Probable appearance of quark-gluon plasma in cosmic ray experiments

A.A.Petrukhin

Moscow Engineering Physics Institute

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Introduction

Problems of QGP are discussed very widely last years, taking into account recent results of RICH.

But solution of many questions connected with QGP behavior is expected when LHC begins to operate.

LHC energy interval 1 – 14 TeV corresponds to cosmic ray energies 10^{15} – 10^{17} eV, at which many unusual events are observed in various experiments.

Question: Can these unusual results evident for QGP appearance?

The situation with unusual events and phenomena was considered in detail at previous Vulcano Workshop 2004 (see Conference Proceedings, p.489 – 500), therefore I remember about them only in brief.

List of unusual events

➲ In **hadron** experiments:

- halos, alignment, penetrating cascades, Centauros (Pamir-Chacaltaya);
- long-flying component, Anti-Centauros (Tien-Shan).

➲ In **muon** experiments:

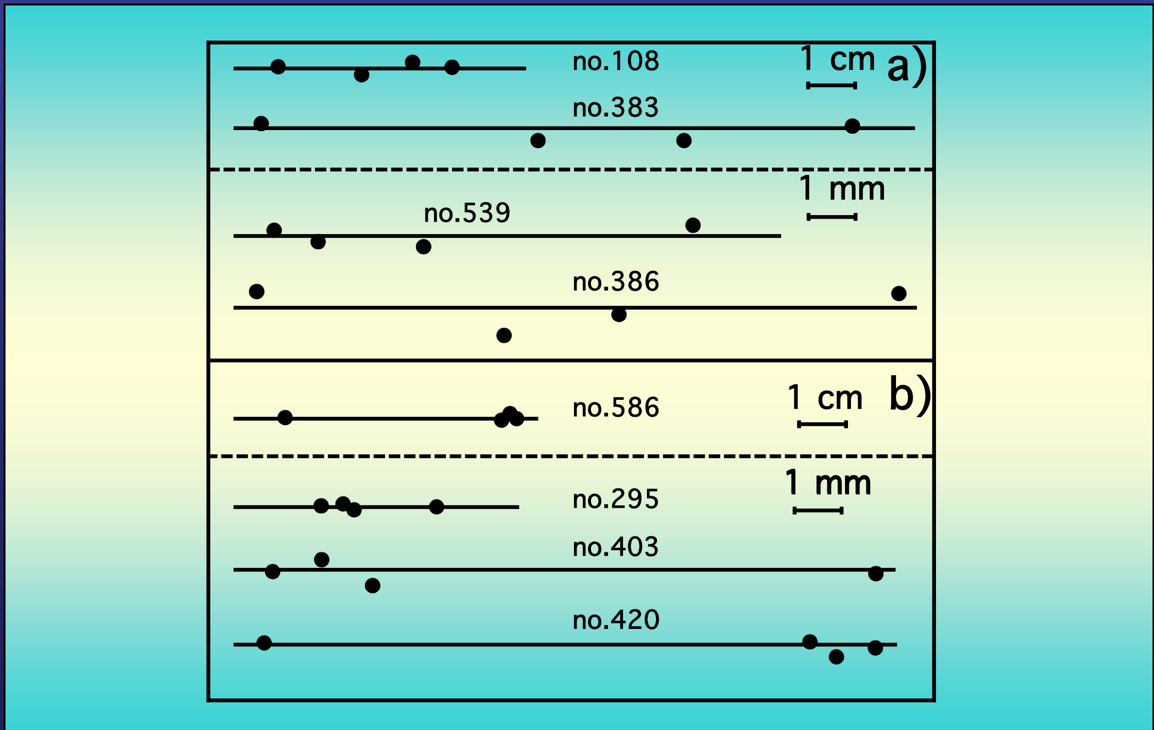
- excess of VHE (~ 100 TeV) single (MSU) and multiple (LVD) muons;
- observation of VHE muons (Japan, NUSEX), the probability to detect which is very small.

➲ In **EAS** investigations:

- change of EAS energy spectrum in the atmosphere, which is explained now as a change of primary energy spectrum.
- changes of behavior of $N_{\mu}(N_e)$ and $X_{max}(N_e)$ dependences, which are explained now as the heaving of CR composition.

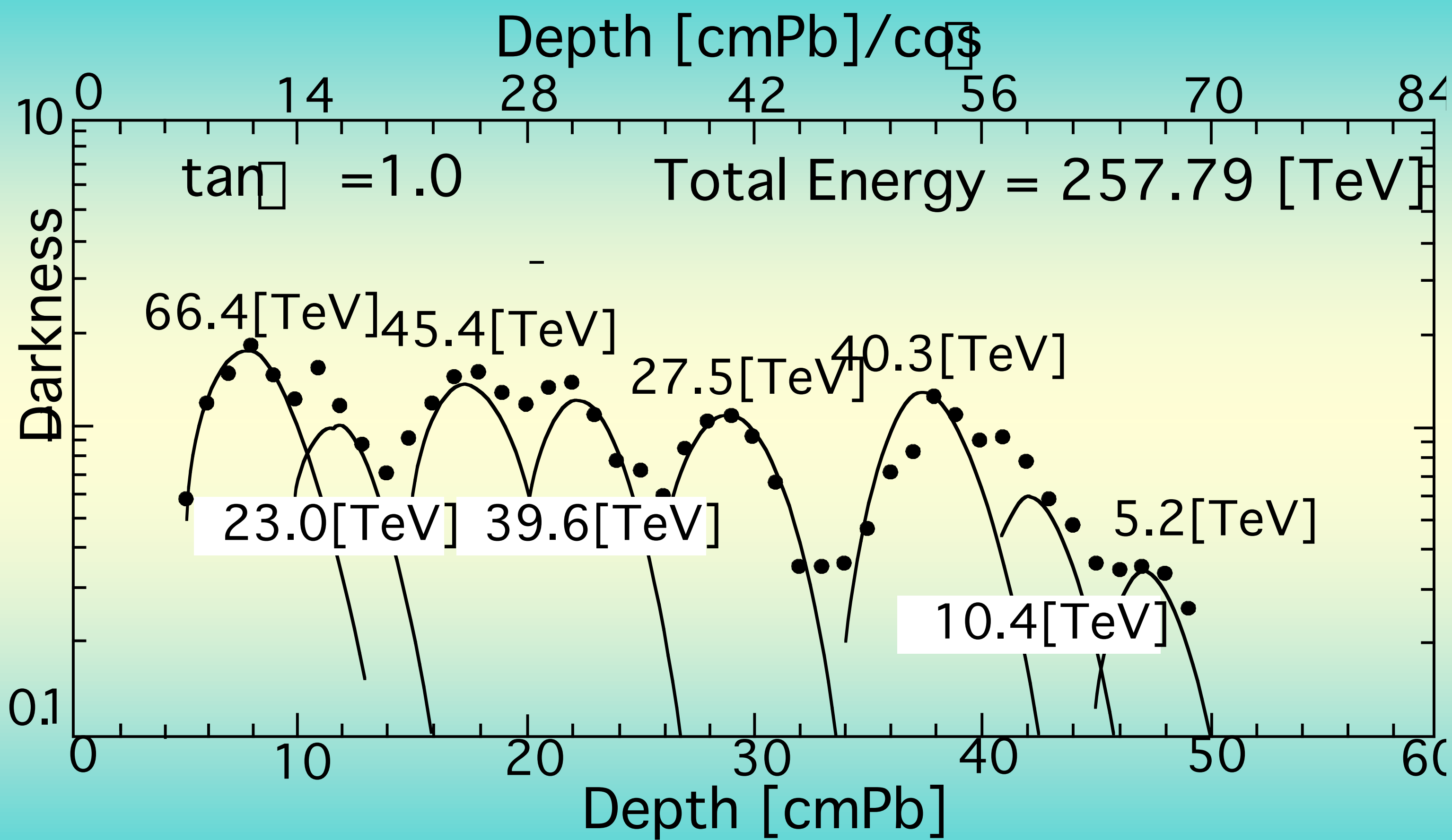
It is important: All these events appear at PeV energies of primary particles.

Alignment

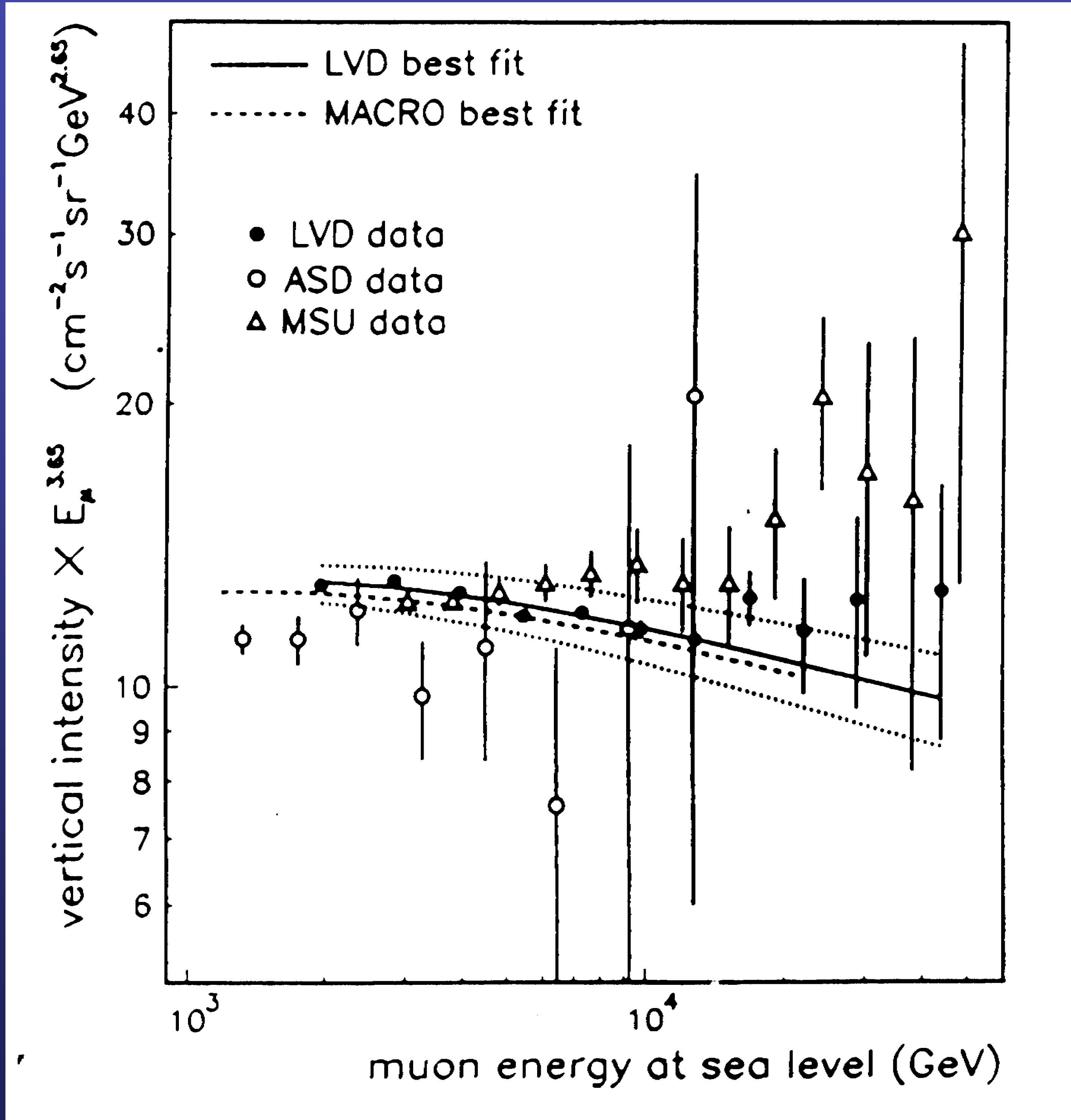


no.108
1 cm
a)
no.383
1 mm
no.539
no.386
no.586
1 cm
b)
1 mm
no.295
no.403
no.420

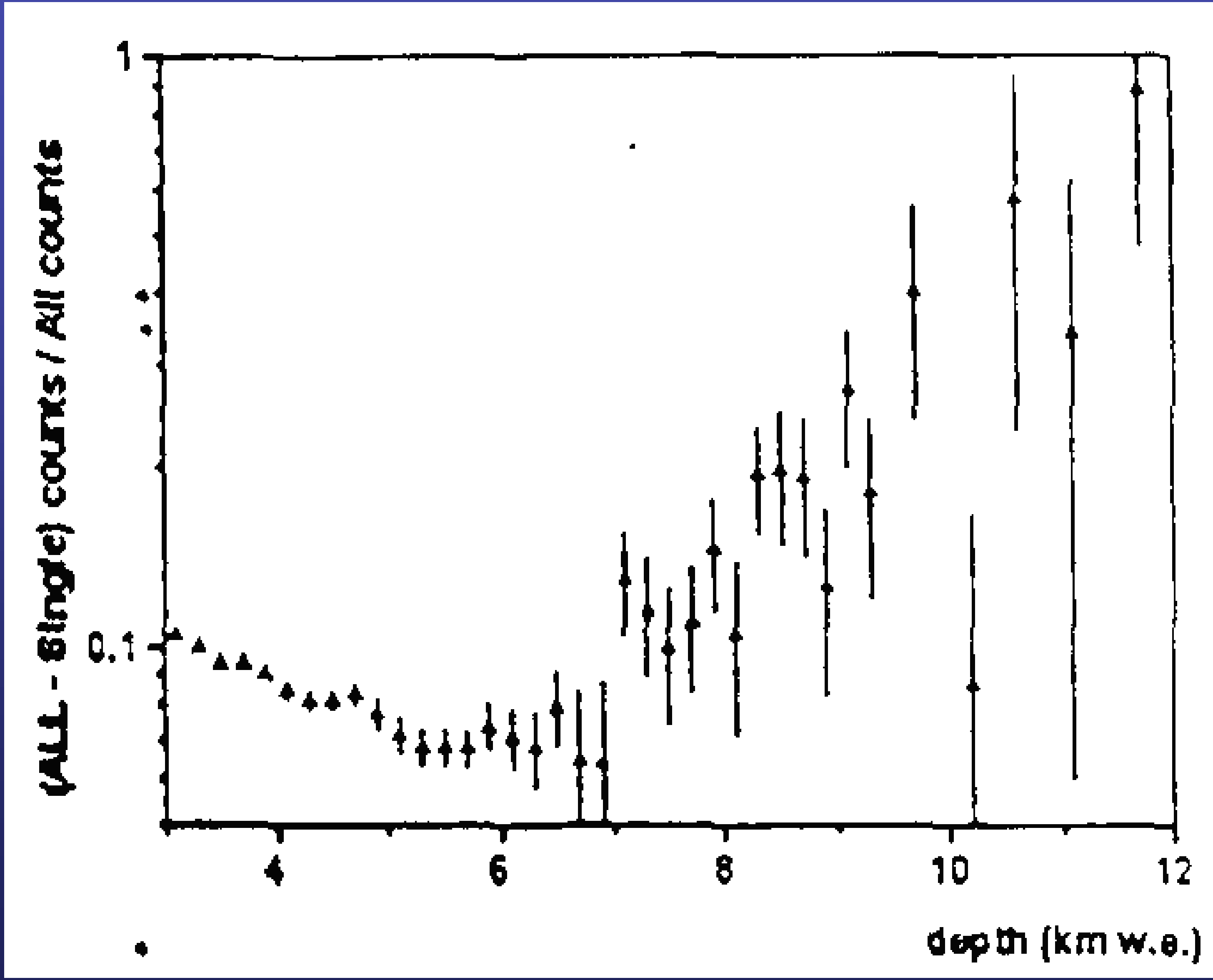
Penetrating cascades



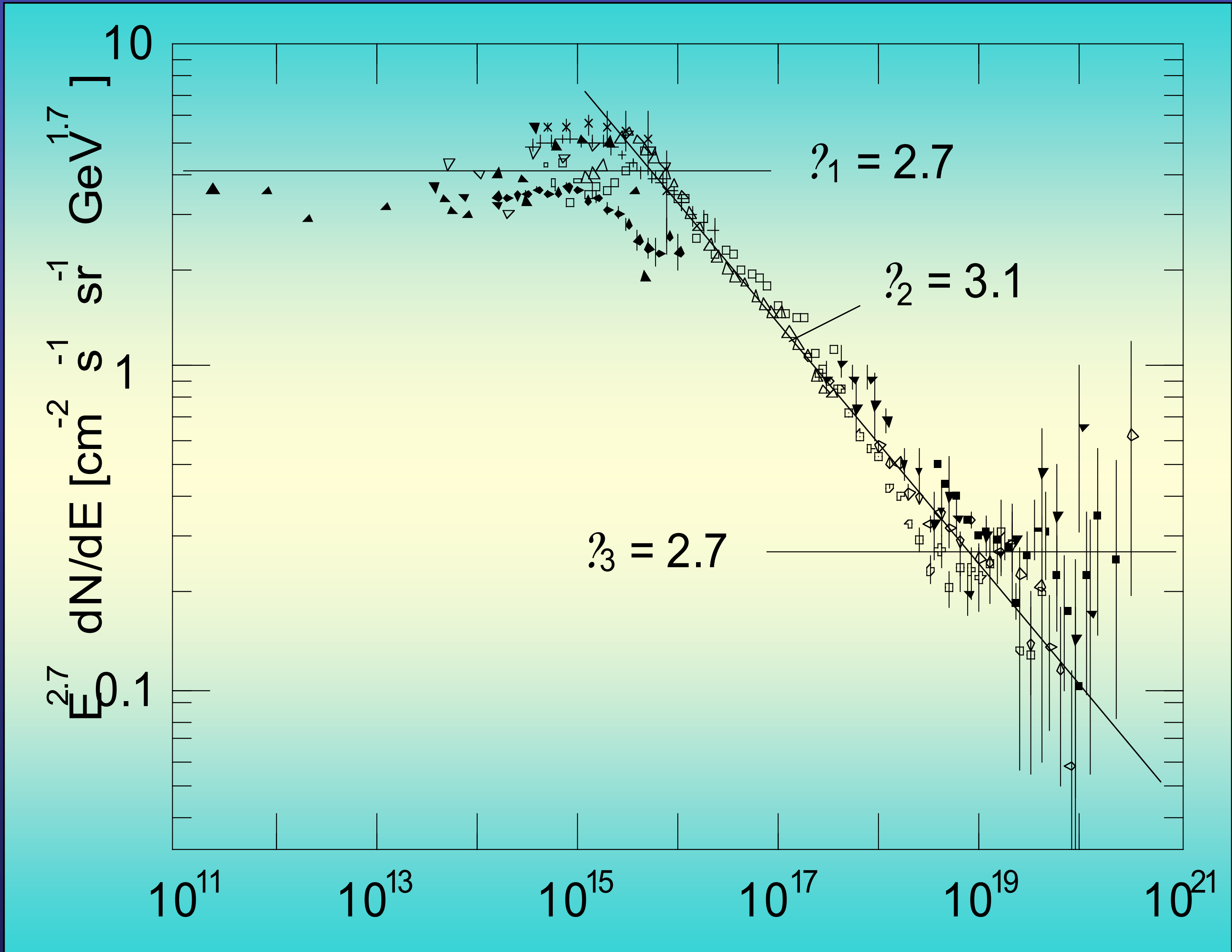
Muon flux excess



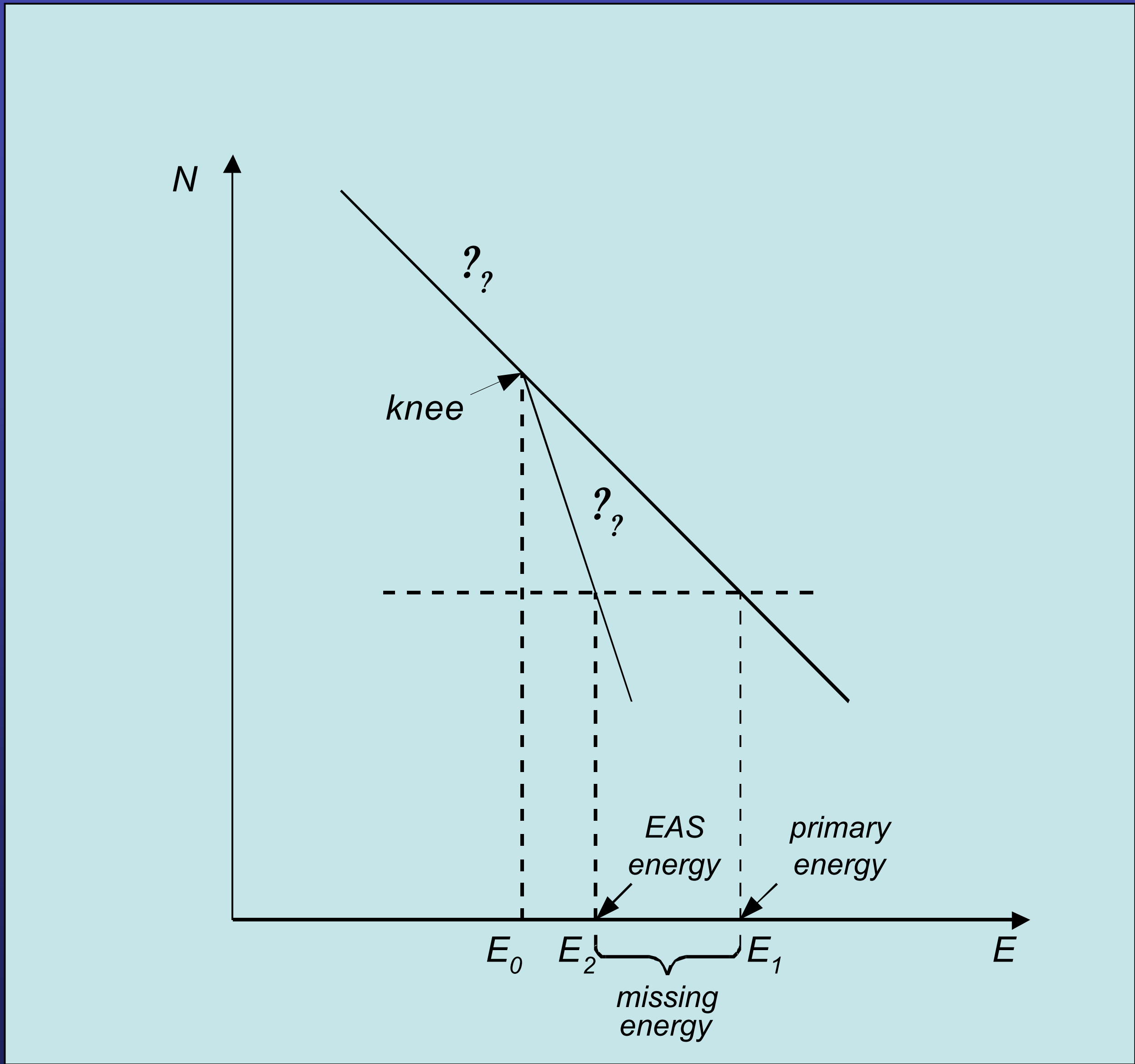
Muon bundles excess



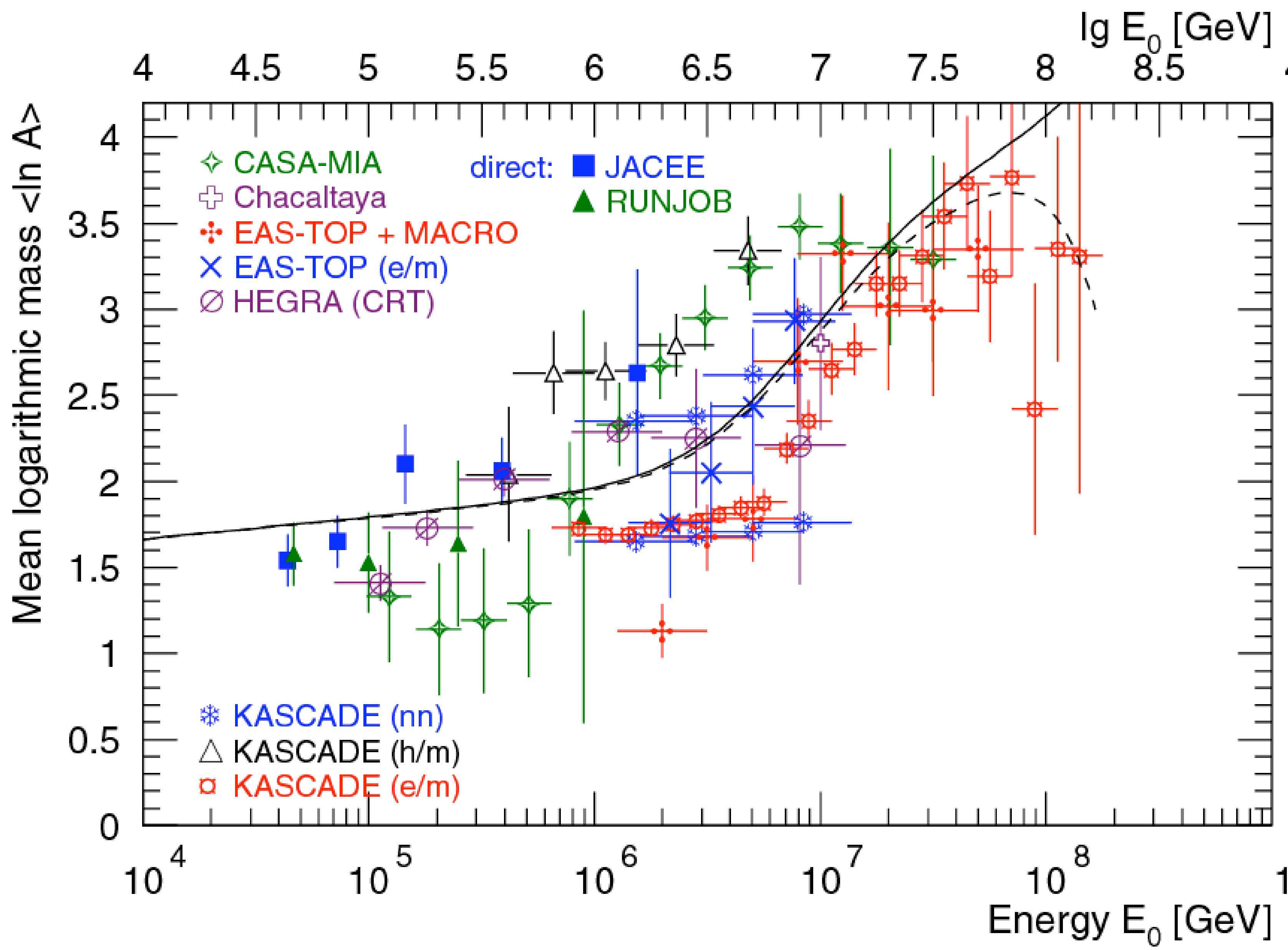
The knee in EAS energy spectrum



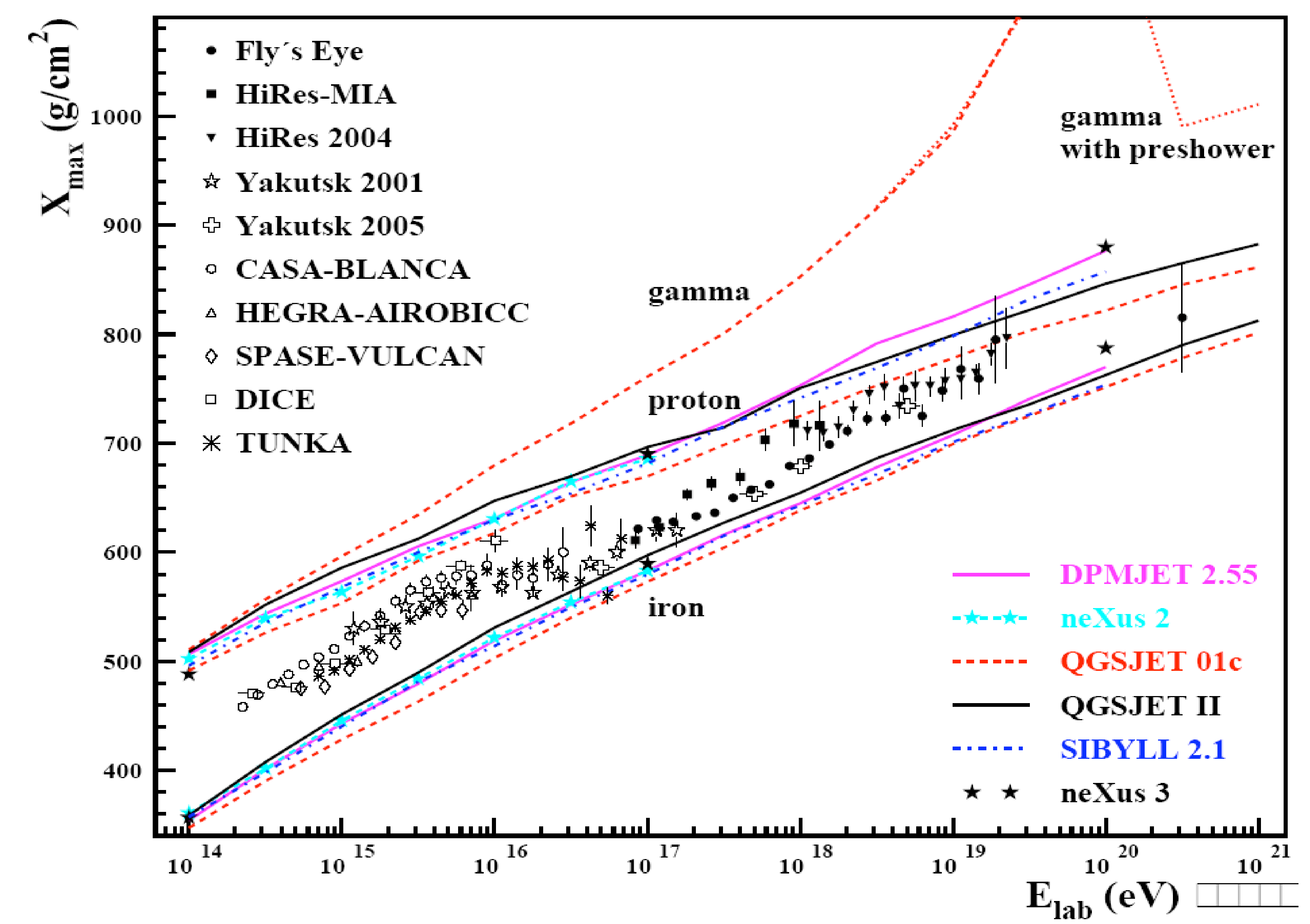
Missing energy determination



Mean <ln A> obtained from N_{μ}/N_e ratio



X_{max}



X_{max} (g/cm^2)
1000
900
800
700
600
500
400
Fly´s Eye
HiRes-MIA
HiRes 2004
Yakutsk 2001
Yakutsk 2005
CASA-BLANCA
HEGRA-AIROBICC
SPASE-VULCAN
DICE
TUNKA
gamma
with preshower
gamma
proton
iron
DPMJET 2.55
neXus 2
QGSJET 01c
QGSJET II
SIBYLL 2.1
neXus 3
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
E_{lab} (eV)

What we need to explain these data?

Model of hadron interactions which gives:

1. Threshold behaviour (unusual events appear at several PeV only).
2. Large cross section (to change EAS spectrum slope).
3. Large yield of leptons (excess of VHE muons and missing energy).
4. Large orbital (or rotational) momentum (alignment).
5. Violation of isotopic invariance (Centauros and Anti-Centauros) .

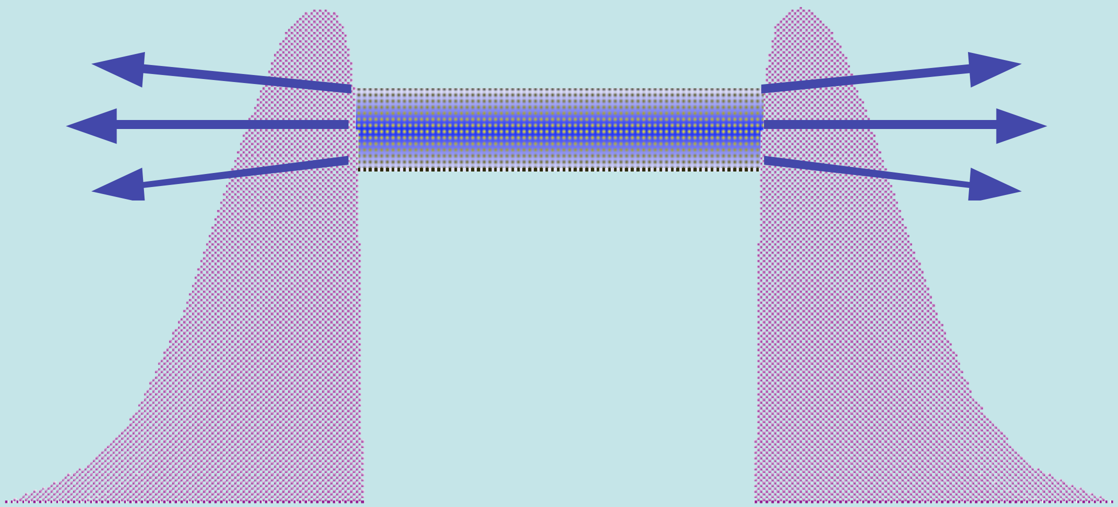
etc.

QGP model is very suitable for that.

Quark-gluon plasma (better, Quark-gluon matter) gives:

1. Threshold behavior, since high temperature and density are required.
2. Large cross section, since transition from quark-quark interaction to some collective interaction of many quarks gives .
3. As was shown by Zuo-Tang Liang and Xin-Nian Vang in non-central collisions a globally polarized QGP with large orbital angular momentum must appear.
4. Centrifugal barrier will be less for heavy particles (quarks and W, Z-bosons), which are necessary to explain leptons production.

Centrifugal barrier for different masses



Some remarks about CR composition

1. At present, information about the composition is extracted from results of EAS investigations, namely from data on the number of muons N_{μ} and elongation rate X_{max}, taking into account results of simulations.

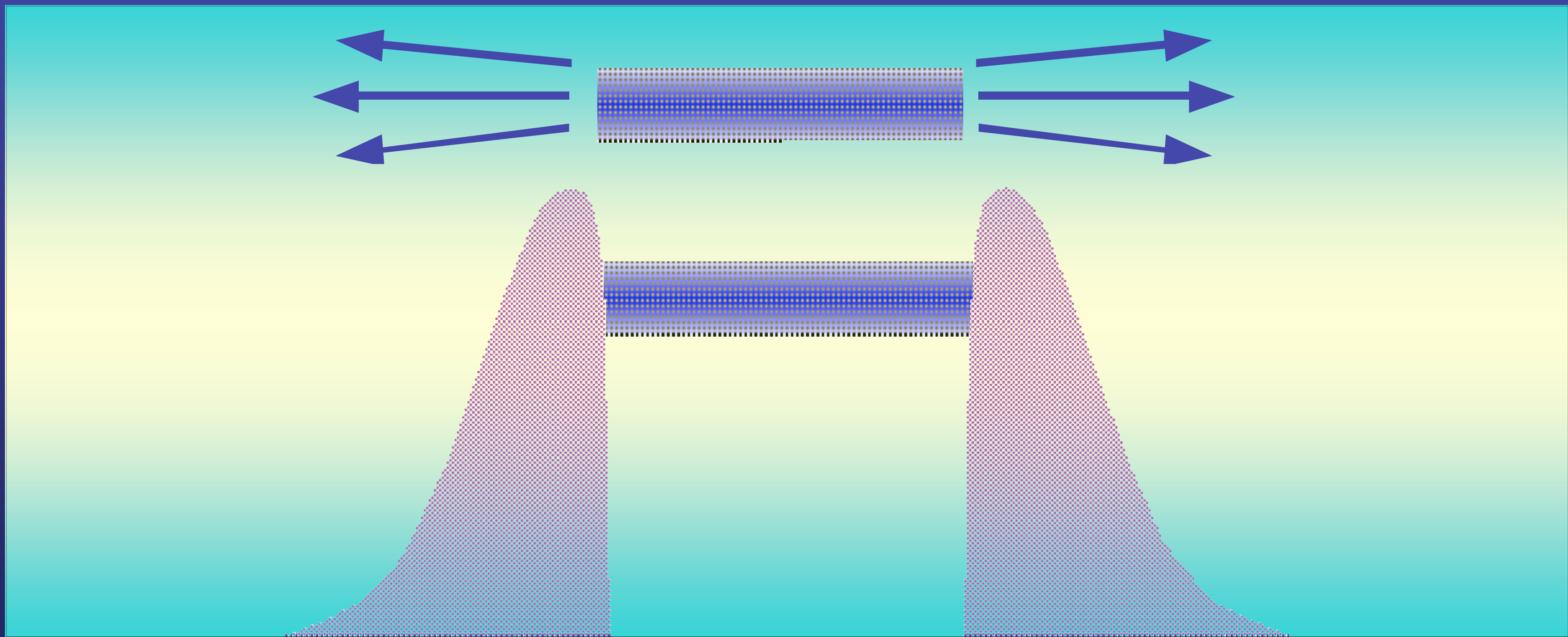
2. If new state of matter with mass ~ 1 TeV is generated, the number of secondary particles will be increased due to decays of W, Z-bosons into hadrons (on average 20 in each).

3. This leads to a more quick development of shower (decreasing of X_{max}) and to increasing N_{μ}.

4. Taking into account a missing energy, instead of proton shower with energy E_0, "iron" shower with lower energy will be “observed”.

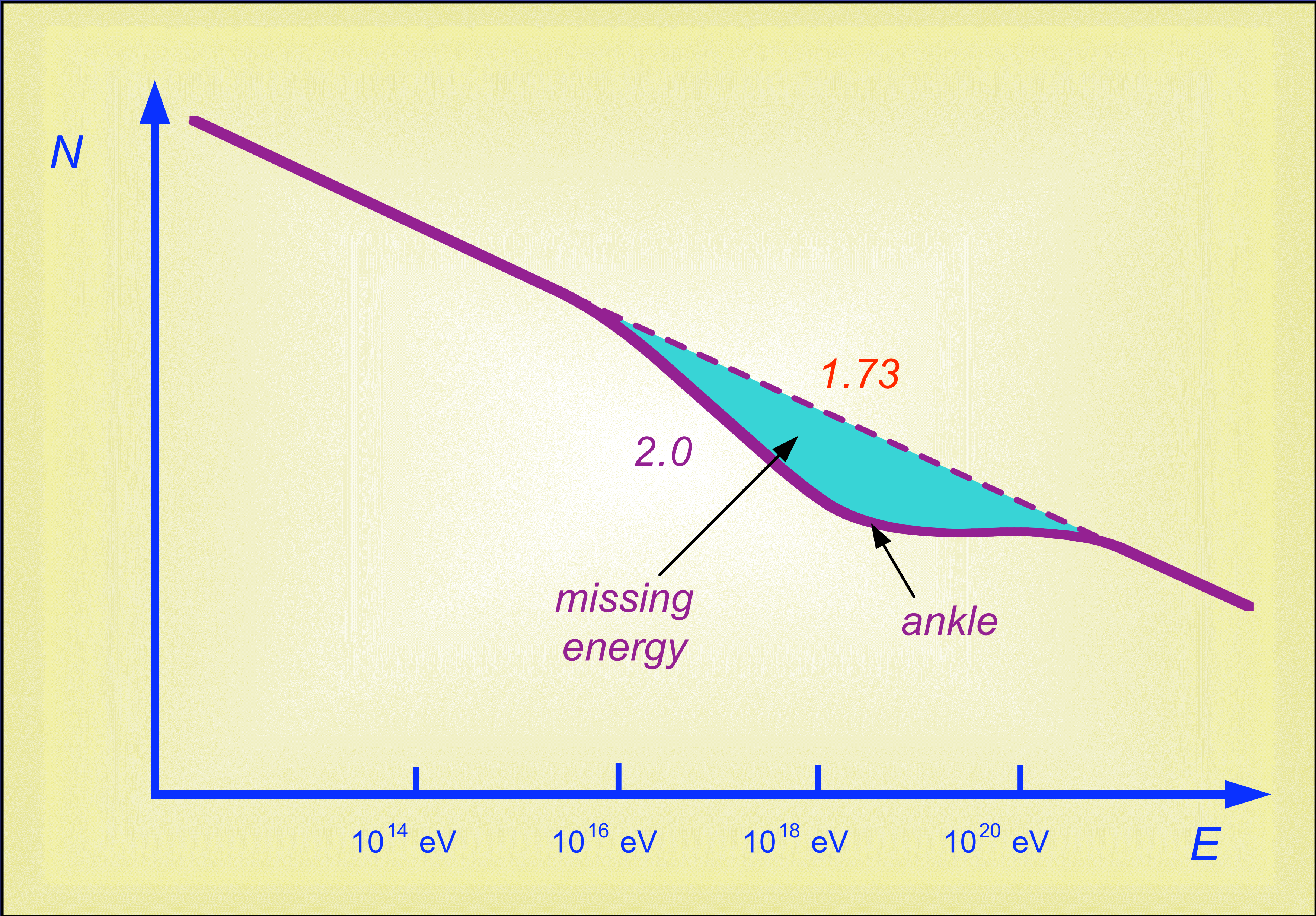
How to explain the ankle appearance?

☞ With increasing of interaction energy, mass and energy of excitation of resonance state can be so large that it begins to decay into hadrons immediately.



 Average missing energy and number of muons will be decreased and the development of EAS will return to a normal behavior.

Region of missing energy

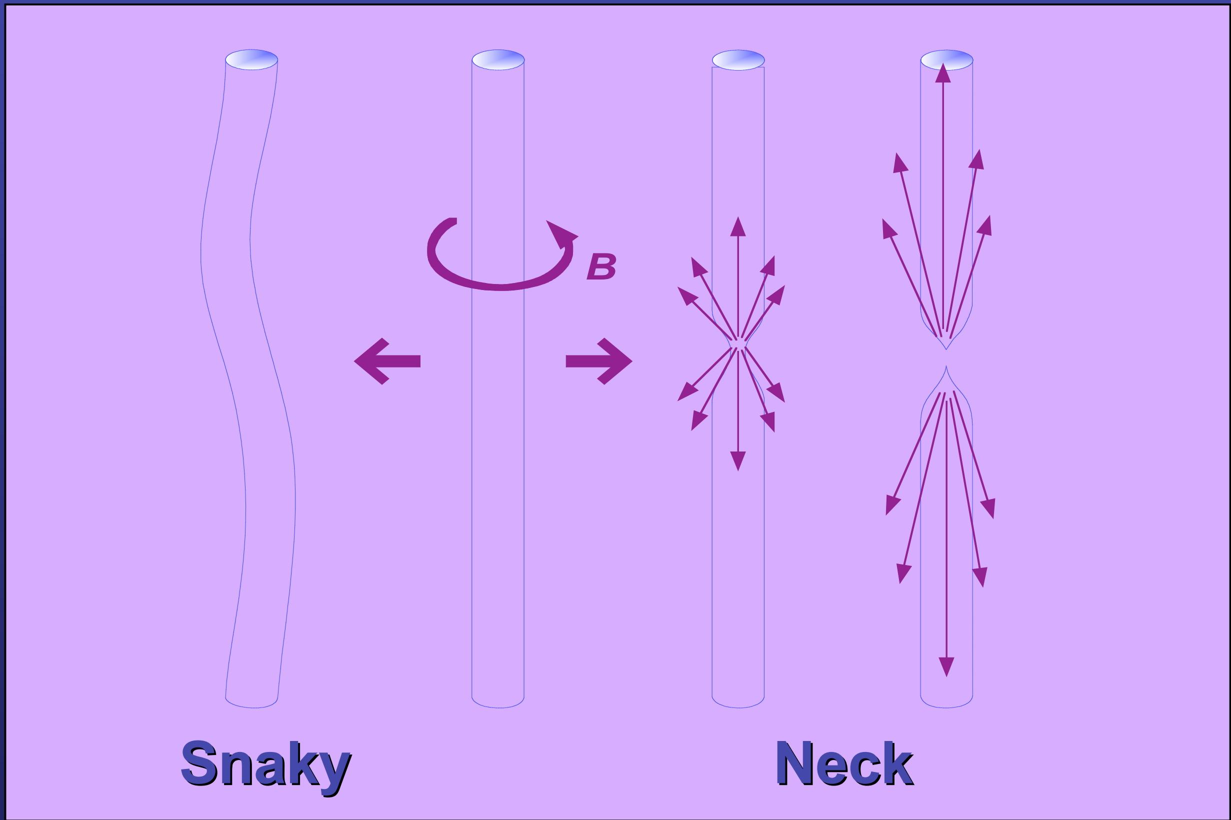


CR generation in plasma pinches
(B.A.Trubnikov et al.)

- This model was considered at previous Vulcano 2004 and has been published in its Proceedings:
- p. 489-500
- where the references to the original paper of authors (B.A.Trubnikov V.P.Vlasov, S.K.Zhdanov) are given.
- Therefore I mention the main ideas and results only.

CR generation in plasma pinches

In cosmic plasma (of any origin) electrical discharges – "cosmic lightnings" – can occur, at which cylindrical pinches are formed.



Plasma jets are squeezed out of pinch neck.
These jets are accelerated particle beams.

CR generation in plasma pinches

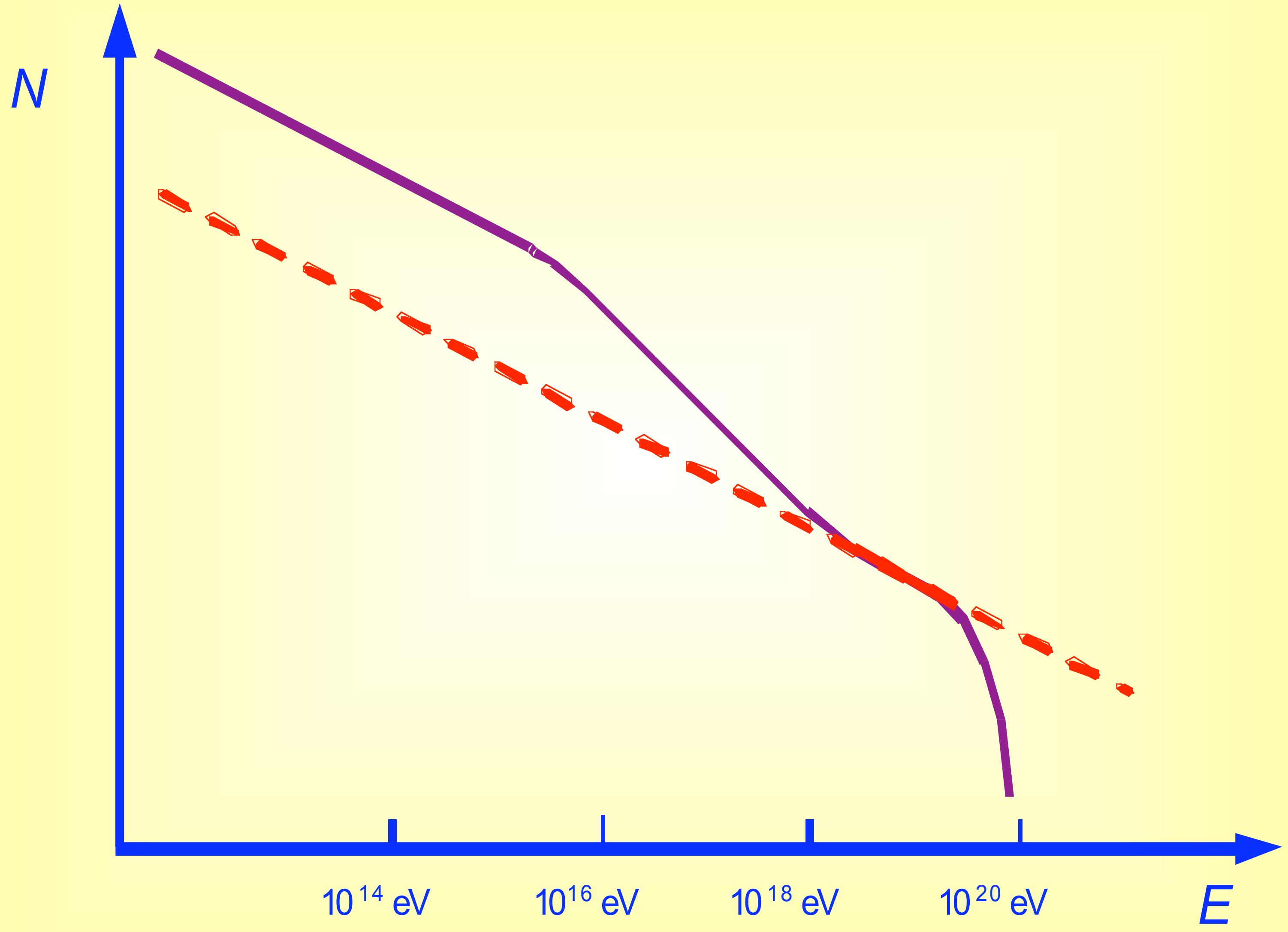
Energy distribution of particles in jets has the form:

which does not depend on pinch sizes, currents in pinches and other parameters, which determine a proportionality coefficient only.

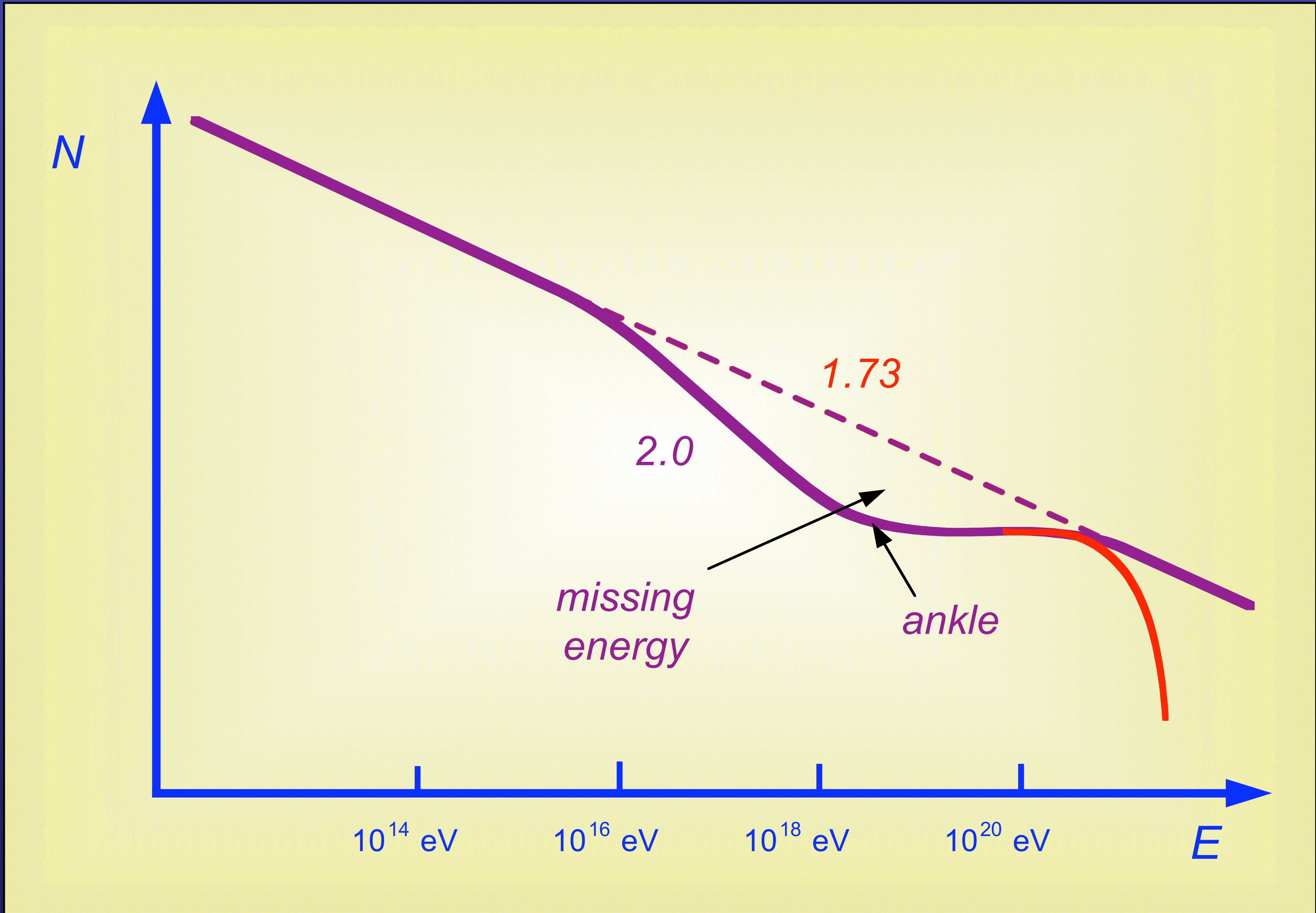
Model has no limitation for accelerated particle energy since in plasma pinch neck

density □□ , when its radius r □ 0.

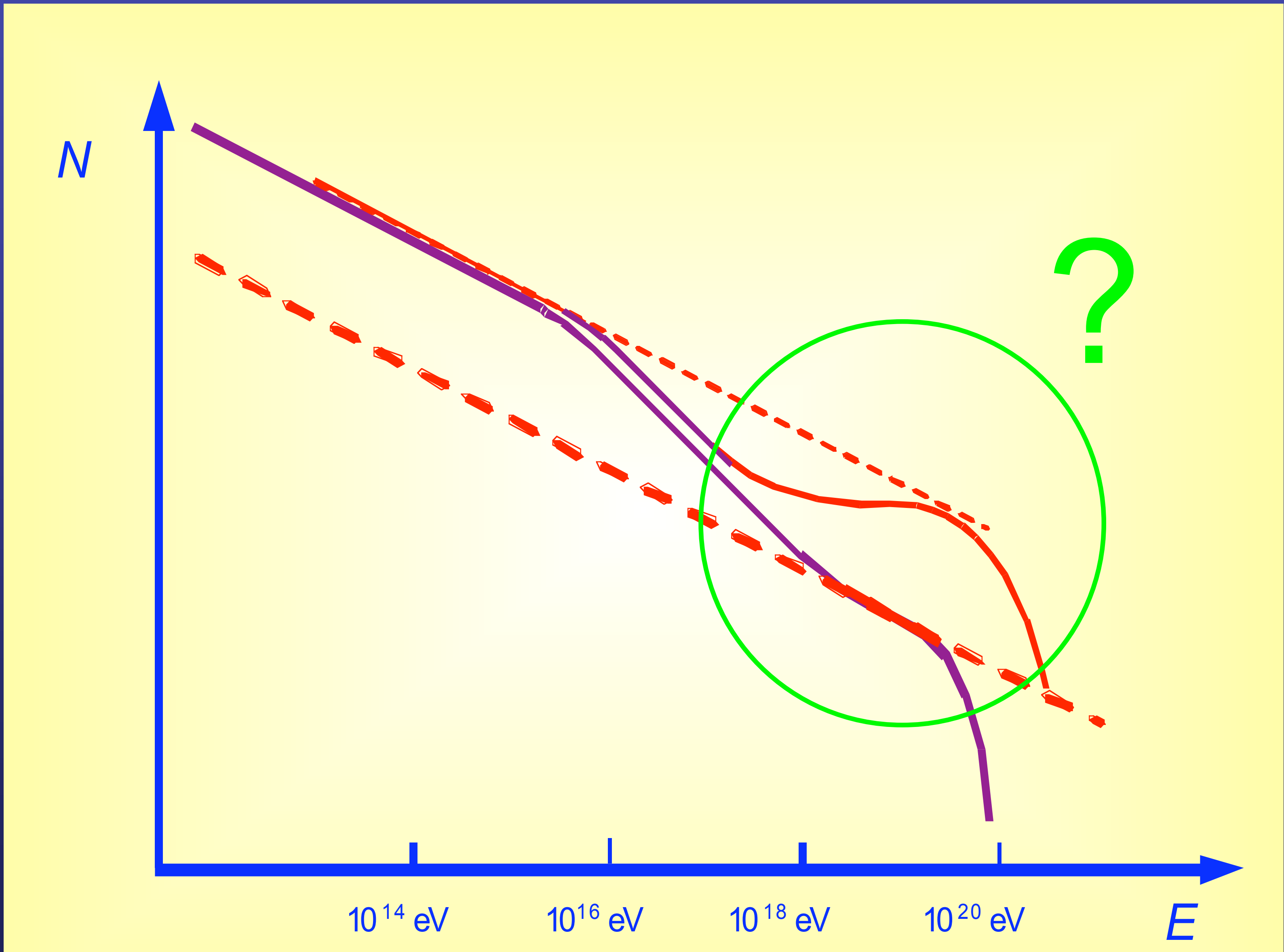
Cut-off influence – existing approach



Cut-off influence – new approach



Two versions of Cut-off influence



Conclusions

1. In cosmic rays many unusual events and phenomena are observed, which cannot be explained in frame of traditional approaches.

2. Generation in non-central collisions of quark-gluon plasma resonances with large angular momentum, which increases with energy, allows to explain these events and phenomena and formulate a new approach to UHECR description.

3. This approach shows that problems of UHECR (especially GZK-cutoff) it is impossible to solve without the solution of the knee problem.