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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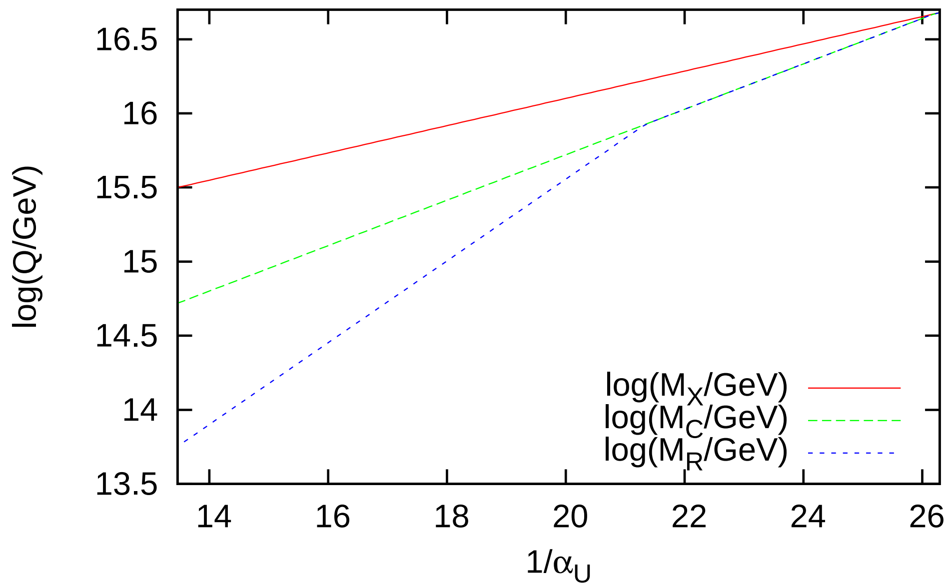
Introduction

- Motivations
  - ⋆ SUSY SO(10) GUTs are most elegant theories of particle physics
    - – Hierarchy problem, Guage 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}
    - – $m_\nu \geq \sqrt{\delta m^2_{atm}} \sim 0.04eV$, 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 $M_R \longrightarrow Y_N$ changes low energy spect. via RGEs
    - – Different phenomenology from that of mSUGRA (cMSSM)

Set-Up

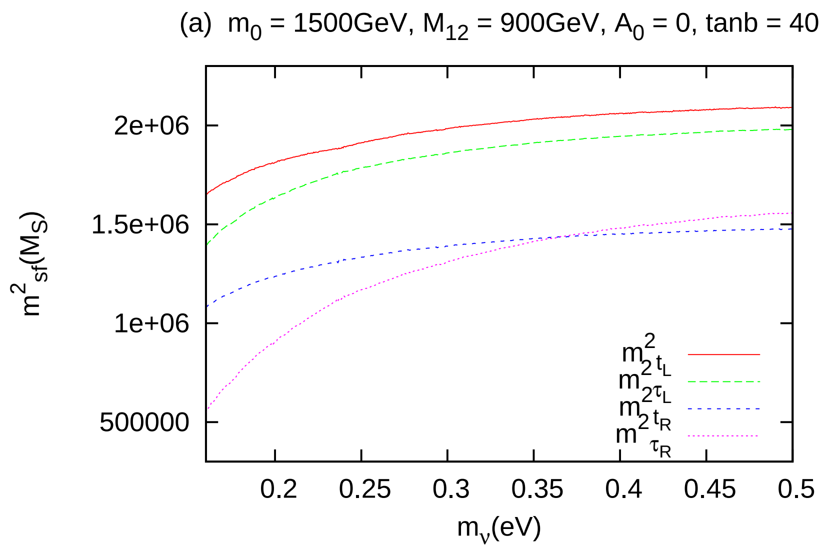
- Higgs superfields in different representations:
  $S : 54, \quad A : 45, \quad \Sigma : 126, \quad \bar{\Sigma} : \overline{126}$
- Superpotential:
  $W = \frac{m_S}{2} TrS^2 + \frac{\lambda_S}{3} TrS^3 + \frac{m_A}{2} TrA^2 + \lambda TrA^2 S + m_\Sigma \Sigma\bar{\Sigma} + \eta_S \Sigma^2 S + \bar{\eta}_S \bar{\Sigma}^2 S + \eta_A \Sigma\bar{\Sigma} A$
- 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, $M_1 \equiv max[\frac{M_R^2}{M_C}, \frac{M_C^2}{M_X}]$, $M_2 \equiv \frac{M_R^2}{M_X}$ $\Rightarrow$ 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 guage couplings in the energy range between G_{SM} and Q_{GUT} $\Rightarrow$ affect RGE's of masses of sparticles and Higgs.

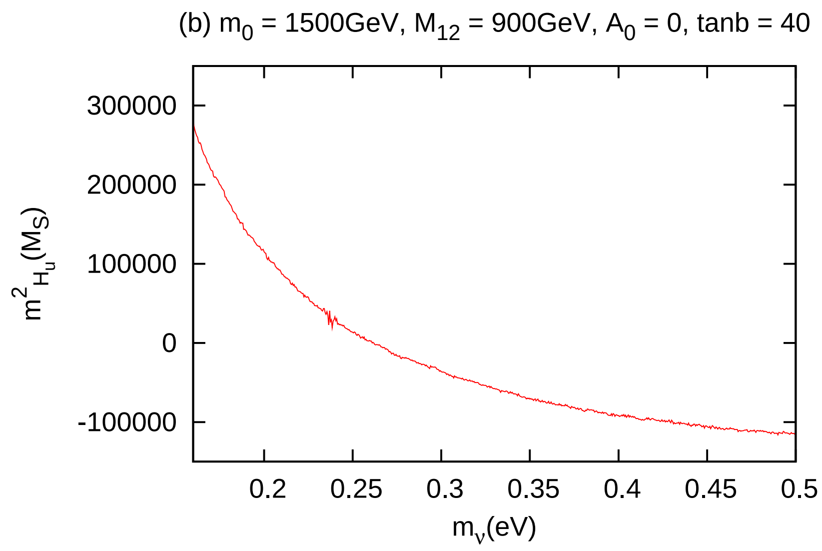
Gauge coupling

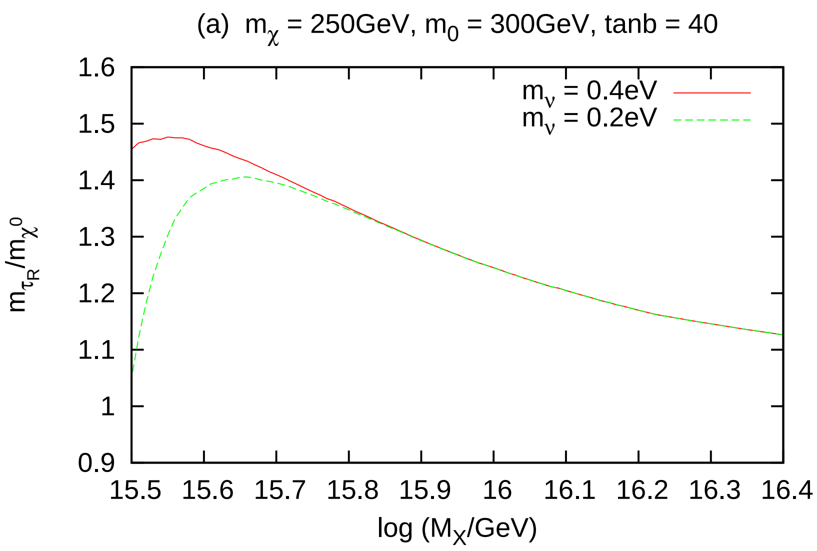


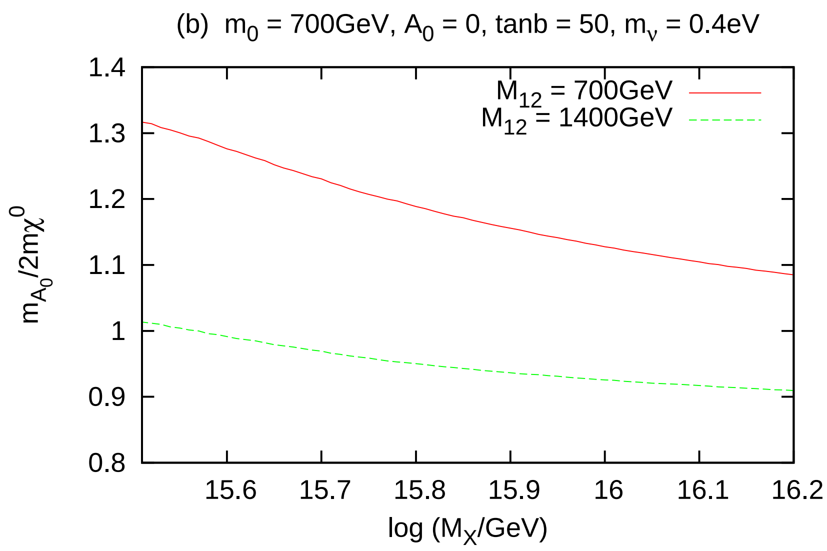
- mSUGRA at $log(M_X/GeV) = 16.6$
- Biggest difference from mSUGRA at $log(M_X/GeV) = 15.5$, $log(M_C/GeV) = 14.72$, $log(M_R/GeV) = 13.75$
- Want to see how 2-step intermediate symmetry breaking scales affect to low energy phenomenology

Mass ratio


(a) m0 = 1500GeV, M12 = 900GeV, A0 = 0, tanb = 40
m2sf(MS)
2e+06
1.5e+06
1e+06
500000
m2tL
m2τL
m2tR
m2τR
0.2 0.25 0.3 0.35 0.4 0.45 0.5
mν(eV)


(b) m0 = 1500GeV, M12 = 900GeV, A0 = 0, tanb = 40
m2Hu(MS)
300000
200000
100000
0
-100000
0.2 0.25 0.3 0.35 0.4 0.45 0.5
mν(eV)


(a) mχ = 250GeV, m0 = 300GeV, tanb = 40
mτR/mχ0
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
mν = 0.4eV
mν = 0.2eV
15.5 15.6 15.7 15.8 15.9 16 16.1 16.2 16.3 16.4
log (MX/GeV)


(b) m0 = 700GeV, A0 = 0, tanb = 50, mν = 0.4eV
mA0/2mχ0
1.4
1.3
1.2
1.1
1
0.9
0.8
M12 = 700GeV
M12 = 1400GeV
15.6 15.7 15.8 15.9 16 16.1 16.2
log (MX/GeV)

Mass ratio - Summary

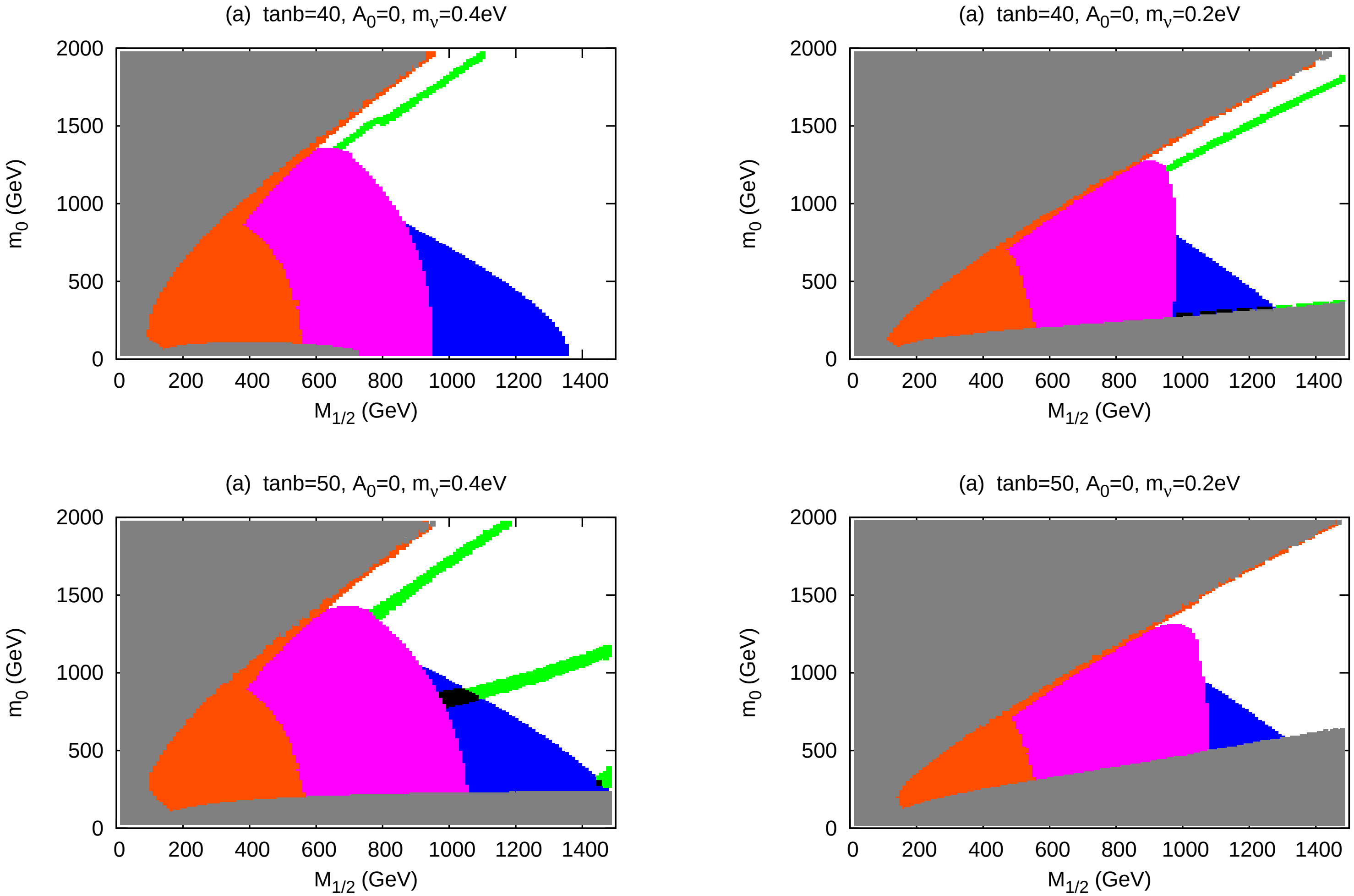
- At low m_ν(high Y_N)
  - ⋆ low sfermion mass
  - ⋆ positively high Higgs mass
- At high m_ν(low Y_N)
  - ⋆ low Higgs mass (negative)
- Implications for dark matter in parameter space

$\longrightarrow$ stau co-annihilation with low $m_\nu(0.2eV)$

$\longrightarrow$ A-funnel region with high $m_\nu(0.4eV)$ for high $M_{1/2}$

$\longrightarrow$ FP-like region with low μ

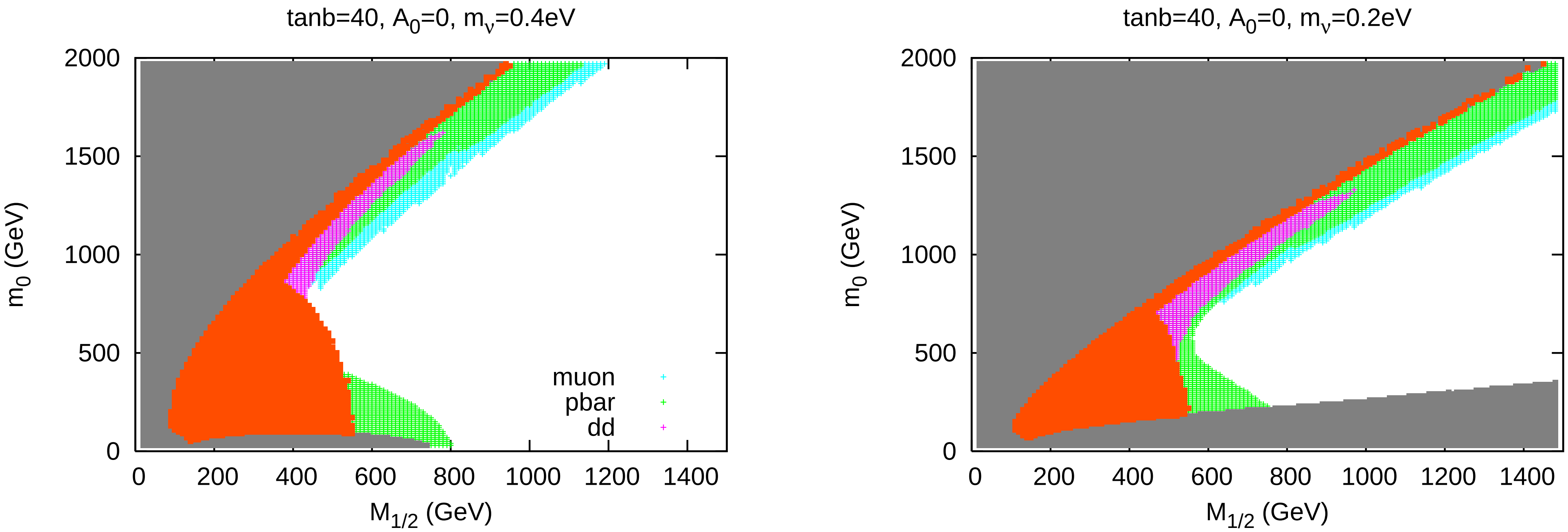
WMAP allowed regions in $m_0 - M_{1/2}$ space



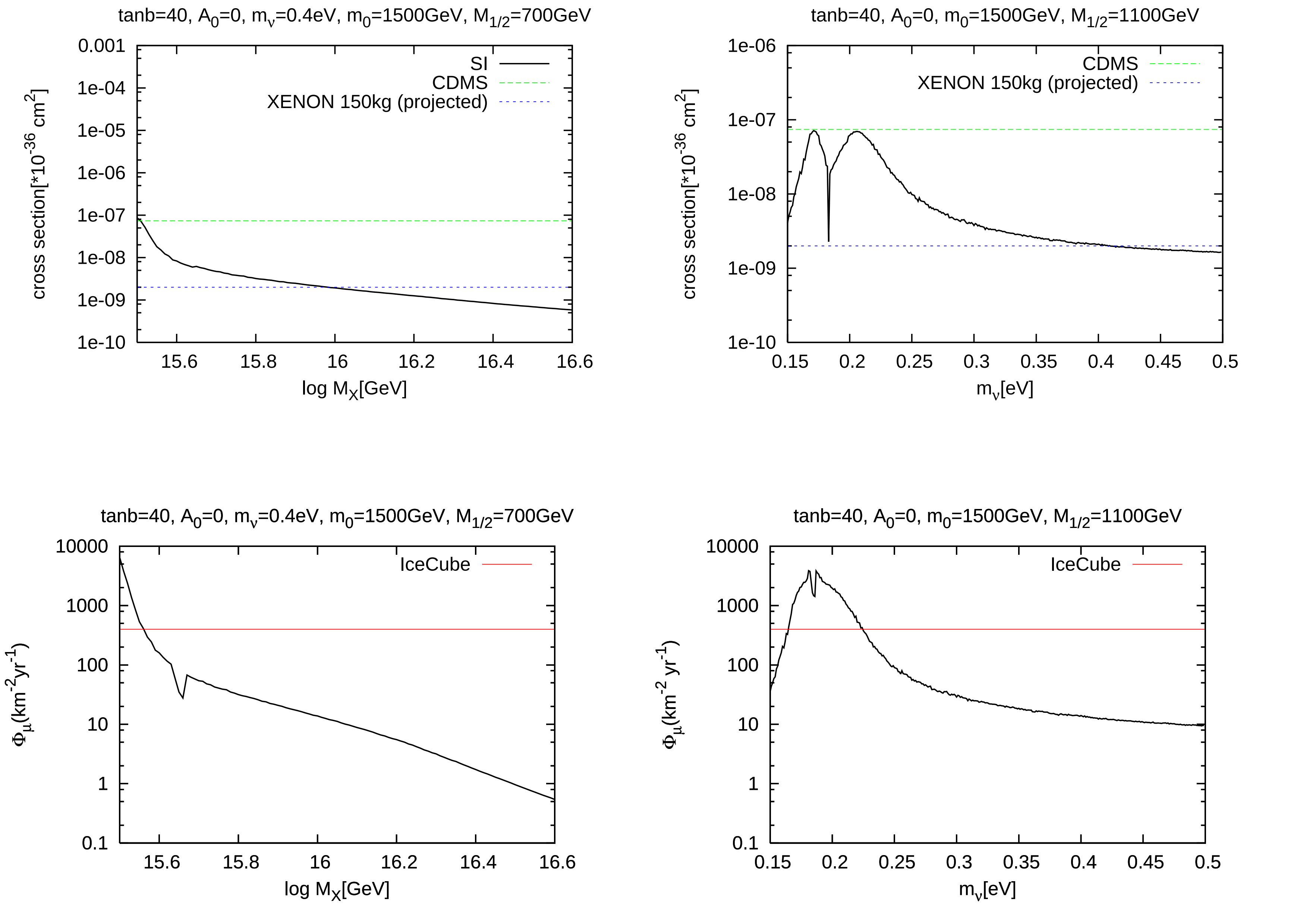
Grey: Theoretically excl., Red: LEP2 excl. by chargino and Higgs masses, Pink: $b \to s\gamma$ excl.,

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: $M_X = 10^{15.5} GeV, m_\nu = 0.2 eV$

    $\longrightarrow$ 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 $|\mu|$

    $\rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ dominant SUSY production mode
- SO(10)2
  - ⋆ gluinos and quarks are relatively lighter $\rightarrow \tilde{g}\tilde{q}$ dominant

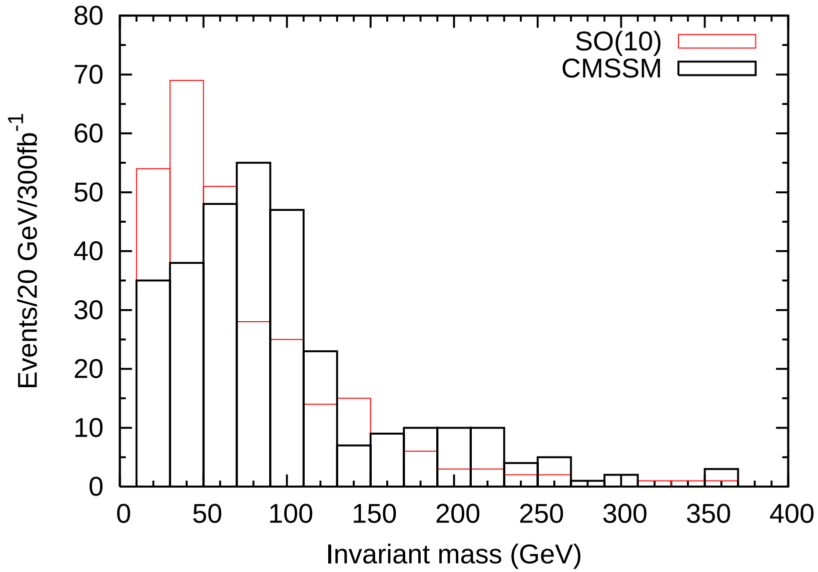
Benchmark Points 2

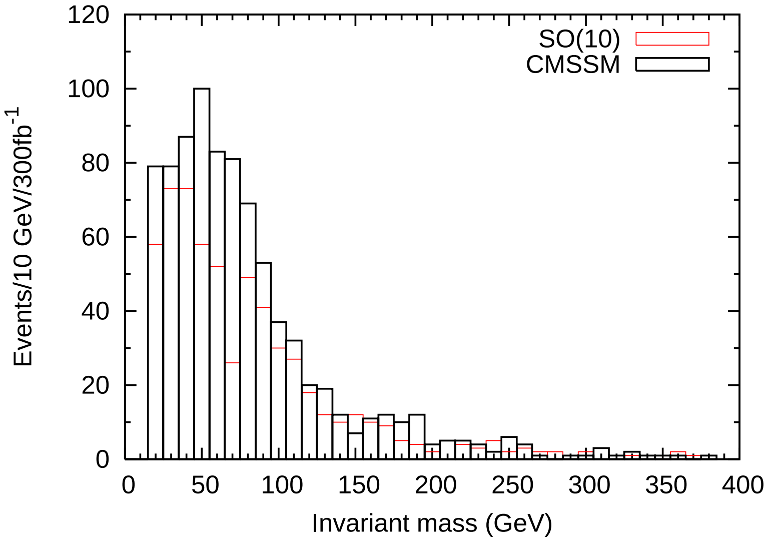
parameter	CMSSM 1	SO(10) 1	CMSSM 2	SO(10) 2
$M_{1/2}$	600	1100	550	1000
m_0	1400	1400	300	300
A_0	900	0	0	0
$\tan\beta$	53	40	40	40
χ_1^0	251	243	227	229
χ_2^0	459	313	430	430
χ_3^0	563	317	671	613
χ_4^0	591	519	680	627
$\chi_1^\pm$	461	298	433	434
$\chi_2^\pm$	588	517	676	623
$\tilde{g}$	1424	1423	1258	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

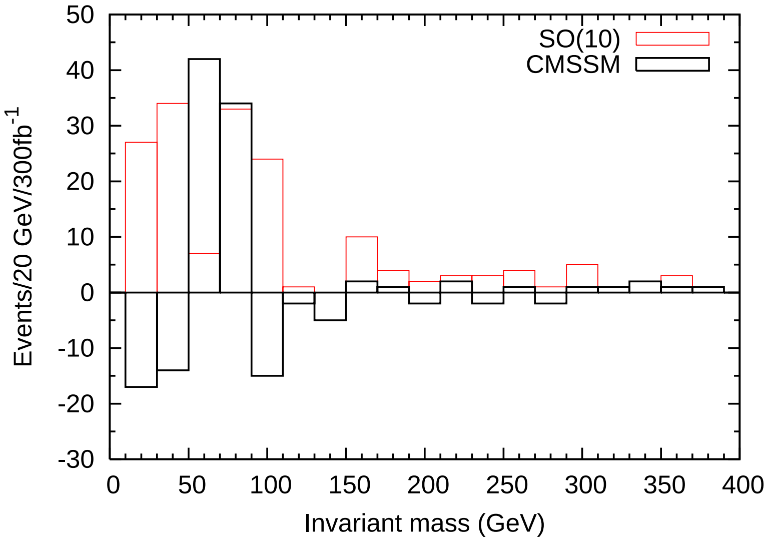
Collider signals at LHC

- Dilepton signals
- $E_T^{miss} > 200GeV$, $S_T > 0.2$, at least 4jets with $p_T > 150GeV$ (at least 1jet $p_T > 300GeV$
- 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





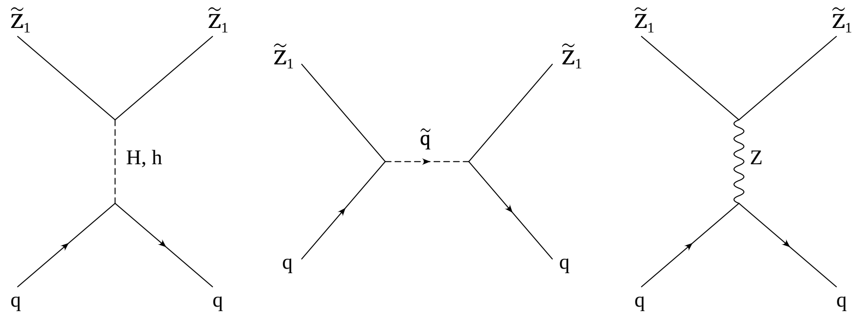


Conclusions

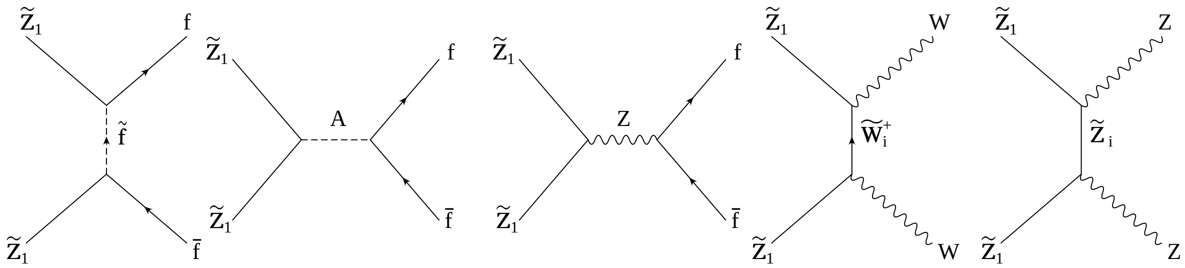
- Discrepancy between seesaw scale and GUT scale can be explained with the enhanced symmetry breaking
- Neutralino dark matter remains viable, for different regions of parameter space with mSUGRA
- Effects of implying two-step intermediate scales are
  - ⋆ Smaller gaugino masses due to the enhanced gauge 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 $\tilde{\chi}^0_{2,3} - \tilde{\chi}^0_1$ or from gluino cascade decay to $\tilde{\chi}^0_{1,2} Z^0$

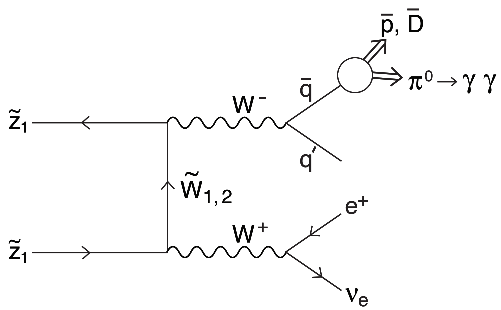
Feynman Diagrams Contributing to Neutralino DM Detection

- Direct Detection



- Indirect Detection





Mass spectrum

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