

Search for New Physics in the Exclusive $\gamma +$ Missing Transverse Energy Channel in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

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We are performing a search for ‘new physics’ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using the Collider Detector at Fermilab in the exclusive $\gamma +$ Missing Transverse Energy Channel. This study will attempt to verify an earlier excess found in the exclusive $\gamma +$ Missing Transverse Energy Channel for photons that appear to be delayed in order to determine if this could be the result of collisions that produce Supersymmetric (SUSY) particles or a prosaic background that is not well understood. If confirmed this would be the first direct evidence of SUSY and give us important clues to the dark matter problem and help understand the early universe. If our results are found to be a product of background sources we will be able to extend the current understandings of models for neutral long lived objects that decay to photons by increasing our current sensitivities to the worlds highest limits.

PACS numbers:

INTRODUCTION

The standard model of particle physics (SM) [1] describes many properties of elementary particles to a high precision. However, motivated by philosophical and computational reasoning, it is believed to be incomplete and simply a low energy approximation of a much more fundamental description.

The observation of an unusual event recorded at the Collider Detector at Fermilab (CDF) during Run I (“CDF $ee\gamma\gamma$ Missing Transverse Energy (MET)”) [2] and the theoretical motivations for extensions to the SM make examining events with photons and missing energy in their final state very compelling. Additionally, the results of a preliminary study of the delayed time distribution for photons in the exclusive $\gamma +$ Missing Transverse Energy (MET) channel have found an excess beyond predictions of the SM. By using the measurement tools of CDF, which has been equipped with a timing system for photons (EMTiming), we will have access to precision measurements of the time of arrival of photons in the detector and will attempt to understand the results of the preliminary study. This project will allow us to further complement studies done in the $\gamma +$ MET+Jet [3] and the $\gamma\gamma +$ MET final state [4] by either explaining a new phenomenon in physics or by extending the limits to our understanding of the SM.

In the following pages the theoretical motivations for searching for new physics in the exclusive $\gamma +$ MET final state will be outlined. A description of the tools used in the search, the changes and improvements to the modeling of the Tevatron at high luminosity that are taking place for use with this thesis, and the outline for the search that is currently under way will also be described. This study offers a unique opportunity to verify interesting and compelling results for a potential new discovery

in particle physics or to extend the limits on our models to the worlds best sensitivity.

THEORY

Supersymmetry

The Standard Model (SM) describes the vast majority of existing experimental data, nevertheless it is considered an incomplete description of the particle world. In addition to being incapable of accounting for many of the cosmological observations indicating that our universe is dominated by a weakly interacting very massive form of matter known as “Dark Matter”, the standard model also suffers from a “Hierarchy” problem [5] with divergences in the calculations of the Higgs mass.

A possible extension of the SM which solves these problems is known as Supersymmetry (SUSY), which postulates a symmetry between fermions and bosons. That is to say, for each type of fermion (quark and lepton) that can exist in nature there would exist a bosonic super partner (squark and slepton), and for each gauge boson (force carrying particles) there would exist a fermionic super partner (gaugino).

There have been no observations of the existence of these supersymmetric counterparts to the SM in experiments; this implies that the symmetry postulated by SUSY must be broken and the masses of the SUSY particles must be greater than their standard model counterparts. The way this symmetry is broken distinguishes the SUSY models into different classifications, three of the most important being: Supergravity (SUGRA) [6], Anomaly Mediated SUSY Breaking (AMSB) [7], and Gauge Mediated SUSY Breaking (GMSB) [8]. Additionally, all of these models theorize that SUSY can be broken

at energies of just a few TeV, thus making the predicted new particles accessible by current and future accelerators like the Tevatron (FNAL) and the LHC (CERN).

Gauge Mediated Supersymmetry Breaking (GMSB)

The model for this analysis that we will be most focused on is the Gauge Mediated Supersymmetry Breaking (GMSB) models with R-parity conservation. In this model the electroweak symmetry breaking mechanism originates in a “hidden sector” (which is not further specified in the model) and is mediated to the visible scalars and fermions by messenger fields. R-parity is a discrete multiplicative symmetry represented by the conservation of the quantum number $R_p = (-1)^{3B+L+2S}$ where B denotes baryon number, L the lepton number, and S the spin of the particle. The SM particles have $R_p = +1$ and their superpartners have $R_p = -1$. If R_p is conserved, superparticles can only be produced in pairs and the Lightest Supersymmetric Particle (LSP) should be stable and would be the Dark Matter candidate.

The version of this model that we will be considering for our analysis is well specified by 6 free parameters: the SUSY breaking scale Λ , which determines the gaugino and scalar masses, the messenger mass scale (M_m), the number of messenger fields (N_m), the ratio of the neutral Higgs vacuum expectation values ($\tan(\beta)$), and the sign of the Higgsino mass parameter ($\text{sgn}(\mu)$). Additionally, in this model (SPS8 GMSB), the next-to-lightest supersymmetric particle (NLSP), $\tilde{\chi}_1^0$, decays via $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$ (\tilde{G} being the LSP) (See Fig 1 for example Feynman Diagram) with a branching ratio of $\sim 100\%$, but leaves the $\tilde{\chi}_1^0$ mass and lifetime as a free parameter.

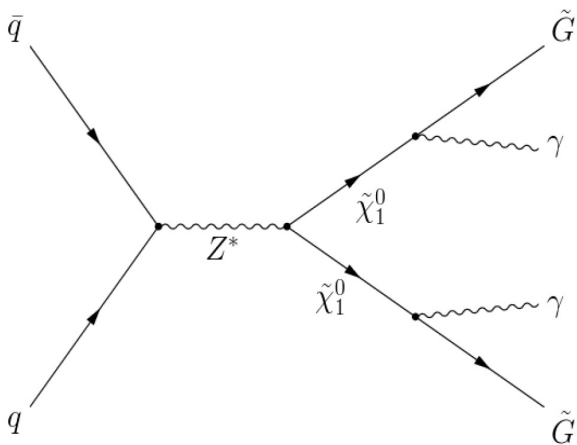


FIG. 1: Feynman diagrams N1 pair production processes at the Fermilab Tevatron for SPS 8 GMSB Model

GMSB models with a nonzero $\tilde{\chi}_1^0$ lifetime and a mass for the $\tilde{G} \sim 1.0 - 1.5 \text{ keV}/c^2$ are favored as they are consistent with current astronomical observations of models

of the early universe that take inflation into account [9]. In this model the $\tilde{\chi}_1^0$ lifetime is related to the \tilde{G} and $\tilde{\chi}_1^0$ masses which favors a $\tilde{\chi}_1^0$ lifetime of several nanoseconds and a decay length that can be macroscopic of the order of meters

TOOLS

Tevatron and the CDF Detector

This analysis will be conducted at the Tevatron at Fermi National Laboratory in Batavia, IL. The Tevatron is a $p\bar{p}$ synchrotron with center-of-mass energy of $\sqrt{s} = 1.96 \text{ TeV}$. The Tevatron collision rate is 1.7 MHz with 396 ns separated bunches.

The Tevatron has two multi-purpose detectors, the Collider Detection at Fermilab (CDF, which is the one we will use) and DØ. CDF is a general purpose solenoid detector which combines precision charged particle tracking with fast projective calorimetry and fine grained muon detection [10]. The tracking systems are contained in a superconducting solenoid 1.5 meters in radius and 4.8 meters in length, which generates a 1.4 Tesla magnetic field parallel to the beam axis. These tracking systems consist of multi-layer silicon microstrip detector (SVXII) and a large open cell drift chamber (COT) covering a pseudo rapidity range $\eta < 1$. The SVX consists of two components: a micro-vertex detector for impact parameter measurements and, for the forward region, $1 < |\eta| < 2$ two silicon layers at intermediate radii and a stand-alone silicon tracking over the full region $|\eta| \leq 2$, which is assisted by the Intermediate Silicon Layer (ISL) at a radius of 22 cm. The COT has 96 measurement layers between the radius of 40 cm and 137 cm organized into alternating axial and stereo superlayers. The calorimeter system is organized into electromagnetic (EM) and hadronic (HAD) sections occupying the region between 150 cm and 350 cm radius covering $|\eta| \leq 3.6$ with the muon detector in the outermost position.

CDF Subdetectors Relevant for This Analysis

We next describe detector elements that are used for photons. The CDF calorimeter plays a key roll in measuring electron, photon, and jet energies. The calorimeter is subdivided into projective towers in η and ϕ which are directed to the nominal interaction point at the center of the detector. The Central region ($|\eta| \leq 1.1$) consists of central electromagnetic (CEM), central hadronic (CHA), and wall hadronic (WHA) calorimeters. The CEM is equipped with a layer of crossed wire and strip gas chambers (Central EM Shower Detector) in order to give two-dimensional profiles of the photon showers. A system in

front of the central electromagnetic calorimeters of proportional wire chambers (the Central Preshower (CPR)) which uses a magnet coil as ‘preradiator’ to determine whether showers start before the calorimeter. Finally, the plug region ($1.1 \leq |\eta| \leq 3.6$) consists of plug EM calorimeter (PEM).

EMTiming

In the fall of 2004, a timing system in the EM calorimeter (EMTiming) [11] was installed and commissioned. In many ways the motivation for the installation of this system was (1) to help reject photons from cosmic ray and beam halo sources and (2) to provide an additional way of identifying any events of the sort of the $e\bar{e}\gamma\gamma$ Missing Transverse Energy that was found in CDF Run I.

The EMTiming system covers the central and plug regions of the calorimeter in the region $|\eta| \leq 2.1$ and measures the arrival time in each tower where the particles (like photons, electrons, or jets) deposit an energy of at least ~ 3 GeV. The basic hardware design for the EMTiming system is similar to the hadron TDC system in that the signal comes out of the photo multiplier tube (PMT) and is collected with the tubes from the rest of the wedge on a transition board. All lines are passed into an Amplifier Shaper Discriminator (ASD) that turns the signal into a pulse for use by a Time to Digital Converter (TDC), which is then read out to the event. Earlier tests of this system have shown that the resolution of the EMTiming system is ~ 0.5 ns [11].

OVERVIEW OF THE SEARCH

This search will select based on kinematic properties of events that may contain long-lived particles that decay to photons as contrasted to photons produced at the collision. A suitable variable to describe the distinction between delayed photons and those produced promptly is known as t_{corr} :

$$t_{corr} \equiv (t_f - t_i) - \frac{|\vec{x}_f - \vec{x}_i|}{c} \quad (1)$$

where $t_f - t_i$ is the time between the collision and the arrival time of the photon and $|\vec{x}_f - \vec{x}_i|$ is the distance between the final position of the photon and the collision point. The scenario can be visualized in Fig 2. [4] All four variables are capable of being measured by the CDF detector [12], and with the sensitivity of the EMTiming system of ~ 0.5 ns the detector should be sensitive to SM

photons, which defined for perfect measurements to have $t_{corr} \equiv 0$, and long-lived particles with t_{corr} of the order of nanoseconds.

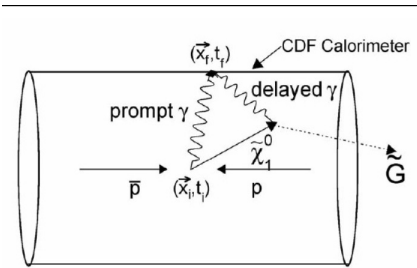


FIG. 2: An example of a GMSB process with a long lived $\tilde{\chi}_1^0$ decaying into a \tilde{G} and a photon inside the CDF detector. The photon produced would travel to the detector wall and deposit its energy in the EM calorimeter. A prompt photon would travel directly to the detector wall and arrive with a t_{corr} on average of 0. However, relative to the collision vertex time, the photon from the $\tilde{\chi}_1^0$ decay would appear ‘delayed’ in time.

The t_{corr} for a perfectly measured prompt photon from SM sources is exactly 0. However, for photons from delayed decays, such as those from SUSY / GMSB, this value will be > 0 . Additionally, the \tilde{G} produced in the decay is expected to leave the detector without interacting, giving rise to significant Missing Transverse Energy that should provide another handle to help separate signal from SM backgrounds.

Previous searches in the γ +MET+Jet and the $\gamma\gamma$ +MET channel has shown great success in utilizing this variable in the search for new physics using photons. While these searches have yet to discover any signal from delayed photons, a preliminary study completed in 2008 [13] has found an excess in the exclusive γ +MET channel as shown in Fig 3. This was an analysis where the background was fit in the region from -7 ns \leq Photon Time ≤ -2 ns and the signal region (2 ns \leq Photon Time ≤ 7) was blinded. However, due to the difficult nature of estimating many of the backgrounds in this type of search, it is not clear that all sources of backgrounds have been taken into account yet, thus making these results difficult to understand. It is the goal of this thesis to expand on these results to take in more available data and to vet all possible background sources for this excess that have not been considered before.

Events Selection and Backgrounds done in Preliminary Study

In this section we will briefly outline the work done previously in the event selection and background rejection for the exclusive γ +MET search that lead to the obser-

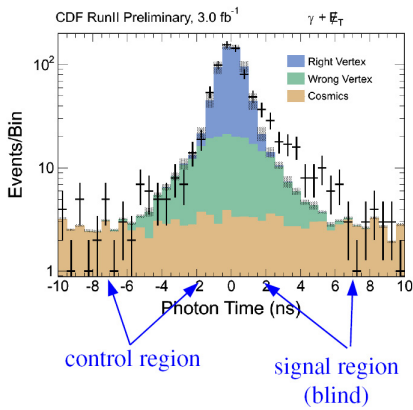


FIG. 3: Preliminary results from a search for exclusive γ +MET showing an excess beyond prediction in the signal region. Note: The blue distribution shows the estimation for the timing distribution if we were to correctly calculate where the collision occurred in our detector (Collision Vertex), and the green shows estimation for the timing distribution arising from when we calculate the wrong Collision Vertex. Finally the brown distribution shows the timing distribution for photons coming from Cosmic Background sources

TABLE I: Event Selection Criteria used in the Preliminary γ +MET Study

Baseline Selection Requirements
Photon $E_T > 45$ GeV
MET > 45 GeV
Veto Jet $E_T > 15$ GeV
Veto Lepton $E_T > 10$ GeV

vance of the excess. The event selection criteria will be considered as a template for the ongoing analysis with the caveat that an optimization and expansion is likely to occur when new sources of possible backgrounds are taken into account.

Table I shows the baseline event selection that was used in the preliminary study of the exclusive γ +MET channel that led to the excess shown in Fig 2. These variables were chosen to reject against backgrounds listed in Table II. While this list of background sources is certainly extensive it is believed that there could be other sources that have not been taken into account and may cause a bias that is not yet accounted for.

TABLE II: Backgrounds in the γ +MET Study

Backgrounds
Cosmic Ray Source Photons
$Z \gamma \rightarrow \nu\nu\gamma$
$W \rightarrow e\nu \rightarrow$ fake photon ν
$\gamma\gamma$
γ +Jet
Beam Halo

The standard photon ID cuts are used in the data selection along with a no track trigger for electrons and photons in the samples. The original data sample was 3 fb^{-1} and plans on expanding the data set are currently underway. To allow for a corrected time of flight to be constructed an event vertex must be chosen. However, since there is lepton and jet rejection as part of the event selection this proves to be a more difficult process and any mis-modeling in the effects of picking the wrong vertex could lead to a time bias. In the preliminary study the vertex was required to have at least 3 tracks and a $\sum P_t > 5$ GeV and gave a wrong vertex estimation of $\sim 30\%$.

Expanding Possible Background Sources and Vertex Finding Algorithms

One of the many possible sources for the excess seen in Fig 2 that needs to be explored is the possibility that there are real SM physics happening out at high vertex position (Z). A good example of this is $W \rightarrow e\nu$ where the W is produced at $|Z| > 80$ cm and the electron flies across the detector and is misidentified as a photon. As figure 3 shows, such physics occurring out at High Z could lead to the excess of the sort that we have seen in the preliminary results. [14]

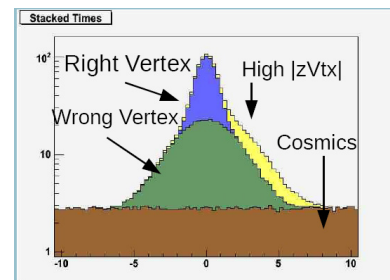


FIG. 4: Toy Monte Carlo Result demonstrating that physics happening at high Z vertex could lead to a timing bias.

In order to properly model this a great deal of work is going into understanding and enhancing our Monte Carlo tools at CDF and attempting to obtain a reasonable estimate as to the effects of this background source.

Additionally there are beam related phenomenon's that may prove to enhance the background source of physics coming from high Z . One case currently being studied that is not taken into account is the widening of the longitudinal beam profile during the course of a store.[15]

Originally in our MC models the width of the proton and anti-proton longitudinal profiles was taken to be a constant and the correlation between the timing distribution and collision position had been measured and understood. However, recent studies have shown that over the

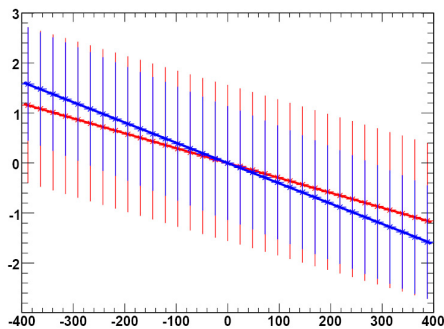


FIG. 5: Monte Carlo Profile Plot of the correlation between the vertex collision position (x axis) and the collision timing information (y-axis) at the beginning of the store (blue) and at the end of the store (red).

course of a store the profile widths for both the protons and anti-protons widen in a significant way and change the correlation for timing and collision position (Fig 5). As shown in Figure 6 this leads to an enhancement of the rate of events occurring out at high Z vertex and could lead to a further unaccounted for timing bias. The full implications of this effect are continuing to be studied in Monte Carlo and in data.

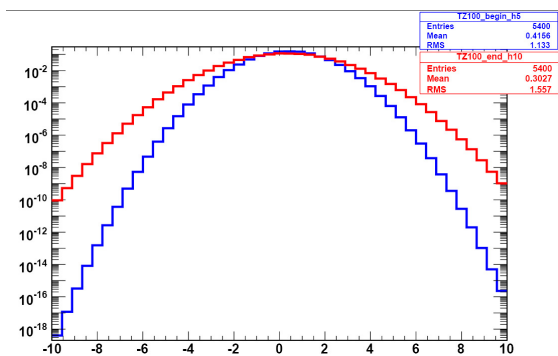


FIG. 6: Time of Collision (ns) when Z Vertex = -100 cm at the beginning of a store (blue) and at the end of a store (red). This demonstrates that as the beam profile widens the rate of events occurring out at large Z vertex could lead to a timing bias. (Note: Event rates has been normalized to 1)

In addition to these processes there is a need explore other sources and hypothesizes. One such example could be a SM event that produces γ +Jet at high Z where the Jet travels down the beam pipe and is thus never identified.

Another study in progress that is currently being explored is to enhance our ability to find the true Z collision point in the exclusive γ +MET channel. Since there are no other objects besides photons available in our final state, vertex selection is very unreliable with an estimate of the wrong vertex rate of $\sim 30\%$. Since, as we've already begun to demonstrate, Z vertex distributions may be important in the distinguishing of large Z vertex physics

from GMSB sources we may need another method of measuring the Z distribution.

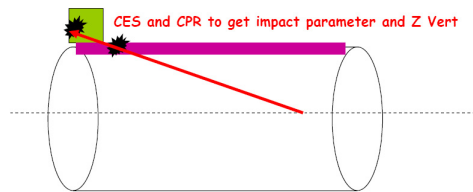


FIG. 7: Representation of how using CPR/CES pointing can provide another measure of the Z vertex for events in exclusive γ +MET

One possible method is the use of the Central Pre Radiator (CPR) and the Central Electromagnetic Strips (CES) to extrapolate a very coarse Z measurement. The basic idea (as shown in Fig 6) is if there is a hit in the CPR we can extrapolate back from the CES cluster and the CPR pad back to the beamline. Using only CES clusters associated with good photon candidates and searching for all pads consistent with $-200 \leq Z \text{ Vertex} \leq 200$ this includes three pads in Z and three pads in ϕ with there being 12.5 cm/pad in Z and 4.19 deg/pad in ϕ .

A early Monte Carlo [14] study has shown some success in using this to gain a coarse handle of the Z vertex and a full study with $W \rightarrow e\nu$ from data is currently taking place.

NEXT STEPS / CONCLUSIONS

A preliminary study in the exclusive γ +MET channel has shown an interesting excess and signature for what would signal new physics. But to quote the great Carl Sagan “*Extraordinary claims require extraordinary evidence*”, and as such there is much work to do before a claim of a discovery can be made. This thesis will focus on answering whether the observed excess in the preliminary study is real and new physics or a prosaic background biasing our results. If this excess is found to be new physics we will begin the process to learn more about the underlying physics that created it. However, if this is found to be a background effect we will unambiguously show this and set limits on our model.

The focus of this thesis will be an attempt to vet all possible SM explanations of this signal and to attempt to understand the physics that could go into producing these ‘delayed’ photons. This work will include, but is not limited to, the changing and enhancing of our models for SM physics in our experiment and in our detector at high luminosity, the use and re-optimization of the set of cuts that will make us most sensitive to GMSB like ‘delayed’ photon physics while attempting to take into account all

relevant backgrounds and remain as model independent as possible

Much work is continuing to reproduce the results that were seen in the preliminary study as well as incorporating new GMSB simulations and other tools into this analysis. While the task remains open and complex, it is still one of possible great discovery and interest to the physics community. This work will go in parallel to other studies done in the $\gamma\gamma$ +MET and γ +MET+Jet and γ +MET+Isolated track final state to enhance the limits on our models for delayed photons or to expand our understanding of elementary particle physics into a new and exciting horizon.

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- [1] See, for example, F. Halzen and A.D. Martin *Quarks and Leptons* (John Wiley and Sons, New York, 1984); C. Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions* (Addison-Wesley, Reading, MA, 1983).
- [2] eeggMET evt: S. Park, in Proceedings of the 10th Topical Workshop on Proton-Antiproton Collider Physics, Fermilab, 1995 p.62
- [3] CDF Collaboration, D. Acosta et. al., Phys. Rev. Lett. 99 (2007) 121801
- [4] CDF Collaboration, D. Acosta et. al., Phys. Rev. D 71 (2005) 031104(R)
- [5] SUSY and Naturalness: C. Kolda, H. Murayam, arXiv:hep-ph/0003170.
- [6] SUGRA: See for example R. Arnowitt, P. Nath, arXiv:hep-ph/9708254
- [7] AMSB: See for example F. Paige, J. Wells, arXiv: hep-ph/0001249
- [8] GMSB: C. Kolda, arXiv:hep-ph/9707450
- [9] GMSB and comol. constr.: H. Pagels, J. Primack, Phys. Rev. Lett. 48 223 (1982); and references therein
- [10] The CDF IIb Collaboration, "CDF Run IIb TDR", CDF 6261; CDF Collaboration, F. Abe et. al., FERMILAB-Pub-96/390-E.
- [11] M. Goncharov, et. al., *The Timing System for the CDF Electromagnetic Calorimeters* Nucl. Instrum. Meth. A563, 543 (2006)
- [12] At CDF x_f is measured by the Shower Max Detector in the electromagnetic calorimeter, x_i is the collision point, determined through methods described within and the Time of Flight systems which use the momentum and the measured time of flight of the charged particles of the underlying event emergin from the collision point, with t_f being the time of arrival of the photon from the EMTiming system.
- [13] M. Goncharov, priv. comm. currently at MIT formerly with TAMU.
- [14] A. Aurisano Collaborator and fellow grad. student working one the exclusive γ +MET analysis
- [15] M. Martens and P. Bagley *Luminosity Distributions During Run II* CDF Note