Theory Group

M. Kawasaki

Theory Group

- Faculty: Masahiro Kawsaki (2004~) cosmology

  Junji Hisano (2002~) particle physics

- Working in wide fields of phenomenology-oriented particle physics, astro/cosmoparticle physics and cosmology including
  - flavor physics in SUSY
  - SUSY dark matter
  - inflation
  - Baryogenesis
  - Big Bang Nucleosynthesis
  - Cosmological constraints on Neutrino Property
  - …

Hadronic Decay of Gravitino

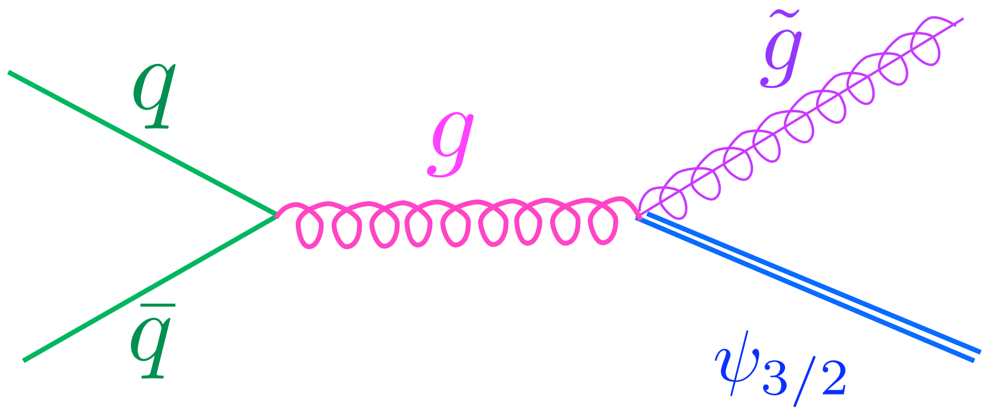
- Gravitino = Superpartner of graviton in SUSY theories

  $\psi_{3/2}$

- In inflationary Universe gravitinos are produced during reheating after inflation

e.g.

$$\bar{q} + q \;\rightarrow\; \psi_{3/2} + \tilde{g}$$

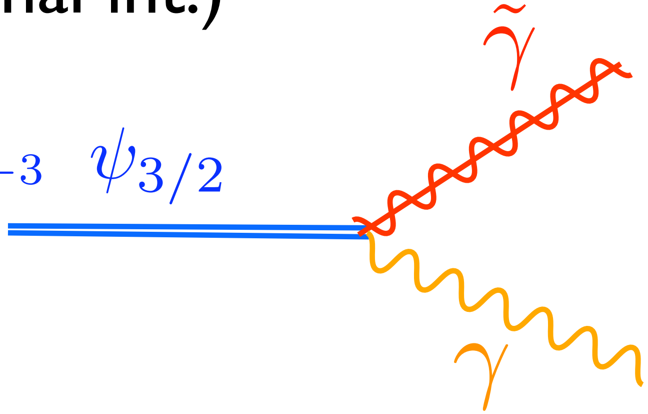


$$Y_{3/2} \equiv \frac{n_{3/2}}{n_\gamma} \simeq 10^{-11} \left(\frac{T_R}{10^{10}\mathrm{GeV}} \right)$$

T_R : Reheating Temperature

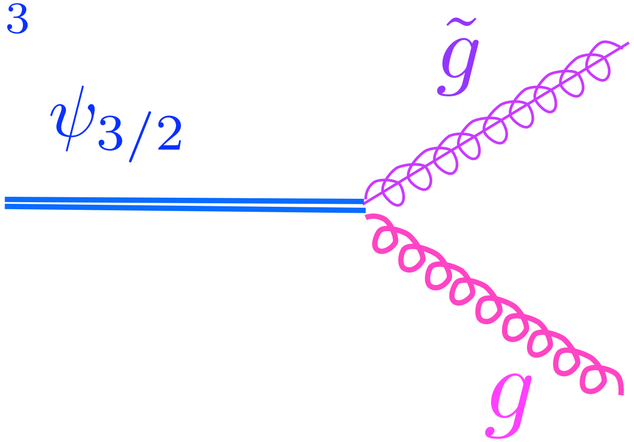
- Gravitino mass $m_{3/2} \sim O(100)\text{GeV} - O(1)\text{TeV}$
- Lifetime (decay only through gravitational int.)
  - Radiative Decay

$$\tau(\psi_{3/2} \to \tilde{\gamma} + \gamma) \simeq 4 \times 10^8 \sec \left(\frac{m_{3/2}}{100\text{GeV}} \right)^{-3}$$



  - Hadronic Decay

$$\tau(\psi_{3/2} \to \tilde{g} + g) \simeq 6 \times 10^7 \sec \left(\frac{m_{3/2}}{100\text{GeV}} \right)^{-3}$$



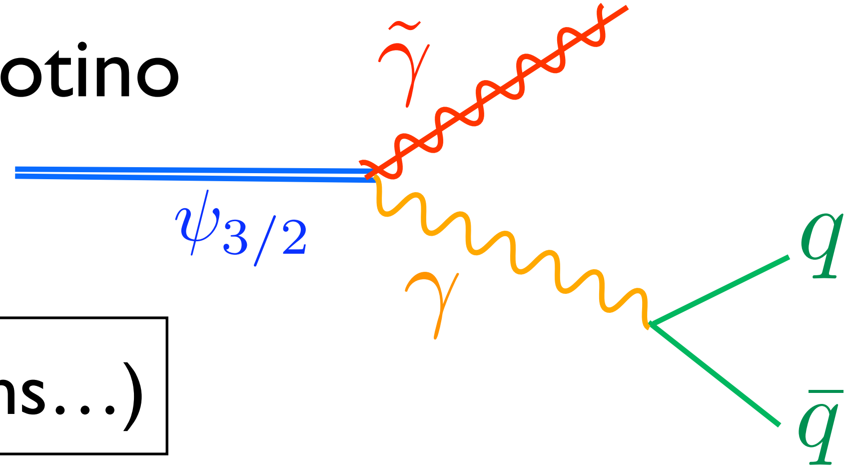
- Decay after BBN

⇨ Effects on Light Elements

In particular, hadronic decay gives stringent constraint

Even if gravitino decay into photino

hadronic branch ~ 10^{-3}



Decay → hadrons (p,n, pions…)

hadronization

↓

hadron shower

↓

hadro-dissociation

↓

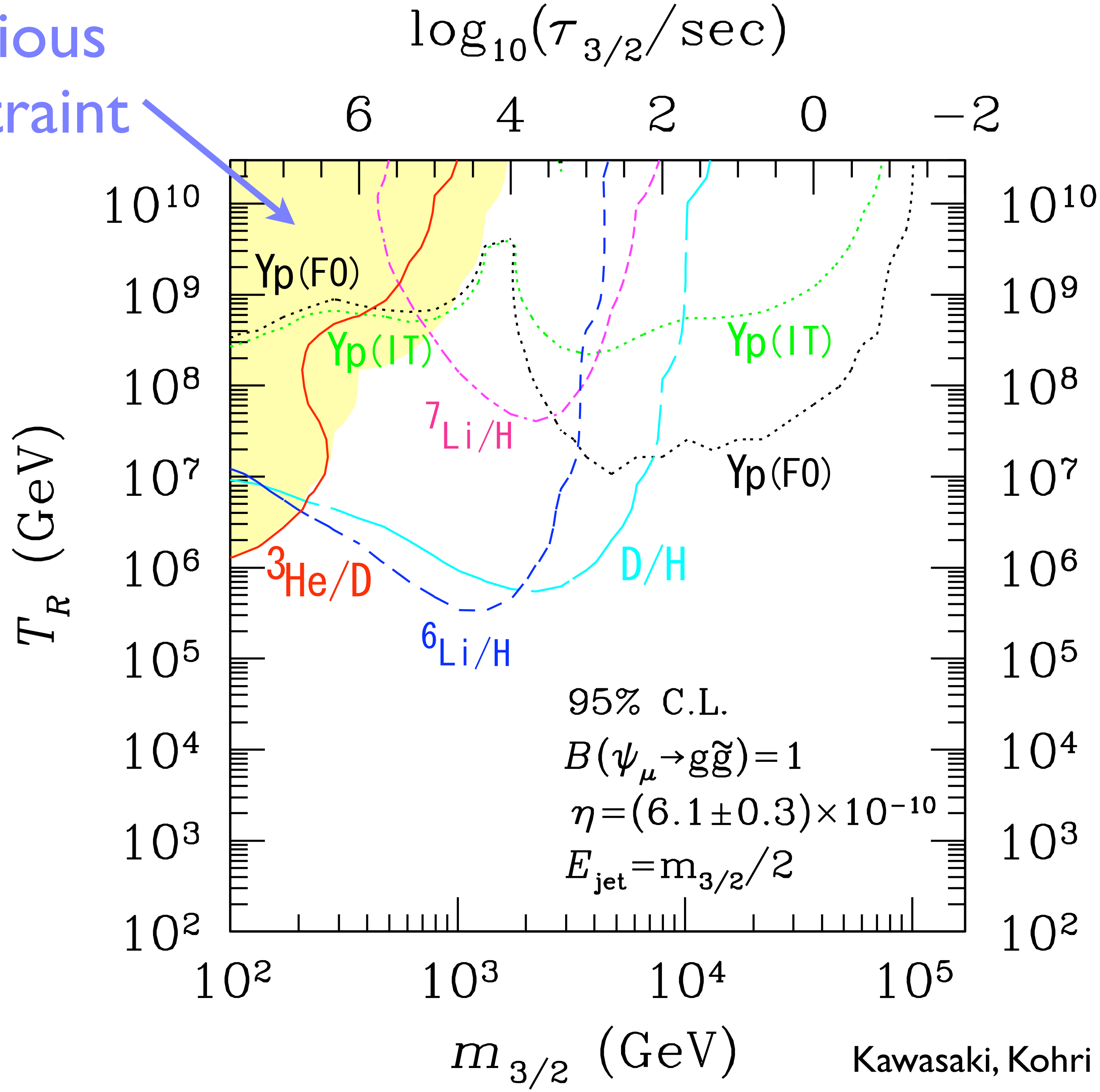
D, He3, Li7 destruction

He4 destruction → D, He3, Li7,Li6 production

Compare theoretical and observational abundances of light elements → constraint on $n_{3/2}$ and T_R

$Y_{3/2} \propto T_R$

previous constraint



Kawasaki, Kohri Moroi (2004)

Hadronic decay gives the most stringent constraint

Limit on Neutrino Mass from WMAP

Tritium beta decay experiments: $m_{\nu_e} < 3 \text{ eV}$

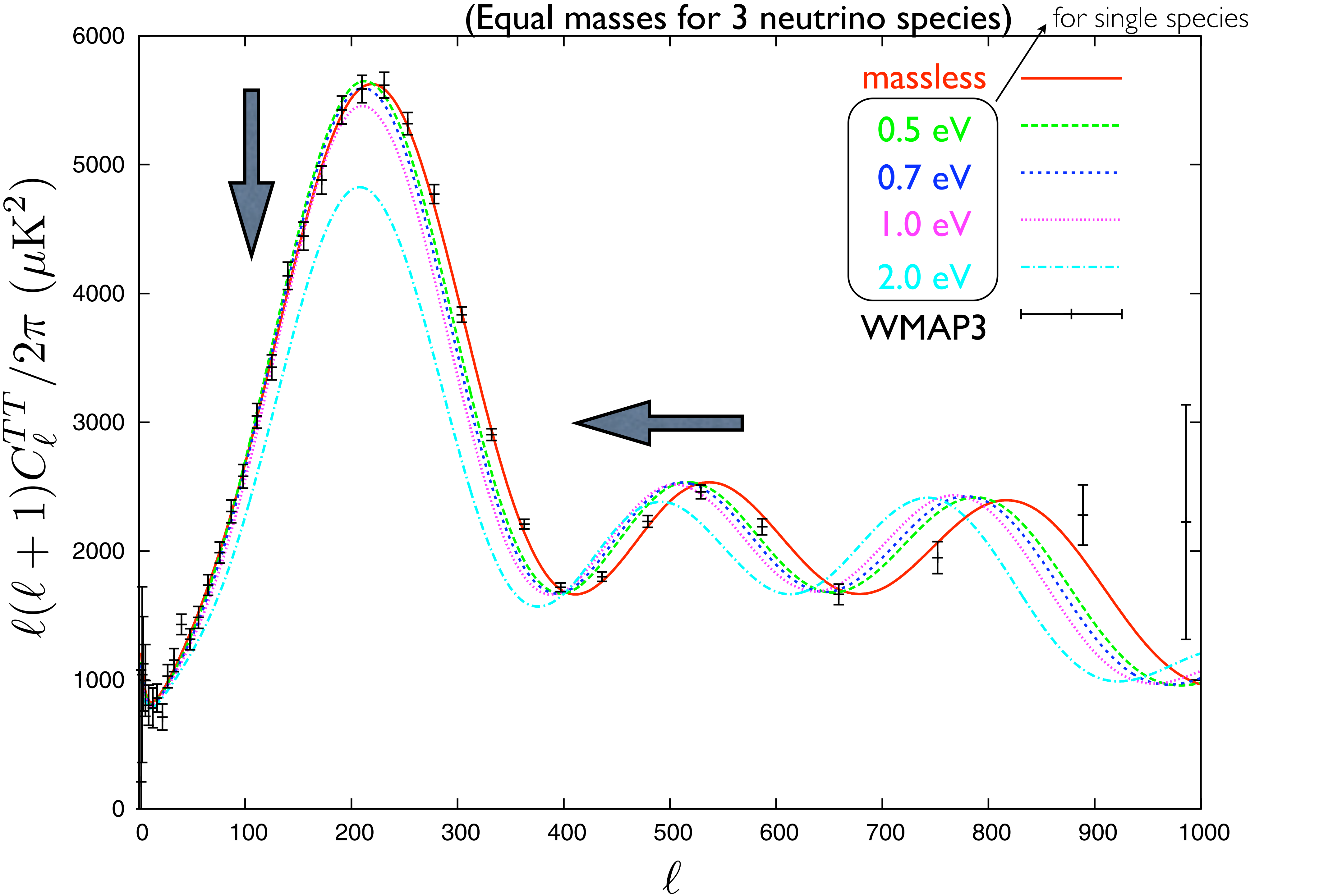
Cosmological bounds:

Spergel et al. [WMAP collaboration]	WMAP1 +2dFGRS	$m_\nu < 0.2 \text{ eV}$
Tegmark et al. [SDSS collaboration]	WMAP1 +SDSS (main sample)	$m_\nu < 0.6 \text{ eV}$ (3.8 eV for WMAP only)

It was thought that no stringent limit on neutrino mass is obtained from CMB experiment alone

Effect of neutrino masses on CMB power spectrum

(Equal masses for 3 neutrino species)

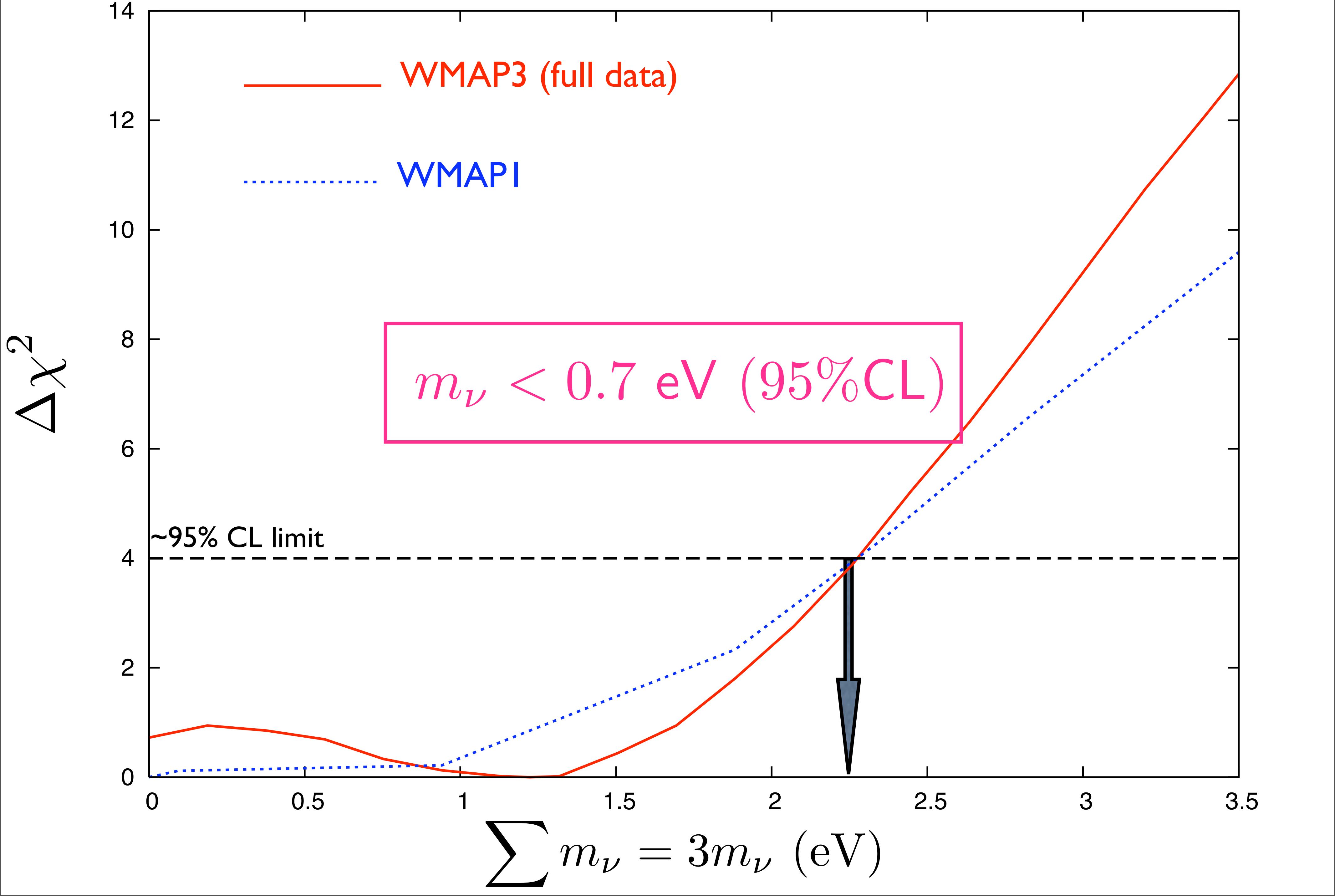


χ^2 analysis

(We marginalized over 6 other LCDM cosmological parameters)

Ichikawa, Fukugita. Kawasaki,(2005)

Fukugita, Ichikawa, Kawasaki, Lahav (2006)



Primordial abundance of He4

- Primordial He4 abundance is inferred by observation of extra-galactic HII regions
- Previous estimations

$$Y_p \equiv \frac{\rho_{^4\text{He}}}{\rho_{\text{tot}}}$$

$$Y_p = 0.238 \pm 0.002 \pm 0.005$$ Fields, Olive (1998)

$$Y_p = 0.242 \pm 0.002$$ Izotov, Thuan (2003)

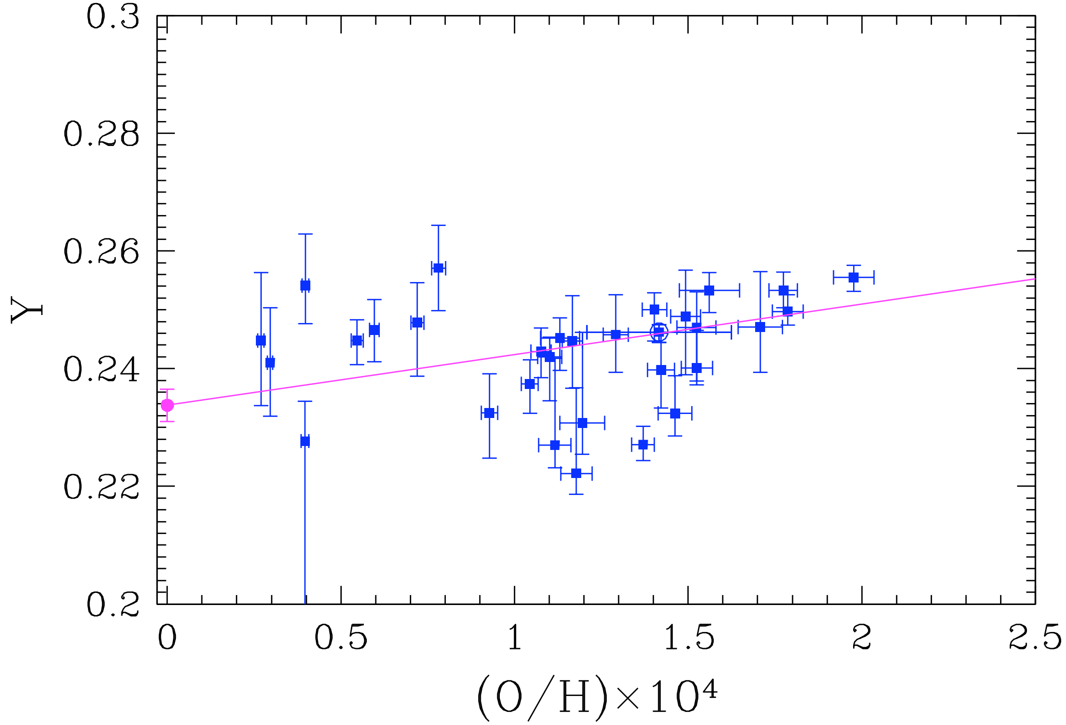
- From WMAP observation

$$Y_p = 0.24815 \pm 0.00068$$

inconsistent?

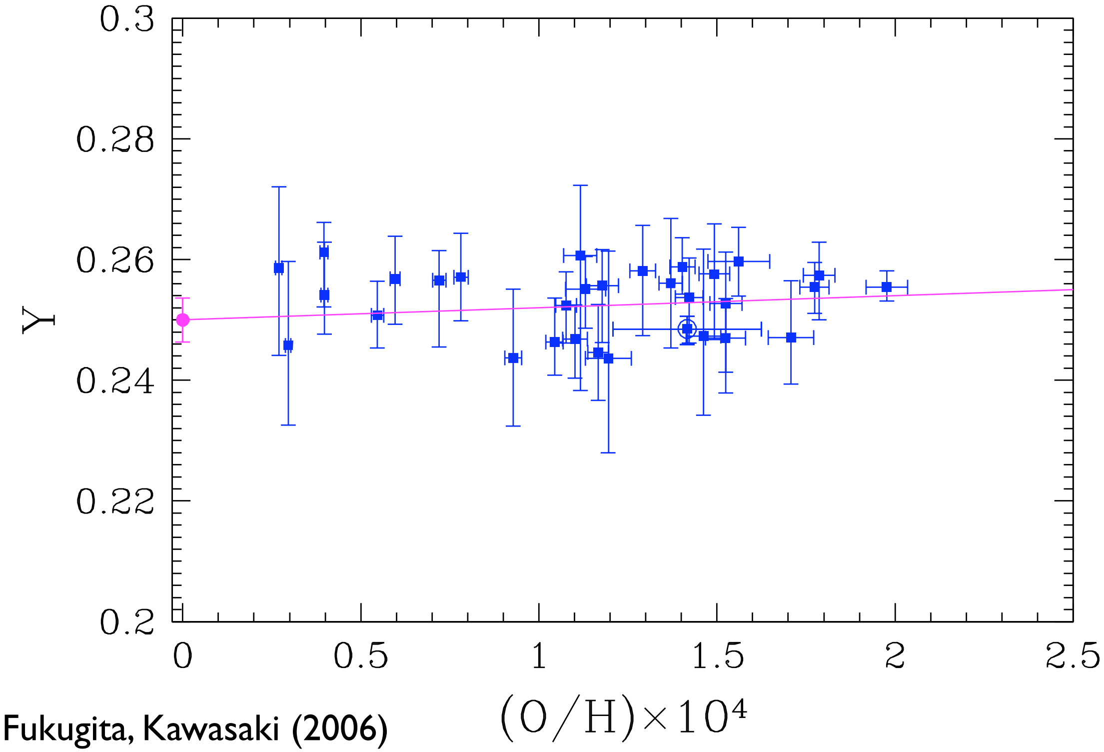
⇨ Re-analysis of Izotov-Thuan (2004) data ⇨ Stellar absorption of He lines is important

31 HII regions



without absorption

$Y_p = 0.234 \pm 0.004$



with absorption

$Y_p = 0.250 \pm 0.004$

consistent with WMAP

$Y_p = 0.24815 \pm 0.00068$

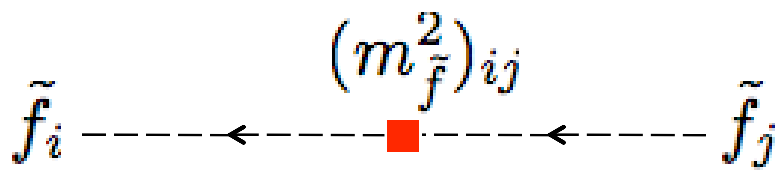
Fukugita, Kawasaki (2006)

Flavor physics in SUSY models

Supersymmetric Standard Model (SUSY SM)

~~SUSY~~ mass terms of SUSY particles:new source of flavor violation (FV)

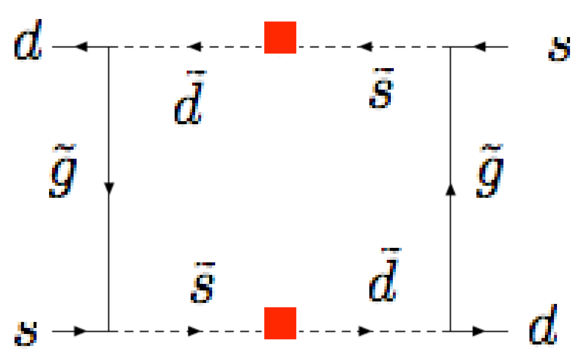
$$\left[m^2_{\tilde{f}}, m^\dagger_f m_f\right] \neq 0 \quad (f = u, d, \nu, e)$$



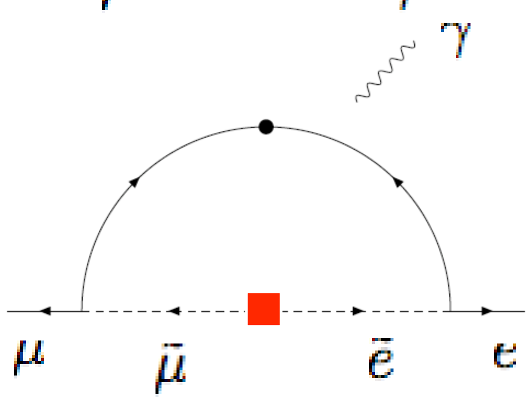
$(i, j = 1, 2, 3)$

Flavor-changing neutral current (FCNC) processes are predicted.

$K^0 - \overline{K}^0$ mixing



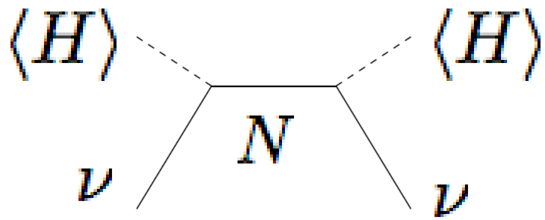
$\mu^+ \to e^+\gamma$



FCNC processes probes models beyond SUSY SM

- Seesaw mechanism

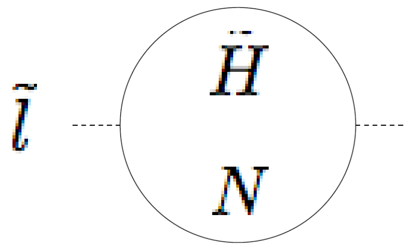
Right-handed neutrinos generate light neutrino masses.



$$\Rightarrow \quad m_\nu = \frac{(f_\nu \langle H \rangle)^2}{M_N}$$

- SUSY seesaw model

Neutrino Yukawa coupling generates FV in scalar lepton mass terms.

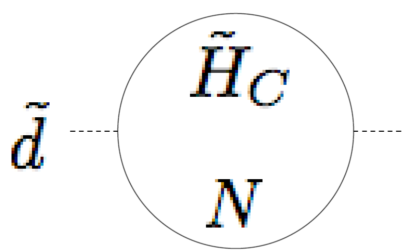


$$\Rightarrow \quad (m^2_{\tilde{l}})_{ij} \simeq \frac{(f^\star_\nu f^T_\nu)_{ij}}{(4\pi)^2}(3m_0^2 + A_0^2) \log \frac{M_N^2}{M^2_{\rm planck}}$$

Lepton-flavor violating processes, such as $\mu^+ \to e^+\gamma$ are predicted.

- SUSY GUT with right-handed neutrinos

Neutrino Yukawa coupling generates FV in scalar quark mass terms, too.



$$\Rightarrow \quad (m^2_{\tilde{d}})_{ij} \simeq \frac{(f^\star_\nu f^T_\nu)_{ij}}{(4\pi)^2}(3m_0^2 + A_0^2) \log \frac{M_{GUT}^2}{M^2_{\rm planck}}$$

Bottom-strange quark transition $\Leftarrow$ atmospheric neutrino results

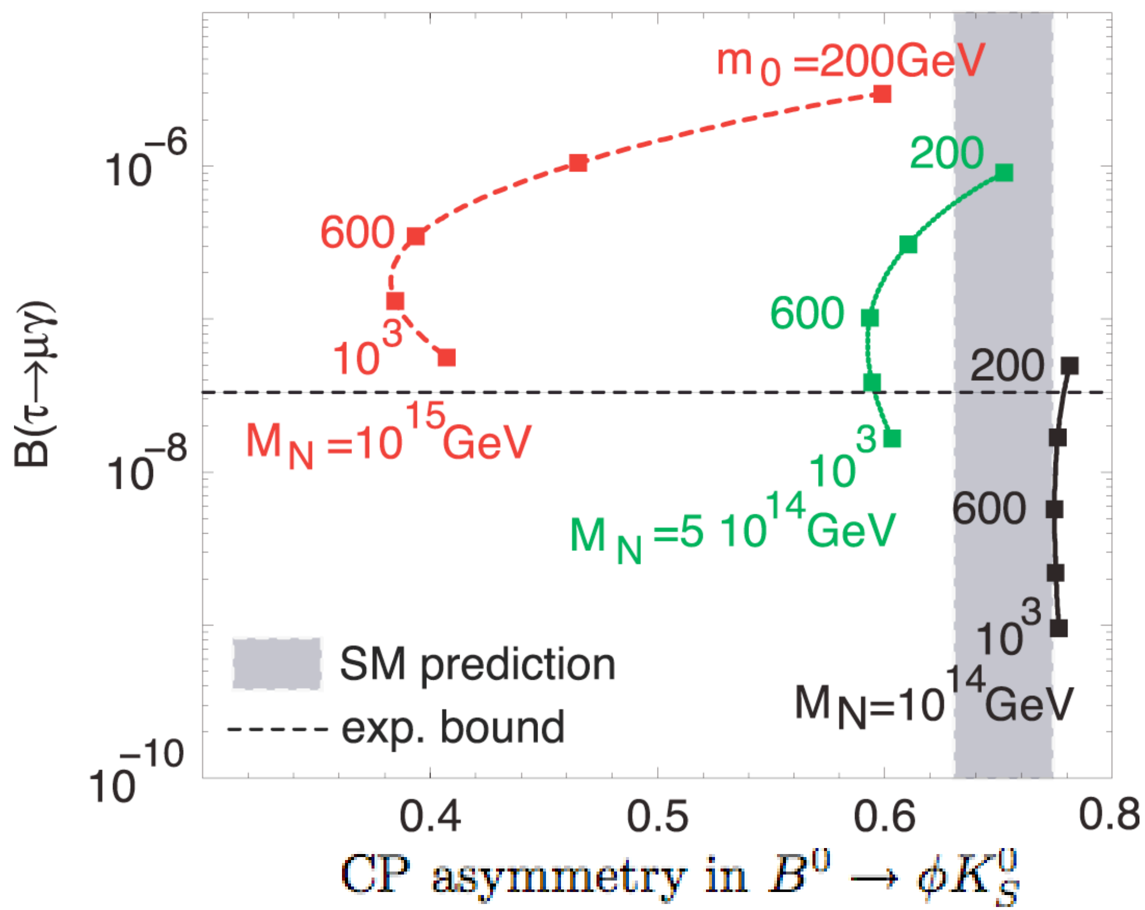
GUT relation between hadronic and leptonic flavor violation

Flavor violations in scalar quark and lepton mass terms are related.

$$(m^2_{\tilde{l}})^{\star}_{32} \simeq (m^2_{\tilde{d}})_{23} e^{i\phi_{23}}$$

CP asymmetries in $b \longrightarrow s\bar{s}s$ modes are well correlated with $Br(\tau \rightarrow \mu\gamma)$.

Rare tau decay bound gives a constraint on large deviation of CP asymmetries in the model.



Hisano, Shimizu (2004)

Dark matter detection

Weakly-interacting massive particles (WIMPs) are candidates for the dark matter in the universe.
In the supersymmetric standard model (SUSY SM) neutralino is the DM candidate.

$$\tilde{\chi}^0 = c_{\tilde{B}^0}\tilde{B}^0 + c_{\tilde{W}^0}\tilde{W}^0 + c_{\tilde{H}_1^0}\tilde{H}_1^0 + c_{\tilde{H}_2^0}\tilde{H}_2^0$$

$$(\tilde{B}^0 \text{ bino}, \tilde{W}^0 \text{ wino, and } \tilde{H}_1^0\ \tilde{H}_2^0 \text{ Higgsinos})$$

Detection methods for the neutralino dark matter are

- direct detection on the earth

$$\tilde{\chi}^0 N \to \tilde{\chi}^0 N$$

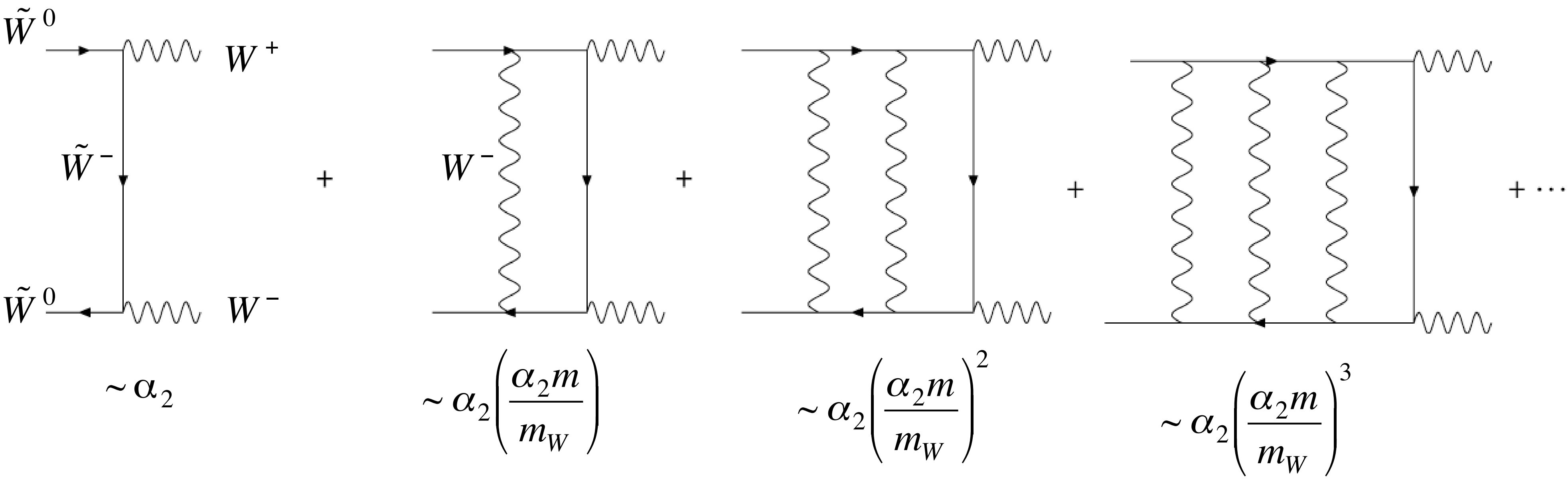
- indirect detection in cosmic rays

$$\tilde{\chi}^0 \tilde{\chi}^0 \to \gamma,\ e^+,\ \bar{p},\ \nu$$

We studied quantum corrections to annihilation processes for Wino-like and Higgsino-like neutralino DMs.

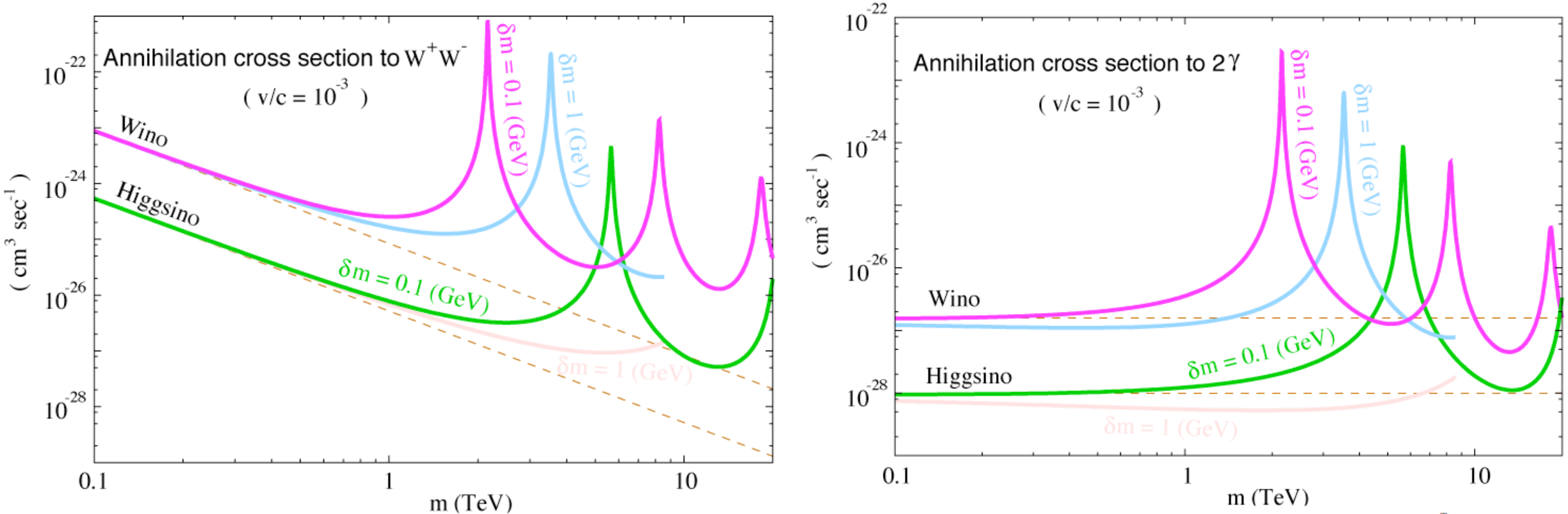
Perturbation is broken in annihilation cross section in $m \gtrsim m_W/\alpha_2$ in a non-relativistic limit due to the threshold singularity.

Amplitude for Wino-like neutralino annihilation to 2 W bosons.



Weak interaction is a long-distance force for them. We need to include non-perturbative effect by evaluating wave functions.

Annihilation cross sections to two gammas and W pair.



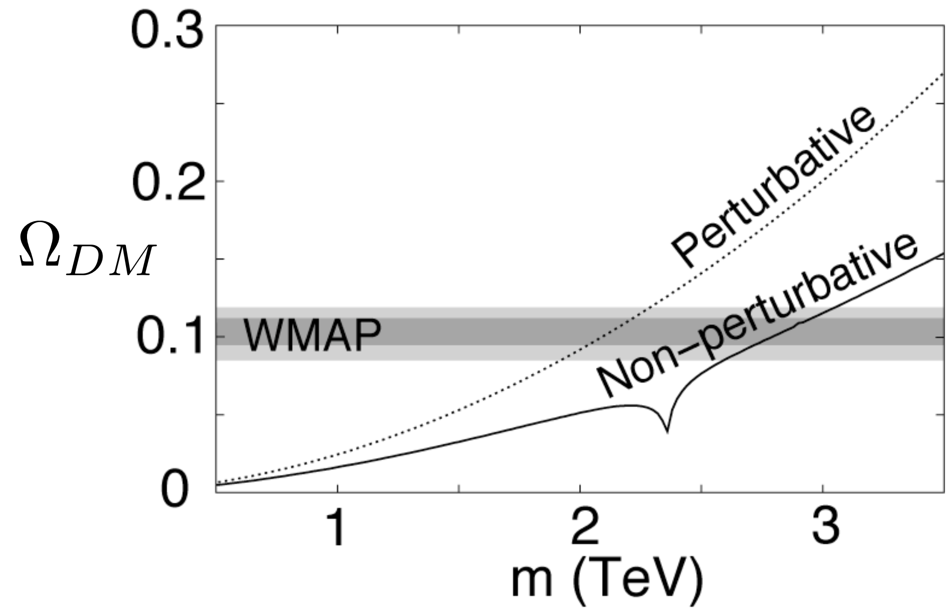
δm :mass difference of $\tilde{\chi}^0$ and $\tilde{\chi}^-$

Hisano, Matsumoto, Nojiri (2004)

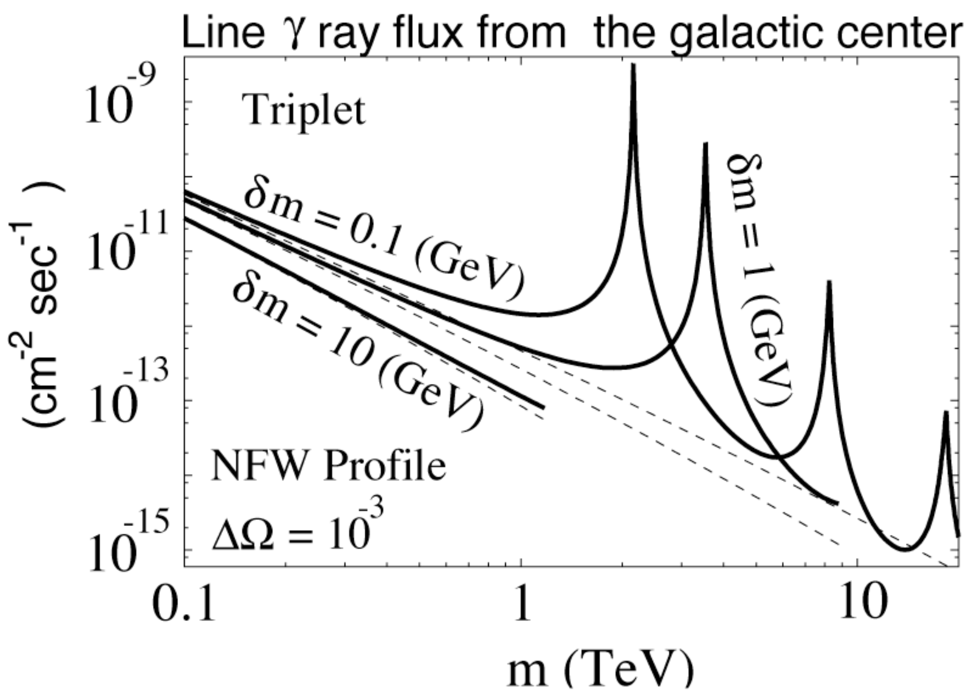
- Cross sections are enhanced significantly around 2(7) TeV for Wino-like (Higgsino-like) due to resonance. A bound state with binding energy close to zero appears.
- Two-gamma process is at one-loop level in perturbation. However, the cross section is not suppressed for m>~TeV, compared with W pair.

Implication to wino-like neuralino DM

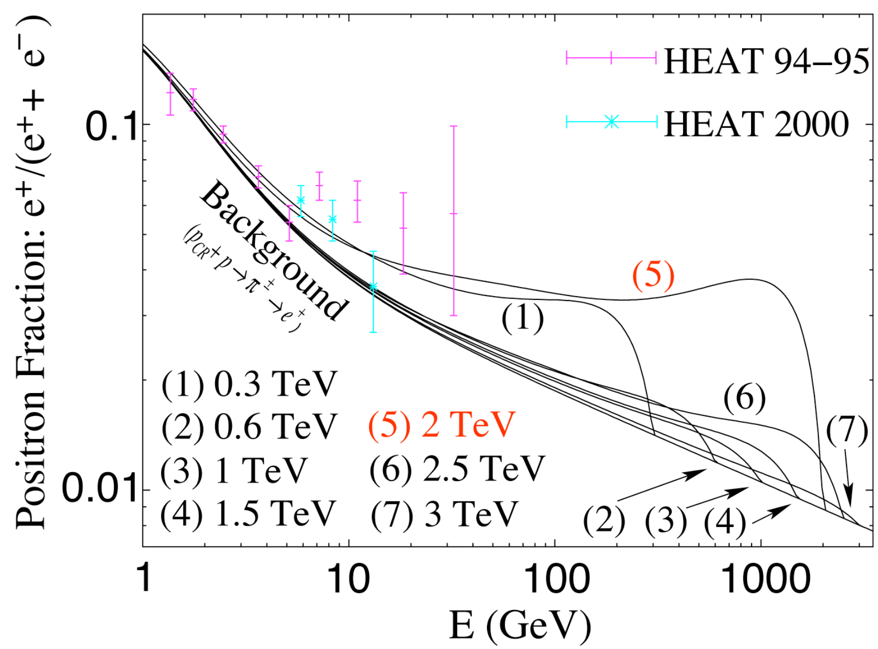
- Thermal relic abundance
- Line gamma rays from Galactic center
- Positron flux from Galactic halo



Detectability is enhanced.



Hisano, Matsumoto, Nojiri, Saito (2005)



Hisano, Matsumoto, Nojiri, Saito, Senami (2006)

Conclusion

- We believe that Theory Group has kept high activity and given significant contribution to particle physics, cosmology and astrophysics