Exotic Photon Searches at CDF II

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We present recent results of searches for exotic photons at CDF II. In the first signature-based search, we search for anomalous production of two photons with additional energetic objects. The results are consistent with the standard model expectations. In the second analysis, we present a signature-based search for anomalous production of events containing a photon, two jets, of which at least one is identified as originating from a bottom quark, and missing transverse energy. We find no indications of non-standard model phenomena. Finally, a search for a fermiophobic Higgs in the diphoton final state is presented. Since no evidence of a resonance in the diphoton mass spectrum is observed we exclude this Higgs boson with mass below 106 GeV/c^2 at a 95% confidence level.

1. Introduction

Over the last decades, the fast developments in phenomenology and model-building have high-energy physicists at the Tevatron with a number of new physics scenarios to investigate. Searches at CDF have been either broad signature-based searches in accessible data samples for any discrepancy with the standard model (SM) in event yields or a specific new physics model-based searches. The signature-based searches proceed quickly in unprejudiced way as well as cover any new physics models. The model-based searches are highly sensitive for a particular model, and provide limits on the model. In this report we present two results using the signature-based search approach and one result in a model-based approach. All of these analyses use photons in the final state.

2. Search for Anomalous Production of

+ X

We define a "baseline" sample with two isolated, central (0.05 < j j < 1.05) photons with \( E_T > 13 \text{ GeV} \). We then select subsamples which also contain at least one more energetic, isolated and well-defined object or where two photons are accompanied by large missing transverse energy \( E_T \). The additional object may be an electron (e), muon (\( \mu \)), lepton (l), or jets. The integrated luminosity for each subsample varies from 1 to 2 fb \(^{-1}\). In next subsections we address each + X (X = e\( \mu \); and \( \ell \)) subsample in turn. We describe the definition of the subsamples, the calculation of the SM predictions, and the comparison of the data and the predictions. Unless it is otherwise noted, all analyses use the same definition of the additional objects and kinematic variables: electrons, muons, leptons, jets, soft unclustered energy, \( E_T \), and \( H_T \). The \( H_T \) is defined as a scalar sum of \( E_T \) and \( E_T \)'s of all identified photons, leptons, and jets.

2.1. The + e Final State

We search in 1.1 fb \(^{-1}\) of data for anomalous production of events containing two photons and at least one additional electron or muon. The selected e and \( \mu \) events must have at least one electron (central or forward) or muon (j j < 1.0) candidate with \( E_T > 20 \text{ GeV} \) and \( p_T > 20 \text{ GeV}/c \), respectively. Backgrounds for the e and \( \mu \) signatures of new physics include the SM production of \( Z \) and \( W \) in association with two photons \( Z ' + W ' \), or the final-state leptons. Also there are m isidentified backgrounds (fake photons or leptons). Backgrounds for the \( Z \) channel is dominated by Z production with an electron being m isidentified as a photon. This is estimated by defining a sample of events with two electrons and one photon, then applying a probability, which is derived in data, for an electron to be misidentified as a photon. We find no events and expect 0.79 \( \pm 0.11 \) events. Figure 1 shows the \( H_T \) distributions from data and the predicted backgrounds and we do not see any evidence for anomalous production of e and \( \mu \) events.

2.2. The + \( \ell \) Final State

We search for 2.0 fb \(^{-1}\) of data for events with two photons and a hadronically decaying \( \ell \) lepton. The selected \( \ell \) events must have at least one \( \ell \) lepton candidate identified using the tight requirements and passing \( E_T > 15 \text{ GeV} \). We consider two sources of backgrounds: the SM production of \( W \) or \( Z \) with photons and events with jets m isidentified as \( \ell \) leptons. The dominant background in this search is from \( \ell \) + jets events where one of the jets is m isidentified as a \( \ell \) lepton. To estimate this background, we select events with two photons and a \( \ell \) loose \( \ell \) lepton candidate and apply the jet
m isolation probability. Since the m isolation probability is different for jets originated by quarks or by gluons, and the ratio of quark jets to gluon jets may be different than in the sample used to derive the jet m isolation probability, we corrected for this effect. We observe 34 events with 46.10 expectation. Figure 2 also shows the Ht distribution for the selected + candidate events and the predicted SM background, which indicates there is no anomaly.

2.3. The + E_{T} Final State

We search for the anomalous production of two photons and large missing transverse energy ($H_{T}$) in 2 fb⁻¹ of data. The $H_{T}$ is defined as an energy imbalance in the calorimeter and is an experimental signature of neutrino or new weakly interacting particle. The $H_{T}$, however, can be mimicked by a simple energy misreconstruction in SM events (false $H_{T}$); for example, fluctuations in jet energy measurements. A better separation between events with real and fake $H_{T}$ can be achieved if a sign of cancels of the measured $H_{T}$ is considered rather than its absolute value. The $H_{T}$ sign of cancels is a dimensionless quantity based on the energy resolution of jets and soft unclustered energy, taking into account the event topology. As shown in Fig. 3, the $H_{T}$ sign of cancels distributions have very different shapes in events with fake and real $H_{T}$: exponentially falling (solid line) and almost at shapes, respectively. Thus, the $H_{T}$ sign of cancels is an effective tool in separating such events. For example, a cut on the $H_{T}$ sign of cancels which reduces the mismeasured-energy background by a factor of 10⁵, the sample becomes dominated by W production, where the electron is m isolated as a photon. This background is estimated from Monte Carlo (MC) normalized to data. We observed 23 events and an expectation of 27.3. 2.3 events.

We have also re-optimized the sample for the GM SB model [1]. In this model, all SUSY pair production decays to two neutralinos, the next-to-lightest SUSY particle, each of which then decays to a photon and a gravitino, the lightest SUSY particle ($\tilde{G}^0$). We thus have two photons, $E_{T}$, and other high-$E_{T}$ objects in the final state. Using an optimized set of cuts ($H_{T}$, sign of cancels, $H_{T}$, and $\tau$ between the two photons) we set the world’s best limit on the mass of 149 GeV/c² at lifetime below 1 ns. The results are shown in Fig. 4.
3. Search for Anomalous Production of Events with , jet, b-quark jet, and \( \mathbb{E}_T \)

We search for new physics in the inclusive \( b\mathbb{E}_T \) channel using 2.0 fb\(^{-1}\) of data. We select an enhanced sample of events collected by an inclusive isolated photon trigger. We require a central (\( j j < 1 \)d) photon with \( \mathbb{E}_T > 25 \) GeV, two jets with \( j j > 20 \) and \( \mathbb{E}_T > 15 \) GeV, at least one of which is identified as originating from a \( b \)-quark (\( b \)-tagged), and \( \mathbb{E}_T \) greater than 25 GeV.

The backgrounds are misidentified photons (\( \text{m
\hspace{0.01cm}misident}\) ), true photon plus light quark jet \( \text{m
\hspace{0.01cm}misident}\) as heavy flavor (\( \text{true
\hspace{0.01cm}miss}\) ), true photon plus true \( b \)-tagged jet (\( b\)), true photon plus \( c \)-quark jet (\( c\)), and true photon plus \( c \)-quark jet (\( c\)). The misidentified background is estimated from the data sample by using cluster-shape variables from the CES and hit rates in the CPR (the CES/CPR method). This technique allows the determination of the number of photon candidates in the sample that are actually misidentified jets as well as the corresponding shapes of the distributions of kinematic variables.

The true \( \text{m
\hspace{0.01cm}misident}\) \( b \) background is estimated by first selecting events and then applying the true-photon weight (the probability that a photon candidate is a photon) determined using the CES/CPR method and the heavy-\( b \) tag method. Because the CES/CPR method and the \( b \) tag method provide event-by-event weights, we are able to determine the shapes of kinematic distributions as well as the number of events for this background.

We estimate the \( b \) and \( c \) backgrounds by generating MC events. We obtain the overall normalizations of these backgrounds by using the secondary vertex \( m \) mass distribution of the tagged jets (\( m \) (SV)), to ten plates built from the \( m \) mass distributions of the expected SM components. We first subtract the contribution due to \( m \) misidentified photon events by using the CES/CPR method to obtain the number of \( m \) misidentified photon events. We then estimate the fraction of heavy flavor events with a misidentified photon by using the secondary vertex \( m \) mass distribution in a sample enriched with jets faking photons. We then
4. Search for a Fermiophobic Higgs Boson

The SM prediction for the Higgs, $h$, branching ratio is extremely small. However, in [fam i lopho bic] models, where the coupling of the Higgs boson to fermions is highly suppressed, the diphoton decay can be greatly enhanced. Since for this fam i lophobic case, the diphoton nominal state dominates at low Higgs boson mass the diphoton nominal state becomes the preferred search channel.

We select a diphoton sample from 3.0 fb$^{-1}$ of data, triggered by diphoton trigger. We then require both photons to be located within central region ($j < 1.05$), referred to as [central-central region], or one photon to be in this region and the other photon in the plug region ($1.2 < j < 2.5$), referred to as [central-forward region]. Individual photons are required to have $E_T > 15$ GeV, while the diphoton pair is required to have mass of $m > 30$ GeV/c$^2$. However, the fam i lophobic Higgs boson is only produced at a non-negligible rate in association with a W/Z boson or via vector boson fusion process. Since associated production dominates the production process the optimization was performed on the basis of the associated production process alone. A selection based on the following observables was optimized: diphoton transverse mass (p$_T$), transverse mass of the second highest p$_T$ jet ($p_T^{2}$) for hadronic decays of $W = Z$, and missing transverse energy ($E_T^*$) or transverse mass of the isolated track ($p_T^{iso}$) for lepton decays of $W = Z$. A variety of sets of these requirements which would select evidence of the $W$ or $Z$ boson were carried out, but the only single requirement that the diphoton transverse mass (p$_T$) be greater than 75 GeV/c$^2$ is approximately as sensitive as any combination of the other selection requirements. With this requirement on p$_T$, roughly 30% of the signal remains while more than 99.5% of the background is removed.

The decay of a Higgs boson into a diphoton pair appears as a very narrow peak in the invariant mass distribution of this diphoton pair. The diphoton mass resolution determined from simulation is better than 3% for the Higgs boson mass region, as shown in...
Figure 7: In (a) and (b) the expected shapes of invariant Higgs mass of the signal from simulation are shown for central-central and central-forward regions, respectively. In (c) the invariant mass distribution of central-central (top) and central-forward (bottom) photon pairs after the requirement of $p_T > 75 \text{ GeV}/c$ with the $t$ to the data for the hypothesis of a $m_h = 100 \text{ GeV}/c^2$.

No evidence of such a resonance appears in the data so we set the 95% C.L. upper limit on its both on the production cross section ($\sigma(h \to \gamma \gamma)$) and the branching fraction for the fermiophobic Higgs boson decay to diphotons as a function of $m_h$ up to 106 $\text{ GeV}/c^2$, as shown in Fig. 8(b). This result is now published \[8\].

Figure 8: The 95% C.L. upper limit on the production cross section (a) and the branching fraction (b) for the fermiophobic Higgs boson decay to diphotons, as a function of $m_h$.

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