Study Horizontal Air Shower with LHAASO-KM2A

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LHAASO 高海拔宇宙线观测站

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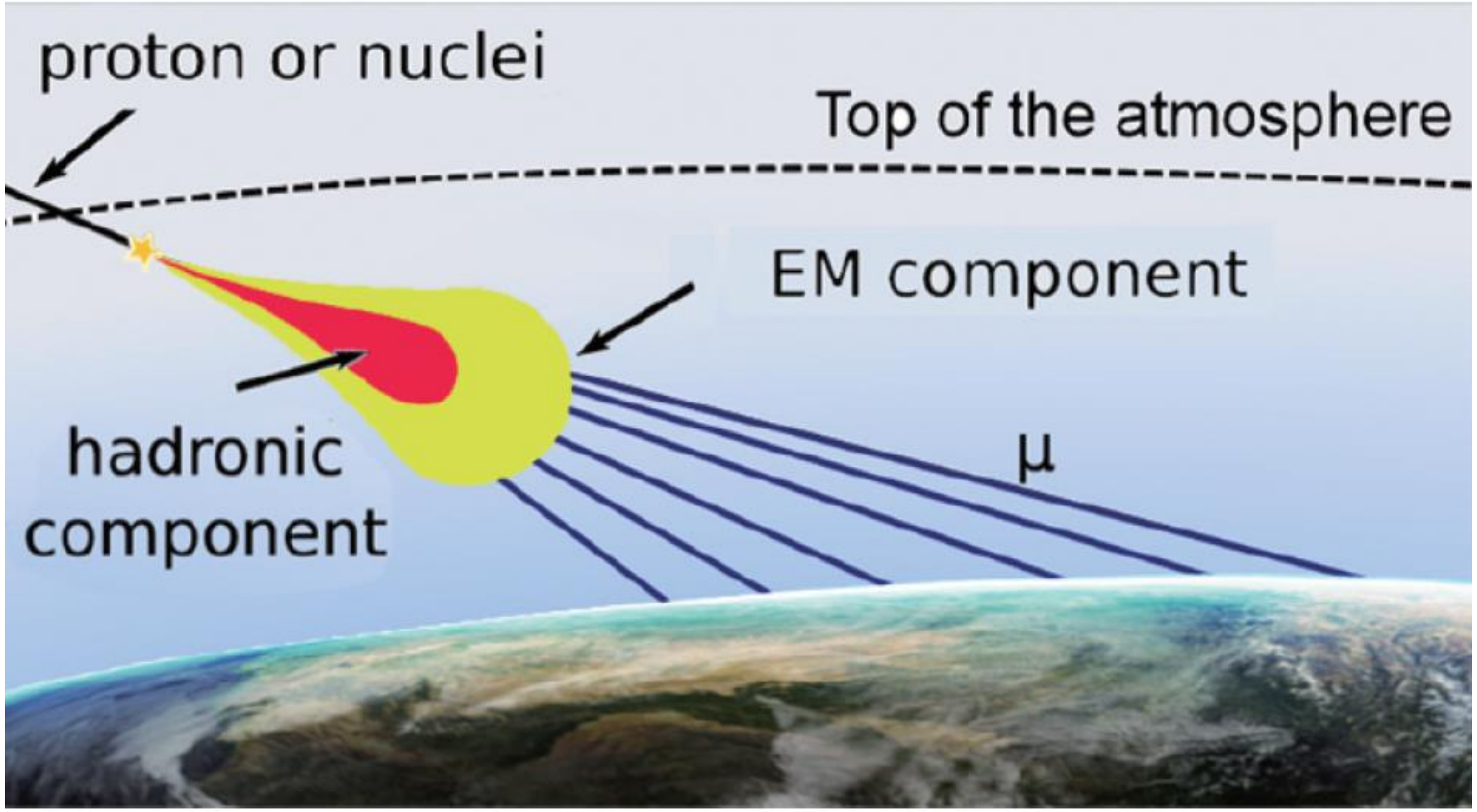
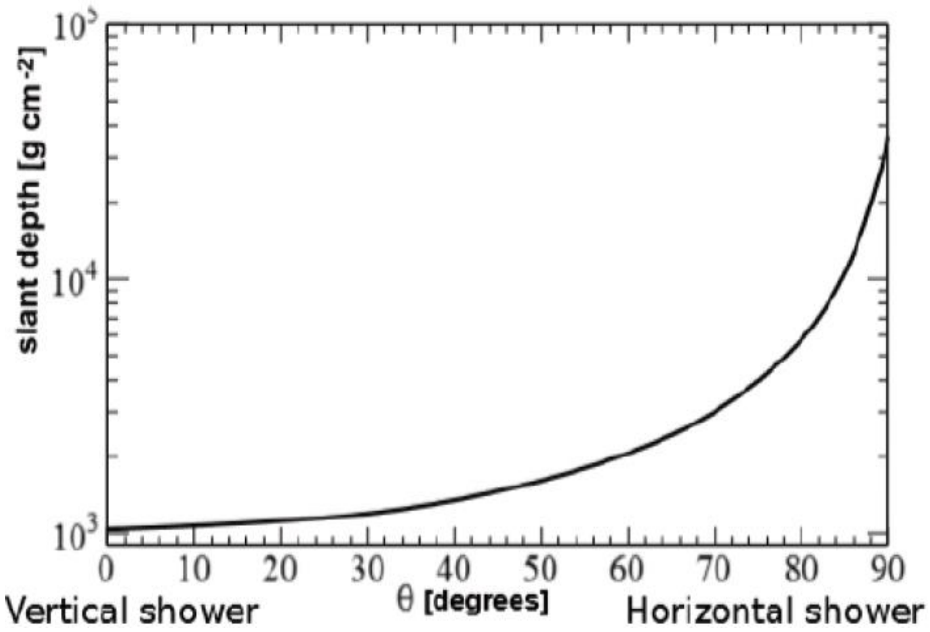
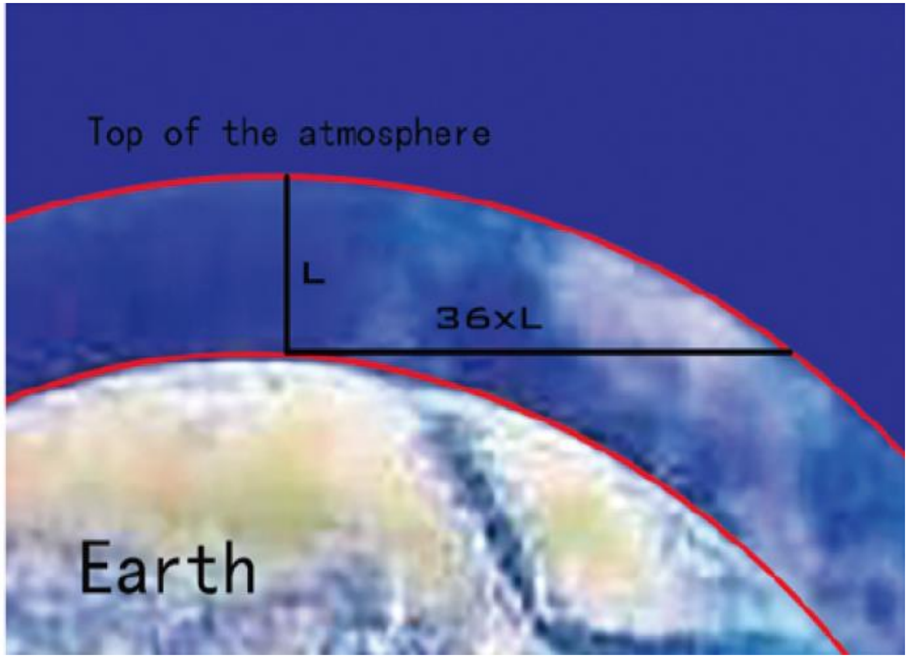
Horizontal Air showers (HAS)

Cosmic Rays can initiate a HAS in the atmosphere.



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

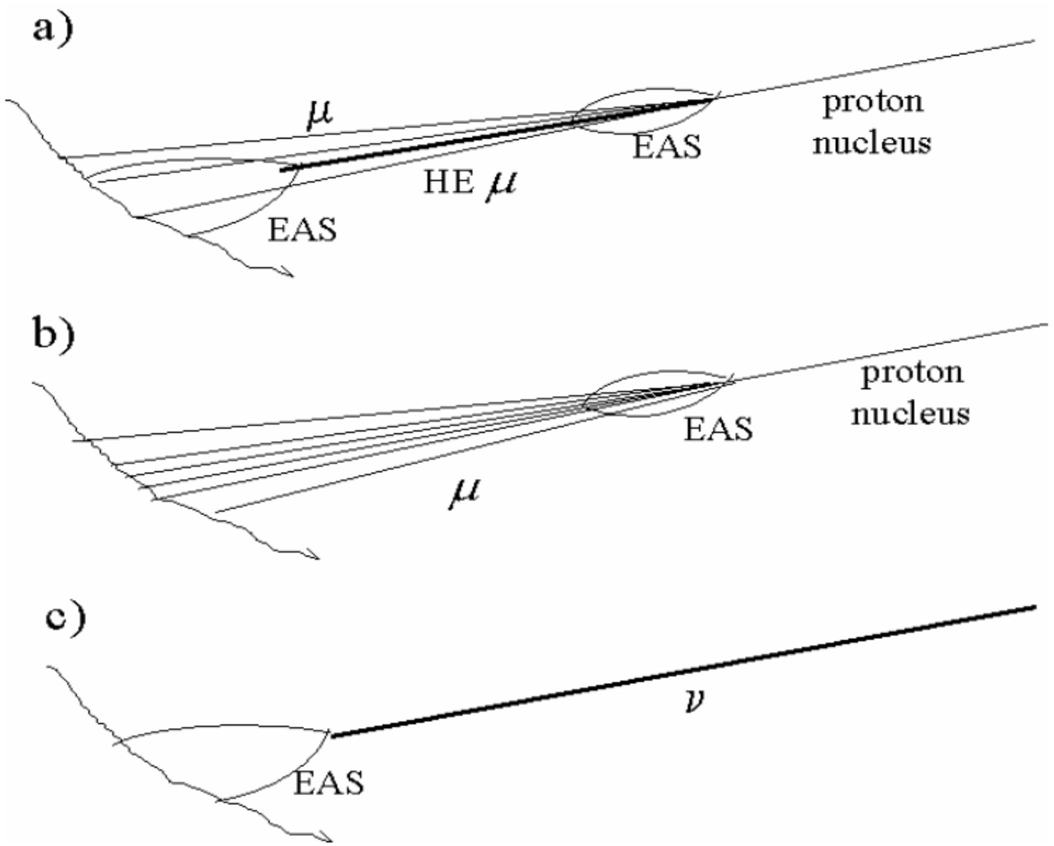




Left: Atmospheric depth as a function of the zenith angle. The amount of matter increases quickly after 60°.

Right: A horizontal shower goes through 36 times more mass than a vertical shower.

Different topologies of the p/ν events



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.

Horizontal Air showers

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. **This is a powerful channel to study hadronic interaction.**

The showers with significant muon component could be further rejected by underground muon detector. **This provides a method to search neutrinos from HAS.**

ARGO-YBJ measurement of HAS

33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

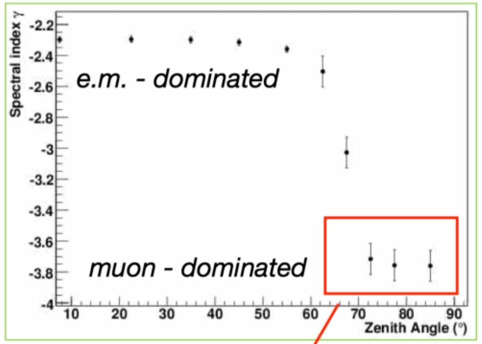
ICRC 2013

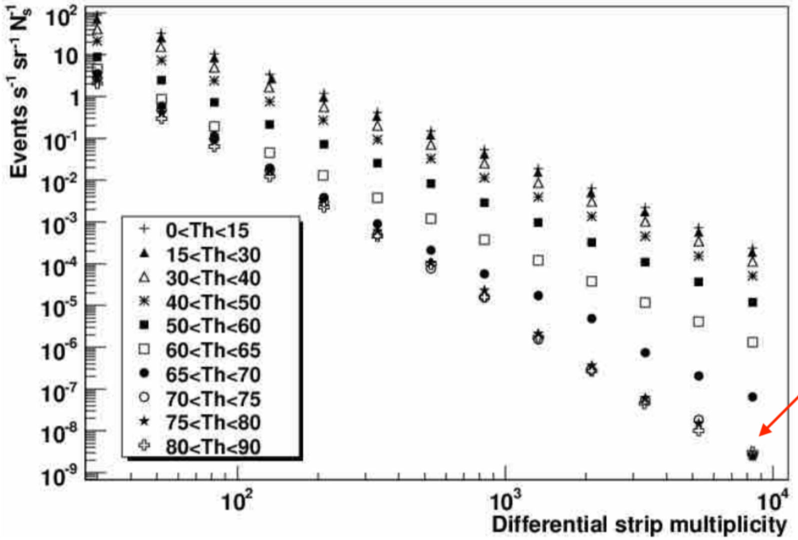
Observation of Horizontal Air Showers with ARGO-YBJ

G. DI SCIASCIO[1], B. PANICO[1] FOR THE ARGO-YBJ COLLABORATION.

Measured Rate of HAS

Strip multiplicity for different zenith angles





$\gamma \approx -3.70$
spectral index muons in EAS

Contents

- Distribution of different variables with zenith angle
- Spectral index change with zenith angle
- Zenith angle distribution
- Simulation vs experiment

LHAASO-KM2A: Event Numbers Change with Zenith Angle of “NfiltE”

Data Selection

- Reconstructed data of 2020 was used
- “NfiltE” was used as N_e
- 20 < NfiltE < 200
- ED(40 m) > ED (40-100 m),
- Age (0.6 - 2.4) ,
- Shower Core falls into the two-circles to obtain a symmetrical shower

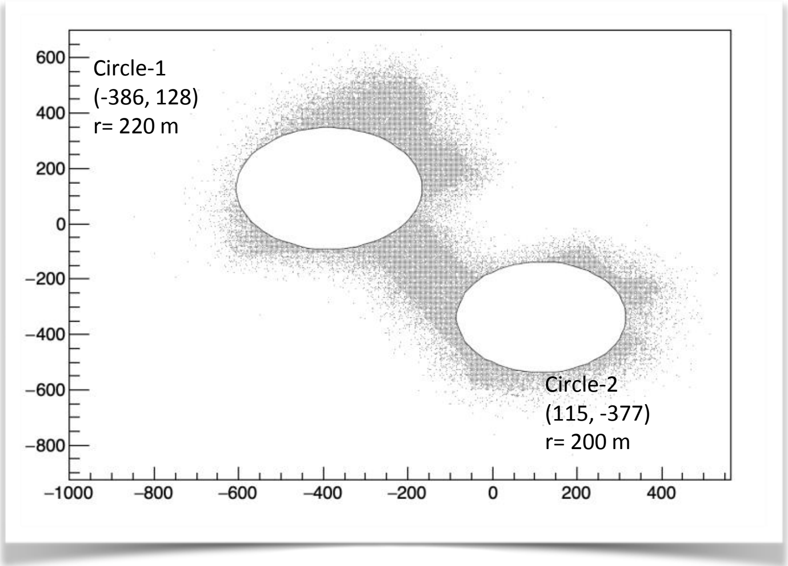


Fig. 4 Demo of CoreY: CoreX of NfiltE inside Half array of KM2A;
Two circles are used for data selection.

Events Change with NfiltE for different zenith angle

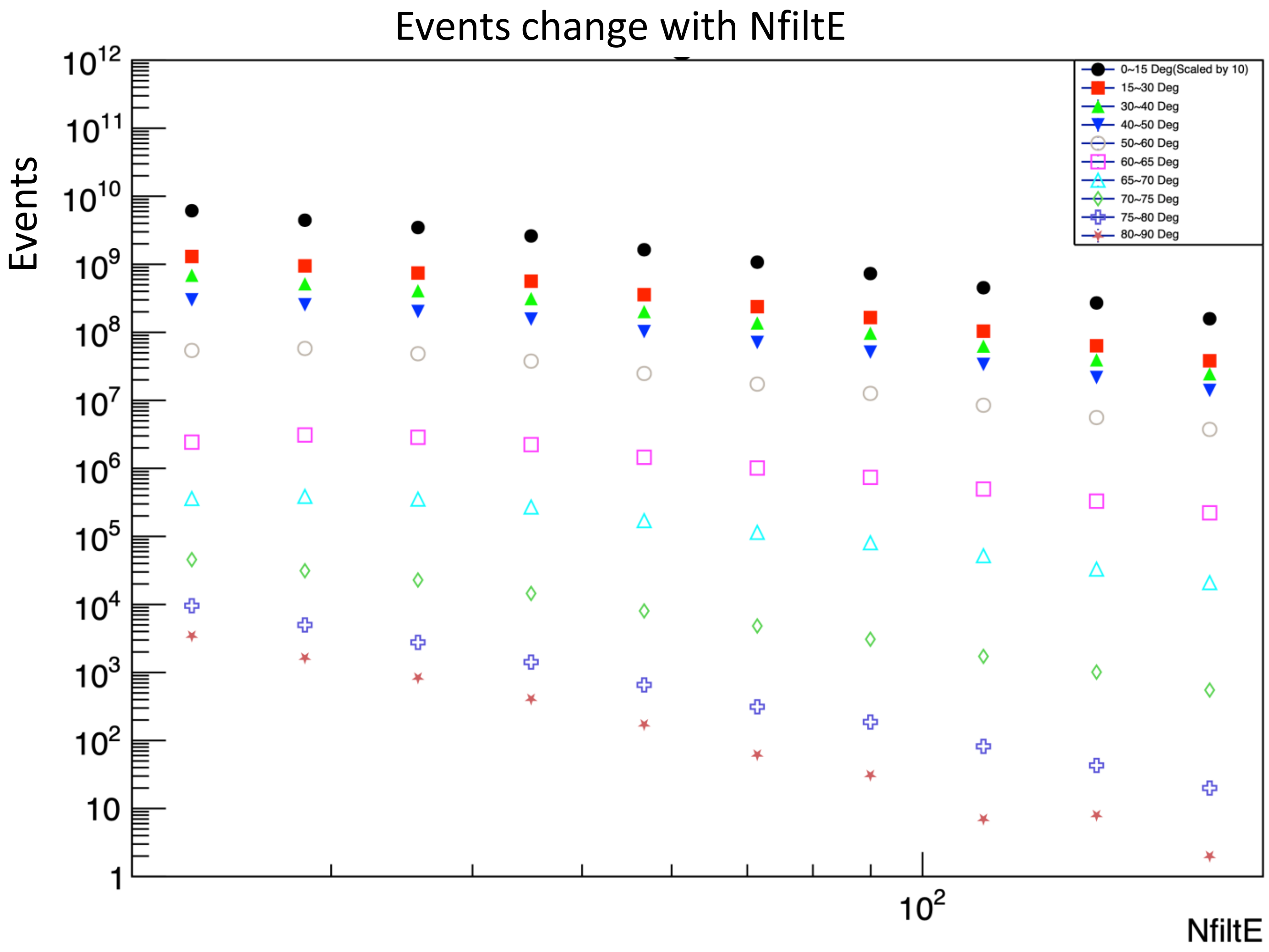


Fig. 5 Events change with NfiltE for different Zenith angle

- the x and y axis was set to log scale
- the x axis range from 20 to 200, with a bin width of (delta log(NfiltE) = 0.1)
- in order to separate the dots, the entries for zenith angle range (0-15) was scaled by 10

Spectral Index Change vs Zenith Angle

(1) The spectral index peaks around 50 - 65 Deg
(2) The muon dominated spectrum does not show up above 70 Deg

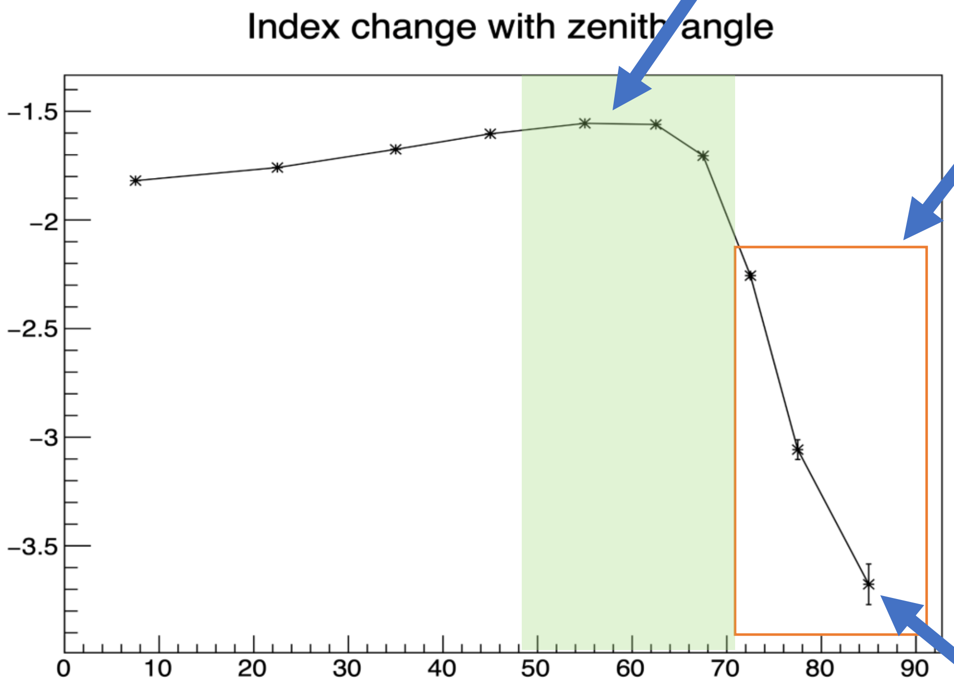


Fig. 6 Index change with zenith angle.
The values are provided by the best fits of the events change with NfiltE multiplicity

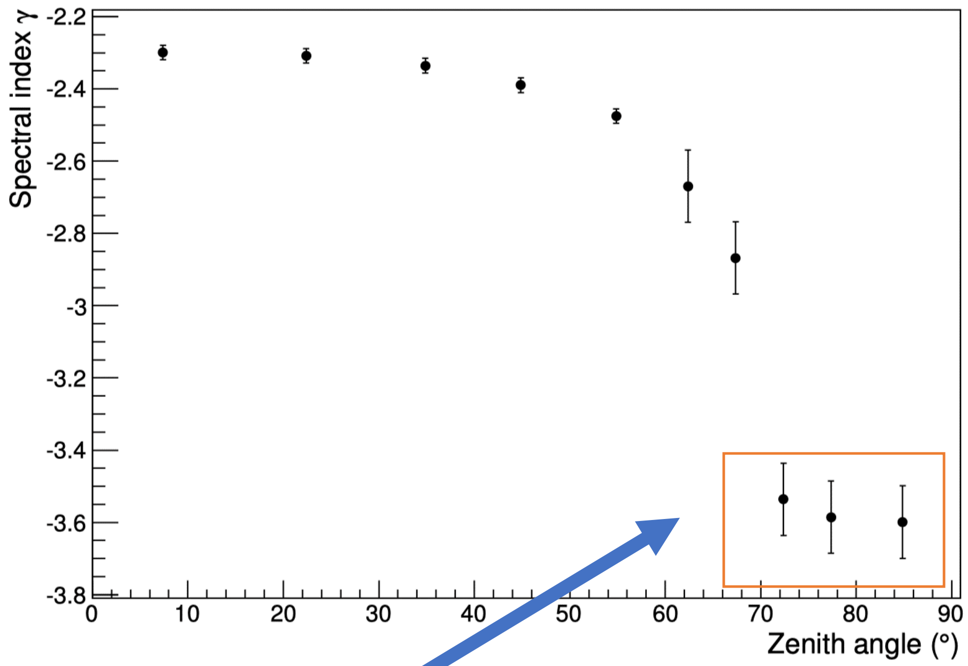


Fig. 7 Spectral index measured for the different bins of zenith angles.

$\gamma = -3.7$
spectral index muons in EAS

This Work

Argo Experiments

Event numbers change with zenith of “NpE3”

Variables in Reconstructed Data

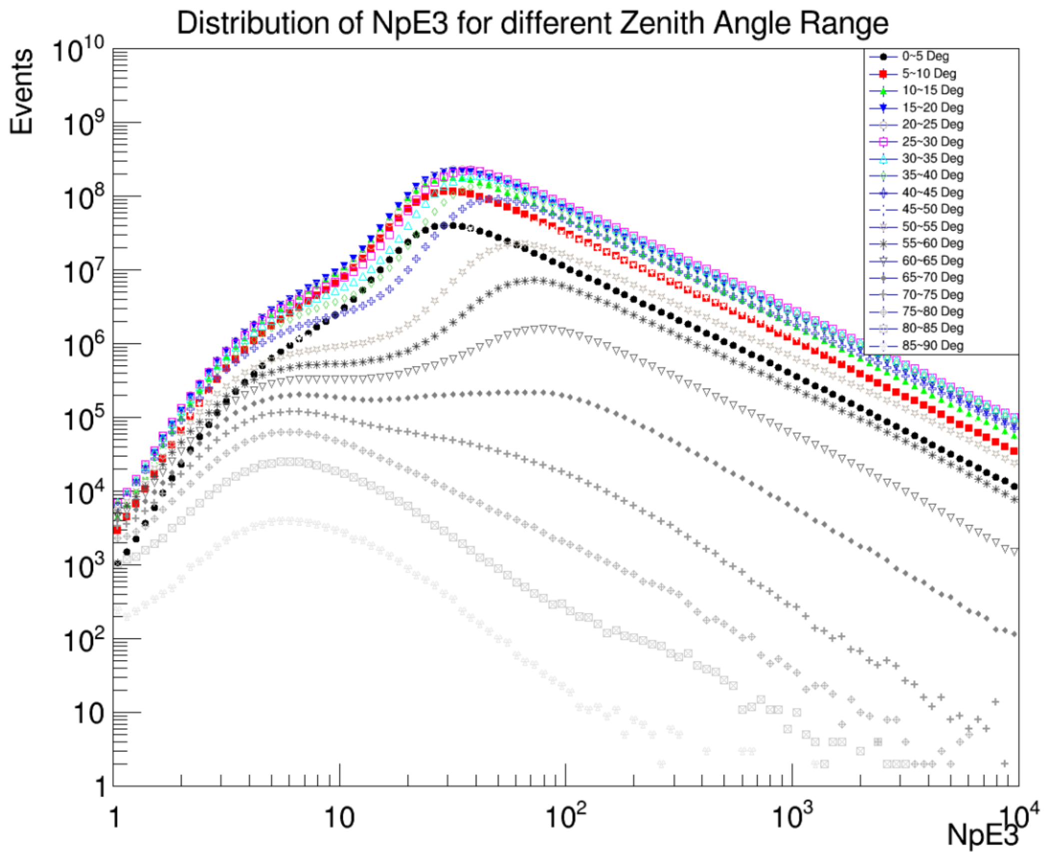
- NfiltE: Number of ED HITs with time window [-50,100ns] and radius window [0,200m], double time window
- NfiltM: Number of MD HITs with time window [-30,50ns] and radius window [0,200m]
- ………………………………………………………………………………………
- NpE1: Number of EM PARTICLES, with time window [-30,50ns] and radius window [0,100m] (NpE1/NpE2 > 2)
- NpE2: Number of EM PARTICLES, with time window [-30,50ns] and radius window [40,100m], NpE2 > 20
- NpE3: Number of EM PARTICLES, with time window [-30,50ns] and radius window [0,200m] , (-200,200ns)
- Size： fitted shower size with NKG,
- ....
- NuM1: Number of muon PARTICLES, with time window [-30,50ns] and radius window [15,200m]
- NuM2: Number of muon PARTICLES, with time window [-30,50ns] and radius window [40,100m]
- NuM3: Number of muon PARTICLES, with time window [-30,50ns] and radius window [40,200m]
- NuM4: Number of muon PARTICLES, with time window [-30,50ns] and radius window [15,400m]

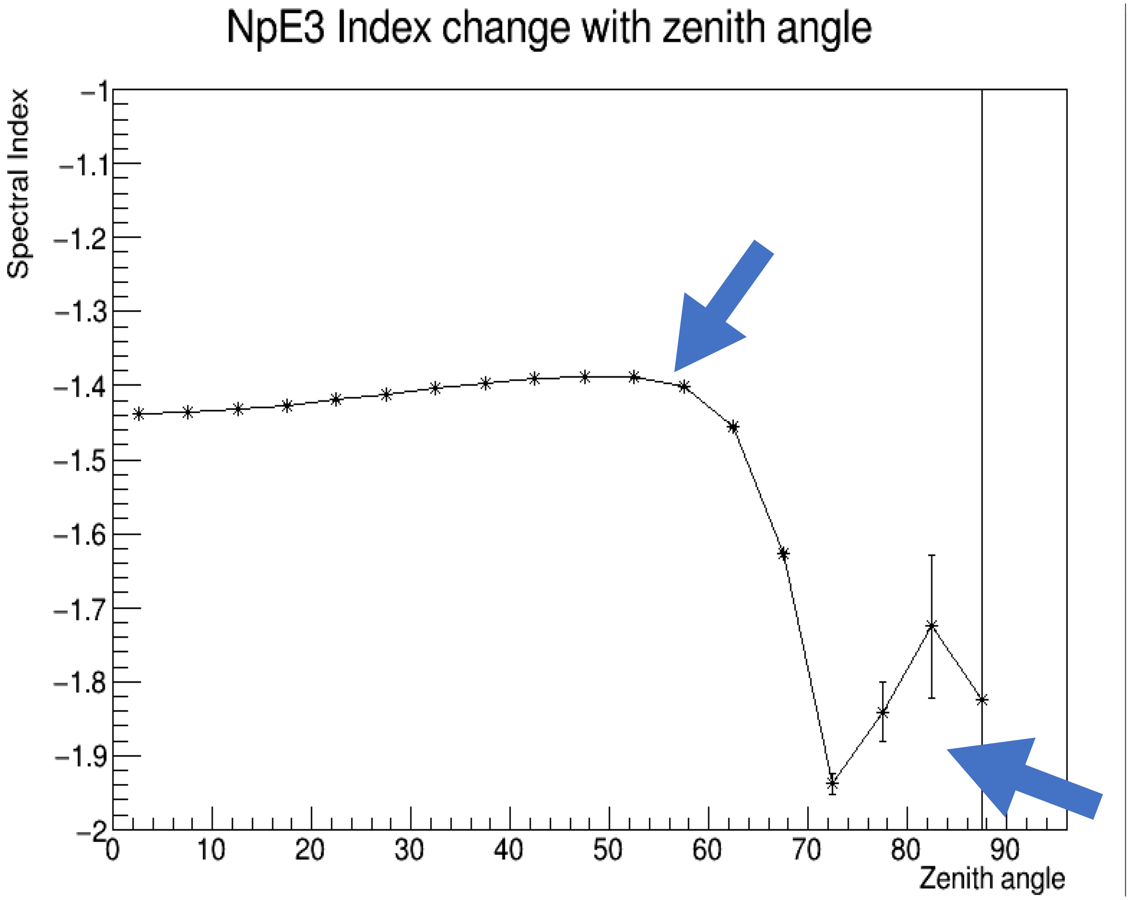
Variables Distribution was checked

- NpE3: particles detected by ED (Ne+Nu)
- NuM1: particles detected by MD (Nu)
- NpE3-NuM1: (Ne)
- (NpE3 - NuM1)/NuM1: (Ne/Nu)
- NpE1: for comparison with NpE3

- Data from 303.997 living days out of 340 duty days in 2020 was used
- without any cut

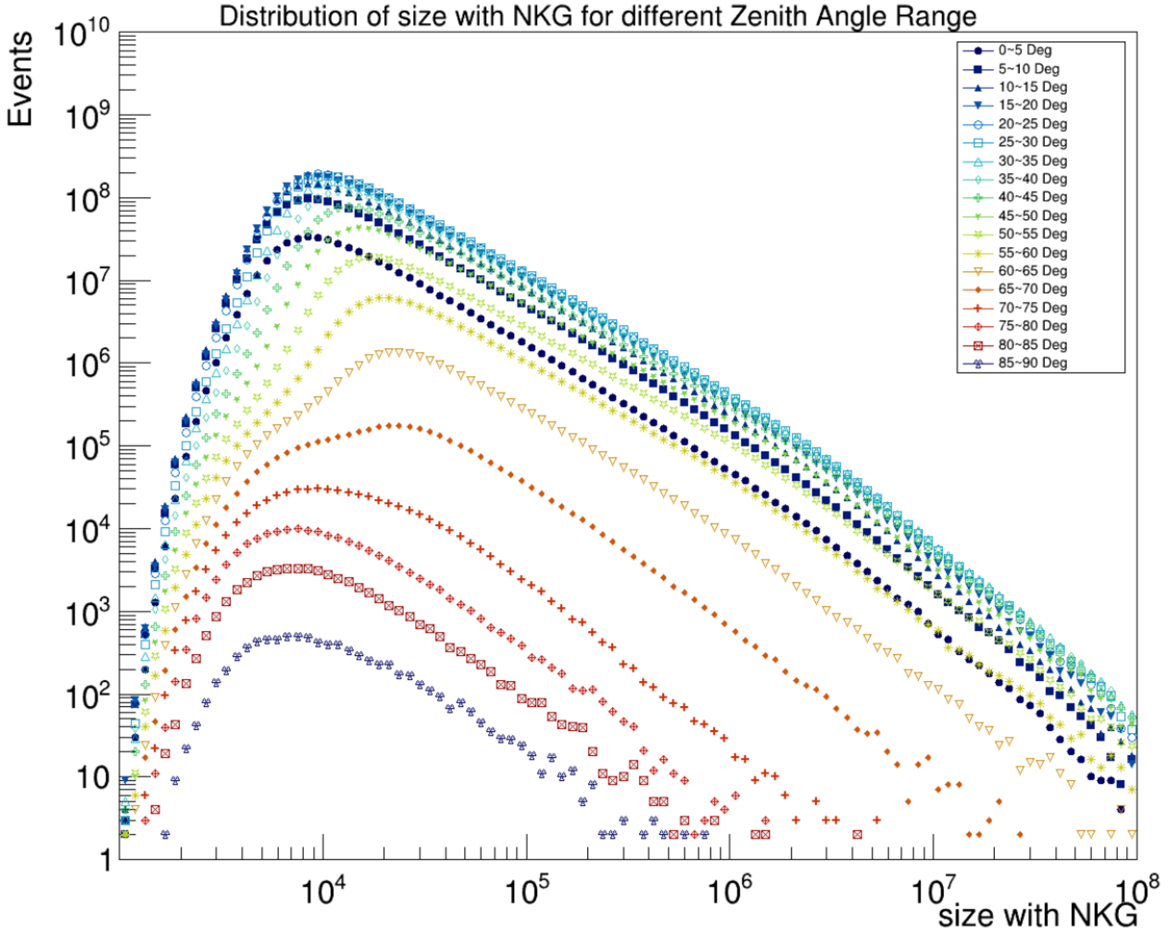
NpE3 Distribution and Spectral index

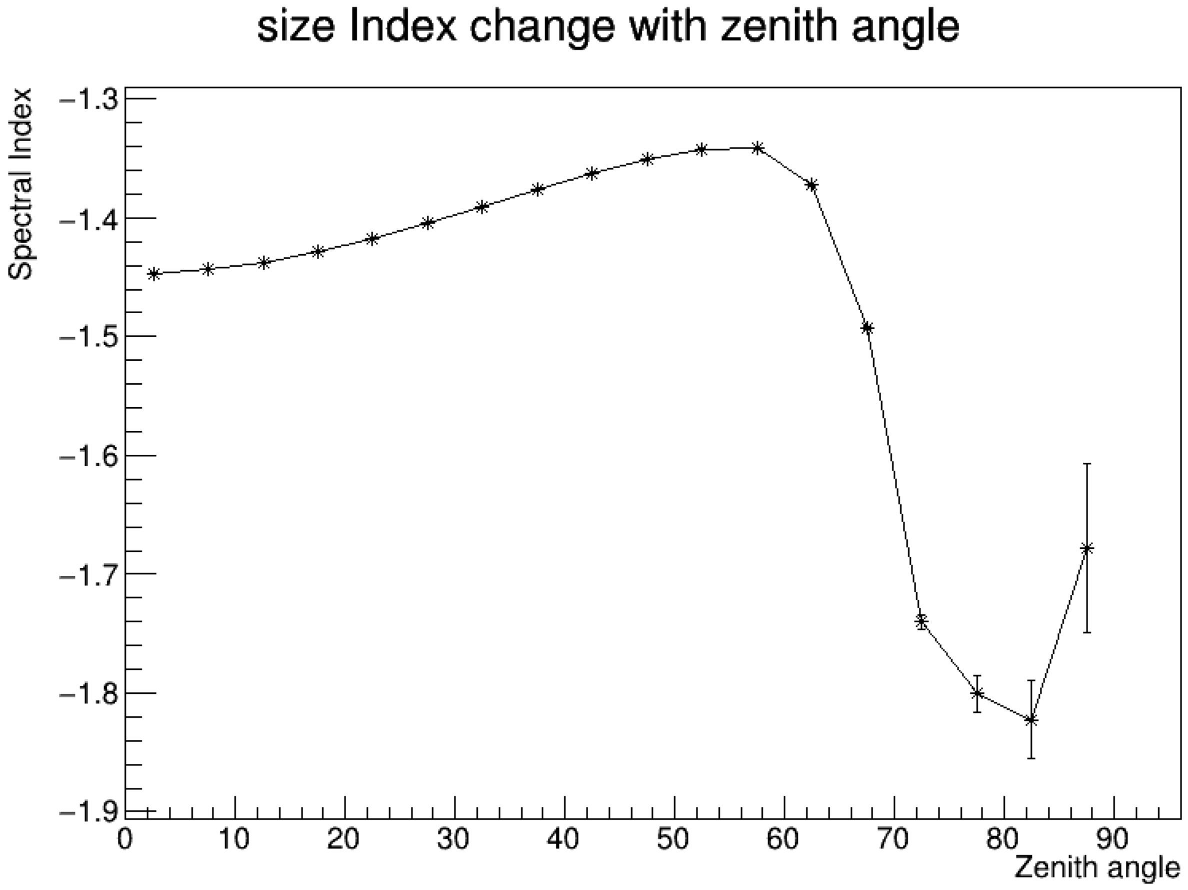




It is hard to get a best fit from these distributions

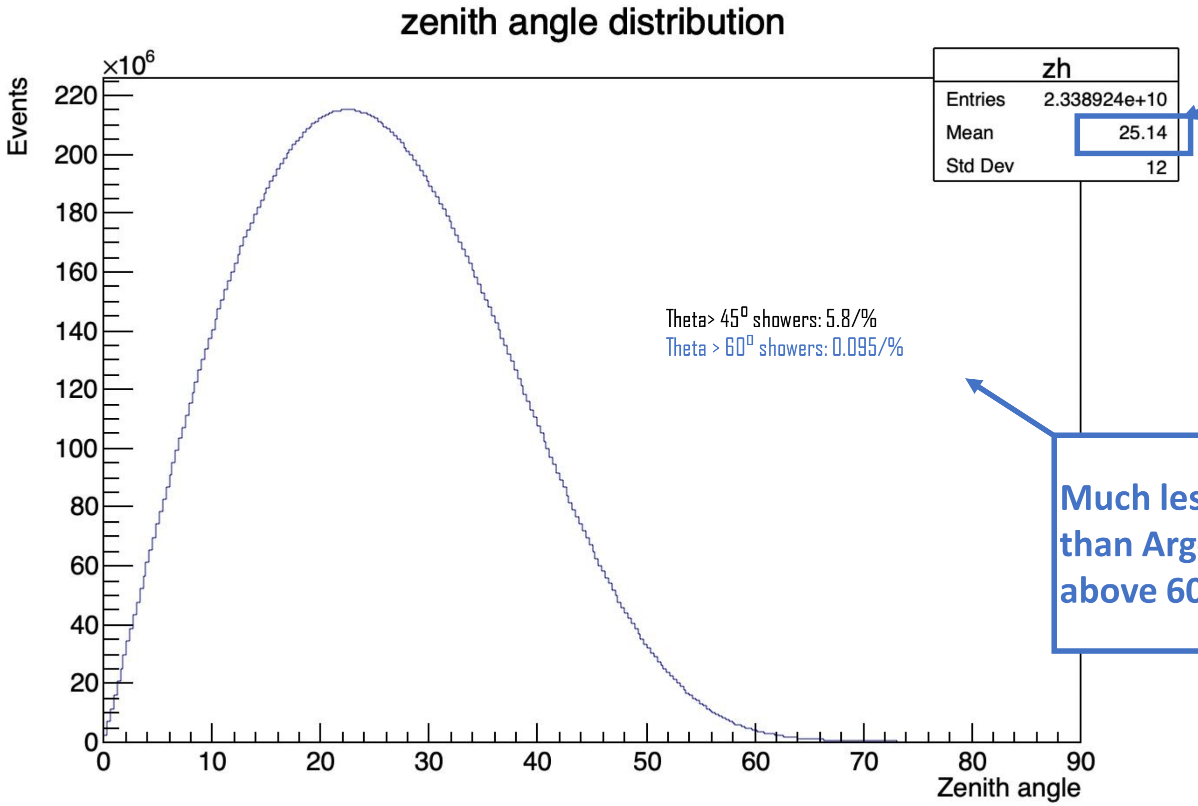
Size Distribution and Spectral index





Fitting Range (3e4, 1e6)

Zenith angle distribution



This work

Same mean

Much less shower than Argo above 60

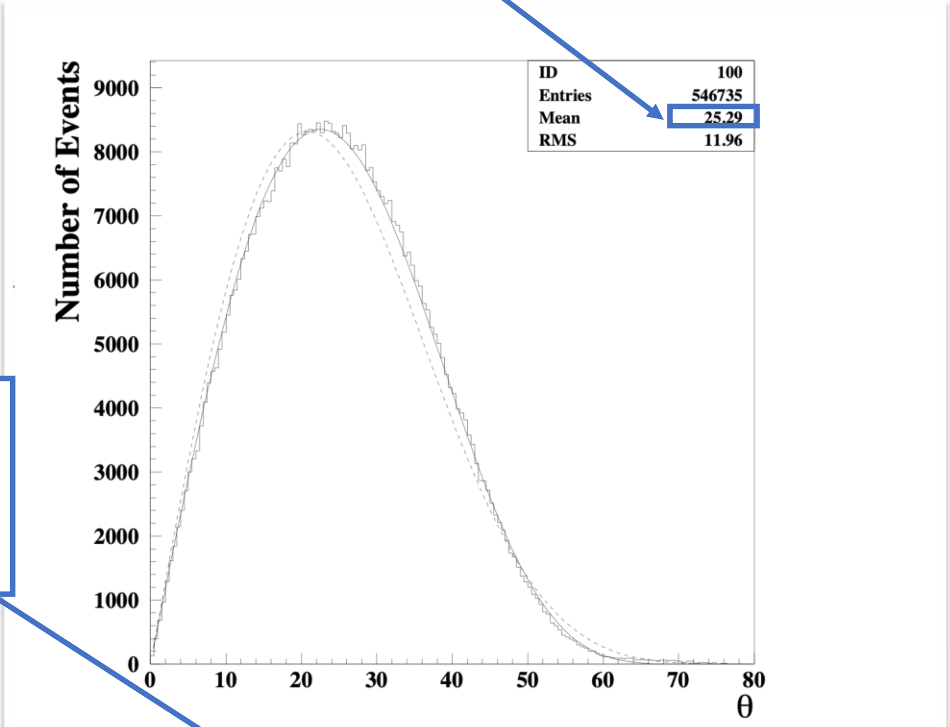
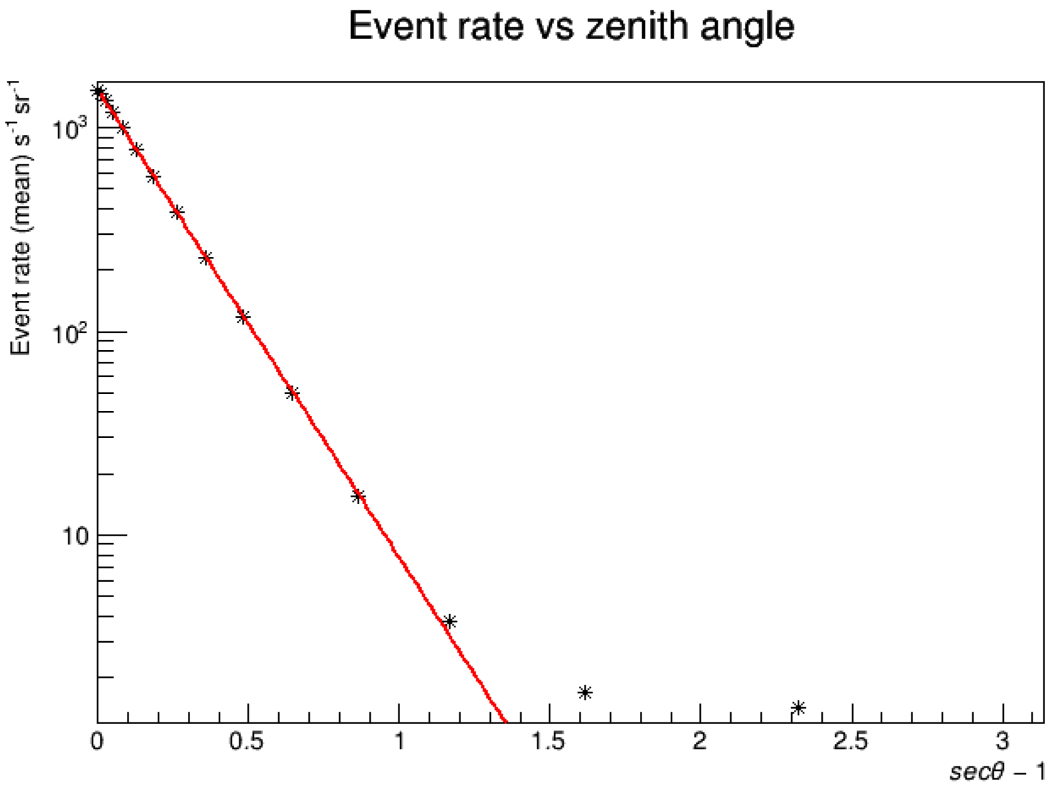


Fig. 3. Measured zenith angle distribution for internal selected events in ARGO-104. The "exponential" (solid line) and "$\cos^n\theta$" (dashed line) best fits are also shown.

Only about 6% (0.3%) of the showers have zenith angles larger than 45° (60°).

Argo experiments

This Work

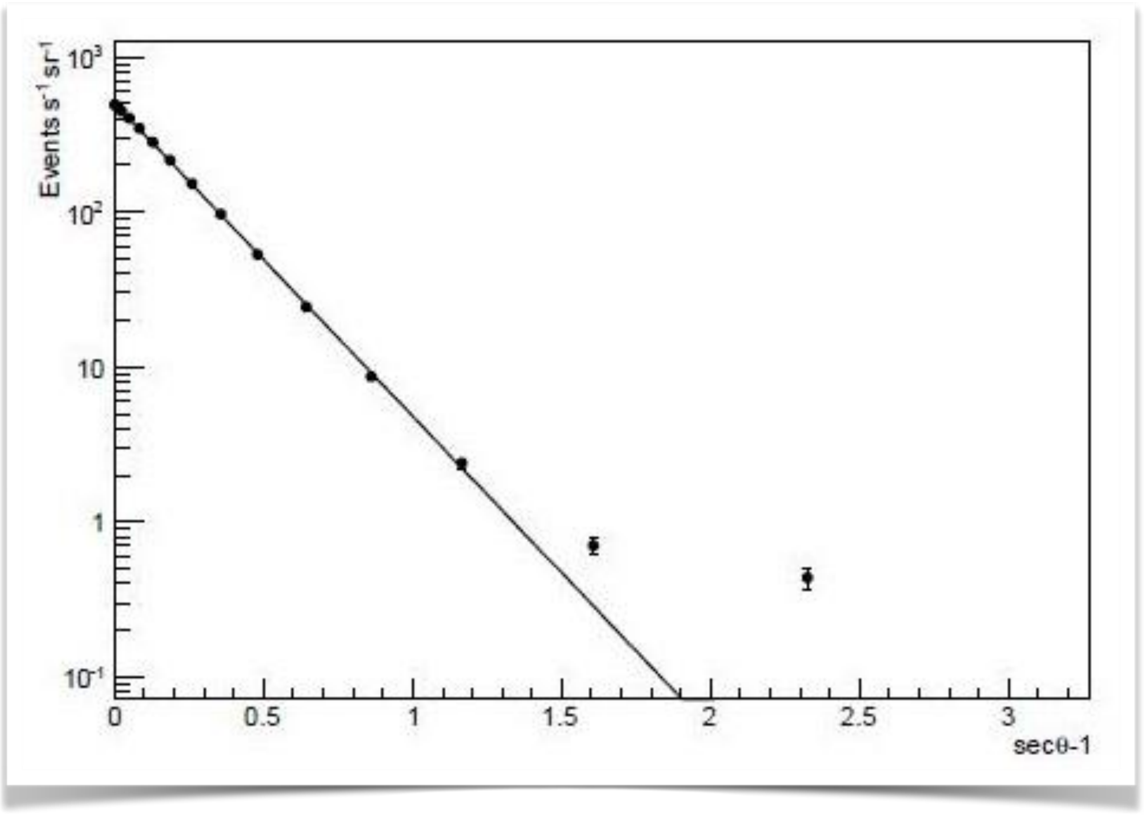


$$I(\theta) = I(\theta = 0^o) * exp\left[-\frac{x_0}{\Lambda_{att}} * (sec\theta - 1)\right]$$

$x_0 = 606\ g/cm^2$, vertical depth

$\Lambda_{att} = 114.4 \pm 0.08\ g/cm^2$, attenuation length

Argo Experiments



$x_0 = 606 g/cm^2$

$\Lambda_{att} = 133.5 \pm 0.4 g/cm^2$

Lhaaso altitude: 4410 m,
Argo altitude: 4310m

Comparison of Simulation with experimental data

More precisely data selection was applied

(0) Basic cut, reconstruction success

0 < Theta < 90, 0 < Phy 90

(1) cut with location

dr > 0;

(2) Cut with a circle

x = -386m;
y = 128m;
r = 220m;

(3) Cut with e.m. particle numbers

NpE1 > 2 * NpE2

(4) Cut with muon particle numbers

NuM1 > 0;

(5) Age

0.6 <= age <= 2.4;

(6) Size

size > 0;

(7) EDs cut

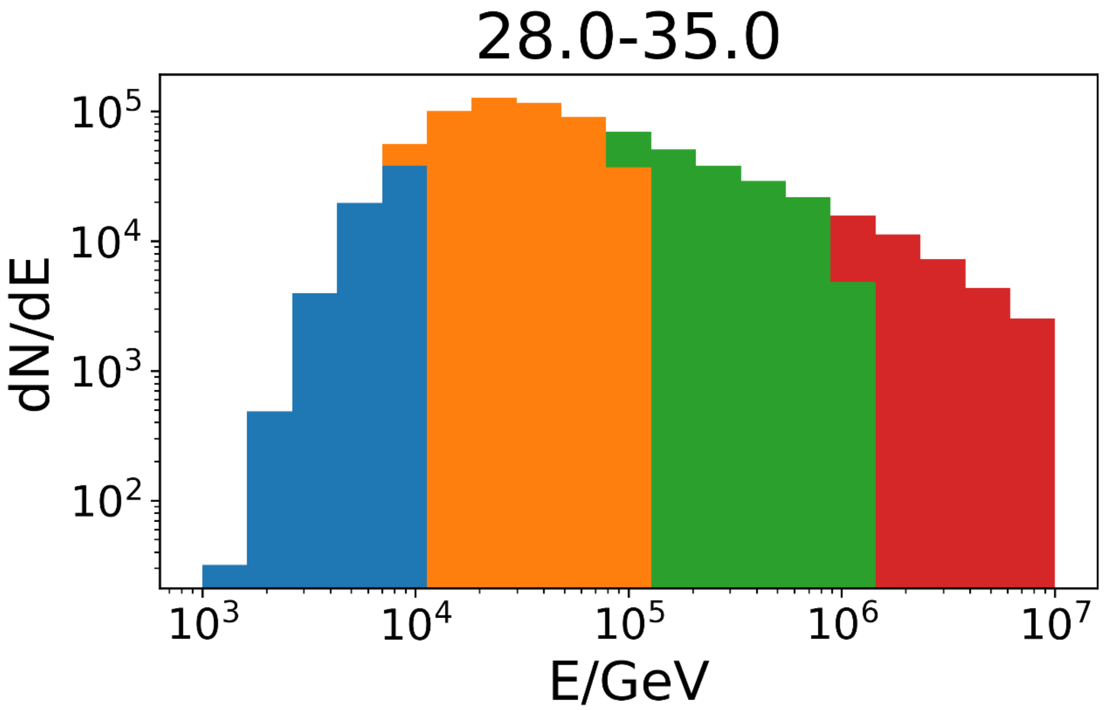
NfiltE > 10;

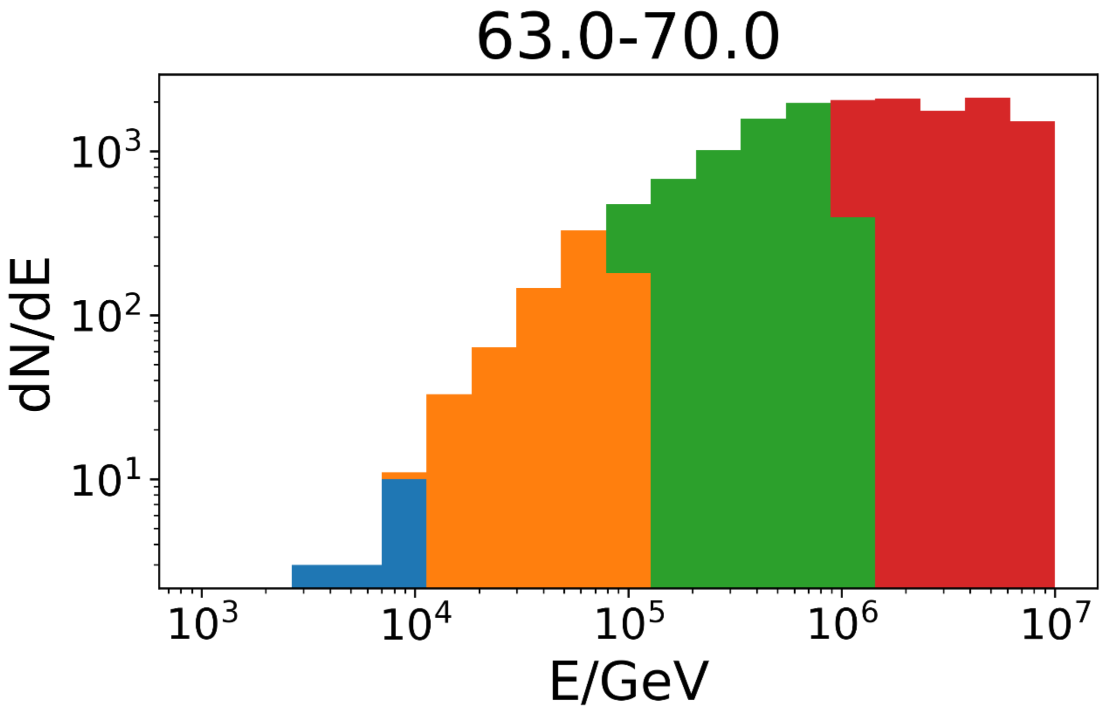
(8) Cut with the number of detectors

nTot = nED + nMD;
nTotbad = nEDbad + nMDbad;
nTot > 2830. && nTot < 2930.;
nTotbad / nTot < 0.01;

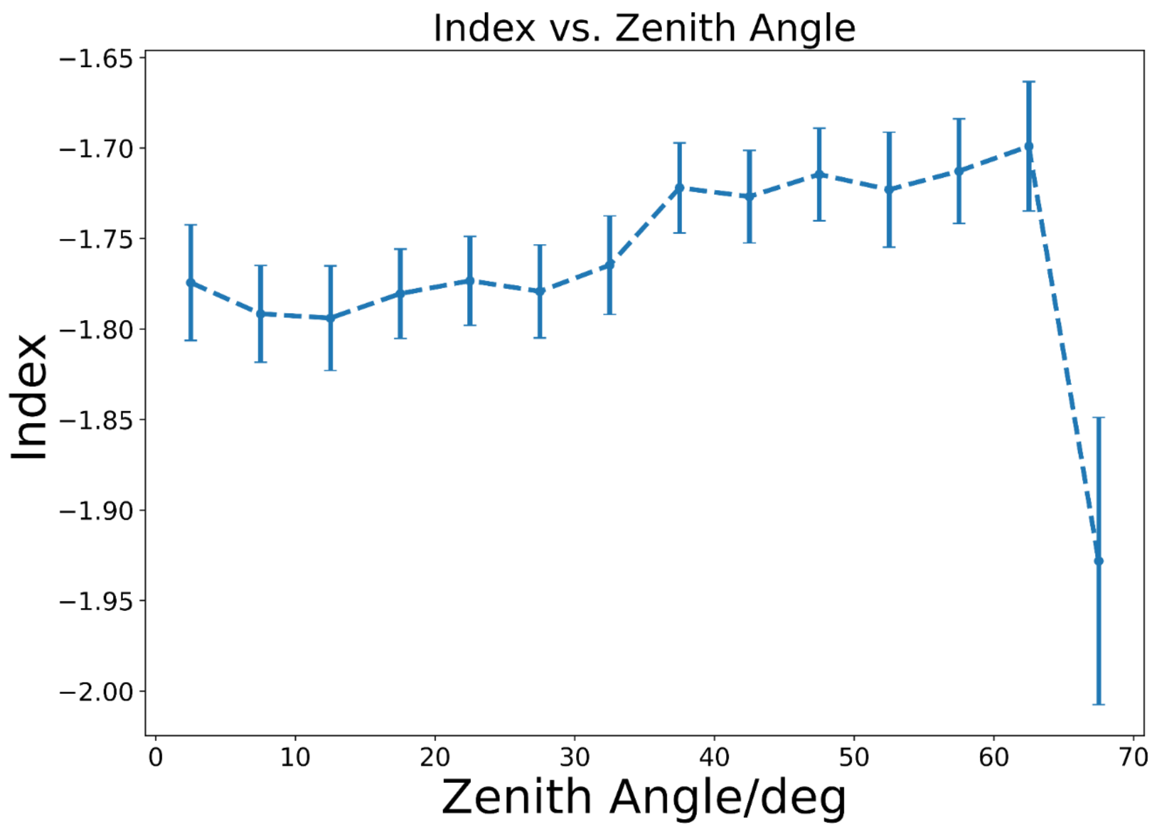
Simulation: hardening toward large angles

Simulation: proton, index -2, zenith <70 degree
Superposition of primary CRs of different energies

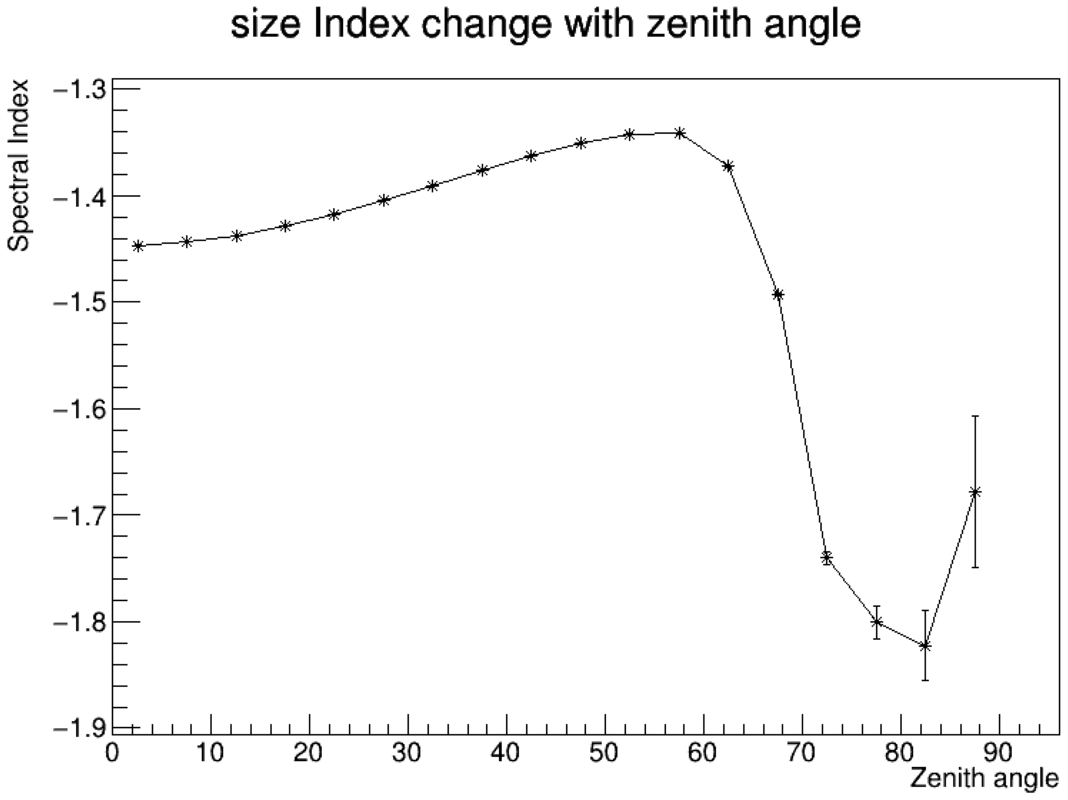




Index of Size Spectrum



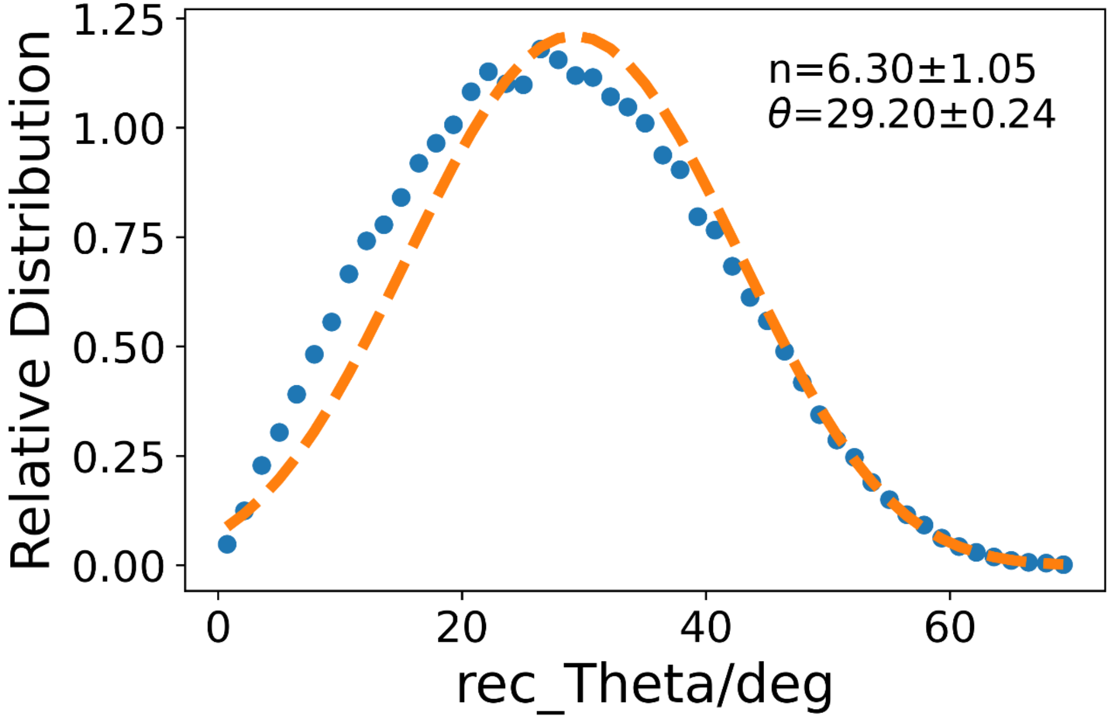
left:simulation

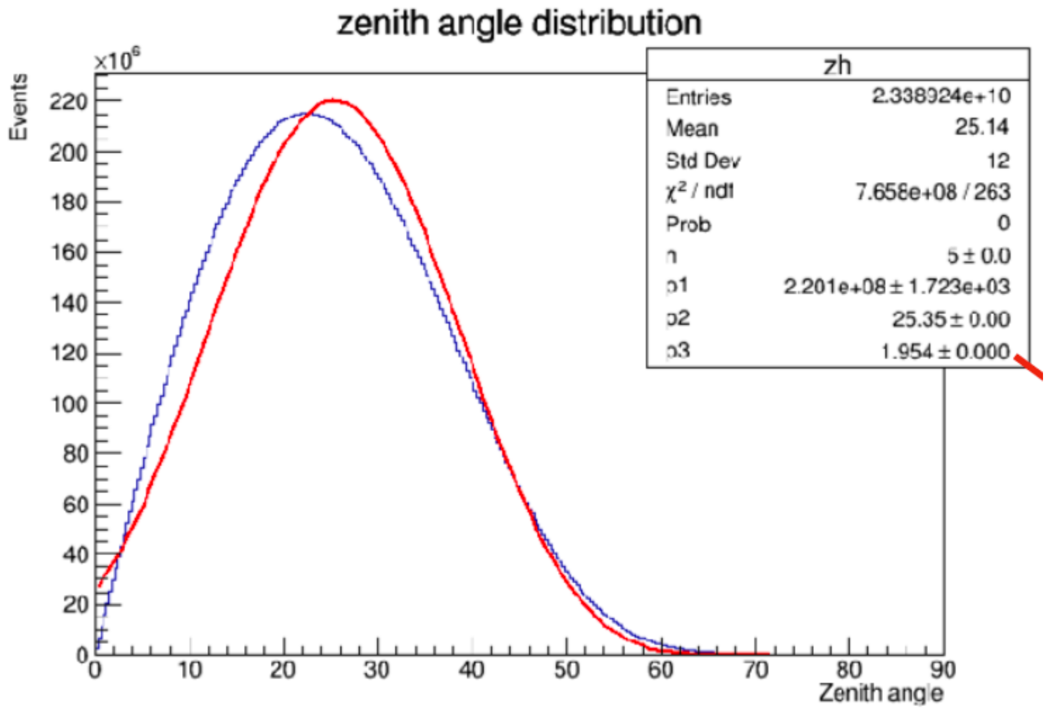


right:experiment data

Zenith angle Distribution

$$Law : cos^n(\theta)$$

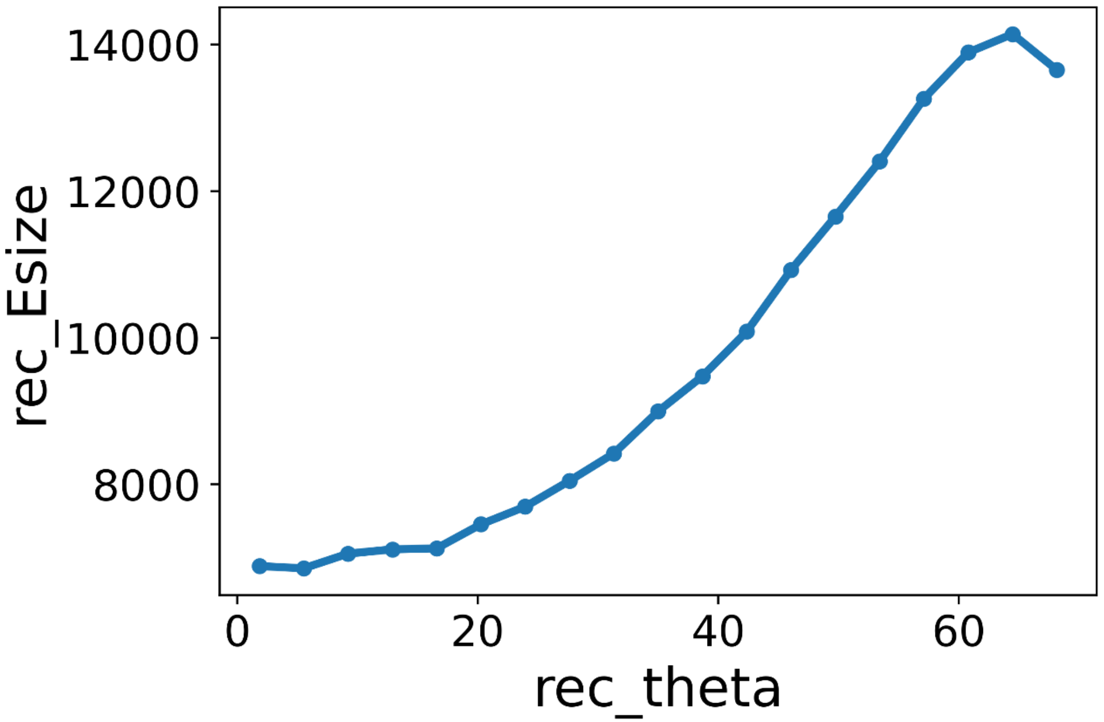


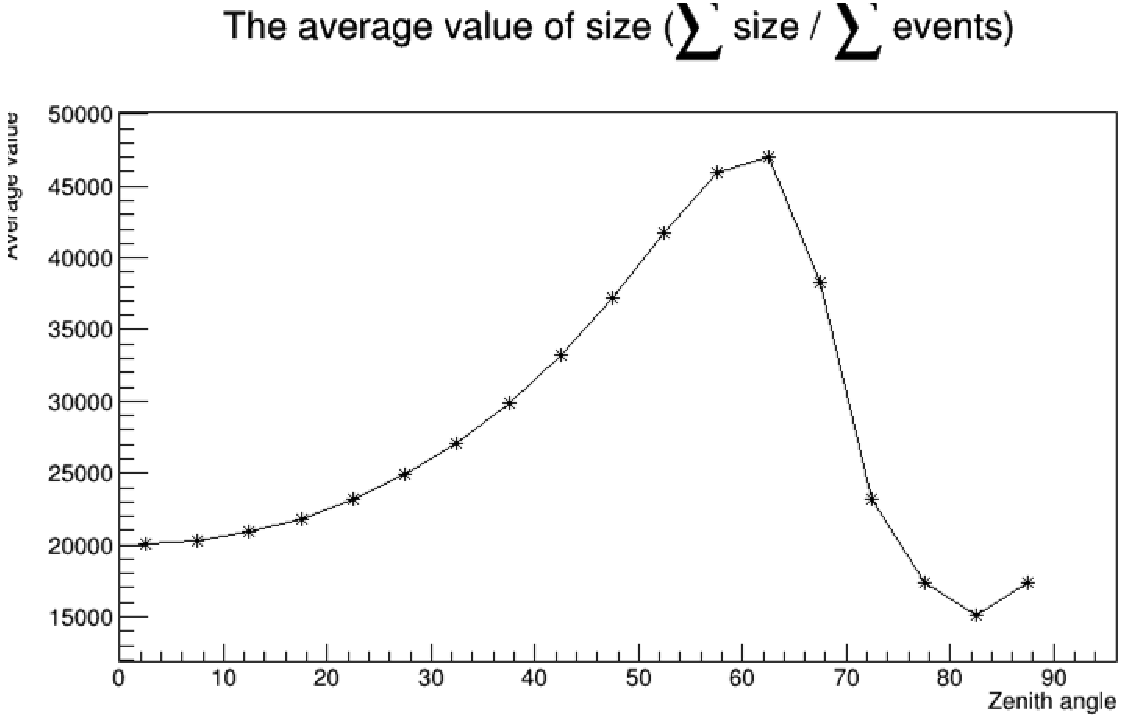


left:simulation

right:experiment data

Average Size vs. Theta

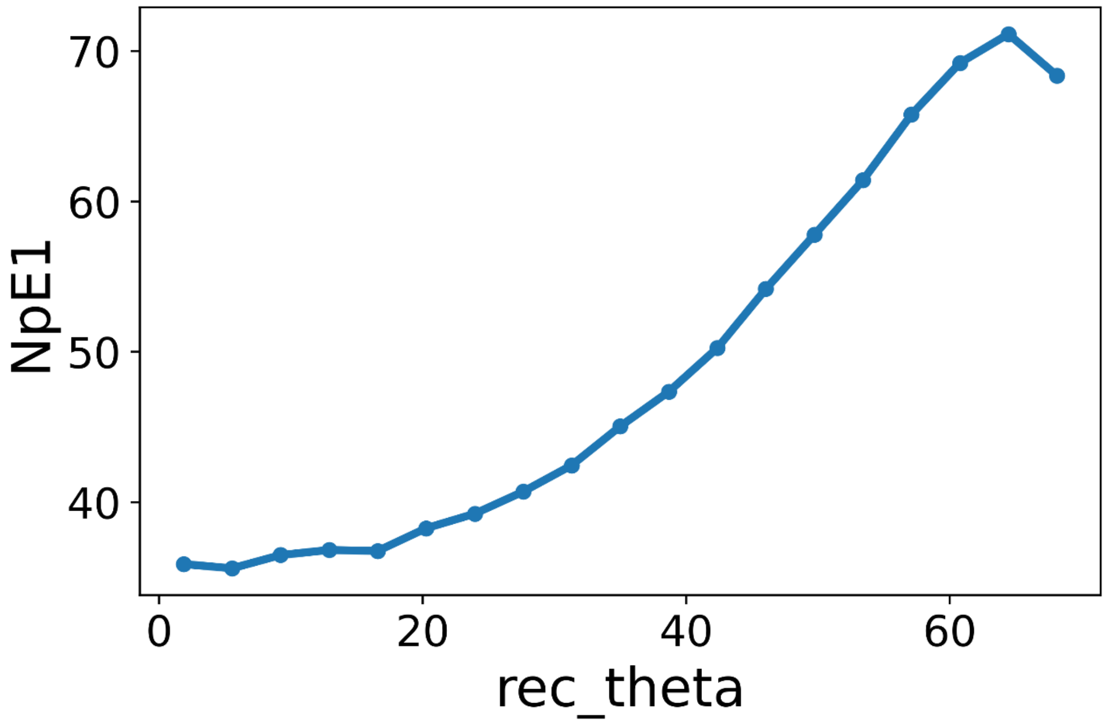


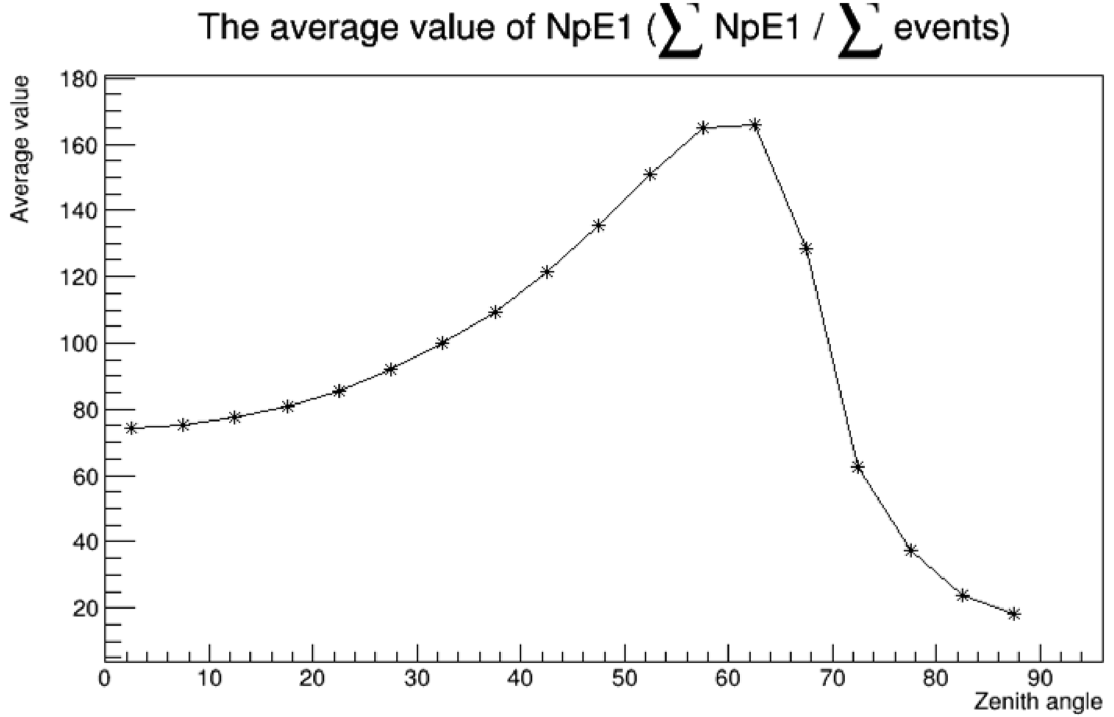


left:simulation

right:experiment data

Average NpE1 vs. Theta

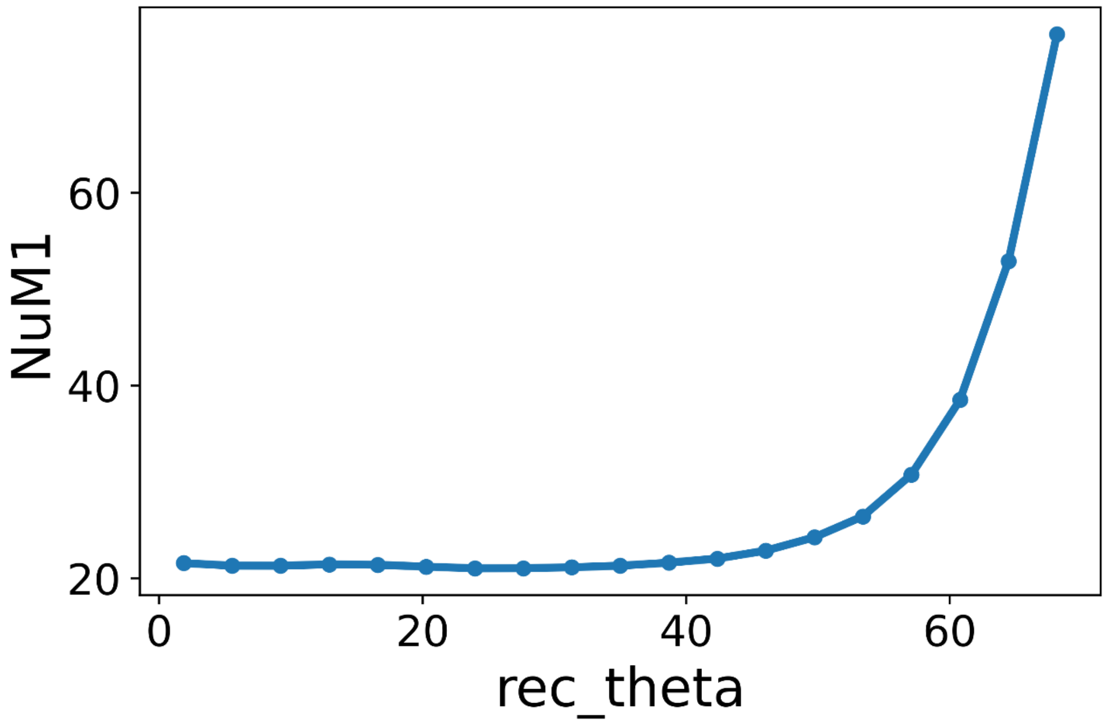


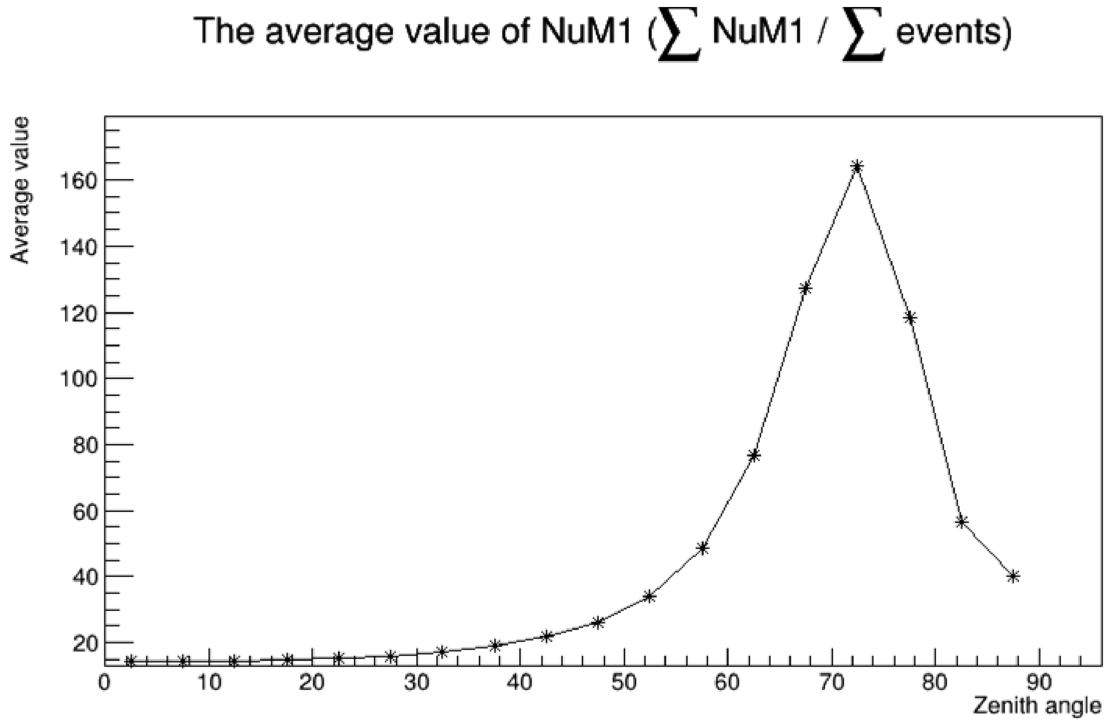


left:simulation

right:experiment data

Average NuM1 vs. Theta





left:simulation

right:experiment data

The purpose of this talk

That is to appeal young students to participate this work.

This work will open a new window for LHAASO. It is attractive and promising!

Thanks a lot for your attention!