Very high-energy gamma-ray analysis with Water Cherenkov Detector Array of LHAASO

Jetsada Maburee

Asst. Prof. Dr. Waraporn Nuntiyakul (Advisor)

Asst. Prof. Dr. Warit Mitthumsiri (Co-Advisor)

Department of Physics and Materials science, Faculty of science

Chiang Mai University, Thailand

OUTLINES

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  - Large High Altitude Air Shower Observatory, LHAASO
  - Water Cherenkov Detector Array, WCDA
- Methodology
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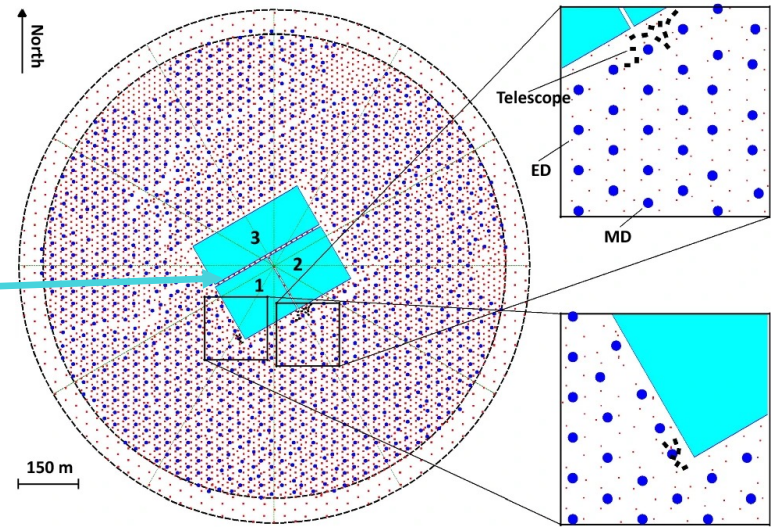
  - To Select N_{hiteff} range
  - Plot sky map
  - Raw counts zenith
  - Effective Area
  - Interpolation Effective Area
- Research Plans

Large High Altitude Air Shower Observatory, LHAASO

KM2A

Square Kilometer array over 1.3 km^2

WCDA



Extensive Air Shower (EAS) detector array, are Electromagnetic particle Detectors (EDs) and Muon Detectors (MDs).

The location at Sichuan Province, China.
(29°21'27.6" N, 100°08'19.6" E), Elevation 4410 m

LHAASO-WFCTA

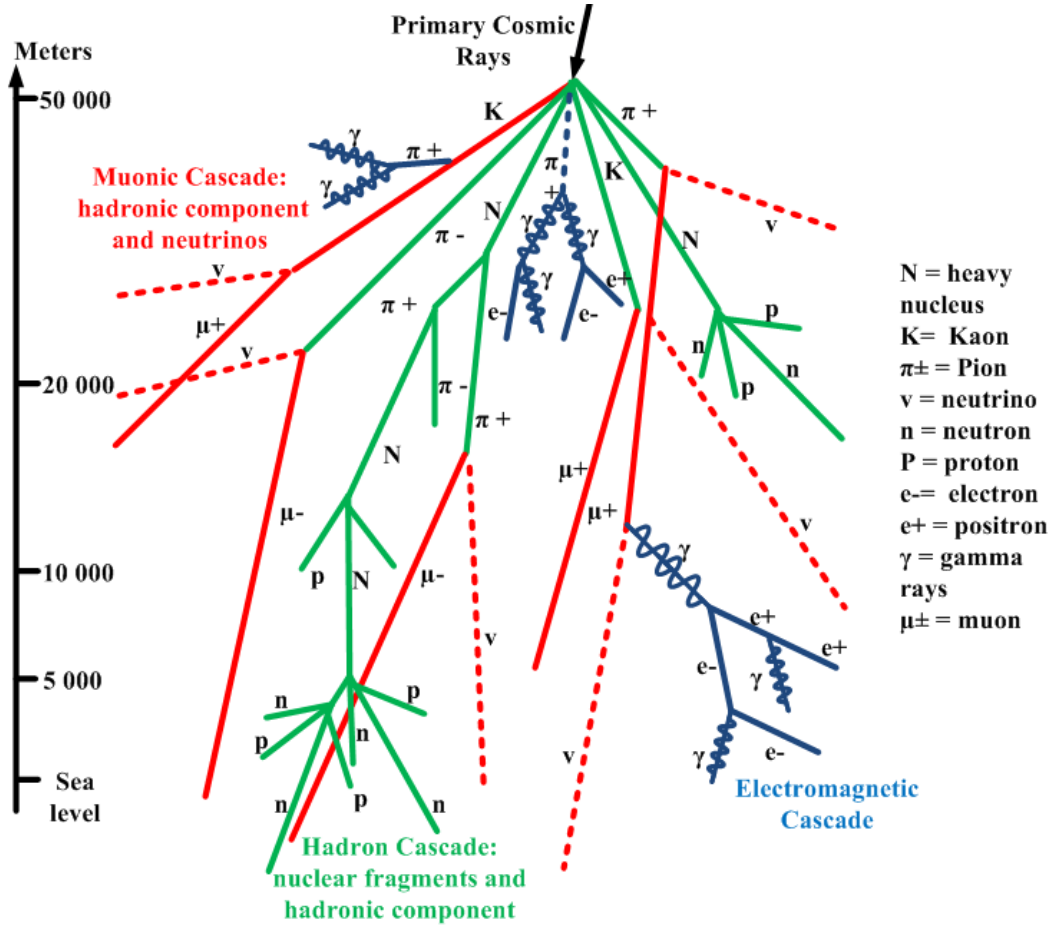
Wide Field-of-view Air Cherenkov/Fluorescence Telescope Array.

The current layout of 18 telescopes.

https://physicsworld.com/a/huge-chinese-cosmic-ray-observatory-begins-operation/

https://link.springer.com/article/10.1140/epjc/s10052-021-09414-z

Cosmic Rays



- Cosmic rays are high energetic energy particles from space.
- Sources of cosmic rays;
  - Solar Energetics Particles, SEPs: Inside the solar system
  - Galactic Cosmic Rays, GCRs: Outside solar system such as Milky Way
  - Extra-Galactic Cosmic Rays, EGCRs: Outside Milky Way

- Primary cosmic rays contain 90% of P^{+}, 9% of α and 1% heavy nuclei.
- Secondary particles ($e^{-}, e^{+}, \gamma, \mu^{+}, \mu^{-}, n, \ldots$) was generated in the Earth's atmosphere.

https://www.researchgate.net/figure/Showers-of-cosmic-ray-reactions-with-particles-of-the-atmosphere-Clo02_fig9_272826408

Methodology

➢ To select of data for gamma-ray analysis WCDA

During the observation 2020 - presents

```
-bash-4.2$  cd /eos/lhaaso/rec/wcda/prod/recdata/Mf/2020/
-bash-4.2$ ls
1101  1106  1111  1116  1121  1126  1201  1206  1211  1216  1221  1226  1231
1102  1107  1112  1117  1122  1127  1202  1207  1212  1217  1222  1227
1103  1108  1113  1118  1123  1128  1203  1208  1213  1218  1223  1228
1104  1109  1114  1119  1124  1129  1204  1209  1214  1219  1224  1229
1105  1110  1115  1120  1125  1130  1205  1210  1215  1220  1225  1230
```

```
-bash-4.2$  cd /eos/lhaaso/rec/wcda/prod/recdata/Mf/2021
-bash-4.2$ ls
0101  0126  0220  0321  0415  0510  0604  0630  0725  0819  0913  1008  1102      1126  1221
0102  0127  0221  0322  0416  0511  0605  0701  0726  0820  0914  1009  1103      1127  1222
0103  0128  0222  0323  0417  0512  0606  0702  0727  0821  0915  1010  1104      1128  1223
0104  0129  0223  0324  0418  0513  0607  0703  0728  0822  0916  1011  1105      1129  1224
0105  0130  0224  0325  0419  0514  0608  0704  0729  0823  0917  1012  1106      1130  1225
0106  0131  0225  0326  0420  0515  0609  0705  0730  0824  0918  1013  1107      1201  1226
0107  0201  0226  0327  0421  0516  0610  0706  0731  0825  0919  1014  1108      1202  1227
0108  0202  0227  0328  0422  0517  0611  0707  0801  0826  0920  1015  1109      1203  1228
0109  0203  0228  0329  0423  0518  0612  0708  0802  0827  0921  1016  1110      1204  1229
0110  0204  0305  0330  0424  0519  0613  0709  0803  0828  0922  1017  1111      1205  1230
0111  0205  0306  0331  0425  0520  0614  0710  0804  0829  0923  1018  1112      1206  1231
0112  0206  0307  0401  0426  0521  0615  0711  0805  0830  0924  1019  1113      1207
0113  0207  0308  0402  0427  0522  0616  0712  0806  0831  0925  1020  1114      1208
0114  0208  0309  0403  0428  0523  0617  0713  0807  0901  0926  1021  1114_old  1209
0115  0209  0310  0404  0429  0524  0618  0714  0808  0902  0927  1022  1115      1210
0116  0210  0311  0405  0430  0525  0619  0715  0809  0903  0928  1023  1116      1211
0117  0211  0312  0406  0501  0526  0620  0716  0810  0904  0929  1024  1117      1212
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0119  0213  0314  0408  0503  0528  0622  0718  0812  0906  1001  1026  1119      1214
0120  0214  0315  0409  0504  0529  0623  0719  0813  0907  1002  1027  1120      1215
0121  0215  0316  0410  0505  0530  0624  0720  0814  0908  1003  1028  1121      1216
0122  0216  0317  0411  0506  0531  0625  0721  0815  0909  1004  1029  1122      1217
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0124  0218  0319  0413  0508  0602  0628  0723  0817  0911  1006  1031  1124      1219
0125  0219  0320  0414  0509  0603  0629  0724  0818  0912  1007  1101  1125      1220
```

The location at LHAASO, China.
(29°21'27.6" N, 100°08'19.6" E),
Elevation 4410 m above sea level.

Right Ascension J2000	02h 31m 48s
Declination J2000	+89° 15' 51"
Galactic Longitude	123.28°
Galactic Latitude	26.46°
Constellation	Ursa Minor

The summarizes the key facts about Polaris.

Right Ascension J2000	06h 45m 08s
Declination J2000	-16° 42' 57"
Galactic Longitude	227.22°
Galactic Latitude	-8.88°
Constellation	Canis Major

The summarizes the key facts about Sirius.

Methodology (Cont2)

➢ To select N_{hit} range

Corrected N_{hit} for cut off energy gamma-ray

- $60 < N_{hit} \leq 100$
- $100 < N_{hit} \leq 300$
- $300 < N_{hit} \leq 1000$
- $N_{hit} \geq 1000$
- All N_{hit}

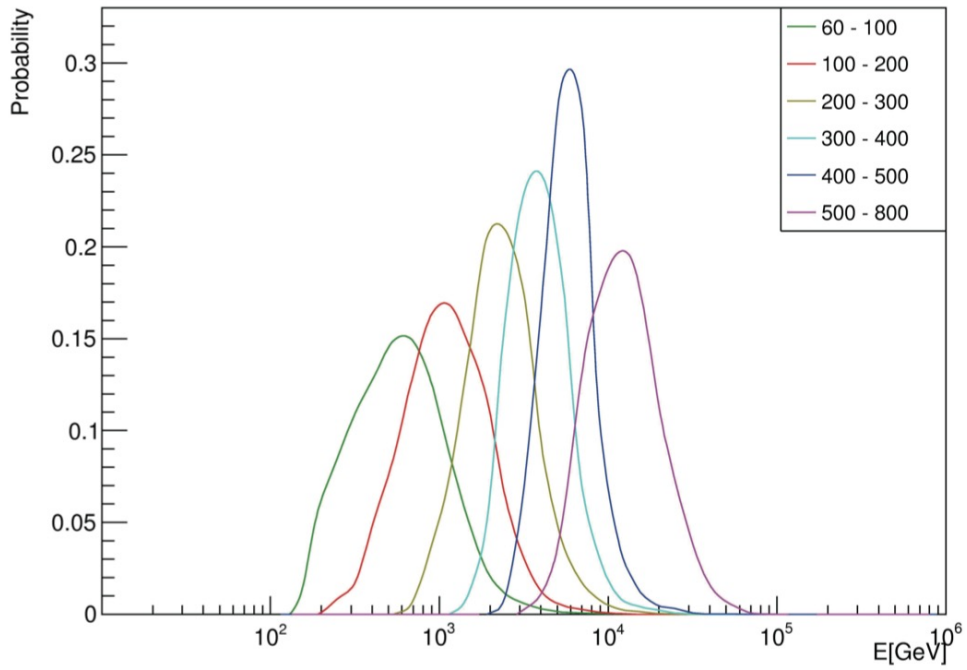


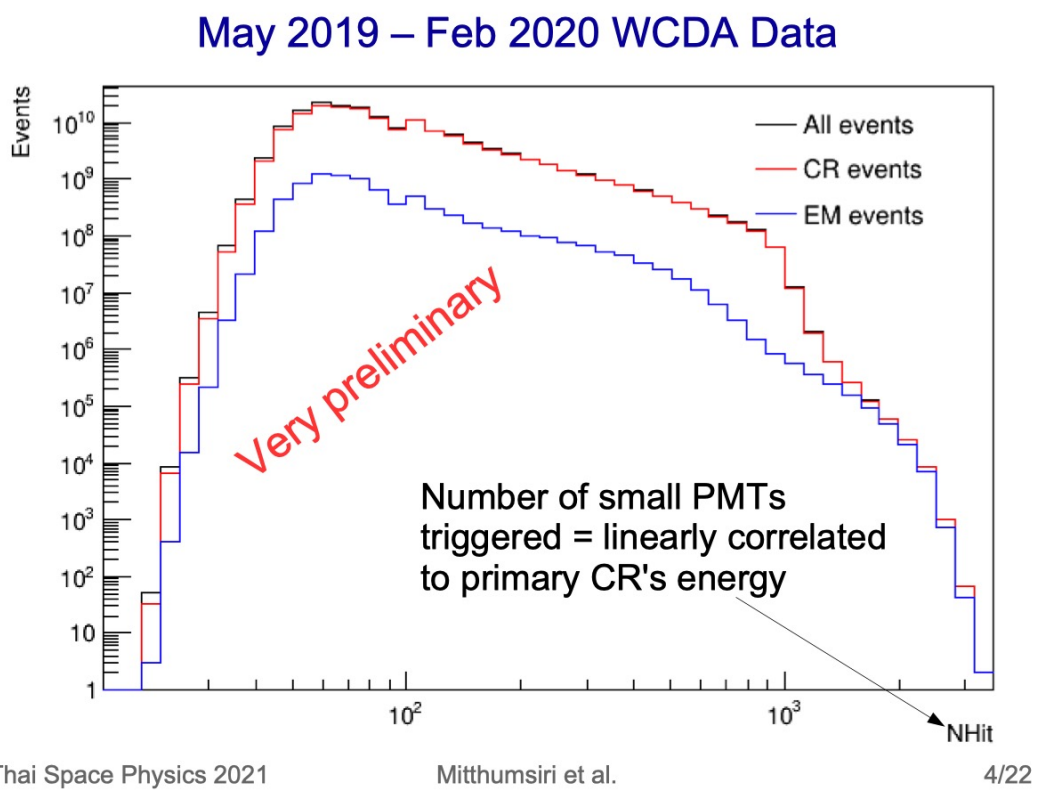
Table 1. Summary of data used in the measurement of SED of the Crab Nebula over 3.57×10^6 seconds.

	N_{hit}	E_{med} (TeV)	Excess	Background	Significance (σ)	Differential Flux ($cm^{-2}s^{-1}TeV^{-1}$)
(a)	60 - 100	0.58	1438.2	24885.8	9.1	$(1.66 \pm 0.20) \times 10^{-11}$
(b)	100 - 200	1.1	1082.7	5202.3	15.0	$(2.89 \pm 0.23) \times 10^{-11}$
(c)	200 - 300	2.4	456.2	1376.8	12.3	$(4.74 \pm 0.48) \times 10^{-12}$
(d)	300 - 400	3.9	161.2	335.8	8.8	$(1.12 \pm 0.17) \times 10^{-13}$
(e)	400 - 500	5.9	60.3	77.7	6.8	$(3.54 \pm 0.74) \times 10^{-13}$
(f)	500 - 800	12.1	82.7	45.3	12.3	$(6.91 \pm 1.0) \times 10^{-14}$

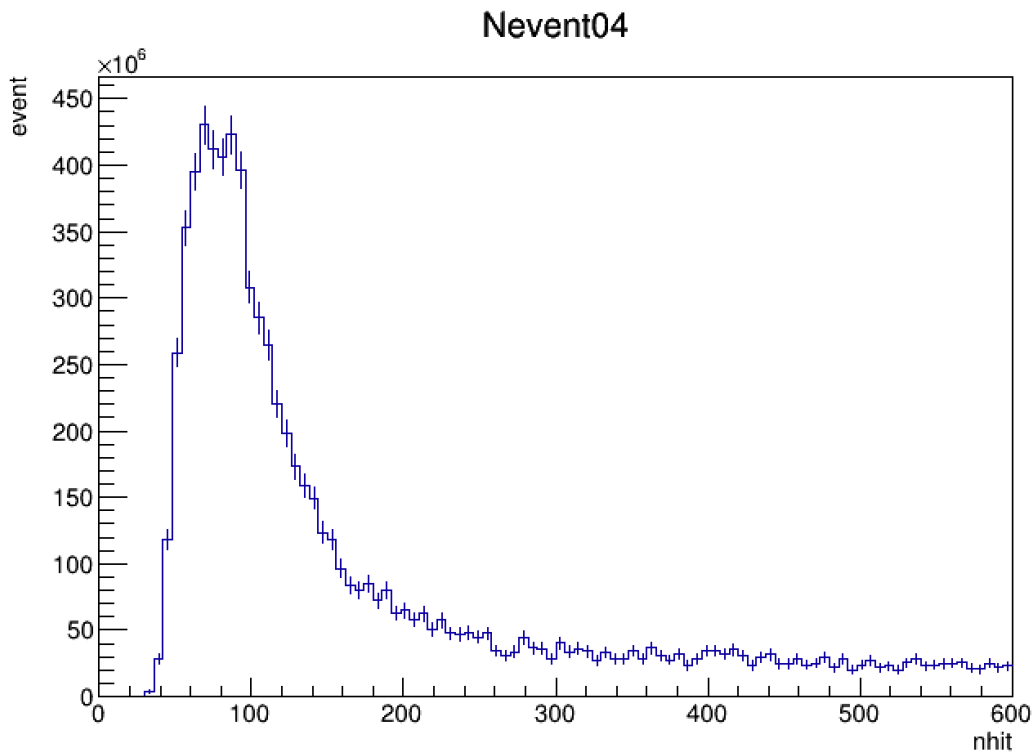
F. Aharonian, Q. An, Axikegu et al.

Methodology (Cont3)

➢ Why are we selecting N_{hit} minimum at 60.



Thai Space Physics 2021 Mitthumsiri et al. 4/22

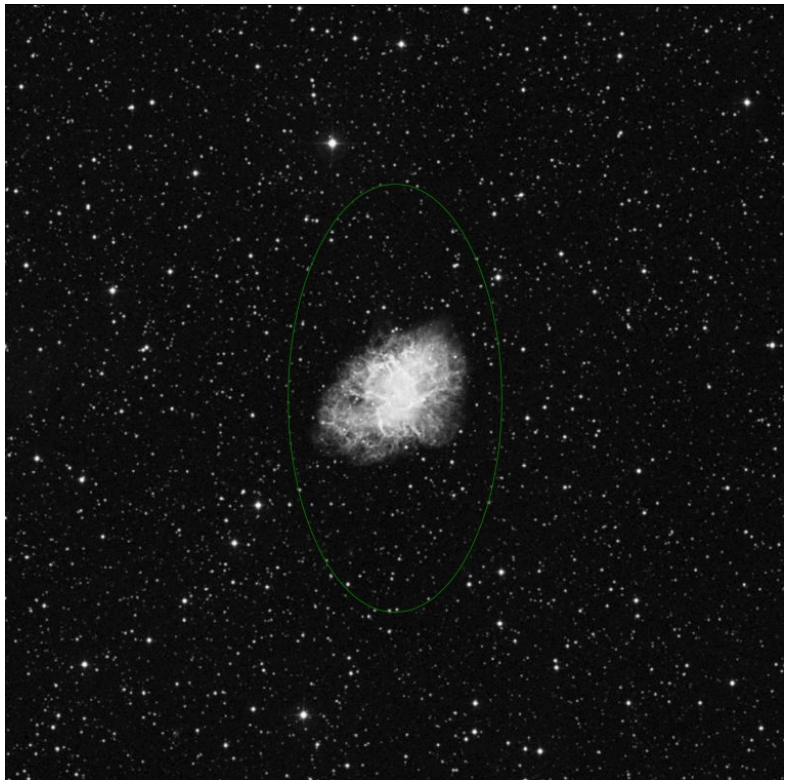


Distribution of nhit with number of event

November 1, 2021 (23:00)

Methodology (Cont4)

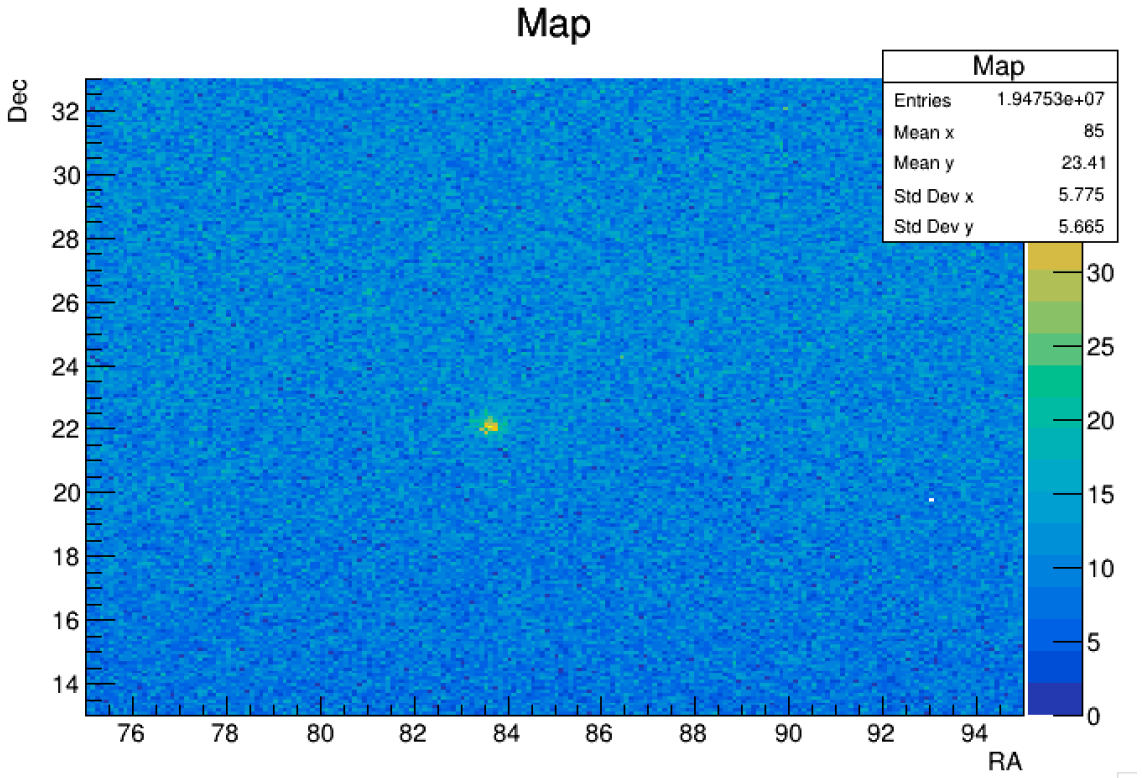
➢ Plot Sky Map



Crab Nebula or Messier 1

R.A. = 83.65° and Dec = 22.05°

https://theskylive.com/sky/deepsky/messier-1-the-crab-nebula-object

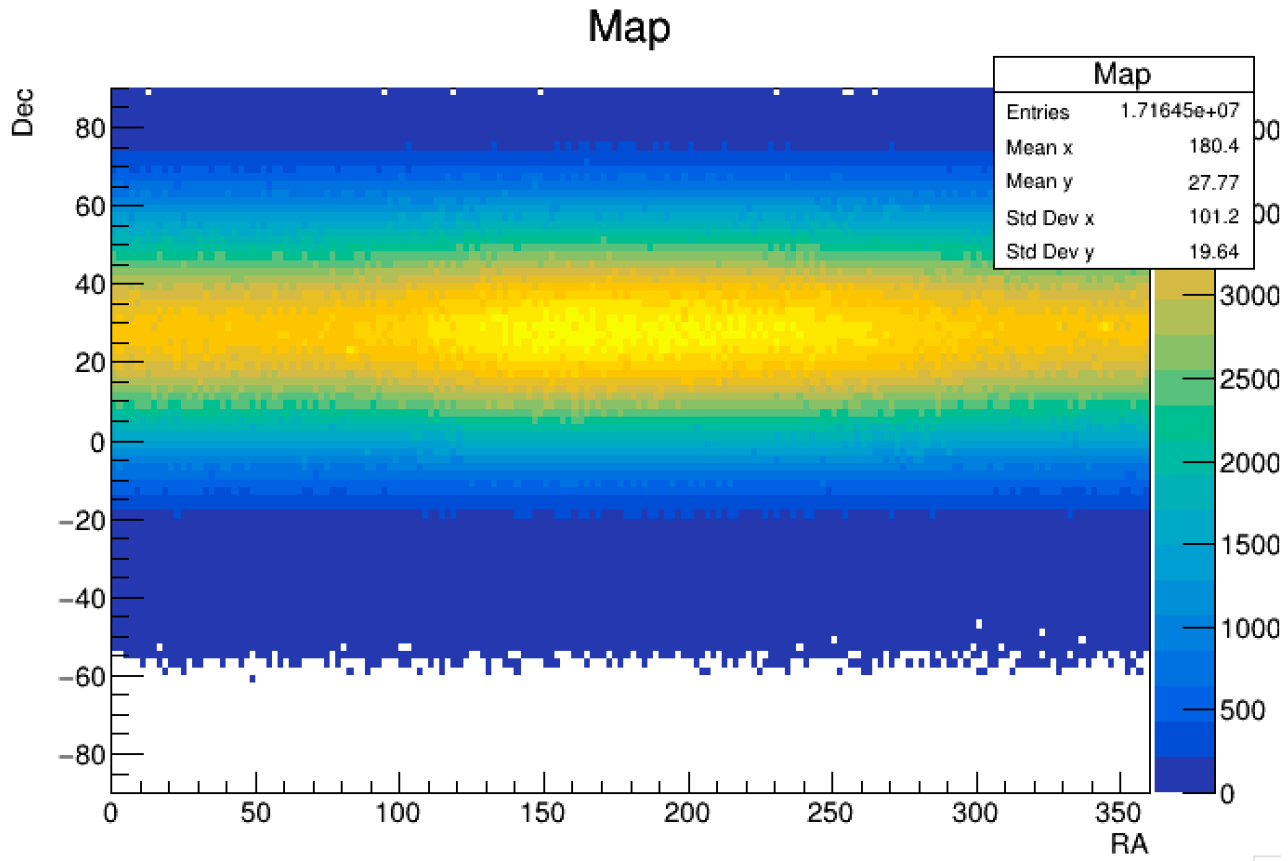


Crab Nebula or Messier 1

R.A. = 83.65° and Dec = 22.05°

Methodology(Cont5)

➢ Plot Sky Map

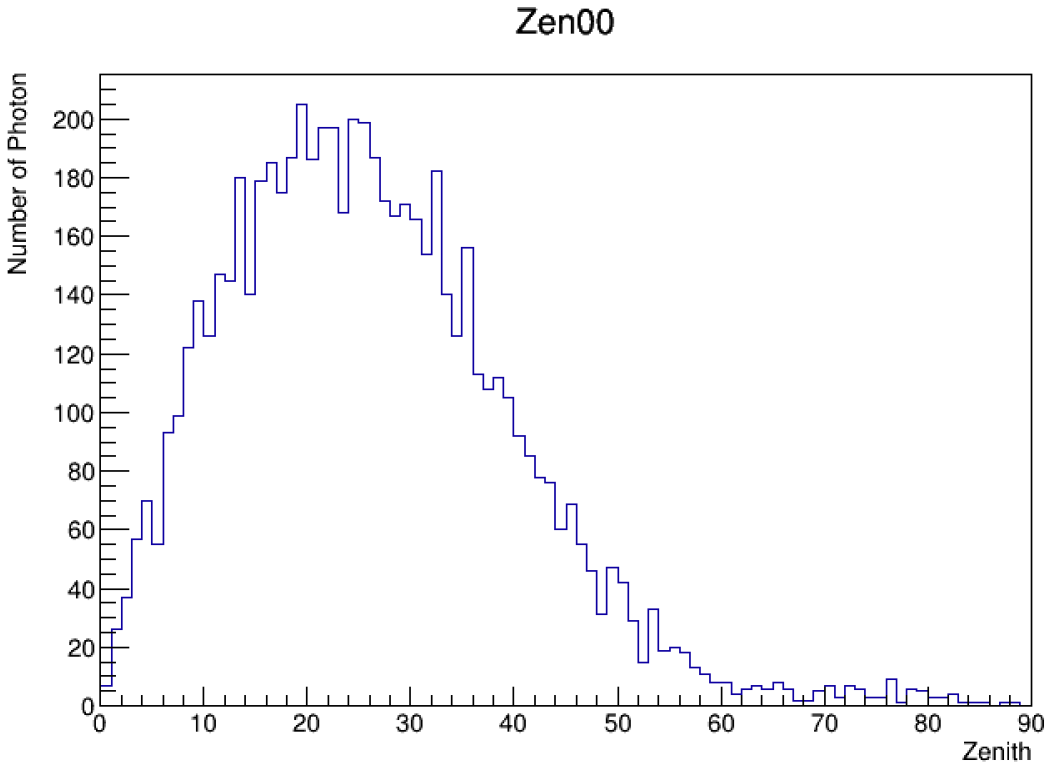


Plot Sky Map using the data November 2021,

and the colors bar represent to number of photon or density of flux

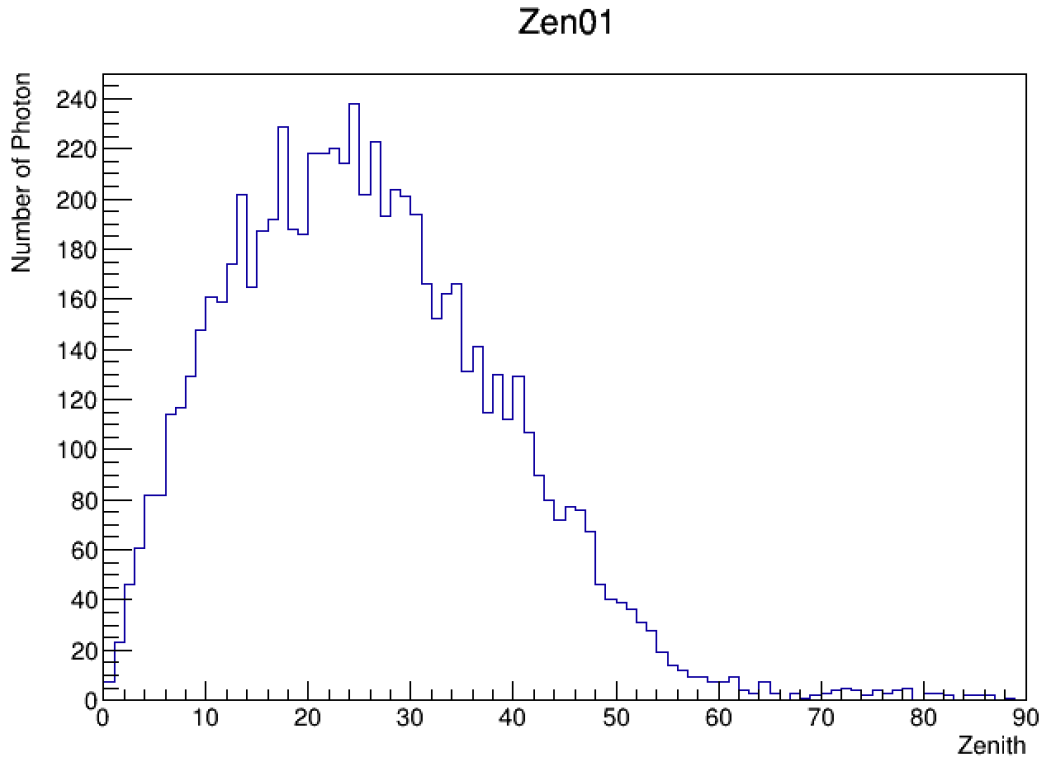
Methodology (Cont6)

➢ Raw counts zenith



Distribution of zenith with number of photon

$60 < N_{hiteff} \leq 100$

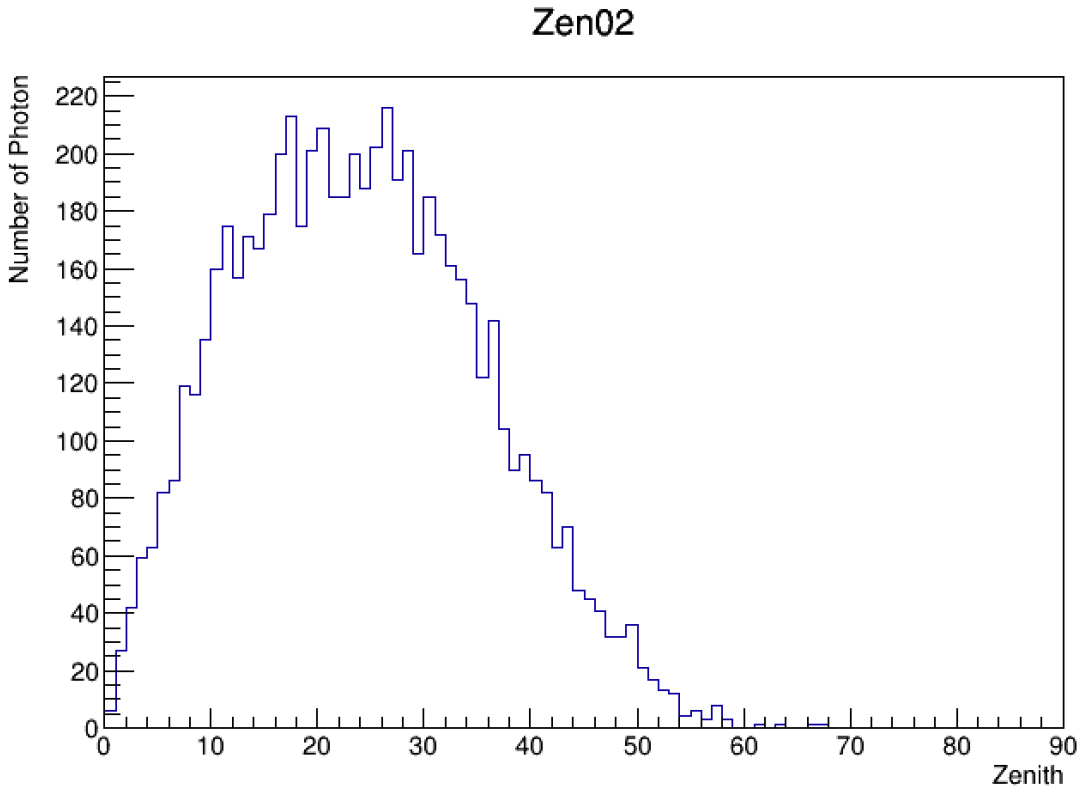


Distribution of zenith with number of photon

$100 < N_{hiteff} \leq 300$

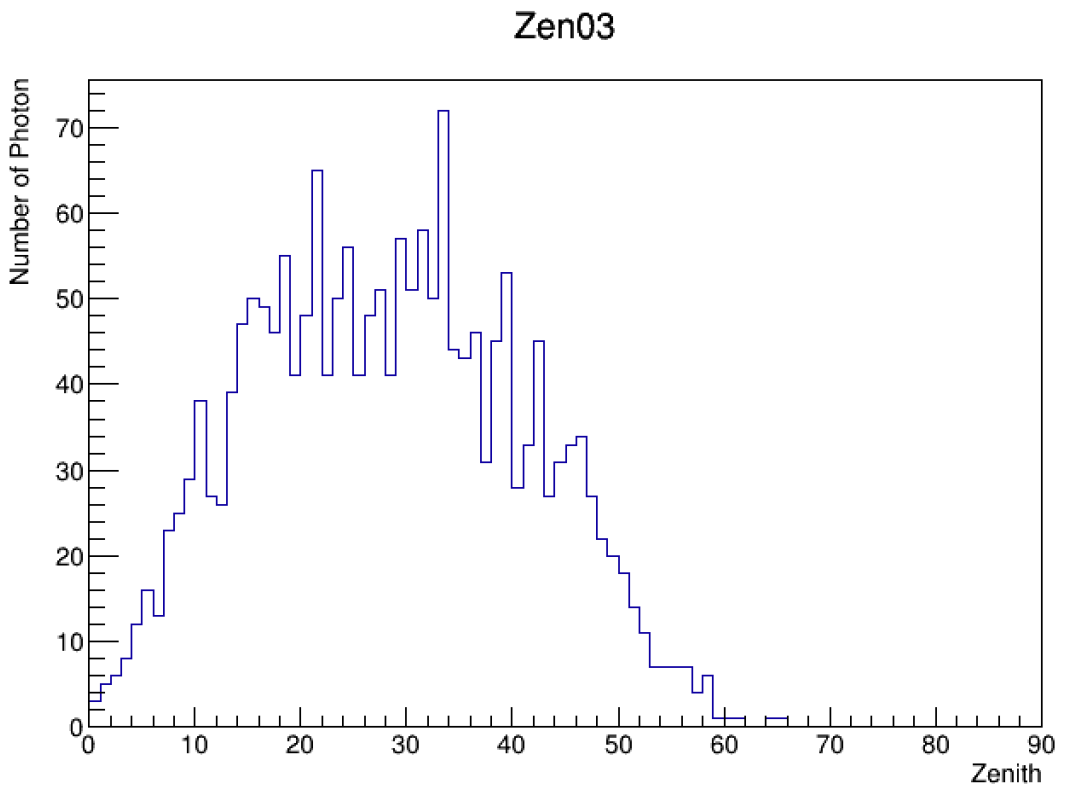
Methodology (Cont7)

➢ Raw counts zenith



Distribution of zenith with number of photon

$300 < N_{hiteff} \leq 1000$

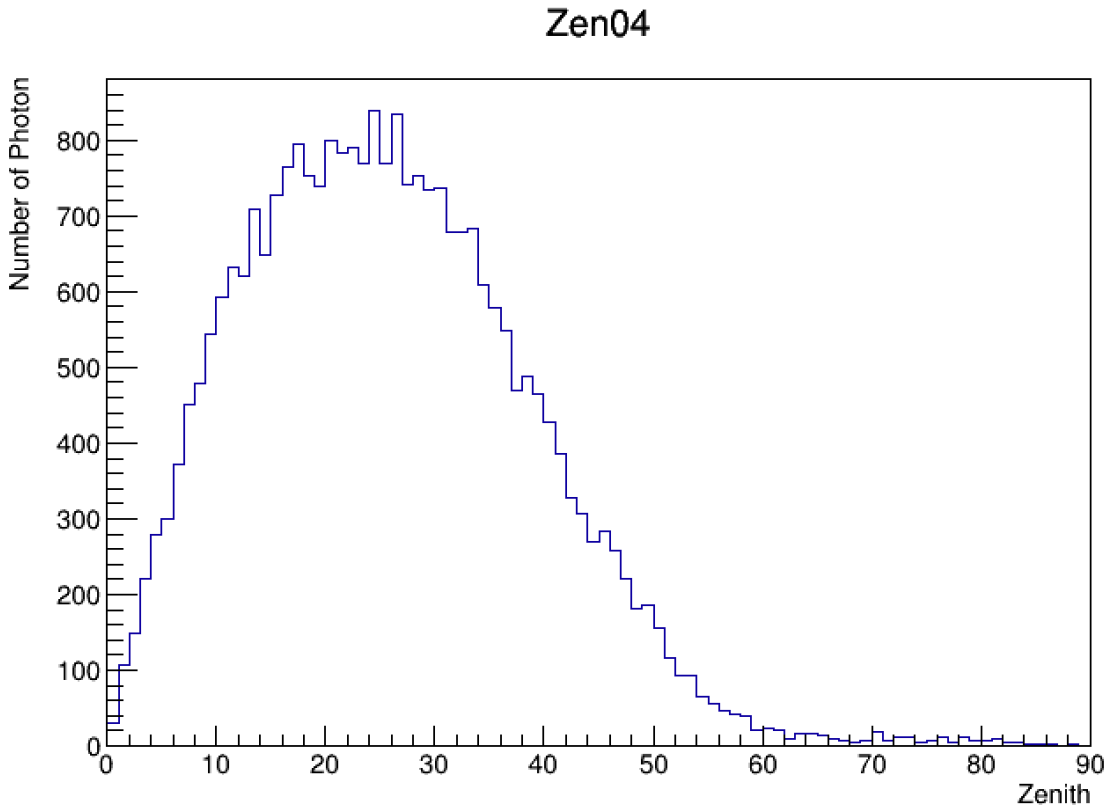


Distribution of zenith with number of photon

$N_{hiteff} \geq 1000$

Methodology(Cont8)

➢ Raw counts zenith

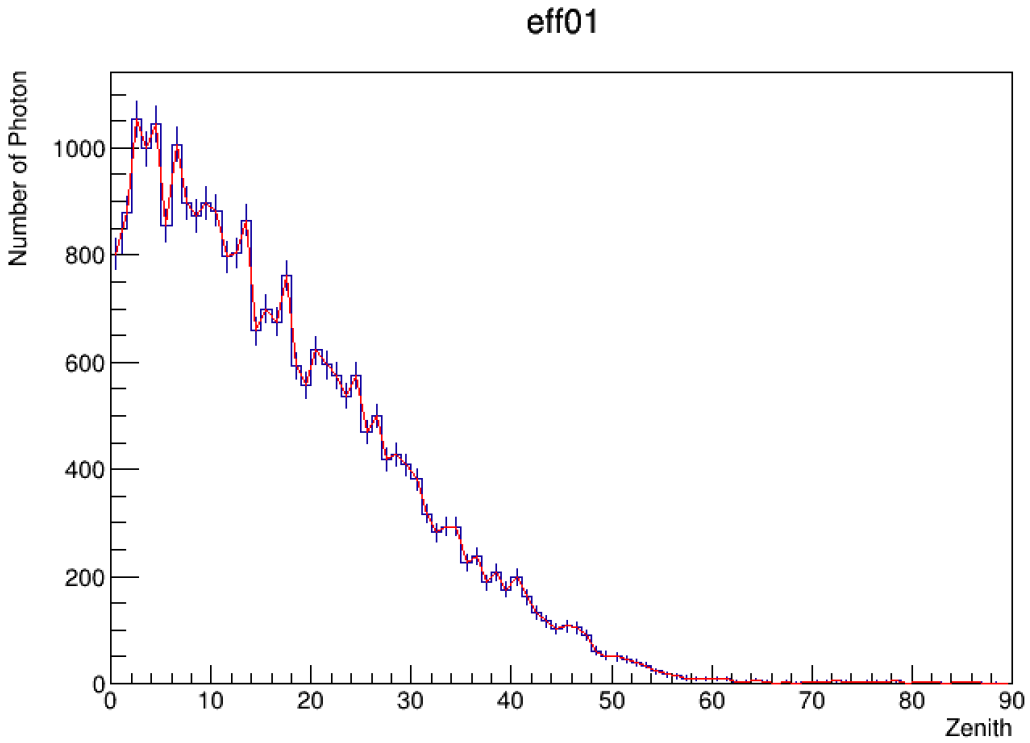


Distribution of zenith with number of photon

All N_{hiteff}

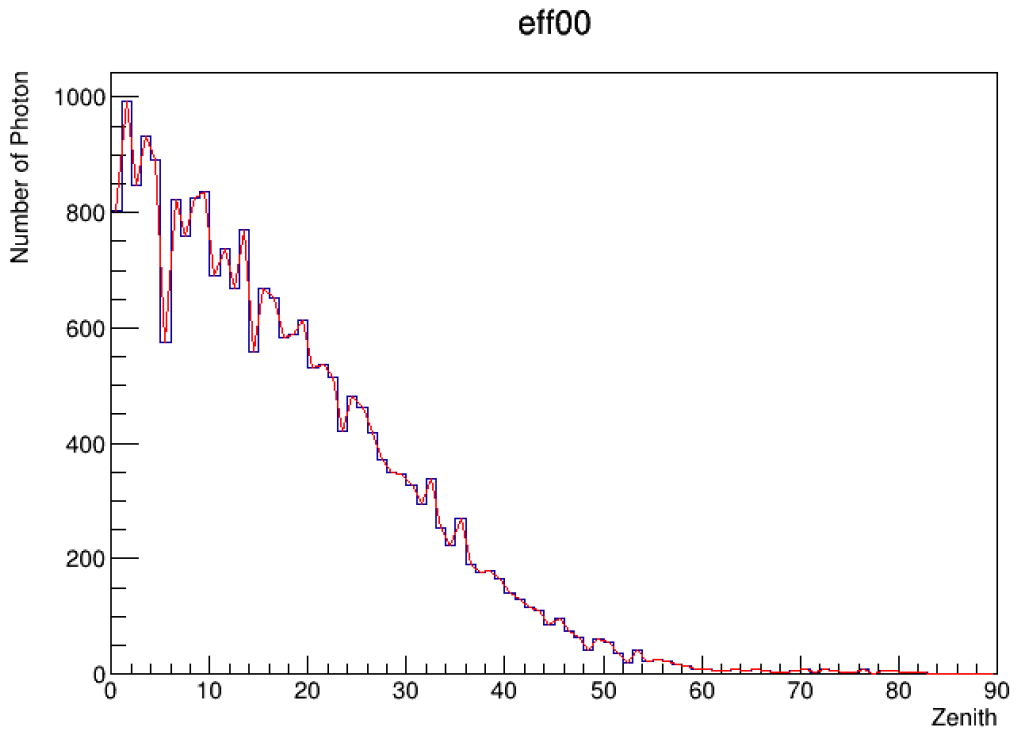
Methodology(Cont9)

➢ Effective Area and Interpolation Effective Area



Distribution between zenith with number of the photon

$60 < N_{hiteff} \leq 100$

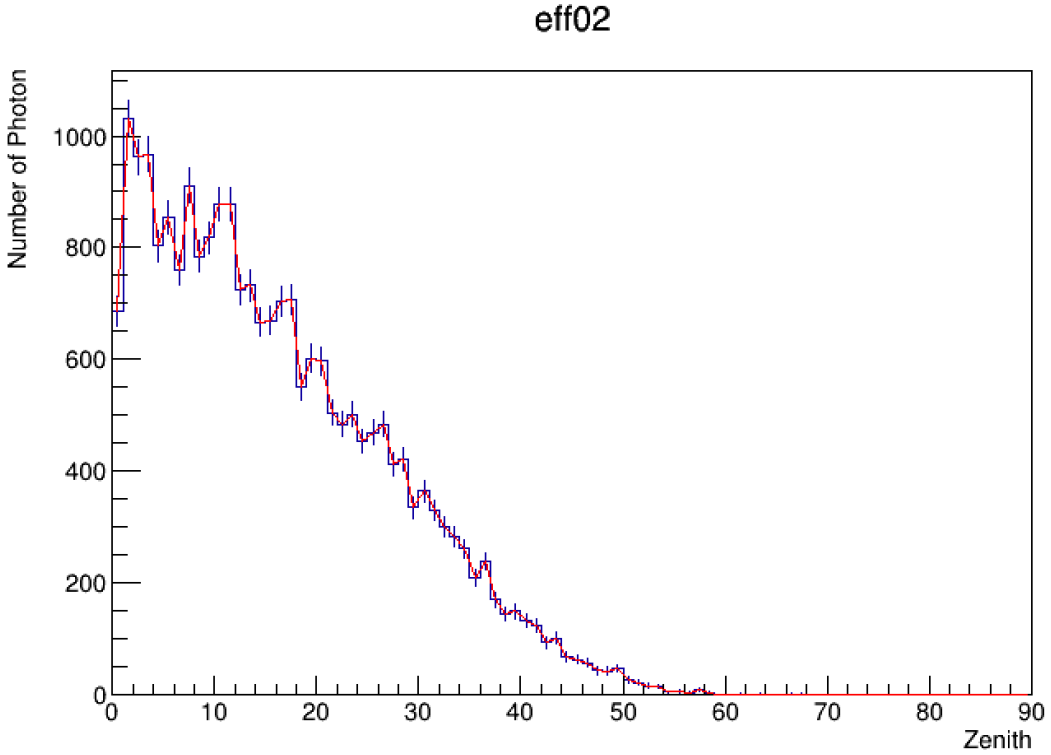


Distribution between zenith with number of the photon

$100 < N_{hiteff} \leq 300$

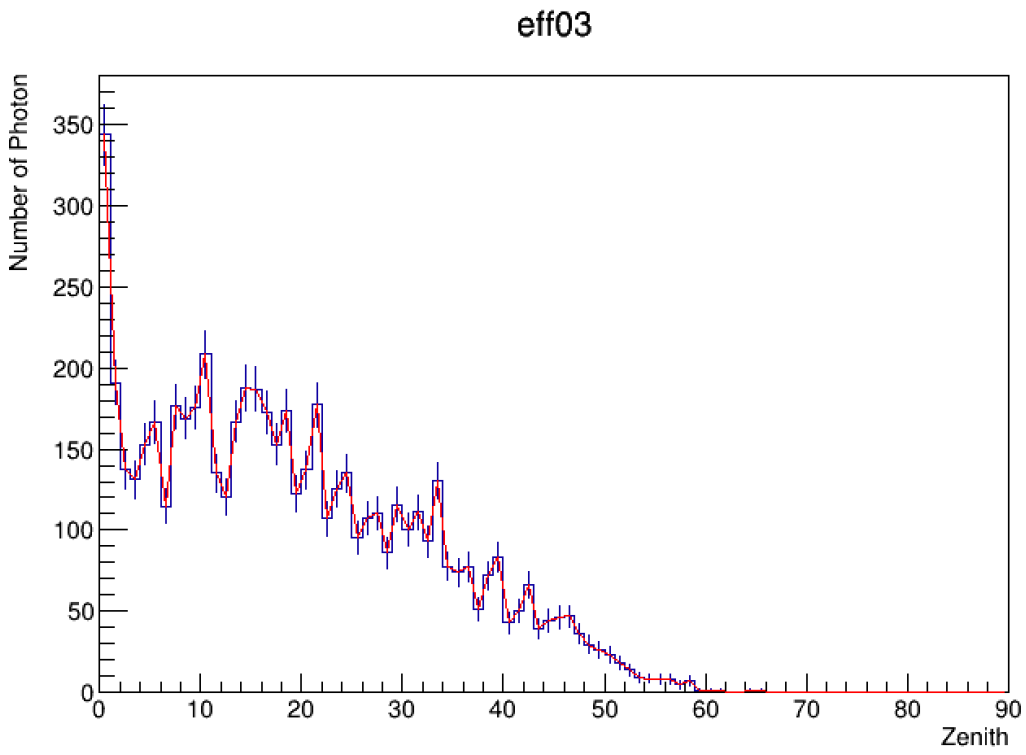
Methodology(Cont1O)

➢ Effective Area and Effective Area



Distribution between zenith with number of the photon

$300 < N_{hiteff} \leq 1000$

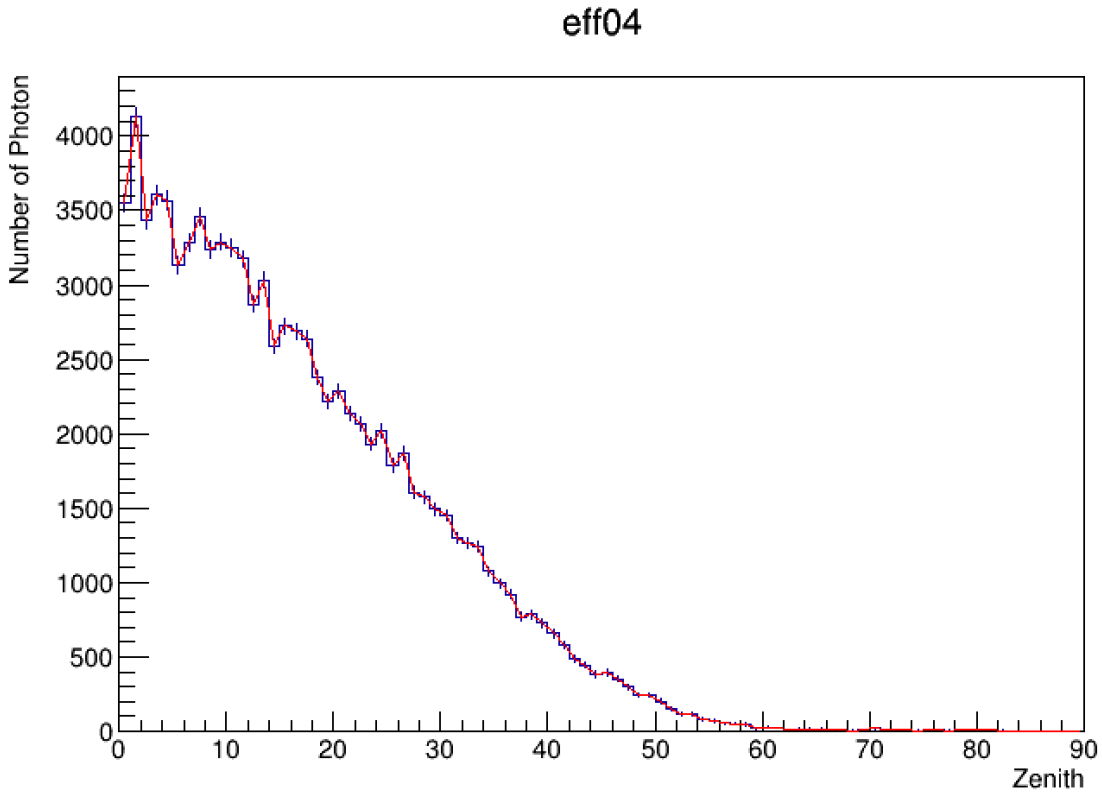


Distribution between zenith with number of the photon

$N_{hiteff} \geq 1000$

Methodology(Cont11)

➢ Effective Area and Interpolation Effective Area

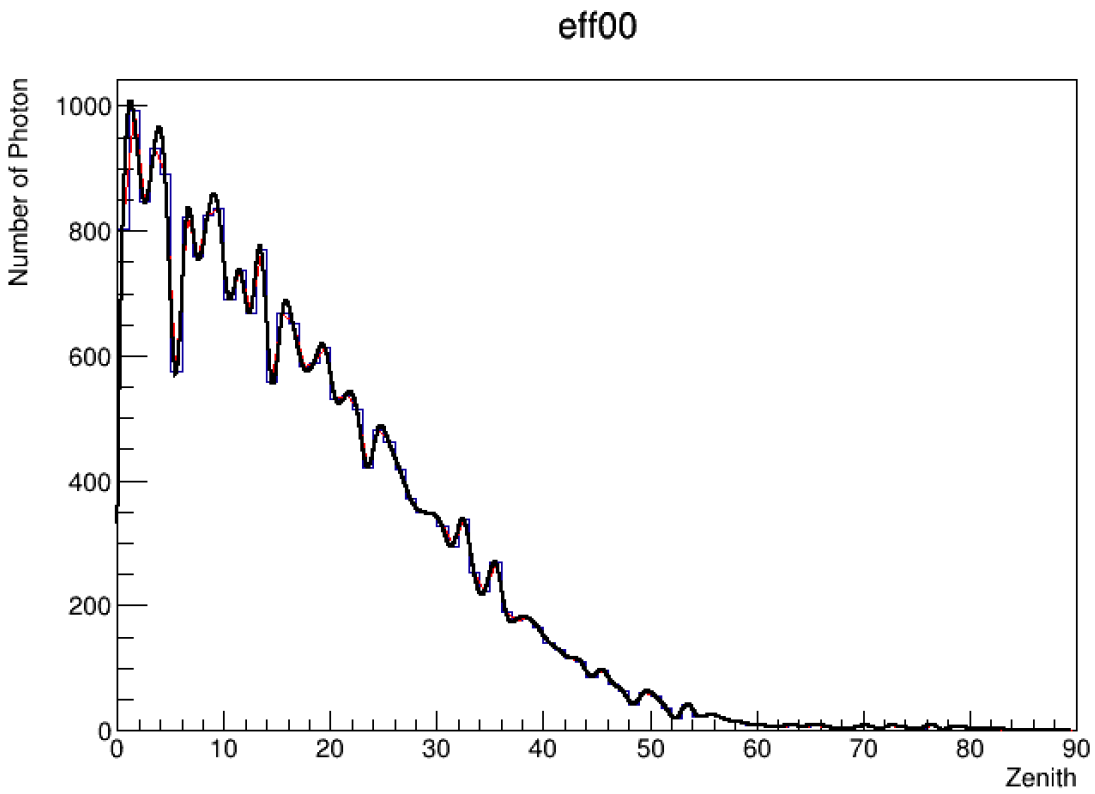


Distribution between zenith with number of the photon

All N_{hiteff}

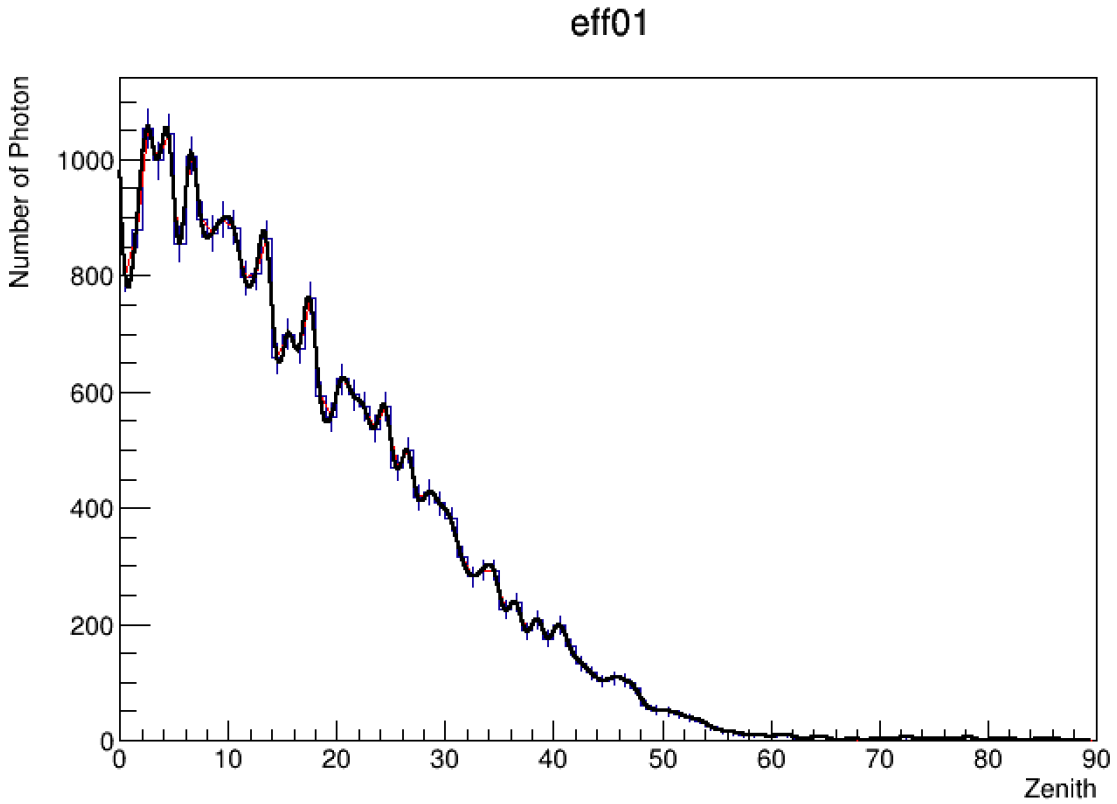
Methodology(Cont12)

➢ Cubic spline Interpolation Effective Area



Distribution between zenith with number of the photon

$60 < N_{hiteff} \leq 100$

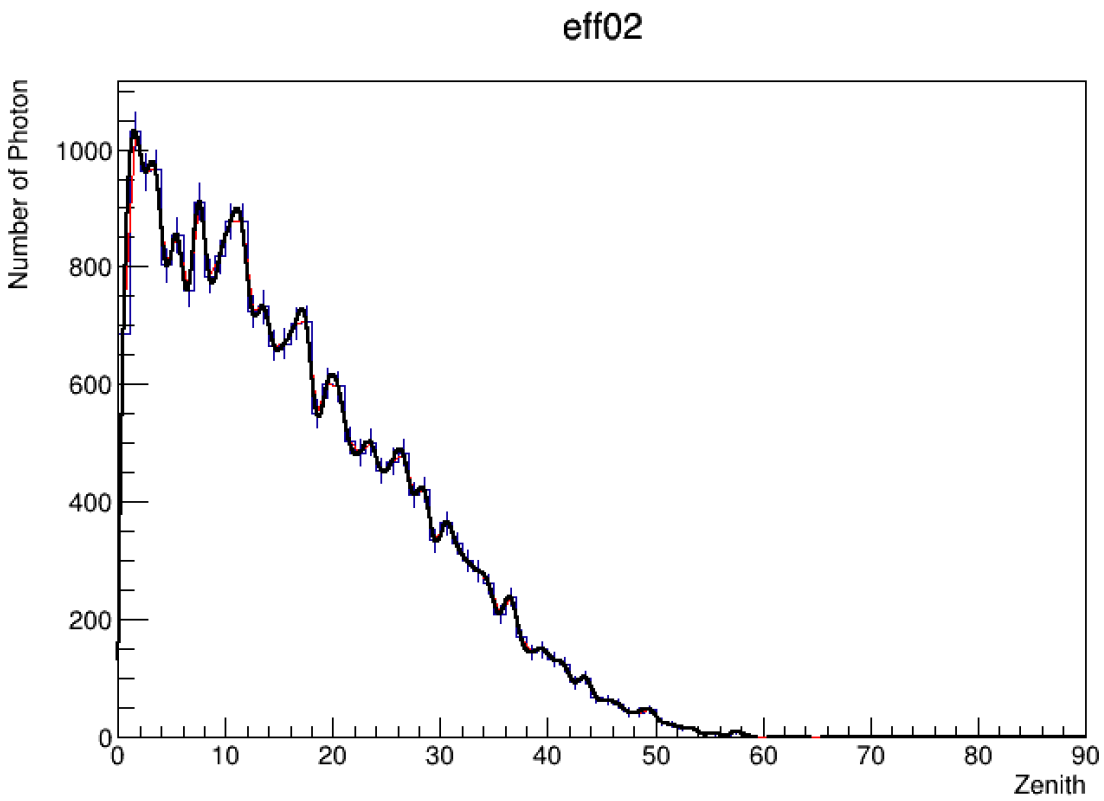


Distribution between zenith with number of the photon

$100 < N_{hiteff} \leq 300$

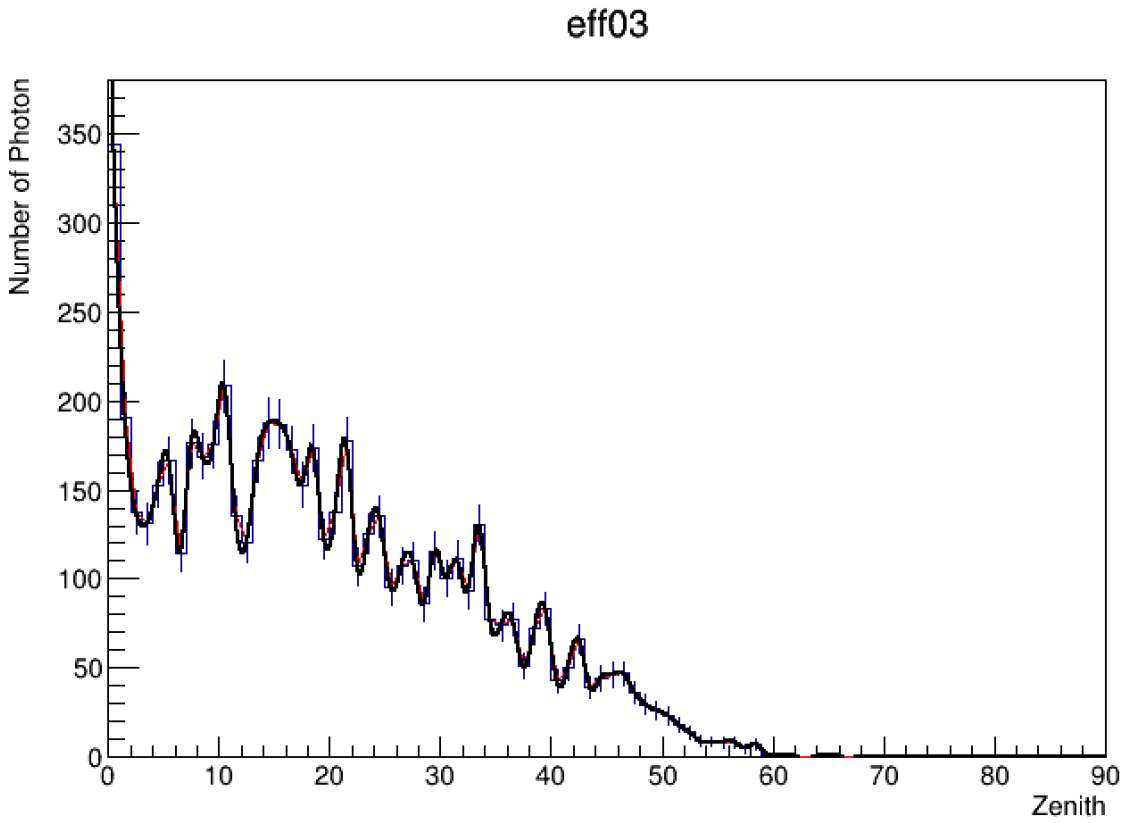
Methodology(Cont13)

➢ Cubic spline Interpolation Effective Area



Distribution between zenith with number of the photon

$300 < N_{hiteff} \leq 1000$

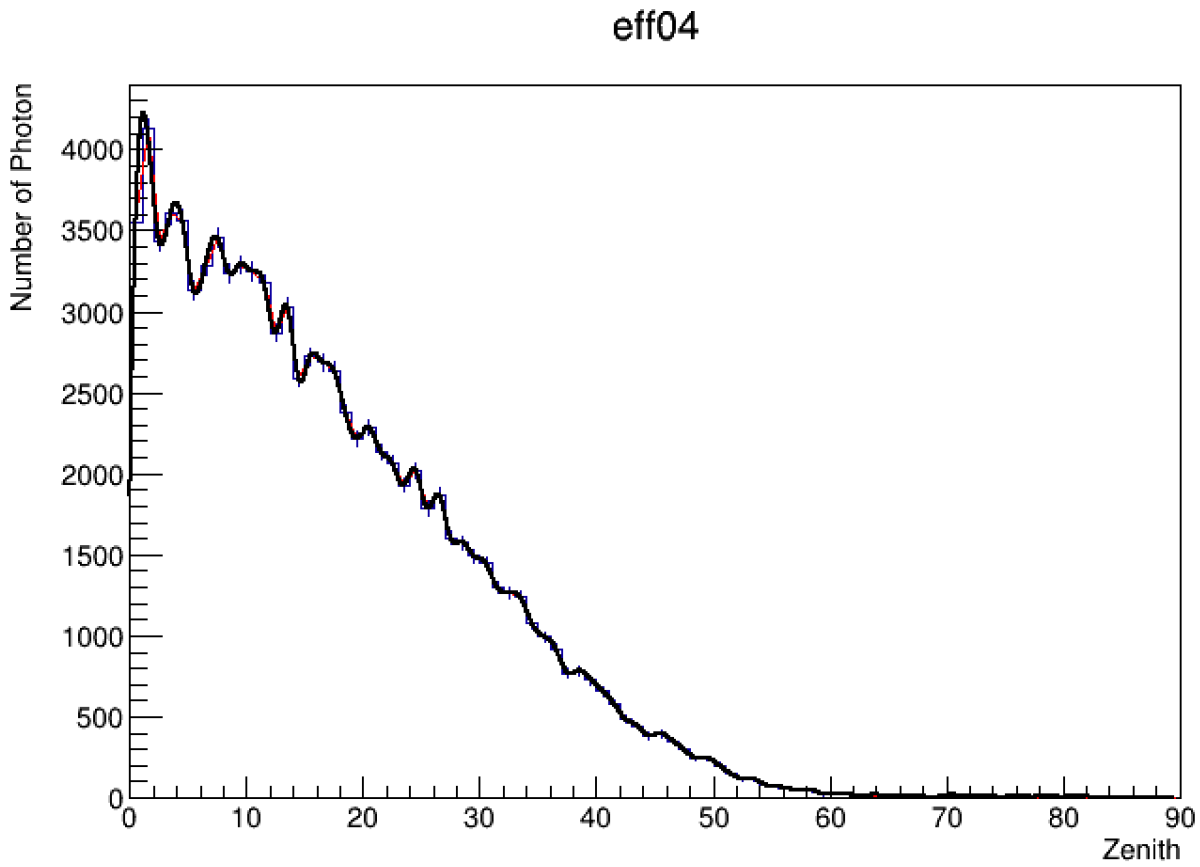


Distribution between zenith with number of the photon

$N_{hiteff} \geq 1000$

Methodology(Cont14)

➢ Cubic spline Interpolation Effective Area



Distribution between zenith with number of the photon

All N_{hiteff}

Research Plans in the future

- AITOFF projection in Galactic coordinates
- Analyze data from 2020 to the present.
- Find the value of significance

Thank you