AEROSPACE REPORT NO.
TOR-2016-03260

# Updated Geant4 Simulations of AeroCube 6 Microdosimeters

September 30, 2016

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Prepared for:

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Contract No. FA8802-14-C-0001

Authorized by: Systems Planning, Engineering, and Quality



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## Abstract

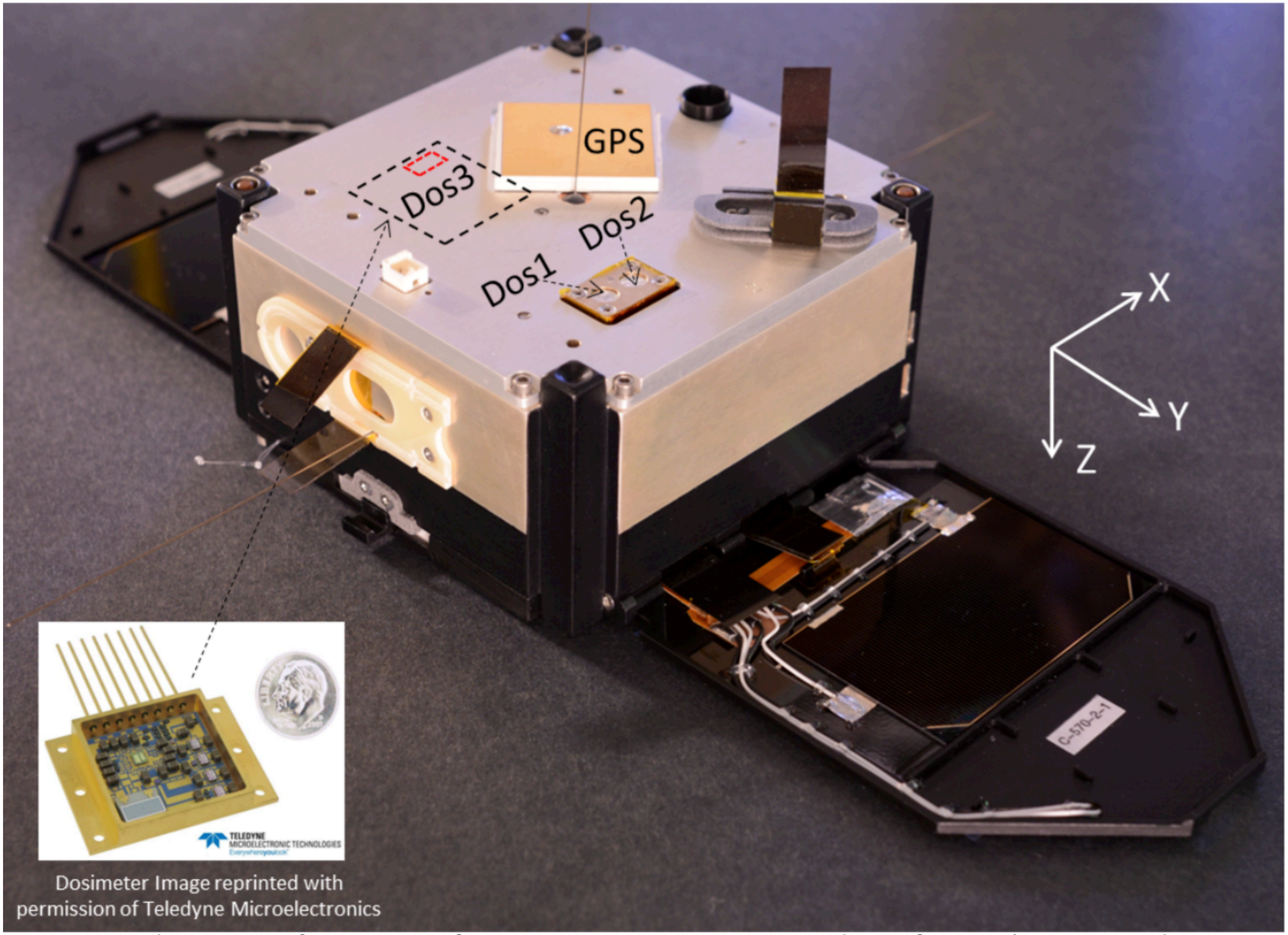
This is an update of the work documented in TOR-2014-01907, "Geant4 Simulations of the AeroCube-6 Satellite." At the time when those simulations were performed using the Geant4 open-source Monte Carlo radiation transport code, the design of the dual, low-energy microdosimeter had not been finalized, so I simulated the response only of the Teledyne microdosimeter also on board and modeled the low-energy microdosimeter housing only as inert shielding. I also tabulated the dose that would be absorbed by bare silicon mounted at any position on either face of the four circuit boards, as a worst-case scenario for parts mounted on those boards given the radiation environment in a notional low Earth orbit.

In the present work, I focus on the microdosimeters as flown, tabulating their response to monoenergetic, isotropically incident electrons and protons; these response functions can be convolved with measured or modeled spectra to determine dose rates. This work is intended as a supplement to TOR-2016-01155, "AeroCube-6 Dosimeter Data README (v3.0)," by O'Brien, Blake, and Gangestad, and simulation result files have been provided to T. Paul O'Brien for use in calculation of response functions, spectral inversions, etc., as for other spaceflight sensors on which we have worked together.

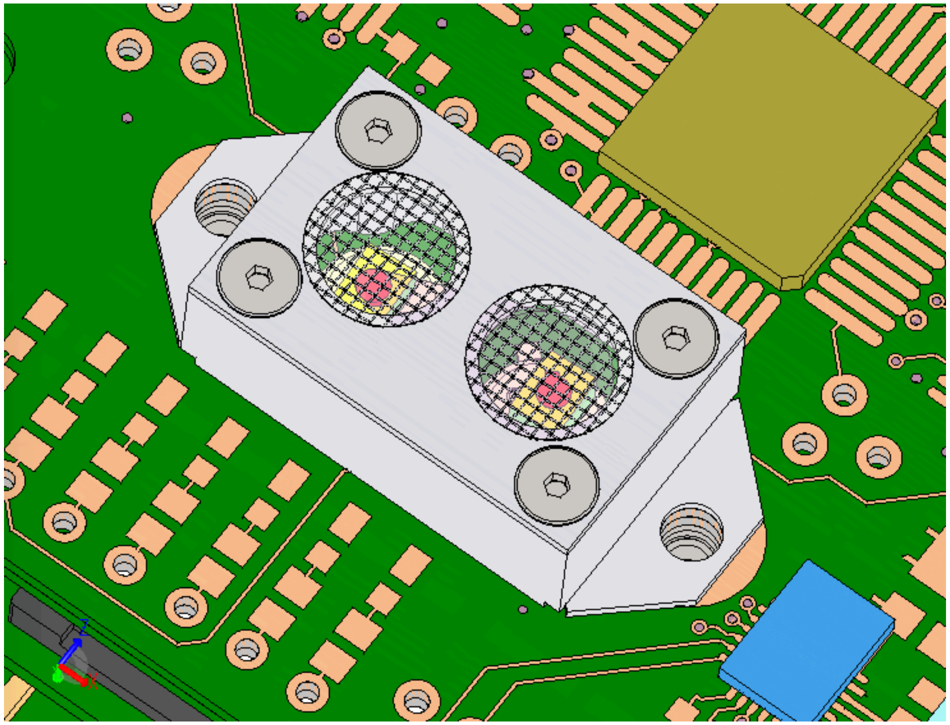
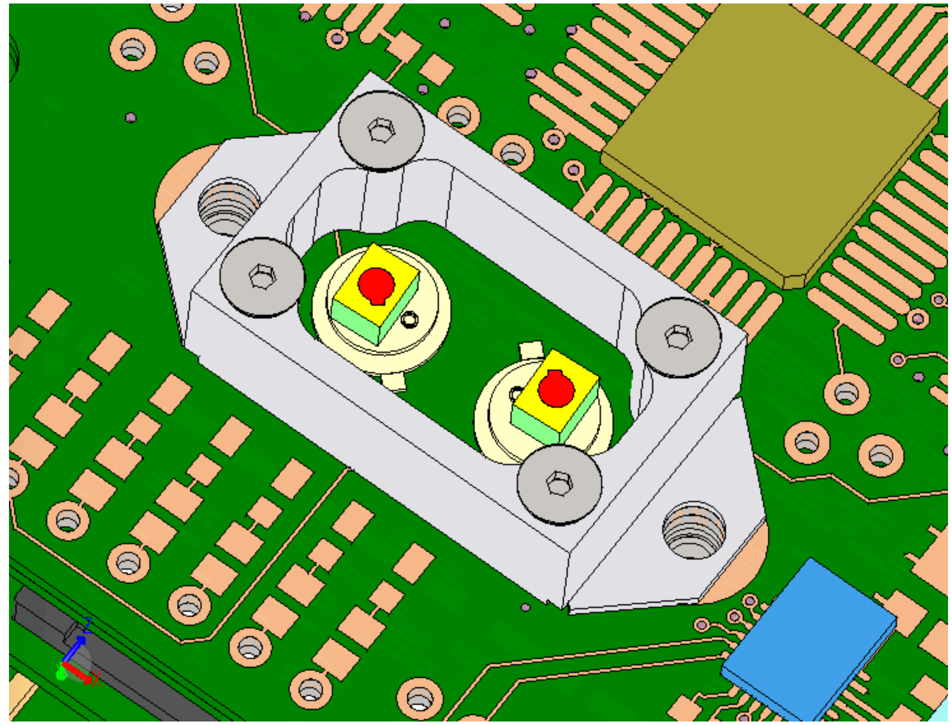
# Updated Geant4 Simulations of AeroCube 6 Microdosimeters

Mark Looper

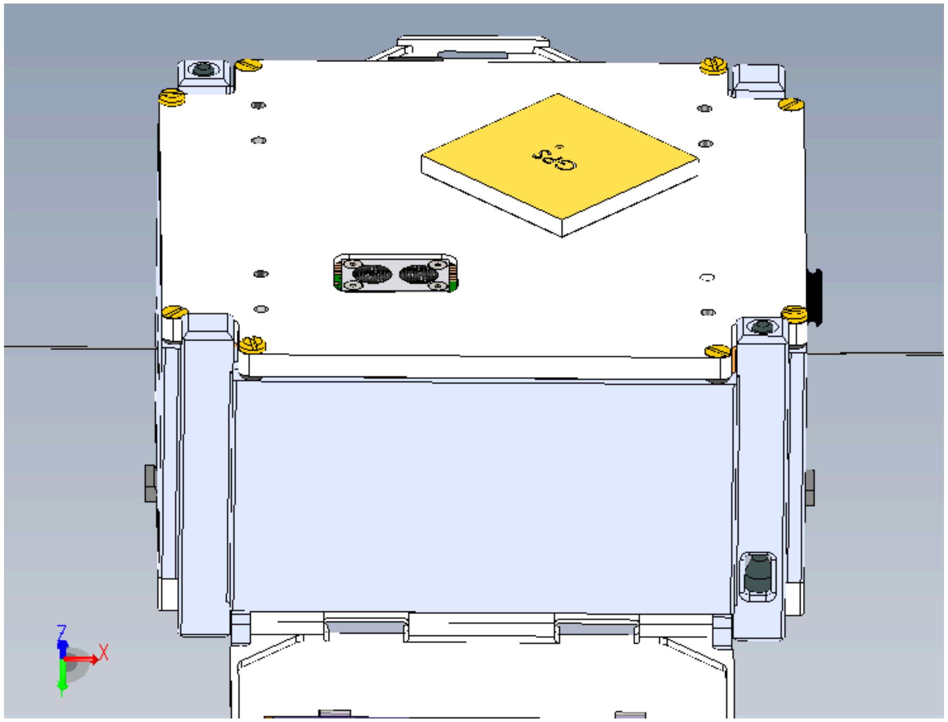
June 22, 2016

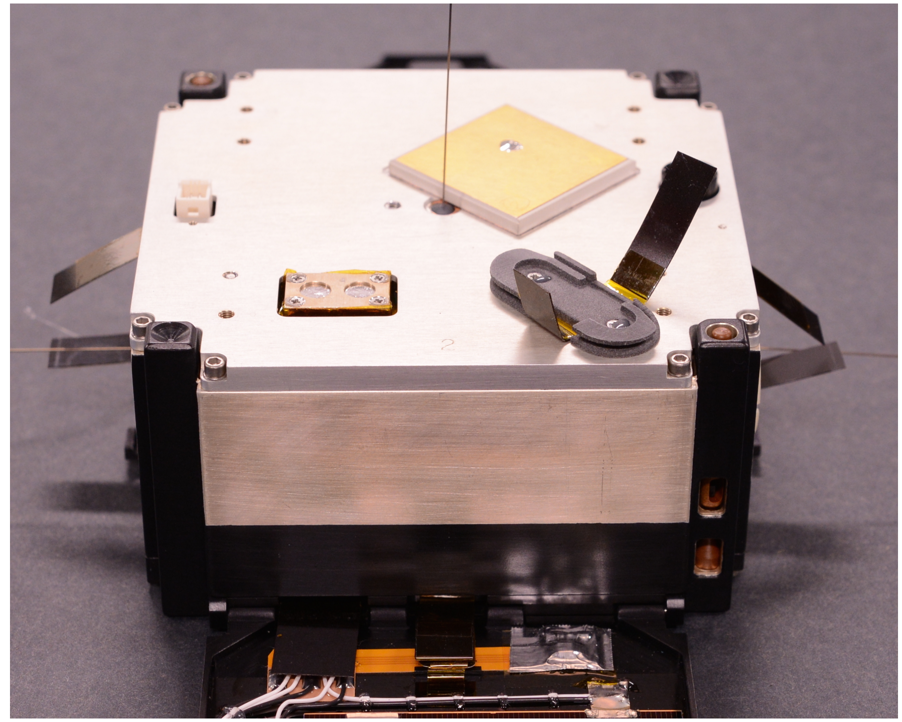



This is a reproduction of Figure 3 from TOR-2016-01155, identifying the microdosimeters. Dos1 and Dos2 are silicon detectors 1.8 mm in diameter and 60 μ thick, shielded by 1.8 μ of aluminum foil; Dos3 is a silicon chip 3 mm x 7 mm x 250 μ under a 10-mil Kovar lid, possibly thinned to 4 mils over the chip, and an Al top panel thinned to 20 mils above the package.

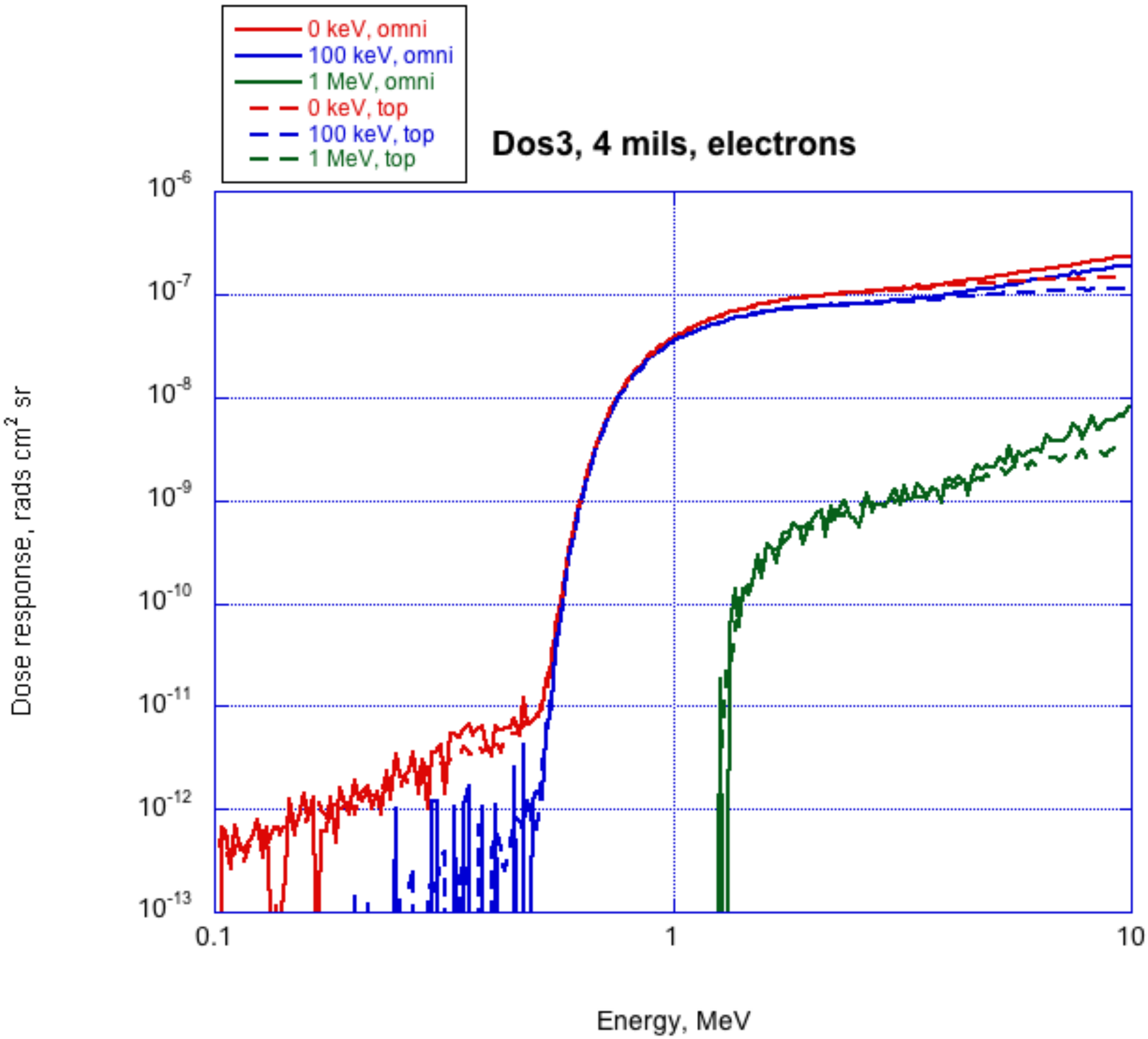
 

Above are screenshots of the Dos1/Dos2 assembly, with and without its lid, from the CAD file used to build the geometry in this work. (The CAD drawing had a fine screen atop each aperture through the lid, but, as is visible in the photograph on the previous slide, the actual configuration had the 1.8-$\mu$ foil under the holes in the lid.) The red circles here are the silicon detectors, mounted on alumina pedestals atop TO can bases. Note that there is no divider inside the housing between the two detectors; this means that each detector can "view" out through the aperture above the other detector as well as through its own. This results in a spike in off-axis response at energies low enough that the particles cannot penetrate the 20-mil Al lid of the housing away from the apertures, at about 60° from the detector/aperture boresight (as is most visible in the last two slides below).

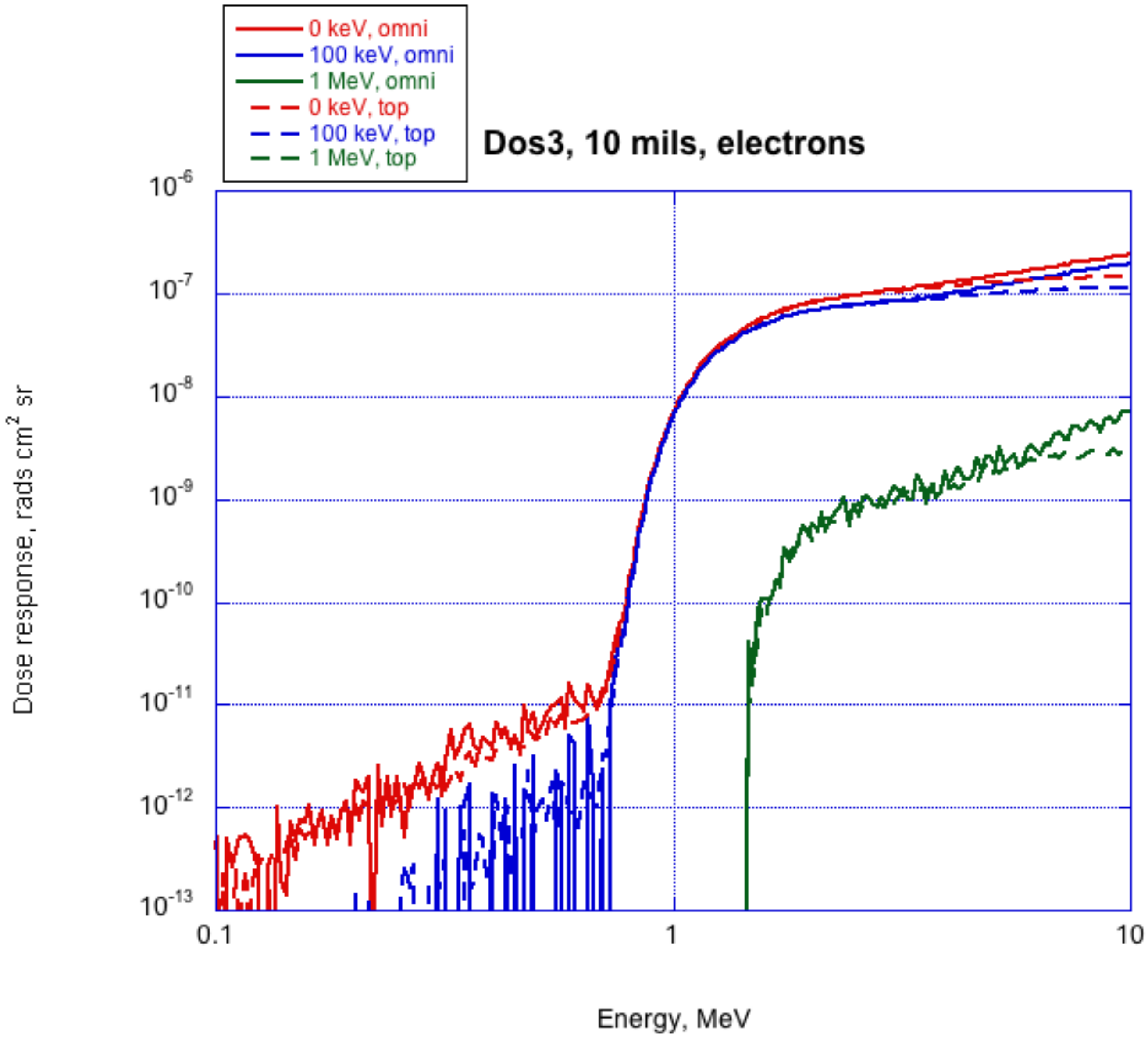




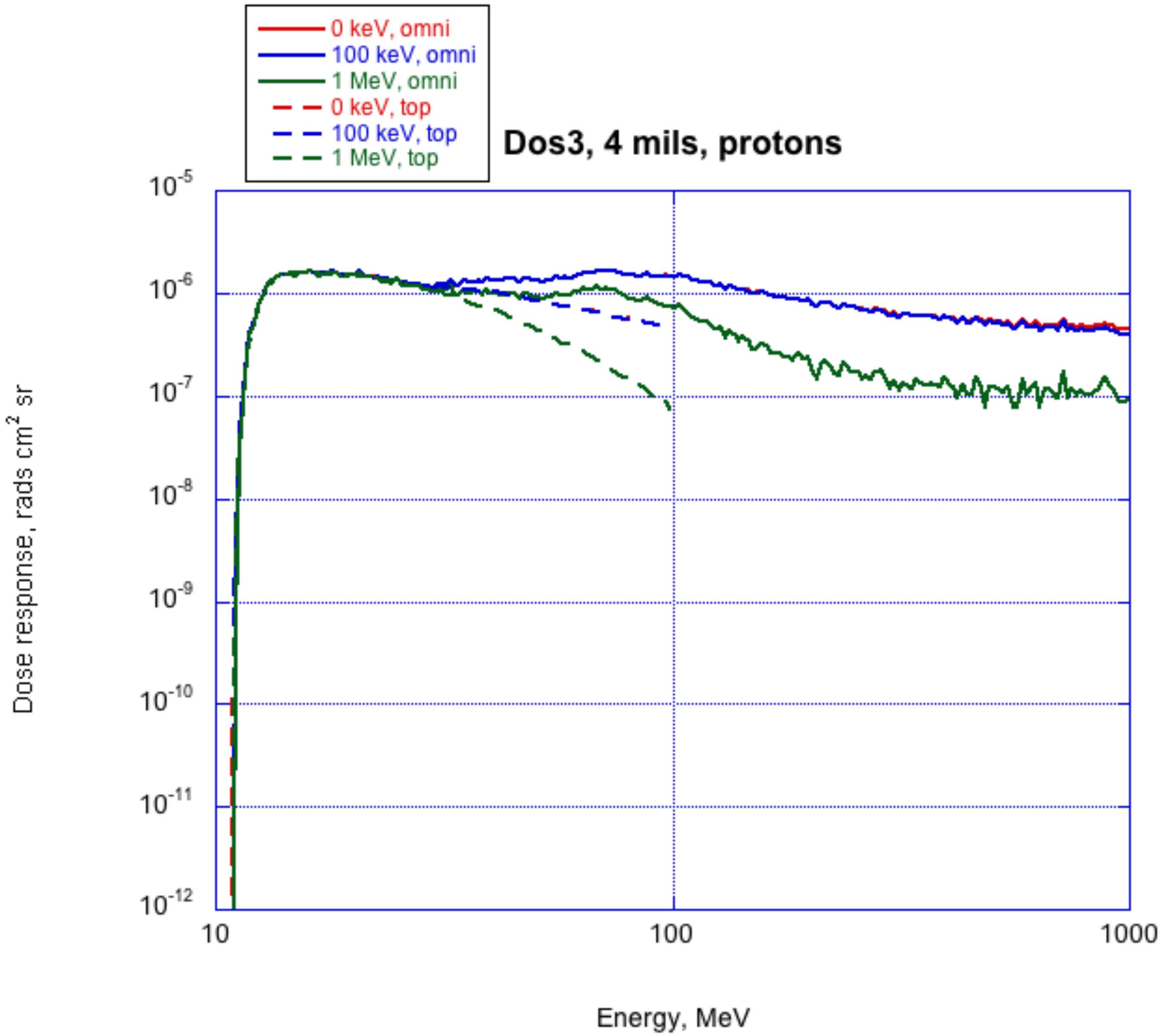
To simulate the response of the microdosimeters aboard the AeroCube 6 satellites, I began with the Geant4 geometry I had constructed two or three years ago from a preliminary eDrawing, “AC6A 4Jun2013.EASM.” The current eDrawing file, which in particular updates the design for the Dos1/Dos2 duo, is “AC6A w Dosimeter Board 19April2016.EASM”; a screenshot is at left above, with a photograph of a flight unit at right. Note that there is a gap between the main body and the top plate in the eDrawing, which causes the low-energy microdosimeter housing to be slightly recessed; in the photo there is no gap, so the housing protrudes slightly. I omitted the gap in the new Geant4 model to match the photo. Other changes from the earlier model include the updated microdosimeter design and the correct location of its aperture in the lid, and thinning of the lid to 20 mils above the Teledyne microdosimeter (I simply missed that last time). The rest of the model is the same (see TOR).



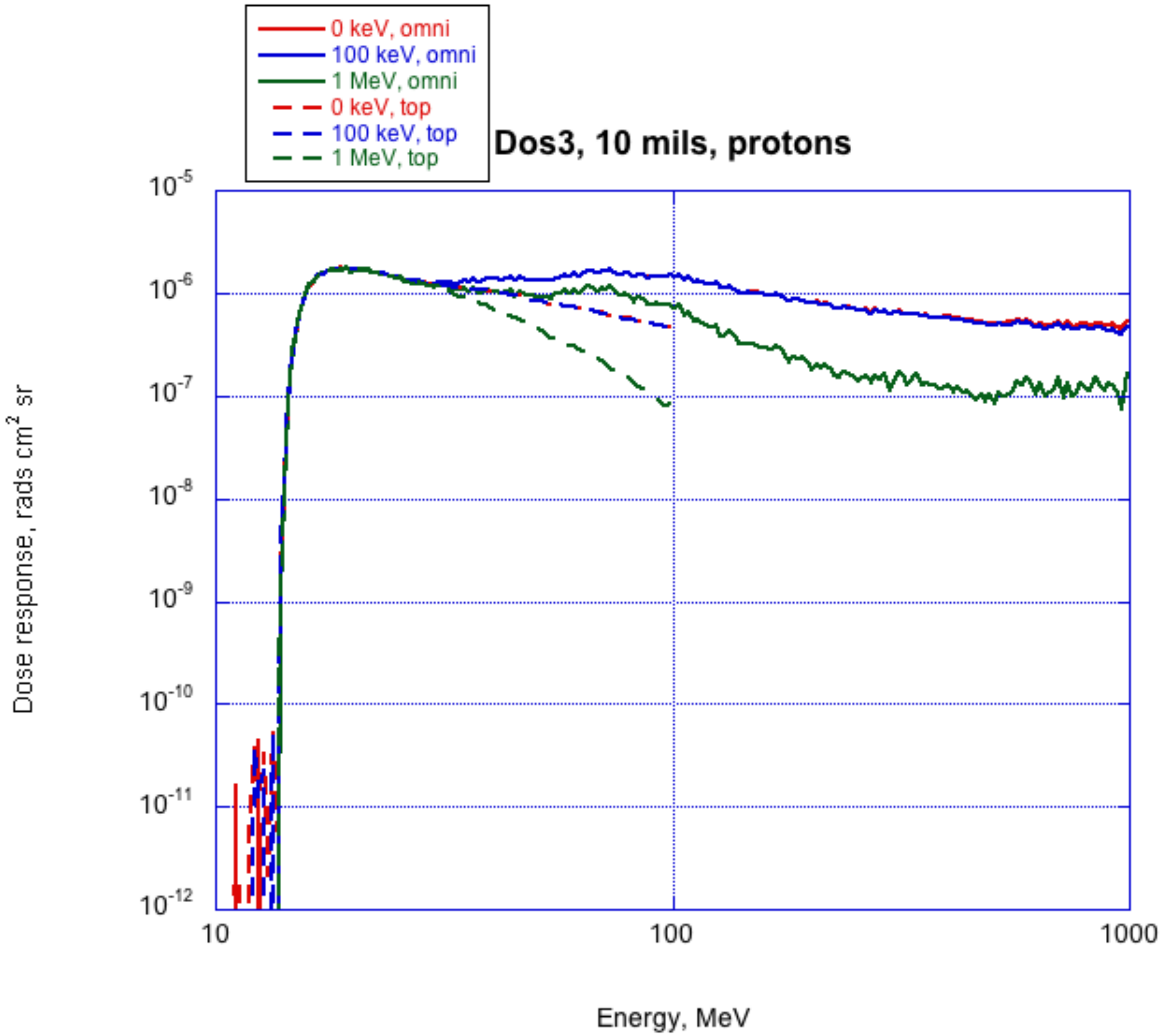

To capture all penetrating response, I illuminated the whole satellite with omnidirectional protons and electrons; I also illuminated just a circle around each microdosimeter on the top to boost statistics at lower (non-penetrating) energies. Since configurations were not completely clear to me, I modeled the Teledyne microdosimeter (Dos3) both with the 10-mil Kovar lid milled to 4 mil above the detector chip, and without; this is with the thinning.



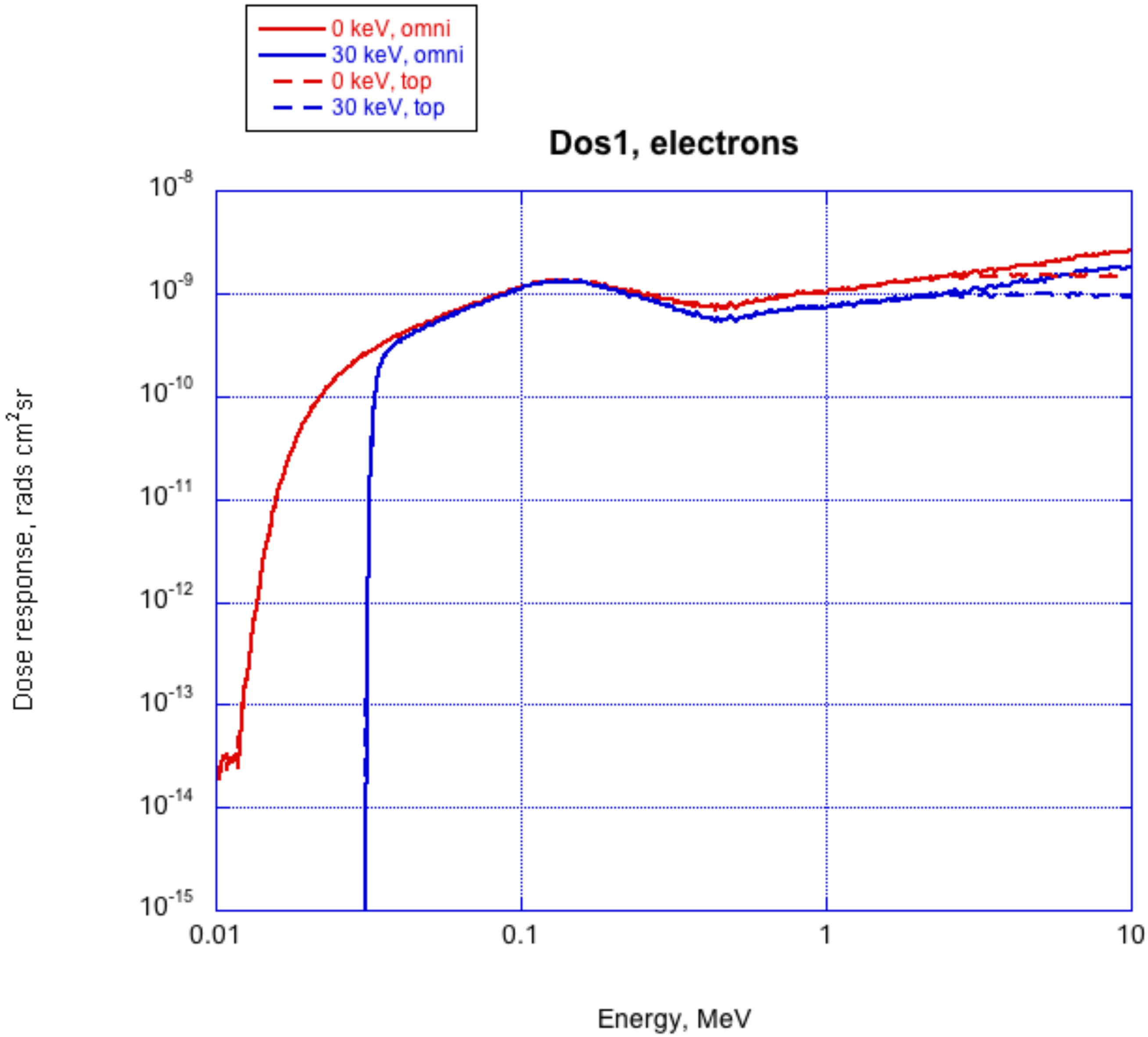

Here is the response of Dos3 without the thinned window. Here and in other Dos3 plots, I show the response with no threshold (all dose counted), and with a threshold of 100 keV or 1 MeV per event. The value plotted is the response in dose per unit fluence; multiply by fluence in particles per (cm$^2$ sr) to get dose in rads (or integrate over energy for a spectrum), or by flux in particles per (cm$^2$ sr s) to get dose rate in rads per second.



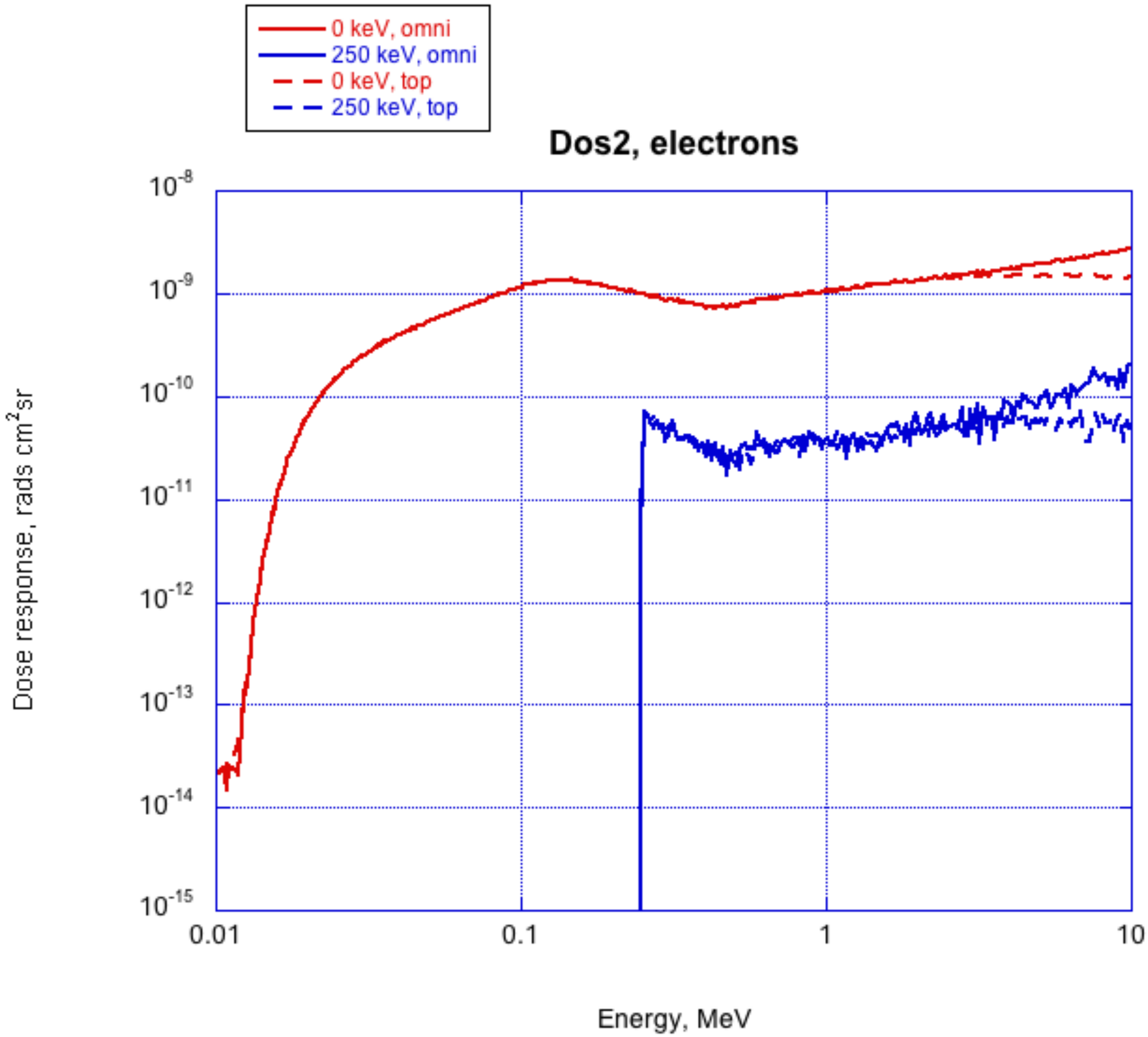

Here is the Dos3 response to protons, with thinned window. I simulated electrons of 10 keV to 10 MeV for both ”omni” and “top” illuminations; for protons I simulated 1 MeV to 1 GeV for “omni,” but because I realized I had the Dos1/2 foil too thick initially (1.8 mils, rather than 1.8 µm!) and 1 MeV was not low enough when I looked at the “omni” results after fixing the thickness, I simulated 100 keV to 100 MeV for “top” illumination.



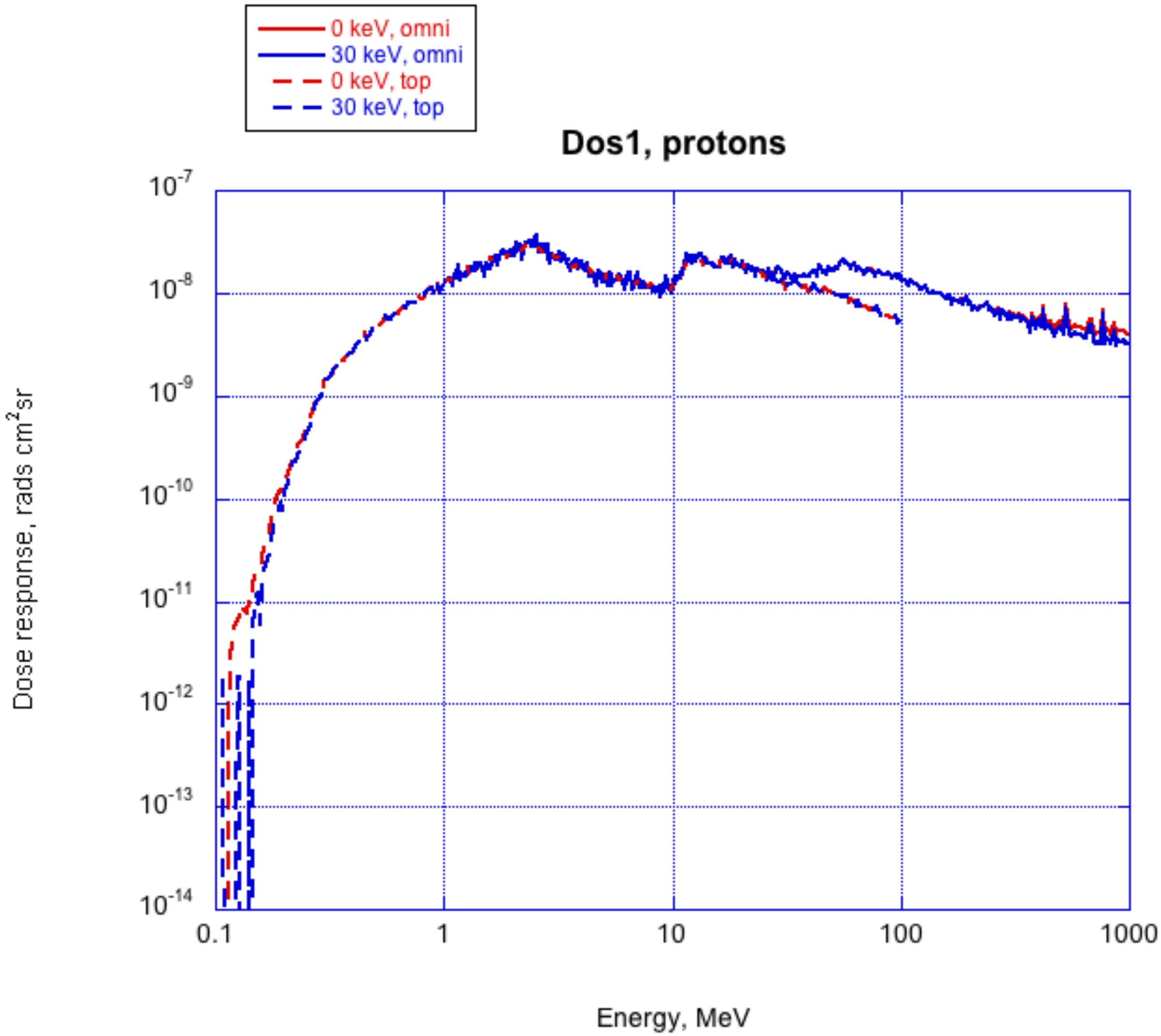

Here is the Dos3 response to protons without the thinned window. In all these plots, the dashed lines indicate the results of simulations with particles incident only in a circle right above the microdosimeter; each dashed line diverges from its solid line where we start to see response to penetration through the spacecraft away from each microdosimeter. Later in this report, I present plots of response vs. angle, which makes this more clear.



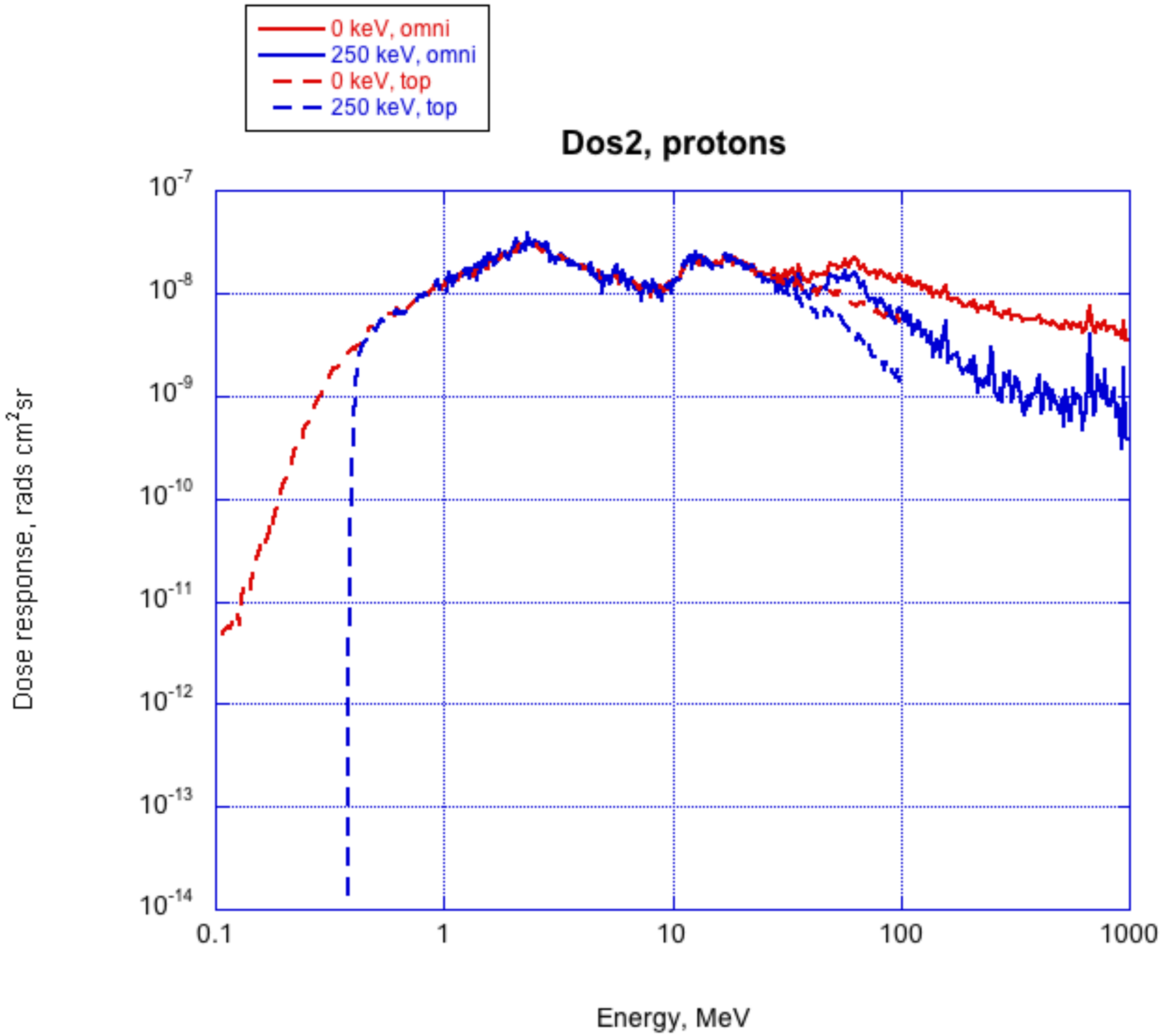

The configuration of the low-energy microdosimeters was a bit more clear to me; both are physically identical, but Dos1 has an electronic threshold of 30 keV and Dos2 has 250 keV. This plot shows the electron response of Dos1, both counting all dose (zero threshold) and after applying the 30-keV threshold.



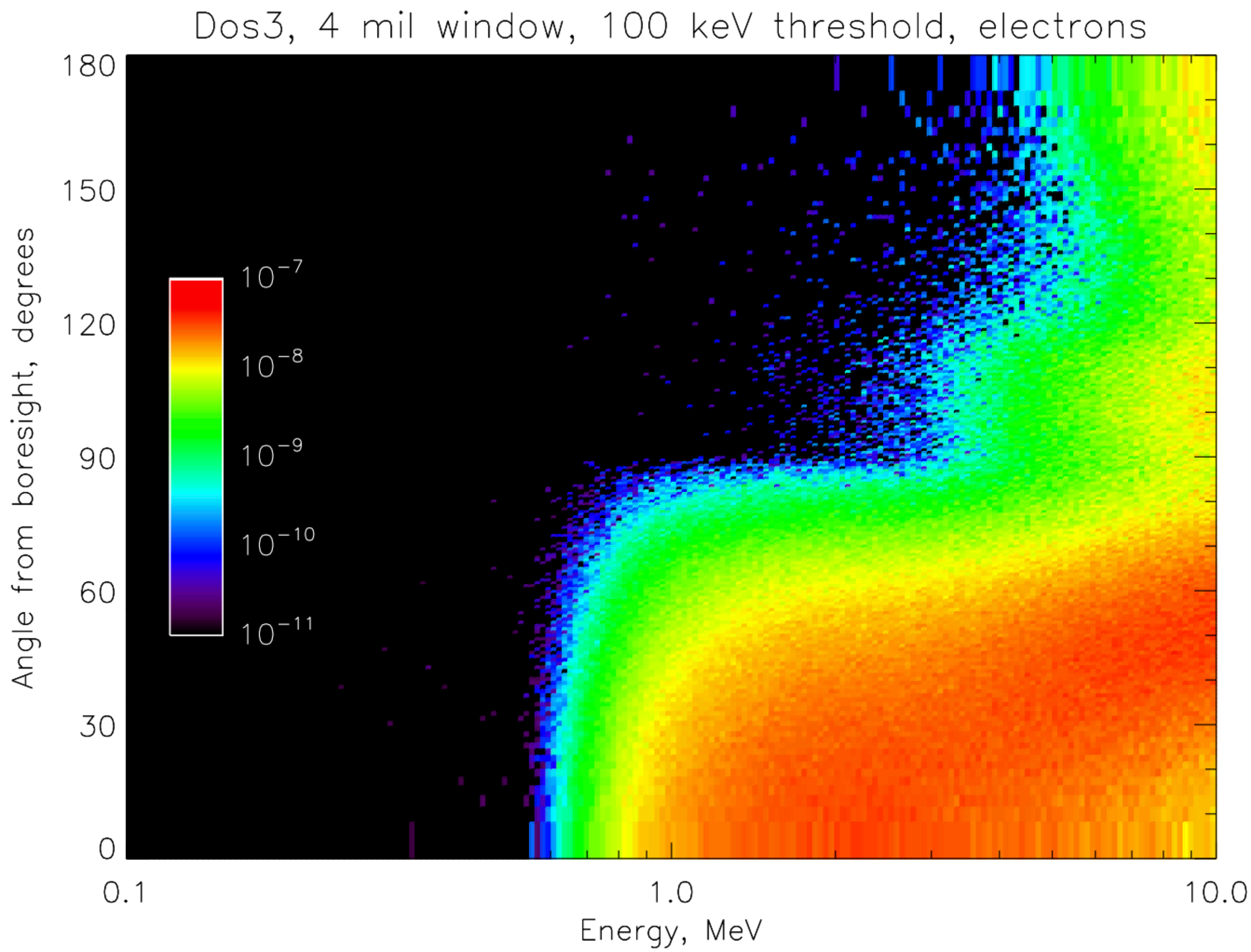

Here is the response of Dos2 to electrons. The higher threshold, like the 1-MeV threshold in the Teledyne microdosimeter (slides 5 and 6) suppresses response to most electron particle events.



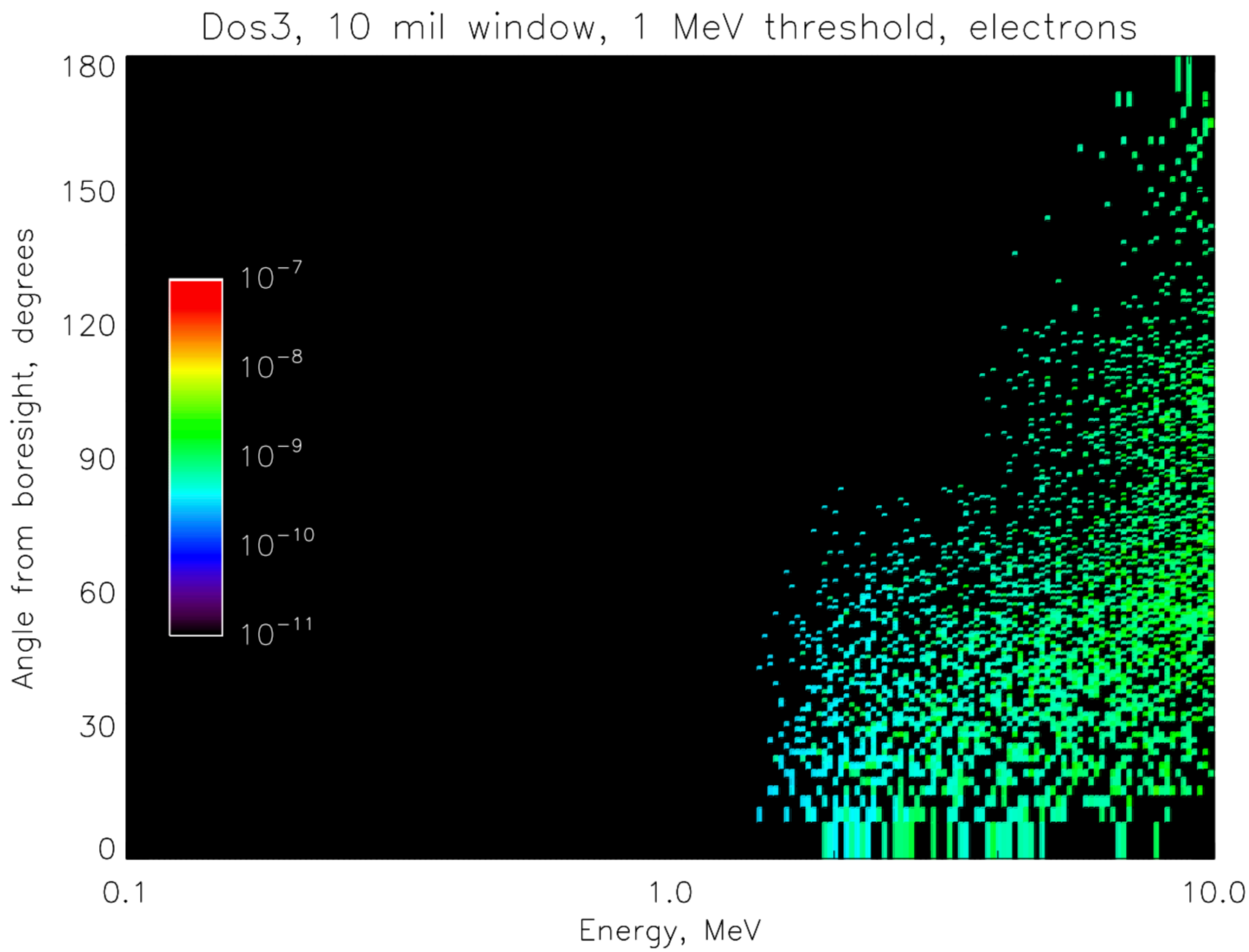

Dos1, with its low threshold, counts nearly all the dose from any proton that can get through the foil or housing to reach its detector.



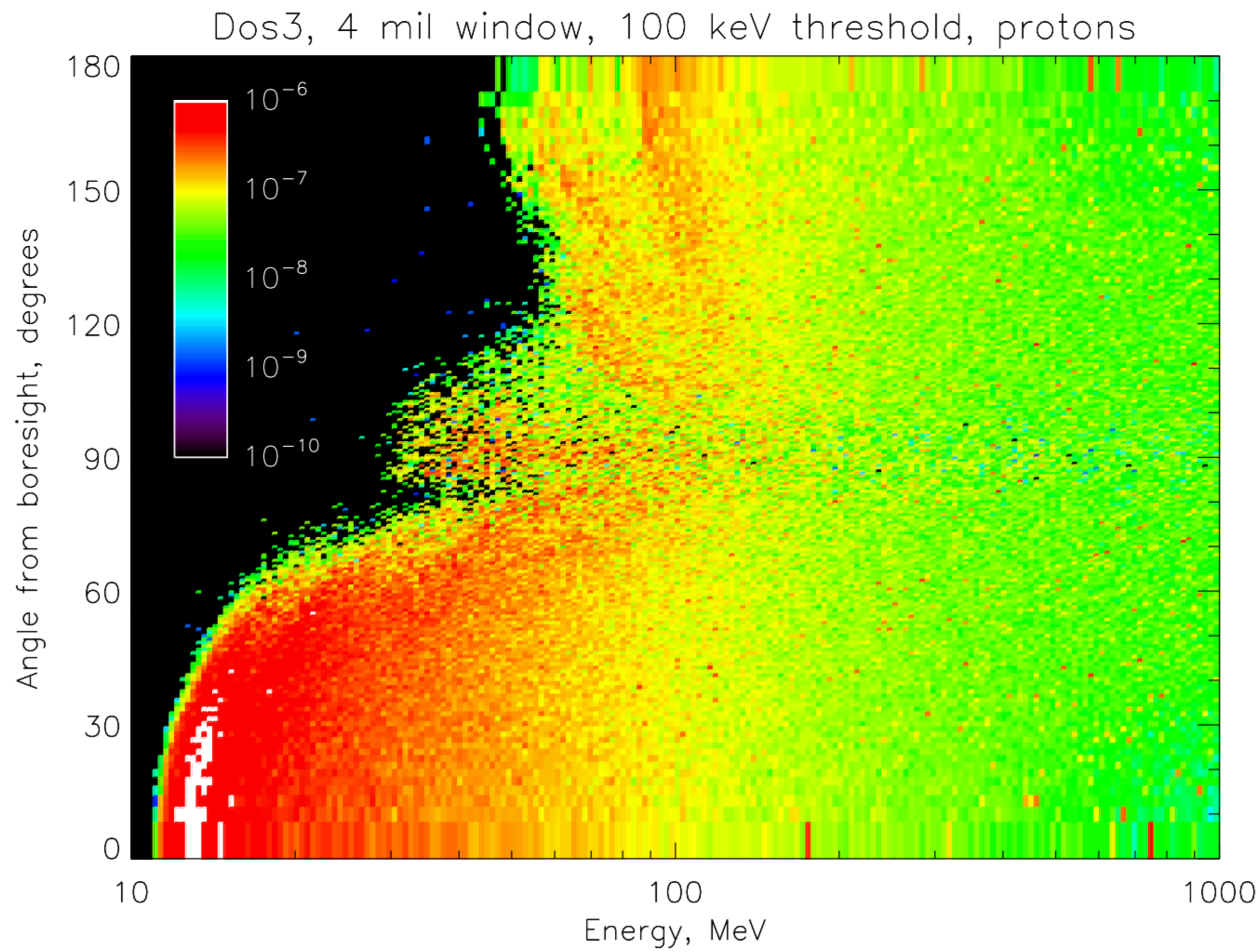

Finally, here is the proton response of Dos2.  The 250-keV electronic threshold imposes a sharp turn-on to its response, but most dose is counted from any event until energies reach high enough values that dE/dx drops considerably.



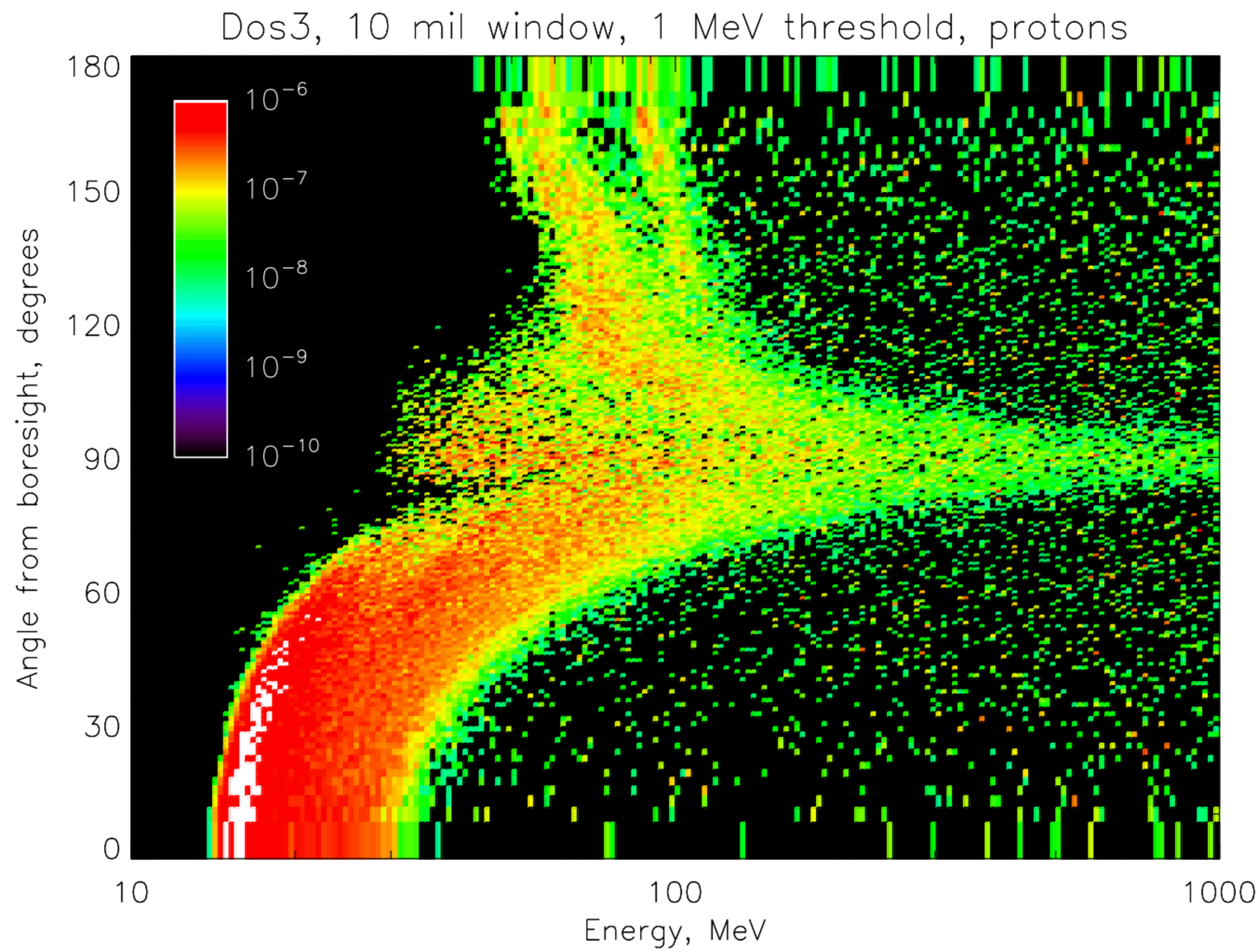

The simulation output included 3D position and momentum information for the incident particles, as well as their energies and the energy deposited in detectors. This is a plot of the response vs. angle off the detector centerline; it does not show the rectangular shape of the acceptance "cone" (or the directions of the dual "cones" of Dos1/2), but gives some idea of the extent. This is for electrons into Dos3, with thin window and low threshold; the thick window simply shifts the main response a bit to the right, leaving the penetrating response (past 90°) the same.



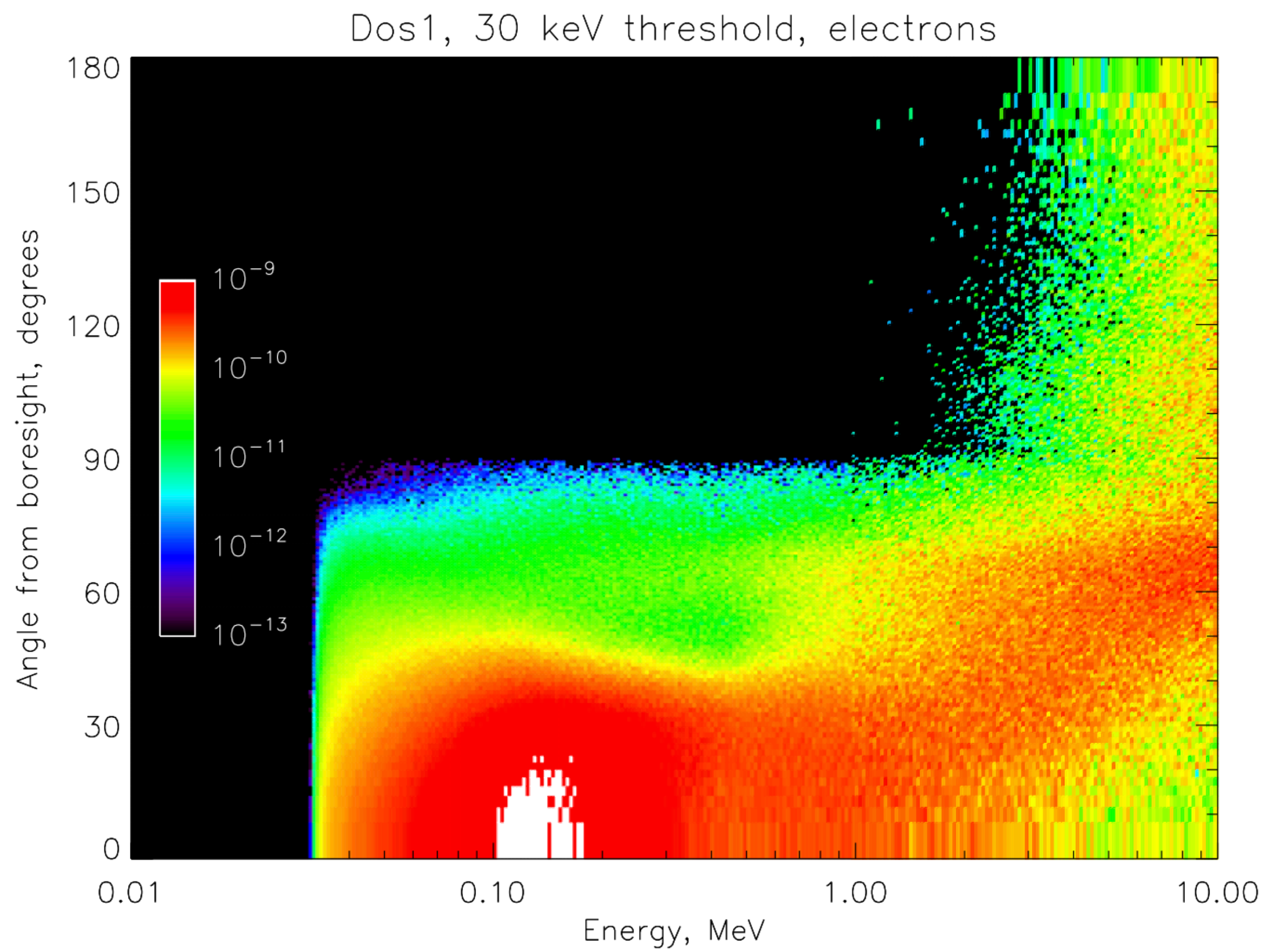

The high threshold, as is clear from slides 5 and 6, greatly suppresses the response. Units on logarithmic colorscale are dose response to particles from the given direction, in rads per (particle per cm$^2$) or just rads cm$^2$ (integrate d$\Omega$ to get the curves in slides 5-12).



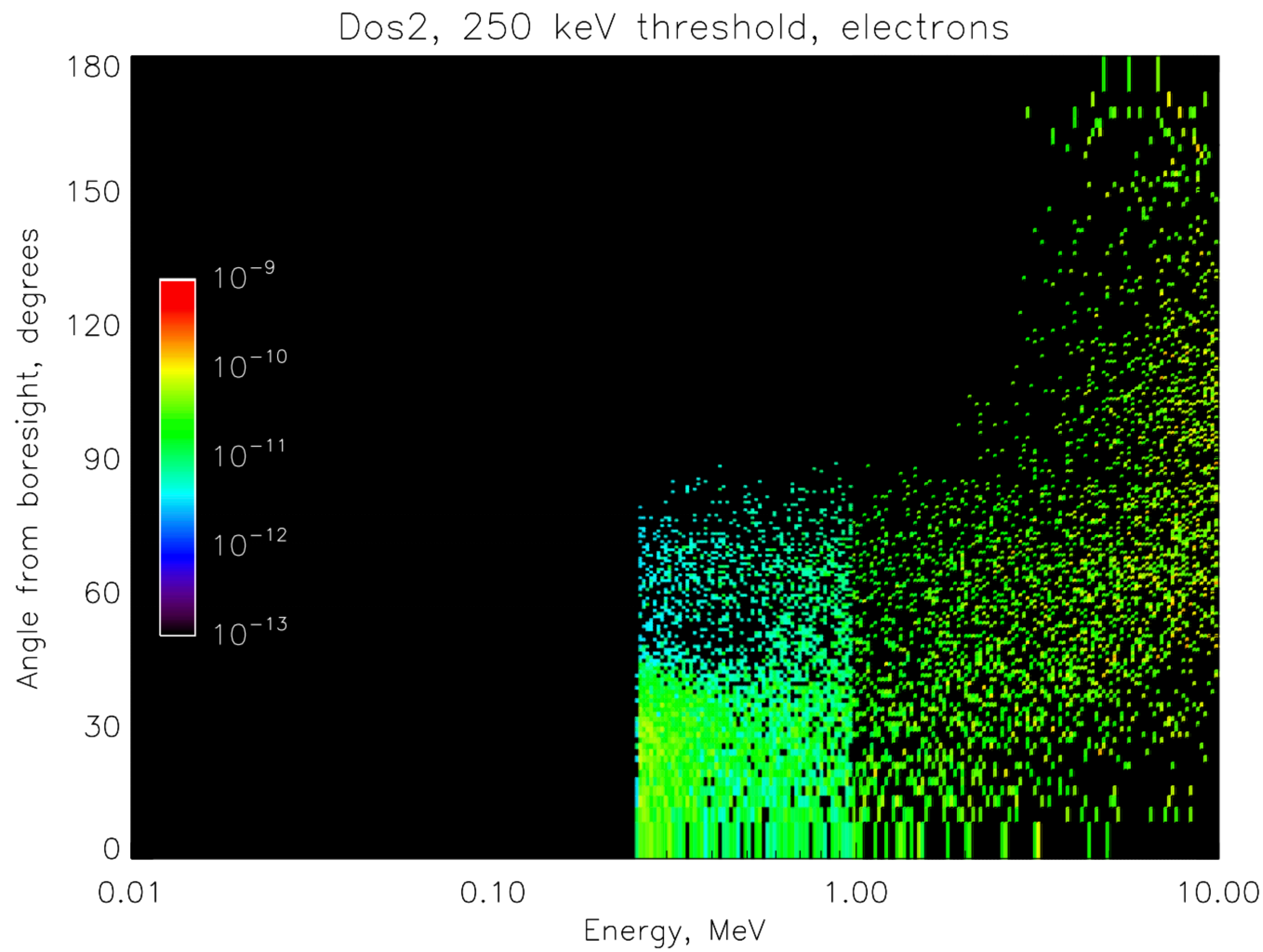

Dos3 proton response with the 100-keV threshold shows a pattern similar to but sharper than that for the electrons on slide 13. This is for the thin window; again, the thick window just shifts the threshold of the main response to the right, leaving the penetrating response the same.



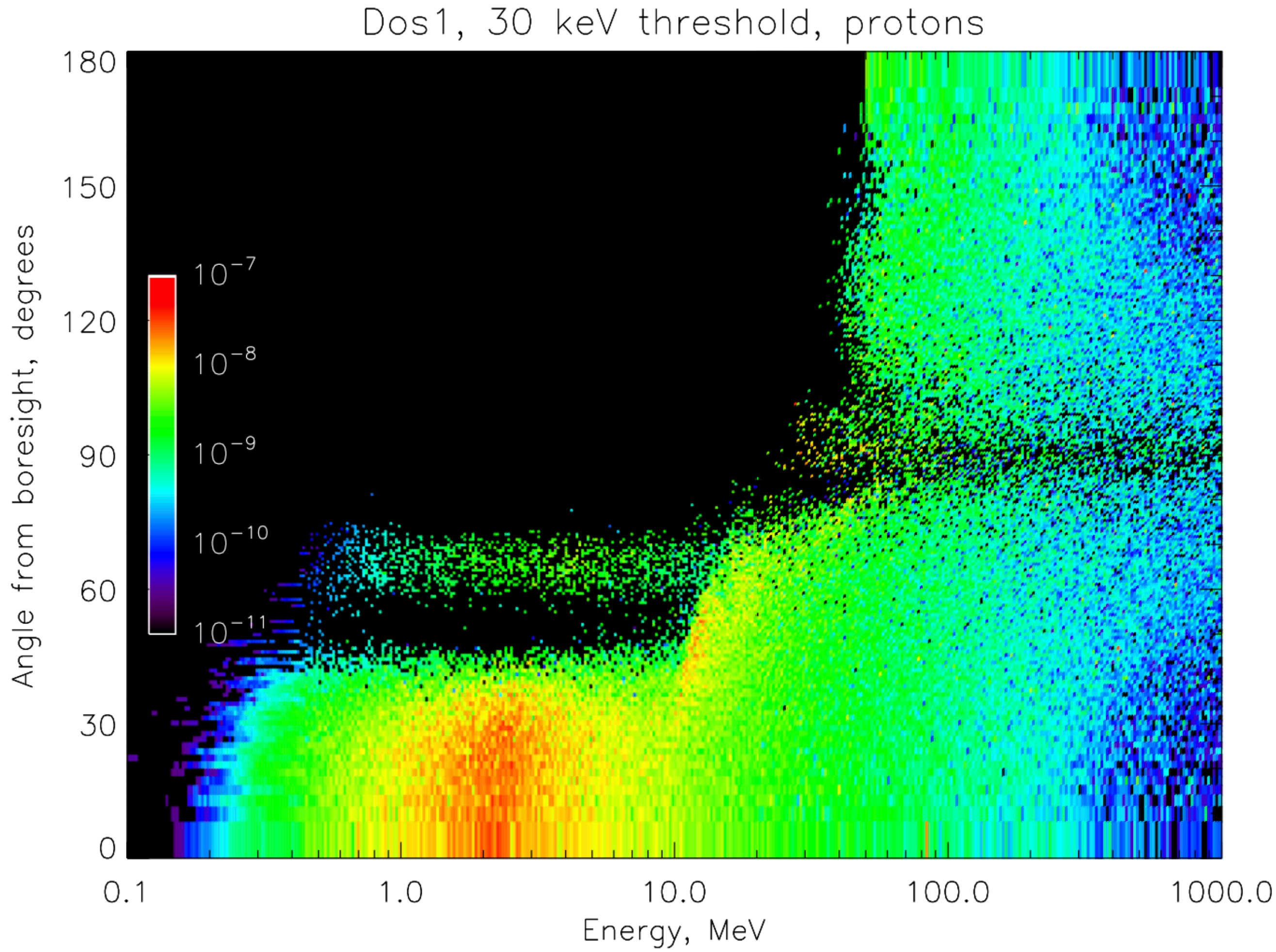

The higher threshold suppresses response at higher energies as dE/dx falls, with a narrow band around 90° surviving as protons at each energy penetrate just enough material that they are nearing the end of their range when they reach the detector.



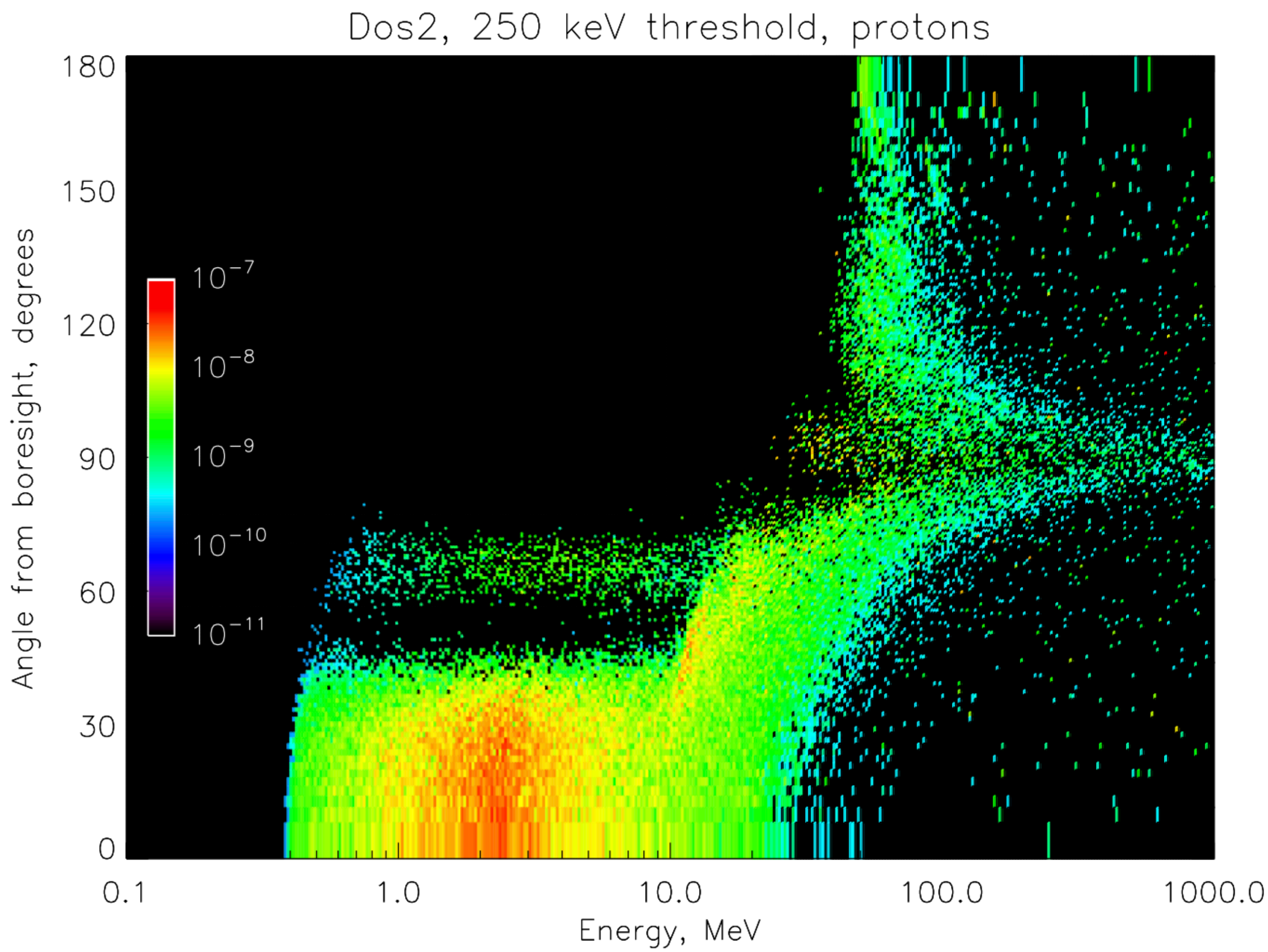

For Dos1 and Dos2, the simulations illuminating just a circle (7 cm dia) around the microdosimeters account for all the response at lower energies (too low to penetrate the housing or the satellite), so I replaced the "omni" response with the "top" response below 1 MeV for electrons and 20 MeV for protons to show better statistics near threshold. Here is the electron response of Dos1 with its low threshold; you can see a faint spike around 60° that is the sign of the response through the Dos2 aperture, but there is enough scattering in the foil to smear the main-aperture response over it.




As is seen on slide 10, the high electronic threshold of Dos2 suppresses response to most electron events.




Protons scatter less in the 1.8-µm foil, so a spike due to the response through the second aperture around 60° off axis is easier to see in this plot for Dos1. As seen on slide 11, with its low threshold it accounts for essentially all proton dose; the falloff at right is not due to suppression of events, but simply to declining dE/dx.




The higher threshold of Dos2 increases the energy at which response turns on (lower left), and also suppresses response to high-energy, low-dE/dx protons (right) as for the 1-MeV threshold on Dos3. I have supplied full position and direction information from these simulations to Paul O'Brien, as I have done for MagEIS and RPS simulations, so he can assemble response libraries as needed.

## External Distribution

| REPORT TITLE | | |
| --- | --- | --- |
| Updated Geant4 Simulations of AeroCube 6 Microdosimeters | | |
| REPORT NO. | PUBLICATION DATE | SECURITY CLASSIFICATION |
| TOR-2016-03260 | September 30, 2016 | UNCLASSIFIED |

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TOR-2016-03260

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SC2676

AEROSPACE REPORT NO.
TOR-2016-03260

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