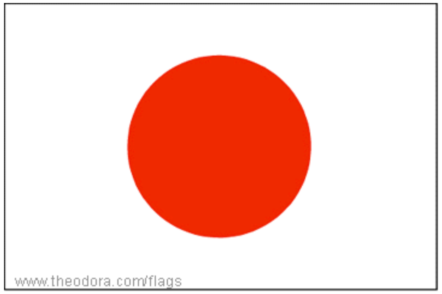
GRAPES-3 Experiment

(Gamma Ray Astronomy at Pev EnergieS

(An India-Japan collaboration)

DHEP Annual Meeting 7 April 2016



1. Tata Institute of Fundamental Research, Mumbai, India
2. Osaka City University, Osaka, Japan
3. Aichi Institute of Technology, Toyota, Japan
4. J.C. Bose Institute, Kolkata, India
5. Indian Institute of Sci. & Engineering Res. Pune, India
6. Indian Institute of Technology, Kanpur, India
7. Chubu University, Kasugai, Aichi, Japan
8. Hiroshima City University, Hiroshima, Japan
9. Kochi University, Kochi, Japan
10. Aligarh Muslim University, Aligarh, India
11. North Bengal University, Siliguri, India
12. Vishwakarma Inst. of Information Tech., Pune, India

S.K. Gupta, H.M. Antia, K.P. Arunbabu, S.R. Dugad, B. Hariharan, I. Mazumdar, P.K. Mohanty, P.K. Nayak, P. Jagadeesan, A. Jain, S.D. Morris, B.S. Rao, L.V. Reddy, Y. Hayashi, S. Kawakami, S. Ogio, H. Kojima, S. Das, S.K. Ghosh, S, Raha, P. Joarder, P. Subramanian, P. Jain, A. Oshima, S Shibata, K. Tanaka, T. Nakamura, S. Ahmad, A. Bhadra, R.K. Dey, C.S. Garde

400 Plastic Scintillator detectors (1 m^2 area)

560 m^2 muon detector (E_μ=1 GeV) (11.4N, 76.7E)

3712 Proportional Counters (6m x 0.1m x 0.1m)

E = 10^{14} eV ~20000 particles over ~1000 m^2

Ph.D. Thesis: (1) M. Sasano (2) H. Tanaka (3) T. Nonaka, (4) A. Oshima
(5) M. Minamino (6) P.K. Mohanty (7) K.P. Arunbabu

Current Ph.D.: (8) A. Chandra, AMU (9) V. Jhansi, TIFR (10) M. Zuberi, AMU
(11) B. Hariharan, MKU, (12) S. Ray, NBU

New Collaborators: (1) N. Gupta, RRI, (2) S. Mahapatra, (3) D.P. Mahapatra, Utkal
(4) R. Nigam, BITS, Hyd.


112
113
114
073

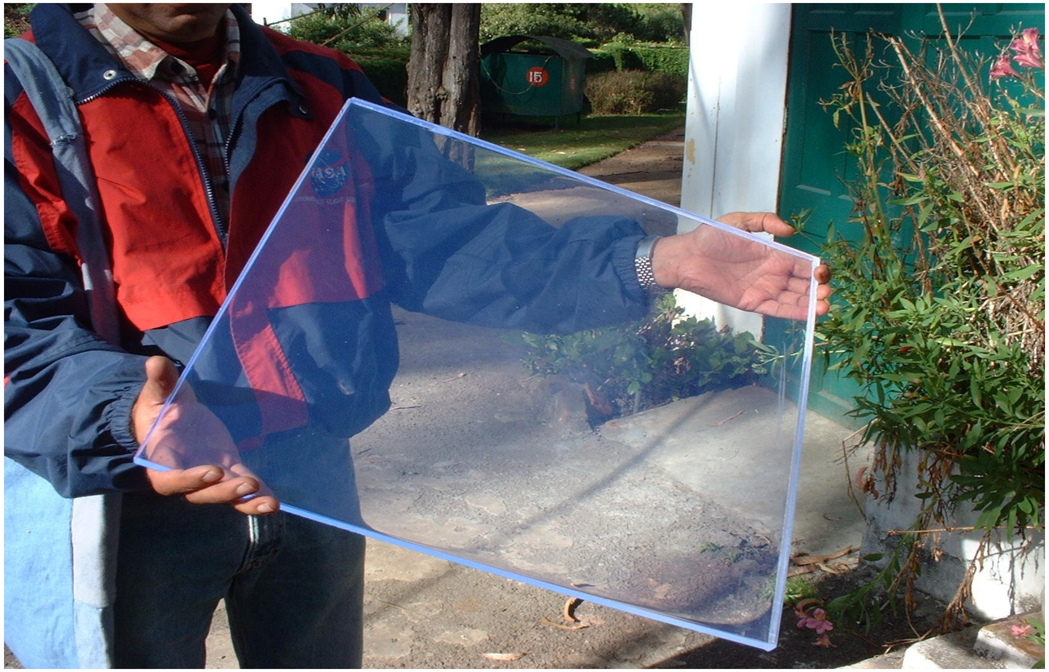
#2 MO
3,28,42

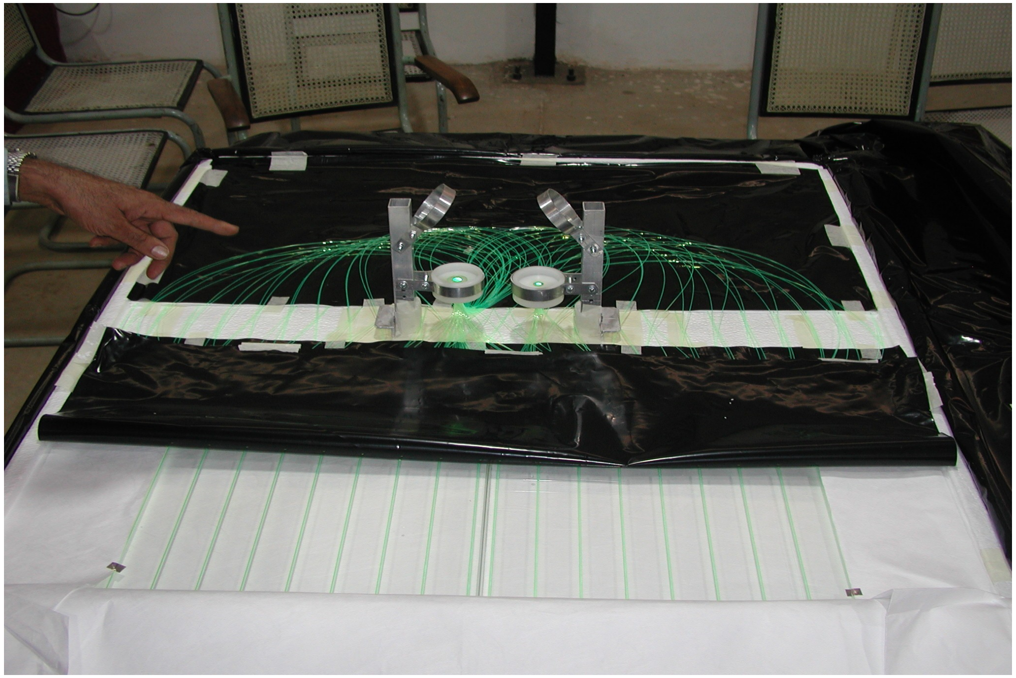
In-house technology development for Fabrication of various detectors

Plastic Scintillator development:

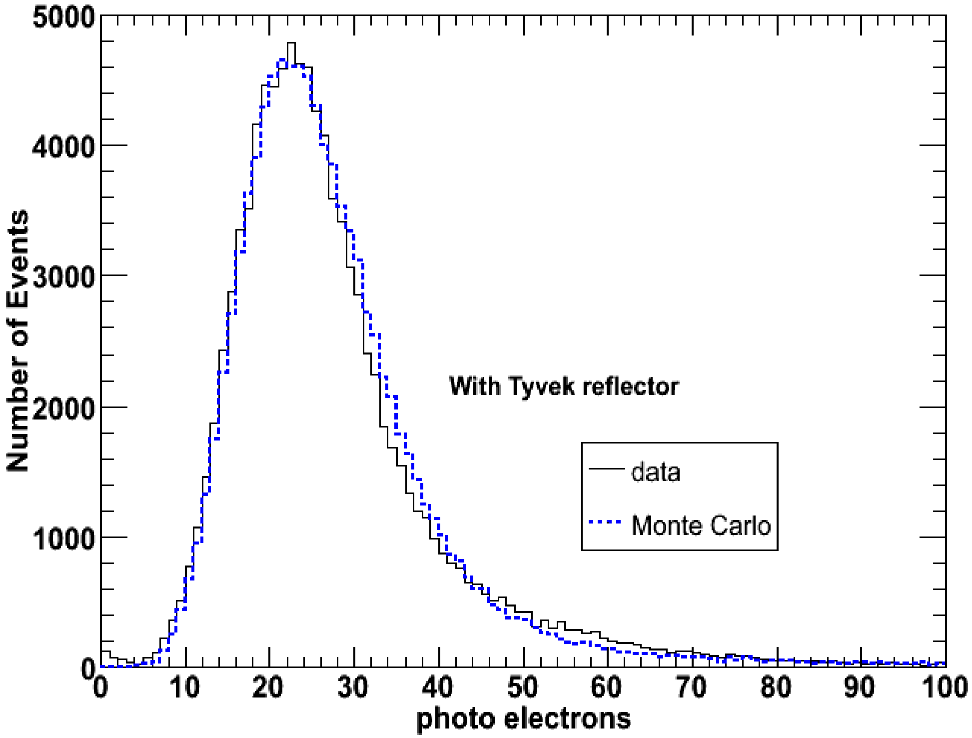
Decay Time= 1.6 ns
Light Output = 85% Bicron (54% anthracene)
Timing 25% faster
Atten. Length $\lambda = 100$cm
Cost ~10% of Bicron
Max Size 100cmX100cm
Total > 2000

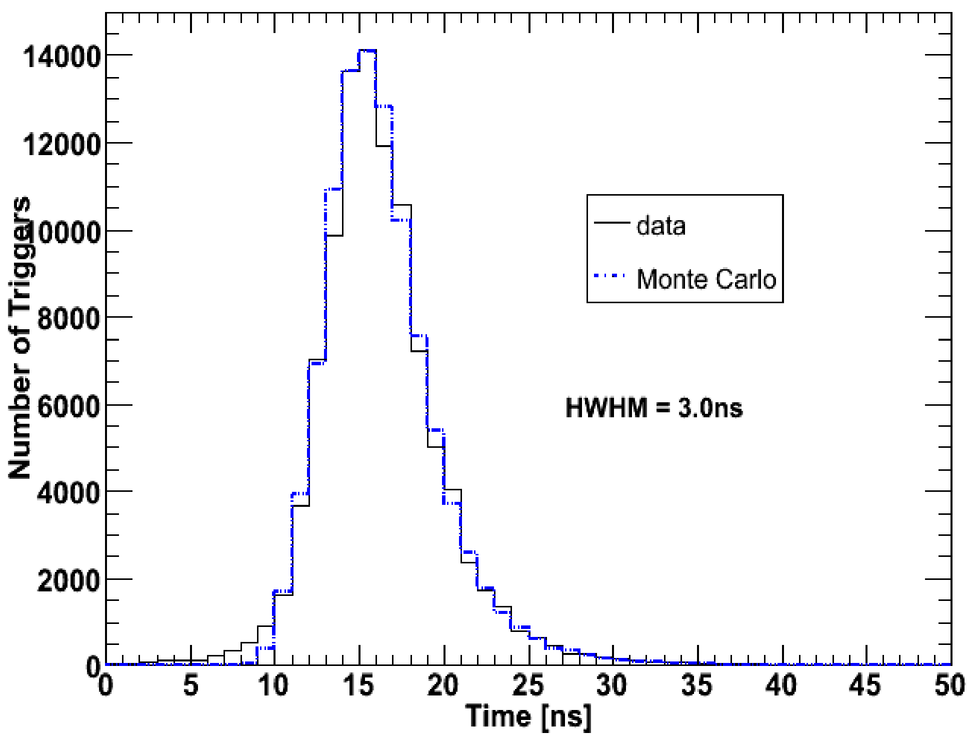
CERN, Osaka, IUAC Delhi, Bose, VECC, BARC etc.



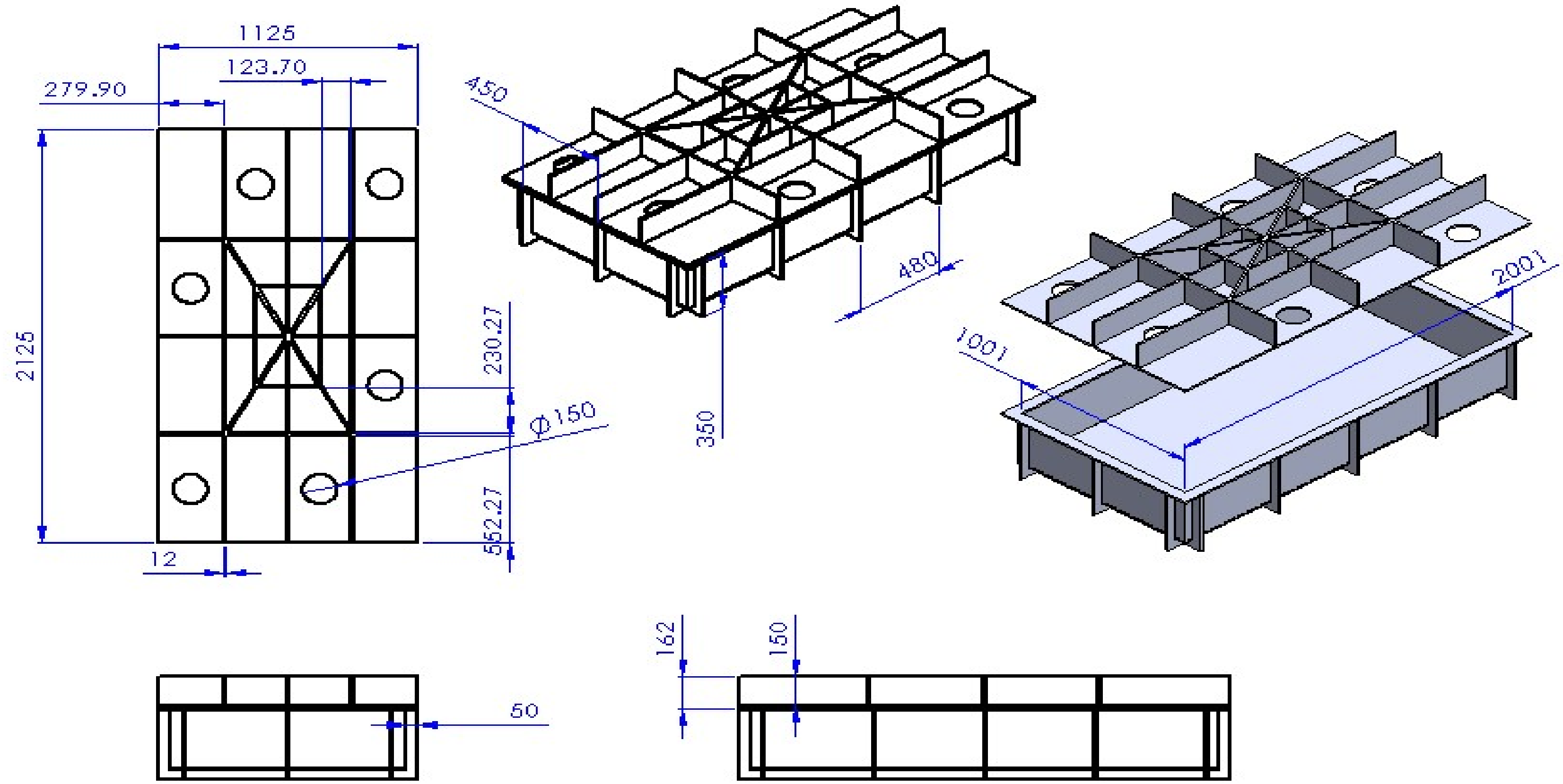


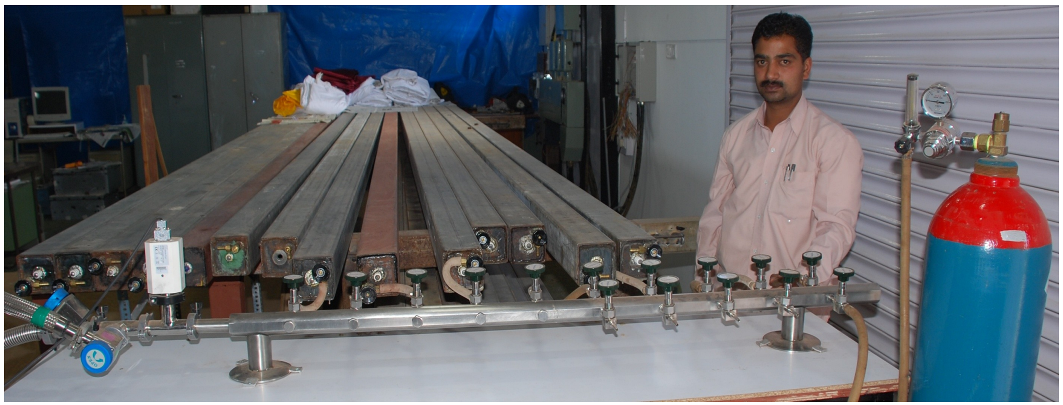
P.K. Mohanty et al. Rev. Sci. Instr. **83** 043301 (2012)





Drawing by P. Verma



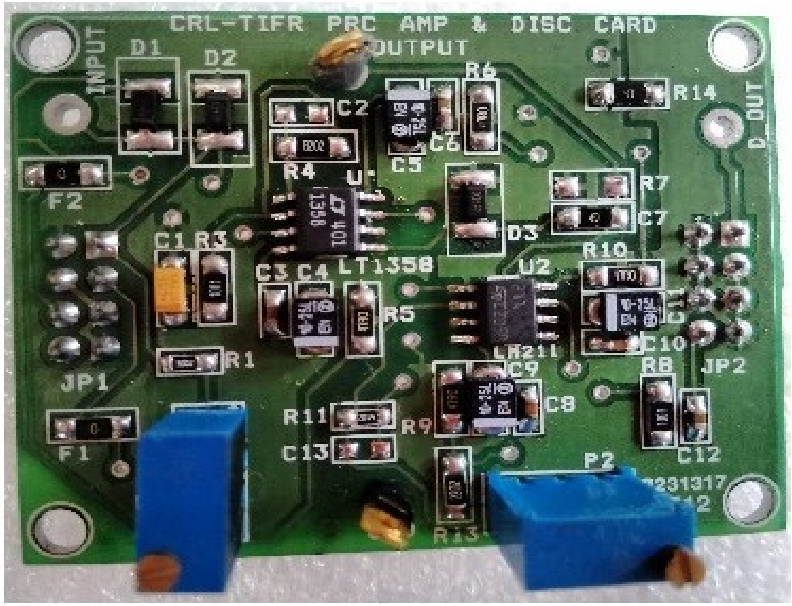


Proportional Counter Test Setup

Proportional Counter (PRC) Fabrication, Talk by Atul

Front end electronics of the Proportional counter

Amplifier and Discriminator PCB

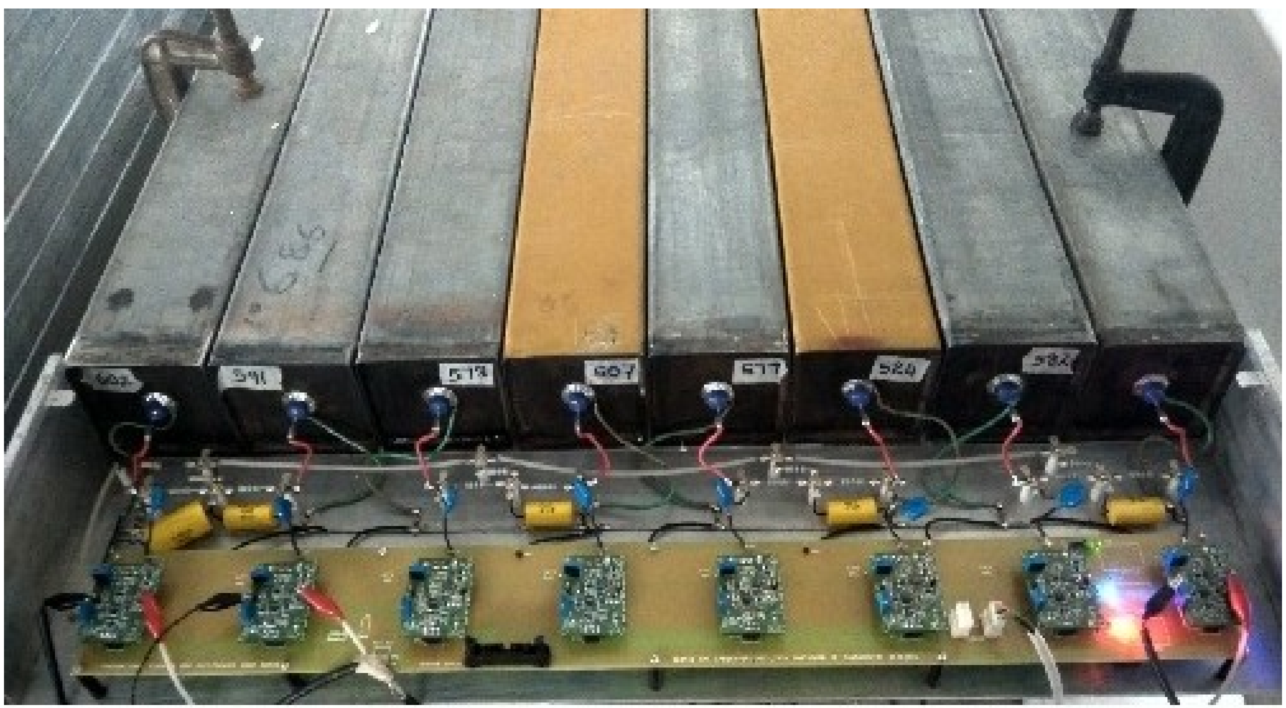


Dimensions: 5cmX4cm

Features:

- Amplification by resistive programmable gain
- Decay constant adjustment by trim POT
- Discrimination(Digitization)
- Threshold adjustment by trim POT
- Additional access to Analog and Digital outputs
- Reverse, transient voltage and short circuit protection

Poster by K. Ramesh

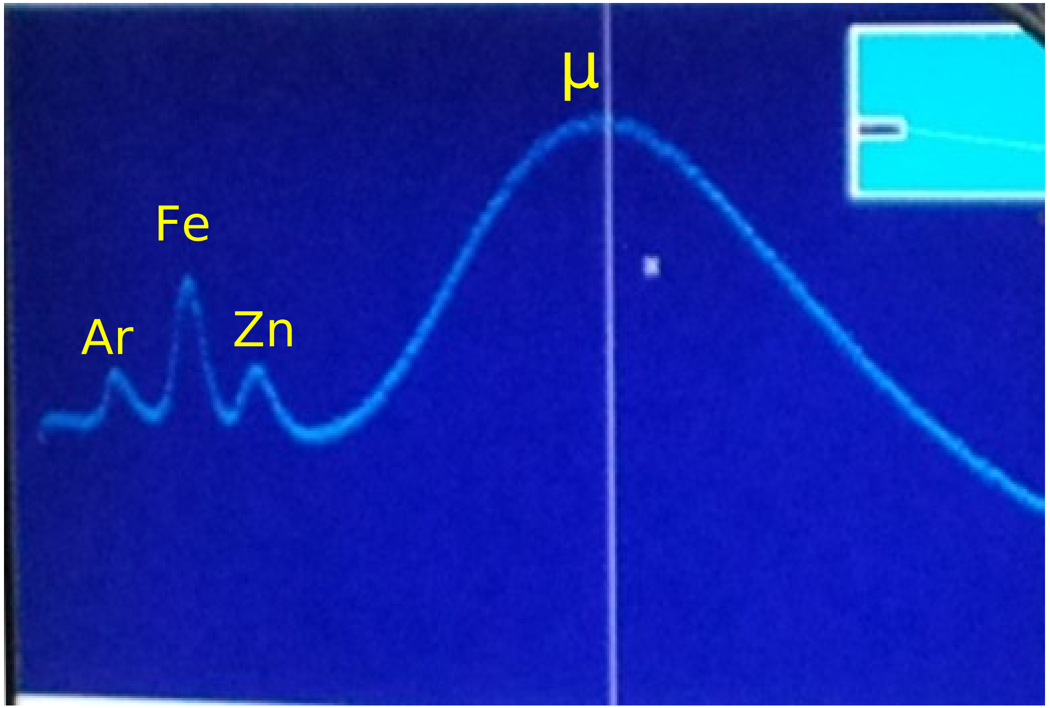


PRC box with front end electronics

A number of interfaces, and control boards using micro-controllers, and FPGAs were developed in collaboration with VIIT that serve as building blocks of larger systems.

Poster by Pankaj Rakshe

1050 PRCs fabricated 28% of required 3780 PRCs



29 September 2015


19 February 2016

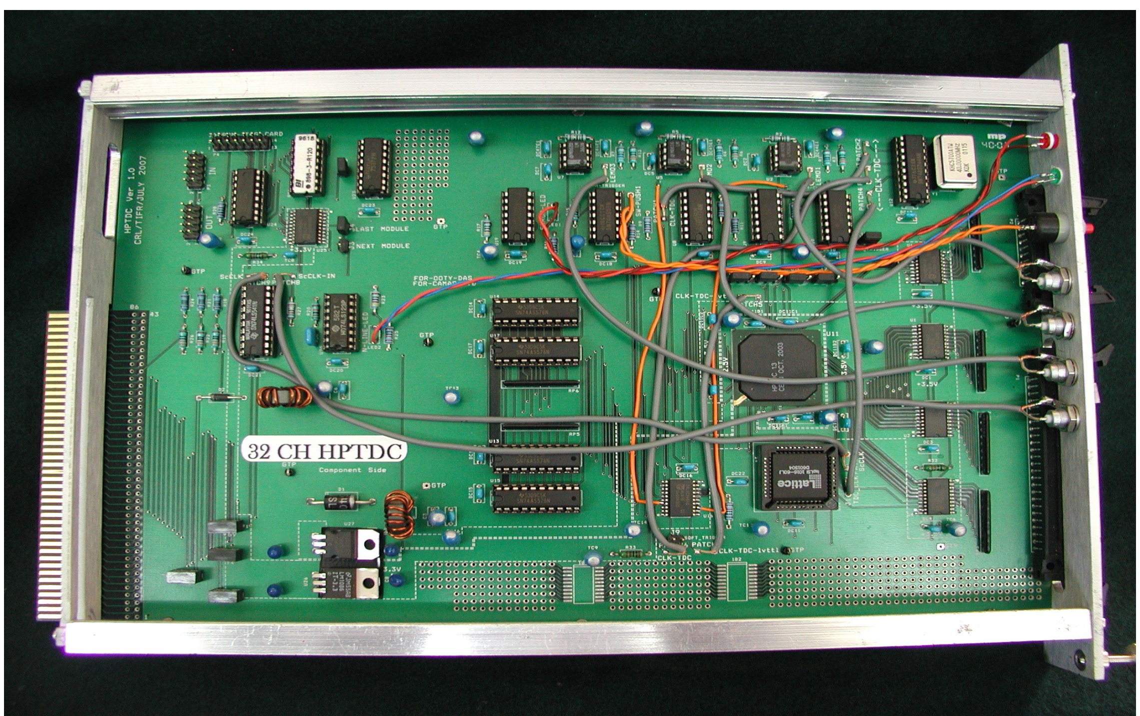
Performance of HPTDC (Stop Watch)

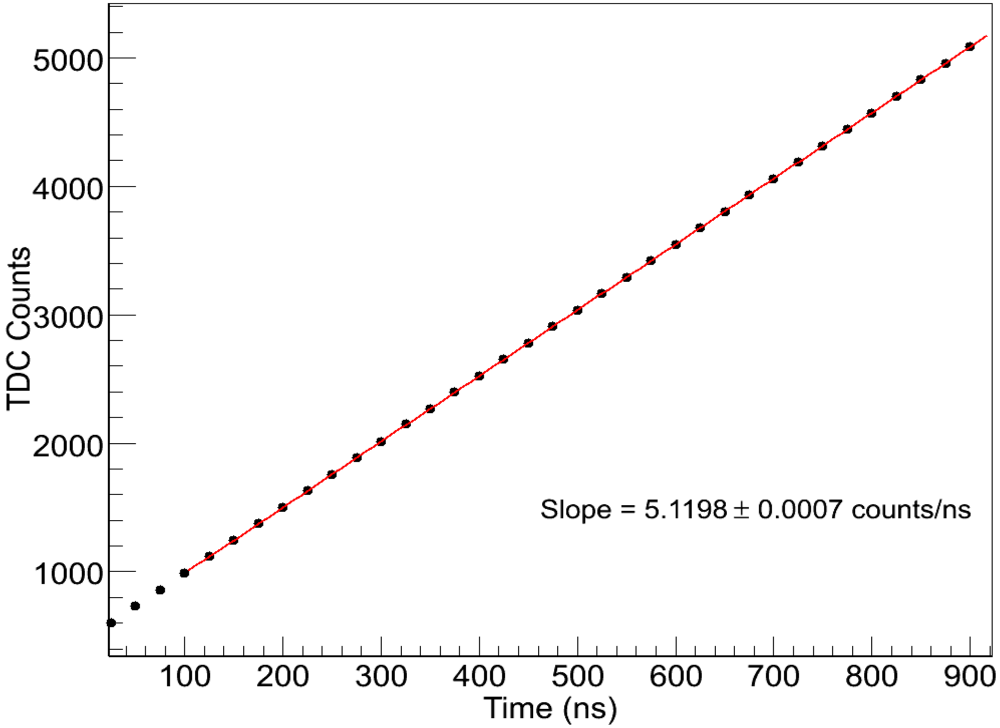
32 Channels, 100 ps time resolution, Multi-hit capability
Huge dynamic range (100 ps - 50 μs), Trigger mode
(avoids delay cables)

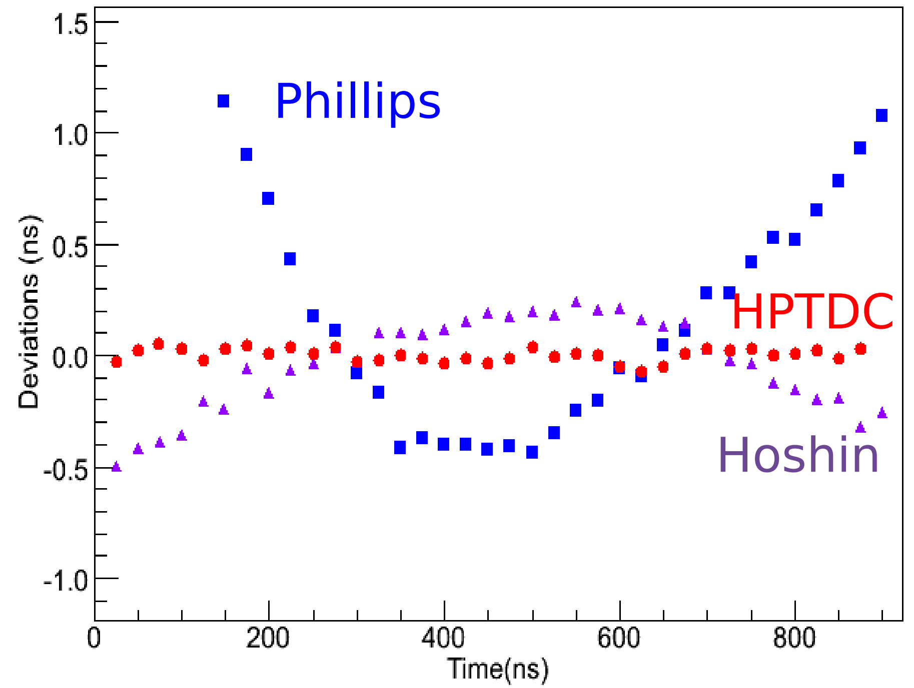
Novel method measuring TDCZero: Poster by Hari

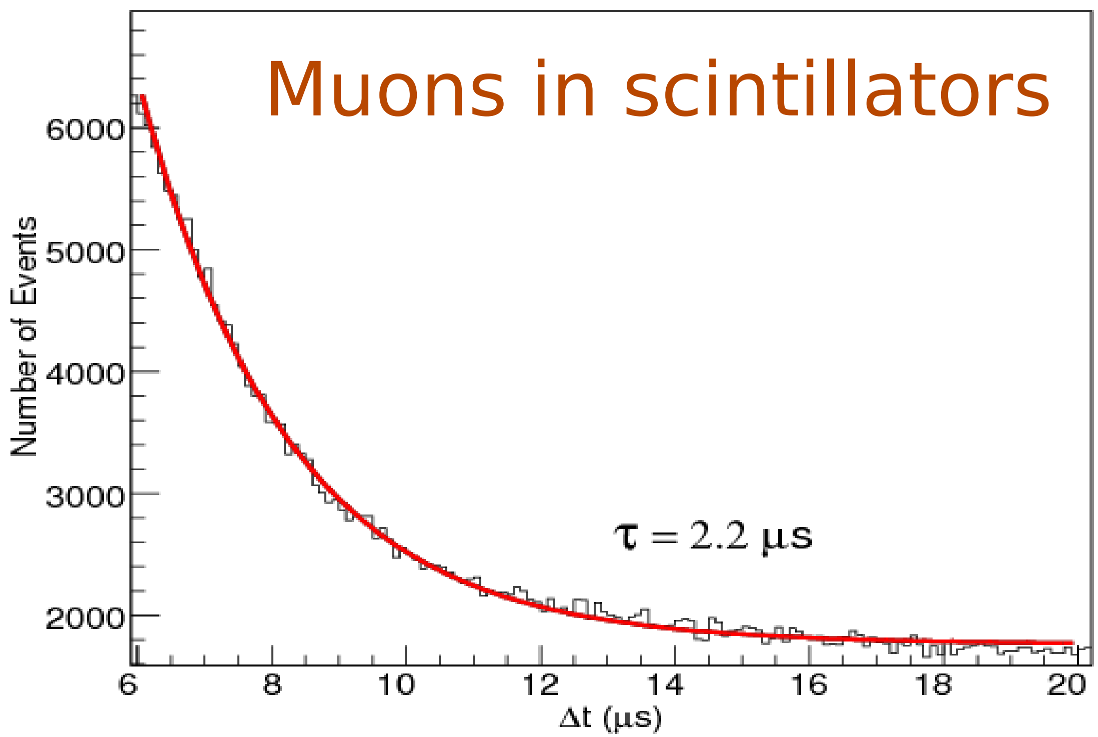
Requests: Atomic, Chemistry, Biology in TIFR, Oulu Finland, IUAC Delhi, Bose Institute, BARC etc.

S.K. Gupta et al. Exp. Astr. DOI 10.1007/s10686-012-9320-3(2012)




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


Phillips
HPTDC
Hoshin
Deviations (ns)
1.5
1.0
0.5
0.0
-0.5
-1.0
0
200
400
600
800
Time(ns)


Muons in scintillators
Number of Events
6000
5000
4000
3000
2000
τ = 2.2 μs
6
8
10
12
14
16
18
20
Δt (μs)

GRAPES-3 Cluster

Poster by Hari

Nodes : 40 (Initial phase)

Total Jobs : 1280

Total Memory : 1280 GB

Storage at nodes: 600 TB

Storage at server : 60 TB

Optical network: 10 Gbps

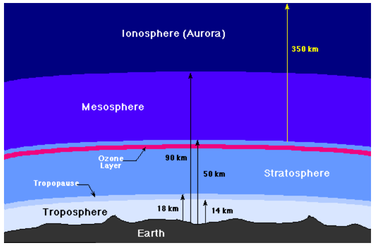
Forced air cooling, 1.2KW removes 25KW of heat

36th Rocks Cluster Rank

Objective: Universe at high energies

Acceleration, propagation of high energy particles,
Extreme conditions may require new physics ...

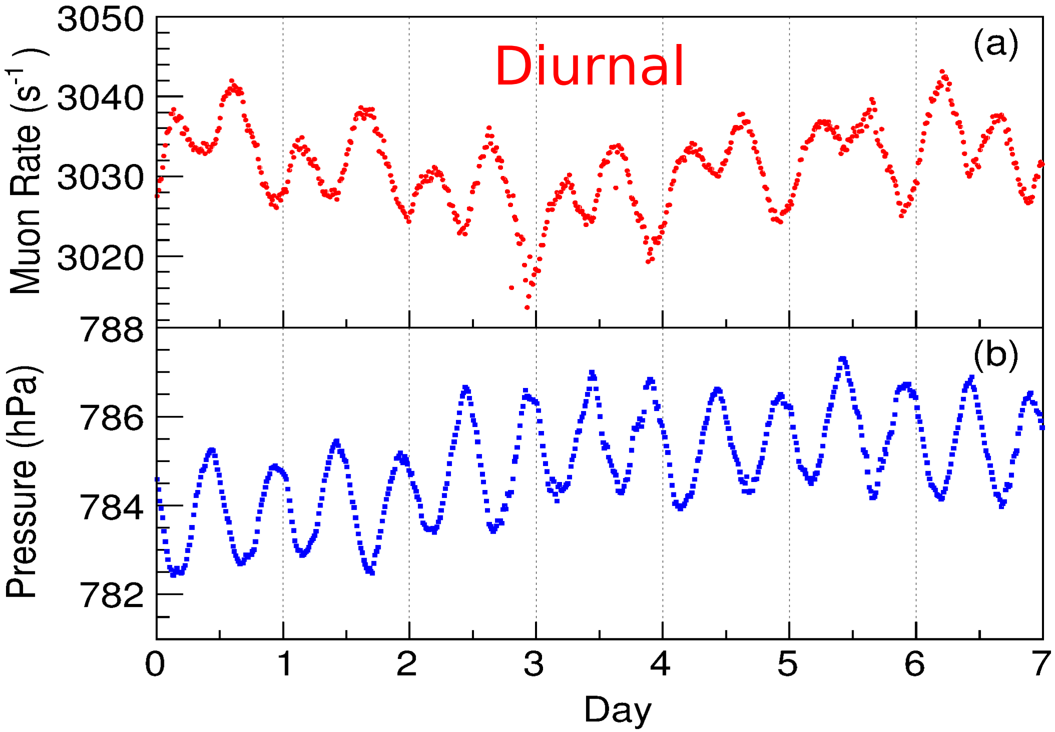
1. Acceleration in atmospheric electric field
   Energy ~100 MeV   Scale ~10^5-10^6 cm

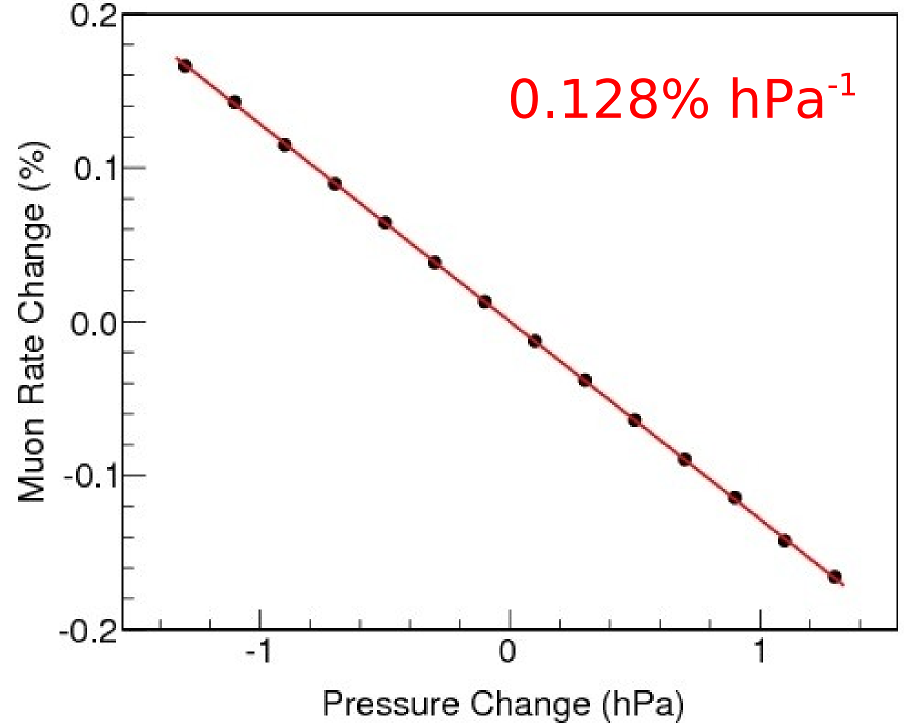


2. Solar flares, Coronal Mass Ejections
   Energy ~10 GeV   Scale ~10^{11}-10^{13} cm

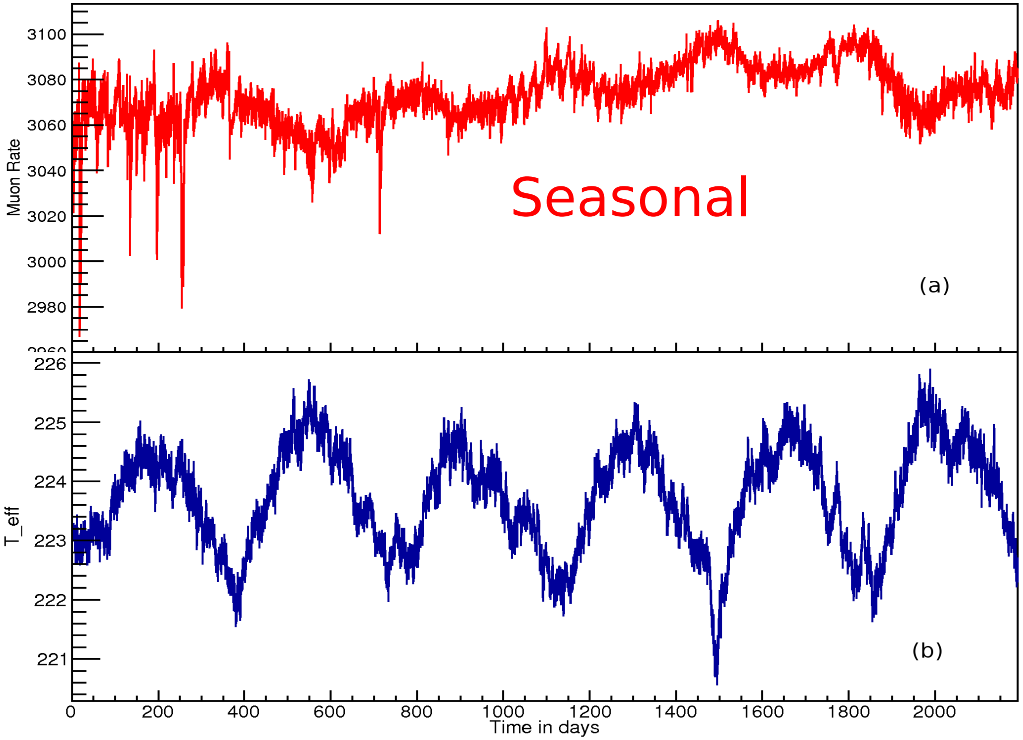
3. Galactic Cosmic Rays at " Knee "
   Energy ~1 PeV   Scale ~10^{21}-10^{23} cm

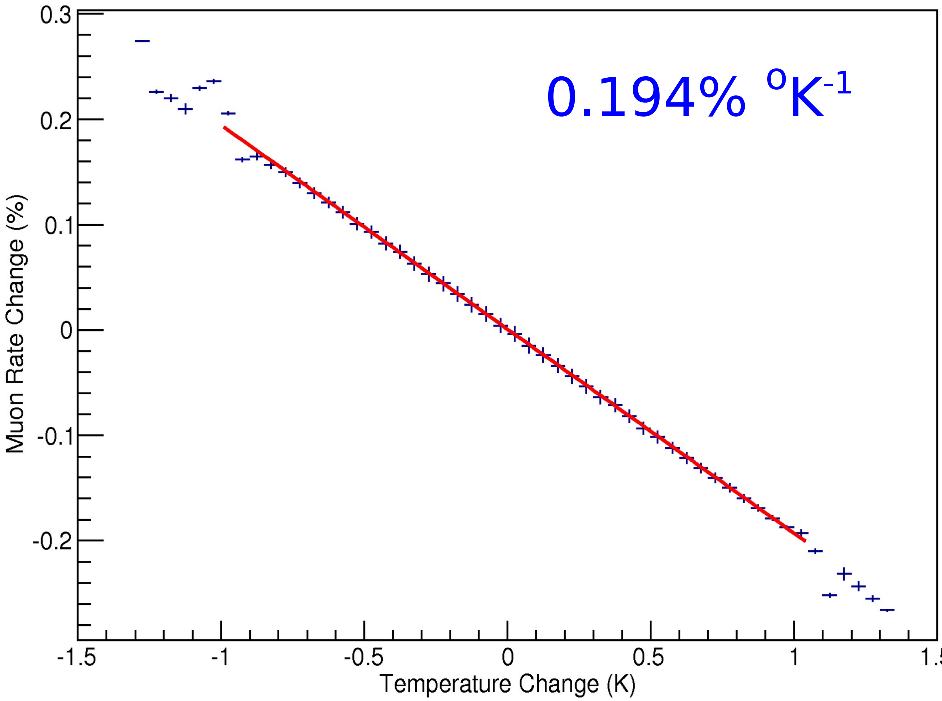
4. Diffuse multi-TeV γ-rays
   Energy ~100 EeV   Scale ~10^{24}-10^{26} cm

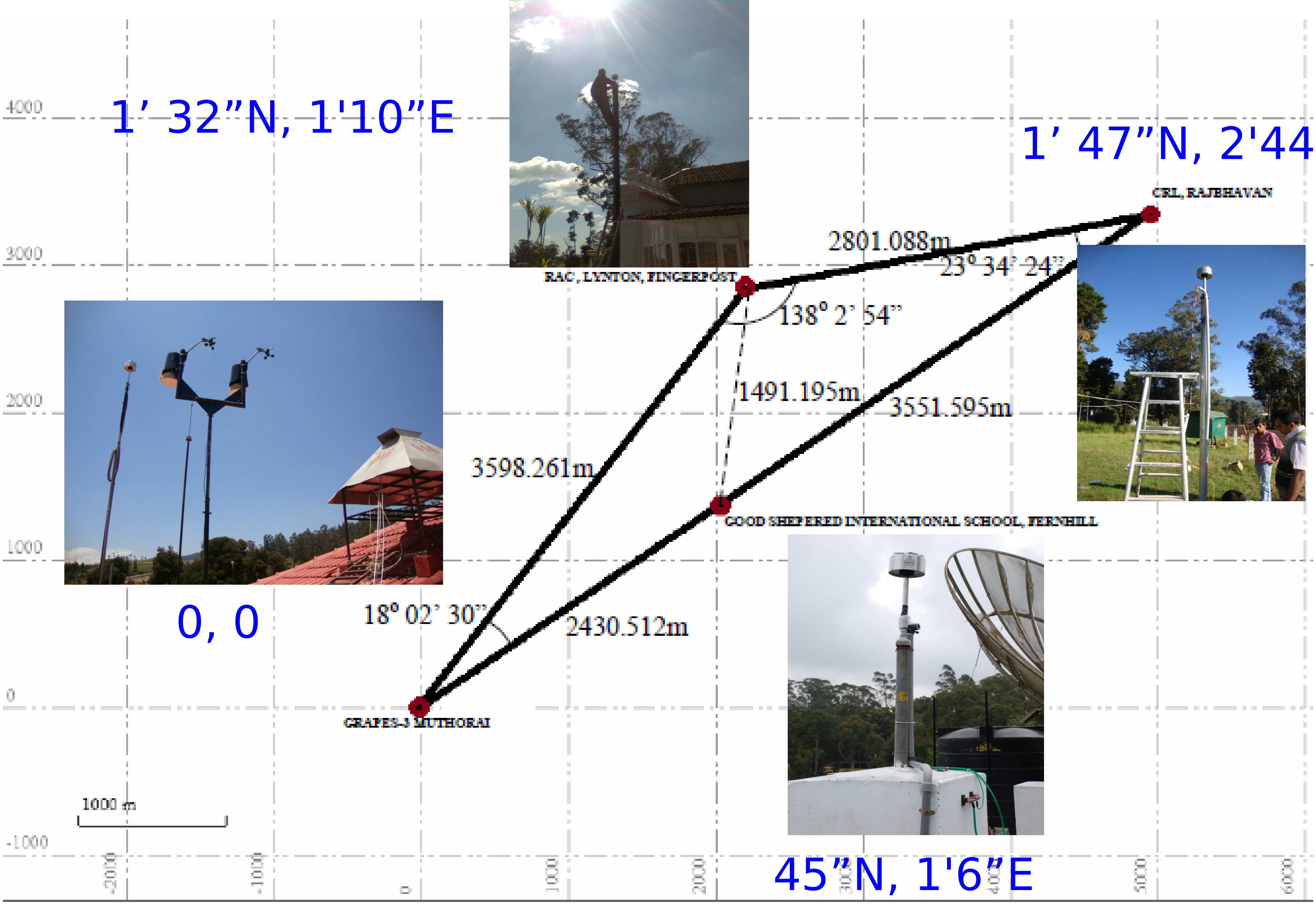




Poster by Arunbabu

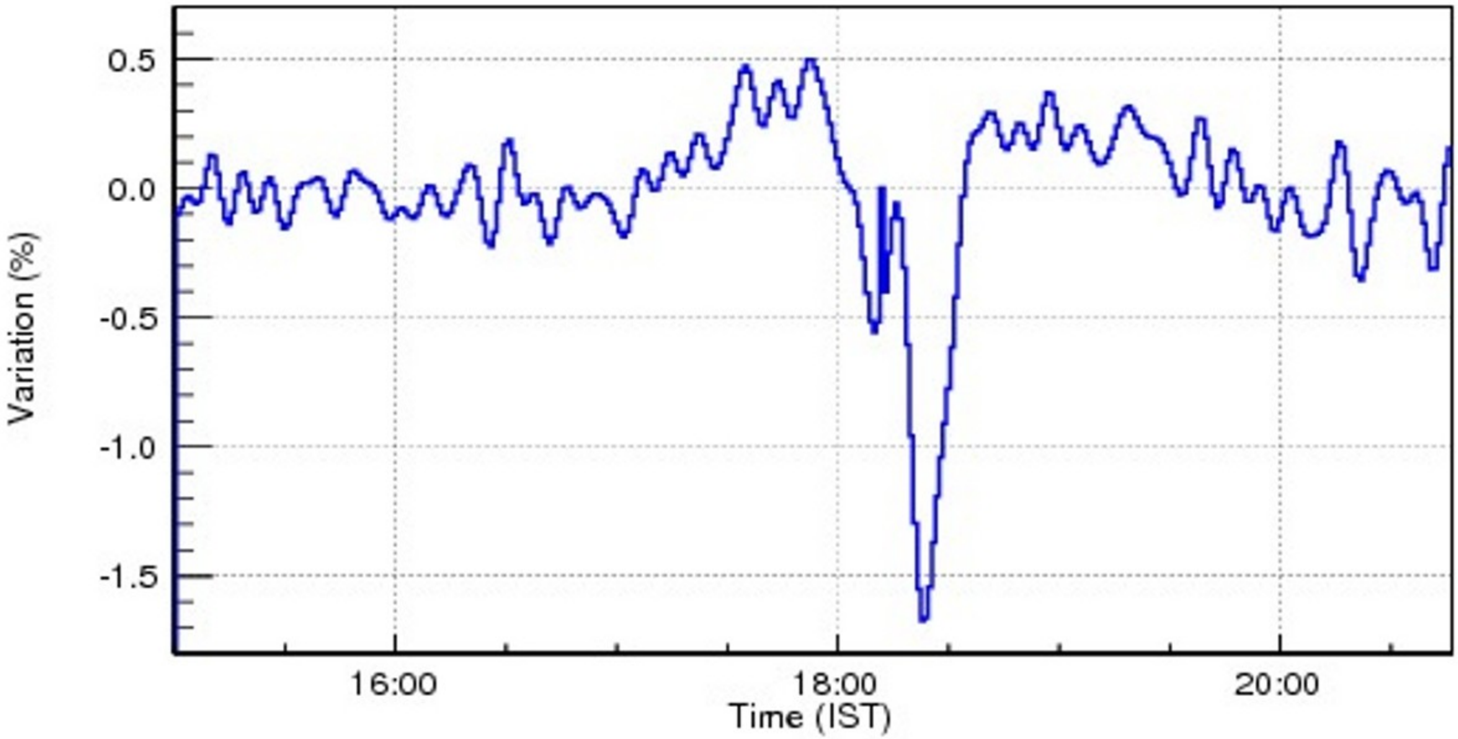




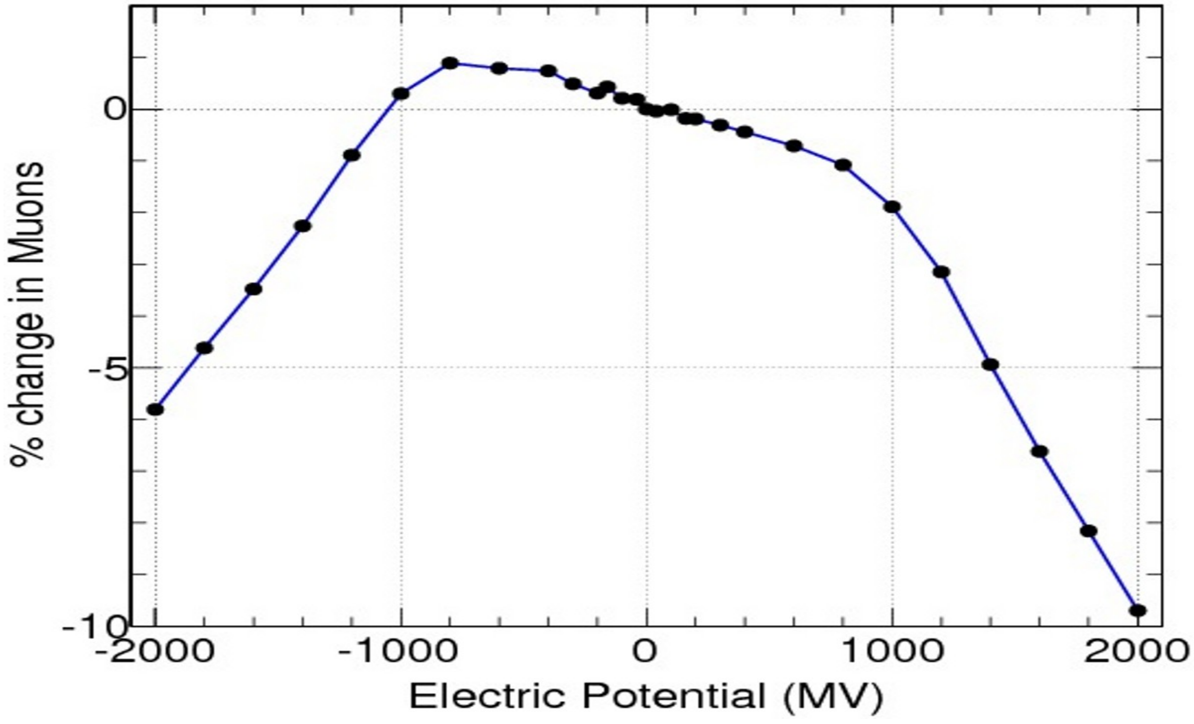


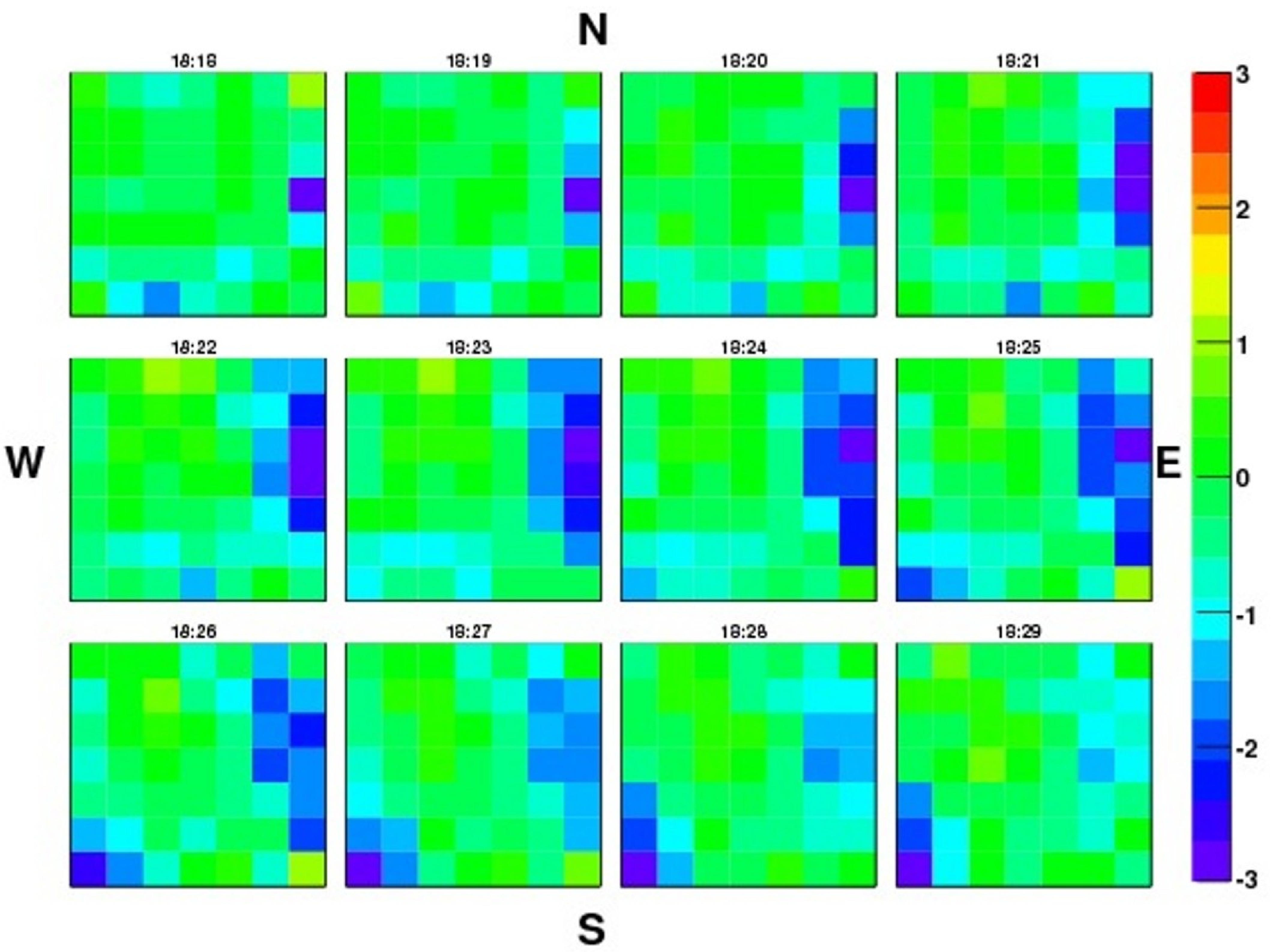
Poster by Pranaba Nayak

GRAPES-3 Lat. = 11° 23’ 26” N Long. = 76° 39’ 50” E



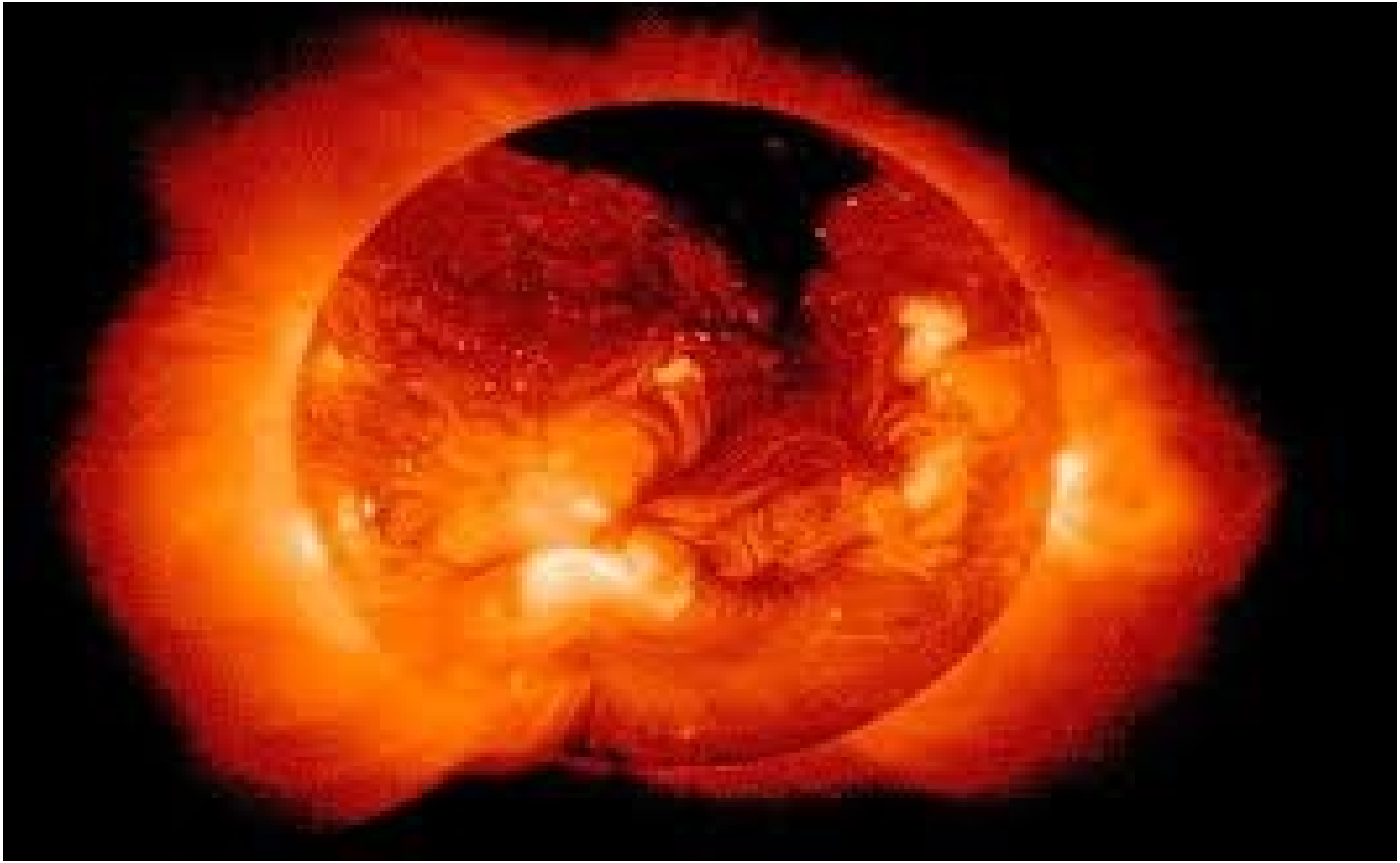
-1.7% --> 1.2 GeV (6kV/cm, BF=10kV/cm)   Poster by Hari



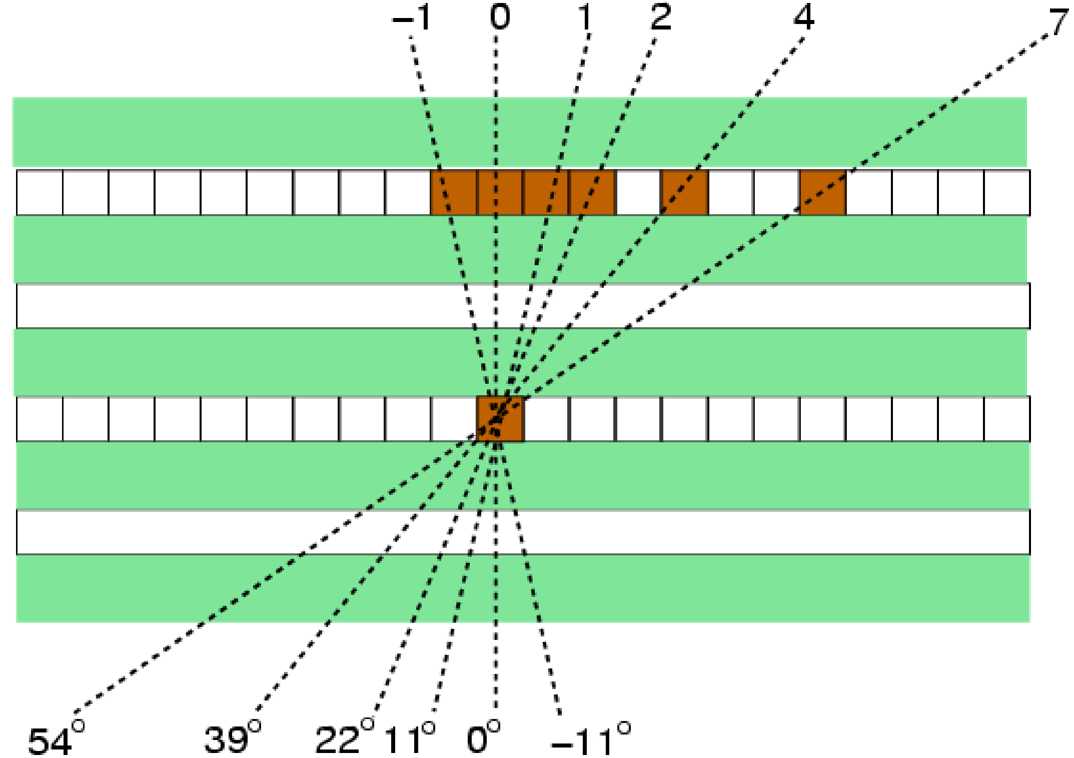

N
S
W
E
18:18
18:19
18:20
18:21
18:22
18:23
18:24
18:25
18:26
18:27
18:28
18:29
3
2
1
0
-1
-2
-3

Solar flares, Coronal Mass Ejections

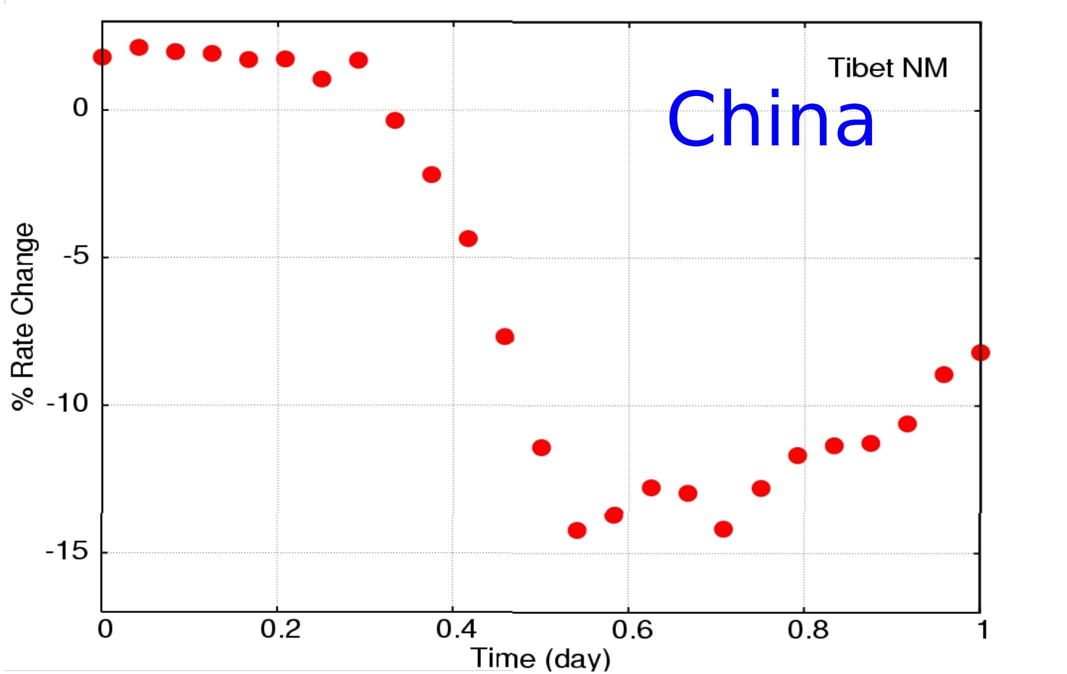
Energy ~10 GeV   Scale ~10^{11}-10^{13} cm

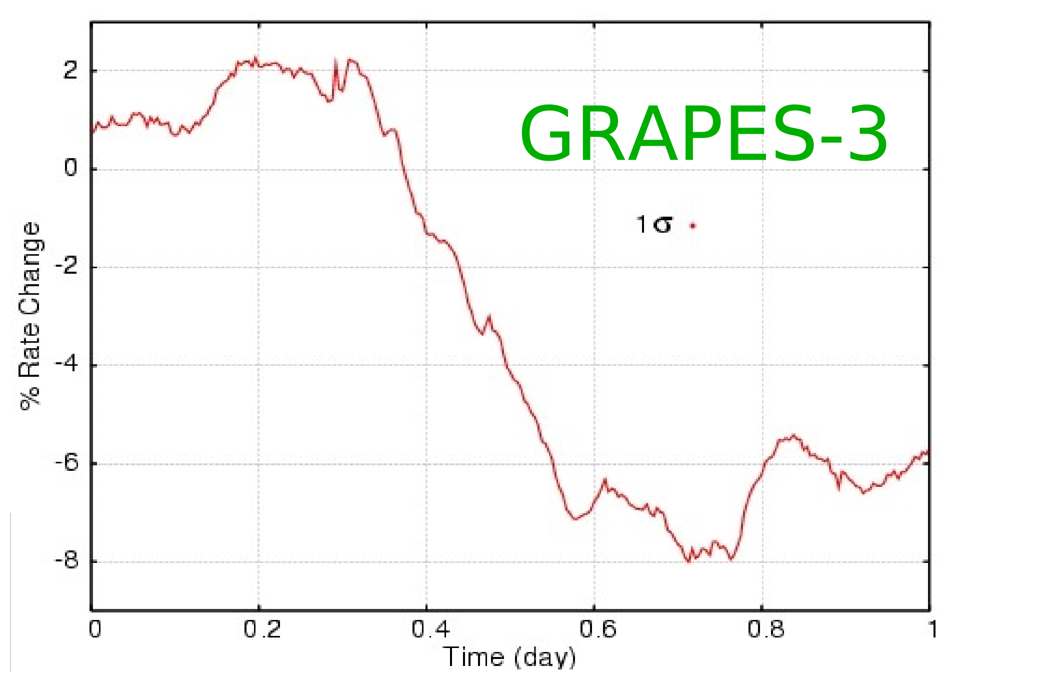


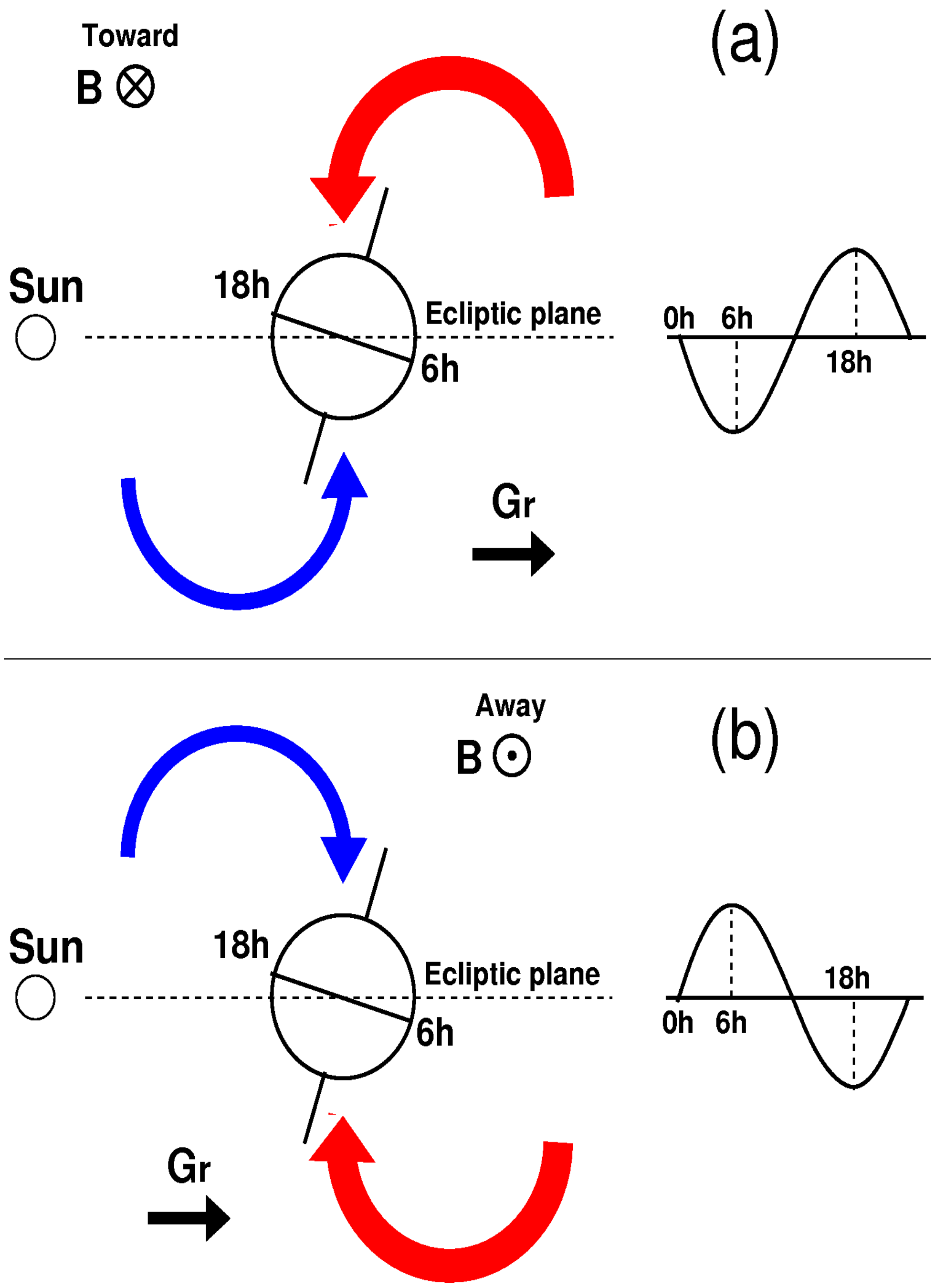
Solar phenomena



Coronal Mass Ejection on 28 October 2003



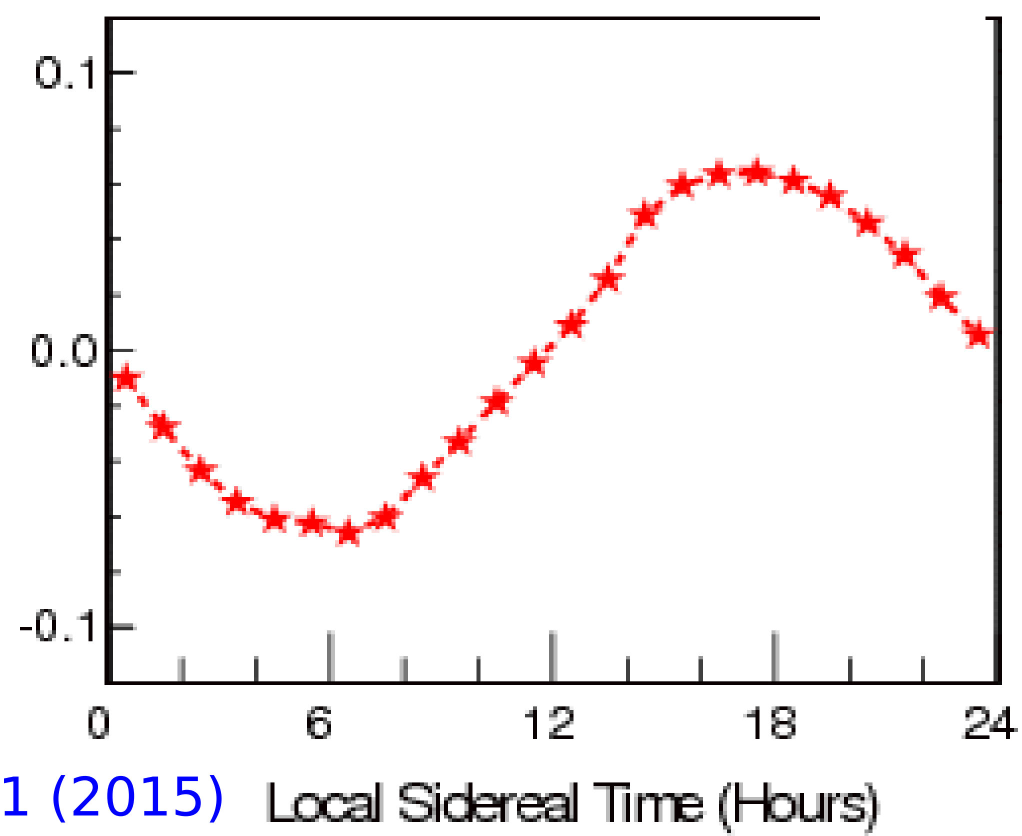




Swinson Flow Amplitude (%)

GRAPES-3 6-Yr Data 2000-2005

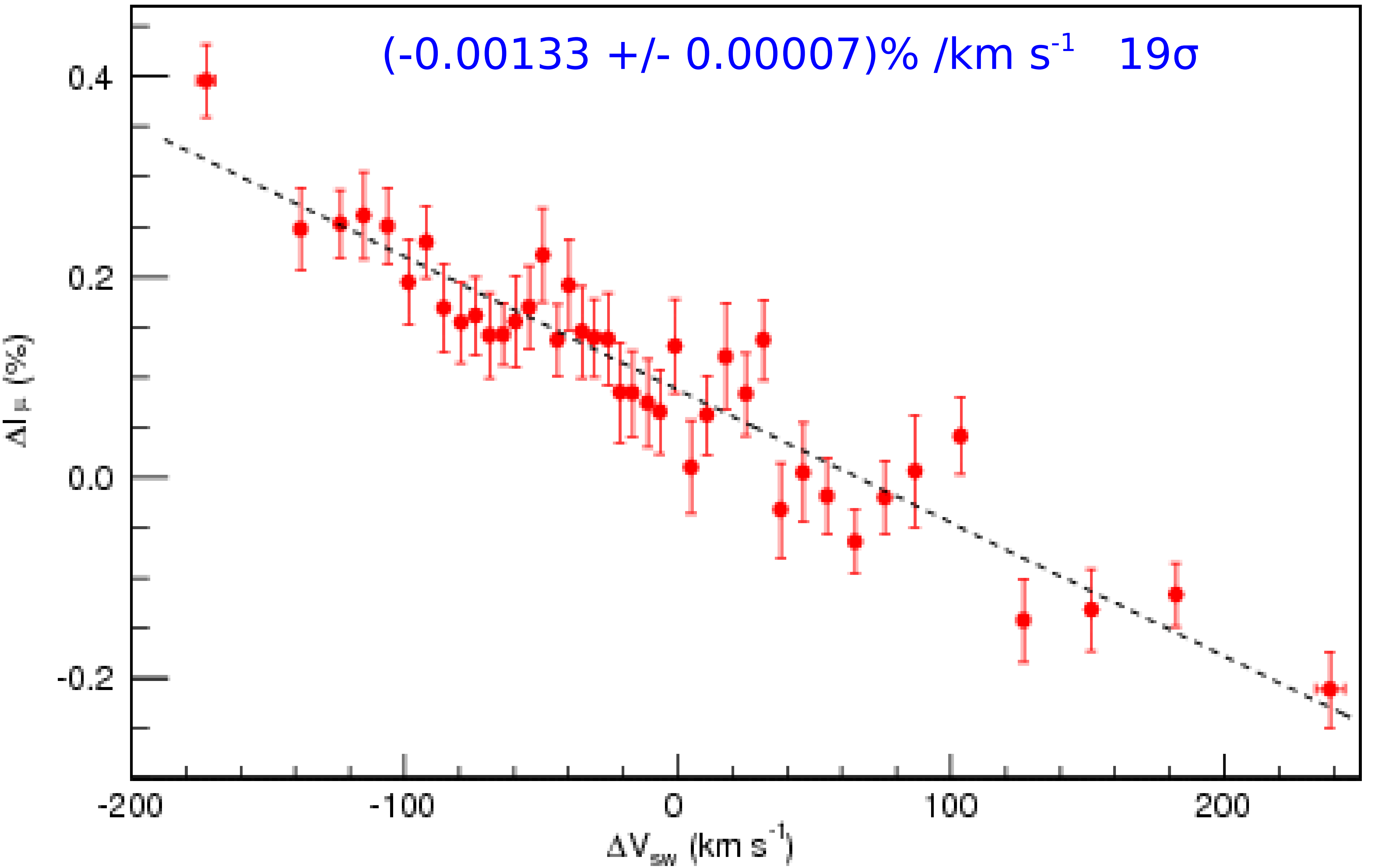
A = (0.0644 +/- 0.0008)% 80σ
ψ = (17.70 +/- 0.05) h



H. Kojima et al., Astropart. Phys. 62 21 (2015)

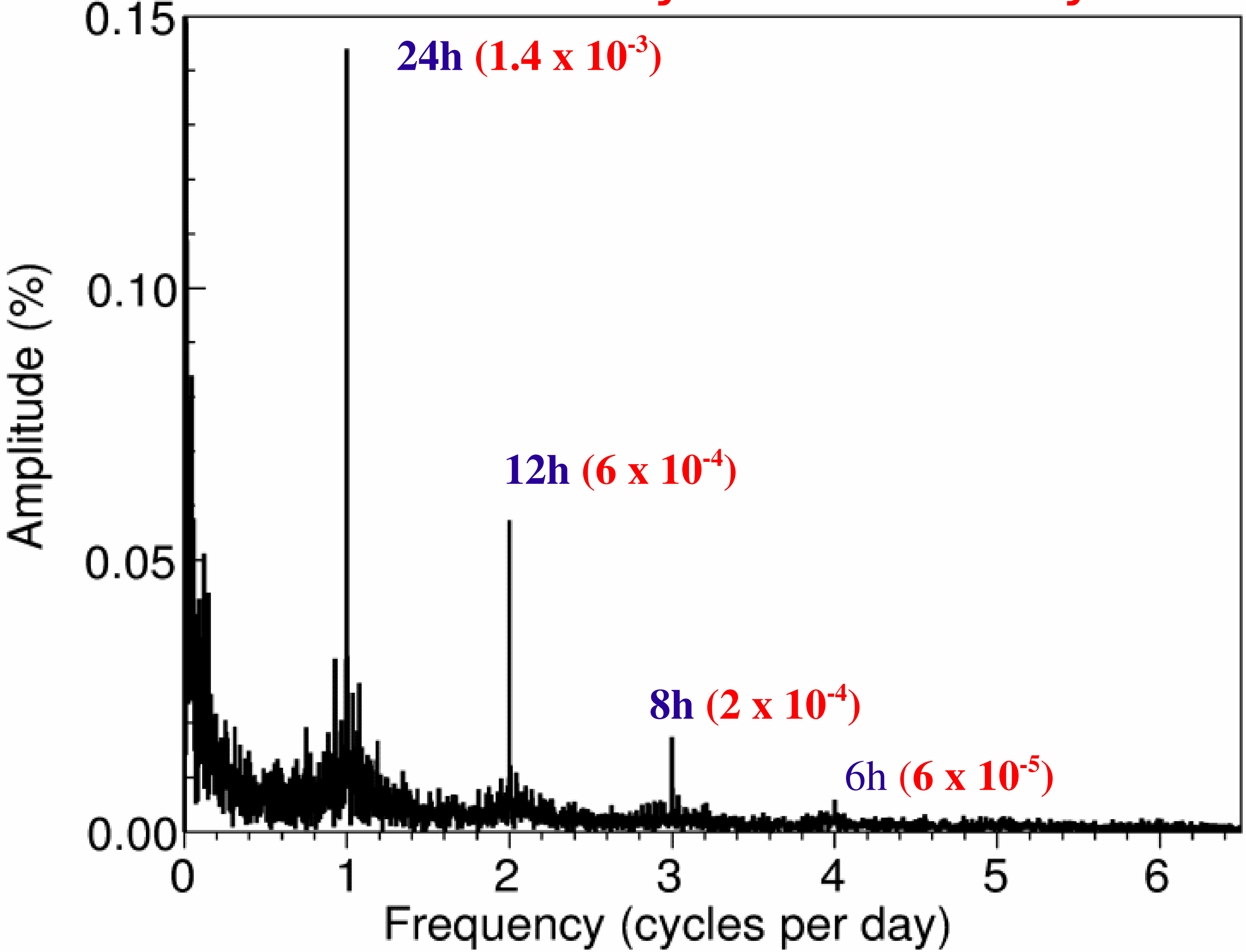
Cosmic Ray-Solar Wind Correlation

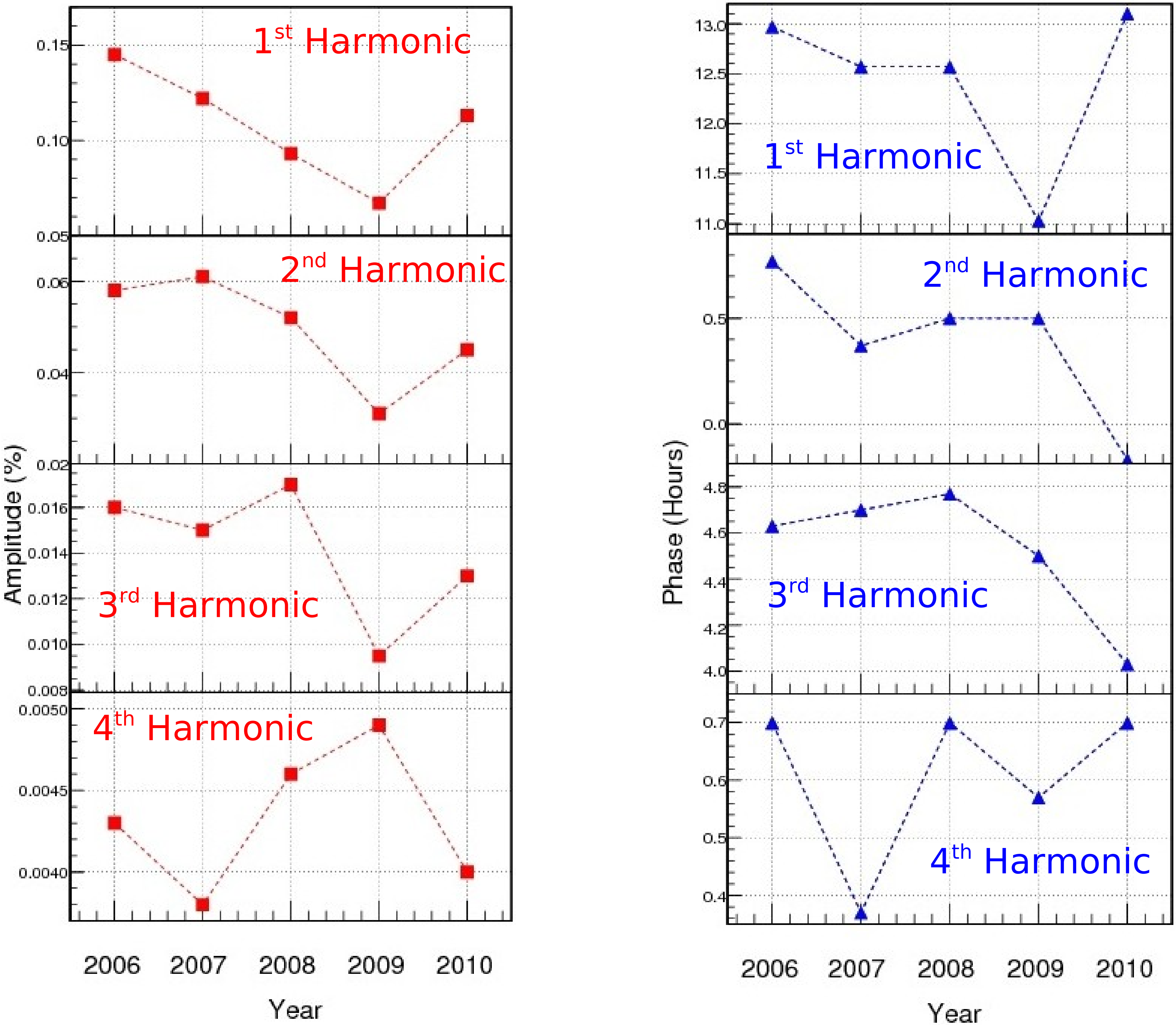
GRAPES-3 6-Yr Data 2000-2005



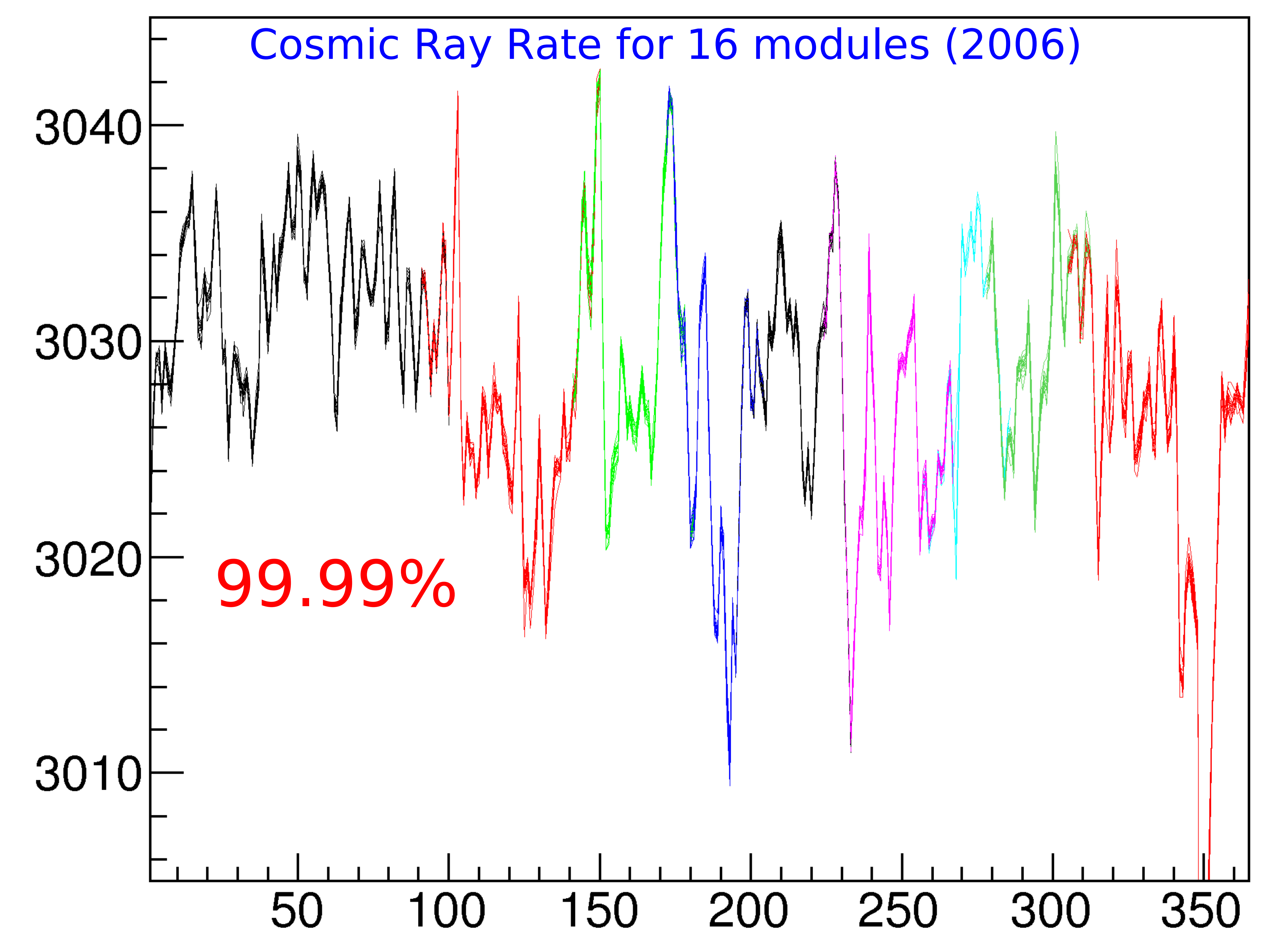
Harmonics of Solar Diurnal Anisotropy (2006)

Talk by P.K. Mohanty



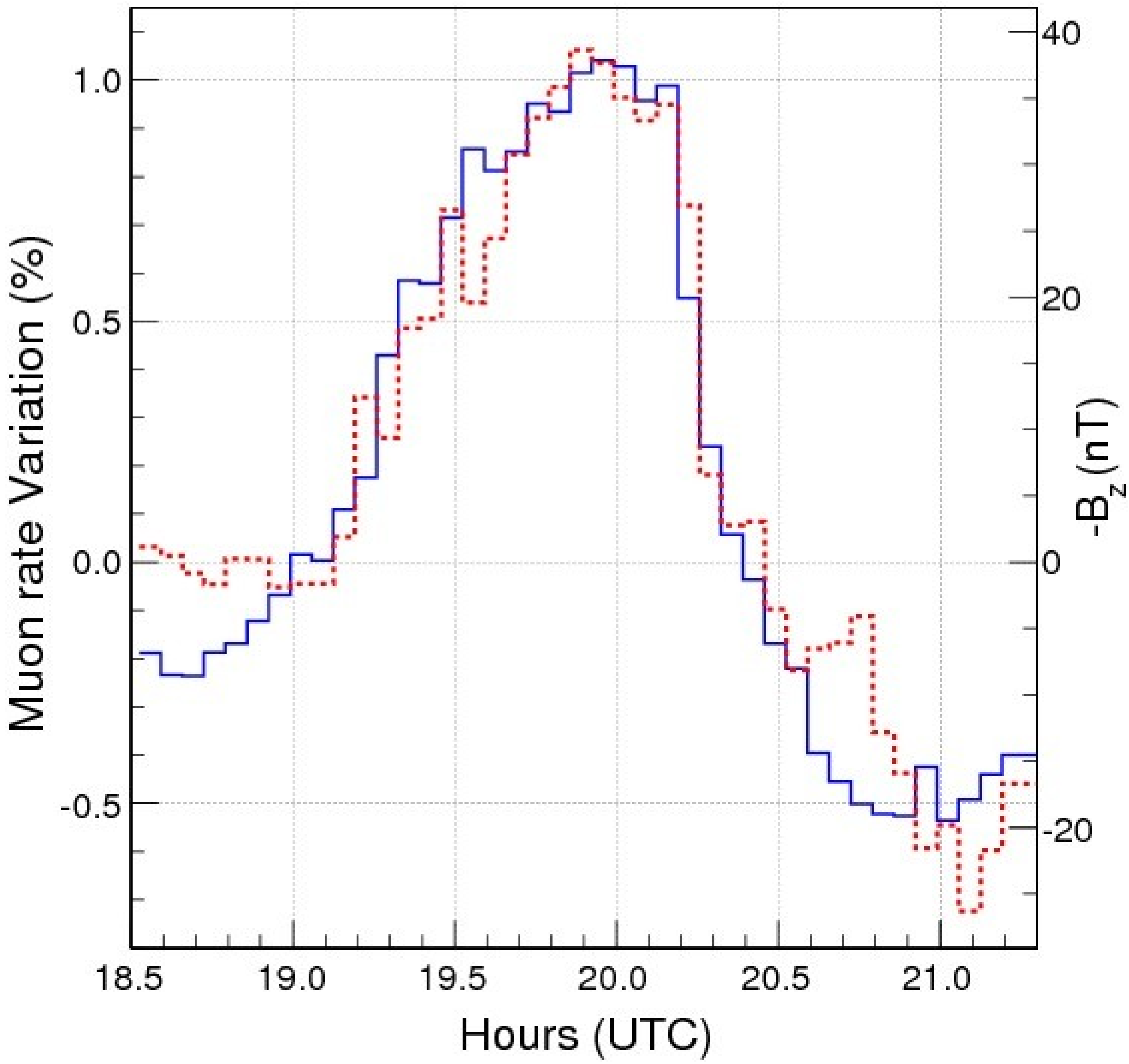


1st Harmonic
2nd Harmonic
3rd Harmonic
4th Harmonic
Amplitude (%)
0.15
0.10
0.05
0.06
0.04
0.02
0.016
0.014
0.012
0.010
0.008
0.0050
0.0045
0.0040
Phase (Hours)
13.0
12.5
12.0
11.5
11.0
0.5
0.0
4.8
4.6
4.4
4.2
4.0
0.7
0.6
0.5
0.4
2006
2007
2008
2009
2010
Year

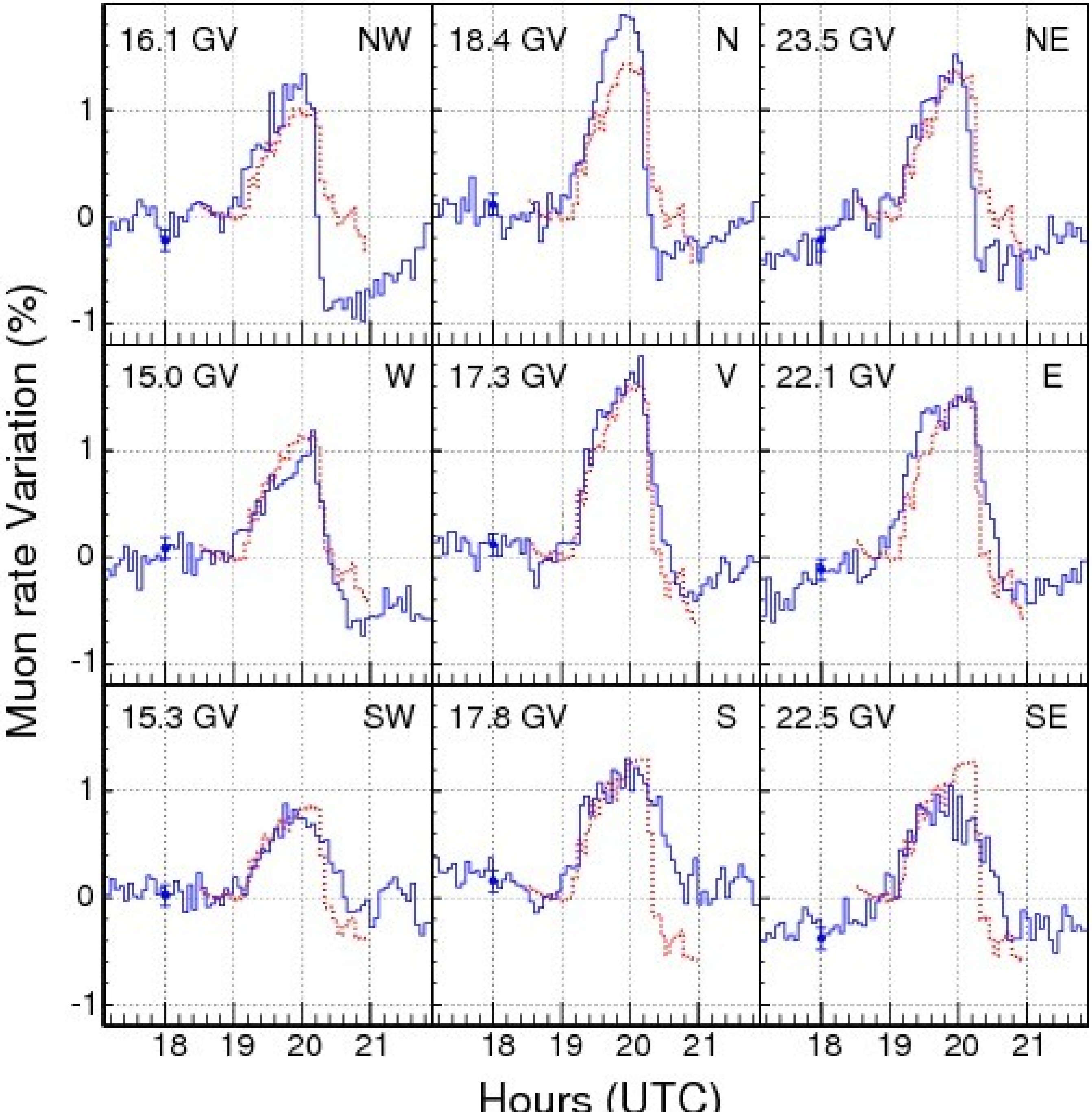


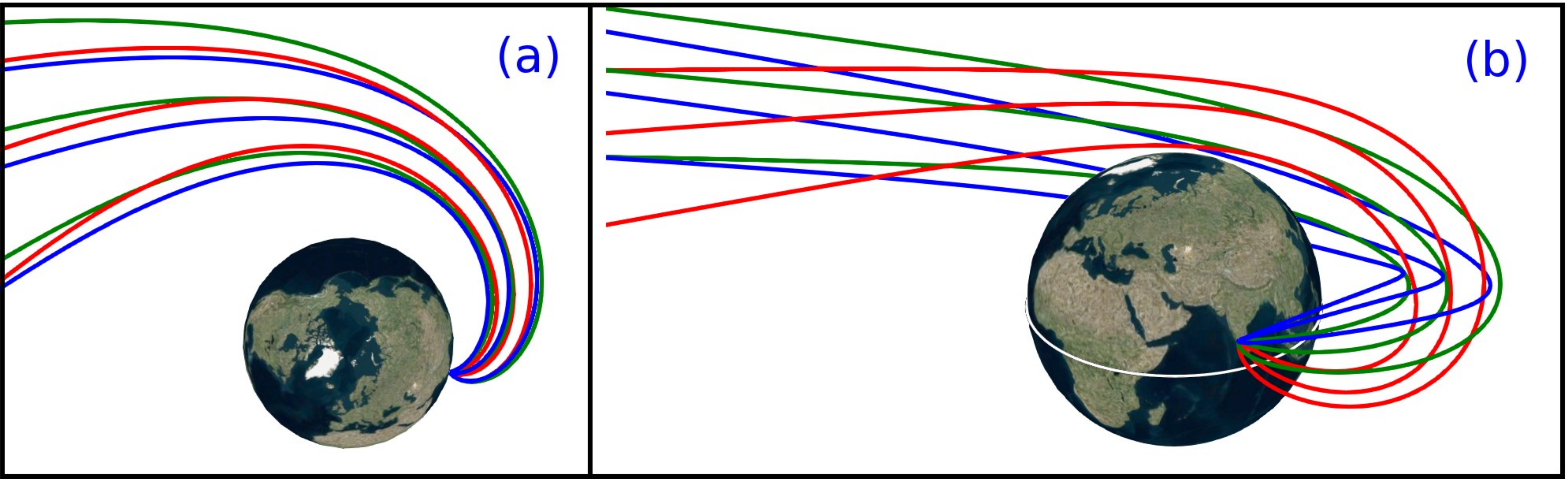
Cosmic Ray Rate for 16 modules (2006)
3040
3030
3020
3010
50
100
150
200
250
300
350
99.99%

22 June 2015 Ooty, midnight



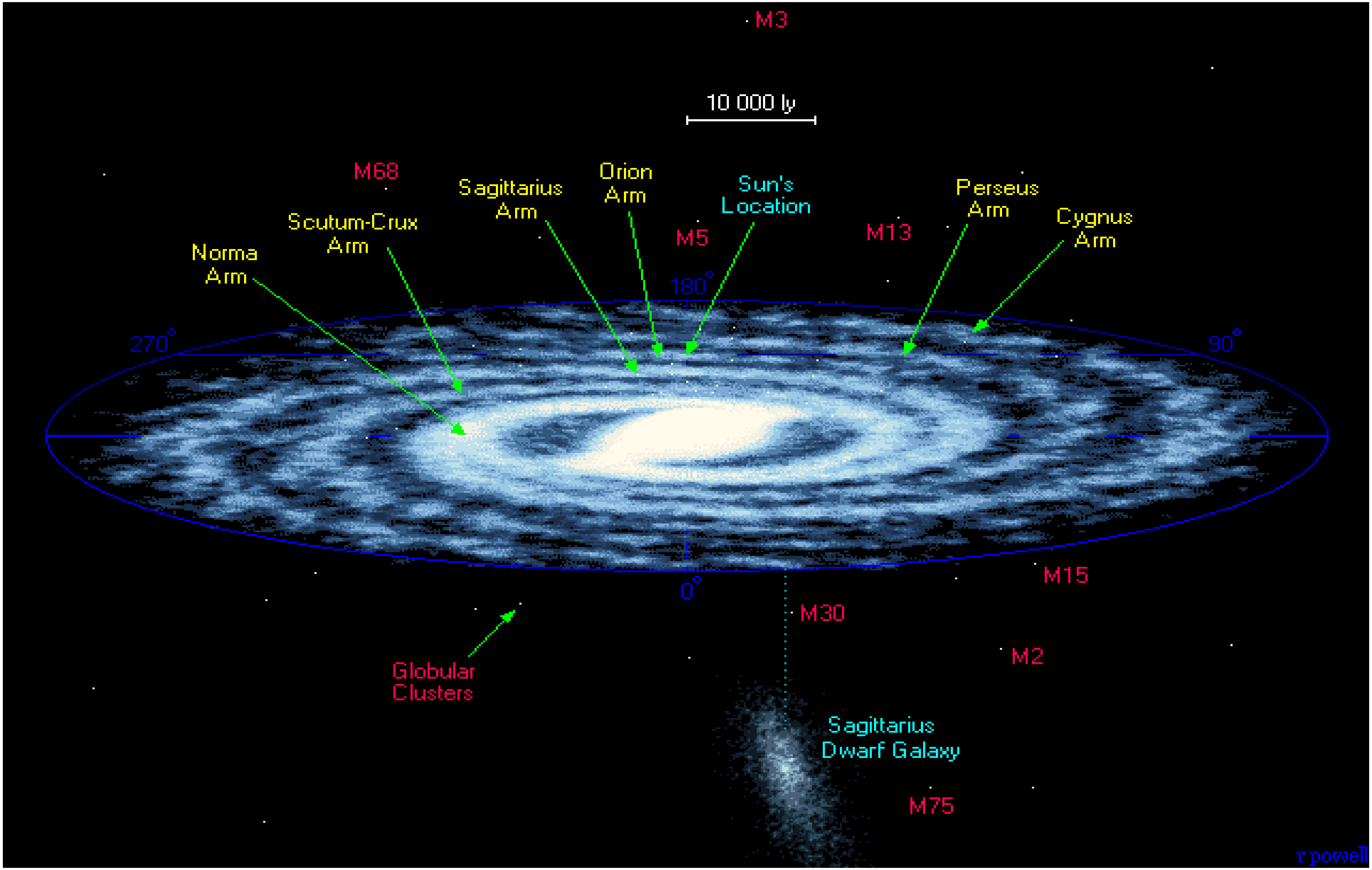
-Bz=680 nT   Talk by Mohanty



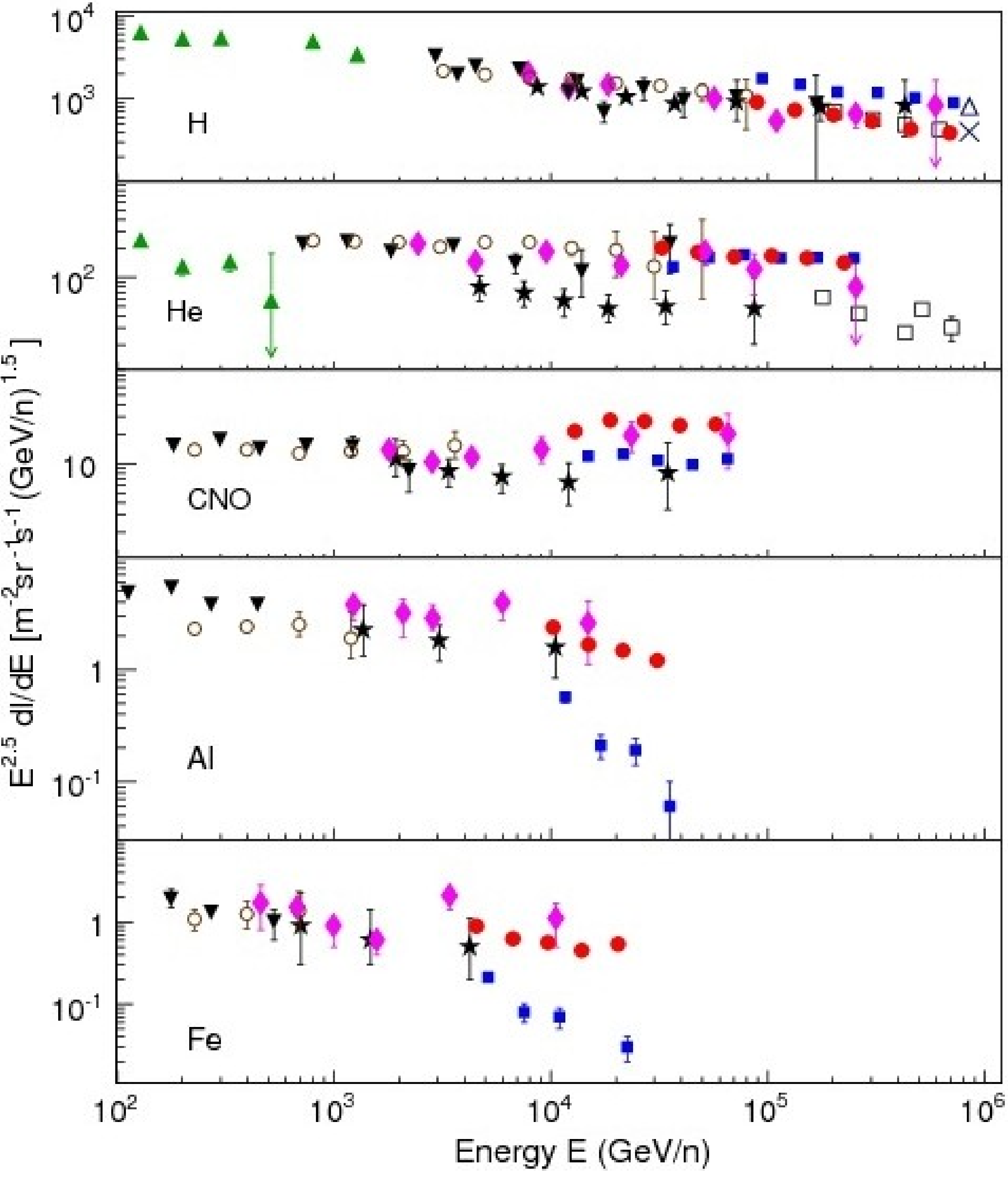


Poster by Sam Morris

Galactic Cosmic Rays at "Knee"
Energy ~1 PeV Scale ~10^{21}-10^{23} cm



Composition at 10^{15} eV



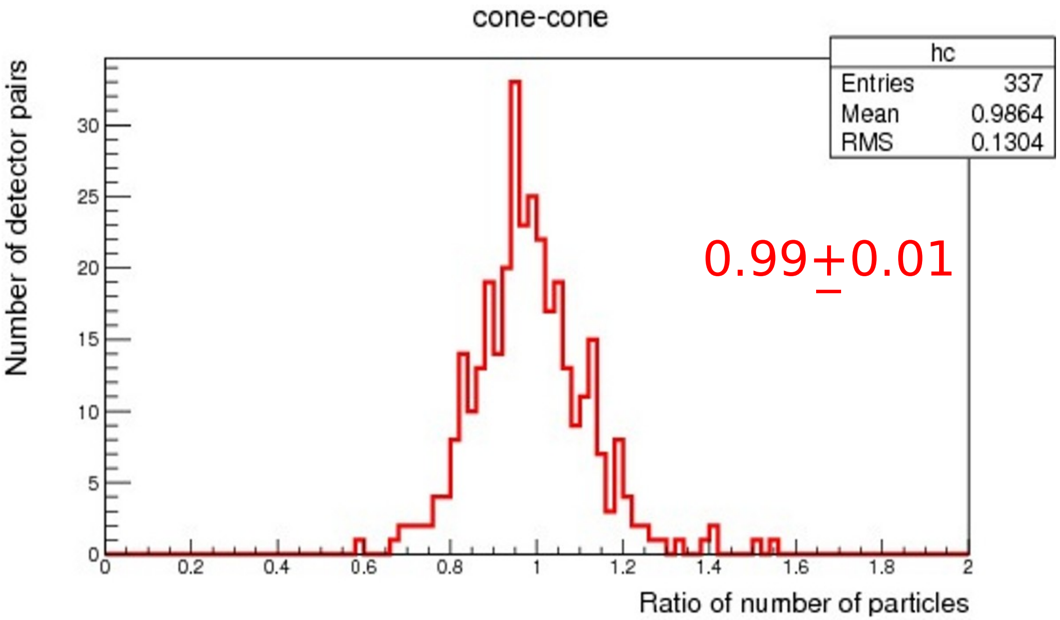
H. Tanaka et al. J. Phys. G: Nucl. Part. Phys. **39** (2012) 025201

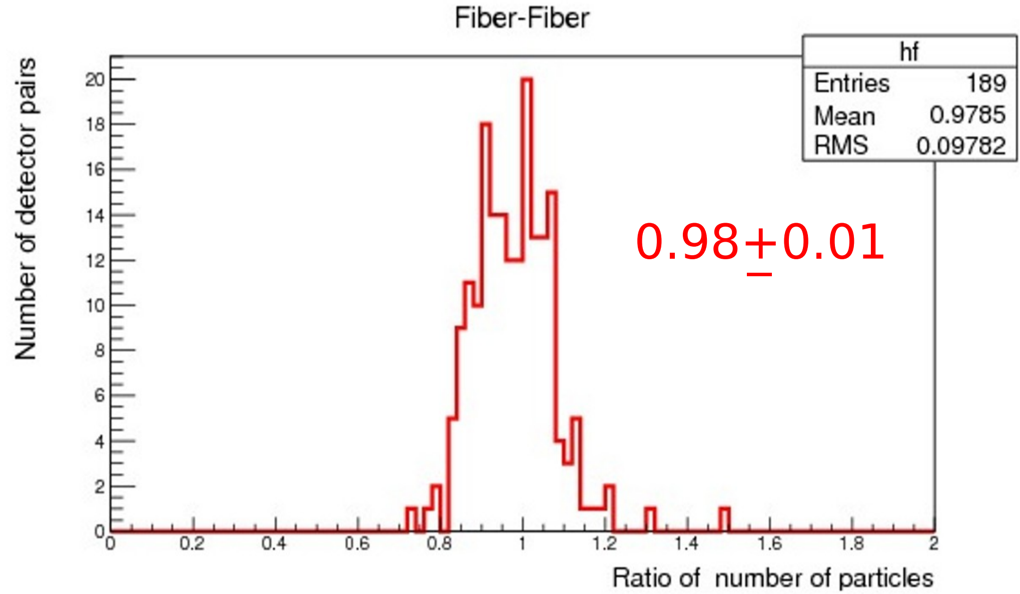
Hadronic Interaction models are key to interpreting composition data.

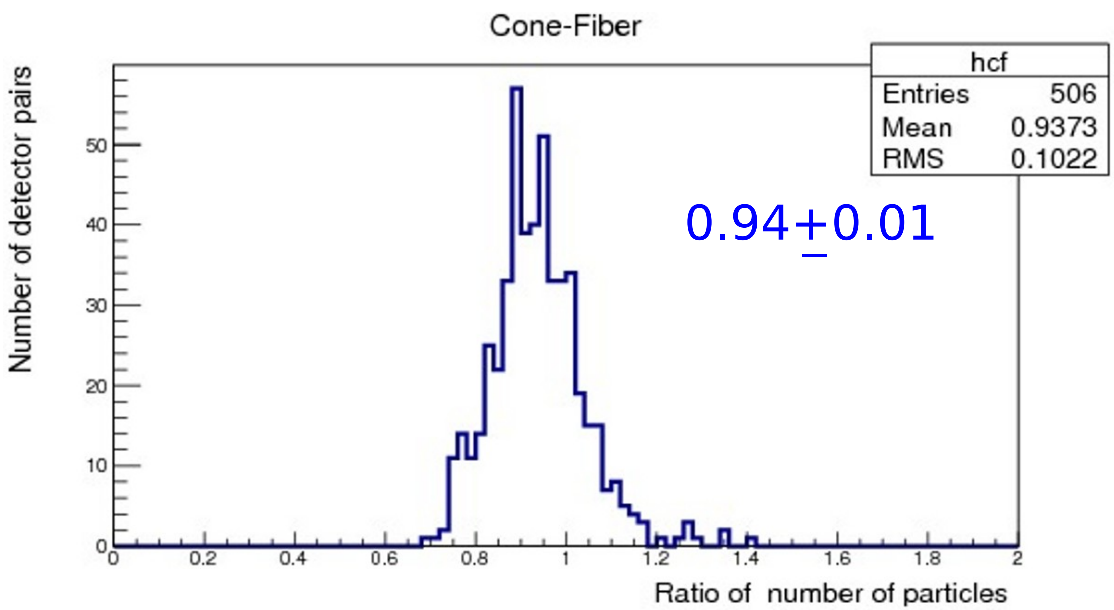
Precision measurement of GRAPES-3 muon angular distribution offers a probe of hadronic interactions.

Poster by Anuj Chandra

Poster by Jhansi







Poster by Meeran Zuberi

EAS trigger rate affected by atmospheric pressure, and temperature

Pressure coefficient = $(-0.85 \pm 0.01)\%\ hPa^{-1}$

Temperature coefficient = $(-0.25 \pm 0.03)\%\ ^{O}C^{-1}$

Diffuse multi-TeV γ-rays

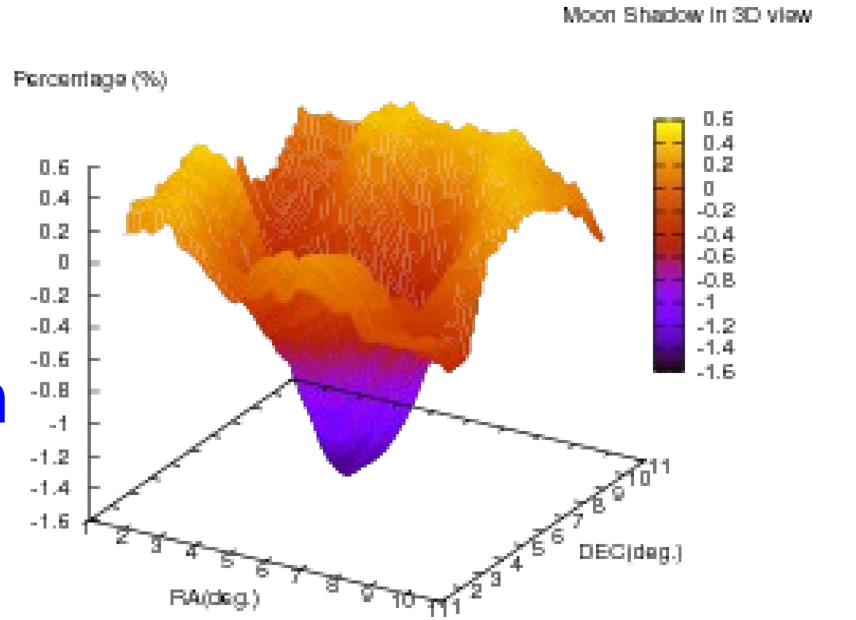
Energy ~100 EeV   Scale ~10^{24}-10^{26} cm

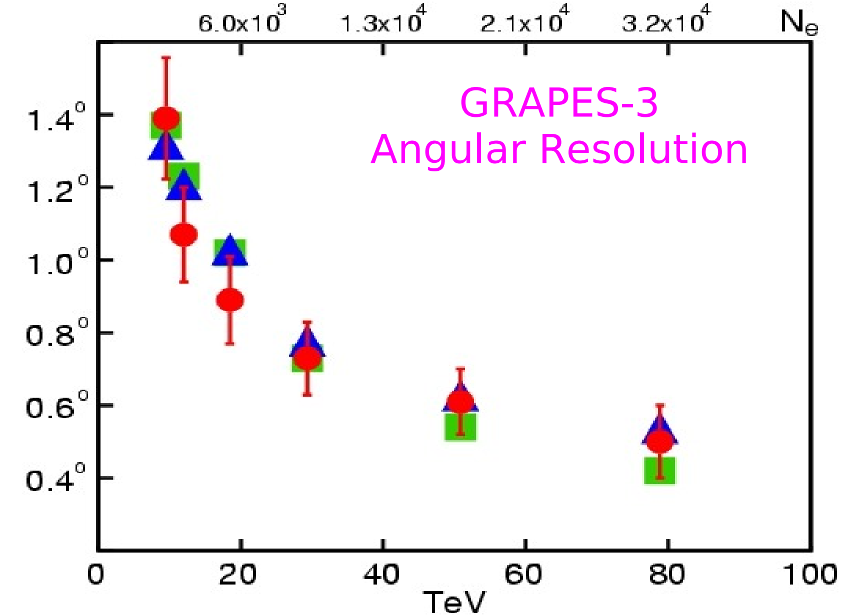
Moon Shadow

γ-ray astronomy σ_θ = 25'

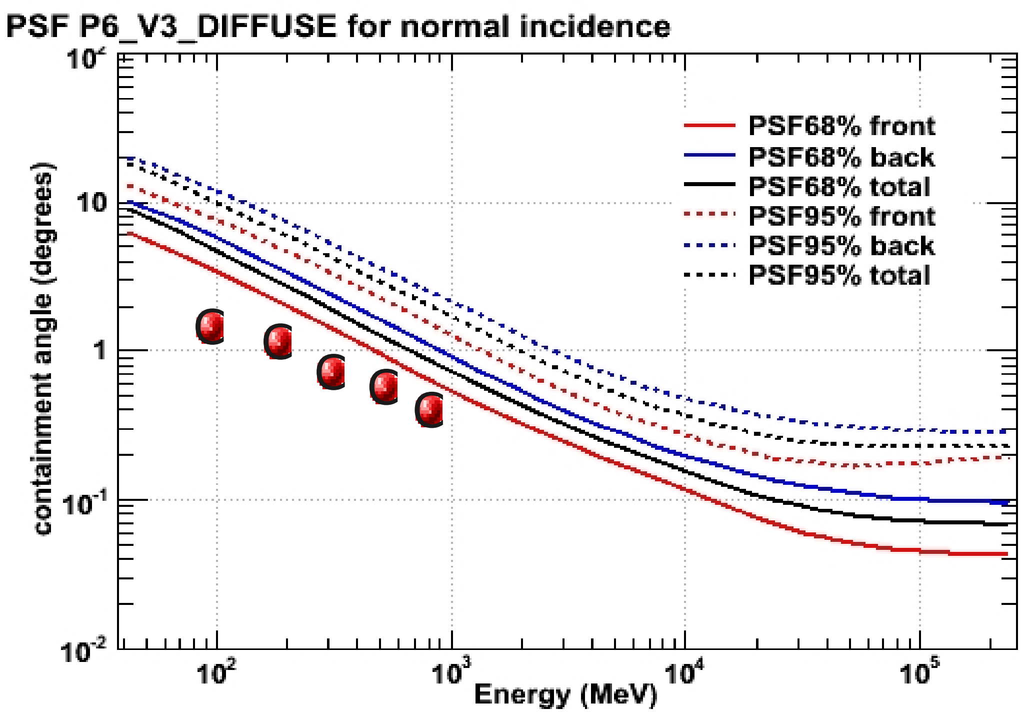
E~100 EeV Size~10^{24}-10^{26} cm

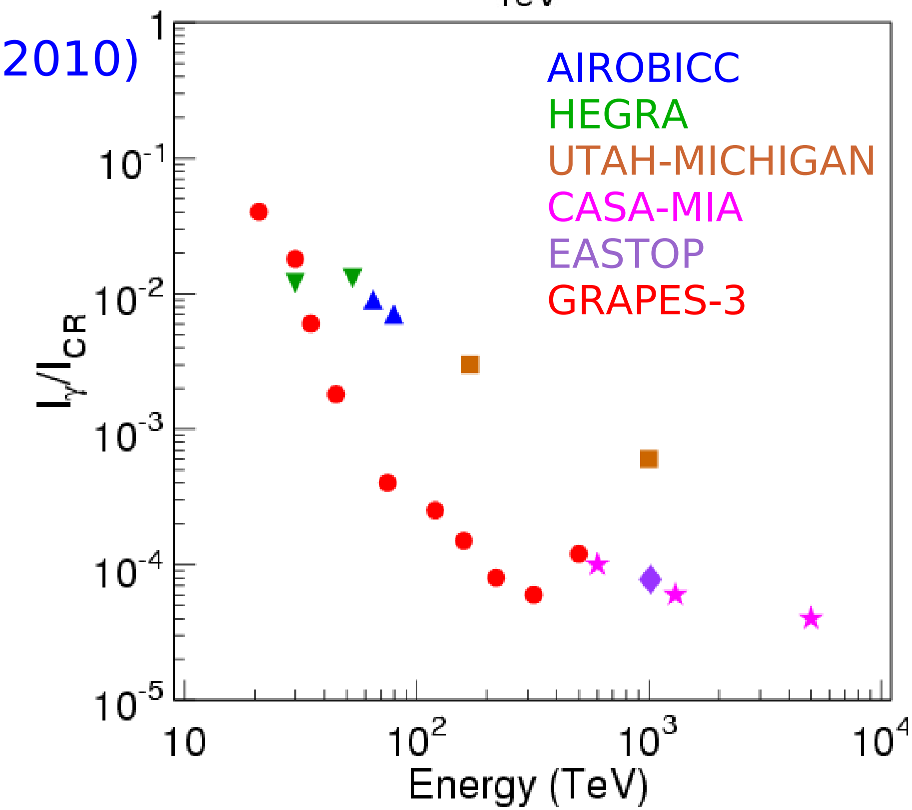
Moon



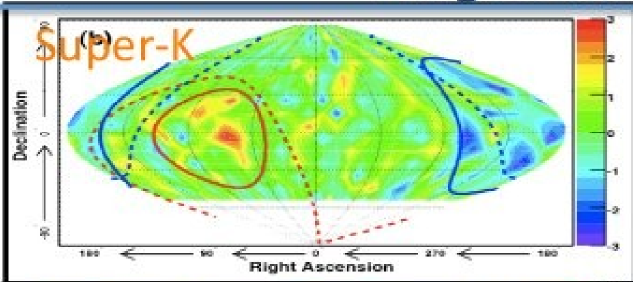


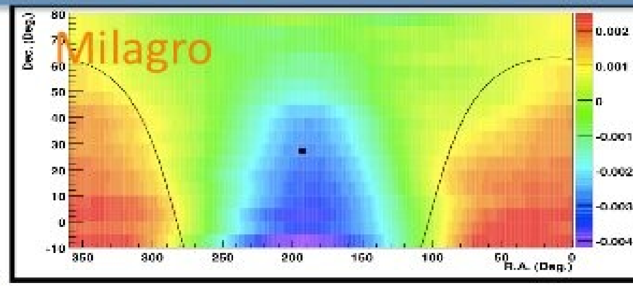
A. Oshima et al. Astropart. Phys. **33** 97-107 (2010)

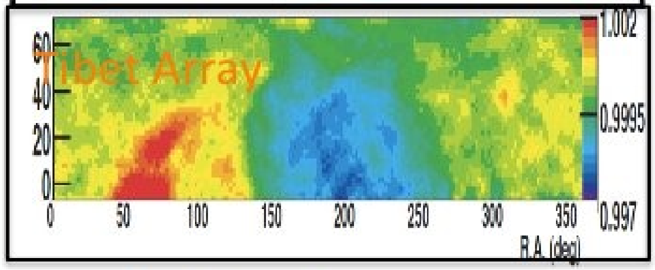


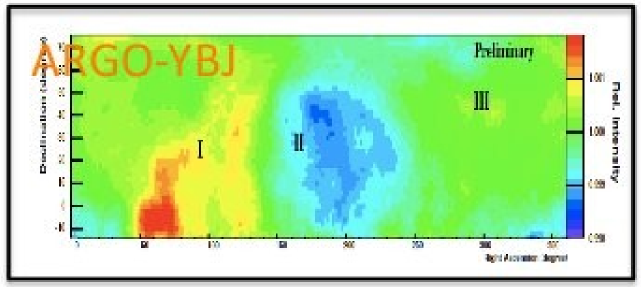


Large Scale Anisotropy and Past Results

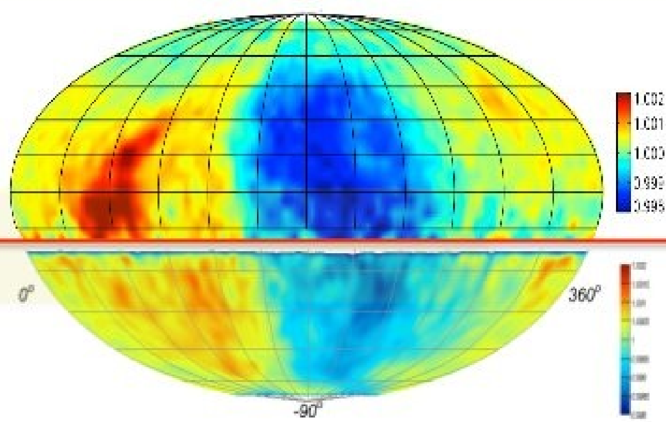








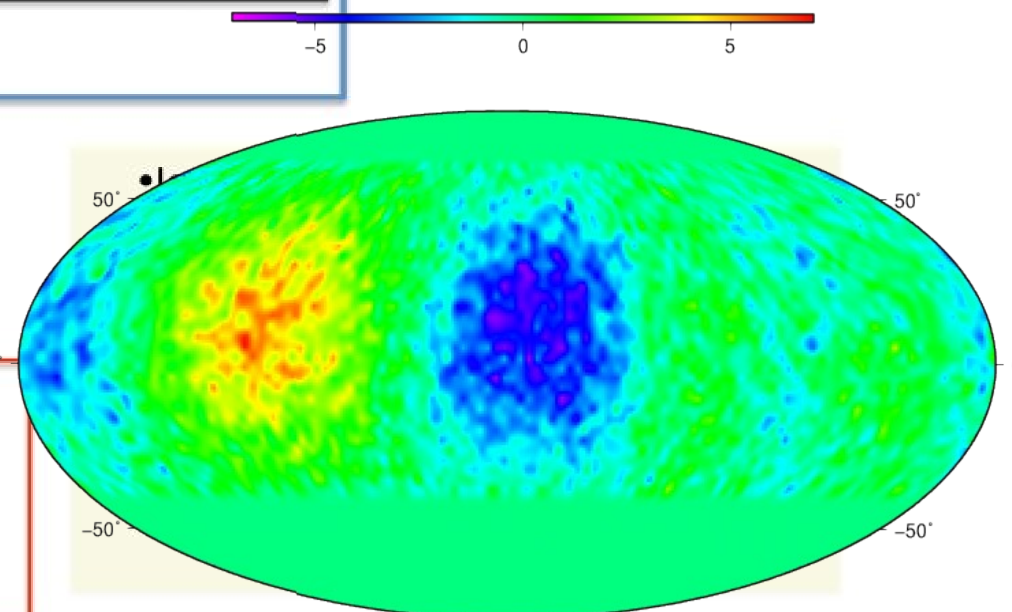
Northern Sky



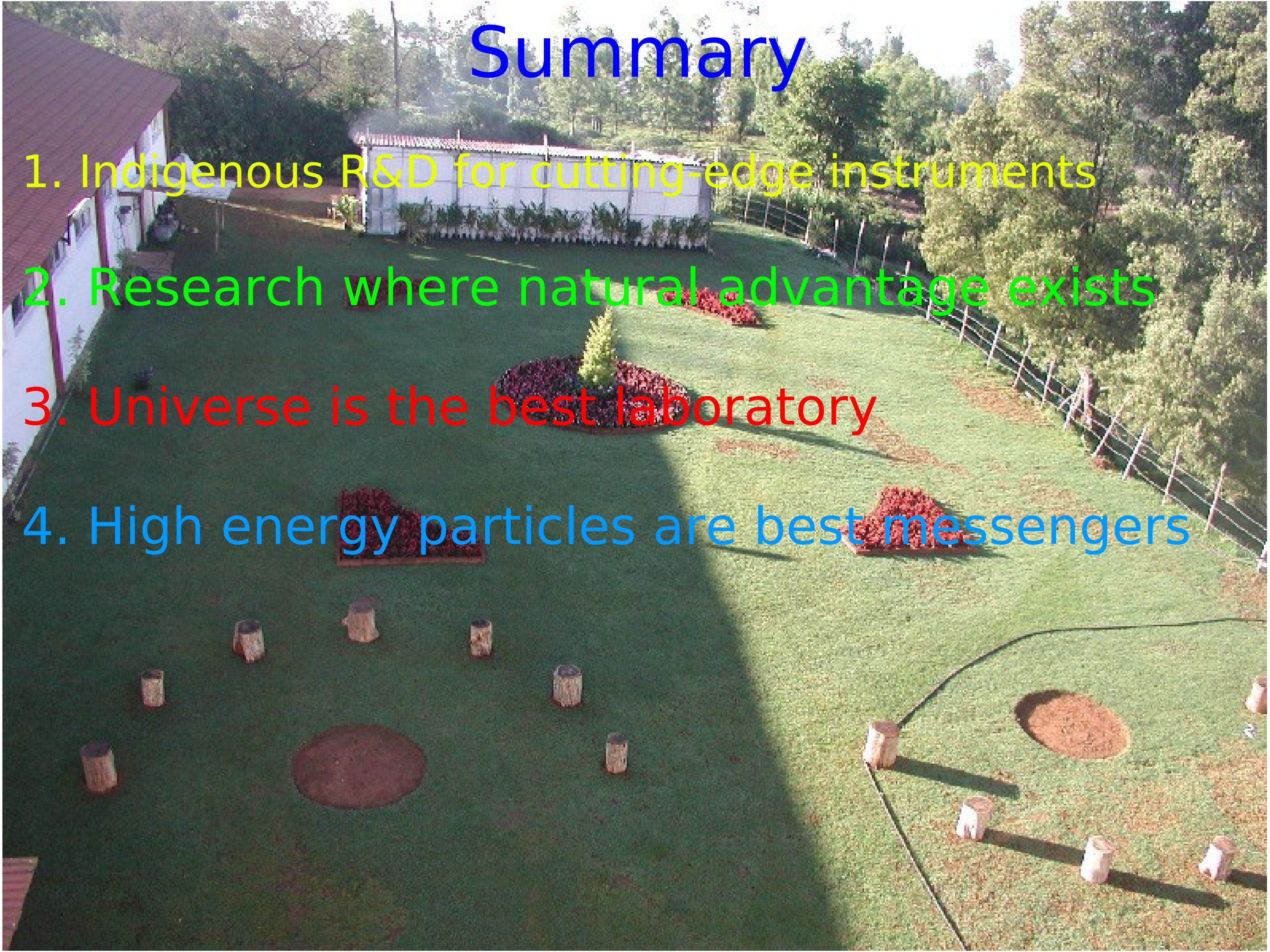
Tibet
Array
5TeV

IceCube
20TeV

Southern Sky



GRAPES-3 >10TeV



Summary

1. Indigenous R&D for cutting-edge instruments

2. Research where natural advantage exists

3. Universe is the best laboratory

4. High energy particles are best messengers

Winter School at Ooty in December 2014

Next edition will be in Ooty in December 2016

http://grapes-3.tifr.res.in

Education: ~350 attended 10 winter schools

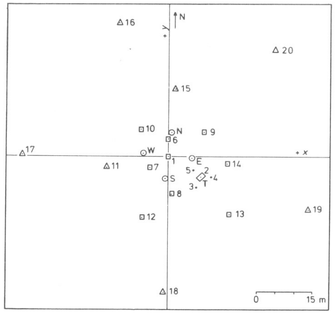
~270 BE/M.Sc students ~70 projects 2010-15

Visitors: ~1500 in 2015

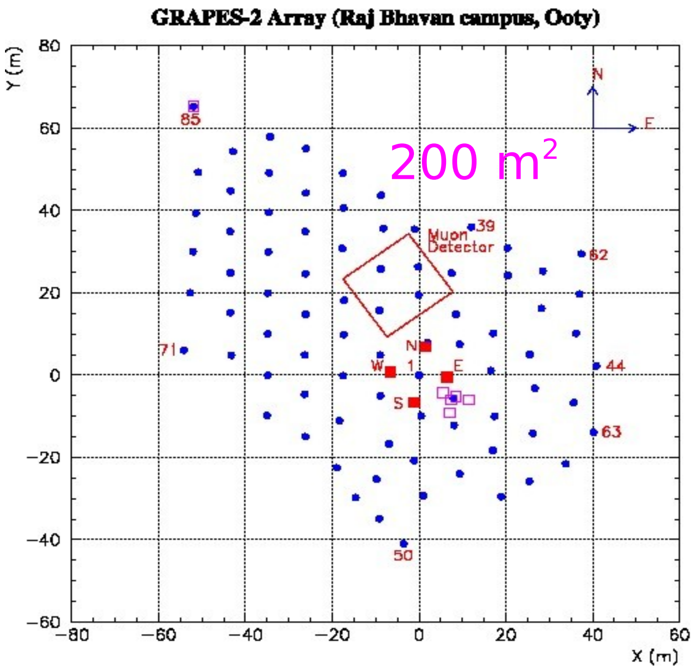
~2000 in 2016 so far.. **Thanks**

Backup slides

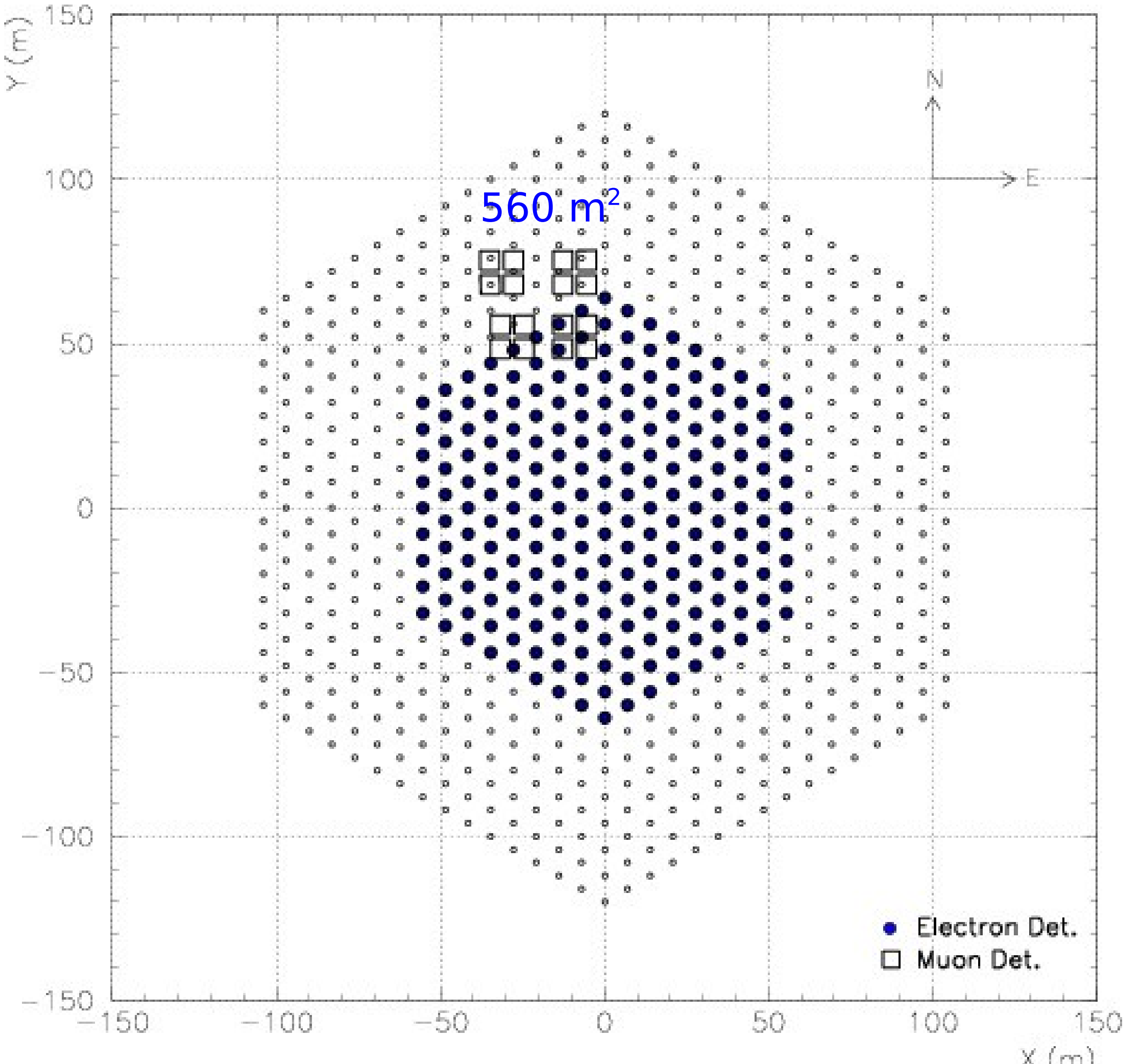
GRAPES-1
1965-1985



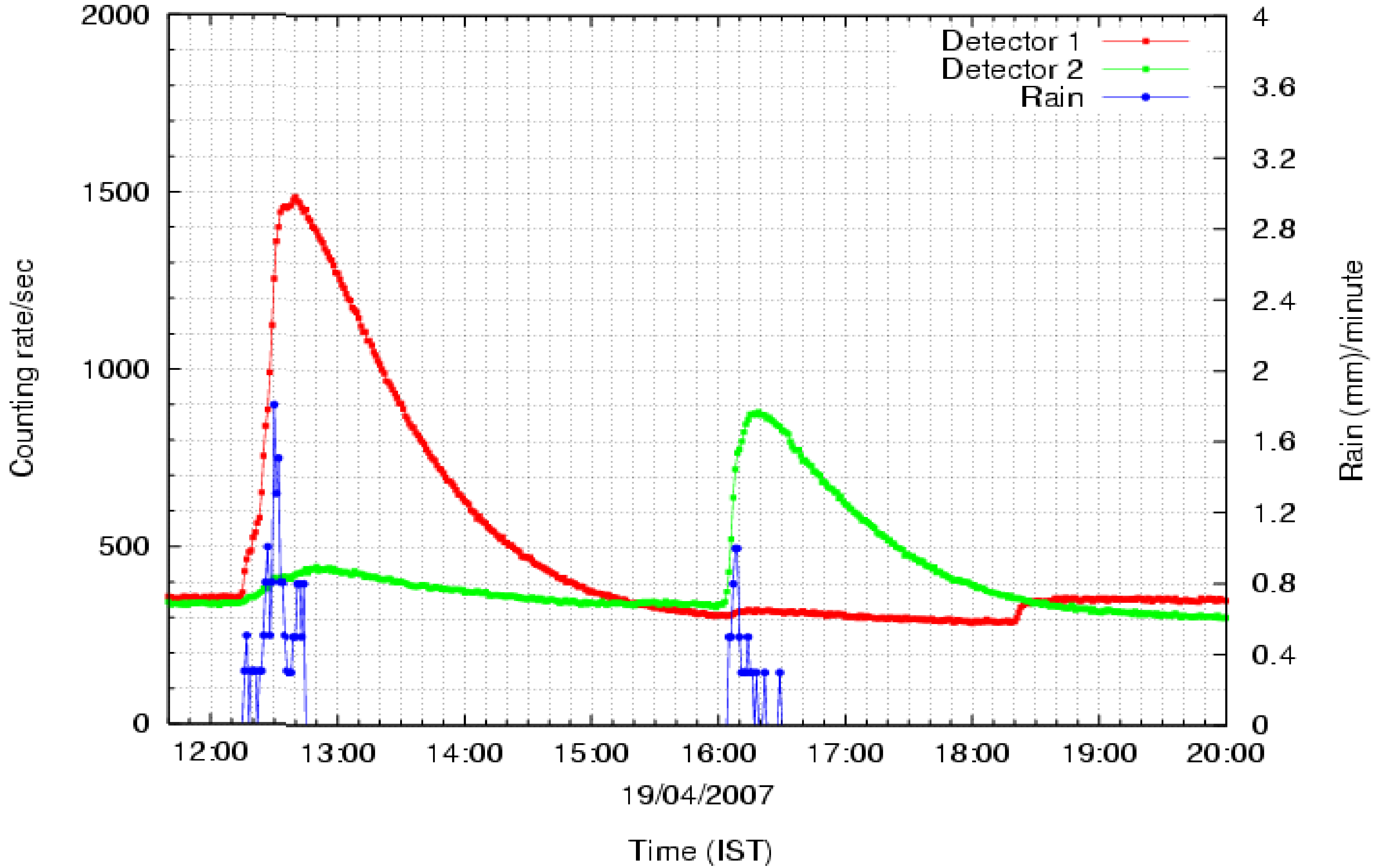
GRAPES-2
1986-Present



GRAPES-3
2001-Present



Radioactivity in fresh rain water using GRAPES-3 scintillators and the story of Earth



The Story of Earth

$_{92}U^{238} \xrightarrow{\alpha} {}_{90}Th^{234} \xrightarrow{\beta} {}_{91}Pa^{234} \xrightarrow{\beta} {}_{92}U^{234}$

$T_{1/2}$: 4.5x10^9 Y, 24.1 d, 70.2 s

$_{92}U^{234} \xrightarrow{\alpha} {}_{90}Th^{230} \xrightarrow{\alpha} {}_{88}Ra^{226} \xrightarrow{\alpha} {}_{86}Rn^{222}$

$T_{1/2}$: 2.5x10^5 Y, 7.5x10^4 Y, 1600 Y

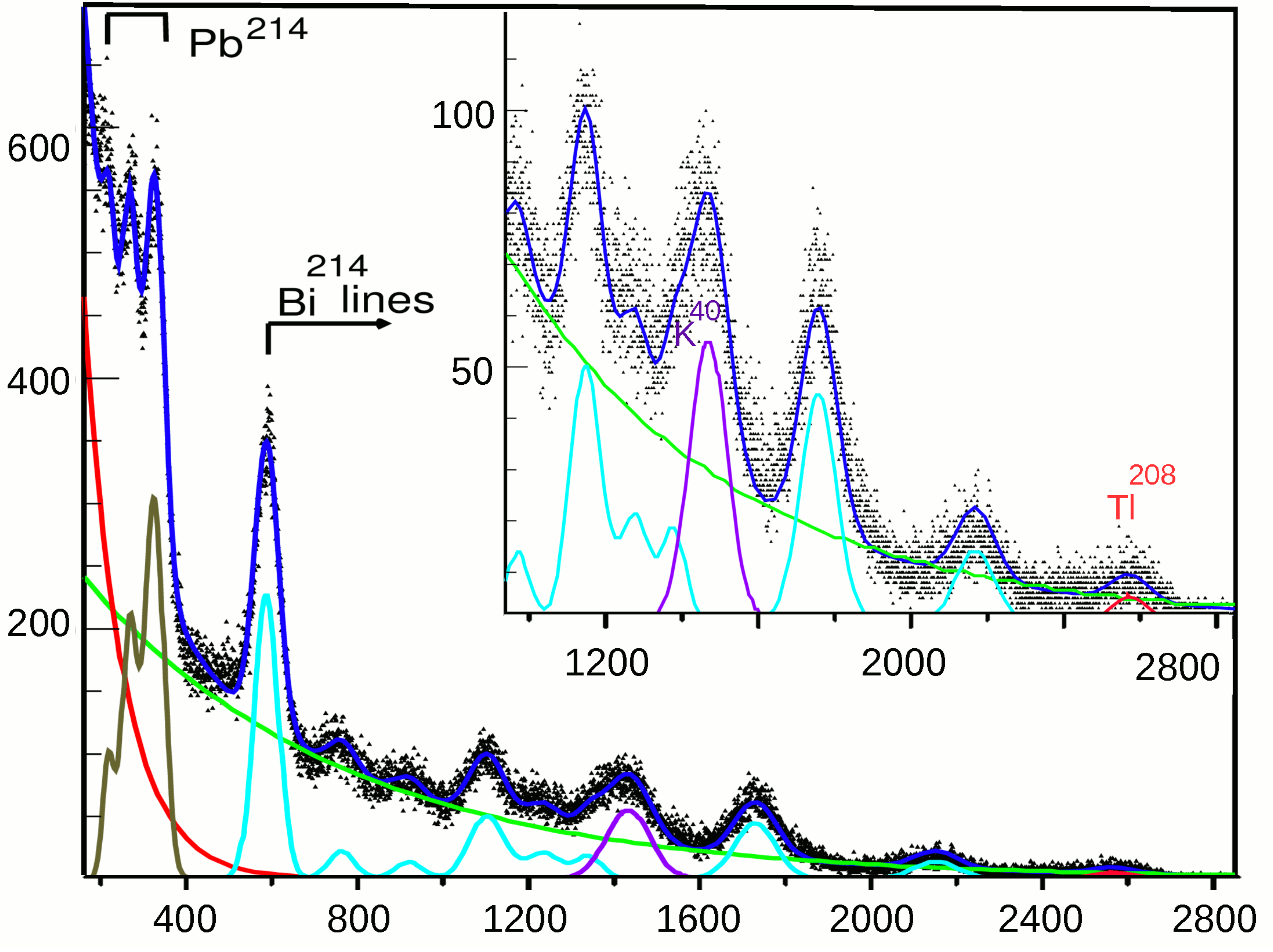
Since $_{92}U^{238}$ has a long half-life of 4.5 billion yr, comparable to age of Earth it acts as constant source of daughter nuclei. Since all $_{92}U^{238}$ daughter nuclei have half-life smaller than 4.5 billion yrs, rate of production of $_{90}Th^{230}$ and $_{88}Ra^{226}$ is constant. At the end of decay chain a steady supply of radon $_{86}Rn^{222}$ a radioactive gas with a half-life of 3.82 days is produced which is mainly responsible for hazardous radiation detected inside underground locations and sealed areas.

	α		α		β,γ	
${}_{86}Rn^{222}$	----->	${}_{84}Po^{218}$	----->	${}_{82}Pb^{214}$	----->	${}_{83}Bi^{214}$
$T_{1/2}$	3.82 d		3.1 d		26.8 min	

	β,γ		α		β	
${}_{83}Bi^{214}$	----->	${}_{84}Po^{214}$	----->	${}_{82}Pb^{210}$	----->	${}_{83}Bi^{210}$
$T_{1/2}$	19.9 min		164 μs		22.2 Y	

	β		α	
${}_{83}Bi^{210}$	----->	${}_{84}Po^{210}$	----->	${}_{82}Pb^{206}$
$T_{1/2}$	5.01 d		138 d	

Since ${}_{86}Rn^{222}$ escapes from soil into atmosphere mixes in air due to 3.82 d half-life before eventually decaying into ${}_{82}Pb^{214}$ and ${}_{83}Bi^{214}$ with half-life of 27 and 20 min. that produce short-term radiation measured here.


Pb214
214
Bi lines
40
K
208
Tl
100
50
1200
2000
2800
600
400
200
400
800
1200
1600
2000
2400
2800

Detection and Measurement of Cosmic Rays:

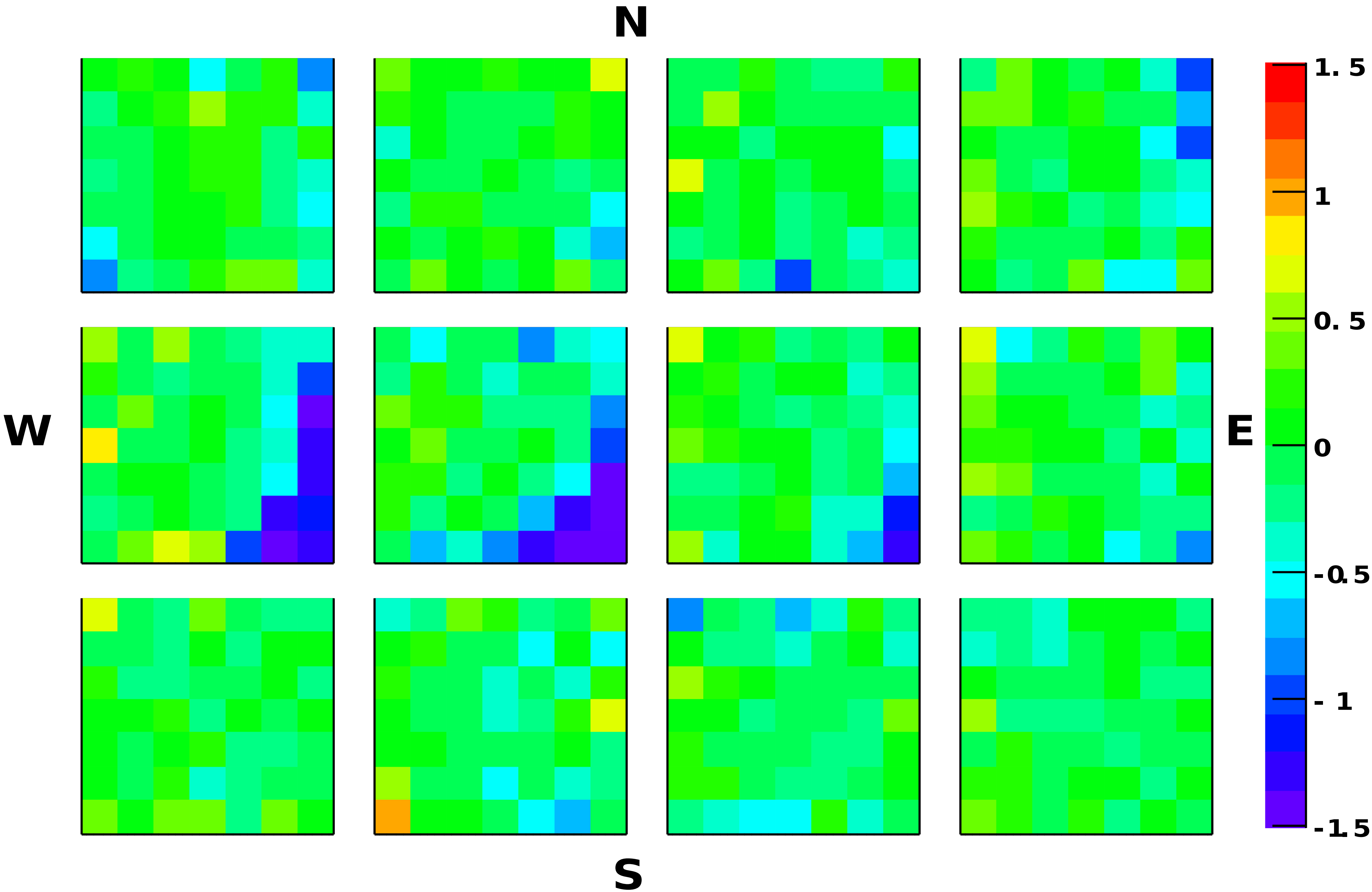
HE particles produce a shower of electromagnetic (e^+, e^-, γ) particles, muons (μ^+, μ^-) and other particles.

Measurement of electron density and time (ns) in the shower provides an estimate of the energy and direction of primary particle.

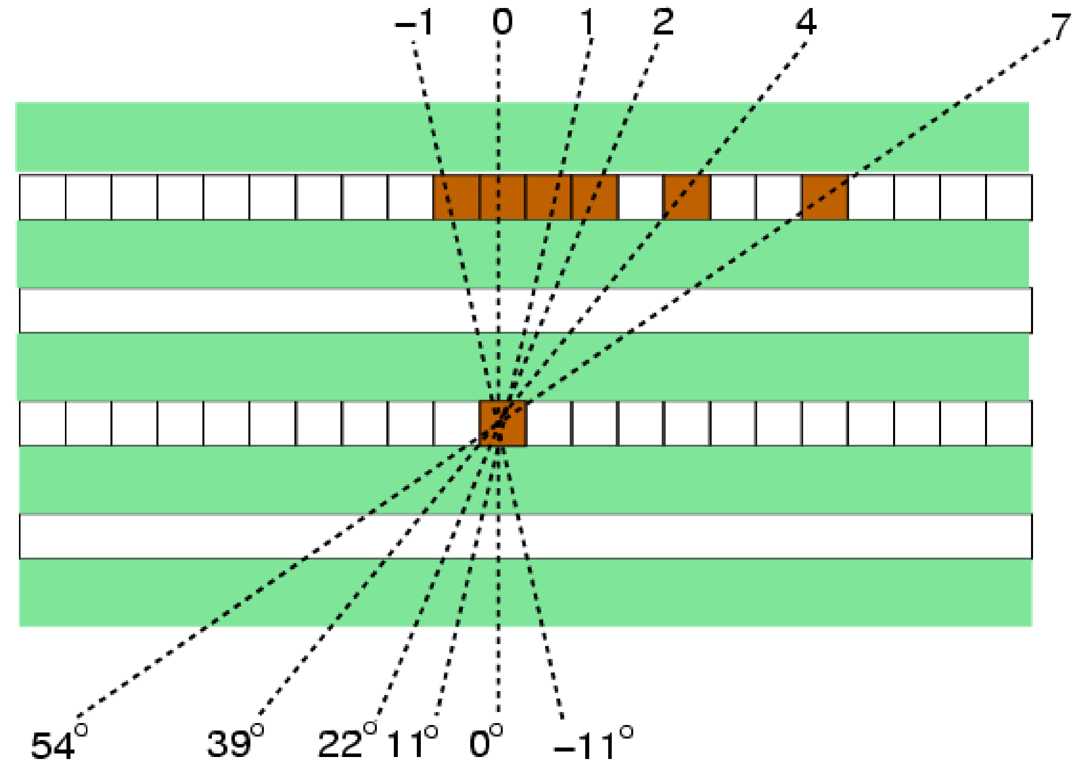
Measurement of muon density in the shower provides information on the nuclear composition of primary particle. It also allows discrimination between γ and protons.

The muons are also sensitive to the flux of solar energetic particles and can be used to study solar and atmospheric phenomena.

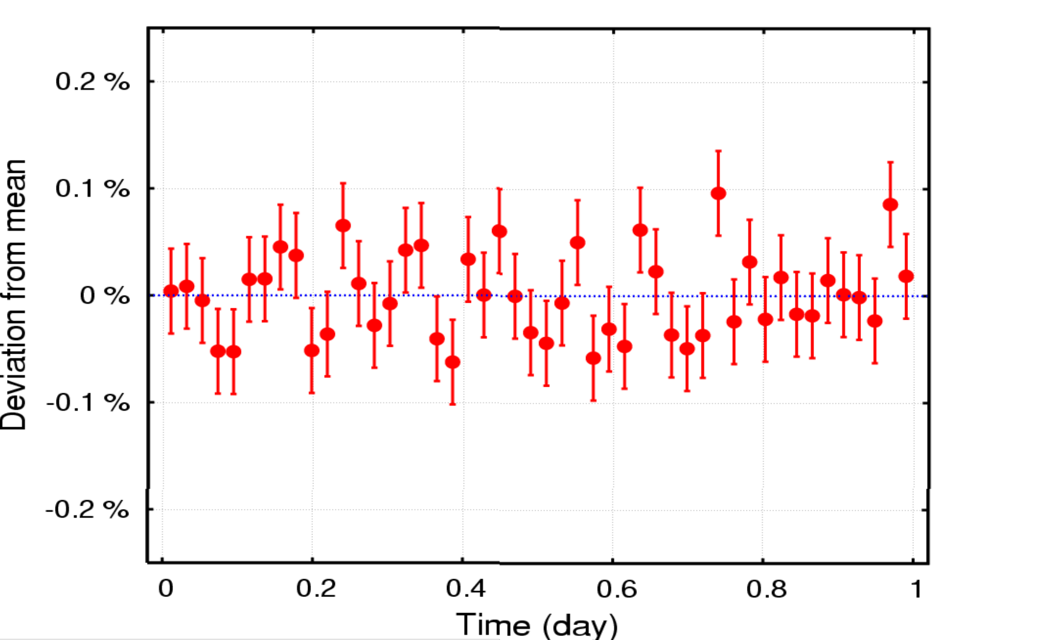
Thunderstorm on 18 April 2011

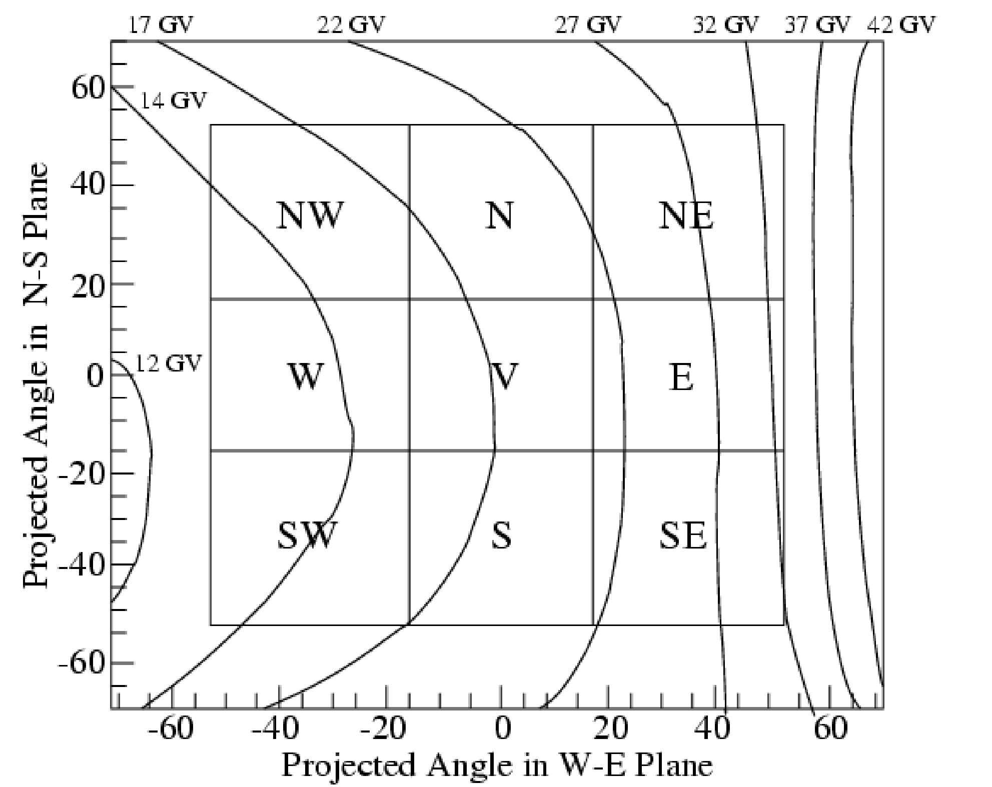


Solar phenomena

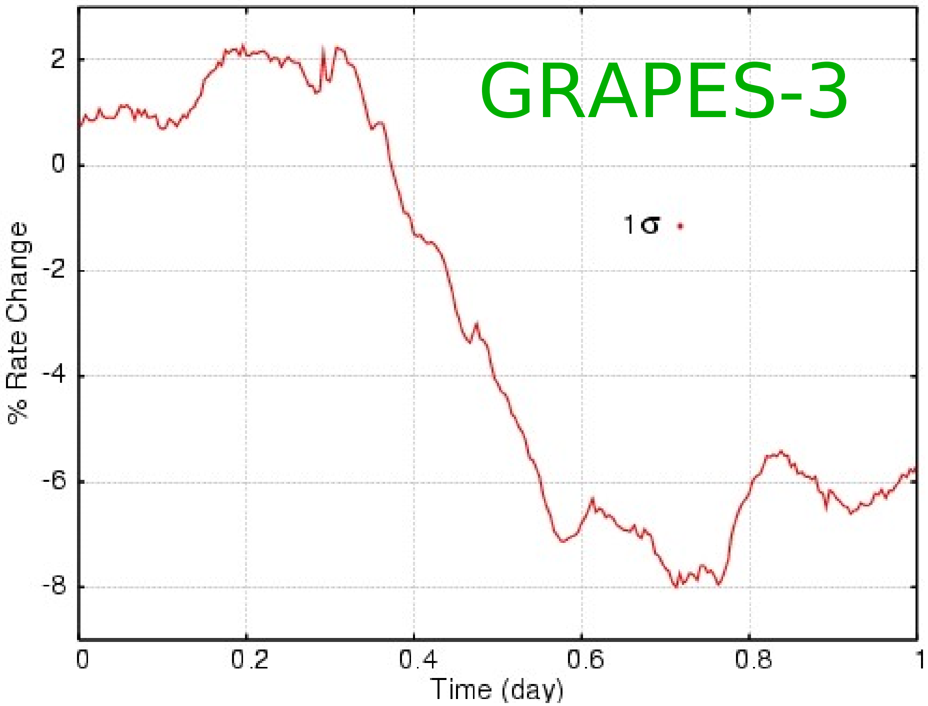


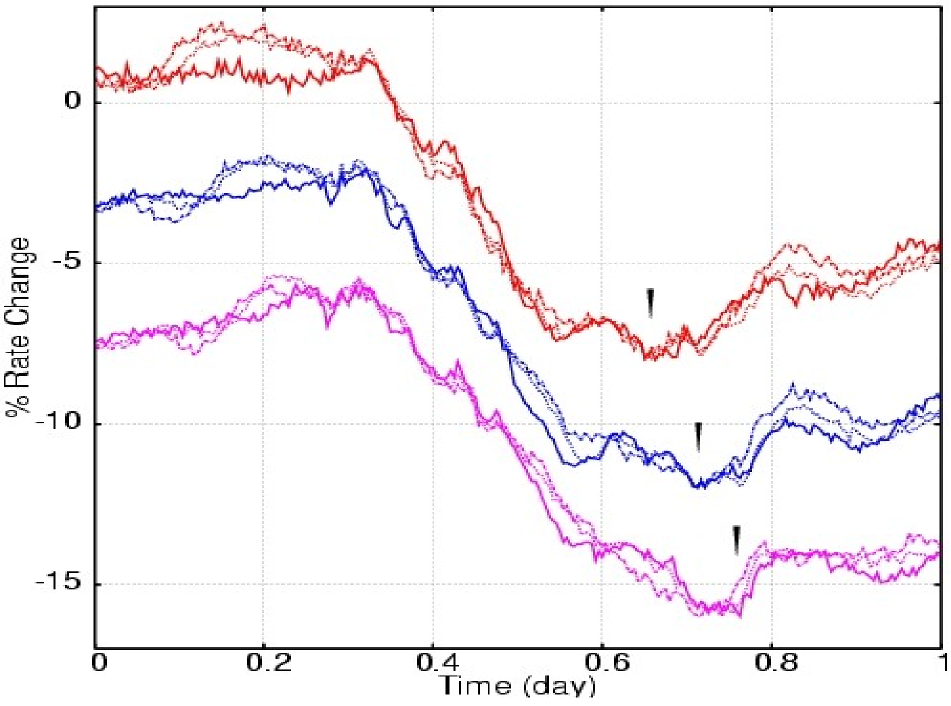
Energy ~10 GeV
Scale ~10^{11}-10^{13} cm

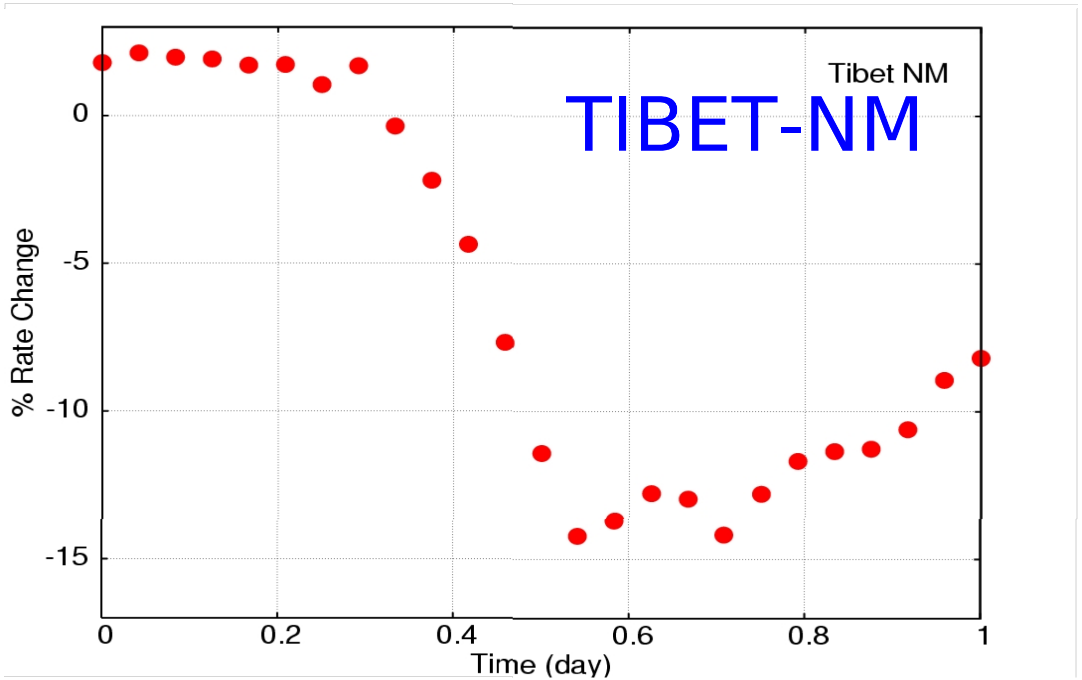




Coronal Mass Ejection (28 October 2003)

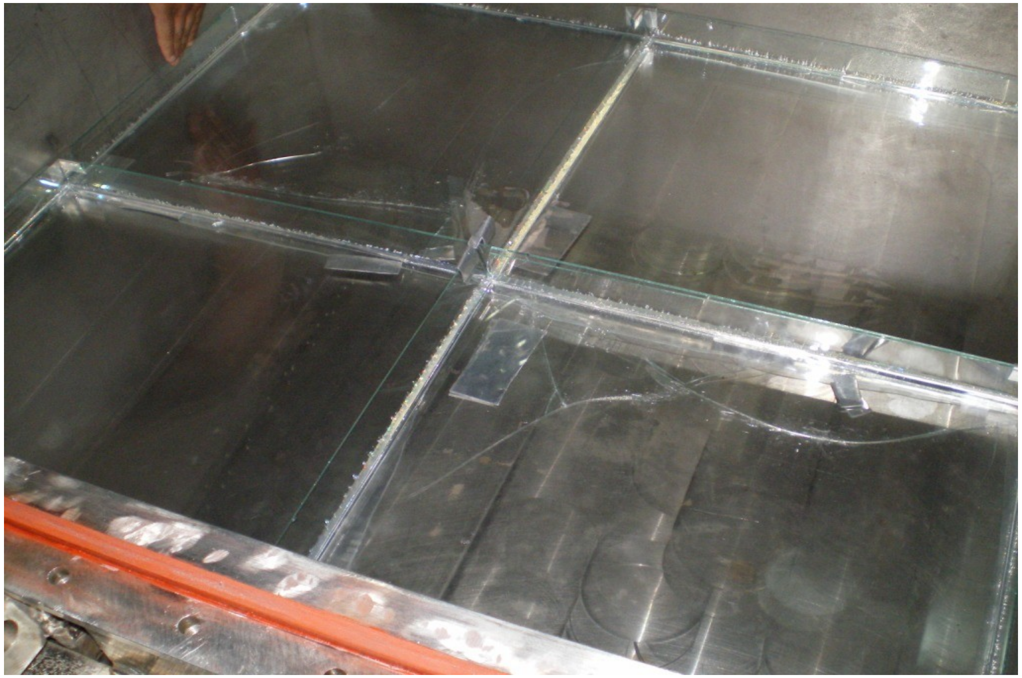






T. Nonaka et al.
Phys. Rev. D **74** 52003 (2006)



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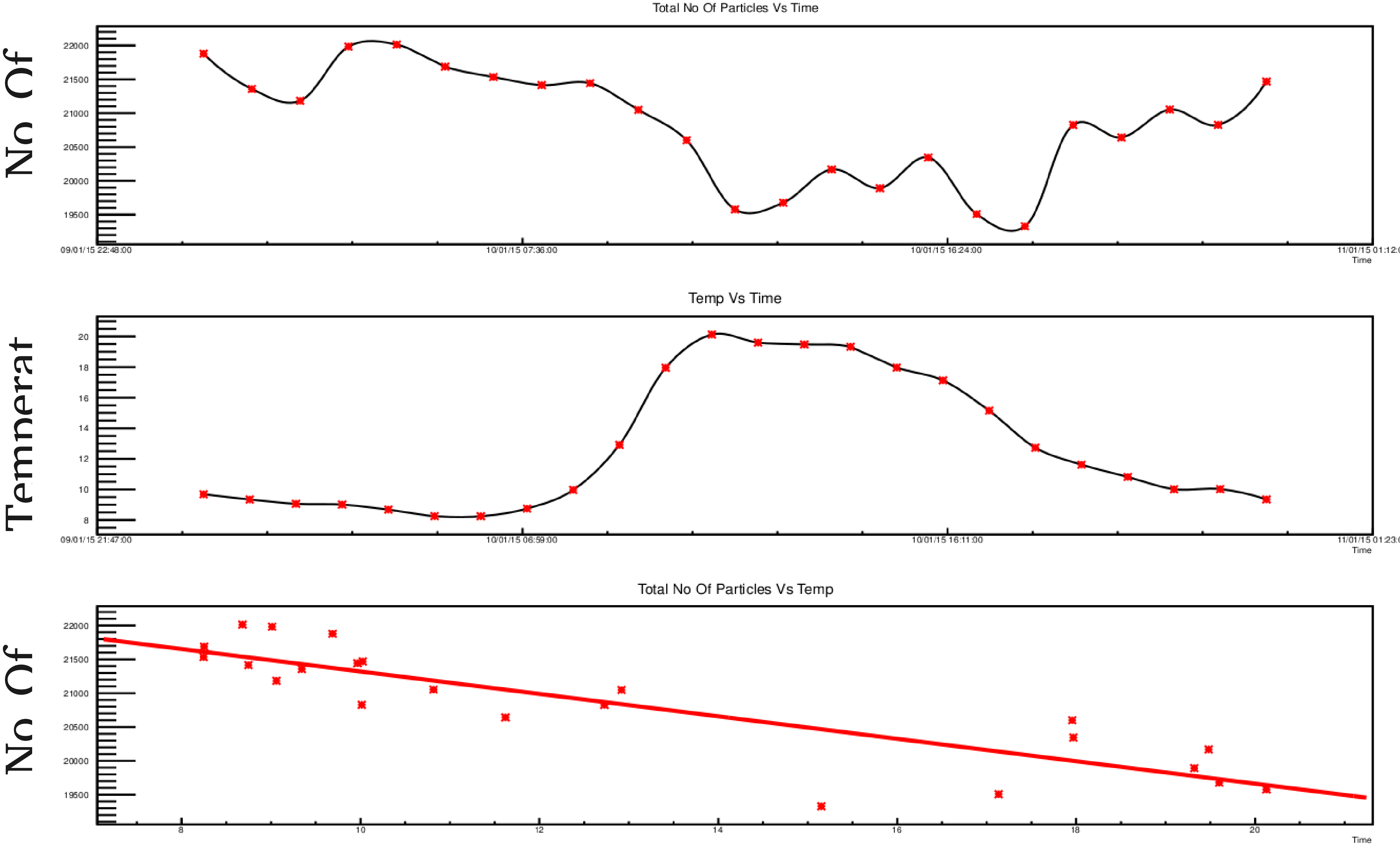
Fiber Detector

10 Jan, 2015

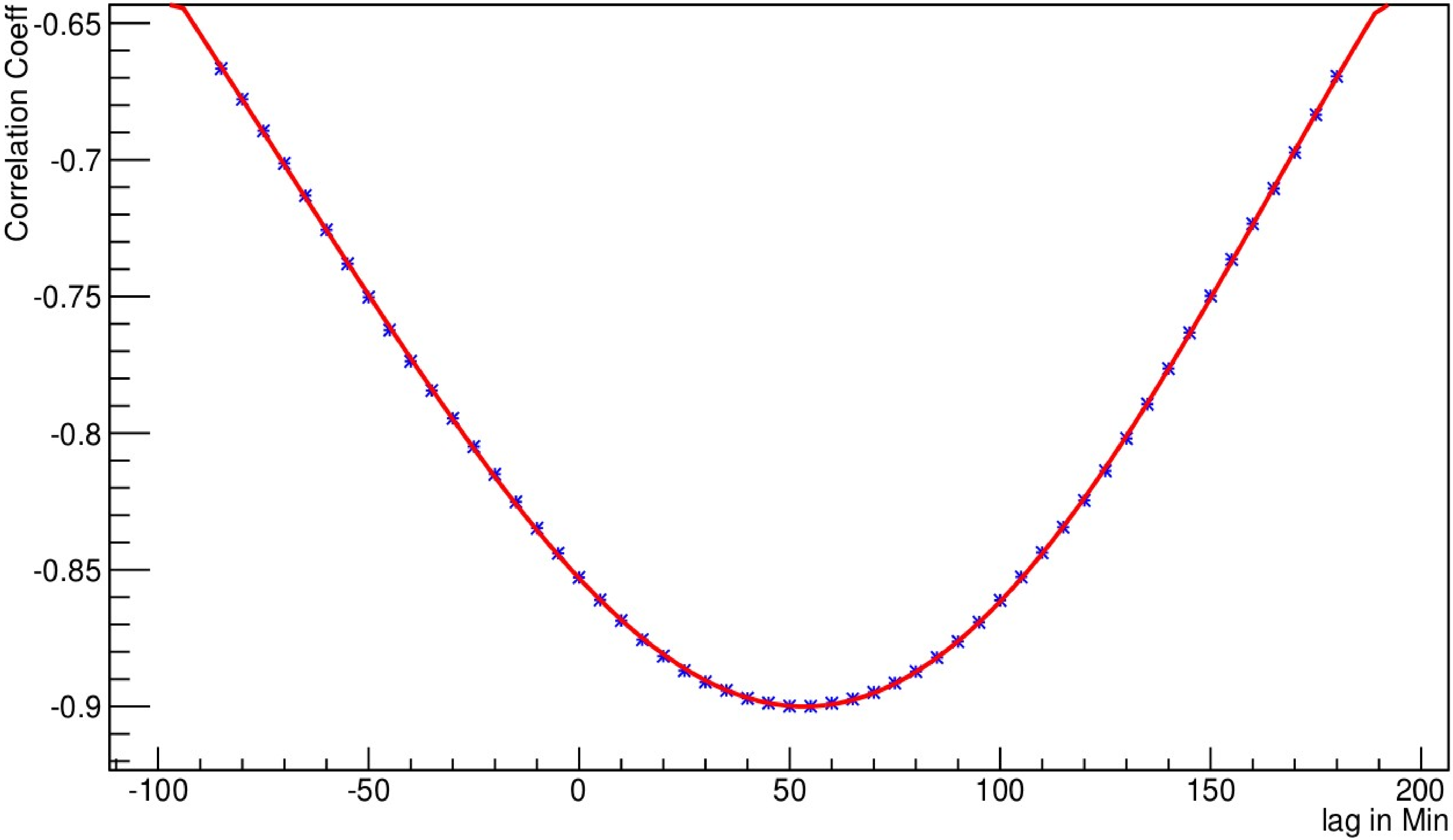


Temperature

Correlation Coefficient = -0.86

Fiber Detector (D#1)

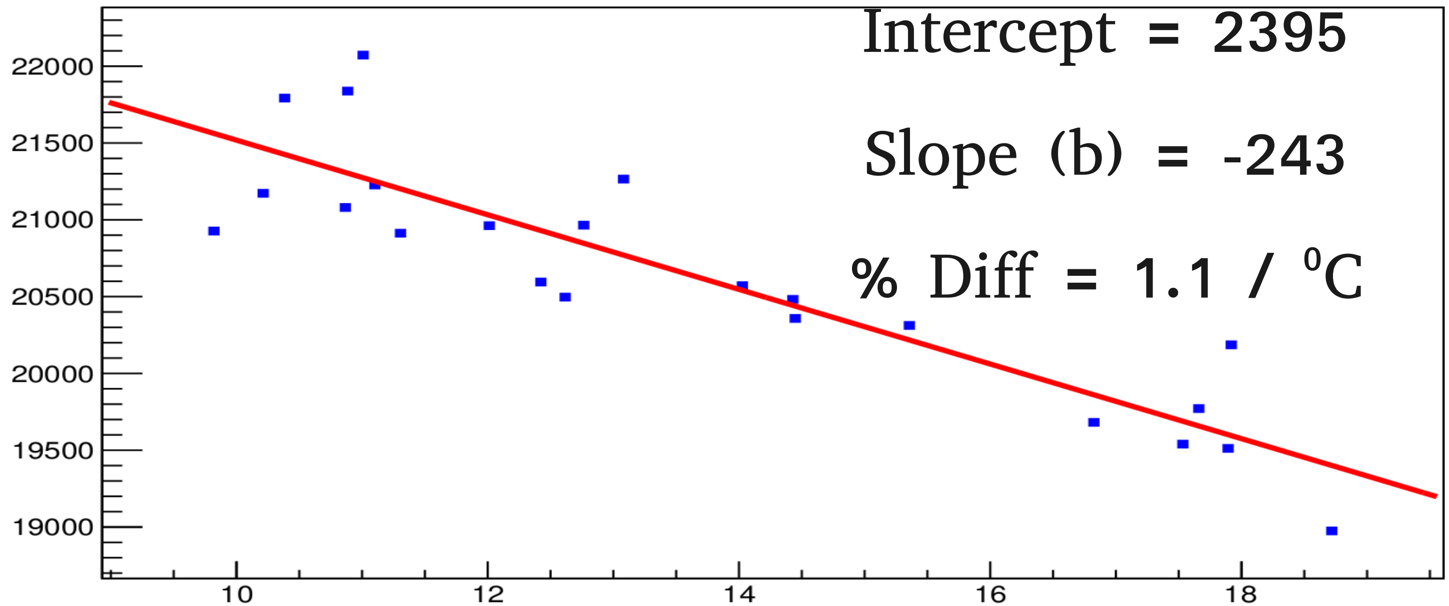
10 Jan, 2015



Max Correlation Coefficient **= -0.90** at ~**55** Min

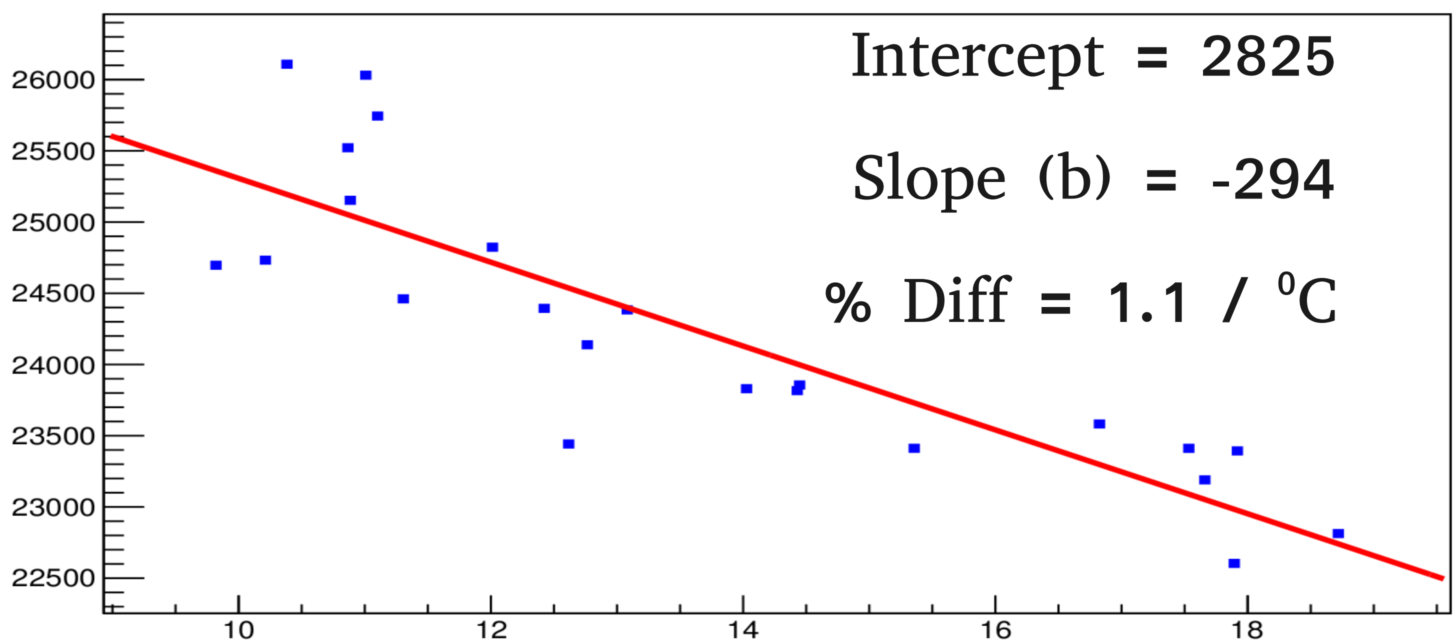
30 Jan,2015

Fiber Detector

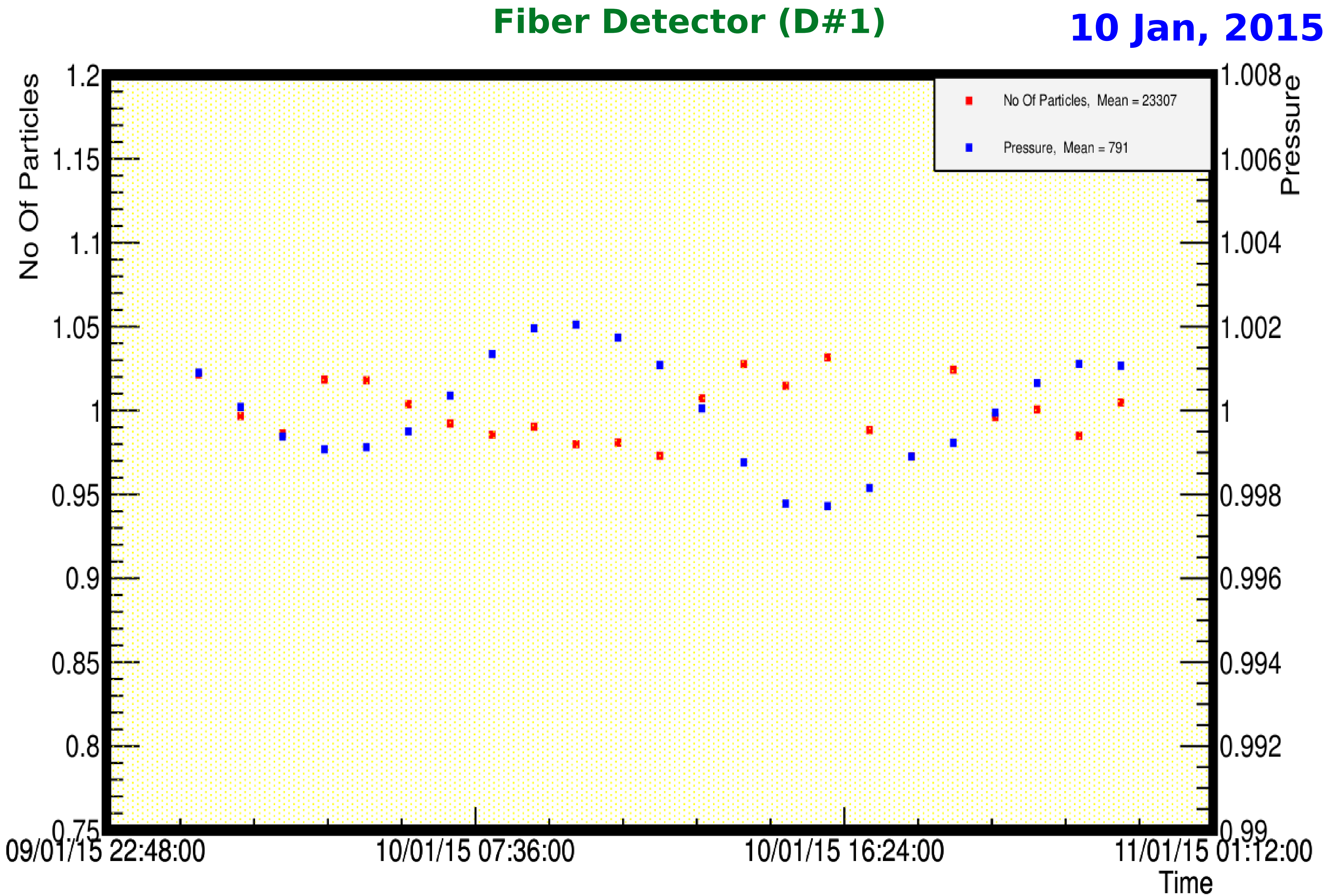


No Of Particles

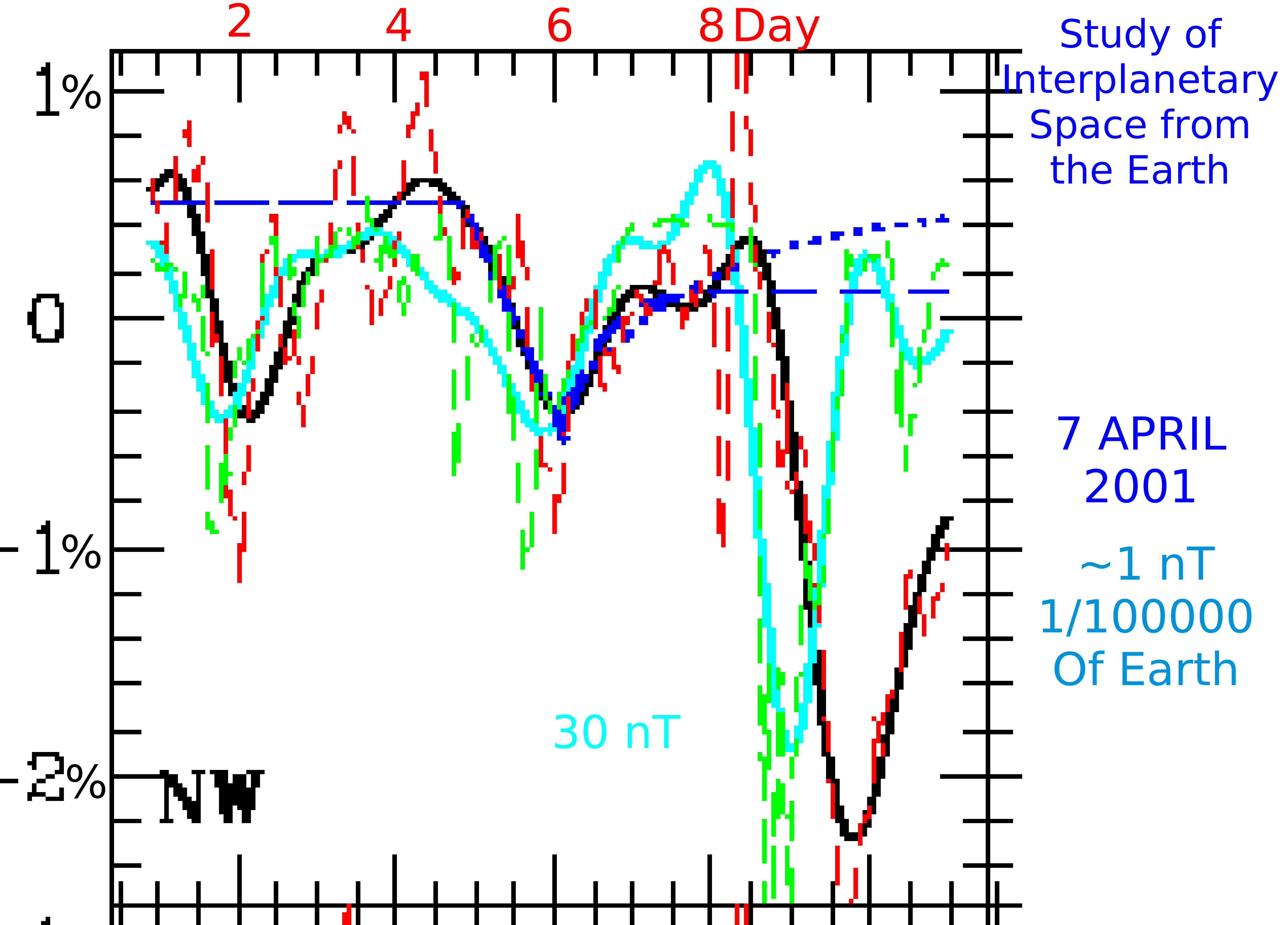
Cone Detector



Temperature

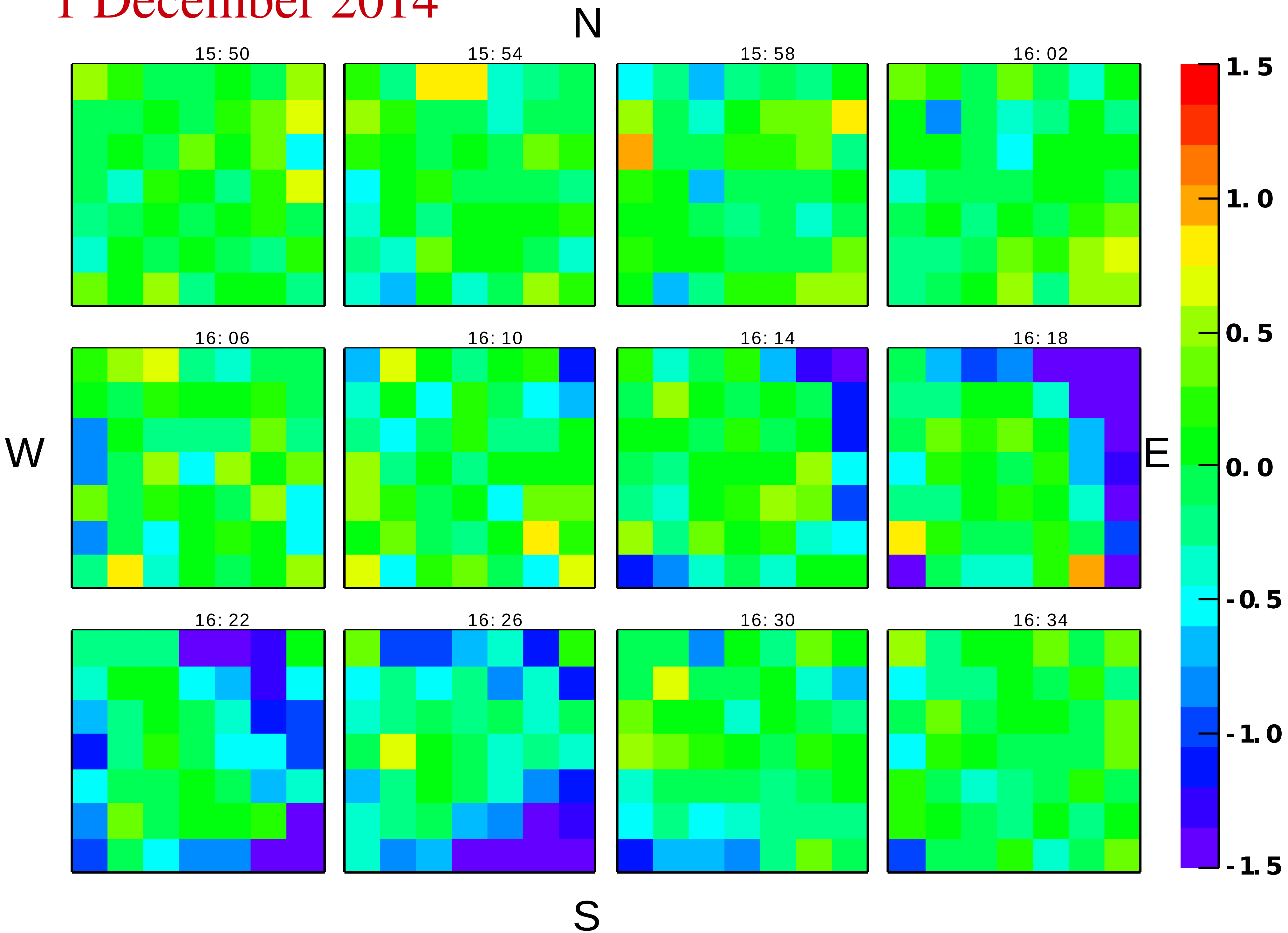


Fiber Detector (D#1)
10 Jan, 2015
No Of Particles
Pressure
No Of Particles, Mean = 23307
Pressure, Mean = 791
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
09/01/15 22:48:00
10/01/15 07:36:00
10/01/15 16:24:00
11/01/15 01:12:00
Time

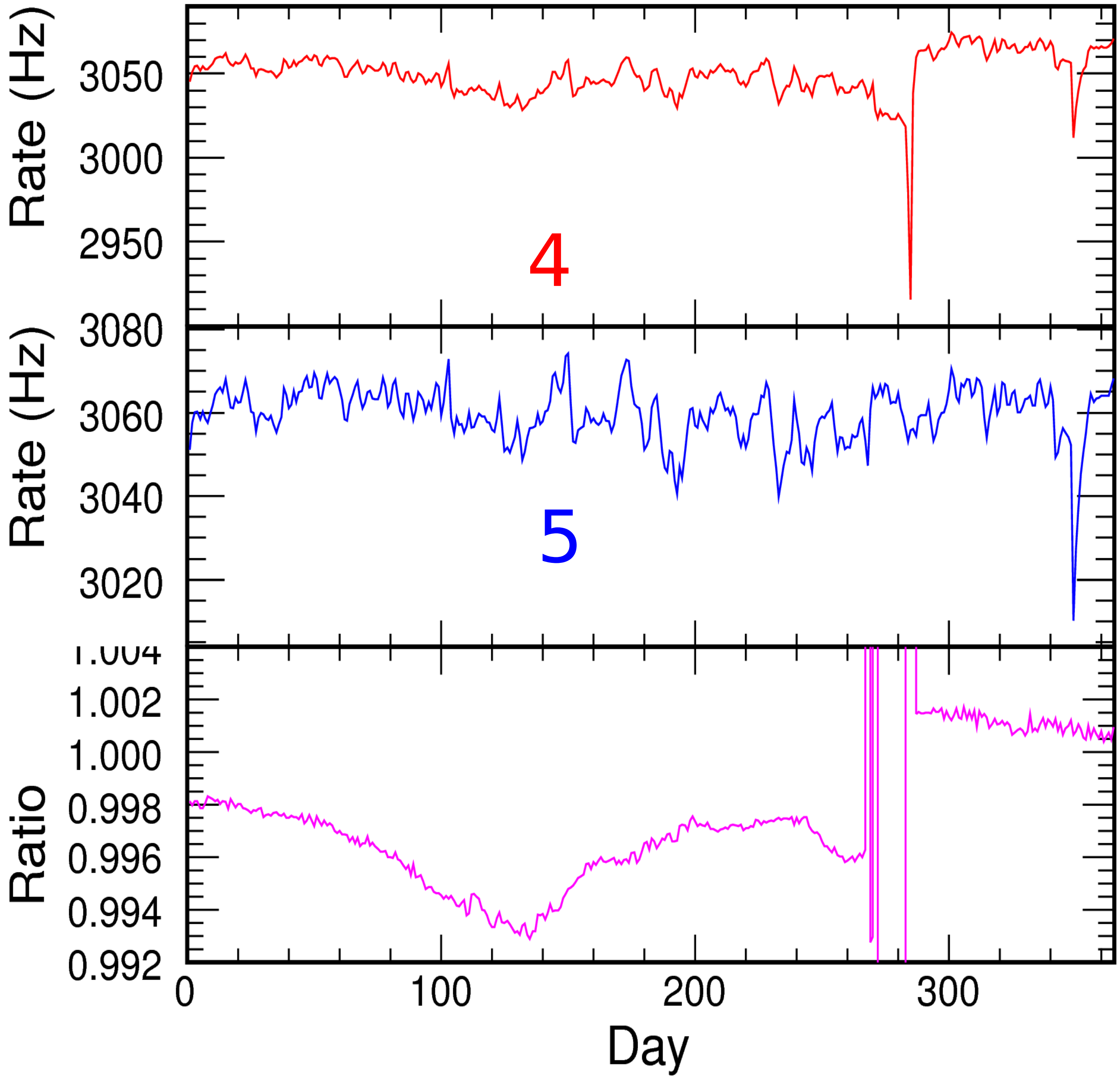


2
4
6
8
Day
1%
0
- 1%
- 2%
NW
30 nT
Study of
Interplanetary
Space from
the Earth
7 APRIL
2001
~1 nT
1/100000
Of Earth

1 December 2014



Daily muon rates in 2 of 16 modules (2006)



1%

Modeling Efficiency Variation

$$R(t) = R_0\, \varepsilon(t)$$

$$\varepsilon(t) = 1 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4$$

$$R_{ij}(t_k) = \frac{R_{0i}(t_k)(1 + a_{1i} t_k + a_{2i} t_k^{\,2} + a_{3i} t_k^{\,3} + a_{4i} t_k^{\,4})}{R_{0j}(t_k)(1 + a_{1j} t_k + a_{2j} t_k^{\,2} + a_{3j} t_k^{\,3} + a_{4j} t_k^{\,4})}$$

taking log and using approximation **$\ln(1+x) \simeq x$**

$$\ln[R_{ij}(t_k)] = \ln(R_{0i}) - \ln(R_{0j}) + (a_{1i} - a_{1j})\, t_k + (a_{2i} - a_{2j})\, t_k^{\,2} + (a_{3i} - a_{3j})\, t_k^{\,3} + (a_{4i} - a_{4j})\, t_k^{\,4}$$

120 x 100 days = 12000 linear equations
solved to get 80 coefficients for 16 module

$$Ga = b$$

Solved using SVD technique

Coefficients obtained from the least square fit using SVD

module	a_0	a_1	a_2	a_3	a_4
1	7.1E-03	1.3E-04	2.8E-03	-6.1E-03	3.5E-03
2	3.5E-03	-8.1E-04	7.5E-04	-7.3E-04	-1.7E-04
3	3.6E-03	9.3E-04	-7.2E-03	9.3E-03	-4.9E-03
4	8.4E-03	-3.5E-03	9.0E-03	-1.4E-02	5.6E-03
5	1.0E-02	-3.3E-03	1.4E-02	-2.0E-02	1.0E-02
6	5.2E-03	1.2E-03	-8.6E-03	1.5E-02	-8.1E-03
7	5.9E-03	-1.7E-03	5.5E-03	-9.3E-03	4.7E-03
8	-7.9E-03	-2.1E-03	-8.5E-04	4.2E-03	-3.5E-03
9	-5.7E-02	3.0E-03	-1.3E-03	-1.6E-03	1.7E-03
10	-4.3E-03	1.6E-03	-9.3E-04	1.8E-04	8.7E-04
11	6.1E-03	9.9E-05	8.1E-03	-1.6E-02	9.5E-03
12	-1.9E-02	1.1E-03	-2.2E-03	4.0E-03	-1.8E-03
13	9.2E-03	4.2E-04	-3.8E-03	9.3E-03	-5.7E-03
14	2.3E-02	5.5E-03	-2.5E-02	3.9E-02	-1.9E-02
15	2.1E-02	6.9E-04	-3.0E-03	5.0E-03	-2.5E-03
16	-1.5E-02	-3.2E-03	1.3E-02	-1.9E-02	8.7E-03