

Dark Matter Detection and Collider Signal in an $SO(10)$ Model with Two-step Intermediate Scale Symmetry Breaking

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in progress
with

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Outline

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 - ★ 2-step intermediate scale symmetry breaking
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Introduction

- Motivations
 - ★ SUSY SO(10) GUTs are most elegant theories of particle physics
 - Hierarchy problem, Gauge coupling unification, Dark matter candidate, ...
 - Room for massive RH- ν via seesaw mechanism
 - Pati-Salam model: parity preserved at high energy and broken spontaneously
 - ★ Intermediate symmetry breaking scale
 - Breaking of SO(10) depends on Higgs field rep. introduced in the theory
 - Consider “intermediate” phases at energy scales well below Q_{GUT}
 - $m_\nu \geq \sqrt{\delta m_{atm}^2} \sim 0.04 eV$, $RH-\nu_N(M_N) \leq 10^{14} GeV$
 - M_N breaks $SU(2)_R \rightarrow$ motivation for L-R symmetric subgroup of SO(10) to be broken at this scale, (M_R)
- Two-step intermediate symmetry breaking
 - ★ SO(10)

$$\xrightarrow[M_X]{54} SU(4)_C \times SU(2)_L \times SU(2)_R \times D \xrightarrow[M_C]{45} SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R \xrightarrow[M_R]{126+\overline{126}} G_{SM}$$
 - ★ Assume universal BC for SSB terms at $M_{GUT} = M_X$
 - ★ Introduce two-intermediate scales (+ additional matter, gaugino and higgs SFs)
 - RH- $\nu \rightarrow M_N$ at scale $M_R \rightarrow Y_N$ changes low energy spect. via RGEs
 - Different phenomenology from that of mSUGRA (cMSSM)

Set-Up

- Higgs superfields in different representations:

$$S : 54, \quad A : 45, \quad \Sigma : 126, \quad \bar{\Sigma} : \overline{126}$$

- Superpotential:

$$W = \frac{m_S}{2} \text{Tr} S^2 + \frac{\lambda_S}{3} \text{Tr} S^3 + \frac{m_A}{2} \text{Tr} A^2 + \lambda \text{Tr} A^2 S + m_\Sigma \Sigma \bar{\Sigma} + \eta_S \Sigma^2 S + \bar{\eta}_S \bar{\Sigma}^2 S + \eta_A \Sigma \bar{\Sigma} A$$

- Symmetry breaking:

$$SO(10) \xrightarrow[M_X]{54} SU(4)_C \times SU(2)_L \times SU(2)_R \times D \xrightarrow[M_C]{45}$$

$$SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R \xrightarrow[M_R]{126 + \overline{126}} G_{SM}$$

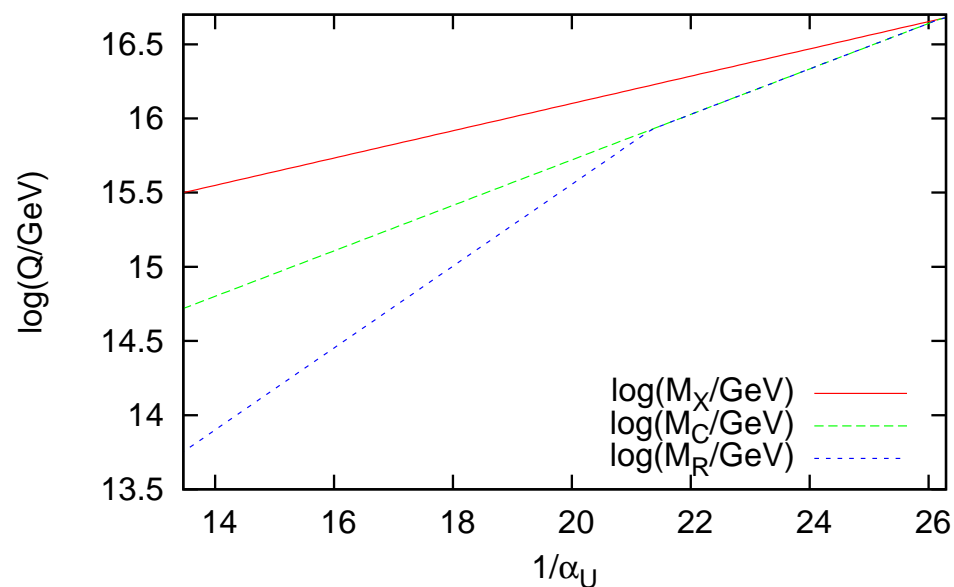
- After symmetry breaking, some components of Higgs fields have much lighter masses than the symmetry breaking scales \rightarrow two additional Higgs mass scales,

$$M_1 \equiv \max\left[\frac{M_R^2}{M_C}, \frac{M_C^2}{M_X}\right], \quad M_2 \equiv \frac{M_R^2}{M_X} \Rightarrow \text{different structures of Yukawa couplings in different mass scale ranges. [C.S Aulakh et. al. Nuc. Phys. B597 (2001) 89]}$$

- $m_\nu = \frac{m_D^2}{M_N} \propto Y_N^{-1}$

- Additional fields lighter than M_R ($\rightarrow M_2$) allows us to have modified running gauge couplings in the energy range between G_{SM} and $Q_{GUT} \Rightarrow$ affect RGE's of masses of sparticles and Higgs.

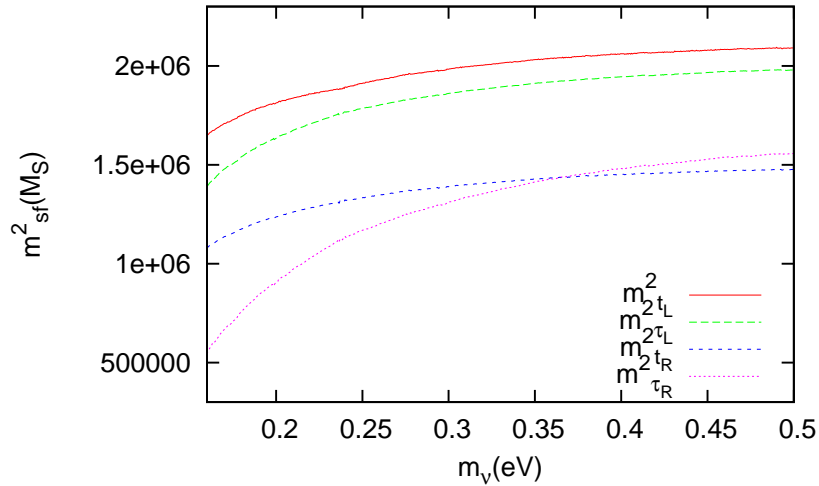
Gauge coupling



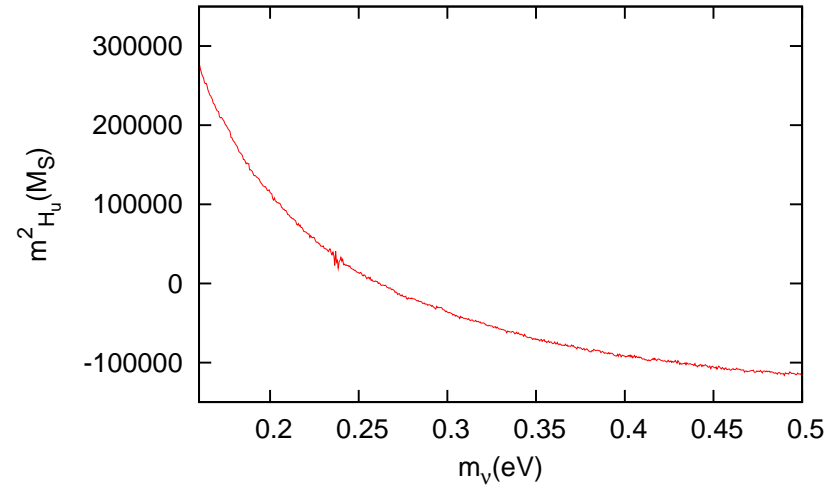
- mSUGRA at $\log(M_X/\text{GeV}) = 16.6$
- Biggest difference from mSUGRA at $\log(M_X/\text{GeV}) = 15.5$, $\log(M_C/\text{GeV}) = 14.72$, $\log(M_R/\text{GeV}) = 13.75$
- Want to see how 2-step intermediate symmetry breaking scales affect to low energy phenomenology

Mass ratio

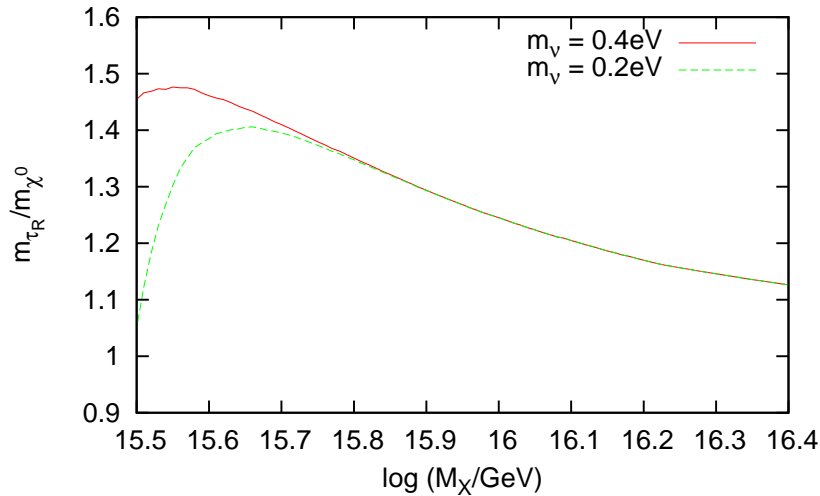
(a) $m_0 = 1500\text{GeV}, M_{12} = 900\text{GeV}, A_0 = 0, \tan\beta = 40$



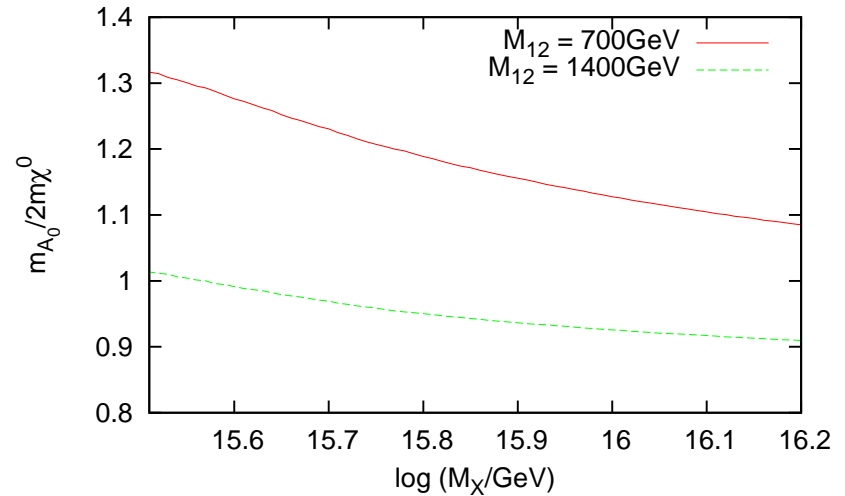
(b) $m_0 = 1500\text{GeV}, M_{12} = 900\text{GeV}, A_0 = 0, \tan\beta = 40$



(a) $m_\chi = 250\text{GeV}, m_0 = 300\text{GeV}, \tan\beta = 40$



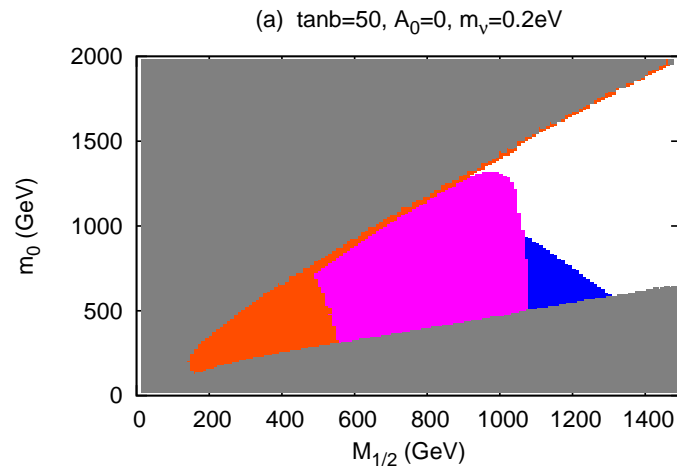
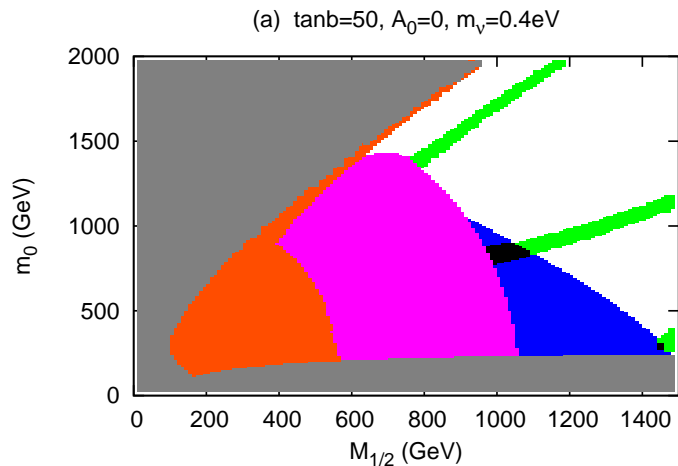
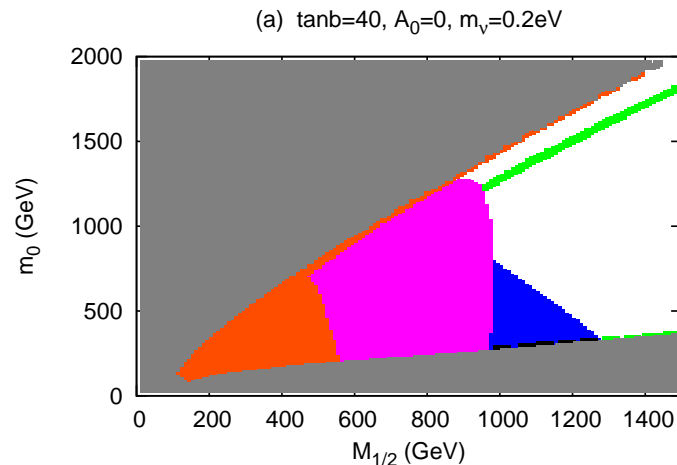
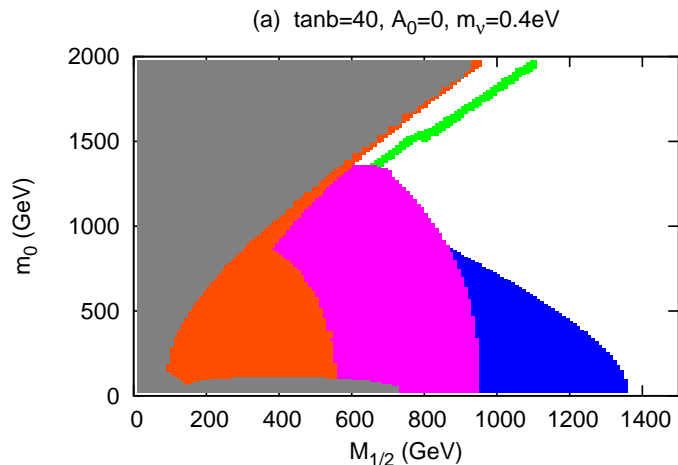
(b) $m_0 = 700\text{GeV}, A_0 = 0, \tan\beta = 50, m_\nu = 0.4\text{eV}$



Mass ratio - Summary

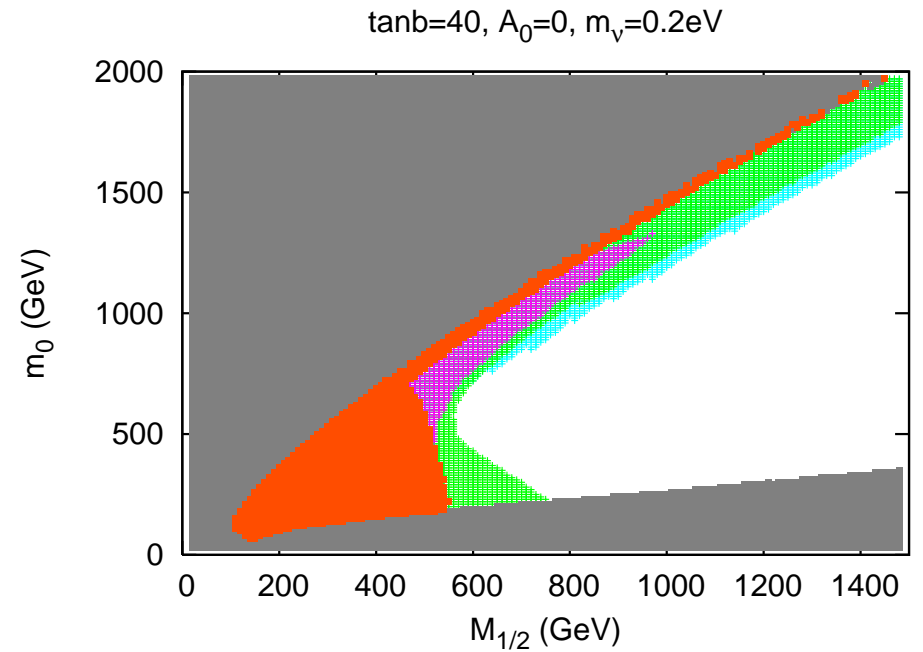
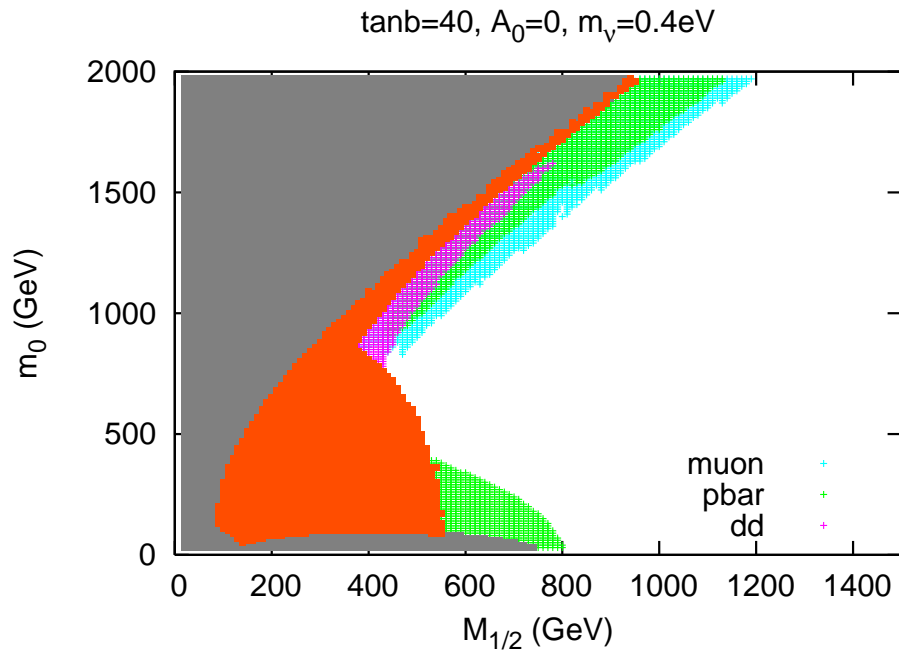
- At low m_ν (high Y_N)
 - ★ low sfermion mass
 - ★ positively high Higgs mass
- At high m_ν (low Y_N)
 - ★ low Higgs mass (negative)
- Implications for dark matter in parameter space
 - stau co-annihilation with low m_ν ($0.2eV$)
 - A-funnel region with high m_ν ($0.4eV$) for high $M_{1/2}$
 - FP-like region with low μ

WMAP allowed regions in $m_0 - M_{1/2}$ space

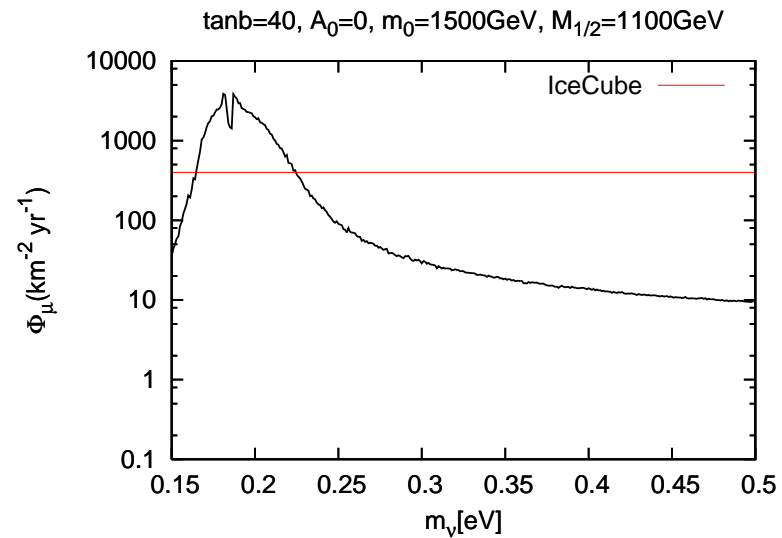
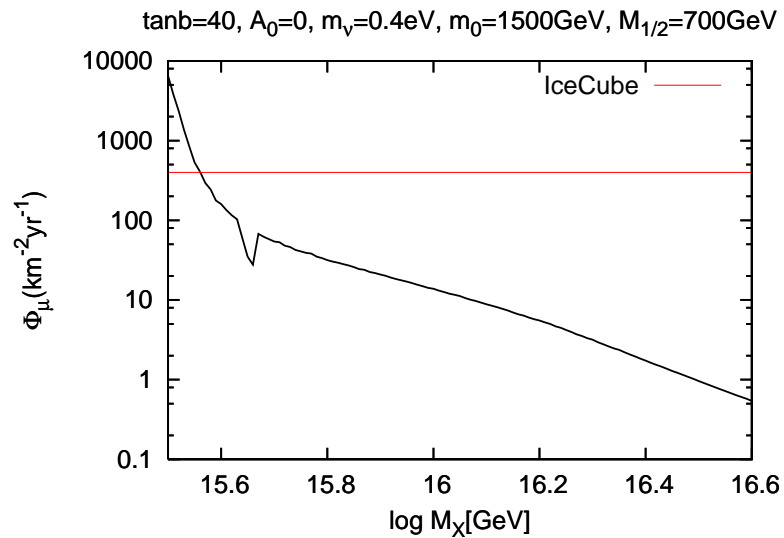
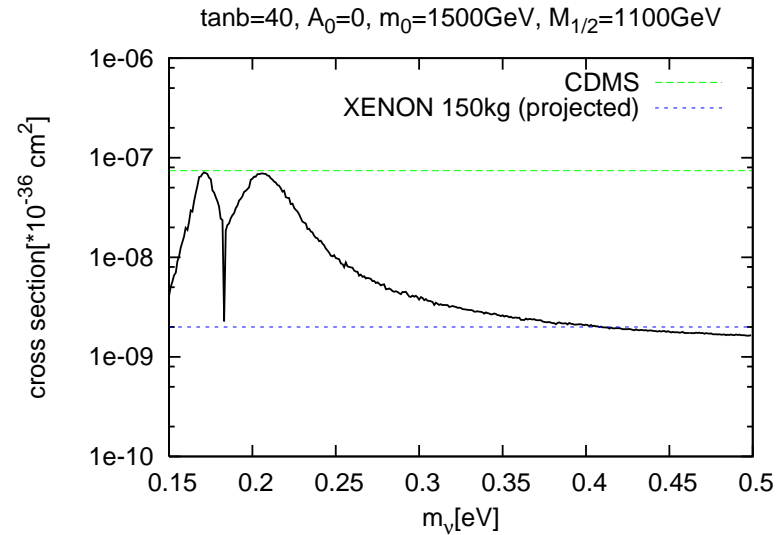
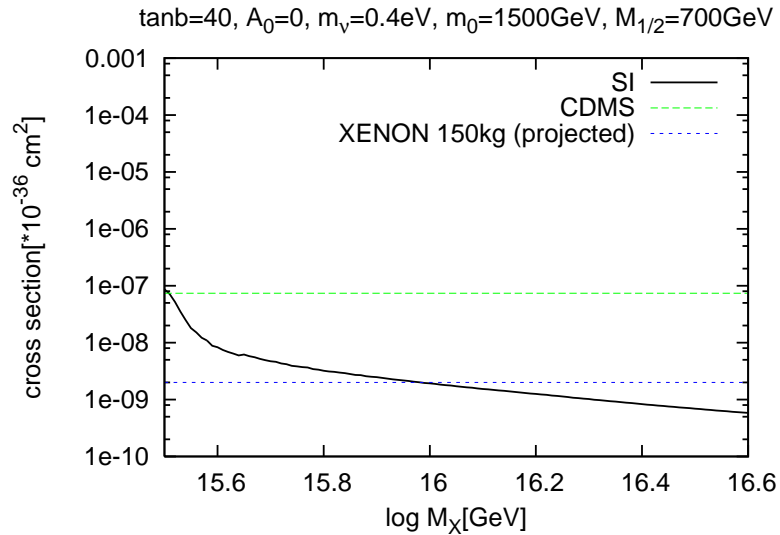


Grey: Theoretically excl., Red: LEP2 excl. by chargino and Higgs masses, Pink: $b \rightarrow s\gamma$ excl.,
 Blue: $g_\mu - 2$ allowed, Green: WMAP allowed

Neutralino DM detection in $m_0 - M_{1/2}$ space



Direct and indirect dark matter detection rates



Benchmark Points 1

- Benchmark points:
 - ★ allowed by EW precision experiments
 - ★ deviation from CMSSM is distinct: $M_X = 10^{15.5} GeV, m_\nu = 0.2 eV$
→ FP-like region(SO(10)1), $\tilde{\tau}$ -coannihilation region(SO(10)2)
- SO(10)1
 - ★ significantly heavier gluinos and squarks than neutralinos and charginos, but low $|\mu|$
→ $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ dominant SUSY production mode
- SO(10)2
 - ★ gluinos and quarks are relatively lighter → $\tilde{g}\tilde{q}$ dominant

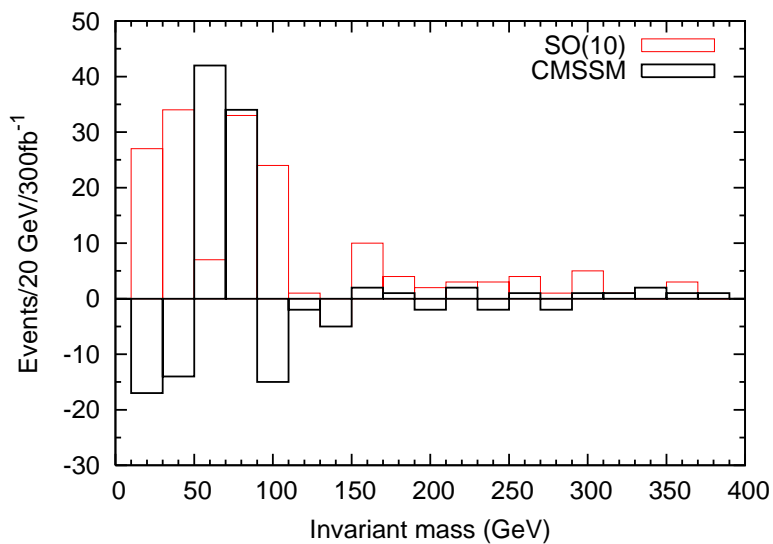
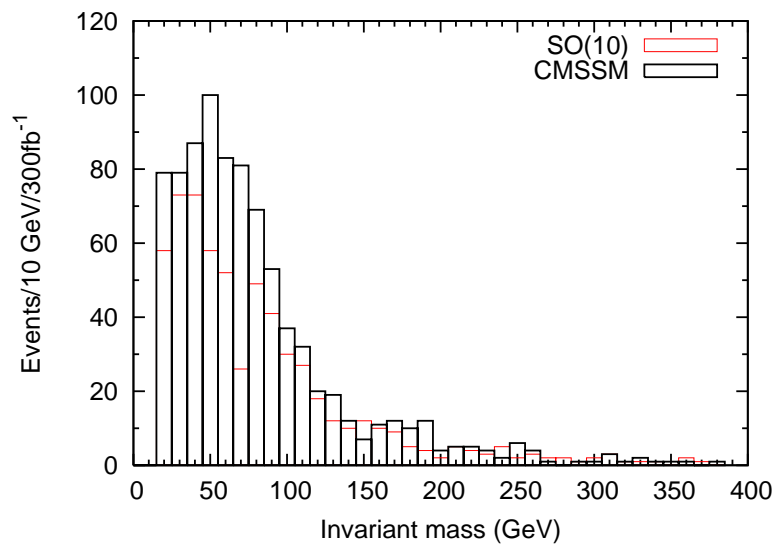
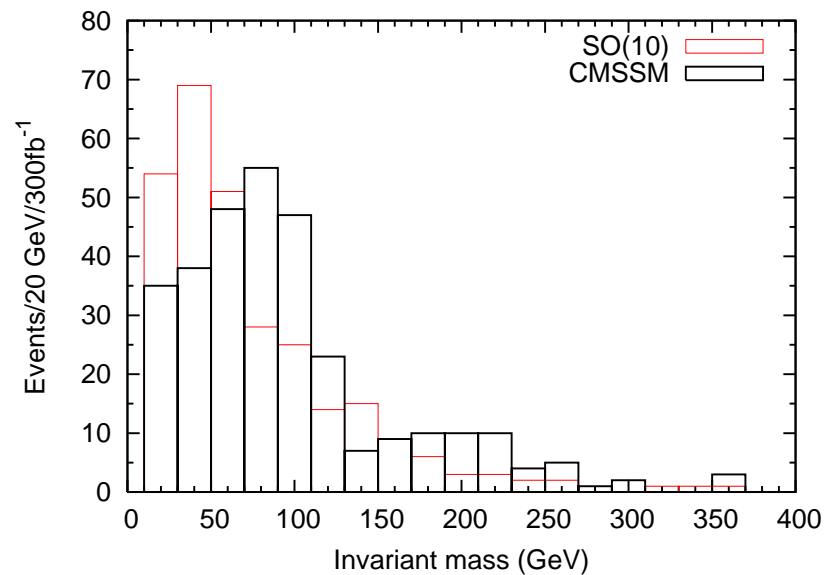
Benchmark Points 2

parameter	CMSSM 1	SO(10) 1	CMSSM 2	SO(10) 2
$M_{1/2}$	600	1100	550	1000
m_0	1400	1400	300	300
A_0	900	0	0	0
$\tan\beta$	53	40	40	40
χ_1^0	251	243	227	229
χ_2^0	459	313	430	430
χ_3^0	563	317	671	613
χ_4^0	591	519	680	627
χ_1^\pm	461	298	433	434
χ_2^\pm	588	517	676	623
\tilde{g}	1424	1423	1258	1246
$u_L(d_L)$	1861(1867)	1865(1870)	1182(1189)	1172(1179)
$u_R(d_R)$	1835(1830)	1842(1843)	1145(1139)	1145(1143)
$t_1(t_2)$	1324(1458)	1205(1409)	900(1063)	876(1034)
$b_1(b_2)$	1464(1526)	1418(1529)	1026(1083)	1000(1058)
$e_L(e_R)$	1461(1421)	1490(1466)	485(370)	555(485)
$\tau_1(\tau_2)$	907(1239)	900(1230)	263(476)	246(495)
h^0	115	116	115	115
Ωh^2	0.08	0.09	0.7	0.2

Collider signals at LHC

- Dilepton signals
- $E_T^{miss} > 200\text{GeV}$, $S_T > 0.2$, at least 4jets with $p_T > 150\text{GeV}$ (at least 1jet $p_T > 300\text{GeV}$)
- mSUGRA : sharp peak at $m(l^+l^-) \sim M_Z$ from $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 Z^0$ decays
- SO(10)1 : peak from $\tilde{\chi}_{2,3}^0 - \tilde{\chi}_1^0$ decays + continuum distribution
- SO(10)2 : sharp peak at $m(l^+l^-) \sim M_Z$ due to larger decay branching ratio of gluino to stops and sbottoms. $\tilde{\chi}_{3,4}^0 \longrightarrow \tilde{\chi}_{1,2}^0 Z^0$

Dilepton signals at LHC

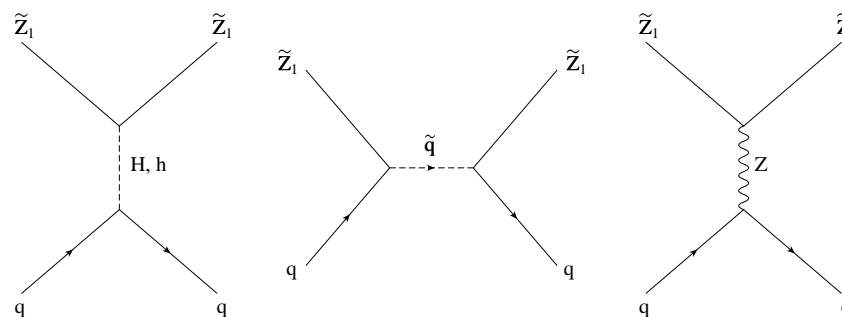


Conclusions

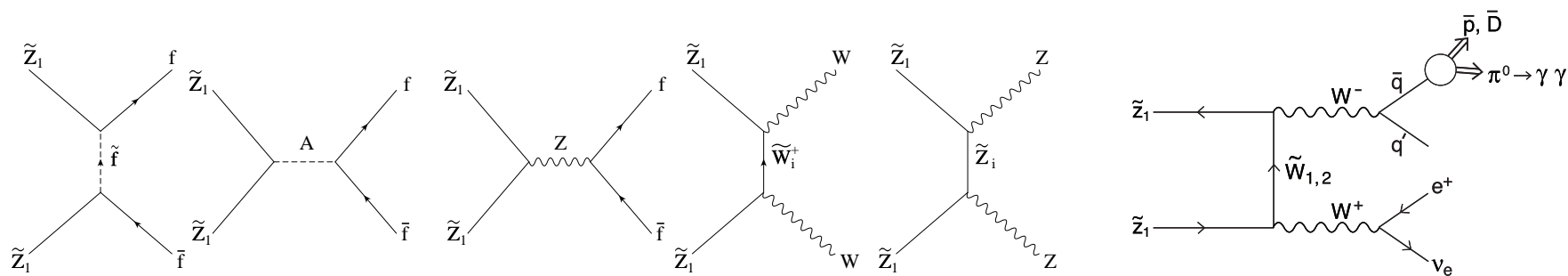
- Discrepancy between seesaw scale and GUT scale can be explained with the enhanced symmetry breaking
- Neutralino dark matter remains viable, for different regions of parameter space with mSUGRA
- Effects of implying two-step intermediate scales are
 - ★ Smaller gaugino masses due to the enhanced gauge symmetries and the large dimensional Higgs used to break them : FP-like region for large $M_{1/2}$
 - ★ Lighter sfermions due to Dirac and Majorana Yukawa coupling :
Coannihilation region for the small neutrino mass
- From benchmark point study, we find distinguishable dilepton mass edges at LHC: peaks from dominant SUSY production mode $\tilde{\chi}_{2,3}^0 - \tilde{\chi}_1^0$ or from gluino cascade decay to $\tilde{\chi}_{1,2}^0 Z^0$

Feynman Diagrams Contributing to Neutralino DM Detection

- Direct Detection



- Indirect Detection



Mass spectrum

State	Mass
all of S all of A , except $(15, 1, 1)_A$ all of Σ and $\bar{\Sigma}$, except $SU(4)_C$ (anti-)decuplets	$\sim M_X$
$(\bar{10}, 3, 1)_{\bar{\Sigma}}$ and $(10, 3, 1)_{\Sigma}$ color triplets and sextets of $(10, 1, 3)_{\bar{\Sigma}}$ and $(\bar{10}, 1, 3)_{\Sigma}$ color triplets of $(15, 1, 1)_A$	$\sim M_C$
$(\delta^0 - \bar{\delta}^0), \delta^+, \bar{\delta}^-$	$\sim M_R$
color octet and singlet of $(15, 1, 1)_A$	$\sim M_1 \equiv \max \left[\frac{M_R^2}{M_C}, \frac{M_C^2}{M_X} \right]$
$(\delta^0 + \bar{\delta}^0), \delta^{++}, \bar{\delta}^{--}$	$\sim M_2 \equiv M_R^2/M_X$