Scaler Effective Areas for Protons

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Introduction

Over the last month or so I have been working to help Jim Ryan analyze the 01/20/05 solar flare event seen in our scaler data. Mainly I have been producing/analyzing low energy Monte Carlo data to estimate the effective area of all the scaler channels we record. This should be useful for the 01/20/05 solar flare and in understanding perhaps other events in our scaler data that might be external physics events.

In this memo I will present to you the current status of this effort. I have put out two earlier memos to a small group of people interested in the solar flare analysis. This memo includes some of those results in addition to newer ones.

This memo includes the following sections:

I. MC Data Set: I describe what data sets I have produced and where they are located.
II. Milagro Scaler System: I briefly refresh you memory on what scaler channels we record.
III. Computation of Effective Areas: I describe how I computed the effective areas.
IV. Comparision with Measured Rates: Here I compute the basic rates for each scaler channel based on my effective areas and on the cosmic rate proton spectrum, as measured by BESS.

MC Data Set

I am generating four "scaler" MC data sets to estimate the various scaler channels to fluxes of primary protons and gammas. These data sets are:

1. Geant 3 Protons on a spectrum:
   a) energy spectrum & range: -2.7, 5 GeV to 1000 GeV
   b) zenith angle range: 0 to 70^{o}
   c) throw distances: 10km x 10km (+/- 5km) and 20km x 20km
   d) # of throws: > 220 million (20km x 20km set).

2. Geant 4 Protons on a spectrum:
   a) energy spectrum & range: -2.7, 5 GeV to 1000 GeV
   b) zenith angle range: 0 to 70^{o}

c) throw distance: 20km x 20km (+/- 10km)
d)# of throws: ~ 1.8 million.

3. Geant 3 Photons on a spectrum:
   a) energy spectrum & range: -2.4, 5 GeV to 1000 GeV
   b) zenith angle range: 0 to 70^o
   c) throw distances: 10km x 10km (+/- 5km) and 20km x 20km
   d)# of throws: 137 million.

4. Geant 3 Protons, Fixed energies:
   a) fixed energies of 1000, 5000, and 10000 GeV
   b) zenith angle range: 0 to 70^o
   c) throw distance: 20km x 20km (+/- 10km)
   d)# of throws: 58,000 @ 1000 GeV, 0 @ 5000 GeV, 0 @ 10000 GeV

I have also made use of the large, standard Geant 3 proton data set, which was thrown to +/- 1km. This has helped to estimate the large multiplicity rates (pmts > 25).

The MC data I have generated resides on the UMD cluster at:

/data/scratch01/shoup/solar/simulations/...

Milagro Scaler System

Before I address what effective areas I have computed and how I compute them, let me remind you of a few facts about our scaler system (A fuller description of the scaler system can be found in David Williams' memo entitled "Analysis of Scaler Data from GRB970417a" dated 01/31/2000).

There are three basic types of scaler data that we can use for the solar event. These are: masked, or'ed and multiplicity. The masked scaler channels are individual pmt one second count rates. Each pmt's rate is measure once each 16 seconds in the following way. The 1^{st} pmt in each patch is measured in the 1^{st} second of a 16 second cycle, then the 2^{nd} pmt in each patch is measured in the 2^{nd} second, etc. So the fundamental time resolution using the masked channels is 16 seconds (One could sum 1 pmt from each patch to get 1 second resolution, but it would be a different set of pmts for each second in the 16 second cycle).

The or'ed scaler channels are basically patch rates, using either the low or the high threshold discriminated signals. For the airshower (AS) layer, low threshold, 8 pmts are hard-wire or'ed together to form two scaler channels per patch. There is a specific geometric layout in which pmts within the patch are or'ed together to form each channel (See David's memo). For the AS layer, high threshold, all 16 pmts in a patch are hard-wire or'ed together to form one scaler channel per patch. For the MU layer, all 16 pmts are or'ed together to form two scaler channels (one low and one high threshold) per patch.

The or'ed channels are read out every second and thus have a 1 second time resolution. However, since they are or'ed signals, there is a minimum two hit time resolution. For the low threshold scaler channels, the time resolution is about 20-30 ns. For the high threshold, it is about 40-50 ns. This needs to be considered when computing effective areas for these channels.

The multiplicity scaler channels are discriminations of the analog sum of all AS layer low threshold hits. The pmt discriminator pulses that go into this analog sum have a fixed width (about 300ns) and height of -25 mV. There are 8 levels of discrimination, corresponding to: 6, 8, 10, 12, 16, 25, 32, and 40 pmt multiplicity. These multiplicity rates are read out every second.

Computation of Effective Areas

To compute the effective areas of the various scaler channels from this MC data set, I started with the code that Andy Smith pointed to in his email message. His code is a good starting point. It computes the effective area of the low threshold (~ 0.25PE) and high threshold (~ 5PE) pmt hit rates for the full AS layer pmts. The low threshold effective area could be used in conjunction with summing up all hits in the top layer pmts (low threshold only). However, in our scaler data, these rates have only a 16 second time resolution as stated above. To be able to use our scaler system's full 1 second resolution and also use the high thresold data, patch rates would need to be used. However, to use patch rates, I need to include the or'ed nature of our patch rates in the effective area computations. I have added code to Andy's program to do this. I have also added code to compute the multiplicity rates as well. My extended version of Andy's program located on the UMD cluster at:

/data/scratch01/shoup/solar/analysis/effarea/andy/UserTasks_MC.cc

Now to show where the current results stand. In all figures I show a fit to an exponential function. I give the fitted parameter results in Table I. Figure 1 shows the low threshold, AS layer effective areas for “summed” “and “or'ed” counting schemes. You can see that the reduction in effective area when including the minimum two pulse time resolution is small, but significant. The low and high threshold AS layer areas are plotted together in Figure 2 (note: if summed or or'ed is not mentioned, then or'ed channels are used).

The results for the multiplicity effective areas for 6 and 12 pmts are shown in Figure 3. The points with very large error bars are points I “fudged” to get the root fitter to work. Those points originally had zeros because of low statistics.

Table I is a listing of all the fit parameter values for all 11 channels of scaler data for protons. The functional form for the fit is:

$$EffArea = e^{(p0 + p1 * \log(E))}$$

where E is in GeV and EffArea is in m^2. Please note that for the larger pmt multiplicity rates I had to use the 5 km and 1km MC data sets because of poor statistics of the 10 km data. So the 25 to 40 pmt multiplicities might be underestimates.

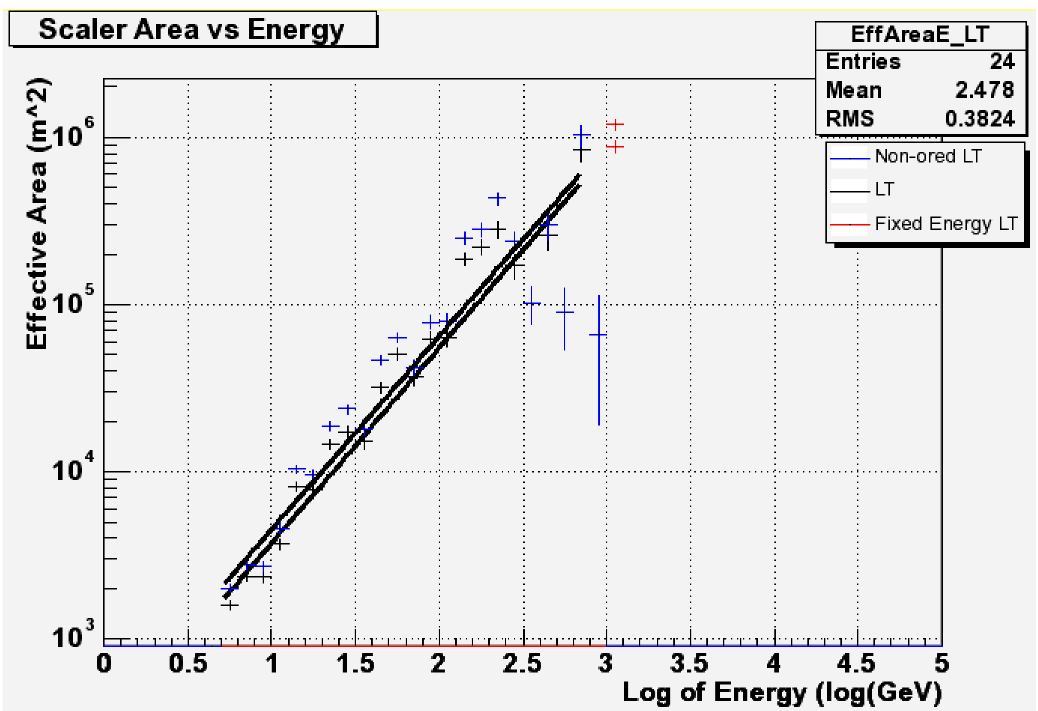

Figure 1: Proton effective area for low threshold AS layer. Blue is non-or'ed, black is or'ed, red is fixed energy points. Fit is to a exponential.

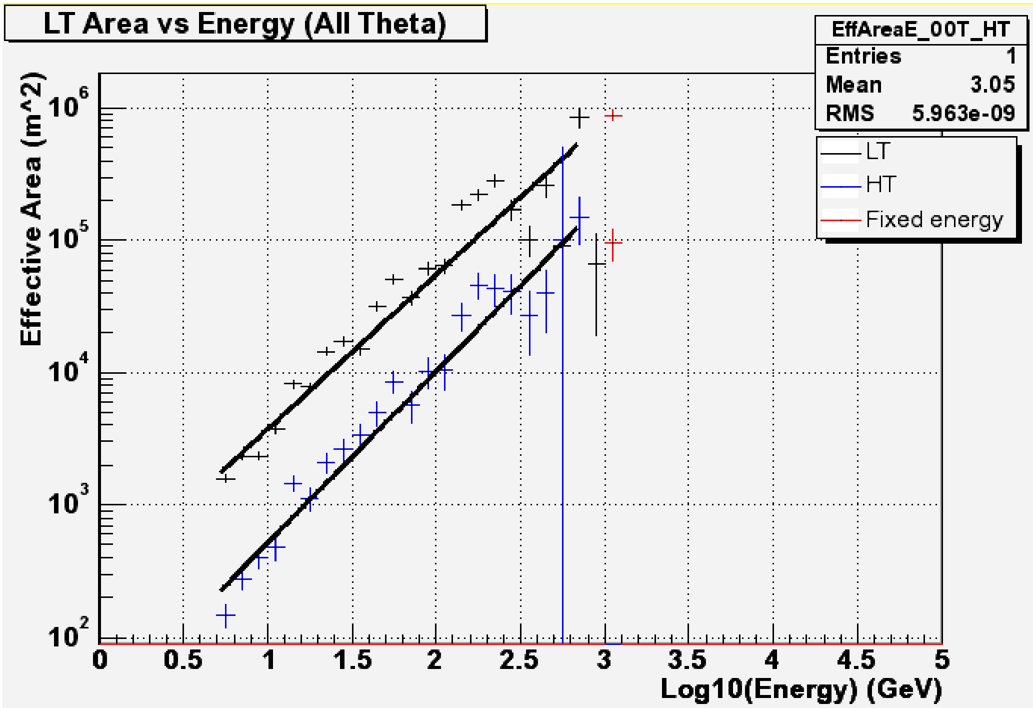

Figure 2: Proton effective area for low and high threshold AS layer. Black is low, blue is high, and red is fixed energy. (both are or'ed values).

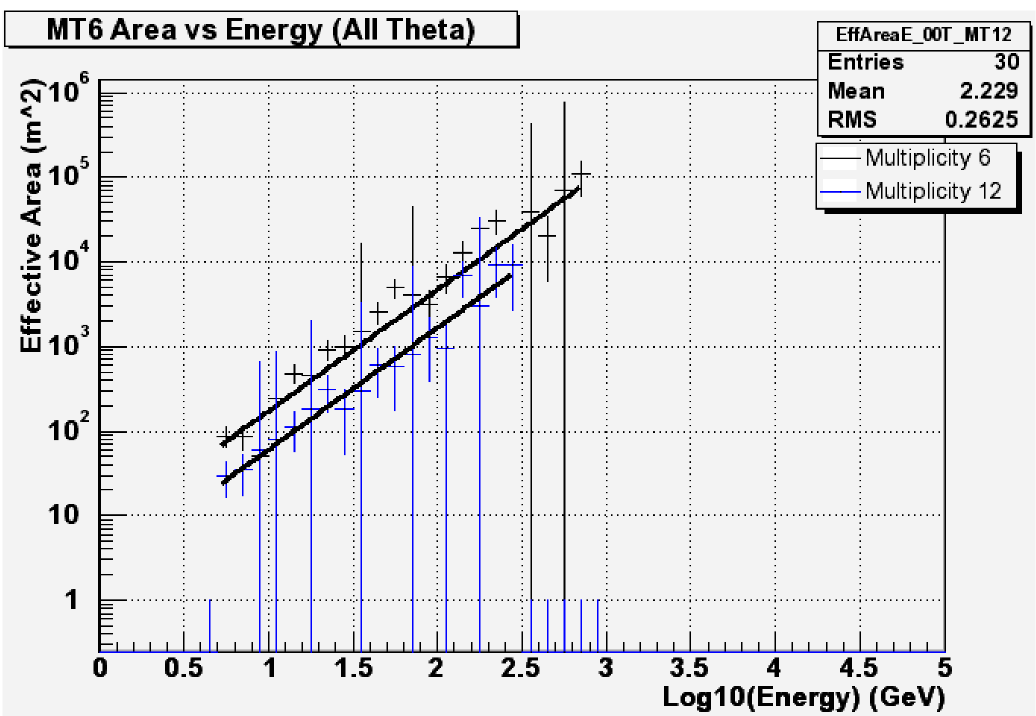

Figure 3: Multiplicity effective areas for multiplicities: 6 & 12.

Scaler Channel	p0	p1
non-ored LT	5.95 +/- 0.04	2.47 +/- 0.02
LT	5.69 +/- 0.04	3.02 +/- 0.03
HT	3.27 +/- 0.1	2.98 +/- 0.08
Multiplicity-6	1.86 +/- 0.19	3.30 +/- 0.13
Multiplicity-8	0.73 +/- 0.35	3.62 +/- 0.22
Multiplicity-10	0.59 +/- ???	3.40 +/- ???
Multiplicity-12	0.90 +/- 0.66	3.25 +/- 0.41
Multiplicity-16*	-1.10 +/- 0.82	3.94 +/- 0.44
Multiplicity-25**	-2.47 +/- 0.10	4.07 +/- 0.04
Multiplicity-32**	-3.13 +/- 0.10	4.22 +/- 0.04
Multiplicity-40**	-3.84 +/- 0.12	4.39 +/- 0.05
* from 5km dataset	** from 1km dataset	

Table I

Comparison of Computed and Measured Rates

Using my scaler effective areas and the cosmic ray proton spectrum (See Figure 4 & Table II) from a BESS paper (S. Haino) I have computed expected rates for the 11 scaler channels for the AS layer. My calculation is outlined as:

$$\mathrm{Rate} = \iint \mathrm{EA}(\mathrm{E}) \frac{\mathrm{dN}(\mathrm{E})}{\mathrm{dE}} \mathrm{dE}\, \mathrm{d}\Omega \approx \sum \mathrm{EA}(\mathrm{E}) * \mathrm{N}(\mathrm{E}) \Omega \Delta \mathrm{E}$$

where the summation is over the BESS energy bins (Table II) up to the limit of their table, then 0.1 bins (in log(E)), ΔE is the size of the energy bins, and Ω is given by:

$$\Omega = 2\pi(\cos\theta_{min} - \cos\theta_{max}) \text{ and } \theta_{min} = 0 \text{ and } \theta_{max} = 70$$

For dN(E)/dE, I used the values from Table II, and above that I used $\frac{\mathrm{dN}}{\mathrm{dE}} = 0.315 \left(\frac{\mathrm{E}}{50\,\mathrm{GeV}} \right)^{-2.74} (\mathrm{m}^2\,\mathrm{s}\,\mathrm{sr}\,\mathrm{GeV})^{-1}$.

Figures 5 thru 14 show plots of the rate versus time for the 11 scaler channels I am considering. The time period is a 28 day period just after the 2003 pmt repair (last time when all but a couple AS layer pmts were on). These comparisons are summarized in Table III. The error bars are computed by changing p0 (constant) in the effective area parameterization by 1 σ. Changing p1 (slope) by 1 σ gives similar ranges in the computed rates. Generally the computed rates are in agreement with the measured rates for that period, with the exception of multiplicities of 32 and 40. All these rates are not very stable as can be seen in Figure 15, so I really need to model more closely the running conditions near the 01/20/05 flare. This is will be done next.

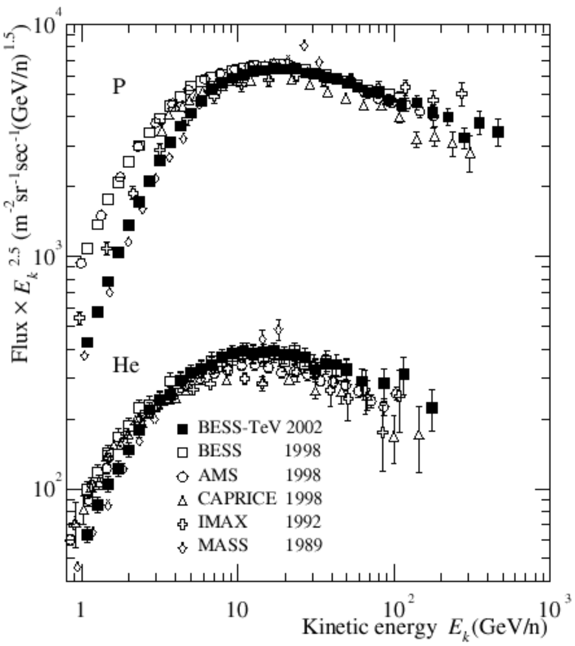

Fig. 7. Absolute differential energy spectra of primary protons and helium nuc multiplied by $E_k^{2.5}$. The spectra obtained by other experiments [6,15,16,31,32,3 are also shown.

Figure 4. Proton & helium spectra from BESS (S. Haino)

Table 1
Primary proton flux at the top of the atmosphere.

Energy range (GeV)		$\overline{E_k}$ (GeV)	Flux $\pm \Delta F_{sta} \pm \Delta F_{sys}$ ($m^{-2}sr^{-1}s^{-1}GeV^{-1}$)
1.00–	1.17	1.08	$3.50 \pm 0.03 \pm 0.11 \times 10^2$
1.17–	1.36	1.26	$3.22 \pm 0.03 \pm 0.10 \times 10^2$
1.36–	1.58	1.47	$2.98 \pm 0.02 \pm 0.09 \times 10^2$
1.58–	1.85	1.71	$2.71 \pm 0.02 \pm 0.08 \times 10^2$
1.85–	2.15	2.00	$2.41 \pm 0.02 \pm 0.07 \times 10^2$
2.15–	2.51	2.33	$2.08 \pm 0.02 \pm 0.06 \times 10^2$
2.51–	2.93	2.71	$1.74 \pm 0.01 \pm 0.05 \times 10^2$
2.93–	3.42	3.16	$1.45 \pm 0.01 \pm 0.04 \times 10^2$
3.42–	3.98	3.69	$1.19 \pm 0.01 \pm 0.03 \times 10^2$
3.98–	4.64	4.30	$9.52 \pm 0.08 \pm 0.27 \times 10^1$
4.64–	5.41	5.01	$7.35 \pm 0.07 \pm 0.21 \times 10^1$
5.41–	6.31	5.84	$5.63 \pm 0.05 \pm 0.16 \times 10^1$
6.31–	7.36	6.81	$4.34 \pm 0.04 \pm 0.12 \times 10^1$
7.36–	8.58	7.93	$3.15 \pm 0.03 \pm 0.09 \times 10^1$
8.58–	10.0	9.25	$2.25 \pm 0.03 \pm 0.06 \times 10^1$
10.0–	11.7	10.8	$1.59 \pm 0.01 \pm 0.05 \times 10^1$
11.7–	13.6	12.6	$1.12 \pm 0.01 \pm 0.04 \times 10^1$
13.6–	15.8	14.7	$7.71 \pm 0.04 \pm 0.28$
15.8–	18.5	17.1	$5.33 \pm 0.03 \pm 0.20$
18.5–	21.5	19.9	$3.63 \pm 0.02 \pm 0.14$
21.5–	25.1	23.2	$2.48 \pm 0.02 \pm 0.10$
25.1–	29.3	27.1	$1.62 \pm 0.01 \pm 0.06$
29.3–	34.1	31.6	$1.09 \pm 0.01 \pm 0.04$
34.1–	39.8	36.8	$7.17 \pm 0.08 \pm 0.30 \times 10^{-1}$
39.8–	46.4	42.9	$4.84 \pm 0.06 \pm 0.21 \times 10^{-1}$
46.4–	54.1	50.0	$3.15 \pm 0.05 \pm 0.14 \times 10^{-1}$
54.1–	63.1	58.3	$2.07 \pm 0.03 \pm 0.09 \times 10^{-1}$
63.1–	73.6	68.0	$1.34 \pm 0.03 \pm 0.06 \times 10^{-1}$
73.6–	85.8	79.2	$9.09 \pm 0.19 \pm 0.43 \times 10^{-2}$
85.8–	100.	92.3	$5.75 \pm 0.14 \pm 0.28 \times 10^{-2}$
100.–	126.	112.	$3.43 \pm 0.11 \pm 0.18 \times 10^{-2}$
126.–	158.	140.	$1.98 \pm 0.07 \pm 0.11 \times 10^{-2}$
158.–	200.	177.	$1.00 \pm 0.05 \pm 0.06 \times 10^{-2}$
200.–	251.	222.	$5.42 \pm 0.31 \pm 0.34 \times 10^{-3}$
251.–	316.	281.	$2.46 \pm 0.19 \pm 0.17 \times 10^{-3}$
316.–	398.	352.	$1.62 \pm 0.14 \pm 0.14 \times 10^{-3}$
398.–	541.	463.	$7.47 \pm 0.69 \pm 0.78 \times 10^{-4}$

Table II. Proton flux values from BESS (astroph/0703704)

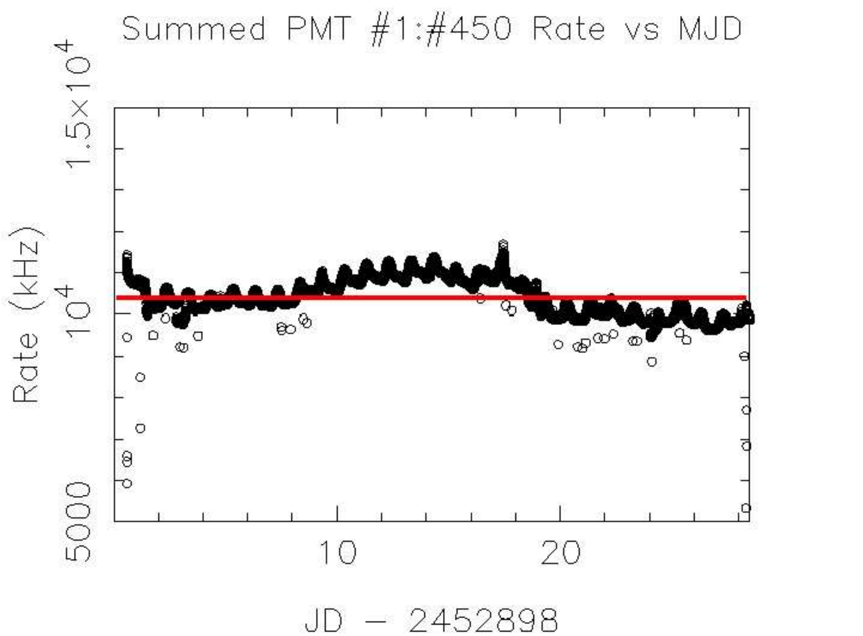

Figure 5: Comparison between computed and measured AS layer low threshold summed scaler rates. Computed rate is 10.4 MHz.

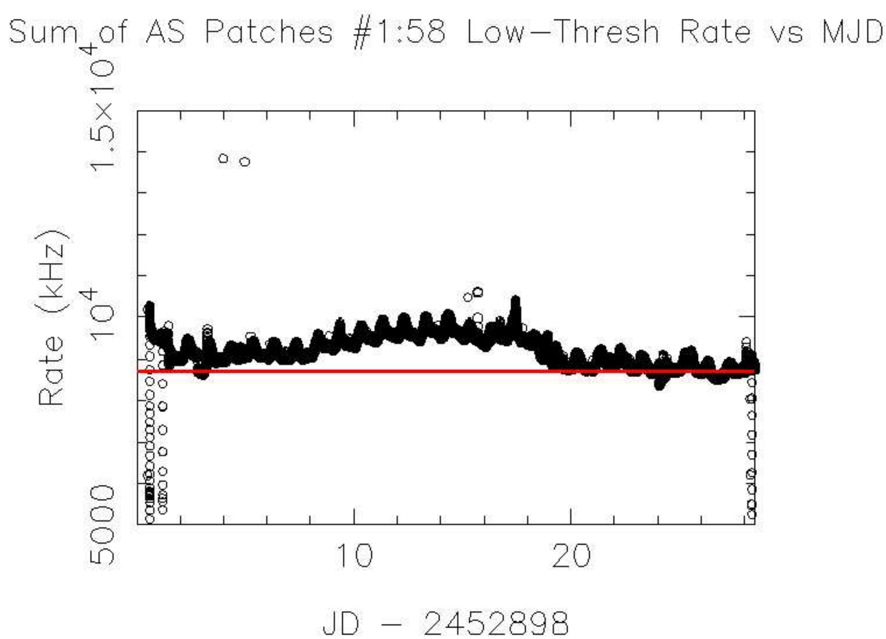

Figure 6: Comparison between computed and measured AS layer low threshold scaler rates. Computed rate of 8.6 MHz.

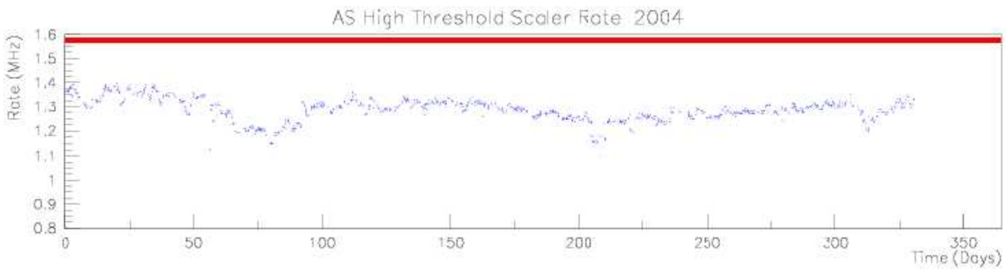

Figure 7: Comparison between computed and measured AS layer high threshold scaler rates. Computed rate of 1.56 Mhz. (Used EMS plot of HT rates because have trouble reading them from scaler files)

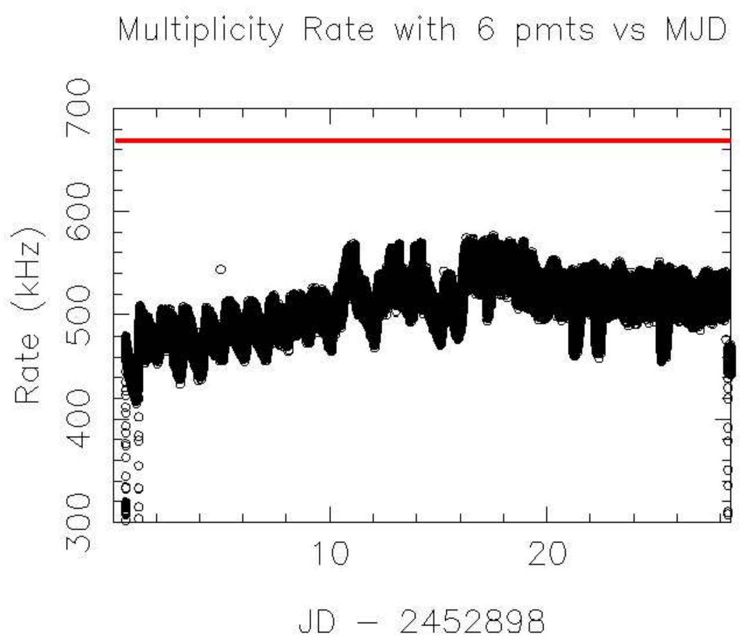

Figure 8: Comparison between computed and measured AS layer multiplicity-6 scaler rates. Computed rate of 673 kHz.

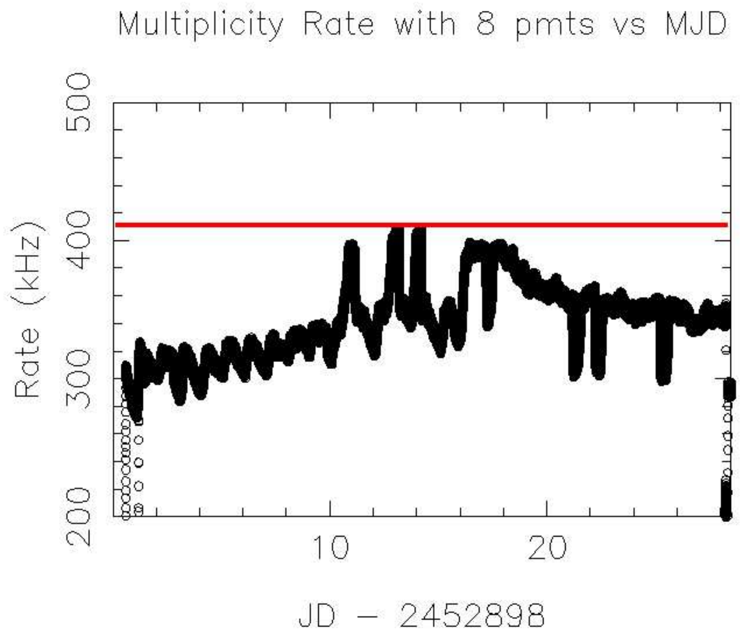

Figure 9: Comparison between computed and measured AS layer multiplicity-8 scaler rates. Computed rate of 412 kHz.

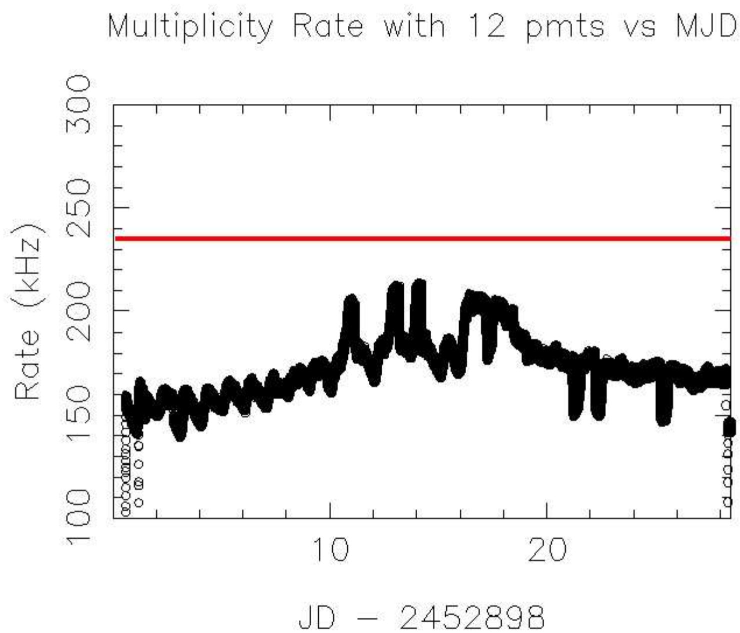

Figure 10: Comparison between computed and measured AS layer multiplicity-12 scaler rates. Computed rate of 235 kHz.

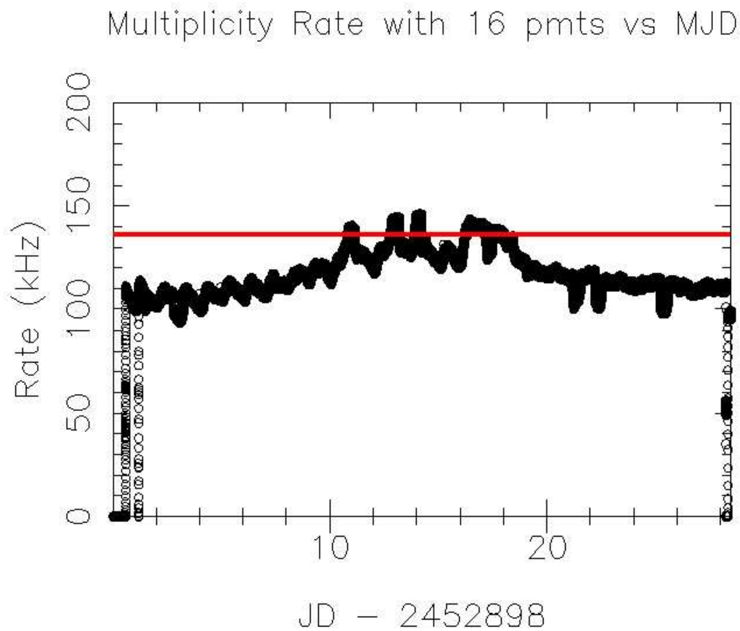

Figure 11: Comparison between computed and measured AS layer multiplicity-16 scaler rates. Computed rate of 136 kHz.

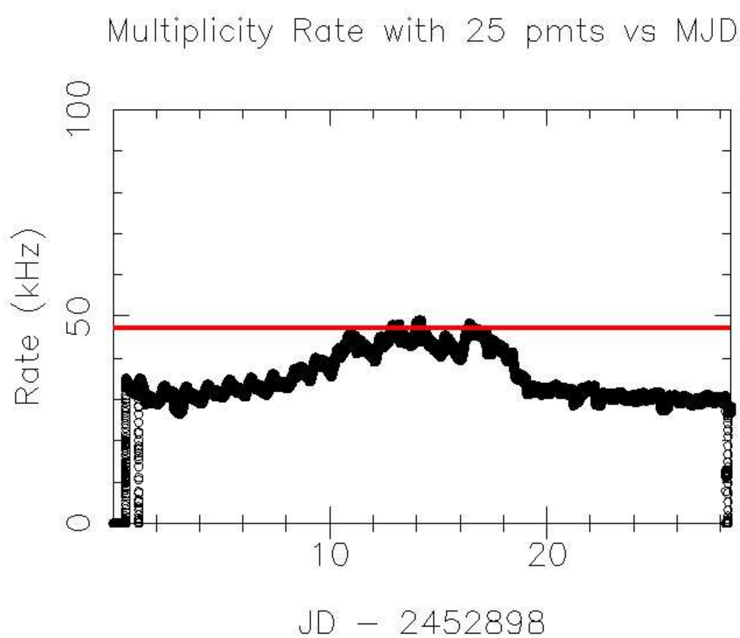

Figure 12: Comparison between computed and measured AS layer multiplicity-25 scaler rates. Computed rate of 47 kHz.

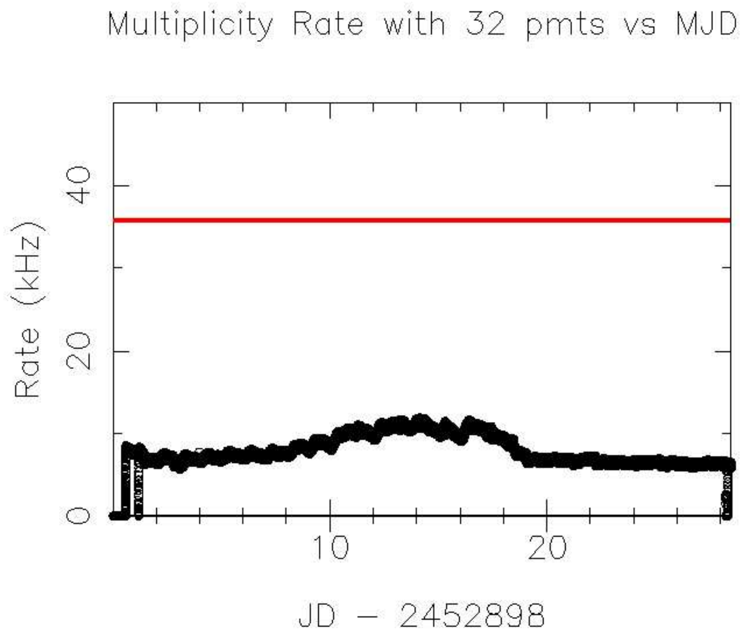

Figure 13: Comparison between computed and measured AS layer multiplicity-32 scaler rates. Computed rate of 36 kHz.

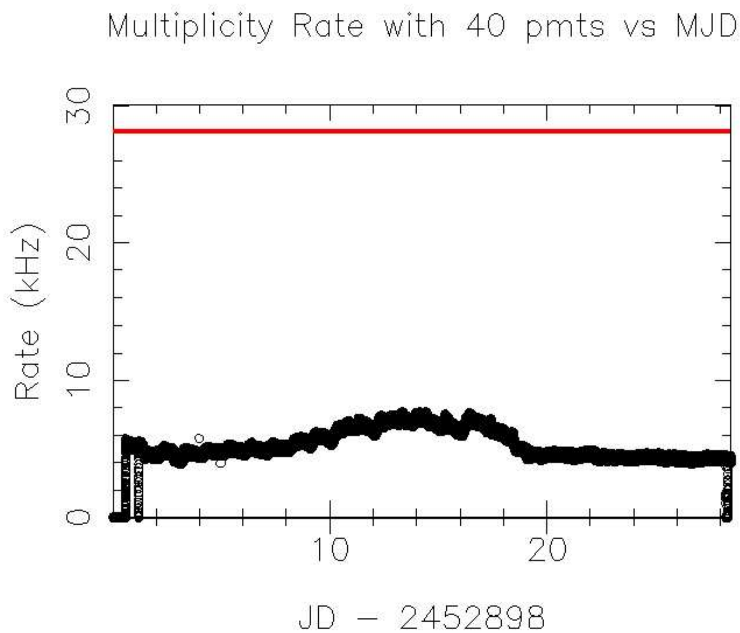

Figure 14: Comparison between computed and measured AS layer multiplicity-40 scaler rates. Computed rate of 28 kHz.

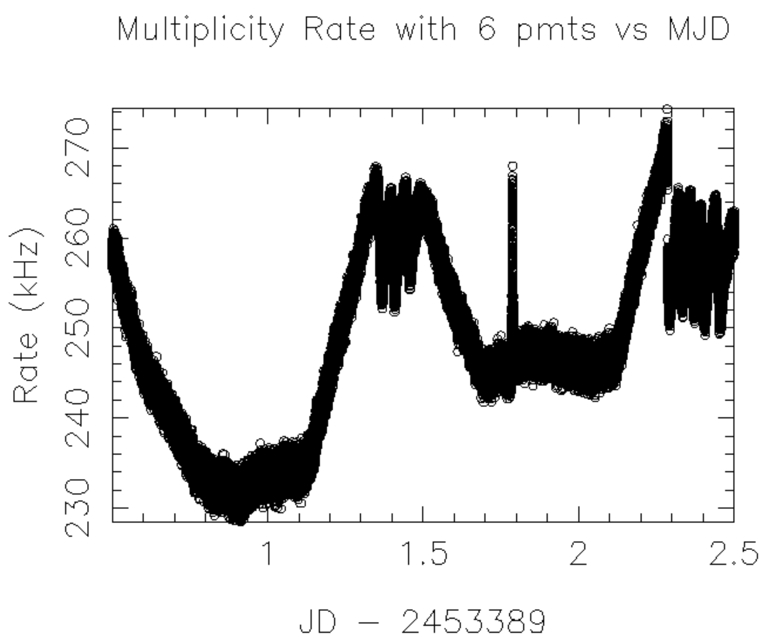

Figure 15: Long term multiplicity-6 rates near 01/20/05 solar flare. Note that computed rate is 673 kHz.

Scaler Channel	Measured Rate	Computed Rate
Non-Ored LT	10 to 11 MHz	10.4 +/- 0.4 MHz
LT	9 to 10 MHz	8.6 +/- 0.4 MHz
HT	1.15 to 1.4 Mhz	1.56 +/- 0.17 MHz
Multiplicity-6	480 to 520 kHz	673 +/- 140 kHz
Multiplicity-8	300 to 400 kHz	412 +/- 170 kHz
Multiplicity-10	dead channel	229 +/- ??? kHz
Multiplicity-12	150 to 210 kHz	235 +/- 219 kHz
Multiplicity-16*	100 to 140 kHz	135 +/- 172 kHz
Multiplicity-25**	30 to 50 kHz	47 +/- ??? kHz
Multiplicity-32	7 to 12 kHz	36 +/- ??? kHz
Multiplicity-40	5 to 7 kHz	28 +/- kHz
* From 5km data	** From 1km data	

References

S. Haino, et.al., “Measurement of the Primary and Atmospheric Cosmic

Ray Spectra with the BESS-TeV Spectrometer”, astro-ph/0403704, (2004).