They were the first
(a retrospective look at some Baksan experiments on the jubilee day)

A.S. Lidvansky

Institute for Nuclear Research, Russian Academy of Sciences

Three meanings of the word "first"

1. The very first experiments made with Baksan facilities and their results
2. The results that retained the first place (were world-best) at least for a short time
3. The results that still hold the first position either in historical records or in modern ratings

Professor A.E. Chudakov - founding father (A.Wolfendale) of gamma-ray astronomy and pioneer of underground physics

Preparations and pre-Baksan studies

- Liquid scintillator, very cheep, transparency L~ 50 m, stability > 40 years.
  - А.В. Воеводский, В.Л. Дадыкин, О.Г. Ряжская, Жидкие сцинтилляторы, Сб. Космические лучи, 1969, №11, стр. 188-191; Жидкие сцинтилляторы для больших сцинтилляционных счетчиков, ПТЭ, 1970, № 1, стр. 85-87.
- Calibration of PM tubes
  - Ю.Н. Коновалов, А.Е. Чудаков, Г.А. Шелков, Портативный импульсный источник рентгеновского излучения для калибровки сцинтилляционных детекторов, Труды ВККЛ, Ташкент, 1968, стр. 133-136.
  - Я.С. Еленский, Источник наносекундных световых импульсов большой интенсивности, ПТЭ, 1971, № 4, стр. 183-184.
- Pilot studies, Ground-surface muon telescope at Dolgoprudnyi near Moscow, 100 standard scintillation detectors
  - E.N. Aleksejev et al., 100-channel scintillation telescope, 12th ICRC, Hobart, Tasmania, v. 6, p. 2516 (1971)
  - В.Г. Сборщиков, Поиски короткопериодических вариаций космических лучей на широте Москвы, Извести АН СССР, сер. физ., 1973, № 6,стр. 1331-1333.
  - Е.Н. Алексеев и др. 100-канальный сцинтилляционный телескоп, Сб. Космические лучи, 1974, № 14, стр. 187-189.

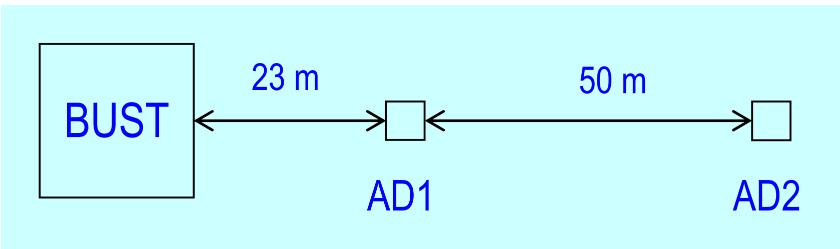
Turin-effect

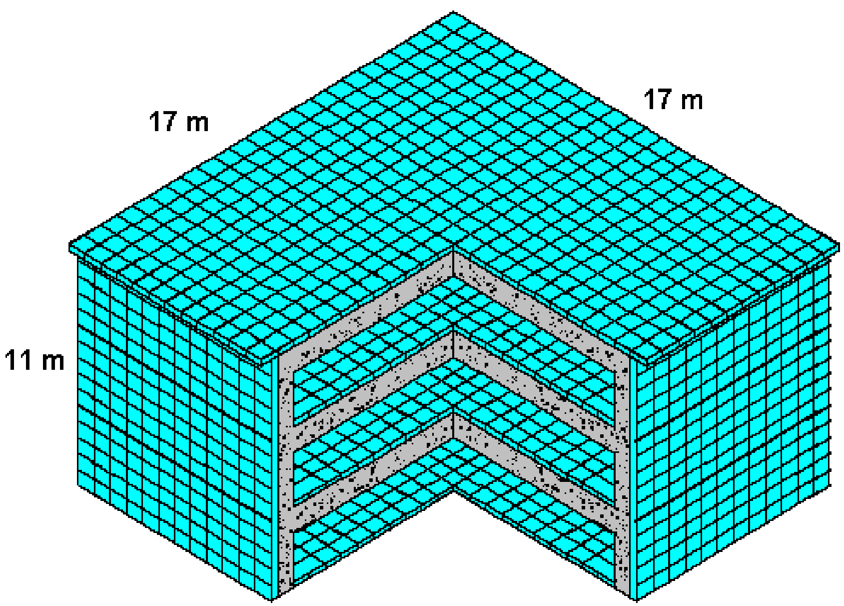
The paper [1] B. Baschiera, L. Bergamasco, C. Castagnoli, P. Picchi, Lett. Nuovo Cimento, 4, 121, (1970) had measured in the tunnel under Mont Blanc the number of stopping muons. At a depth of 4500 m.w.e. the measured value was found to exceed predicted number of stopping muons by a factor of 10.

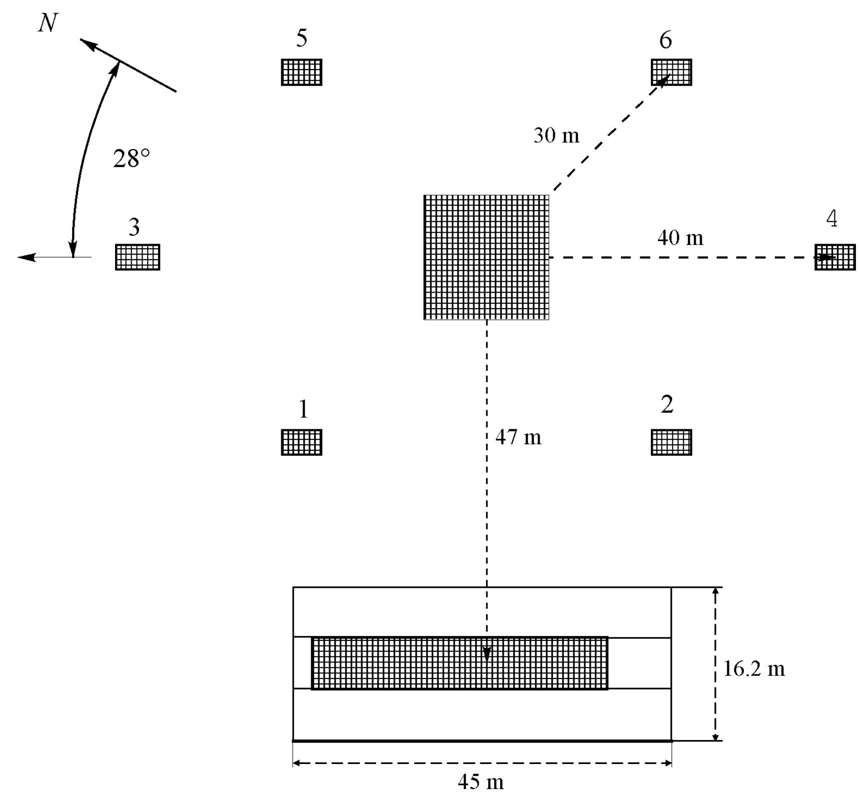
When no experimental setups did yet exist, one liquid scintillator detector was placed in horizontal mine at different distances from the entry. This experiment showed that "within traditional concepts and knowledge about interactions of muons there is no simple explanation of the result of paper [1]". So elegant and polite was formulation of the fact that the Turin-effect was closed.

Е.Н. Алексеев, В.Н. Гуренцов, С.П. Михеев, В.А. Тизенгаузен, А.Е. Чудаков, Интенсивность останавливающихся мюонов на глубине 60 и 850 м.в.э., Известия АН СССР, сер. физ., т. 37, № 7 (1973).

The BUST and the Carpet facilities



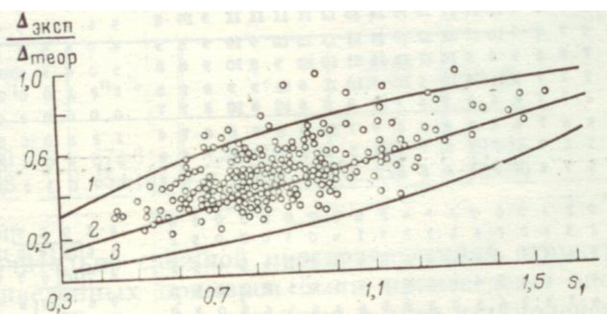




EAS studies with the Carpet array

- High-precision measurements of LDF and its fluctuations
- E.N. Alexeyev et al., Lateral distribution of electrons in EAS with Ne ≥ $2 \cdot 10^5$, 15th ICRC, Plovdiv, Bulgaria, v. 8, p. 52 (1977).
- Е.Н. Алексеев и др., Функция пространственного распределения электроновв ШАЛ на высоте 1700 м над уровнем моря, Изв. АН СССР, сер. физ., 1978, т. 42, № 7, стр. 1417-1419.
- Д.Д.Джаппуев и др. Флуктуации формы пространственного распределения ШАЛ на расстояниях < 50 м от оси, ЯФ, 1979, т. 29, №4, стр. 957-961.
- Study of EAS structure near its axis and estimation of the flattening region near the core
- E.N. Alexeyev et al., Structure of the central part of EAS with Ne ≥ $2 \cdot 10^5$, 15th ICRC, Plovdiv, Bulgaria, v. 8, p. 56 (1977).
- Е.Н. Алексеев и др. Пространственная структура ШАЛ вблизи оси, Изв. АН СССР, сер. физ., 1978, т. 42, № 7, стр. 1420-1424.

Рис. 1. Распределение отношений экспериментальной нормированной центральной плотности к расчетной. Кривые соответствуют разным радиусам уплощения $r_{упл}$=0,4 м (1); 0,8 м (2); 1,2 м (3)



Multi-core EAS and high transverse momenta in hadron-hadron interactions

- From the analysis of multicore showers (Carpet) the cross section of generation of high Pt jets at √S ~ 500 GeV is estimated and demonstrated to be in agreement with QCD predictions (1981, at least one year before the similar results of UA1 and UA2 collaborations at the CERN SPS-collider).
- (The plot from this report was reprinted in CERN Courier immediately)

A.E. Chudakov, D.D. Dzhappuyev, A.S. Lidvansky, V.A. Tizengauzen, V.P. Sulakov, G. Navarra, Investigation of EAS with multicore structure,
16th ICRC, Kyoto, Japan, v. 8, p. 222 (1979).

A.E. Chudakov, K. Dobrzynski, E. Krys,
A.S. Lidvansky, G. Navarra, V.A. Tizengauzen,
J. Wdowczyk. The data on multicore air showers and cross-section of high-Pt jet production at √S ~ 500 GeV, Proc. of 17th ICRC, Paris, 1981, v.6, p. 183-186.

EA3.2-21

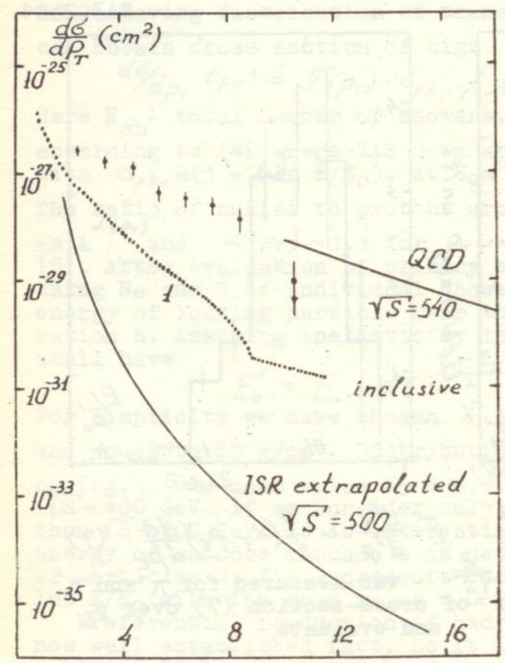
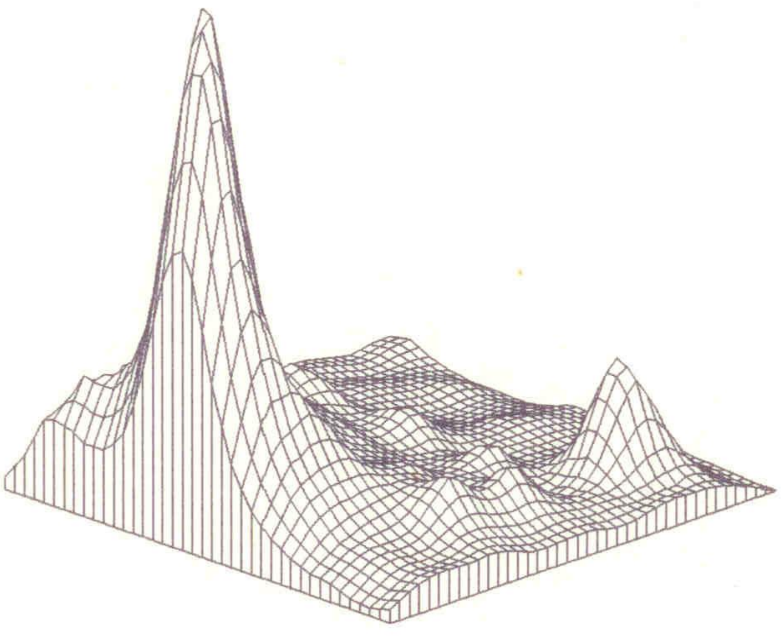


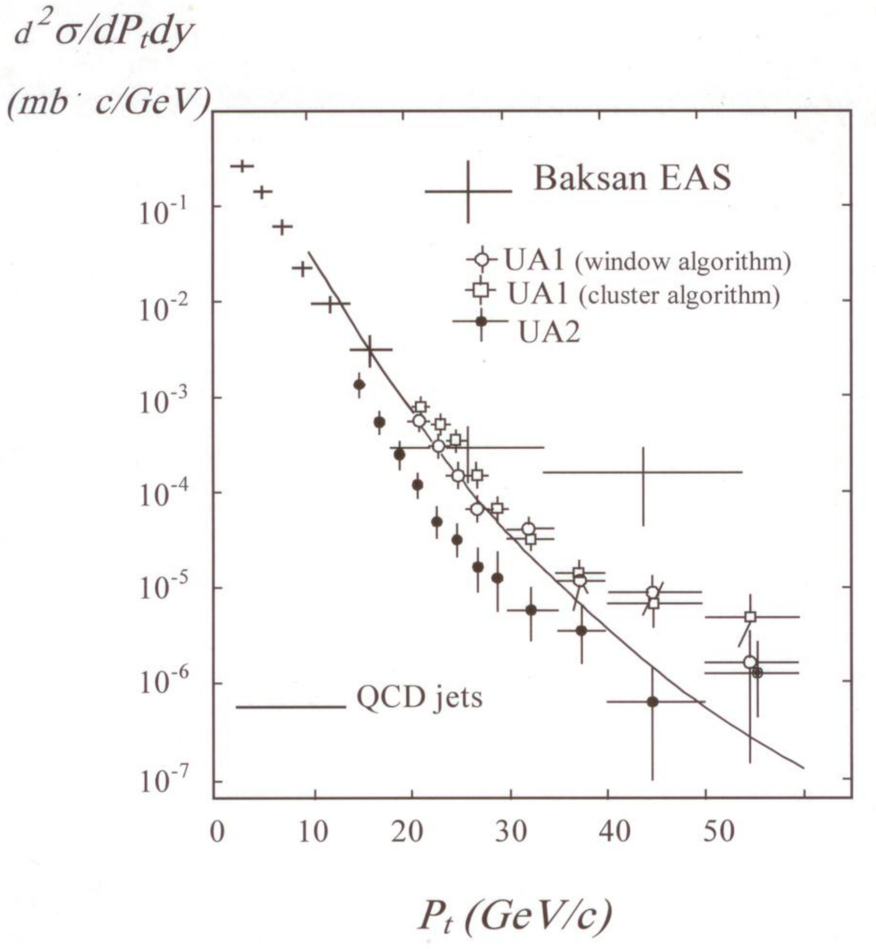
Fig.3

P_T but the tendency of theoretical curve is in remarkable agreement with experimental points. Of course experimental data on Fig.3 have considerable uncertainties but theoretical calculations have the same as well. If we consider experimental $d\sigma/dP_T$ as valid for neutral pions then jet cross-section should be an order of magnitude or so higher, but even in this case this discrepancy would be much less than that for extrapolated data of present-day experiments.

First confirmation of QCD
in high-Pt physics



An example of multicore event
(smoothed particle density)



Cross-section of high P_t events in an air shower experiment compared to a calculation for QCD jets and first experiments at CERN SPS collider.

The flux of vertical neutrinos and parameters of neutrino oscillations

- Vertical intensity of upward-going neutrino-induced muons was measured for the first time (1980). The limits for parameters of neutrino oscillations were obtained (1985-1990).

- М.М. Болиев и др., ЯФ, **34**, стр. 1418-1421 (1981).
- M.M. Boliev A.V. Butkevich, A.E. Chudakov, B.A. Makoev, S.P. Mikheyev, V.N. Zakidyshev, Baksan Neutrino experiment, Proc. of Neutrino81 Conf., Honolulu, Hawaii, v. 1, p. 283 – 290.
- Particle Data Group, 1982

- Ratio of measured to expected events R = 0.95 ± 0.22. At 90% CL the limit was $\Delta m^2 \leq 6\ 10^{-3}$ eV^2 (two types of neutrinos and maximum mixing). This limit was stronger than those of other experiments by a factor of 100. But due to small statistics it is rapidly became weaker with decreasing mixing and at $\sin^2 2\alpha \leq 0.65$ completely disappeared.

Proton lifetime

- **Е.Н. Алексеев и др., Ограничение на время жизни протона по данным Баксанского подземного сцинтилляционного телескопа, Письма в ЖЭТФ, т. 33, вып.12, 664 (1981).**
- **E.N. Alexeyev, V.N. Bakatanov, A.V. Butkevich, A.V. Voevodsky, A.A. Gitel'son, A.E. Danshin, G.P. Keidan, A.A. Kiryushin, O.I. Petkova, A.E. Chudakov, B.E. Shtern, Lower limit on the proton lifetime according to data from the Baksan Underground Scintillation Telescope, ZhETP Letters, v. 33, no. 12, 651- 653 (1981).**
- Some construction changes improving anti-coincidence shield were made for this experiment. Two inner layers of detectors were used to search for proton decays, six outer layers being the anti-coincidence shield.
- The lower limit on proton (neutron) lifetime established in this paper was equal to $1.25.10^{30}$ years (90% confidence level) for all neutrinoless modes of decay.
- The world-best limit approximately for half a year.

Upper limits on the flux of magnetic monopoles

- The upper limit for the magnetic monopole flux was world-best for almost 20 years.
- First published 1983:
- E.N. Alexeyev et al., Search for slowly moving penetrating particles at Baksan underground telescope, 18th ICRC, Bangalore, India, 1983, vol. 5, pp. 52-55.

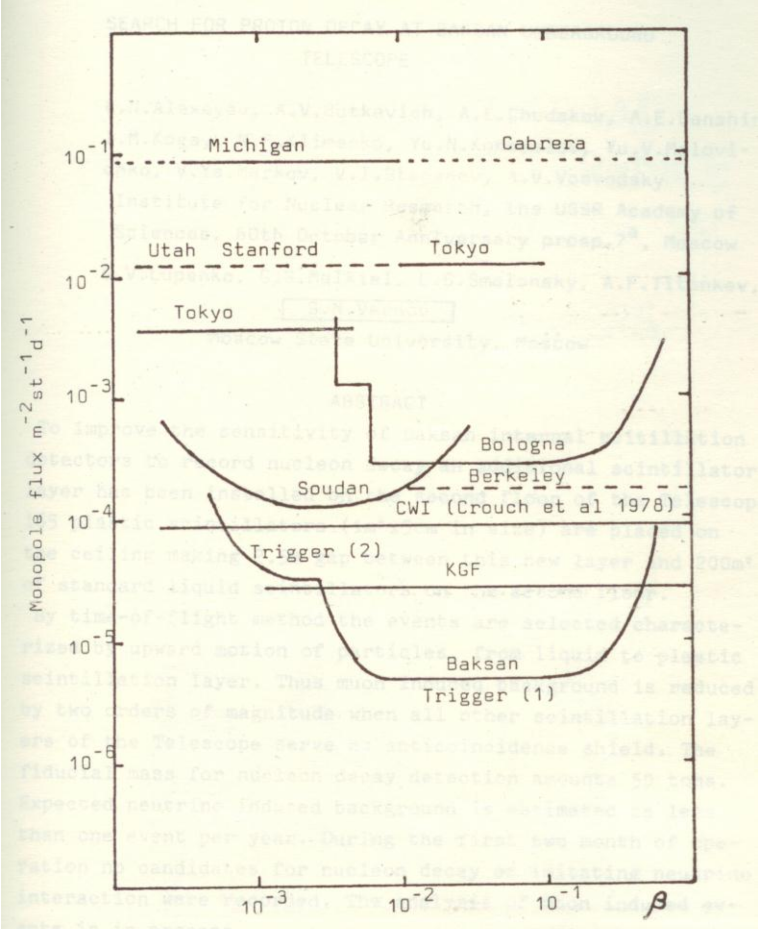


Fig.1 Upper limits for flux of superheavy magnetic monopole (for references see E.C.Loh 1982).

Upper limits on the flux of magnetic monopoles

The American-Italian collaboration MACRO (1988-2000) in LNGS

"Its principal goal was to observe magnetic monopoles or set significantly lower experimental flux limits than had been previously available in the velocity range from about $\beta=10^{-4}$ to unity."

M. Ambrosio et al., The MACRO detector at Gran Sasso, Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment 486(3):45 · July 2002

- Thus, the upper limit for the magnetic monopole flux was world-best for almost 20 years. The MACRO collaboration, for which this problem had been the main task, finally succeeded in reaching the level of Baksan, but practically failed to improve it.

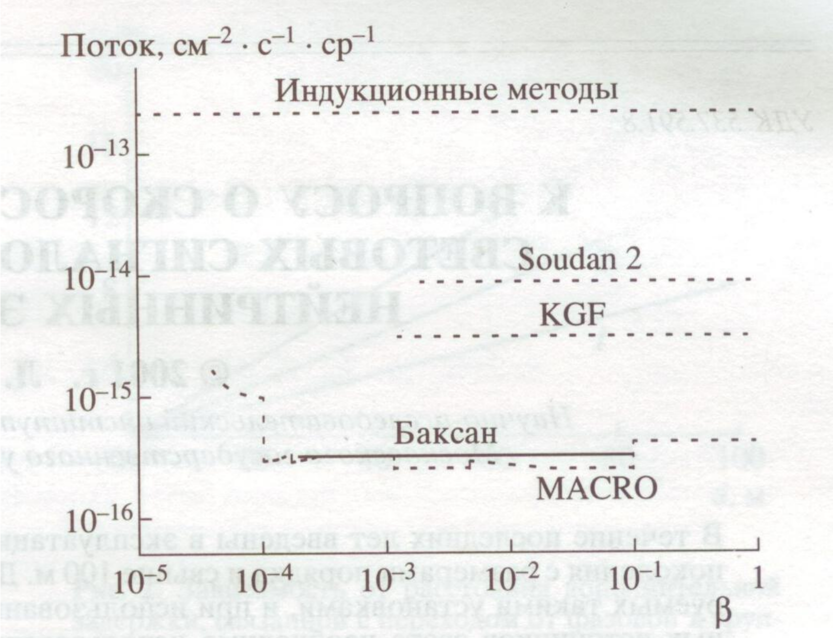


Рис. 2. Ограничение на поток магнитных монополей, полученное в данной работе, в сравнении с результатами других экспериментов.

Поиск магнитных монополей на Баксанском подземном сцинтилляционном телескопе, Изв. РАН, сер. физ. 65, №11, стр. 1662-1663 (2001)

Inelastic interactions of muons

- Бакатанов В.Н., Новосельцев Ю.Ф., Новосельцева Р.В., Семенов А.М., Стенькин Ю.В, Чудаков А.Е., Сечение фотоядерного взаимодействия при энергии фотонов в диапазоне от 0,9 до 10 ТэВ, Письма в ЖЭТФ, 1988, т. 48, стр. 121-123.

Верешков Г.М., Лалакулич О.Д., Новосельцев Ю.Ф., Новосельцева Р.В., Полное сечение γ-N взаимодействия в области энергий $\sqrt{s}$ = 40 - 250 ГэВ, Ядерная физика, 2003, т.66, вып.3, стр. 591 – 600

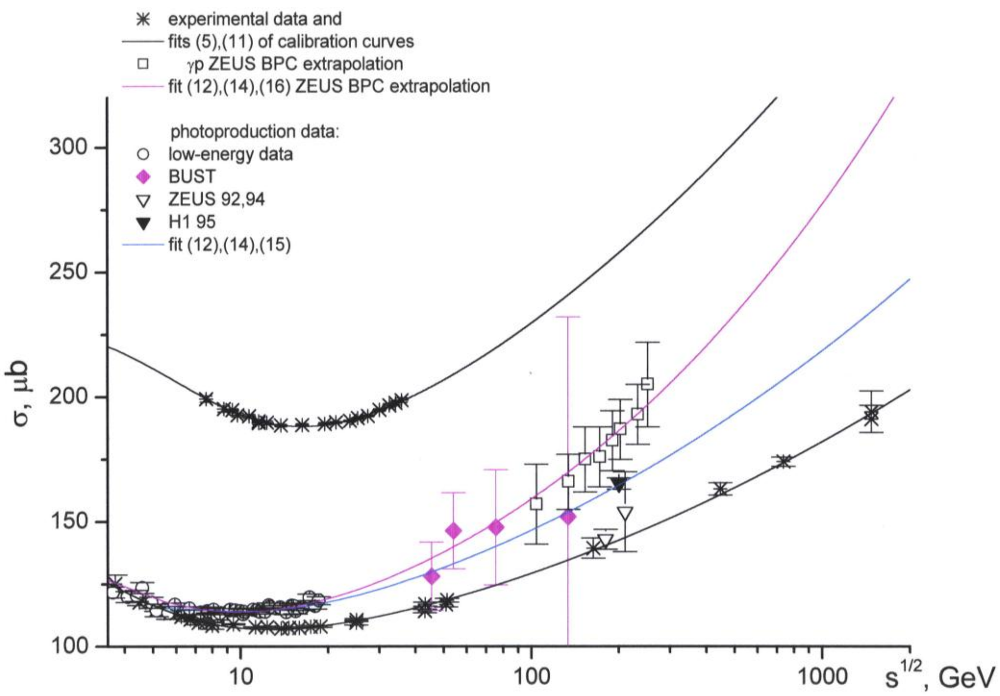


Fig.1. Calibration curves and cross section of γp interaction.

Muon bundles underground

V.N. Bakatanov, Yu.F. Novosel'tsev, R.V. Novosel'tseva, Observation of "the knee" in cosmic ray energy spectrum with underground muons and the primary mass composition in the range 10^{15} -10^{17} eV, Astroparticle Physics, 1999, v.12, p.19.

Y.F. Novoseltsev, R.V. Novoseltseva and G.M..Vereshkov,
On the mass composition of primary cosmic rays in the energy region 1015–1016 eV, J. Phys. G: Nucl. Part. Phys. **39** (2012) 105202

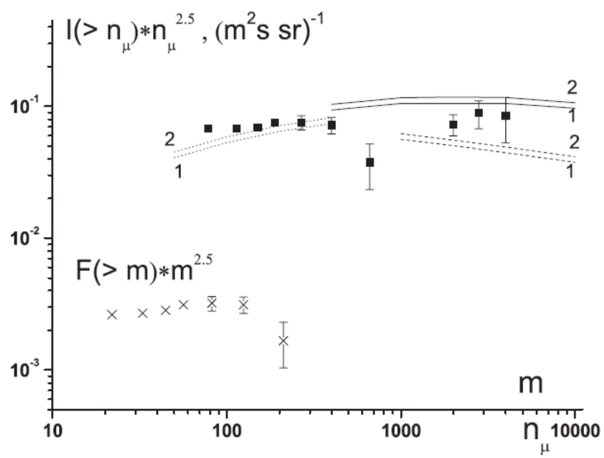
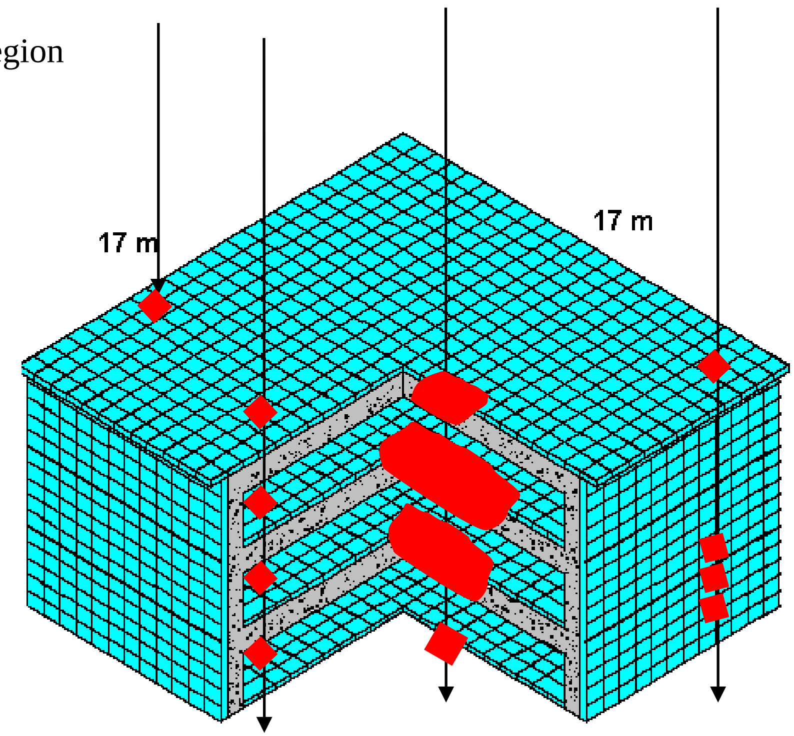
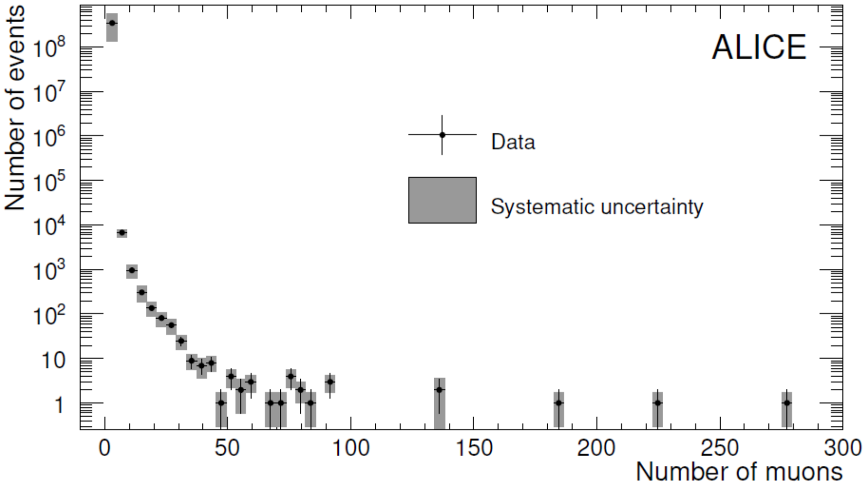


Figure 1. Squares are the EAS spectrum versus n_μ (experimental data). The muon threshold energy is $E_{th} = 235$ GeV if $n_\mu < 1000$ and $E_{th} = 220$ GeV at $n_\mu > 1000$ [16, 18]. Crosses show the muon multiplicity spectrum obtained in [15] (m and $F(m)$ correspond to the multiplicity spectrum). Solid curves are the expected fluxes ($E_{th} = 220$ GeV) for the case $E_k = Z \times 3 \times 10^{15}$ eV, dashed curves – the case $E_k = 3 \times 10^{15}$ eV/nucleus. Dotted curves show the expected fluxes for the case $E_k = Z \times 3 \times 10^{15}$ eV at $E_{th} = 235$ GeV. Numbers near curves denote the mass composition variants: 1 is the 'standard' (low energy) composition, 2 is the composition (2).



Muon bundles underground

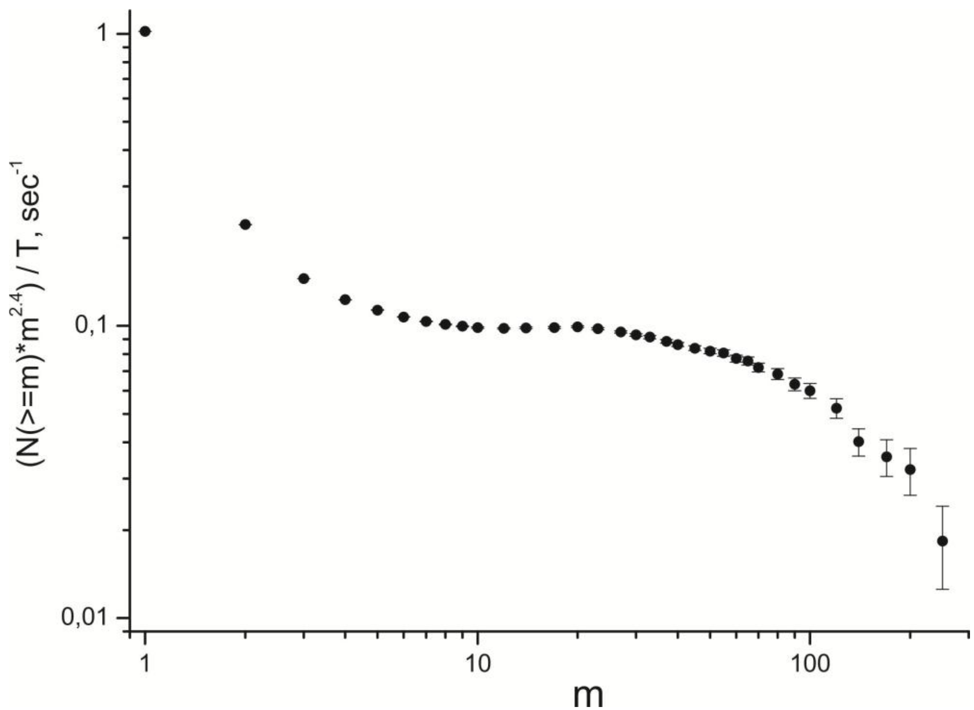


Highest multiplicities

Integral spectrum of BUST multiplicities

$\theta \leq 20^{o}$ for 9.8 years (1984 - 1995).

m	events
100	295
120	166
140	88
170	49
200	30
250	10

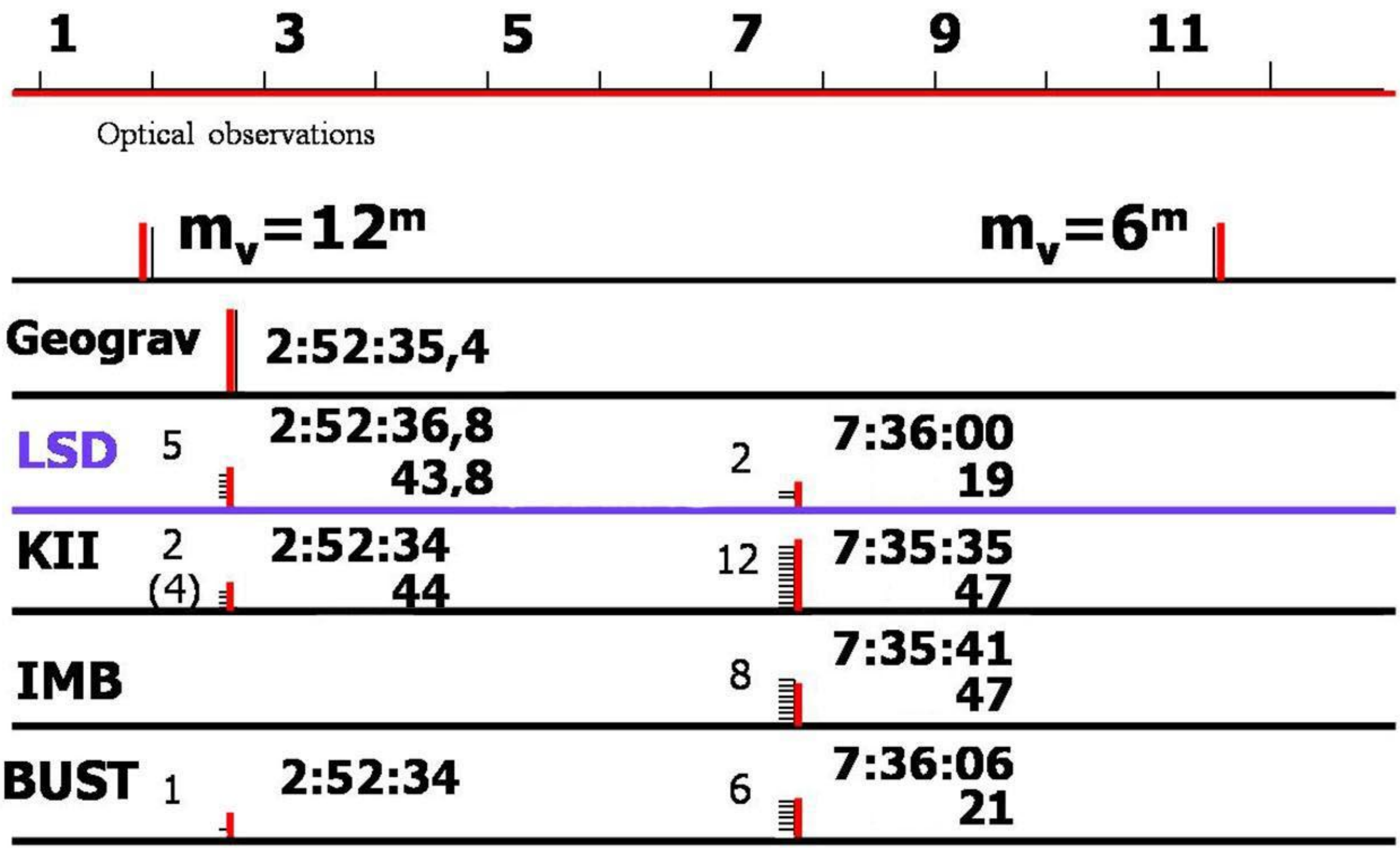


Neutrino bursts from collapsing stars

- The BUST appeared to be one of four instruments in the world that succeeded in detecting the neutrino signal from collapsing star during explosion of supernova SN1987A in the Large Magellanic Cloud

E.N. Alexeev, L.N. Alexeeva, I.V. Krivosheina, V.I. Volchenko, Detection of the Neutrino Signal from SN1987A in the LMC using the INR Baksan Underground Scintillation Telescope, Phys.Lett. B205 (1988) 209-214.

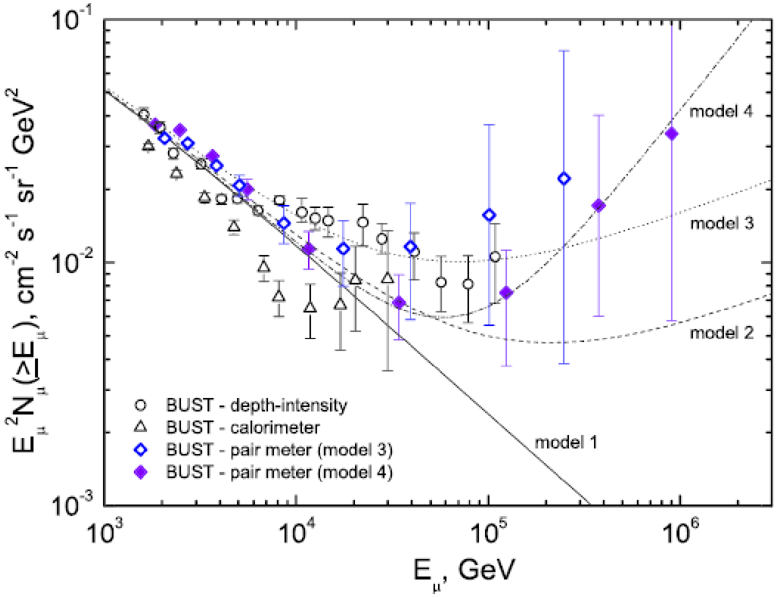
February 23, 1987

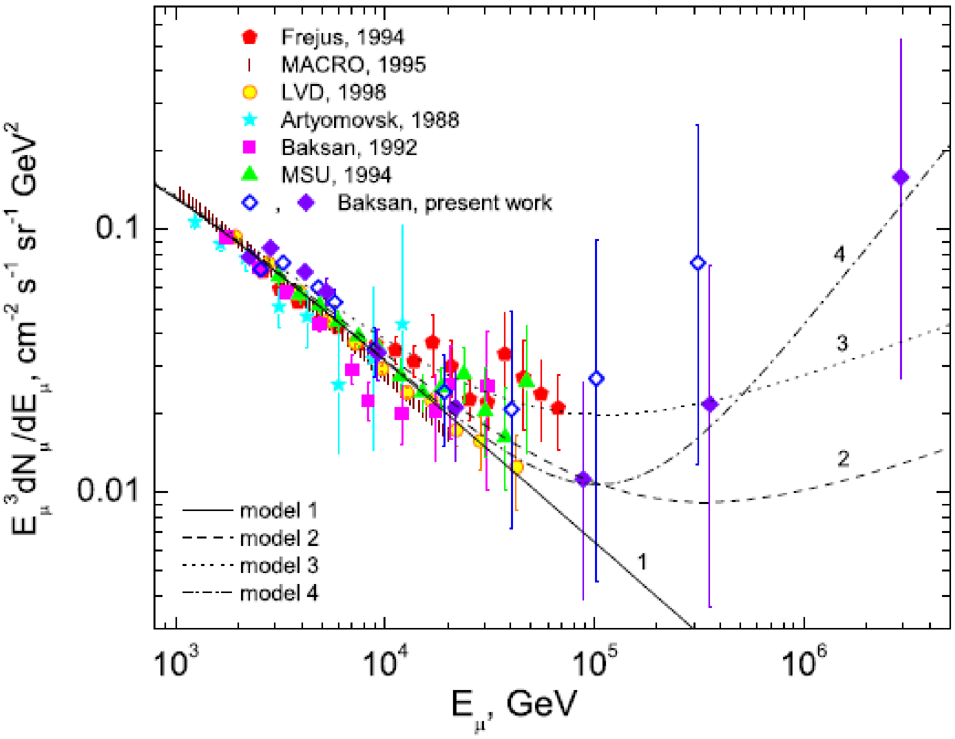


Energy spectrum of high-energy muons

V.N. Bakatanov, A.E. Chudakov, Yu.F. Novosel'tsev, R.V. Novosel'tseva, A.M. Semenov, Yu.V.Sten'kin. Study of muon spectrum and muon inelastic scattering at Baksan underground scintillation telescope. Proc. of 21 ICRC, Adelaide, 1990, v.9, p. 375-378.

A.G. Bogdanov, R.P. Kokoulin, Yu.F. Novoseltsev, R.V. Novoseltseva, V.B. Petkov, A.A. Petrukhin, Energy spectrum of cosmic ray muons in 100 TeV energy region reconstructed from the BUST data, Astroparticle Physics, 36 (2012) 224–236





Gamma-ray astronomy

The Crab Nebula burst on Feb 23, 1989 г.

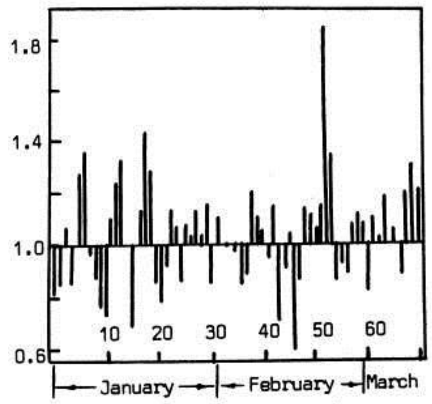
V.V. Alexeenko, A.S. Lidvansky, V.A. Tizengauzen,

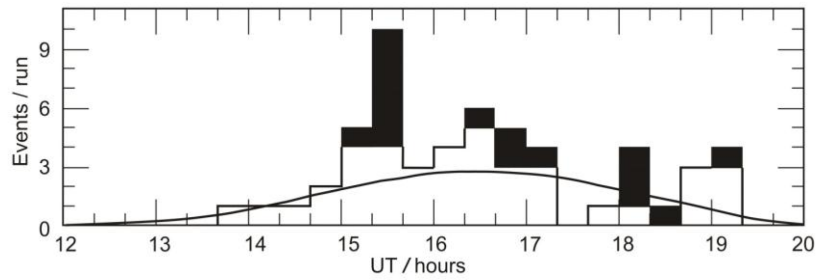
A Search for > 10^{14} eV Gamma Rays from Point Sources at Baksan Air Shower Array, Proceed. of Intern. Workshop on Very High Energy Gamma Ray Astronomy, Crimea, 1989, ed. by A.A. Stepanyan, D.J. Fegan, and M.F. Cawley, p. 137

- Acharya B.S., Rao M.V.S., Sivaprasad K., Sreekantan B.V., and Vishwanath P.R., First simultaneous detection of PeV energy burst from the Crab Nebula,

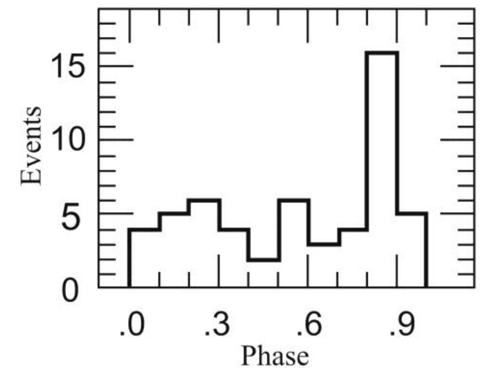
  Nature, **347** (1990)**,** 364-5.

- V.V. Alexeenko, Yu.M. Andreyev, A.E. Chudakov, Ya.S. Elensky, A.S. Lidvansky, S.Kh. Ozrokov, Yu.V. Stenkin, V.A. Tizengauzen, L.J. Graham, J.L. Osborne, A.W. Wolfendale. The ultra-high energy gamma-ray burst from the Crab Nebula observed by the Baksan EAS array. Journ. of Phys. G : Nucl. Part. Phys. 18 (1992) L83-L88.

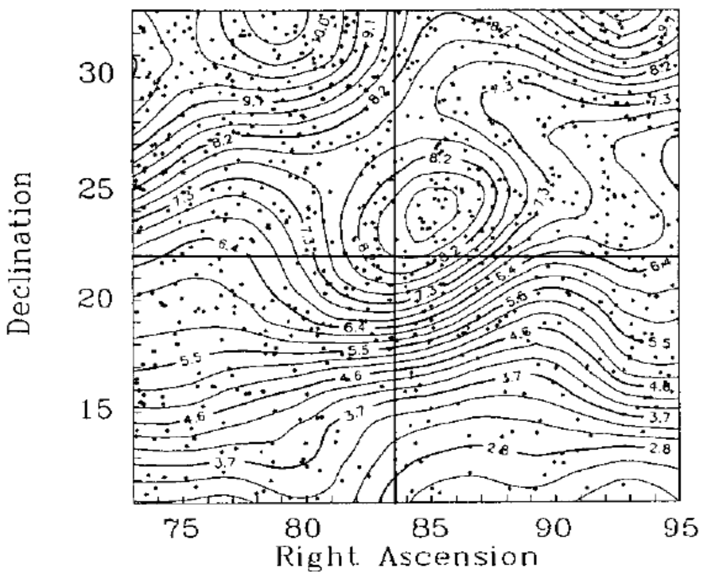


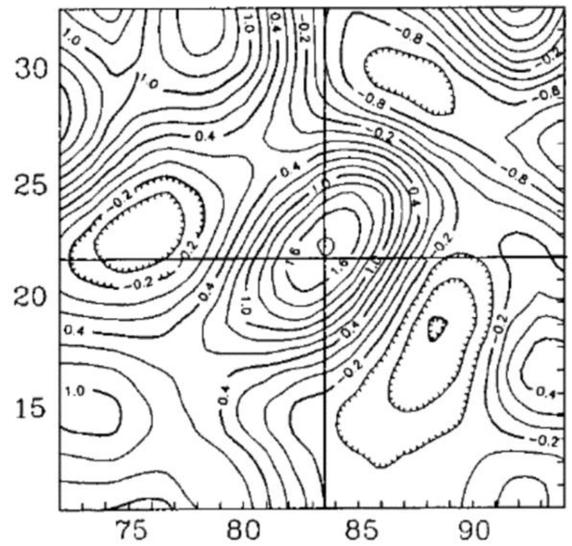


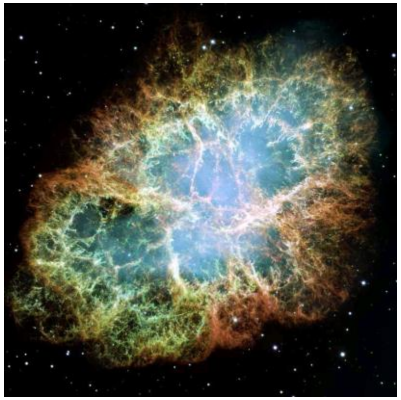
Time dependence of the counting rate in the source cell with a radius of 2.5°



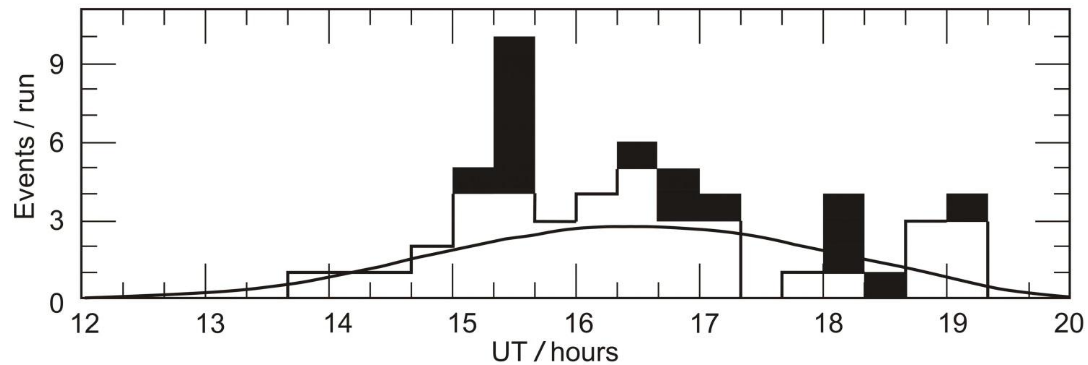
Phase analysis with period of pulsar PSR0531 (without absolute time reference)

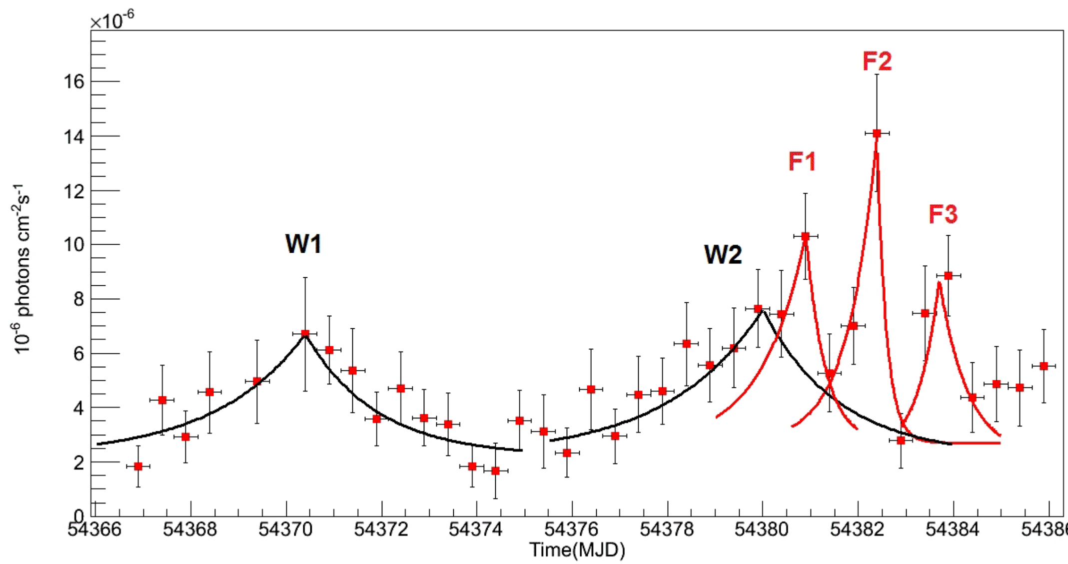


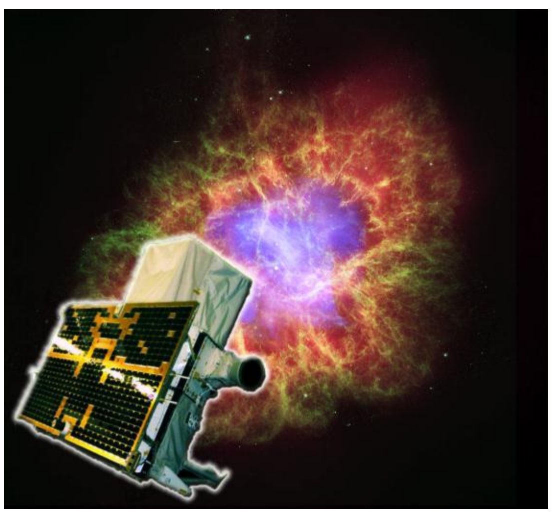




Similar triple time structure of flares for energies differing by a factor of 10^6. Single scale factor (about 20, hours and days, for a period of repetition and duration of pulses).

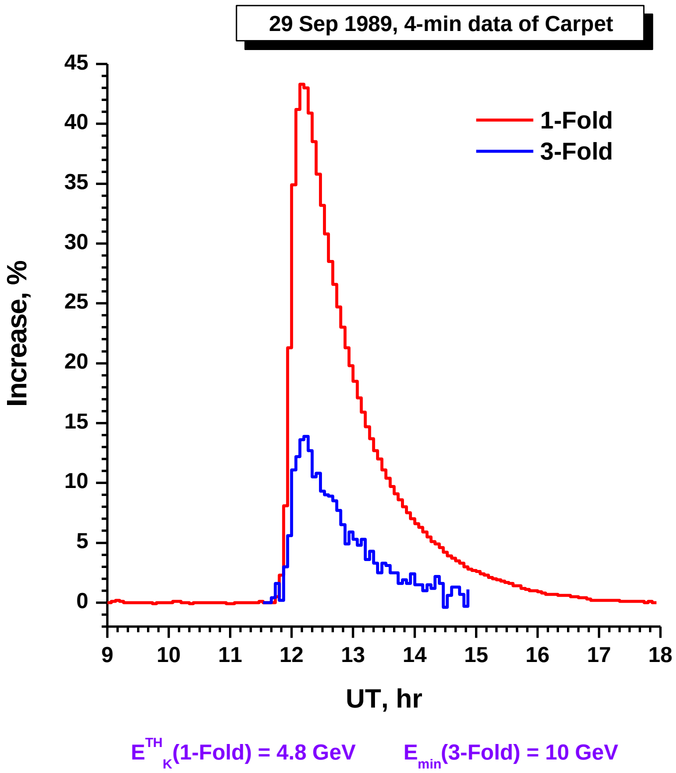


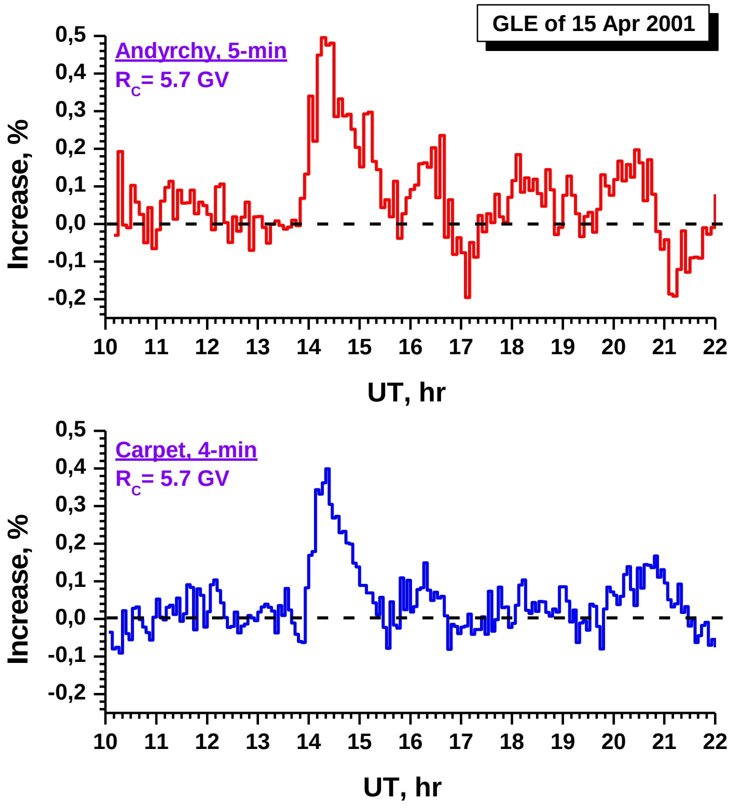




E. Striani et al., Variable gamma-ray emission from the Crab Nebula: short flares and long “waves”, Astrophys. Journ., 76552, 2013 March 1

Detection of GLE from solar flares





Anisotropy of cosmic rays

10 TeV Carpet 1981
2.5 TeV BUST 1987
100 TeV Andyrchi 2004

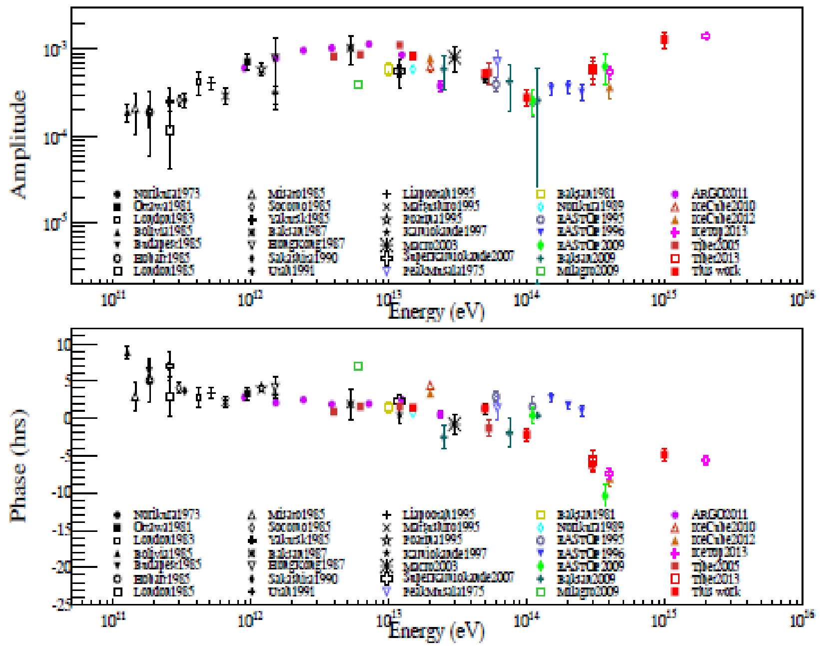
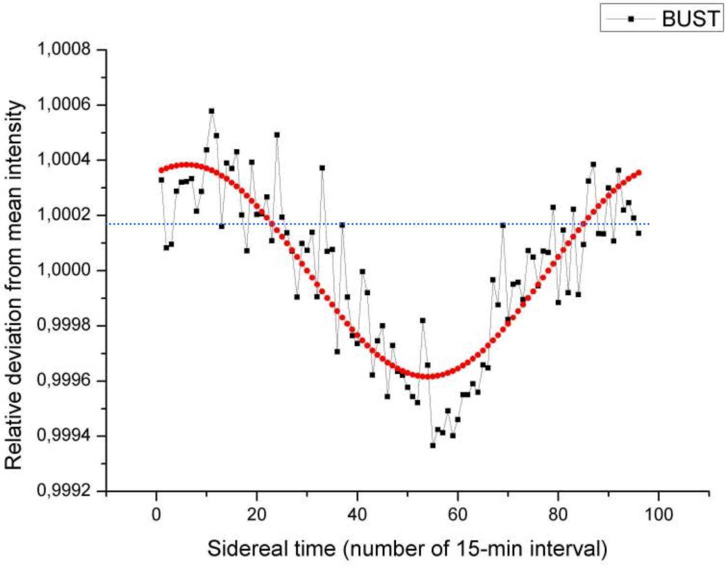
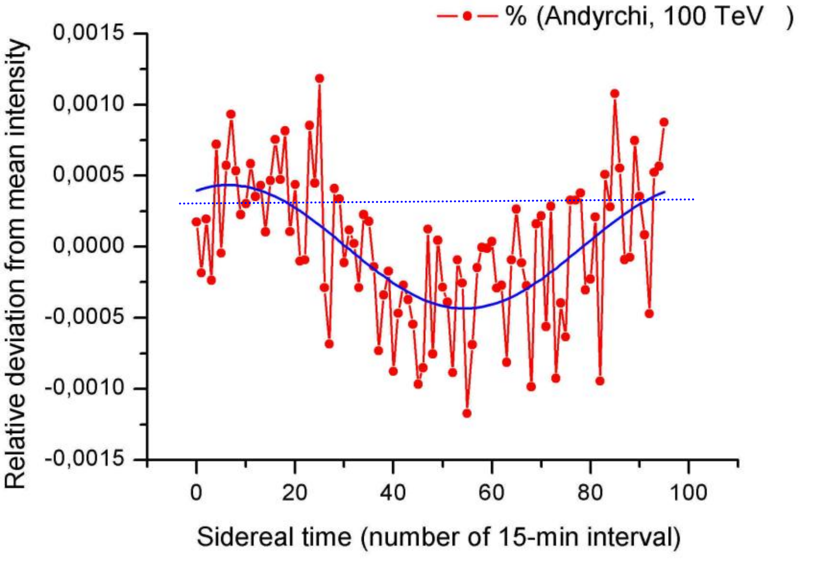


FIG. 5.— The energy dependences of amplitude (top) and phase (bottom), of the first harmonics of the CRs anisotropy obtained in this work, and reported from previous measurements. They are underground muon observations: Norikura(1973) (Sakakibara et al. 1973), Ottawa(1983) (Bercovitch & Agrawal 1981), London(1983) (Thambyahpillai 1983), Bolivia(1985) (Swinson & Nagashima 1985), Budapest(1985) (Swinson & Nagashima 1985), Hobart(1985) (Swinson & Nagashima 1985), London(1985) (Swinson & Nagashima 1985), Misato(1985) (Swinson & Nagashima 1985), Socorro(1985) (Swinson & Nagashima 1985), Yakutsk(1985) (Swinson & Nagashima 1985), Banksan(1987) (Andreyev et al. 1987), HongKong(1987) (Lee & Ng 1987), Sakashita(1990) (Ueno et al. 1990), Utah(1991) (Cutler & Groom 1991), Liapootah(1995) (Munakata et al. 1995), Matsushiro(1995) (Mori et al. 1995), Poatina(1995) (Fenton et al. 1995), Kamiokande(1997) (Munakata et al. 1997), Marco(2003) (Ambrosio et al. 2003), SuperKamiokande(2007) (Guillian et al. 2007), and air shower array experiments: PeakMusala(1975) (Gombosi et al. 1975), Baksan(1981) (Alexeyenko et al. 1981), Norikura(1989) (Nagashima et al. 1989), EASTOP(1995,1996,2009) (Aglietta et al. 1995, 1996, 2009), Baksan(2009) (Alekseenko et al. 2009), Milagro(2009) (Abdo et al. 2009), IceCube(2010,2012) (Abbasi et al. 2010, 2012), IceTop(2013) (Aartsen et al. 2013), ARGO-YBJ(2015) (Bartoli et al. 2015), Tibet(2005,2013) (Amenomori et al. 2005b; Amenomori et al. 2013).

Anisotropy of cosmic rays:

in high-energy muons (underground) and in small-size EAS (on the ground surface)





First harmonic of sidereal daily wave as measured by the BUST (threshold for primaries 2.5 TeV) and air shower Andyrchi array (100 TeV)

Variations of cosmic rays during thunderstorms

Disturbances in secondary cosmic ray intensity during thunderstorms were first discovered in pioneering experiment in 1985 г.

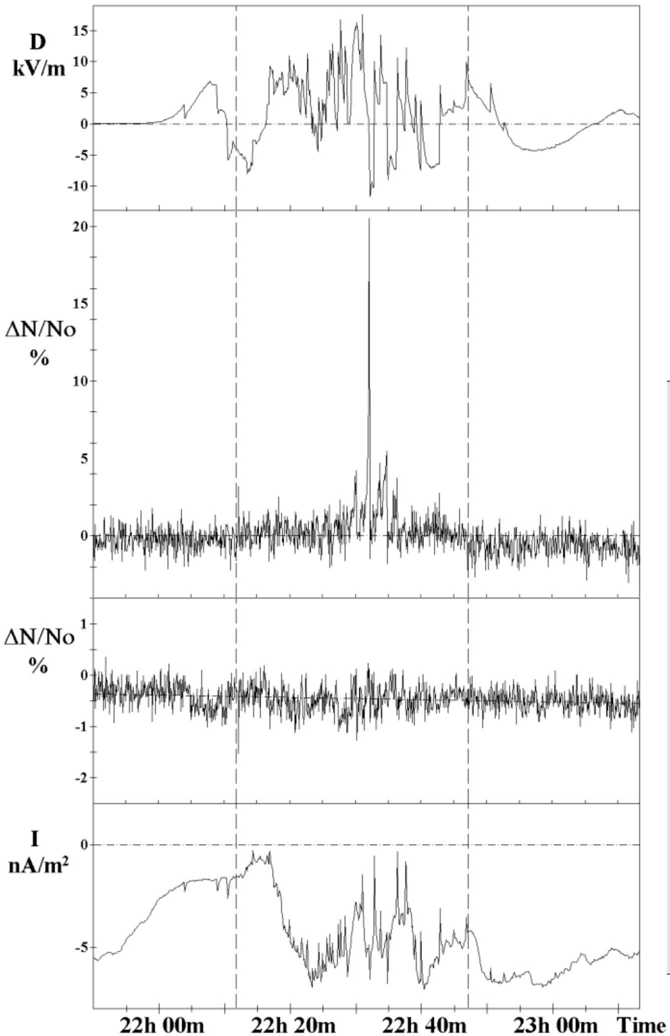
Alexeyenko, V.V., Chudakov, A.E., Sborshikov, V.G., and Tizengauzen, V.A., Short perturbations of cosmic ray intensity and electric field in atmosphere, Proc. 19th ICRC, La Jolla, 1985, vol. 5, pp. 352-355.

The experiment restarted again at a new level in 2000.

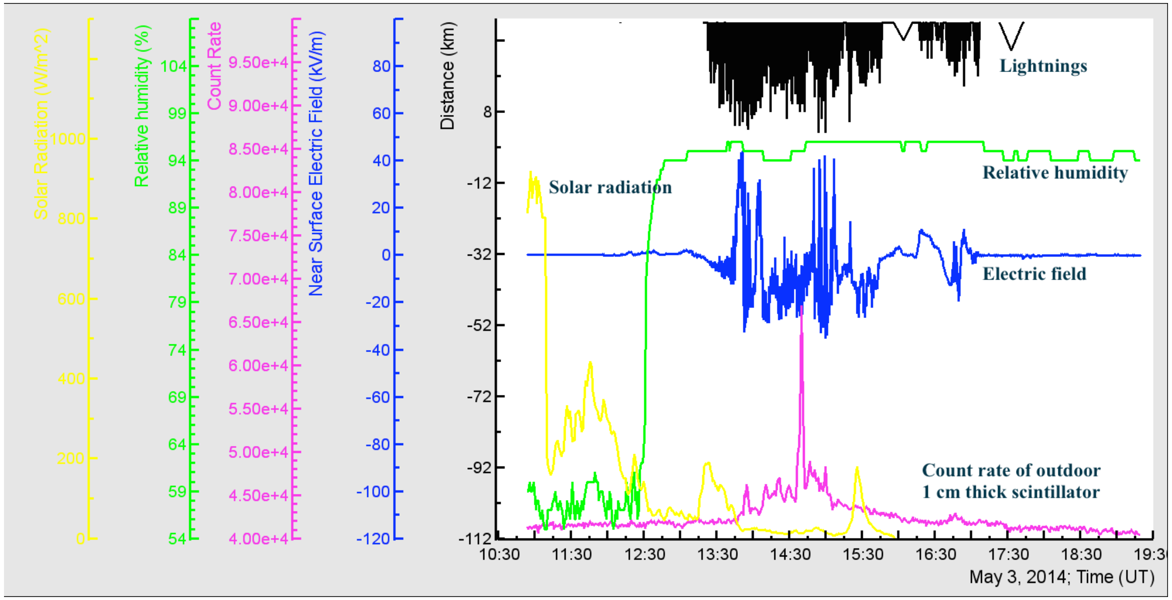
V.V. Alexeenko, N.S. Khaerdinov, A.S. Lidvansky, and V.B. Petkov, Transient Variations of Secondary Cosmic Rays due to Atmospheric Electric Field and Evidence for Pre-Lightning Particle Acceleration, Physics Letters A, 2002, vol. 301, issues 3-4, pp. 299-306.

At the moment this line of research represents the separate field of science. The specialized annual TEPA (Thunderstorm Elementary Particle Acceleration) workshops are carried out at Nor-Amberd (Armenia).

Strong enhancement of the soft component on September 7, 2000, Baksan Valley.

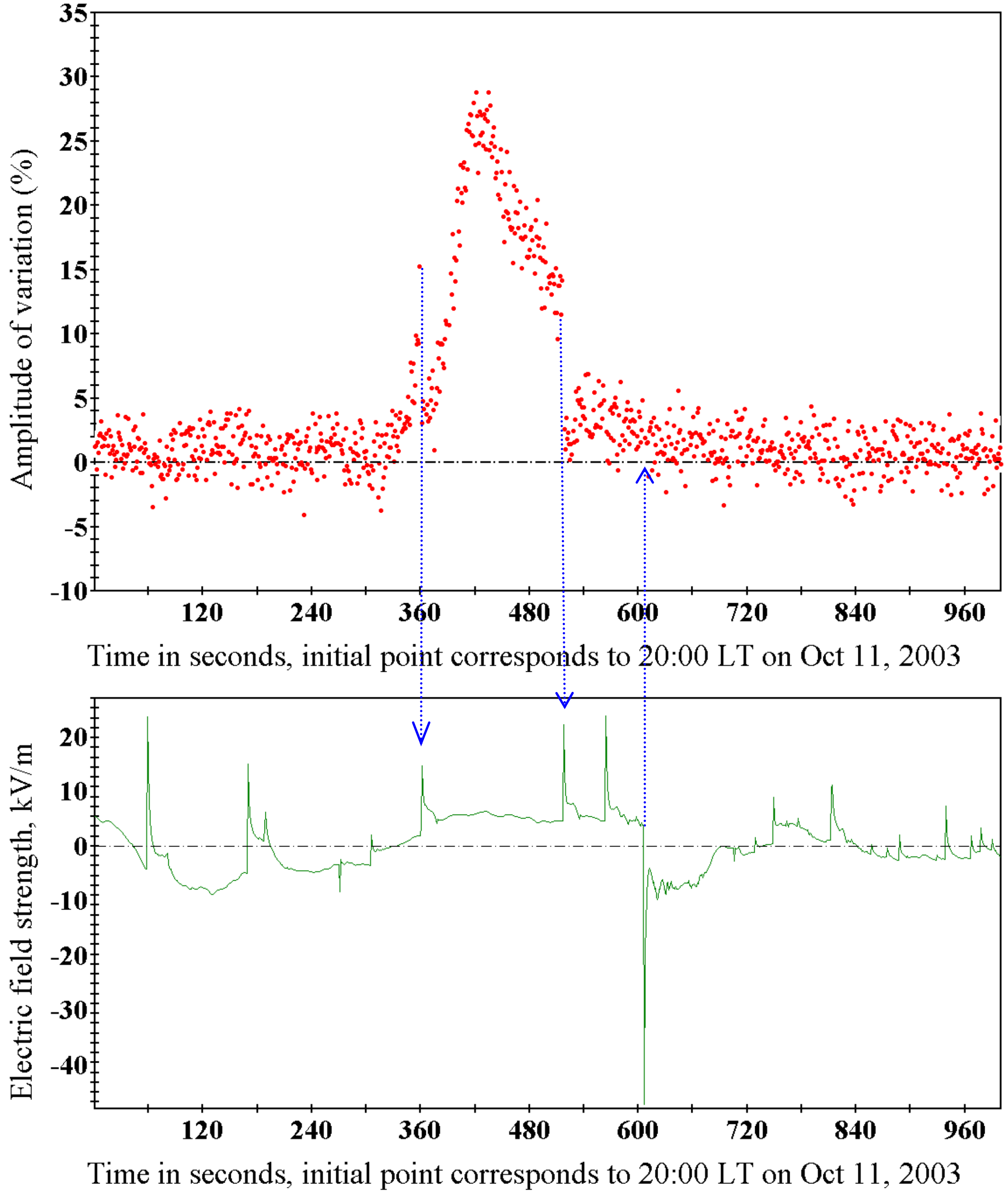


Mt. Aragats experiment in Armenia. Very similar example of TGE.

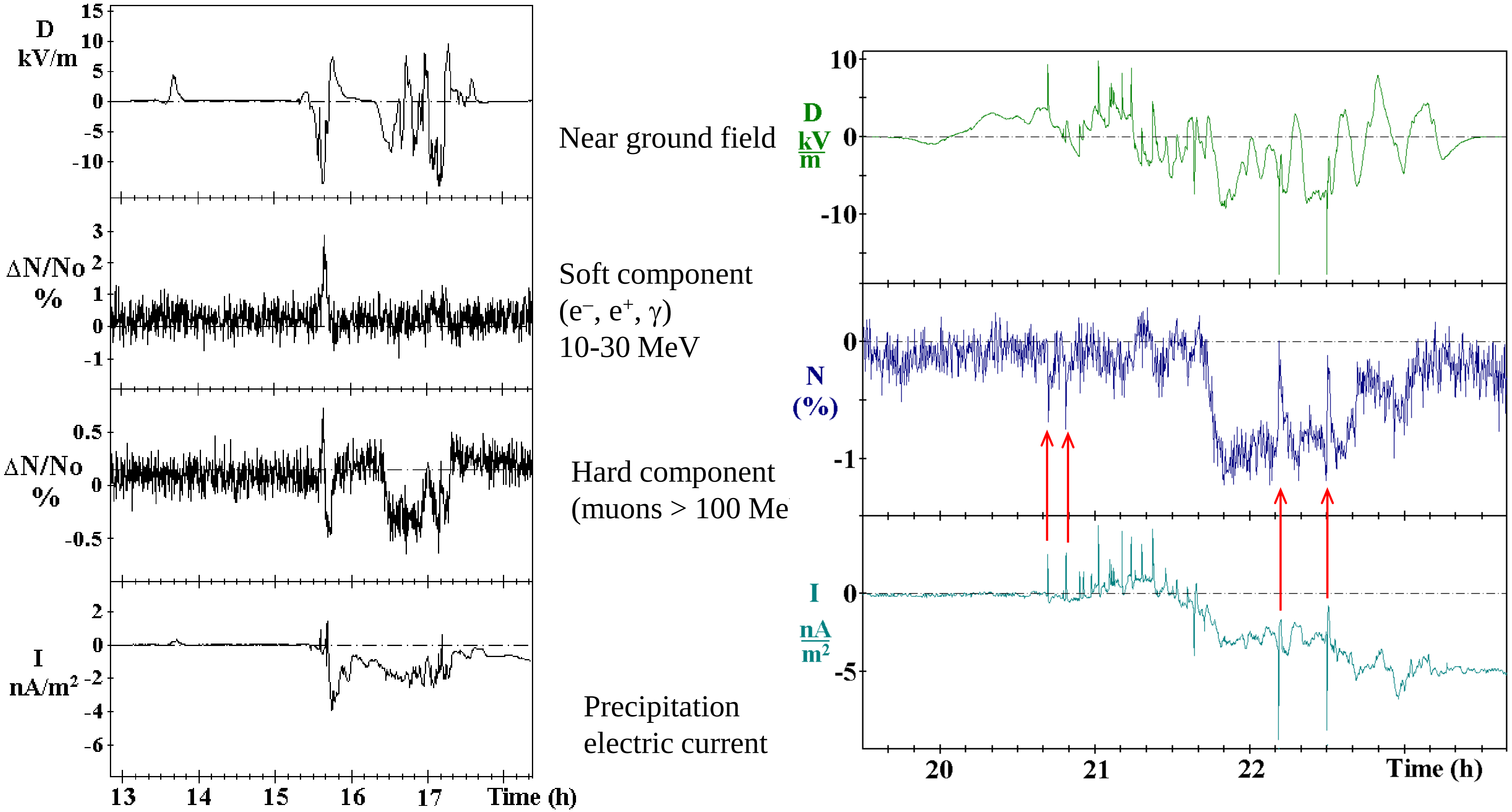


Record enhancement during thunderstorm on October 11, 2003

Estimates of minimal distance to two lightning strokes exerting strong effect on the intensity are 4.4 and 3.1 km. Other lightning discharges, including very near, give no such an effect.



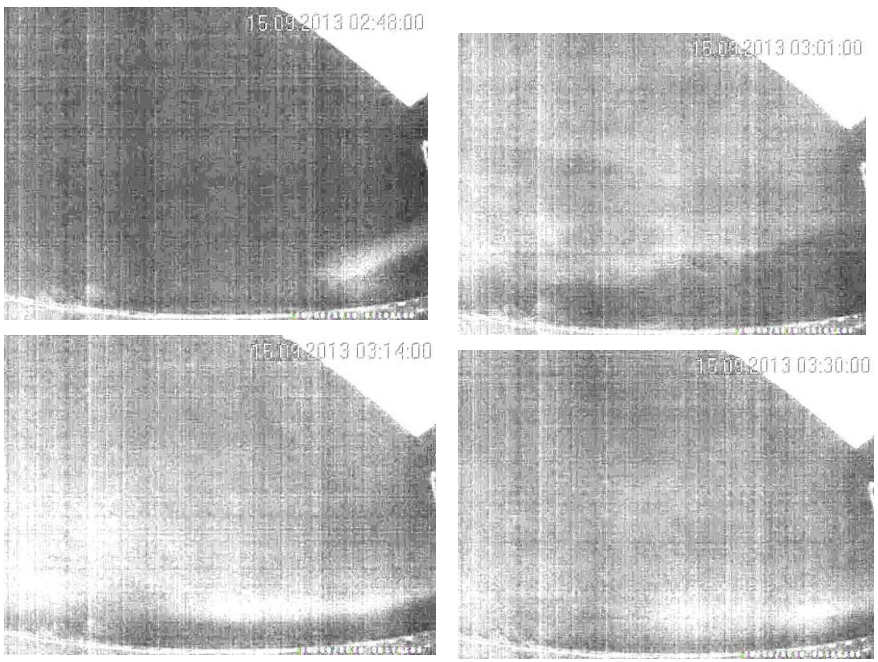
Two strong variations of muons on one day of a year separated by seven years: September 24, 2000 and 2007. In the latter event sharp variations associated with lightning discharges are observed



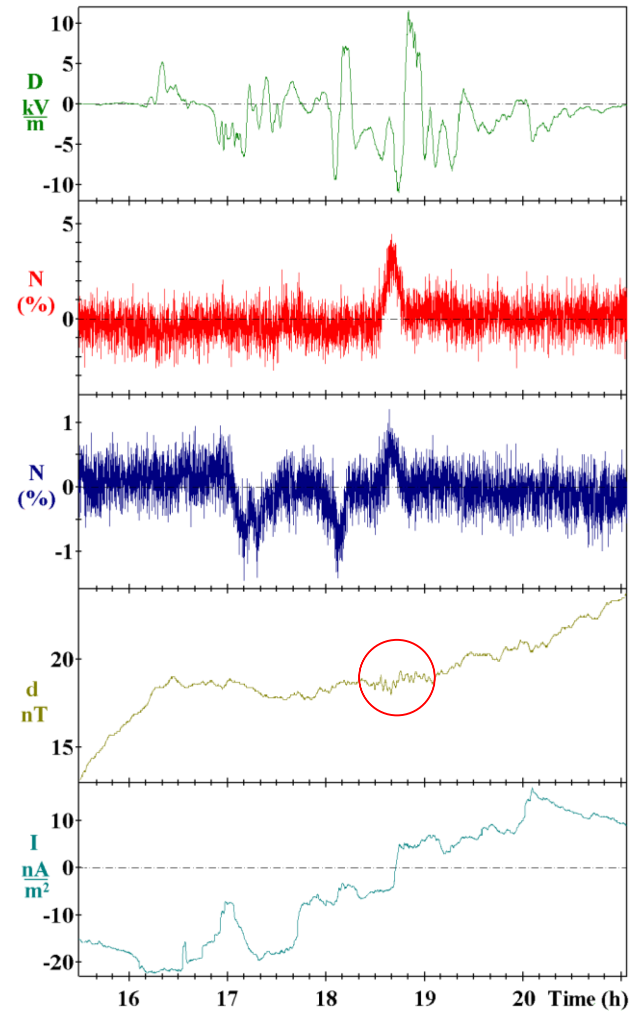
CR Variations during thunderstorms:

geomagnetic pulsations and new type of high-altitude discharge coincident with muon intensity disturbances

Thunderstorm event on September 15, 2013.



The event on October 15, 2007



Upper limits on the Dark Matter (neutralino) parameters

M.M. Boliev, E.V. Bugaev, A.V. Butkevich, A.E. Chudakov, S.P. Mikheev, O.V. Suvorova, V.N. Zakidyshev, Nucl. Phys. Proc. Suppl. (1996) 83-86

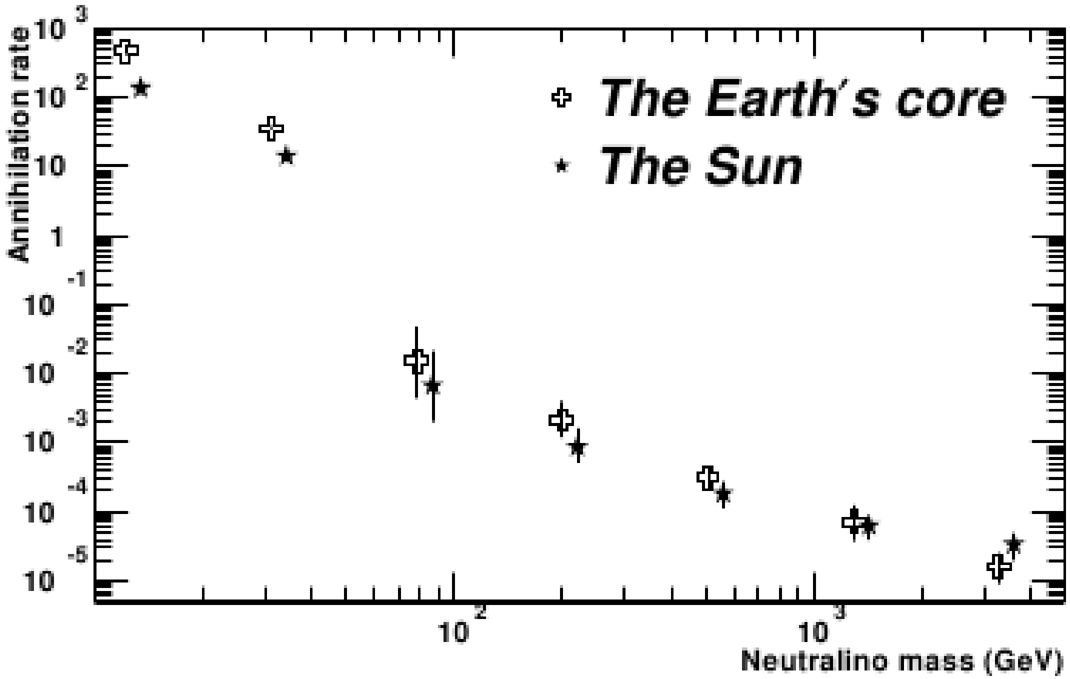
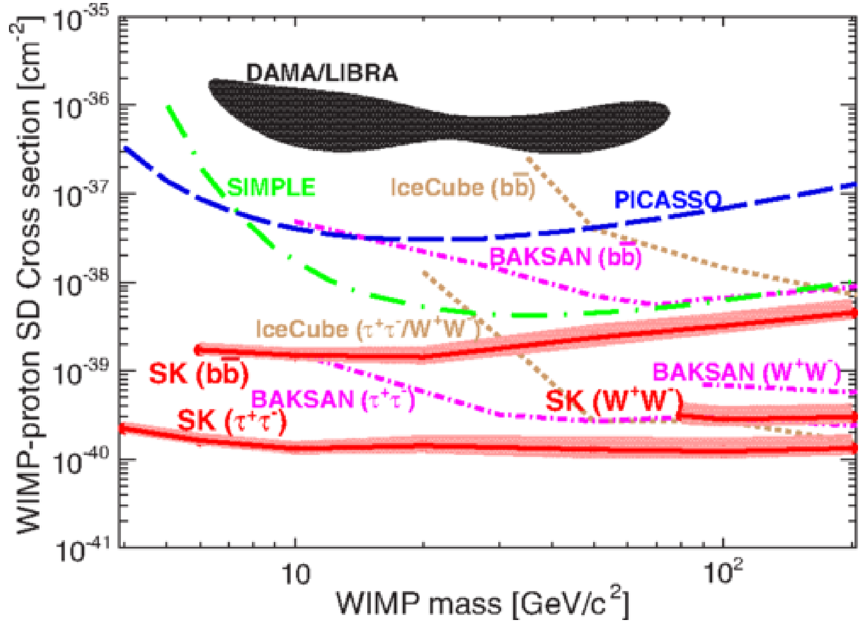
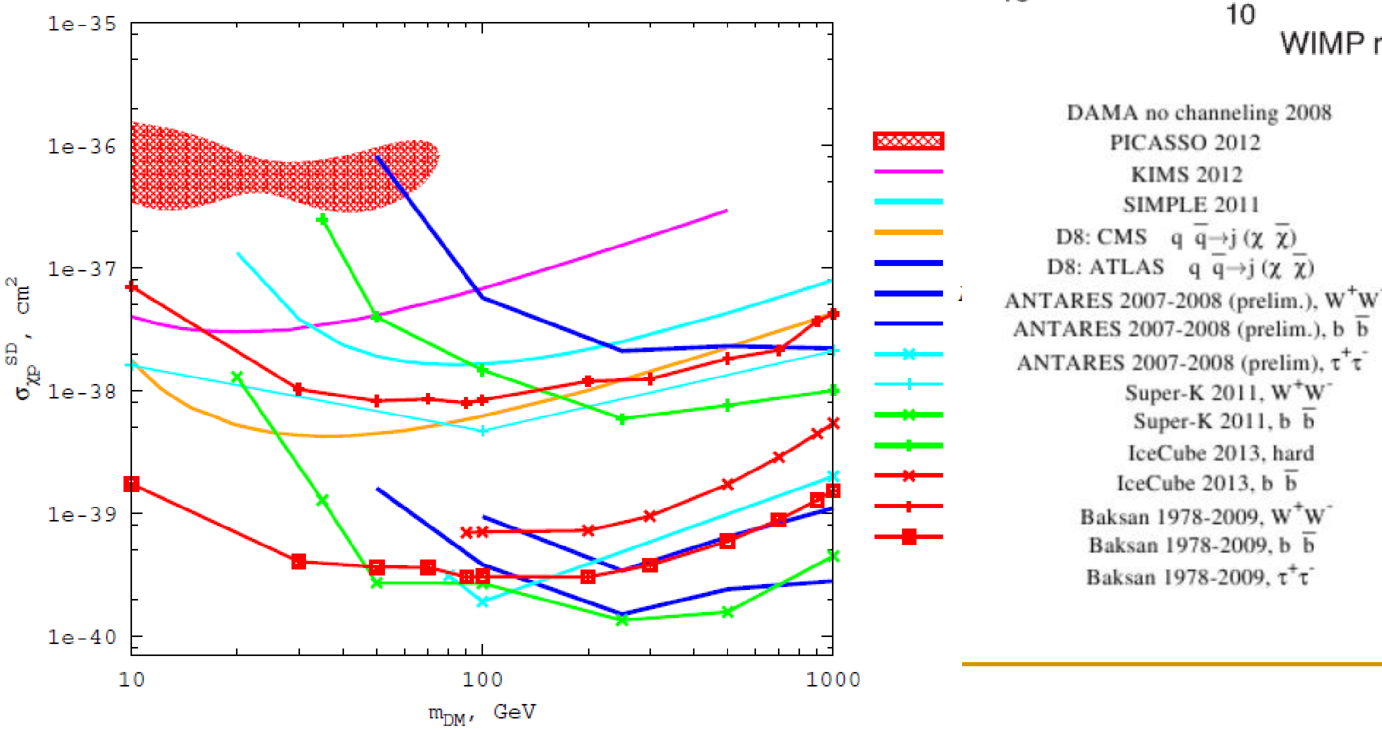


Fig. 4. Upper limits at 90% confidence level on annihilation rate in units of $10^{15} s^{-1}$ ($10^{24} s^{-1}$) for the Earth's core (crosses) (the Sun (stars)) as a function of neutralino mass. Vertical bars show spread due to variations of another model parameters.

Dark matter. Upper limits on the cross section of WIMP scattering





The Baksan limits on SD elastic cross section of dark matter particle on proton in comparison with other experimental results in direct and indirect DM searches.

Thermal neutrons: new methods of studying EAS and geophysical phenomena

- A new type of detectors of thermal neutrons was developed and first applied for studies in cosmic ray physics (the PRISMA project) and geophysics

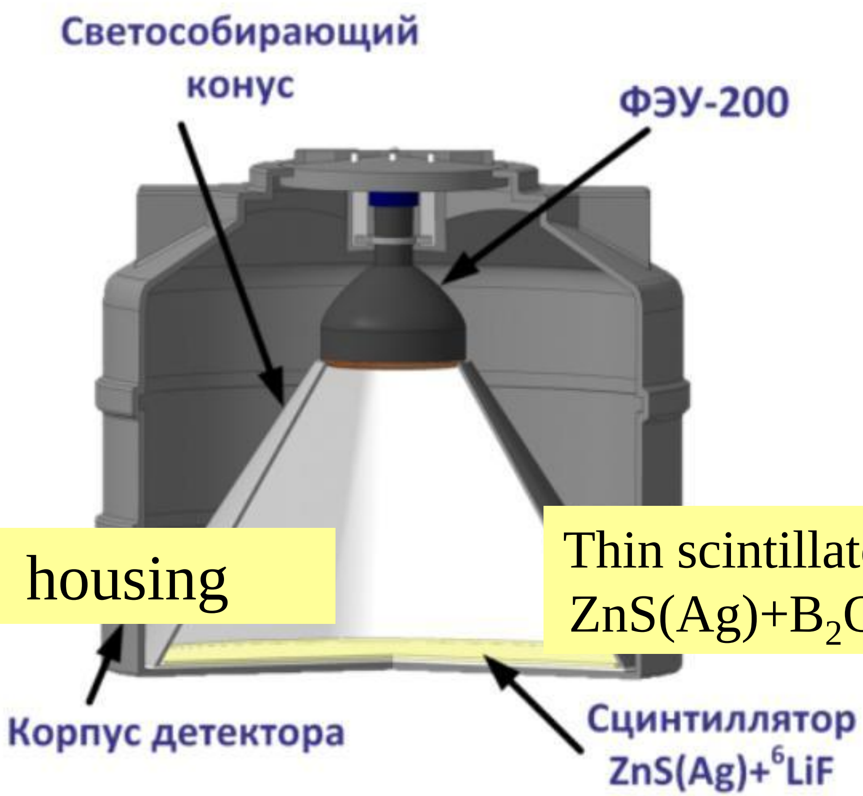
- Currently, as a part of the PRISMA project three experimental setups operate in collaboration with MEPhI and IHEP (China): two in Moscow (MEPhI) PRISMA-32 and URAN, and one in Tibet at an altitude of 4300 m a.s.l. (PRISMA-YBJ).

- On a larger scale these detectors will be used in the LHAASO project.

Light collecting cone

PMT FEU-200

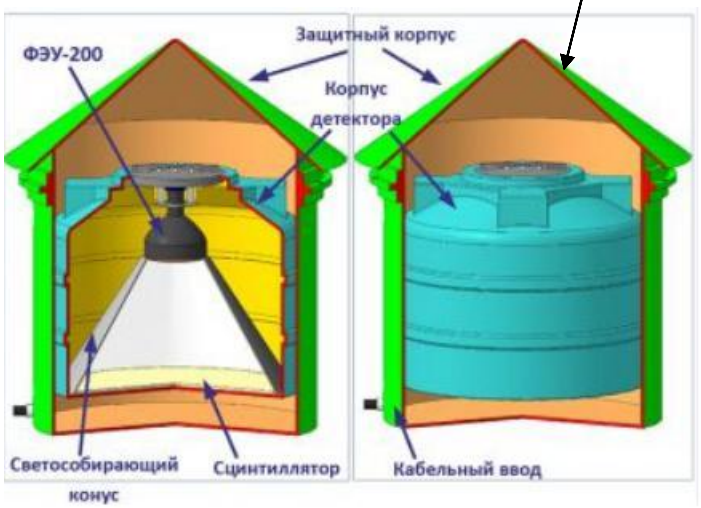
Scintillation detector that is capable of recording simultaneously two basic components of EAS (electromagnetic and hadronic).



housing

Thin scintillator $ZnS(Ag)+B_2O_3$

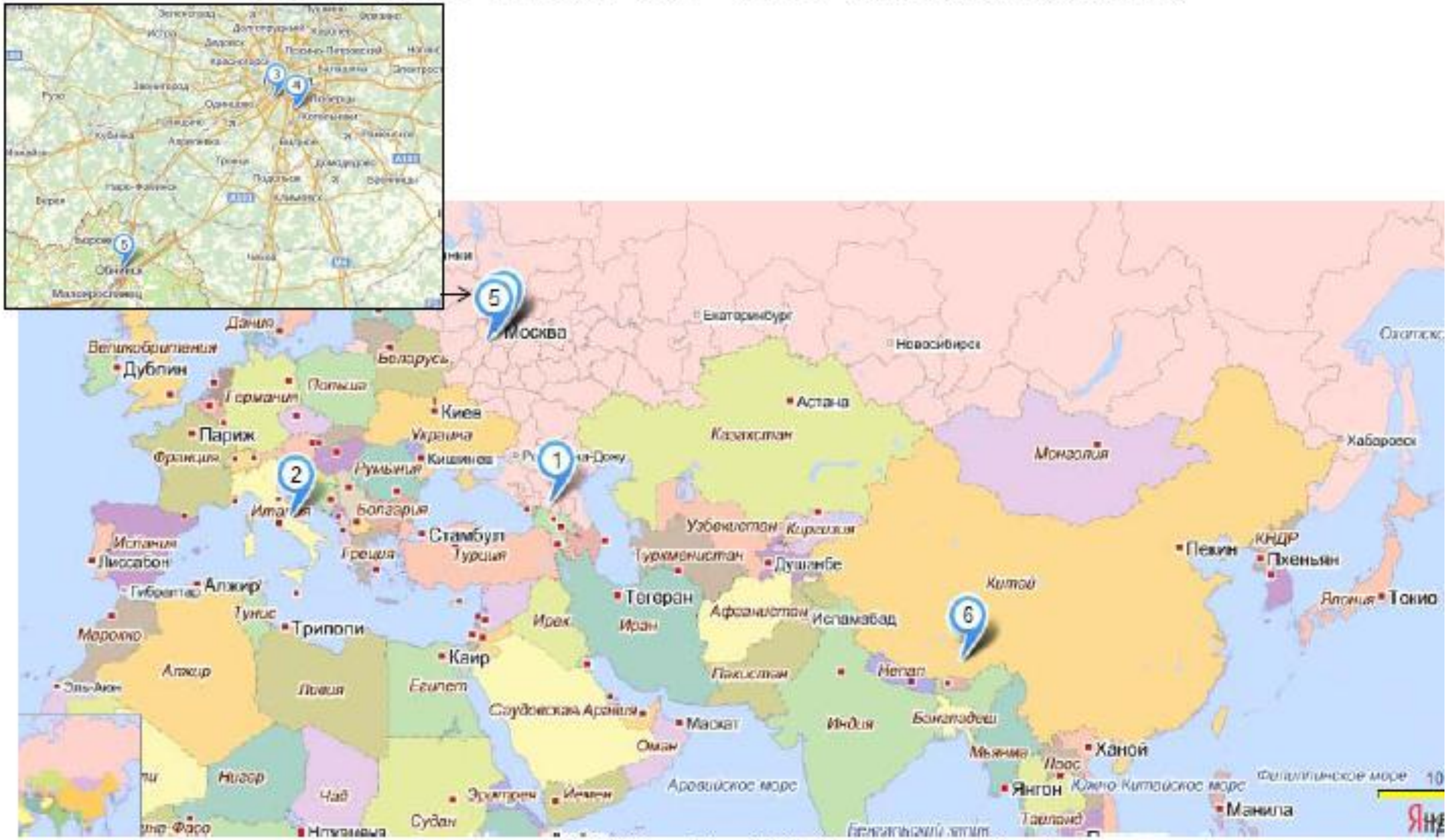
Environmental protecting housing



Design of n-detector

Geophysical research

Global net of en-detectors



Summary: the results that still hold first positions either in history or at the moment

- The results obtained for the first time (first vertical neutrino detection, first QCD confirmation, …)
- One-shot (single occurrence) events (bursts of gamma and neutrino emission, outstanding solar flares)
- The results still not repeated (high-energy muons, muon and electron flux variations during thunderstorms under the action of electric field)
- Pioneering works and methods (electric field effects on CR, n-detectors)