The Next-to-Lightest Neutralino decay at LHC

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Topics:

- Motivation
- Tree-level Calculation
- One-Loop Corrections
- Summary

Motivation

Minimal Supersymmetric Standard Model

MSSM = SM + Supersymmetry

Supersymmetry: Fermion $\longleftrightarrow$ boson

Particle content of the MSSM

Fermions	Bosons
Quarks	Squarks
Leptons	Sleptons
Higgsinos	Higgses
Gauginos	Gauge Bosons
Gluino	Gluon

Neutral higgisinos and gauginos $\rightarrow$ neutralinos

Four neutralinos

$\tilde{\chi}_4^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_2^0$(next-to-lightest) $\tilde{\chi}_1^0$(lightest)

depend on MSSM parameters M_1, M_2 and μ

$$
\begin{pmatrix}
M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\
0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\
-c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\
s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0
\end{pmatrix}
$$

$$
\longrightarrow \begin{pmatrix}
M(\tilde{\chi}_1^0) & 0 & 0 & 0 \\
0 & M(\tilde{\chi}_2^0) & 0 & 0 \\
0 & 0 & M(\tilde{\chi}_3^0) & 0 \\
0 & 0 & 0 & M(\tilde{\chi}_4^0)
\end{pmatrix}
$$

$s_w = \sin\theta_W, c_W = \cos\theta_W$,

$s_\beta = \sin\beta, c_\beta = \cos\beta$,

assuming $M_1 \approx 0.5 M_2$

A discrete symmetry: R-parity

SM-type particles $P_R = 1$

All supersymmetry particles $P_R = -1$

Consequences if R-parity is conserved

- Supersymmetry particles only be produced in pairs

- Lightest Supersymmetry particle (LSP) is stable

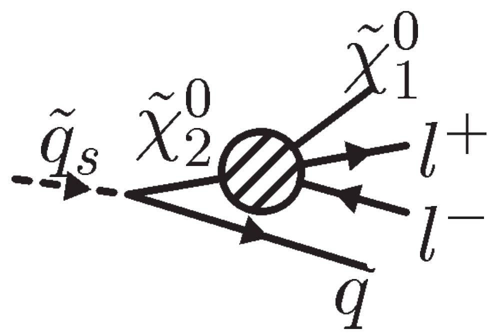
Assuming lightest neutralino $\tilde{\chi}_1^0$ is LSP

Supersymmetry particle $\rightarrow$
lightest neutralino $\tilde{\chi}_1^0$

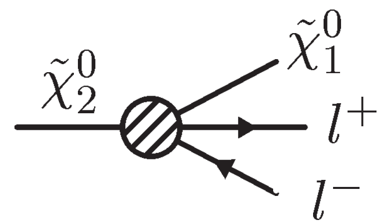
Phenomenological signature:

missing energy

Measure neutralinos masses at LHC

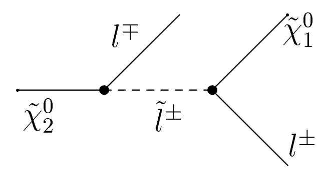


three-body decay
$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$

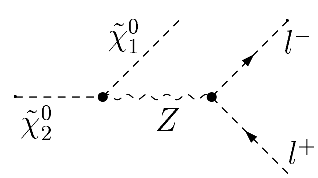


two-body decay

case a: $\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-$



case b: $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z \to \tilde{\chi}_1^0 l^+ l^-$

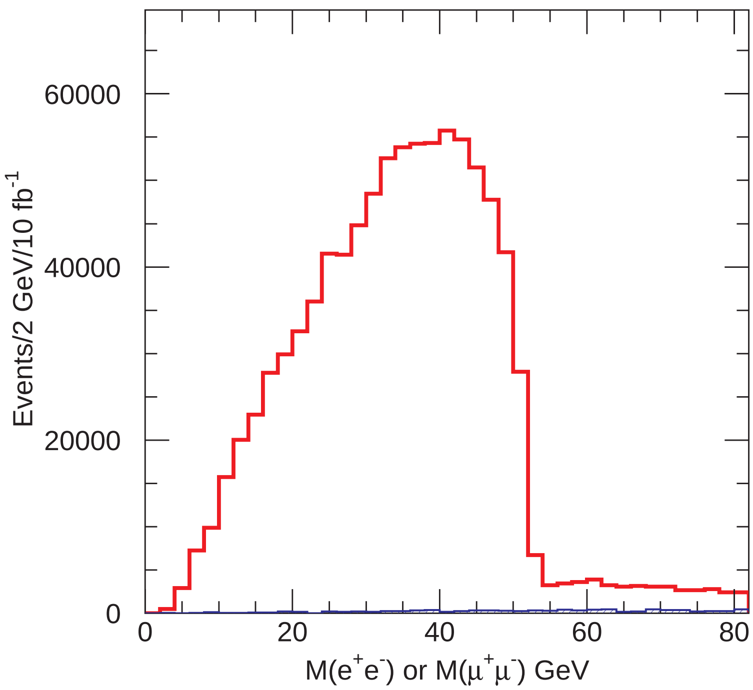


visible dilepton invariant mass distribution
$\Longrightarrow$ mass of invisible neutralino

The dilepton invariant mass defined as

$$M_{l^+l^-} = \sqrt{(k_{l^+} + k_{l^-})^2}$$

Figures from ATLAS Technical Design Report



$M(\tilde{\chi}_2^0) = 97 GeV$
$M(\tilde{\chi}_1^0) = 45 GeV$
$\tilde{l}^{\pm} \approx 200 GeV$

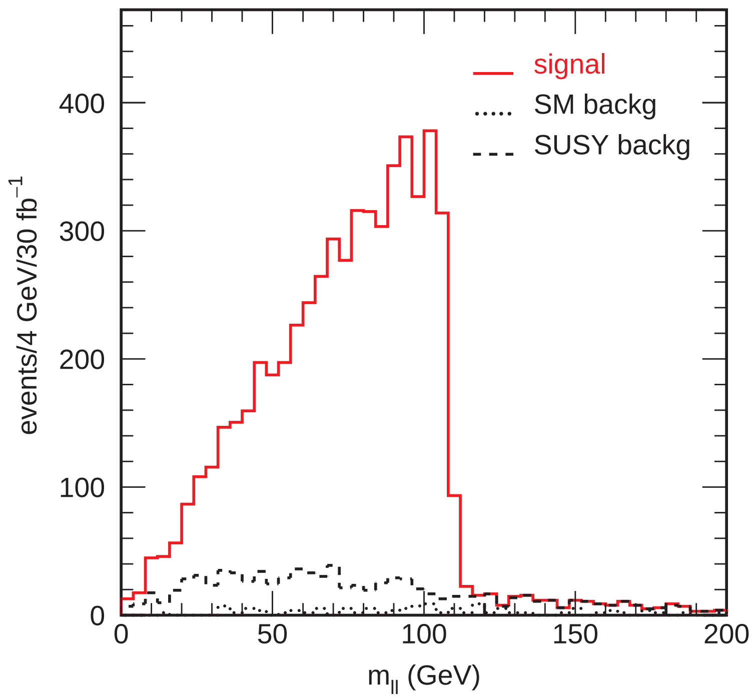
Figure 1: Dilepton mass distribution for three-body decay(solid) and SM background(shaded)

A sharp edge

Endpoints depends on kinematics

three-body decay

$$M_{l^+l^-}^{max} = M(\tilde{\chi}_2^0) - M(\tilde{\chi}_1^0)$$



$M(\tilde{\chi}_2^0) = 233GeV$

$M(\tilde{\chi}_1^0) = 122GeV$

$\tilde{l}_R^{\pm} = 157GeV$

Figure 2: Dilepton $\tilde{\chi}_2^0 \longrightarrow \tilde{l}_R^{\pm} l^{\mp} \longrightarrow \tilde{\chi}_1^0 l^+ l^-$ decay signal

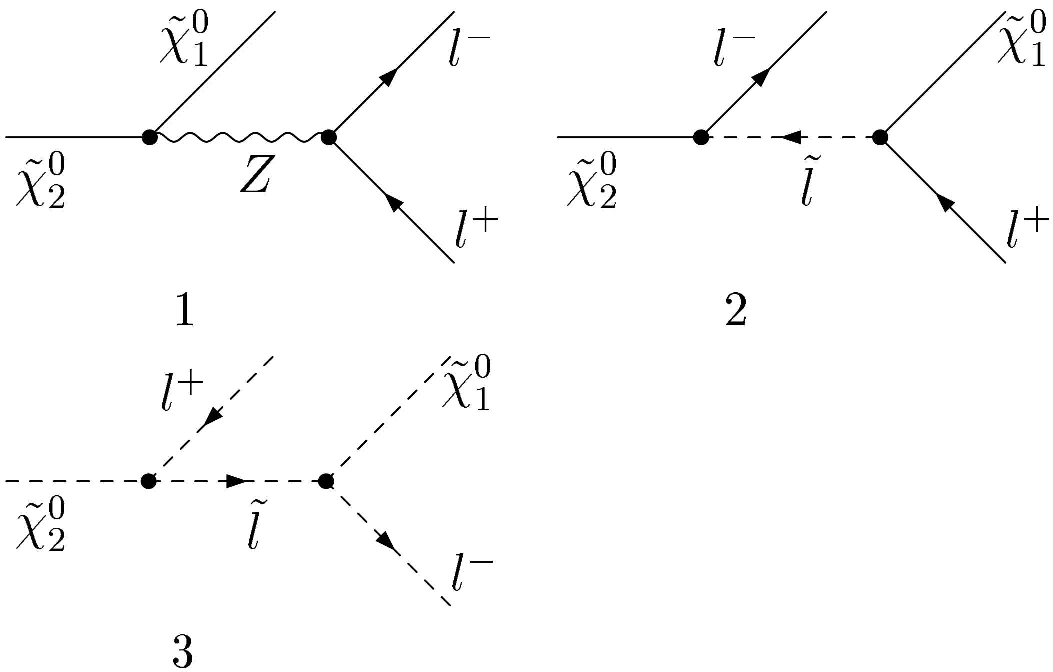
two-body decay(case a)

$$M_{l^+l^-}^{max} = M(\tilde{\chi}_2^0)\sqrt{1 - \frac{M(\tilde{l}^{\pm})^2}{M(\tilde{\chi}_2^0)^2}}\sqrt{1 - \frac{M(\tilde{\chi}_1^0)^2}{M(\tilde{l}^{\pm})^2}}$$

two-body decay(case b) $M_{l^+l^-} = m_Z$

Tree-level Calculation

$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^- l^+$ diagrams at tree-level



propagator $\sim \frac{1}{k^2 - M_v^2}$

problem in two-body decay process:

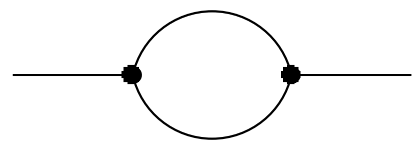
$k^2 = M_v^2 \to$ singularity

Solution A: implement A finite width

$$\frac{1}{k^2 - M_v^2} \longrightarrow \frac{1}{k^2 - M_v^2 + iM_v\Gamma_v} \qquad (1)$$

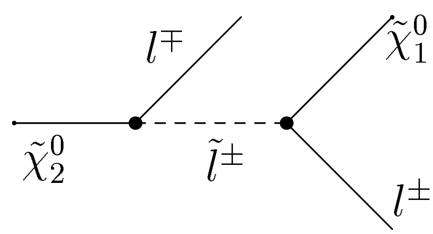
$M_v\Gamma_v$: imaginary part of

self-energy $\Sigma(M_v^2)$



Solution B:

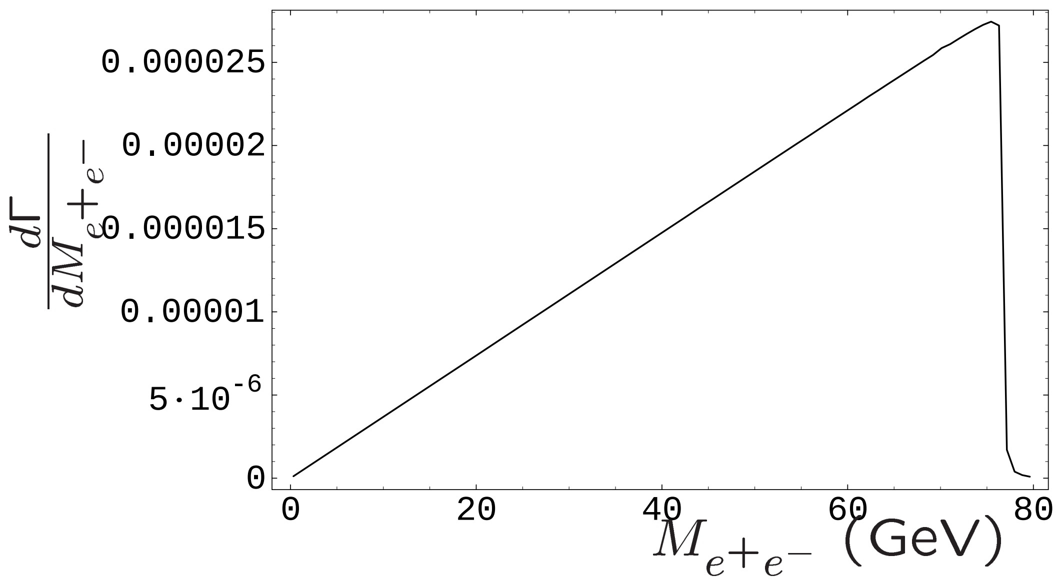
in case of
$\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-$



$$\Gamma(\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-)$$
$$\simeq \Gamma(\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp}) Br(\tilde{l}^{\pm} \to \tilde{\chi}_1^0 l^{\pm})$$

$$Br(\tilde{l}^{\pm} \to \tilde{\chi}_1^0 l^{\pm}) = \frac{\Gamma(\tilde{l}^{\pm} \to \tilde{\chi}_1^0 l^{\pm})}{\Gamma_{\tilde{l}^{\pm}}}$$

tree-level result for $SPS1a$ parameter



SPS1a : a low energy MSSM parameters

$M(\tilde{\chi}_2^0) = 176.57 GeV \quad M(\tilde{\chi}_1^0) = 96.15 GeV$
$\tilde{e}_R^{\pm} = 142.67 GeV \quad \tilde{e}_L^{\pm} = 202.28 GeV$

$M_{e^+e^-}^{max} = 76.85 GeV$

One-loop corrections

Meassure dilepton invariant mass distribution
to a precision of about 0.1%

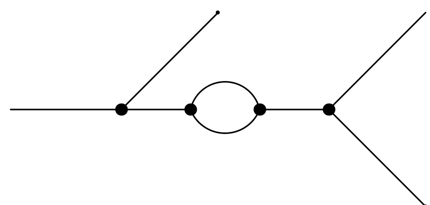
need **higher order corrections**

virtual corrections

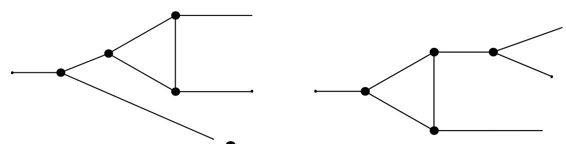
<u>three-body decay</u>

virtual corrections are classified:

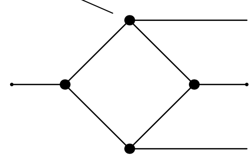
self-energy contributions



vertex contributions



box contributions



counterterm contributions
from renomalization

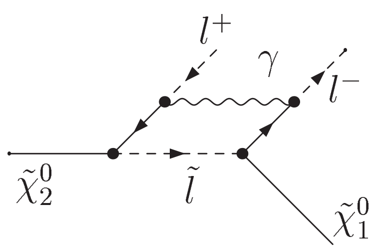
FeynArts, FormCalc and LoopTools

Amplitude $M = M_{tree} + M_{virtual}$

Results include virtual correction:

$$\Gamma = \Gamma_{tree} + \Gamma_{virtual}$$

problem: infrared (IR) divergences



photon mass = 0, $E_\gamma^{min} = 0 \longrightarrow$

IR divergences

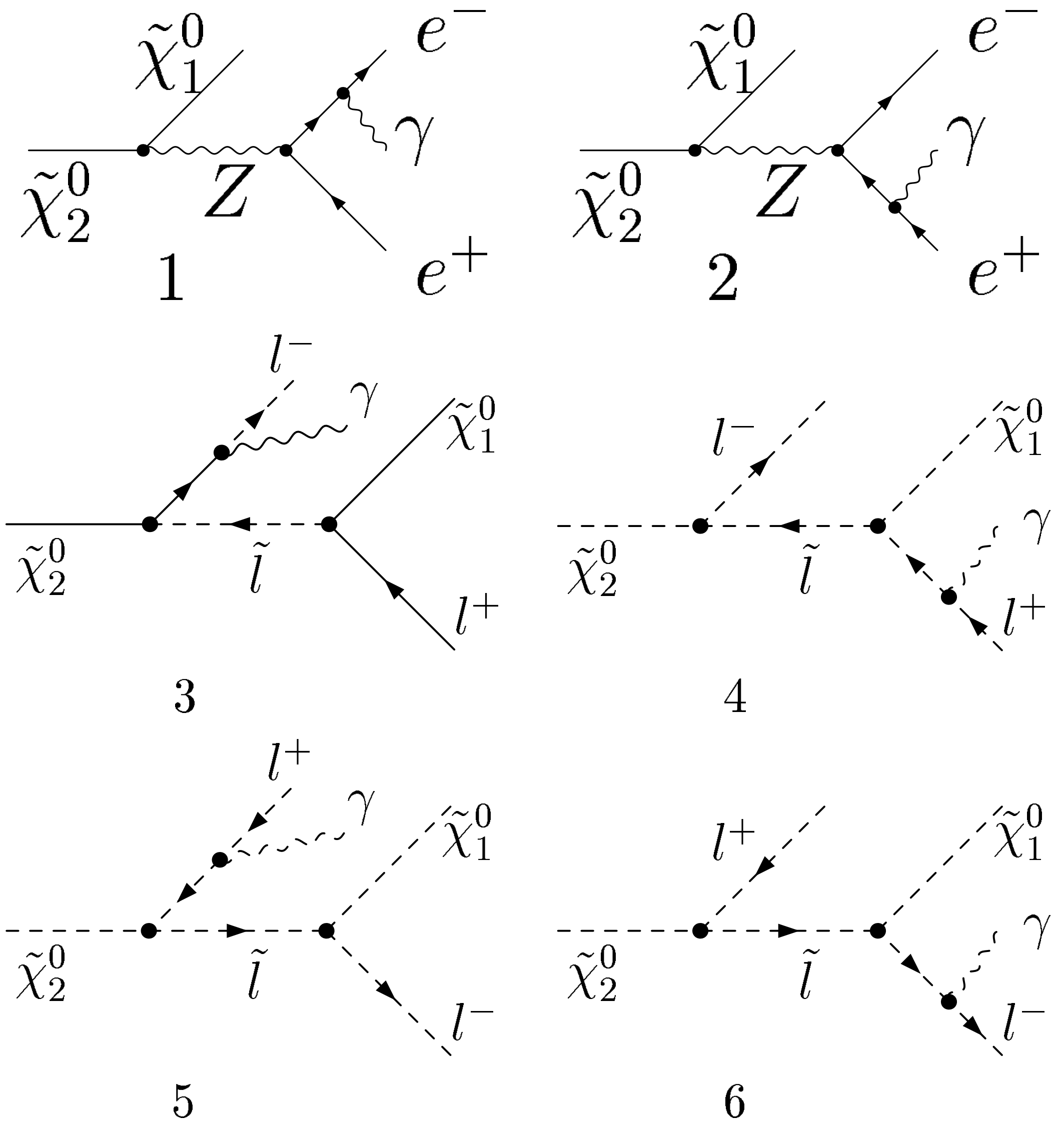
solution: regularized with a photon mass λ

IR divergence cancel

if add real photon bremsstrahlung

real photon bremsstrahlung

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^- l^+ \gamma$$



soft photon bremsstrahlung: $E_\gamma \leq E_{cut}$

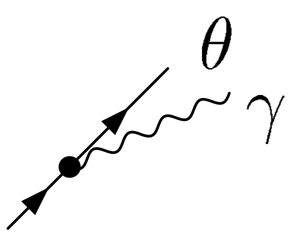
hard photon bremsstrahlung: $E_\gamma > E_{cut}$

cutoff parameter E_{cut}
is small compared to relevant energy

$$\Gamma_{real} = \Gamma_{soft}(E_{cut}) \text{ (IR-divergent)}$$
$$+\Gamma_{hard}(E_{cut}) \text{ (IR-finite)}$$

$\Gamma_{virtual} + \Gamma_{soft}$ is IR finite

avoiding numerical instablities



collinear $\theta \leq \theta_{cut}$
non-collinear $\theta > \theta_{cut}$

$$\Gamma_{hard}(E_{cut}) = \Gamma_{collinear}(E_{cut}, \theta_{cut})$$
$$+ \Gamma_{non-collinear}(E_{cut}, \theta_{cut})$$

soft and collinear parts $\rightarrow$ analytically

non-collinear part $\rightarrow$ numerically

Multi-channel Monte Carlo

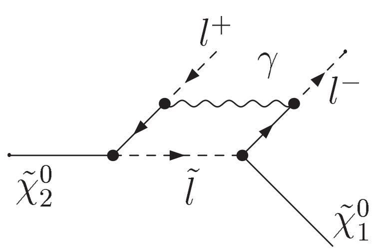
$\Gamma_{1-loop} = \Gamma_{virtual} + \Gamma_{real}$

two-body decay

in case of
$\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-$

$\Gamma(\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-)_{1-loop}$
$\simeq \Gamma(\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp})_{1-loop} Br(\tilde{l}^{\pm} \to \tilde{\chi}_1^0 l^{\pm})_{tree} +$
$\Gamma(\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp})_{tree} Br(\tilde{l}^{\pm} \to \tilde{\chi}_1^0 l^{\pm})_{1-loop} +$
$\Gamma_{non-fac}$

non-factorizable contributions



$\Gamma_{non-fac} \sim \frac{\alpha}{\pi} \log \frac{\Gamma_{\tilde{l}^{\pm}}}{M_{\tilde{l}^{\pm}}} \Gamma_{tree}$

summary

- dilepton invariant mass distribution determine neutralino mass
- higher order corrections are necessary
- virtual correction is done
- hard -photon bremsstrahlung is at work