Solar Flares and CME as modulated agents of the Cosmic Ray flux incident on terrestrial atmosphere. What can we deduce from particle detector data?

A.Chilingarian

Cosmic Ray Division,
Alikhanyan Physics Institute, Armenia

Scientific Goals of the Solar Physics and Space Weather Fundamental Research

Sentinels Science Goals and Objectives

I. Understand and Characterize the Sources, Acceleration, and Transport of Solar Energetic Particles

Determine the roles of CME-driven shocks, flares, and other processes in accelerating energetic particles
- When and where are energetic particles accelerated by the Sun?
- How are energetic particles observed at the Sun related to those observed in the interplanetary medium?
- What conditions lead to the jets/narrow CMEs associated with impulsive SEP events?
- What physical processes accelerate SEPs?

Identify the conditions that determine when CME-driven shocks accelerate energetic particles
- What are the seed populations for shock-accelerated SEPs and how do they affect SEP properties?
- How do CME/shock structure and topology as well as ambient conditions affect SEP acceleration?

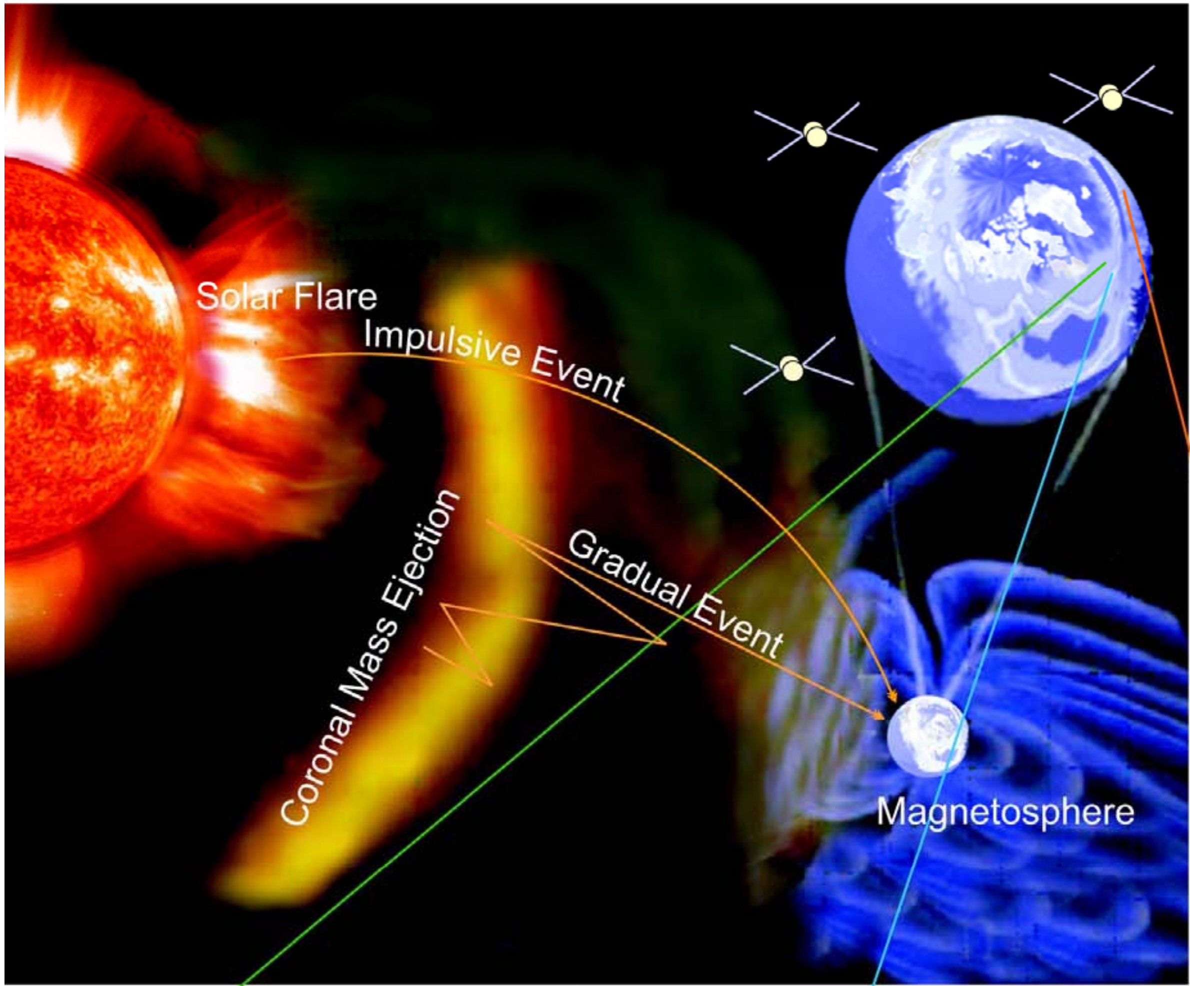
Determine how energetic particles are transported from their acceleration site and distributed in radius, longitude, and time
- What processes scatter and diffuse SEPs both parallel and perpendicular to the mean heliospheric magnetic field?
- What are the relative roles of scattering, solar wind convection, and adiabatic cooling in SEP event decay

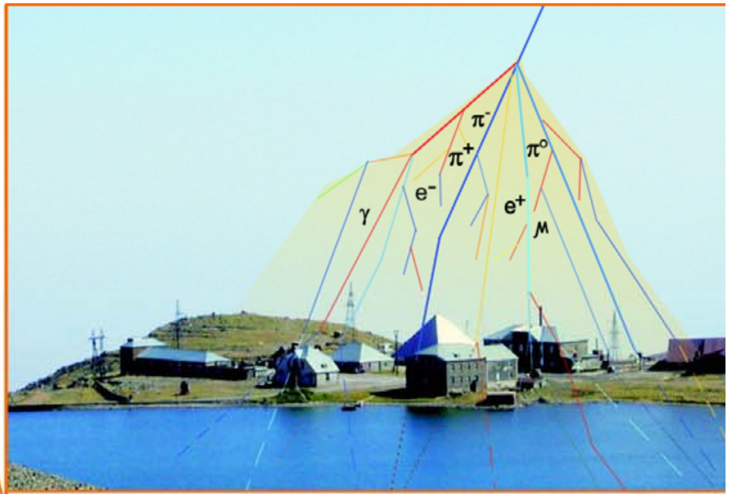
II. Understand and Characterize the Origin, Evolution, and Interaction of CMEs, Shocks, and Other Geoeffective Structures

Determine the physical mechanisms of eruptive events that produce SEPs
- What solar conditions lead to CME onset?
- How does the pre-eruption corona determine the SEP-effectiveness of a CME?
- How close to the Sun and under what conditions do shocks form?

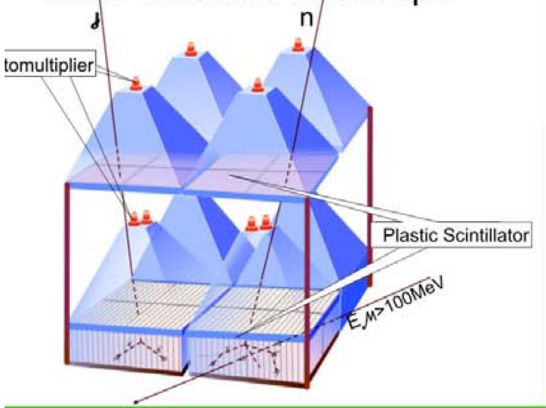
Determine the multiscale plasma and magnetic properties of ICMEs and shocks
- How does the global 3D shape of ICMEs/shocks evolve in the inner heliosphere?
- How does CME structure observed at the Sun map into the properties of interplanetary CMEs?

Determine how the dynamic inner heliosphere shapes the evolution of ICMEs
- How is the solar wind in the inner heliosphere determined by coronal and photospheric structure?
- How do ICMEs interact with the pre-existing heliosphere?
- How do ICMEs interact with each other?

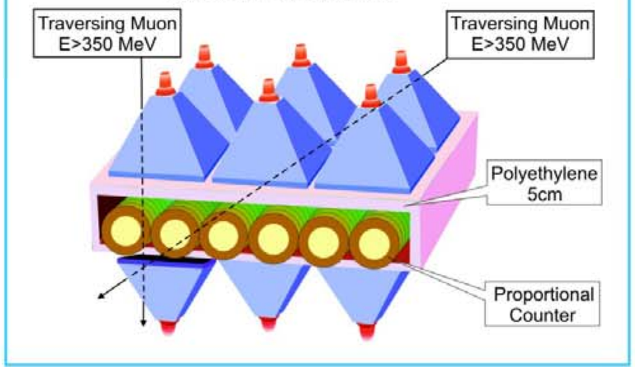




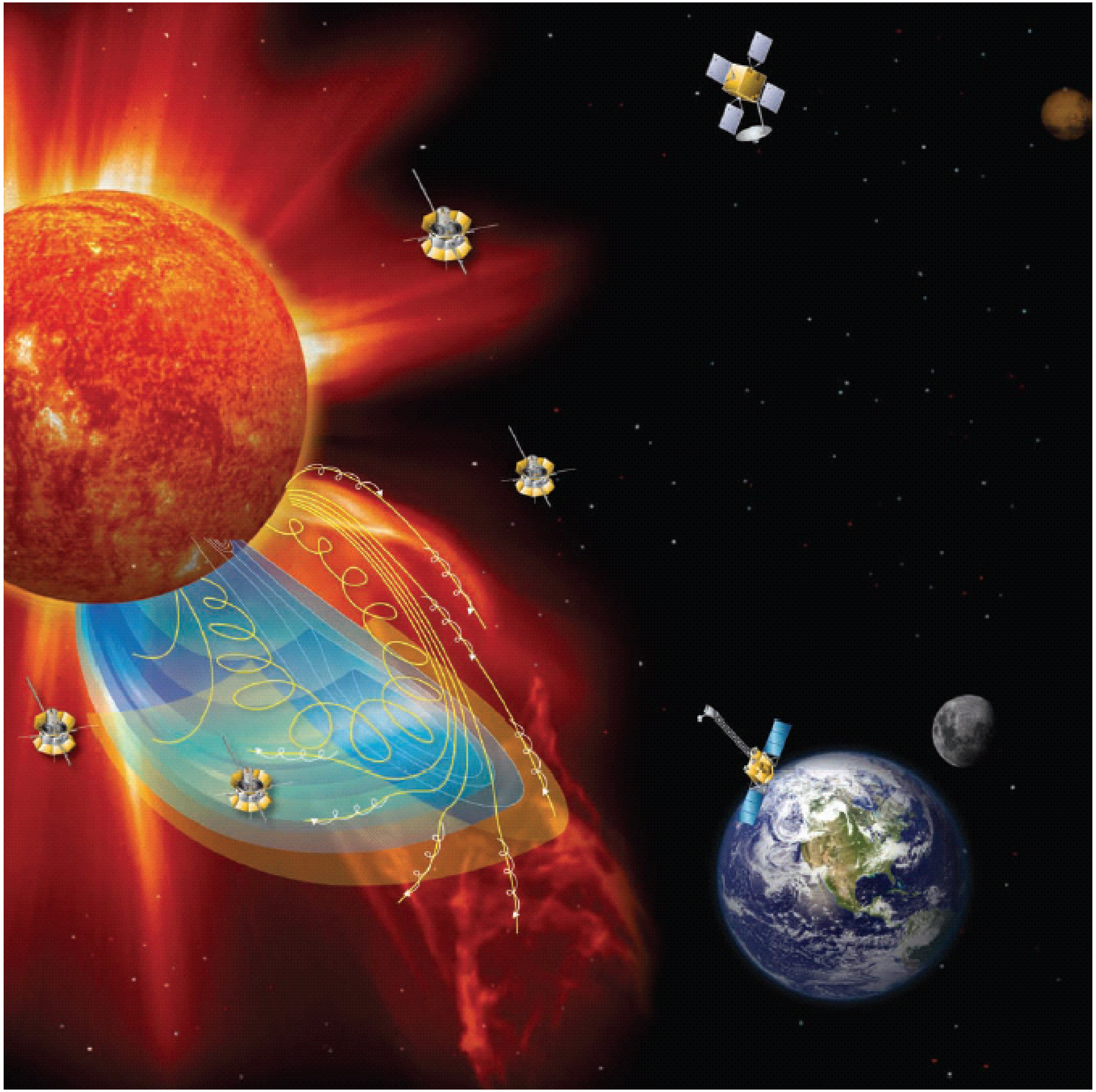
Solar-Neutron Telescope



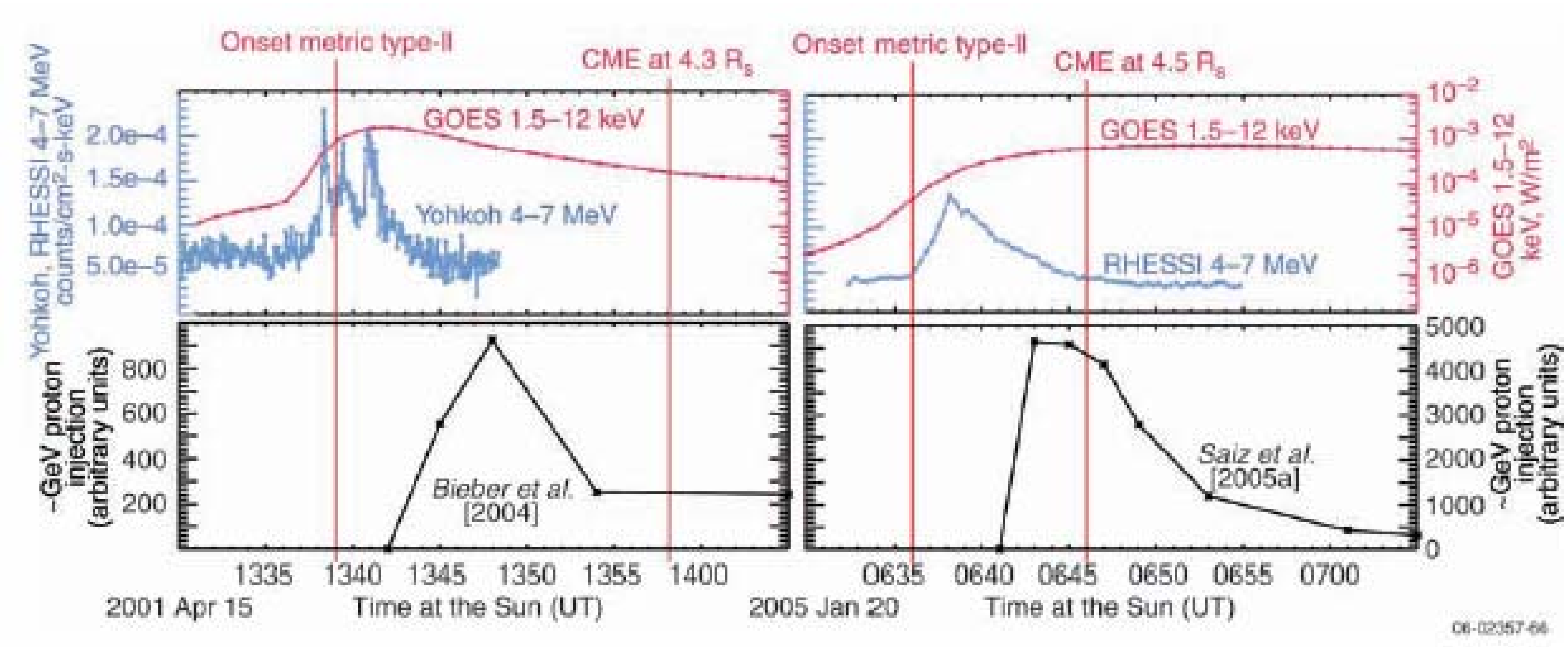
Nor-Amberd Multidirectional Muon Monitor



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 A
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

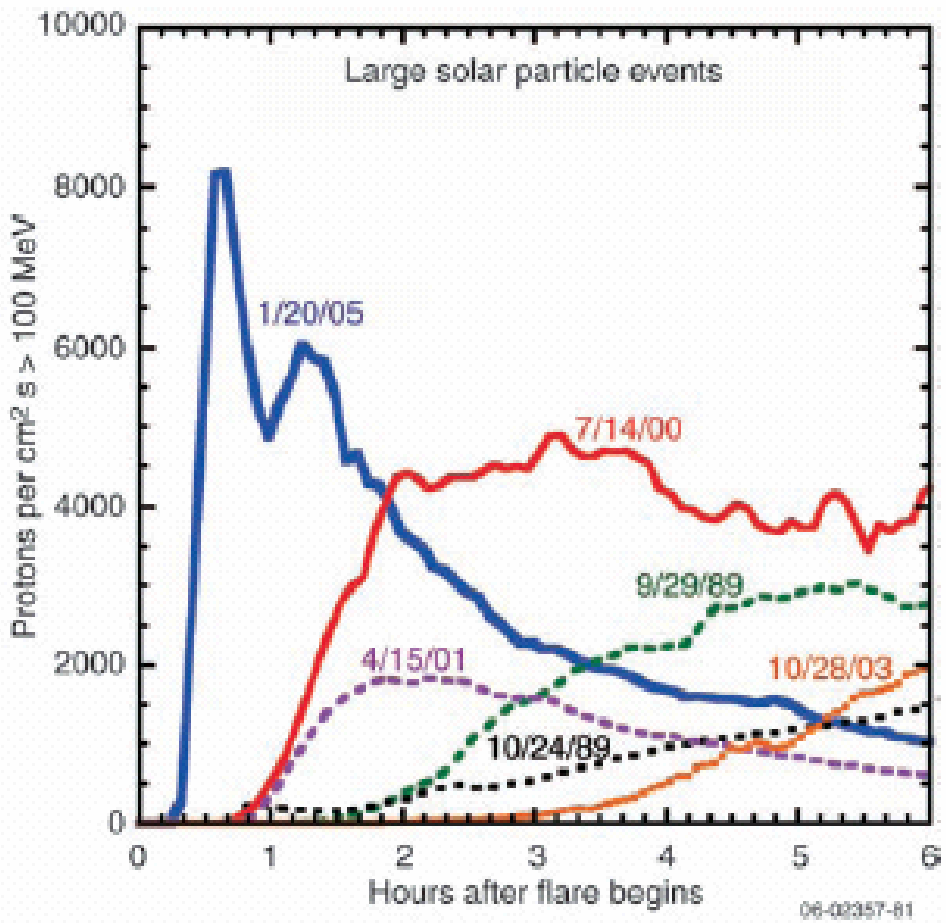


Flare versus Shock SEP acceleration scenarios



Time profiles in the two largest ground level events (GLEs) of solar cycle 23, on 15 April 2001 (left panels) and 20 January 2005 (right panels). The top panels show gamma-rays at 4 to 7 MeV (in blue; left axis) and soft X-rays (in red; right axis). The bottom panels show the injection profile of ~GeV protons at the Sun, as deduced from modeling the response of the Spaceship Earth worldwide neutron-monitor network [*Bieber et al*., 2004; *Saiz et al*., 2005a]. All times are corrected for propagation from the Sun. The vertical lines mark the onset times [*Gopalswamy et al*., 2005a] of metric type II radio emission (indicating the formation of a shock in the low corona) and the first CME observation from SOHO/LASCO.

Rise of the Largest SEP/GLE events



Time profiles of >100 MeV protons
The 20 January 2005 event was the fastest rising event in the last 20 years of GOES data [*Mewaldt et al*., 2005a].

- **Determine physical mechanism of particle acceleration on the Sun;**

Determine the parallel and perpendicular diffusion of the accelerated particles;

- **Determine multiscale plasma properties of ICMEs and Shocks.**

- **Determine how dynamic heliosphere shapes evolution ICMEs.**

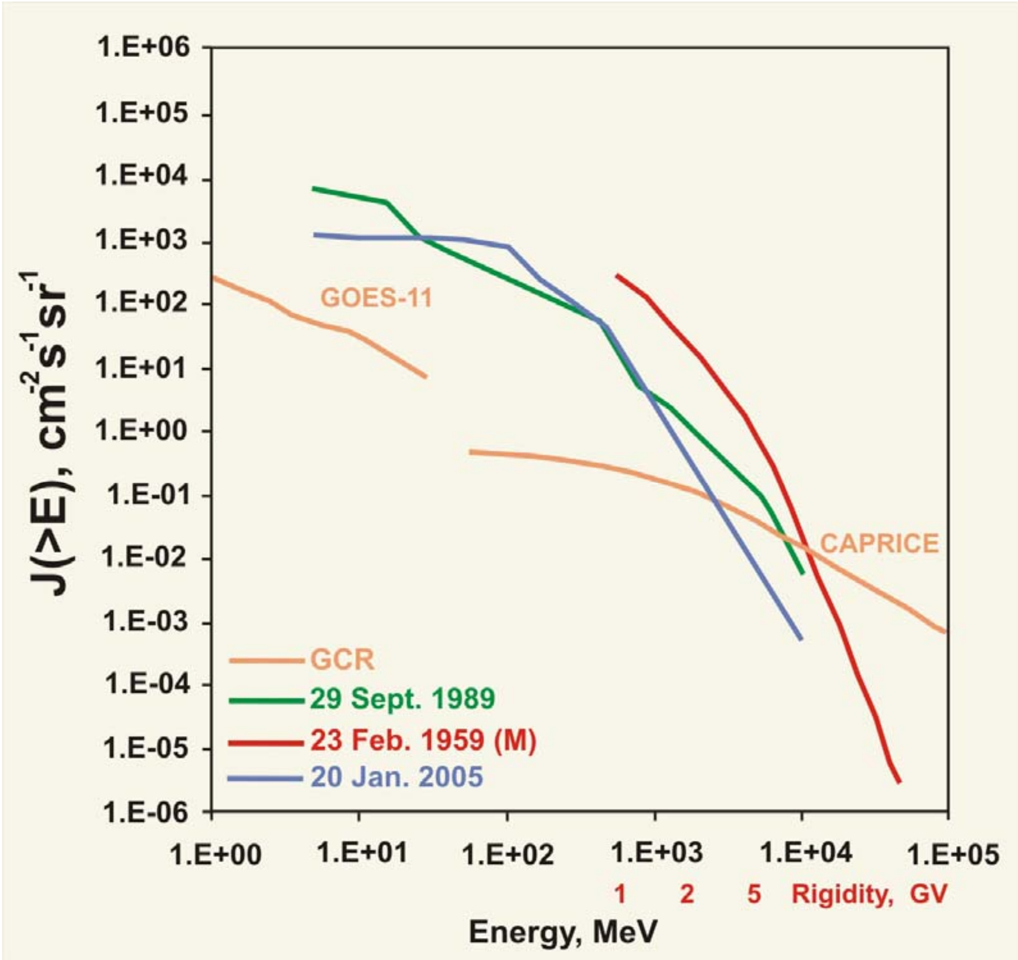
GLE of 23rd cycle detected by the Aragats Neutron Monitor

Date	**Monitors**	**X-Ray Flare**	**Onset**	**First Max**	**σ**	**Second Max**	**σ**	I(E>10Mev) >100/cm^2 * s*ster S3
4/15/2001	ArNM	X14.4	13:55	14:05	4.5	14:30	3.0	14:25
GLE 60	NaNM		13:55	14:05	5.9	14:30	5.9	
4/18/2001	ArNM	C2/2	2:35	3:05	4.5	4:15	5.2	05:15
GLE 61	NaNM		2:35	3:05	3.2	4:15	5.8	
10/28/2003	ArNM	X17	11:25	11:45	6.7	12:10	6.5	12:35
GLE 65	NaNM		11:30	11:35	5.0	12:10	5.2	
1/20/2005	ArNM	X7	6:55	7:10	4.4			6:55
GLE 69	NaNM		6:55	7:00	4.5			

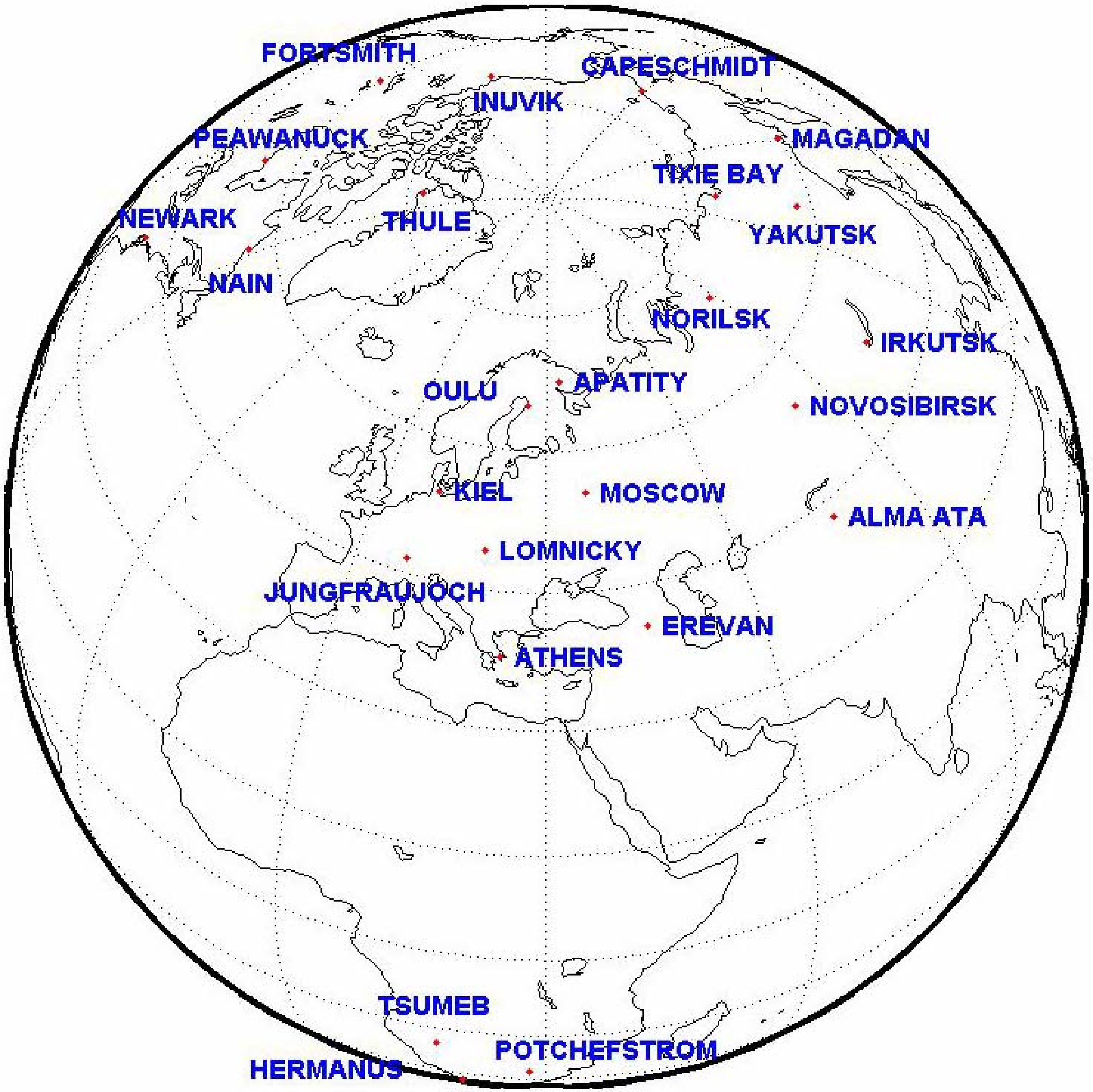
Inverse problems of Solar Physics and Space Weather research

- By secondary particle fluxes reconstruct fluxes incident on terrestrial atmosphere;
- By time history of the particle fluxes in vicinity of Earth reconstruct time profile of the particle injection on Sun;
- By modulating effects of approaching ICME estimate its geoeffectiveness (frozen magnetic field, size…)

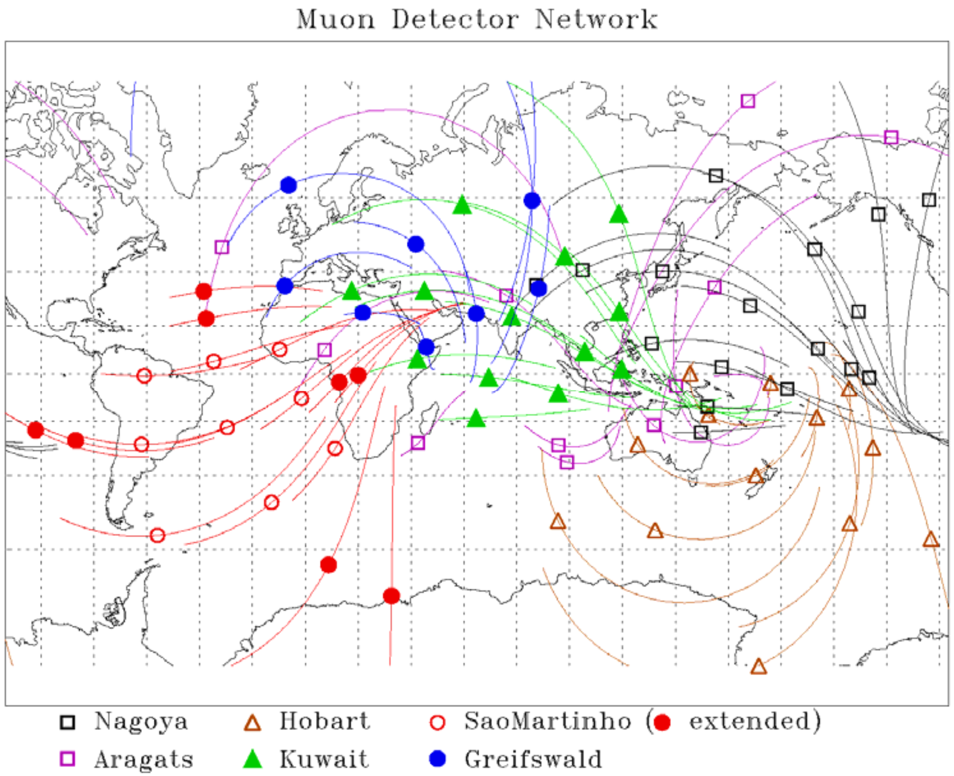
Galactic and Solar Cosmic Rays

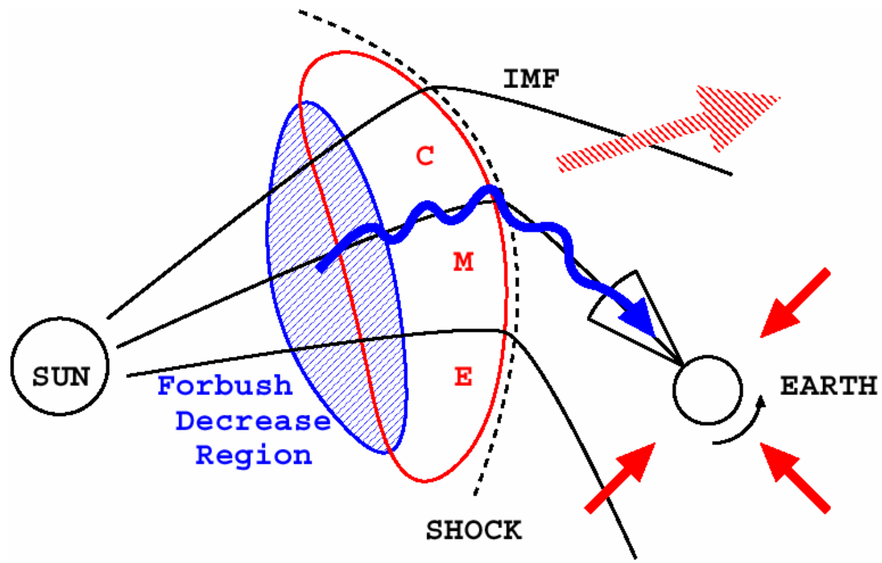


Neutron Monitors World-Wide Network



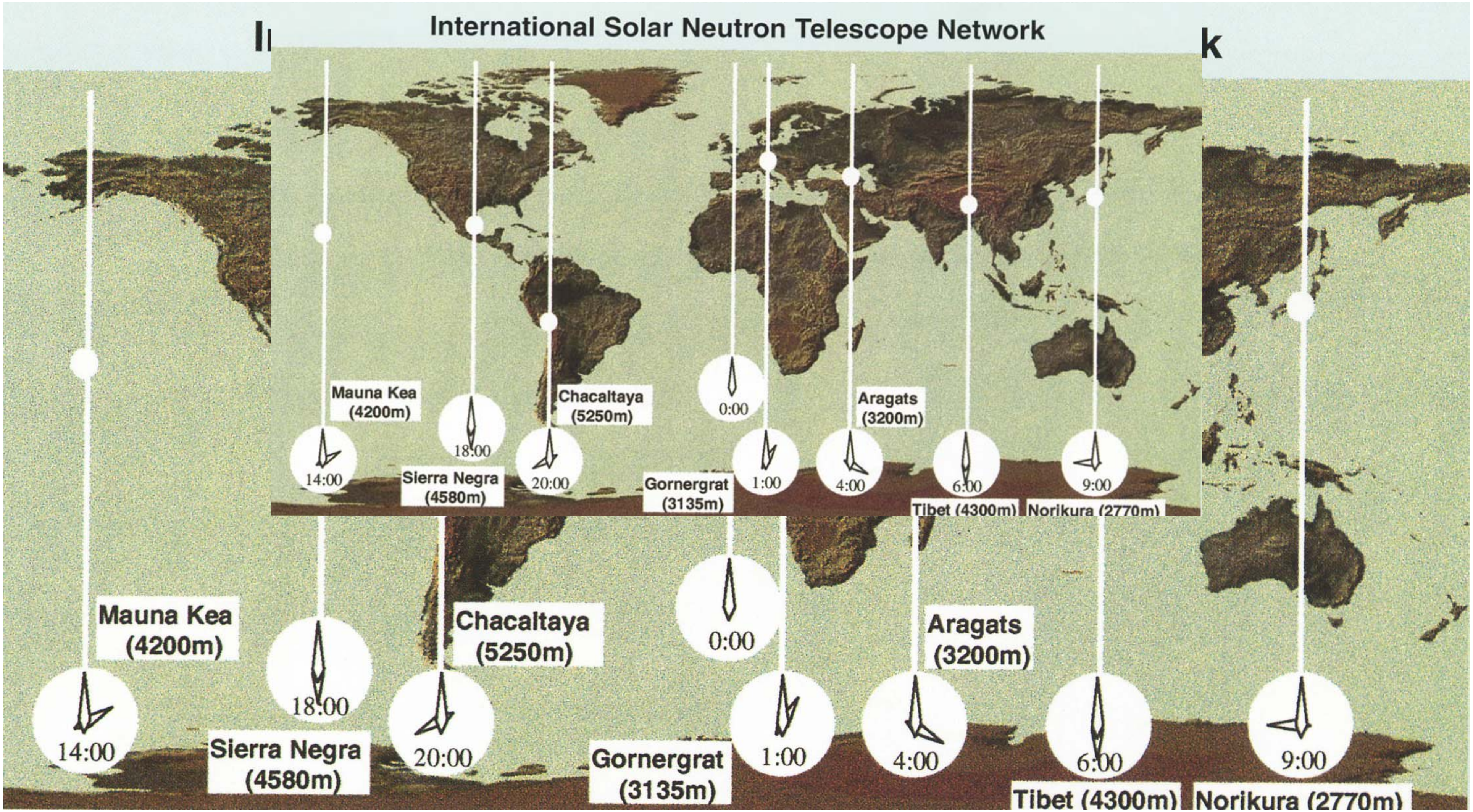
World-wide Networks of Particle Detectors



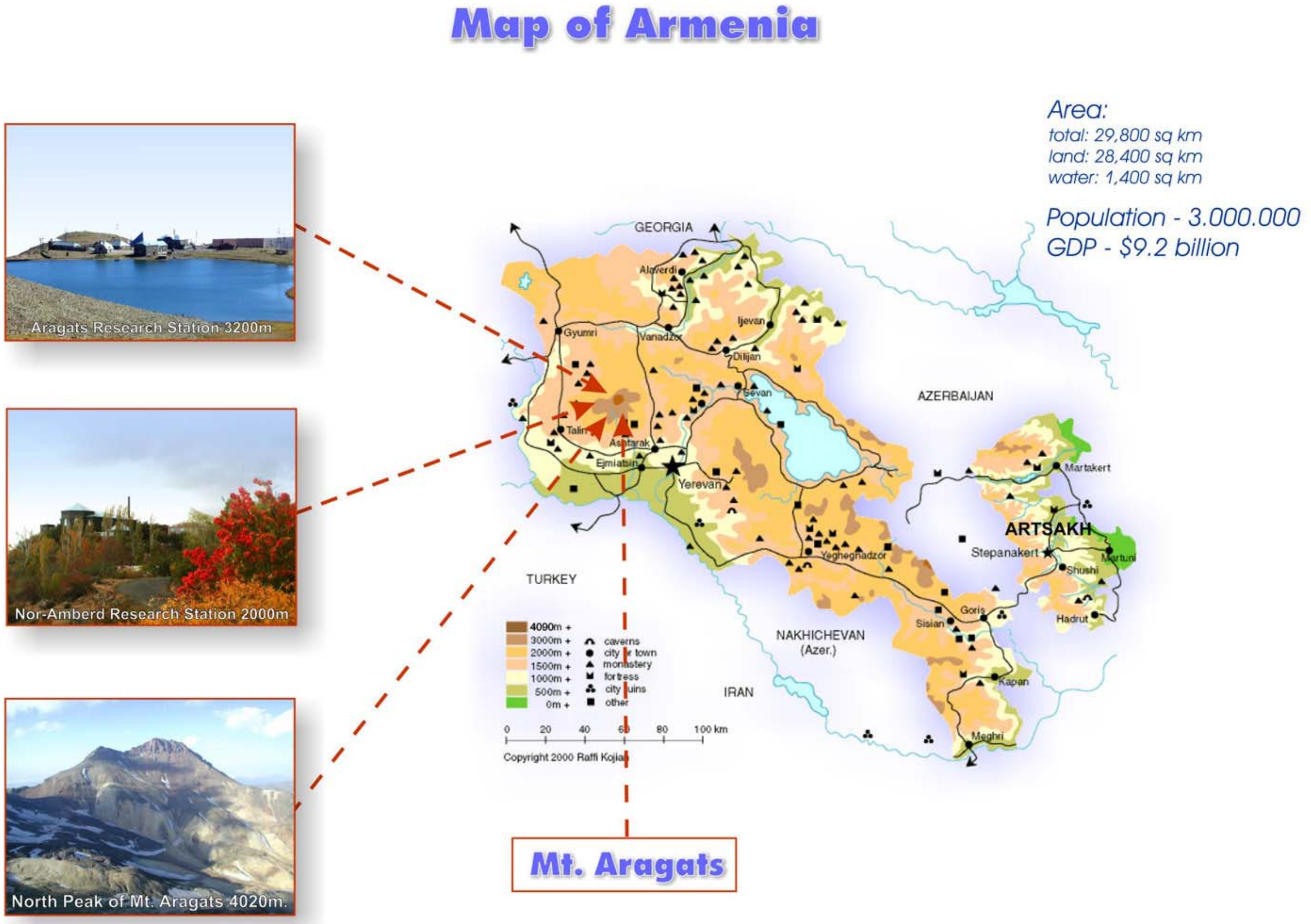


A CME propagating away from the Sun with a shock ahead of it affects the pre-existing population of galactic cosmic rays in a number of ways. Most well known is the Forbush decrease, a region of suppressed cosmic ray density located downstream of a CME shock. Some particles from this region of suppressed 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).

Worldwide network of neutron detectors



Aragats Space-Environmental Center (ASEC), Cosmic Ray Division (CRD), Alikhanyan Physics Institute



Aragats Space-Environmental Center

- Measure as much as possible secondary CR fluxes with different energy thresholds;
- Monitor not only changing count rates, but also correlations between changing CR fluxes;
- Measure particle arrival directions;
- Use same detectors for both SW and high energy CR studies;
- Perform simulation of the time-series registered by the ASEC monitors;
- Correlate surface and space-born detectors data assessable from the Internet;
- Be part of world-wide networks and create new networks;
- Develop methodologies of physical inference from multiple time series;
- Provide forecasting and alerts on severe conditions of the SW.

List of ASEC Particle Detectors

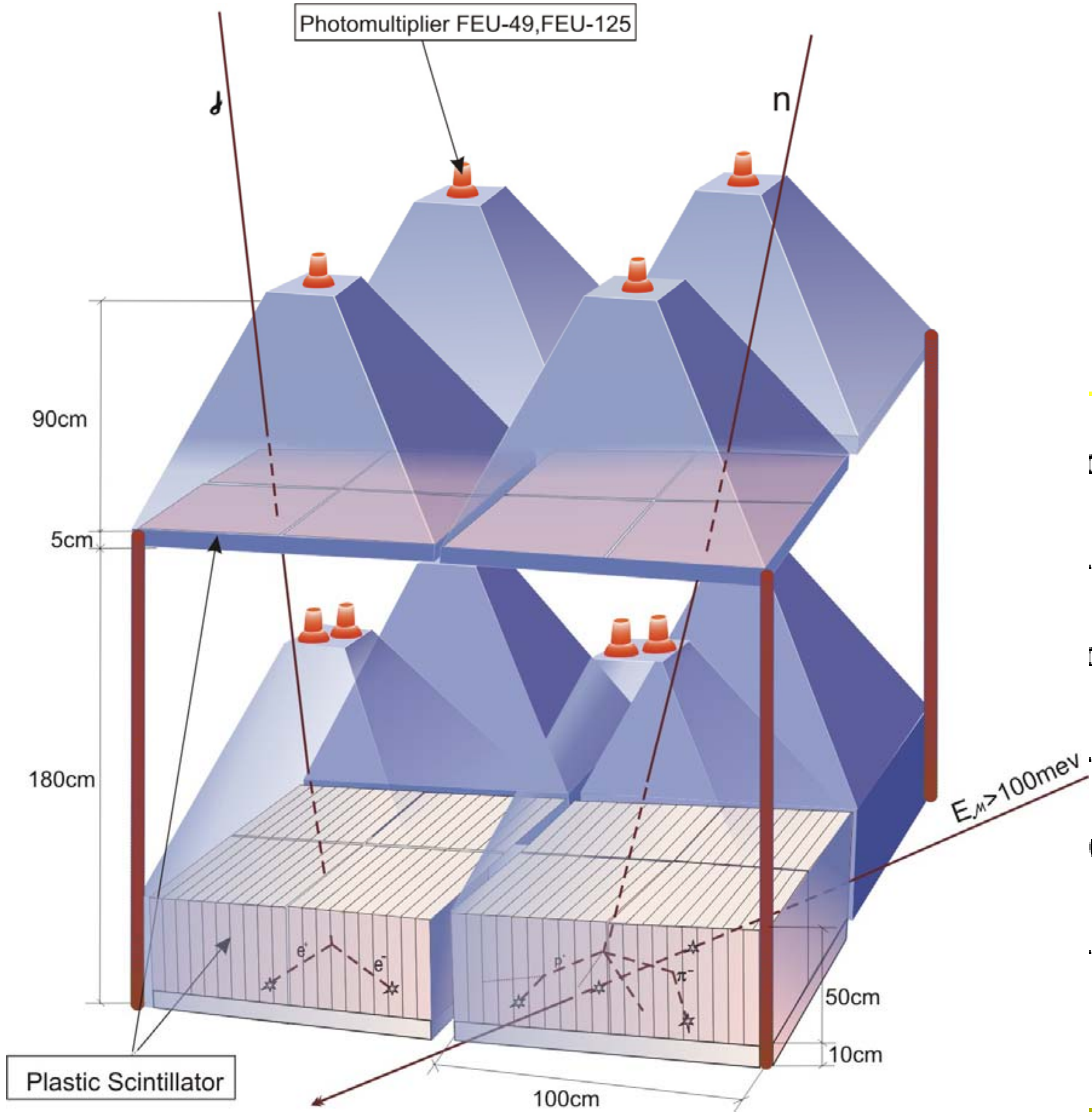
Detector	Altitude m	Surface m^2	Threshold(s) *MeV*	Operation	Count rate (min^{-1})
NANM (18NM64)	2000	18	50	1996	2.7×10^4
ANM (18NM64)	3200	18	50	2000	6.1×10^4
SNT-4channels +	3200	4 (60cm thick)	120, 200, 300, 500	1998	$5.2 \times 10^{4*}$
veto		4 (5cm thick)	7		1.2×10^5
NAMMM	2000	5 + 5	7 ; 350***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

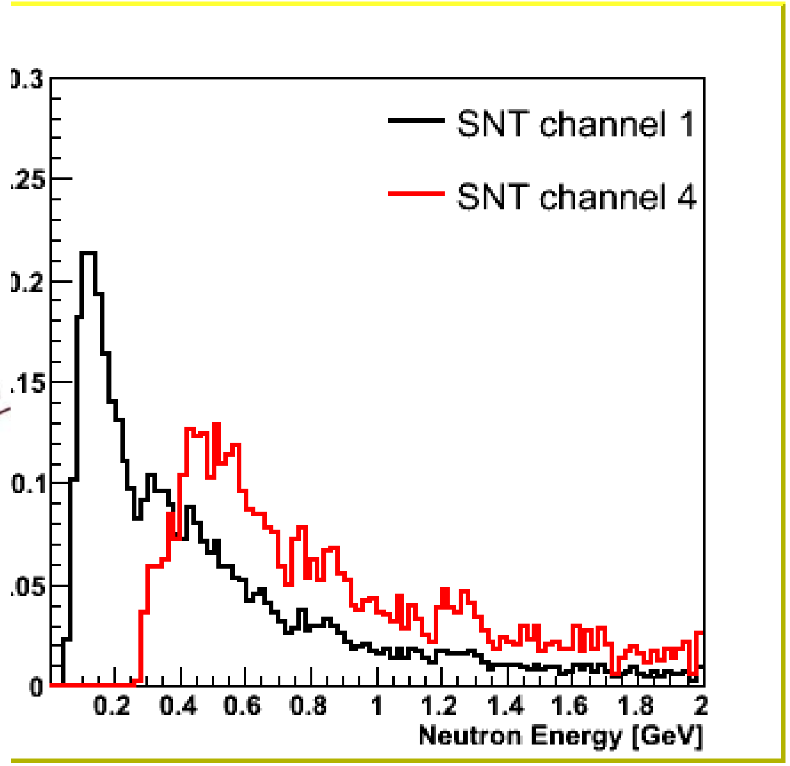
*Count rate for the first threshold; near vertical charged particles are excluded

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

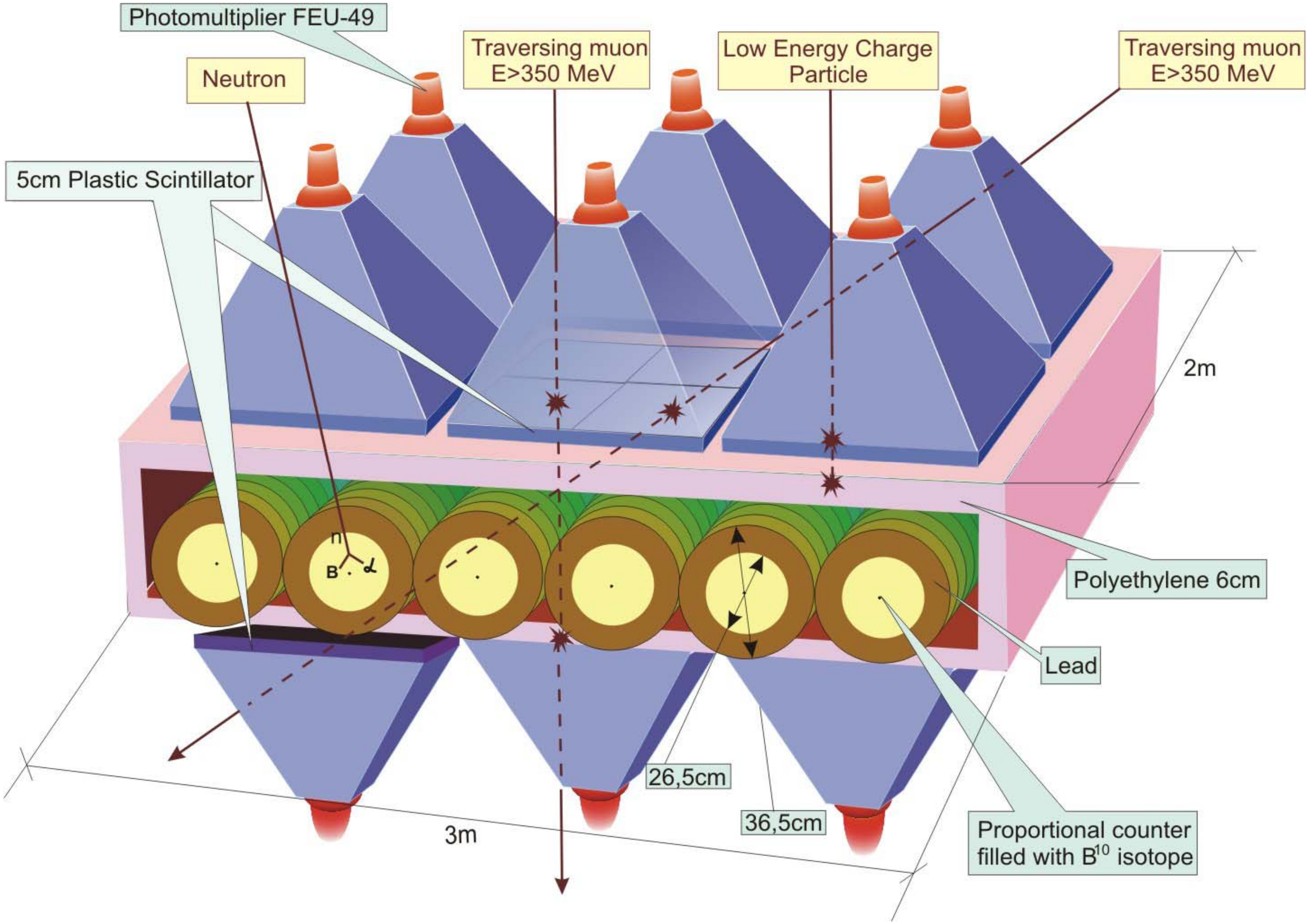
*** First number – energy threshold for the upper detector, second number – bottom detector.

Solar Neutron Telescope

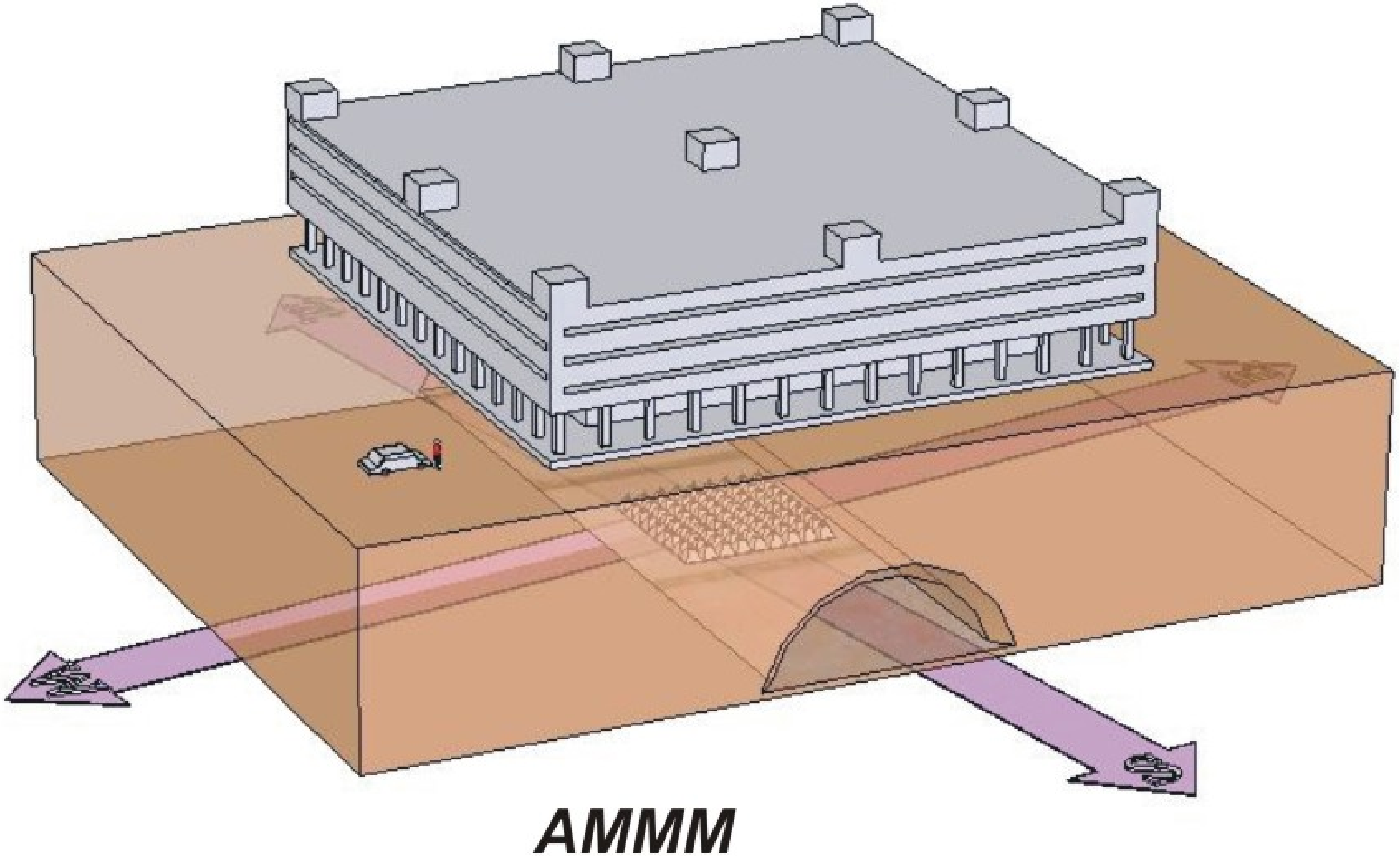




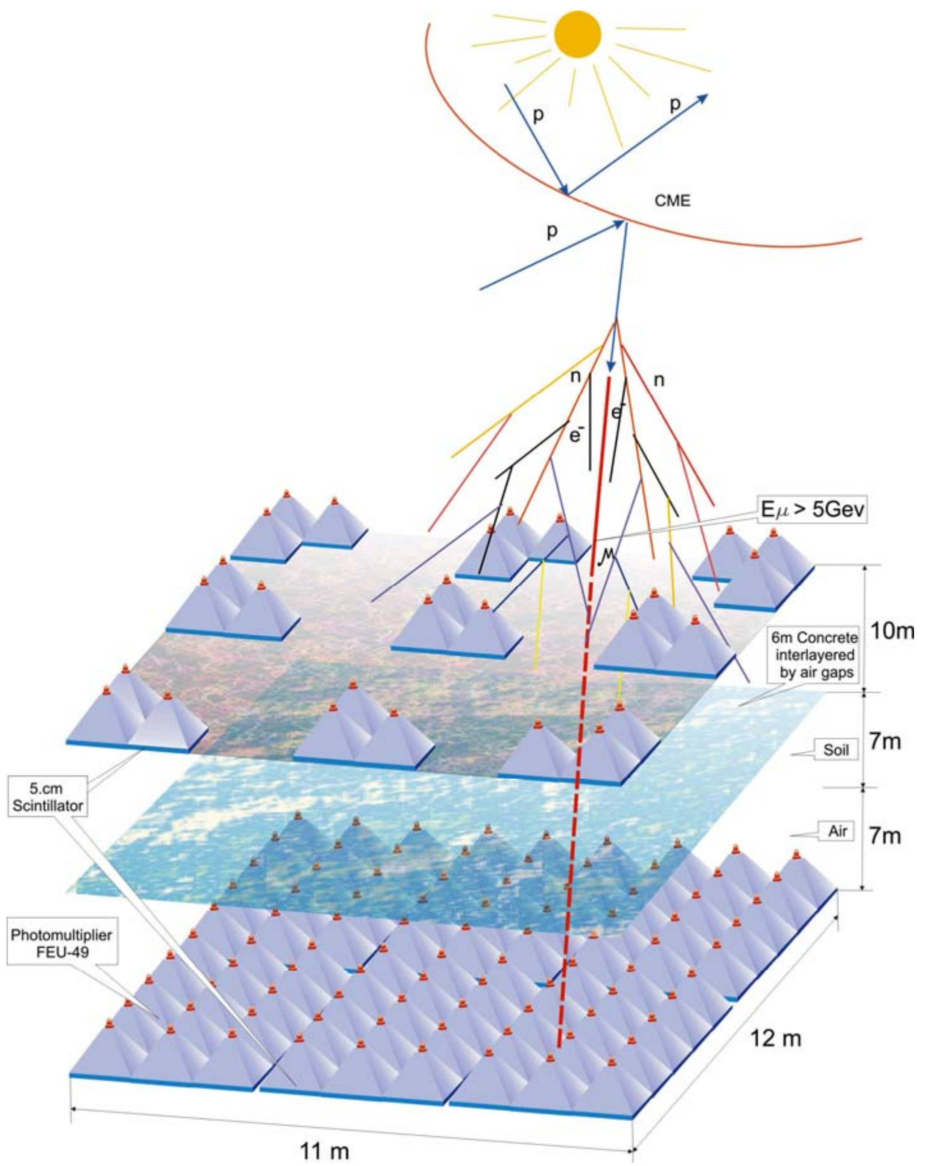
Nor Amberd Multidirectional Muon Monitor

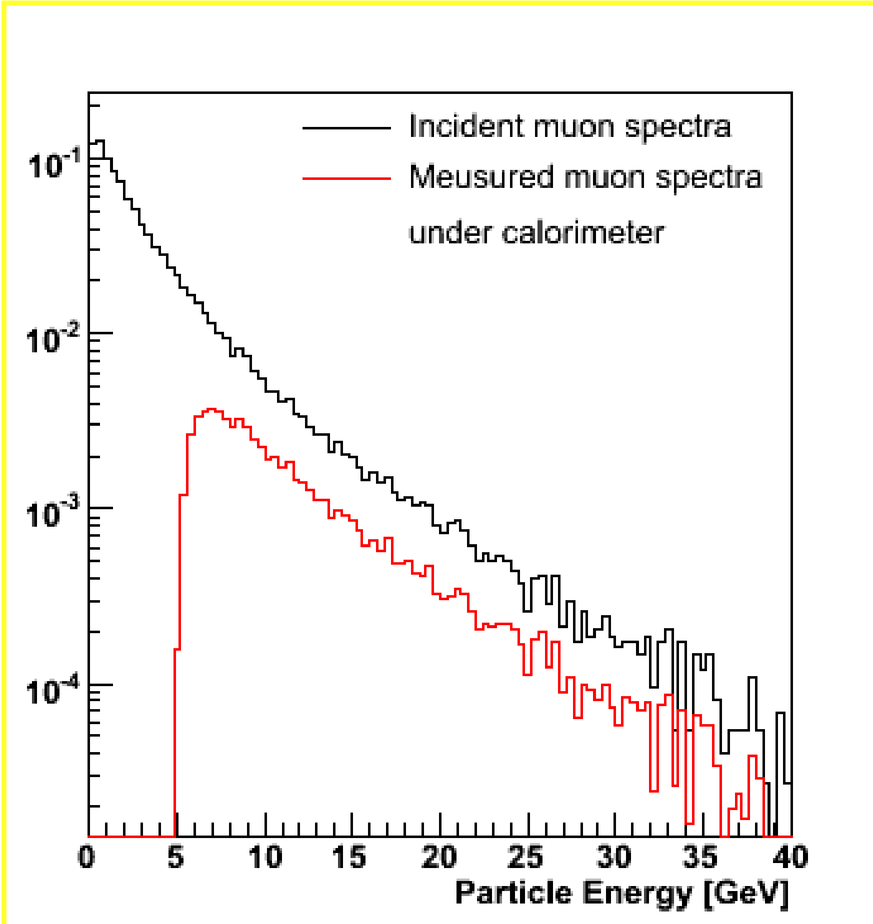


Aragats Multidirectional Muon Monitor (AMMM)

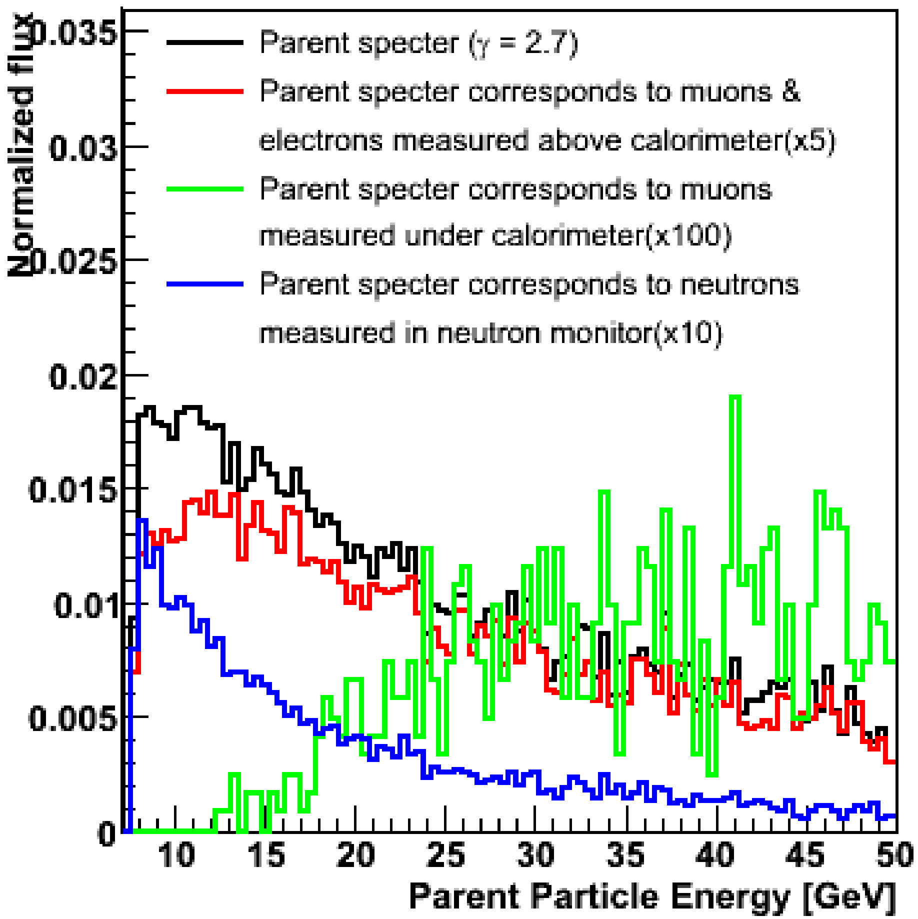


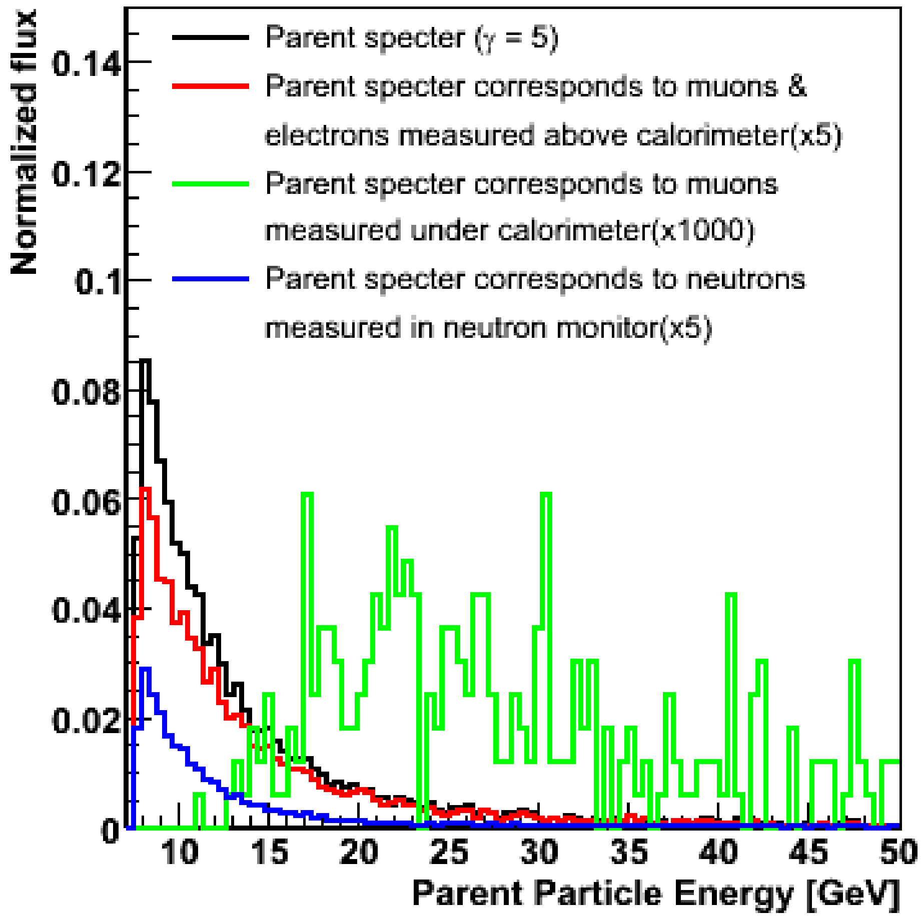
Aragats Multidirectional Muon Monitor (AMMM)





ASEC monitor are “selecting” different energy populations of GCR and SCR

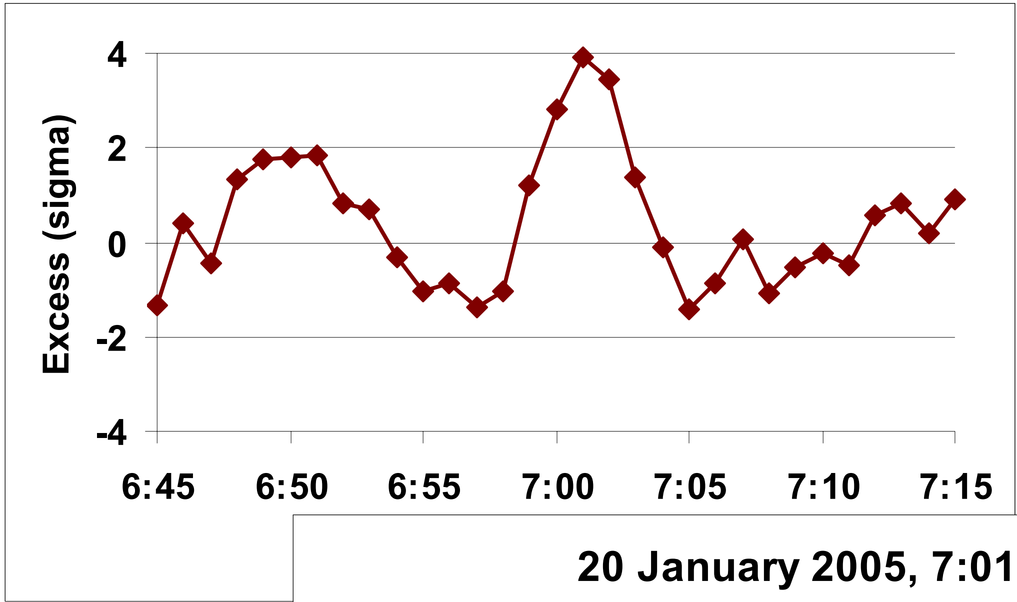


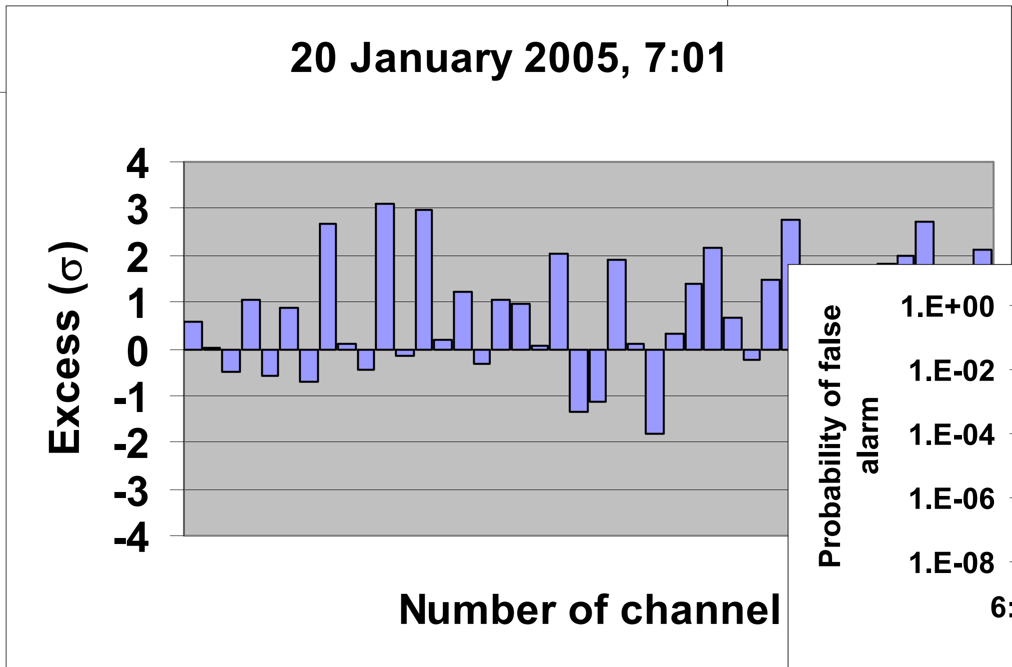


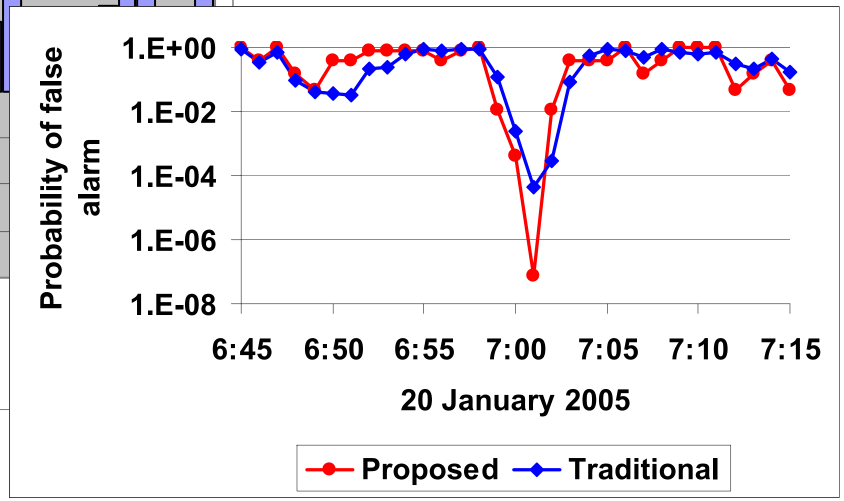
Solar Transient Events influencing count rate of surface particle detectors

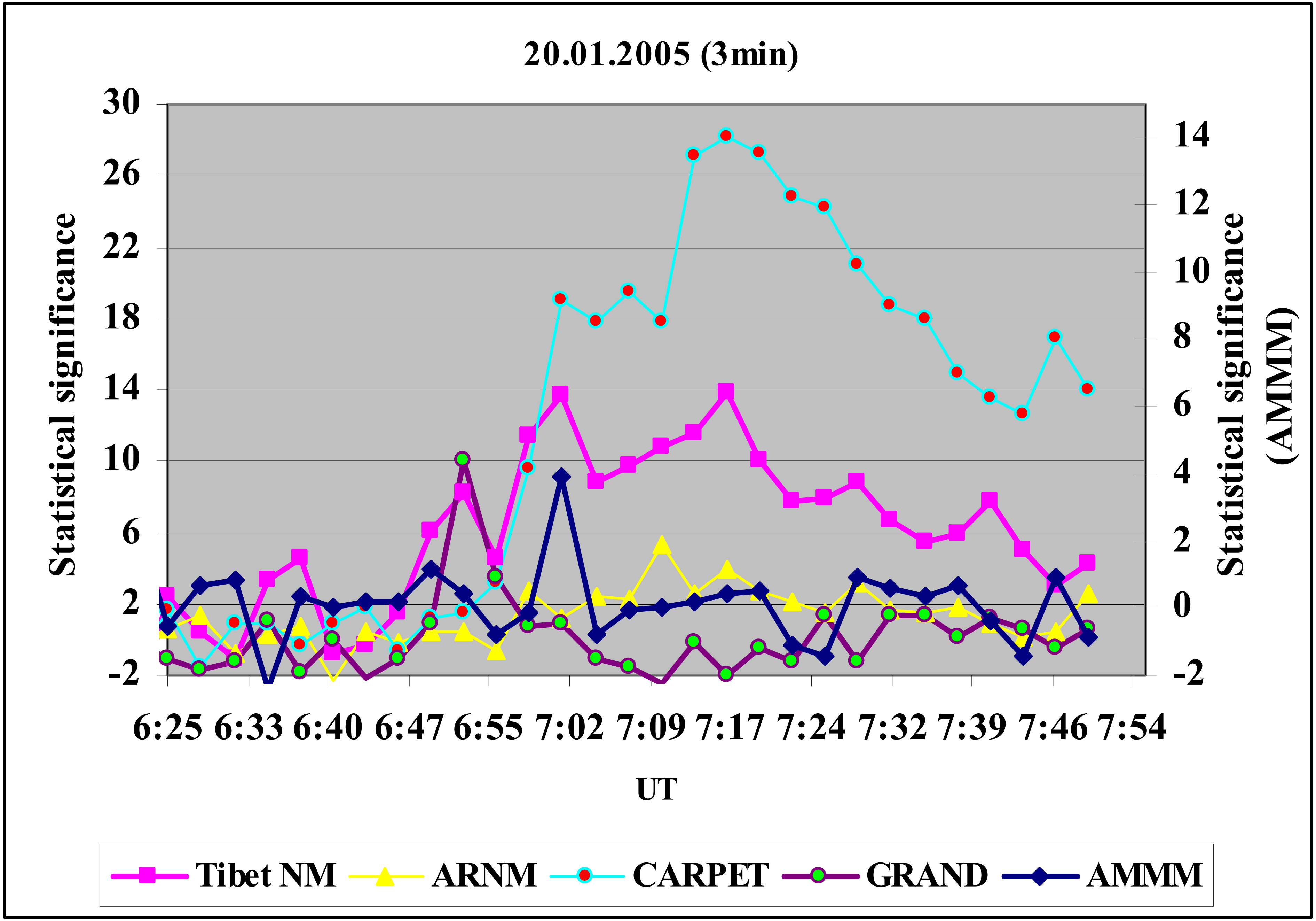
- Ground Level Enhancements GLE, only some of SEP events produce GLEs, and only most energetic ones at middle and low latitudes ~ 10 per cycle
- Fd – abrupt decrease of the monitor count rates better pronounced at high latitudes; ~100 per cycle;
- Cutoff Rigidity decrease, produce relative enhancement of count rate of middle latitude particle detectors, appear on the recovering phase of Fd coincides with strong GMS

January 20, 2005, >5GeV muons



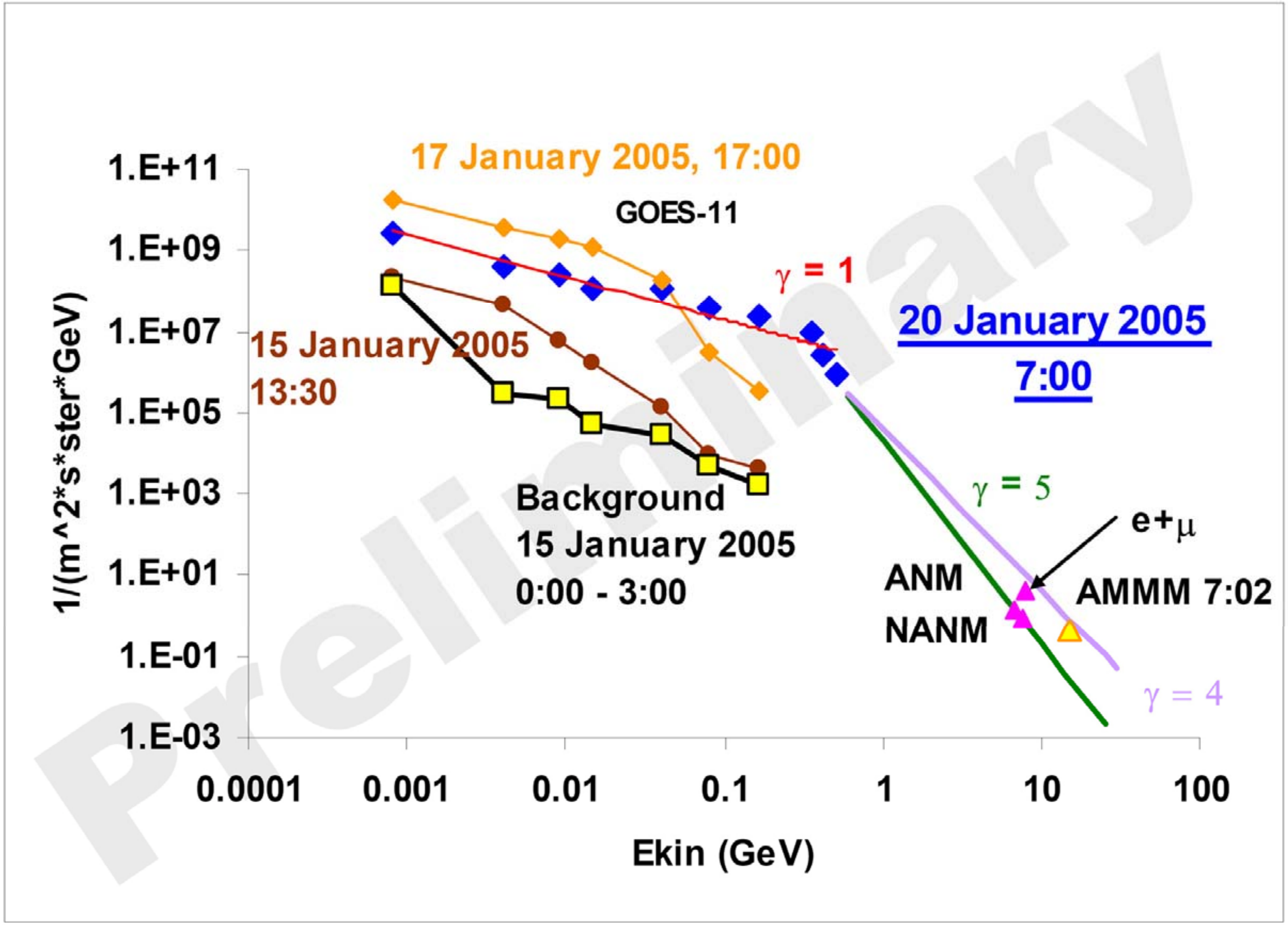




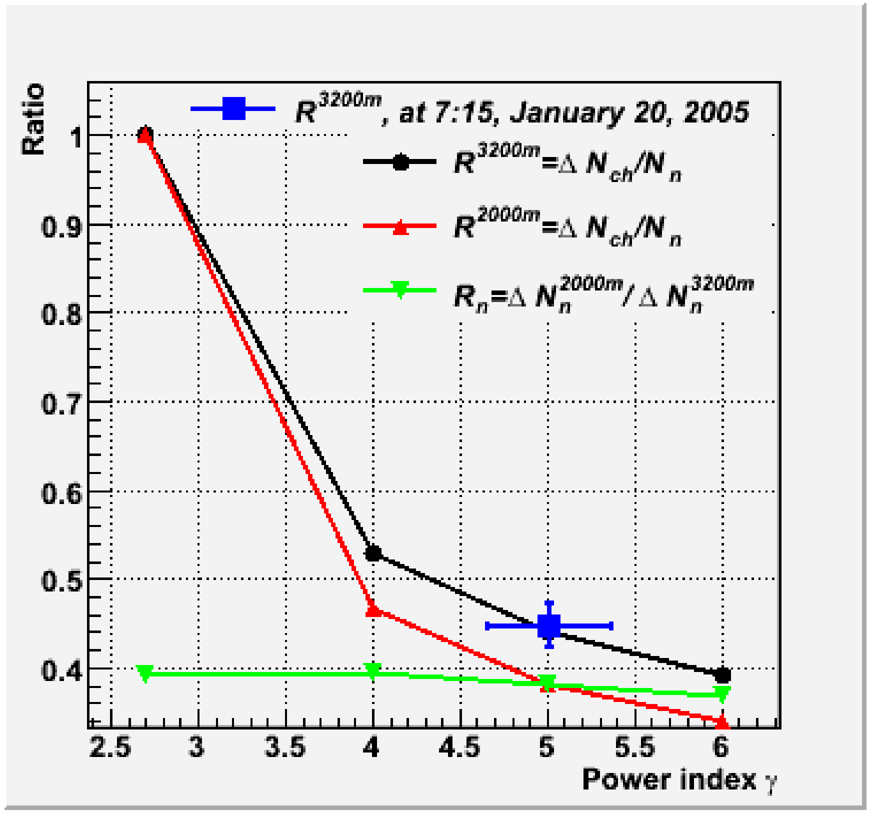


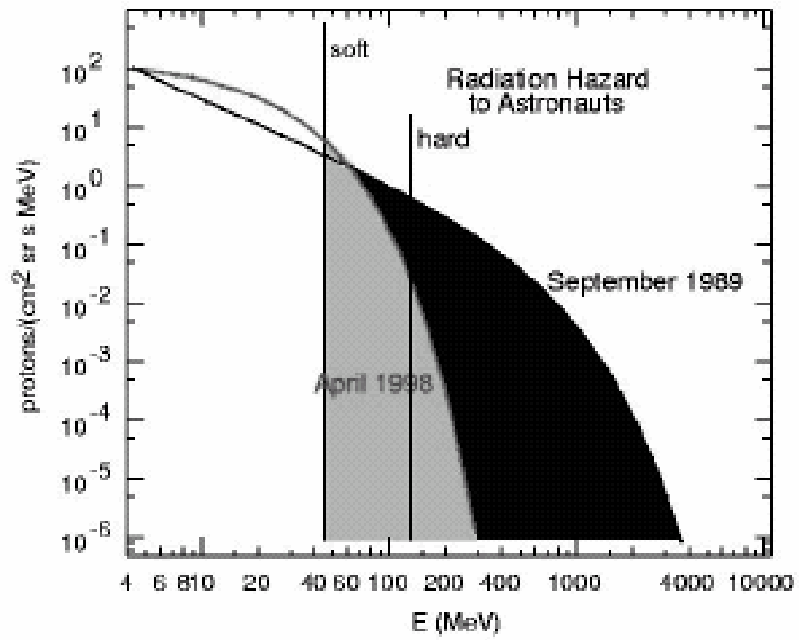
20.01.2005 (3min)
Statistical significance
Statistical significance (AMMM)
UT
30
26
22
18
14
10
6
2
-2
14
12
10
8
6
4
2
0
-2
6:25 6:33 6:40 6:47 6:55 7:02 7:09 7:17 7:24 7:32 7:39 7:46 7:54
Tibet NM
ARNM
CARPET
GRAND
AMMM

Highest Energies of 20 January GLE

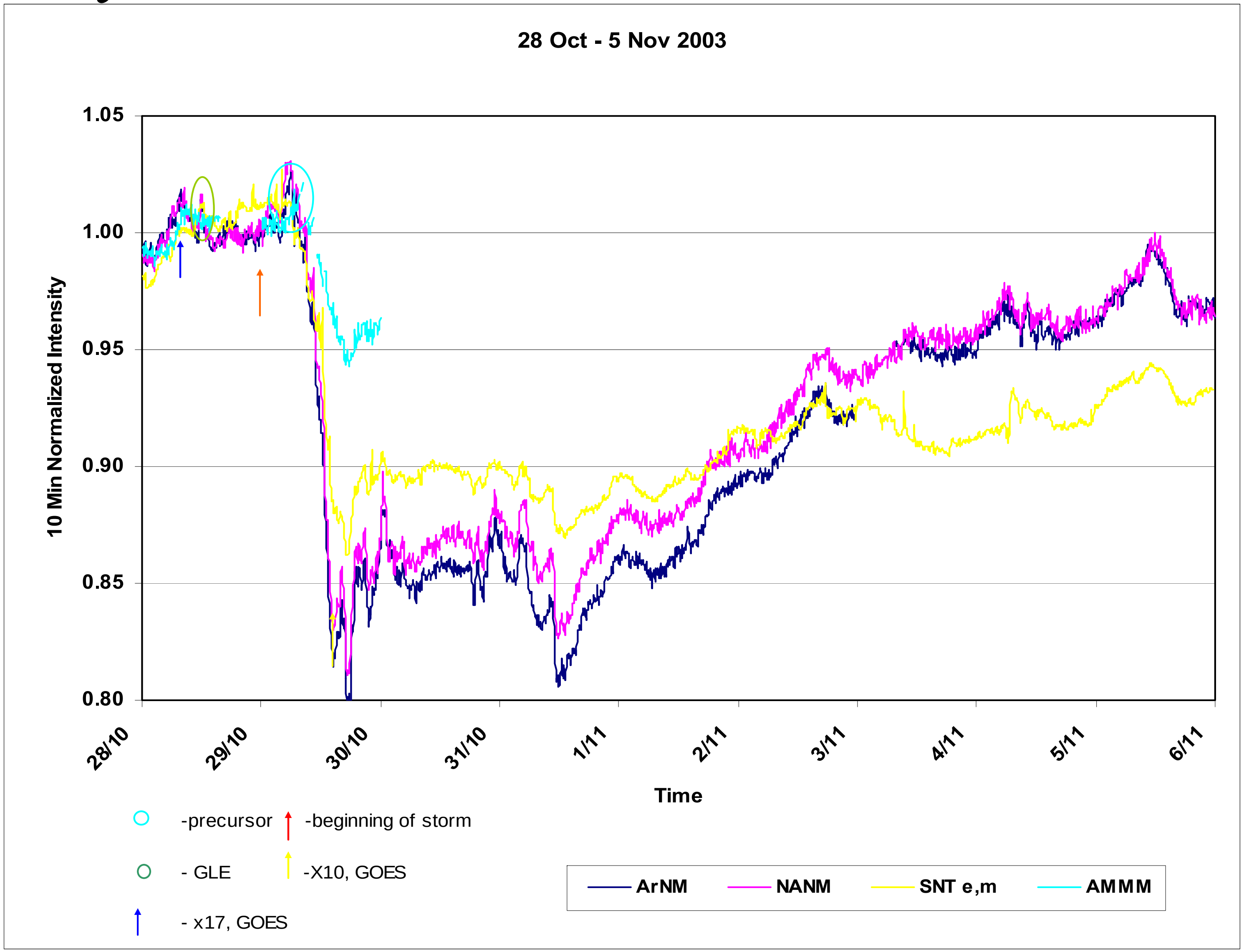


Estimation of the Energy Spectra Power Index





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



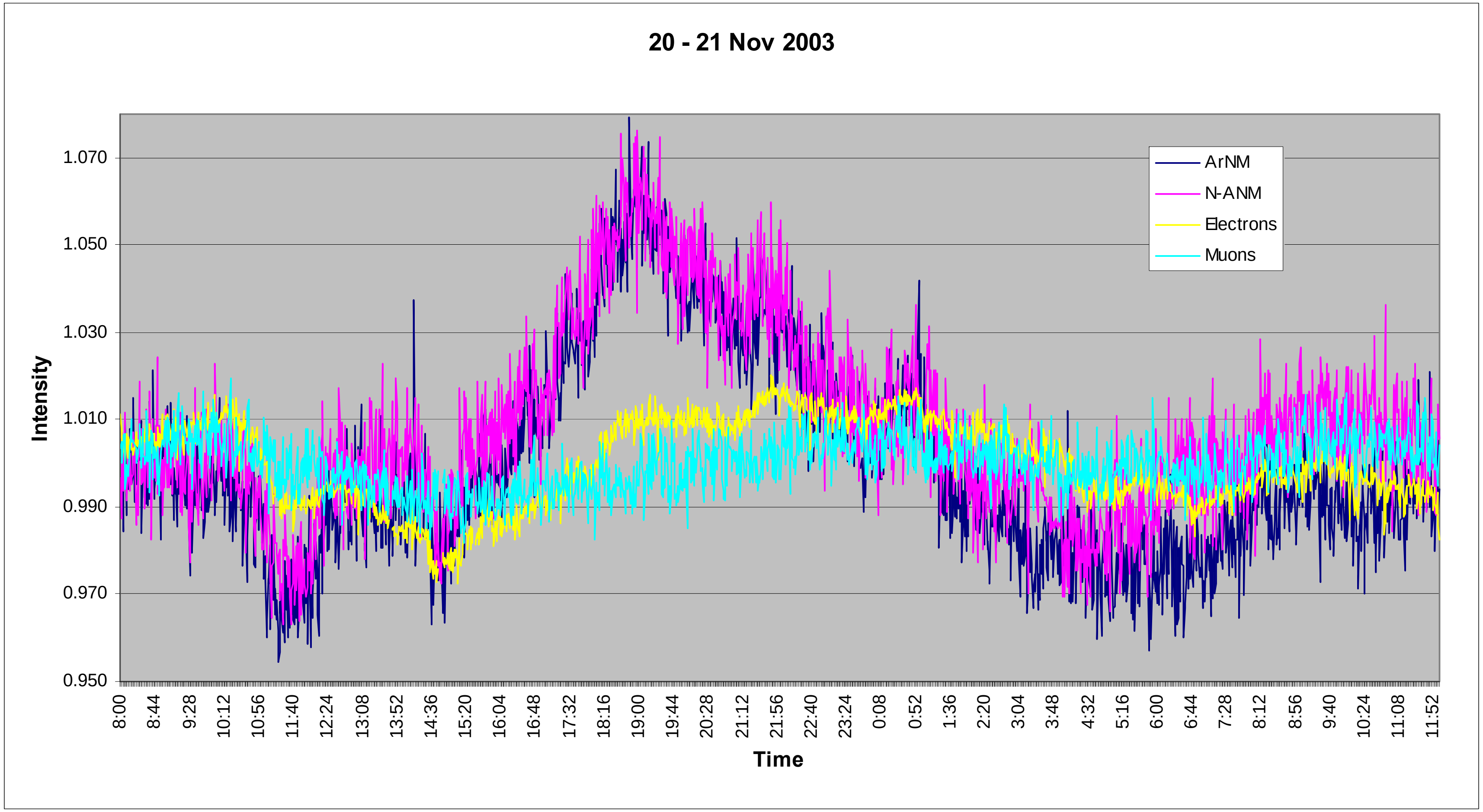
Correlation Matrix of ASEC monitors for 29 October 2003 (6:09 – 14:39), Fd

	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**

ASEC Monitors Correlation Matrix 25 Jan 2003, (quiet time)

	ArNM	NANM	AMMM	SNTe,μ	SNT thr1	SNT thr2	SNT thr3	SNT thr4
ArNM	1							
NaNM	0,01	**1**						
AMMM	0,03	0,02	**1**					
SNTe,μ	0,02	-0,01	0,12	**1**				
SNT thr1	0,05	0,03	0,08	0,06	**1**			
SNT thr2	0,04	-0,04	-0,04	-0,05	0,43	**1**		
SNT thr3	0,03	0,03	0,00	-0,01	0,31	0,42	**1**	
SNT thr4	0,01	-0,02	-0,04	0,03	0,15	0,33	0,46	**1**

Geomagnetic Disturbance of 20 November

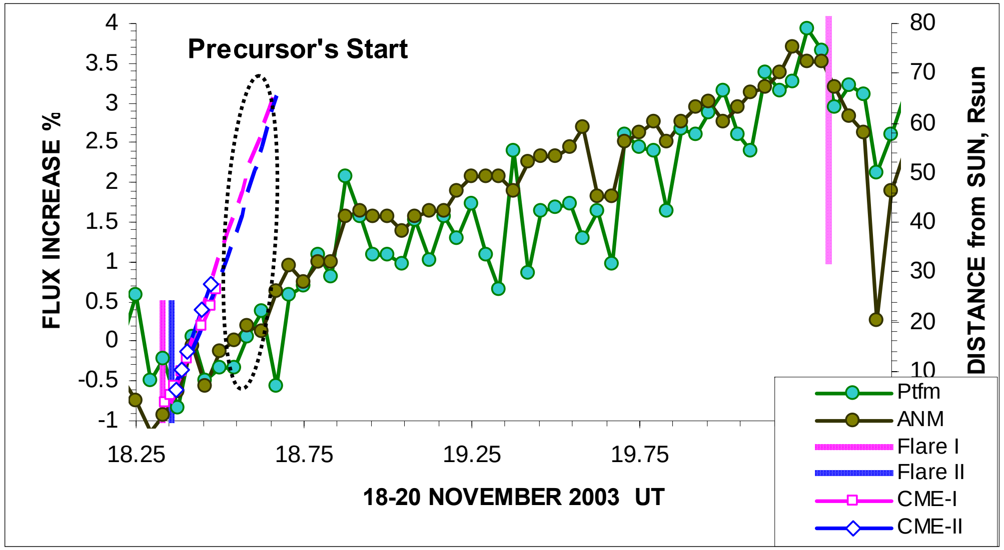


Correlation Matrix of ASEC monitors for 20-21 November 2003 г. (14:40 – 6:00), Geomagnetic Storm

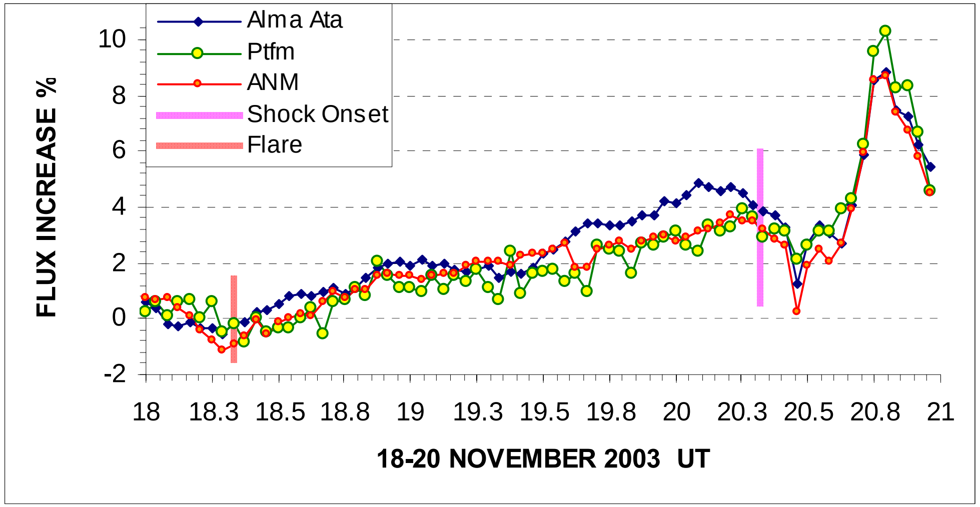
	ArNM	**NANM**	**AMMM**	**SNT**e,μ	**SNT** thr1	**SNT** thr2	**SNT** thr3	**SNT** thr4
ArNM	1	0.89	-0.01	0.47	0.81	0.85	0.67	0.38
NANM	0.89	1	-0.04	0.44	0.79	0.83	0.65	0.35
AMMM	-0.01	-0.04	1	0.53	0.14	-0.04	0.13	0.13
SNTe,μ	0.47	0.44	0.53	1	0.62	0.36	0.50	0.36
SNT thr1	0.81	0.79	0.14	0.62	1	0.87	0.72	0.43
SNT thr2	0.85	0.83	-0.04	0.36	0.87	1	0.81	0.48
SNT thr3	0.67	0.65	0.13	0.50	0.72	0.81	1	0.68
SNT thr4	0.38	0.35	0.13	0.36	0.43	0.48	0.68	1

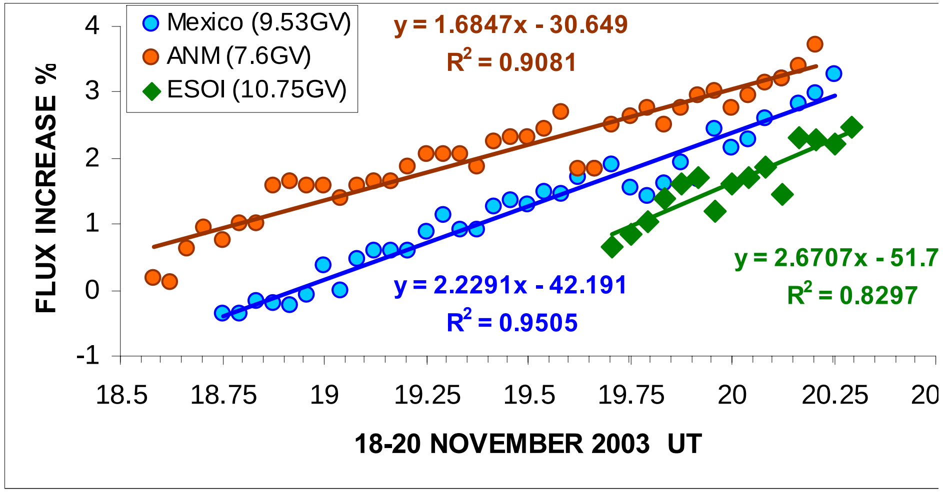
CME responsible for Greatest GMS 20 November 2003

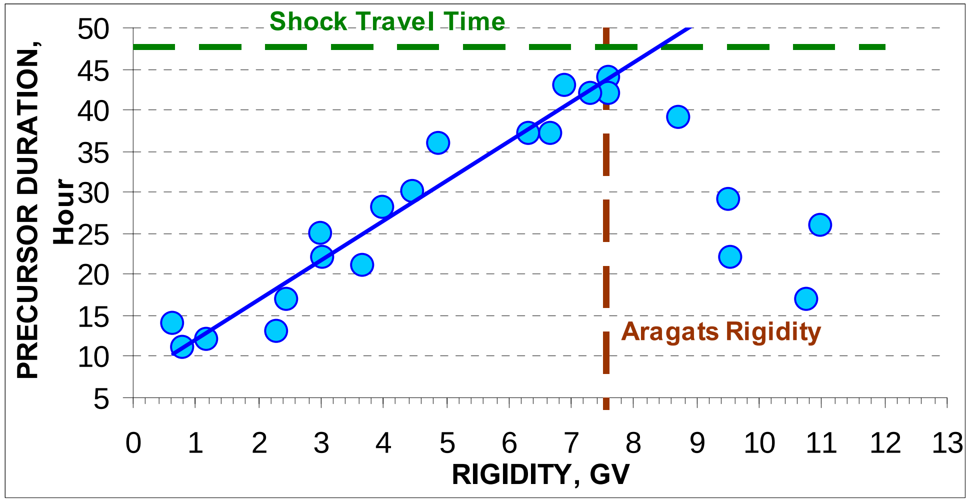
Date	Time UT	Heliocoorditas	Angular depth (^{0})	CME velocity км/sec	Kinetic Energy эрг
18-11-2003	**8:06**	**N01E19**	**>104**	**1223**	**$1{,}3.10^{32}$**
18-11-2003	**8:50**	**N02E18**	**360**	**1660**	**$3{,}3.10^{32}$**
18-11-2003	9:50	S13E89	>197	1824	$3{,}6.10^{32}$



Precursor of GMS by Surface particle detectors





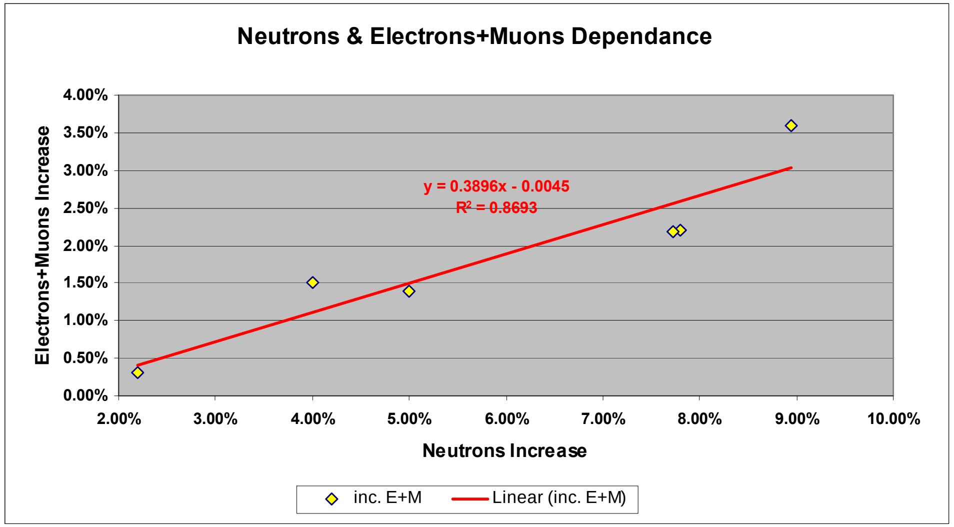


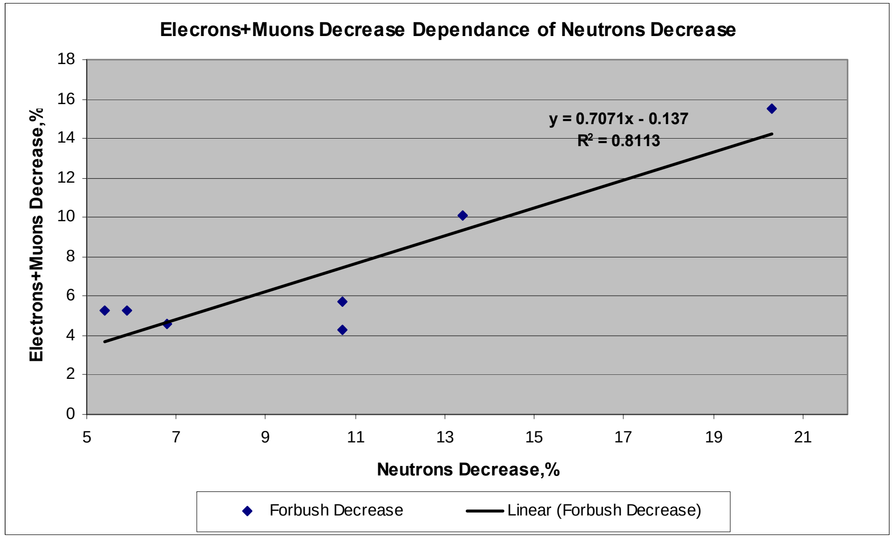
Detection of GMS and Fd by ASEC monitors

Date	K_p, max	DST,min	Neutrons Rel.Increase	Charged Rel.Increase
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%

Date	ArNM	Charged	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

Relative neutral/charge Change





Summary

- Investigations of the highest energy solar cosmic rays are very difficult problem, requiring large surfaces of the particle detectors at middle and low latitudes. For the energy spectra estimation detection of the various neutral and charged secondary particles are necessary.
- Spectra of energy releases in the particle detectors are more informative comparing with simple count rates expressed as time series.
- 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.