8. CONCLUSIONS

8.1 Summary of the Search

This dissertation has presented the first systematic search for new physics in the exclusive $\gamma_{delayed}$+ $\not\!\!E_T$ final state which was a follow up on an intriguing excess that was observed in the same final state in early 2008. The candidate events were selected based on the corrected arrival time of the photon at the calorimeter as measured with the EMTiming system. The data sample analyzed represent data taken from December 2004 to June 2010 and correspond to an integrated luminosity of 6.3 ± 0.4 fb^{-1}. While we have endeavored to keep the same event selection, we decided to add a number of new requirements to reduce a number of newly understood backgrounds that produce biased events. We also used a new background estimate that takes into account that this final state has collision backgrounds that have a wrong vertex timing mean that is not actually zero. Using a data-driven background prediction method we predict 257 ± 35 events expected in the signal region (2 ns $< t_{corr} <$ 7 ns) and observe 322 events resulting in a modest excess remaining of observed minus predicted ($N_{Observed} - N_{Predicted}$) of 65 events. We can calculate the significance of this excess as $N_\sigma = 1.65$ which gives a one sided p-value (the estimatied probability that this excess is inconsistent with a null hypothesis) of $\sim 5\%$.

8.2 Interpretation of the Data

Our primary interpretation of the data is that we see no evidence for new physics in the exclusive $\gamma_{delayed}$ + $\not\!\!E_T$ final state. That being said, we make note that the modest excess of $N_\sigma = 1.65$ is present without any optimization for sensitivity to GMSB models. In addition we note that the shape of the excess is just what we would expect for a signal of new physics in that it is present in almost every timing bin in roughly the shape of an exponential.

The second conclusion is our answer to the question "what should we make of the preliminary search performed in 2008?" To answer this question we have followed up by using many of the analysis identification and selection variables to be identical to the previous search. This was done to aid in the interpretation of the previous search which showed an excess of $N_\sigma \sim 4$ using the previous background estimation technique which incorrectly assumed a timing distribution centered at $t_{corr} = 0$ ns. We arrive at the conclusion that the bulk of the previously seen excess was largely due to an incorrect background estimation assumption as well copious amounts of SM backgrounds with large times and poor calibration methods.

Since this search was performed in a quasi-model independent approach, and there is a modest excess, we do not set a direct cross-section limits on any one particular model. However, we do note that we anticipate that this search is sensitive to GMSB breaking models of SUSY in Light Neutralino and Gravitino (LNG) models [43]. As discussed in Chapter 1, the LGN models sparticle production is dominated by $h^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$ pairs, which is significantly different from those of the more conventional SPS-8 models which produce $\tilde{\chi}_1^0$ pairs at the end of long decay chains. It is certainly possible to do a quantitative estimate of the sensitivity to models amenable to LNG scenarios, but this will be done in the next generation of this analysis using the full Tevatron dataset of $\sim$10 fb^{-1}. For completeness we note that a phenomenology paper [43] shows that we expect to have sensitivity to the regions where the $\tilde{\chi}_1^0$ has long enough lifetime to produce a delayed photon and assume that only $\tilde{\chi}_1^0$ pairs are produced in the final state. In the next section we address future prospects that can lead to a more sensitive search to $h^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma + \not{E}_T$ as well as a further exploration of the intriguing excess that remains in the exclusive $\gamma_{delayed} + \not{E}_T$ final state.

8.3 Future Prospects

At the end of a analysis it is always worth looking back to see what areas could be improved, and followed up on by future scientists. A few areas that remain to be explored that could result in improving upon the analysis laid forth in this thesis include:

- **Analyze the full 10 fb^{-1} dataset:**

  The most straightforward thing to do is to add more data. Since this analysis only utilized $\sim$60% of the Tevatron data set, adding the additional data will enhance our sensitivity to new physics models as well as aid in clarifying if the modest excess is due to a statistical fluctuation or not.

- **Reducing the systematic error on the wrong vertex mean:**

  The largest systematic uncertainty on the number of background events in the signal region comes from the measurement of $< t^0_{corr} >$ using the "no vertex" sample. The Gaussian fit results in an uncertainty of 0.17 ns on the mean which in turn causes a $\pm$35 event uncertainty in our prediction.

  We quickly describe a second method that has been explored [84] in order to reduce this uncertainty. This method utilizes a binned maximum likelihood fit of the data in the no vertex sample as well as in the control and bulk regions. The likelihood fit is performed over events with a vertex in the bins spanning $V \equiv t_{corr} \in$ [-7 ns, 2 ns] $\cup$ [20 ns, 80 ns], and for events without a vertex in the bins spanning $N \equiv t^0_{corr} \in$ [-3 ns, 5 ns] $\cup$ [20 ns, 80 ns]. This method of estimating the wrong vertex mean is shown to reduce the overall uncertainty and thus improves our sensitivity to new physics. We anticipate that this technique will reduce the uncertainty on the number of SM background events in the signal region by $\sim$30%. However, we do not speculate on how it will affect the prediction of the mean value of the SM background prediction.

- **Reducing the cosmics ray background:**

  The largest background in the exclusive $\gamma_{delayed} + \not\!\!E_T$ analysis remains events coming from cosmic ray events. We estimate a cosmic ray event rate of ∼32 events per nanosecond. This rate remains even after new optimized cuts outlined in Section 4.2. One additional option that takes advantage of the fact that there is no true collision for cosmic ray backgrounds is that all vertices must be produced by an unrelated min-bias collision. Thus, one way to reduce this background is to increase the ΣP_T required on reconstructed SpaceTime vertices. This has the additional advantage that it would increase the overall number of events which are classified as not reconstructing a vertex, giving more statistics to the no-vertex sample and thus reducing the uncertainty of the measurement of the wrong vertex mean.

  An important caveat comes along with increasing the ΣP_T required on the SpaceTime vertex, namely the effect this could potentially have on reducing the efficiency for a hypothetical signal. Thus a study would need to be performed on various signal models to determine what trade-off, if any, between efficiency and rejection power can be made.

- **Optimizing event level cuts:**

  As mentioned before, many of the event level selection requirements were kept the same in order to allow a comparison with the previously performed analysis. A study of optimizing the E_T and $\not\!\!E_T$ kinematic requirements as well as the optimizing of jet and track veto parameters may allow this search to extend its potential sensitivity to new phyiscs. For example, we note that the trigger we use in this analysis (see Section 2.3) allows us to move the E_T and $\not\!\!E_T$ thresholds down to 30 GeV. The previous reason for choosing an E_T cut of 45 GeV was to reduce the $W \rightarrow e\nu \rightarrow \gamma_{fake} + \not\!\!E_T$, but now that additional cuts already reduce this background we can consider lowering this cut. We expect that a Higgs of 125 GeV would produce low E_T photons and $\not\!\!E_T$, but this would require a full optimization between background and signal expectations. A second possibility is to allow the presence of a second photon in the event since there is a reasonable possibility that one might have been created in our signal production model, especially at low lifetimes.

In conclusion, we have presented a search for new physics in the exclusive $\gamma_{delayed}$ + $\not\!\!E_T$ final state. We have used more data, multiple analysis improvements, and a better understanding of the backgrounds to follow up on a interesting hint in a preliminary search. We have found that the majority of that excess was from previously unknown and poorly modeled backgrounds, but a modest excess remains. With a clear view of potential new physics models, the rest of the Fermilab Tevatron data and potential improvements and optimization to a future analysis, we will either uncover a discovery or show that this was just one of the many statistical fluctuations that occur in collider experiments. Only time will tell.