Light Higgs Boson Scenario of the MSSM

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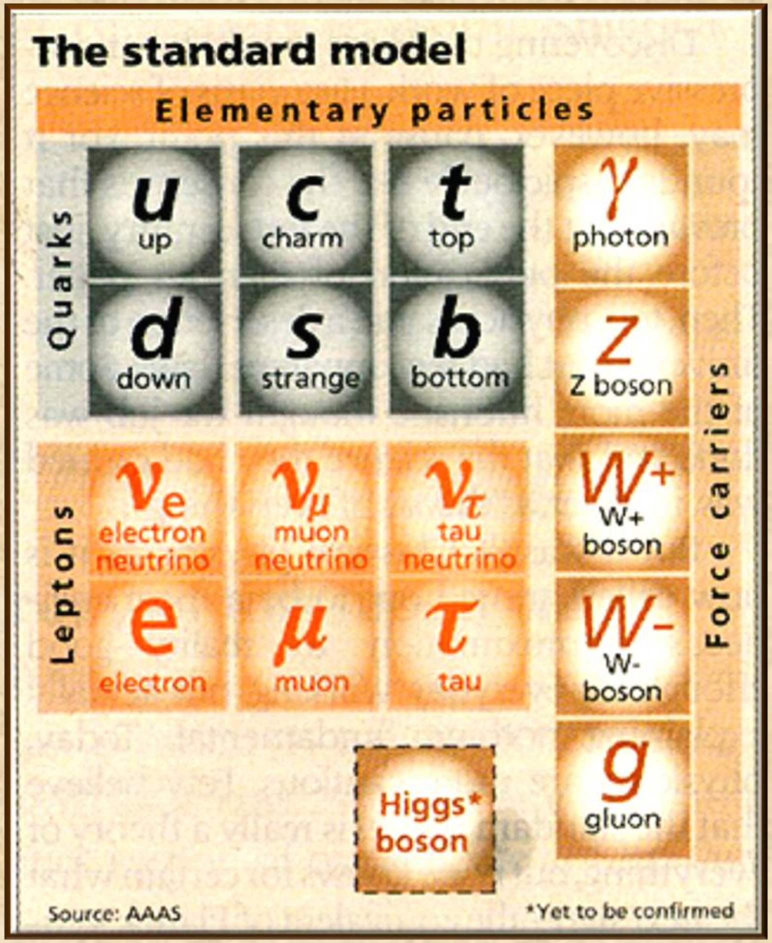
Contents

The Standard Model of Particle Physics

1. The standard model (SM), which is based on SU(3)xSU(2)xU(1) gauge theory, is the most successful model to describe physics of elementary particles.
2. The gauge symmetries SU(2)xU(1) are postulated to be broken down to the $U_{EM}(1)$ gauge symmetry. (The breaking of EW gauge sym.)
3. The SM explains almost all results experimentally performed so far.
4. Physics related to the EW symmetry breaking, Higgs sector, is not confirmed yet.



However, there are some problems that can not be explained in the SM.
Hierarchy problem, Neutrino mass problem, …
Dark Matter problem, Dark Energy problem, …

Hierarchy Problem

1. Higgs boson is the only scalar (spin 0) particle contained in the SM.
2. Mass of a scalar particle receives large quantum corrections.

$$m_h^2 = \boxed{\text{Tree level mass } (m_0^2)} + \boxed{\text{Quantum Corrections}}$$

$O(10^2 \text{ GeV})^2$ $O(10^{-2})\Lambda^2$

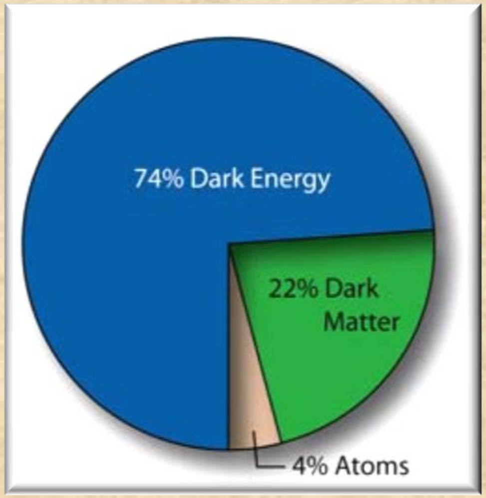
where Λ is the cutoff scale of the SM.

If Λ = 1 TeV = 10^3 GeV,
Higgs mass is obtained thorough $m_h^2 = O(10^2 \text{ GeV})^2 + O(10^2 \text{ GeV})^2$.
If Λ = 1 PeV = 10^6 GeV,
Higgs mass is obtained thorough $m_h^2 = O(10^5 \text{ GeV})^2 + O(10^5 \text{ GeV})^2$.

The cutoff scale Λ should be smaller than 1 TeV to naturally realize the higgs mass of $O(10^2)$ GeV.

Dark Matter Problem

1. The existence of dark matter has been established by cosmological observations.
2. However, there is no candidate for dark matter in the standard model.
3. Dark matter is expected to be unknown neutral, stable, and cold particle.
4. Current mass density of dark matter is about $\rho_{DM} \sim 10^{-6}$ [GeV/cm^3].



WIMP (Weakly interacting Massive Particle) hypothesis

Neutral & Stable Heavy particle

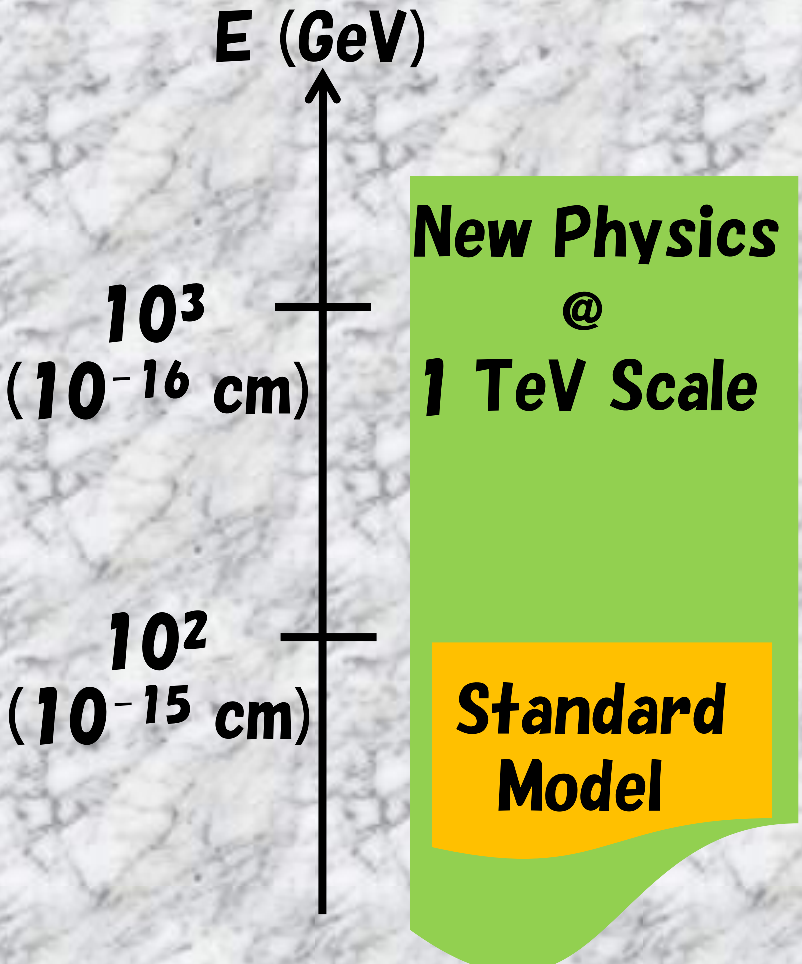
Boltzmann eq.

1. The motion of the WIMP dark matter becomes non-relativistic.
2. Mass density is predicted to be $\rho_{DM} \sim 10^{-6} (m_{DM}/1\ \mathrm{TeV}/g^2)^2$[GeV/cm^3].

The new particle (dark matter) will be at the TeV scale. → New physics at the TeV scale!

New Physics beyond the Standard Model

1. Two Problems **does not mean** the failure of the Standard Model.
2. The Standard Model should be regarded as **an effective field theory** describing physics below 100 GeV.



- Both two problems indicate that the "New Physics" appears at the 1 TeV scale, and the "New Physics" will solve those.
- Many scenarios for the "New Physics" have been proposed.

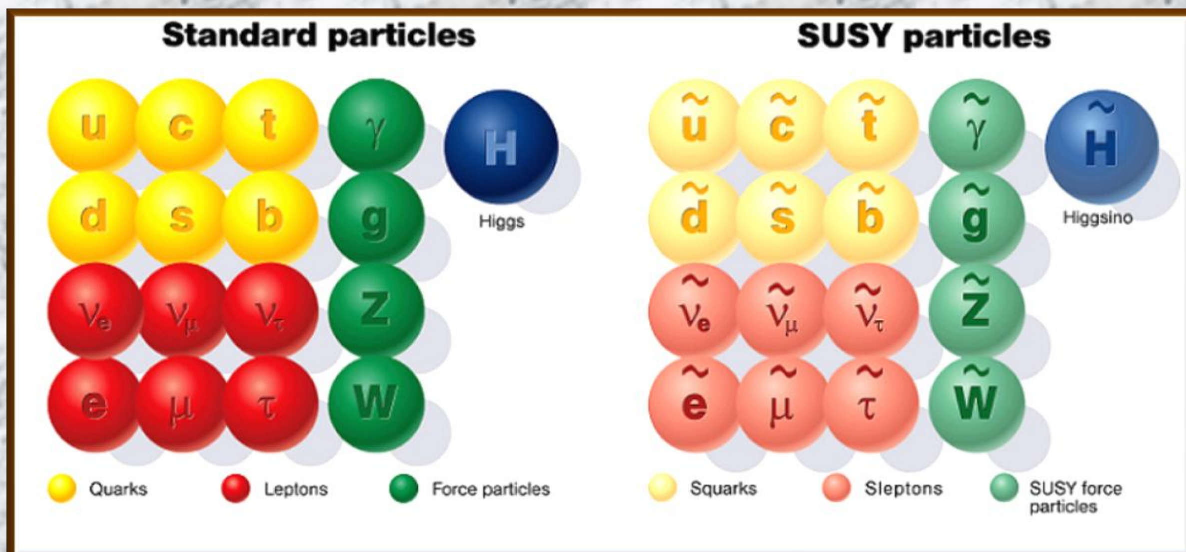
1. **Supersymmetric Scenario**
2. Little Higgs Scenario
3. Extra-dimension Scenario
4. Gauge Higgs Scenario
5. …

Supersymmetric scenario for the New Physics

Supersymmetry: a symmetry that relates particles of one spin to
(SUSY) other particles that differ by half a unit of spin.

SUSY scenario with SM particles —Extension of the SM→ **New particles are introduced**

For example,



1. SUSY scenario **can solve** hierarchy & dark matter problems.
2. The simplest extension → Minimal Supersymmetric SM (**MSSM**).

Resolutions of Hierarchy & Dark Matter Problems

$$m_h^2 = \boxed{\text{Tree level mass } (m_0^2)} + \boxed{\text{Quantum Corrections (SM Int.)}} + \boxed{\text{Quantum Corrections (New Int.)}}$$

Cancelled

No large quantum corrections in the SUSY scenario!

1. It is possible to impose the Z_2-symmtry (R-parity) in the scenario.
2. SM particles are even, while SUSY ones are odd under the parity.

One SUSY particle → One SUSY particle + SM particles

~~One SUSY particle → Only SM particles~~

The Lightest SUSY particle is stable!

Good candidate for dark matter in the SUSY scenario!

Light Higgs Boson Scenario (LHS) of the MSSM

1. We will focus on the MSSM scenario.
2. The MSSM scenario still has many model parameters.
3. Considering the Higgs sector $\supset H_u$ & H_d
4. EW symmetry breaking → $H^{\pm}$, A, & two CP-even higgs bosons

$$\begin{pmatrix} m_A^2 s_\beta^2 + m_Z^2 c_\beta^2 + \Delta_{dd} & -(m_A^2 + m_Z^2) s_\beta c_\beta + \Delta_{du} \\ -(m_A^2 + m_Z^2) s_\beta c_\beta + \Delta_{du} & m_A^2 c_\beta^2 + m_Z^2 s_\beta^2 + \Delta_{uu} \end{pmatrix}$$

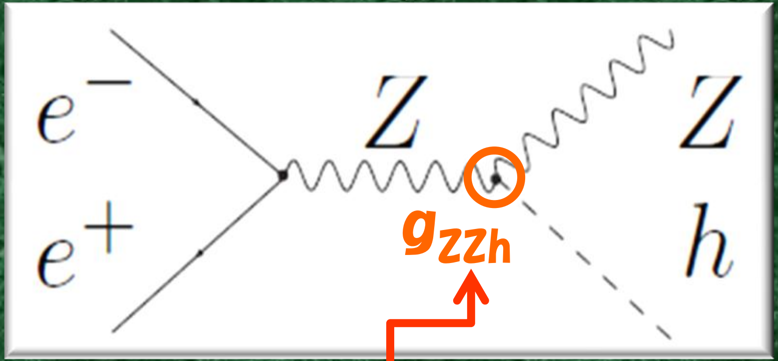
$\tan\beta = \langle H_u^0 \rangle / \langle H_d^0 \rangle$ & assuming $\tan\beta >> 1$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} -\sin\alpha & \cos\alpha \\ \cos\alpha & \sin\alpha \end{pmatrix} \begin{pmatrix} \mathrm{Re}\, H_d^0 \\ \mathrm{Re}\, H_u^0 \end{pmatrix}$$

- If $m_A >> m_Z$, $\sin(\alpha) \sim 0$ and $h \sim \mathrm{Re}\, H_u^0$.
- If $m_A \sim m_Z$, $\sin(\alpha) \sim \pi/2$ and $h \sim \mathrm{Re}\, H_d^0$.
  1. The second case = The Light Higgs Scenario
  2. Masses of all Higgs bosons are light

Light Higgs Boson Scenario (LHS) of the MSSM

LEP bound on m_h > 114.4 GeV



$$|D_\mu H|^2 \sim Z_\mu Z^\mu \langle H^0 \rangle H^0$$

Usual case ($m_A >> m_Z$)

$h \sim H_u$

$(g_{ZZh})_{MSSM} \sim (g_{ZZh})_{SM}$

LHS case ($m_A \sim m_Z$)

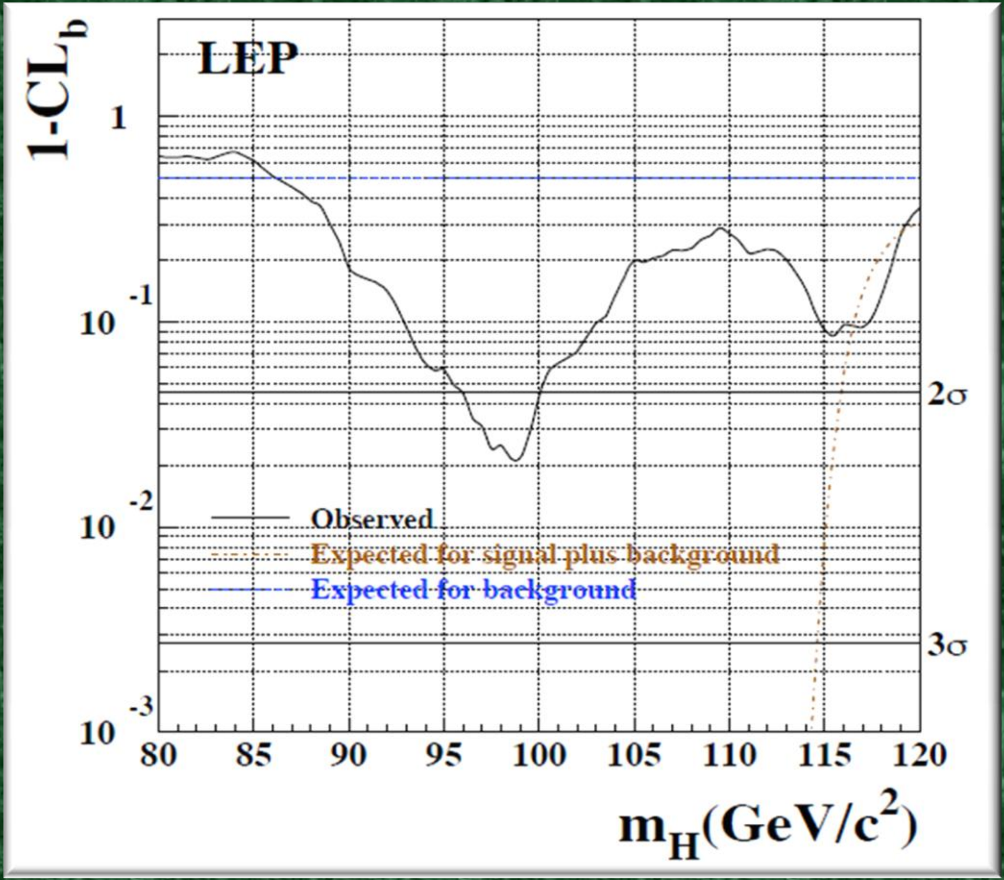
$h \sim H_d$

$(g_{ZZh})_{MSSM} << (g_{ZZh})_{SM}$

1. In this scenario, the mass of h can be lighter than 114.4 GeV.
2. Originally, this scenario has been proposed for the LEP anomaly.

Light Higgs Boson Scenario (LHS) of the MSSM

LEP Anomaly (Excess of Higgs-like event)



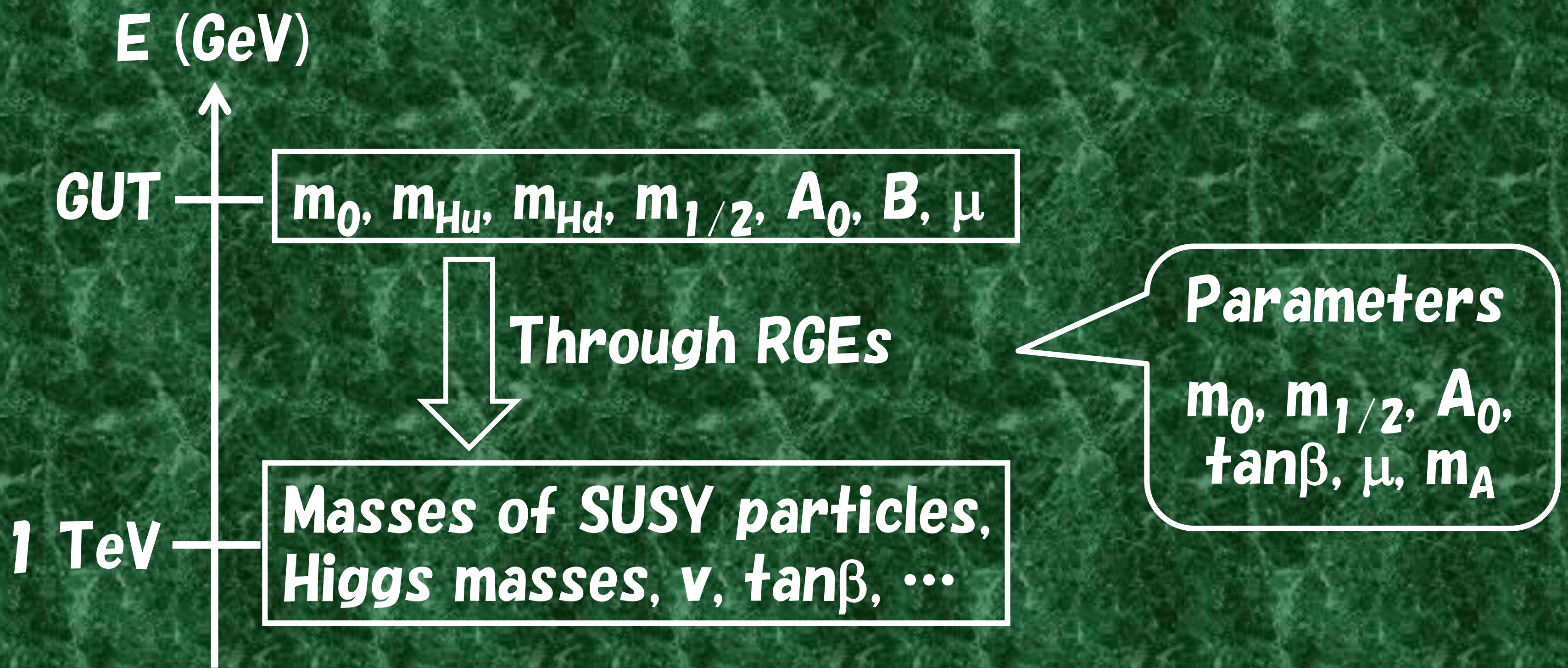
LEP has found the excess from expected background at m_h = 98 GeV.

1. SM Higgs cannot explain the excess, because the number of the excess events corresponds to about 10% of that predicted in SM.
2. MSSM can explain this excess if the LHS is realized.

Realization of the Light Higgs Boson Scenario

Purpose: Dark Matter phenomenology in the LHS

1. MSSM has many parameters, so that it is difficult to handle with the model to explore the region realizing the LHS.
2. We have considered the NUHM (Non-universal Higgs Mass) model, which can realize the LHS. In this model, GUT relation on gaugino masses is assumed.



Realization of the Light Higgs Boson Scenario

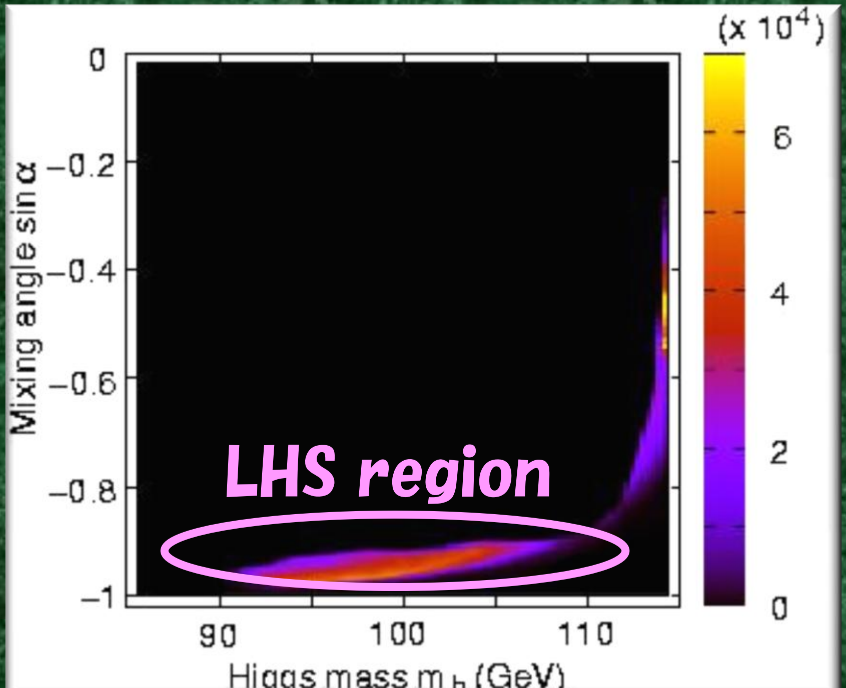
	Constraints	References
Relic abundance of dark matter ($\Omega_{\rm DM}h^2$)	0.1099 ± 0.0062	[1] (WMAP only)
BR($b \to s\gamma$)	$(3.52 \pm 0.25) \times 10^{-4}$	[17]
ρ-parameter ($\Delta\rho$)	0 ± 0.0009	[18] (p. 137)
BR($B_s \to \mu^+\mu^-$)	$< 5.8 \times 10^{-8}$	[19]
Upper bound on g_{ZZh} (g_{ZZH})	Function of m_h (m_H)	[10]
Upper bound on g_{ZAh} (g_{ZAH})	Function of $m_h(m_H) + m_A$	[10]
Lightest neutralino mass	> 50.3 GeV	[20]
Chargino mass	> 103.5 GeV	[20]
Right-handed selectron mass	> 99.9 GeV	[20]
Right-handed smuon mass	> 94.9 GeV	[20]
Right-handed stau mass	> 86.6 GeV	[20]
Sneutrino masses	> 94 GeV	[21]
Stop and sbottom masses	> 95 GeV	[20]
Gluino mass	> 308 GeV	[22]
Squark masses (1st and 2nd generations)	> 379 GeV	[22]

Constraints on NUHM

MCMC Method

2.0×10^7 samples

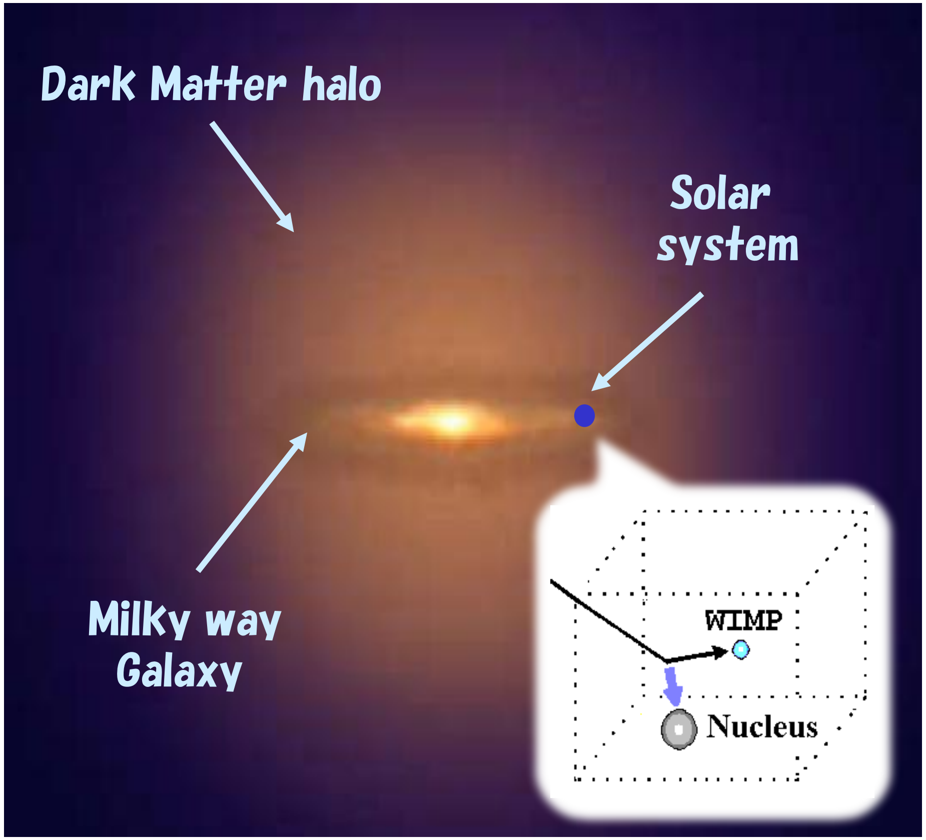
Distribution of Samples



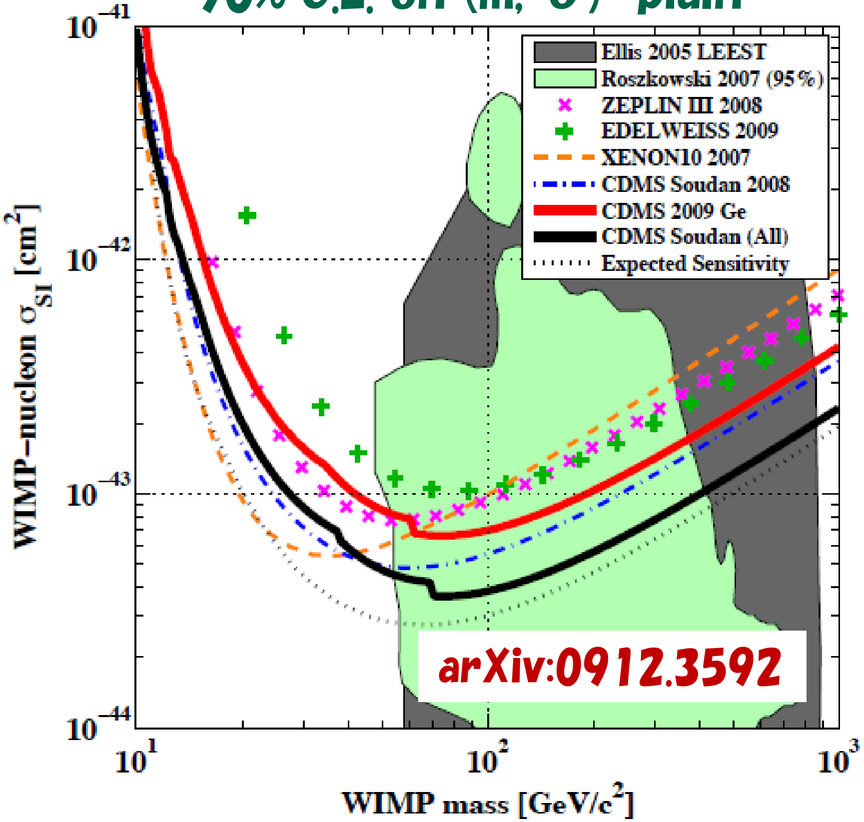
Dark Matter is the lightest neutralino composed mostly of Bino, which is the super-partner of U(1) gauge boson

Detection of Dark Matter at the LHS

LHS has an important prediction on direct detection of dark matter



90% C.L. on (m, σ)-plain



Experimental data are now placing the strong constraints on dark matter-nucleon scattering cross section especially at the region $m_{DM} \sim 100$ GeV.

Detection of Dark Matter at the LHS

Important predictions are

1. $\sigma(\mathrm{DM}\ N \to \mathrm{DM}\ N) \sim 10^{-44}\mathrm{cm}^2$
2. $50\ \mathrm{GeV} < m_{DM} < 200\ \mathrm{GeV}$

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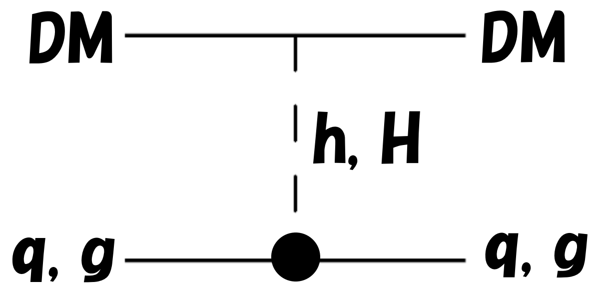

Detection of Dark Matter at the LHS

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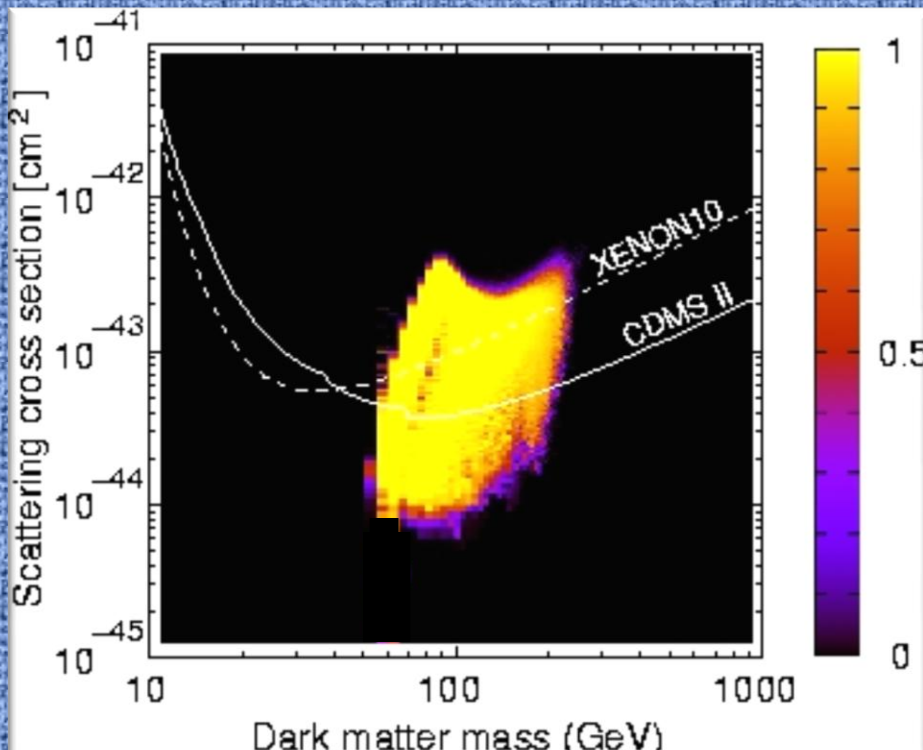
I. LEP search < Chargino mass
II. Chargino mass < $Br(b \rightarrow s\gamma)$

⇩

Bound on the dark matter mass

Likelihood maximum $[\mathrm{Exp}(-\chi^2/2)]$



Summary & Discussions

- The Standard Model is the successful model to describe physics below the scale of O(100) GeV. However, there are some problems which can not been explained in this framework, and the existence of "New Physics" is expected to solve these problems naturally.

- Many scenarios of the "New Physics" have been proposed so far, and supersymmetric scenario is one of the most attractive scenarios.

- In this talk, we have focused on the Light Higgs Boson Scenario (LHS) of the MSSM, where the scenario has not been considered carefully so far. It is shown that the NUHM model realizes the LHS.

- One of interesting predictions of the LHS is coming from dark matter phenomenology. In this model, the mass of the dark matter is expected to be about 100 GeV, and its scattering cross section with a nucleon is
- about $10^{-44}\mathrm{cm}^2$. As a result, the dark matter in the LHS can be easily discovered at near future direct detection experiments.

- Since almost all new particles are predicted to be large, it is interesting to consider signals of new physics at the LHC. It is also interesting to consider signals at the ILC, because higgs sector of the scenario can be explored carefully.