

Combination of CDF and DØ Limits on a Gauge Mediated SUSY Model Using Diphoton and Missing Transverse Energy Channel

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We combine the results of the CDF and DØ searches for chargino and neutralino production in Gauge-Mediated SUSY using the two-photon and missing E_T channel. The data are $p\bar{p}$ collisions produced at the Tevatron with $\sqrt{s} = 1.96$ TeV, with 202 pb⁻¹ collected at CDF and 263 pb⁻¹ collected at DØ. The combined limit excludes a chargino mass less than 209 GeV/ c^2 . This result significantly extends the individual experimental limits.

I. INTRODUCTION

Both CDF[1] and DØ [2] have reported on the search for an excess of events containing two high- p_T photons and significant missing transverse energy. The results have been interpreted in the framework of a model of Gauge-Mediated Supersymmetry-Breaking (GMSB) with a neutralino as the next-to-lightest supersymmetric particle.

The details of the model were chosen at the Snowmass Workshop[3]. The complexity of a GMSB model is reduced to a one-parameter model, or model-line, that is qualitatively representative of the phenomenology. The model-line is defined as a function of a single mass parameter, Λ , which is varied to scan the masses of the particles in the model. At the Tevatron, this model allows for a significant production of the lightest chargino and second-lightest neutralino. These particles undergo a cascade decay to the lightest neutralino, which itself decays to a photon and a gravitino. The searches require two identified photons and large missing E_T .

Since the two experiments investigated the same model-line, the mechanics of the combination are straightforward. The details are explained in Section IV. As the cross sections and detection efficiencies vary along the model-line, the particle mass limits are set at the highest mass where the model can be excluded. We will report the limits on chargino mass and Λ . For clarity, we will discuss the details of the results for a chargino mass of approximately 200 GeV/ c^2 , which is near the combined limit, and summarize information for other mass points. The experiments chose different arbitrary mass points to measure efficiencies, so the CDF measurements have been interpolated to the DØ masses. In the following sections, we report the information that enters the combination: efficiency, luminosity, background expectations and data observations.

II. EFFICIENCY AND LUMINOSITY

A. CDF

The CDF analysis requires that each event has a reconstructed interaction vertex, the absolute value of the vertex z is less than 60 cm and the event passes the one of the diphoton triggers. Both photons must be reconstructed in the central detector ($|\eta| < 1$) with $E_T > 13$ GeV and pass fiducial cuts. For isolation CDF requires E_T in a $\eta - \phi$ cone of 0.4 to be less than $0.1E_T$ if $E_T < 20$ GeV, and $2 + 0.02E_T$ if $E_T > 20$ GeV. Photon identification also includes requirements on tracking isolation, the ratio of hadronic to electromagnetic energy, and shower shape. The topological cuts require that the \cancel{E}_T does not point along or opposite to a jet and that there is no evidence of a cosmic ray or beam-related accidental energy deposition. The \cancel{E}_T cut is 45 GeV. The total acceptance times efficiency for signal events with a chargino mass of 200 GeV/ c^2 is 7.3%.

The systematic uncertainty on the efficiency of the photon identification cuts is 13%, determined from the variation of the result using different techniques. Varying the parton distribution functions (PDF) causes a 5% change in the efficiency. Varying the initial- and final-state radiation implies a 10% systematic uncertainty and varying the hard scale Q^2 gives a 3% systematic uncertainty on the acceptance times efficiency.

The analysis includes 202 ± 12 pb⁻¹, where the uncertainty is systematic, coming from the inelastic cross section and the total detector acceptance for inelastic events.

B. DØ

The DØ analysis requires that both photons are reconstructed in the central calorimeter ($|\eta| < 1.1$) and have $E_T > 20$ GeV. The events are triggered by a combination of single-cluster and two-cluster electromagnetic triggers. The events are required to have a reconstructed vertex and not to exhibit patterns of correlated calorimeter noise. Photon clusters are selected from all calorimeter clusters by requiring that: (i) at least 90% of the energy is deposited in the EM section of the calorimeter, (ii) the calorimeter isolation variable $I = [E_{tot}(0.4) - E_{EM}(0.2)]/E_{EM}(0.2)$ is less than 0.15, where $E_{tot}(0.4)$ is the total energy in a cone of radius 0.4 in $\eta - \phi$ space and $E_{EM}(0.2)$ is the EM energy in a cone of radius 0.2, (iii) the transverse and longitudinal shower profiles are consistent with those expected for an EM shower, and (iv) the scalar sum of the P_T of all tracks in annulus of $0.05 < \mathcal{R} < 0.4$ around the cluster is less than 2 GeV/ c . Finally, to reject electrons, photon candidates are required to have no central track well-matched to the cluster.

The efficiency for photon reconstruction and identification was obtained by reconstructing Monte Carlo events passed through a detailed GEANT simulation of the DØ detector. The simulation was verified by comparing to $Z \rightarrow e^+e^-$ data. Special attention has been paid to efficiency dependence on the number of jets in the event and on the distance between the electron and the closest jet. The estimated systematic uncertainty on total efficiency from photon acceptance and identification cuts is 8%.

The \cancel{E}_T in the event is required to be larger than 40 GeV. The event must also pass topological cuts on the direction of \cancel{E}_T , namely that it is not opposite to the leading jet (if present) or along any of the photons.

The total efficiency for a chargino mass of 196 GeV/ c^2 is 14.9%. In addition to the acceptance and photon identification uncertainty, there is an additional systematic uncertainty coming from the choice of PDF (5%) and Monte Carlo statistics (4%).

The DØ analysis includes 263 ± 17 pb $^{-1}$, where the uncertainty is systematic, coming from the inelastic cross section and the detector acceptance for inelastic events.

C. Correlations

The systematic uncertainties on the efficiencies of photon identification variables are assumed to be uncorrelated since the two analyses are based on different detectors, cuts and methods. Since the 5% PDF systematic originates from the same source for both experiments, and reflects effects such as changing particle P_T , which would affect both experiments similarly, the 5% PDF systematics are assumed 100% correlated. Since both experiments base their luminosity estimates on the same inelastic cross section measurement, and both base their acceptance on the same Monte Carlo generator, the luminosity systematics are assumed to be 100% correlated. The uncorrelated CDF uncertainty on acceptance times efficiency is 17%. The corresponding uncorrelated DØ uncertainty is 9%.

III. BACKGROUND AND DATA OBSERVATIONS

A. CDF

CDF considers the following sources of backgrounds. The background from photons and jets faking photons with fake \cancel{E}_T is estimated to be $0.01 \pm 0.01(\text{stat}) \pm 0.01(\text{syst})$ events and is small enough to ignore in the combination. The background from events with a true electron and a real or fake photon, where the electron then fakes a photon is $0.14 \pm 0.06(\text{stat}) \pm 0.05(\text{syst})$ events. The systematic uncertainty is from the uncertainty in the purity of the electron in the $e\gamma$ sample. The background from non-collision sources is $0.12 \pm 0.03(\text{stat}) \pm 0.09(\text{syst})$ events. The total background is $0.27 \pm 0.07(\text{stat}) \pm 0.10(\text{syst})$ events. The total statistical and systematic uncertainty is then 12%.

CDF observed no events passing all cuts.

B. DØ

DØ considers two types of backgrounds. Background from QCD events with either real or fake photons and mis-measured \cancel{E}_T is estimated to be 2.8 ± 0.5 events, with uncertainty dominated by statistics in the sample used for the estimate. The background from events with an electron mis-identified as a photon is 0.9 ± 0.2 events, with an uncertainty dominated by statistics. The total background is 3.7 ± 0.6 events.

DØ observed 2 events passing all cuts.

C. Correlations

Since only $D\tilde{\chi}_1^0$ has a significant QCD background, its uncertainty is uncorrelated with CDF. The systematic uncertainty on the $e\gamma$ background is considered to be uncorrelated since $D\tilde{\chi}_1^0$ is dominated by statistics. The background from non-collision sources is negligible in $D\tilde{\chi}_1^0$ and the corresponding uncertainty is therefore not correlated.

IV. COMBINATION

The combination proceeds using the data in Table I and the prescription from [4]. The method forms a Bayesian likelihood from the product of likelihoods of the individual experiments, with flat priors. Each correlated and uncorrelated systematic uncertainty is represented by an appropriate Gaussian function. Finally we integrate over all parameters except the cross section, and integrate the cross section to the 95% confidence level point.

The table also includes the expected limit for the experiments and the combination. The expected limit is found by computing the limit for each possible outcome, given the expected background, and taking the average, weighted by the probability of that outcome.

CDF					
χ_1^\pm Mass (GeV/ c^2)	154	168	182	196	209
ϵ (%)	6.4	6.8	7.2	7.4	7.6
$\sigma(\epsilon)/\epsilon$ (%) uncorrelated	17				
$\sigma(\epsilon)/\epsilon$ (%) correlated, from PDF	5				
\mathcal{L} (pb)	202				
$\sigma(\mathcal{L})/\mathcal{L}$ (%) correlated	6				
b (events)	0.27				
$\sigma(b)$ (events) uncorrelated	0.12				
observed events	0				
CDF cross section \times BR ² limit (pb)	0.254	0.239	0.225	0.219	0.213
CDF cross section \times BR ² expected limit (pb)	0.294	0.277	0.261	0.254	0.247
$D\tilde{\chi}_1^0$					
χ_1^\pm Mass (GeV/ c^2)	154	168	182	196	209
ϵ (%)	11.1	12.4	13.7	14.9	15.4
$\sigma(\epsilon)/\epsilon$ (%) uncorrelated	9				
$\sigma(\epsilon)/\epsilon$ (%) correlated PDF	5				
\mathcal{L} (pb)	263				
$\sigma(\mathcal{L})/\mathcal{L}$ (%) correlated	6.5				
b (events)	3.7				
$\sigma(b)$ (events) uncorrelated	0.6				
observed events	2				
$D\tilde{\chi}_1^0$ cross section \times BR ² limit (pb)	0.153	0.137	0.124	0.114	0.110
$D\tilde{\chi}_1^0$ cross section \times BR ² expected limit (pb)	0.214	0.192	0.174	0.160	0.154
Combined CDF and $D\tilde{\chi}_1^0$					
χ_1^\pm Mass (GeV/ c^2)	154	168	182	196	209
cross section \times BR ² limit (pb)	0.099	0.090	0.083	0.077	0.075
cross section \times BR ² expected limit (pb)	0.141	0.129	0.118	0.111	0.108
LO model cross section \times BR ² (pb)	0.317	0.202	0.143	0.094	0.068
NLO model cross section \times BR ² (pb)	0.349	0.224	0.159	0.106	0.077

TABLE I: The numbers used in the combined limits. The branching ratio for the lightest neutralino to decay to a photon and gravitino is 0.95. The symbols ϵ , \mathcal{L} , b , and $\sigma(x)$ represent acceptance times efficiency, integrated luminosity, predicted background event counts, and the uncertainty on x , respectively.

V. LIMIT

The combined analyses set a limit on the a total production cross section for supersymmetric particles with the decay of the lightest neutralino into a photon and a gravitino. The cross section limit is interpreted as a chargino

mass for a point along the model–line described above.

The branching ratio for the lightest neutralino to decay to a photon and gravitino is computed by ISAJET V7.51[5] and is included in the limit setting process. This has a value of approximately 0.95 at a chargino mass of $200 \text{ GeV}/c^2$. The LO and NLO production cross sections were computed with Prospino 2.0[6] using the same GMSB parameters. The cross sections and the cross section limits as a function of chargino mass are displayed in Fig. 1. The final mass limit for the lightest chargino is $209 \text{ GeV}/c^2$ which translates to a mass limit of $114 \text{ GeV}/c^2$ on the lightest neutralino and a limit of 84.6 TeV on Λ . This result improves significantly on the mass limits of the individual experiments, which exclude charginos with a mass below $195 \text{ GeV}/c^2$ ($D\bar{O}$) and $167 \text{ GeV}/c^2$ (CDF), both derived using slightly different predictions for cross section times branching ratio.

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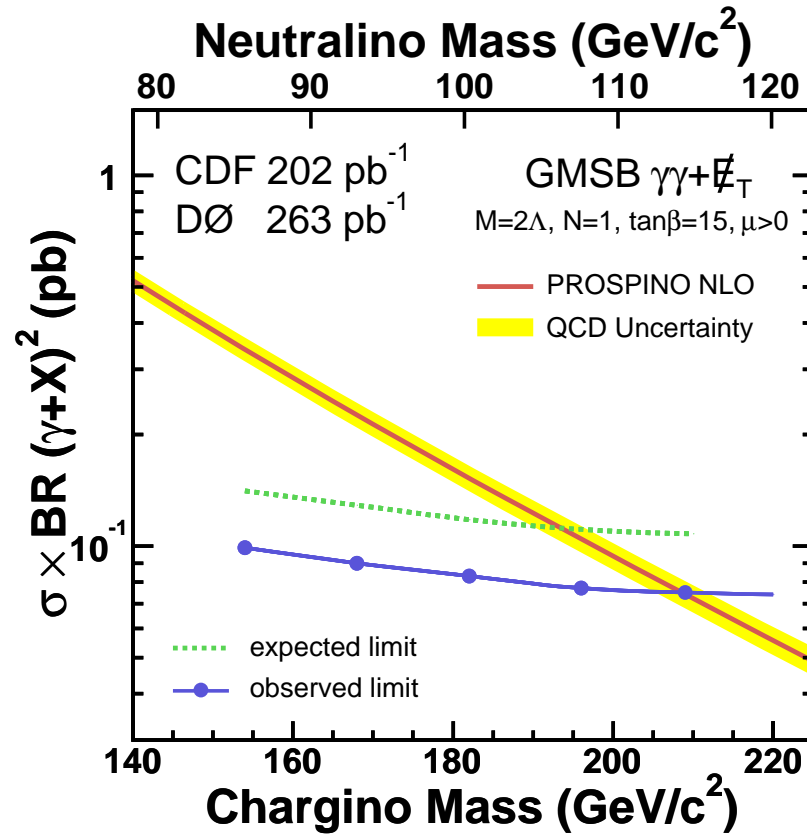


FIG. 1: The next-to-leading-order cross section and combined experimental limits as a function of chargino and neutralino mass.