Fermi National Accelerator Laboratory

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New Phenomena Results from CDF

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NEW PHENOMENA RESULTS FROM CDF

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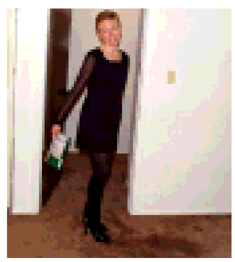

This article summarizes CDF results on neutral and charged Higgs searches, a SuperSymmetry search in trilepton and dilepton plus jets channels and a search for SuperSymmetric signatures involving photons.

1 Introduction

The Standard Model (SM) has a tremendous success and is consistent with experiments to date. But it is not problem free. The Standard Model Lagrangian contains terms that are divergent unless exceptional fine tuning takes place [1]. In addition the Standard Model fails to provide a Dark Matter candidate.

1.1 SuperSymmetry

SuperSymmetric models [2] introduce a new type of symmetry - between bosons and fermions. It means that all the particles that we know have a Superpartner with a spin different by $\frac{1}{2}$. This helps to solve the problem of fine-tuning and provides a Cold Dark Matter candidate. The price for this is a large number of free parameters in the model, which can be greatly reduced if we demand a grand unification [3]. Then only 4.5 independent parameters survive- m_0, ,$m_{1/2}$, A_t, $tan\beta$ and $sgn(\mu)$, where m_0 is the common boson mass, $m_{1/2}$ is the common fermion mass at the GUT scale, A_t is the trilinear coupling, $tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets and μ is the Higgs mass parameter. Here we present the results of a set of searches for new physics performed using the CDF detector which operates at the Tevatron $p\bar{p}$ collider at FermiLab. The center of mass energy of the $p\bar{p}$ collisions is 1.8 TeV.

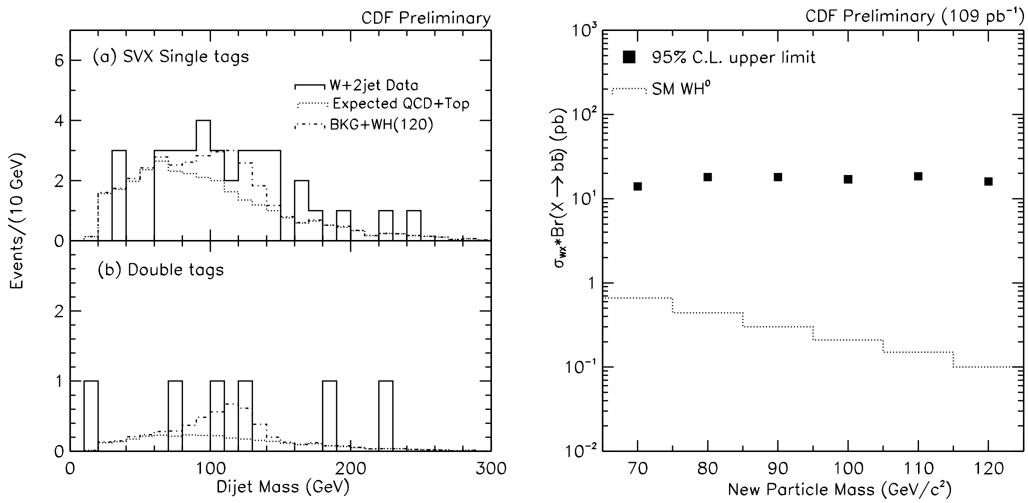

Figure 1: Dijet mass distribution in $W + 2$ jets samples; 95% C.L. limit on the cross section of Higgs production; Overlayed is the predicted Standard Model cross section for associated WH^0 production.

2 Neutral Higgs

With the discovery of the top quark at the Tevatron the Standard Model particle spectrum is almost complete with only the Higgs boson lacking direct experimental confirmation. A neutral Higgs boson would produced directly in $p\bar{p}$ collisions in association with W or Z bosons [4]. Since its coupling to particles is proportional to particle mass Higgs will decay predominantly to $b\bar{b}$. CDF has searched for Higgs in the

$$p\bar{p} \rightarrow WH^0,\ W \rightarrow l\nu,\ H^0 \rightarrow b\bar{b}$$

channel. The signature of this process is a high transverse momentum (P_T) lepton and missing transverse energy ($\not{E}_T$) from W decay and a pair of b jets from Higgs decay. We select events [5] that have leptons with P_T greater than 20 GeV/c, $\not{E}_T$ greater than 20 GeV and two jets with transverse energy (E_T) greater than 15 GeV. CDF tags b-jets by requiring a secondary vertex reconstructed in the silicon vertex detector or/and a presence of a soft lepton in a cone of 0.4 around the jet. For this analysis we consider single and double b-tagged events separately since they have different backgrounds. In the $W + 2jets$ sample we find 1527 events before b-tagging. 36 of these events have 1 b-tag with expected background of 30 ± 5 from top quark and $W + jets$ production. 6 events have 2 b-tags with an expected background of 3.0 ± 0.6 events.The probability that the background fluctuated up to the number of observed events is 19% for the single tags and 9% for the double tags. The combined significance corresponds to about 1.5σ deviation. The dijet mass distribution for single and double tags is shown in Figure 1. Overlayed is the expected background mass distribution and the best fit for the signal $M(H^0) = 120\, GeV/c^2$. The results of the fit are used to set 95% C.L. limit on the cross section of Higgs production which is shown in Figure 1. Overlayed is the predicted Standard Model cross section for associated WH^0 production.

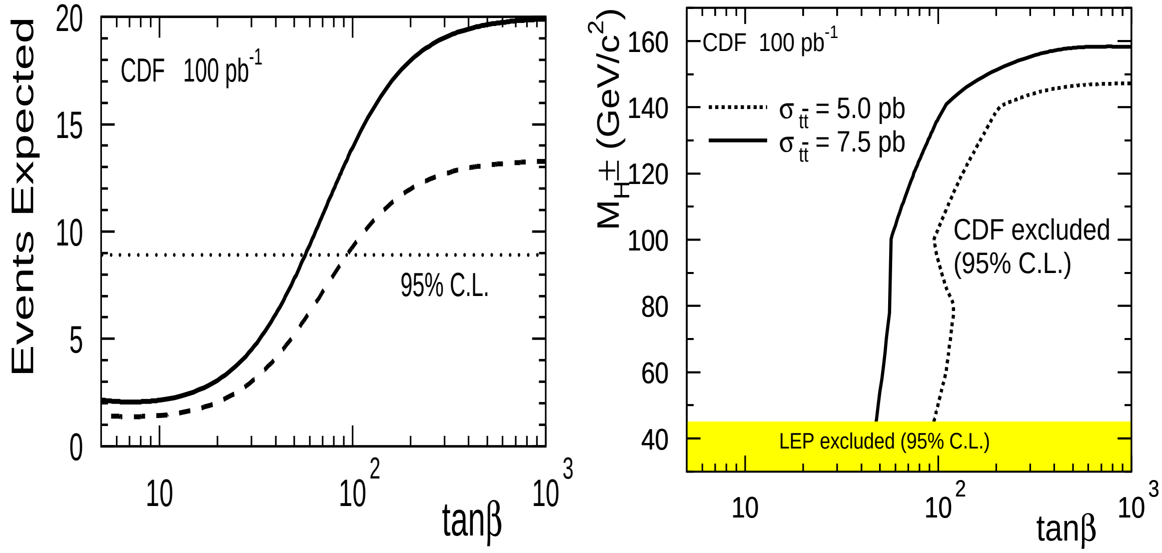

Figure 2: The expected number of charged Higgs events as a function of $tan\beta$ for two different top production cross sections: 5.0(dashed) and 7.5 pb(solid). Dotted line shows our 95% C.L. exclusion level. CDF 95% C.L. exclusion region in the $tan\beta$ M_{H+} plane.

3 Charged Higgs

The Minimal SuperSymmetric extension to the Standard Model(MSSM) requires the existence of two Higgs doublets - one doublet couples to up-type quarks and neutrinos, the other one couples to down-type quarks and leptons. $tan\beta$ is the ratio of the vacuum expectations of the two doublets[6]. After ElectroWeak Symmetry Breaking we are left with 3 neutral and two charged Higgs bosons. If a charged Higgs is light enough it can be produced in top quark decays:

$$p\bar{p} \to t\bar{t},\ t \to bH^+,$$

which competes with the SM top decays to bW. Because of the nature of its coupling H^+ decays preferably to $c\bar{s}$ at low $tan\beta$ and to $\tau\nu$ at high $tan\beta$. Thus an excess over the SM expectation of events with τ's would signal charged Higgs production in the high $tan\beta$ scenario. CDF uses its τ identification capability to search for charged Higgs[7]. Two final states are considered "τjjX" and di-tau. The "τjjX" state requires a τ lepton with $E_T > 20\ GeV$, 2 jets and an additional object X which could be a lepton or a jet. At least one jet must be b-tagged. In the di-tau final state events are selected to contain two energetic ($E_T > 30\ GeV$) hadronically decaying taus. Both final states require missing transverse energy $\not{E}_T > 30\ GeV$. 7 events pass the "τjjX" selection criteria with an expected SM background of 5.1 ± 1.3. 0 events are found in the di-tau channel with 2.2 ± 1.3 expected. At the 95% C.L. we can exclude ≥ 8.9 charged Higgs events after this cuts. Figure 2(a) shows the expected number of charged Higgs events as a function of $tan\beta$ for two different top production cross sections: 5.0(dashed) and 7.5 pb(solid). The dotted line shows our 95% C.L. exclusion level. The resulting 95% C.L. exclusion region in the $tan\beta$ M_{H+} plane is shown in Figure 2(b).

4 SUSY in Trilepton Channel

If Superpartners of gauge bosons - charginos and neutralinos are produced in $p\bar{p}$ collisions their decay can produced a distinct trilepton + $\not{E}_T$ signature[8]:

$$p\bar{p} \to \tilde{\chi}_1^+\tilde{\chi}_2^0,\ \tilde{\chi}_1^+ \to l\nu\tilde{\chi}_1^0,\ \tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0.$$

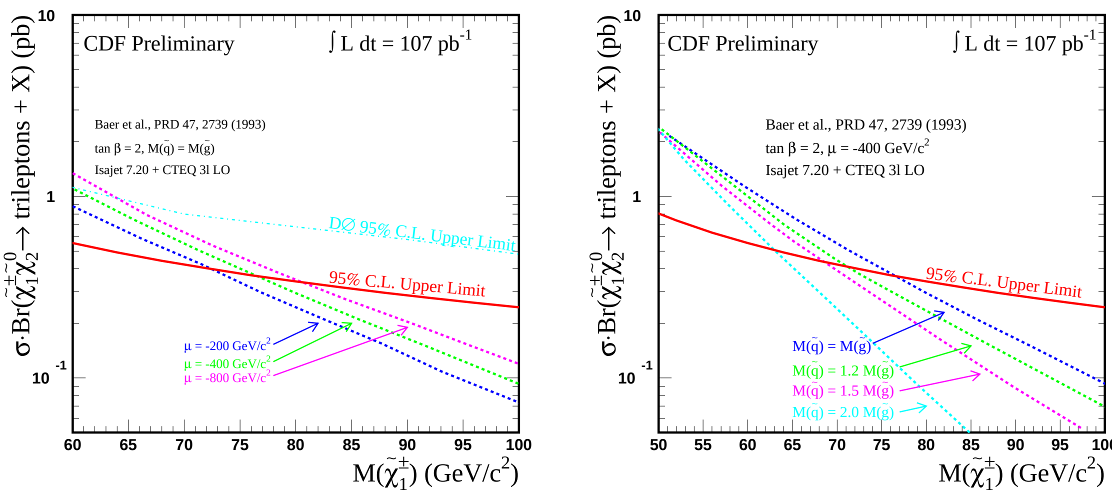

Figure 3: CDF 95% C.L. limit on the production cross section times Branching Ratio as a function of chargino mass. Overlayed are the theoretical predictions for different values of μ(a) and different squark to gluino mass ratio (b). We exclude model that predict cross section that is higher then our 95% C.L. limit.

The $\tilde{\chi}_1^0$ is assumed to be the lightest SuperSymmetric particle and if R parity is conserved it is stable and carries away energy without being detected producing the $\not\!\!E_T$ signature. This process is considered to be the golden signature of the SuperSymmetry because of the low SM backgrounds. We have searched for events with 3 isolated leptons and $\not\!\!E_T > 15\ GeV$ and found none[9]. The expected SM background is 1.2 ± 0.2 events. We use this result to set limit on models that predict production of more than 3.2 events. Figure 3 shows CDF 95% C.L. limit on the production cross section times Branching Ratio as a function of chargino mass. Overlayed are the theoretical predictions for different values of μ(a) and different squark to gluino mass ratio (b).

5 SUSY in Dilepton+Jets Channel

If Superpartner of gluons - gluinos are produced in $p\bar{p}$ collisions directly or via squark decay, their cascade decays produce another distinct SuperSymmetric signature - like sign dilepton plus $\not\!\!E_T$[8], e.g.:

$$p\bar{p} \to \tilde{g}\tilde{g},\ \tilde{g} \to qq'\tilde{\chi}_1^+,\ \tilde{\chi}_1^+ \to l^+\nu\tilde{\chi}_1^0.$$

Since the gluino is a Majorana fermion production of like and opposite sign leptons is equally probable. We select events with 2 like-sign isolated leptons, 2 jets with $E_T > 15\ GeV$ and $\not\!\!E_T > 15\ GeV$. 2 events survive our selection with an expected SM background of $1.3 \pm 0.5(stat) \pm 0.5(syst)$. We use this result to set a limit in squark vs. gluino mass plane which is shown in Figure 4.

6 Photon Enriched SUSY

One of the features of SuperSymmetry is a wide variety of predicted signatures. After CDF recorded the famous $ee\gamma\gamma\not\!\!E_T$[10] several scenarios have been suggested to explain it.

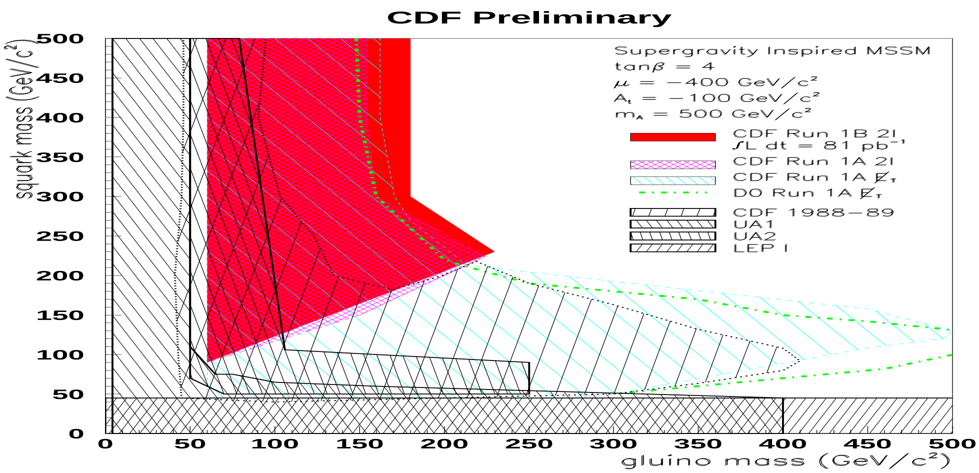

Figure 4: Excluded region in squark vs gluino mass plane from the like-sign dilepton analysis.

6.1 Light Gravitino LSP

In the framework of gauge mediated models in the MSSM the gravitino could be the LSP [11]. In this case for most of the parameter space the lightest neutralino decays to a photon and gravitino: $\tilde{\chi}_1^0 \to \gamma\tilde{G}$. Therefore, any pair produced sparticles will yield a pair of photons and $\not{E}_T$. CDF has performed systematic searches for events with 2 photons and any additional signature $\gamma\gamma X$ [10]. The results of these searches are summarized in Table 1 for two photon energy thresholds - 12 and 25 GeV. The number of observed events is in good agreement with that expected from SM sources. We use the results of the counting experiment in $\gamma\gamma\not{E}_T$ channel to set limits on the light gravitino models. In a Minimal Gauge-Mediated Model M_2 is a parameter which together with $tan\beta$ and sign of μ controls the gaugino masses. The masses of the lightest chargino and the second lightest neutralino are approximately equal to M_2. In Figure 5 we present the excluded region of M_2 vs $tan\beta$ plane for the positive and negative signs of μ.

6.2 Higgsino LSP

Other way to produce photon enriched signatures is to have a photino-like $\tilde{\chi}_2^0$ and Higgsino-like $\tilde{\chi}_1^0$. In association with the light stop (top Superpartner) hypothesis this scenario yields a photon plus heavy flavor plus $\not{E}_T$ signature [12]:

$$p\bar{p} \to \tilde{\chi}_2^0\tilde{\chi}_1^+,\ \tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0,\ \tilde{\chi}_1^+ \to b\tilde{t},\ \tilde{t} \to c\tilde{\chi}_1^0.$$

CDF has searched for events with an isolated photon $E_T > 25\ GeV$ and a b-tagged jet. The $\not{E}_T$ spectrum of these events is shown in Figure 6. Overlayed are the SM prediction and the expected signal distributions. For $\not{E}_T > 40GeV$ we find 2 events. Without attempting background subtraction we set the 95% C.L. limit at 6.46 event level. We can exclude a region in squark and gluino mass plane (see Figure 6) for the processes where squarks and gluinos cascade down to charginos and neutralinos.

$E_T^\gamma > 12$ GeV Threshold		
Signature (Object)	Obs.	Expected
$\not\!\!E_T > 35$ GeV, $\lvert\Delta\phi_{\not E_T-\mathrm{jet}}\rvert > 10°$	1	0.5 ± 0.1
$N_{\mathrm{jet}} \geq 4$, $E_T^{\mathrm{jet}} > 10$ GeV, $\lvert\eta^{\mathrm{jet}}\rvert < 2.0$	2	1.6 ± 0.4
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	3	0.3 ± 0.1
Central τ, $E_T^{\tau} > 25$ GeV	1	0.2 ± 0.1
b-tag, $E_T^{b} > 25$ GeV	2	1.3 ± 0.7
Central γ, $E_T^{\gamma_3} > 25$ GeV	0	0.1 ± 0.1
$E_T^\gamma > 25$ GeV Threshold		
Object	Obs.	Exp.
$\not\!\!E_T > 25$ GeV, $\lvert\Delta\phi_{\not E_T-\mathrm{jet}}\rvert > 10°$	2	0.5 ± 0.1
$N_{\mathrm{Jet}} \geq 3$, $E_T^{\mathrm{Jet}} > 10$ GeV, $\lvert\eta^{\mathrm{Jet}}\rvert < 2.0$	0	1.7 ± 1.5
Central e or μ, $E_T^{e \text{ or } \mu} > 25$ GeV	1	0.1 ± 0.1
Central τ, $E_T^{\tau} > 25$ GeV	0	0.03 ± 0.03
b-tag, $E_T^{b} > 25$ GeV	0	0.1 ± 0.1
Central γ, $E_T^{\gamma_3} > 25$ GeV	0	0.01 ± 0.01

Table 1: Number of observed and expected $\gamma\gamma$ events with additional objects in 85 pb^{-1}

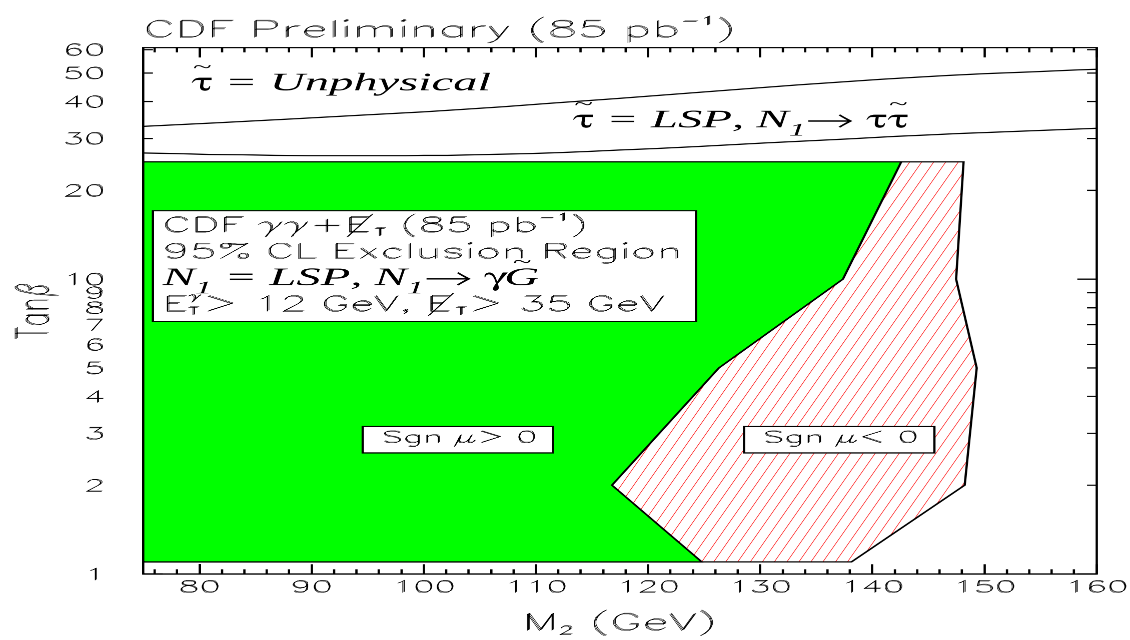

Figure 5: The excluded region of M_2 vs $tan\beta$ plane for positive and negative signs of μ.

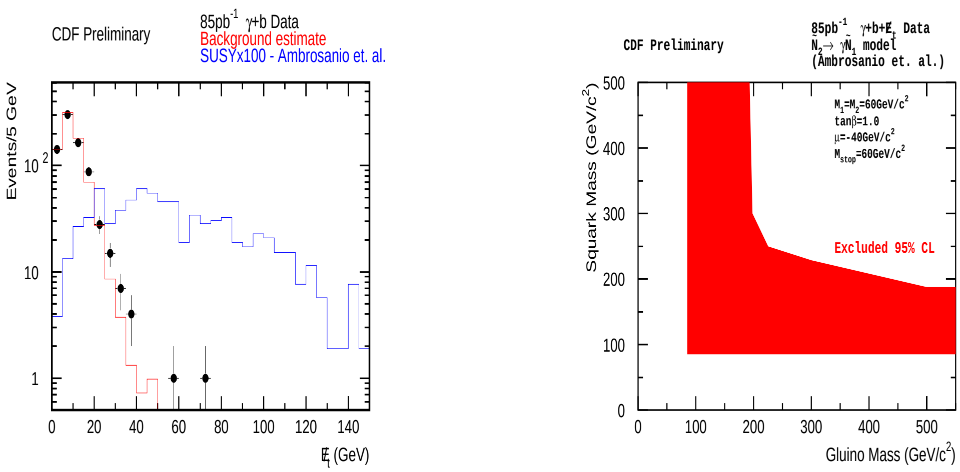

Figure 6: The $\not\!\!E_T$ spectrum of the γb events. Overlayed are the SM prediction and the expected signal distributions. Excluded region in squark and gluino mass plane.

7 Conclusion

CDF has performed searches for the Standard Model Higgs boson in WH channel and was able to put a 95% C.L. limit on the production cross section that is about an order of magnitude higher then the predicted SM cross section. Thus no mass range is excluded. Based on the negative results of the charged Higgs search in top decays we a exclude region in $tan\beta\ vs.\ M_H$ plane. CDF excludes a charged Higgs with $M_H < 140\ GeV/c^2$ for $tan\beta > 70$. We have searched for associated chargino-neutralino production which would produce a distinct trilepton signature. No such events were found and we put a 95% C.L. limit on the chargino-neutralino production cross section which excludes a class of models that predict chargino mass under 65-80 GeV/c^2. If gluinos are produced at the Tevatron their cascade decays could result in another interesting signature - like-sign dilepton production which is accompanied by jets and missing energy. The number of events that we find in this channel is consistent with our SM background estimation and allows us to exclude a region in squark vs. gluino mass plane. For equal mass values and under certain assumptions for MSSM parameters we exclude squarks or gluinos with masses under 230 GeV/c^2. Our searches for SuperSymmetric signatures enriched in photons are again consistent with SM expectations.

8 Acknowledgements

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