



中國科學院高能物理研究所  
*Institute of High Energy Physics*  
*Chinese Academy of Sciences*

# Cosmic Ray detector module with liquid scintillator

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# Motivation

- The detection of Cosmic ray muon or electromagnetic particles is one of the basic requirements of most particle experiments.

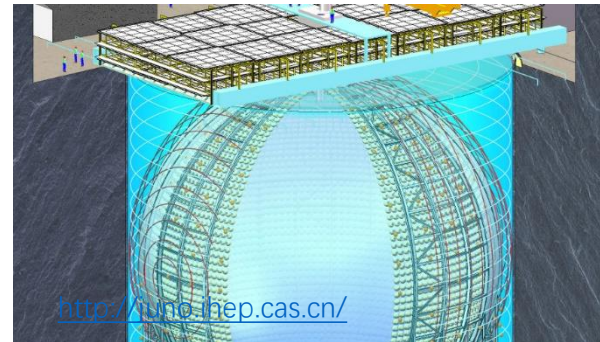
LAHHSO



Auger



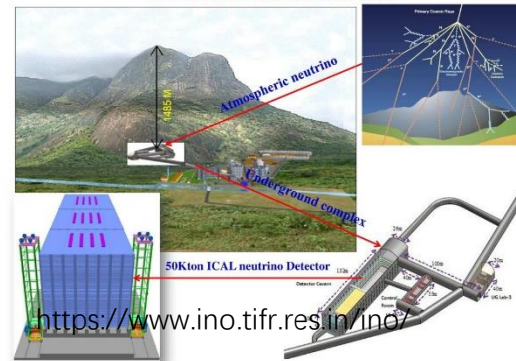
JUNO



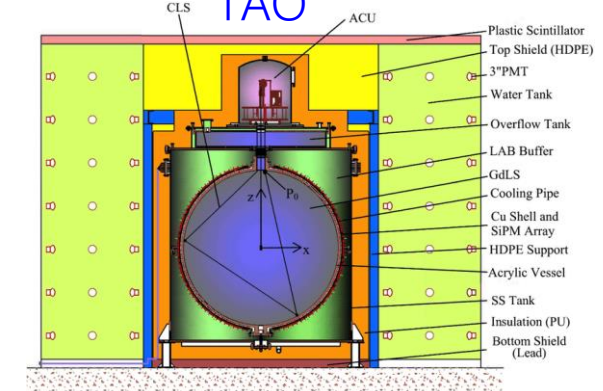
DayaBay



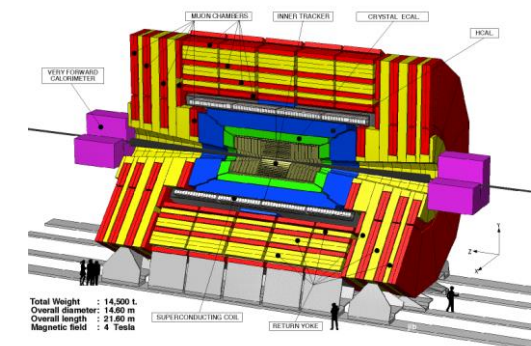
INO site at BodiHills



TAO



CMS



# Cosmic ray detectors

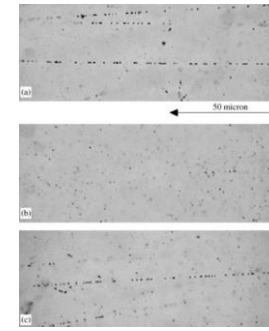
- Hit/trigger
- Timing
- Position/track
- S/N
  
- Cost
- Reliability
- Robustness
- .....

Solid based

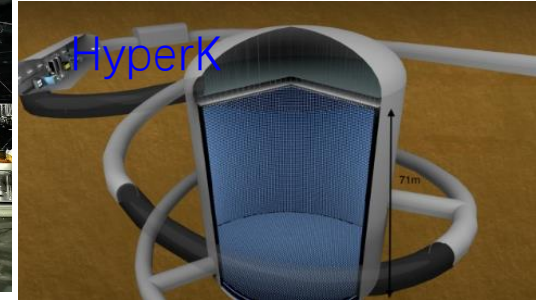


Plastic scintillator (+ fiber)

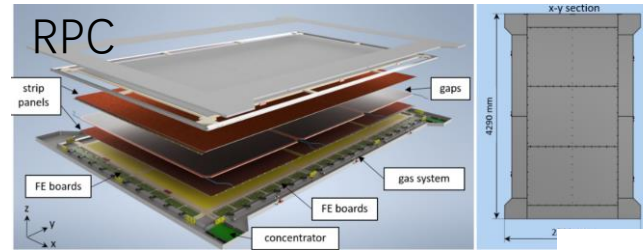
Film, OPERA



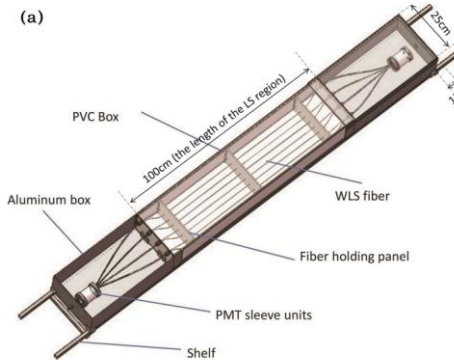
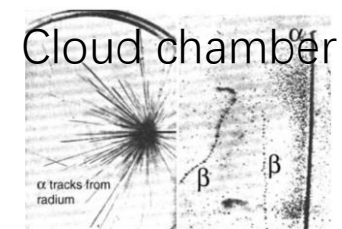
Water based



Gas based

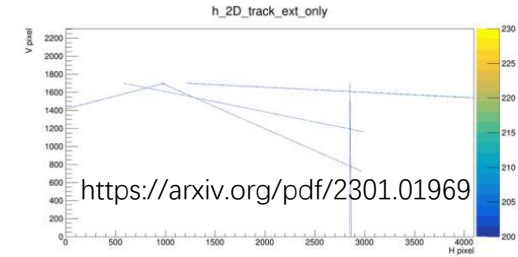


Fluid based

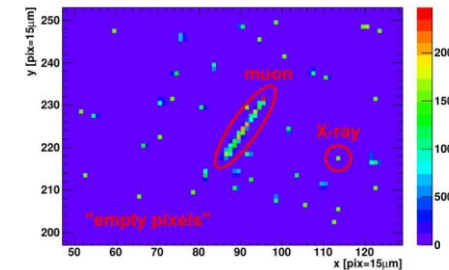
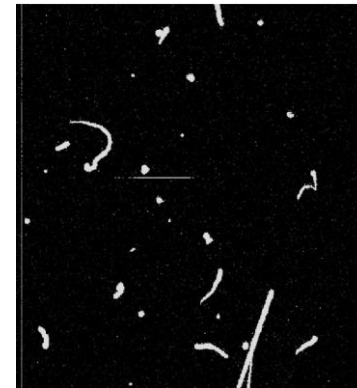


Liquid scintillator (+ fiber)

Crystal + camera

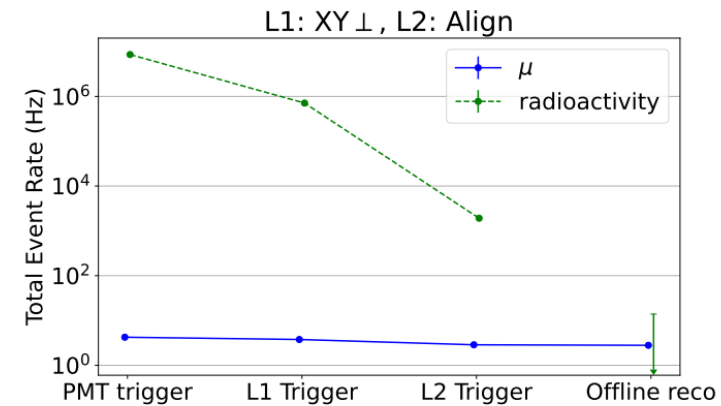
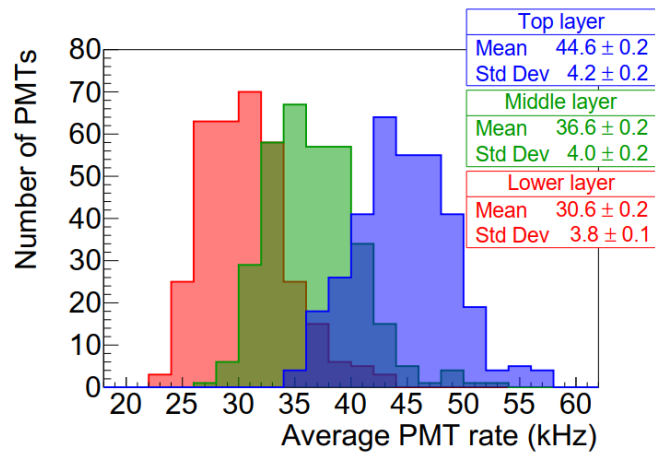
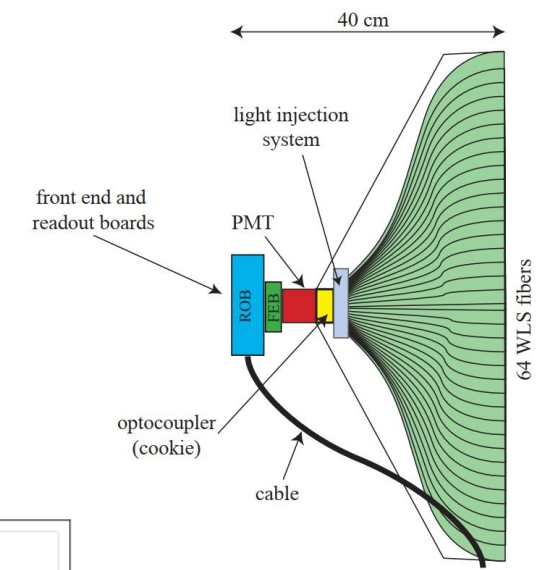
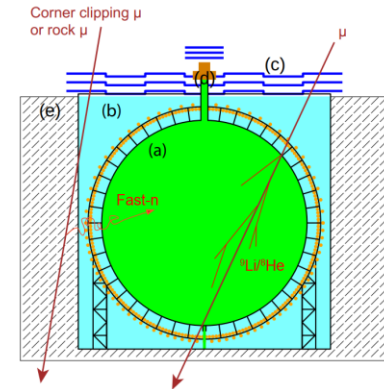
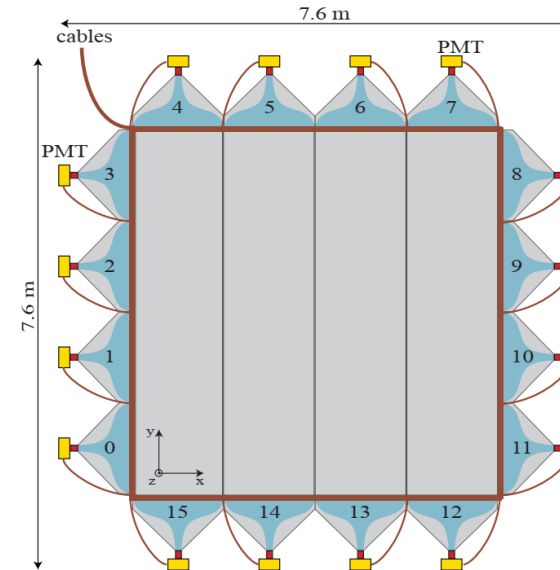
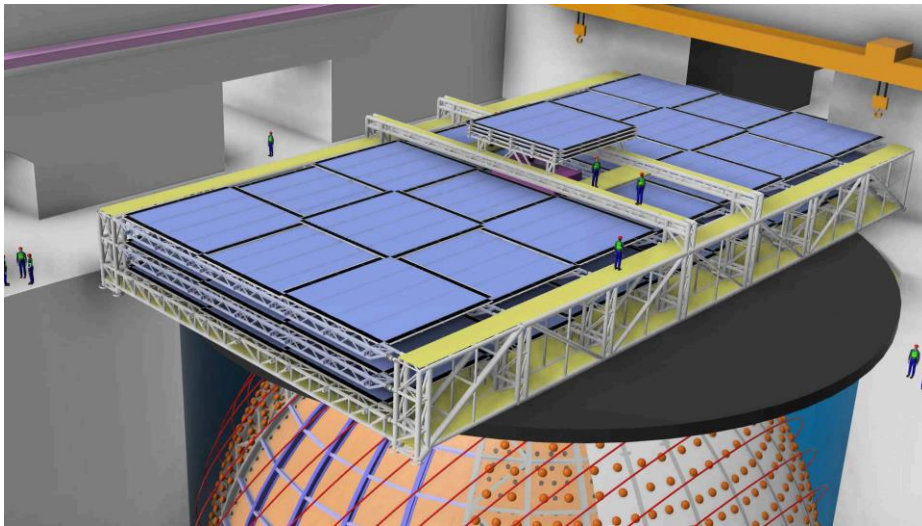


Skipper CCD

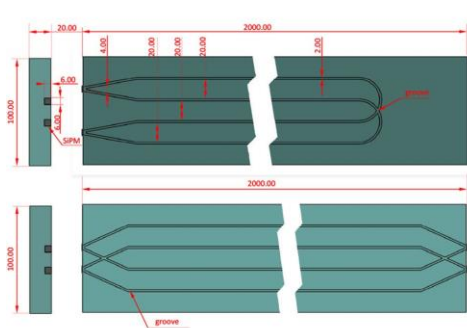


<https://indico.stanfordlab.org/event/28/contributions/360/attachments/227/511/SURFK20-%20SENSEI.pdf>

# Example I: JUNO TT, plastic scintillator



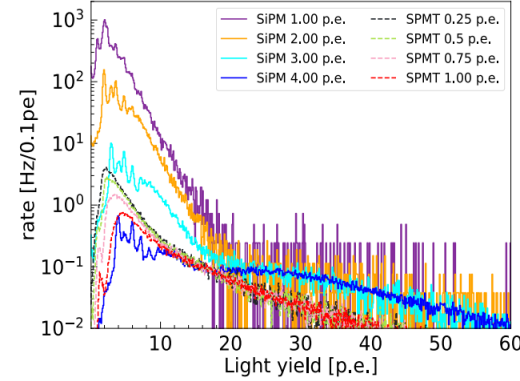
# Example II: TAO plastic scintillator



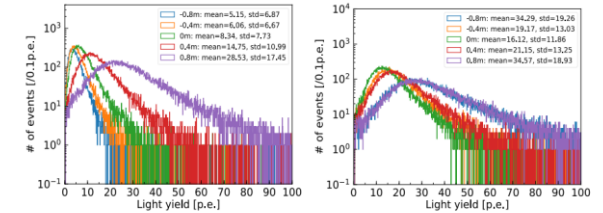
(a)



(b)

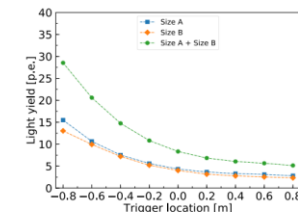


(a)

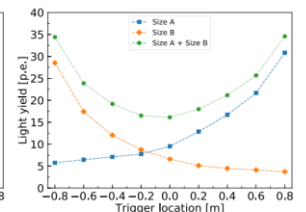


(a)

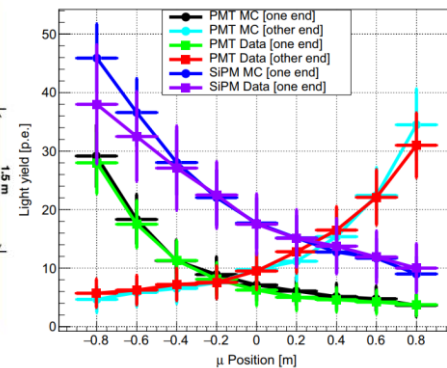
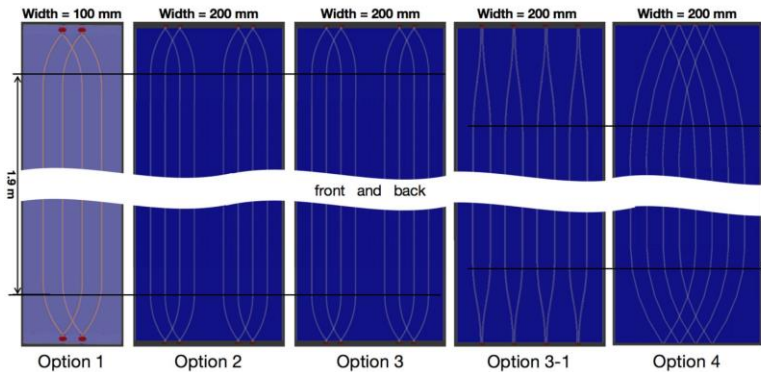
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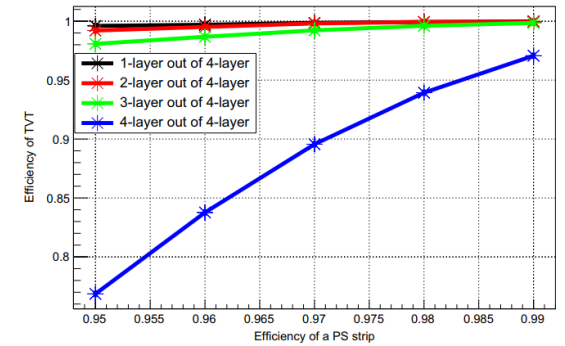
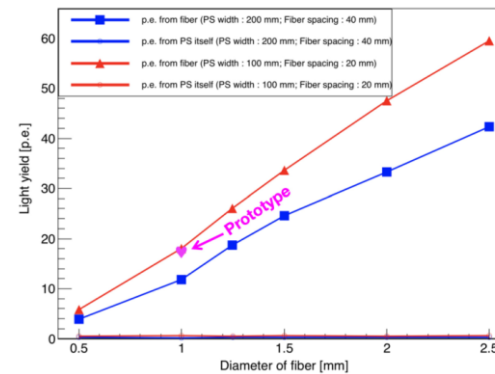
(c)



(d)



(a)

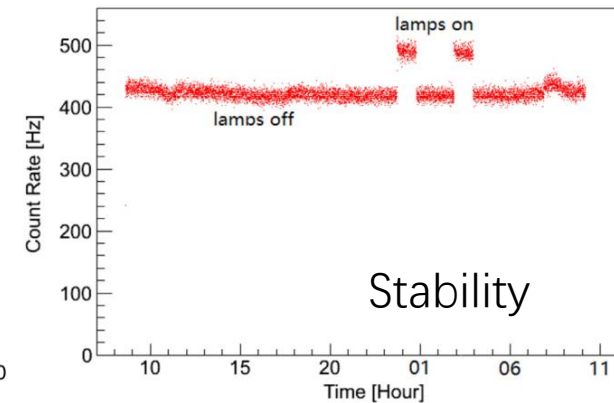
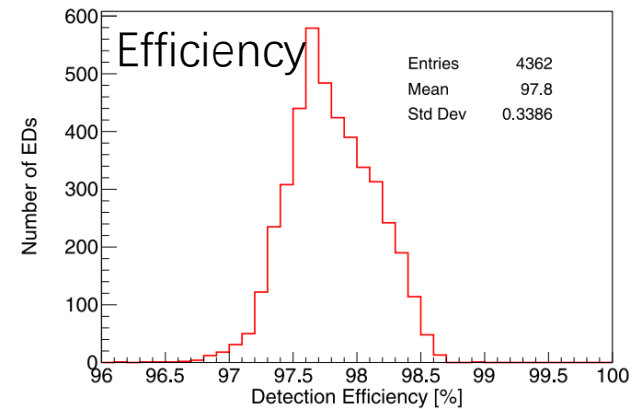
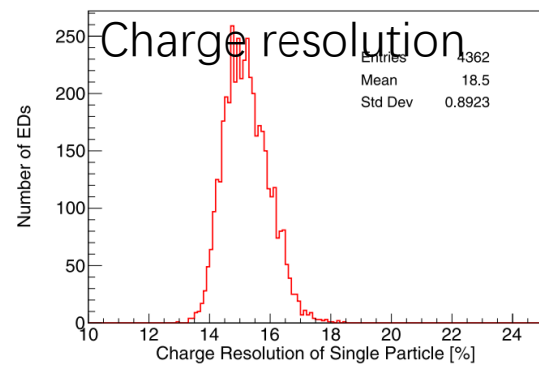
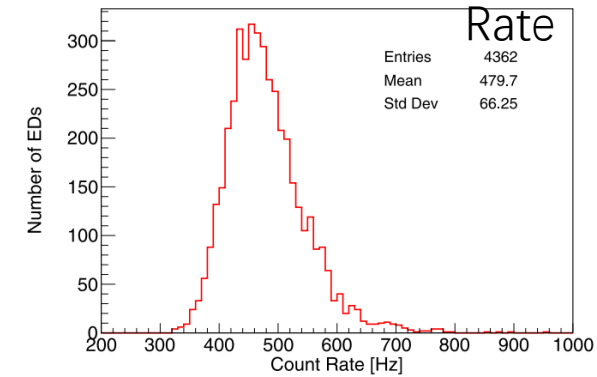
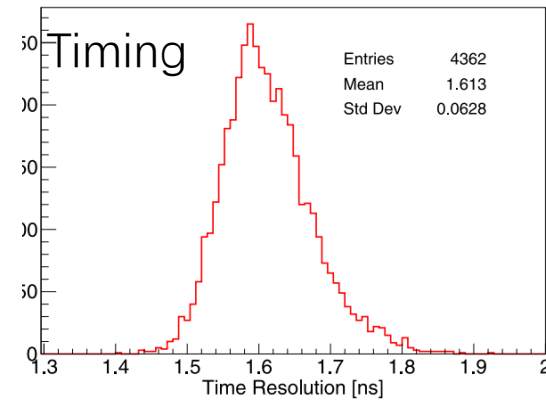
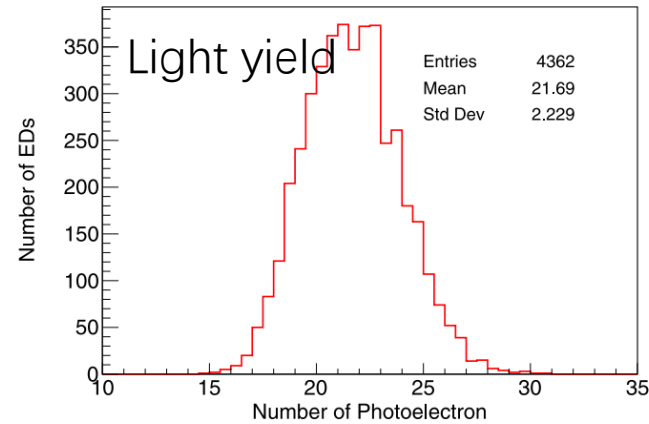
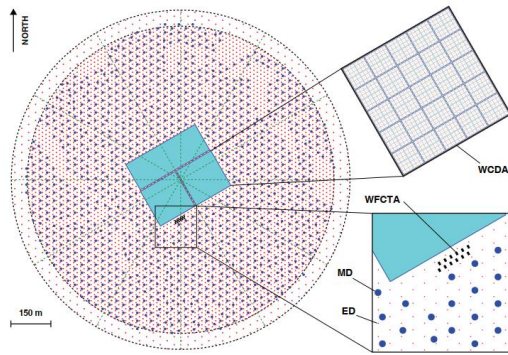


(b)

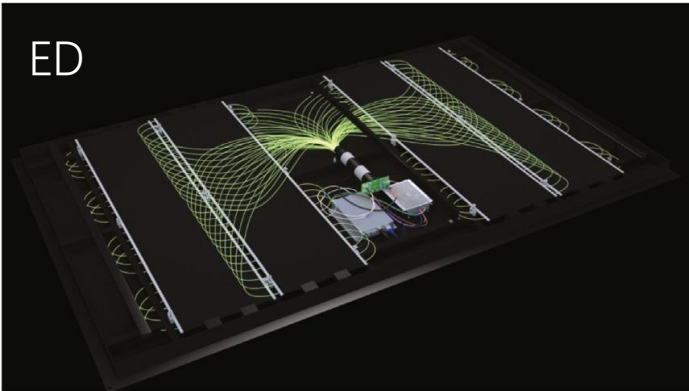
# Example III: LAHHSO ED

- $1\text{m}^2$  sensitive area of each ED
- sensitivity to the electromagnetic components, including  $e$ ,  $\gamma$  and  $\mu$ .
- time resolution better than 2 ns.
- detection efficiency greater than 95%.
- $1 \sim 10^4/\text{m}^2$  dynamic range of particle density, with charge resolution of 25% @ single particle, and 5% @  $10_4$  particles.
- count rate  $< 2$  kHz at working gain and given threshold.

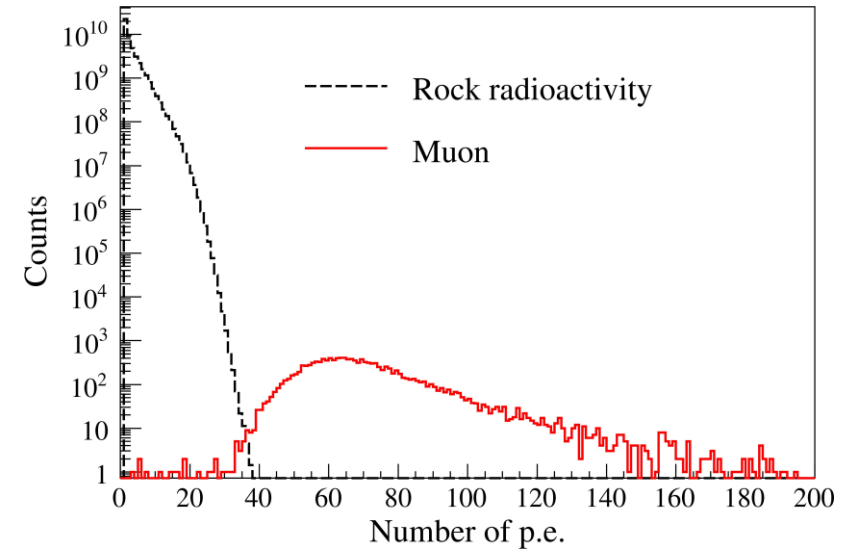
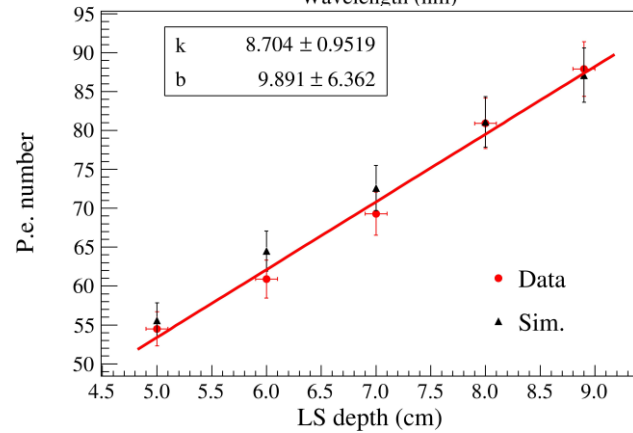
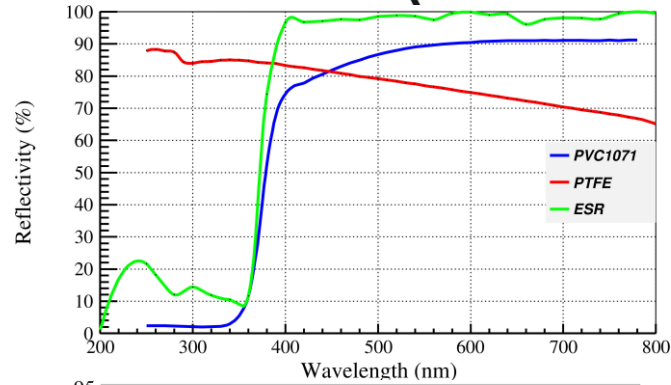
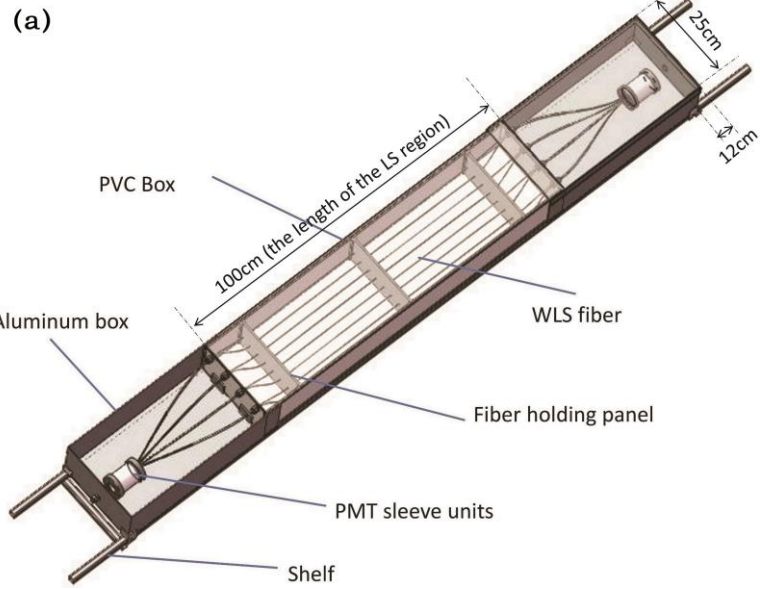
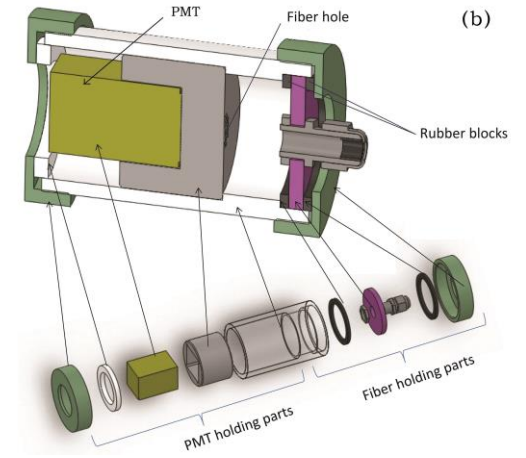
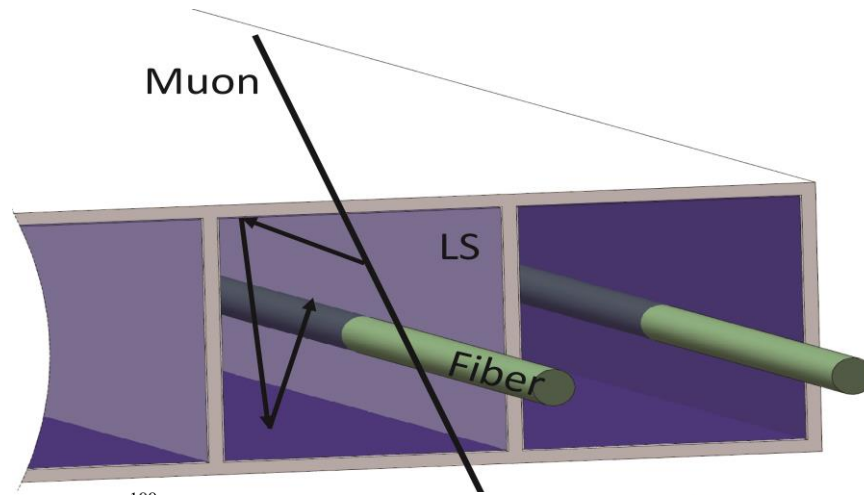
LAHHSO



ED



# Example IV: LS module



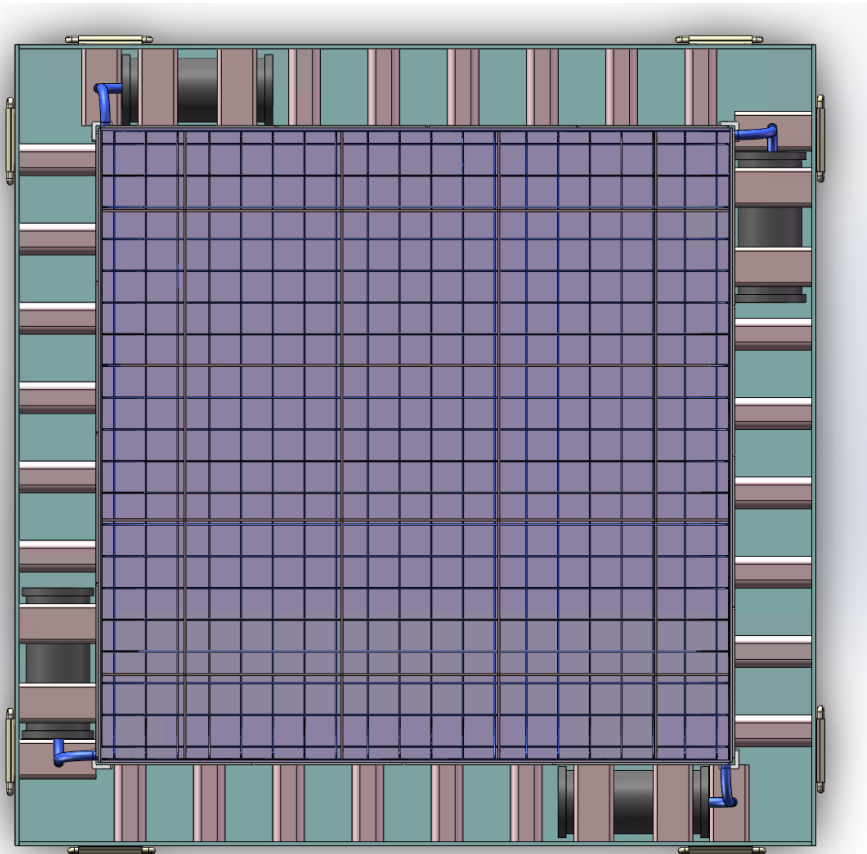
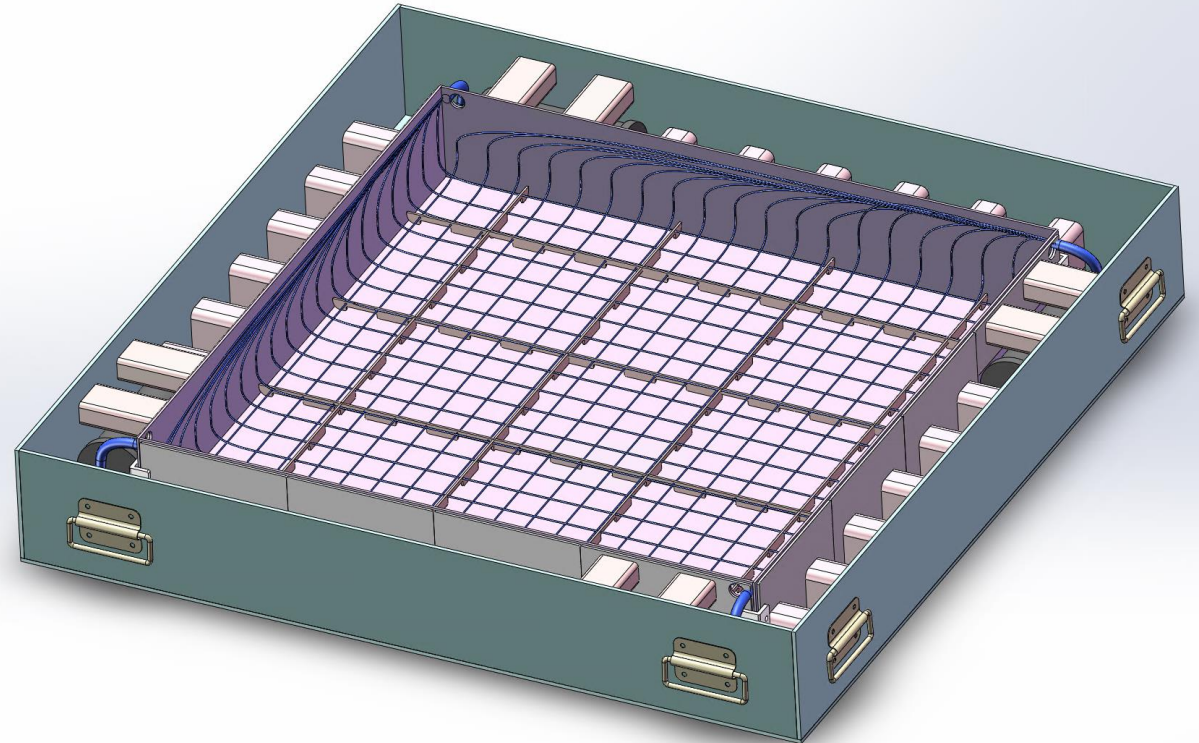
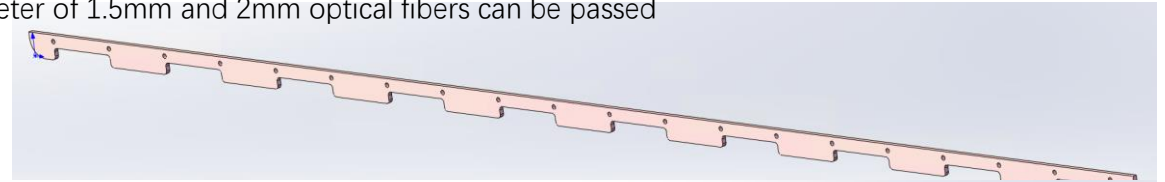
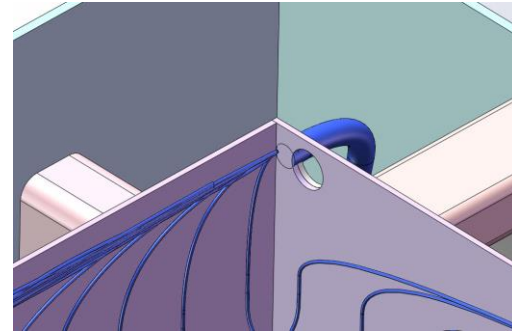
# Proposal

- Liquid scintillator
  - Performance similar to plastic scintillator
  - But cheaper
  - Easy to produce/model for different shapes
  - But, Difficult to seal tightly
- Wavelength shift fiber
  - For larger dimension
- PMT or SiPM
  - Sensitive to single photon, then aim to lower energy events

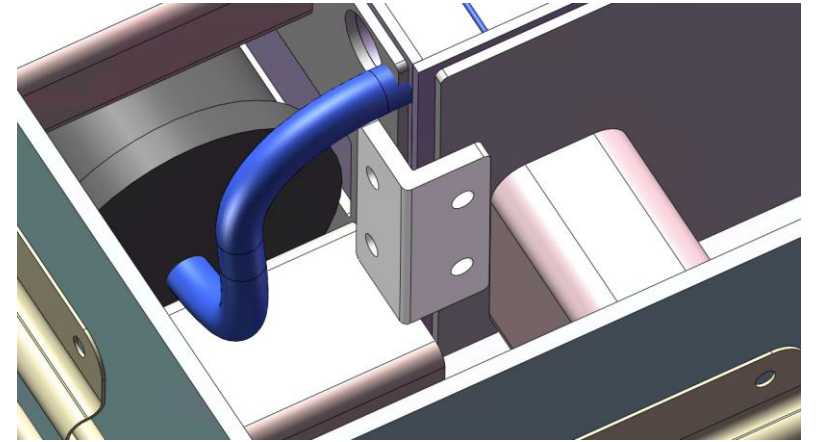
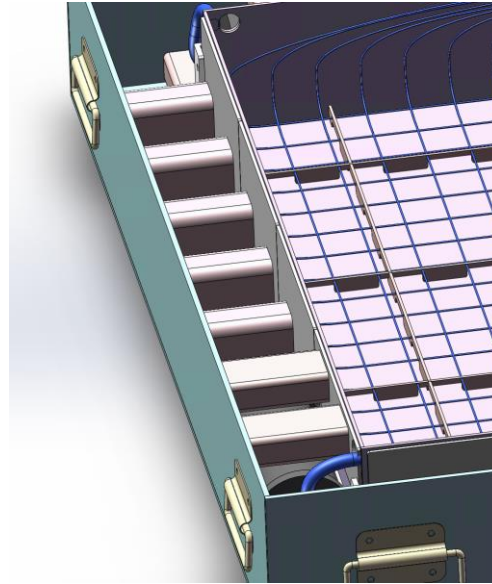


# Pre-Design

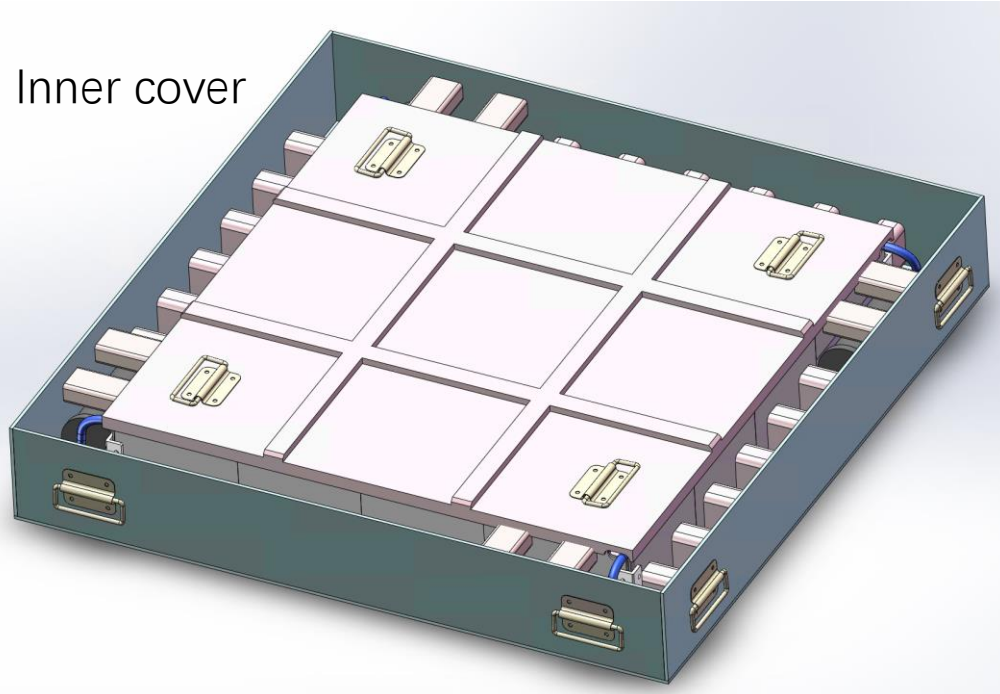
- 1m\*1m
- Max. height: inside 12cm (liquid max. 8cm)
- Inner: White PVC: 6mm
- Outer: Al
- 40 fibers in 1.5mm: 20 vertical, 20 horizontal
  - Fiber to bottom 11.5mm
  - Distance between neighbors: 40mm
- Fiber support frame 13.5mm high The aperture of the optical fiber is 2.5mm, and the diameter of 1.5mm and 2mm optical fibers can be passed



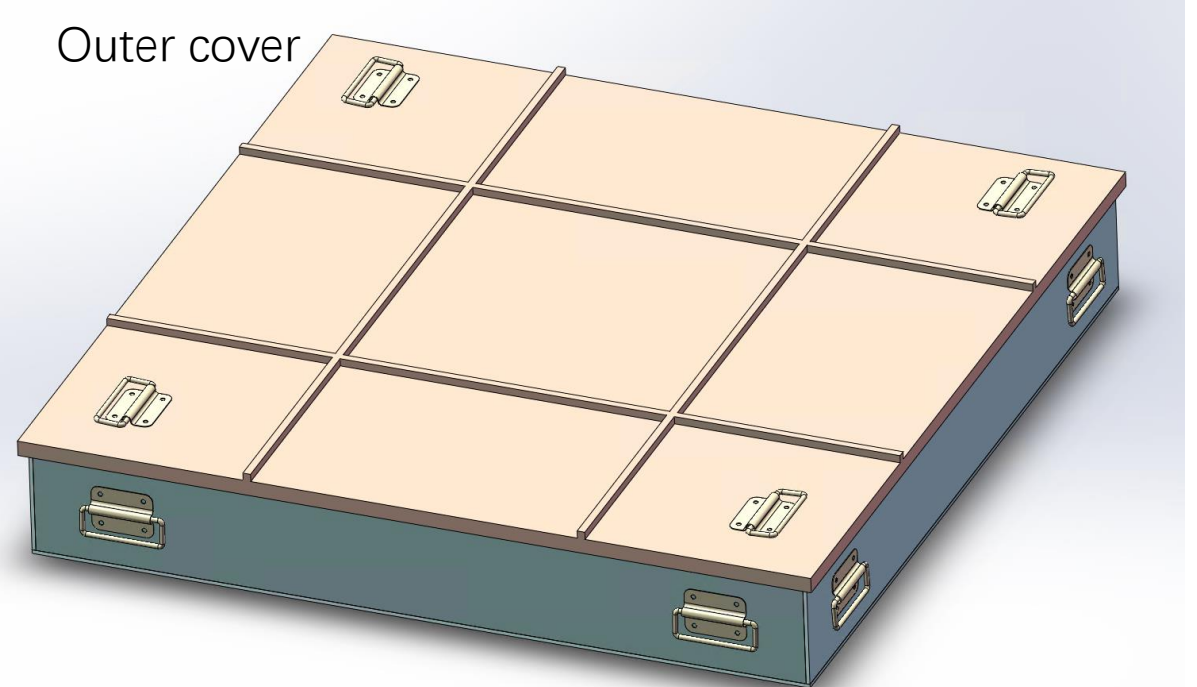
# More details



Inner cover

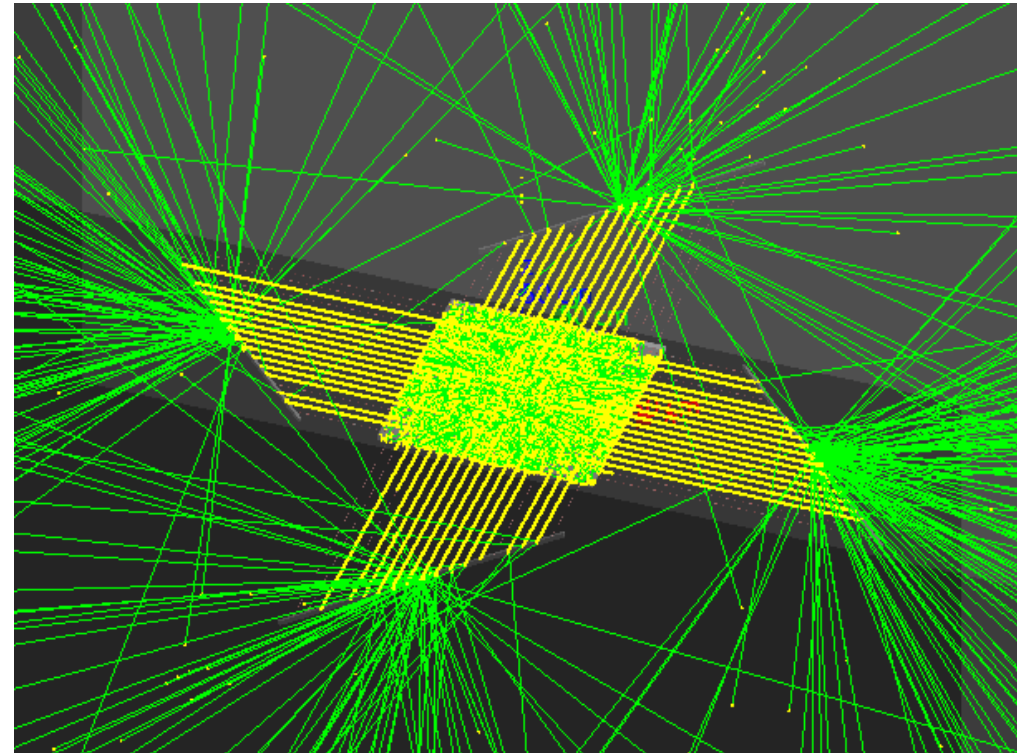
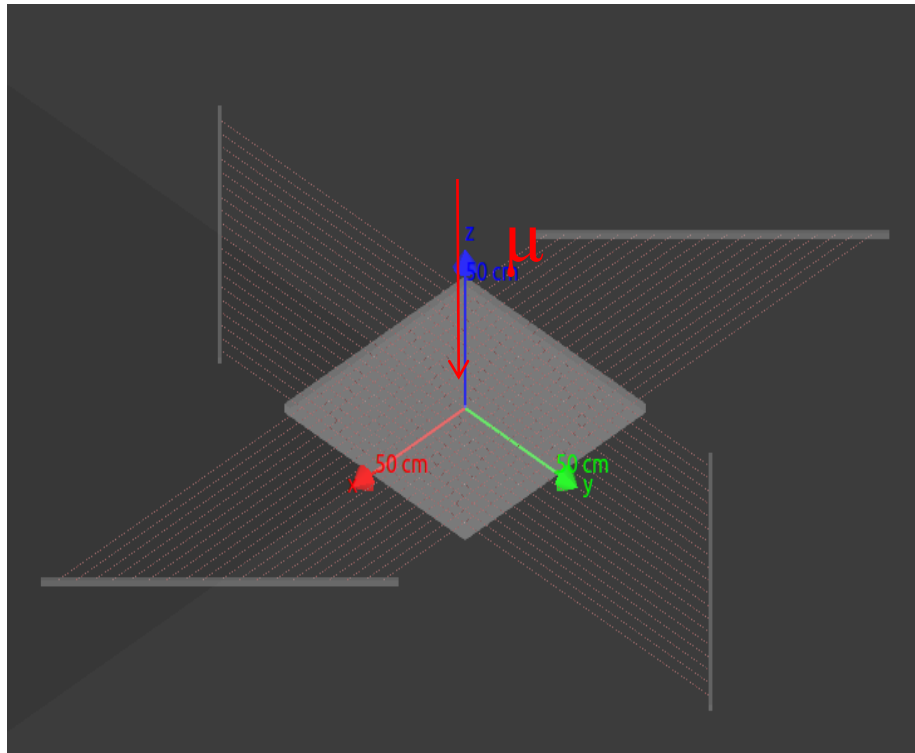


Outer cover

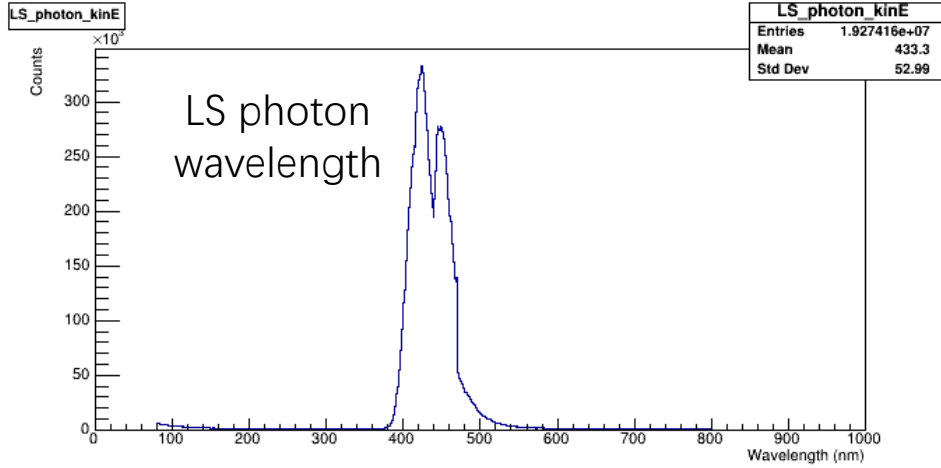


# Simulation

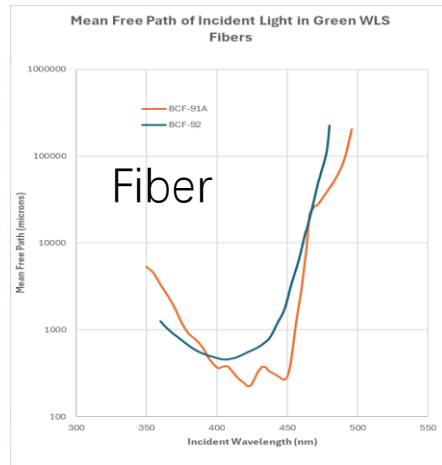
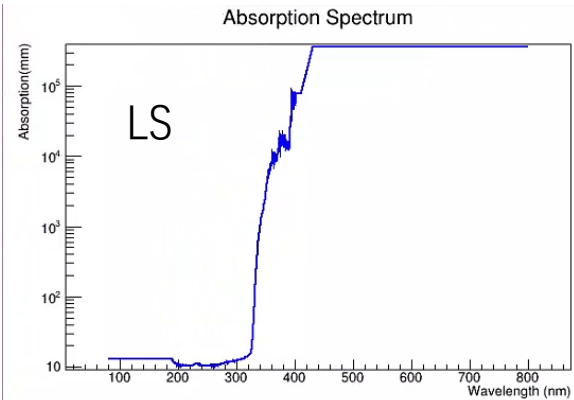
- LS thickness: 2cm
- 80\*80cm liquid scintillator,
- 19 optical fibers in the XY direction
  - Length 2.4m, type: BCF92
- 4 PMTs



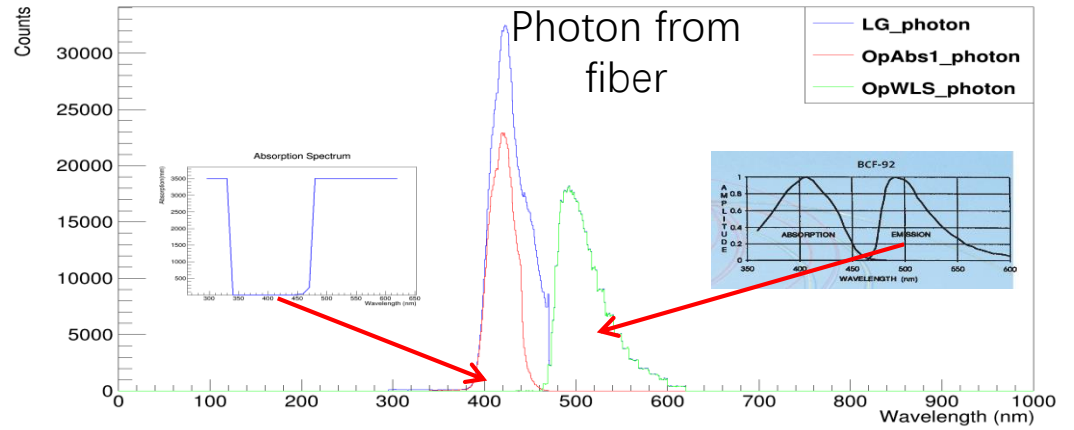
# Setting



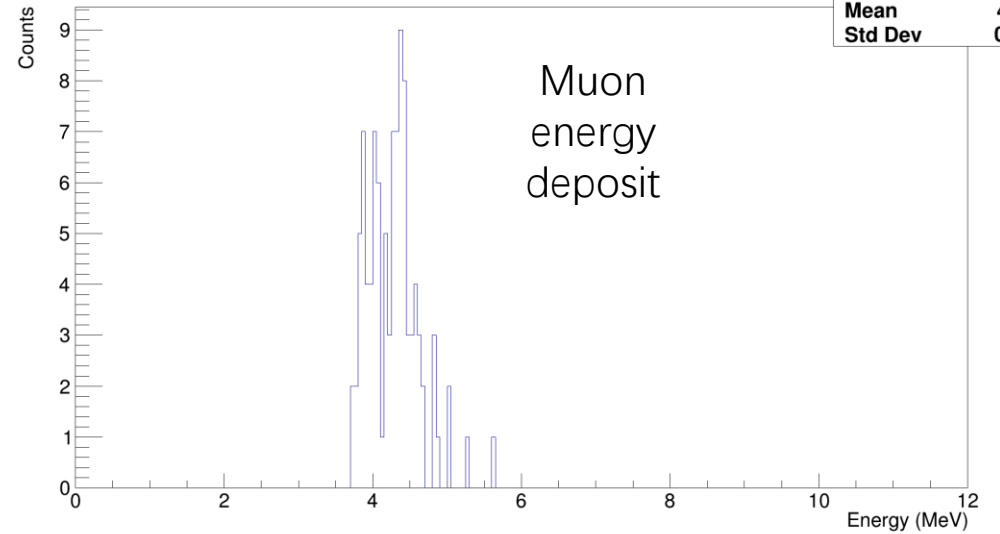
BCF92



LG\_photon

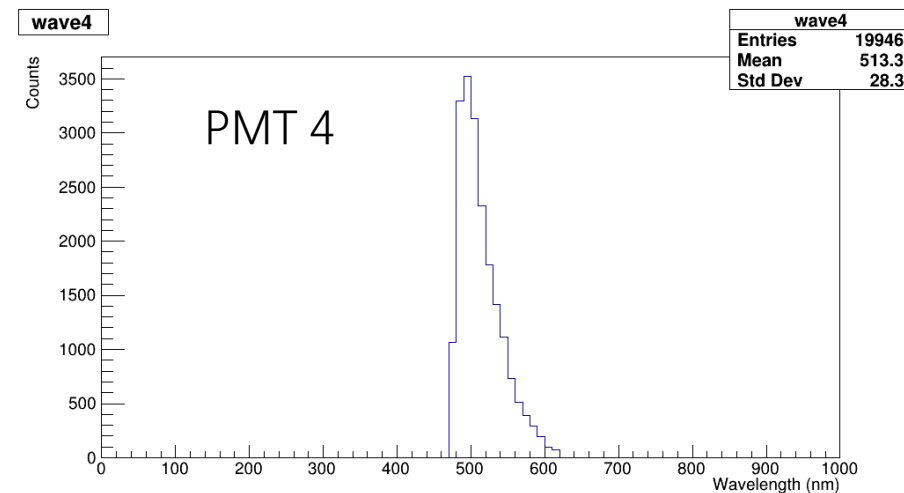
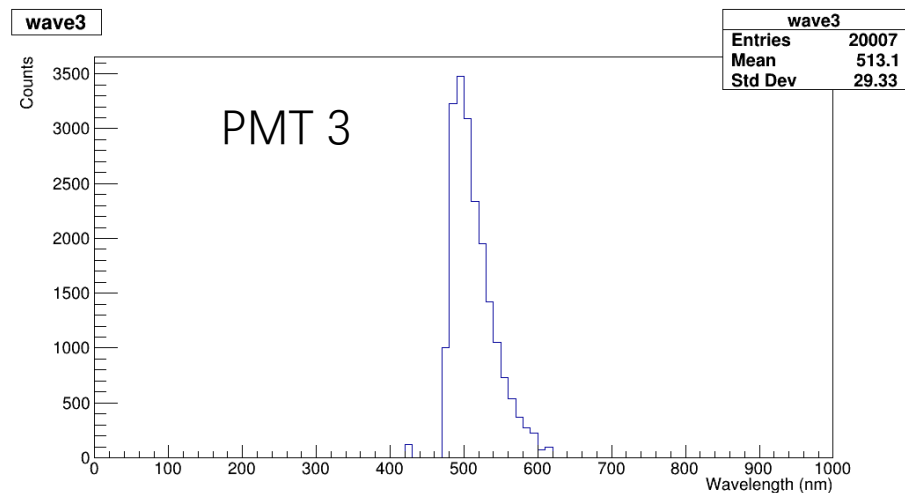
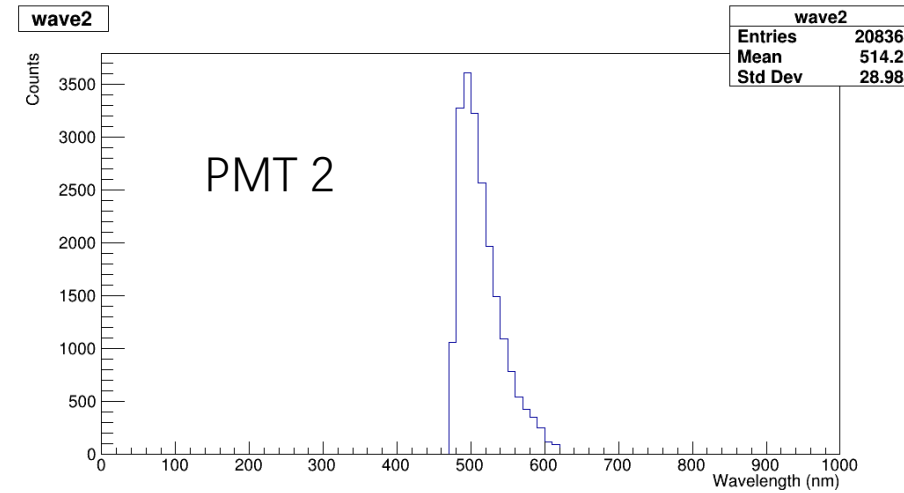
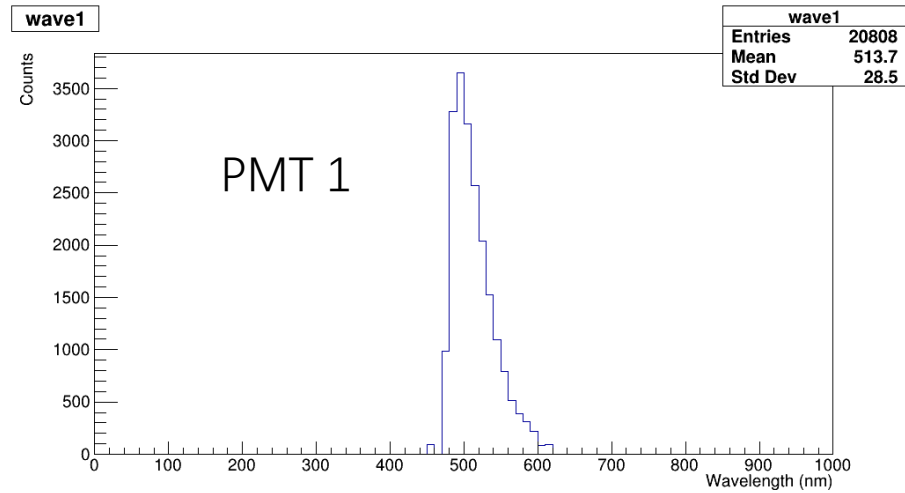


mu\_edep

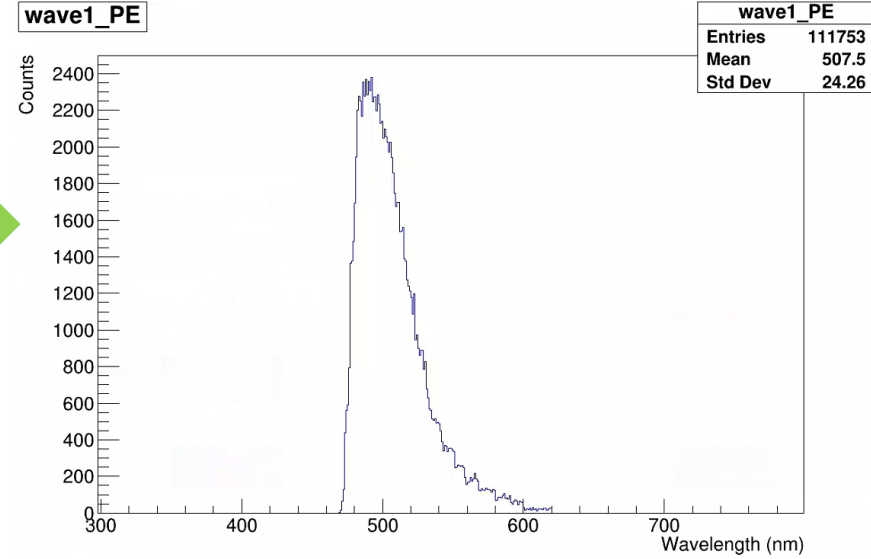
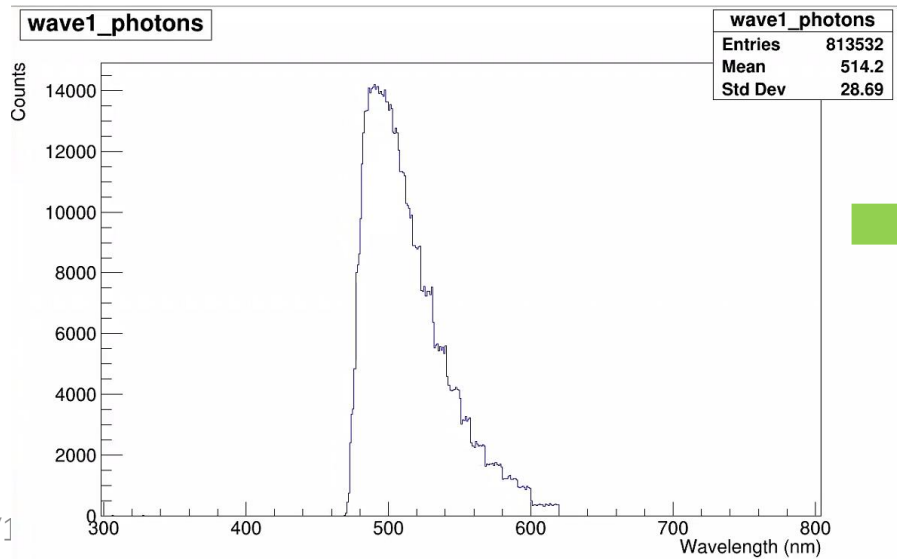
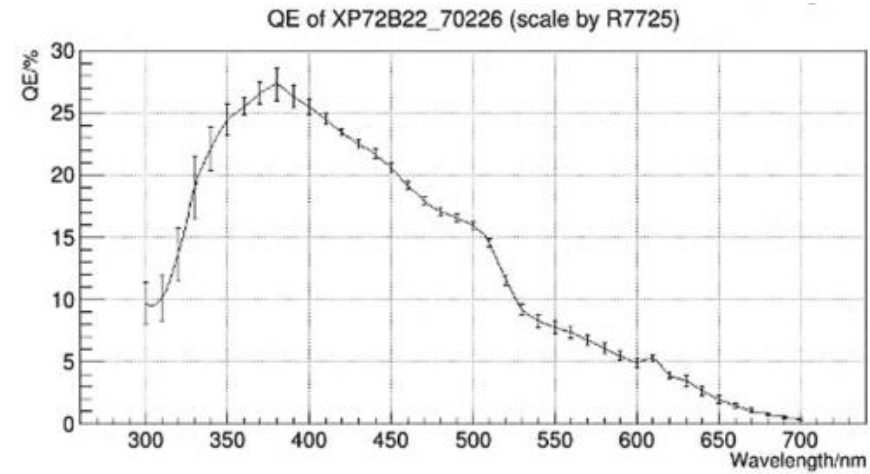


# Photon received by PMTs

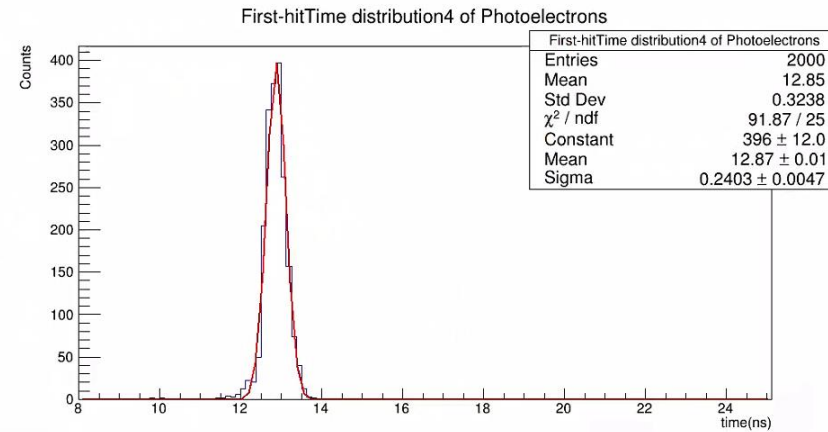
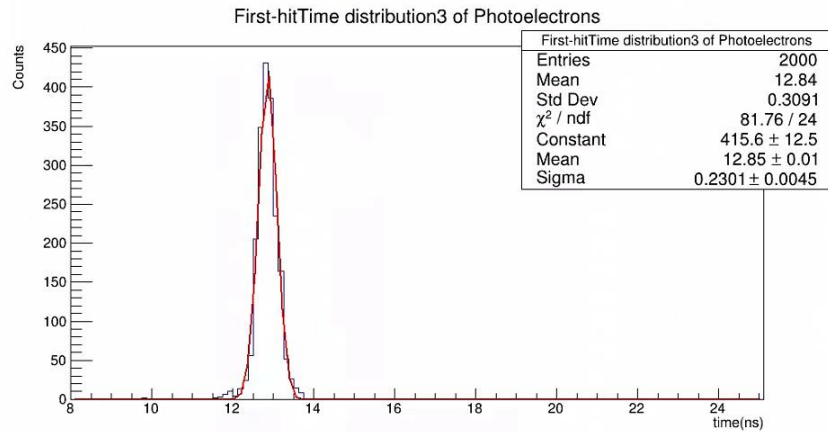
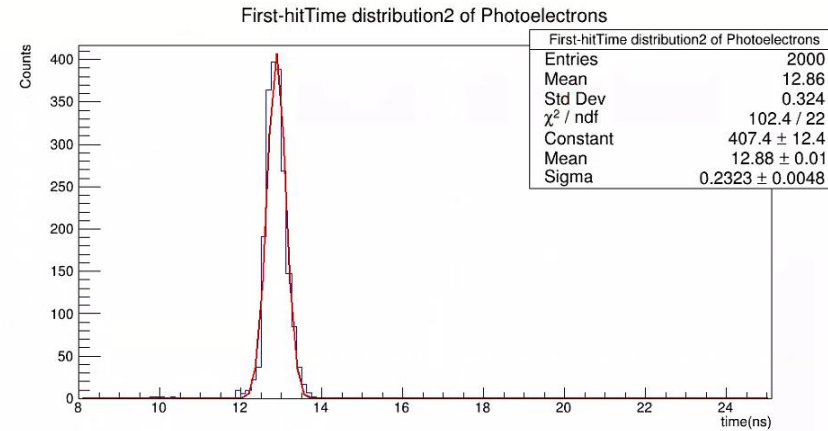
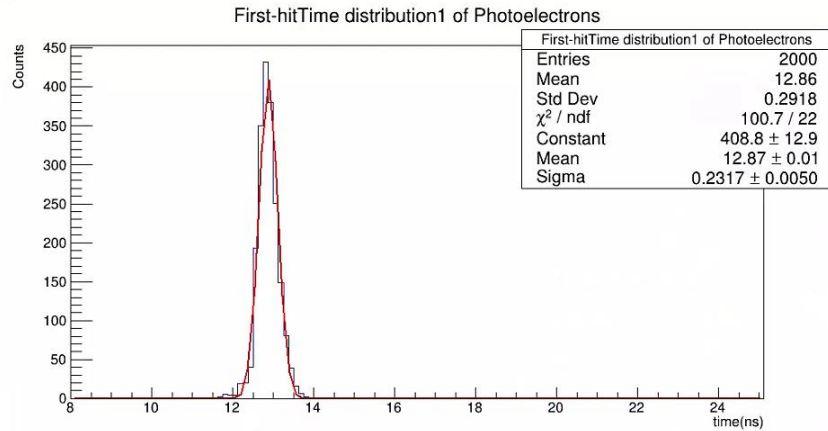
2cm thickness liquid scintillator,  
The QE of PMT is calculated at 20%.



# Considering PMT's response



# Time resolution



PMT序号

1

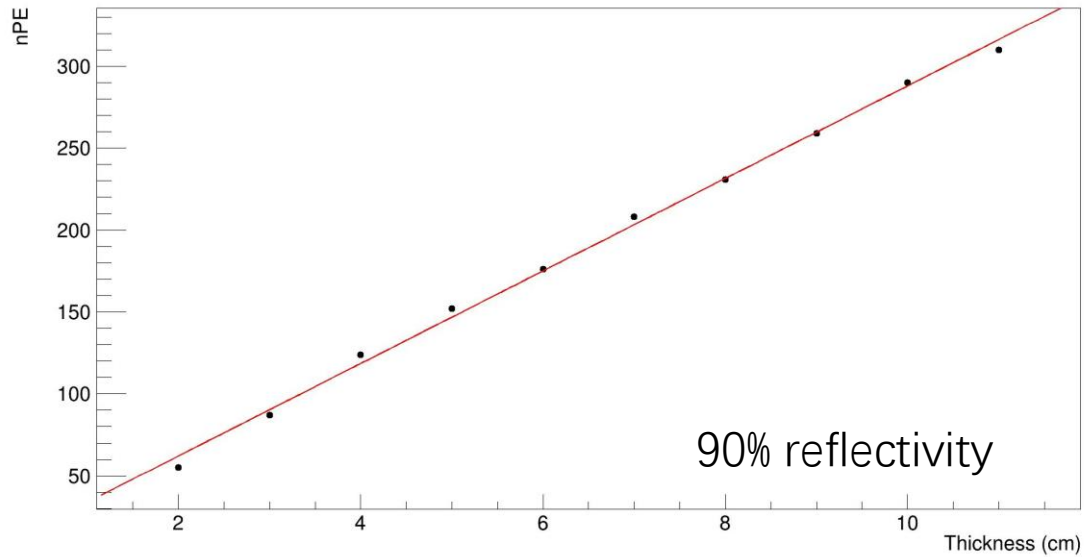
2

3

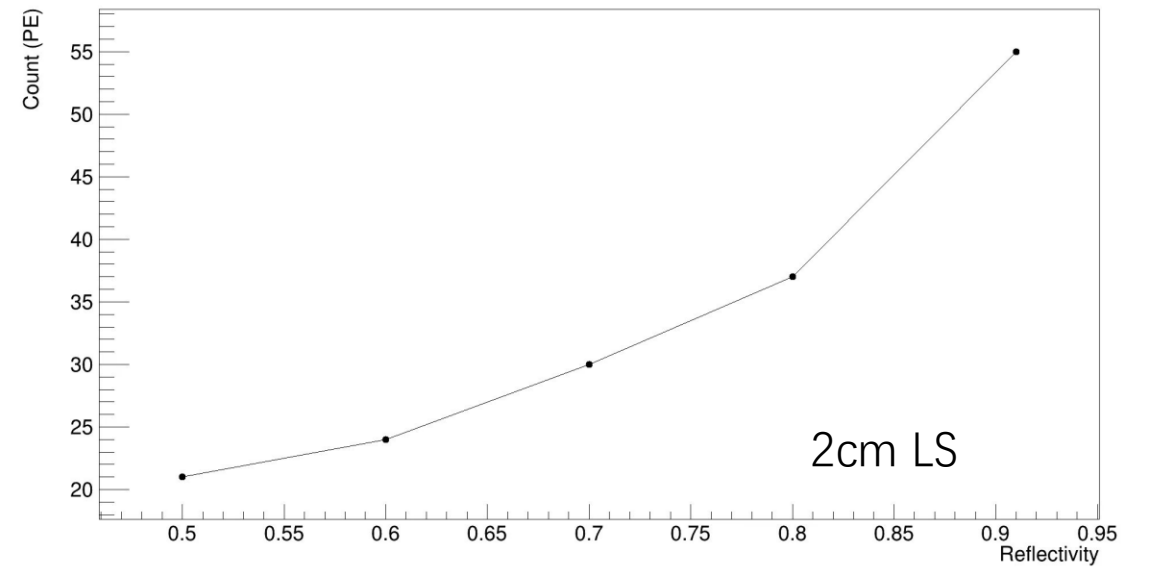
4

# Light yield of the module

nPE vs. Thickness



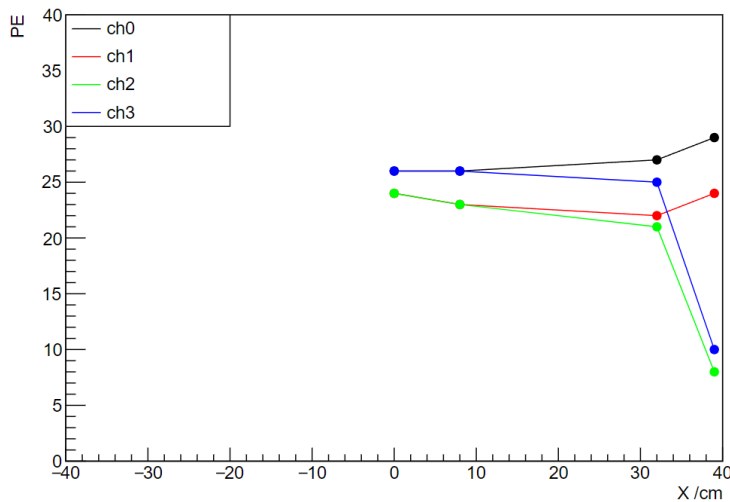
nPE vs. Reflectivity



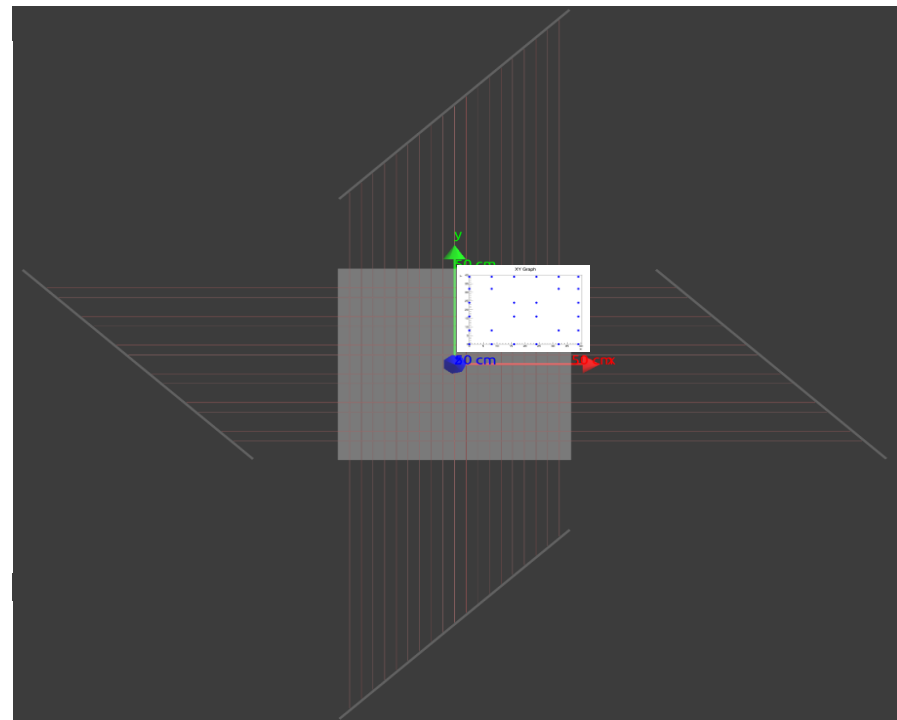
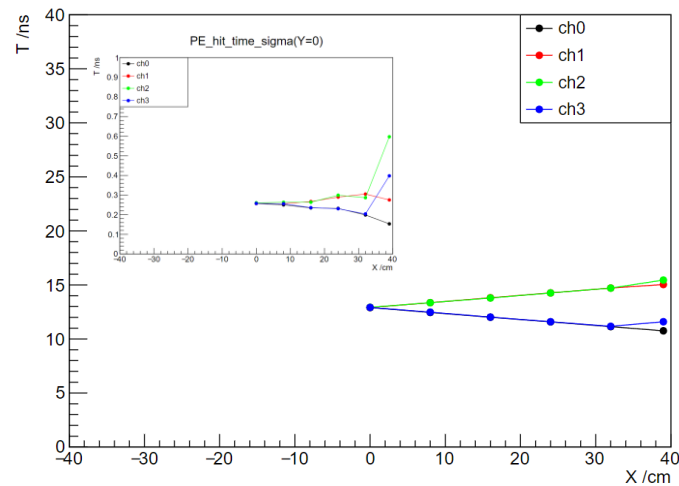


# Position response

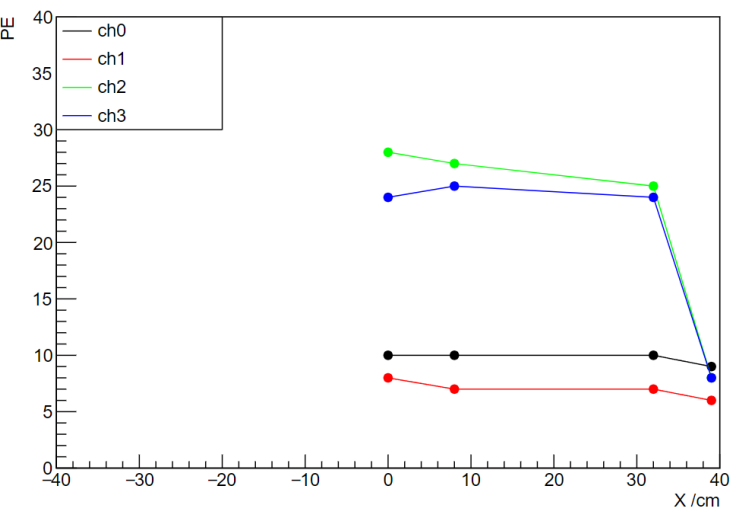
Y=0



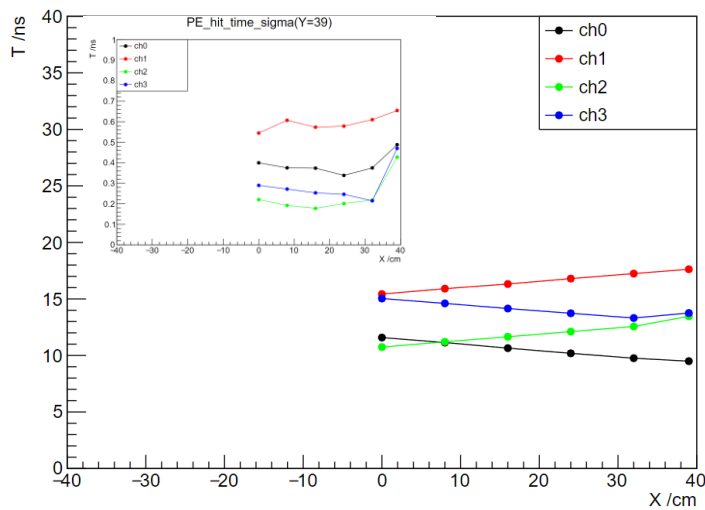
PE\_hit\_time(Y=0)



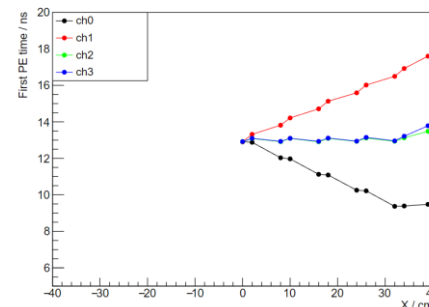
Y=39



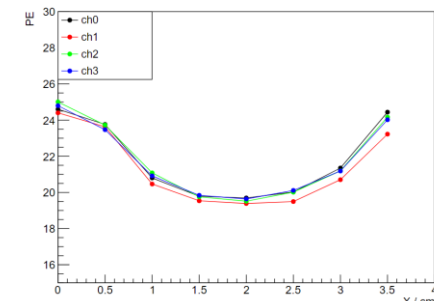
PE\_hit\_time(Y=39)



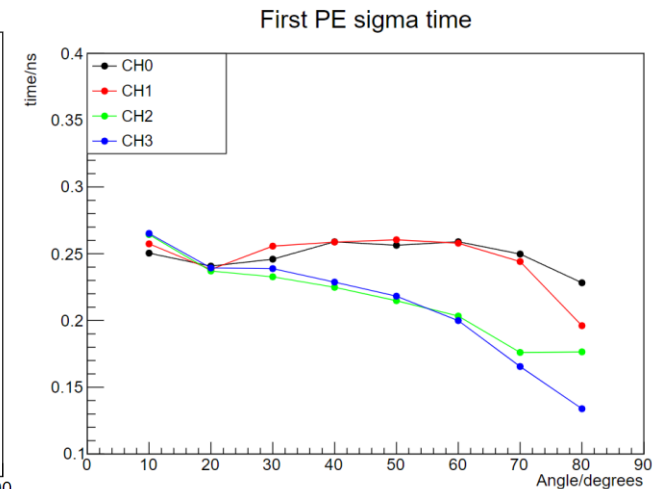
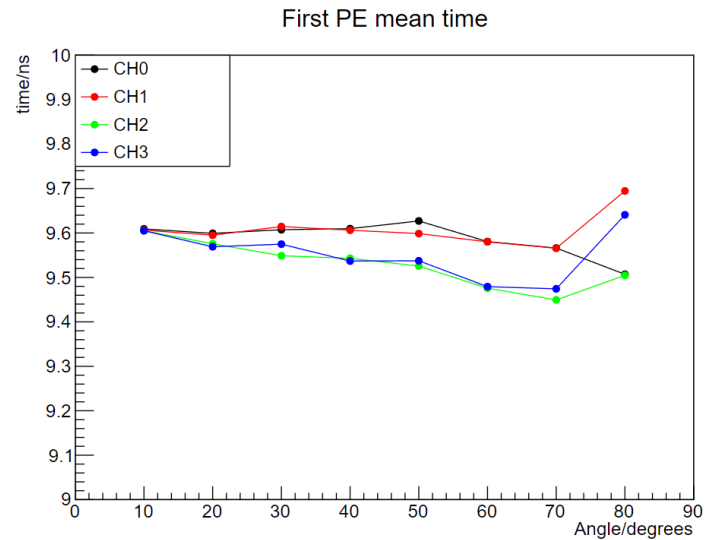
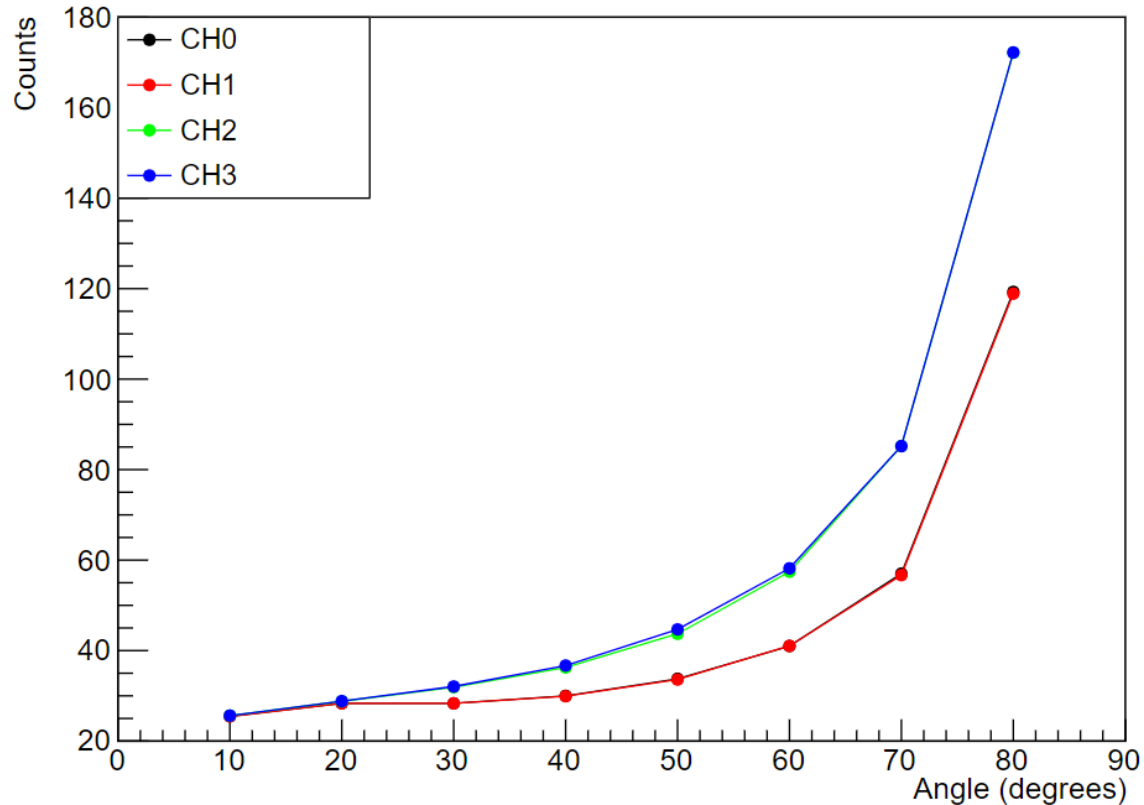
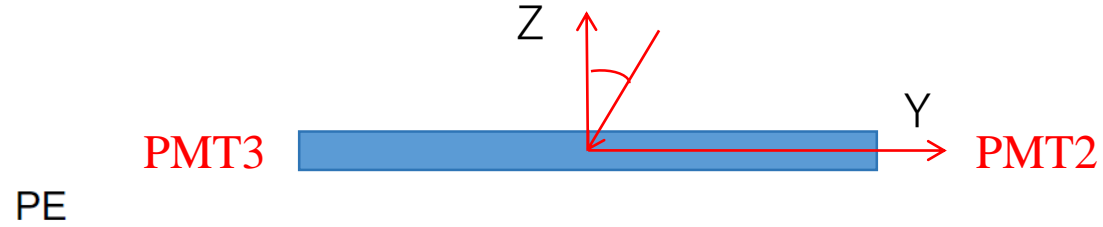
PE Mean Time(x=y)



PE (x=y)

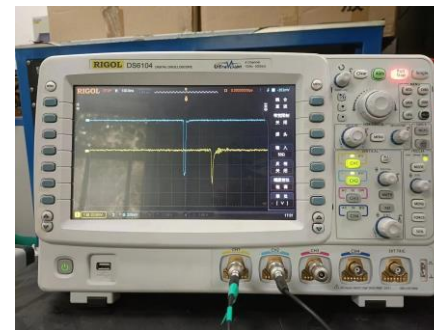
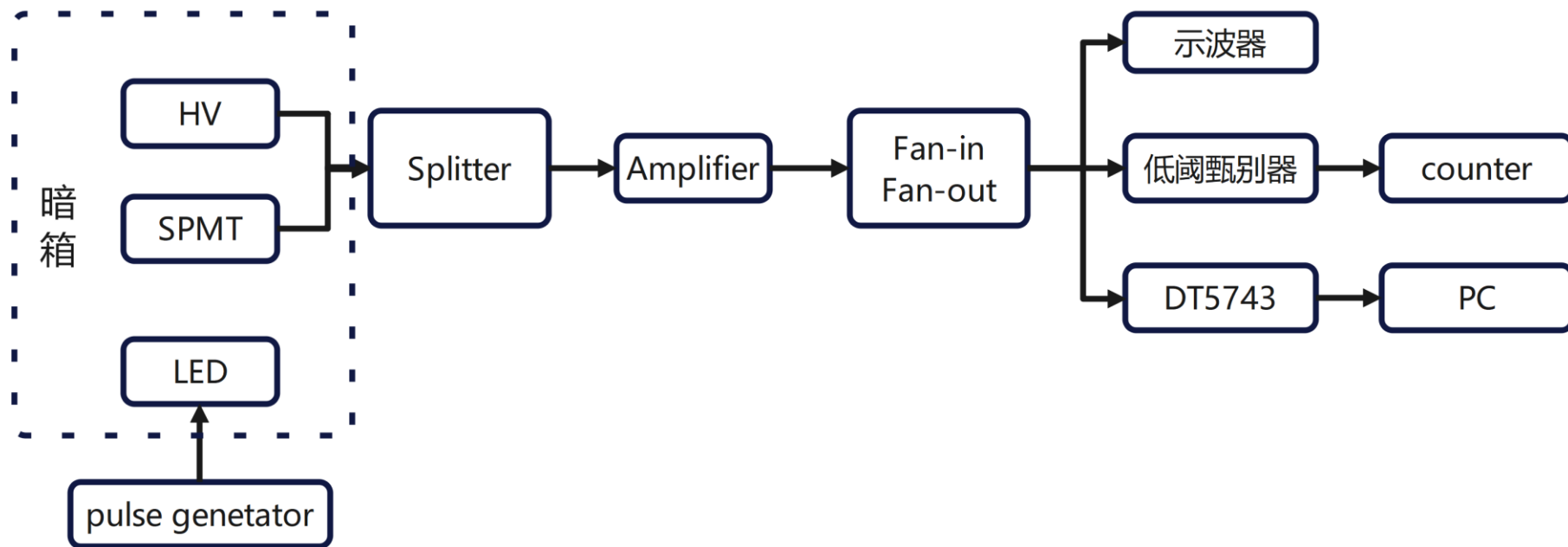


# Muon with different angle



# PMT testing

PMT测试原理



目前已用DT取数，后续需要修改程序，读取数据文件处理分析数据，即可出图

# Fiber preparation

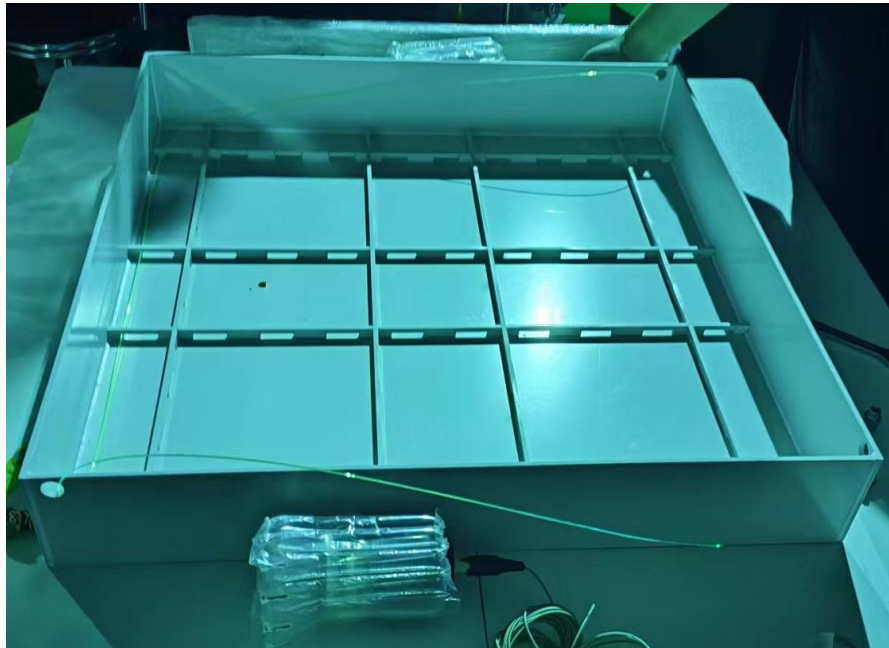
Optical fiber grinding machine: with grinding paper, polish the end face of the optical fiber that is subsequently cut;

A complete set of grinding process takes about 10min, grinding 4-5 at a time

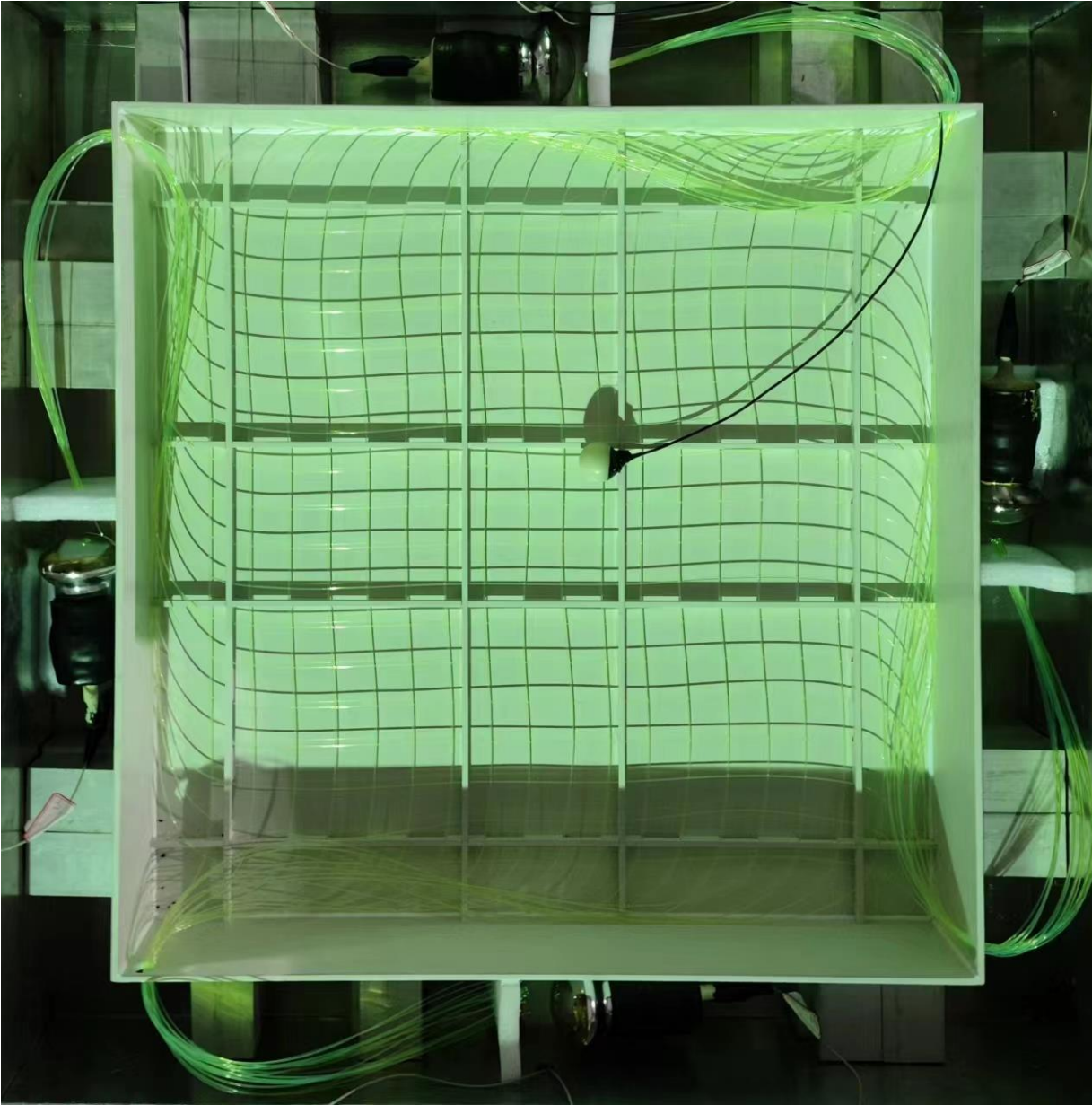


# The detector assembly

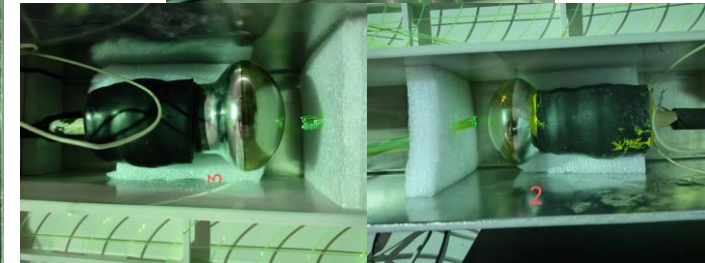
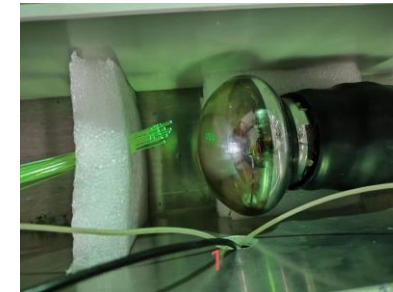
The container is shown below;



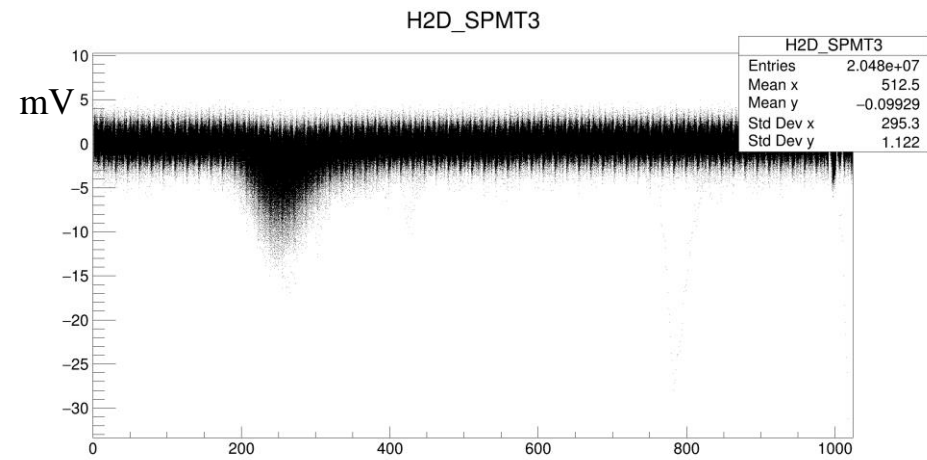
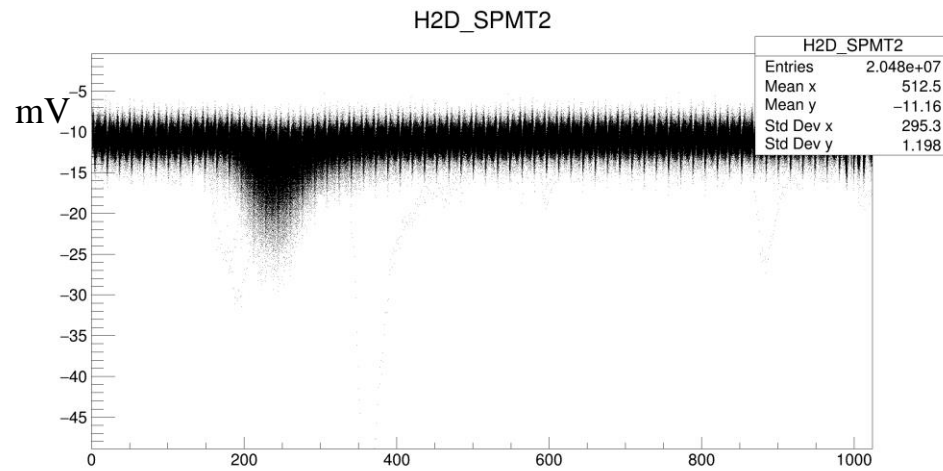
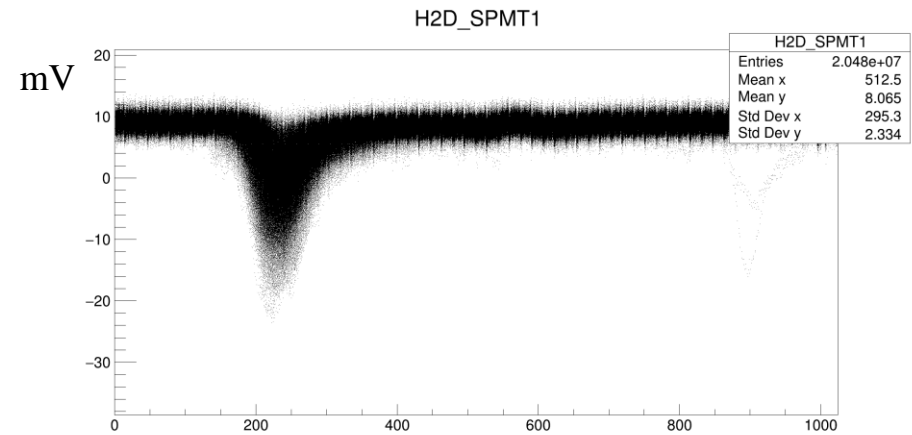
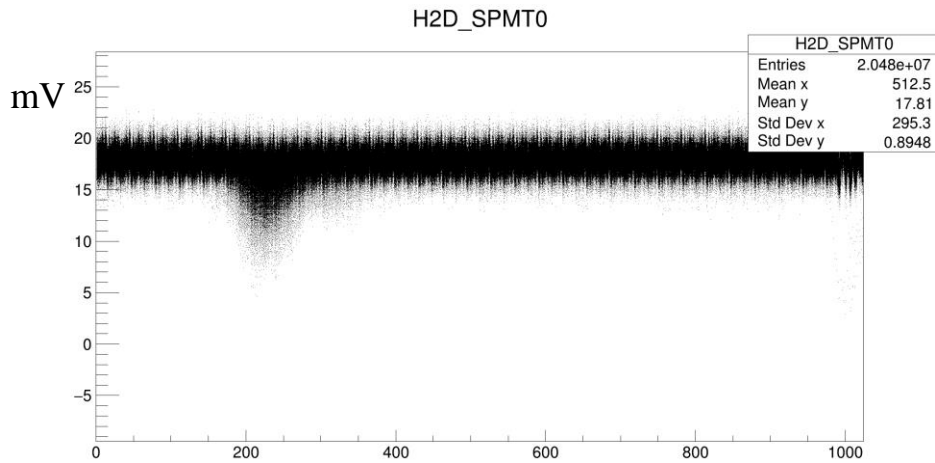
# Detector assembly



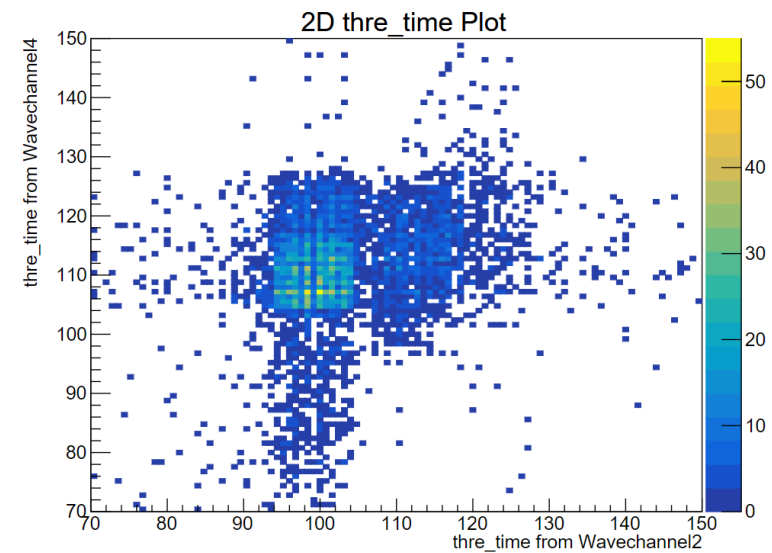
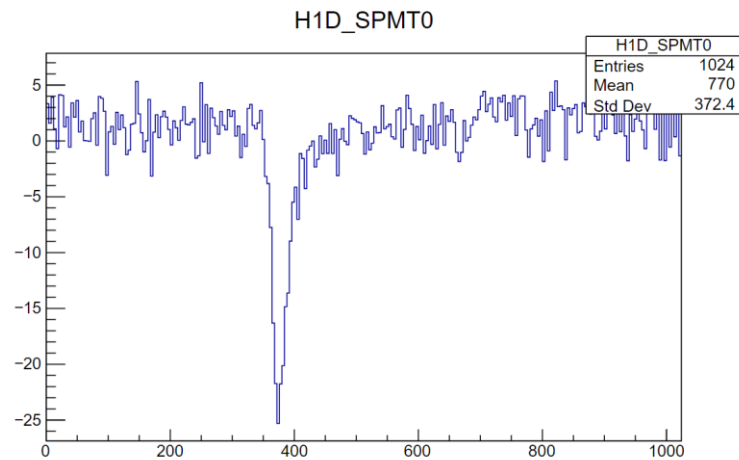
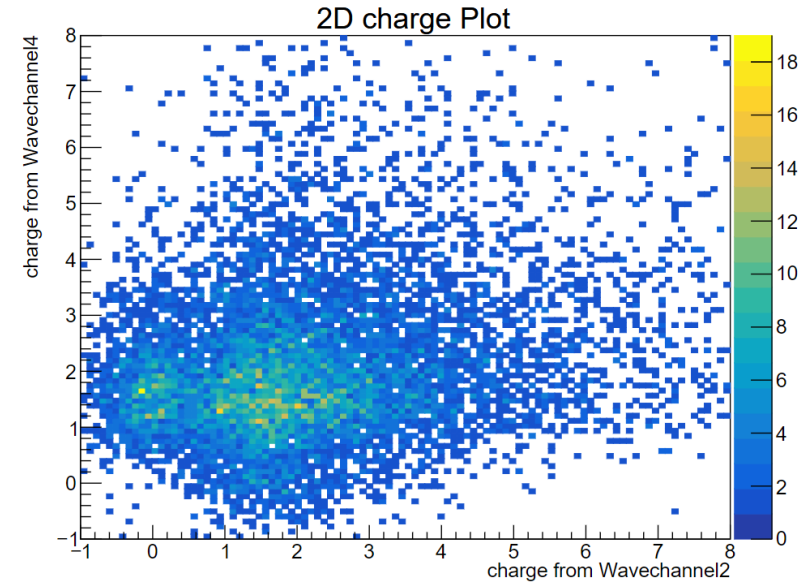
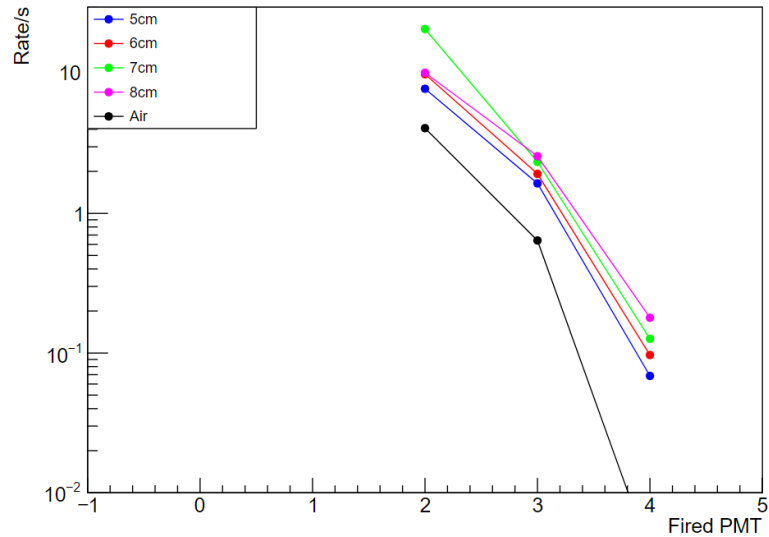
The optical fiber is determined to be 2.4m, and the distance between the two ends after the optical fiber comes out is shown in the figure below



# External trigger with LED



# Testing with Muon in air/water





# Summary

- Cosmic ray detector with liquid scintillator + WLS fiber proposed
- Simulation shows good performance
- A prototype designed and assembled firstly
- Pre-testing shows good with the structure
  - In air or in water
- More testing with LS is going on

شكرا لك, 谢谢

*Thanks for your attention!!*