# Horizontal air showers and neutrino search with LHAASO-KM2A

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# Contents

- Introduction
- The first experimental results
- Neutrino identification
- Summary

# Introduction

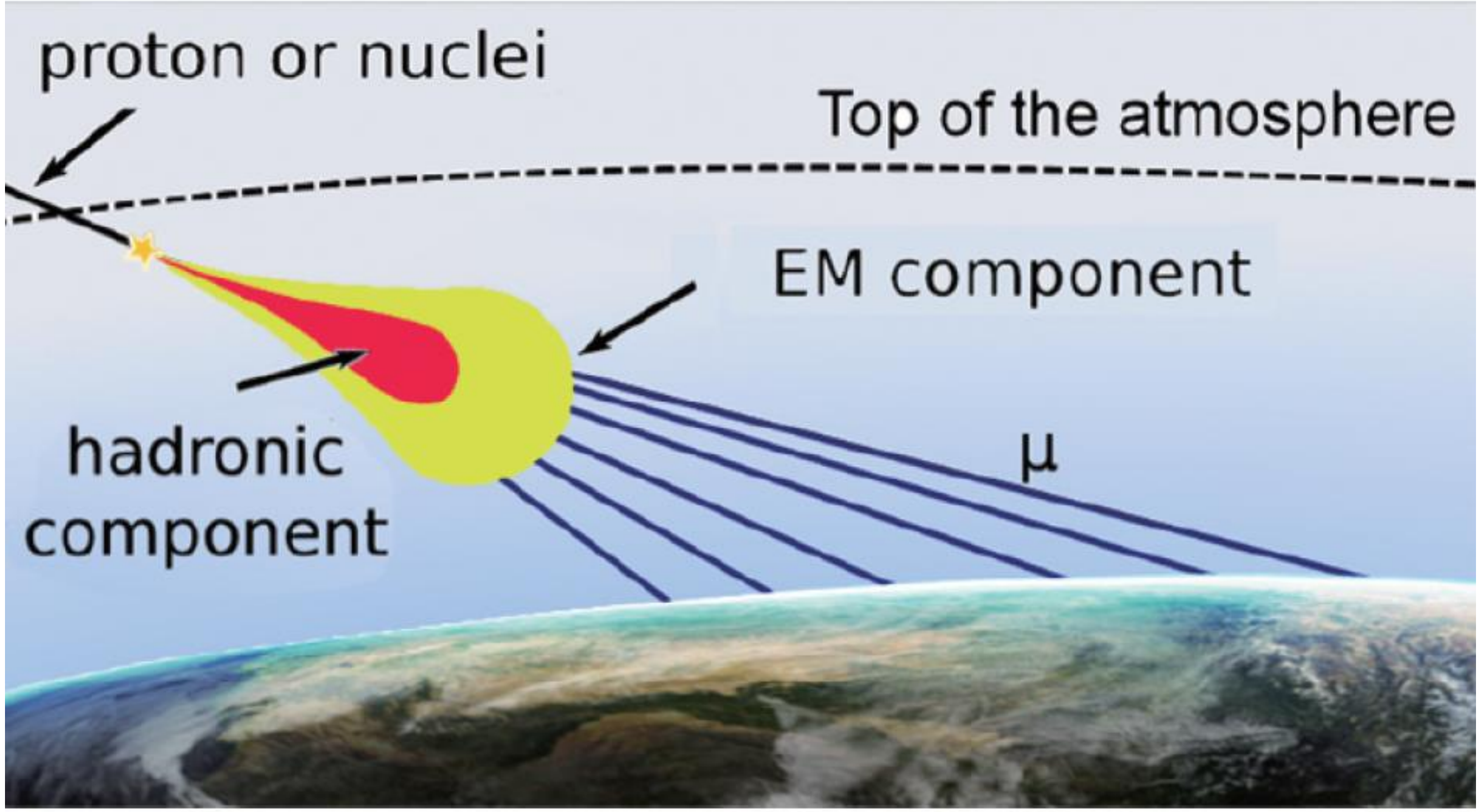
The observation of HAS provides a “well shielded laboratory” for the detection of penetrating particles: high energy muons, cosmic neutrinos, possible weakly interacting particles produced in the decays of cosmological super heavy particles, will leave a clear signature.

The showers with significant muon component could be further rejected by underground muon detector of LHAASO-KM2A.

**The goal of this analysis is to study muon content in EAS and search for neutrino-induced EAS from flaring phenomena like GRBs.**

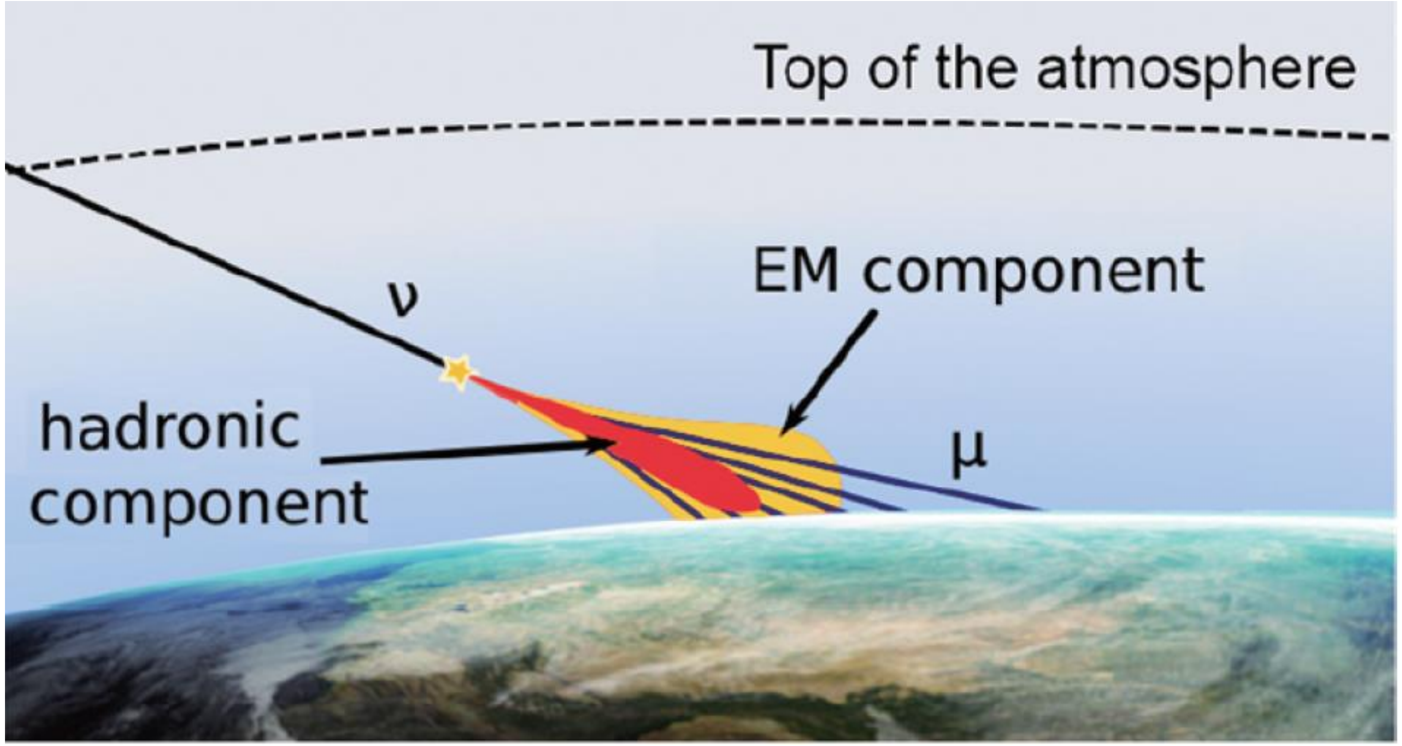
# Horizontal Air showers (HAS)

Cosmic Rays can initiate a HAS in the atmosphere.

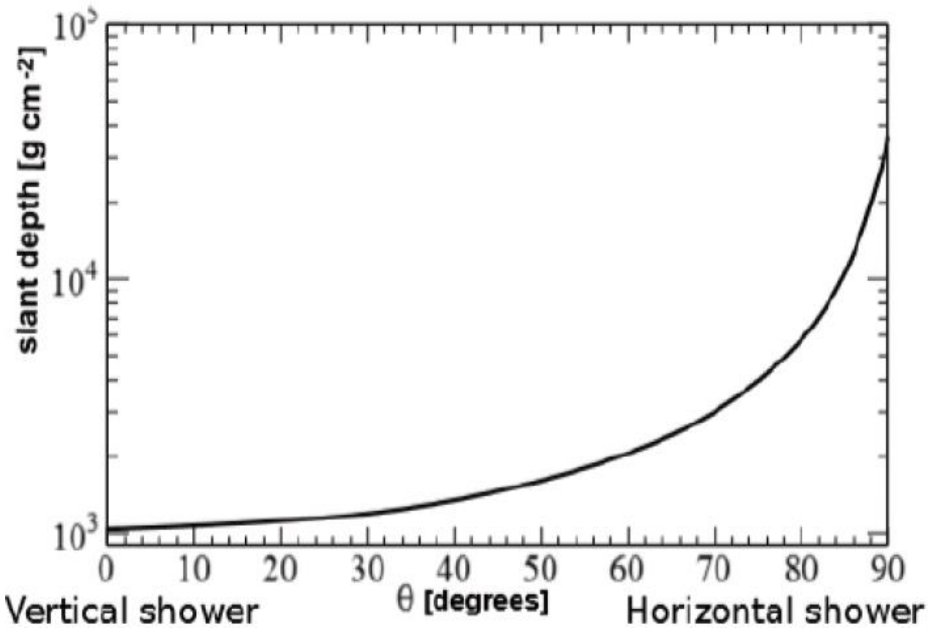


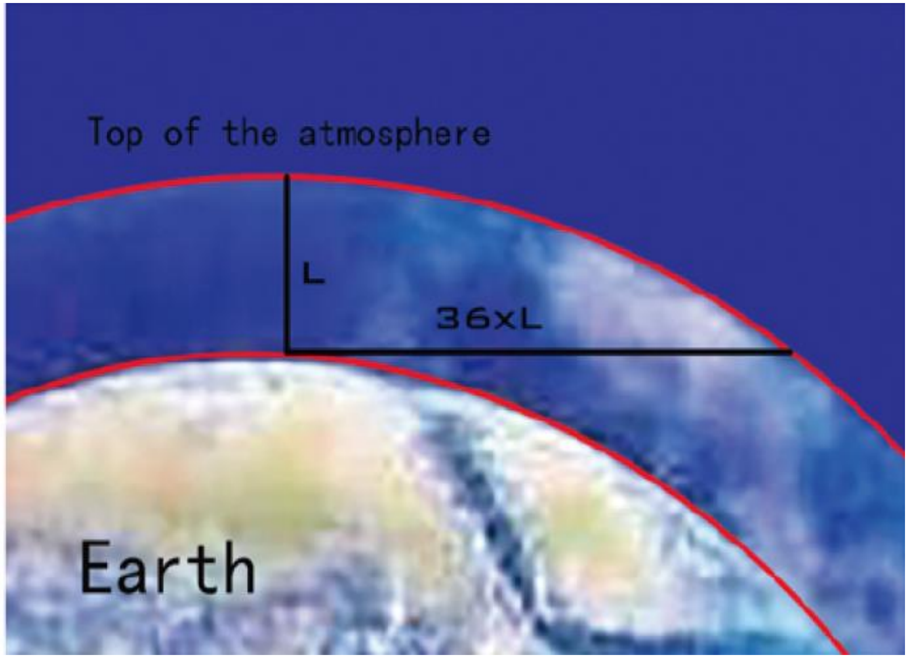

The hadronic and EM components are absorbed and only muons reach the Earth.

Neutrinos can initiate a HAS in the atmosphere




In this kind of events both the EM and the muonic components reach the surface.




Left: Atmospheric depth as a function of the zenith angle. The amount of matter increases quickly after 60°.
Right: A horizontal shower goes through 36 times more mass than a vertical shower.

# First experimental results

# Data Selection

Reconstructed data of 2020 was used

Theta >= 0;

dr > 0;

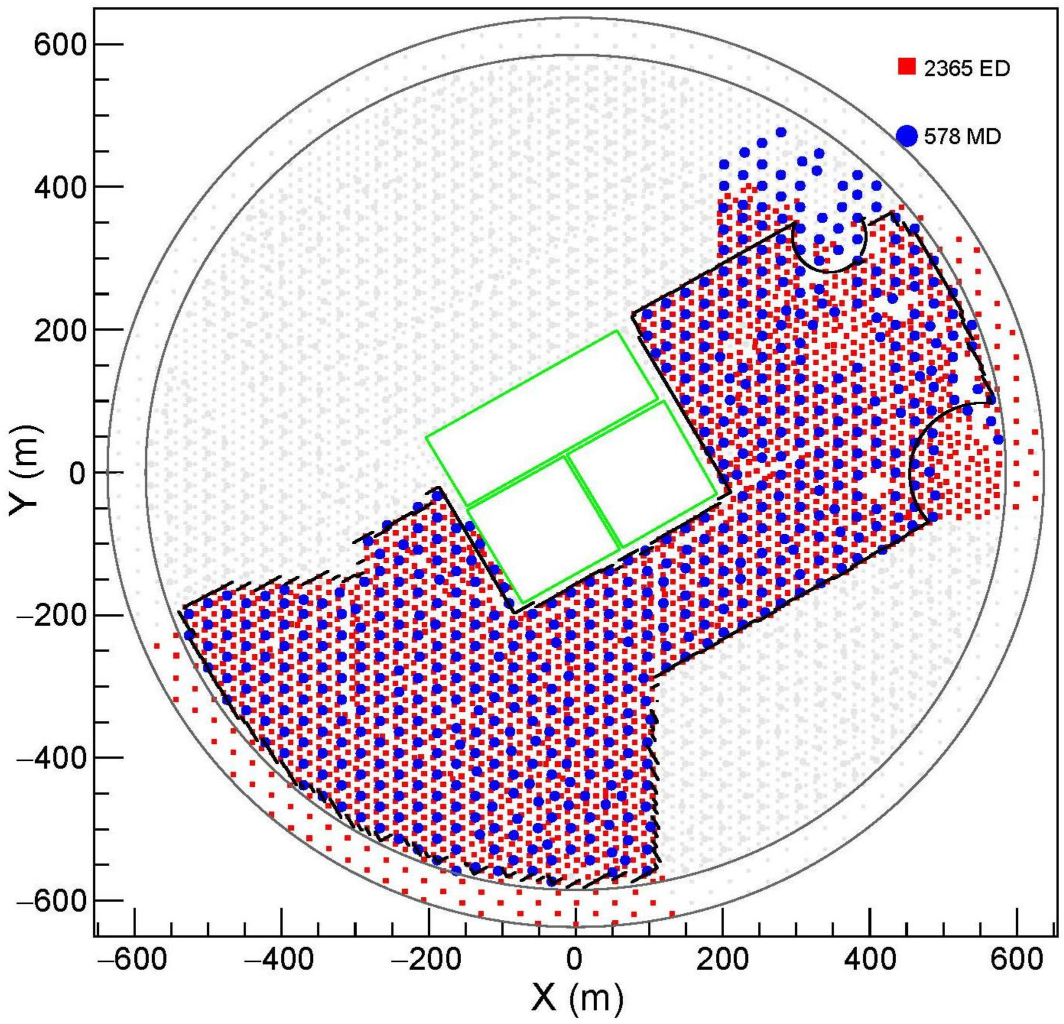
NuM2 > 0;

age > 0.6 && age < 2.2;

size > 20000;

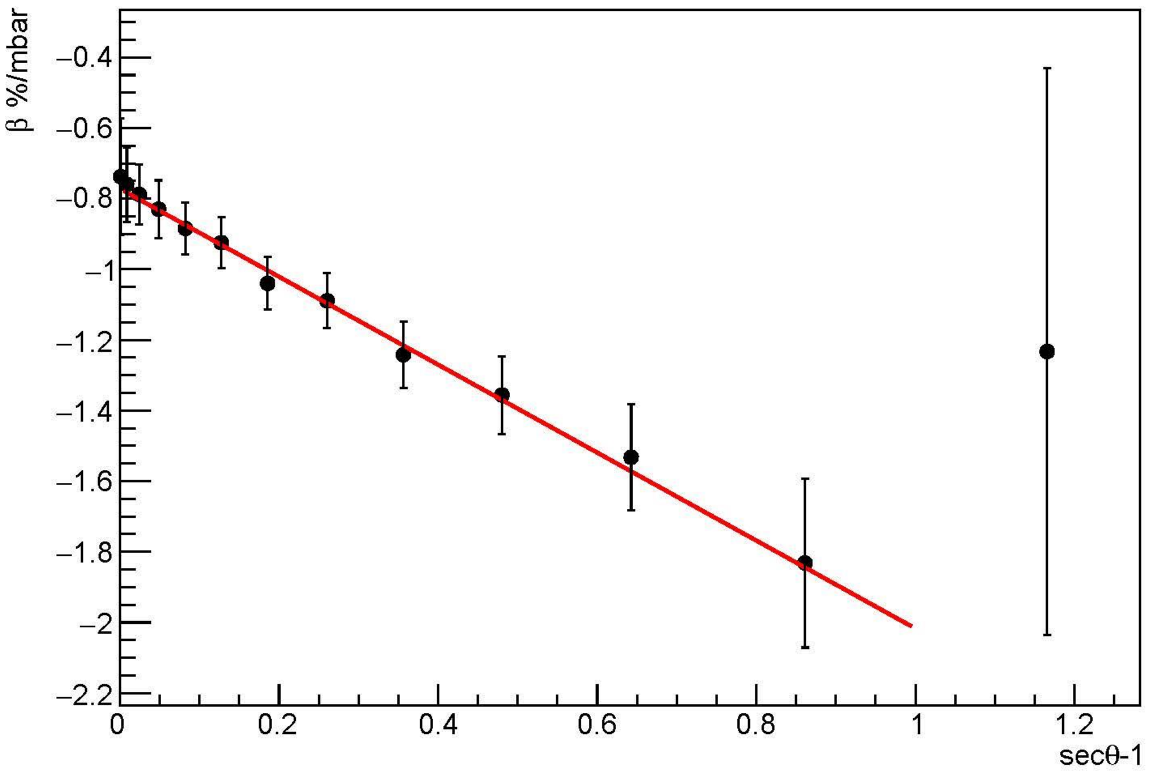
NtrigE >= 10;

There are 218.85 live days out of 323 duty days in the year of 2020 after data selection.




The layout of LHAASO-KM2A detectors. The area enclosed by the dotted black line outlines the fiducial area of the current KM2A half-array used in this analysis. The central green squares indicate the LHAASO-WCDA array region.

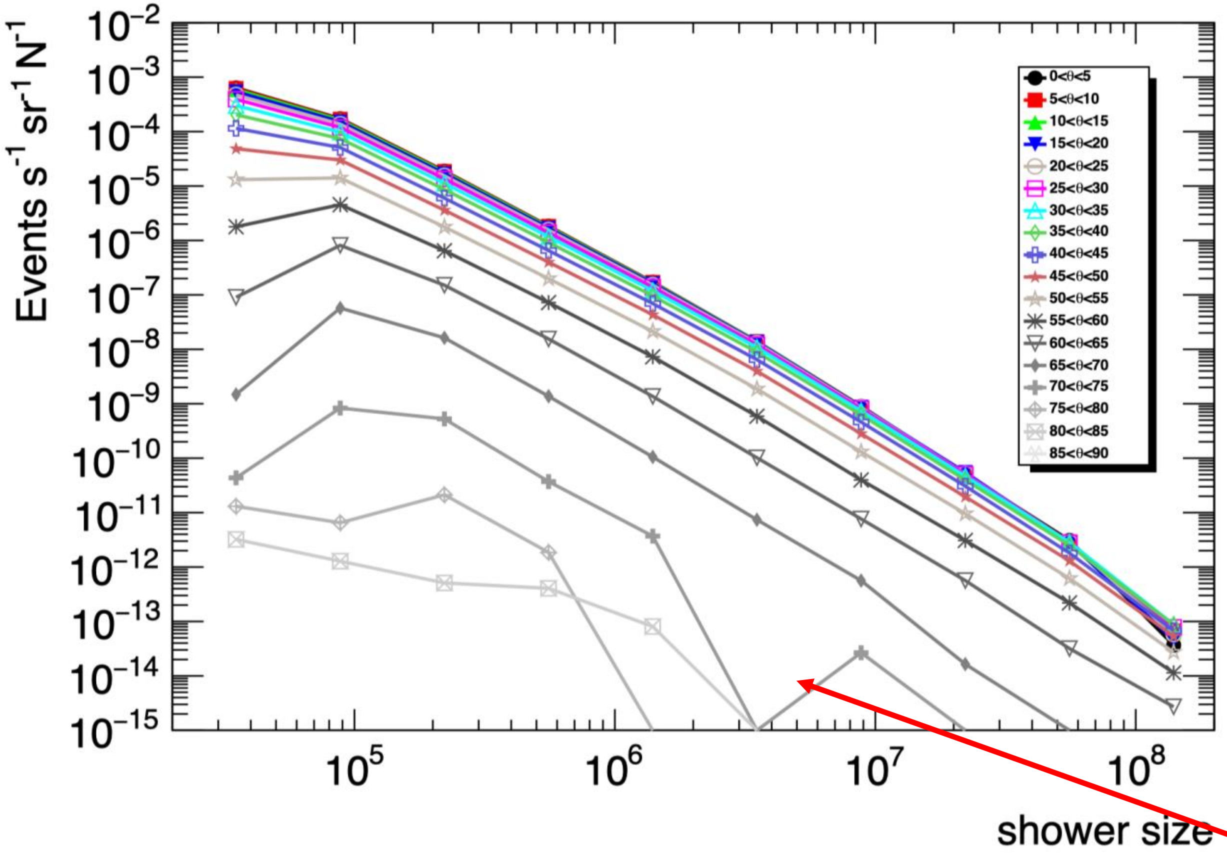
The barometric coefficient at different zenith angles



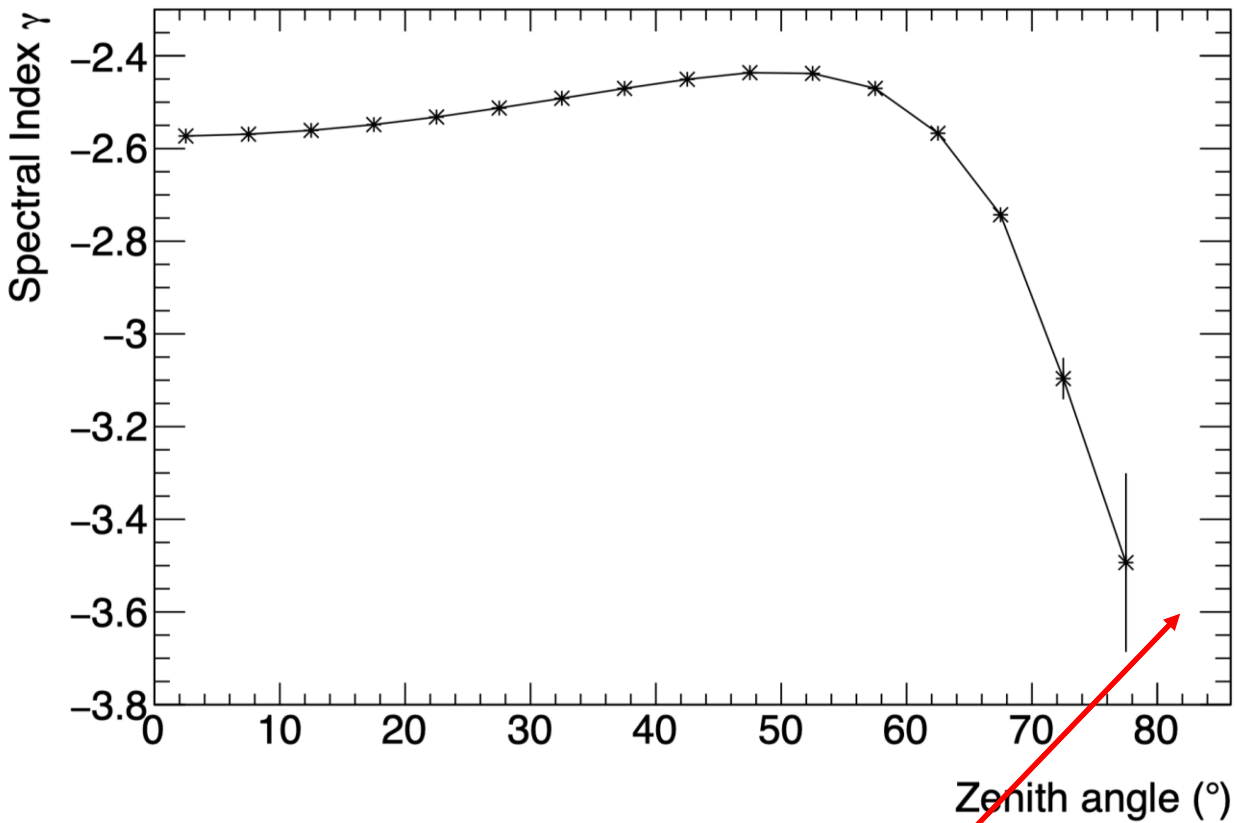

The dependence of the barometric effect on the zenith angle clearly shows a deviation for $\sec\theta > 2$.
$\sec\theta = 2$ corresponds to $\theta = 60^{o}$. Above $60^{o}$, the electromagnetic component is completely absorbed.

The barometric coefficient $\beta = (1/n)(dn/dx)$ (n = counting rate, x = atmospheric pressure) is related to the zeni th angle as: $\beta(\theta) = \beta(0^{\circ}) \sec\theta$.

# Event rates and Spectral index




Distribution of size at different zenith angle range

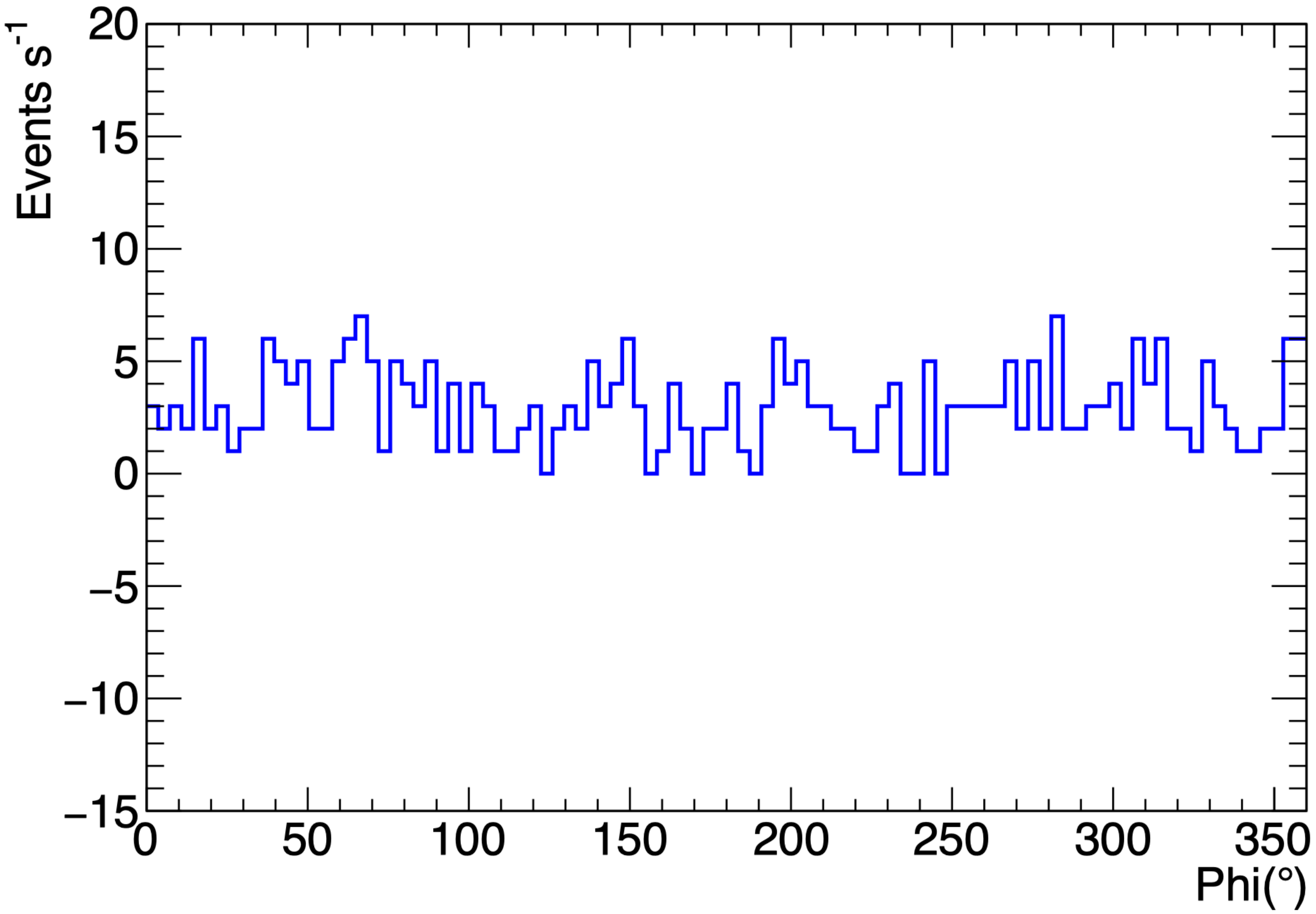



Best-fit spectral indices calculated from the spectra of size

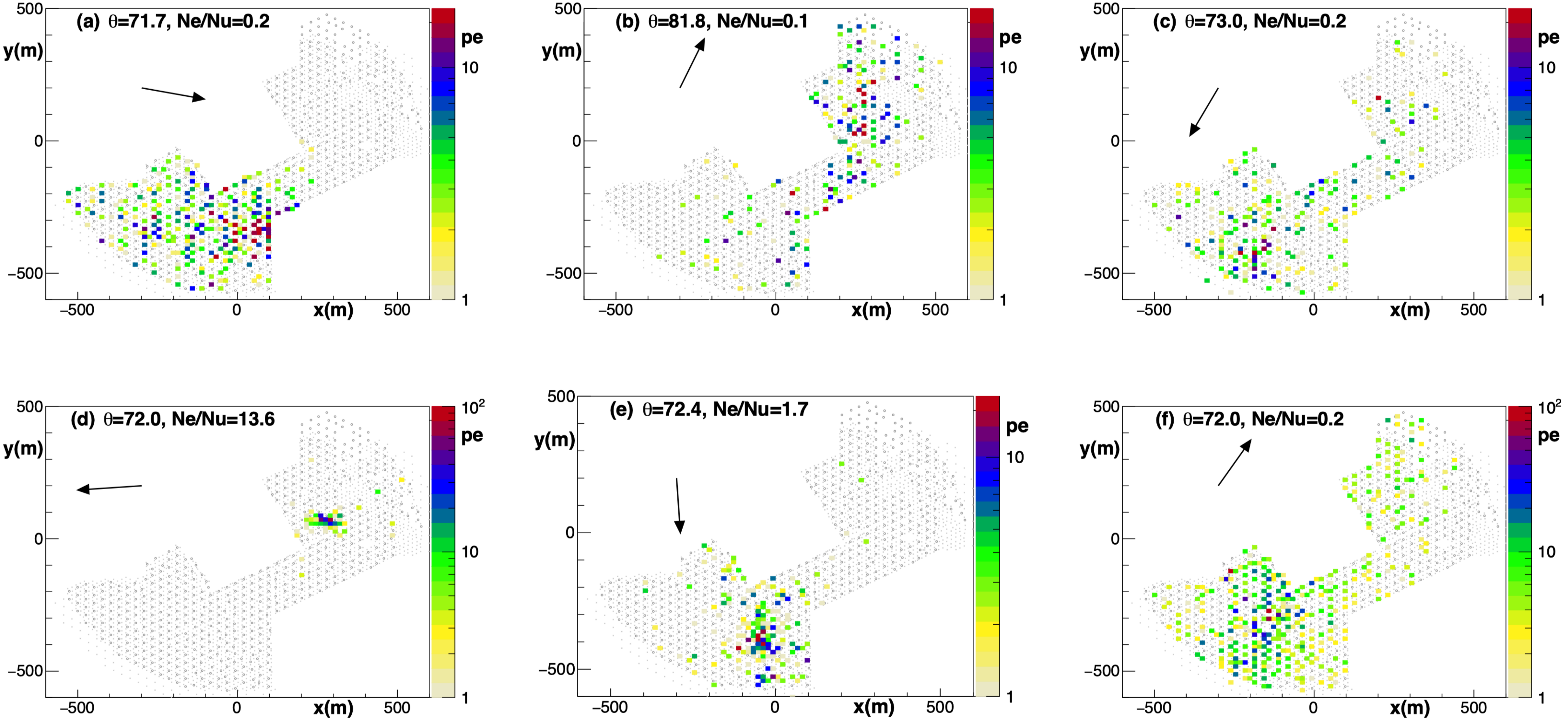
Fitting Range (1e5, 1e7)

The muon dominated spectrum is puzzled by statistics at present above 80 Deg

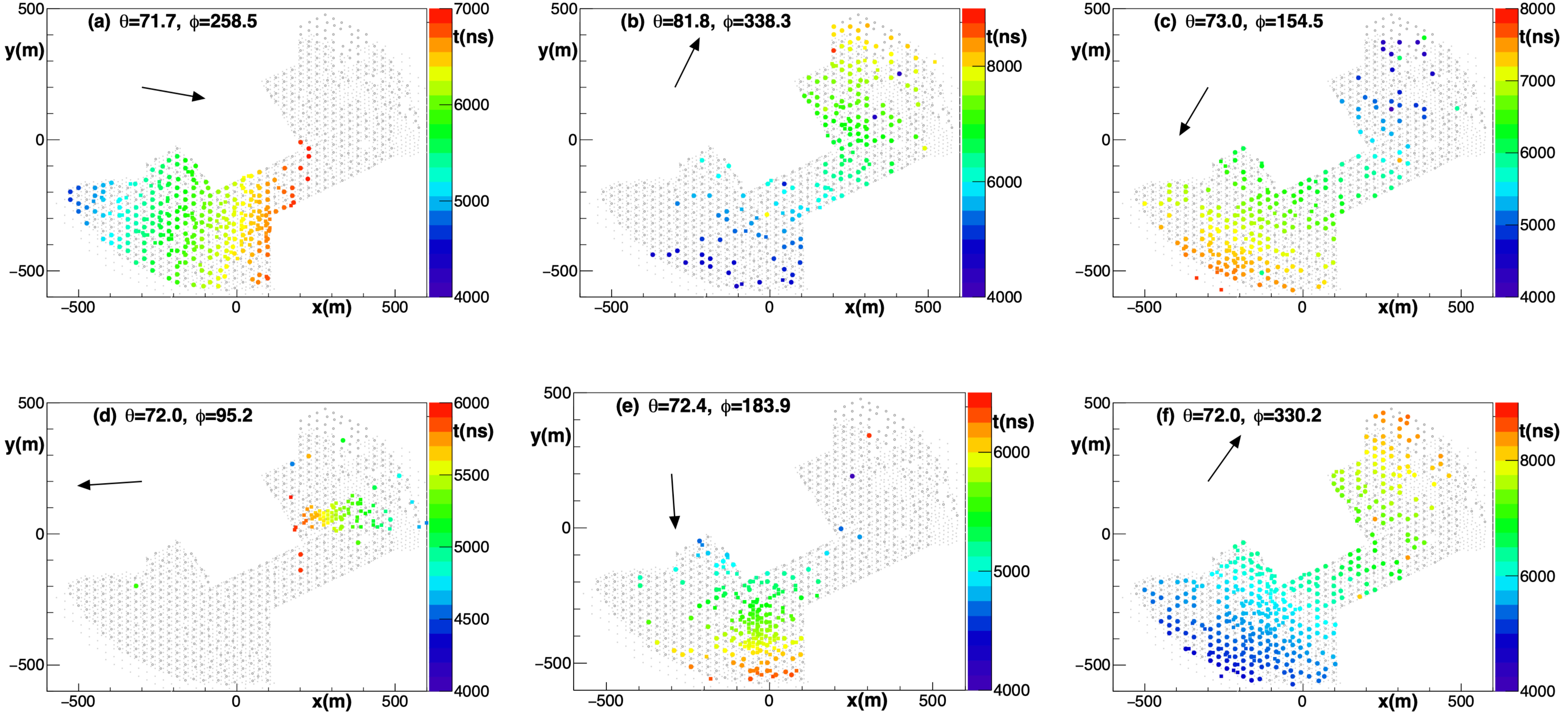
# Event rates Change with azimuth angle （Theta > 70 )



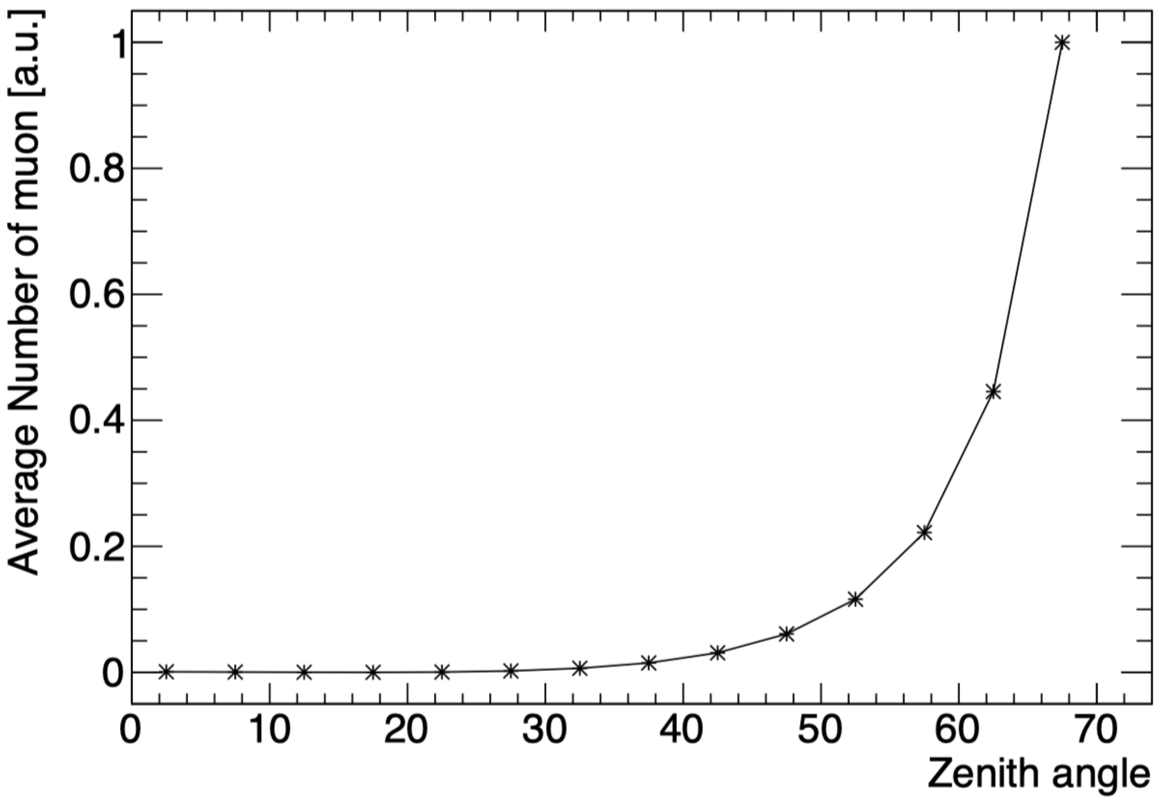

It is consistent with the flat landscape around the LHAASO experiment.



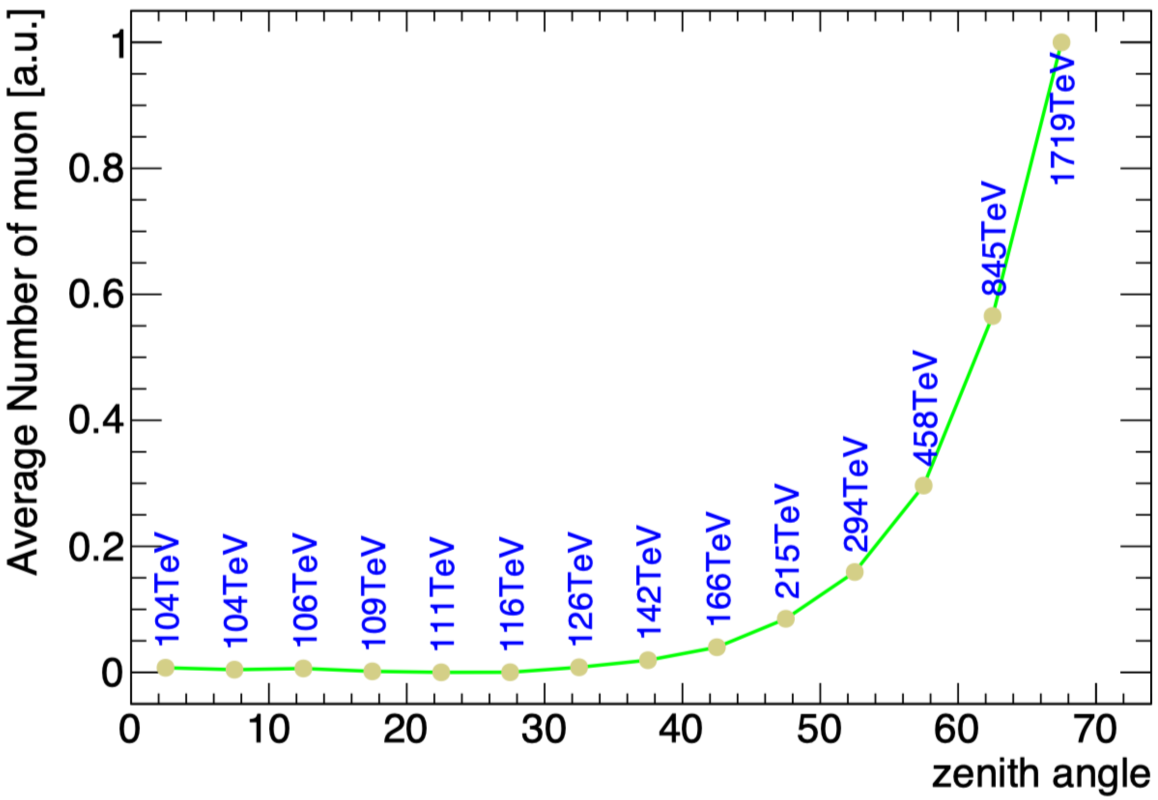

In figures (a), (b), (c) and (f), **the events show that the ratio of Ne/Nu is ≤ 1 as expected in HAS.** In figures (d) and (e), the ratio of Ne/Nu is greater than one. They are rare events, selected for comparison and data selection.




The arrival time of the shower is clearly shown.




(a) data

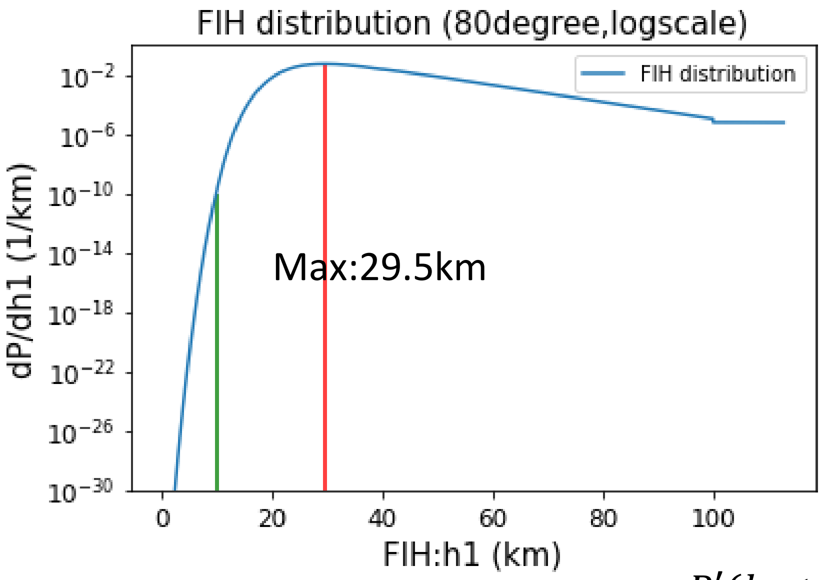



(b) simulation

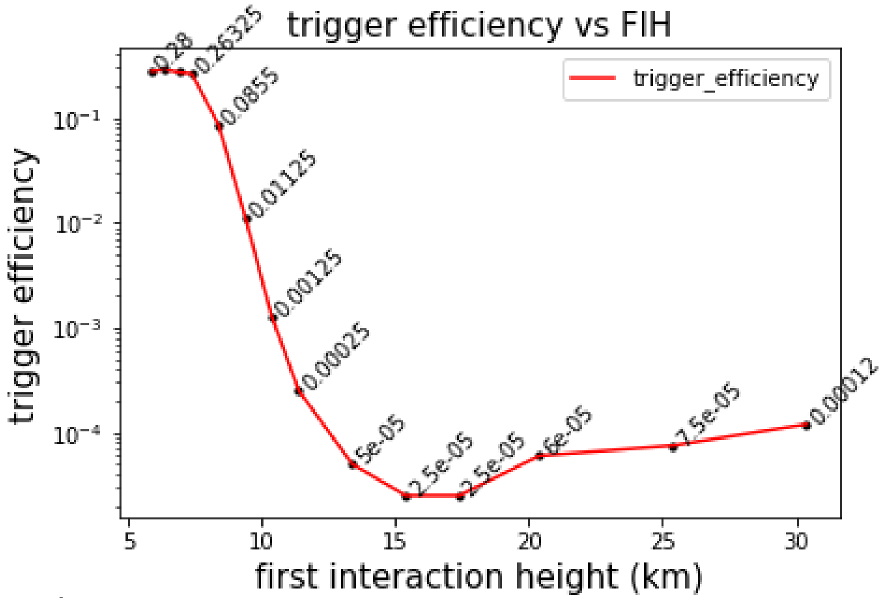
# Neutrino identification

# FIH of triggered proton events

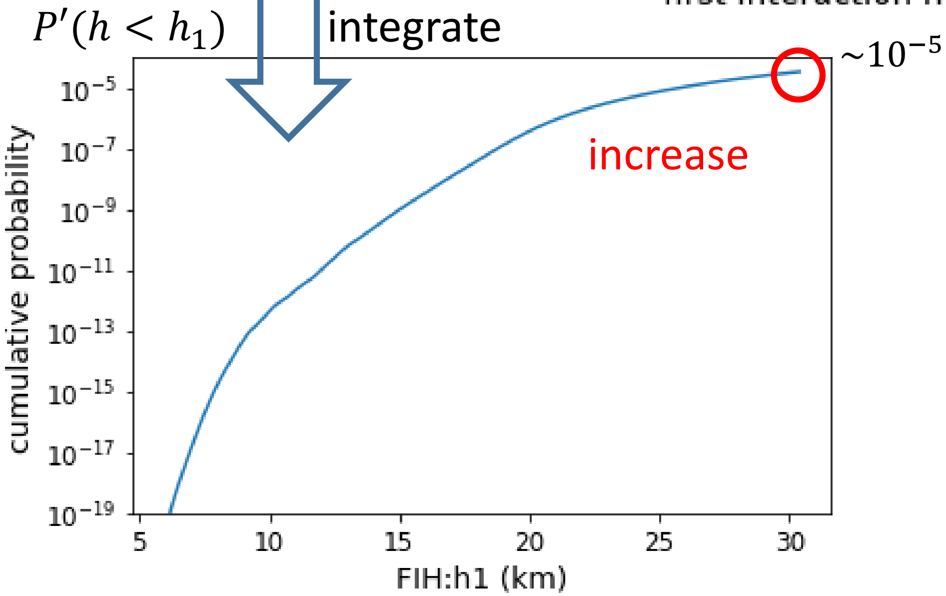
Energy:1~10PeV
Zenith angle:80 deg
First interaction height(FIH) fix at some value




×




integrate



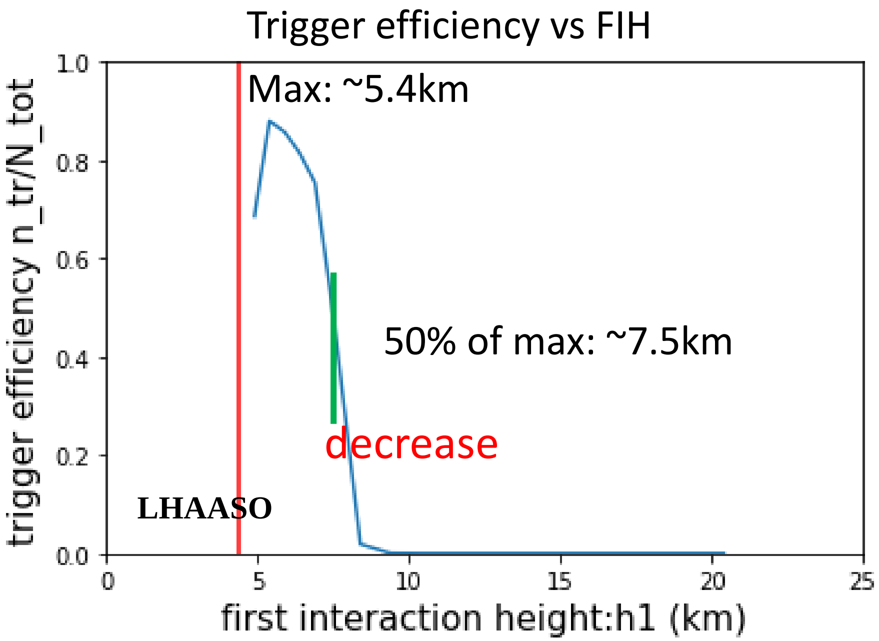

The proton events which can be detected by LHAASO are dominated by events with first interaction height ~30 km

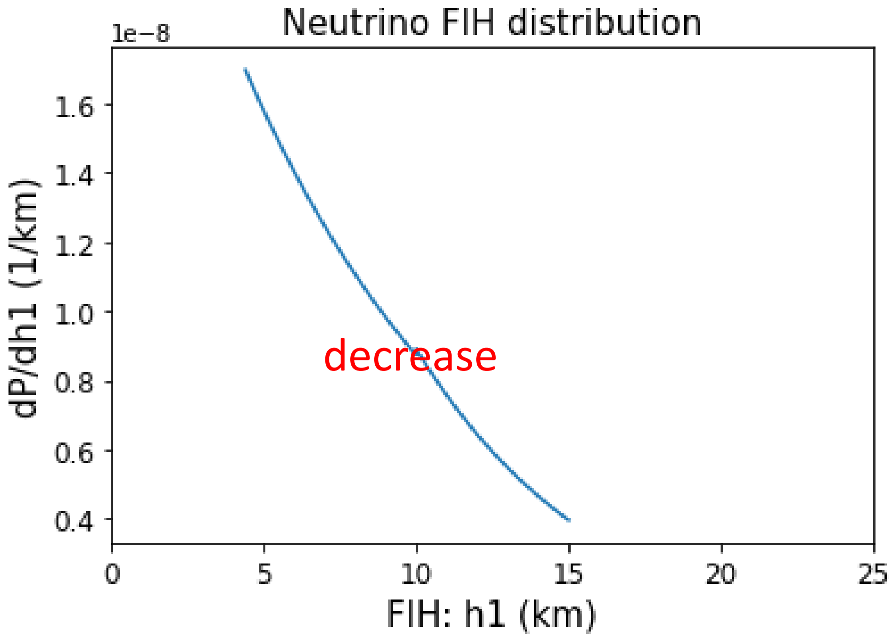
# FIH of triggered neutrino events

Primary particle: $\upsilon_e$
Energy:1PeV
Zenith angle:80 deg

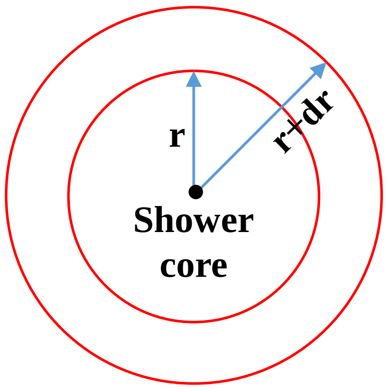
Both FIH distribution and trigger efficiency decrease as FIH increase. So neutrino events with small FIH(4.5~7.5km) dominate the trigger events

Effective height: 3~4 km above lhaaso

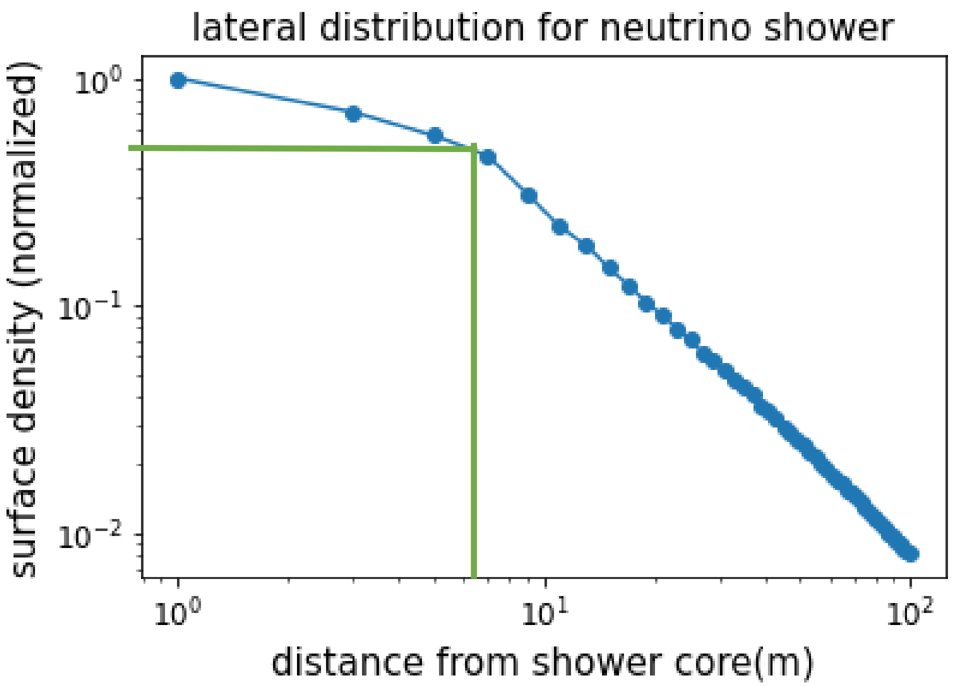


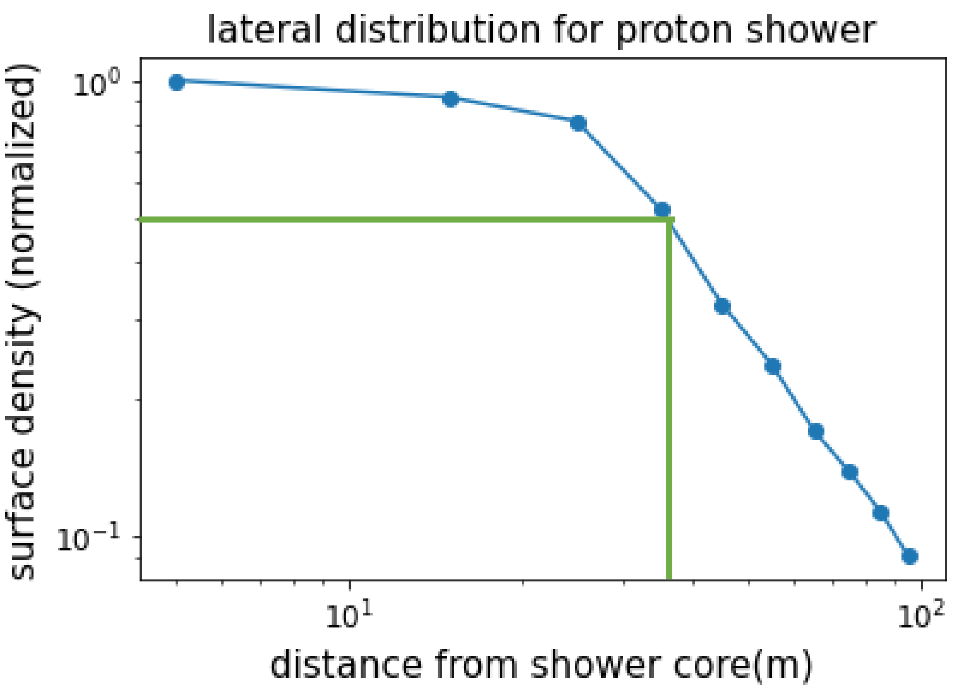
# Lateral distribution




Neutrino: 1 PeV 80deg FIH=5.4km




Proton: 1.5 PeV 80deg FIH=30.4km




radius bin(dr):
2m for neutrino
10m for proton

All secondary particle

Green line: 50% of max
Radius: ~6m

Green line: 50% of max
Radius: ~35m

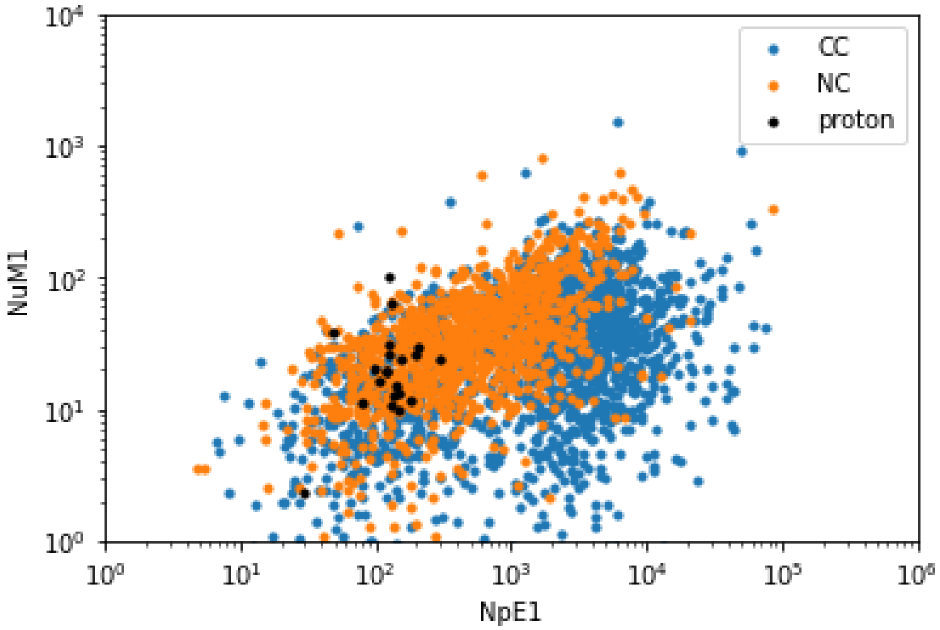
Neutrino shower is more compact

# EM particle vs. muon

CC interaction trigger efficiency is higher

NC： 53%      CC： 87%

(100TeV~1PeV, 80 degree, electron neutrino Fixed FIH=5.4km)




NpE1 and NuM1 in g4 and rec

NpE1: charged particles in (0,100m)

NuM1: Muon in (15m,200m)

# Summary

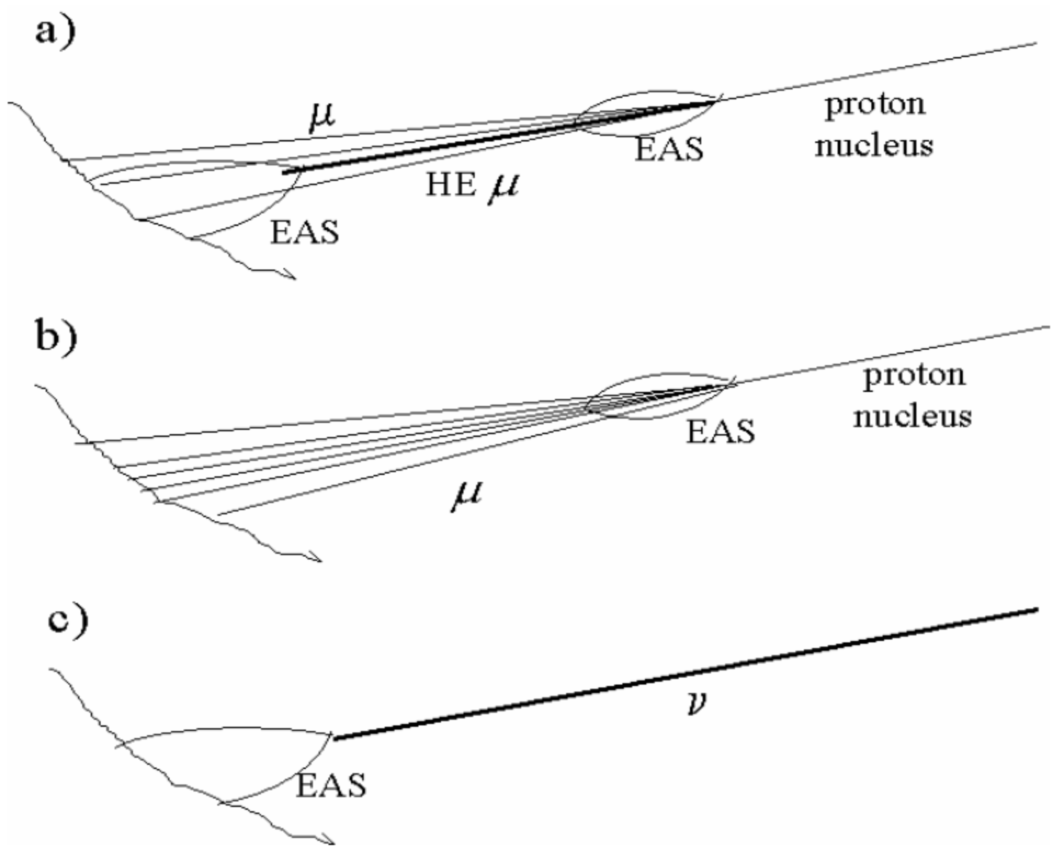
1. The first observations of HAS with LHAASO-KM2A are presented.

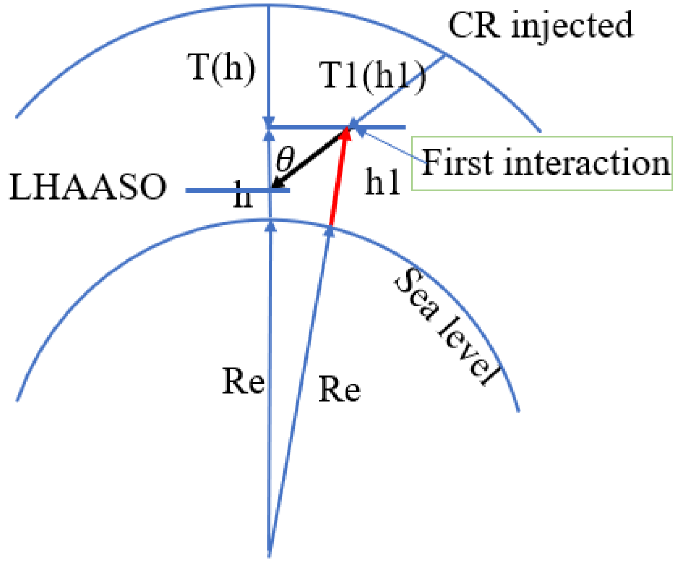
2. The zenith and azimuth angle distribution of EAS and the transition from electromagnetic-dominated showers to muon-dominated ones above a zenith angle of 60 degree are observed.

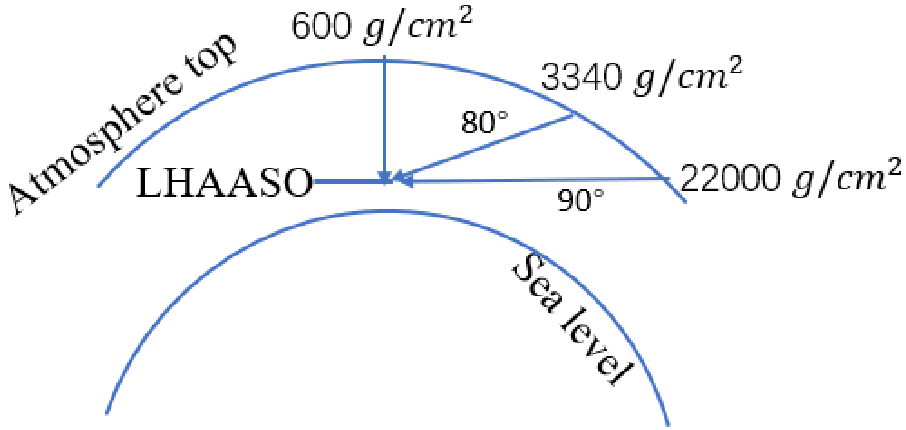
3. The methods of neutrino identification are investigated.

4. This analysis has shown that LHAASO is able to observe HAS and can be used to **study muon content in EAS and search for neutrino-induced EAS from flaring phenomena like GRBs.**

Thanks!




Possible sources of Horizontal Air Showers:
a) ”local” high energy muon interactions, b) muon dominated showers, residuals from an UHE c.r. interaction at very large distance, c) neutrino events.