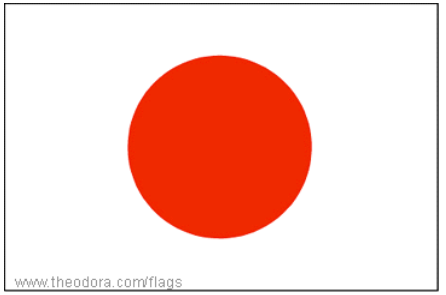
Muons studies in GRAPES-3

(Gamma Ray Astronomy at Pev EnergieS

(An India-Japan collaboration)

WAPP-2013, 17 December 2013



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

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2. Osaka City University, Osaka, Japan
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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. Kochi University, Kochi, Japan
9. Hiroshima City University, Hiroshima, Japan
10. Chubu University, Kasugai, Japan
11. Aligarh Muslim University, Aligarh, India
12. North Bengal University, Siliguri, India
13. Vishwakarma Institute of Information Technology, Pune, India

Other GRAPES-3 talks

1. Precision simulation of muon flux for GRAPES-3: Anuj Chandra

2. Cosmic ray interaction models: Shakeel Ahmad

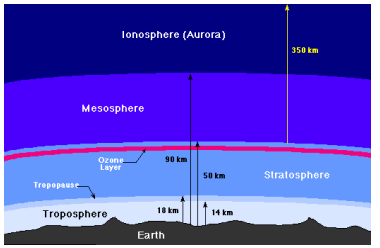
3. Development of electronics and software tools: C.S. Garde

4. Status and planned upgrade of GRAPES-3 DAQ: P. Jagadeesan

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

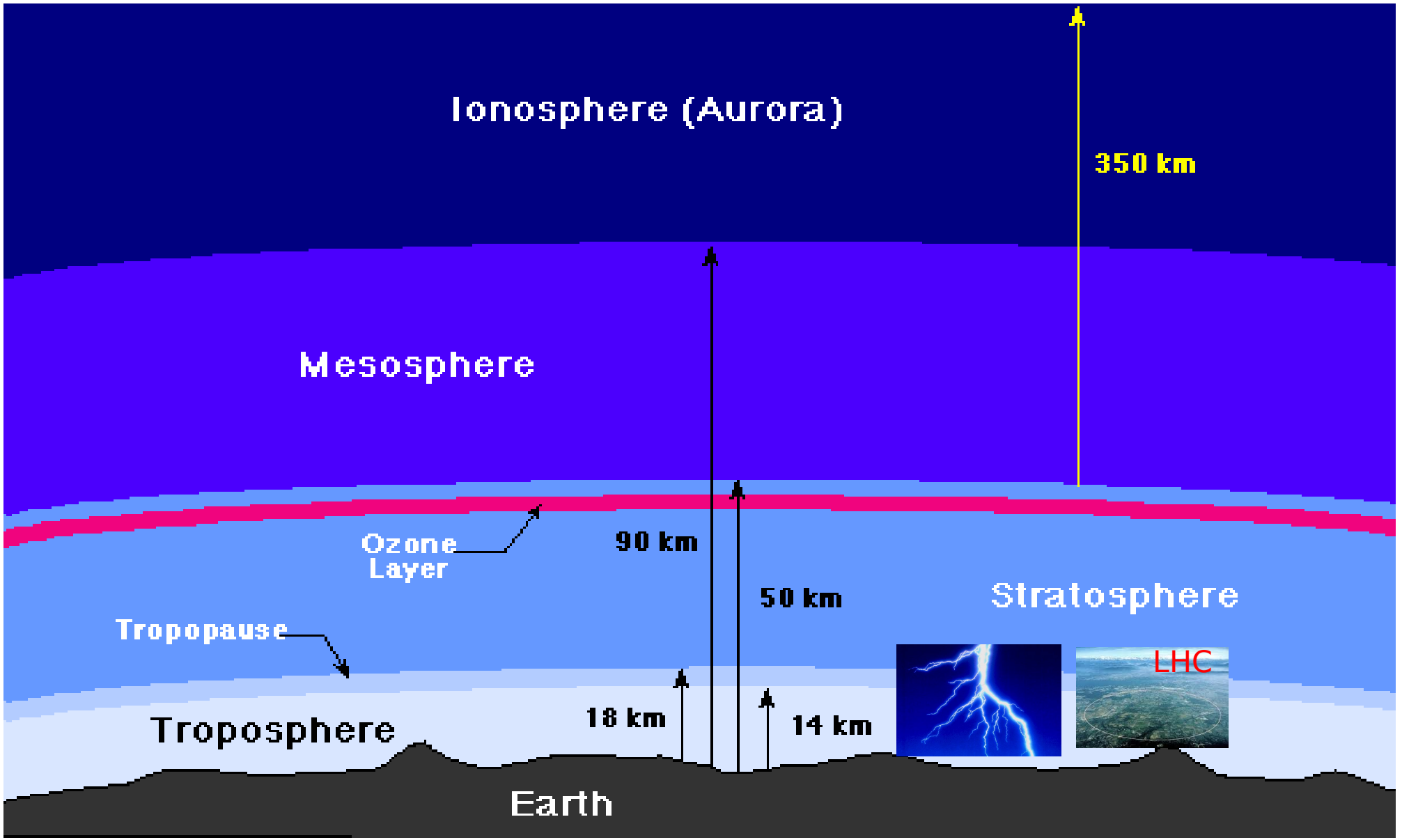
3. Galactic Cosmic Rays at " Knee "
   Energy ~1 PeV Scale ~10^{21}-10^{23} cm

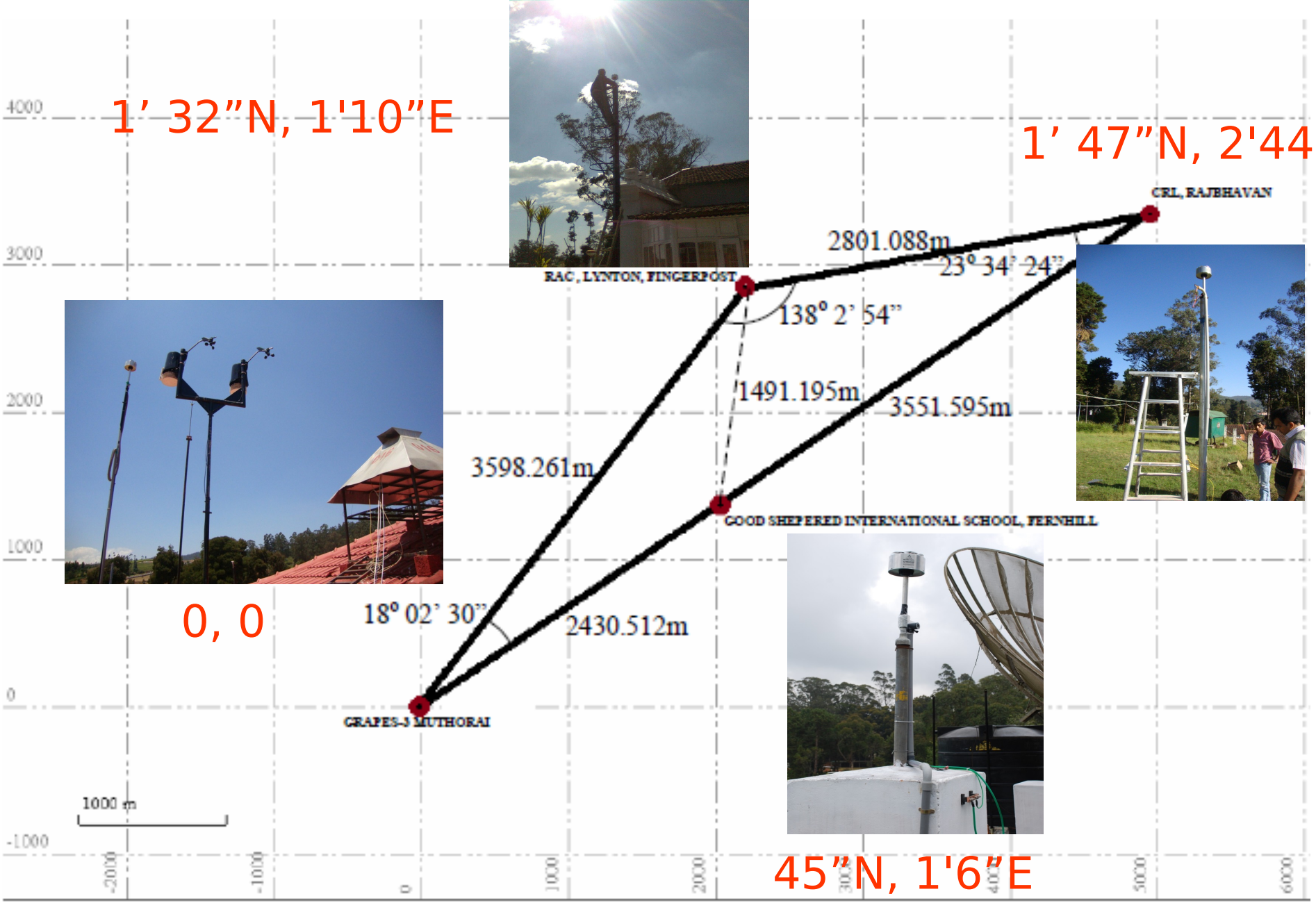
4. Diffuse multi-TeV γ-rays
   Energy ~100 EeV Scale ~10^{24}-10^{26} cm

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

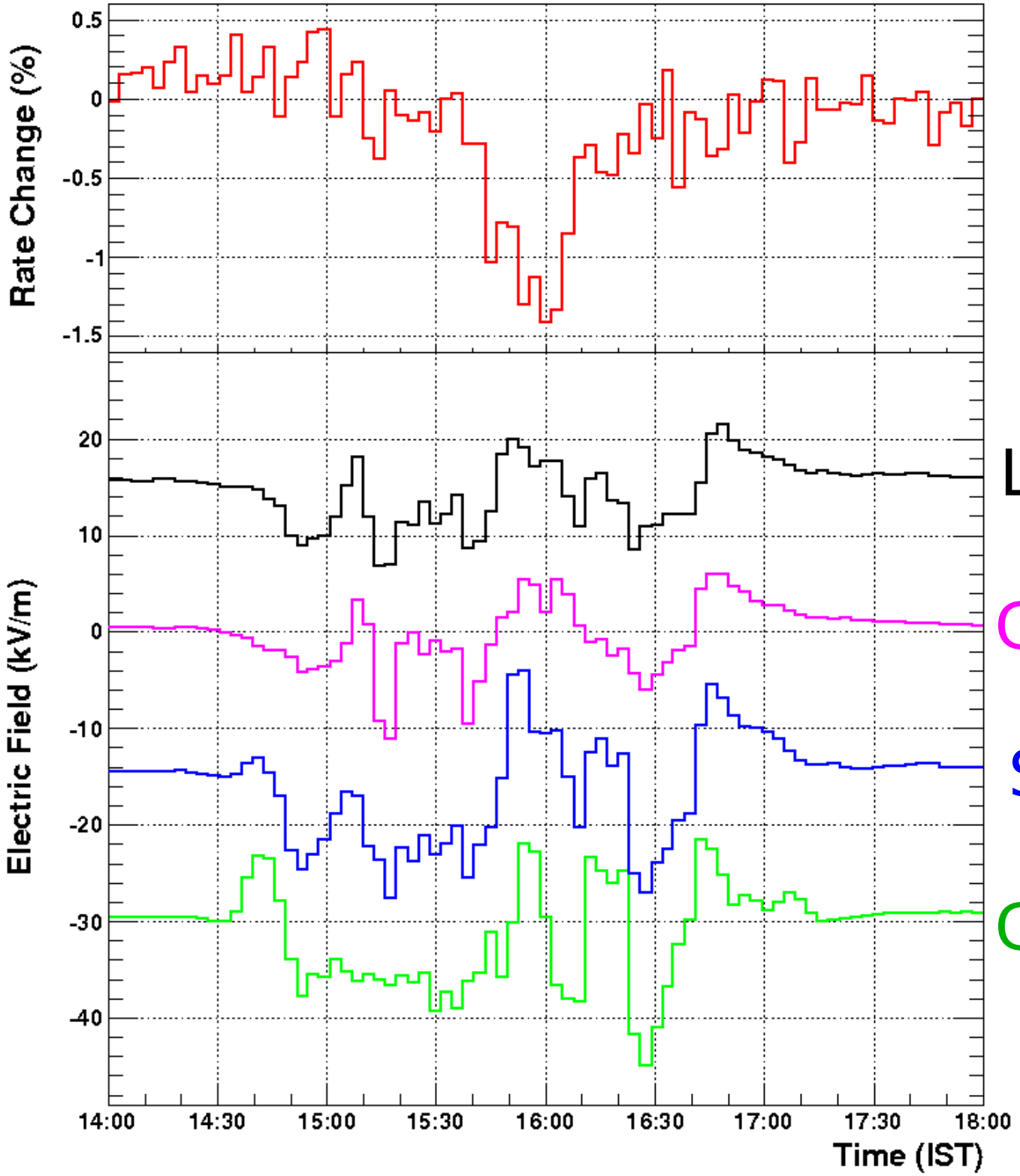
S.K. Gupta et al. Nucl. Instr. and Meth. **A 540** 311-323 (2005)
S.K. Gupta et al. Pramana **65** 273-283 (2005)
Y. Hayashi et al. Nucl. Instr. and Meth. **A 545** 643-657 (2005)

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



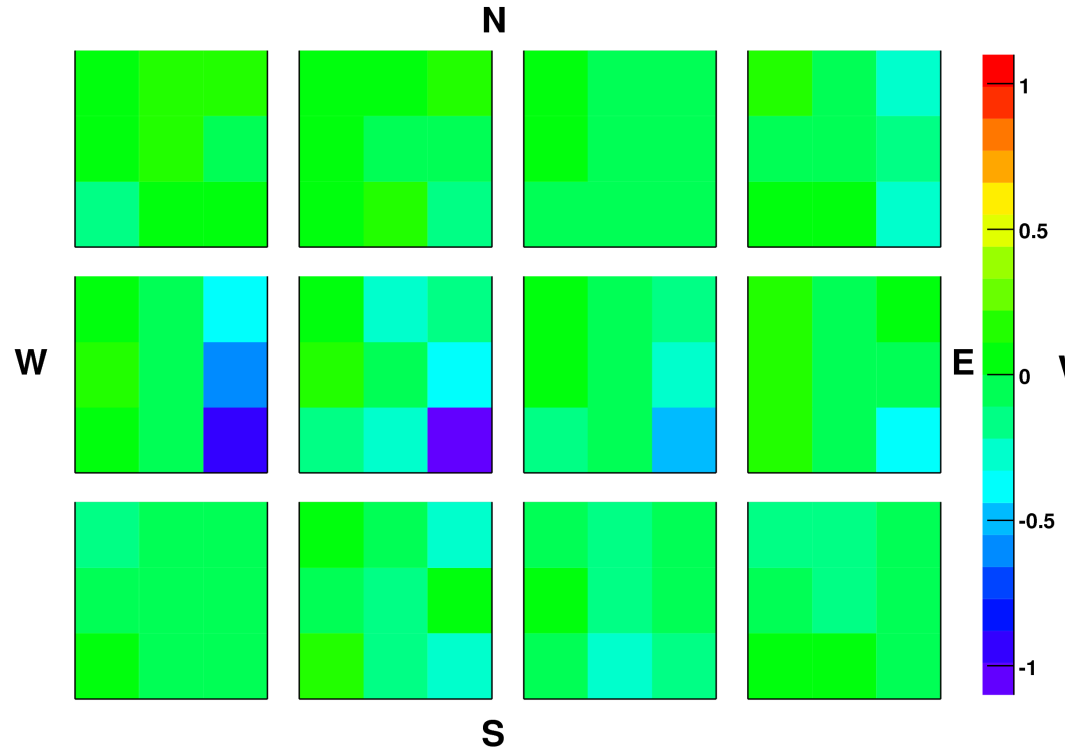


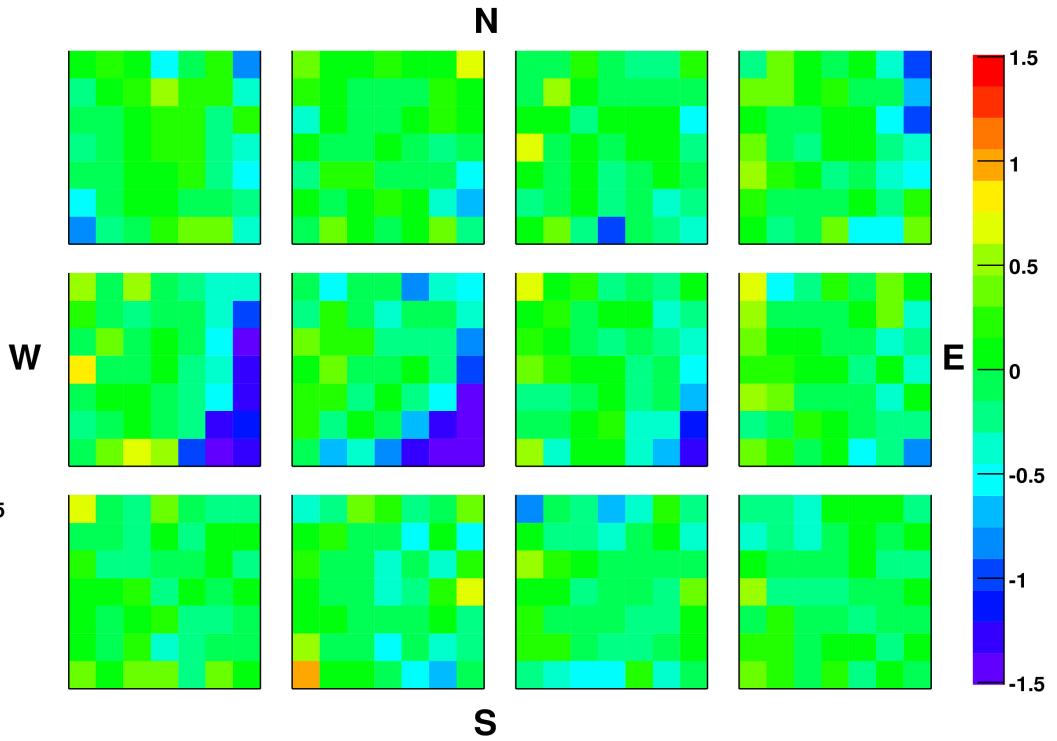
GRAPES-3 Lat. = 11° 23’ 26” N Long. = 76° 39’ 50” E

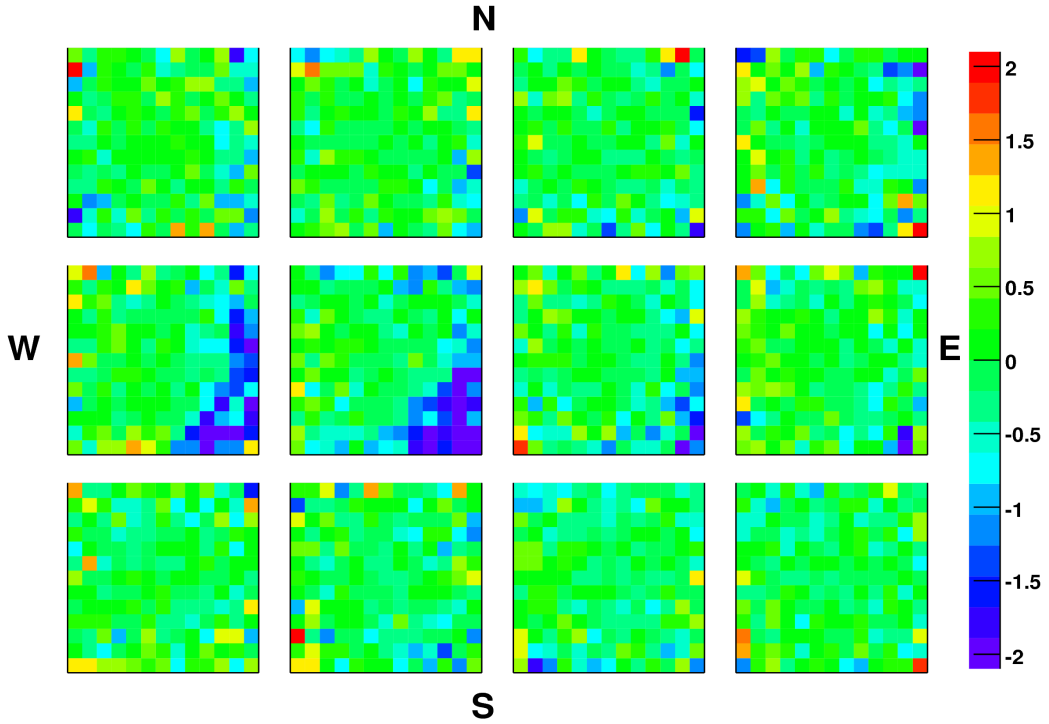


Muon rate variation on 18 April 2011

EFM data -15 kV/m





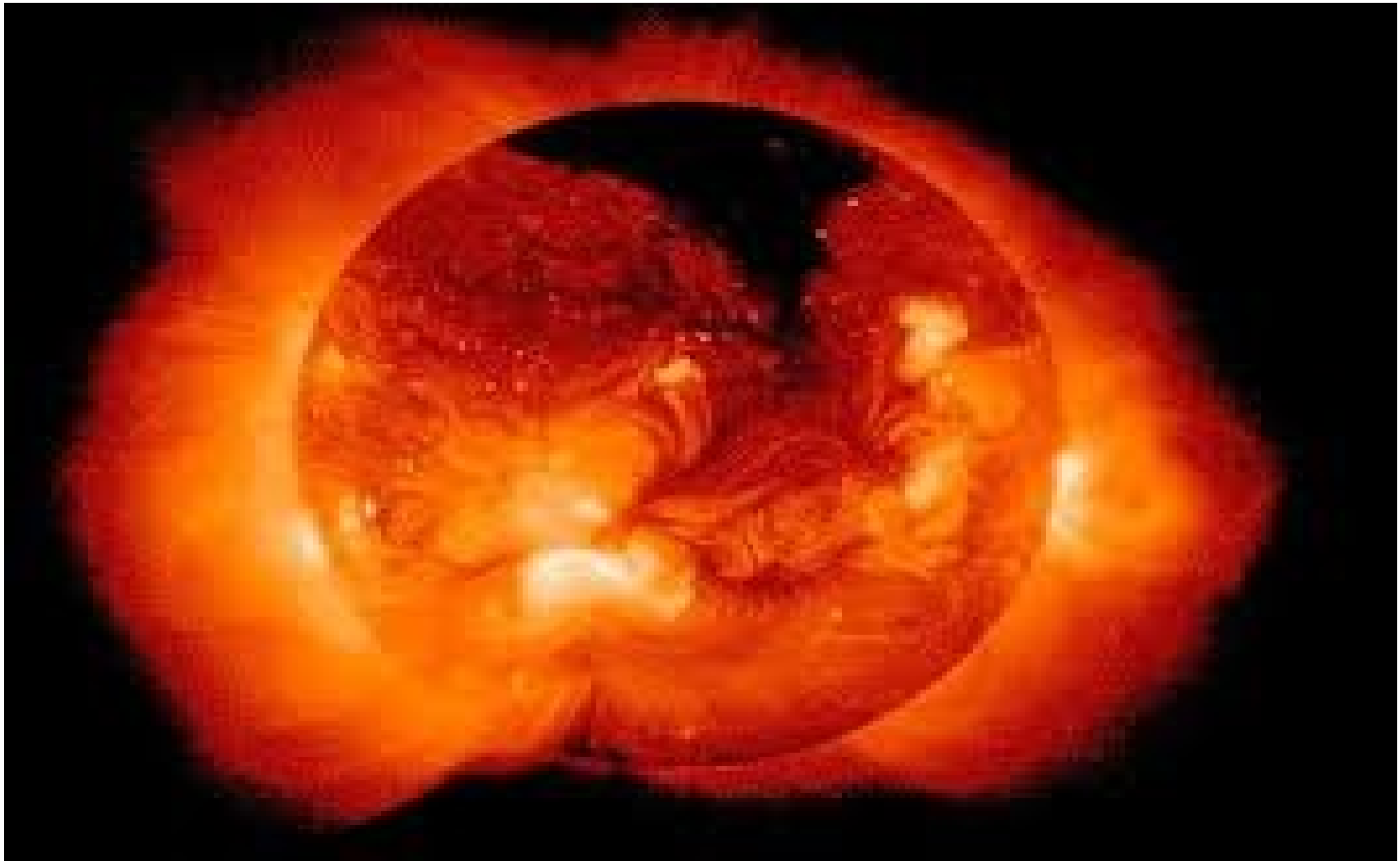


Thunderstorm 18 April 2011

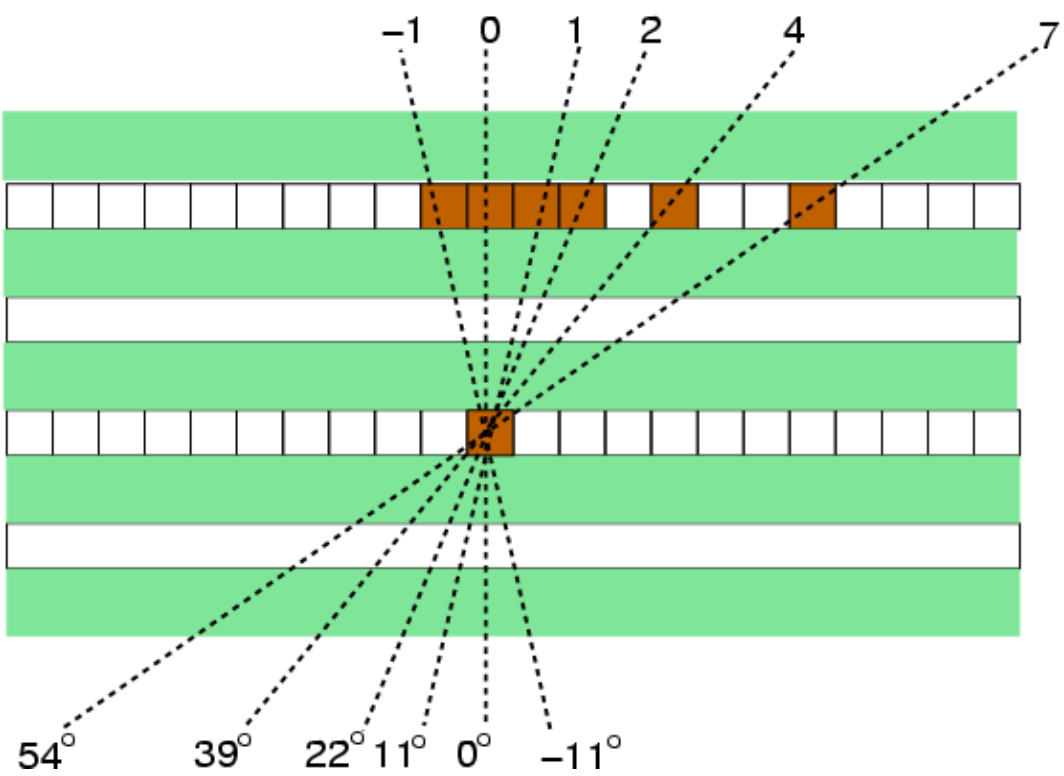
P.K. Mohanty et al.
B. Hariharan
CORSIKA (70K)
Electric field incl.

Solar flares, Coronal Mass Ejections

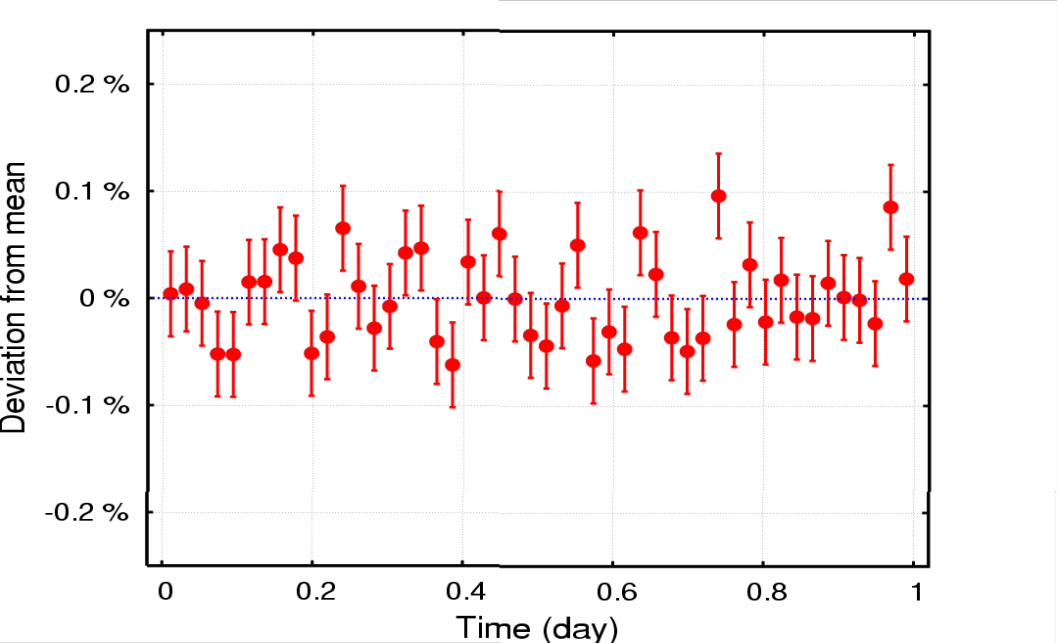
Energy ~10 GeV Scale ~10^{11}-10^{13} cm

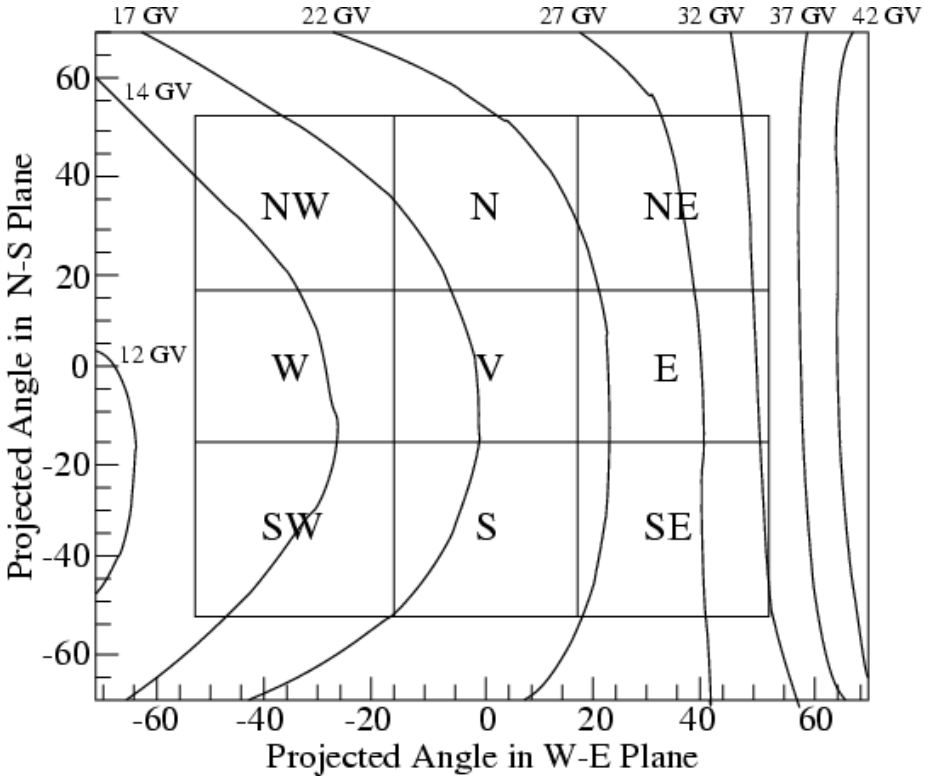


Solar phenomena

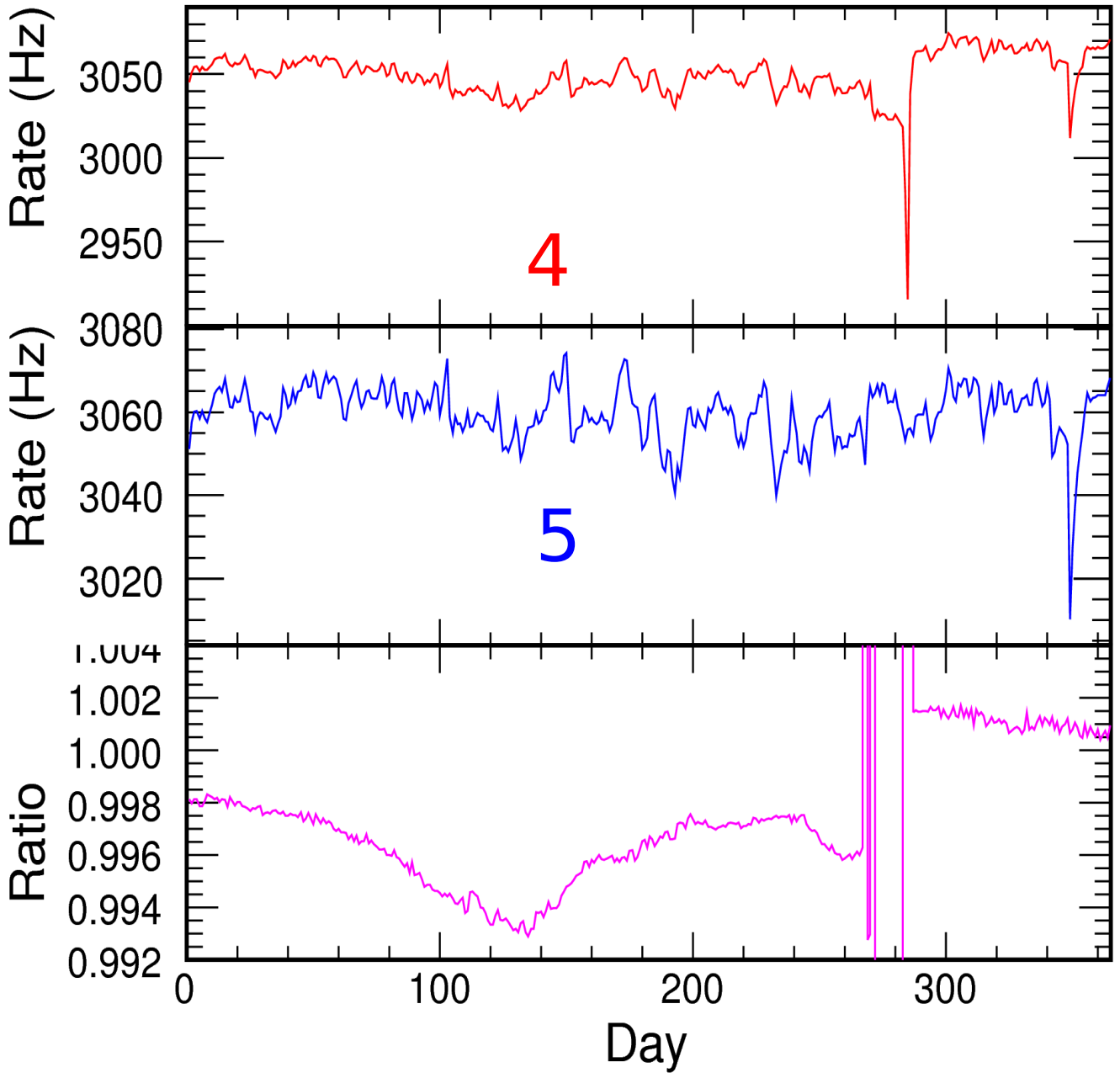


Energy ~10 GeV
Scale ~10^{11}-10^{13} cm





Daily muon rates in 2 of 16 modules (2006)



1%

Modelling of efficiency variation

$$R(t) = a(1 + bt + ct^2 + dt^3 + et^4) \tag{3}$$

The ratio between two modules i and j, for time t_k, can be written as

$$r_{ij}(t_k) = \frac{a_i(1 + b_i t_k + c_i t_k^2 + d_i t_k^3 + e_i t_k^4)}{a_j(1 + b_j t_k + c_j t_k^2 + d_j t_k^3 + e_j t_k^4)} \tag{4}$$

Expanding the denominator of Eq.2 by Taylor series and retaining only the linear terms of the coefficients and with little rearrangement, Eq.2 can be written as

$$r_{ij}(t_k) = \frac{a_i}{a_j}[1 + (b_i - b_j)t_k + (c_i - c_j)t_k^2 + (d_i - d_j)t_k^3 + (e_i - e_j)t_k^4] \tag{5}$$

By taking natural log of Eq.2 and using the aproximation ln(1+x)=x, we will get

$$ln[r_{ij}(t_k)] = ln(a_i) - ln(a_j) + (b_i - b_j)t_k + (c_i - c_j)t_k^2 + (d_i - d_j)t_k^3 + (e_i - e_j)t_k^4 \tag{6}$$

Redefining some of the terms we get

$$f_{ij}(t_k) = a_i - a_j + (b_i - b_j)t_k + (c_i - c_j)t_k^2 + (d_i - d_j)t_k^3 + (e_i - e_j)t_k^4 \tag{7}$$

For different combinations, we will write explicitly

$$a_1 - a_2 + (b_1 - b_2)t_1 + (c_1 - c_2)t_1^2 + (d_1 - d_2)t_1^3 + (e_1 - e_2)t_1^4 = f_{1,2}(t_1) \tag{8}$$

$$a_1 - a_3 + (b_1 - b_3)t_1 + (c_1 - c_3)t_1^2 + (d_1 - d_3)t_1^3 + (e_1 - e_3)t_1^4 = f_{1,3}(t_1) \tag{9}$$

The total number of such linear equation is 120x100=12000 for 100 days of data.

The above equations can be put in the form

$$\begin{bmatrix} 1 & t_1 & t_1^2 & t_1^3 & t_1^4 & -1 & -t_1 & -t_1^2 & -t_1^3 & -t_1^4 \\ 0 & 0 & 0 & 0 & \cdots & & & & & \\ 1 & t_1 & t_1^2 & t_1^3 & t_1^4 & 0 & 0 & 0 & 0 & 0 \\ -1 & -t_1 & -t_1^2 & -t_1^3 & -t_1^4 & \cdots & & & & \\ 1 & t_1 & t_1^2 & t_1^3 & t_1^4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \cdots & & & & & \end{bmatrix} \begin{bmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ a_2 \\ b_2 \\ c_2 \\ d_2 \\ e_2 \\ a_16 \\ b_16 \\ c_16 \\ d_16 \\ e_16 \\ \vdots \end{bmatrix} = \begin{bmatrix} f_{1,2}(t_1) \\ f_{1,3}(t_1) \\ f_{15,16}(t_1) \\ \vdots \\ \vdots \\ \vdots \end{bmatrix}$$

or in matrix notation

Matrix G dimension 12000 x 80

$$Ga = b \tag{11}$$

The actual number of parameters is 80, but the number of indepedent parameters is 75. The total number of equations is 120000 much larger than the number of parameters. This is also over determined system. In such cases, the singular value decompsition (SVD) method is known to give best solutions. Using SVD the above matrix has been solved ??. In SVD, the matrix G can be decomposed as

$$G = U\Sigma V^T \tag{12}$$

where U and V are orthogonal matrices and Σ =diag(σ1, σ1,.....,σn) is the diagonal matrix.

Fit parameters

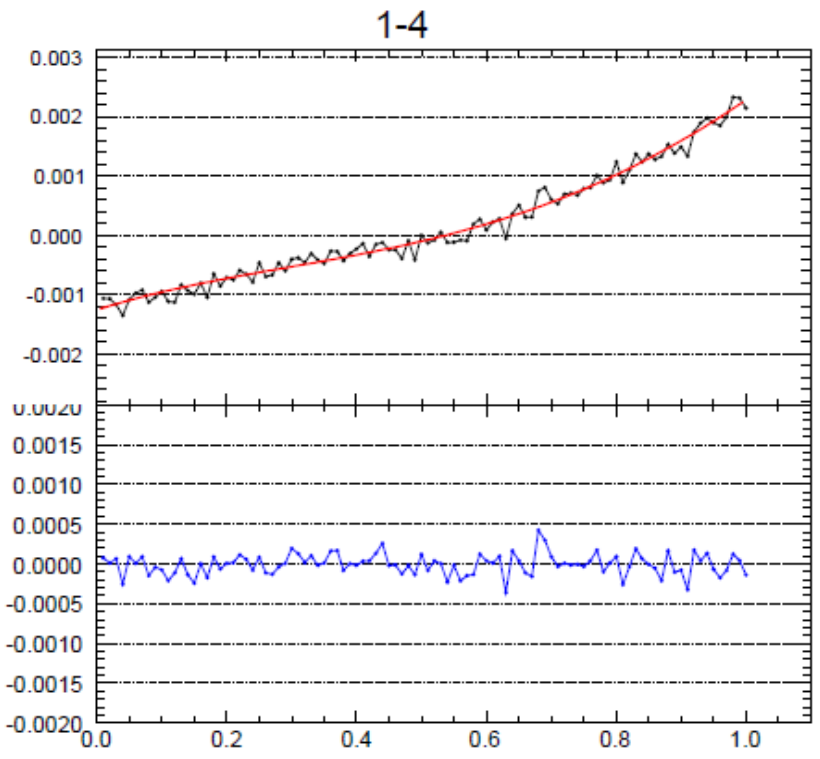
Table 1

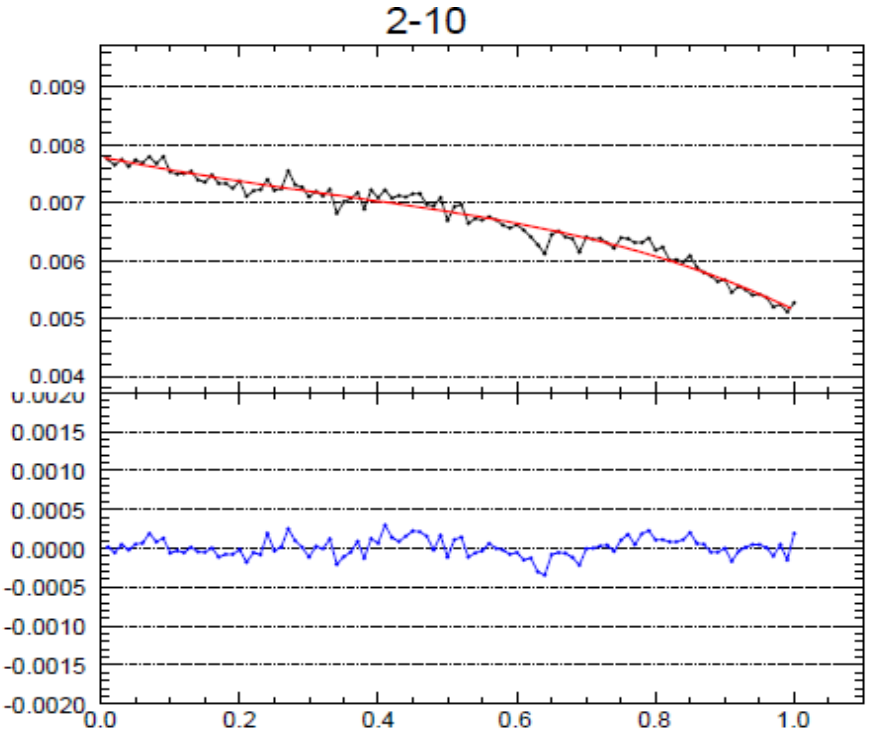
Fit parameters

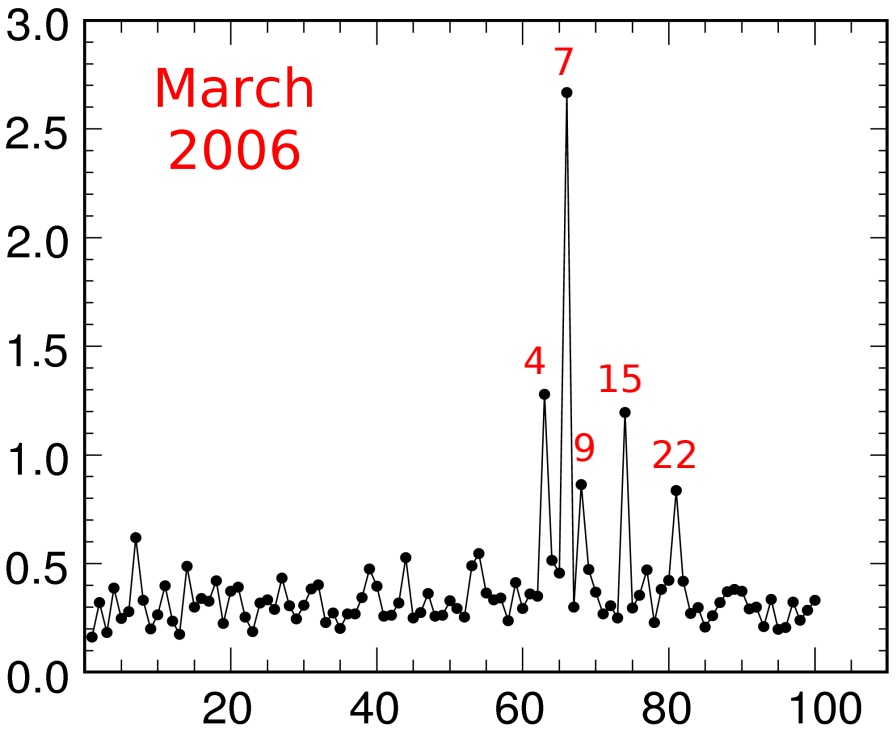
mod	a	b	c	d	e
1	7.139E-03	1.321E-04	2.796E-03	-6.144E-03	3.487E-03
2	3.514E-03	-8.112E-04	7.492E-04	-7.340E-04	-1.711E-04
3	3.591E-03	9.290E-04	-7.156E-03	9.258E-03	-3.978E-03
4	8.407E-03	-3.498E-03	8.952E-03	-1.433E-02	5.586E-03
5	1.027E-02	-3.305E-03	1.371E-02	-2.032E-02	1.034E-02
6	5.171E-03	1.177E-03	-8.624E-03	1.542E-02	-8.063E-03
7	5.872E-03	-1.670E-03	5.504E-03	-9.267E-03	4.674E-03
8	-7.884E-03	-2.068E-03	-8.482E-04	4.223E-03	-3.519E-03
9	-5.709E-02	2.973E-03	-1.273E-03	-1.587E-03	1.688E-03
10	-4.276E-03	1.554E-03	-9.312E-04	1.826E-04	8.678E-04
11	6.077E-03	9.948E-05	8.106E-03	-1.562E-02	9.533E-03
12	-1.896E-02	1.095E-03	-2.213E-03	3.976E-03	-1.827E-03
13	9.173E-03	4.170E-04	-3.770E-03	9.294E-03	-5.683E-03
14	2.337E-02	5.504E-03	-2.490E-02	3.925E-02	-1.911E-02
15	2.062E-02	6.880E-04	-3.019E-03	5.040E-03	-2.475E-03
16	-1.510E-02	-3.215E-03	1.292E-02	-1.863E-02	8.654E-03

The solution is obained using the iversion of matrix G and vector b

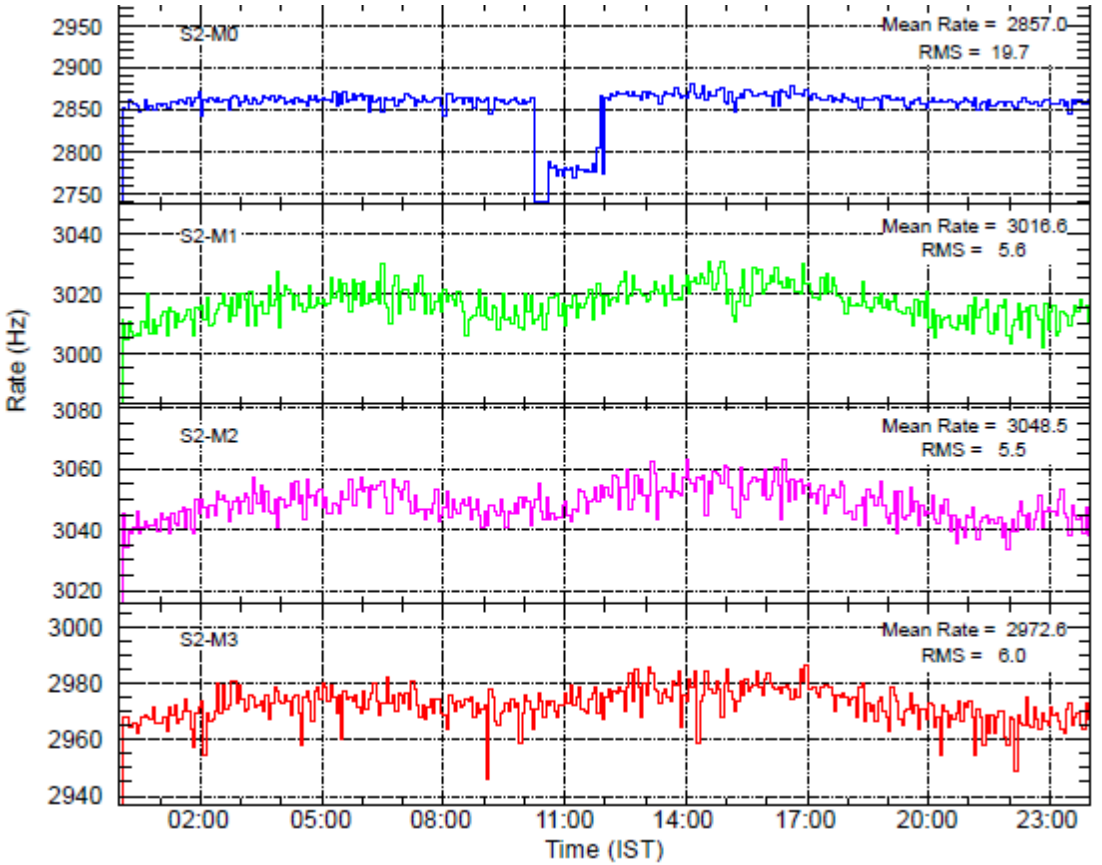
$$G^{-1}b = (V\Sigma^{1}U^{T})b \tag{13}$$


1-4
0.003
0.002
0.001
0.000
-0.001
-0.002
0.0015
0.0010
0.0005
0.0000
-0.0005
-0.0010
-0.0015
-0.0020
0.0
0.2
0.4
0.6
0.8
1.0


2-10
0.009
0.008
0.007
0.006
0.005
0.004
0.0015
0.0010
0.0005
0.0000
-0.0005
-0.0010
-0.0015
-0.0020
0.0
0.2
0.4
0.6
0.8
1.0


March
2006
7
4
15
9
22
3.0
2.5
2.0
1.5
1.0
0.5
0.0
20
40
60
80
100

Timing capacitor



Saturday, March 04, 2006

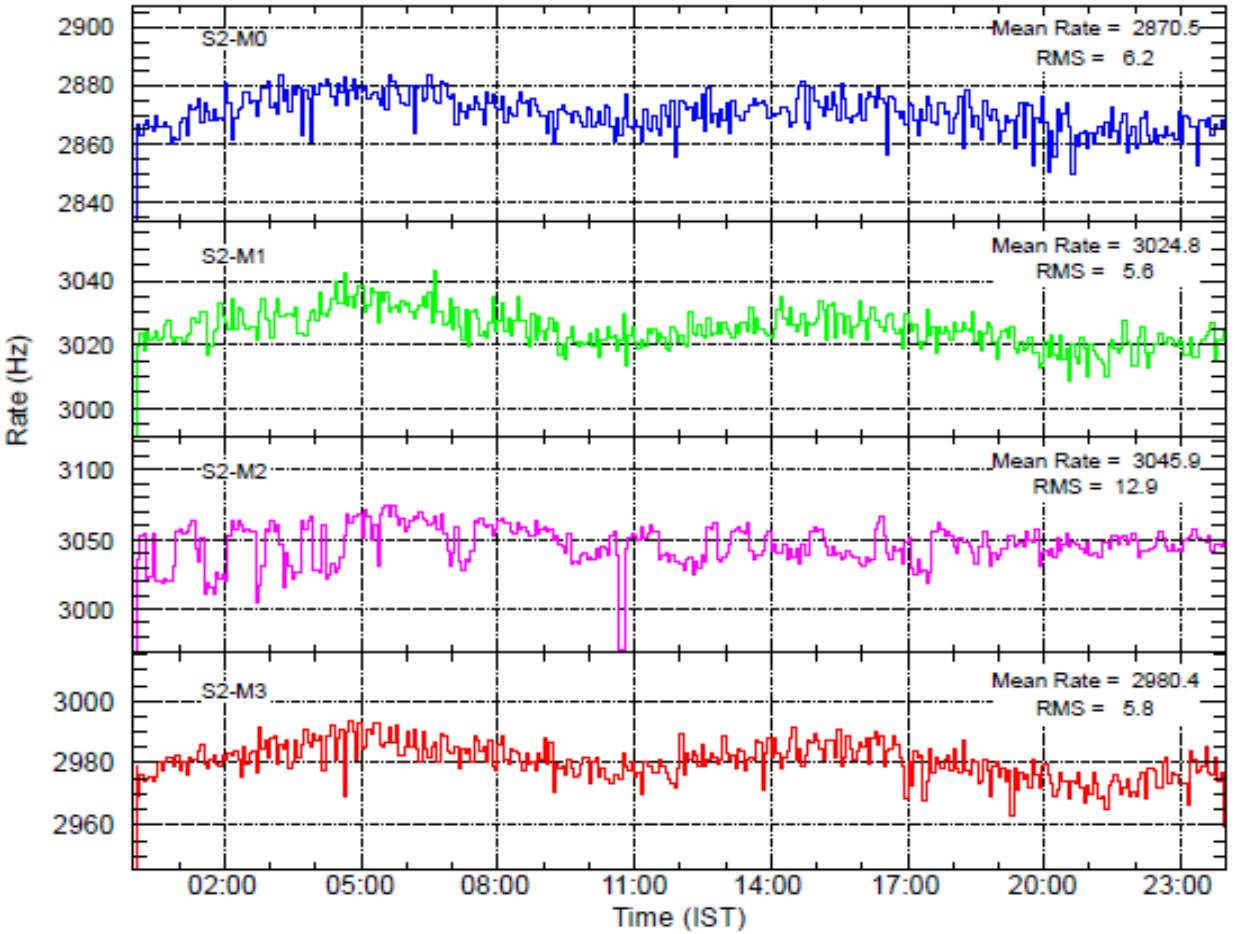
EHT details
Mu_1 - 2932V
Mu_3 - 2730V
Mu_3 Humidity -39%

While checking Mudtsum of Mu2 we found that Mu2-0-3-Box1 rate was almost zero. Same problem happened last month 22nd feb for box 3. So we are suspecting some loose contact problem wiring was done in GPP area in RAM card where the BOX rate output taken. Re-soldering the wired point in RAM card we remove the this card ~10:14Hrs and after soldering the points we put back the card ~10:36Hrs. But the problem remaining same. After that ~12:00hrs we removed LATCH3 IC (71083) where box rate output is coming and after cleaning the base we put back the IC. After that we check the data the problem existing.

~13:50Hrs we check the signal. At that time we found that Box2 corresponding 74ls123 output timing instead 0f 8microsec it was 2microsec. We found that corresponding timing capacitor(300pf) having loose contact. ~13:55Hrs we solder the capacitor. After that we check the data it was found normal.

Manjunath/Murugapandian

Amplifier card

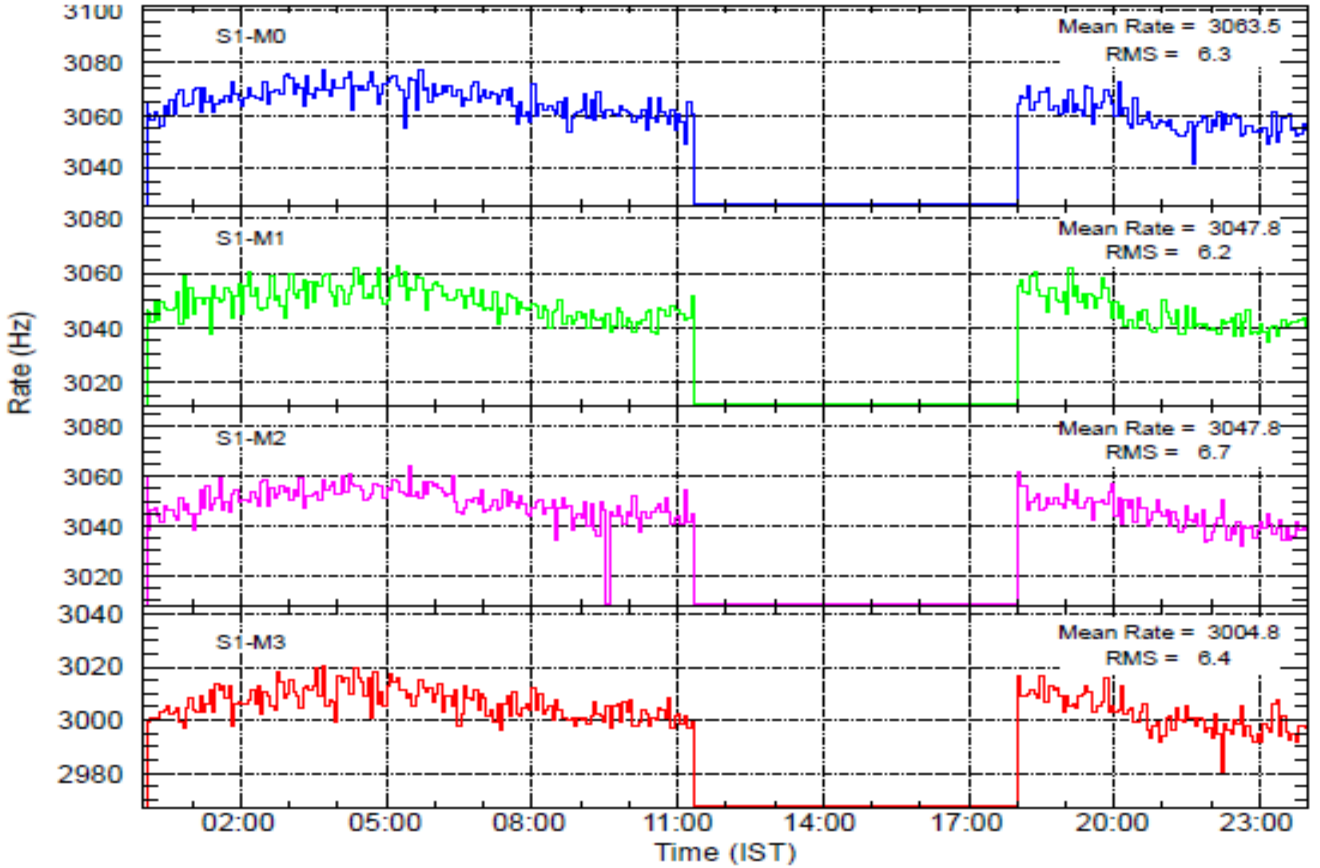


Tuesday, March 07,2006

EHT details
Mu_1 - 2932V
Mu_3 - 2730V
Mu_3 Humidity -38%

When we are checking muon data we found that Mu2-2-3-52 was found noisy. So cleaning this counter we remove the H.T. for corresponding Layer ~10:42Hrs. After cleaning the counter we apply H.T. ~10:45Hrs. After that we check the pulse. Still small
Noise was there so we swap the amplifier card ~10:47Hrs and check the pulse. It was found normal. After that we check the data, the counter started giving normal counting rate.

Manjunath/Suresh



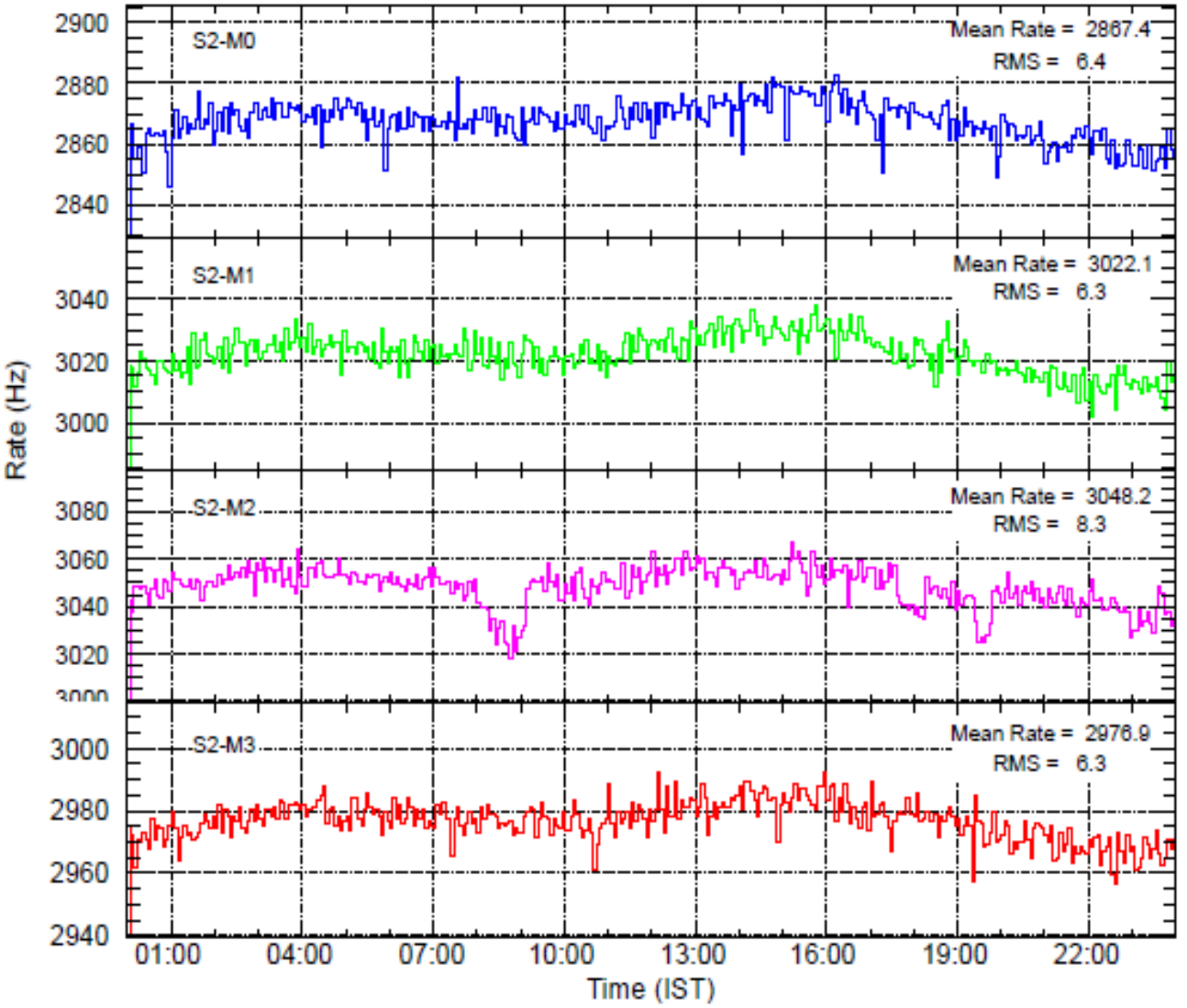
+12V
fuse blew

Thursday, March 09,2006

Today while checking station Mu-1 we found four fold and any three rate for all four modules was zero from morning ~11:20hrs. While checking we found +12V supply fuse has blown off. Replaced the fuse at ~17:59hrs with file Mu106888.y06.

Suresh /Kingston

EHT details
Mu_1 - 2932V
Mu_3 - 2730V
Mu_3 Humidity -38%



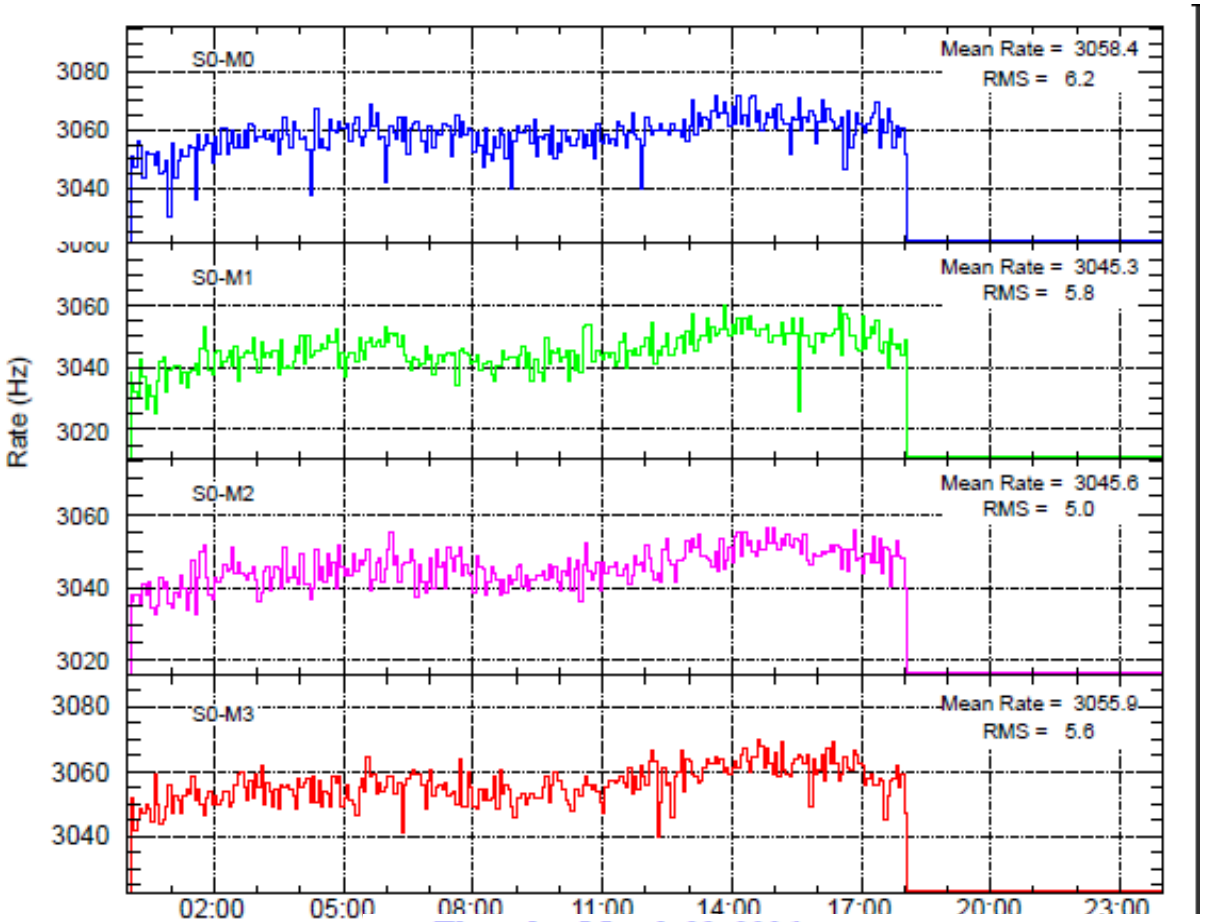
Unknown problem

Wednesday March 15, 2006

EHT details
Mu_1 - 2931V
Mu_3 - 2729V
Mu_3 Humidity -38%

Note: Mu2-2 have rate drop. No mention in the logbook. P.K. Mohanty

DAQ PC Hanging

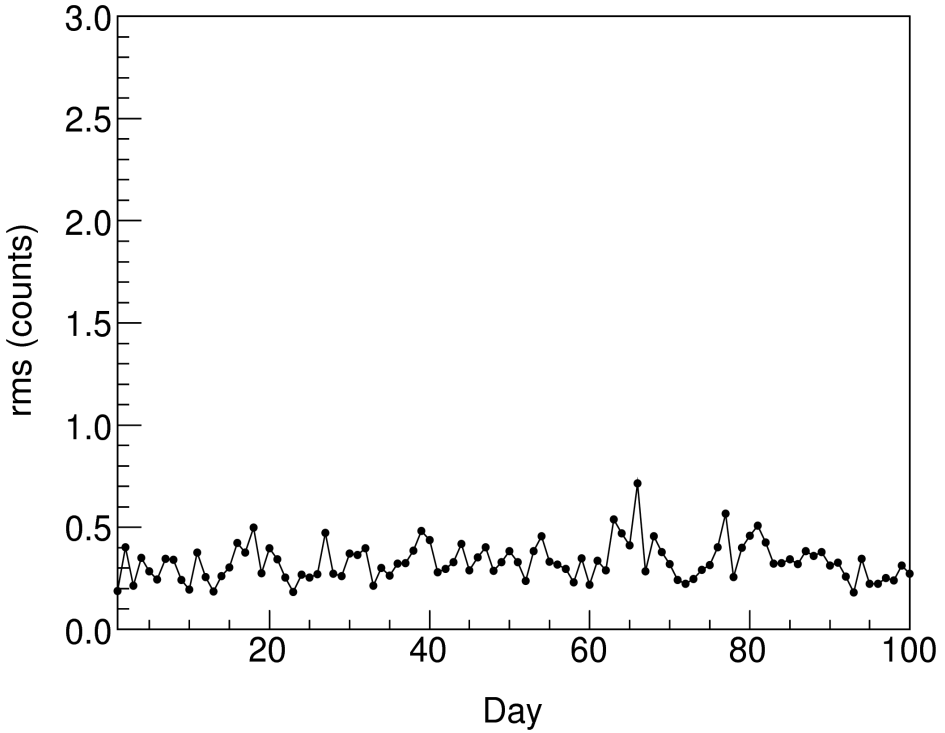


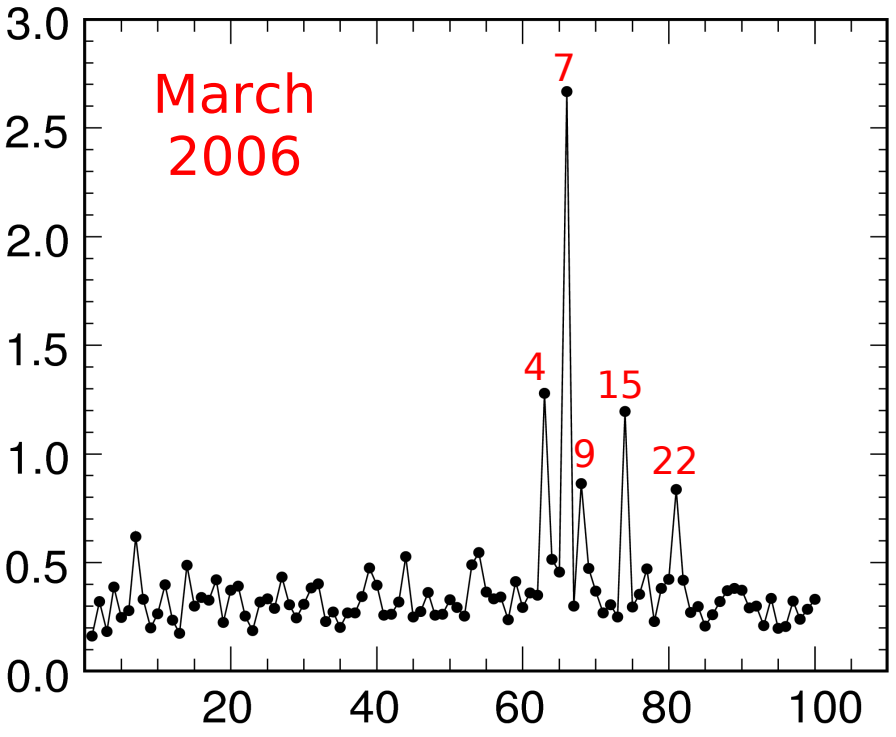
Thursday March 23, 2006

It was noticed Muang _0 PC was displaying message "An OE error has occurred and Press any key to continue or press Ctrl + Alt +Del to restart PC. So I tried to press the Ctrl + Alt + Del key to restart the PC but by mistake I did this in the keyboard which belongs to the Mumain_0 PC which is nearby. So Main_0 Run was also terminated at ~ 09:58hrs. Run was started at ~ 10:14hrs with file no Mu008240.y06 / Crm, Pwa0357.y06 after adjusting the CPU Time. In Muang_0 PC error has occurred at ~ 18:00hrs and after file did not complete. Pc was restarted and run started at ~ 10:15hrs with file No. Ma0m1737.*. File Ma0m1736.* was recovered by scandisk.

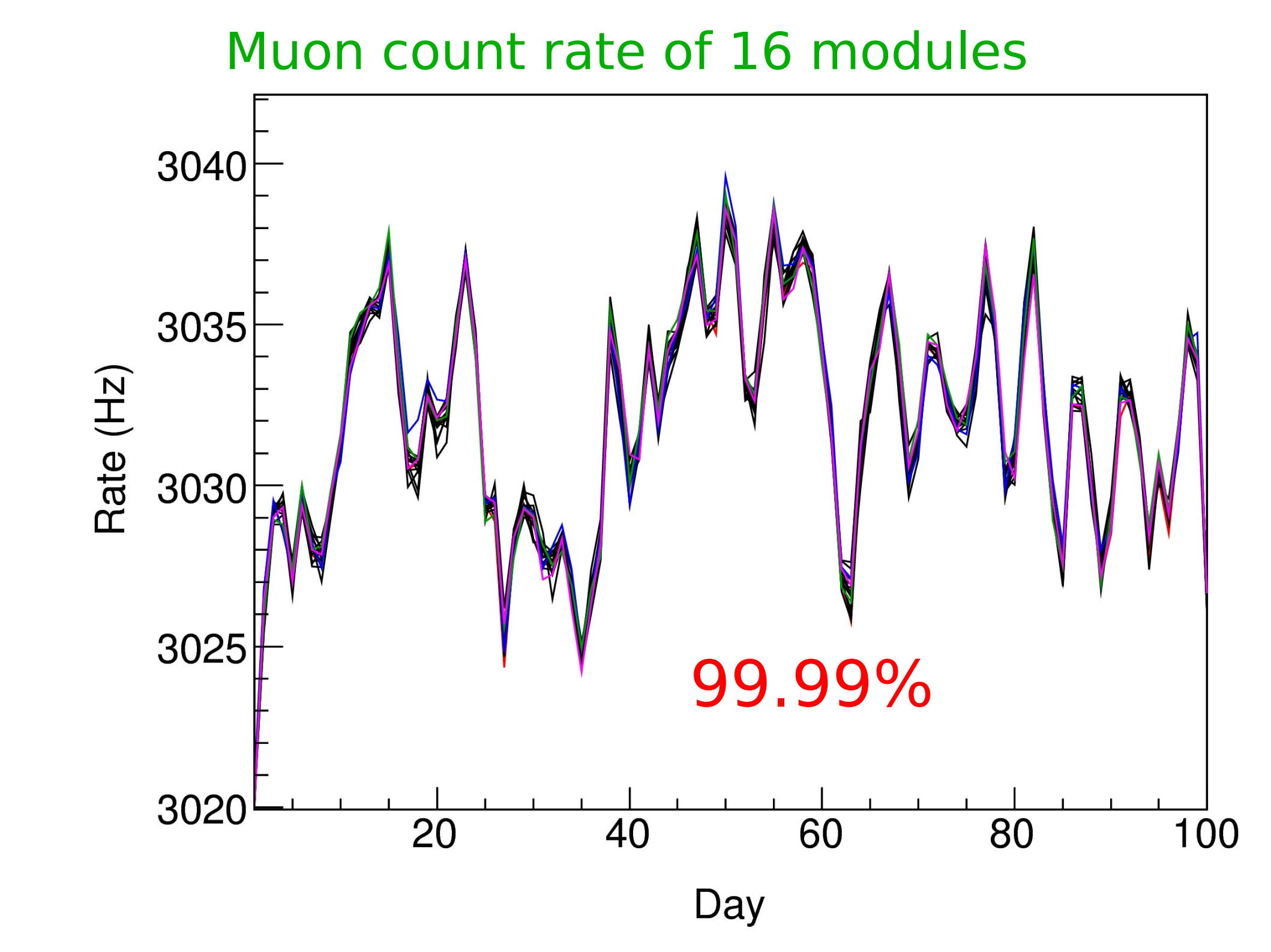
S. Murugapandian.

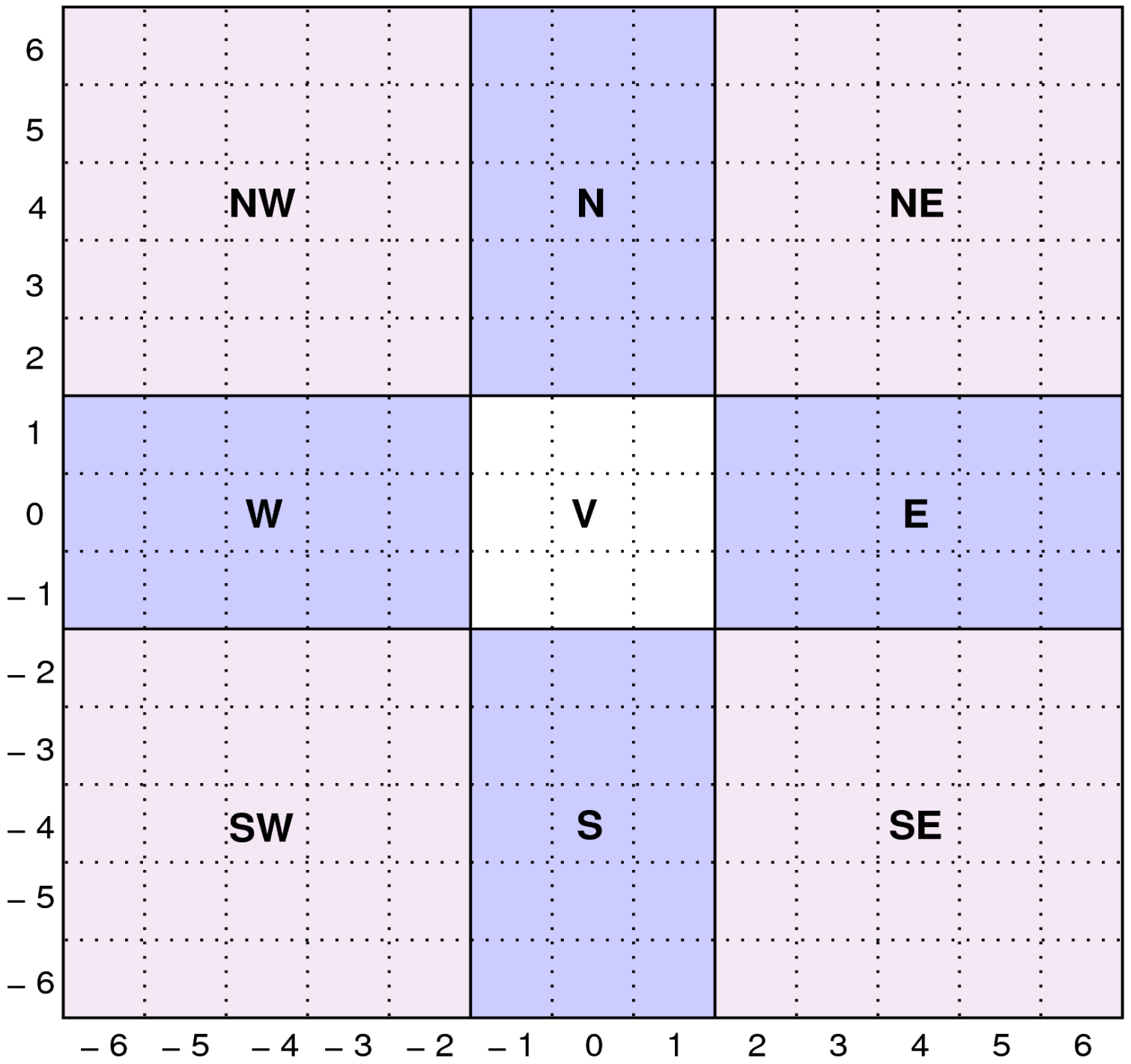
EHT details
Mu_1 - 2932V
Mu_3 - 2729V
Mu_3 Humidity -35%





RMS = 0.33 Statistical = 0.26
Mean = 3000
Fractional Error = 1 part in 10^4


Muon count rate of 16 modules
Rate (Hz)
3040
3035
3030
3025
3020
20
40
60
80
100
Day
99.99%


NW
N
NE
W
V
E
SW
S
SE
6
5
4
3
2
1
0
– 1
– 2
– 3
– 4
– 5
– 6
– 6
– 5
– 4
– 3
– 2
– 1
0
1
2
3
4
5
6

N

	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	112.0	107.0	99.0	94.4	93.8	93.9	95.9	97.5	101.3	107.3	116.6	127.6	140.8
-5	105.1	97.6	91.5	87.4	86.4	85.2	87.2	90.5	94.4	100.6	107.7	118.9	131.0
-4	96.6	89.7	83.4	80.6	78.1	78.7	80.2	83.4	88.0	94.2	102.3	112.9	122.9
-3	90.3	83.6	78.3	74.4	72.5	72.6	74.3	77.9	82.6	89.5	97.6	107.6	117.6
-2	87.5	80.5	74.3	70.1	68.3	68.3	70.1	73.4	78.4	85.6	94.0	104.6	115.9
-1	85.8	78.7	72.0	67.9	66.0	65.9	67.4	71.1	76.2	83.1	92.2	102.5	112.8
0	85.3	77.6	71.4	67.1	64.9	64.9	66.4	69.9	75.0	82.6	91.4	102.1	113.8
1	85.3	78.4	72.0	67.7	65.6	65.2	67.0	70.4	75.7	82.7	91.2	102.5	112.8
2	87.5	79.9	73.8	69.9	67.3	67.4	68.8	72.2	77.1	83.9	92.8	103.5	113.6
3	91.6	83.6	76.8	73.3	71.0	71.4	72.6	75.6	80.5	86.7	95.5	105.3	115.2
4	95.8	89.1	82.3	78.5	76.7	76.5	77.9	81.2	85.2	91.5	98.3	108.5	120.2
5	104.8	95.5	88.4	85.2	83.4	83.1	84.9	86.9	91.1	96.8	106.0	116.1	130.8
6	109.5	103.9	97.0	92.8	90.3	90.1	92.1	94.6	97.8	104.3	113.0	124.3	139.5

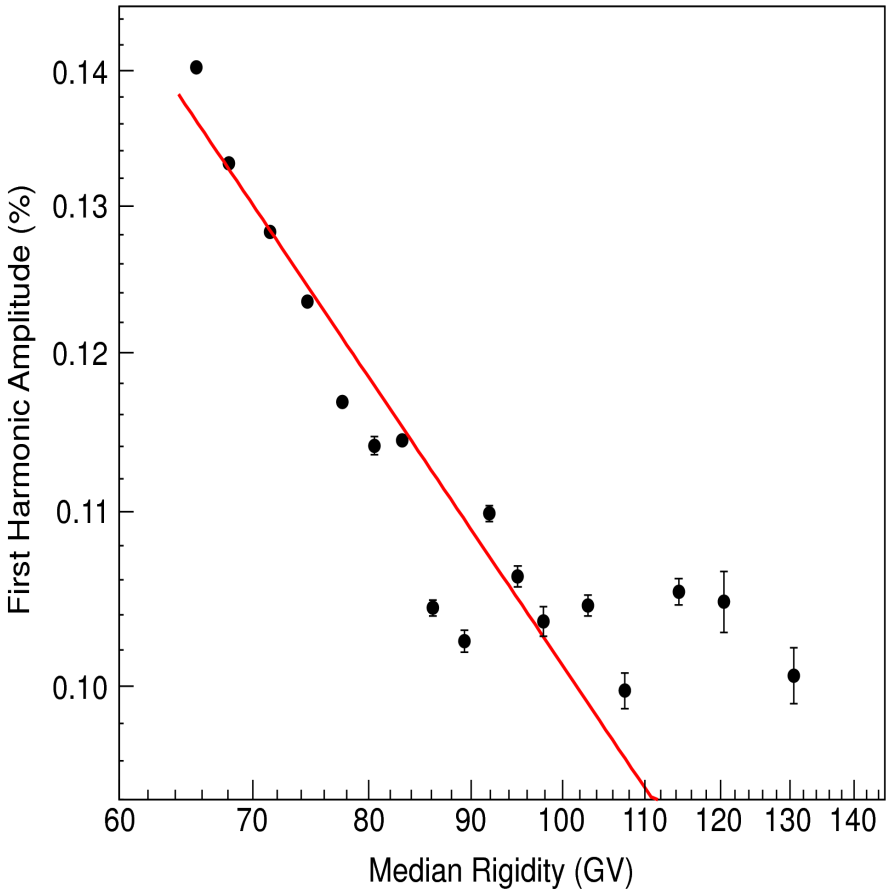
W

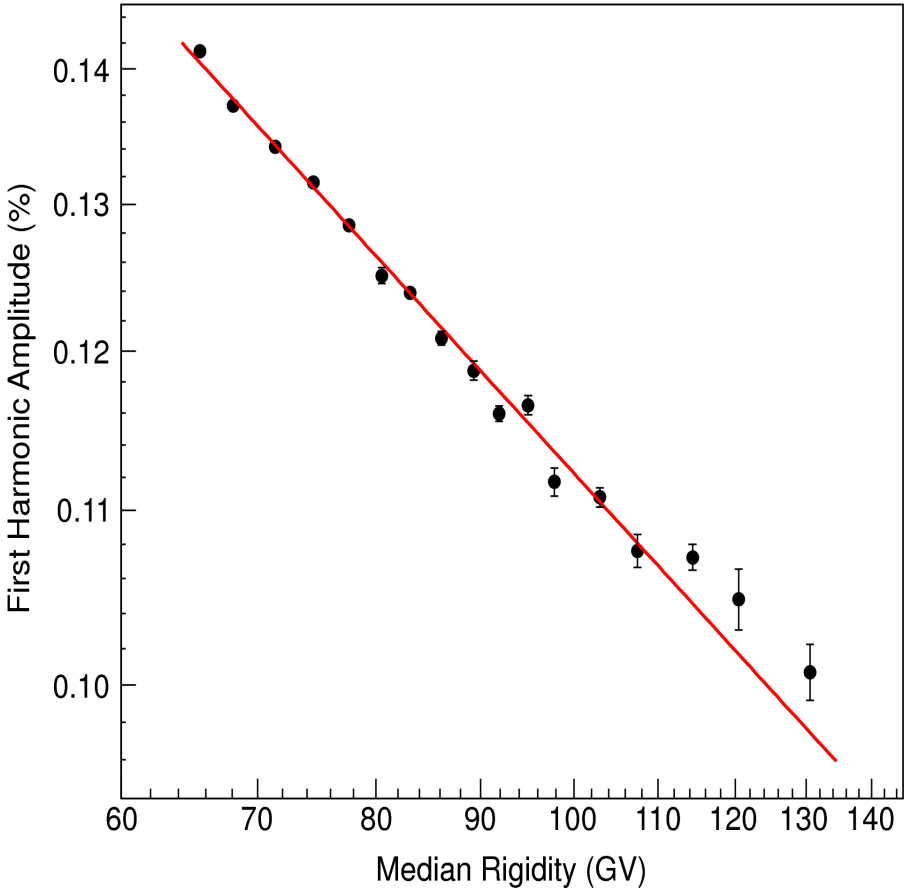
E

S

First Harmonic
BEFORE and AFTER time offset correction

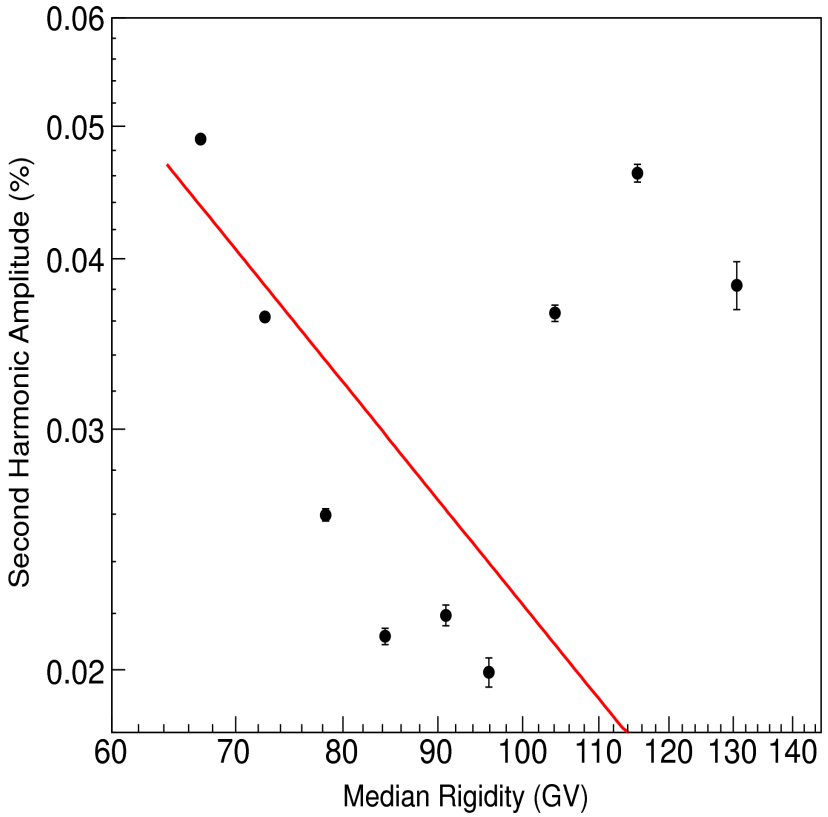
-0.531±0.006

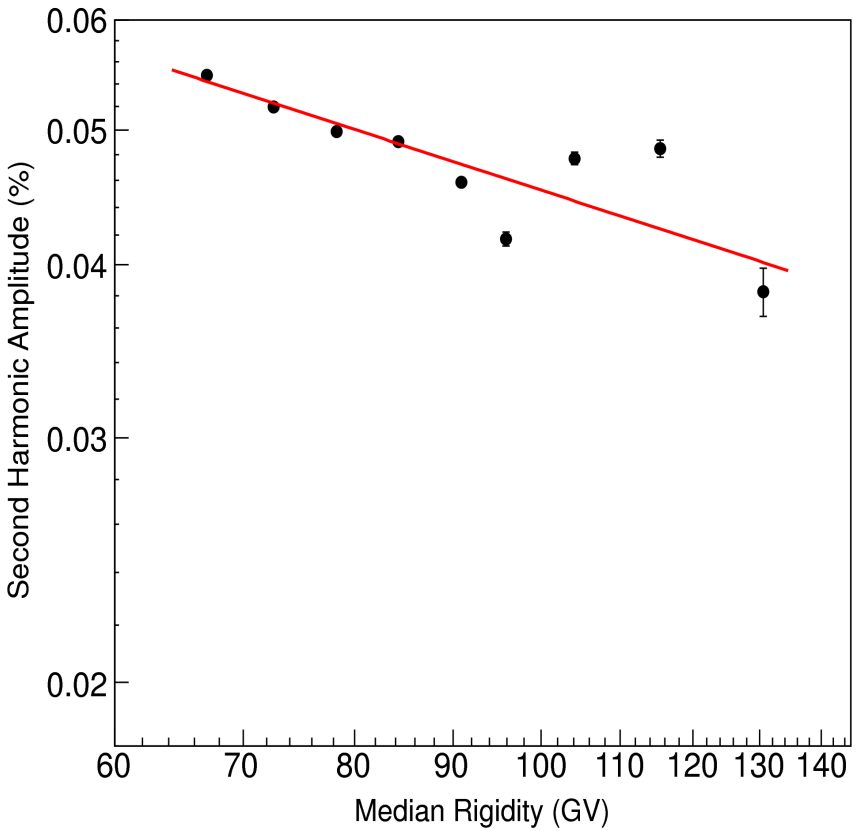




Second Harmonic
BEFORE and AFTER time offset correction

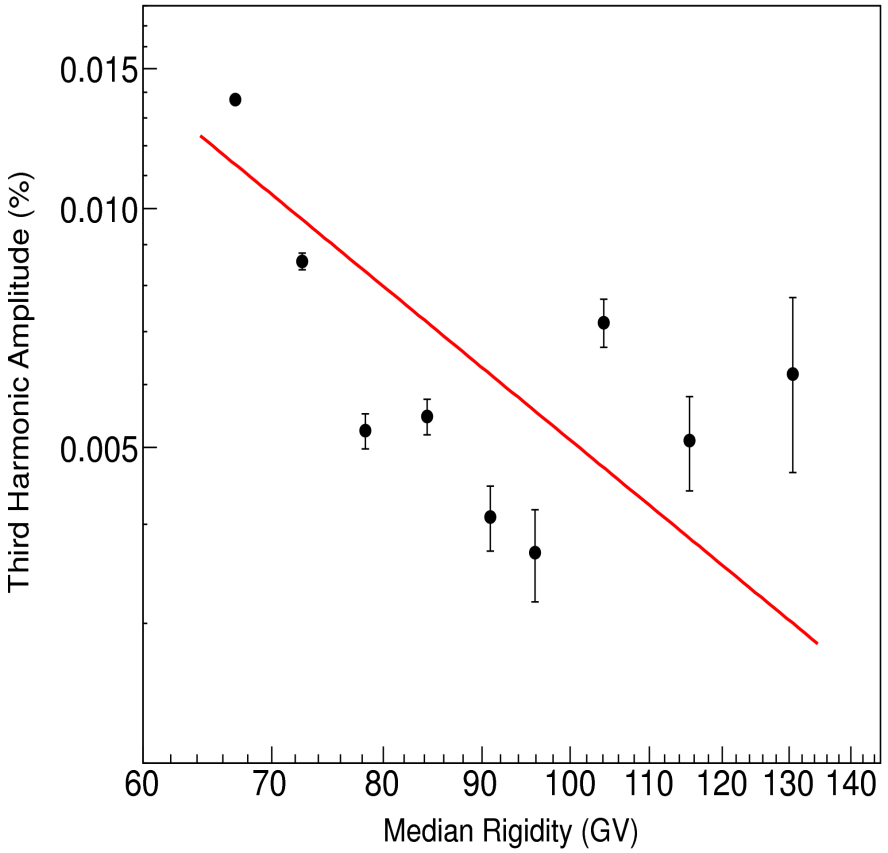
-0.45±0.02

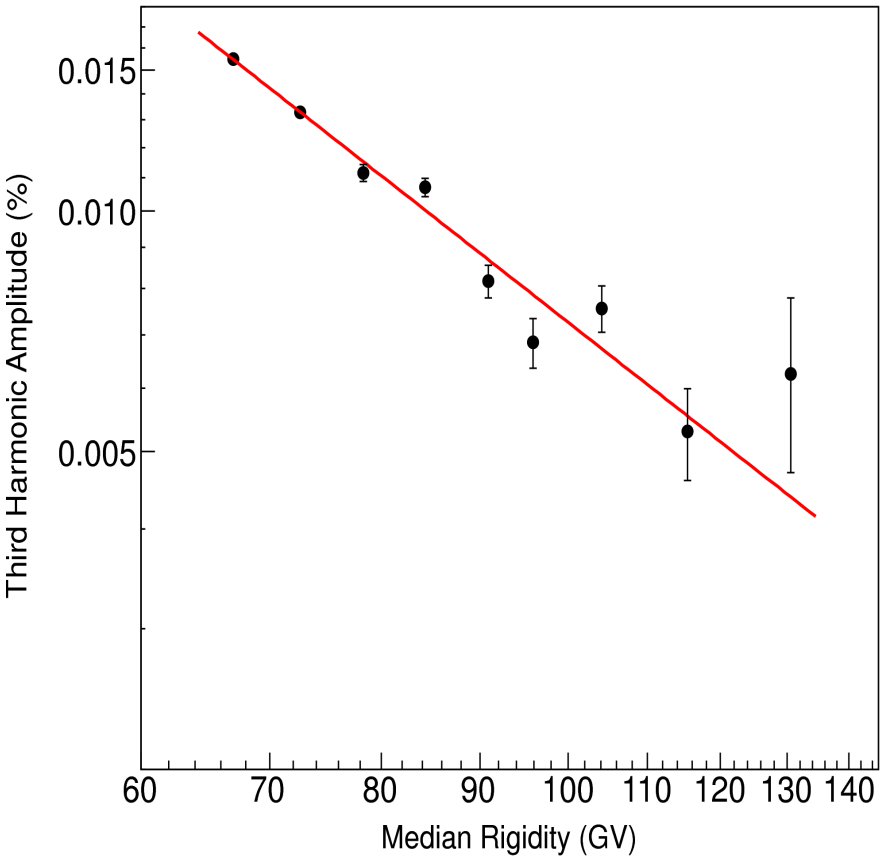




Third Harmonic
BEFORE and AFTER time offset correction

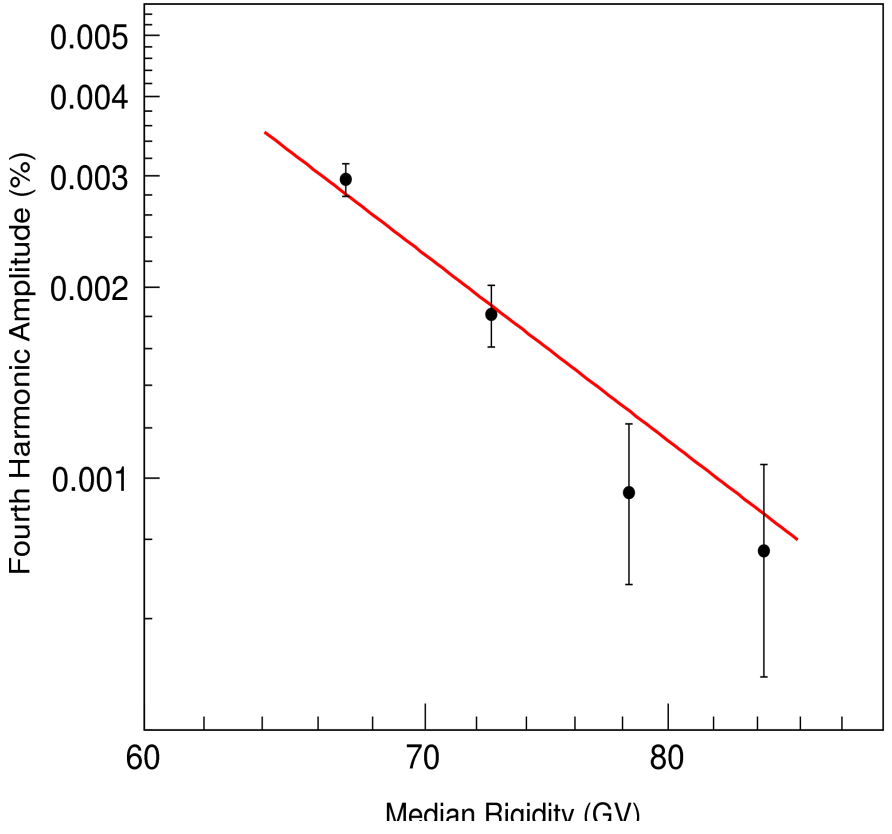
-1.89±0.08

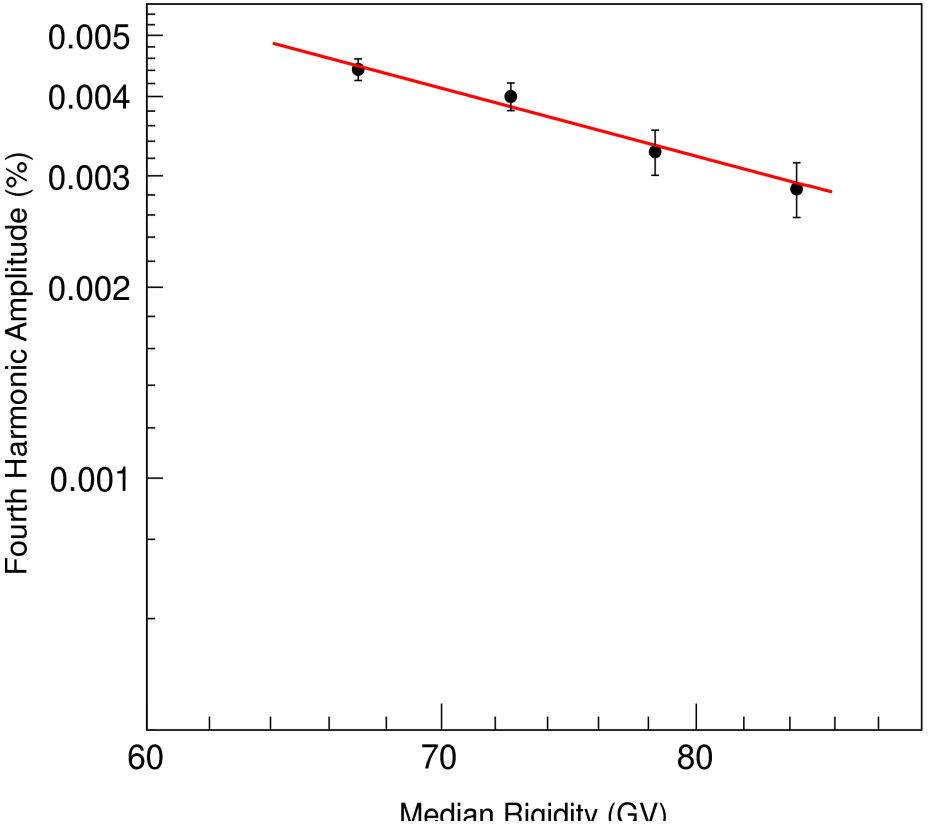




Fourth Harmonic
BEFORE and AFTER time offset correction

-1.8±0.4



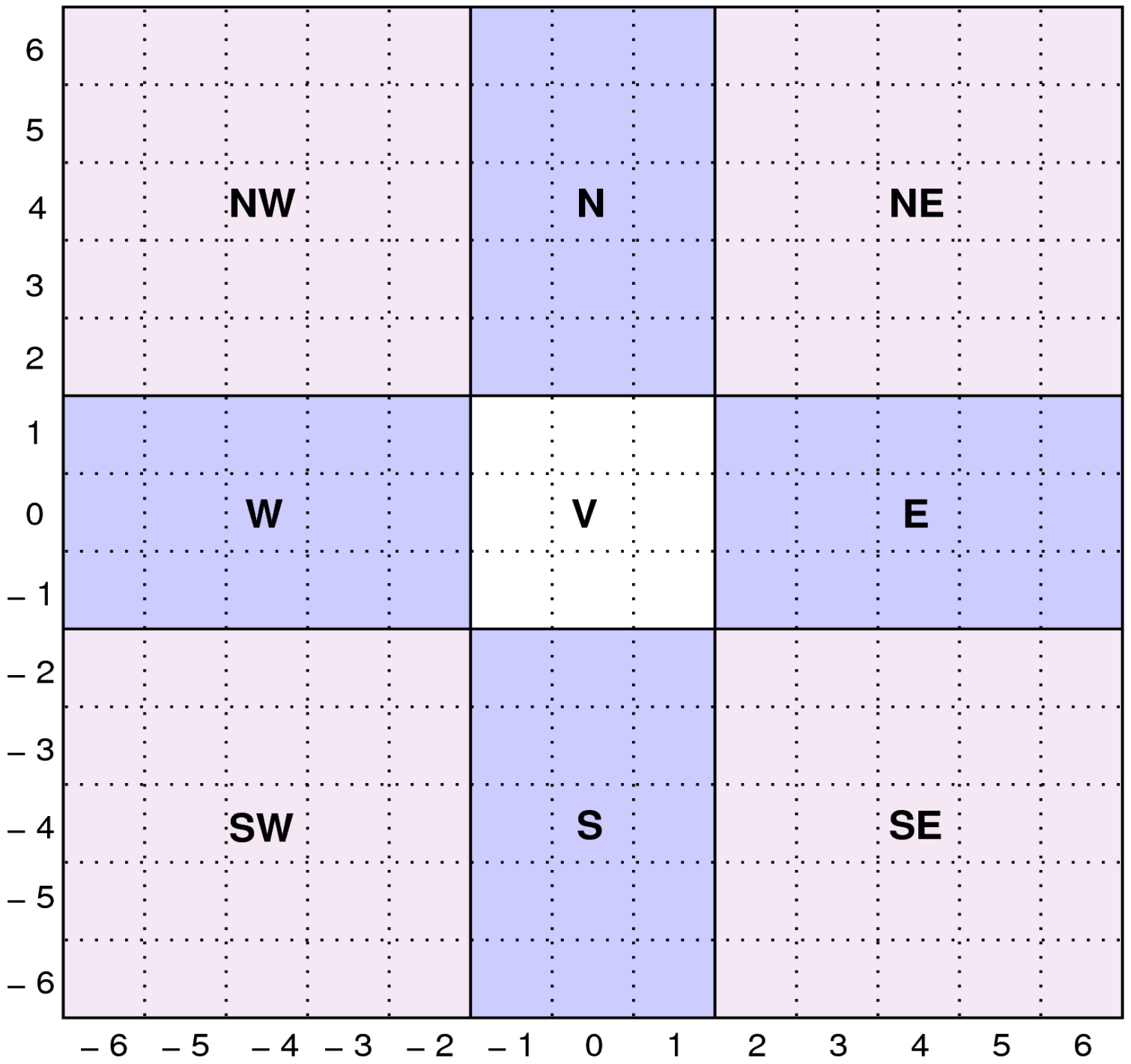


Summary of GRAPES-3 Harmonic Measurements

Harmonic	Amplitude (%)	Phase	Spectral index (γ)
1	0.132	12.4 h $\pm$ 0.3 h	0.53 $\pm$ 0.01
2	0.054	12.4 h $\pm$ 0.3 h	0.45 $\pm$ 0.02
3	0.014	12.7 h $\pm$ 0.2 h	1.9 $\pm$ 0.1
4	0.004	12.9 h $\pm$ 0.2 h	1.8 $\pm$ 0.1

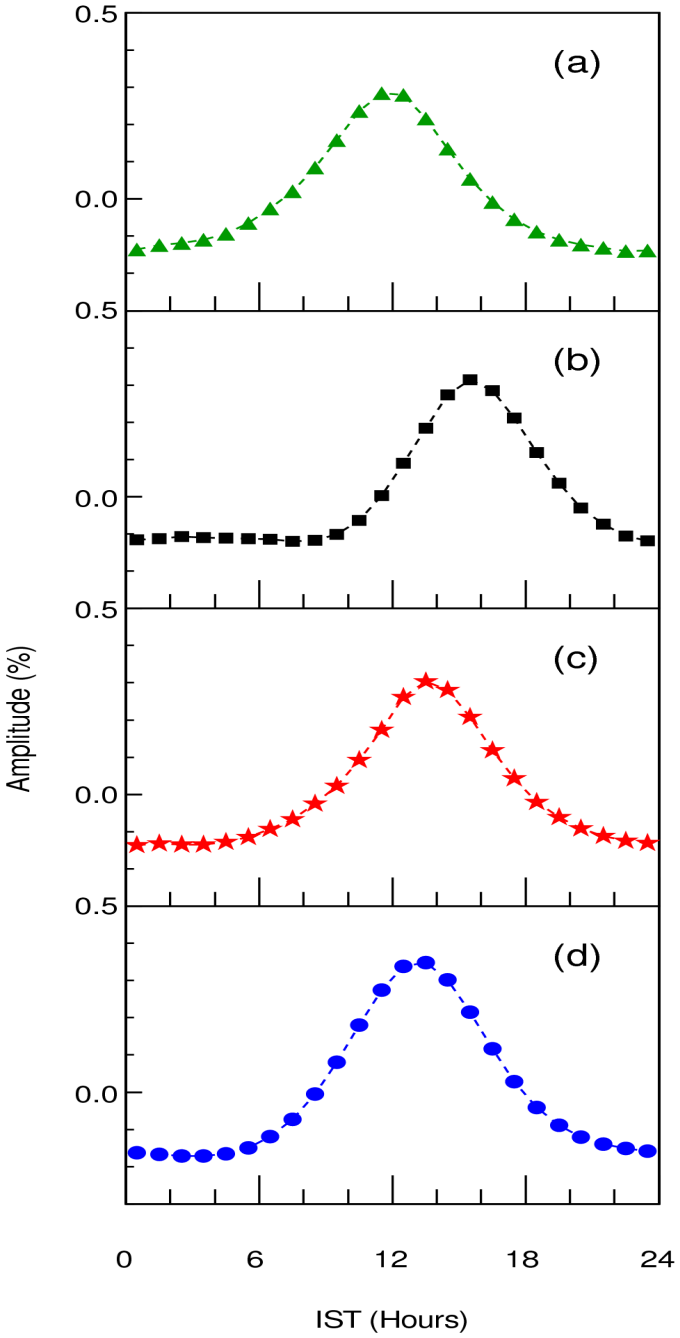
Measurement of first three harmonics by Bieber and Pomerantz (1983) neutron monitor data during 1965–1976 from Swarthmore observatory.

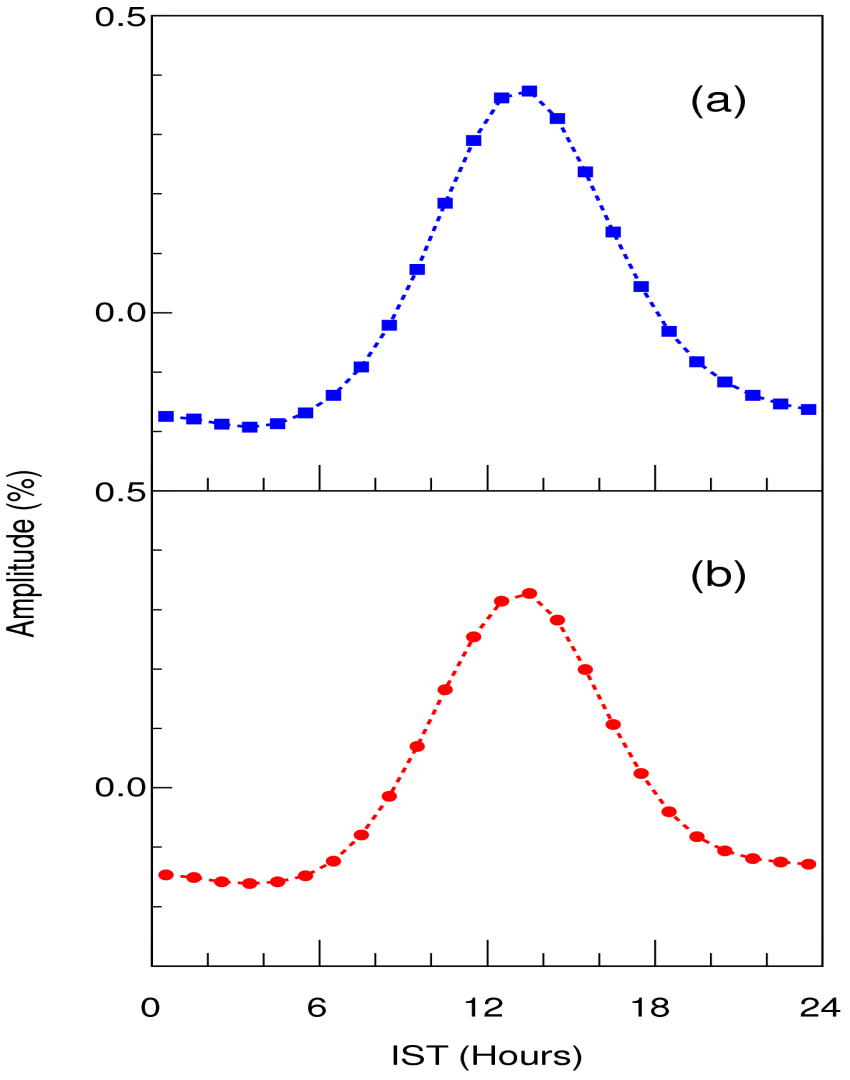
Harmonic	Amplitude (%)	Phase
1	0.277	14.1 h
2	0.057	13.5 h
3	0.014	13.5 h

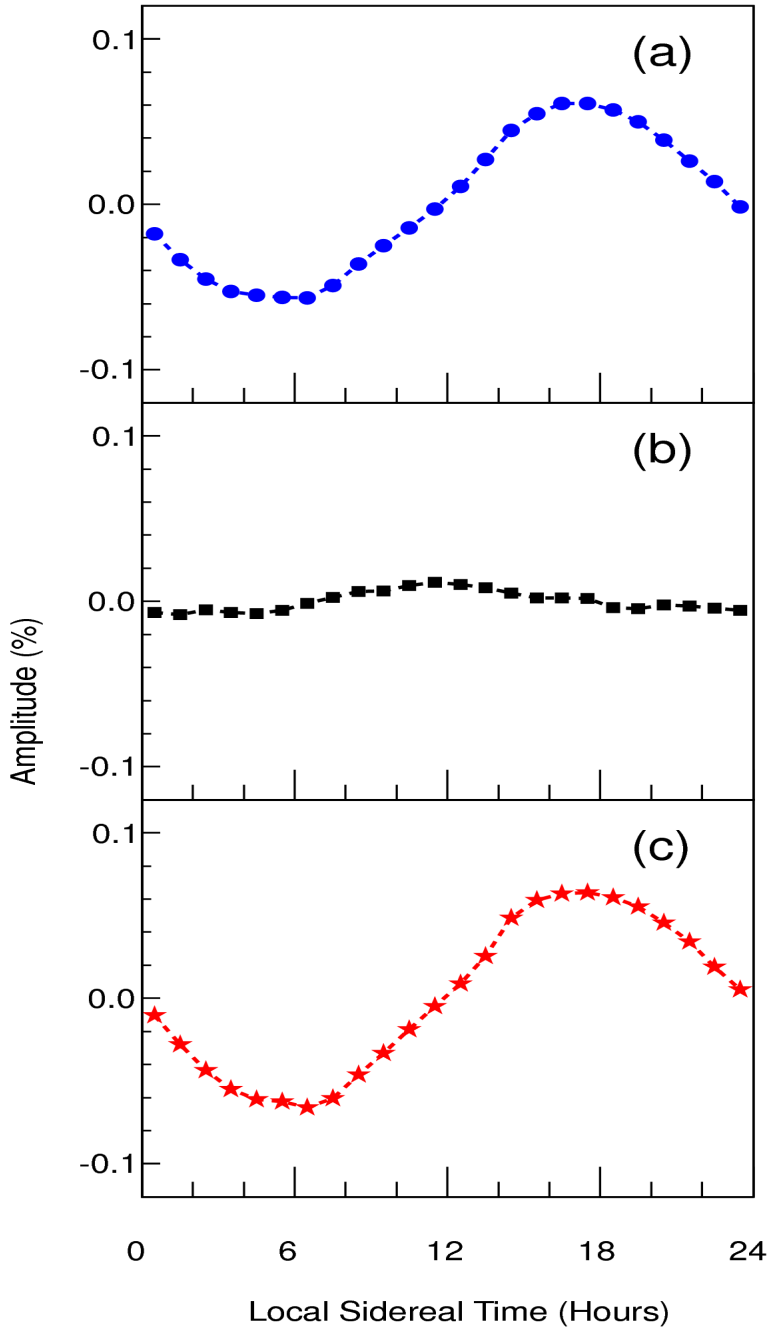

NW
N
NE
W
V
E
SW
S
SE
6
5
4
3
2
1
0
– 1
– 2
– 3
– 4
– 5
– 6
– 6
– 5
– 4
– 3
– 2
– 1
0
1
2
3
4
5
6

$$E(t) - W(t) = I(t + \tau/2) - I(t - \tau/2)$$

$$\Delta I = I(t + \tau/2) - I(t - \tau/2) = E(t) - W(t)$$







$N(\theta) = A\cos(\theta) + B\sin(\theta)$

$A = (-0.0050 \pm 0.0008)\%\ (6\sigma)$

$B = (-0.0642 \pm 0.0008)\%\ (80\sigma)$

$C = (-0.0644 \pm 0.0008)\%\ (80\sigma)$

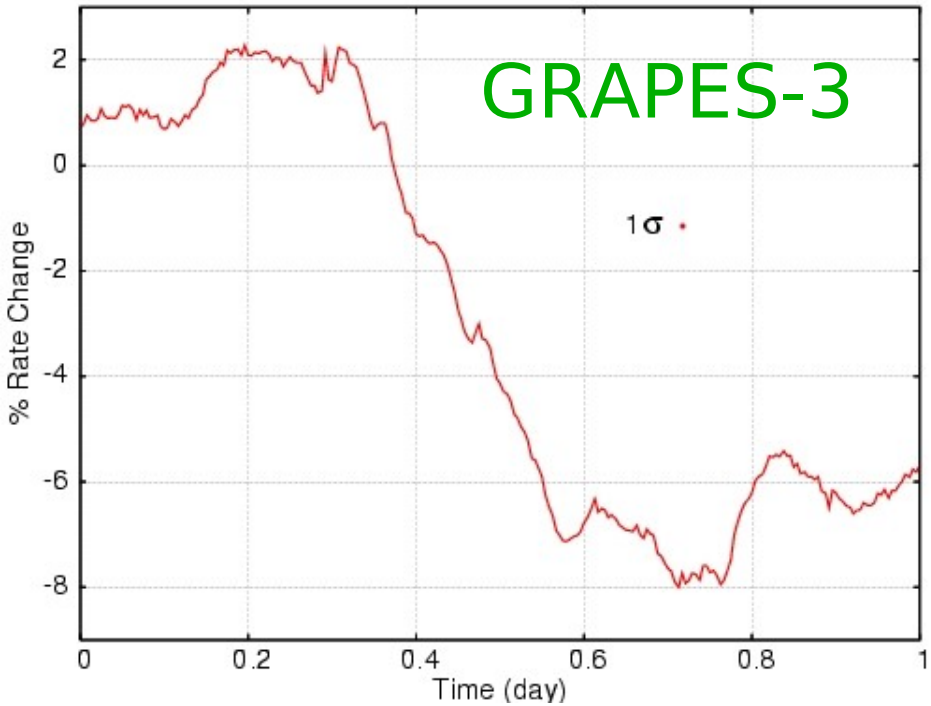
$\Psi = (17.70 \pm 0.05)\ \mathrm{h}$

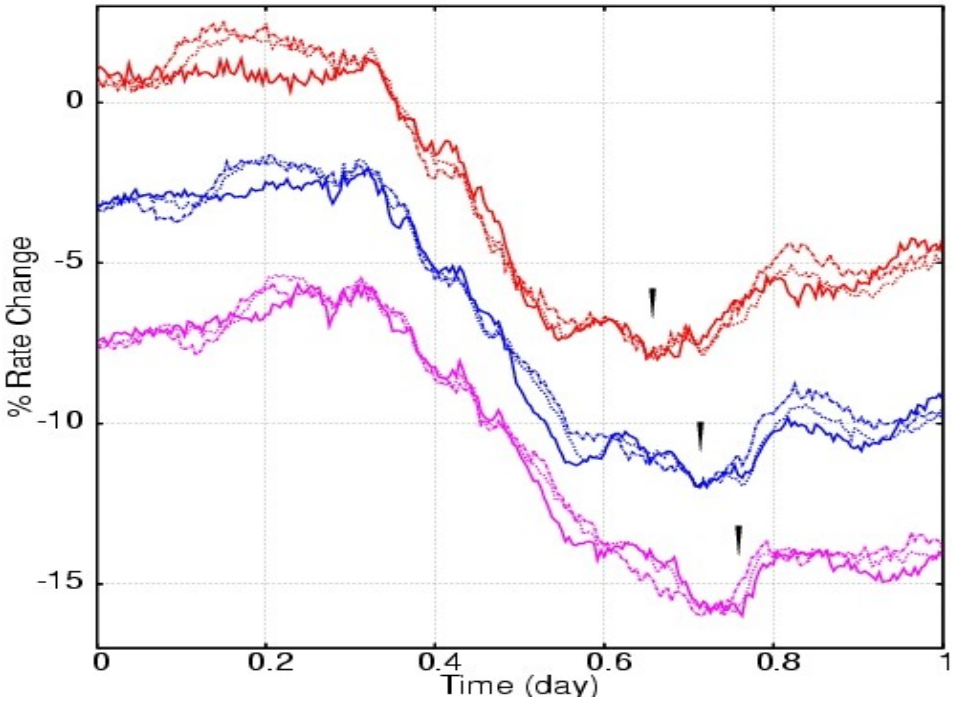
$\mathrm{Amplitude} = (0.355 \pm 0.005)\%$

$\mathrm{Gradient} = 1.4\ \%\ /\ \mathrm{A.U.}$

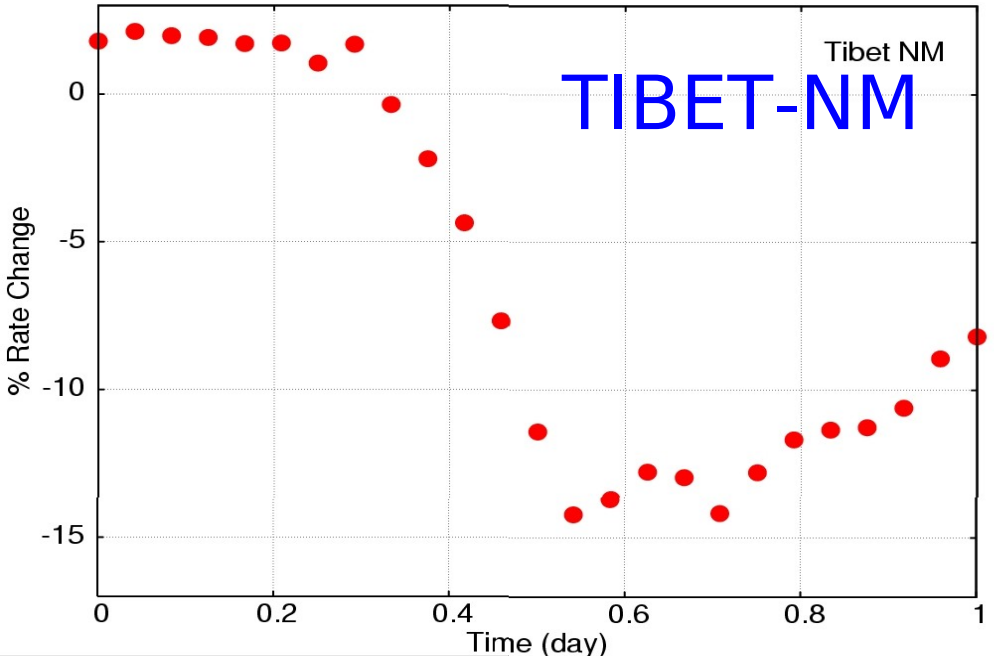
$\mathrm{Current} = 10^{6}\ \mathrm{Amp}\ /\ \mathrm{A.U.}^{2}$

Coronal Mass Ejection (28 October 2003)





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

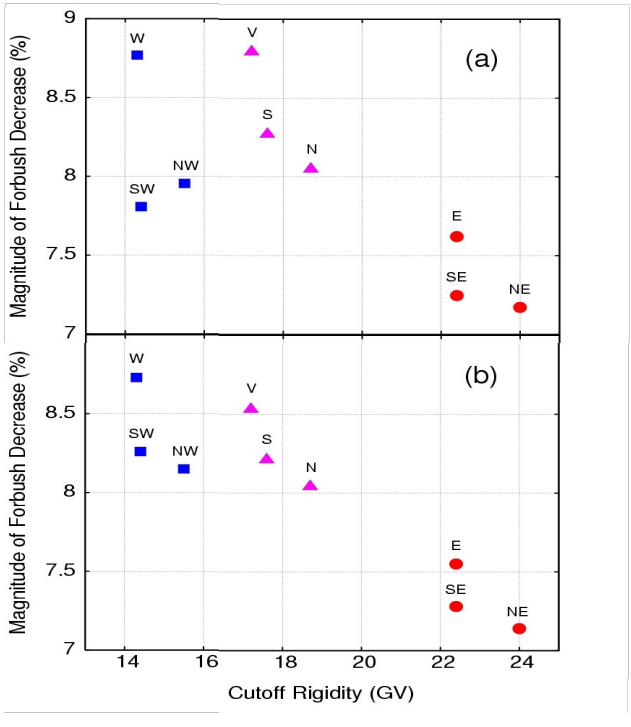


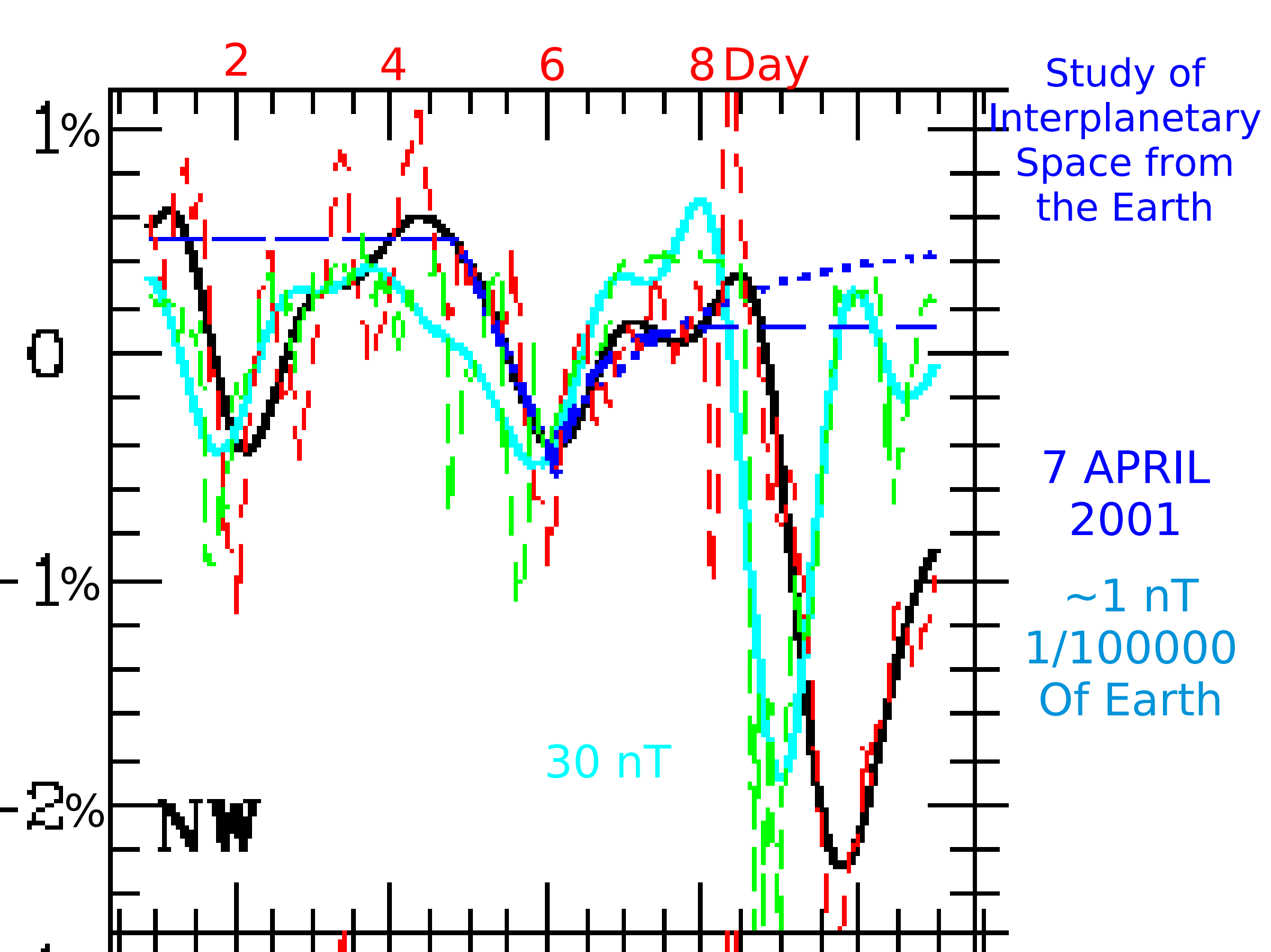
$A(r) = K \times r^{-\gamma}$

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

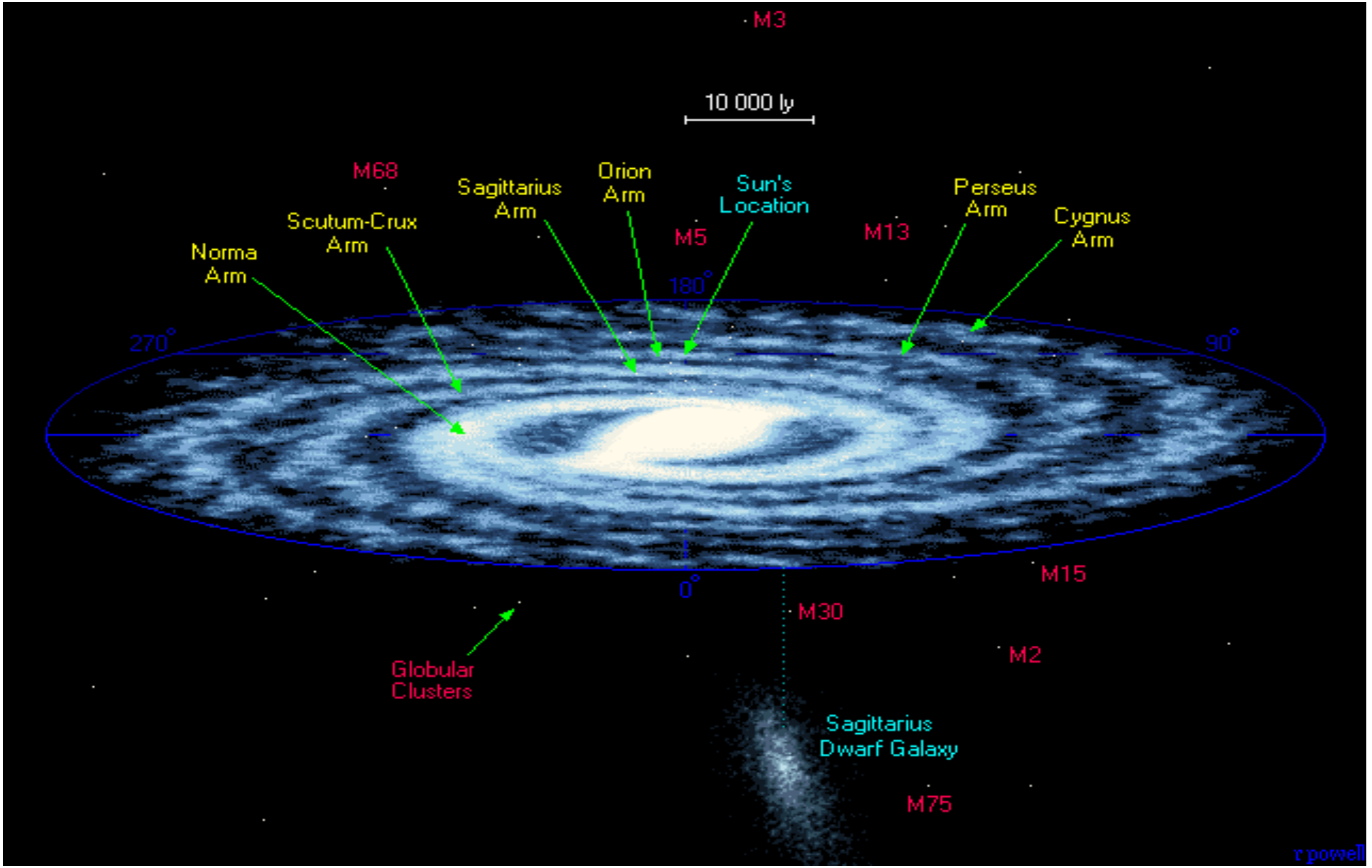
$\gamma = (0.53 \pm 0.04)$

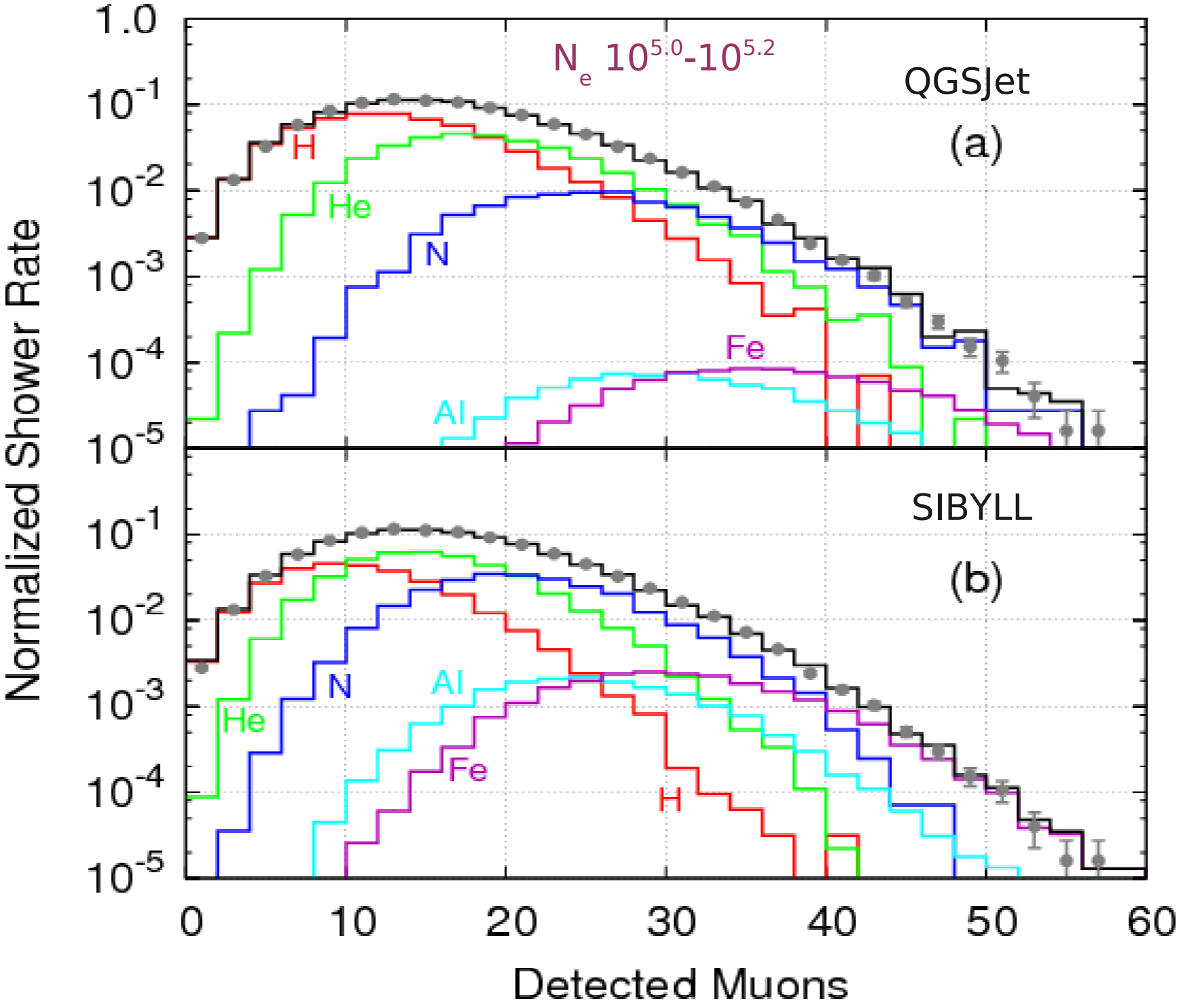
$\gamma = 0.4 - 1.2$



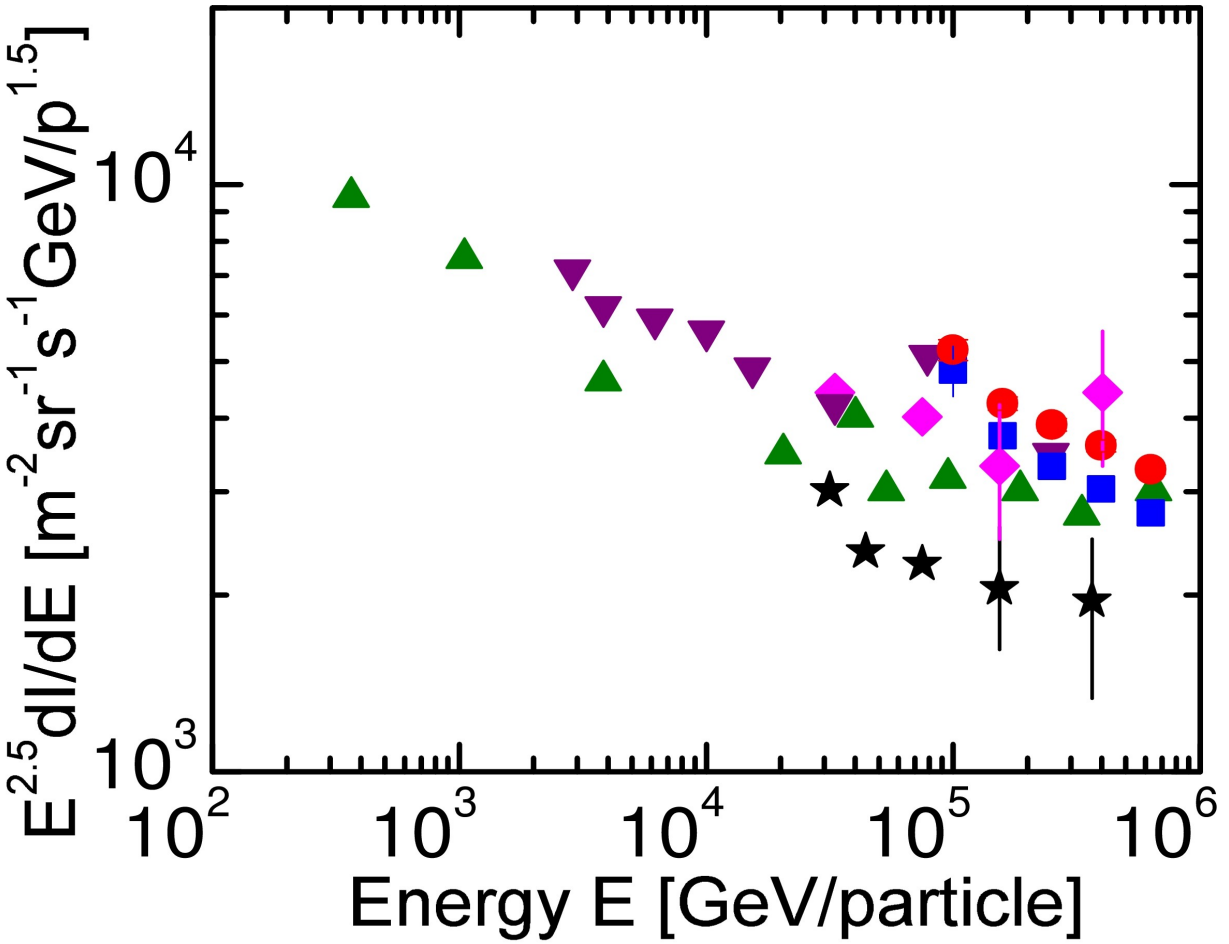

2
4
6
8 Day
1%
0
-1%
-2%
NW
30 nT
Study of Interplanetary Space from the Earth
7 APRIL 2001
~1 nT
1/100000
Of Earth

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

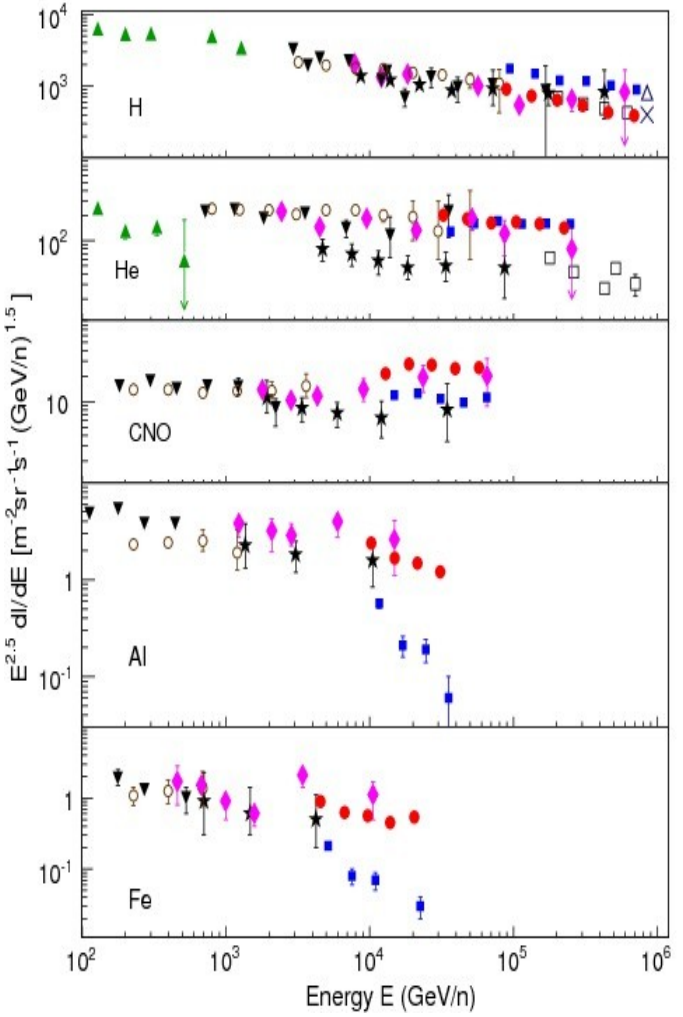



N_e $10^{5.0}$-$10^{5.2}$
QGSJet
(a)
SIBYLL
(b)
H
He
N
Al
Fe
Normalized Shower Rate
Detected Muons
1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
60

All particle energy spectrum



Nuclear group spectrum



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

CORSIKA simulations of 10^9 CR protons >10 GeV,

Produced muons = (1.96 – 2.30) 10^8

Normalized muons = $2x10^8$

Used IGRF-2011 for rigidity cutoff calculations

Then calculate muons in 9 directions

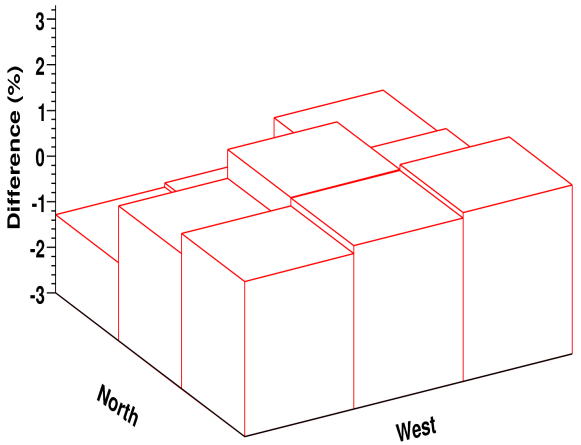
High energy hadronic interaction models: EPOS, SIBYLL, QGSJet-II

Low enegy hadronic interaction models: GHEISHA, FLUKA, UrQMD

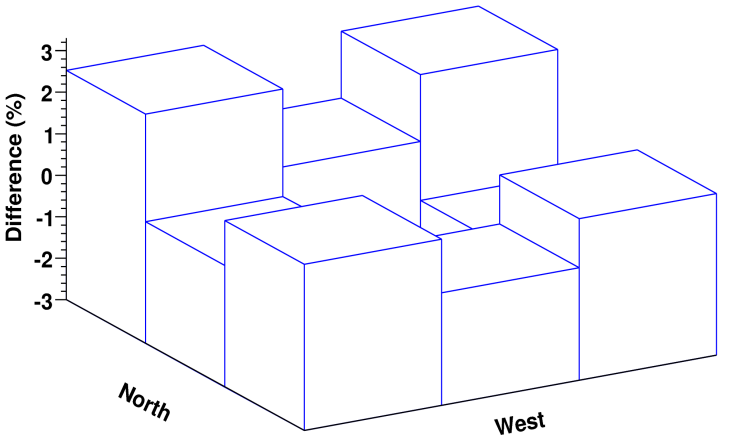
Calculate percent difference in muon content in 9 directions

FLUKA - GHEISHA

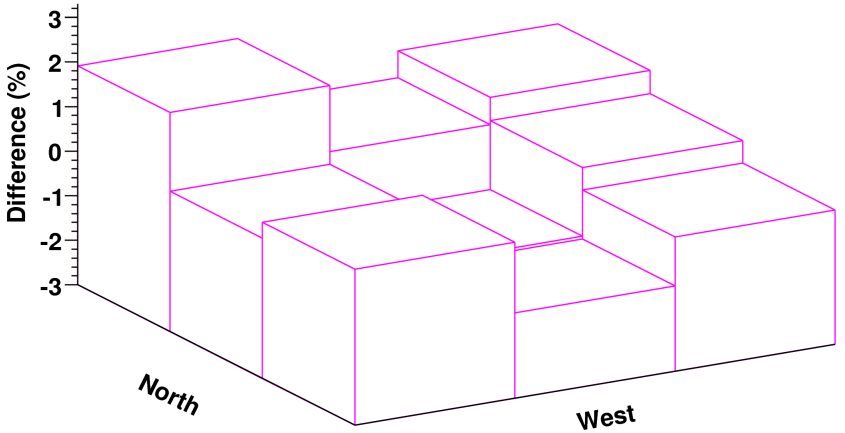
EPOS 1.9



QGSJet-II

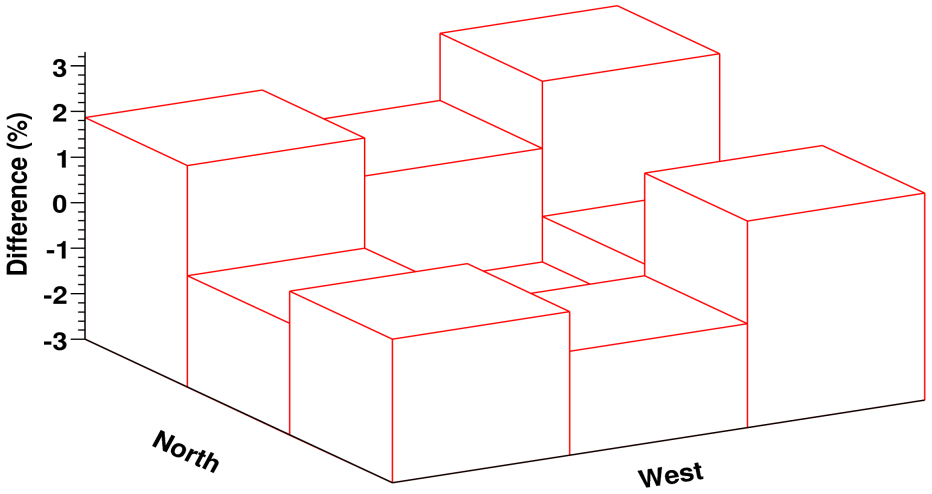


SIBYLL 2.1

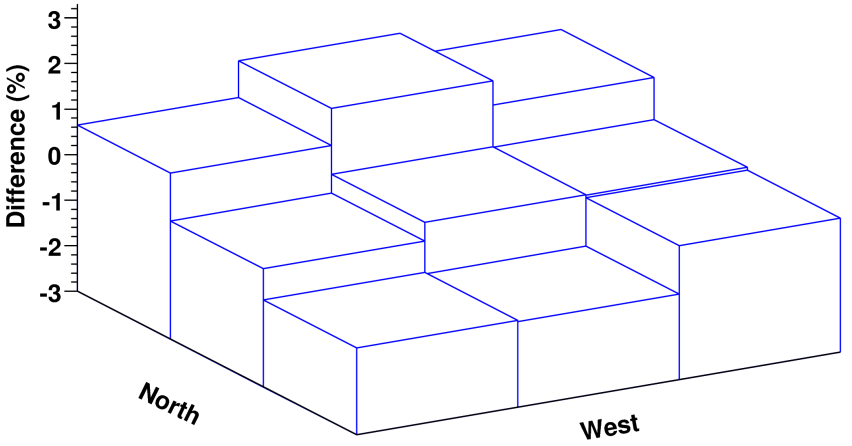


FLUKA - UrQMD

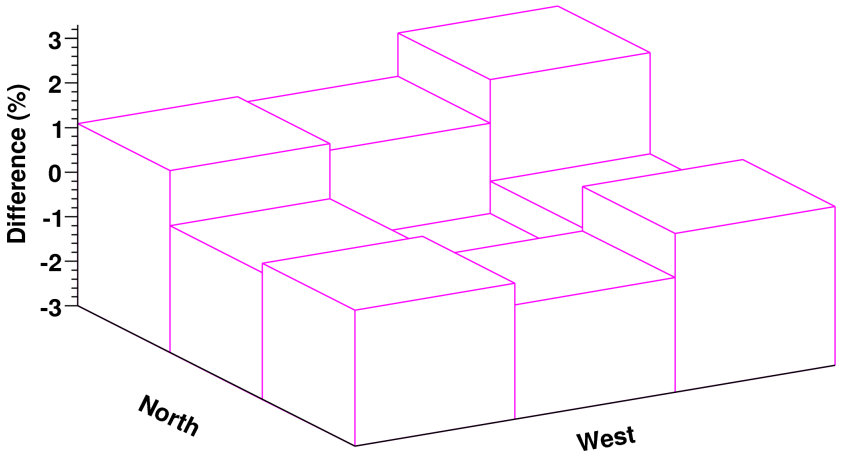
EPOS 1.9



QGSJet-II

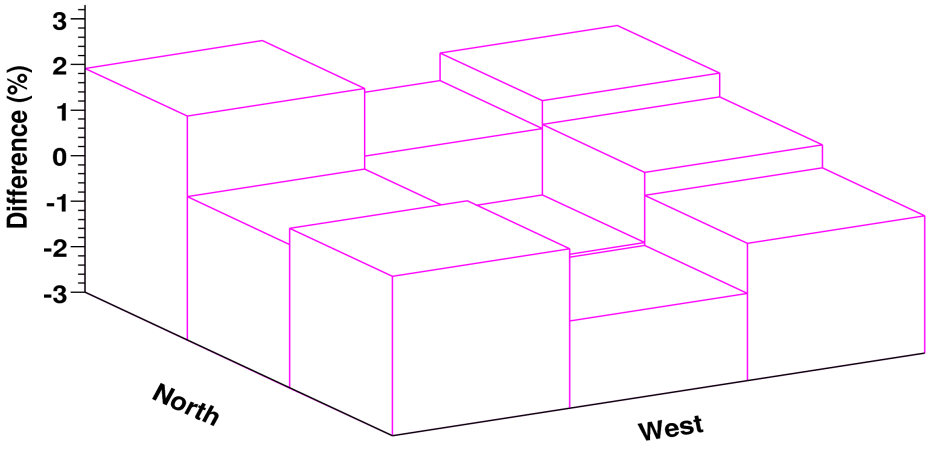


SIBYLL 2.1

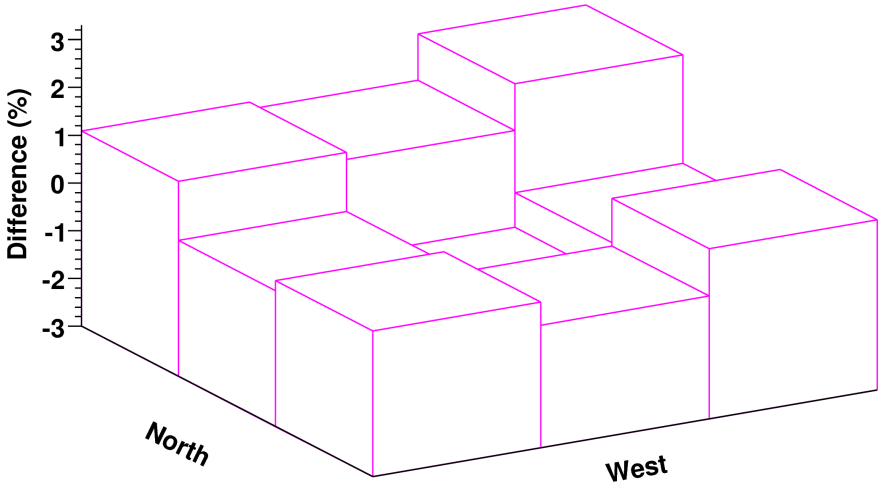


SIBYLL 2.1

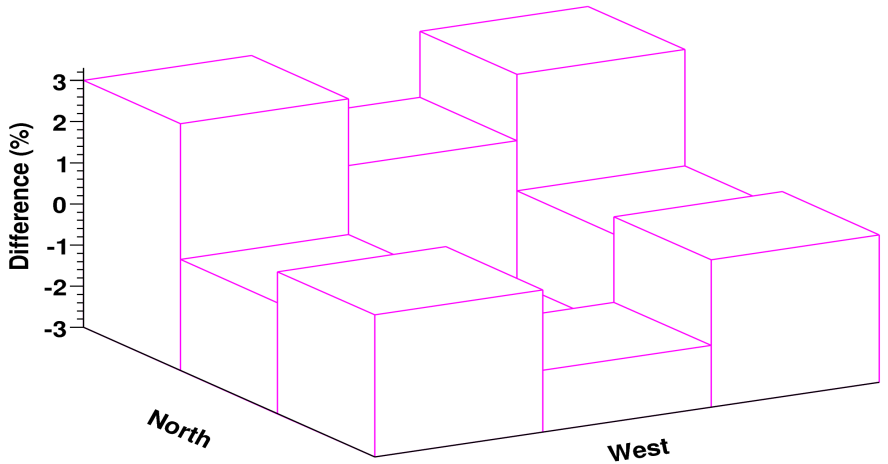
FLUKA - GHEISHA



FLUKA - UrQMD

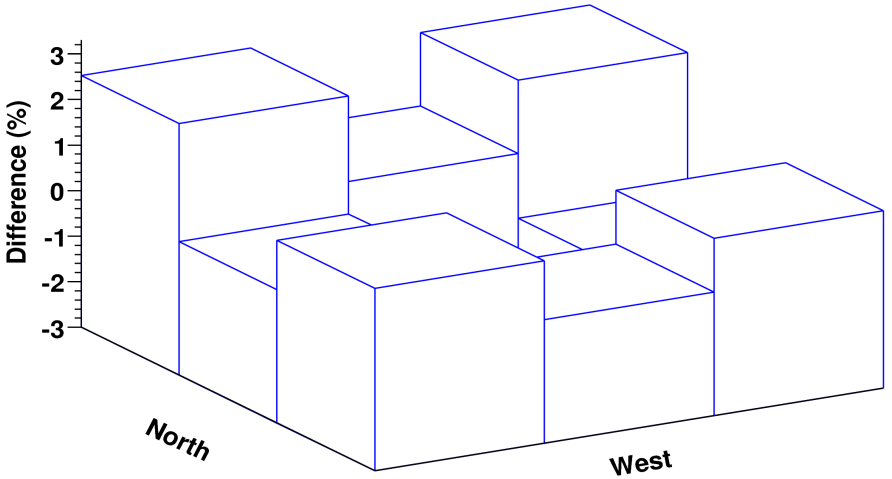


GHEISHA - UrQMD

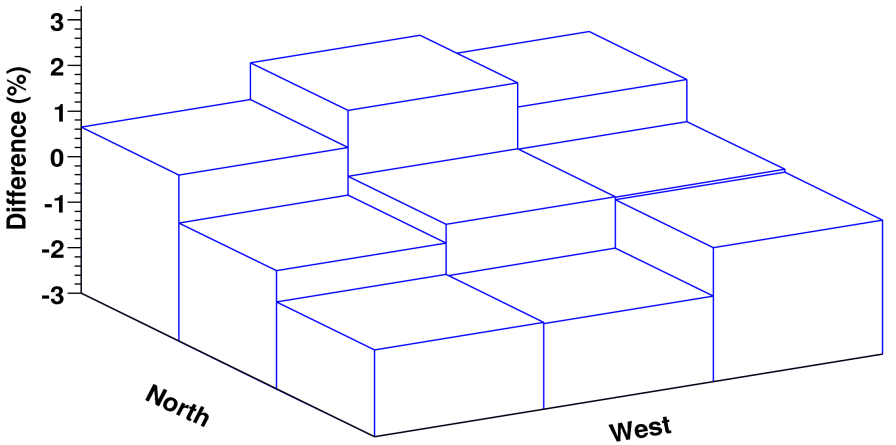


QGSJet-II

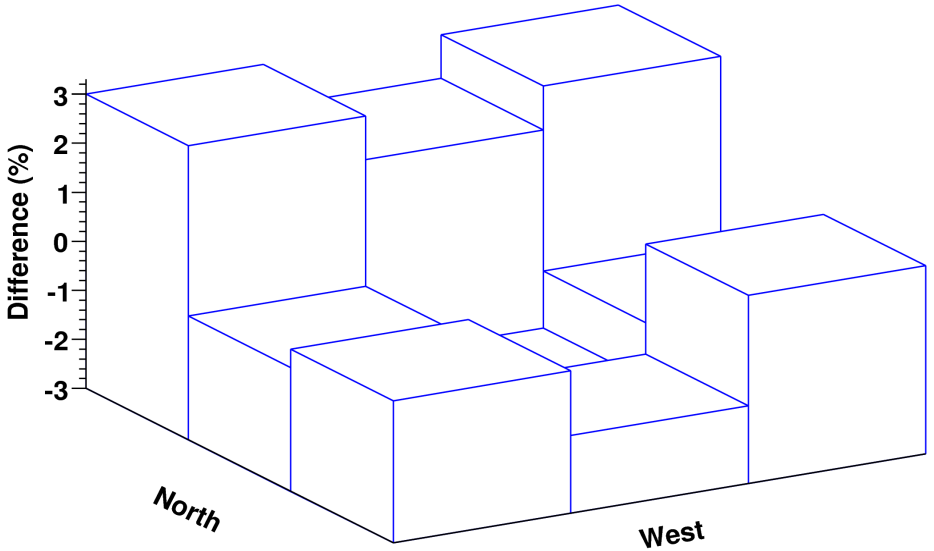
FLUKA - GHEISHA



FLUKA - UrQMD

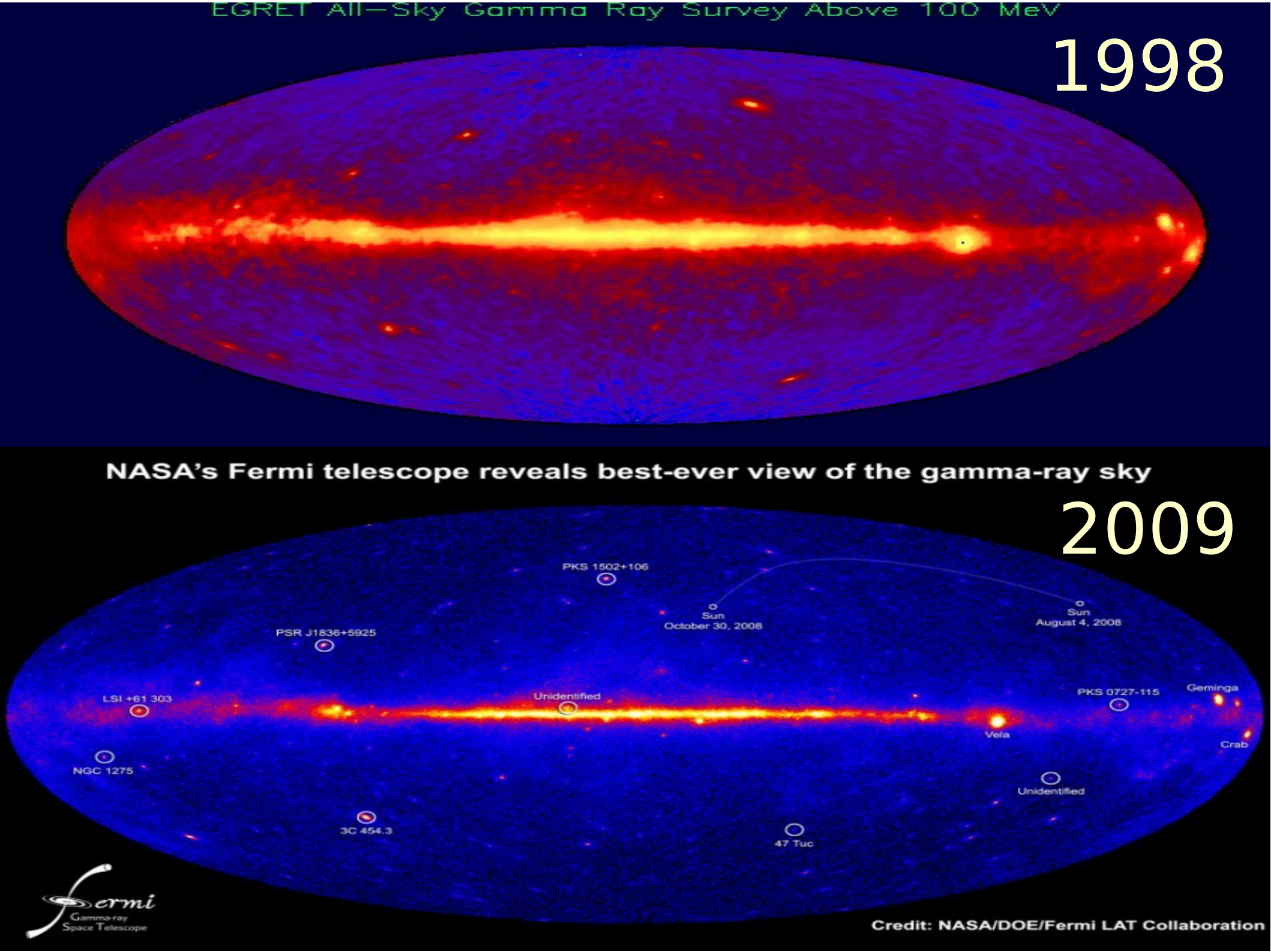


GHEISHA - UrQMD



Diffuse multi-TeV γ-rays

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

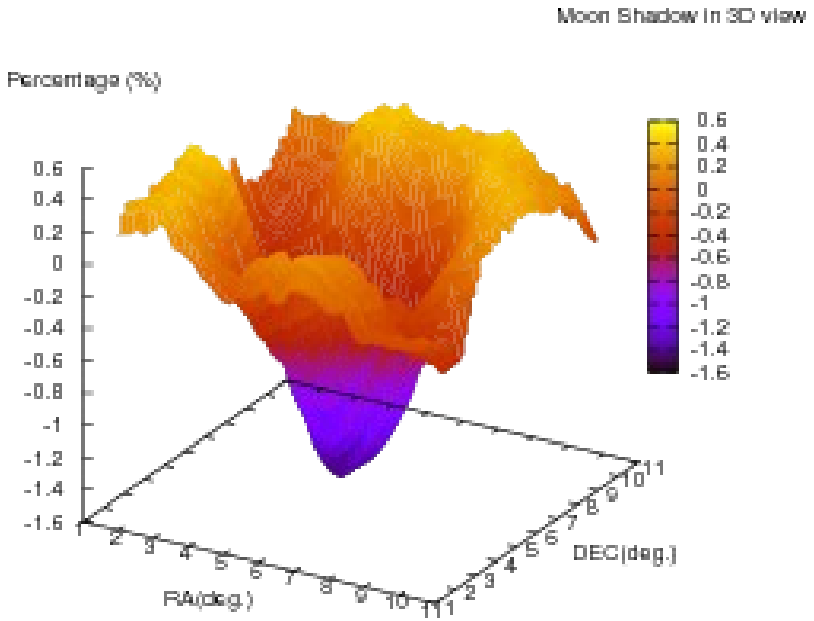

EGRET All-Sky Gamma Ray Survey Above 100 MeV
1998
NASA's Fermi telescope reveals best-ever view of the gamma-ray sky
2009
PKS 1502+106
Sun
October 30, 2008
Sun
August 4, 2008
PSR J1836+5925
LSI +61 303
Unidentified
PKS 0727-115
Geminga
Vela
Crab
NGC 1275
Unidentified
3C 454.3
47 Tuc
Fermi
Gamma-ray
Space Telescope
Credit: NASA/DOE/Fermi LAT Collaboration

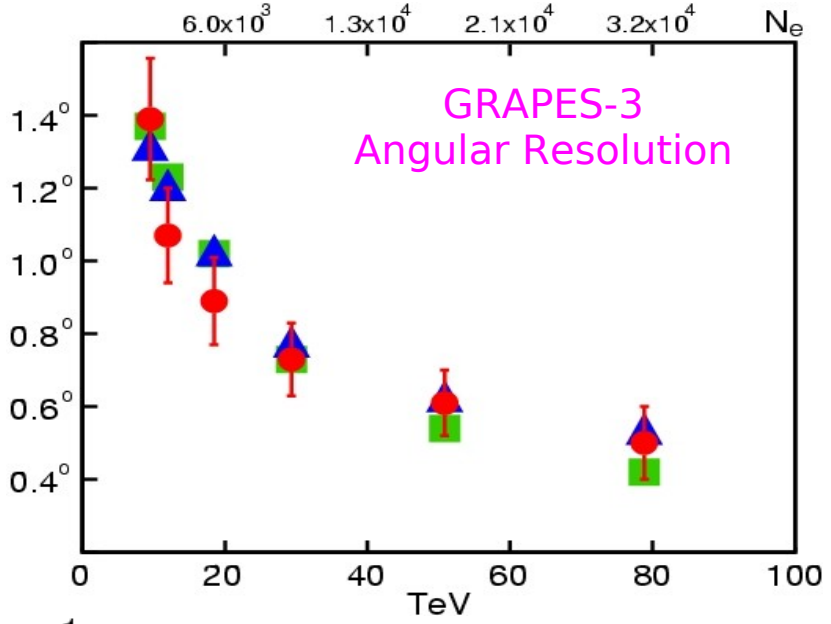
Moon Shadow

γ-ray astronomy σ_θ = 25'

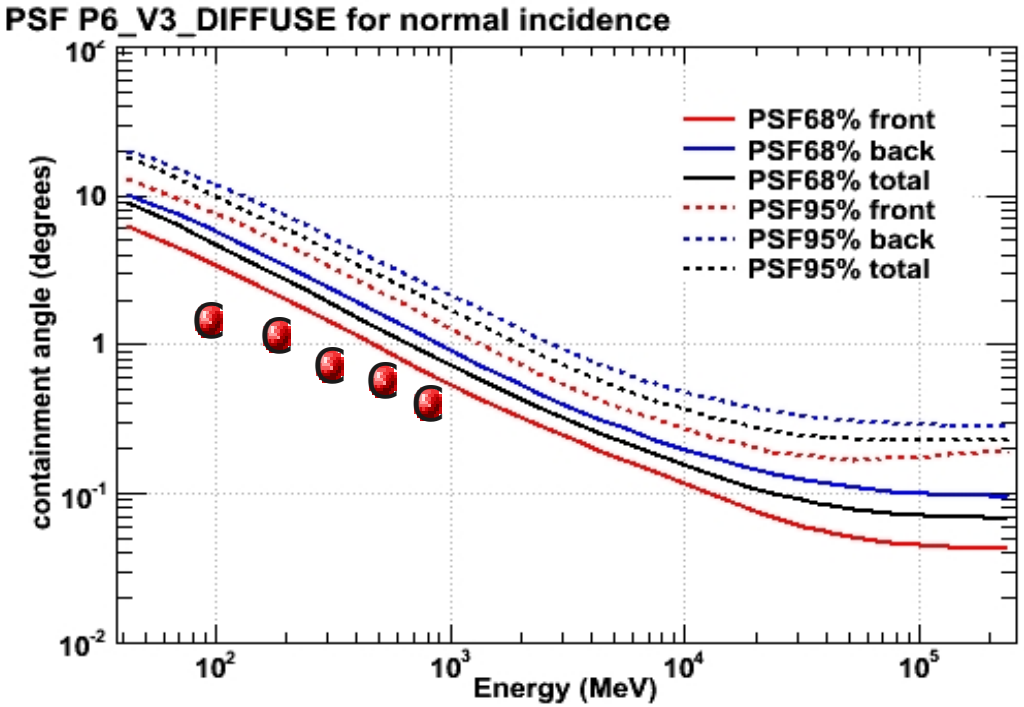
E~100 EeV Size~10^{24}-10^{26} cm

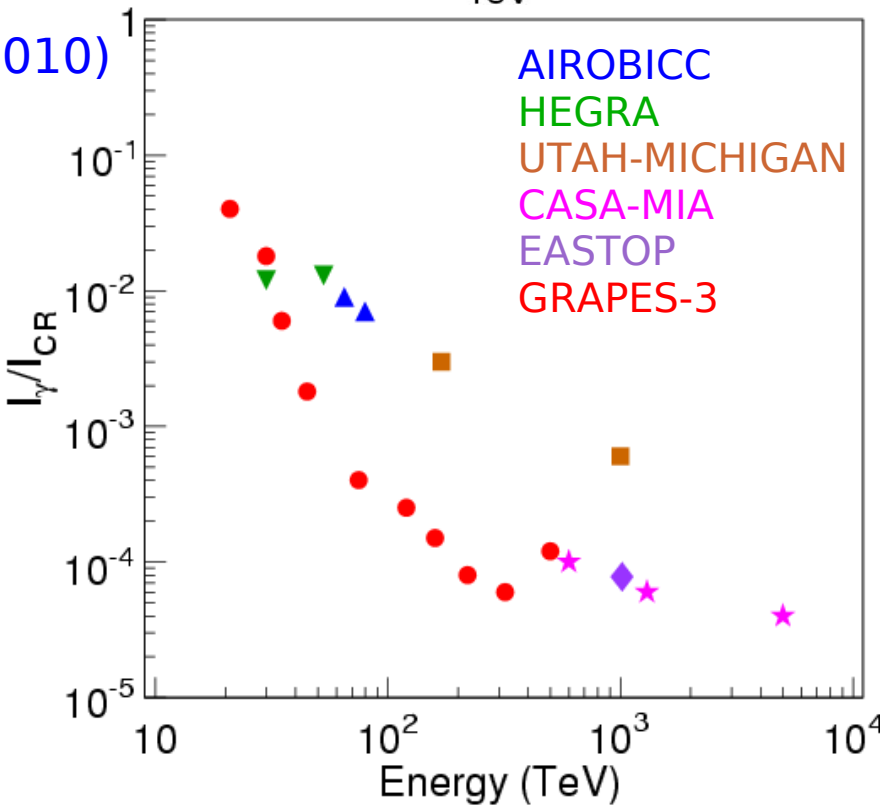
Moon



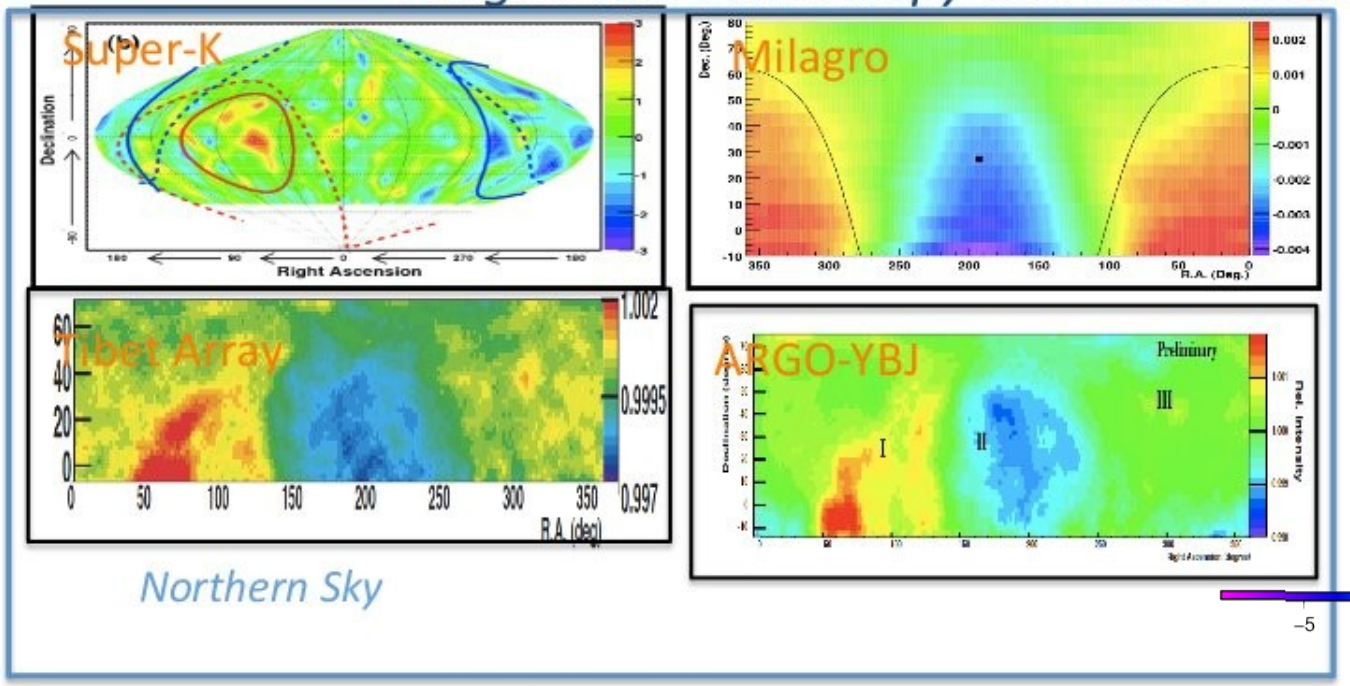


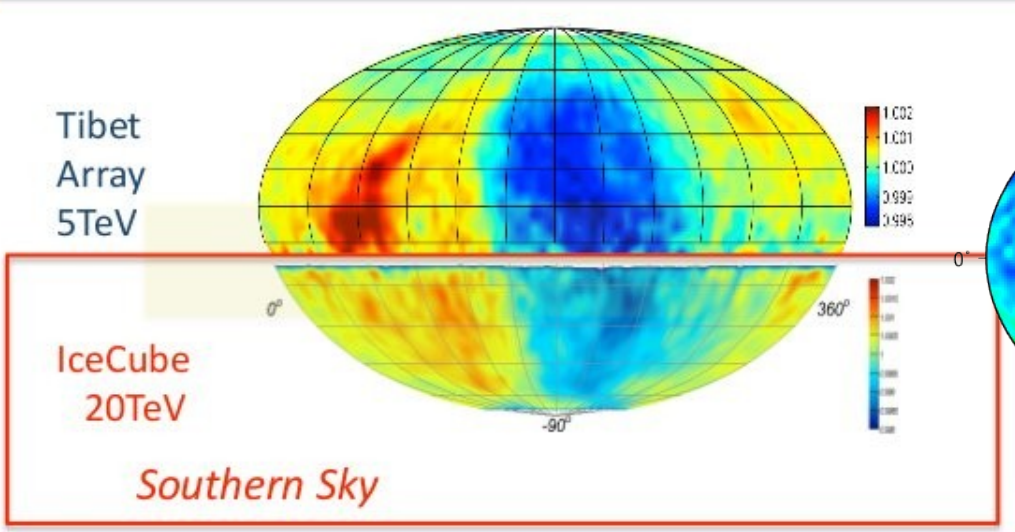
A. Oshima et al. Astropart. Phys. **33** 97-107 (2010)

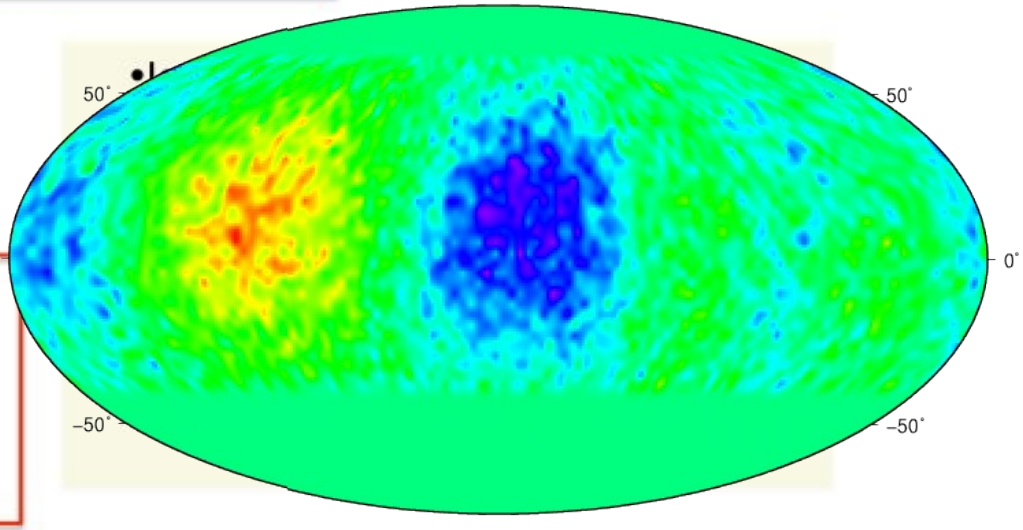




Large Scale Anisotropy and Past Results







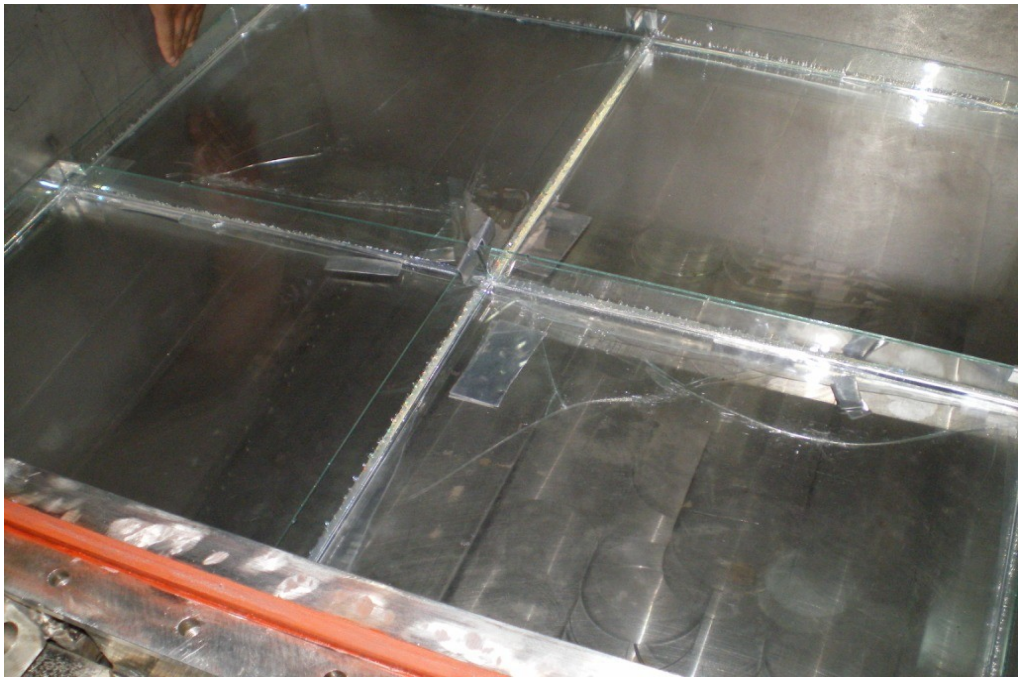
GRAPES-3 >10TeV

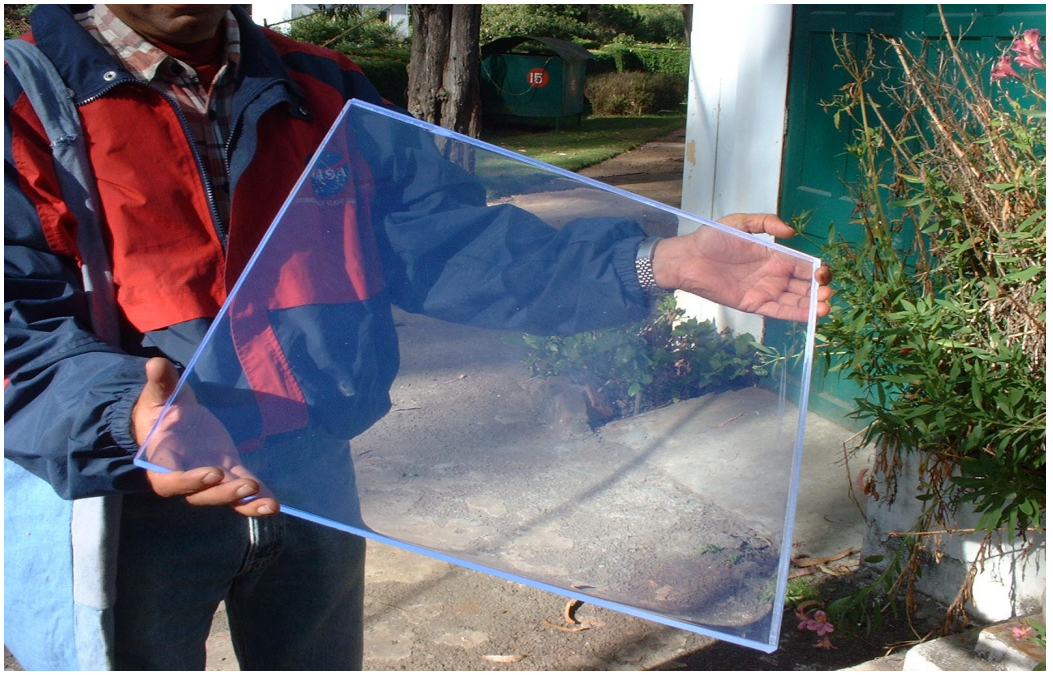
In-house technology for the Fabrication of Various Detector Components

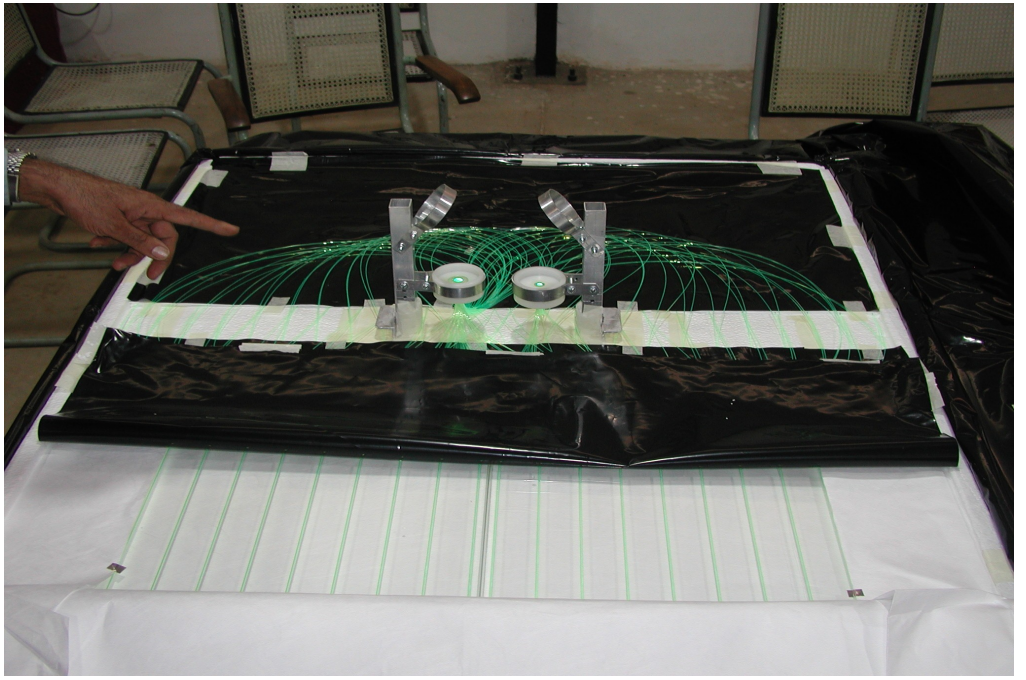
Plastic Scintillator development:

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

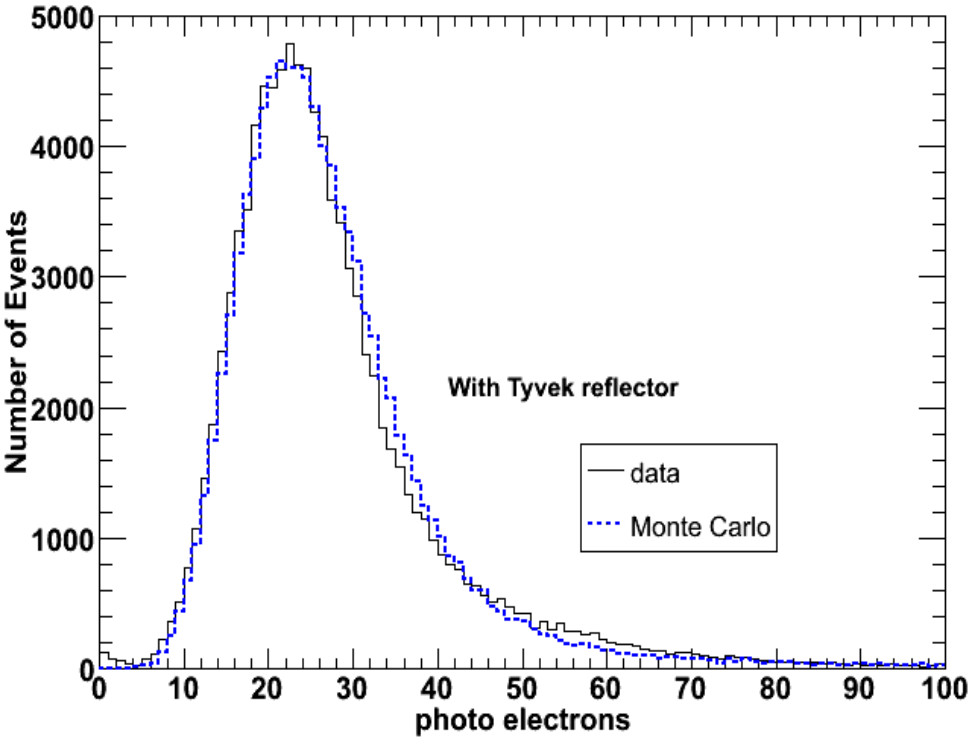
CERN, Osaka, IUAC Delhi, Bose, VECC, BARC etc.

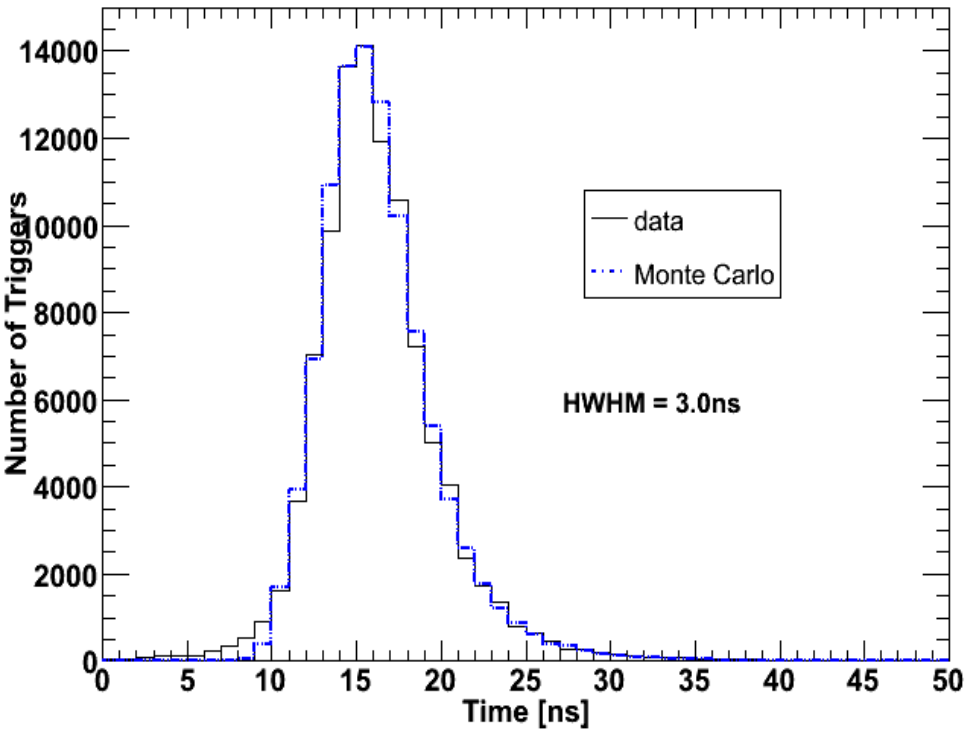


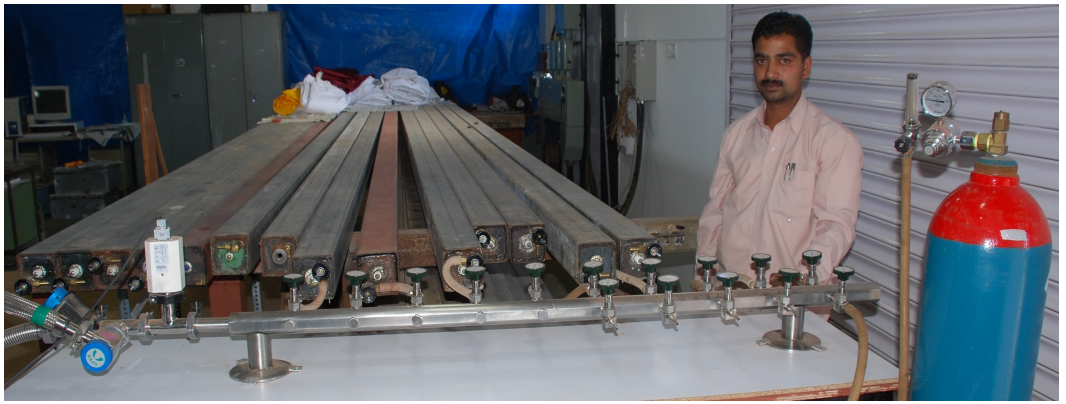


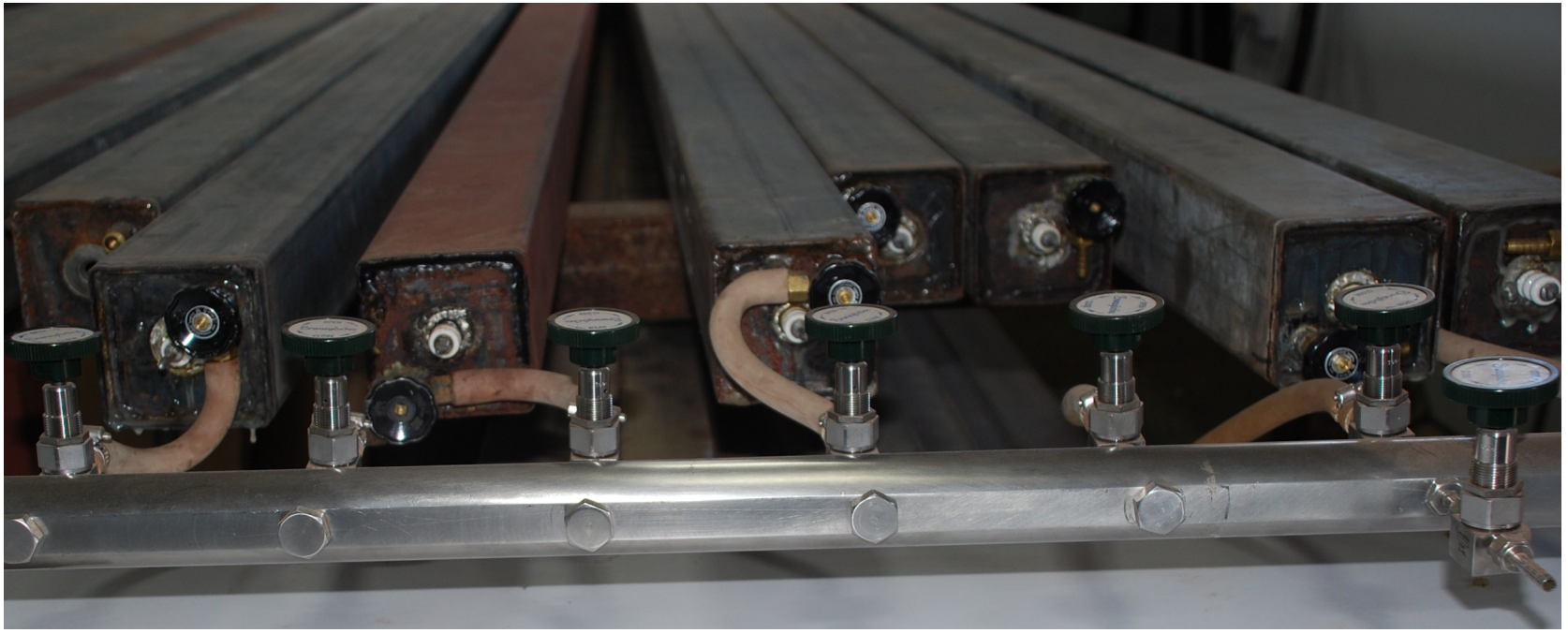


P.K. Mohanty et al. Rev. Sci. Instr. **83** 043301 (2012)

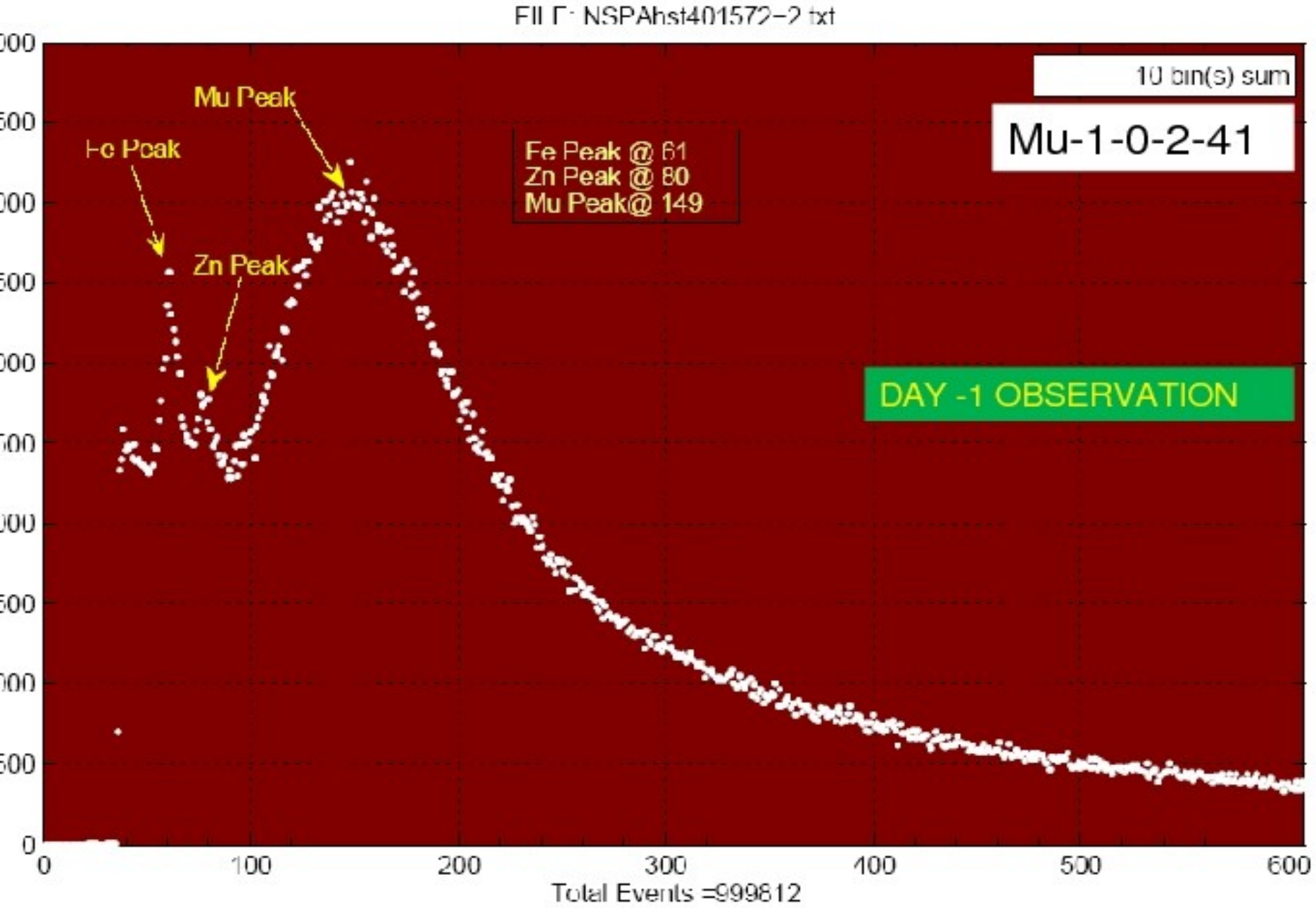








Proportional Counter Test Setup

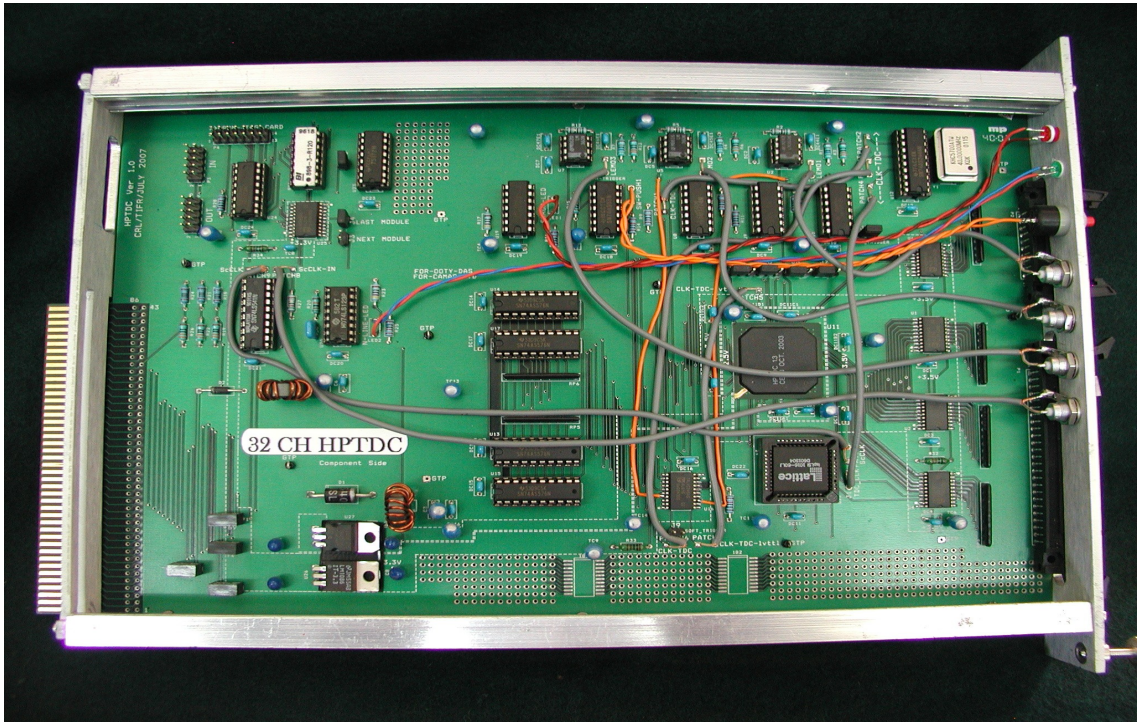

Mu Peak
Fe Peak
Zn Peak
Fe Peak @ 61
Zn Peak @ 80
Mu Peak@ 149
10 bin(s) sum
Mu-1-0-2-41
DAY -1 OBSERVATION
0
100
200
300
400
500
600
Total Events =999812

Performance of HPTDC (Stop Watch)

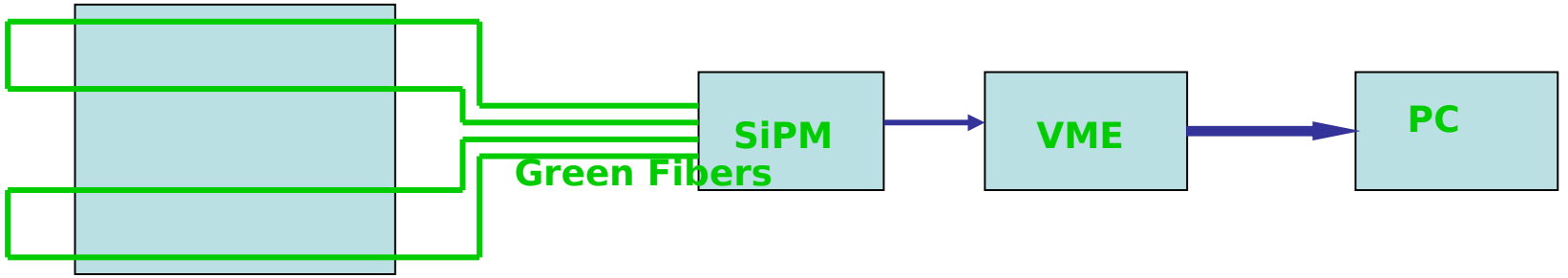
32 Channels
100 ps time resolution
Multi-hit capability
Huge dynamic range (100 ps - 50 μs)
Trigger mode (avoids delay cables)

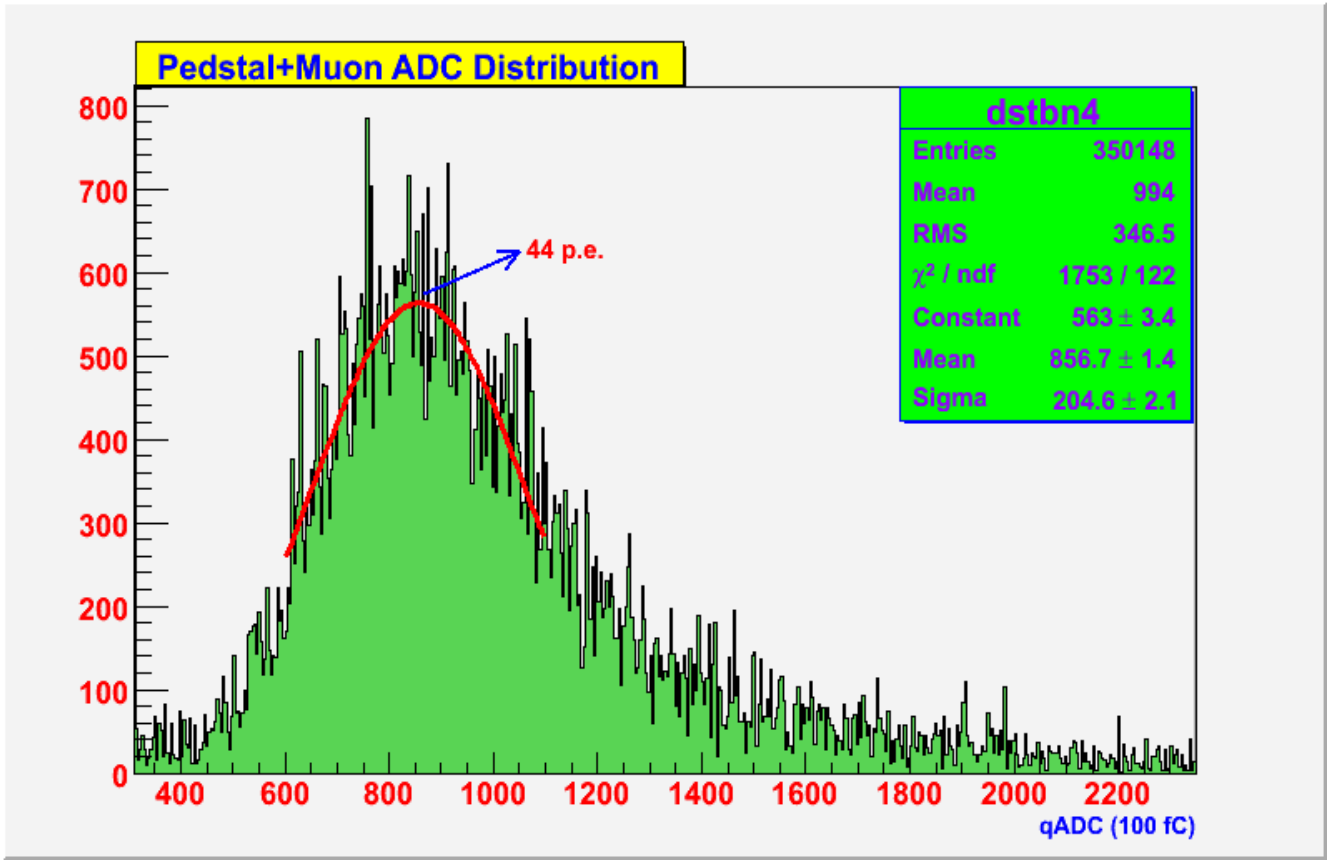
Requests: Atomic, Chemistry, Biology in TIFR, Oulu Finland, IUAC Delhi, Bose Institute, BARC etc.

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



Muon Signal with SiPM





Scintillator Size
25x25x1 cm^3

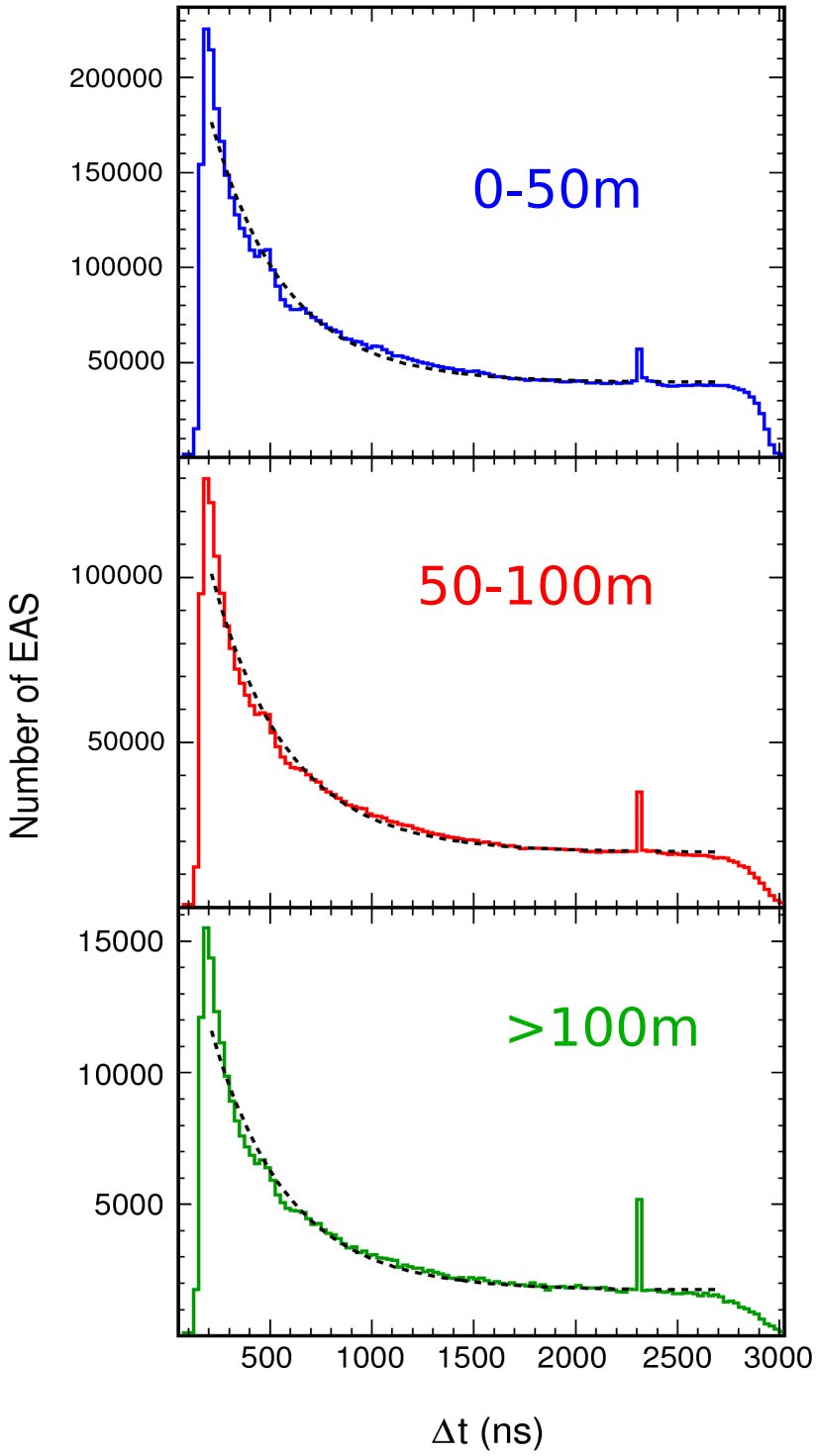
Ped. Peak = 90.3
Single p.e.= 17.4
p.e. at peak = 44
p.e. at mean ~ 50

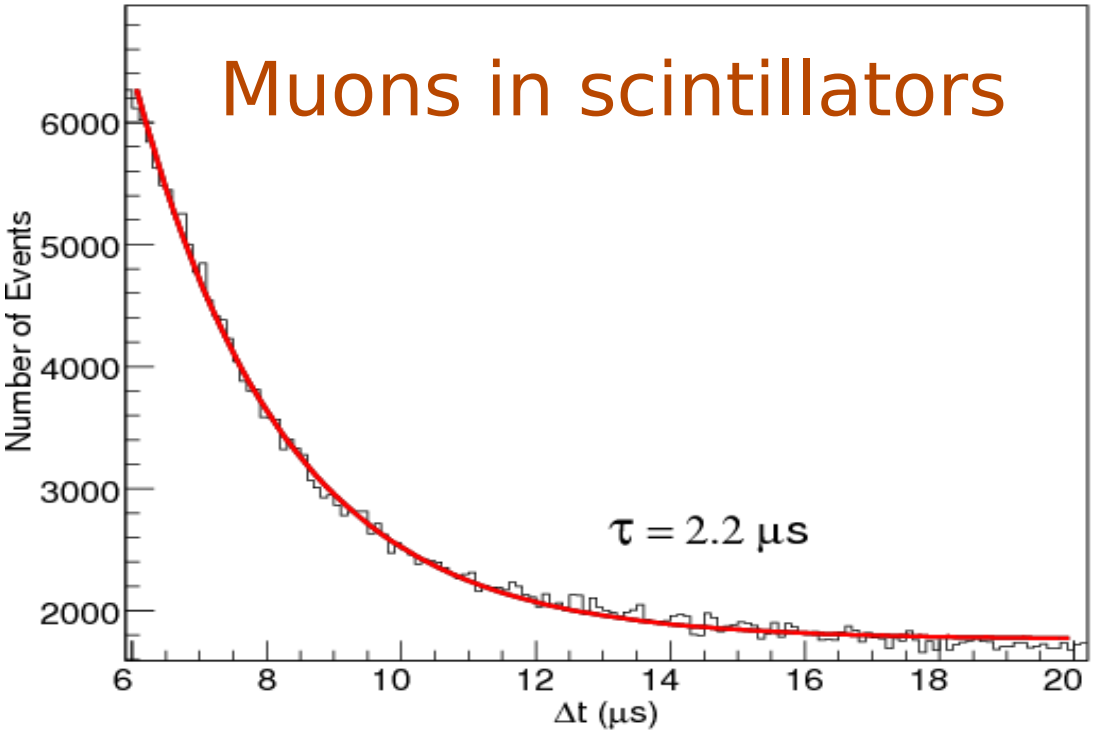
QE: SiPM=3xPMT

Recent results

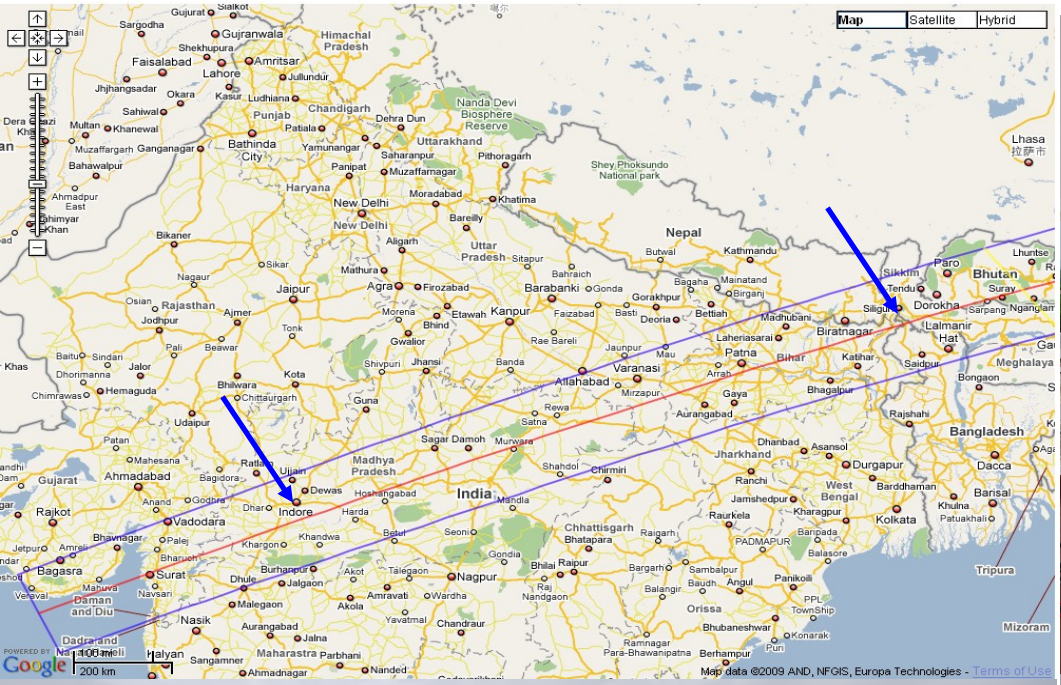
EAS neutrons in scintillator detectors

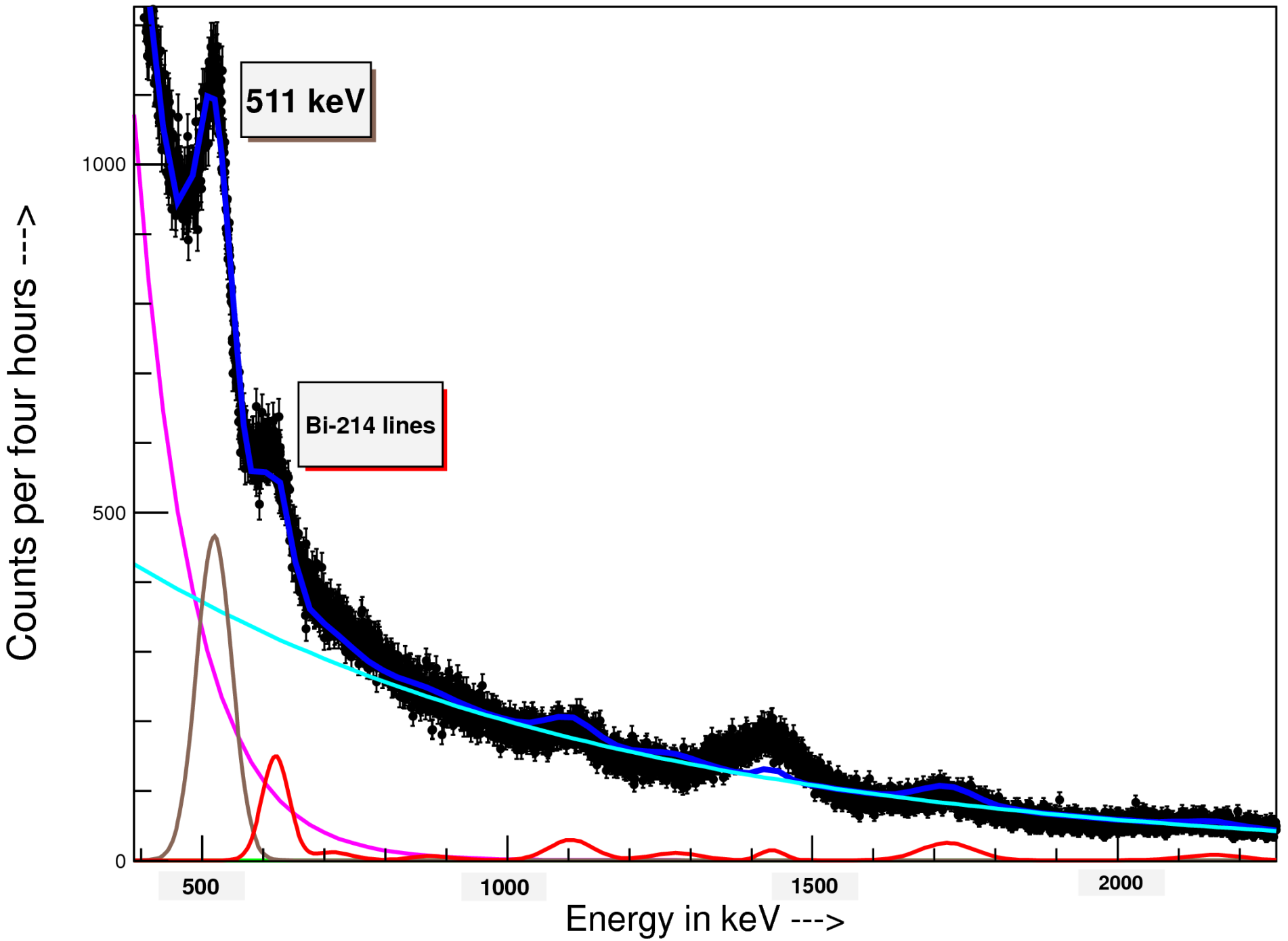
Multi-hit = 2

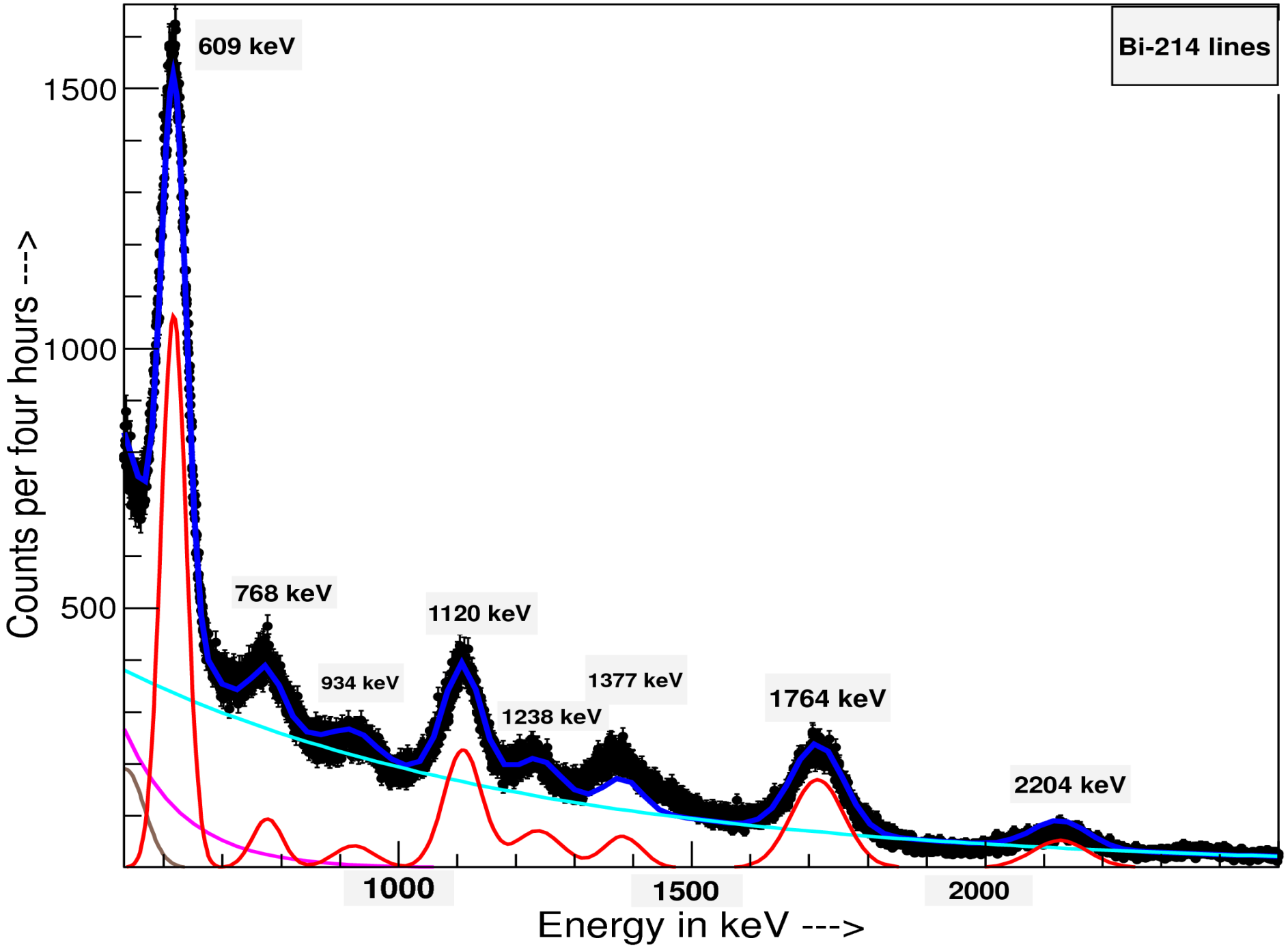




γ-ray variation during total solar eclipse, 22 July 2009




511 keV
Bi-214 lines
1000
500
0
500
1000
1500
2000
Counts per four hours --->
Energy in keV --->


Bi-214 lines
609 keV
768 keV
934 keV
1120 keV
1238 keV
1377 keV
1764 keV
2204 keV
1500
1000
500
Counts per four hours --->
1000
1500
2000
Energy in keV --->

Summary of recent results

1. Muon detection efficiency calculated to 99.99%

2. Uninterrupted data in 2006, possibly for 2001-12
   Higher harmonics up to Fourth detected

3. Muon angular distribution sensitive to H.E. models
   (EPOS1.99, QGSJet-II, SIBYLL-2.1)

4. Muon angular distribution sensitive to L.E. models
   (FLUKA, GHEISHA, UrQMD)

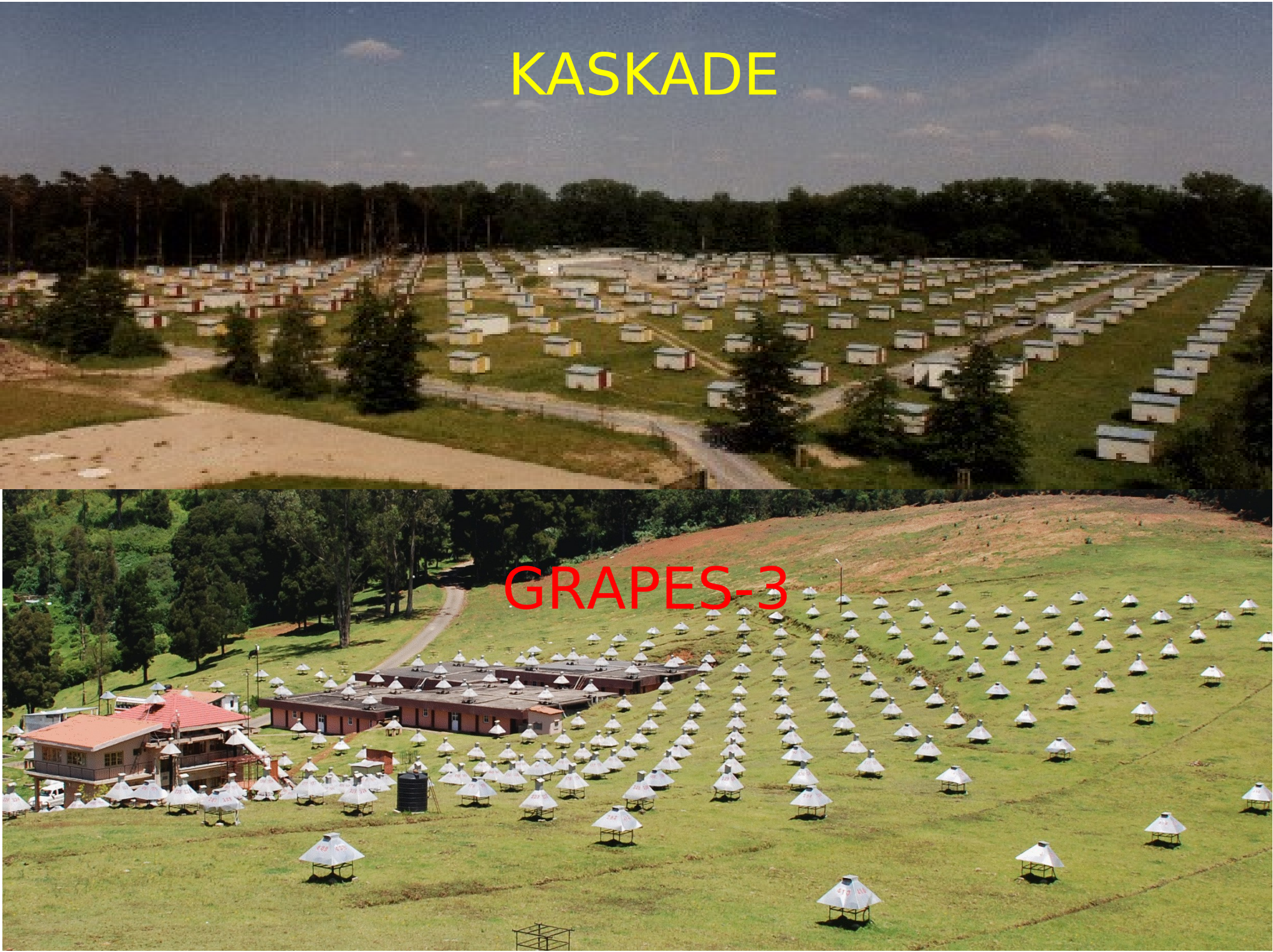
5. Global anisotropy seen, bridging both hemispheres

6. Detection of neutrons in EAS through scintillators

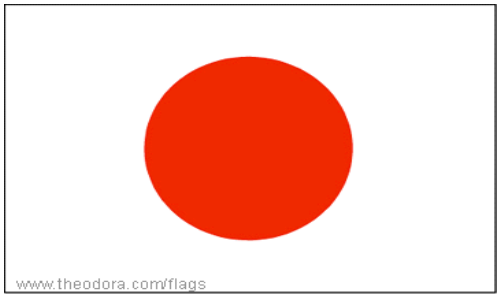
7. Precision measurement of Swinson flow

NEXT WAPP at GRAPES-3 Ooty December 2014

THANKS


KASKADE
GRAPES-3

KASKADE and GRAPES-3



1. Tracking muon detectors with high efficiency, large area

2. Similar arrays but with different elevations (0, 2200m)

3. Capture EAS at different stages of development thus provide complementary information

4. Should be able to nail composition with greater precision than any one single experiment could


THANKS

VIIT, Pune and GRAPES-3 joint R&D activity

Hardware Projects GRAPES-3 and E&TC dept.

(1) SiPM design using SILVACO
(2) 64 channel FPGA based scalar with ethernet readout
(3) 32 channel FPGA based scalar and pulse width with USB
(4) Monitoring 1000 channels of HV using ethernet
(5) Programmable power supply (100 V)
(6) Solar energy generation

Software Projects: GRAPES-3 and Computer Science dept.

(7) Development of web-tools for remote processing of data
(8) Web based database management of calibration and other data
(9) Development of web-based tools for monitoring of experiment
(10) CORSIKA simulations using parallel processing

Participation during 2013-14:

VIIT:	10 faculty, 37 B.E. Final students	Total=10+37
GRAPES-3:	4 faculty, 4 scientific, 2 JRF	Total=10

N

W	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	E
-6	112.0	107.0	99.0	94.4	93.8	93.9	95.9	97.5	101.3	107.3	116.6	127.6	140.8	
-5	105.1	97.6	91.5	87.4	86.4	85.2	87.2	90.5	94.4	100.6	107.7	118.9	131.0	
-4	96.6	89.7	83.4	80.6	78.1	78.7	80.2	83.4	88.0	94.2	102.3	112.9	122.9	
-3	90.3	83.6	78.3	74.4	72.5	72.6	74.3	77.9	82.6	89.5	97.6	107.6	117.6	
-2	87.5	80.5	74.3	70.1	68.3	68.3	70.1	73.4	78.4	85.6	94.0	104.6	115.9	
-1	85.8	78.7	72.0	67.9	66.0	65.9	67.4	71.1	76.2	83.1	92.2	102.5	112.8	
0	85.3	77.6	71.4	67.1	64.9	64.9	66.4	69.9	75.0	82.6	91.4	102.1	113.8	
1	85.3	78.4	72.0	67.7	65.6	65.2	67.0	70.4	75.7	82.7	91.2	102.5	112.8	
2	87.5	79.9	73.8	69.9	67.3	67.4	68.8	72.2	77.1	83.9	92.8	103.5	113.6	
3	91.6	83.6	76.8	73.3	71.0	71.4	72.6	75.6	80.5	86.7	95.5	105.3	115.2	
4	95.8	89.1	82.3	78.5	76.7	76.5	77.9	81.2	85.2	91.5	98.3	108.5	120.2	
5	104.8	95.5	88.4	85.2	83.4	83.1	84.9	86.9	91.1	96.8	106.0	116.1	130.8	
6	109.5	103.9	97.0	92.8	90.3	90.1	92.1	94.6	97.8	104.3	113.0	124.3	139.5	

S