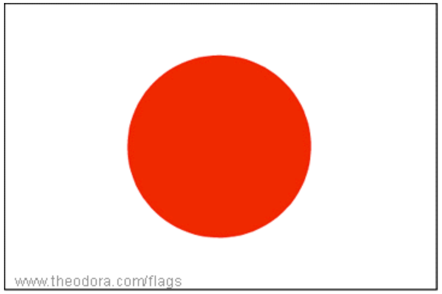
Status of GRAPES-3 Experiment

(Gamma Ray Astronomy at Pev EnergieS

(An India-Japan collaboration)

14 December 2010



S.K. Gupta, H.M. Antia, S.R. Dugad, A. Iyer, P. Jagadeesan, A. Jain, S.D. Morris, P.K. Mohanty, P.K. Nayak, B.S. Rao, K.C. Ravindran, Y. Hayashi, S. Kawakami, T. Matsuyama, M. Minamino, H. Kojima, R. Koul, V.K. Dhar, S. Das, S.K. Ghosh, P. Joarder, S. Raha, P. Subramanian, P. Jain, A. Oshima, H. Tanaka, S. Shibata, U.D. Goswami, S. Panda

1. Tata Institute of Fundamental Research, Mumbai, India
2. Osaka City University, Osaka, Japan
3. Aichi Institute of Technology, Toyota, Japan
4. Bhabha Atomic Research Centre, Mumbai, India
5. J.C. Bose Institute, Kolkata, India
6. Indian Institute of Science and Engineering Research, Pune, India
7. Indian Institute of Technology, Kanpur, India
8. National Astronomical Observatory of Japan, Tokyo, Japan
9. IPMU, University of Tokyo, Tokyo, Japan
10. Chubu University, Kasugai, Japan
11. University of Dibrugarh, Dibrugarh, India
12. Indian Institute of Science and Engineering Research, Bhopal, India

GRAPES-3 Talks

(1) Data analysis using ROOT framework	Shashi Dugad	Next talk
15 December 2010		
(2) Diffuse γ-rays	Y. Hayashi	14:00 hrs
(3) CMEs	P. Subramanian	14:45 hrs
(4) Angular Resolution	A. Oshima	15:30 hrs
(5) HPTDC	A. Iyer	16:20 hrs
(6) Silicon PMT	K.C. Ravindran	16:50 hrs
16 December 2010		
(7) EAS Time Measurement	P.K. Mohanty	14:10 hrs
(8) Particle Calibration	P. Tiwari	14:45 hrs
(9) γ-ray flux variation during TSE	A. Jain	15:00 hrs

Objective: The universe at the high 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.

5. Acceleration of particles in thunderstorms and atmospheric electricity.

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)

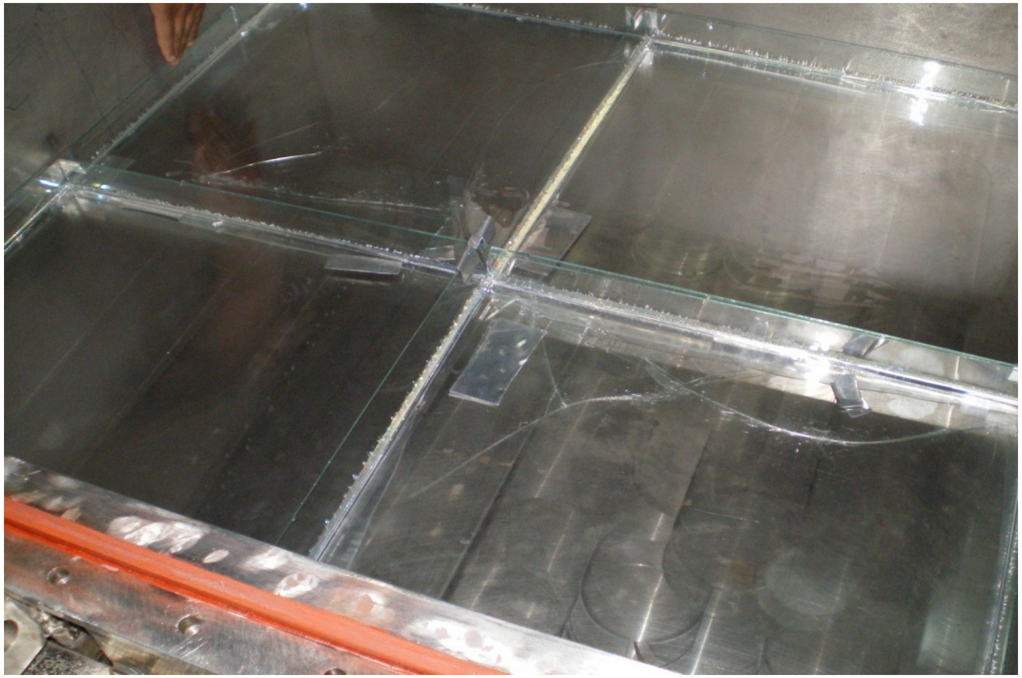

112
113
114
073

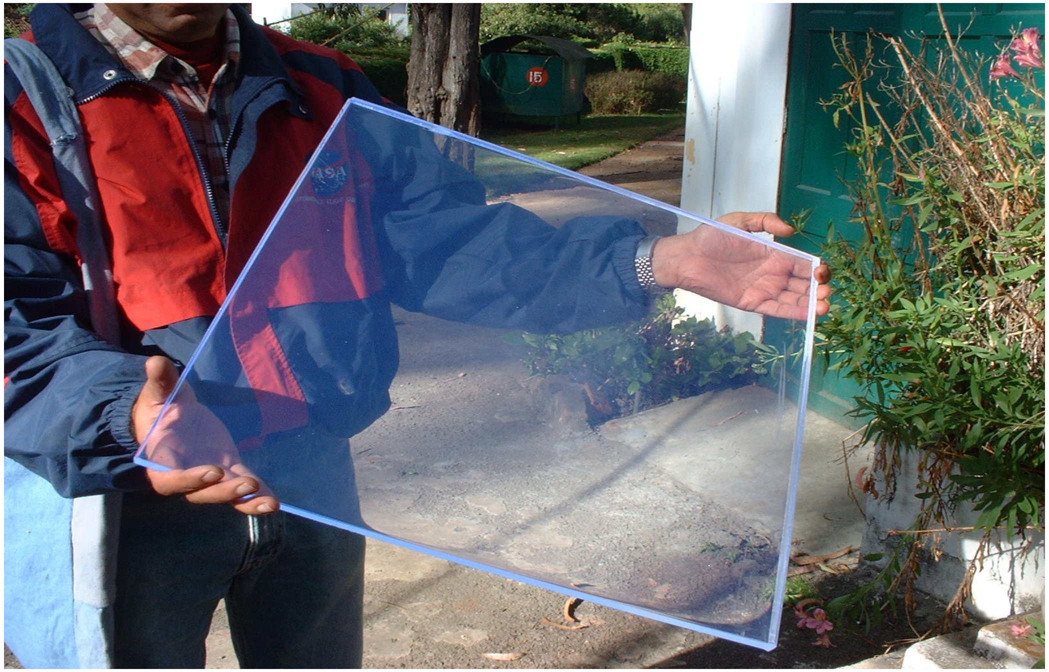
In-house technology for the Fabrication of Various Detector Components

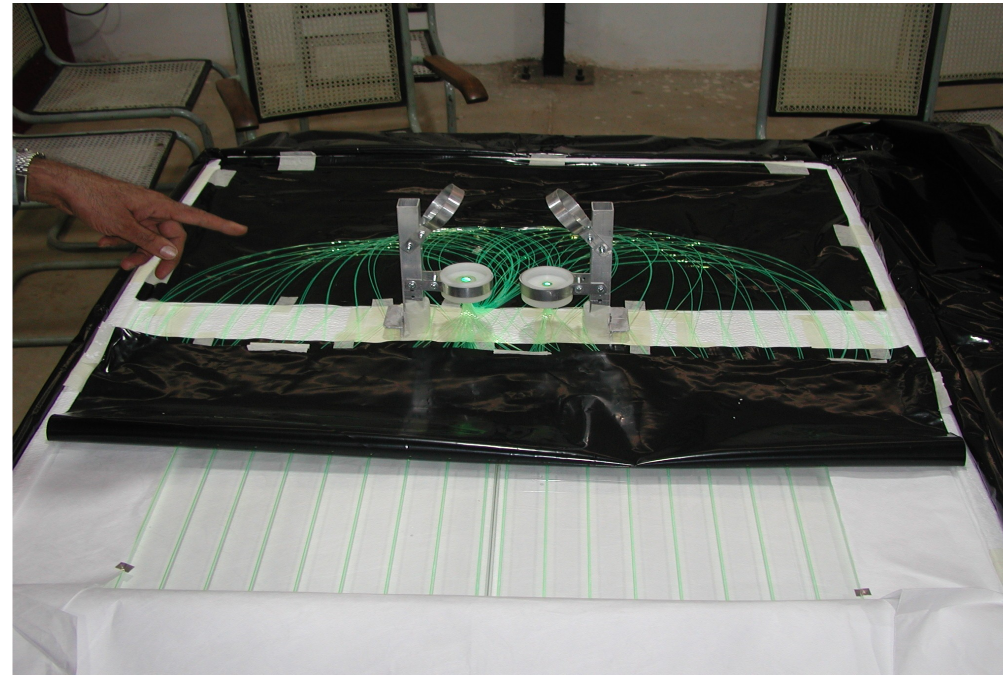
Plastic Scintillator development:

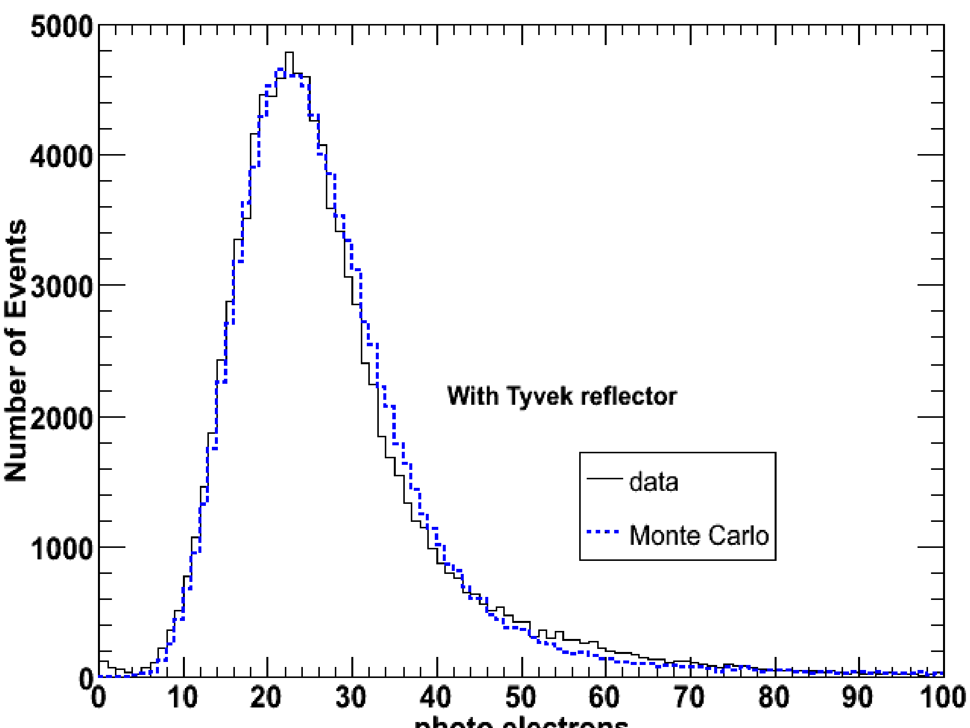
Decay Time= 1.6 ns
Light Output = 85% Bicron (54% anthracene)
Timing 25% faster
Atten. Length λ= 100cm
Cost ~10% of Bicron
Max Size 100cmX100cm
Total > 2000

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

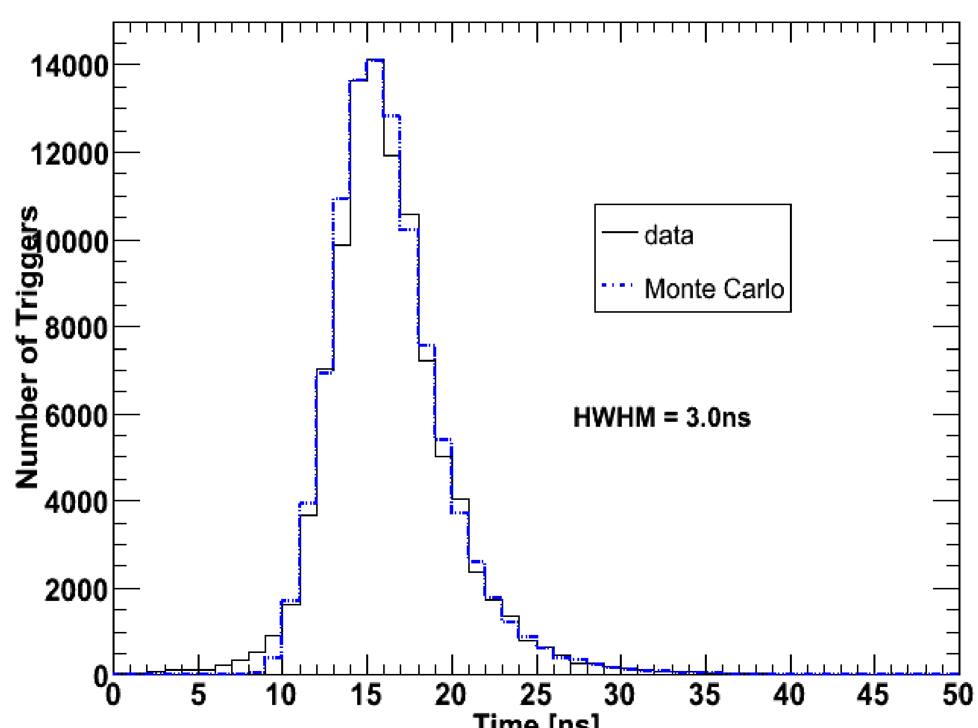




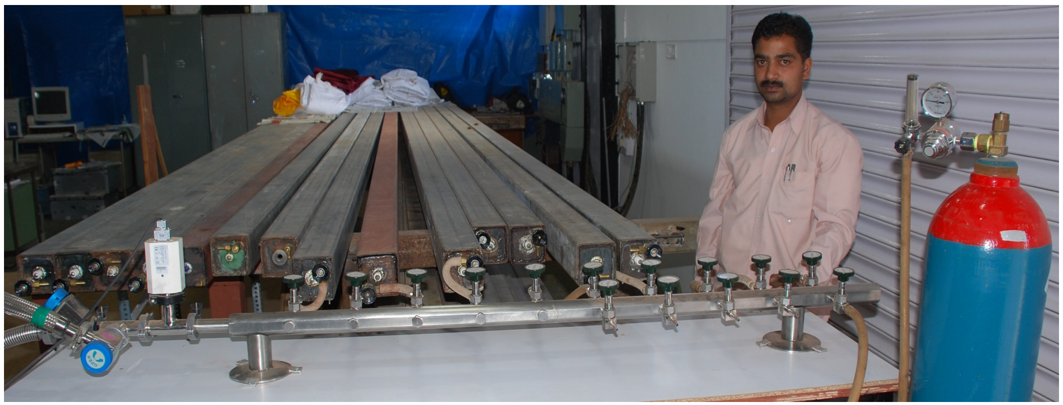




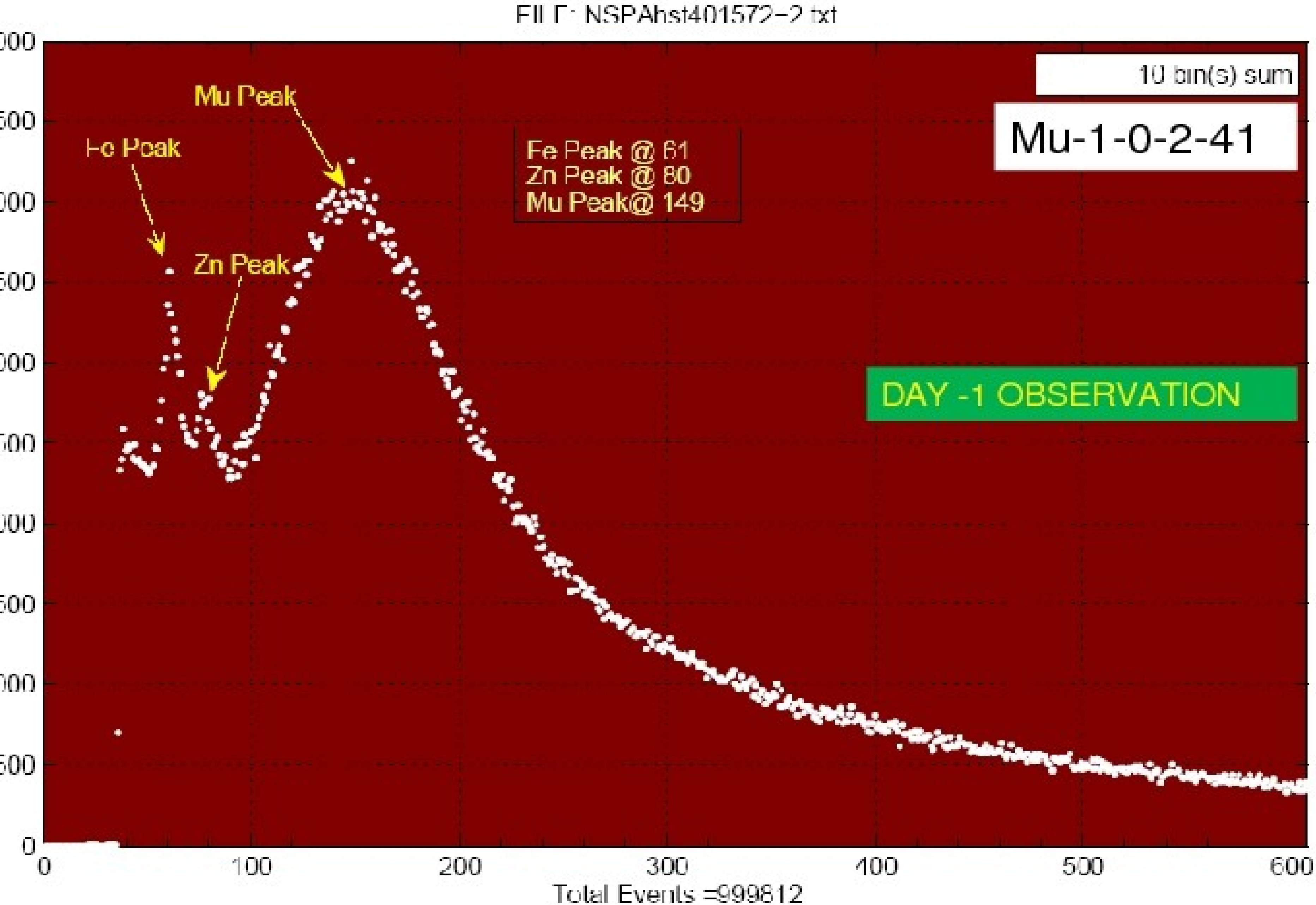
Number of Events
photo electrons
With Tyvek reflector
data
Monte Carlo
0
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
70
80
90
100



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



Proportional Counter Test Setup



FILE: NSPAhst401572-2.txt
10 bin(s) sum
Mu-1-0-2-41
Mu Peak
Fe Peak
Zn Peak
Fe Peak @ 61
Zn Peak @ 80
Mu Peak@ 149
DAY -1 OBSERVATION
0
100
200
300
400
500
600
Total Events =999812

Signal processing electronics & detection:

(1) Fast Amplifiers with >300 MHz bandwidth

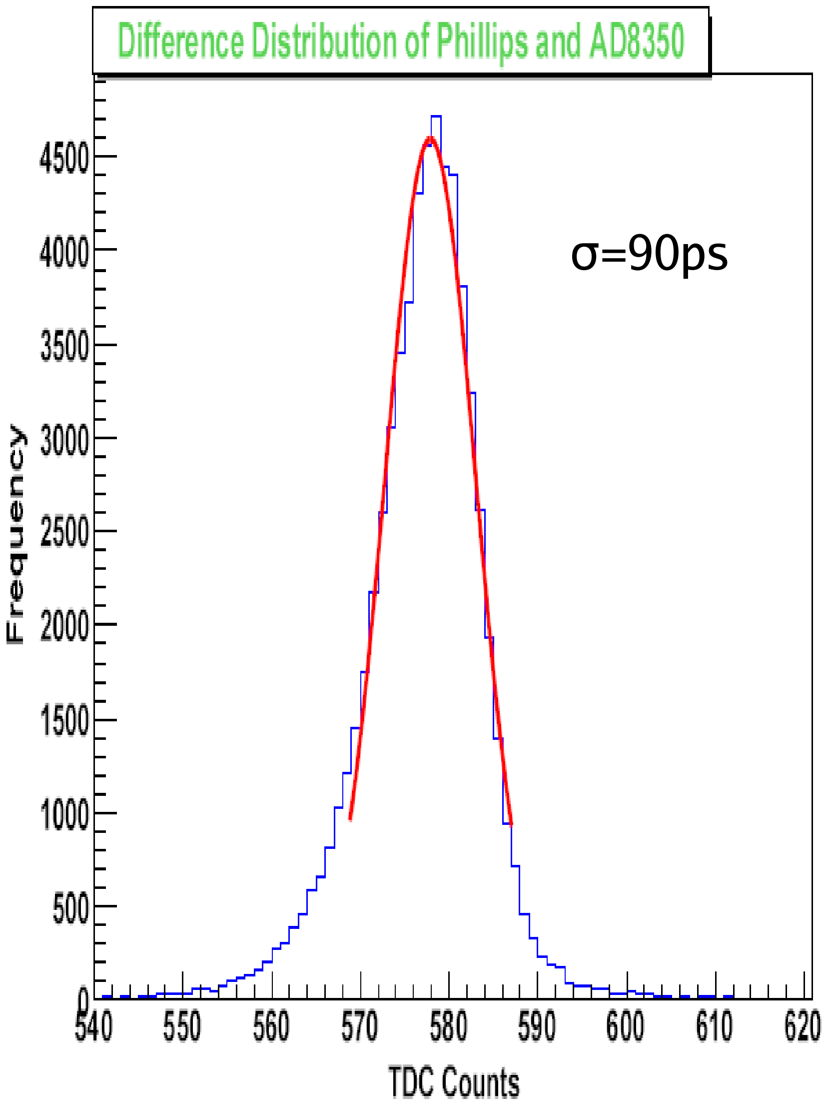
(2) Fast Discriminators with <100 ps time jitter

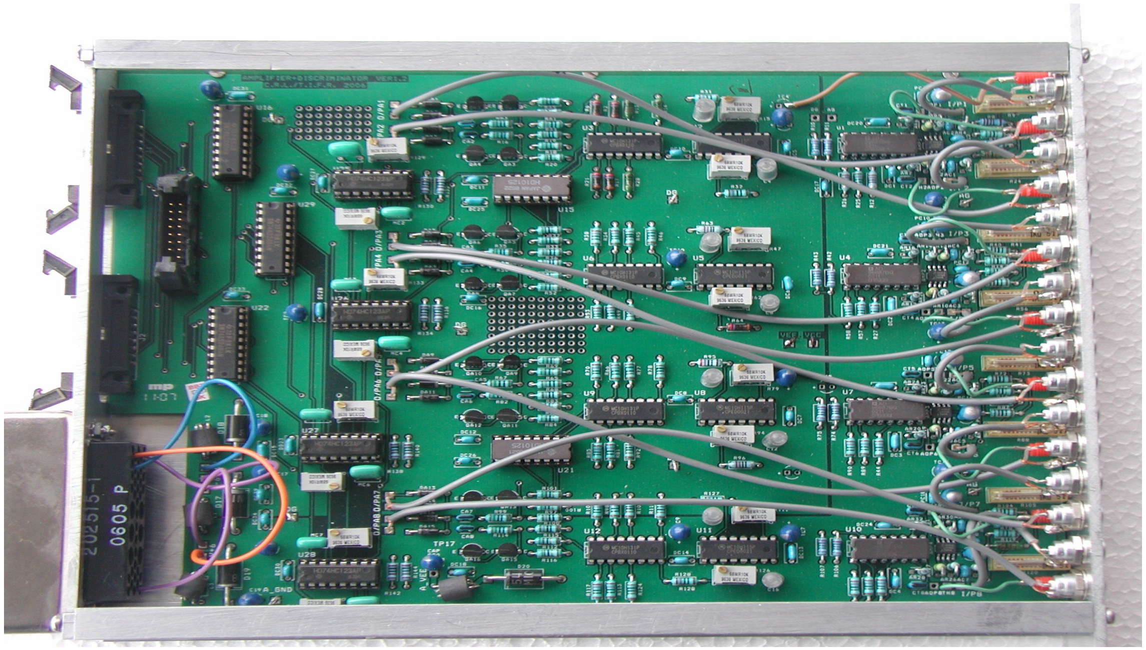
(3) Charge integrating ADCs ≥12 bit dynamic range

(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 (Stop Watch)

32 Channels

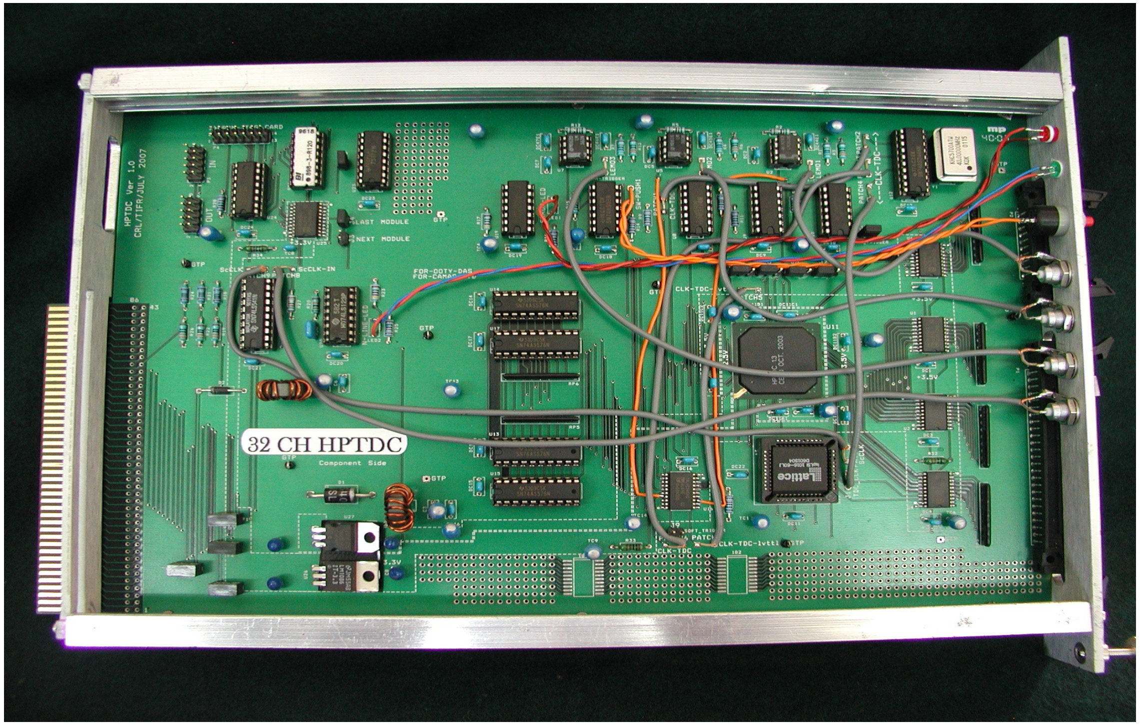
100 ps time resolution

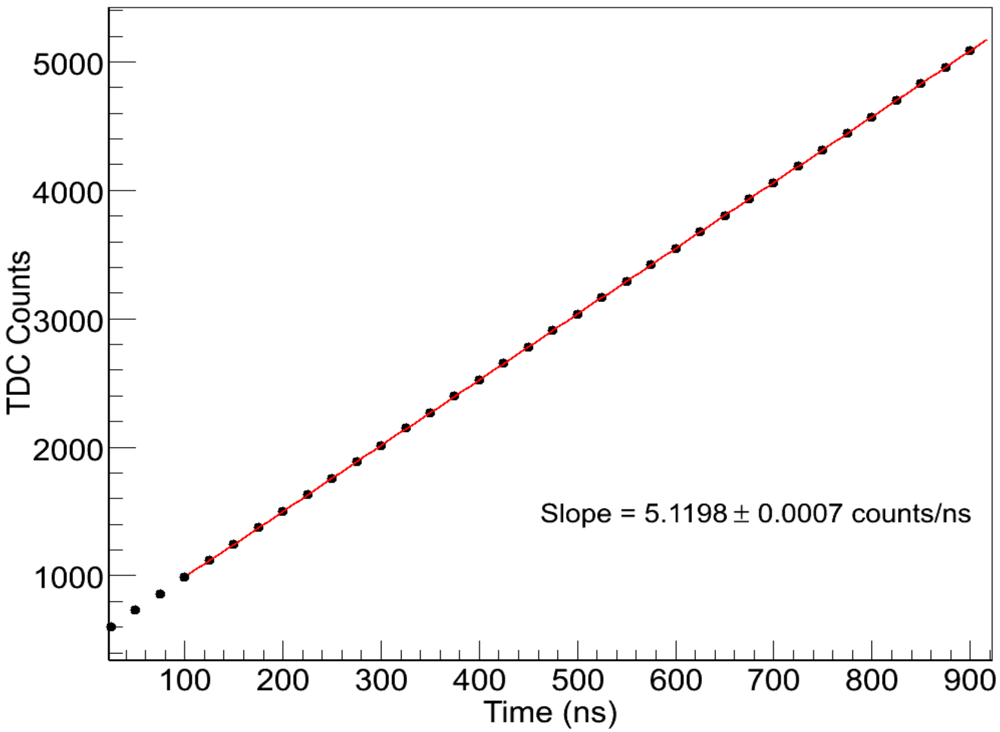
Multi-hit capability

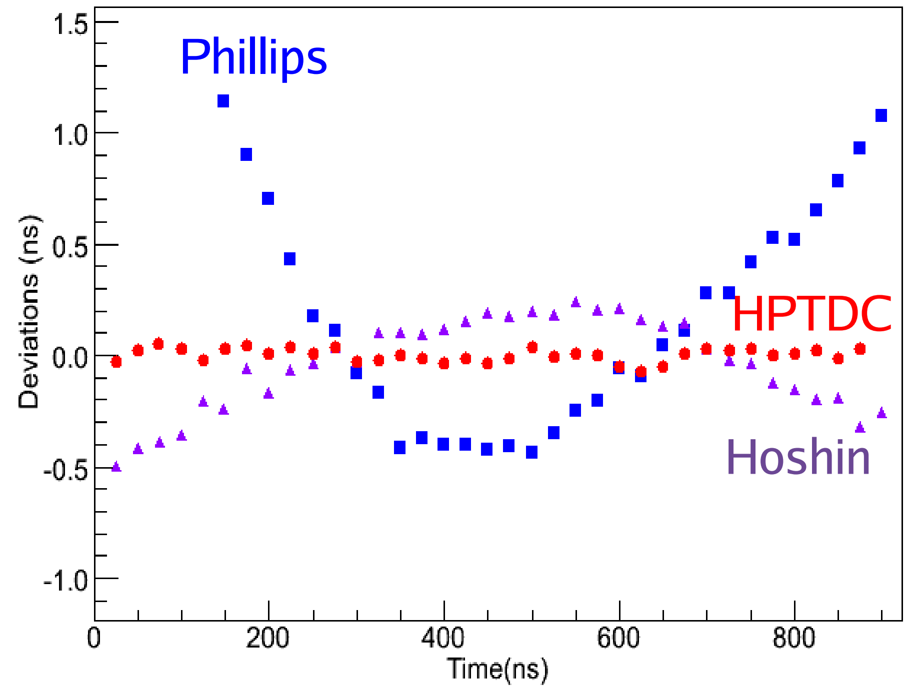
Huge dynamic range (100 ps - 50 μs)

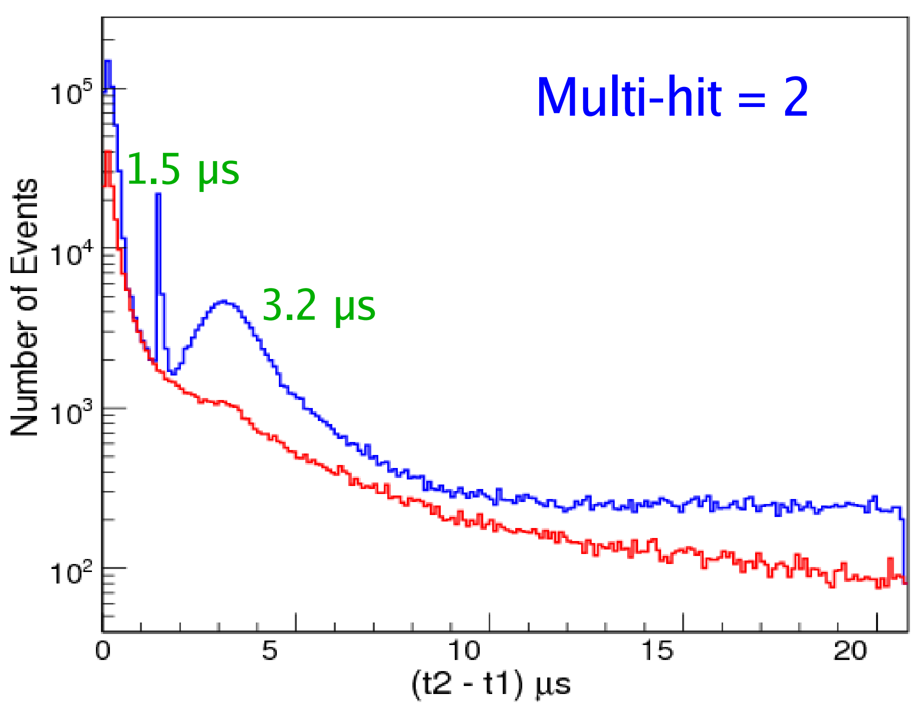
Trigger mode (avoids delay cables) PKM, AJAI

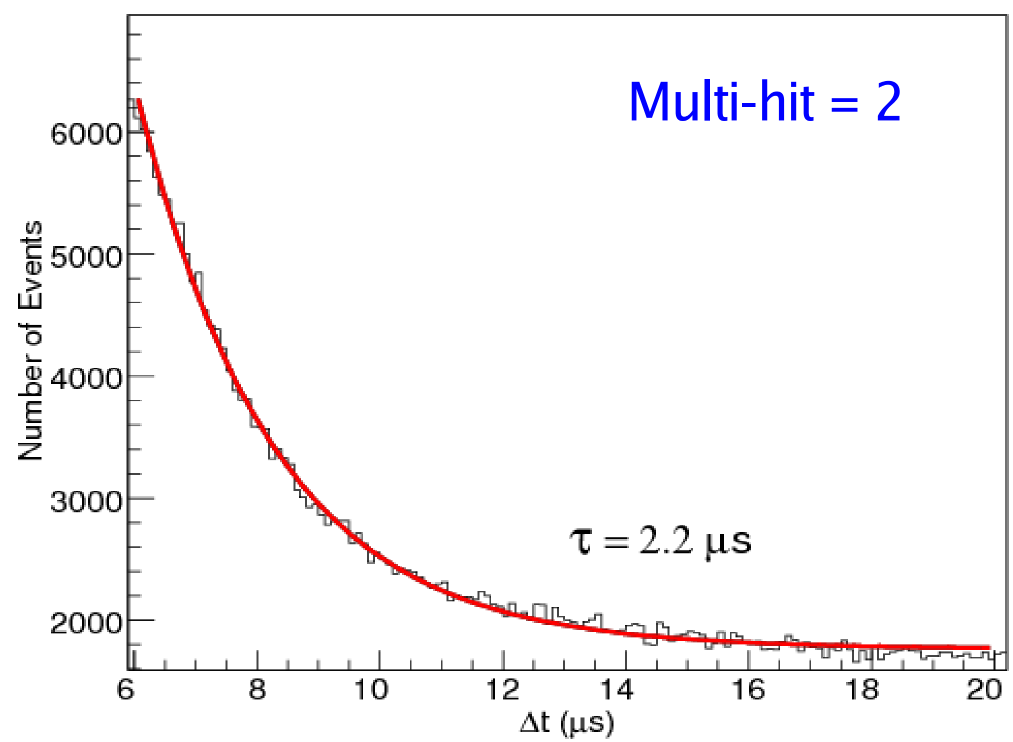
Requests: Atomic, Chemistry, Biology in TIFR, Oulu Finland, IUAC Delhi, Bose Institute, BARC etc.



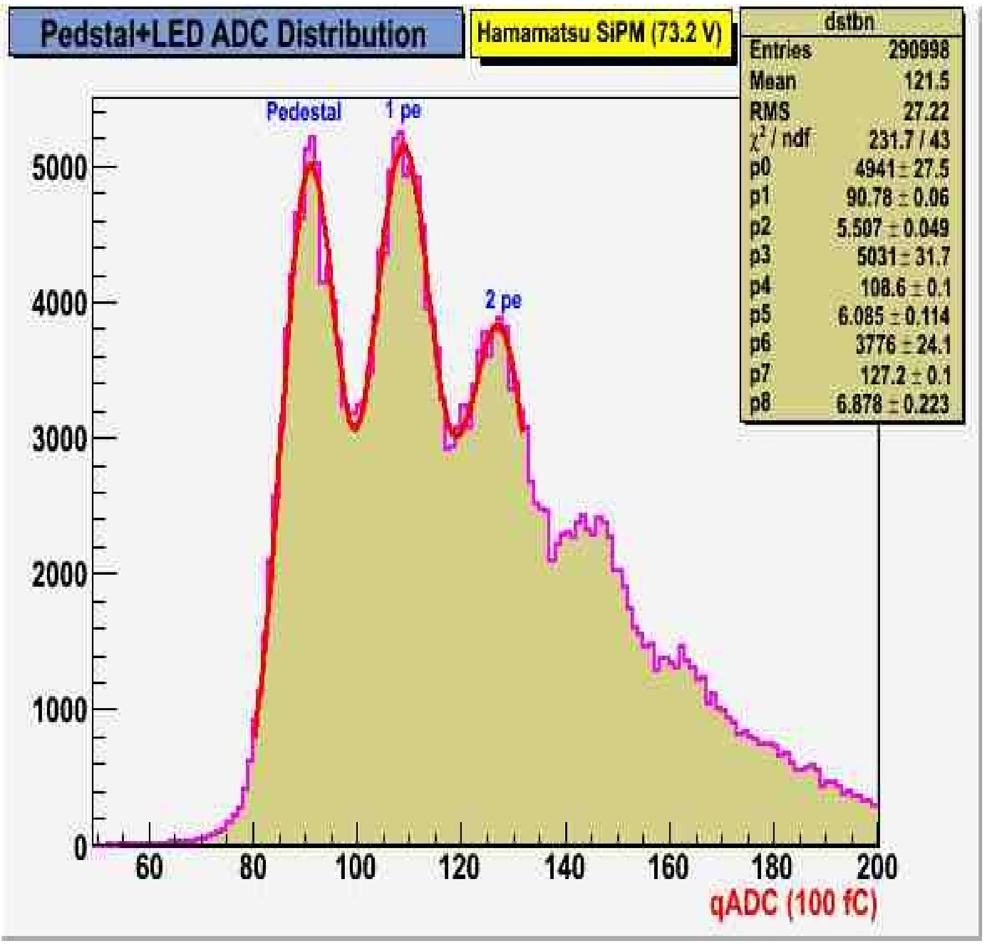

TDC Counts
Time (ns)
Slope = 5.1198 ± 0.0007 counts/ns

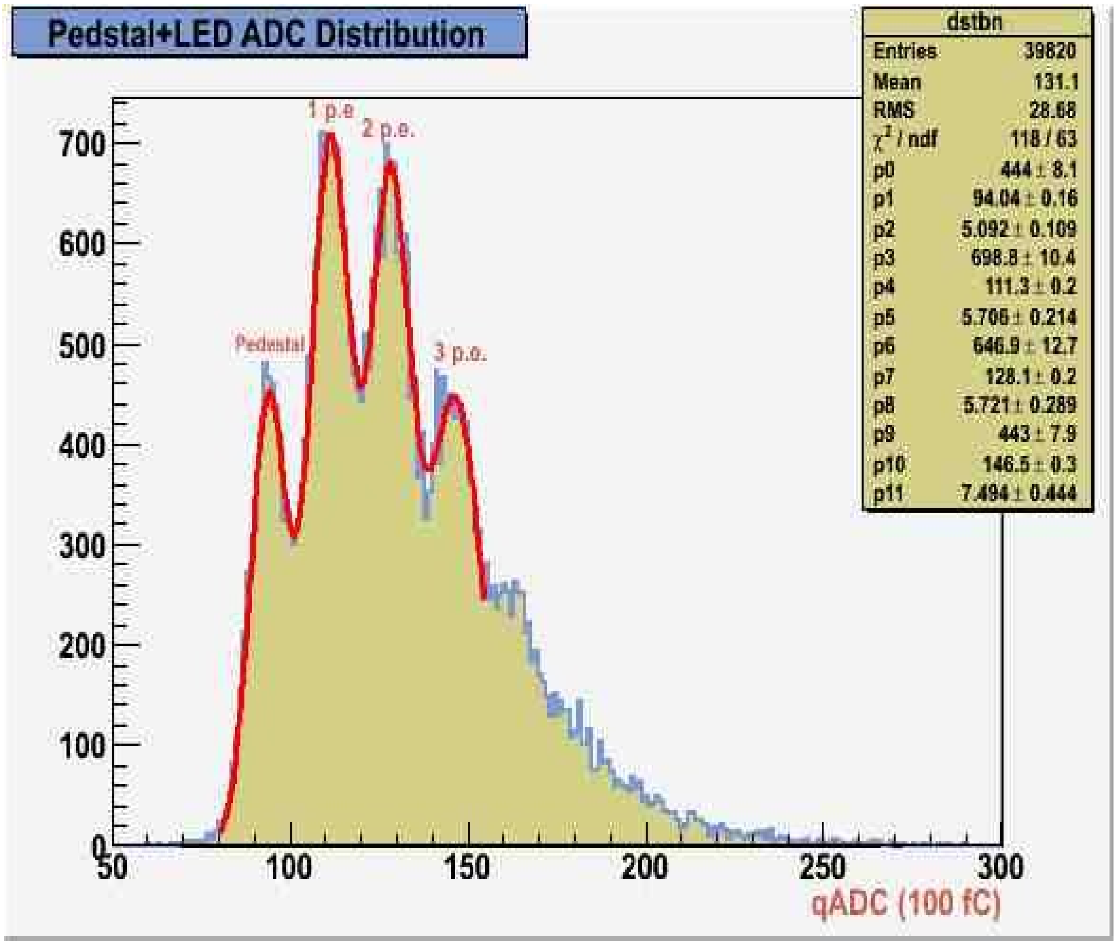

Phillips
HPTDC
Hoshin
Deviations (ns)
Time(ns)


Multi-hit = 2
1.5 μs
3.2 μs
Number of Events
(t2 - t1) μs

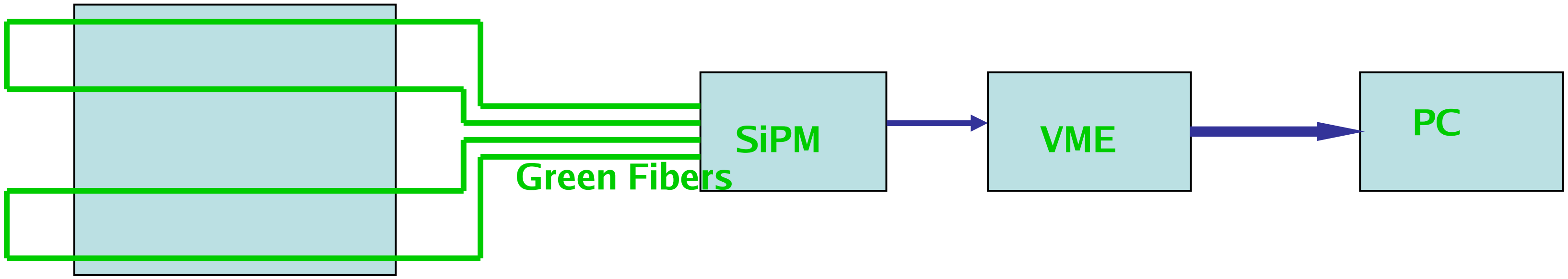

Multi-hit = 2
τ = 2.2 μs
Number of Events
Δt (μs)

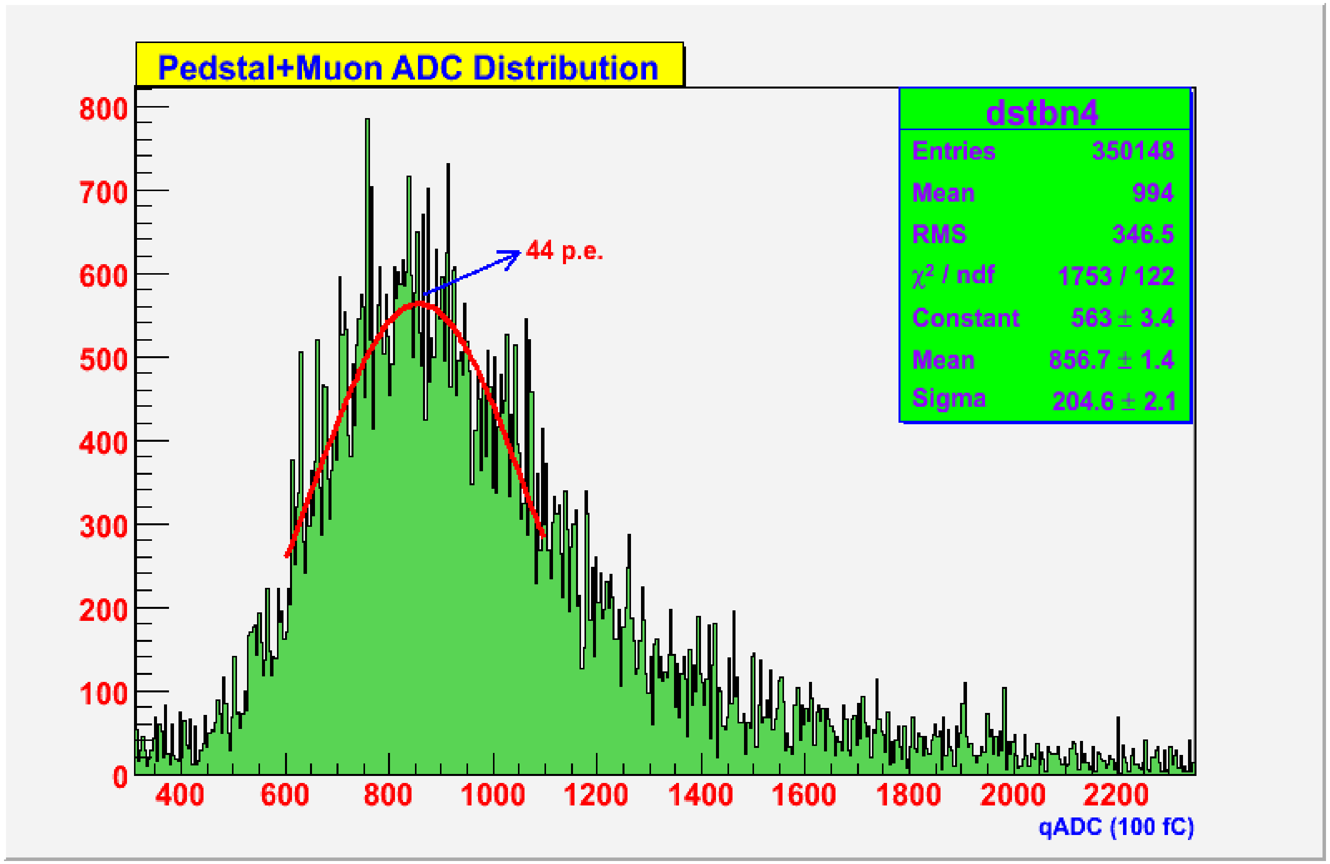
SiPM Results using LED as a Source





Muon 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

KCR

ROOT Based Data Analysis

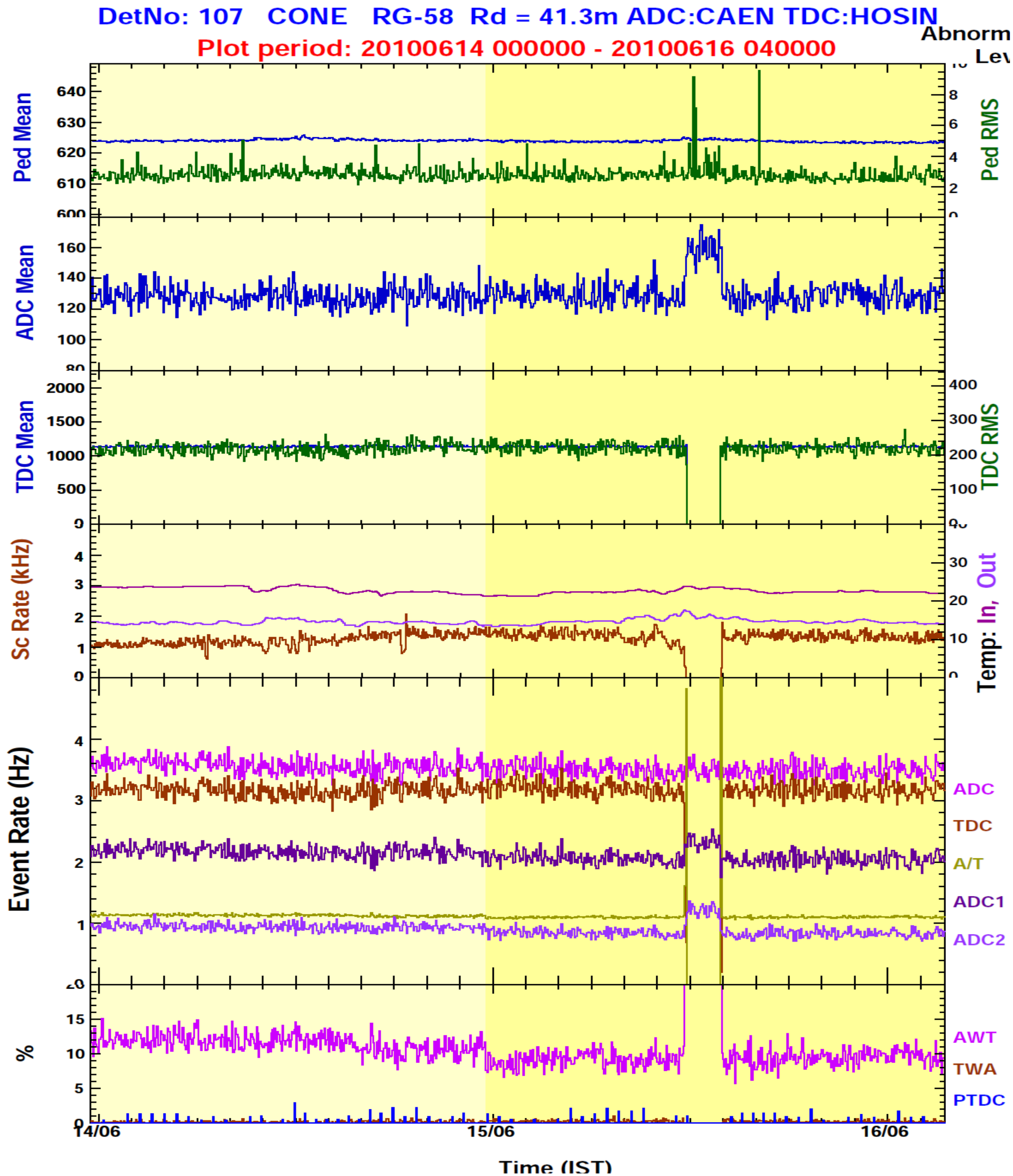
A modular, efficient ROOT based framework is being developed for the analysis of GRAPES-3 data. Use of OOP allowed independent development of code and portability.

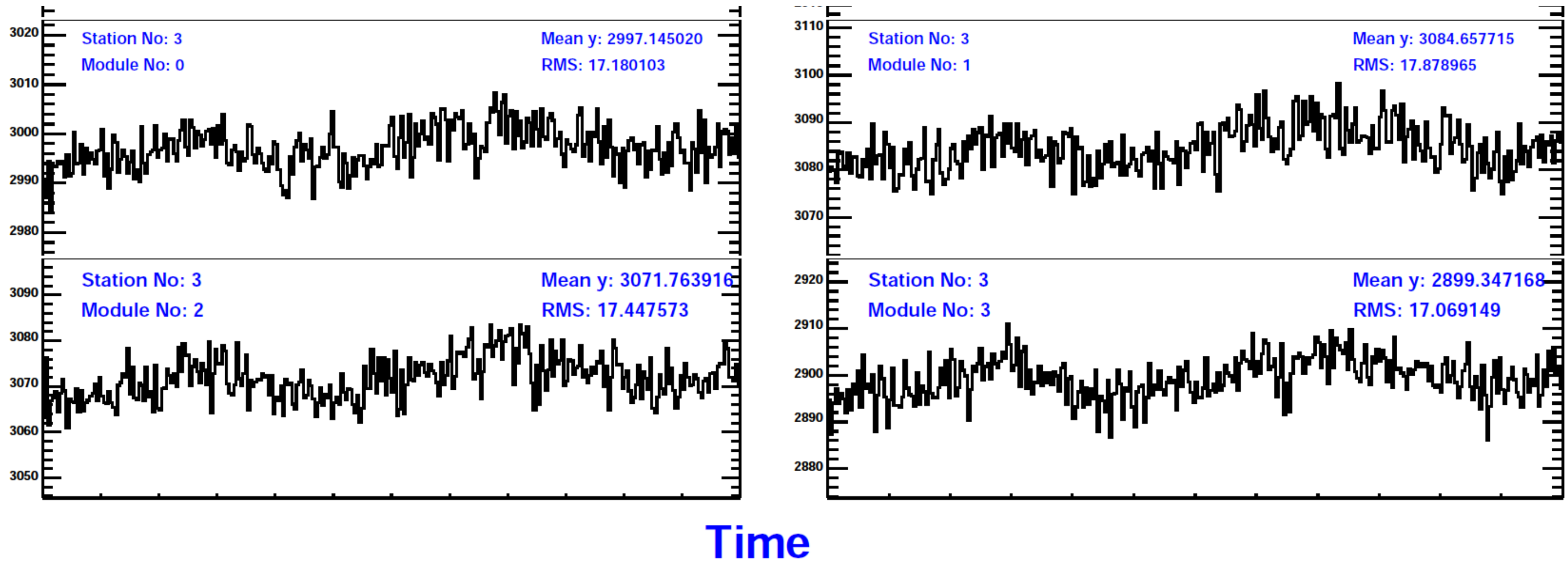
Tasks completed:

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

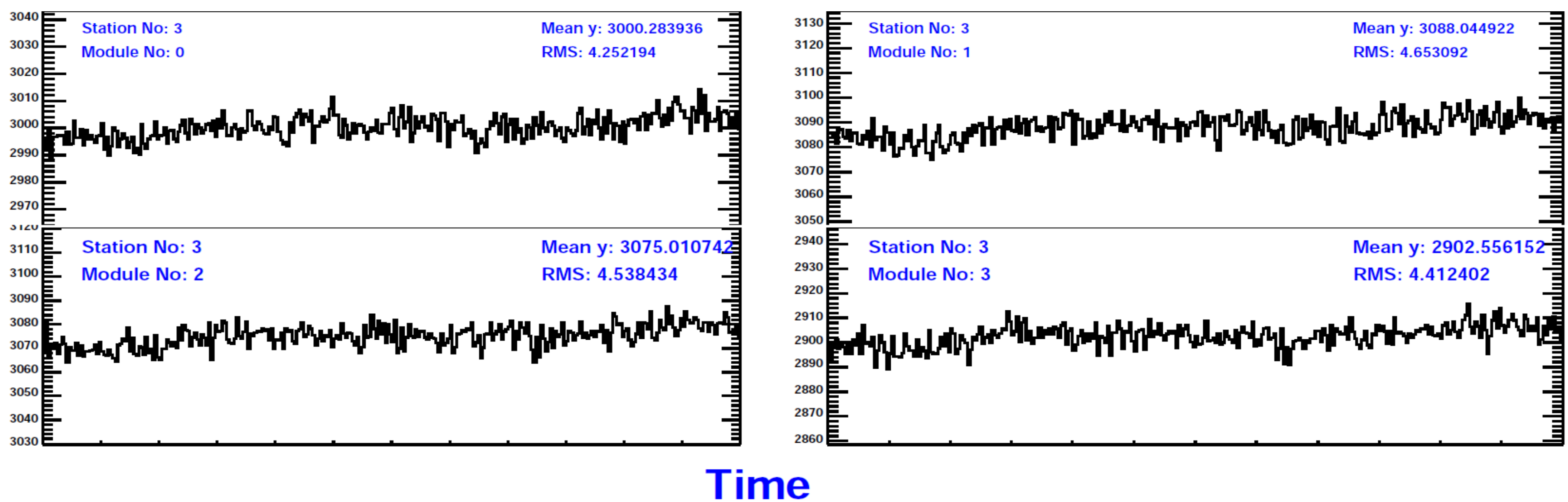
Integration of calibration and other important house-keeping data. Efficient monitoring tools to aid trouble-shooting.

Online Solar Flare and CME watch   SRD


DetNo: 107 CONE RG-58 Rd = 41.3m ADC:CAEN TDC:HOSIN
Plot period: 20100614 000000 - 20100616 040000
Abnorm
Lev
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)

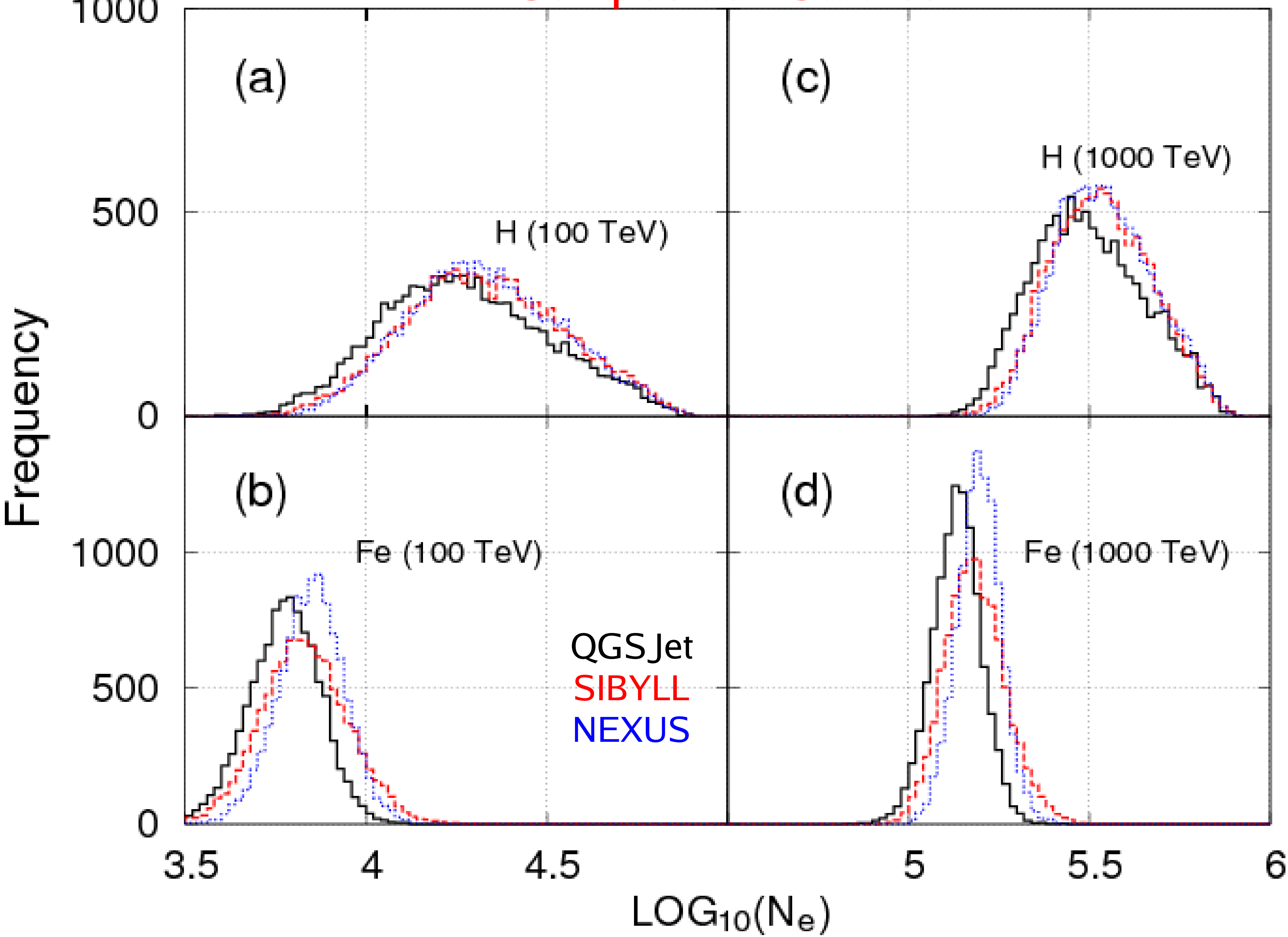


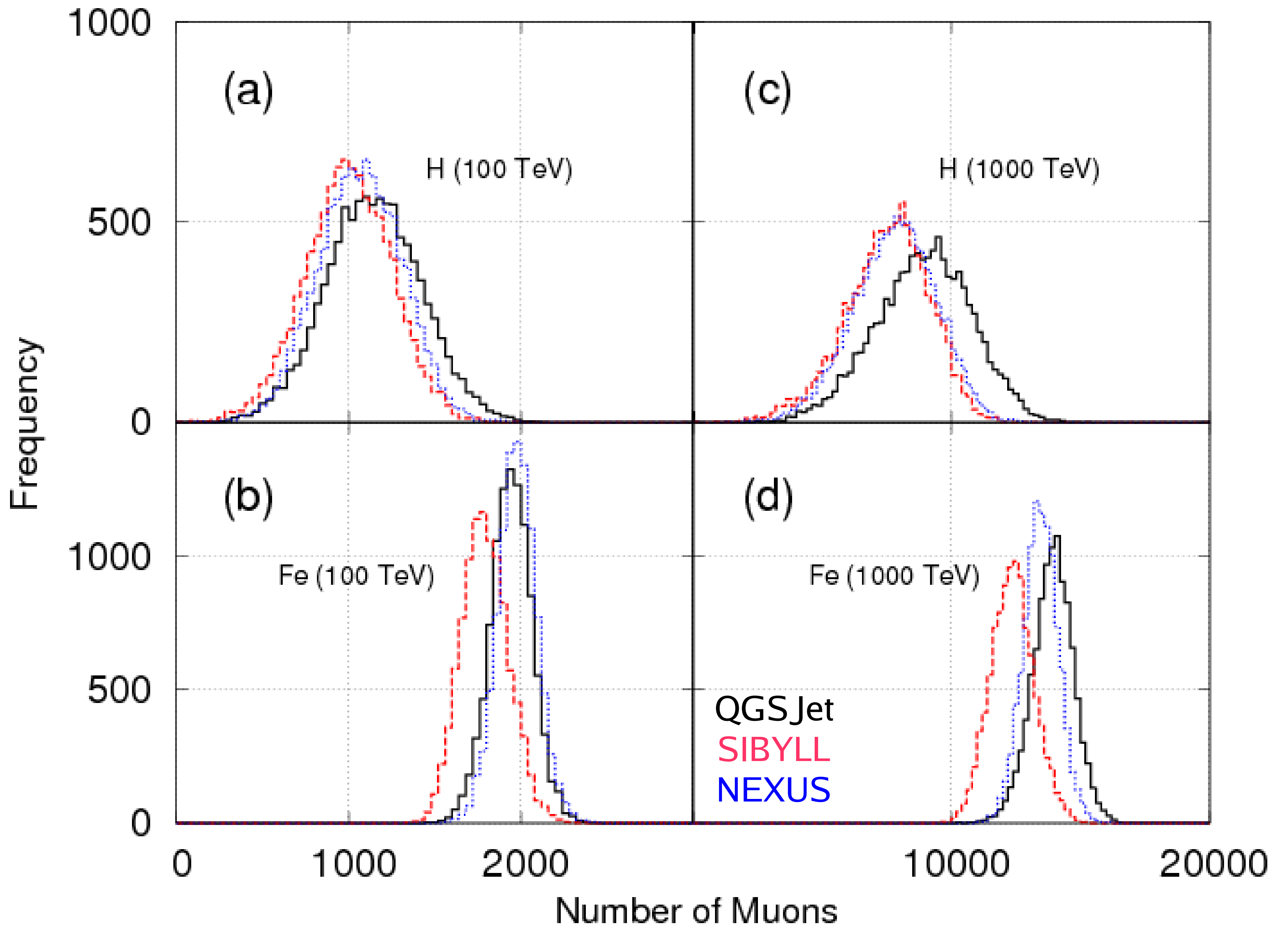
Pressure corrected Inclusive Mean Angle Rate (Hz) after validation: 20100604 000000 to 20100604 235959



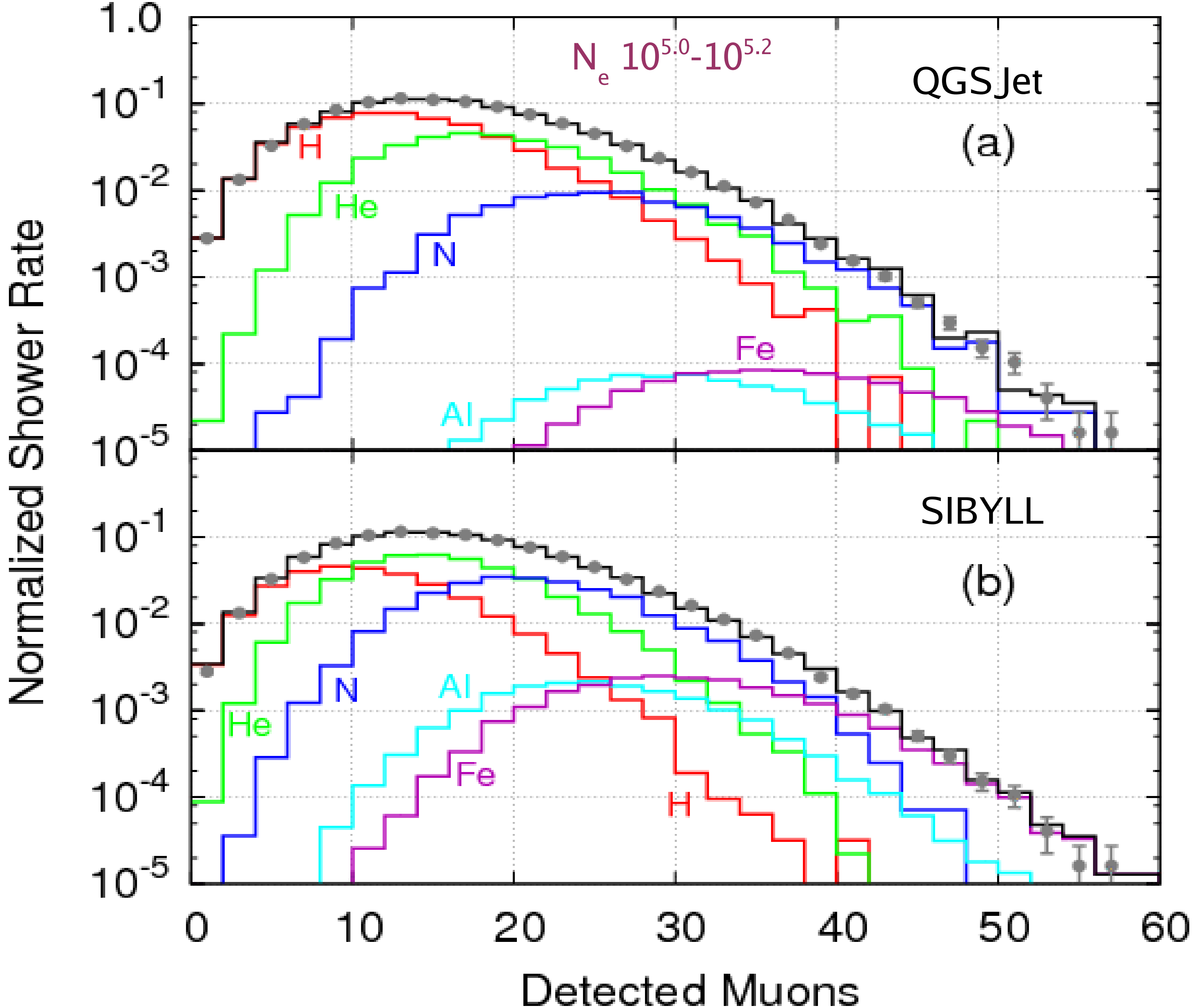
GRAPES-3 Results

Composition Studies



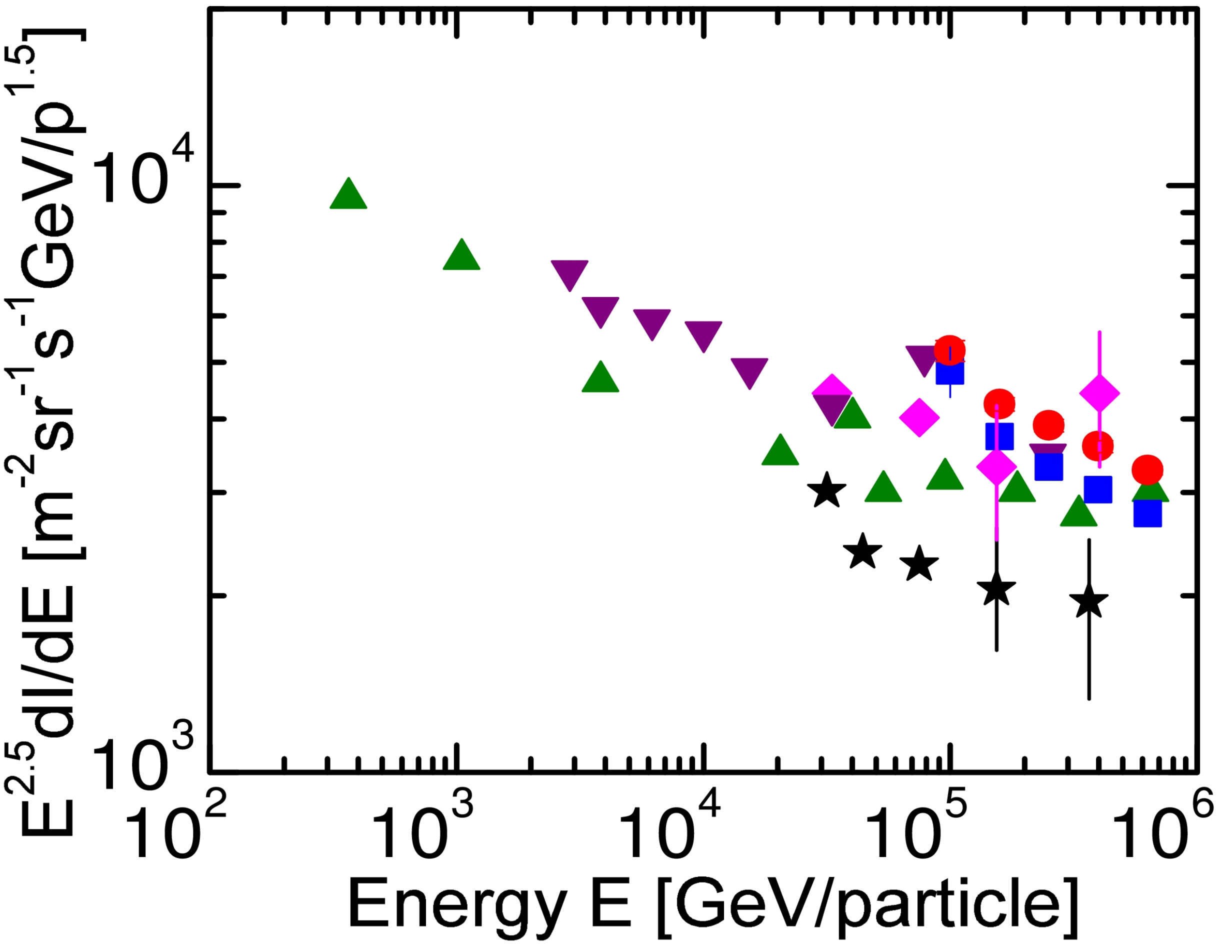


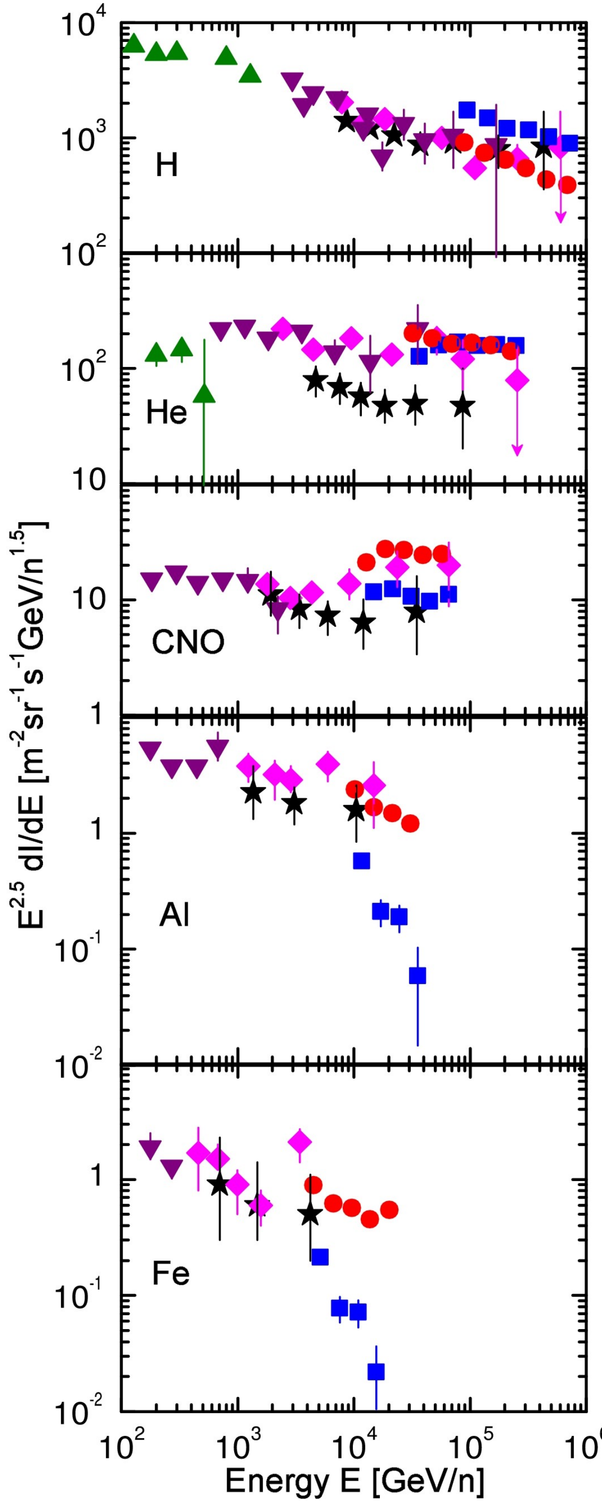
(a)
H (100 TeV)
(b)
Fe (100 TeV)
(c)
H (1000 TeV)
(d)
Fe (1000 TeV)
QGSJet
SIBYLL
NEXUS
Frequency
Number of Muons
0
500
1000
0
500
1000
0
1000
2000
10000
20000

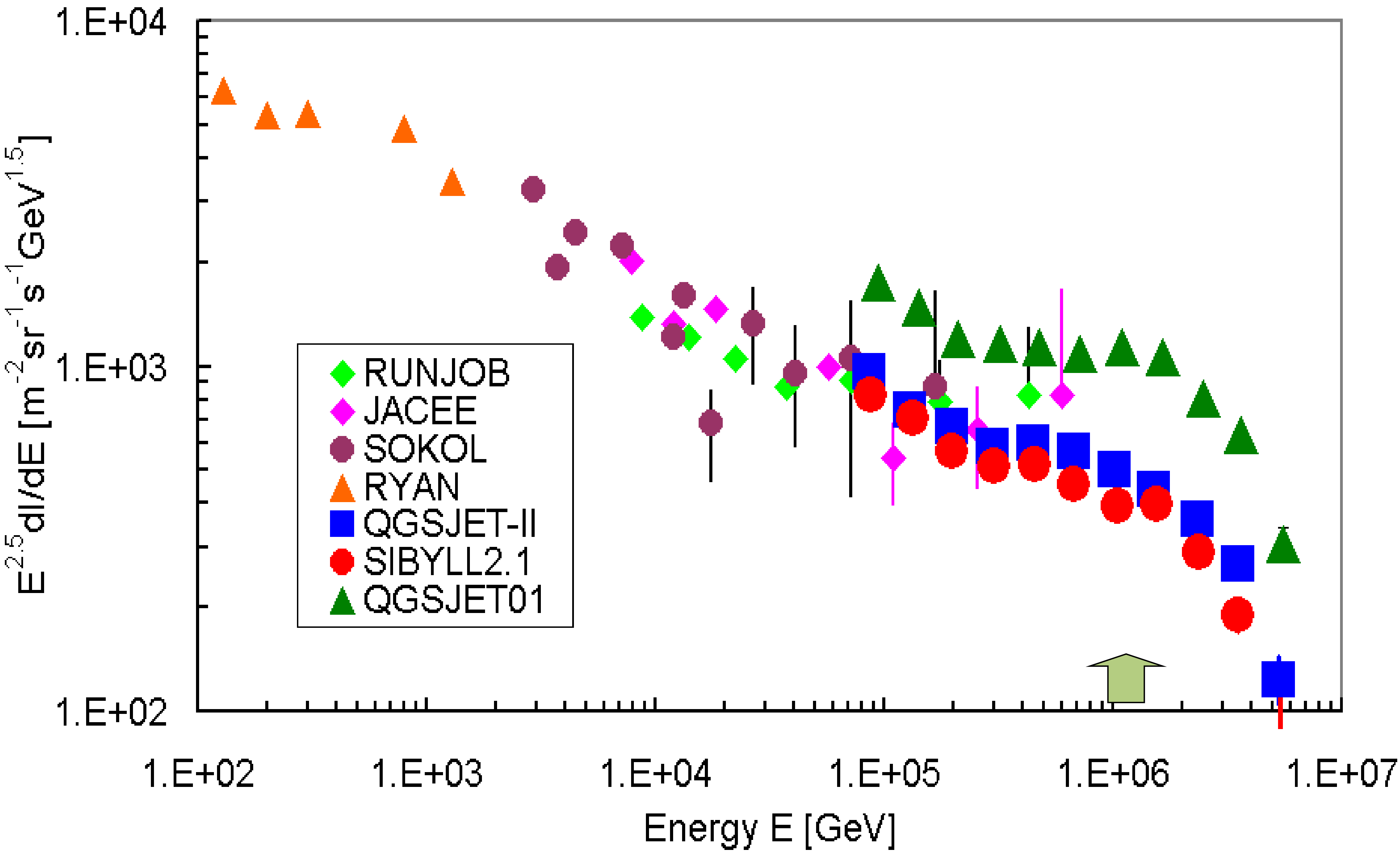


N_e $10^{5.0}$-$10^{5.2}$
QGSJet
(a)
SIBYLL
(b)
H
He
N
Al
Fe
Normalized Shower Rate
Detected Muons
1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60

All particle energy spectrum

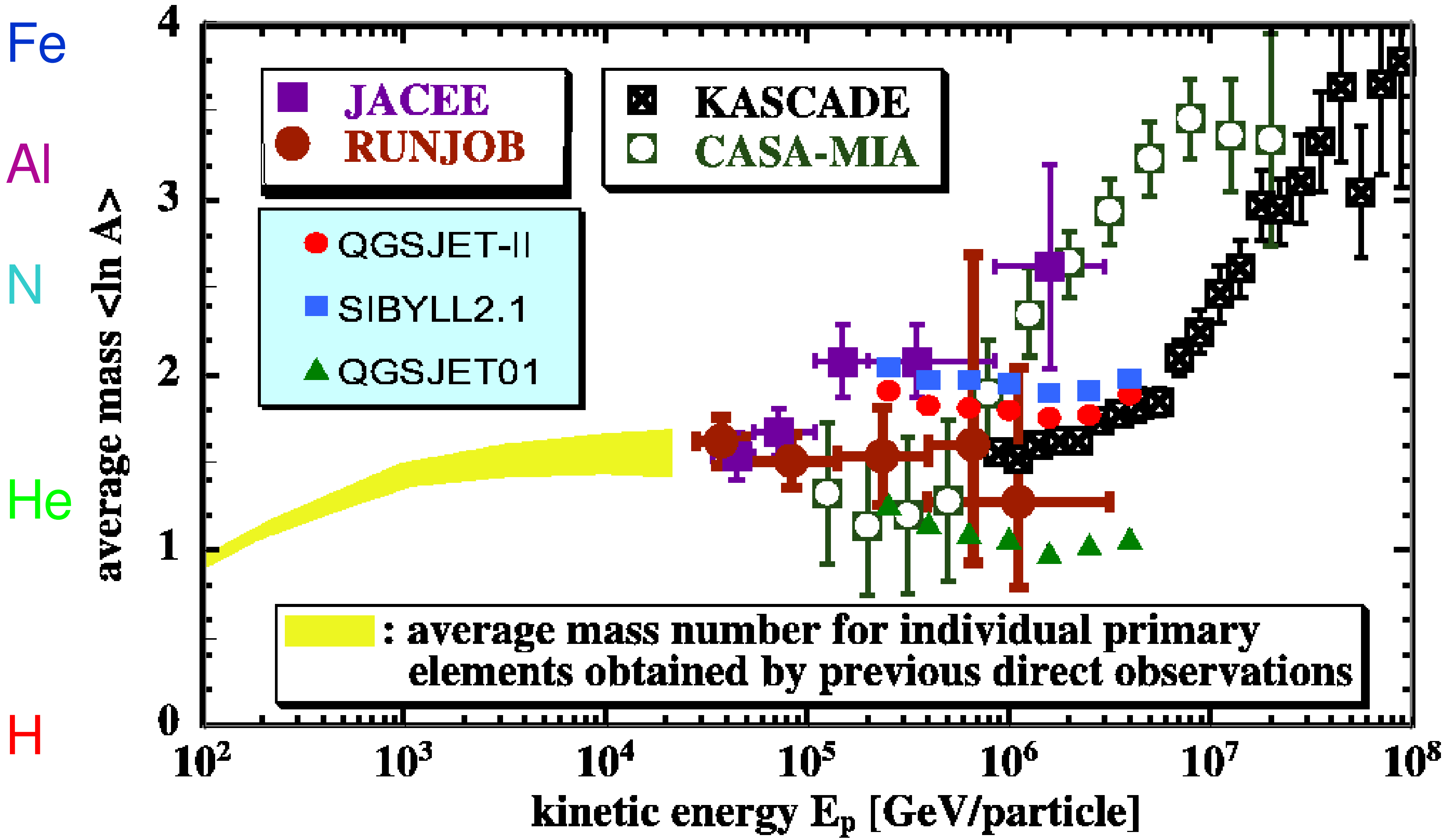




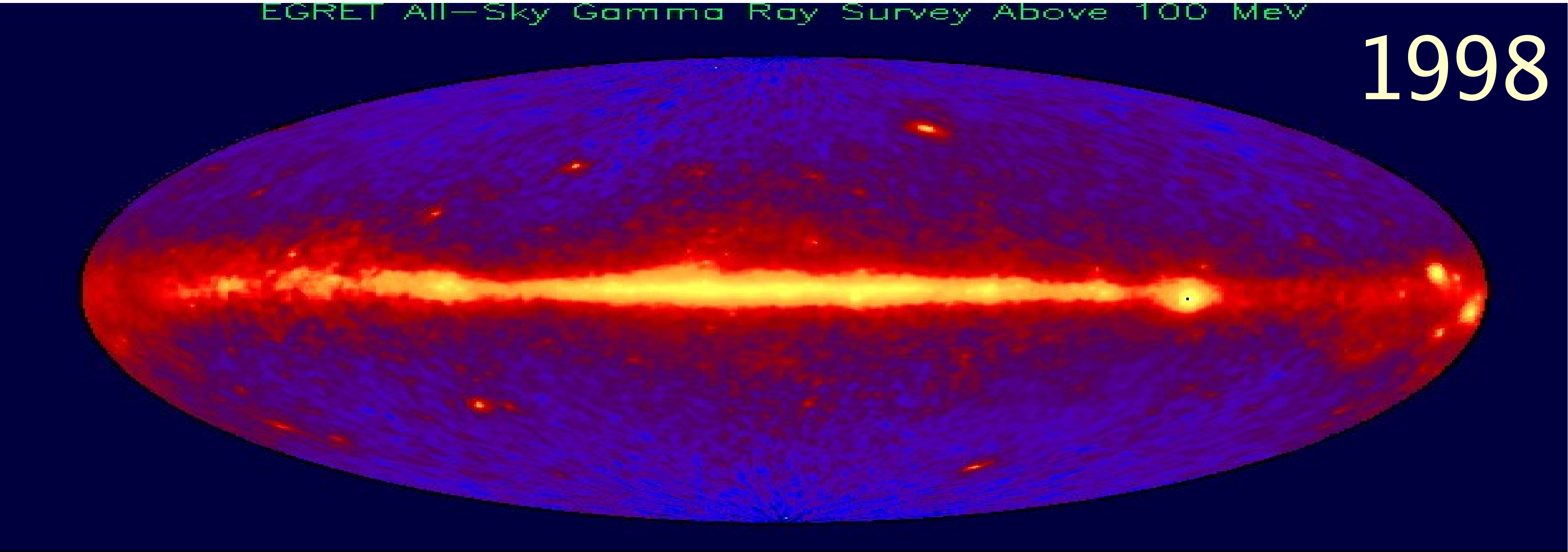


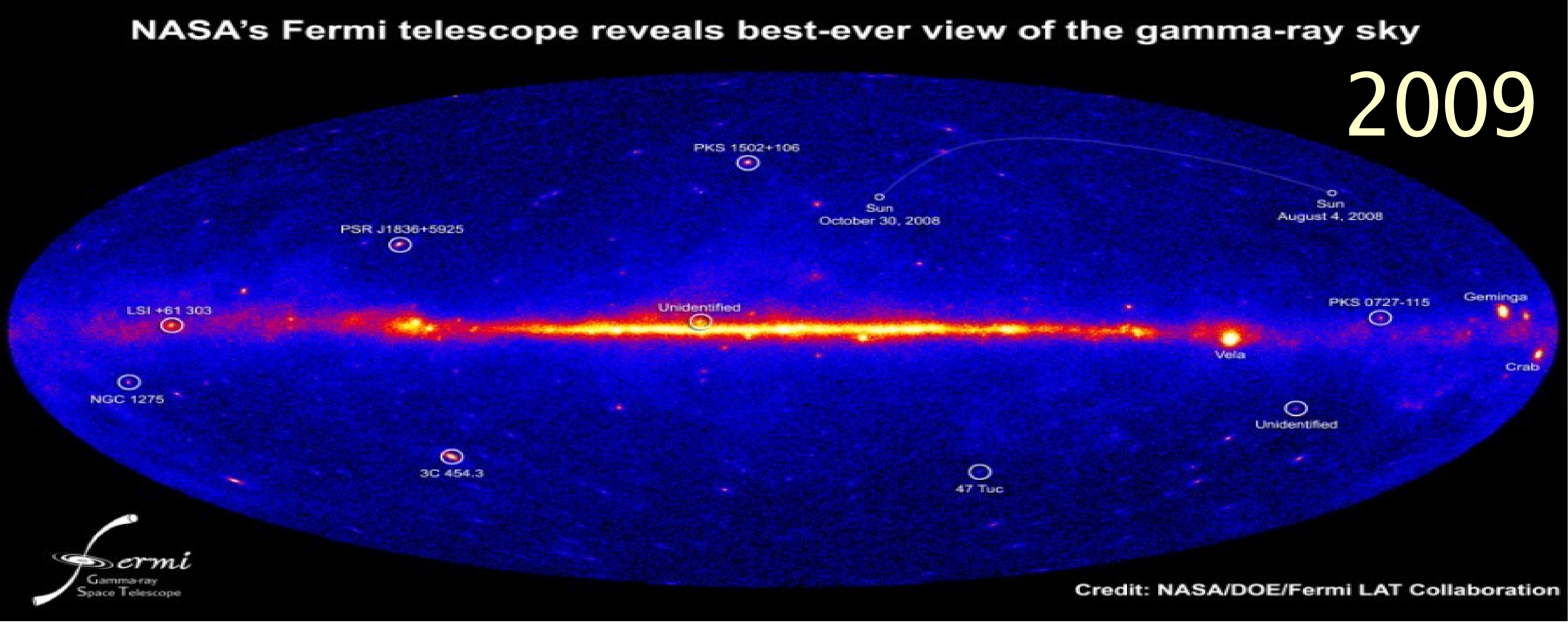
Comparison with direct measurements is possible

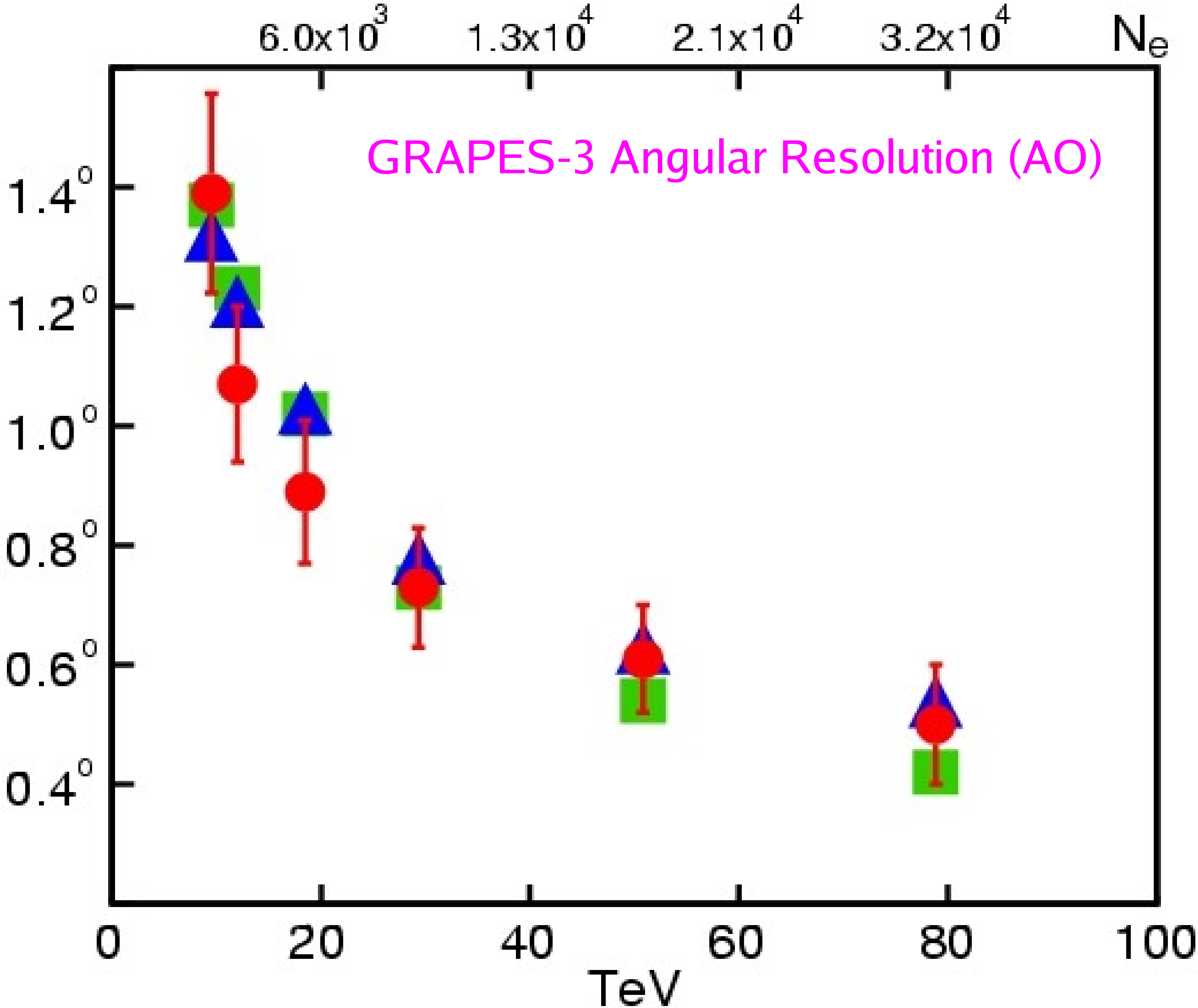
Mean Mass Number



Lower threshold enables data to compare with direct measurements.


EGRET All-Sky Gamma Ray Survey Above 100 MeV
1998

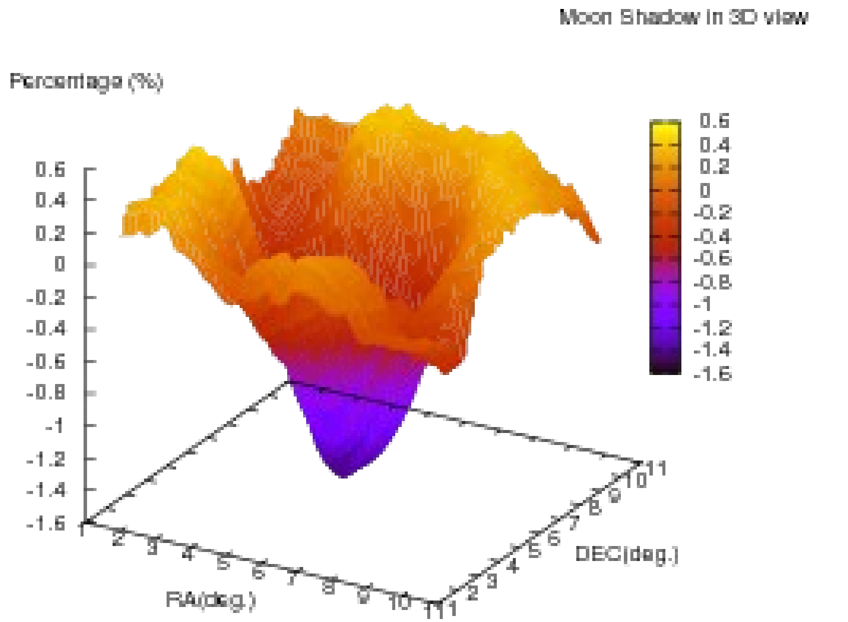

NASA's Fermi telescope reveals best-ever view of the gamma-ray sky
2009
PKS 1502+106
Sun
October 30, 2008
Sun
August 4, 2008
PSR J1836+5925
LSI +61 303
Unidentified
PKS 0727-115
Geminga
Vela
Crab
NGC 1275
Unidentified
3C 454.3
47 Tuc
Fermi
Gamma-ray Space Telescope
Credit: NASA/DOE/Fermi LAT Collaboration



6.0x10^3
1.3x10^4
2.1x10^4
3.2x10^4
Ne
GRAPES-3 Angular Resolution (AO)
1.4°
1.2°
1.0°
0.8°
0.6°
0.4°
0
20
40
60
80
100
TeV

Moon Shadow

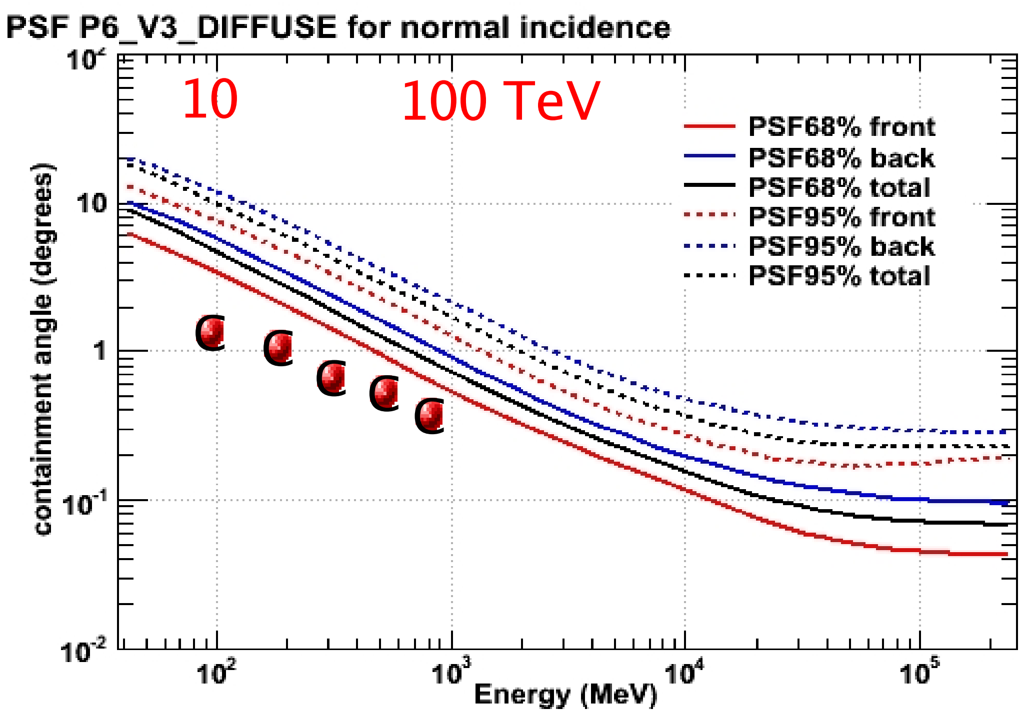
Moon

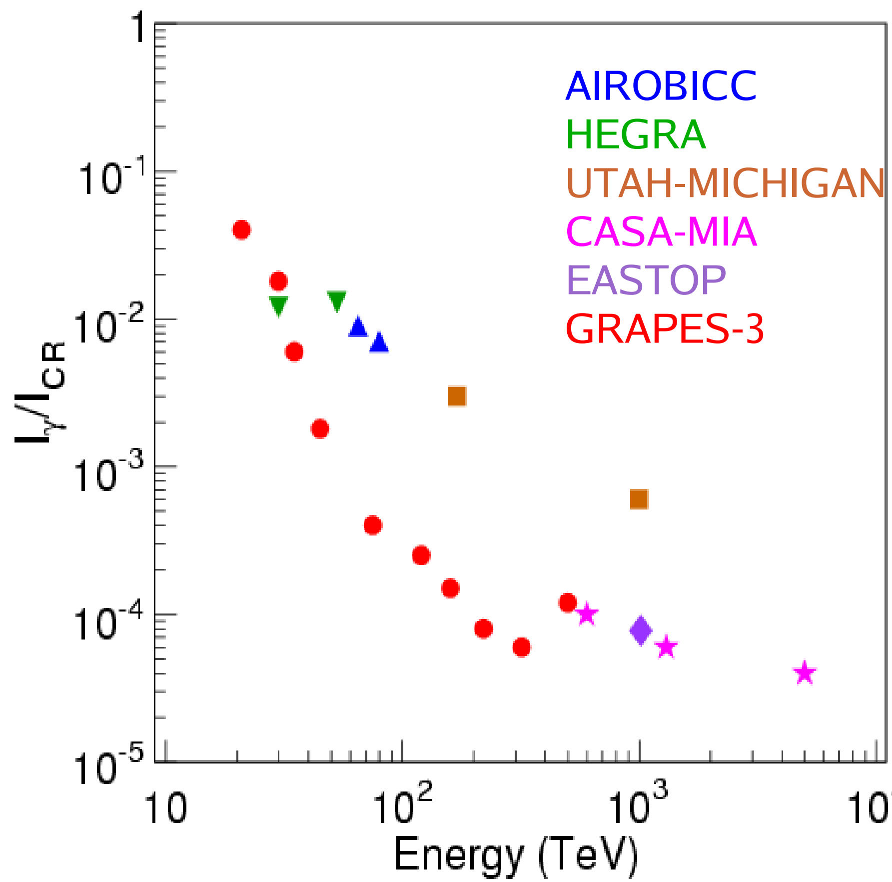


γ-ray astronomy

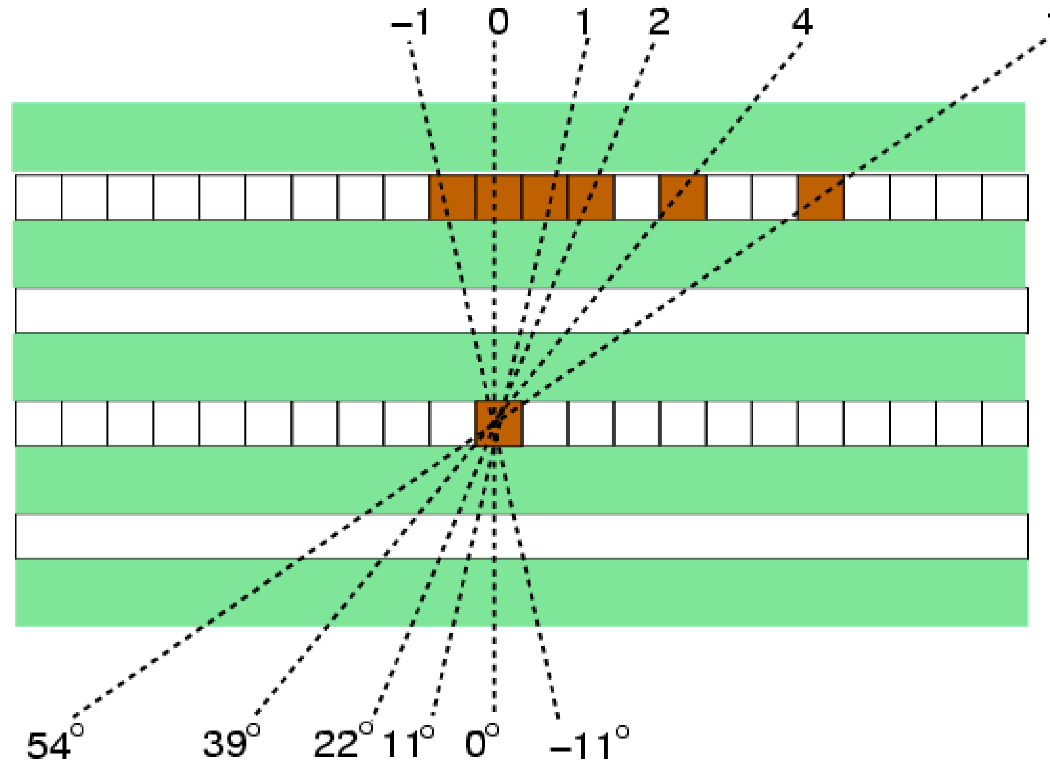
σ_θ = 25 arc min.

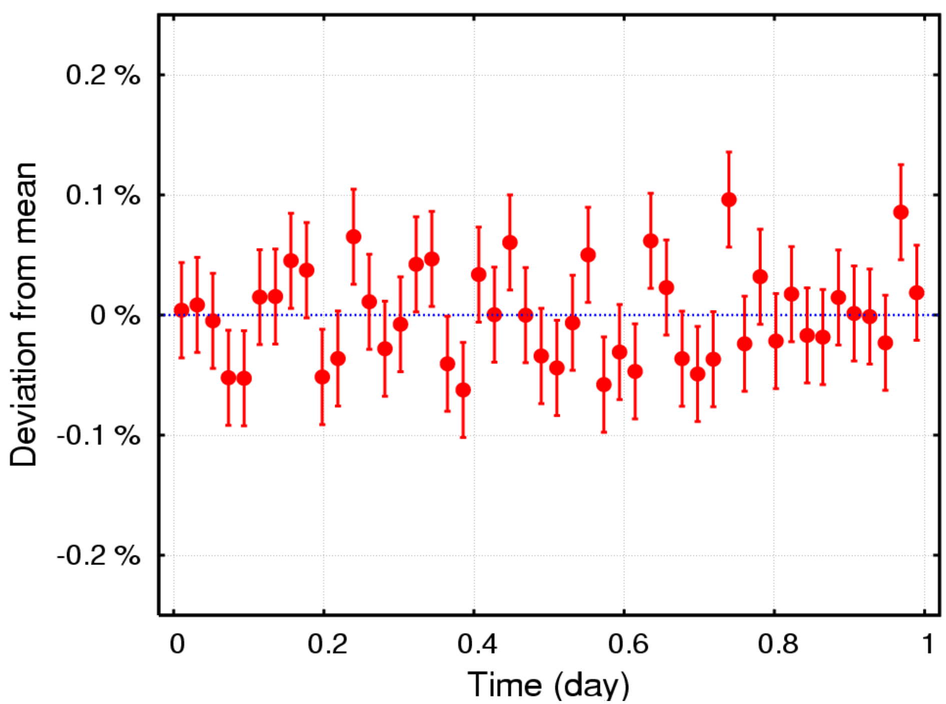
YH

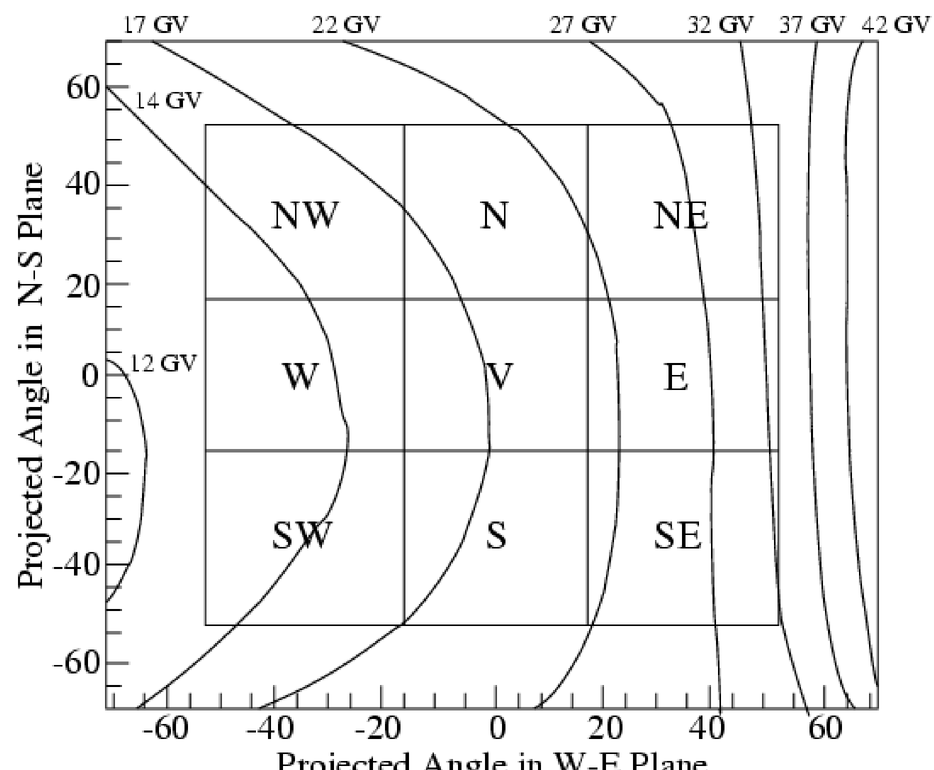




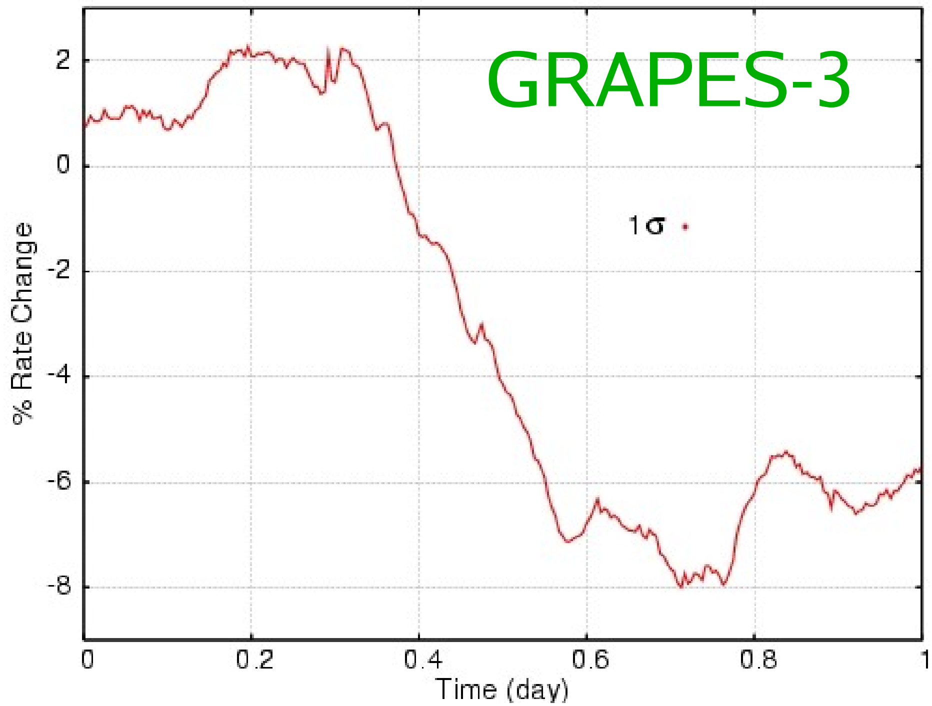
Solar phenomena

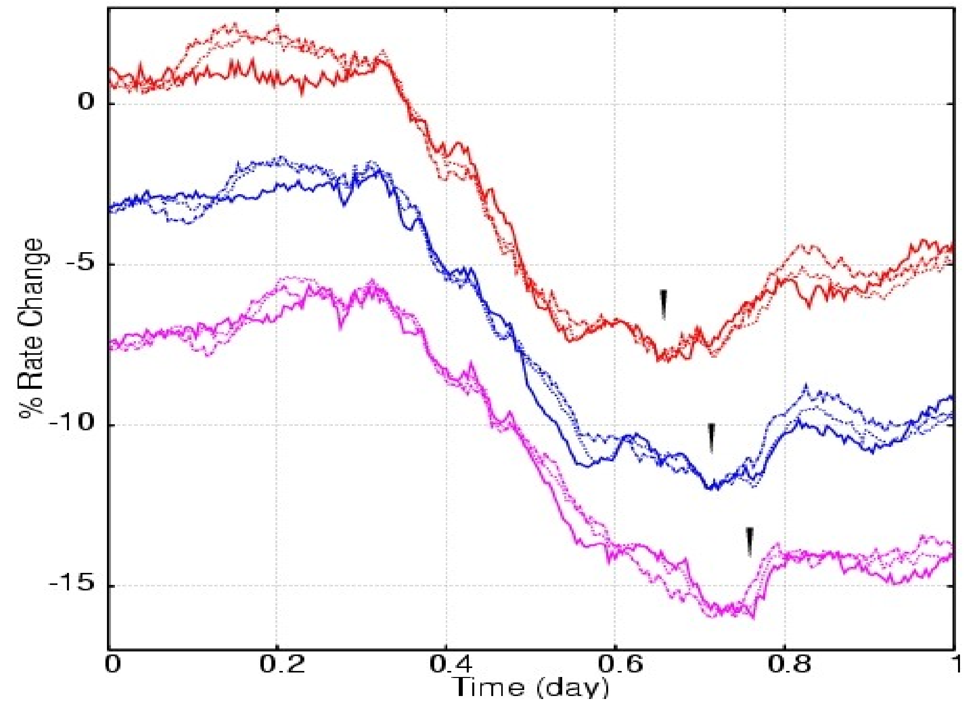


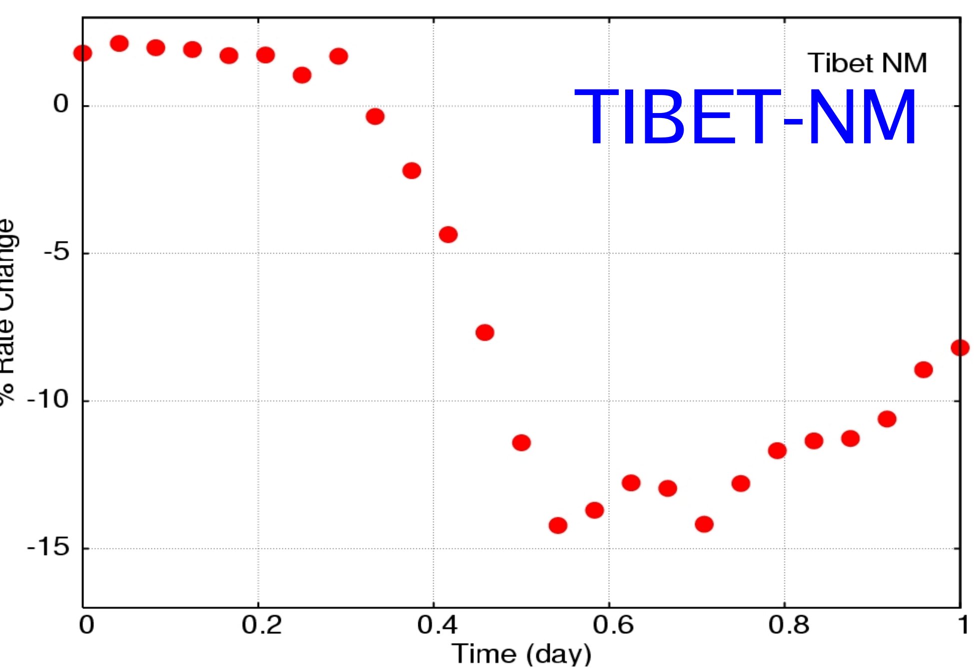


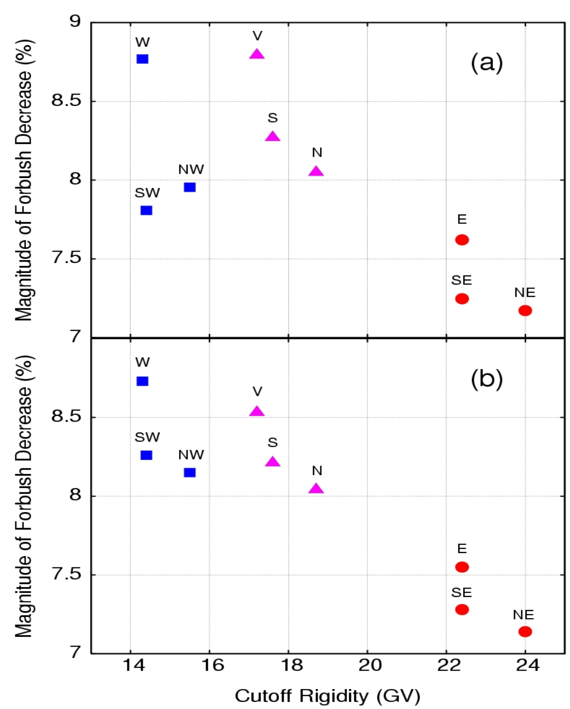


Coronal Mass Ejection (28 October 2003)







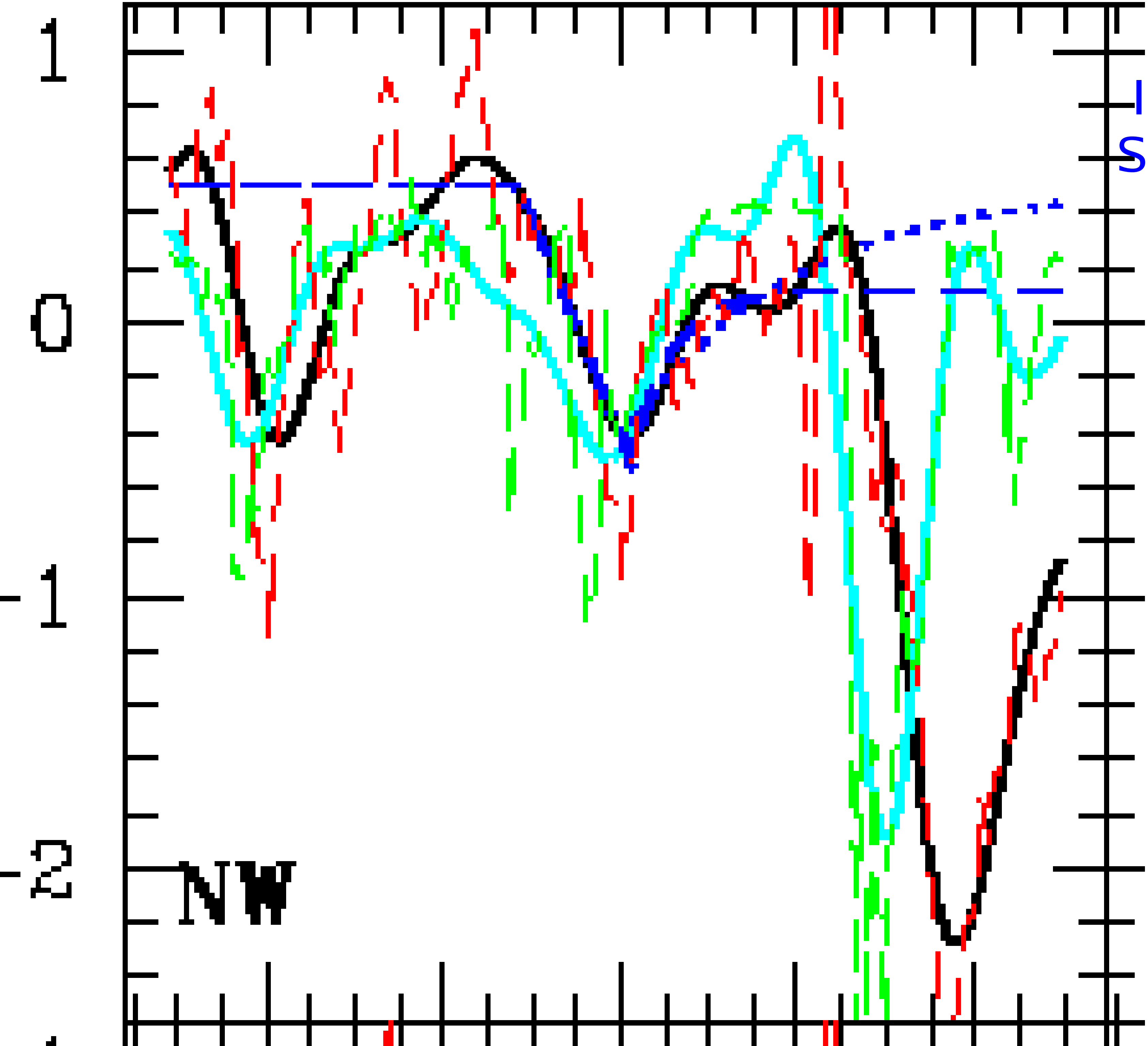


$A(r) = K \times r^{-\gamma}$

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

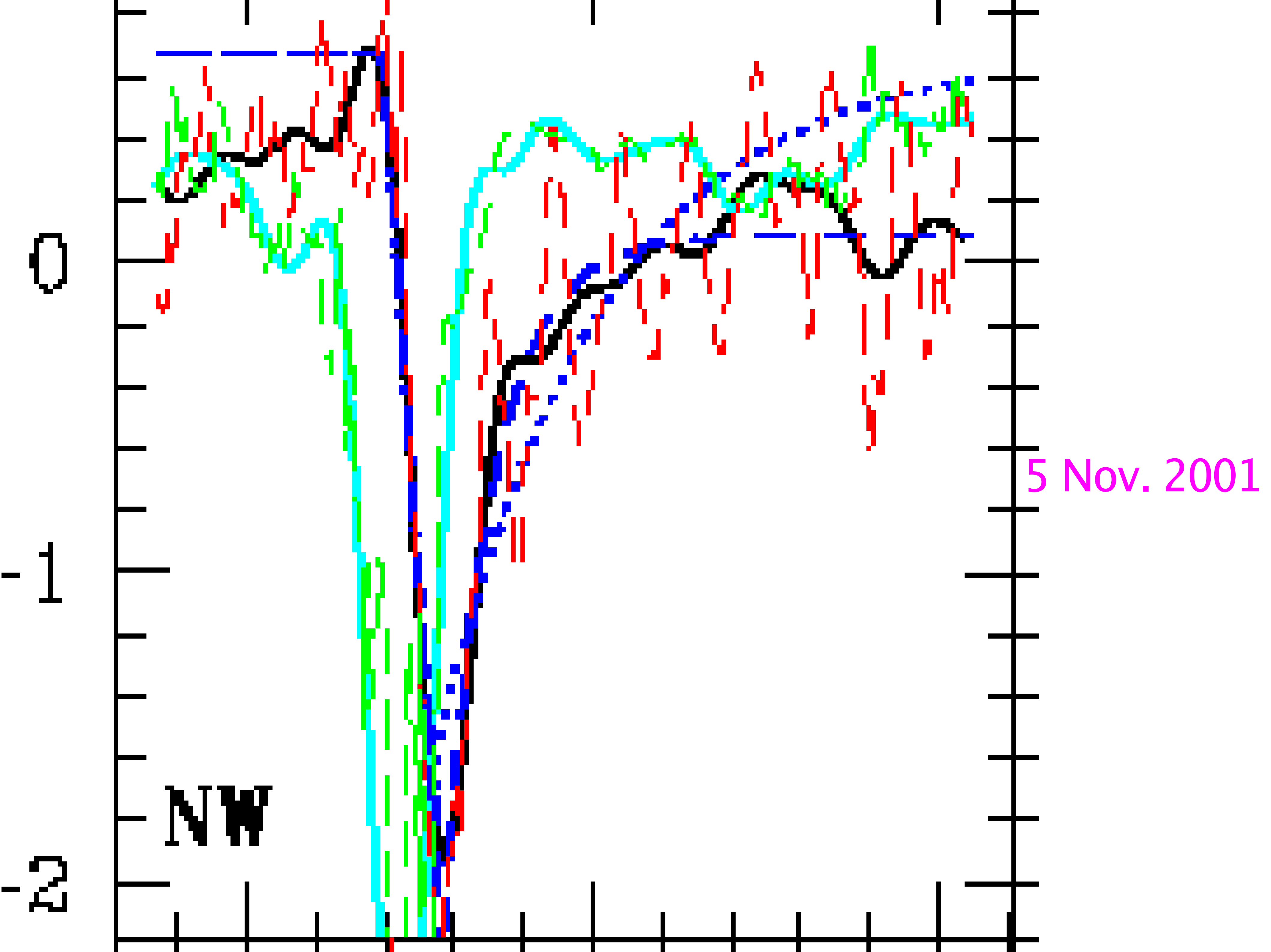
$\gamma = (0.53 \pm 0.04)$

$\gamma = 0.4 - 1.2$

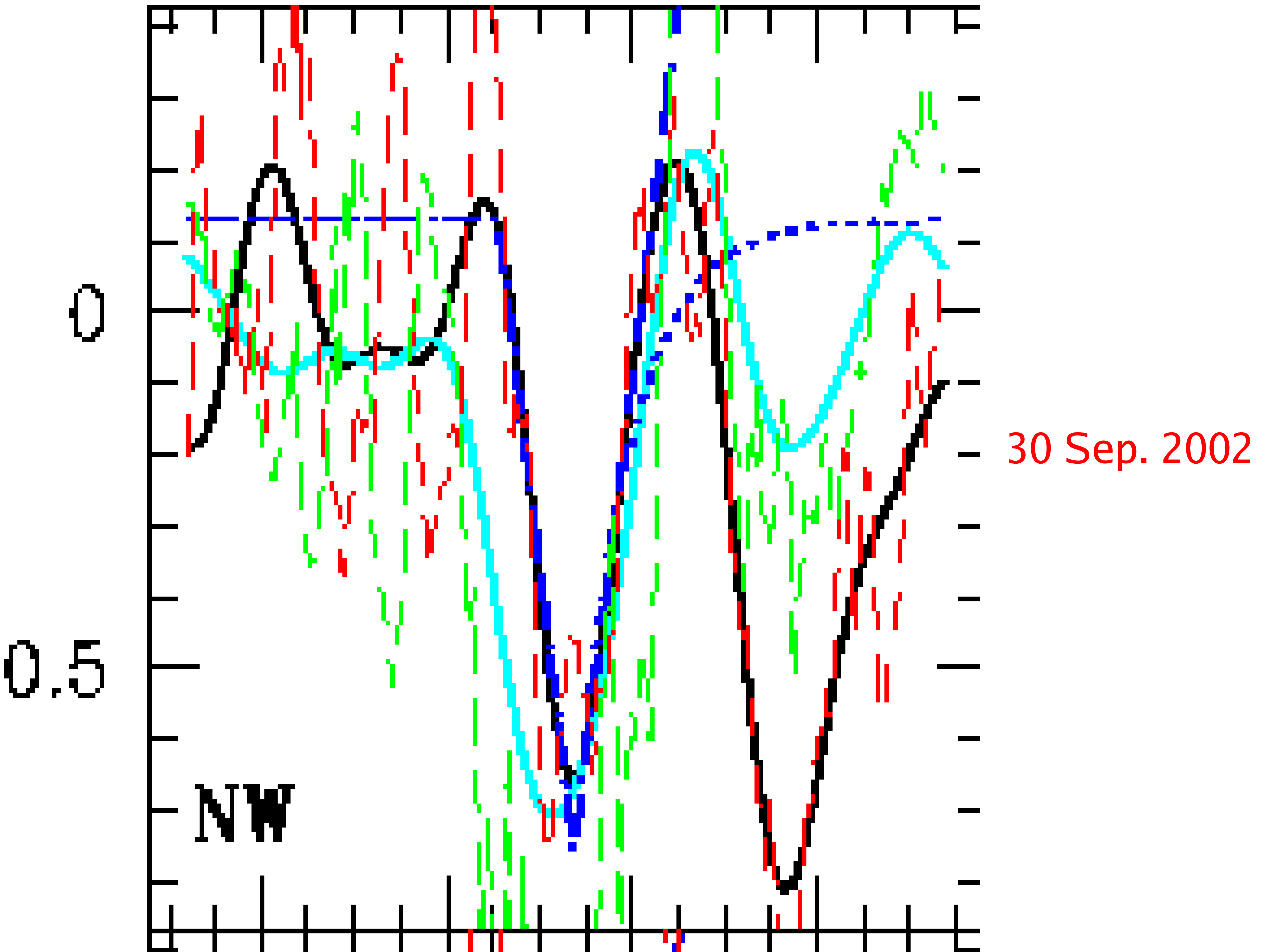


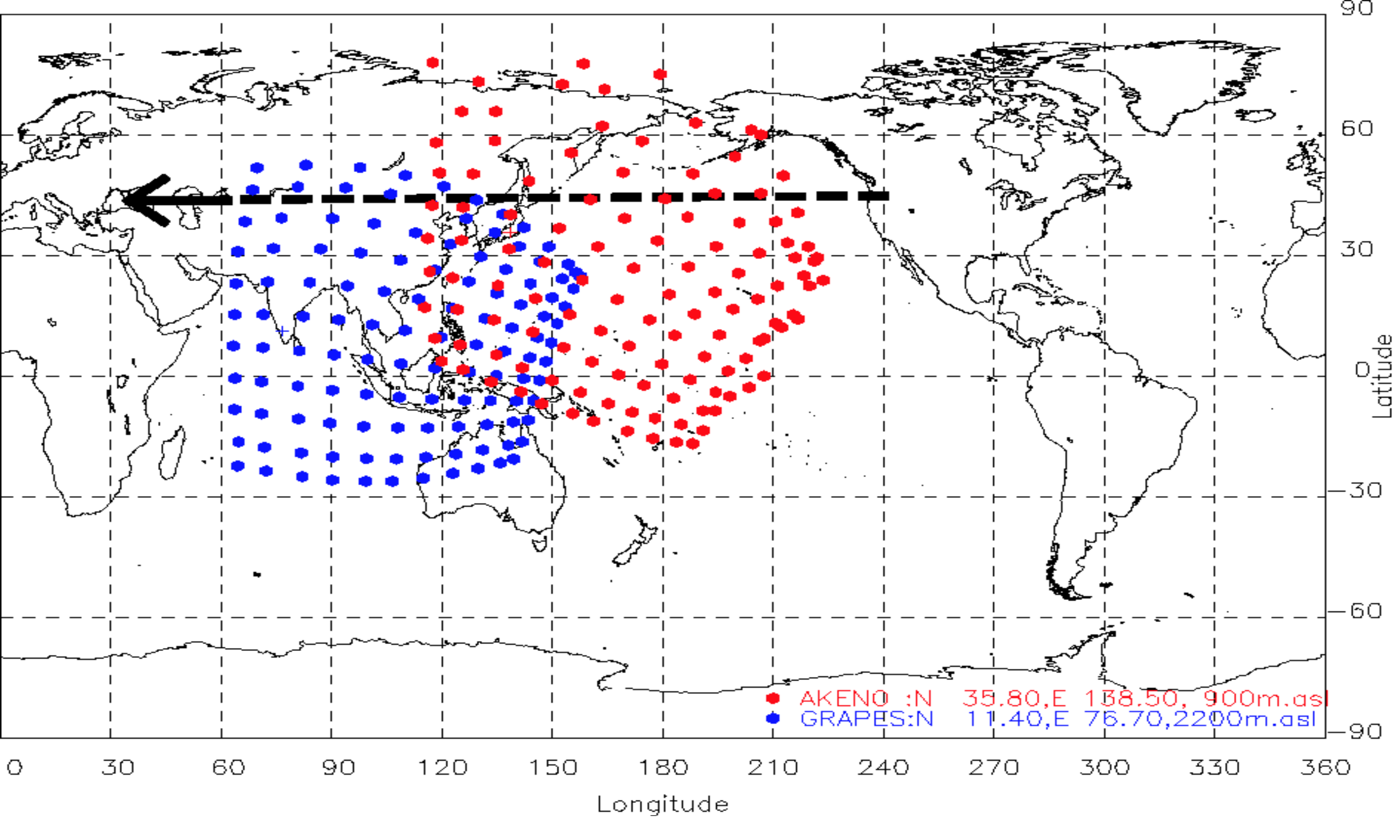
Study of Interplanetary Space from the Earth

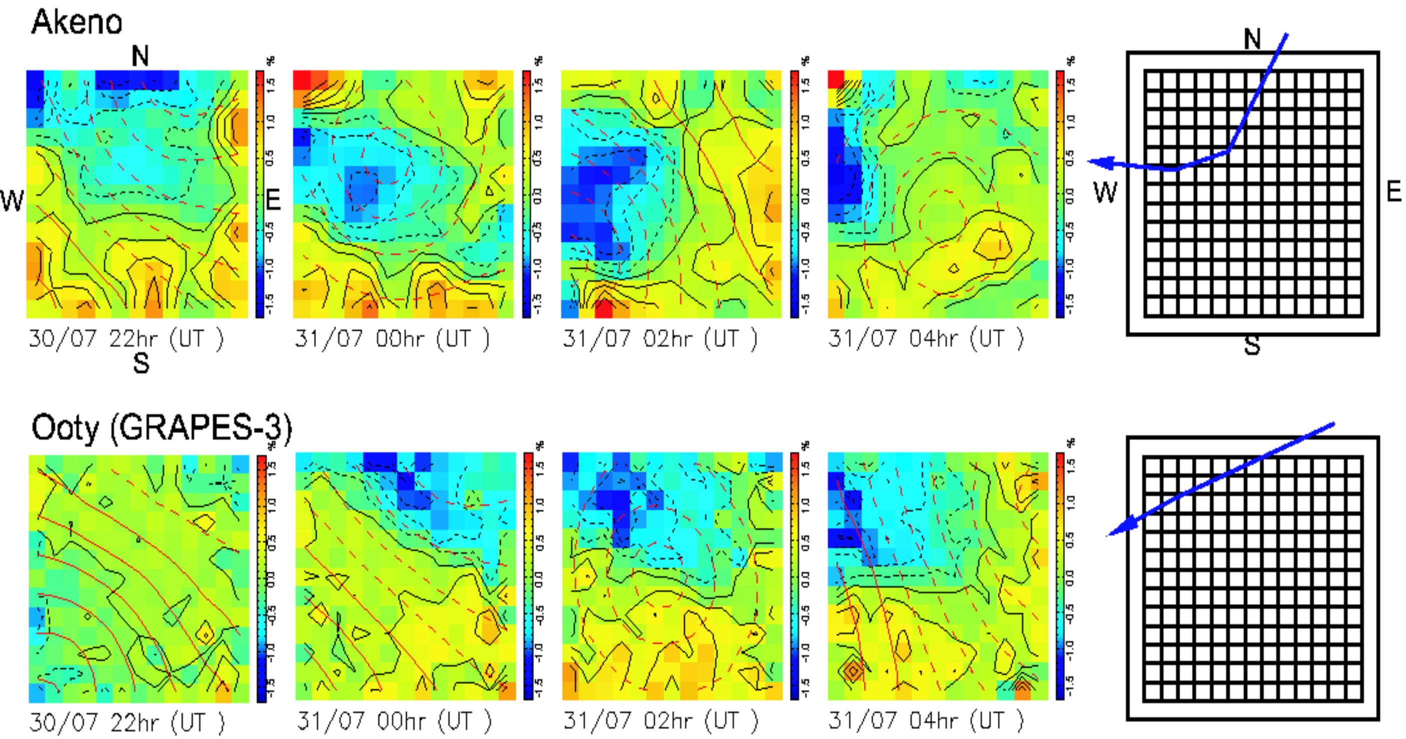
7 April 2001



0
-1
-2
NW
5 Nov. 2001


0
0.5
NW
30 Sep. 2002



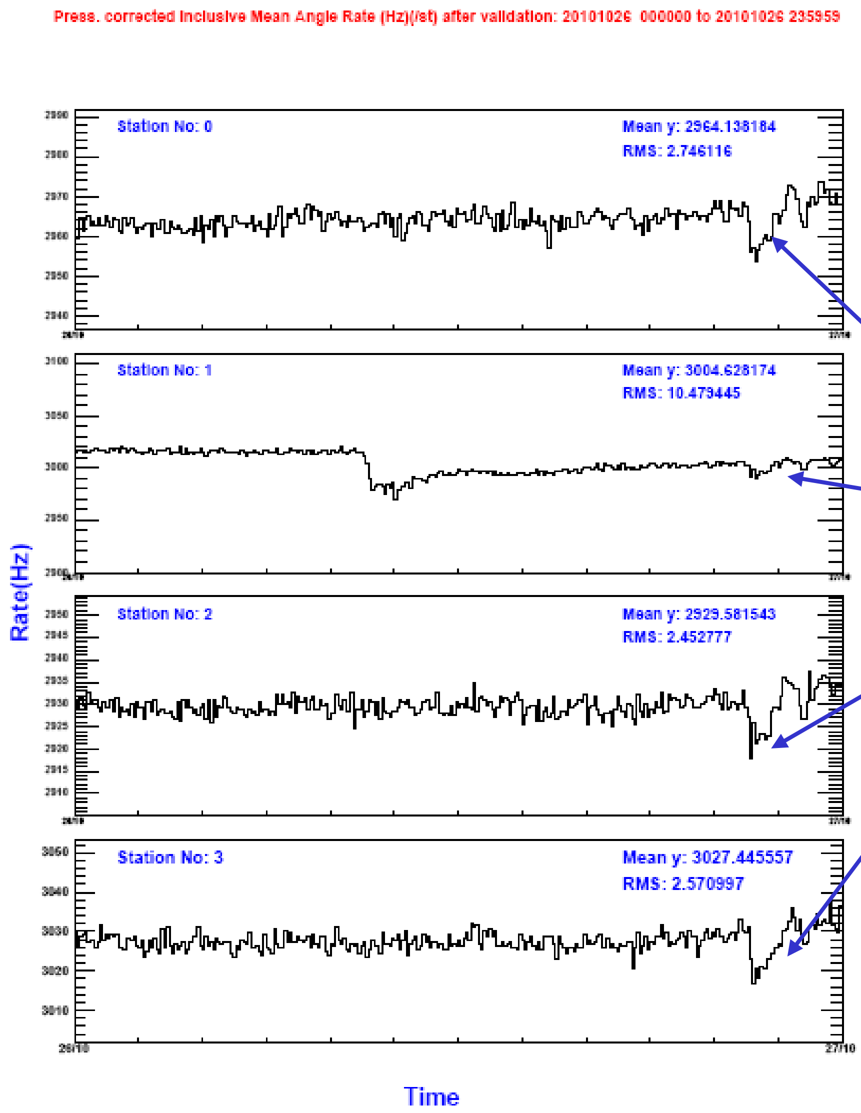


Future probe Space Weather:

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

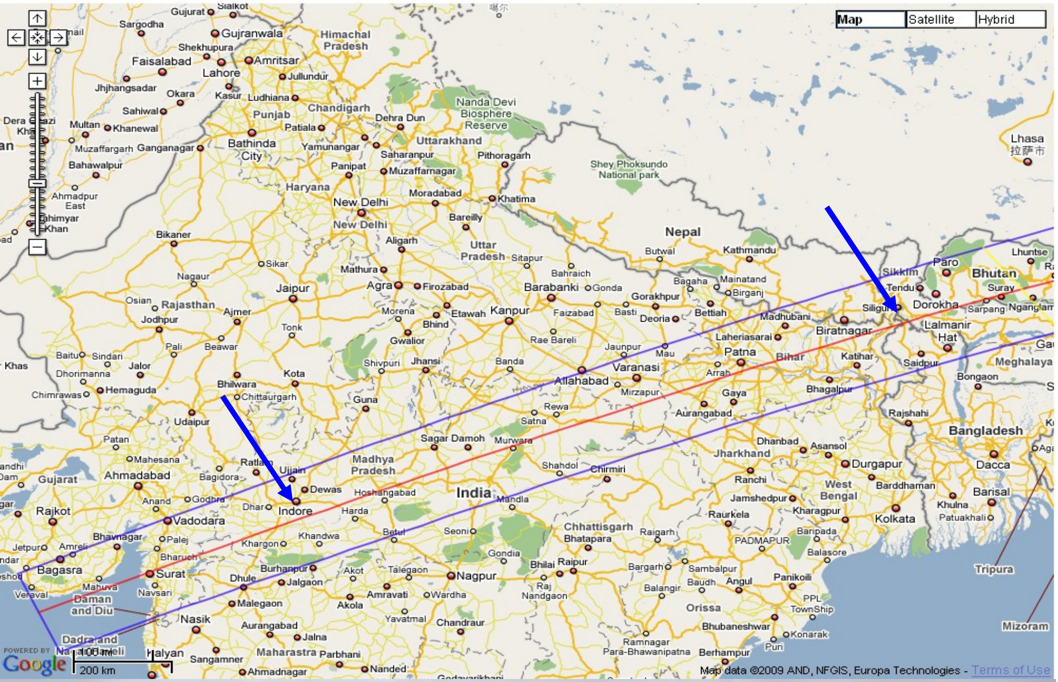
Prasad

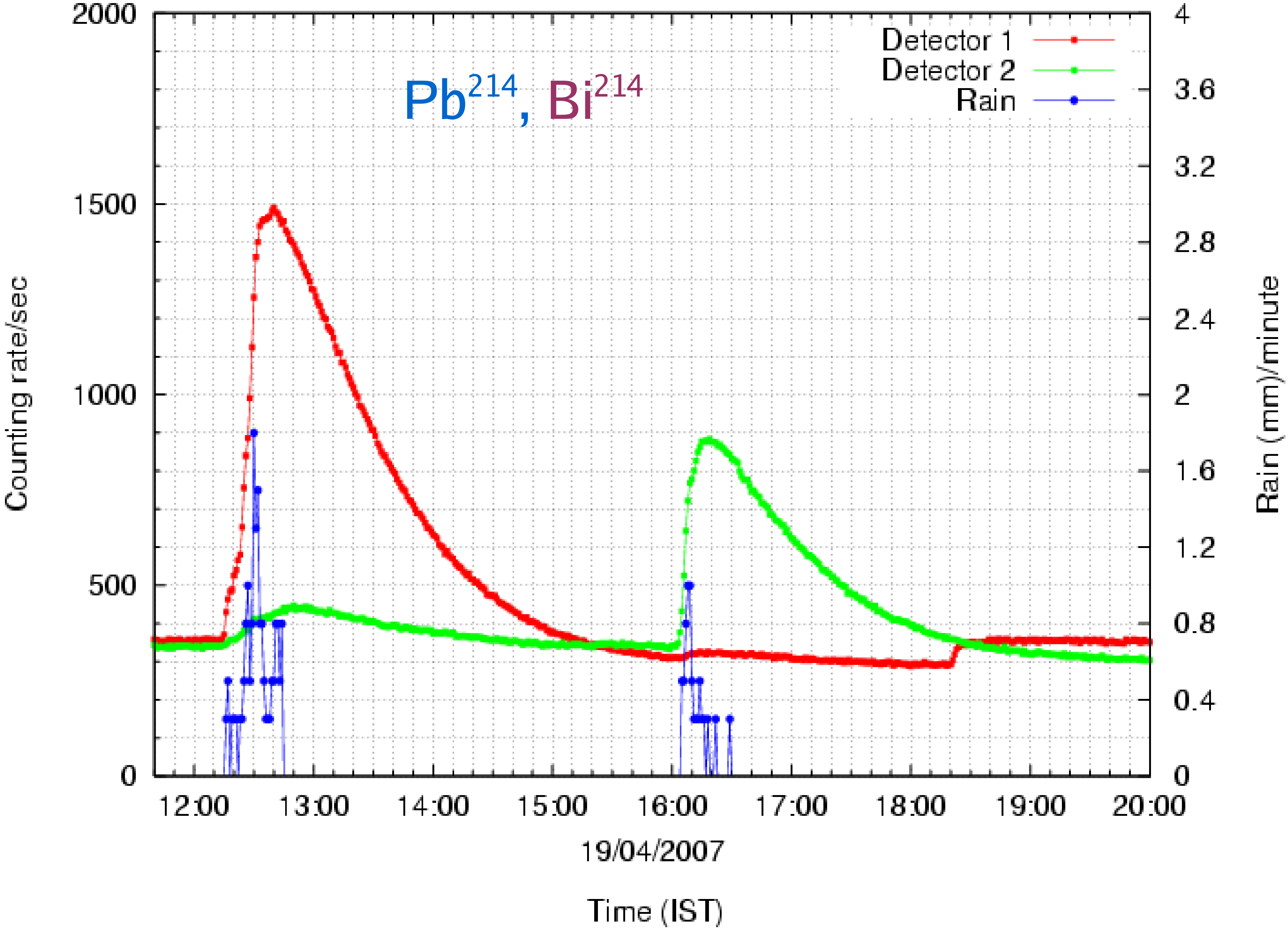
Thunderstorm Event



Decrease in muon rate at shorter time scale

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





Pb214, Bi214
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)

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,

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

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

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

Future Expansion Plans

Double muon detector 560 ---> 1120 m^2 (2011)

Wide-angle Cerenkov telescope (2012)

Expansion to ~1 km^2 (2015)

Neutron monitors for solar studies (2012)

Electric field measurement and correlated study with muon variation (2011)

THANKS

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

Backup Slides

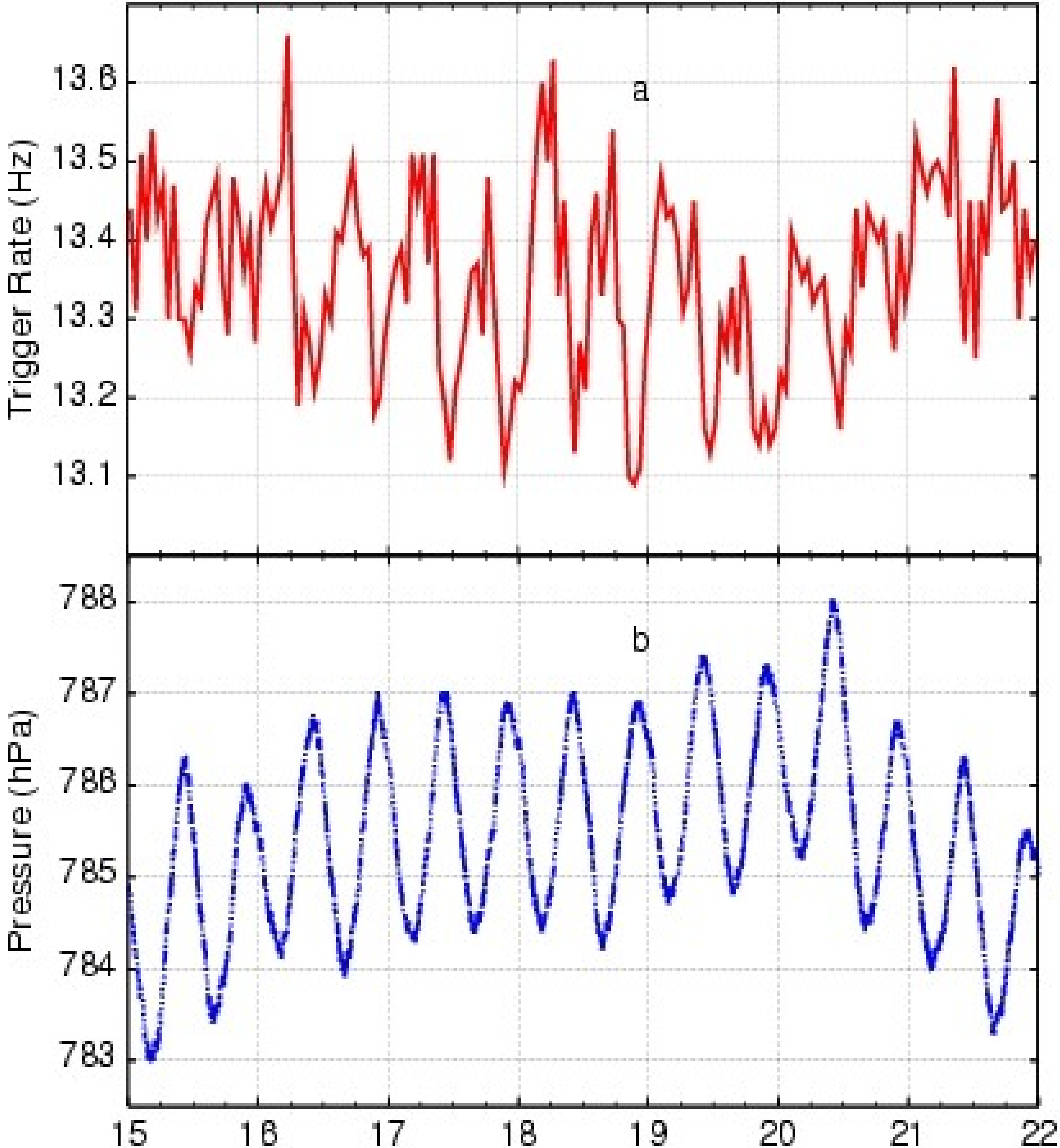
MILESTONES:

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

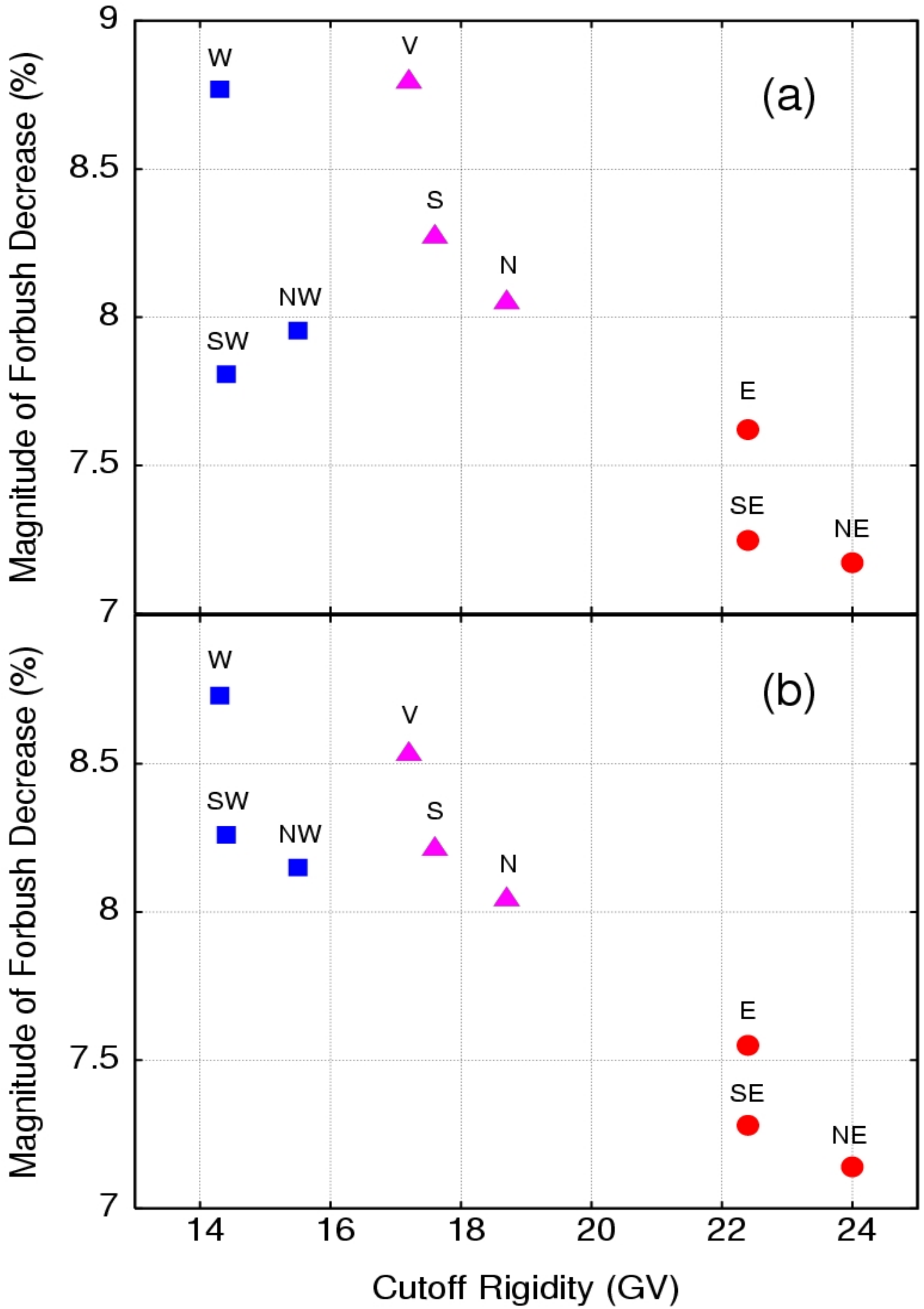
GRAPES-3 activity to be utilized as a nucleating centre for astroparticle physics.., Panel Report, 19 December 2006

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



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

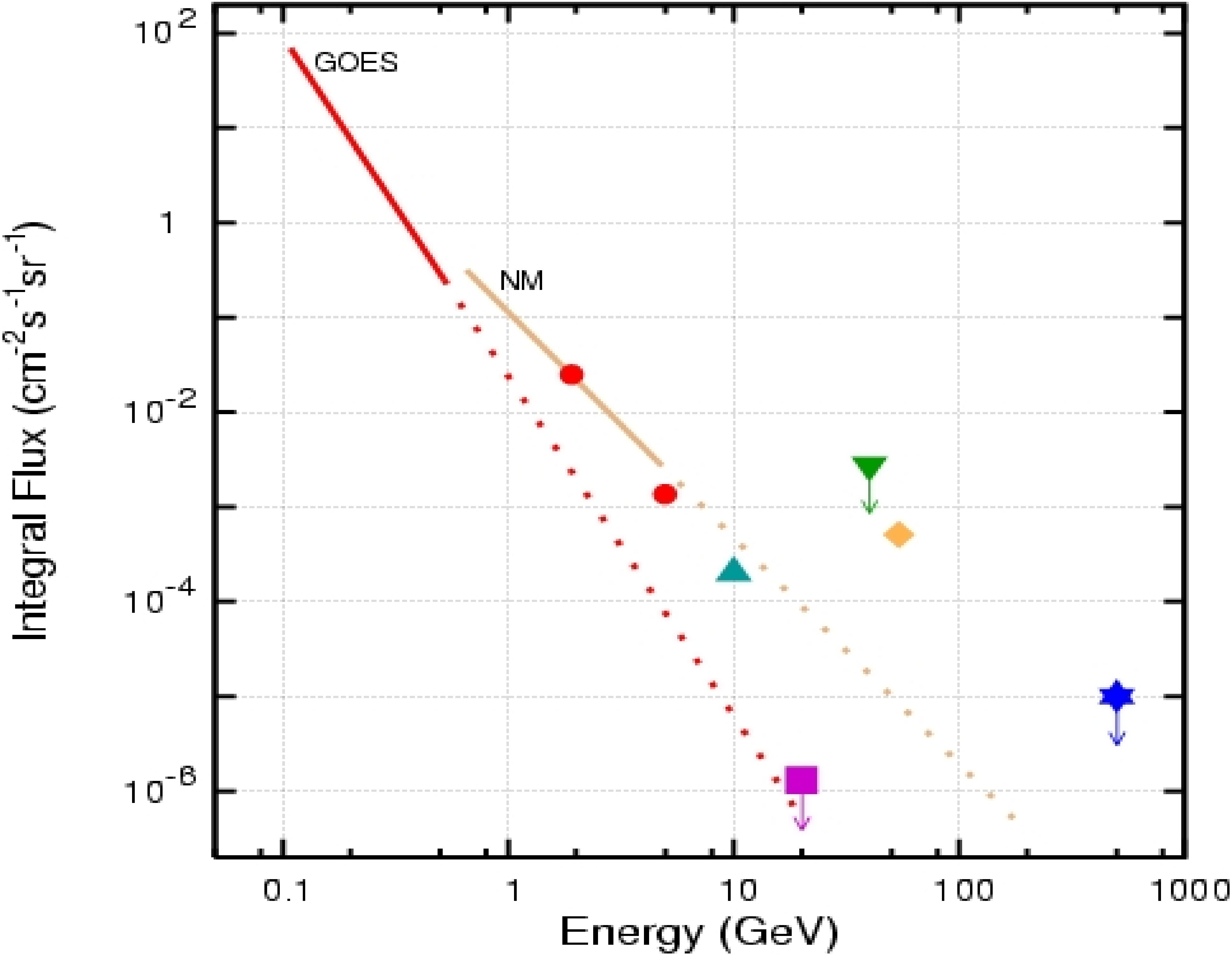


$$A(r) = K \times r^{-\gamma}$$

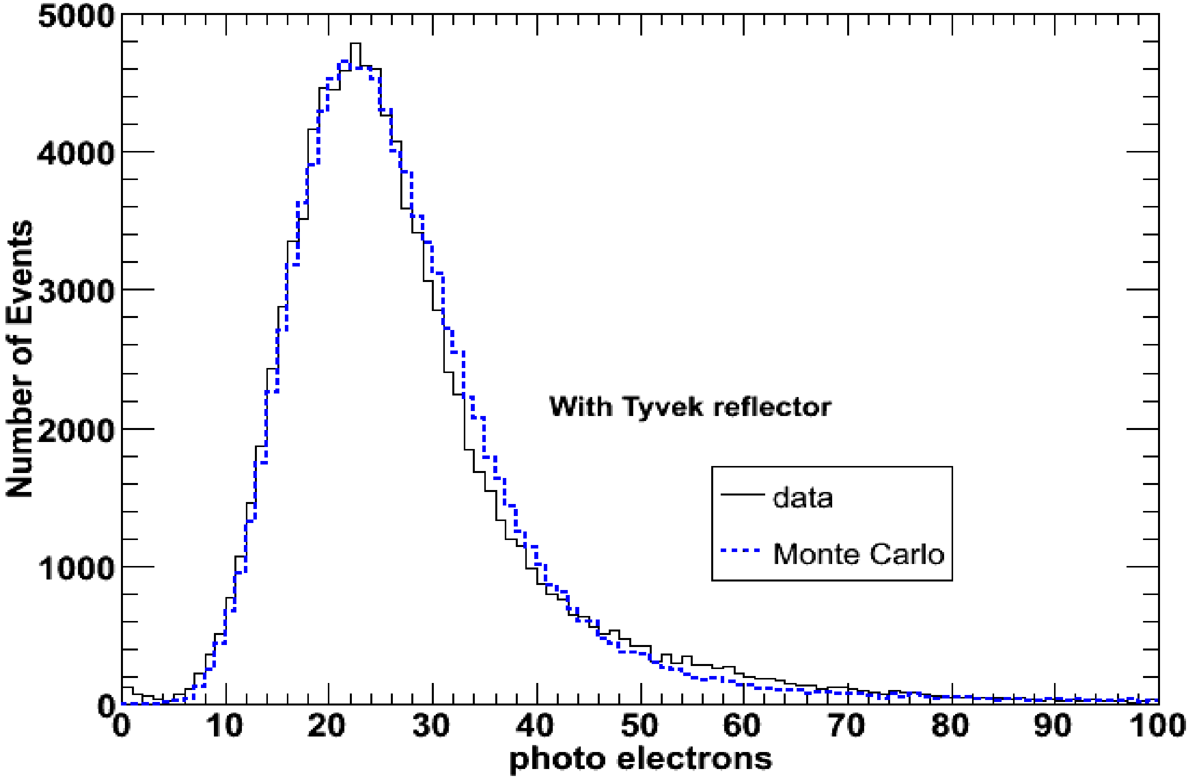
$$K = (12.3 \pm 0.3)\%$$

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

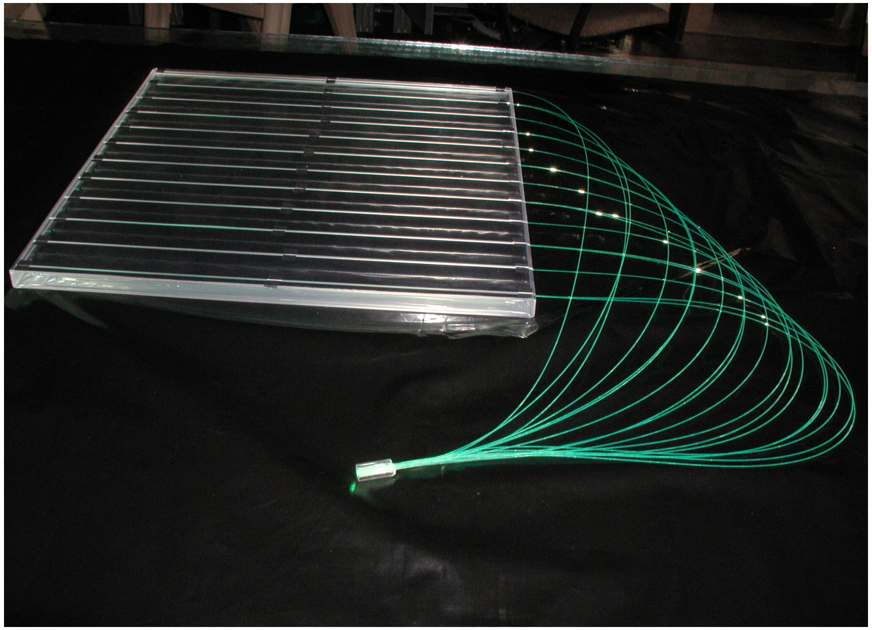
$$\gamma = 0.4 - 1.2$$

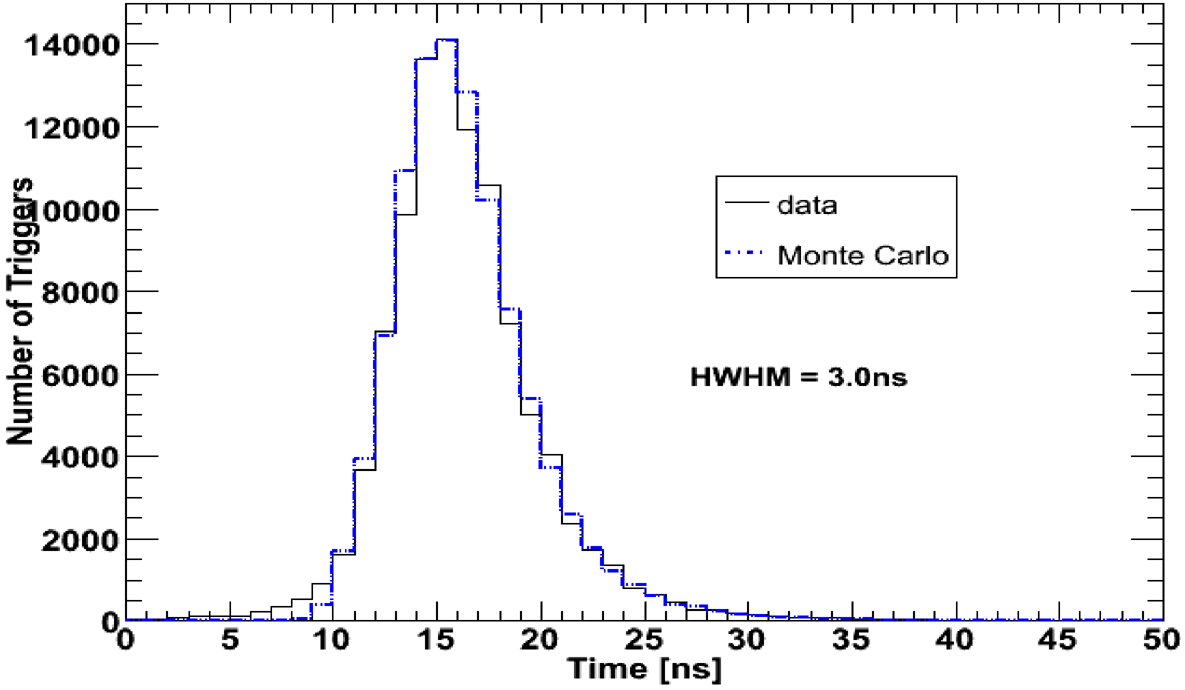


GOES
NM
Integral Flux (cm^{-2}s^{-1}sr^{-1})
Energy (GeV)
10^{2}
1
10^{-2}
10^{-4}
10^{-6}
0.1
1
10
100
1000



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





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

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. **33** 97-107 (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