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Part I

A search for highly ionising, short tracks at the CMS detector

1 Discussion and conclusion

The here presented search for highly ionising, short tracks is motivated by supersymmetric models with almost mass-degenerate wino-like charginos $\tilde{\chi}_1^{\pm}$ and neutralinos $\tilde{\chi}_1^0$. Such scenarios can have interesting astrophysical impacts [1] and occur naturally in Supersymmetry, if the wino mass parameter is much smaller than the bino and higgsino mass parameters.

The presented analysis targets SUSY models with intermediate chargino lifetimes which haven't received much attention so far. It extends the search for disappearing tracks [2] by the inclusion of the variable dE/dx. In order to increase the search sensitivity with respect to shorter lifetimes, energy information from the pixel silicon tracker is taken into account. For this purpose, a dedicated pixel energy calibration was carried out within this thesis to ensure stable energy measurements over time and across pixel modules. This is thus the first analysis at CMS that makes use of energy information from the pixel tracker. By adding pixel energy information, the discrimination power of dE/dx is significantly increased.

Overall, dE/dx inclusion allows for loosening the requirement on the number of hits in the tracker with respect to [2] that leads to a strong suppression of signal events for low chargino lifetimes. The Asymmetric Smirnov discriminator, I_{as}, which is used for dE/dx discrimination in this analysis, shows good separation power and can lead to sensitivity increases up to 400% in this search (cf. Fig. **??**).

The Standard Model background is mainly estimated with data-based techniques. The main background to this search is arising from fake tracks, i. e. tracks that are reconstructed out of the tracker hits of more than one particle. Fake tracks are typically short and can have large values of I_{as}, thus showing a very signal-like signature in the detector.

In the current analysis, the background is estimated at $19 - 24$ events in the low I_{as} signal regions and $2.5 - 2.6$ events in the high I_{as} regions. This background estimate is confronted with collision data recorded during the year 2012 at the CMS experiment at a centre-of-mass energy of 8 TeV. No evidence for physics beyond the Standard Model is found. Thus, the absence of any deviation from the Standard Model prediction is used to constrain the supersymmetric parameter space. Wino-like charginos are excluded down to lifetimes of $c\tau = 2\,\mathrm{cm}$ for $m_{\tilde{\chi}_1^{\pm}} = 100\,\mathrm{GeV}$. For high mass scenarios of $m_{\tilde{\chi}_1^{\pm}} = 500\,\mathrm{GeV}$, the excluded lifetime ranges between $c\tau = 70 - 500\,\mathrm{cm}$. This confirms the parameter exclusion limits of the search for disappearing tracks [2]. Interestingly, the signal regions of the here presented search and the search from [2] show little overlap. Therefore, this analysis serves as an independent cross check of [2]. Improvements of the exclusion of SUSY models with respect to existing searches of around $10 - 40\,\mathrm{GeV}$ in chargino mass are achieved in the low lifetime region.

While this analysis is able to exclude many SUSY models with intermediate lifetime charginos, there are several promising avenues for even enhancing the search sensitivity.

First, since the sensitivity of the current analysis is mainly limited by large systematic uncertainties originating from low statistical precision in the simulated datasets, simulating more events could significantly improve the search sensitivity. This strategy is however technically challenging, since storage capacity limits were already reached within the current analysis. Still, reducing the systematic uncertainty will be one of the main tasks for future research.

Second, even though this search already features low background, a further background suppression is desirable. However, the impact on the search sensitivity will be limited because of the high relative Poisson error on low background predictions. For instance, a reduction of the number of background events by 50% from 2 to 1 reduces the signal yield required for a 5σ-discovery by around 8%, whereas a 50% reduction of expected background events from 200 to 100 reduces the required signal yield by 26%.

Thus, in order to improve the here presented analysis, the focus should be on the other determinant of search sensitivity: the signal acceptance. First and foremost, it is important to lower the signal losses due to trigger requirements. For this purpose, a dedicated track trigger is indispensable and it is, therefore, very promising that such a trigger is included in Run II trigger menues.

Furthermore, an implementation of a dedicated track reconstruction algorithm optimised for short tracks could increase the reconstruction efficiency of possible chargino tracks, which is currently $\sim$40% for chargino tracks with $3 - 4$ hits. Additionally, a track reconstruction optimised for the reconstruction of soft particles that are not produced in the primary vertex could allow for a reconstruction of the Standard Model decay products of charginos, thereby enabling a better discrimination against Standard Model background.

In summary, the here presented analysis approach remains interesting since there is still room for improvement that can allow for accessing new, unexplored SUSY models with long-lived charginos. Additionally, a search in collisions at a centre-of-mass energy of $13\,\mathrm{TeV}$ with increased cross sections makes the exploration of SUSY models with higher chargino masses possible. In this context, the inclusion of dE/dx in this analysis will become even more powerful, since dE/dx is much more discriminating for high masses.

Bibliography

[1] T. Moroi, M. Nagai, and M. Takimoto, "Non-Thermal Production of Wino Dark Matter via the Decay of Long-Lived Particles", *JHEP* **07** (2013) 066, arXiv:1303.0948. doi:10.1007/JHEP07(2013)066.

[2] CMS Collaboration, "Search for disappearing tracks in proton-proton collisions at $\sqrt{s} = 8$ TeV", *JHEP* **01** (2015) 096, arXiv:1411.6006. doi:10.1007/JHEP01(2015)096.