CEPC Note

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Prospect for a search for direct stau production at the CEPC

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The Circular Electron Positron Collider (CEPC) is a large international scientific facility proposed by the Chinese particle physics community in 2012, which will be operated at 240 GeV as a Higgs factory, offers an unmatched opportunity for precision measurements and searches for BSM physics. This document presents example benchmark studies for direct stau production. Using the full simulation, the CEPC is expected to discover the potential stau signal up to XXX GeV or exclude it up to YYY (119) GeV.

Contents

1 Introduction

Supersymmetry (SUSY) proposes for every boson (fermion) of the Standard Model (SM) there exists a fermionic (bosonic) partner. The existence of SUSY particles with masses at the electroweak scale leads to contributions that can cancel quadratic divergences to the Higgs mass corrections. SUSY can also accommodate the unification of the gauge interactions and a radiative breaking of the electroweak symmetry. Under the conservation of R-parity, SUSY particles are always produced in pair, and the lightest SUSY particle (LSP) is stable and is an excellent candidate to account for the dark matter in the universe.

In SUSY models, the sector of sparticles with only electroweak interactions contains charginos ($\tilde{\chi}_i^{\pm}$, $i = 1$, 2 in order of increasing masses), neutralinos ($\tilde{\chi}_j^0$, $j = 1, 2, 3, 4$ in order of increasing masses), charged sleptons ($\tilde{\ell}$), and sneutrinos ($\tilde{\nu}$). Charginos and neutralinos are the mass eigenstates formed from the linear superpositions of the superpartners of the charged and neutral Higgs bosons and electroweak gauge bosons. The sleptons are the superpartners of the charged leptons and are referred to as left or right ($\tilde{\ell}_{\mathrm{L}}$ or $\tilde{\ell}_{\mathrm{R}}$) depending on the chirality of their SM partners. The slepton mass eigenstates are a mixture of $\tilde{\ell}_{\mathrm{L}}$ and $\tilde{\ell}_{\mathrm{R}}$, and are labelled as $\tilde{\ell}_1$ and $\tilde{\ell}_2$ (with $\tilde{\ell}_k$, $k = 1, 2$ in order of increasing masses). In this work, the scalar superpartner of the left-handed tau lepton (the stau-left) and right-handed tau lepton (stau-right) are considered to be mass degenerate.

Models with light staus can lead to a dark-matter relic density consistent with cosmological observations and light sleptons in general could play a role in the co-annihilation of neutralinos. Sleptons are expected to have masses of order 100 GeV in gauge-mediated and anomaly-mediated SUSY breaking models.

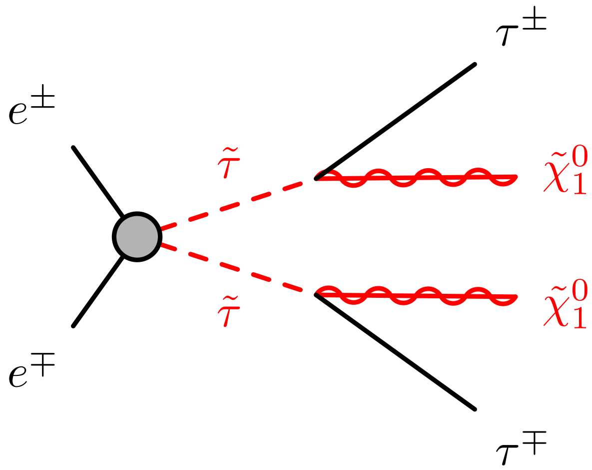


Figure 1: Representative diagram illustrating the pair production of charged staus and subsequent decay into a two-tau final state.

The search for direct stau has been performed in LHC, both by ATLAS and CMS experiments, In the simplified models studied in this doc, the lightest neutralino is the LSP and purely bino, and the two charged staus are assumed to be mass-degenerate. The left- and right-handed staus decay with a 100 % branching fraction to a bino-like neutralino ($\tilde{\tau}^+_{R,L}\tilde{\tau}^-_{R,L} \rightarrow \tilde{\chi}_1^0\,\tau^{\pm}$). All sparticles other than those explicitly mentioned here are assumed to be inaccessible at the CEPC energy. This doc focuses on the direct production of a stau pair, leading to the final state illustrated in Figure 1.

stau masses from 120 GeV to 390 GeV are excluded at 95% confidence level (CL) for a massless lightest neutralino. From LEP, searches set a lower limit of 86.6 GeV at 95% CL on the mass of promptly decaying staus. The clean collision environment of the CEPC, as well as higher energy comparing to LEP, will provide the great opportunity to cover the gap from these different experiments.

2 Samples and software

Monte Carlo (MC) simulated event samples were used to estimate the SUSY signal yields and to aid in evaluating the SM backgrounds. The signal samples are parametrized as function of the stau and neutralino LSP mass, where the stau mass is bounded from below by the LEP limit, and the neutralino mass is bounded from above by the stau mass. The mixing matrix for the scalar taus is antidiagonal such that no mixed production modes are expected. The masses of all charginos and neutralinos apart from the $\tilde{\chi}_1^0$, were set to 2.5 TeV to forbid all other decay channels. Three signal point, with $\tilde{\tau}$ mass 100 GeV, $\tilde{\chi}_1^0$ mass 10, 50 and 90 GeV are used for event selection optimization as reference points.

process	cross-section [fb]
$m_{\tilde{\tau}}$ = 80 GeV	419.6
$m_{\tilde{\tau}}$ = 90 GeV	293.0
$m_{\tilde{\tau}}$ = 100 GeV	171.1
$m_{\tilde{\tau}}$ = 110 GeV	64.6
$m_{\tilde{\tau}}$ = 115 GeV	23.6
$m_{\tilde{\tau}}$ = 119 GeV	2.2
$\tau\tau$	4374.94
$ZZorWW > \nu\nu\tau\tau$	205.84
$\nu\ Z, Z > \tau\tau$	14.57
$ZZ > \nu\nu\tau\tau$	9.20
$\nu\nu\ H, H > \tau\tau$	3.07

Table 1: Cross-sections of the direct stau signals and dominant backgrounds in CEPC.

The backgrounds are categorized by the number of final state fermions at the parton level. At 240 GeV centre-of-mass energy, the dominant SM backgrounds are the 2-fermion and 4-fermion backgrounds. The 2-fermion backgrounds are the qq, Bhabha, $\mu\mu$ and $\tau\tau$ processes; the 4-fermion backgrounds include the ZZ, the WW, the single W, the single Z, and the interfering processes. The latter is denoted as ZZorWW and ZorW process since the final state fermion combination allows multiple intermediate states and their interferences. The cross sections for signal and backgrounds are summarized in Table 1.

The detector model used in the simulation is the CEPC baseline detector, a Particle Flow Oriented detector. It is composed of a low-material tracking system, a high granularity calorimeter system, and a 3-Tesla large radius solenoid that hosts both ECAL and HCAL inside. A baseline CEPC simulation-reconstruction software has been established. It uses the Whizard (MadGraph+Pythia8) as the generator for background sample (signal sample), the MokkaPlus for the full detector simulation, the Clupatra for tracking, and the Arbor for the PFA reconstruction.

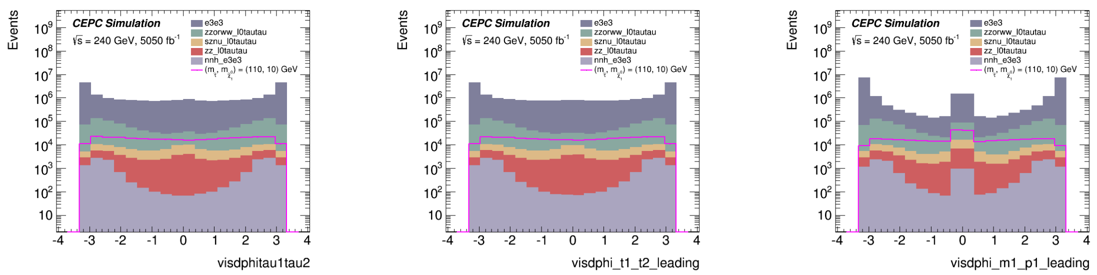
Using the CEPC baseline geometry, an official MC sample production is performed, corresponding to the nominal setting of the CEPC Higgs runs. The samples are scaled according to the luminosity for this massive production. For the Higgs processes with small cross-section, typically under 20 fb^{-1}, and the SUSY signal processes with different mass parameters, the samples are simulated to a minimal statistic of 100 k. For leading 2-fermion standard model background, the production only simulates a fraction (20%) of the expected statistics, to save the computing resource. For all 4-fermion backgrounds, the samples are generated with full statistics.

3 Search for the direct production of staus

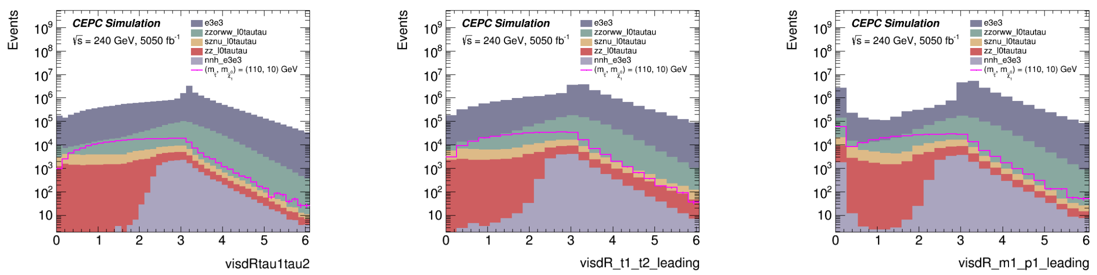
The main signatures of the signal process are two tau leptons and large missing energy. The expected background is dominated by WWorZZ, sznu_tautau and vvHtautau.

3.1 Signal region selection

The event selection is based on the topology of the signal decay, with two tau leptons decaying from a pair of back-to-back stau, and large missing mass from the LSP which will escape from the detector. Therefore, the invariant mass, recoil mass and the angular variables of the tau leptons are very efficient to separate the signal events from SM backgrounds.



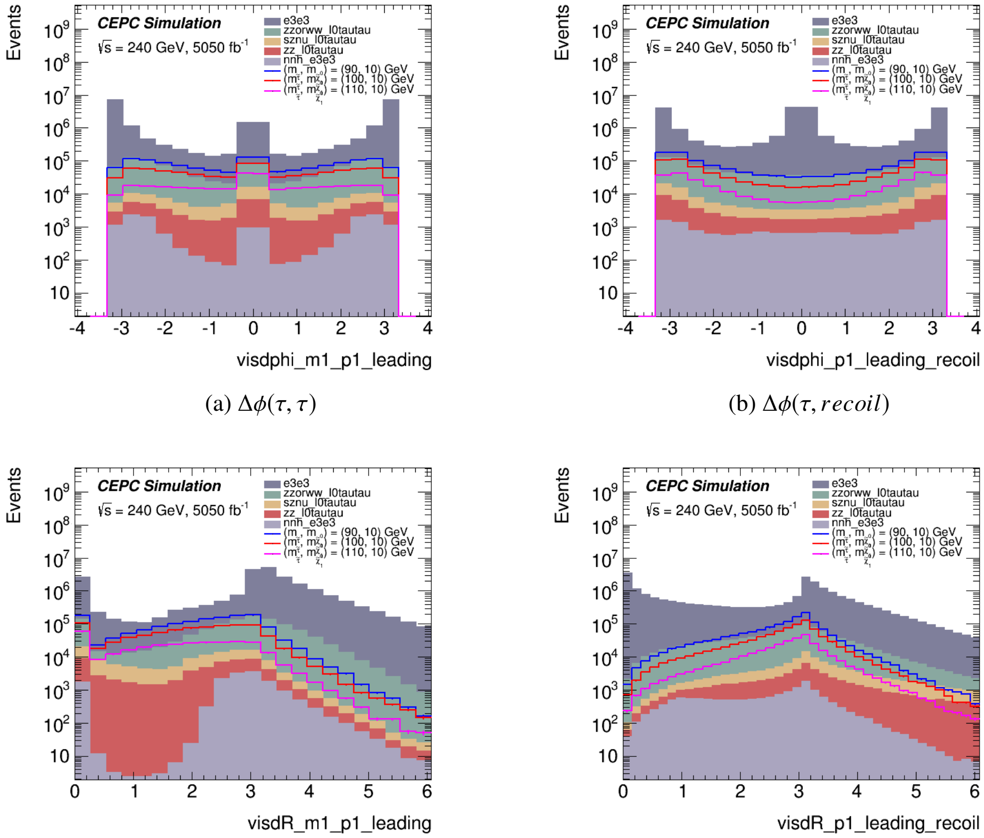
(a) truth tau leptons (b) leading track from tau lepton (c) Recon leading OS tracks



(d) truth tau leptons (e) leading track from tau lepton (f) Recon leading OS tracks

Figure 2: The comparison of the $\Delta\phi$ (top) and ΔR (bottom) variables from leading reconstructed OS tracks with truth tau leptons.

In this study, we use the angular information from the leading track with minus (positive) charge to represent the tau (anti-tau) lepton for simplicity. This assumption is validated by comparing the angular distributions from reconstructed leading tracks with opposite sign (OS) with those from truth taus, as shown in Figure 2. The shapes are in nice agreement especially with high ΔR, where $\Delta R = \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$. From Figure 3 it's clear that requirements on the angular between τ and the recoil system is very efficieny to suppress the $\tau\tau$ background. Further more, the ΔR between two τ leptons are also useful to decress the number of backgrounds.



(a) $\Delta\phi(\tau,\tau)$ (b) $\Delta\phi(\tau, recoil)$

(c) $\Delta R(\tau,\tau)$ (d) $\Delta R(\tau, recoil)$

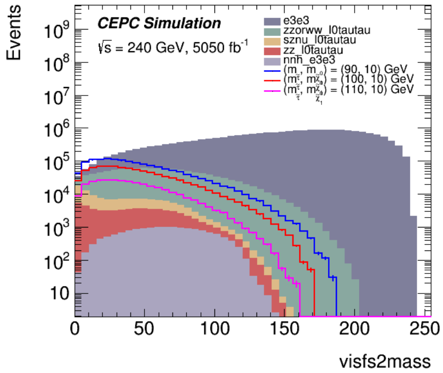
Figure 3: The angular variables between two τ leptons (left) and between τ and recoil system.

Apart from the angular information, the missing mass information is essential for R-Parity conserved SUSY searches. Thanks to the very clean collision environment in CEPC, almost all the visible stable particles can be detected and reconstructed, so it's possible to calculate the kinematics of the visible system, and the missing mass can be represented by the recoil mass of this visible system. The tau leptons can also decay leptonically to produce neutrinos, which are also included in the recoil system. The invariant mass, total energy and total pT of the visible system as well as the recoil mass are shown in Figure 4.

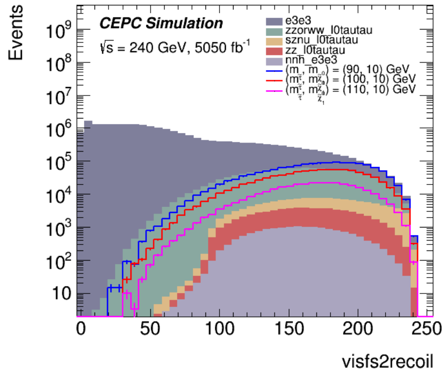
Further optimization is performed using the invariant mass of the visible system, using $\frac{S}{\sqrt{S+B}}$ as the sensitivity. Figure 5 shows the sensitivities of 3 reference points as a function of the different upper cut on invariant mass. The best selection varies from different signal parameter settings, an upper cut at 100 GeV is used to avoid over optimization.

3.2 Expected sensitivity

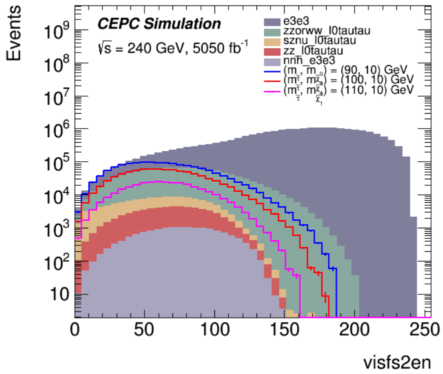
The cutflow for the dominant backgrounds and the reference signal points can be found from Table 2.



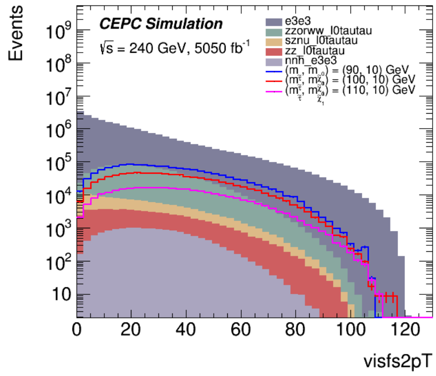
(a) invariant mass



(b) recoil mass



(c) Total enerty



(d) p_T

Figure 4: The kinematic variables of the total visible system.

Selection	$\tau\tau$	$ZZorWW > \nu\nu\tau\tau$	$\nu\ Z, Z > \tau\tau$	$ZZ > \nu\nu\tau\tau$	$\nu\nu\ H, H > \tau\tau$
Raw events	22093447	1039492	73578.5	46460	15503.5
$\lvert\Delta\phi(\tau, recoil)\rvert > 1$	3000040	680170	56313.3	35145.8	8285.3
$0.2 < \lvert\Delta\ R(\tau,\tau)\rvert < 2.8$	496144	289414	41129.3	25060.5	3140.11
m^{vis}_{recoil} > 100 GeV	4906.41	275448	40707.7	24653.1	3081.66
effieciency	0.02%	26.50%	55.33%	53.06%	19.88%
Selection	Total backgrounds	(100, 10)	(100, 50)	(100, 90)	
Raw events	23268481	864055			
$\lvert\Delta\phi(\tau, recoil)\rvert > 1$	3779950	680916	681279	676700	
$0.2 < \lvert\Delta\ R(\tau,\tau)\rvert < 2.8$	854888	507134	510884	555638	
m^{vis}_{recoil} > 100 GeV	348797	490762	510884	555638	
effieciency	1.50%	56.80%	59.13%	64.31%	

Table 2: Event yields of reference points and dominant backgrounds after different selections.

After applying the selections described in Section 3.1, we have calculated the sensitivity of all the signal points, and derive the sensitivity map with the systematic uncertainty of 0, 5% and 10%, as shown in Figure 6.

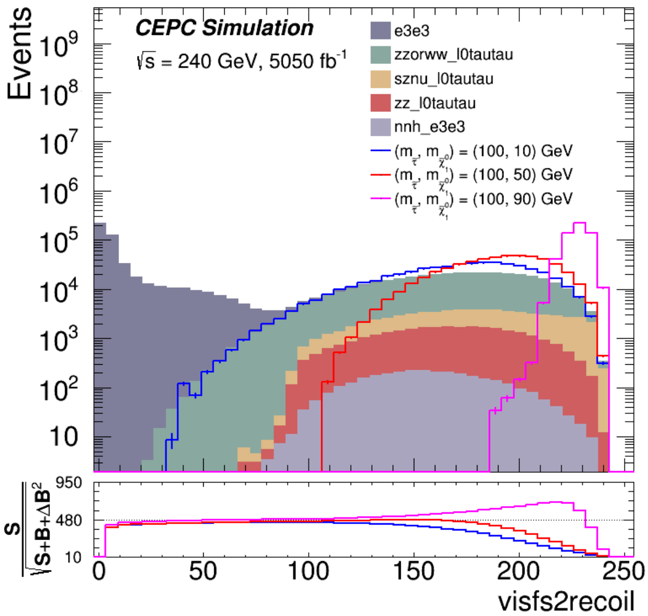


Figure 5: The sensitivities of three reference points as a function of different cut on the recoil mass of the visible system.

4 Conclusions

Feasibility studies on benchmark SUSY scenarios for direct stau pair production in CEPC are carried out with MC samples, the sensitivities with the assumption of different systematic uncertainties are given, the exclusion limit reaches XXX (119) GeV in stau mass with massless LSP, and the discovery sensitivity reaches YYY (ZZZ) GeV with a massless LSP with 5% (10%) systematic uncertainty.

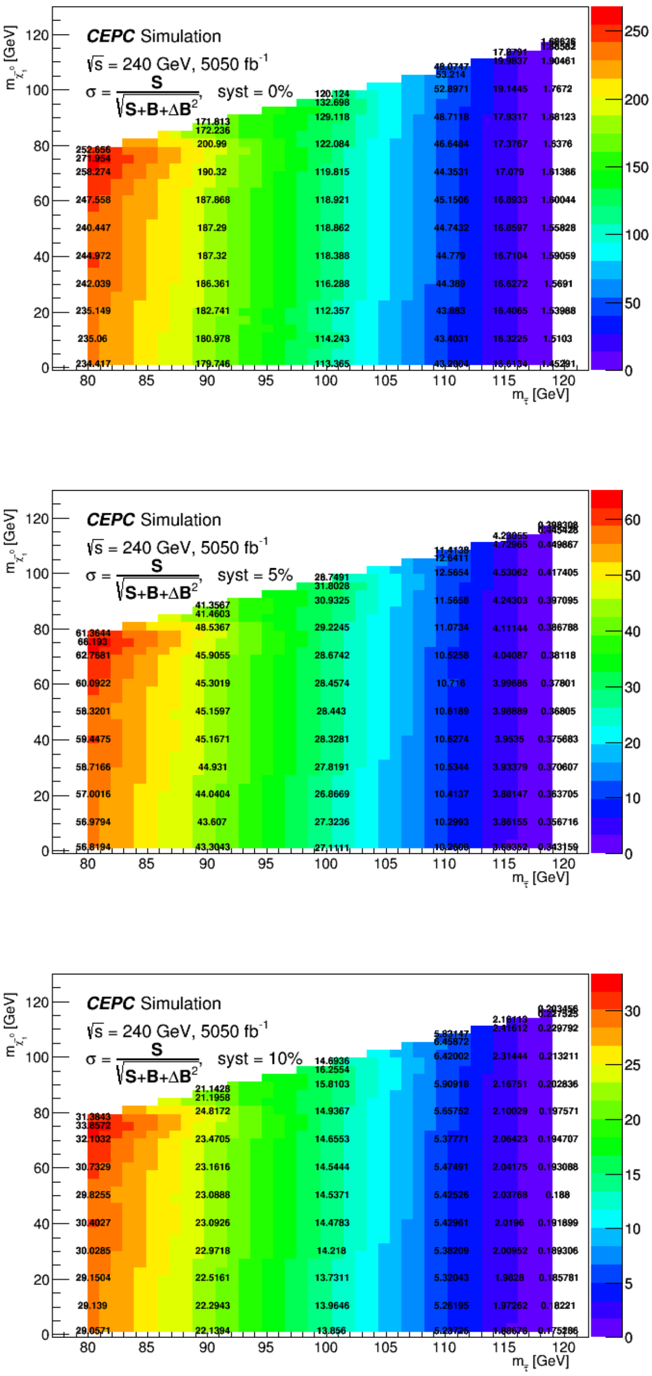


Figure 6: The sensitivities map with no syst (top), 5% (middle) and 10% (bottom) flat syst assumption.