The Influence of Results of UHECR Detection on LHC Experiments

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Outline

1. Introduction.
2. Some results of CR investigations.
3. Their possible explanation.
4. Consequences for LHC experiments.
5. Conclusions.

Introduction - 1

- Discovery of Higgs boson is the main task for LHC.
- This task in the nearest future will be solved (positively or negatively).

What are the next tasks?

- Of course there are many various theoretical ideas: supersymmetry, dark matter etc.

- The purpose of my talk to pay attention at one another possibility which follows from results of CR investigations.

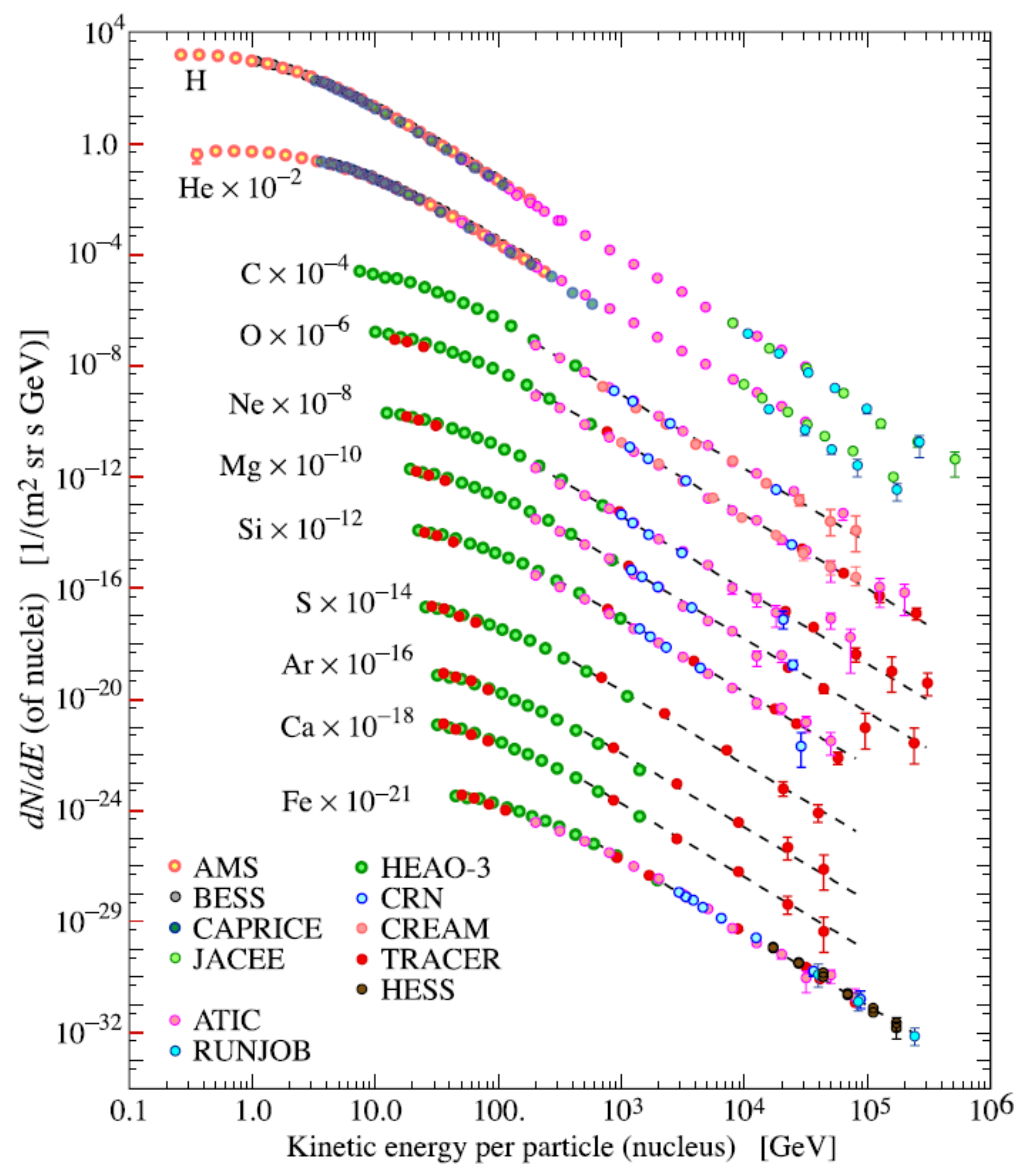
Introduction - 2

- LHC energies 1-14 TeV correspond to the interval 10^15 – 10^17 eV in laboratory system for pp-interaction (for nuclei-nuclei interactions the upper limit will be higher).

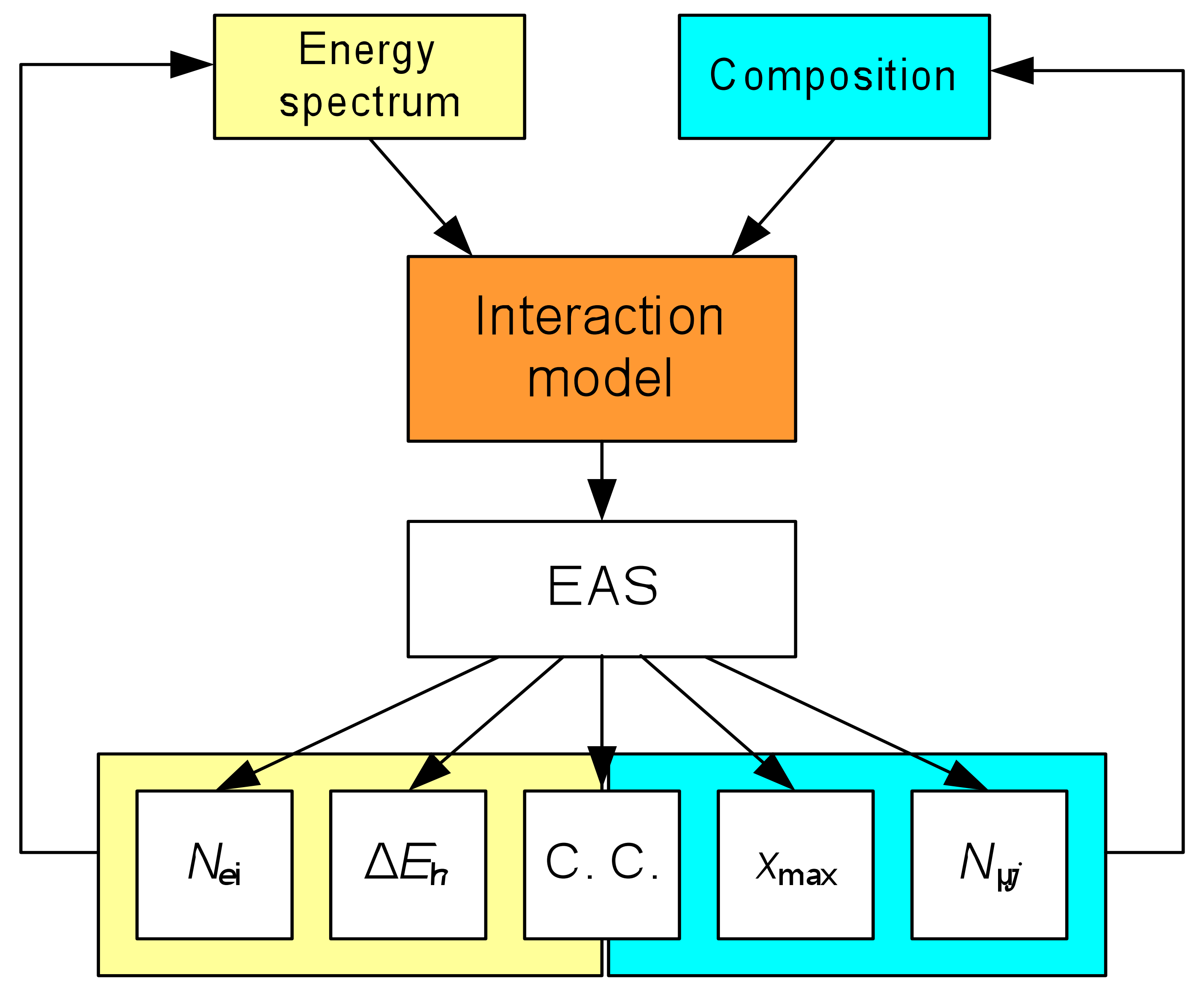
- And namely at these energies many interesting and sometimes unusual results in CR investigations were obtained.

•. Bellow 10^15 eV no serious deviations from standard CR energy spectrum and composition and interaction model in direct measurements were observed.

Primary spectra of various nuclei



General schema of EAS investigation



Energy spectrum

Composition

Interaction model

EAS

N_{ei}

ΔE_h

C. C.

X_{max}

$N_{\mu j}$

Two possible approaches to EAS analysis

Cosmophisical approach:

EAS energy is equal to the energy of primary particle.

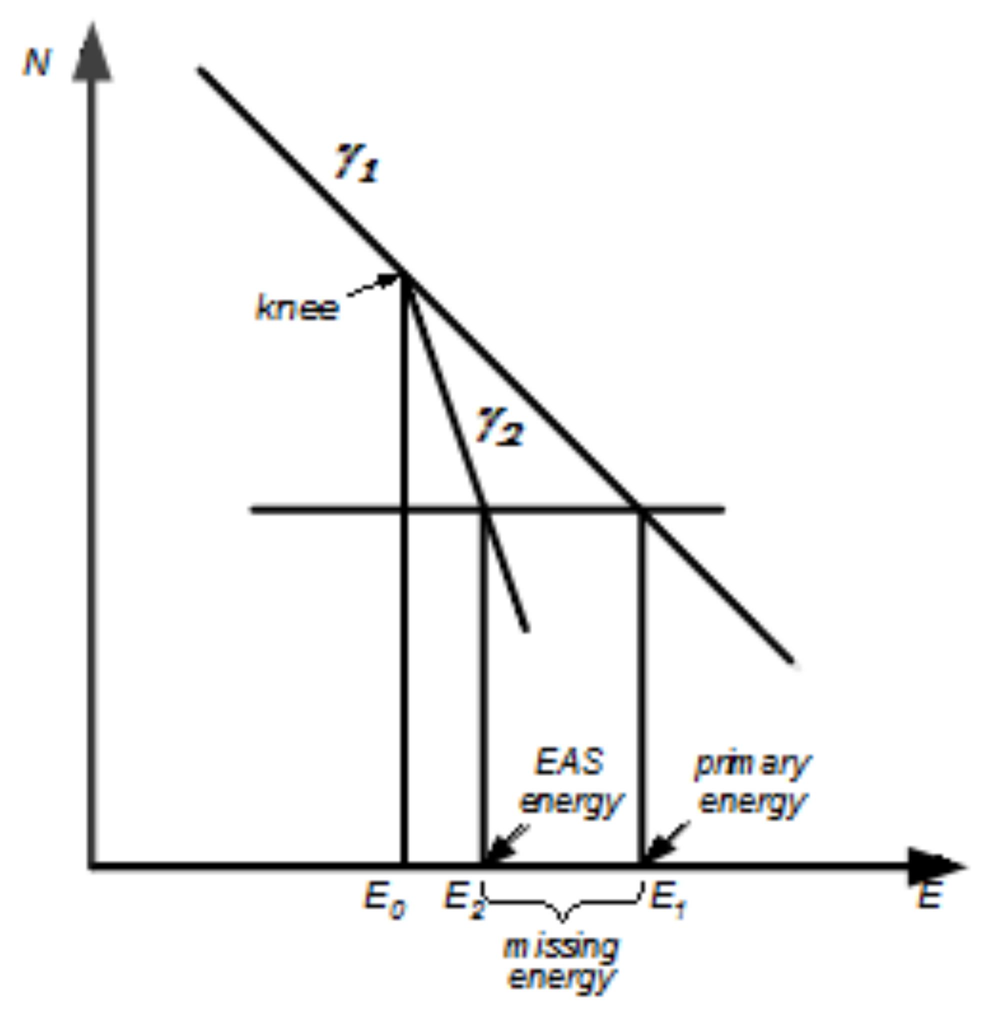
All changes of EAS parameters in dependence of energy are result of energy spectrum or/and composition changes only.

Nuclear-physical approach:

Changes of EAS parameters are the result of inclusion of new processes of interaction or/and production of new particles, states of matter, etc.

EAS energy can be not equal to primary particle energy.

The knee as a result of new interaction



In this case a difference between primary and EAS energies, so-called missing energy, appears.

Arguments in favor of interaction model change

➲ In **hadron** experiments:

- Appearance of unusual events: halos, alignment, penetrating cascades, long-flying component, Centauros, Anti-Centauros.

➲ In **muon** experiments:

- Excess of HE single and multiple muons;
- Observation of VHE (~100 TeV) muons, the probability to produce which in meson decays is very small.

➲ In **EAS** investigations:

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

Important: Unusual events and other phenomena appear only at PeV energies of primary particles.

Requirements to new model of hadron interaction

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, missing energy and penetrating cascades).
4. Large orbital momentum (alignment).
5. More quick development of EAS (for increasing the N_μ / N_e ratio and decreasing X_{max} elongation rate).

Possible variants

- Inclusion of new (f.e. super-strong) interaction.
- Appearance of new massive particles (supersymmetric, Higgs bosons, relatively long-lived resonances, etc.)
- Production of blobs of quark-gluon plasma (QGP) (better to speak about quark-gluon matter (QGM), since usual plasma is a gas but quark-gluon matter is a liquid).

The last model allows demonstrably explain the inclusion of new interaction.

Quark-gluon matter

1. Production of QGM provides two main conditions:

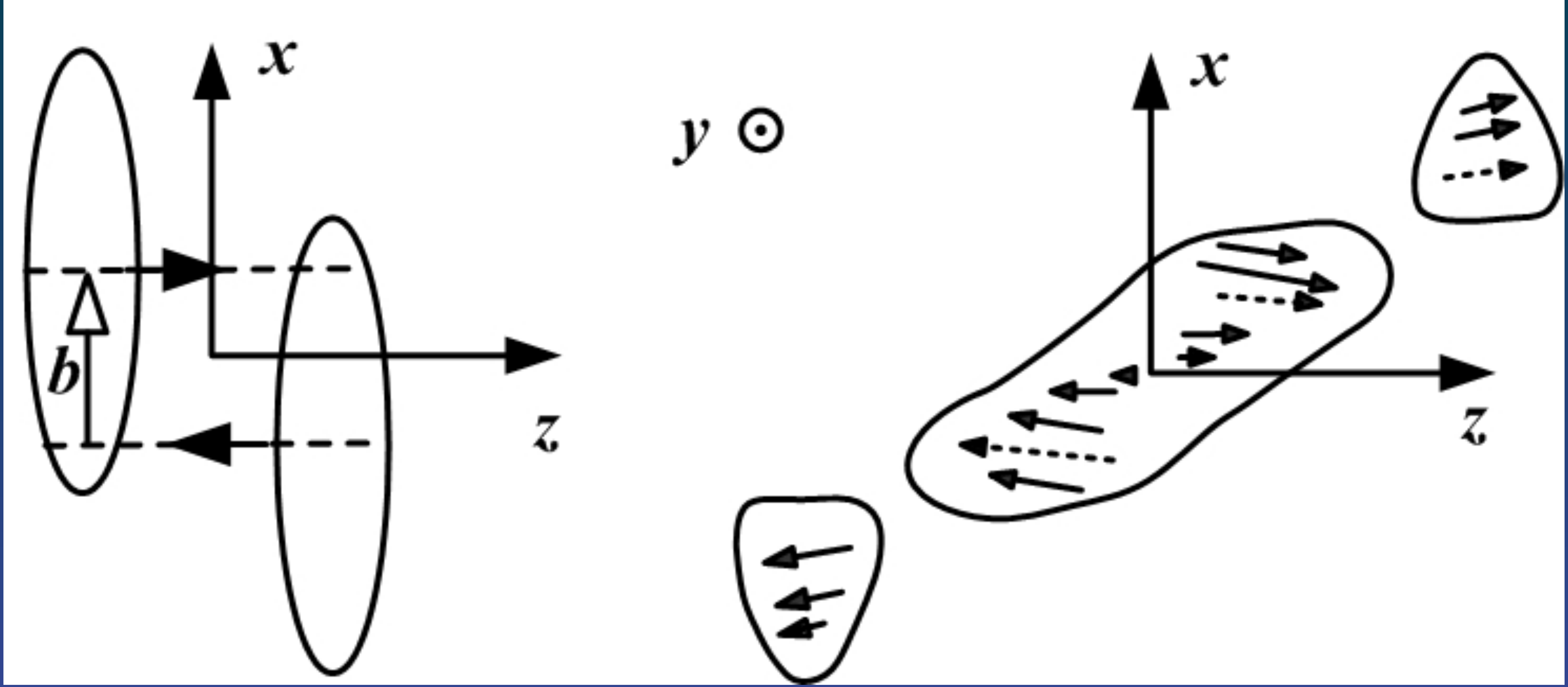
   - threshold behavior, since for that large temperature (energy) is required;
   - large cross section, since the transition from quark-quark interaction to some collective interaction of many quarks occurs:

$$\sigma = \Box\bar{\lambda}^2 \; \Box \quad \Box \sim \Box\left(\bar{\lambda} + R\right)^2 \; or \; \Box\left(R_1 + R_2\right)^2$$

where R, R_1 and R_2 are sizes of quark-gluon blobs.

2. But for explanation of other observed phenomena a large value of orbital angular momentum is required.

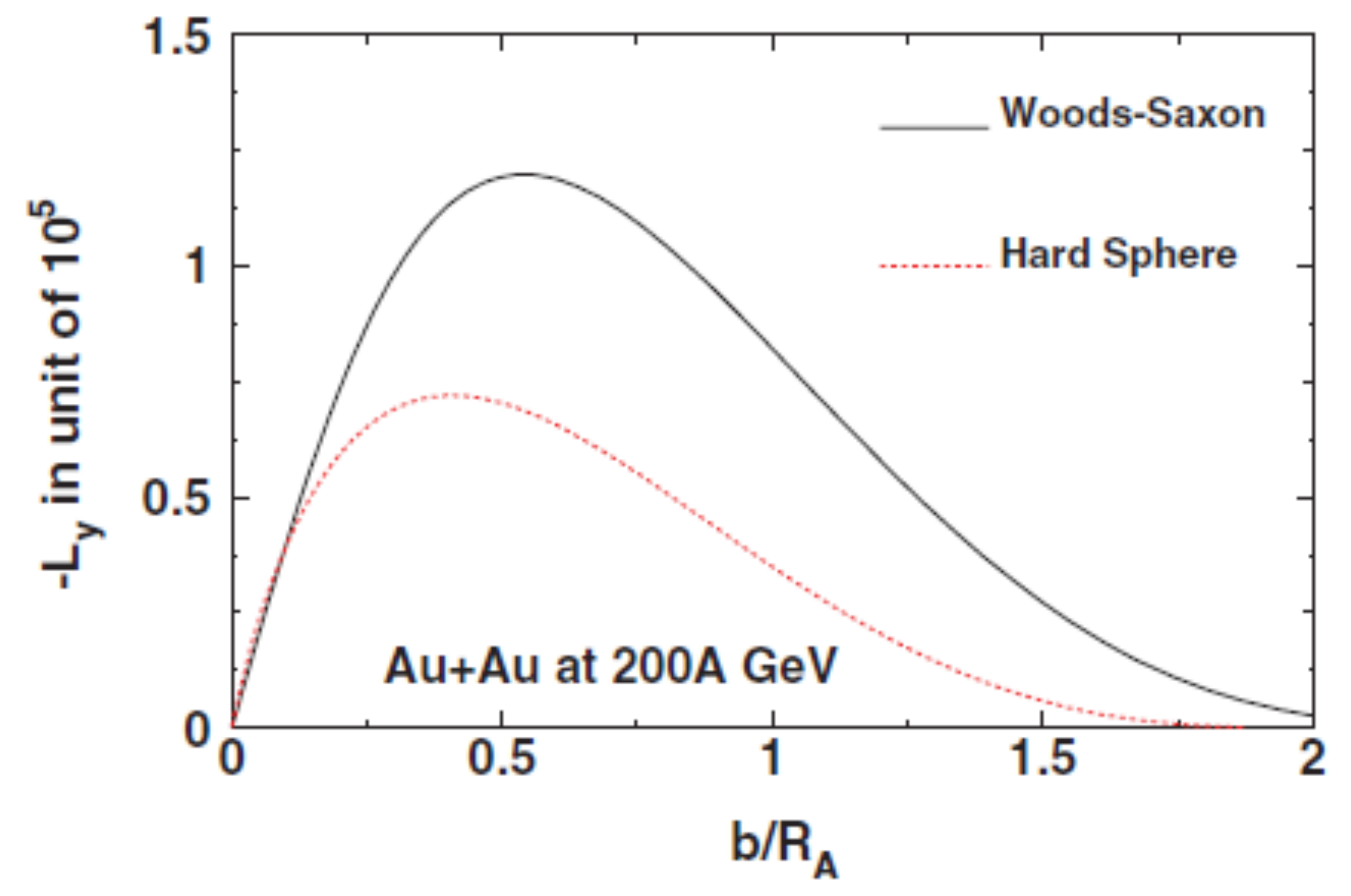
Orbital angular momentum in non-central ion-ion collisions



Zuo-Tang Liang and Xin-Nian Wang,
PRL 94, 102301 (2005); 96, 039901 (2006)

Orbital momentum value

Jian-Hua Gao et al., Phys. Rev. C 77 (2008) 044902

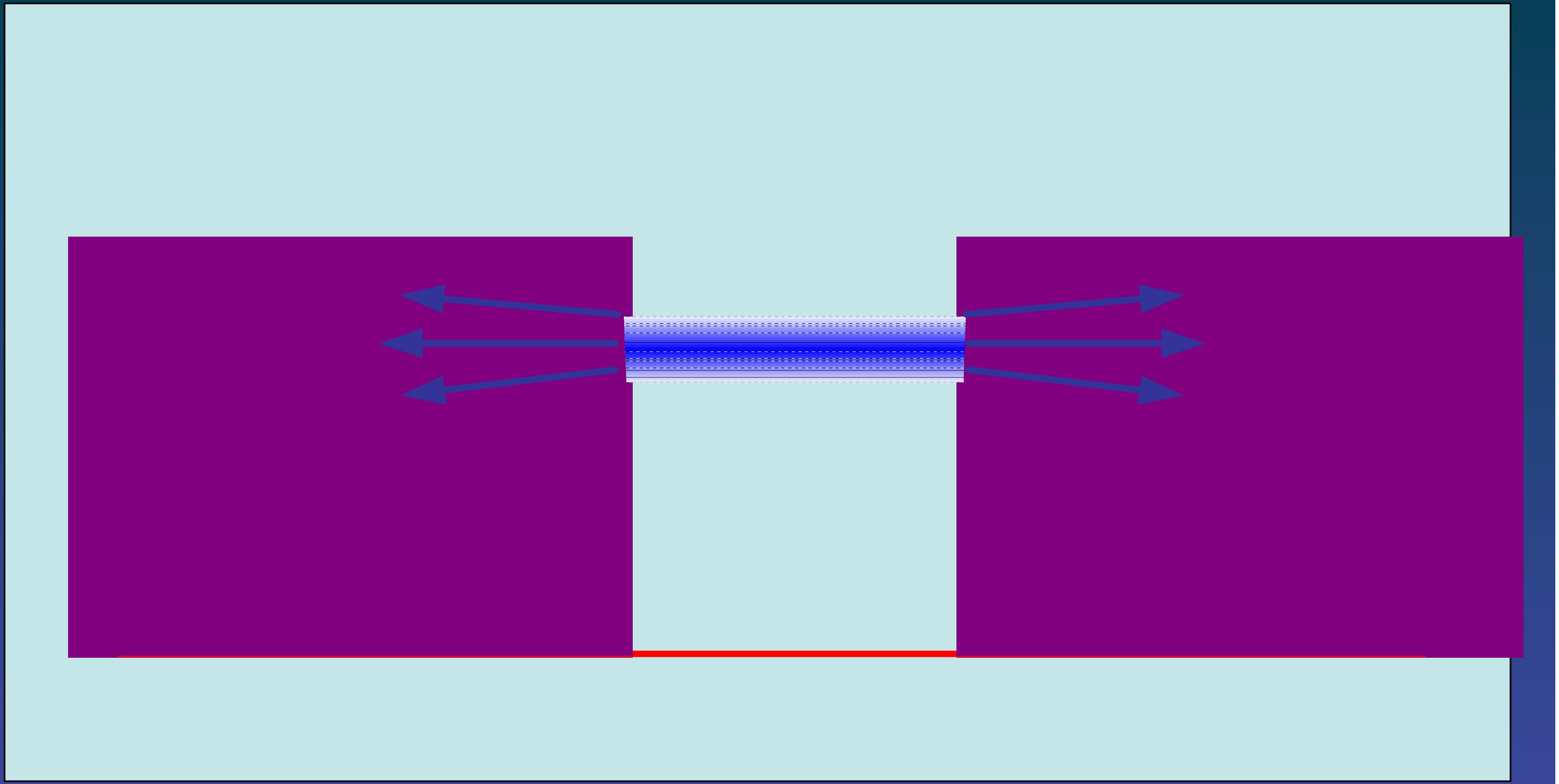


Total orbital angular momentum of the overlapping system in Au+Au collisions at the RHIC energy as a function of the impact parameter b.

Centrifugal barrier

1. As was shown by Zuo-Tang Liang and Xin-Nian Vang, in non-central collisions a globally polarized QGP with large orbital angular momentum which increases with energy $L \sim \sqrt{s}$ appears.
2. In this case, such blob of quark-gluon matter can be considered as a usual resonance with a large centrifugal barrier.
3. Centrifugal barrier $V(L) = L^2 / 2mr^2$ will be large for light quarks but small for top-quarks or other heavy particles.

Centrifugal barrier for different masses



How interaction is changed in frame of a new model?

1. Simultaneous interactions of many quarks change the energy in the center of mass system drastically:

$$\sqrt{S} = \sqrt{2m_p E_1} \rightarrow \sqrt{2m_c E_1}$$

where $m_c \approx nm_N$. At threshold energy, n ~ 4 (α - particle)

2. Produced $t\bar{t}$-quarks take away energy $\varepsilon_t > 2m_t \approx 350$ GeV, and taking into account fly-out energy, $\varepsilon_t > 4m_t \approx 700$ GeV in the center of mass system.

3. Decays of top-quarks $t(\bar{t}) \rightarrow W^+(W^-) + b(\bar{b})$

W –bosons decay into leptons (~30%) and hadrons (~70%);

$b \rightarrow c \rightarrow s \rightarrow u$ with production of muons and neutrinos.

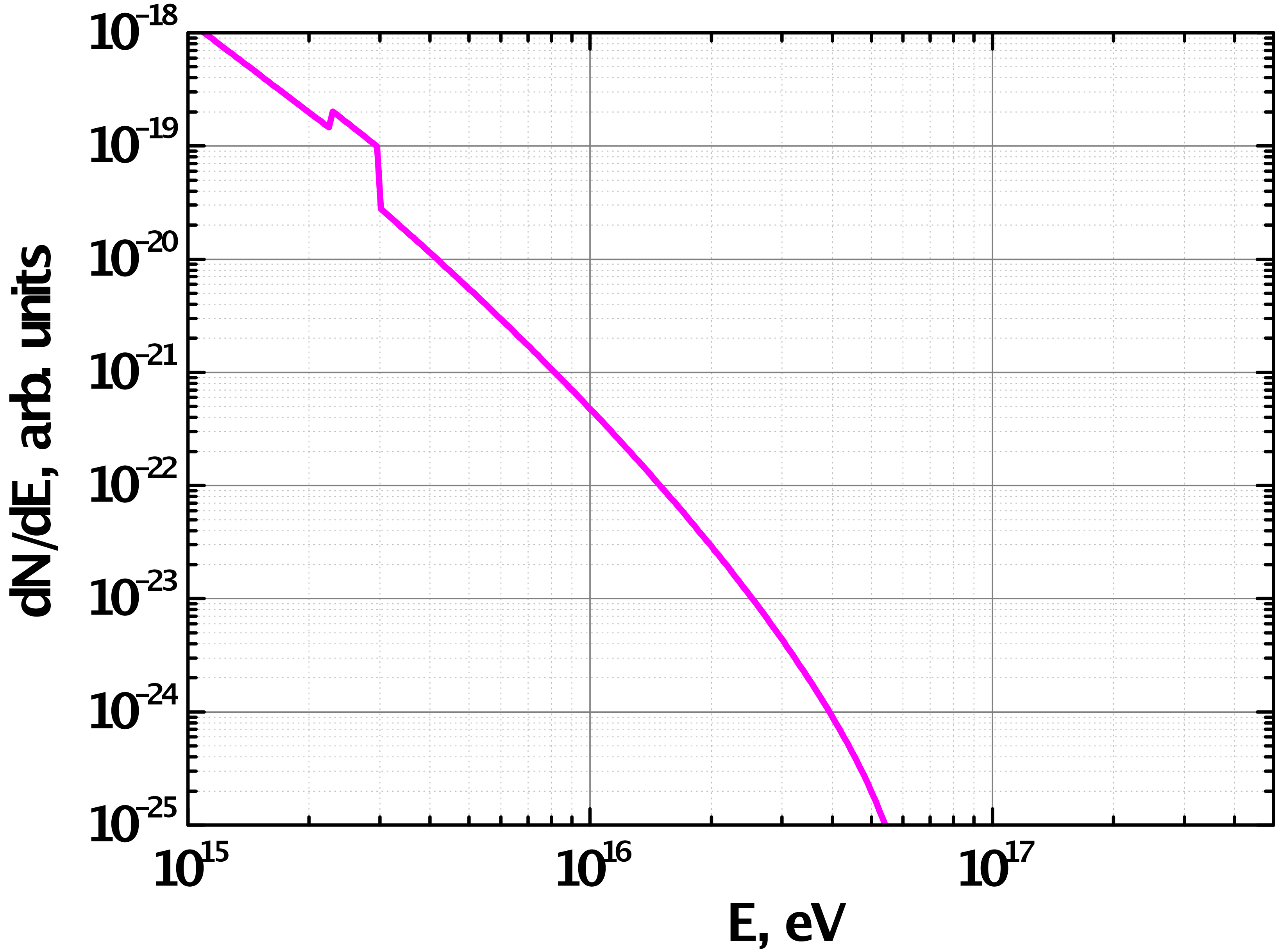
How the energy spectrum is changed?

1. One part of t-quark energy gives the missing energy (ν_e, ν_μ, ν_τ, μ), and another part changes EAS development, especially its beginning, parameters of which are not measured.

2. As a result, measured EAS energy E_2 will not be equal to primary particle energy E_1 and the measured spectrum will be differed from the primary spectrum.

3. Transition of particles from energy E_1 to energy E_2 gives a bump in the energy spectrum near the threshold.

Change of primary energy spectrum



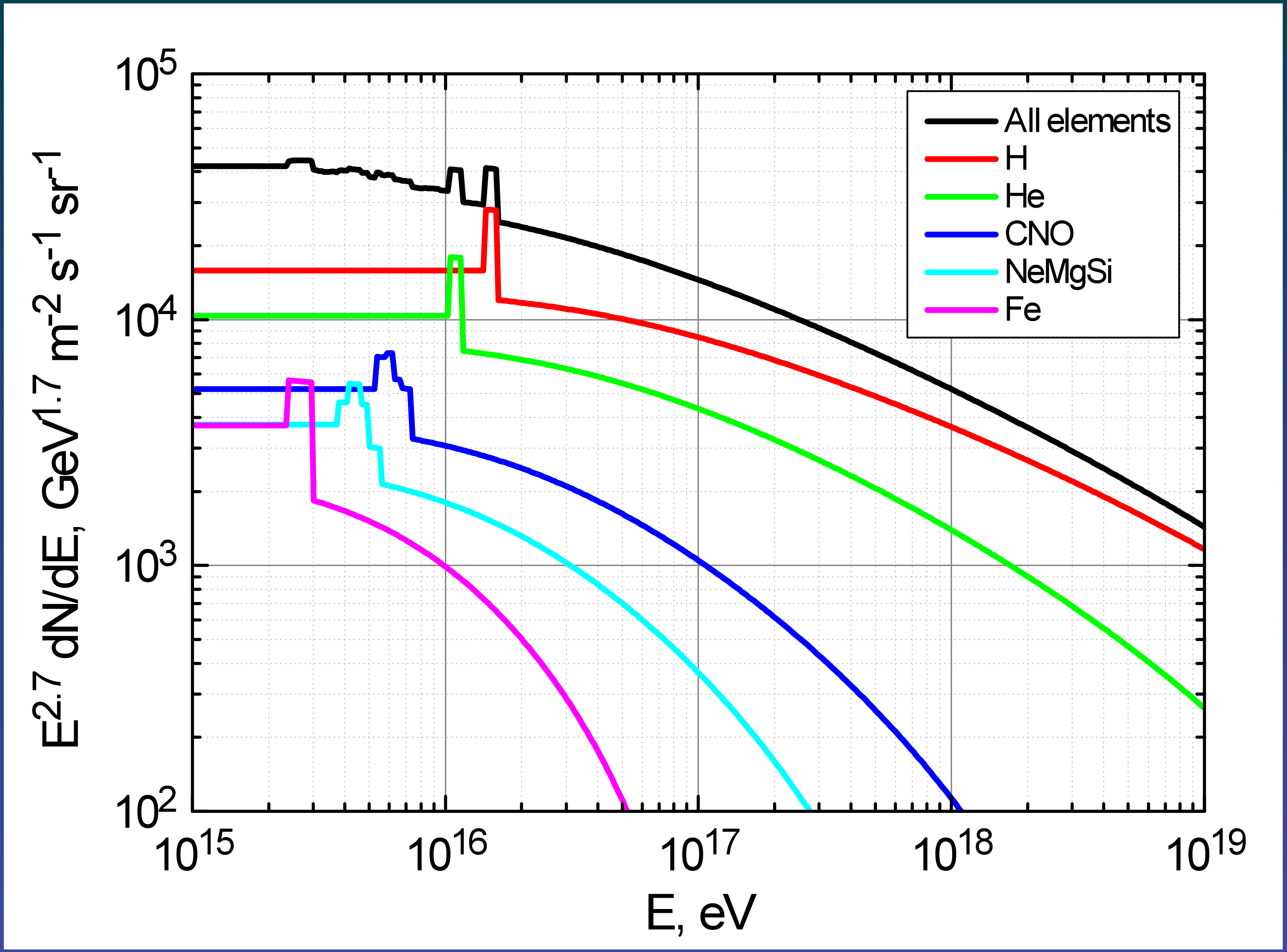
How measured composition is changed in frame of the new approach

Since for QGM production not only high temperature (energy) but also high density is required, threshold energy for production of new state of matter for heavy nuclei will be less than for light nuclei and protons.

Therefore heavy nuclei (f.e., iron) spectrum is changed earlier than light nuclei and proton spectra!!!

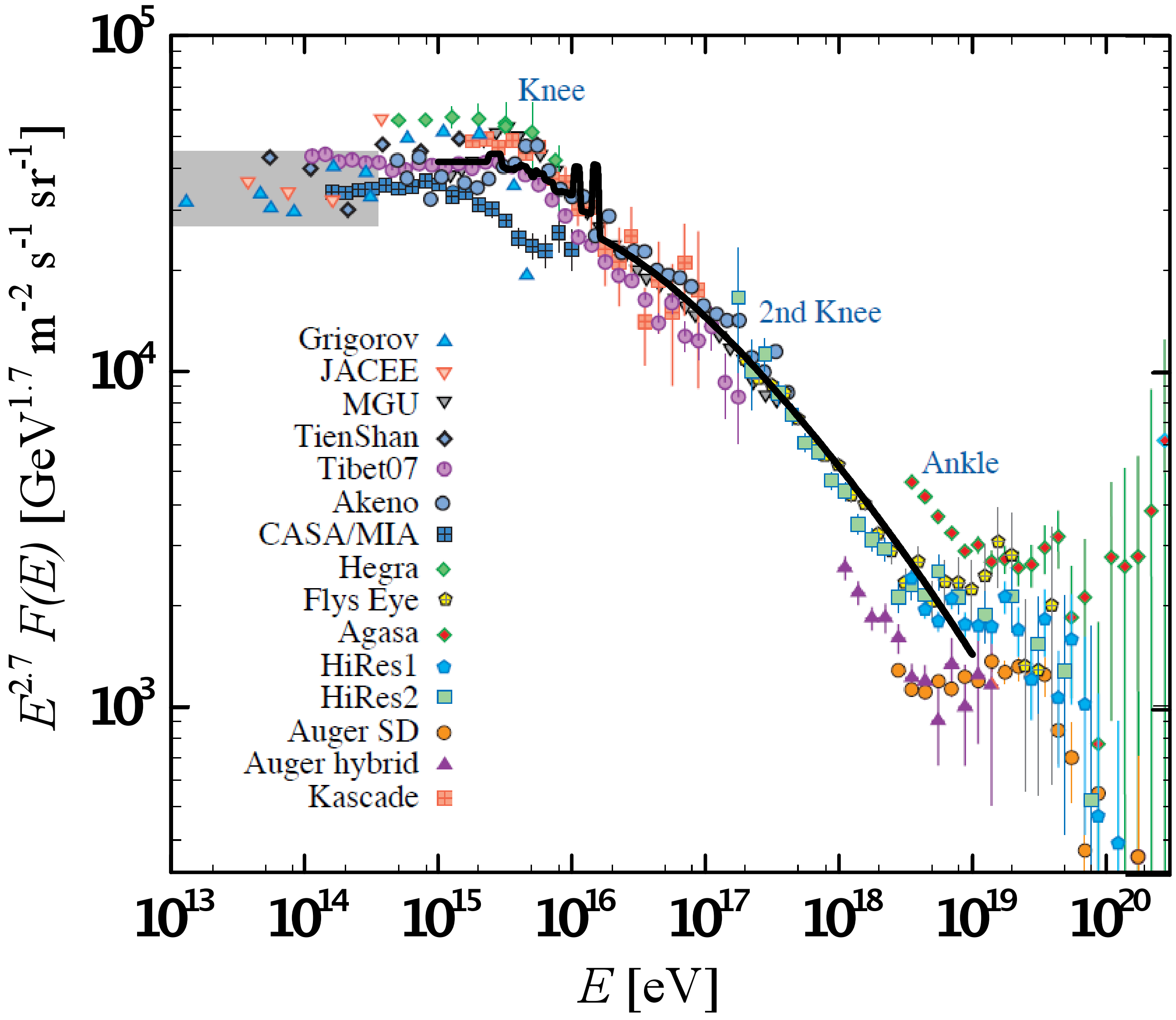
Measured spectra for different nuclei will be not equal to primary composition!!!

Measured spectra for some nuclei and spectrum of all particles



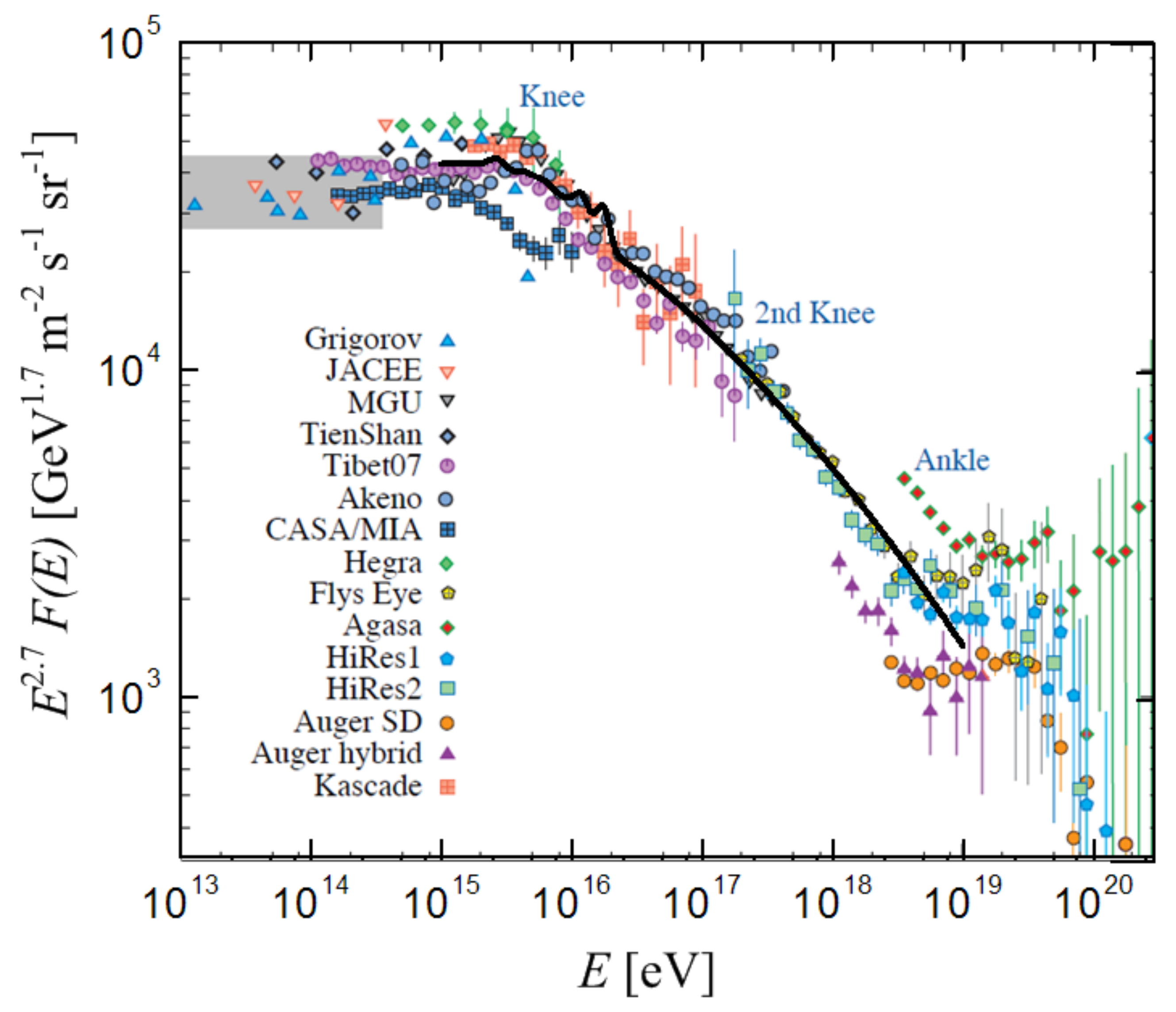
Comparison with experimental data

(without energy measurement straggling)

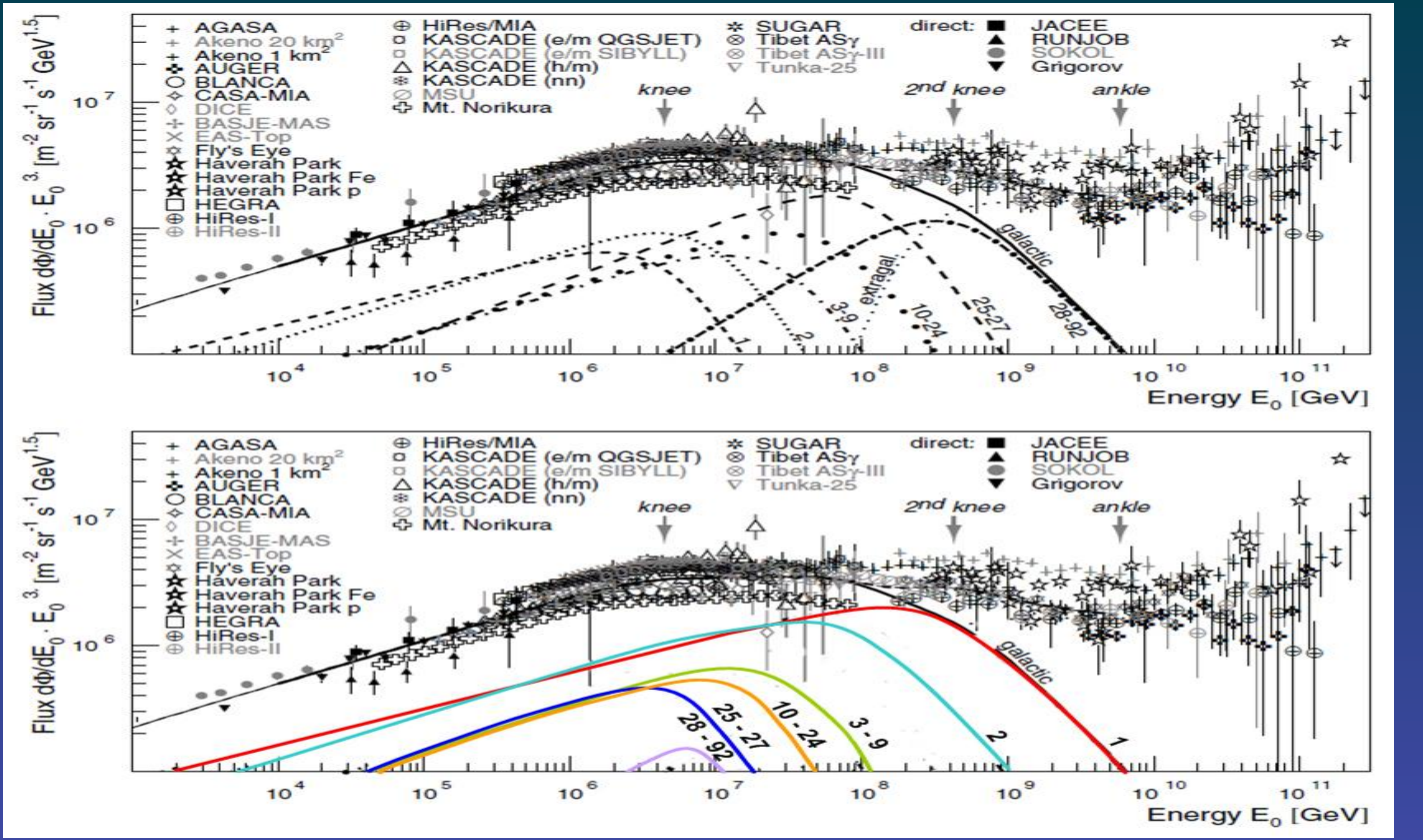


Comparison with experimental data

(with 10% straggling)



CR composition in two approaches



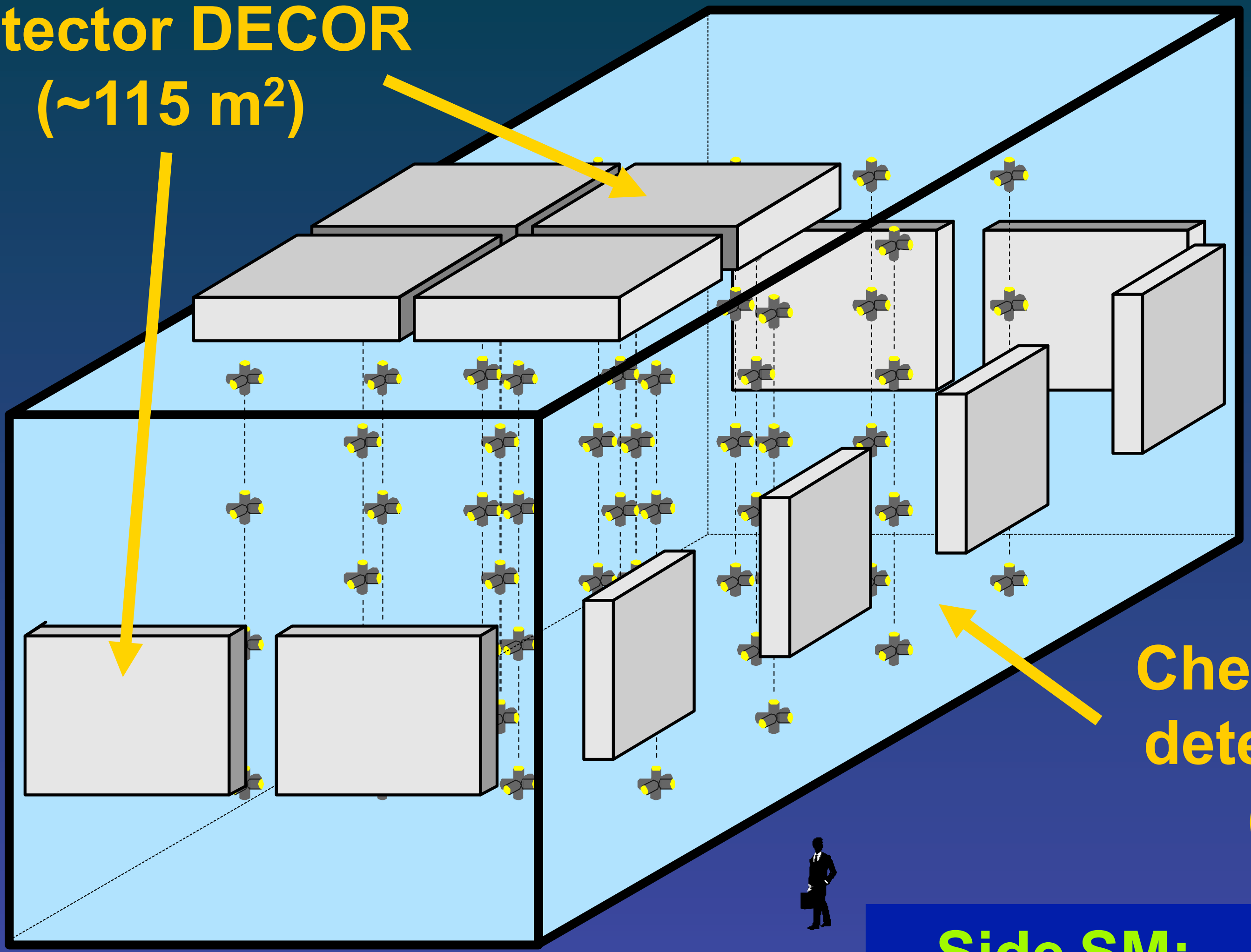
Muon problem (Muon puzzle)

This problem appeared in the last years when number of measured EAS muons began to overdraw simulated number of muons even for pure iron composition of primary CR.

Firstly this result was obtained in Russian-Italian experiment NEVOD-DÉCOR (2007) in which muon bundles were detected at large zenith angles.

Then the same results were obtained in Auger and other experiments. During UHECR meeting in CERN (February, 2012) muon problem was discussed in many talks.

Russian-Italian experiment NEVOD-DECOR



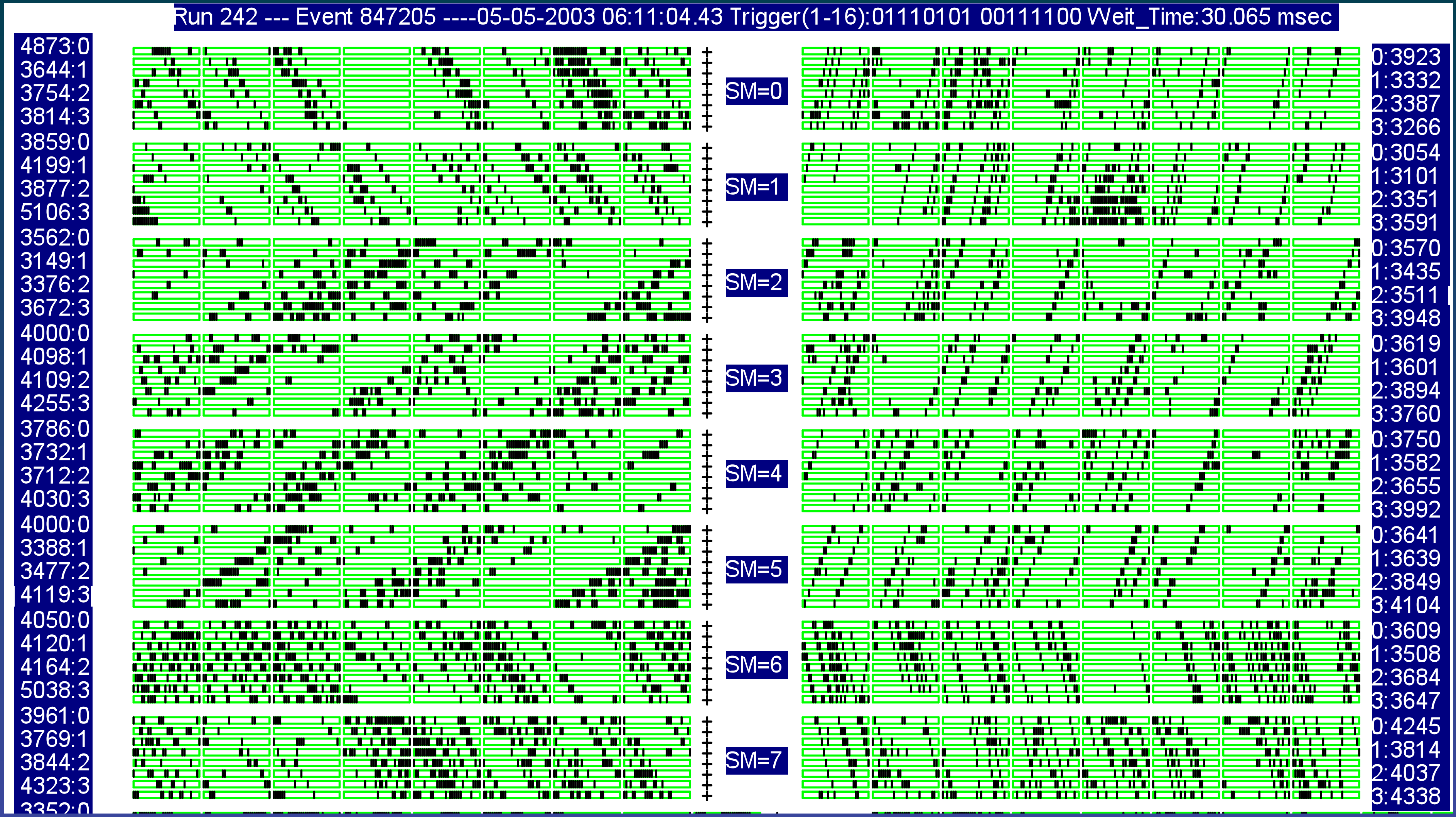
Coordinate-tracking detector DECOR ($\sim 115\ m^2$)

Cherenkov water detector NEVOD ($2000\ m^3$)

Side SM: $8.4\ m^2$ each

- $\sigma_x \sim 1$ cm; $\sigma_\psi \sim 1°$

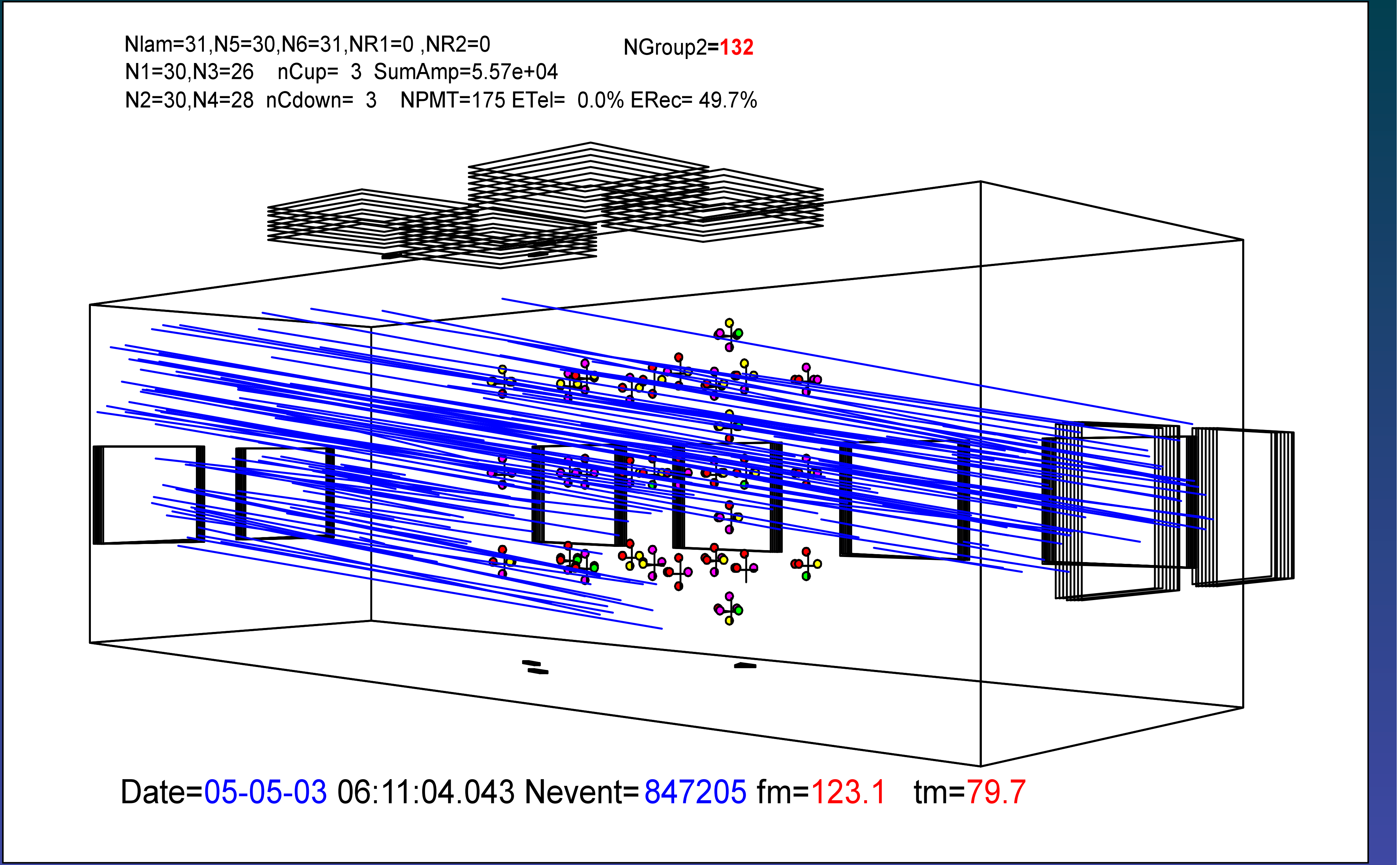
A “record” muon bundle event



Run 242 --- Event 847205 ----05-05-2003 06:11:04.43 Trigger(1-16):01110101 00111100 Weit_Time:30.065 msec

Y-projection X-projection

Muon bundle event (geometry reconstruction)



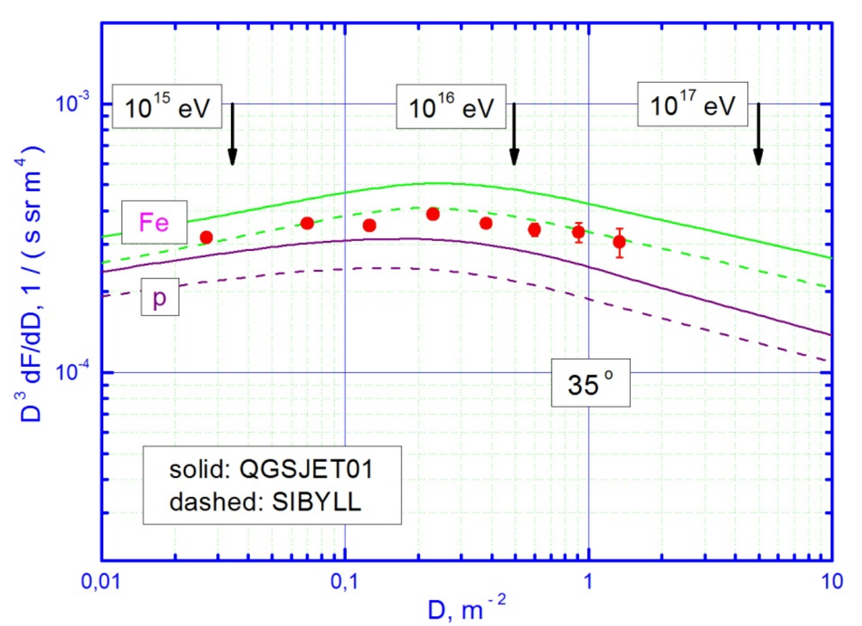
Nlam=31,N5=30,N6=31,NR1=0 ,NR2=0 NGroup2=132

N1=30,N3=26 nCup= 3 SumAmp=5.57e+04

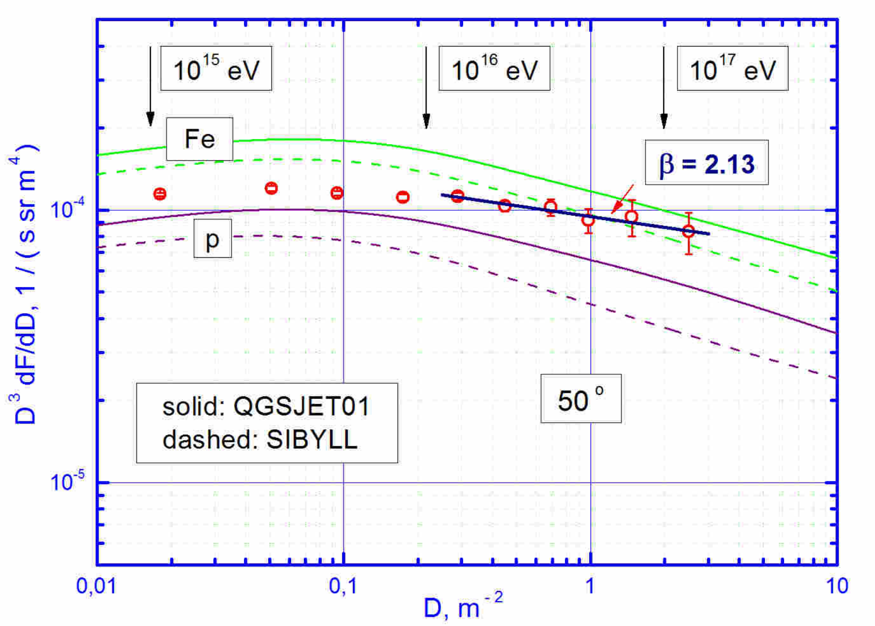
N2=30,N4=28 nCdown= 3 NPMT=175 ETel= 0.0% ERec= 49.7%

Date=05-05-03 06:11:04.043 Nevent=847205 fm=123.1 tm=79.7

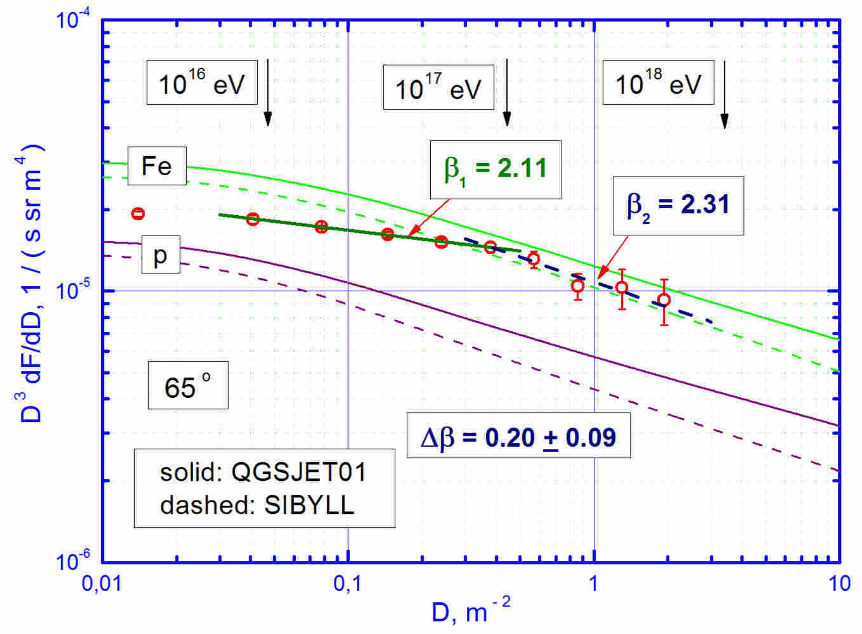
Low angles: around the “knee”



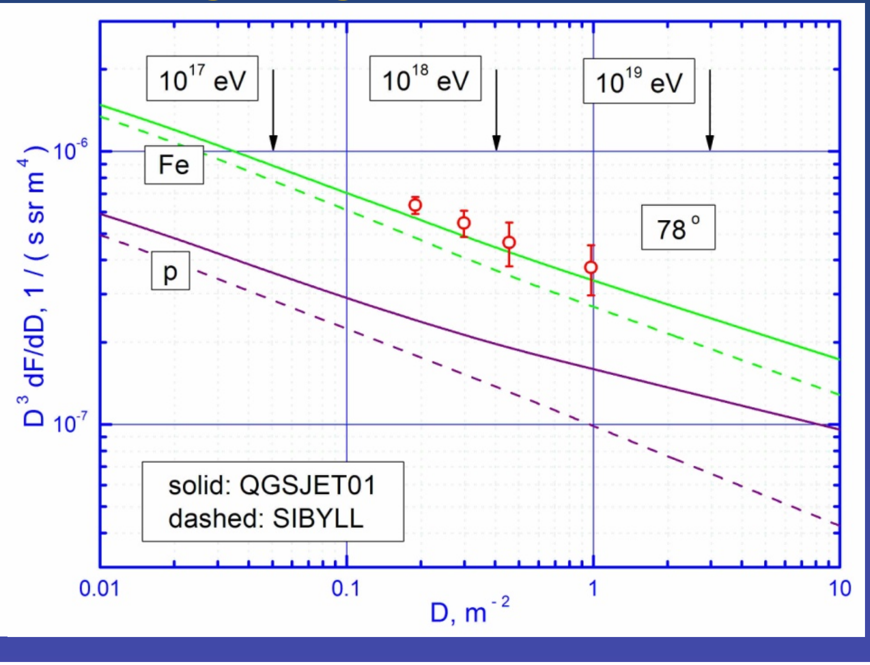
$\theta = 50^o : 10^{16} - 10^{17}$ eV



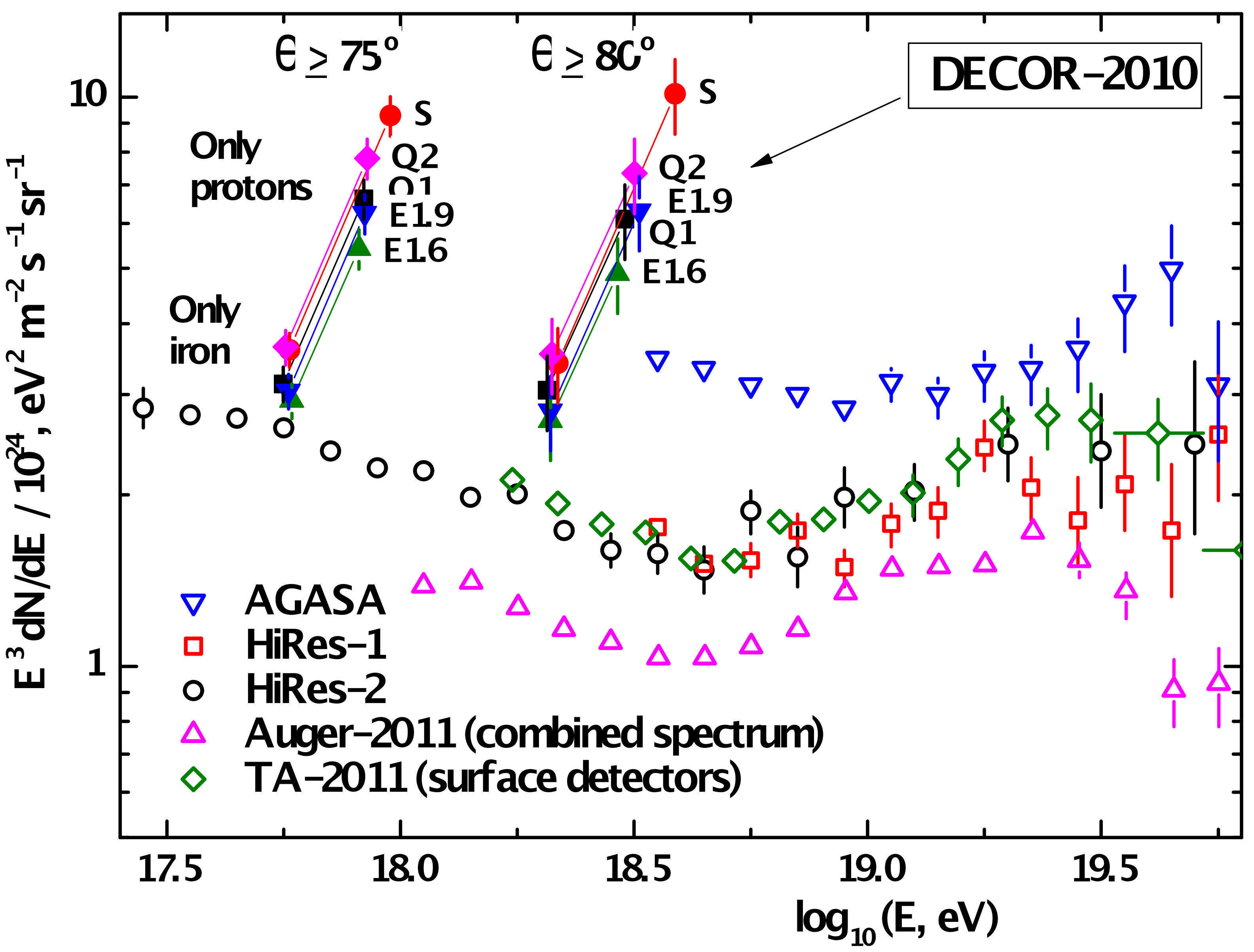
$\theta = 65^o : 10^{16} - 10^{18}$ eV



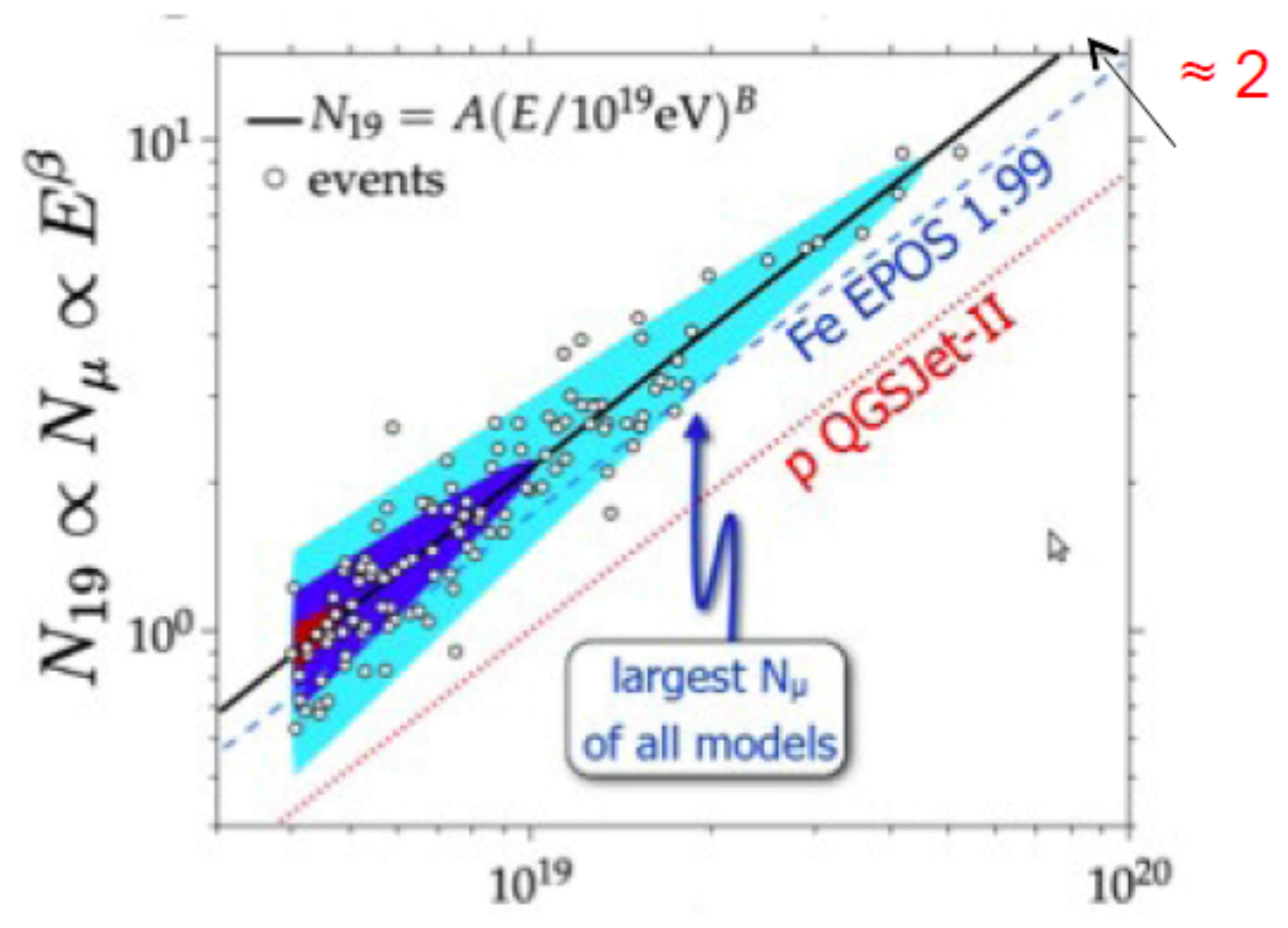
Large angles: around 10^{18} eV



Comparison with other data



Muons in Auger



P. Sokolsky, UHE Cosmic Rays: Setting the Stage

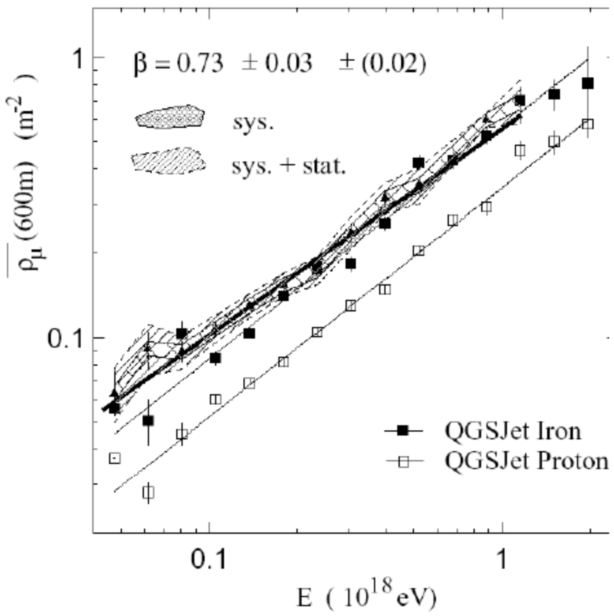


FIG. 2. Average Muon density at 600 m from the shower core. Same as FIG 1

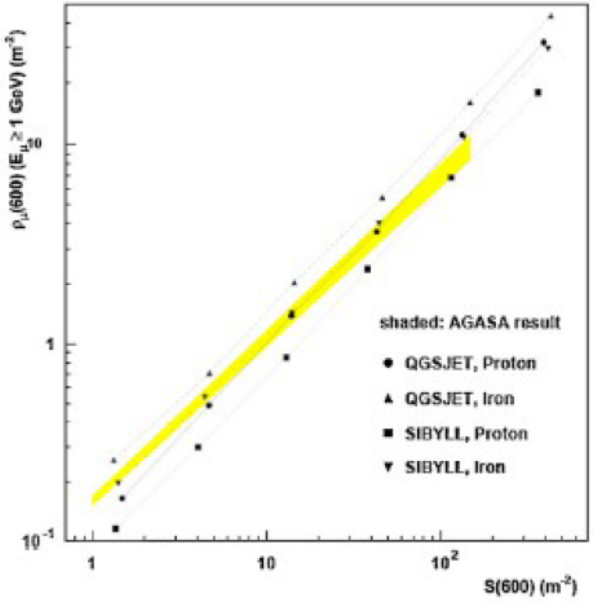


Figure 13. AGASA data on muon density as a function of energy estimator S(600) and comparison with predictions.

Muon content of showers in HiRes/MIA higher than expected!

Discussion of results

1. Energy spectrum obtained in frame of this model surprisingly well describes experimental data.

2. Changes of composition are explained:
   - a sharp increase of average mass at detection of EAS from heavy nuclei,
   - and then slow transition to proton composition.

3. So called “muon problem” (“muon puzzle”) is explained, too. Number of muons is increased not as a result of muon production in EAS initiated by heavy nuclei but through decays of massive particles into pions with large multiplicity.

Possibility to check the new approach in LHC experiments

On the face of it the search of QGM with described characteristics (excess of *t*-quarks, excess of VHE muons, sharp increasing of missing energy, etc.) is very simple task.

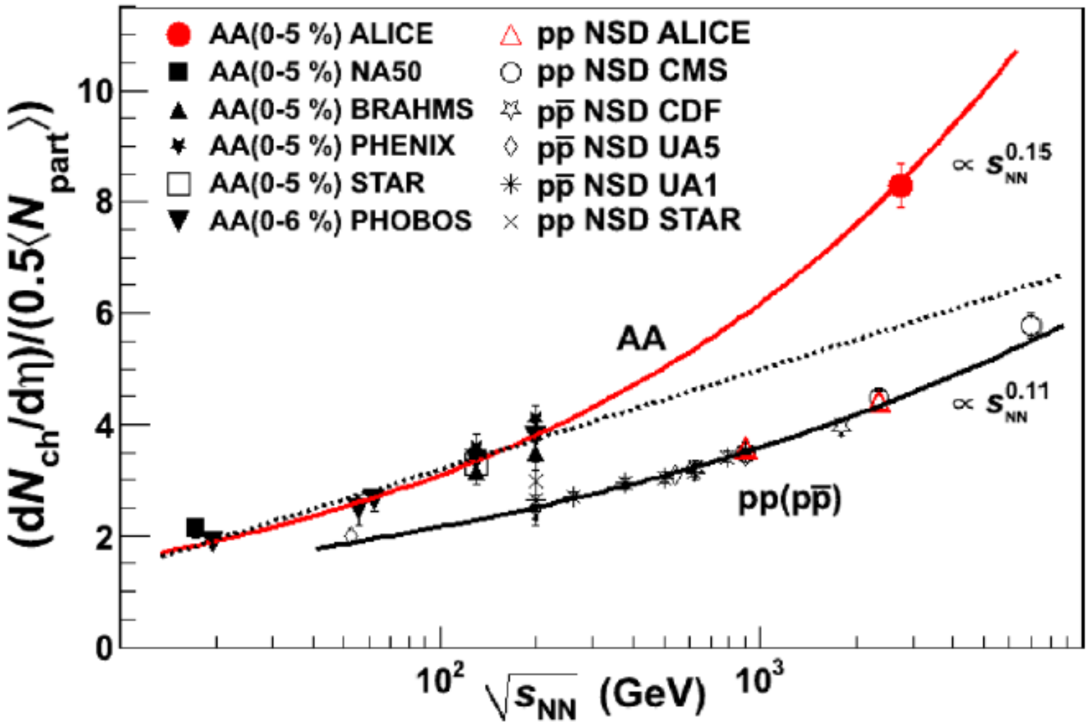
But apparently there are no possibility to observe it in pp-interactions even at full energy 14 TeV, since for that nuclei-nuclei interactions are required.

Unfortunately the methods of top-quark searches are prepared only for pp-collisions and development of new methods is required.

In spite of this some interesting results in nuclei-nuclei interactions have obtained yet.

Charged Particle Multiplicity

most central collisions: ~ 1600 charged particles per unit of η



ALICE: PRL105 (2010) 252301

$\sqrt{s_{NN}}$=2.76 TeV Pb+Pb, 0-5% central, |η|<0.5

2 dNch/dη / <Npart> = 8.3 ± 0.4 (sys.)

log extrapolation fails (finally!)

2.2 x central Au+Au

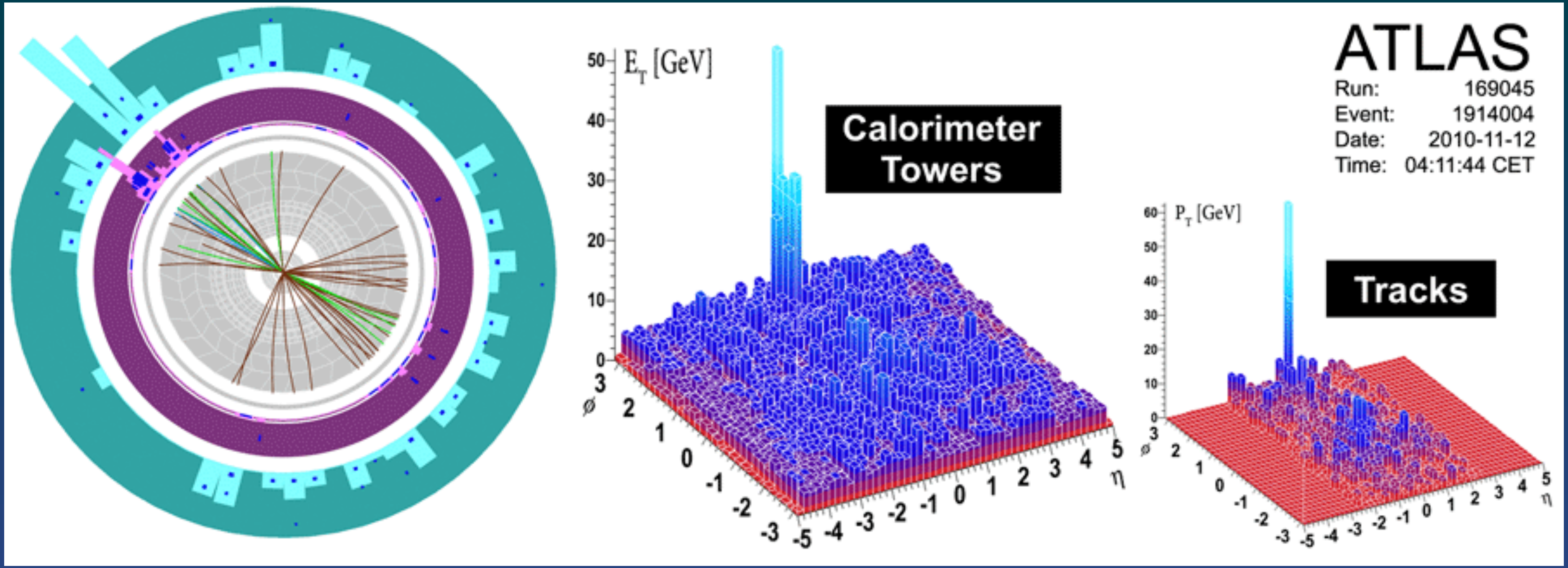
($\sqrt{s_{NN}}$=0.2 TeV)

1.9 x pp (NSD)

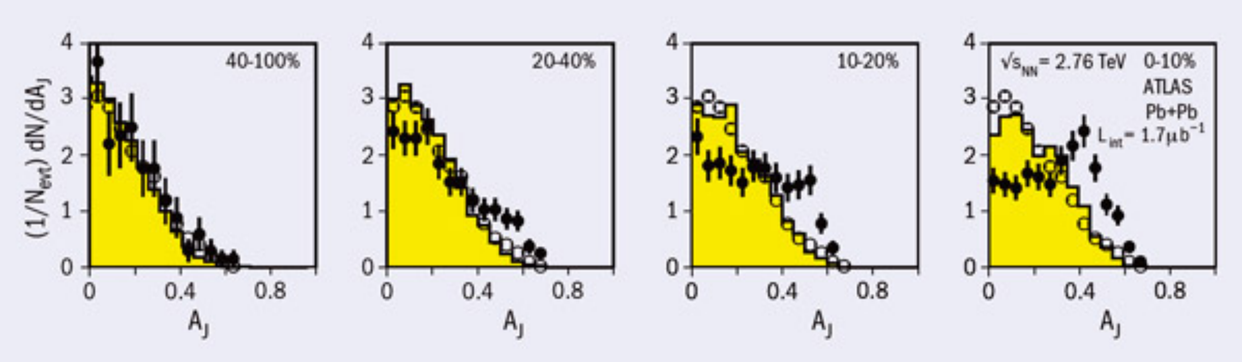
($\sqrt{s_{NN}}$=2.36 TeV)

ATLAS observes striking imbalance of jet energies in heavy ion collisions

(CERN Courier, January/February 2011)



Highly asymmetric dijet event



Dijet asymmetry distributions

How to explain the ATLAS results in frame of considered approach?

$$t \to W^+ + b$$

In the center-of-mass system of top-quark

$$T_b \sim 65 \text{ GeV} \qquad T_W \sim 25 \text{ GeV}.$$

If to take into account fly-out energy, T_b can be more than 100 GeV.

In the case if b gives a jet and $W \to \sim 20\ \pi$, the ATLAS experiment picture will be obtained.

How to check the new model in cosmic ray experiments?

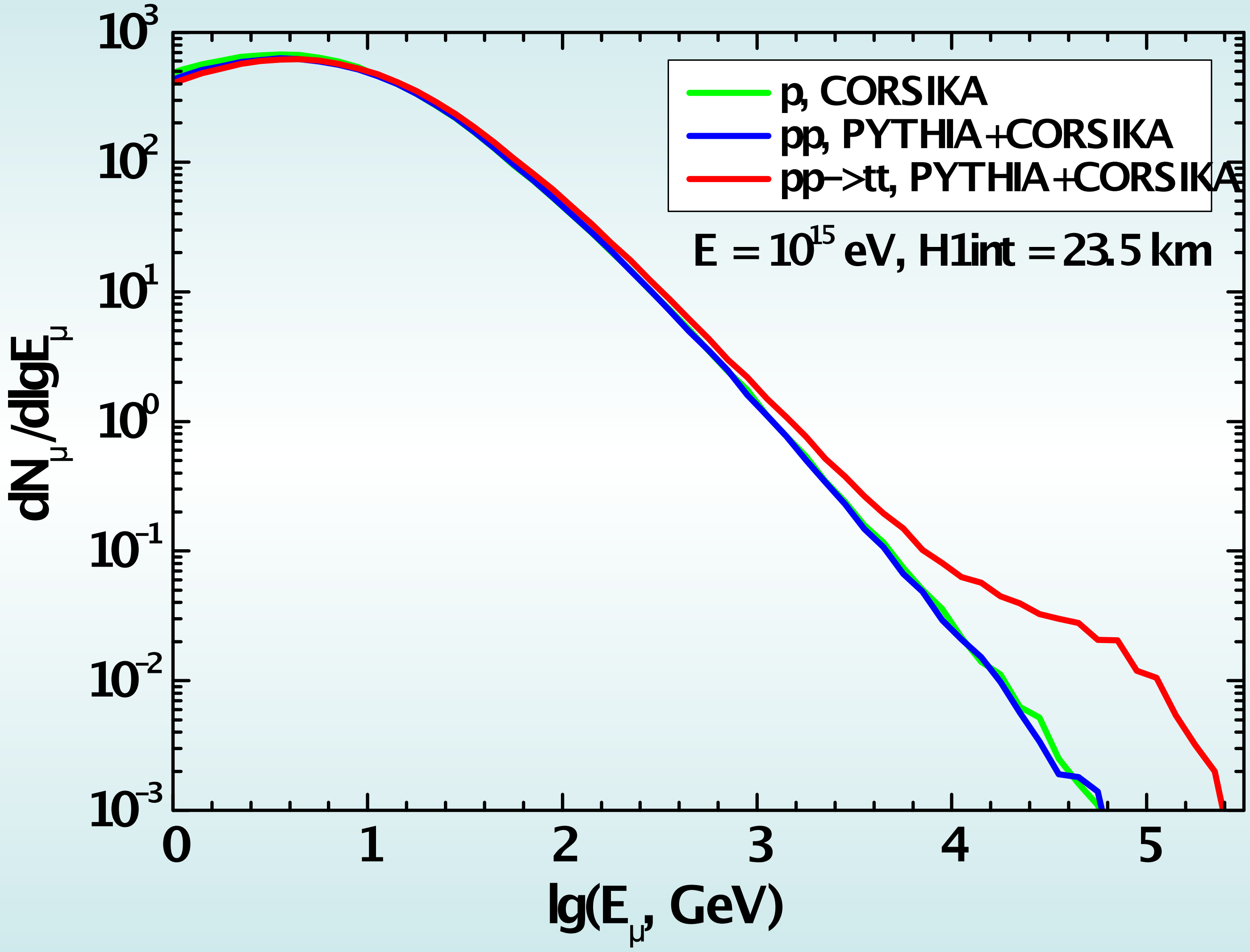
One possibility is direct measurements of various nuclei spectra in space. Changes in spectra must begin from heavy nuclei. But this possibility is not real in observable future.

Two other possibilities are connected with VHE muon detection:

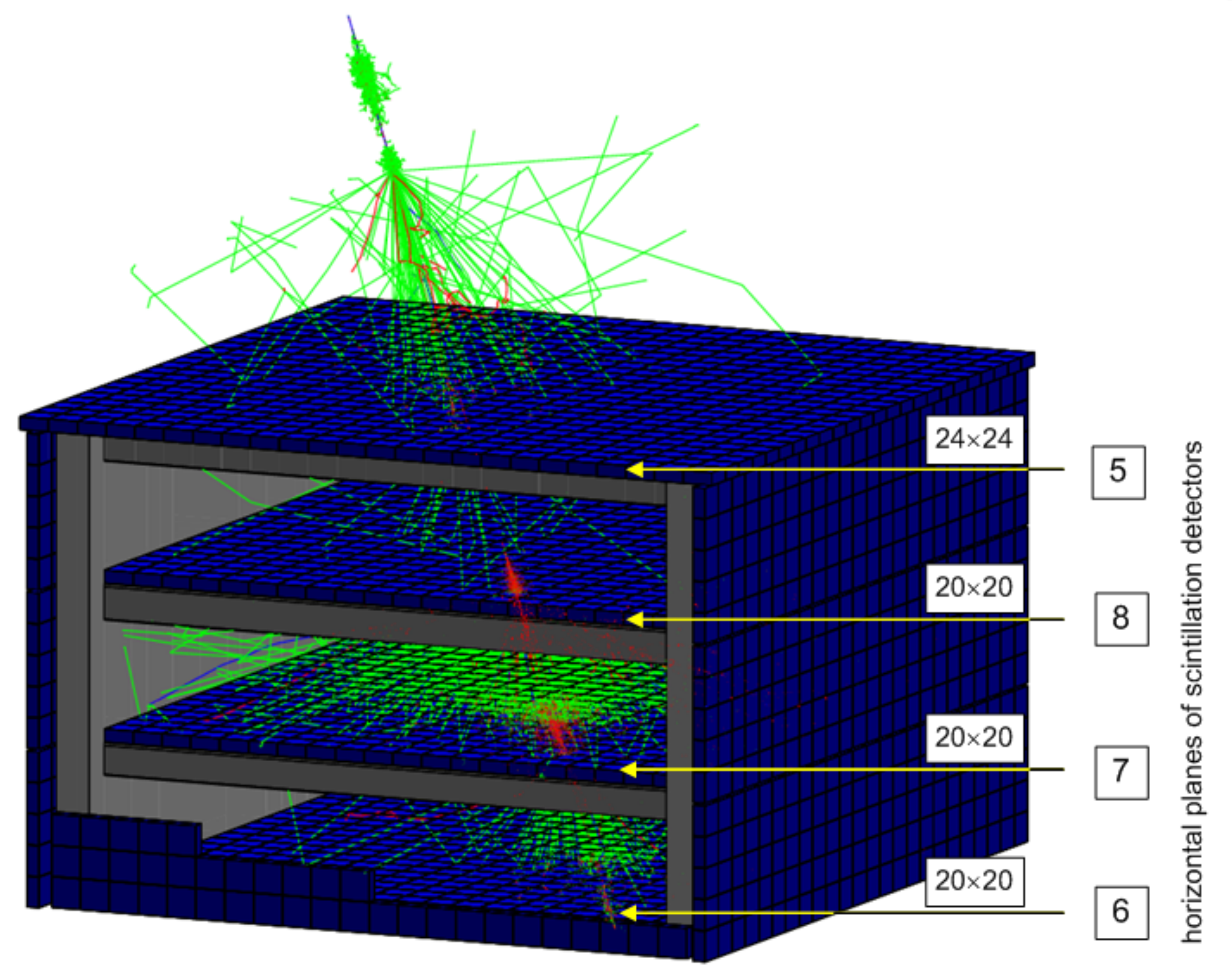
- measurements of muon energy spectrum above 100 TeV;
- measurements of energy deposit of EAS muon component below and above the knee.

For that, existing muon and neutrino detectors can be used: BUST, NEVOD-DECOR, Baikal, ANTARES, IceCube, etc.

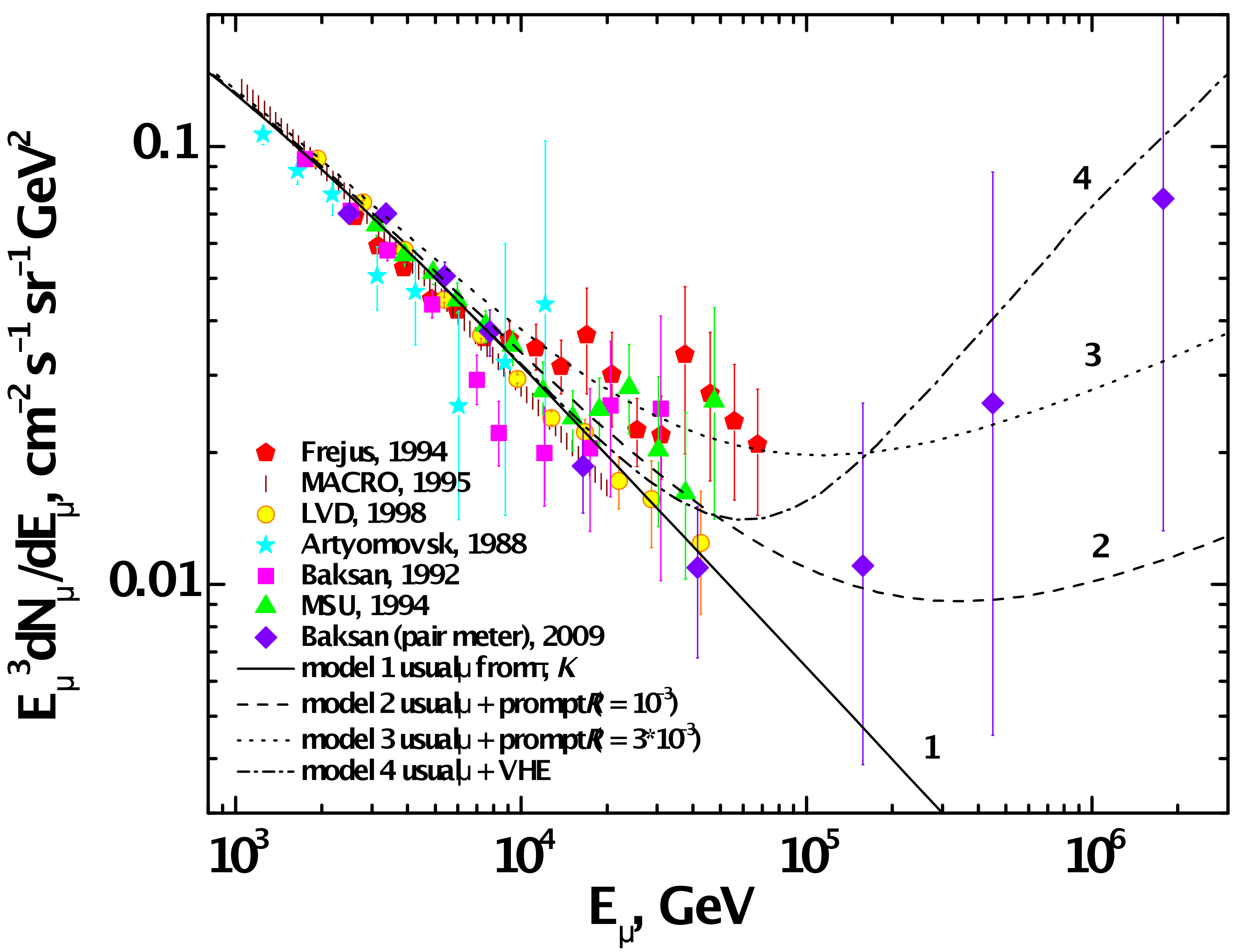
Predicted muon energy spectrum



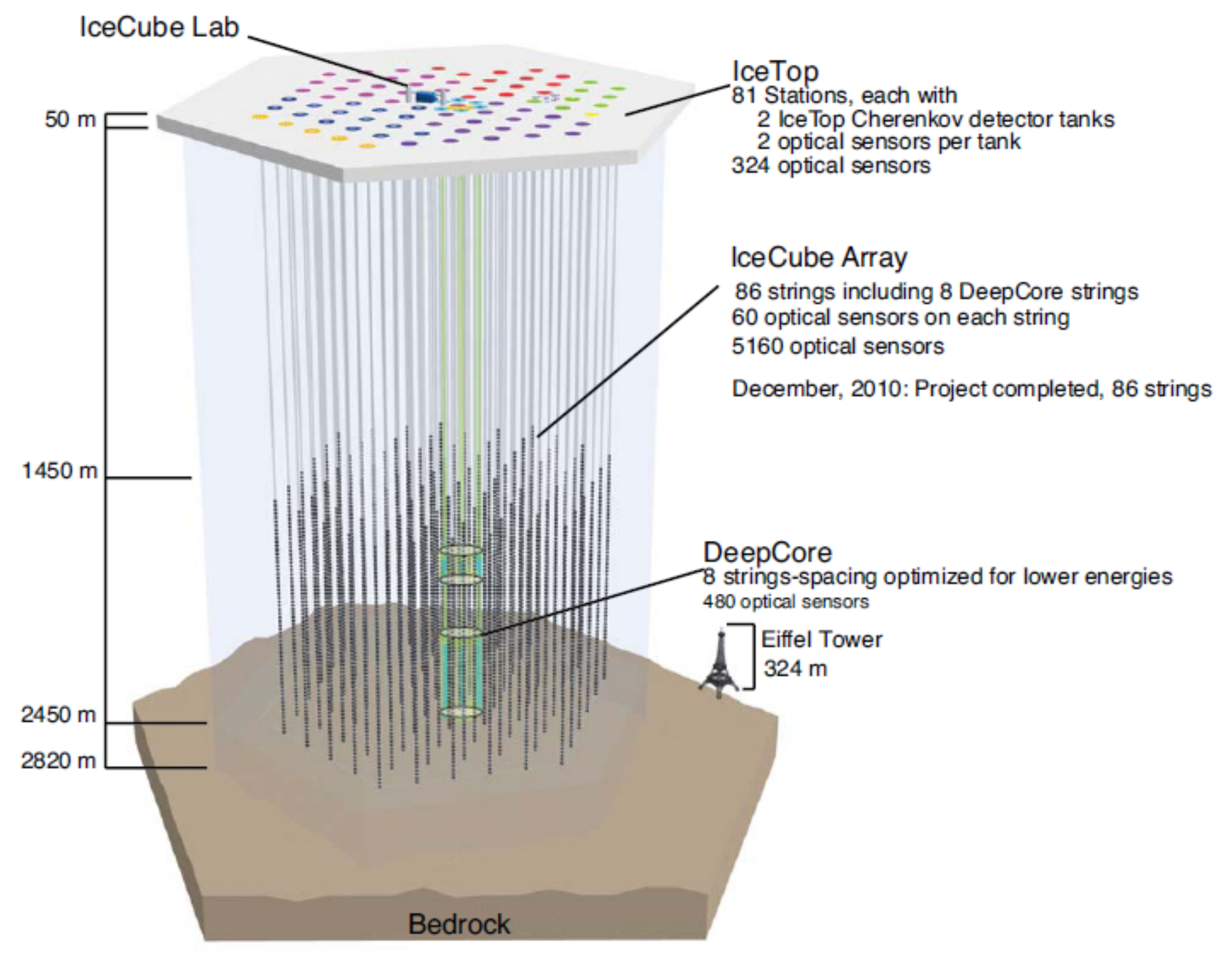
BUST


24×24
5
20×20
8
20×20
7
20×20
6
horizontal planes of scintillation detectors

Bust muon energy spectrum



Ice-Cube



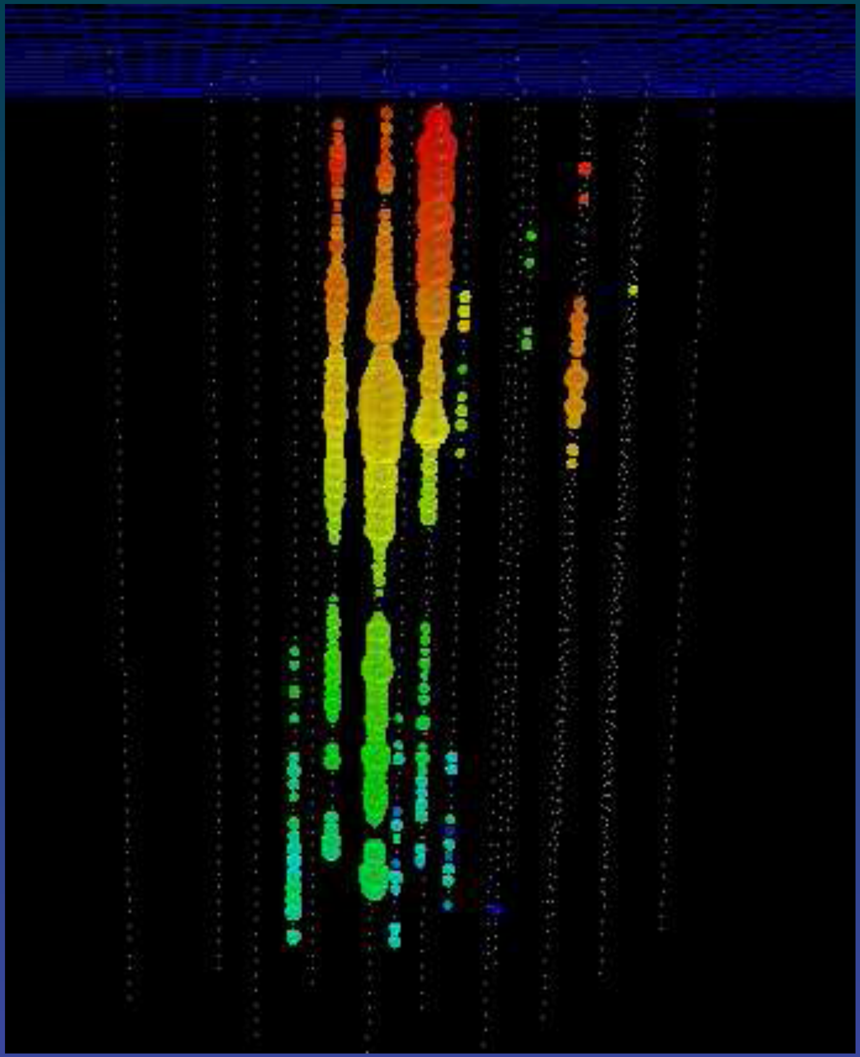
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors

December, 2010: Project completed, 86 strings

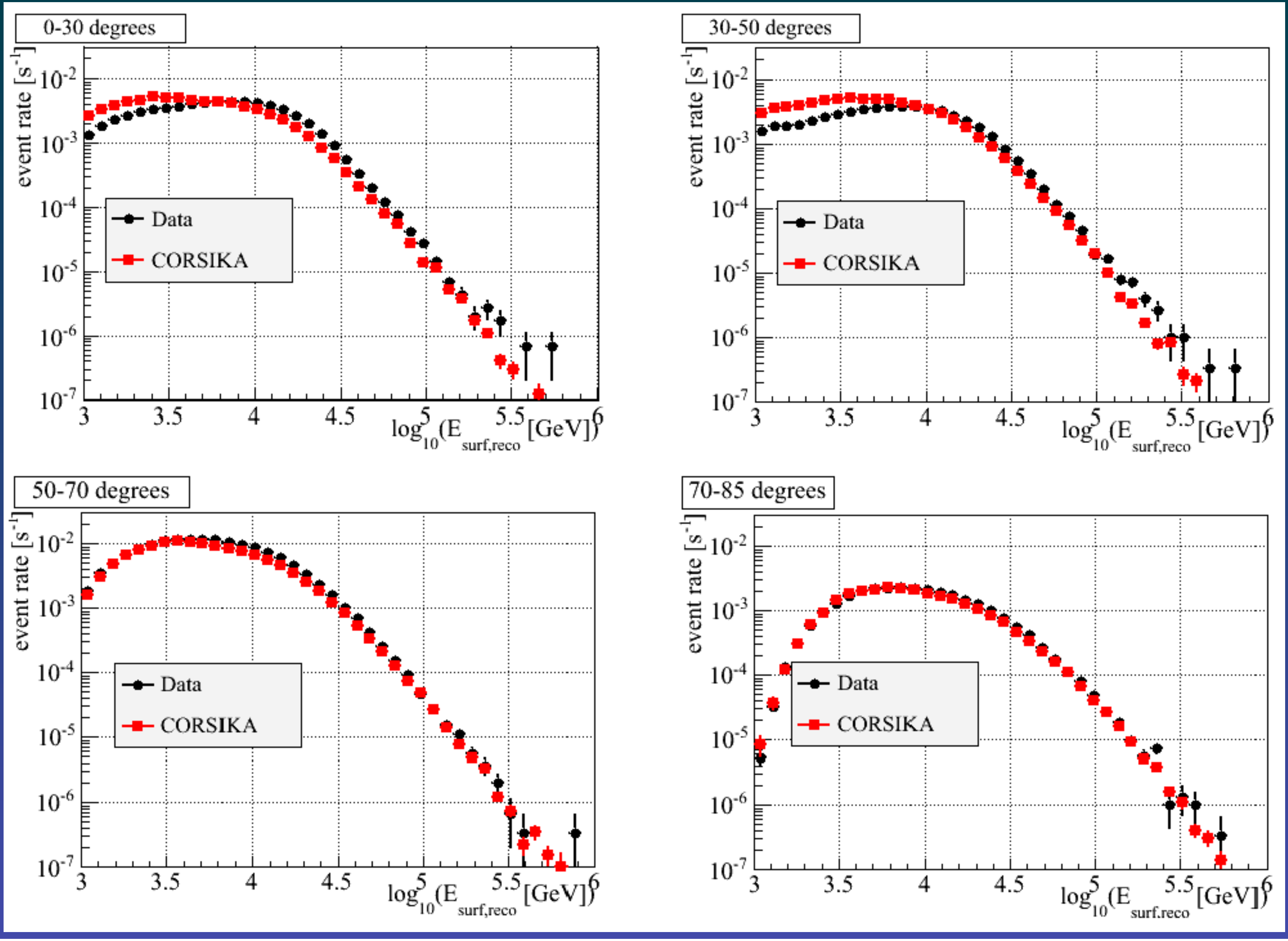
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors

Muons in Ice-Cube



Candidate shower with a high pT muon. The cosmic ray bundle is on the left and the high p_T muon is on the right.

Results of 2011



Conclusion

Considered approach allows explain practically all problems of cosmic ray investigations above the knee and there are few doubts that it will be confirmed (earlier or later) in LHC experiments.

Cosmic ray community has unique possibility to obtain more impressive proof of new physics existence before that this will be done in accelerator experiments.

If this approach is correct, it is an excellent present to 100 year anniversary of cosmic ray discovery!
And it will provide a good job for next generations of cosmic ray physicists during the second century of cosmic ray investigations!

Thank you!