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The hypothesis of strangelets in cosmic rays.

Sergey Shaulov

P.N.Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia

Moscow Institute of Physics and Technology (State University), Russia

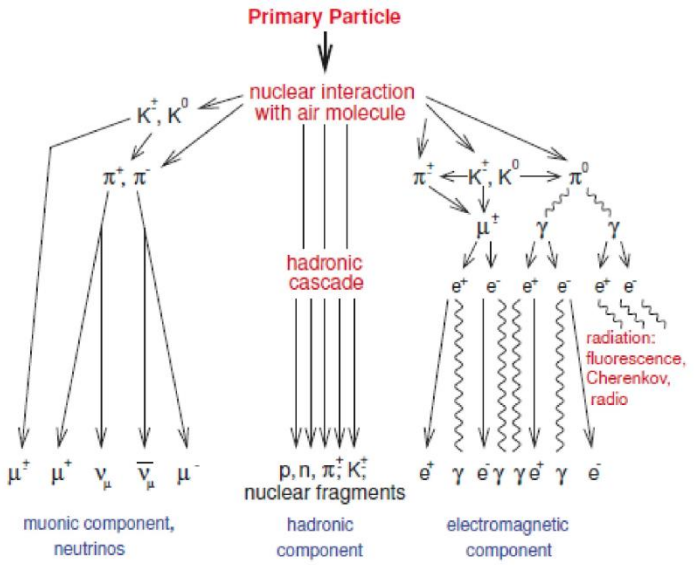
The knee problem in the spectrum of extensive air showers (EAS).

-The knee problem arises because of the indirect nature of determining the spectrum of cosmic rays (CR). In ground-based experiments, the spectrum of EAS rather than the CR spectrum is measured. In this case, both the energy and the type of nuclei that formed the shower are unknown.

-EAS consists of two parts: the core (~1 m), where the most energetic hadrons are concentrated and electromagnetic periphery of hundreds of meters in size .

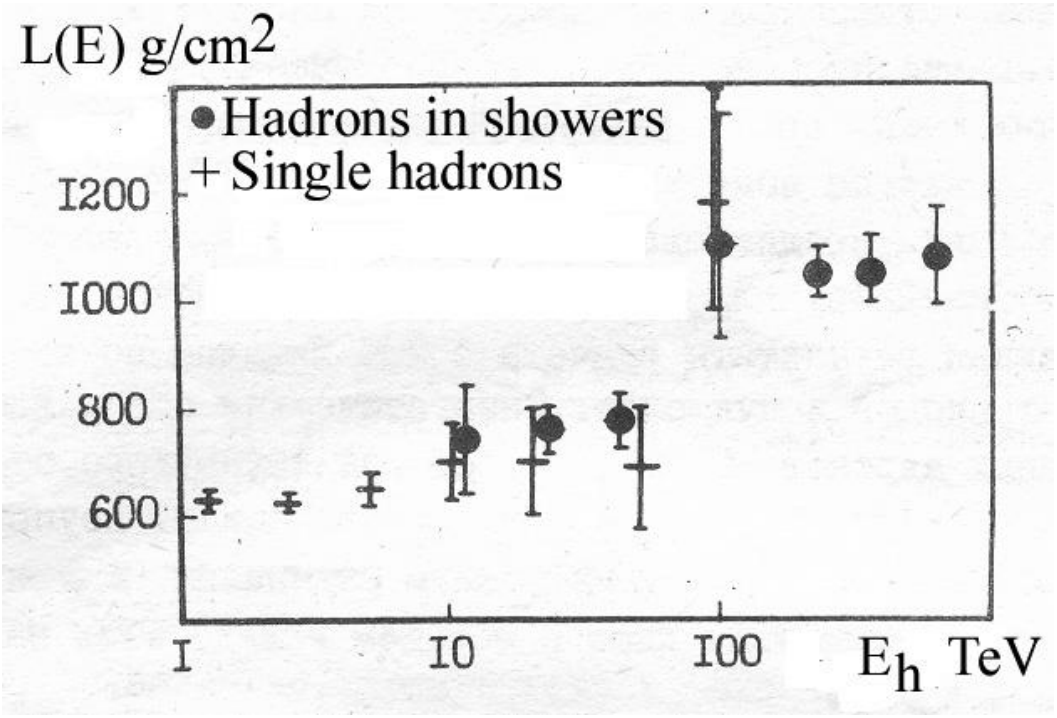
Experiments are divided into two types depending on whether the EAS cores are registered in them or not. In the experiments of the first type, the so-called penetrating component of CR was found.

It seems that the definition nature of penetrating component is the key to the problem of the knee.



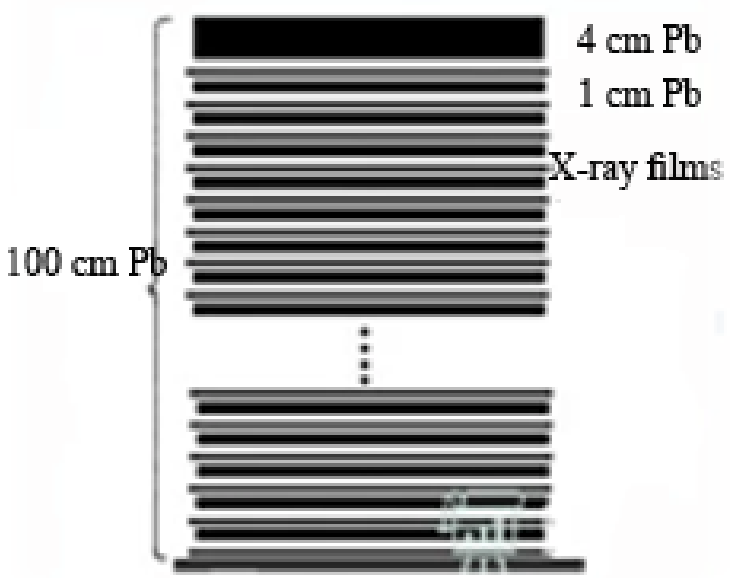
Penetrating component (Tien-Shan).

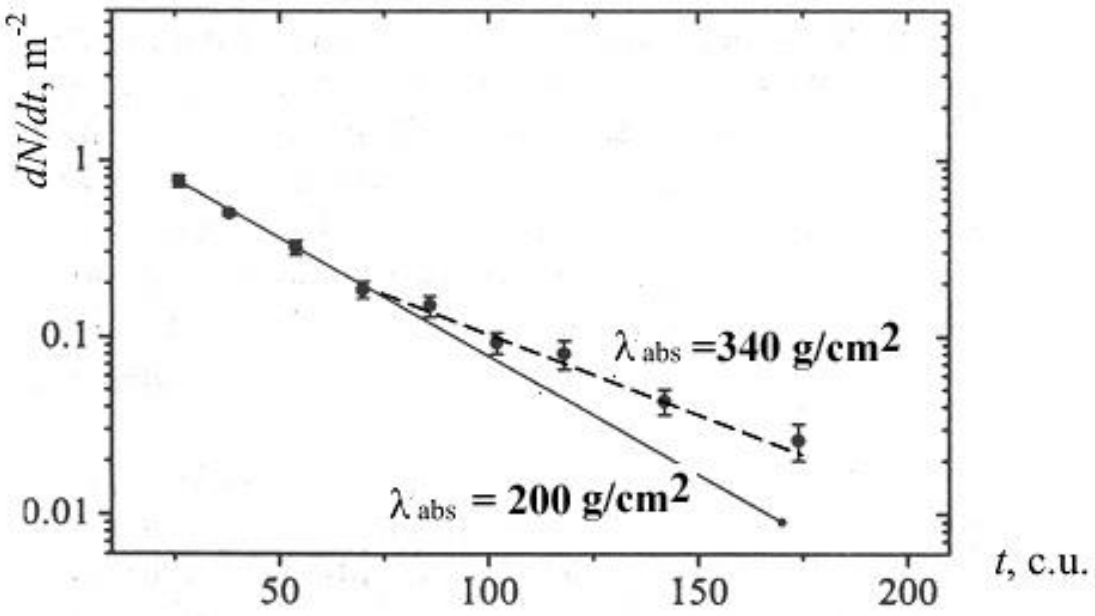
The first indication of a penetrating component in cosmic rays were obtained by Yakovlev in the experiment with the calorimeter . In 1980, it was found that at the hadron energies of ~100 TeV, the absorption length of cascade in the lead calorimeter increases from 500 to 1000 g/cm^2. This component was named long flying component.



Penetrating component (Pamir).

A few years later, the effect was confirmed in the works cooperation PAMIR. In deep lead x-ray emulsion chambers (XREC), a penetrating component of cosmic rays was observed. At a depth of more than 50 cm of lead (70 c.u.) an absorption of hadrons with energies $E_h^{\gamma} \geq 6.3$ TeV was becoming slower. The absorption length of hadrons in XREC λ_{abs} was changing from 200±5 to 340±80 g/cm^2.





Interpretation

Both effects were explained by Dremin as the possible increase in the birth cross-section of the charmed particles in lead. To explain effect in the XREC the cross-section of the charm birth in the lead should be (50±10)% of the full inelastic cross-section at an energy of about 75 TeV. But according to LHC data for pp: $\sigma_c / \sigma_{in} \leq 0.14$.

- The data of *HADRON* experiment presented here confirm the existence of the penetrating component, but its interpretation is different.
- First of all, this distinction *HADRON* experiment data is due to the fact that the effect is observed not in the lead absorber, but in the atmosphere.

The hypothesis leading charm cannot explain the decrease in the absorption of the cascade in the light material (air), that is confirmed by calculations (Dunaevsky, Sveshnikova, Krutikova, Karpova).

In addition we also found that the penetrating component appears in the limited energy region.

Penetrating component arise threshold way at an energy 3 PeV and vanishes at energy interval ~50-100 PeV.

Basic idea of this report is as follow.

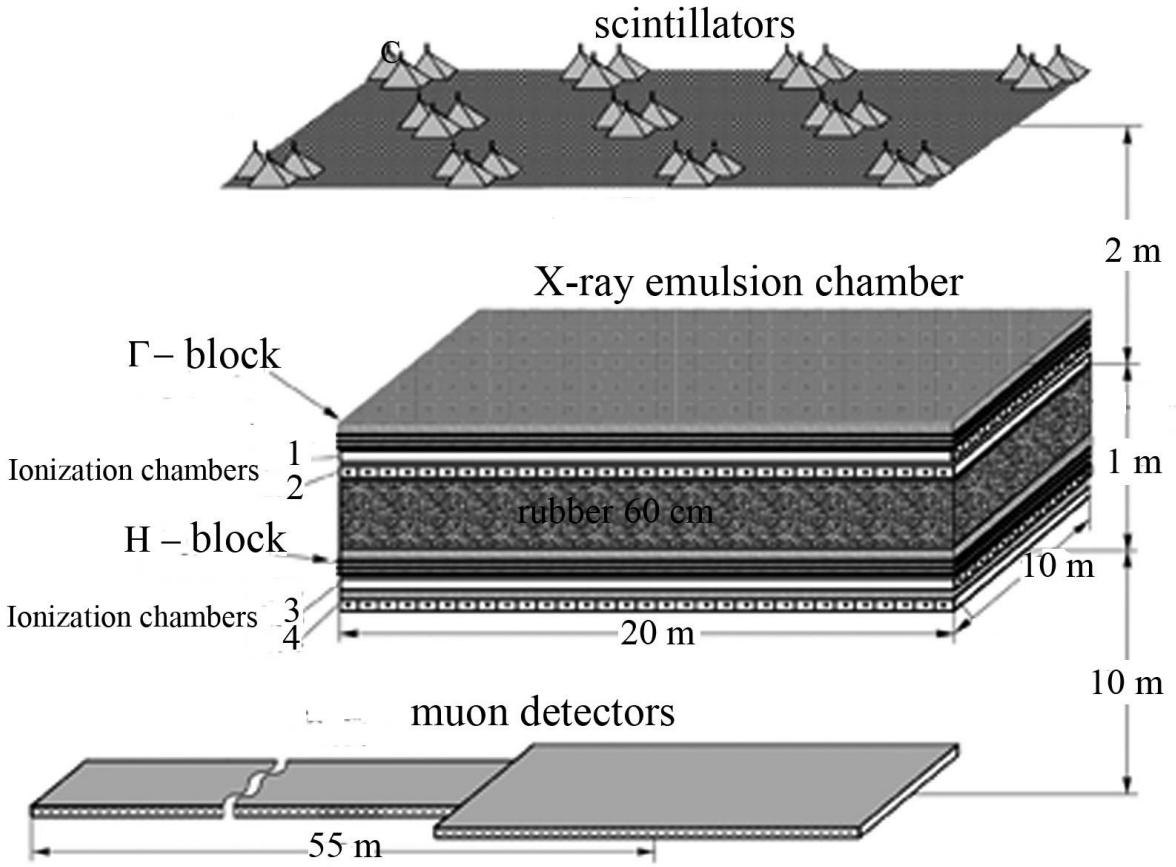
● In the *HADRON* experiment, an confirmation of the existence of a penetrating component in extensive air showers (EAS) was obtained.

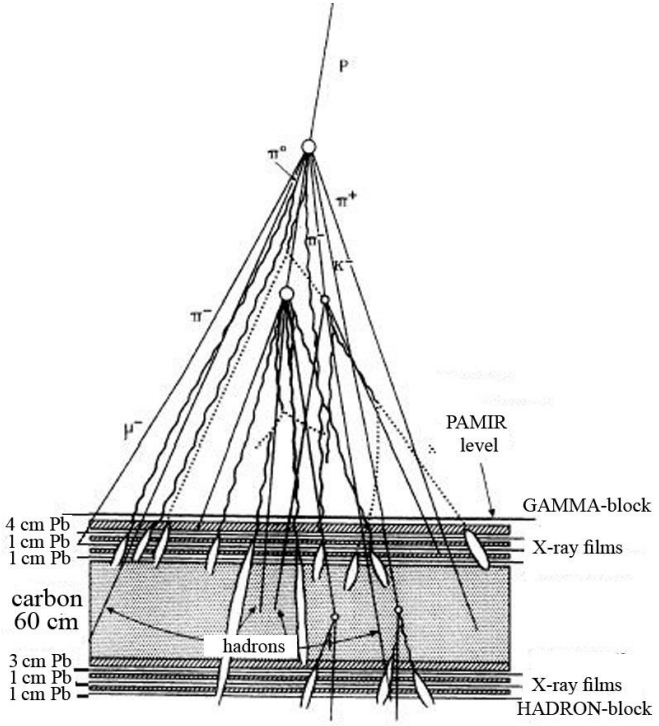
● Unlike previous experiments, it is shown that this component is not born in the lead of the detectors, but is present in the CR primary radiation.

● In this case, the particles forming the penetrating component must be stable as all Galactic CR near the Earth. Among the nuclear-active particles, there are only two stable variants.
These are nuclei, among which the most penetrating are protons, and hypothetical particles of strange quark matter - strangelets (quasi-nuclei).

● The analysis of the muon component is not consistent with the proton option. It remains to suggest the presence of strangelets in CR.

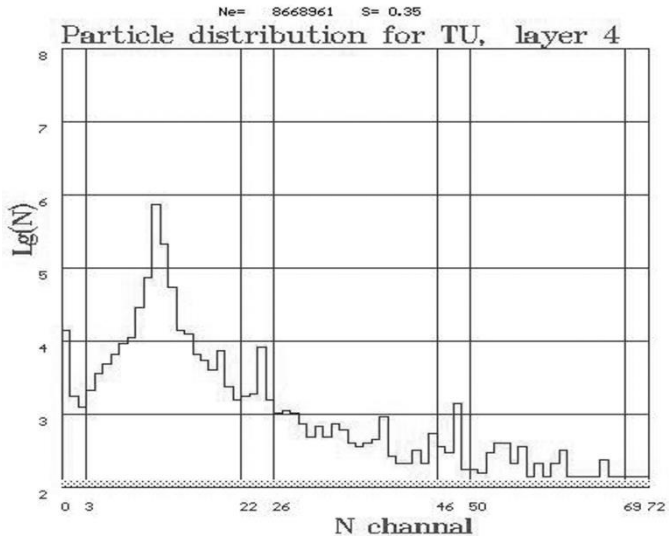
Scheme of central part of installation HADRON

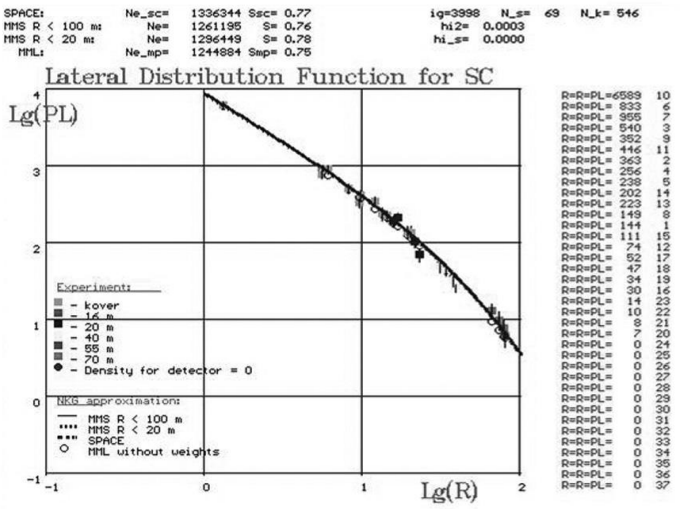




Carbon XREC registers γ-quanta and hadrons formed in the air cascade.

Determination of EAS axis and Ne



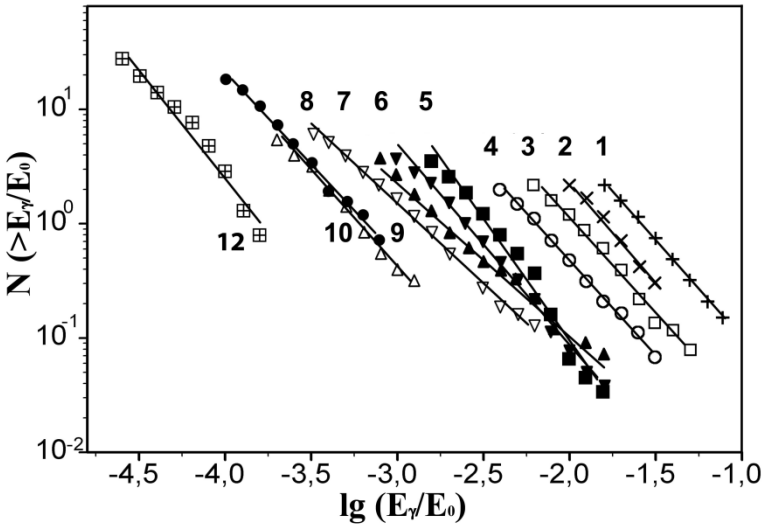


The position of an axis of EAS was determined by the maximum bump in ionization chambers with an accuracy not worse than 25 cm.

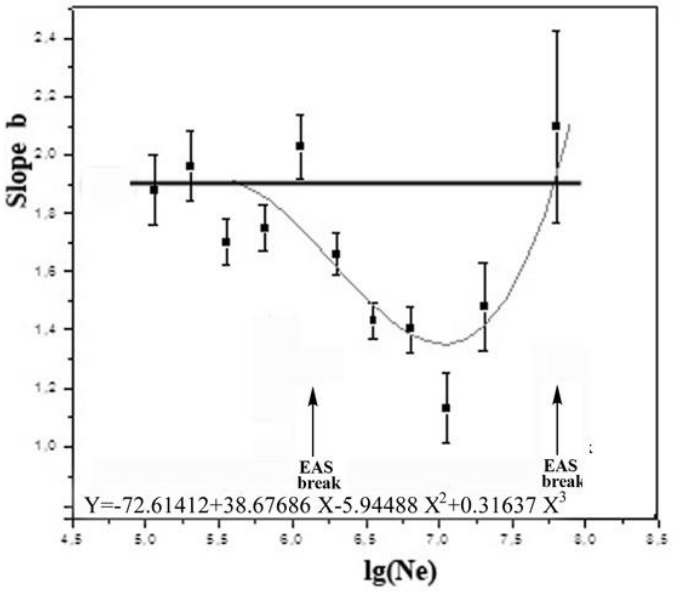
The EAS s and Ne parameters were determined by approximation of data of scintillation counters by Nishimury-Kamata's function in approximation of the Greisen.

Eγ spectra (π^0) at different primary energies.

Numbers 1-12 define different Ne intervals
from lg(Ne)=5.0 to 8.0, Δlg(Ne)=0.25



Slope of spectra **b** ($I \sim E_\gamma^{-b}$) depending on Ne.

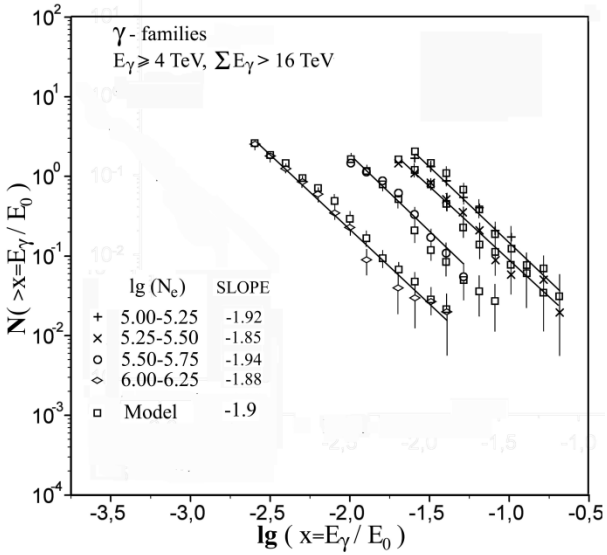


Monte Carlo calculations and LHC results predict scaling, i.e. b=1.9 - horizontal line.

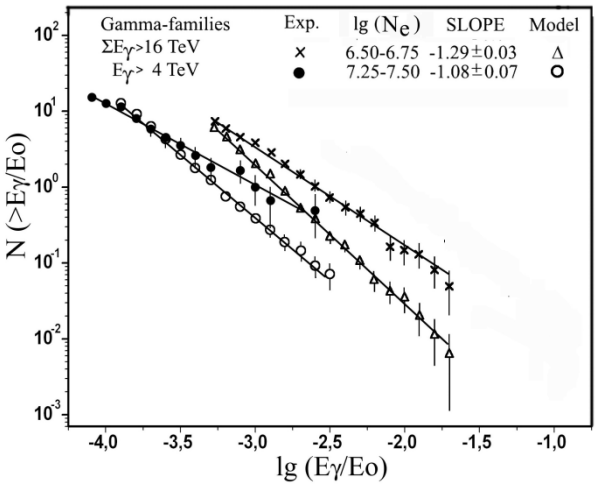
Reducing the slope of the spectra b from -1.9 to -1.2 means a local increase in the energy of the hadrons, i.e. the appearance of a penetrating component with a maximum at Ne=10^7 (E_0=10^{16} eV).

The penetrating component is formed by particles of primary cosmic radiation!

E_γ-spectra in comparison with model MQ1n.



In the scaling region, the experimental and model spectra practically coincide. This means that the model correctly describes the spectra before the EAS spectrum break at 3 PeV.



At knee region the experimental data disagree with model calculations on value ~5σ.

Two variants of the penetrating component.

1. The particles of PCR forming the penetrating component must be stable or metastable.
2. Among the nuclear-active particles, there are only two such options.
3. These are nuclei, among which the most penetrating are protons, and

   hypothetical particles of strange quark matter - strangelets which can be considered as quasi-nuclei.

   So we have to choose between protons and strangelets.

   To do this, let's consider the muon data.

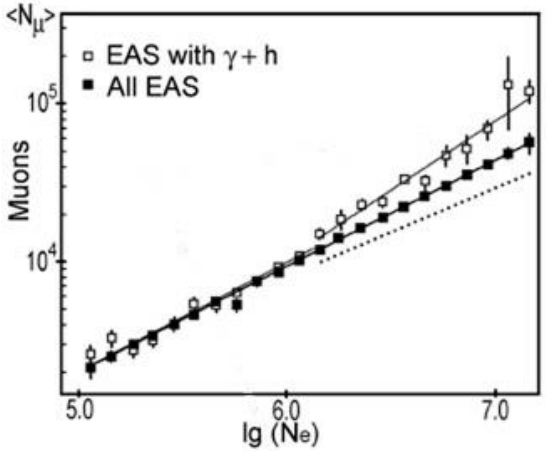
Ne dependence <Nμ> for EAS and EAS+γ

In left figure the <Nμ> dependences from Ne are compared for all EAS and EAS with γ-families.

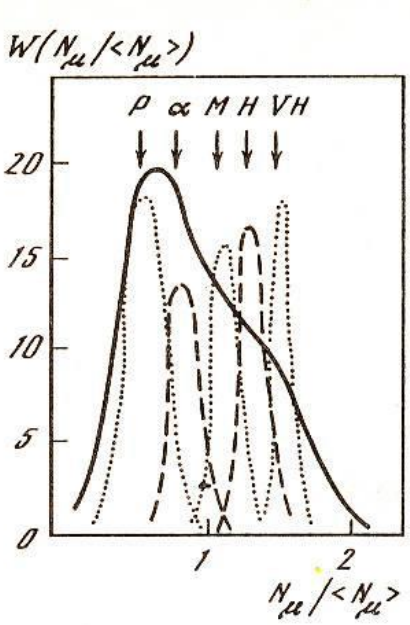
In region Ne>10^6, the values < Nμ > for EAS with gamma-families are systematically greater than one's for all EAS.

According to the models the bulk of γ-families are generated by proton showers. Therefore, as it follows from the figure on the right, the number of muons in the EAS+γ events should be smaller than for all EAS (dotted line at left figure).

It means a clear contradiction with the nuclear cascade. In that case we have to assume that the EAS with γ-families in large part not formed by nuclei.



The experimental Ne dependance of <Nμ > :
- full squares for all EAS (slope = 0.7),
- empty squares for EAS with γ-families (slope = 0.9).
-dotted line - expected dependance for EAS with γ-families.



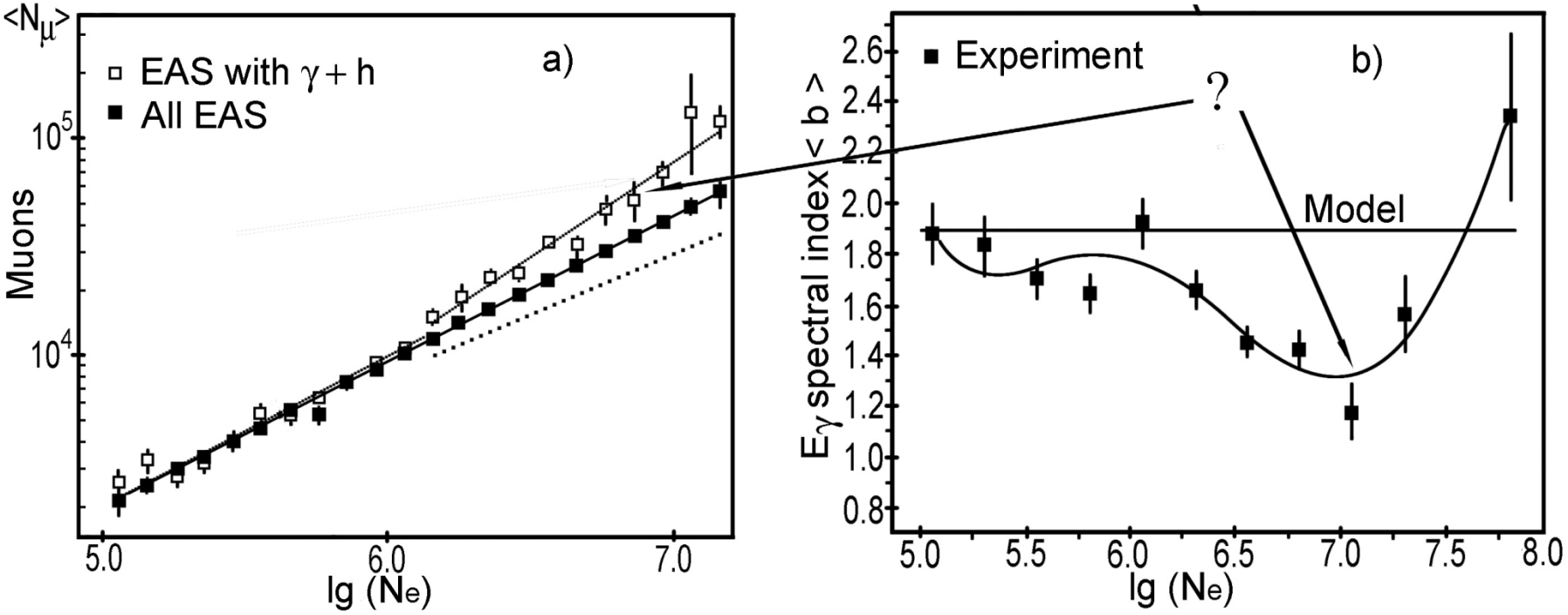
The muon number distribution for different nuclei.

Dependence <Nμ > from Ne for EAS+γ-families contradicts sharply to the proton option.

In addition, it should be noted that the given two dependences for EAS+γ-family contradict each other in the event of a nuclear composition of cosmic rays.

Growth <Nμ> means increase in dissipation of primary energy of EAS in the atmosphere, then how growth of Eγ opposite means reduction of energy dissipation.

Any nuclear composition of CR or his change can't explain both effects at the same time.



We must conclude that in cosmic rays are present component which generates cascades in the atmosphere with characteristics different from conventional nuclear one.

Conclusions.

The following hypothesis can be formulated based on the data of *HADRON* experiment.

- The penetrating component of EAS is formed by stable particles of primary cosmic radiation: protons or strangelets.
- The excess of muons in EAS+γ indicate its strangelets origin.

It means the existence in nature stable particles of strange quark matter - strangelets.

- Up to energies 10^{15}-10^{16} eV CR consist of nuclei, at higher energies they consist of strangelets.

In the transition region, both nuclei and stranglets can exist.

That's not all...

Conclusions.

- Cutoff of the CR spectrum is not due to the GZK-effect, but by reducing the stranglet electric charge with the increase of it's mass M_s.

  At large values of M_s the concentrations of u,d,s-quarks in strangelets are aligned, for $n_u=n_d=n_s$ the electric charge becomes $Z=0$ and it's acceleration stops.

- All cosmic rays are of Galactic origin in that case.
- There should be strange quark stars in the Galaxy. As Witten suggested they can form dark matter.
- In addition this model allows to explain a wide scop of 'exotic' phenomena in CR physics such as Centauro-events, halo and linear alignment in γ-families .

Thank you for attention!