Document Title **Effect of Secondary Particles on the PSF**

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Prepared by **R. M. Kippen**

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References

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2. *Monte Carlo Simulation of the COMPTEL Gamma-Ray Telescope*, R.M. Kippen, Master’s Thesis, University of New Hampshire, May, 1991.

3. “COMPTEL Data Analysis Standards,” COM-MO-DRG-MGM-231, R. Diehl, 19 Oct., 1993.

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1 Introduction

As described at the last COMPTEL team meeting (Feb. 1996 @ SRON), all current and previous COMPTEL simulation software (the SIM subsystem of COMPASS) uses two important approximations to improve the performance of telescope mode processing. These are:

1) *Narrow Beam Approximation:* The incident photon beam illuminates only the seven D1 scintillator volumes. Events caused by particles from outside this beam are ignored.

2) *Secondary Particle Approximation:* Secondary particles produced in interactions outside the D1/D2 scintillators are ignored.

Recent studies (see reference 1) have shown that significant numbers of telescope events are being ignored by the combination of both approximations. Removing the approximations significantly increases the integrated COMPTEL efficiency (or effective area) for incident photon energies above ~8 MeV, especially at large incident zenith angles. The "new" events contribute mainly to a low-energy tail E_{tot} < 5 MeV.

It is the purpose of this report to describe the effect of removing approximations 1) and 2) on the simulated point-spread-functions and the source parameters derived from them. The effects on the standard $E^{-2.0}$ power law PSF are not expected to be as severe as for the integrated efficiency, since the PSFs use the response of a power law energy distribution and source parameters are most heavily weighted by the diagonal elements (as opposed to "tail" events) of the PSF. Note that the removal of approximations 1) and 2) degrades the performance of the simulation software by roughly a factor of two. Incorporating a wide incident photon beam and tracking all secondary particles also makes the simulations more sensitive to the detailed mass distribution of the COMPTEL SIM mass model (particularly around the D1 modules). A revised SIM mass model which pays more attention to the detailed mass distribution is currently being developed, but is not available for use in this report. *The results of this report should therefore be considered preliminary estimates.*

2 Analysis

To investigate the effect of secondary particles of the PSF, a new version of the COMPASS task SIMGAM (Monte Carlo simulation of incident gamma-ray photons using the GEANT system) was used in a test environment. This version was modified so as to 1) track all secondary particles, no matter where in the mass model they are created and 2) start incident photons over a wide beam which illuminates all of the D1 platform (radius ~ 74 cm). Eight separate SIMGAM runs were performed in order to construct PSFs for an $E^{-2.0}$ power law energy spectrum for sources at incident zenith angles of 10° and 40° in each of the four standard energy ranges. The PSFs were used to image Observation period 1.0 data from the Crab Nebula using the standard SRCLIX approach. Details of the construction of the new PSFs are described in the next section, followed by a comparison to the current standard SIM and Model PSFs.

2.1 PSF Description

The approach used to create the PSFs in this report is to *directly* simulate a power law spectrum of photons from a given source direction using the COMPASS task SIMGAM. The resulting ideal events are then processed through the task SIMFIN, where instrumental broadening and thresholds are applied. Finally, the broadened events are processed by the task SIMPSF, where they are binned into properly normalized 2-D and 3-D PSFs (IAQ and FAQ, respectively). Note that this approach differs from that used to create the "standard" SIM PSFs, which are "synthesized" from a library of monoenergetic source simulations. The *direct* and *synthesis* methods have been shown in the past to yield consistent results. **However, the *directly* simulated PSFs used is this report incorporate far fewer events than the standard *synthesized* PSFs.** Standard data selections were applied in creating the SIM PSFs.

Table 3.1 $E^{-2.0}$, Θ=10° **Beam area = 17456.00 cm²**

E_{tot}	E_{input}	QEV	N_{input}	EVP	FAQ	IAQ	N_{events}
0.75-1	0.7-99	4749†	21334633	13437†	10218†	10274†	5543
1-3	0.84-99	4745†	20039872	13438†	10214†	10270†	23762
3-10	2.7-99	4746†	13705644	13439†	10215†	10271†	19397
10-30	9-99	4747†	7726447	13440†	10217†	10273†	7756

†Dataset exists only in MTK test environment.

Table 3.2 $E^{-2.0}$, Θ=40° **Beam area = 15081.19 cm²**

E_{tot}	E_{input}	QEV	N_{input}	EVP	FAQ	IAQ	N_{events}
0.75-1	0.7-99	4763†	38408125	13445†	10220†	10276†	5179
1-3	0.84-99	4764†	37909139	13446†	10221†	10277†	24170
3-10	2.7-99	4765†	34460744	13447†	10222†	10278†	17005
10-30	9-99	4766†	22231796	13449†	10225†	10281†	5075

†Dataset exists only in MTK test environment.

2.2 PSF Comparisons

The following figures compare the $E^{-2.0}$ power law PSFs generated for this report (called “New SIM 10°” and “New SIM 40°”), with the standard synthesized SIM (called “Old SIM 10°”) and Model PSFs. IDL routines have been used to create contour plots and slices in various directions, using the IAQ datasets as inputs.

The following qualitative differences can be observed:

1) The low numbers of counts in the new PSFs are evident in the noisy contours.
2) In the 0.75-1 MeV range, the overall normalization of the model PSF is significantly larger than any of its simulated counterparts.
3) All PSFs are roughly consistent in the 1-3 MeV energy range.
4) Above 3 MeV, the new SIM PSFs are significantly larger than the old.
5) Above 3 MeV, the new 40° PSFs are significantly larger than the 10° PSFs.
6) Above 3 MeV, the model PSF is significantly smaller than any of its simulated counterparts.

These comparisons indicate that the addition of secondary particles and use of a wide photon beam affects the $E^{-2.0}$ power law PSF mainly in the 3-10 and 10-30 MeV energy ranges and is more pronounced at larger zenith angles.

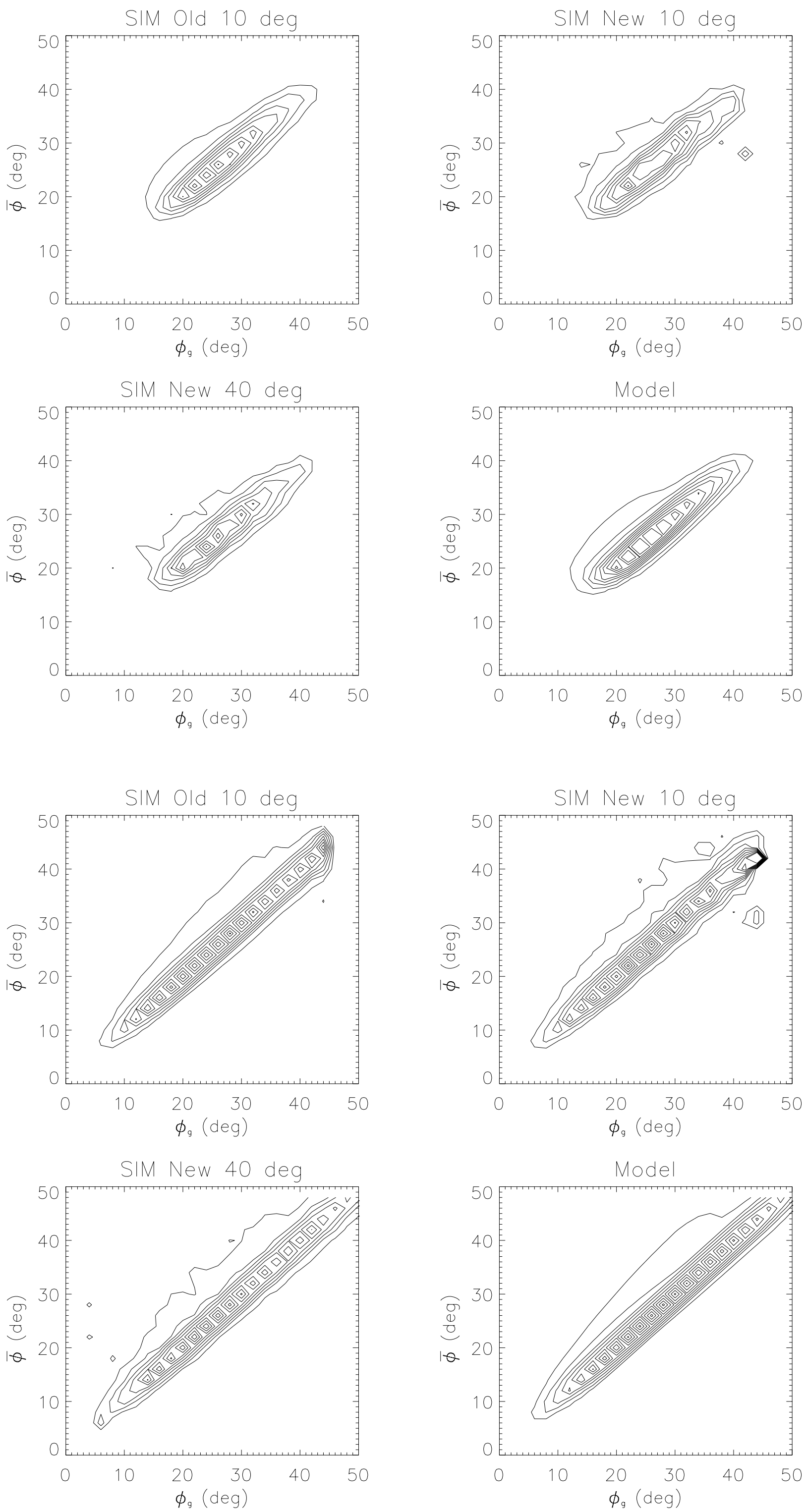


Fig. 2.1. IAQ contour comparisons for the 0.75–1 MeV (upper four plots) and 1–3 MeV (lower four plots) energy ranges.

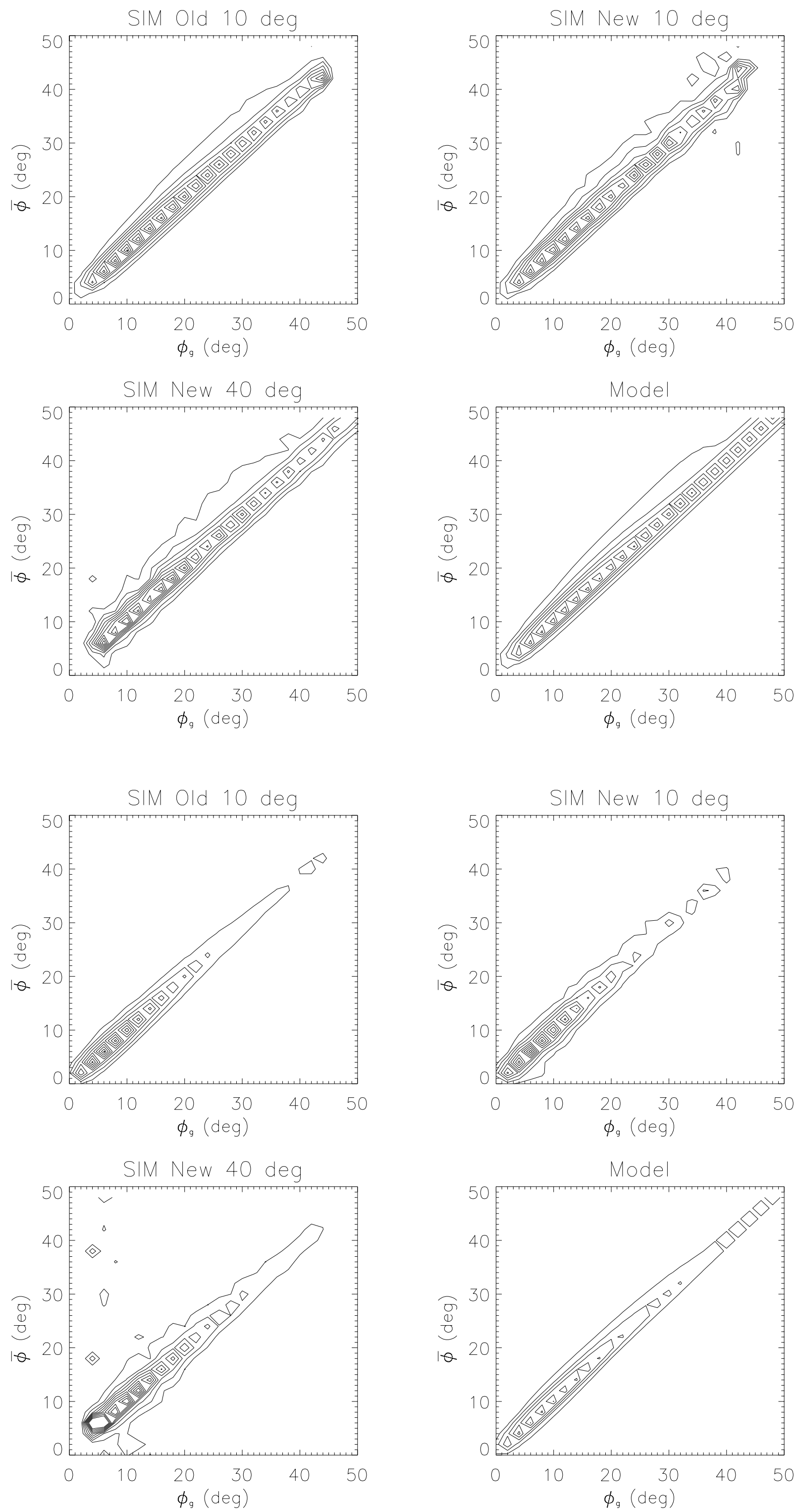


Fig. 2.2. IAQ contour comparisons for the 3–10 MeV (upper four plots) and 10–30 MeV (lower four plots) energy ranges.

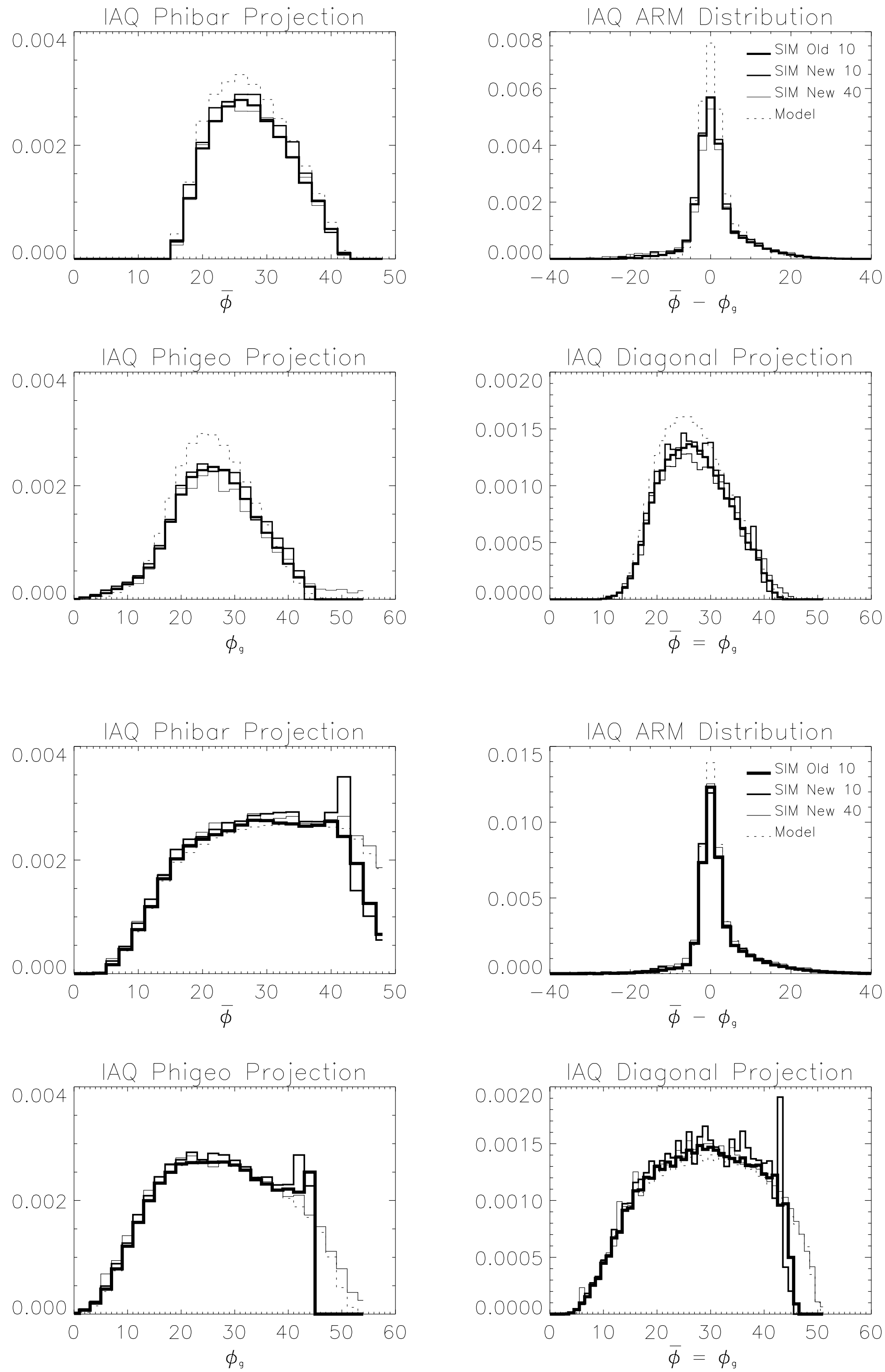


Fig. 2.3. IAQ projection comparisons for the 0.75–1 MeV (upper four plots) and 1–3 MeV (lower four plots) energy ranges.

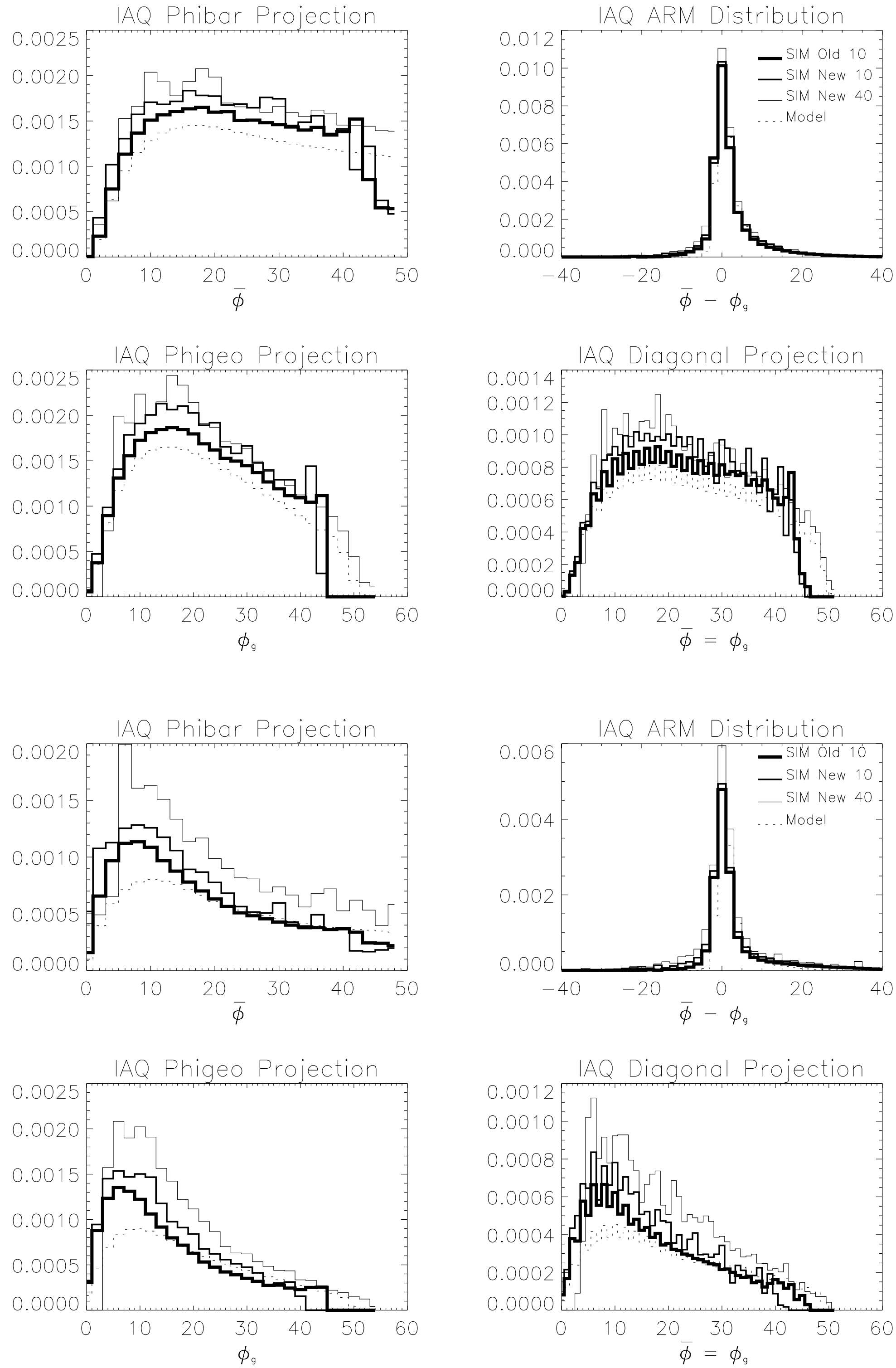


Fig. 2.4. IAQ projection comparisons for the 3–10 MeV (upper four plots) and 10–30 MeV (lower four plots) energy ranges.

3 Crab Imaging Results

Using the standard SRCLIX (version 16) task, the PSFs created for this report were used to image Observation Period 1.0 data, where the Crab is in the field-of view at a zenith angle θ=6.6°. Standard datasets and data selections (as defined in COM-MO-DRG-MGM-231.6) have been used for the flight data. Source parameters (source counts, source flux and log likelihood ratio) have been derived from the resulting MLM datasets at the position of the Crab (l = 184.5, b = -5.8). Note that no ToF corrections have been applied to the source fluxes. The following tables and figures compare the source parameters obtained using the various PSFs as defined in section 3.

Table 3.1. Crab Obs. 1.0: 0.75–1.0 MeV — PHIBAR 4-50°

Item	Old SIM 10°	New SIM 10°	New SIM 40°	Model
DRE Dataset	M-37879	M-37879	M-37879	M-37879
DRG Dataset	M-26095	M-26095	M-26095	M-26095
DRX Dataset	M-23985	M-23985	M-23985	M-23985
FAQ Dataset	U-8160	U-10218†	U-10220†	R-716
MLM Dataset	U15401†	U15402†	U15403†	U15421†
Source counts	2362 ± 263	2398 ± 274	1944 ± 257	2163 ± 229
Source Flux(*10-4)	5.19 ±0.58	4.92 ±0.56	4.43 ±0.59	3.89 ±0.41
Source -2Ln(R)	90.5	86.4	65.9	101.4
counts Δmodel (%)	+ 9.2	+10.9	-10.1	0
flux Δmodel (%)	+33.4	+26.5	+13.9	0
lik ratio Δmodel (%)	-10.7	-14.8	-35.0	0
counts Δoldsim (%)	0	+ 1.5	-17.7	- 8.4
flux Δoldsim (%)	0	- 5.2	-14.6	-25.6
lik ratio Δoldsim(%)	0	- 4.5	-27.2	+12.0

†Dataset exists only in MTK test environment.

Table 3.2. Crab Obs. 1.0: 1.0–3.0 MeV — PHIBAR 4-50°

Item	Old SIM 10°	New SIM 10°	New SIM 40°	Model
DRE Dataset	M-37881	M-37881	M-37881	M-37881
DRG Dataset	M-26095	M-26095	M-26095	M-26095
DRX Dataset	M-23985	M-23985	M-23985	M-23985
FAQ Dataset	U-8174	U-10214†	U-10221†	R-717
MLM Dataset	U15405†	U15406†	U15407†	U15420†
Source counts	9006 ± 472	9299 ± 489	8276 ± 470	8339 ± 439
Source Flux(*10-4)	9.57 ±0.50	9.35 ±0.49	8.21 ±0.47	8.81 ±0.46
Source -2Ln(R)	411.4	408.9	354.2	407.5
counts Δmodel (%)	+ 8.0	+11.5	- 0.8	0
flux Δmodel (%)	+ 8.6	+ 6.1	- 6.8	0
lik ratio Δmodel (%)	+ 1.0	+ 0.3	-13.1	0
counts Δoldsim (%)	0	+ 3.3	- 8.1	- 7.4
flux Δoldsim (%)	0	- 2.3	-14.2	- 7.9
lik ratio Δoldsim(%)	0	- 0.6	-13.9	- 0.9

[†]Dataset exists only in MTK test environment.

Table 3.3. Crab Obs. 1.0: 3.0–10.0 MeV — PHIBAR 4-50°

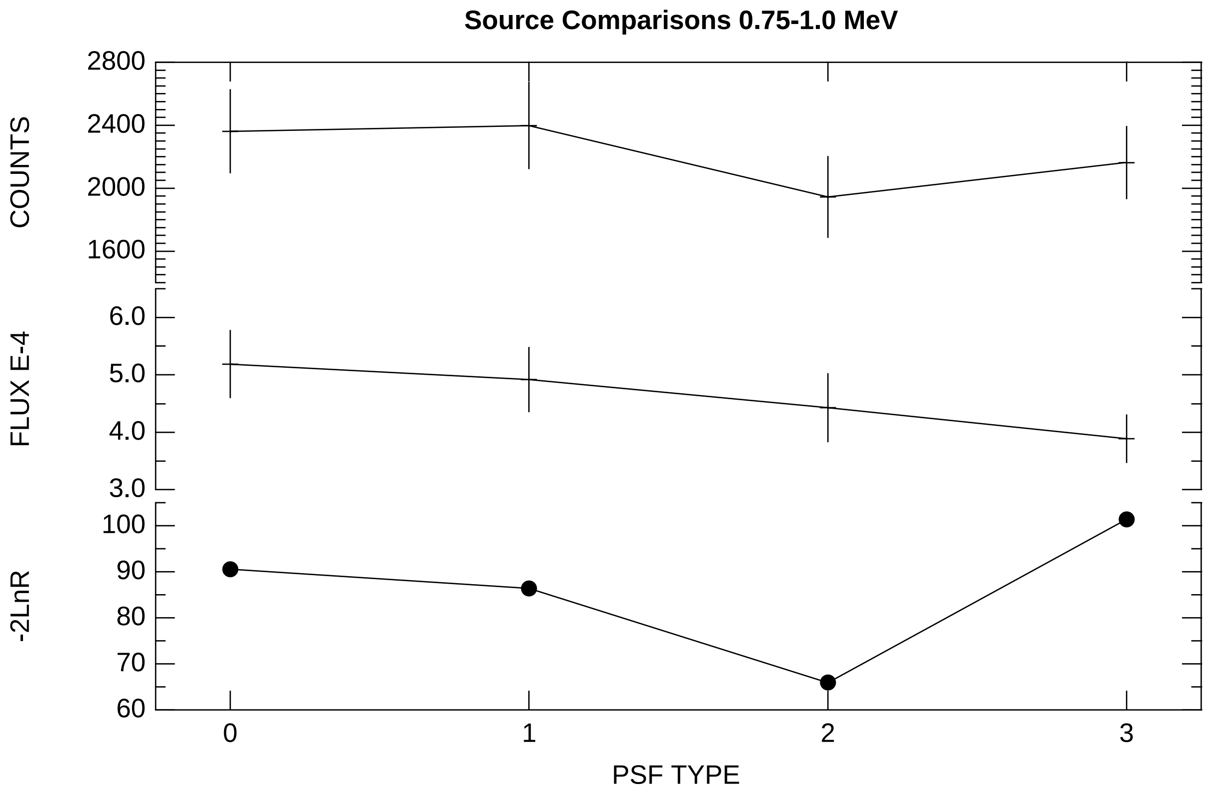
Item	Old SIM 10°	New SIM 10°	New SIM 40°	Model
DRE Dataset	M-37882	M-37882	M-37882	M-37882
DRG Dataset	M-26095	M-26095	M-26095	M-26095
DRX Dataset	M-23985	M-23985	M-23985	M-23985
FAQ Dataset	U-8188	U-10215†	U-10222†	R-718
MLM Dataset	U15409†	U15410†	U15411†	U15419†
Source counts	3356 ± 226	3592 ± 245	3240 ± 232	3091 ± 212
Source Flux(*10-4)	3.32 ±0.22	3.19 ±0.22	2.74 ±0.20	3.40 ±0.23
Source -2Ln(R)	251.1	245.8	221.3	241.4
counts Δmodel (%)	+ 8.6	+16.2	+ 4.8	0
flux Δmodel (%)	- 2.4	- 6.2	-19.4	0
lik ratio Δmodel (%)	+ 4.0	+ 1.8	- 8.3	0
counts Δoldsim (%)	0	+ 7.0	- 3.5	- 7.9
flux Δoldsim (%)	0	- 3.9	-17.5	+ 2.4
lik ratio Δoldsim(%)	0	- 2.1	-11.9	- 3.9

†Dataset exists only in MTK test environment.

Table 3.4. Crab Obs. 1.0: 10.0–30.0 MeV — PHIBAR 4-30°

Item	Old SIM 10°	New SIM 10°	New SIM 40°	Model
DRE Dataset	M-37883	M-37883	M-37883	M-37883
DRG Dataset	M-26095	M-26095	M-26095	M-26095
DRX Dataset	M-23985	M-23985	M-23985	M-23985
FAQ Dataset	U-8202	U-10217†	U-10225†	R-719
MLM Dataset	U15413†	U15414†	U15415†	U15418†
Source counts	385 ± 51	420 ± 56	327 ± 47	342 ± 45
Source Flux(*10-4)	0.642 ±0.085	0.611 ±0.082	0.389 ±0.056	0.722 ±0.096
Source -2Ln(R)	67.9	67.1	59.5	69.0
counts Δmodel (%)	+12.6	+22.8	- 4.4	0
flux Δmodel (%)	-11.1	-15.4	-46.1	0
lik ratio Δmodel (%)	- 1.6	- 2.8	-13.8	0
counts Δoldsim (%)	0	+ 9.1	-15.1	-11.2
flux Δoldsim (%)	0	- 4.8	-39.4	+12.5
lik ratio Δoldsim(%)	0	- 1.2	-12.4	+ 1.6

[†]Dataset exists only in MTK test environment.



Source Comparisons 0.75-1.0 MeV
COUNTS
2800
2400
2000
1600
FLUX E-4
6.0
5.0
4.0
3.0
-2LnR
100
90
80
70
60
0
1
2
3
PSF TYPE

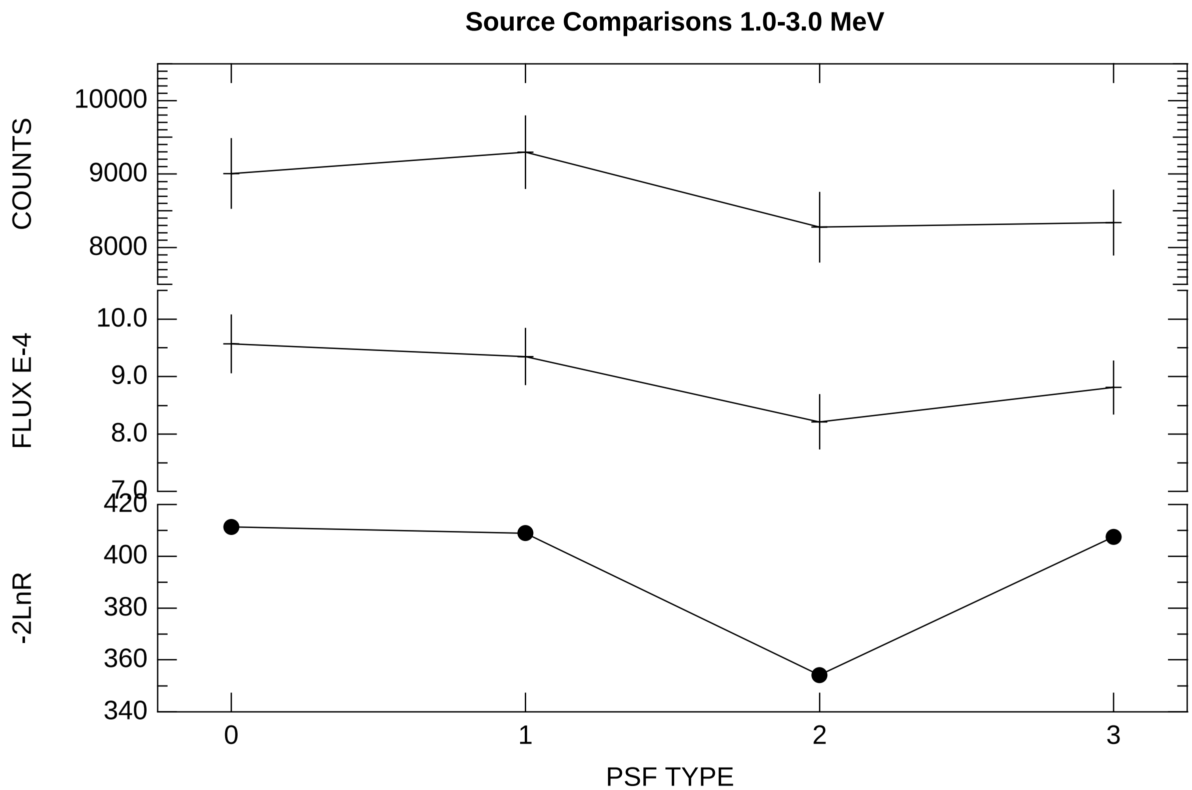
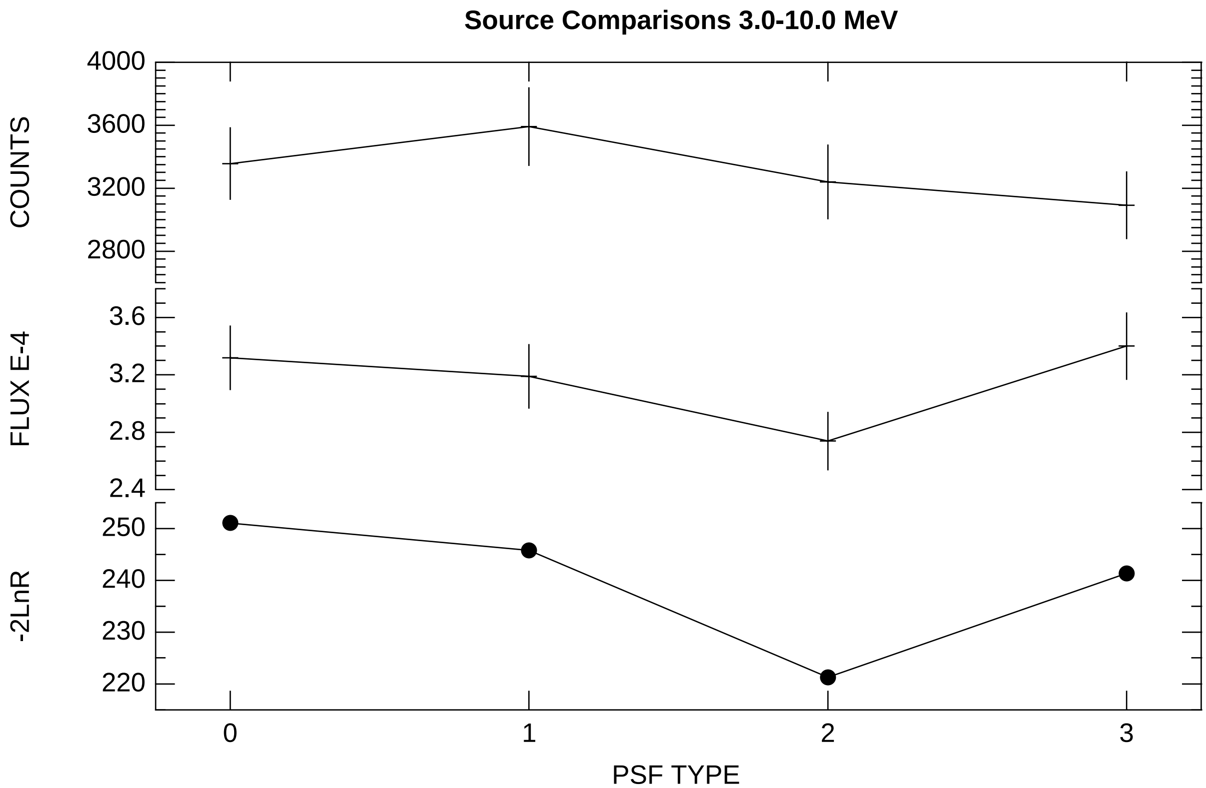


Fig. 3.1. Source parameter comparisons (PSF Type: 0="Old SIM 10°", 1="New SIM 10°", 2="New SIM 40°", 3="Model").


Source Comparisons 3.0-10.0 MeV
COUNTS
4000
3600
3200
2800
FLUX E-4
3.6
3.2
2.8
2.4
-2LnR
250
240
230
220
0
1
2
3
PSF TYPE

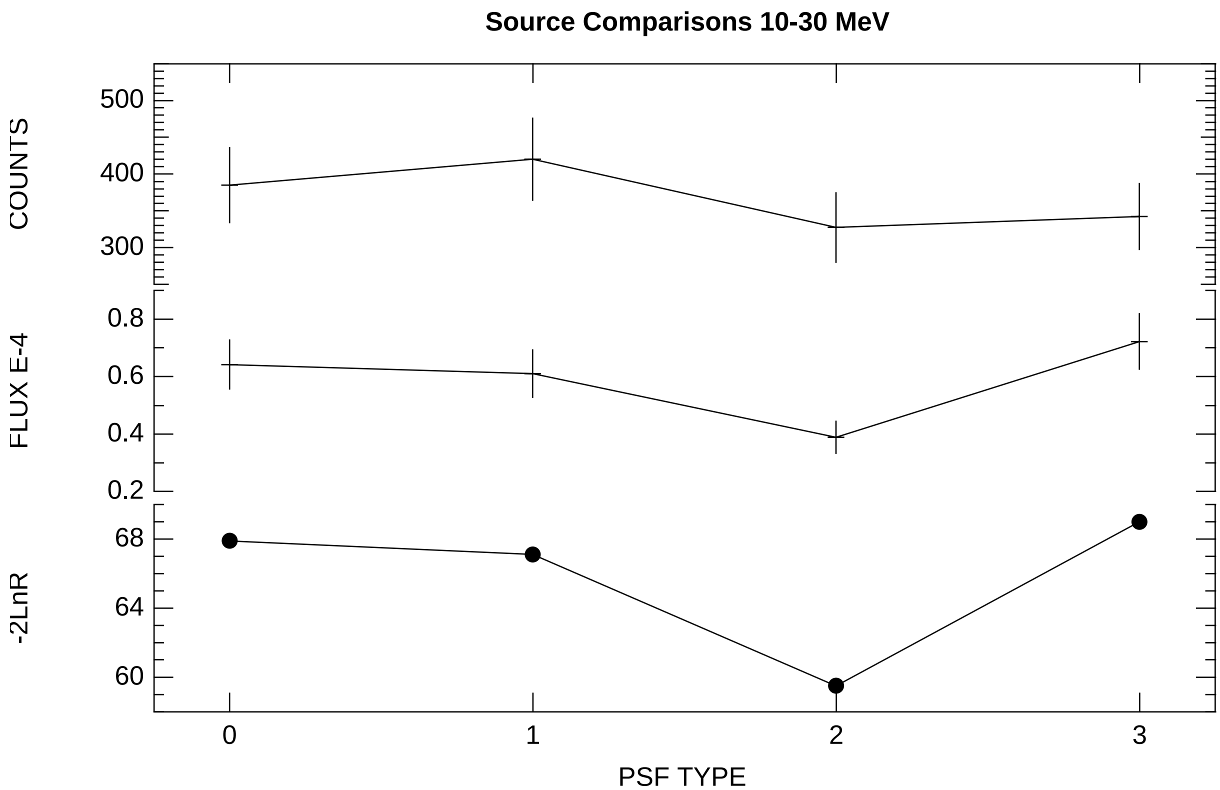


Fig. 3.2. Source parameter comparisons (PSF Type: 0="Old SIM 10°", 1="New SIM 10°", 2="New SIM 40°", 3="Model").

4 Conclusions

Statistical uncertainty in the source parameters derived at the position of the Crab are quite large compared to the differences obtained with the different PSFs. However, several systematic trends are clearly apparent.

1) Source fluxes based on the new 10° PSFs are lower (by about 3–5%) than those obtained with the old PSFs, with no obvious dependence on energy range.

2) Source fluxes based on the new 40° PSFs are lower (by about 14–40%) than those obtained with the old PSFs, with the difference being most pronounced in the 3-10 and 10-30 MeV energy ranges.

3) In the 0.75-1 MeV range, source fluxes based on the model PSFs are lower (by at least 25%) than those obtained with any of the SIM PSFs.

4) In the 3-10 and 10-30 MeV ranges, source fluxes based on the model PSFs are higher (by at least 2-12%) than those obtained with any of the SIM PSFs.

These trends are consistent with those observed by directly comparing the PSFs as in section 3. As expected, the systematic effects of including secondary-particle-induced events in the PSF are much smaller than the change in total integrated efficiency. It should be stressed that these results are preliminary and need to be repeated with a revised mass model. However, the revised mass model is not expected to make the systematic differences significantly larger.

Given the minimal (~5%) effect on 10° PSFs and the large computational expense, it does not appear advantageous to re-generate the standard SIM PSFs. It may, however, be worth while to consider a PSF library for sources at large zenith angles, where the systematic effects are more pronounced.