COMPARATIVE ANALYSIS OF DATA FROM NEUTRON AND MUON DETECTORS AT ANTARCTICA

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WHAT ARE COSMIC RAYS ?

- High Energy particles or γ-rays from space
- sources of cosmic rays :
  - from solar winds, solar storms → solar energetic particles
  - from supernova explosions inside the Galaxy → galactic cosmic rays
  - from gamma-ray bursts (GRBs), AGN outside the Galaxy → extragalactic cosmic rays

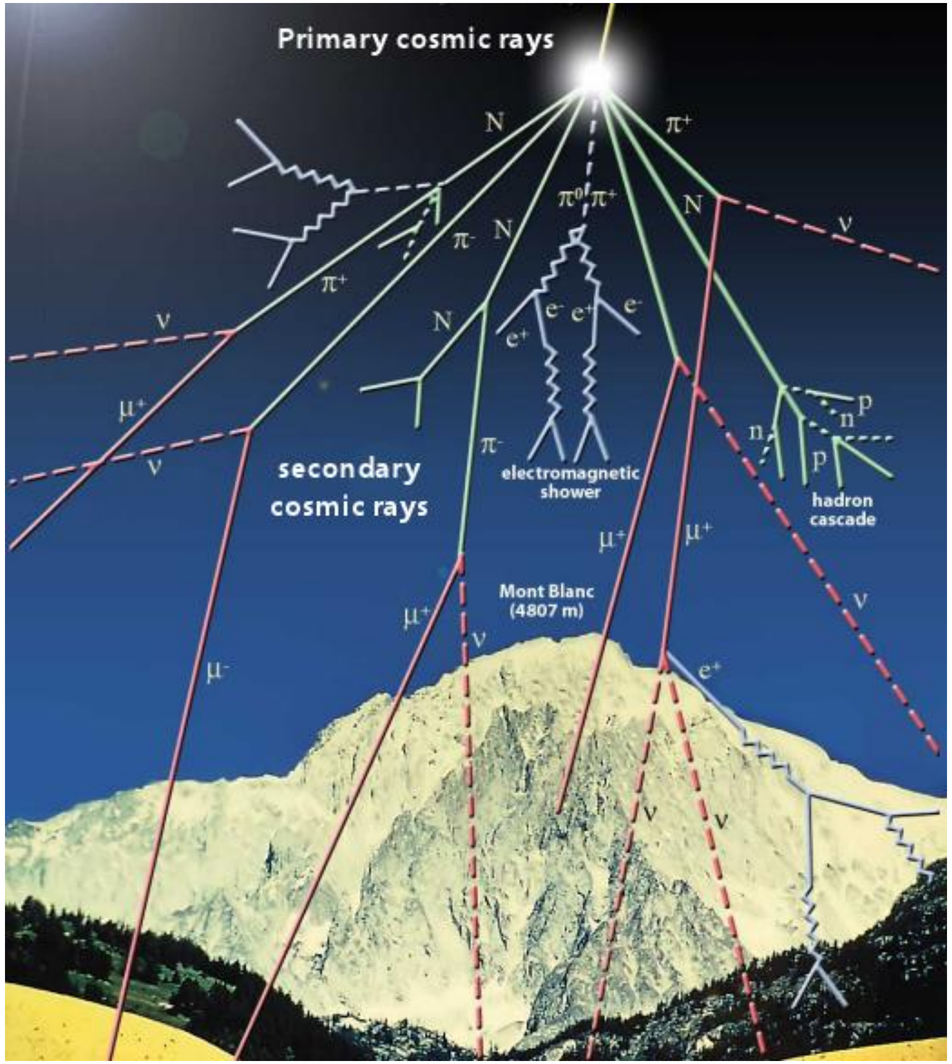
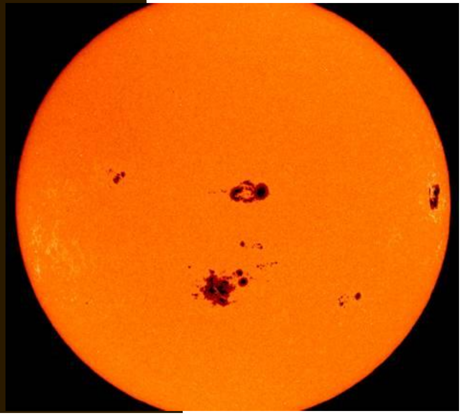


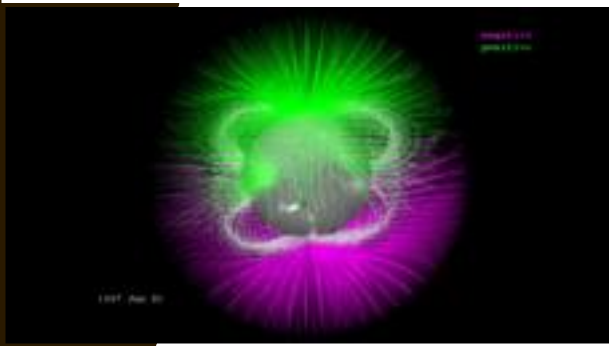
Fig 1. Schematic diagram of a cosmic ray air shower. (Credit: CERN)

SOLAR MODULATION



Credit: NASA

Credit: NASA/GSFC/PFSS



(Poopakun et al., 2021)

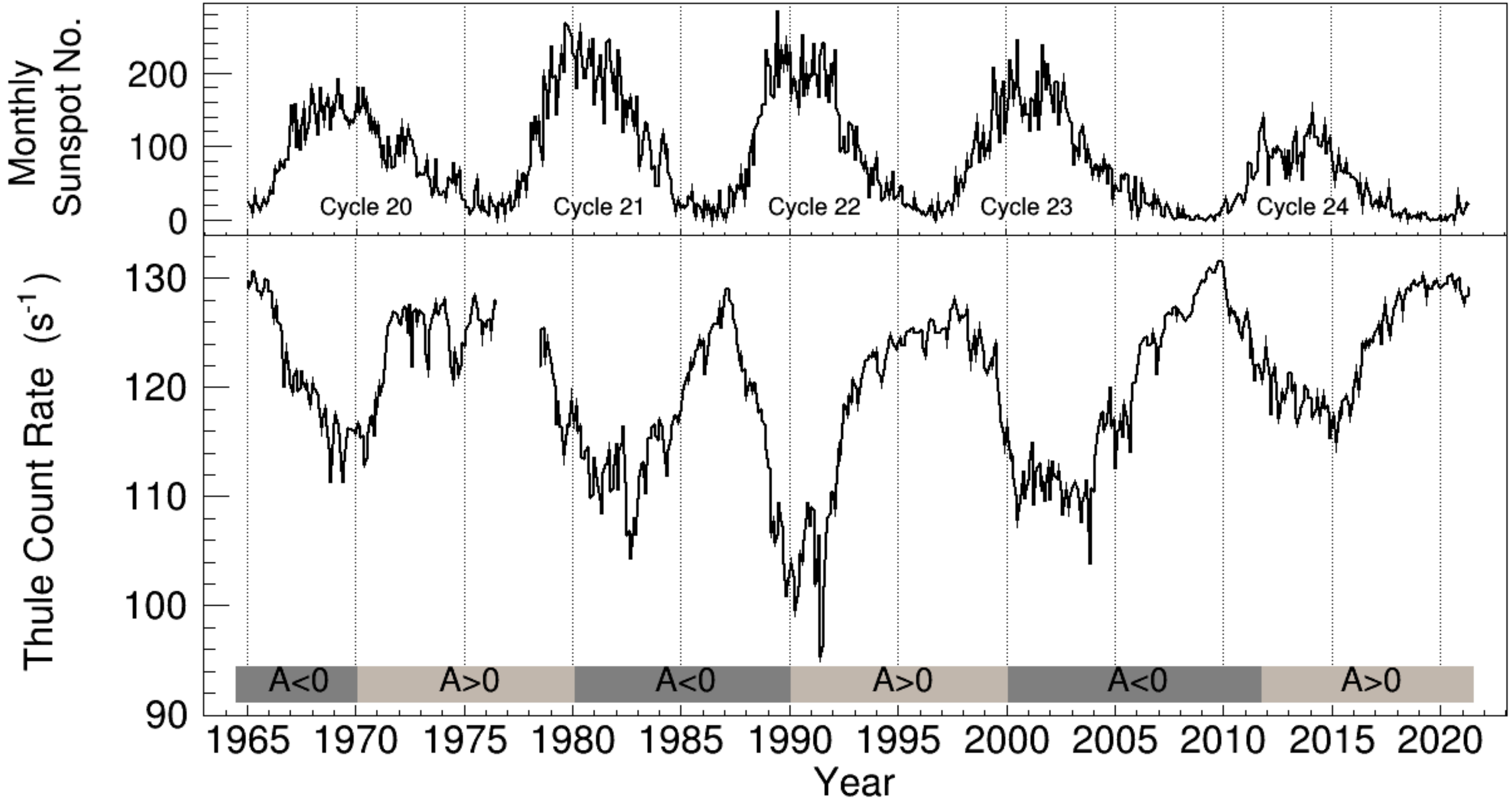


Fig 2. Solar modulation : As solar activity rises (top panel, Source: WDC-SILSO Royal Observatory of Belgium, Brussels), the pressure-corrected count rate recorded by the neutron monitor in Thule decreases (bottom panel, Source: Bartol Research Institute, University of Delaware, USA). The solar magnetic polarity reversal can be seen between positive (denoted by A > 0) and negative (denoted by A < 0)

SHORT-TERM MODULATION

FORBUSH DECREASE

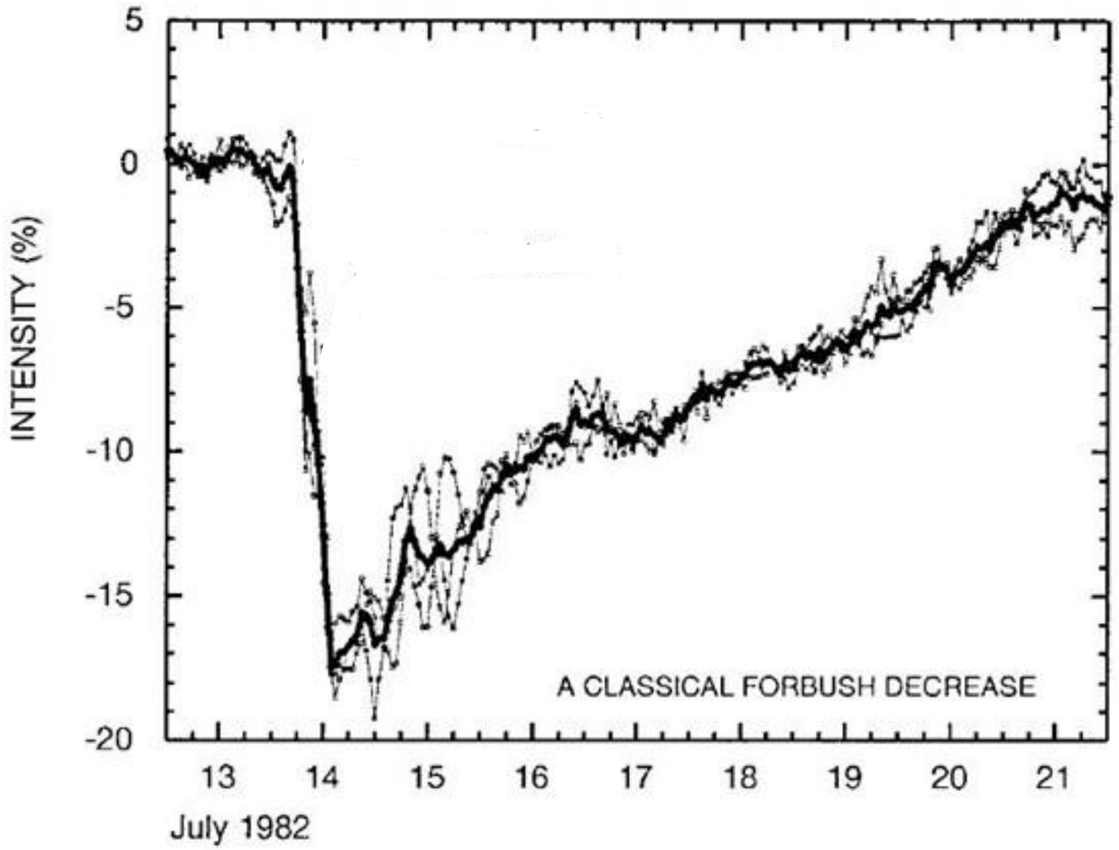


Fig 3. A rapid decrease in the observed galactic cosmic ray intensity

GROUND LEVEL ENHANCEMENT

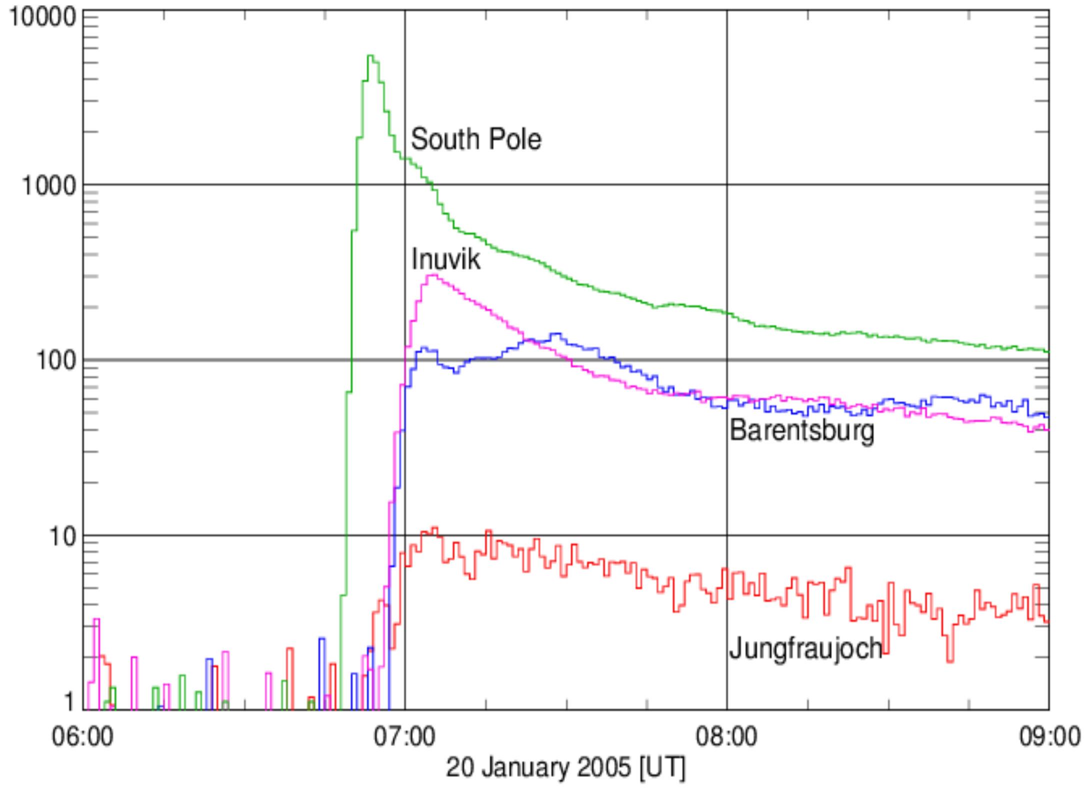


Fig 4. Ground level enhancement onsets at four NM stations recording the event of January 20, 2005 (Flückiger et al., 2005)

CROSSOVER

(Moraal et al.,1989)

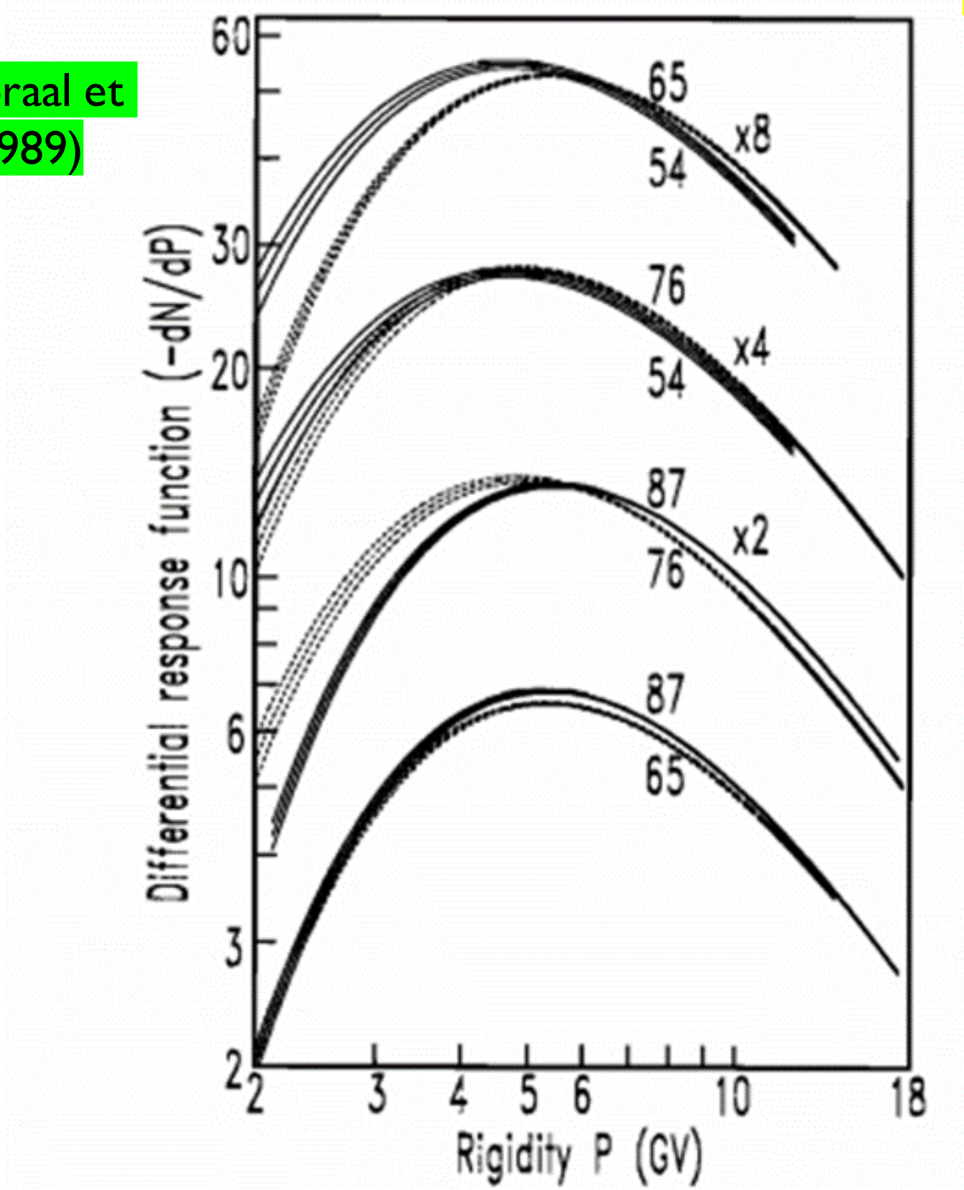


Fig 5. Differential response functions (Moraal et al.,1989)

(Nuntiyakul et al., 2014)

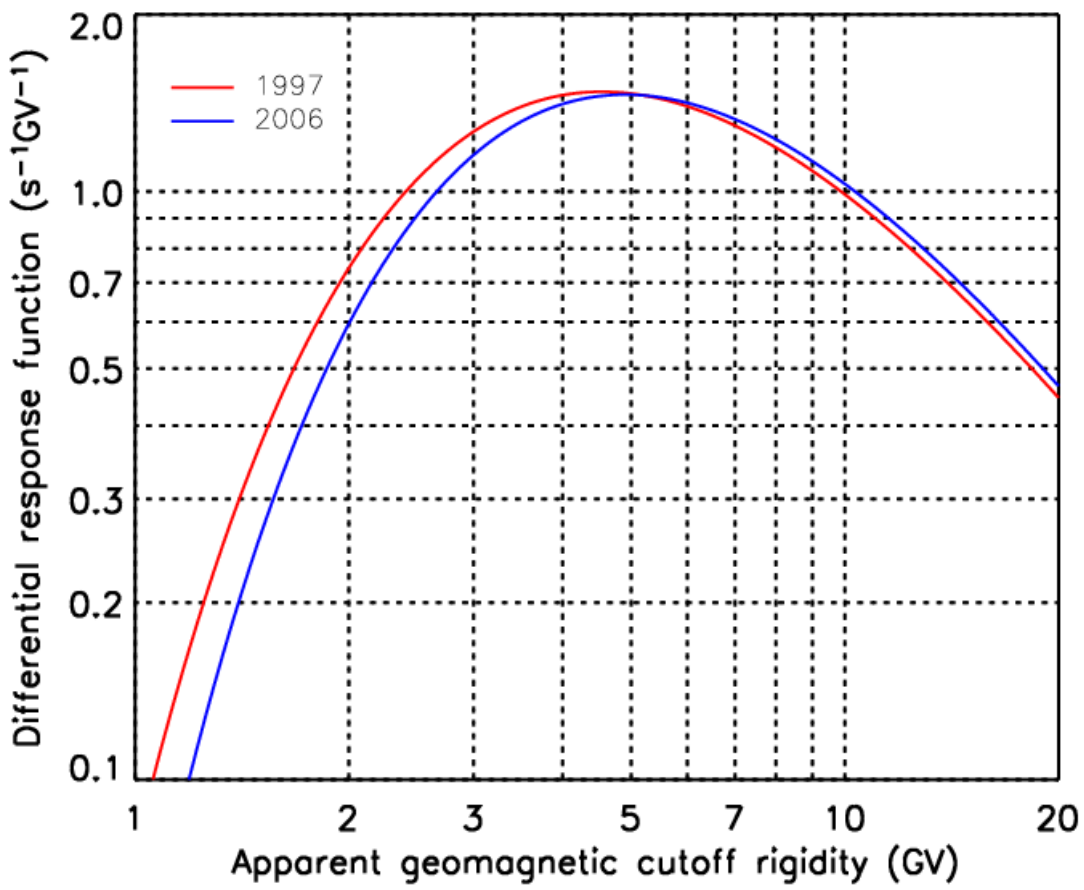
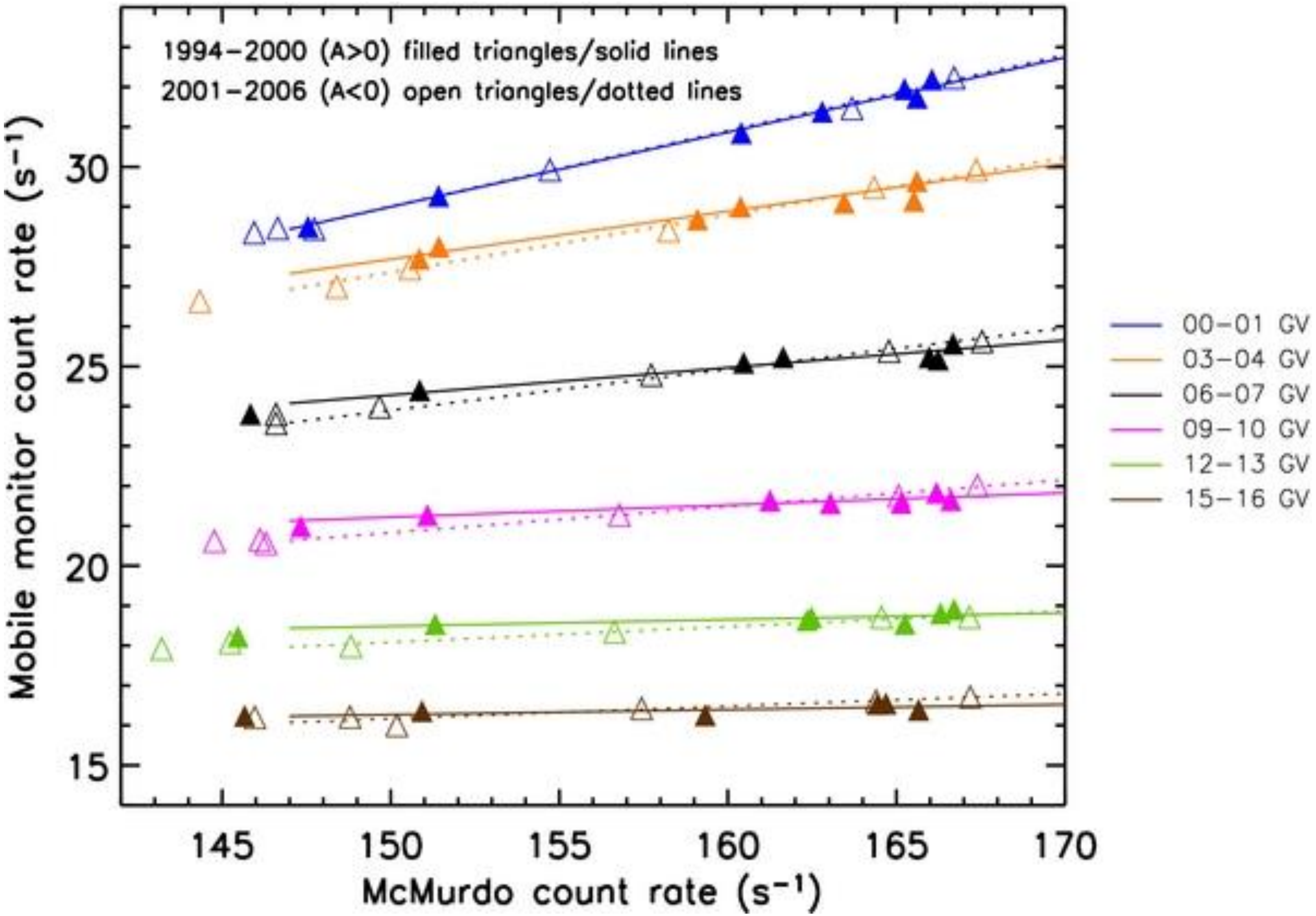


Fig 6. Differential response functions for two survey years, near solar minimum, of opposite polarity and similar modulation level. A crossover is apparent at 4.9 GV. (Nuntiyakul et al., 2014)

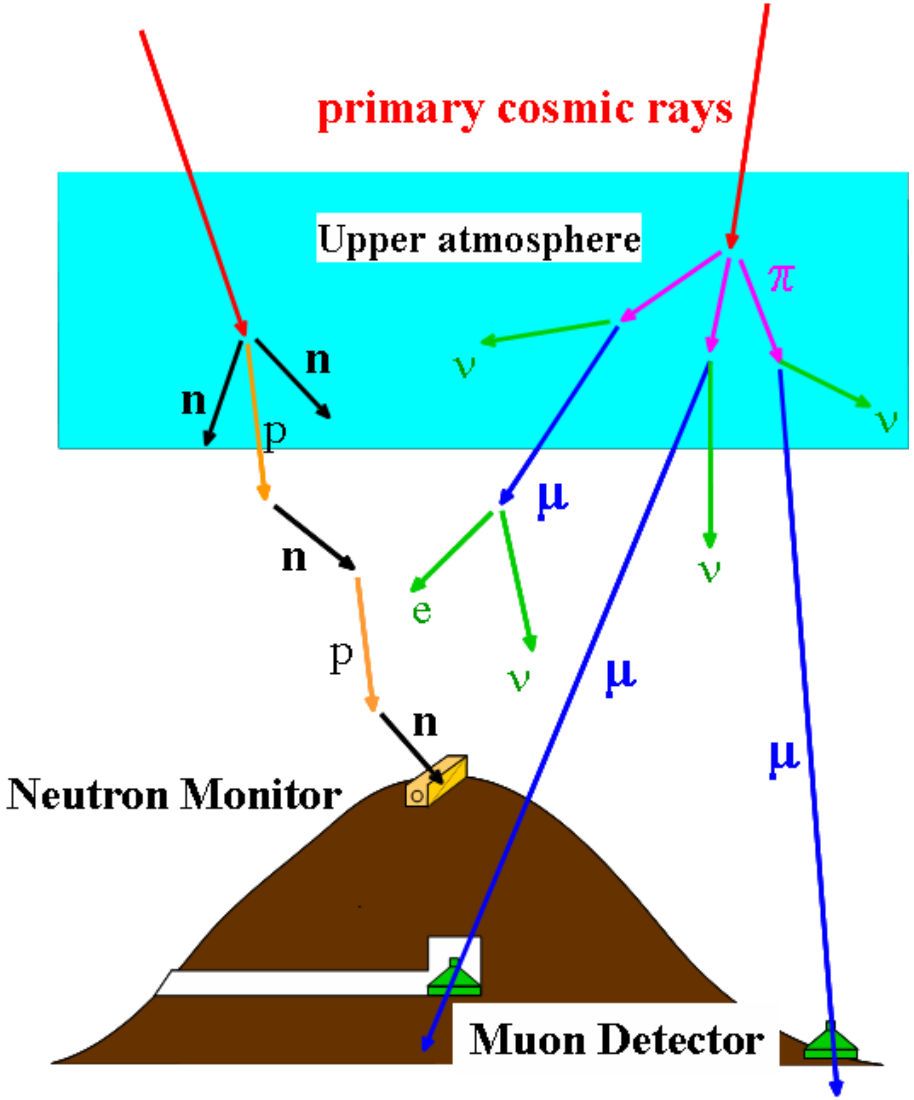
CROSSOVER

Fig 7.

Alternative presentation of the averaged data using selected rigidity bins and superimposing the data for different solar magnetic polarities. A filled triangle is used to indicate positive (A > 0) solar magnetic polarity with solid lines showing the linear fits. Open triangles indicate data for negative (A < 0) solar magnetic polarity while the dotted lines are linear fits to these data. There are clear differences in cosmic ray modulation before and after the solar magnetic polarity reversal. (Nuntiyakul et al., 2014)



OBSERVATION OF COSMIC RAYS WITH GROUND-BASED DETECTORS



- Ground-based detectors measure byproducts of the interaction of primary cosmic rays with Earth's atmosphere
- Two common types:

  Neutron Monitor

  Typical energy of primary: ~1 GeV for solar cosmic rays,

  ~10 GeV for Galactic cosmic rays

  Muon Detector

  Typical energy of primary:~50 GeV for Galactic cosmic rays (surface muon detector) and greater for underground muon detector

(Adapted from Ground-Based Cosmic Ray Detectors for Space Weather Applications slide, Bieber, 2011)

AIM OF THIS STUDY

- To analyze linear regression of the mobile neutron monitor count rates during the years 1994-2007 and 2018-2020 against Mawson neutron monitor count rates. We are also interested in finding linear regression of the mobile neutron monitor count rate in survey years 2018 and 2019 against Jang Bogo's count rate (installed and operated later in 2016) for comparative purposes with the obtained linear regression against Mawson.
- To use the muon data at Mawson station for different zenith angles to study the spectrum variations.

OBSERVATIONS

LATITUDE SURVEY

Fig 8. 3NM64 installed inside the container for 1994-2007 latitude survey (Nuntiyakul et al., 2014)

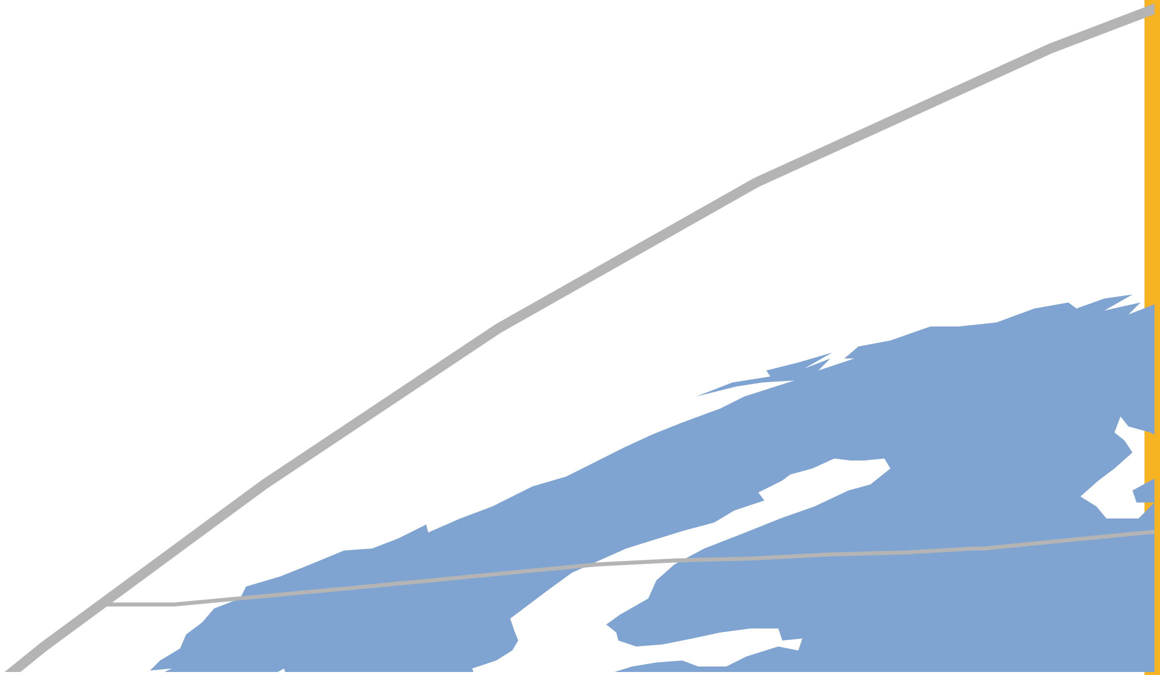
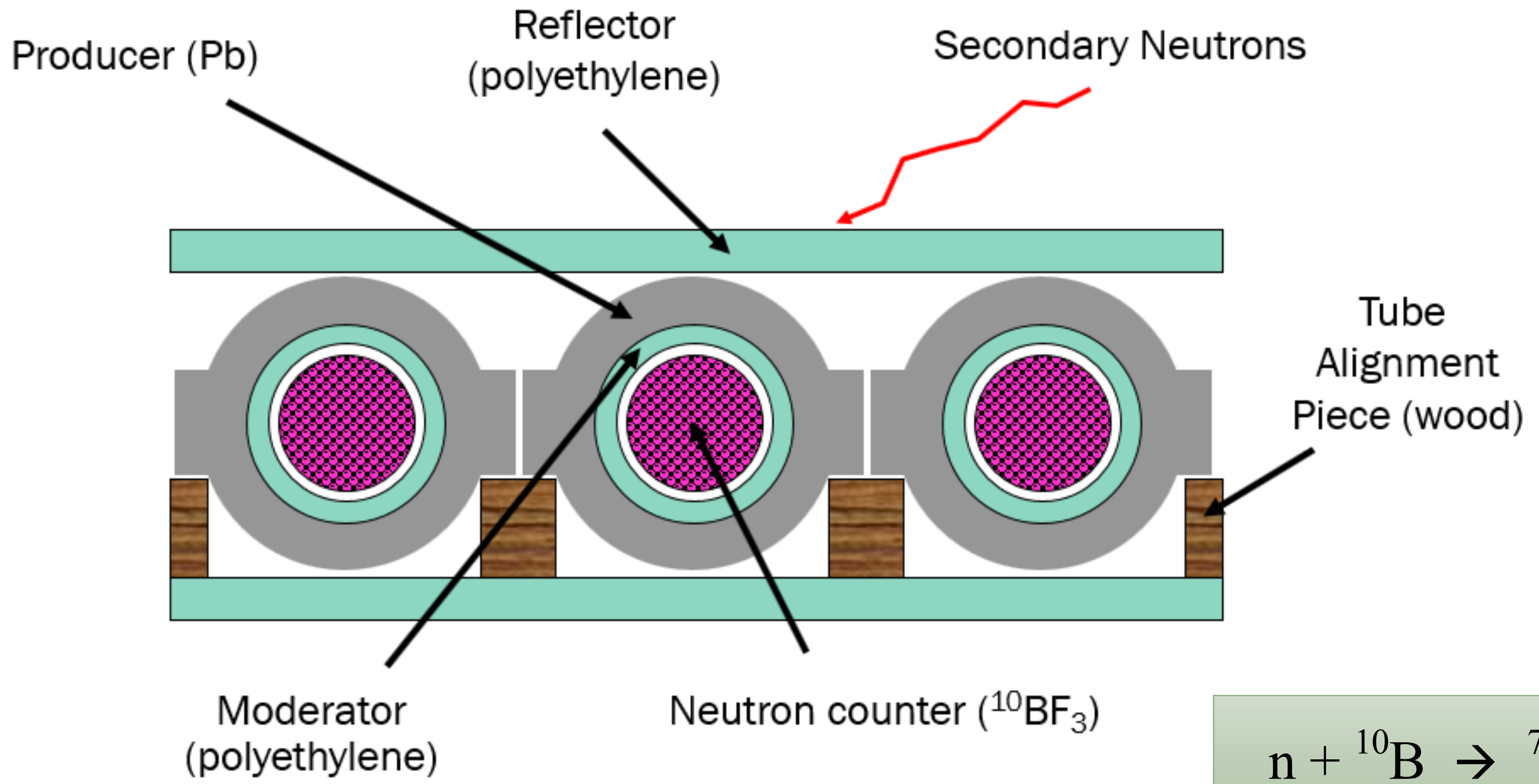


Fig 9 . The track of the ship-borne neutron monitor latitude surveys for 1994-2007 and 2018-2019 superimposed on contours of the vertical cutoff rigidity.

STANDARD NEUTRON MONITOR (NM64)



$$n + {}^{10}B \rightarrow {}^{7}Li + \alpha$$

Fig 10. Standard neutron monitor (3NM64)

(Adapted from NM Bootcamp 2020 slide, Nuntiyakul)

SAMI-LEADED NEUTRON MONITOR

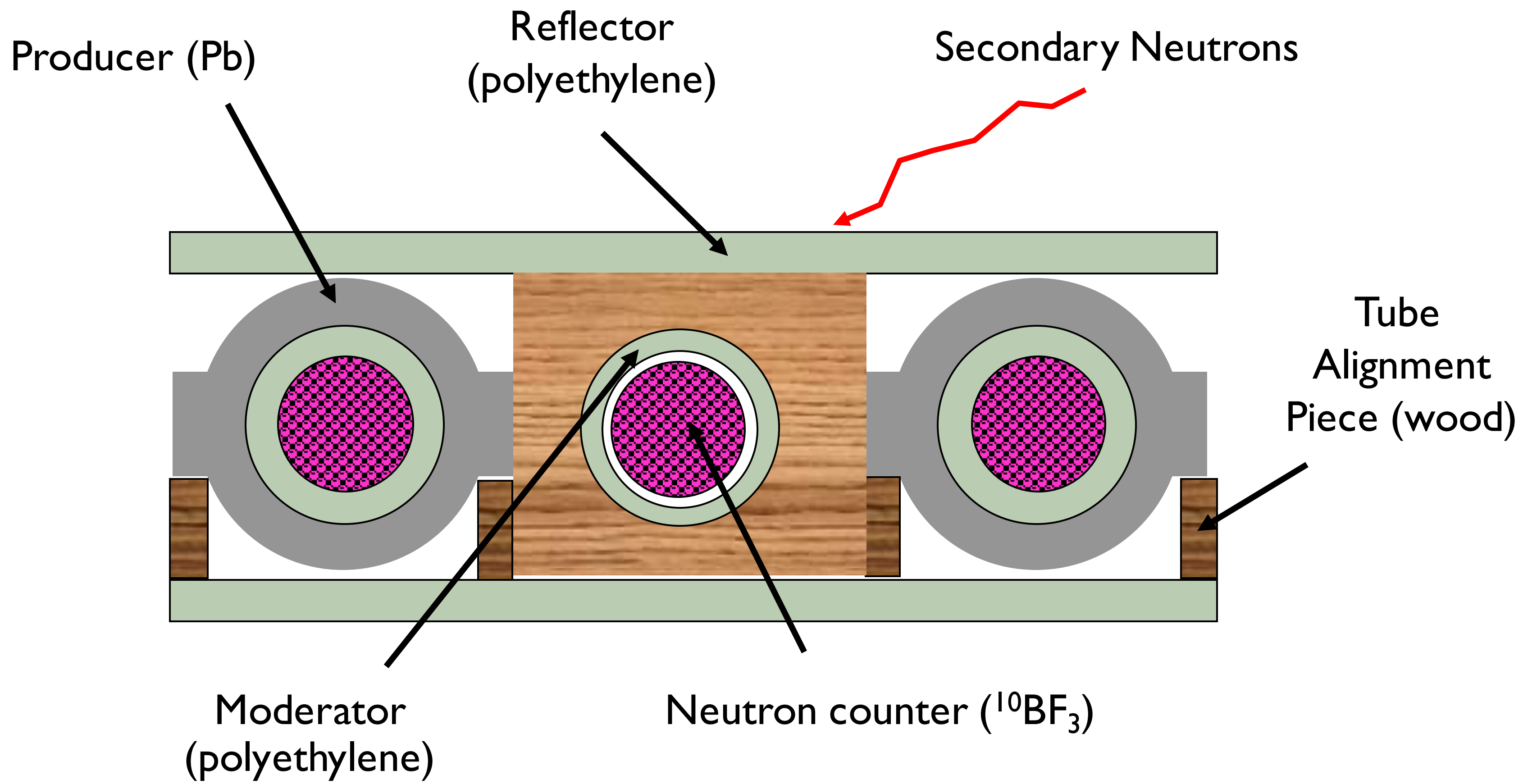
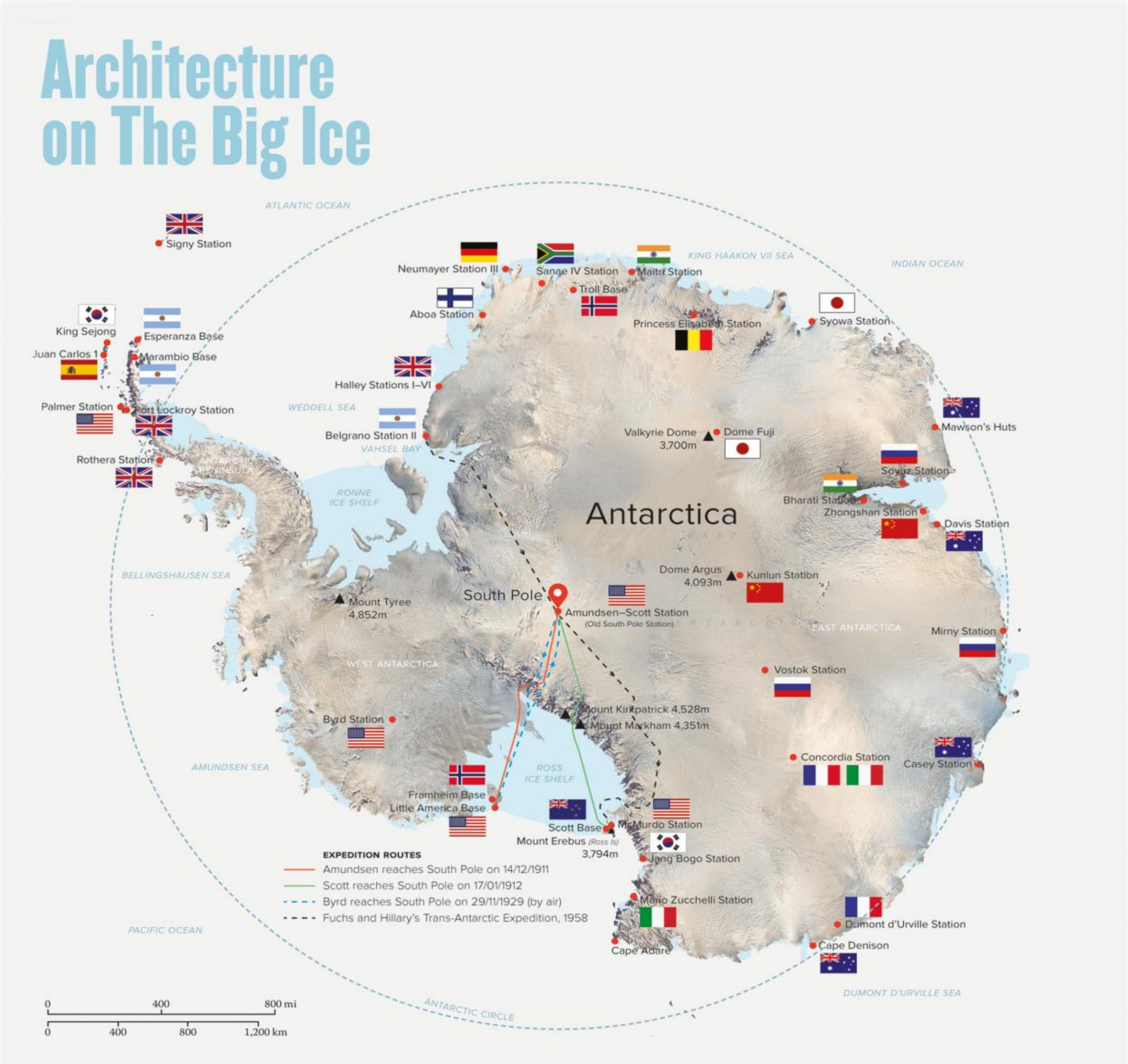


Fig 11. Semi-Leaded Neutron Monitor which used for survey year 2018-2019

NEUTRON DETECTORS AT ANTARCTICA

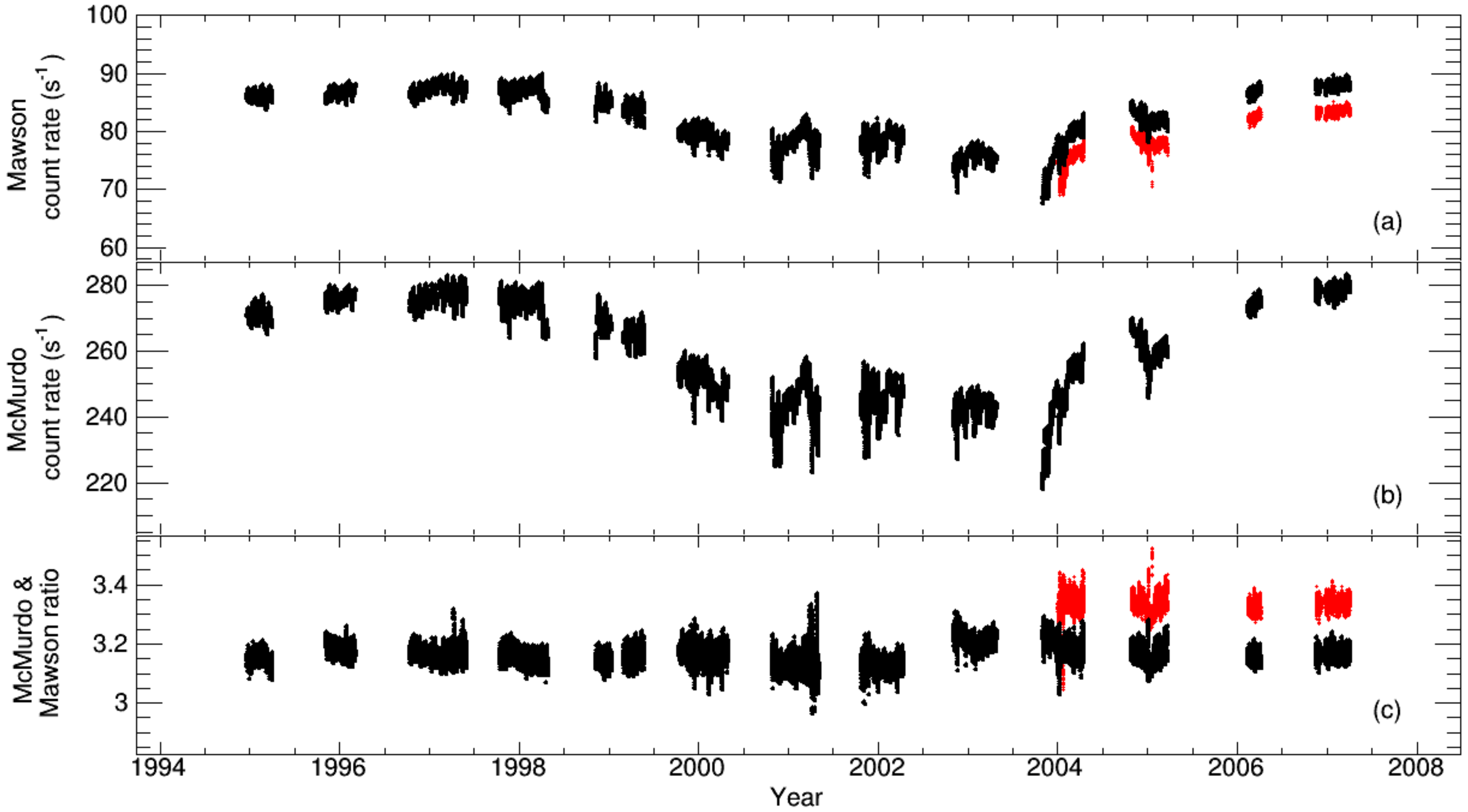


Mawson Station

- Detector Type : Feb 1986 - Oct 2002 - 6NM64
  Oct 2002 - 18NM64.
- Latitude : 67.60S
- Longitude : 62.88E
- Altitude : abount 30 m
- Rigidity (1965) : 0.22 GV

Jang Bogo Station

- Detector Type: 18-tube NM64
- Latitude: 74.6S
- Longitude: 164.2E
- Altitude: 28 m
- Rigidity : <0.3 GV

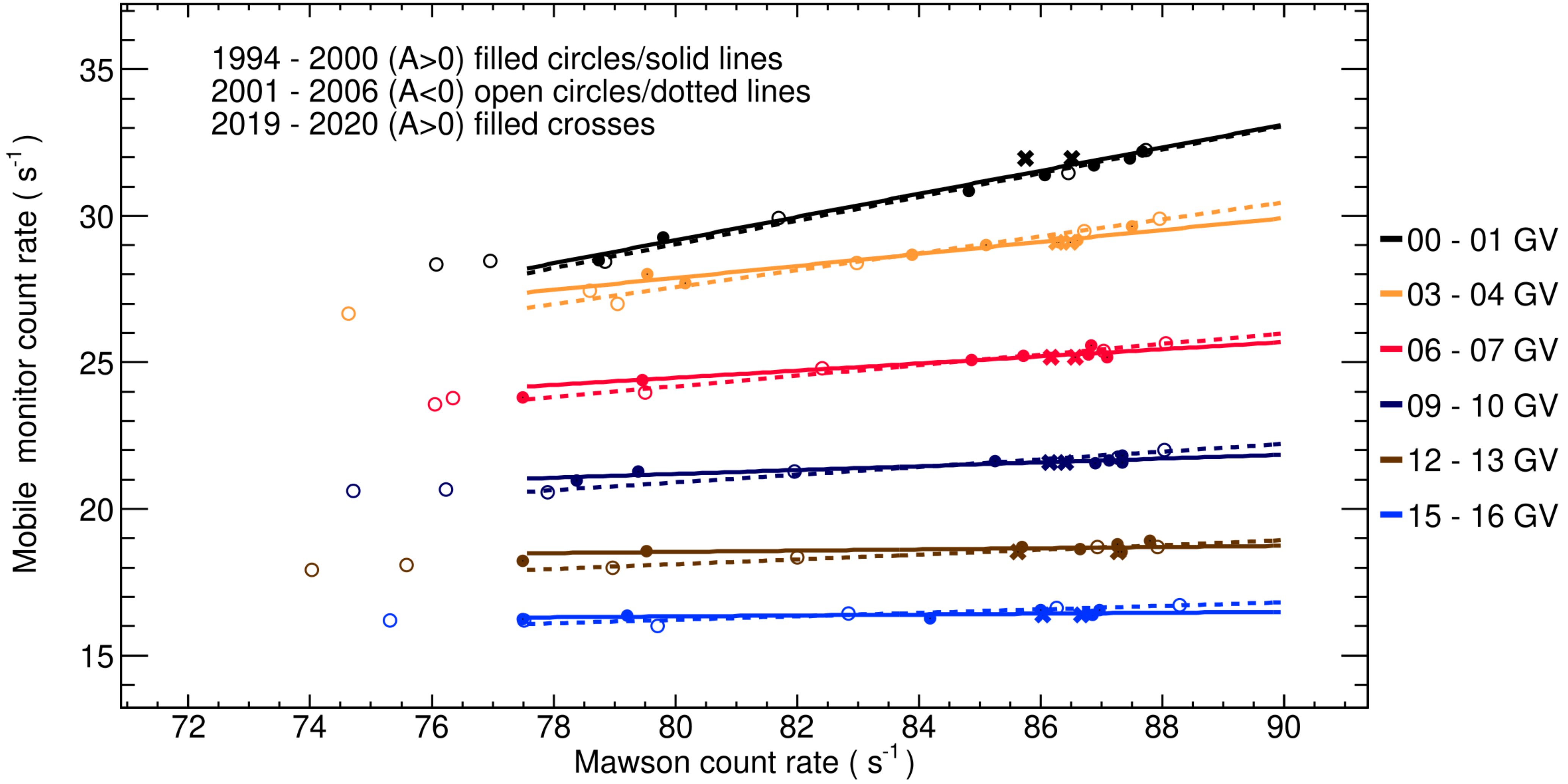


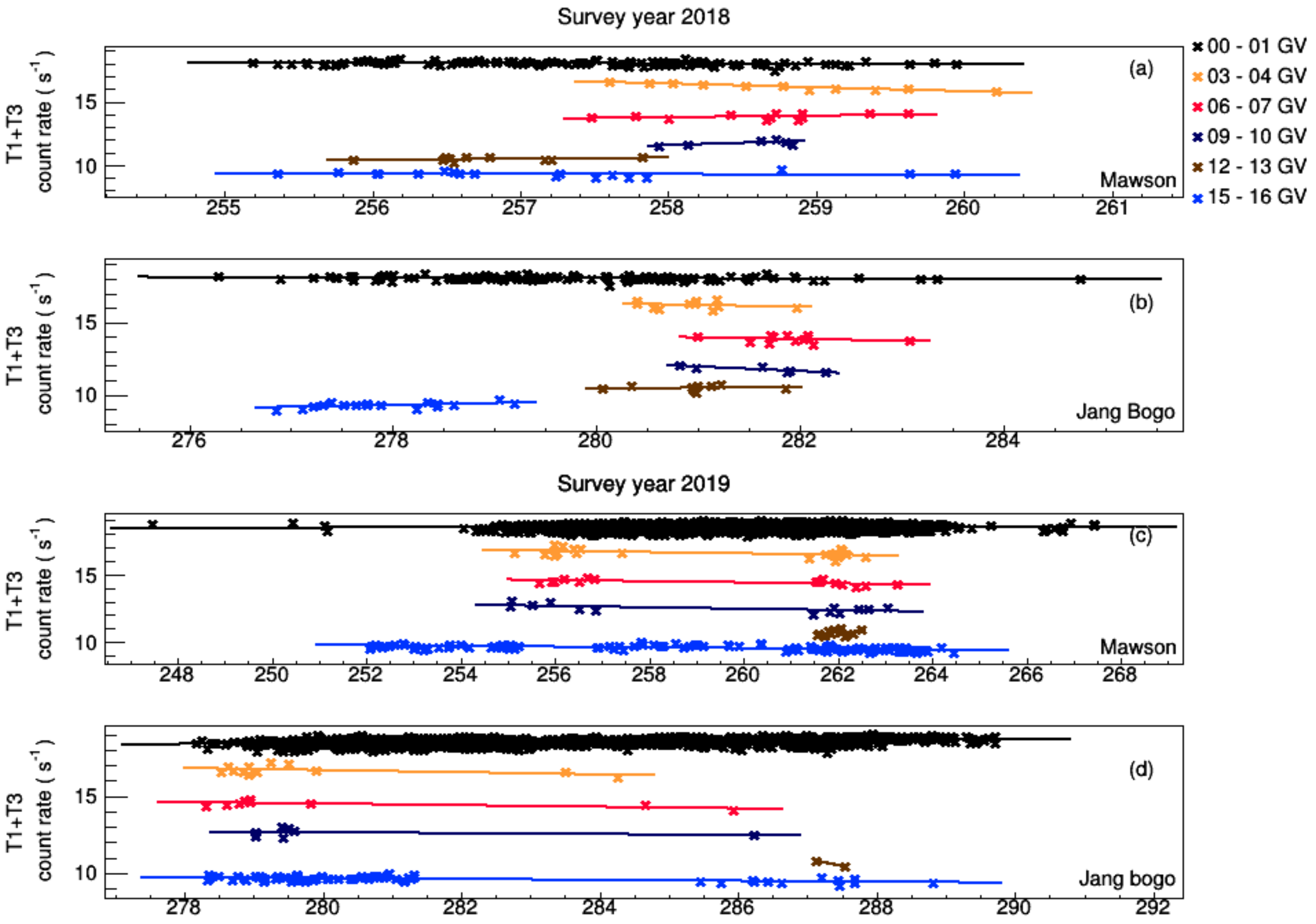
Mawson count rate (s^{-1})
McMurdo count rate (s^{-1})
McMurdo & Mawson ratio
(a)
(b)
(c)
Year

COMPARE CHANGVAN TO 3NM64

- To compare the two tubes in the recent survey years to the 3NM64 in a 13-year survey, we find multiplicative factors from the ratio of 3NM64 1997 /(T1+T3) 2018−2020

- We apply a normalization factor of 1.80 for the survey year 2018 and that of 1.75 for the survey year 2019 to T1+T3.


1994 - 2000 (A>0) filled circles/solid lines
2001 - 2006 (A<0) open circles/dotted lines
2019 - 2020 (A>0) filled crosses
Mobile monitor count rate (s⁻¹)
Mawson count rate (s⁻¹)
00 - 01 GV
03 - 04 GV
06 - 07 GV
09 - 10 GV
12 - 13 GV
15 - 16 GV
15
20
25
30
35
72
74
76
78
80
82
84
86
88
90



Survey year 2018
T1+T3 count rate (s-1)
(a)
Mawson
(b)
Jang Bogo
Survey year 2019
(c)
Mawson
(d)
Jang bogo
00 - 01 GV
03 - 04 GV
06 - 07 GV
09 - 10 GV
12 - 13 GV
15 - 16 GV

(Nuntiyakul et al, 2014)

DRF FOR 1997 (+)AND 2006(-)

$$N = N_0(1 - e^{-\alpha P_c^{-\kappa}}),$$

$$N = \int_{P_c}^{\infty} (\mathrm{DRF})\, dP$$

$$\mathrm{DRF} = N_0 \alpha P^{-\kappa-1} \kappa (e^{-\alpha P^{-\kappa}}),$$

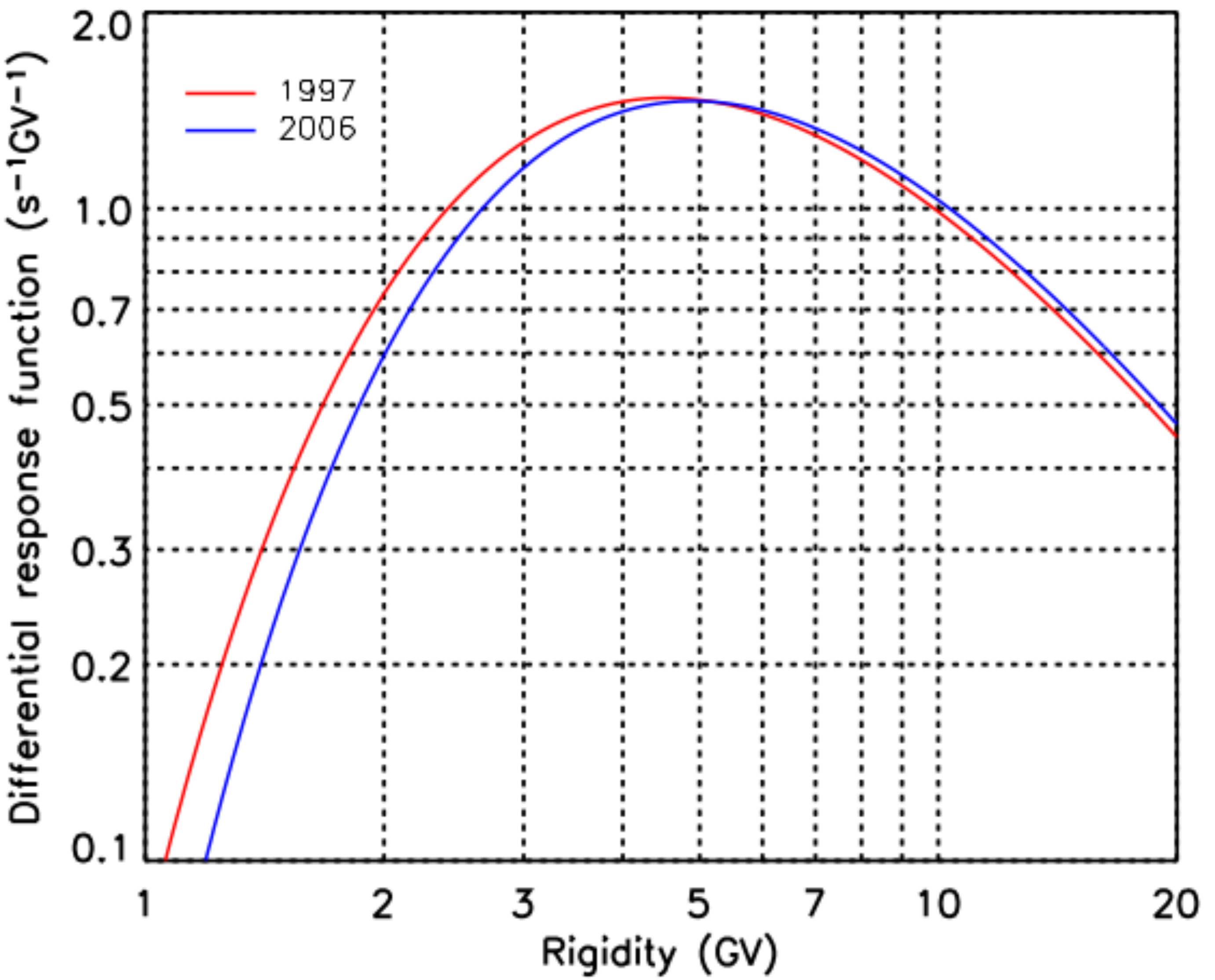
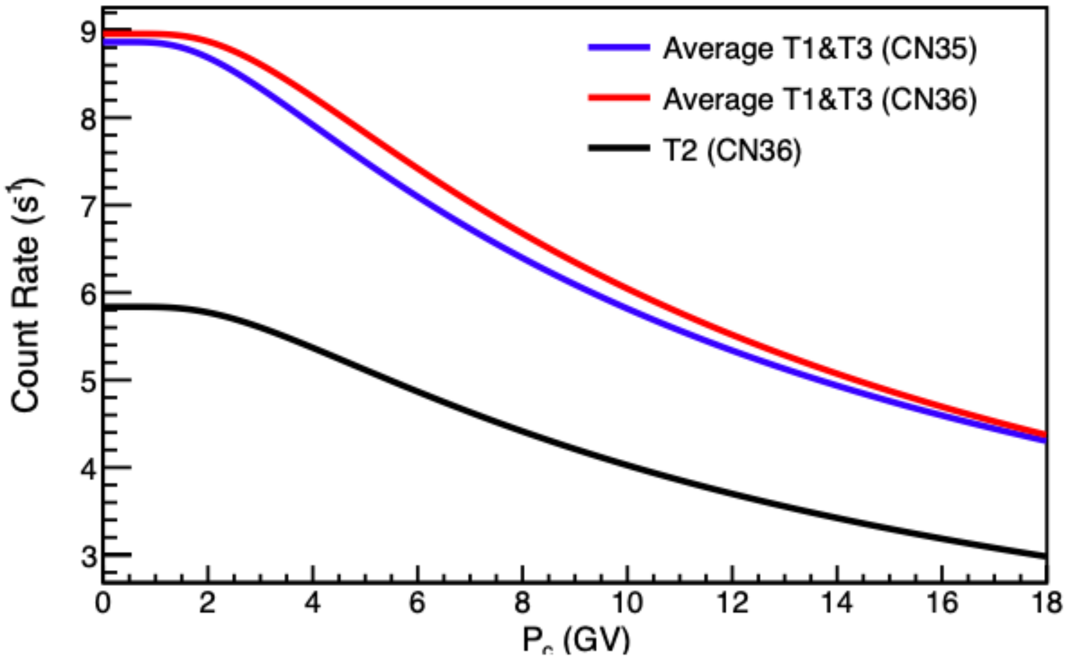


Figure 8. Differential response functions for two survey years, near solar minimum, of opposite polarity and similar modulation level. A crossover is apparent near 5 GV.

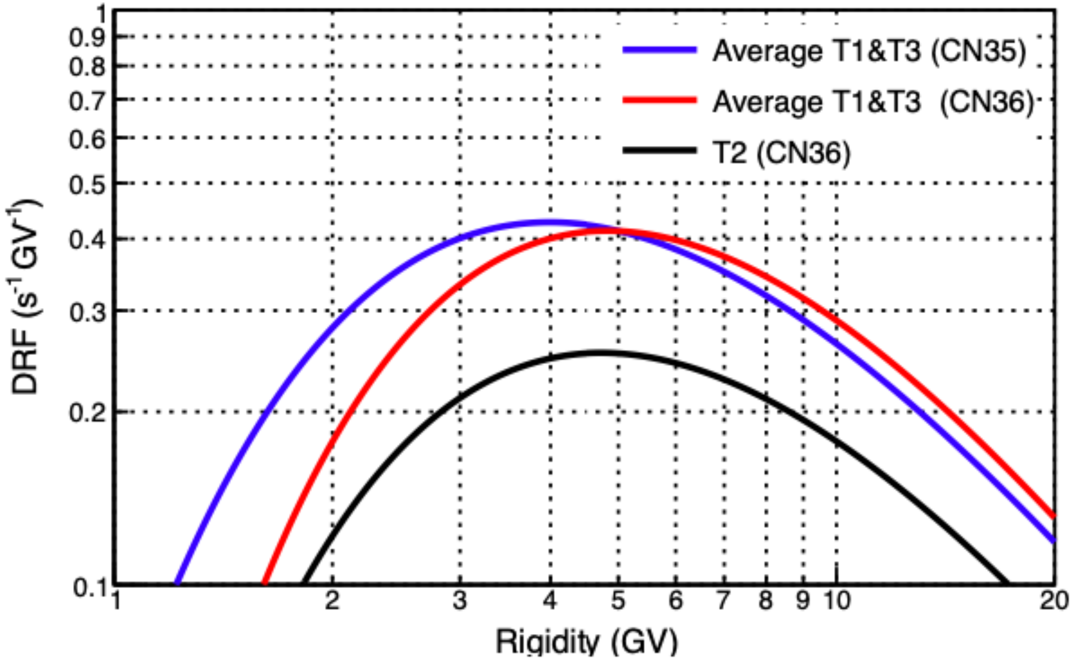
Update Dorman Function 2018-2019 (30Nov21)

- Used Dorman Parameter from yakum et al., 2021->fit data by group data into rigidity bin and find mean value of each bin

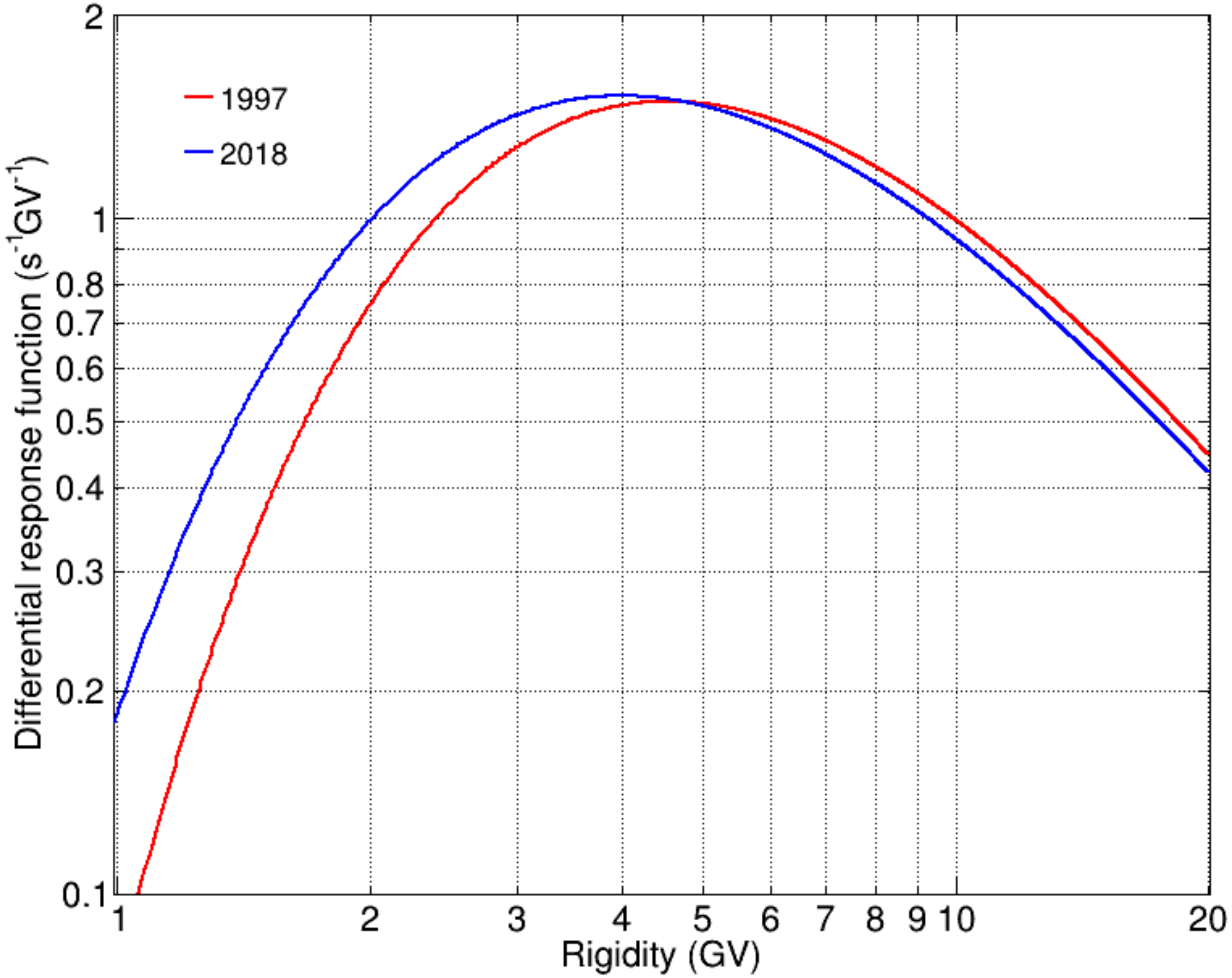
Year	No	alpha	kappa
2018	8.87	6.84	0.807
2019	8.96	8.54	0.881



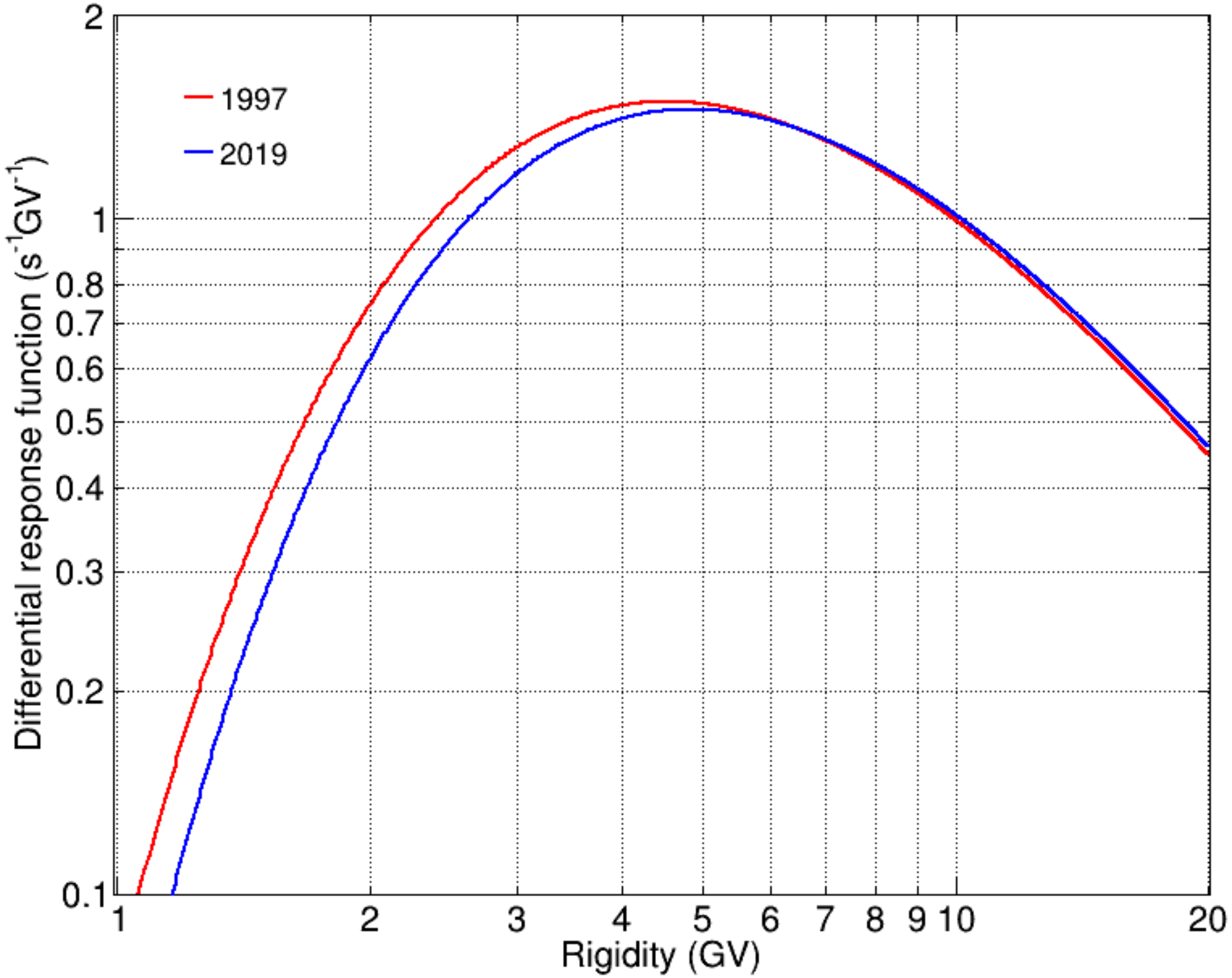
Average T1&T3 (CN35)
Average T1&T3 (CN36)
T2 (CN36)
Count Rate (s-1)
Pc (GV)



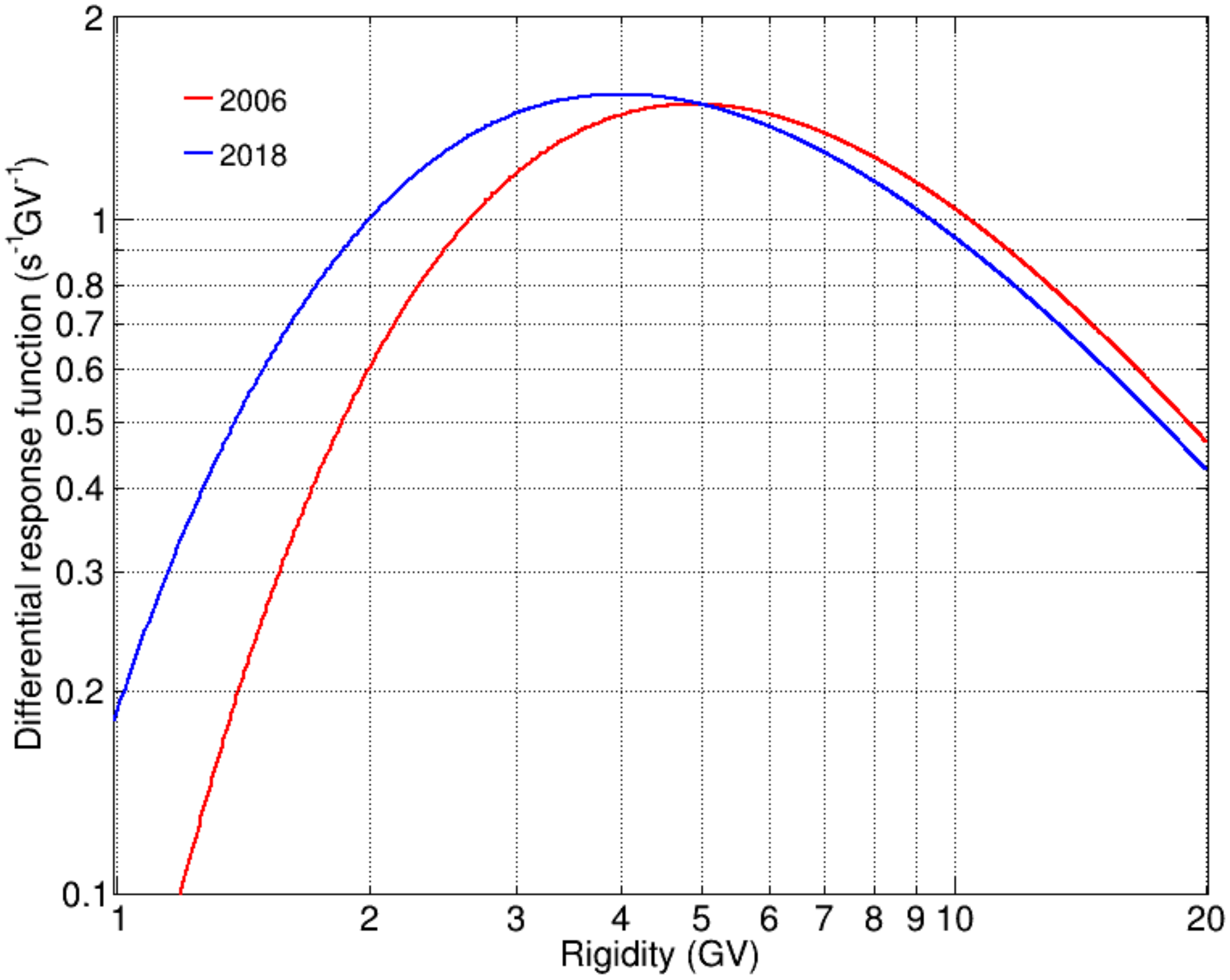
Average T1&T3 (CN35)
Average T1&T3 (CN36)
T2 (CN36)
DRF (s-1 GV-1)
Rigidity (GV)



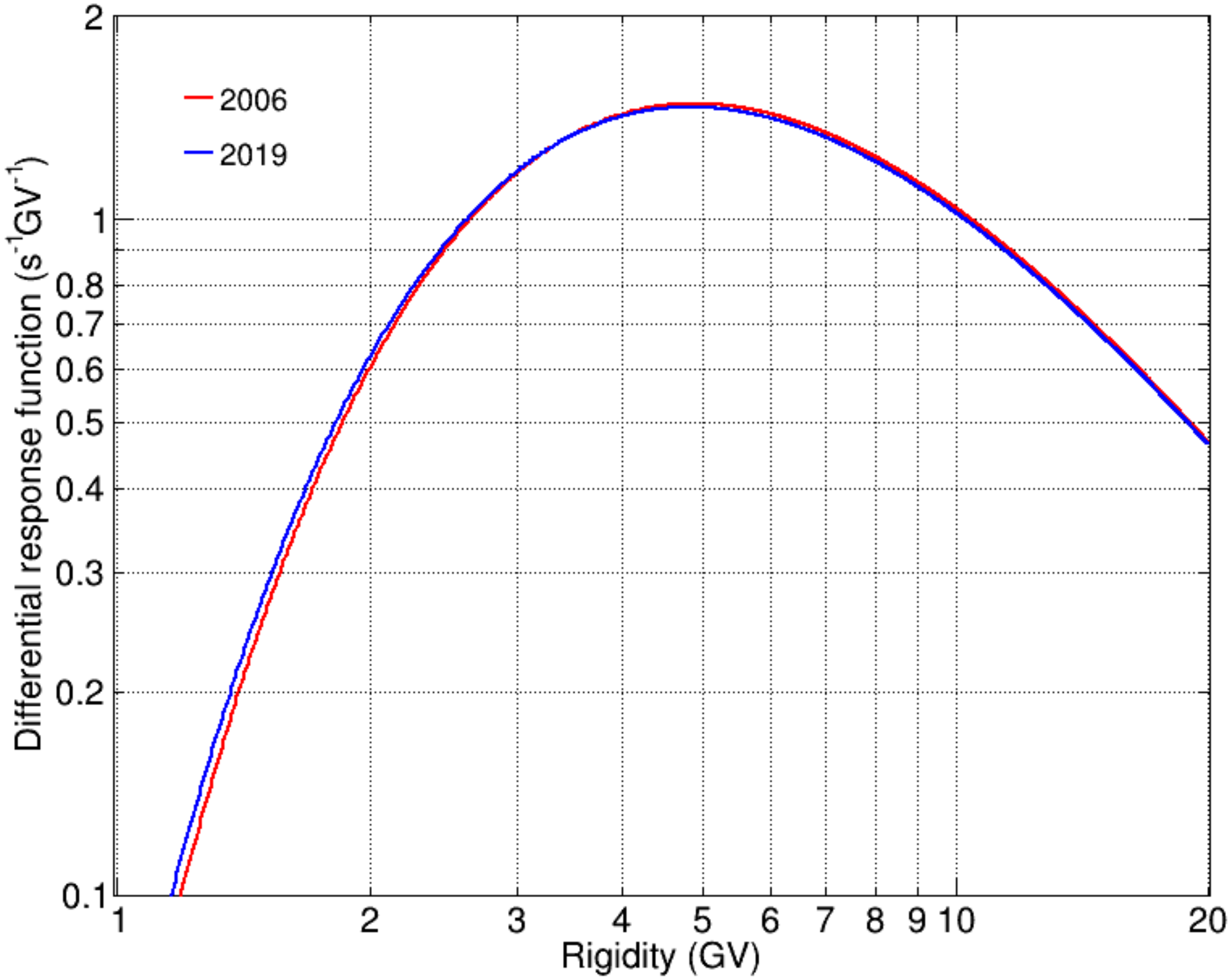
DRF of year 1997 (positive) and 2018 (positive)



DRF of year 1997 (positive) and 2018 (positive)



DRF of year 1997 (positive) and 2018 (positive)

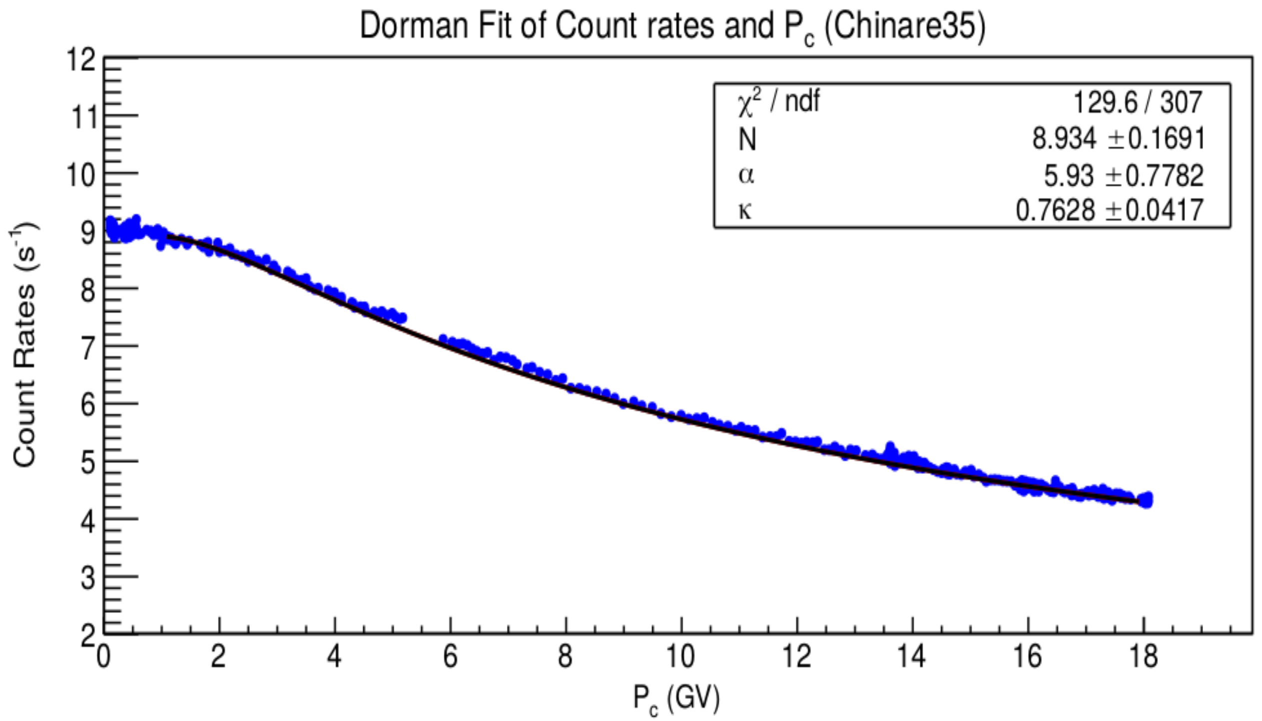


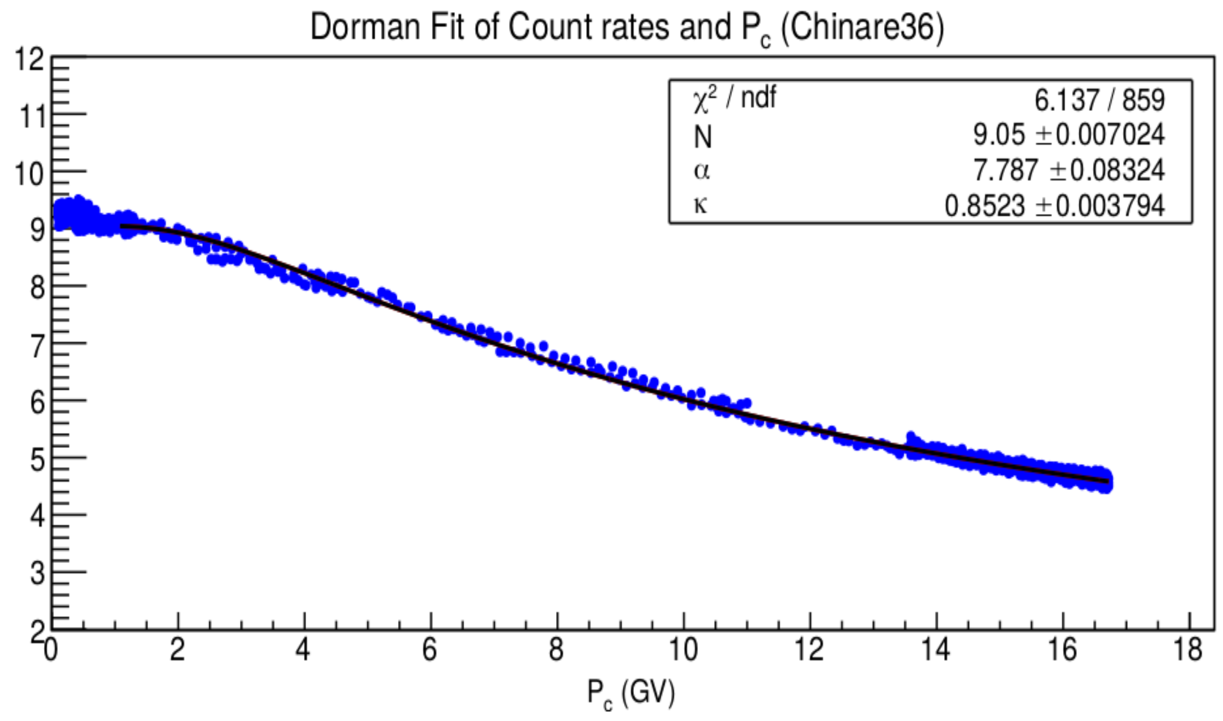
DRF of year 1997 (positive) and 2018 (positive)

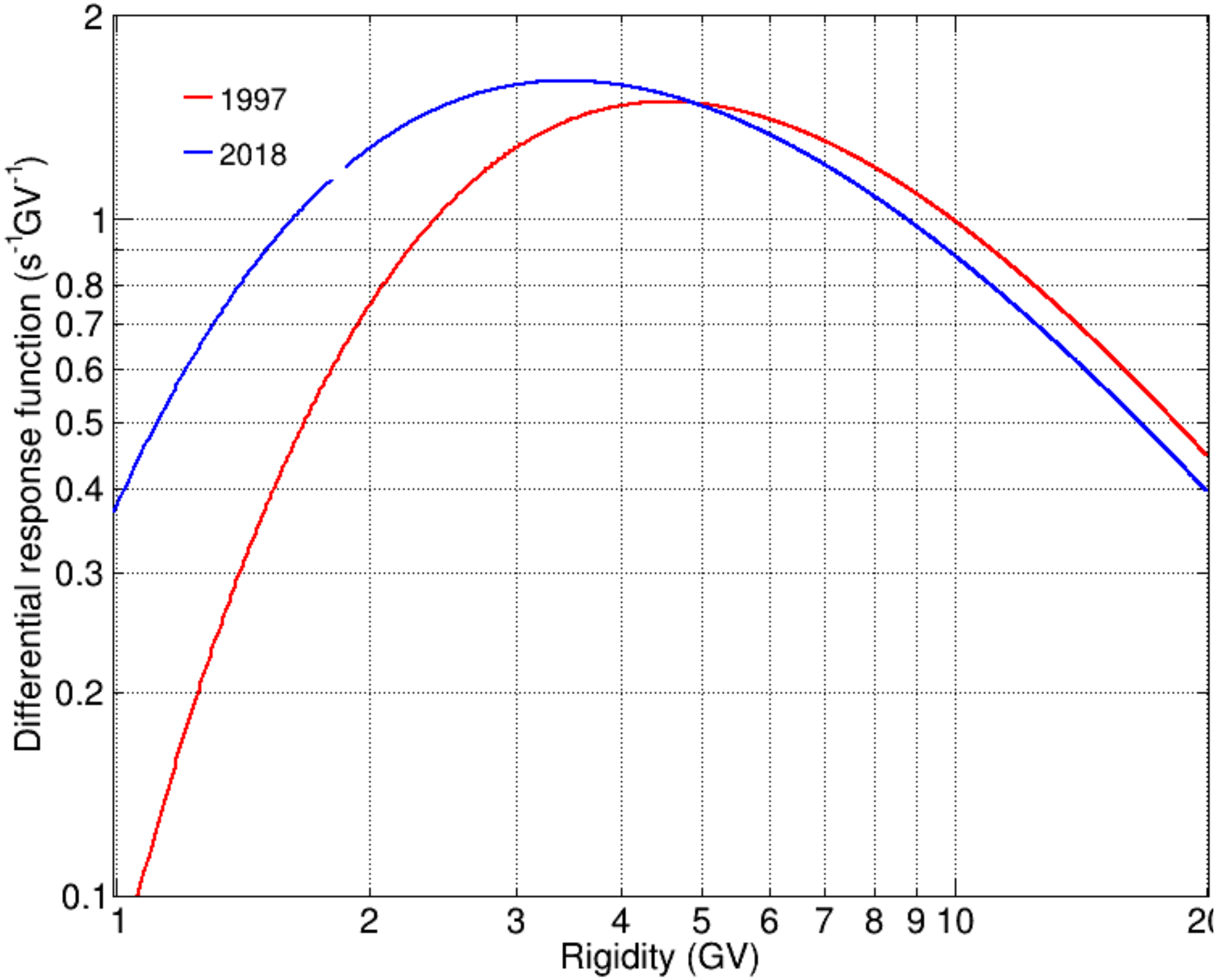
Update Dorman Function 2018-2019 (20Dec21)

- Used Dorman Parameter from Fern จากการปรับการ fit โดยใช้ข้อมูลทั้งหมดแทนค่าเฉลี่ย cutof bin แทนค่ะ

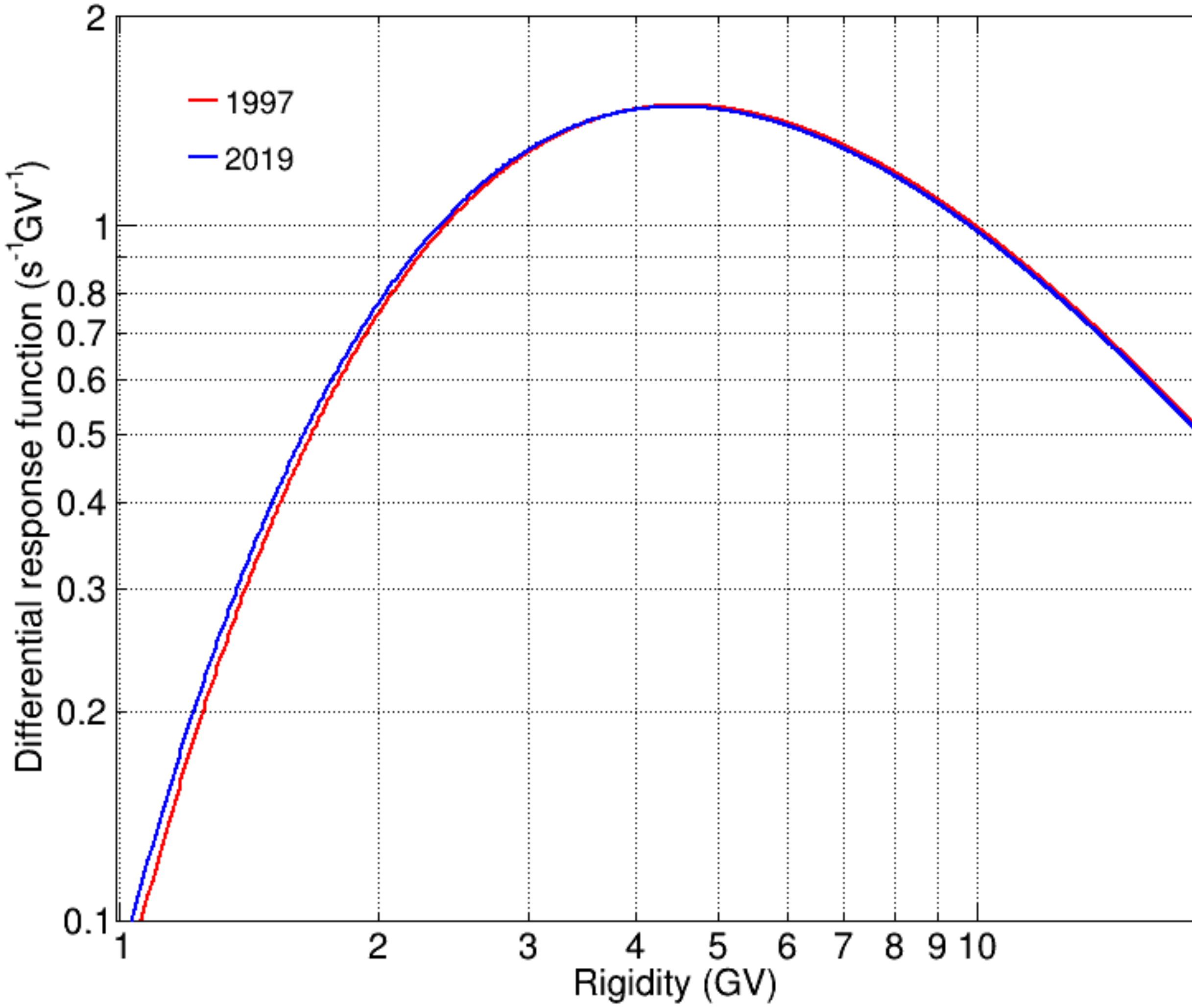
Year	No	alpha	kappa
2018	8.93	5.93	0.763
2019	9.05	7.787	0.852


Dorman Fit of Count rates and P_c (Chinare35)
χ² / ndf 129.6 / 307
N 8.934 ±0.1691
α 5.93 ±0.7782
κ 0.7628 ±0.0417
Count Rates (s⁻¹)
P_c (GV)

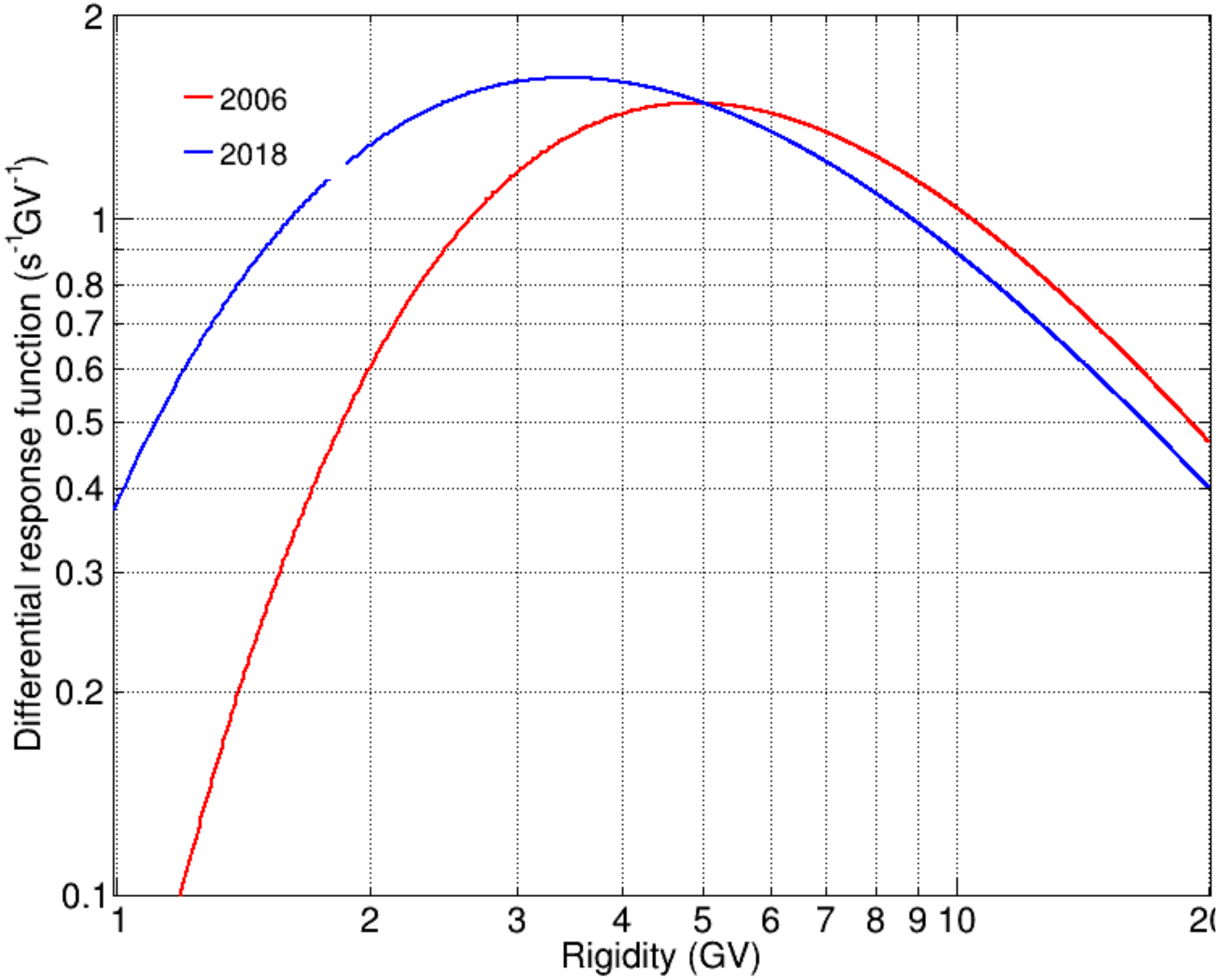

Dorman Fit of Count rates and P_c (Chinare36)
χ² / ndf 6.137 / 859
N 9.05 ±0.007024
α 7.787 ±0.08324
κ 0.8523 ±0.003794
P_c (GV)



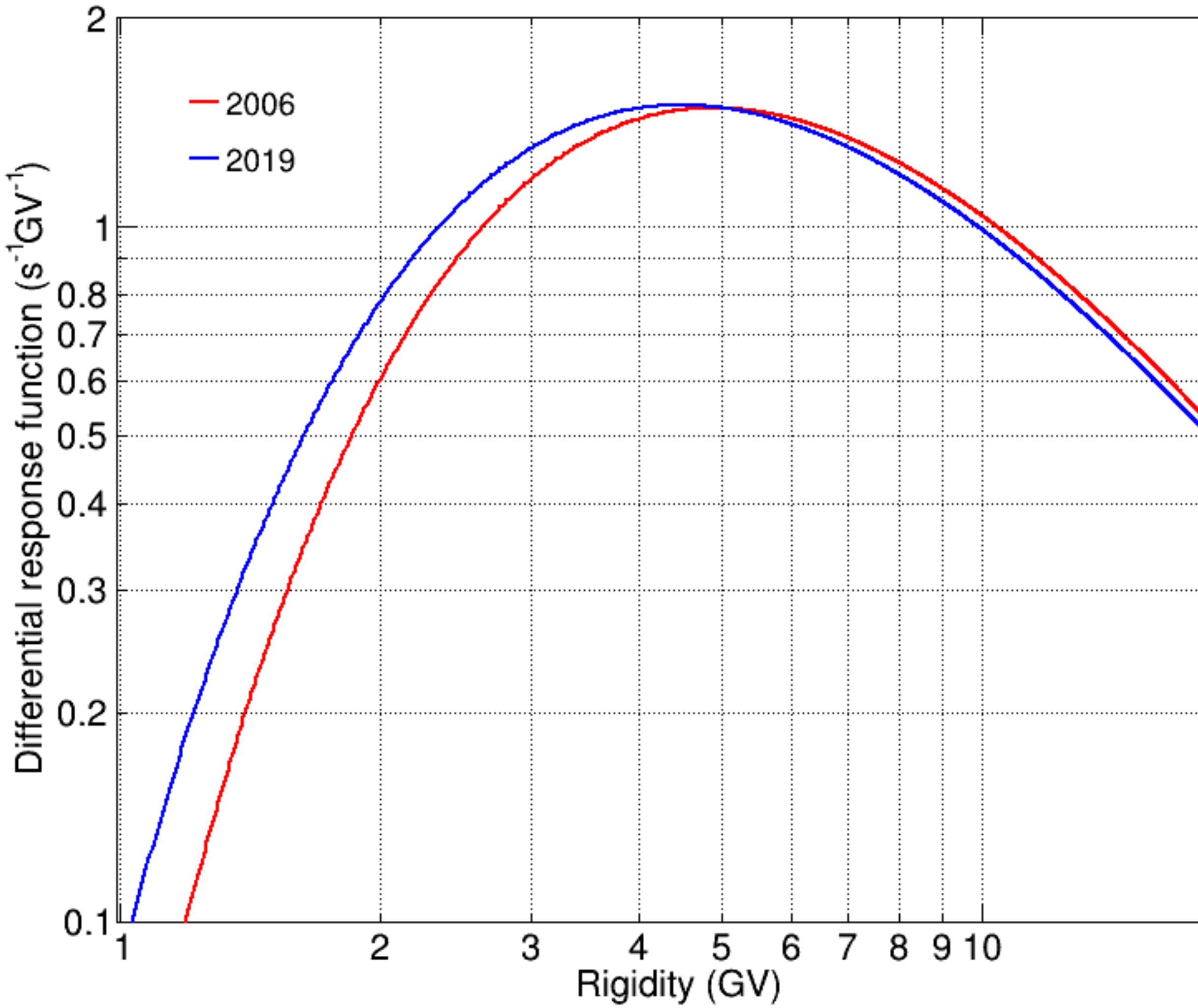
DRF of year 1997 (positive) and 2018 (positive)



DRF of year 1997 (positive) and 2018 (positive)

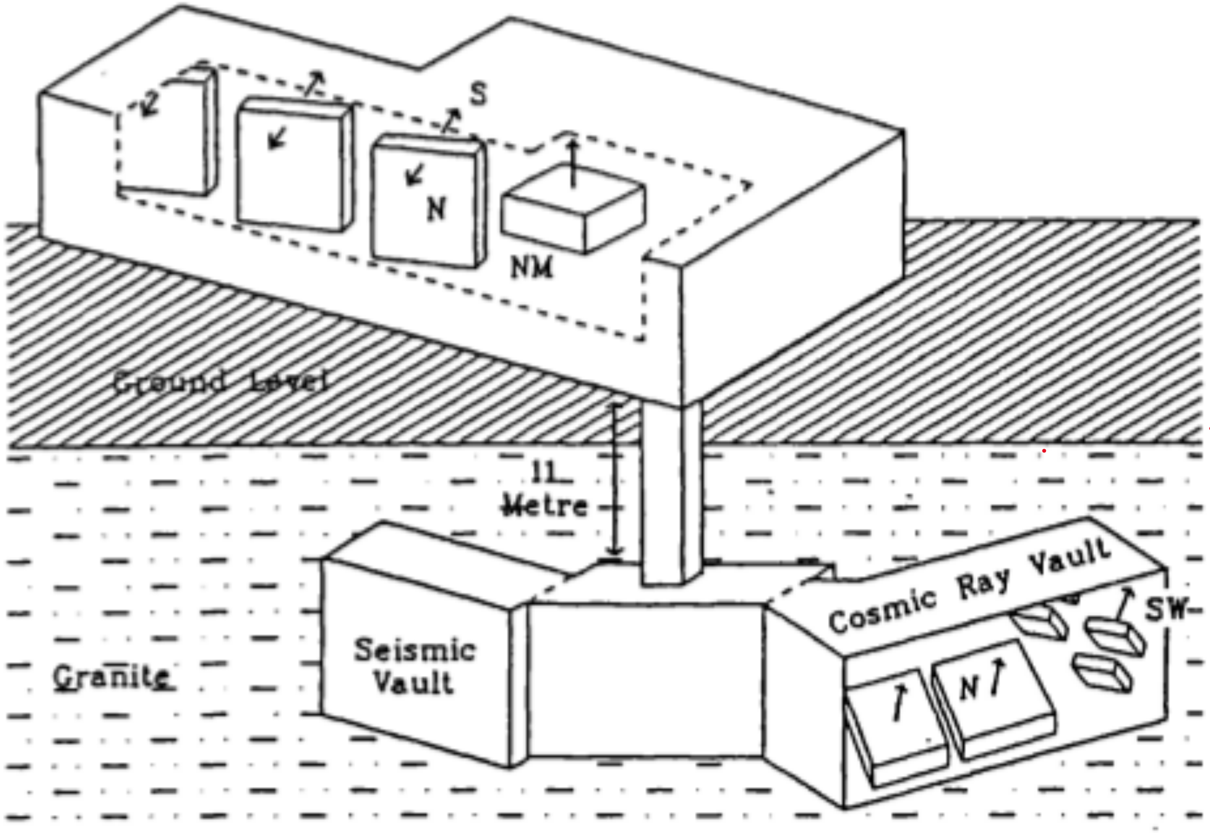


DRF of year 2006 (negative) and 2018 (positive)

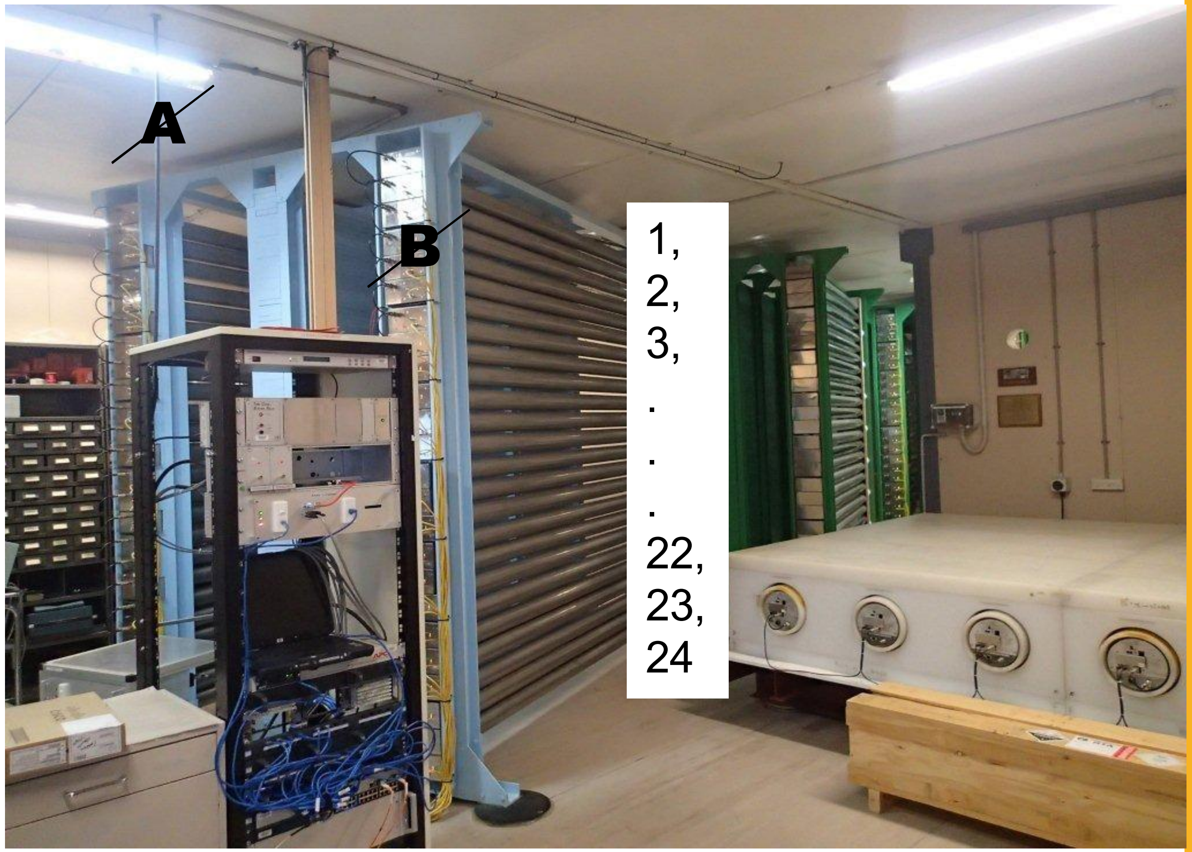


DRF of year 2006 (negative) and 2019 (positive)

MAWSON MUON TELESCOPE



Geometry of Mawson station



Summary of muon telescope parameters at the Mawson Automated Cosmic Ray Observatory.

	SURFACE		UNDERGROUND	
	NORTH	SOUTH	NORTH	SOUTH WEST
Cutoff Rigidity	13 GV	13 GV	13 GV	13 GV
Effective Median Rigidity	35-200 GV 190 GV		35-200 GV	180 GV
Azimuth	North	South	330°	215°
Zenith	34° -84°	34°-84°	24°	40°
Absorber	.13m (steel)	.13m (steel)	48 m.w.e. (granite)	53 m.w.e. (granite)

(Duldig, 1990)

THE DATA OF MUON TELESCOPE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     <name>Mawson</name>
     <latitude>67 deg 36 min South</latitude>
     <longitude>62 deg 52 min East</longitude>
 </station>
 <telescope>
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     <tubes_per_wall>24</tubes_per_wall>
 </telescope>
 <comments>Telescope P1 is a surface muon telescope located at Mawson station, Antarctica.</comments>
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 </record>
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Date and time

location

Telescope detail

Recorded data

Accidental vs Coincidental rate

Accidental rate = independent particles pass through difference trays

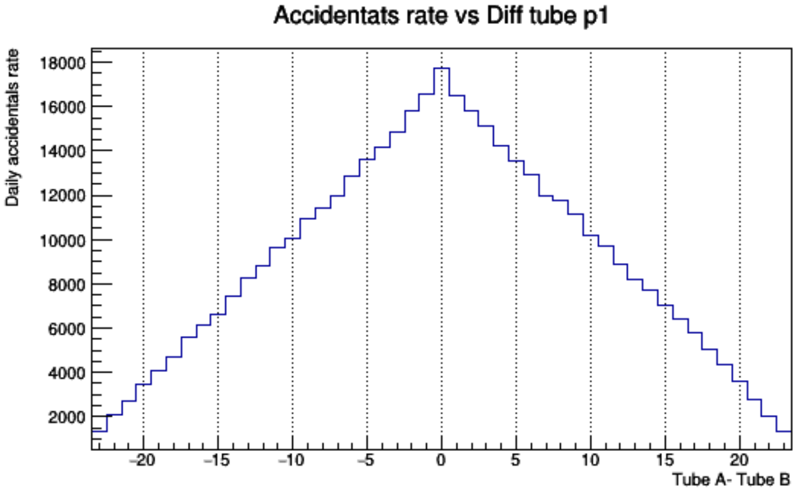
Coincidental rate = a single particle pass through both trays

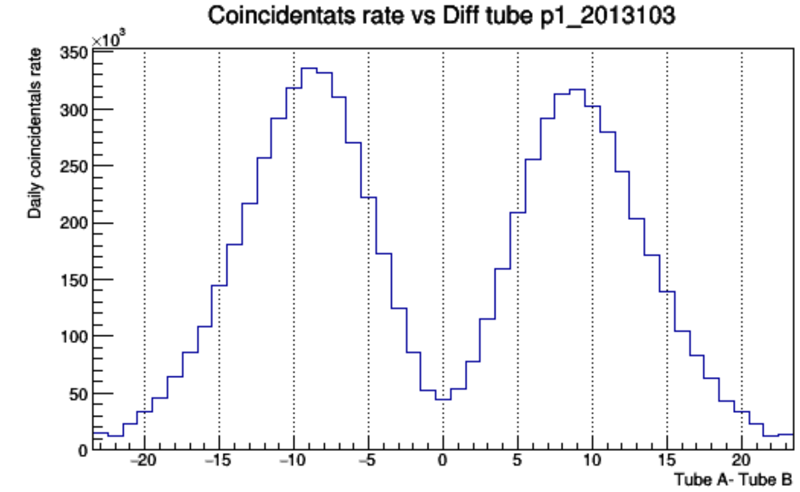
the accidental rate can be removed to give the true coincidence rate.

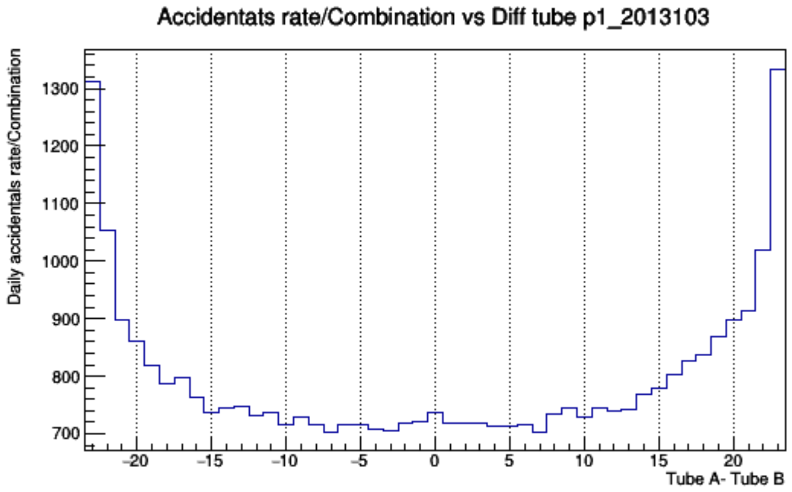
When $\tau << 1/C$	$R(\tau) = C + A(\tau)$
and for $\tau_2 = 2\tau_1$	$A(\tau_2) = 2A(\tau_1)$
solving for C gives	$C = 2R(\tau_1) - R(\tau_2)$
and	$A(\tau_1) = R(\tau_2) - R(\tau_1)$

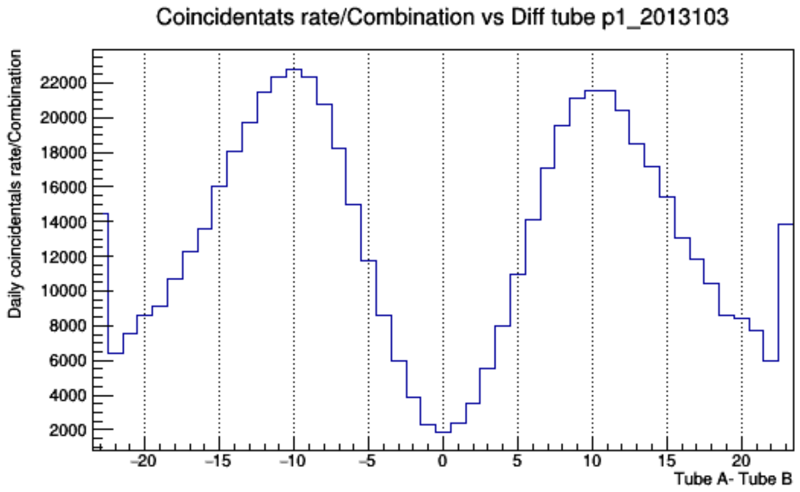
The coincidence rate for the new telescope is 180000 particles/hour (i.e. the average time between particles is 20 ms)

Surface Muon Telescopes

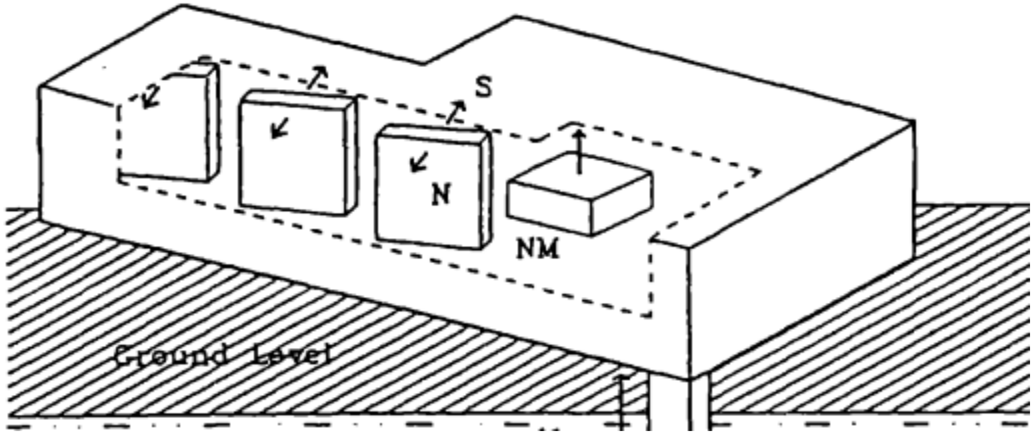








ground Level



- P1, 2 & 3 have effective mean Rigidity 35-200 GV both north and south and have 0.13m steel absorber between the counter walls.

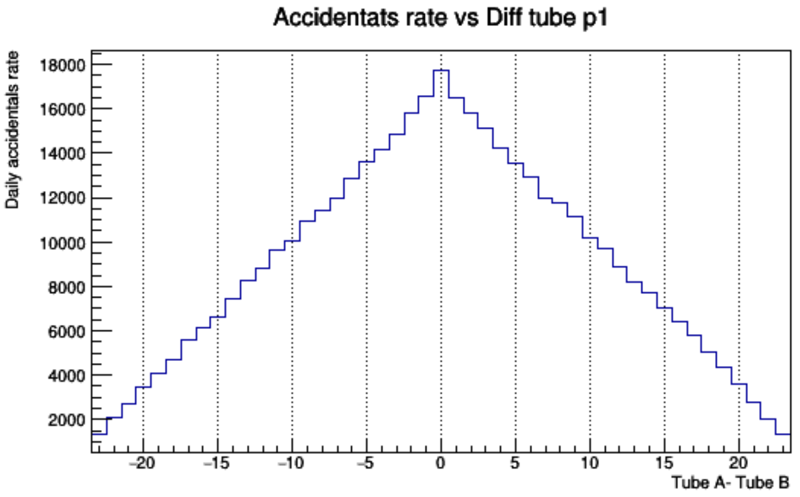
P1, 2 & 3 North view equatorial to mid southern latitudes. Effective mean Rigidity 35-200 GV.

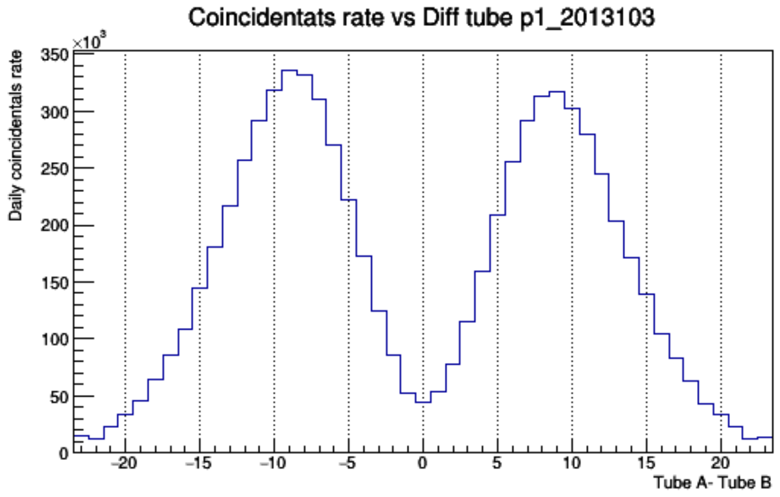
P1, 2 & 3 South view across the south pole into the opposite temporal hemisphere but have maximum geomagnetic deflection due to viewing across the field and so effectively spread spectral phenomena out in time. Effective mean Rigidity 35-200 GV.

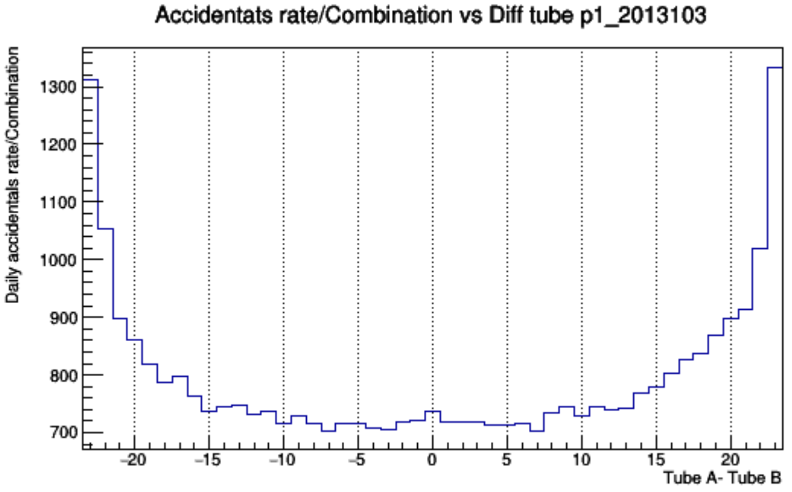
Manson Muon zenith angle

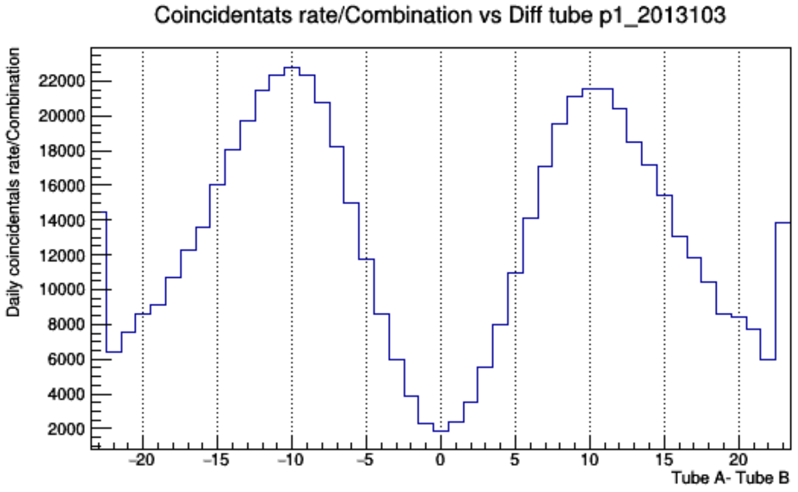
P1, 2 & 3

P1

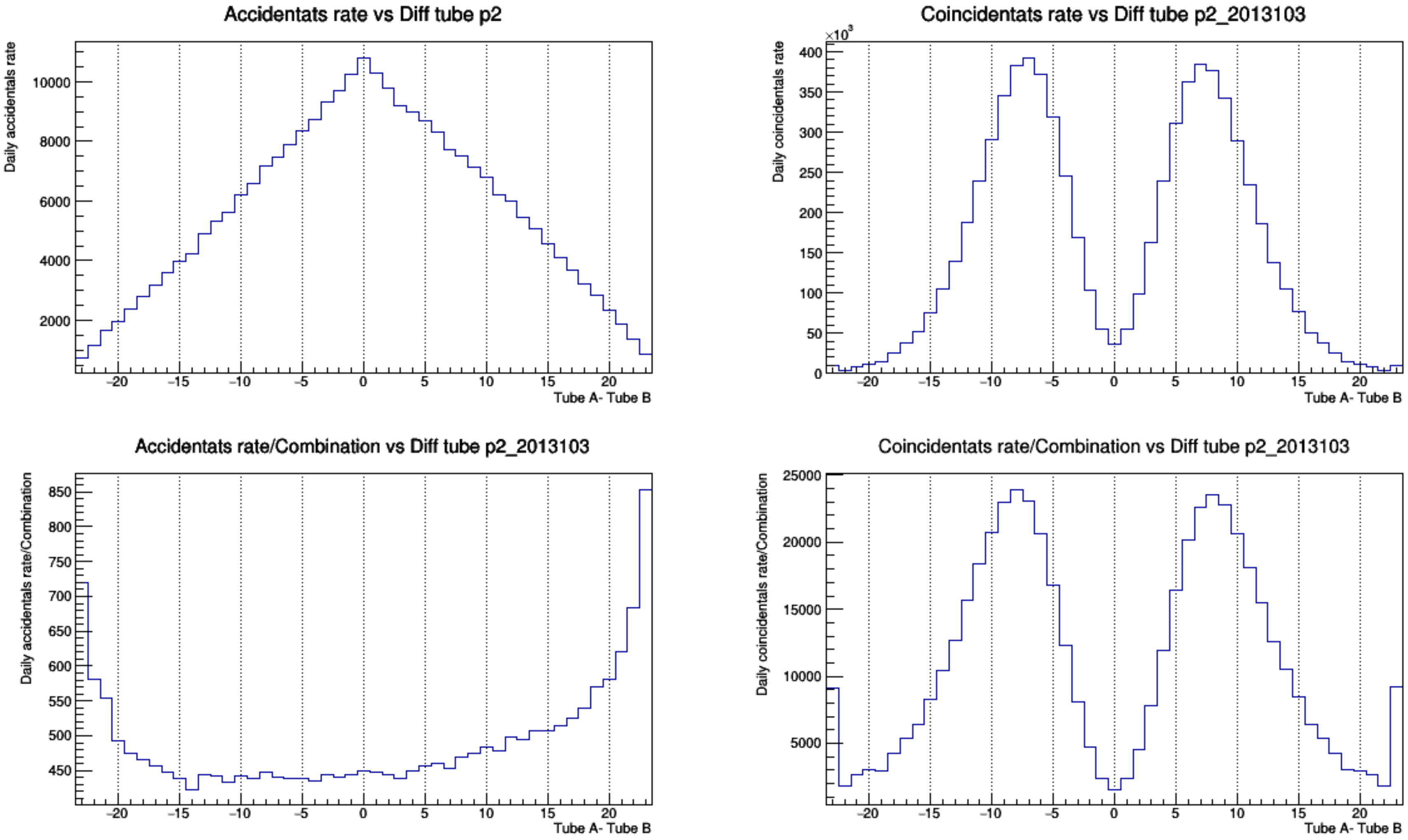

Accidentats rate vs Diff tube p1
Daily accidentals rate
Tube A- Tube B


Coincidentats rate vs Diff tube p1_2013103
Daily coincidentals rate
Tube A- Tube B


Accidentats rate/Combination vs Diff tube p1_2013103
Daily accidentals rate/Combination
Tube A- Tube B

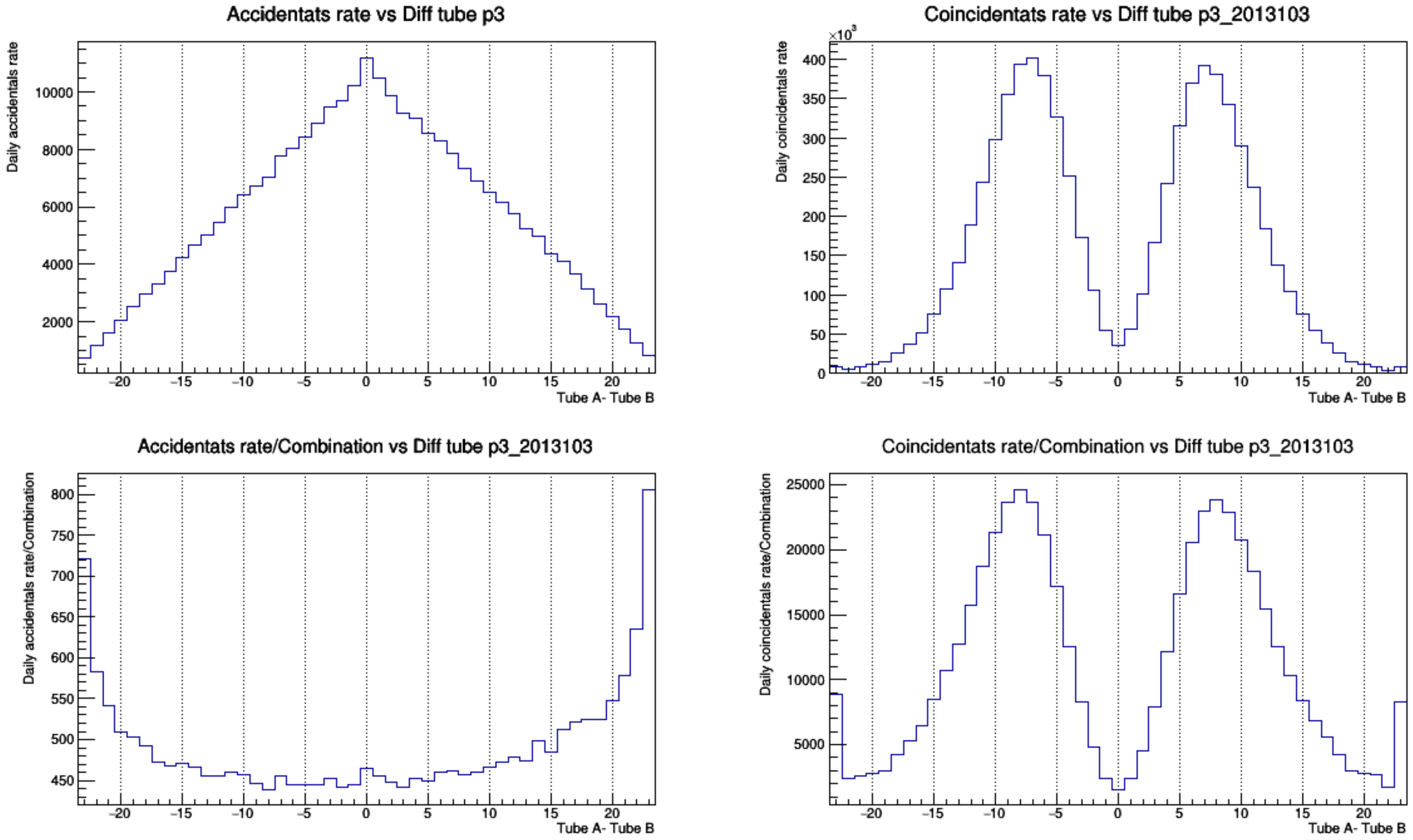

Coincidentats rate/Combination vs Diff tube p1_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

P2



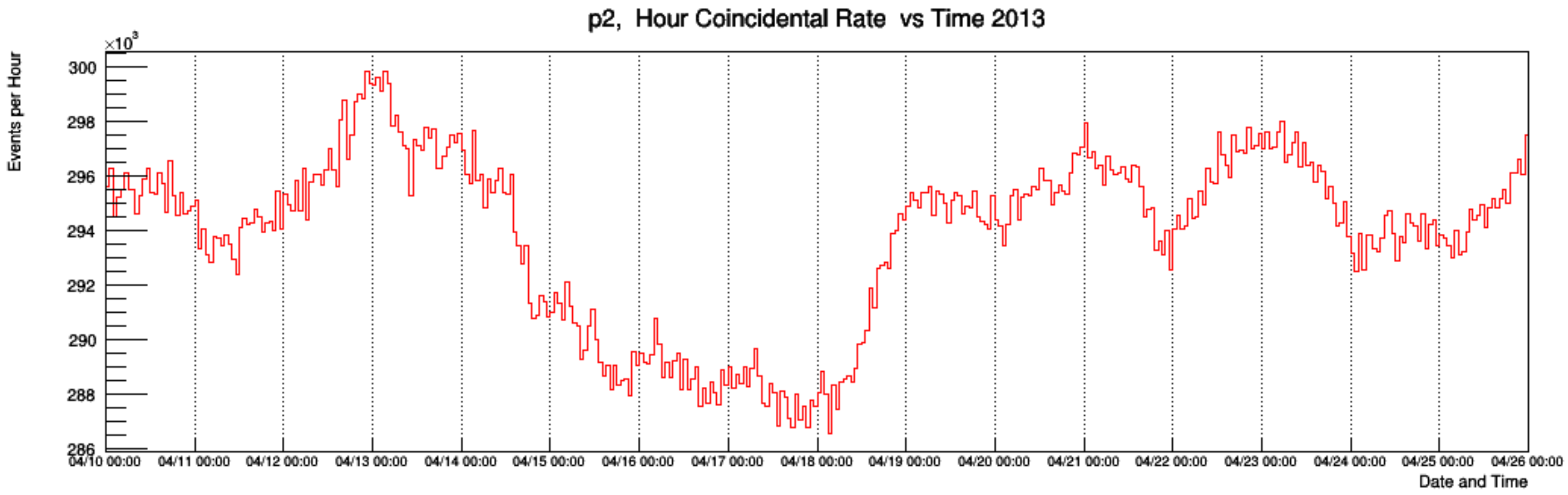
Accidentats rate vs Diff tube p2
Daily accidentals rate
Tube A- Tube B
Coincidentats rate vs Diff tube p2_2013103
Daily coincidentals rate
Tube A- Tube B
Accidentats rate/Combination vs Diff tube p2_2013103
Daily accidentals rate/Combination
Tube A- Tube B
Coincidentats rate/Combination vs Diff tube p2_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

P3



Accidentats rate vs Diff tube p3
Daily accidentals rate
Tube A- Tube B
Coincidentats rate vs Diff tube p3_2013103
Daily coincidentals rate
Tube A- Tube B
Accidentats rate/Combination vs Diff tube p3_2013103
Daily accidentals rate/Combination
Tube A- Tube B
Coincidentats rate/Combination vs Diff tube p3_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

Hour data P2



p2, Hour Coincidental Rate vs Time 2013
×10³
Events per Hour
300
298
296
294
292
290
288
286
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
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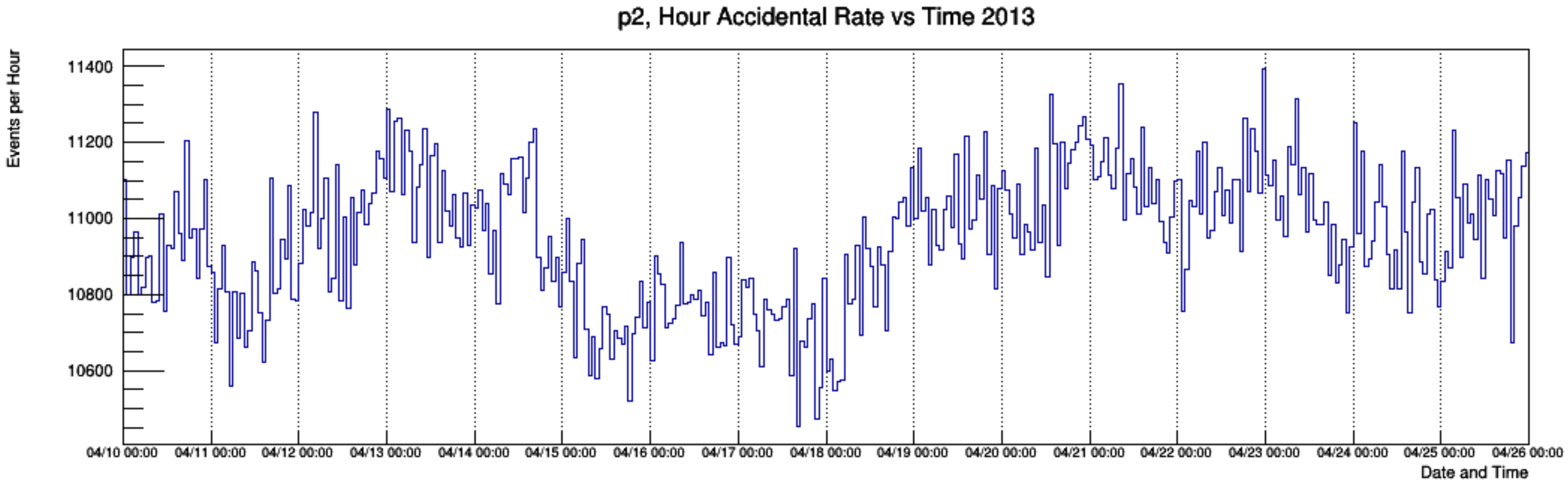
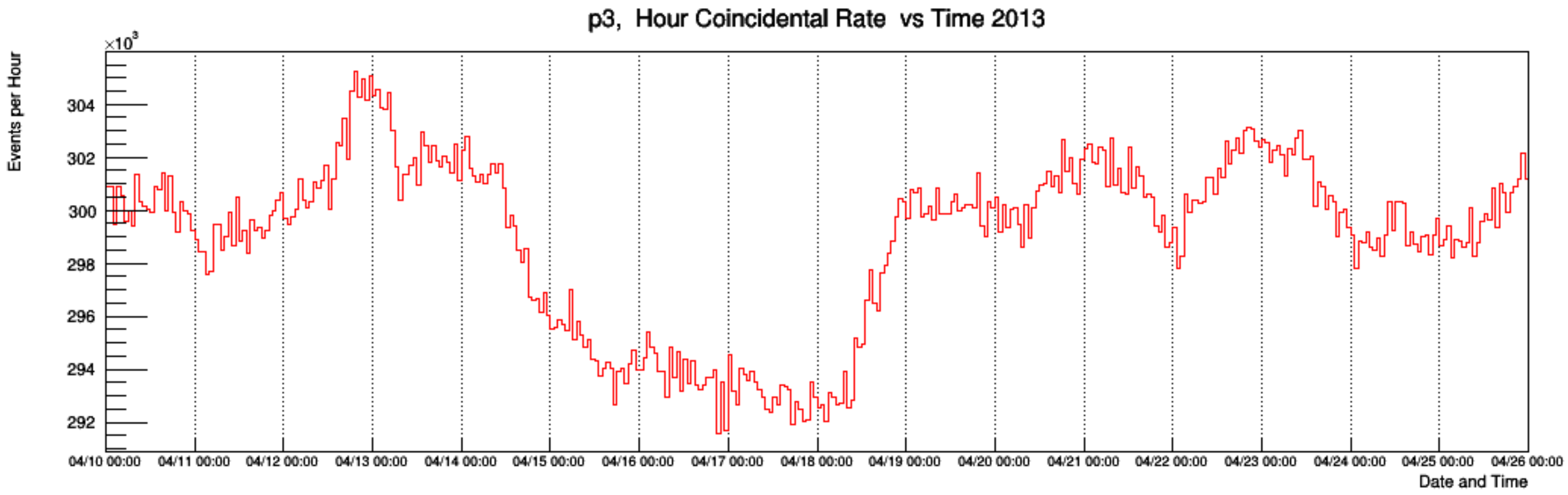
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

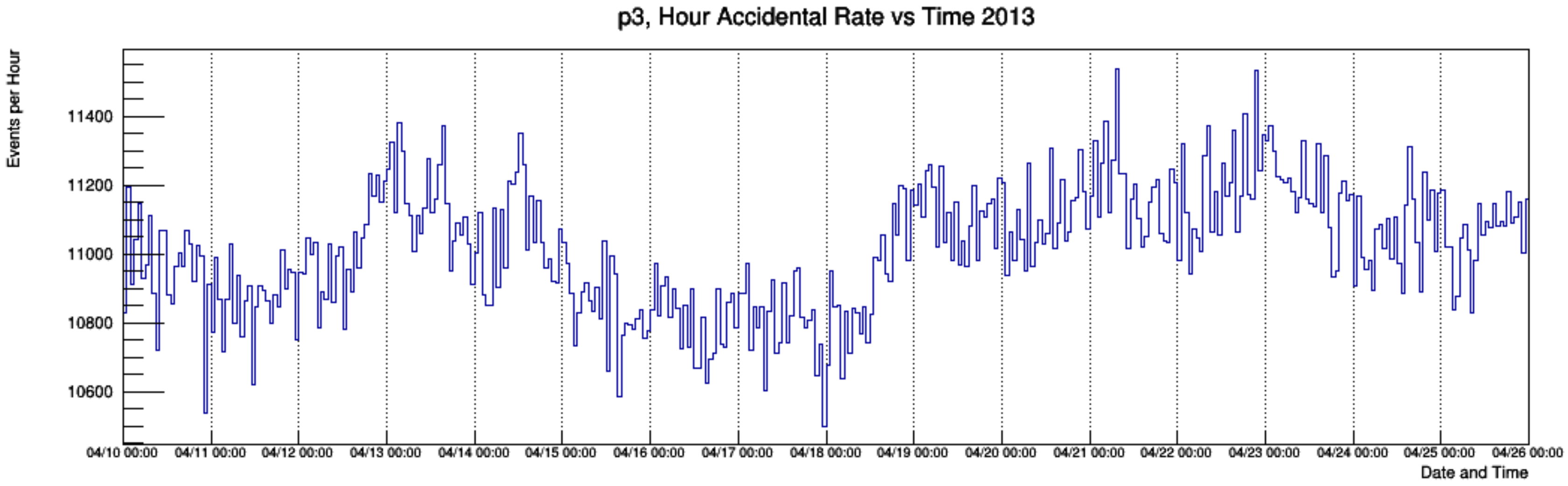


p2, Hour Accidental Rate vs Time 2013
Events per Hour
11400
11200
11000
10800
10600
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

Hour data P3

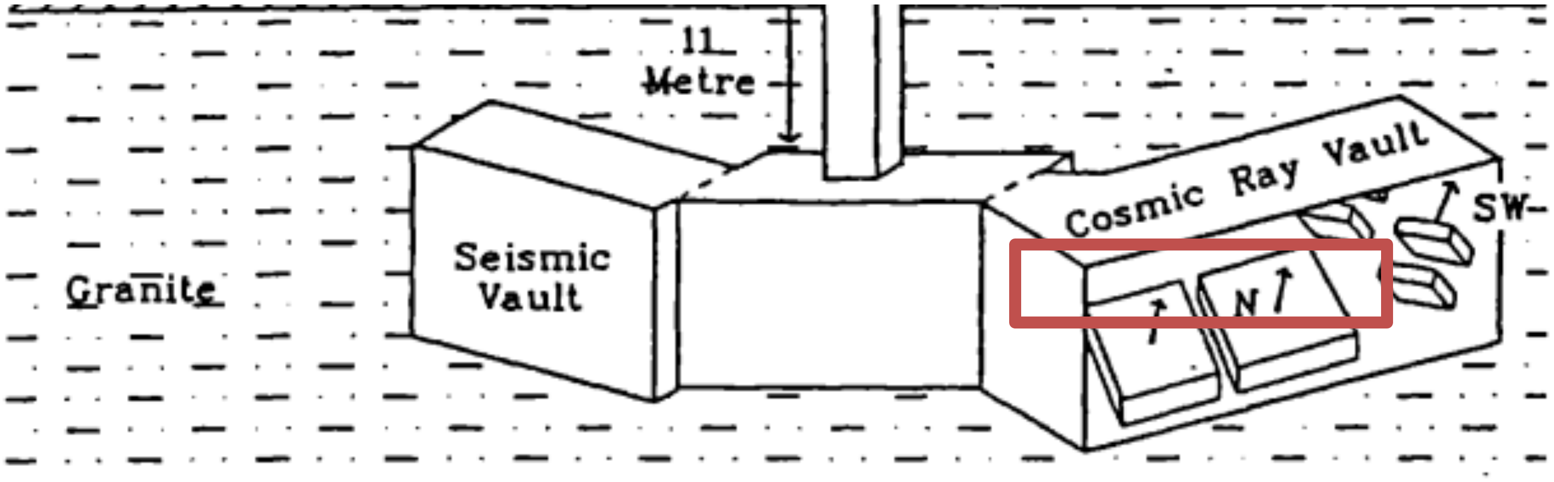


p3, Hour Coincidental Rate vs Time 2013
×10^3
Events per Hour
304
302
300
298
296
294
292
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time



p3, Hour Accidental Rate vs Time 2013
Events per Hour
11400
11200
11000
10800
10600
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

Underground Level

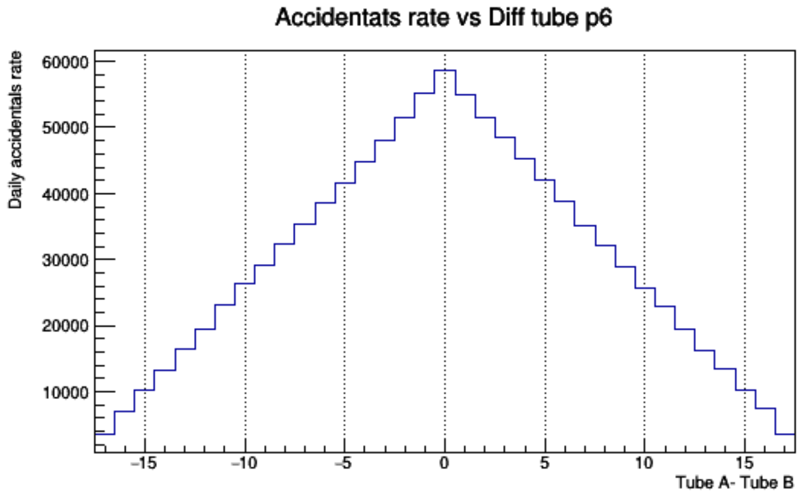


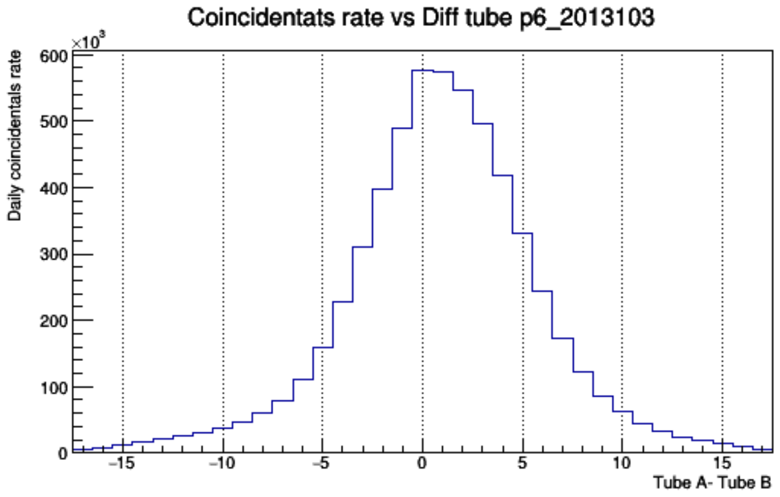
- P6 & 7 view along the local geomagnetic field and thus have minimal geomagnetic deflection and view mid southern latitudes very close to the Mawson NM view. Effective mean Rigidity 180 GV resulting from 48 mwe granite absorber along the central viewing direction.

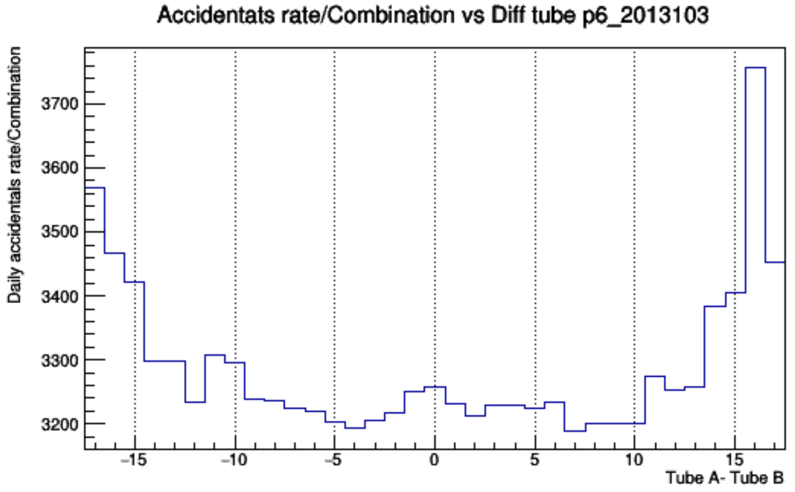
Manson Muon zenith angle

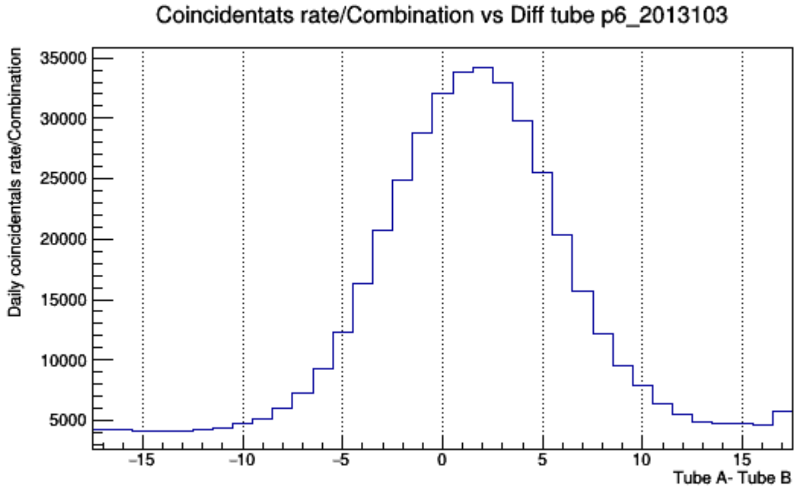
P6 & 7

P6

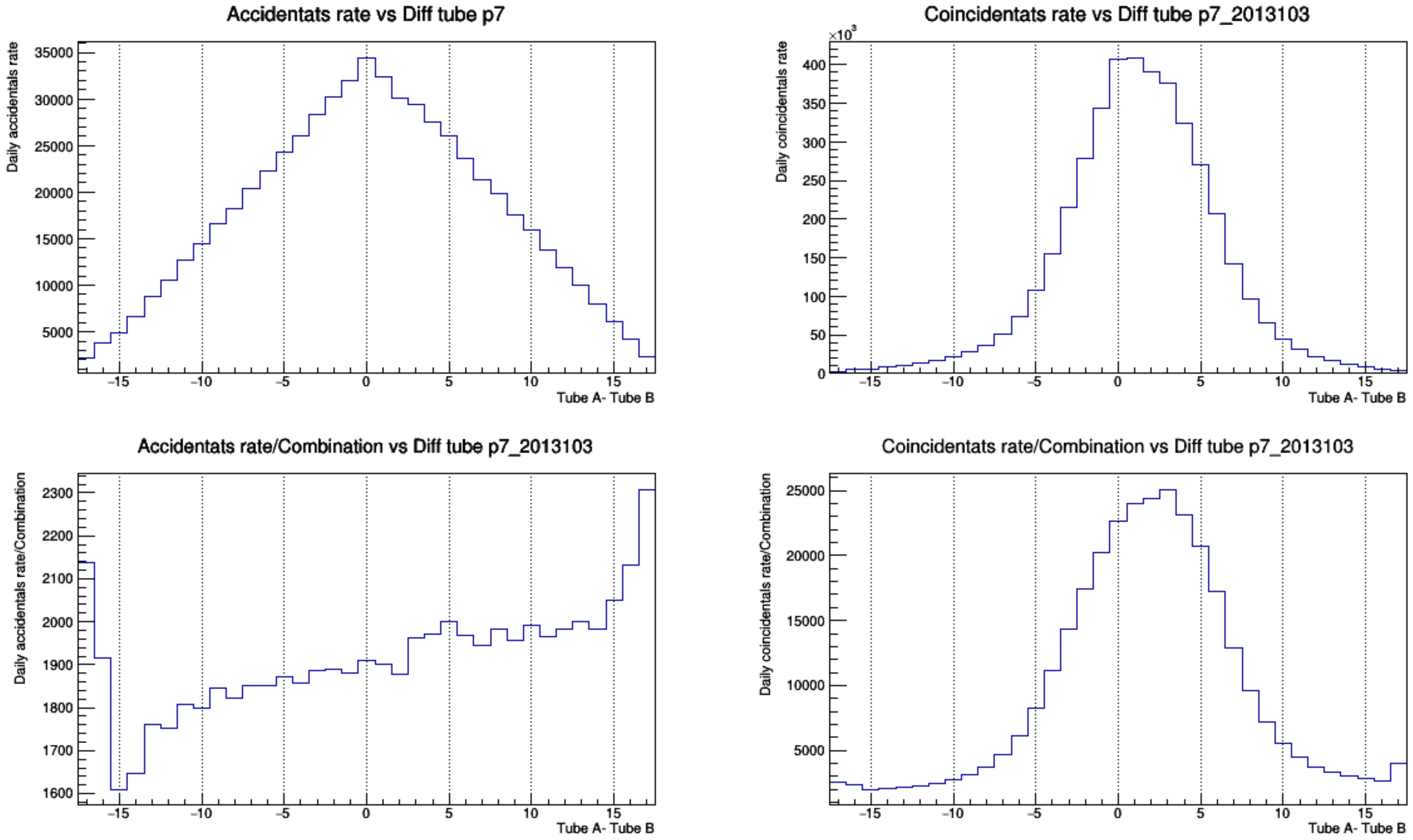

Accidentats rate vs Diff tube p6
Daily accidentals rate
Tube A- Tube B


Coincidentats rate vs Diff tube p6_2013103
Daily coincidentals rate
Tube A- Tube B


Accidentats rate/Combination vs Diff tube p6_2013103
Daily accidentals rate/Combination
Tube A- Tube B

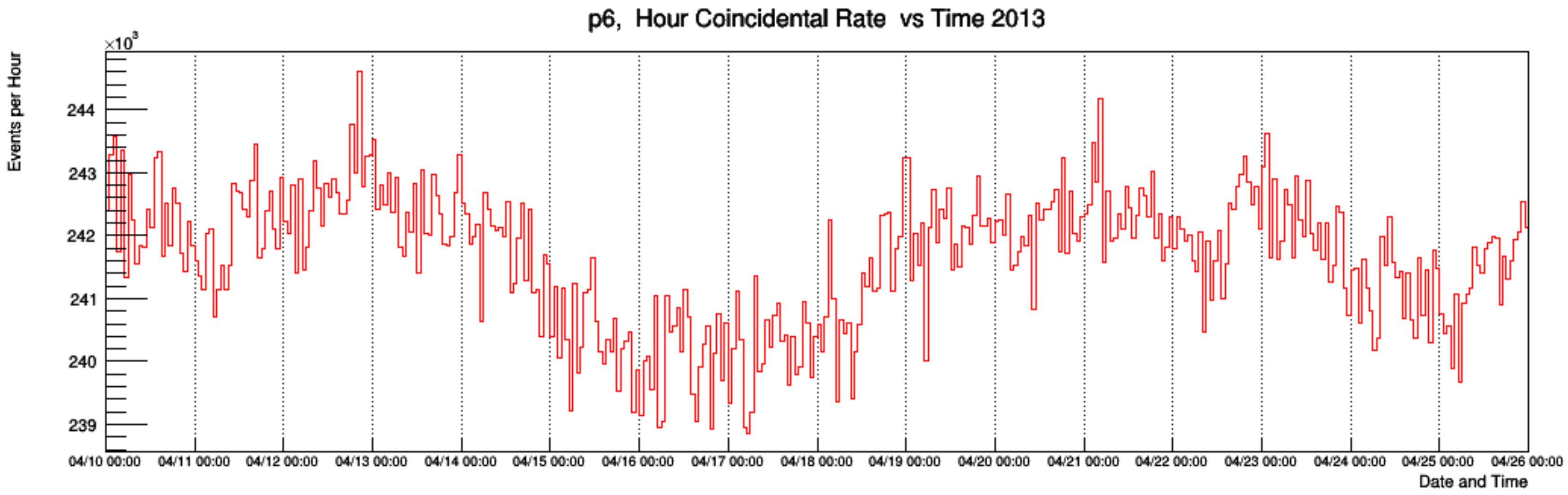

Coincidentats rate/Combination vs Diff tube p6_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

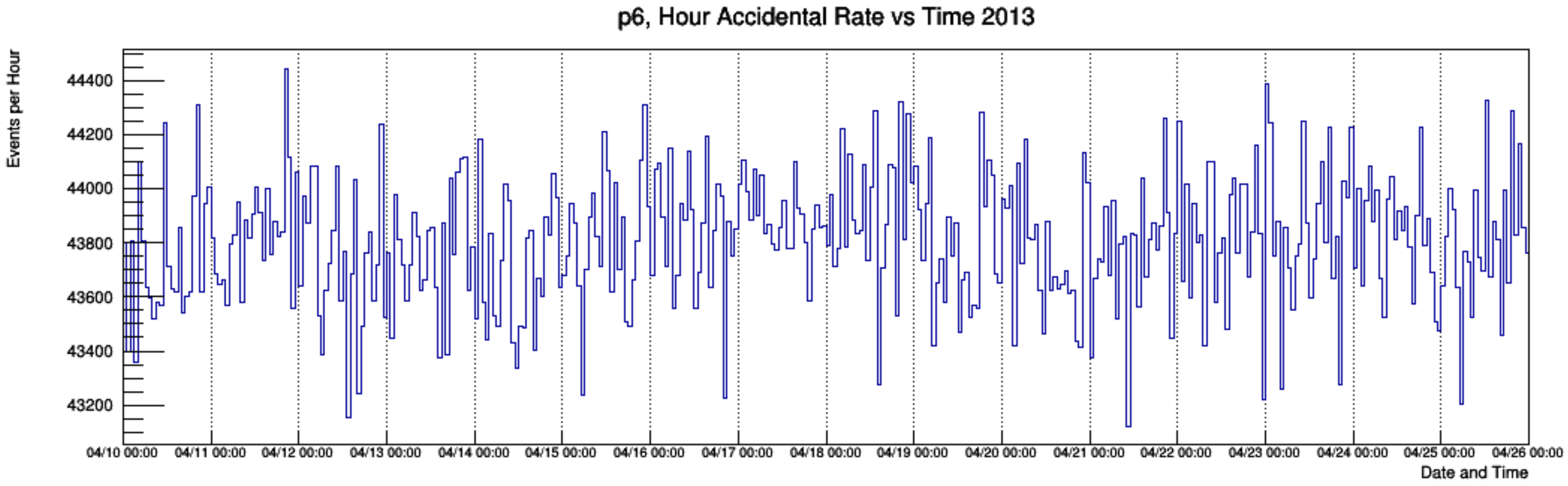
P7



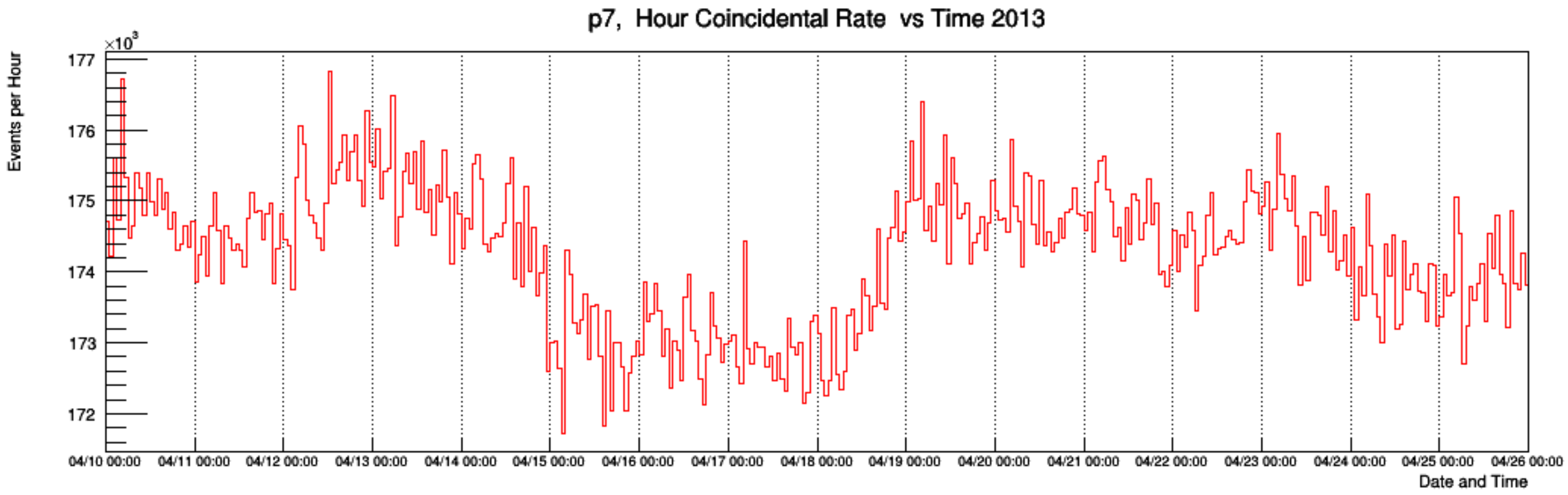
Accidentats rate vs Diff tube p7
Daily accidentals rate
35000
30000
25000
20000
15000
10000
5000
−15
−10
−5
0
5
10
15
Tube A- Tube B
Coincidentats rate vs Diff tube p7_2013103
$\times10^3$
Daily coincidentals rate
400
350
300
250
200
150
100
50
0
Tube A- Tube B
Accidentats rate/Combination vs Diff tube p7_2013103
Daily accidentals rate/Combination
2300
2200
2100
2000
1900
1800
1700
1600
Tube A- Tube B
Coincidentats rate/Combination vs Diff tube p7_2013103
Daily coincidentals rate/Combination
25000
20000
15000
10000
5000
Tube A- Tube B

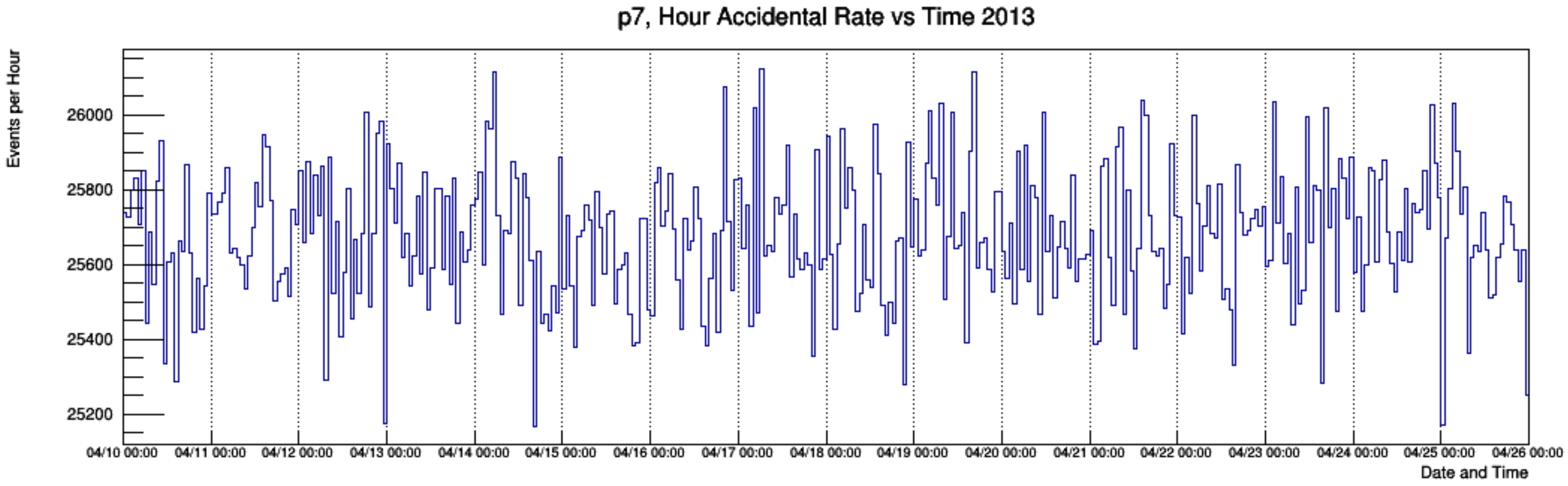
Hour data P6


p6, Hour Coincidental Rate vs Time 2013
×10³
Events per Hour
244
243
242
241
240
239
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

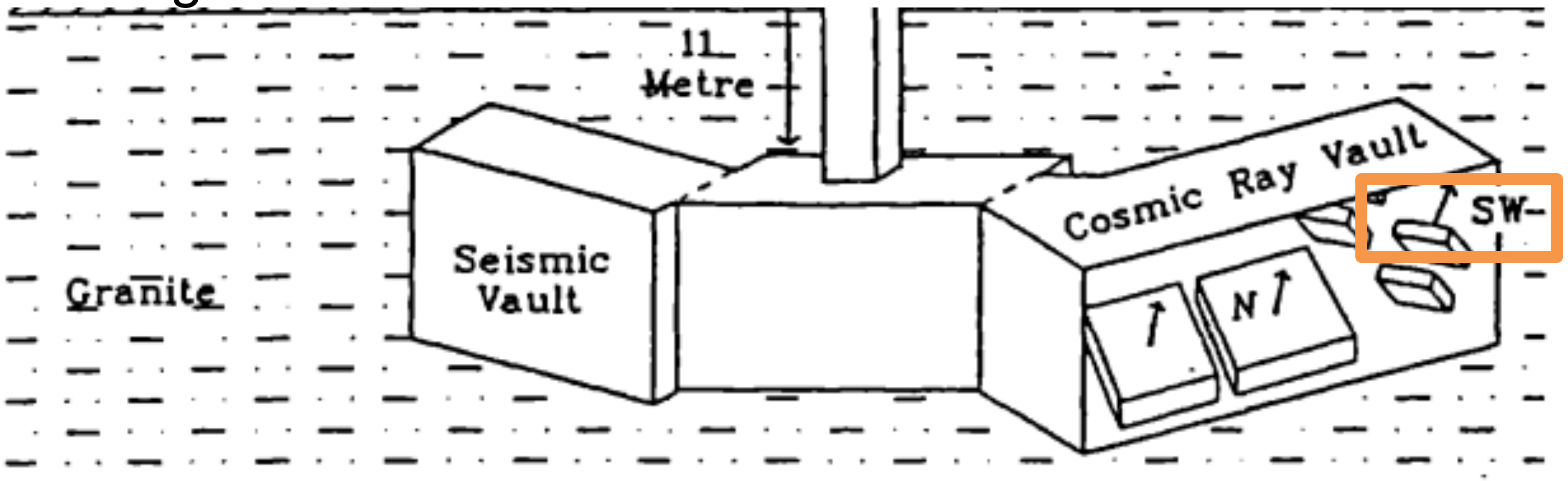

p6, Hour Accidental Rate vs Time 2013
Events per Hour
44400
44200
44000
43800
43600
43400
43200
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

Hour data P7


p7, Hour Coincidental Rate vs Time 2013
Events per Hour
×10^3
177
176
175
174
173
172
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time


p7, Hour Accidental Rate vs Time 2013
Events per Hour
26000
25800
25600
25400
25200
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

Underground Level

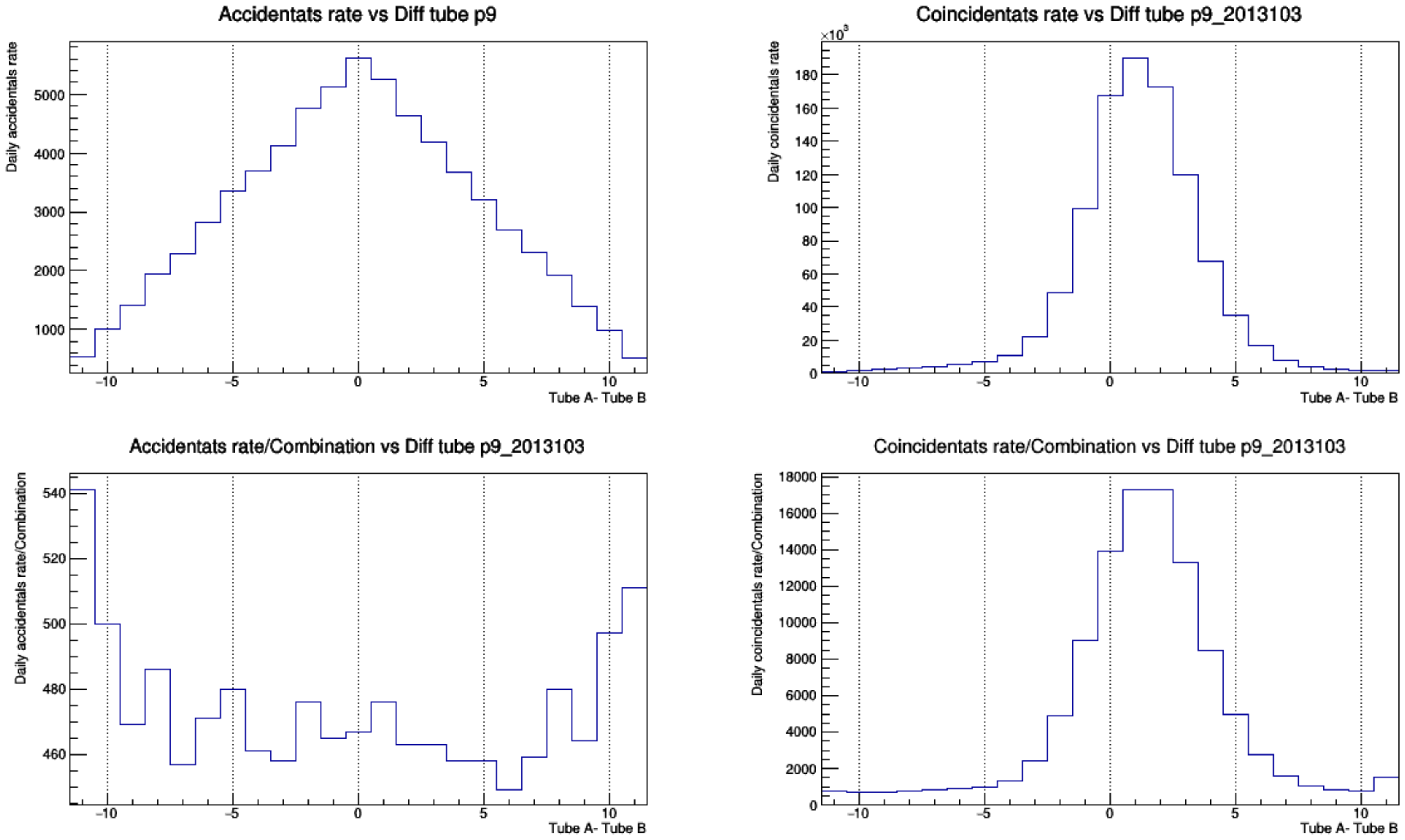


- P9 & 10 view approximately along the southern polar rotation axis after geomagnetic bending, therefore measuring the isotropic intensity. Effective mean Rig 190 GV resulting from 53 mwe granite absorber along the central viewing direction.

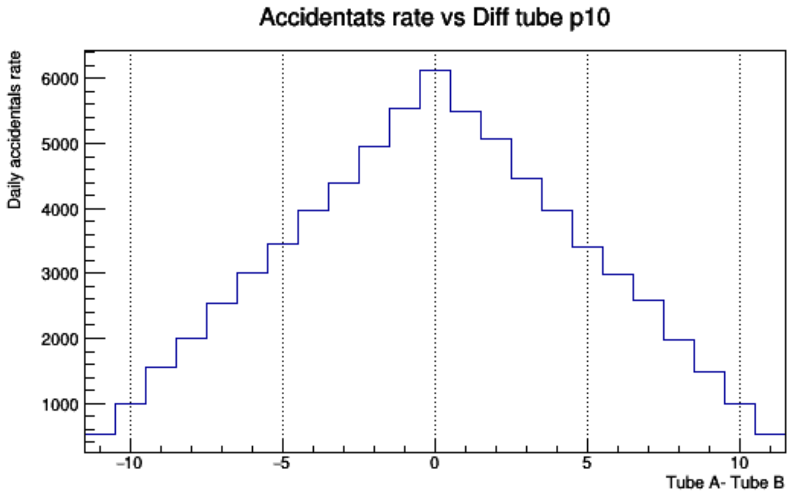
Manson Muon zenith angle

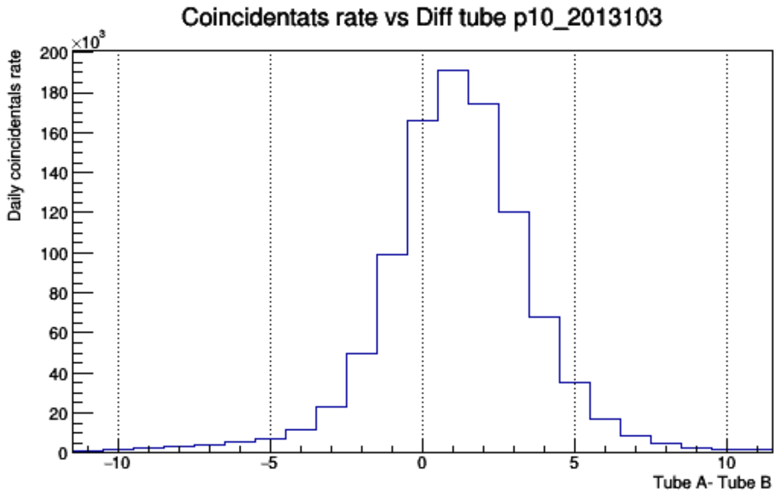
P9 & 10

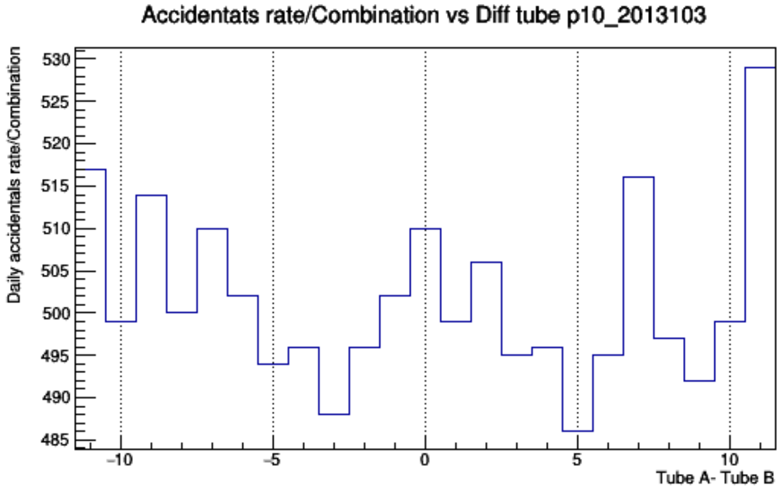
P9

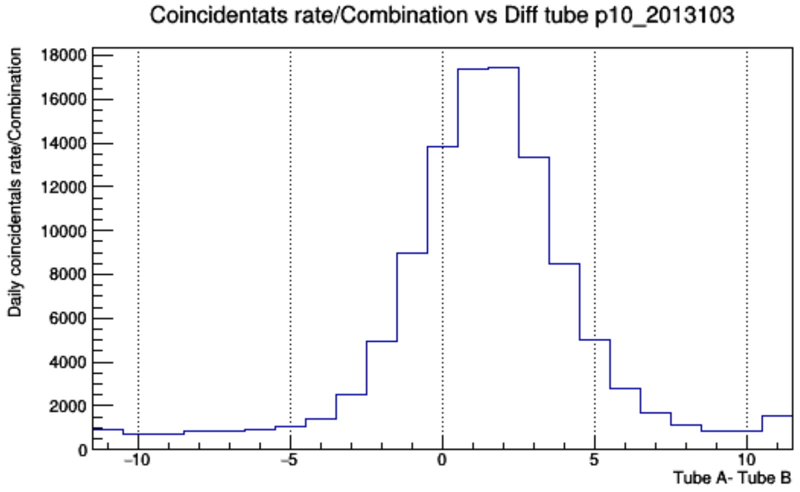

Accidentats rate vs Diff tube p9
Daily accidentals rate
Tube A- Tube B
Coincidentats rate vs Diff tube p9_2013103
Daily coincidentals rate
×10³
Tube A- Tube B
Accidentats rate/Combination vs Diff tube p9_2013103
Daily accidentals rate/Combination
Tube A- Tube B
Coincidentats rate/Combination vs Diff tube p9_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

P10

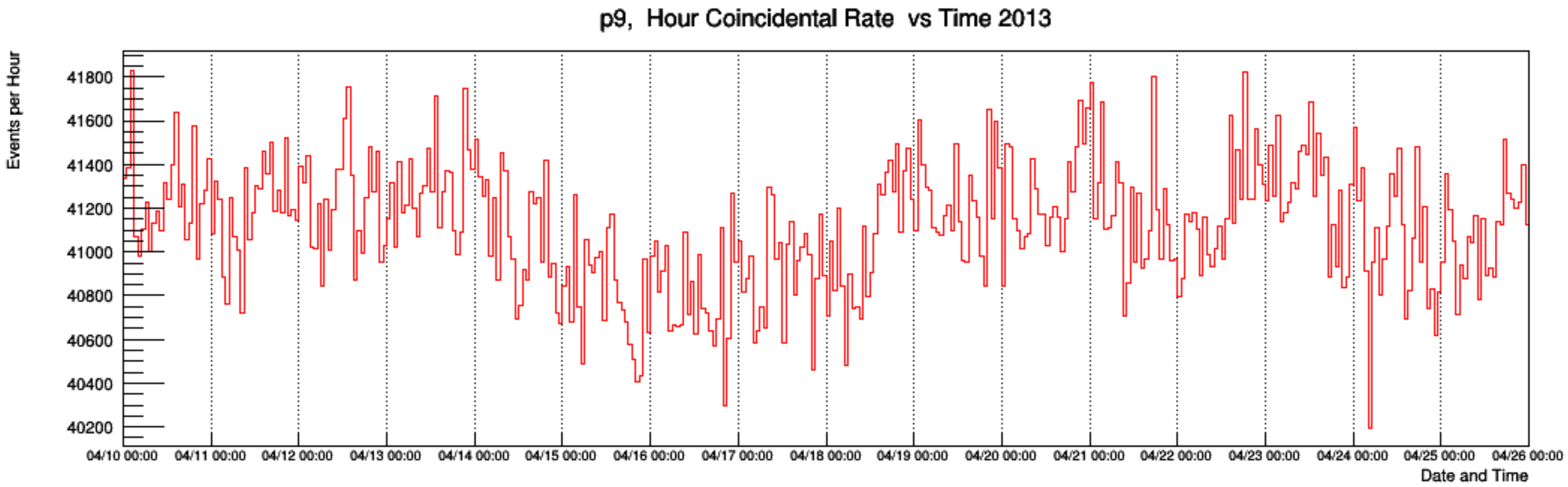

Accidentats rate vs Diff tube p10
Daily accidentals rate
Tube A- Tube B

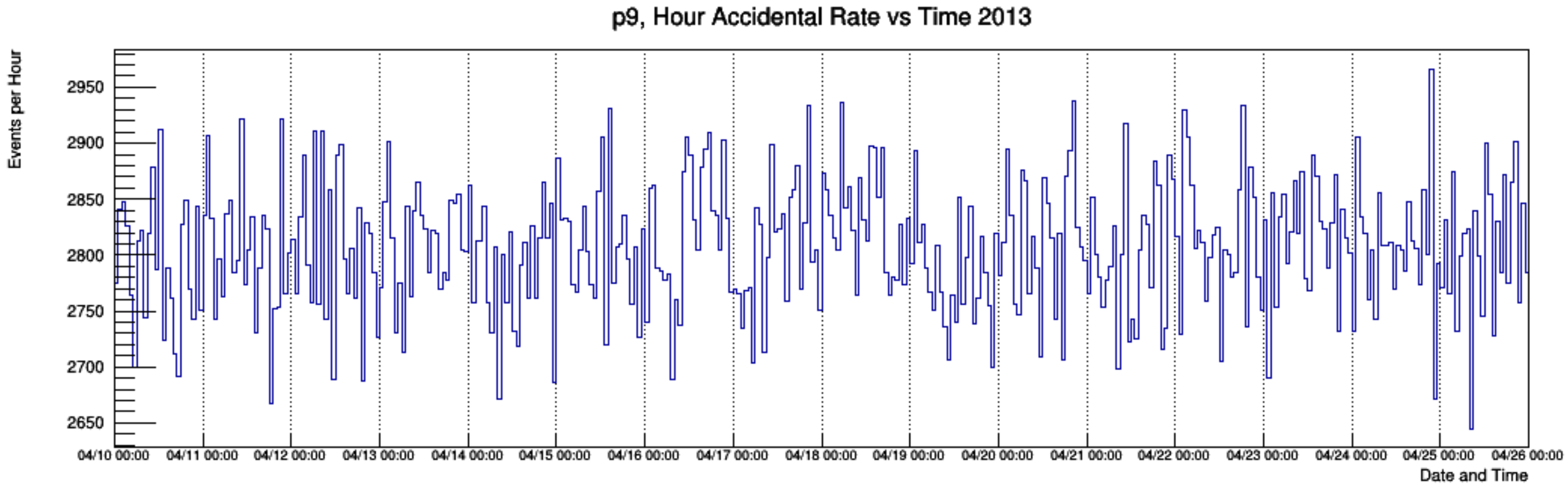

Coincidentats rate vs Diff tube p10_2013103
Daily coincidentals rate
Tube A- Tube B


Accidentats rate/Combination vs Diff tube p10_2013103
Daily accidentals rate/Combination
Tube A- Tube B

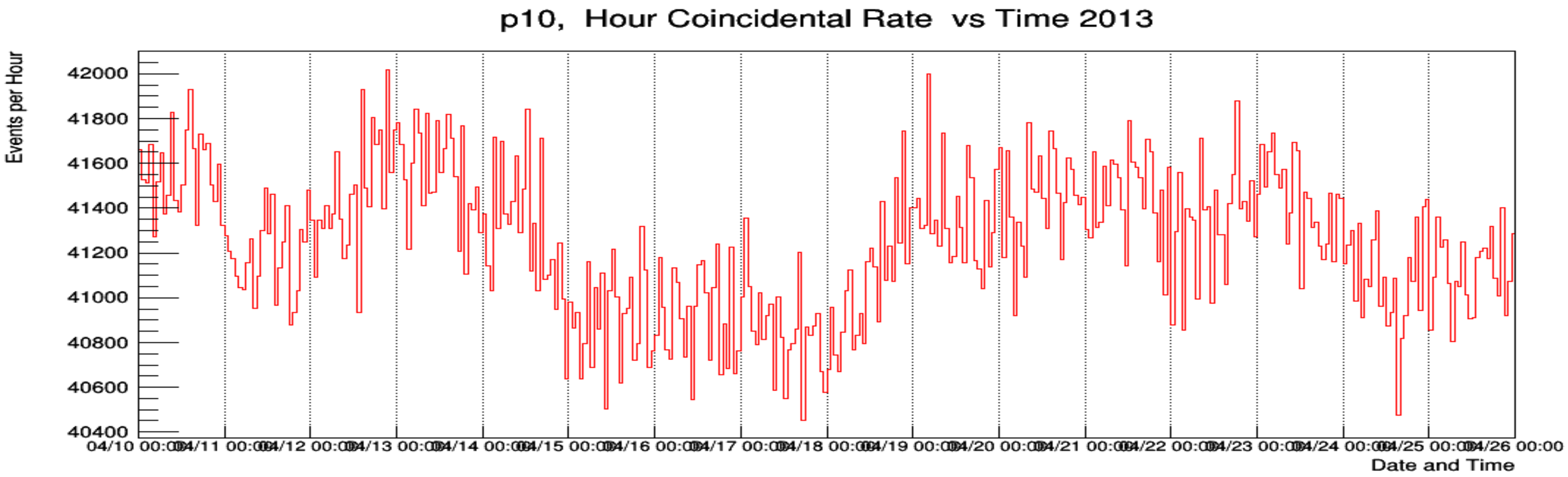

Coincidentats rate/Combination vs Diff tube p10_2013103
Daily coincidentals rate/Combination
Tube A- Tube B

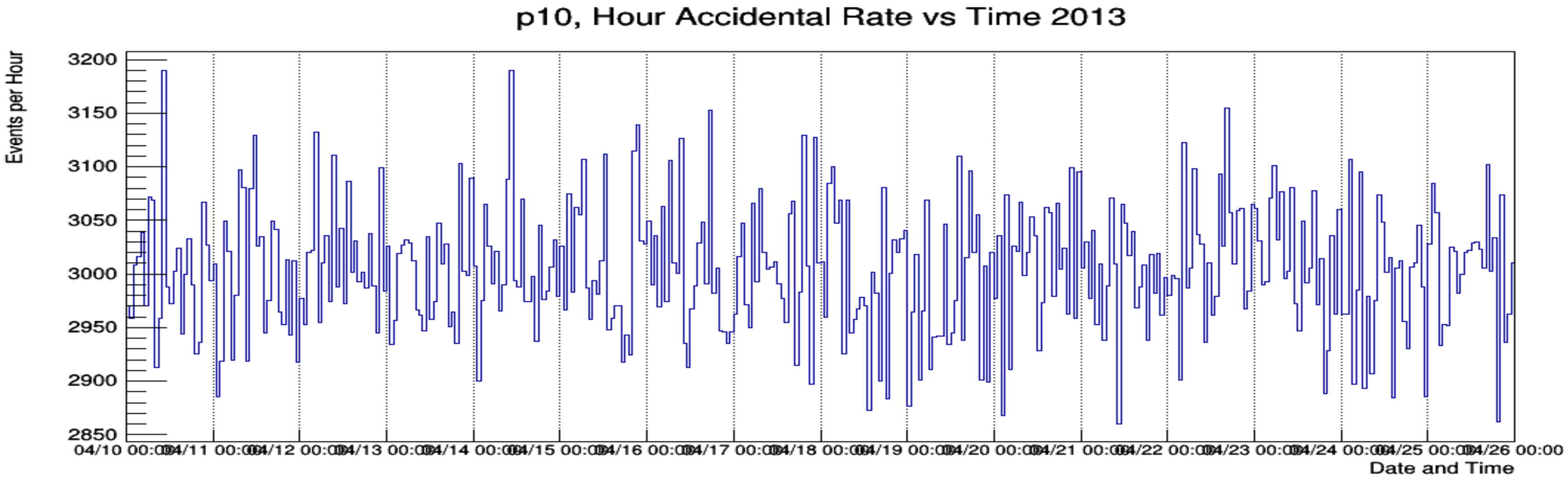
Hour data P9


p9, Hour Coincidental Rate vs Time 2013
Events per Hour
41800
41600
41400
41200
41000
40800
40600
40400
40200
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

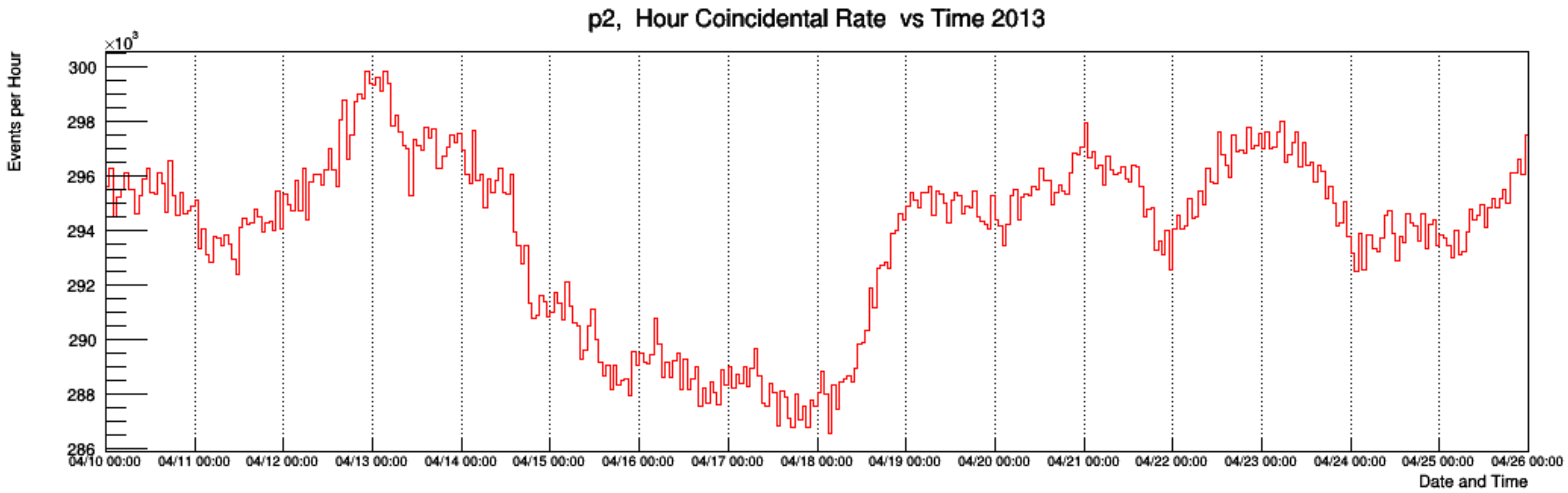

p9, Hour Accidental Rate vs Time 2013
Events per Hour
2950
2900
2850
2800
2750
2700
2650
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

Hour data P10





Hour data


p2, Hour Coincidental Rate vs Time 2013
×10³
Events per Hour
300
298
296
294
292
290
288
286
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
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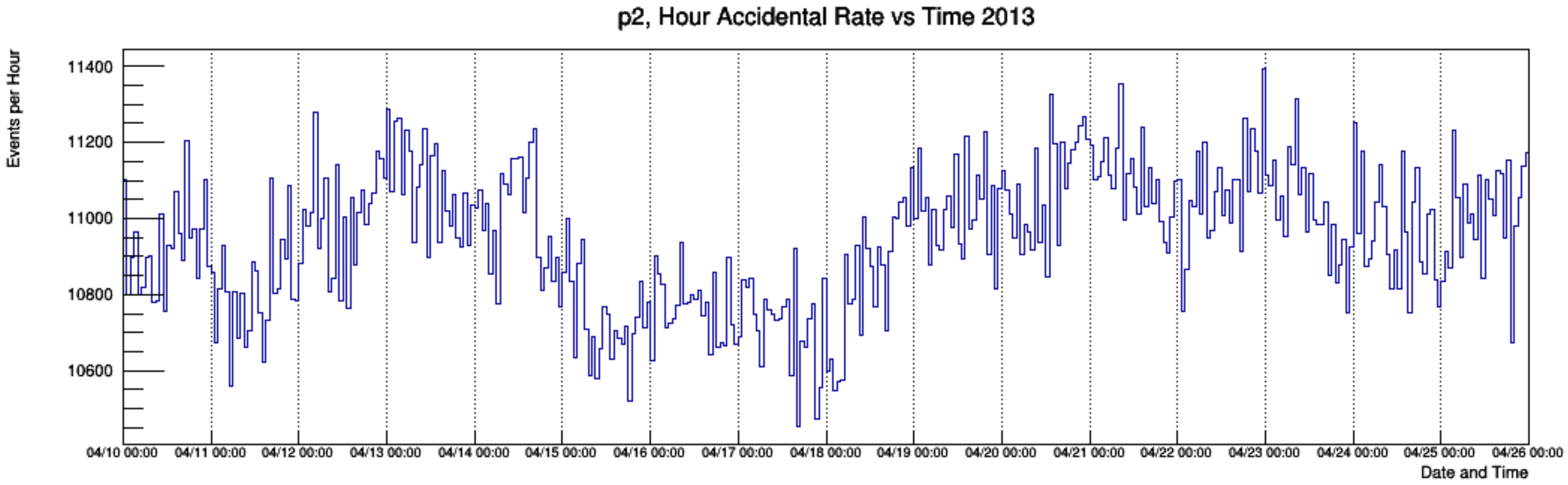
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time


p2, Hour Accidental Rate vs Time 2013
Events per Hour
11400
11200
11000
10800
10600
04/10 00:00
04/11 00:00
04/12 00:00
04/13 00:00
04/14 00:00
04/15 00:00
04/16 00:00
04/17 00:00
04/18 00:00
04/19 00:00
04/20 00:00
04/21 00:00
04/22 00:00
04/23 00:00
04/24 00:00
04/25 00:00
04/26 00:00
Date and Time

THANK YOU

ANY QUESTIONS ?

REFERENCE

Duldig, L. M. (1990). The Mawson Automatic Cosmic Ray Observatory (MACRO). In *International Cosmic Ray Conference*, volume 7 of *International Cosmic Ray Conference*, page 288.

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Mavromichalaki, H., Plainaki, C., Gerontidou, M., Sarlanis, C., Souvatzoglou, G., & Mariatos, G. et al. (2007). GLEs as a Warning Tool for Radiation Effects on Electronics and Systems: A New Alert System Based on Real-Time Neutron Monitors. *IEEE Transactions On Nuclear Science*, *54*(4), 1082-1088.

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GEOMAGNETIC CUTOFF RIGIDITY

- **Rigidity** is defined as momentum per unit charge

magnetic field   momentum

$$P = Br = pc/q$$

rigidity   gyroradius   charge

- The magnetic field of the Earth excludes particle below a well-defined rigidity at any given location known as cutoff rigidity

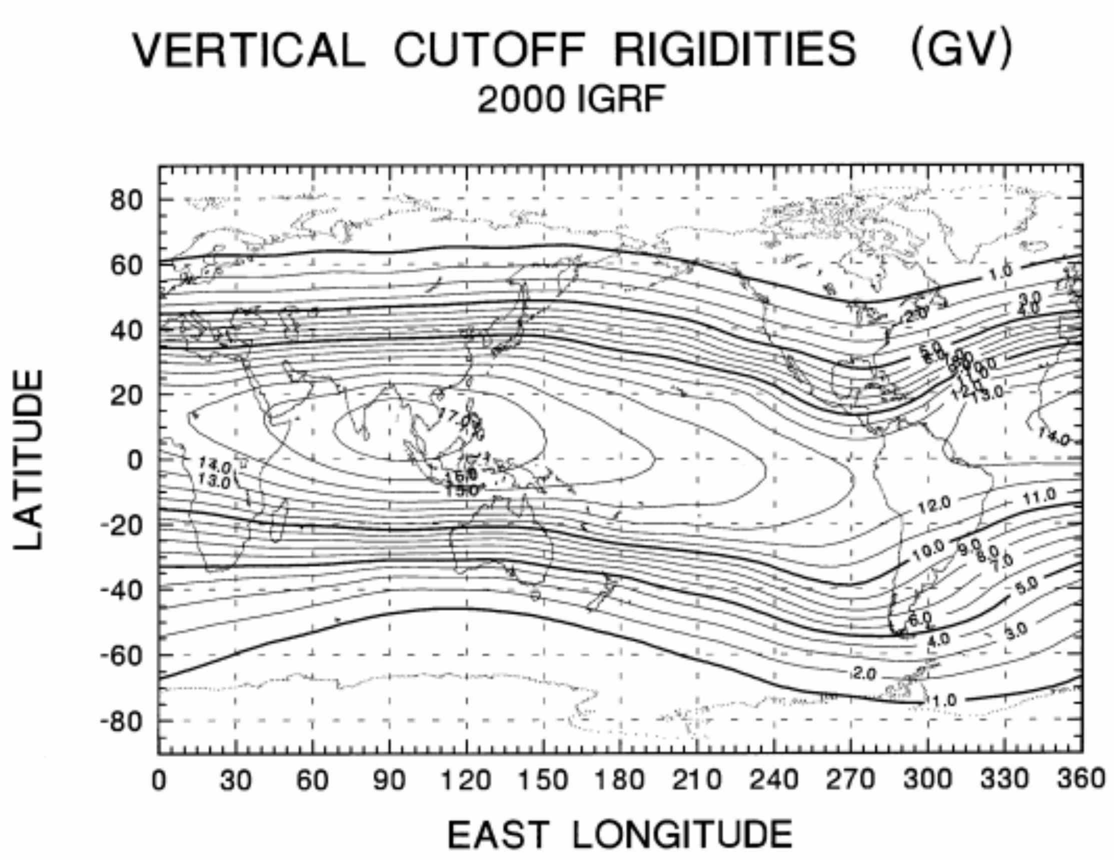


Fig 7. Rigidity contours for vertical geomagnetic cutoff rigidities for epoch 2000. (Smart & Shea, 2006)

Vertical cutoff rigidity
→ the minimum rigidity for a vertical incident particle

Apparent cutoff rigidity
→ an estimate rigidity for each possible direction of incident particle

CUTOFF-RIGIDITY

- $R_c = [M \cos\lambda^4]/\{r^2\ [\,1 + (1 - \sin\epsilon \sin\xi \cos\lambda^3\ )^{1/2}]^2\}$

Where

- R_c is the geomagnetic cutoff rigidity
- λ is the latitude
- M is the magnitude of the dipole moment
- r is the distance from the dipole center in centimeters

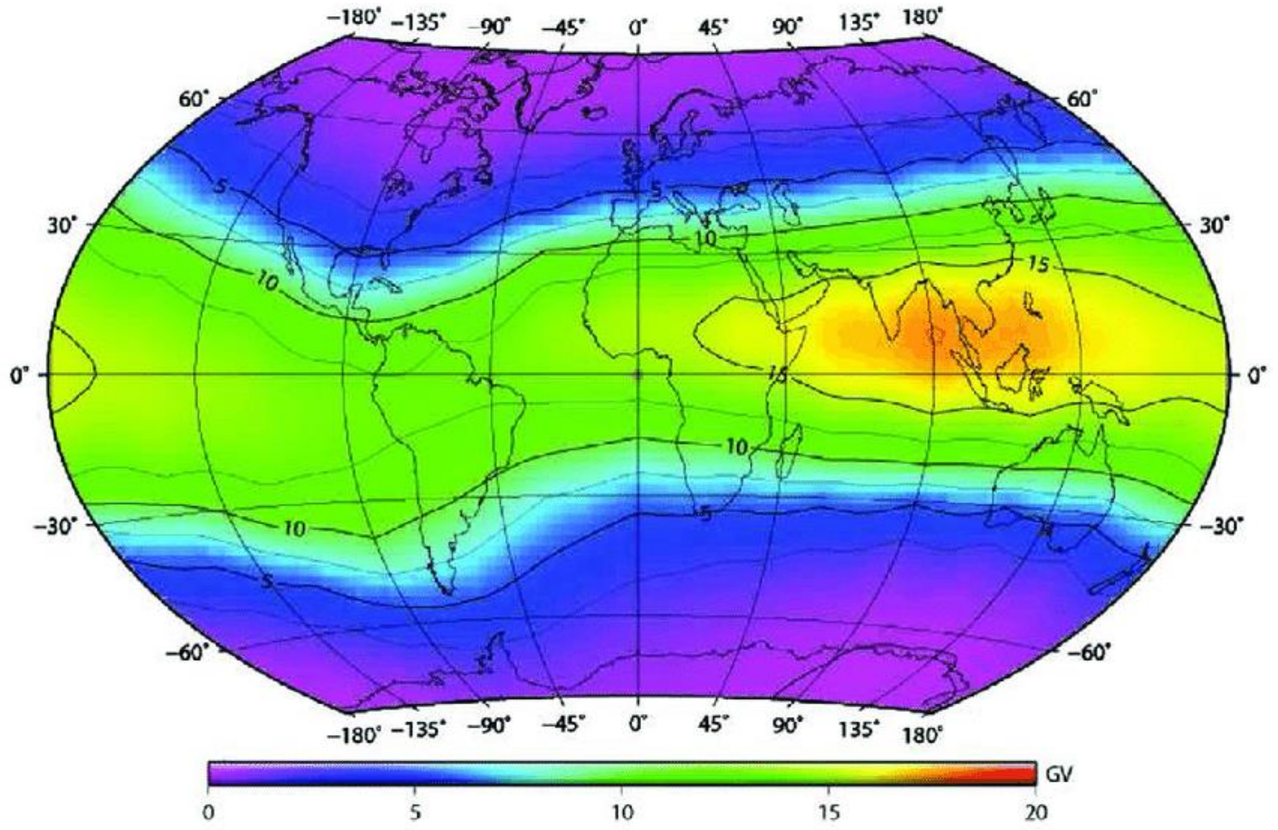


Fig 11. The effective vertical geomagnetic cutoff-rigidity (Nevalainen, Usoskin & Mishev, 2013)

NM64 RESPONSE ENERGY

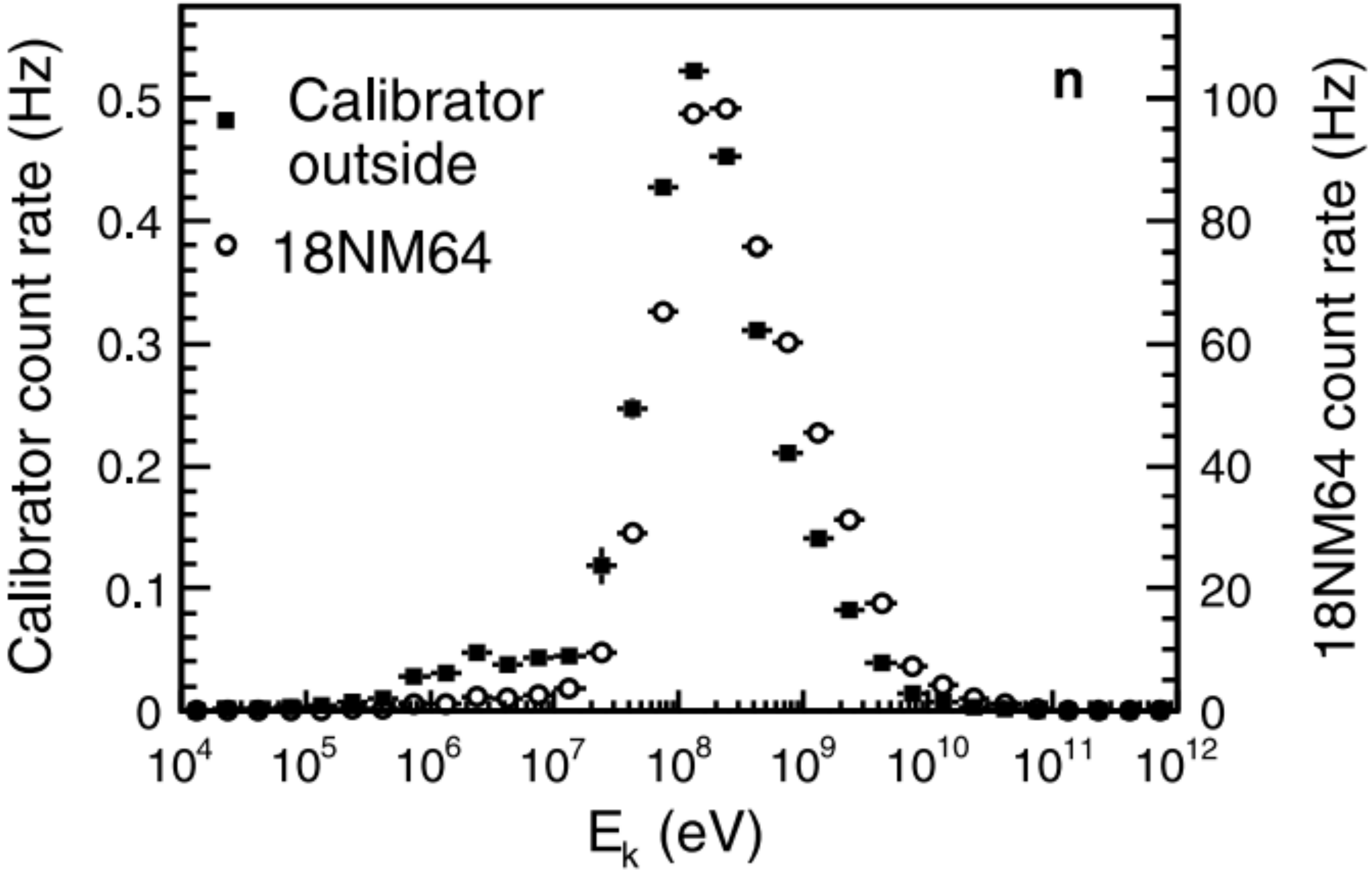


Fig 13
Simulated neutron monitor count rates produced by various types of atmospheric secondary cosmic rays arriving to ground level (Aiemsa-ad et al.. 2015)

DIFFERENTIAL RESPONSE FUNCTION

$$N(P_c) = N_0\left(1 - e^{-\alpha P_c^{-\kappa}}\right),$$

$$N(P_c) = \int_{P_c}^{\infty} DRF(P)\,dP,$$

$$DRF(P) = N_0 \alpha P^{-\kappa-1} \kappa e^{-\alpha P^{-\kappa}}.$$

$$DRF(P) = -\left[\frac{dN}{dP_c}\right]_p = \sum G(P)M(P,t)Y(P,h)$$

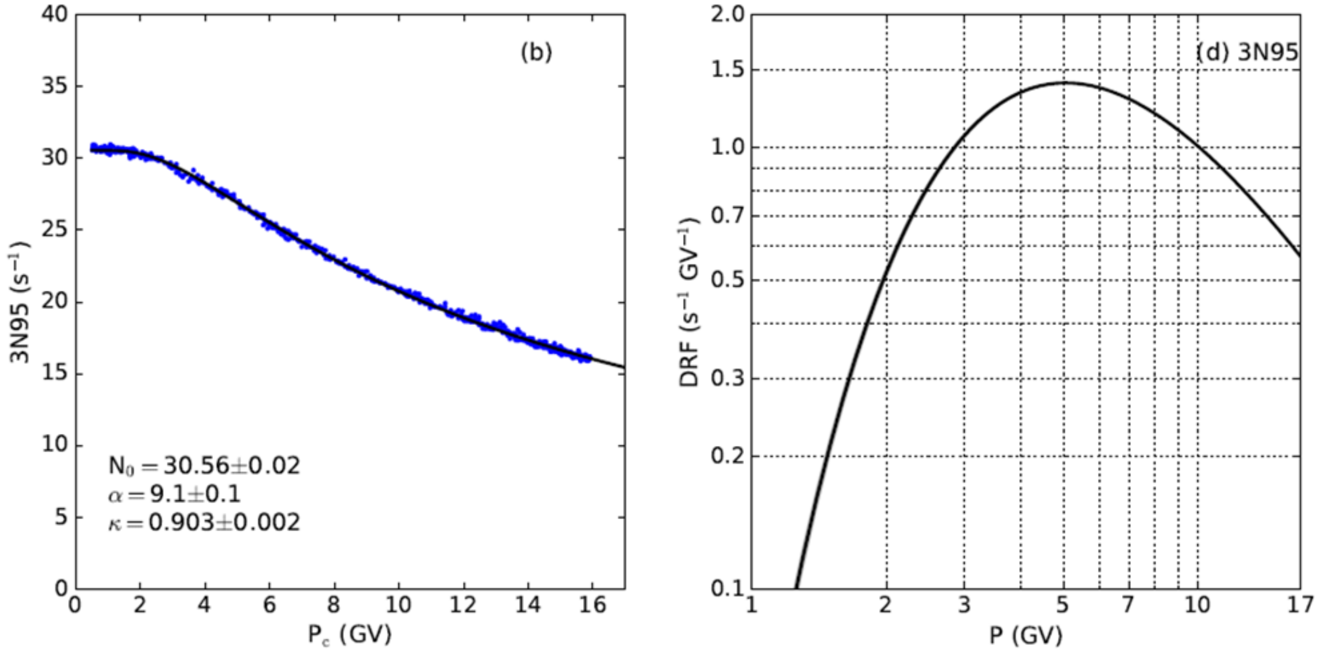
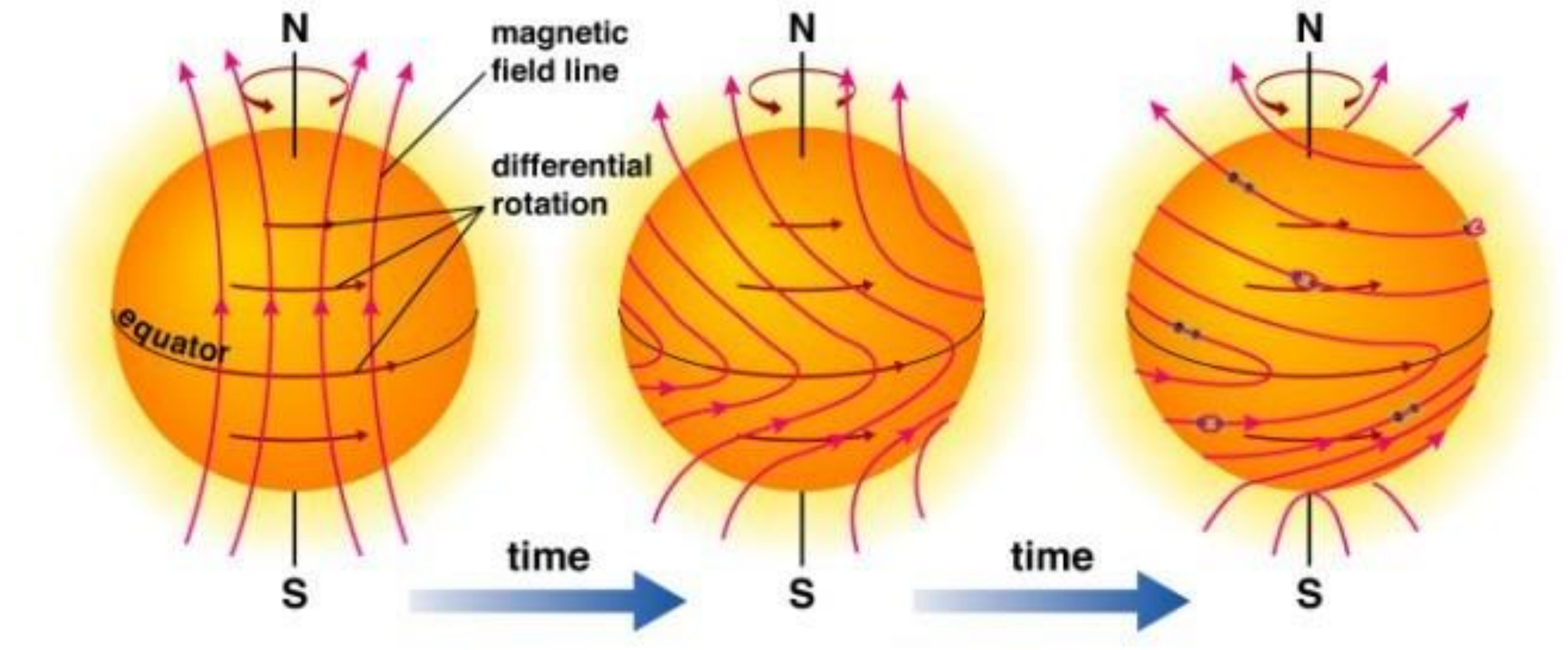


Fig 12 Dorman function fits to neutron monitor data (b) and show the resulting differential response functions (DRFs) (d) (Nuntiyakul et al., 2018)

WHAT CAUSES THE SUN'S MAGNETIC FIELD FLIP?



DATA REDUCTION

I : Tube ratio cleaning

DOY	T1	T2	T3	T1/T2	T2/T3	T3/T1
307.0104	8.35	9.25	8.28	0.902703	1.117150	0.991617
307.0316	8.54	9.41	8.4	0.907545	1.120238	0.983607
307.0528	8.47	9.36	8.44	0.904915	1.109005	0.996458

S1 D2 D3

Average whole survey

S1/S2 S2/S3 S3/S1

- If one tube was removed

  -> tube 1, corrected count = $\left(\frac{s_1+s_2+s_3}{s_2+s_3}\right)(D_2 + D_3)$

- If two tubes were removed

  -> remaining actual count rate x average ratio of whole survey

  -> Only Tube 1 remaining, corrected count Tube 2 = $\left(\frac{D_1}{s_1/s_2}\right)$

  , corrected count Tube 3 = $\left(\frac{D_1}{s_1/s_3}\right)$

- If three tubes were removed -> DATA GAP

Applied for Mobile NM And Mawson NM data since Oct 2002 to Dec 2002

II : Pressure correction

Barometric pressure was corrected using Equation as follow;

Pressure [mmHg]

Count rate corrected for tube and pressure

$$C_{TP} = C_T e^{\beta(P-P_{ref})}$$

Standard atmospheric pressure [mmHg] (760 mmHg for McMurdo and Mobile survey)

Count rate corrected for tube

For latitude survey

Pressure coefficient [% per mmHg]

$$\beta = 1.006 - 0.0153 P_c$$

Apparent cutoff rigidity [GV]

Mawson station

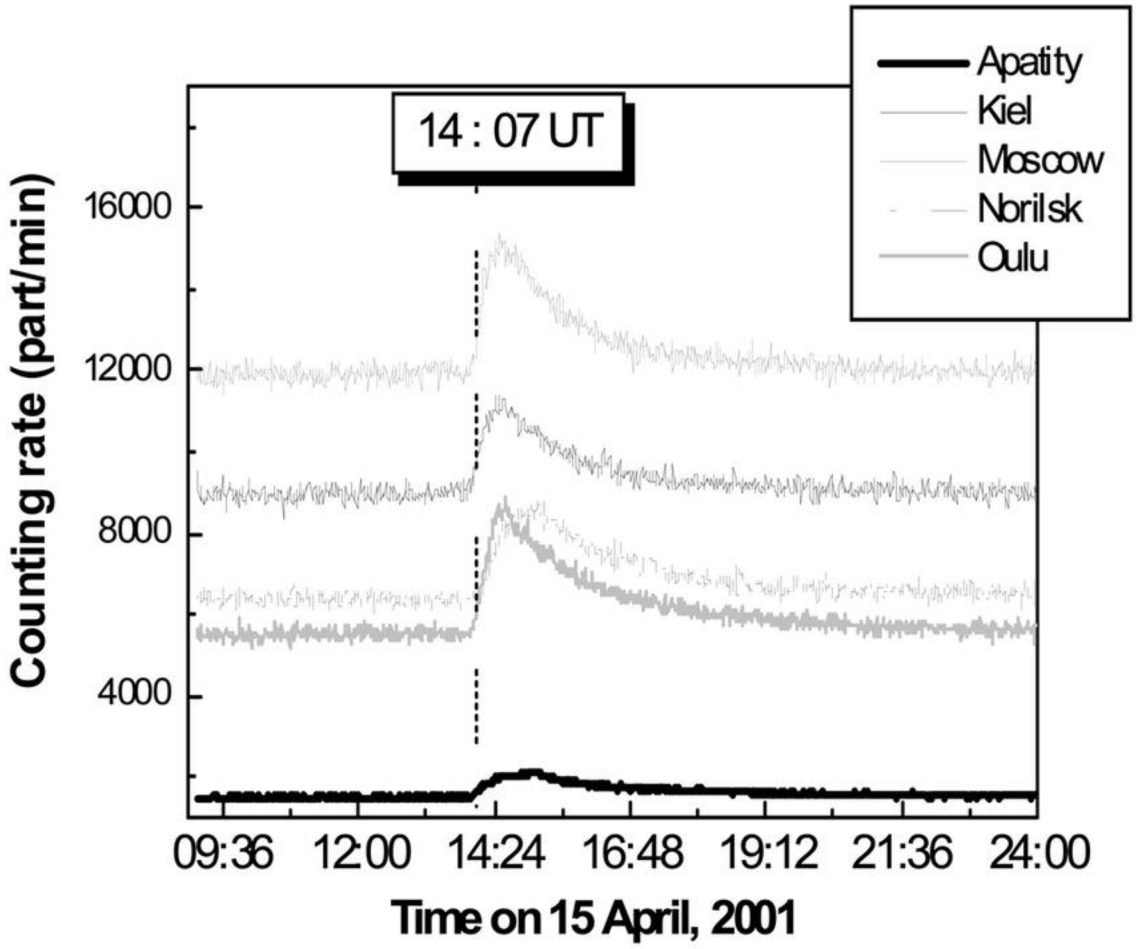
Standard atmospheric pressure: 990.0 mb

Barometric coefficient (2004): -0.708%/mb

* 1 mbar = 0.750062 mmHg

Applied for All data set

GROUND LEVEL ENHANCEMENT



- Ground level enhancement onsets at five NM stations recording the event of April 15, 2001 (Mavromichalaki et al., 2007)

FORBUSH DECREASE

- A rapid decrease in the observed galactic cosmic ray intensity following a coronal mass ejection (CME).