Prototype Test of a Water Cherenkov Detector Designed Based on SWGO Lake Concept

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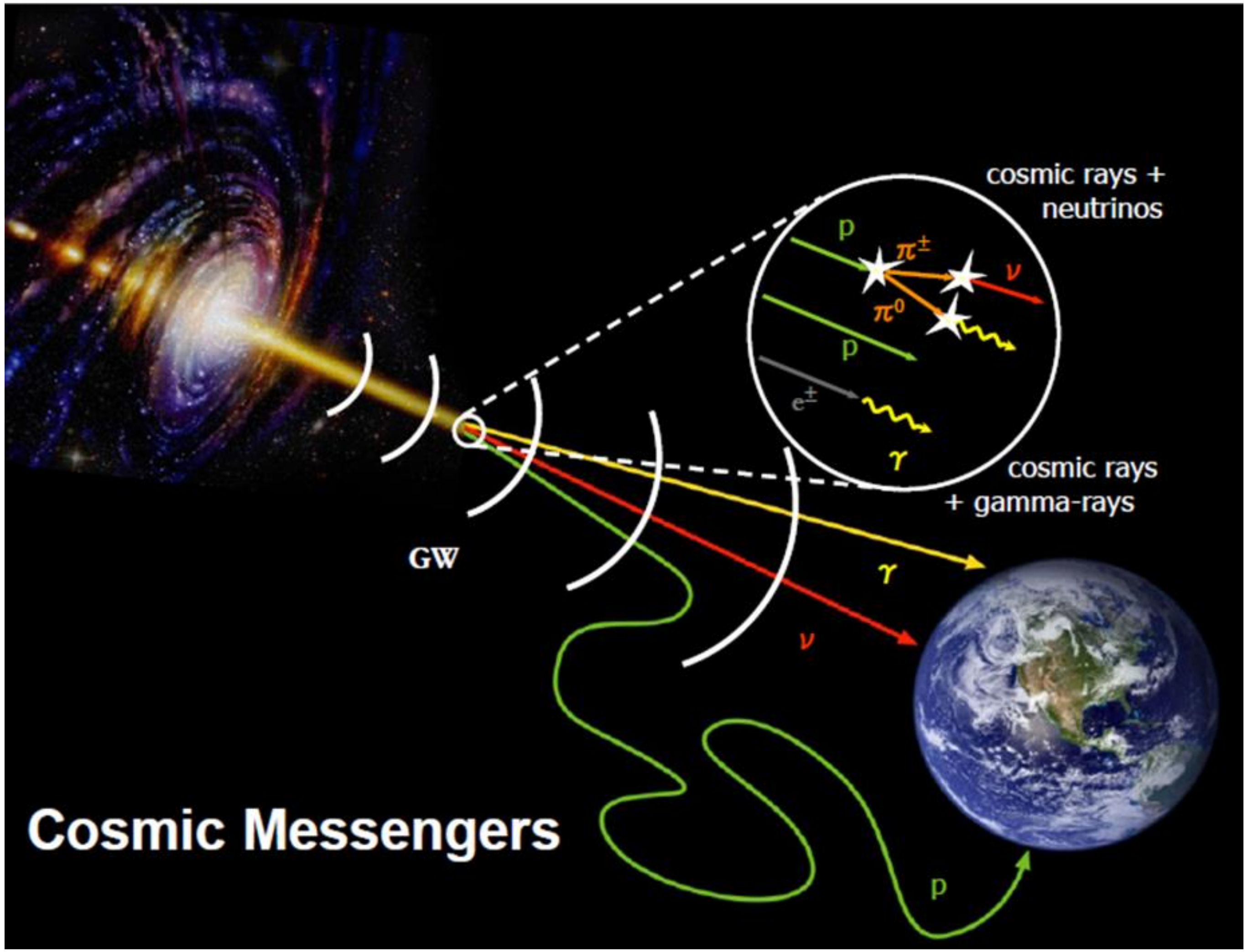
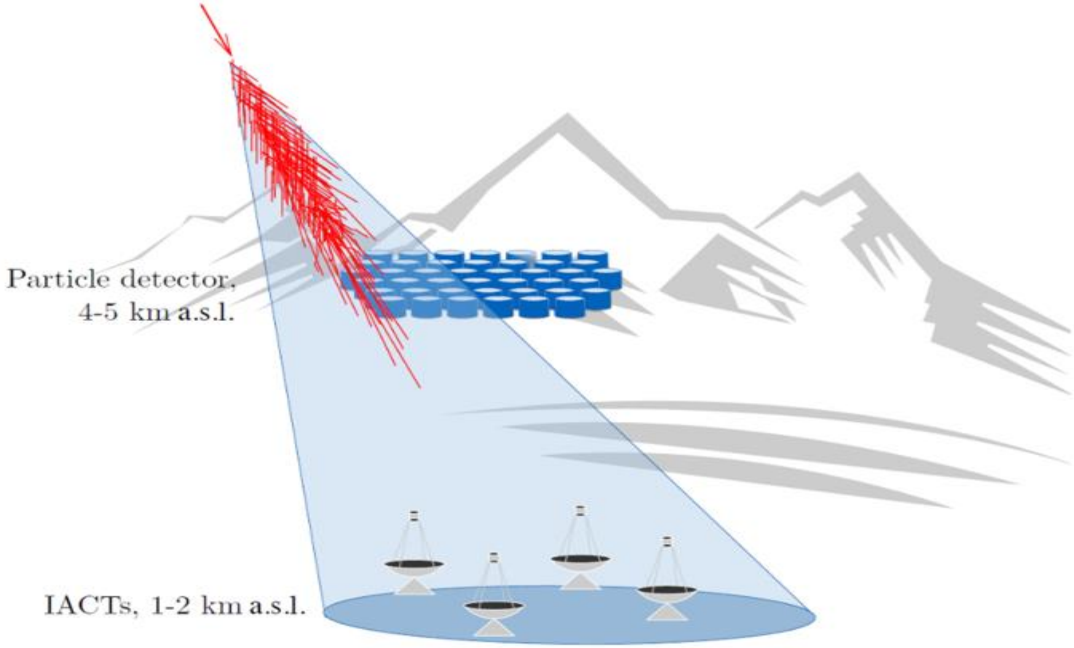
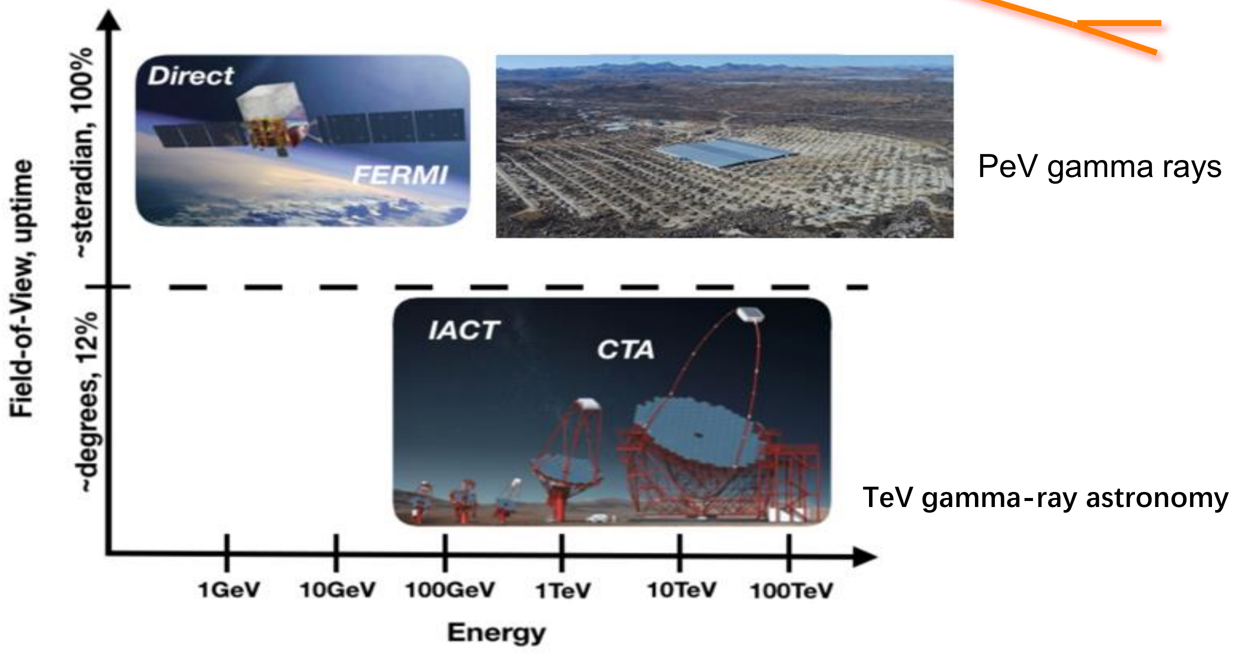
Searching for the Origin of UHECRs



- The Origin of Ultra-High-Energy Gamma-Ray (UHECR) : A "Mystery of the Century".
- A recognized grand challenge highlighted by the U.S. National Research Council and Science magazine.
- Multi-messenger Astrophysics: Gravitational-wave, Neutrino, Cosmic ray and Gamma ray.

Ground-based gamma-ray astronomy





◎ **Imaging Atmospheric Cherenkov Telescope(IACT) arrays:**

(H.E.S.S., VERITAS, MAGIC, CTA …)

- → **Angular resolution： 0.05°- 0.1°;**
- → **Duty cycle： ~10%;**
- → **field of view： <5°;**
- → **Energy threshold： <100 GeV;**

➔ **Mainly focused on deep observation.**

◆ **Ground-level detector arrays :**

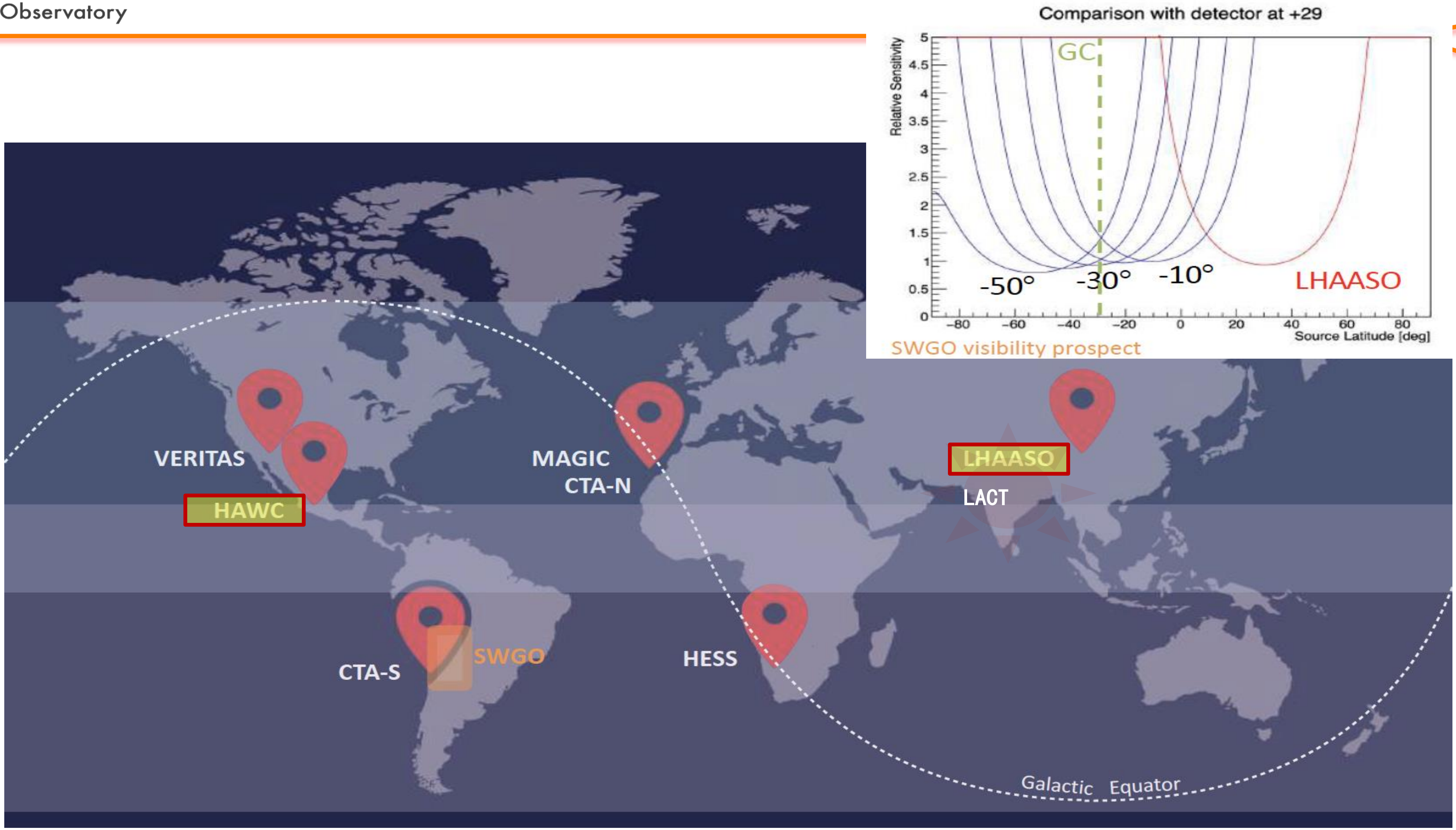
(ASγ, ARGO-YBJ, Milagro, HAWC, LHAASO…)

- ◆ **Angular resolution： 0.2~0.5°;**
- ◆ **Duty cycle： >95%;**
- ◆ **field of view： >2/3π;**
- ◆ **Energy threshold ： >1 TeV;**

➔ **Good at sky survey, extended sources.**

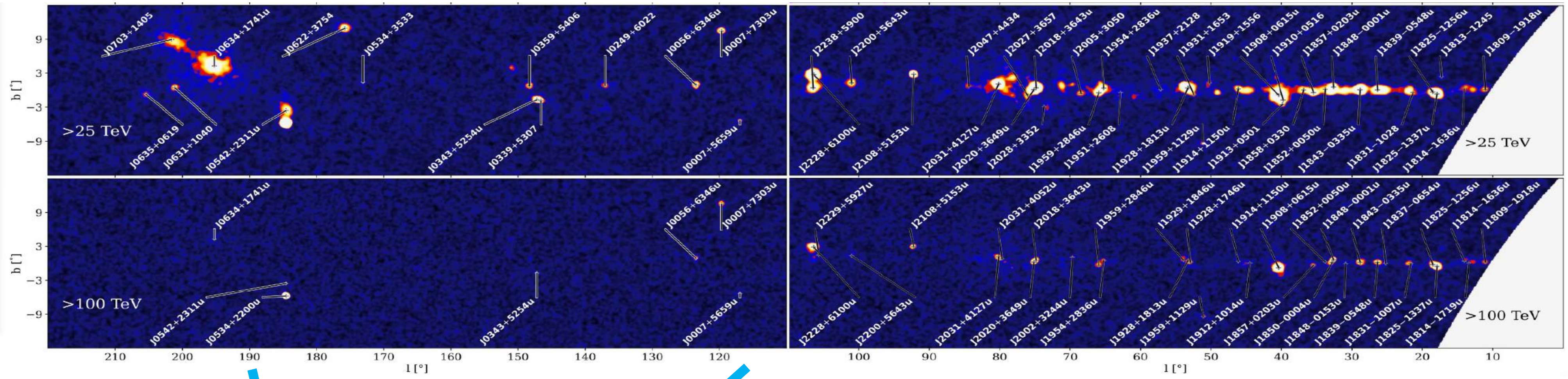
Global Gamma-Ray Observatories Location

The Southern Wide-field Gamma-ray Observatory

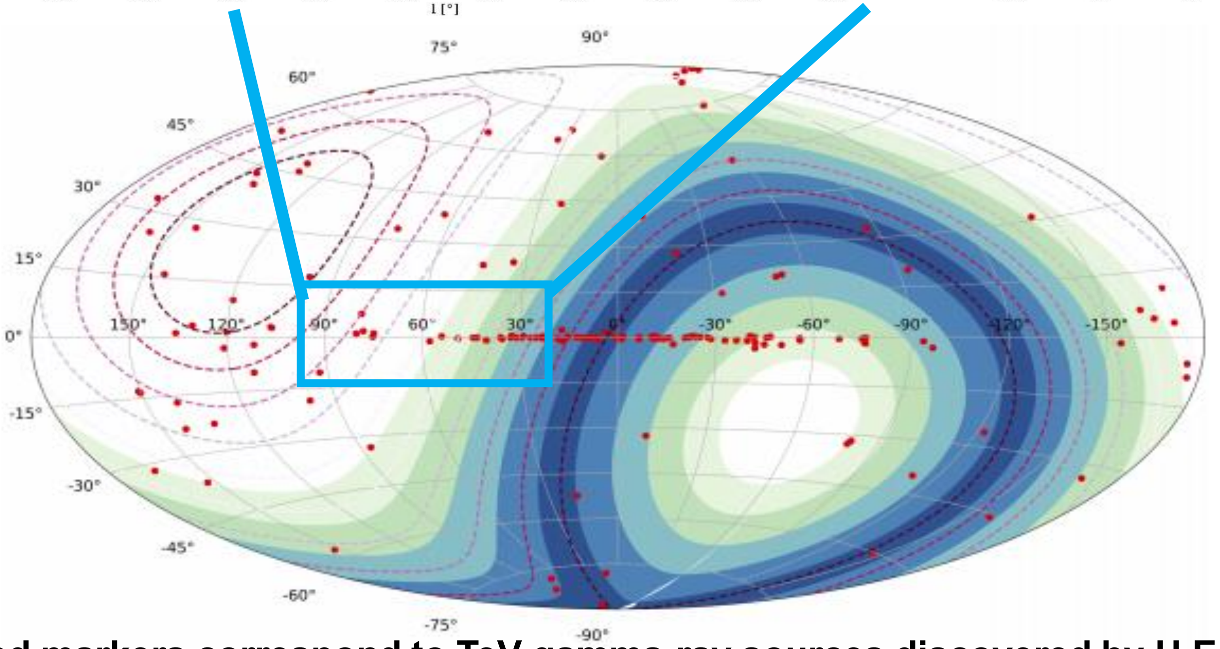


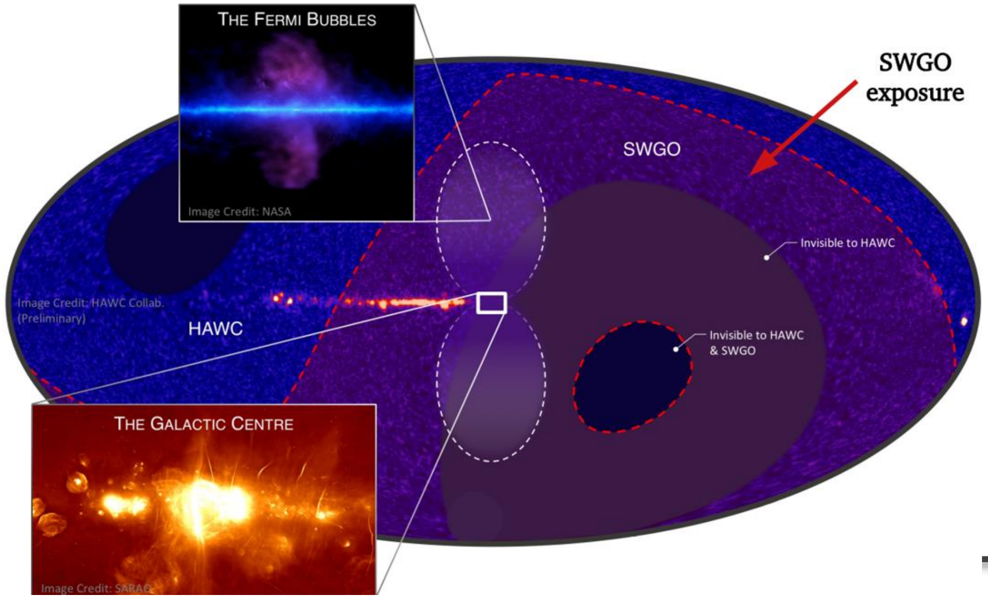
SWGO: First Wide-field Instrument to the South Sky

The Southern Wide-field Gamma-ray Observatory



TEV gamma-ray sources detected by LHAASO

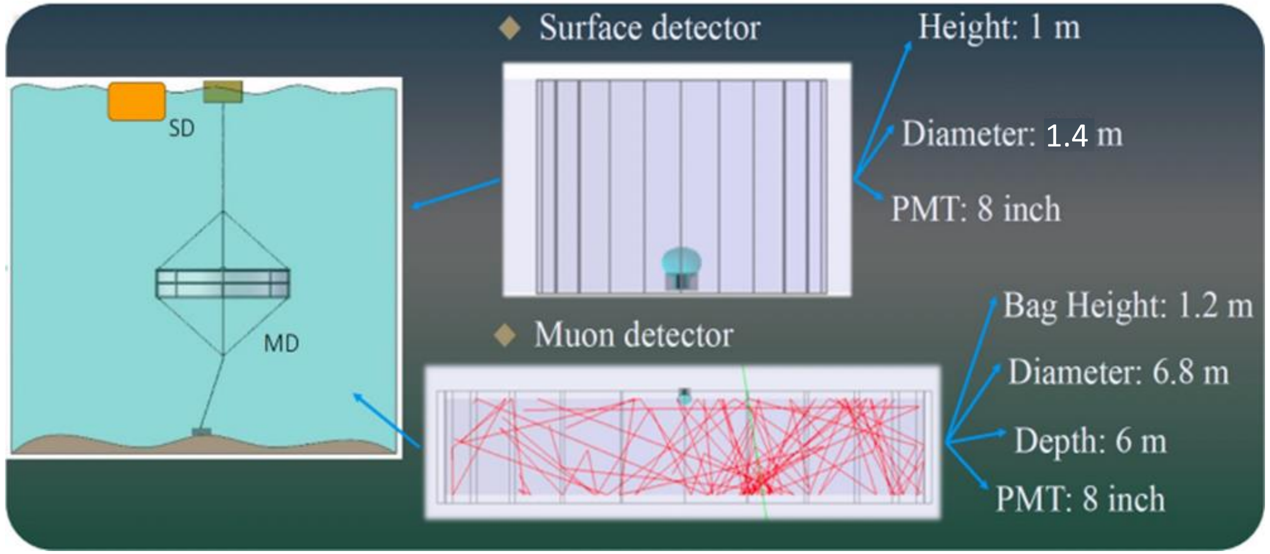




The red markers correspond to TeV gamma-ray sources discovered by H.E.S.S., MAGIC and VERITAS

SWGO Lake Concept

LHAASO MD: nearly 600,000 cubic meters construction volume.



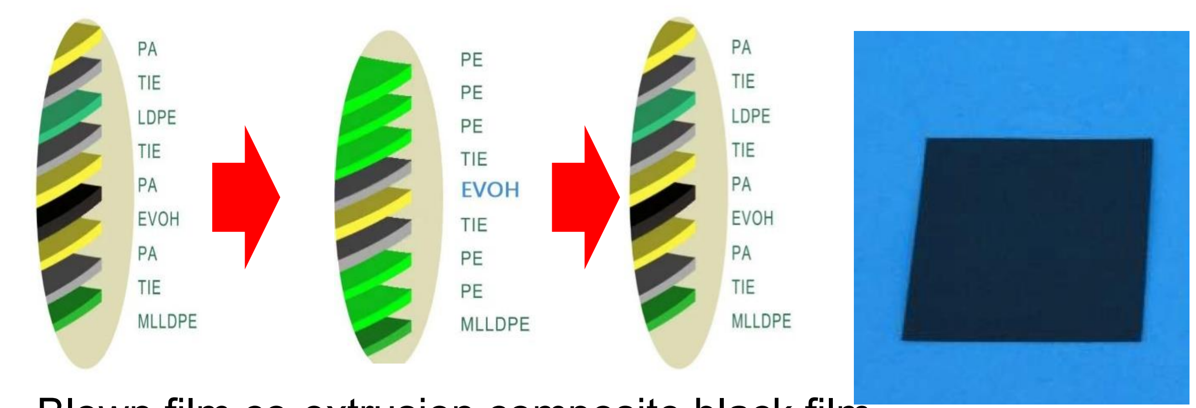
Project Goals:

- Sensitive at UHE
- significantly larger area than LHAASO
- Design to suit conditions in South America.
- Lake concept

Advantage:

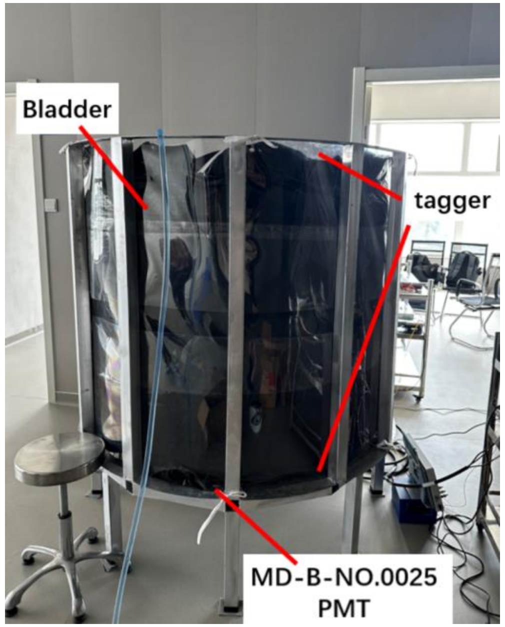
- low cost
- modular design
- easy to install
- Artificial/Natural Lake

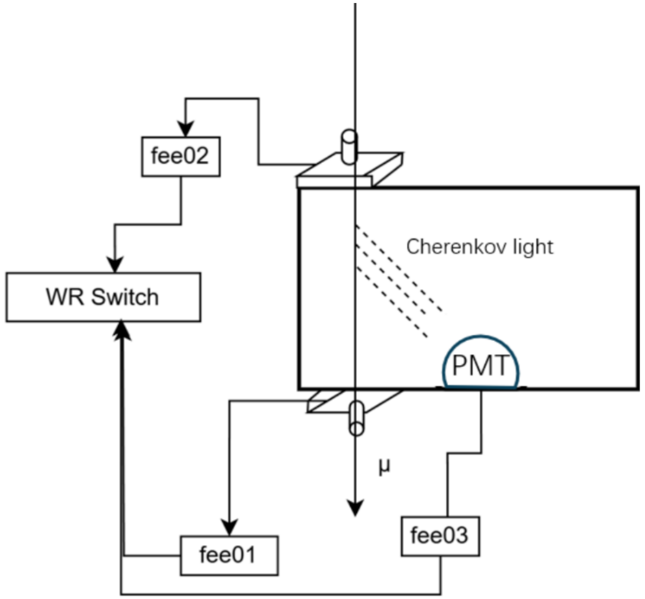
Prototype Surface Detector test in lab



Blown film co-extrusion composite black film

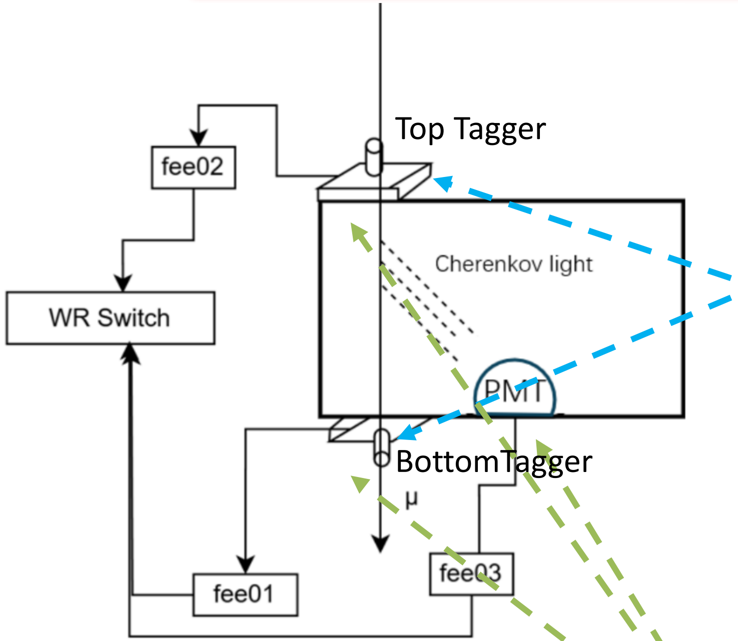
- Black film for bladder
  - multi-layer co-extrusion technology
  - PE + EVOH + MLLDPE
  - light-tight and durable





- Geometry: Diameter 1.4 m Height 80/106 cm
- 8-inch PMT(R5912) gain: 6.7e5
- threshold: 7mV(~5 SPE)
- window:100ns

Event Rate and Detection Efficiency

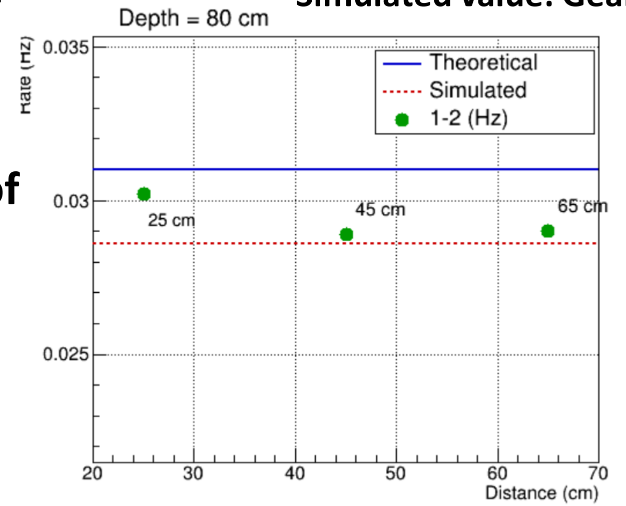


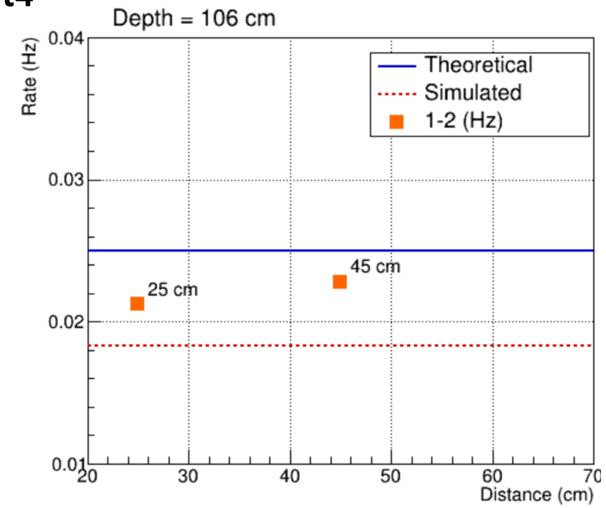
Depth:80cm/ 106cm

Event rate:
2-coincidence rate of tagger 1,2

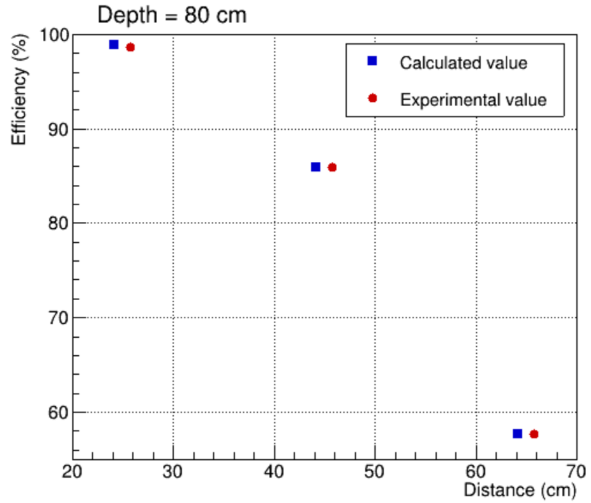
Detection efficiency:
3-coincidence rate of tagger 1,2 and PMT

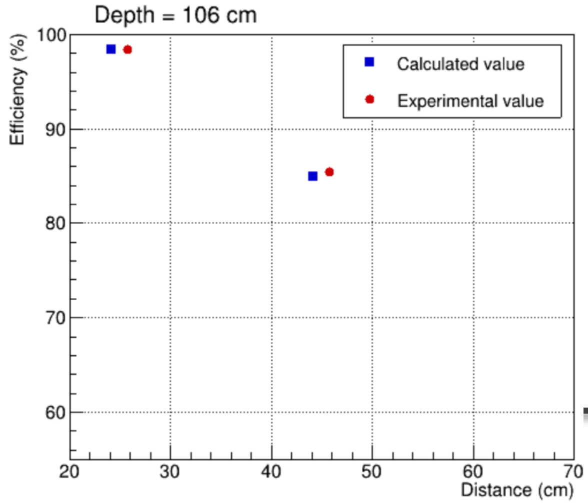
Theoretical value: calculated by dark count rate
Simulated value: Geant4



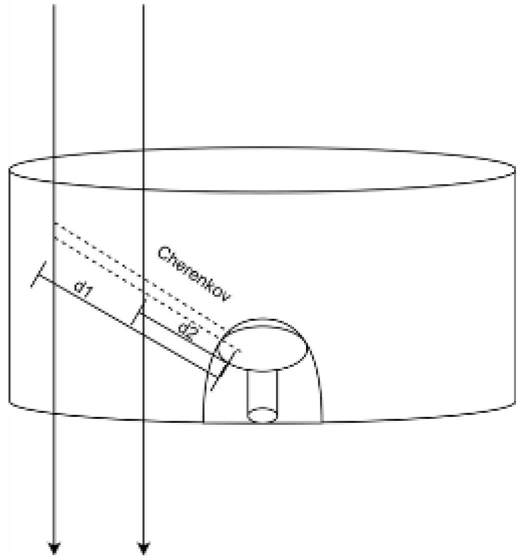


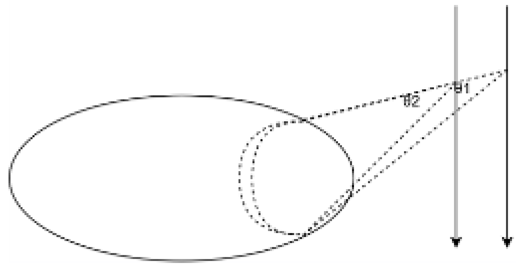
change the position of taggers





Light Yield Analysis





In the experiment, the measured results are as follows: The total number of photons generated between wavelengths λ_1 and λ_2 in a medium of length L is given by:

$$N = \int_{\lambda_1}^{\lambda_2} \frac{2\pi L \alpha z^2}{\lambda_1^2} \sin^2\theta_c \, d\lambda$$

If only the visible light region is considered, i.e., $\lambda = 400 - 700\,nm$, the number of photons per unit length is:

$$N/L = 490 \times \sin^2\theta_c$$

To approximate the theoretical number of photons, consider the following approximations:

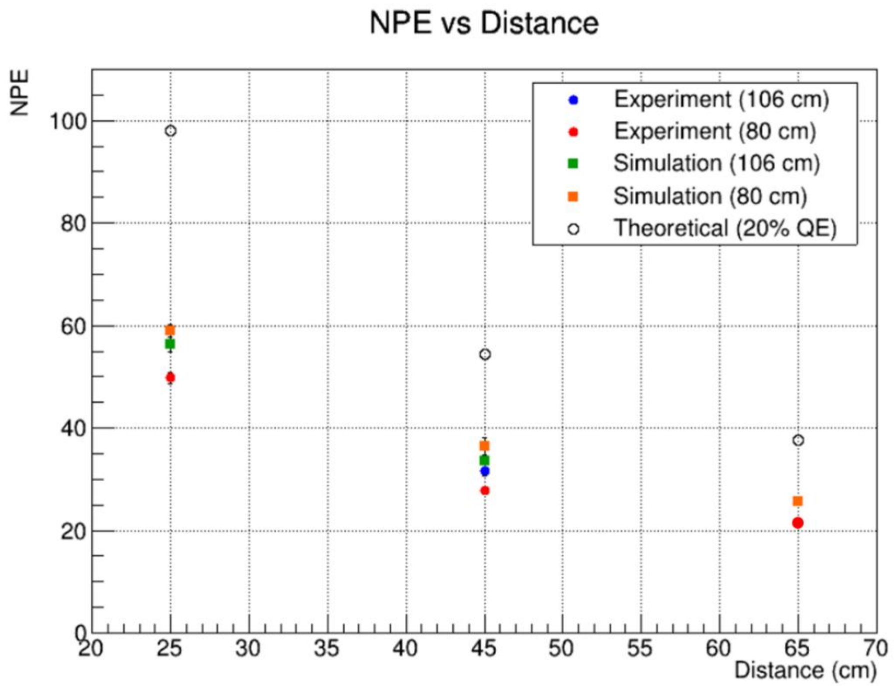
1. $\theta_c \approx 41°$
2. The light-sensitive surface is approximately circular with a diameter of $\sim 20\,cm$.
3. Let r be the distance from the probe to MD-B-NO.0025, and d be the distance from the Cherenkov light emission point to the receiving surface. Then:

$$d = r/\tan\theta_c$$

The theoretical number of photons is:

$$N_{theory} \approx 490\,cm^{-1} \times \frac{1}{2} \times 20\,cm \times \frac{\pi \times 10^2}{\pi\left((r+10)^2 - (r-10)^2\right)} = \frac{12250}{r}$$

Water Depth (cm)	Distance from Center (cm)	NPE (p.e.)	product
106	25	56.66 ± 0.87	1416.5
106	45	31.74 ± 1.16	1428.3
80	25	49.75 ± 1.16	1243.5
80	45	27.82 ± 0.41	1251.9
80	65	21.02 ± 0.78	1366.3

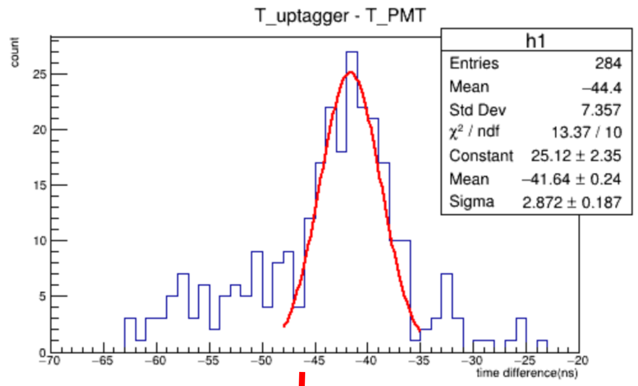


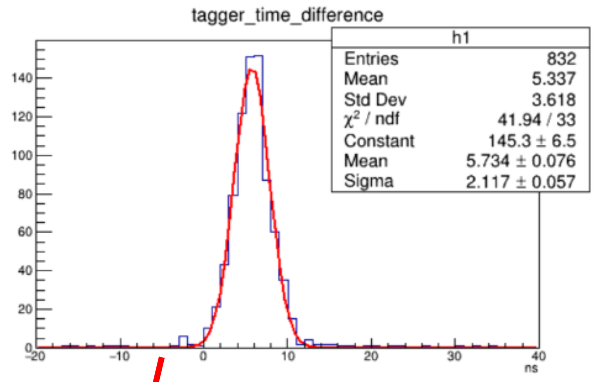
SWGO
The Southern Wide-field Gamma-ray Observatory

Time Resolution

Time_uptagger – Time_PMT **Time difference between taggers**

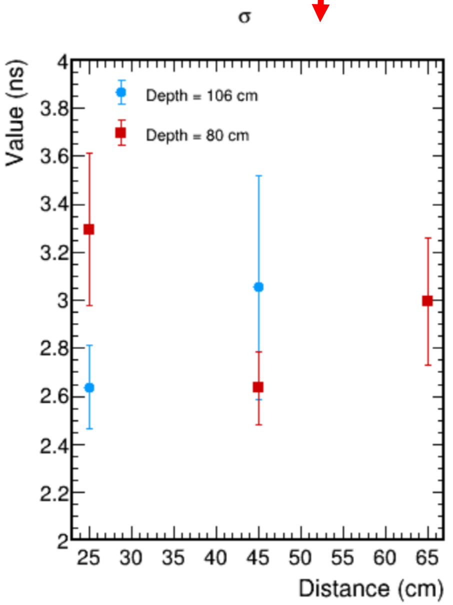
Fit with gaussian curve to get σ as time jitter

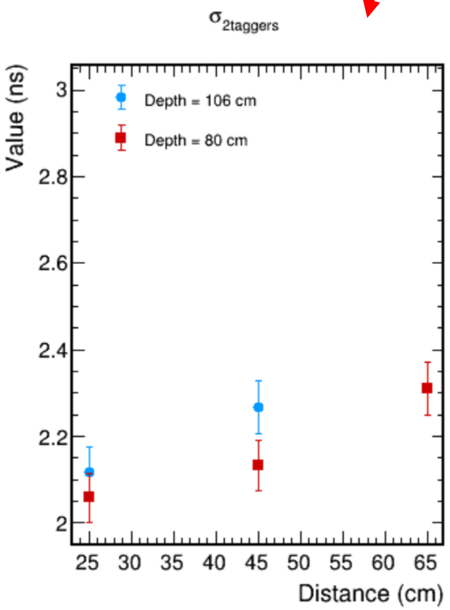


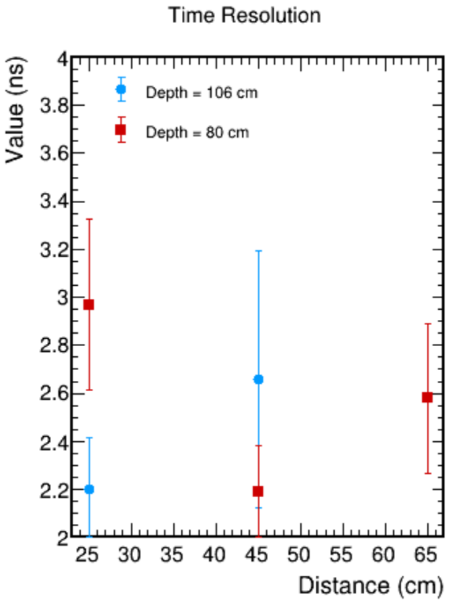


$$\sigma_{\rm tagger} = \frac{\sigma_{\rm 2taggers}}{\sqrt{2}}.$$

Remove the influence of the tagger's intrinsic time jitter



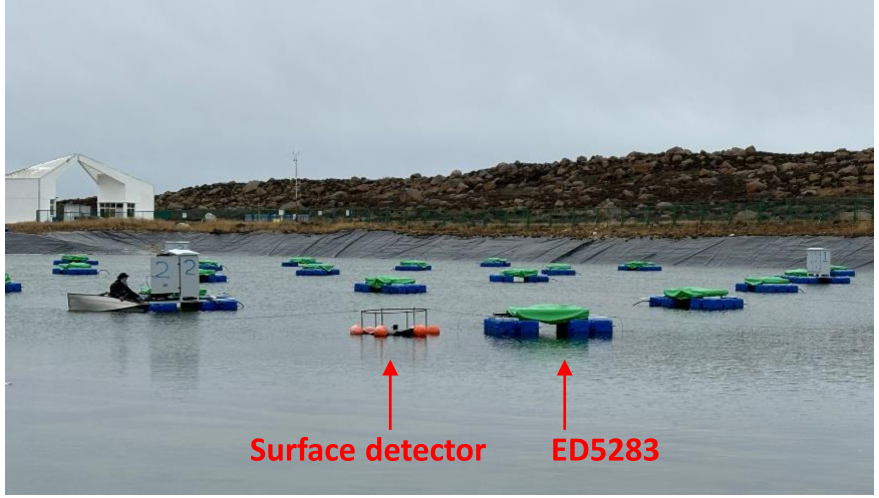




$$\sigma_{\rm detector} = \sqrt{\sigma_{\rm all}^2 - \sigma_{\rm tagger}^2}.$$

Installation at LHAASO site

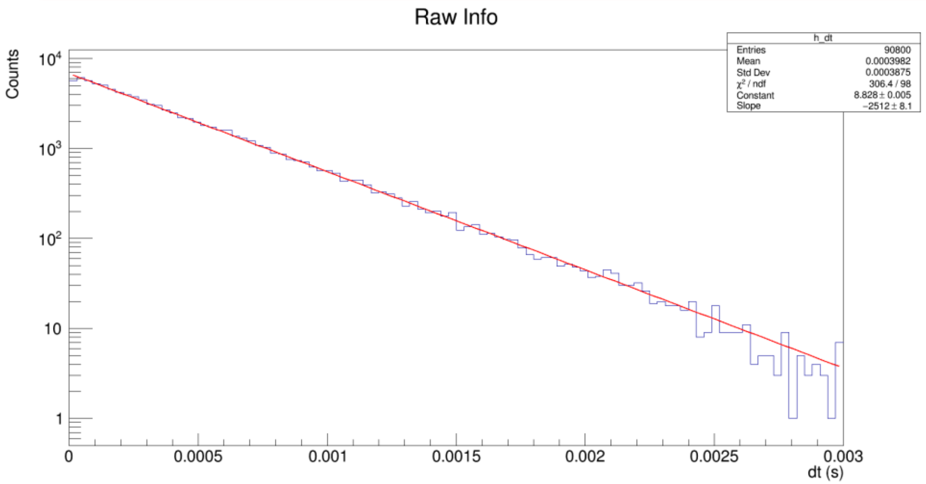
a small on-water array and experimental platform in the lake at the LHAASO Site

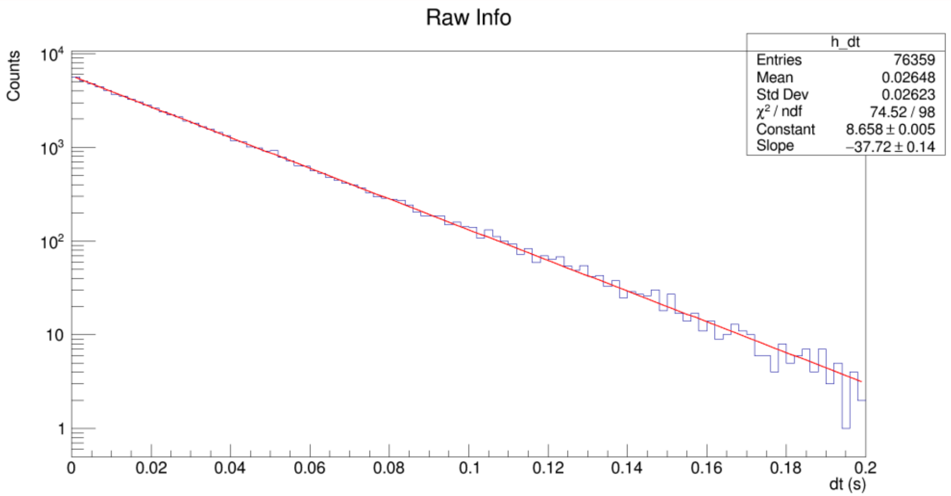


flange-mounted PMT

Detector Prototype Deployment

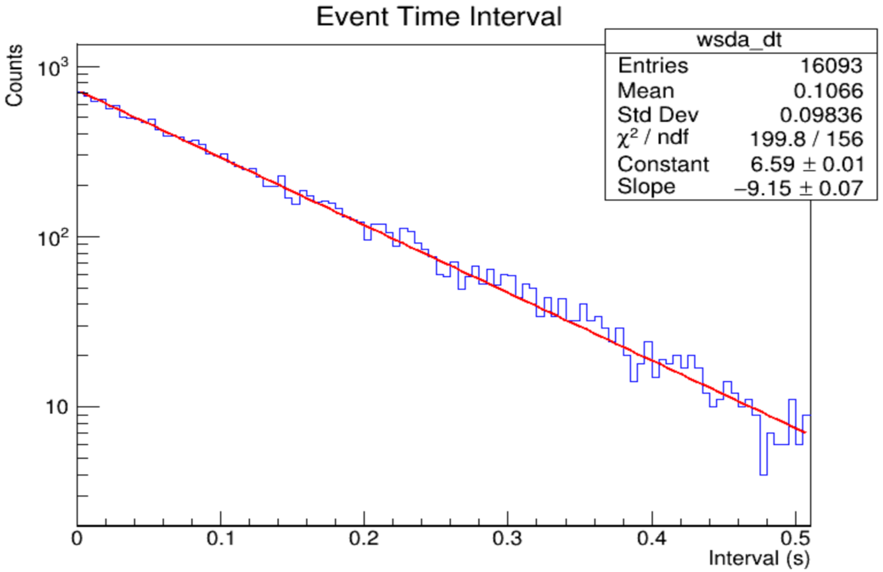
Coincidence with KM2A





LHAASO-KM2A event rate： ~ 2500Hz

WSDA (water surface detector array) event rate：~37Hz

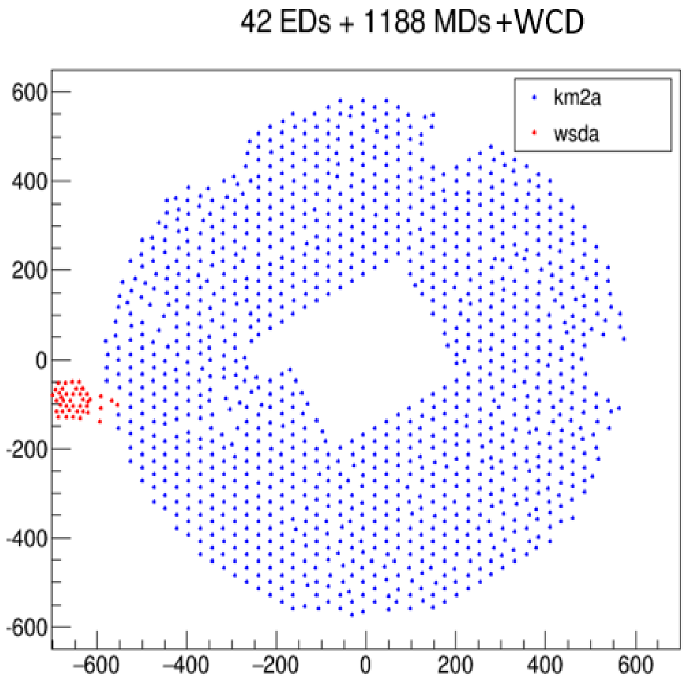


matching timestamps with a 1000ns window

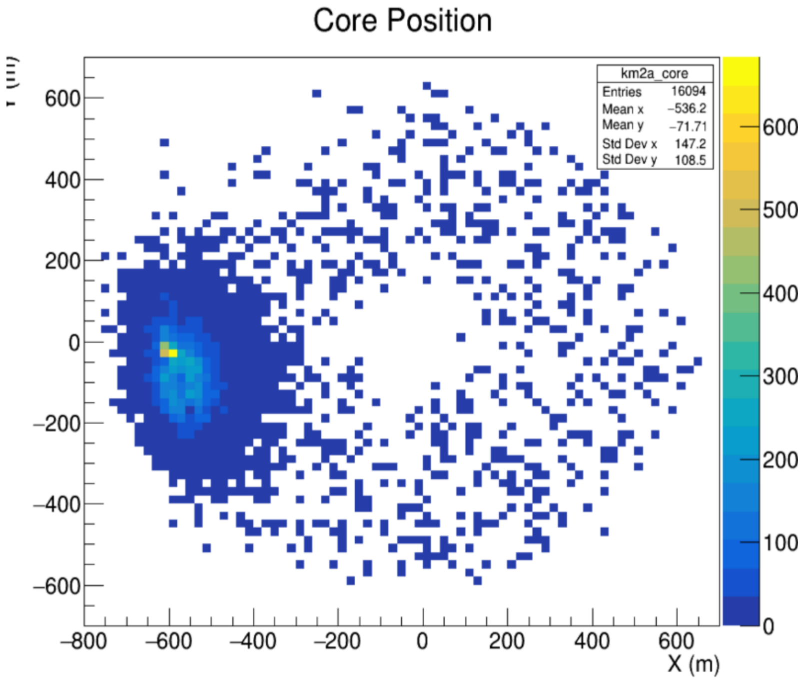
Coincidence rate of WSDA and KM2A: ~9.15Hz。

Accident coincidence rate : ~0.19Hz <<9.15Hz

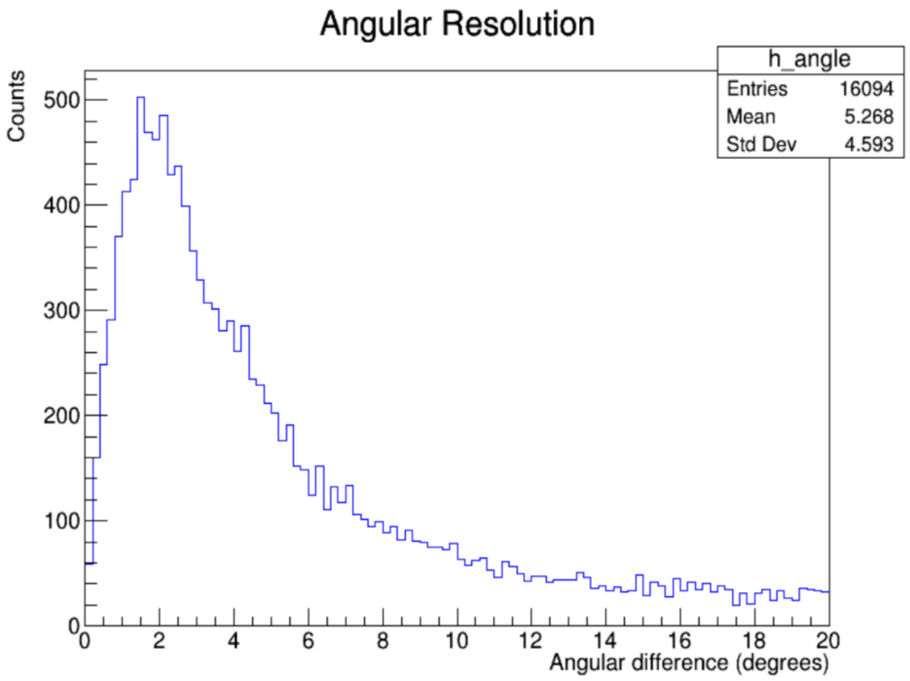
Shower Reconstruction



Position of WSDA and KM2A



Core position reconstructed by KM2A



Space angular between WSDA and KM2A

occupancy

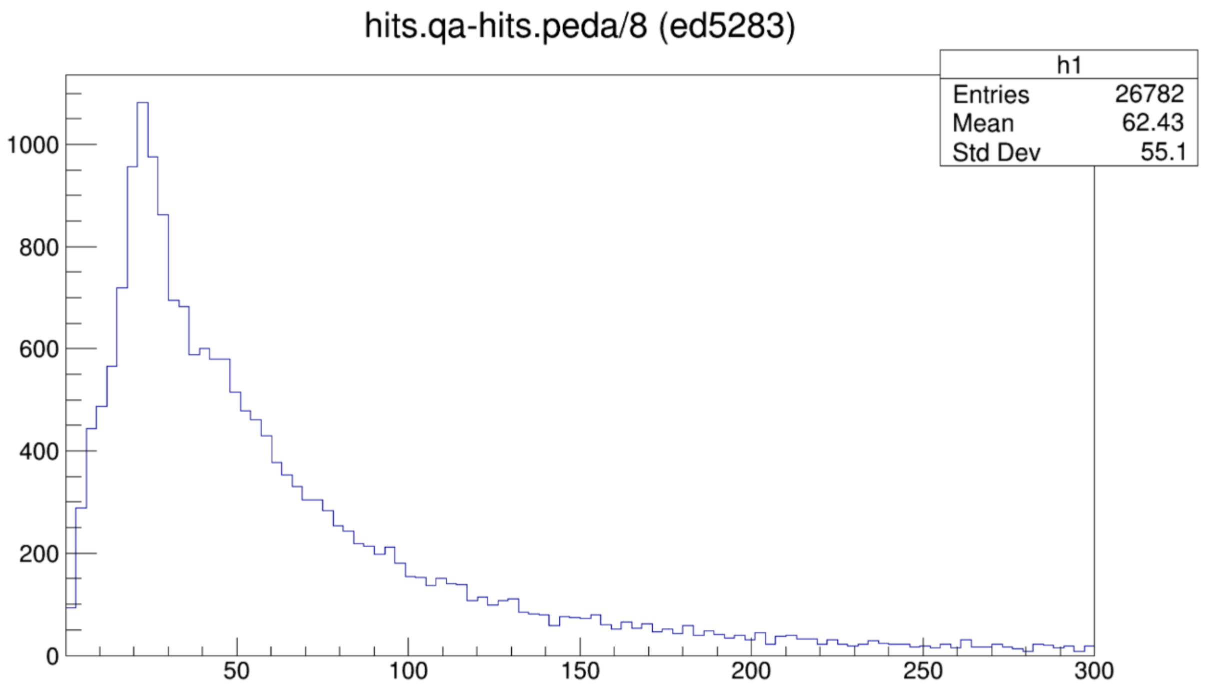
Detector	Active area	Coincidence event	Hit number	Triggered by shower
ED5283	~1m^2	16094	7057	6588
WCD	~1.5m^2(1m height)	16904	7528	7161

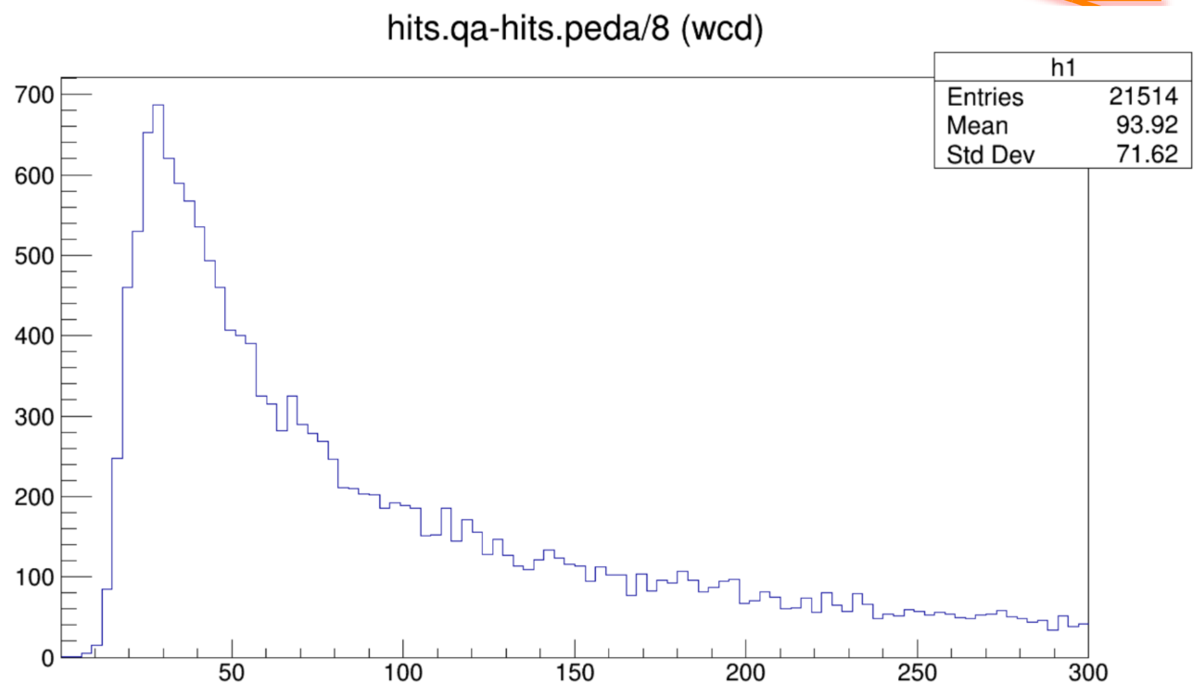
Significantly larger area, why not significantly higher occupancy?

- Cherenkov emission mechanism: charged particle and energy restrict
- The uniformity of detector: lower detection efficiency

× **low energy γ**

Single particle peak





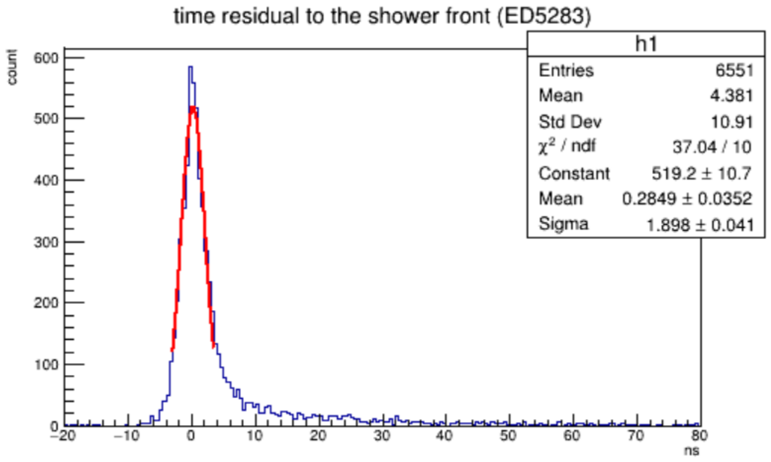
ED: a counter for the number of particles

Charge: mostly around several tens of pCs.

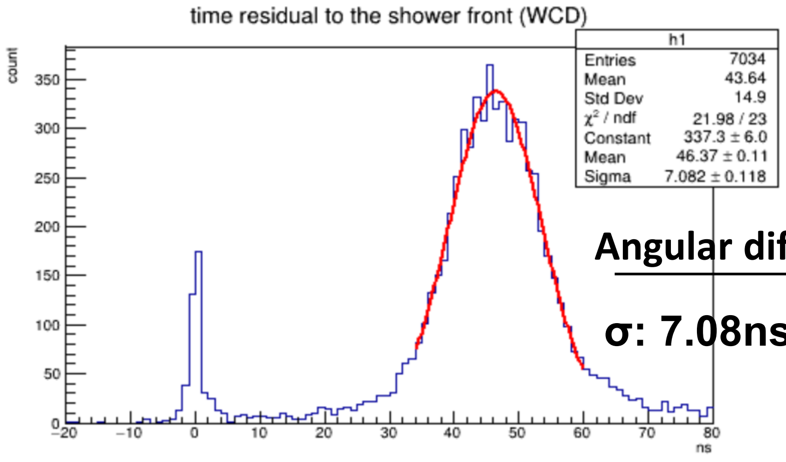
WCD: functions more like a calorimeter.

Charge: extend to several hundred pCs and even higher.

Time residual to shower front



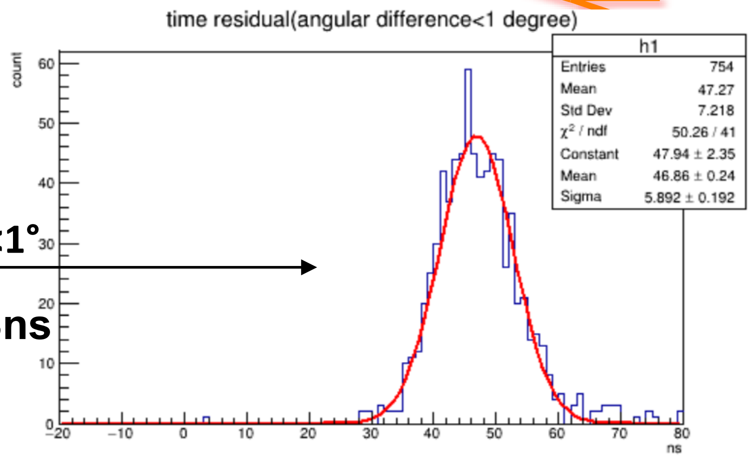
ED5283 time residual



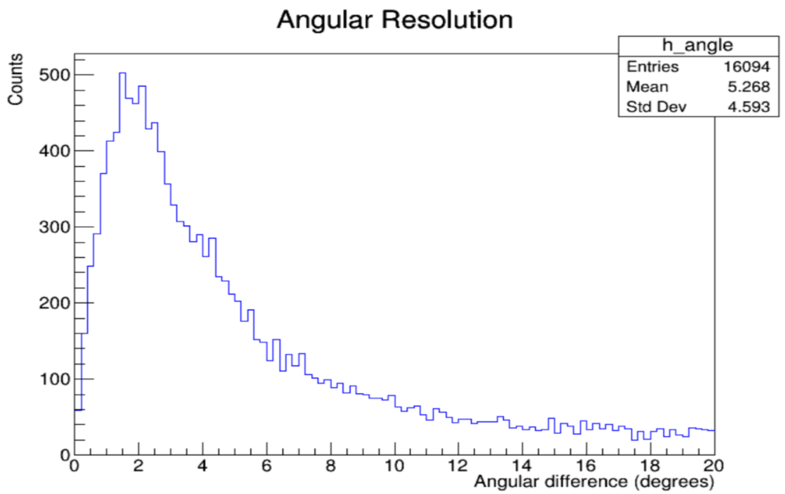
WCD time residual

Angular difference<1°

σ: 7.08ns → 5.98ns



WCD time residual



Space angular between WSDA and KM2A

Influence factor

- Signal of electromagnetic particle / muon
- Lake environment
- Reconstruction accuracy of WSDA

Summary

◎ **Muon & EM Tests Completed**

◎ **Room for Performance Improvement**

◎ **Valuable Experience for Surface Detector Construction**

◎ **Further plans:**

- **Adjusting the thresholds to test the changes in performance.**
- **Exploring optimizations for the detector structure.**
- **Conducting simulations for the full array.**

Thank you!

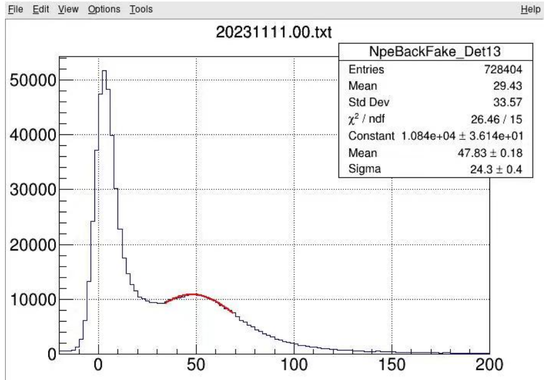
backup

Prototype Muon Detector and Underwater test

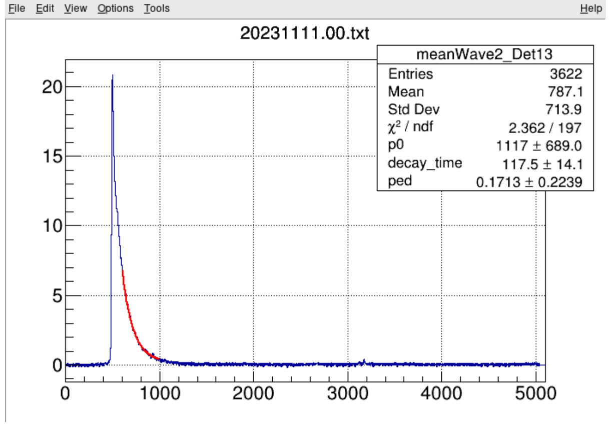
- ◎Fill the bladder with the water
- ◎Verify the installation on the water surface
- ◎The bladder is installed @Qingdao and LHAASO site respectively
- ◎Some data is collected @LHAASO site, the single muon signal and water attenuation length are similar as those of LHAASO Muon detector.

installation in the lake @Qingdao

Installation @ LHAASO

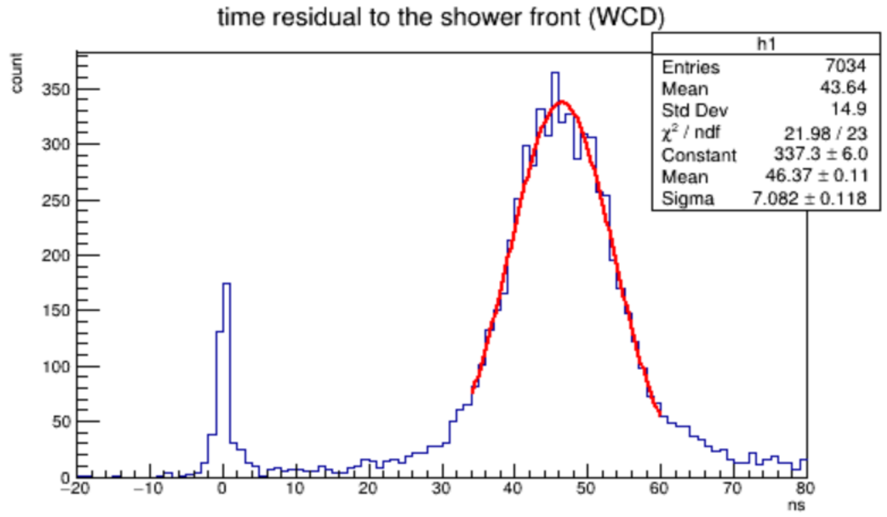


Charge resolution ~ 50%;
Mixed with Punch-through electromagnetic signals

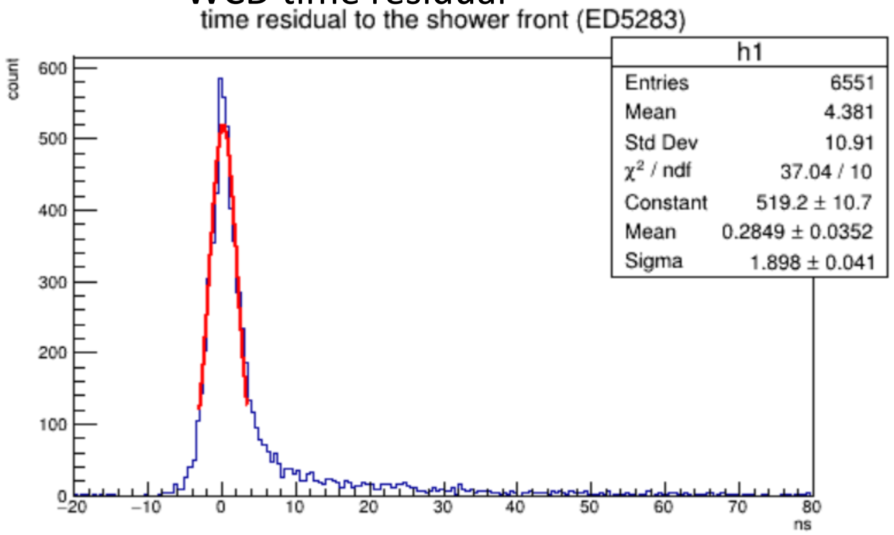


Decay time: 117.5ns

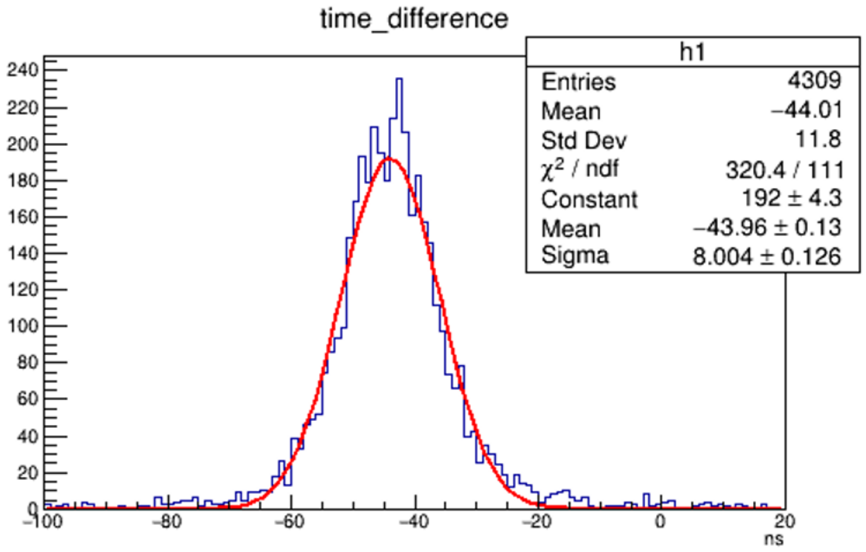
Time residual to shower front



WCD time residual



ED5283 time residual



time difference between ED5283 and WCD