Search For Long Lived Charginos

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Abstract

This report contains the signal production and track selection in the search for long lived charginos. Multiple signals for different chargino decay lengths were produced, using the same pMSSM benchmark point. The decay lengths are 56, 10, 100 and 1000 cm.

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1 Introduction

The Standard Model (SM) is the theory that describes three out of four fundamental forces in the universe: namely, electromagnetic, weak and strong interactions. It also classifies all known elementary particles. The theory was developed in the late 20th century, with the hard work of many scientists from all around the world.

Even though the SM has been a very succesful theory in providing experimental predictions, it is inherently an incomplete theory. One of the main reasons the SM is considered to be incomplete, is the lack of explanation it provides for the fourth force of nature: Gravity.

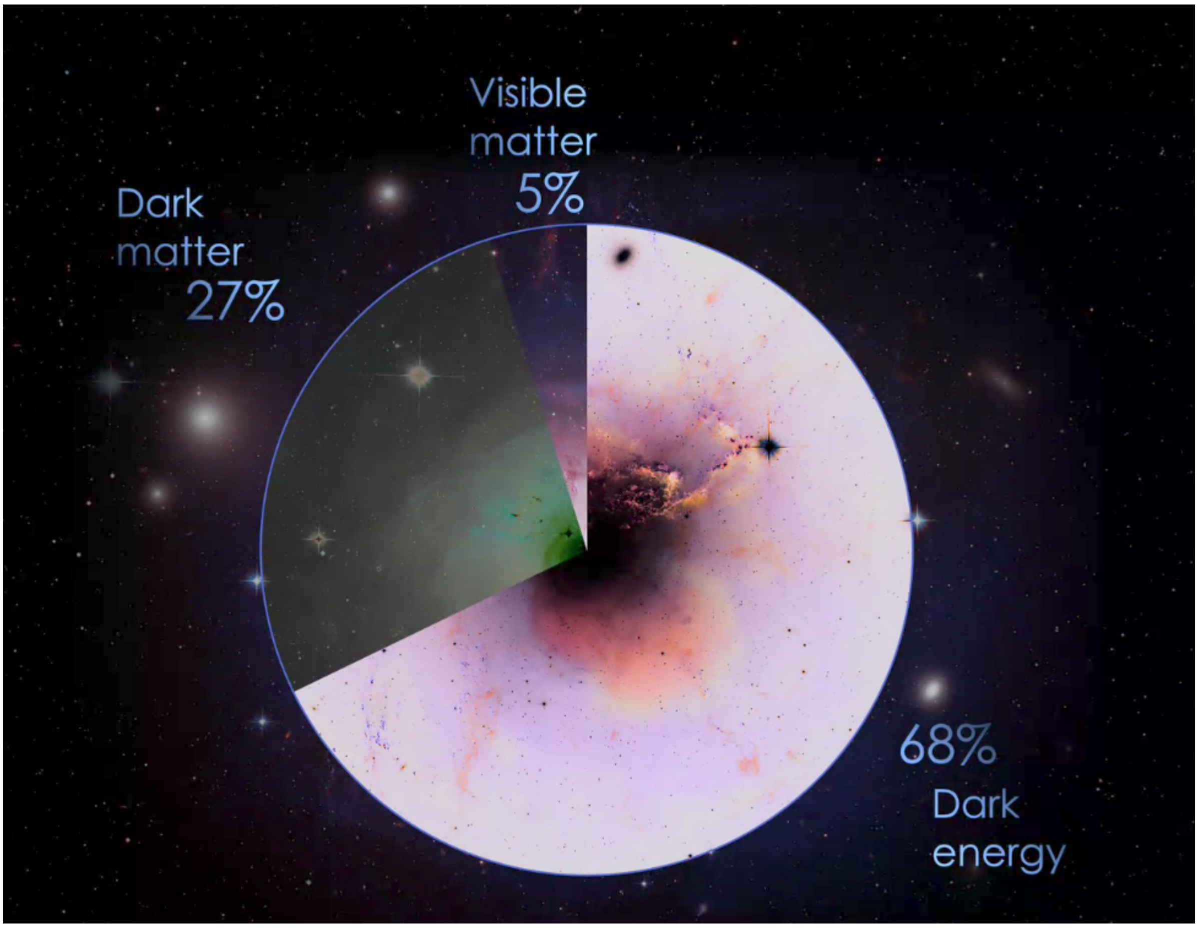


Figure 1: Content of the universe pie chart.
Retrieved from https://svs.gsfc.nasa.gov/12307, *Goddard Media Studios*

In addition, the theory suffers to explain dark matter and dark energy. In Figure 1 the content of the universe is shown as a pie chart. It can be seen that the SM only explains about 5% of the total energy in the universe.

Another problem is the neutrino masses. Neutrinos are massless particles according to the SM. Nonetheless, neutrino oscillation experiments have shown that, neutrinos do have mass. When the mass terms are added to the SM by hand, theoretical problems rise.[1]

Furthermore, the SM predicts the same amount of matter and antimatter to have been created after the big bang. There is no aspect of the SM that would explain the asymmetry.

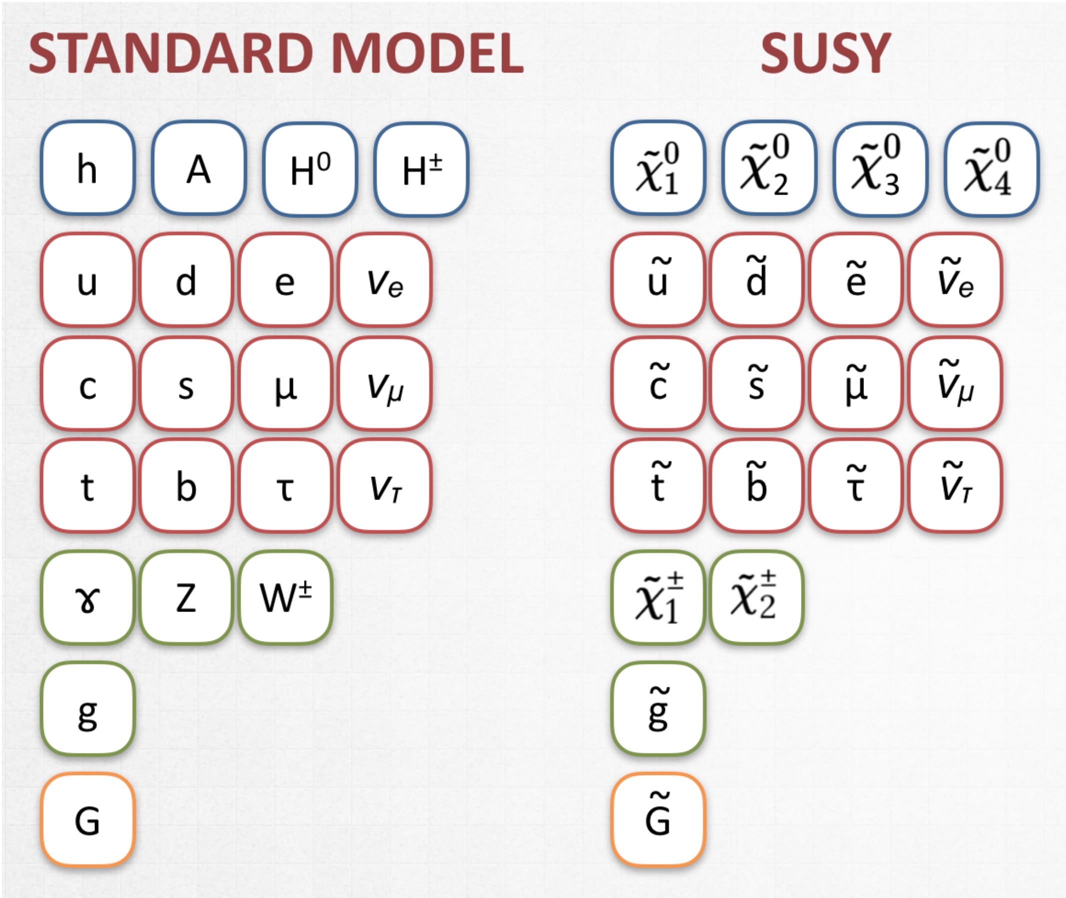


Figure 2: SM and SUSY Particles

Supersymmetry (SUSY) is a spacetime symmetry that relates the major types of elementary particles: bosons (with integers spin) and fermions (half-integer spin). SUSY states that for every fermion there exists at least one corresponding boson with the same quantum numbers, but the spin differing by 1/2 and that for every boson there exists a fermion. The masses of the SUSY particles should be the same as their SM partners.

But if this were the case, we should have been able to find them by now.

So, SUSY must be a broken symmetry that makes all the superparticles much heavier than their SM partners. There are many ways that this symmetry might be broken.

SUGRA: Short for supergravity, SUGRA is a field theory that combines supersymmetry and general relativity. According to this theory, the mediating interactions are gravitational.

GMSB: Gauge mediated supersymmetry breaking. It is a method of relating SUSY breaking to SSM via gauge interactions. In this theory, mediating interactions are electroweak & QCD gauge interactions.

AMSB: Anomaly mediated supersymmetry breaking is a gravity mediated SUSY breaking. SUSY breaks on different brane in a higher dimensional theory.

This analysis is based on the AMSB model in which the most common scenario contains a mass degeneracy between the chargino and the lightest neutralino, which is the lightest supersymmetric partner (LSP).

Due to the mass degeneracy the chargino decays as dollows: $\widetilde{\chi}_1^+ \rightarrow \pi\ \widetilde{\chi}^0$.

The charginos in previous SUSY analyses were decaying promptly. But in our analysis, the charginos are long lived. They decay within silicon tracker, and have tracks that are disappearing because of the pion with low momentum. In this analysis, we keep our AMSB model constant and look at the chargino tracks with different decay lengths. Namely, 56 cm, 10 cm, 100 cm and 1000 cm.

2 Producing The Signal

This analysis is fairly new, hence there is no signal samples provided by CMS. Consequently, the signal must be produced from scratch. The simulation was done with Pythia 8 [2] and the $\tilde{\chi}_1^+$ decays were handled with Geant4.

Firstly, benchmark points that are representative of a range of topologies and areas of phase space needed to be chosen. The process that would make up the events can be seen in Figure 3.

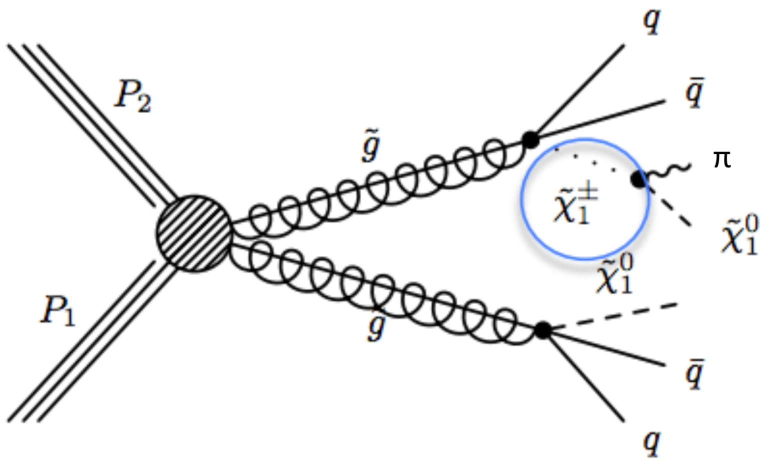


Figure 3: The Diagram of our process.

The goal is to simulate the exact process, but for that some modifications have to be made in the SLHA file. Essentially, gluinos were needed to decay into charginos. Therefore, gluino decays that contain charginos were selected, and rest of the strings referring to the prodution and decay of other SUSY particles were commented out. A critical point here is to not forget about the branching ratio. New branching ratio must be calculated and modified for every chosen decay, e.g. in this analysis, there are six different gluino decays and the branching ratio is $\simeq$1.66.

Furthermore, there are "unnecessary" particles in terms of this process, that should be kept from being produced. Such thing can be achieved by stating the process in the Pythia file, as

```
'SUSY:gg2gluinogluino = on',
'SUSY:qqbar2gluinogluino = on'
```

It is required for Pythia to avoid decaying the $\tilde{\chi}_1^+$ as a result of a software issue. As can be seen in Table 1, the mass difference between mother $\tilde{\chi}_1^+$ and daughter $\tilde{\chi}^0$ particles is very small. Pythia 8 has a minimum mass difference demand between the decaying

Table 1: Particle Masses

	Mass [GeV]
Chargino $\widetilde{\chi}_1^+$	1.77129037E+02
Neutralino $\widetilde{\chi}^0$	1.76977134E+02
Gluino $\widetilde{g}$	1.86340709E+03

mother mass and the sum of the daughter masses, kept as a safety margin to avoid numerical problems in the decay generation. Consequently in this analysis, Pythia was not able to successfully decay $\widetilde{\chi}_1^+$. Therefore, the $\widetilde{\chi}_1^+$ decays in the SLHA file were turned off, and instead, passed to Geant4 with a mini SLHA file that contains the masses, and widths of particles. As shown in Table 2. In an SLHA file, the information concerning each particle can be followed by their particle ID. The IDs are listed in the official Monte Carlo particle numbering scheme [3].

Table 2: Decay lengths and calculated widths for $\widetilde{\chi}_1^+$.

ctau [CM]	Width [GeV]
56	3.52330032E-16
10	2.16666666E-15
100	2.16666666E-16
1000	2.16666666E-17

After selecting the benchmark point, and making sure our process is defined correctly, a ladder of steps that make up the production can be followed.

- **GENSIM**: Physics and detector simulation
- **GENSIMRAW**: Digitisation of electronic signals to make simulated events look like data.
- **AODSIM**: Reconstruction and object identification, e.g tracks, electrons, muons, jets, ...
- **miniAODSIM**: Skimmed version of AODSIM where only the most important variables are stored.
- **nTuples** NTuple with the variables defined by indiviudual users.

To produce the signal, one needs to have a cmsDriver recipe. The recipe has to be customized according to the used physical model. In this analysis, charginos are coming from direct gluino production, and are decaying into a neutralino, and a pion. The customization begins with the GENSIM step.

```
cmsDriver.py LLP_pMSSM12_MCMC1_27_200970_cff_1000.py
   --fileout file:pMSSM12_MCMC1_27_200970_step1_GENSIM_100.root
   --mc
   --eventcontent RAWSIM
   --customise
   SLHCUpgradeSimulations/Configuration/postLS1Customs.customisePostLS1,
   Configuration/DataProcessing/Utils.addMonitoring,
   SimG4Core/CustomPhysics/Exotica_HSCP_SIM_cfi,
   DisappTrks/SignalMC/genParticlePlusGeant.customizeProduce,
   DisappTrks/SignalMC/genParticlePlusGeant.customizeKeep
   --datatier GEN-SIM
   --conditions MCRUN2_71_V1::All
   --beamspot Realistic50ns13TeVCollision
   --step GEN,SIM
   --magField 38T_PostLS1
   --python_filename pMSSM12_MCMC1_27_200970_GENSIM_1000.py
```

This is a Monte Carlo simulation produced with the help of Pythia 8 and Geant4. Our event content in this step, is RAWSIM. Under –customize, the file *Exotica_HSCP_SIM_cfi* is for chargino simulation. The file requires a flavor which we state in the genfragment file *LLP_pMSSM12_MCMC1_27_200970_cff_1000.py* as stau.

genParticlePlusGeant helps overcome the issue with $\widetilde{\chi}_1^+$ decay. It passes the information to Geant.

3 Track Selection

3.1 Fiducial Track Selection

It is favorable to avoid tracks that are missing muon chamber hits and associated calorimeter energy due to some inefficiencies in the detector, therefore the tracks that are in known high inefficiency regions are vetoed.

First, some η regions need to be vetoed. These regions can be examined in more detail in Figure 4, through highlighted sections in the image.

- $0.15 < |\eta| < 0.35 \rightarrow$ Gap between wheels 0 and 1
- $1.42 < |\eta| < 1.65 \rightarrow$ Barrel and endcap overlap in ECAL
- $1.55 < |\eta| < 1.85 \rightarrow$ Transition region between the outermost and innermost rings of the CSCs.

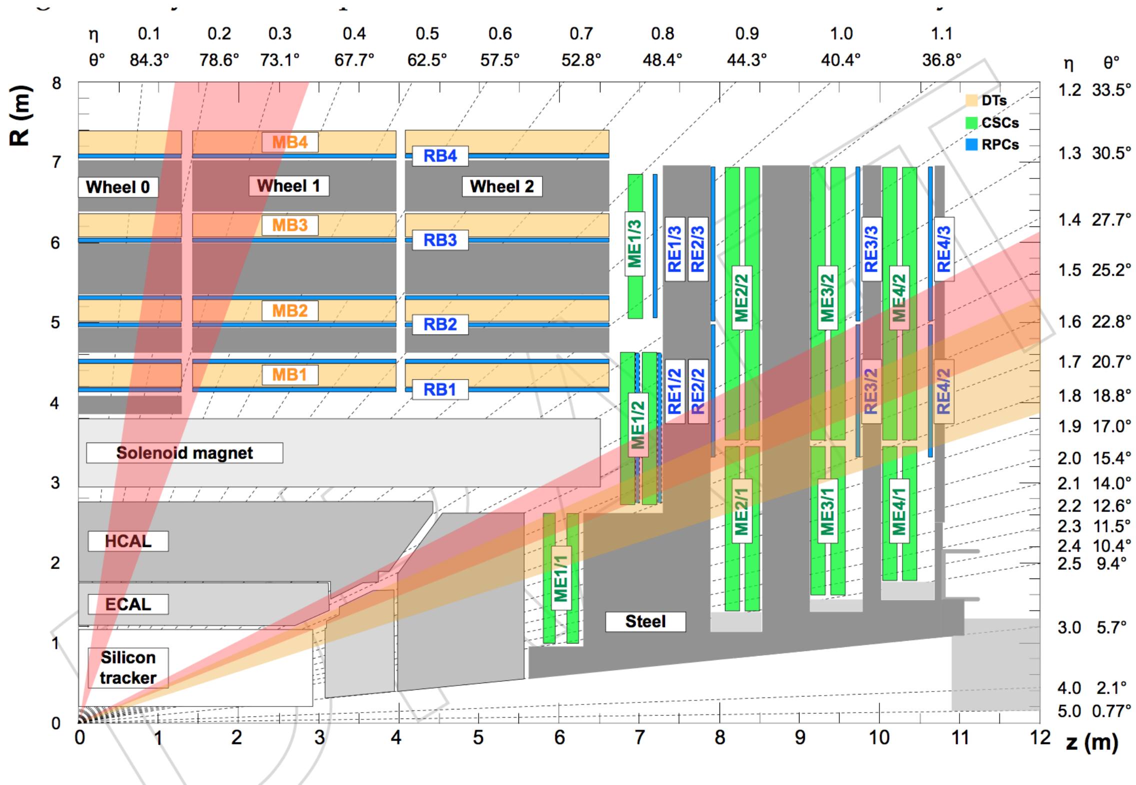


Figure 4: One quarter of the CMS detector layout with corresponding eta regions. .

3.2 Search Region

The selection for the search consists of multiple steps.

- Basic Selection
- Isolated Track Selection
- Candidate Track Selection
- Disappearing Track Selection

Starting from the basic selection, the events that satisfy the requirements are subjected to the next selection step after the end is reached. The events that can pass the missing transverse energy (MET) triggers are subjected to the basic selection. This phase defines the event topology. The main requirement is a high-p_T ISR jet.

After requiring the tracks to be isolated, i. e. no activity in a cone of $\Delta R = 0.3$ around the track, we apply additional cuts that can be seen in Table 3

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} \tag{1}$$

In the candidate track selection, the tracks that are matching to leptons (electrons, taus, muons) with ΔR <0.15 can be rejected.

The ΔR variable also helps looking at the best matched object between different stages. In this case it is the truth level $\tilde{\chi}_1^+$ tracks, and all the other reconstructed tracks. The track candidate collection is matched to the MC truth particles based on a minimum ΔR. [4] In Figure 5, ΔR between the generator level $\tilde{\chi}_1^+$ and the reconstructed tracks can be seen as an example.

Table 3: Track Selection Requirements

quantity	object	selection
$\geq$1	tracks	p_T >50 GeV
$\geq$1	tracks	$\|\eta\|$ <2.1
$\geq$1	tracks	number of pixel hits ≥ 3
$\geq$1	tracks	number of valid hits ≥ 7
$\geq$1	tracks	missing inner hits ≤ 1
$\geq$1	tracks	missing middle hits ≤ 1
$\geq$1	tracks	rel. track-based iso. < 0.05

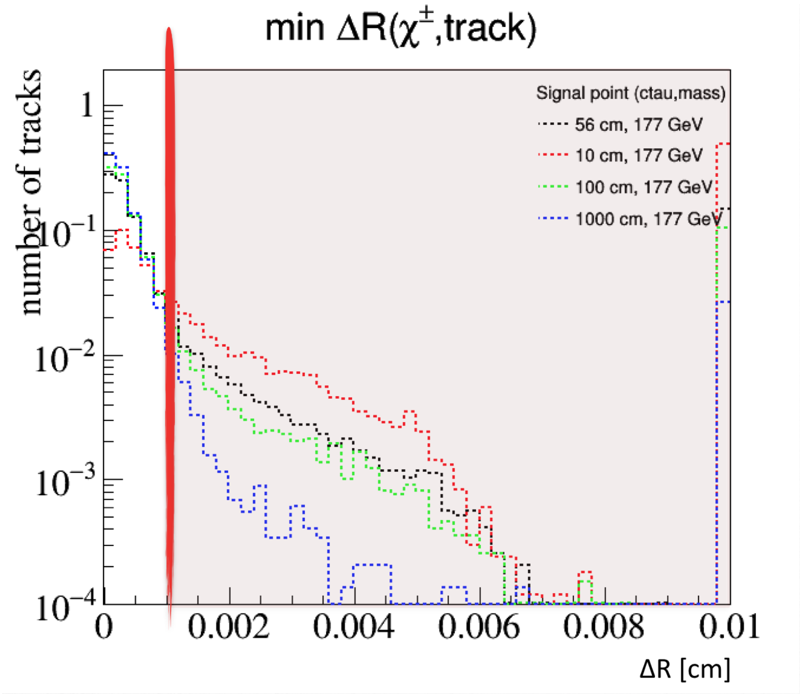
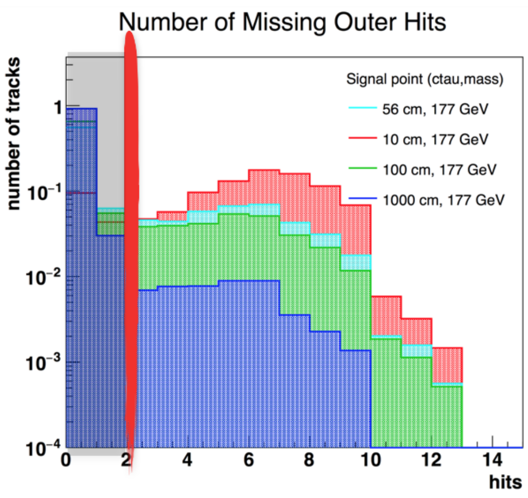


Figure 5: Minimum ΔR between generator level $\tilde{\chi}_1^+$ tracks and all the other reconstructed tracks.

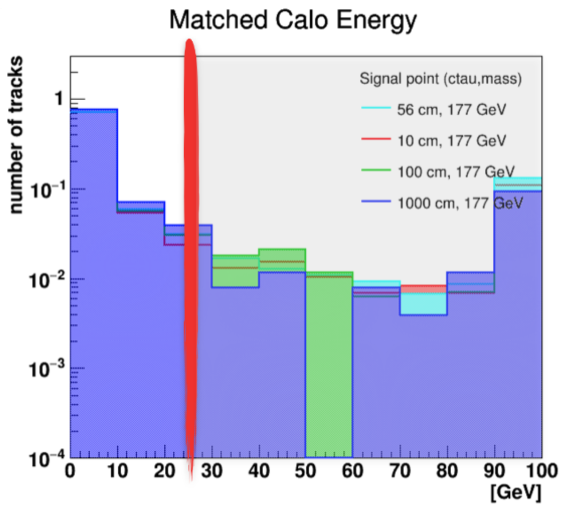
When selecting the disappearing tracks, there are certain criteria. Because the $\tilde{\chi}^0$ do not deposit energy in the calorimeter, the amount of energy in the examined area must be limited to a maximum of 25GeV. This variable is called the *matched calorimeter energy* and shown as $E_{calo}^{DR<0.001}$

Also, the fact that the track is disappearing due to low energy daughter particle and the $\tilde{\chi}^0$, looking at the missing outer hits information is considerably helpful. Including outer hits, there are three types of missing hits, with remaining two being inner and middle. Sometimes in a track, there can be two types of missing hits at the same time. This disrupts the track, and is interpreted as a bad reconstruction.

The demand for a disappearing track is a continious track with only missing outer hits. The selection requirement is to have at least two missing outer hits. Complete selection criteria of disappearing tracks can be seen in Table 4.



(a) Number of missing outer hits.



(b) Matched calo energy.

Figure 6: The criteria for disappearing track selection. (signal)

Table 4: The criteria defining the disappearing track selection.

quantity	object	selection
≥ 1	tracks	$E_{calo}^{DR<0.001} < 25$ GeV
≥ 1	tracks	missing outer hits ≥ 2

Track reconstruction efficiency is an important parameter to analyse. The efficiency must be checked for all produced signals with different lifetimes. In Figure 7, the x-axis is the logarithmic scaled decay length for each track, and y-axis is the efficiency. One can see that the reconstruction begins only after the signals reach a minimum length of 10 cm. All signal samples presented have the same turn-on, meaning that the efficient reconstruction begins at the same length no matter which signal. The longer the signals get, the more efficient the reconstruction becomes.

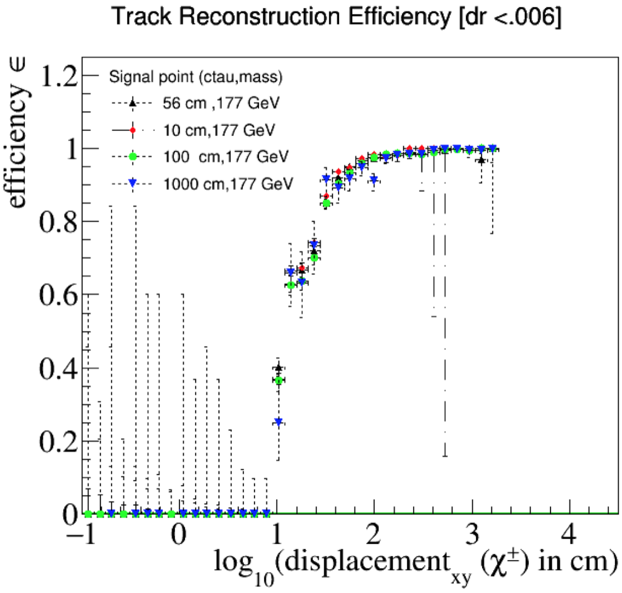
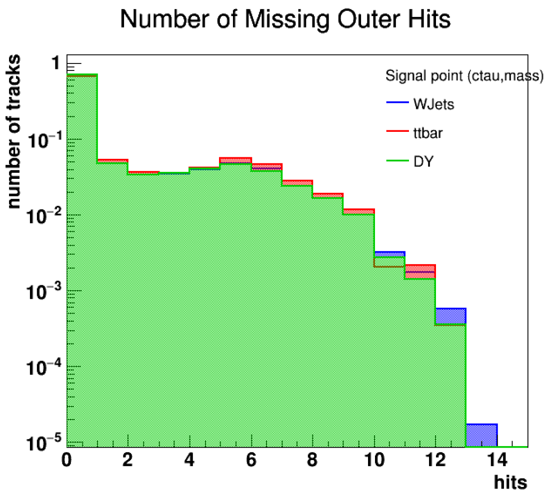


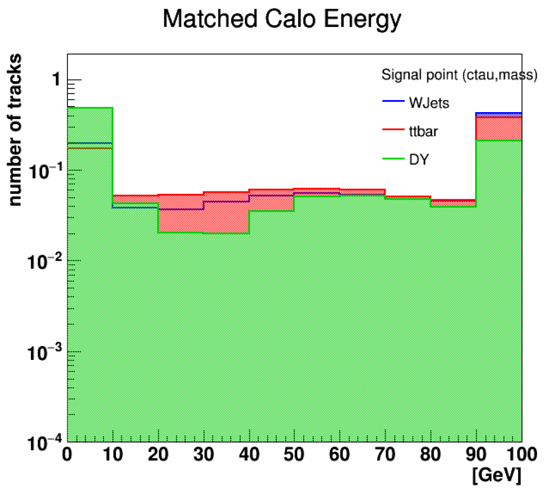
Figure 7: Track reconstruction efficiency.

3.3 Background Estimation

Although the signal samples were not given and had to be produced, background samples were provided. Three sets of background samples were used in this analysis, namely, W Jets, $t\bar{t}$, and Drell Yan processes. The background contribution of missing outer hits and matched calorimeter energy can be seen in Figure 8.



(a) Number of missing outer hits.



(b) Matched calo energy.

Figure 8: Background contribution to the number of missing outer hits, and matched calorimeter energy. The plots are produced without applying any cuts.

The selection requirements are decided with (N-1) method, but further on, Random Grid Search (RGS) will be implemented in the analysis. [5]

3.4 Event Selection

In this section there will be much details on the event selection, but a new parameter will be introduced; $\Delta\Phi$ between MET and disappearing tracks. In this analysis, MET is caused by the $\tilde{\chi}^0$. Natually, MET and $\tilde{\chi}^0$ point in the same direction. In Figure 9, it can be seen that the MET and the disappearing track, $\tilde{\chi}_1^+$, is also pointing in the same direction.

Therefore, one would expect to observe a Φ difference of zero in the signal, and an even distribution in the background. Such expected signal peaks, and background distribution can be seen in Figure 10.

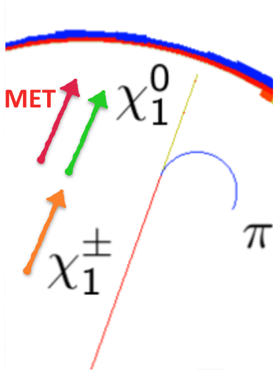
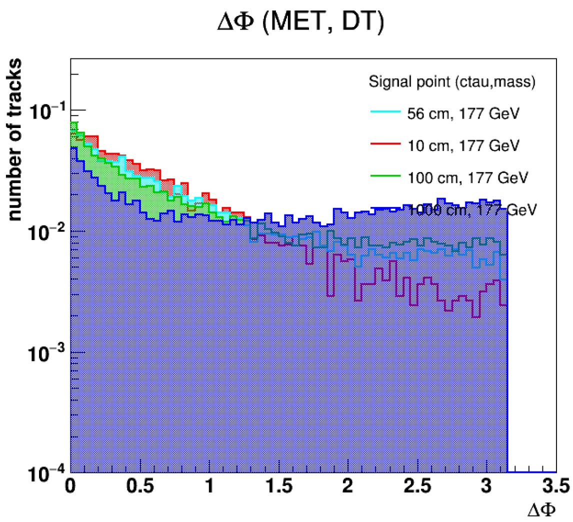
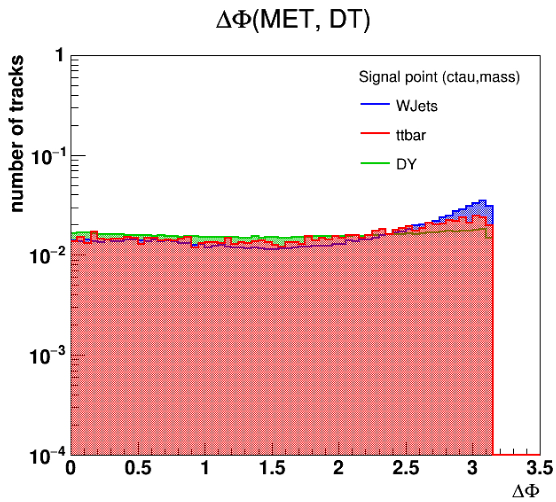


Figure 9: Track reconstruction efficiency.



(a) Signal



(b) Background

Figure 10: $\Delta\Phi(MET, DT)$ distribution for signal and background. For signal, a peak at 0 can be seen as expected, whereas for the background there is an even distribution.

4 Conclusion

A search for the long-living charginos that decay within the CMS detector has been presented in this report.. These long lived charginos produce the signature of a disappearing track. Signal events have been generated at center of mass energy of 13 TeV.

The signal production steps were followed. In total, four signals were produced for charginos with different lifetimes of 56, 10, 100 and 1000 cm. Over these signals, the track selection requirements were studied. Background signals provided by CMS were also studied and (N-1) plots were produced for both the signal and background samples, validating the selections.

Additionaly, a new event selection variable named $\Delta\Phi(MET, Tracks)$ was studied.

5 Acknowledgements

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