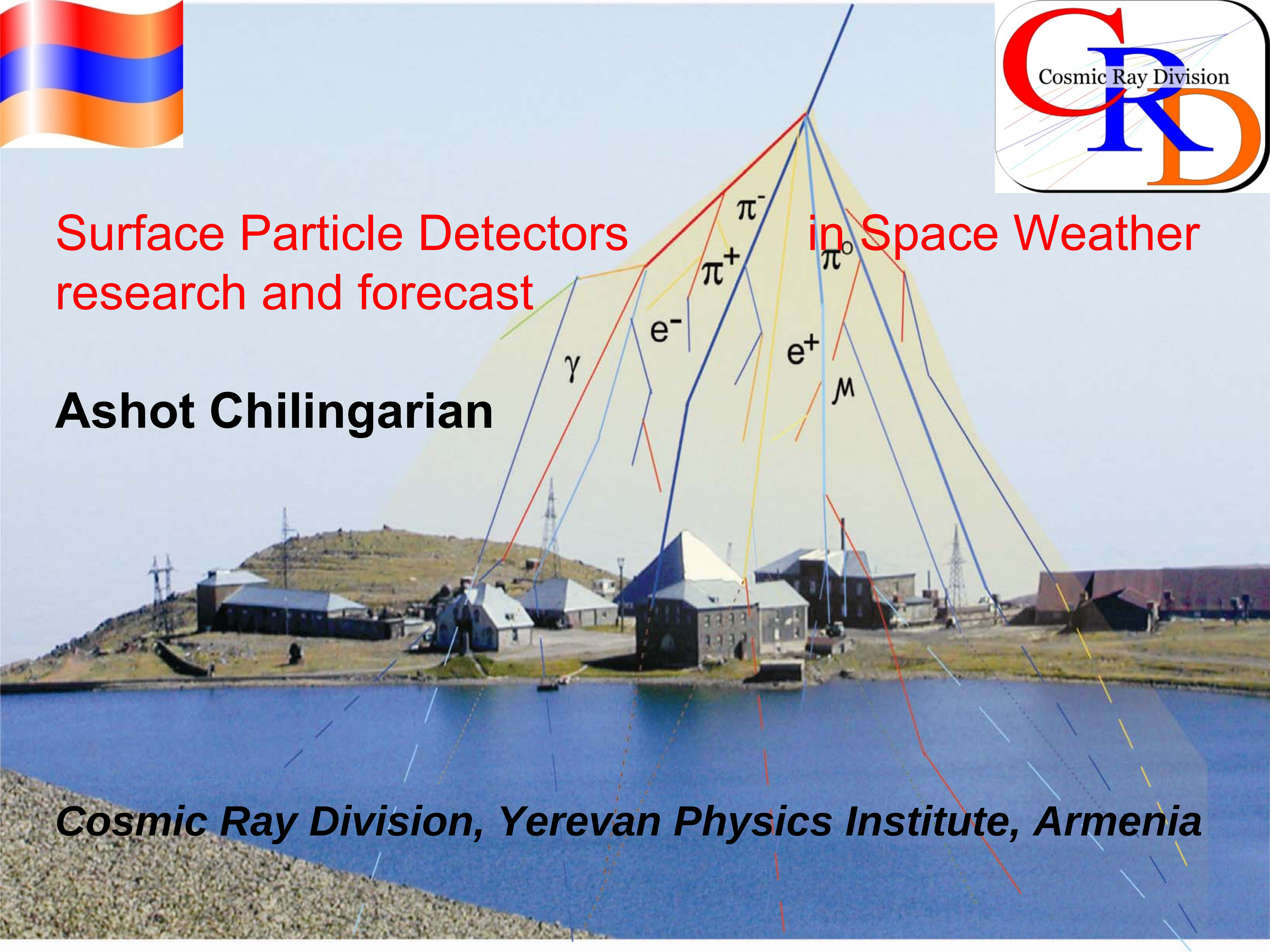
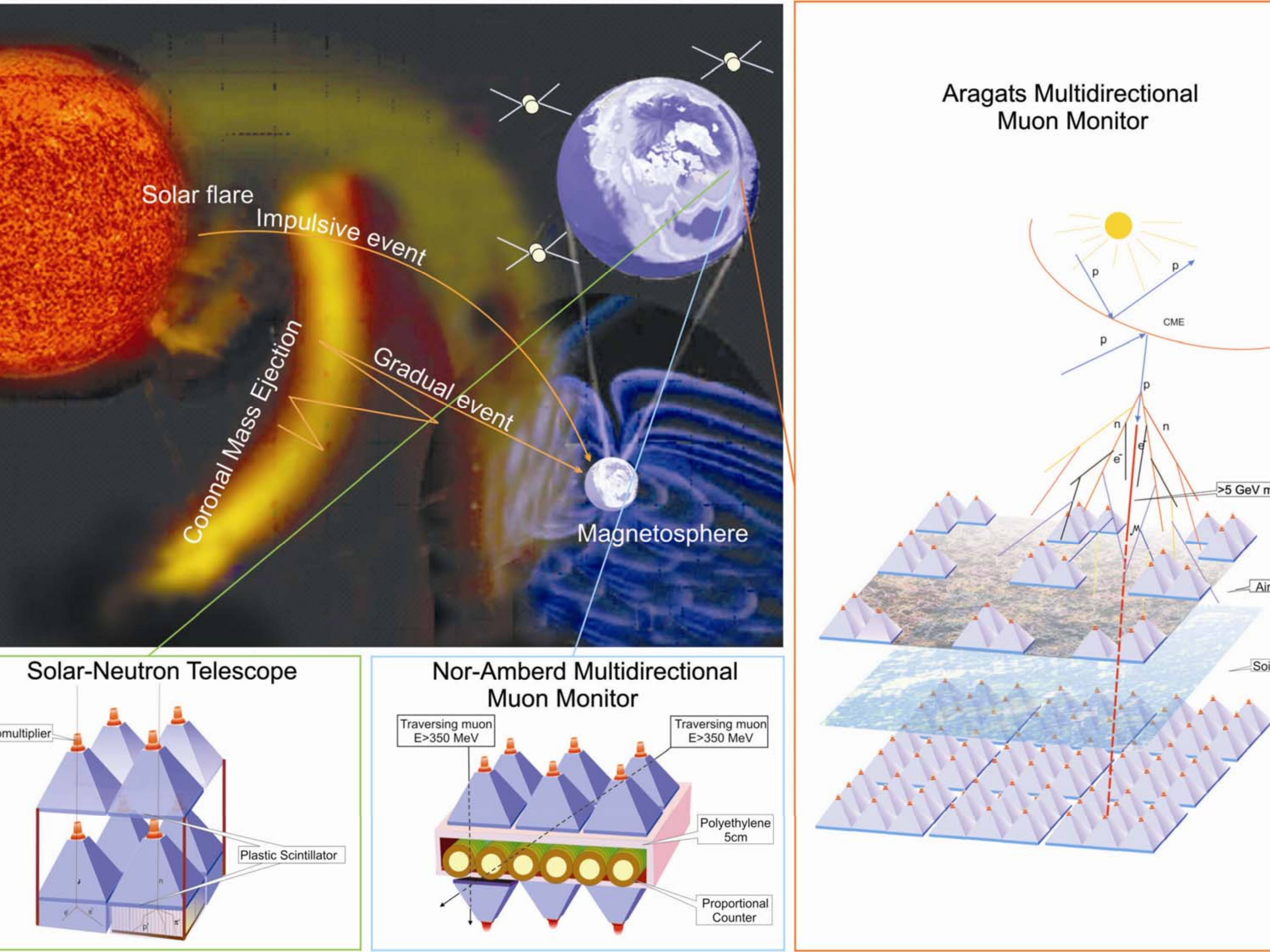
Surface Particle Detectors in Space Weather research and forecast

Ashot Chilingarian

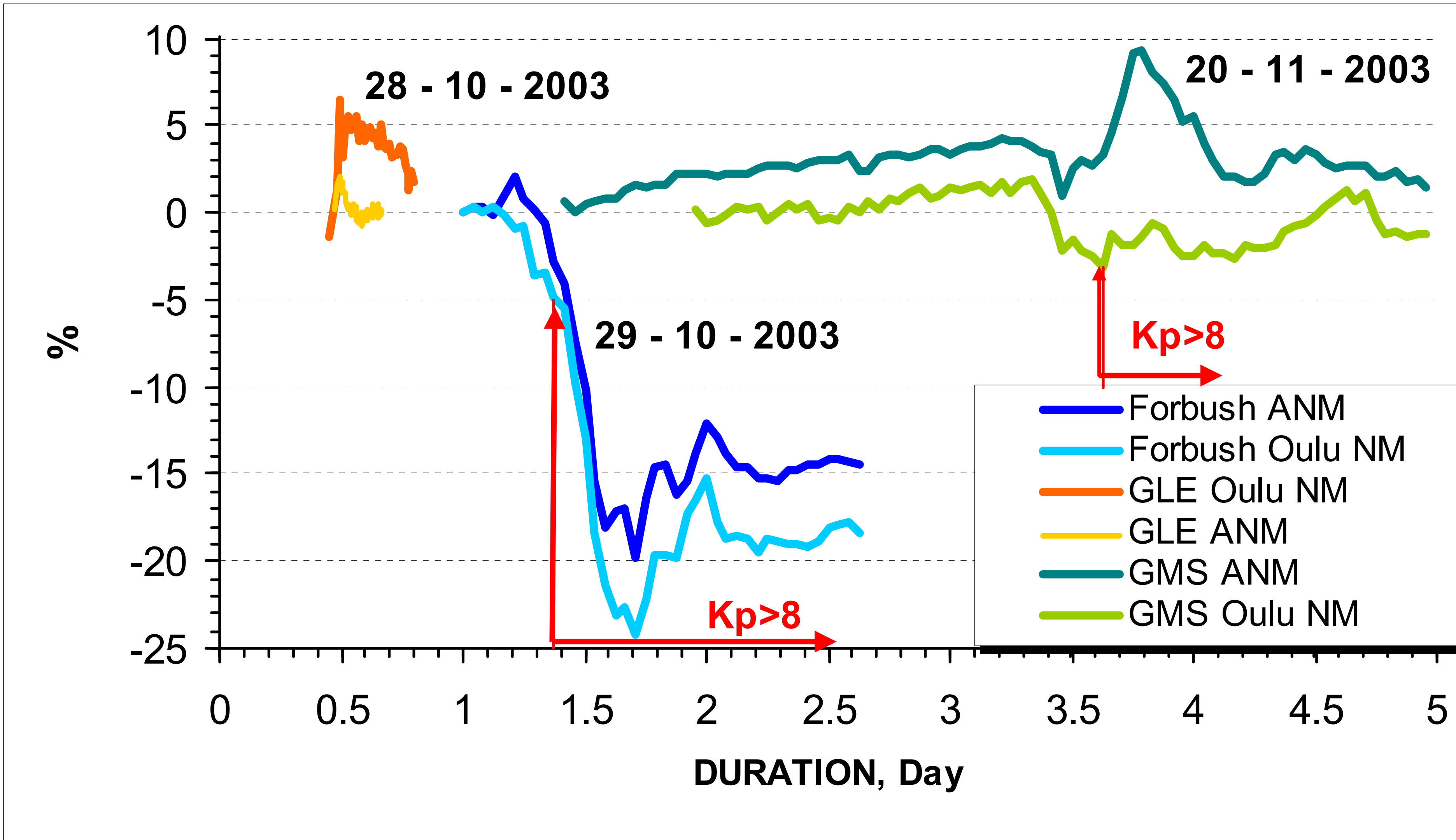


Cosmic Ray Division, Yerevan Physics Institute, Armenia

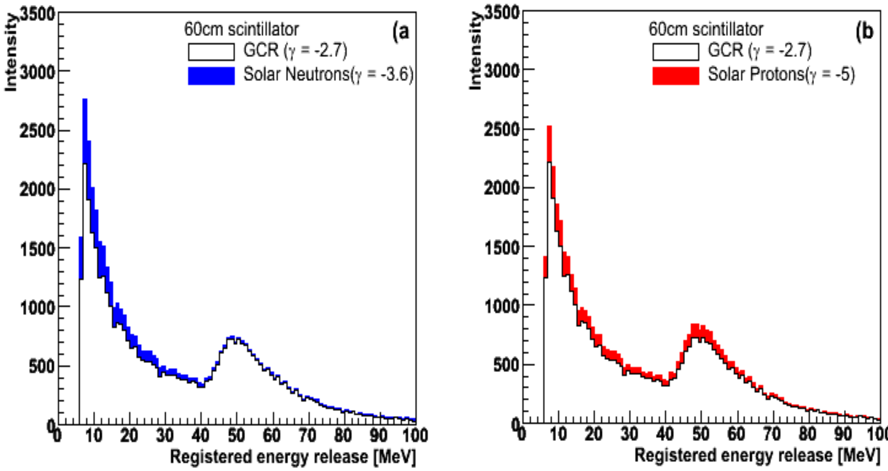


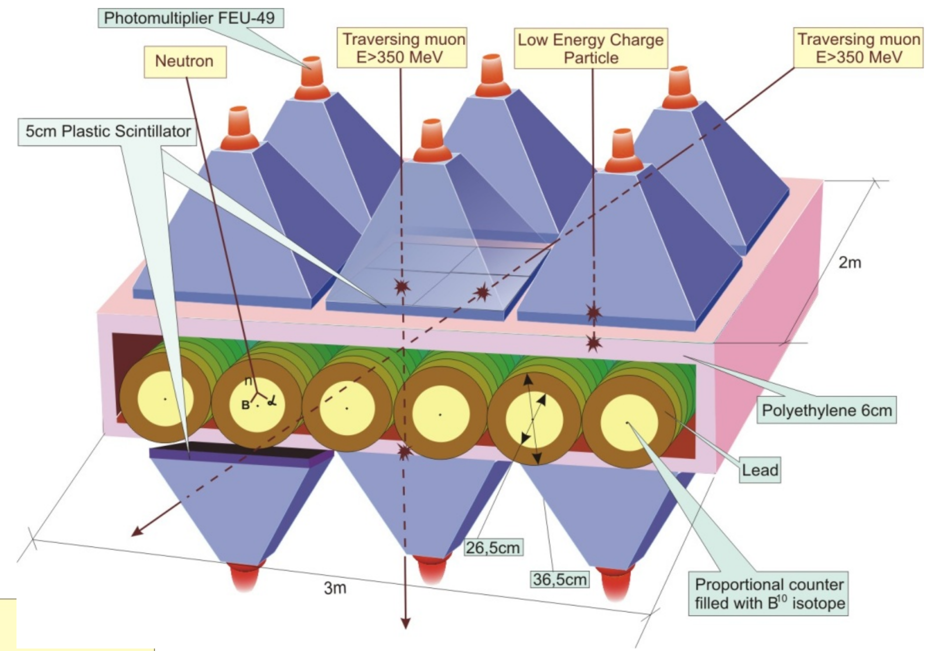
Solar flare
Impulsive event
Coronal Mass Ejection
Gradual event
Magnetosphere
Solar-Neutron Telescope
multiplier
Plastic Scintillator
Nor-Amberd Multidirectional Muon Monitor
Traversing muon E>350 MeV
Traversing muon E>350 MeV
Polyethylene 5cm
Proportional Counter
Aragats Multidirectional Muon Monitor
p
p
CME
p
p
n
n
>5 GeV m
Air
Soi

Solar Modulations Effects

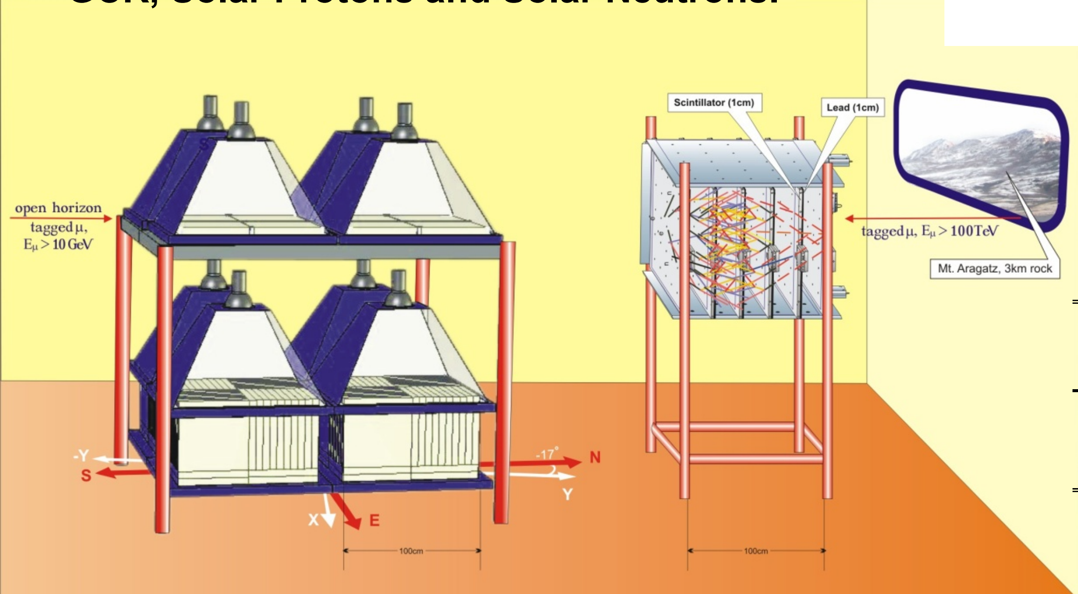


Particle Detectors Operated at Aragats Space Environmental Center (ASEC)



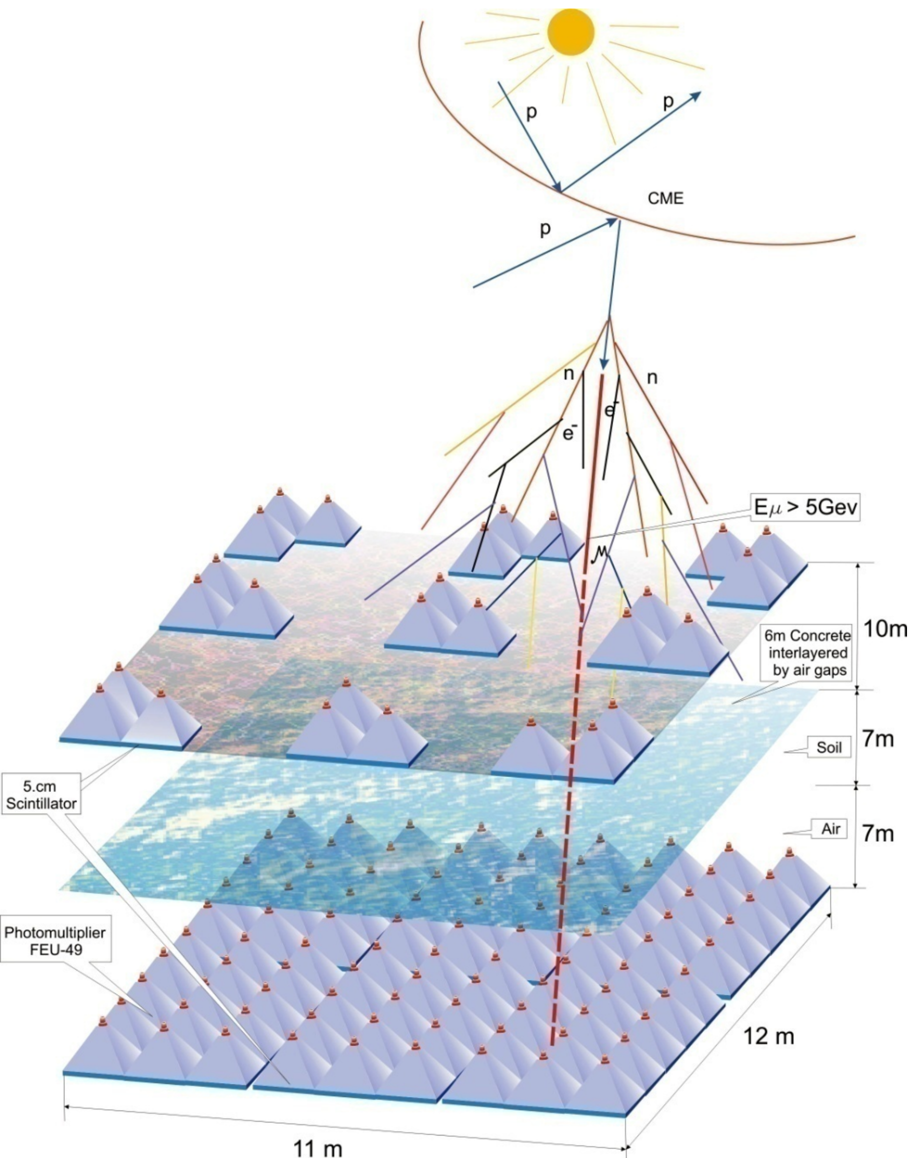


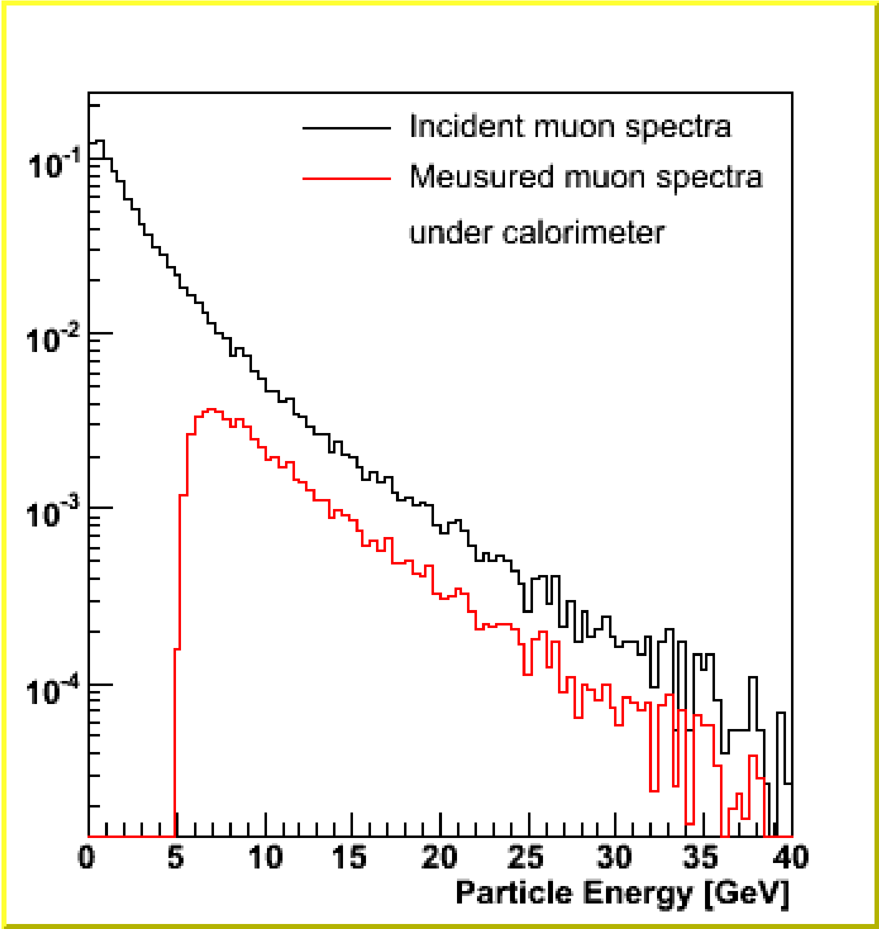
Registered energy deposit corresponding to GCR, Solar Protons and Solar Neutrons.



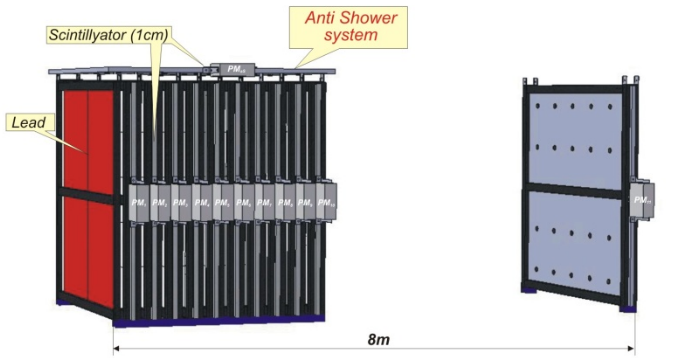
Detector layer	Solar Protons	Solar Neutrons
Upper 5cm scintillator	4.8σ	2.6σ
Middle 25 cm scintillator	1.7σ	6.4σ

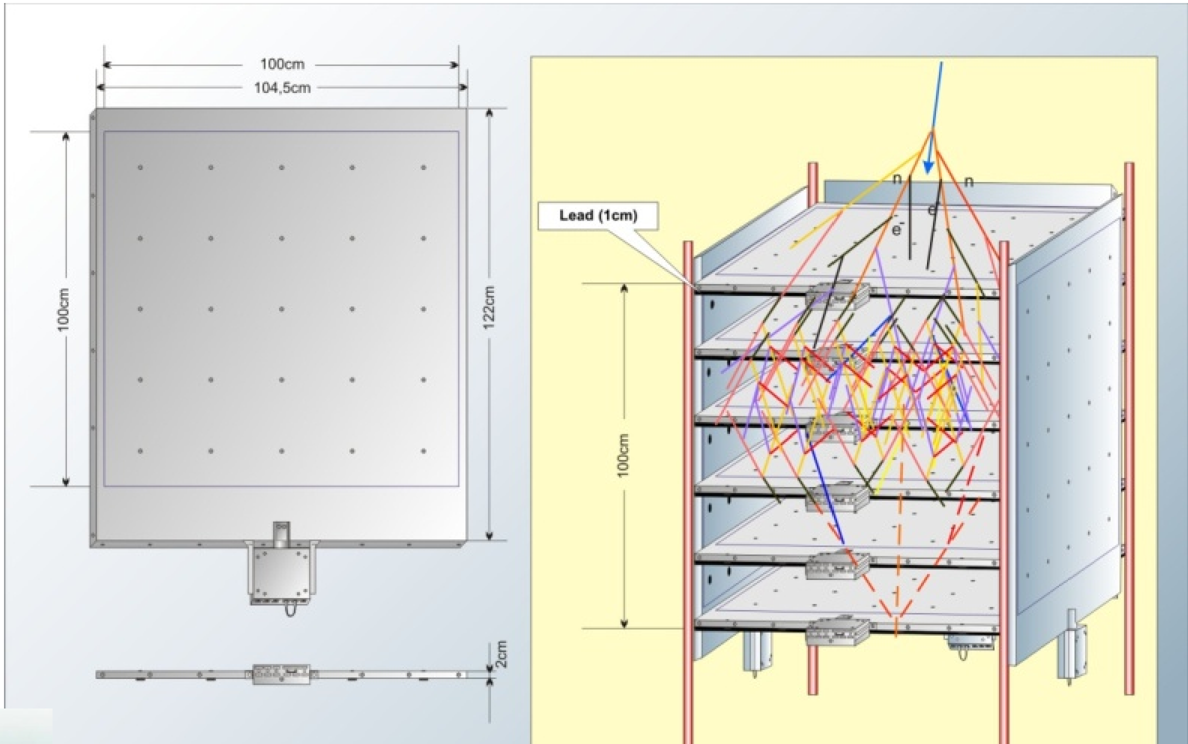
Aragats Underground Muon Monitor (AUMM)



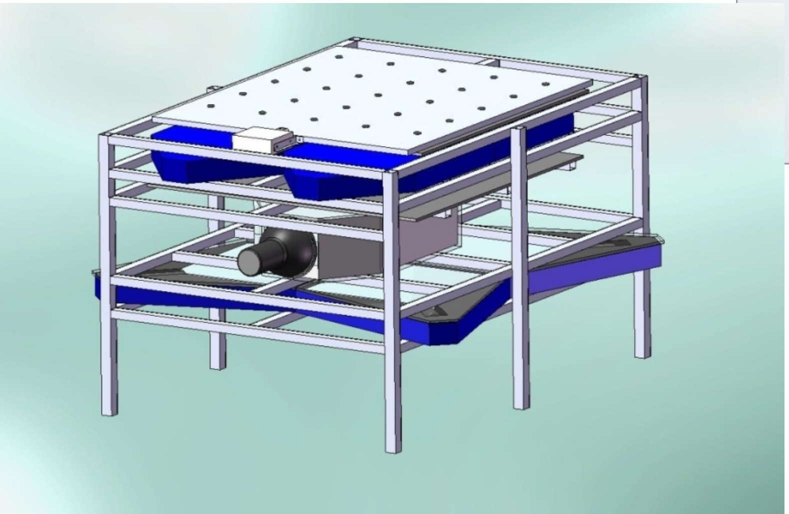


New multilayered particle detectors

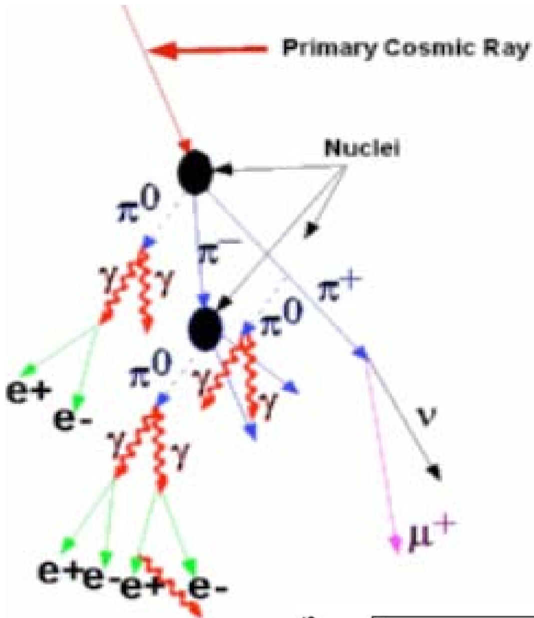


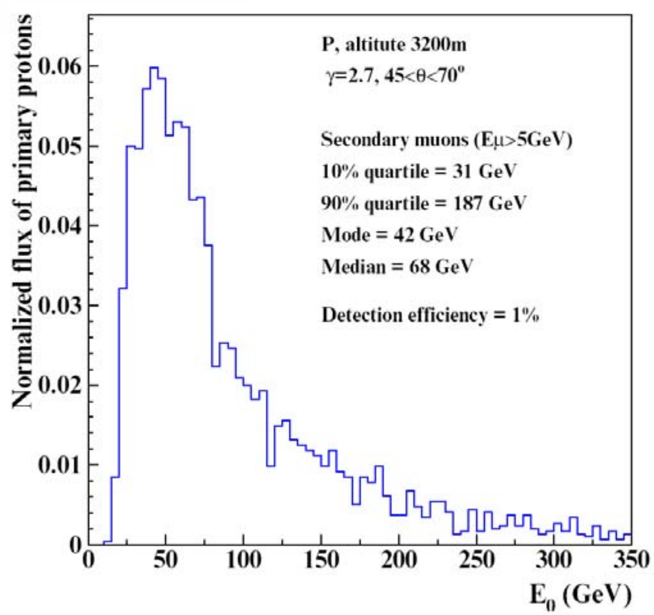


Aragats Hadron-Electromagnetic Calorimeter (AHEC)



Direct Problem of Cosmic Rays: Cascade in atmosphere + detector response





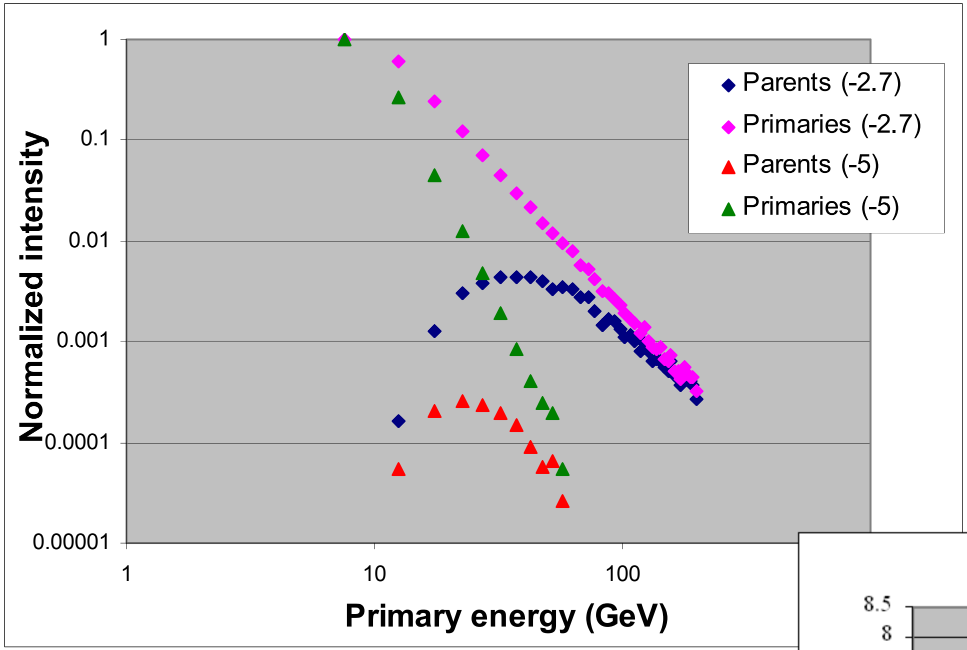
Distribution Mode – most probable energy (robust parameter)

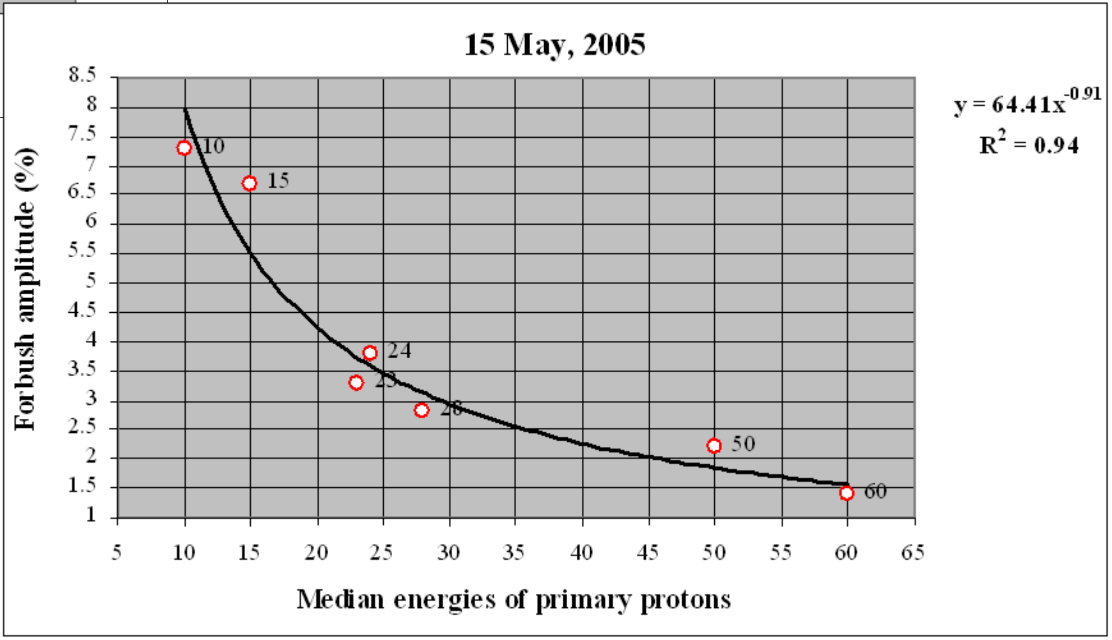
Neutrons	GHEISHA	FLUKA
10% quartile	8.1 GeV	7.8 GeV
90% quartile	45.8 GeV	38 GeV
Mode	7.1 GeV	7.1 GeV
Median	15.3 GeV	12.8 GeV

Charged/ 3200 m.	GHEISHA	FLUKA
10% quartile	10 GeV	8.8 GeV
90% quartile	78 GeV	67.6 GeV
Mode	10.9 GeV	10.3 GeV
Median	24 GeV	20.4 GeV

Muons > 5 GeV/3200	GHEISHA	FLUKA
10% quartile	28 GeV	26.5 GeV
90% quartile	170 GeV	183 GeV
Mode	37 GeV	37.7 GeV
Median	61 GeV	63 GeV

Detector response to Galactic and Solar CR flux

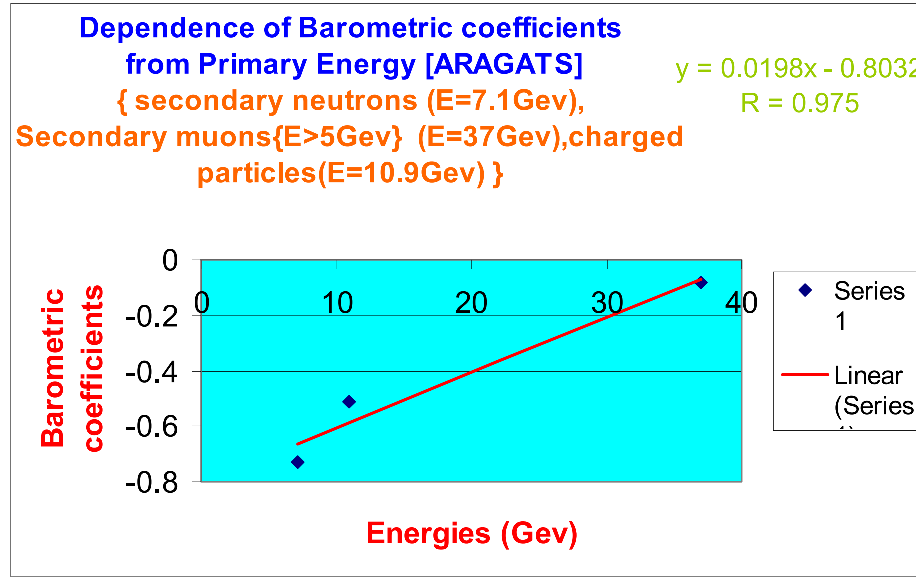


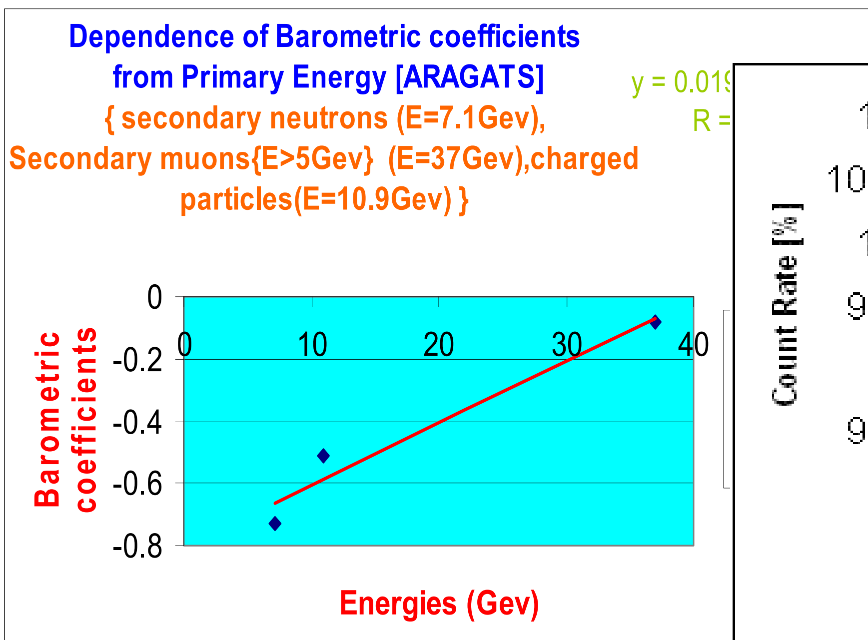


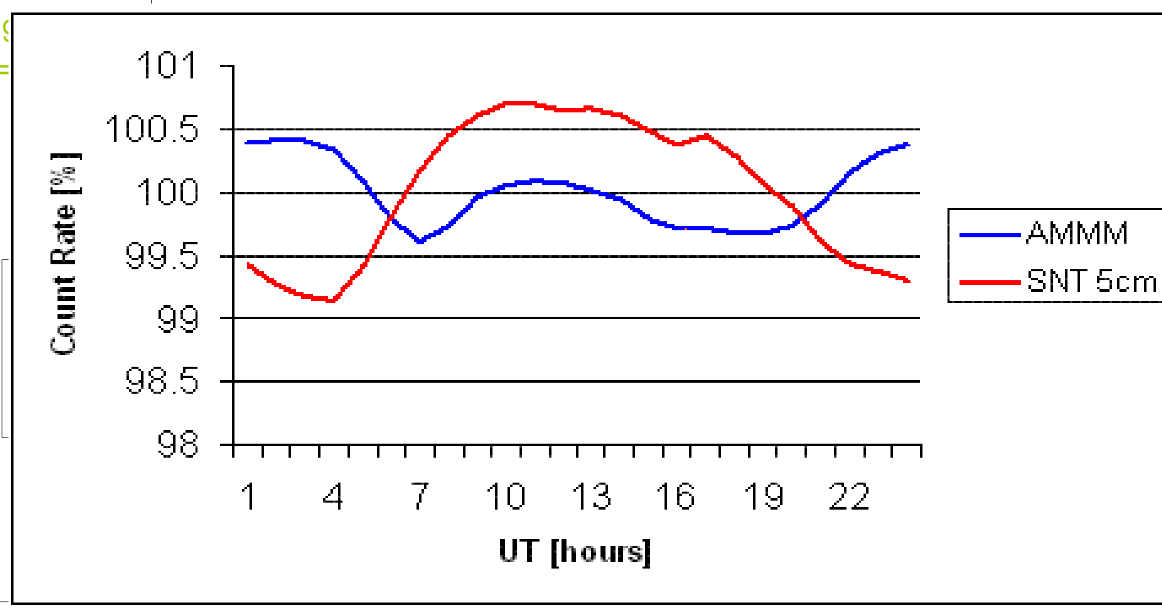
MONITORS	BAROMETRIC COEFFICIENT	ERROR	CORRELATION COEFFICIENT
Nor Amberd neutron monitor 0.4us	-0.695 %/mb	±0.0133	0.997
Nor Amberd neutron monitor 250us	-0.678 %/mb	±0.0127	0.997
Nor Amberd neutron monitor 1250us	-0.670 %/mb	±0.0216	0.995
Aragats neutron monitor 0.4us	-0.730 %/mb	±0.0185	0.997
Aragats neutron monitor 250us	-0.713%/mb	±0.0183	0.997
Aragats neutron monitor 1250us	-0.688%/ mb	±0.0182	0.996
Nor Amberd multidirectional muon monitor(1) (upper layer)	-0.324%/mb	±0.012	0.992
Nor Amberd multidirectional muon monitor(1) (lower layer)	-0.223%/mb	±0.0135	0.987
Nor Amberd multidirectional muon monitor(2) (upper layer)	-0.323%/mb	±0.0136	0.991
Nor Amberd multidirectional muon monitor(2) (lower layer)	-0.225%/mb	±0.0135	0.987
Aragats underground muon Telescope E>5 Gev	-0.08%/mb	±7.57E-05	0.924
Aragats Solar Neutron Telescope (5 cm)	-0.507%/mb	±0.022	0.994
Aragats Solar Neutron Telescope (60 cm)	-0.427%/mb	±0.017	0.994
Aragats Solar Neutron Telescope Threshold E>7Mev	-0.42%/mb	±0.0167	0.994
Aragats Solar Neutron Telescope Threshold E>85Mev	-0.406%/mb	±0.0328	0.977
Aragats Solar Neutron Telescope Threshold E>170Mev	-0.945%/mb	±0.1383	0.932
Aragats Solar Neutron Telescope Threshold E>255Mev	-0.986%/mb	±0.1462	0.939
Aragats Solar Neutron Telescope Threshold E>380Mev	-1.165%/mb	±0.1307	0.958

Barometric coefficients and Diurnal variations measured by various detectors related to different primary energies

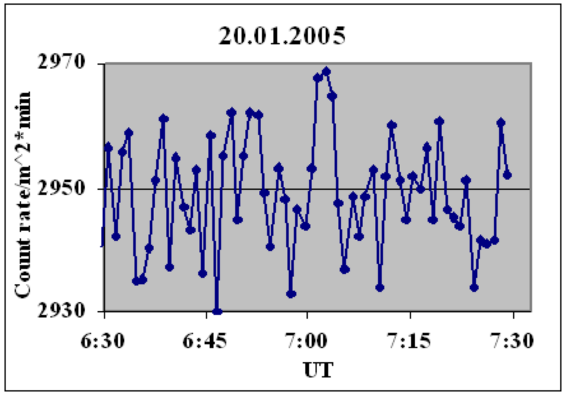
Greater most probable energy of primary proton generation secondary CR – smaller abs of barometric coeff.; Greater most probable energy – smaller diurnal variations of secondary CR

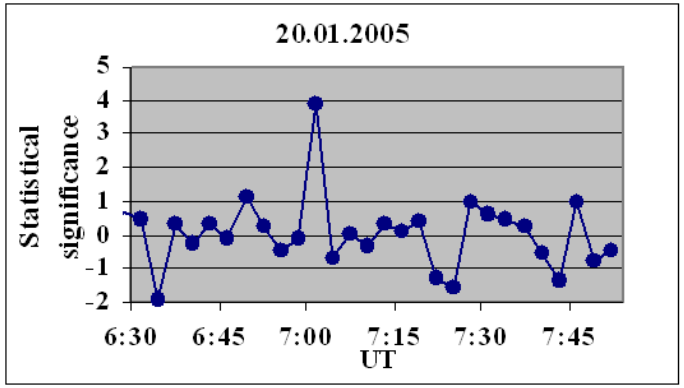




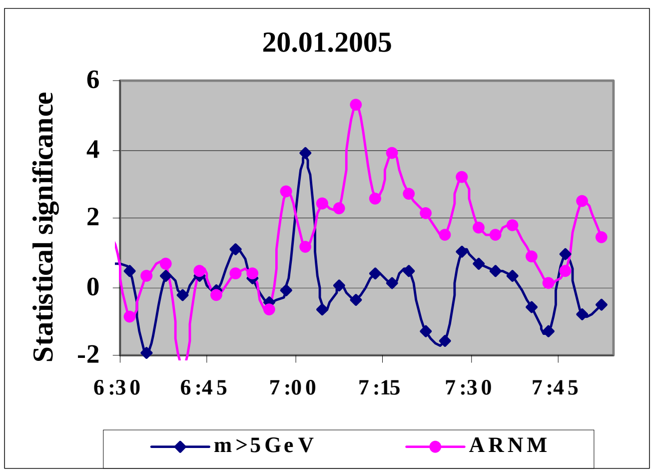


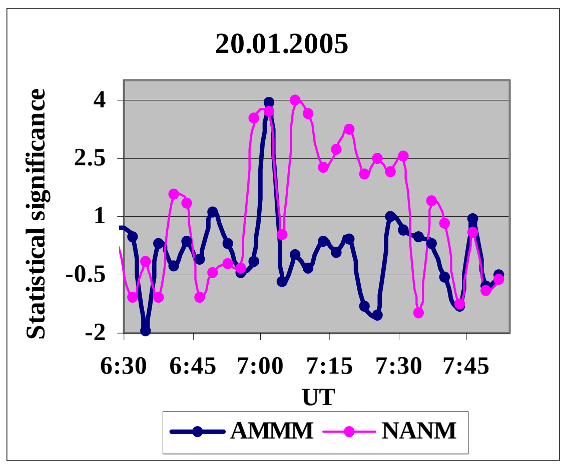
AMMM Detection of GLE 20 January 2005

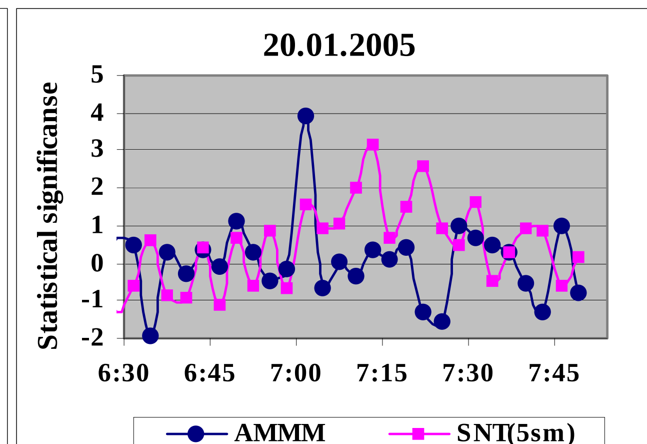




The additional signal at 7:02-7:04 UT equals 2354 (0.644%) If we adopt the Poisson SD~ 0.164%, significance = 3.93σ

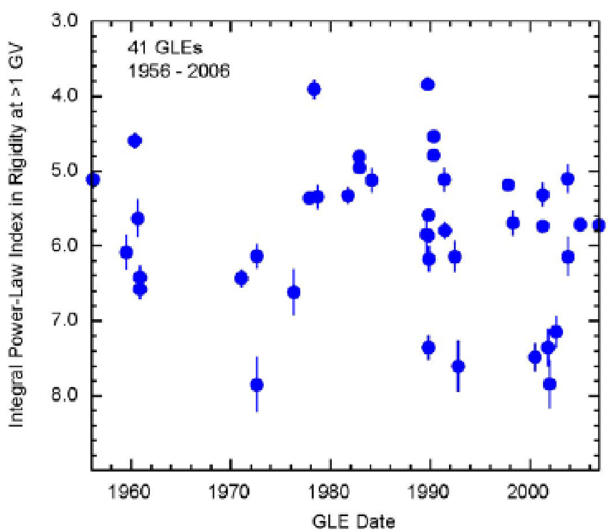


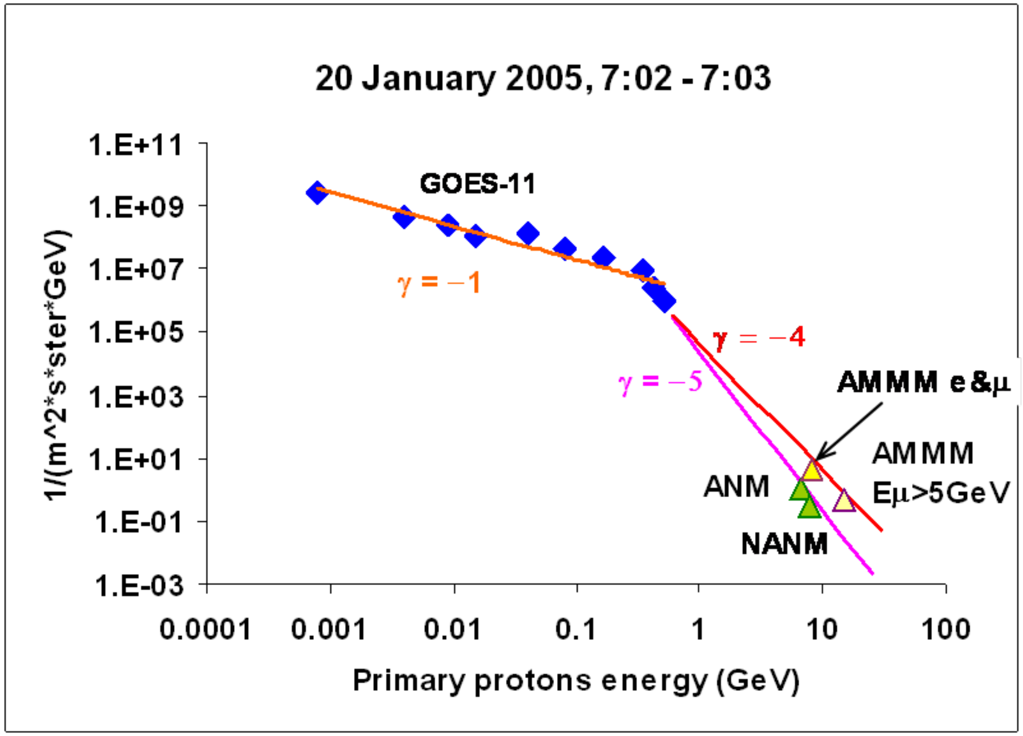


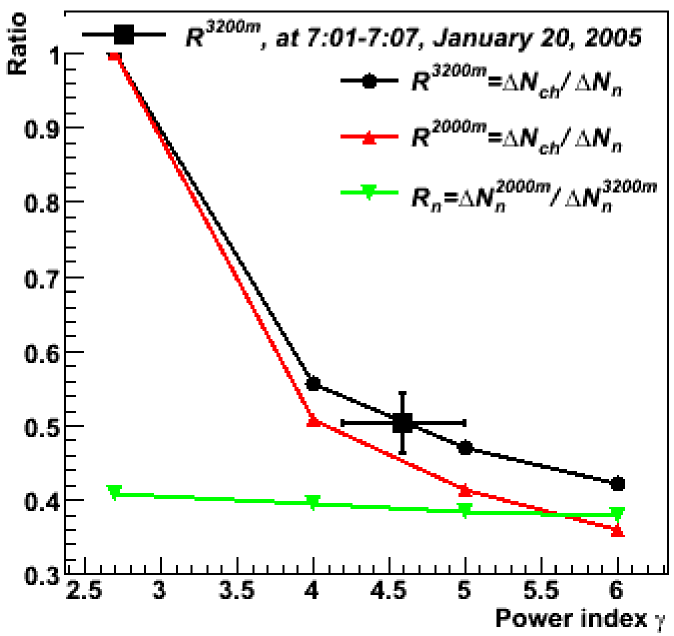


Energy Spectrum of the GLE from 20 January 2005

>1 GV Spectral Index



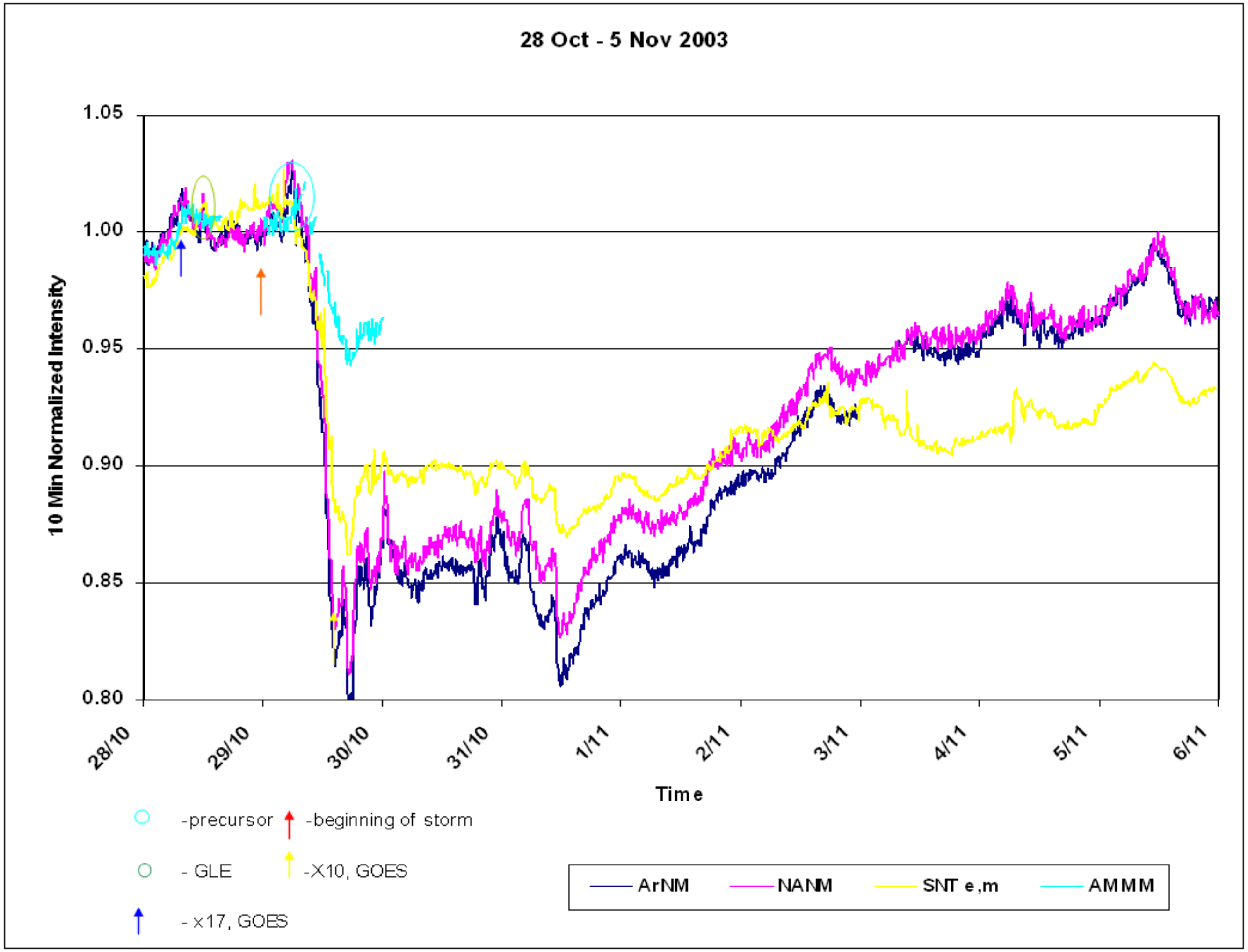




N.Kh. Bostanjyan , A.A. Chilingarian, V.S. Eganov, G.G. Karapetyan, **On the production of highest energy solar protons on 20 January 2005,** Advances in Space Research 39 (2007) 1456–1459

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

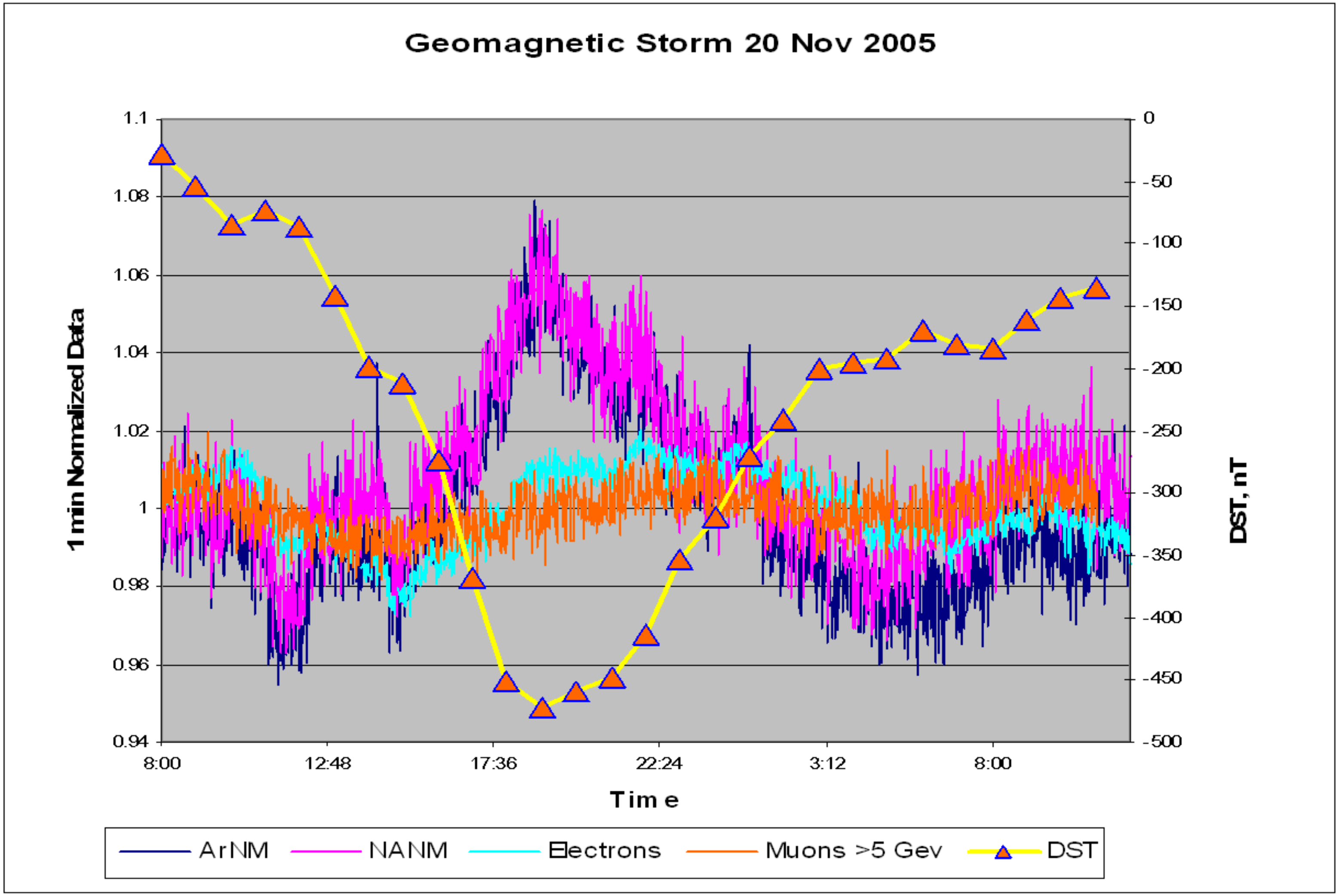
Famous “Halloween” events of 2003, detected in electron & muon and neutron fluxes by ASEC monitors at different altitudes



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

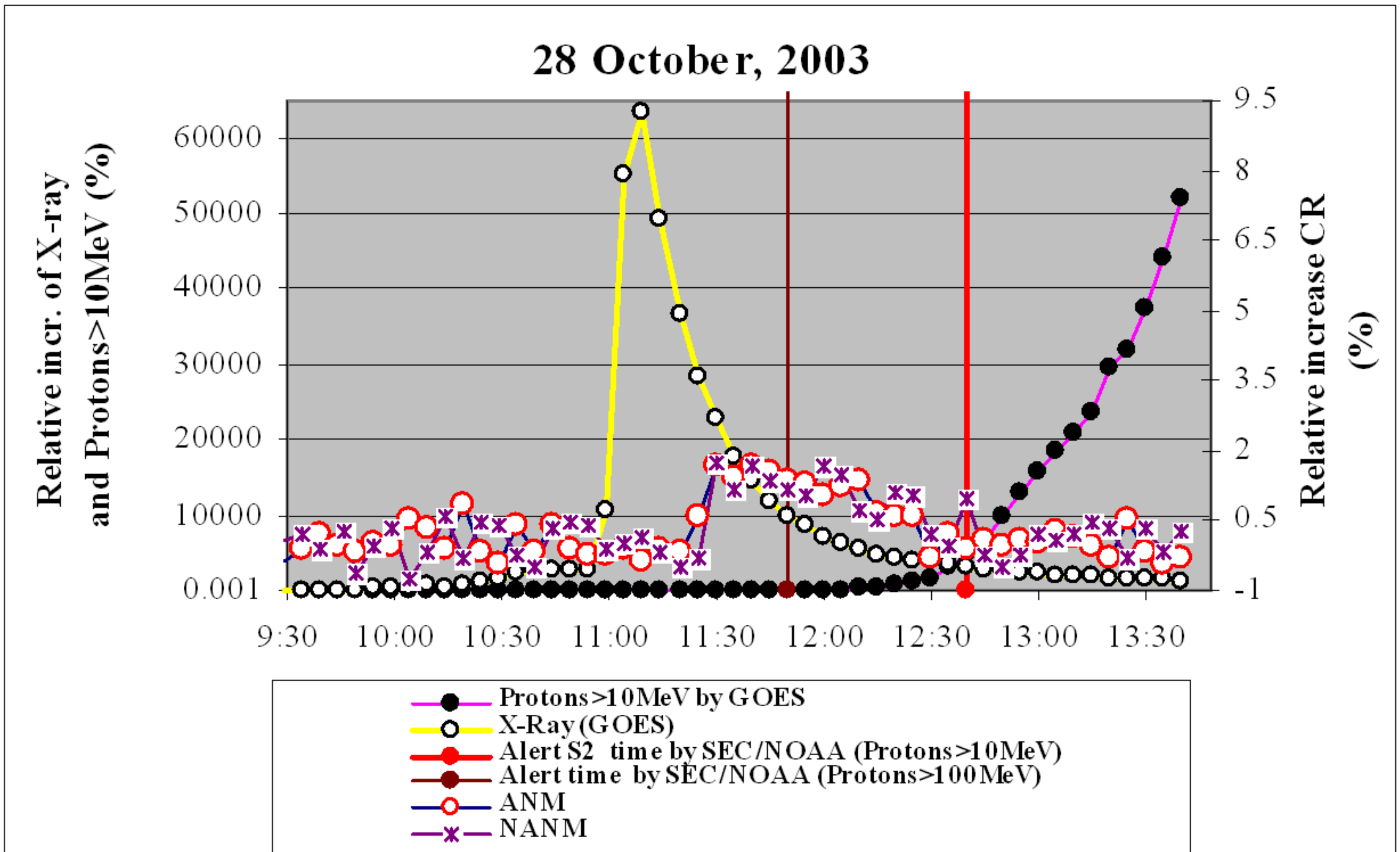
Geomagnetic Disturbance of 20 November 2003



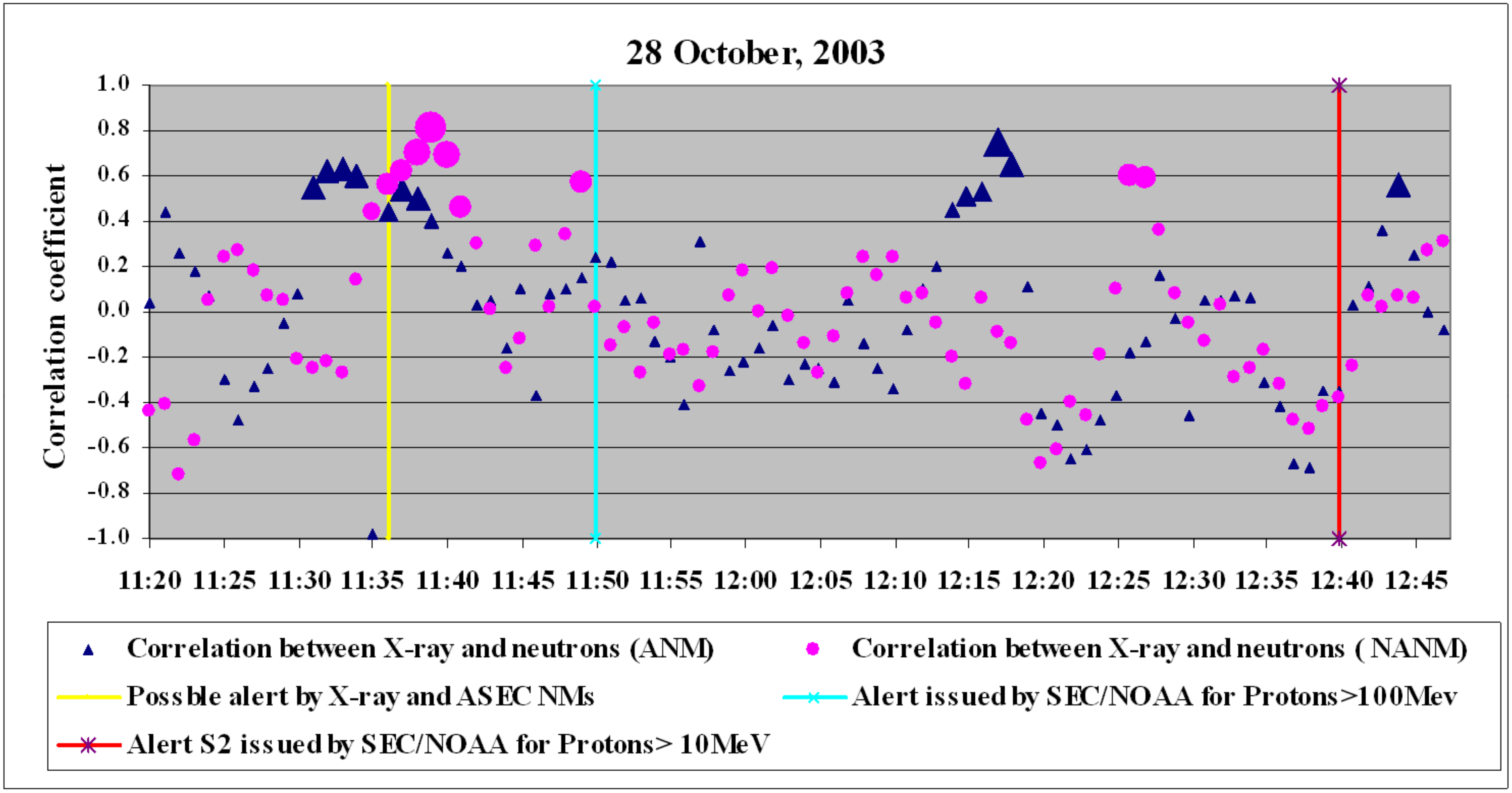
Correlation Matrix of ASEC monitors for 20-21 November 2003 г. (14:50 – 19:10), Geomagnetic Storm

	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

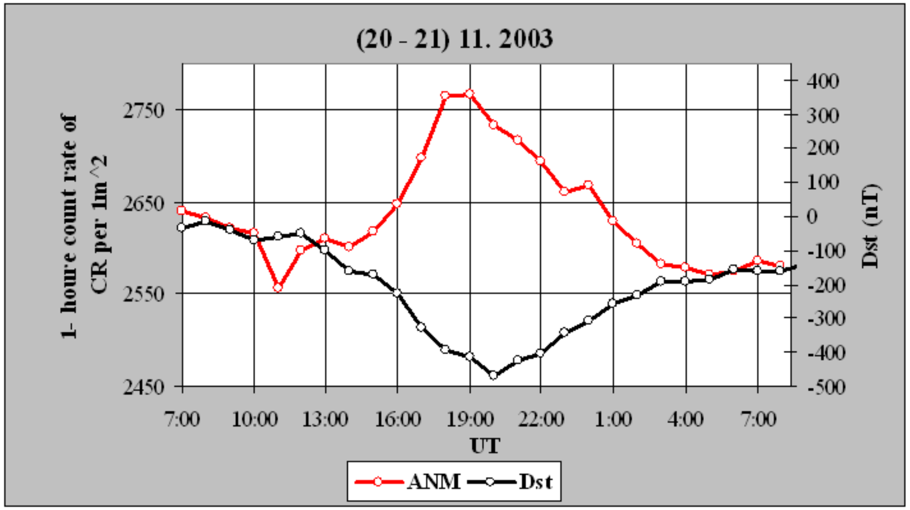
Radiation from 28 October 2003 X14.4 flare (flux maximum at 11:10). SEC/NOAA alerts on 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the ANM and NANM) reaches ~1.7% at ~11:35.

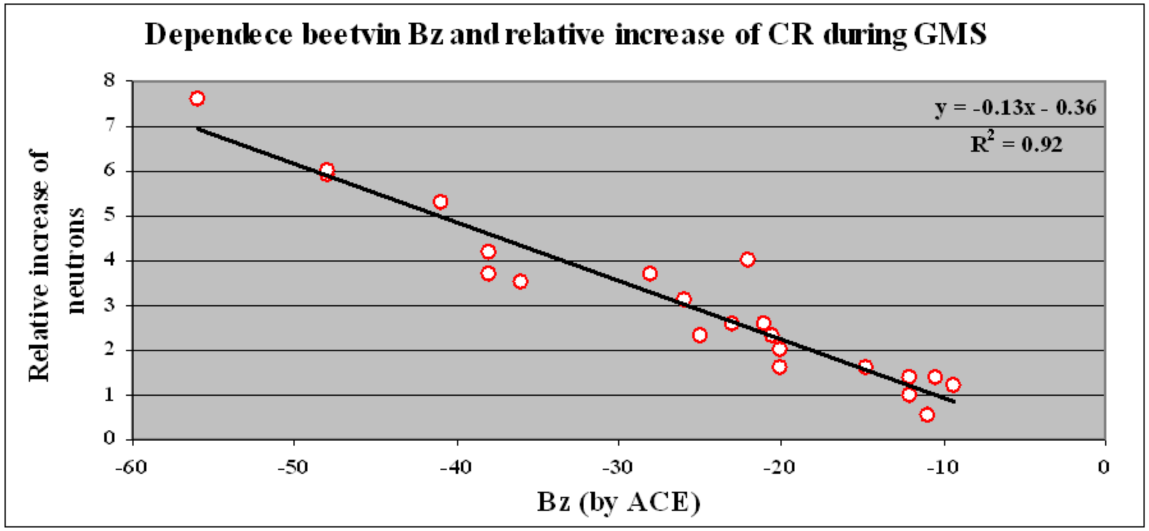


Pattern of correlations between neutron flux and X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates.

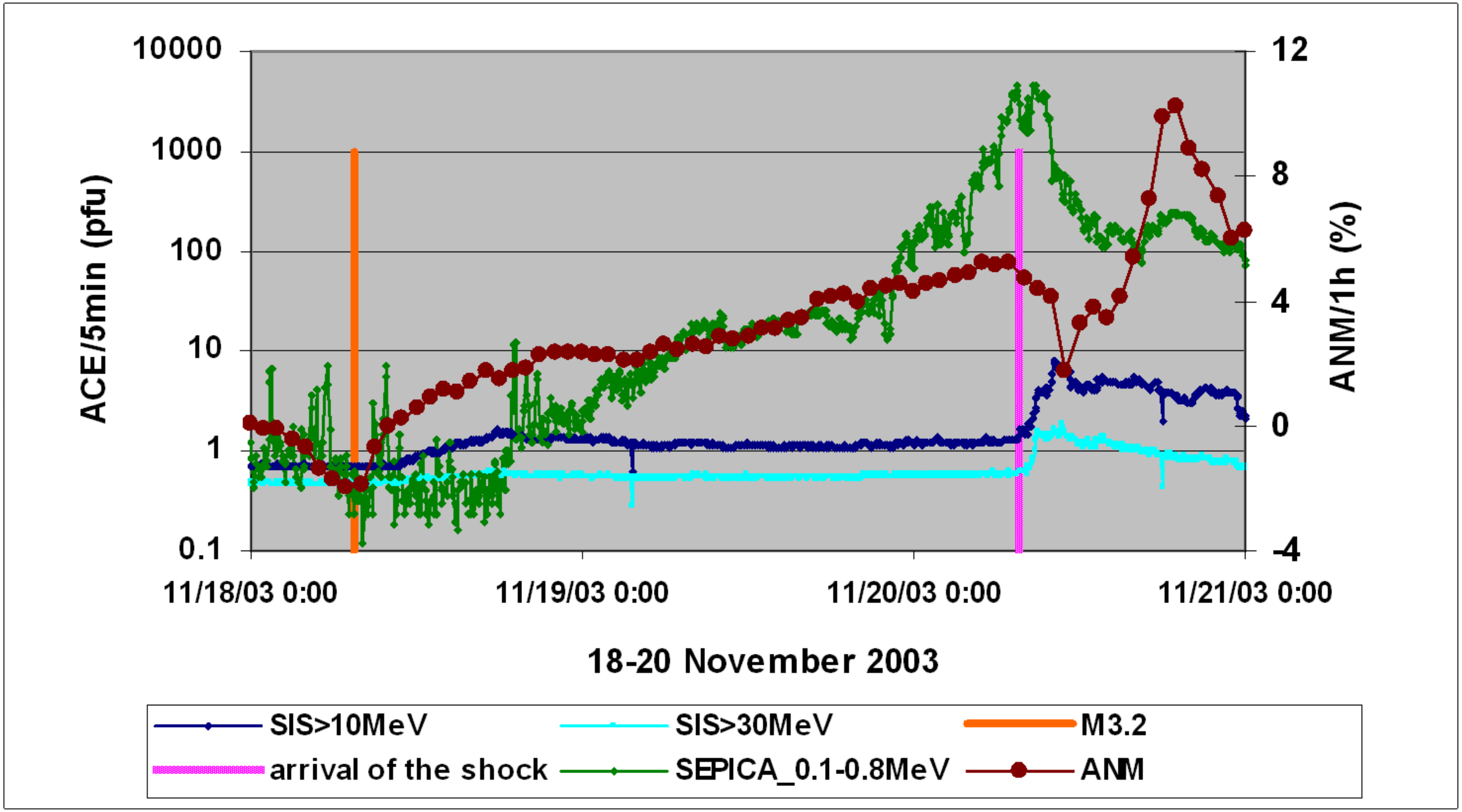


Geomagnetic Storms: interrelations of Dst, Bz and cosmic ray increase



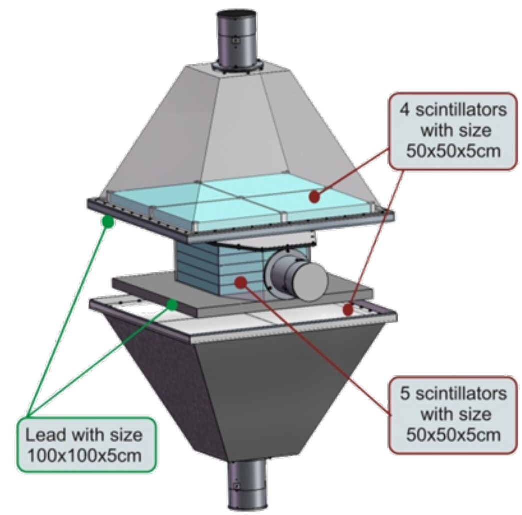


ICME modulation effects in KeV; MeV; and GeV particle fluxes



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.

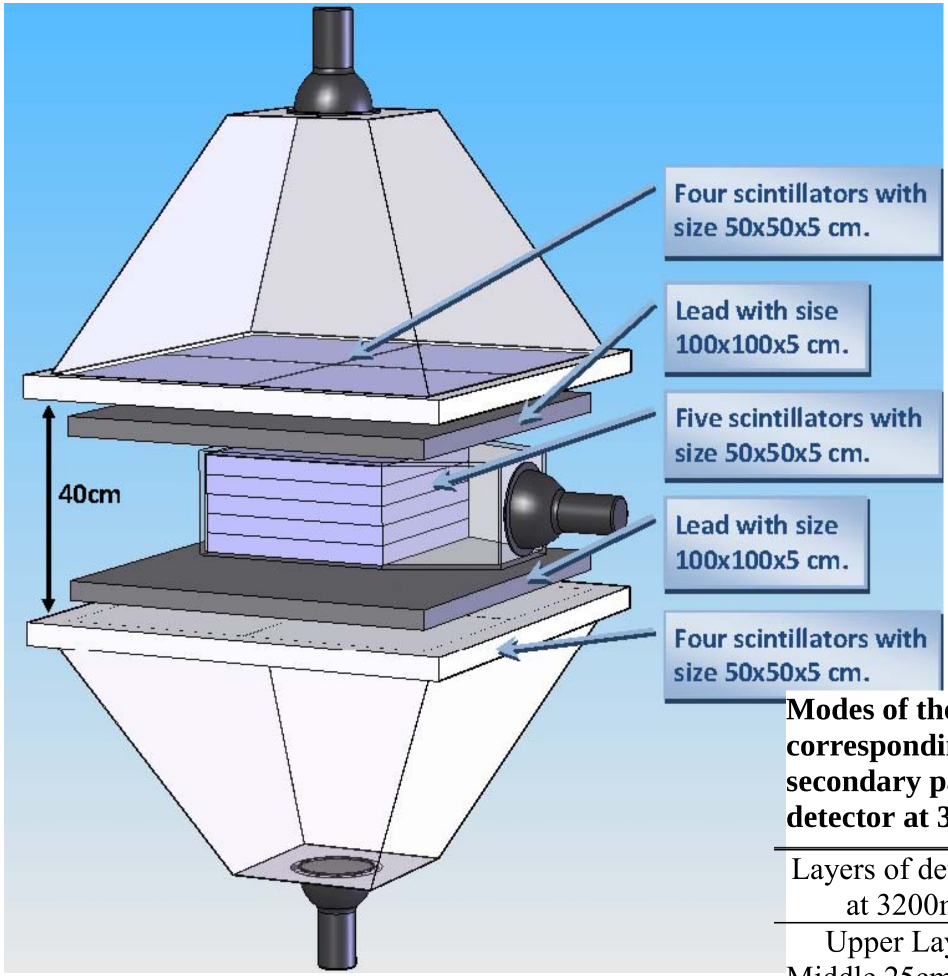


COSMIC RAY DIVISION
Alikhanyan Physics Institute,
Alikhanyan Brothers 2,
Yerevan 375036, Armenia

NMDB neutron monitor database
ASEC
ISTC A1554
INTAS 8777
FA8655
COSPAR

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

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
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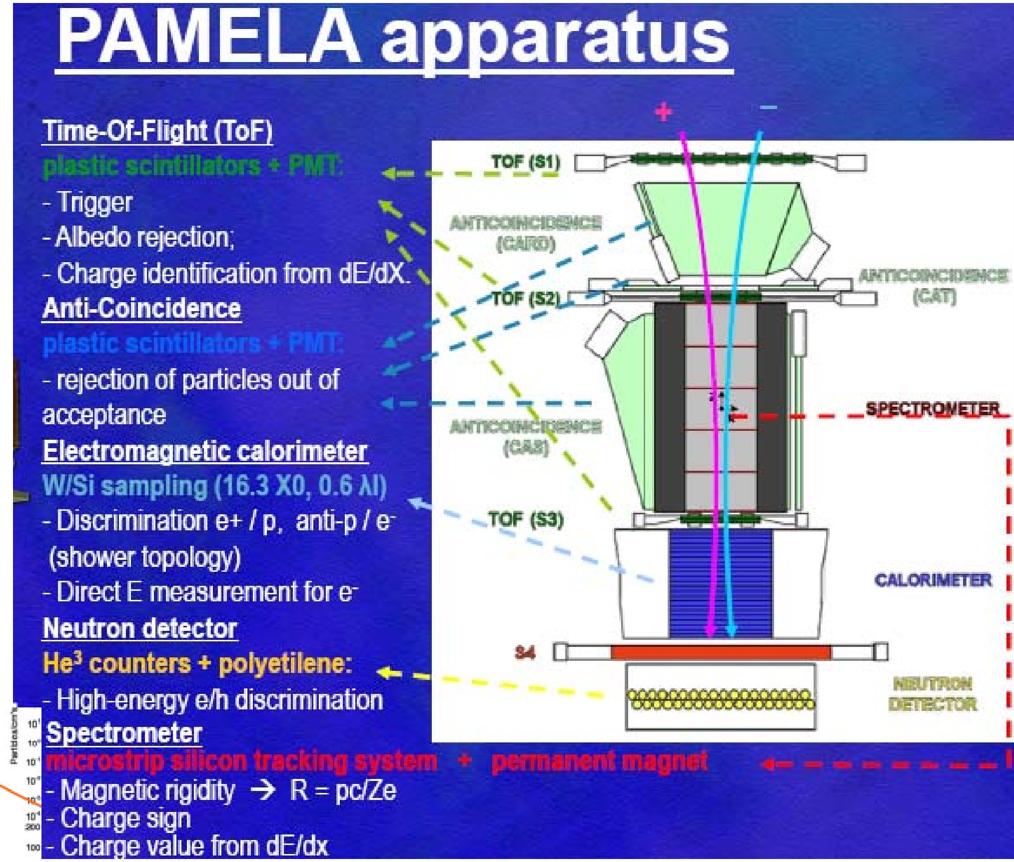
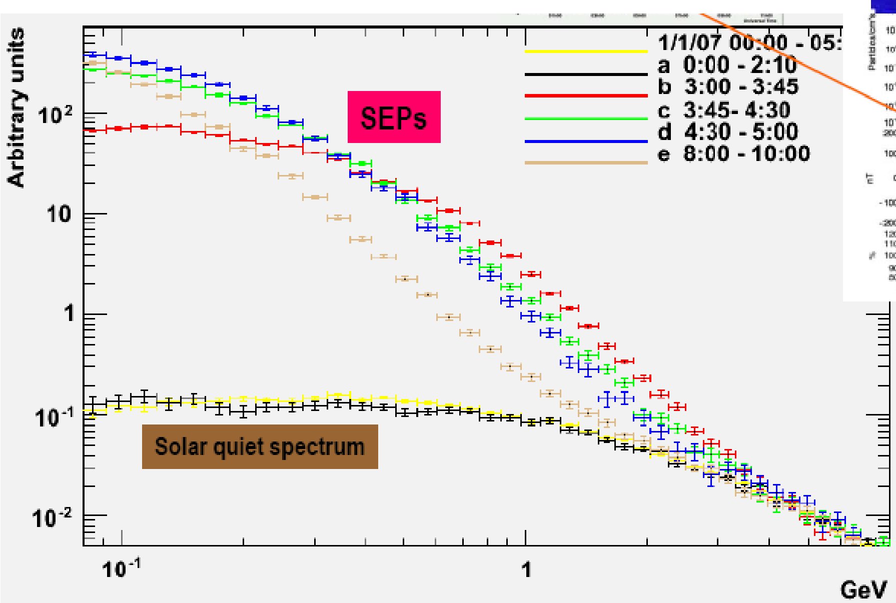
Energy Spectra measured by PAMELA

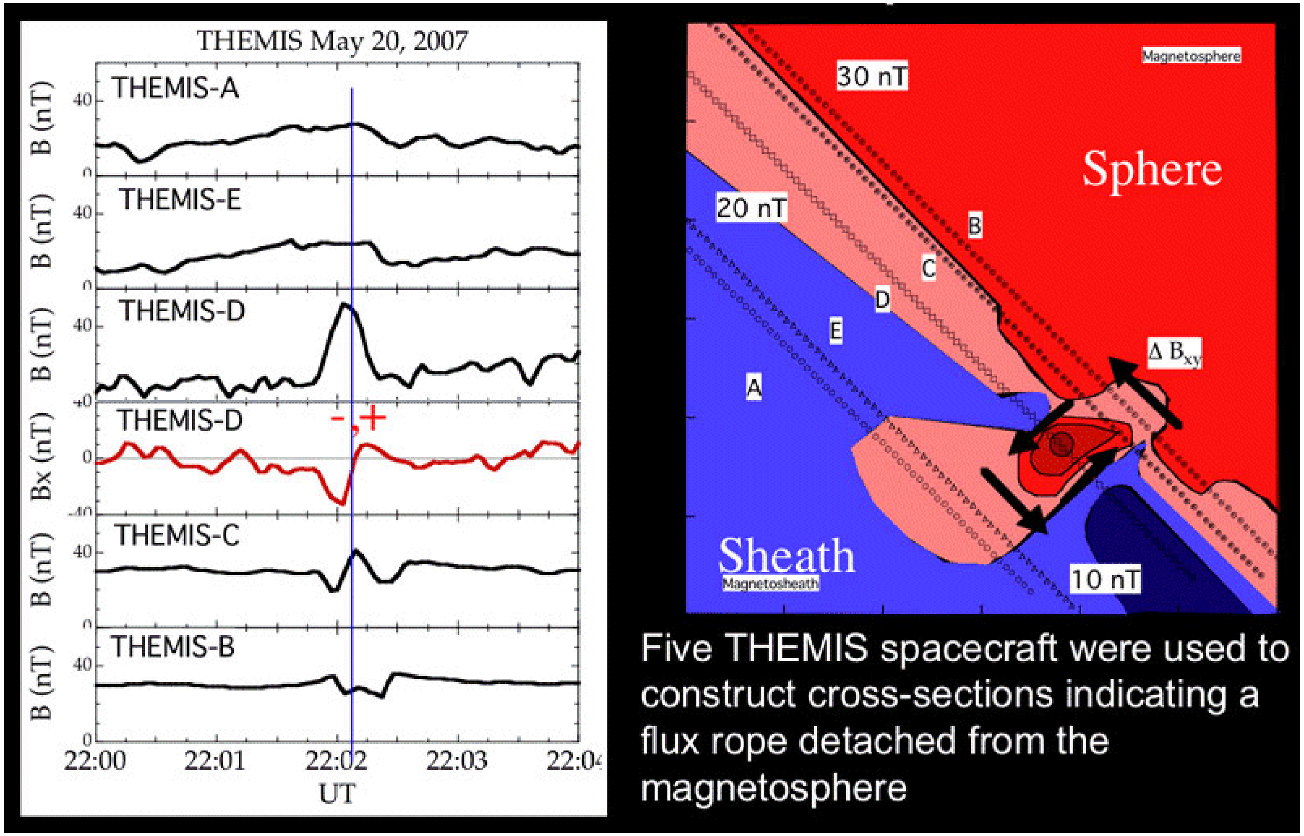
Proton spectra measured by PAMELA during SEP event from December 13, 2006





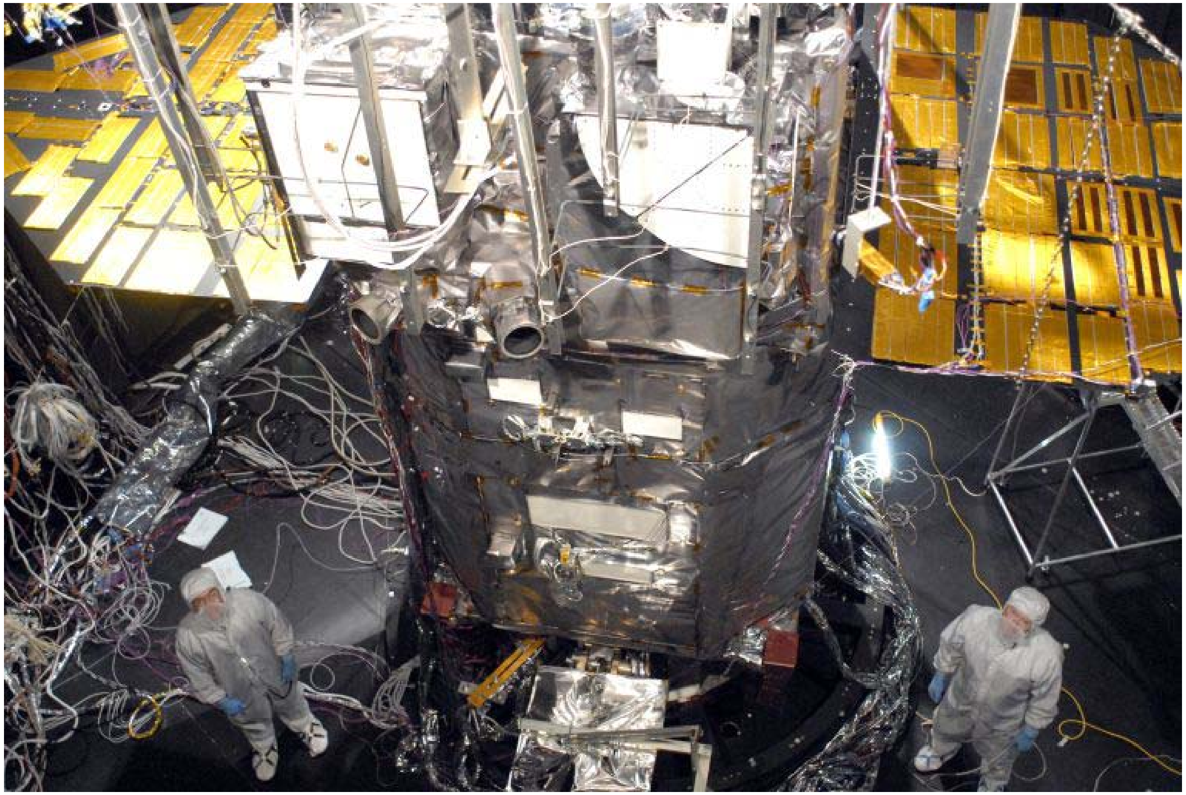
Courtesy Emiliano Mocchiutti

A magnetic map of a magnetospheric "rope" observed in cross-section by the THEMIS satellites on May 20, 2007 – **collisionless transport!.**



The satellites have detected magnetic 'ropes' connecting Earth's upper atmosphere directly to the Sun," says Dave Sibeck, project scientist for the mission at the Goddard Space Flight Center. "We believe that solar wind particles flow in along these ropes, providing energy for geomagnetic storms and auroras."

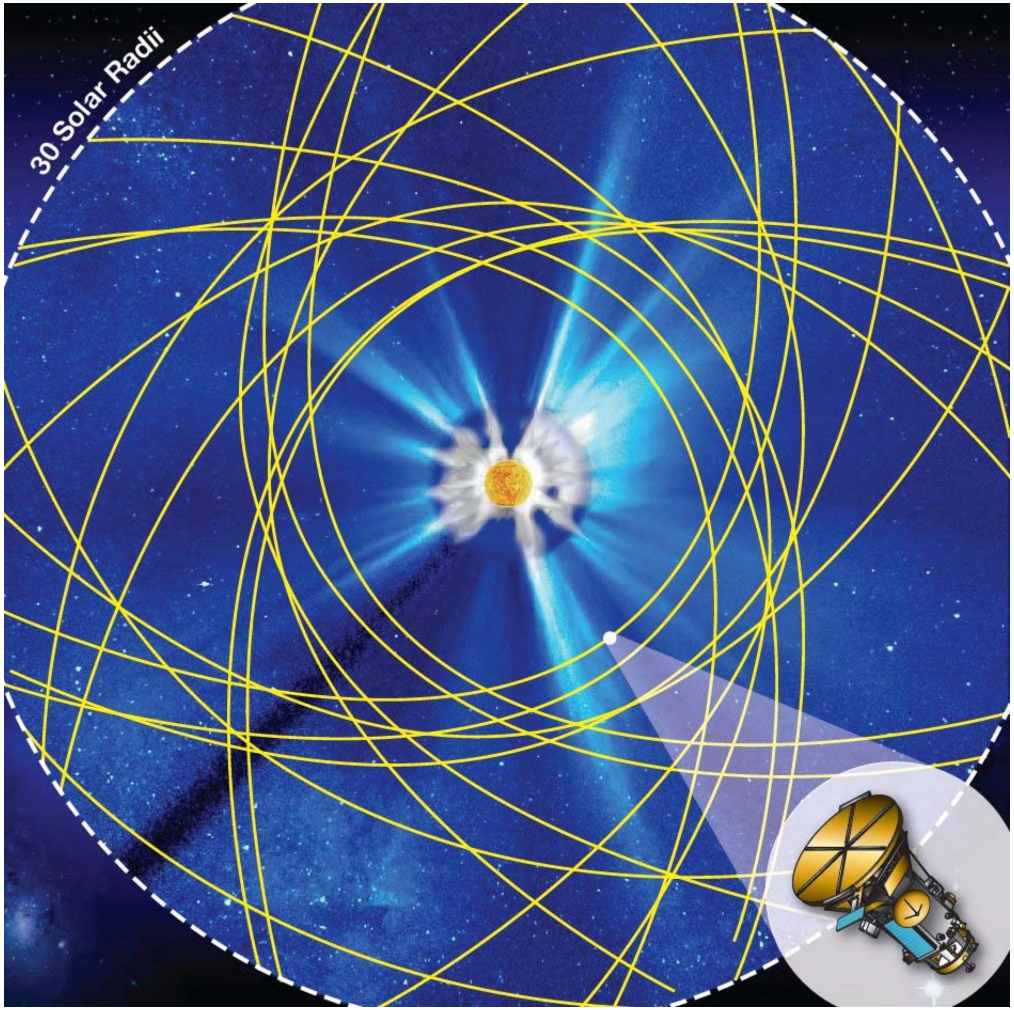
The Solar Dynamics Observatory (SDO) - is built and almost ready to go



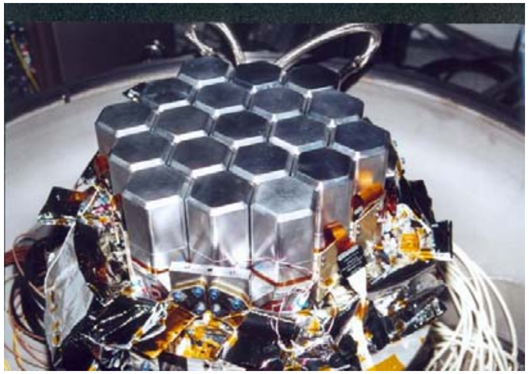
A camera onboard the observatory will take HDTV quality photographs of sunspots and solar flares, revealing the onset of storms in never-before-seen detail.

SDO will be able to produce detailed maps of magnetism on the sun, and look inside the sun by helioseismic imaging

Solar Probe Plus: the most exciting mission of all; a heat-resistant spacecraft will go, only 7 million km from the surface

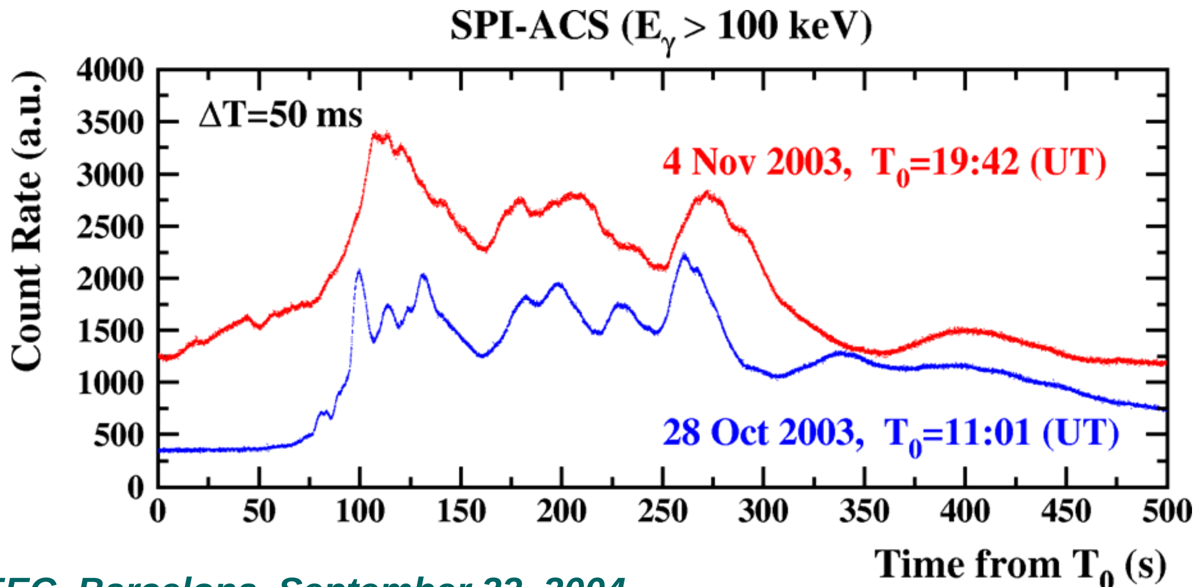


Interest of ACS for solar flare physics



- Compact array of 19 hexagonal Ge detectors (S_{tot}=500 cm^2): good efficiency at high energy (compared to RHESSI) using "multiple events"

- Anti-Coincidence veto System (ACS) of 91 BGO scintillator crystals: S_{pro}~6000–9000 cm^2

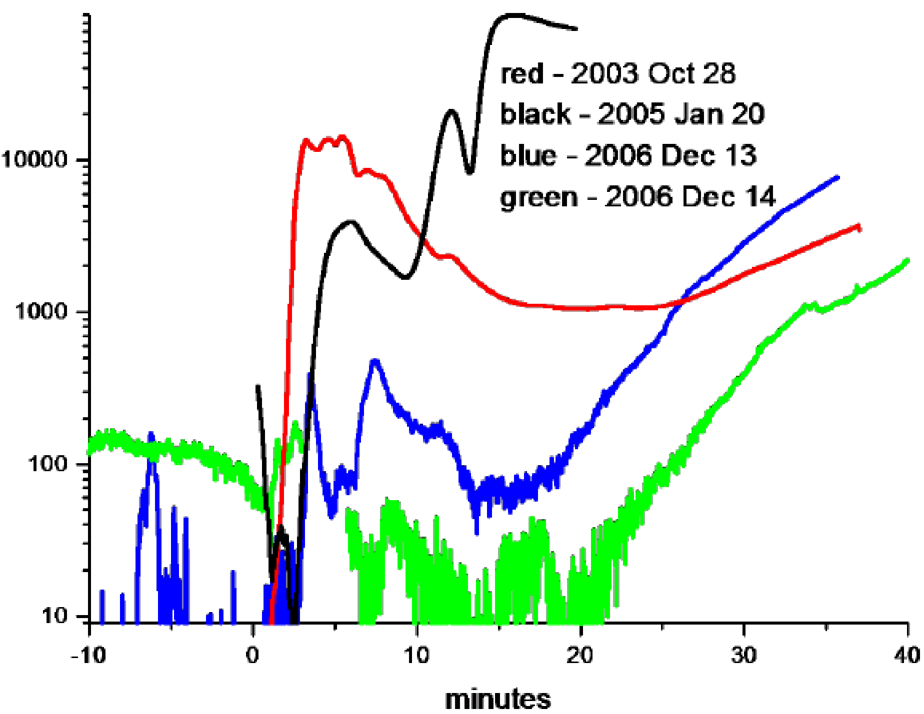


THE ANTI COINCIDENCE SHIELDING

- ACS which provides a large effective area for the detection of bursts, flares and charged particle fluxes;
- The main task of the ACS as a detector is the generation of a veto signal for the camera to suppress charged particles and gamma -rays coming from outside the FoV. But the signals from the ACS can also be used for scientific purposes.
- The count rate of the overall veto counter is sampled every 50 milliseconds
- The ACS consists of 91 BGO crystals which are arranged in 4 subunits , arranged hexagonally around the cylindrical axis of SPI. The thickness of the crystals increases from 16 mm at the top to 50 mm at the bottom. The total mass of BGO used for the ACS is 512 kg resulting in the obvious use of the ACS as a burst monitor.
- Each BGO crystal of the ACS is viewed by two photomultipliers (PMTs). Due to the redundancy concept used for the ACS, each of the 91 front-end electronic boxes (FEEs) sums the anode signals of two PMTs, which view different BGO crystals. This cross strapping of
- The actual energy-threshold settings of the ACS will be the result of a tradeoff between background reduction and deadtime for the SPI camera.

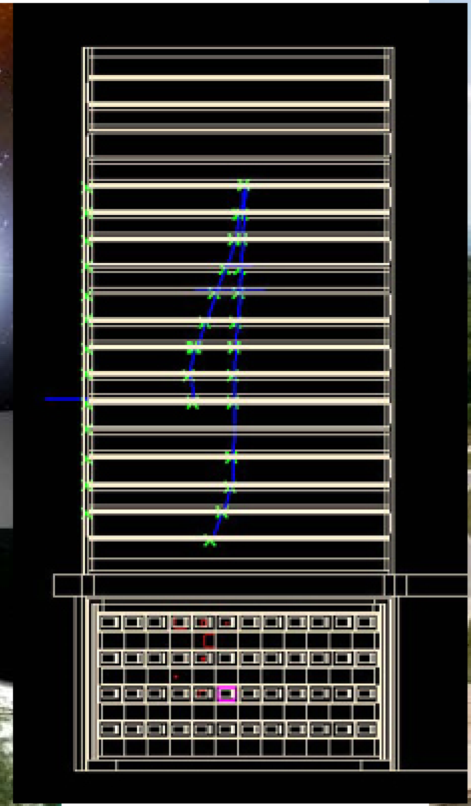
First Proton Arrival

During the 2006 December 13 event, when the intensity of primary gamma-rays was rather low, a massive gamma-ray space born detector (ACS SPI) appeared to be a more effective instrument for observation of the proton event onset than the NM network. The proton event onset was observed by the ACS SPI about 11 min earlier than the GLE onset.



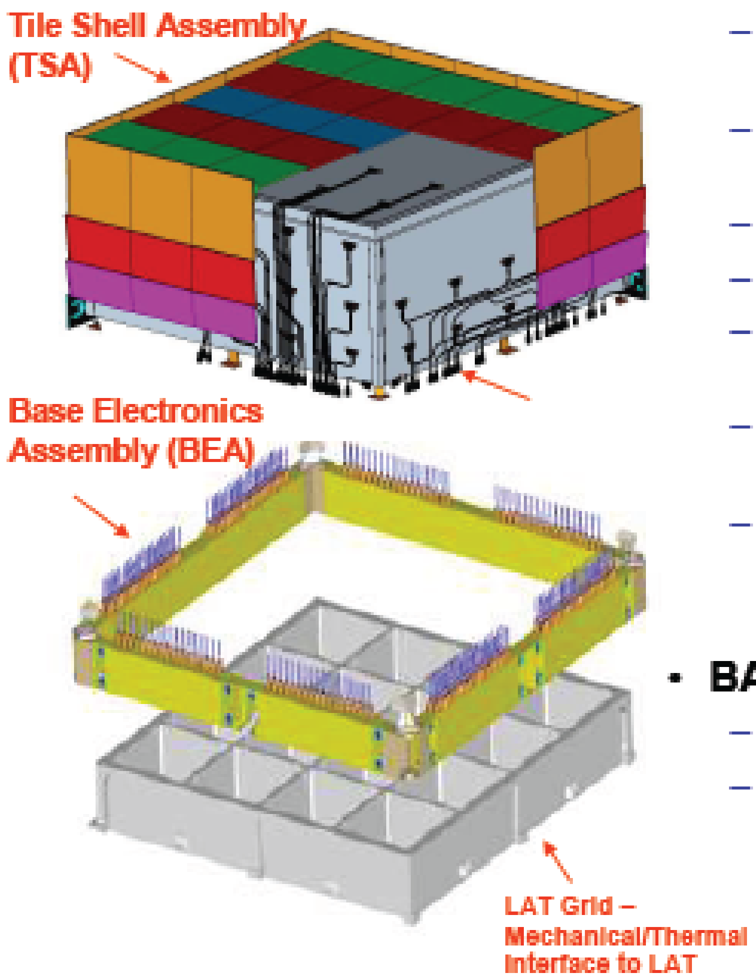
Courtesy Alexey Struminsky

GLAST (Enriko Fermi) LAT detection of a possible new gamma-ray flaring blazar: PKS 1502+106



- Exploring the most extreme environments in the Universe, where nature harnesses energies far beyond anything possible on Earth
- Searching for signs of new laws of physics and what composes the mysterious dark matter
- Understanding how black holes accelerate immense jets of material to nearly light speed
- Cracking the mysteries of stupendously powerful explosions known as gamma-ray bursts
- Answering long-standing questions about solar flares, pulsars and the origin of cosmic rays

GLAST ACD



- **TILE SHELL ASSEMBLY**
  - 89 Plastic scintillator tiles – 1 cm thick (5 tiles are 12 mm thick), various sizes
  - Waveshifting fiber light collection (with clear fiber light guides for long runs)
  - Two sets of fibers interleaved for each tile
  - Tiles overlap in one dimension
  - 8 scintillating fiber ribbons cover gaps in other dimension – 4.5 mm x 12 mm x ~ 3 m
  - Supported on self-standing composite shell
  - Covered by thermal blanket + micrometeoroid shield (not shown)
- **BASE ELECTRONICS ASSEMBLY**
  - 194 photomultiplier tube sensors (2/tile)
  - 12 electronics boards (two sets of 6), each handling up to 18 phototubes. Two High Voltage Bias Supplies on each board.

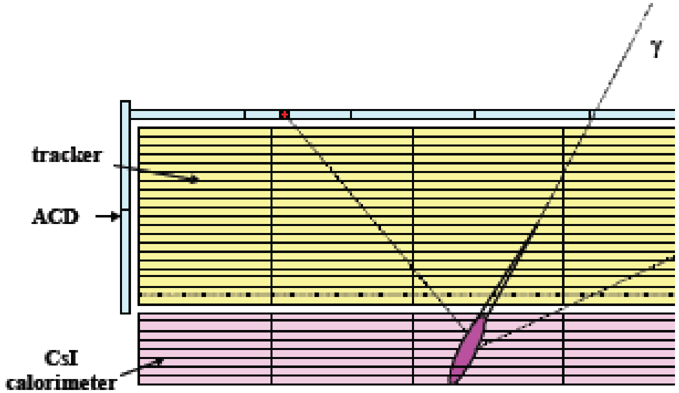
ACD goal

• LAT will have to identify cosmic gamma-rays from 4-5 orders of magnitude more intense background of charged cosmic rays

• The majority of the rejection power against cosmic rays will be provided by ACD

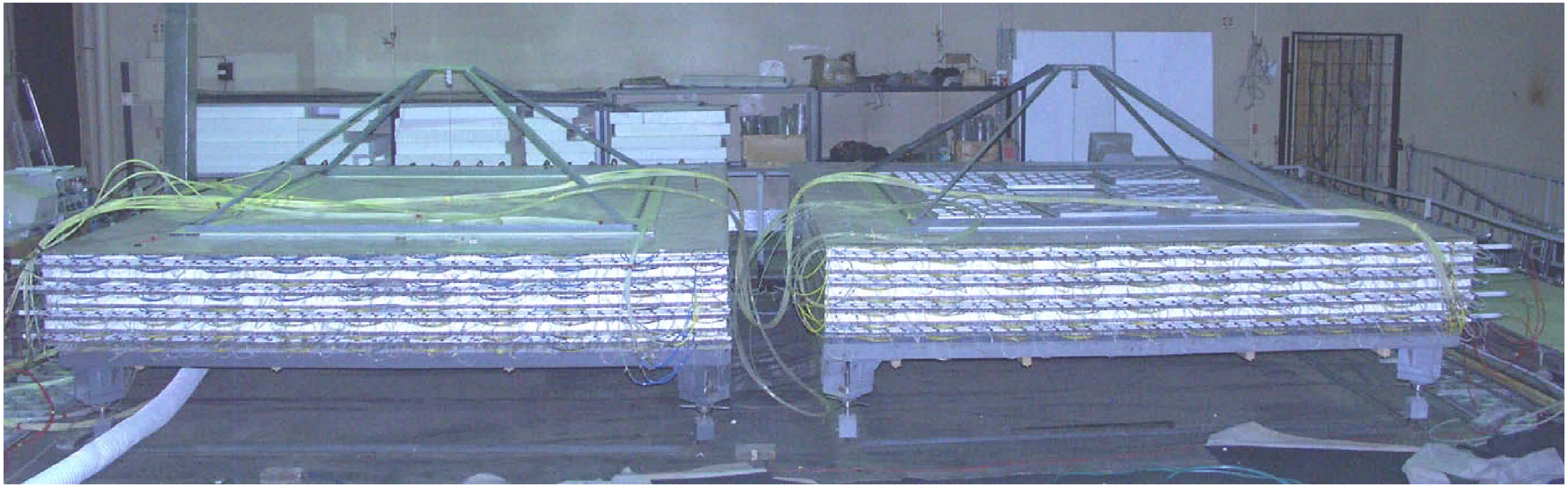
• Required efficiency for charged particle detection for the ACD is 0.9997 over the entire area

• EGRET has experienced the efficiency degradation by 50% at 10 GeV in respect to that at 1 GeV due to backsplash caused self-veto in ACD



• Our goal is to approach at least 300 GeV maintaining at least 80% of the maximum efficiency

Russian-Italian muon hodoscopes



Angular resolution   < 0.7°

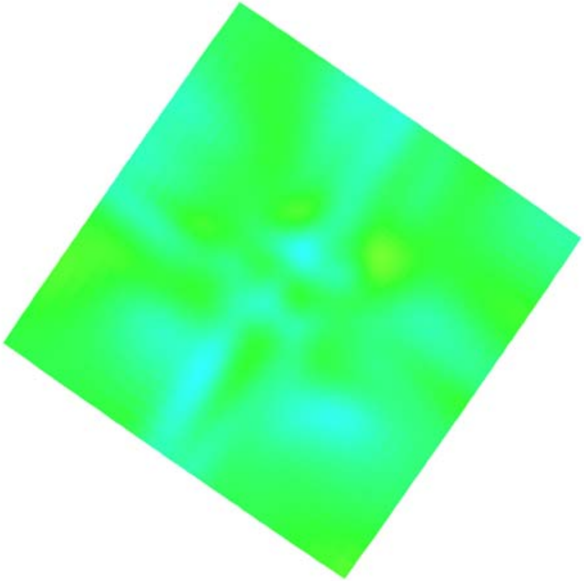
Area   ~ 45 (34.5) м^2

2D-muon intensity matrix:

✓averaging

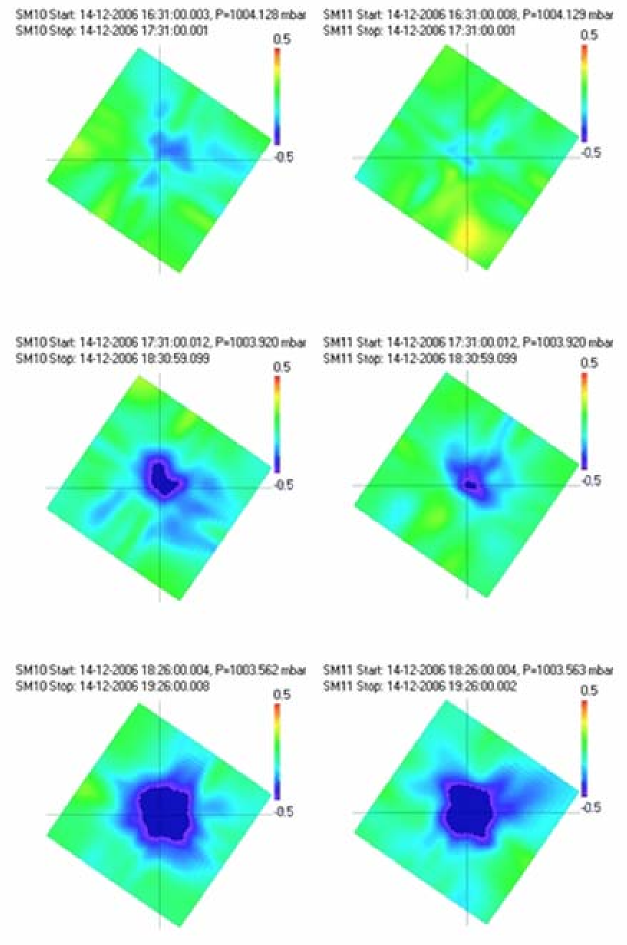
✓normalizing

✓filtering



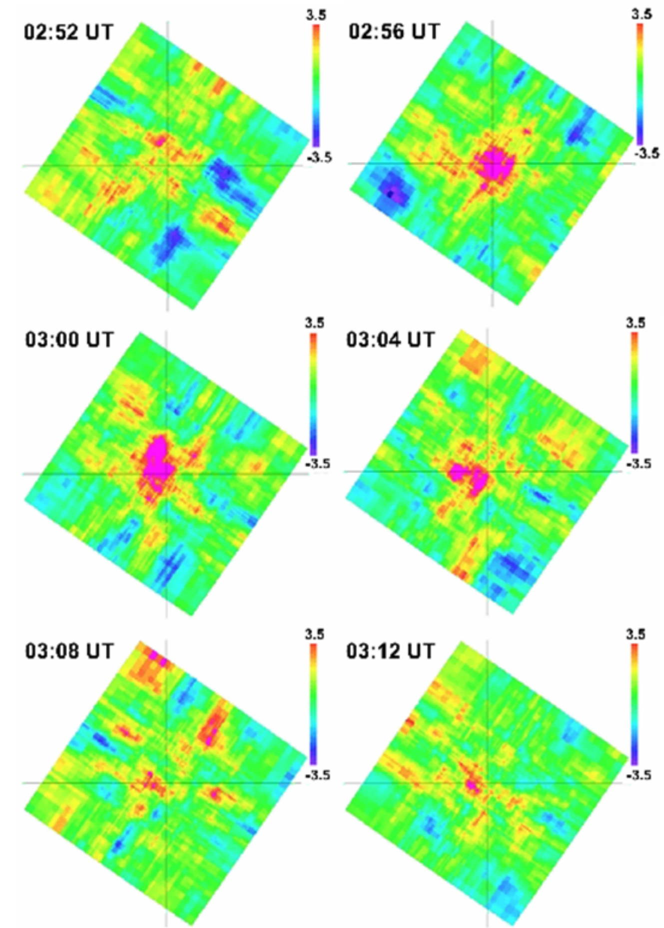
First results

Forbush decrease studies



30th ICRC, SH2.1, ID0305

GLE 2D-dynamics measurements

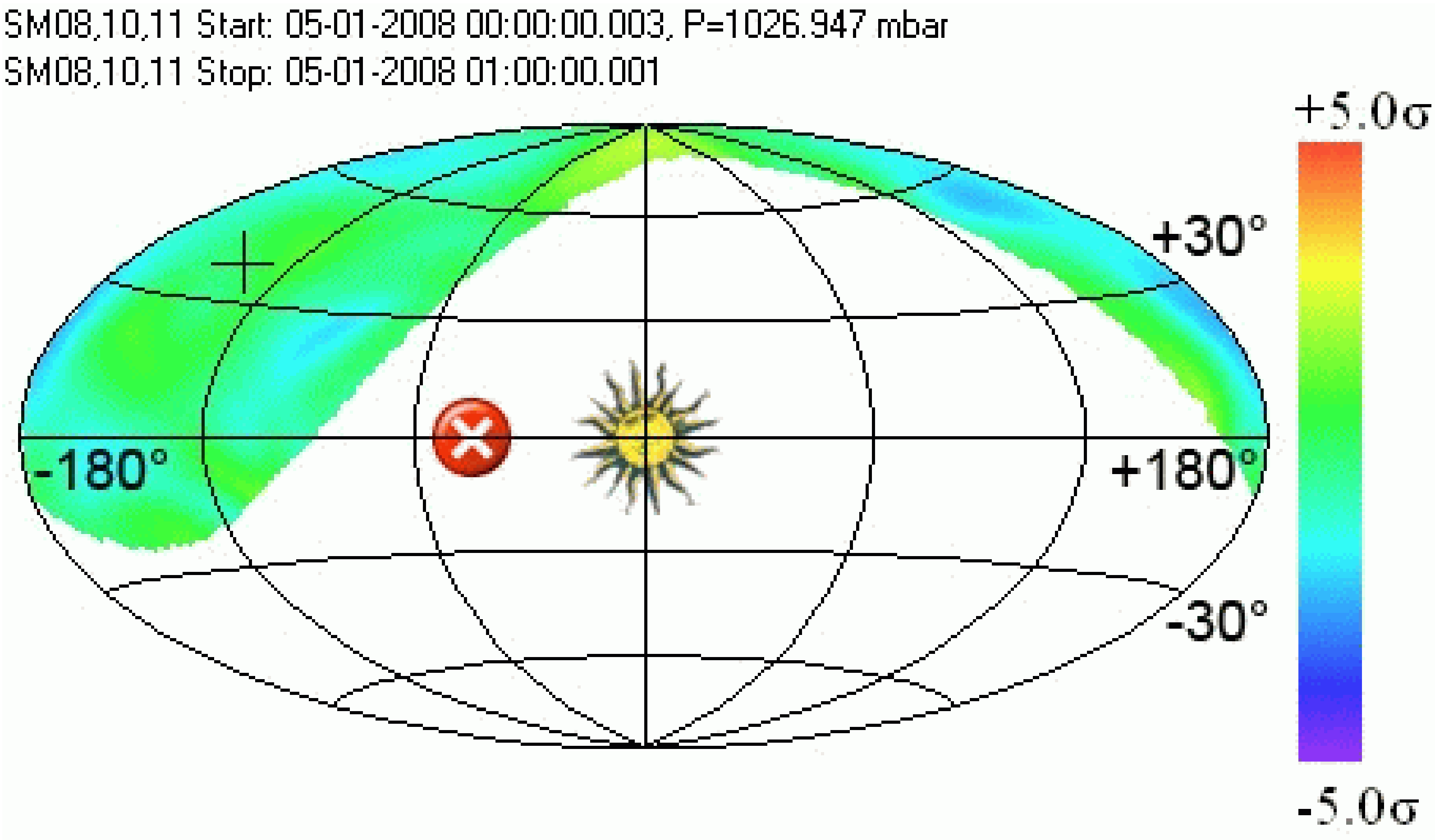


30th ICRC, SH1.8, ID0298

Examples of events January 5, 2008

Turbulance of Bz IMF 02:00

Fast solar wind 16:00



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