Neutralino pair annihilations with supersymmetric CP violation

T. Nihei (Nihon Univ.)

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1. Introduction

Relic density

Recent cosmological observations have convinced us that Our Universe $\approx$ Dark Energy $+$ CDM.

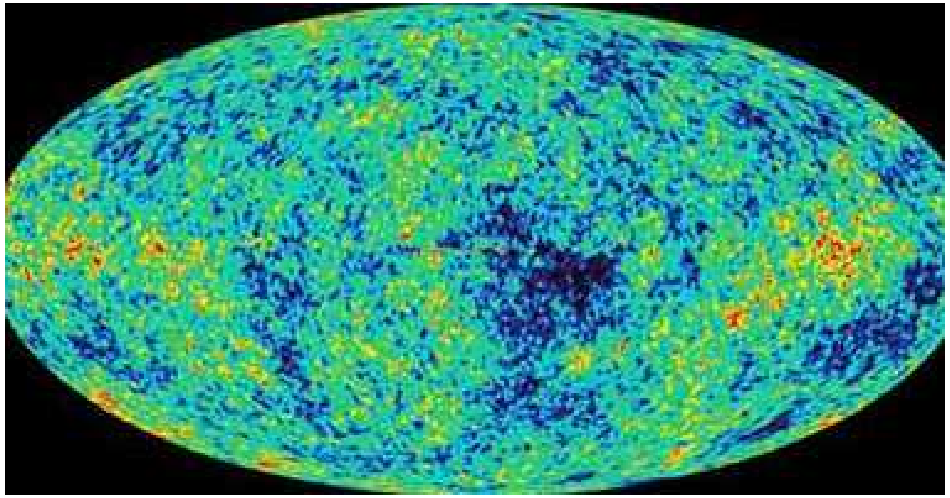
WMAP (2001–, NASA)

$$\Omega_\chi h^2 = 0.1126^{+0.008}_{-0.009}$$

(χ: CDM)

$$\Omega_\chi \equiv \rho_\chi / \rho_c$$

$h \approx 0.7$ ($H_0 = 100\,h$ km/s/Mpc)



SUSY naturally accommodates a candidate for CDM.

Effect of supersymmetric CP violation on DM observables

2. Minimal SUSY SM with CP violation

- Relevant parameters

M_1, M_2	–	gaugino mass
μ	–	higgsino mass
m_0	–	sfermion mass for the 3rd generation
		(10 TeV for the first two gen. to suppress EDM)
A	–	scalar trilinear coupling for the 3rd gen.
$\tan\beta$	–	ratio of higgs vevs
m_A	–	pseudoscalar higgs mass

- CP violating phases

$$\mu = |\mu| \exp(i\,\theta_\mu), \quad A = A_0 \exp(i\,\theta_A)$$

- GUT relation for gaugino masses

$$M_1 = \frac{5}{3} \tan^2\theta_W M_2 \quad (M_i : \text{real})$$

- Scalar–pseudoscalar mixing   Pilaftsis (1998)

  Im($A\,\mu$) induces S–PS mixing at one-loop level.

$$\begin{pmatrix} H_1^0 \\ H_2^0 \\ H_3^0 \end{pmatrix} = O_H \begin{pmatrix} \phi_1 \\ \phi_2 \\ A \end{pmatrix}$$

  For $\theta_\mu = \theta_A = 0, \;\; H_1^0 = H, \;\; H_2^0 = h, \;\; H_3^0 = A$

- Neutralino DM

$$\chi = N_{11}\widetilde{B} + N_{12}\widetilde{W}^3 + N_{13}\widetilde{H}_1^0 + N_{14}\widetilde{H}_2^0$$

  $M_1 \ll |\mu| \rightarrow \widetilde{B}$-like LSP

  $M_1 \approx |\mu| \rightarrow$ Mixed LSP

  $M_1 \gg |\mu| \rightarrow \widetilde{H}$-like LSP

3. Neutralino pair annihilations

- Relic density

  Boltzmann equation

  $$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle \sigma v \rangle (n_\chi^2 - n_\chi^{eq2})$$

- Indirect detection

  Positron flux from χ pair annihilation in the halo

  Most important process
  $\chi\chi \to W^+W^-$ followed by $W^+ \to e^+\nu_e$

  $$\frac{dF(e^+)}{dE} = \frac{\rho_0^2}{m_\chi^2} \int d\epsilon\, G(E,\epsilon) \sum_i \langle \sigma_i v \rangle f_i(\epsilon)$$

  Local halo DM density $\rho_0 = 0.43$ GeV/cc
  Containment time $\tau = 10^7$ yr

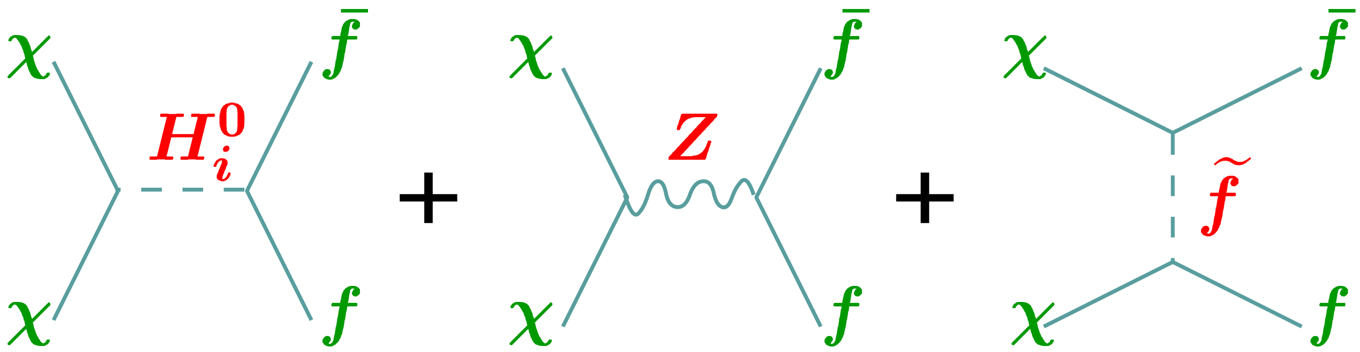
  Galactic Halo: $v \approx 10^{-3}$

Kamionkowski–Turner (1991)

Cross sections

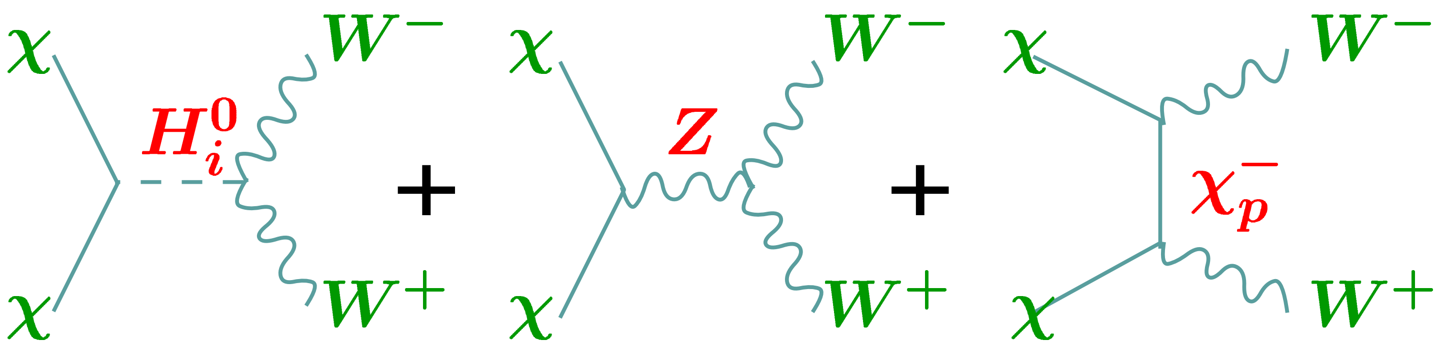
	Process	s-channel	t & u-channel
$\widetilde{B}$-like	$\chi\chi \to f\bar{f}$	H_i^0, Z	$\tilde{f}_{1-6}$
	$\chi\chi \to H_i^0 H_j^0$	H_k^0, Z	χ_{1-4}^0
	H^+H^-	H_i^0, Z	$\chi_{1,2}^\pm$
$\widetilde{H}$-like	$\chi\chi \to W^+W^-$	H_i^0, Z	$\chi_{1,2}^\pm$
	ZZ	H_i^0	χ_{1-4}^0
	$\chi\chi \to ZH_i^0$	H_j^0, Z	χ_{1-4}^0
	$W^\pm H^\mp$	H_i^0	$\chi_{1,2}^\pm$

$$\chi\chi \to f\bar{f}$$



- Typically dominant for $\tilde{B}$-like LSP
- S-wave suppression for $v \ll 1$ $(\sigma v \sim m_f^2/m_\chi^2)$

$\chi\chi \to W^+W^-$



- Open for $m_\chi > m_W$
- Typically dominant for $\widetilde{H}$-like LSP
- No s-wave suppression

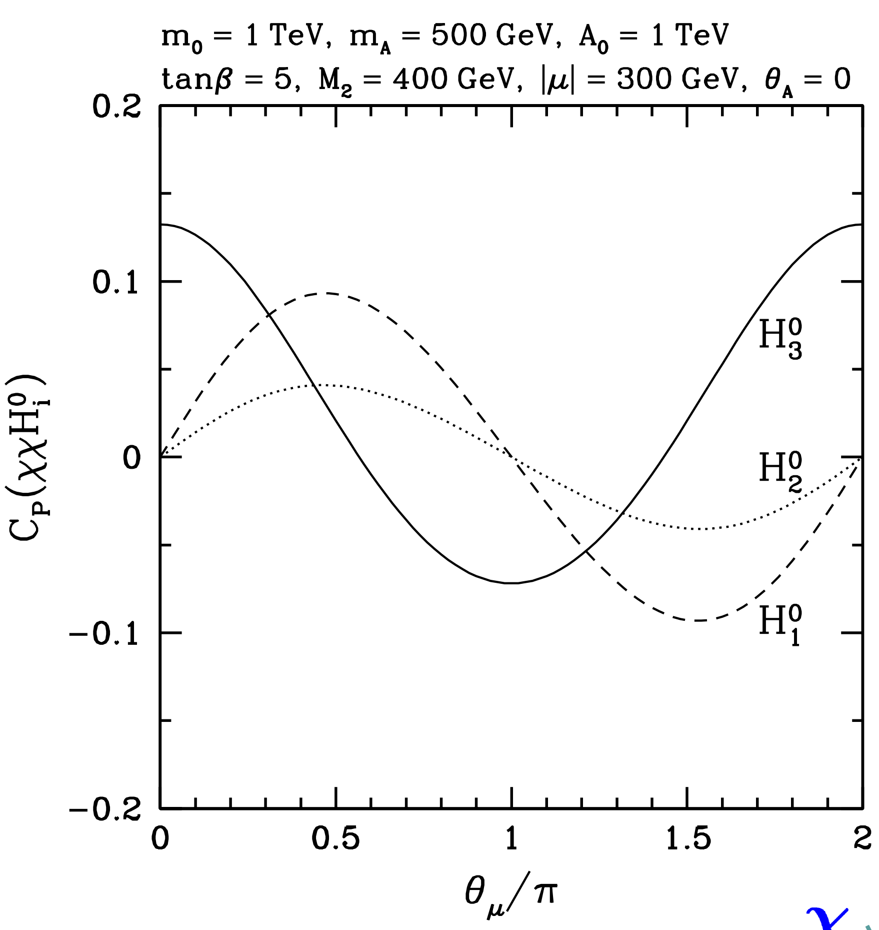
$\chi\chi H^0$ interaction

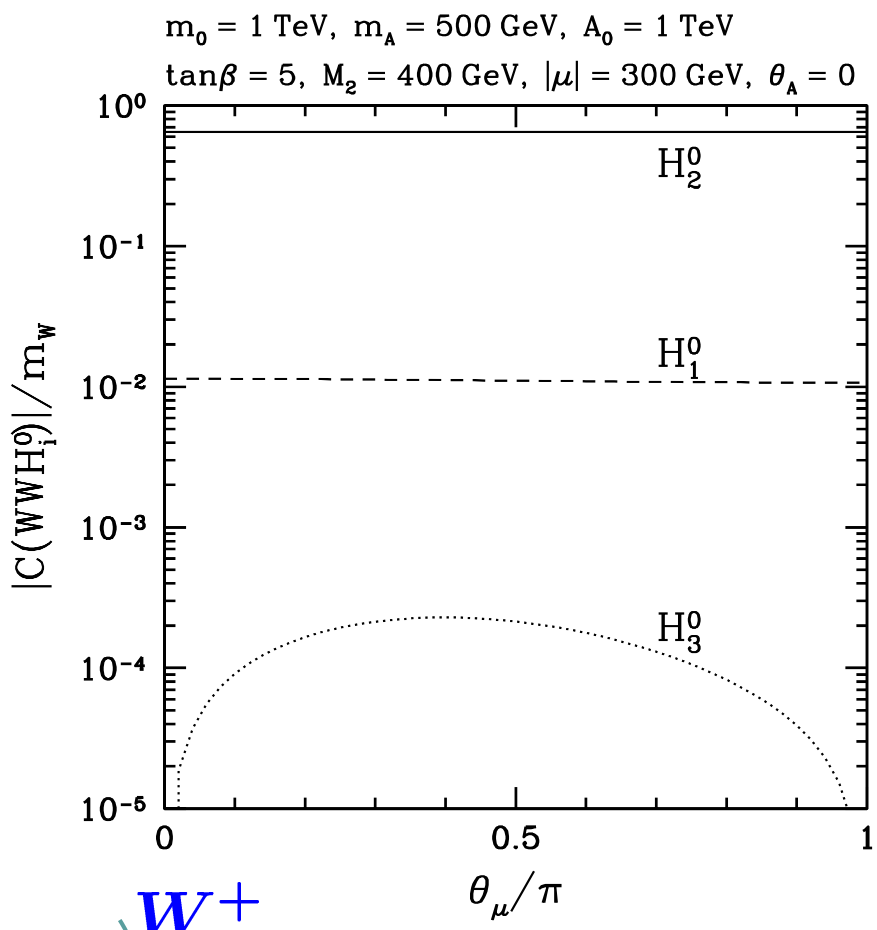
$$\mathcal{L} = \sum_{i=1}^{3} \bar{\chi} \left(C_S^{\chi\chi H_i^0} + C_P^{\chi\chi H_i^0} \gamma_5 \right) \chi H_i^0$$

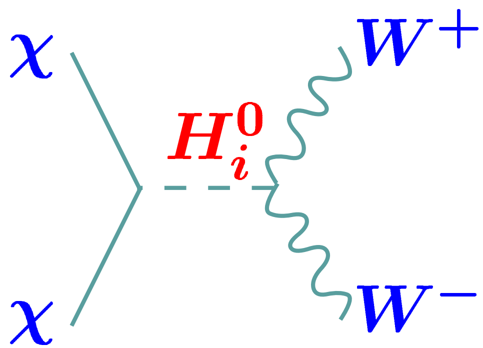
H_i^0 exchange contribution to $\chi\chi \to WW$

$$\sigma v = \frac{1}{32\pi m_\chi^2}\left[(s-4m_\chi^2)\left|\sum_{r=H_i^0}\frac{C^{WWr}\,C_S^{\chi\chi r}}{s-m_r^2+i\,\Gamma_r\,m_r}\right|^2 + s\left|\sum_{r=H_i^0}\frac{C^{WWr}\,C_P^{\chi\chi r}}{s-m_r^2+i\,\Gamma_r\,m_r}\right|^2\right]\frac{s^2-4m_W^2 s+12m_W^4}{8m_W^4}$$

Relevant couplings for H_i^0 exchange







4. Numerical results

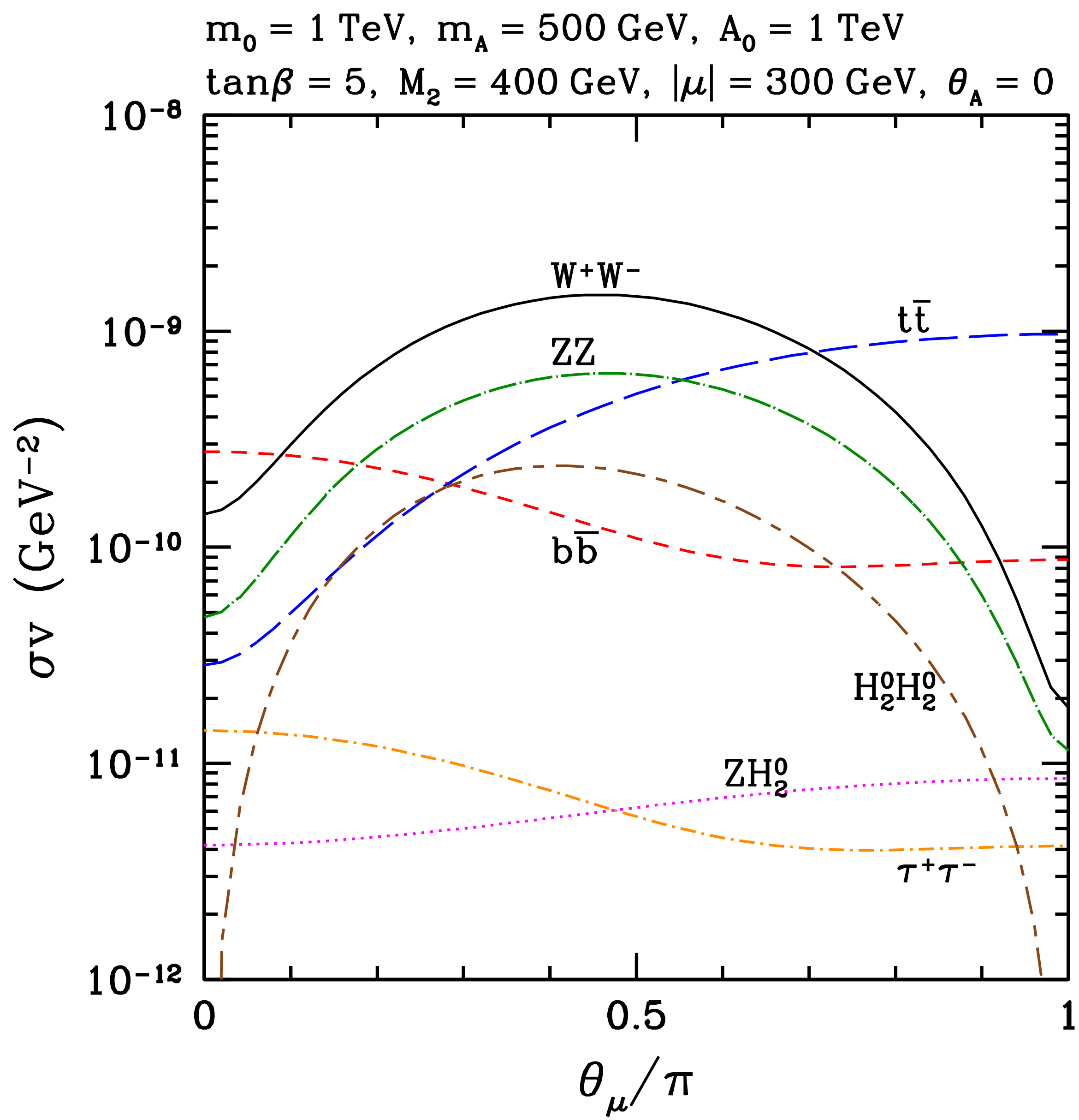
Parameters

$m_0 = A_0 = 1$ TeV
$m_A = 500$ GeV, $\tan\beta = 5$

$\theta_\mu = 0 - \pi$
$\theta_A = 0 - \pi$
$M_2 = 100 - 700$ GeV
$|\mu| = 100 - 700$ GeV

$\longrightarrow \sigma v$ at $v = 10^{-3}$
relic density ($\Omega_\chi h^2$)
positron fraction ($e^+/(e^+ + e^-)$)

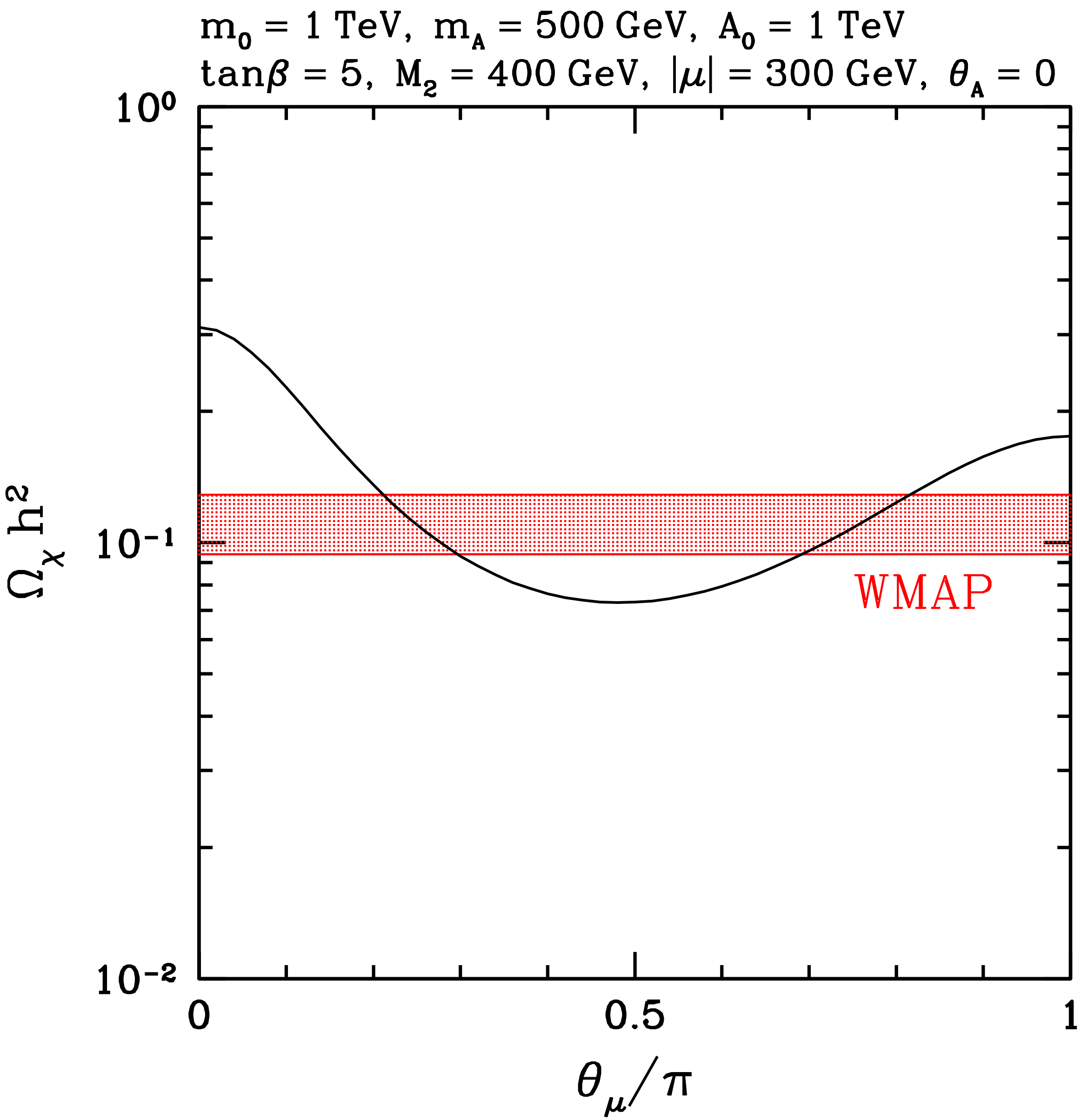
σv at $v = 10^{-3}$



WW is significantly enhanced due to lightest higgs exchange for $\mathbf{Im}(\mu) \neq 0$.
($\widetilde{B}$-like or mixed LSP)

$$|N_{11}| \approx 0.9$$
$$|N_{12}| \approx 0.01$$
$$|N_{13}| \approx |N_{14}| \approx 0.05$$

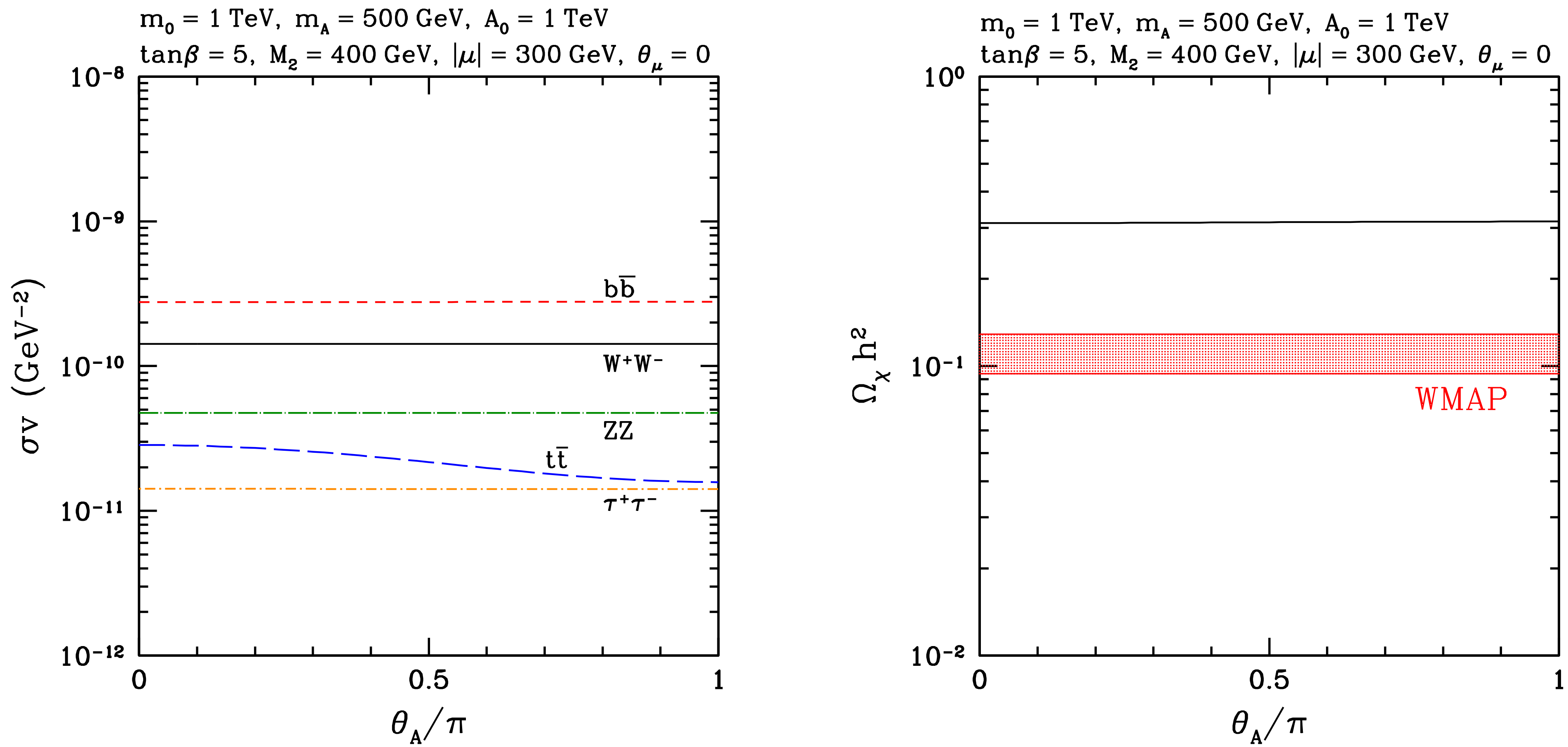
Relic density



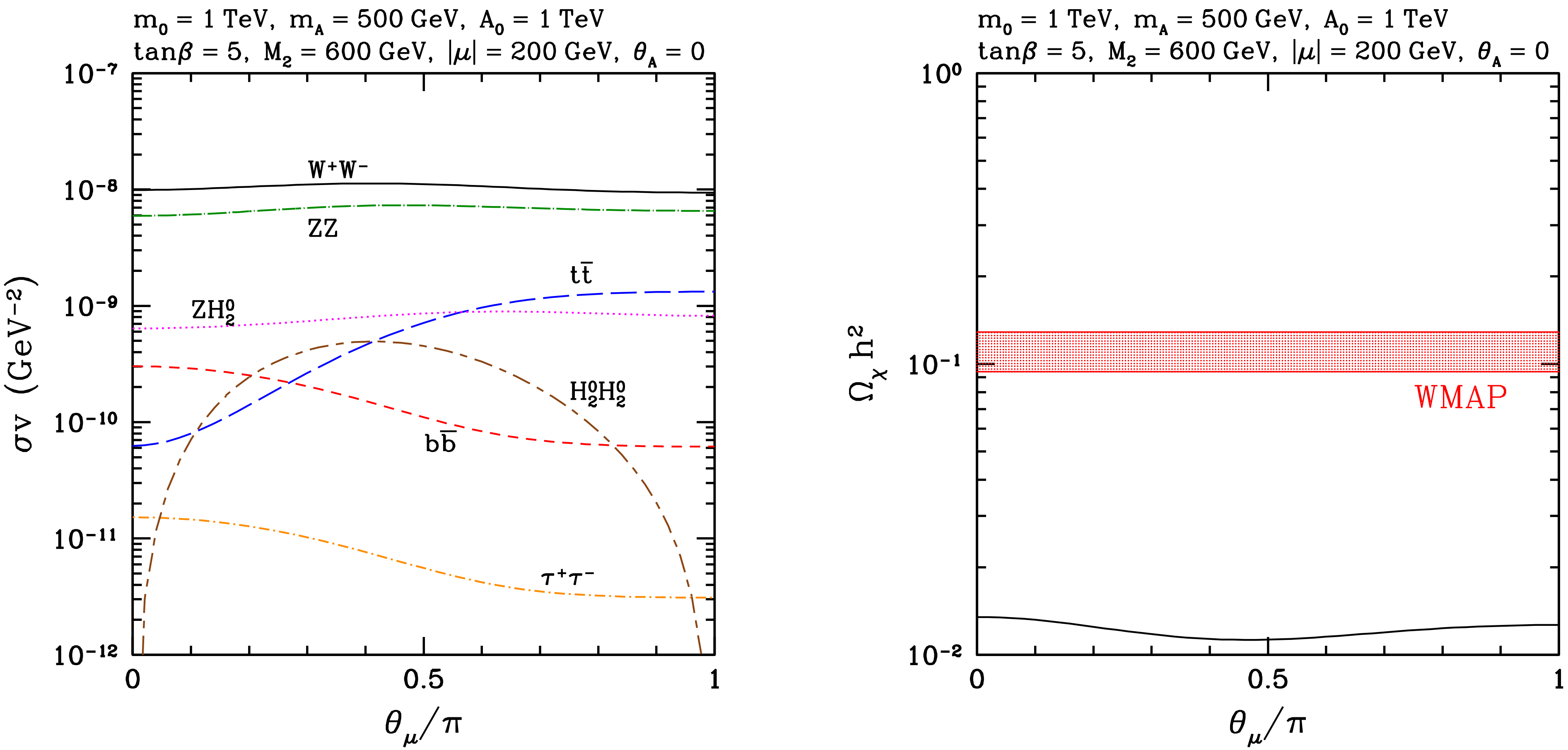
(cf) T.N.–Sasagawa (PRD70, 2004)

$\Omega_\chi h^2$ depends on θ_μ significantly.

Allowed regions consistent with WMAP appear for non-trivial θ_μ.

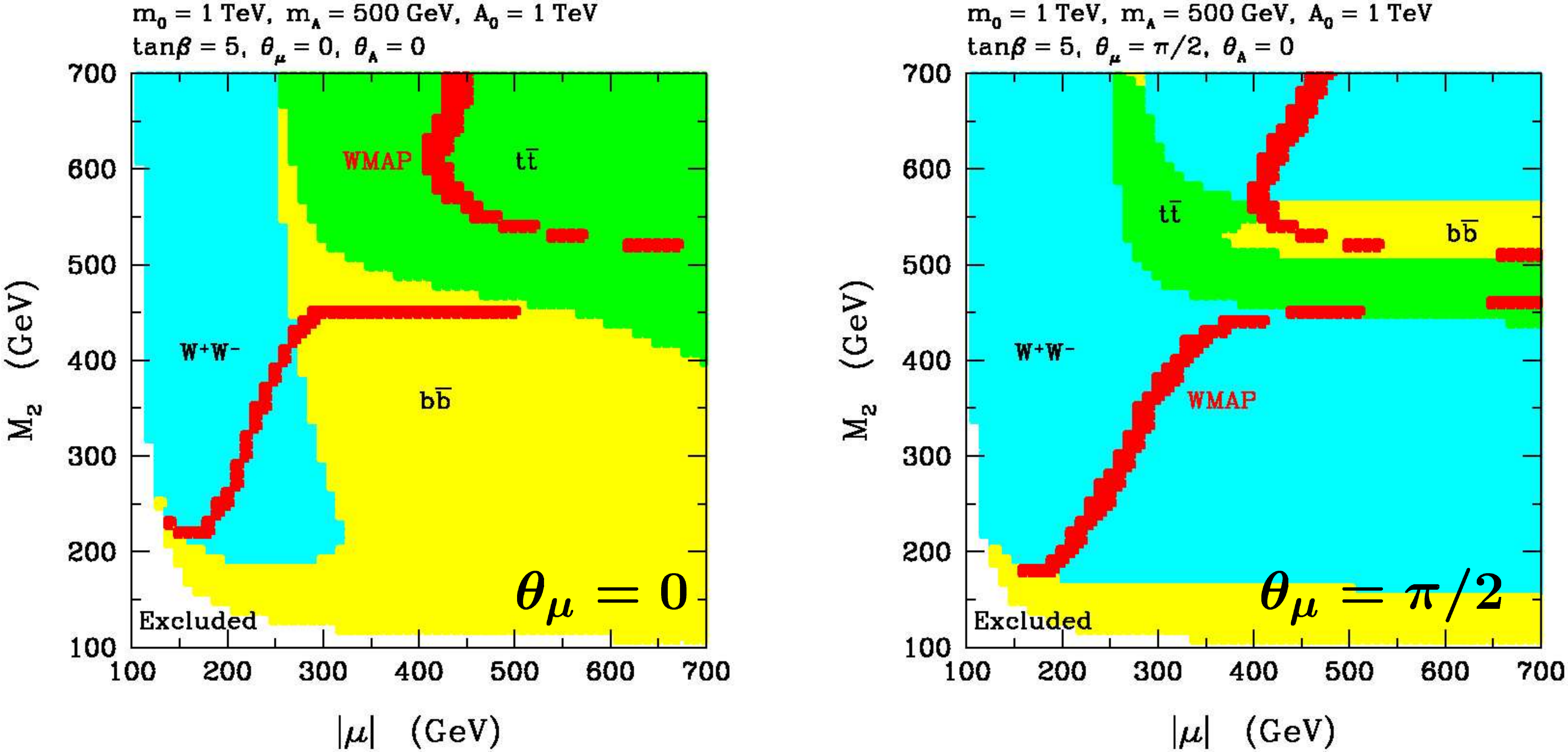


Effect of θ_A is typically small.



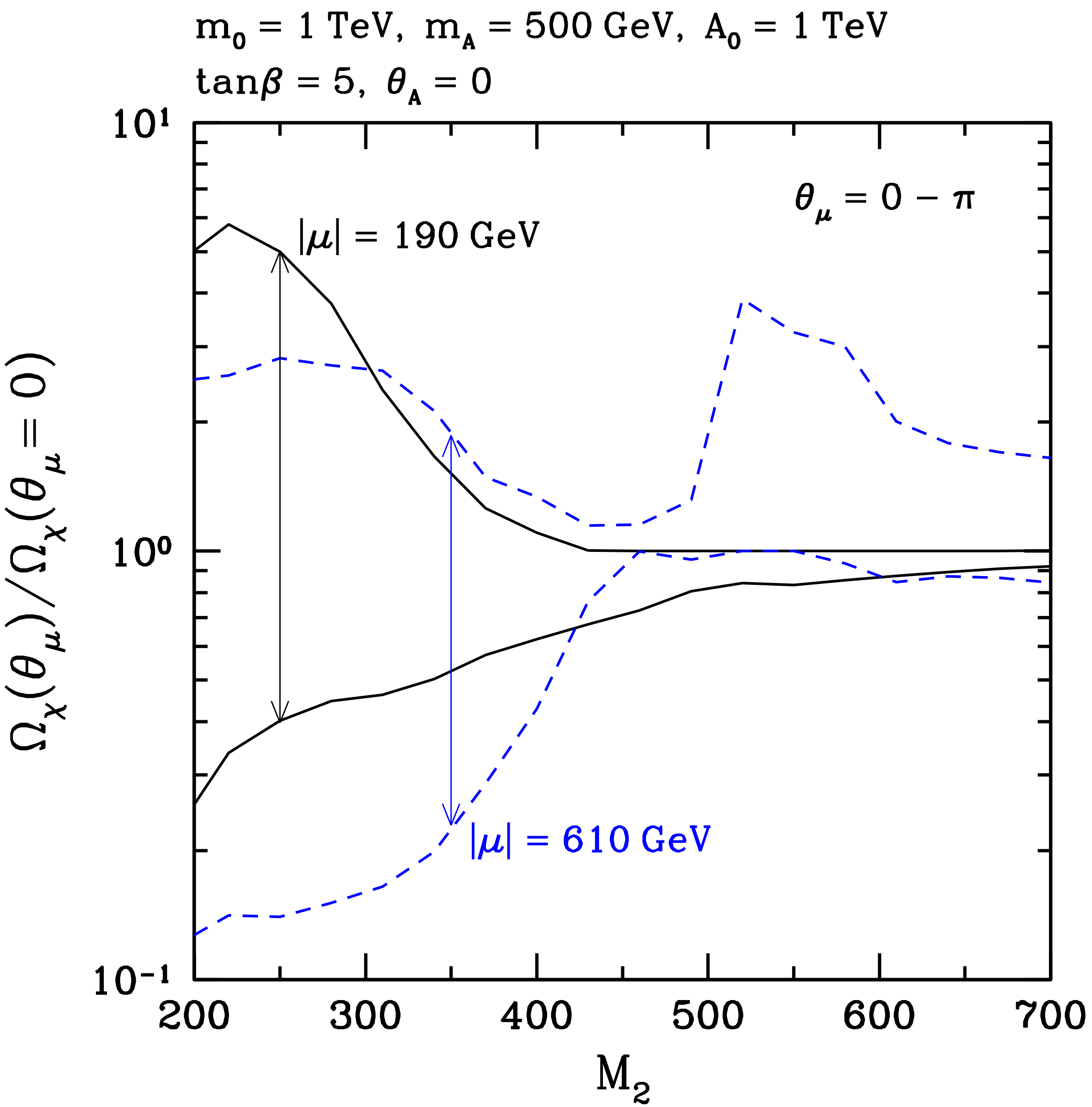
For $\widetilde{H}$-like LSP, θ_μ dependence is weak.
(Chargino exchange is dominant.)

Dominant final state at $v = 10^{-3}$



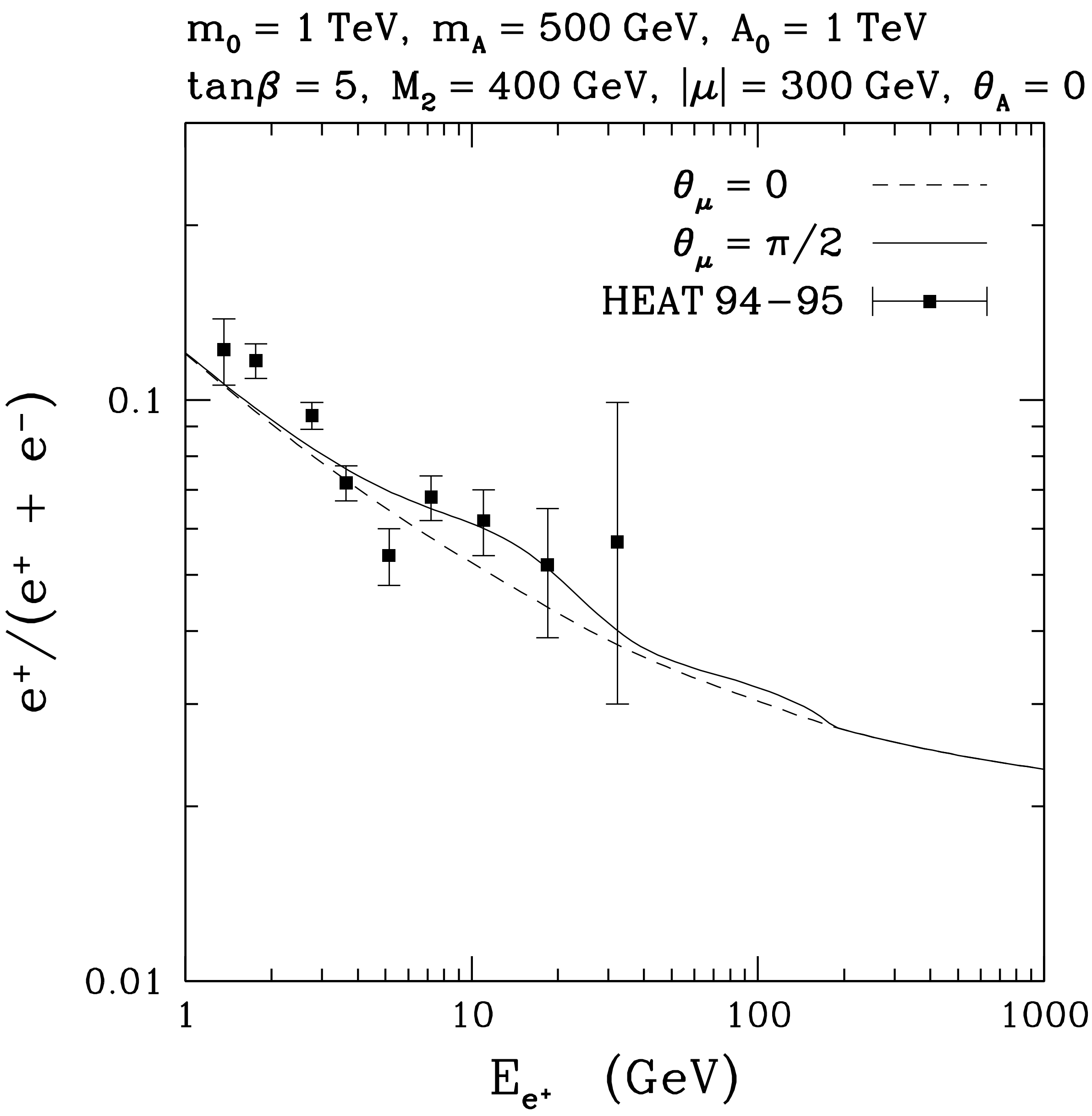
In the presence of CP violation,
W^+W^- final state can be dominant even for $\widetilde{B}$-like LSP.

Variation with θ_μ



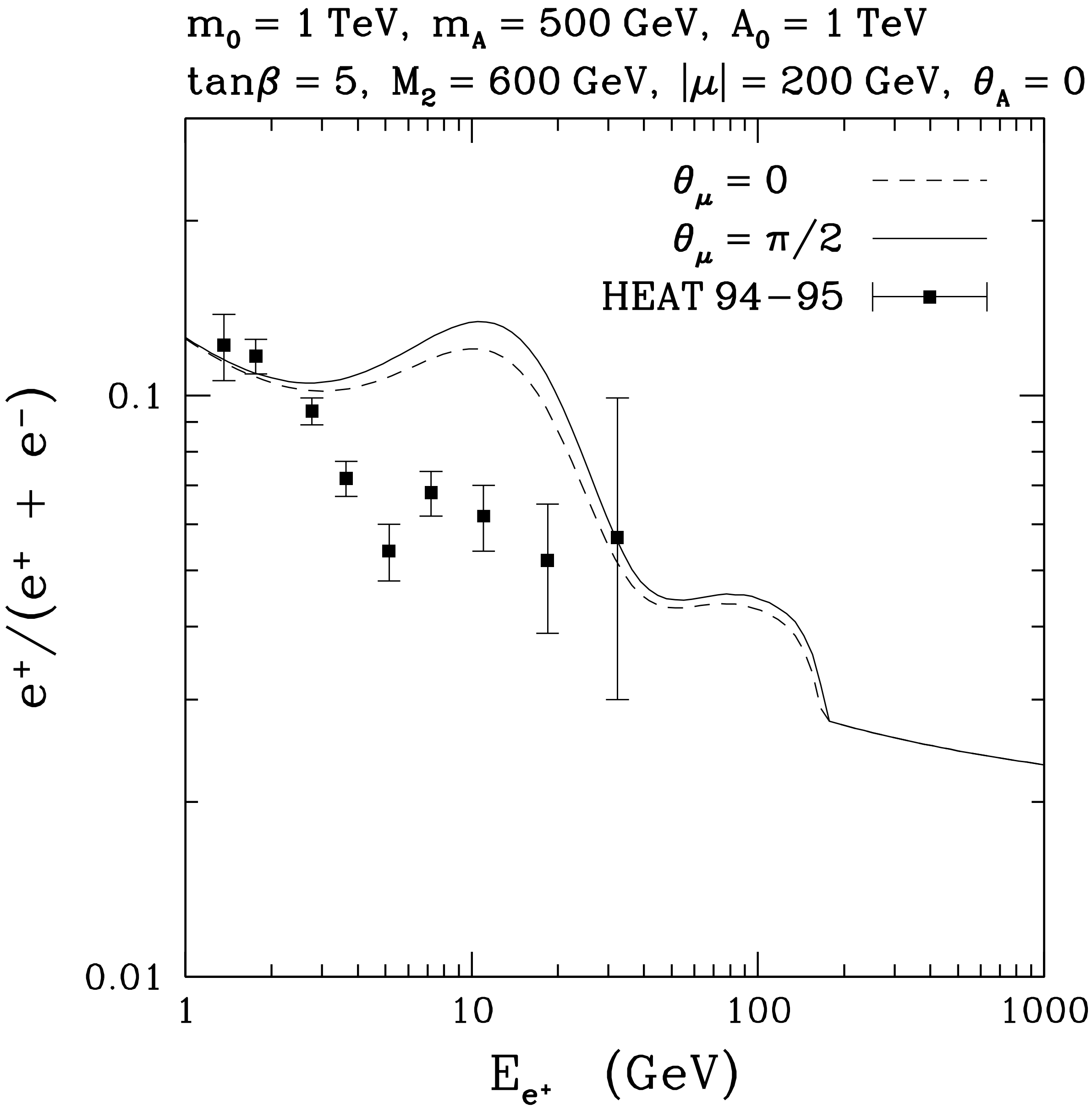
Strong θ_μ dependence for $\widetilde{B}$-like or mixed LSP.

Positron fraction



Sizable effect
in the e^+ flux

$$\Omega_\chi h^2 = 0.312 \ \ (\theta_\mu = 0)$$
$$0.073 \ \ (\theta_\mu = \pi/2)$$



Large excess
for $\widetilde{H}$-like LSP

$$\Omega_\chi h^2 = 0.013 \;\; (\theta_\mu = 0)$$
$$0.011 \;\; (\theta_\mu = \pi/2)$$

5. Conclusions

Neutralino (χ) dark matter with SUSY CP violation

- Effect of supersymmetric CP-violating phases (θ_μ , θ_A) on χ pair annihilation cross section

  - $\chi\chi \to W^+W^-$ is significantly enhanced due to lightest higgs exchange for $\mathbf{Im}(\mu) \neq \mathbf{0}$. ($\widetilde{B}$-like or mixed LSP)
  - Strong phase dependence of $\Omega_\chi h^2$
  - WMAP allowed region for nonvanishing CP phases
  - Sizable effect in the positron flux