# The Arrival Direction of EAS Observed by Kinki Array with Energy Around $10^{15}$ eV

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**Abstract**

A search for the arrival direction of EAS has been studied for the data of Kinki array and the galactic coordinates with energy range between $10^{14}$ and $10^{17}$eV at sea level. No strong statistical significance of deviation from isotropy was found for the galactic plane enhancemcnt. Concerning on the galactic enhancement tactor $f_e$ a comparison with some other higher energy experiment is also presented. It seems that the distribution of arrival direction of EAS suggests very weak energy dependence of fe for EAS at low energy region. In this report, I will present some basic calculation results about the distribution of arrival distribution of EAS in the galactic coordinates.
**Key words:** EAS, arrival direction, the galactic plane enhancement, Durham formulation.

## 1 Introduction

There has been published many papers on the direction of cosmic rays at high energy[1 etc.]. We analysed approximately 54k events of the Kinki data period between

1989 and 1992[2]. For the data, an anisotropic distribution for the galactic plane was investigated. Also we compared forcibly from low energy EAS to most high energy ones.

## 2 The Galactic Plane Enhancement of EAS

An analysis on the galactic latitude has been studied. The galactic latitude enhancement factor, fe values were calculated from ratio of the number of observed events to expected events, $n_{obs}/n_{exp}$. The fe values for the directions of the galactlc centre and anti-centre were compared. It evaluated with fit of Durham formulation[3]:

$$I(b)/I_o=n_{obs}/n_{exp}$$
$$=(1-f_e)\ (\mathrm{const})\ f_e\ e^{-b2},$$

where $I(b)$ is the observed cosmic rays intensity at the galactic latitude $b$, $I_o$ is the overall average intensity, and 'const' is a correct average intensity for normalisation which is currently taken to be 1.4. And calculations were done for the data dividing into two direction concerning on the galactic longitude $l$, i.e.,the galactic 'centre' and the galactic 'anti-centre', corresponding to $270<l<90$ and $90<l<270$ in unit of degrees, respectively. Calculation results for our data with cut of these directional criteria are shown in Table-1. Fig-1(a)-(c) are shown their plot with other experimental data.

## 4 Results

Next $f_e$ are evaluated for the data of EAS at the Kinki array: $f_e$(uncut)=0.064 ± 0.012, $f_e$(centre)=0.100 ± 0.020, $f_e$(anti-centre)=0.040 ± -0.016. It seems that the distribution of arrival direction of EAS suggests very weak energy dependence of fe for EAS at low energy region


## Acknowledgement

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## References


[1]MS Gillmann and AA Watson: 23rd ICRC(Calgary), (1993)
M Giller et al.: Proc . 23rd CRC(Calgary)2, 81(1993)
DJ Cutler et al.: Astrophys. J 376, 322(1991)
K Nagashima et al.: Nuovo Cimento, 12C N.6, 695(1989)
[2]M Chikawa et al.: 23rd ICRC(Calgary), HE, Vol4, 219(1993)
M Chikawa et al.: 24th ICRC(Rome), OG3.1.6, 780(1995)
[3]X Chi, AA Ivanov and AW Wolfendale: J. Phys. G., 18, 1259(1992)

Table-1 Calculation results of 'Harmonic Analysys' for 1st and 2nd order for the Kinki data.

Total 54k evs, Harmonic analysis.

< 1st harmonic >

| # | Mid-pnt deg | Obs. evs. | cos | Ni*cos | sin | Ni*sin |
|---|---|---|---|---|---|---|
| 1 | 5.0 | 1530 | 0.9962 | 1524.178 | 0.0872 | 133.348 |
| 2 | 15.0 | 1560 | 0.9659 | 1506.844 | 0.2588 | 403.758 |
| 3 | 25.0 | 1506 | 0.9063 | 1364.900 | 0.4226 | 636.463 |
| 4 | 35.0 | 1504 | 0.8192 | 1232.005 | 0.5736 | 862.659 |
| 5 | 45.0 | 1597 | 0.7071 | 1129.250 | 0.7071 | 1129.249 |
| 6 | 55.0 | 1553 | 0.5736 | 890.764 | 0.8192 | 1272.143 |
| 7 | 65.0 | 1469 | 0.4226 | 620.826 | 0.9063 | 1331.366 |
| 8 | 75.0 | 1403 | 0.2588 | 363.123 | 0.9659 | 1355.194 |
| 9 | 85.0 | 1531 | 0.0872 | 133.436 | 0.9962 | 1525.174 |
| 10 | 95.0 | 1481 | -0.0872 | -129.078 | 0.9962 | 1475.364 |
| 11 | 105.0 | 1469 | -0.2588 | -380.205 | 0.9659 | 1418.945 |
| 12 | 115.0 | 1471 | -0.4226 | -621.671 | 0.9063 | 1333.179 |
| 13 | 125.0 | 1543 | -0.5736 | -885.028 | 0.8192 | 1263.952 |
| 14 | 135.0 | 1517 | -0.7071 | -1072.681 | 0.7071 | 1072.681 |
| 15 | 145.0 | 1442 | -0.8192 | -1181.217 | 0.5736 | 827.097 |
| 16 | 155.0 | 1507 | -0.9063 | -1365.806 | 0.4226 | 636.886 |
| 17 | 165.0 | 1464 | -0.9659 | -1414.115 | 0.2588 | 378.911 |
| 18 | 175.0 | 1455 | -0.9962 | -1449.463 | 0.0872 | 126.812 |
| 19 | 185.0 | 1407 | -0.9962 | -1401.646 | -0.0872 | -122.628 |
| 20 | 195.0 | 1400 | -0.9659 | -1352.296 | -0.2588 | -362.346 |
| 21 | 205.0 | 1474 | -0.9063 | -1335.898 | -0.4226 | -622.939 |
| 22 | 215.0 | 1373 | -0.8192 | -1124.696 | -0.5736 | -787.520 |
| 23 | 225.0 | 1404 | -0.7071 | -992.778 | -0.7071 | -992.778 |
| 24 | 235.0 | 1454 | -0.5736 | -833.981 | -0.8192 | -1191.047 |
| 25 | 245.0 | 1421 | -0.4226 | -600.540 | -0.9063 | -1287.863 |
| 26 | 255.0 | 1466 | -0.2588 | -379.429 | -0.9659 | -1416.047 |
| 27 | 265.0 | 1503 | -0.0872 | -130.995 | -0.9962 | -1497.281 |
| 28 | 275.0 | 1521 | 0.0872 | 132.564 | -0.9962 | -1515.212 |
| 29 | 285.0 | 1527 | 0.2588 | 395.217 | -0.9659 | -1474.969 |
| 30 | 295.0 | 1542 | 0.4226 | 651.677 | -0.9063 | -1397.527 |
| 31 | 305.0 | 1572 | 0.5736 | 901.662 | -0.8192 | -1287.707 |
| 32 | 315.0 | 1504 | 0.7071 | 1063.488 | -0.7071 | -1063.489 |
| 33 | 325.0 | 1550 | 0.8192 | 1269.686 | -0.5736 | -889.044 |
| 34 | 335.0 | 1510 | 0.9063 | 1368.525 | -0.4226 | -638.154 |
| 35 | 345.0 | 1616 | 0.9659 | 1560.936 | -0.2588 | -418.252 |
| 36 | 355.0 | 1508 | 0.9962 | 1502.262 | -0.0872 | -131.431 |
| Total | | 53754 | | 959.818 | | 86.951 |

```
******************** 1-st HARMONIC ANALYSIS *****************
R_bar=  0.0359  S0=1-R_bar=0.9641
s0=sqrt[2 ln(1-rc)]=147.823(deg)
<mean angle> =      5.176(deg)     2n(R_bar)^2=  138.231
          k0 =  17.28
**************************************************************
**     p(>=r) = exp(-k0) = 3.1e-008                         **
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```

< 2nd harmonic >

| # | Mid-pnt deg | Obs. evs. | cos | Ni*cos | sin | Ni*sin |
|---|---|---|---|---|---|---|
| 1 | 5.0 | 1530 | 0.9848 | 1506.756 | 0.1736 | 265.682 |
| 2 | 15.0 | 1560 | 0.8660 | 1351.000 | 0.5000 | 780.000 |
| 3 | 25.0 | 1506 | 0.6428 | 968.038 | 0.7660 | 1153.663 |
| 4 | 35.0 | 1504 | 0.3420 | 514.398 | 0.9397 | 1413.298 |
| 5 | 45.0 | 1597 | 0.0000 | 0.000 | 1.0000 | 1597.000 |
| 6 | 55.0 | 1553 | -0.3420 | -531.157 | 0.9397 | 1459.343 |
| 7 | 65.0 | 1469 | -0.6428 | -944.255 | 0.7660 | 1125.319 |
| 8 | 75.0 | 1403 | -0.8660 | -1215.034 | 0.5000 | 701.500 |
| 9 | 85.0 | 1531 | -0.9848 | -1507.741 | 0.1736 | 265.856 |
| 10 | 95.0 | 1481 | -0.9848 | -1458.500 | -0.1736 | -257.173 |
| 11 | 105.0 | 1469 | -0.8660 | -1272.191 | -0.5000 | -734.500 |
| 12 | 115.0 | 1471 | -0.6428 | -945.541 | -0.7660 | -1126.851 |
| 13 | 125.0 | 1543 | -0.3420 | -527.737 | -0.9397 | -1449.946 |
| 14 | 135.0 | 1517 | 0.0000 | 0.000 | -1.0000 | -1517.000 |
| 15 | 145.0 | 1442 | 0.3420 | 493.193 | -0.9397 | -1355.037 |
| 16 | 155.0 | 1507 | 0.6428 | 968.681 | -0.7660 | -1154.429 |
| 17 | 165.0 | 1464 | 0.8660 | 1267.861 | -0.5000 | -732.000 |
| 18 | 175.0 | 1455 | 0.9848 | 1432.895 | -0.1736 | -252.658 |
| 19 | 185.0 | 1407 | 0.9848 | 1385.625 | 0.1736 | 244.323 |
| 20 | 195.0 | 1400 | 0.8660 | 1212.436 | 0.5000 | 700.000 |
| 21 | 205.0 | 1474 | 0.6428 | 947.469 | 0.7660 | 1129.150 |
| 22 | 215.0 | 1373 | 0.3420 | 469.594 | 0.9397 | 1290.198 |
| 23 | 225.0 | 1404 | 0.0000 | 0.000 | 1.0000 | 1404.000 |
| 24 | 235.0 | 1454 | -0.3420 | -497.296 | 0.9397 | 1366.313 |
| 25 | 245.0 | 1421 | -0.6428 | -913.401 | 0.7660 | 1088.549 |
| 26 | 255.0 | 1466 | -0.8660 | -1269.593 | 0.5000 | 733.000 |
| 27 | 265.0 | 1503 | -0.9848 | -1480.166 | 0.1736 | 260.993 |
| 28 | 275.0 | 1521 | -0.9848 | -1497.893 | -0.1736 | -264.119 |
| 29 | 285.0 | 1527 | -0.8660 | -1322.421 | -0.5000 | -763.500 |
| 30 | 295.0 | 1542 | -0.6428 | -991.179 | -0.7660 | -1181.240 |
| 31 | 305.0 | 1572 | -0.3420 | -537.656 | -0.9397 | -1477.197 |
| 32 | 315.0 | 1504 | -0.0000 | -0.000 | -1.0000 | -1504.000 |
| 33 | 325.0 | 1550 | 0.3420 | 530.131 | -0.9397 | -1456.524 |
| 34 | 335.0 | 1510 | 0.6428 | 970.609 | -0.7660 | -1156.728 |
| 35 | 345.0 | 1616 | 0.8660 | 1399.497 | -0.5000 | -808.001 |
| 36 | 355.0 | 1508 | 0.9848 | 1485.090 | -0.1736 | -261.862 |
| Total | | 53754 | | -8.491 | | -474.579 |

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******************** 2-nd HARMONIC ANALYSIS *****************
R_bar=  0.0177  S0=1-R_bar=0.9823
s0=sqrt[2 ln(1-rc)]=162.793(deg)
<mean angle> =  268.975(deg)     2n(R_bar)^2=   33.530
          k0 =    4.19
**************************************************************
**     p(>=r) = exp(-k0) = 1.5e-002                         **
**************************************************************
```

total 56804 EAS : centre=20485 anticentre=36319

*** no cut 56804 evs ***

| b | obs error | exp(int) | exp error | obs/exp error |
|---|---|---|---|---|
| -85 | 0.00+/- 0.00 | 0.11 | 0.11+/- 0.07 | 0.000+/-0.000 |
| -75 | 206.00+/-14.35 | 244.25 | 244.14+/- 4.40 | 0.844+/-0.061 |
| -65 | 335.00+/-18.30 | 573.96 | 329.71+/- 5.20 | 1.016+/-0.058 |
| -55 | 630.00+/-25.10 | 1275.22 | 701.27+/- 8.13 | 0.898+/-0.037 |
| -45 | 1713.00+/-41.39 | 3007.15 | 1731.93+/- 14.06 | 0.989+/-0.025 |
| -35 | 3217.00+/-56.72 | 6142.83 | 3135.68+/- 19.54 | 1.026+/-0.019 |
| -25 | 4630.00+/-68.04 | 10658.90 | 4516.07+/- 23.89 | 1.025+/-0.016 |
| -15 | 5408.00+/-73.54 | 15914.60 | 5255.70+/- 25.47 | 1.029+/-0.015 |
| -5 | 5379.00+/-73.34 | 21310.97 | 5396.38+/- 25.39 | 0.997+/-0.014 |
| 5 | 5184.00+/-72.00 | 26316.45 | 5005.47+/- 23.06 | 1.036+/-0.015 |
| 15 | 4624.00+/-68.00 | 30900.98 | 4584.54+/- 20.42 | 1.009+/-0.015 |
| 25 | 4388.00+/-66.24 | 35247.56 | 4346.58+/- 18.94 | 1.010+/-0.016 |
| 35 | 4349.00+/-65.95 | 39539.38 | 4291.82+/- 18.71 | 1.013+/-0.016 |
| 45 | 4536.00+/-67.35 | 44161.61 | 4622.23+/- 20.81 | 0.981+/-0.015 |
| 55 | 4299.00+/-65.57 | 48545.81 | 4384.20+/- 19.96 | 0.981+/-0.016 |
| 65 | 3947.00+/-62.83 | 52600.43 | 4054.62+/- 19.10 | 0.973+/-0.016 |
| 75 | 2872.00+/-53.59 | 55648.59 | 3048.16+/- 15.58 | 0.942+/-0.018 |
| 85 | 1087.00+/-32.97 | 56804.57 | 1155.98+/- 7.87 | 0.940+/-0.029 |

*** centre : 20485 evs ***

| b | obs error | exp(int) | exp error | obs/exp error |
|---|---|---|---|---|
| -85 | 0.00+/- 0.00 | 0.02 | 0.02+/- 0.01 | 0.000+/-0.000 |
| -75 | 23.00+/- 4.80 | 38.89 | 38.88+/- 0.84 | 0.592+/-0.124 |
| -65 | 128.00+/-11.31 | 168.55 | 129.66+/- 2.23 | 0.987+/-0.089 |
| -55 | 143.00+/-11.96 | 330.77 | 162.22+/- 2.30 | 0.882+/-0.075 |
| -45 | 314.00+/-17.72 | 642.03 | 311.26+/- 3.24 | 1.009+/-0.058 |
| -35 | 602.00+/-24.54 | 1245.91 | 603.88+/- 4.60 | 0.997+/-0.041 |
| -25 | 1007.00+/-31.73 | 2231.45 | 985.54+/- 6.06 | 1.022+/-0.033 |
| -15 | 1439.00+/-37.93 | 3635.39 | 1403.94+/- 7.35 | 1.025+/-0.028 |
| -5 | 1767.00+/-42.04 | 5339.89 | 1704.50+/- 8.09 | 1.037+/-0.025 |
| 5 | 1906.00+/-43.66 | 7229.11 | 1889.23+/- 8.50 | 1.009+/-0.024 |
| 15 | 2002.00+/-44.74 | 9203.17 | 1974.05+/- 8.65 | 1.014+/-0.023 |
| 25 | 2036.00+/-45.12 | 11178.65 | 1975.48+/- 8.58 | 1.031+/-0.023 |
| 35 | 1954.00+/-44.20 | 13150.47 | 1971.82+/- 8.54 | 0.991+/-0.023 |
| 45 | 2101.00+/-45.84 | 15341.46 | 2190.98+/- 10.67 | 0.959+/-0.021 |
| 55 | 1761.00+/-41.96 | 17196.79 | 1855.34+/- 8.60 | 0.949+/-0.023 |
| 65 | 1560.00+/-39.50 | 18852.71 | 1655.92+/- 8.39 | 0.942+/-0.024 |
| 75 | 1238.00+/-35.19 | 20192.07 | 1339.36+/- 7.60 | 0.924+/-0.027 |
| 85 | 504.00+/-22.45 | 20736.96 | 544.90+/- 4.05 | 0.925+/-0.042 |

*** anti-centre : 36319 evs ***

| b | obs error | exp(int) | exp error | obs/exp error |
|---|---|---|---|---|
| -85 | 0.00+/- 0.00 | 0.09 | 0.09+/- 0.06 | 0.000+/-0.000 |
| -75 | 183.00+/-13.53 | 205.35 | 205.26+/- 3.66 | 0.892+/-0.068 |
| -65 | 207.00+/-14.39 | 405.41 | 200.05+/- 3.32 | 1.035+/-0.074 |
| -55 | 487.00+/-22.07 | 944.45 | 539.05+/- 6.70 | 0.903+/-0.042 |
| -45 | 1399.00+/-37.40 | 2365.11 | 1420.66+/- 12.30 | 0.985+/-0.028 |
| -35 | 2615.00+/-51.14 | 4896.90 | 2531.80+/- 17.13 | 1.033+/-0.021 |
| -25 | 3623.00+/-60.19 | 8427.41 | 3530.51+/- 20.92 | 1.026+/-0.018 |
| -15 | 3969.00+/-63.00 | 12279.15 | 3851.74+/- 21.59 | 1.030+/-0.017 |
| -5 | 3612.00+/-60.10 | 15971.00 | 3691.85+/- 20.79 | 0.978+/-0.017 |
| 5 | 3278.00+/-57.25 | 19087.22 | 3116.22+/- 17.52 | 1.052+/-0.019 |
| 15 | 2622.00+/-51.21 | 21697.68 | 2610.45+/- 13.75 | 1.004+/-0.020 |
| 25 | 2352.00+/-48.50 | 24068.74 | 2371.07+/- 11.68 | 0.992+/-0.021 |
| 35 | 2395.00+/-48.94 | 26388.71 | 2319.96+/- 11.44 | 1.032+/-0.022 |
| 45 | 2435.00+/-49.35 | 28819.93 | 2431.22+/- 13.01 | 1.002+/-0.021 |
| 55 | 2538.00+/-50.38 | 31348.77 | 2528.84+/- 13.84 | 1.004+/-0.021 |
| 65 | 2387.00+/-48.86 | 33747.45 | 2398.68+/- 12.95 | 0.995+/-0.021 |
| 75 | 1634.00+/-40.42 | 35456.23 | 1708.78+/- 9.65 | 0.956+/-0.024 |
| 85 | 583.00+/-24.15 | 36067.30 | 611.08+/- 4.43 | 0.954+/-0.040 |

**Table-2** Calculation results of $n_{obs}/n_{exp}$ and their errors for the Kinki data.

summary of fe values of experiments

| | <Eshw>(EeV) | fe | err | events |
|---|---|---|---|---|
| *** uncut *** | | | | |
| HP | 1.361 | 0.032 | 0.032 | 7320 |
| | 2.628 | 0.084 | 0.060 | 2443 |
| | 5.437 | 0.204 | 0.104 | 706 |
| | 10.861 | 0.100 | 0.176 | 249 |
| | 22.125 | 0.316 | 0.240 | 99 |
| | 63.789 | -0.644 | 0.324 | 66 |
| SUGER | 11.04 | 0.364 | 0.192 | 183 |
| | 22.08 | 0.100 | 0.292 | 114 |
| | 54.93 | 0.332 | 0.272 | 84 |
| YAKUTSK | 17.43 | 0.368 | 0.184 | 233 |
| Volcano Ranch | 27.96 | -0.24 | 0.48 | 44 |
| Akeno | 0.018 | 0.006 | 0.017 | |
| | 0.058 | 0.024 | 0.036 | |
| | 0.135 | 0.000 | 0.025 | |
| | 0.234 | 0.006 | 0.041 | |
| | 0.407 | -0.060 | 0.020 | |
| | 0.741 | -0.018 | 0.027 | |
| | 1.315 | 0.006 | 0.030 | |
| | 2.410 | -0.072 | 0.081 | |
| | 4.236 | 0.163 | 0.111 | |
| | 7.621 | 0.121 | 0.216 | |
| | 17.22 | 0.195 | 0.148 | |
| Kinki | 0.003 | 0.064 | 0.012 | 56804 |
| *** centre *** | | | | |
| Kinki | 0.003 | 0.100 | 0.020 | 20485 |
| *** anti-centre *** | | | | |
| Kinki | 0.003 | 0.040 | 0.016 | 36319 |

**Table-3** Asummary of $f_e$ values of our data and some other experiments.

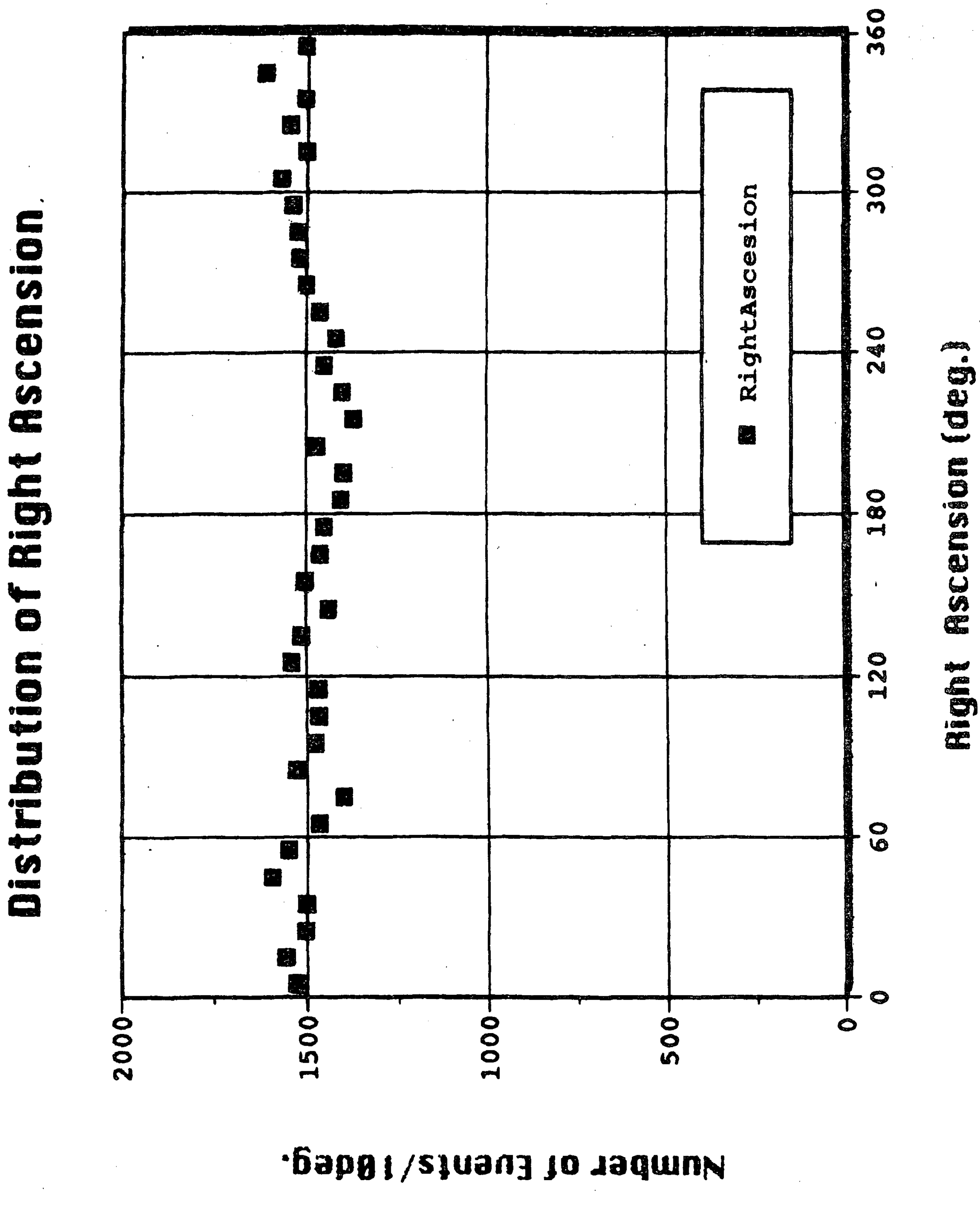


**Fig.-1** A distibution of our data in celestial coordinates.

The KINKI Array View of the Sky

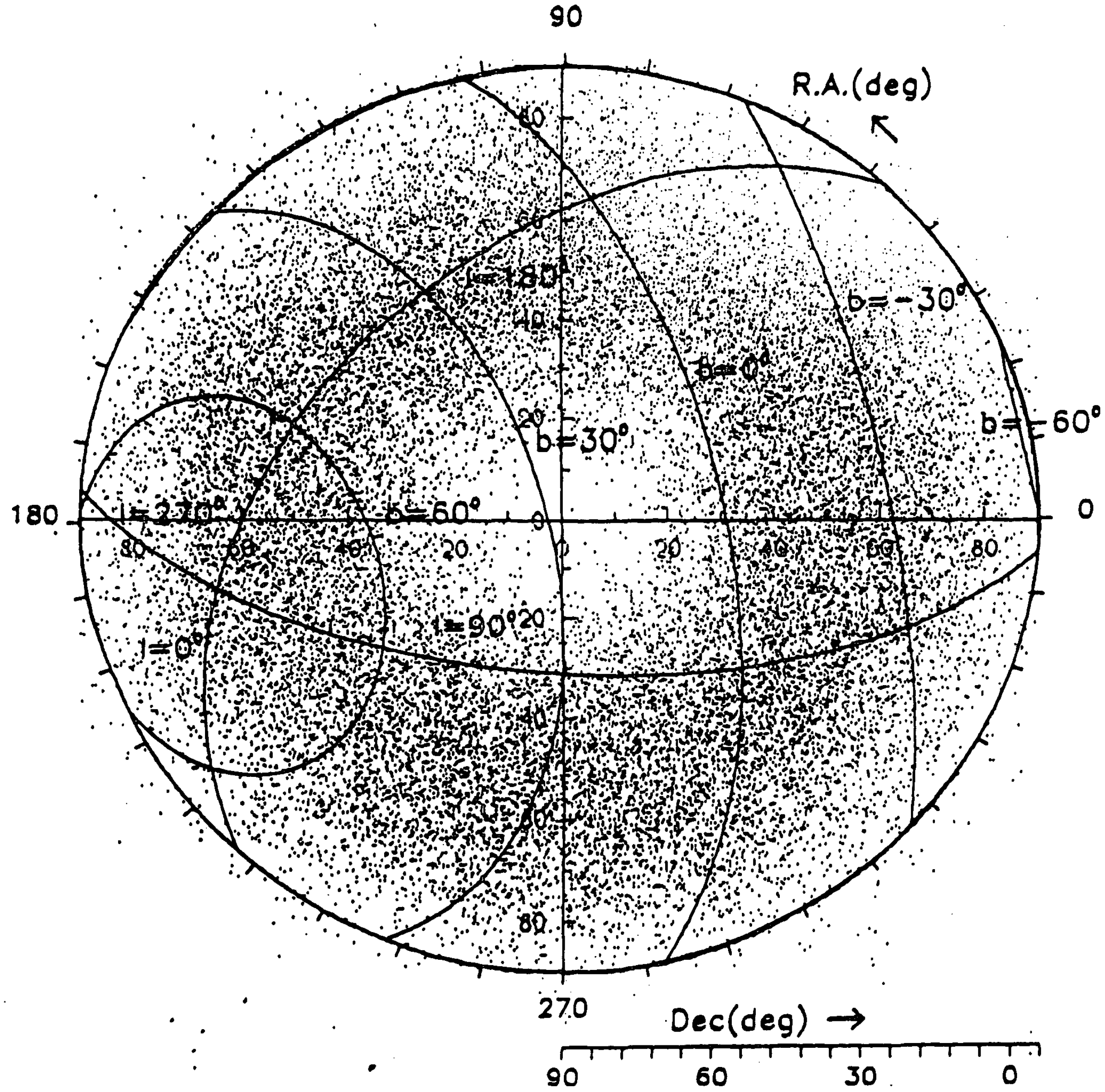


**Fig.-2** A sky view of observation events of the Kinki array. Celestial and the galactic coordinates are indicated in the figure.

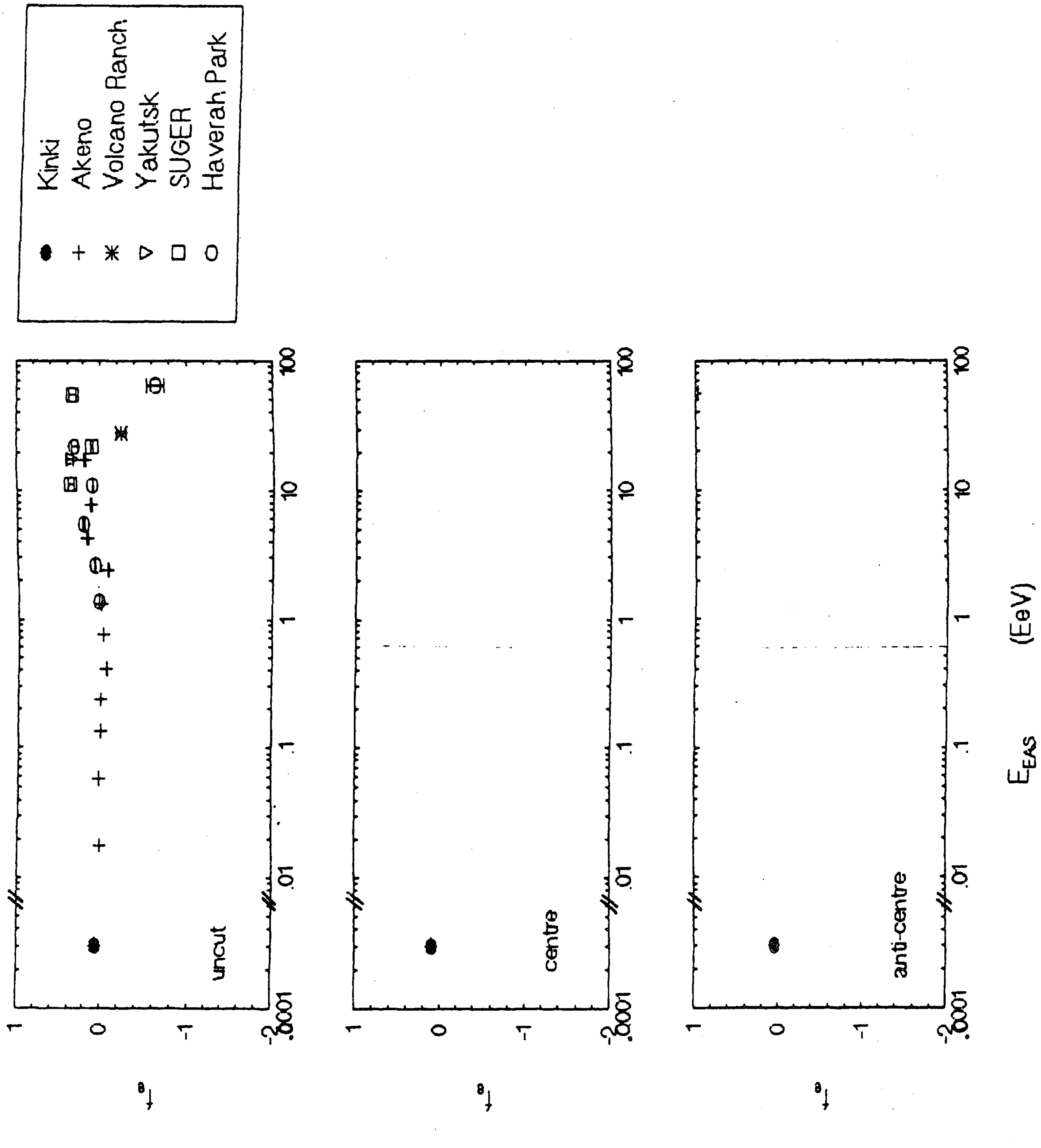


**Fig.-3** The galactic enhancement factor $f_e$ for directions of (a)'uncut', (b)'centre', and (c)'anti-centre'.