Comments on the Milagro Crab Signal

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I have some comments on the putative Crab signal from Milagro that I would like to share. Many in the collaboration seem so concerned with "number of sigmas" that we have seen, but I have another view that I have been wrestling with. Since I have been struggling with this for many weeks now, I thought I would share my own view with the collaboration in an attempt to gain insight and understanding. I haven't yet figured out why my reasoning is wrong. Basically, rather than thinking about the signal-to-sqrt(background), I'm worried about the signal level.

Here is the situation that we know:

Final results of Milagrito Crab data (according to a conference paper by S. Westerhof)

- observed a 0.6 sigma excess from the Crab.
- only cuts were theta<45 degrees and Nfit>40.
- The background in a 1.1 degree round Crab bin was 828,540 events.
- Thus, 0.6 sigma is an excess of 546 events (give or take a little rounding error on my part) +/- 910 events
- Or the signal was 0.066% ± 0.11% of the background

Preliminary Milagro Crab data (taken from Tony Shoup email of 1/7/00 titled "Food for thought" as it had the most details)

- 3.5 weeks of "high-rate" data, only cut was theta<45 degrees.
- Bin of 0.75 degrees radius
- 80,268 events "on", 78,989 events "off" or 1,279 events excess
- Excess was 1.62% of the background in 0.75 degree bin.

So, let us take the above measurements of the Crab flux by Milagro at face value, and see if I can understand what we would expect to see in Milagrito data. I can do this without Monte Carlo calculations by introducing a free parameter. Roughly speaking Milagro has a factor of 2 larger effective area than Milagrito, and a threshold about 1.5-2 times lower than Milagrito. What I've got to know is the relative effective area of Milagrito and Milagro to cosmic rays and gamma-rays (I suspect they are about the same over the energy region where the thresholds differ). Said in symbols, let [Aeff] represent the spectrally averaged effective area of the detector of interest to cosmic-rays or gamma-rays. Let R-gamma represent this relative ratio of effective areas (R-gamma = [Aeff-gamma]/[Aeff-CR], sound familiar to some of you?). Then I suspect R-gamma for Milagrito is about the same as R-gamma for Milagro.

The ratio of R-gamma for Milagro to R-gamma for Milagrito being approximately equal to 1 is certainly a reasonable assumption, given that the cosmic-ray spectrum and the Crab spectrum are not too different. In fact, a lower threshold for Milagro and the Crab spectrum being harder than the CR spectrum suggests that if anything the signal-to-background effective area ratios for Milagro would be worse than Milagrito.

This physical reasoning is borne out by numerical integration of the effective area curves for Milagro and Milagrito. Stefan has recently provided effective area curves for Milagro for an 80 PMT threshold; and I have taken the "official" effective area curve from the NIM paper for Milagrito's effective area. These curves may not apply precisely to the problem at hand (they undoubtedly are not both averaged over the proper track of a source through the sky, probably do not have exactly the same cuts, and certainly do not have a well defined and measured energy scale), but they are representative and all that I have available. I have numerically integrated these curves for the Crab and cosmic-ray spectra. I find R-gamma = 0.988 (units are totally arbitrary) for Milagro, and R-gamma = 1.177 (with same arbitrary units) for Milagrito. So, unless I have made a numerical mistake, I find that if anything one expects Milagrito to have a higher signal-to-background ratio than Milagro, as expected from the physical line of reasoning.

I then follow this simple line of reasoning, without much other knowledge:

- Let R = (R-gamma)-Milagrito/(R-gamma)-Milagro is the relative ratio of R-gamma's between the two detectors.
- Let e1 (e1.le.1) be the fraction of gamma-ray events observed by Milagro within the 0.75 degree bin. Then there were a total of 1,279/e1 gamma-rays from the Crab observed by Milagro, or a fraction of 1.62%/e1 of the background in the 0.75 degree bin.
- Let e2 be the fraction of gamma-ray events observed by Milagrito that fall within the 1.1 degree bin

The Milagrito exposure to the Crab corresponds to 507,412 events in a 0.75 degree bin, or an exposure of about 6.4 times the Milagro exposure in terms of number of events. I therefore expect the TOTAL number of signal events in the Milagrito data set to be approximately (1.62%/e1)*507,412events * R = 8,220 (R/e1) events. Then I expect 8,220 * (R*e2/e1) events in the signal region in the Milagrito data set. At face value, this corresponds to an expected significance of 9.03 * (R*e2/e1) sigmas!!! The non-observation by Milagrito does not seem to agree with the inferred ~8,000 events excess from the Milagro observation.

When a conclusion to a line of reasoning is a contradiction, either the reasoning is wrong, or the assumptions are wrong, or both. The assumption I made was that the Milagro observation of the Crab was correct, neither a statistical fluctuation nor a systematic error. The reasoning I used was that the value of R*e2/e1 is approximately 1; $R \cong 1$ is borne out by more detailed estimates. So, my conclusion is that either:

1) the Milagro observation of the Crab was not real but caused at least in part by a systematic error or statistical fluctuation, or
2) the relative effective area for Milagro and Milagrito are very different than my expectation and our simulations, or
3) the relative angular resolutions for Milagro and Milagrito are very different than expectation, or
4) some combination of 1-3.

My bottom line is a very simple question: where are those missing signal events in the Milagrito data set?