CREDO
THE QUEST FOR UNEXPECTED

Discovering new physics in EAS, or communal resistance to new approaches

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A path to discovery – who and how

- Often a new discovery gets a push-back from a community. Some reasons can be:
  - Political/Financial
  - Social inertia
  - Too radical idea/change
  - Very large changes are required in retrospective
  - Many others…
- As we are in Cosmic Rays, let’s see some examples that are connected with cosmic rays and EAS…

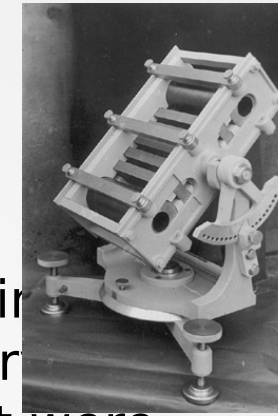
Discovery of EAS

https://www.seeker.com/cloud-chamber-tracks-make-beautiful-music-1765169524.html

- In 1927-1929, Dmitri Vladimirovich Skobeltsyn (Russian: Дмитрий Владимирович *Скобельцын*) who was a Soviet physicist, academician of the Soviet Academy of Sciences, was observing cosmic rays by placing Wilson chamber (e.g. cloud chamber) in B-field.
- Two things he noted: particles not only pass as single muons from cosmic background (as we know today) but sometimes as a group. The tracks for such groups would be ~straight lines so he called such spurs the showers of cosmic particles and concluded that they have very high energy.

Discovery of EAS

https://en.wikipedia.org/wiki/Bruno_Rossi



- In 1933, famous Italian scientist Bruno Rossi, usir new improved coincidence trigger, was obser coincidences in several cosmic rays detectors that were separated by up to 100 m.
- In 1938-39, the works by Skobeltsyn and Rossi were repeated and proved by Pierre Auger.
- Note that today Wikipedia only lists Auger as a person who did the discovery:
  - “In his work with cosmic rays, he found that the cosmic radiation events were coincident in time meaning that they were associated with a single event, an air shower. He estimated that the energy of the incoming particle that creates large air showers must be at least 10^{15} electronvolts (eV) = 10^{6} particles of 10^{8} eV (critical energy in air) and a factor of ten for energy loss from traversing the atmosphere (Auger *et al.*, 1939)”
- Often people call EAS an Auger showers, so other work was politically swept under the rug.

Discovery in EAS

- Cosmic rays and EAS have been a source of many discoveries:
  - Positron
  - Muon + lifetime
  - Pion
  - Several hadronic processes and cross-sections
  - New physics to follow?
    - Delayed particles?

Delayed Particles in EAS

400 NATURE September 2, 1950 Vol. 166

Delayed Particles in Extensive Air Showers

An attempt has been made, using two different experimental arrangements, to detect delayed particles in extensive air showers. In the first experiment (carried out under a thick concrete roof at University College, Dublin) extensive showers were selected by coincidences of three trays of Geiger–Müller counters, each tray of area 750 cm.². The trays were placed at the apices of a triangle of sides 5·3, 7·3 and 8·5 metres. Pulses from a fourth tray of area 360 cm.² occurring 1·4–11·4 μsec. later were recorded.

In the second experiment showers were selected by two trays (*A* and *B*) each of area 1,500 cm.², horizontally separated by 2 m. Counts from a third tray, *C*, also of area 1,500 cm.², which occurred 1·5–6·5 μsec. afterwards, were recorded. Undelayed coincidences *A*, *B*, *C* were also recorded. In the first part of this experiment, tray *C* was unshielded; later, it was shielded by 20 cm. of carbon, and finally, with its area reduced to 600 cm.², it was shielded by 20 cm. of lead. This second experiment was per-

Arrangement	Rate of 3-fold undelayed coincidences per hr.	Time	No. of delayed events	Rate of delayed events per hr.	Expected rate of spurious delayed events per hr.
1st experiment	2·8 ± 0·08	375 hr.	0	0	0·001
2nd experiment *C* unshielded; area = 1,500 cm.²	45 ± 4	3 hr.	0	0	0·14
C shielded by 20 cm. of carbon; area = 1,500 cm.²	30 ± 1	18 hr.	2	0·1 ± 0·07	0·14
C shielded by 20 cm. of lead; area = 600 cm.²	1 ± 0·14	50 hr.	2	0·04 ± 0·028	0·04

No. 4218 September 2, 1950 NAT

formed under a light roof. The results of both experiments are given in the accompanying table.

It will be seen that in all cases the expected rate of spurious event is equal to or greater than the rate of delayed events recorded. Thus, in these experiments no evidence was found under a variety of conditions for particles delayed by more than 1·5 μsec. in air showers. It is unlikely that the fraction of delayed particles, if they occur, is greater than 5 per cent in any case.

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- This is the first mention of delayed particles I found in google, may be there are earlier ones.

Delayed Particles in EAS

The Time Distribution of Delayed Particles in Extensive Air Showers using a Liquid Scintillation Counter of Large Area

By J. V. JELLEY and W. J. WHITEHOUSE
Atomic Energy Research Establishment, Harwell, Didcot, Berks.

MS. received 21st November 1952, and in revised form 7th January 1953

Abstract. A liquid scintillation counter, of area 1000 cm^2 and depth 15 cm has been developed for experiments on the delayed particles in extensive air showers. The scintillator was used in conjunction with two trays of Geiger counters to select showers of average density 10/m^2; the prompt and delayed particles traversing the scintillator were recorded photographically in an arrangement in which possible sources of spurious delays were eliminated.

The existence of delayed particles has been confirmed and the delay distribution obtained over the range $(3–70) \times 10^{-8}$ second. This distribution could be represented by an exponential function with half of the delayed particles arriving within $(10 \pm 2) \times 10^{-8}$ second. The total fraction of shower particles that suffer delays in the above range was found to be $(0{\cdot}85 \pm 0{\cdot}05)$%.

There is evidence that showers with delayed events do not differ in average density from those without such events.

A control experiment was carried out to investigate any spurious effects; this revealed μ–e decay events in the scintillator at approximately the expected rate.

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- The typical reference is for (J V Jelley and W J Whitehouse 1953 *Proc. Phys. Soc. A* **66** 454) for confirmation of the existence of delayed particles. Note that he does reference the previous article.

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- Since 1950-es, lost of work done on delayed particles…

Delayed Particles in EAS

- All this work (there may be more recent publications I didn't include here) did not shed any light on what causes the delayed particle effect, what are the particles, what is the mechanism of this double pulse formation, etc…
- It became clear that old EAS analysis methods developed at Pamir by Skobeltsyn group in 1942 that are still being used (particle distribution, ρ(600) – ρ(1000) methods) are yielding no results for analysis of delayed particles and new approaches may be needed.
- Yet community resists with very slow change if any
- Some possible changes:
  - Record and analyze waveform, not just total charge
  - Go to few ns-level resolution of the pulse, best at current – 100 to 50ns
  - Start developing new analysis methods of the collected data using old ones as the base
- Resistance to start this change (its politics, money, effort and social inertia combined) also produces resistance to acknowledge new data or rejection of papers with comments like: 'this phenomena is already well explained by CORSIKA' (really? It's the most standard EAS simulated there! this is an actual comment…), or: why are you not using the same 1942 methods (not a direct quote but that was a meaning behind the comment)

Conclusion

Need to introduce new hardware/new analysis methods

More visibility and stay united to overcome social inertia

Higher visibility/outreach

More and more of new projects to give weight to newest approaches and new data!

GO CREDO ⏪

Additional materials on multi-modal events follow

Extensive Air Showers with Unusual Spatial and Temporal Structure

By: Dmitriy Beznosko

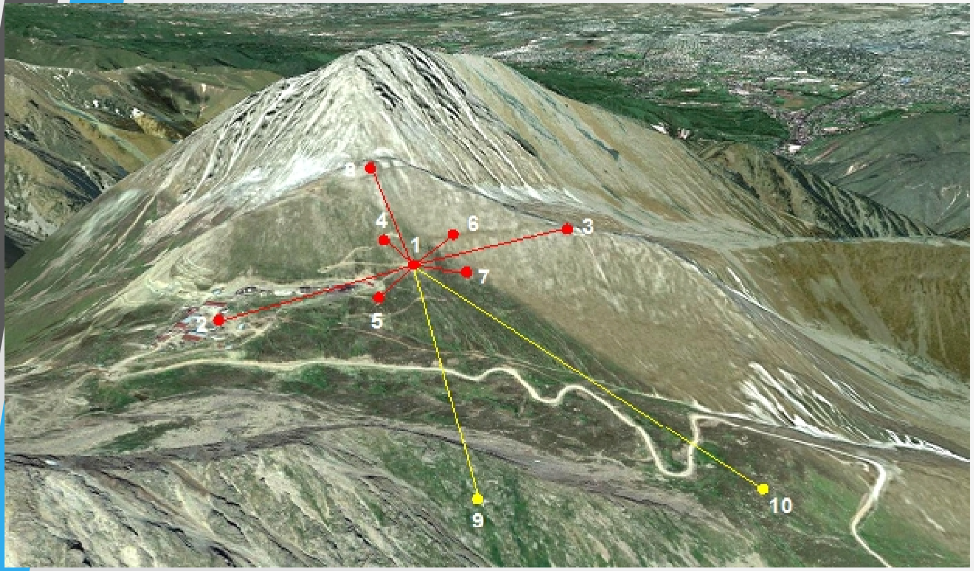
For Horizon-t group

k given at ISVHECRI2018 conference

Horizon-T Group

- R. U. Beisembaev, E. A. Beisembaeva, O. D. Dalkarov, V. A. Ryabov, S. B. Shaulov, M. I. Vildanova, V. V. Zhukov
  - P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
- K. A. Baigarin, A. Batyrkhanov, T. Uakhitov
  - Nazarbayev University, Astana, Kazakhstan
- T. X. Sadykov
  - LLP “Institute of Physics and Technology”, Almaty, Kazakhstan
- D. Beznosko, A. Iakovlev
  - Bard College, New Orleans, USA

Horizon-10T (HT) Detector System [1, 2, 3]



Station name	Center	Yastrebov	Stone Flower	Left	Kurashkin	Right	Bottom	Upper	Cher	600m	Bunker
Station #	1	2	3	4	5	6	7	8	VCD	9	10

- An innovative detector system
  - pulse shape -> disk width information
  - 2 ns resolution
- EAS E> 10^{16} eV ; Zenith angles (0^o - 85^o).
- At Tien Shan high-altitude Science Station ~3340 meters above the sea level
- **TEN** (points 9 and 10 are recent upgrade) charged particle detection points [8]
  - separated by the distance up to 1.3 kilometer
- Hardware trigger points 5+6
- Optical detector subsystem
  - to view the Vavilov-Cherenkov light from the EAS

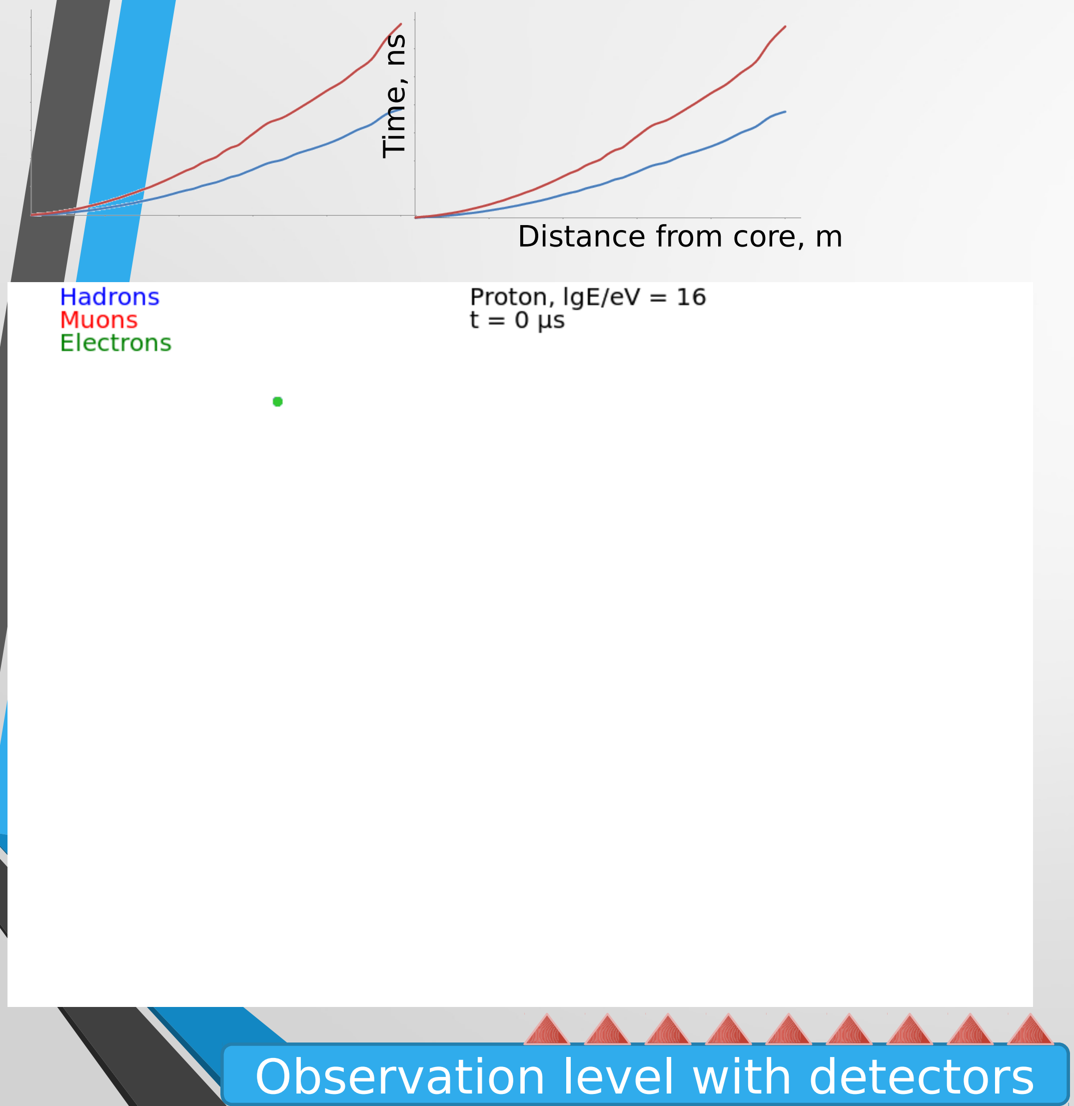
Horizon-T (HT) Detector System

- Z plane detectors
  - R7723 Hamamtsu [6] PMT (1.2 ns resolution) at points 1-8
  - H6527 Hamamatsu PMT at points 9-10
- 5-12 m^2 at far points planned [8]
- 500 MHz digitization CAEN [9] DT5730 ADC
- Cherenkov-Vavilov light detector
  - with Hamamtsu H6527 PMTs
- All channels MIP/cable/linear range calibrated
- Two physics runs: 2016-2017 and 2017-2018

R7723 PMT with glass gives pulse front resolution of ~2.2ns

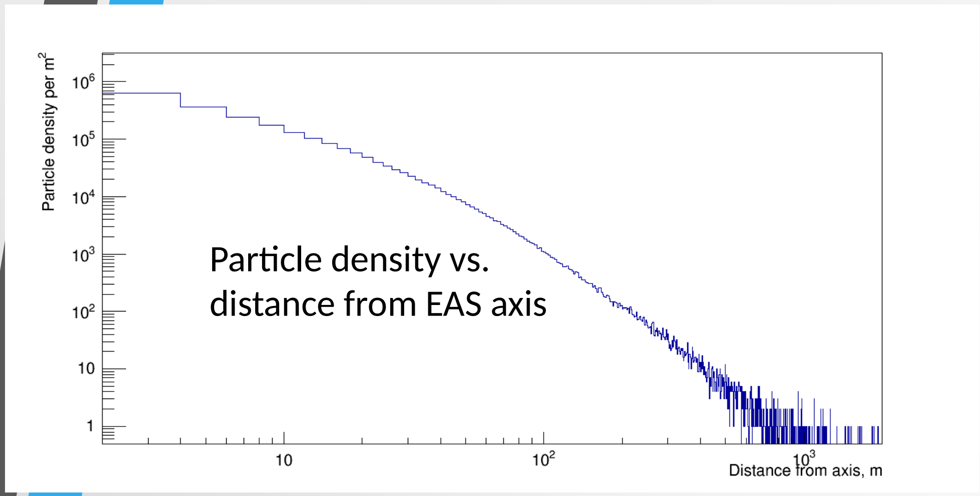
Scintillator additional contribution ~5ns

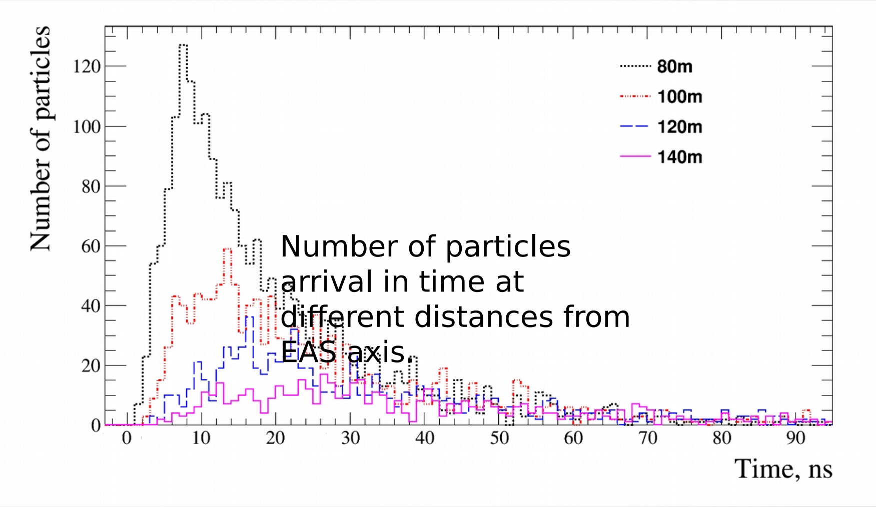
Typical methods of CR physics



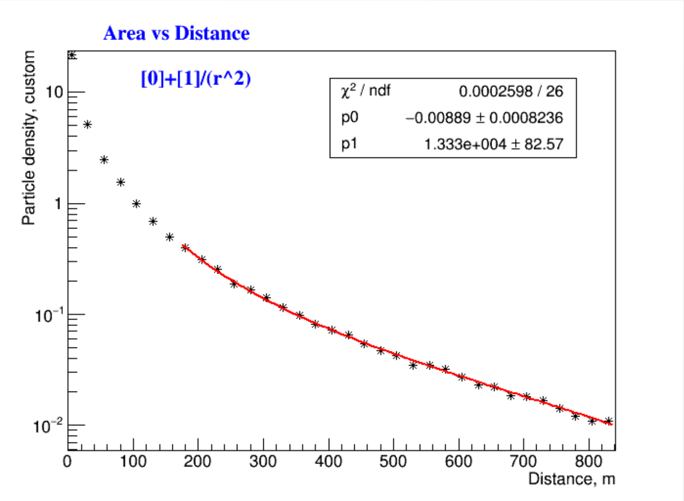
- Can reconstruct using particle density distribution
- Need to calibrate detection points to obtain equivalent MIP number
- If know time and width, additional methods can be used (CORSIKA) [5]

Standard EAS Definition





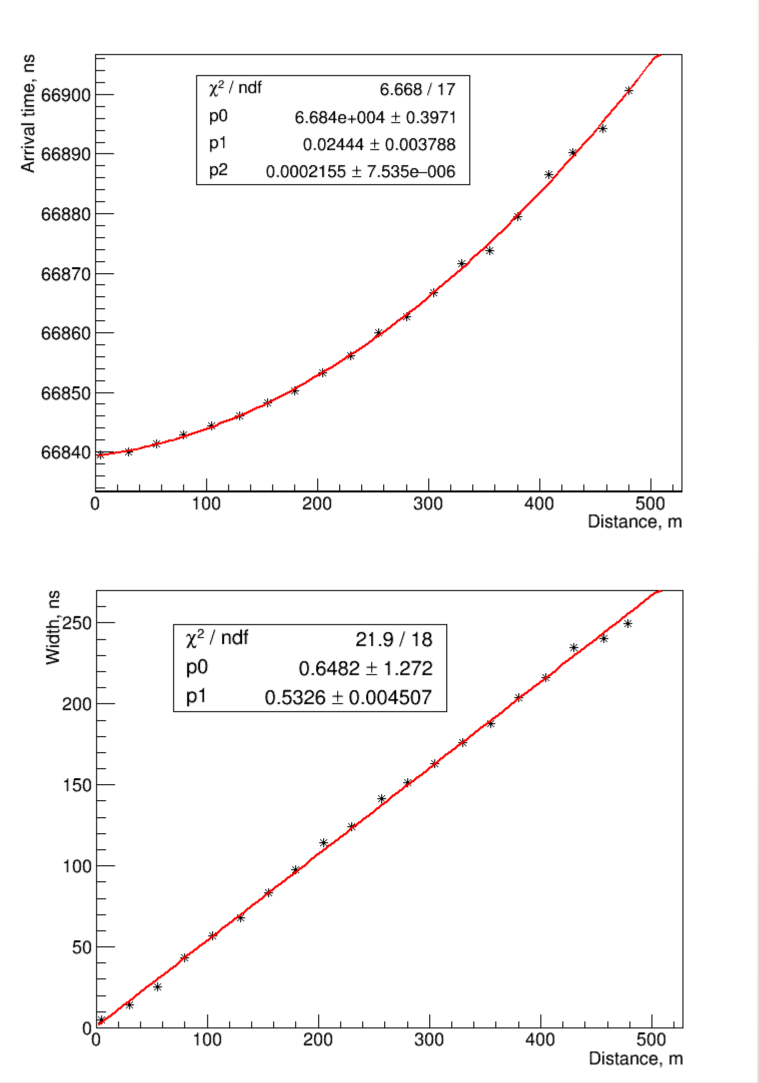
- CORSIKA* simulation software is based on our understanding of HEP, thus simulating a '**standard**' shower.
  - Plots are for E=10^{17} eV proton.
- At observation level, such EAS has a single disk with particle density decreasing as ~$1/r^2$ (far) from the axis



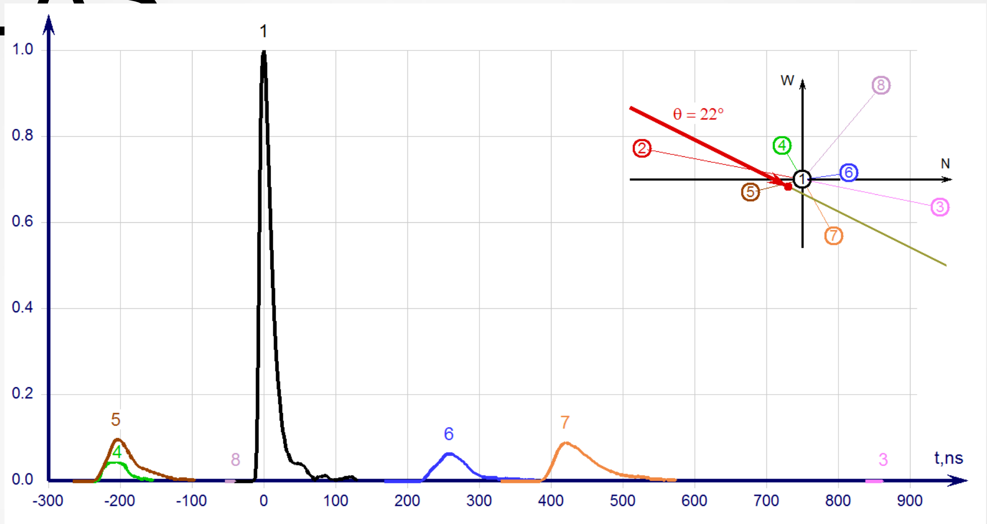
* D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz, T. Thouw. CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers, Forschungszentrum Karlsruhe Report FZKA (6019)

Standard EAS characteristics

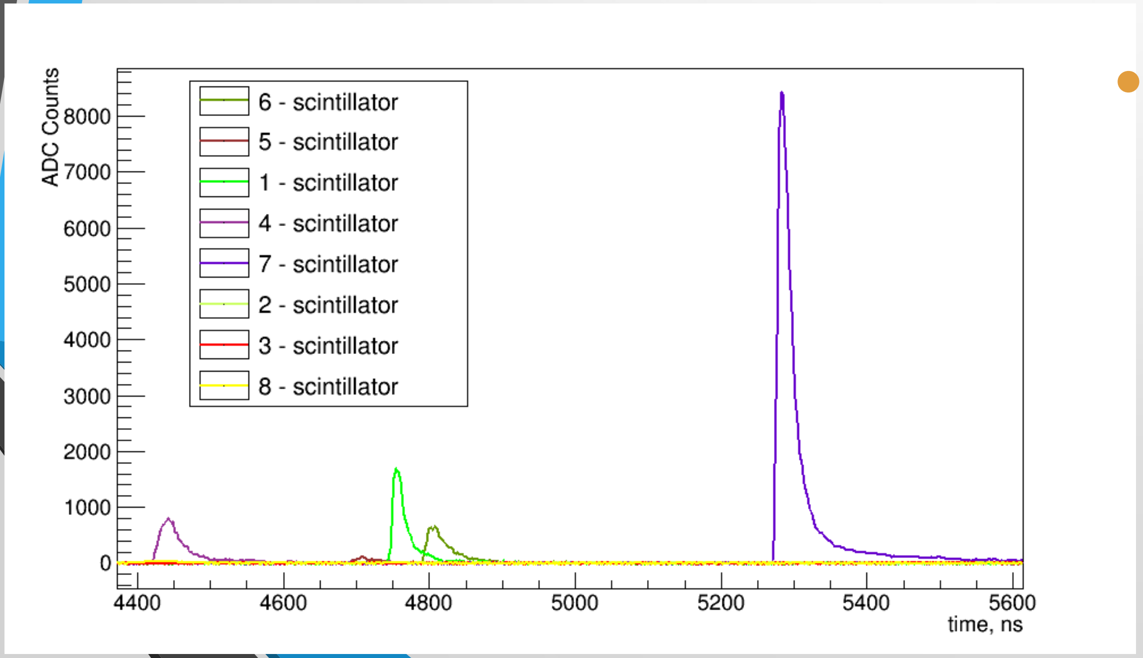
- Disk arrival time ~r² (used for arrival direction determination)
- Disk passage time (e.g. width) is growing with ~r
- *Can use particle density and <u>pulse width</u> additional information from each detection point*
  - *<u>Need time resolution <10ns</u>*



Data examples for Standard EAS



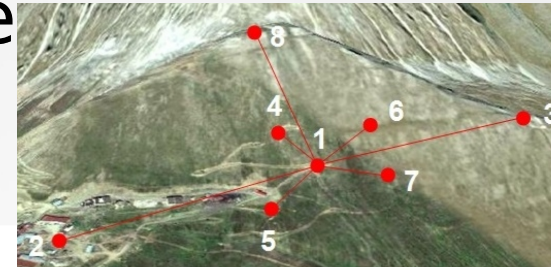
- Standard EAS signal from each HT detector
- Corresponds to simulation

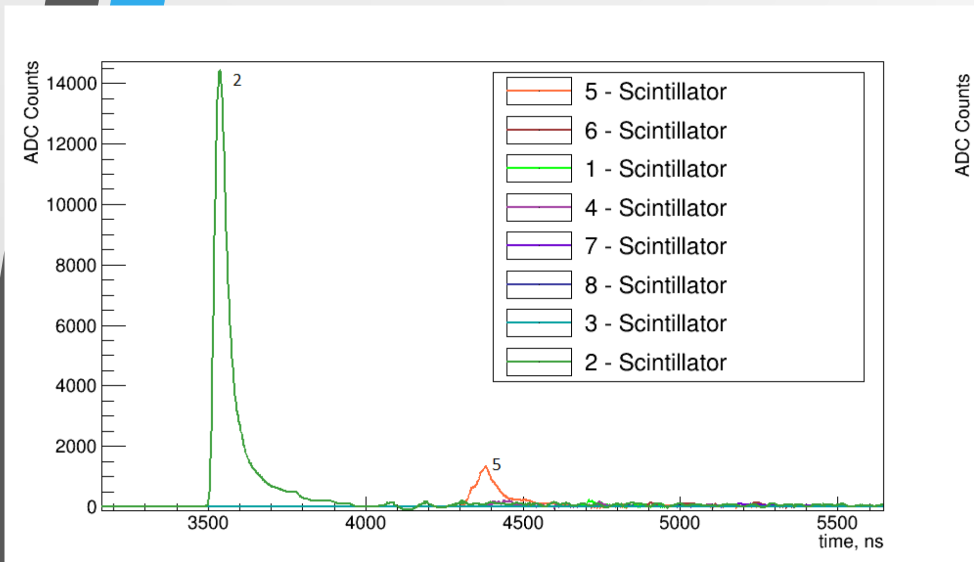


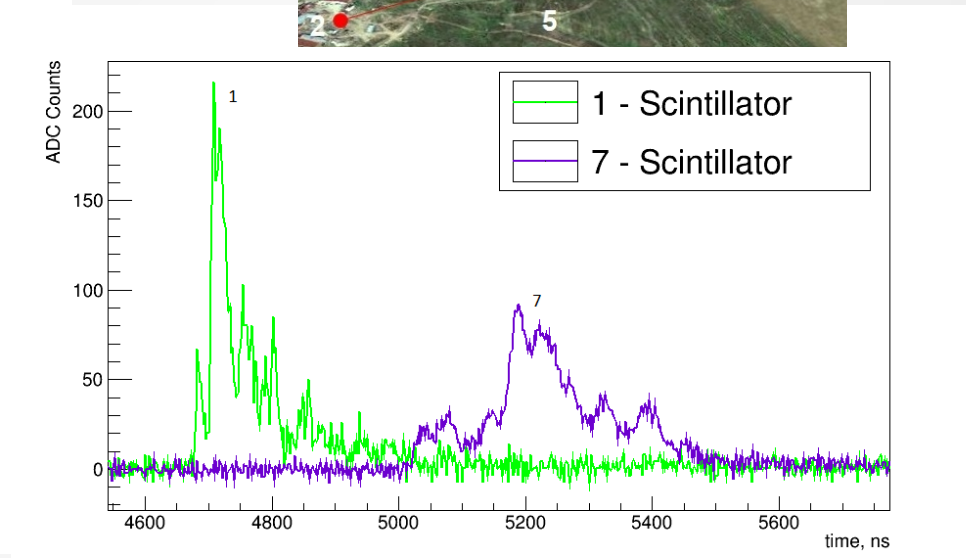
- Estimated Energy:
  - ~10^{16} eV (top) at low angle
  - ~$2 \cdot 10^{16}$ eV (left) high zenith angle

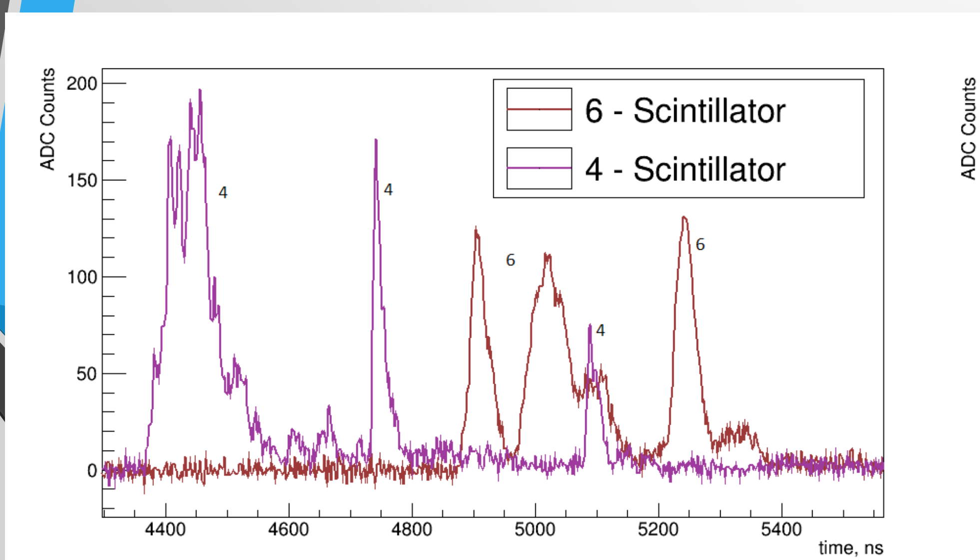
Unusual EAS at HT example [4]

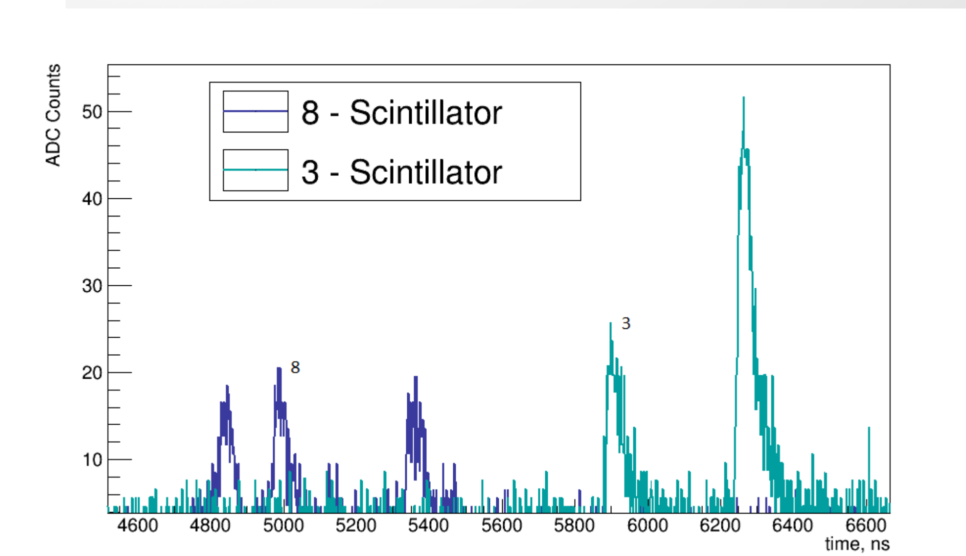
Event of Jan26 ’16.





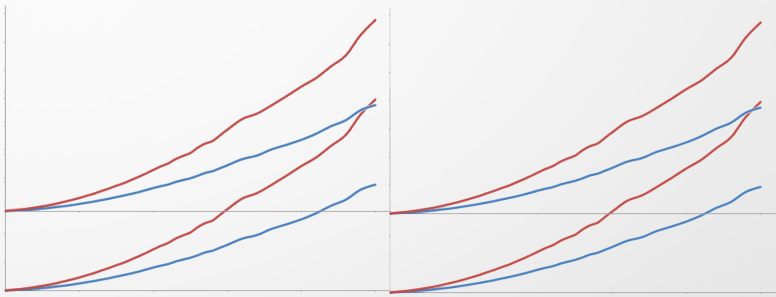


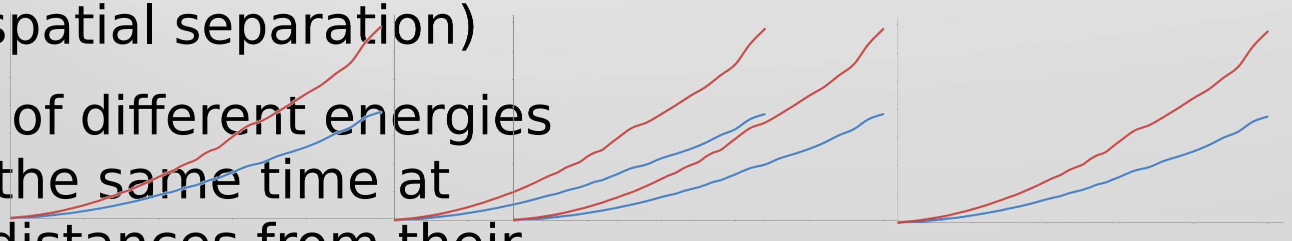




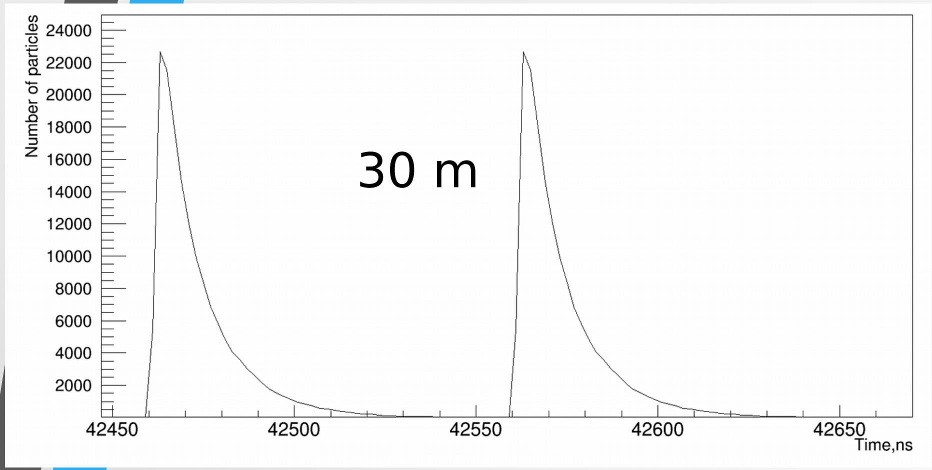
Modeling attempt at unusual events by Combining Simulated disks

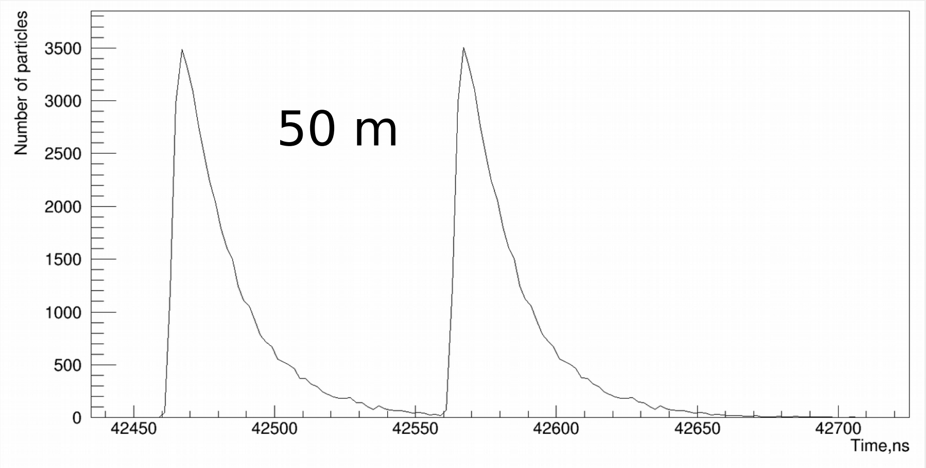
- To approximate response of a detector from arrival of two disks separated in time and space, two simulated disks are overlaid.
- Following cases were simulated:
  - Two disks of the same energy falling with delay at the same distance from their centers (time delay)
  - Two disks of the same energy falling at the same time at different distances from their centers (spatial separation)
  - Two disks of different energies falling at the same time at different distances from their

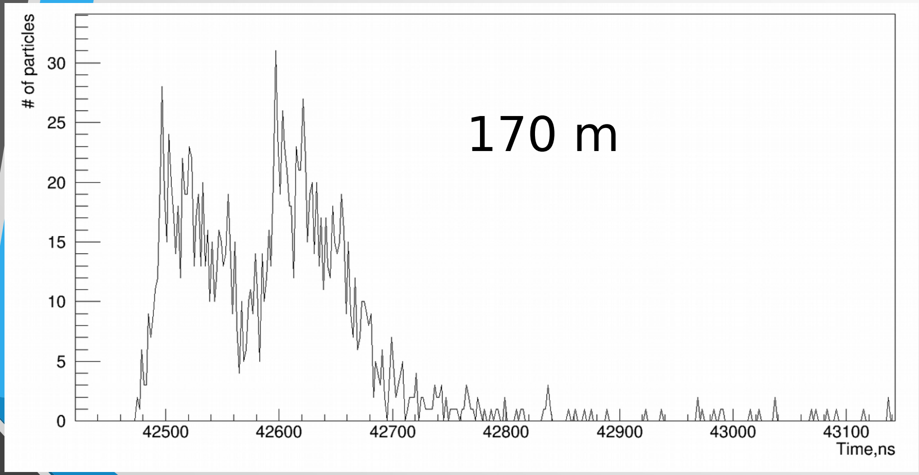




Combining Simulated disks: Time delay







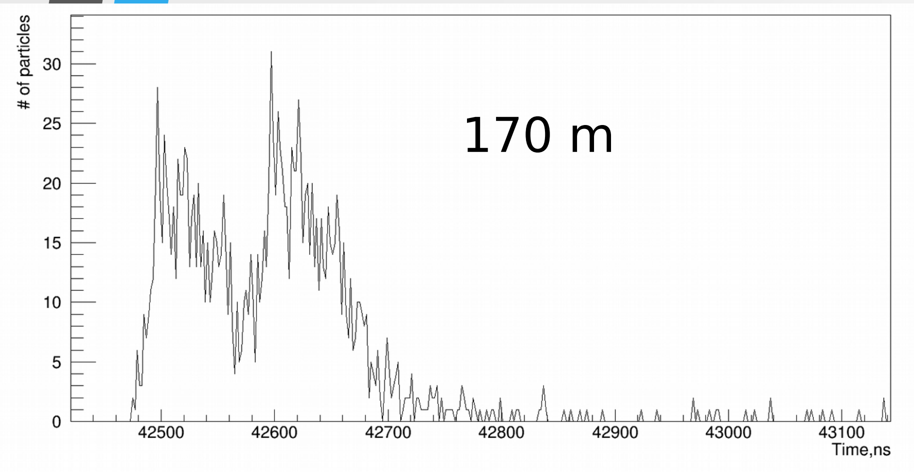
Time delay between disks centers - **100** ns.

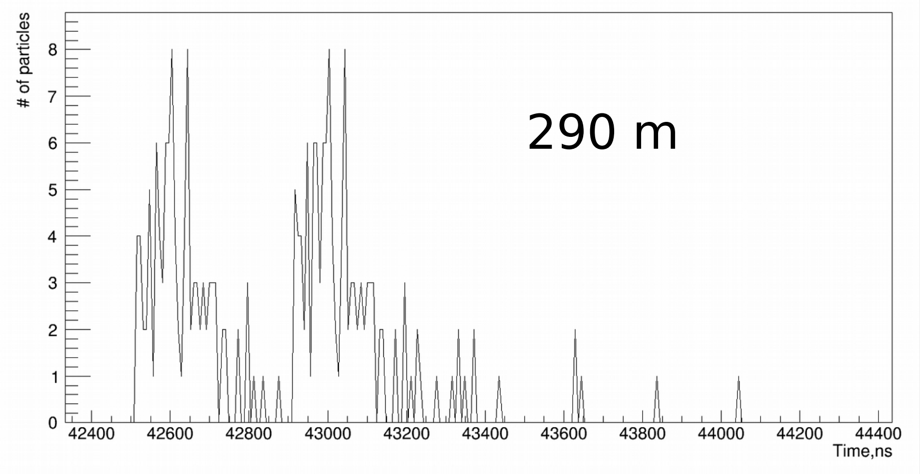
Energy of each primary – 10^{17} eV

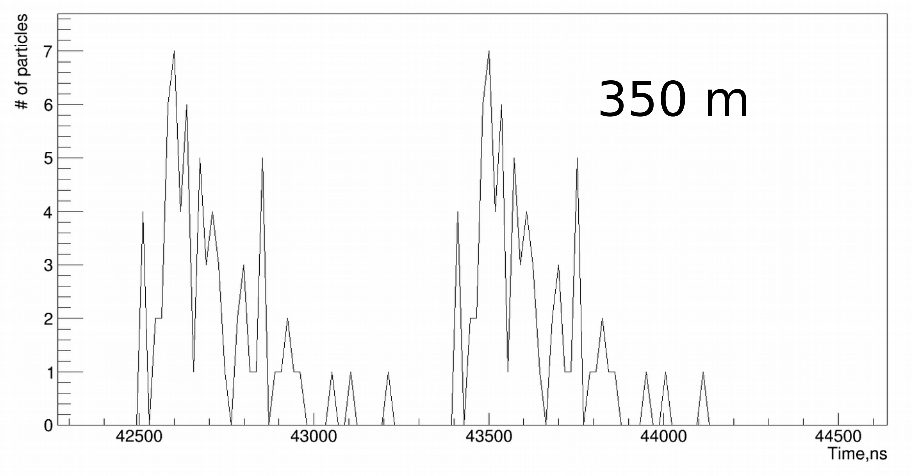
Farther from the EAS axis the disks become wider, so combining two pulses results in overlapping of the shower fronts.

CLOSE TO THE CENTER, EACH DISK SIGNAL COULD BE DIFFERENTIATED EASILY. HOWEVER, HARDLY DISTINGUISHABLE MULTIPEAK EVENT CAN OCCUR FAR FROM THE CENTER

Combining Simulated disks: Time delay 2

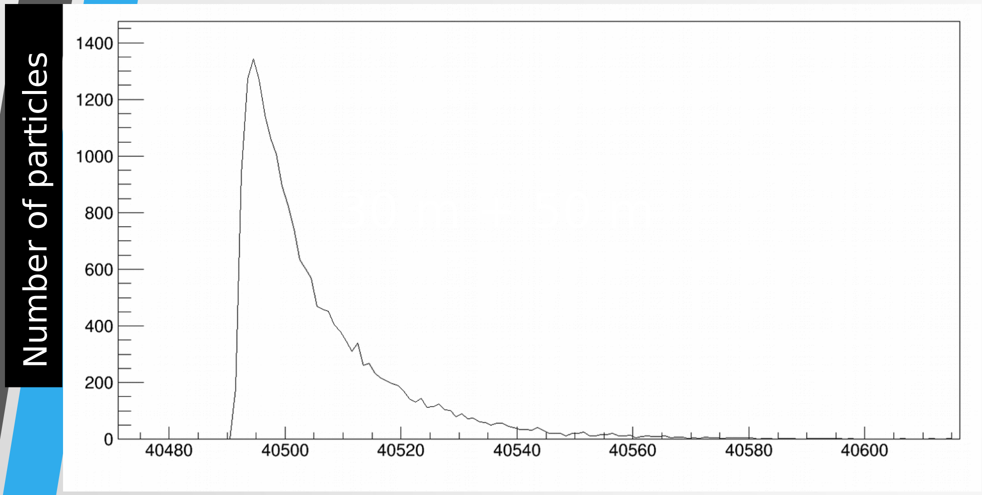


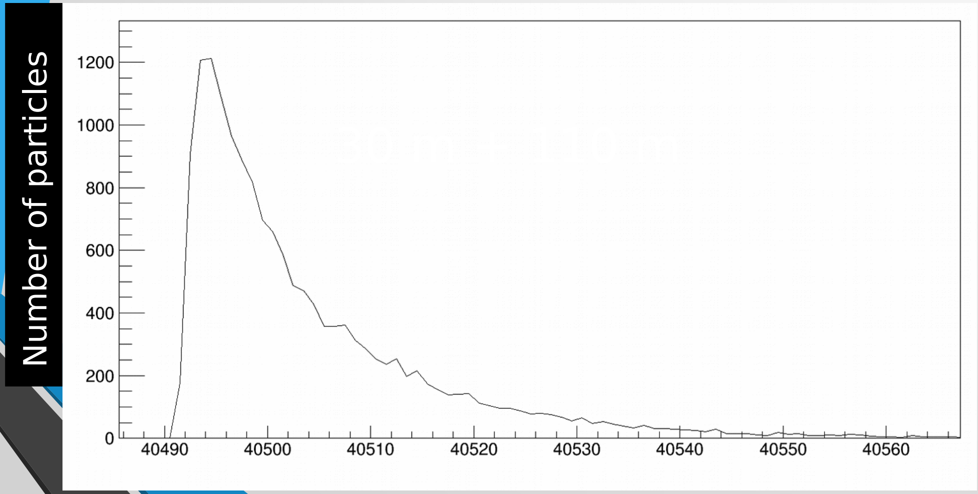




Although at even larger distances from the center of the shower (>300 meters) signals become separated clearer, it happens because of low density of particles in the shower disk. Still, wide particle distributions are observed as expected from disk width.

Combining Simulated disks: spatial separation



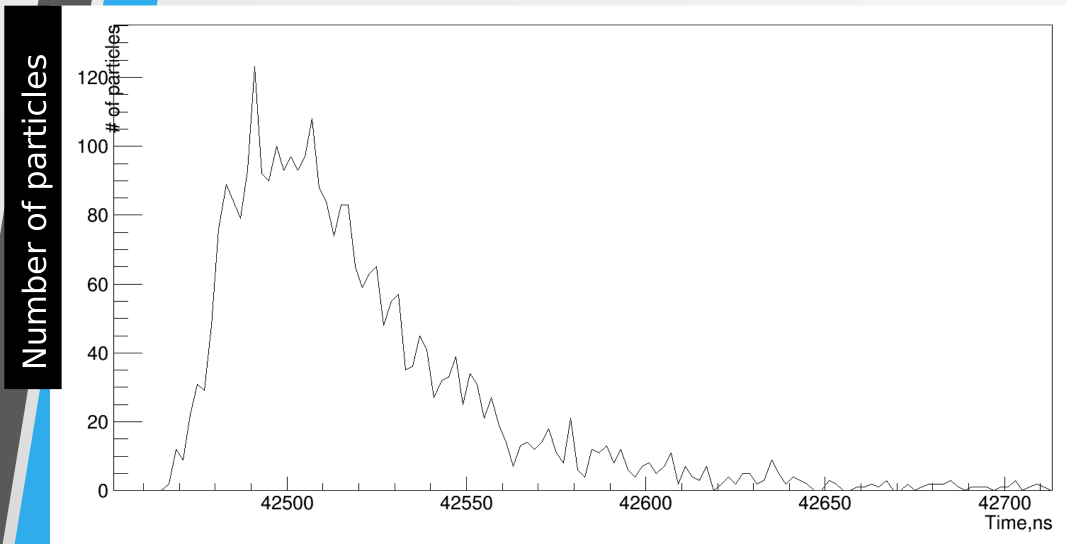


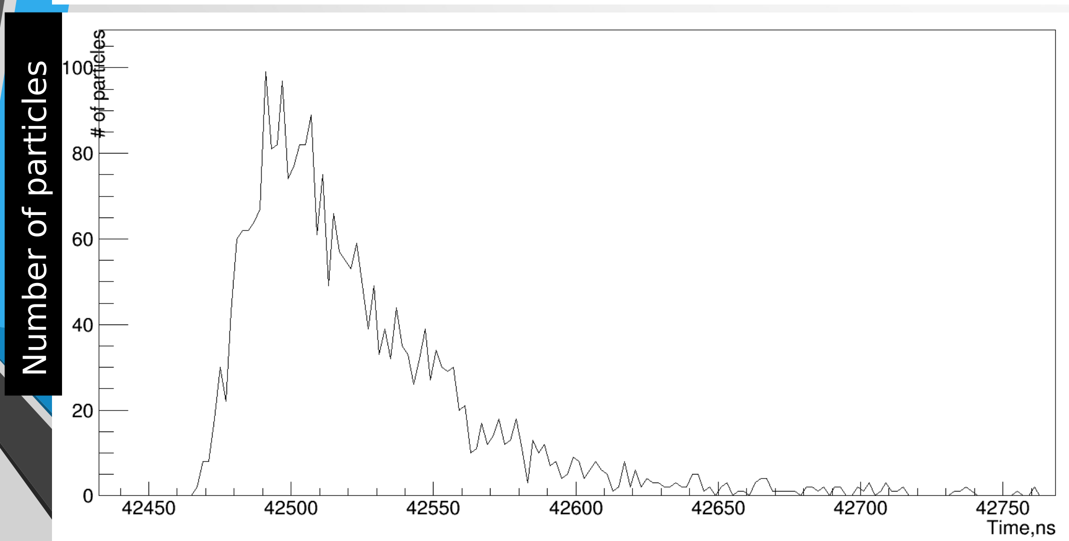
ENERGY – 10^16 EV

THE PARTICLE DENSITY SO MUCH HIGHER CLOSER TO THE AXIS THAT CONTRIBUTION OF THE SECOND DISK IS NOT CLEARLY VISIBLE

EACH FIGURE SHOWS DISTANCES FROM THE DISK AXIS ON THE LEFT THEN FROM THE AXIS ON THE RIGHT

Combining Simulated disks: spatial separation





ENERGY – 10^17 EV

EVEN FAR FROM THE CENTER OF THE SHOWER COMBINATION DOES NOT GIVE ANY DISTINGUISHABLE PEAKS

THUS, NO MULTI-PEAK BEHAVIOR CAN BE SEEN IN THIS CASE

Conclusion

- In HT data, ‘unusual’ events have been identified
- Simple combination of simulated disks doesn’t give similar picture
- The data analysis continues and more physics runs are planned
- Far periphery detectors upgrade to larger areas is planned

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