Document Title **Effect of Secondary Particles on the Telescope Response**

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References

1. "Simulation Status Report," R.M. Kippen, COMPTEL Team Meeting Handout, 27 Feb., 1996, SRON-Utrecht.

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.

4. "Overview of COMPASS Simulation Tasks (SIM Subsystem)," J.G. Stacy, COM-RP-UNH-SIM-038, 18 Feb., 1994.

5. "Revised COMPTEL SIM Mass Model Description," R.M. Kippen, COM-RP-UNH-SIM-047, Second Issue, 25 April 1996.

6. "Effect of Secondary Particles on the PSF," R.M. Kippen, COM-RP-UNH-SIM-046, 25 March 1996.

7. "COMPTEL In-Flight Efficiency Study," C. Kappadath, COM-RP-UNH-SIM-040, 26 September 1994.

8. "COMPTEL Effective Areas," R. Much and W. Collmar, COM-RP-MPE-CAL-056, 11 October 1990.

1 Introduction

As described at the last COMPTEL team meeting (Feb. 1996 @ SRON), all simulation software prior to the release of COMPASS tasks SIMGAM16 and SIMENE12 used 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 study (see reference 1) has shown that significant numbers of telescope events are ignored by the combination of both approximations. New versions of the COMPASS simulation tasks (SIMGAMv.16 and SIMENEv.12) have been created which remove these approximations.

It is the purpose of this report to describe the effect of removing approximations 1) and 2) on the simulated ***telescope*** response. The effect on other processing modes will be described in later reports. Note that the removal of these approximations 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 (in principle) makes the simulations more sensitive to the detailed mass distribution of the COMPTEL SIM mass model (particularly around the D1 modules). Improved versions of the simulation mass model have been created (see reference 5). The high-resolution mass model ("HIres") incorporates a more detailed description of the COMPTEL mass distribution than has been used previously, while the low-resolution ("LOres") model is similar to the previous standard mass model. Dependence of the telescope response on mass model complexity will be investigated by comparing results obtained with the HIres and LOres models.

2 Data and Analysis

To investigate the effect of secondary particles on the telescope response, the COMPASS task SIMGAM16 (Monte Carlo simulation of incident gamma-ray photons using the GEANT3.21 package) was used to simulate monoenergetic gamma-ray point sources. This task tracks all secondary particles, no matter where in the mass model they are created and starts incident photons over a wide beam which illuminates the entire D1 platform (78 cm radius). Six different source configurations were simulated, each with 10,000 raw "QEV" events, as described in the tables below. For "in-flight" simulations, incident photons are propagated parallel to the source direction and empty regions of the instrument model are filled with vacuum. For "calibration" runs, the beam diverges from a nearby source ~8.5 m from D1 and empty regions of the mass model contain air.

Table 3.1. In-flight Simulations: Zenith = 0° (Beam Area = 19113.45 cm^2)

LOres Model (UNH-IDT-1018)			**HIres** Model (UNH-IDT-1020)		
E_{inp}(MeV)	UNH-QEV	UNH-EVP	E_{inp}(MeV)	UNH-QEV	UNH-EVP
0.835	4834	13495	0.835	4869	13534
1.275	4835	13496	1.275	4870	13535
1.800	4836	13497	1.800	4871	13536
2.754	4837	13498	2.754	4872	13537
4.430	4838	13499	4.430	4873	13538
6.130	4839	13500	6.130	4874	13539
8.000	4840	13501	8.000	4875	13540
12.14	4841	13502	12.14	4876	13541
16.57	4842	13503	16.57	4878	13543
20.53	4843	13504	20.53	4879	13544
25.00	4844	13505	25.00	4880	13545
30.00	4845	13506	30.00	4881	13546

Table 3.2. In-flight Simulations: Zenith = 40° (Beam Area = 17148.62 cm^2)

LOres Model (UNH-IDT-1018)			**HIres** Model (UNH-IDT-1020)		
E_{inp}(MeV)	UNH-QEV	UNH-EVP	E_{inp}(MeV)	UNH-QEV	UNH-EVP
0.835	4846	13507	0.835	4886	13551
1.275	4847	13508	1.275	4887	13552
1.800	4848	13509	1.800	4888	13553
2.754	4849	13510	2.754	4889	13554
4.430	4850	13511	4.430	4890	13555
6.130	4851	13512	6.130	4891	13556
8.000	4852	13513	8.000	4892	13557
12.14	4853	13514	12.14	4893	13558
16.57	4854	13515	16.57	4894	13559
20.53	4855	13516	20.53	4895	13560
25.00	4856	13517	25.00	4896	13561
30.00	4857	13518	30.00	4897	13562

Table 3.3. Calibration Simulations: Zenith = 1.14° (Beam Area = 19187.26 cm^2)

LOres Model (UNH-IDT-1017)			**HIres** Model (UNH-IDT-1019)		
E_{inp}(MeV)	UNH-QEV	UNH-EVP	E_{inp}(MeV)	UNH-QEV	UNH-EVP
0.835	4913	13573	0.835	4925	13585
1.275	4914	13574	1.275	4962	13609
1.800	4915	13575	1.800	4963	13610
2.754	4916	13576	2.754	4964	13611
4.430	4917	13577	4.430	4965	13612
6.130	4918	13578	6.130	4966	13613
8.000	4919	13579	8.000	4967	13614
12.14	4920	13580	12.14	4968	13615
16.57	4921	13581	16.57	4969	13616
20.53	4922	13582	20.53	4970	13617
25.00	4923	13583	25.00	4971	13618
30.00	4924	13584	30.00	4972	13619

The raw, unbroadened “QEV” events produced by SIMGAM16 are converted into processed “EVP” events with task SIMFIN10 using the standard instrument status table UNH-ISS-1008. This processing results in events which are broadened by the instrumental energy and event location resolutions and have standard module energy thresholds. In the following sections, simulated EVP datasets listed in tables 3.1–3.3 are compared to previous SIM results described in reference 7, which incorporate approximations (1) and (2).

3 Effective Area Comparison

The effective detection area of each simulated source was computed as follows. The total number of events N_{sel} passing a particular set of data selections is computed using the COMPASS task SIMSRV03. This task is required to properly account for PSD selections, through its use of the IFCPCF library routines (SIM does not directly compute PSD). The effective detection area and its statistical uncertainty are then given by

$$A_{\mathrm{eff}} = A_{\mathrm{beam}}\left(\frac{N_{\mathrm{sel}}}{N_{\mathrm{inp}}}\right) \pm A_{\mathrm{beam}}\left(\frac{\sqrt{N_{\mathrm{sel}}}}{N_{\mathrm{inp}}}\right) \qquad , \tag{1}$$

where N_{inp} is the number of photons in the incident beam and A_{beam} is the incident beam area normal to the source direction. The following sets of data selections were used for comparisons with previous SIM results.

- "Standard Selections"

```
TOF: 115-130   D1E:  70-20000
PSD:   0-110   D2E: 650-30000
PHI:   4-50
```

- "No Selections"

```
TOF:  95-200   D1E:  70-20000
PSD:   0-255   D2E: 650-30000
PHI:   0-180
```

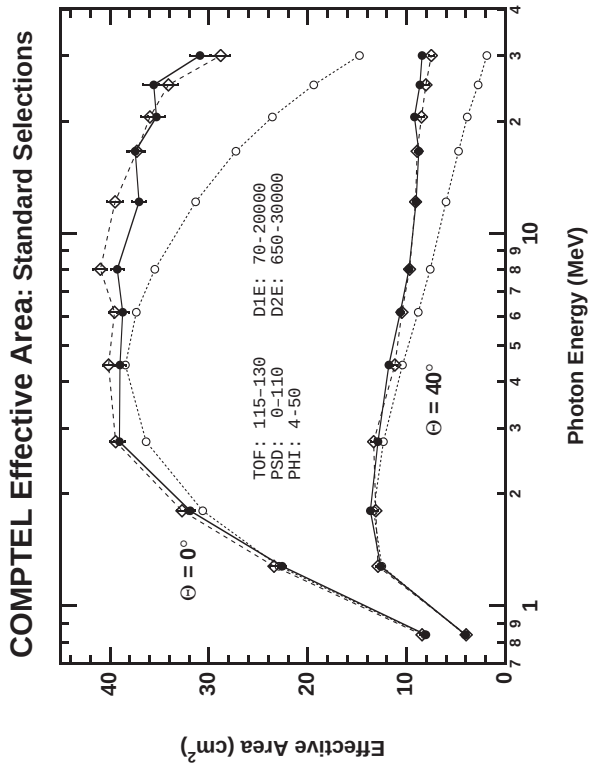
- "±10° ARM Selection"

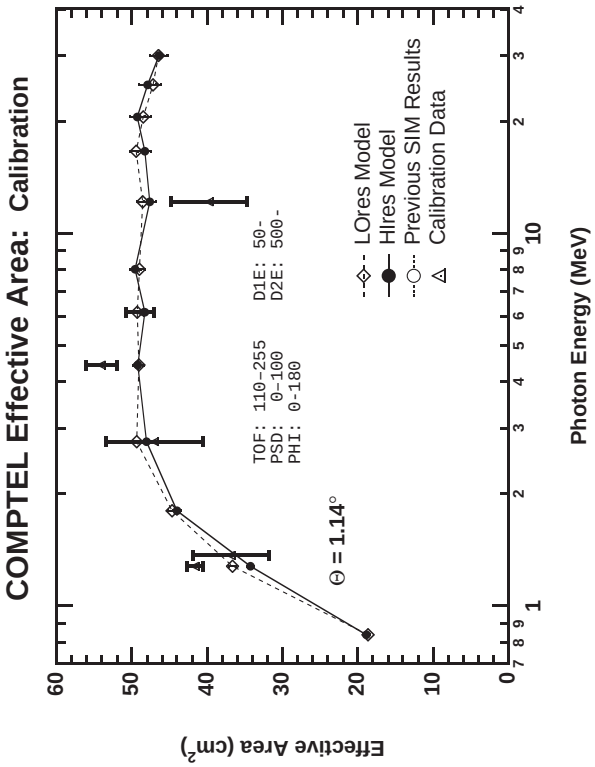
```
TOF:  95-200   D1E:  70-20000
PSD:   0-255   D2E: 650-30000
PHI:   0-180   ARM: ±10
```

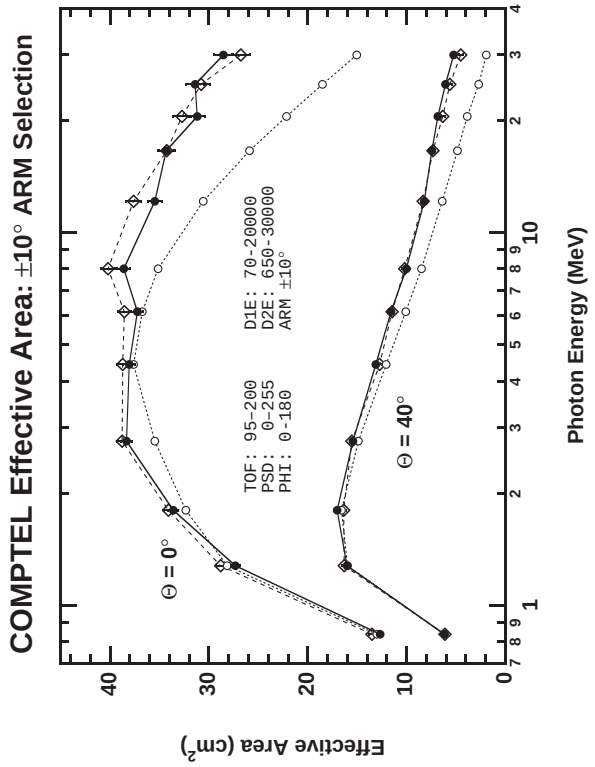
- "Calibration Selections"

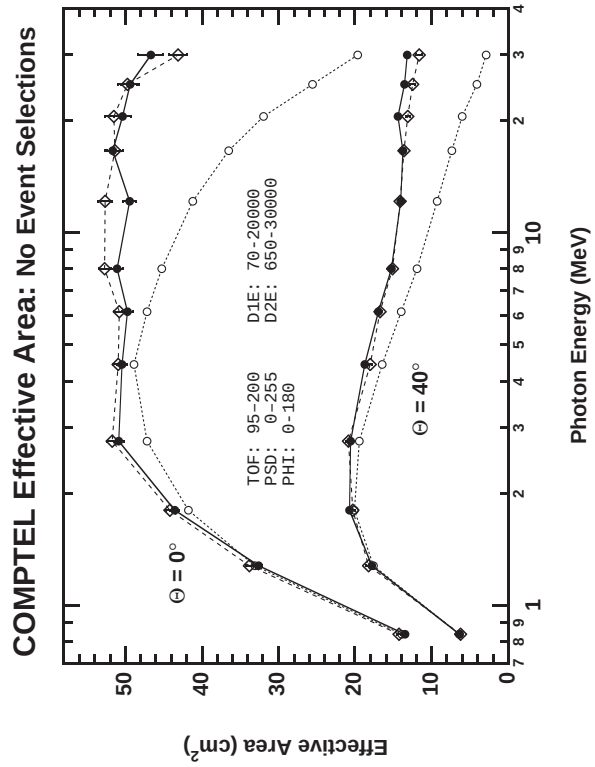
```
TOF: 110-255   D1E:  50-90000
PSD:   0-100   D2E: 500-90000
PHI:   0-180
```

The following figures compare the integrated effective areas for the different source configurations with previous SIM results and calibration results. Note that the previous SIM results incorporate 3x more events in each source than the new simulations, there is thus more statistical scatter in the new results. Note also that the effective areas from calibration data (see reference 8) do not account for the potential events which originate in a low energy deposit tail. The calibration data points are thus underestimated, especially at energies above 10 MeV.


COMPTEL Effective Area: Standard Selections
Θ = 0°
TOF: 115-130
PSD: 0-110
PHI: 4-50
D1E: 70-20000
D2E: 650-30000
Θ = 40°
Effective Area (cm²)
Photon Energy (MeV)

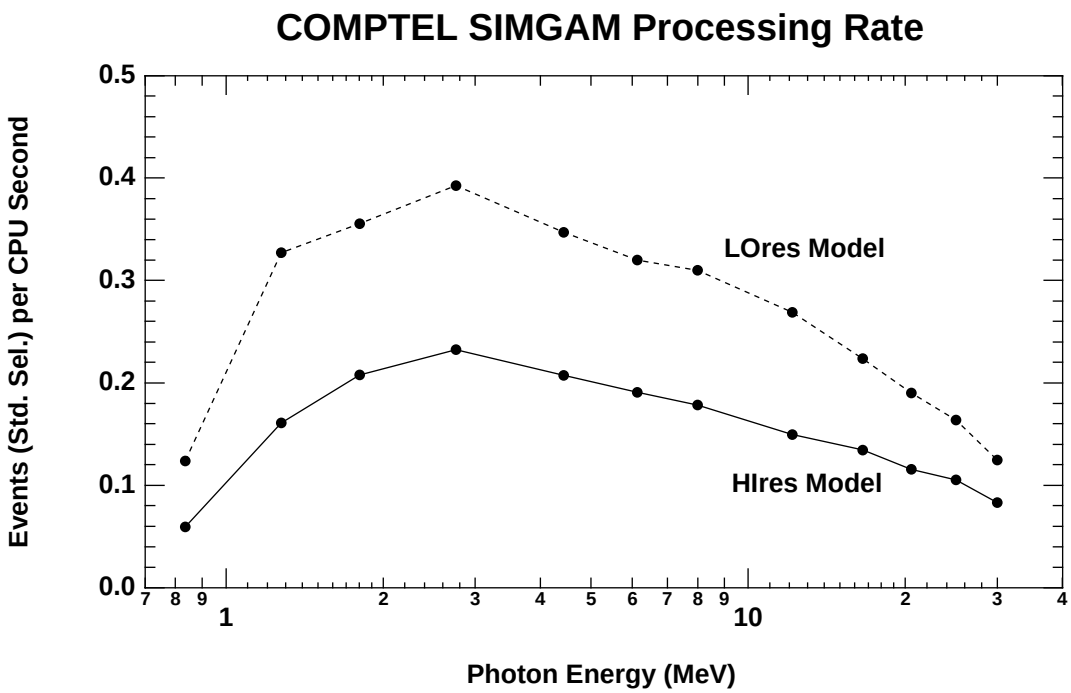

COMPTEL Effective Area: Calibration
Θ = 1.14°
TOF: 110-255
PSD: 0-100
PHI: 0-180
D1E: 50-
D2E: 500-
LOres Model
HIres Model
Previous SIM Results
Calibration Data
Effective Area (cm²)
Photon Energy (MeV)


COMPTEL Effective Area: ±10° ARM Selection
Θ = 0°
TOF: 95-200
PSD: 0-255
PHI: 0-180
D1E: 70-20000
D2E: 650-30000
ARM ±10°
Θ = 40°
Effective Area (cm²)
Photon Energy (MeV)

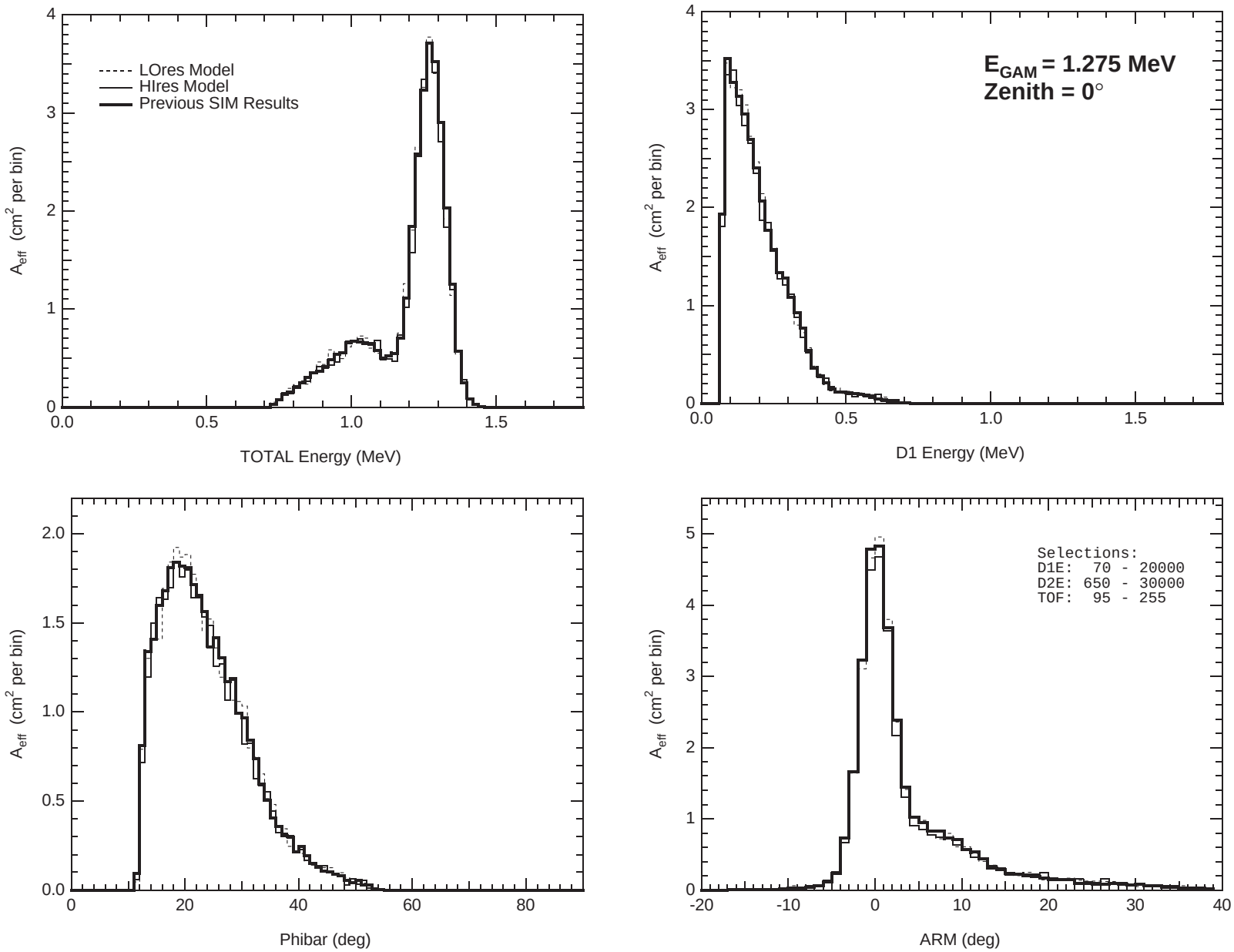

COMPTEL Effective Area: No Event Selections
Θ = 0°
TOF: 95-200
PSD: 0-255
PHI: 0-180
D1E: 70-20000
D2E: 650-30000
Θ = 40°
Effective Area (cm²)
Photon Energy (MeV)

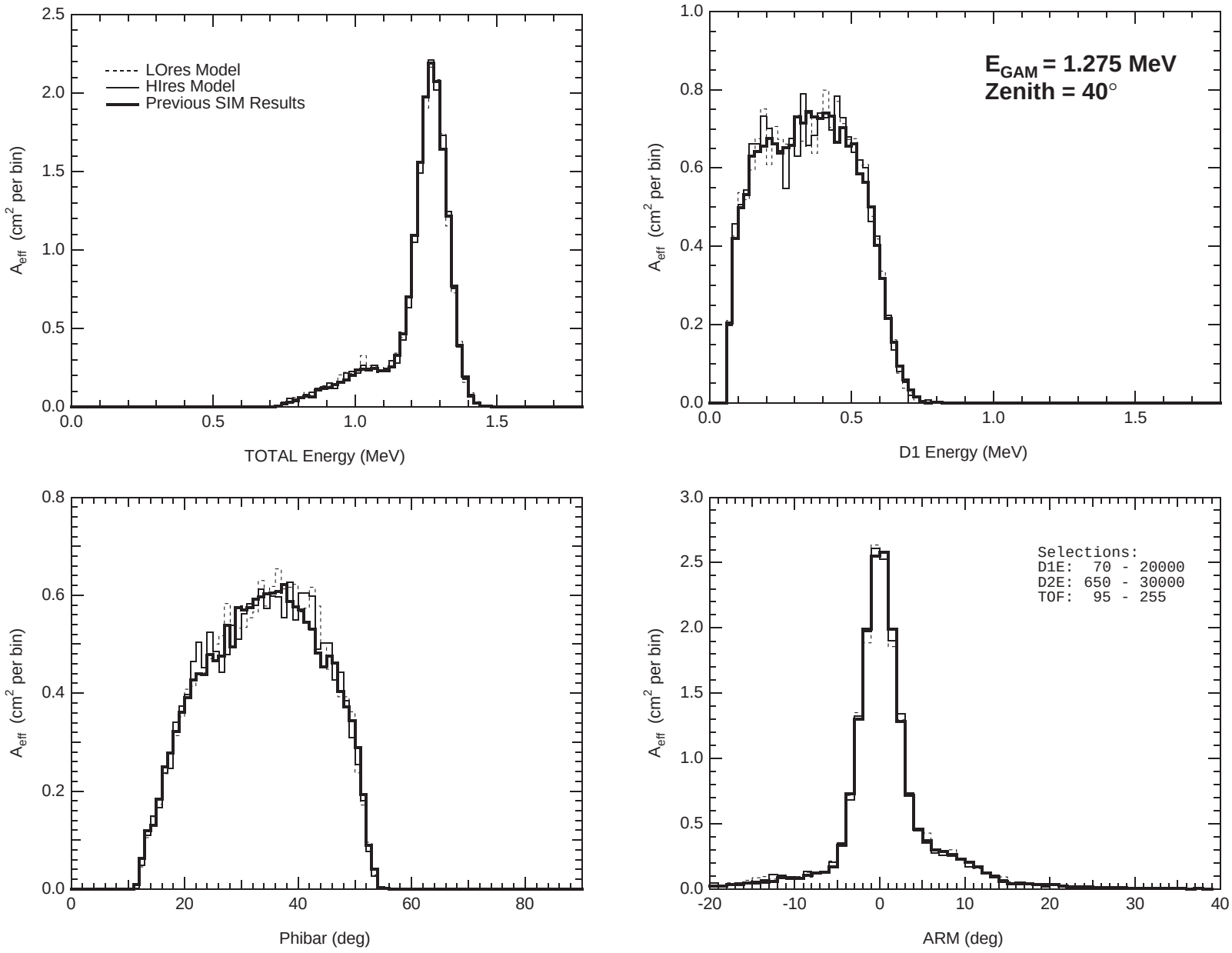
4 Detailed Comparison

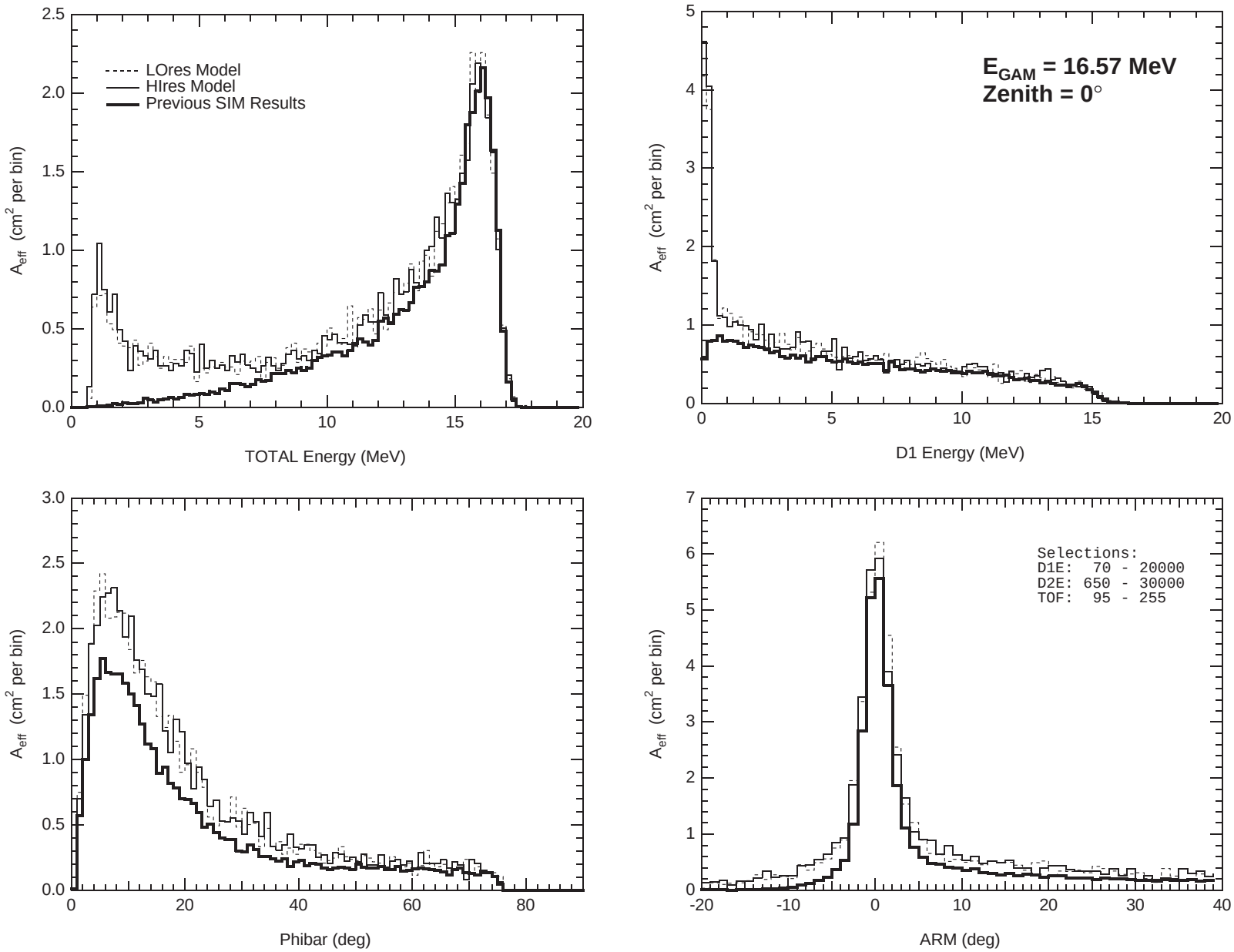
The following figure shows the difference in performance between the HIres and LOres mass models with SIMGAM16 as a function of photon energy for in-flight sources at normal incidence. Plotted are the number of events (satisfying standard selections) generated per CPU second on the main UNH Sun computer. Use of the HIres model degrades computing performance by roughly a factor of two.

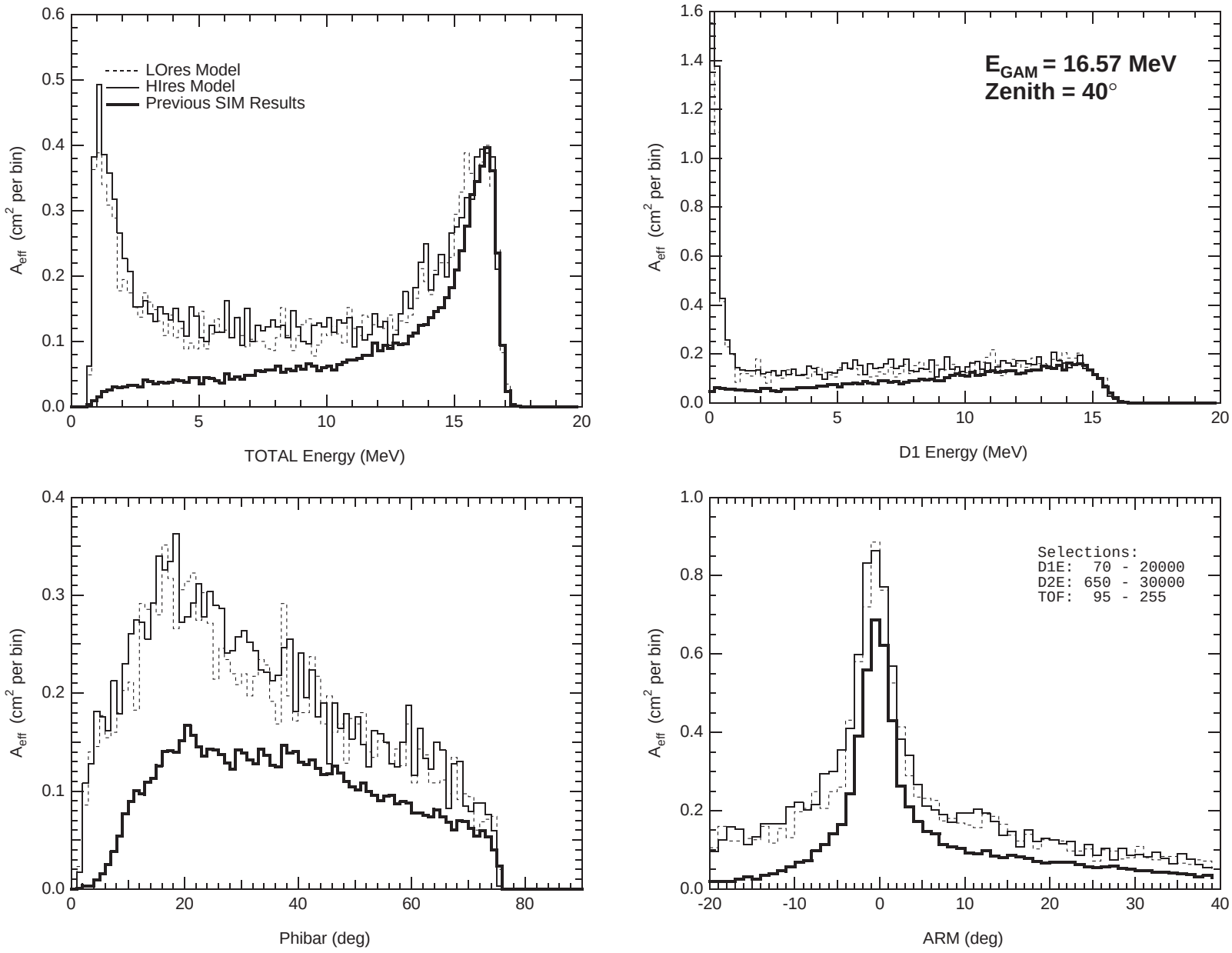


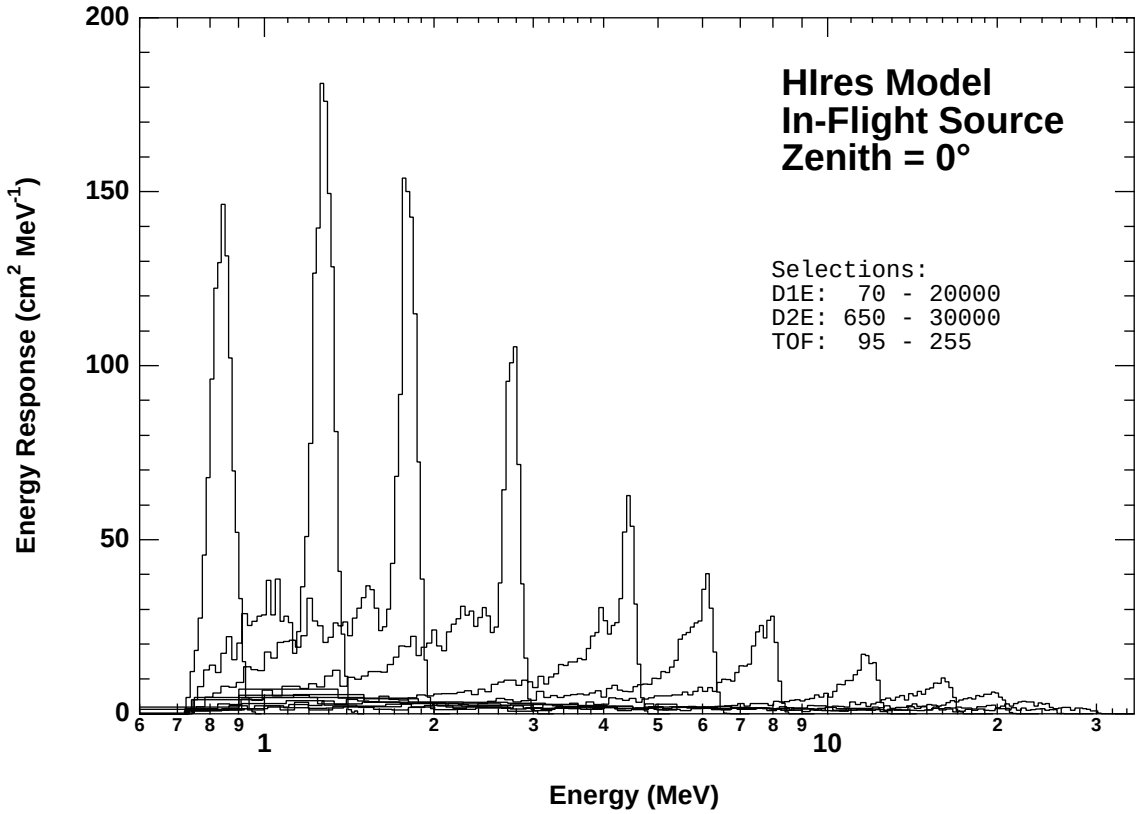
The following figures show total energy deposit, D1 energy deposit, phibar and ARM spectra from in-flight simulations at 1.275 and 16.57 MeV. Results from the LOres and HIres models using SIMGAM16 are compared to the previous simulations described in reference 7. Energy spectra from the HIres model simulations are compared in detail in the final figure of this section. To generate this figure, energy spectra from the individual simulations have been normalized as in Eq. 1 to show the relative response at different energies.

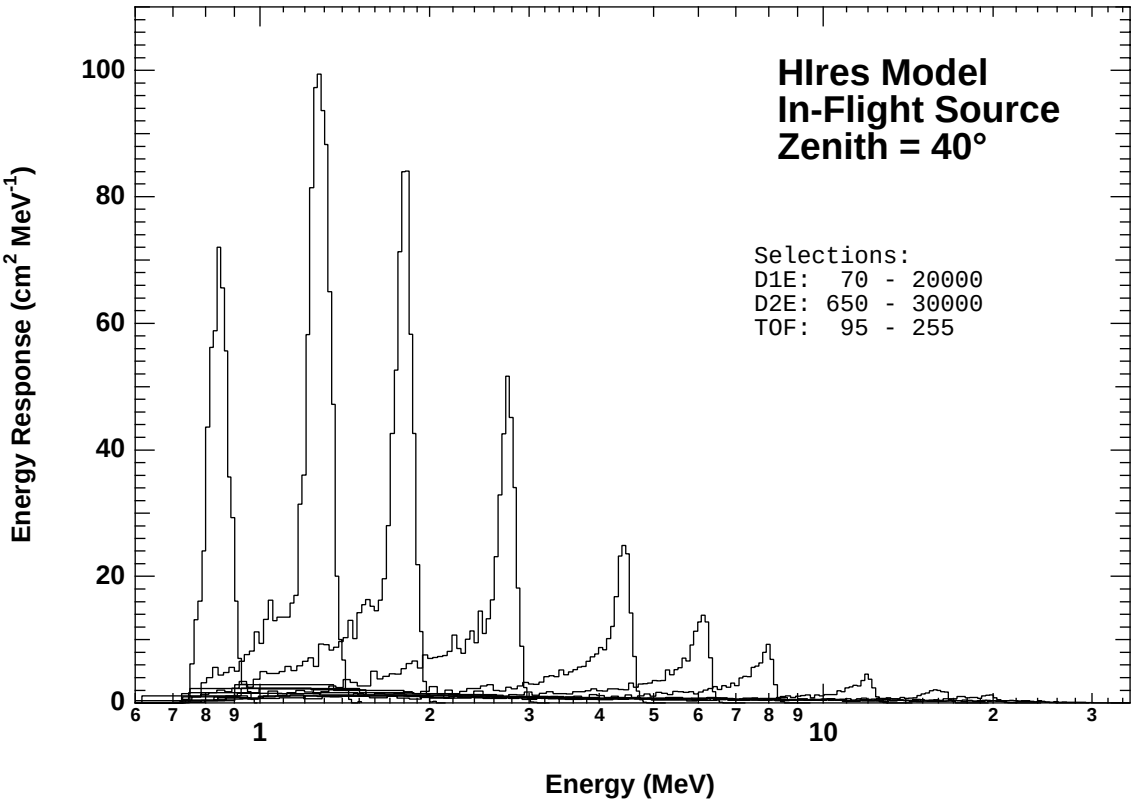

LOres Model
HIres Model
Previous SIM Results
A_{eff} (cm^2 per bin)
TOTAL Energy (MeV)
E_{GAM} = 1.275 MeV
Zenith = 0°
D1 Energy (MeV)
Phibar (deg)
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
ARM (deg)


LOres Model
HIres Model
Previous SIM Results
A_{eff} (cm^2 per bin)
TOTAL Energy (MeV)
E_{GAM} = 1.275 MeV
Zenith = 40°
D1 Energy (MeV)
Phibar (deg)
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
ARM (deg)


LOres Model
HIres Model
Previous SIM Results
A_{eff} (cm^2 per bin)
TOTAL Energy (MeV)
E_{GAM} = 16.57 MeV
Zenith = 0°
D1 Energy (MeV)
Phibar (deg)
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
ARM (deg)


LOres Model
HIres Model
Previous SIM Results
A_{eff} (cm^2 per bin)
TOTAL Energy (MeV)
E_{GAM} = 16.57 MeV
Zenith = 40°
D1 Energy (MeV)
Phibar (deg)
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
ARM (deg)


HIres Model
In-Flight Source
Zenith = 0°
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
Energy Response (cm^2 MeV^{-1})
Energy (MeV)


HIres Model
In-Flight Source
Zenith = 40°
Selections:
D1E: 70 - 20000
D2E: 650 - 30000
TOF: 95 - 255
Energy Response (cm^2 MeV^{-1})
Energy (MeV)

5 Conclusions

Telescope events resulting from the interactions of secondary particles produced outside the D1/D2 detector modules clearly contribute to a low-energy tail which was not present in previous simulations. As expected, the new secondary-induced events contribute most for incident photon energies > 10 MeV (where pair production is probable) and at large zenith angles (where more passive material is traversed). For example, the plots of section 4 show little, if any, contribution of secondary particles at 1.275 MeV, whereas secondary-induced events dominate the response at 16.57 MeV. The most evident features of the new events are a low-energy tail in the total energy spectrum and a pronounced peak around 0.5 MeV in the D1 energy spectrum (presumably due to pair production in the material around D1).

There is no significant difference in the telescope response between the HIres and LOres mass models. Given the poor computing performance caused by the HIres model, the LOres model should become the preferred default for most telescope mode simulations. The HIres model may be useful in cases where the mass distribution plays a more important role (e.g., ^{24}Na cascade mode, burst mode, cosmic diffuse mode, etc.).

An earlier report (see Ref. 6) described the effect of secondary-induced events on the point-spread-function using an earlier mass model (UNH-IDT-1011, which is very similar to the LOres model). The results of that study are still valid given that there is no significant difference in the telescope response between the LOres and HIres models. That is, that secondary induced events effect the PSF mainly at energies > 10 MeV for sources at large zenith angles.