Observation of the large-scale anisotropy of cosmic rays with LHAASO

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Large-scale anisotropy with KM2A

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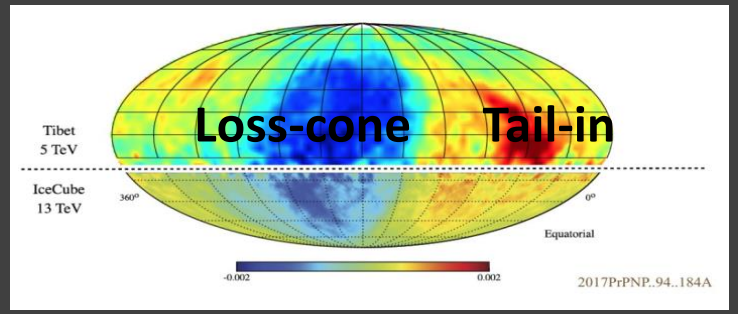
Introduction

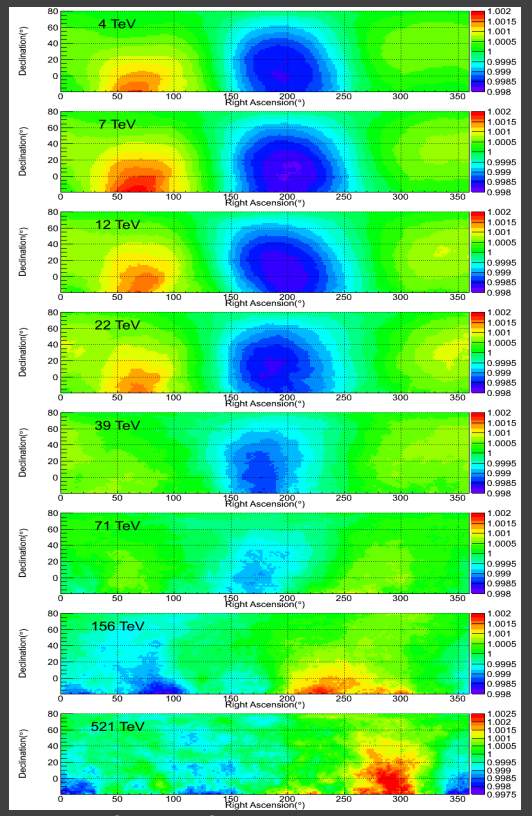
- Anisotropy

- a probe to study the origin and propagation of cosmic rays

- the intensity and phase are obviously in energy dependence



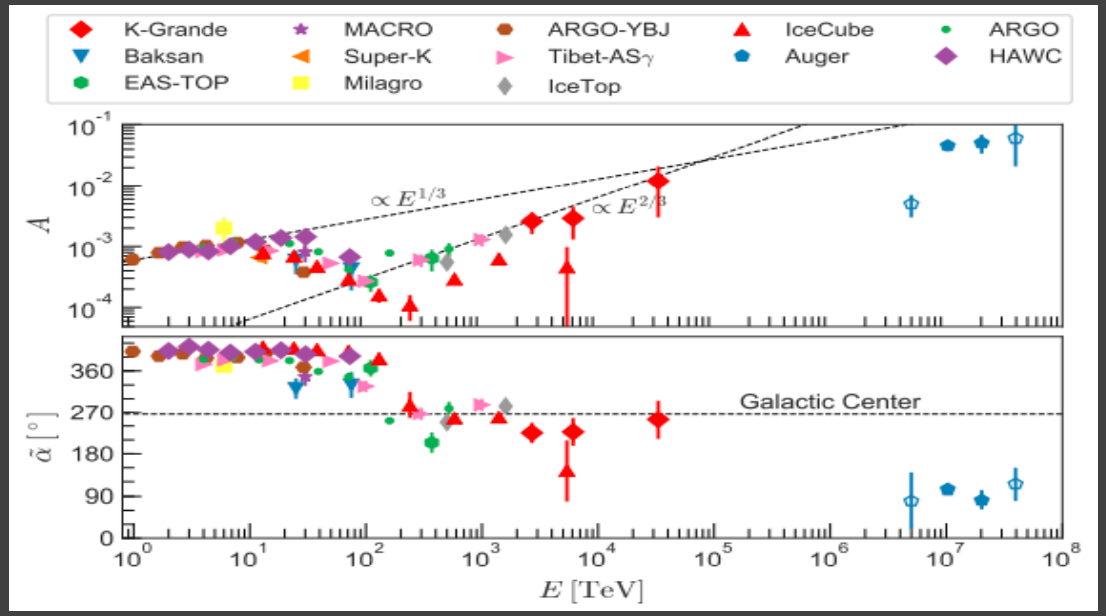
ARGO



Bartoli et al. 2018

Puzzles

The irregularity of energy dependence of amplitude and phase —Why ?



JuliaBecker Tjus et al., Physics Reports, 872

Large-scale anisotropy with KM2A

- simulation

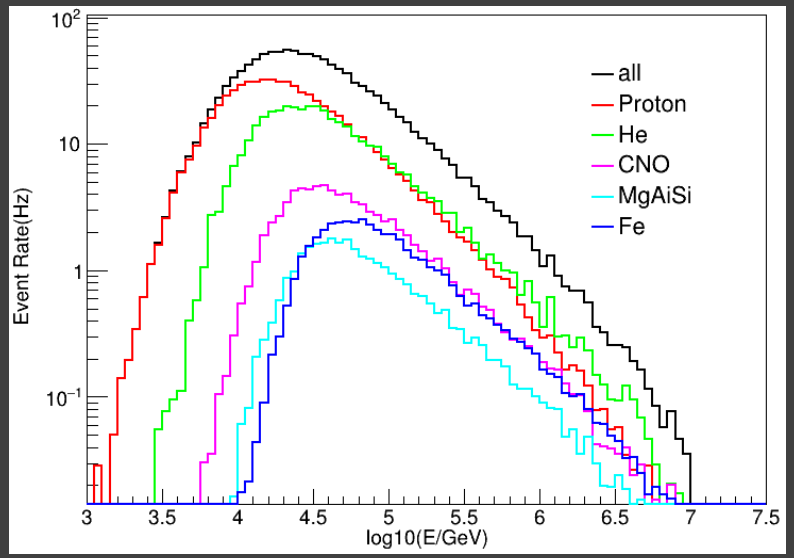
QGSJETII-04 & Gheisha

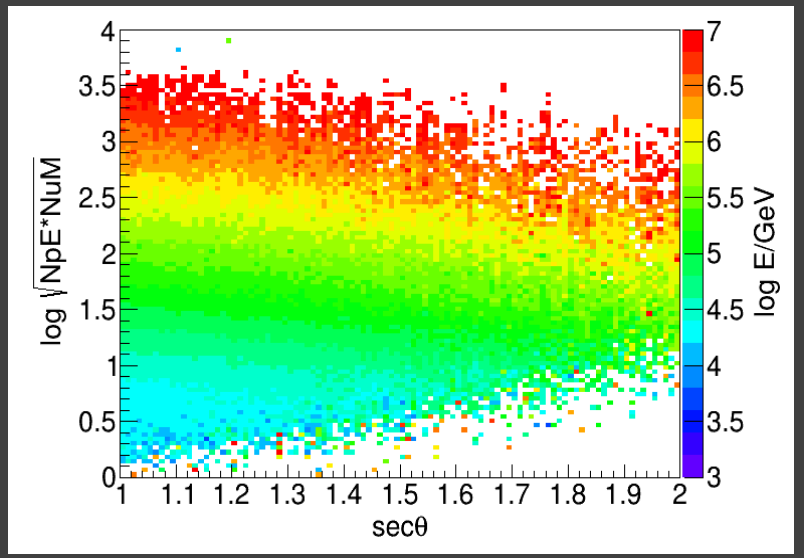
1TeV-10PeV

Zenith 0-70°

$\sim 7.8 \times 10^7$ events

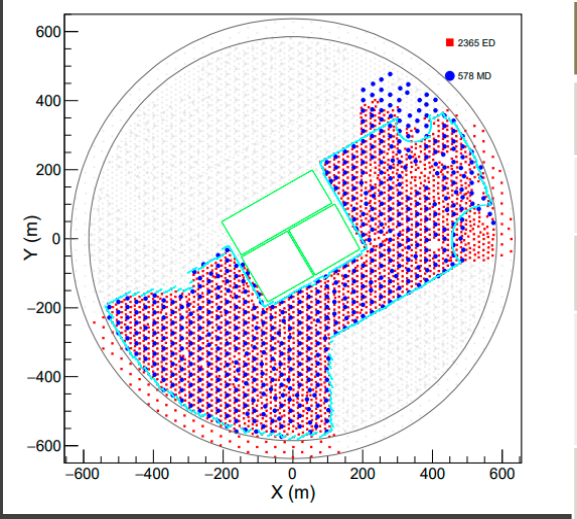
Gaisser model





$$logE = f(log\sqrt{NpE * NuM}, \theta)$$

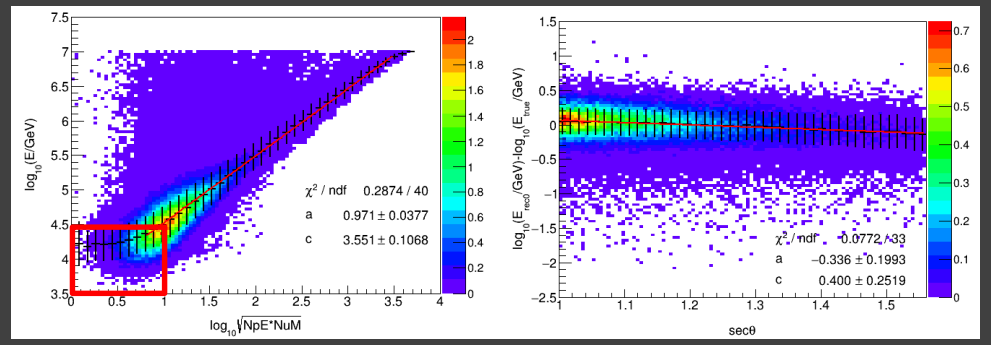
- full year of 2021
- core locate in the half array of KM2A

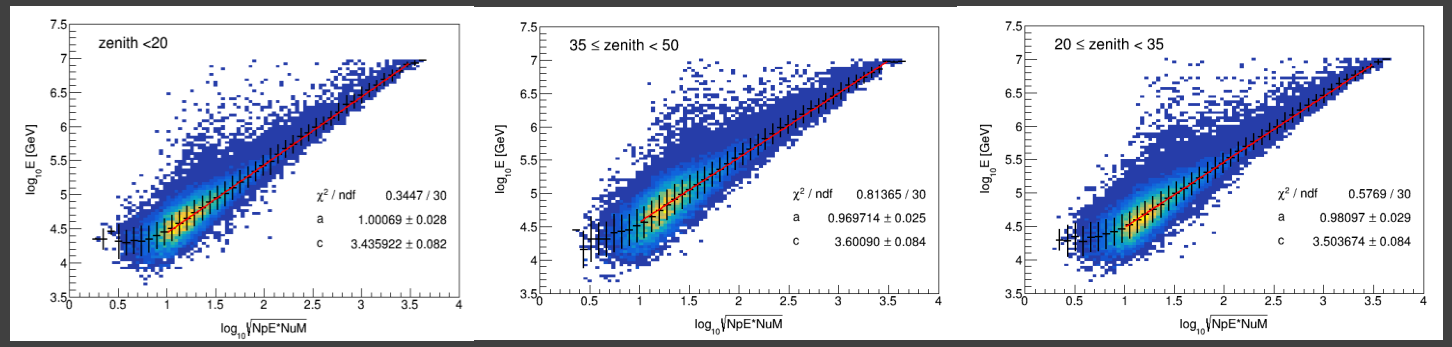


parameter	sample1	Sample2
zenith	<50	<50
NtrigE	>=20	>=20
NfiltE	>=20	>=20
NpE2 （r=40-100, dt:-50,100）	>0	>15
NuM3 （r=40-200, dt:-50,100）	>0	>0
dr (芯位距离边界距离)	>0	>0
NpE1 （r<rwind+50, dt:-50,100）	-----	NpE1/NpE2>2

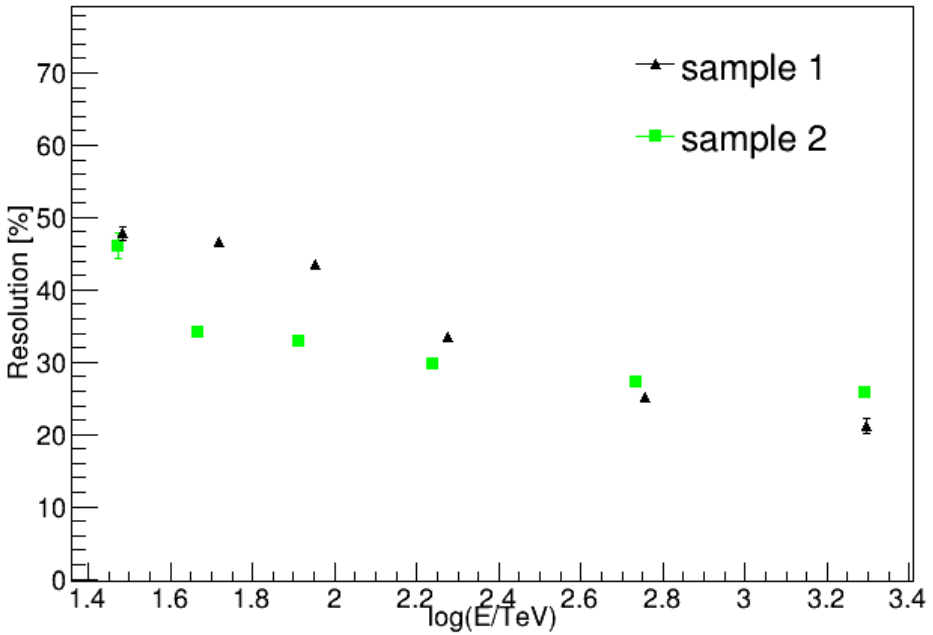
Energy estimation

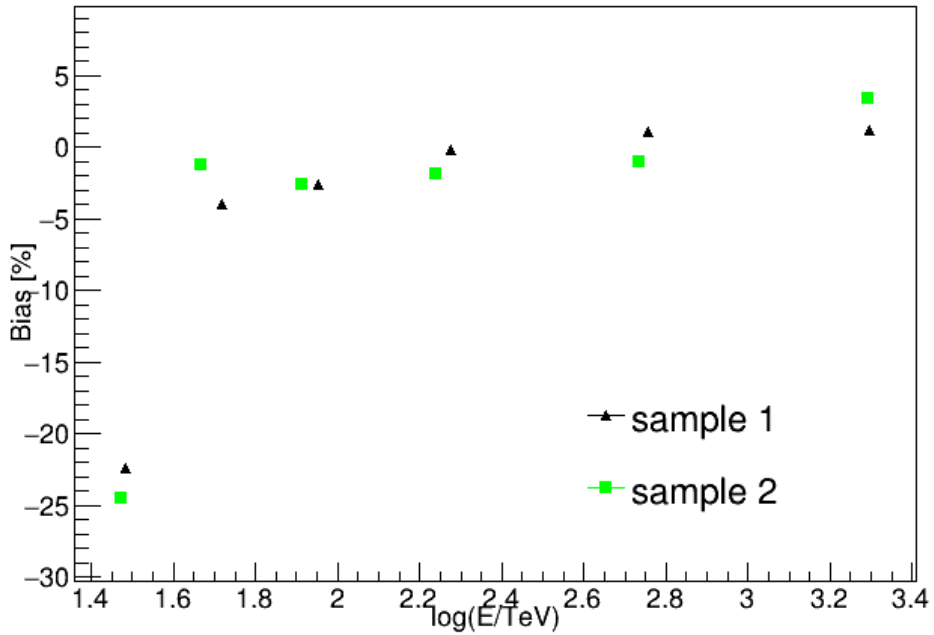
- Sample 1 $logE = f(log\sqrt{NpE * NuM}, \theta)$
- Sample 2 $logE = f(log\sqrt{NpE * NuM})$





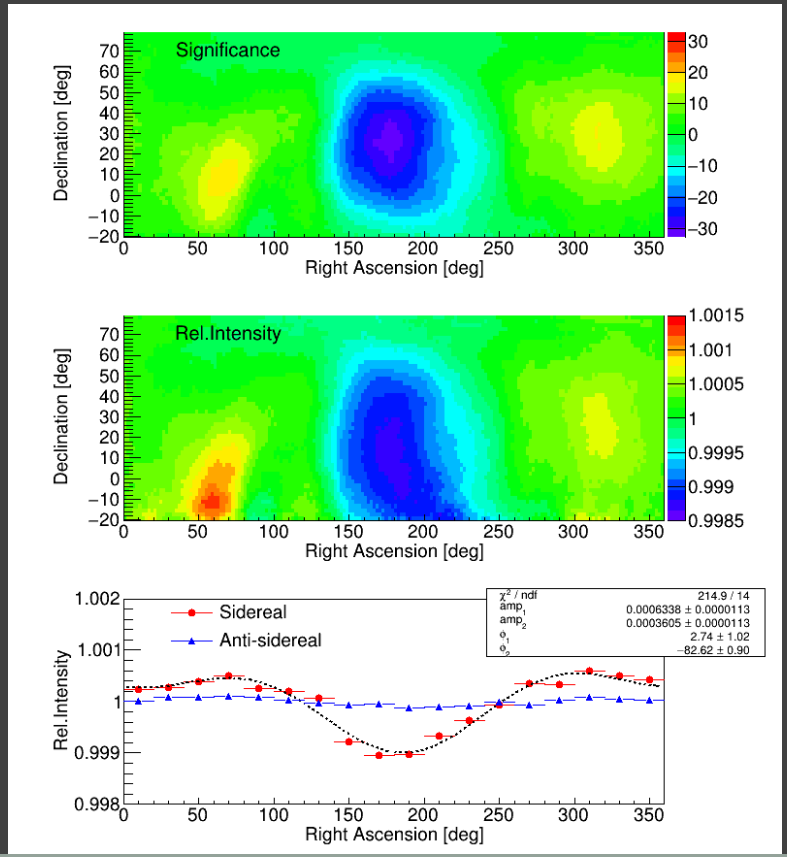
logErec	Sample 1 77.5			Sample 2 （3 zenith bins）96.7		
	mean (TeV)	Resolution (%)	Bias (%)	mean (TeV)	Resolution (%)	Bias (%)
3.5~4.5	30.43	47.8±1.0	-22.4	29.60	46.1±1.8	-24.5
4.5~4.75	52.24	46.6±0.8	-4	46.54	34.2±0.3	-1.2
4.75~5.0	89.89	43.6±0.8	-2.6	81.56	32.8±0.3	-2.6
5.0~5.5	188.92	33.4±0.5	-0.2	173.23	29.8±0.2	-1.9
5.5~6	570.26	25.1±0.6	1.1	542.61	27.3±0.3	-1
>=6	1983.24	21.2±1.1	1.2	1967.07	25.87±0.6	3.4


sample 1
sample 2
Resolution [%]
log(E/TeV)
0
10
20
30
40
50
60
70
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4

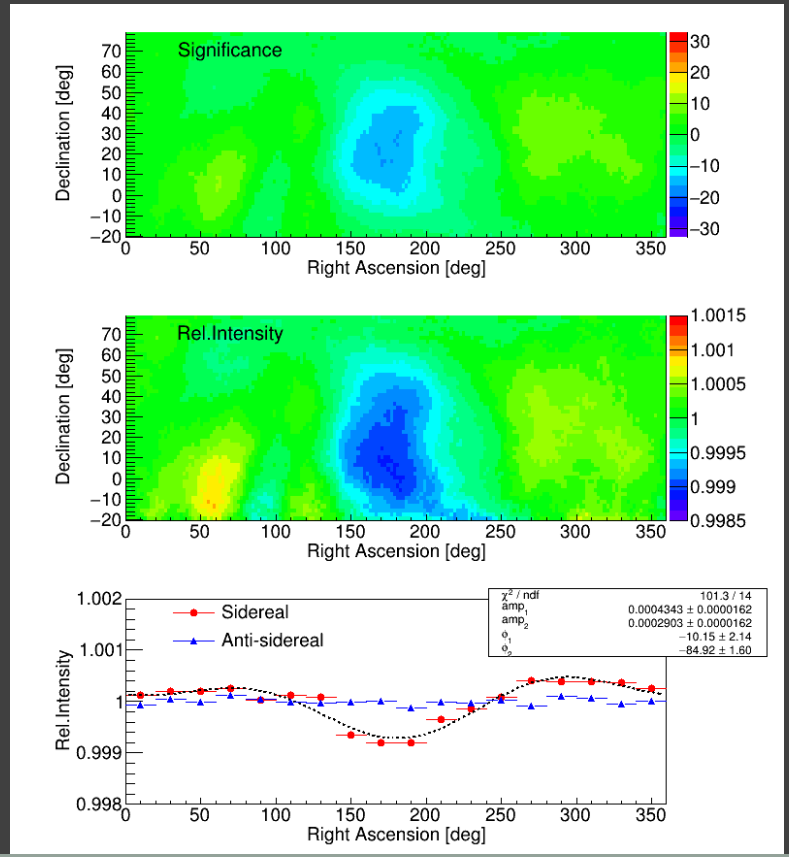

sample 1
sample 2
Bias [%]
log(E/TeV)
5
0
−5
−10
−15
−20
−25
−30
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4

Anisotropy in sidereal time

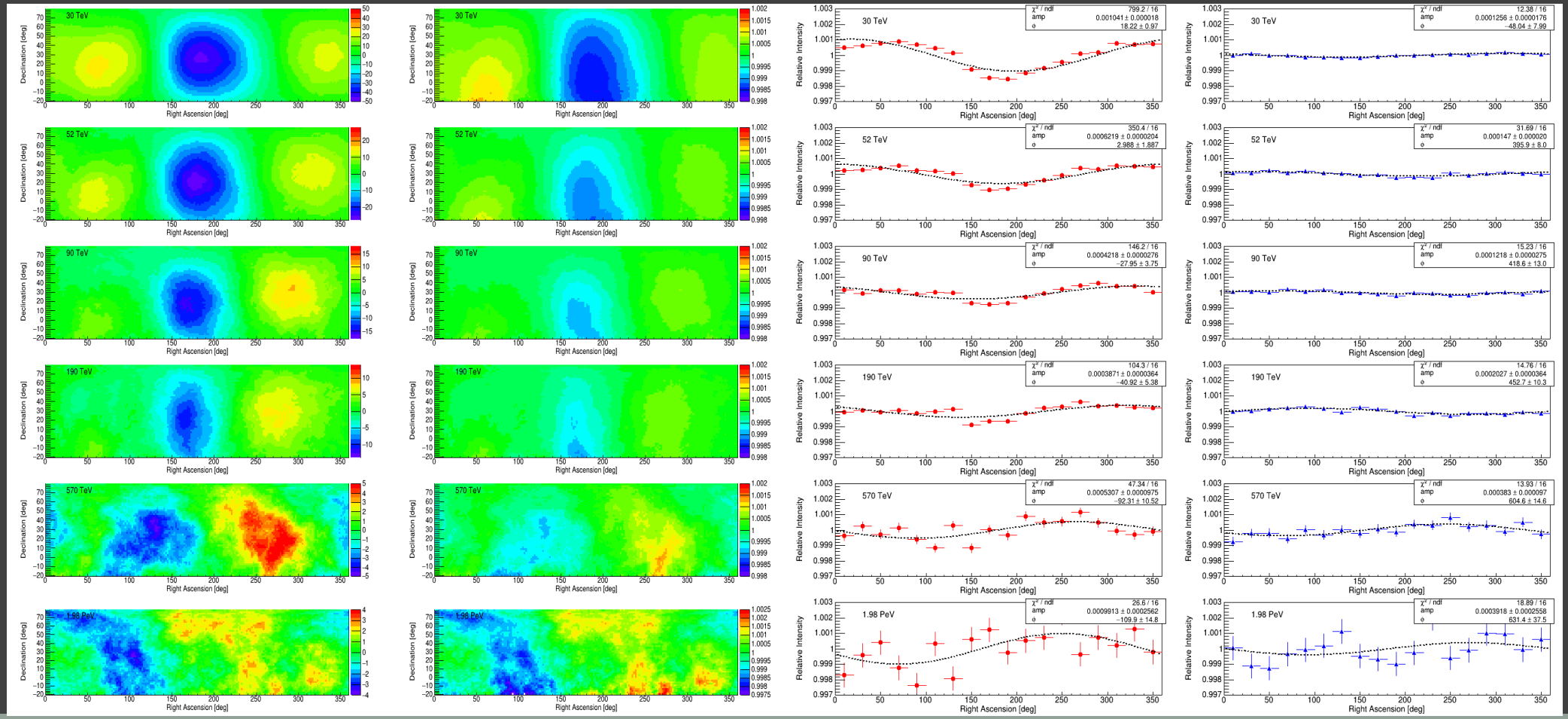
- sample 1 ~ 1.6×10^{10} events



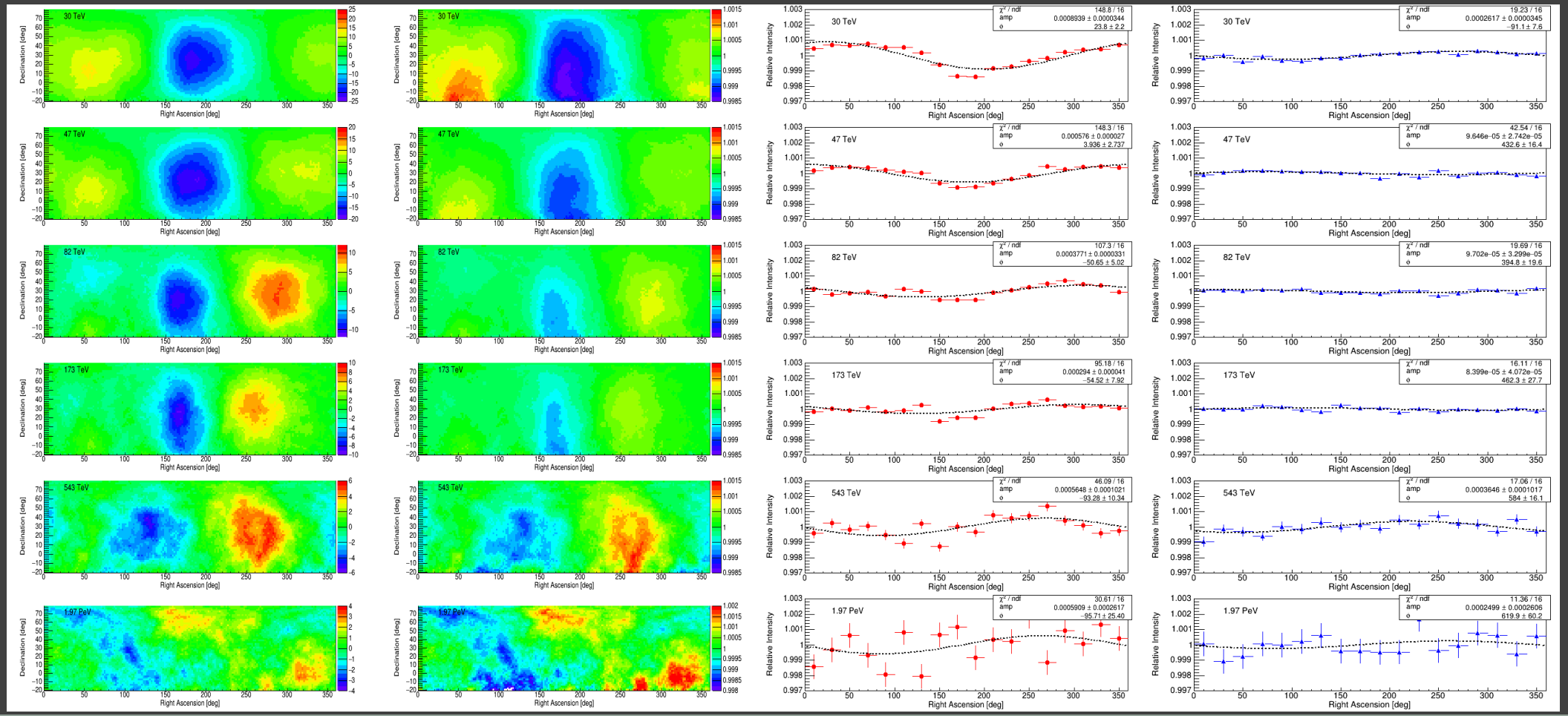
- sample 2 ~ 7.6×10^{9} events



Evolution with energy-sample 1



Evolution with energy-sample 2



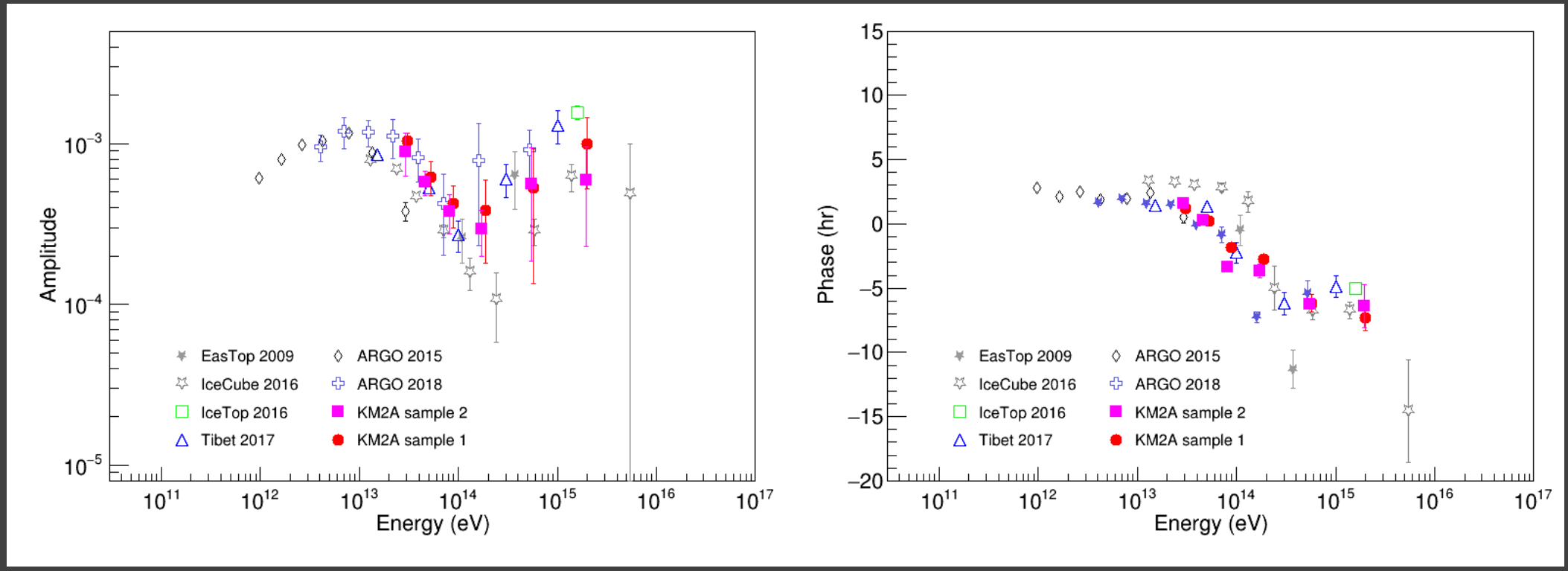
Sample 1

Bin	log(Erec) (GeV)	Mean Energy (TeV)	Events (10^8)	Amp (10^-4)	Φ (deg)	Amp_Anti (10^-4)
1	3.5~4.5	30.43	64.66	10.41±0.18	18.22±0.97	1.256
2	4.5~4.75	52.24	47.75	6.22±0.20	2.99±1.89	1.47
3	4.75~5.0	89.89	26.24	4.22±0.28	-27.95±3.75	1.218
4	5.0~5.5	189.92	15.10	3.87±0.36	-40.92±5.38	2.027
5	5.5~6	570.26	2.10	5.31±0.98	-92.31±10.52	3.83
6	>=6	1983.24	0.30	9.91±2.56	-109.9±14.8	3.918

Sample 2

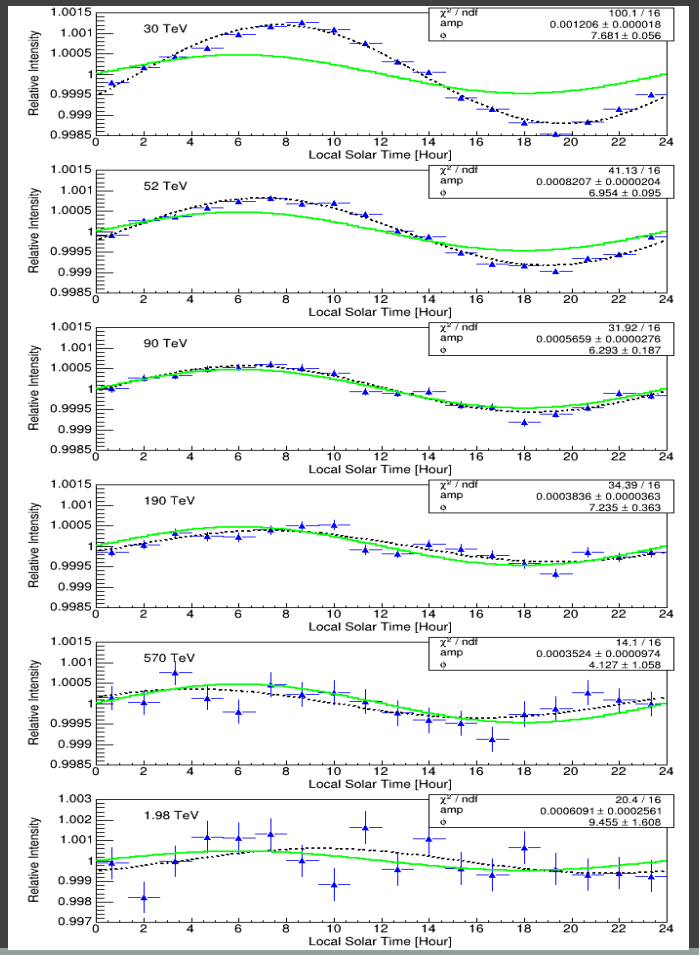
Bin	log(Erec) (GeV)	Mean Energy (TeV)	Events (10^8)	Amp (10^-4)	Φ (deg)	Amp_Anti (10^-4)
1	3.5~4.5	29.60	16.81	8.94±0.34	23.8±2.2	2.62
2	4.5~4.75	46.54	26.48	5.76±0.27	3.94±2.74	0.96
3	4.75~5.0	81.56	18.27	3.77±0.33	-50.65±5.02	0.97
4	5.0~5.5	173.23	12.07	2.94±0.41	-54.52±7.92	0.84
5	5.5~6	542.61	1.92	5.65±1.02	-93.28±10.34	3.65
6	>=6	1967.07	0.29	5.91±2.62	-95.71±25.40	2.50

Evolution with energy - amplitude & phase

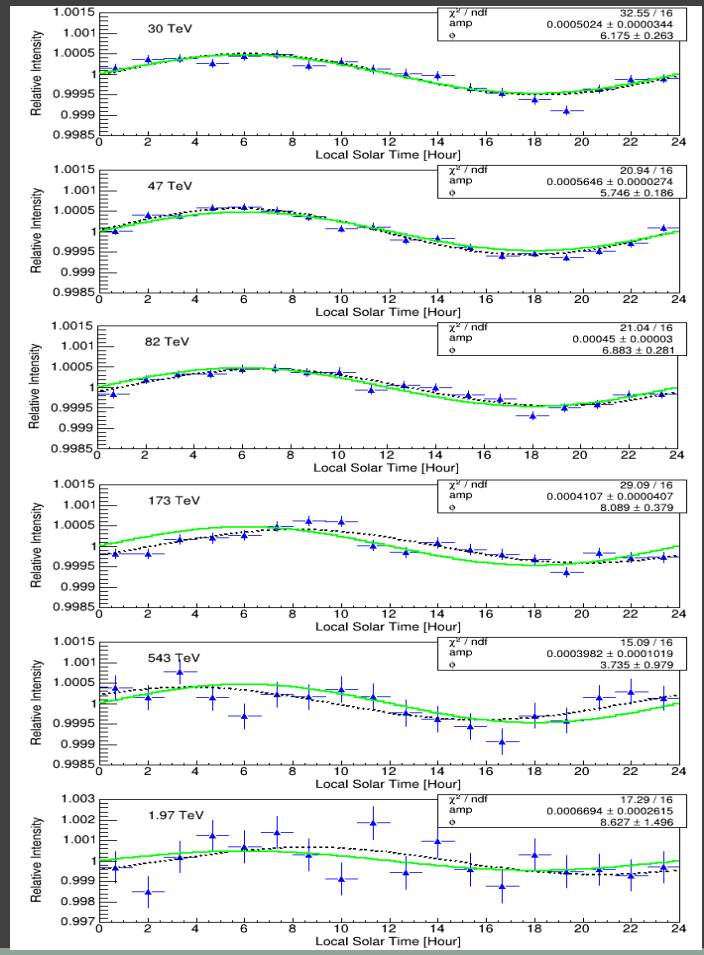


Solar

- Sample 1



- Sample 2



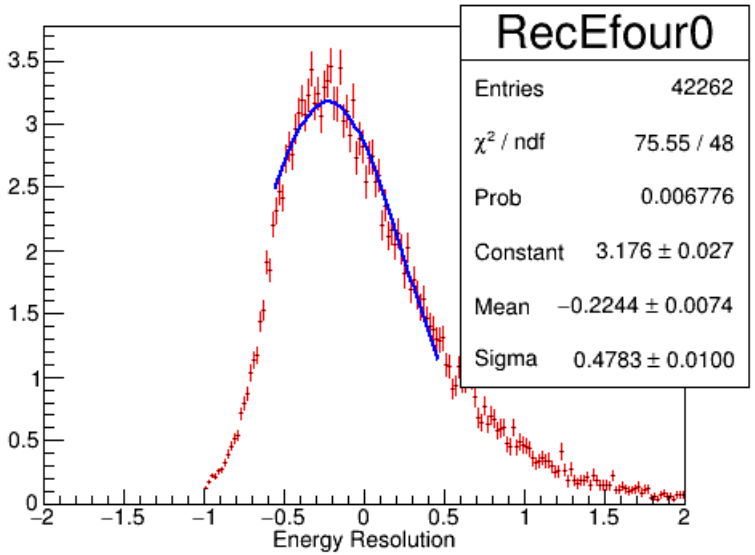
Conclusion

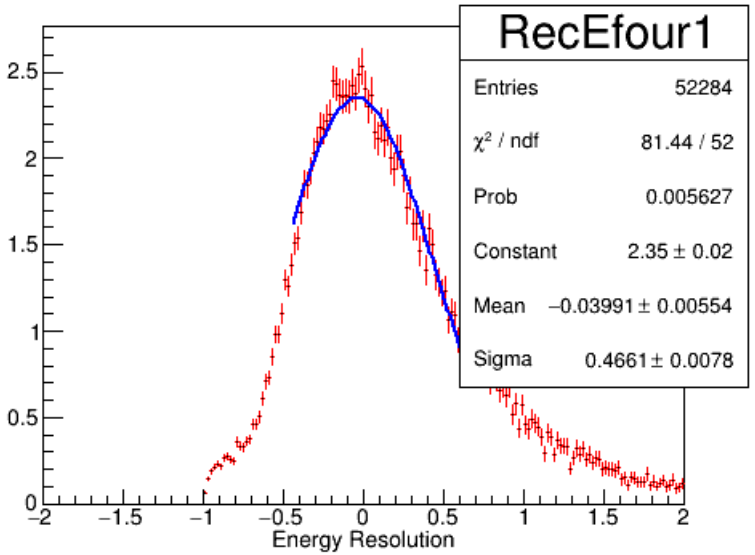
- Consistent results of large-scale anisotropy in sidereal with the others were observed.
- Relative intensity from stricter-cut sample more approach the expected CG anisotropy.
- Project :

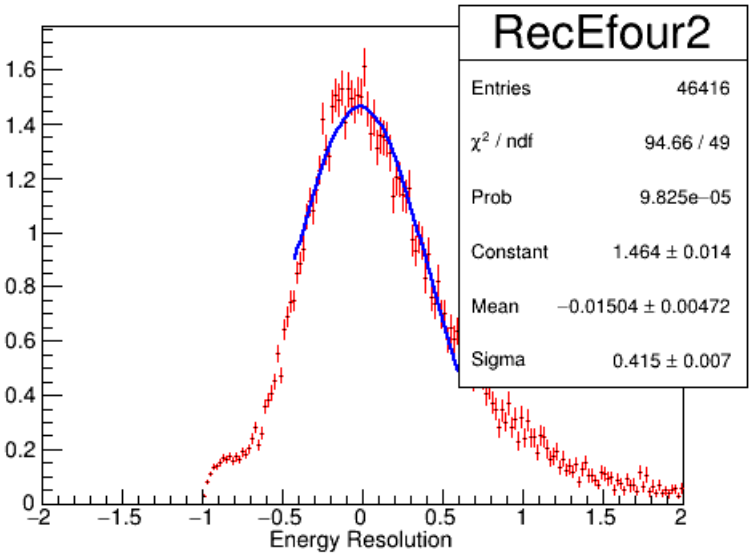
- more works for the CG effect
- extend the high energy range
- anisotropy of heavy and light component of cosmic rays

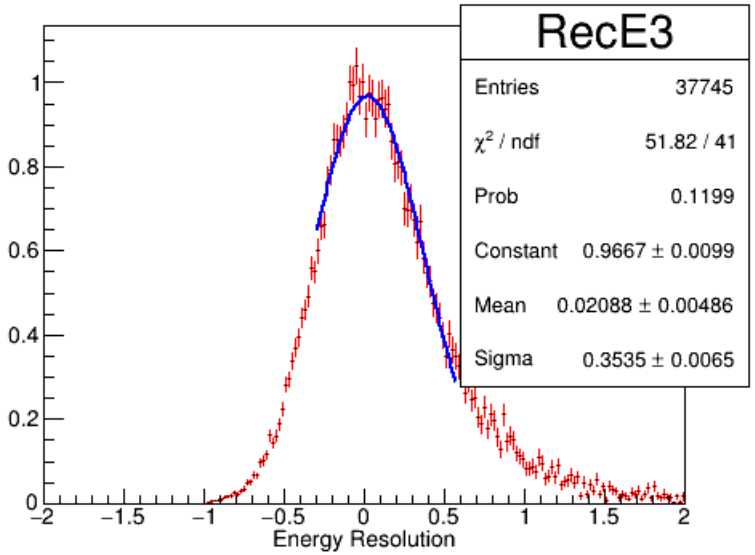
Thanks for your attention !

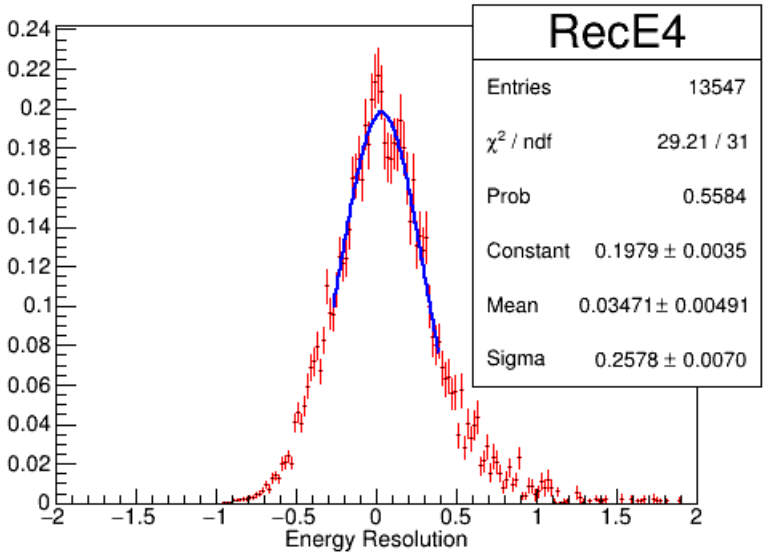
Supplement

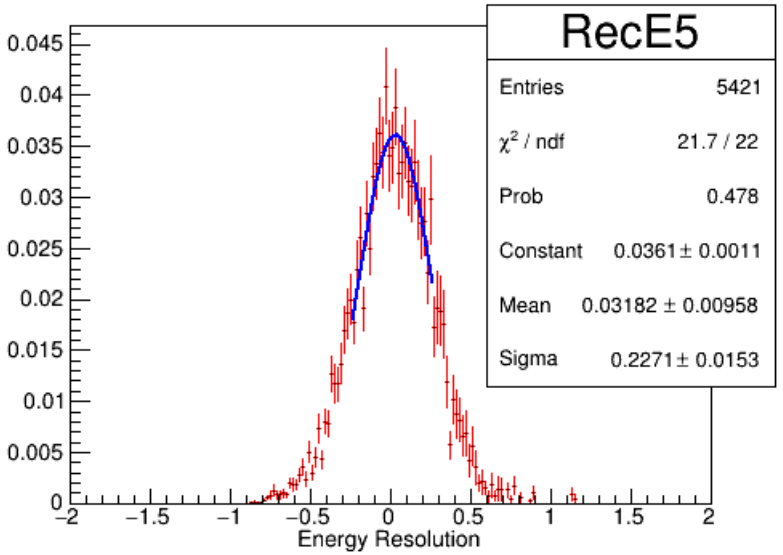

RecEfour0
Entries 42262
χ² / ndf 75.55 / 48
Prob 0.006776
Constant 3.176 ± 0.027
Mean −0.2244 ± 0.0074
Sigma 0.4783 ± 0.0100
Energy Resolution

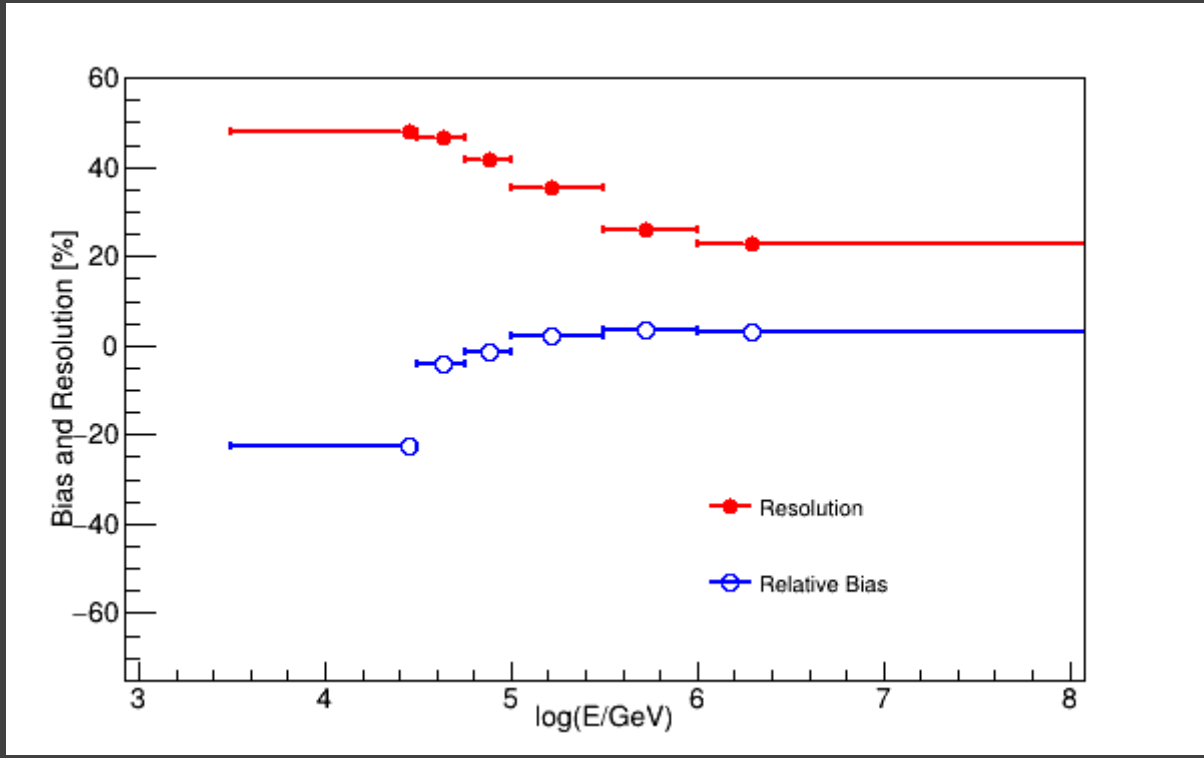

RecEfour1
Entries 52284
χ² / ndf 81.44 / 52
Prob 0.005627
Constant 2.35 ± 0.02
Mean −0.03991 ± 0.00554
Sigma 0.4661 ± 0.0078
Energy Resolution

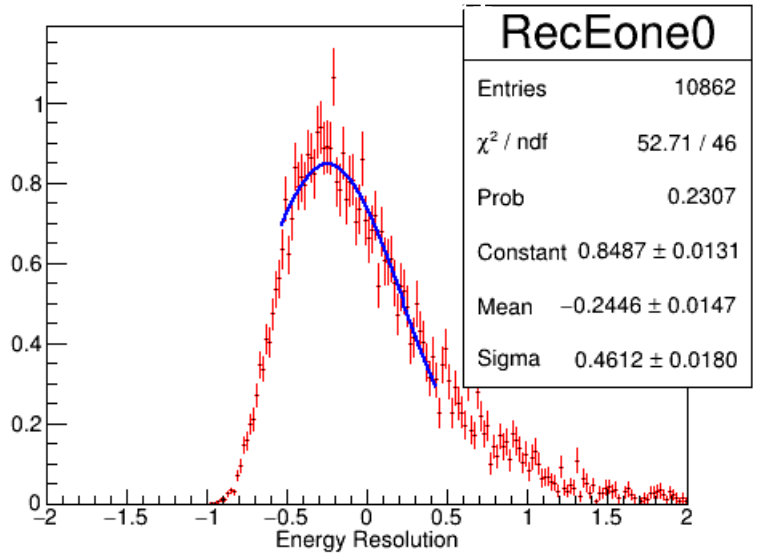

RecEfour2
Entries 46416
χ² / ndf 94.66 / 49
Prob 9.825e−05
Constant 1.464 ± 0.014
Mean −0.01504 ± 0.00472
Sigma 0.415 ± 0.007
Energy Resolution

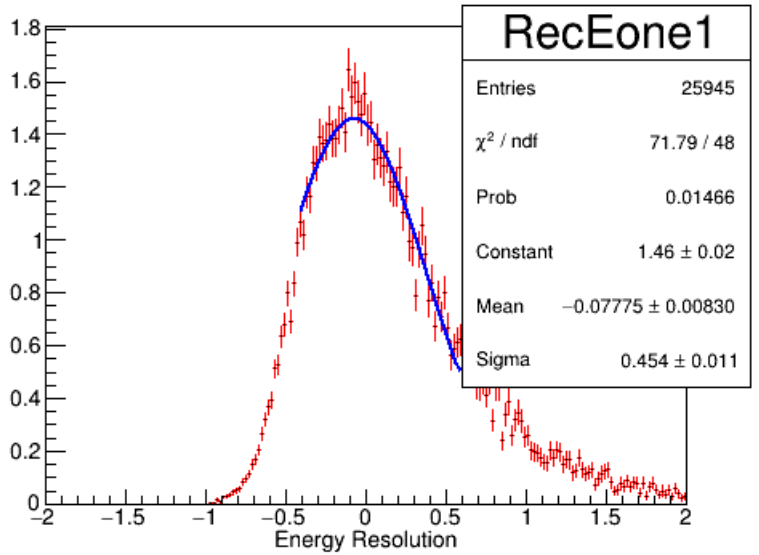

RecE3
Entries 37745
χ² / ndf 51.82 / 41
Prob 0.1199
Constant 0.9667 ± 0.0099
Mean 0.02088 ± 0.00486
Sigma 0.3535 ± 0.0065
Energy Resolution

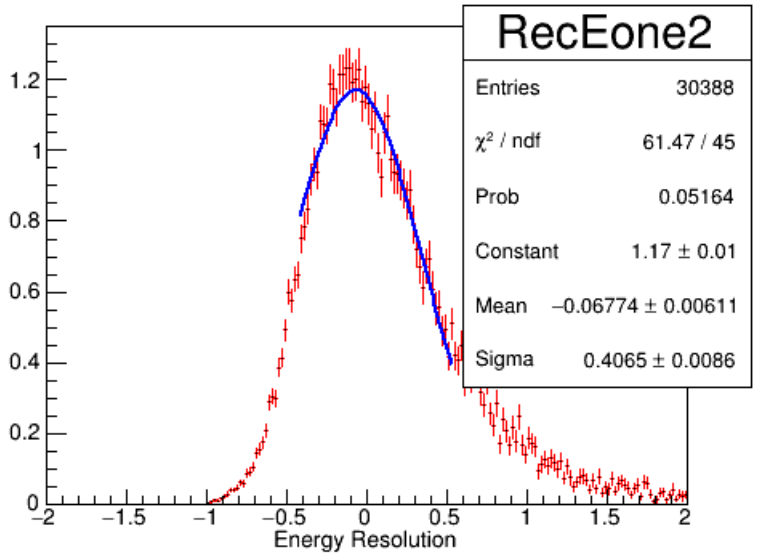

RecE4
Entries 13547
χ² / ndf 29.21 / 31
Prob 0.5584
Constant 0.1979 ± 0.0035
Mean 0.03471 ± 0.00491
Sigma 0.2578 ± 0.0070
Energy Resolution

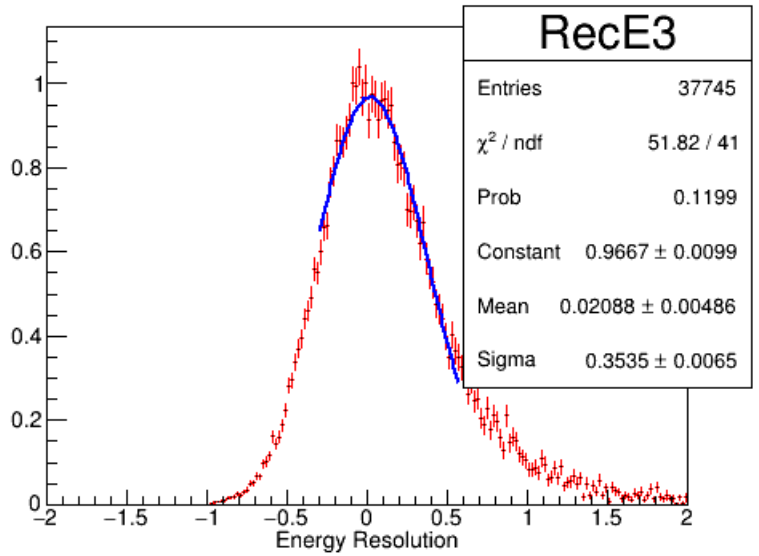

RecE5
Entries 5421
χ² / ndf 21.7 / 22
Prob 0.478
Constant 0.0361 ± 0.0011
Mean 0.03182 ± 0.00958
Sigma 0.2271 ± 0.0153
Energy Resolution


60
40
20
0
−20
−40
−60
Bias and Resolution [%]
3
4
5
6
7
8
log(E/GeV)
Resolution
Relative Bias


RecEone0
Entries 10862
χ² / ndf 52.71 / 46
Prob 0.2307
Constant 0.8487 ± 0.0131
Mean −0.2446 ± 0.0147
Sigma 0.4612 ± 0.0180
Energy Resolution


RecEone1
Entries 25945
χ² / ndf 71.79 / 48
Prob 0.01466
Constant 1.46 ± 0.02
Mean −0.07775 ± 0.00830
Sigma 0.454 ± 0.011
Energy Resolution


RecEone2
Entries 30388
χ² / ndf 61.47 / 45
Prob 0.05164
Constant 1.17 ± 0.01
Mean −0.06774 ± 0.00611
Sigma 0.4065 ± 0.0086
Energy Resolution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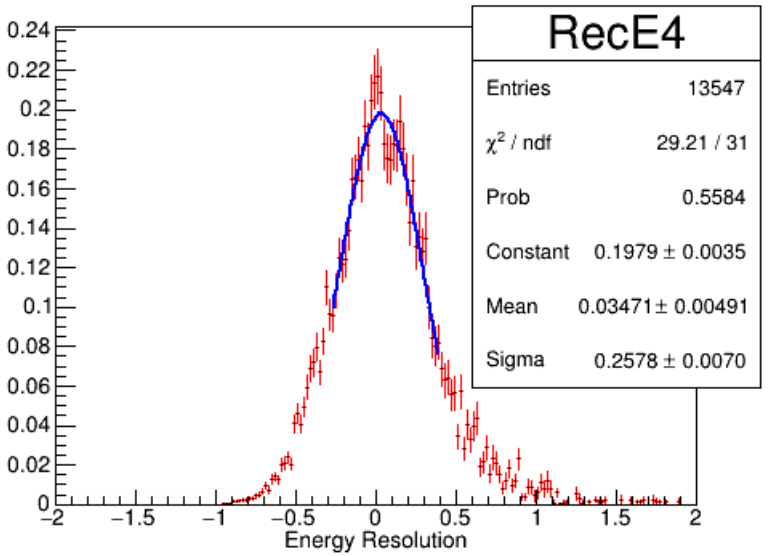
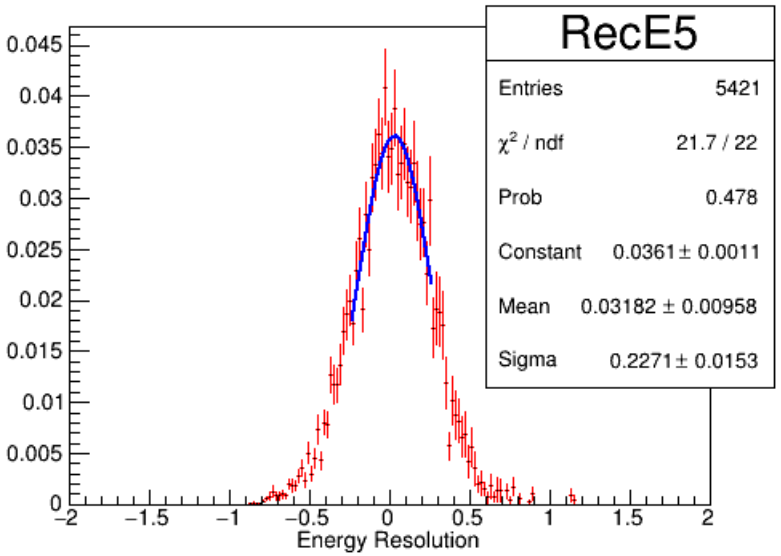
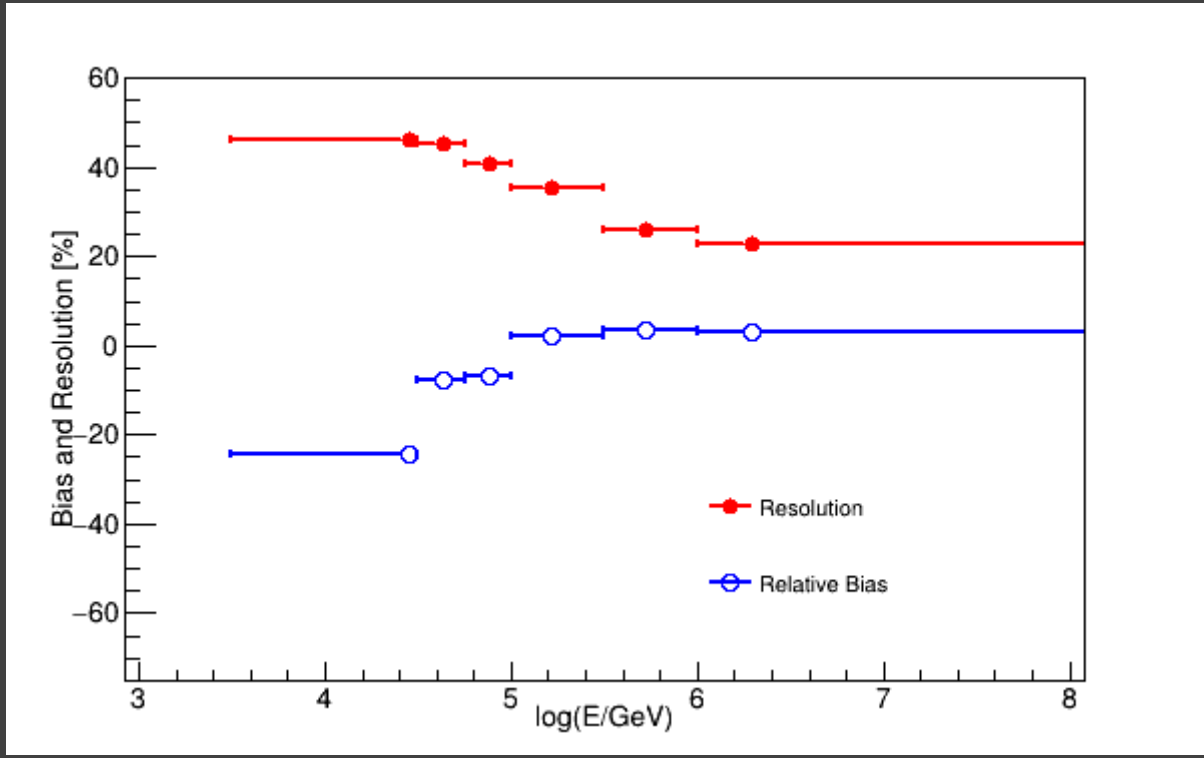

RecE4
Entries 13547
χ² / ndf 29.21 / 31
Prob 0.5584
Constant 0.1979 ± 0.0035
Mean 0.03471 ± 0.00491
Sigma 0.2578 ± 0.0070
Energy Resolution


RecE5
Entries 5421
χ² / ndf 21.7 / 22
Prob 0.478
Constant 0.0361 ± 0.0011
Mean 0.03182 ± 0.00958
Sigma 0.2271 ± 0.0153
Energy Resolution


60
40
20
0
−20
−40
−60
Bias and Resolution [%]
3
4
5
6
7
8
log(E/GeV)
Resolution
Relative Bias