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Status of Cosmic Rays Physics at Knee

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In this contribution the results obtained in the last years in cosmic rays physics around the knee of the primary spectrum are reviewed. The experimental situation about the primary spectrum and the chemical composition of the primaries are discussed, trying to emphasize the dependence on the primary interaction models.

1. Introduction

The primary cosmic rays spectrum is described by a power law over many order of magnitude (from 10^9 to 10^{20} eV), at energies around 10^{15} eV a change of slope, known as the knee, has been observed[1]. Various hypotesis (see [2] and references therein) have been made to explain this feature, to disentagle them precise measurements of the cosmic rays chemical composition, of the single element spectra and of the anistropy of the cosmic rays arrival direction are required.

Energies above 10^{14} eV cannot be investigated by satellite- or balloon- borne experiments (as the primary flux is too low) so measurements have to be performed by earth based experiments which detect the secondary particles produced in the development of Extensive Air Showers. These arrays must cover wide surfaces (from 10^5 to 10^6 m^2) and must use different detectors to measure different components of the EAS (electromagnetic, muons, hadrons). The more widely diffused tecnique are scintillator detector for the electromagnetic component and either wire-chambers or scintillators for muon detectors (shilded by absorbers of different depths according to the experimental setup).

In this brief review I will present and discuss some of the results obtained by experiments that have operated in the last decade, some of these (i.e. CASA[3]-MIA[4], EAS-TOP[5]) have been stopped, some others (i.e. KASCADE[6], TIBET ASγ[7], TUNKA[8]) are still operating.

I have restricted this review to results concerning the spectrum, the chemical composition and the single elements spectra; those about the anisotropies are not presented even if they are of main importance to try to fully understand the knee.

2. Spectra of EAS components

EAS experiments sample different secondary components of the showers.

An important result obtained by all the experiments is that the knee of the spectrum is visible in all the spectra of the secondary components that have been investigated, i.e. electromagnetic[9,11], muons[10,12], hadrons[13]. Figure 1, as an example, shows the Ne spectra measured by the EAS-TOP experiment.

The EAS-TOP collaboration[10] has compared the parameters of the spectra of the electromagnetic and muonic components of EAS at the knee, obtaining that the Ne_k and $N\mu_k$ values are in agreement with usual EAS develepment and that the integral fluxes above the knees are consistent within the experimental errors. These results do not depend on the EAS development simulation and give a clear indication that the knee is a charachteristic of the primary spectrum; disfavouring hypotesis based on changes of the intercation of the primaries with air nuclei.

Selecting showers with a low (high) percentage of muons compared to electrons the light (heavy) component of primary cosmic rays can be sampled. This selection obviously depends

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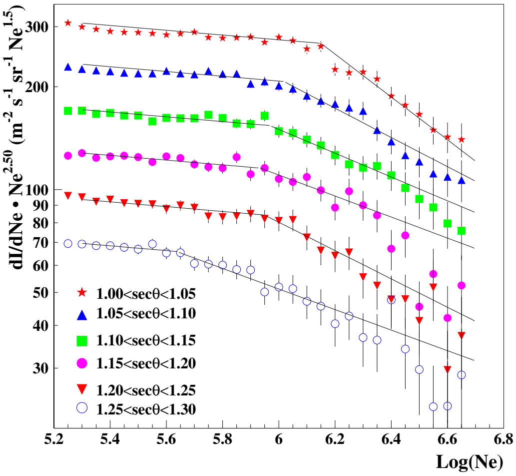

Figure 1. Shower size spectra measured in different zenith angle bins by the EAS-TOP experiment[9]

on shower simulations, but differences between light and heavy components scarcely depend on the primary interaction model used in the EAS simulation. Figure 2 shows the spectrum of the muon density, at fixed distance from the core, for elctron rich and electron poor showers measured by the KASCADE collaboration[12]. It is clear that the change of slope is observed only for electron rich showers thus indicating that the knee is due to ligth elements.

3. Primary Chemical Composition and Single Elements Spectra

Most of the experiments measure the cosmic rays chemical composition correlating the electron and the muon numbers in EAS. These measurements must then be interpreted using a complete EAS simulation, so the conclusions depend on the interaction model used. Nevertheless there are some qualitative features that are common to almost all experiments and to all interaction models, while the situation is different if one tries to infer quantitative results.

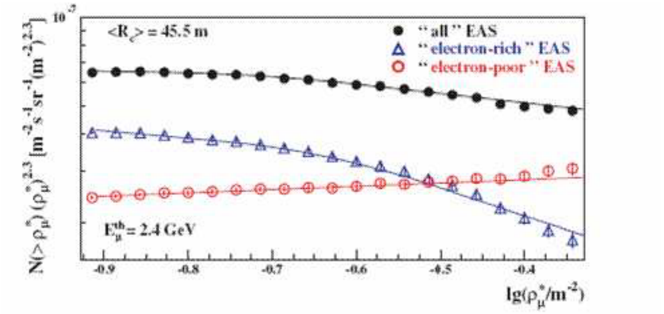

Figure 2. Spectrum of the muon density measured at fixed distance from the EAS core by the KASCADE experiment for electron rich and electron poor events

The KASCADE experiment obtains, with an unfolding analysis, the spectra of single elements (H, HE, C, SI and FE)[14]. The relative abundances of elements heavily depends on the interaction model used but all off them indicate that the spectra of light elements show the change of slope, while those of the heavier ones don't.

Similar analysis has been made by the EAS-TOP experiment correlating the electron number either with the muon densities (at fixed core distance) measured on the surface ($E\mu > 1$ GeV)[10] or with the number of muons detected underground by the MACRO experiment ($E\mu > 1.3$ TeV) [15]. Again the change of slope is visible for ligth elements, while it isn't for heavy elements. An important contribution of these combined analysis is that the result on the element spectra do not depends by the kinematical region of the primary interaction investigated by the detected muons.

A different approach has been followed by the TIBET ASγ experiment, located at 4300 m a.s.l. (i.e. near the shower maximum at knee energies), that measures the electron number (through scintillator detectors) and the gamma families (by emulsion chambers). The authors claim that the experiment is almost blind to heavy primaries and that through a neural network analysis they sepa-

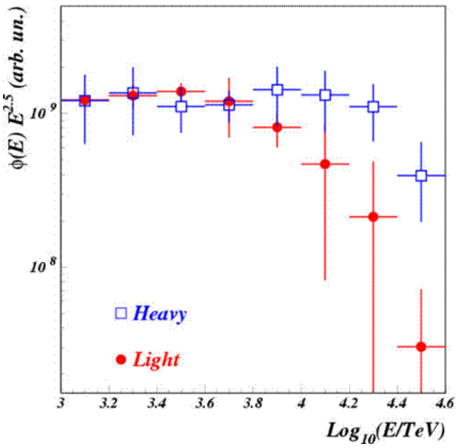

Figure 3. Spectra of light and heavy elements obtained from the EAS-TOP and MACRO correlated data[15]

rate H and HE events[16]. The measured spectra are steeper than those measured at lower energies and by other experiments. The claim of the collaboration is that the H and HE spectra have already changed their slope and their knee should be at a lower energy (below the energy range of the experiment). The knee observed at 10^{15} eV is thus due to heavy elements.

4. Concluding remarks

Summarizing the main results that have been obtained in the last years in cosmic rays physics, at energies around the knee of the primary spectrum, are:

- the change of slope has been observed in all the secondary components of EAS at different atmospheric depths.
- The chemical composition of the primaries evolves, above the knee, towards heavier elements.
- The knee is observed (by most experiments exepct Tibet ASγ) in the spectra of the light elements.

To further investigate the knee of the cosmic ray spectrum it so important to study the energy range from 10^{16} to 10^{18} eV, where the change of slope of the heavy elements is expected (if the knee is due to ligth components). Various experiment are in preparation, among these is the KASCADE-Grande[17], an extension of the former KASCADE array using detectors arriving from the EAS-TOP experiment.

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