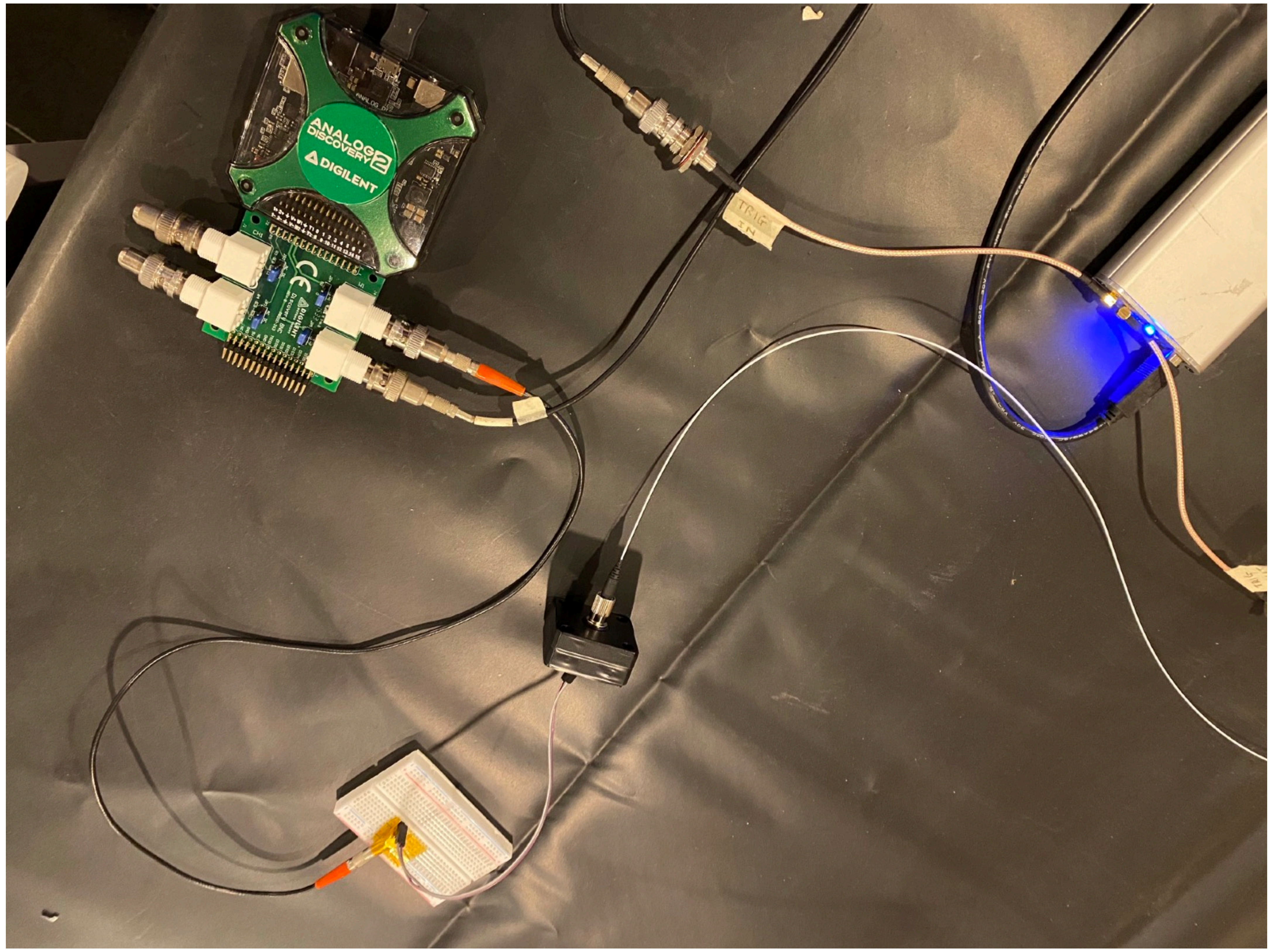
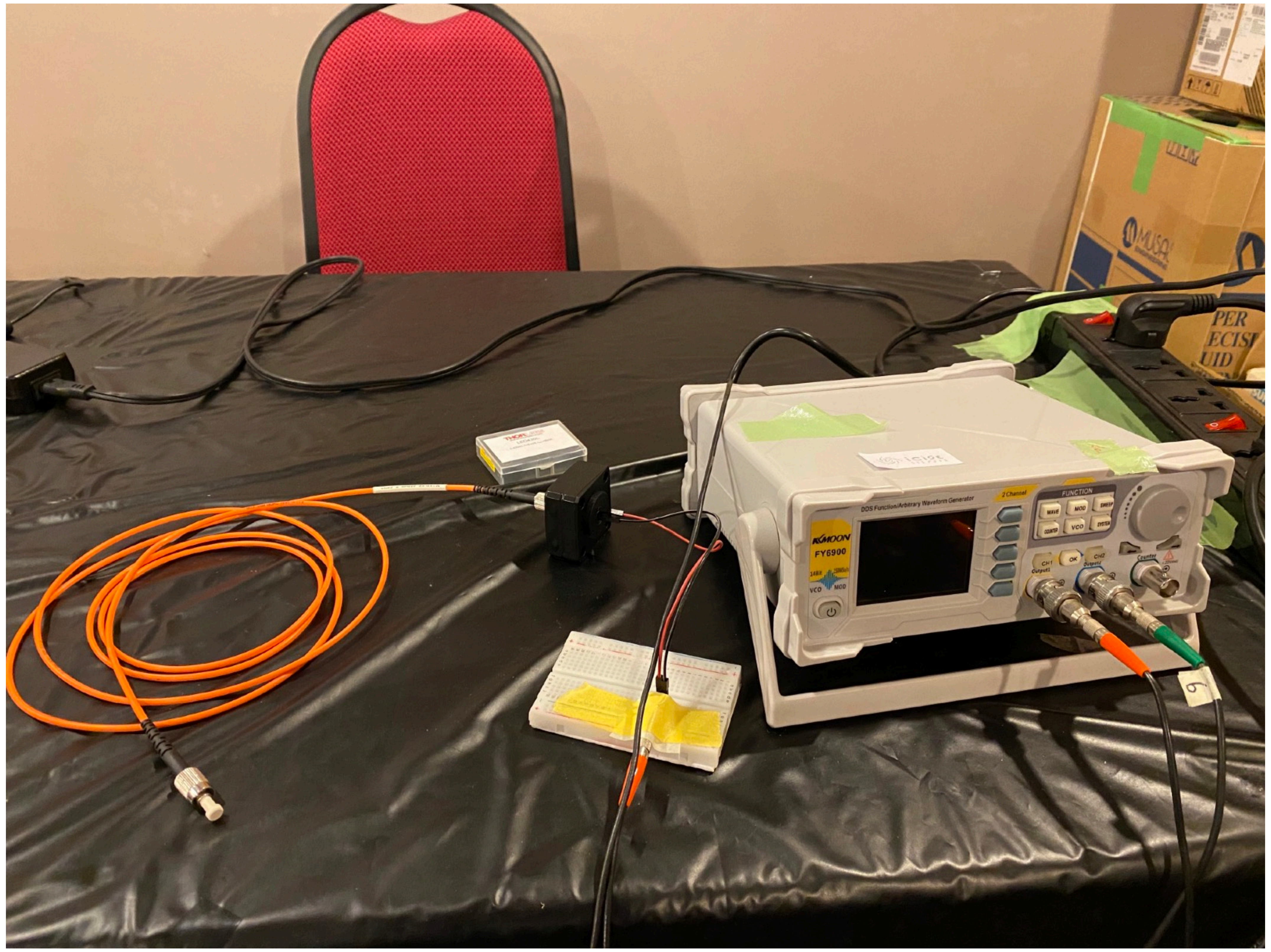
Without their generosity, this hardware training is impossible.

Additional tools: Light manipulation to mimic the signal but we may have no time for it





Can reach ~few 10ns optical pulse and level of few photons