Snowmass2021 - Letter of Interest

Searching for the Stop-Bino Coannihilation Using CMS Open Data

Thematic Areas: (check all that apply □/■)

■ (EF08) Model Specific BSM
■ (EF09) General BSM
■ (EF10) Dark Matter
■ (TF07) Collider Phenomenology
■ (TF08) BSM Model Building

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Abstract: (maximum 200 words)
Light top superpartner is the key ingredient for supersymmetry to solve the electroweak hierarchy problem. The compressed region of the parameter space that $m_{\tilde{t}_1} \approx m_{\chi^0}$ is notoriously difficult to search. The case of bino lightest supersymmetric partner (LSP) is of special interest. The bino overcloses the universe. It can become a viable dark matter candidate by having the light top superpartner nearby via the coannihilation mechanism. In this case, if the flavor changing decay channel of the $\tilde{t}_1$ is forbidden, $\tilde{t}_1$ will be long-lived and therefore, can produce displaced vertices in the detectors. The search for such a signal suffers the challenges both from being compressed and being displaced, where the background cannot be faithfully estimated using the standard generator plus fast-detector simulation approach. To explore tackle these challenges that pushes the observable limit and demonstrate the validity of our proposed search strategy, we used the CMS open data. In this study, we propose to use missing transverse energy trigger plus the analysis of displaced vertices to cover this region. We apply this method to the 8 TeV CMS Open Data with a luminosity of 11.6 fb^{-1}, and find that a 95% confidence level limit of $m_{\tilde{t}}$ in the region $m_{\tilde{t}} - m_{\chi^0} \approx 15$ GeV is about $m_{\tilde{t}} > 350$ GeV. This is stronger than the 8 TeV ATLAS and CMS constraints with a luminosity of about 20 fb^{-1}.

Introduction

A light top partner plays a key role in most of the models trying to solve this problem. In supersymmetry, the mass of the stops $\tilde{t}$ should be O(TeV) to solve the fine-tuning problem. Traditional searches of $\tilde{t}$ focus on the pair production of $\tilde{t}$, where both of the $\tilde{t}$ decay into energetic standard model (SM) particles (charged leptons or jets) plus the neutralino χ which leads to large transverse missing energy (MET). However, there are special regions in the parameter space that difficult to search. The most notorious one is the region where $m_{\tilde{t}_1} \sim m_{\chi_1^0}$, where $\tilde{t}_1$ is the lighter stop eigenstate, and χ_1^0 is the lightest neutralino and also the lightest superpartner (LSP). In this region $\tilde{t}_1$ once produced decays into χ_1^0. This region is of special interest if χ_0^1 is pure bino-like since, in this case, the annihilation rate of the LSP is so small that its relic abundance will overclose the universe. One way to solve this problem is to require the gap $\Delta m \equiv m_{\tilde{t}_1} - m_{\chi_1^0}$ to be smaller than about 40 GeV to open the coannihilation channel[1].

In specific for the region $m_{\tilde{t}_1} \gtrsim m_{\chi_1^0}$, most of the energy of $\tilde{t}_1$ goes into χ_1^0. Therefore if one triggers a large missing transverse energy (MET), the signal becomes jets + MET, which is by now a standard channel in the region of parameter space. However, there are a couple of issues with this channel. Firstly, it suffers from the irreducible background from Z^0+jet with Z^0 subsequently decaying into neutrinos. Secondly, if the gap between the $m_{\tilde{t}}$ and m_χ as large as about 10-20 GeV, some of the decay products of the $\tilde{t}$ may be energetic enough to get vetoed by a monojet cut, and therefore signal efficiency becomes lower.

In this region, there are two decay channels. One is the flavor-conserving four-body decay through an off-shell t quark and an off-shell W boson. This channel is suppressed by a factor of $\Delta m^8/(m_t^2 m_W^4 m_{\tilde{t}})$, if we neglect the mass of the bottom quark, and assume the $\tilde{t}_1$ to be righthanded, the $c\tau$ value of $\tilde{t}$ is about 2 mm. If $\tilde{t}_1$ is lefthanded, its $c\tau$ value is even longer due to the spin structure of the decay process. On the experimental side, both ALTAS and CMS have the ability to distinguish a displaced vertex from the primary one once their transverse distance is larger than about 0.5 mm. A 20 GeV mass gap can produce charged tracks with a few GeV transverse momentum, which can be detected by ALTAS and CMS. Therefore, in this paper, we propose to use the displaced vertices to search for $\tilde{t}_1$ in this region.

The GeV scale tracks themselves can be detected, but cannot trigger the detector to record the events. Therefore, we need to trigger some hard objects. Similar to the traditional search, we choose to trigger a monojet-like signal. In contrary to the traditional channel, here, the information from the displaced vertices automatically kills the Z^0+jets background. In SM, the only source for largely displaced vertices are from B-mesons with $c\tau$ about 0.5 mm. B mesons are copiously produced in the LHC from QCD effects. However, these events are usually accompanied by multi-jets and small MET. Therefore, we expect the monojet configuration will veto most of the QCD background. The B mesons from top decay are with large MET. However, these events usually contains multiple hard jets and charged leptons which can be vetoed by the monojet configuration. Furthermore, in the SM background, the B-meson itself is usually inside a hard jet. However, in the signal, the tracks from the displaced vertices are soft and therefore, the directions of the displaced vertices are not likely to be coincident with the hard jets. This fact can also be used as a veto for the SM B mesons.

Without the ability to do a full detector simulation, we are not able to determine the background. Therefore, to test how good this method is, we apply it to the publicly available data provided by the CMS collaboration [2]. The data set is from collisions with the center-of-mass energy of 8 TeV and a luminosity of about 11.6 fb^{-1}. We impose our cuts on both the open data and the simulated events. To get a conservative limit without the simulation of the background, we assume that all the events that can pass all the cuts are from the signal. We also use the CMS Open Data to study the efficiencies of the cuts on Monte Carlo simulation.

Plan of our work

We have already setup tools to do the analysis of the CMS Open Data. We also have set up the simulation tools. We plan to publish the details of the analysis in a paper, which will form the basis for a contributed paper to the Snowmass studies.

In this analysis, we use the public collider data from the CMS experiment to investigate the background of our signal search. We apply a single unprescaled trigger HLT_PFMET150 for the 2012 MET primary dataset[2], which includes valid runs from RunB, RunC, and corresponds to an integrated luminosity of 11.6 fb^{-1}[3]. The dataset is provided in a format called analysis object data (AOD) in the CMS. It is a compact format suitable for most physics analysis, which holds parameters of high-level physics objects and additional event- and sector-based information that allows for offline corrections and kinematic refitting. Analysis of the dataset is performed using the CMS software (CMSSW) version 5.3.32, which is provided by the Docker image released through the CMS Open Data portal. Tools build-in the CMSSW for offline analyses are described in the CMS public offline workbook[4].

Due to the considerable complexity of experimental data, we need to overcome challenges to exploit the CMS Open Data. First of all, the rare possible signals are mixed inside an extremely high-frequency background environment, a suitable trigger and selection need to be applied to obtain the dataset of interest. Next, the selected events of interest contain, on average, hundreds of tracks from tens of primary vertices. To identify the leading primary vertex and clean up tracks that are not of our interest is challenging. Moreover, with displaced tracks of interest selected, a suitable vertex reconstruction and selection procedure are crucial to obtain reasonable signal yield. Without doing full detector simulation, one need to parametrize and compute the selection and reconstruction efficiencies carefully. Last but not least, a reasonable statistic method needs to be applied so that the obtained limits can be compared to other experimental results.

To tackle these problems, we propose the following strategies:

- Apply a single unprescaled trigger HLT_PFMET150. As physically large missing energy can be generated only through processes involving EW interactions, the rate is much lower, allowing data acquisition without a prescale.
- Apart from the selections of an energetic jet and the missing transverse momentum vector, which are reconstructed using the standard particle flow (PF) algorithm[5–7], we perform the remaining part of the analysis based on a set of high-quality tracks. In this way, we make it possible to parametrize and compute detector efficiencies of selections on the vertices and tracks.
- Include track identification and reconstruction efficiency and selection efficiency under the transverse impact parameter through functions of track kinematic variables. The latter is derived based on the resolution of real tracks.
- Compute the vertex reconstruction efficiency for different numbers of signal-like-tracks that can be used for vertex reconstruction. A fully simulated $t\bar{t}$ sample from the CMS open data portal is used for this purpose.
- Use stringent selections to decrease data down to zero events, in which way we get rid of the majority effect of systematic uncertainties. As under the background-only hypothesis, any background contribution in the region without data will lead to a stronger constraint on the signal, we adopt a conservative approach and assumes no background in the search region.

With the proposed procedures, we are able to provide realistic results with reasonable qualities. Comparing to previous Run-1 analysis, we are able to improve limits of the top squark search significantly in the compressed region. The simplified treatment provided in the analysis is complementary to the official CMS analysis and provides a schematic but intuitive view of the data analysis. A preliminary result shows that within the case that $\Delta m \sim 15 - 20$ GeV, the two sigma limit of our proposed search using the 8 TeV CMS Open Data can be around 350 GeV. This is stronger than CMS and ATLAS 8 TeV results of the monojet analysis.

References

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