Statement of interest

My research has focused on using data from the LHC to search for signatures of Beyond Standard Model (BSM) physics which may resolve fundamental problems in particle physics, such as the origin of dark matter. In the three years of my PhD I have taken a leading role in the α_{T} analysis group searching for generic models of Supersymmetry (SUSY) and dark matter. Within the SUSY group in the CMS collaboration, we used the first data at 13 TeV from Run 2 of the Large Hadron Collider (LHC) to place strong constraints on a wide-range of BSM physics models. As part of a small group, I had direct involvement in areas throughout the α_{T} search. This has allowed me to gain wide ranging experience in both rapid comprehension and analysis of data from the LHC as well as understanding how sensitivity to BSM physics signatures can be maximised while maintaining a robust analysis. In parallel, I have gained experience in hardware though work on the level one (L1) trigger and in phenomenology through my involvement with the MasterCode collaboration.

In the coming years the jumps in energies and luminosity that marked the previous running of the LHC will come to an end. While inclusive style analyses will continue to play a role in exploring ever larger phase space, targeted searches for particular models may provide the best chance for discovery. In the following paragraphs I describe how the experience gained during my PhD has prepared me well for the challenge of discovering BSM physics at the LHC.

Research activities since January 2014

Search for BSM physics

SUSY is a leading candidate as a BSM theory to resolve problems in the Standard Model. For SUSY to naturally predict a Higgs boson mass at $m_H \approx 125$ GeV, coloured SUSY particles at the TeV scale may be expected. SUSY may also offer a compelling dark matter candidate, the lightest supersymmetric particle (LSP). The final state from the coloured SUSY particle decays typically contains hadronic activity (in the form of jets) as well as momentum imbalance ($E_{\mathrm{T}}^{\mathrm{miss}}$) from the LSP. When the mass splittings in the SUSY spectra are small, discovery may be particularly challenging as the energy in the final state is reduced.

The record energy reached for Run 2 of the LHC provided an excellent possibility of discovery in the first months of operation. I worked on the α_{T} analysis searching for BSM phyiscs in a final state containing jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. Taking advantage of this opportunity for discovery required rapid and reliable analysis of this dataset. I held a pivotal role in ensuring the results from the α_{T} analysis were among the first to be shown publicly with 2.3 fb^{-1} of data at CERN in November 2015 and with 12.9 fb^{-1} of data at ICHEP16, for which I gave the successful approval talk. My key involvement in the analysis allowed me to gain important experience in quickly and robustly understanding and then analysing data to search for BSM physics.

The first task I undertook with the α_{T} analysis built on my experience with the trigger, described below, to design a L1 trigger strategy to increase acceptance for compressed models, which have lower energies in the final state, while maintaining a low trigger rate. For any analysis the trigger is critical as data lost at this stage cannot be recovered. Taking advantage of the new L1 jet algorithm I was able to significantly increase acceptance for compressed models, beneficial for a wide ranges of searches.

My main responsibility for the α_{T} analysis has been the statistical interpretation of the data collected by the search. This requires a holistic and deep understanding of all sections of the analysis that are included in the final likelihood model. During my PhD I have worked to completely rewrite the statistical framework and redesign the likelihood mode. I have been instrumental in efforts to measure systematic uncertainties in data and through simulation and to ensure their effects are robustly included in the likelihood model with the correct correlation scheme. This is particularly important for compressed models, which typically contribute most significantly in systematic limited regions. This experience is extremely valuable for future searches for BSM physics as correctly modelling the backgrounds and their uncertainties in a systematics dominated environment could be crucial for discovery.

Another of my responsibilities has been the inclusion of $E_{\mathrm{T}}^{\mathrm{miss}}$ shapes into the α_{T} analysis. This was a significant change in strategy as the analysis moved from a simple 'cut and count' to a shape based analysis. While this change allows significant increase in sensitivity to a wide range of models, it also provides challenges to ensure the analysis is robust. I achieved this by ensuring the modeling of the $E_{\mathrm{T}}^{\mathrm{miss}}$ shape was validated, and systematic uncertainties derived, using signal depleted control regions in data. In addition, systematic effects on the $E_{\mathrm{T}}^{\mathrm{miss}}$ shape from known sources, as well as their correlation, were derived from simulation and considered within the likelihood model.

Alongside my work in the α_{T} analysis I have actively contributed within the SUSY group. As well as my work on the trigger strategy I was part of a working group that investigated the reliability of limits for the SUSY models in the 'top corridor'. In such models, the mass splitting of the supersymmetric top (stop) and the LSP is close to the top mass. This work required an in depth study of the features of the stop decay and how the signal may be separated from background in this regime and is useful experience for future searches for such 'stealth stops'.

Hardware

My hardware experience has centred on the level 1 hardware trigger and its upgrade for the start of Run 2. Initially, I contributed to the development of the emulator for the upgraded trigger system which simulates the algorithms used in the hardware. This required a good understanding of the operation of the algorithms in the firmware. Building on this, I worked on designing an algorithm to identify jets and subtract contributions from simultaneous collisions, pile-up (PU). This required close collaboration with firmware and reconstruction experts to ensure the algorithm was both viable and effective. By taking advantage of the increased granularity and flexibility of the upgraded system the new algorithm saw a significant increase in performance, beneficial to all analyses on CMS involving jets. Such service work is not only an important duty for the collaboration but is also highly useful for gaining understanding of the detector performance and can provide important lessons for analysis. As the LHC moves to higher instantaneous luminosities and pile-up, effective triggering will become an ever greater challenge for which my experience will be highly useful.

Simplified Likelihood

Independently from my group, I worked with a collaborator in CMS to make a proposal for additional material to be released by CMS analyses to allow their searches to be easily reinterpreted by those outside the collaboration. This work built on my experience with the statistical framework for α_T as well as being informed by my work with the MasterCode collaboration. The predictions and covariances between analysis bins may be used to define a simplified likelihood to allow reinterpretation for any search. A recommendation to release this information for all analyses will be made in the SUSY and exotica groups. In addition, I co-authored a document, that will be made public, describing generically how this may be used to reinterpret a search.

Phenomenology

As part of the MasterCode collaboration I developed a framework for deriving constraints from direct searches for BSM physics on GUT scale models of SUSY. This required the comprehension, implementation and validation of several searches from both the CMS and ATLAS experiments. Through this work, I gained experience with event generation (PYTHIA) as well as fast detector simulation (DELPHES). Using this framework, I worked to show that through combining several inclusive analyses targeting different final states the sensitivity of the limit to the non-coloured sector of the SUSY spectra can be approximately removed. These 'universal limits' can be used to greatly reduce the time taken to sample a GUT model parameter space.

In addition to my work for the mastercode collaboration I have worked on studies of the discovery potential for SUSY at future colliders and how metastable supersymmetric taus (staus), predicted in certain SUSY models to provide the observed dark matter relic density, may be discovered at experiments at the LHC. This work on metastable staus has been cited by both the CMS and MoEDAL collaborations.

My phenomenology experience has been very useful in understanding the kinds of models that are well motivated theoretically and evade current experimental limits and may be targeted in the future, such as anomaly mediated supersymmetry breaking models (mAMSB). I have also gained an appreciation of the information which is needed to reliably reinterpret an analysis and so should be released in CMS publications.

Research Plans

My extensive experience in

- rapid data comprehension and analysis
- designing a search and optimising sensitivity for BSM physics signatures
- likelihood model building and statistical analysis
- triggering algorithms and strategies
- phenomenology

will allow me to take a leading and pivotal role in searches for BSM physics within a large collaboration. I would like to continue searching for signatures of such BSM physics using CMS data from collisions at the LHC. In addition, I would like to take a greater role in contributing directly to the detector to improve performance as well as gaining further understanding of detector performance. As inclusive searches have failed to uncover any evidence for BSM physics, I believe the best opportunity for discovery will come from searches targeting specific models using the large datasets produced by continued LHC operation at 13 TeV. For example, as I have seen within the MasterCode collaboration, the most stringent limits from colliders on the mAMSB model require searches for disappearing tracks. Such searches will require good understanding of the detector, the ability to optimise the sensitivity of a search and a robust evaluation of the background model.

Over the last three years as a PhD student on CMS I have seized the opportunity to gain experience with real data and work effectively as part of a large collaboration, being based at CERN much of this time. I have played a key role within the very successful α_{T} search as well as contributing to the SUSY group as a whole. I am eager to build on my experience on the LHC to play a pivotal role in searches for BSM physics as the LHC moves into this new and exciting phase. Santa Barbara has a strong and leading presence within the particle physics community with major contributions in calorimetry and for searches for interesting and sensitive signature of BSM physics models. I believe it would be the ideal place to continue contributing to the search for BSM physics.