Wavelength-shifting fiber enhancing PMT for the water Cherenkov detector prototype at very high energy Gamma-ray observatory

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Technology & Instrumentation in Particle Physics (TIPP2023)

4-8 September 2023

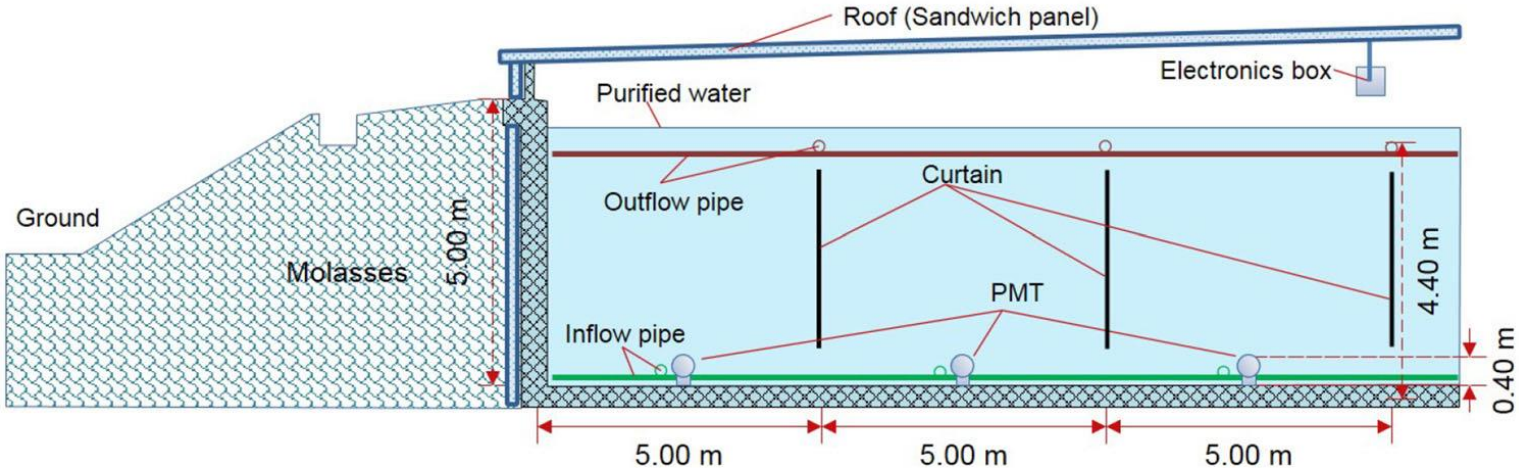
Outline

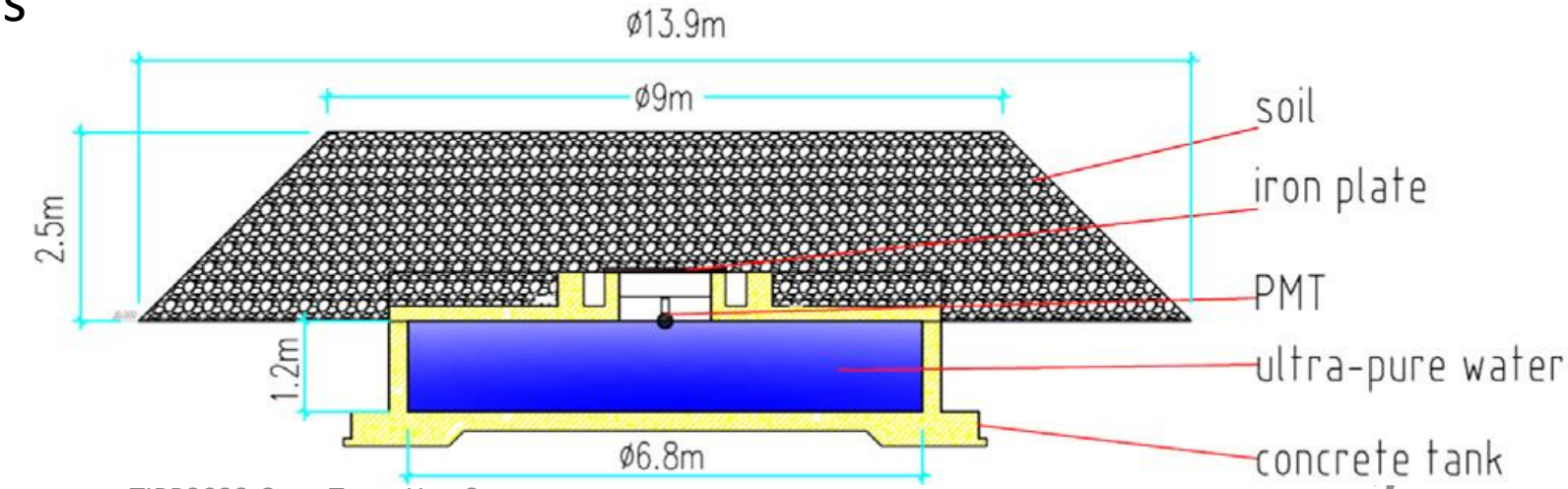
- Water Cherenkov detector(WCD) and PMT
- WLS fiber enhanced PMT
- Time performance test
- WCD prototype performance test using cosmic ray
- Primary detector simulation
- Summary

WCD (Water Cherenkov detector) in LHAASO

Large photocathode PMT used to collect the photon of WCD

- WCDA: cell size: 5 m* 5 m* 4m
  20” PMT + 3” PMT in pond 2/3
- Muon detector: ϕ6.8 m* 1.2 m
  8” PMT, time resolution < 10ns

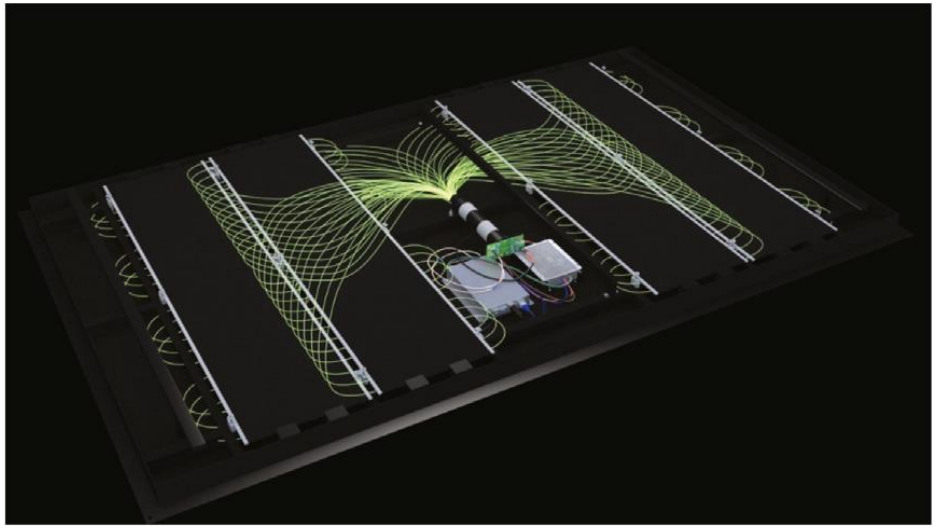




LHAASO ED (Electromagnetic particle Detector)

WLS (Wave length shift) fiber + small PMT (XP3960)

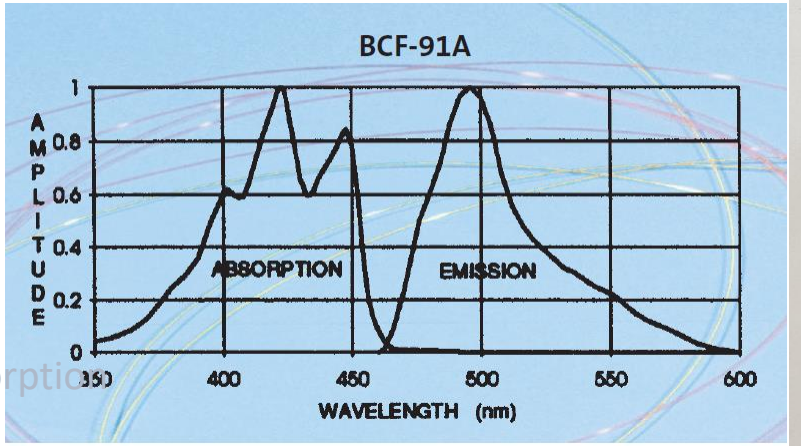
- ✓ WLS fiber couple to scintillator (25 cm width)
- ✓ PMT TTS: ~ 1 ns
- ✓ ED time resolution: < 2ns
- ✓ VME: ~20 PE

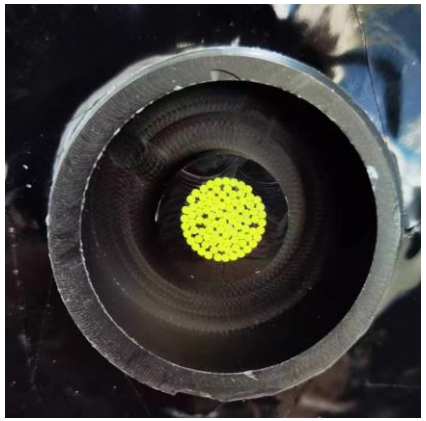


PMT + WLS Fiber to enhance the collecting effiency for water Cherenkov light

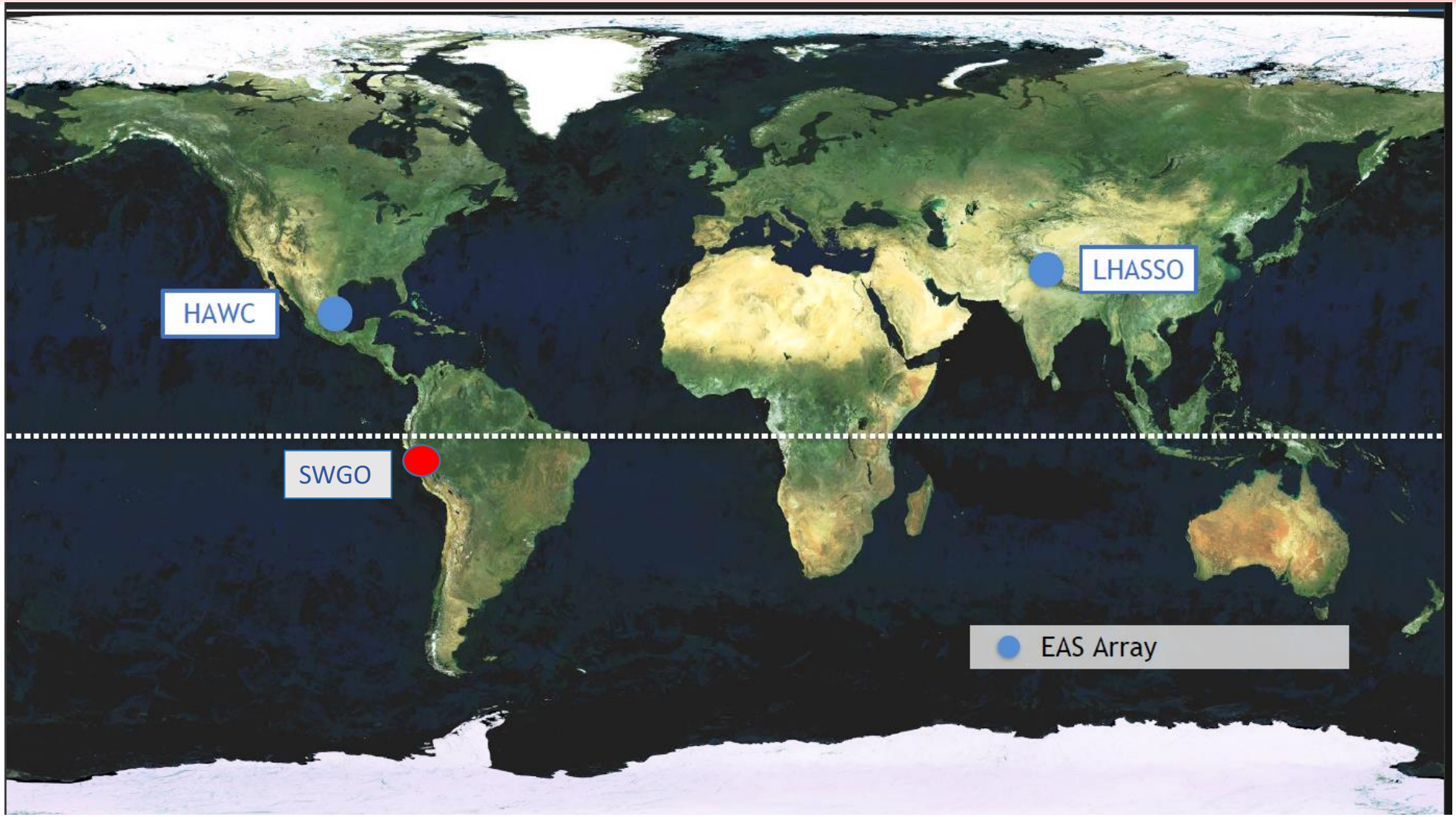
WLS Fiber enhanced PMT

- WLS Fiber
  - Saint-Gobain BCF91A: ϕ 1 mm，
    Multi-cladding
  - Saint-Gobain BCF92： improved absorption spectrum for shorter wave length
- PMT
  - HZC XP3960: 1.5”,
- Fiber bunch couple to PMT through flange
  - ✓ 50 fibers (1 m length) bounded,
  - ✓fiber ends polished

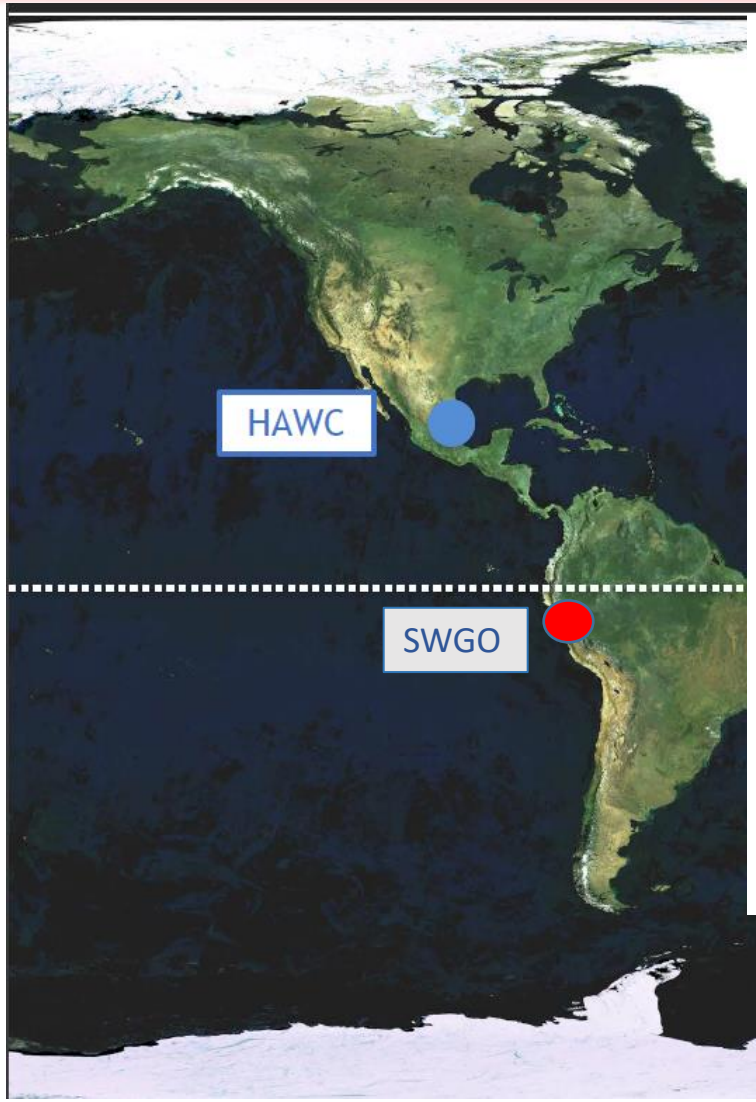




The Southern Wide-field Gamma-ray Observatory (SWGO)



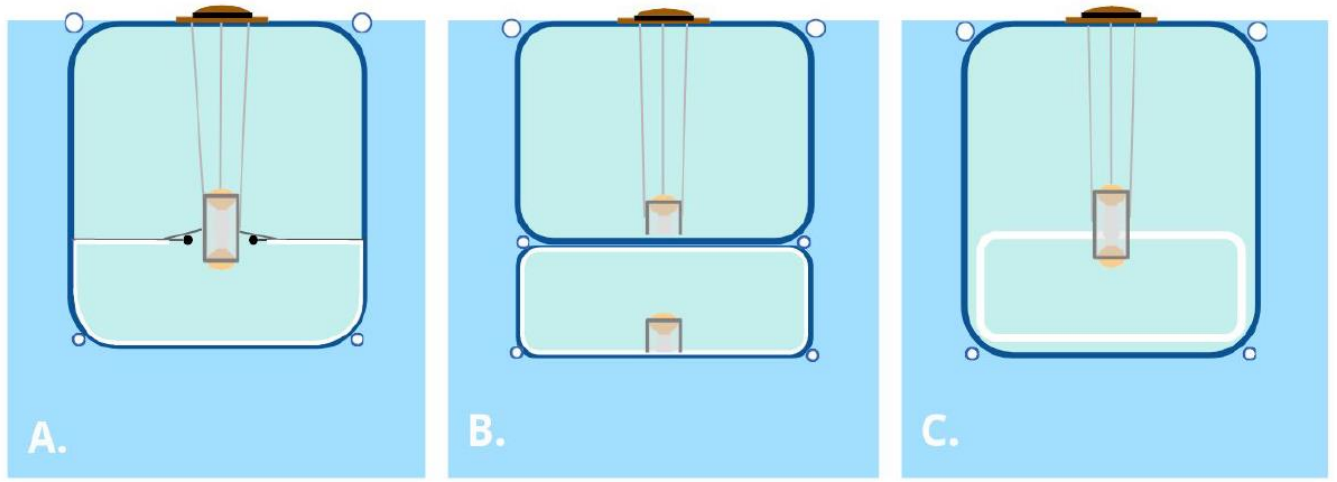
Water Cherenkov detector consept design for SWGO



SWGO
The Southern Wide-field Gamma-ray Observatory

Towards a Double-Layered Bladder

- Lower Chamber Alternatives

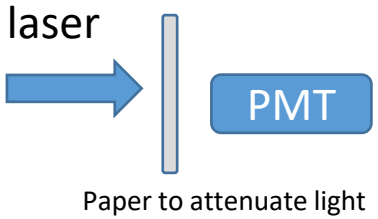


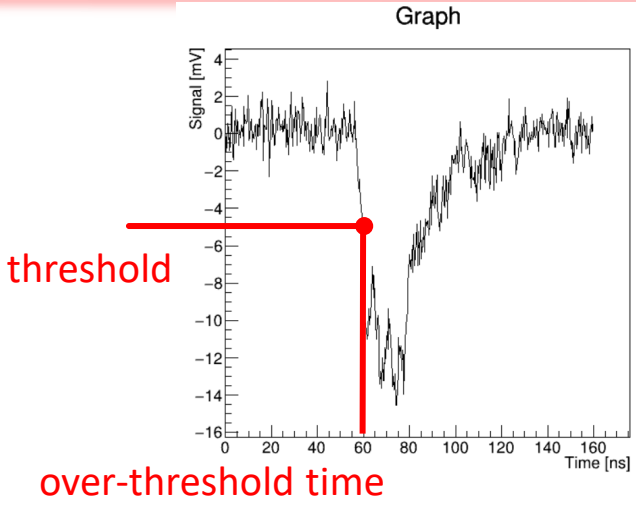
Double Layered Bladder with a Membrane

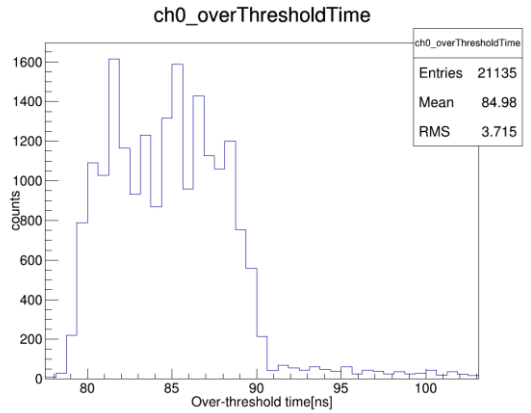
Two Separate Bladders connected in the Middle

A tyvek-only Bladder immersed in bigger Bladder

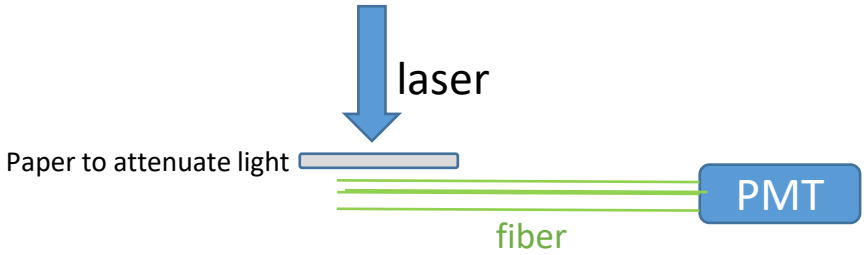
Time shift of Fiber-PMT



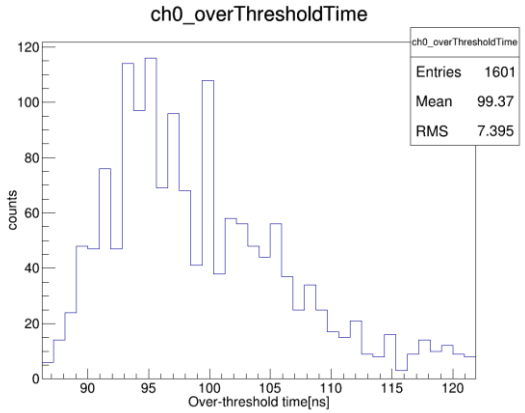




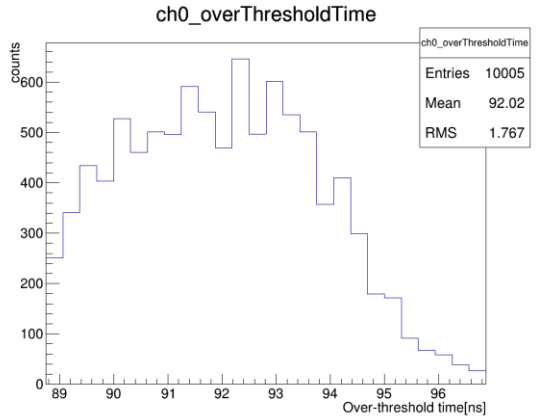
PMT time shift: stdev 3.7 ns



Test setting diagram



Fiber +PMT time shift: stdev 7.4 ns



multi-photoelectron : stdev ~1.8ns

Performance Test of Fiber-PMT in WCD

Fig1. Pure Water tank with Fiber-PMT

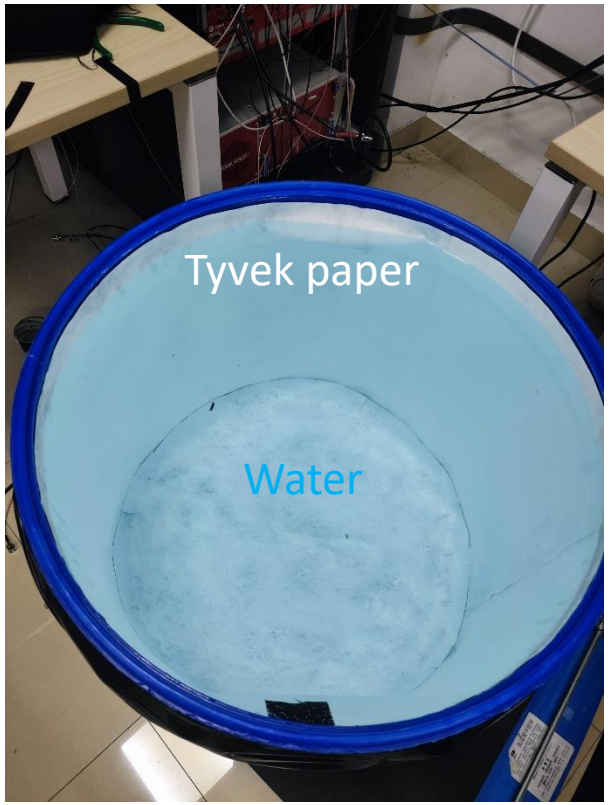


Fig2. Reflect layer: Tyvek (1085D): reflectivity 93.5%

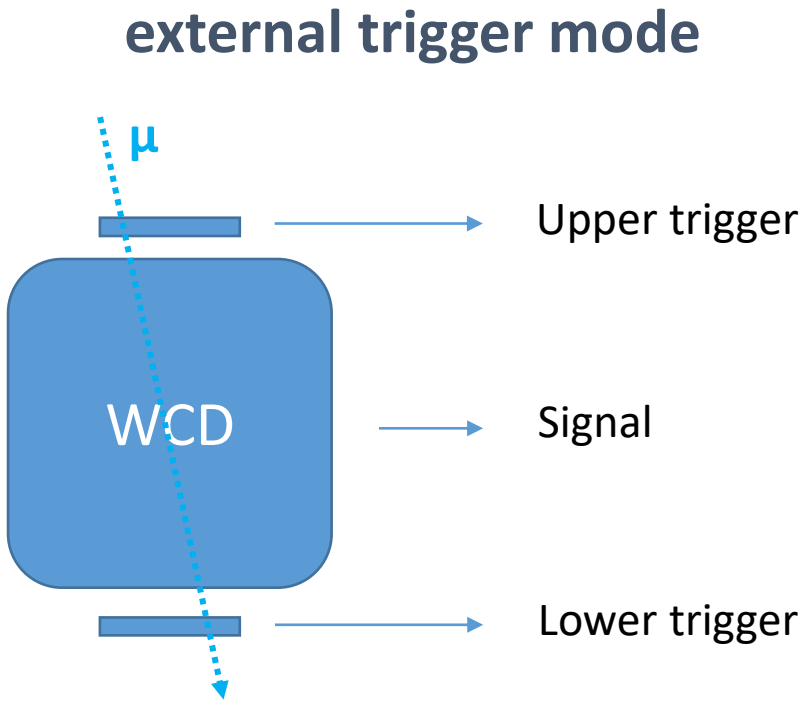


Fig.3 External trigger diagram

Performance Test with VEM (Vertical equivalent muon)

- Cosmic ray test result of fiber enhanced PMT in WCD

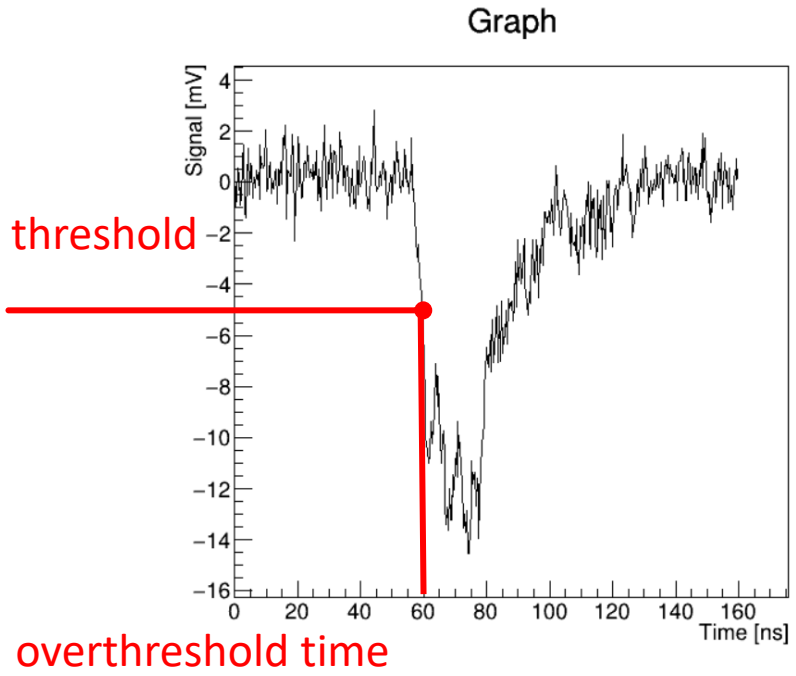


Fig.1 waveform of one event

Threshold: -5mV. PMT Gain: 3.4E5

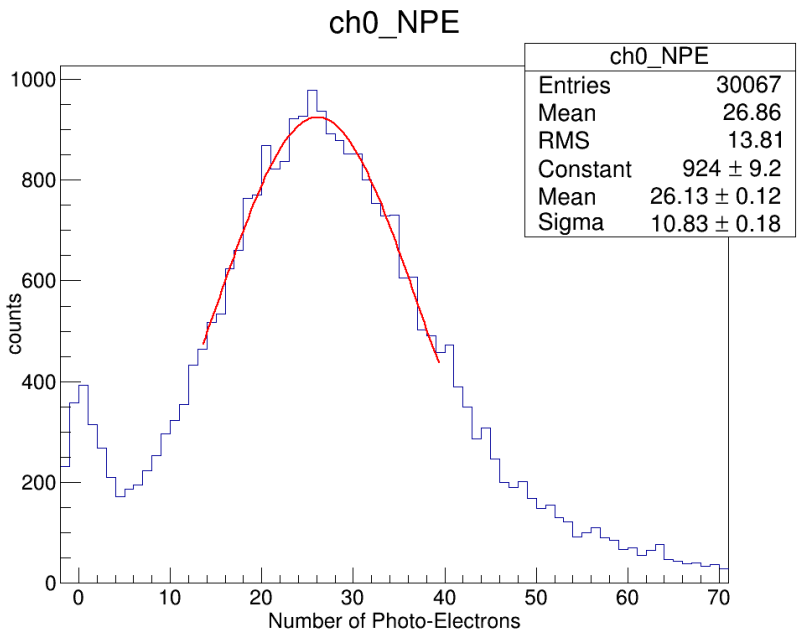


Fig.2 Number of PE for VEM.
Peak value: **26.1 PE**

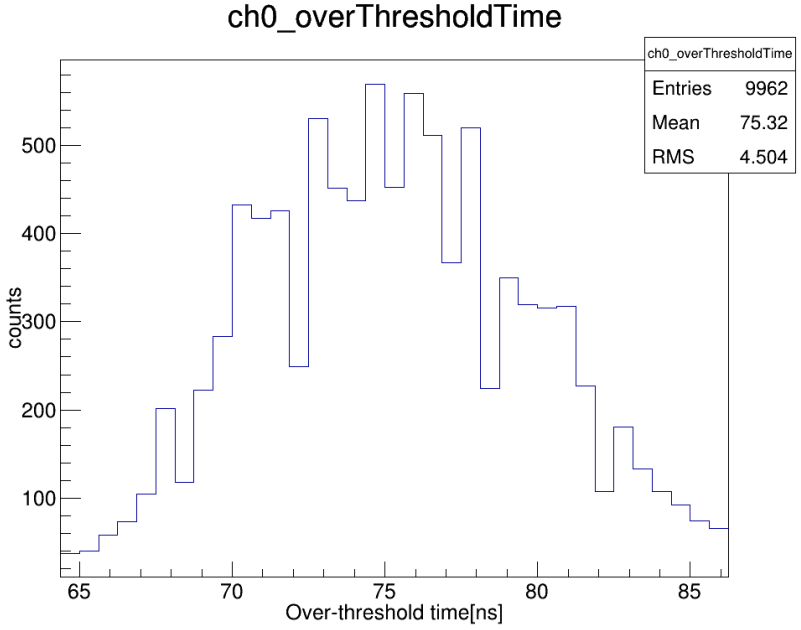


Fig.3 overthreshold time. The time resolution about **4.5 ns**

Performance Test

- tilted incidence

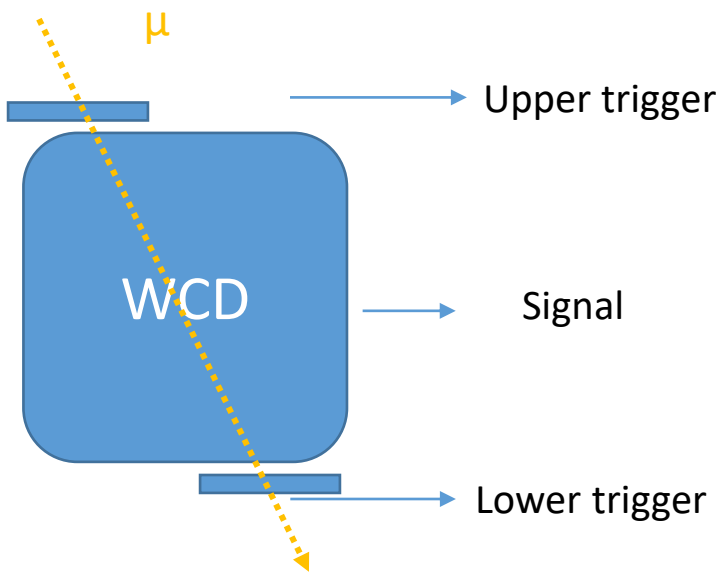


Fig. Tilted trigger diagram

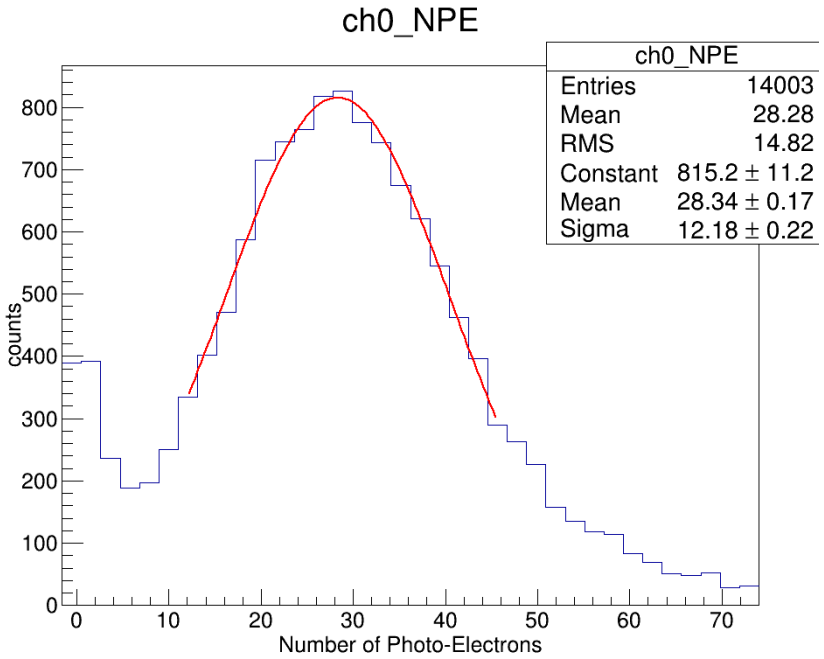


Fig.2 Number of PE. little large than VEM peak value: **28.3**

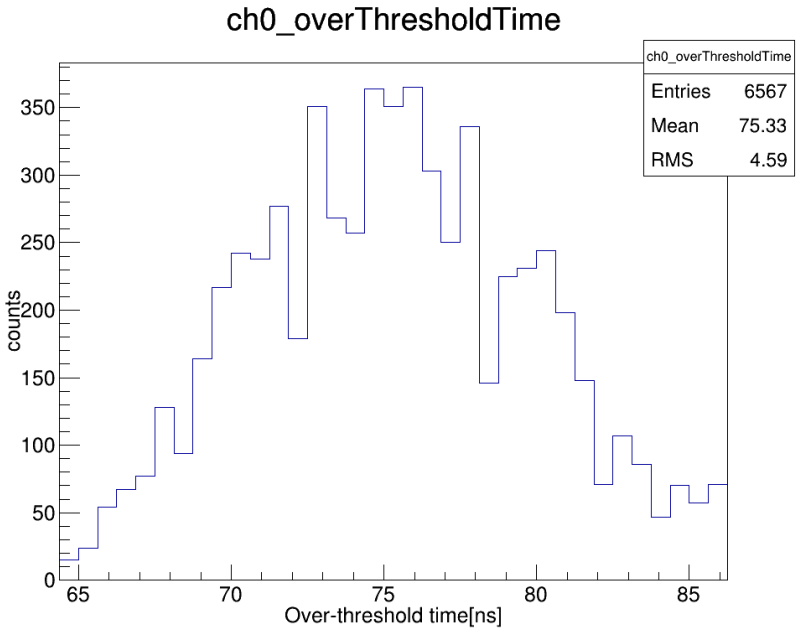


Fig.3 overthreshold time. The time resolution about **4.6 ns**. Similar as VEM.

Performance Test

- middle and edged incidence

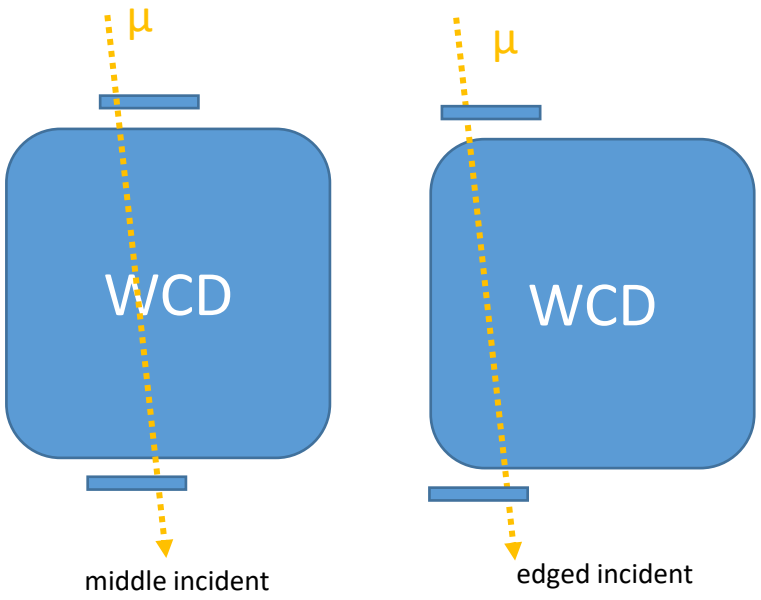


Fig1. Trigger diagrams

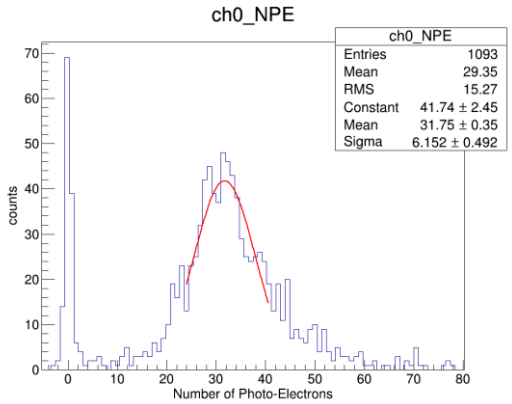


Fig.2 Number of PE histogram for middle incident event

NPE mean value: 31.6

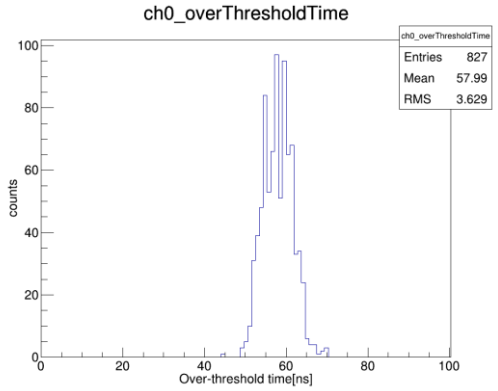


Fig.3 Over-threshlod time histogram for middle incident event

stdev : 3.6ns

22%

5.5%

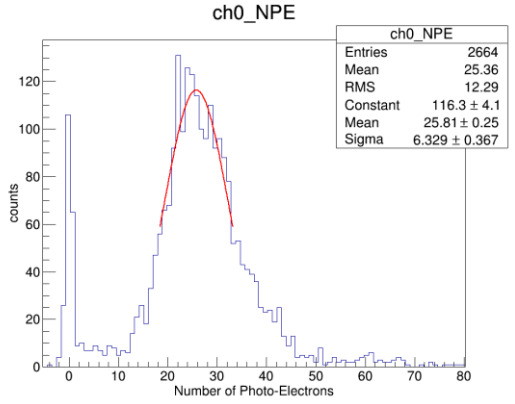


Fig.4 Number of PE histogram for middle incident event

NPE mean value: 25.8

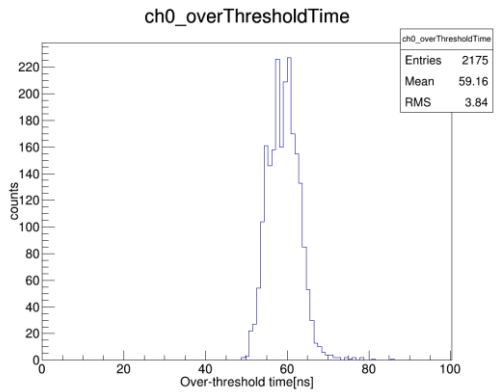


Fig.5 Over-threshlod time histogram for middle incident event

stdev : 3.8ns

Performance Test

- Self trigger test

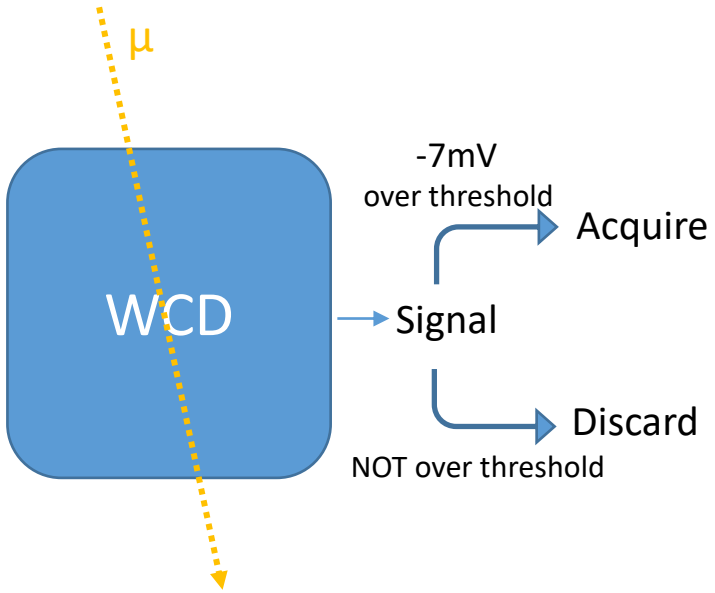


Fig1. Self trigger diagram

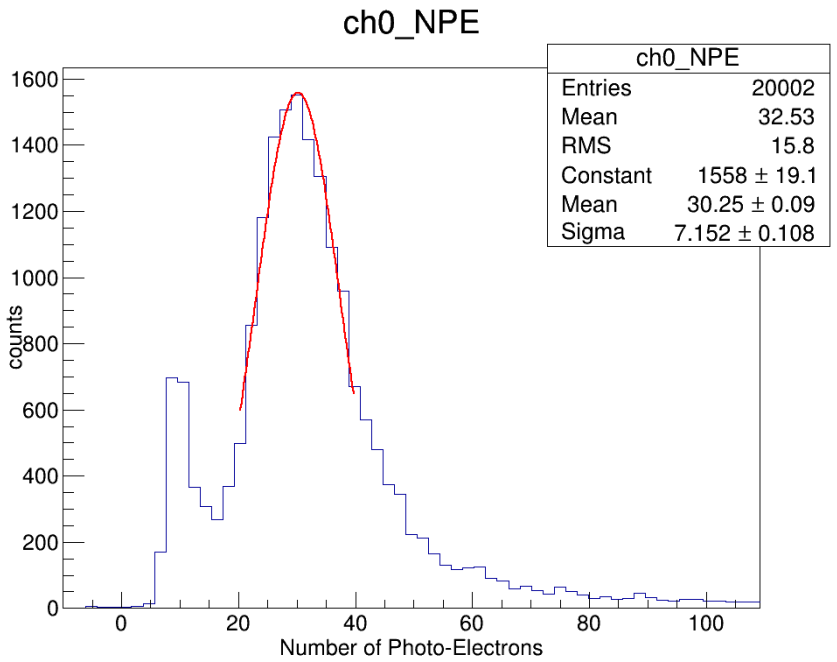


Fig.2 Number of PE for **self trigger**
Peak NPE value: 30.25

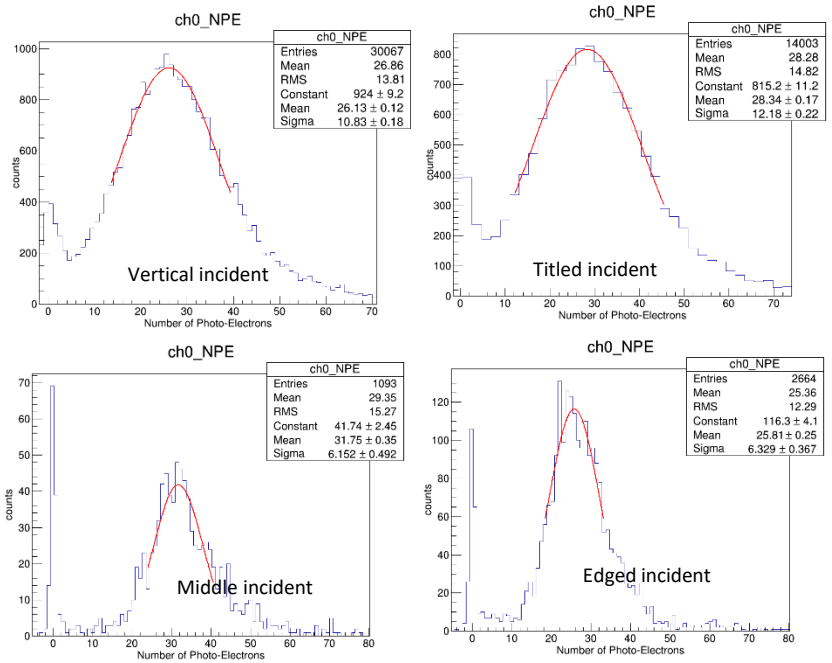


Fig.3 **External trigger** result summary

WCD test for PMT without WLS fiber

- removed WLS fiber

Fig1. removed fiber

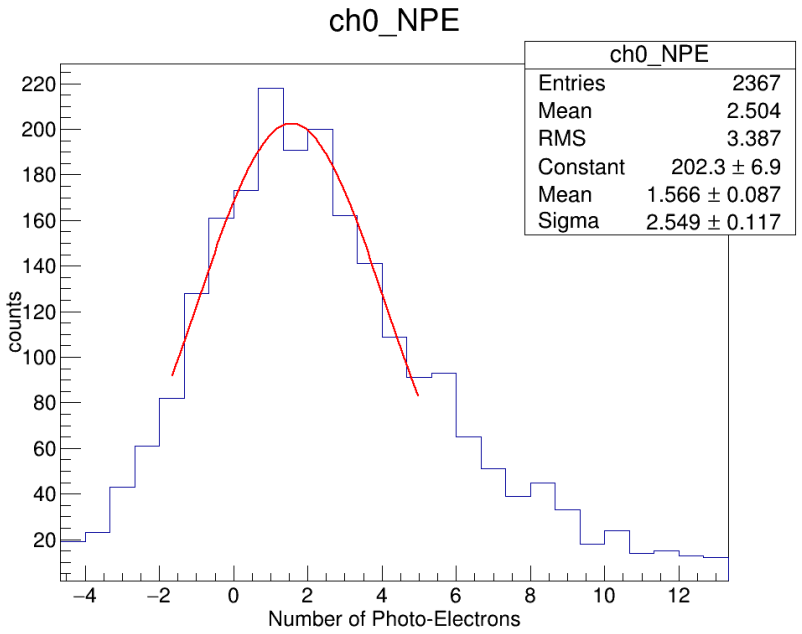


Fig.2 Number of PE **without** fiber.
peak value: **1.6**

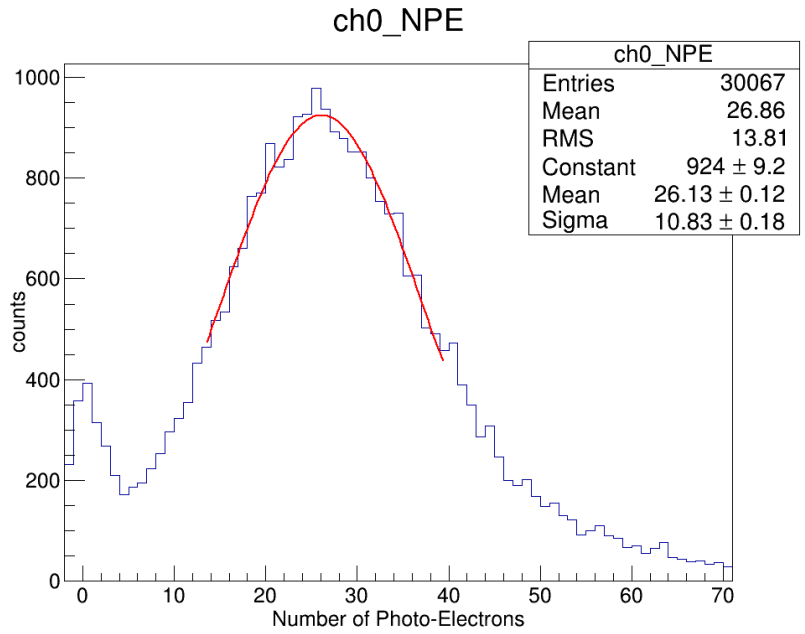


Fig.2 Number of PE **with** fiber.
peak value: **26.1**

Primary detector simulation

- Simulation setting

Muon particle 5GeV 100000 vertical incident events

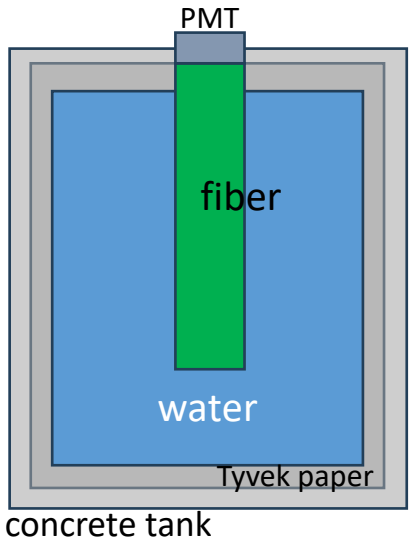
Geant4 software

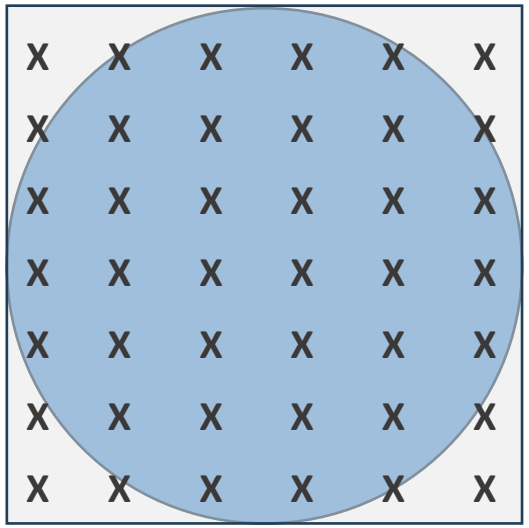
Fiber radius: 1.5cm

Fiber length: 48cm

Tank radius: 30cm

Tank height: 60cm





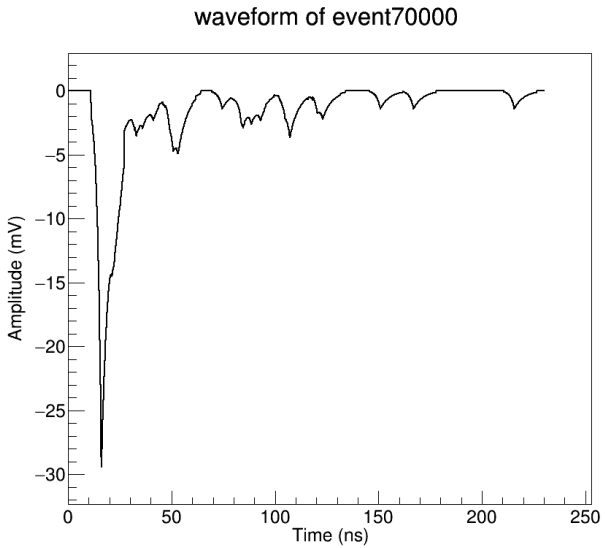


Fig1. WCD structure in simulation. Fiber is a whole

Fig2. Throw incident points above detector plane from top

Fig3. Simulated waveform

Primary detector simulation result

- Simulation result

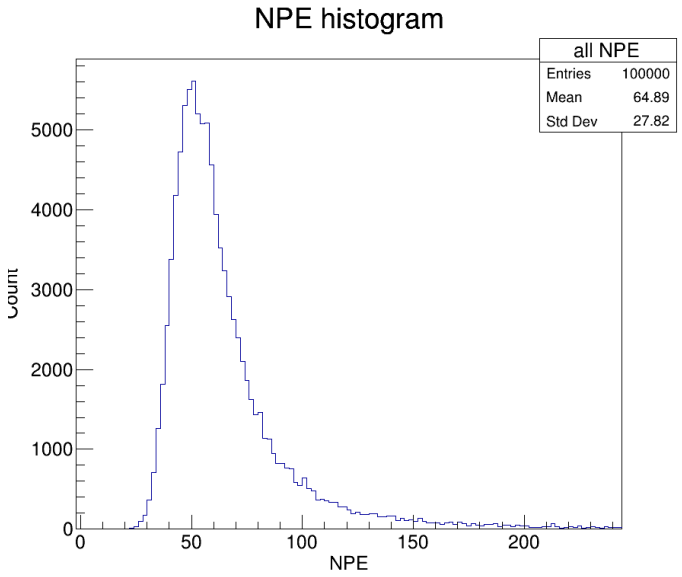


Fig1. NPE histogram

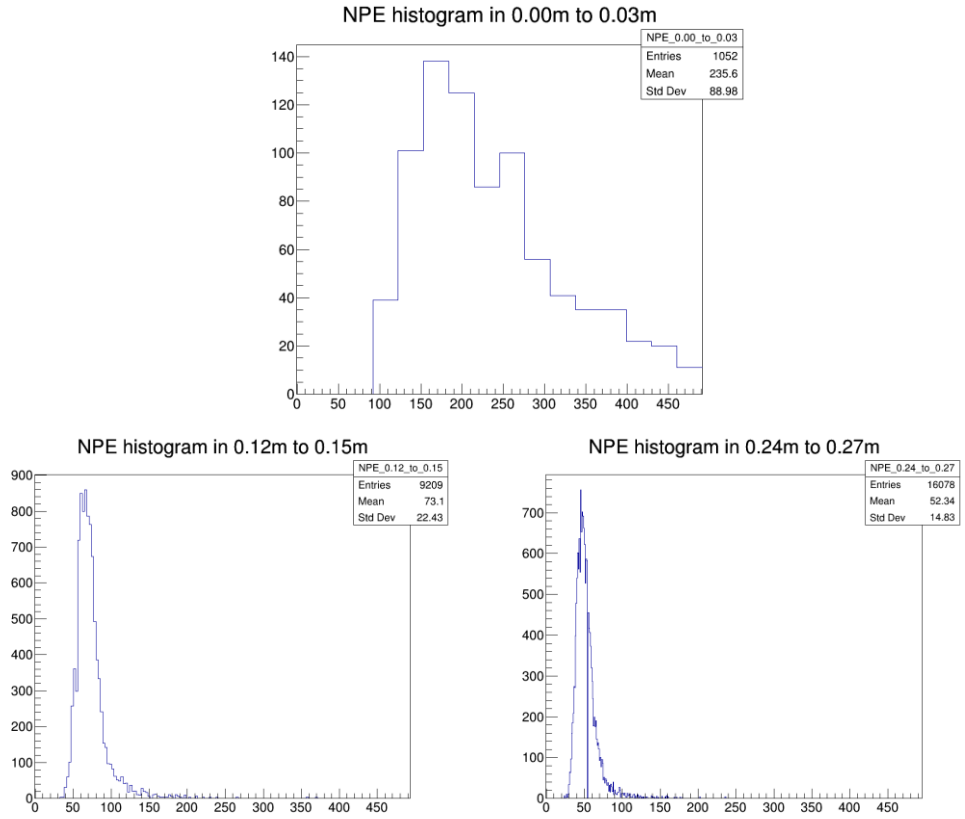


Fig2. NPE histograms at different distance to fiber

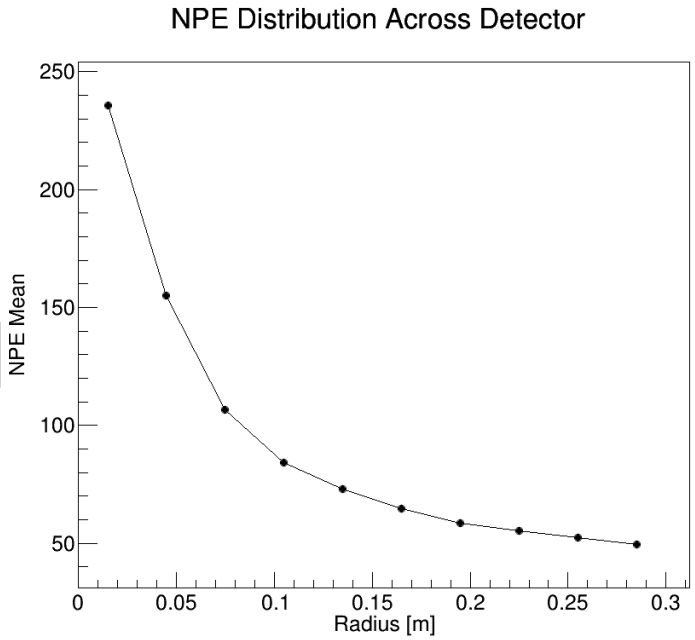


Fig3. NPE mean distribution across detector plane

50~240

Primary detector simulation result

- Simulation result

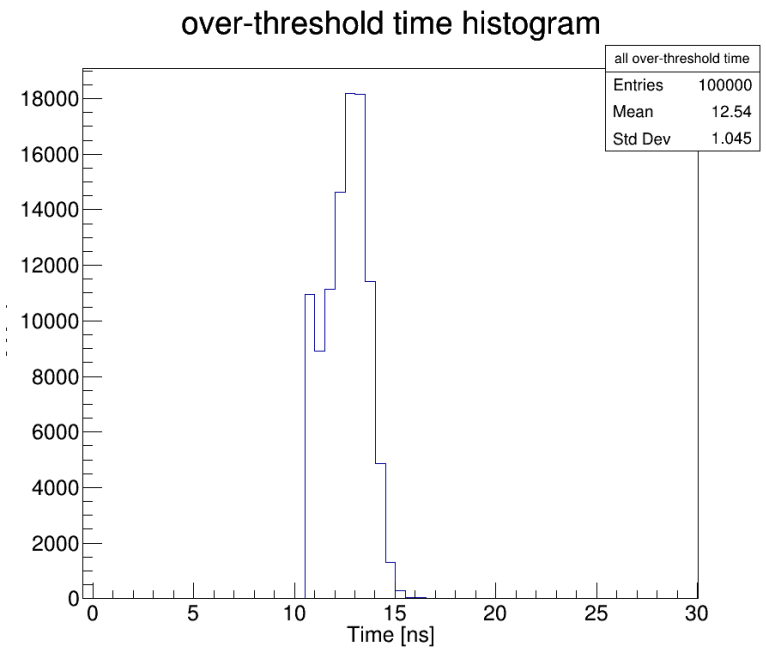


Fig1. over-threshold time histogram, threshold **-5mV** , stdev **1.045ns**

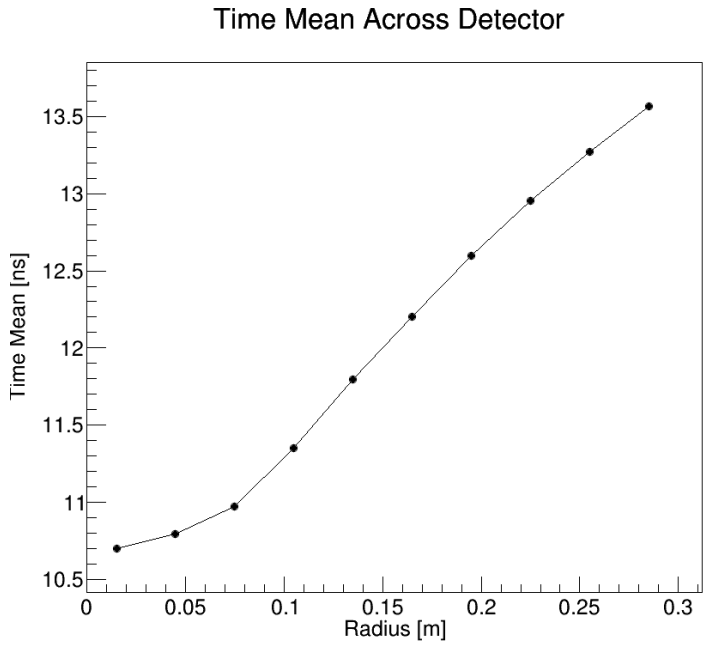


Fig2. over-threshold time mean distribution

10.7ns~13.5ns

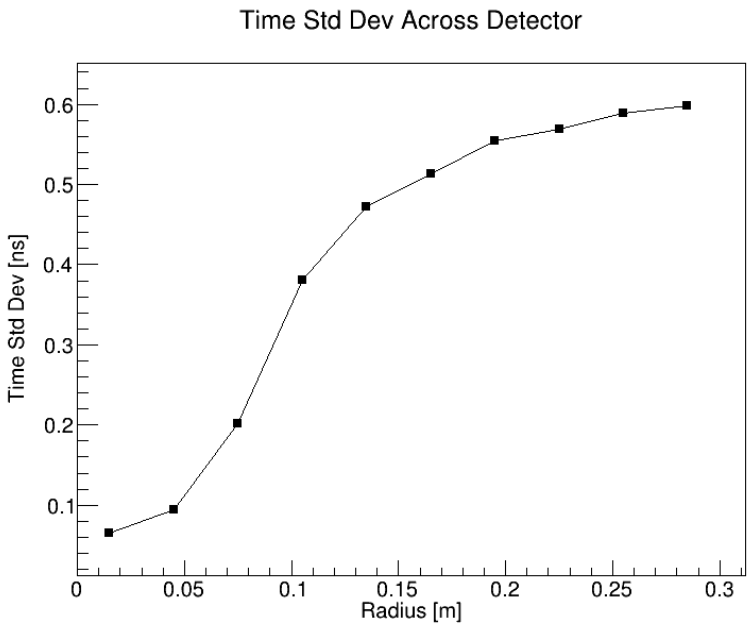


Fig3. over-threshold time stddev distribution

0.06ns~0.6ns

Summary

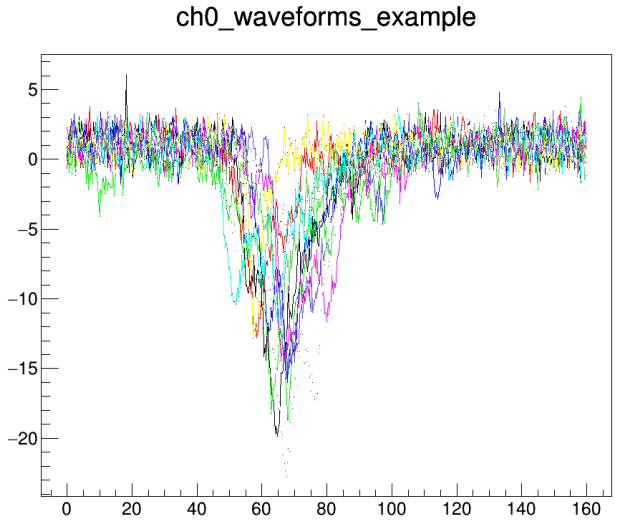
- WLS fiber enhanced PMT was proposed to use in WCD
  - The time resolution(TTS): 7.4 ns (single photoelectron)
- The performance of Fiber-PMT test in small water tank
  - **The WLS fiber improved the PMT light collection in WCD**
  - Peak value of vertical equivalent muon: >20 PE
  - Time resolution: ~4.5 ns
  - Able to work and show a clear single-muon peak under self trigger mode
- Simulation
  - We developed the simulation program and obtained some primary results
  - May continue to optimize the program and study the performance of detectors in different sizes in the future

Thanks for your attention!

Backup slides

3.2GS/s Digitizer

- **Calculate number of photo-electrons(NPE)**
- Calculate **the charge** of signal
  1) perform an integral over the entire waveform
  2) subtract the baseline from the waveform integral
- NPE = charge / (1.6 * 10^-19) / gain




```
Phi             = 2.24179
Corex           = -0.500036
Corey           = 0.00470904
HitsE           = 5
HitsE.fUniqueID = 0, 0, 0, 0, 0
HitsE.fBits     = 33554432, 33554432, 33554432, 33554432, 33554432
HitsE.id        = 0, 0, 0, 0, 0
HitsE.status    = 0, 0, 0, 0, 0
HitsE.time      = 15.6503, 21.8578, 16.9085, 37.8177, 16.9137
HitsE.pe        = 2.30795, 2.52396, 2.38154, 2.49784, 2.44836
HitsE.np        = 62, 98, 51, 147, 42
root [4]
```

Simulation output data