Relation of CLFV to cosmological observables in the CMSSM coannihilation scenario with SeeSaw mechansism

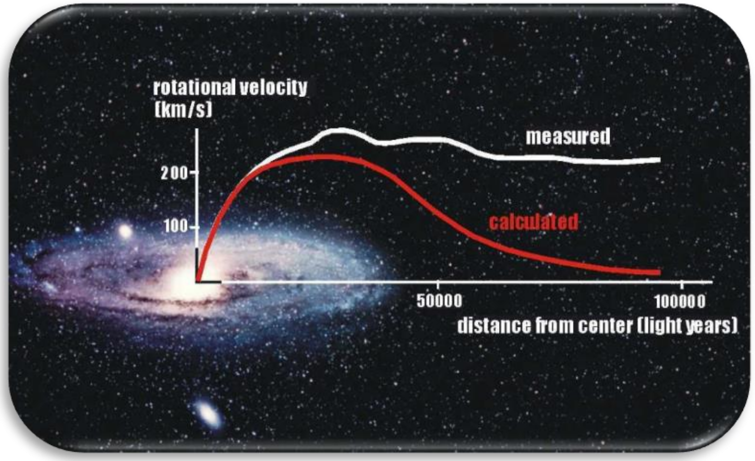
Masato Yamanaka (Maskawa Institute, Japan)

arXiv:1803.XXXXX

collaborator : M. Kubo, J. Sato, T. Shimomura, Y. Takanishi

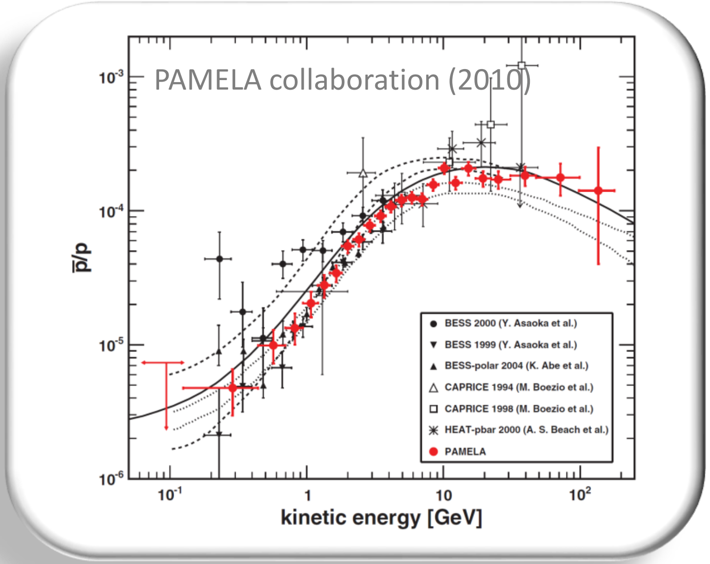
Predictions for CMSSM observables and for CLFV from Higgs, dark matter, BBN and leptogenesis

Current status



Evidence of new physics

- Dark matter
- Lithium problem
- Neutrino mass
- Baryon asymmetry
- etc.



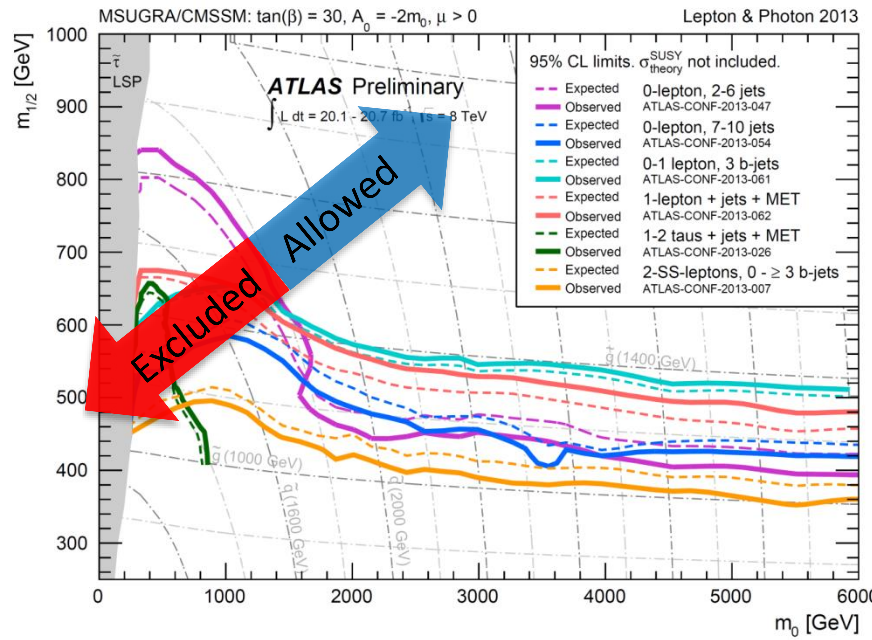
Candidate of new physics: **CMSSM with seesaw mechanism**

Where is the realistic parameter region?

Lightest SUSY particle (LSP): Bino-like neutralino $\tilde{\chi}$

Nest LSP (NLSP): stau-like lightest slepton $\tilde{\ell}$

Large allowed region???



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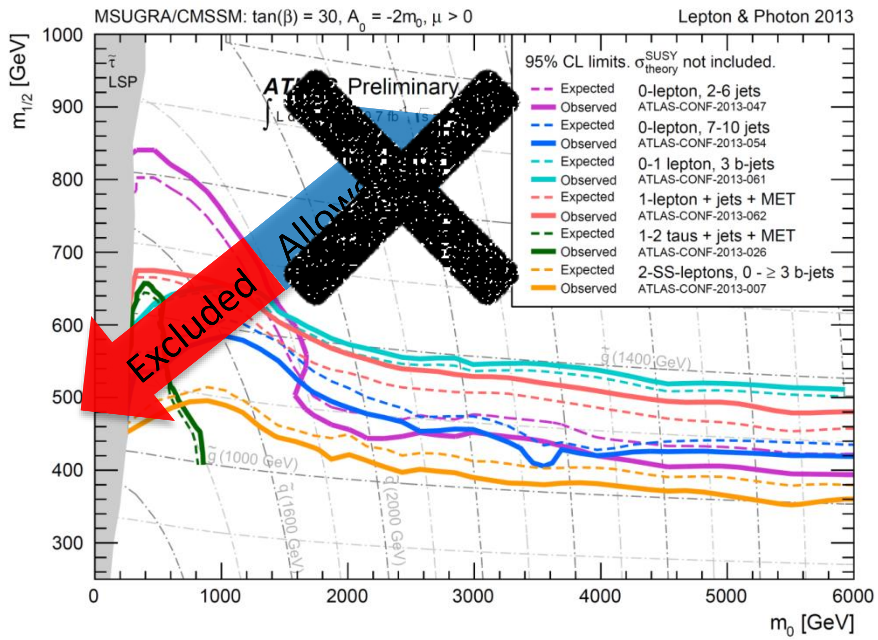
Over abundance of dark matter!



Where is the realistic parameter region?

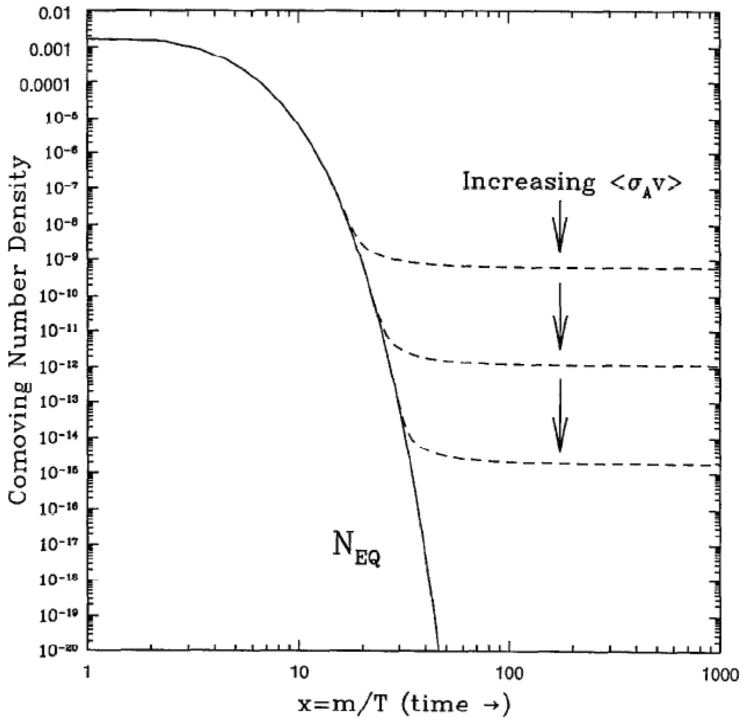
Coannihilation mechanism

$m_{\tilde{\chi}} \simeq m_{\tilde{\ell}}$

→ Large rate of $\tilde{\chi} + \mathrm{SM} \to \tilde{\ell} + \mathrm{SM}$

→ $\tilde{\ell}$ pair-annihilation

Reducing DM density by long chemical equilibrium of SUSY and SM particles



Where is the realistic parameter region?

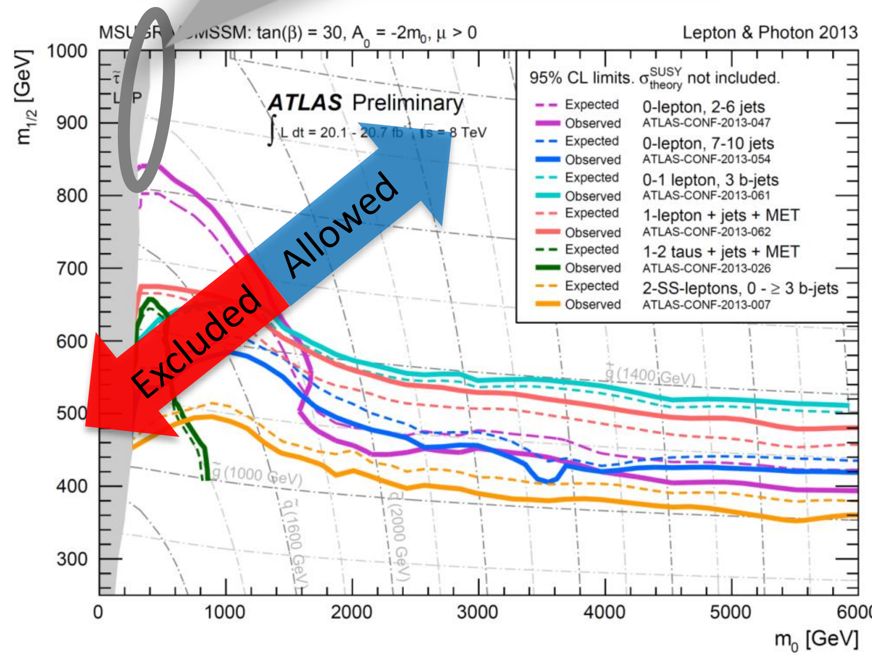
Realistic region in light of Higgs mass, muon g-2, and so on

$$\delta m \equiv m_{\tilde{\ell}} - m_{\tilde{\chi}} < m_\tau$$

L. Aparicio, D. Cerdeno, L. Ibanez, JHEP (2012)
M. Citron, J. Ellis, F. Luo, et al, PRD87 (2013)

Consistent with DM observation

Coannihilation region



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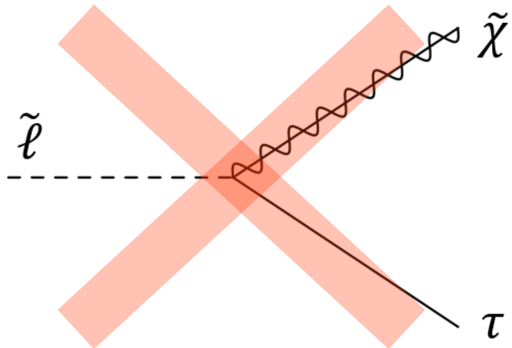
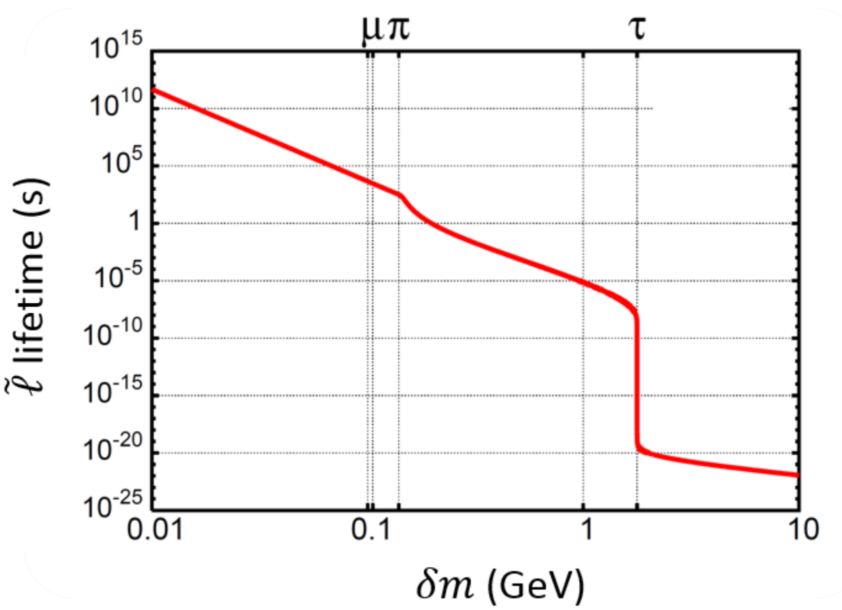


Long-lived slepton due to phase space suppression for $\delta m < m_{\tau}$



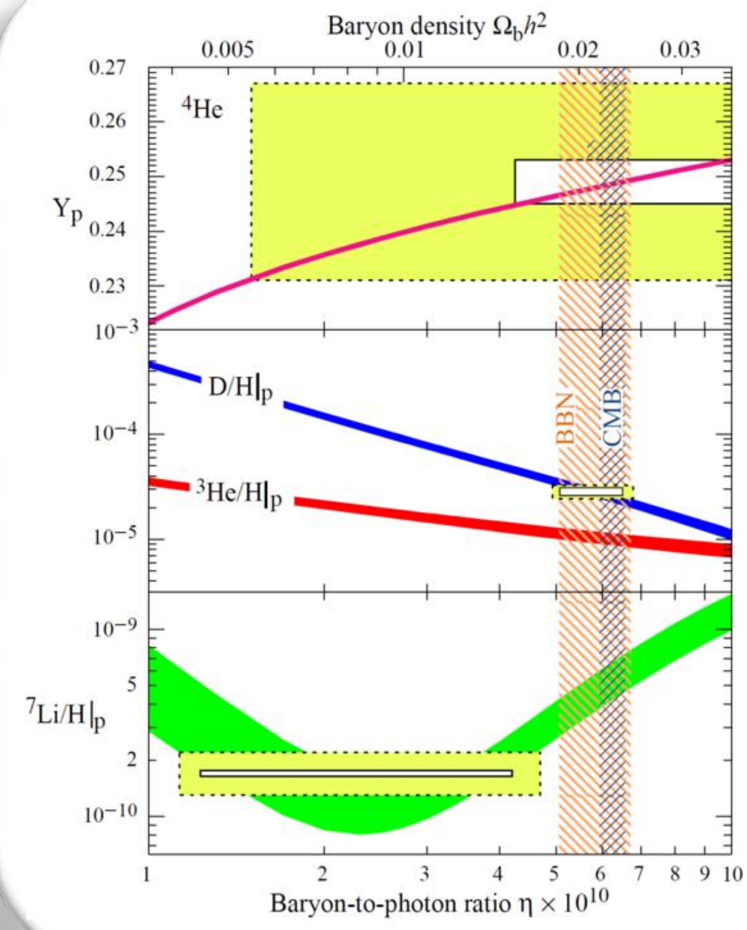
T. Jittoh, J. Sato, T. Shimomura, MY, PRD73 (2006)

Long-lived slepton

Discrepancy between observed and predicted Li abundance

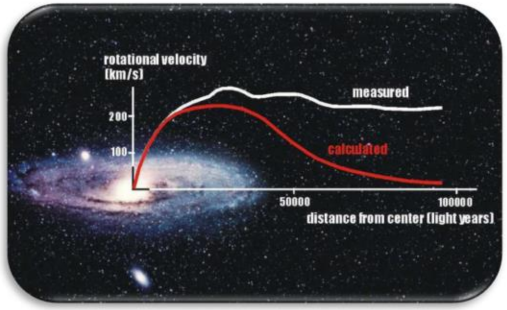
Long-lived slepton solves Li problems

T. jittoh, et al, PRD76 (2007)
C. Bird, et al, PRD78 (2008)



The scenario can describe our universe or not?

Current status



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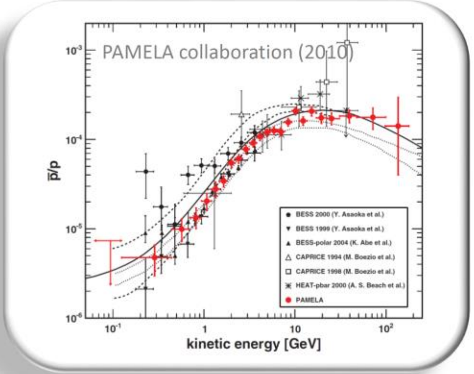
- etc.



Candidate of new physics: **CMSSM with seesaw mechanism**

If this scenario describes our universe,
the baryon asymmetry must be generated

Aim and outline

Aim

- ☑ accounting for baryon asymmetry in the scenario
- ☑ find a unique signal/relation to confirm the scenario

Outline

1. model and notation
2. How to find allowed parameters
3. Numerical results
4. Summary

Model and notation

CMSSM with RH neutrinos

Parameter : $M_{1/2},\ m_0,\ A_0,\ \tan\beta,\ \text{sign}(\mu)$

LSP : Bino-like neutralino $\tilde{\chi}$

NLSP : stau-like slepton $\tilde{\ell} = \sum_{f=e,\mu,\tau} C_f \tilde{f}$ $\left(\tilde{f} = \cos\theta_f \tilde{f}_L + \sin\theta_f \tilde{f}_R\right)$

RH neutrino : $\mathcal{W} = (\hat{y}_\ell)_\alpha L_\alpha H_d E^c_\alpha + (y_\nu)_{\alpha i} L_\alpha H_u N^c_i + (\hat{M}_R)_i N^c_i N^c_i$

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induces slepton mixing C_f and LR mixing θ_f through RG equations

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- constraint on θ_f from DM abundance
- upper bound on C_f from BBN
- constraint on $(y_\nu)_{\alpha i}$ and M_R from leptogenesis

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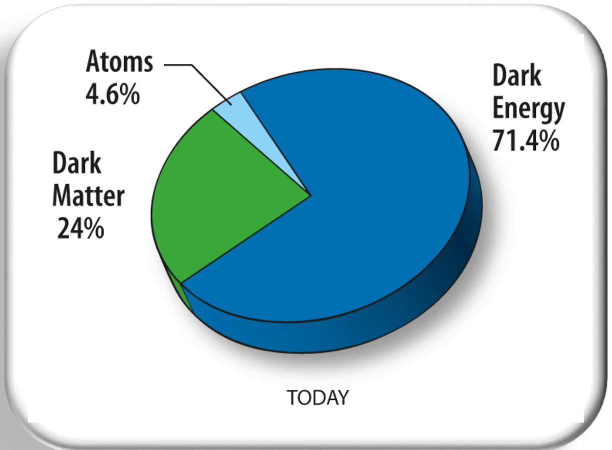
A unique relation on CMSSM observables and CLFV

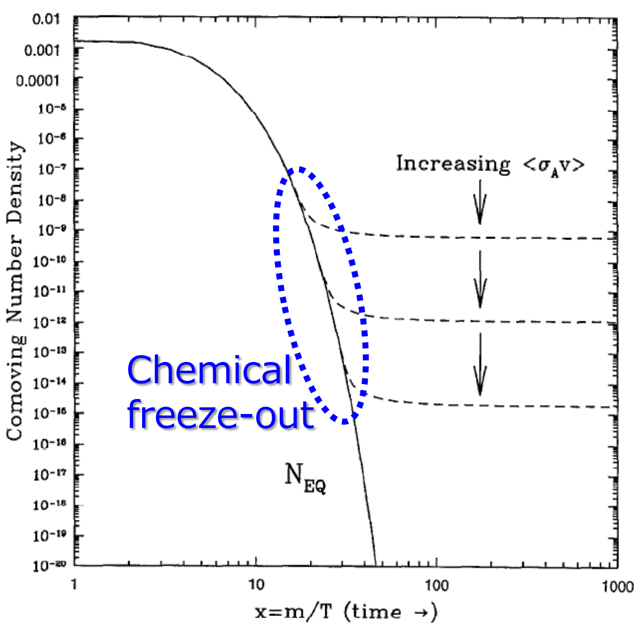
How to find allowed parameters

DM relic abundance



DM relic abundance   PLANCK 2015 results

$$0.1126 \leq \Omega_{\mathrm{DM}} h^2 \leq 0.1246$$



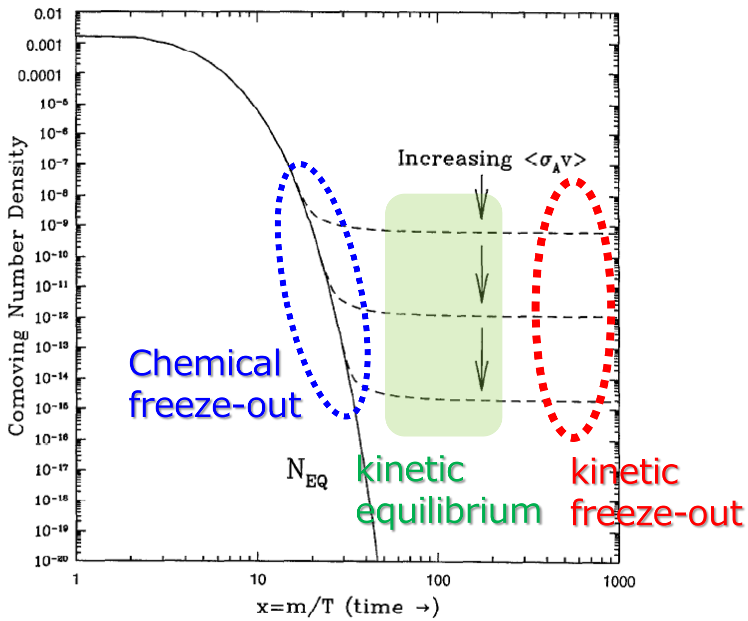
Freeze out of total SUSY density@$T \simeq m_{\tilde{\chi}}/25$

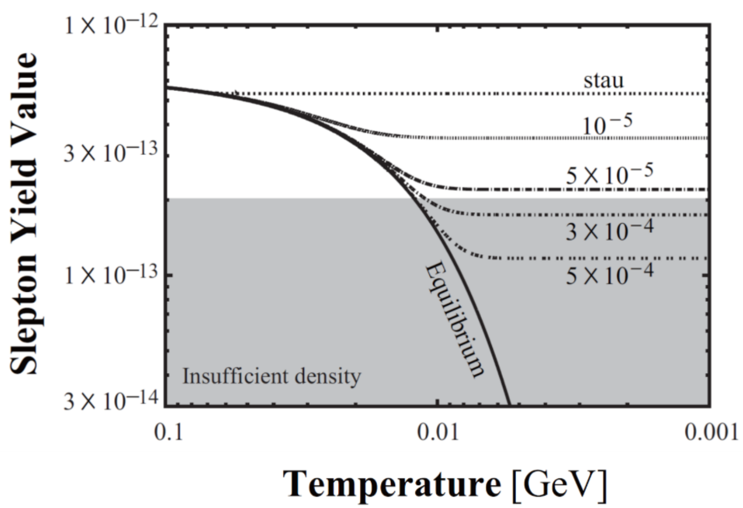
$$n \equiv n_{\tilde{\chi}} + n_{\tilde{\ell}^-} + n_{\tilde{\ell}^+}$$

CMSSM parameters ($M_{1/2}, m_0, A_0, \tan\beta$, etc.) are constrained by this condition

Note: Slepton density is not frozen yet!

Slepton density





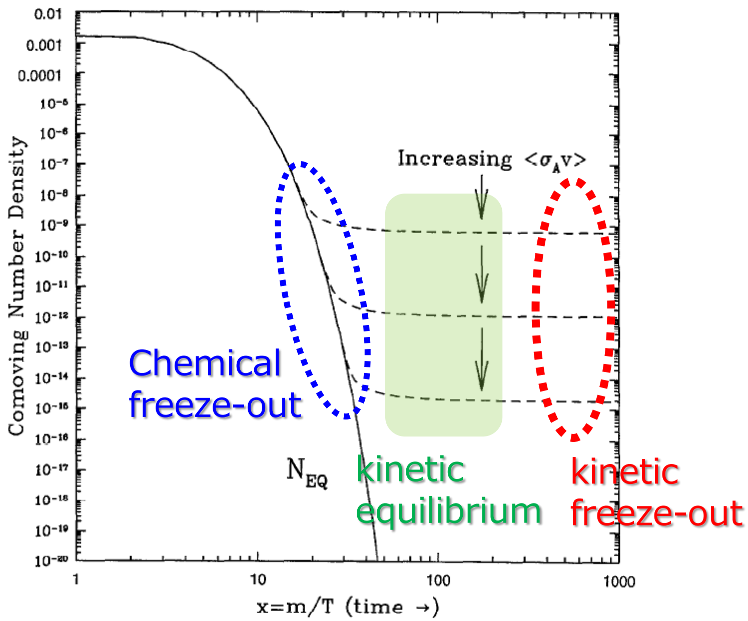
Kinetic equilibrium with SM sector through SUSY-SM scattering

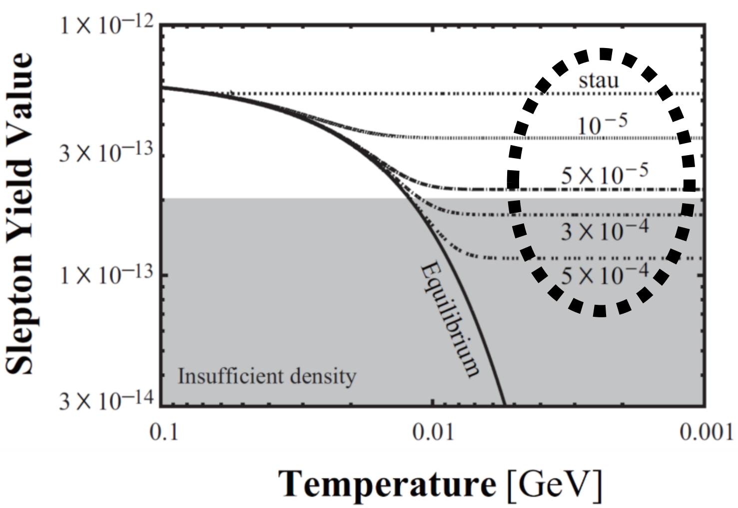
$$\tilde{\ell}\gamma \leftrightarrow \tilde{\chi}\tau, \quad \tilde{\ell}\gamma \leftrightarrow \tilde{\chi}\mu,$$
$$\tilde{\ell}\tau \leftrightarrow \tilde{\chi}\gamma, \quad \tilde{\ell}\mu \leftrightarrow \tilde{\chi}\gamma, \quad \tilde{\ell}e \leftrightarrow \tilde{\chi}\gamma$$

Slepton density continues to decrease as long as being in kinetic equilibrium

$$n_{\tilde{\ell}^-} = \frac{n_{\tilde{\ell}_1^-}}{n_{\tilde{\chi}_1^0}} \frac{n_{\tilde{\chi}_1^0}}{n} n = n \frac{e^{-\delta m/T}}{2\left(1+e^{-\delta m/T}\right)}$$

Slepton density





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Kinetic freeze-out temperature strongly depends on slepton mixing

Large density is required for solving Li7 (Li6) problem

→ **Upper bound on slepton mixing**

→ **Upper bound on Majorana mass**

Leptogenesis

To correctly constrain each component of $(y_\nu)_{\alpha i}$, it's important to take into account spectator and flavor effects

$$\frac{dY_{N_1}}{dz} = -\frac{z}{sH(z=1)}\left(\frac{Y_{N_1}}{Y_{N_1}^{eq}} - 1\right)\left[\gamma_D + 2\gamma_{Ss} + 4\gamma_{St}\right]$$

$$\frac{dY_{\Delta_i}}{dz} = -\frac{z}{sH(z=1)}\left\{\left(\frac{Y_{N_1}}{Y_{N_1}^{eq}} - 1\right)\epsilon_{1i}\gamma_D + K_i^0 \sum_j \left[\frac{1}{2}\left(C_{ij}^l + C_j^H\right)\gamma_D \right.\right.$$
$$\left.\left. + \left(\frac{Y_{N_1}}{Y_{N_1}^{eq}} - 1\right)\left(C_{ij}^l \gamma_{S_s} + \frac{C_j^H}{2}\gamma_{S_t}\right) + \left(2C_{ij}^l + C_j^H\right)\left(\gamma_{S_t} + \frac{\gamma_{S_s}}{2}\right)\right]\frac{Y_{\Delta_i}}{Y_l^{eq}}\right\}$$

- $Y_i = n_i/s$ (s: entropy density)
- $z = M_1/T$
- γ_D $(\gamma_{S_s}, \gamma_{S_t})$: reduced thermal averaged decay rate (cross section)

Leptogenesis

- Conversion rate of flavored L asymmetry onto flavored $(B-L)$ asymmetry
- $Y_{L_i} = -(C^l_{ie} Y_{\Delta_e} + C^l_{i\mu} Y_{\Delta_\mu} + C^l_{i\tau} Y_{\Delta_\tau})$

$$\frac{dY_{\Delta_i}}{dz} = -\frac{z}{sH(z=1)} \left\{ \left(\frac{Y_{N_1}}{Y^{eq}_{N_1}} - 1\right) \epsilon_{1i} \gamma_D + K_i^0 \sum_j \left[\frac{1}{2} \left(C^l_{ij} + C^H_j\right) \gamma_D + \left(\frac{Y_{N_1}}{Y^{eq}_{N_1}} - 1\right) \left(C^l_{ij} \gamma_{S_s} + \frac{C^H_j}{2} \gamma_{S_t} \right) + \left(2C^l_{ij} + C^H_j\right) \left(\gamma_{S_t} + \frac{\gamma_{S_s}}{2} \right) \right] \frac{Y_{\Delta_i}}{Y^{eq}_l} \right\}$$

- Conversion rate of spectator contribution onto flavored $(B-L)$ asymmetry
- $Y_H - Y_{\bar{H}} = -(C^H_e Y_{\Delta_e} + C^H_\mu Y_{\Delta_\mu} + C^H_\tau Y_{\Delta_\tau})$

Leptogenesis

- Flavored decay parameter determined by structure of neutrino Yukawa

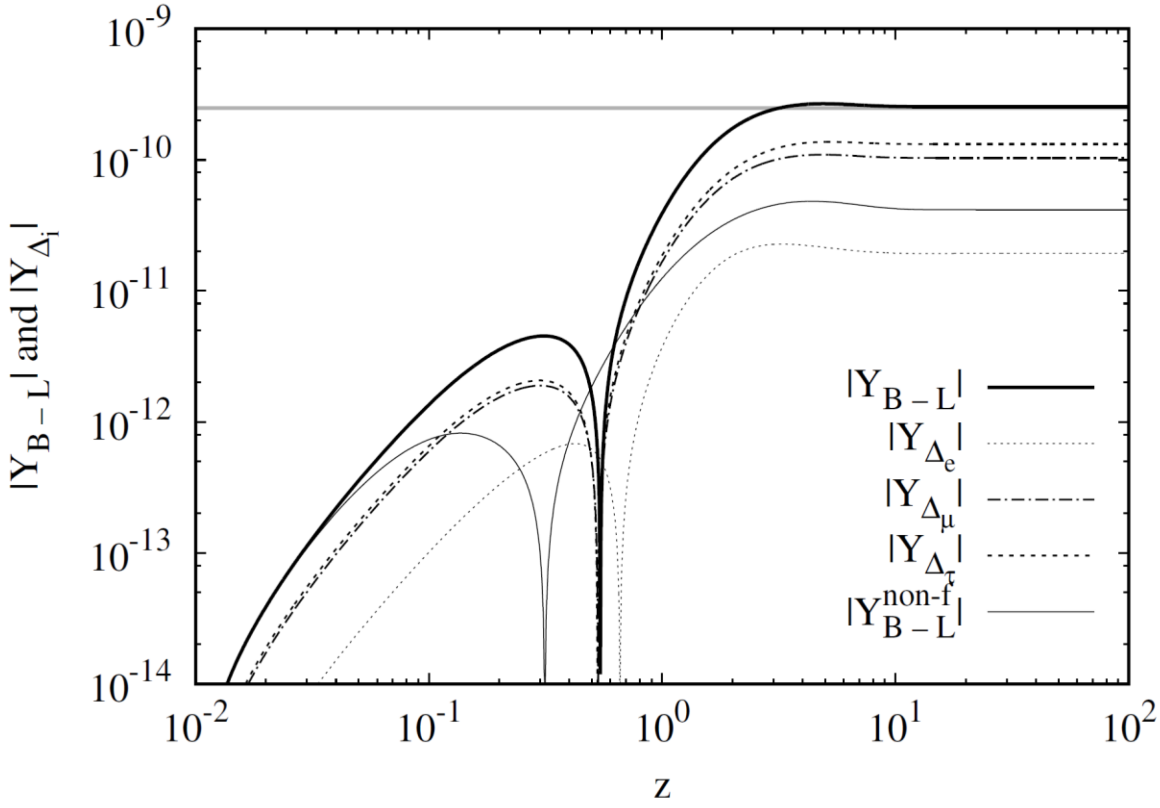
- Flavored CP asymmetry

$$\frac{dY_{\Delta_i}}{dz} = -\frac{z}{sH(z=1)}\left\{\left(\frac{Y_{N_1}}{Y_{N_1}^{eq}}-1\right)\epsilon_{1i}\gamma_D + K_i^0\sum_j\left[\frac{1}{2}\left(C_{ij}^l + C_j^H\right)\gamma_D\right.\right.$$
$$\left.\left. + \left(\frac{Y_{N_1}}{Y_{N_1}^{eq}}-1\right)\left(C_{ij}^l\gamma_{S_s} + \frac{C_j^H}{2}\gamma_{S_t}\right) + \left(2C_{ij}^l + C_j^H\right)\left(\gamma_{S_t} + \frac{\gamma_{S_s}}{2}\right)\right]\frac{Y_{\Delta_i}}{Y_l^{eq}}\right\}$$

Each component of neutrino Yukawa strongly affects the final baryon asymmetry

Numerical analysis

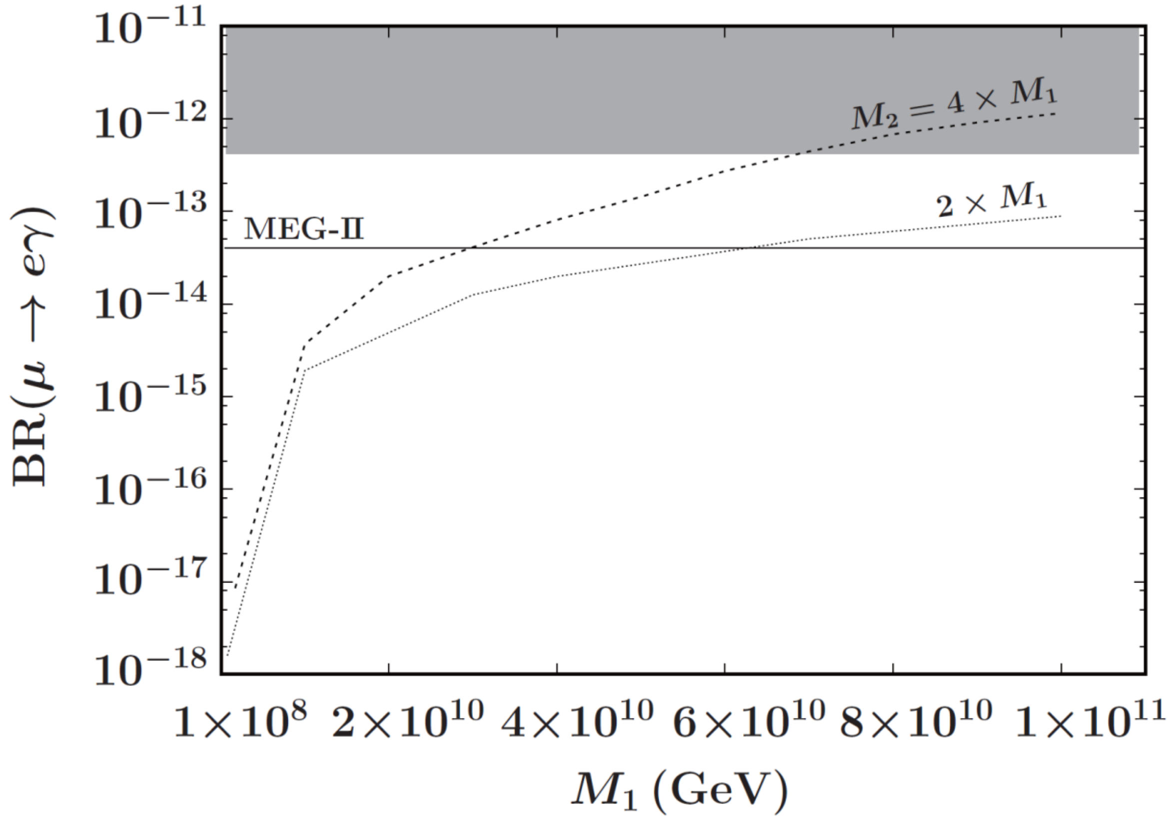
Baryon asymmetry



Successfully observed baryon asymmetry is generated in the scenario

- Flavor effect largely enhances the baryon asymmetry
- Important to include the effect to correctly determine $(y_\nu)_{\alpha i}$

BR($\mu \to e\gamma$) vs M_1



Upper bound on M_1 from BBN: $M_1 \sim 1 \times 10^{11}$ [GeV]

Lower bound on M_1 from leptogenesis: $M_1 \sim 5 \times 10^{8}$ [GeV]

- Most of region can be tested at next (next-next) generation experiments
- BR(tau CLFV decay) $< 10^{-14}$, we need much much higher intensity

Summary

Summary

New physics candidate: CMSSM

- Gauge unification
- Hierarchy problem
- etc.

$\tilde{\ell}$-$\tilde{\chi}$ coannihilation

- DM abundance

$\delta m < m_\tau$

- Li7 (Li6) problem
- Higgs mass
- muon g-2

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Flavored SUSY leptogenesis sets lower bound on M_1, and BBN sets the upper one

→ a unique prediction for CLFV

Seesaw mechanism

- baryon asymmetry
- neutrino mass

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CMSSM coannihilation scenario with seesaw mechanism can describe our universe!

Backup slides