Unusual structures in ultra-high energy cosmic ray air showers - new physics indication

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for Horizon-T group

Cosmic Rays and Particles Group

Horizon-T Group

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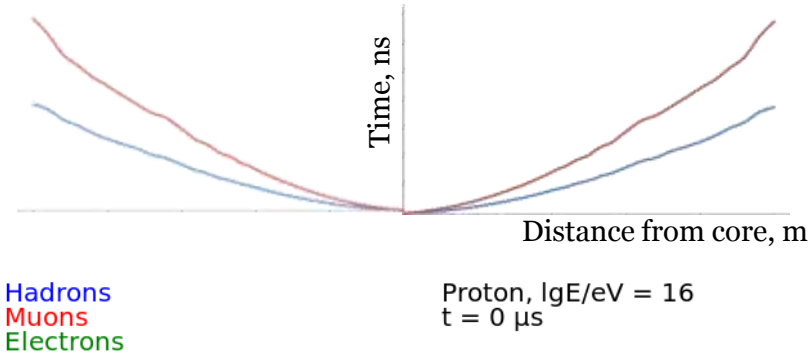
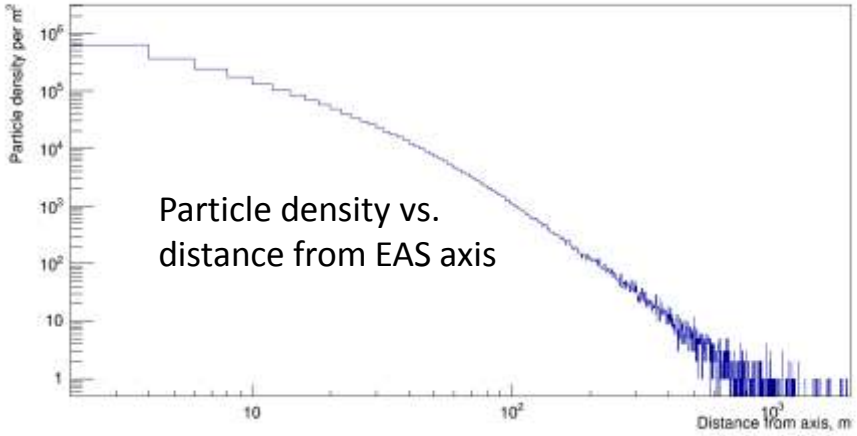
Typical methods of CR physics

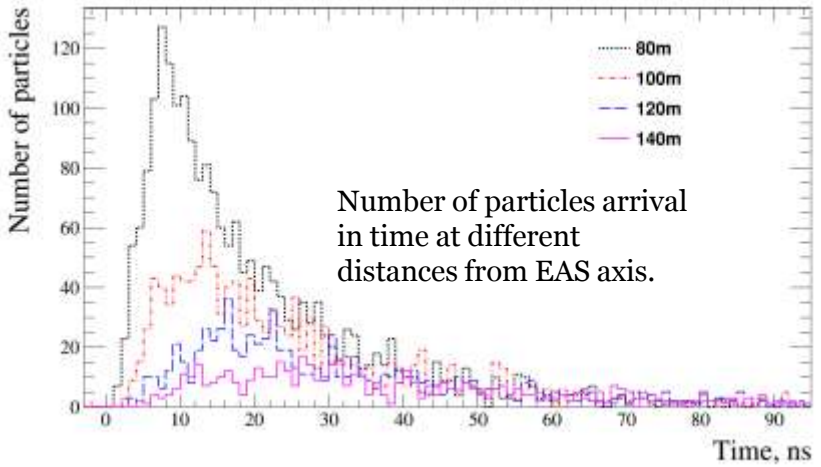


- Can reconstruct using particle distribution
- Need to calibrate detection points to obtain equivalent MIP number
- If know time and width, additional methods can be used (CORSIKA)

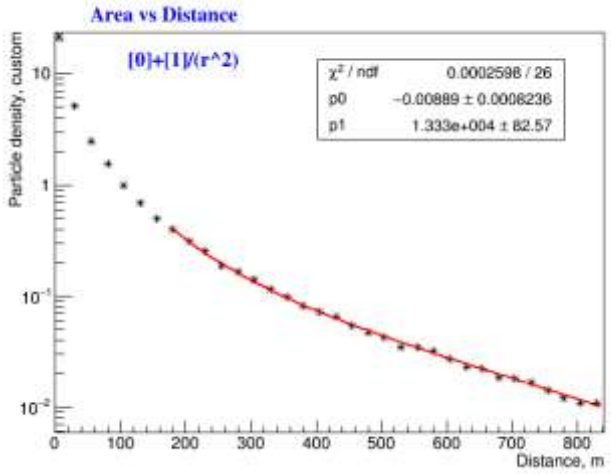
Observation level with detectors

Standard EAS Definition [1]





- 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)

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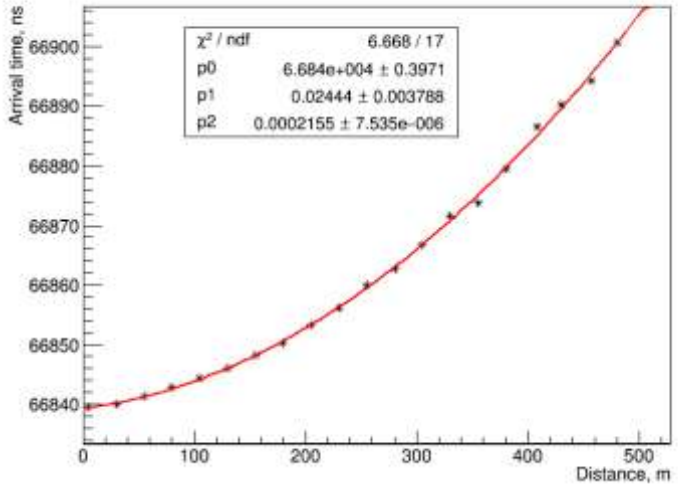
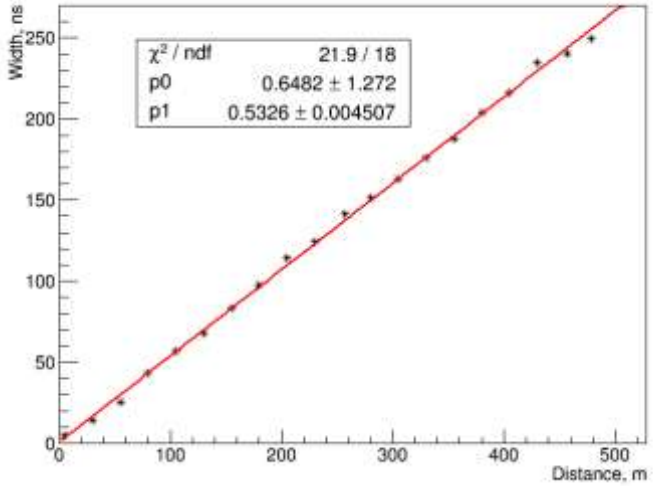
Standard EAS characteristics

- Disk arrival time ~r^2
- Disk passage time (e.g. width) is growing with r
- *Can use both particle density and pulse shape information with arrival timing from each detection point*
  - *Need time resolution <10ns*





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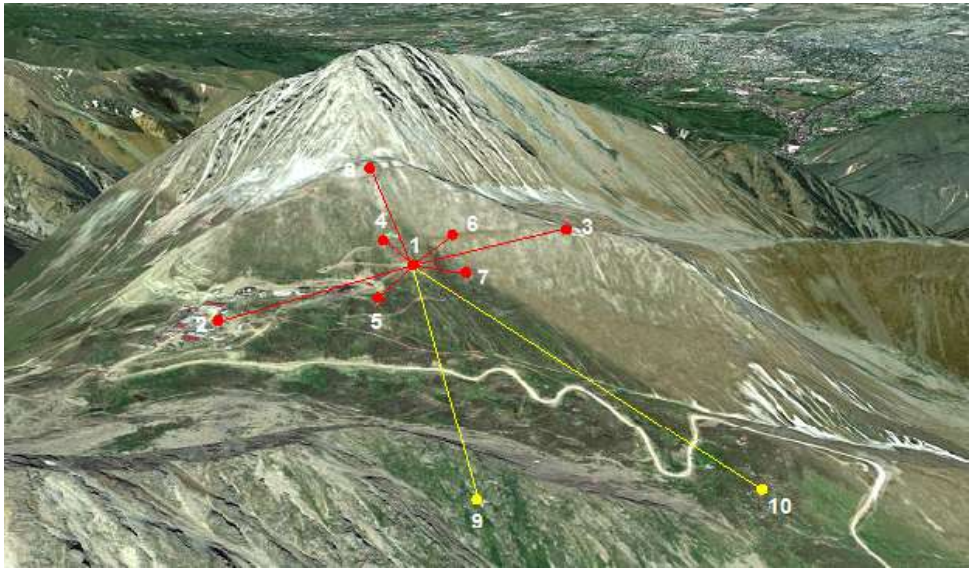
Horizon-T (HT) Detector System [1][2]



- An innovative detector system
  - pulse shape -> disk width information, 2ns resolution
- EAS E> $2 \cdot 10^{15}$ eV ; Zenith angles (0^o - 85^o).
- At Tien Shan high-altitude Science Station at ~3340 meters above the sea level
- **Eight** (points 9 and 10 will be commissioned soon) charged particle detection points [3] [4]
  - separated by the distance up to one kilometer
- Optical detector subsystem
  - to view the Vavilov-Cherenkov light from the EAS

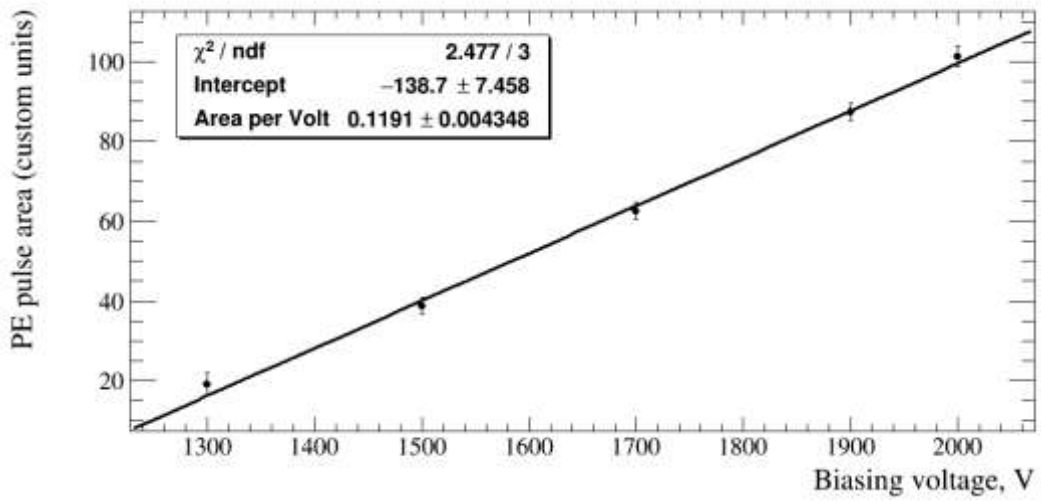
Horizon-T (HT) Detector System

- X-y-z plane detectors at center and near points
  - R7723 Hamamtsu PMT (1.2 ns resolution)
- 5-12 m² at far points
- 500 MHz digitization CAEN DT5730 ADC
- Cherenkov-Vavilov light detector
  - with Hamamtsu H6527 PMTs

Detection point calibration

- Things that need calibration:
  - PMT (PE response, linearity)
  - Cable
  - MIP response
    - Includes cable effects
  - Bias and threshold
  - Calibration monitoring

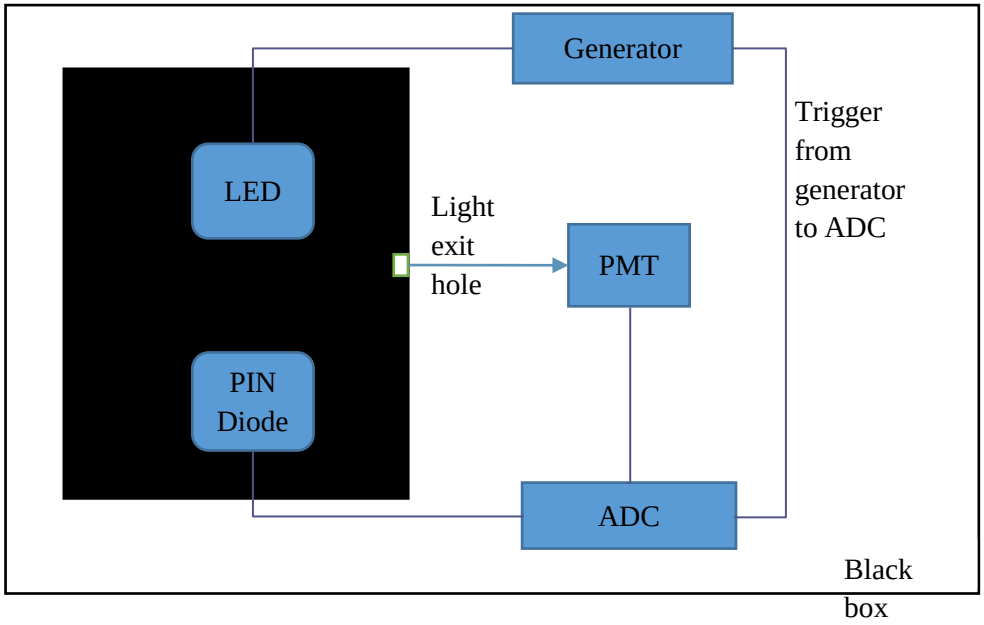
PMT calibration – PE response



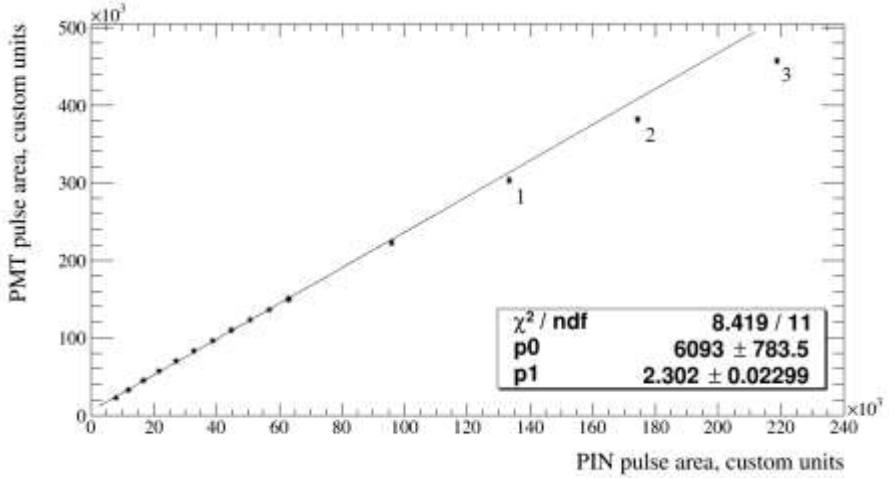
PMT single PE pulse area vs. biasing voltage.

- Single photo-electron (PE) response of a PMT as a pulse area
- at different biasing voltages.
- Low light LED pulse is fed to PMT. Trigger is provided by the LED power source
- Pedestal has about 80% of all events in order for single photon detection assurance

PMT calibration - linearity



Schematic of PMT linearity measurement setup.

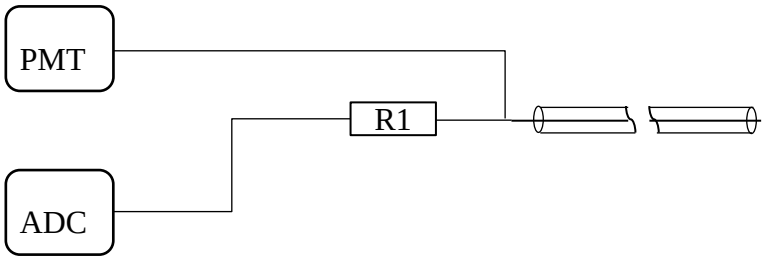


PIN diode pulse area vs. PMT pulse area.

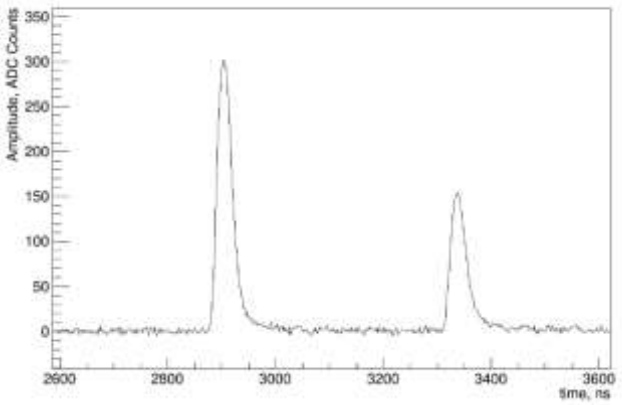
- Fast LED (blue) and a Hamamatsu S3883Si PIN diode in a light-tight box
- At the low light levels, the relationship between the PIN diode and PMT pulse areas is linear.
- As amount of light is increased, PMT output is no longer linear. The PMT at 1500V biasing voltage.

Cable calibration

- Can model cable as RC, low-pass filter
  - Change pulse shape
- Need to calibrate length of cable
  - Reflection method
- Use pulse areas
  - Time at 10, 50 and 90 %



Cable calibration setup schematic: ADC is used with PMT as signal source.

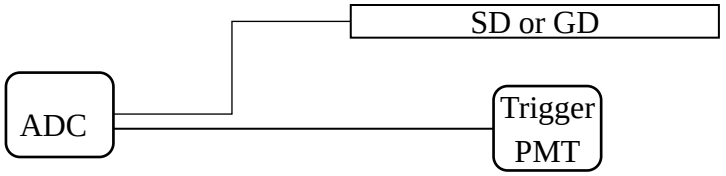


Calibration signal waveform, inverted, baseline subtracted and zoomed.

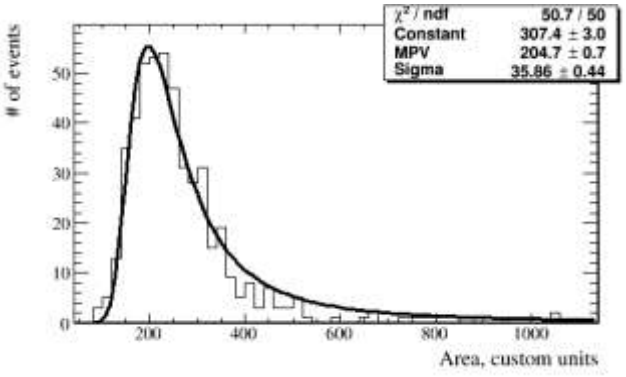
Station and cable	Time diff. at 10% (ns)	Time diff. at 50% (ns)	Time diff. at 90% (ns)	Area ratio
Center Blue New	102.14 ± 0.08	103.28 ± 0.08	108.39 ± 0.45	0.719 ± 0.005

MIP calibration – time and area

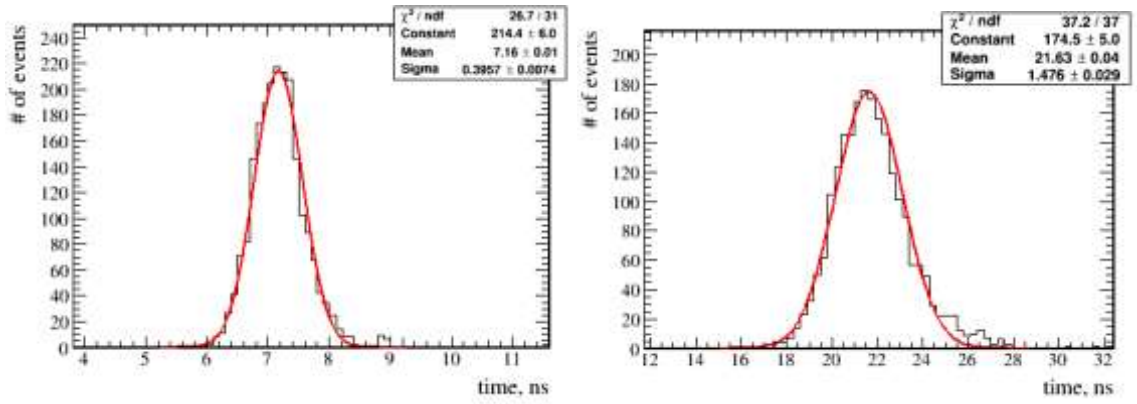
- Need area for *effective particle number* calibration and response time of each detector.
- Since measured at DAQ, all cable effects included.
- SD data on this slide only



MIP calibration setup schematic for SD/GD.

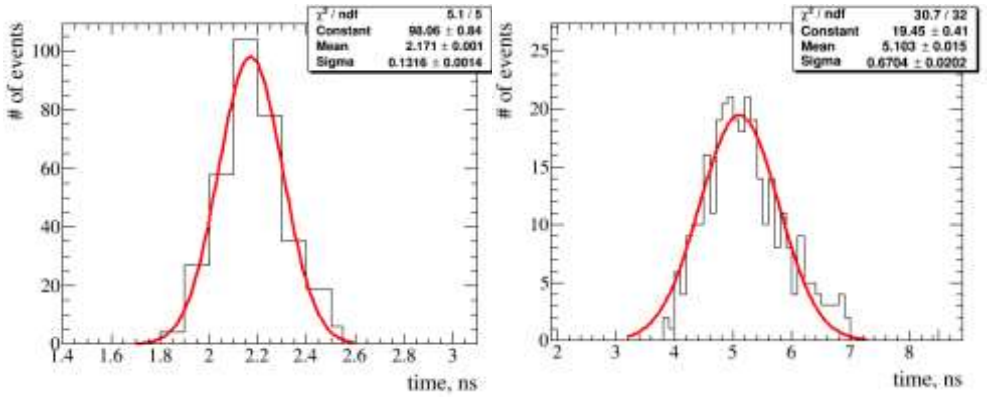


SD detector response to MIP signal

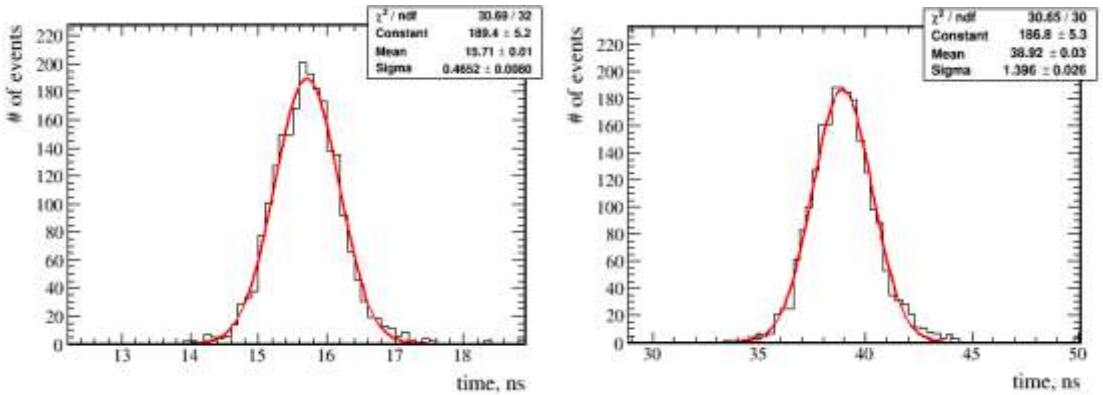


Pulse front (left) and total duration for R7723 PMT with scintillator

MIP calibration - continued



Pulse front (left) and total duration for R7723 PMT with glass



Pulse front (left) and total duration for FEU49B PMT with scintillator

- R7723 PMT with glass gives pulse front resolution of ~2.2ns
  - Scintillator contribution ~5ns
- For completeness, FEU49 data in same conditions

Bias, threshold and monitoring

- Each PMT bias is chosen so that MIP data is clearly identifiable
- Threshold is chosen at plateau of events/time vs. threshold value
- Event rate is checked regularly using DAQ
  - MIP calibration sample result ->

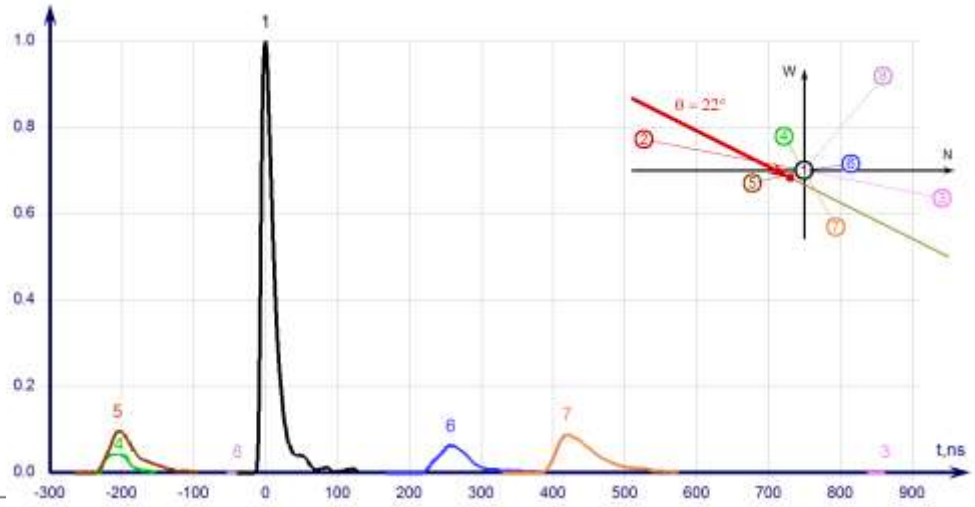
Name	Voltage	MPV	MPV Error	sigma	Sigma Error
Bottom SC	1100	218.4	4.5	44.2	2.5
	1200	342.7	7.3	60.8	3.7
	1250	418.1	8	76.5	4.9
	1300	528.6	10	90.9	6.6
	1350	629.7	13.8	109.8	8.7
	1400	694.3	13.4	123.2	8.3

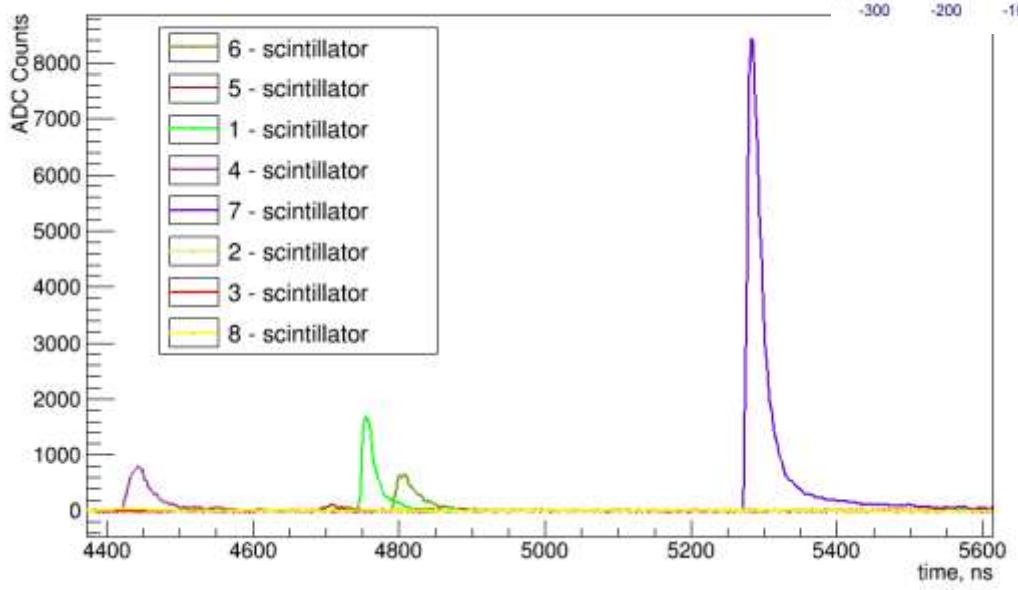
Trigger Logic

- The DAQ is triggered when the detection points (4 and 7) or (5 and 6), report the passage of charged particles from EAS disk. This relaxed hardware trigger allows keeping a larger data sample for further offline analysis. Typical offline trigger that is applied later requires a signal from all four detection points (4 & 5 & 6 & 7) and results in EAS registration intensity rate of ~7 events/hour at the Horizon-T.

Data for Standard EAS

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





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

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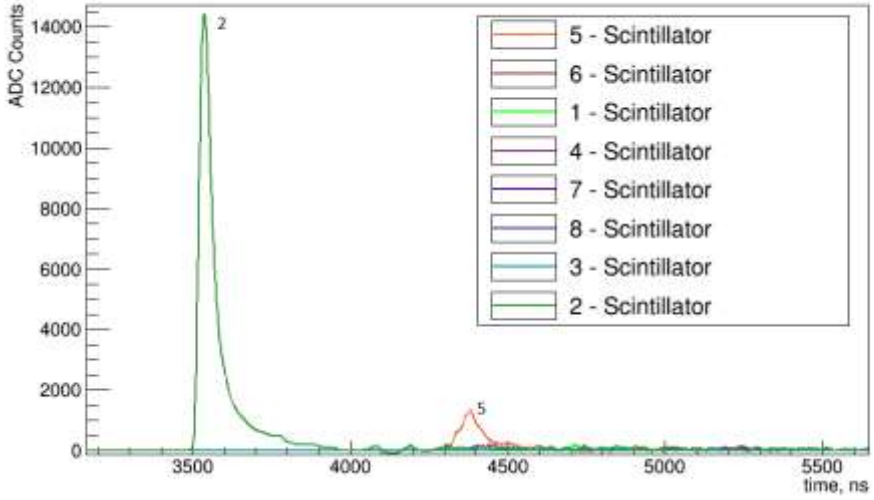
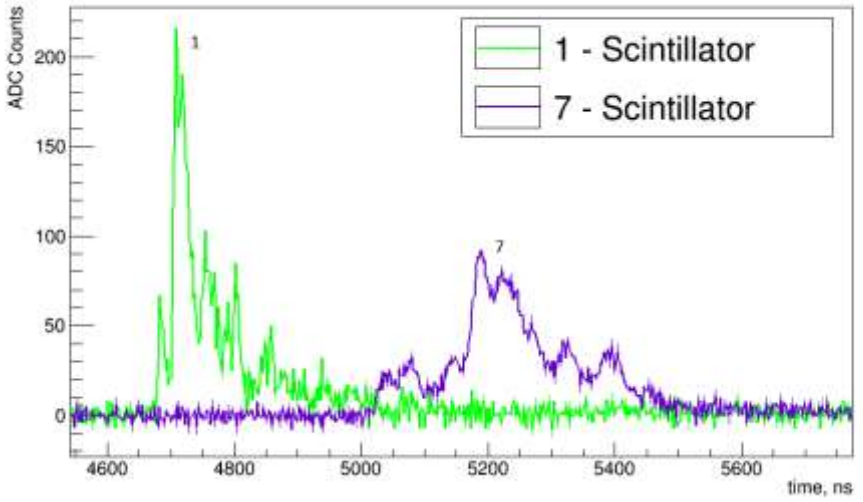
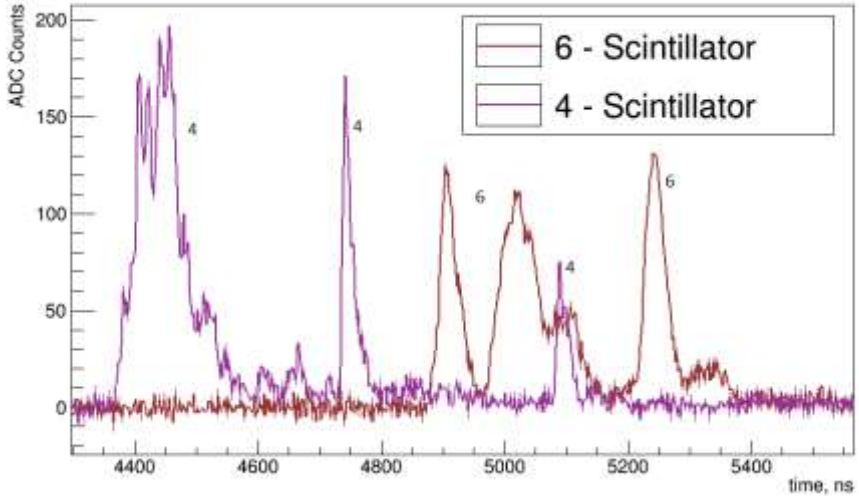
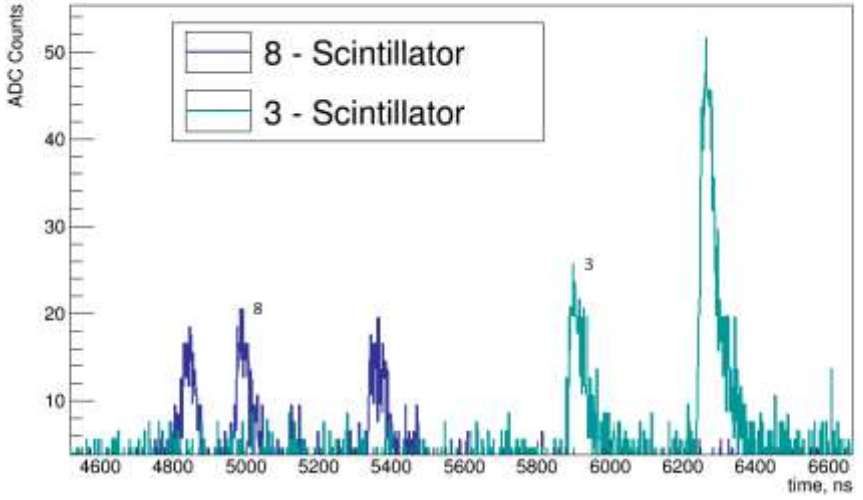
Unusual EAS at HT



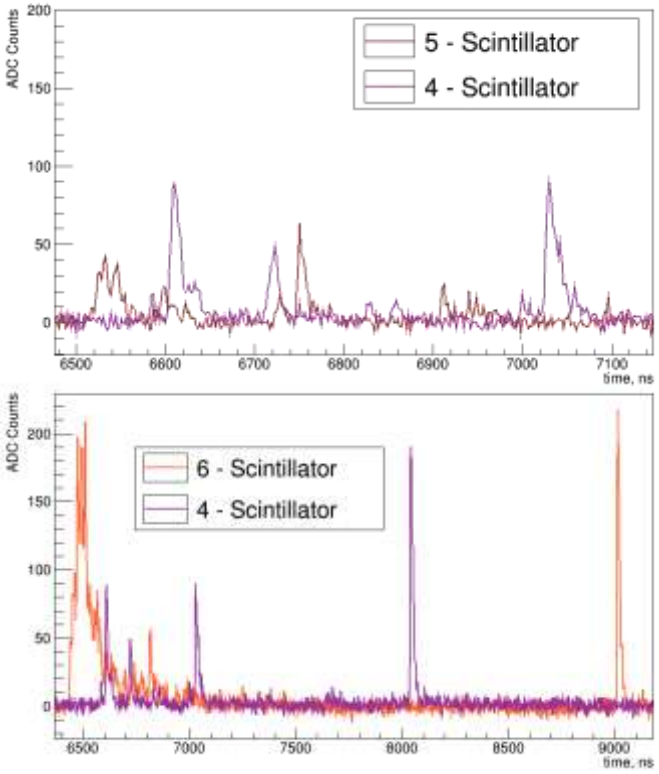


Event of Jan26 '16



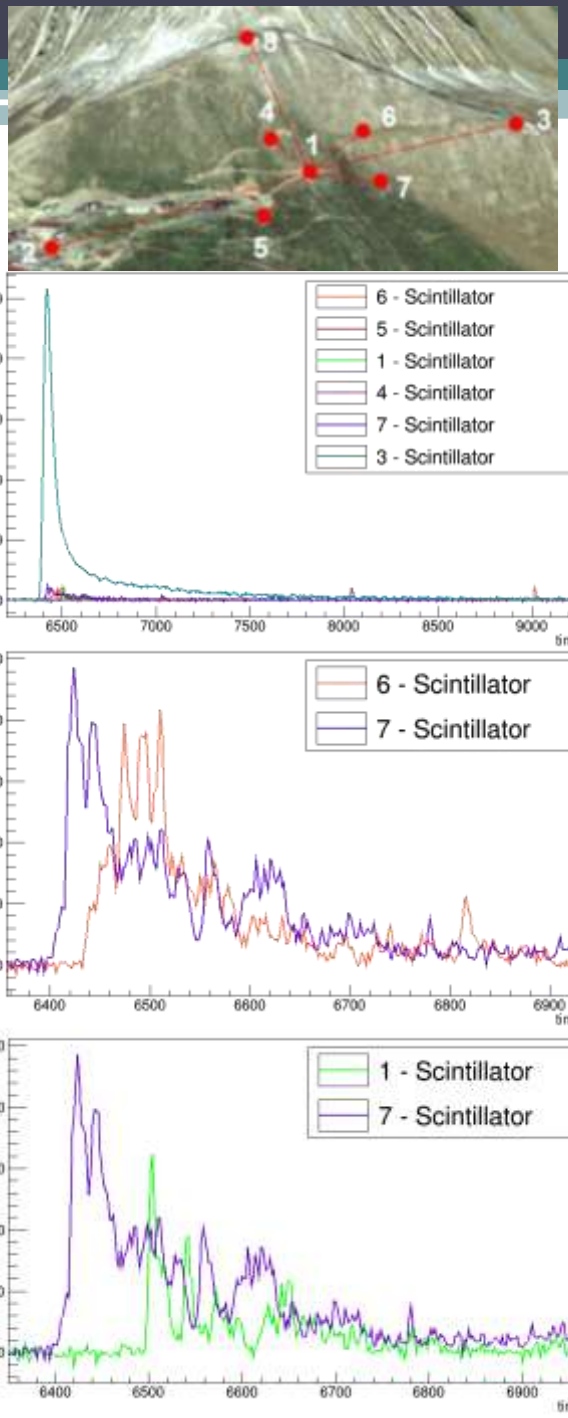


Unusual EAS at HT



Event of Oct 07 '16

New class of events



- Observe similar features:
  - One large pulse near core
  - Multi-peaked mashed pulses at mid-range
  - Highly separated multi-modal pulses at large distances from core

Conclusions

- HT detector is calibrated, can give
  - Particle density
  - Arrival time
  - Disk width
- Can handle standard events well
  - Using density distribution
  - Using time data
- At E>about const*10^{17} eV
  - Most events exibit unusual structure

Thank you for your attention.

- Any questions?

- References:

- [1] D. Beznosko et al., "Horizon-T Extensive Air Showers detector system operations and performance," in PoS(ICHEP2016)784, proceedings of ICHEP2016, Chicago, 2016.
- [2] RU Beisembaev, EA Beisembaeva, OD Dalkarov, VA Ryabov, AV Stepanov, NG Vildanov, MI Vildanova, VV Zhukov, KA Baigarin, D Beznosko, TX Sadykov, NS Suleymenov, "The 'Horizon-T' Experiment: Extensive Air Showers Detection," arXiv:1605.05179 [physics.ins-det], May 17 2016.
- [3] D Beznosko, T Beremkulov, A Iakovlev, Z Makhataeva, M I Vildanova, K Yelshibekov, V V Zhukov, "Horizon-T Experiment Calibrations-Cables," arXiv:1608.04312, 8/2016.
- [4] Adil Baitenov, Alexander Iakovlev, Dmitriy Beznosko, "Technical manual: a survey of scintillating medium for high-energy particle detection," arXiv:1601.00086, 2016/1/1.
- [5] Duspayev et al., "The distributed particle detectors and data acquisition modules for Extensive Air Shower measurements at "Horizon-T KZ" experiment," in PoS(PhotoDet2015)056, in proceedings to PhotoDet2015 conference, Moscow, 2015.