PROCEEDINGS OF SCIENCE

Search for Supersymmetry in the Vector Boson Fusion topology in proton-proton collisions at $\sqrt{s}$=8 TeV

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The Vector Boson Fusion (VBF) topology offers a promising avenue for the study of electroweak sector of supersymmetry. The first search for supersymmetry with VBF topology is presented using 19.7 fb^{-1} of pp collision data at 8 TeV collected with the CMS detector. The search targets the final states with at least two leptons, large missing transverse momentum, and two jets with a large separation in rapidity. The observed dijet invariant mass spectrum after the final selections is found to be consistent with the expected standard model predictions, hence the upper limits are set for the production of charginos and neutralinos with two associated jets, assuming the supersymmetric partner of the τ-lepton to be the lightest slepton and the lightest slepton to be lighter than the charginos.

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PoS(ICHEP2016)750

1. Introduction

The successful operation of the Large Hadron Collider (LHC) at CERN has led to numerous results by CMS and ATLAS experiments, placing constraints on various extensions of the Standard Model (SM). In particular, in models of supersymmetry (SUSY) [1]-[4], stringent limits of more than 1 TeV have been placed on the masses of the strongly produced gluinos and first and second-generation squarks. In contrast, the mass limits on the weakly produced charginos ($\tilde{\chi}_i^{\pm}$) and neutralinos ($\tilde{\chi}_i^0$) having much smaller production cross sections, are much less severe. The limits for charginos and neutralinos are especially weak in the so-called compressed-mass-spectrum scenarios, in which the mass of the lightest supersymmetric particle (LSP) is only slightly less than the masses of other SUSY states. The chargino-neutralino sector plays a crucial role in the connection between dark matter and SUSY: in SUSY models with R-parity conservation [5], the lightest neutralino ($\tilde{\chi}_1^0$) often takes the role of the LSP and is a dark matter candidate.

Previous LHC searches [6, 7] for electroweak chargino and neutralino production have focused on final states with one or more leptons (ℓ) and missing transverse momentum ($\vec{p}_T^{\,miss}$), e.g., $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production followed by $\tilde{\chi}_1^{\pm} \to \ell\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell\ell\tilde{\chi}_1^0$, where $\tilde{\chi}_1^{\pm}(\tilde{\chi}_2^0)$ is the lightest (next-to-lightest) chargino (neutralino), and where the LSP $\tilde{\chi}_1^0$ is presumed to escape without detection leading to significant $\vec{p}_T^{\,miss}$. However, these searches exhibit limited sensitivity in cases where the $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ are nearly mass degenerate with the $\tilde{\chi}_1^0$. The mass difference Δm = $m_{\tilde{\chi}_1^{\pm}}$ - $m_{\tilde{\chi}_1^0}$ is a crucial parameter dictating the sensitivity of the analysis. While the exclusion limits in refs. [6, 7] can be as large as $m_{\tilde{\chi}_1^{\pm}} < 720$ GeV for a massless $\tilde{\chi}_1^0$, they weaken to only ≈ 100 GeV for Δm $<$ 50 GeV. The current searches also exhibit limited sensitivity to models with SUSY particles that decay predominantly to τ-leptons, even for LSP masses near zero, due to the larger backgrounds associated with τ-lepton reconstruction compared to electrons or muons.

2. Event Selection

A single-muon trigger [8] with a p_T threshold of 24 GeV is used for the $\mu\mu jj$, eμjj, and $\mu\tau_{\mathrm{h}}jj$ final states while $\tau_{\mathrm{h}}\tau_{\mathrm{h}}jj$ channels use a double-τ_{h} trigger [9] that requires $p_T > 35$ GeV for each τ_{h}. A requirement on pseudorapidity ($|\eta| < 2.1$) is applied to select high quality and well-isolated leptons ($e, \mu, \tau_{\mathrm{h}}$) within the tracker acceptance. The p_T thresholds defining the search regions are chosen to achieve a trigger efficiency greater than 90%. For final states with at least one muon ($\mu\mu jj, e\mu jj, \mu\tau_{\mathrm{h}}jj$), events are selected by requiring a muon with $p_T > 30$ GeV. For the $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ channels, both τ_{h} candidates are required to satisfy $p_T > 45$ GeV.

The following requirements are referred to as the “central selection", and are applied to all final states. Pairs of leptons are required to be separated by $\Delta R > 0.3$ and to originate from the primary vertex. All channels require exactly two leptons satisfying selection criteria. Events with an e or μ are required to have $\vec{p}_T^{\,miss} > 75$ GeV, while a requirement $\vec{p}_T^{\,miss} > 30$ is used for the $\tau_{\mathrm{h}}\tau_{\mathrm{h}}jj$ final state to compensate for the loss in acceptance due to the higher p_T threshold of τ_{h} leptons while maintaining similar background rejection. Background from $\mathrm{t\bar{t}}$ events is reduced by removing events in which any jet has $p_T > 20$ GeV, is separated from the leptons by $\Delta R > 0.3$, and is identified as b-quark jet using the loose working point of the CSV algorithm.

PoS(ICHEP2016)750

The "VBF selection" refers to the requirement of at least two jets in opposite hemispheres ($\eta_1 * \eta_2 < 0$) with large separation ($|\Delta\eta| > 4.2$). Events are selected with at least two jets with $p_T > 50$ GeV and pseudorapidity $|\eta| < 5.0$. The $\mu^{\pm}\mu^{\pm}jj$ search region has a lower background rate with respect to other final states, which makes it possible to relax the jet p_T requirement to 30 GeV to increase the signal acceptance. The event selection criteria with $p_T > 30$ GeV are referred to as "Loose". The event selection criteria with $p_T > 50$ GeV are referred to as "Tight". Selected events are required to have a dijet candidate with $m_{jj} > 250$ GeV. The signal region (SR) is defined as the events that satisfy the central and VBF selection criteria.

3. Background Estimation

The general methodology used to evaluate the background is the same for all final states. For all the final states, various control regions (CR) are created to measure the VBF efficiencies and m_{jj} shapes from data. These control regions are also used for the validation of modeling of central selection criteria, and determination of a correction factor to account for the selection efficiency by assessing the level of agreement between data and simulation. For each final state, the same trigger is used for the CRs as for the corresponding SR. The VBF efficiency, measured in a CR satisfying only the central selection, is defined as the fraction of events in the CR additionally passing the VBF event selection criteria.

The $t\bar{t}$, W + jets, and VV backgrounds are evaluated using the following equation:

$$N_{\mathrm{BG}}^{\mathrm{pred}}(m_{jj}) = N_{\mathrm{BG}}^{\mathrm{MC}}(\mathrm{central}) \times SF_{\mathrm{BG}}^{\mathrm{CR1}}(\mathrm{central}) \times \varepsilon_{\mathrm{VBF}}^{\mathrm{CR2}}(m_{jj}), \tag{3.1}$$

where $N_{\mathrm{BG}}^{\mathrm{pred}}$ is the predicted background yield in the signal region, $N_{\mathrm{BG}}^{\mathrm{MC}}$(central) is the rate predicted by the "BG" simulation (with BG = $t\bar{t}$, W + jets, or VV) for the central selection, $SF_{\mathrm{BG}}^{\mathrm{CR1}}$(central) is the data-to-simulation correction factor for the central region, given by the ratio of data to the "BG" simulation in control region CR1, and $\varepsilon_{\mathrm{VBF}}^{\mathrm{CR2}}$ is the VBF efficiency, determined as a function of m_{jj} in data control sample CR2 or, in the case of VV events, from simulation.

The background estimation technique used to measure the VBF efficiency and m_{jj} shape from data is performed with simulated events to test the closure, where closure refers to the ability of the method to predict the correct background yields when using simulation in place of data. The closure tests demonstrate that the background determination techniques reproduce the expected background distributions in both rate and shape to within the statistical uncertainties. The difference between the nominal MC background yields and the yields predicted from the closure test are added in quadrature with the statistical uncertainties of the prediction to define a systematic uncertainty.

4. Results and interpretation

The combined results from all channels are shown in Fig. 1. Numerical results for opposite-sign (OS) channels are given in Table 1. The observed numbers of events are seen to be consistent with the expected SM background in all search regions. Therefore the search does not reveal any evidence for new physics.

PoS(ICHEP2016)750

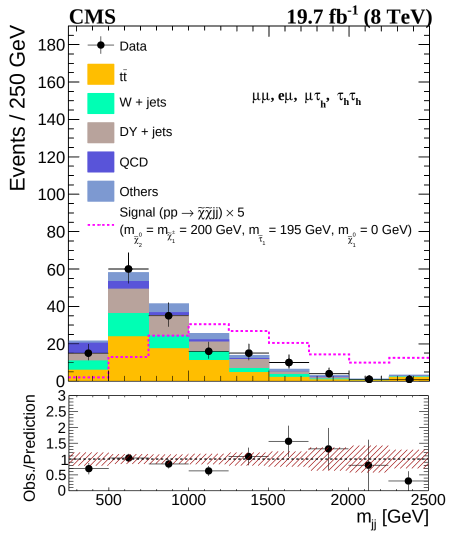


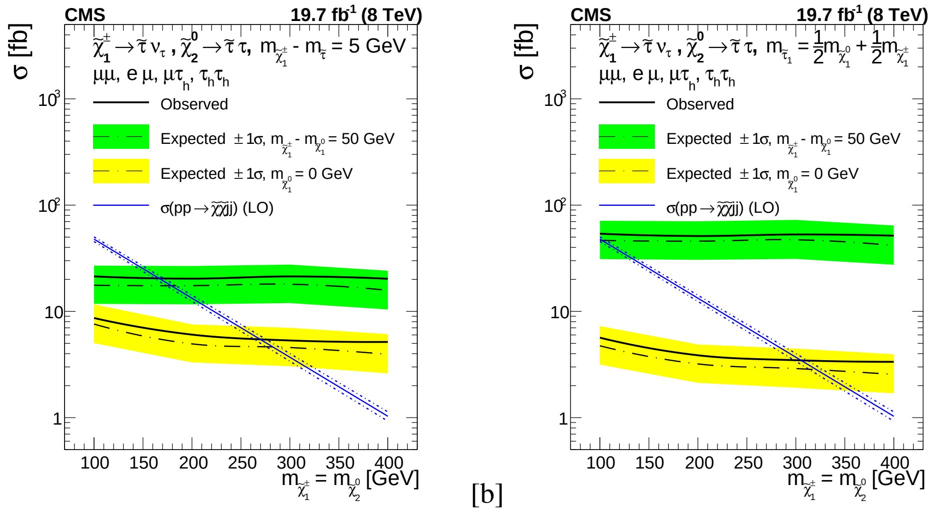
Figure 1: Dijet invariant mass distribution for the combination of all search channels. The signal scenario with $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^\pm} = 200$ GeV, $m_{\tilde{\tau}} = 195$ GeV, and $m_{\tilde{\chi}_1^0} = 0$ GeV, is shown. The signal events are scaled up by a factor of 5 for purpose of visibility. The shaded band in the ratio plot includes the systematic and statistical uncertainties in the background prediction.

Table 1: Number of observed events and corresponding background predictions for the OS channels. The uncertainties are statistical, including the statistical uncertainties from the control regions and simulated event samples.

Process	$\mu^\pm\mu^\mp jj$	$e^\pm\mu^\mp jj$	$\mu^\pm\tau_h^\mp jj$	$\tau_h^\pm\tau_h^\mp jj$
Z + jets	4.3 ± 1.7	$3.7^{+2.1}_{-1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.1	$4.2^{+3.3}_{-2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0^{+2.3}_{-2.4}$	11.7 ± 2.8	–
QCD	–	–	–	6.3 ± 1.8
Higgs boson	1.0 ± 0.1	1.1 ± 0.5	–	1.1 ± 0.1
VBF Z	–	–	–	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1^{+4.6}_{-4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

Figures 2(a) and 2(b) show the expected and observed limits as well as the theoretical cross section as functions of $m_{\tilde{\chi}_1^\pm}$ for, respectively, the fixed- and average-mass $m_{\tilde{\tau}}$ assumptions. For the fixed-mass assumption with a compressed-mass spectrum ($m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50$ GeV), $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ gauginos with masses below 170 GeV are excluded. For the average-mass assumption with an uncompressed-mass spectrum ($m_{\tilde{\chi}_1^0} = 0$ GeV), the corresponding limit is 300 GeV. These mass limits are conservatively determined using the theoretical cross-section minus its one standard deviation uncertainty.

PoS(ICHEP2016)750



[a] [b]

Figure 2: Combined 95% CL upper limits on the cross section as a function of $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^\pm}$. (a) The results for the fixed-mass difference assumption, in which $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\tau}} = 5$ GeV, for $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50$ GeV (compressed-mass spectrum) and $m_{\tilde{\chi}_1^0} = 0$ GeV (uncompressed-mass spectrum). (b) The corresponding results for the average-mass assumption, in which $m_{\tilde{\tau}} = 0.5 m_{\tilde{\chi}_1^\pm} + 0.5 m_{\tilde{\chi}_1^0}$.

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PoS(ICHEP2016)750