Hardware orientation & Training

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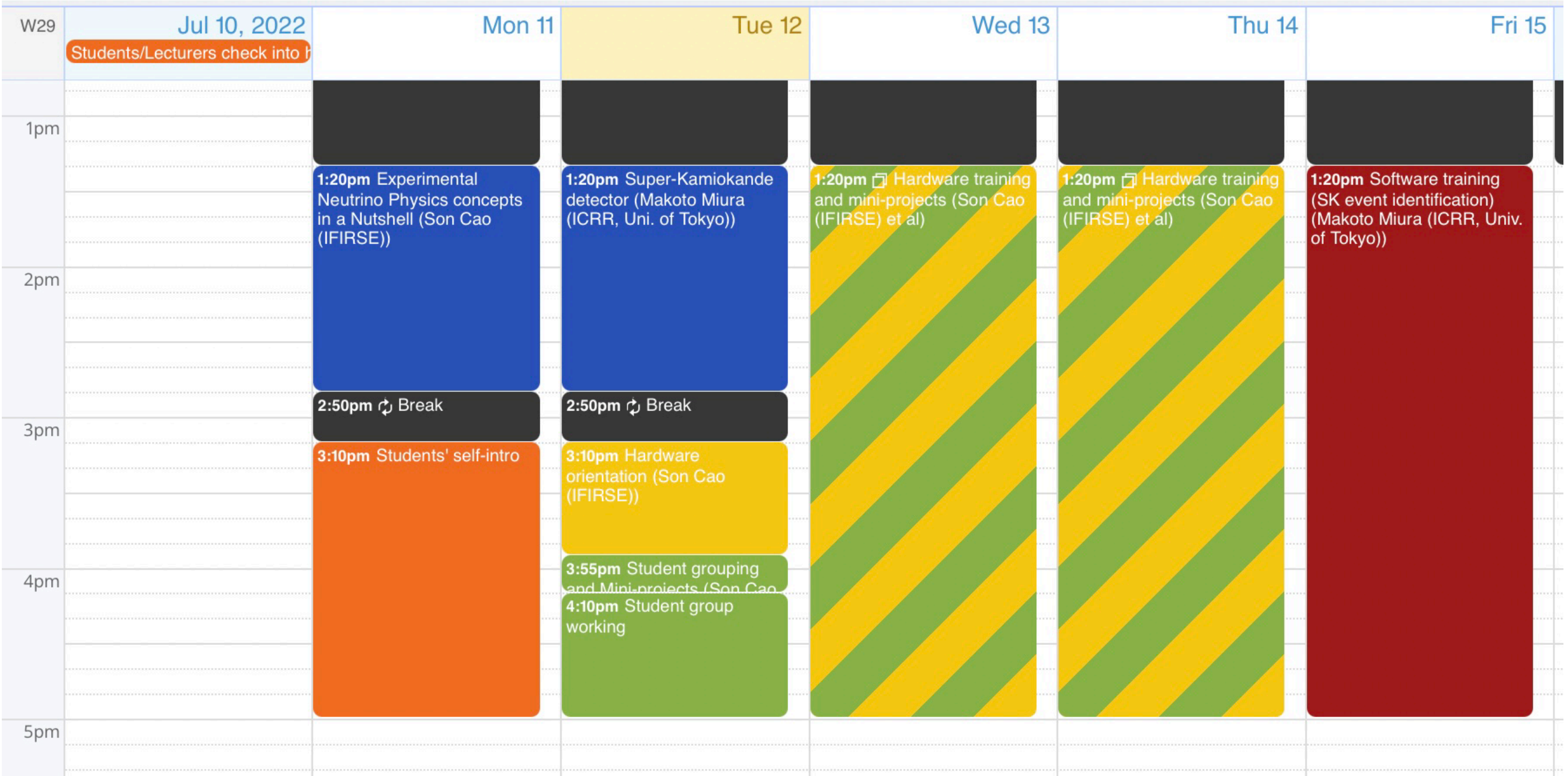
6th Vietnam School on Neutrinos, July 12, 2022

Time allocated for Hardware training



- 45 mins. for hardware orientation
- 4.0 hours x 2 (sec., Wed. And Thu.) for hand-on experience in total
  - But the lab is small and we are lack of human power to have all four groups trained at the same time.
  - Each time, we manage to have 2 groups → 2 hours x 2 (sec.) for each person

Student grouping & protocol for hardware training

Same grouping scheme as software training

- Detail of student grouping will be discussed in next section
- Students are divided into 4 groups: Group-A, Group-B, Group-C, and Group-D
- We prepare two independent setups. *They are not identical but the concept is similar*
- Training protocol (for Wed. and Thu. Afternoon section)
  1. Group A + B go for hardware training (13:20 - 15:00) while Group C+D work on mini-projects
  2. 20 minus break (15:00-15:20)
  3. Group C+D go for hardware training (15:20 - 17:00) while Group A+B work on mini-projects


Study place
for mini-project
Hardware training

Goals of hardware training

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

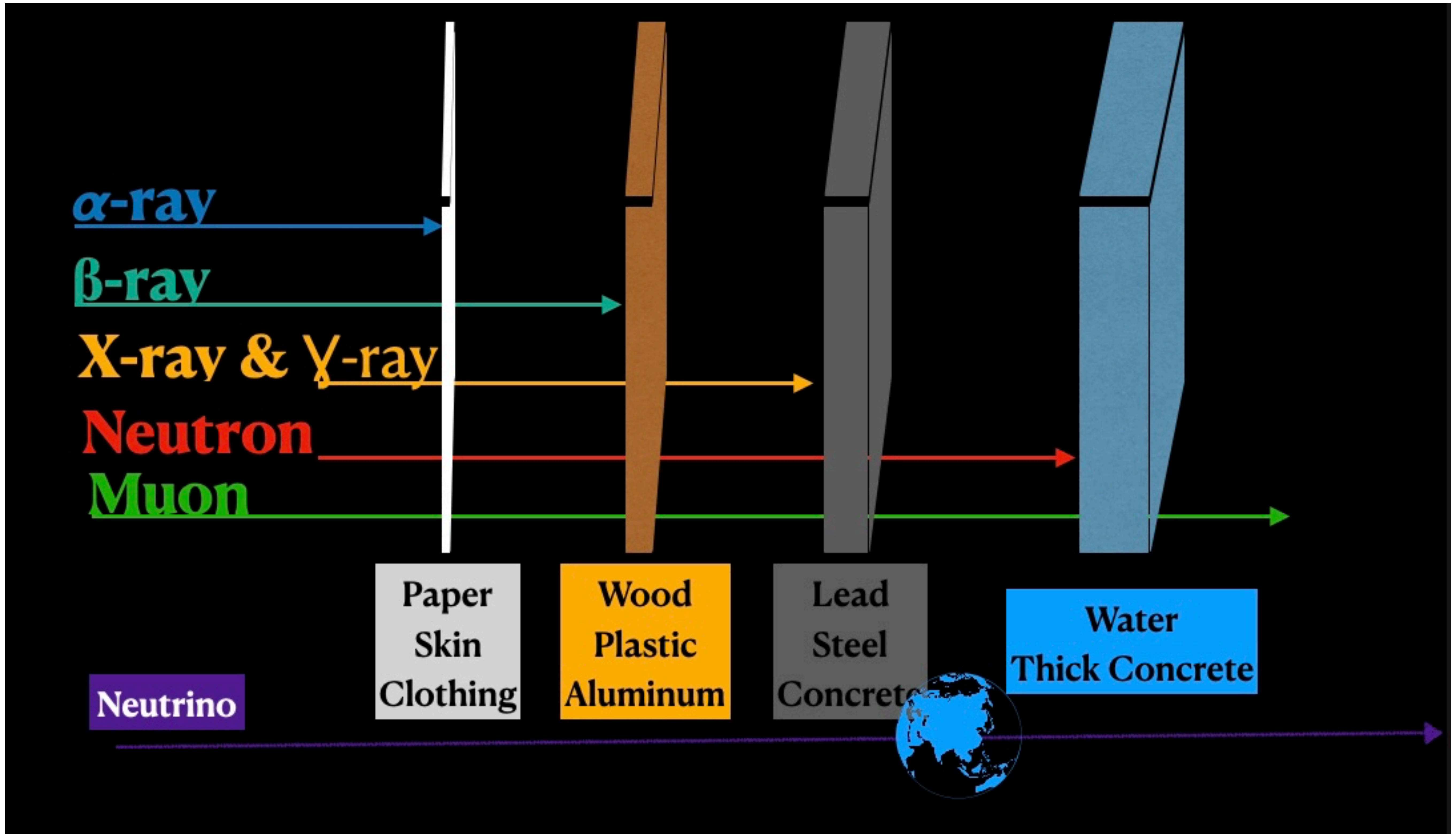
Vietnamese students lack skills with hardware, especially in particle and nuclear physics

- 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?
- ….

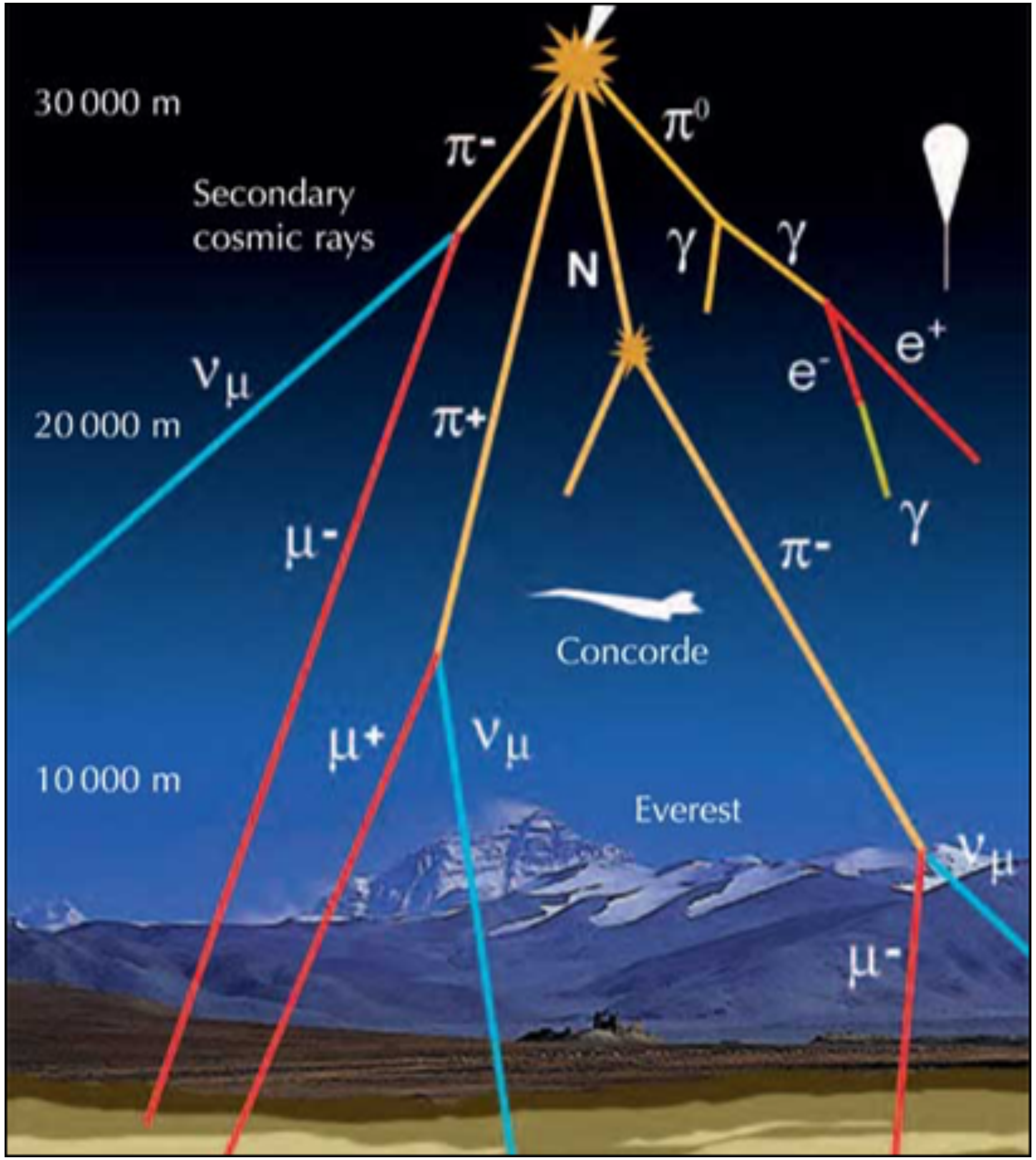
Goals of hardware training

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*)**



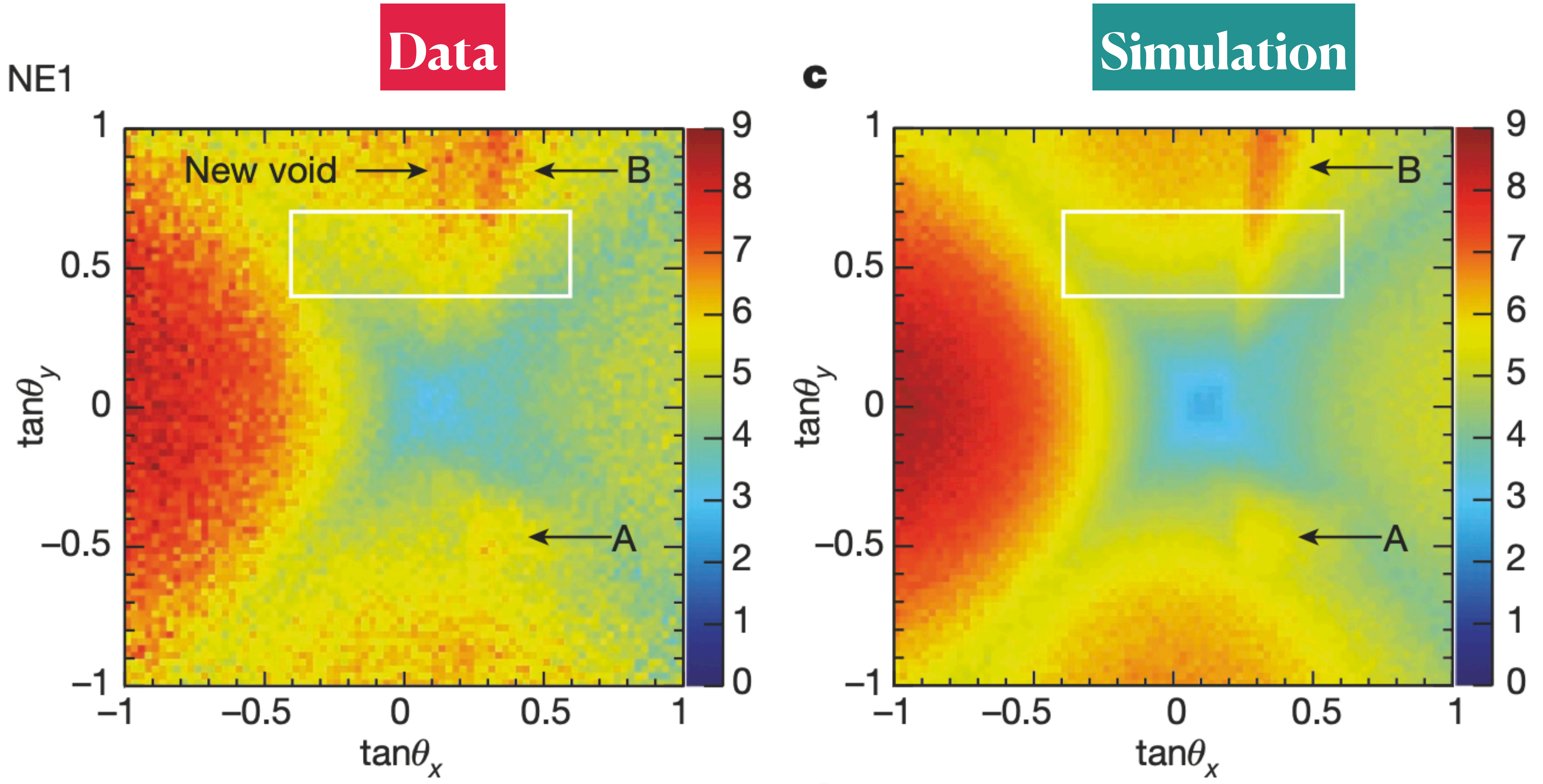
High energy astrophysical particles (eg. hydrogen & helium from the Sun) interact with the Earth's atmosphere
→produce vast amount of muons
~ 1 muon/cm²/s



Muon can be used for a practical application

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

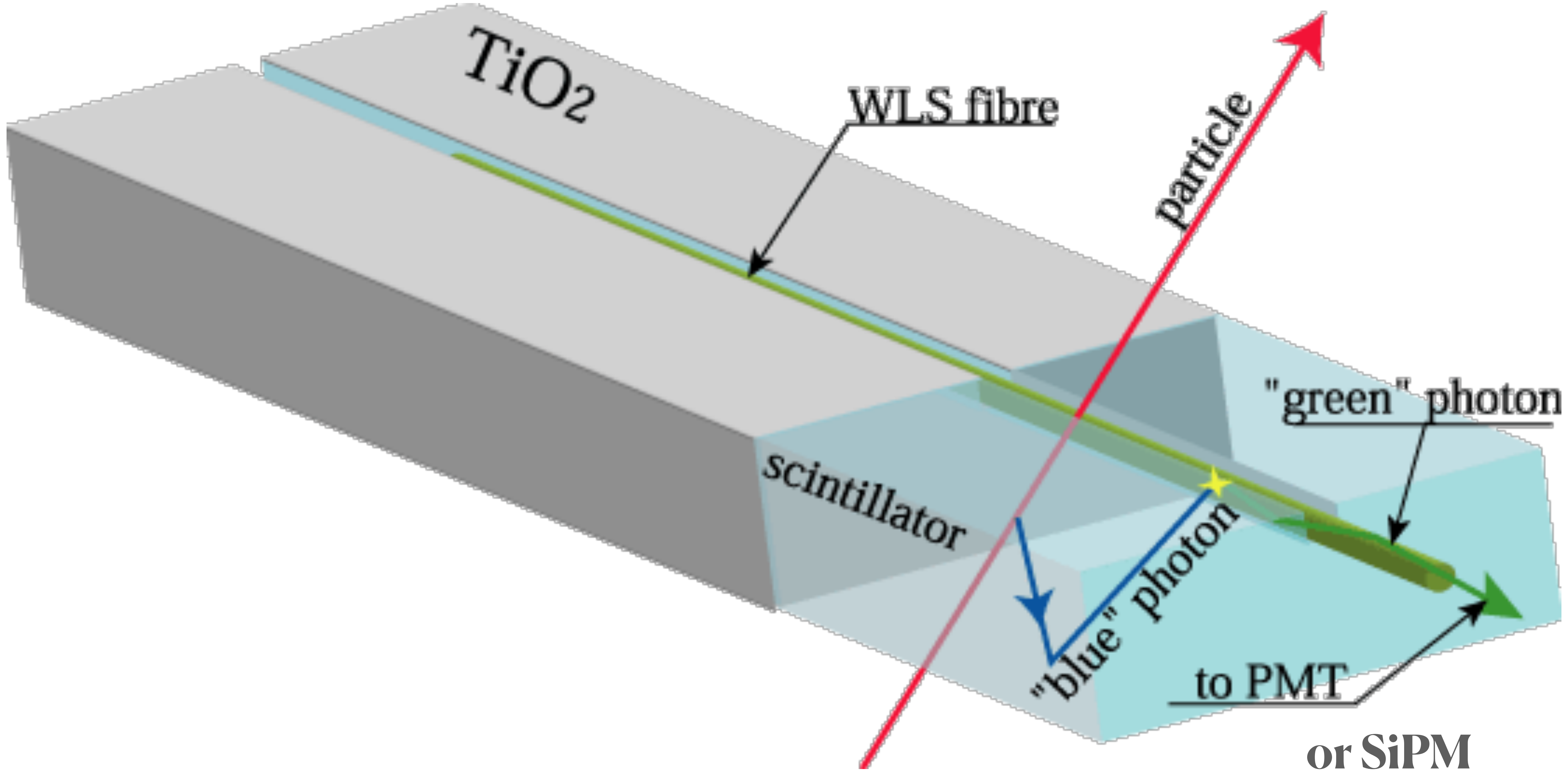
called: muon radiography technique



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

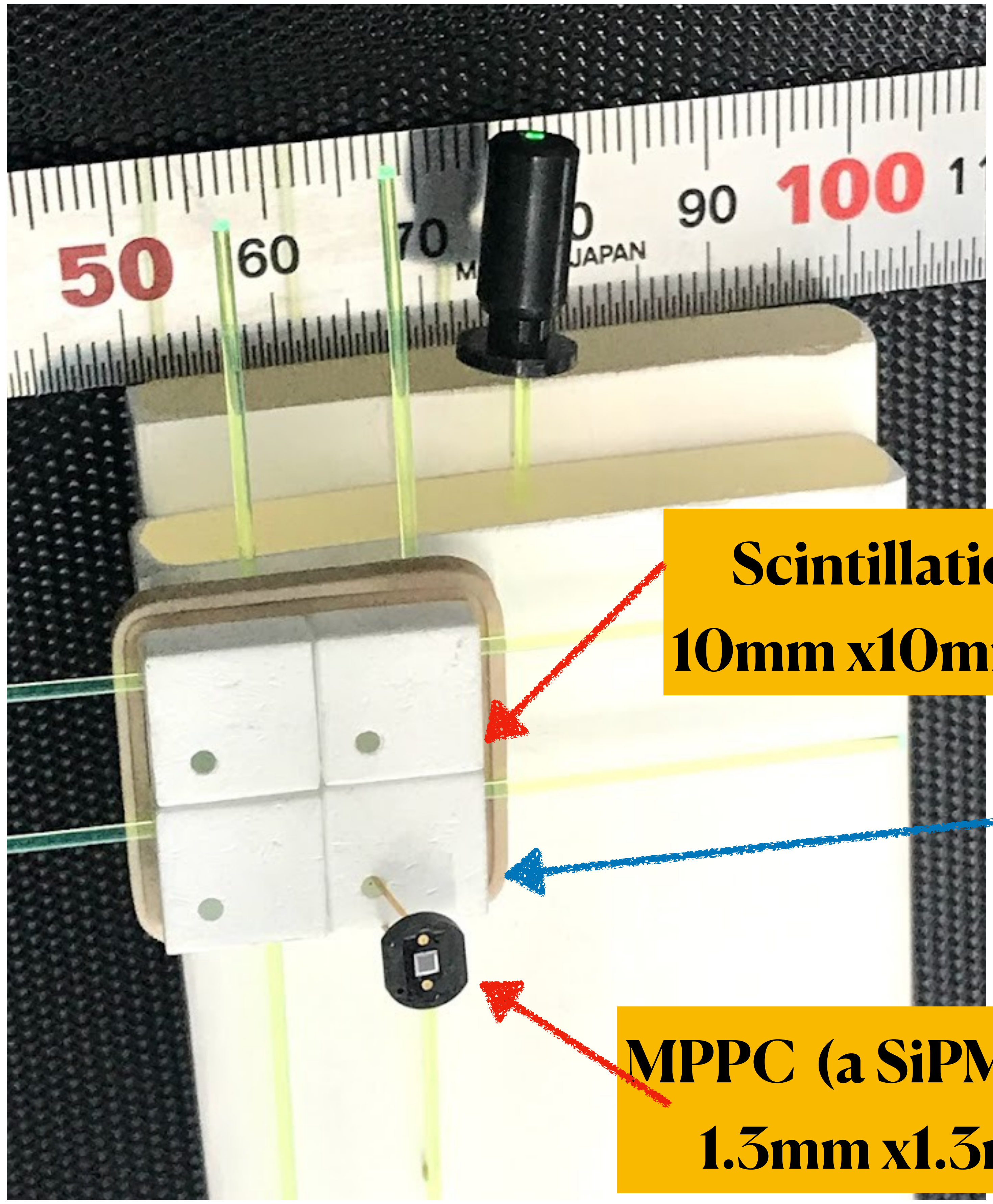
How can we see muons and measure their characteristics with *what we have in the lab?*

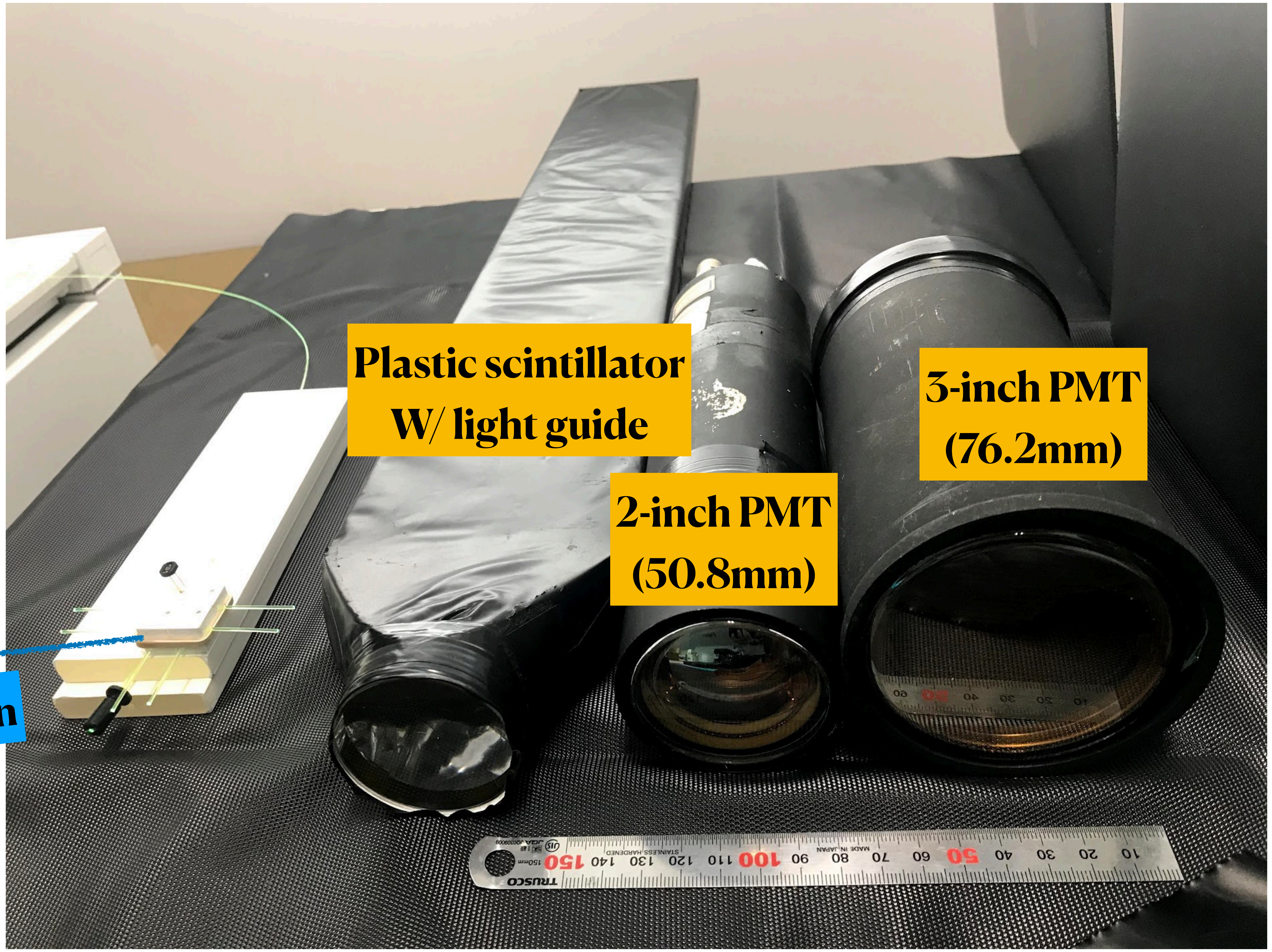
Tracking the charged particle w/ scintillator



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

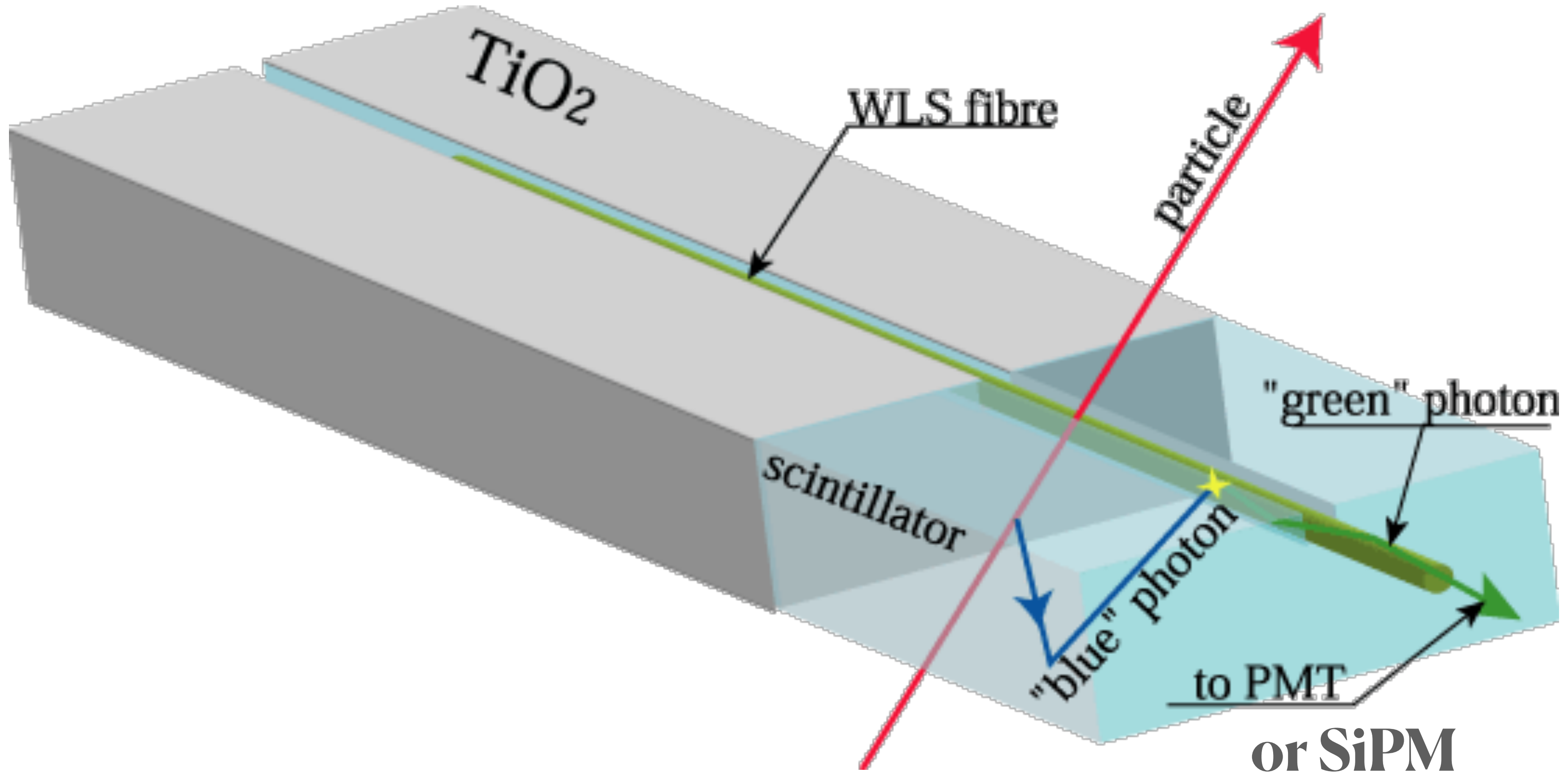




When passing through the scintillator, charged particles (μ, π, e,...) deposits energy and excite the scintillation photons, which are collected and guided to the photosensor for converting to the electrical signals (more convenient to manipulate) for data recording.

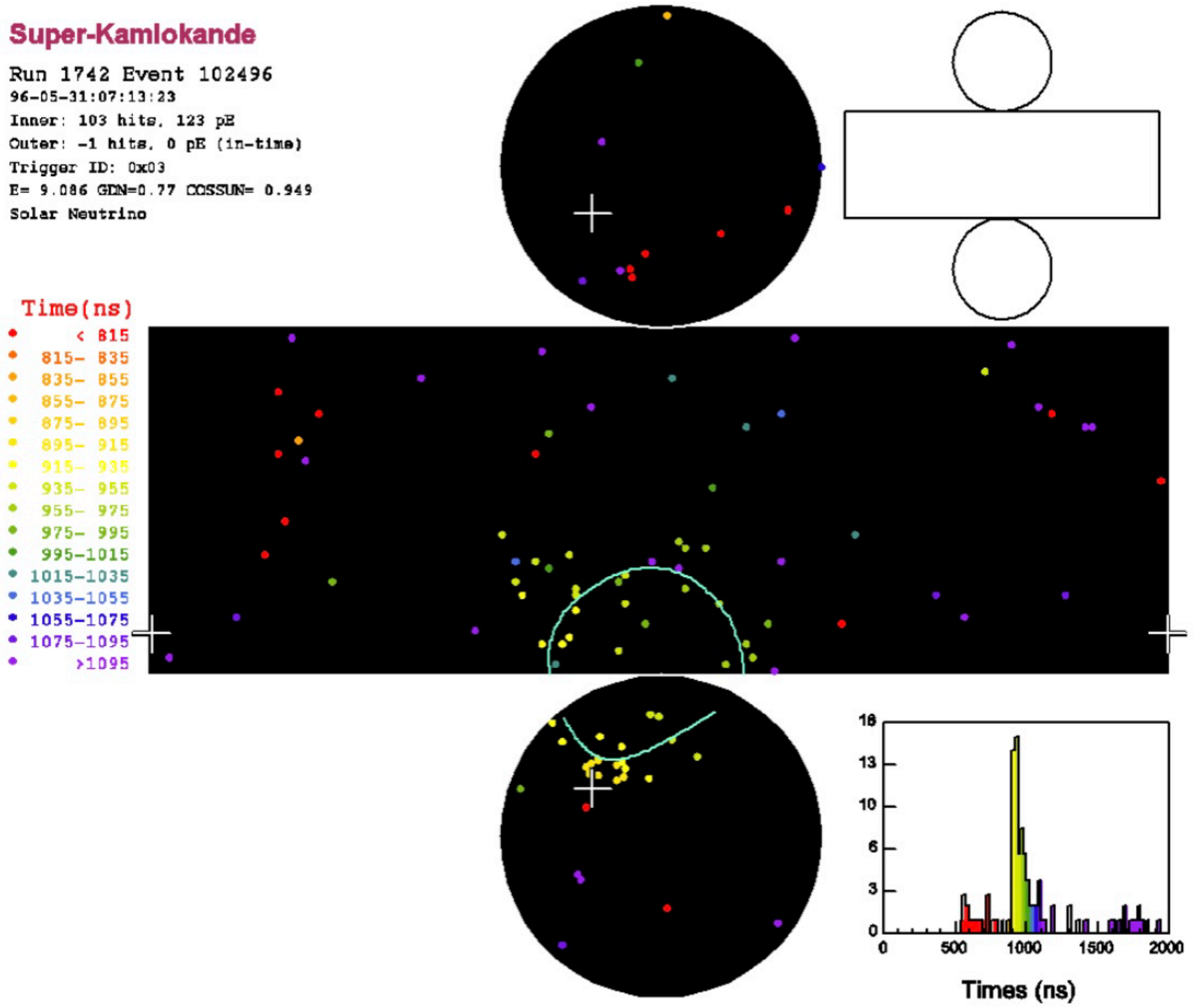
Tracking the charged particle w/ scintillator

- Muon deposits ~ 2MeV per 1cm path in the plastic scintillator
- 2MeV 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

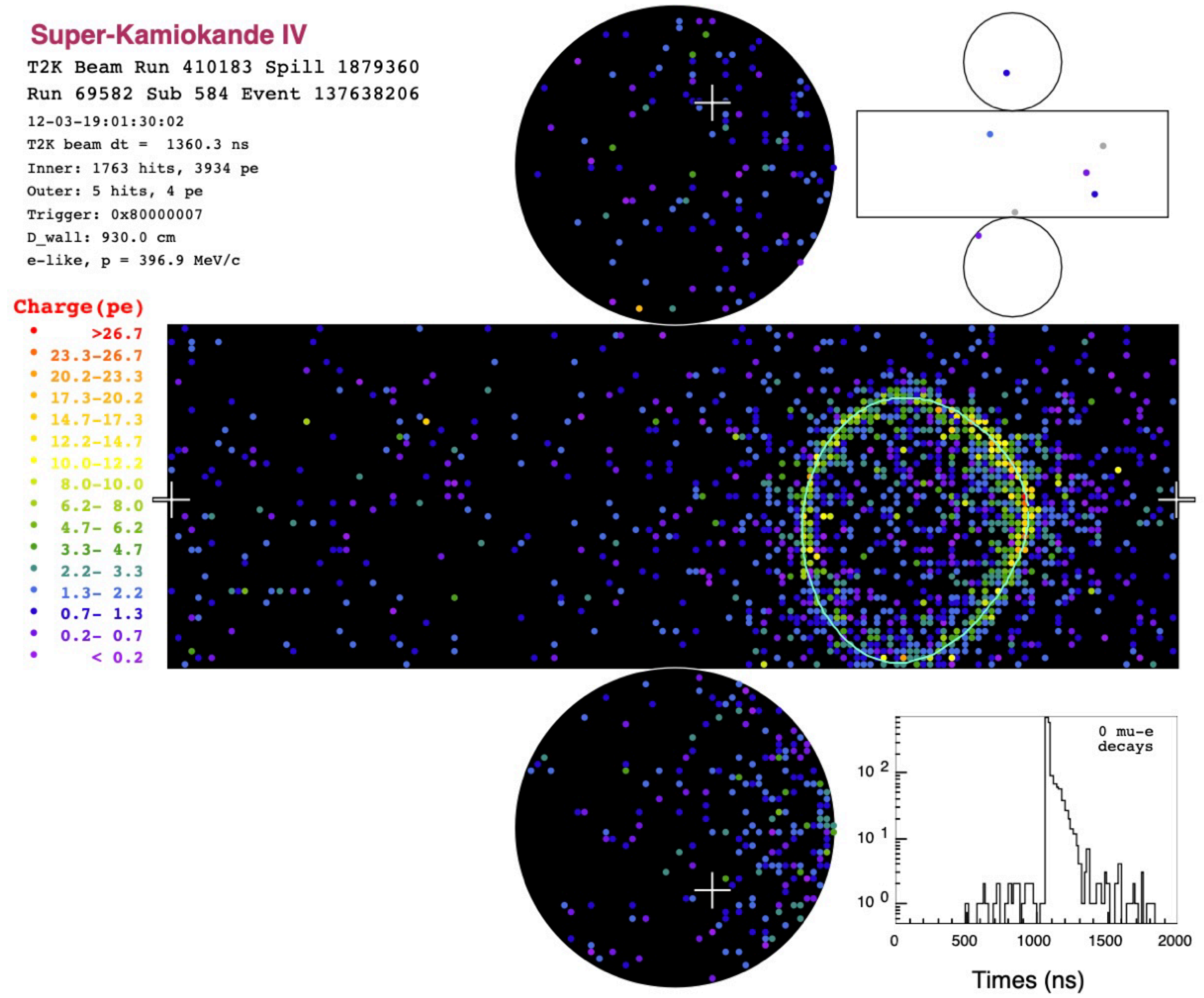


Trace of neutrinos: (typically) very faint flash of light

"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

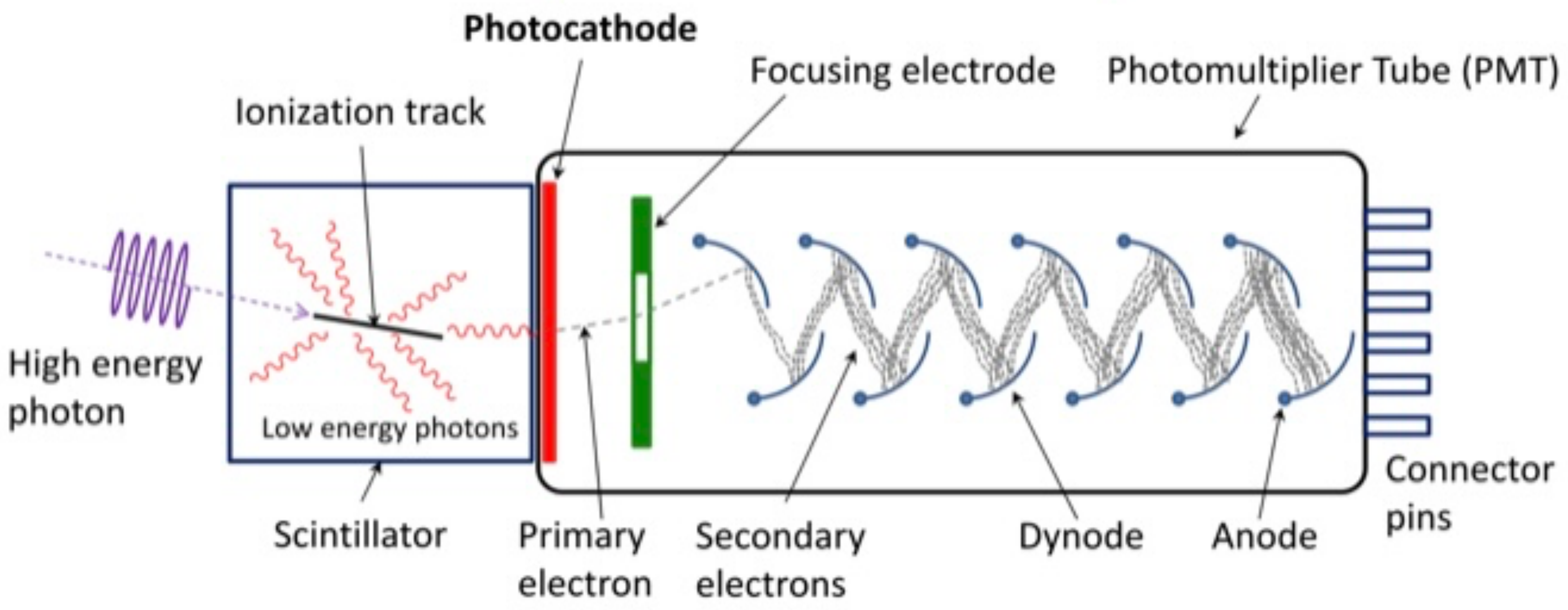
↓

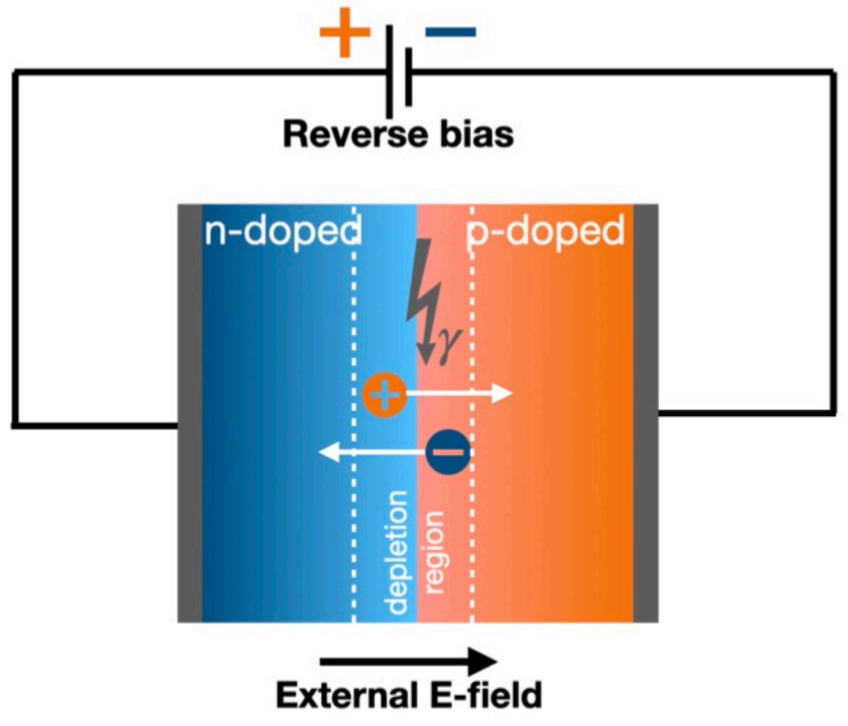
We need a very good "Eyes"

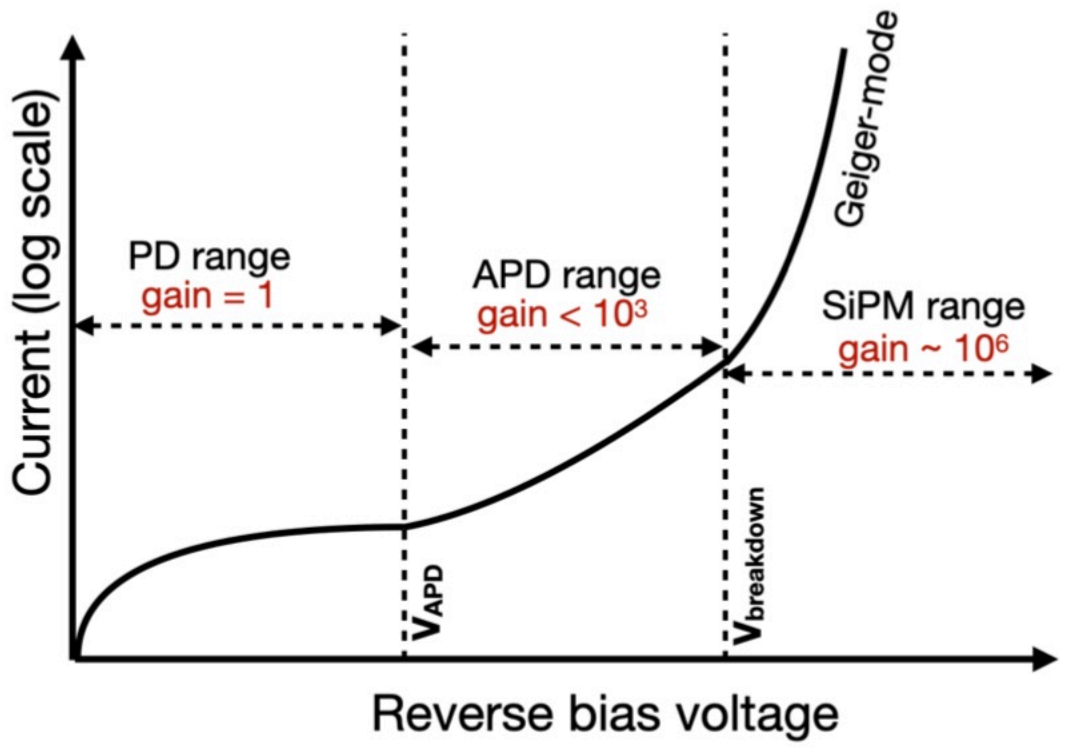
Photosensors: Extremely important to extend particle frontiers (precision, sensitivity, intensity…)

https://hub.hamamatsu.com/us/en/technical-note/WITS-guide-detector-selection/index.html

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



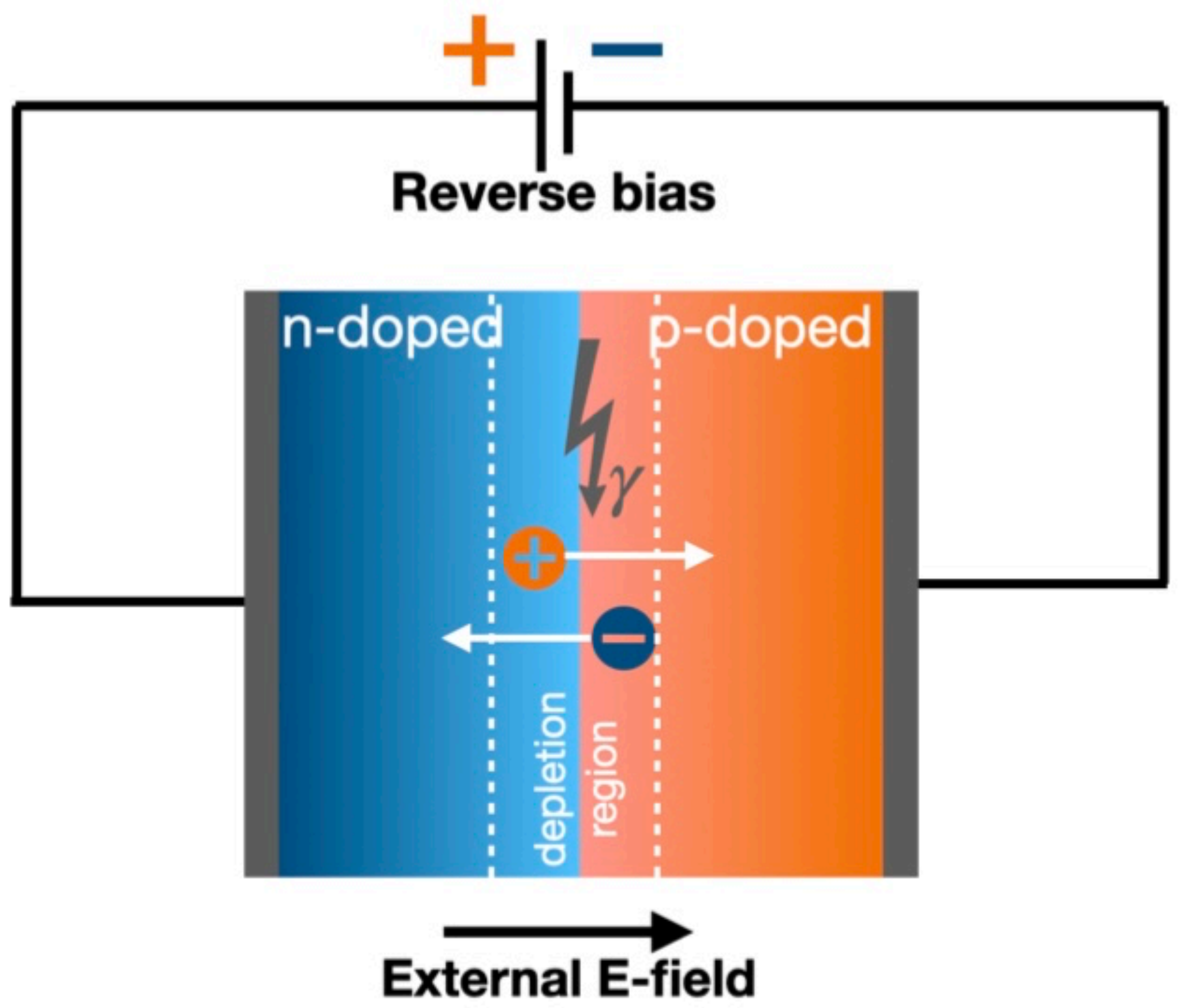


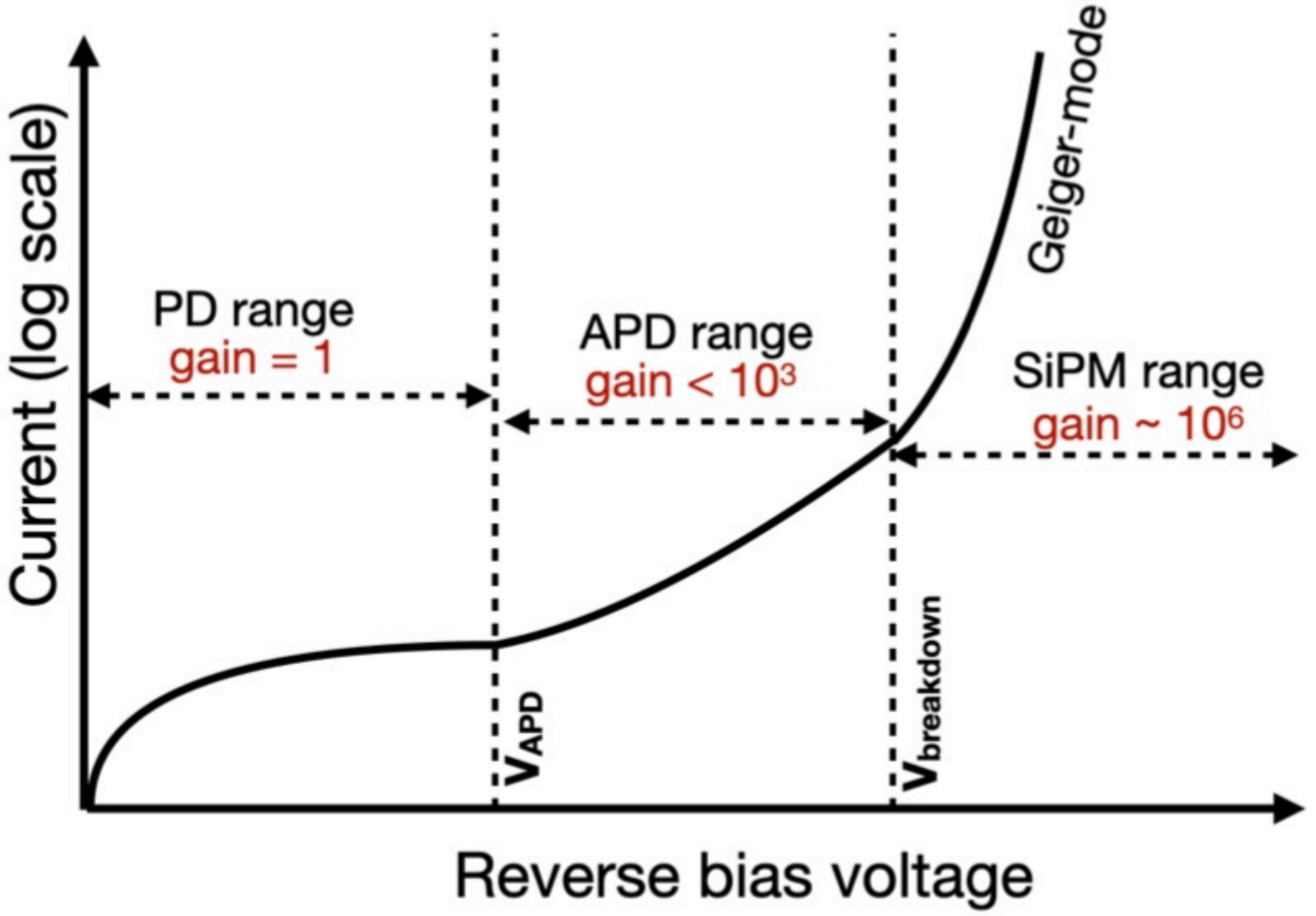


“The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes”

Marcel Proust

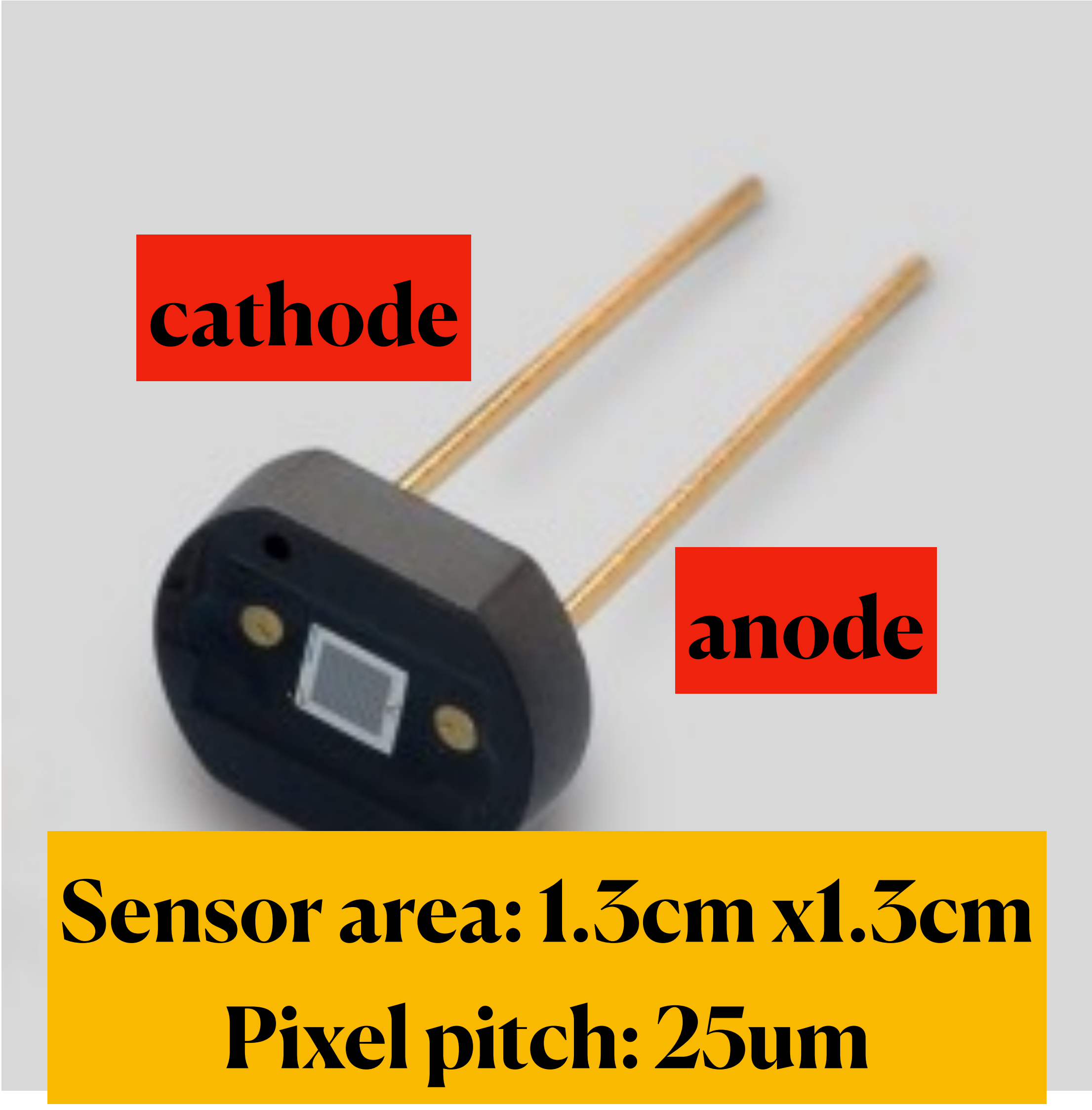
Photon detection principle w/ Silicon photomultiplier (SiPM)



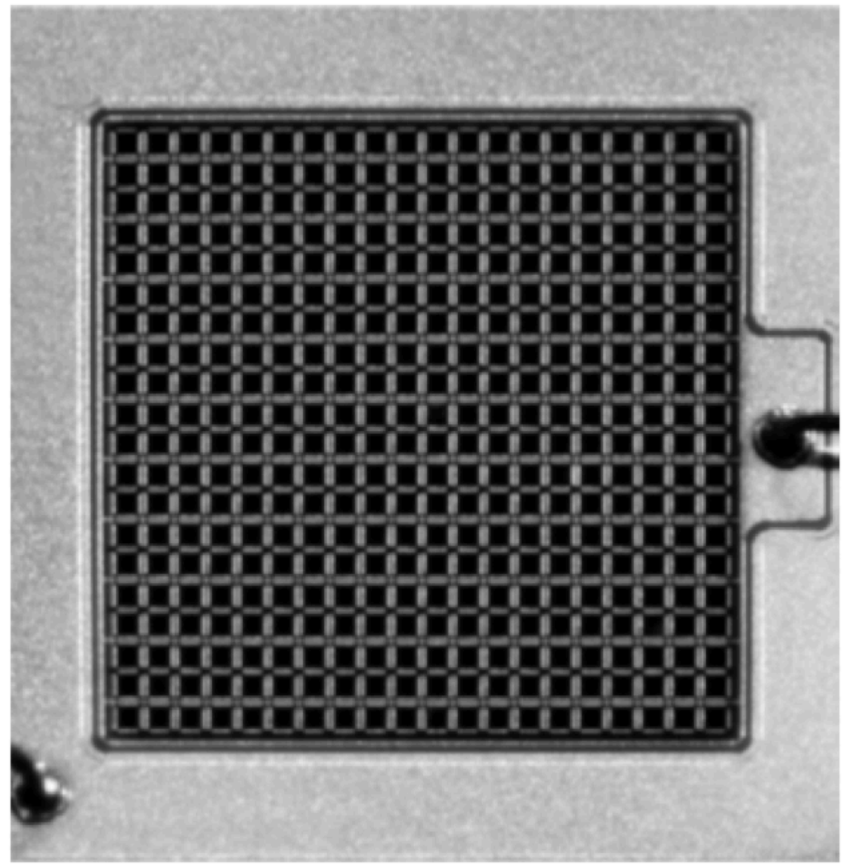


- Based on photoelectric effect: photon strikes and produce a pair of electron/hole
- Various types, selection depending on the measurement
- "Breakdown" here mean both hole and electron play roles in avalanche process

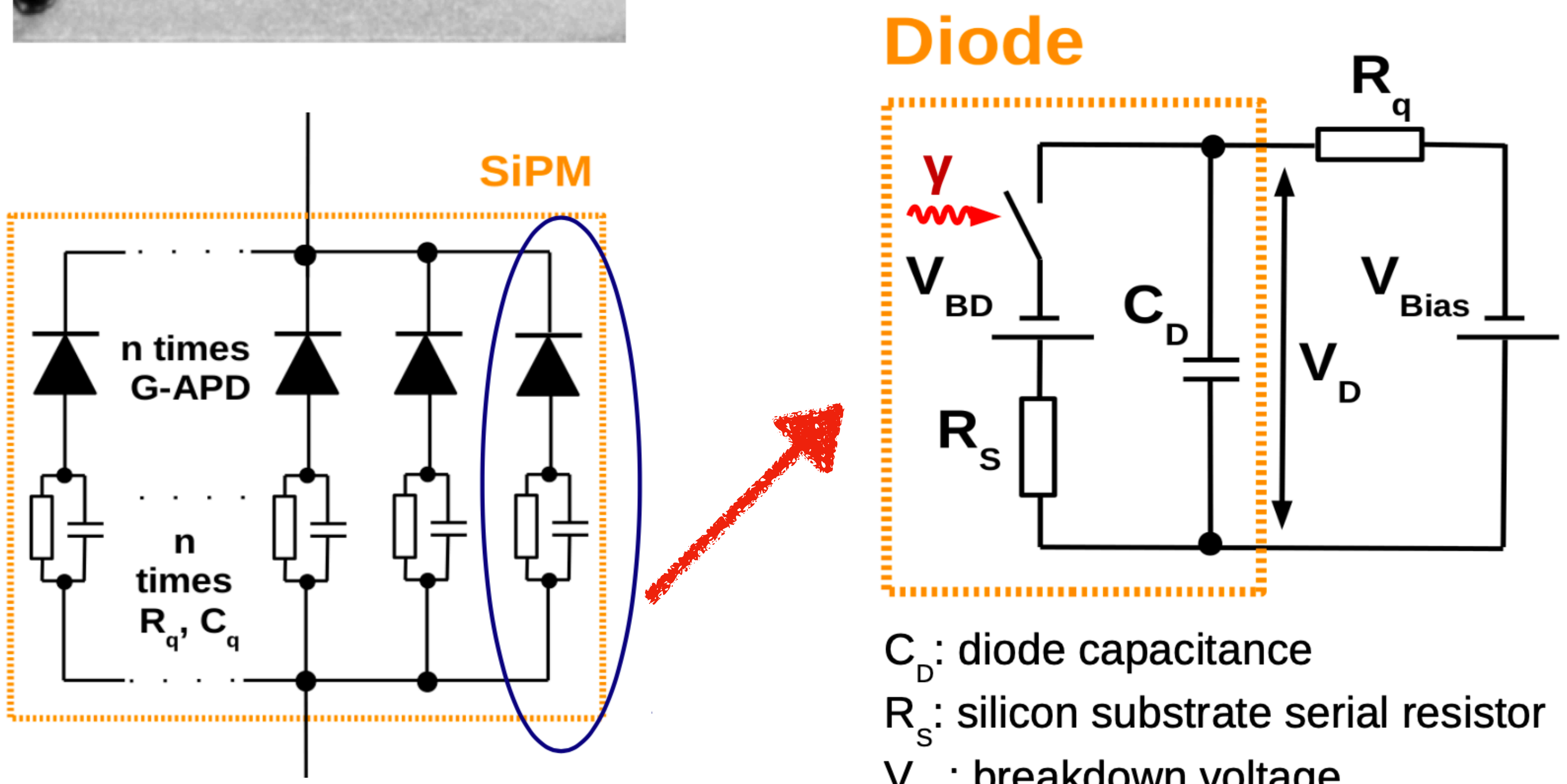
MPPC: a type of SiPM, developed by Hamamatsu



Hamamatsu S13360-1325CS

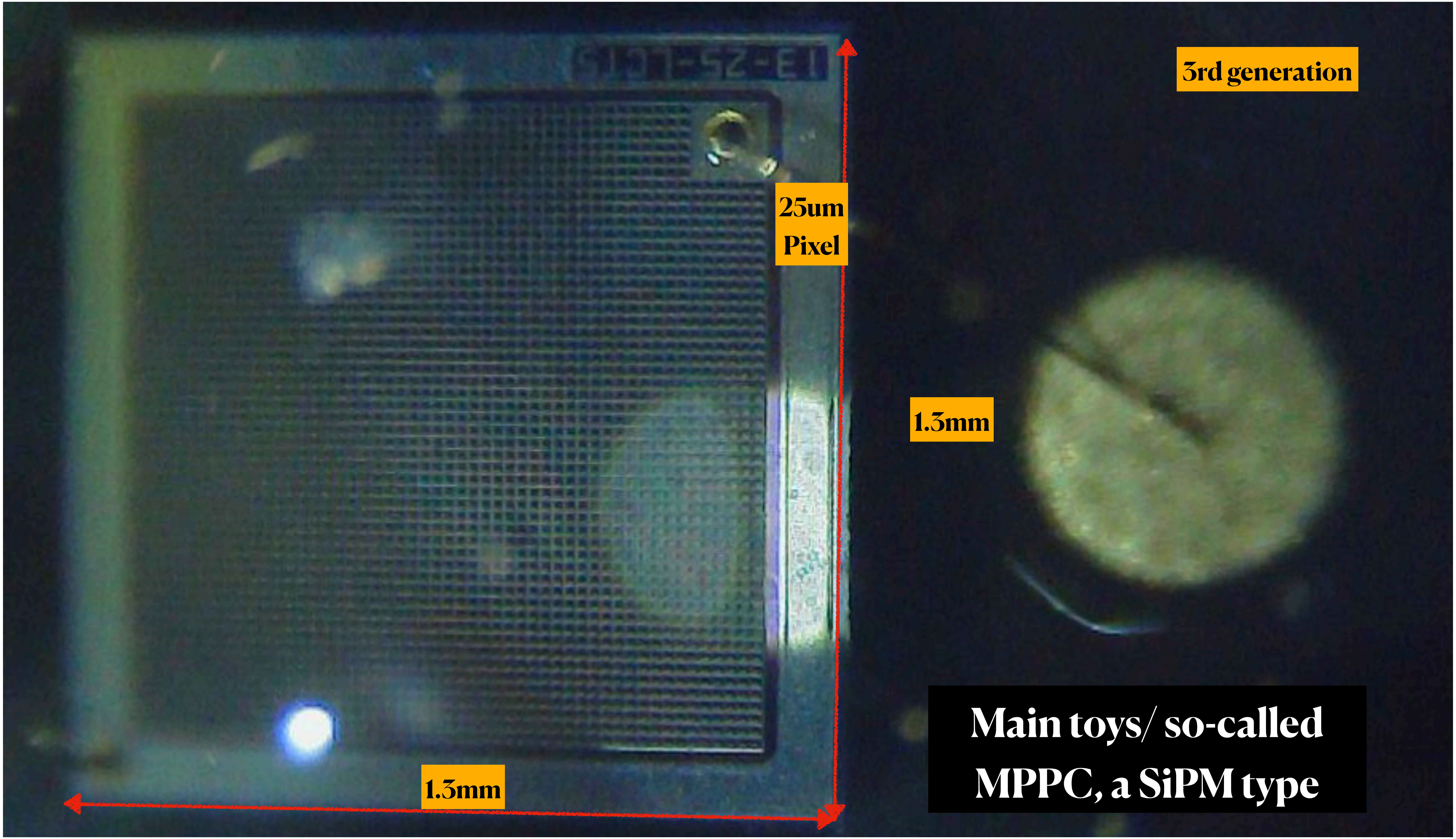


Array of pixels



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

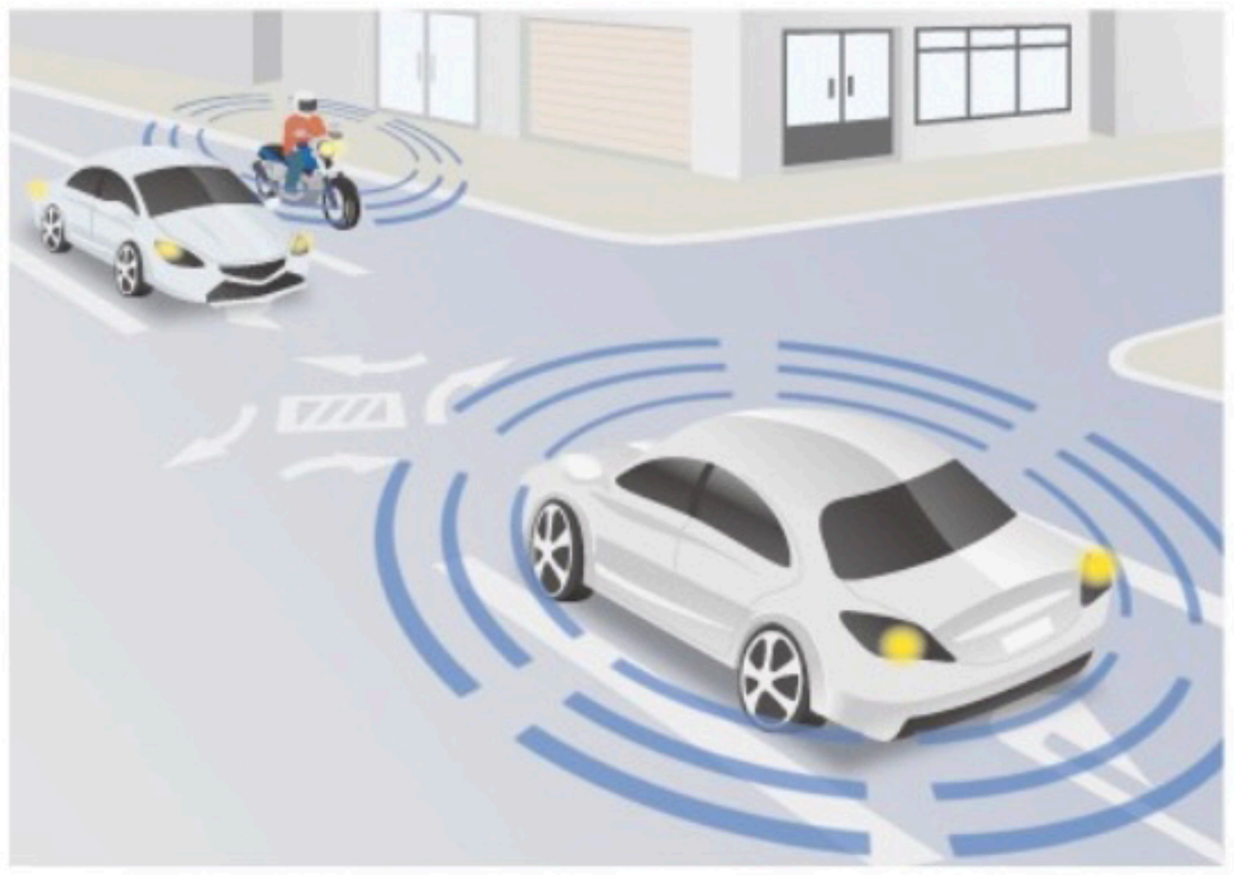
https://www.hamamatsu.com/us/en/product/type/S13360-1325CS/index.html


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

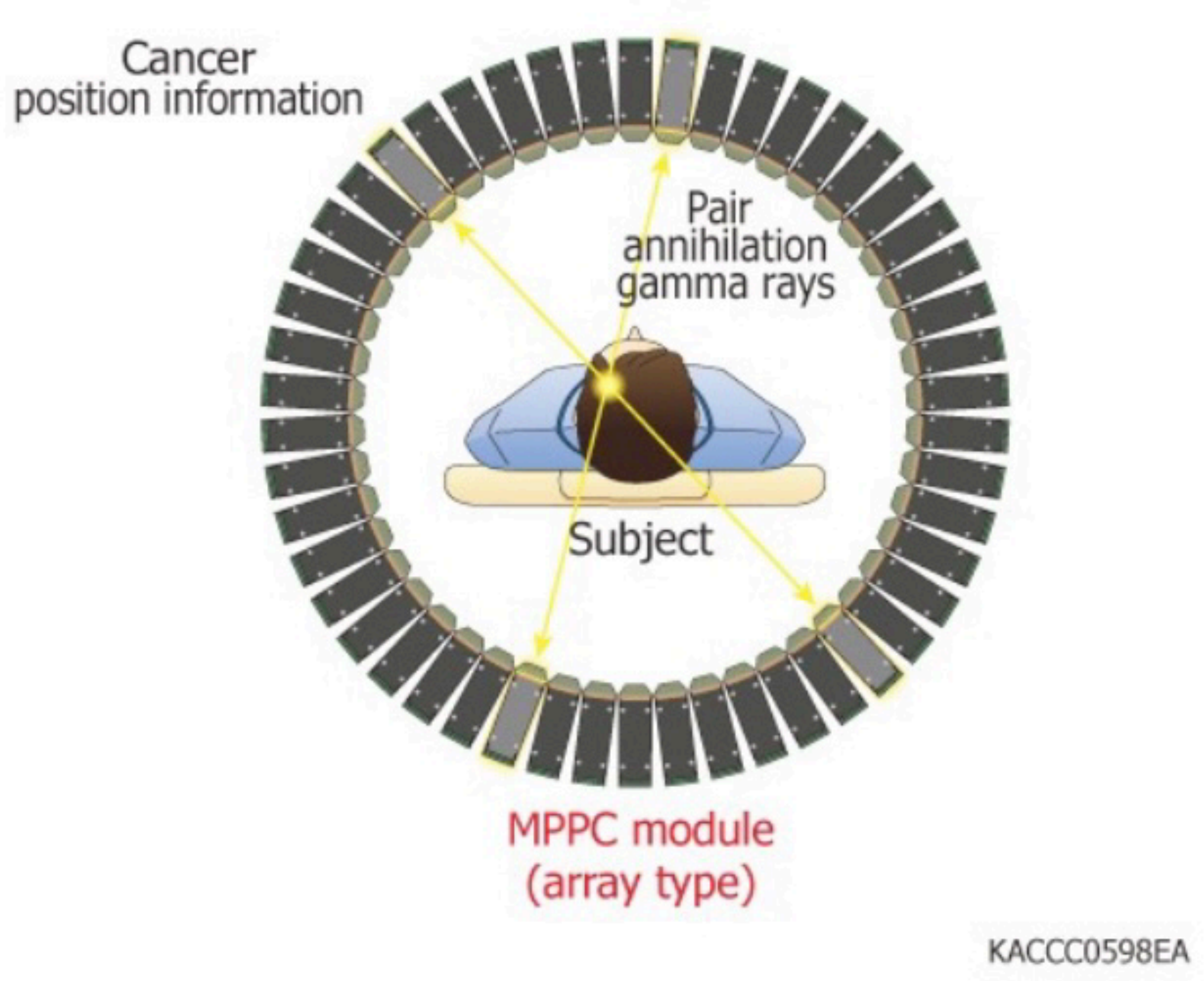
MPPC applications

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

Distance Measurement (LiDAR)



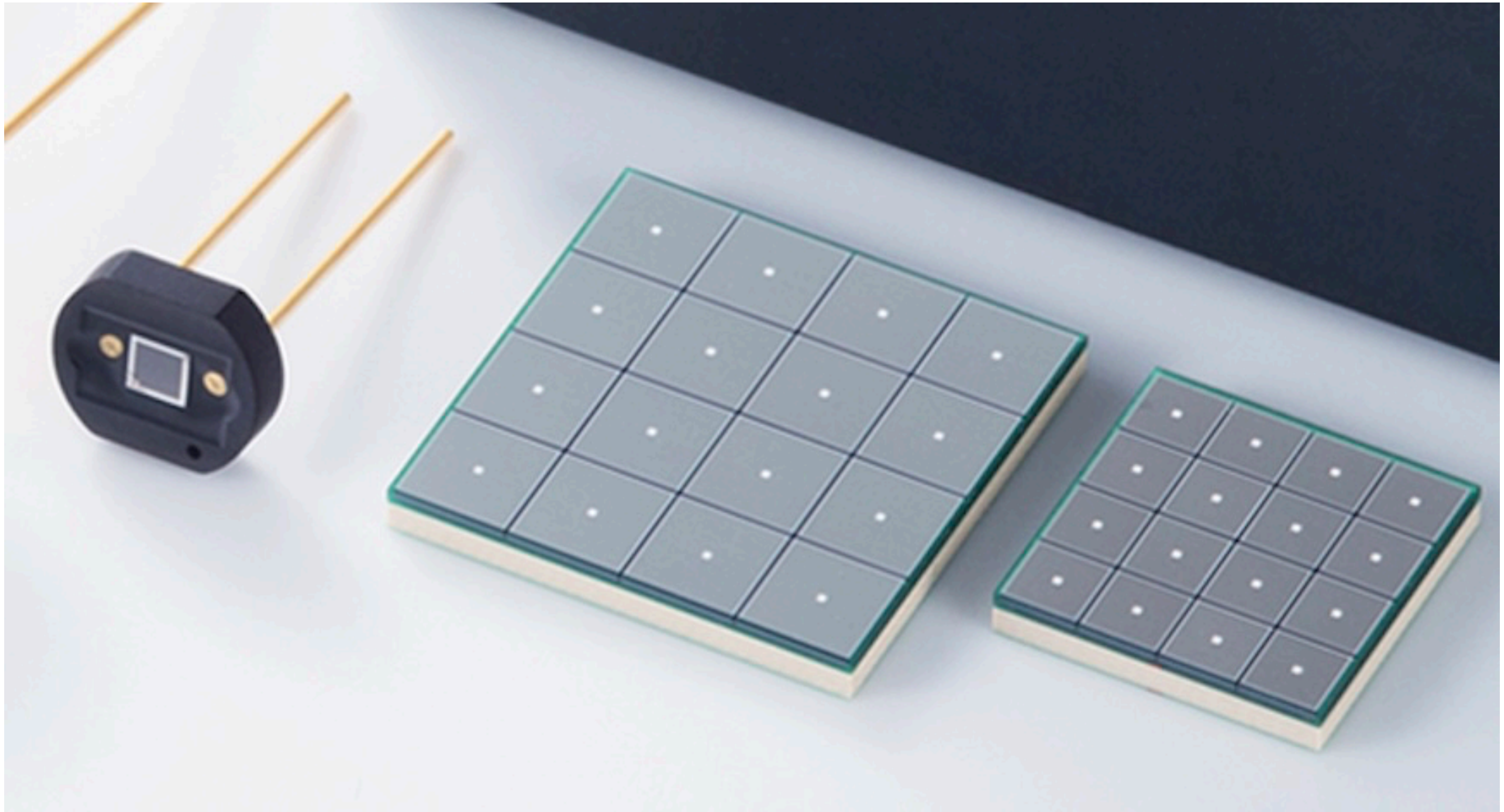
PET (Positron Emission Tomography)



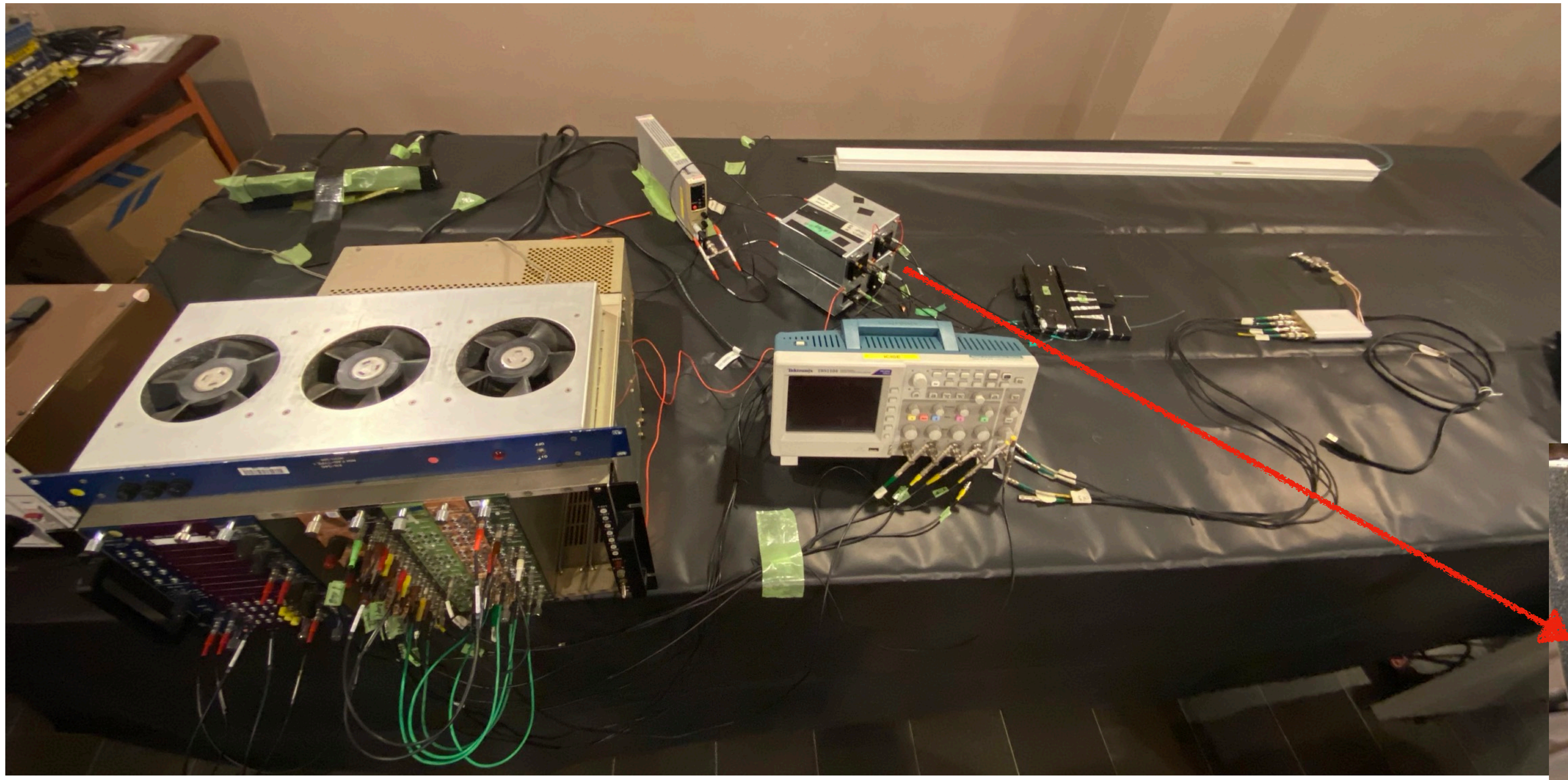
And many other applications

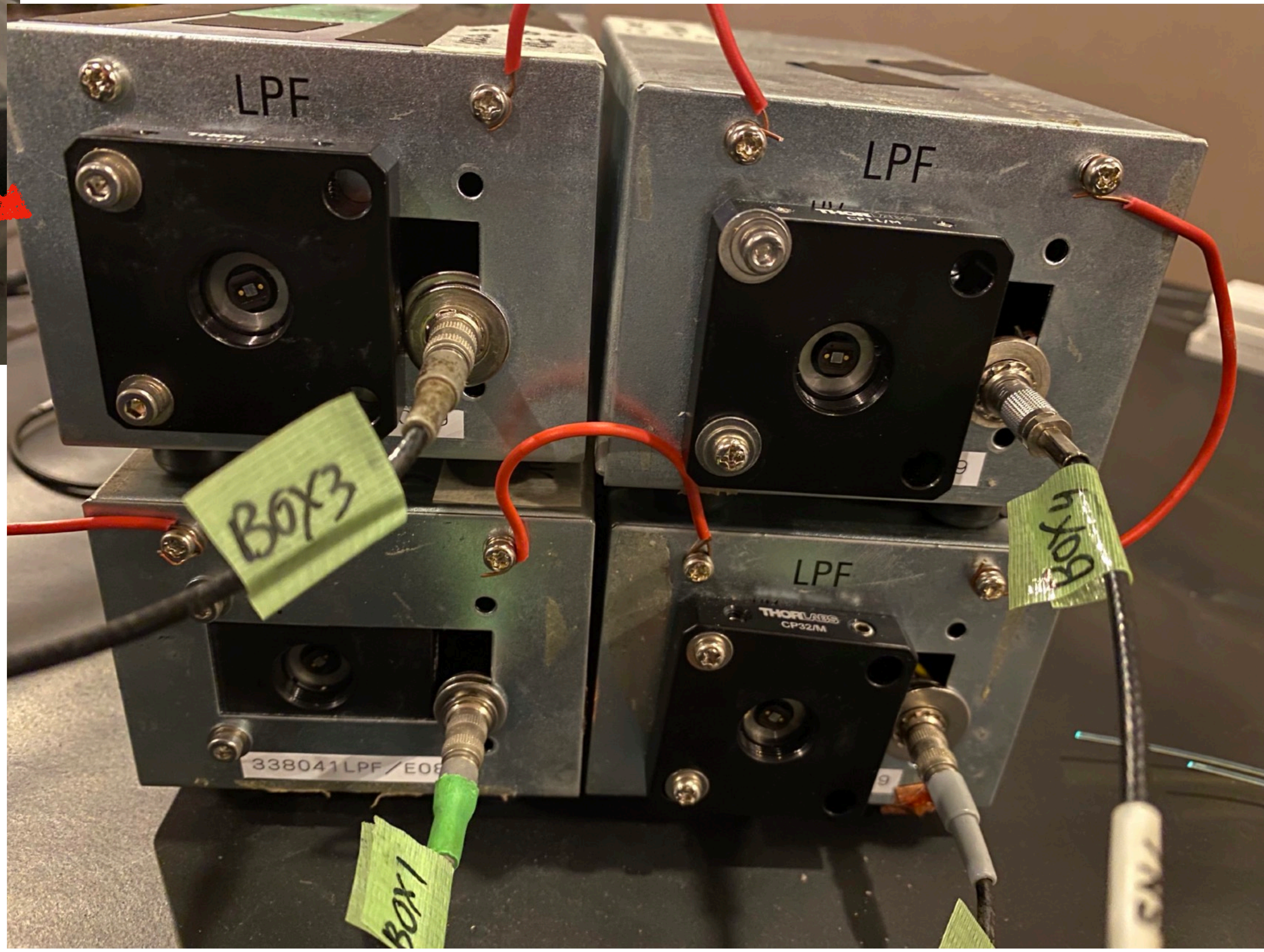
We will have two setups

One is with single MPPC and the other is with MPPC arrays

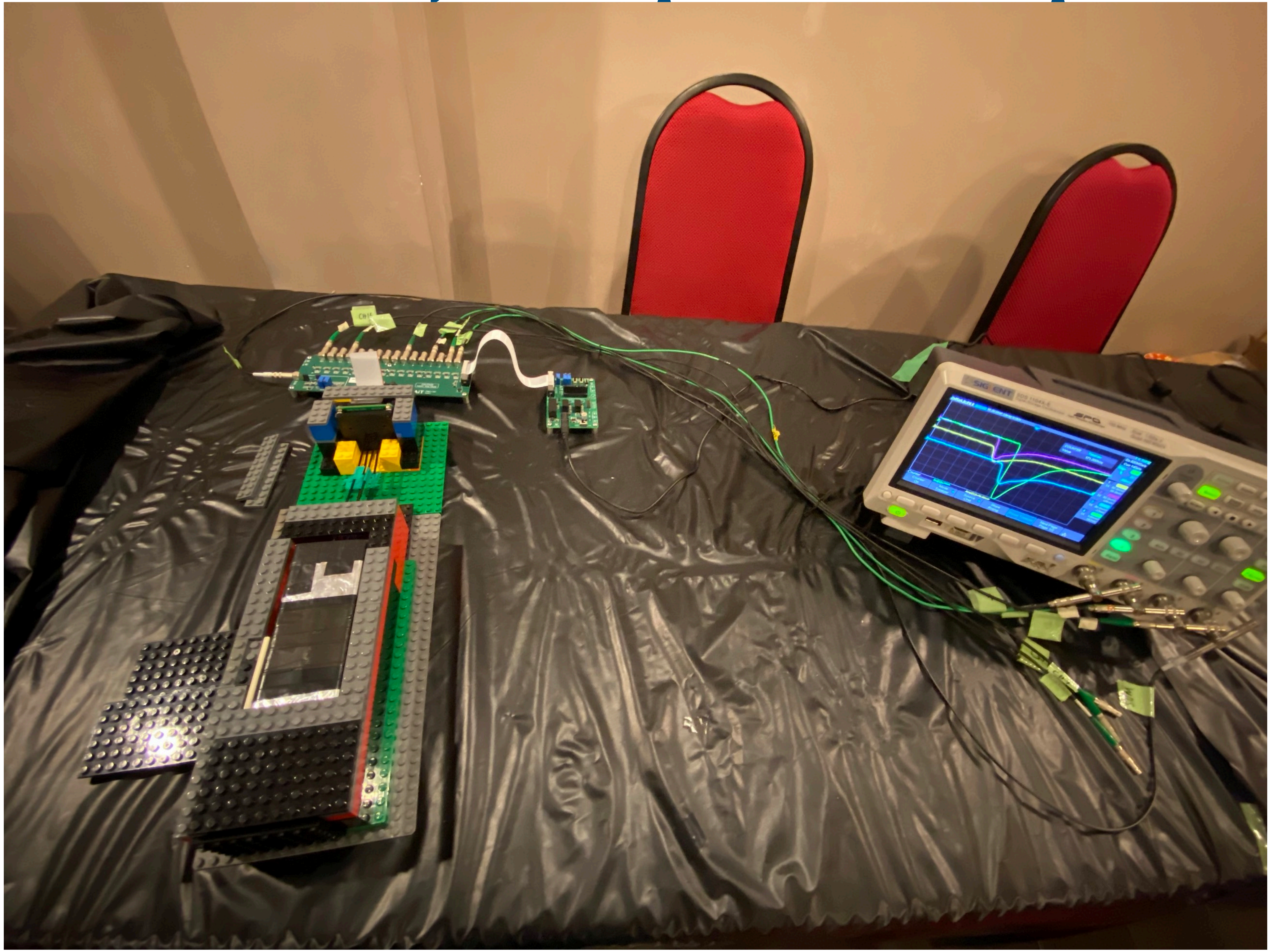


Setup with single MPPCs (Group A and group C)

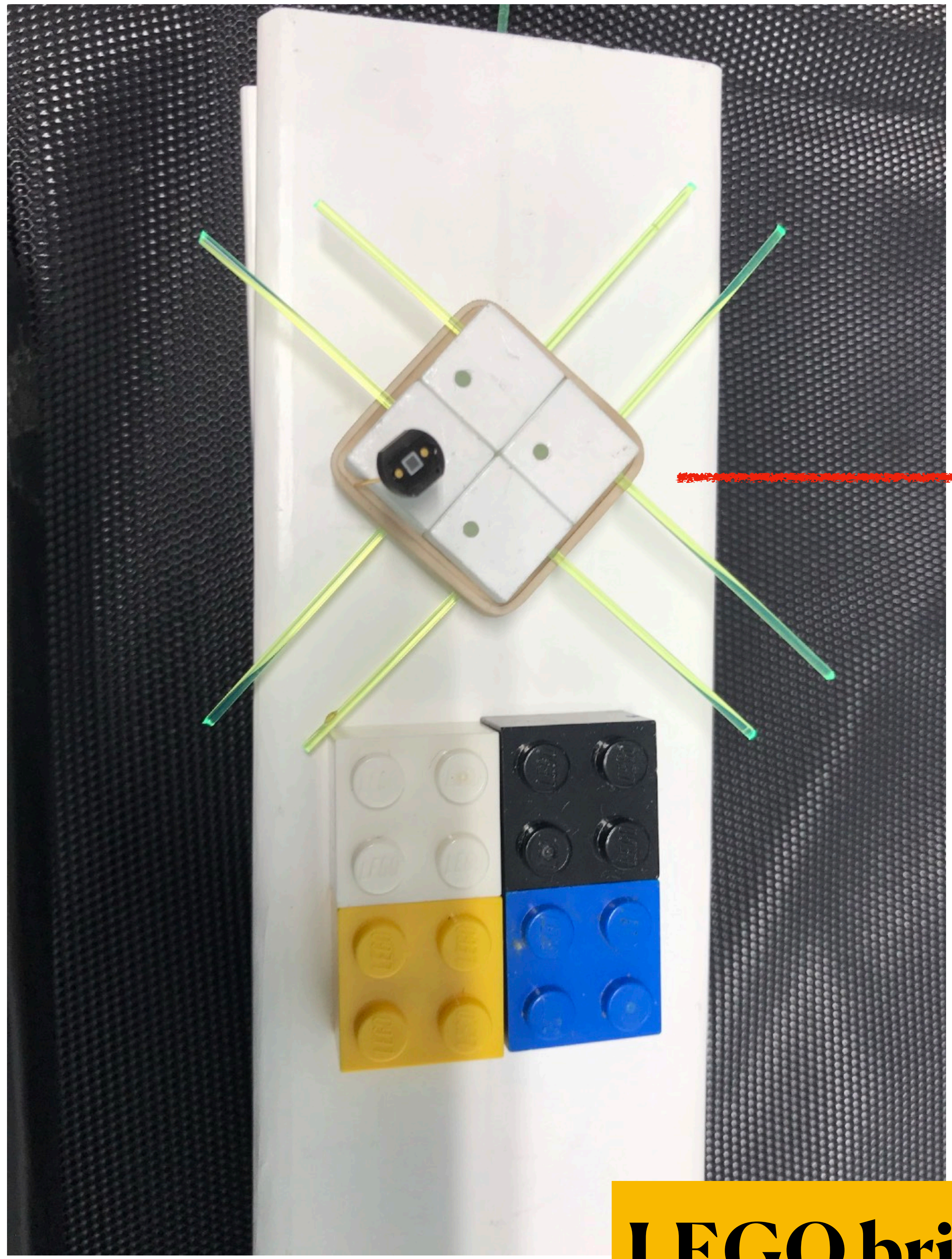


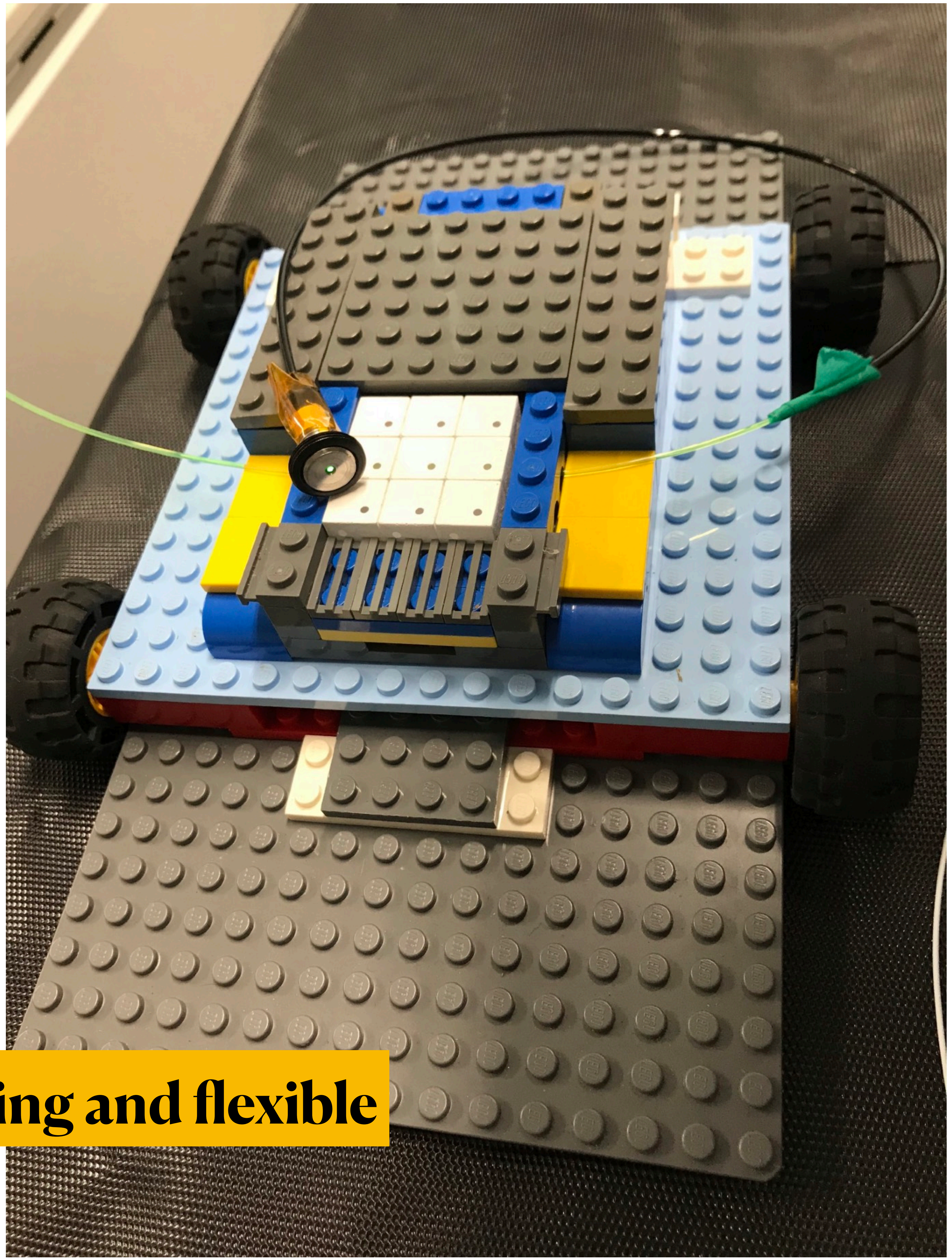


Setup with MPPC array (Group B and Group D)



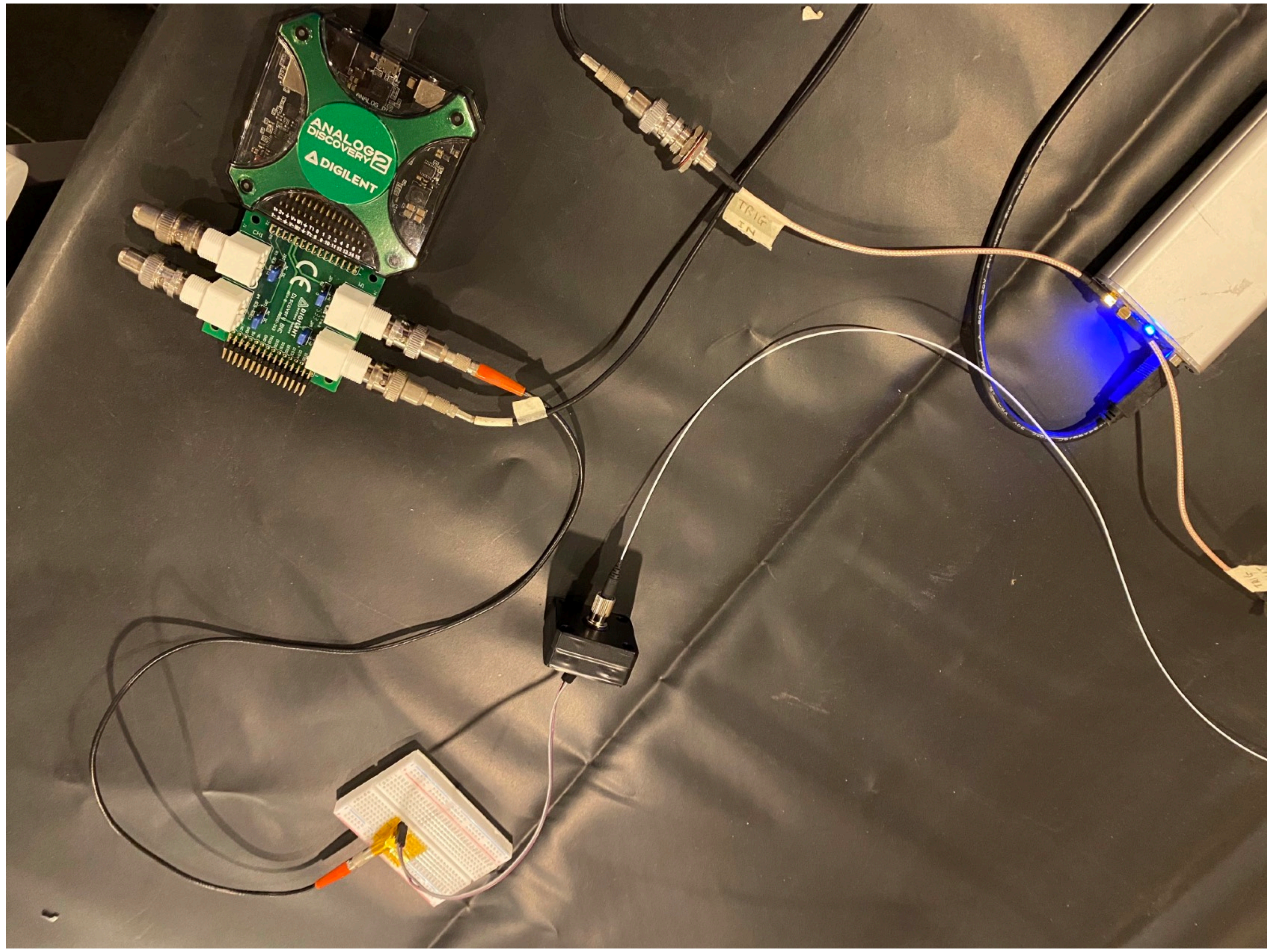
Really LEGO is using...



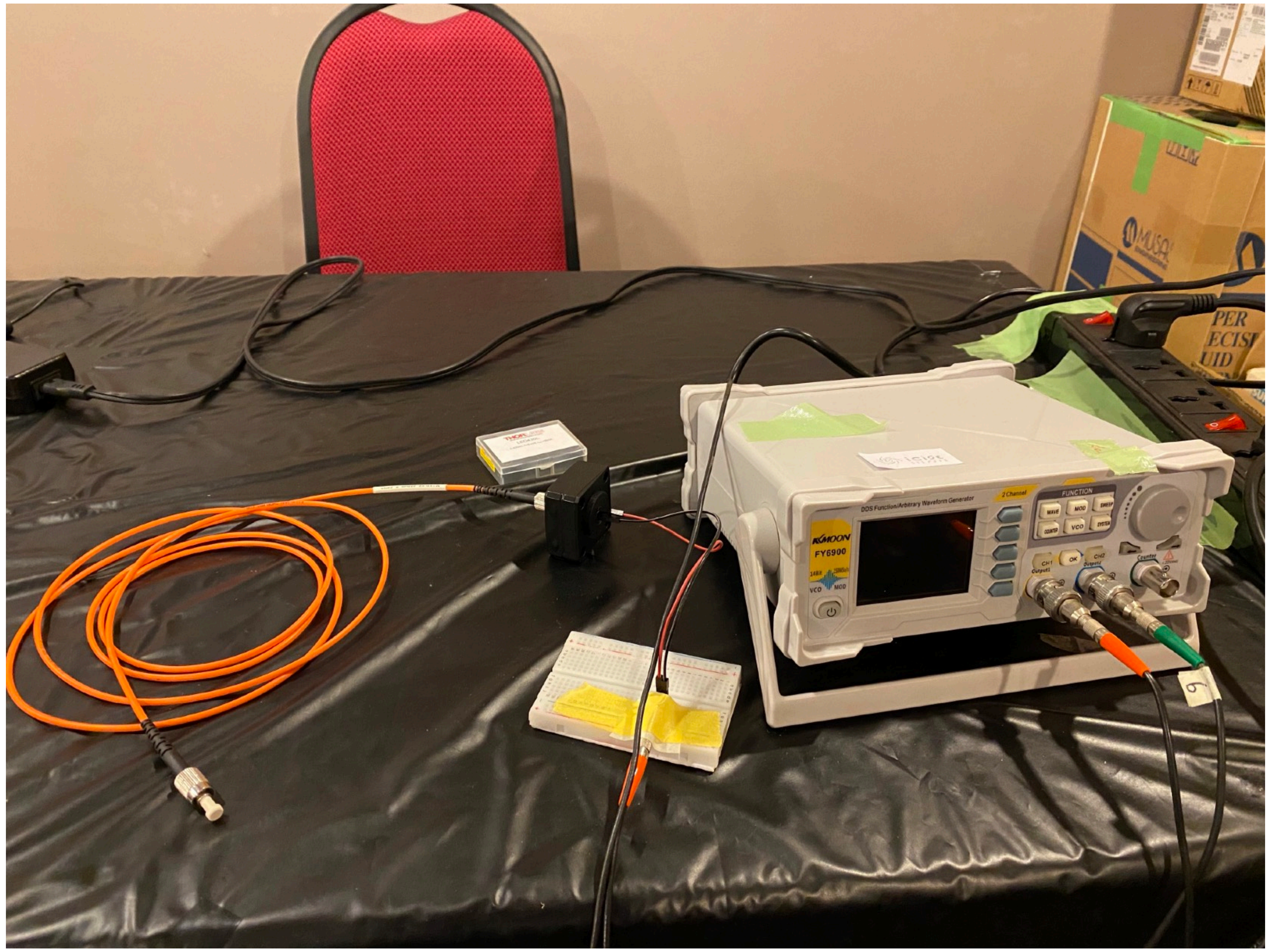


LEGO bricks: precise manufacturing and flexible

Additional tools: Light manipulation



Use for group A and group C



Use for group B and group D

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

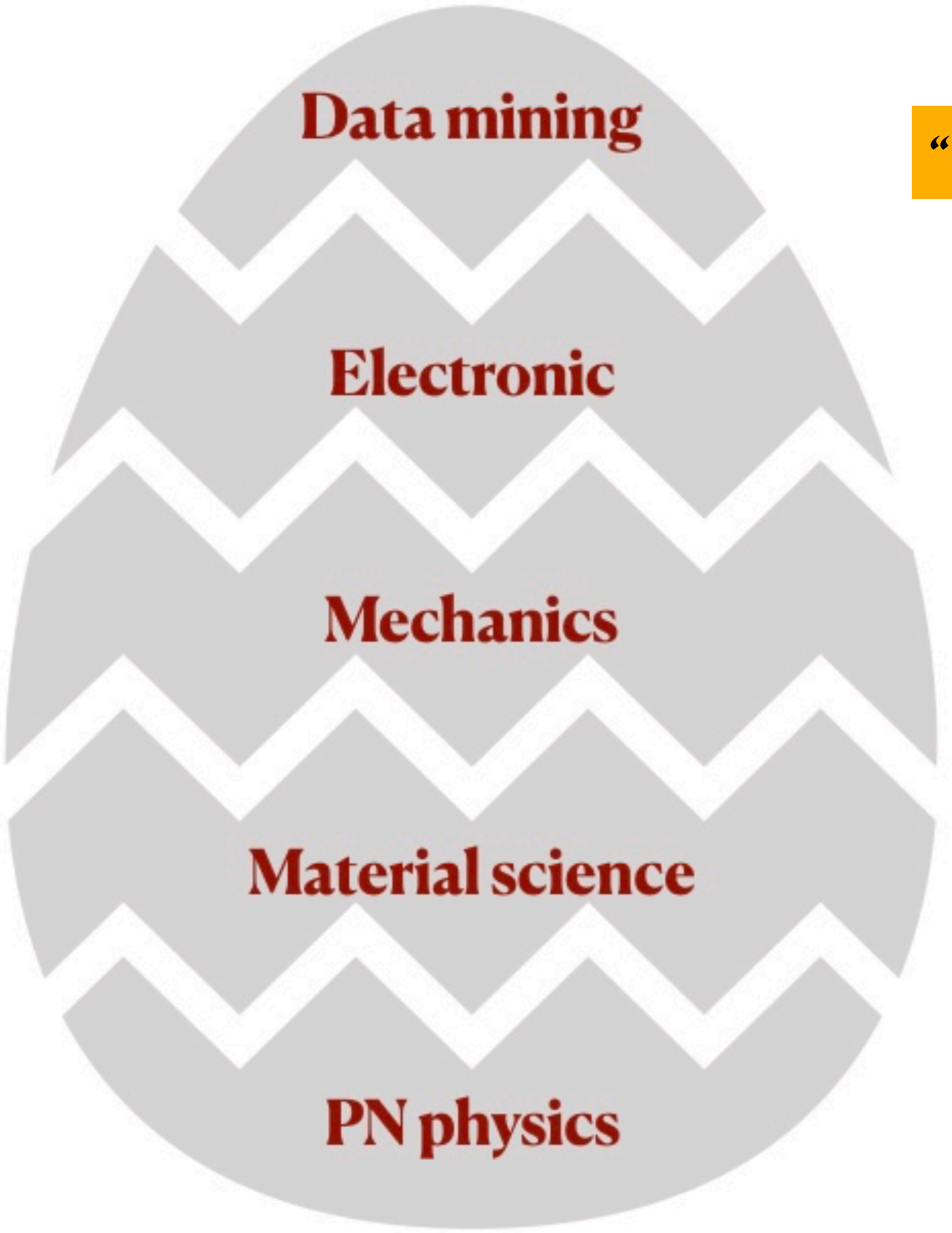
What we will explore (*detail will be explained on whiteboard during the training*)

Day 1, July 13th (Wed.)

- Familiar with hardwares
- Explore MPPC properties
  - Observe single photoelectrons w/ oscilloscope
  - Optical cross talk
  - Charge integration and electric gain calculation
- Signal processing
  - Threshold setting
  - Discriminator
  - Coincidence
  - Counter

Day 2, July 14th (Thu.)

- 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*)



"Experimental neutrino experiment in the nutshell"

We will touch very small part of it.

Neutrino detection is a complicate, interdisciplinary field

Additional mentors

- Dr. Dung Nguyen
- M.Sc. Quyen Phan, B.Sc. Bao Ton
- Some students may be familiar with the setup

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

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

We thank for your donation

KEK

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Without their generosity, this hardware training is impossible.