The GRAPES-3 Experiment

(Gamma Ray Astronomy at Pev Energies Phase-3)

(An Indian-Japanese collaboration)

ISVHECRI Fermilab, 30 June 2010

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Objective: The universe at the highest energies

The origin, acceleration, propagation of these particles,
Extreme conditions require modification laws of physics …

1. UHE (>10^{14}eV) particles in the galaxy through study of their composition at "Knee" in energy spectrum.
2. Diffuse γ-rays at >100 TeV as probe of highest energy (~10^{20}eV) particles in the universe.
3. Multi-TeV γ-rays from neutron stars, other compact objects.
4. Impact of solar flares, CMEs on Earth and space weather studies.

400 Plastic Scintillator detectors (1 m^2 area)
560 m^2 muon detector (1 GeV) (11.4N, 76.7E)

400 Plastic Scintillator detectors (1 m^2 area)

560 m^2 muon detector (E_{μ}=1 GeV)


114
113
112
073
111

Technology driven activity, with additional requirement of large number of instruments

Plastic Scintillator development:

Decay Time= 1.6 ns
Light Output = 85% Bicron (54% anthracene)
Timing 25% faster
Atten. Length λ= 100cm
Cost ~10% of Bicron
Max Size 100cmX100cm
Total > 1500

CERN, Osaka, IUAC Delhi, Bose, VECC, Agra etc.

Signal processing electronics & detection:

(1) Fast Amplifiers with >300 MHz bandwidth

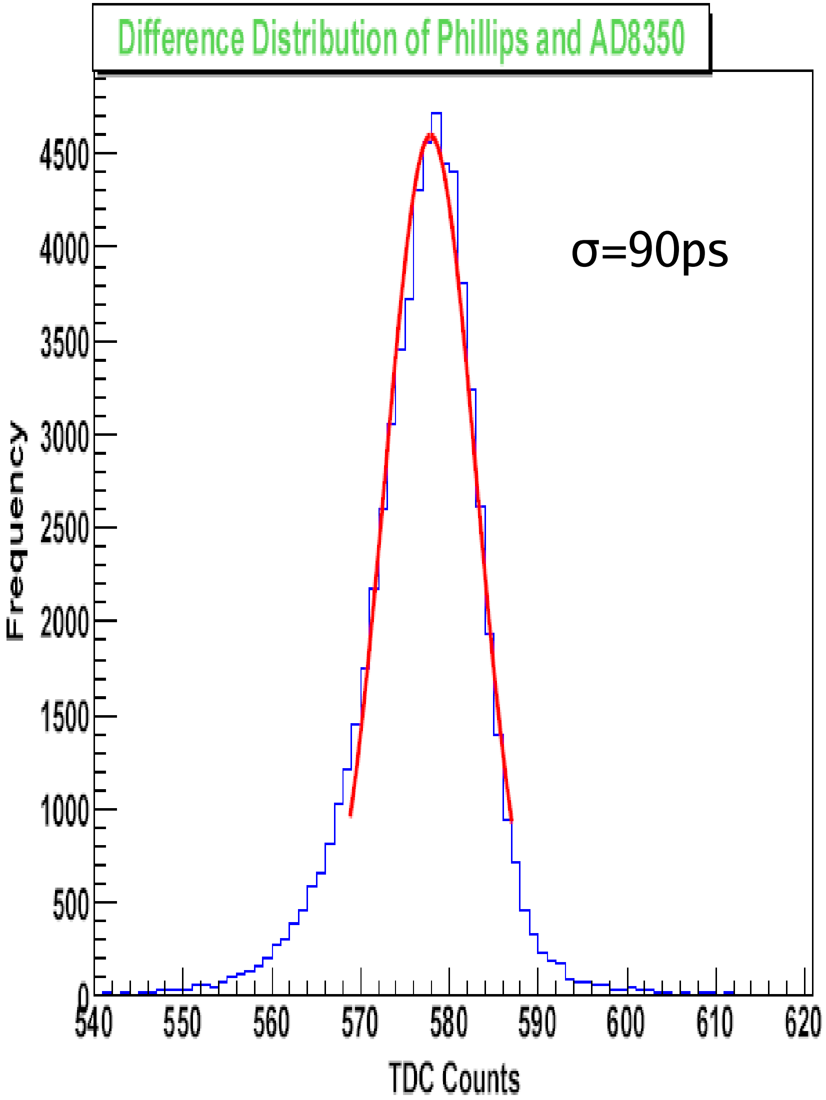
(2) Fast Discriminators with <100 ps time jitter

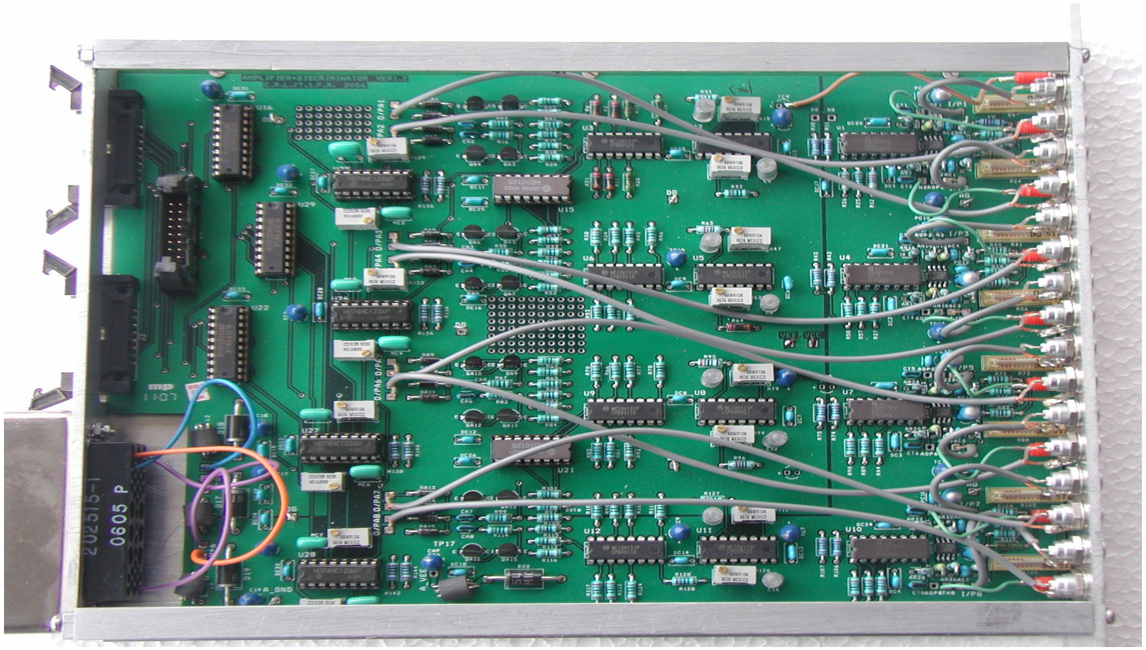
(3) Charge integrating ADCs ≥12 bit dynamic range

(4) Time measurement TDCs ≥12 bit, 100 ps
multi-hit, triggered operation

(5) Si photomultiplier, high quantum efficiency, high
photon resolution

Amplifier-Discriminator response using muons

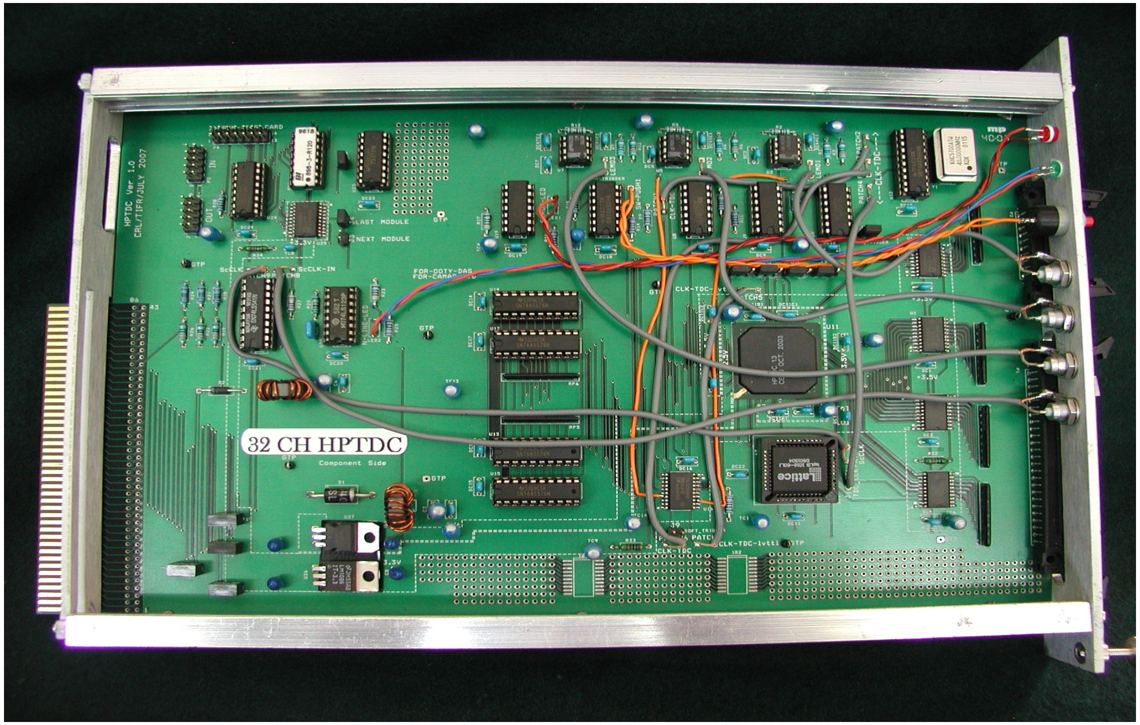


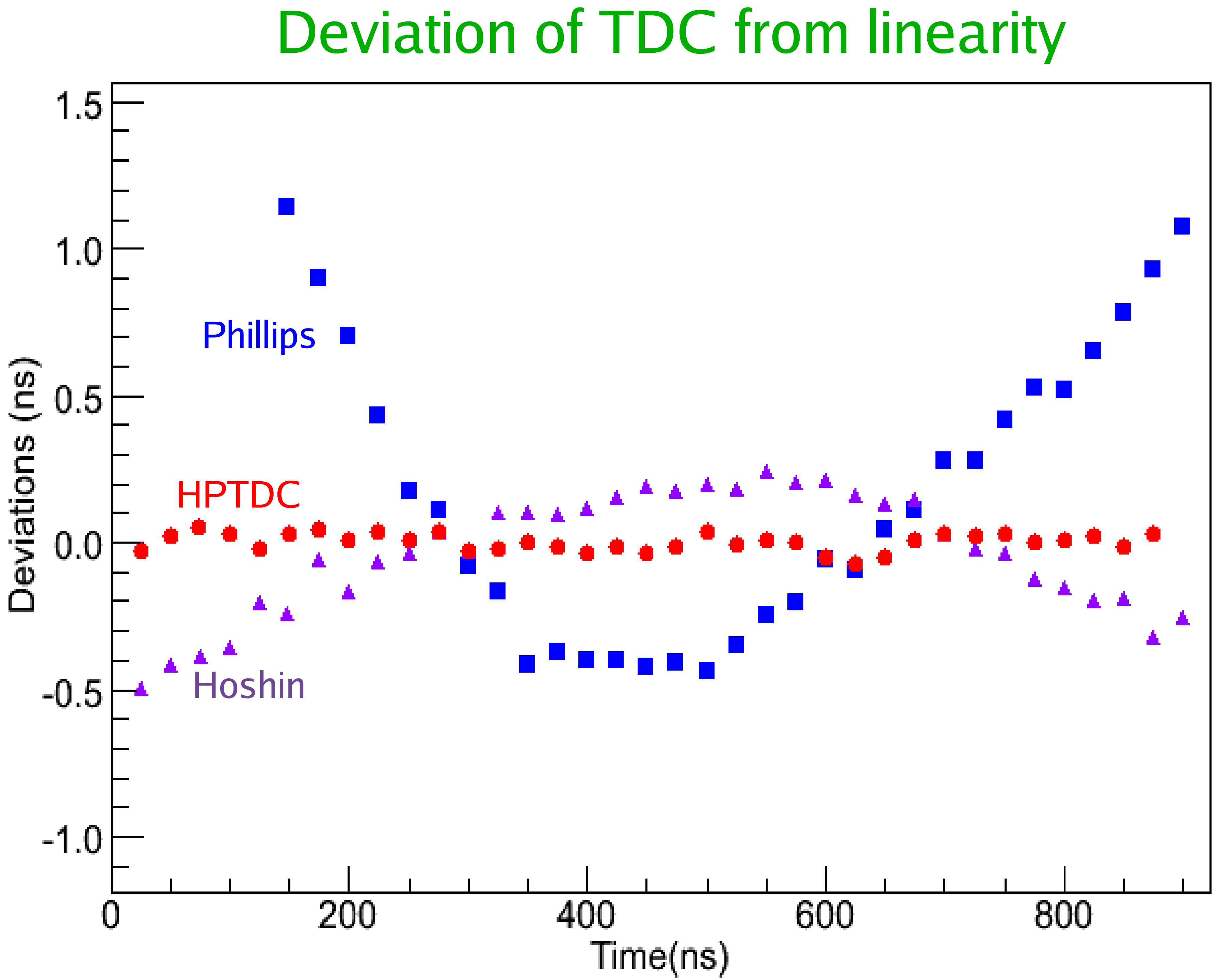


Performance of HPTDC

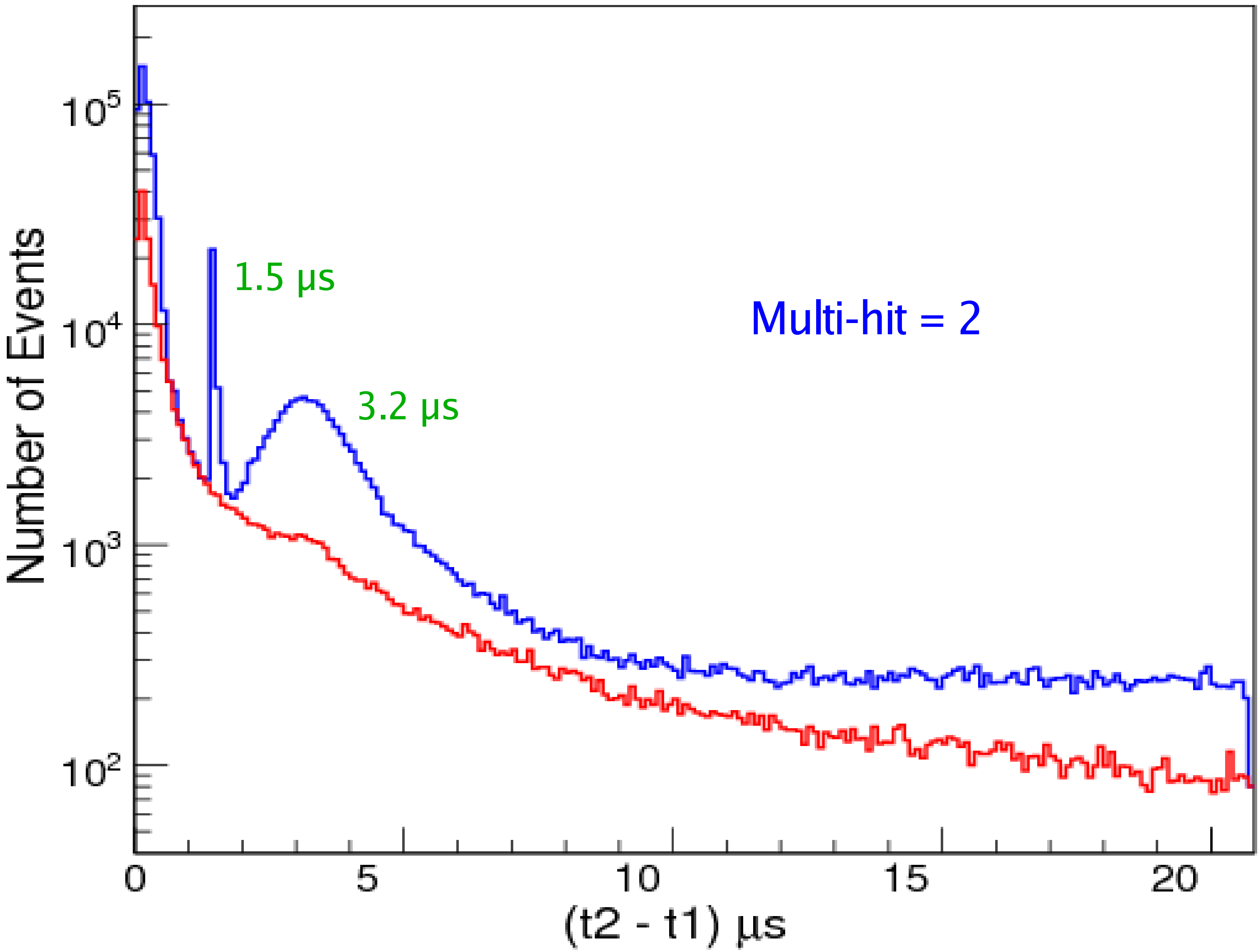
32 Channels
100 ps time resolution
Multi-hit capability
Huge dynamic range (100 ps - 50 μs)
Trigger mode (avoids delay cables)

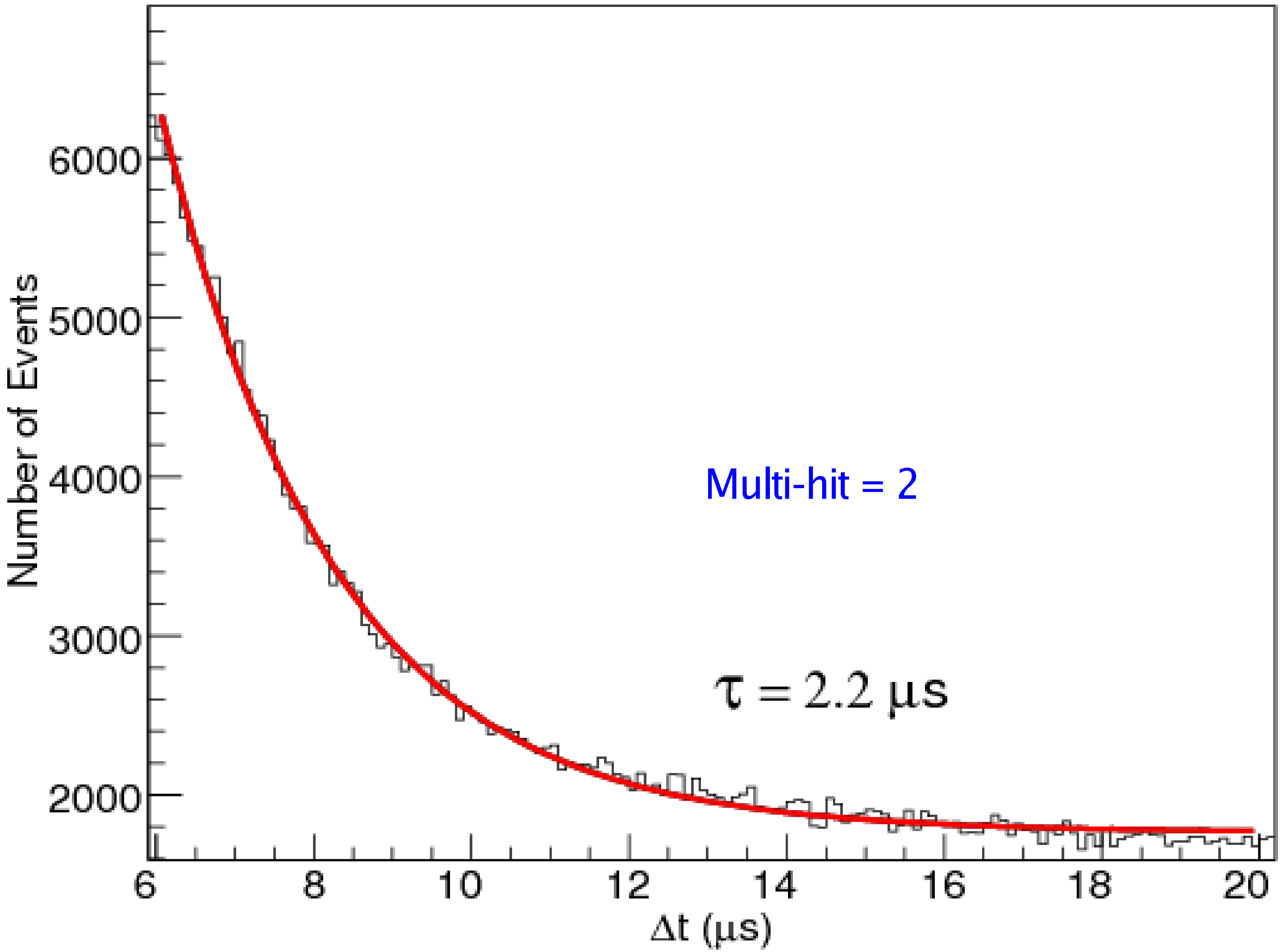
Requests: Single photon (chem, bio) TIFR, Oulu Finland, IUAC New Delhi, Bose Institute etc.





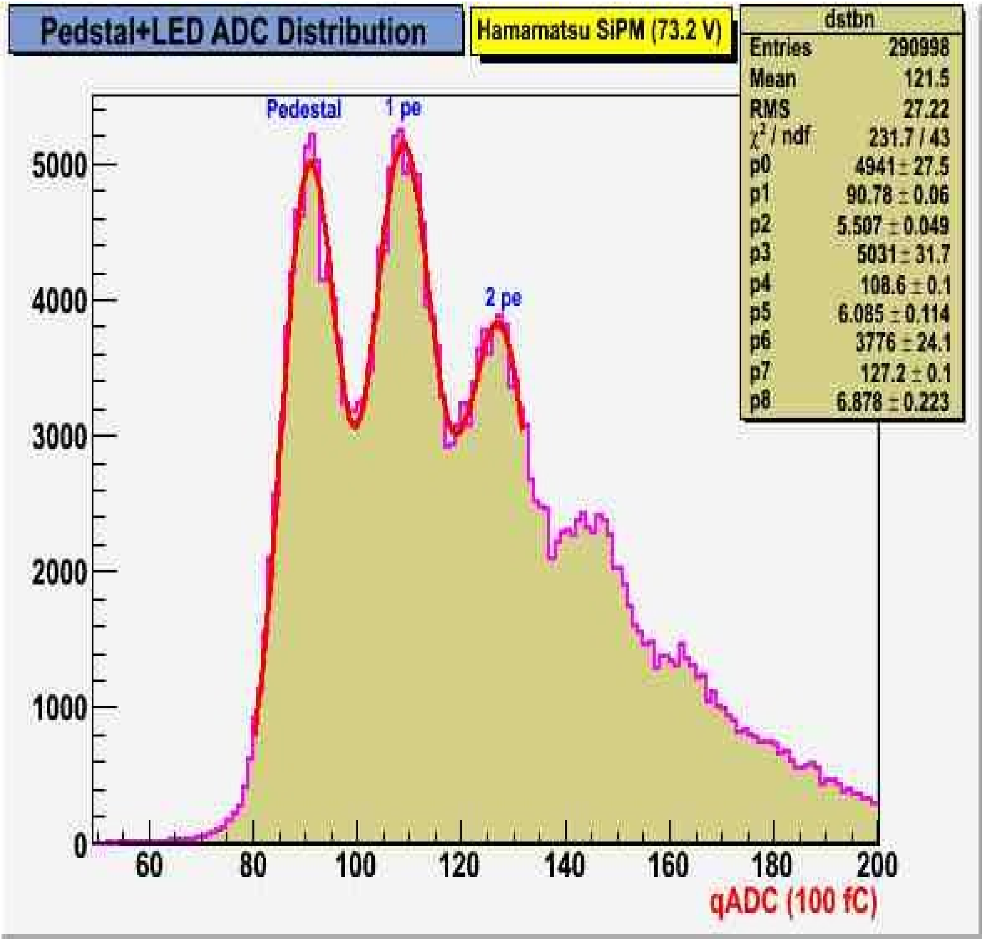
Deviation of TDC from linearity
1.5
1.0
0.5
0.0
-0.5
-1.0
Deviations (ns)
Phillips
HPTDC
Hoshin
0
200
400
600
800
Time(ns)

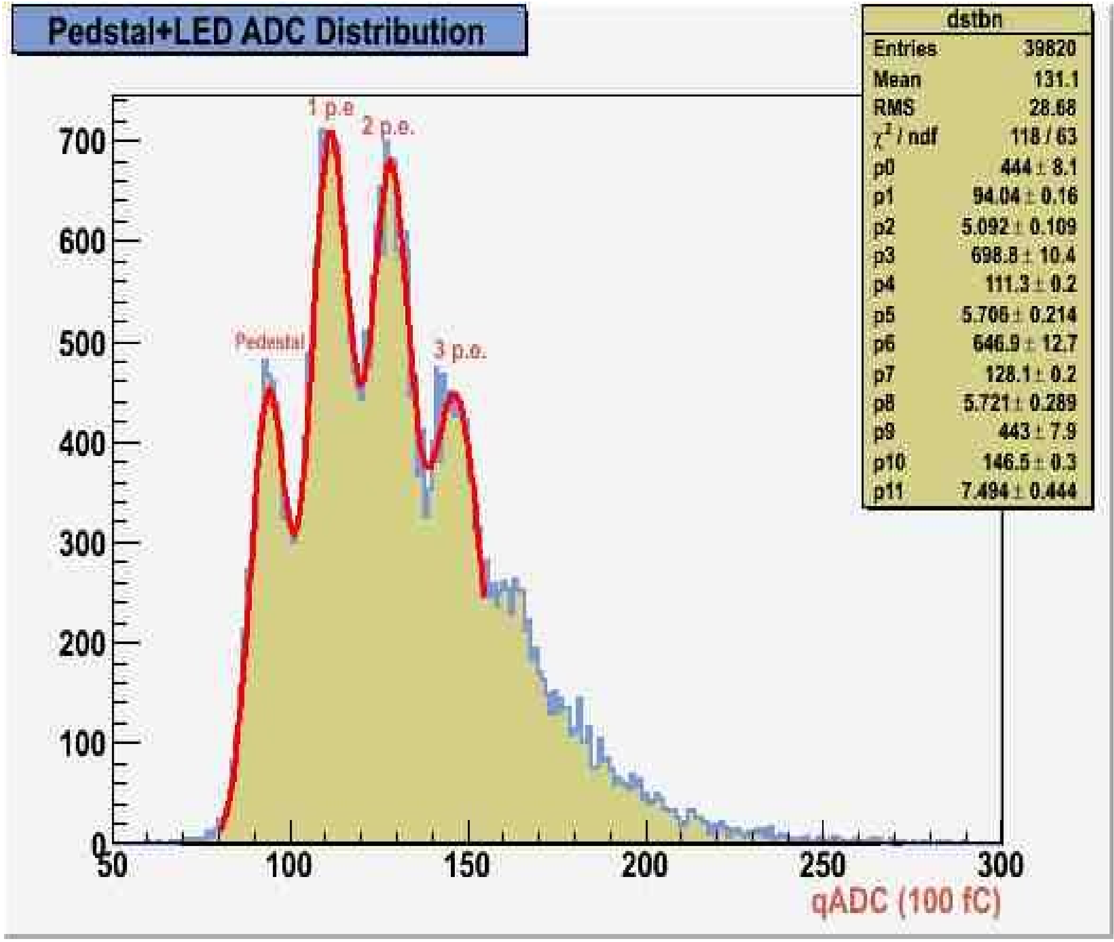

1.5 μs
Multi-hit = 2
3.2 μs
Number of Events
10^5
10^4
10^3
10^2
0
5
10
15
20
(t2 - t1) μs



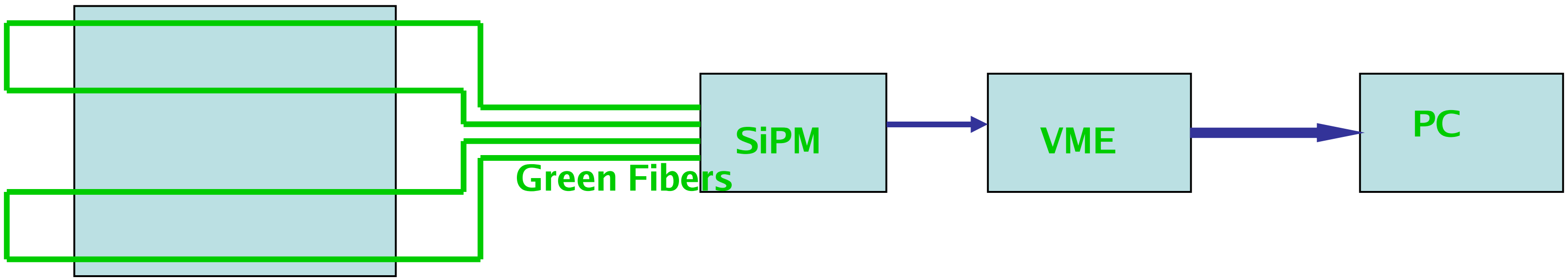
Number of Events
6000
5000
4000
3000
2000
6
8
10
12
14
16
18
20
Δt (μs)
Multi-hit = 2
τ = 2.2 μs

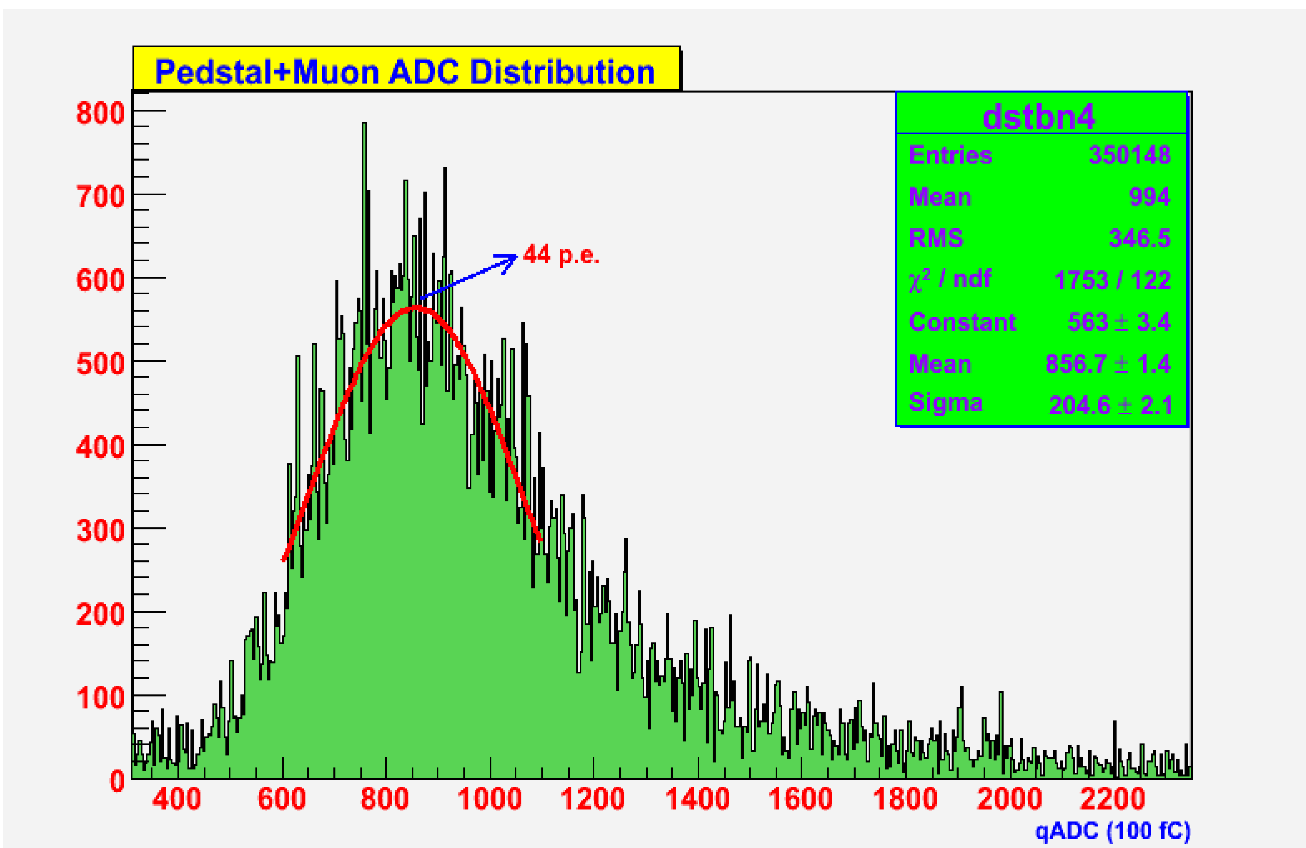
SiPM Results using LED as a Source





MIP Signal with SiPM





Scintillator Size
25x25x1 cm^3

Ped. Peak = 90.3
Single p.e.= 17.4
p.e. at peak = 44
p.e. at mean ~ 50

QE: SiPM=3xPMT

ROOT Based Data Analysis

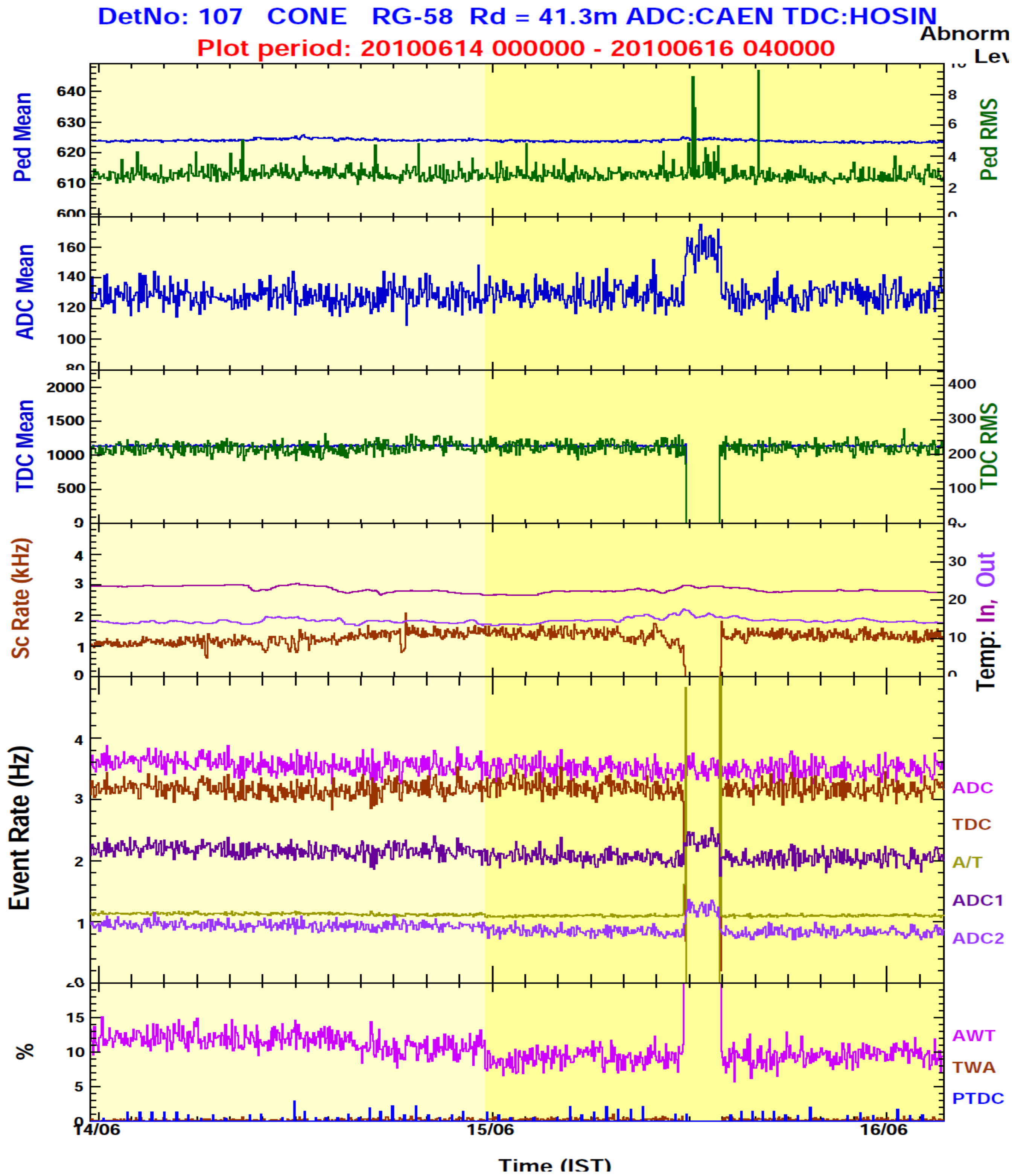
A modular, efficient ROOT based framework is being developed for the analysis of GRAPES-3 data. Use of OOP allowed independent development of code and portability.

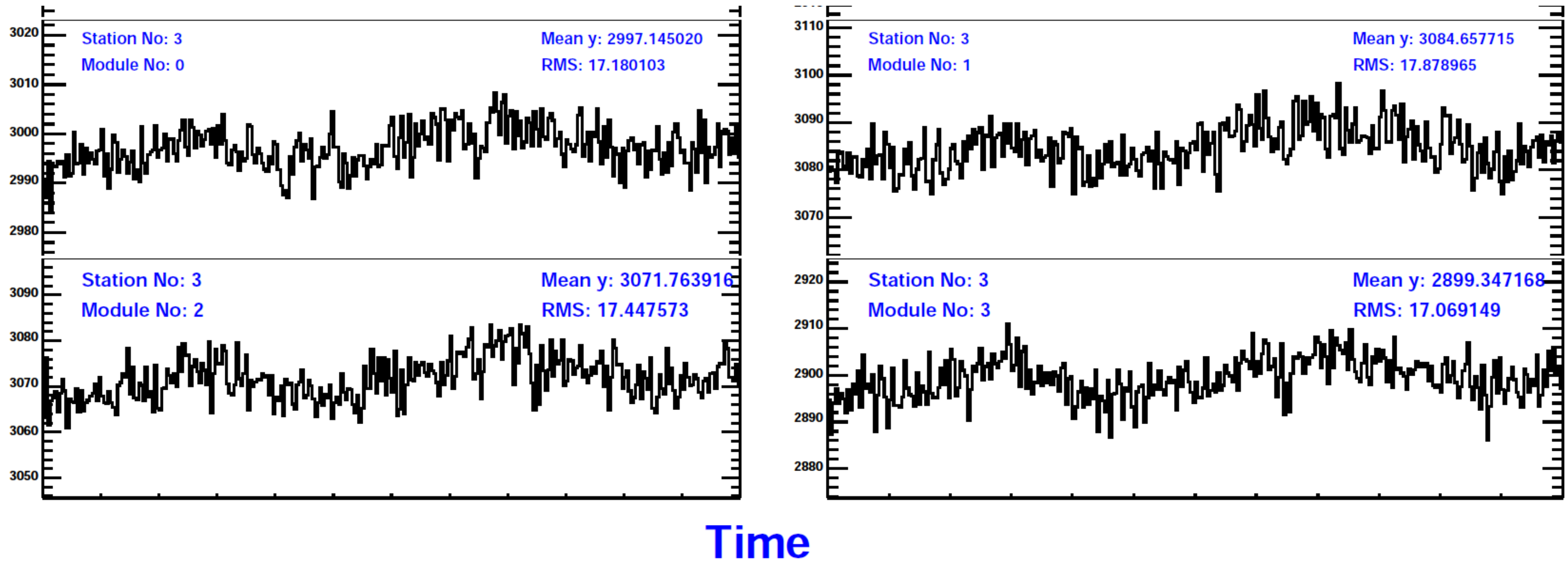
Tasks completed:

Conversion of shower (scintillator) and muon (proportional counter) data.

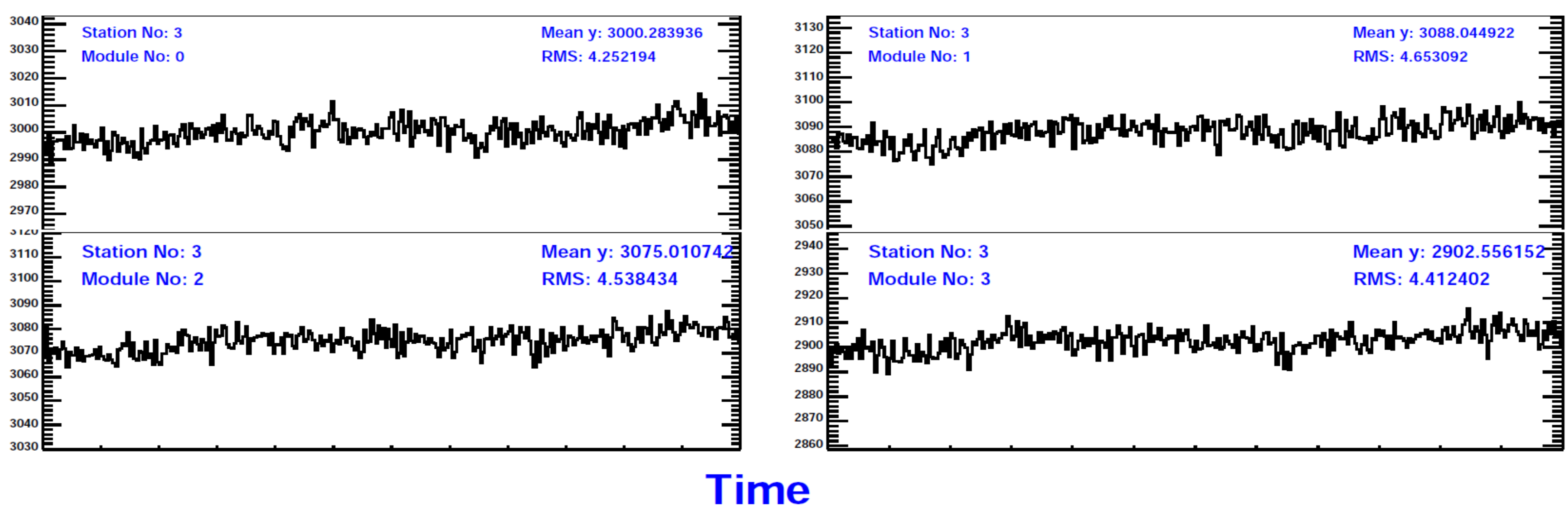
Integration of calibration and other important house-keeping data. Efficient monitoring tools to aid trouble-shooting.

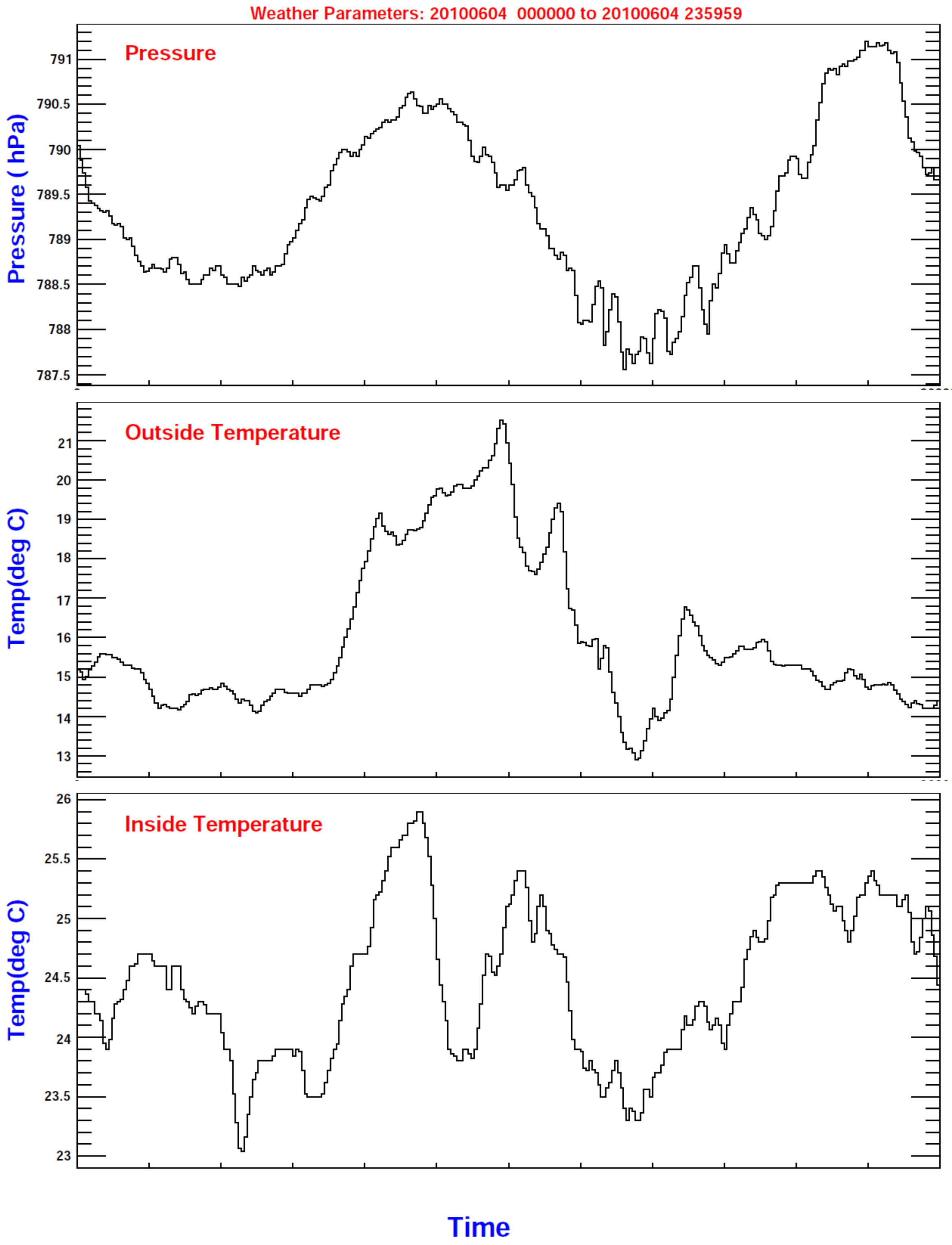
Online solar flare and CME watch


DetNo: 107 CONE RG-58 Rd = 41.3m ADC:CAEN TDC:HOSIN
Plot period: 20100614 000000 - 20100616 040000
Ped Mean
Ped RMS
ADC Mean
TDC Mean
TDC RMS
Sc Rate (kHz)
Temp: In, Out
Event Rate (Hz)
ADC
TDC
A/T
ADC1
ADC2
%
AWT
TWA
PTDC
14/06
15/06
16/06
Time (IST)



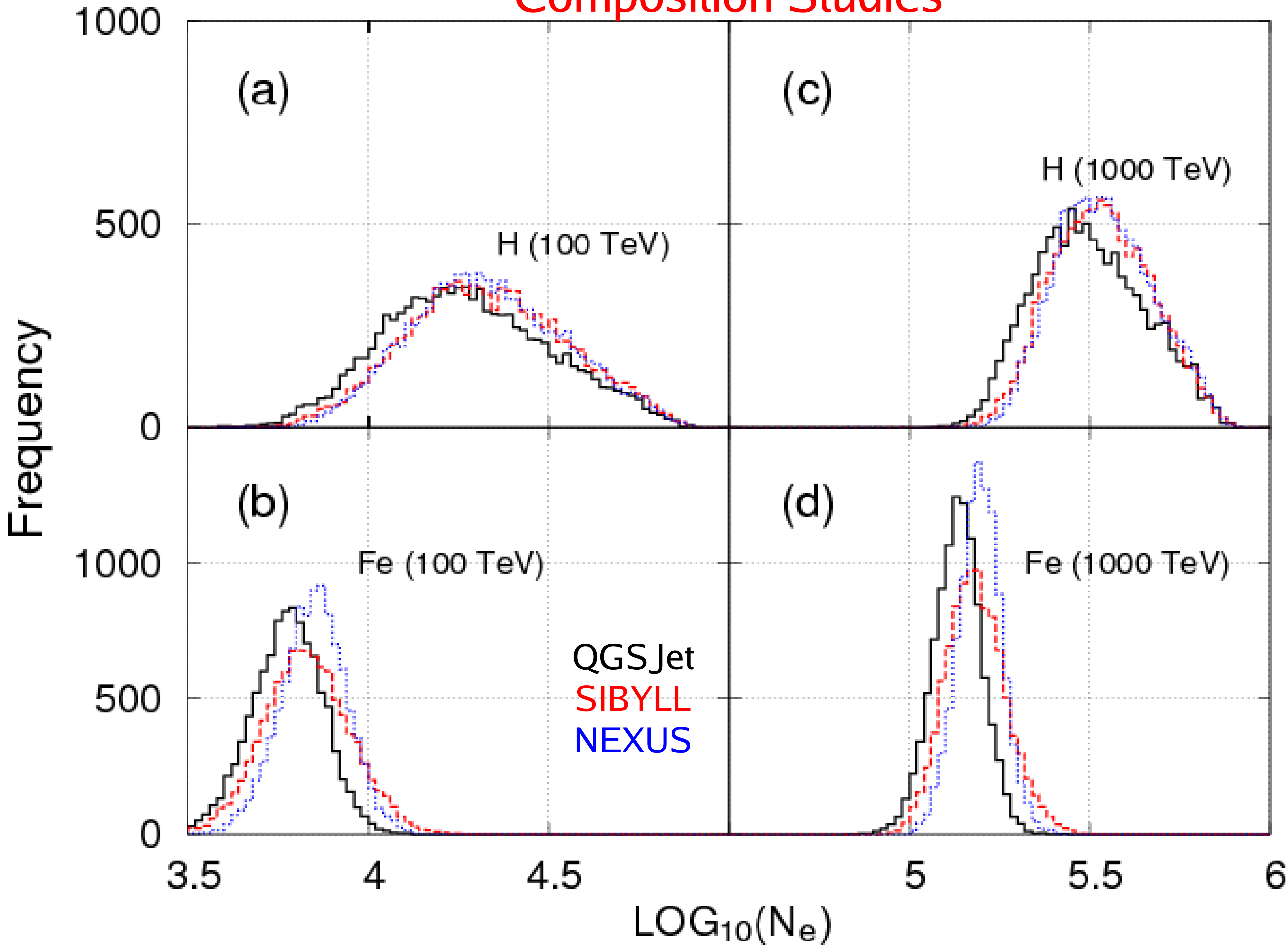
Pressure corrected Inclusive Mean Angle Rate (Hz) after validation: 20100604 000000 to 20100604 235959

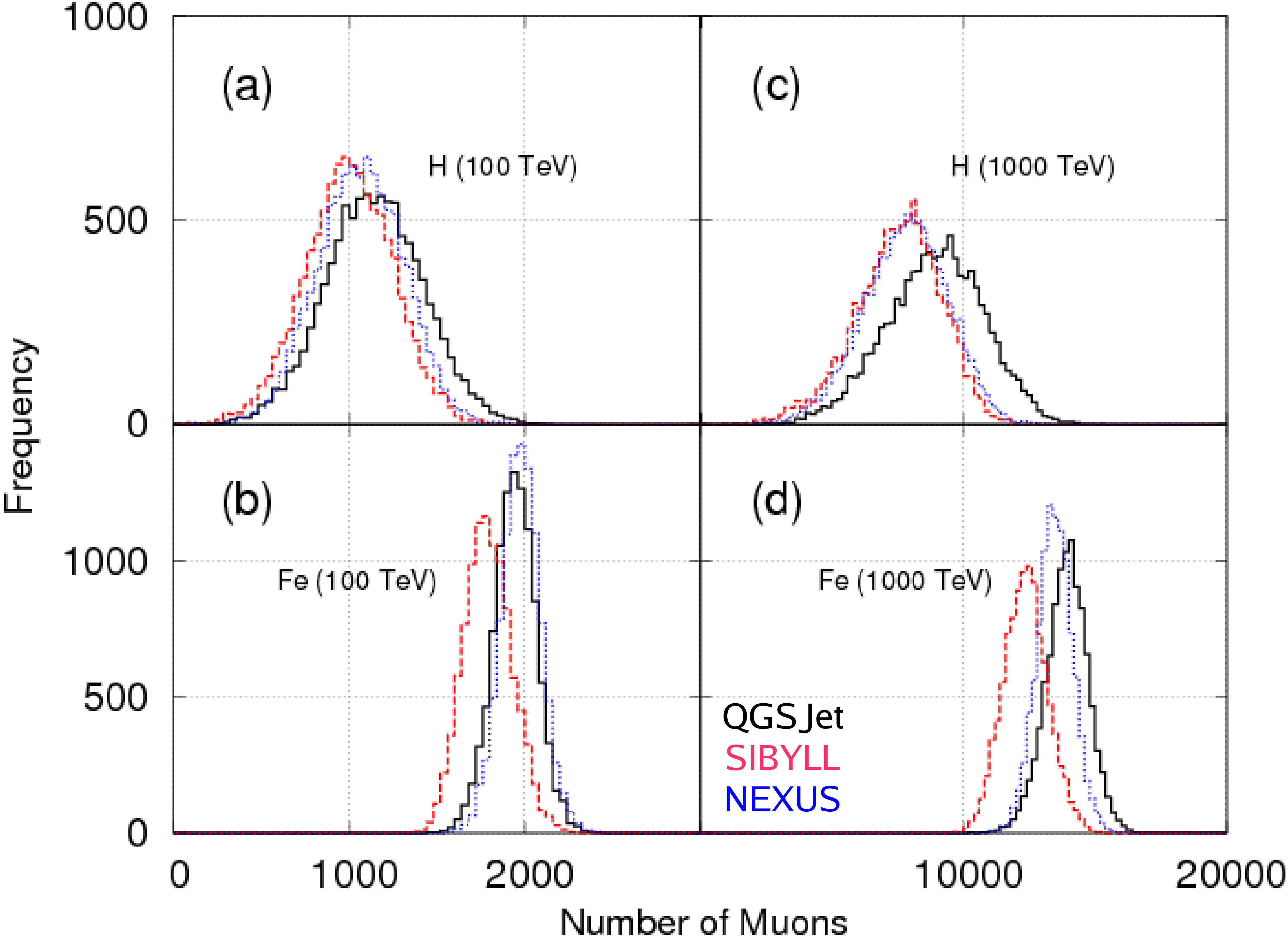




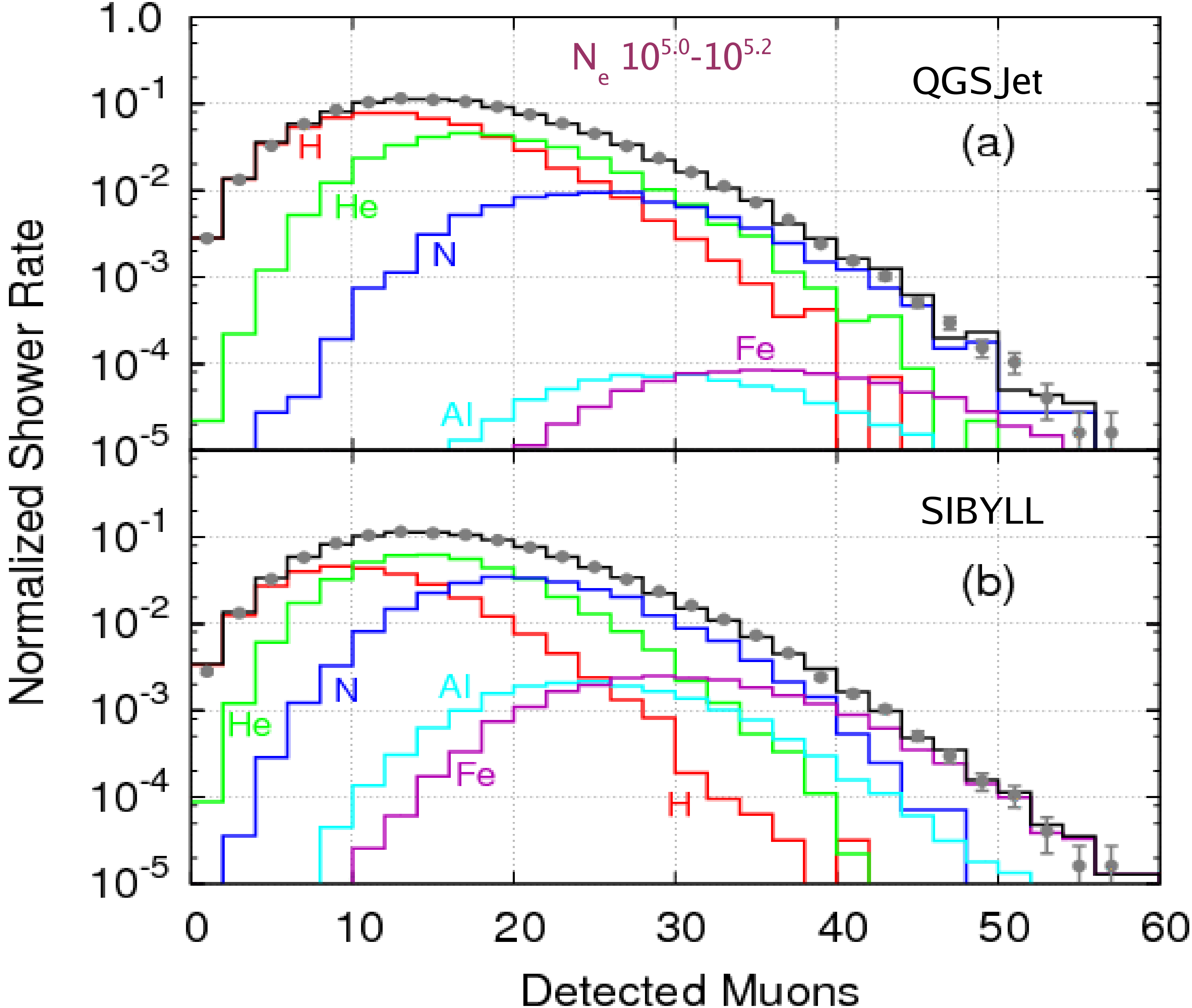
Weather Parameters: 20100604 000000 to 20100604 235959
Pressure
Pressure (hPa)
791
790.5
790
789.5
789
788.5
788
787.5
Outside Temperature
Temp(deg C)
21
20
19
18
17
16
15
14
13
Inside Temperature
Temp(deg C)
26
25.5
25
24.5
24
23.5
23
Time

Composition Studies



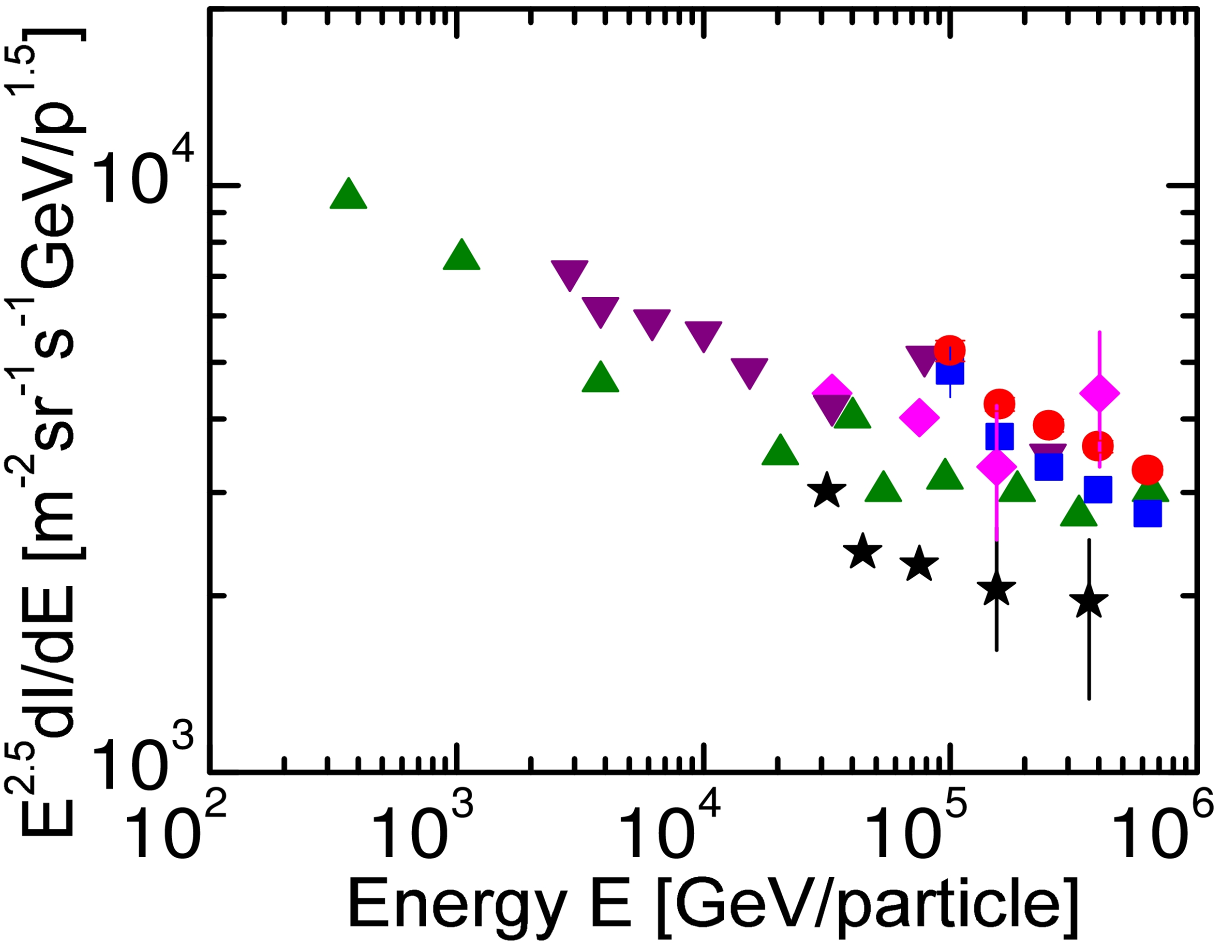


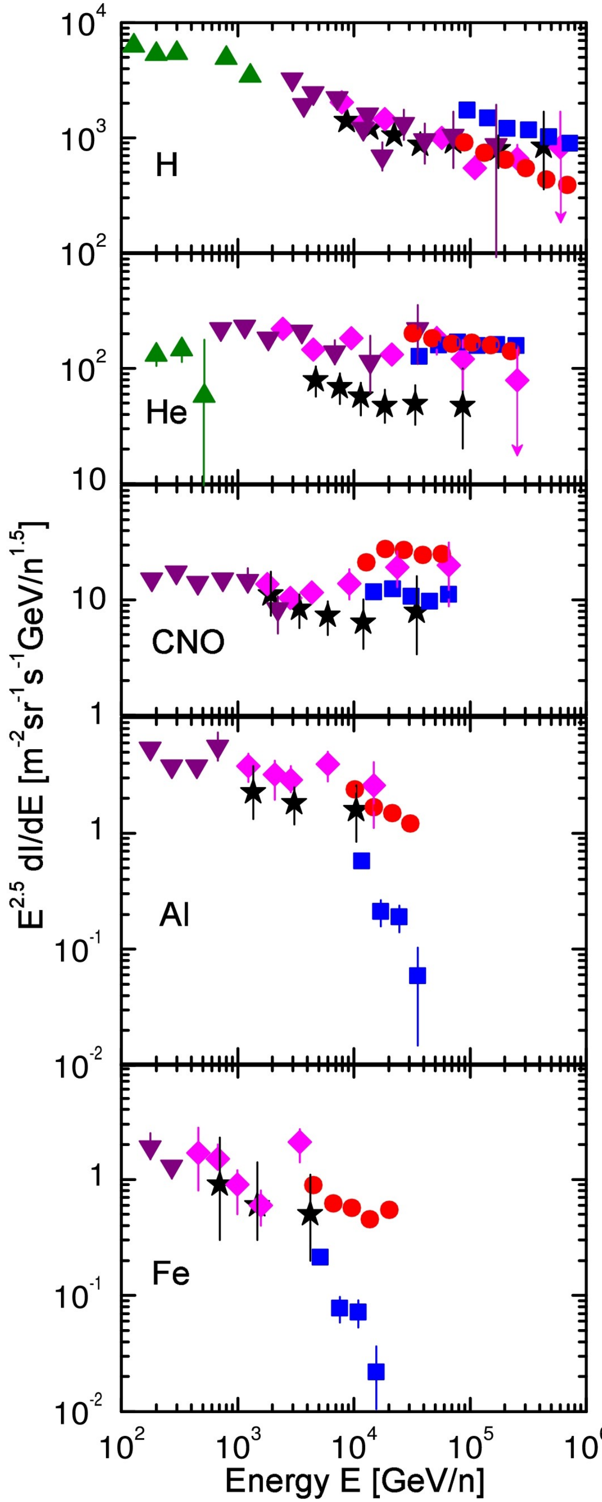
1000
500
0
1000
500
0
Frequency
(a)
H (100 TeV)
(c)
H (1000 TeV)
(b)
Fe (100 TeV)
(d)
Fe (1000 TeV)
QGSJet
SIBYLL
NEXUS
0
1000
2000
10000
20000
Number of Muons

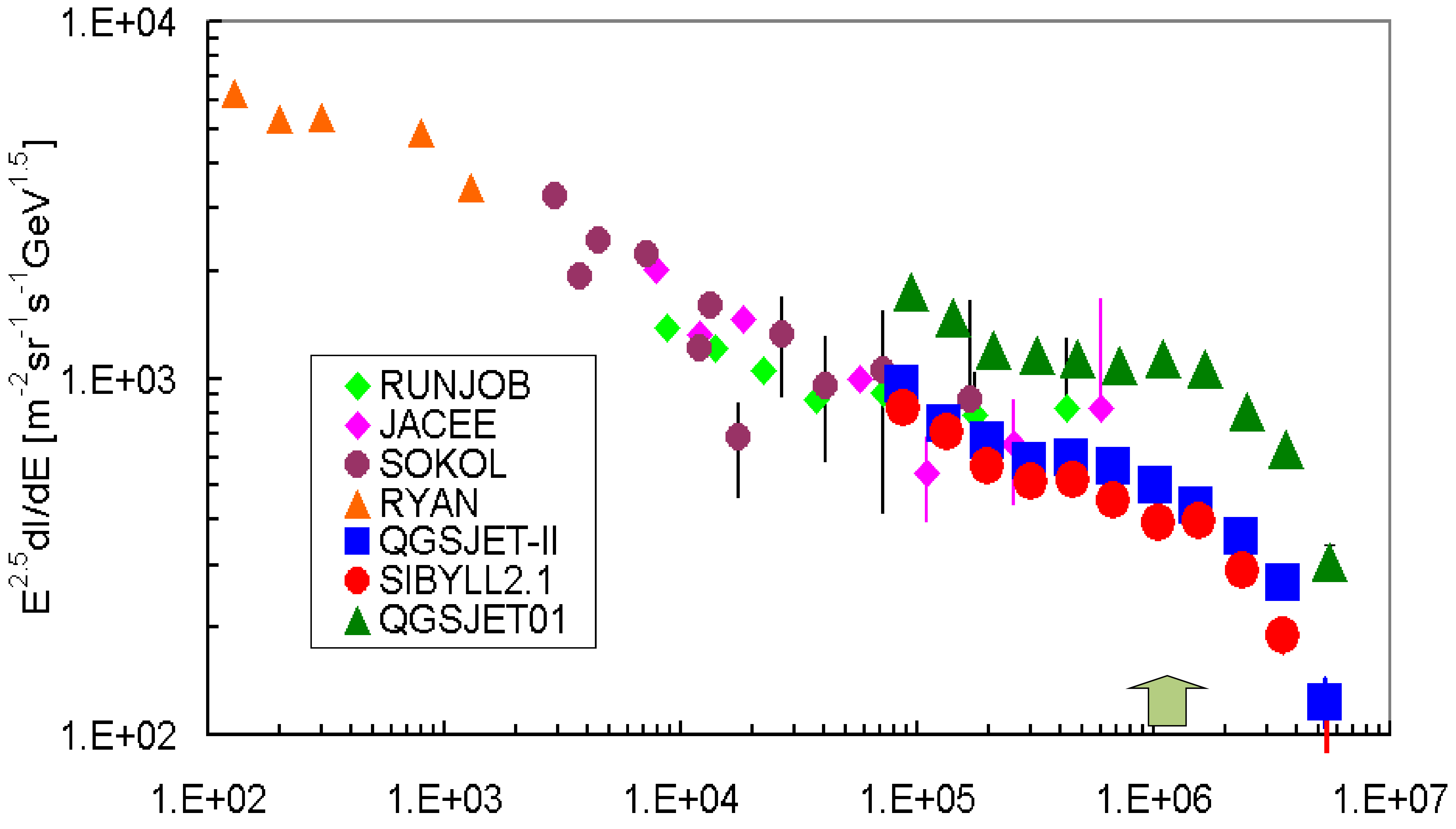


Normalized Shower Rate
Detected Muons
N_e $10^{5.0}$-$10^{5.2}$
QGSJet
(a)
SIBYLL
(b)
H
He
N
Al
Fe
1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60

All particle energy spectrum

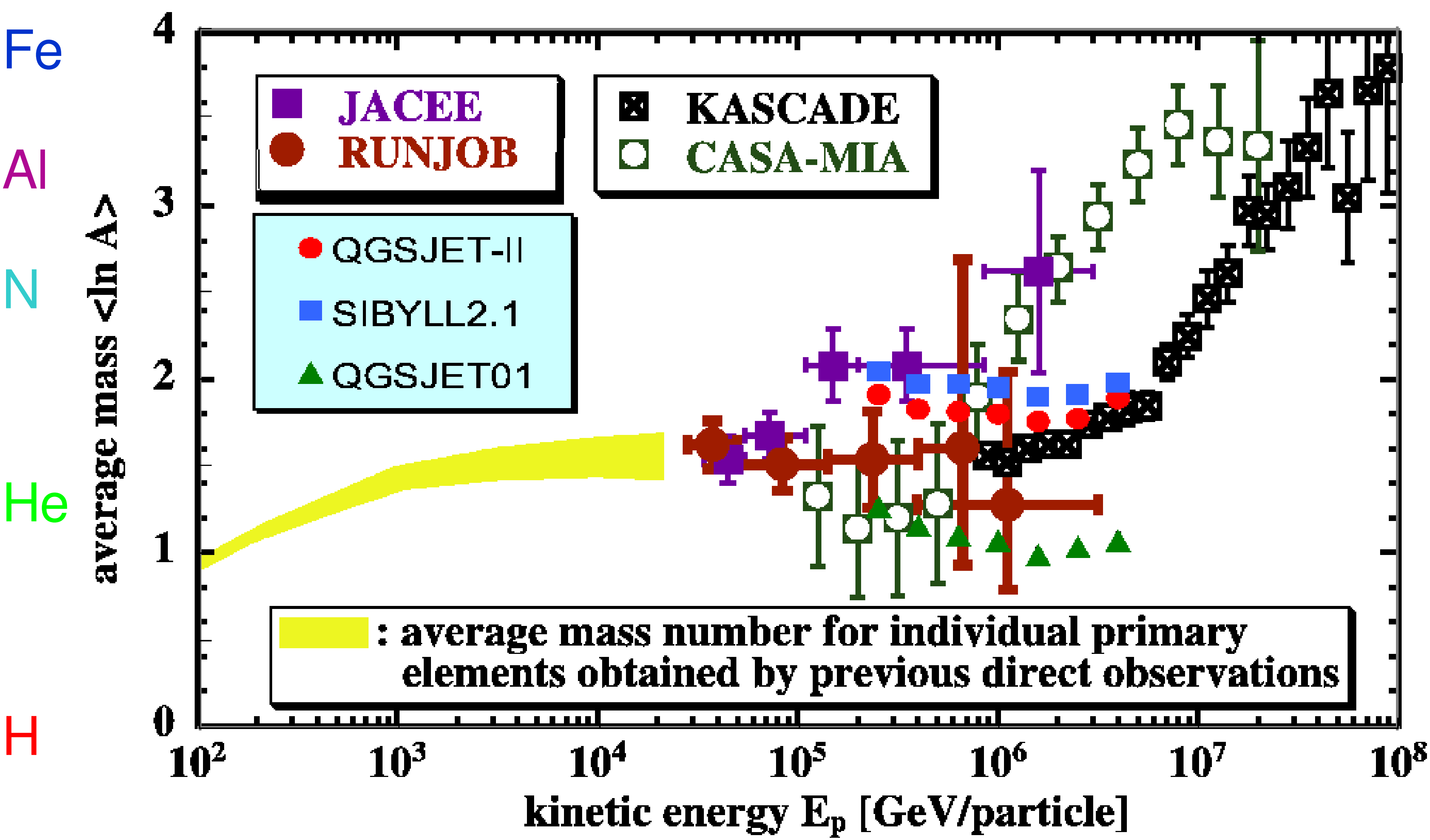




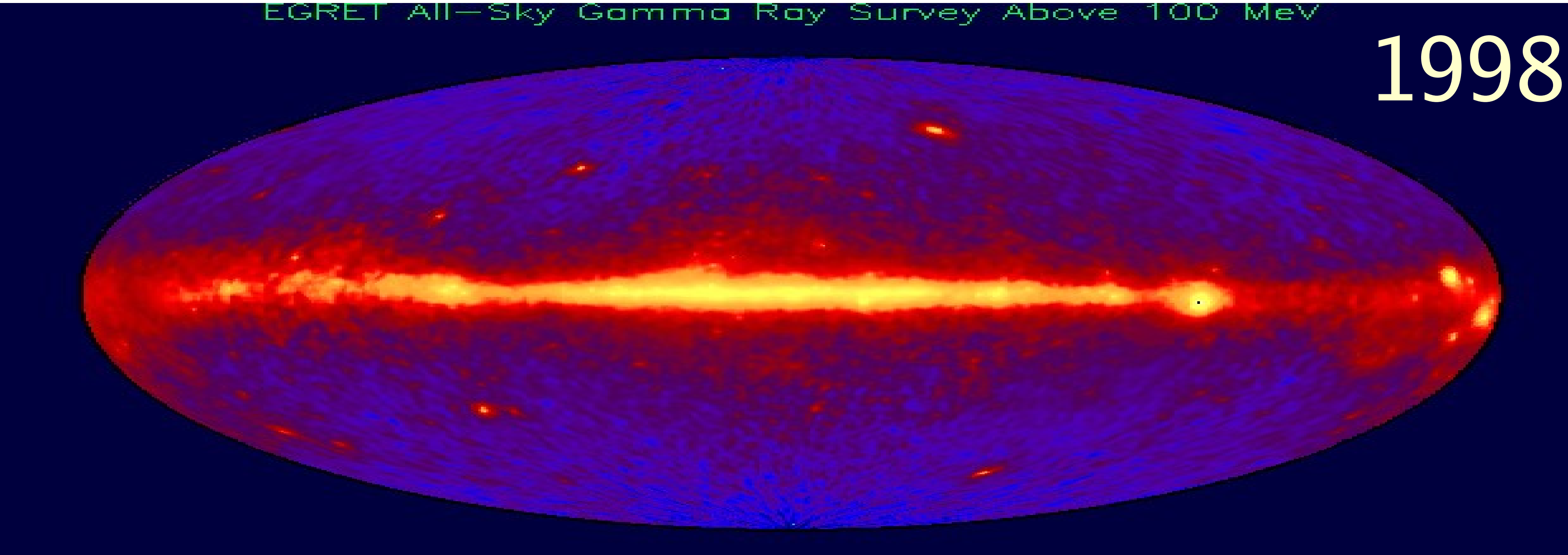


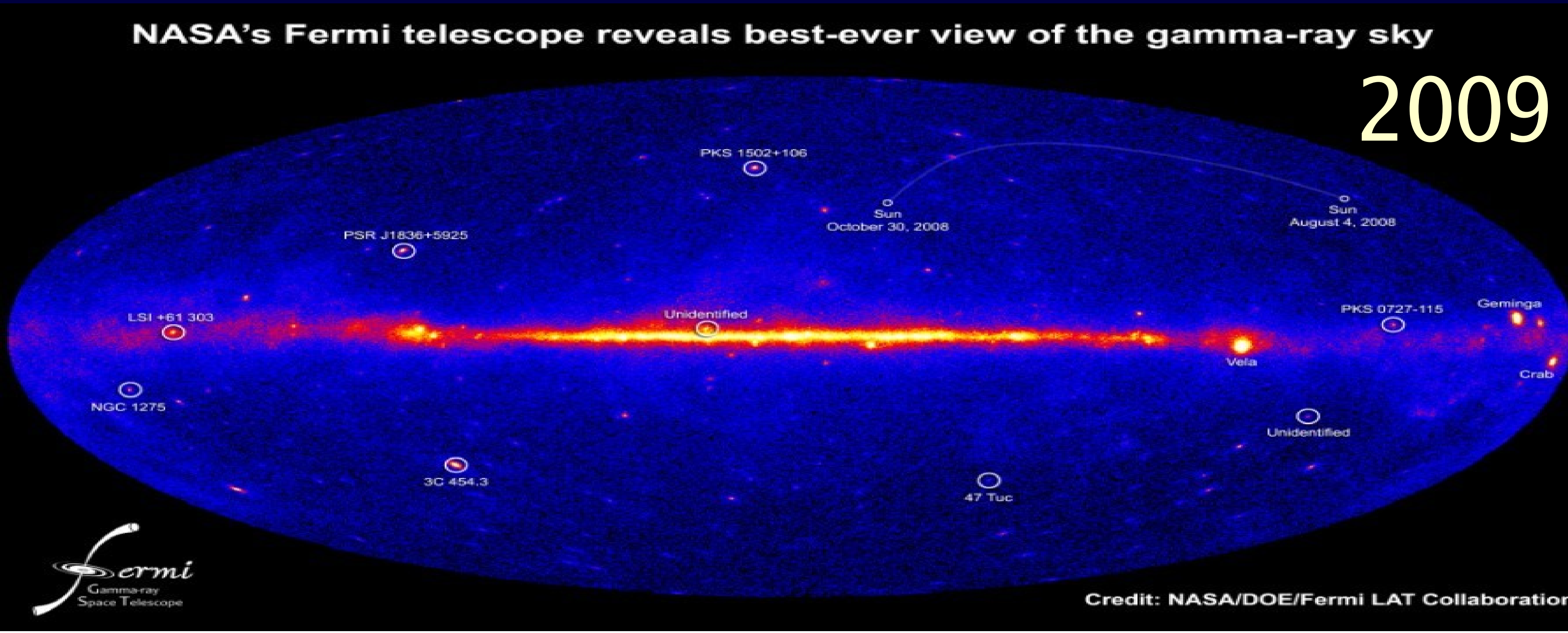
Comparison with direct measurements is possible

Mean Mass Number



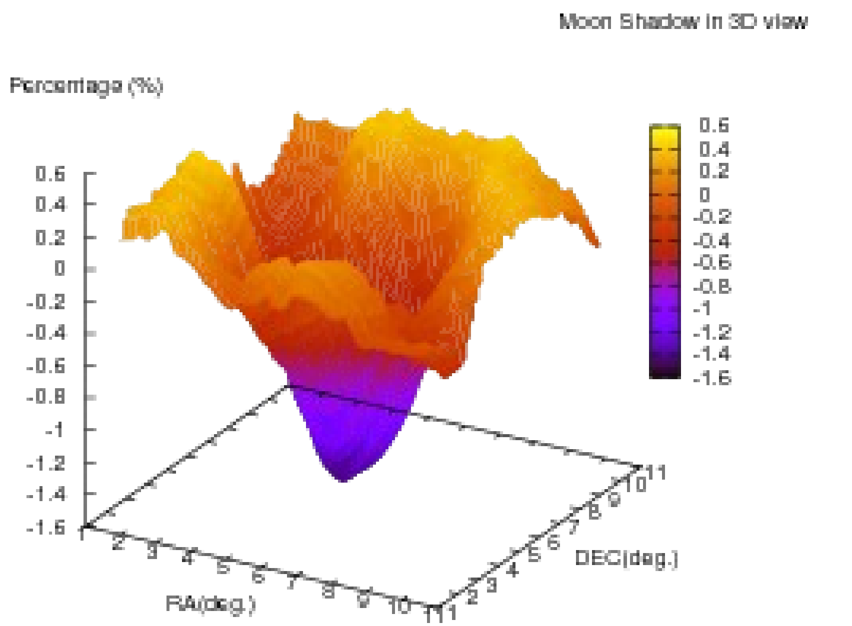
Lower threshold enables data to compare with direct measurements.

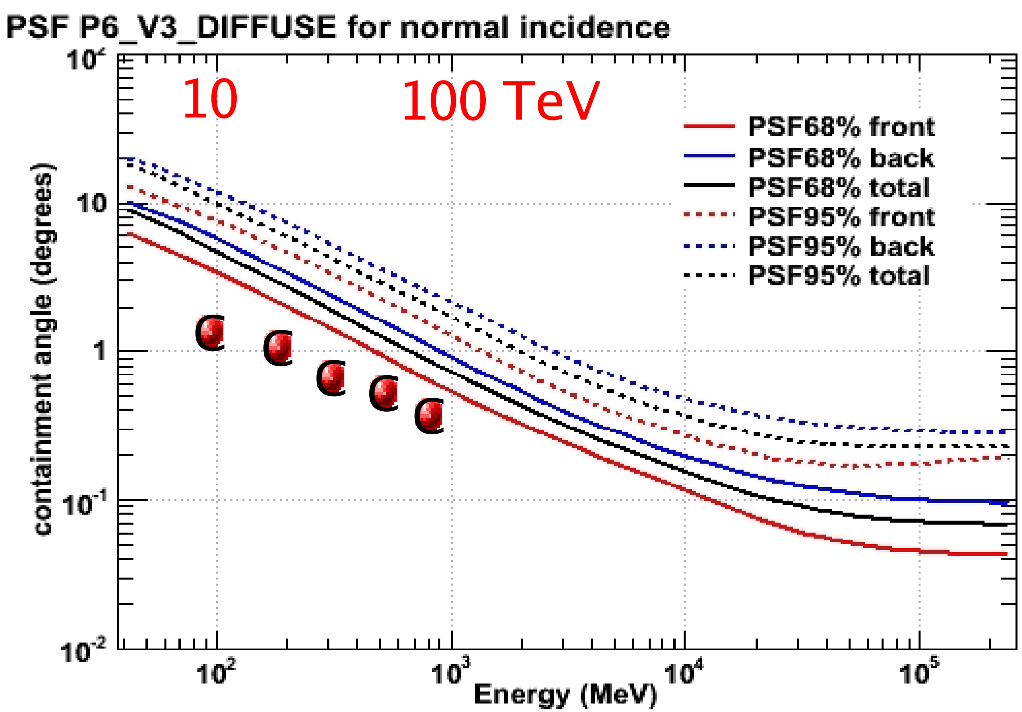

EGRET All-Sky Gamma Ray Survey Above 100 MeV
1998


NASA's Fermi telescope reveals best-ever view of the gamma-ray sky
2009
PKS 1502+106
Sun
October 30, 2008
Sun
August 4, 2008
PSR J1836+5925
LSI +61 303
Unidentified
PKS 0727-115
Geminga
Vela
Crab
NGC 1275
Unidentified
3C 454.3
47 Tuc
Fermi
Gamma-ray
Space Telescope
Credit: NASA/DOE/Fermi LAT Collaboration

Moon Shadow

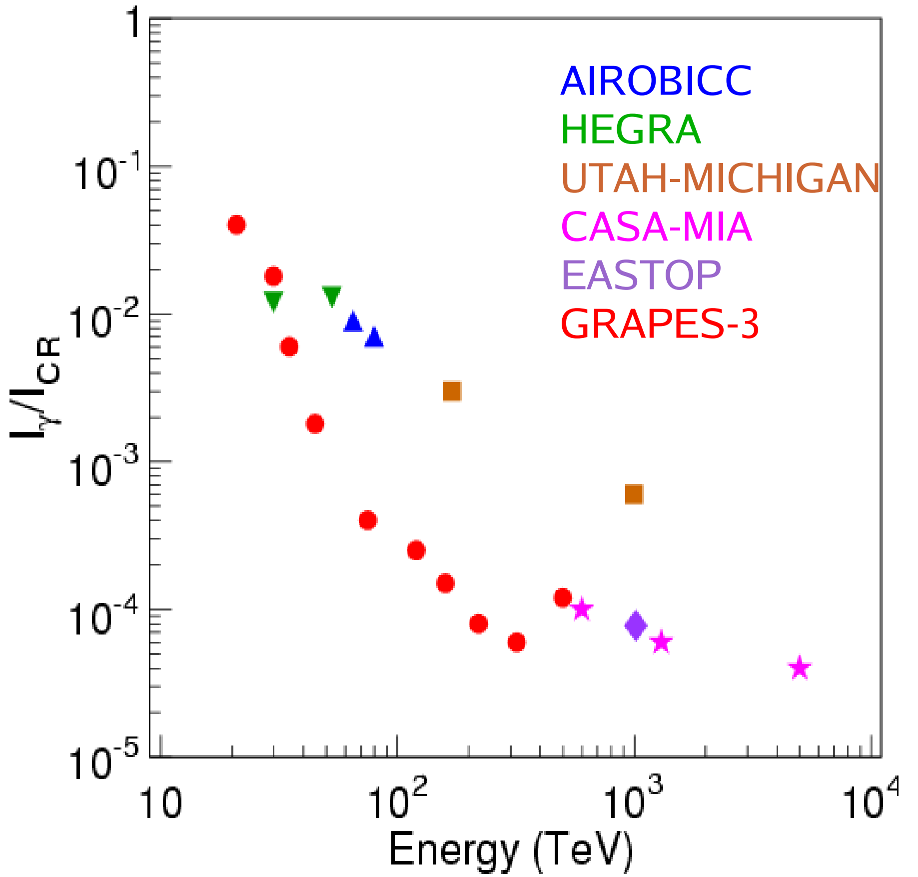
Moon



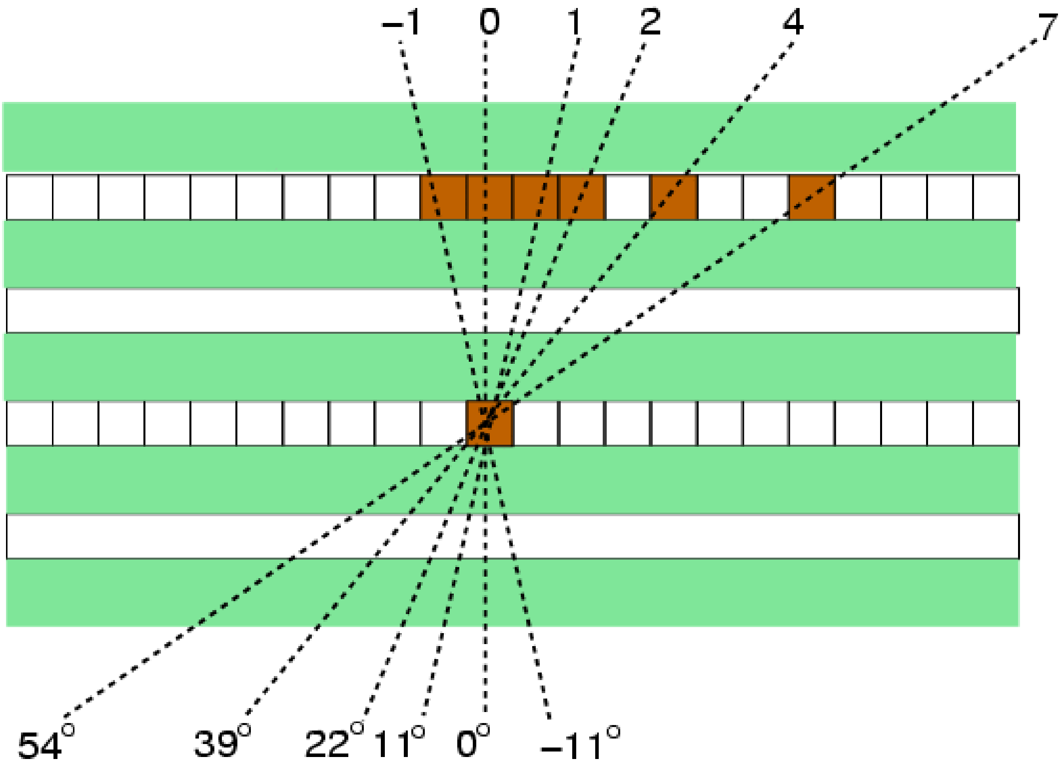


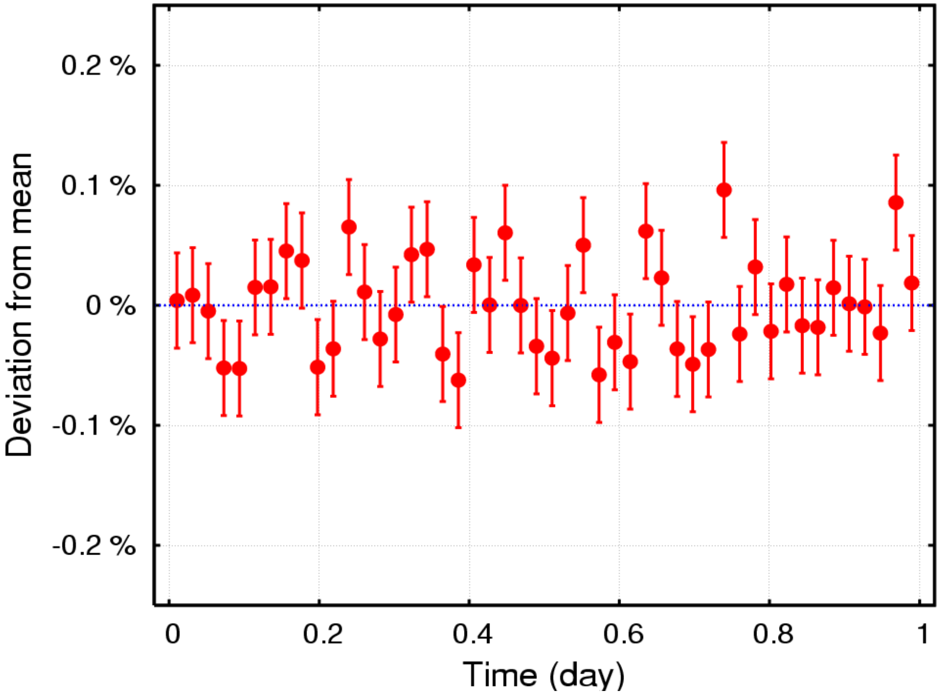
γ-ray astronomy

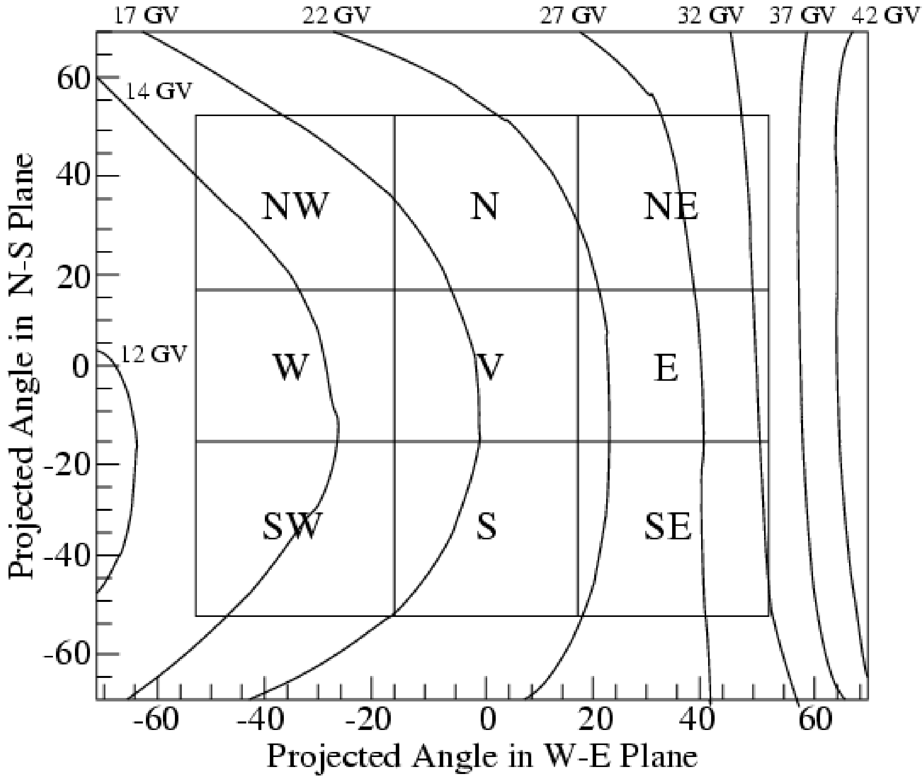
σ_θ = 25 arc min.



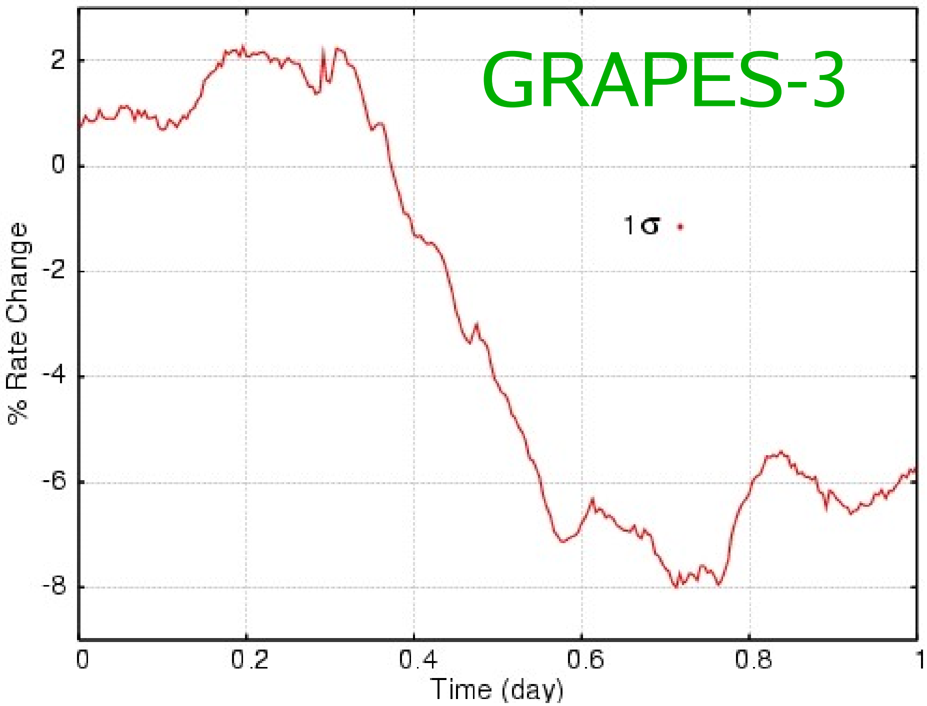
Solar phenomena

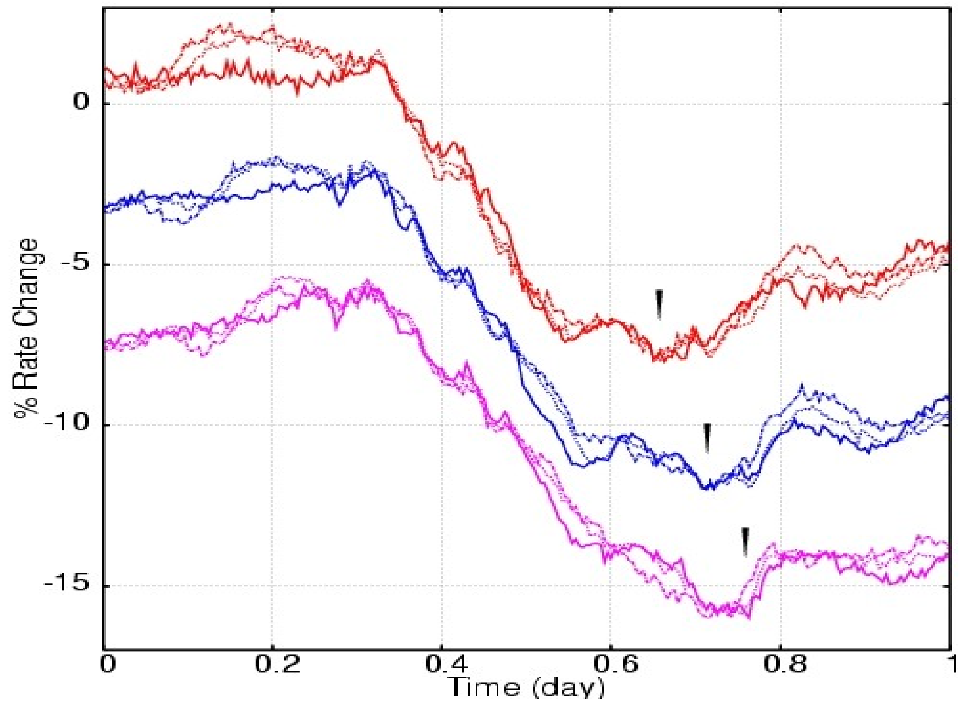


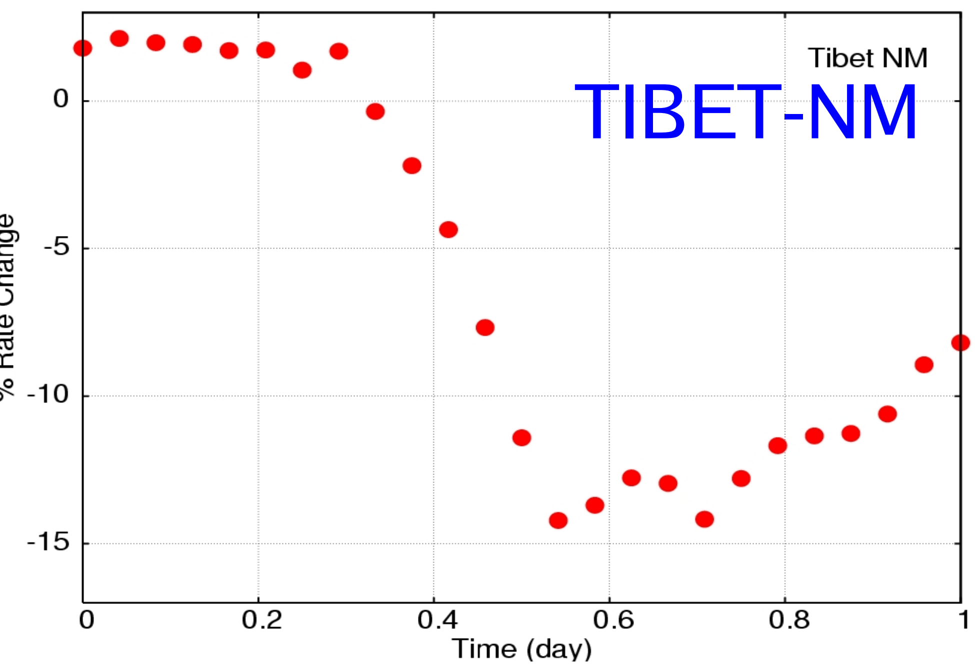


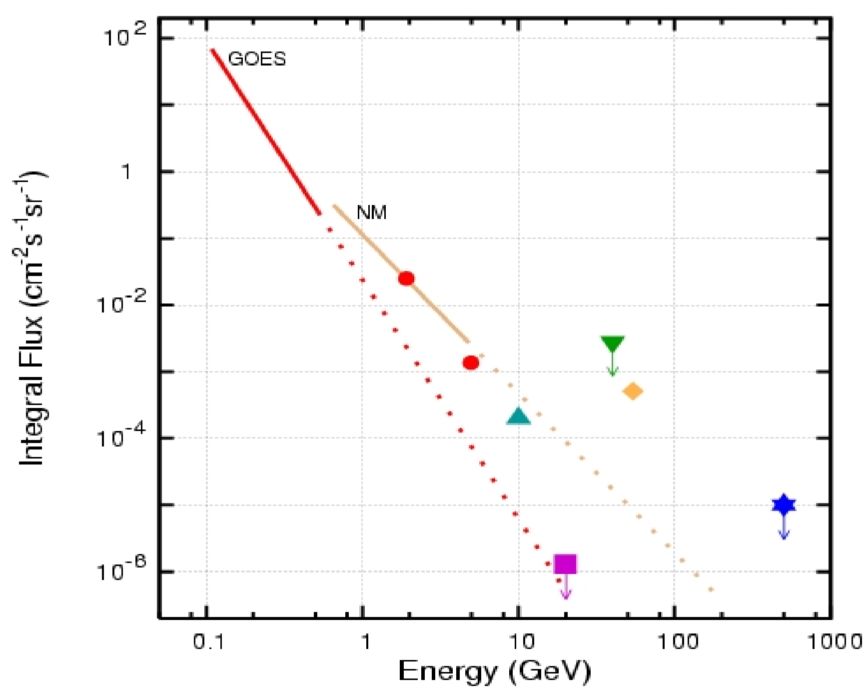


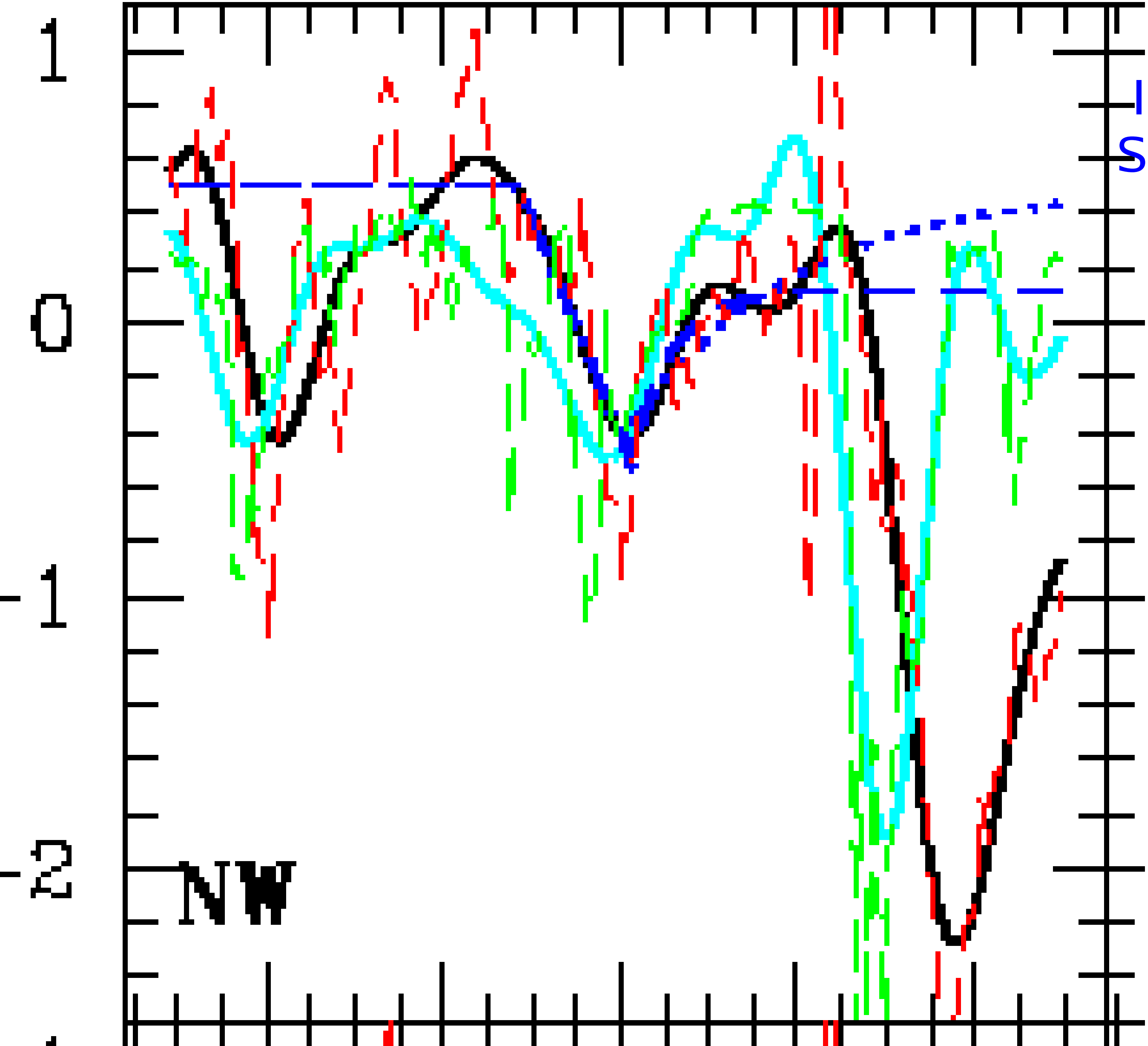
Coronal Mass Ejection (28 October 2003)





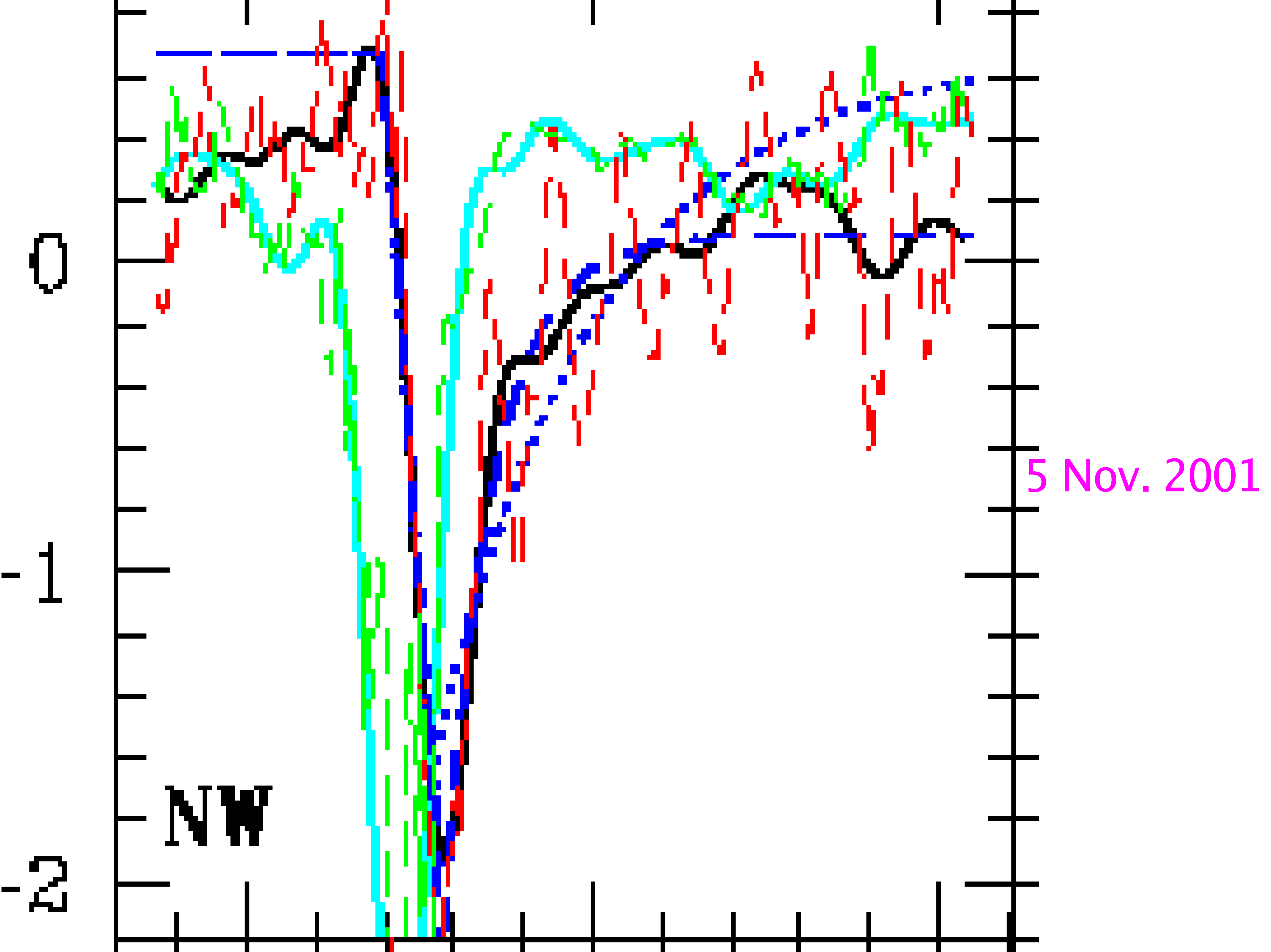


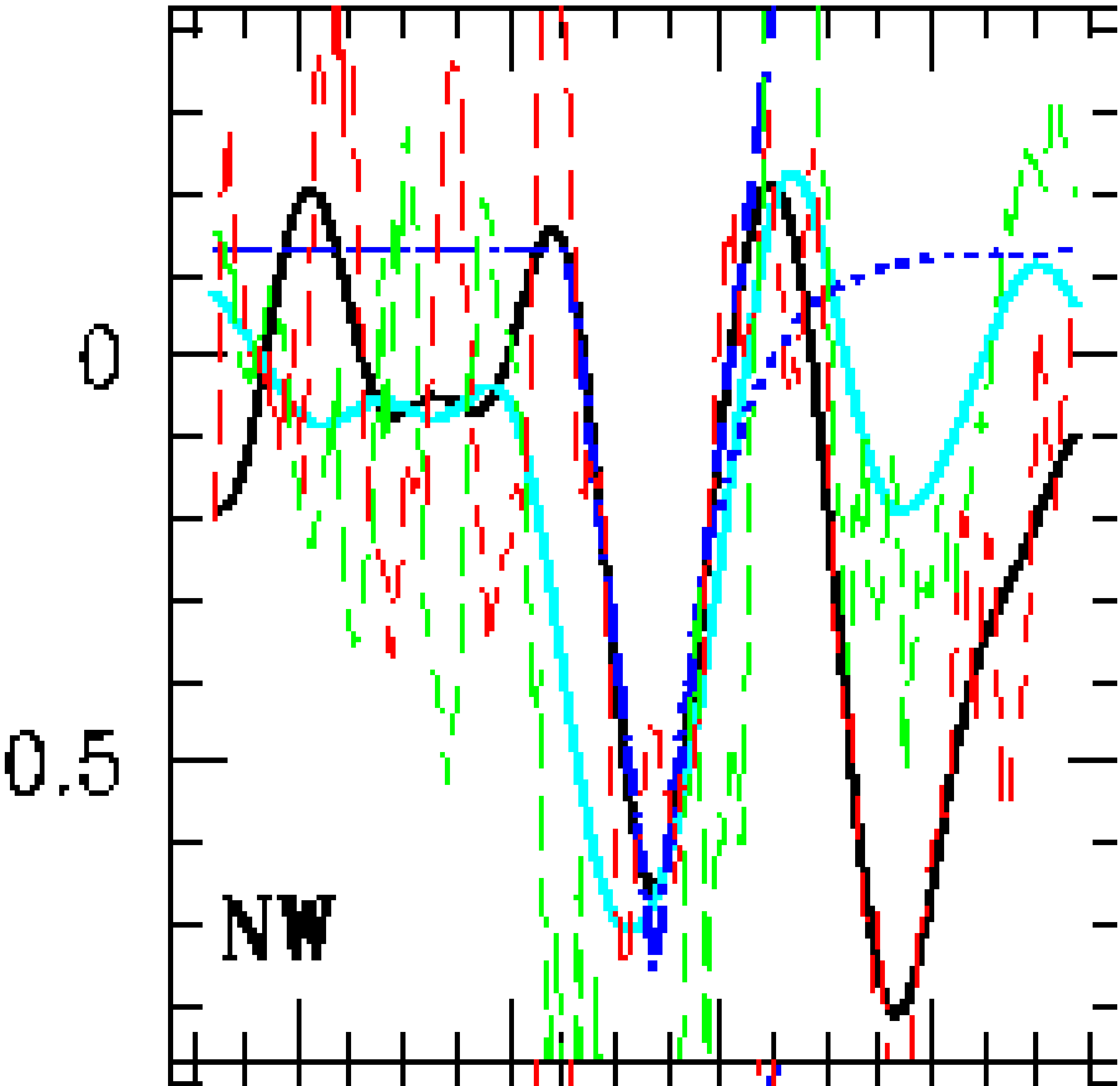




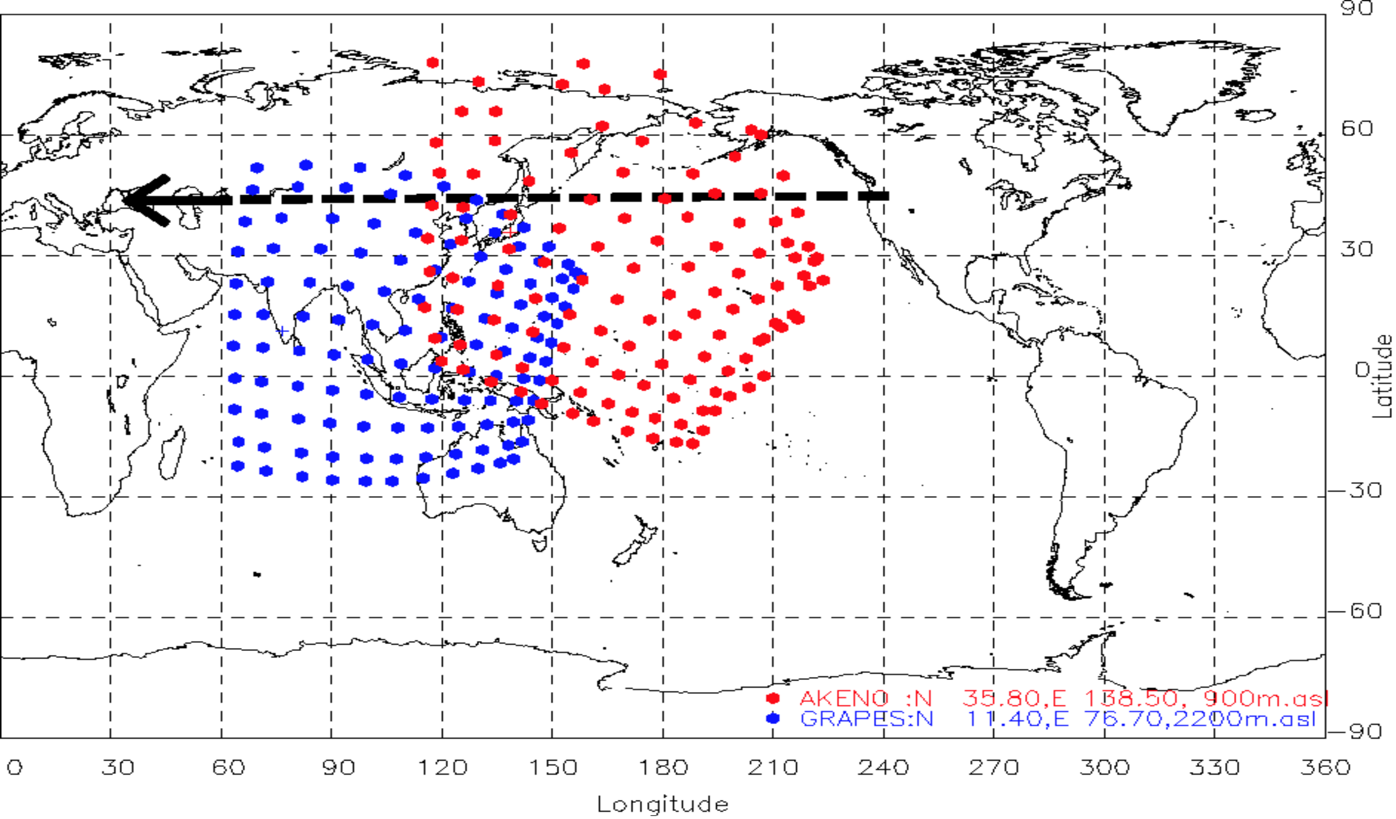
Study of Interplanetary Space from the Earth

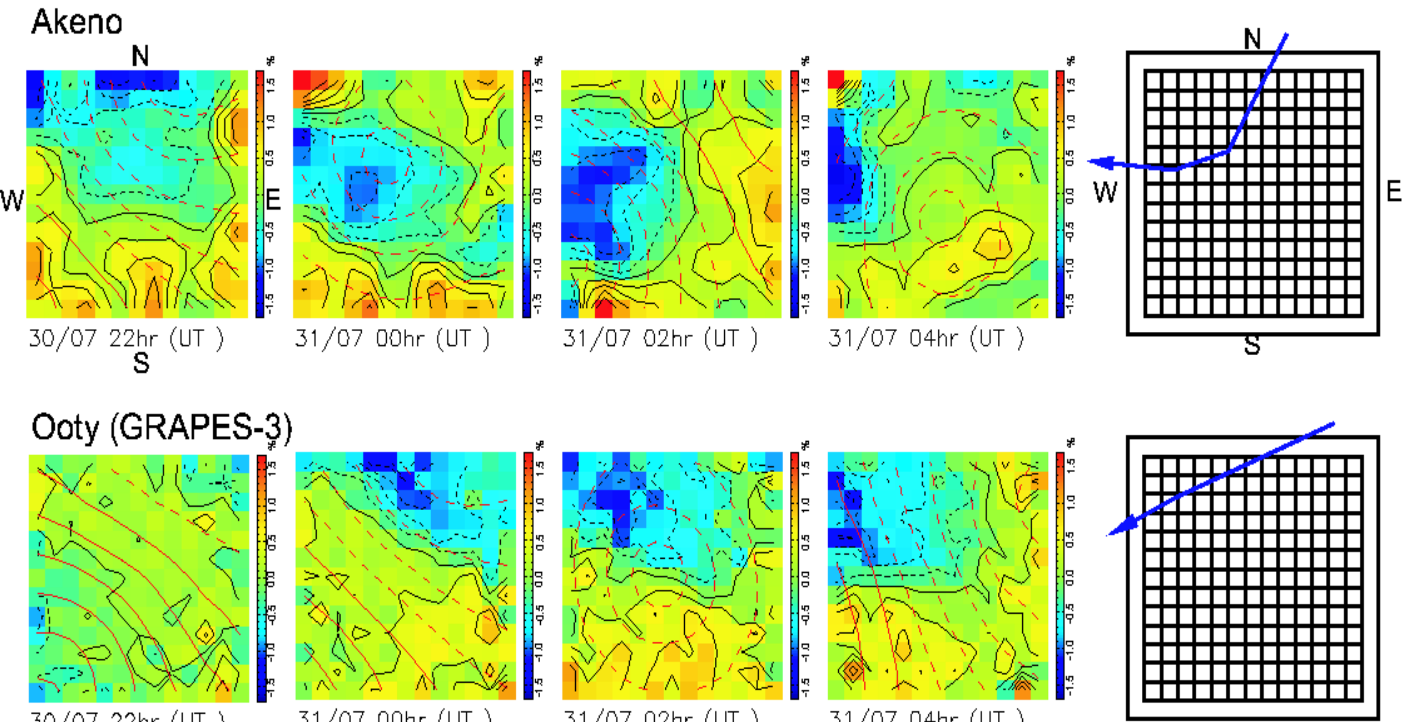
7 April 2001


0
-1
-2
NW
5 Nov. 2001



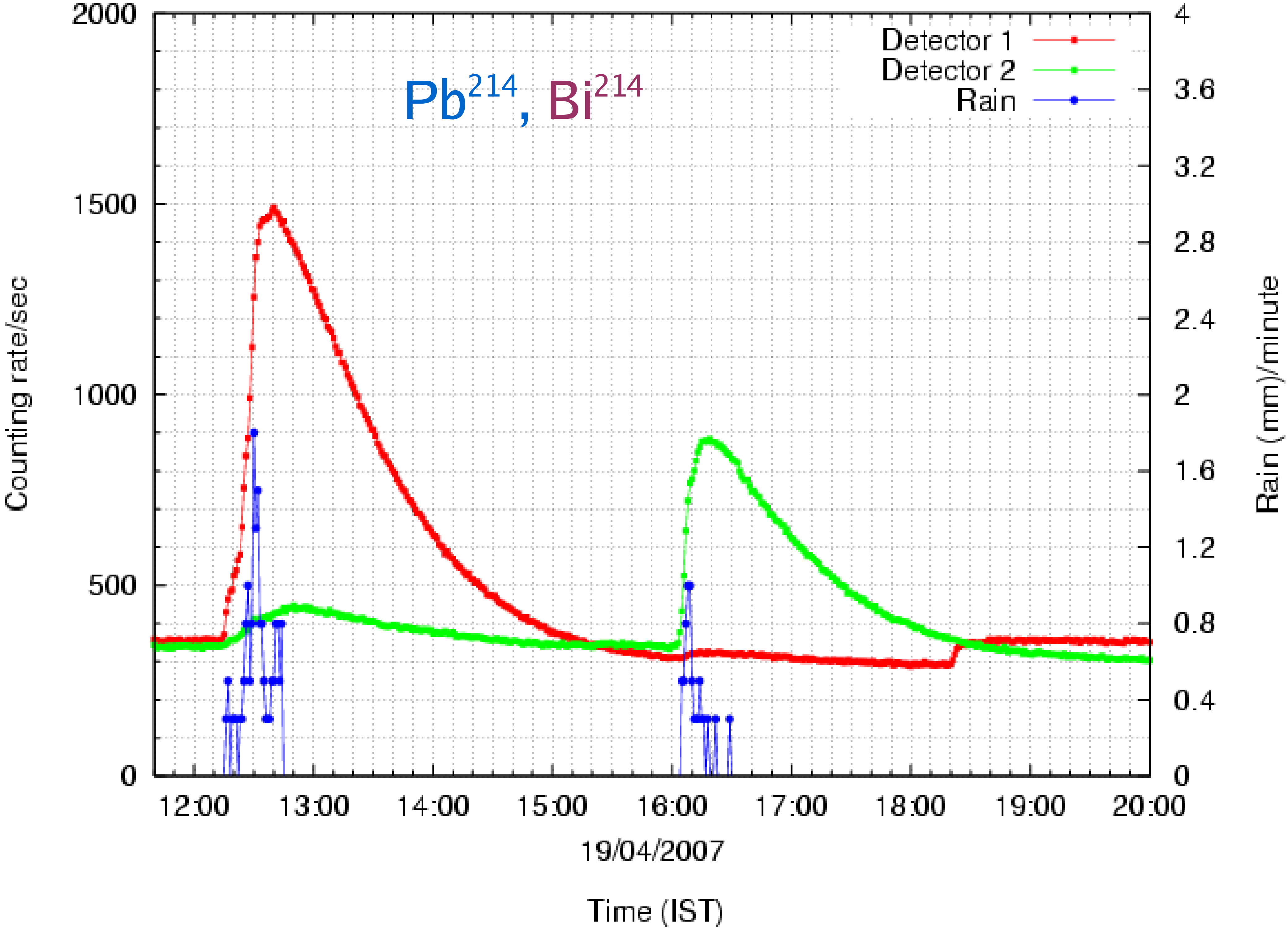
30 Sep. 2002





Future probe Space Weather:

Through the study of interplanetary medium using CMEs, flares, anisotropies and long-term study of cosmic ray variation.


Pb^{214}, Bi^{214}
Detector 1
Detector 2
Rain
Counting rate/sec
Rain (mm)/minute
2000
1500
1000
500
0
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
19/04/2007
Time (IST)

Future Expansion Plans

Double muon detector 560 ---> 1120 m^2 (2012)

Wide-angle Cerenkov telescope (2012)

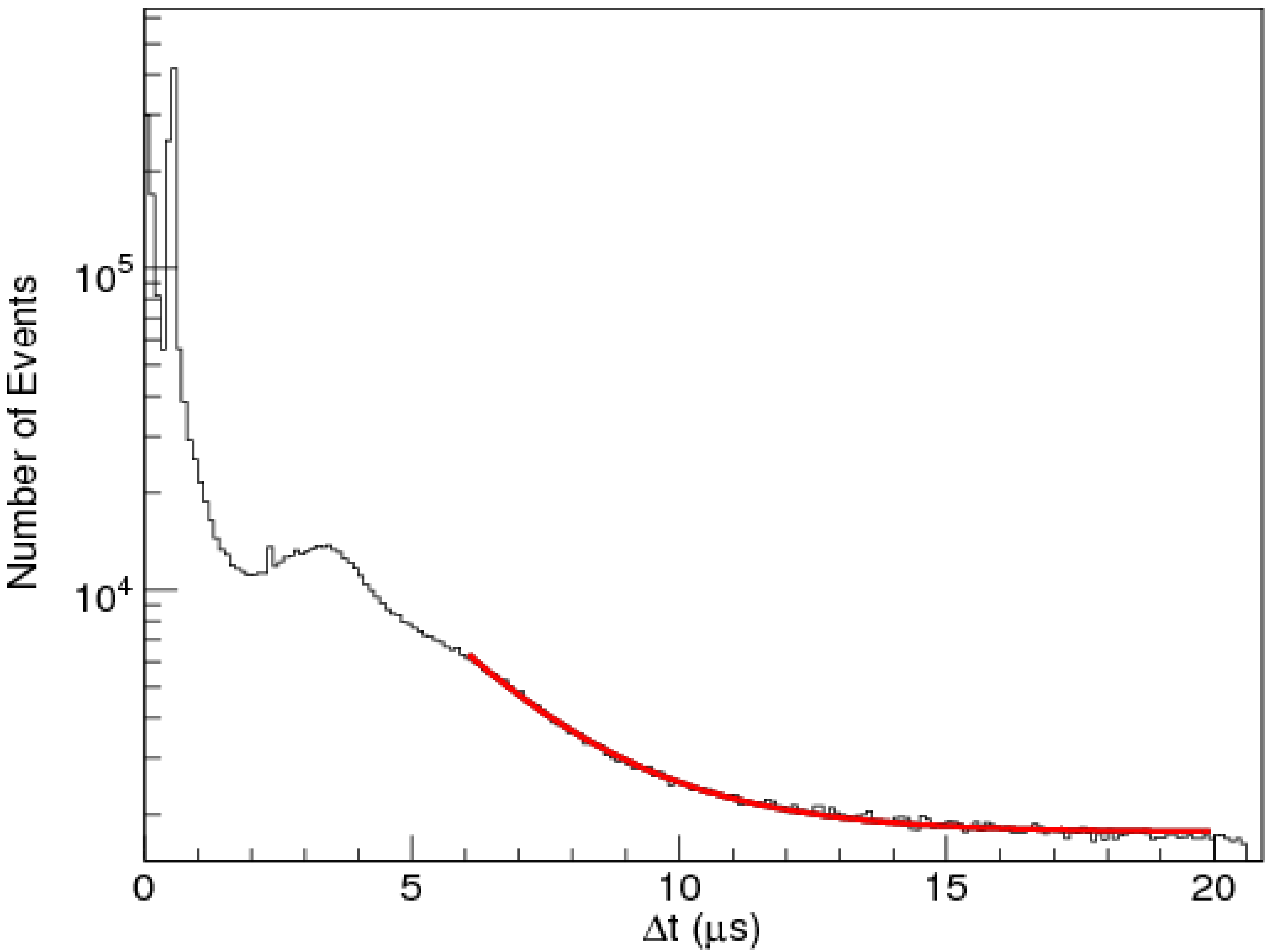
Expansion to ~1 km^2 (2015)

Neutron monitors for solar studies (2012)

Low frequency dipole array to detect radio emission from cosmic ray showers (?)


THANKS
Dr. HOMI. J. BHABHA CENTENARY
3rd Workshop & Winter School on AstroParticle Physics
December 18-29, 2008 at CRL (TIFR), Ooty
14-16 December 2010, Ooty

Backup Slides



Number of Events
10^5
10^4
0
5
10
15
20
Δt (μs)

MILESTONES:

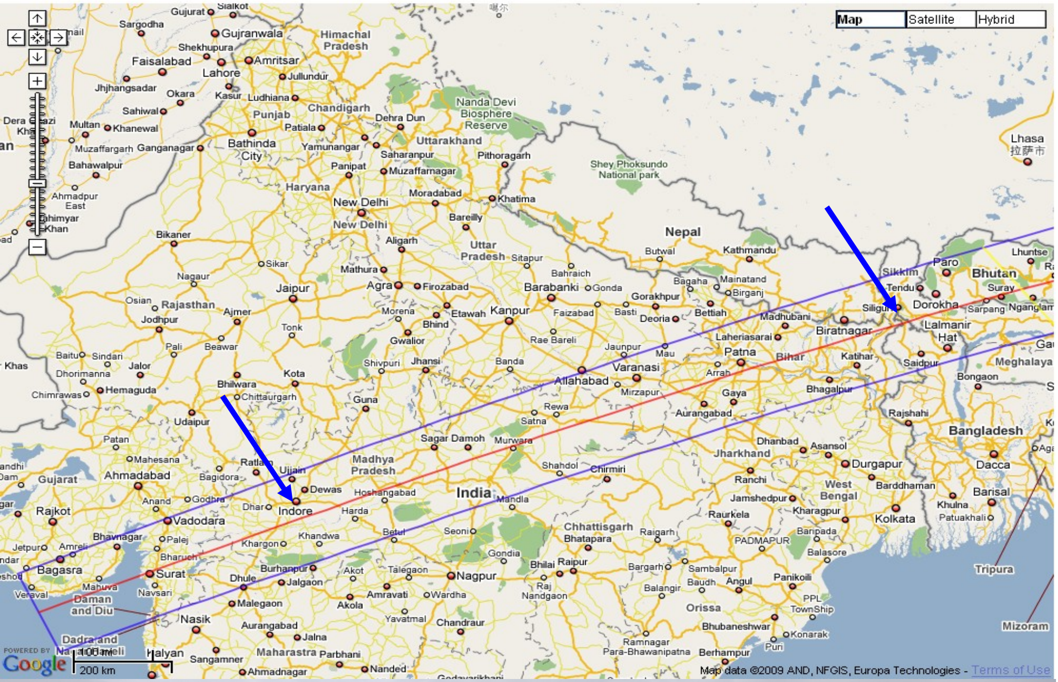
DST-DAE Vision 2020 meeting accorded highest priority to the GRAPES-3 experiment.., 7-8 April 2006

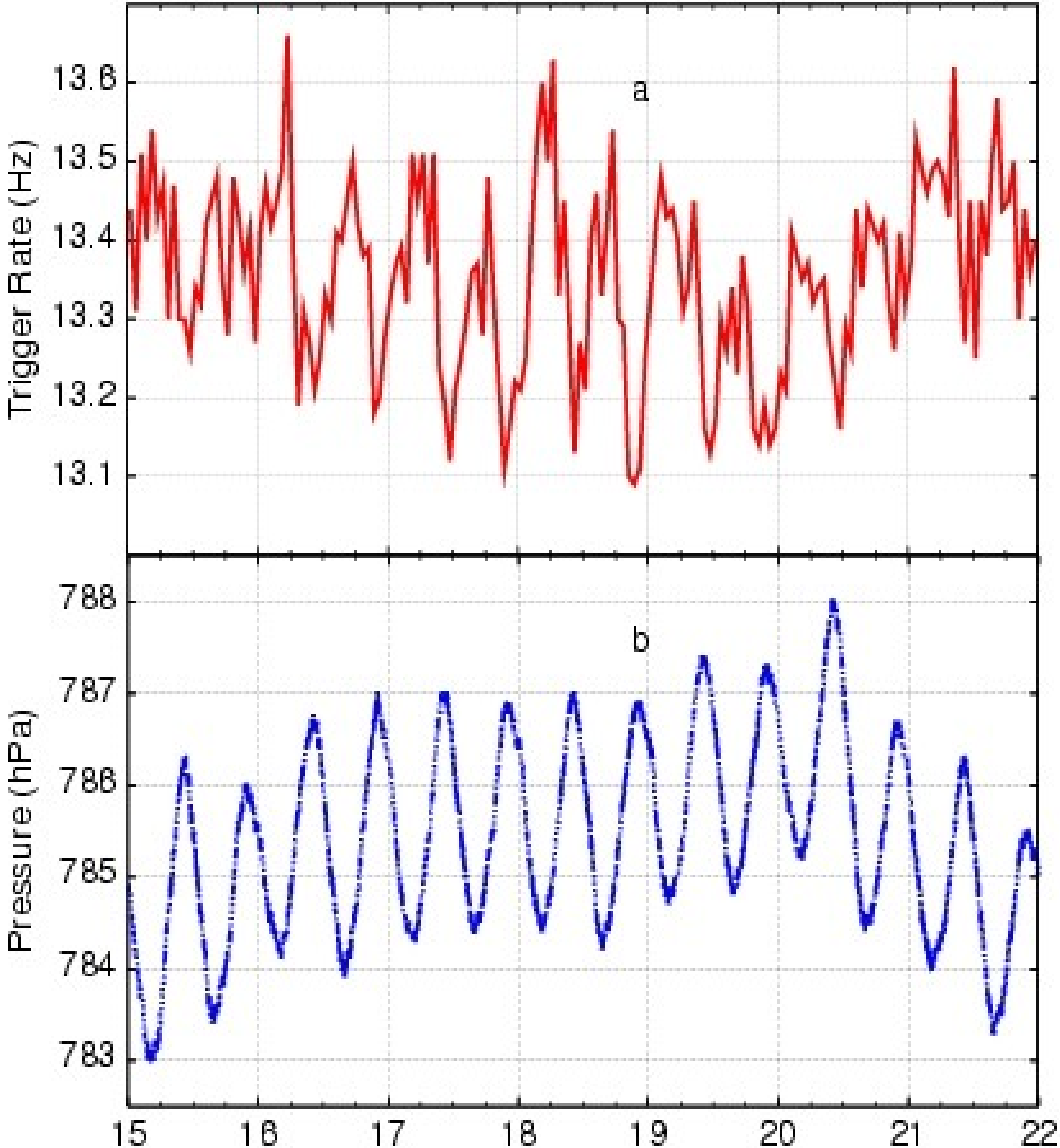
GRAPES-3 activity to be utilized as a nucleating centre for astroparticle physics.., Panel Report, 19 December 2006

Future activity at Ooty will offer a basis for a national facility in this area of science.., DHEP Review Report, 17 January 2008

With enhanced resources in manpower and funding would allow success on all three fronts, namely, science, R&D, training and education

γ-ray variation during total solar eclipse. 22 July 2009





Trigger Rate (Hz)
13.6
13.5
13.4
13.3
13.2
13.1
a
Pressure (hPa)
788
787
786
785
784
783
b
15
16
17
18
19
20
21
22

Detection and Measurement of Cosmic Rays:

Shower of electromagnetic (e^+, e^-, γ), muons (μ^+, μ^-) etc. in atmosphere.

Measure particle density and time (ns) ---> Energy and direction of primary particle.

Muon content of shower ---> composition of primary
Also discrimination between γ–rays and protons.

Muon ---> solar wind and Sun induced phenomena.

The main, naturally occurring radioactive nuclei is U^{238} which is present in the soil in very very small concentration ~1 part in 10^9. The decay chain of U^{238} results in production of other radioactive nuclei as shown below,

$$\begin{array}{lccccccc} {}_{92}U^{238} & \xrightarrow{\alpha} & {}_{90}Th^{234} & \xrightarrow{\beta} & {}_{91}Pa^{234} & \xrightarrow{\beta} & {}_{92}U^{234} \\ T_{1/2} & 4.5\times 10^{9}\ \text{yr} & & 24.1\ \text{day} & & 70.2\ \text{sec} & \end{array}$$

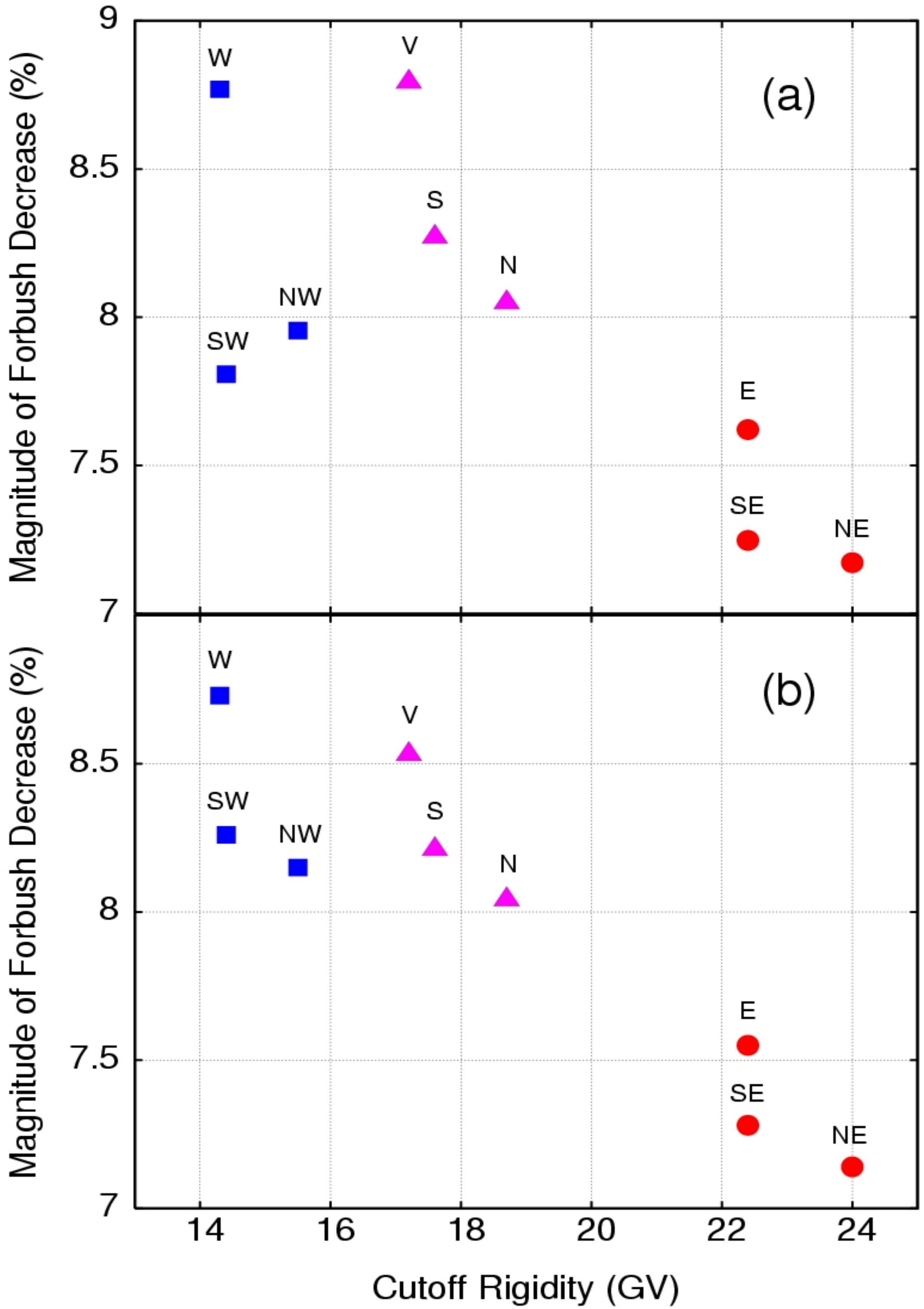
$$\begin{array}{lccccccc} {}_{92}U^{234} & \xrightarrow{\alpha} & {}_{90}Th^{230} & \xrightarrow{\alpha} & {}_{88}Ra^{226} & \xrightarrow{\alpha} & {}_{86}Rn^{222} \\ T_{1/2} & 2.5\times 10^{5}\ \text{yr} & & 7.5\times 10^{4}\ \text{yr} & & 1600\ \text{yr} & \end{array}$$

Daughter product of U^{238} is Rn^{222} a gas, that escapes from the soil into the atmosphere where it mixes in the air due to its half-life of 3.82 days, before decaying into Po^{218}. The decay chain of Rn^{222} is schematically shown below. Radon daughter products are heavy metals are precipitated along with rain-fall. The radon daughter nuclei Pb^{214} ($T_{1/2}$=26.8 minutes) and Bi^{214} ($T_{1/2}$=19.9 minutes) are the two most important radioactive nuclei,

$$\begin{array}{lccccccc} {}_{86}Rn^{222} & \xrightarrow{\alpha} & {}_{84}Po^{218} & \xrightarrow{\alpha} & {}_{82}Pb^{214} & \xrightarrow{\beta} & {}_{83}Bi^{214} \\ T_{1/2} & 3.8\ \text{day} & & 3.1\ \text{min} & & 26.8\ \text{min} & \end{array}$$

$$\begin{array}{lccccccc} {}_{83}Bi^{214} & \xrightarrow{\beta} & {}_{84}Po^{214} & \xrightarrow{\alpha} & {}_{82}Pb^{210} & \xrightarrow{\beta} & {}_{83}Bi^{210} \\ T_{1/2} & 19.9\ \text{min} & & 164\ \mu s & & 22.2\ \text{yr} & \end{array}$$

$$\begin{array}{lccccc} {}_{83}Bi^{210} & \xrightarrow{\beta} & {}_{84}Po^{210} & \xrightarrow{\alpha} & {}_{82}Pb^{206} \\ T_{1/2} & 5.01\ \text{day} & & 138.4\ \text{day} & \end{array}$$

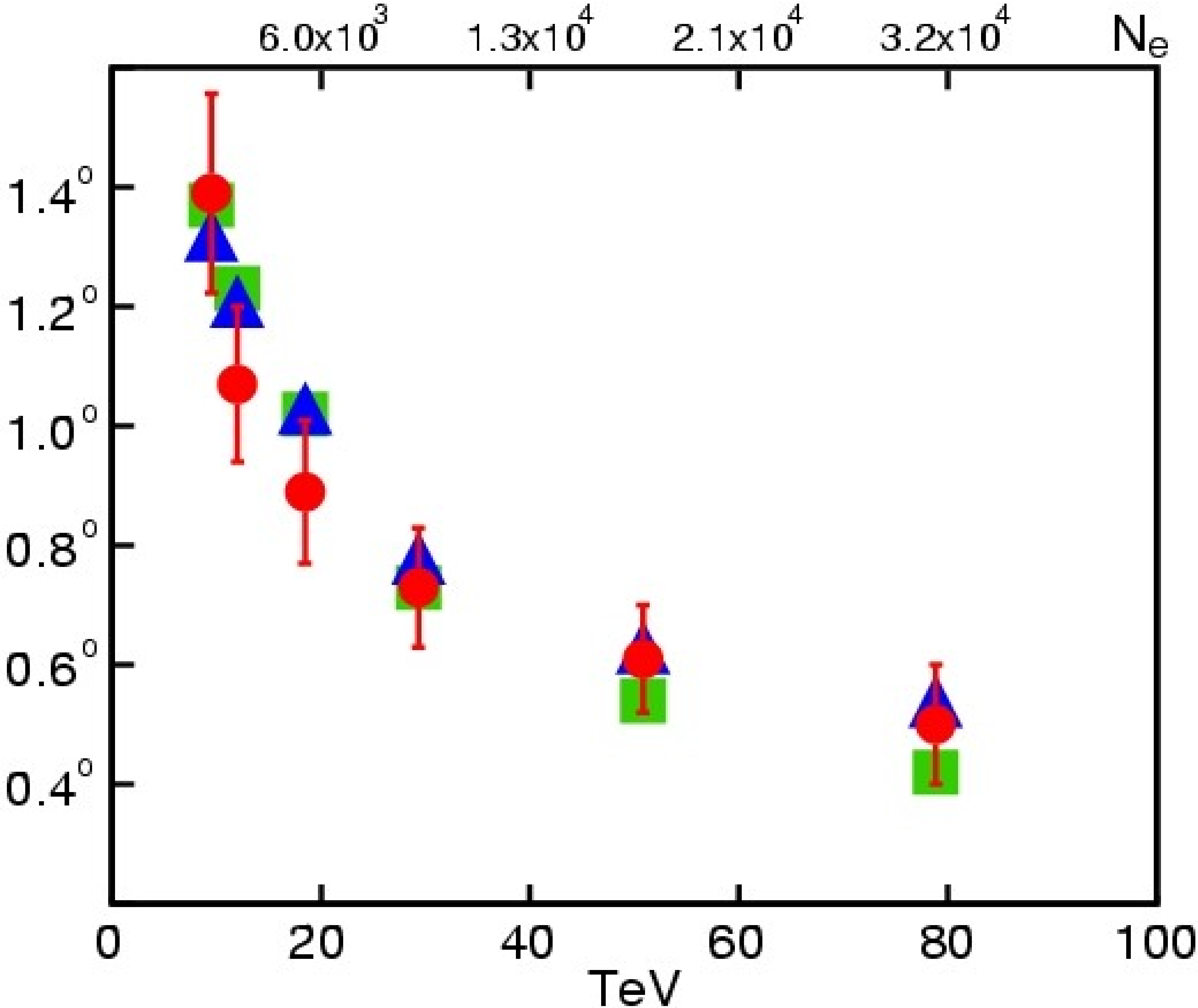


$$A(r) = K \times r^{-\gamma}$$

$$K = (12.3 \pm 0.3)\%$$

$$\gamma = (0.53 \pm 0.04)$$

$$\gamma = 0.4 - 1.2$$



6.0x10^3
1.3x10^4
2.1x10^4
3.2x10^4
Ne
1.4°
1.2°
1.0°
0.8°
0.6°
0.4°
0
20
40
60
80
100
TeV

GRAPES-3: A powerful tool for Astroparticle Physics.

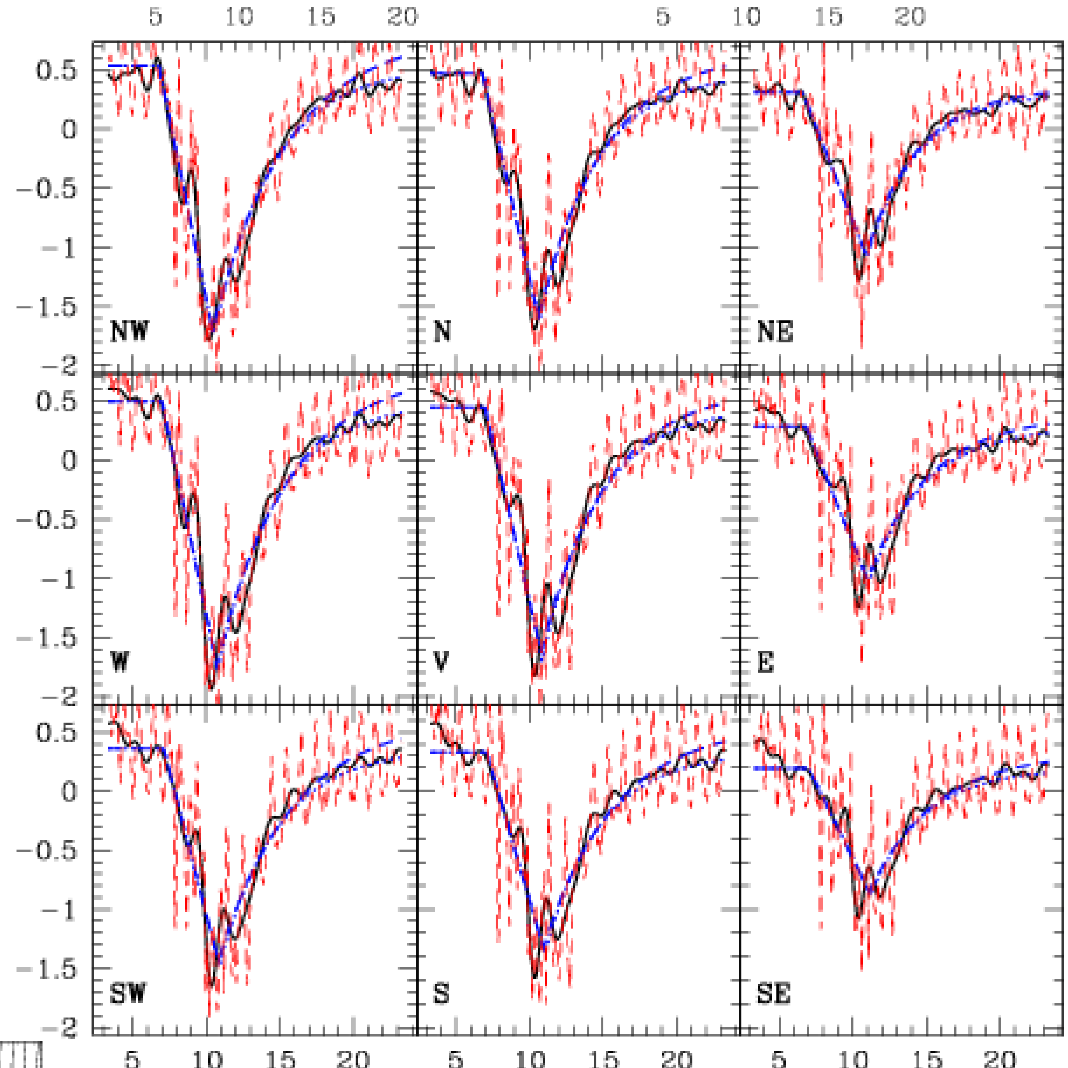
Conventional array with high density of detectors

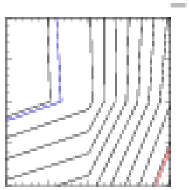
Basic Detector Component:

~400 - Plastic Scintillator detectors (1 m^2 area)

3712 - Proportional Counters (6m x 0.1m x 0.1m) deployed in four crossed layer configuration as 1 GeV muon detector of area 560 m^2.


278
223
224
225
222





6 November 2004 21:52

CME: 11/03/16:06 (2.4×10^{31} ergs 1128 km/s Halo) & 11/04/23:30 (7.8×10^{31} ergs 1050 km/s Partial Halo) & 11/06/02:06 (3.7×10^{31} ergs 1176 km/s Partial Halo) & 11/07/16:54 (2.2×10^{32} ergs 1713 km/s Halo) & 11/09/17:26 (1.8×10^{32} ergs 1936 km/s Halo) & 11/10/02:26 (5.5×10^{32} ergs 3330 km/s Halo)

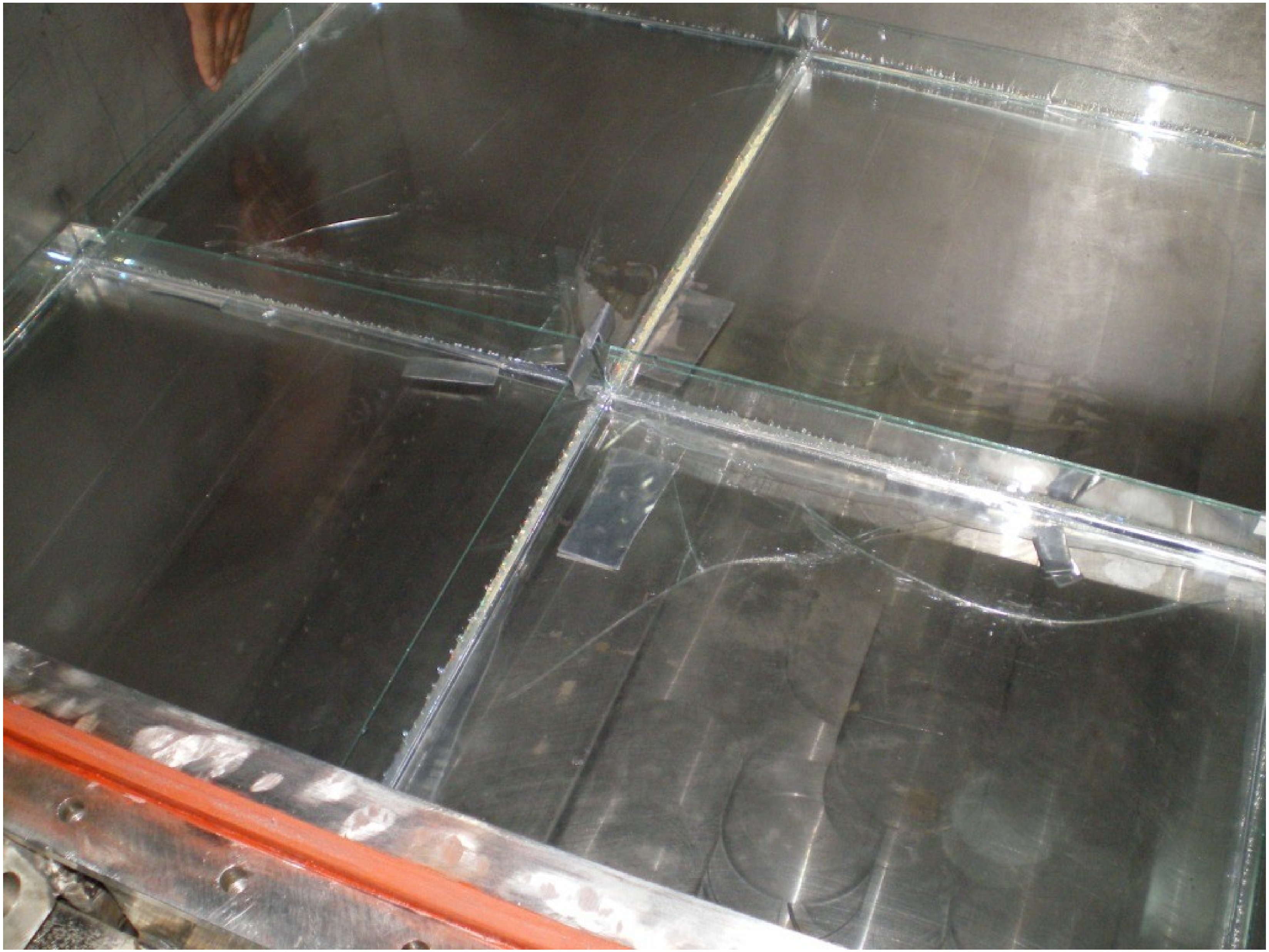
Flare: 11/03/15:47 (M5 N08E05) & 11/04/23:09 (M5.4 N08E17) & 11/06/00:34 (M9.3 N08E05) & 11/07/16:06 (X2 N09W17) & 11/09/17:19 (M8.9 N07W51) & 11/10/02:13 (X2.5 N09W47)

ICME: 11/07/17:00 (720 km/s) & 11/09/09:30 (790 km/s) & 11/09/18:00 (820 km/s) & 11/12/01:30 (700 km/s)

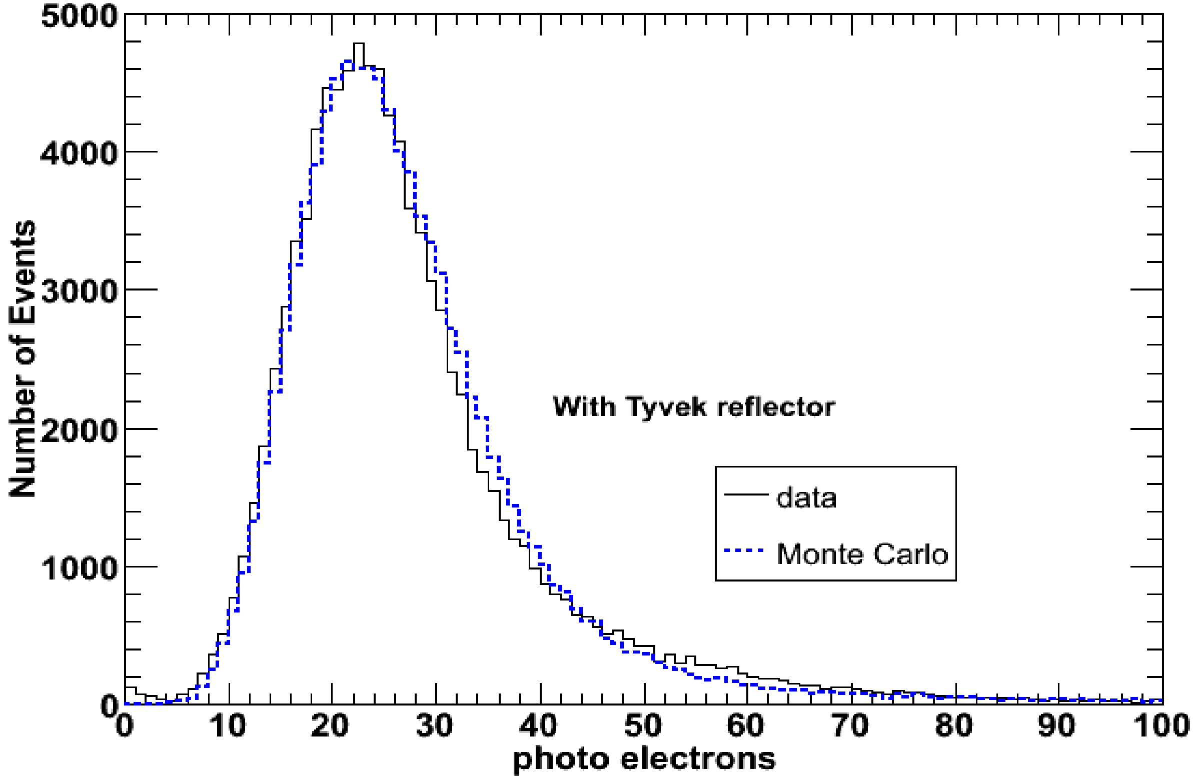
FD: (2.28, 2.10, 1.39, 2.27, 2.12, 1.32, 1.83, 1.70, 1.07)%

τ: (4.0, 3.8, 3.5, 4.0, 3.8, 3.8, 3.9, 3.8, 3.7) days

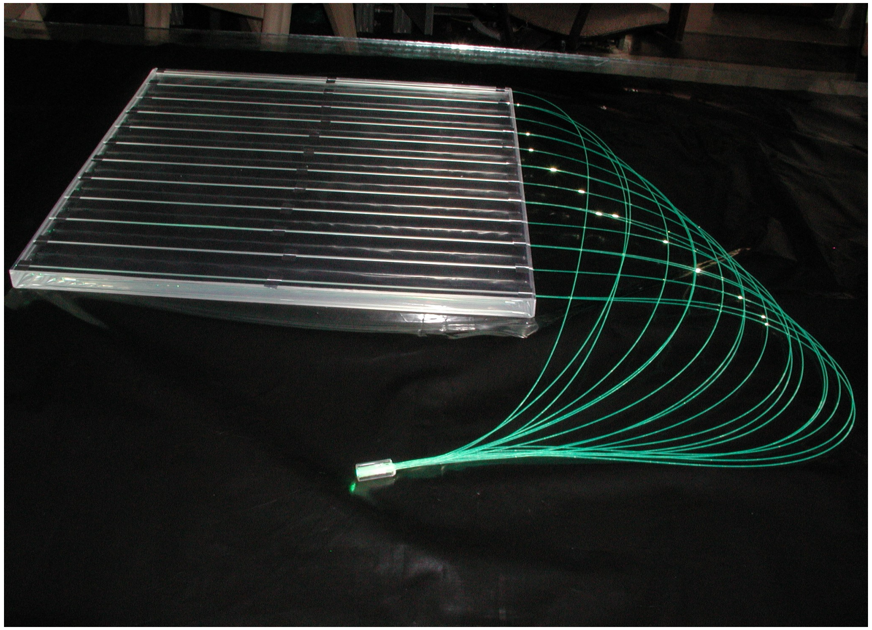
Onset date: (6.78, 6.80, 6.61, 6.99, 6.97, 6.84, 7.11, 7.08, 7.01)

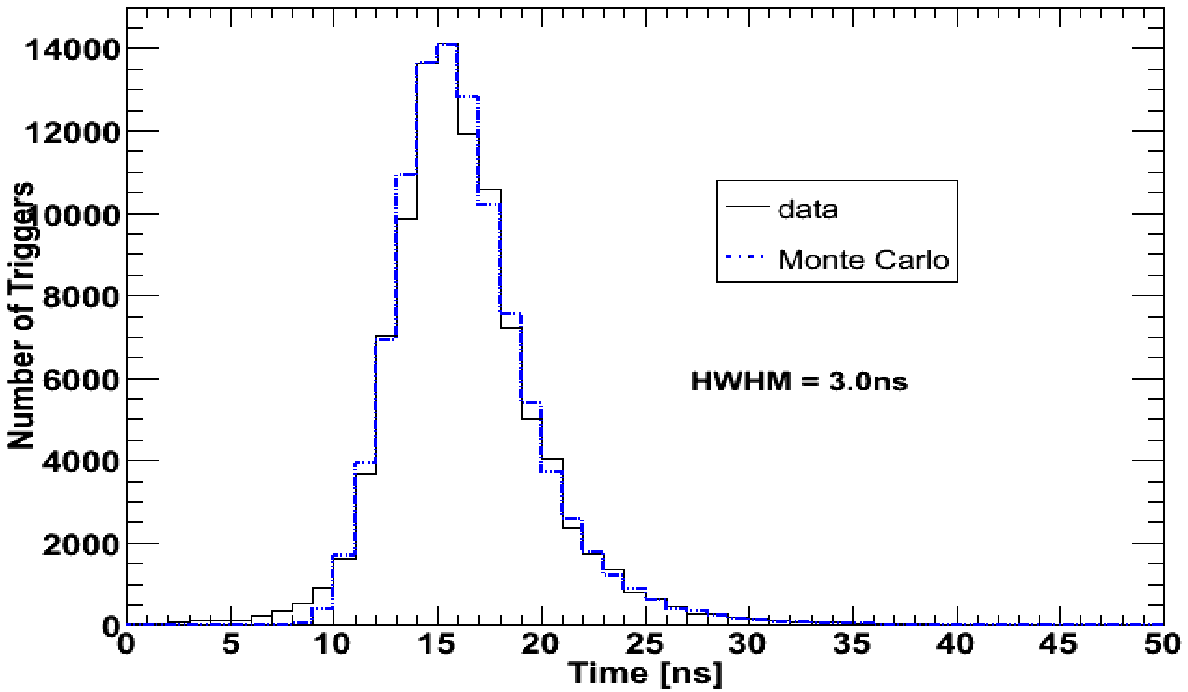



15

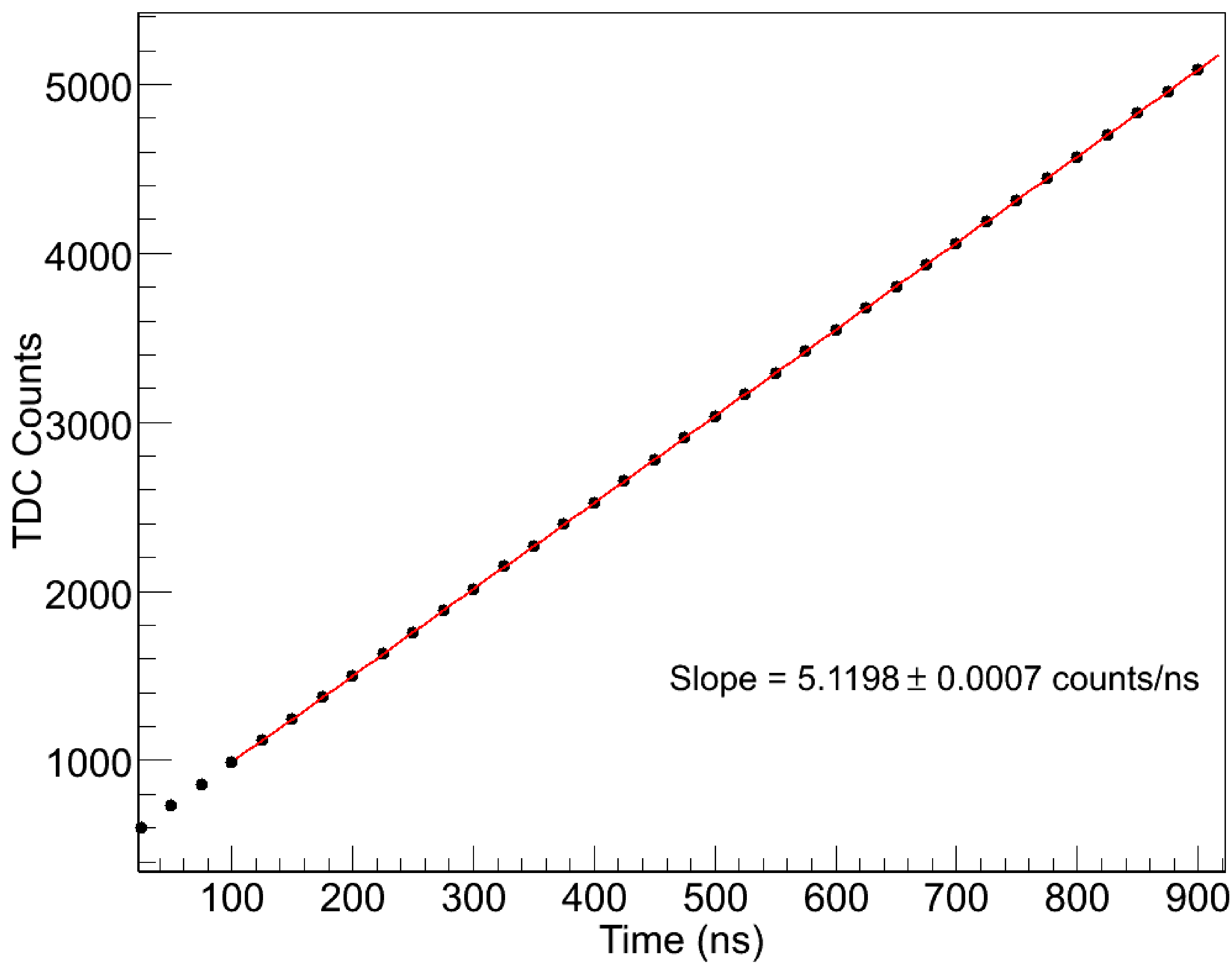


5000
4000
3000
2000
1000
0
Number of Events
0
10
20
30
40
50
60
70
80
90
100
photo electrons
With Tyvek reflector
data
Monte Carlo





14000
12000
10000
8000
6000
4000
2000
0
Number of Triggers
0
5
10
15
20
25
30
35
40
45
50
Time [ns]
data
Monte Carlo
HWHM = 3.0ns



TDC Counts
5000
4000
3000
2000
1000
100
200
300
400
500
600
700
800
900
Time (ns)
Slope = 5.1198 ± 0.0007 counts/ns

SiPM

5 nos of SiPM (Made in Russia)

5 nos of Pre-Amplifier boards (NE5539)

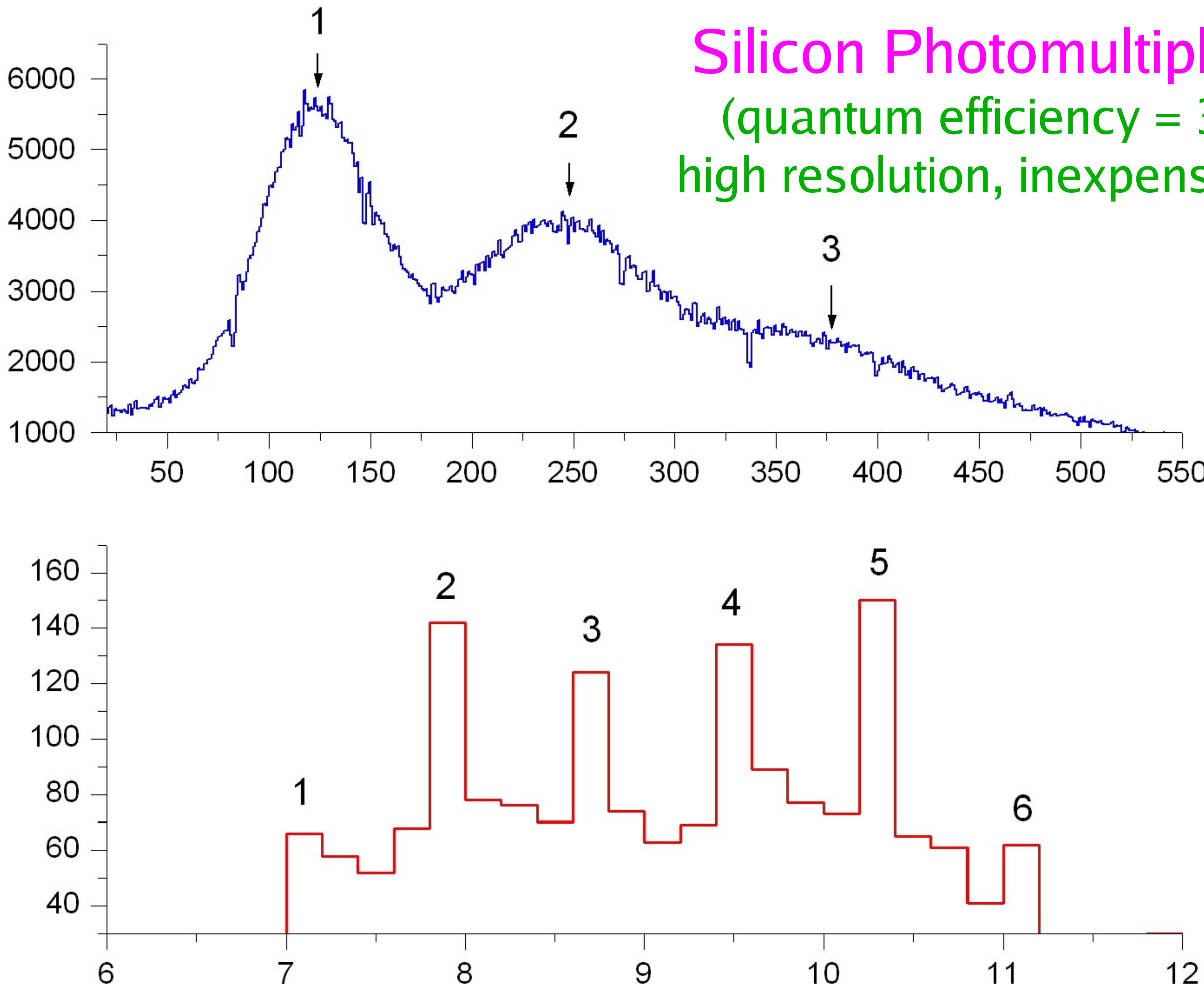
900 pixels (30x30 matrix) covering an area of 1mm²

Photon Detection Efficiency ~35%

Operating Voltage ~ 50 - 58 Volts (SRD)

Silicon Photomultiplier

(quantum efficiency = 3x
high resolution, inexpensive)



GRAPES-3 Publications during 2005-2010:

(1) S.K. Gupta et al. Nucl. Instr. and Meth. **A 540** 311-323 (2005)

(2) S.K. Gupta et al. Pramana **65** 273-283 (2005)

(3) S.C. Tonwar et al. Int. J. Mod. Phys. A **20** 6852-6854 (2005)

(4) Y. Hayashi et al. Nucl. Instr. and Meth. **A 545** 643-657 (2005)

(5) S.C. Tonwar et al. Nucl. Phys. B Proc. Suppl. **151** 477-480 (2006)

(6) T. Nonaka et al. Phys. Rev. D **74** 52003 (2006)

(7) H. Tanaka et al. Nucl. Phys. B Proc. Suppl. **175-176** 280-285 (2008)

(8) P.K. Mohanty et al. Astropart. Phys. **31** 24-36 (2009)

(9) P. Subramanian et al. Astron. Astrophys. **494** 1107-1118 (2009)

(10) P.K. Nayak et al. Astropart. Phys. **32** 286-293 (2010)

(11) S.K. Gupta et al. Nucl. Phys. B Proc. Suppl. **196** 153-156 (2009)

(12) A. Oshima et al. Astropart. Phys. In press (2010)

Training & Education:

(1) Schools, workshops, symposia
(2) Projects, thesis (M.Sc., B.E.)
(3) NSF --> training of new staff
(4) CORSIKA school, 2010 at Ooty

Backbone: 25 staff members, very skilled, motivated, multi-tasking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