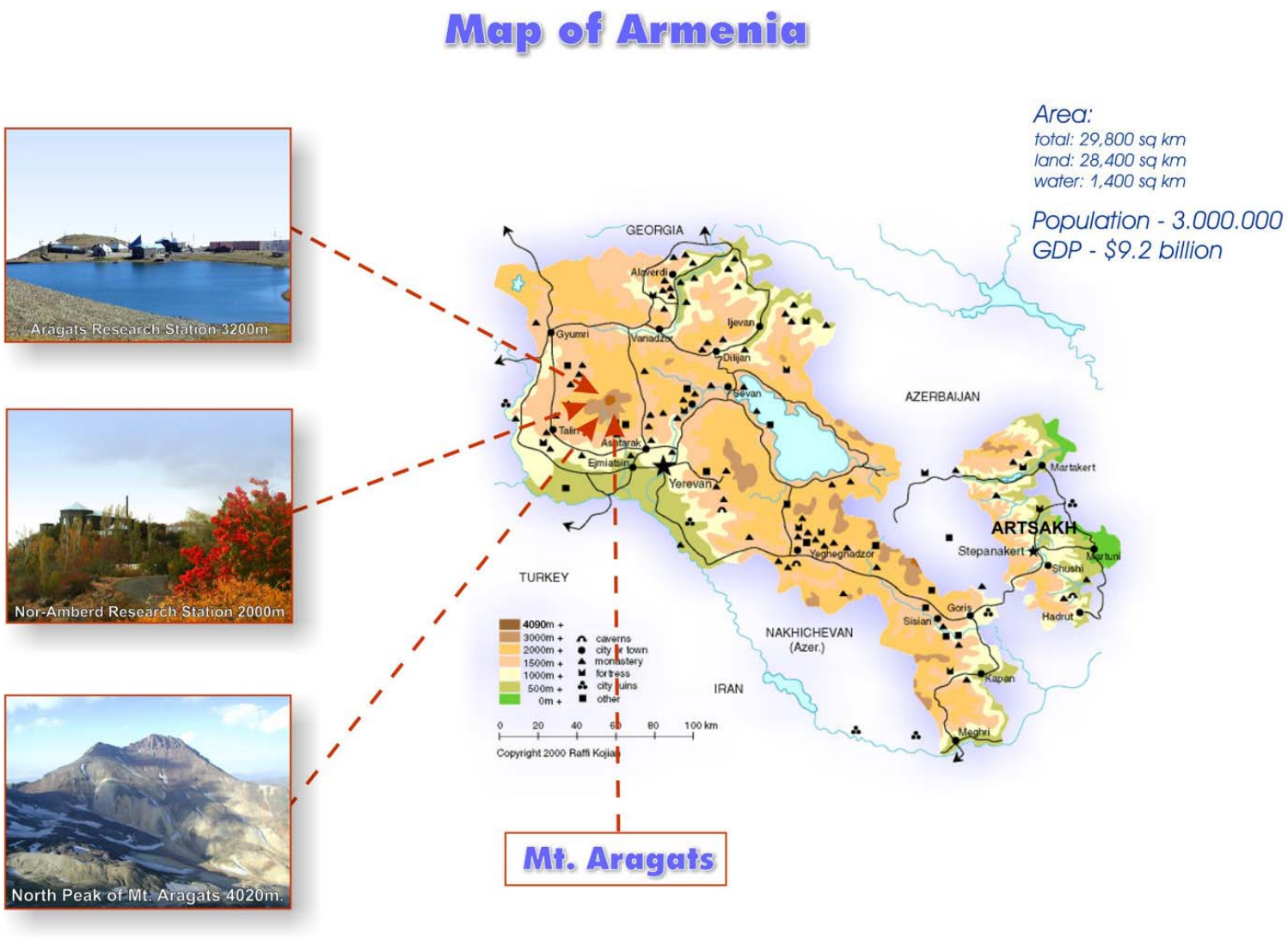
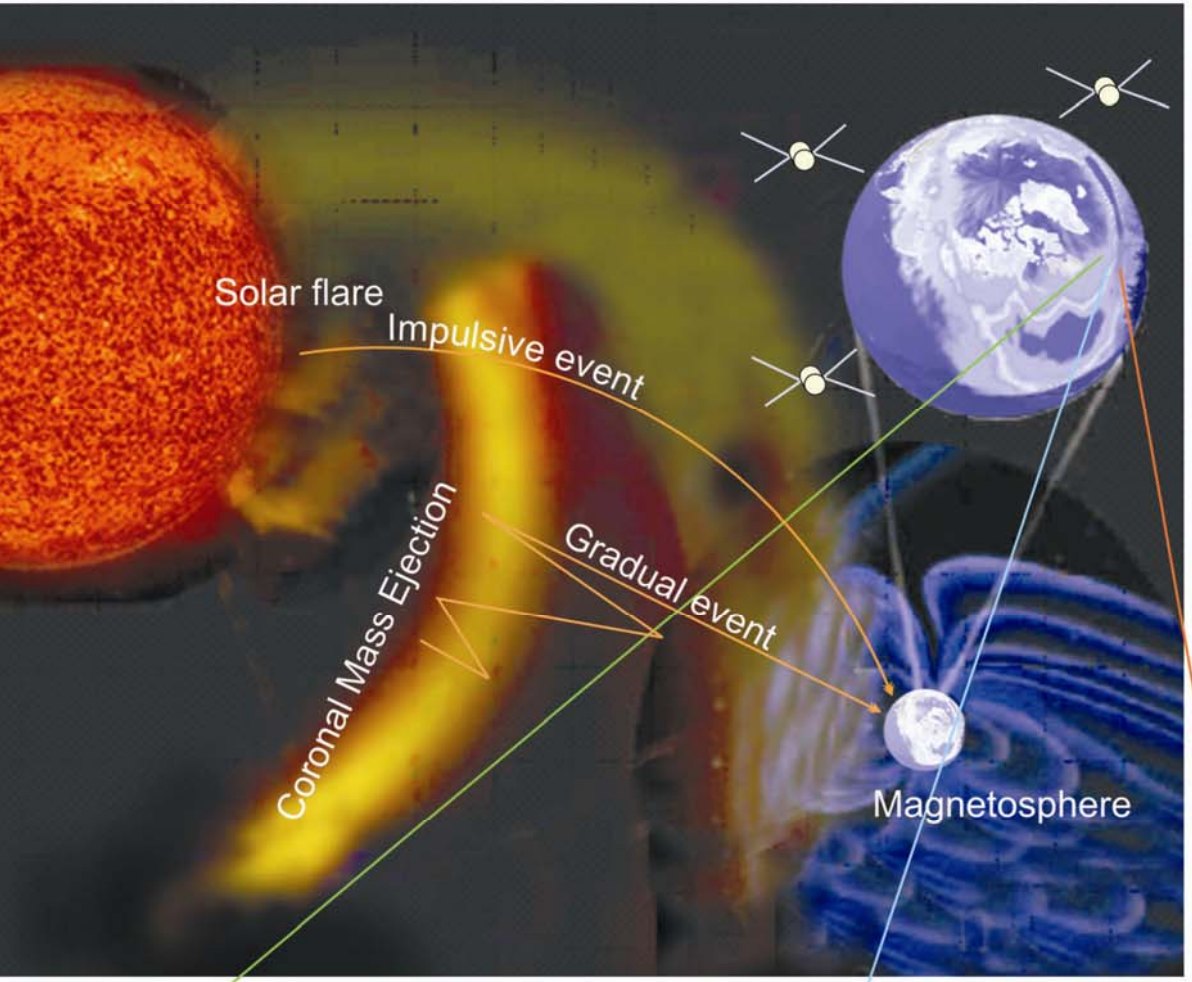
On the possibility to forecast severe radiation storms by data from surface and space-born facilities

Ashot Chilingarian

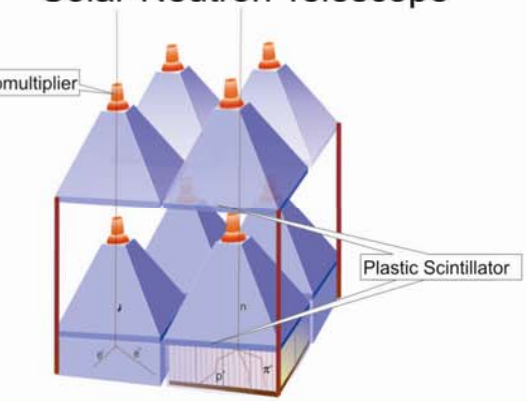
Cosmic Ray Division, Yerevan Physics Institute, Armenia

Aragats Space-Environmental Center (ASEC)

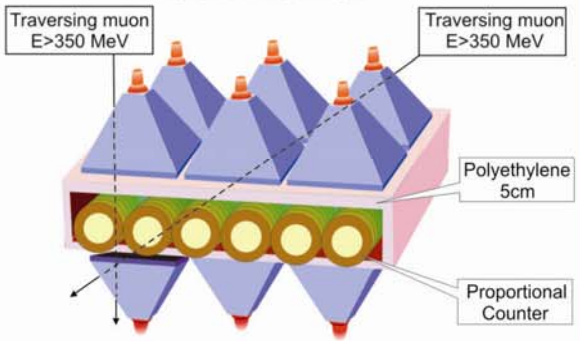




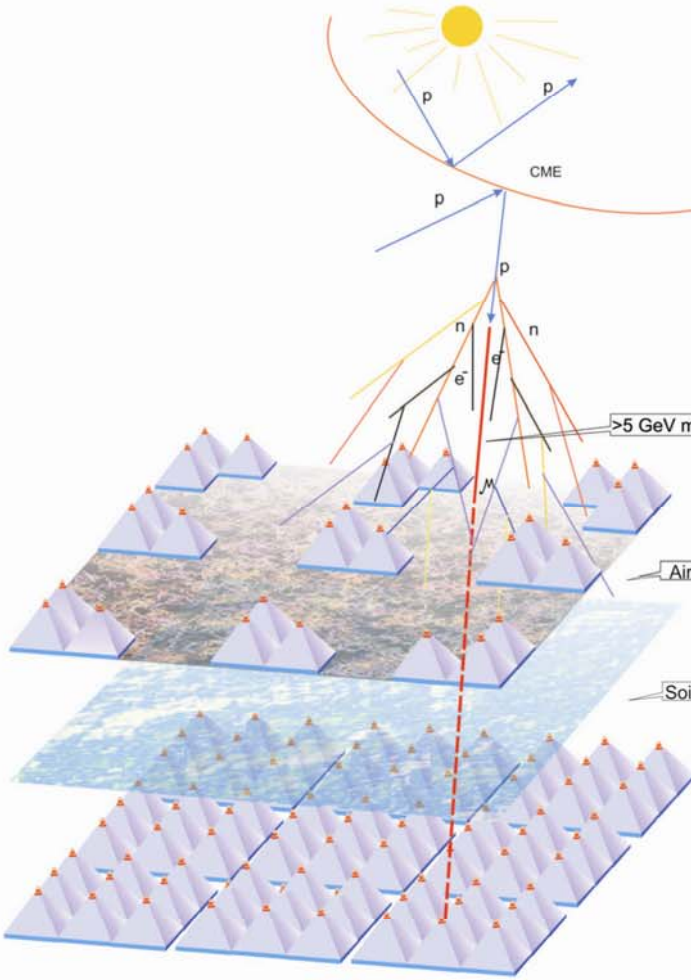
Solar-Neutron Telescope



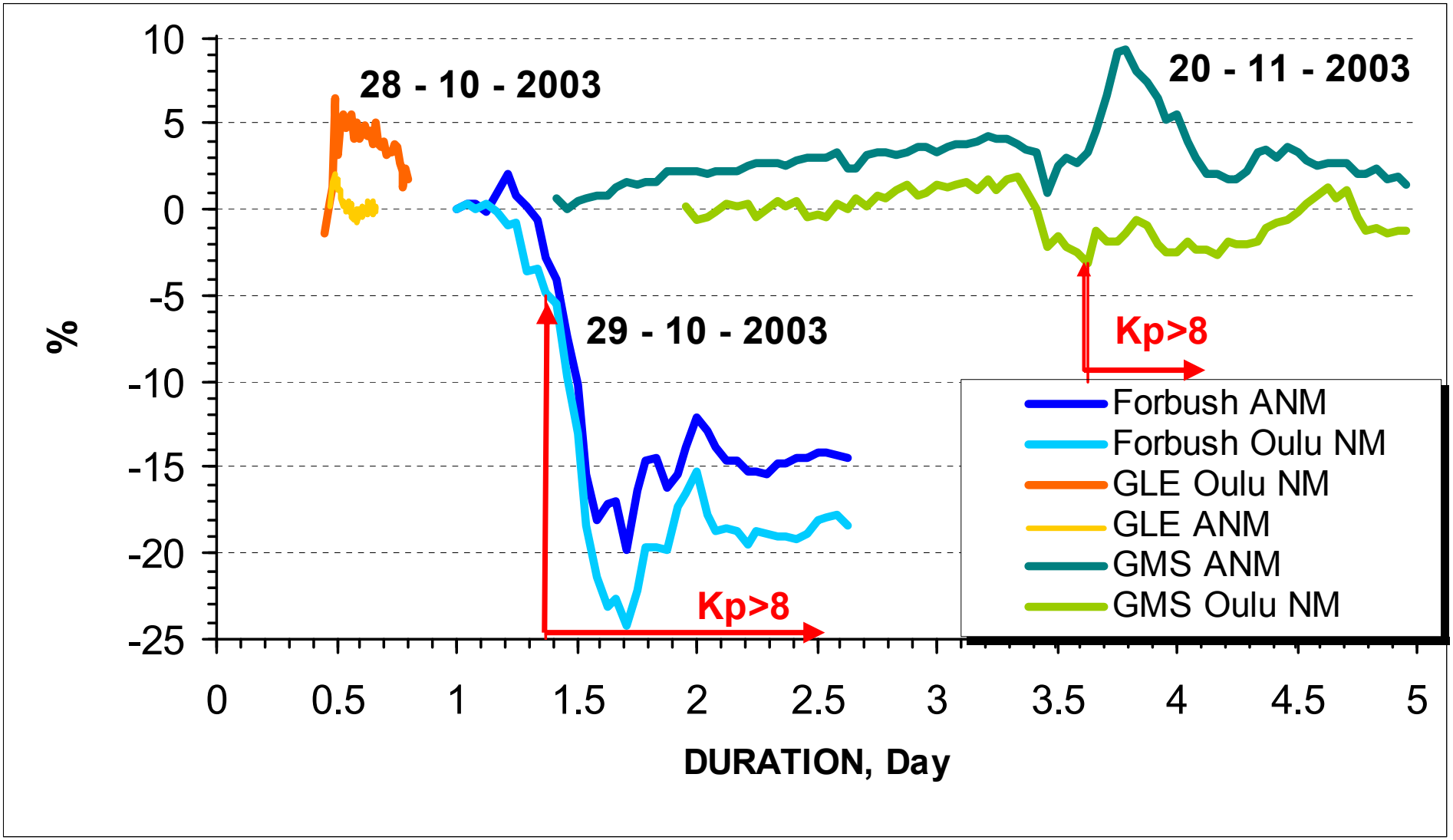
Nor-Amberd Multidirectional Muon Monitor



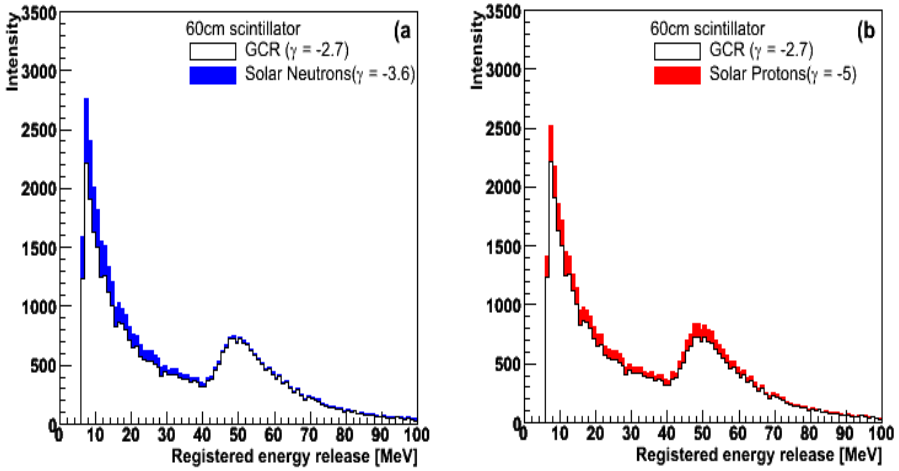
Aragats Multidirectional Muon Monitor



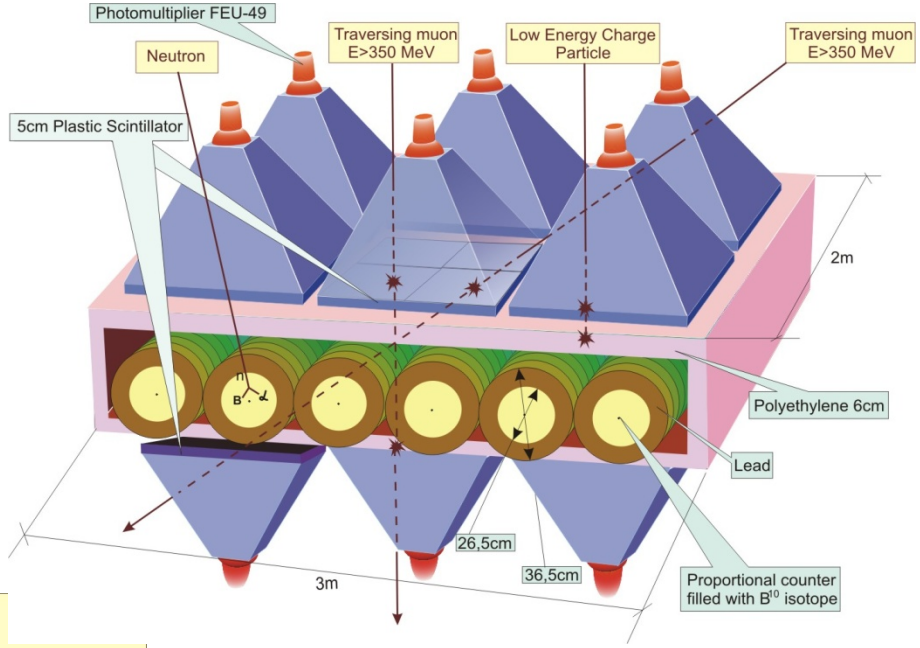
Solar Modulations Effects

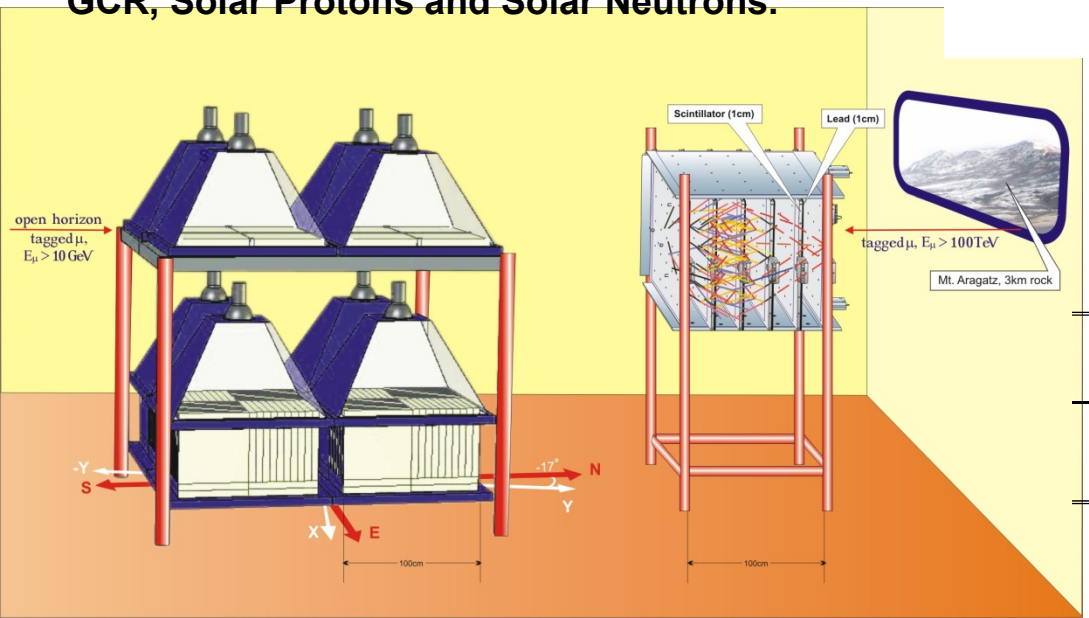


Particle Detectors Operated at Aragats Space Environmental Center (ASEC)



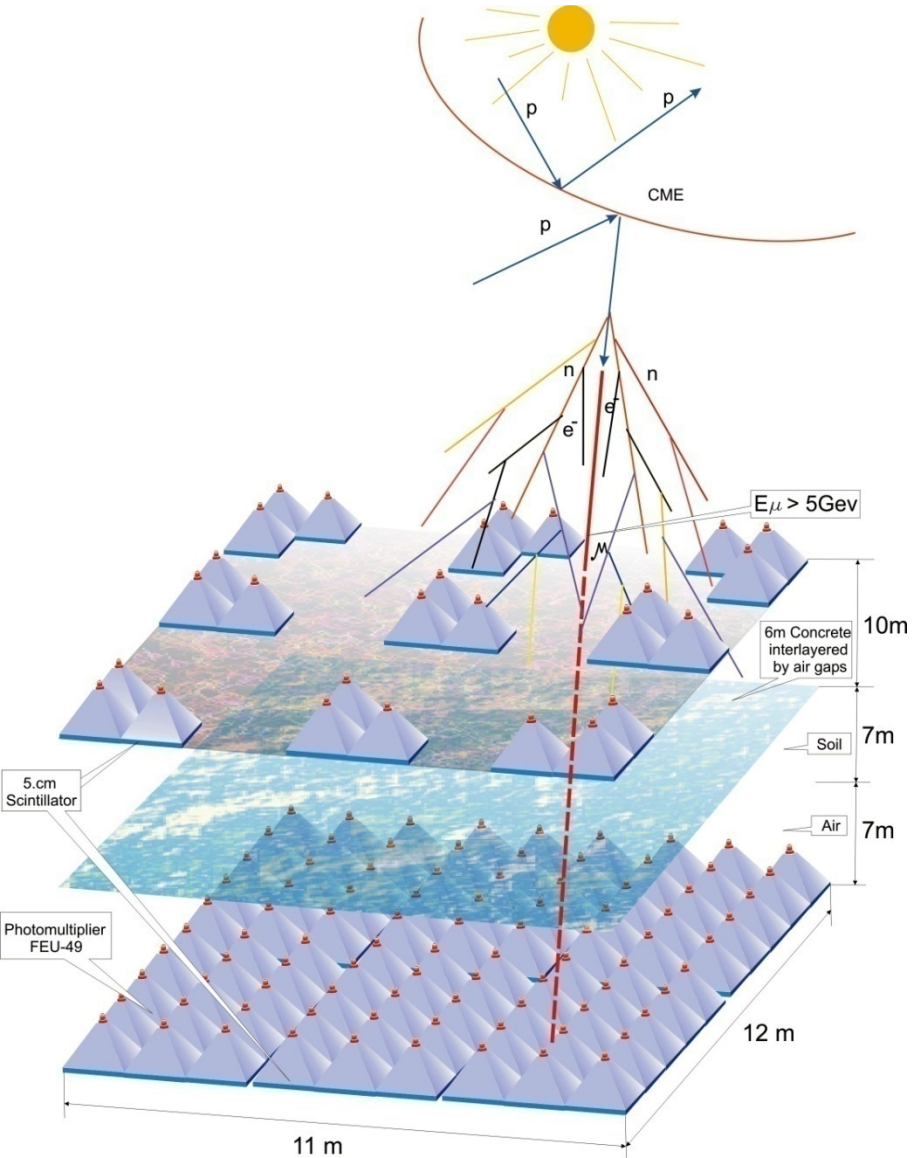
Registered energy deposit corresponding to GCR, Solar Protons and Solar Neutrons.

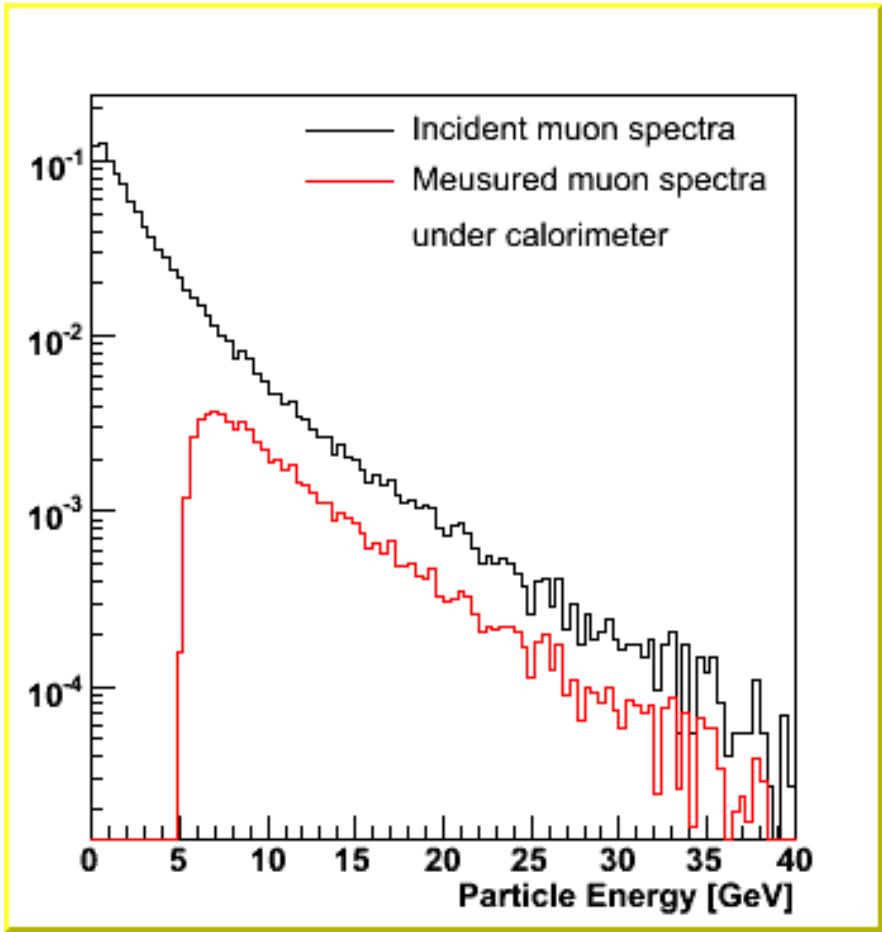




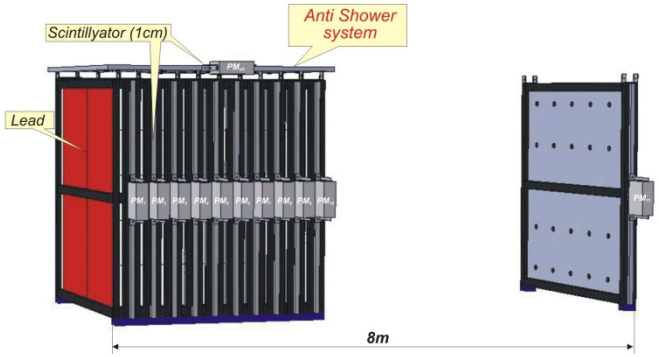
Detector layer	Solar Protons	Solar Neutrons
Upper 5cm scintillator	4.8σ	2.6σ
Middle 25 cm scintillator	1.7σ	6.4σ

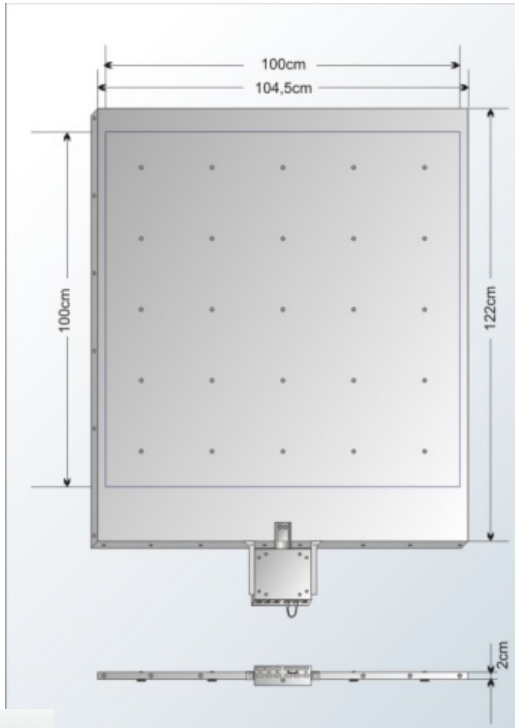
Aragats Underground Muon Monitor (AUMM)

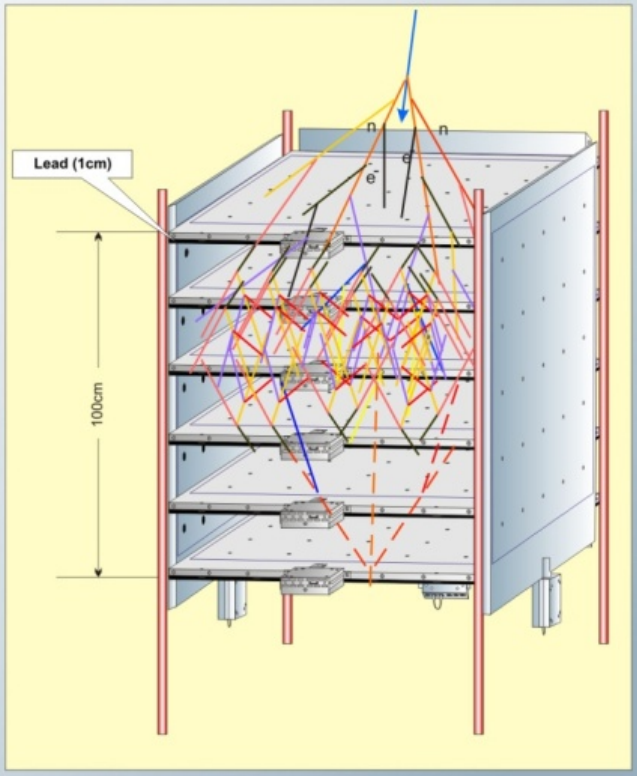




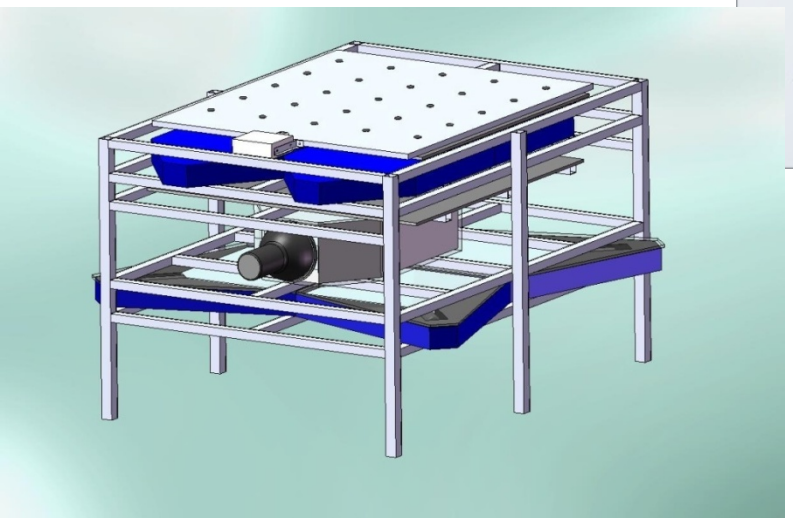
New multilayered particle detectors



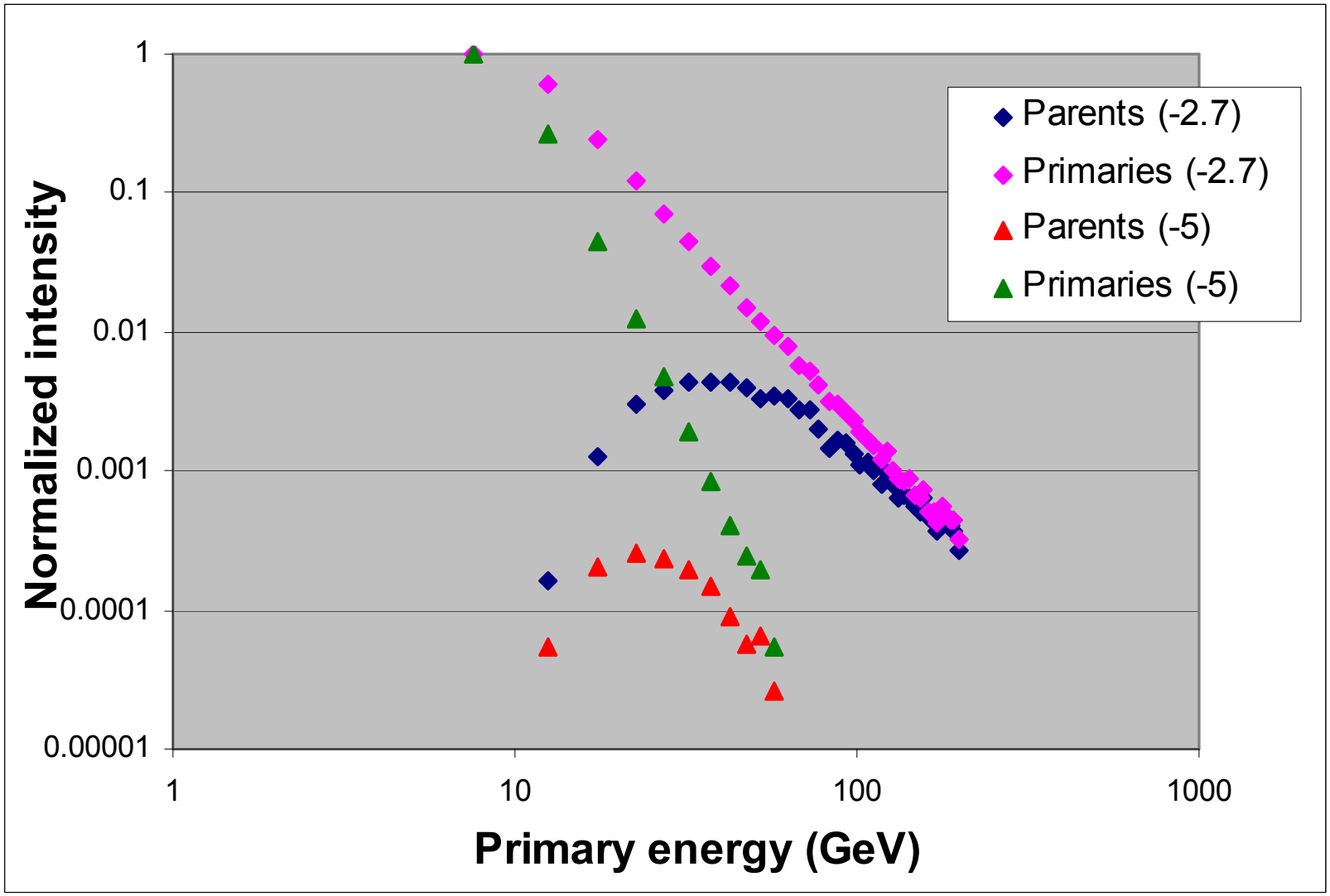




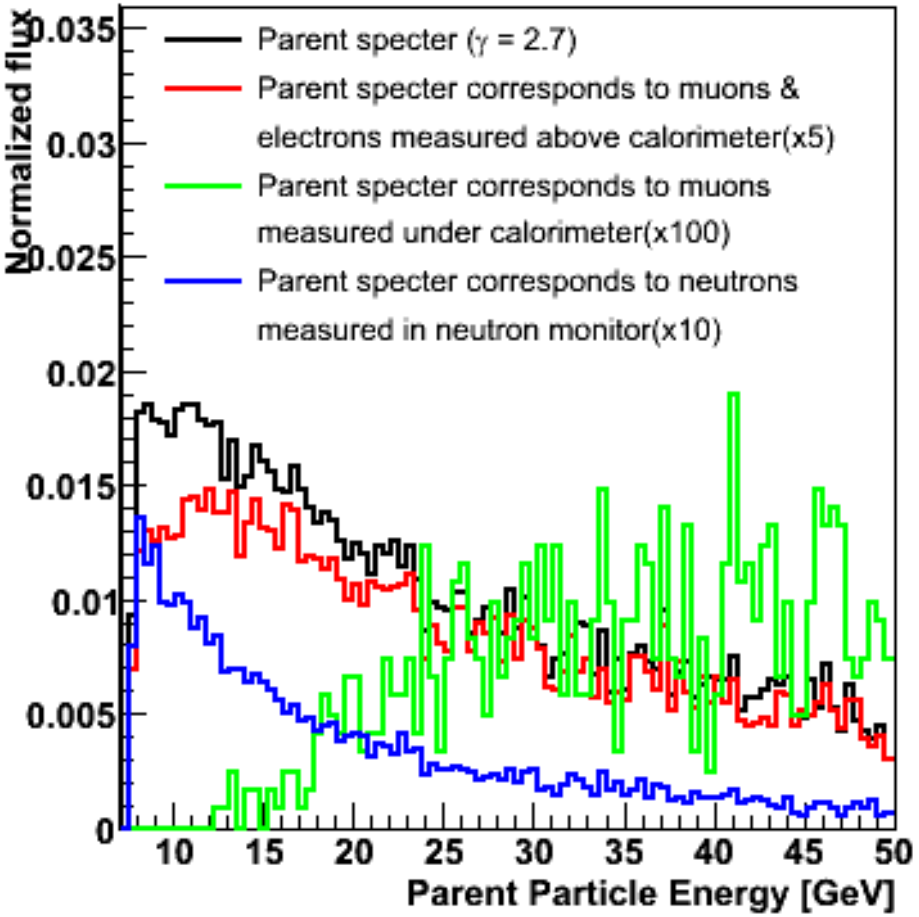
Aragats Hadron-Electromagnetic Calorimeter (AHEC)

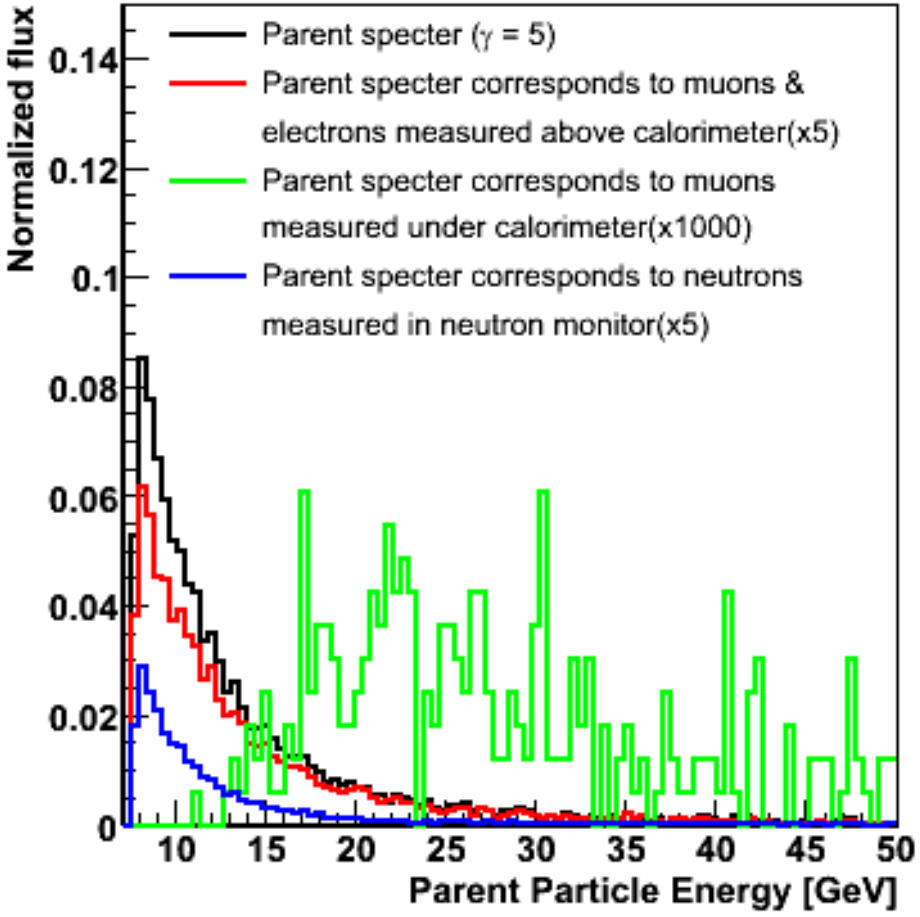


Detector response to Galactic and Solar CR



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



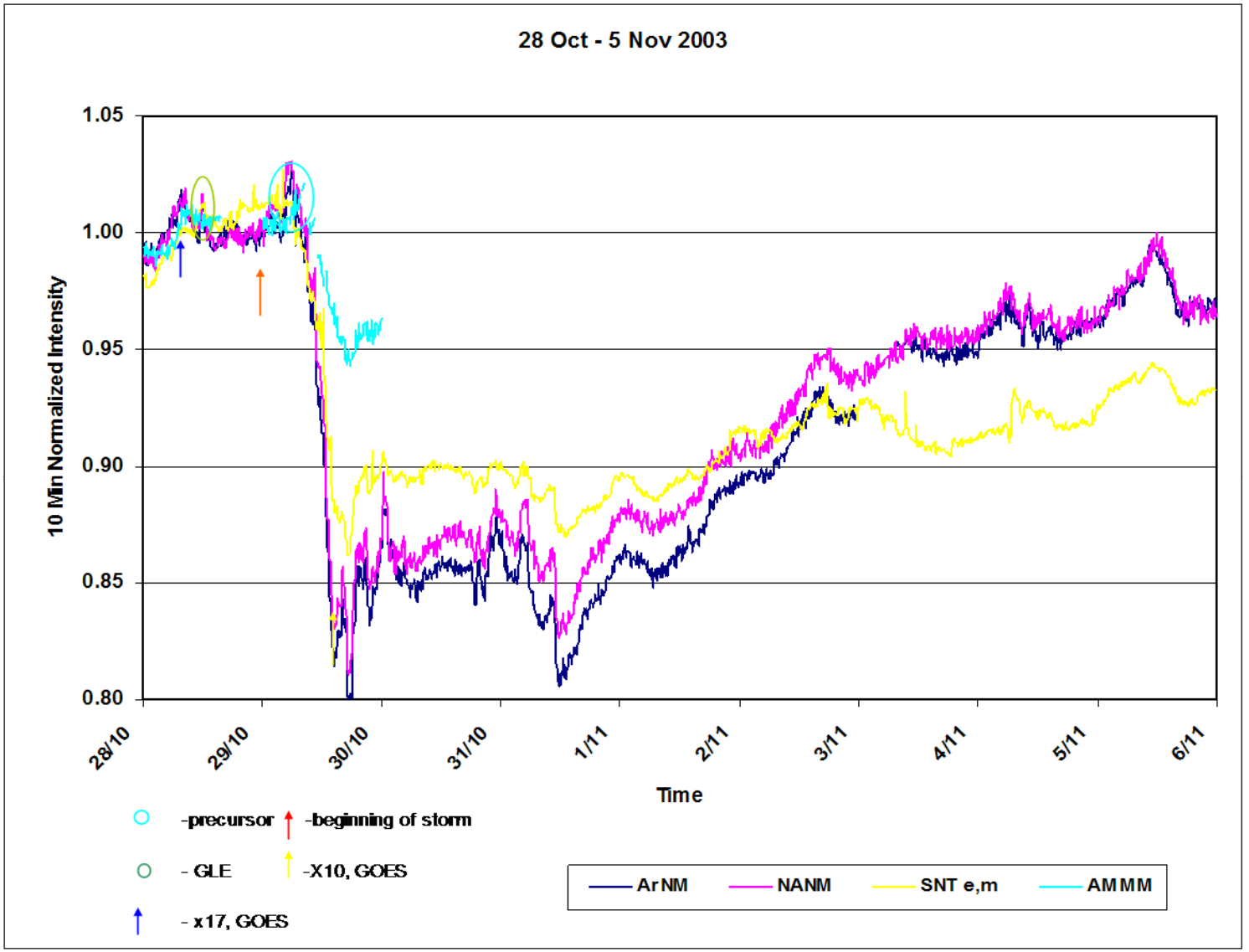


$\pm \frac{1}{\sqrt{N}}$

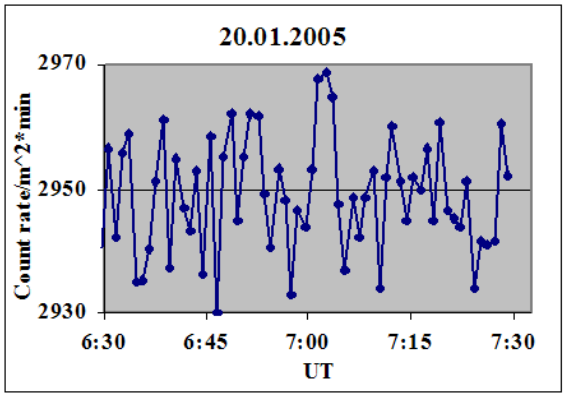
ASEC Monitors

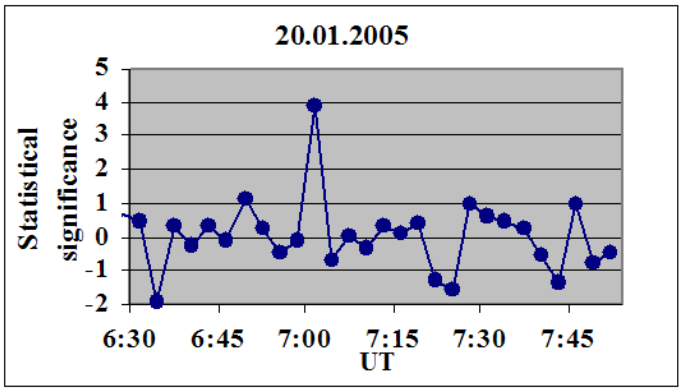
Monitor	Barometric Coefficient %/mb	Correlation Coefficient	Count rate [min]	Relative error %	
Nor Amberd neutron monitor 1250us	-0.670 0.021	0.995	22561	0.008	0.0066
Nor Amberd neutron monitor without lead (two channel)	-0.698 0.031	0.989	683	0.038	0.0383
Aragats neutron monitor 1250us	-0.688 0.018	0.996	35911	0.005	0.0052
Nor Amberd multidirectional muon monitor(1) (upper layer) E>7 mev	-0.324 0.012	0.992	81557	0.004	0.0035
Nor Amberd multidirectional muon monitor(1) (lower layer)E>250 mev	-0.223 0.013	0.987	44420	0.006	0.0047
Nor Amberd multidirectional muon monitor(2) (upper layer) E>7 mev	-0.323 0.013	0.991	81548	0.004	0.0035
Nor Amberd multidirectional muon monitor(2) (lower layer)E>250 mev	-0.225 0.013	0.987	44423	0.006	0.0047
Aragats underground muon Telescope E>5 Gev	-0.08 7.6E-05	0.924	261051	0.005	0.0019
Nor Amberd SEVAN Low energy charged particles (Coincidence 100)	-0.281 0.022	0.957	5941	0.013	0.0129
Nor Amberd SEVAN High energy muons (Coincidence 111+ Coincidence 101)	-0.242 0.022	0.952	1988	0.026	0.0224
Nor Amberd SEVAN neutrons (Coincidence 010)	-0.54 0.070	0.899	674	0.037	0.0385
Aragats SEVAN Low energy charged particles (Coincidence 100)	-0.5 0.018	0.995	15389	0.007	0.0080
Aragats SEVAN High energy muons (Coincidence 111+ Coincidence 101)	-0.351 0.038	0.96	3868	0.014	0.0161
Aragats SEVAN neutrons (Coincidence 010)	-0.511 0.018	0.995	1959	0.019	0.0225
Aragats Solar Neutron Telescope (5 cm)	-0.507 0.022	0.994	96721	0.003	0.0023
Aragats Solar Neutron Telescope (60 cm)	-0.427 0.017	0.994	175372	0.005	0.0035

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

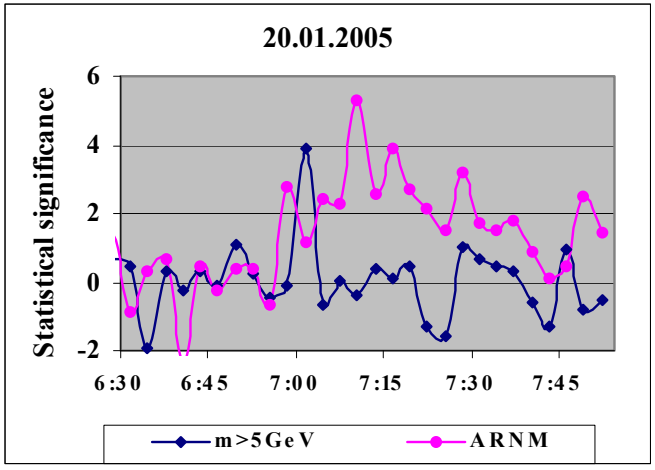


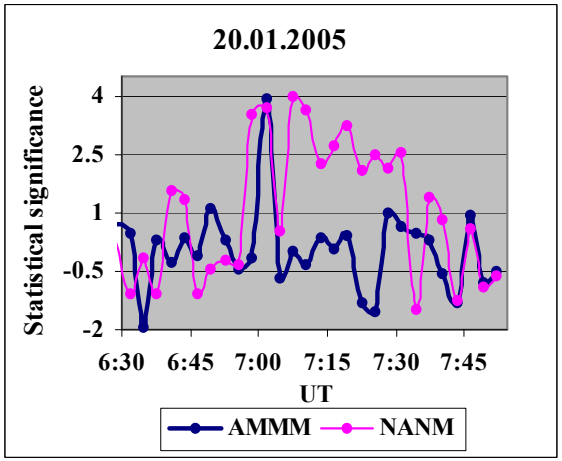
AMMM Detection of GLE 20 January 2005

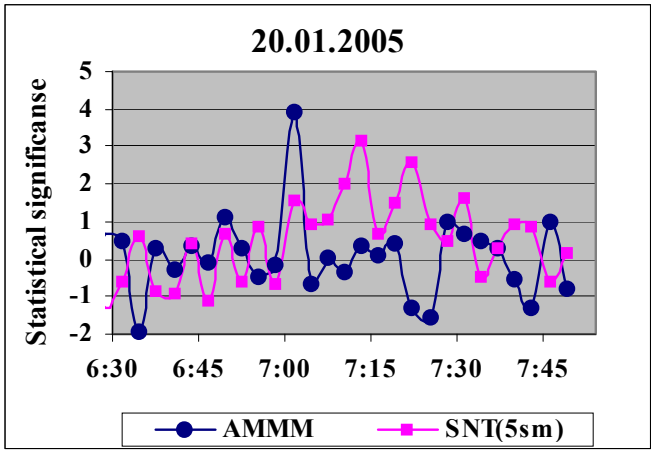




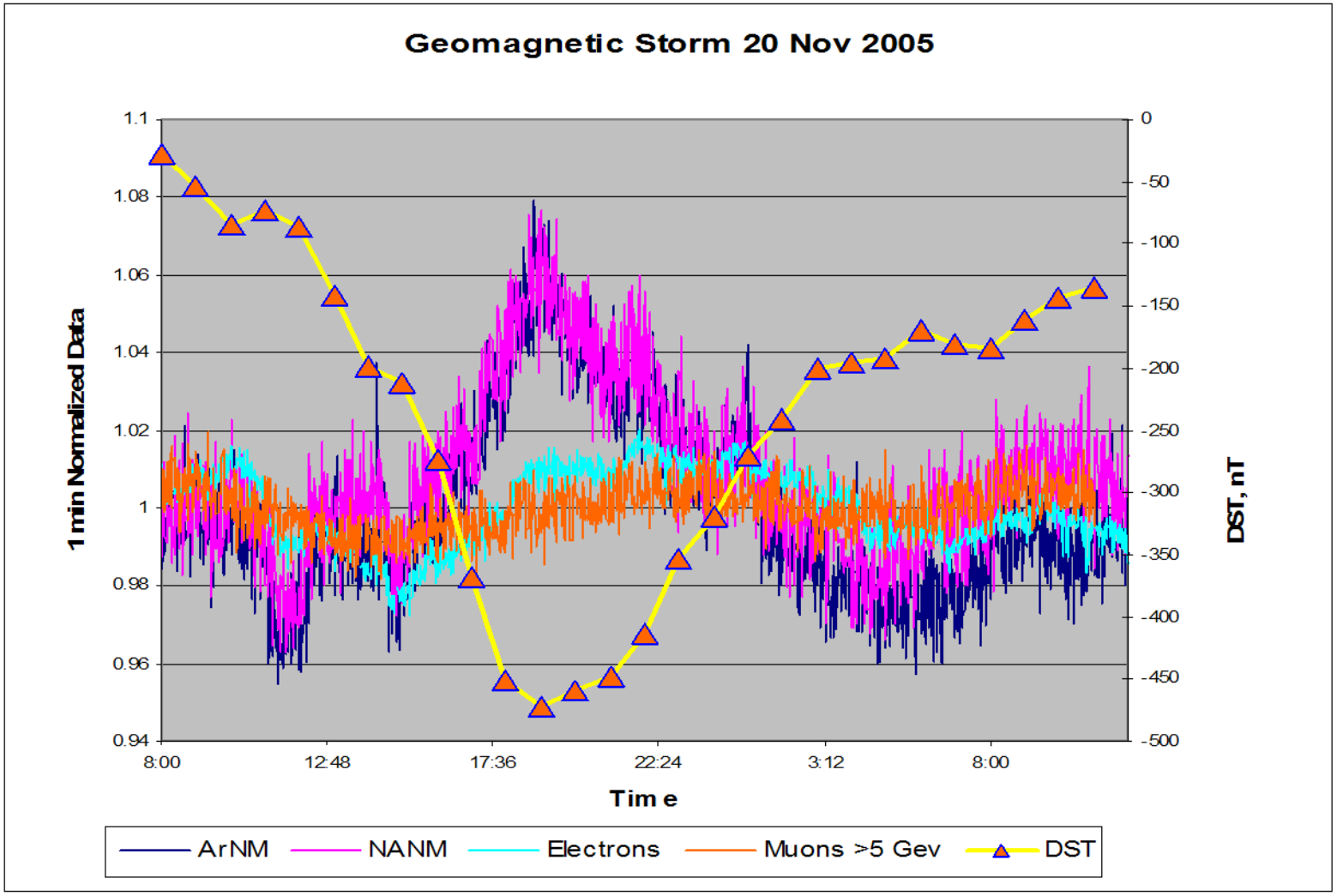
The additional signal at 7:02-7:04 UT equals 2354 (0.644%) If we adopt the Poisson standard 0.164%, significance = 3.93σ







Geomagnetic Disturbance of 20 November 2003



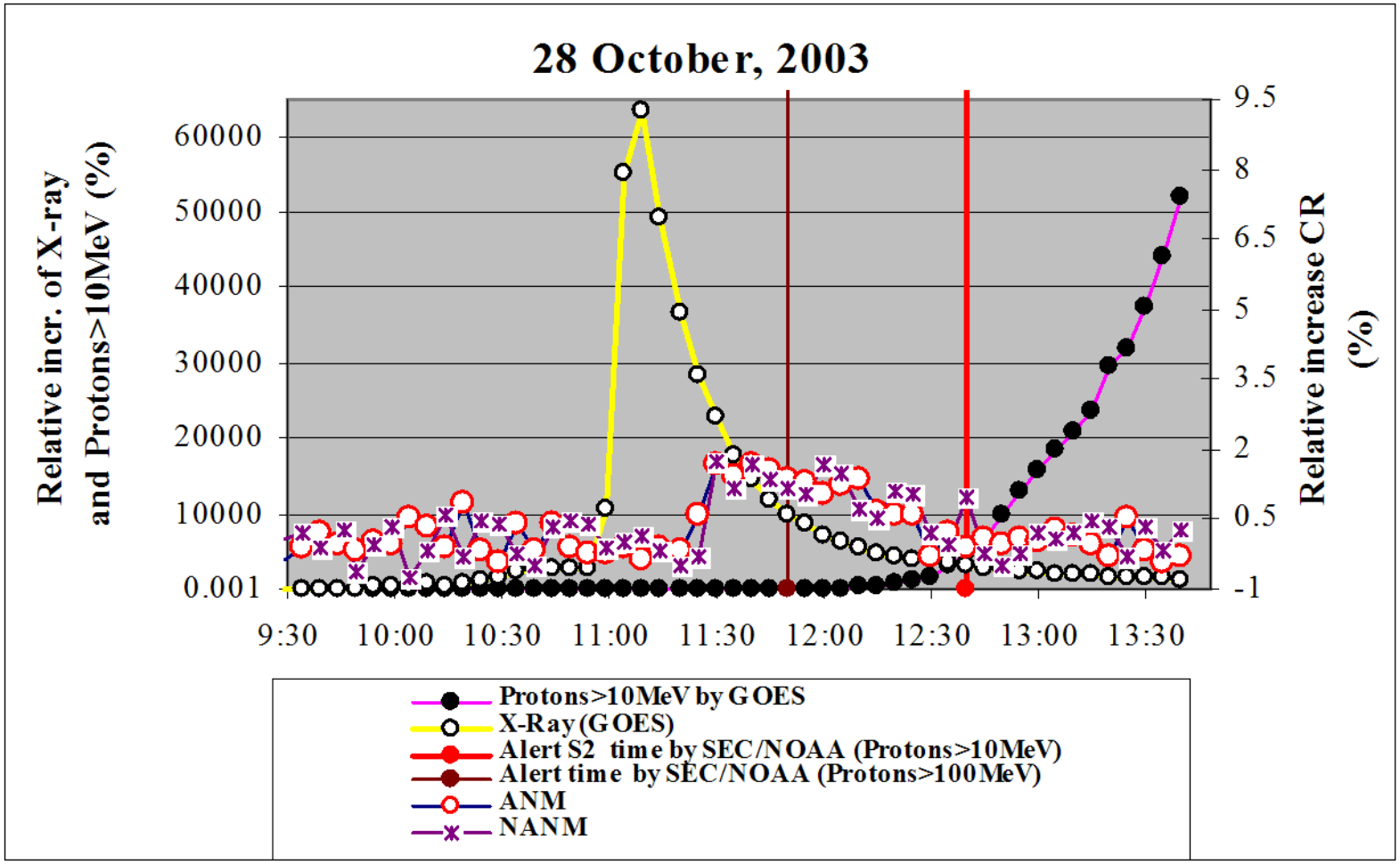
Correlation Matrix of ASEC monitors for 20-21 November 2003 г. (14:50 – 19:10), Geomagnetic Storm

	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

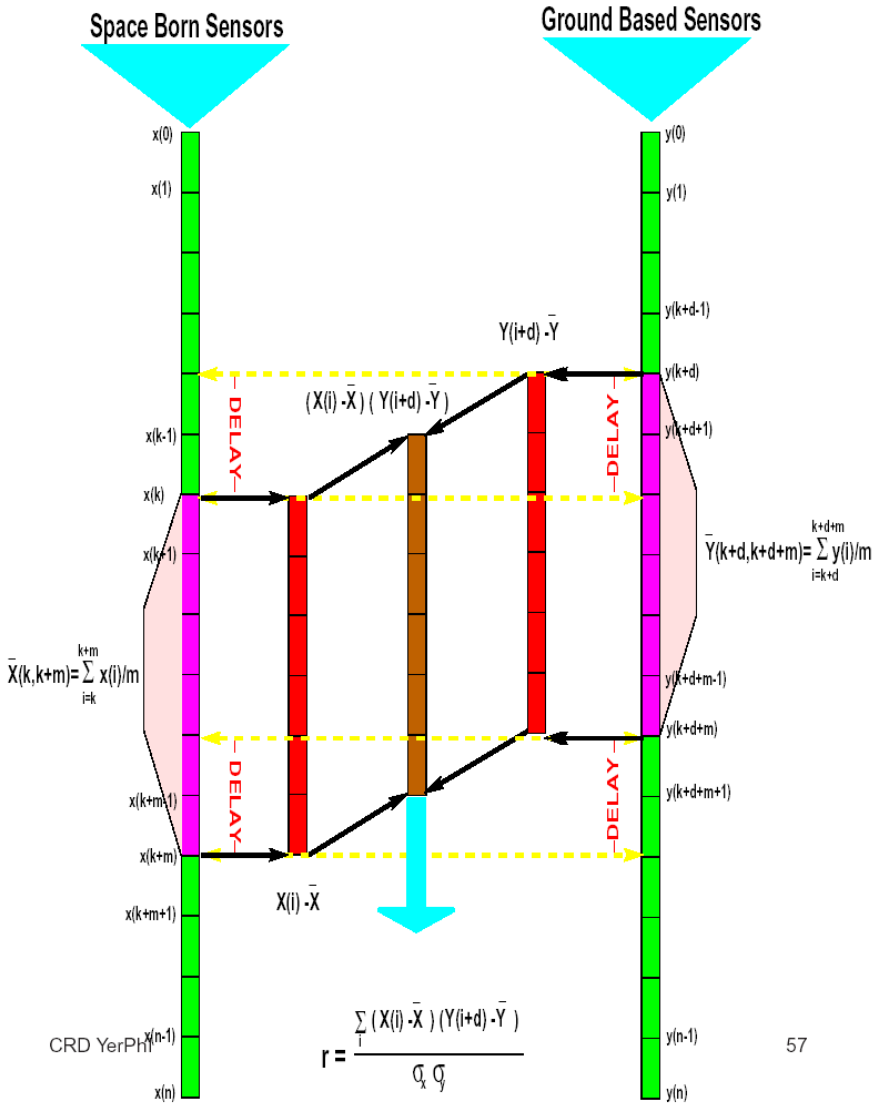
GLE of 23rd cycle detected by the ASEC particle monitors

GLE number and date	X-Ray Flare	ASEC Monitor	GLE onset	Time of 1 peak	σ	Time of second peak	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			

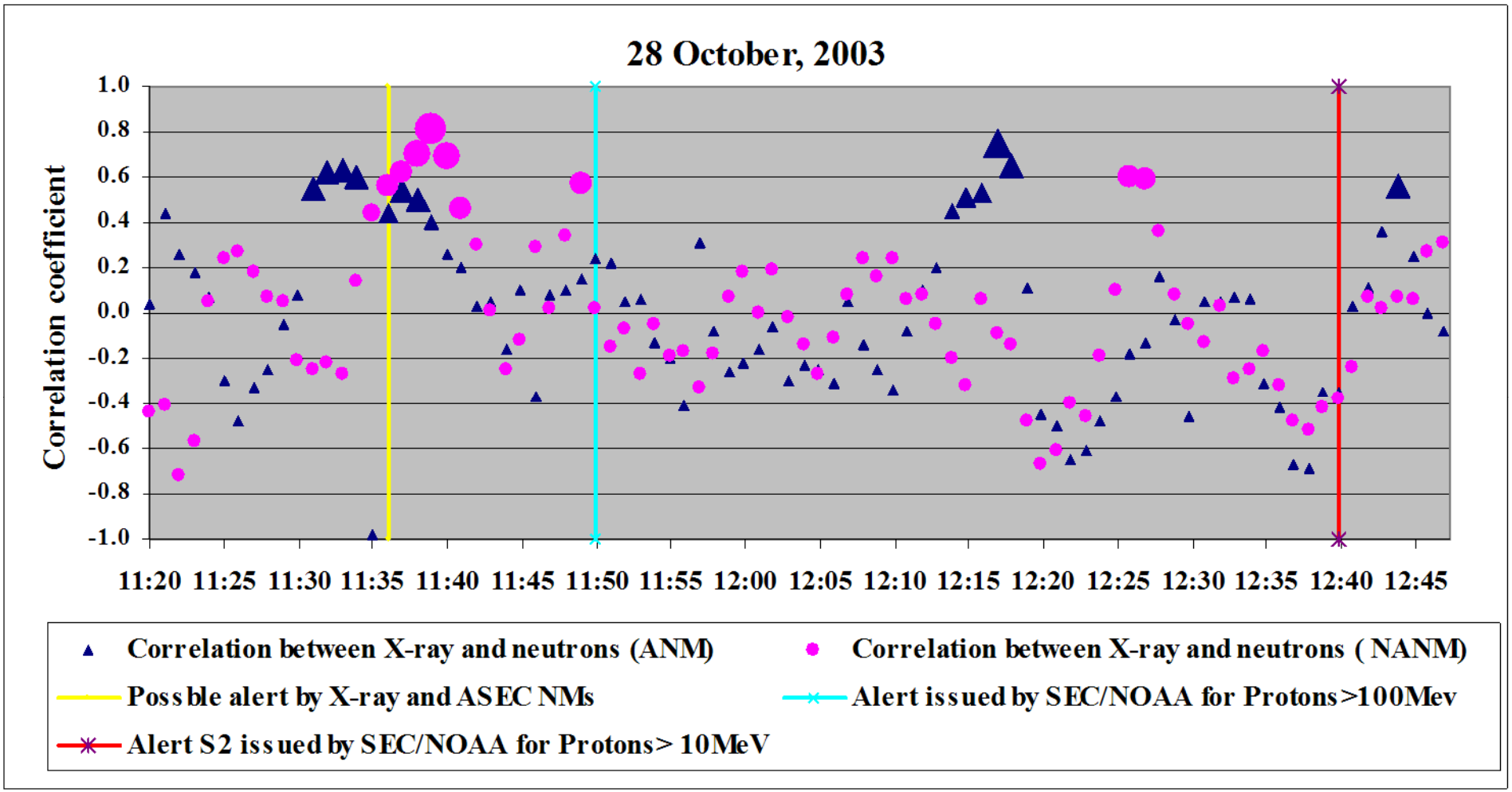
Radiation from 28 October 2003 X14.4 flare (flux maximum at 11:10). SEC/NOAA alerts on 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the ANM and NANM) reaches ~1.7% at ~11:35.



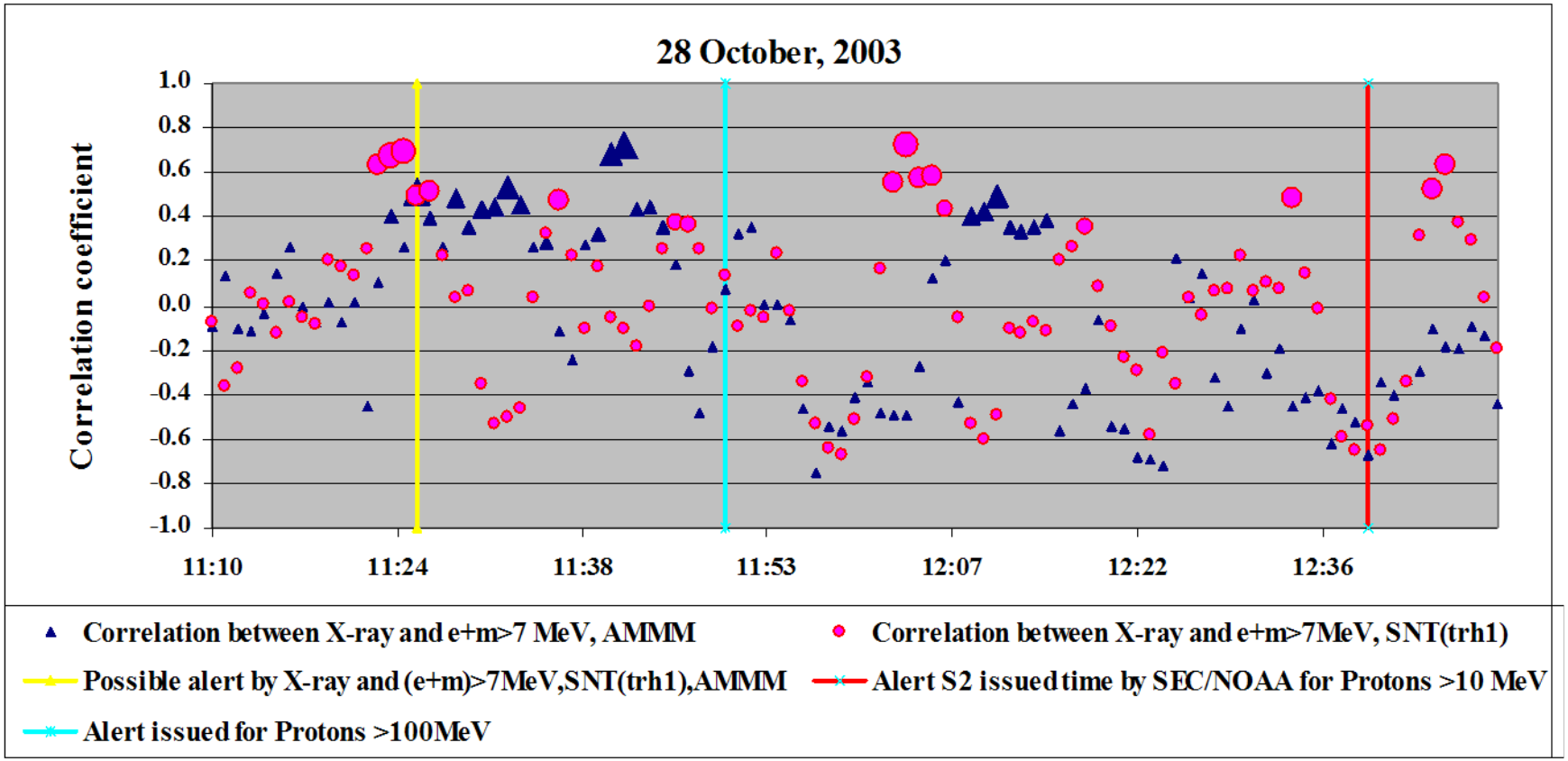
Delayed Correlations



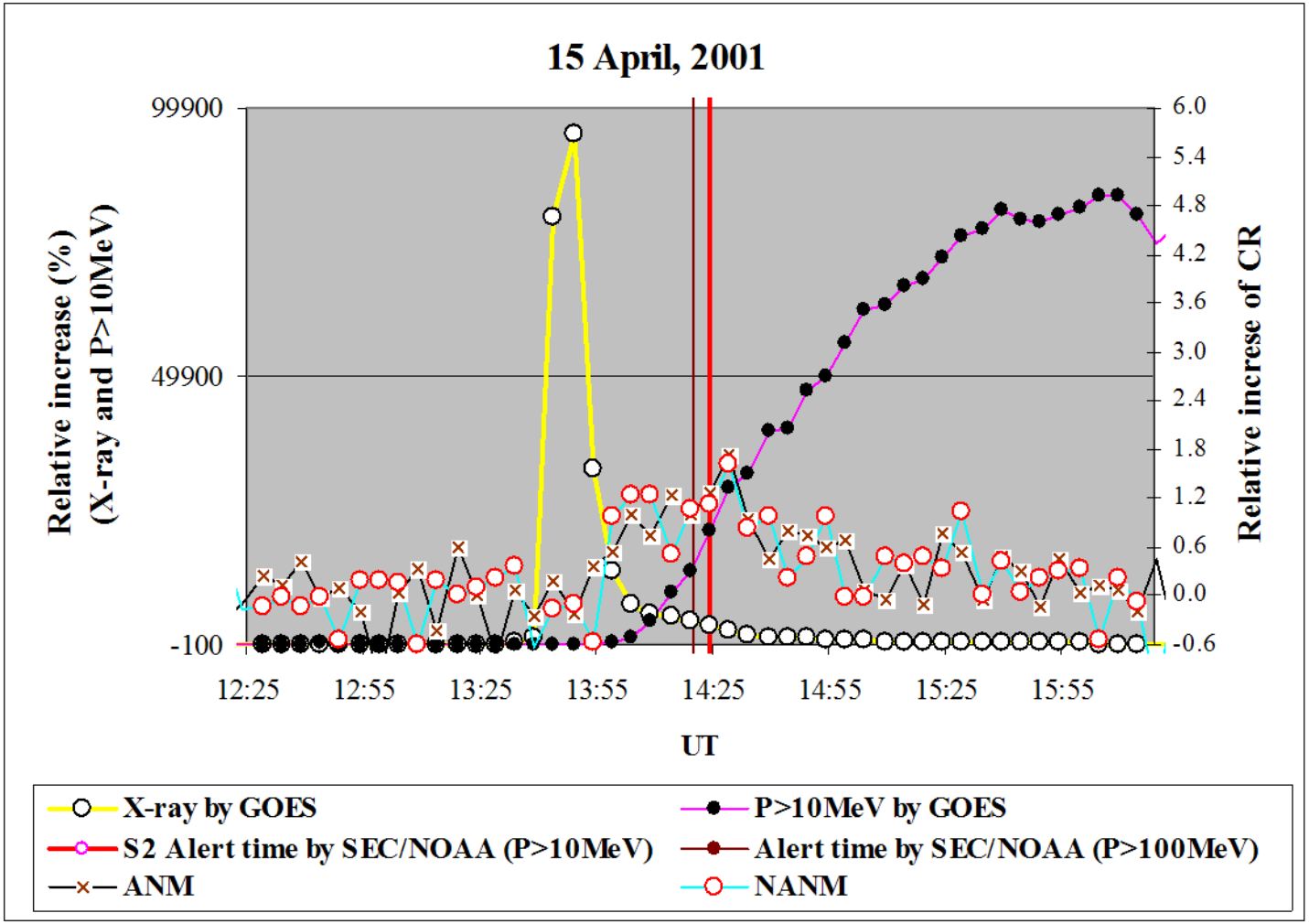
Pattern of correlations between neutron flux and X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates.



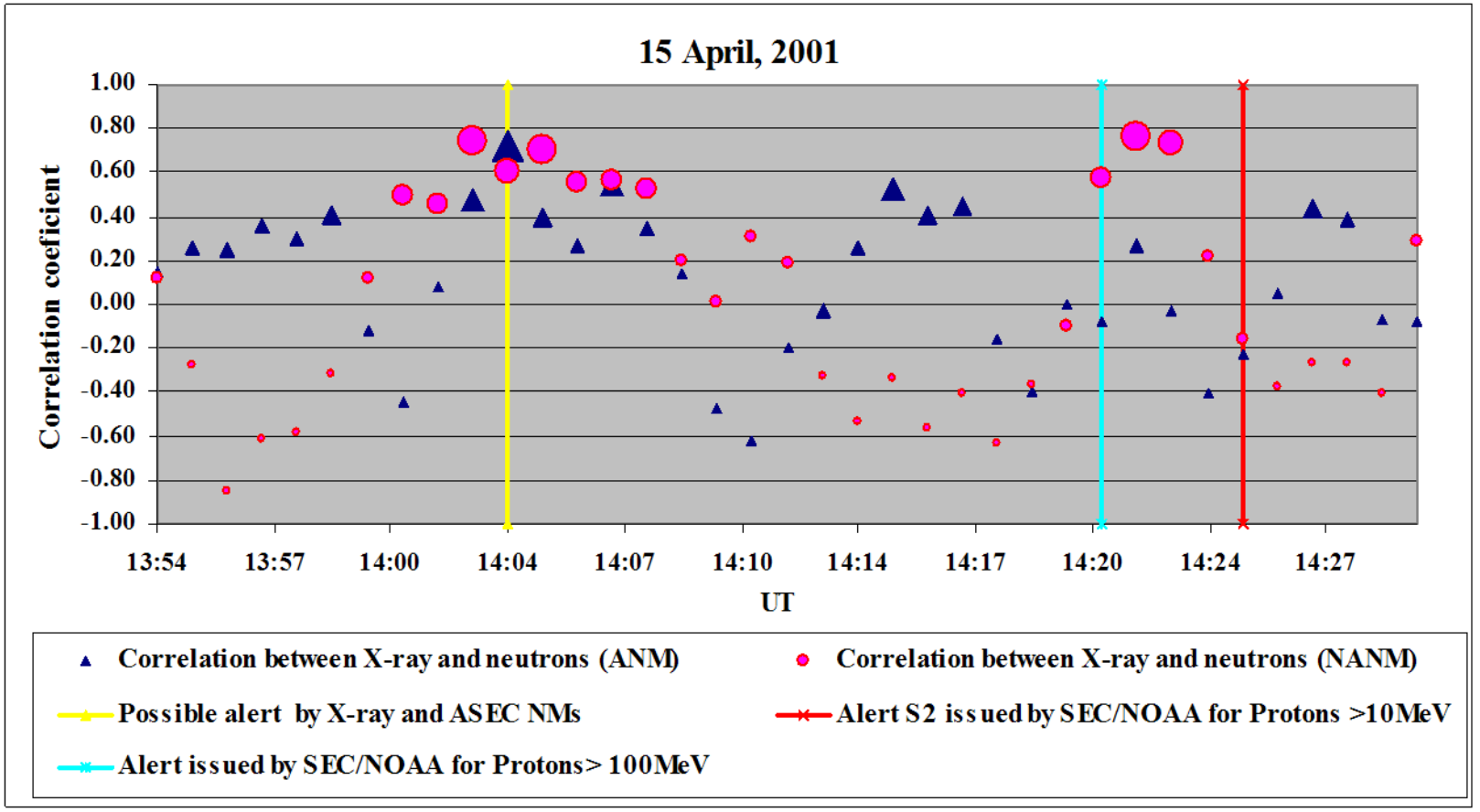
Pattern of correlations between muon flux and X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates



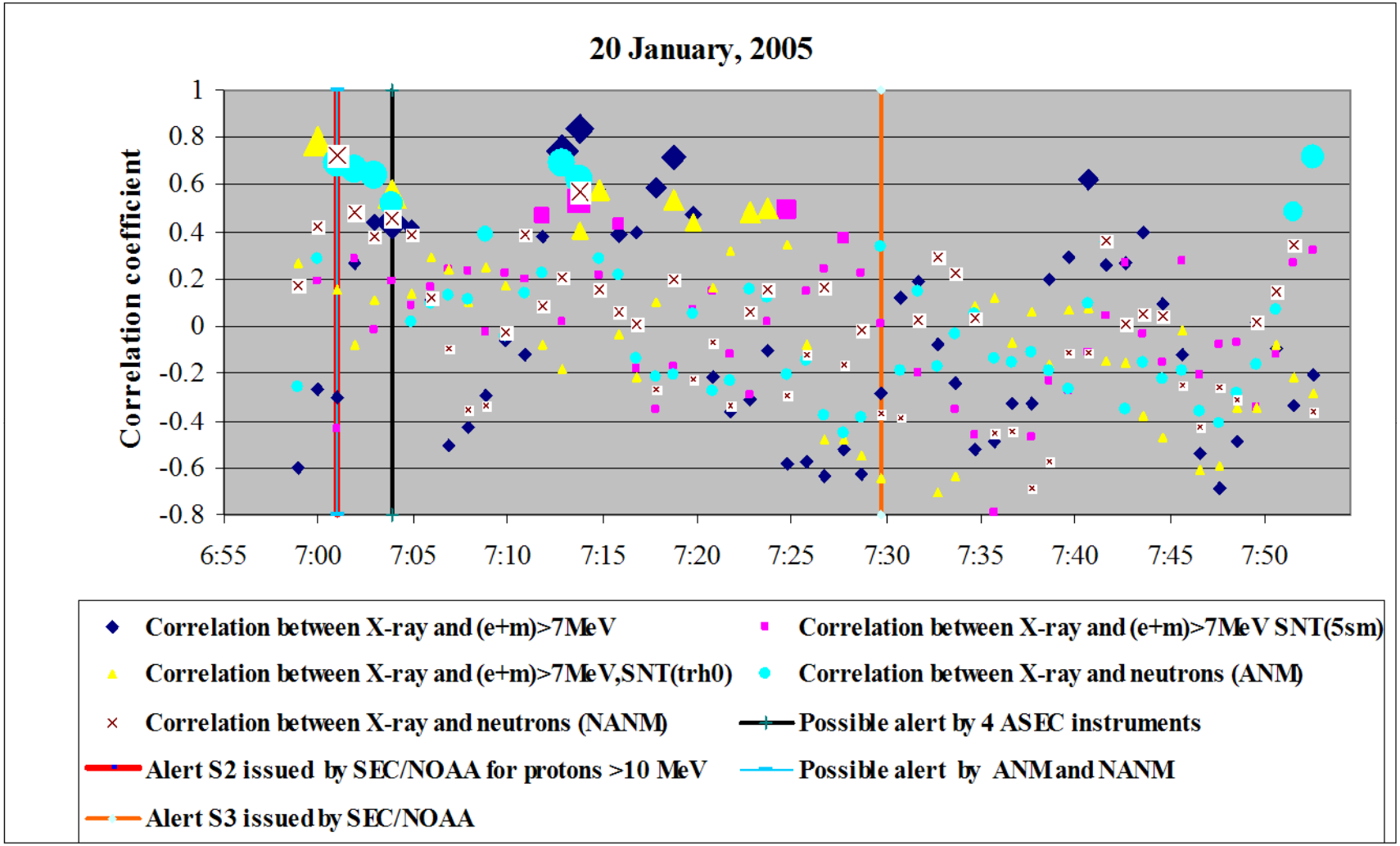
Radiation from 15 April 2005 X17.2 flare. SEC/NOAA alerts enhancement of 100 MeV protons at 14:21 and S2 alert for 10 MeV protons at 14:25. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.4% and reaches maximum at ~14:00.



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

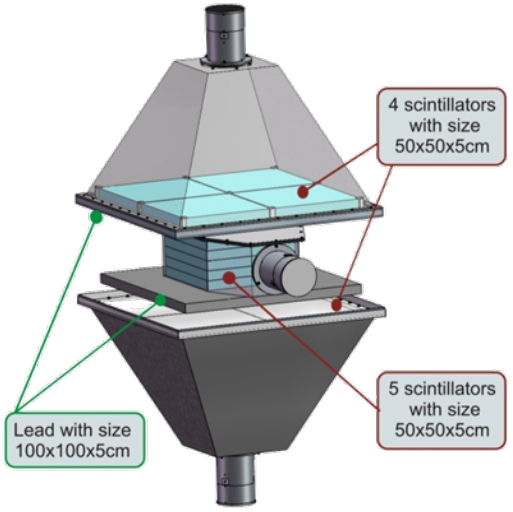


The alert service for warning on upcoming SEP event

- 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 Aragats 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 at 3 altitudes (1000, 2000, 3200 m. A.S.L.) and X-ray flux measured by satellite facilities.

Space Environmental Viewing and Analysis Network (SEVAN)

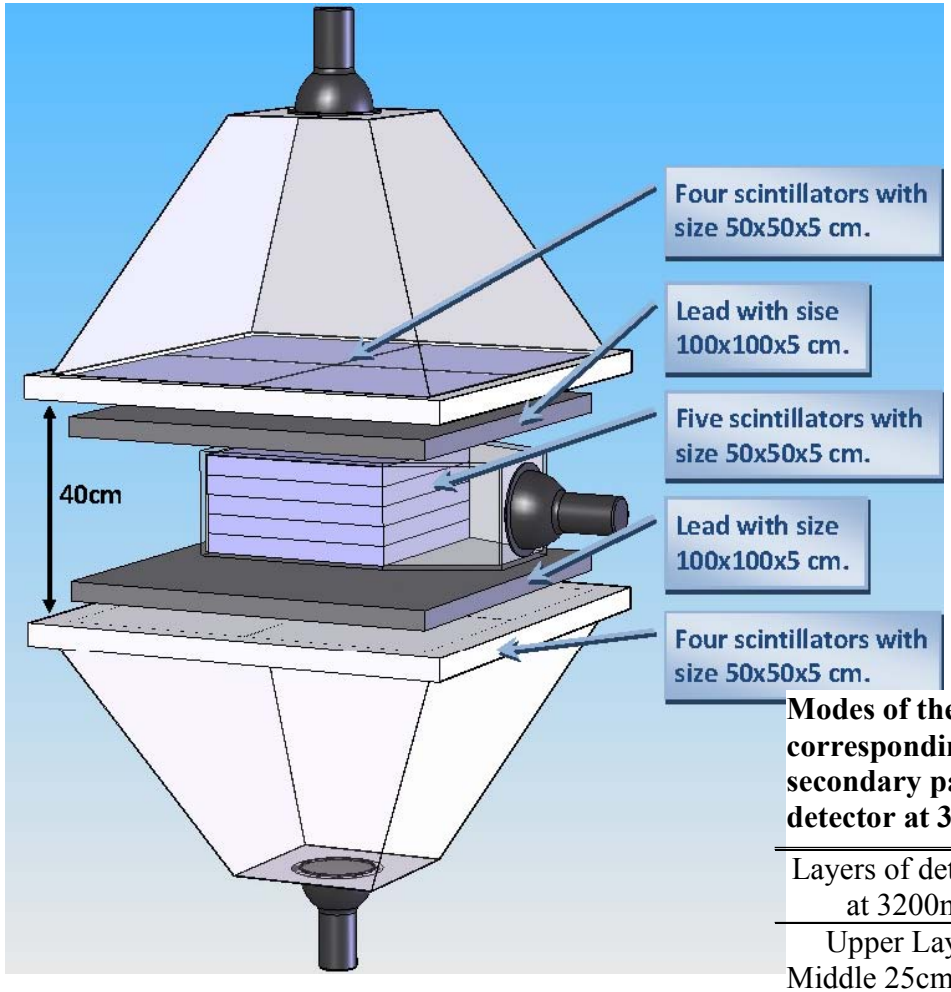
A network of middle to low latitude particle detectors called SEVAN (Space Environmental Viewing and Analysis Network) is planned in the framework of the International Heliophysical Year (IHY), to improve fundamental research of the Solar accelerators and Space Weather conditions.



COSMIC RAY DIVISION
Alikhanyan Physics Institute,
Alikhanyan Brothers 2,
Yerevan 375036, Armenia

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

111 ; 101– traversal of high energy muon;
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)

First SEVAN modules at Aragats

	(1000m)		NorAmberd (2000m)		Aragats (3200m)	
Type of Secondary particle	Measured count rate	simulated count rate	Measured count rate	simulated count rate	Measured count rate	simulated count rate
Low energy charged particles	8862±108	7202	11593±16	10220	16010±13	17330
Neutral particles	363±19	359	690±27	795	2007±46	1680
High energy muon	4337±67	5477	4473±99	5548	4056±64	8051

SEVAN Network

Summarizing, the hybrid particle detectors, measuring neutral and charged fluxes provide following advantages upon existing detector networks measuring single species of secondary CR:

- Enlarged statistical accuracy of measurements;
- Probe different populations of primary cosmic rays with rigidities from 7 GV up to 20-30 GV;
- Reconstruct SCR spectra and determine position of the spectral “knees”;
- Classify GLEs in “neutron” or “proton” initiated events;
- Estimate and analyze correlation matrices among different fluxes;
- Significantly enlarge the reliability of Space Weather alerts due to detection of 3 particle fluxes instead of only one in existing neutron monitor and muon telescope world-wide networks.

COSMIC RAY DIVISION
Alikhanyan Physics Institute,
Alikhanyan Brothers 2,
Yerevan 375036, Armenia

Space Weather Research and Forecasting by Networks of Particle Detectors Measuring

- **24 hour, whole year monitoring of the secondary cosmic rays by networks of particle detectors. Providing data to world-wide networks and partners in real time;**
- **Prepare integrated database of solar events, including parameters of flare, coronal mass ejection (CME), Solar Wind, Interplanetary Magnetic Field (IMF) and geophysical parameters;**
- **Develop Space Weather portal and its mirrors.**
- **Select of the subset of variables from space-born and surface facilities for prognosis of severity of upcoming space storms;**
- **Develop Bayesian statistical models and Neural Net models for the forecasting and estimating severity of Space Storms;**
- **Develop and test Space Weather forecasting methods. Design and implement automatic systems of issuing alerts and warnings;**
- Wide-aperture muon hodoscopes open a new possibilities of inner heliosphere investigations by penetrative high energy particle;
- Large mass ACSs of gamma-observatories (INTEGRAL, Enriko Fermi) provides huge statistics (10,000,000 in minute) of particles and can be used for the SEP forecasting;
- Solar Sentinels will bring most direct information about violent processes on Sun