DM and new physics

What is the connection to DM and LHC

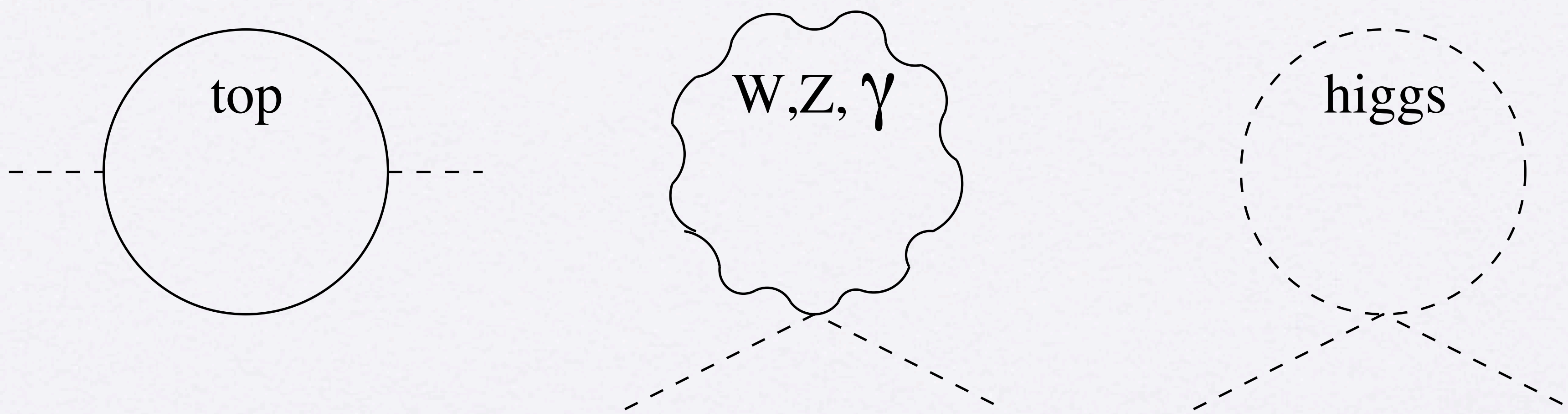
- In the big-bang senario DM must be produced at high energy collisions. LHC, pp collider at 14 TeV make a collision of particle at 1 TeV

- Standard model has hierarchy problem. To solve this the modification of gauge and top sector required.

→ Observation of DM production at LHC

New Physics, Clue

Fine tuning in the Higgs sector

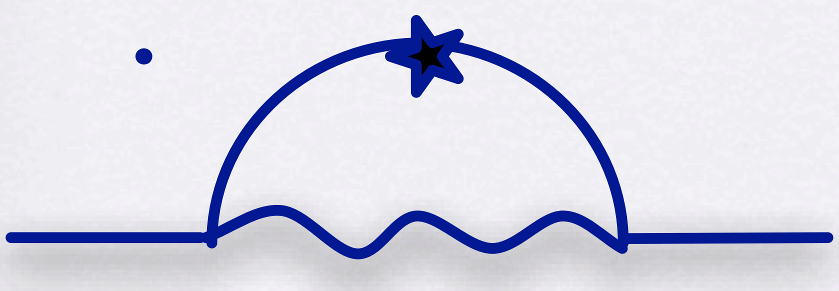


$$
\begin{array}{rcl}
\text{top loop} & -\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 & \sim \; -(2\ \text{TeV})^2 \\
SU(2)\ \text{gauge boson loops} & \frac{9}{64\pi^2}g^2\Lambda^2 & \sim \; (700\ \text{GeV})^2 \\
\text{Higgs loop} & \frac{1}{16\pi^2}\lambda^2\Lambda^2 & \sim \; (500\ \text{GeV})^2.
\end{array}
$$

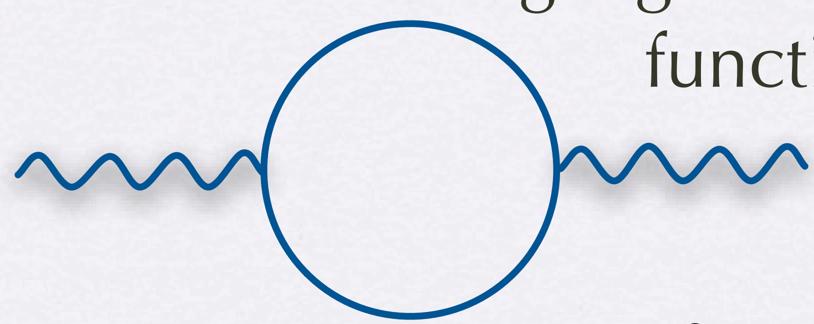
Others are reasonable

Why Higgs vev is O(200) GeV??

$m_f \log \Lambda$ fermion mass



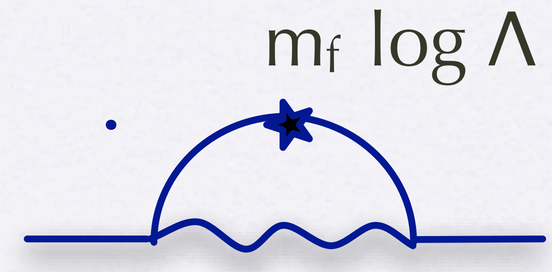
gauge two point function



$$\Pi_{\mu\nu} = (g_{\mu\nu}p^2 - p_\mu p_\nu)\Pi$$

New Symmetry →New Particle

- Need control on the radiative correction to the Higgs sector



- ideas
    - chiral symmetry (extended to boson sector)
    - global symmetry(little Higgs model)
    - gauge symmetry (gauge higgs unification)

- **Or planck scale is low (Extra dimension model)**

- On the other hand< we see no effect of BSM in radiative correction

$$\delta L = \frac{(h^\dagger D_\mu h)^2}{\Lambda^2} \quad \Lambda > 5\text{TeV}$$

Classic Solution:Supersymmetry

- exchange boson and fermion. $\phi \leftrightarrow \psi$
    - sfermions(0), gaugino(1/2), higgsinos(1/2)
- SUSY change "dimension" (1 for boson 3/2 for fermion), relate mass and couplings

$$\Phi = \frac{1}{g^2} + M\theta^2 \qquad \Phi WW = \frac{1}{g^2} F_{\mu\nu}F^{\mu\nu} + M\tilde{g}\tilde{g}$$

- chiral symmetry is extended to boson sector. No new demension less coupling and no quadratic divergence

$$\lambda\psi_L\psi_R H \rightarrow \lambda\phi_L\psi_R\tilde{H} + \lambda\psi_L\phi_R\tilde{H}$$

- R parity conservation. New stable particle→ DM candidate.

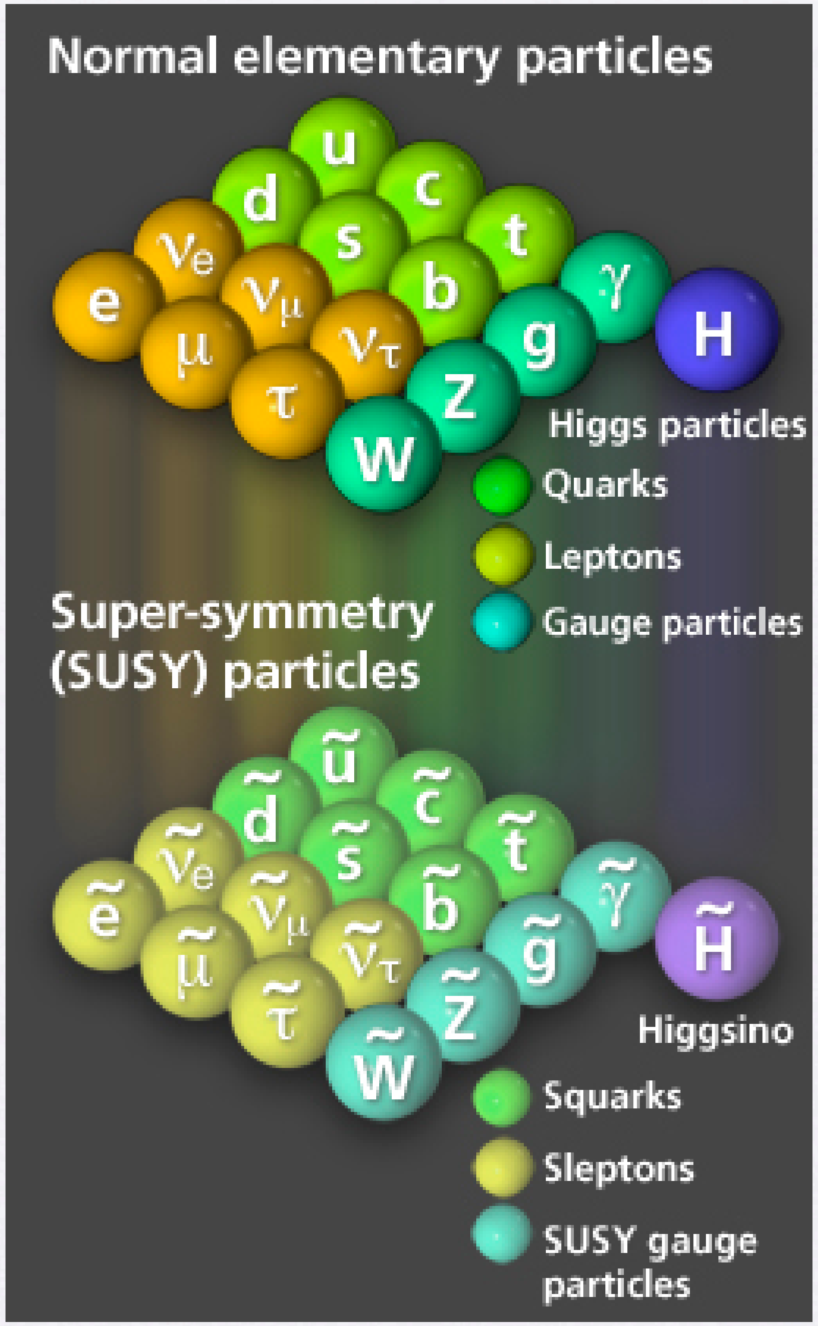
matter content of MSSM

	quark	squarks
$(3,2)_{1/6}$ $(3^*,1)_{-2/3,1/3}$	$q_L=(u,d)_L$ u^c, d^c	$\tilde{q}_L=(\tilde{u}_L\tilde{d}_L)$ $\tilde{u}^c, \tilde{d}^c$
	lepton	slepton
$(1,2)_{1/2}$ $(1,1)_1$	$l_L=(\nu,e)_L$ $l_R=e^c_R$	$\tilde{l}_L=(\tilde{\nu}_L,\tilde{e}_L)$ $\tilde{e}^c_R$
	higgsino	higgs
$(1,2)_{-1/2}$ $(1,2)_{1/2}$	$(\tilde{H}^0_1,\tilde{H}^-_1)$ $(\tilde{H}^+_2\tilde{H}^0_2)$	$H_1=(H^0_1,H^-_1)$ $H_2=(H^+_2,H^0_2)$

vector multilets

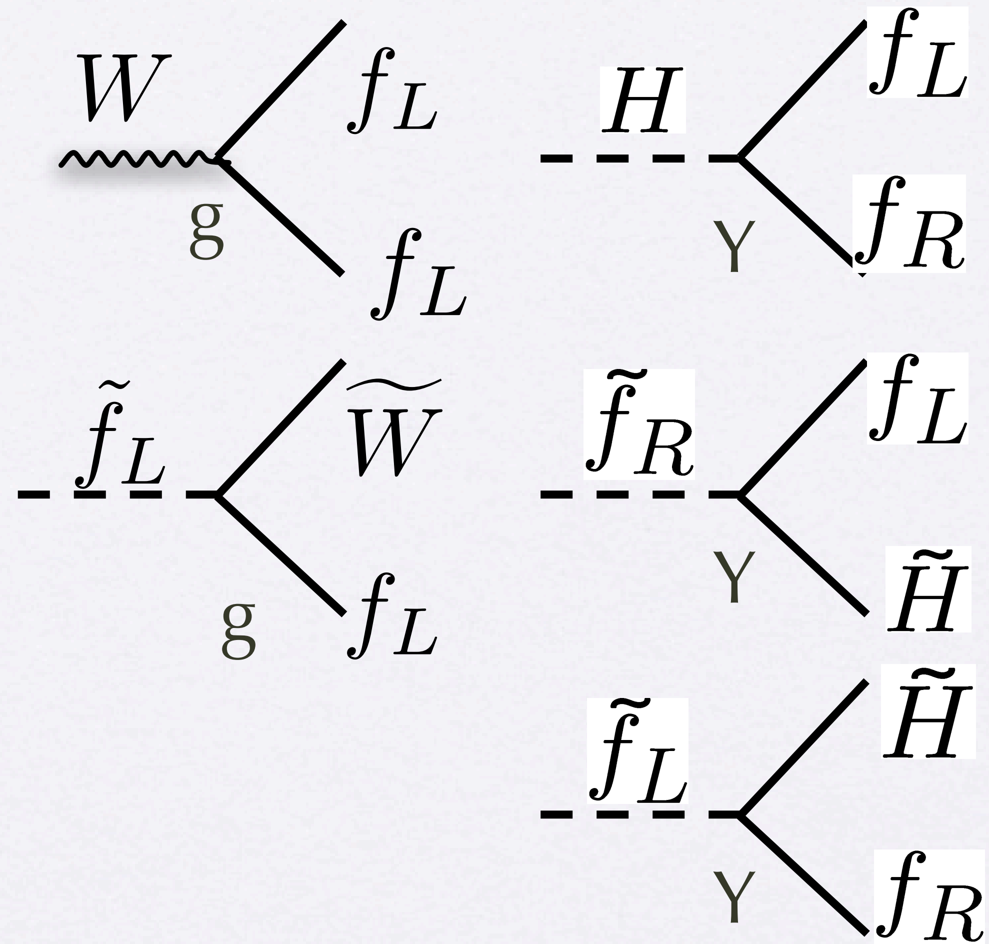
$G_\mu, W_\mu, B_\mu \leftrightarrow \tilde{G}, \tilde{W}, \tilde{B}$ (gluino, wino, bino)

gravity $\tilde{\psi}^\mu$ (gravitino), $g_{\mu\nu}$ (graviton)



R parity, SUSY relation

- R parity conservation
    - SUSY particles will be pair produced.
    - SUSY particles decay into SUSY particles
- There are no new dimension less couplings
    - gaugino interaction is gauge coupling
    - Higgsino matter interaction is yukawa coupling



Higgino-gaugino mix sfermion left night also mix due to sclar 4 point couplings

Should we only consider SUSY
Dynamical symmetry breaking ?

- Technicolor→ Little Higgs model
  - Higgs boson is goldstone boson of a large symmetry. SU(5)→SO(5)
  - Gauge symmetry: $SU(2)_1 \times SU(2)_2 \times U(1)_1 \times U(1)_2$
    (g_1, g_2, g'_1, g'_2)
  - quadratic correction to Higgs sector starts from 2 loop
  - top sector must be extended (extra top quark). afterall top-higgs coupling is the source of fine tuning.
    $\chi = (b_3, t_3, \tilde{t})$ $\tilde{t}, \tilde{t}'$
- However it is rather difficult to make simple Little Higgs model and LEP data consistent .

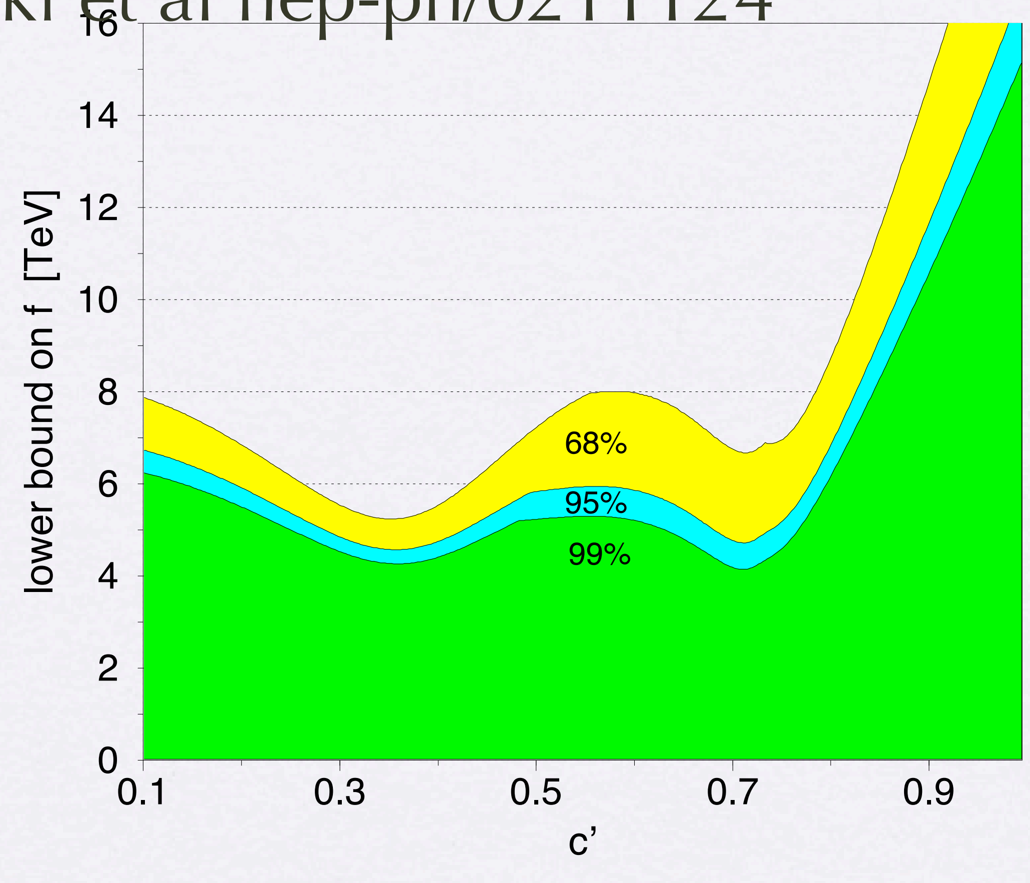
LEP Anchor

difficulty comes from tree level Heavy-Light mixing

$$L_2 \to -\frac{g_1 g_2 (g_1^2 - g_2^2)}{4(g_1^2 + g_2^2)} W^a_{\mu L} W^{a\mu}_H h^2 \longrightarrow -\frac{g^2(s^2-c^2)^2}{8f^2} W_L W_L h^4$$

$$(W^a_L = sW^a_1 + cW^a_2)$$

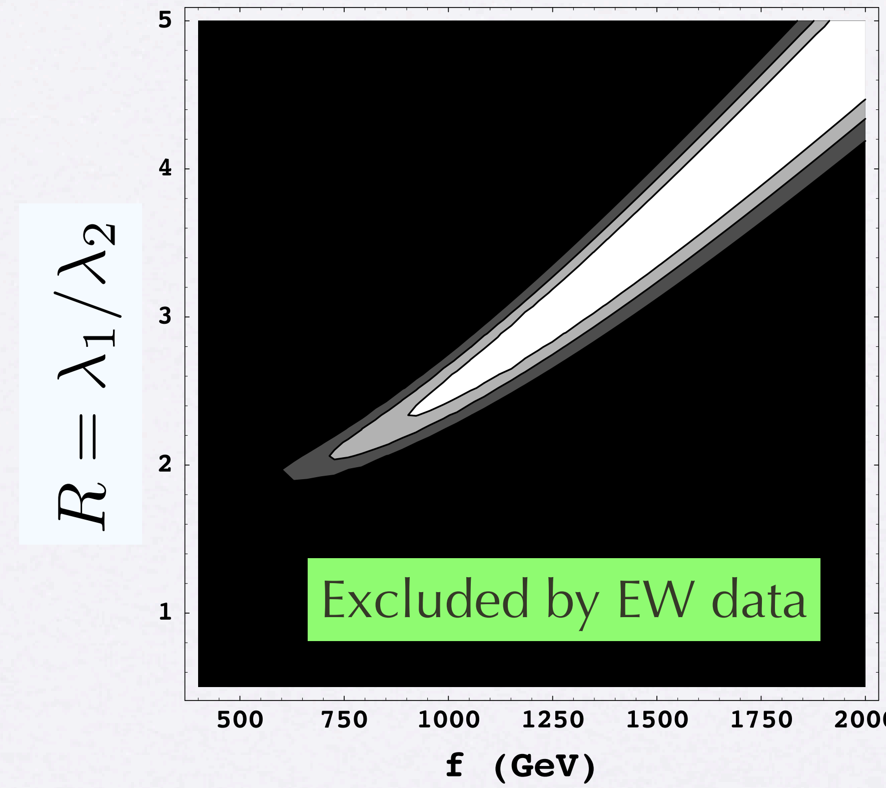
Csaki et al hep-ph/0211124



- Various v^2/f^2 corrections. proportional to the coupling difference, $\Delta g = g_1 - g_2$
- $M^2(W_H) = (g_1{}^2 + g_2{}^2)\, f^2/4 \sim (gf/2)^2 > 2.7$TeV
- f>4TeV m(t')>7TeV, (Hewett et al JHEP, 2003) Fine turning is reintroduced

Little Higgs with T-parity

Hubisz et al 0411264



$$m_{T_-} = \lambda_2 f$$

- gauge groups and matter contents respect T parity. $SU(2)_1 \rightleftarrows SU(2)_2$ $U(1)_1 \rightleftarrows U(1)_2$
- T-odd matters are introduced. Looks like SUSY without gluino
- LEP constraint is weaker.
  - Heavy gauge bosons and triplet higgs boson live in T-odd sector. No tree level mixing
- **Need more attempts to construct a model including symmetry breaking sector. (cf. the study of SUSY breaking sector.)**
- UED has similar nature.

The Lesson is ......

- LEP constraint (small radiative correction)
  - New Physics scale Λ is high, suggesting fine tuning.
  - Need symmetry to cancel divergence
  - top partner → top must be involved in the symmetry.
- "DM" and "radiative correction"→parity structure

LHC signature:strongly interacting particle decay into DM (and flavor sector involving b quark.....)

Supersymmetry and DM

SUSY mass spectrum

Radiative correction due to the gauge interactions. Strongly interacting particles are heavy weakly interaction particles are light.

Common scalar mass m0
common gaugino mass M1/2
at Unification scale.

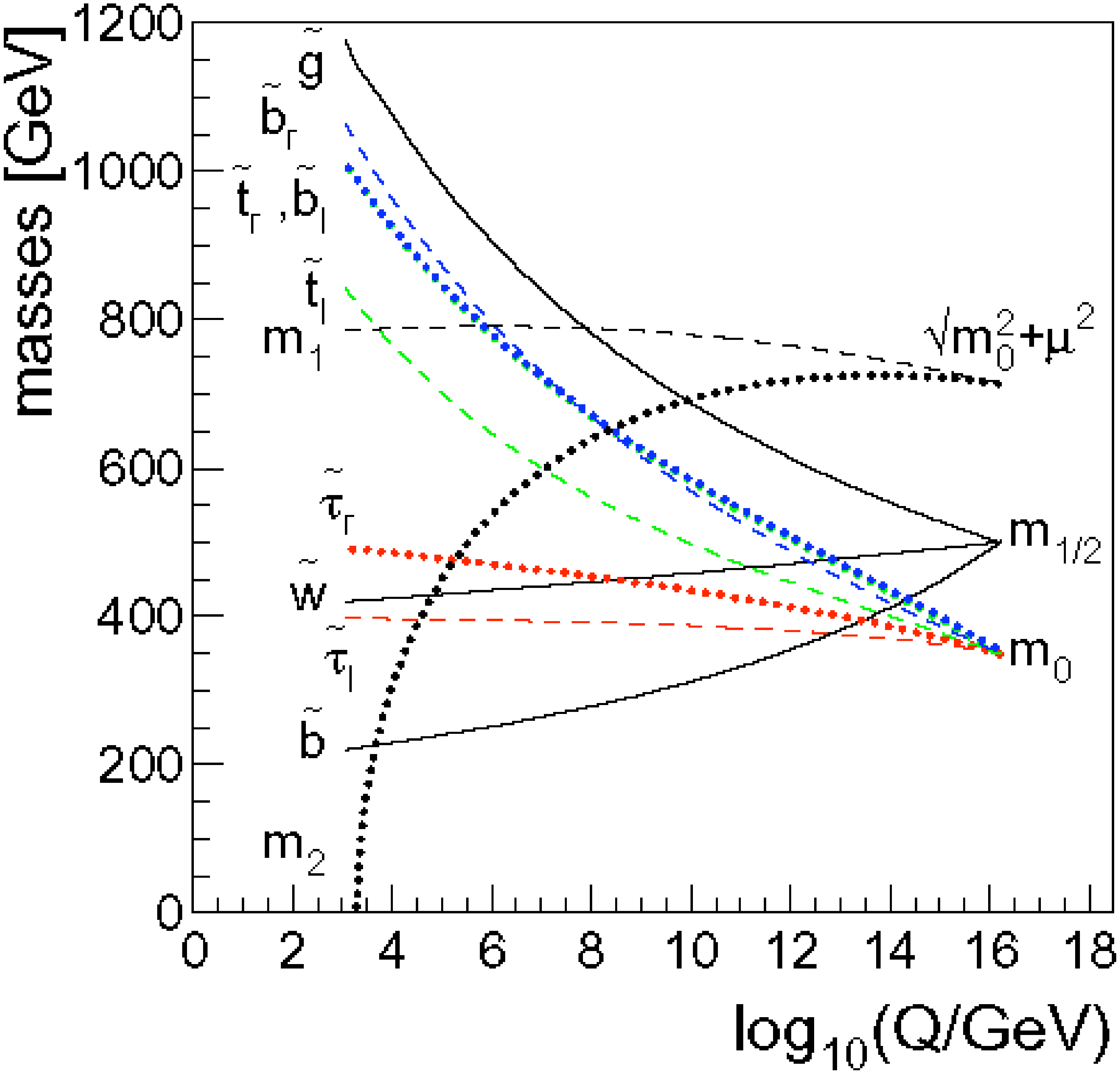
working assumption

$$m^2_{\tilde{q}L} = m_0^2 + 4.5 M^2_{1/2}$$
$$m^2_{\tilde{l}L} = m_0^2 + 0.5 M^2_{1/2}$$
$$m^2_{\tilde{l}R} = m_0^2 + 0.16 M^2_{1/2}$$

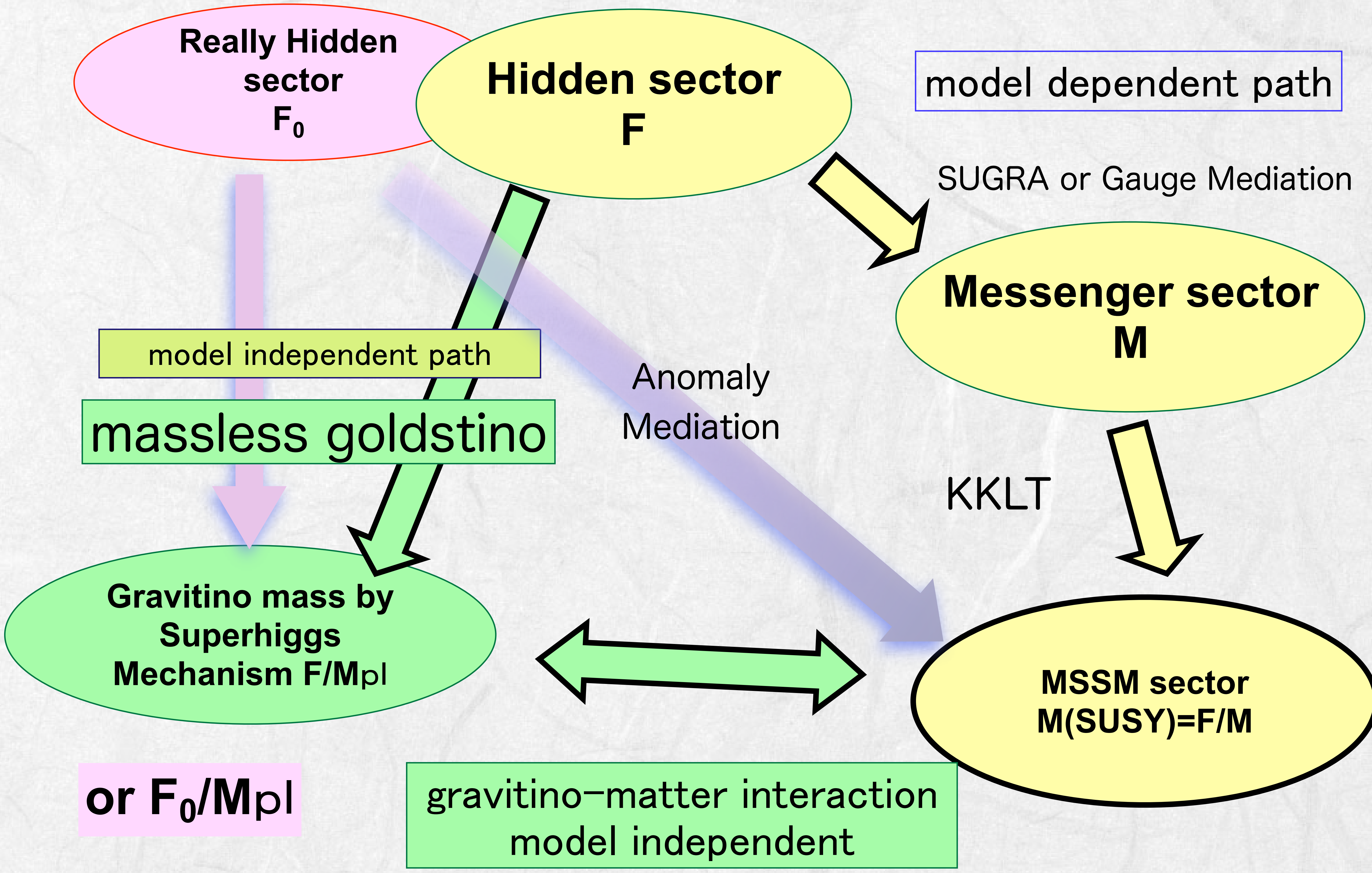
Yukawa interaction
mass difference among generations , Effects on generation mixing of SUSY particles

Low energy mass spectrum of SUSY particles

Radiative Symmetry Breaking



Supersymmetry-a picture



SUSY breaking scenarios and mass spectrum

- Low energy phenomenology is not the end of the story .
- Hidden sector break supersymmety. “flavor and CP” problem
  - gravity mediation, gauge mediation, anomaly mediation(string inspired mixed cases) , “geometric separation”
- Problems (why alternatives are searched for)
  - Light higgs boson (hope and/or worry) little hierarchy
  - DM constraints
  - gravitino, string moduli.....

Rich Field!

DM candidate in SUSY

- neutralino LSP
  - a neutralino is a mixture of gauginos and Higgsinos
  - Ω(th)h2~0.1⇄ light slepton, Higgs exchange, or gaugino-higgsino mixing , light connihilation.
- gravitino LSP
  - no prediction on the density.
  - direct detection is not possible
  - need additional trick to explain cosmic ray anomaly. (for example R parity violation --later)
- sneutrino essentially excluded

But in general, it is good to have
a DM candidate in the model

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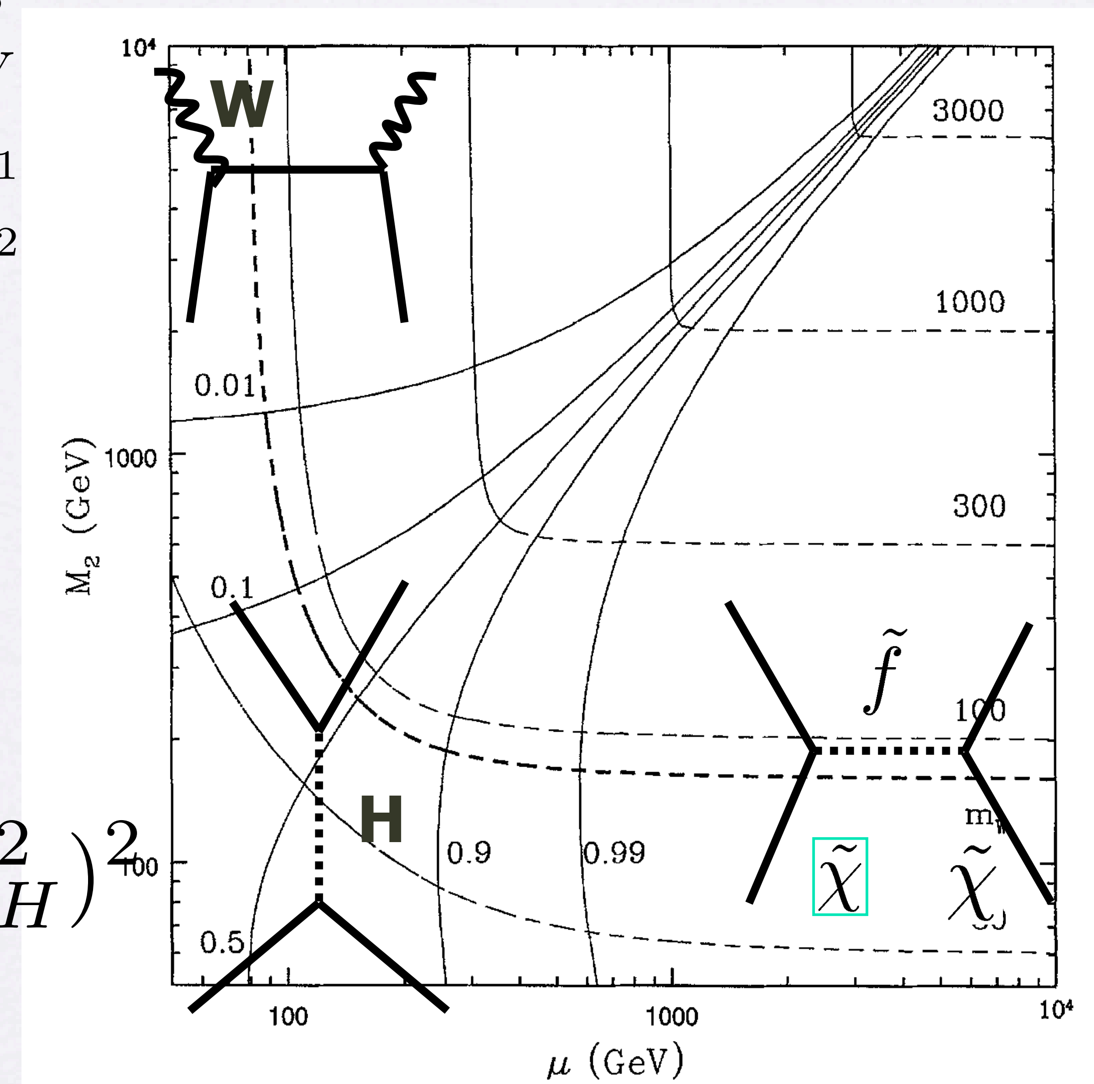
The nature of the Lightest Neutralino

Neutralino mass matrix

$$M = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ & & 0 & -\mu \\ & & -\mu & 0 \end{pmatrix} \begin{matrix} \tilde{B} \\ \tilde{W} \\ \tilde{H}_1 \\ \tilde{H}_2 \end{matrix}$$



$$M_1 \ll \mu \quad \sigma v \propto m_{\tilde{\chi}}^2 / m_{\tilde{l}}^4$$

$$M_1 \gg \mu \quad \sigma v \propto 1/m_{\tilde{\chi}}^2$$

$$M_1 \sim \mu \quad \sigma v \propto m_{\tilde{\chi}}^2 / (4m_\chi^2 - m_H^2)^2$$

DM density constraint is important in "MSUGRA"

1)bulk: LSP is Bino like.
Slepton exchanges fix the density 。

$$\Omega h^2 \propto m_{\tilde{l}}^4 / m_{\tilde{\chi}}^2$$

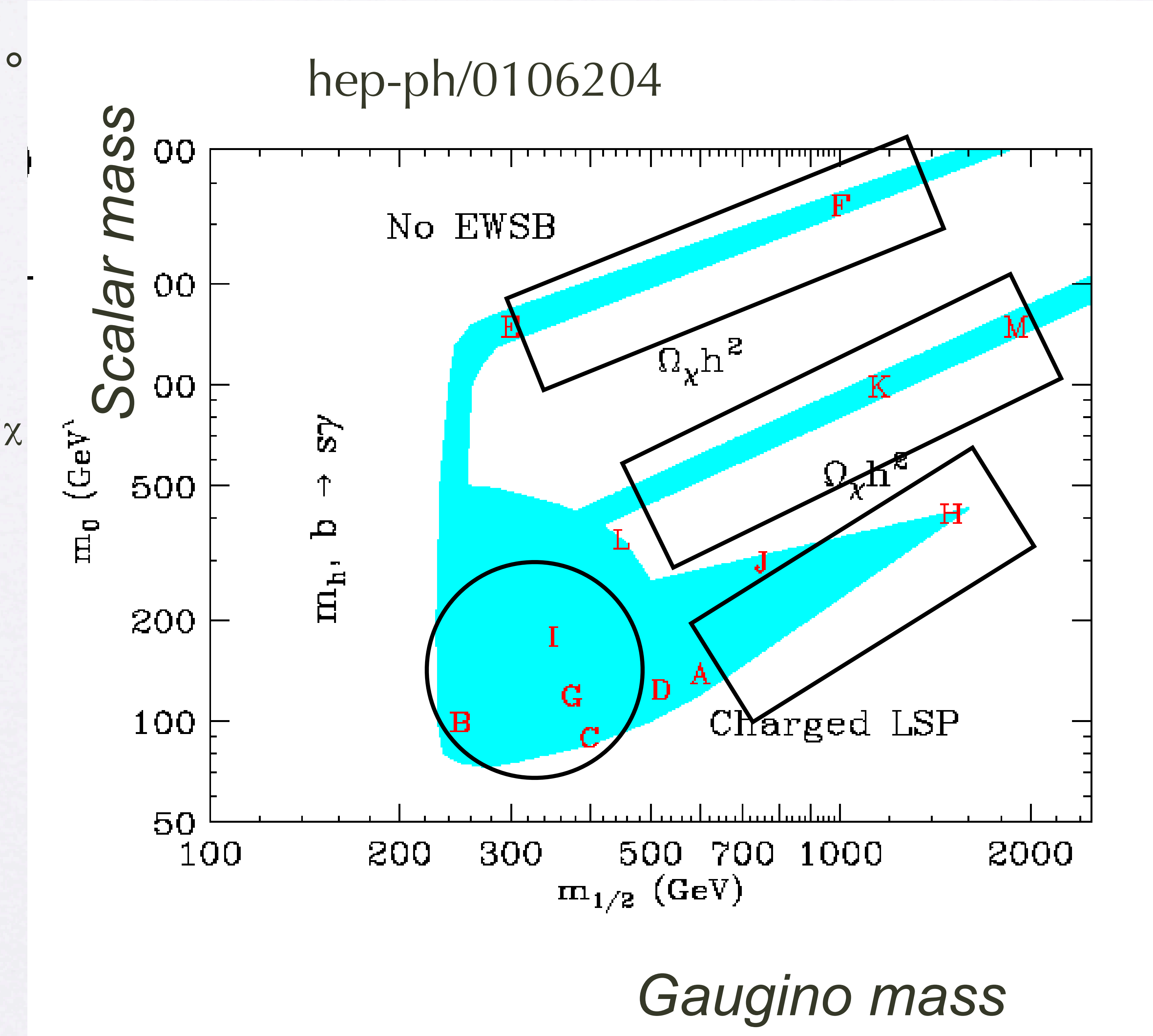
too large mass density

2)Higgs pole effects $m_H = 2m_\chi$

3)coannihilation region

$$\tilde{\tau}\tilde{\chi}$$

4)focus point region:
higgsino-gaugino mixing



Target at LHC

- finding LSP
- measure gaugino and chargino masses to fix M1, M2, μ, tanβ
- stau masses.
- measure HIggs mass (especially heavy ones)
- gravitino? (if I have a time)