Search for chargino and neutralino production in final states with two same-sign leptons, jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector

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Introduction

Introduction

Standard Model : Fundamental Particles

- Standard Model(SM) is the current mainstream theory to describe the electromagnetic force, weak force and strong force.

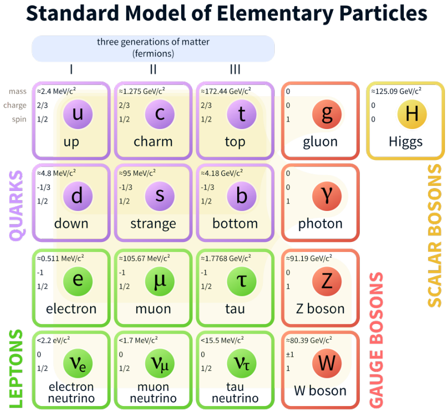


Figure: The "periodic" table for all fundamental particles in SM.

Standard Model : Fundamental Interaction

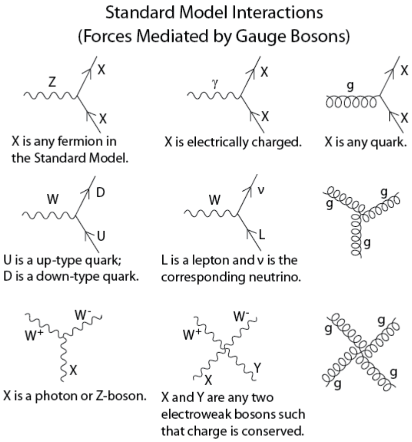


Figure: All allowed fundamental Feynman vertices in SM, except higgs-related vertices.

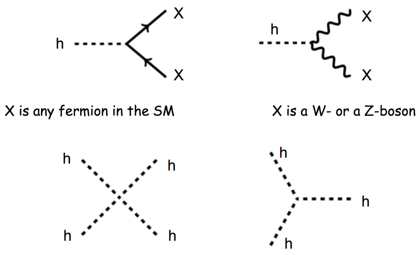


Figure: All allowed fundamental higgs-related Feynman vertices in SM.

Standard Model : Limitation

- SM cannot explain gravity.
- SM cannot explain the nature of dark matter.
- The hierarchy problem
  - Why the weak force is stronger than the gravity by 10^{24}.
  - Why the Higgs mass is much lighter than the Planck mass.
  - At very high energy scale, the Higgs boson mass is strongly sensitive to quantum corrections.

Supersymmetry

- Supersymmetry(SUSY) is an extension of the Standard Model.
- It can solve the hierarchy problem of Higgs mass.
- It can explain the nature of dark matter.

Supersymmetry : MSSM

- Minimal Supersymmetric Standard Model(MSSM) is the simplest realization of the supersymmetry.
- It predicts that each particle in the Standard Model has its own partner particle, called the superpartner.
- The spin of the superpartner will differ from the Standard Model particle by 1/2.
- A symmetry between the fermions and bosons.

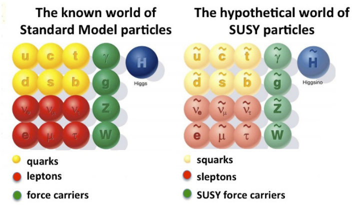


Figure: The particles in Standard Model and their corresponding superpartners and their names.

Supersymmetry : Superpartners

- In the MSSM, one more neutral Higgs filed H and two more charged Higgs fileds H^+, H^- needed to be introduced.
- In SM electro-weak bosons, there are in total 4 neutral bosons: γ, Z, h and H, and 4 charged bosons: W^+, W^-, H^+ and H^-.
- The superpartners of the 4 neutral bosons together form 4 mass eigenstates, called neutralinos: $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$.
- The superpartners of the 4 charged bosons together form two mass eigenstates with electric charge ±1, called charginos: $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^\pm$.

Type	SM particle	Symbol	Spin	R-parity	Superpartner	Symbol	Spin	R-parity
Fermions	Quark	q	$\frac{1}{2}$	+1	Squark	$\tilde{q}$	0	-1
	Lepton	l	$\frac{1}{2}$	+1	Slepton	$\tilde{l}$	0	-1
Gluon	Gluon	g	1	+1	Gluino	$\tilde{g}$	$\frac{1}{2}$	-1
Neutral EW Bosons	Photon	γ	1	+1	Neutralinos	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$	$\frac{1}{2}$	-1
	Z Boson	Z	1	+1				
	Neutral Higgs	h,H	0	+1				
Charged EW Bosons	W Boson	W^+, W^-	1	+1	Charginos	$\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm$	$\frac{1}{2}$	-1
	Charged Higgs	H^+, H^-	0	+1				

Table: The spin and R-parity for the Standard Model particles and their superpartners.

Supersymmetry : R-parity

- The baryon number B is defined by $\frac{1}{3}(n_q - n_{\bar{q}})$, where n_q is the number of quarks and $n_{\bar{q}}$ is the number of anti-quarks.
- The lepton number L is defined by $n_l - n_{\bar{l}}$, where n_l is the number of leptons and $n_{\bar{l}}$ is the number of anti-leptons.
- In SM, $(B - L)$ is conserved. But in MSSM, it is no longer conserved.
- To keep $(B - L)$ conservation and prevent the proton decay, the R-parity P_R is introduced.

$$P_R = (-1)^{3(B-L)-2s}$$

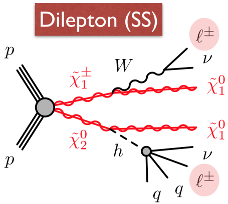
where s is the spin.

Supersymmetry : R-parity

- All SM particles have R-parity $+1$, while all SUSY particles have R-parity -1.
- If the R-parity is conserved, the lightest supersymmetric particle (LSP) cannot decay and is stable.
- If the LSP is electrically neutral and interacts with matter only by the weak interaction and gravity, it could be a candidate for dark matter, for example the lightest neutralinos $\tilde{\chi}_1^0$.
- In this thesis, the R-parity is assumed to be conserved, and the lightest neutralino $\tilde{\chi}_1^0$ is assumed to be the LSP.
- Due to the conservation of R-parity, the supersymmetric particles can only be pair-produced, and will eventually decay into SM particles and the lightest neutralino $\tilde{\chi}_1^0$ (i.e. LSP).

Our Signal Scenario : Motivation

- In the recent searches for the squarks ($\tilde{q}$) and gluinos ($\tilde{g}$), the masses of gluinos and the first and second generation squarks are suggested to be larger than 1 TeV, while the masses of the third generation squarks are still allowed to be below 1 TeV.
- In this case, the direct pair production of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ may be the dominant SUSY production process at the LHC, if the masses of them are below 1 TeV.
- In this thesis, their masses are assumed to be the same, and denoted by $m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0}$.



Our Signal Scenario : Decay Processes

- If all the slepton ($\tilde{l}$) are heavier than $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$:
  1. $\tilde{\chi}_1^{\pm}$ will decay to W boson and $\tilde{\chi}_1^0$:
     $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_1^0$
  2. $\tilde{\chi}_2^0$ will decay to the lightest MSSM Higgs boson h and $\tilde{\chi}_1^0$:
     $\tilde{\chi}_2^0 \rightarrow h + \tilde{\chi}_1^0$

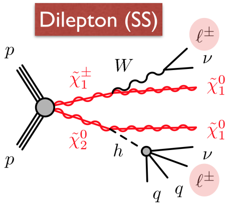
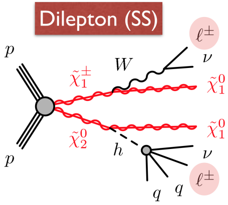


Figure: The Feynman diagram for our Wh same-sign signal scenario.

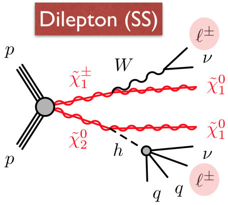
Our Signal Scenario : Decay Processes

- The W boson will further to one lepton (electron or muon) and one neutrino with the SM branching ratio : $W^{\pm} \to \ell^{\pm} + \nu$
- The Higgs boson h will eventually decay to one lepton (electron or muon), quarks (i.e. jets) and neutrino(s) by various decay modes with the SM branching ratios. (For example, $h \to W^{+}W^{-}$ and $h \to \tau^{+}\tau^{-}$)
- From now on, a lepton $\ell^{\pm}$ only refer to an electron or muon, but not τ lepton or neutrino.



Our Signal Scenario : Signal Signature in the Final State

- In this thesis, we only search for two same-sign(SS) leptons, in order to suppress the SM backgrounds.
- A large missing energy is expected, due to the undetected neutralinos $\tilde{\chi}_1^0$ and neutrinos ν.
- Each quark will eventually become a particle shower within a narrow cone, called a jet, by the process of hadronization.
- The mass difference between the two lightest neutralinos $(m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$ should be larger than the Higgs mass ($\sim$ 125 GeV).



Our Signal Scenario : Sensitive Region

- If the mass difference $(m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$ is slightly larger than the Higgs mass, it is called the compressed region.
- In the compressed region, one of the lepton may have low energy, due to the low momentum of the Higgs boson, and hence it may not be detected.
- In this case, there may be originally 3 leptons, but only 2 leptons are detected.
- This allows more decay modes for Higgs boson, which produce two leptons. (For example, $h \to ZZ$)
- Hence, the signal will be more sensitive in the compressed region.