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宇宙线探测器阵列的研发与优化

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Abstract

This project established a cosmic ray detector array with five plastic scintillators, calibrated for photomultiplier tubes(PMT), and simulated air showers. The array enables detection of high-energy cosmic rays exceeding 10 TeV.

Research Background

Cosmic ray particles, as abundant high-energy particles in the environment, have long been a focus of extensive research. With advances in technology, experimental methods have continuously evolved, leading to significant breakthroughs in related astronomical studies.

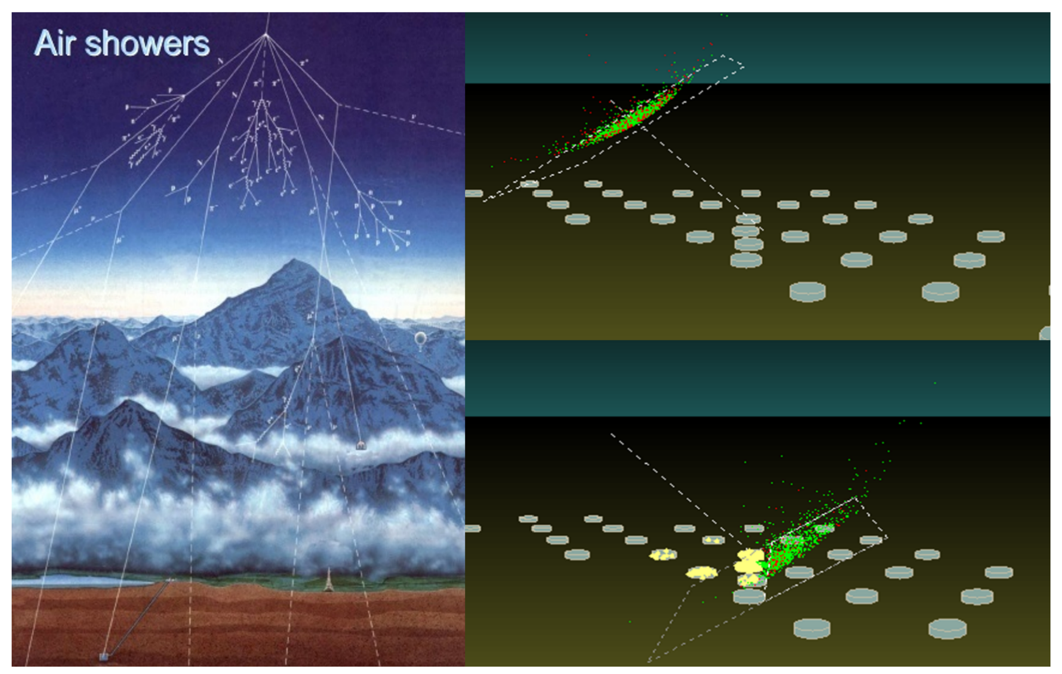

Fig. 1. Schematic Diagram of Cosmic Rays and Detector Array

Our research team currently possesses several cosmic ray detection devices and plans to simulate both the response of detectors and the air shower signals produced by cosmic rays.[1] By integrating simulation results, we aim to design and optimize the deployment of the detection array.Furthermore, in collaboration with experimental projects at other institutions, we will establish real-time nationwide cosmic ray observation, enabling data sharing and joint analysis.

Research Methods and Innovation Points

Experimental Approach

1. Waveform Recognition and Numerical Integration of Detector Output Signals
2. Particle Type Identification Based on Signal Characteristics
3. Array Deployment and Event Information Inference Based on CORSIKA Simulations
4. Real-Time Data Upload via Cloud Services for Unattended Remote Data Collection

Innovation Points

This project builds upon scintillator detectors to construct a detection array, optimize its configuration, and develop accompanying software to enable coincidence measurements. By utilizing the Geant4 software package for simulations, the project aims to infer event information based on data collected by the detector array.

Furthermore, the project aligns with current advancements in the intelligent development of detectors, focusing on improving the design of the detection array and its associated software. The ultimate goal is to achieve automation of the detector system and intelligent data processing.

Research Process and Results

Device Design and Deployment

The geometric dimensions of a single detector and the relative arrangement of the five detectors are shown in the figures

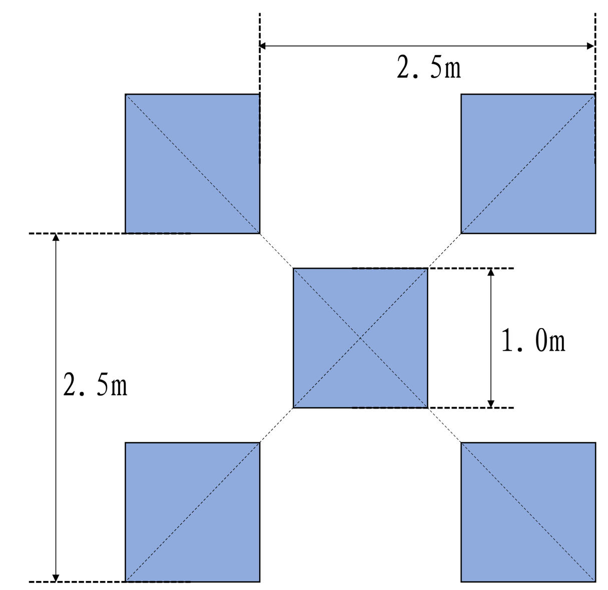

Fig. 2. Detector Deployment.

Fig. 3. Team Members

Calibration of the Photomultiplier Tube (PMT)

The current gain μ (i.e., Gain) has the following relationship with the operating voltage V:

$$\mu = (a\cdot E^k)^n = a^n(\frac{V}{n+1})^{kn} = A\cdot V^{kn}$$

Within a certain voltage range (below 1200V), the gain of the photomultiplier tube (PMT) can be considered to have a linear relationship with the applied voltage (V). Therefore, using the laboratory darkroom, multiple sets of data are collected within the voltage range of 900-1100V for single-photon calibration. Finally,after taking the logarithm，a linear fit is performed, and the high voltage is adjusted to ensure that the gain values of the five detectors are all around 5×10^6.

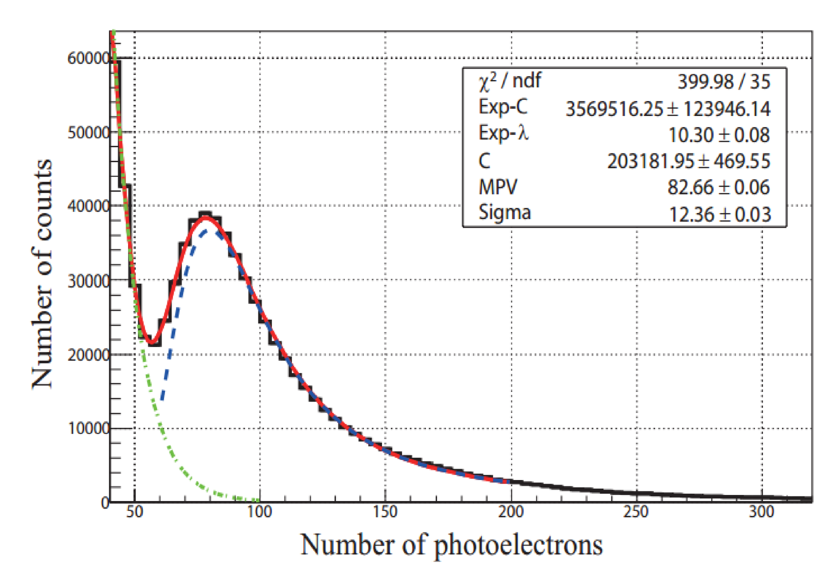

Fig. 4. Single-photon calibration theoretical curve.

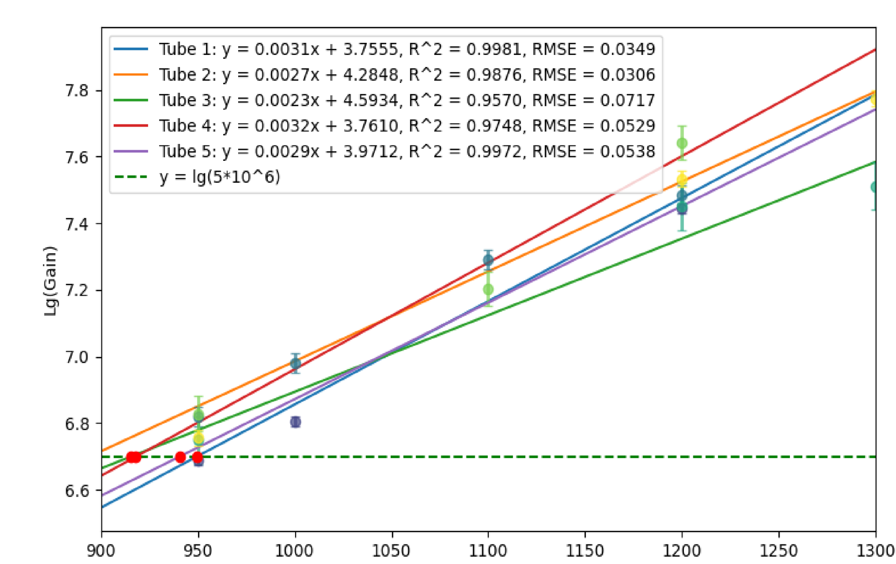

Fig. 5. Lg(Gain) Linear Fitting

Simulation and Modeling Work

a) Air Shower Size: Our experiments were conducted in Zhuhai, which is approximately at sea level (0m). To investigate the theoretical performance of the detector array we constructed, we utilized CORSIKA[2] to simulate extensive air showers. For one of the simulations (1 alpha particle, 10TeV), the coordinate distribution of the secondary particles on the observation plane is as follows, with the particles within the detector range marked in red.

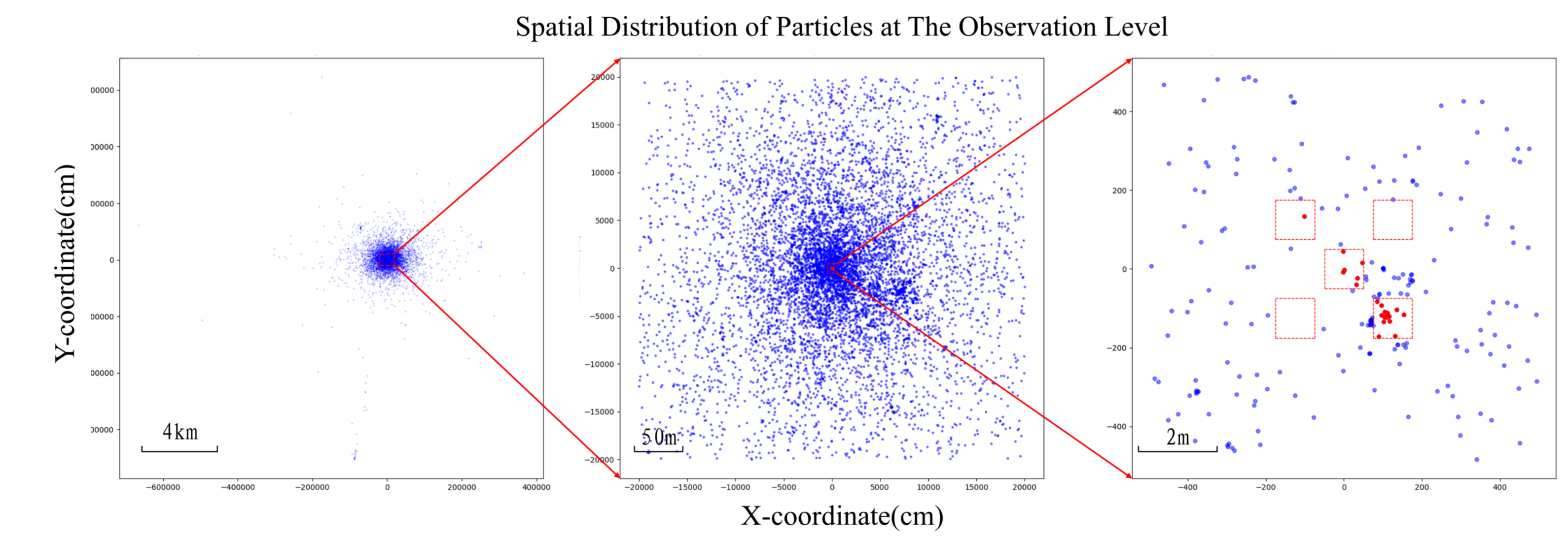

Fig. 6. Simulation of Airshower

At sea level, extensive air showers of cosmic rays with 10 TeV typically span over 4 square kilometers, with our detector capturing a minuscule portion of the particles. Thus, our instrument is primarily suited for logging the frequency of cosmic ray occurrences.

b) Energy Detection Threshold: We simulated proton events at different energies, calculating the air shower density at the core and the fraction of particles detected within our instrument for 100 simulations per energy level, and correlated these findings with energy.

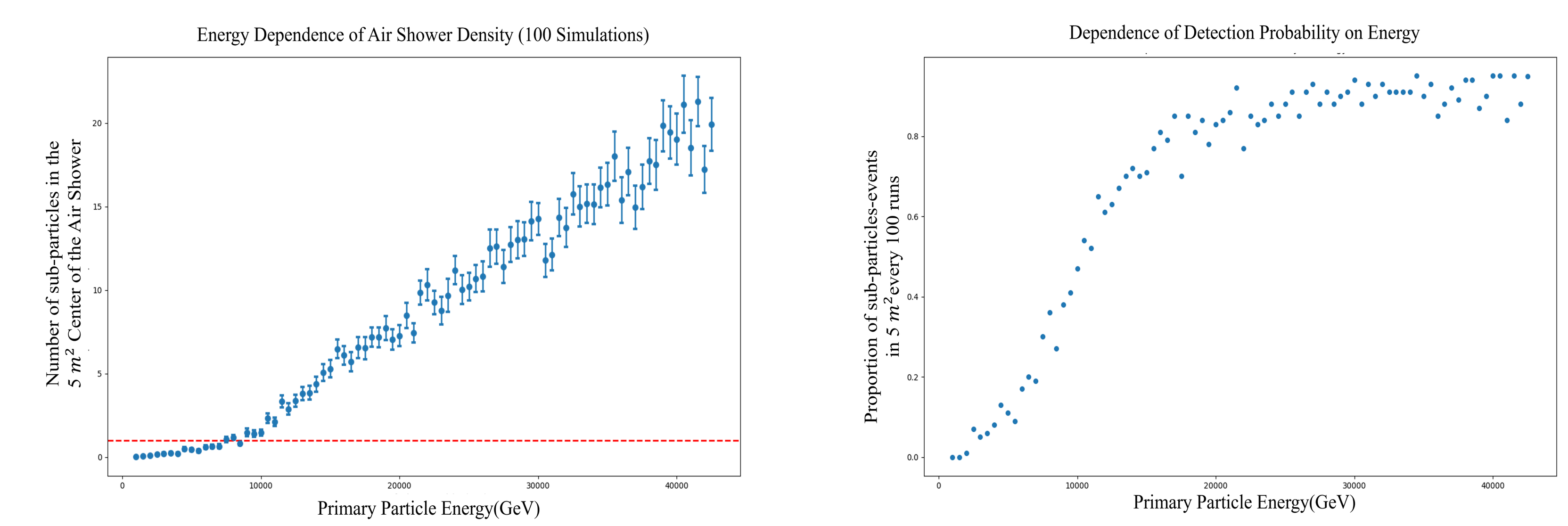

Fig. 7. Energy-Related Simulation

Based on our simulations, we estimate the energy detection threshold of our detector to be approximately 10 TeV, with a detection probability exceeding 80% starting from around 18 TeV.

Future Work

Our detector array, constrained by size limitations, does not achieve the energy reconstruction or particle identification capabilities of experiments such as LHASSO and $AS\gamma$. However, it serves as a sensitive high-energy cosmic ray counter, capable of statistically analyzing charged particles reaching the observation plane under various events and weather conditions. In the future, we can further optimize its electronic system and data acquisition and analysis systems to achieve stable real-time measurements and analysis.

Reference

[1] Zhang, Youni Gou, Q.-B Cai, Huaxuan Chen, Tian-Lu .etc (2017). New prototype scintillator detector for the Tibet ASγ experiment. Journal of Instrumentation. 12. P11011-P11011. 10.1088/1748-0221/12/11/P11011.

[2] Heck D, Knapp J, Capdevielle J N, Schatz G, Thouw T. CORSIKA: a Monte Carlo code to simulate extensive air showers[M]. 1998.

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