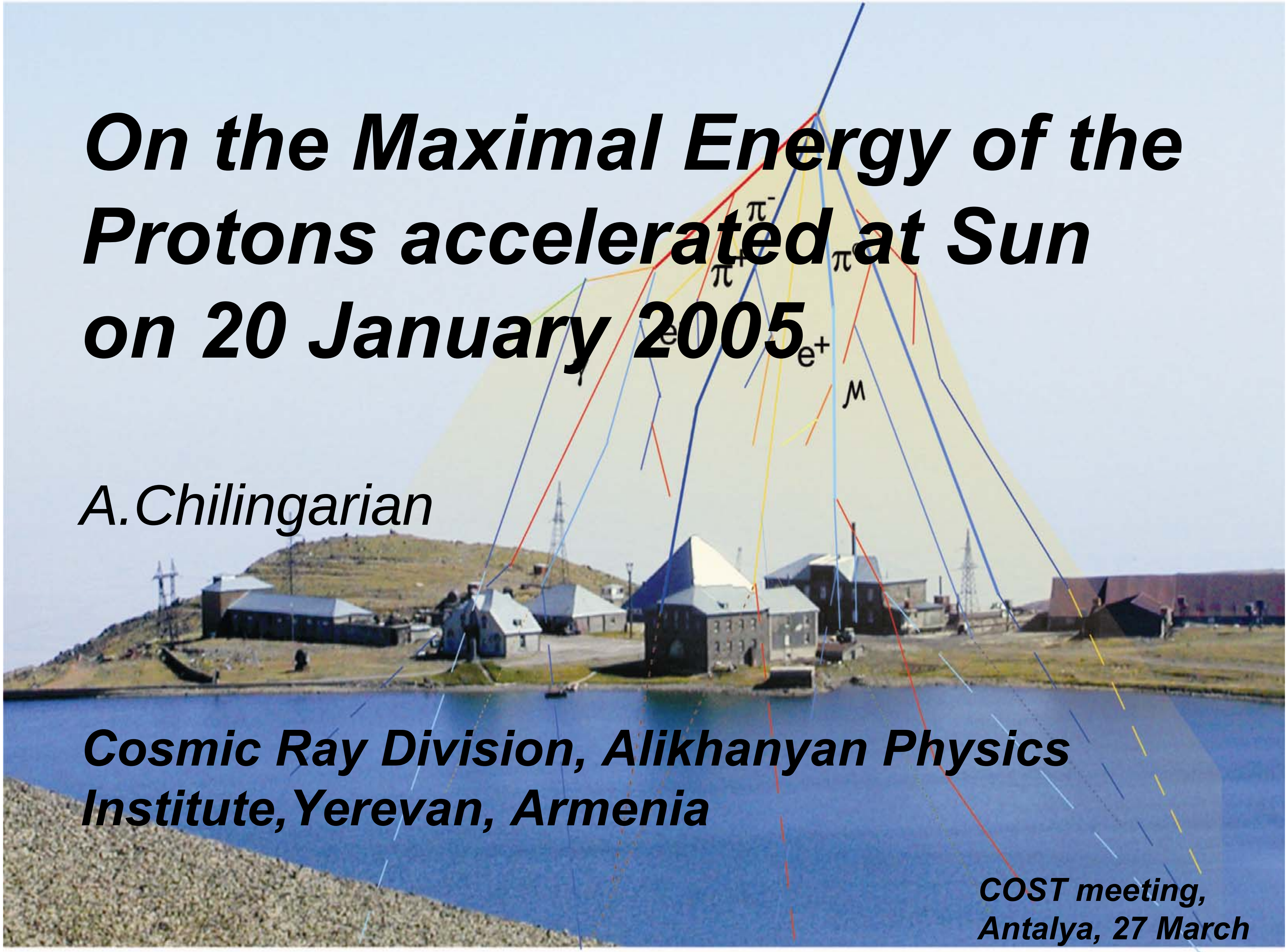


On the Maximal Energy of the Protons accelerated at Sun on 20 January 2005

A.Chilingarian

Cosmic Ray Division, Alikhanyan Physics Institute,Yerevan, Armenia

COST meeting, Antalya, 27 March

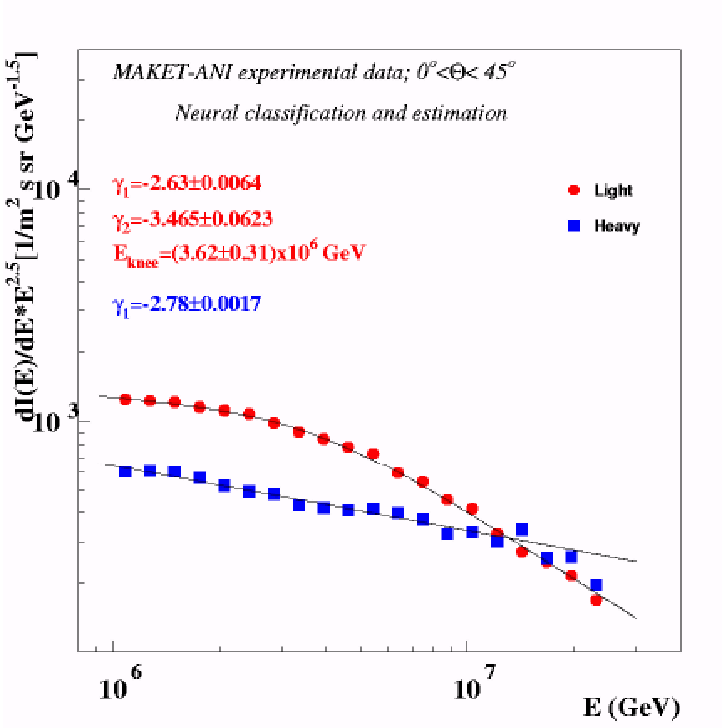
Nor Amberd Research Station

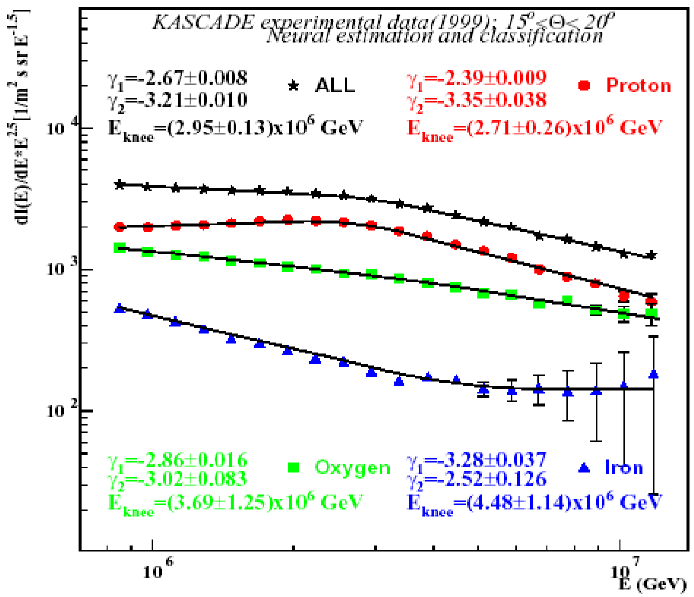
Opening of the Road to Aragats, May, 2003

CRD Research Profile

- Cosmic Ray Astrophysics – Research of Cosmic Ray Sources and Acceleration Mechanisms by ground based surface detectors.
- Solar Physics – Detection on Earth by neutron monitors and muon telescopes Solar Energetic Particles.
- Monitoring and Forecasting of the Space Weather.
- Multivariate Data Analysis - Monte Carlo Statistical Inference

Partial Energy Spectra of Light and Heavy CR –first published by CRD, YerPhI





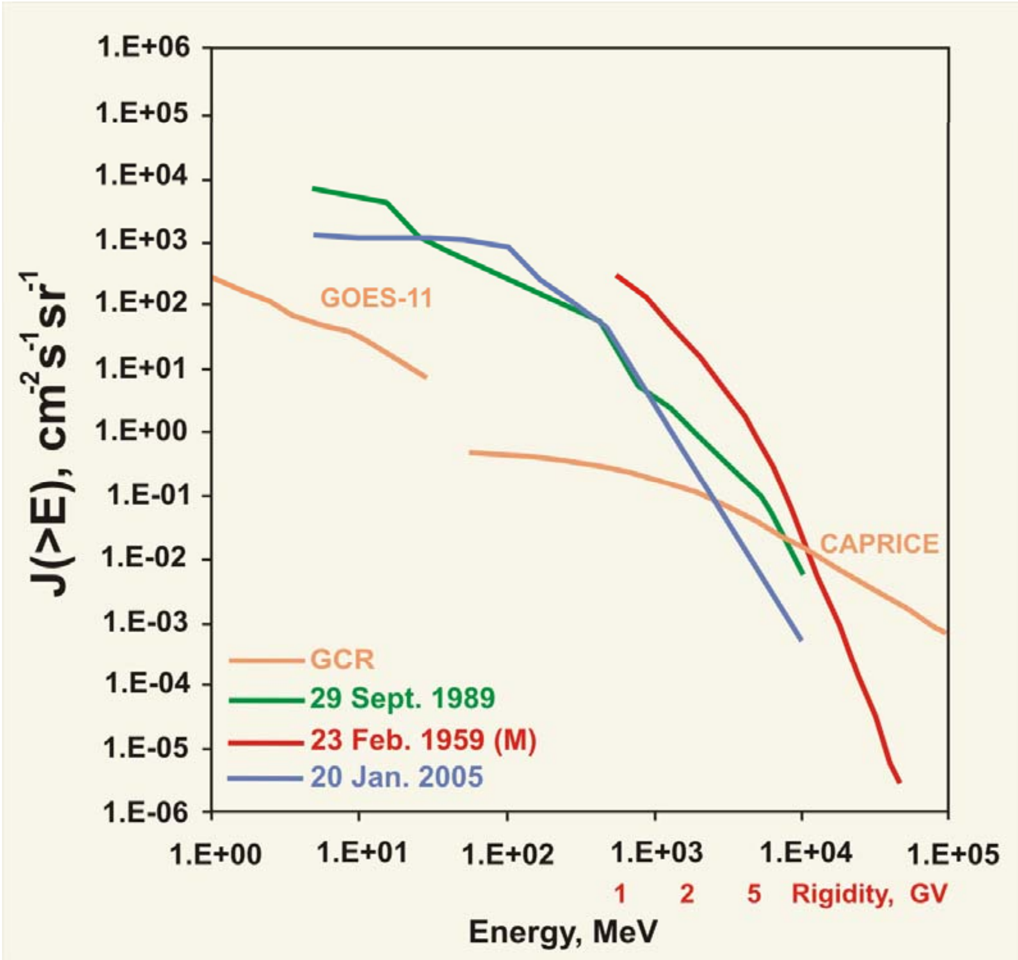
Sharp "Knee" is observed in the spectra of light elements ~3-4 PeV, Δγ~0.4;

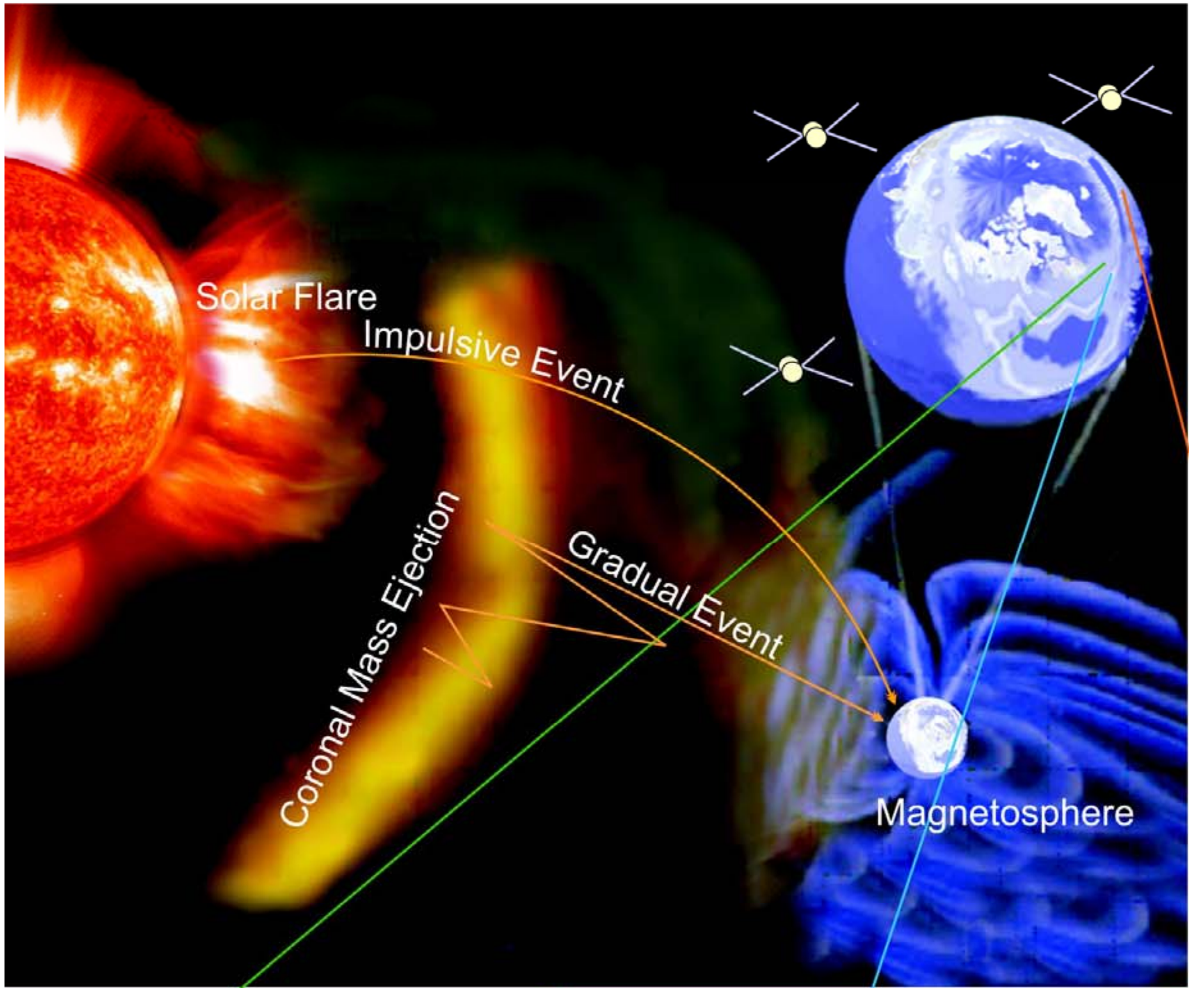
No "Knee-like" structure is observed in the Spectra of heavy elements;

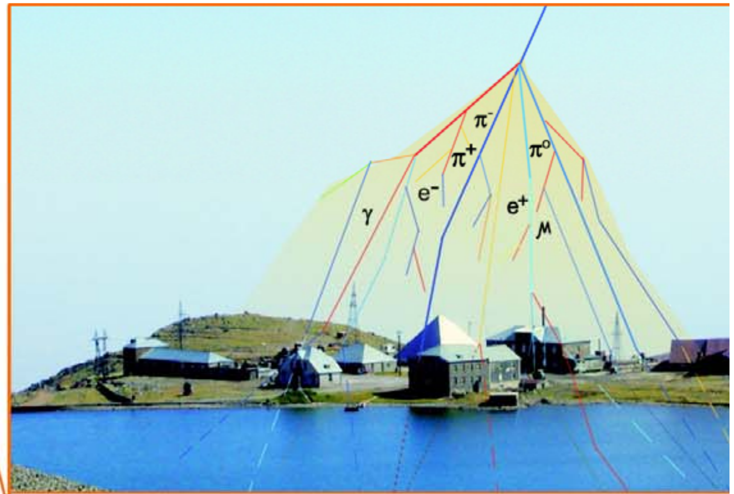
A. Chilingarian, G. Gharagozyan, G. Hovsepian, S. Ghazaryan, L. Melkounyan, and A. Vardanyan, (2004) **Light and Heavy Cosmic-Ray Mass Group Energy Spectra as Measured by the MAKET-ANI Detector,** The Astrophysical Journal, vol. 603, pp. L29

B. A.Vardanyan, T.Antoni, et al. for the KASCADE collaboration, (2003) **Preparation of Enriched Cosmic Ray Mass Groups with KASCADE**, Astroparticle Physics **19**,715

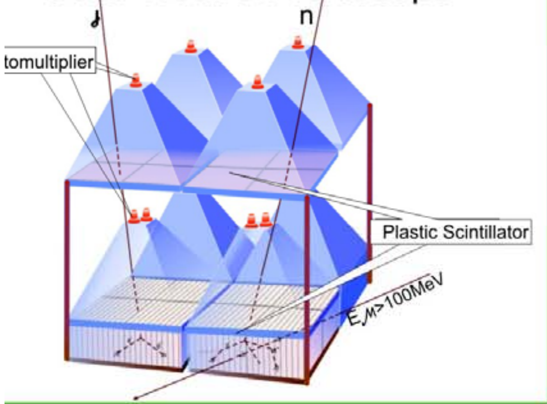
Galactic and Solar Cosmic Rays



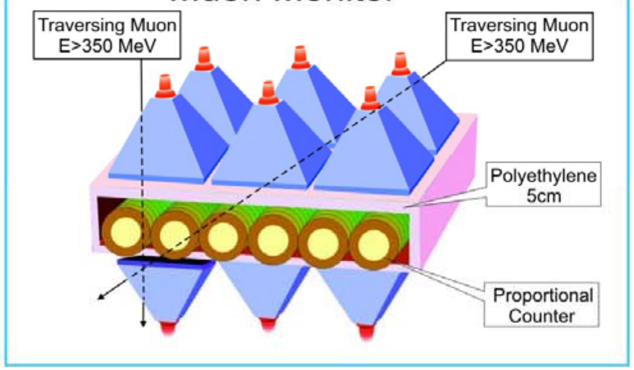




Solar-Neutron Telescope

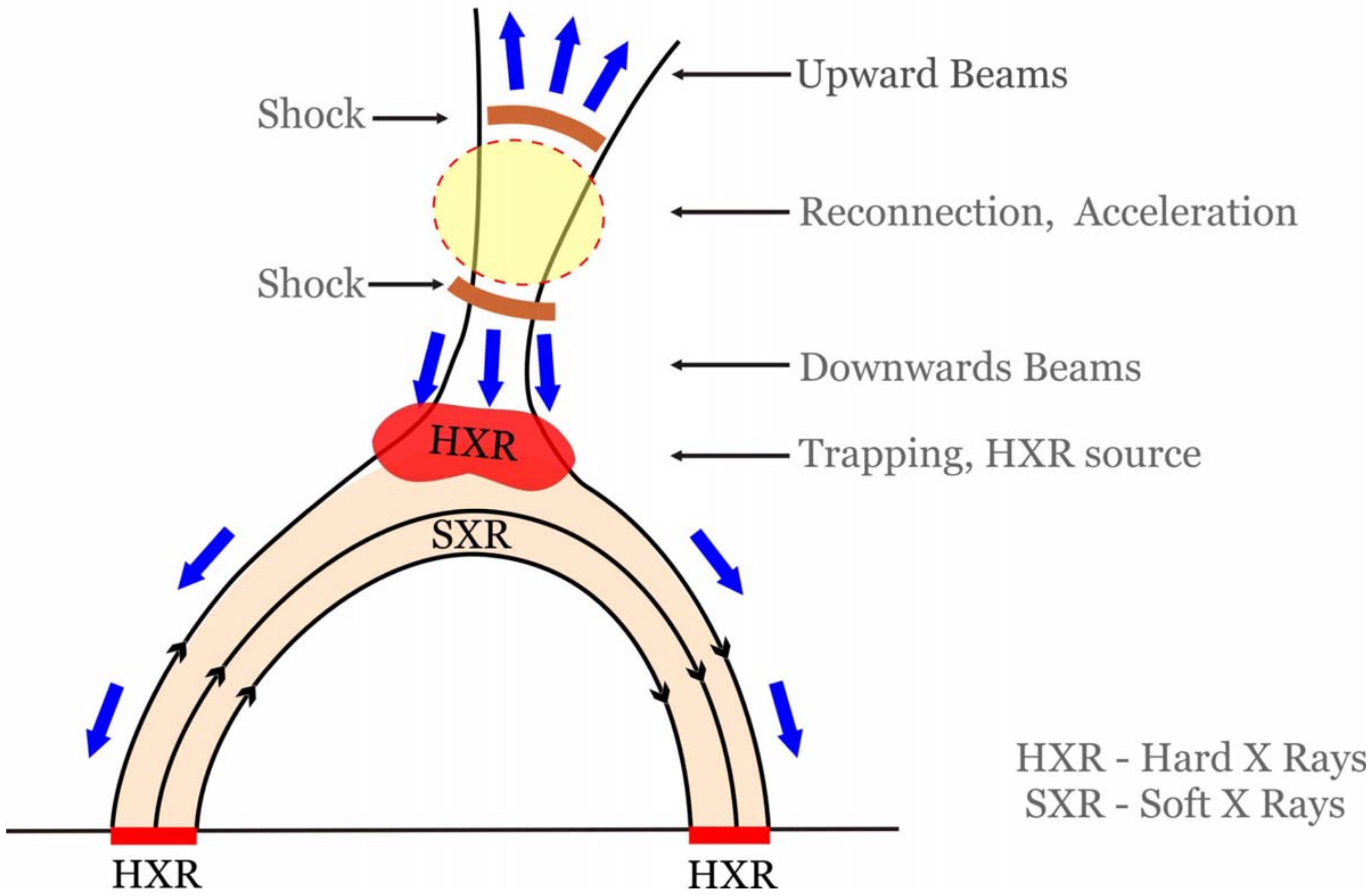


Nor-Amberd Multidirectional Muon Monitor

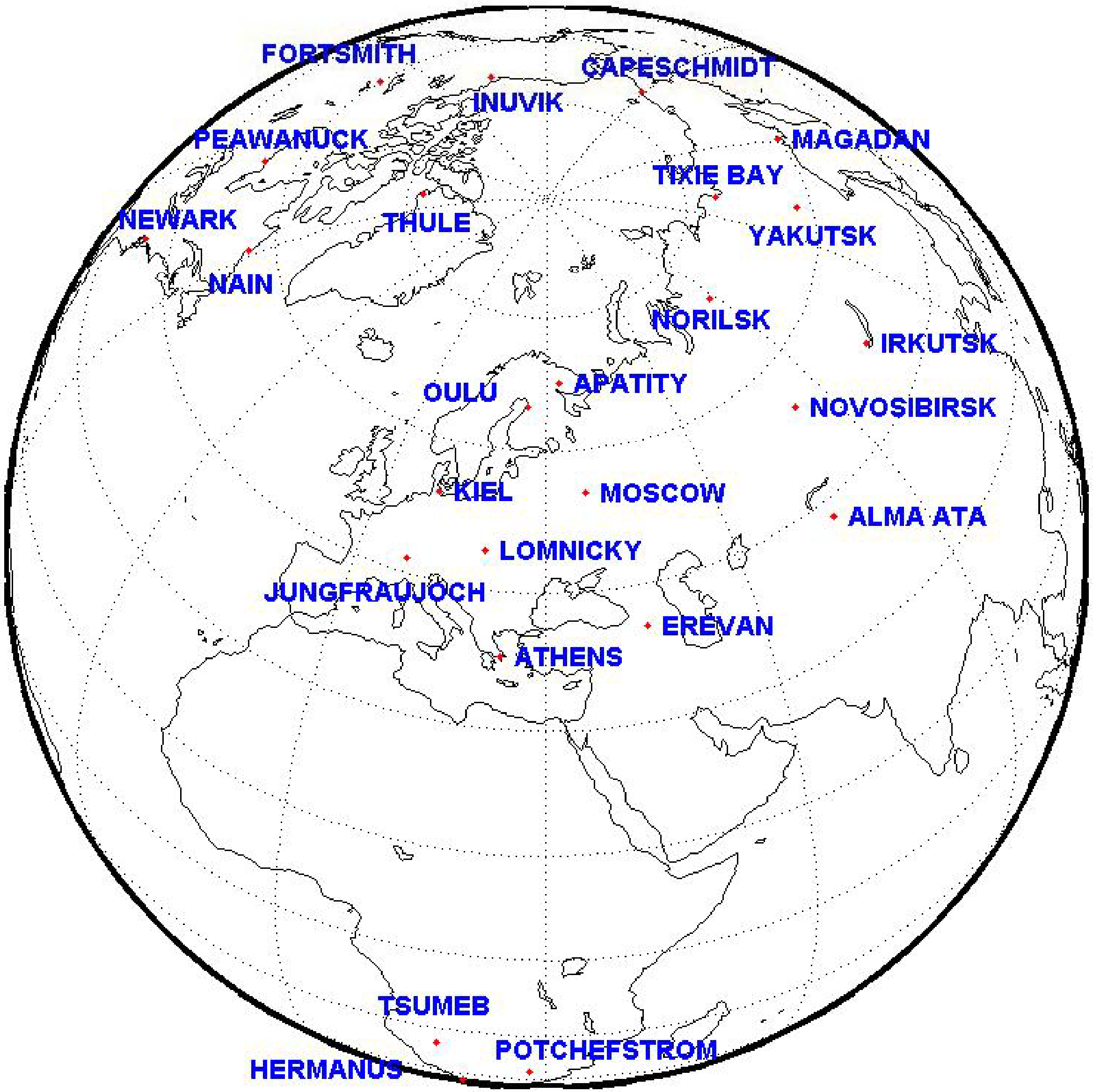


High energy cosmic rays open a window for the exploration of the d
and forceful processes in the far-corners of the universe. The A
Space-Environmental Center (ASEC) of the Cosmic Ray Division in Ar
http://crdlx5.yerphi.am, conducts research in the field of Galactic Cosmi
and Solar Physics. The two research stations, at 3200m and 2000m el
on Mt. Aragats, are equipped with modern scientific detectors and instr
which allow the scientists to make new discoveries in high energy astrop
The ASEC explores the activity of our own star, the Sun, and is dev
Space Weather forecasting and early warning systems and technique
strategic geographic coordinates of the ASEC research stations and the
based particle detector systems developed by the ASEC scientists, c
with data from detectors in space and on the ground, will allow the intern
community to develop a reliable and global Space Weather forecasting
to protect astronauts and satellites in space and power grids on the grou

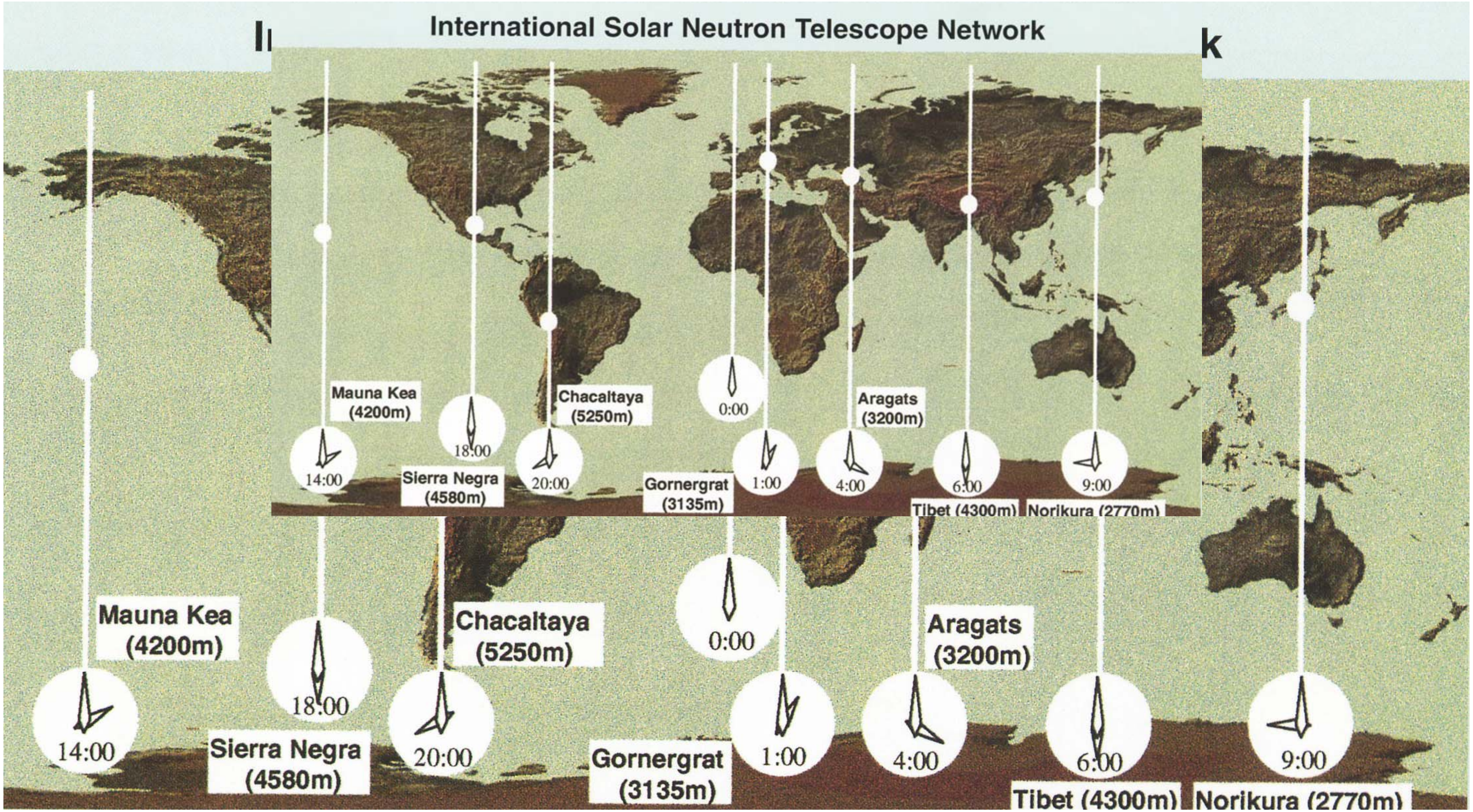
Particle Acceleration in Solar Flare



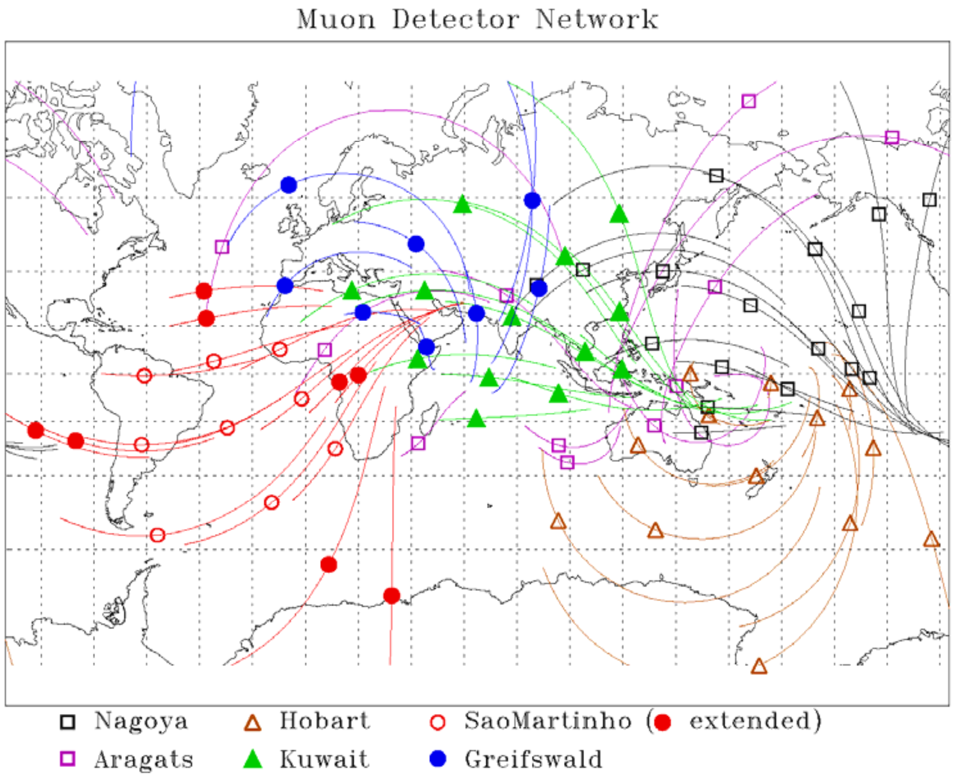
Neutron Monitors World-Wide Network

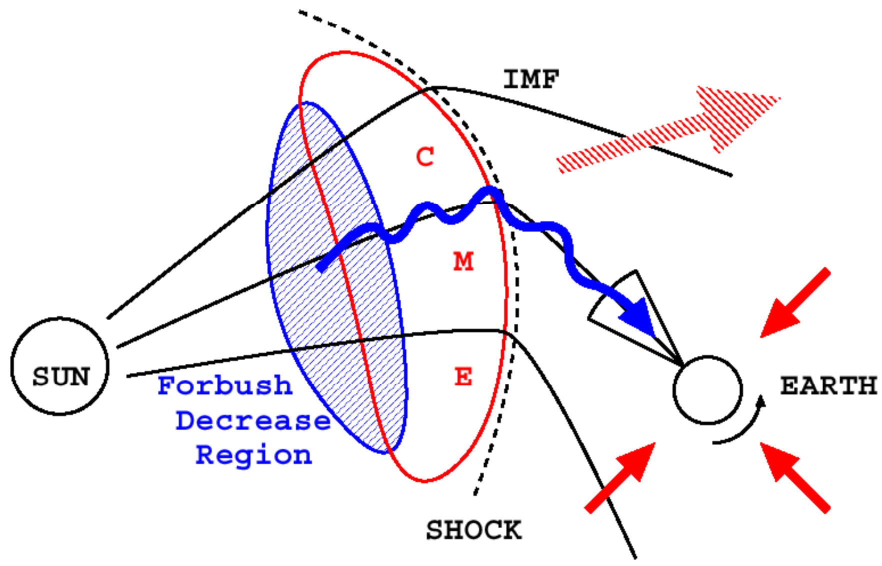


Worldwide network of neutron detectors



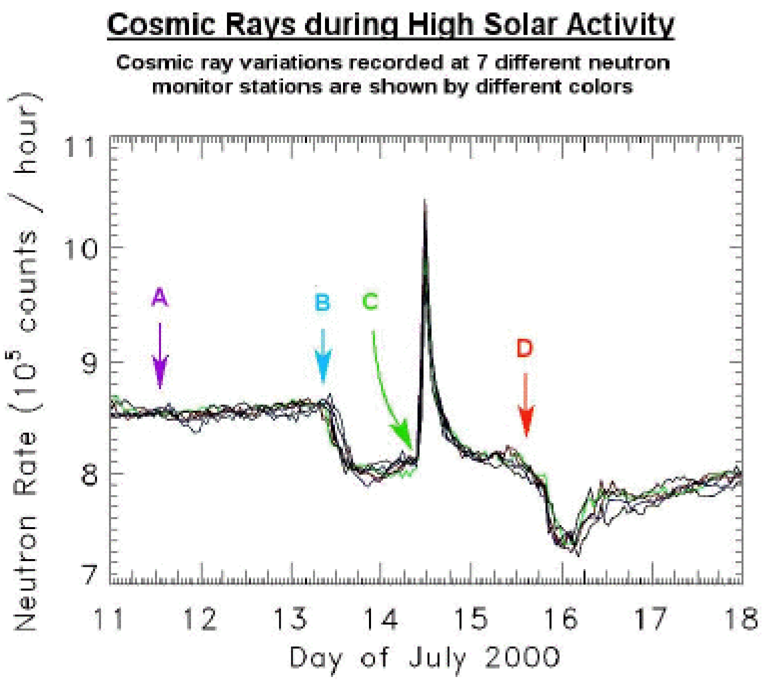
World-wide Networks of Particle Detectors





A CME propagating away from the Sun with a shock ahead of it affects the pre-existing population of galactic cosmic rays in a number of ways. Most well known is the Forbush decrease, a region of suppressed cosmic ray density located downstream of a CME shock. Some particles from this region of suppressed density leak into the upstream region and, traveling nearly at the speed of light, they race ahead of the approaching shock and are observed as precursory loss-cone anisotropy far into the upstream region. Loss-cones are typically observed 4-8 hours ahead of shock arrival for shocks associated with major geomagnetic storms (Munakata et al., JGR, 105, 2000).

GLE at High and Low Latitudes

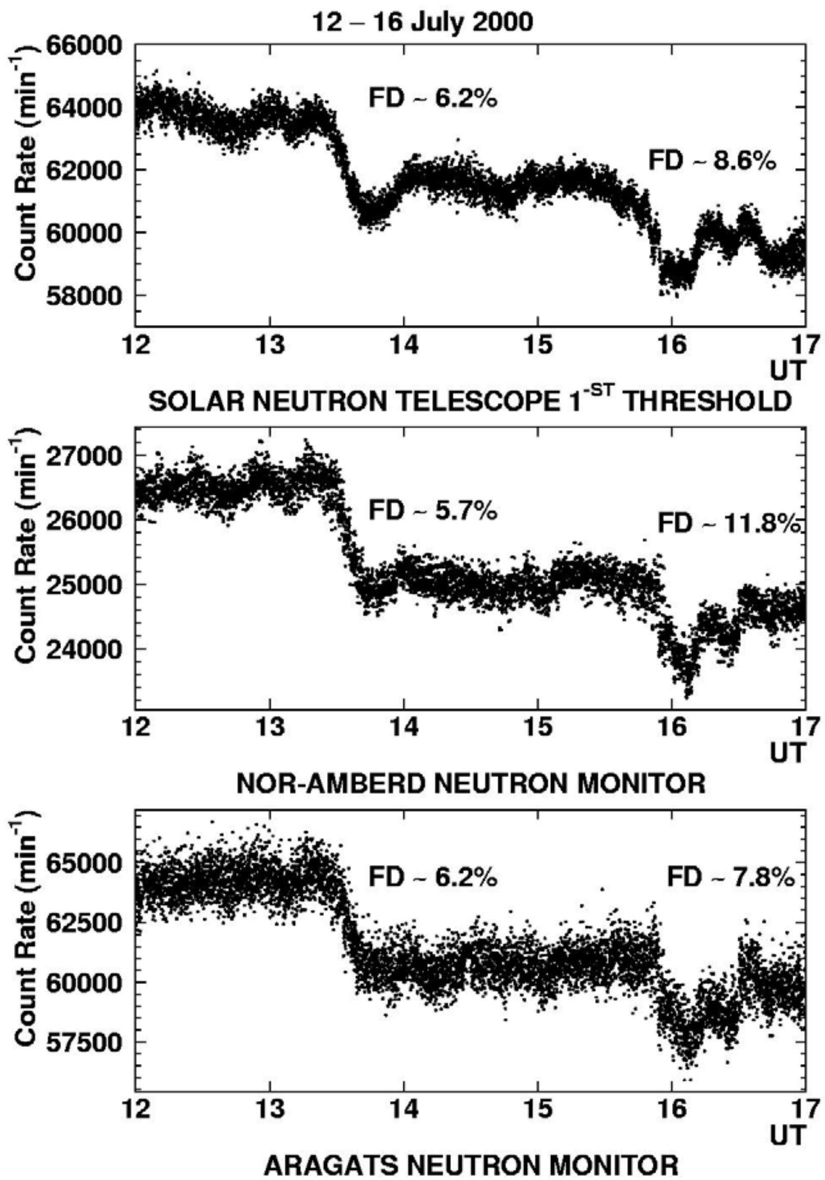


A: First coronal mass ejection (CME) at Sun.

B: First CME arrives at Earth. Cosmic rays decrease suddenly — a "Forbush decrease."

C: Second CME at Sun. This one accelerates high energy particles that reach Earth minutes later. The sudden increase recorded by the neutron monitor is a "ground level enhancement."

D: Second CME arrives at Earth. Cosmic rays decrease again. This CME produces the largest geomagnetic storm in 10 years. Aurora observed as far south as Georgia.



ASEC Monitors

Detector	Altitude *m*	Surface m^2	Threshold(s) *MeV*	Operation	Count rate (min^{-1})
NANM (18NM64)	2000	18	50	1996	2.7×10^4
ANM (18NM64)	3200	18	50	2000	6.1×10^4
SNT-4channels +	3200	4 (60cm thick)	120, 200, 300, 500	1998	$5.2\times 10^{4*}$
veto		4 (5cm thick)	7		1.2×10^5
NAMMM	2000	5 + 5	7 ; 350***	2002	7.0×10^4
AMMM	3200	45	5000	2002	$1.3 \times 10^{5**}$
MAKET-ANI	3200	6	7	1996	1.5×10^5

*Count rate for the first threshold; near vertical charged particles are excluded

**Total count rate of 45 muon detectors from 150 (100 to be put in operation in 2006)

*** First number – energy threshold for the upper detector, second number – bottom detector.

Solar Extreme Events: Fundamental Science and applied Aspects (SEE - 2005)

International Symposium

Nor Amberd, Armenia

26 - 30 September 2005

Topics

- Energetic processes on the Sun during the extreme events
- Propagation of the solar energetic particles and interplanetary CMEs
- Magnetospheric response to the solar extreme events
- Methodologies of forecasting of space weather conditions Effects of Space Weather on technology infrastructure and human environment

Co-sponsored by COSPAR, ISTC, NFSAT, YerPHI, WEB - limited, SCACRD

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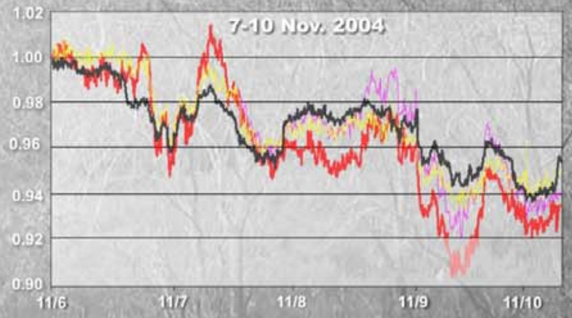
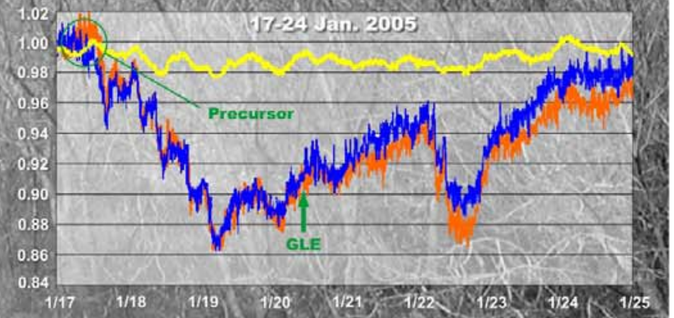
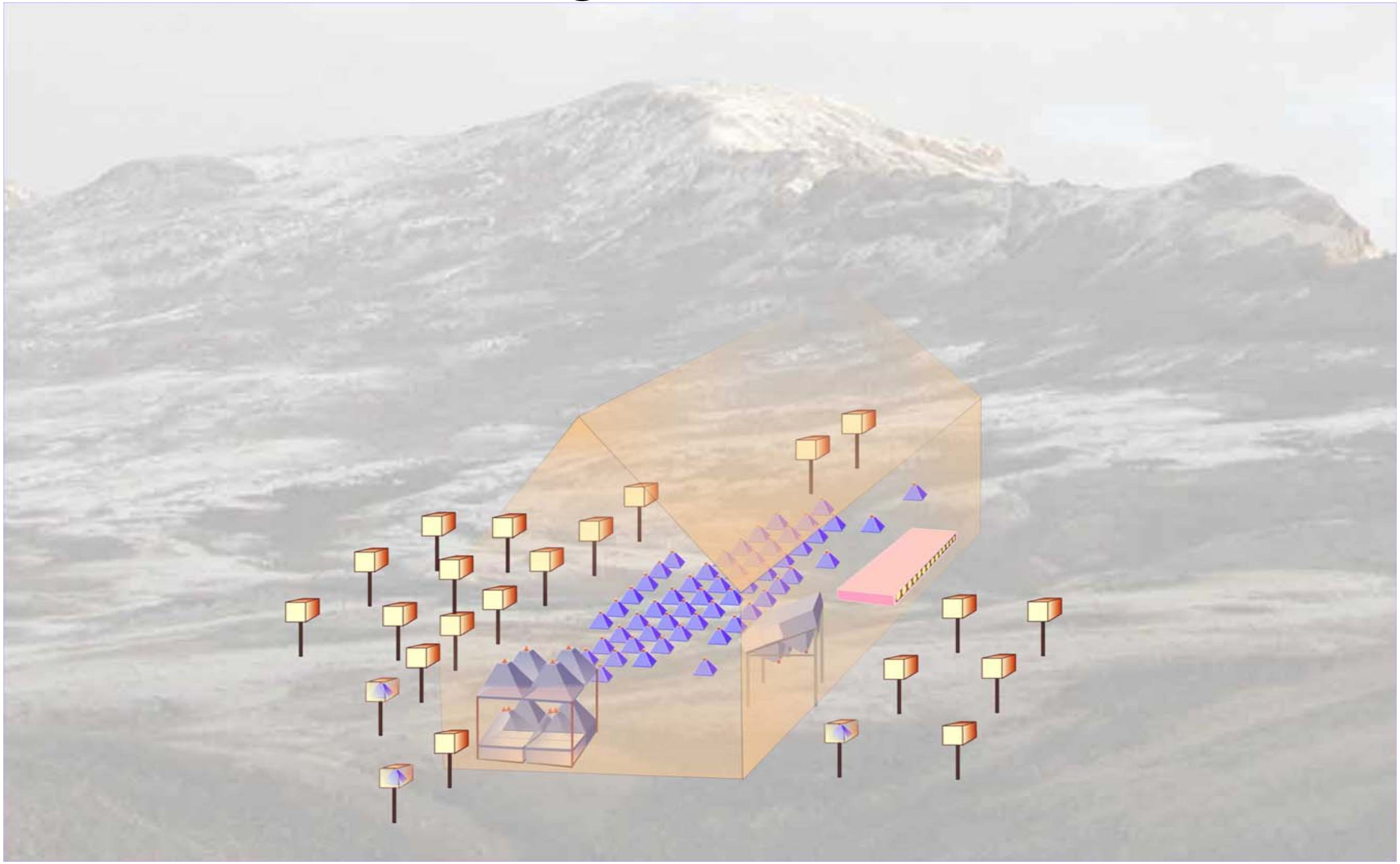
Igor Veselovsky, Moscow State University, Russia
Yuri Yermolaev, Space Reseearch Institute, Russian Academy of Science

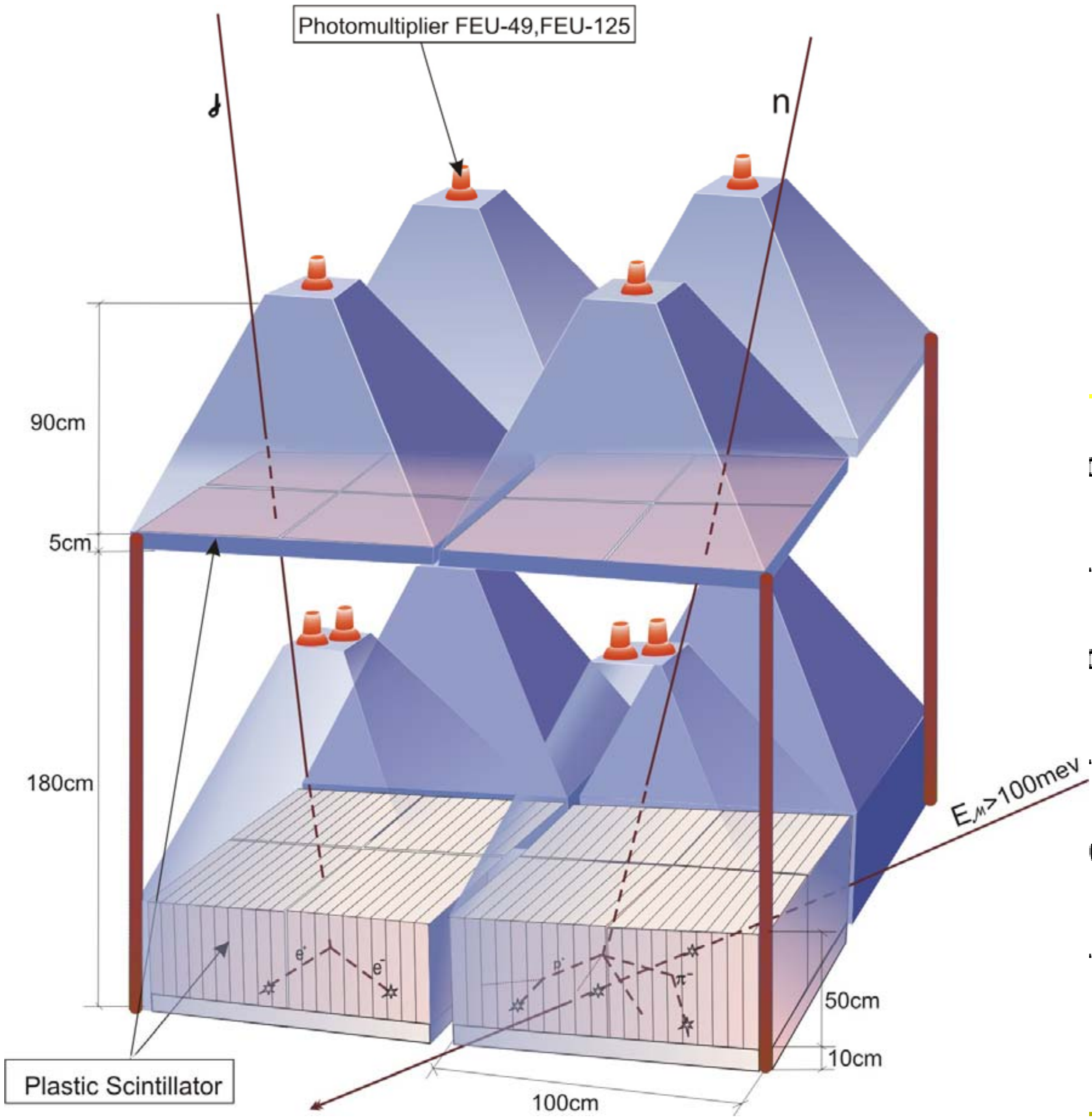


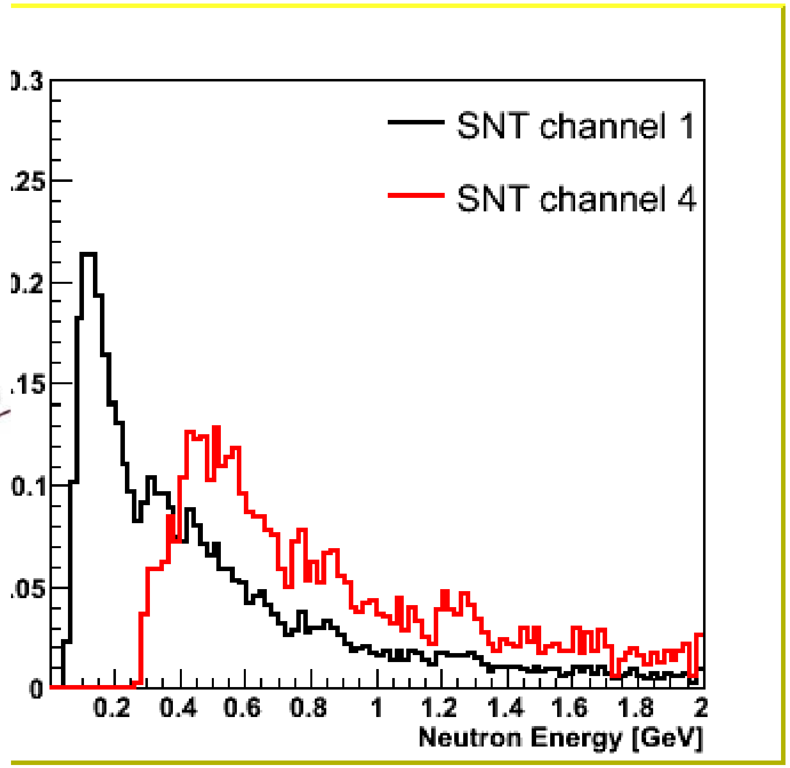


Main Experimental Building at Aragats station

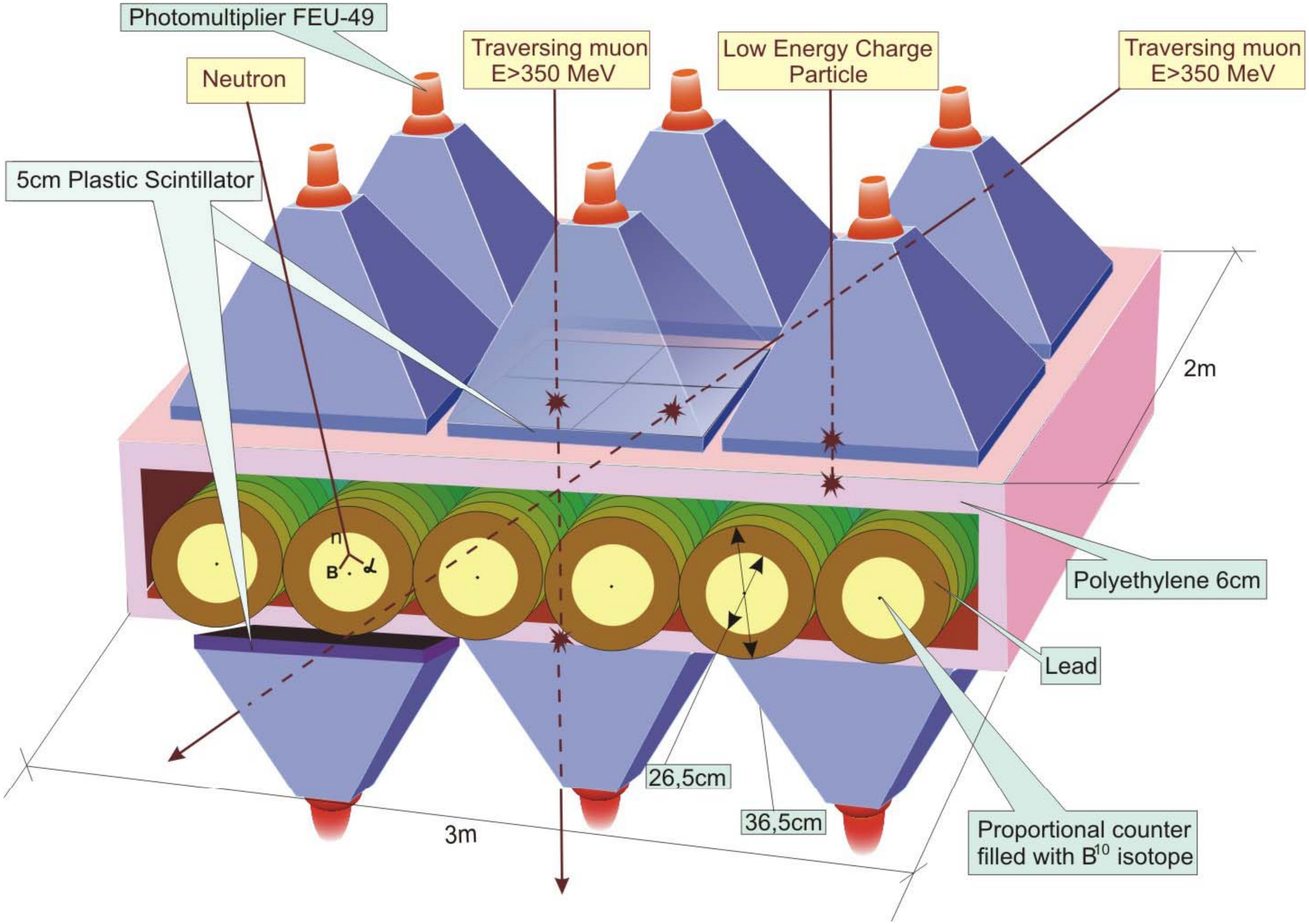


Solar Neutron Telescope

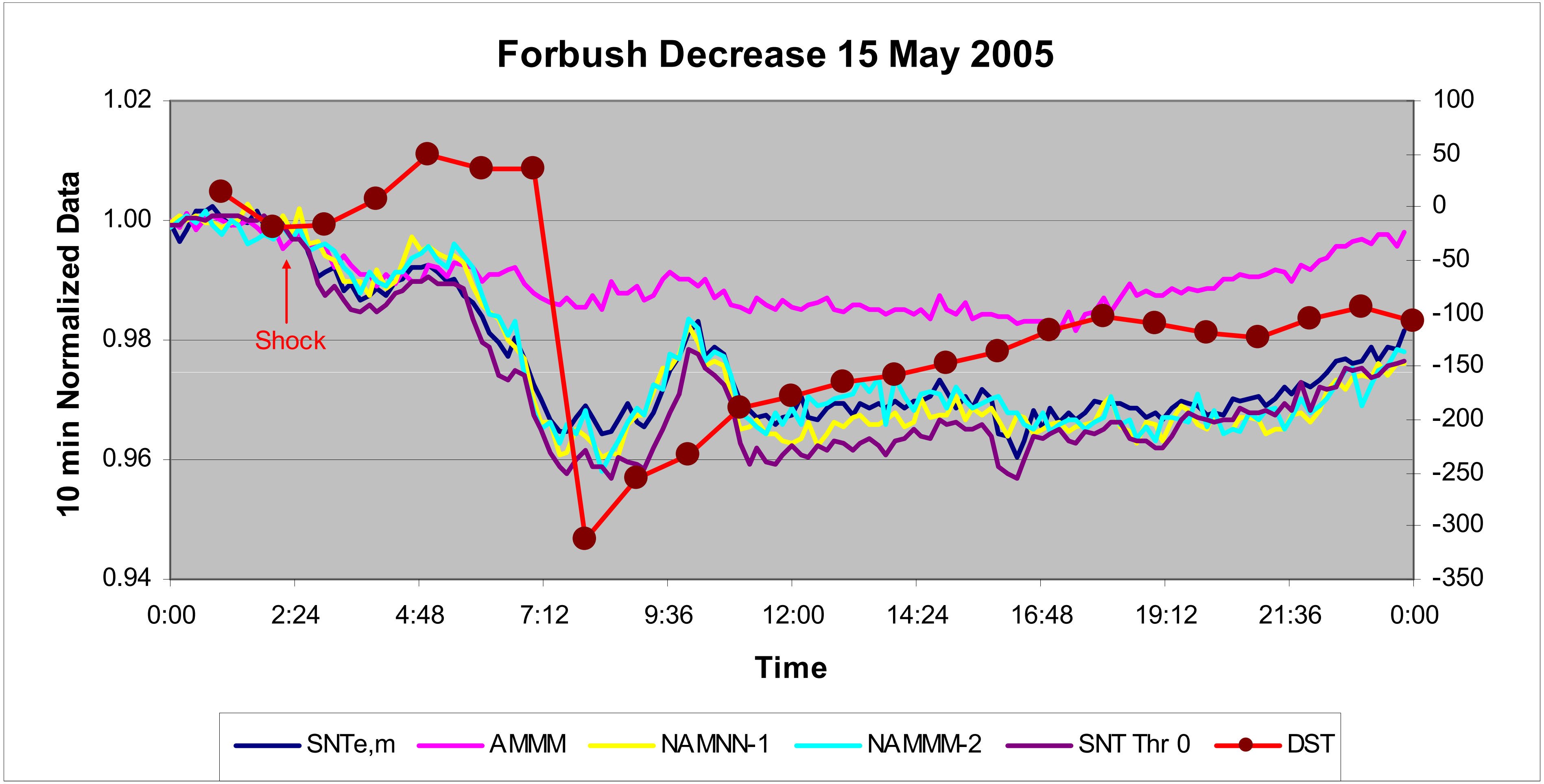


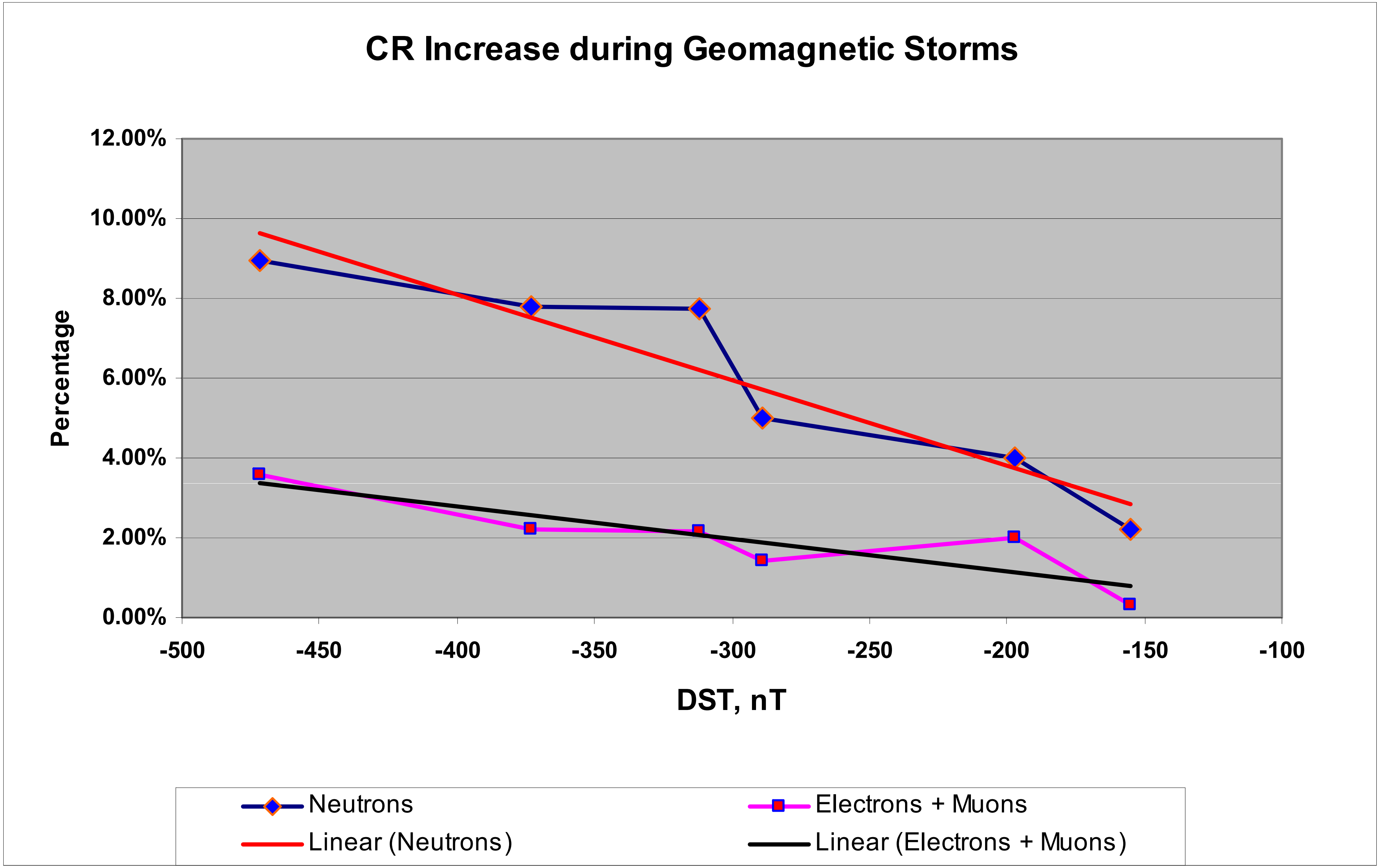


Nor Amberd Multidirectional Muon Monitor

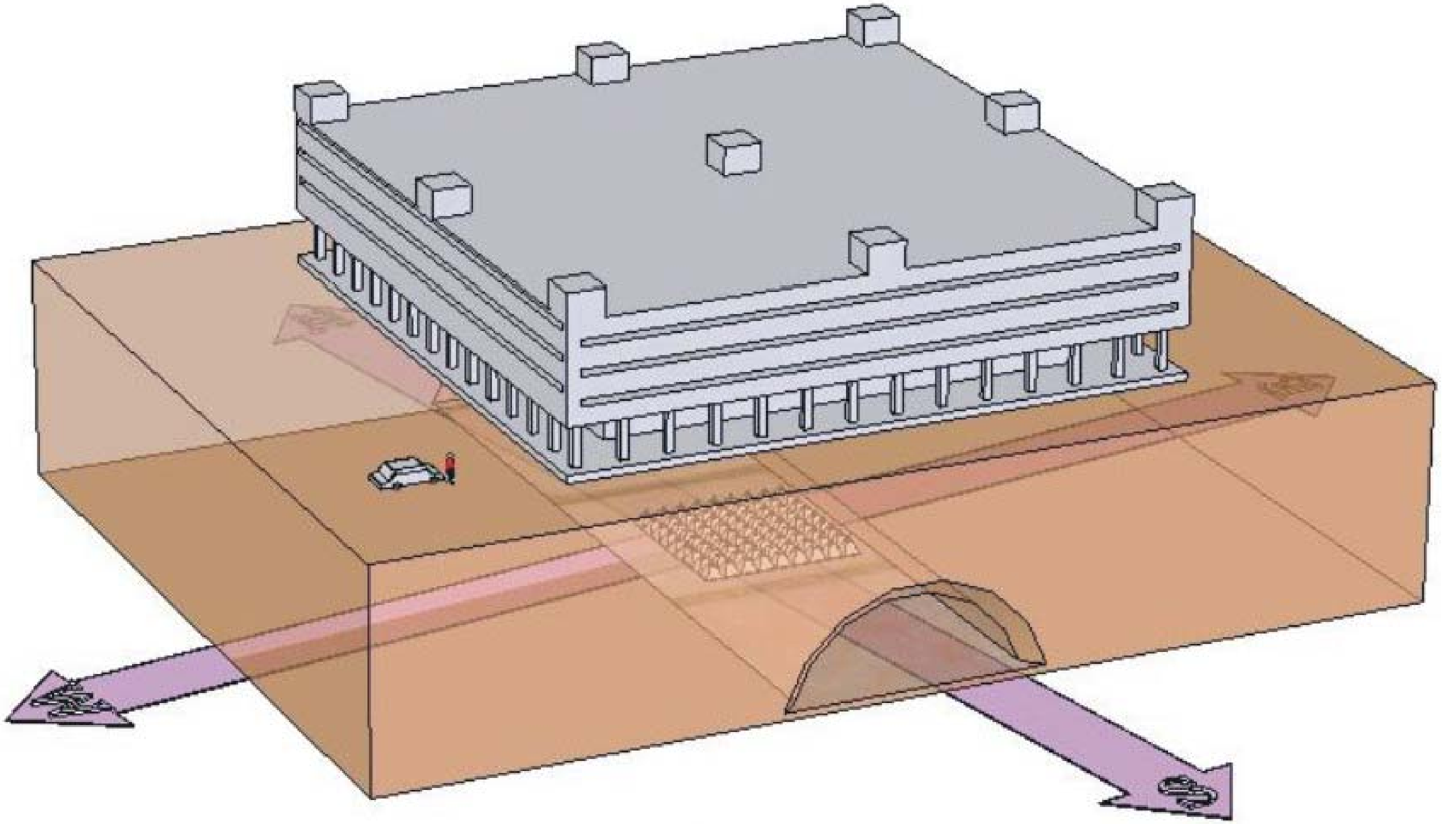


Fd from 15 May 2005 as detected by the ASEC monitors (charged particles detectors)



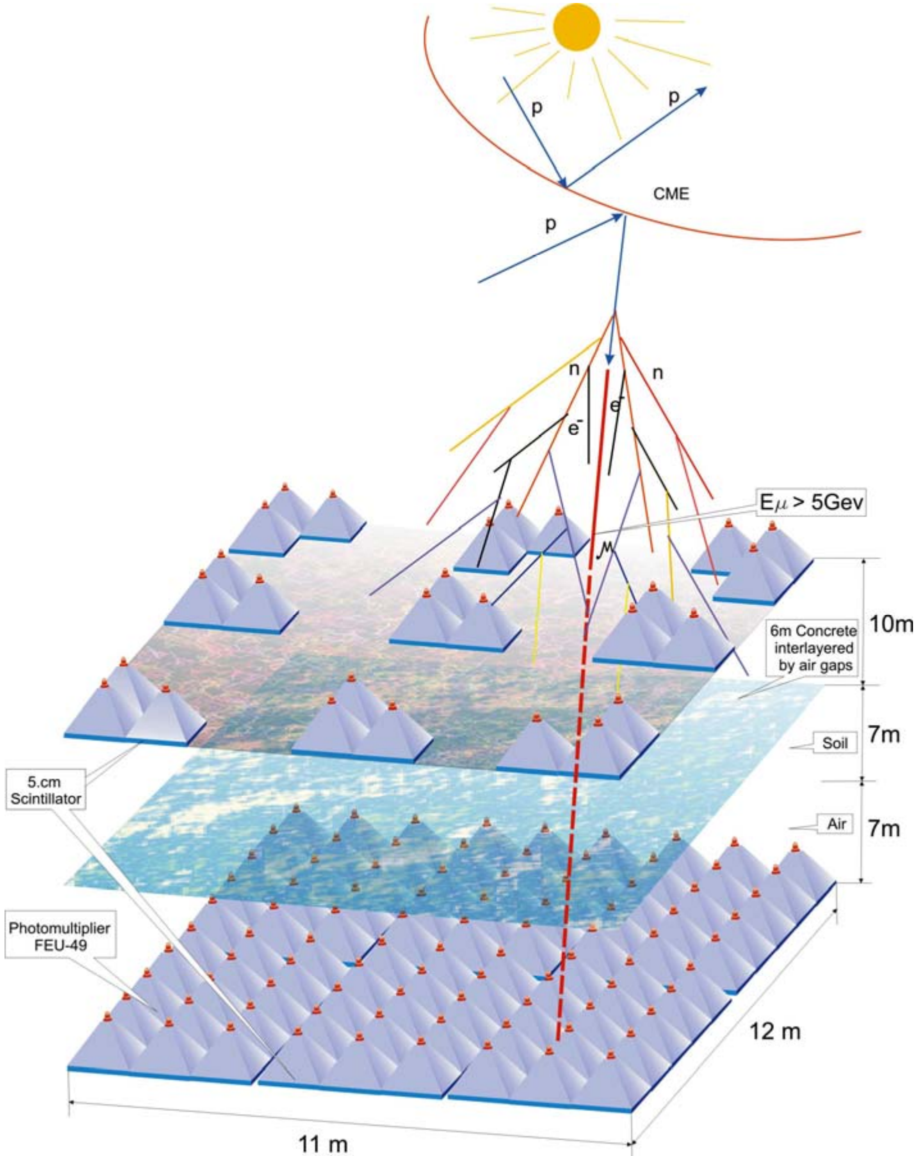

CR Increase during Geomagnetic Storms
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
Percentage
-500
-450
-400
-350
-300
-250
-200
-150
-100
DST, nT
Neutrons
Electrons + Muons
Linear (Neutrons)
Linear (Electrons + Muons)

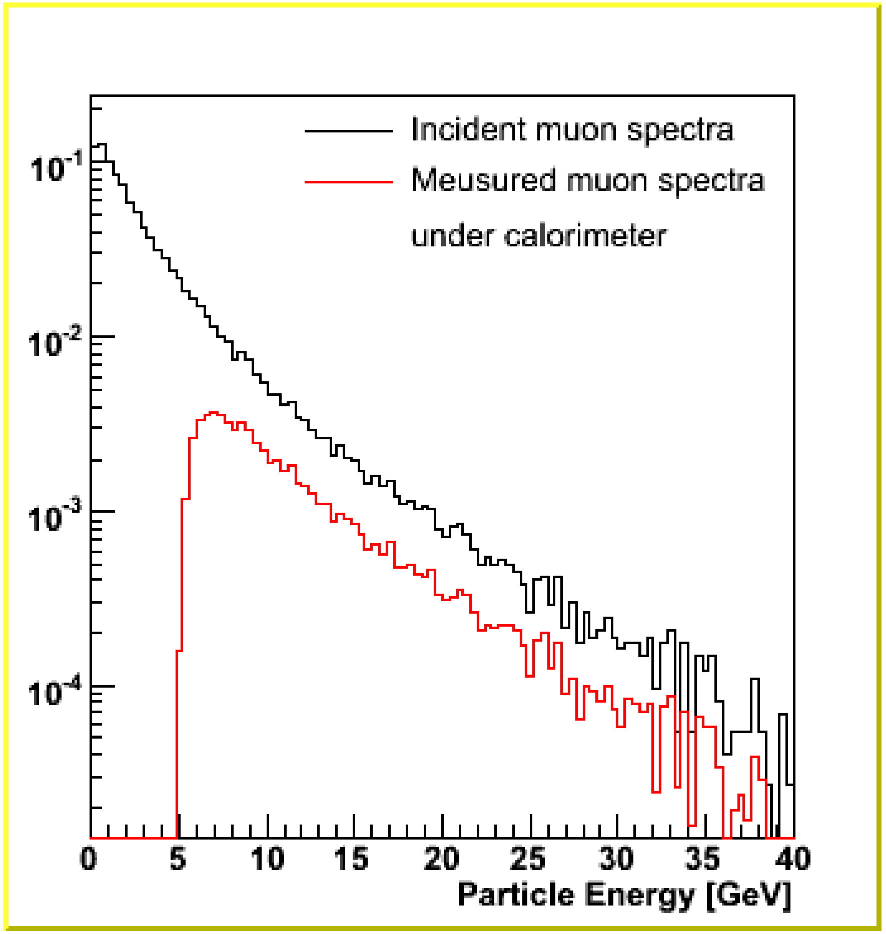
Aragats Multidirectional Muon Monitor (AMMM)



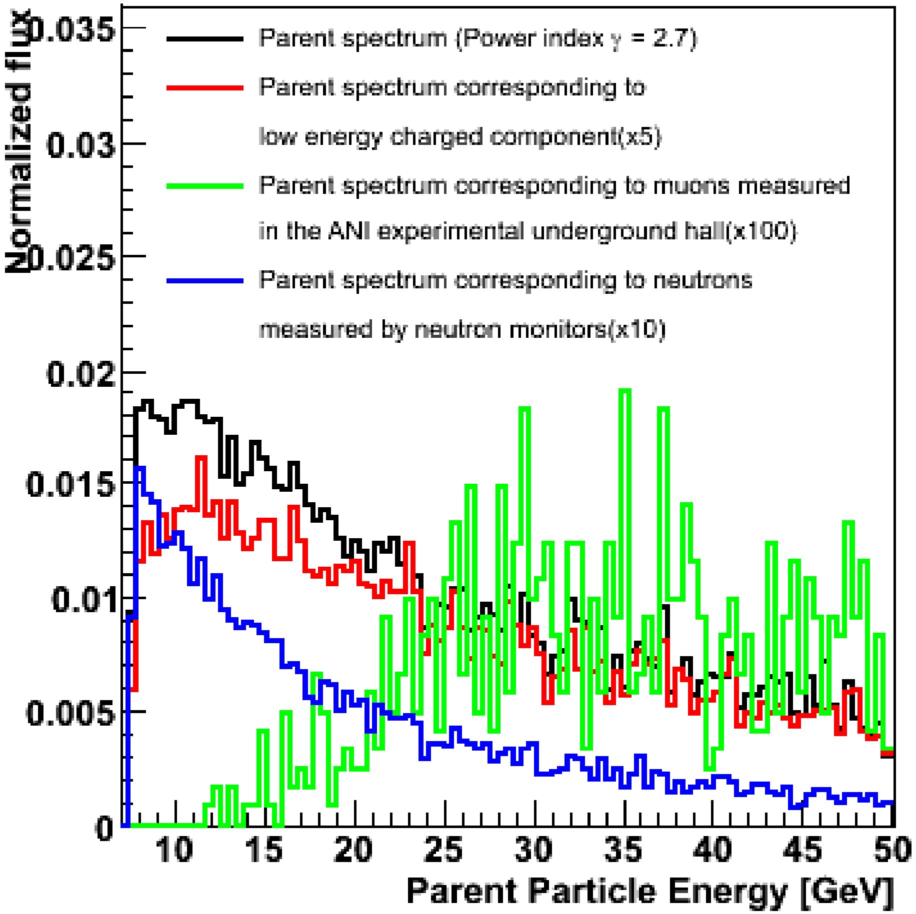
AMMM

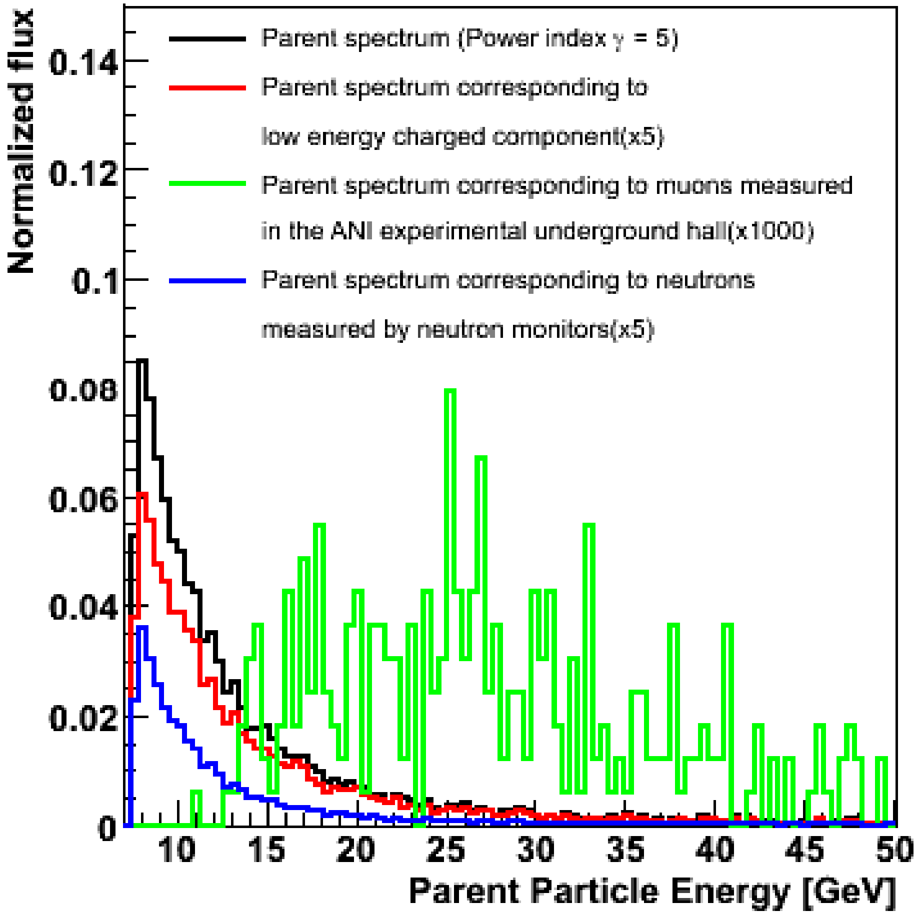
Aragats Multidirectional Muon Monitor (AMMM)



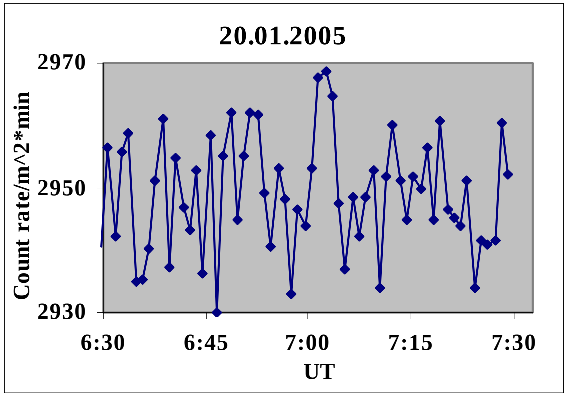


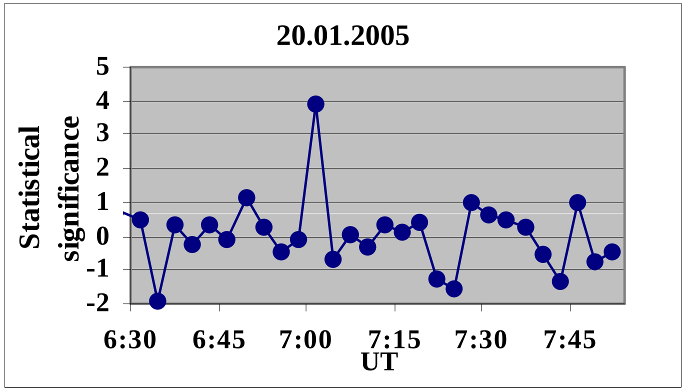
Energy range of Aragats Monitors



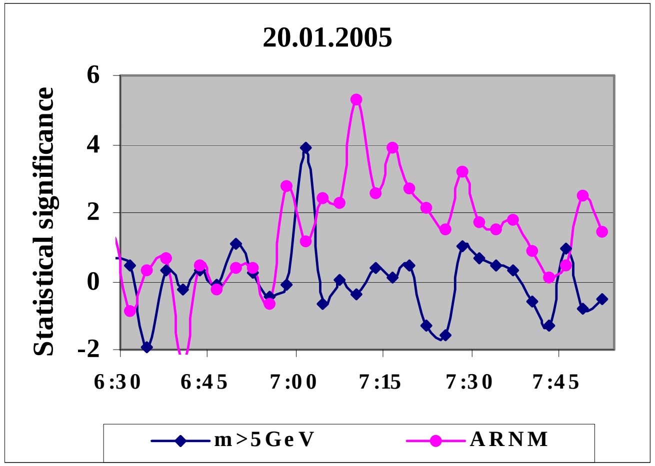


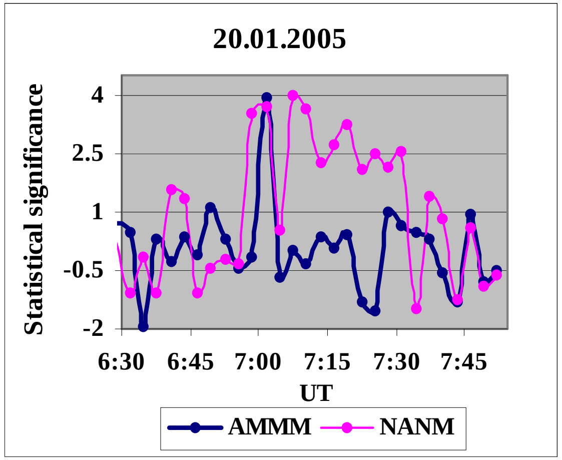
AMMM Detection of GLE 20 January 2005

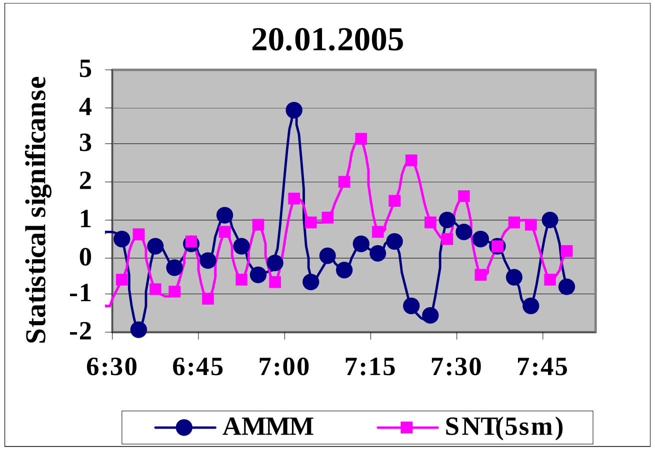




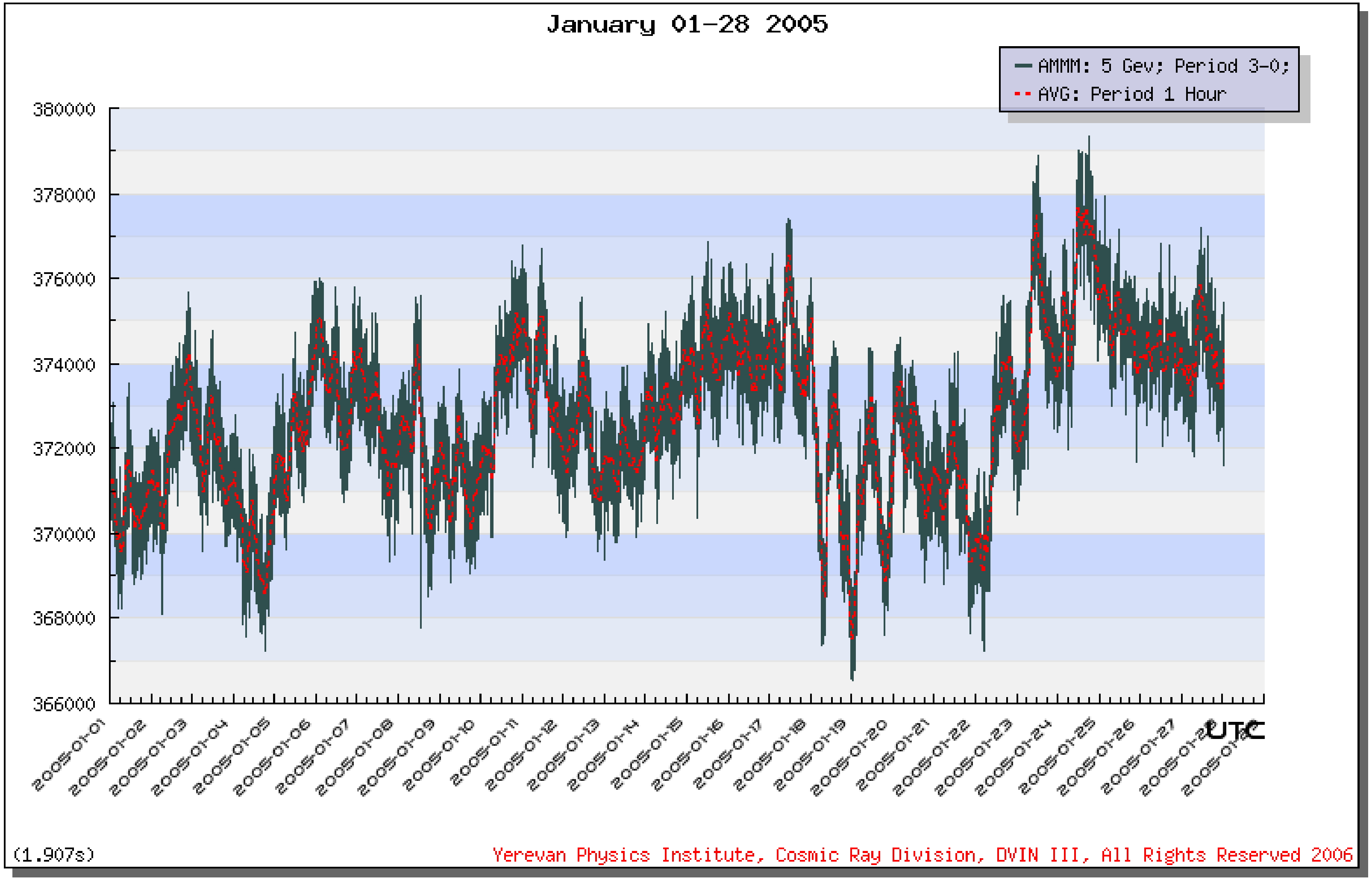
The additional signal at 7:02-7:04 UT equals 2354 (0.644%) If we adopt the Poisson standard 0.164%, significance = 3.93σ



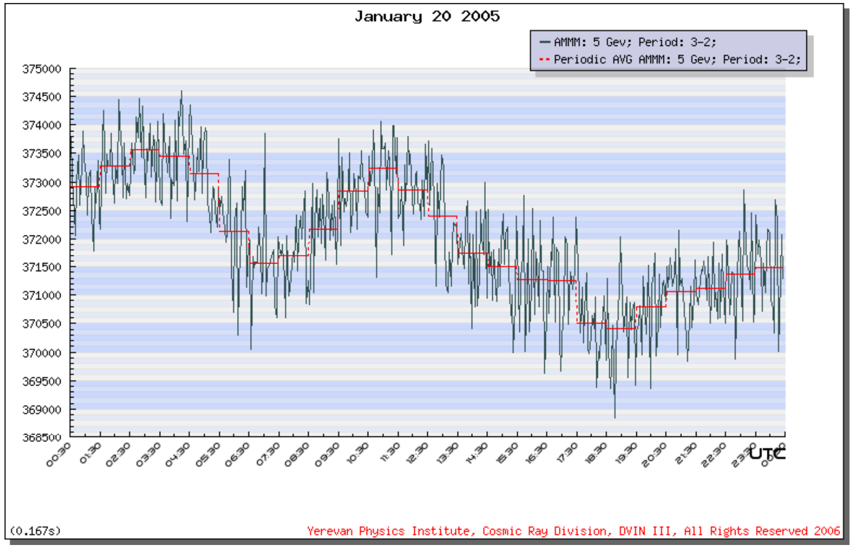




January 2005 AMMM(2% changes)



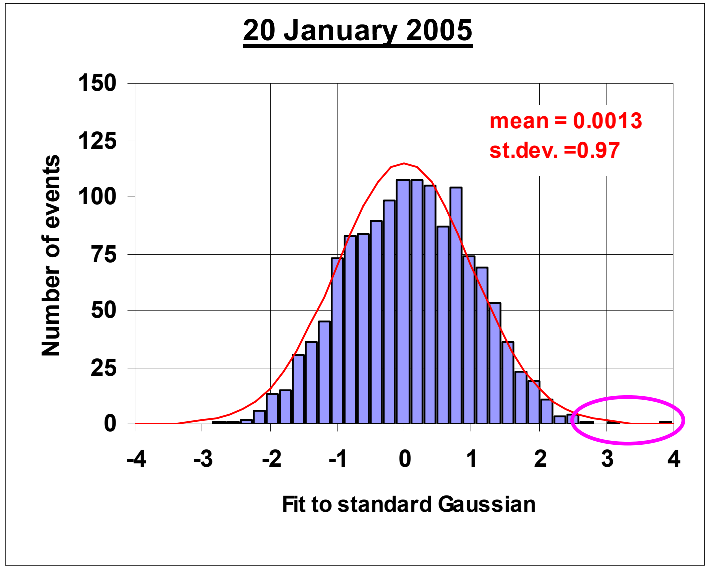
Estimating the Detector Accuracy

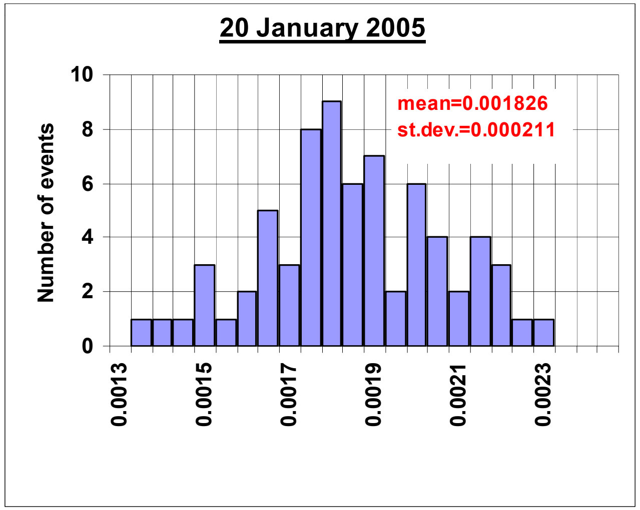


$$\sigma_p = 1/\sqrt{Count\ rate} = 0.00164$$

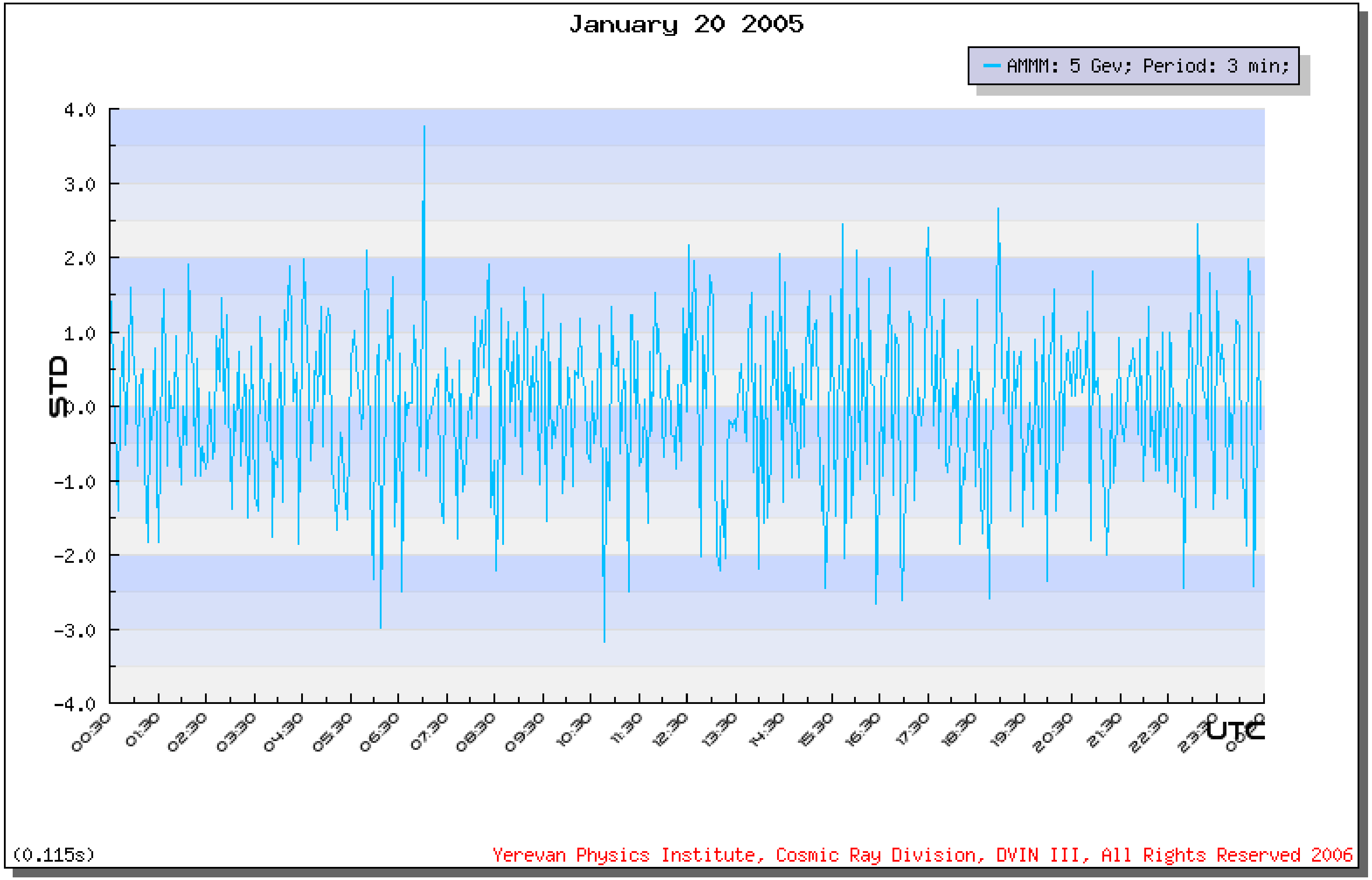
$$X_{i,j} = \frac{C_{i,j} - \bar{C}_j}{S_j}, \quad i = 1,20 \quad j = 1,24$$

$$RMSD_j = \sqrt{\left(\frac{\sum_{i=1}^{i=N}(C_{i,j} - \bar{C}_j)^2}{N-1}\right)} / \bar{C}_j, \quad j = 1,24$$

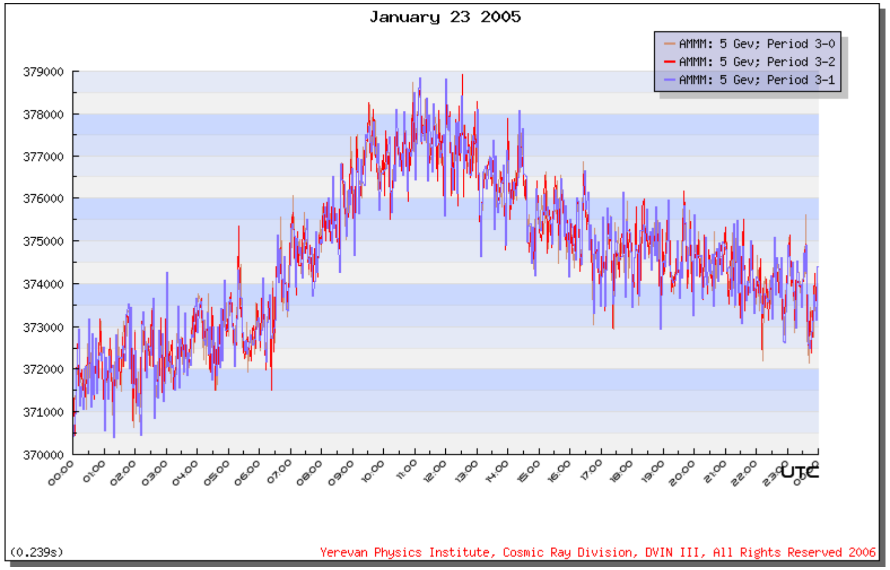


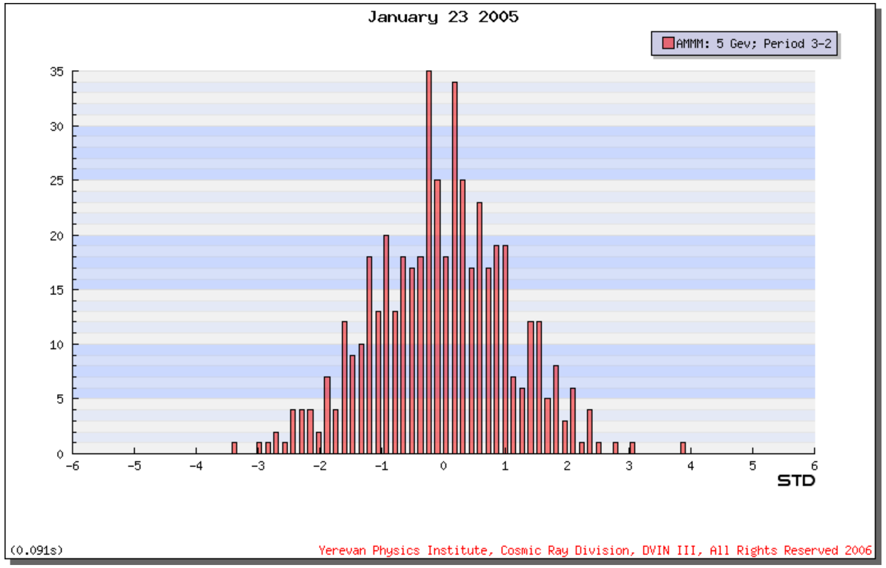


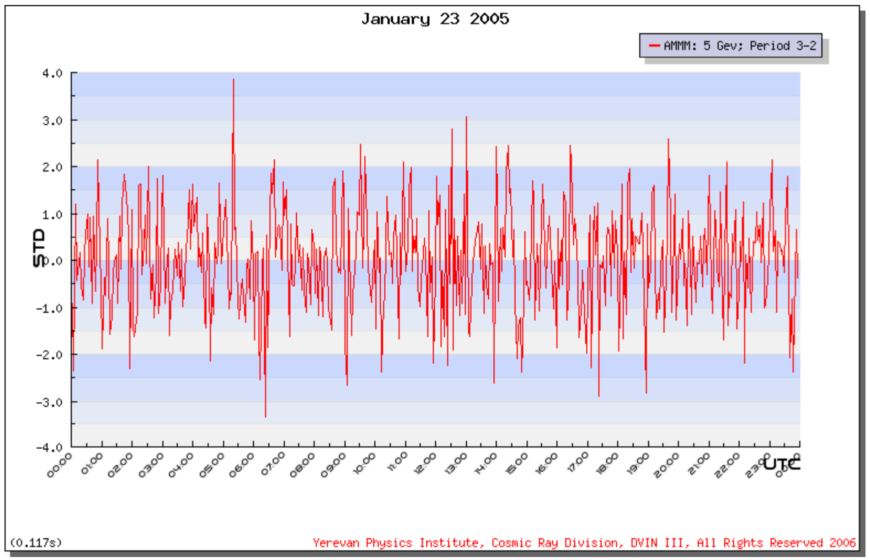
Significance Distribution for 20 January 2005

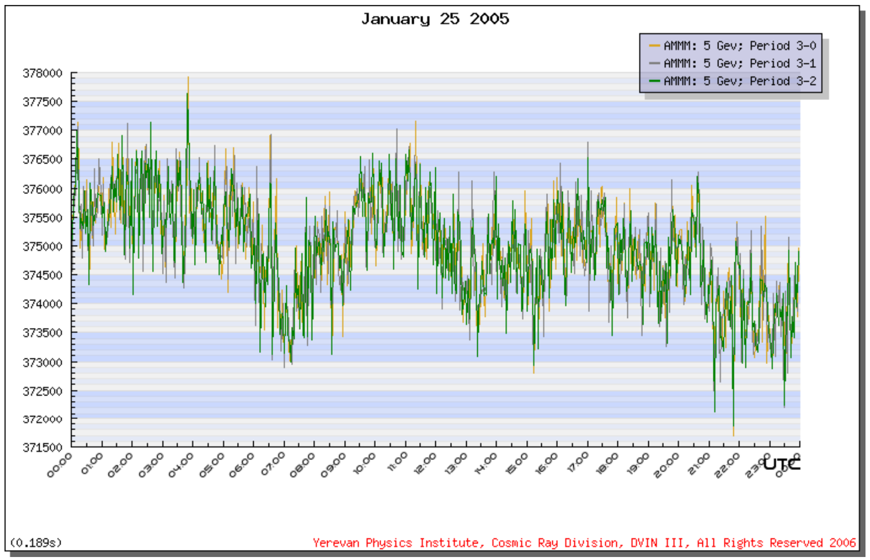


Additional ~4σ peaks in January 2005

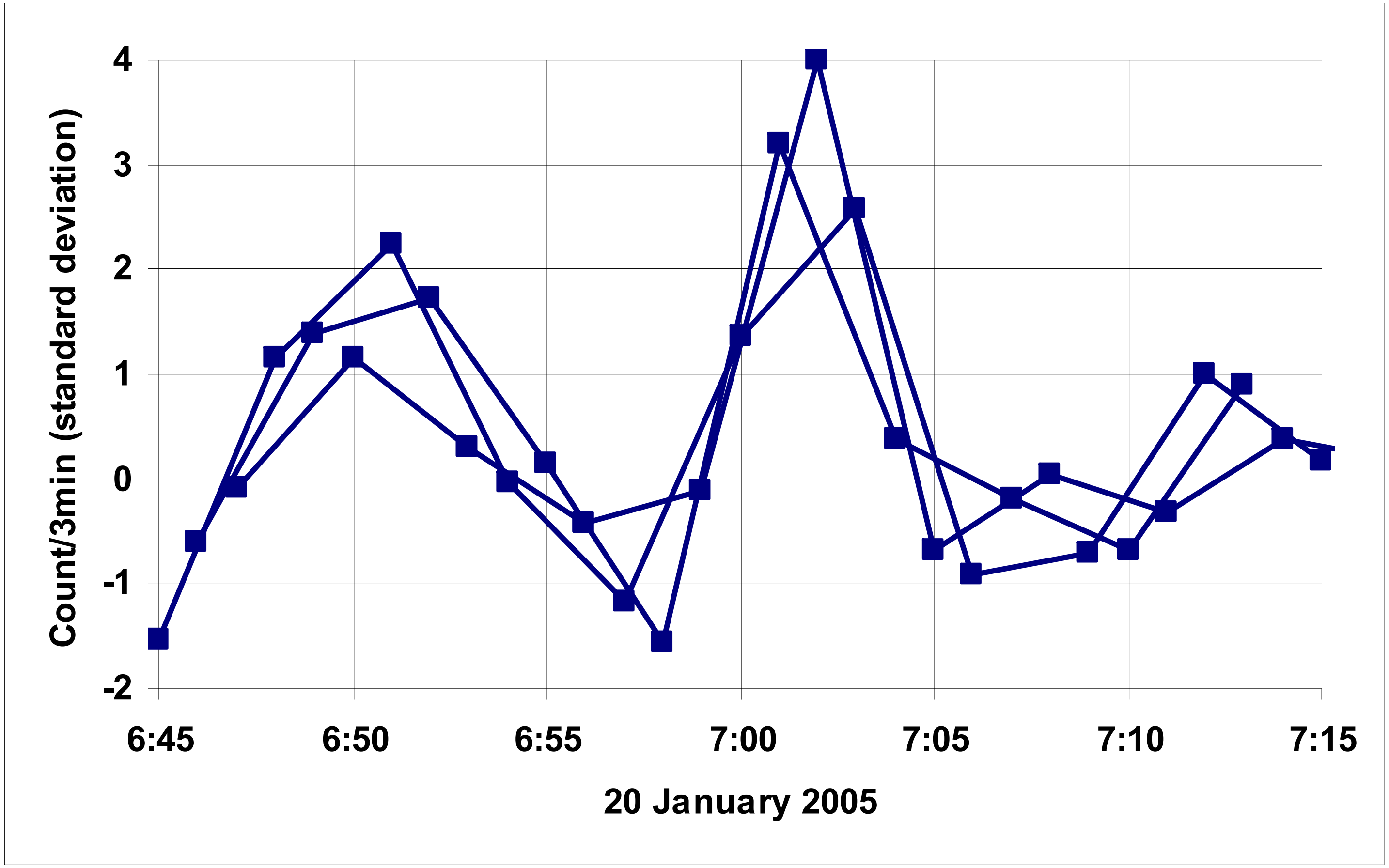




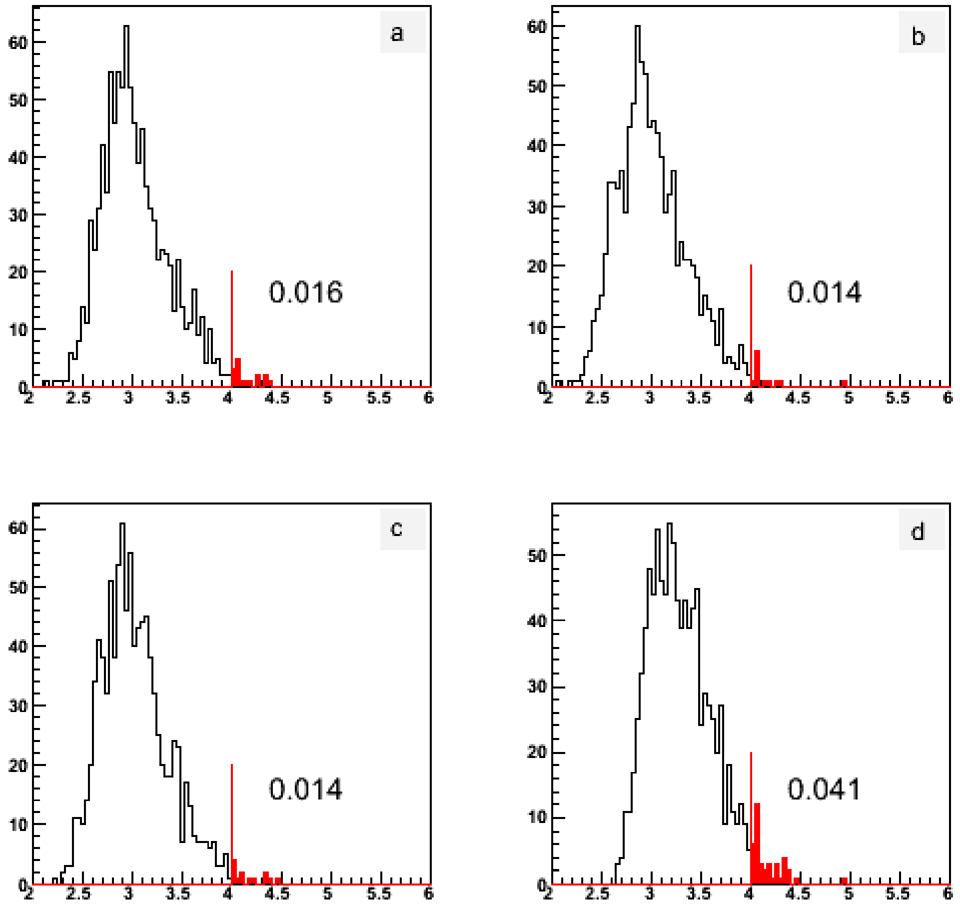




Re-binning effects



Modeling Rebinning effect



Simulation Algorithm

- generate 1443 numbers from the standard normal distribution N(0,1);
- form 3 time series summing 3 consequent numbers of the raw, starting from the first, second and the third elements. Each of time series will contain 481 element (a day);
- perform normalization procedure to each of three “3-minute” time series;
- determine and store the maximal element of each of normalized time series;
- determine and store the maximal element among time-series maximums (we model in this way selection of the largest signal from 3 equivalent time-series shifted by one minute from each other);
- repeat i-vi 1000 times and form a histogram of residuals;
- from the histogram calculated the frequency of obtaining residual value equal or greater than 4 (this fraction is shown in the Figure 10 by red).

CERN ROOT Peak Fitting

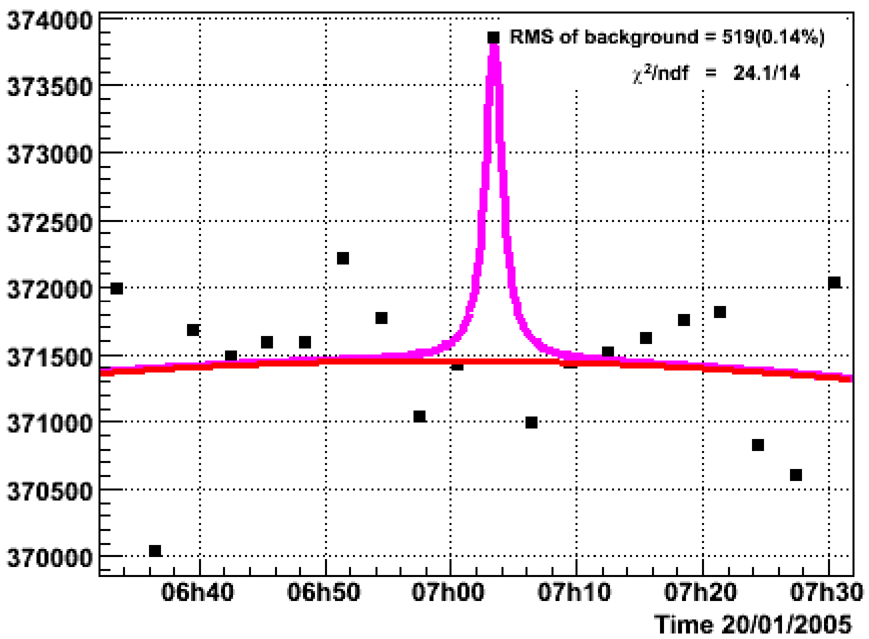


Figure 8a Polynomial fit of the background and corresponding Lorentzian peak

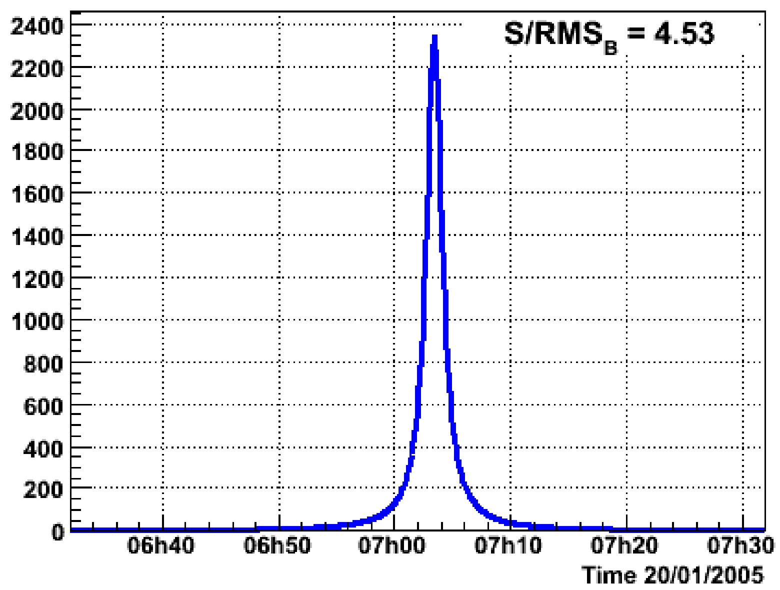
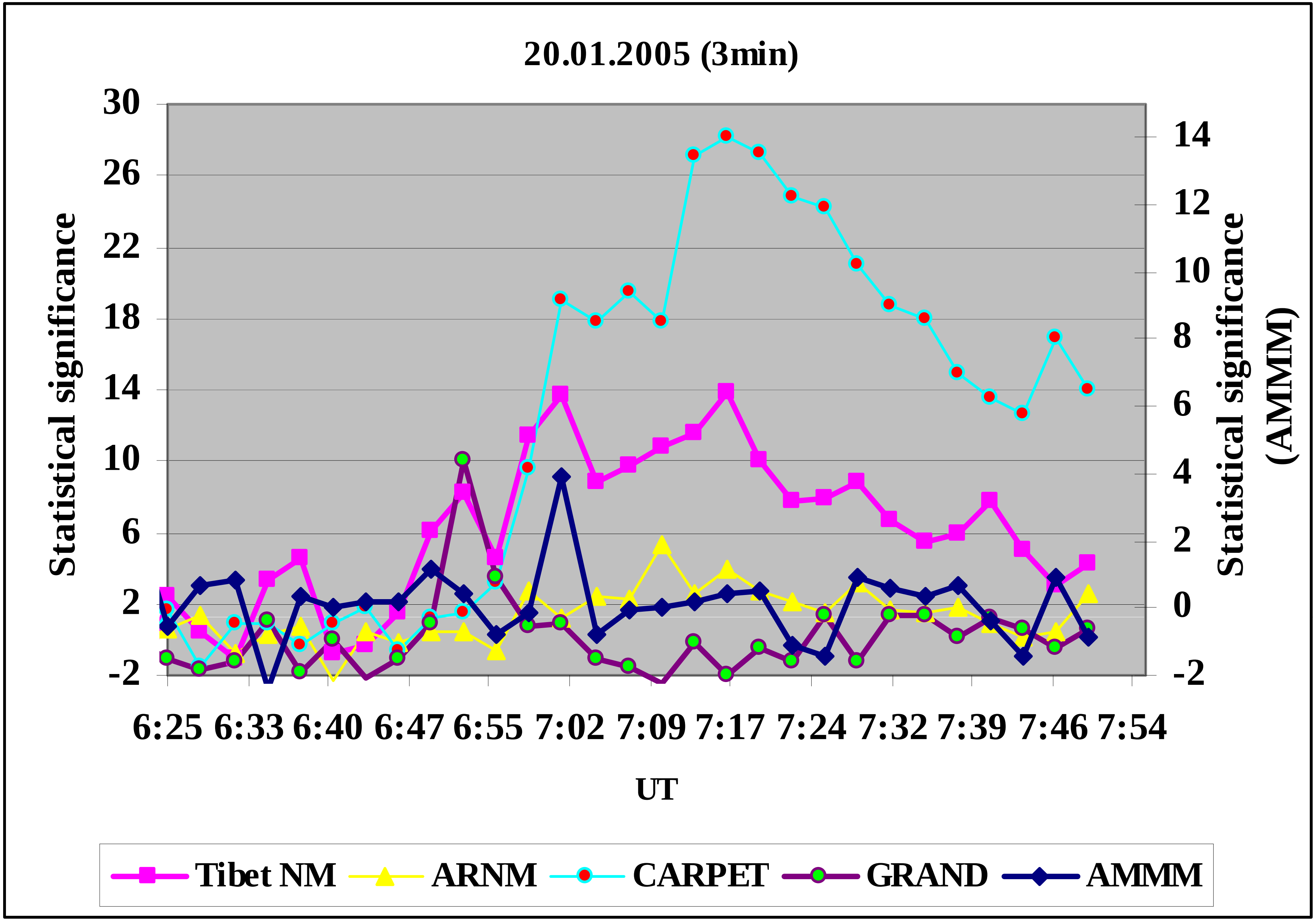
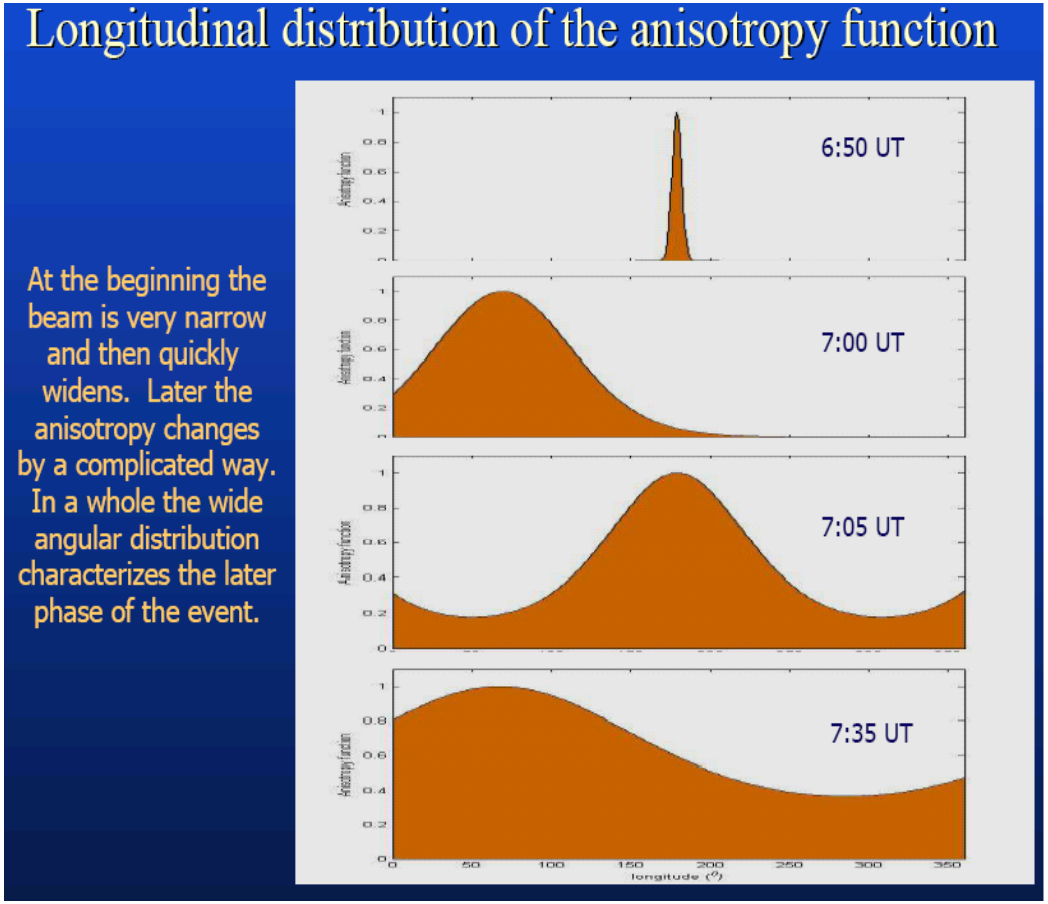


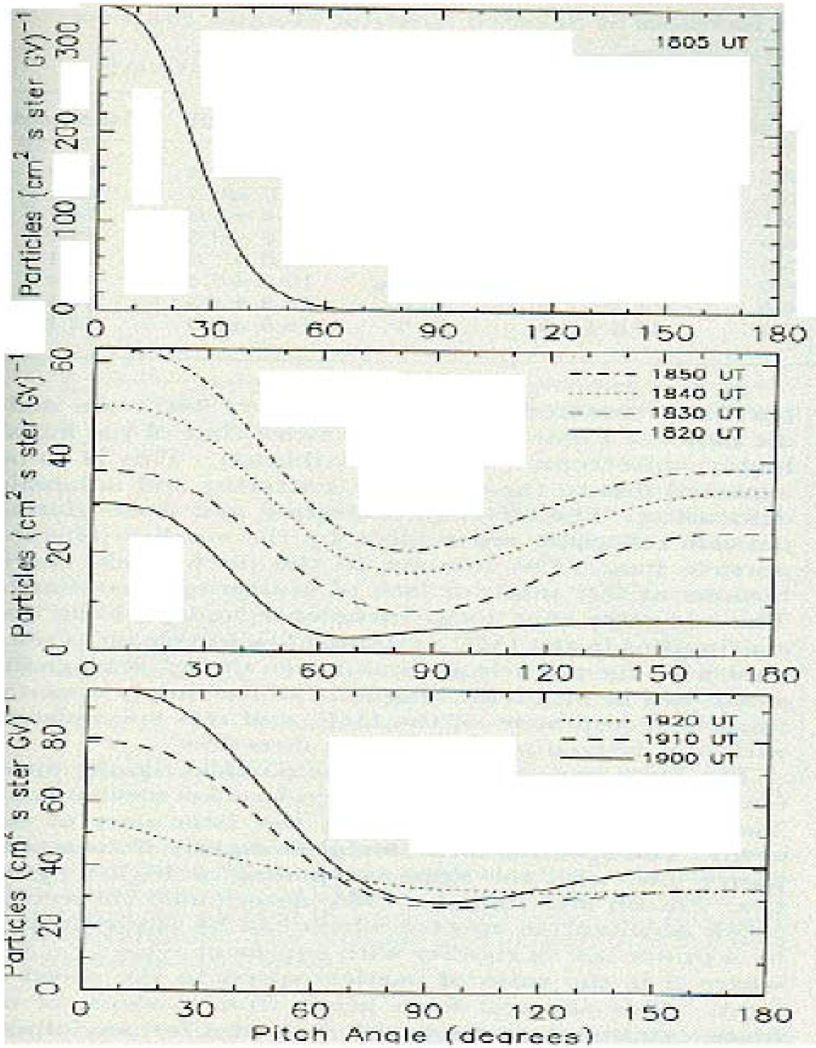
Figure 8b Extracted Lorentzian peak



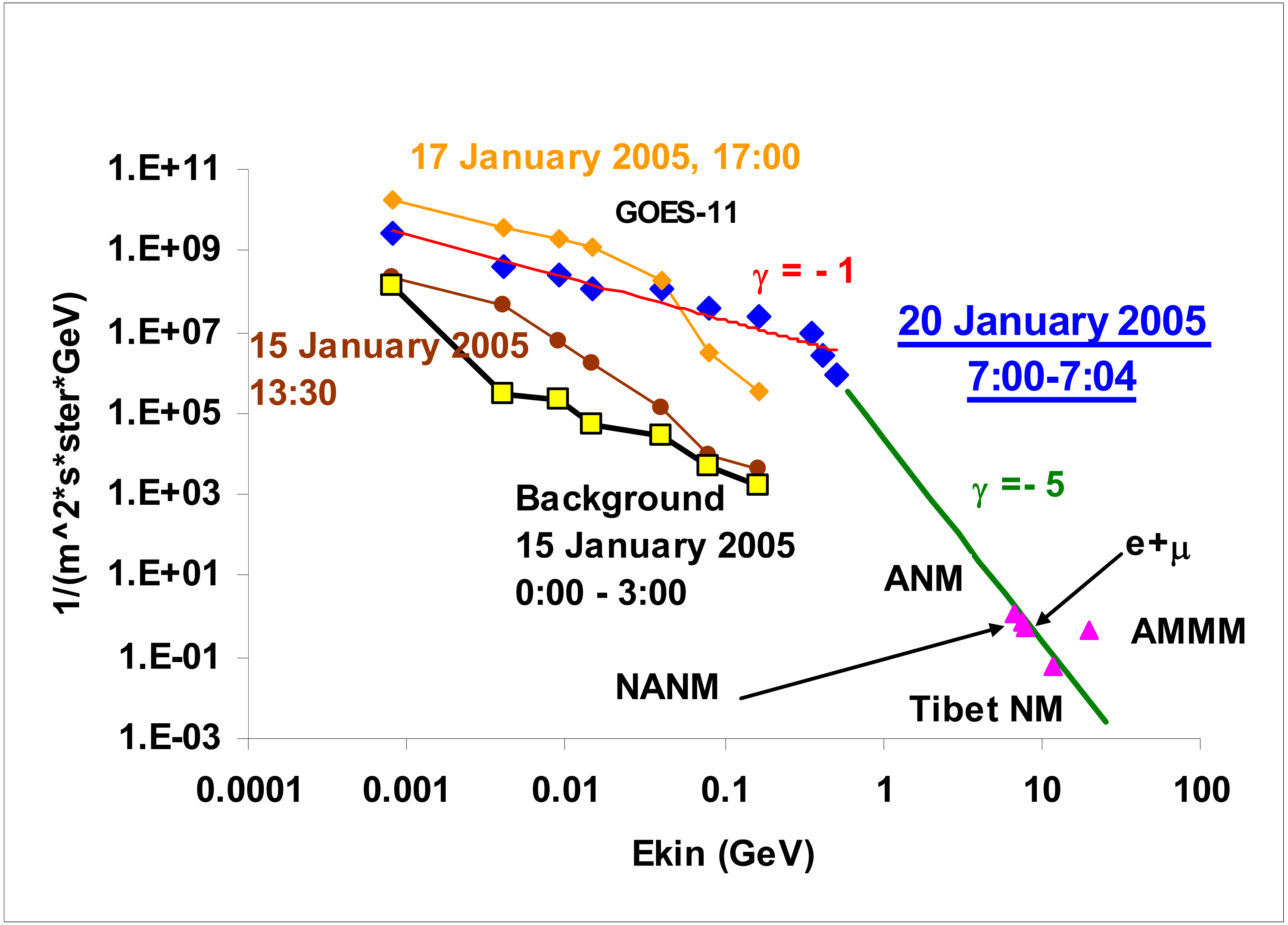
20.01.2005 (3min)
Statistical significance
Statistical significance (AMMM)
30
26
22
18
14
10
6
2
-2
14
12
10
8
6
4
2
0
-2
6:25 6:33 6:40 6:47 6:55 7:02 7:09 7:17 7:24 7:32 7:39 7:46 7:54
UT
Tibet NM
ARNM
CARPET
GRAND
AMMM

Modeling of Anisotropies, C. Plainaki, A. Belov, E.Eroshenko, H. Mavromichalaki,Yanke(2005), Cramp et al (1997, 22 October 1989

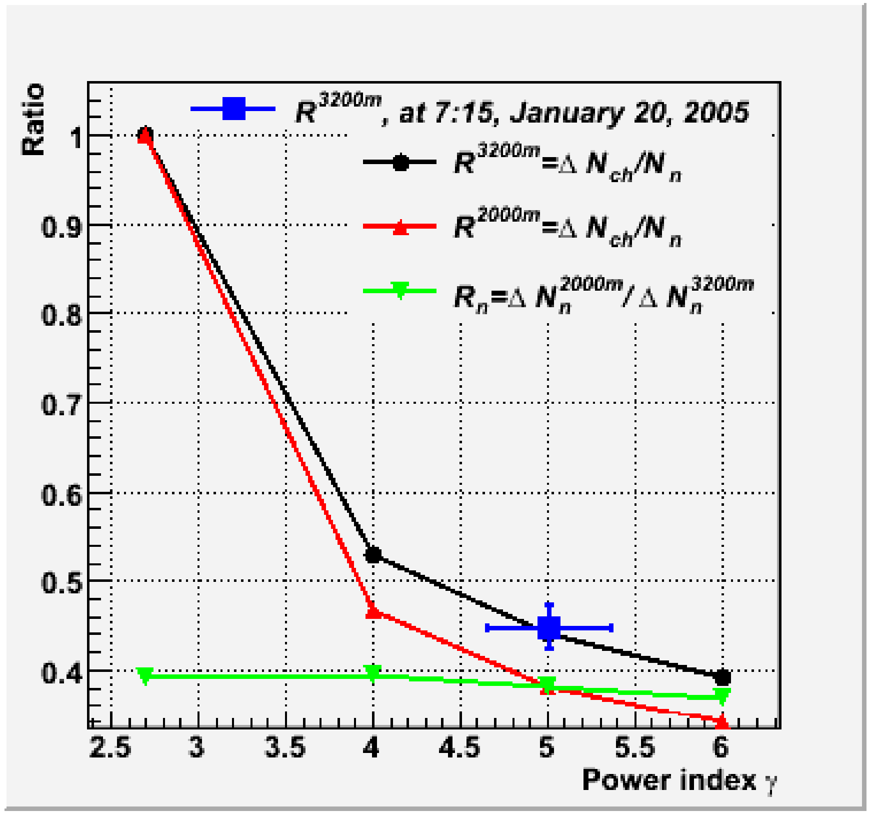




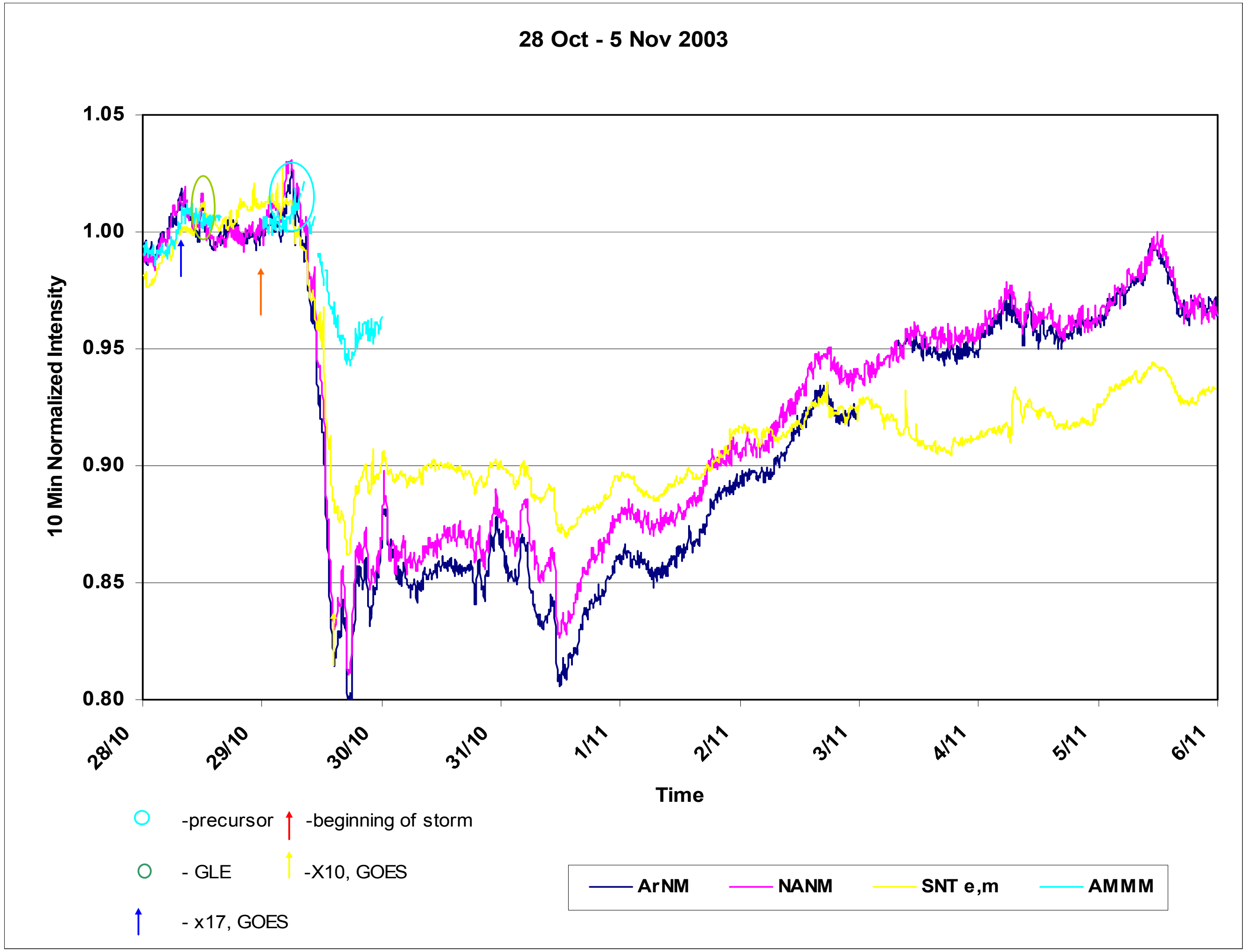
Highest Energies of 20 January GLE



Estimation of the Energy Spectra Power Index



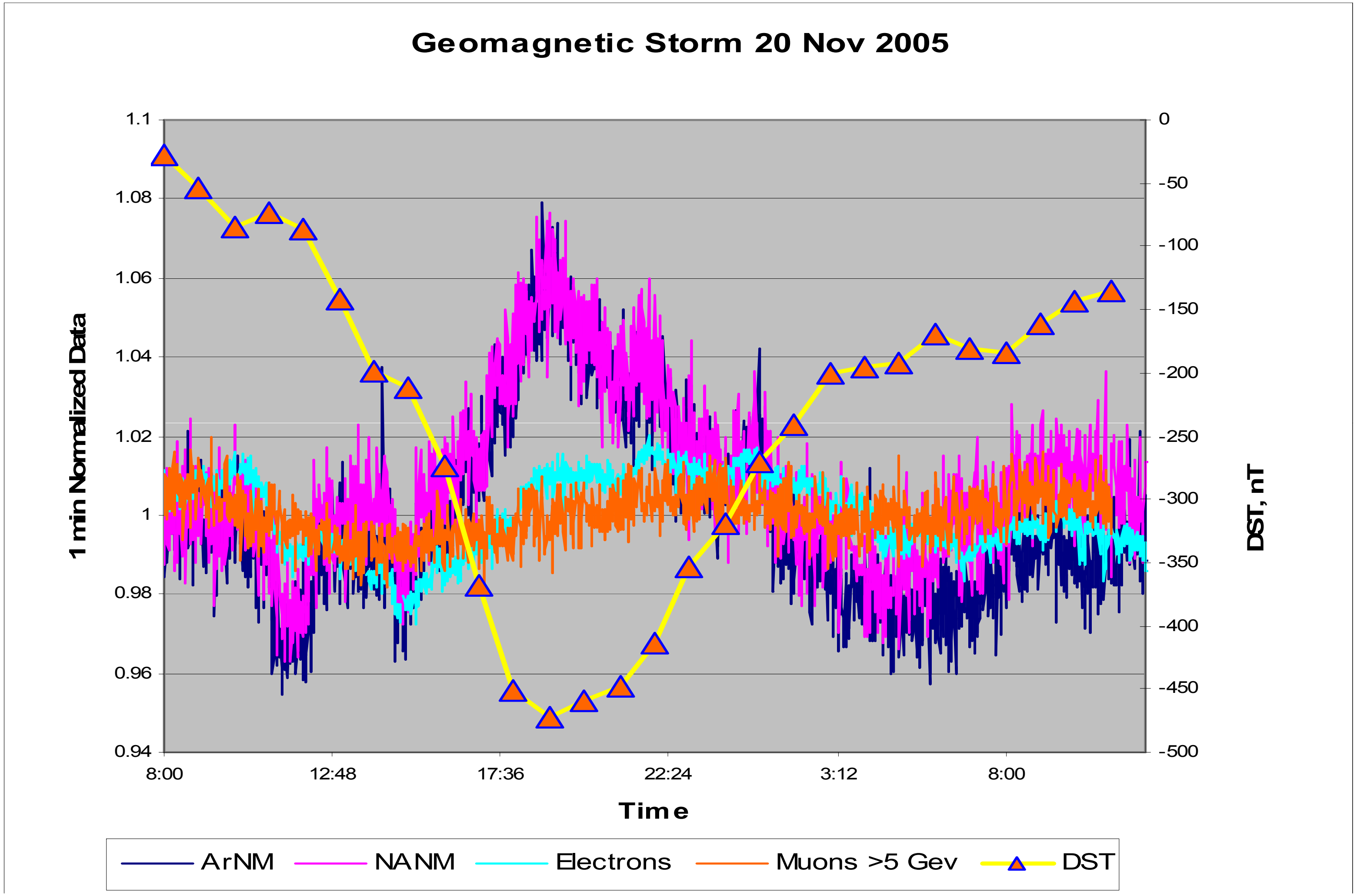
Famous “Halloween” events of 2003, detected in electron & muon and neutron fluxes by ASEC monitors at different altitudes



Correlation Matrix of ASEC monitors for 29 October 2003 (6:09 – 14:39), Fd

	ANM	NANM	AMMM	SNTe,μ	SNT thr1	SNT thr2	SNT thr 3	SNT thr4
ANM	**1**	1,00	0,97	0,99	0,99	0,97	0,95	0,98
NANM	**1,00**	**1**	0,97	0,99	0,99	0,97	0,95	0,98
AMMM	0,97	0,97	**1**	0,97	0,97	0,95	0,93	0,95
SNTe,μ	0,99	0,99	0,97	**1**	1,00	0,99	0,97	0,99
SNT thr1	0,99	0,99	0,97	1,00	**1**	0,99	0,96	0,99
SNT thr2	0,97	0,97	0,95	0,99	0,99	**1**	0,99	0,99
SNT thr3	0,95	0,95	0,93	0,97	0,96	0,99	**1**	0,97
SNT thr4	0,98	0,98	0,95	0,99	0,99	0,99	0,97	**1**

Geomagnetic Disturbance of 20 November



Correlation Matrix of ASEC monitors for 20-21 November 2003 г. (14:50 – 19:10), Geomagnetic Storm

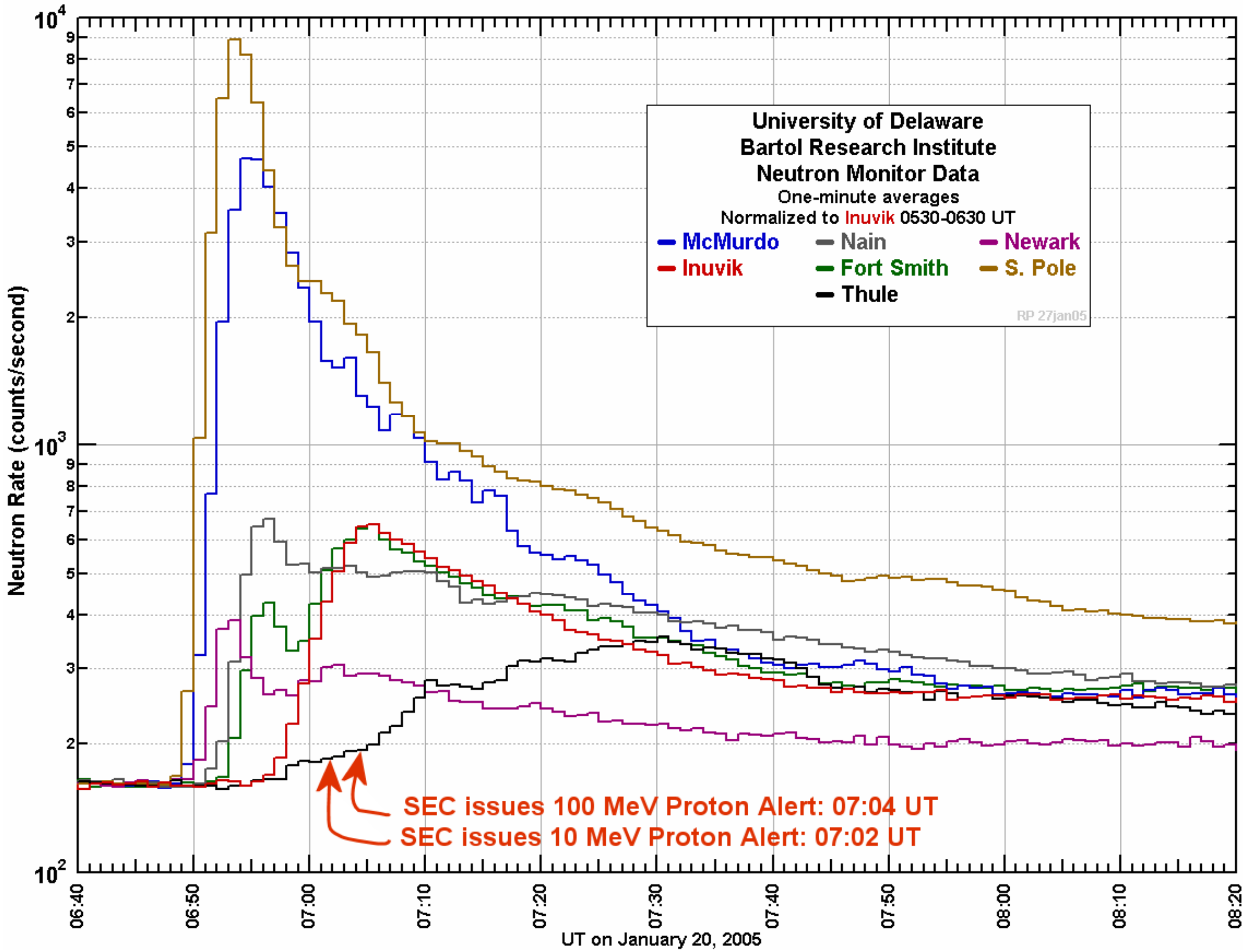
	ArNM	NANM	AMMM	SNTe,m	Thr0	Thr1	Thr2	Thr3	Thr4
ArNM	1.00								
NANM	0.90	1.00							
AMMM	0.29	0.23	1.00						
SNTe,m	0.90	0.88	0.23	1.00					
Thr0	0.91	0.88	0.26	0.91	1.00				
Thr1	0.83	0.82	0.28	0.83	0.88	1.00			
Thr2	0.78	0.78	0.23	0.80	0.81	0.80	1.00		
Thr3	0.65	0.65	0.14	0.65	0.64	0.67	0.76	1.00	
Thr4	0.43	0.43	0.05	0.42	0.43	0.46	0.47	0.62	1.00

GLE of 23-rd cycle detected by ANM

Table 2 GLE of 23-rd cycle detected by the Aragats Neutron Monitor

1	2	3	4	5
Date and Order No. of GLE	Flare Importance	GLE start at ASEC, in UT	Estimates of Significance %	$I(E_p>10MeV) >100/cm^2.s.sr.$ S2 Onset, UT*
02-05-1998 56	X1.1	**13:47**	2.3 (3.2σ)	**15:25**
06-05-1998 57	X2.7	**8:08**	2.4 (3.4σ)	**9:15**
15-04-2001 60	X14.4	**13:53**	2.5 (3.6σ)	**14:25**
26-12-2001 63	M7.1	**5:52**	2.4 (3.4σ)	**6:35**

Neutron Monitors Can Provide the Earliest Alert of a Solar Energetic Particle Event



- In the January 20, 2005 GLE, the earliest neutron monitor onset preceded the earliest Proton Alert issued by the Space Environment Center **by 14 minutes.**

Courtesy John Bieber

Solar Ions Identification

Table 1 Correlations between fluxes of different components initiated by GCR protons with rigidities 7.5<R< 20GV.

proton	e, μ	μ (>350 M3V)	μ (>5GeV)	n
e, μ	1.00	0.40	0.32	-0.21
μ (>350 MeV)	0.45	1.00	0.70	-0.37
μ (5GeV)	0.32	0.70	1.00	-0.24
n	-0.21	-0.37	-0.24	1.00

Table 2 Correlations between fluxes of different components initiated by GCR iron nuclei with rigidities 7.5<R< 20GV.

proton	e, μ	μ (>350 M3V)	μ (>5GeV)	n
e, μ	1.00	0.73	0.60	0.35
μ (>350 MeV)	0.73	1.00	0.82	0.28
μ (5GeV)	0.60	0.82	1.00	0.24
n	0.35	0.28	0.24	1.00

Conclusions

1. On January 20, 2005 at 7:02-7:05 UT the Aragats Multidirectional Muon Monitor registered additional flux of - high energy muons equal to 3.1 (+/- 0.8) 10-5 particle/cm2/sec.
2. Relativistic protons with energies ~ [7.6 – 10] GeV giving rise to the enhancement of the count rate of Neutron monitors located at slope of mt. Aragats were ejected into the interplanetary space ~3 minutes earlier than the ~20 GeV protons.
3. Particles forming the second peak of the GLE have less energy compared with the first peak. And if we adopt the hypothesis that the event in the first interval was from a flare- acceleration process while the event in the second interval was from the shock acceleration, as discussed at ICRC and SEE-2005 conferences, then we can conclude that the highest energy protons were accelerated in the flare-process.

Conclusions

- Investigations of the highest energy solar cosmic rays are very difficult problem, requiring large surfaces of the particle detectors at middle and low latitudes and high altitudes. For the energy spectra estimation detection of the various neutral and charged secondary particles are necessary.
- As the benefit of variety information from different type particle detectors are both the basic knowledge on the universal processes of particle acceleration and warnings on the Space Weather severe conditions. The second is of huge importance taking into account results of the newest model of solar activity (Dikpati, 2006), claiming ~50% enhancement of solar activity in 24-th cycle comparing with 22 and 23 cycles.