Simulation and design of the HT-KZ Ultra-high energy cosmic rays detector system for cosmic rays with energies above 10^{17} eV

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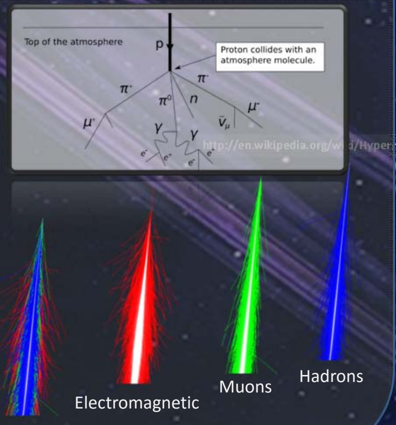
One of the remaining mysteries in HEP is the origin and the nature of the Ultra-high energy Cosmic Rays (UHECR). When primary cosmic particle enters the atmosphere of the Earth, it causes extensive air shower (EAS) that can be detected. There is an active project at Nazarbayev University (NU) to construct the HT-KZ (HorizonT-Kazakhstan) detector system in collaboration with FIAN Tyan Shan high-altitude Science Station. A significant part of this process is the simulation, testing and construction of individual particle detectors due to the requirements of robustness and high linear range of such detectors combined with low cost and long-term operations with minimal maintenance.

EAS GENERAL INFO

When the particle from the cosmic ray enters the atmosphere, its collisions with the nuclei results in EAS. During its development different components are born as the results of the interactions between secondary particles. Each component forms a thin disk (about 2-3 meters thick and 1-2km in diameter) moving at ~c. [2]



Shower simulation was done using the CORSIKA [1] software package version 7.4005

MOTIVATION

- ❑ The Horizon-T experiment has confirmed the "multimodal" EAS originating from 2-3 UHECRs arriving almost simultaneously with the distances from each other on the order of hundreds meters.
- ❑ There seems to be no anisotropy in the detected events (no direction to origin(s) if any)
- ❑ Plausible explanations of this discovery currently include:
  - ✓ a decay of the very unknown heavy parent into several UHECRs
  - ✓ from some exotic source (dark matter decay/ejection etc…)
- ❑ More data is required before a statement with some certainty can be made. A second system to verify results is needed.
- ❑ Utilizing new approach of mapping cascade curve to signal shape – needs fast detectors and fast DAQ signal recording

TOTAL SCHEMATIC OF HT-KZ SYSTEM

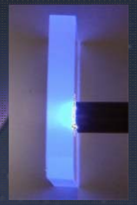
- ❑ Modules are to be on the roofs of NU
  - ✓ Energy sensitivity: E≥ 10^{17} eV
  - ✓ Time resolution ~1ns using modern photodetectors and DAQ
  - ✓ >1 event/km² per day with E above is expected (~1000 per year)
- ❑ Offline global trigger from time stamp
- ❑ Individual module trigger rate < 10/sec estimated dead time << 1%
- ❑ Total data per module <200kbyte/s
- ❑ Each module will be independent - 3 particle detectors per module with X-Y-Z alignment

Schematic of the module location on the roof of NU

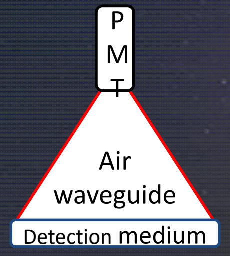
SIMULATION RESULTS ⟵ PARTICLE DETECTOR R&D ⟶ PMT MEASUREMENTS

SIMULATION RESULTS

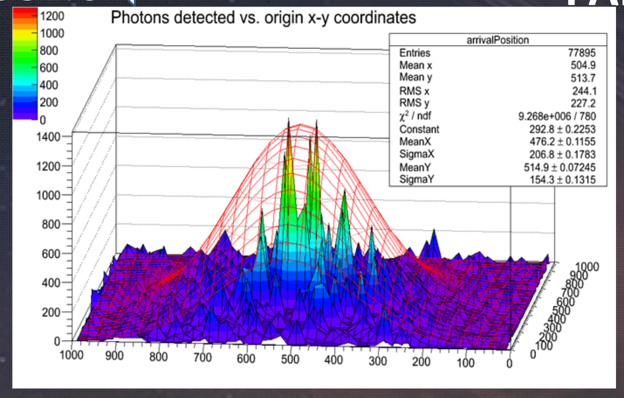
- ❑ Geometries to be tested
  - ✓ Square, circle
  - ✓ PMT placement: edge, center, away
  - ✓ Uniformity (edge effects)
  - ✓ Possible detection medium: glass, Cerenkov plastic or fast plastic scintillator (both Eljen [7])



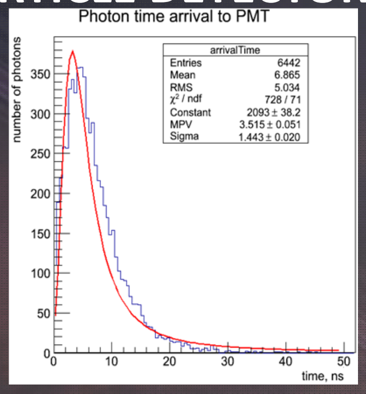
Plastic scintillator



Simple scheme of the single particle detector



Simulation of the square detector (1x1 m base, 10 cm height)



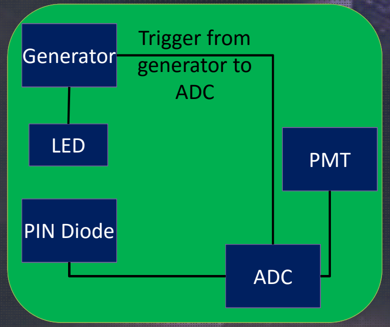
Signal width from the simulation

- ❑ Detector simulation was performed:
  - ✓ PMT is placed on the front side; air waveguide causes more uniform detection distribution than the face touching arrangement
  - ✓ Cerenkov plastic gives better photon production and enables uniform & efficient detection probability then glass; scintillator gives more light.

PARTICLE DETECTOR R&D

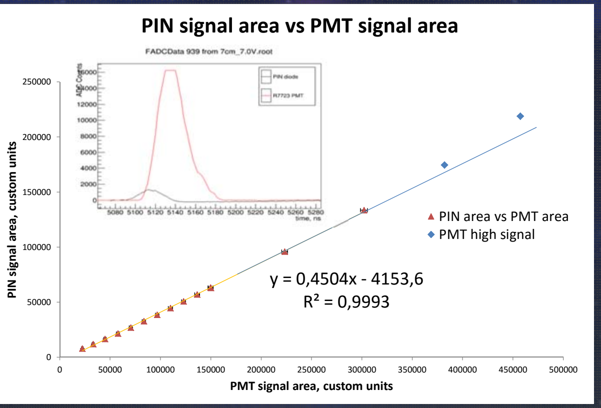
- ❑ PMT Choice
  - ✓ R7723 assembly
  - ✓ Other options (MPPC?)
- ❑ Tests to conduct
  - ✓ Dynamic range (1 to ~10^3 MIP)
  - ✓ Signal rise time, width
  - ✓ Time resolution
- ❑ PMT Linearity response test
  - ✓ Use LED signal
  - ✓ Monitor with PIN diode
  - ✓ Signal width to resemble data
  - ✓ Test over ADC range into saturation
  - ✓ Needs MIP calibration

R7223 PMT from Hamamatsu [6]



Schematic of the PMT linearity measurement experiment

PMT MEASUREMENTS

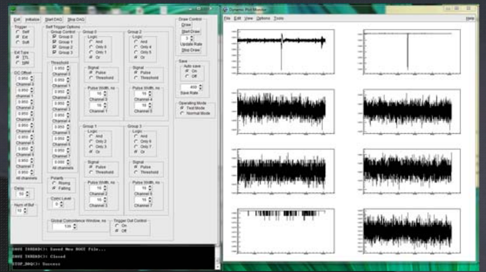


Non-linearity due to PMT signal exceeding ADC range, area is being cut

✓Non-linearity measurements were conducted on the range of voltage signals that exceeds the ADC range. PMT signals were chosen such that their width are comparable with the real data. Then the integrated signal area values were used for the analysis. The graph above shows that the PMT signal linearity is conserved in the ADC range.

DAQ

- ❑ **Using CAEN [5] DT 5743 ADC**
  - ✓ Trigger level and logic are software controlled
  - ✓ 12bit 2.5Vpp; Dead time 125µs
  - ✓ 3.2 Gsample/s max (plan to use 0.8gs/s)
  - ✓ 40bit internal time stamp 5ns resolution



Output of the sample data acquisition interface developed at NU

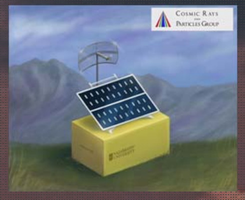
- ❑ **Synchronization and analysis**
  - ✓ Multithreaded DAQ software failure-resistant
  - ✓ Offline trigger analysis
  - ✓ Data via network to server
  - ✓ Using internal time stamp initially
  - ✓ Want ns level resolution for better:
    - • direction to the origin and shower structure
    - • will need R&D to reach down to 1-2ns

CAEN DT5743 ADC

Software for DAQ is still in the process of development!!!

FUTURE PLANS

- ❑ Detector R&D finishing
  - ✓ Attempting other options for detection medium
  - ✓ Testing other possible geometries and PMT placements (check for the rise time and signal width)
- ❑ Pulse synchronization R&D – requires improvements in the DAQ software: work in process
- ❑ Constructing detection units and installation on the rooftops of NU
  - ✓ Installation arrangement will depends on the simulation results
- ❑ Collecting first data and comparing with the existing outcomes



Artist's concept of HT-KZ detector, by Tatiana Beznosko

References:

[1] CORSIKA: a Monte Carlo code to simulate extensive air showers., by Heck, D.; Knapp, J.; Capdevielle, J.~N.; Schatz, G.; Thouw, T..~ Forschungszentrum Karlsruhe GmbH, Karlsruhe (Germany)., Feb 1998, V + 90 p., TIB Hannover, D-30167 Hannover (Germany)

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[3] R.U. Beisembaev et al., EAS late muons and showers with two fronts, Nucl. Physics. 2009. Volume 72, #11, pp 1-4)

[4] R. U. Beisembaev, Yu. N. Vavilov, M. I. Vildanova, N.G. Vildanov, O. D. Dalkarov, V. V. Zhukov, R. A. Nam, V. P. Pavlyuchenko, V. A. Ryabov, N. O. Saduev, T. H. Sadykov, A. V. Stepanov, Zh. S. Takibaev. The first results obtained with the installation HORIZON-T. Journal of Physics. 409. 012127. (2013).

[5] CAEN S.p.A.Via della Vetraia, 11, 55049 Viareggio Lucca, Italy. http://caen.it.

[6] HAMAMATSU PHOTONICS K.K., Electron Tube Division, 314-5, Shimokanzo, Iwata City, Shizuoka Pref., 438-0193, Japan, http://www.hamamatsu.com/

[7] Eljen Technology, 1300 W. Broadway, Sweetwater, Texas 79556, United States, www.eljentechnology.com