Search for supersymmetry in two photon + jet events in pp collisions at $\sqrt{s} = 8$

with a brief discussion:

Motivation and trigger strategies for displaced jet searches in LHC Run 2 data

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Abstract:

A search for supersymmetry in pp collisions, in events with at least two photons and one jet, is presented. The dataset, collected at a center-of-mass energy $\sqrt{s} = 8$ TeV in 2012, corresponds to an integrated luminosity of 19.7 fb^{-1}. The signal is characterized as a peak on a falling background in the razor kinematic variable $\mathrm{M_R}$, for events in the tail of the razor ratio R^2. The observed event distribution in $\mathrm{M_R}$ is compatible with the prediction derived by the events with small values of R^2. This result is interpreted as an exclusion limit on a set of simplified model spectra for squarks and gluinos, inspired by the phenomenology of gauge-mediated supersymmetry breaking.

Additionally, the prospects for displaced jet searches will be discussed. Current triggering algorithms will be outlined as well as possible discovery motivated analysis strategies.

Displaced Jet Tagging in Run 2 Data

A search for long-lived beyond the Standard Model physics is proposed to include a number of final states and models. To be precise, the long-lived particles must decay at a position measurably "displaced" from the initial interaction point. Motivated by split supersymmetry's characteristically long-lived gluinos and a variety of hidden valley models with long-lived neutral particles, these displaced signals have little to no Standard Model background. The analysis will constrain a number of beyond the Standard Model physics scenarios by developing categories of displaced jet tags similar to strategies used in b quark identification.

Split-Susy and Naturalness at the LHC

The expectation of discovering supersymmetry (SUSY) at the TeV scale has been largely motivated by arguments based on naturalness. Since the mass of the Standard Model Higgs boson is sensitive to the high energy scale where SUSY is broken (m_{SUSY}), its mass, of order the electroweak scale, ($m_h \approx m_{EW} \ll m_{SUSY}$) would need to be tuned to order m_{EW}^2/m_{SUSY}^2. To avoid fine-tuning, we would like $m_h^2 \approx m_{SUSY}^2 \implies m_{SUSY} \leq 1$ TeV. More specifically, knowing $m_H \approx 125$ GeV we expect light SUSY partners (in particular, light stops) near $\lesssim 1$ TeV to stabilize the quadratic divergences of 1 loop corrections to the Higgs mass [1]. Unfortunately these scalar partners have yet to be discovered.

It is important to note that the stability of the Higgs boson mass is not the only fine-tuning problem in particle physics. When the same argument is made for the cosmological constant we arrive at $\Lambda \geq m_{SUSY}^4$, where experimentally $\Lambda = 10^{-59}$ TeV^4. If we use the same SUSY scale as we did for the Higgs mass, $m_{SUSY} = 1$ TeV we have a new fine tuning problem of 10^{60}.

As addressed by Arkani-Hamed and Dimopoulos [2], many theoretical approaches have been motivated by a natural explanation for the Higgs mass while separately seeking an explanation of the cosmological constant through some other mechanism. Arkani-Hamed and Dimopoulos propose a reconsideration of naturalness, entertaining the idea that fine tuning could have a role to play in beyond the Standard Model physics. Conceivably, both Λ and m_h fine tuning could be resolved by the same mechanism. This un-natural model was further investigated by Giudice and Romanino [3] and dubbed "split supersymmetry".

Split SUSY assumes a much higher SUSY scale $m_{SUSY}^2 \gg 1$ TeV where all scalars (excluding the Higgs) become very heavy $O(m_{SUSY})$ and the lightest sparticles (Higgsinos and gluinos) are kept at the TeV scale by requiring the lightest neutralino to be a good dark matter candidate.

Because the scalars are so much heavier, the decay of gluinos through squarks is suppressed. The characteristic signature of split supersymmetry is thus long-lived gluinos; such processes with long lifetimes are rare in the SM.

Outlook

As the Higgs at 125 GeV has been the only scalar discovered in the LHC's $\sqrt{s} = 7$ and 8 TeV program, the natural SUSY parameter space has become more tightly constrained. If no new scalar superpartners are found at $\sqrt{s} = 13$ TeV, less natural scenarios like split SUSY would become even stronger candidates for beyond the Standard Model physics. CMS is well prepared for most, if not all, SUSY final states with prompt decays. This analysis aims to fill in the complementary parameter space not explored by current long-lived searches by analyzing underlying event kinematics in categories in displaced jet tags.

Triggering in Run 2 Data

Currently two triggers targeting displaced jet signatures are implemented in the CMS high level trigger (HLT) menu, both seeded from `L1_HTT175`. Due to the L1 H_T in-efficiency at it's nominal threshold, we are constrained to at least a cut of $H_T > 350$ GeV at the high level trigger.

- `HLT_HT350_DisplacedDijet80_DisplacedTrack`
- `HLT_HT650_DisplacedDijet80_Inclusive`

Both triggers consist of an H_T requirement (the scalar sum of the transverse momentum of jets within the tracker acceptance), two calorimeter based jets with $p_t > 80$ GeV and requirements on the tracks matched to both jets. To enforce the tracking requirements we require the jets to be central $|\eta| < 2.0$. For both paths, the jets are required to have at most 2 "prompt" tracks. For the displaced track trigger, we additionally require a track matched to the jet with high transverse displacement significance (2 dimensional impact parameter (IP) significance) with at least a transverse displacement of 0.05 cm. The significance is determined as the transverse track displacement L_{xy} divided by the error on the measurement. The displaced track trigger utilizes a special iteration of tracking designed to reconstruct tracks with 3D impact parameters as high as 20 cm.

Due to tight rate constraints in the CMS High Level Trigger menu, the two trigger strategy is employed to be as inclusive as possible to differing signal scenarios. When the signal events occur beyond the $H_T = 650$ GeV kinematic threshold, the inclusive trigger is most effective. The farther the long lived particle decays from the beam line, the better the inclusive trigger performs relative to the displaced track trigger, which needs to reconstruct a displaced track. The displaced track trigger has relatively better performance below the $H_T = 650$ GeV threshold, but is insensitive to Higgs related signatures where the higgs decays to two long lived neutral X's.

To target higgs portal processes where $H \to XX$ `L1_TripleJet_92_76_64_VBF` seeded triggers are currently being developed and studied:

- `HLT_VBF_HadronJet40`
- `HLT_VBF_DisplacedJet40`

Both triggers require two back to back jets with high eta separation and a minimum invariant mass (to match the VBF condition) and a single jet with $p_t > 40$ GeV with at most 2 prompt tracks. The hadron jet trigger is designed for decays with long life-times which occur inside the hadron calorimeter by requiring a high hadronic energy fraction of the jet. It is important to note that this signature is difficult to distinguish from noise in the hadronic calorimeter. It is possible that significant contributions to the rate would come from noise, and this contribution would need to be measured separately. The displaced jet trigger track requirements are the same as the displaced dijet track trigger above, requiring a single track of high IP significance. As before, the displaced jet trigger would target shorter lifetimes.

Displaced Jet Tags

The focus of the analysis will be defining displaced jet tags capable of targeting a variety of long lived signatures. The generation of these sequences will closely mirror those of b quark identification algorithms. The goal will be to design the identification sequence in such a way that the b-tagging community can provide insight and other displaced analyses can reuse the software.

As the characteristics of a displaced jet and its associated tracks can vary significantly with the associated physics we will generate discriminants based on generic characteristics of the calorimeter based jets:

- Number of matched prompt tracks and their IP significance
- Number of matched displaced tracks and their IP significance
- Clustering of displaced track impact parameters
- Secondary vertices reconstructed within a jet and the associated displacement
- Hadronic energy fraction (for decays inside the hadronic calorimeter)
- Muons stubs matching the jet from heavy flavor quark decays
- Missing Energy in the event

For a given category of signal, a sub-set of these quantities would be combined into a single discriminant (possibly utilizing multi-variate techniques). Examples:

- Short Lifetimes: Displaced tracks, a reconstructed secondary vertex, and high IP significance. This would be the most similar to b-tagging and likely the highest discrimination power for decays still within the pixel layers.
- Long Lifetimes: In the regime where we cannot reliably reconstruct the displaced tracks we would ask for small numbers of prompt tracks. Lacking a secondary vertex we could regain sensitivity by using muon stubs from heavy flavor decays.
- Hadron Calorimeter decays: When we do not expect any tracks we require high hadronic energy fraction and small numbers of prompt tracks. Again, looking for muon stubs could be beneficial.
- Singly Produced: Long lived particles are not always pair produced. In some scenarios, a long lived particle (that would decay in the detector) and a "WIMP-y" hidden sector particle (that would not decay in the detector) are produced. This topology would have displaced jets and missing energy. The missing energy in the event could be used as a discriminator for this variety of jet.

Discovery Motivated Analysis

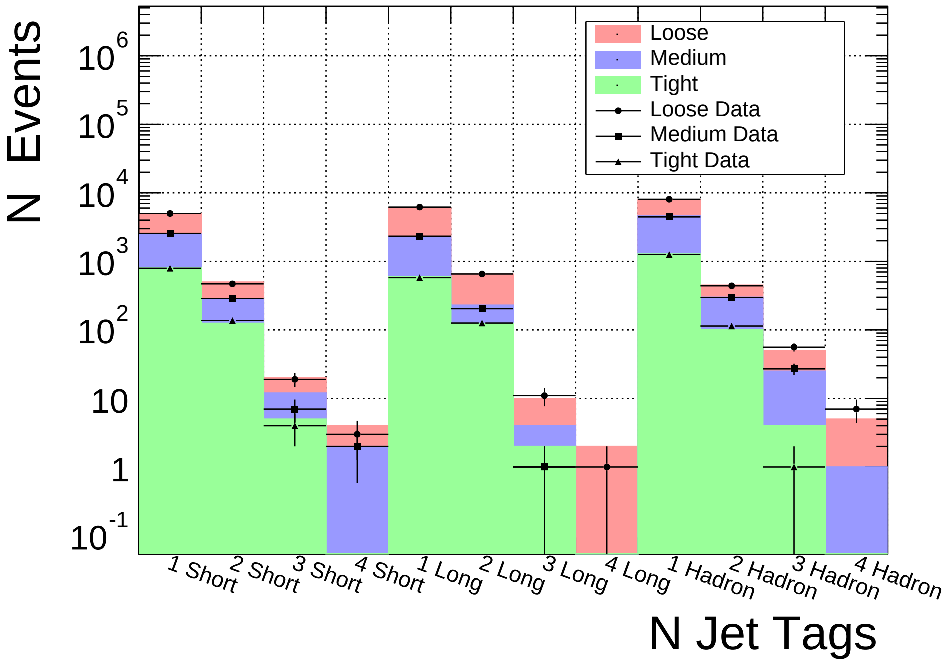

Figure 1: An example background prediction made in categories of displacement and varied working points.

One of the most important aspects of displaced jet analysis, is how visibly striking the signature can be. This is especially the case for decays within the tracker. If we are able to reject enough QCD events and detector effects to narrow the selected number of events, we could look through the event displays by hand. In many scenarios the events would be self-diagnostic.

The coarse level of the analysis will be performed in loose, medium, and tight working points for each of the categories (Figure 1). These distributions would give an inclusive view of possible displaced physics, and point us in directions to review event displays.

It is a goal to perform the background estimation with limited dependence on the trigger path (such as the ABCD approach). In this way, we could run the analysis over multiple primary datasets in search of displaced physics. For instance, by looking at the single electron and single muon datasets would give sensitivity to associated higgs production where the higgs is coupled to a hidden sector. Even though the un-seen width of the higgs would be sensitive to such a signature, the presence of displaced jets can be much more convincing.

It would also be interesting to analyze the 8 TeV parked VBF data for displaced jets. Such an analysis would likely need to wait till the end of Run 2.

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