Cosmic Ray measurements in the region 1-100 TeV: combined proton and helium spectrum.

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1. The ARGO-YBJ laboratory in Tibet

Many experimental efforts were devoted to study the cosmic rays properties. The observation techniques can be grouped into two broad classes: direct measurements up to few hundreds TeV, and indirect measurements which access energies up to 10^{20} eV. A better understanding of the comparison between direct and indirect data can be obtained by extending the indirect measurements in the low energy region covered by balloons and satellite detectors. The ARGO-YBJ experiment [1,2], with low energy threshold and high duty cycle, is able to overlap the measurements in a wide region covered by the direct technique.

2. The ARGO-YBJ experimental hall

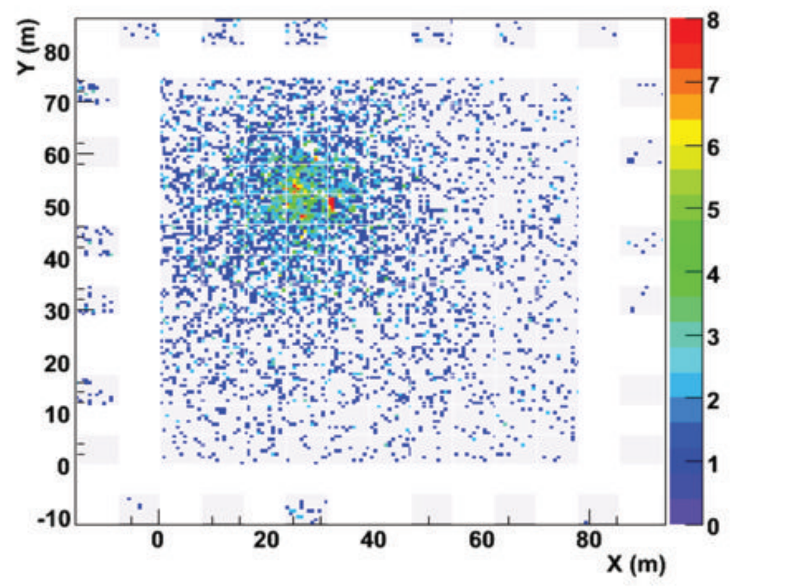
The ARGO-YBJ Experiment

ARGO-YBJ is a "full coverage" air shower array operating in the YBJ International Cosmic Rays Observatory located at Yangbajing, in the Tibet region, (P.R. China), at an altitude of 4300 m above sea level

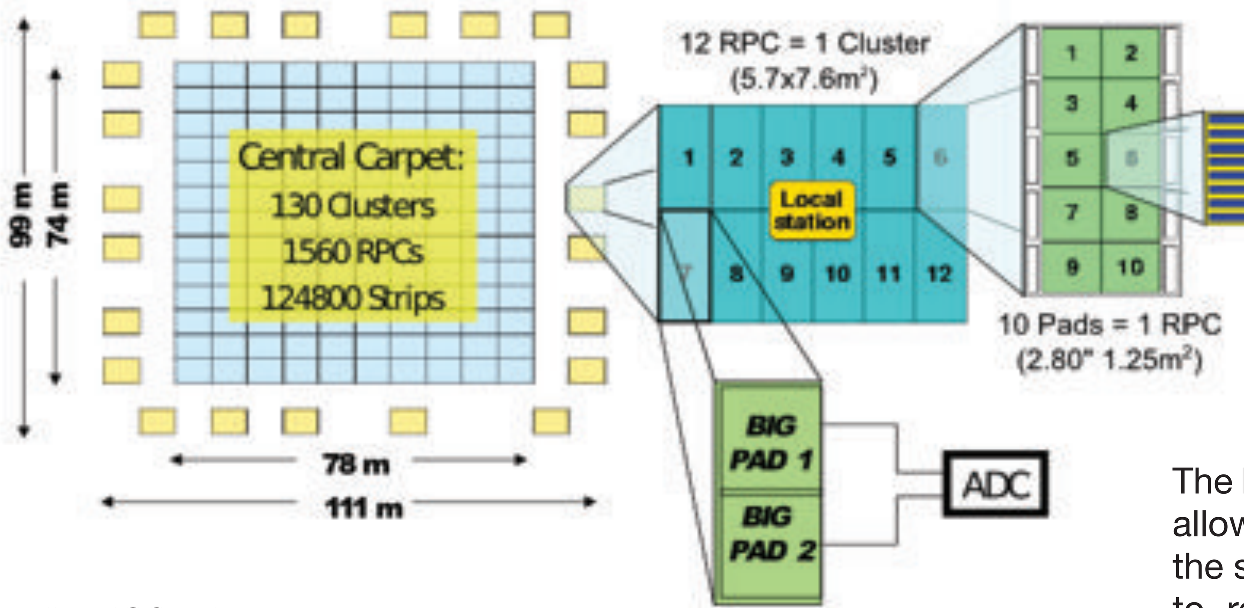
The detector consists of a single layer of resistive plate chambers (RPCs) covering a central area of 74 X 78 m² and logically divided into 130 clusters (fig 3). Additional 23 clusters form a guard ring surrounding the central part, they are used to improve the core reconstruction.

The ARGO-YBJ experiment is in stable data taking in its full configuration since November 2007.

In order to extend the detector operating range up to energies of about 1 PeV, a system for the analog charge readout has been implemented.



4. A typical event triggered by the ARGO-YBJ detector



3. ARGO-YBJ detector layout

Time resolution ~ 1 ns
Space Pixel = 5,6 X 62 cm²

The high segmentation of the read-out allows a high granularity imaging of the shower front (fig. 4), which is used to reconstruct the shower direction and the core position

Data Analysis

Since atmospheric showers present large fluctuations in their development, the energy distribution of cosmic rays must be evaluated by using an unfolding procedure that can be dealt with the Bayesian unfolding method [3,4].
A detailed Monte Carlo simulation of the shower development and of the detector response is needed in order to compute the conditioned probabilities required by the Bayesian framework.

Monte Carlo data sample

Protons, Helium, CNO
- CORSIKA (QGSJET + GEISHA)
- Energy range: (1-10^4) TeV
- Zenith angle range: (0-45)°

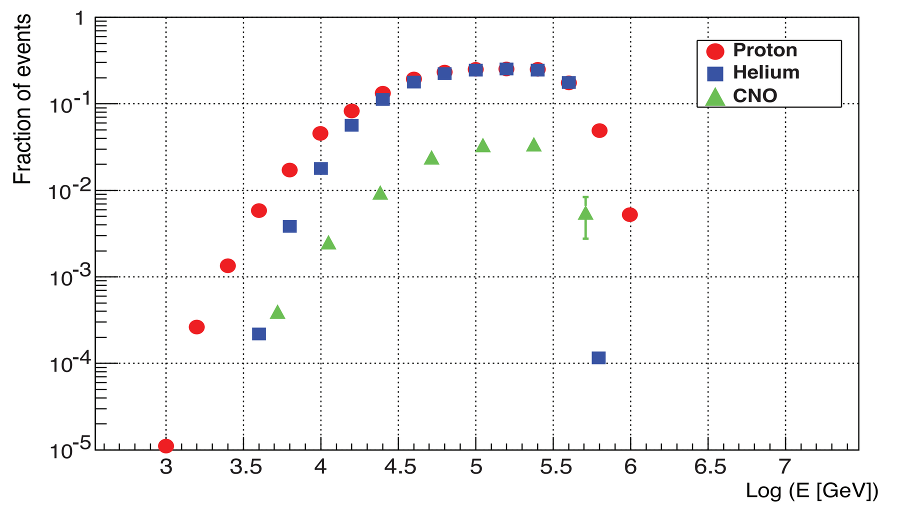
Data sample

The detector was in stable data taking during the runs selected for this analysis with a resulting trigger rate of ~ 3.5 kHz and a dead time of ~4%.
The data sample used in this analysis consists of three runs of about 25.0×10^6 events each, collected during the period January–May 2008.

Selection criteria

The following selection criteria have been applied to the Monte Carlo and Data sample:
- Zenith angle range
- Multiplicity range
- Particle density on the detector surface

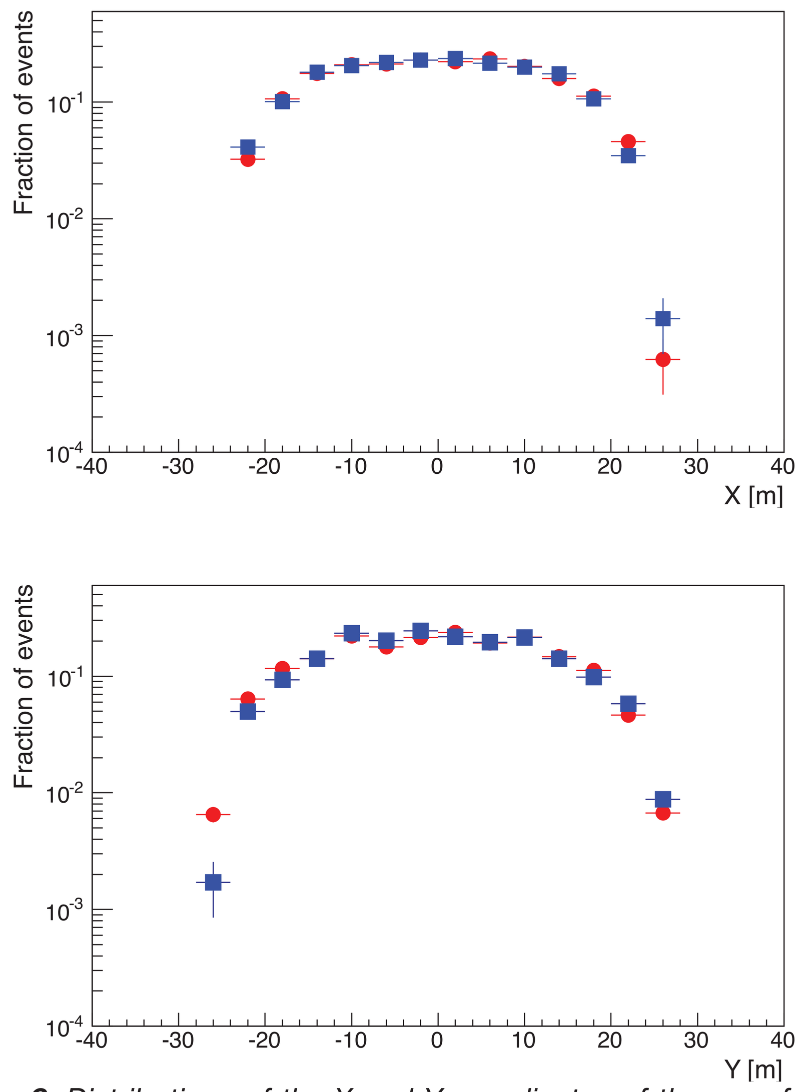
Only about 2% of the showers induced by the CNO group pass the cuts used in this analysis, the cut on the particle density (pin) selects showers with well-shaped core discarding events induced by heavier primaries (see fig 5).



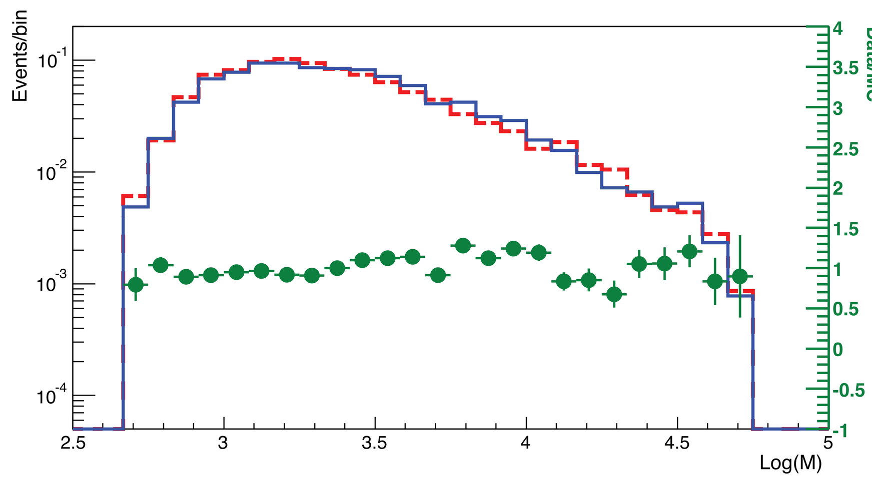
5. The fraction of the simulated events selected by the cuts used in this analysis is shown as a function of the energy for proton induced events (red circles), helium induced events (blue squares) and CNO induced events (green triangles).

Data and Monte Carlo comparison

The distribution of the core position, (fig. 6), shows that the same fraction of events in the data and Monte Carlo sample has been selected in the same inner detector area. Moreover, the strip multiplicity distribution obtained from the Monte Carlo events has been compared with the experimental distribution (fig. 7) showing a good agreement.



6. Distributions of the X and Y coordinates of the core for Monte Carlo events (red circles) and for data (blue squares) selected by the criteria used in this analysis.



7. Normalized strip multiplicity distribution for Monte Carlo events (dashed red line) and data (solid blue line). The green points represent the ratio the two distributions

Results

The Bayesian unfolding has been performed on the selected data sample.
The contributions to the energy spectrum of elements heavier than Helium are neglegible.

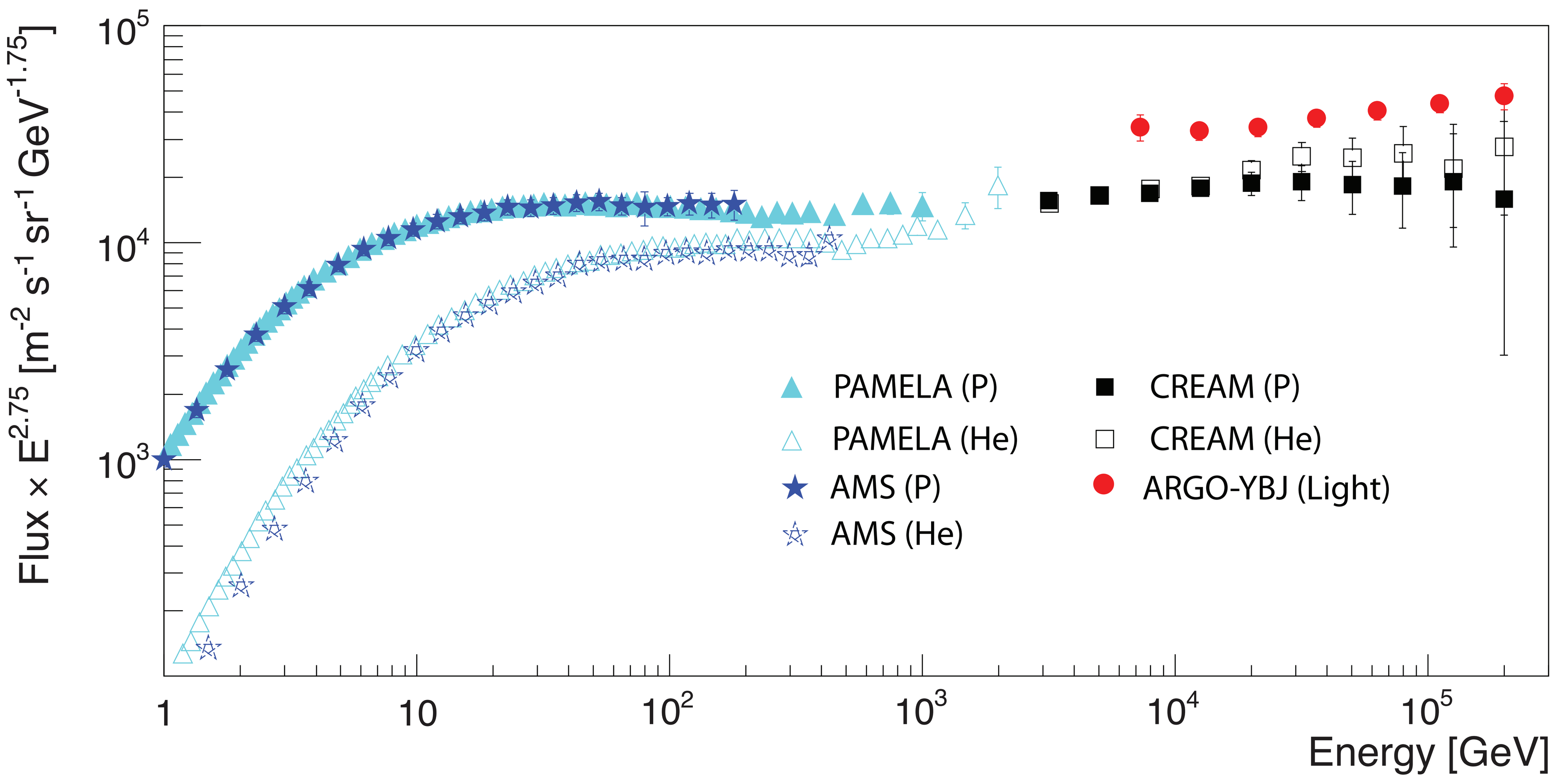
The Light Component Spectrum

The light component spectrum measured by the ARGO-YBJ experiment [5] (fig. 8 and 9) agree remarkably well with the values obtained by adding up the the proton and helium fluxes measured by CREAM [6,7] either concerning the total intensities as well as the spectrum.

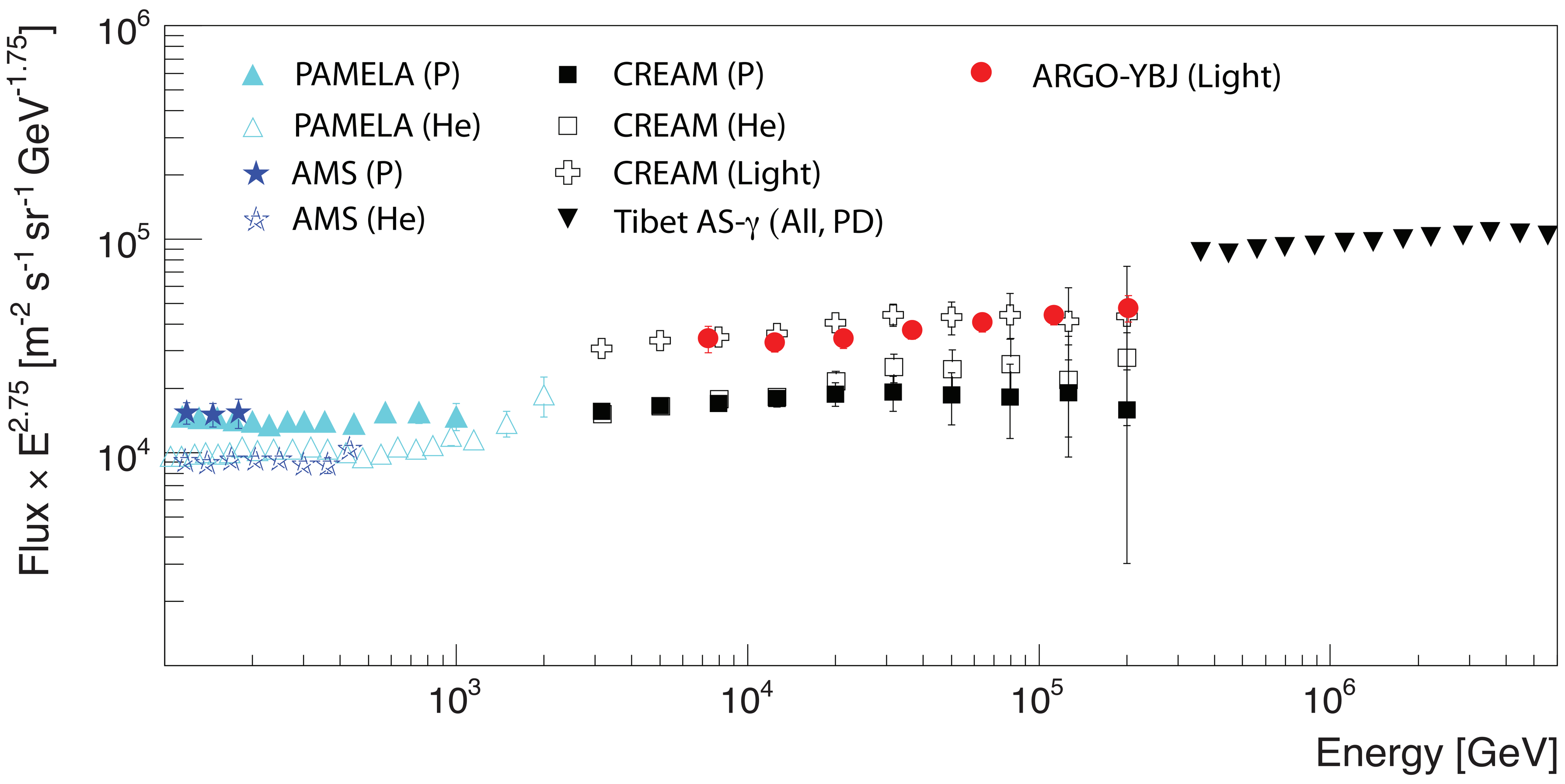
The value of the spectral index of the power-law fit representing the ARGO-YBJ data is –2.61 ± 0.04

Sources of systematical uncertainties:
- Effects due to the selection cuts on the measured quantities (zenith angle, multiplicity, particle density)
- Effects due to the reliability of the simulation of the detector response
- effects related to the fraction of helium component used to evaluate the Bayesian probabilities

Statistical uncertainty ~ 1% - Total uncertainty not exceeding 10%



8. The Light Component Spectrum measured by ARGO-YBJ compared with proton and helium spectra measured by other direct experiments (PAMELA [8], AMS [9], CREAM)



9. The 1-100 TeV energy region. The light component spectrum measured by ARGO-YBJ compared with the sum of the proton and helium spectra measured by CREAM. The all-particle spectrum measured by Tibet AS-γ [10] is also shown

Conclusions

The peculiar features of the ARGO-YBJ experiment (full coverage, high altiude location and high segmentation coupled to a digital readout) allow the imaging of the front of small size showers induced by primaries with energies down to a few TeV, so far accessible only with balloon-borne experiments. Showers with multiplicity in the range 500<M<50000 are mainly produced by primaries in the energy range 1-300 TeV. A sample of events mainly induced by protons and helium nuclei have been selected by requiring quasi-vertical showers and by applying a selection cut based on the particle density on the detector surface. An unfolding technique based on the Bayesian approach has been applied to the strip multiplicity dis- tribution in order to obtain the differential energy spectrum of the light-component (proton and helium nuclei) affected by a systematic uncertainty not exceeding 10%.

This measurement bridges the energy gap between the lower energy balloon-borne detectors and the indirect EAS experiments. For the first time direct and ground-based measurements overlap for a wide energy range.

References

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