Milagro Memo
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The Crab: Milagrito vs. Milagro

There has been discussion about the apparent contradiction between Milagro's tentative observation of the Crab and Milagrito's rather convincing non-observation of the Crab. In this note I attempt to collate all of the relevant facts and see if in fact any contradiction exists. The approach will be based mainly on the data however; one cannot rely completely upon the data if the *shape* of the area vs. energy plots is different for the two detectors. In particular if R_γ is different for Milagro and Milagrito. For this I will use the results of the Monte Carlo simulations. While it is different, this is a relatively small effect and does not quantitatively change the conclusion. Much of the information in this memo has come from sources beside myself. Thanks to Andy, Stefan, Tony, and Joe for many of the relevant numbers.

Relevant Factors:

1. <u>The trigger rate:</u> this tells us how to scale the background rate for the two instruments.
2. <u>The convolution of A(E)*I(E) for gammas for the 2 detectors:</u> this tells us how to scale the signal rate for the two instruments.
3. <u>The angular resolution:</u> This tells us what bin size to use and what fraction of the signal events will fall within this bin.
4. <u>The NFIT distribution:</u> In conjunction with 2 this tells us the fraction of signal and background events (that triggered the detectors) that survive all of our cuts.
5. <u>What Milagrito observed:</u> this tells us the upper limit on what the flux from the source is.
6. <u>The analysis performed:</u> Tony and Andy each performed different analyses. Andy has himself performed several analyses, various binsizes, calibrations, etc. I will "normalize" their results to a particular analysis to ease comparison. The default analysis is 2 weeks of data with an NFIT>20 cut and a 0.9 degree radius bin, with a cut on the zenith angle of the events (θ<45 degrees).

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	Trigger Rate	A(E)*I(E)	s_q	NFit/Frac	Observed
Milagro	1200	12	X	20/0.85	2.3 σ/2 weeks
Grito	300	2.1	X	40/0.57	0.8 σ/yr (<2.2σ/yr)

There are two equivalent paths to take. One is to work in number of events and the other is to work in number of sigmas. Though equivalent it is instructive to see the actual numbers of expected signal and background events.

<u>Scaling the sigmas:</u>

First: Milagrito observed a 0.8σ excess from the Crab, thus a 90%CL upper limit to the number of signal events, would give 2.2σ as the upper limit. We actually observed 735 excess events on a background of 828,000 events (in a 1.1 degree radius bin), giving an upper limit of 2000 events from the source at the 90% CL. These numbers for Milagrito's results are taken from Stefan's memo "*Rate Comparison between Milagrito Data and Simulation*".

Second: The angular resolution. Figure 1 shows the DELEO distribution for Milagro and for Milagrito. For Milagro the distribution is shown for 1200 Hz data with an NFIT >20 cut applied to the data. For Milagrito it is the 1-meter water depth data with an NFIT of 40 cut applied to the data. We see that for these two values of NFIT the angular resolution of Milagro is comparable to that of Milagrito. From now on I will ignore the angular resolution in the calculation. If this had not been the case one would have to worry about the fraction of signal events retained in the respective bins. However, I should add one caveat to this. As we all know DELEO does not include the error we make in reconstructing the direction when the core of the shower lies off of the pond. Thus if the fraction of events with cores off the pond is different for the two instruments there will be an effect on the final answer. Stefan has looked at this for me and found that according to the simulation 20% (15%) of gamma (proton) showers that trigger Milagro have their cores on the pond. This is consistent with the numbers for Milagrito.

The scaling:

$$\frac{S_{GRO}}{S_{ITO}}=\frac{\int A_{GRO}(E)I_{Crab}(E)dE}{\int A_{ITO}(E)I_{Crab}(E)dE}\frac{T_{GRO}}{T_{ITO}}\frac{F_{GRO}(NFIT>20)}{F_{ITO}(NFIT>40)}\frac{\sqrt{F_{ITO}(NFIT>40)Rate_{ITO}T_{ITO}}}{\sqrt{F_{GRO}(NFIT>20)Rate_{GRO}T_{GRO}}}\frac{s_q(GRO)}{s_q(ITO)}$$

$$=\frac{12}{2.1}\frac{0.85}{0.57}\frac{\sqrt{2}}{\sqrt{52}}\frac{\sqrt{0.57x300}}{\sqrt{0.85x1200}}=0.68$$

Which says that 1 month of Milagro data is equivalent to 1 year of Milagrito data. Thus it all gets down to what did we observe with Milagrito. We saw a 0.8σ excess, but of course the error on this is huge. The upper limit on what we observed in Milagrito is 2.2σ excess. So based on the above we would expect to see 0.55 σ after two weeks of Milagro and we should not see more than 1.5σ from Milagro. In fact Andy's result is 2.3σ at the location of the Crab, and Tony's yields a ~4 sigma excess in 3 weeks. While I have not completed the analysis of the optimal bin size and NFIT cut, it seems clear from Figure 1 that for NFIT>20 we should be using a bin of comparable size to what was used in analyzing Milagrito data with an NFIT cut of 40 (1.1 degrees).

From the above considerations I would conclude that Milagro's observation of the Crab is not too inconsistent with Milagrito's non-observation of the Crab. Clearly we need to analyze more Milagro data.

Scaling events:

To scale the number of excess events the scaling given above is only slightly modified. Simply remove the ratio of the square root of the trigger rates.

The result is: $\frac{N_{Excess}(GRO)}{N_{Excess}(ITO)}=\frac{12}{2.1}\frac{0.85}{0.57}\frac{2}{52}=0.33$

So after 2 weeks of Milagro running we should see 1/3 the number of excess events from the Crab that we observed after one year of running with Milagrito. We observed a 735 event (<2000) excess with Milagrito so we should have observed 242 events (<660) after 2 weeks with Milagrito. A similar calculation for the number of background events we should have in the same bin size yields $N_{Back}(GRO)/N_{Back}(ITO)$ = 0.229. All of this is based on using the same binsize in Milagro as we did in Milagrito (1.1 degree radius).

The table below compares Tony's and Andy's analyses to an extrapolation of our upper limit from Milagrito. Tony and Andy used different bin sizes and spanned different time intervals. Andy did not employ a zenith angle cut. I have scaled everything to a 1.1-degree radial bin and a 2-week observation period. Note that this scaling of signal events is NOT straightforward, as the fraction of signal events retained in the various bins does not scale like r^2. To scale this I use the deleo plot for NFIT>40 from Milagrito (Figure 1 below). The scaling goes as follows:

Bin Size (Radius)	Fraction of Signal Events in Bin
0.75	0.372
0.90	0.456
1.10	0.553
1.41	0.667

To find the effect of the zenith angle cut I ran on 200 runs of Milagrito data (Runs 600-800) and looked at the number of events in the Crab bin with and without a zenith angle cut. The zenith angle cut removes about 7% of the Crab data.

Scaling	Tony Days	Tony binsize	Tony background	Tony Excess	Milagro Expected Background	Milagro Max Excess
Actual	16	0.75 radius	78988.9	1279.1		
Time	14	0.75	69115	1119		
BinSize	16	1.10	170000	1901		
Both	14	1.10	148675	1664	190000	660
Rate Scaling	14	1.10	148675	1664	148675	660

Scaling	Andy Days	Andy binsize	Andy background	Andy Excess	Milagro Expected Background	Milagro Max Excess
Actual	13	2.5 square	271245	1142		
Time	14	2.5	292110	1229		
BinSize	13	1.10	164970	947		
Both	14	1.10	177660	1019		
Zenith cut	14	1.10	165223	948	190000	660
Rate Scaling	14	1.10	165223	948	165223	660

Note the scaling for number of observation days. While Tony reported 24 days of data in fact many of the days yield very few events, implying that we were down for most of the Crab transit. Using several apparently "full" days from his email message I inferred that 5000 events constituted a full Crab transit and arrived at an effective exposure of 16 days. Andy's 13 effective days occurred over an 18-day period. The fact that the background levels do not match the prediction can be blamed on the trigger rate. In fact our trigger rate during the pre-repair data was in flux. If I scale the background to match the expectations this implies that during the time period when the data that Tony analyzed was acquired we were running at a trigger rate of 940 Hz, and while Andy's data were taken 1045 Hz. The final row in each table assumes this was the case and compensates the number of expected signal and background events accordingly. Note that the number of expected signal events does not change. This should is because the number of signal events predicted came from the ratio of effective areas for gamma showers between Milagrito and Milagro according to the simulation. The Milagro simulation assumed an 80 PMT trigger (in fact we have a 65-70 PMT trigger at 1200 Hz), so we may even expect more signal events. There may still be relatively large errors in these numbers.

Conclusion:

An observation of a 0.8σ excess can not be used to derive a flux. Instead I use the 90% CL upper limit to the measurement from Milagrito to establish an upper limit to what we should have observed with Milagro after 2 weeks of data taking on the Crab. For Tony's analysis there is an inconsistency with Milagrito (a factor of ~2.5). Andy's analysis yields results that are not too inconsistent with the results from Milagrito (~45% too high). We should perform the analysis in an unbiased manner, deducing the appropriate bin size from DELEO (and not by scanning the excess from the direction of the Crab). Furthermore we should use the pedestal and slewing calibrations derived from the laser data and find the excess at the position of the Crab. One should not use a 2σ excess to measure a systematic pointing error.

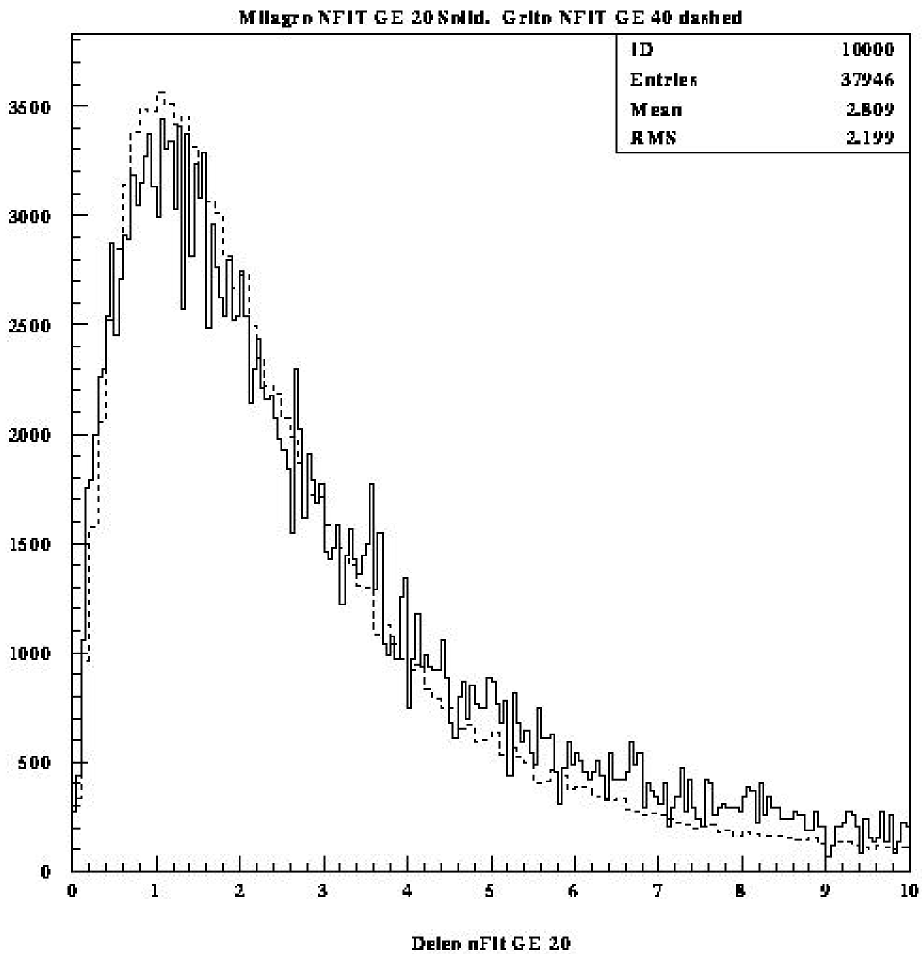

Figure 1 Comparison of DELEO for Milagro and Milagrito. NFIT>20 for Milagro and NFIT>40 for Milagrito.