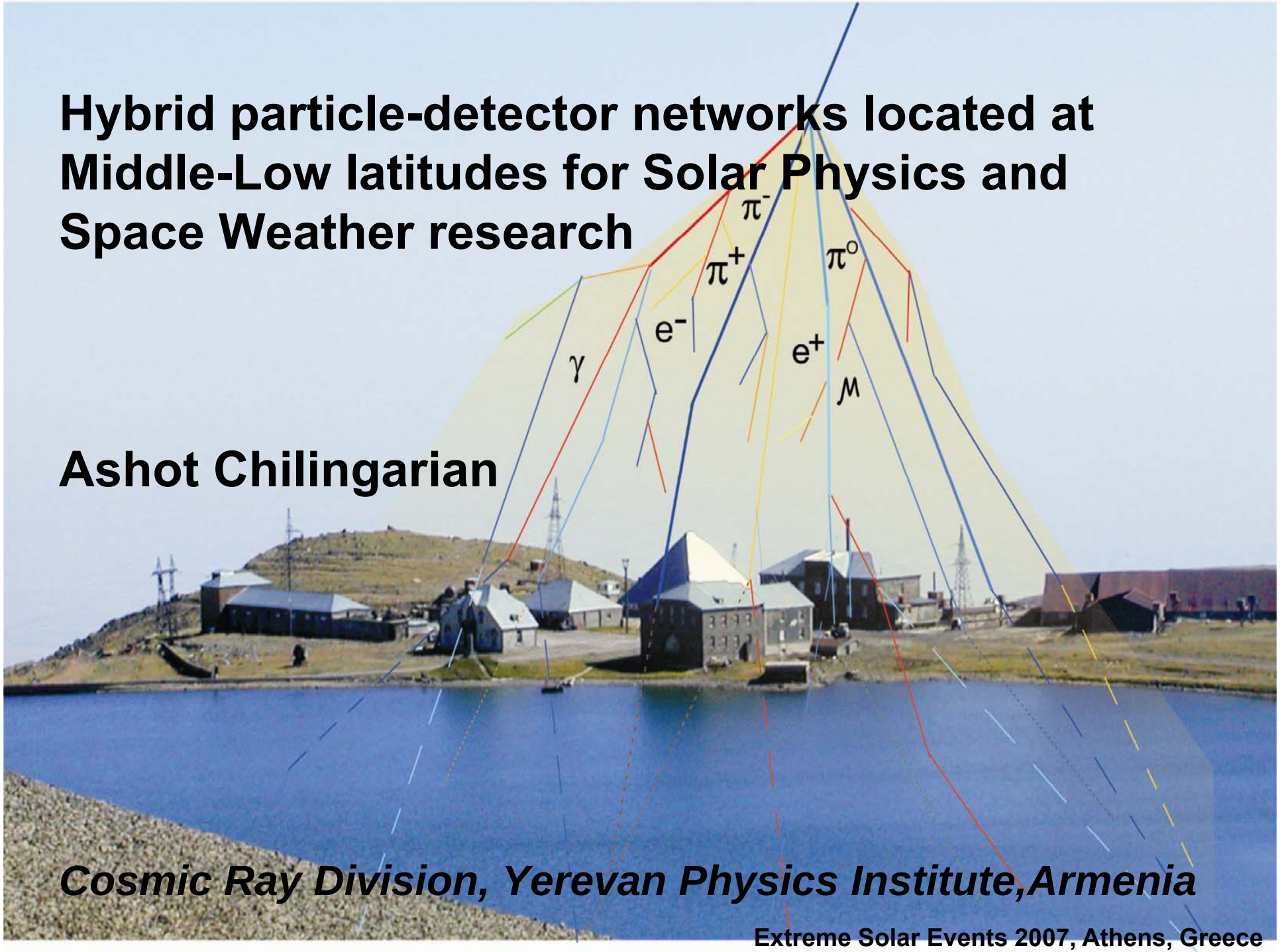
Hybrid particle-detector networks located at Middle-Low latitudes for Solar Physics and Space Weather research



Ashot Chilingarian

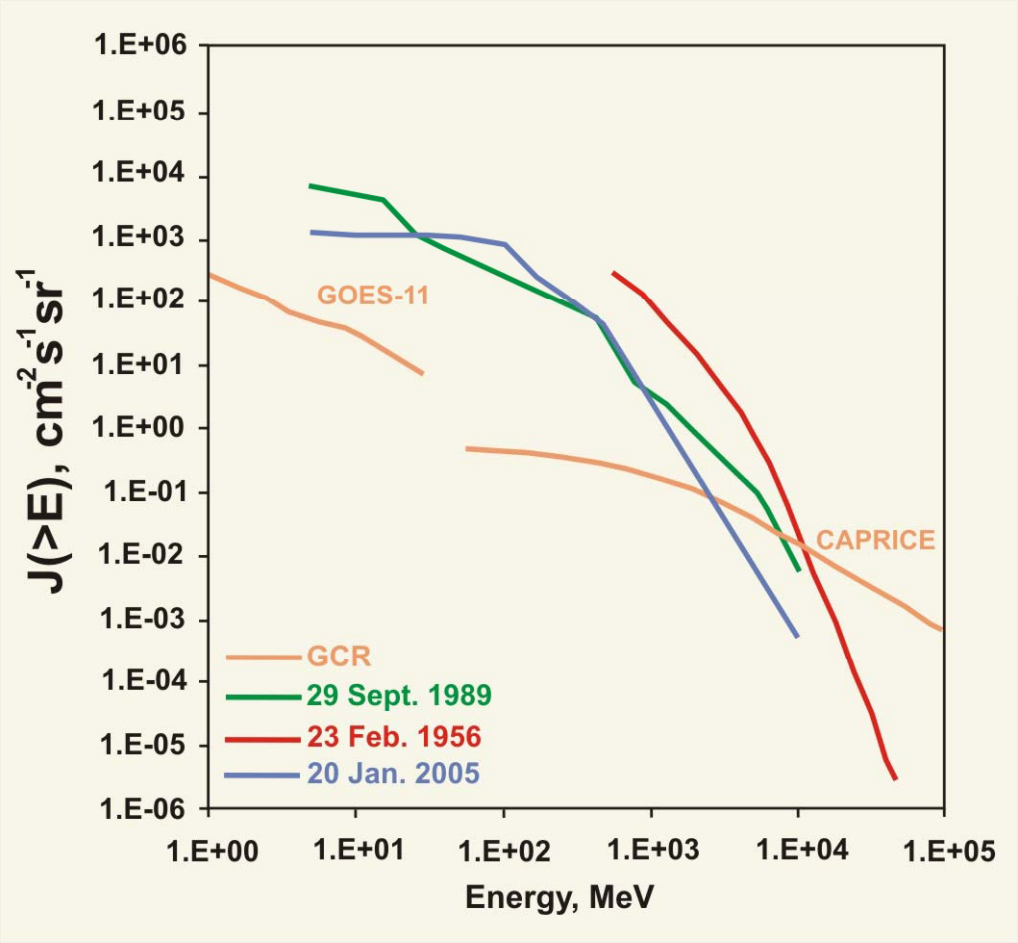
Cosmic Ray Division, Yerevan Physics Institute,Armenia

Extreme Solar Events 2007, Athens, Greece

Accompanied Posters

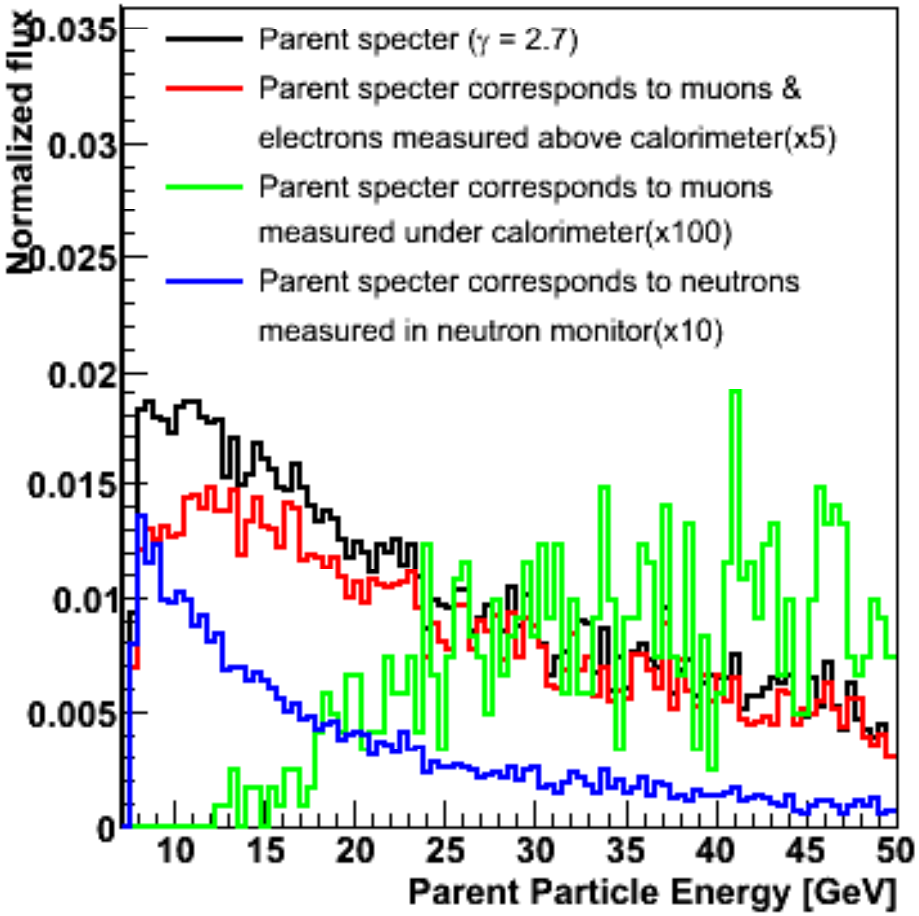
- **Advanced date acquisition system for the SEVAN (Space Environmental Viewing and Analysis Network), 9:55**
- **PD-3 ‘On the Possibility to modernize existent network of Neutron Monitors’**
- **PD-4 ‘Data Visualization Interactive Network 3-rd for ASEC’**
- **PD-5 ‘Characteristics of the Space Environmental Viewing and Analysis Network’**
- **PD-6 ‘Electronics for the Space Environmental Viewing and Analysis Network’**

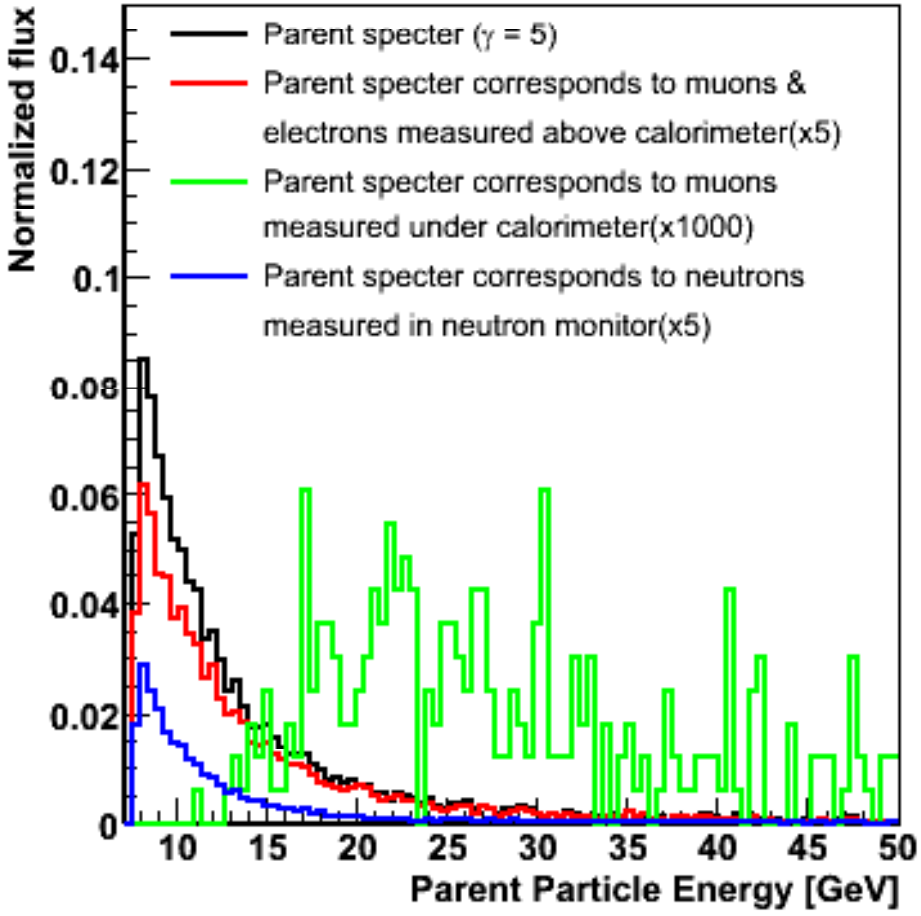
Galactic and Solar Cosmic Rays



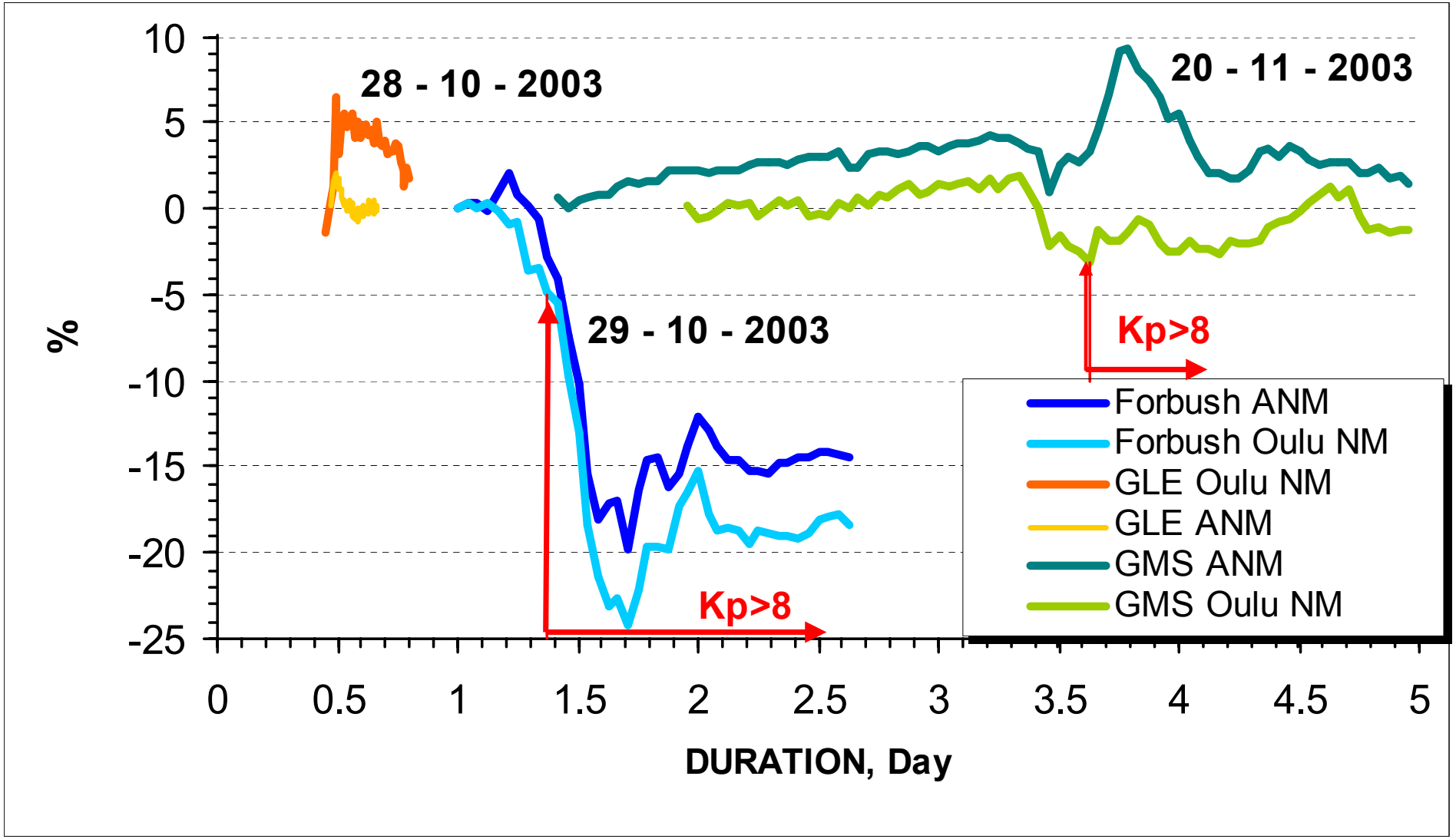
After 10 GeV the intensity of GCR become increasingly higher comparing with ever detected SCR

Energy spectra of Galactic and Solar proton detected by ASEC Monitors (Rc ~ 7.1 GV)



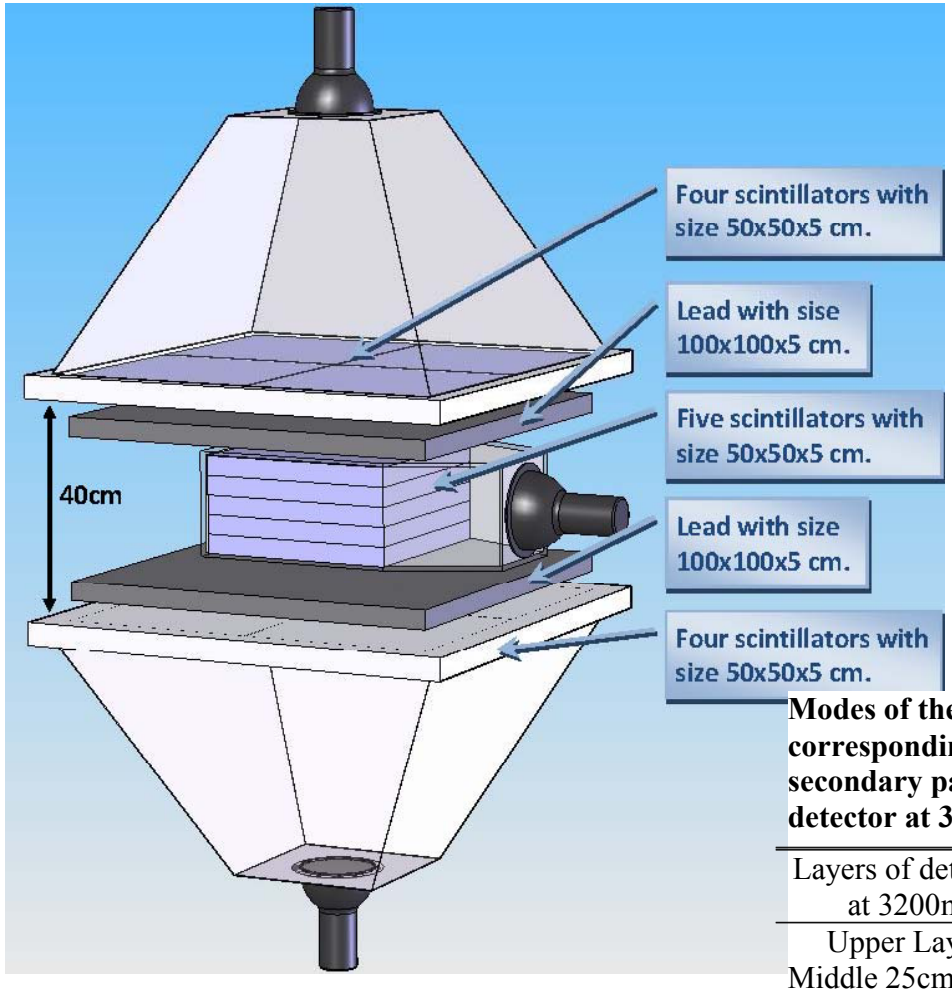


Solar Modulations Effects



Hybrid Particle Detectors for the Space Environmental Viewing and Analysis Network (SEVAN)

111 – traversal of high energy muon;
011 and 010 – traversal of the neutral particle;
100 – traversal of low energy charged particle.
110 – traversal of higher energy charged particle stopped in the second lead absorber.
001 – registration of the inclined charged particles.

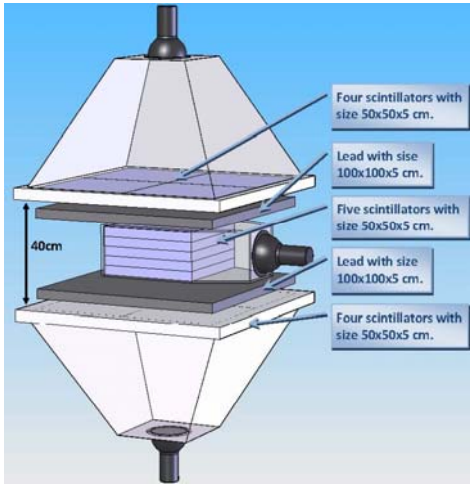


Modes of the GCR Energy spectra corresponding to the different species of secondary particles registered by SEVAN detector at 3200m above sea level.

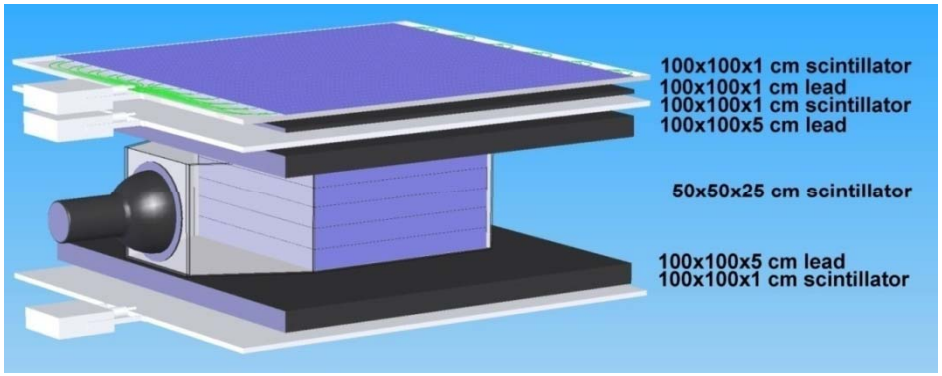
Layers of detector at 3200m	Mode of the parent "GCR" Energy spectrum [GeV]
Upper Layer	11.5
Middle 25cm layer	8.5
Down Layer	14.5

Information, detector charts, agreements in:
http://crdlx5.yerphi.am/index.php?Page=/IHY-CRD/SEVAN/&Title=SEVAN

Purity of Selected Events



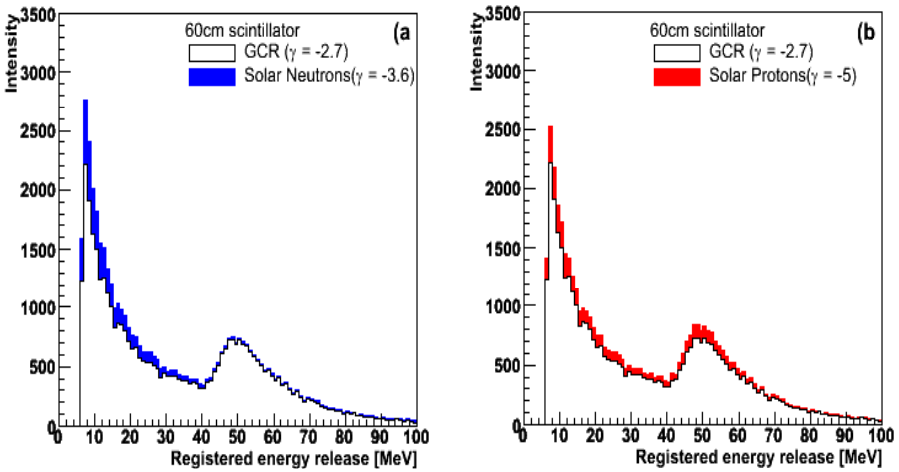
3-layered detector, 3200m, 1min						
Coincidence type	**Total Count Rate**	**Electrons #(%)**	**Muons #(%)**	**Gamma #(%)**	**Neutrons #(%)**	**Protons #(%)**
'1--'	26575	7700 (29)	14943 (56.2)	2007 (7.6)	641 (2.4)	1257 (4.7)
'01-'	2284	173 (7.6)	533 (23.4)	874 (38.3)	670 (29.3)	31 (1.4)
'--1'	16254	673 (4.1)	13998 (86.1)	449 (2.8)	534 (3.3)	584 (3.6)
4-layered detector, 3200m, 1min						
'1---'	26010	8073 (31)	15007 (57.7)	1325 (5.1)	357 (1.4)	1220 (4.7)
'01--'	9057	158 (1.7)	483 (5.3)	8002 (88.4)	384 (4.2)	28 (0.3)
'-01-'	1724	187 (10.9)	468 (27.2)	376 (21.8)	661 (38.4)	28 (1.7)
'---1'	16245	688 (4.2)	14038 (86.4)	591 (3.6)	374 (2.3)	539 (3.3)



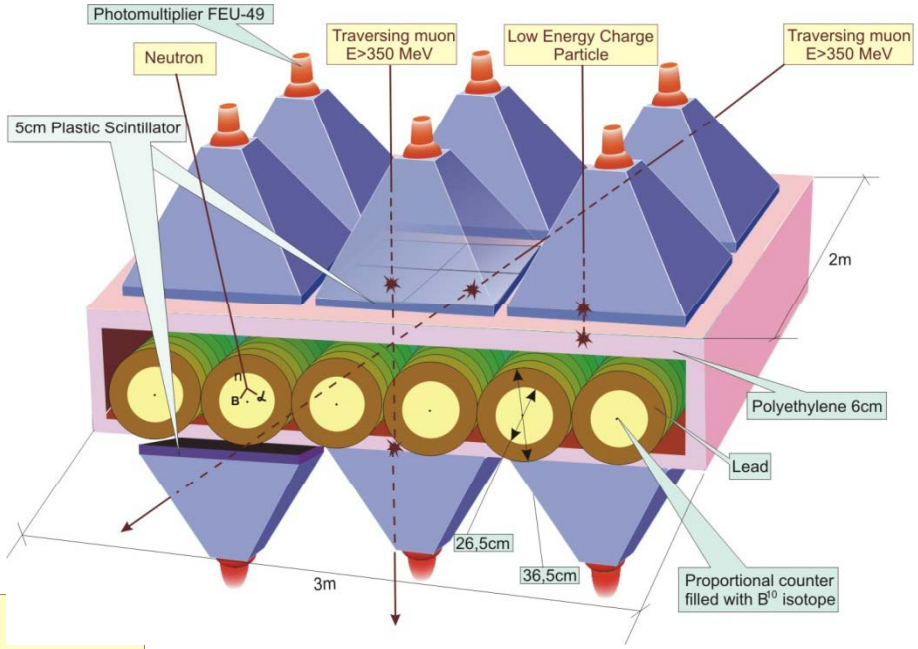
Possible SEVAN sites.

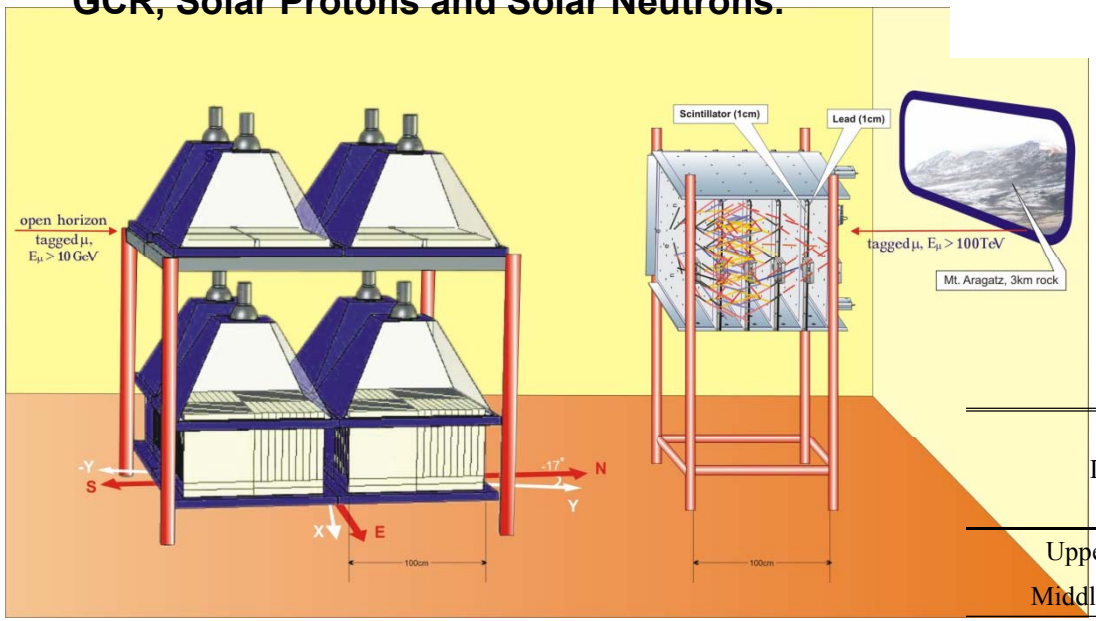
		Latitude	Longitude	Altitude [m]	R_c [GV]	Time [UT]
Germany	(Greifswald)	54.5N	13.23E	6	2.34	50m
Slovakia	(Lomnicky Stit)	49.2N	20.22E	2634	3.88	1h28m
Croatia	(Zagreb)	45.82N	15.97E	120	4.89	1h
Bulgaria	(Musala)	42.1N	23.35E	2430	6.19	1h35m
Armenia	(Aragats1)	40.25N	44.15E	3200	7.1	2h56m
Armenia	(Aragats2)	40.25N	44.15E	2000	7.1	2h56m
Israel	(Hermon)	33.18N	35.47E	2025	10.39	2h20m
Costa Rica	(San Jose)	10.0N	84.0W	1.2	10.99	-5h36m
China	(Tibet)	30.11N	90.53E	4300	13.86	6h
India	(Delhi)	28.61N	77.23E	239	14.14	5h8m
Indonesia	(Jakarta)	6.11S	106.45E	8	16.03	7h6m

SEVAN Prototype Detectors at ASEC



Registered energy deposit corresponding to GCR, Solar Protons and Solar Neutrons.

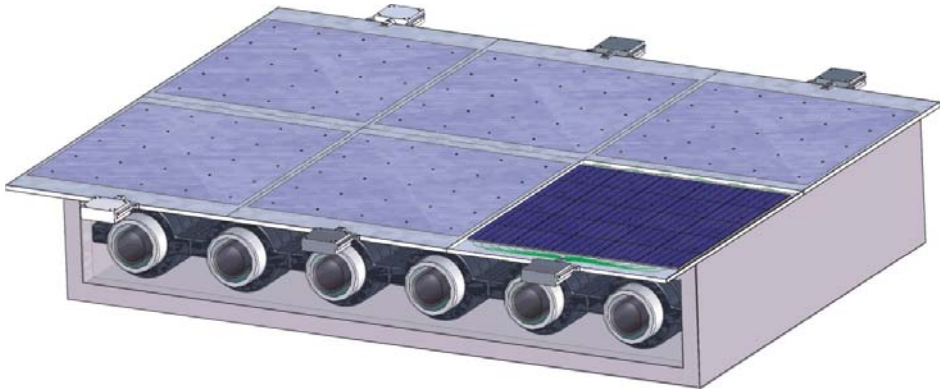


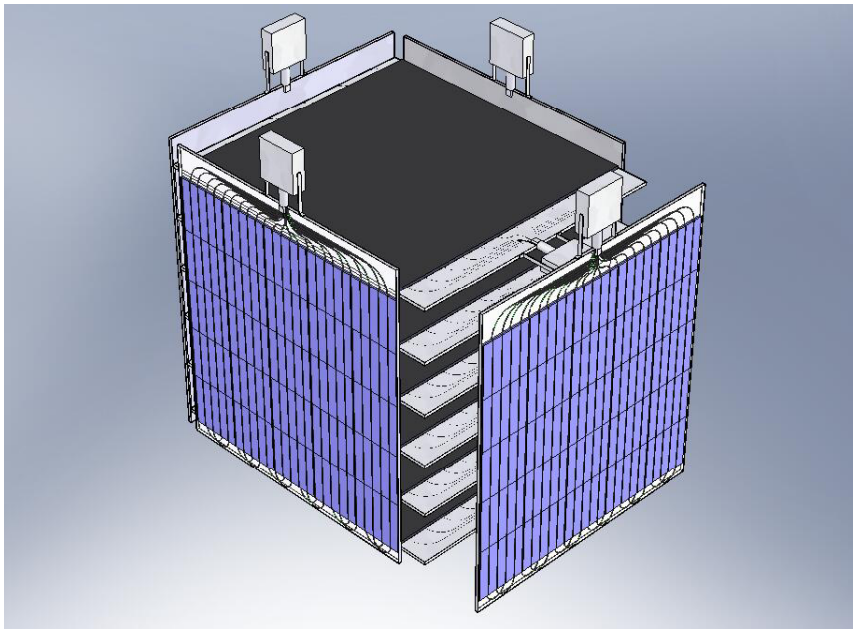


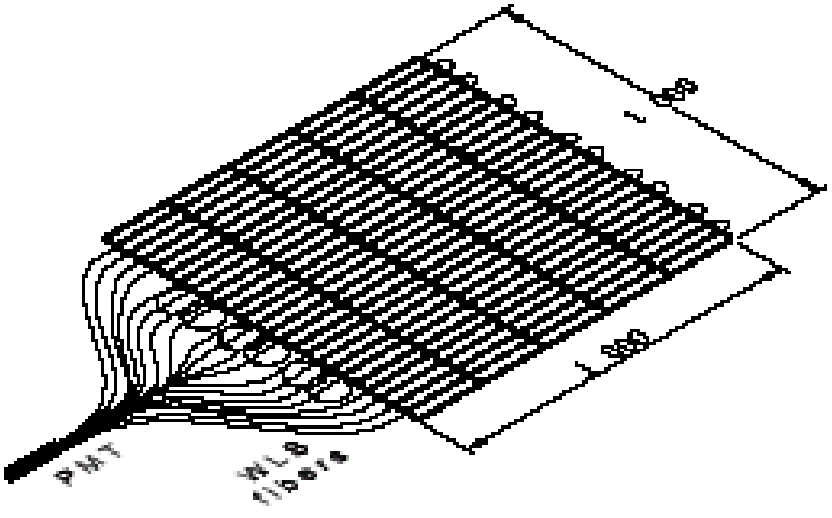
Simulated enhancement of the 5-munute count rates due to Neutron and Proton event.

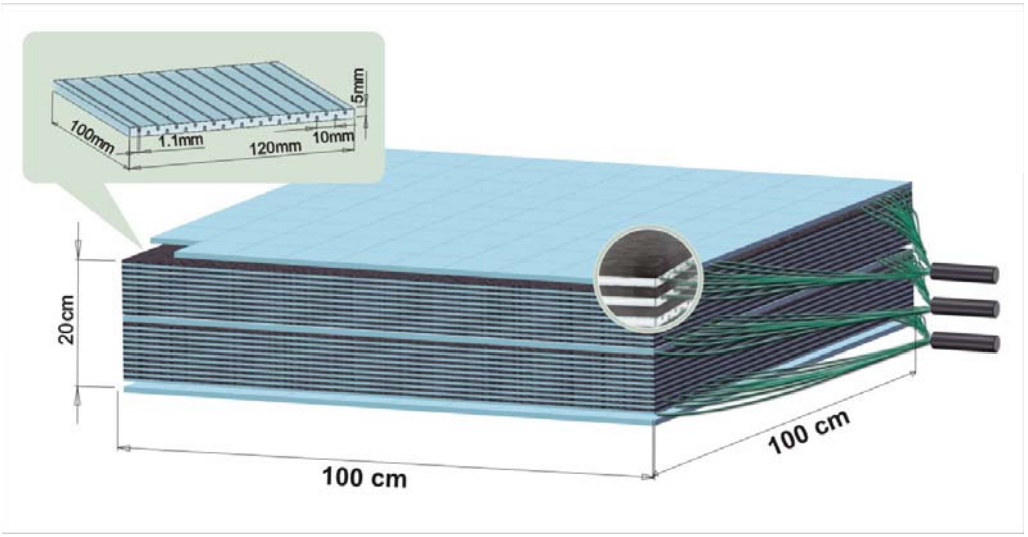
Detector layer	Solar Protons	Solar Neutrons
Upper 5cm scintillator	4.8σ	2.6σ
Middle 25 cm scintillator	1.7σ	6.4σ

Advanced Particle Detectors for Surface CR monitoring







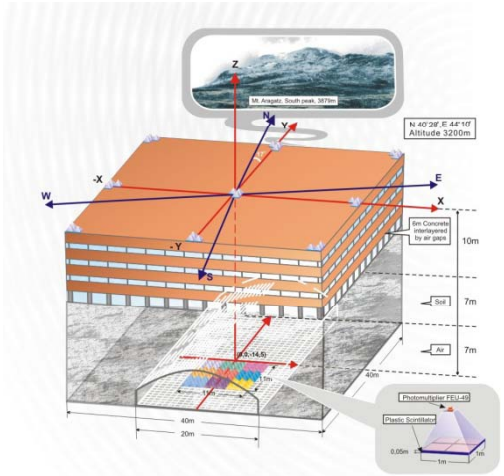


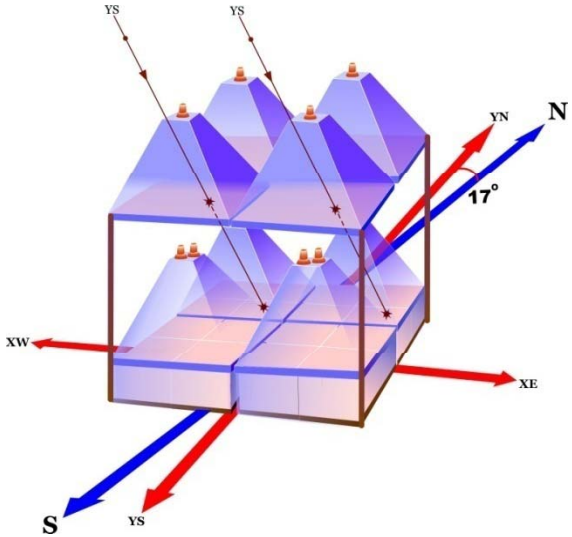
Additional possibilities of measuring multiple secondary fluxes

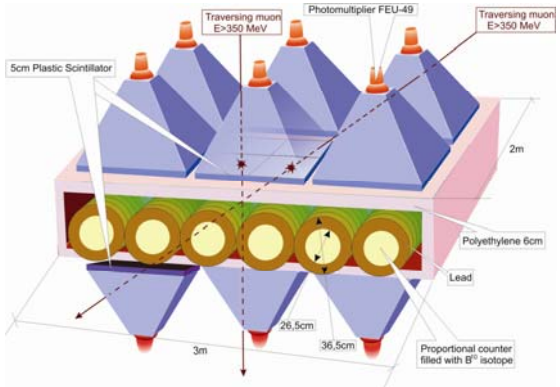
- Enlarge statistical accuracy of detection different solar modulation effects;
- Probing different populations of primary CR, up to 20-30 GV;
- Reconstructing SCR spectra and spectral “knees”;
- Classification of primary particles: “neutron” or “proton” SEP events;
- Correlation matrices between different fluxes;
- Statistical analysis of the Fd and GMS events: understanding physics of IMCE interactions with magnetosphere;
- Space Weather forecasting, to be tested by extensive data base of ASEC monitors operation during 23 cycle.

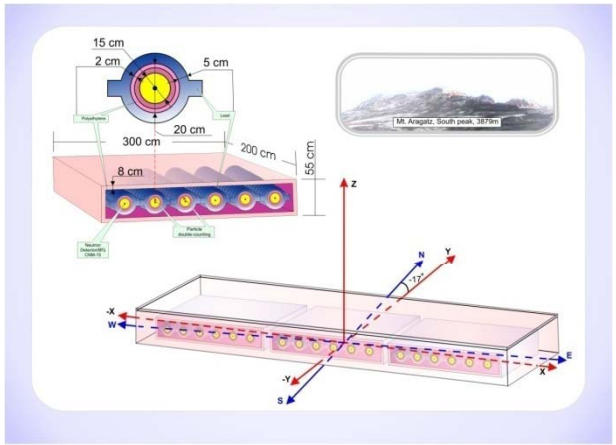
GLE of 23rd cycle detected by the ASEC particle monitors

GLE number and date	X-Ray Flare	ASEC Monitor	GLE onset	First Peak time	σ	Second Peak time	σ	Time of S2 Alert by SEC/NOAA
GLE 60	X14.4	ANM	13:55	14:00	3.8	14:30	5.3	14:25
4/15/2001		NANM	13:55	14:00	3.5	14:30	4.1	
GLE 65	X17	ANM	11:25	11:45	4.6	12:10	4	12:40
10/28/2003		NANM	11:30	11:35	3.5	12:05	3.6	
GLE 69	X7	ANM	6:55	7:10	5.6			7:01
1/20/2005		NANM	6:55	7:00	4.5			

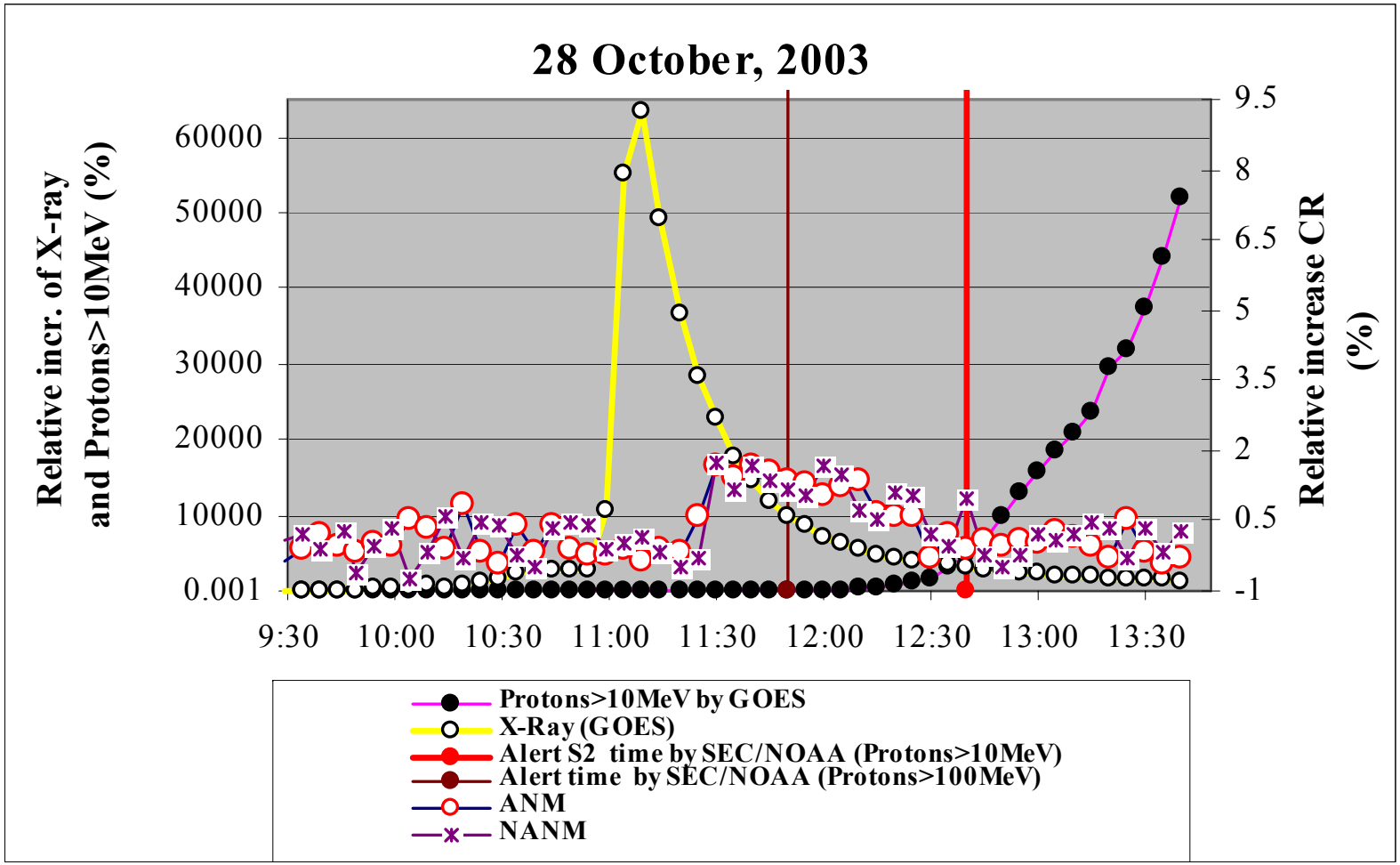




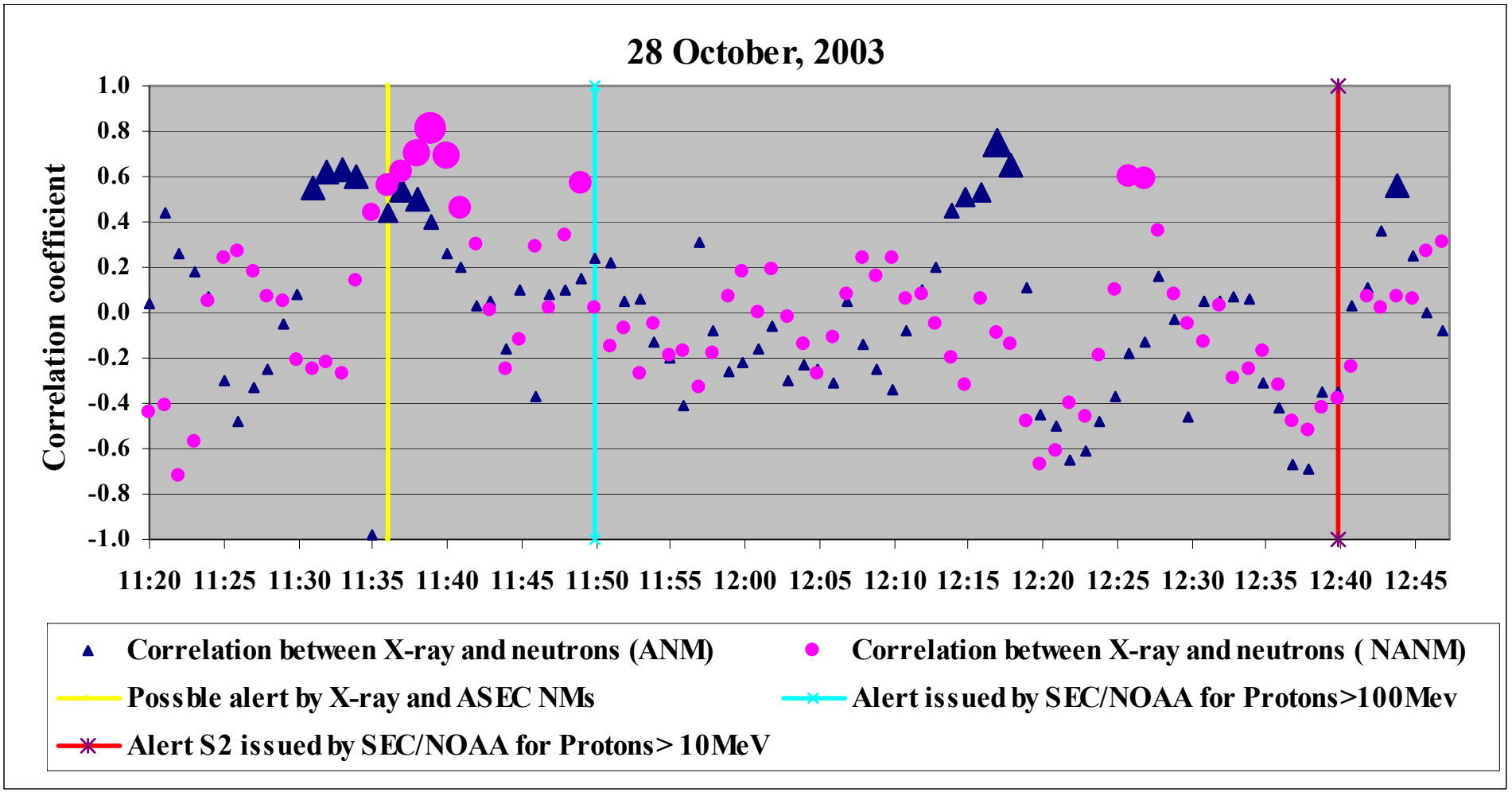




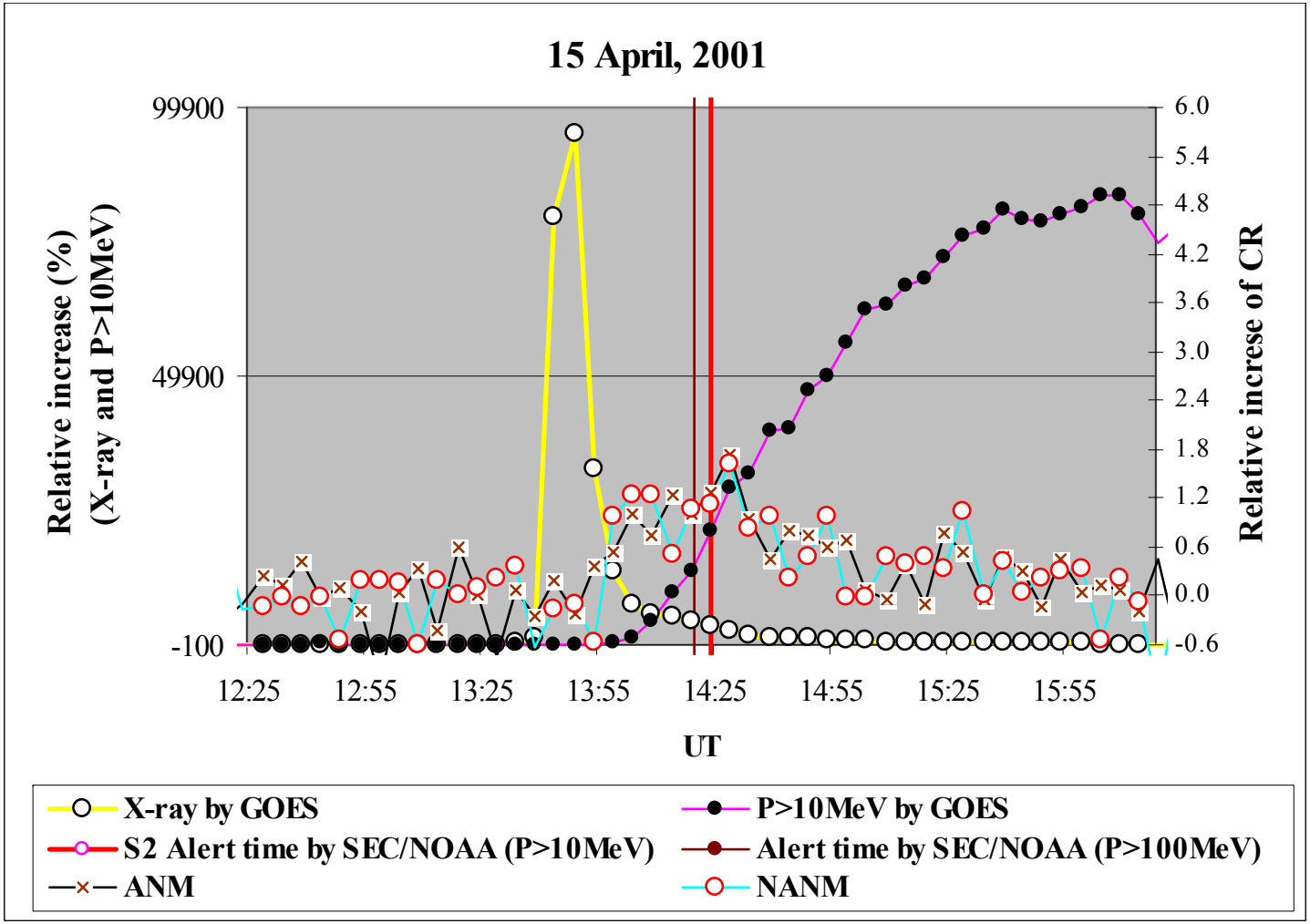
Radiation from 28 October 2003 X14.4 flare (flux maximum at 11:10). SEC/NOAA alerts on 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the ANM and NANM) reaches ~1.7% at ~11:30.



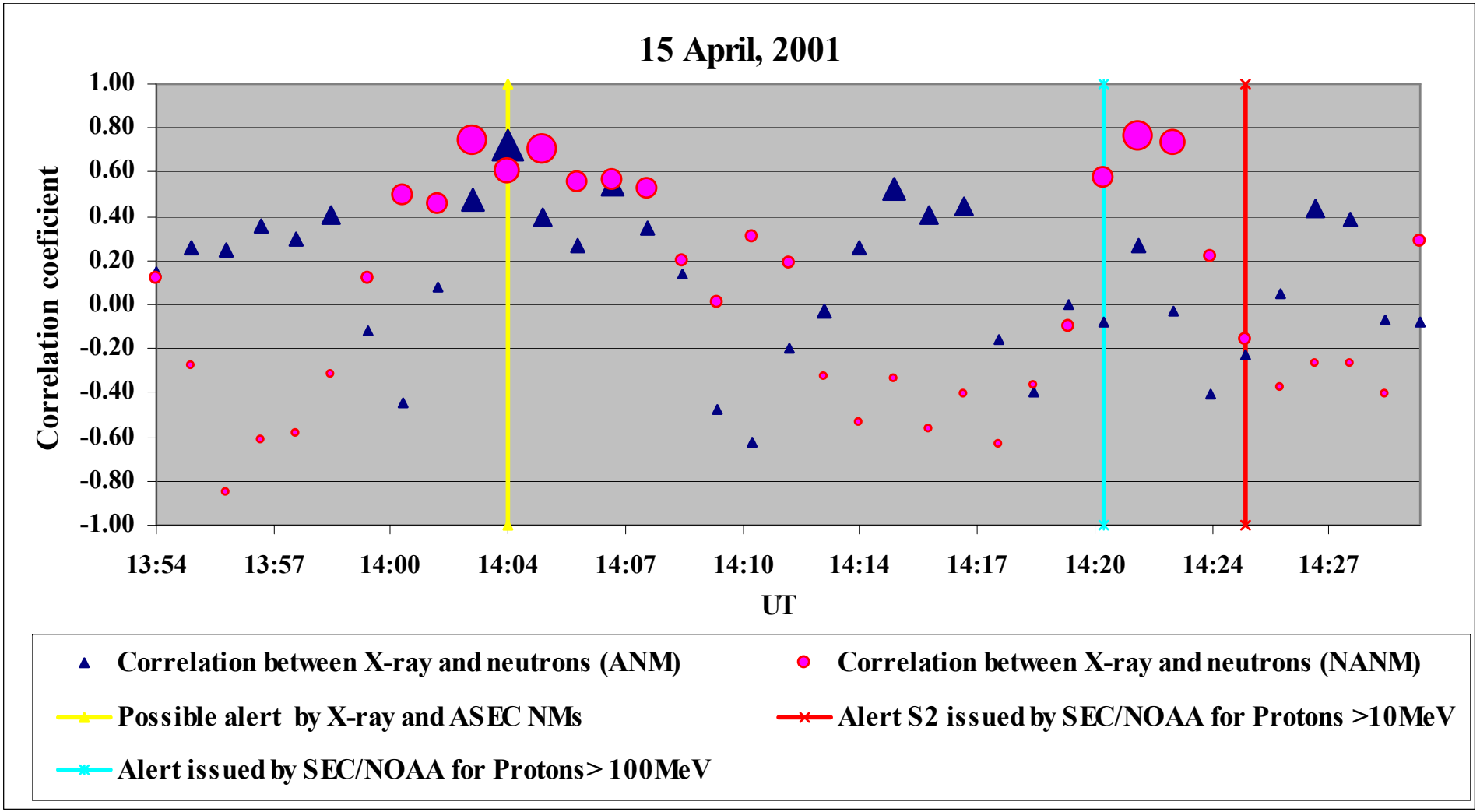
Pattern of correlations between neutron flux and X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates.



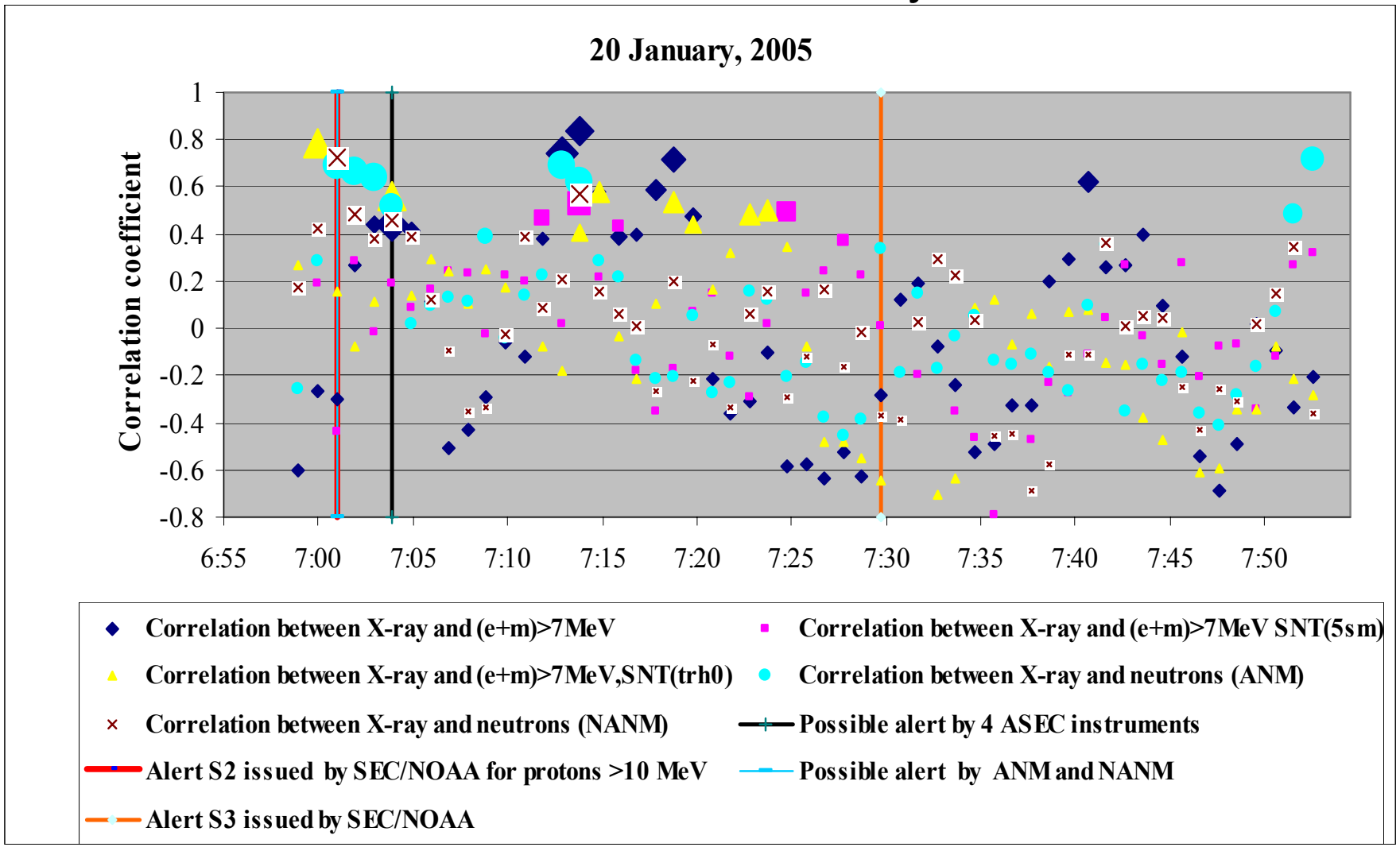
Radiation from 15 April 2005 X17.2 flare. SEC/NOAA alerts on100 MeV protons at 14:21 and S2 alert for 10 MeV protons at 14:25. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.4% at ~14:00.



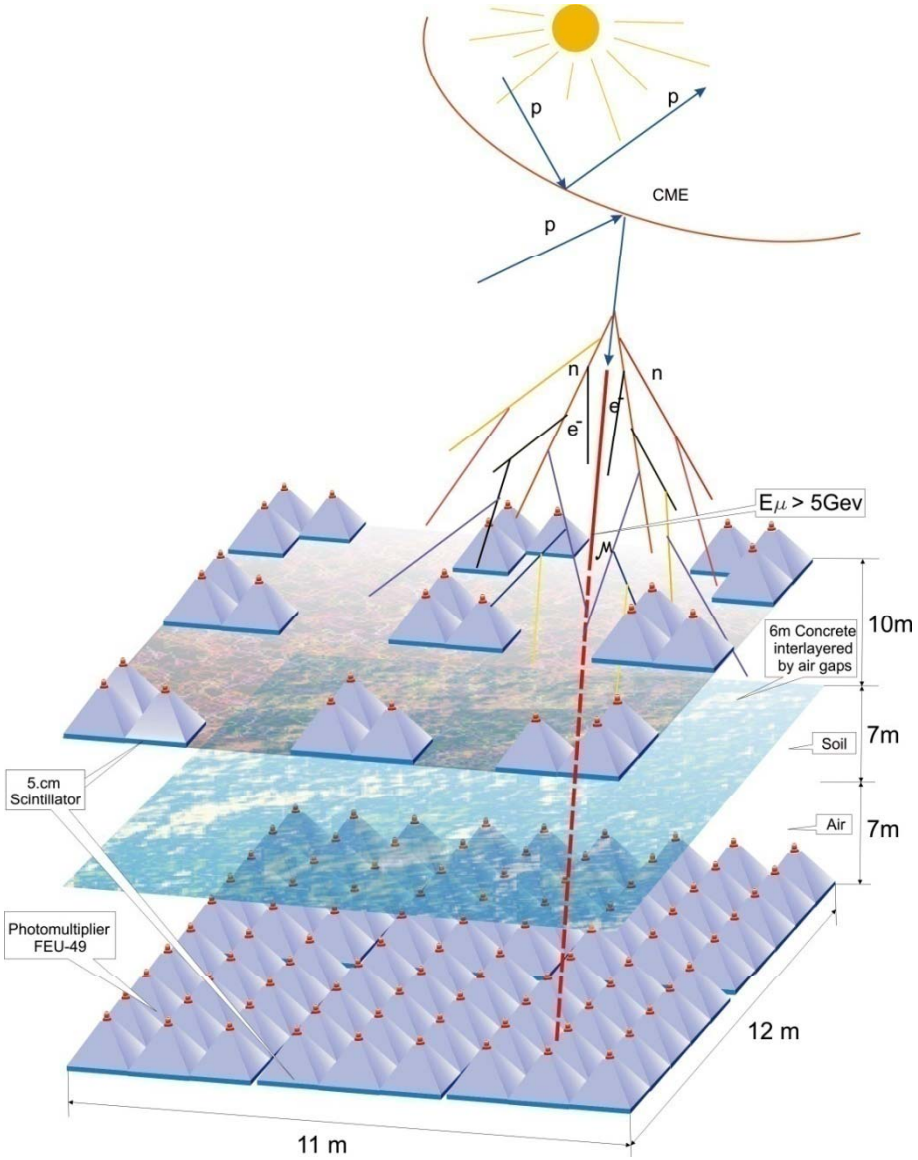
Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux at 15 April 2001. Correlation between X-ray and Neutrons peaks reach values 0.6-0.8 at 14:04, 20 minutes after X-ray maximum.

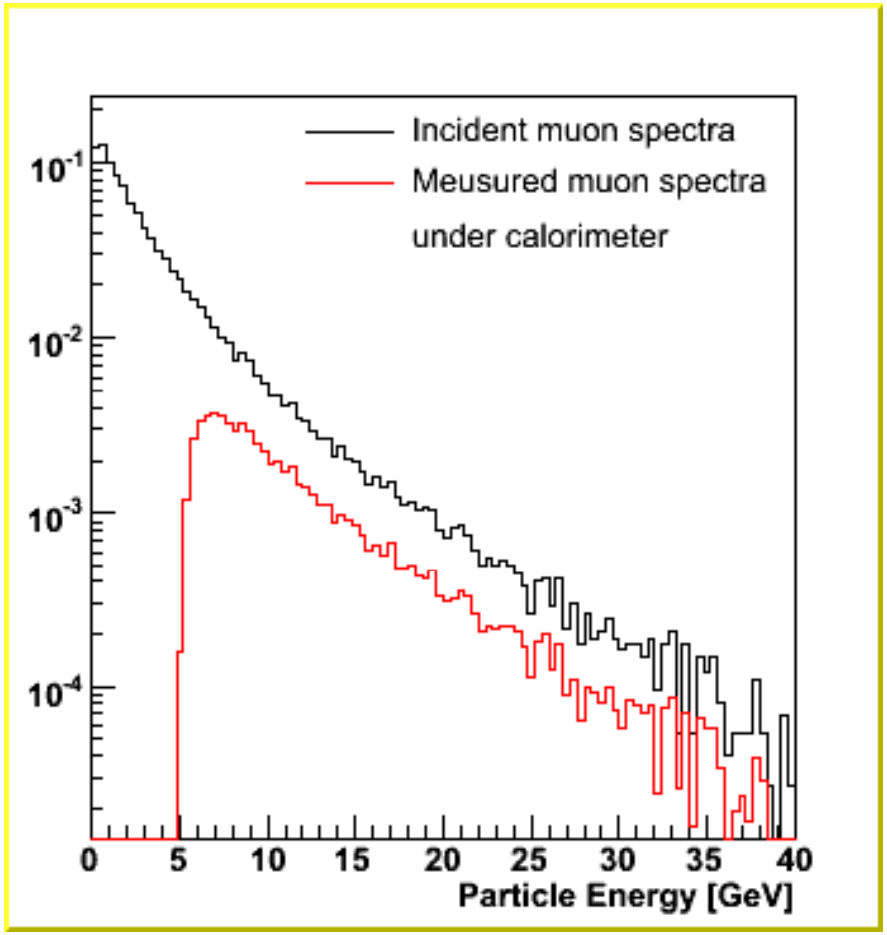


Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux at 15 20 January 2005. Correlation between X-ray and ASEC monitors reach values 0.6-0.8 at 7:01, 20 minutes after X-ray maximum

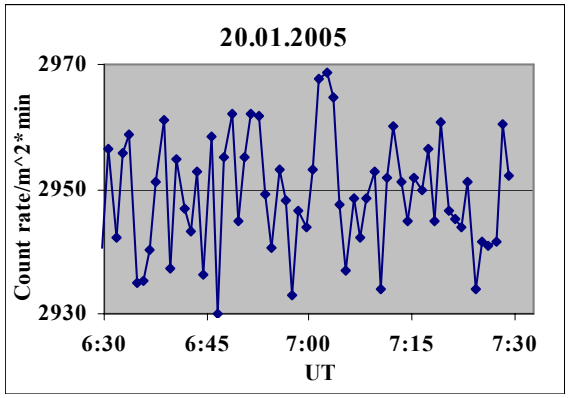


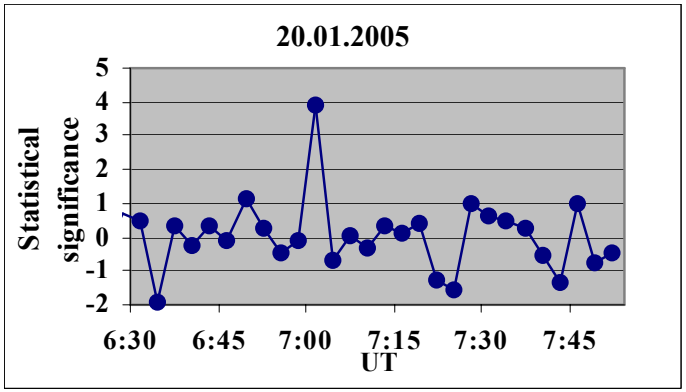
Aragats Multidirectional Muon Monitor (AMMM)



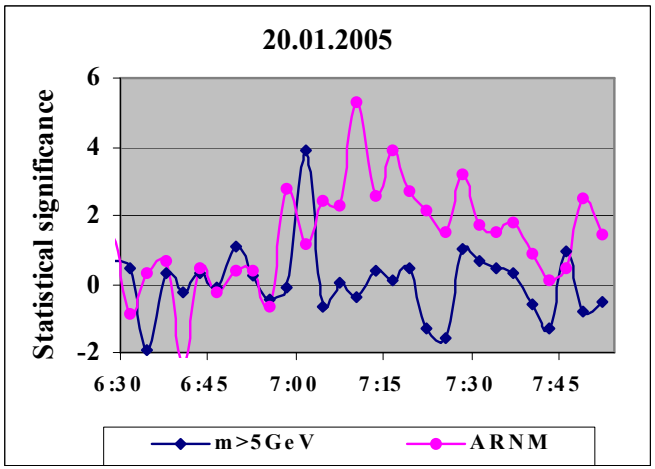


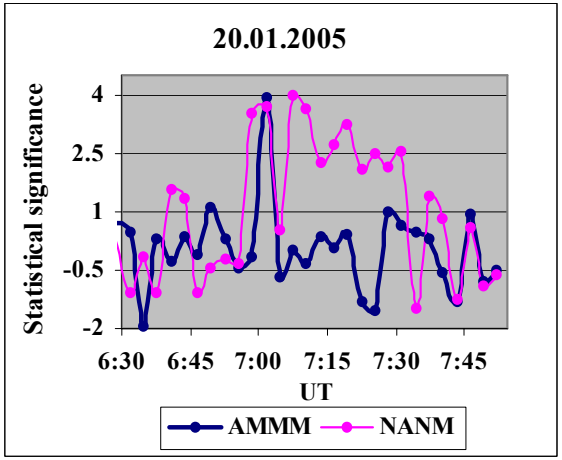
AMMM Detection of GLE 20 January 2005

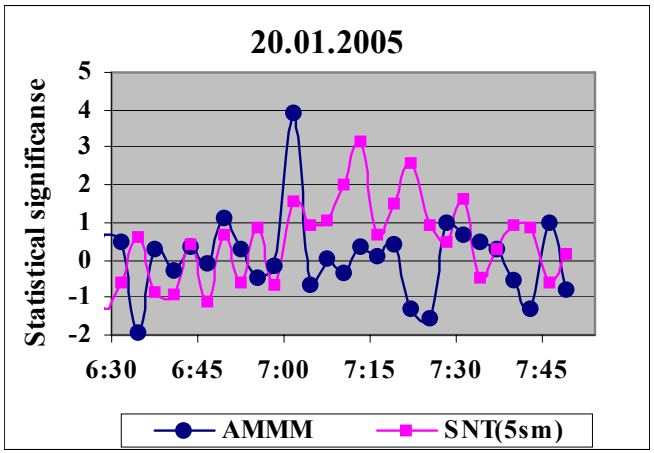


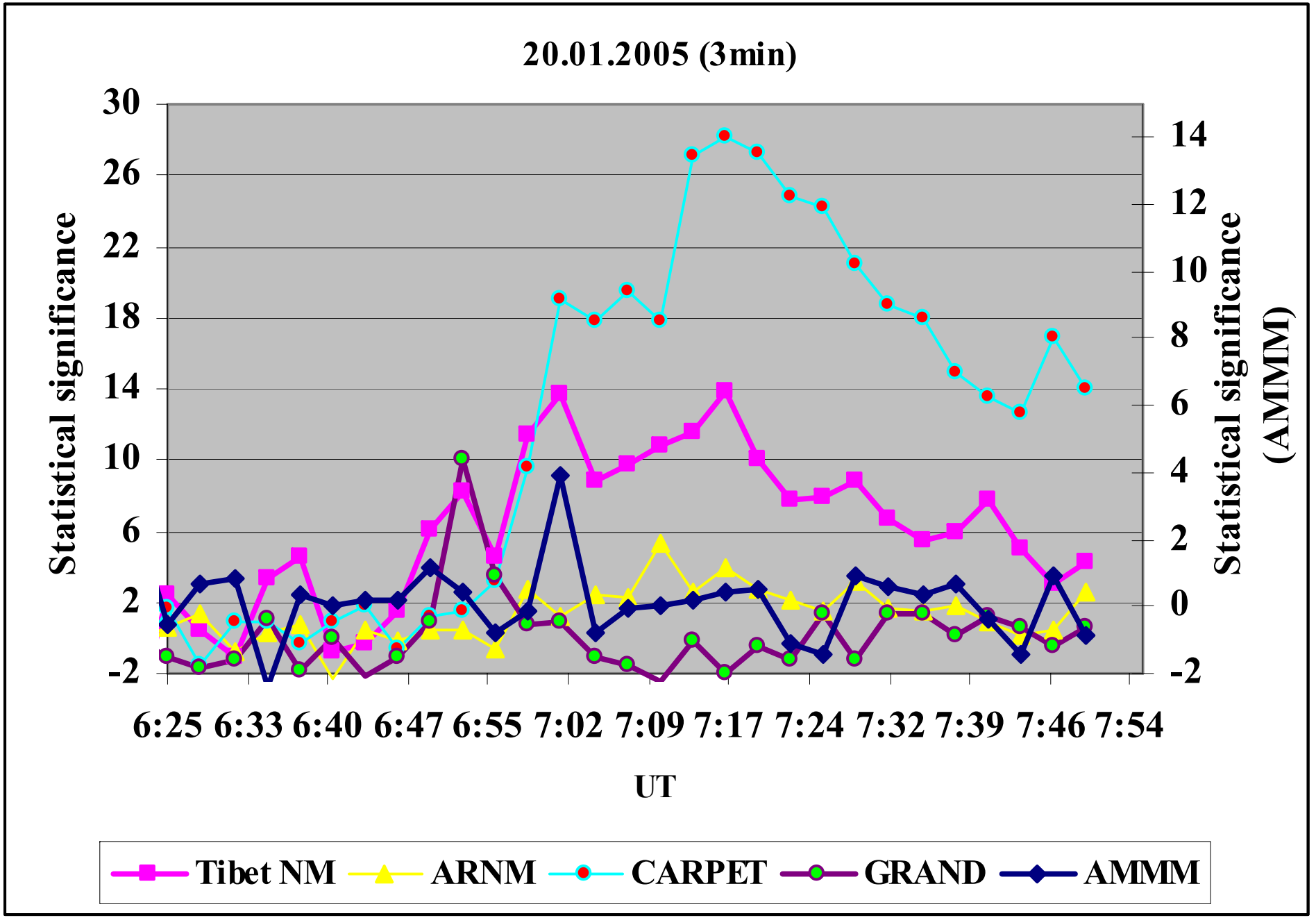


The additional signal at 7:02-7:04 UT equals 2354 (0.644%)
If we adopt the Poisson SD~ 0.164%, significance = 3.93σ

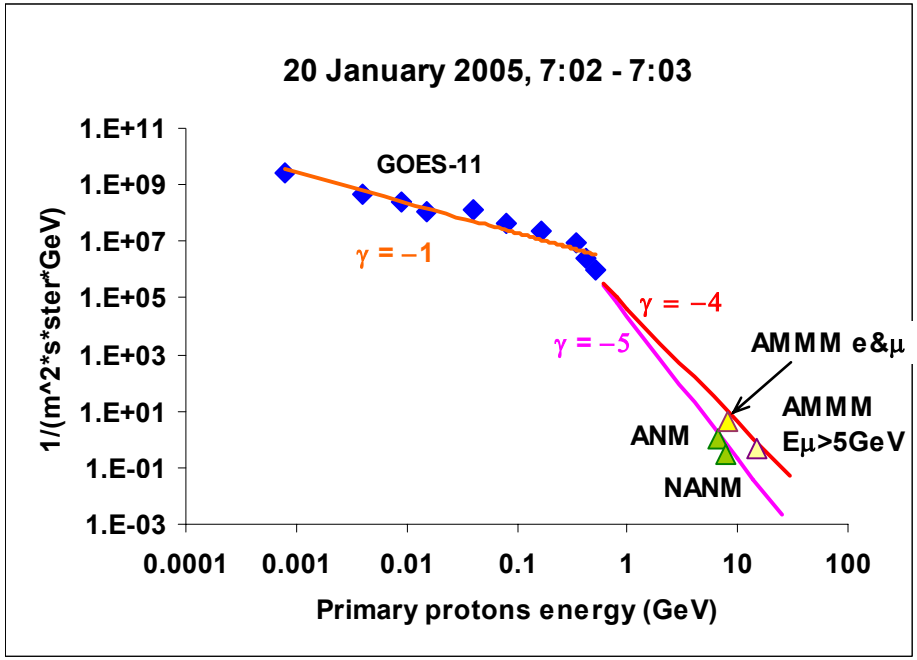


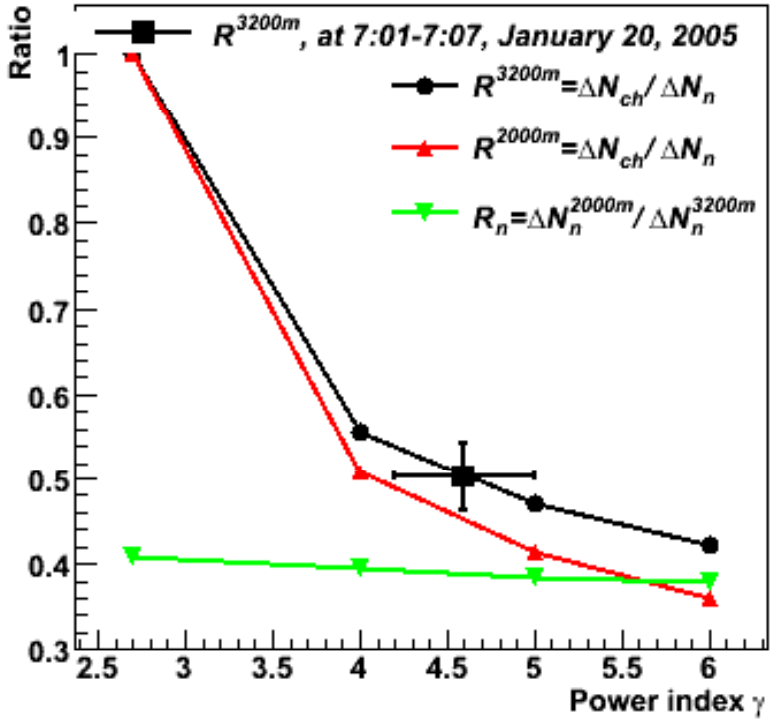





20.01.2005 (3min)
Statistical significance
30
26
22
18
14
10
6
2
-2
14
12
10
8
6
4
2
0
-2
Statistical significance
(AMMM)
6:25 6:33 6:40 6:47 6:55 7:02 7:09 7:17 7:24 7:32 7:39 7:46 7:54
UT
Tibet NM
ARNM
CARPET
GRAND
AMMM

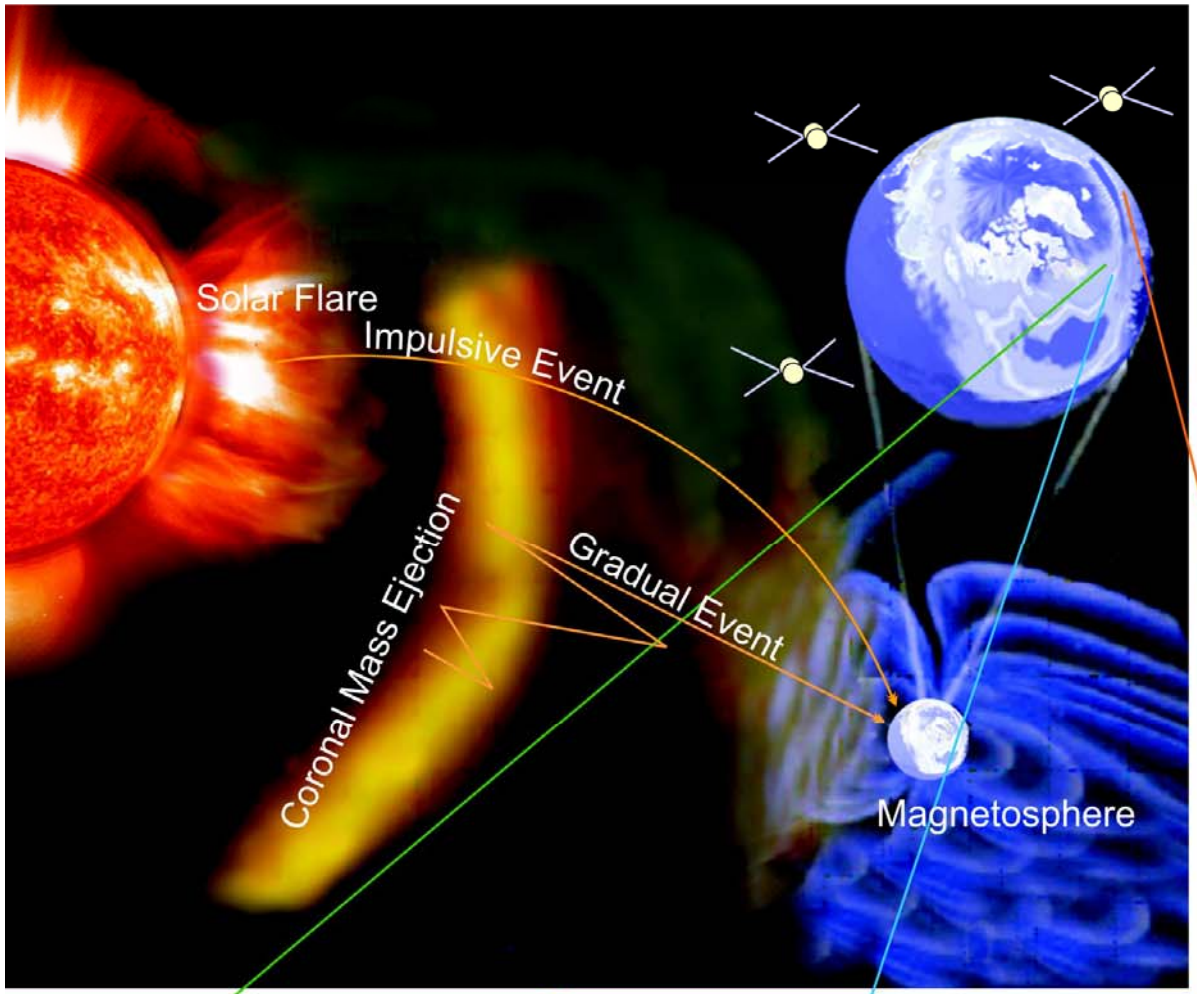
Energy Spectrum of the GLE from 20 January 2005

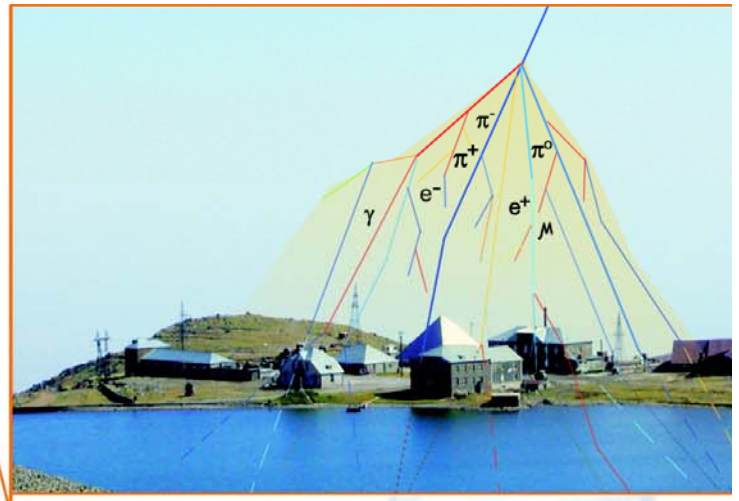




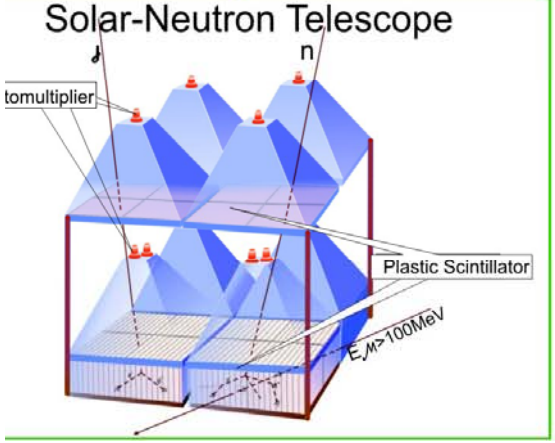
N.Kh. Bostanjyan , A.A. Chilingarian, V.S. Eganov, G.G. Karapetyan, **On the production of highest energy solar protons on 20 January 2005,** Advances in Space Research 39 (2007) 1456–1459

A.A.Chilingarian, A.E.Reimers, **Particle detectors in Solar Physics and Space Weather research**, Astroparticle Physics 27 (2007) 465–472

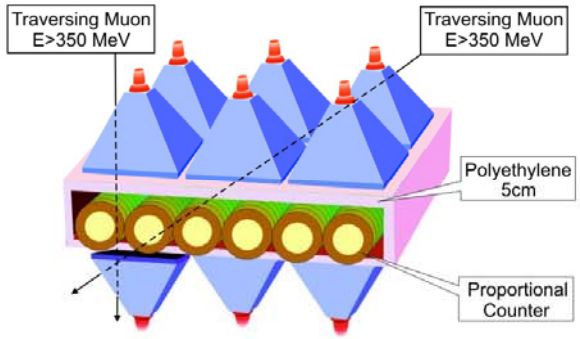




Solar-Neutron Telescope

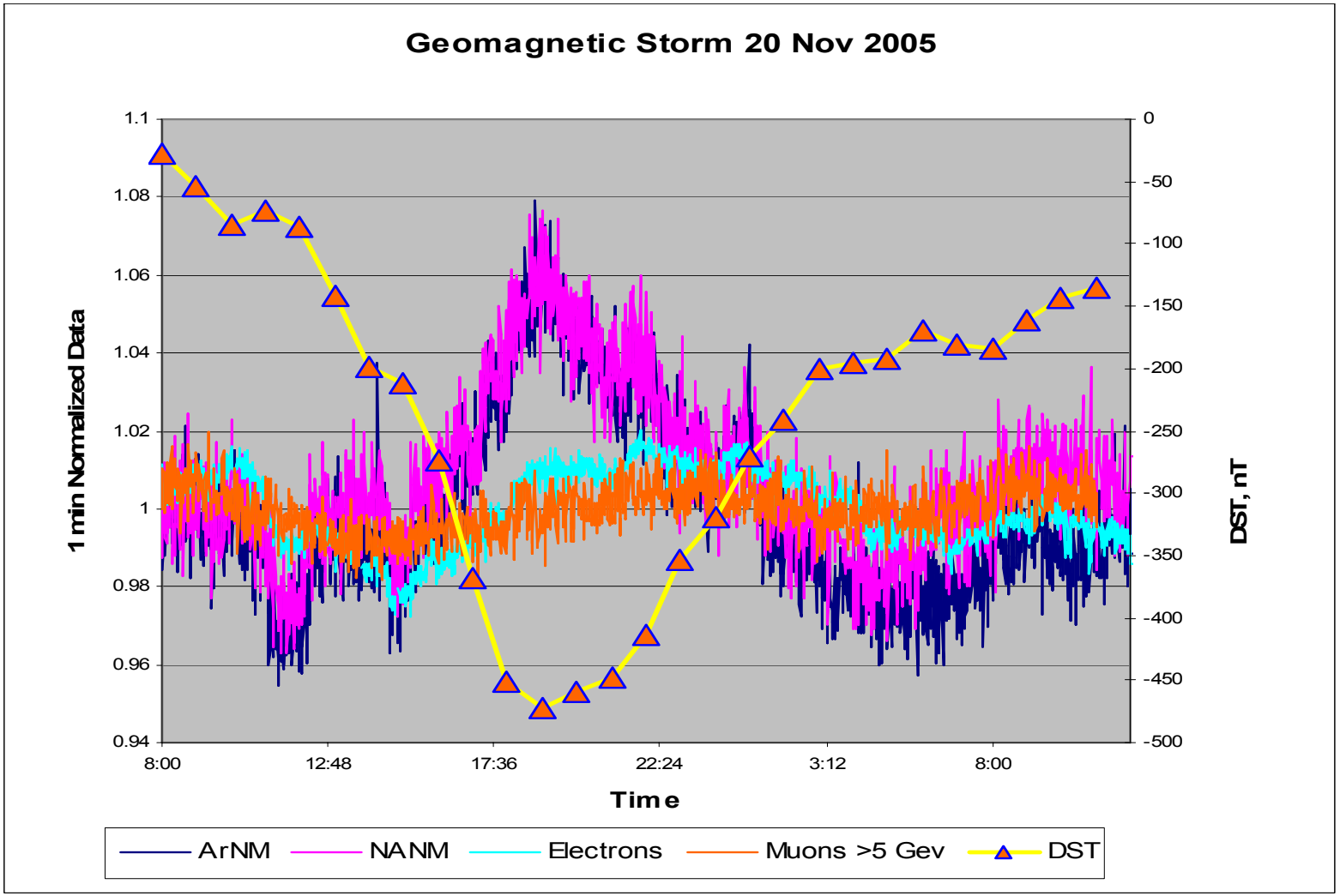


Nor-Amberd Multidirectional Muon Monitor



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 inter community to develop a reliable and global Space Weather forecasting to protect astronauts and satellites in space and power grids on the grou

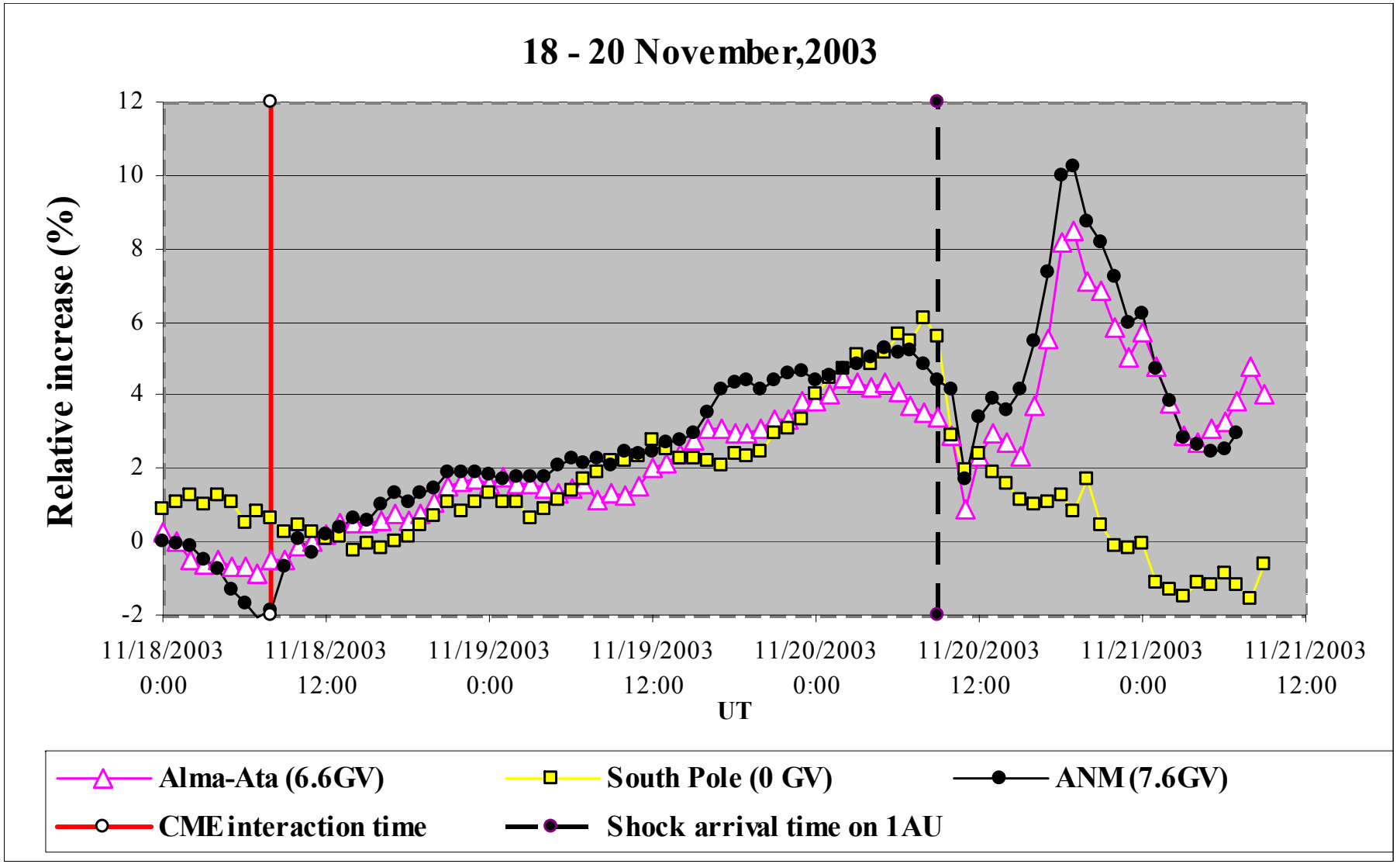
Geomagnetic Disturbance of 20 November 2003



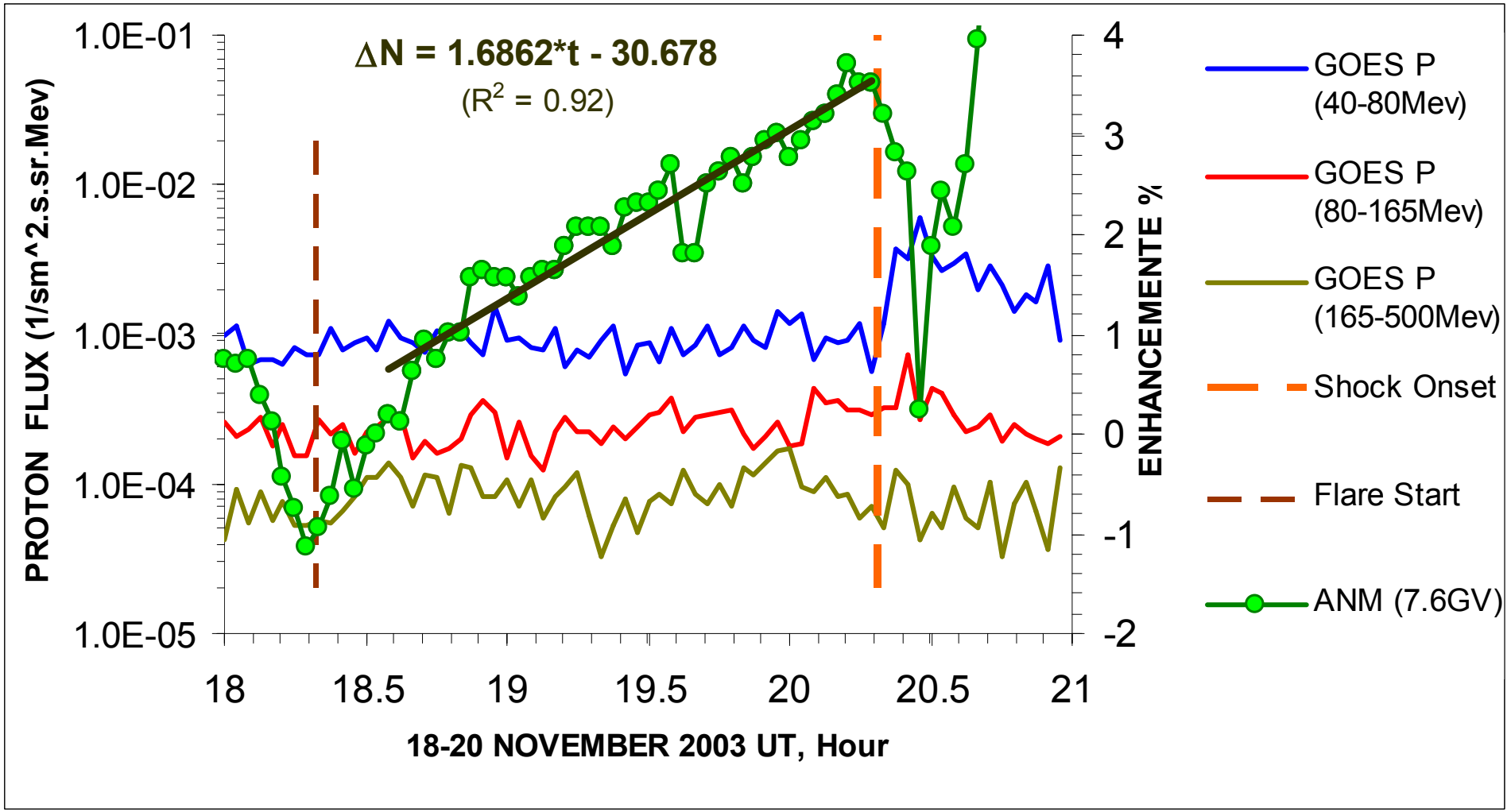
Parameters of the fast CMEs unleashed at 18 November 2003 from ASR 501 and 508

Date	Time UT	Heliocoorditas	Angular depth (^{0})	CME velocity км/sec	Kinetic Energy erg
18-10-2003	11:30	S16E08	360	2459	$1.3 \cdot 10^{33}$
18-11-2003	**8:06**	**N01E19**	**>104**	**1223**	**$1.3 \cdot 10^{32}$**
18-11-2003	**8:50**	**N02E18**	**360**	**1660**	**$3.3 \cdot 10^{32}$**
18-11-2003	9:50	S13E89	>197	1824	$3.6 \cdot 10^{32}$

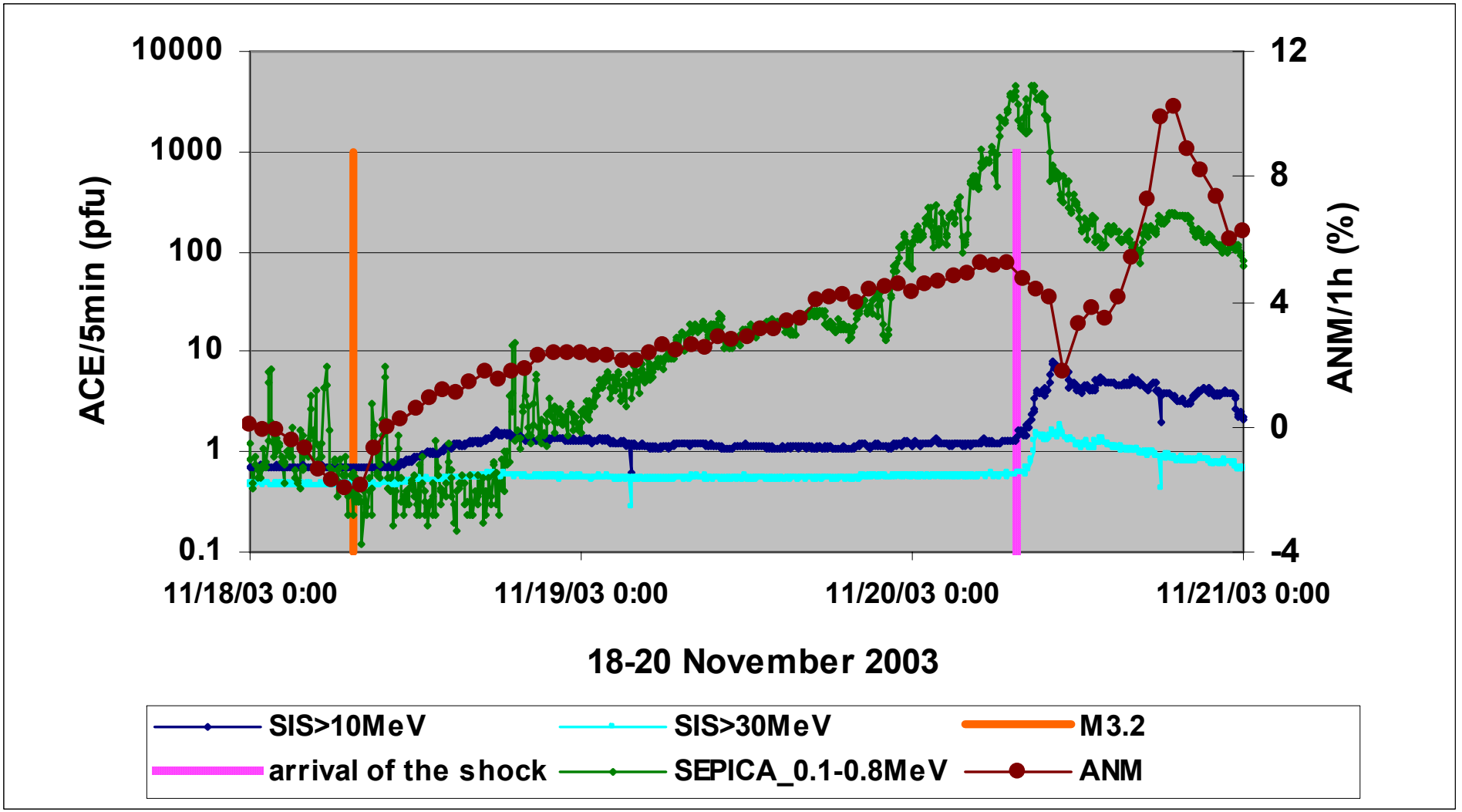
Time history of count rate enhancements of high and middle latitude Neutron Monitors.



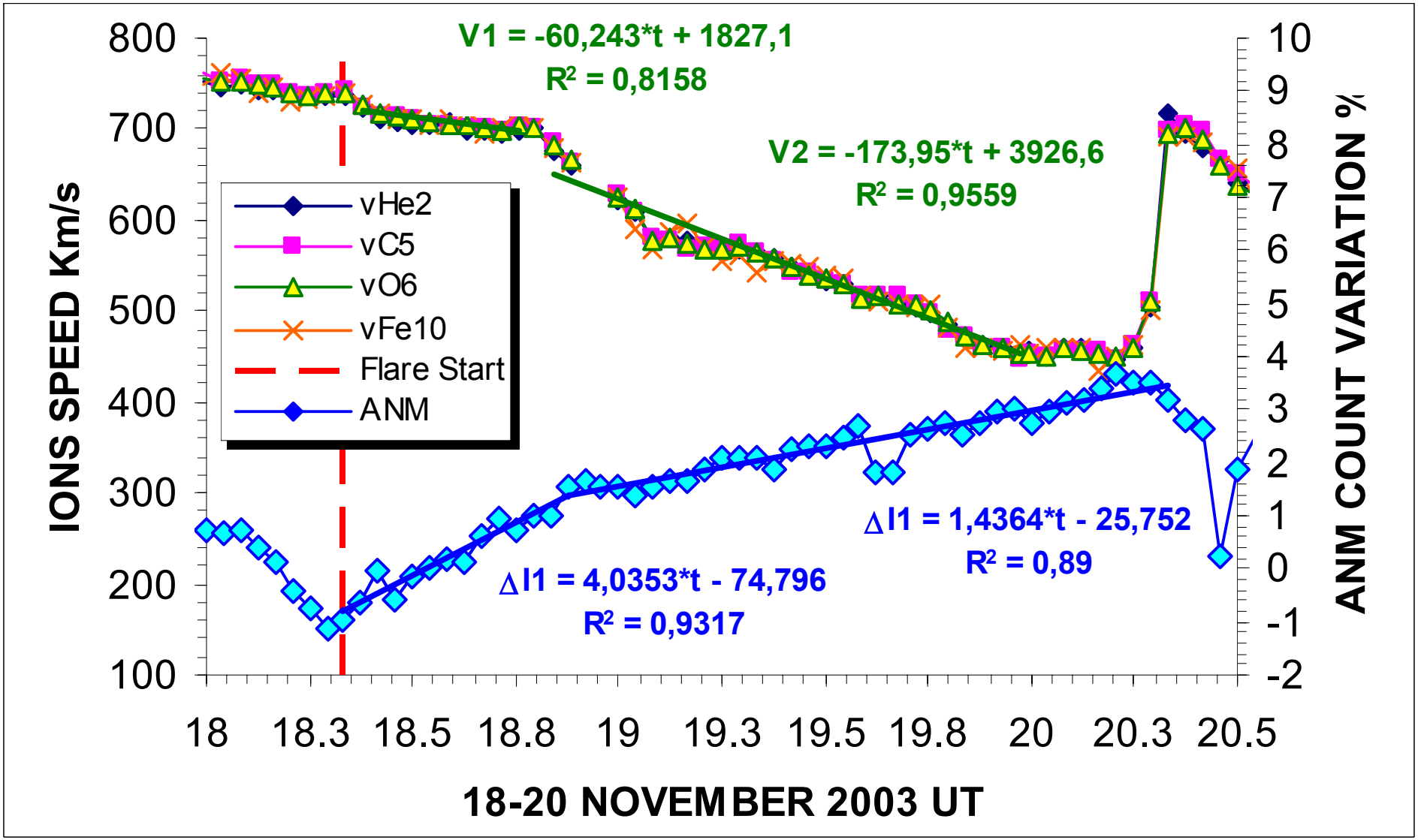
Time history of count rate enhancements ANM and GOES MeV proton detector channels.



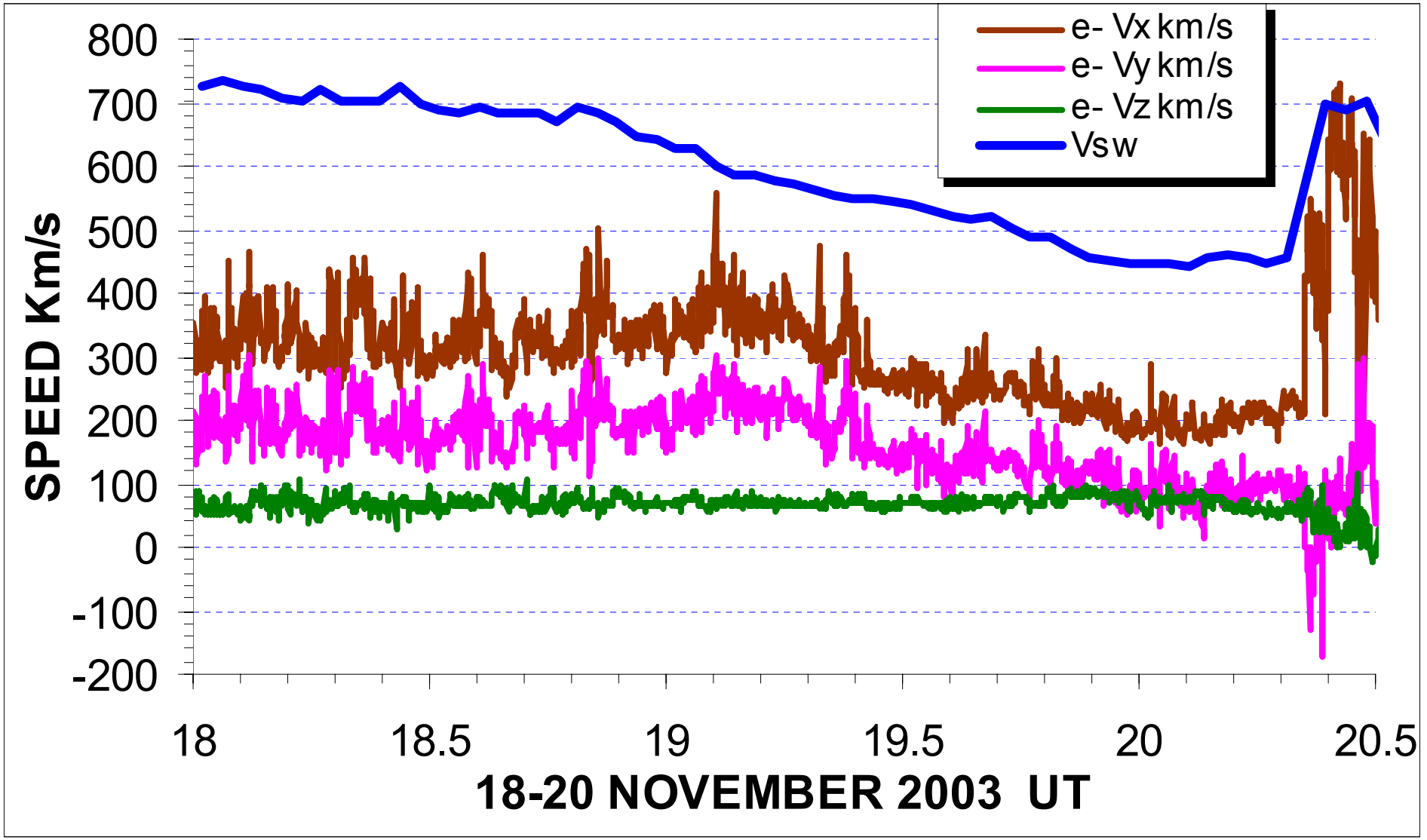
ICME modulation effects in KeV; MeV; and GeV particle fluxes



ICME modulation effects on the Solar Wind speed and GeV particles flux



ICME modulation effect on Solar Wind and electron velocities

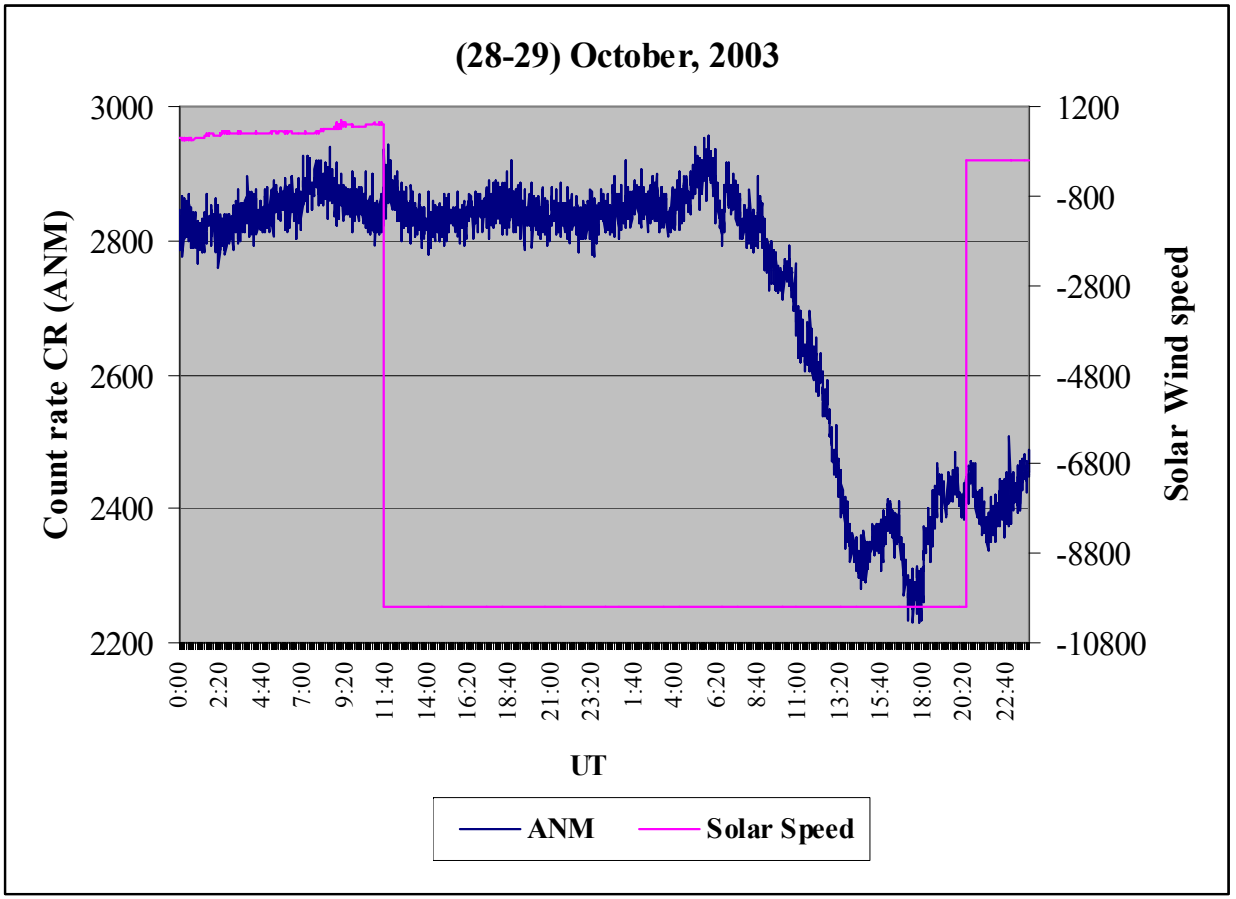


Statistics of GMS precursors based on ASEC particle detector data

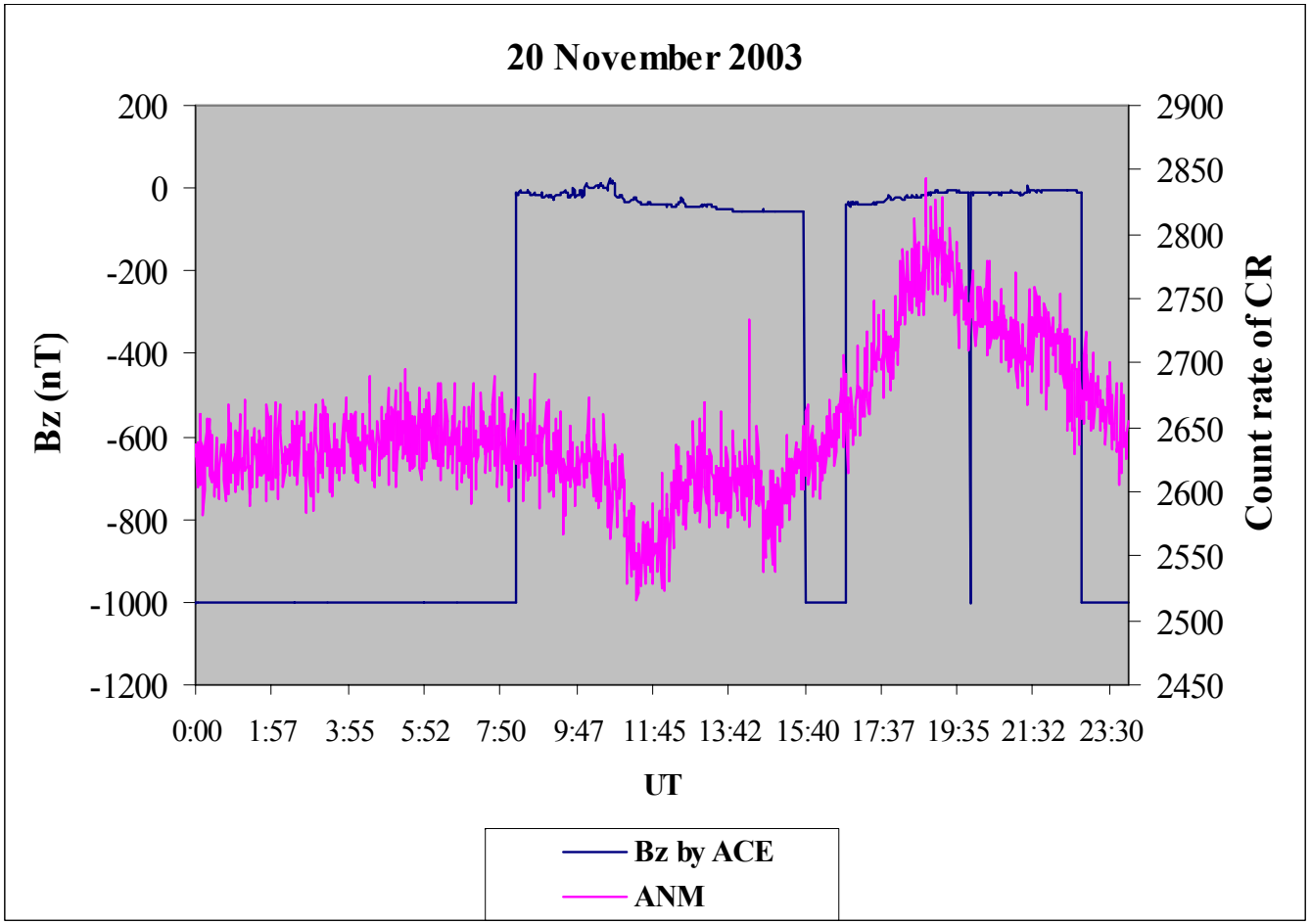
Kp	Pr.: yes	Pr.: no	total	Npr./Ntotal
≤3	3	17	20	0.15
4	2	17	19	0.105263
5	2	12	14	0.142857
6	0	11	11	0
7	2	6	8	0.25
8	5	0	5	1
9	5	1	6	0.833333

Efficiency of warning on the very severe geomagnetic storm (Kp ≥8) is very high ~0.91, the corresponding false alarm probability is unfortunately also rather high 0.45.

Failure of the ACESWEPAM solar wind detector on board of the ACE space station during extreme solar event of 28 October 2003. In contrast the ASEC monitors is registering the ground level enhancement at 28 October and largest detected Intensity decrease (~20%) at 29 October.



Failure of the Magnetometer on board of the ACE space station during extreme geomagnetic storm of 20 November 2003 (The measurement of the B_z component of the interplanetary magnetic field is disabled as well as of other parameters of the ICME) . In contrast the Aragats Neutron monitor is registering the huge increase of count rate due to effective decreasing of the geomagnetic cutoff energy at Aragats latitude.



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

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

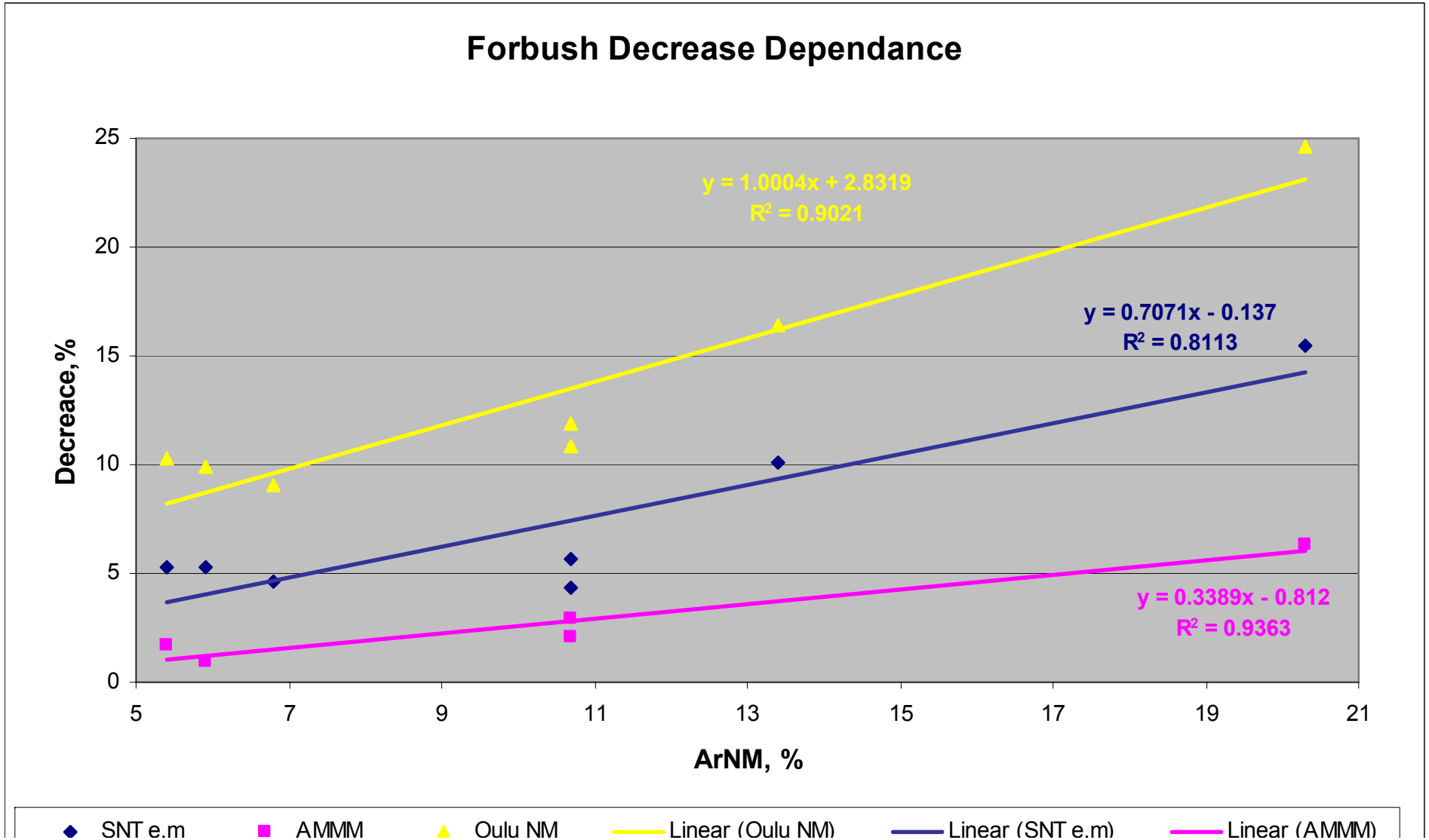
Fd of 23 solar cycle (-%)

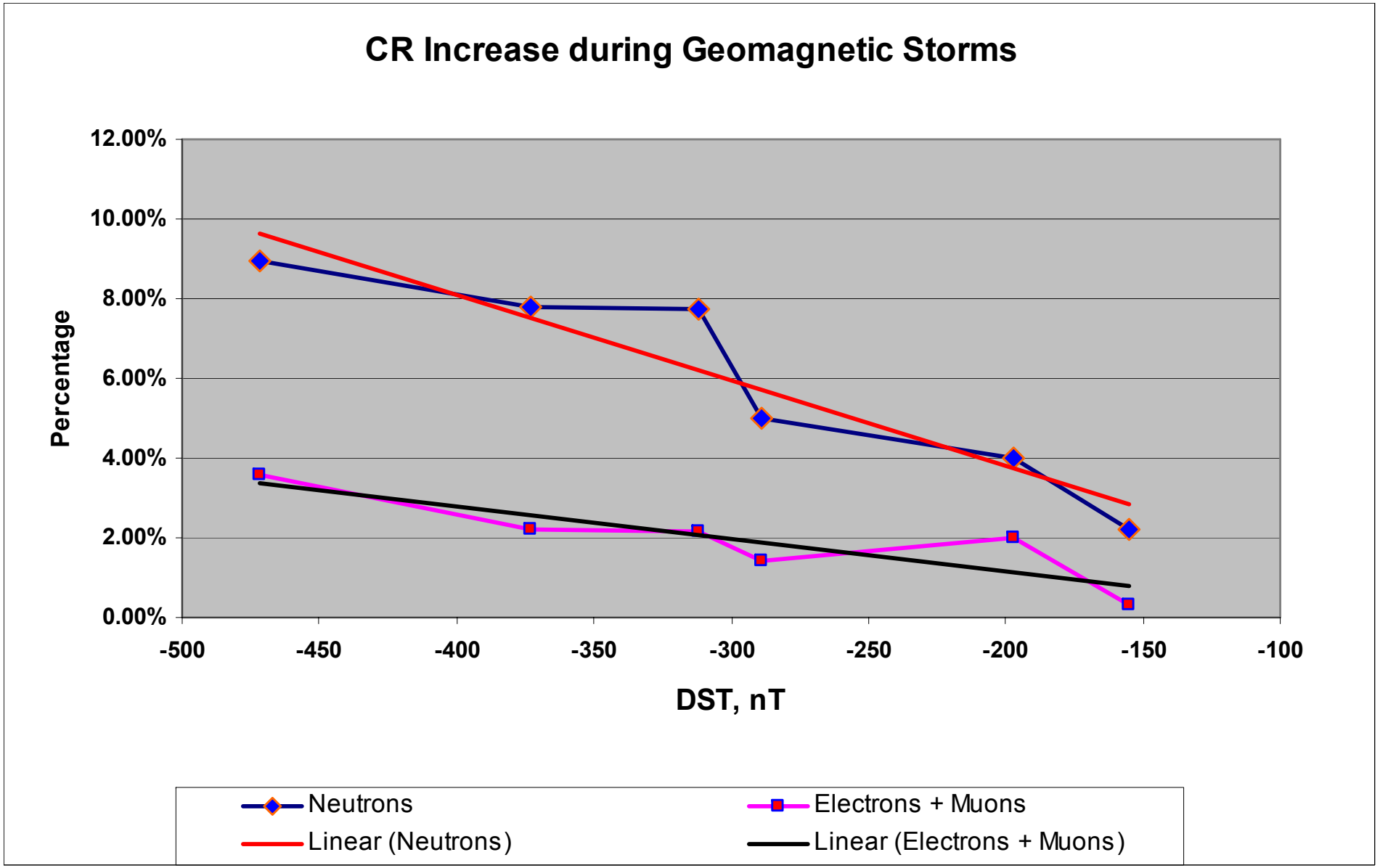
Date	ArNM	SNT e,m	AMMM
29.05.03	6.8	4.6	3.1
29.10.03	20.3	15.5	6.3
26.07.04	10.7	5.7	2.9
17.01.05	13.4	10.1	2.2
21.01.05	5.9	5.3	0.9
15.05.05	5.4	5.3	1.7
10.09.05	10.7	4.3	2.1

Geomagnetic Storms of 23 cycle

Date	Kp, max	DST,min	Increase, Neutrons	Increase, charged
20.Nov.03	9	-472	8.95%	3.59%
7-8 Nov 2004	9	-373	7.80%	2.20%
15.May.05	8	-312	7.73%	2.18%
10.Nov.04	8	-289	5.00%	1.40%
27.Jul.04	9	-197	4.00%	2.00%
09.Nov.04	9	-155	2.20%	0.30%

Fd measured by different secondary fluxes




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)

Space Weather Alerts for Radiation Storm

- **The reliable alert service for warning on upcoming SEP event can be established as follows. As soon as strong flare (X-class according to the NOAA scale) is reported by the GOES satellites (available on-line from SEC/NOAA) the 2 alert programs started:**
- **The first one is examining the enhancement of count rates in all channels of neutron and muon monitor routinely calculated by the Advanced Data Acquisition System (ADAS); Enhancements and corresponding statistical significances are calculated each minute by twelve 5-second count rates. Examining of the inter-channel correlation matrix, also calculated by ADAS, will help to prove that enhancement is not failure of one of channels, but consistent enhancement.**
- **The time history of the X-ray flux (from start till maximum, usually ten 1-minute numbers) is memorized and a "delayed correlation routine start to calculate correlation of X-ray peak with also 10 counts of ASEC monitors. Counts are shifted and map of moving correlations is constructed.**
- **Dependent on the values of peak statistical significance and value of the correlation between X-ray flux enhancements and enhancements of neutral and charged fluxes, measured by surface particle detectors different warnings and alerts are issued.**
- **Described scheme of alert service will be highly reliable, because it uses different particle fluxes measured by SEVAN detectors at different latitudes, longitudes and altitudes and X-ray flux measured by satellite facilities.**

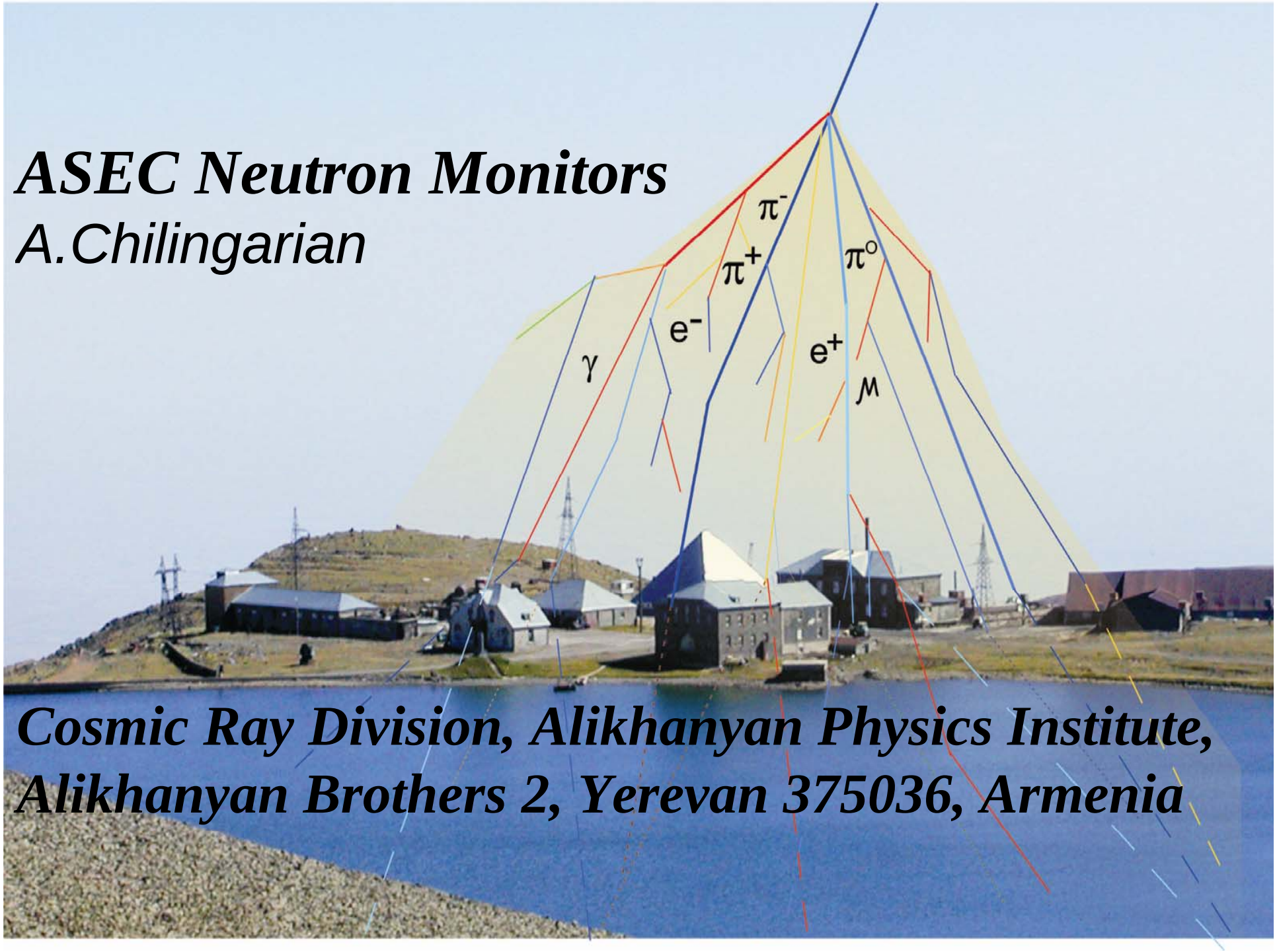
●

Space Weather Alerts for GMS

- **The reliable alert service for warning on upcoming GMS can be established as follows. As soon as Halo CME is reported by the SOHO/LASCO or SOHO Extreme ultraviolet Imaging Telescope (available on-line from SEC/NOAA) the 2 alert programs started:**
- The first one is examining the enhancement of count rates in all channels of neutron and muon monitors routinely calculated by the Advanced Data Acquisition System (ADAS); the linear regression of count rate enhancement s on the time is constructed started from CME launch, or started from CMEs interaction. At each moment the correlation coefficient and linear regression parameters are available on-line.
- The second program is reading MeV and KeV particle fluxes as well as Solar Wind velocity from appropriate channels of GOES and ACE satellites. The correlation coefficients and parameters of linear regression are calculated and made on-line accessible same as in point 1.
- Dependent on the values of duration of the enhancement, correlation coefficients, percents of enhancements, parameters of linear regressions and other available information different warnings and alerts are issued.
- Described scheme of alert service will be highly reliable, because it uses different particle fluxes measured by SEVAN detectors at different latitudes, longitudes and altitudes (and lower energy particle fluxes and Solar Wind speed measured by satellite facilities.

ASEC Neutron Monitors

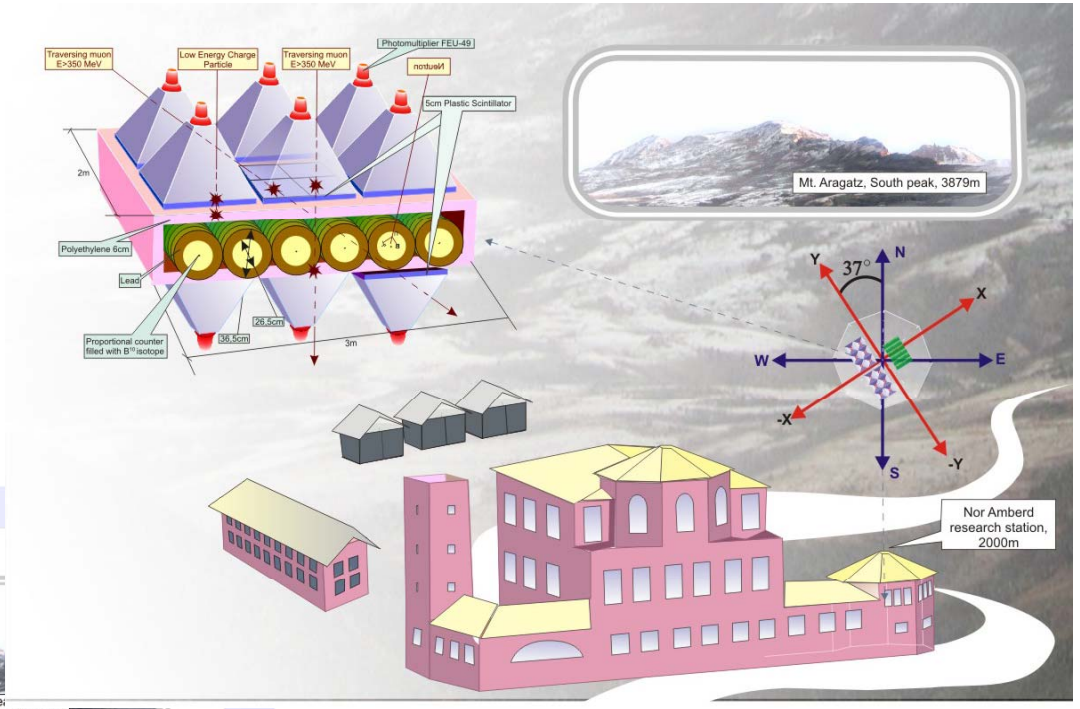
A.Chilingarian

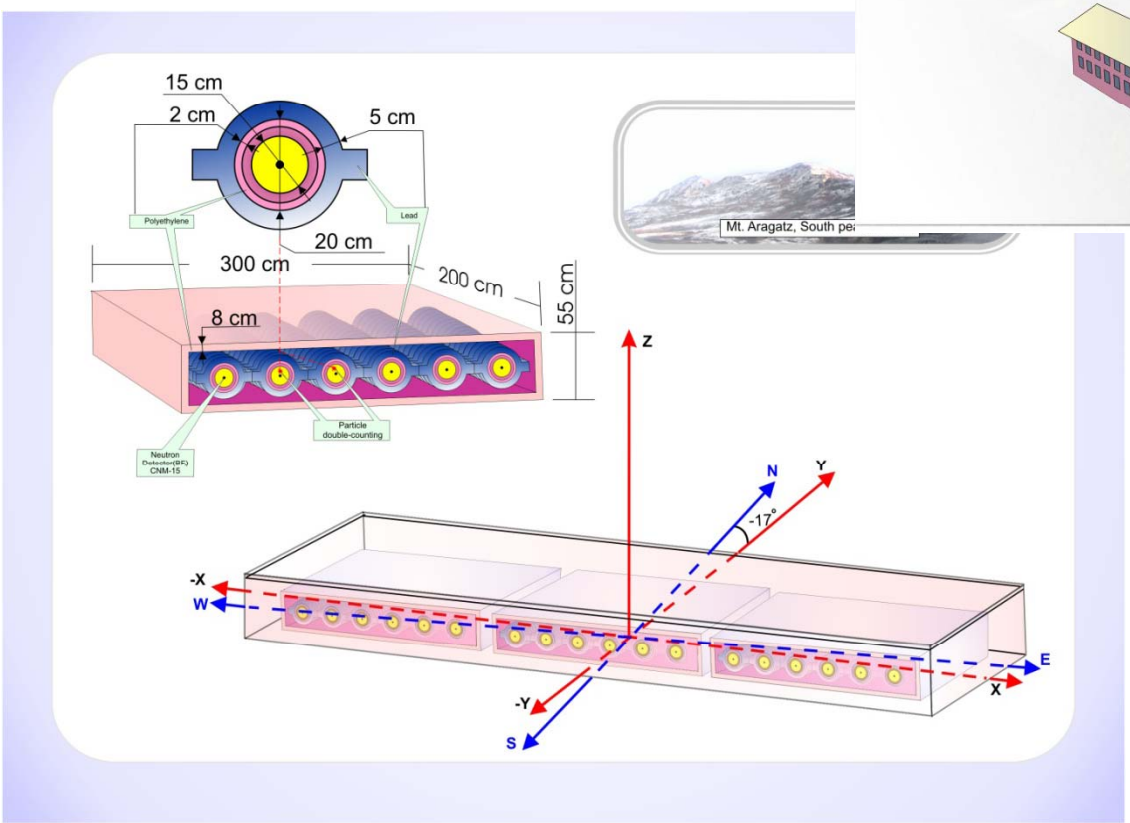


Cosmic Ray Division, Alikhanyan Physics Institute, Alikhanyan Brothers 2, Yerevan 375036, Armenia

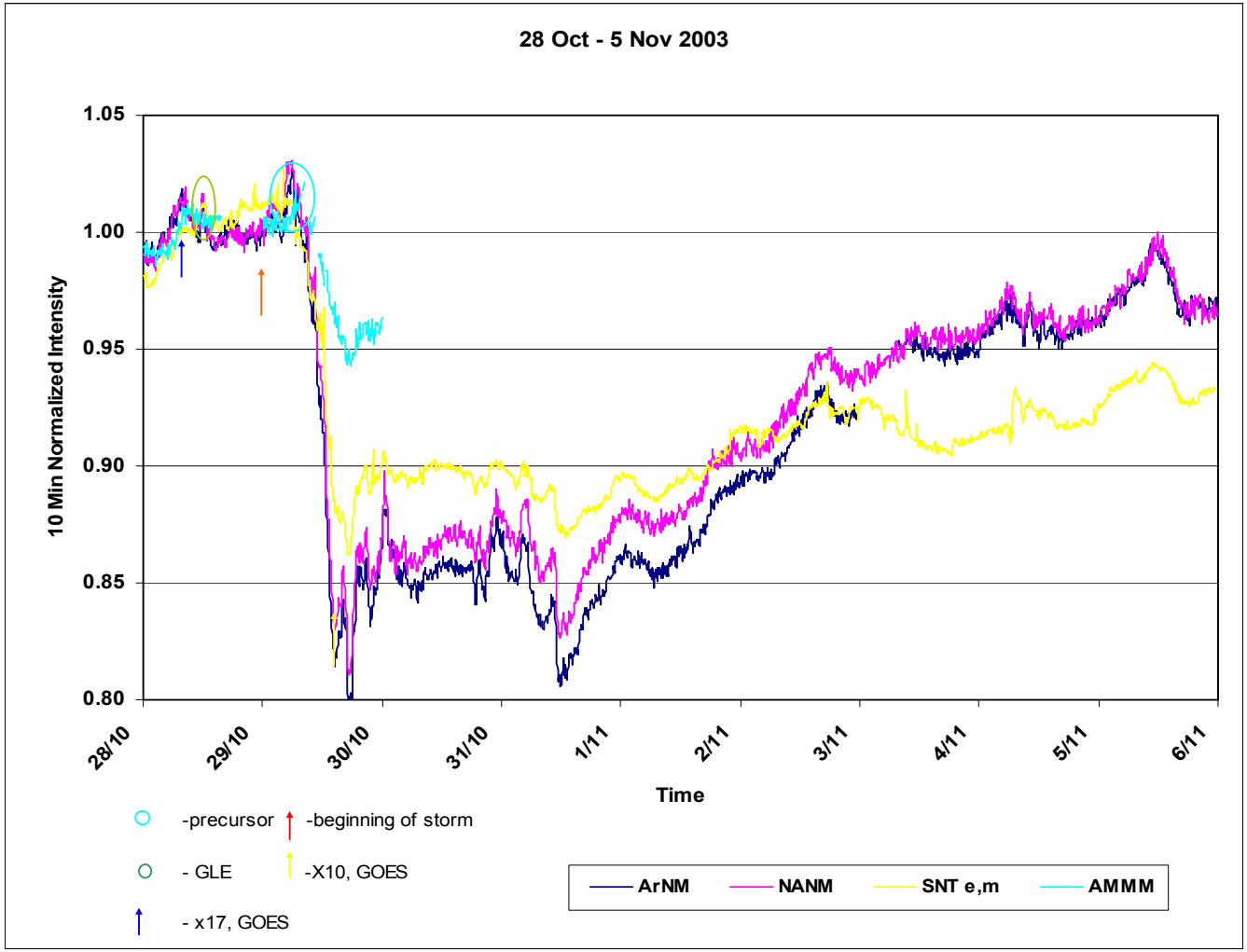
Aragats NM and Nor - Amberd NM are 18 NM64

Location	Altitude [meter]	Latitude [degree]	Longitude [degree]	Rc - [GV]
Yerevan	1093	40.20	44.48	7.06
Antarut	1580	40.35	44.27	6.99
Nor Amberd	2005	40.37	44.26	6.92
Aragats	3221	40.47	44.18	6.95

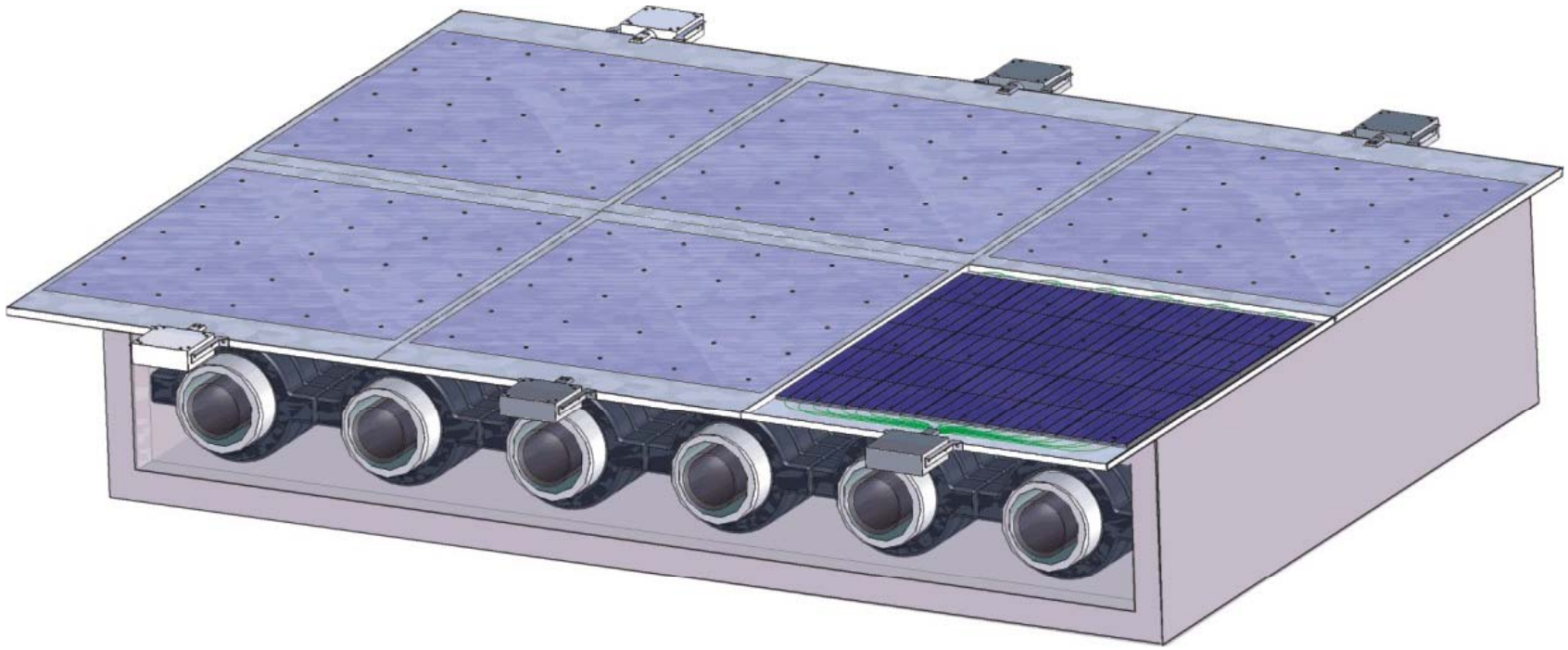




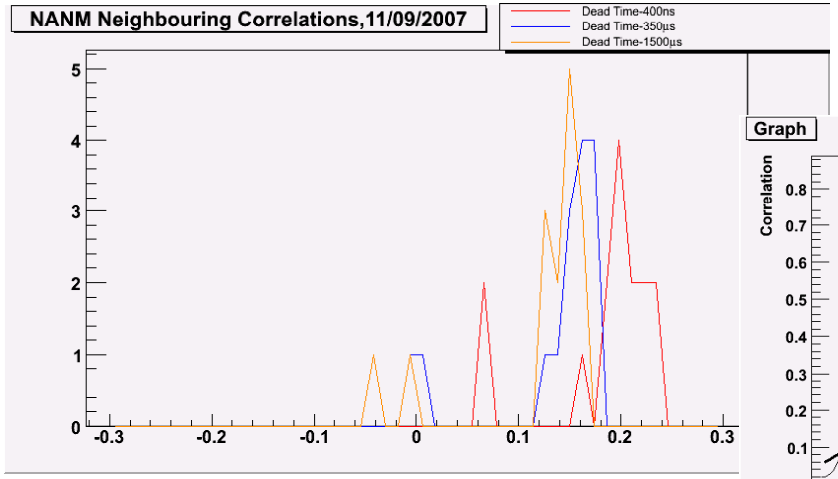
Famous “Halloween” events of 2003, detected in electron & muon and neutron fluxes by ASEC monitors at different altitudes

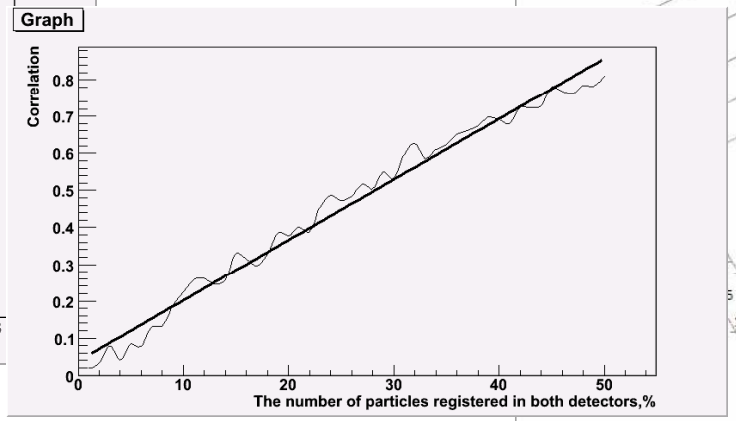


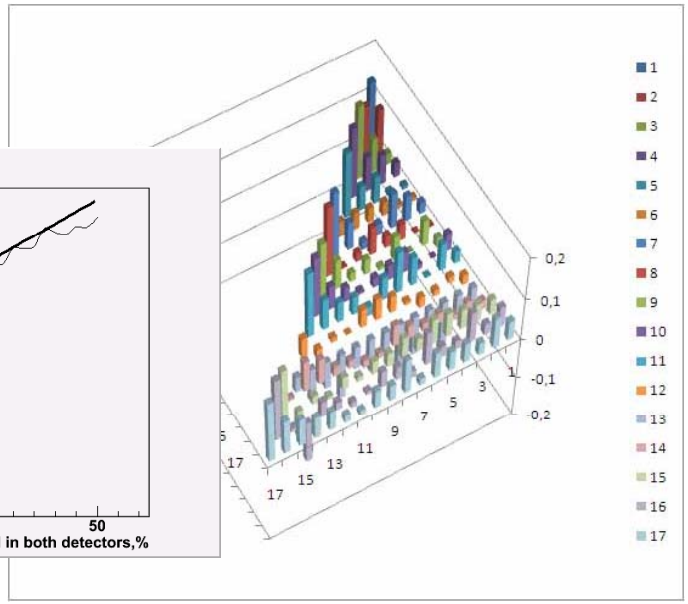
Modernization of the Neutron Monitors

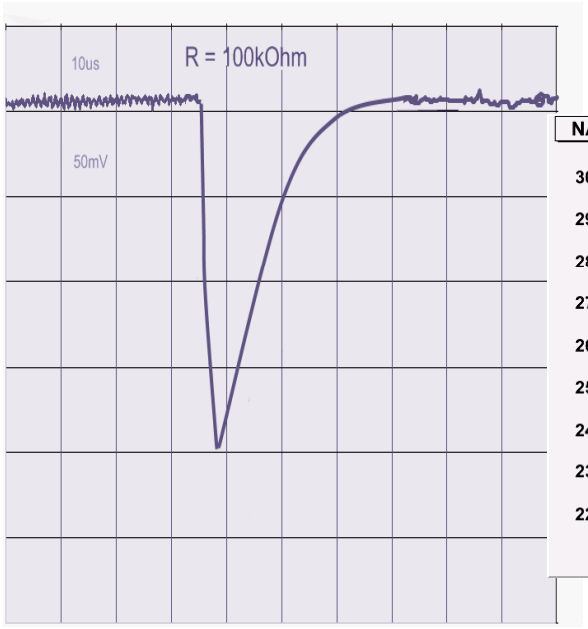


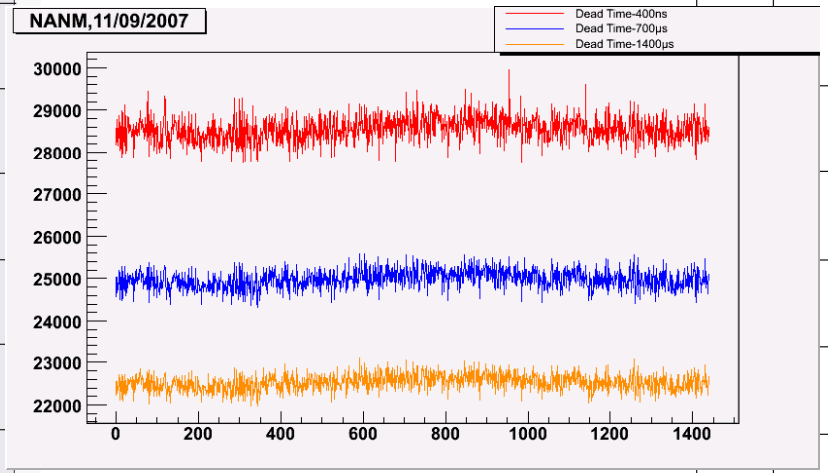
Neutrons inside the Neutron Monitor

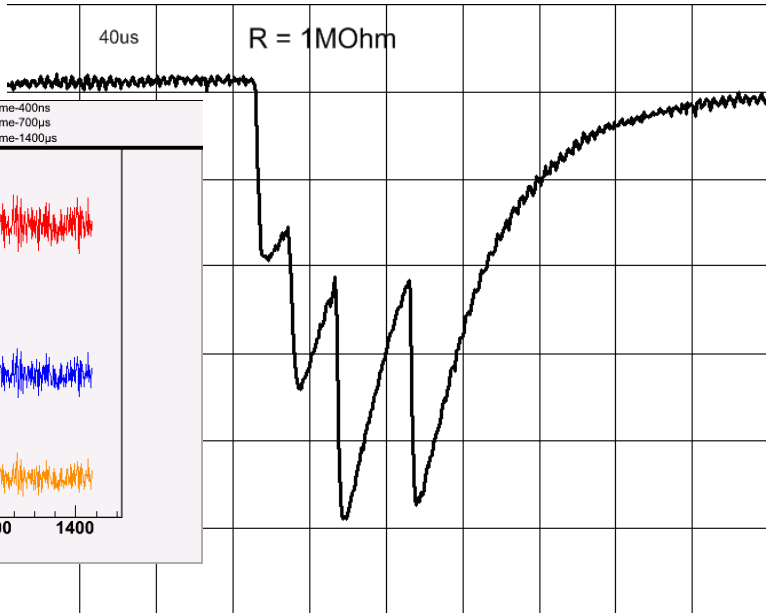




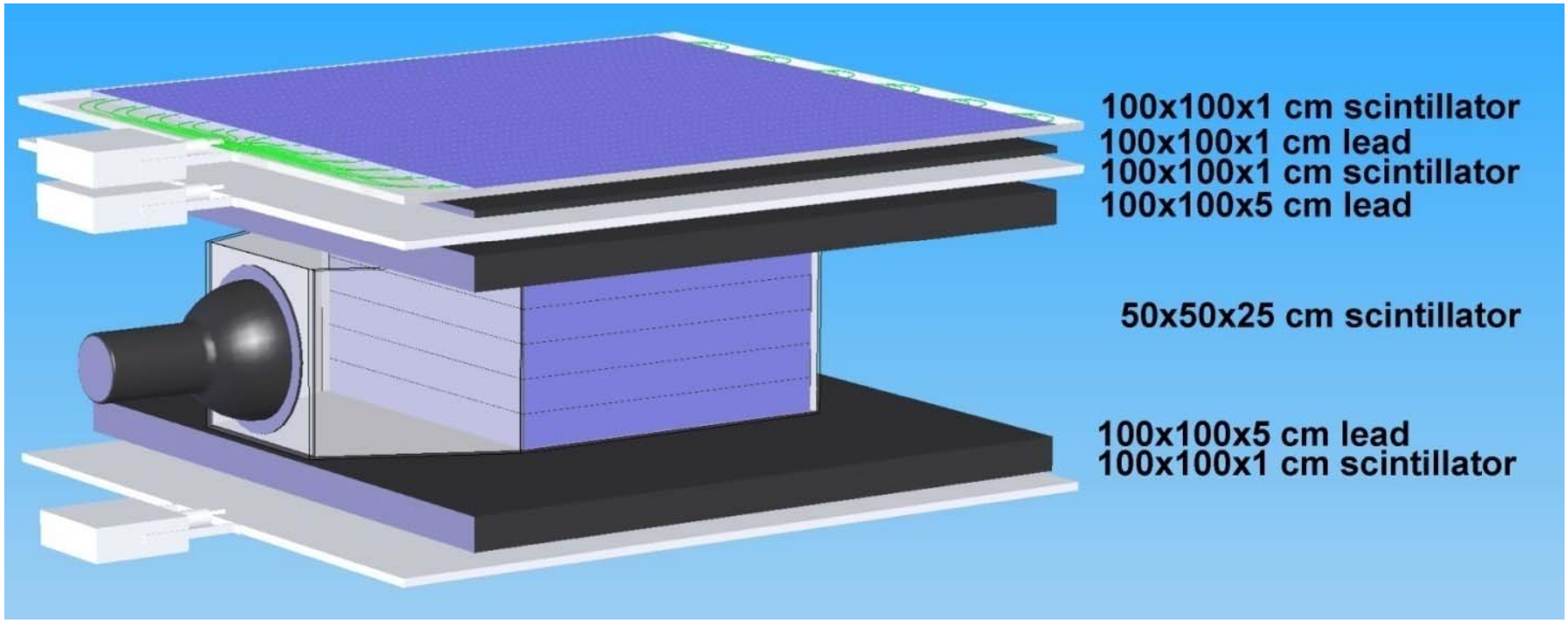




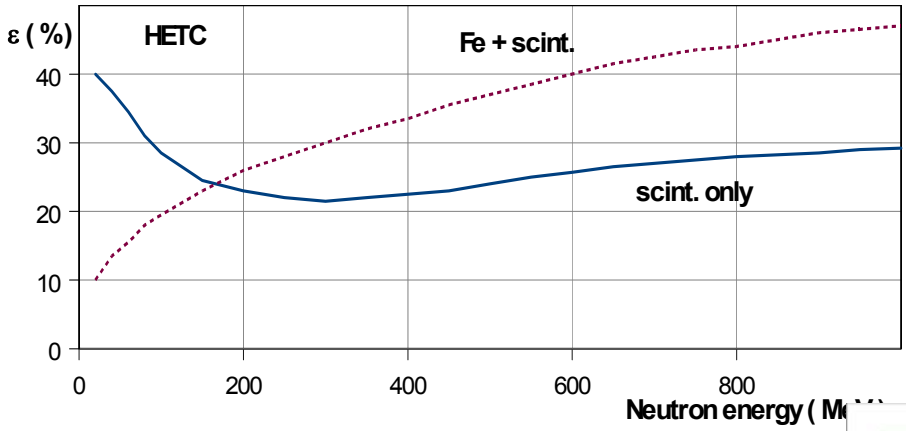


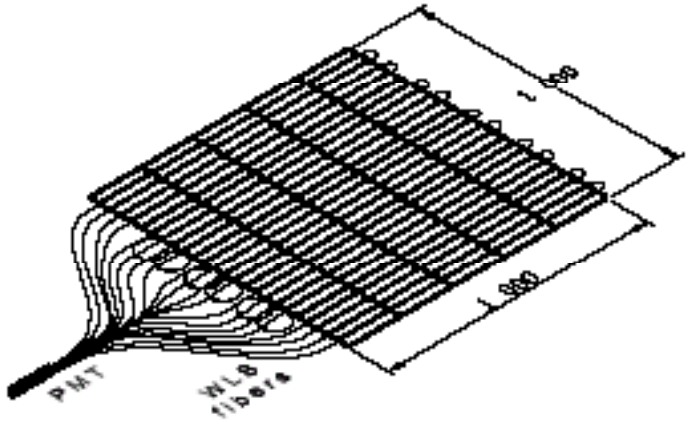


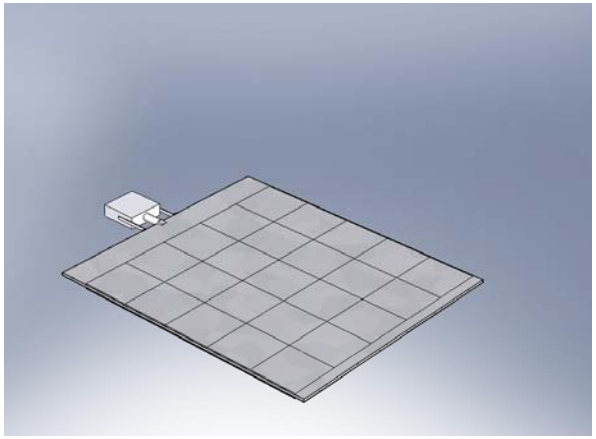
Hybrid Particle Detector

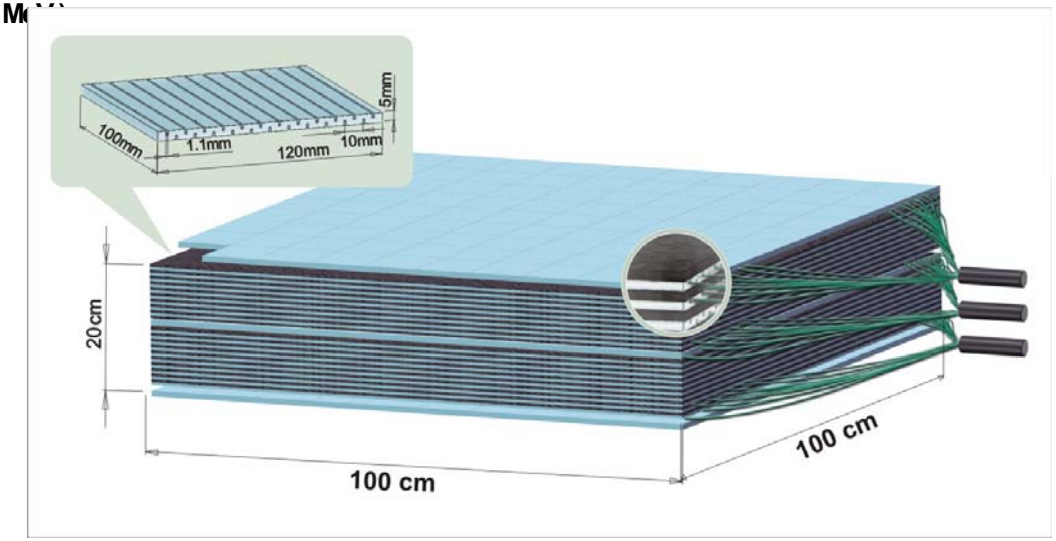


New Neutron Detector: Multilayered structures composed of molded polystyrene scintillation plates of the SC-301 lateral sizes 20x20 cm2, thickness 0.5 cm2, light output about 60% of that of anthracene; wavelength shifting (WLS) fibers in grooves 2.5 mm deep and 1.2 mm wide, produced by Institute for High Energy Physics (IHEP) in Protvino, Russia.









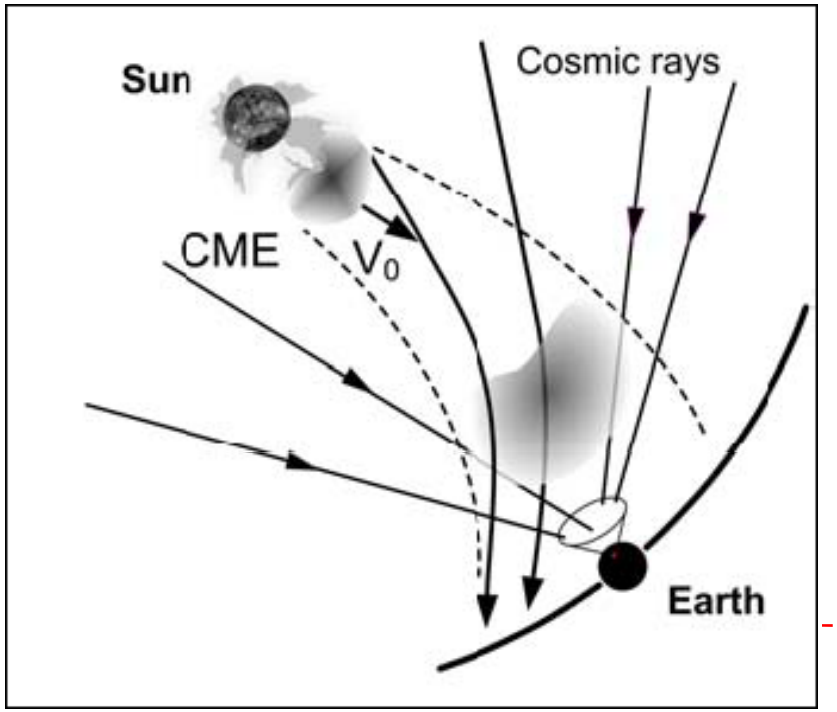
Miscelaneous

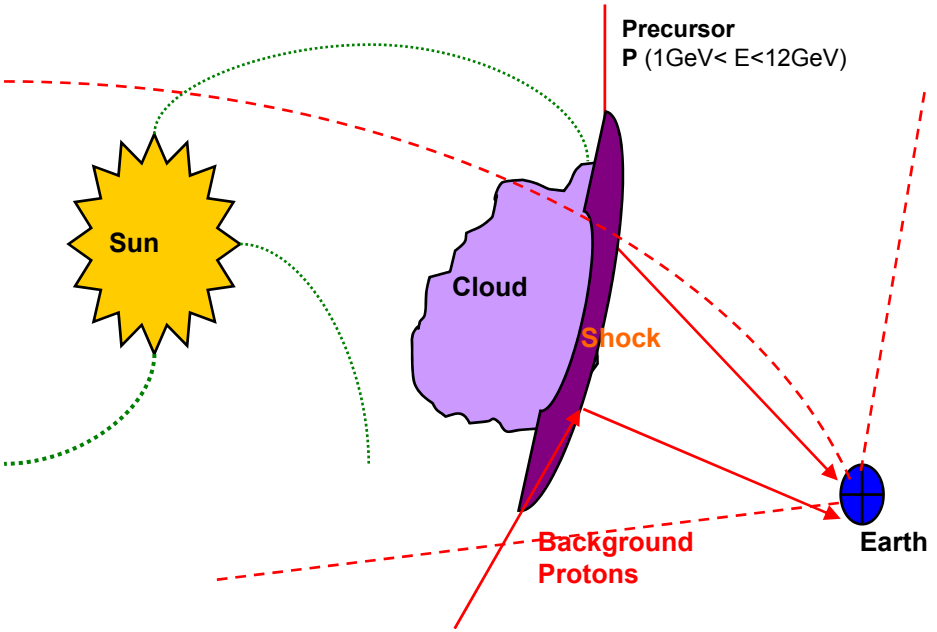
Aragats Space Environmental Center (Observatory) (ASEC)

Location	Altitude [meter]	Latitude [degree]	Longitude [degree]	Rc - Cutoff Rigidty [GV]
Yerevan	1093	40.20	44.48	7.06
Antarut	1580	40.35	44.27	6.99
Nor Amberd	2005	40.37	44.26	6.92
Aragats	3221	40.47	44.18	6.95

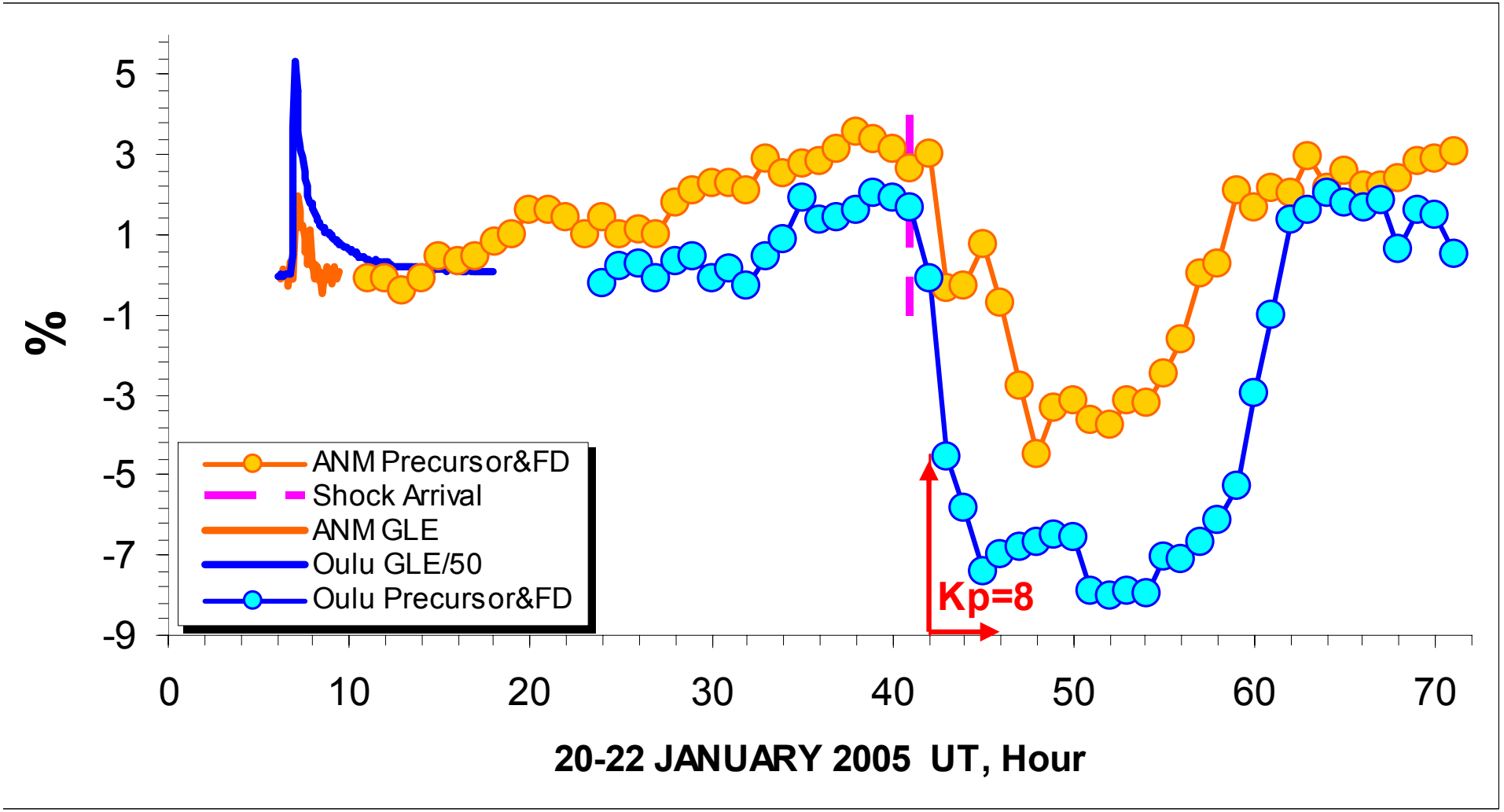
Наименование установки	Барометрический коэффициент	Ошибка	Коэффициент корреляции
Арагацский нейтронный монитор	-0,631%/мб	±0,0028	0,960
Нор-Амбердский нейтронный монитор	-0.712%/мб	±0,0021	0,981
Нор-Амбердский многонаправленный мюонный монитор(1) (верхняя часть)	-0,365%/мб	±0,0009	0,984
Нор-Амбердский многонаправленный мюонный монитор(1) (нижняя часть)	-0,253%/мб	±0,001	0,962
Нор-Амбердский многонаправленный мюонный монитор(2) (верхняя часть)	-0,354%/мб	±0,0008	0,986
Нор-Амбердский многонаправленный мюонный монитор(2) (нижняя часть)	-0,260%/мб	±0,001	0,951

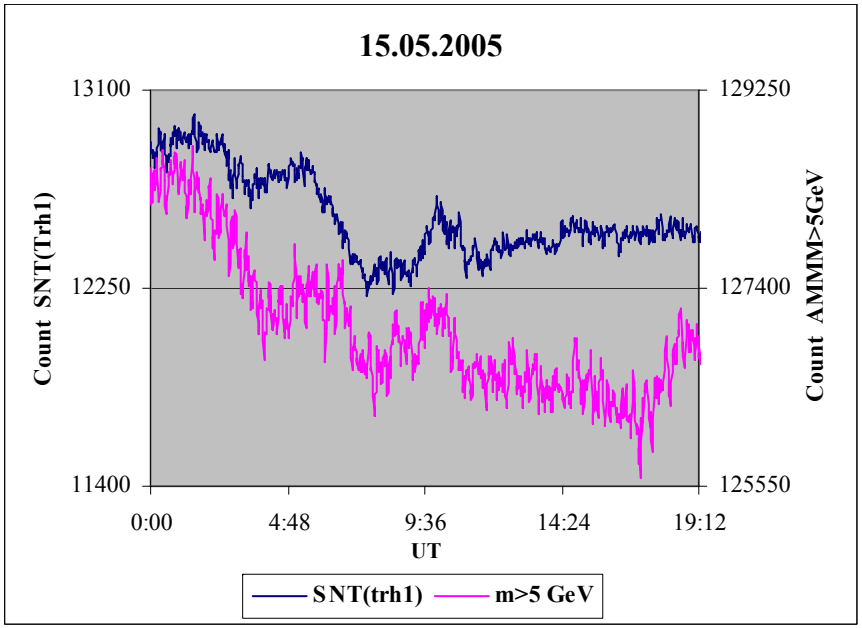
IMCE modulation of GCR

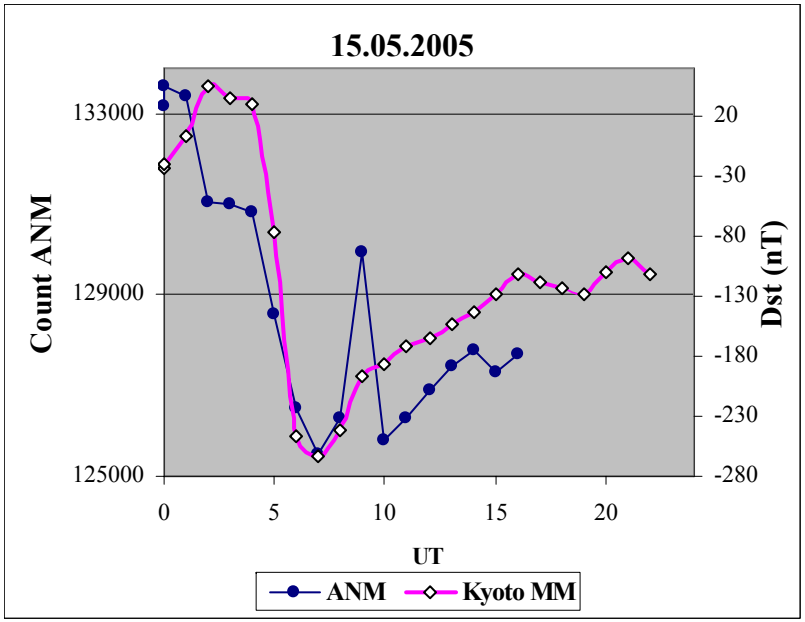


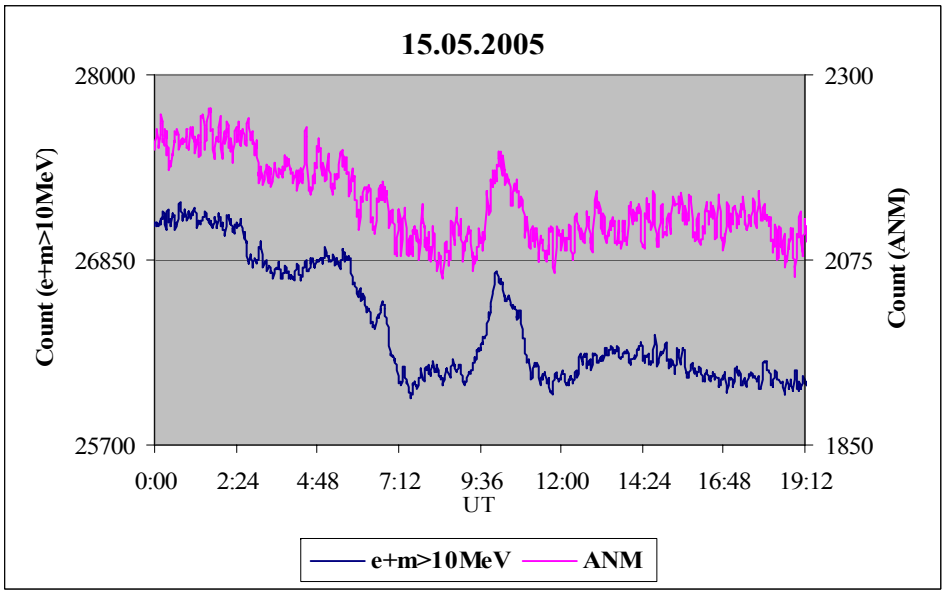


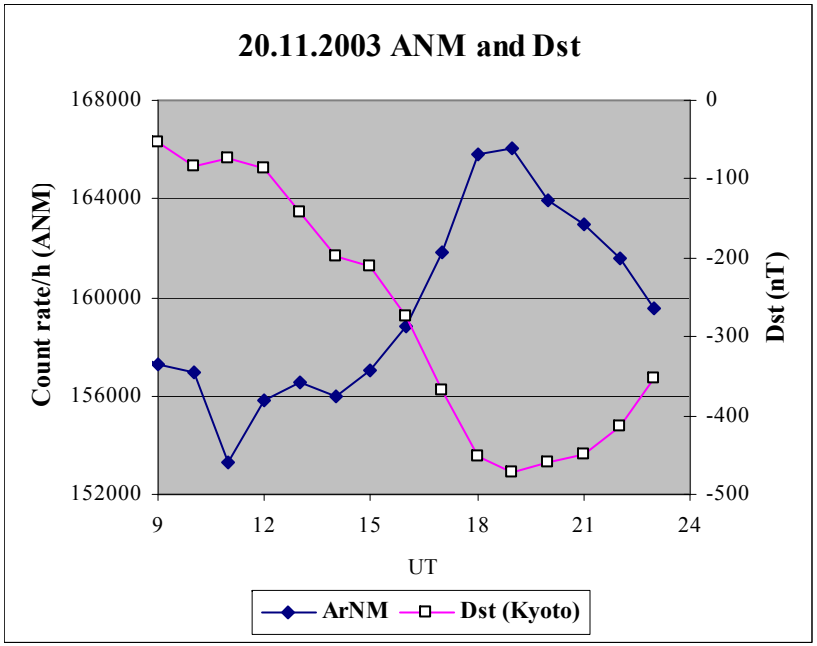
Solar Modulation effects-2



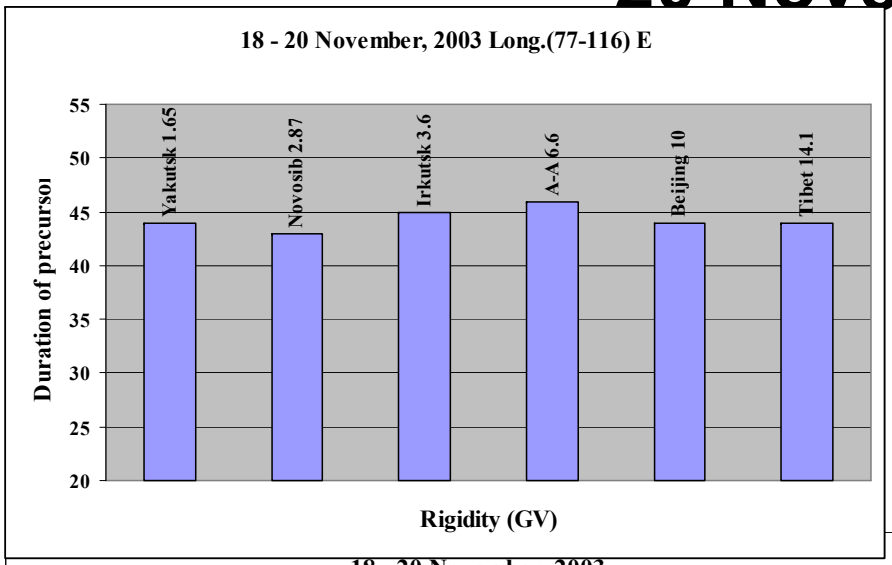

15.05.2005
13100
12250
11400
129250
127400
125550
Count SNT(Trh1)
Count AMMM>5GeV
0:00
4:48
9:36
14:24
19:12
UT
SNT(trh1)
m>5 GeV

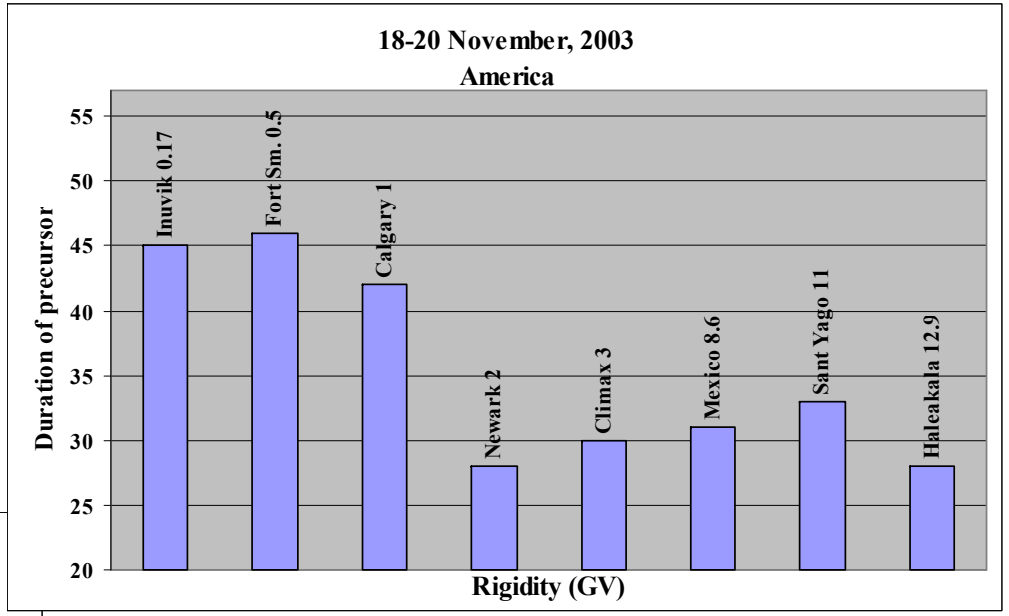

15.05.2005
133000
129000
125000
20
-30
-80
-130
-180
-230
-280
Count ANM
Dst (nT)
0
5
10
15
20
UT
ANM
Kyoto MM

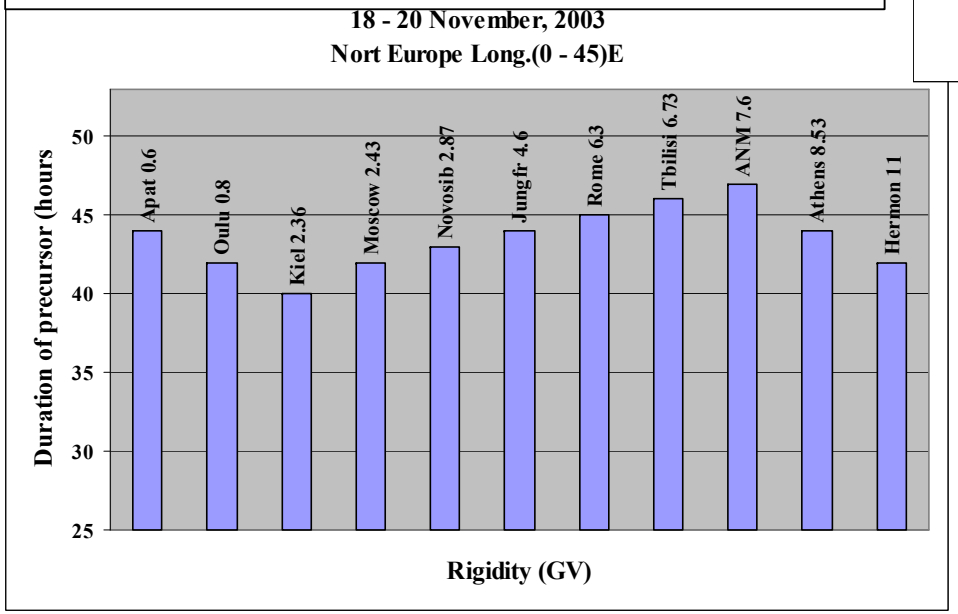

15.05.2005
28000
26850
25700
2300
2075
1850
Count (e+m>10MeV)
Count (ANM)
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
UT
e+m>10MeV
ANM

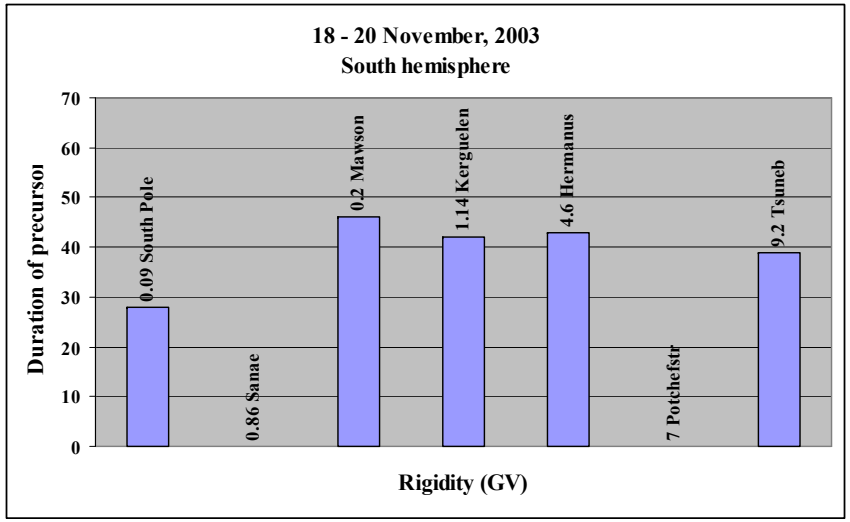

20.11.2003 ANM and Dst
168000
164000
160000
156000
152000
0
-100
-200
-300
-400
-500
Count rate/h (ANM)
Dst (nT)
9
12
15
18
21
24
UT
ArNM
Dst (Kyoto)

Response of the world-wide network of NM on approaching to Earth magnetize structure 18-20 November 2003









Fd measured by different secondary fluxes