荷電ウィーノと中性ウィーノの質量差の2ループレベルの計算

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“Mass Splitting between Charged and Neutral Winos at Two-Loop Level”,
M. Ibe, S. Matsumoto and R. Sato,

arXiv:1212.5989 [hep-ph], Phys. Lett. B 721 (2013) 252-260

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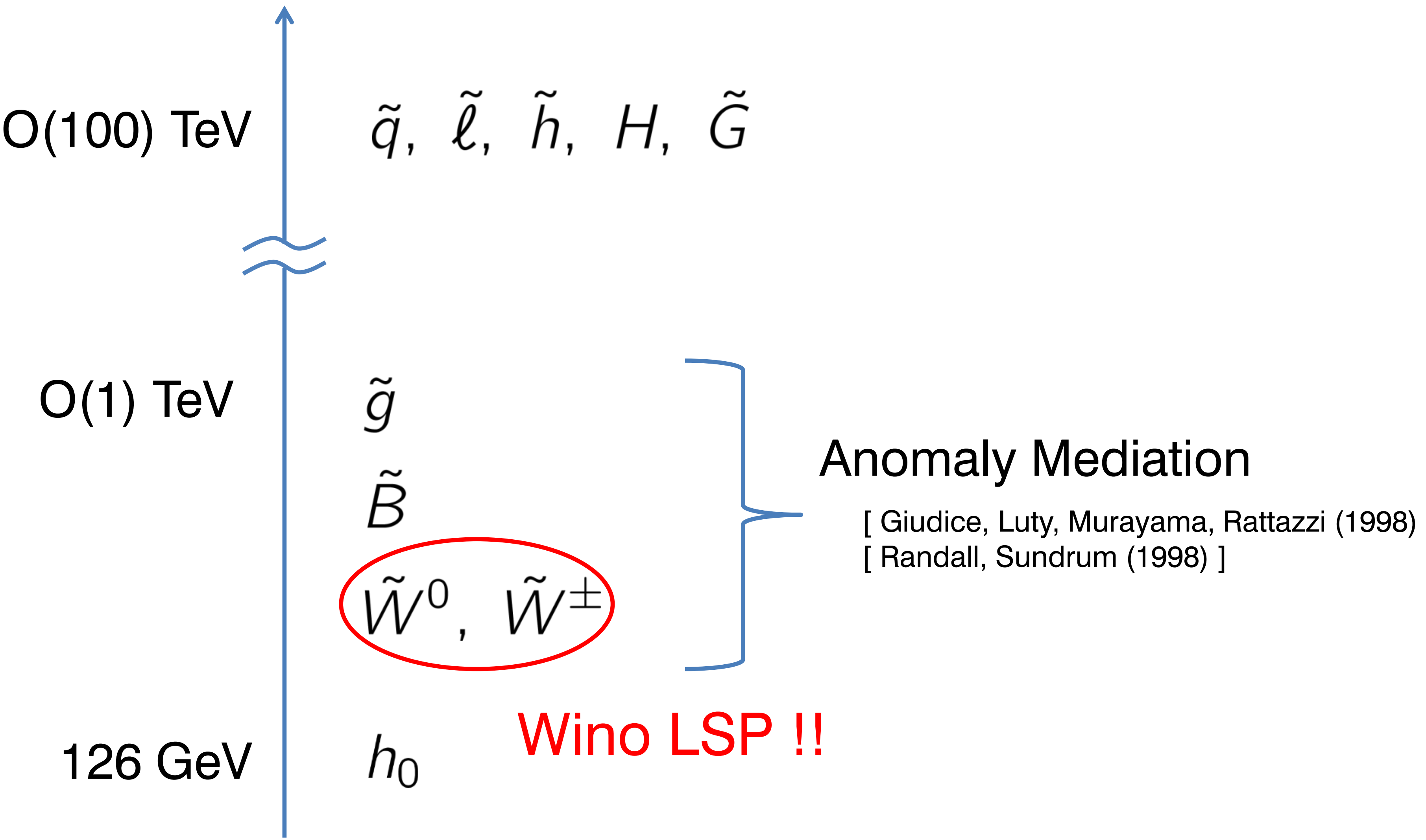
High scale SUSY

PeV-SUSY : [Wells (2004)]
Spread SUSY : [Hall, Nomura (2011)]
Pure Gravity Mediation : [Ibe, Yanagida (2011)]



$m_{\tilde{W}^\pm} - m_{\tilde{W}^0}$ *at tree-level*

- Wino = SU(2) triplet Majorana fermion $(\tilde{W}^+,\ \tilde{W}^0,\ \tilde{W}^-)$

$$\delta m|_{\rm mixing} \simeq \frac{0.014\ \rm MeV}{\tan^2\beta}\left(\frac{300\ \rm GeV}{M_1 - M_2}\right)\left(\frac{100\ \rm TeV}{\mu}\right)^2$$

Dimension 5 :

$$\frac{M_2}{\Lambda^2}\epsilon_{abc}\tilde{W}^a\tilde{W}^b(H^\dagger\tau^c H)$$

(WinoはMajorana fermion)

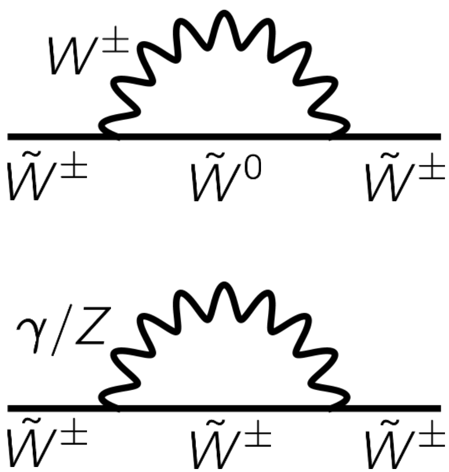
Dimension 7 :

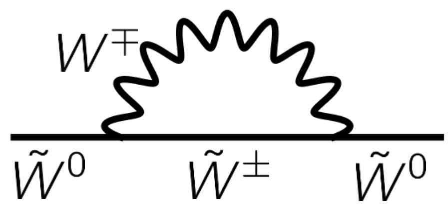
$$\frac{M_2}{\Lambda^4}\tilde{W}^a\tilde{W}^b(H^\dagger\tau^a H)(H^\dagger\tau^b H)$$

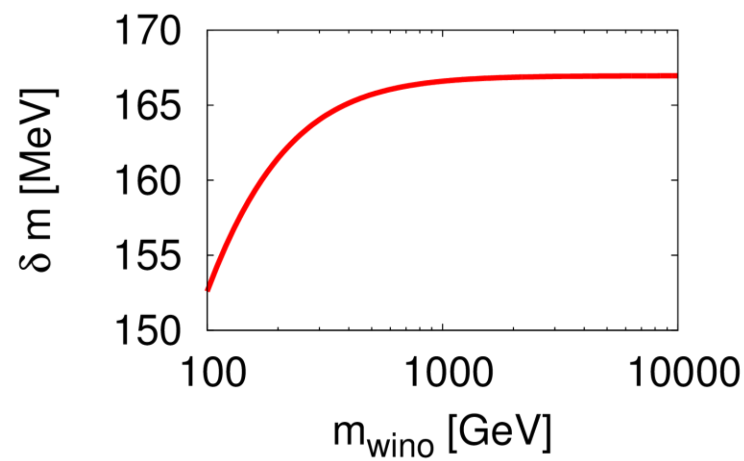
$m_{\tilde{W}^\pm} - m_{\tilde{W}^0}$ at one-loop level

- One-loopの寄与が主要。

[Cheng, Dobrescu, Machev (1998)]
[Gherghetta, Giudice, Wells (1999)]
[Feng, Moroi, Randall, Strassler, Su (1999)]







Naïve estimation of two-loop contribution

- Winoのmass splittingは、custodial symmetryの破れ。
    - U(1)Yゲージ相互作用
    - top mass (top yukawa)

	$SU(2)_L \times SU(2)_R$
(t_L, b_L)	$(2, 1)$
(t_R, b_R)	$(1, 2)$
H	$(2, 2)$
$\tilde{W}$	$(3, 1)$

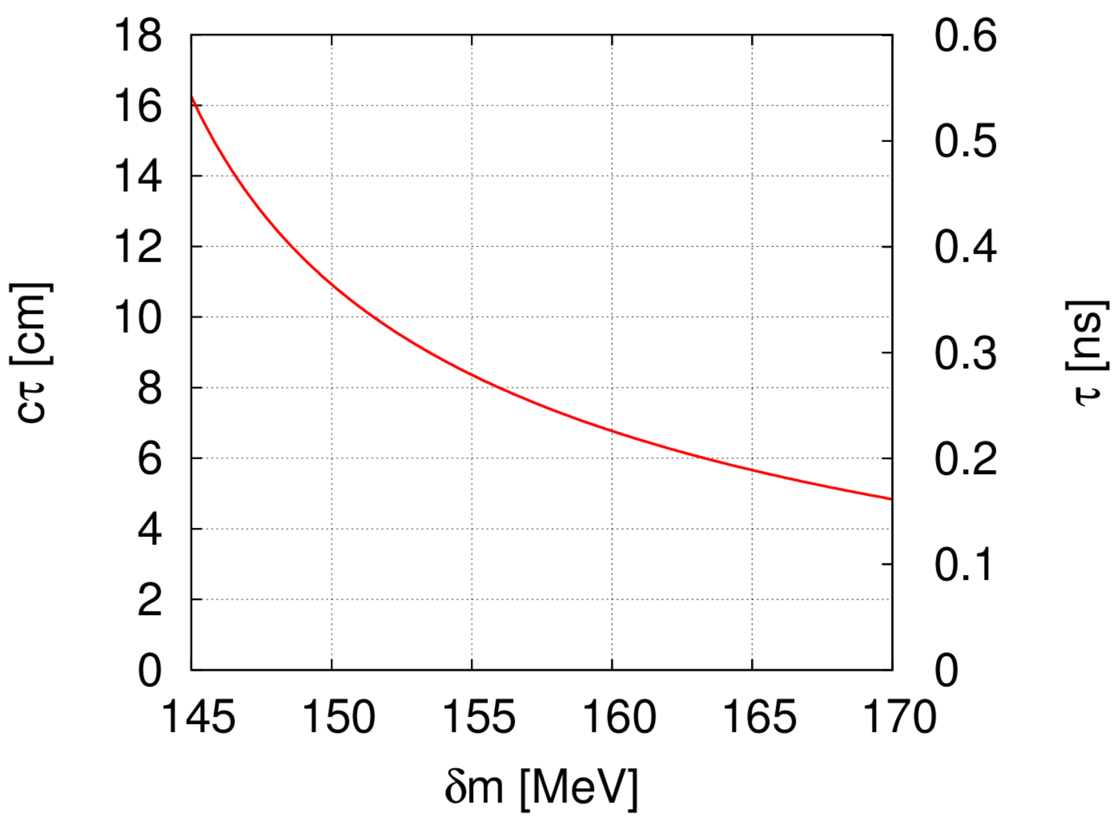
- Two loopの寄与　(very naïve estimation)

$$\Delta_{2-\text{loop}}\delta m \;=\; \left(\frac{\alpha_2}{4\pi}\right)^2 \pi m_t \;\simeq\; 3.9\ \text{MeV}$$

Lifetime of charged wino : $\tau_{\tilde{W}^\pm}$

- 主要な崩壊モード : $\tilde{W}^\pm \to \tilde{W}^0 \pi^\pm$
- 寿命は δm に強く依存する。

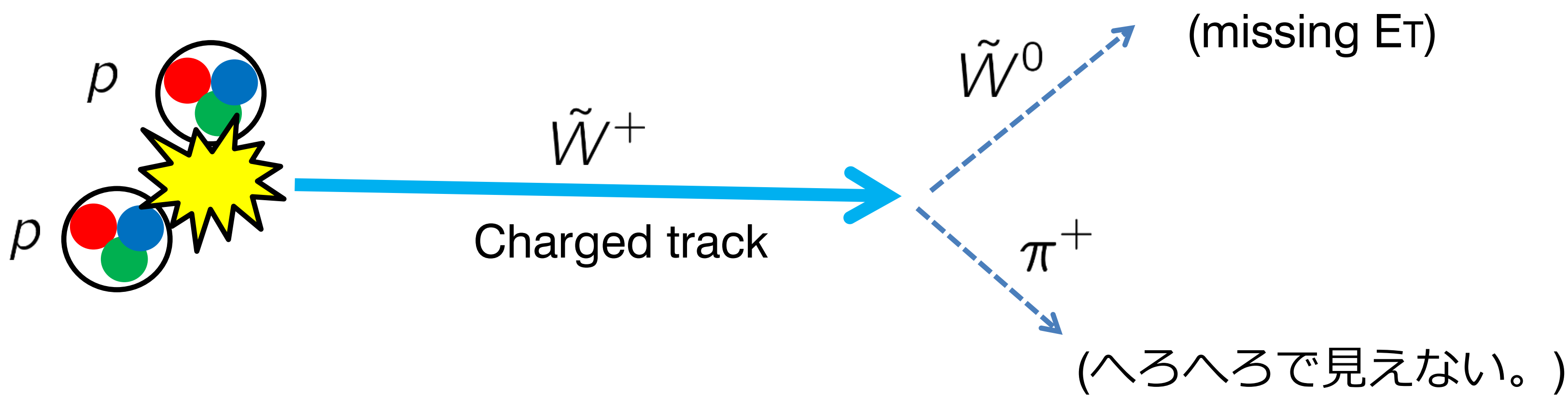
$$\tau_{\tilde{W}^\pm}^{-1} \simeq \frac{2G_F^2 f_\pi^2 |V_{ud}|^2}{\pi} \delta m^3 \sqrt{1 - \frac{m_\pi^2}{\delta m^2}}$$



[6]

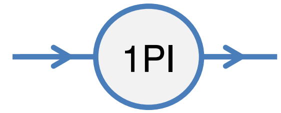
Decay of charged wino at LHC

- Charged WinoがLHCでできたらこんなシグナルが見えるはず。



Decay lengthを計算の精度を上げるためには、mass splittingの精度が必要。

Two-loop calculation

- 1PIのself energyを計算すればよい。 

- Sfermion, Higgsino, Heavy Higgsの質量は $\mathcal{O}(100)$ TeV → 寄与は無視できる。
- この状況下ではgluino, binoも無視できる。

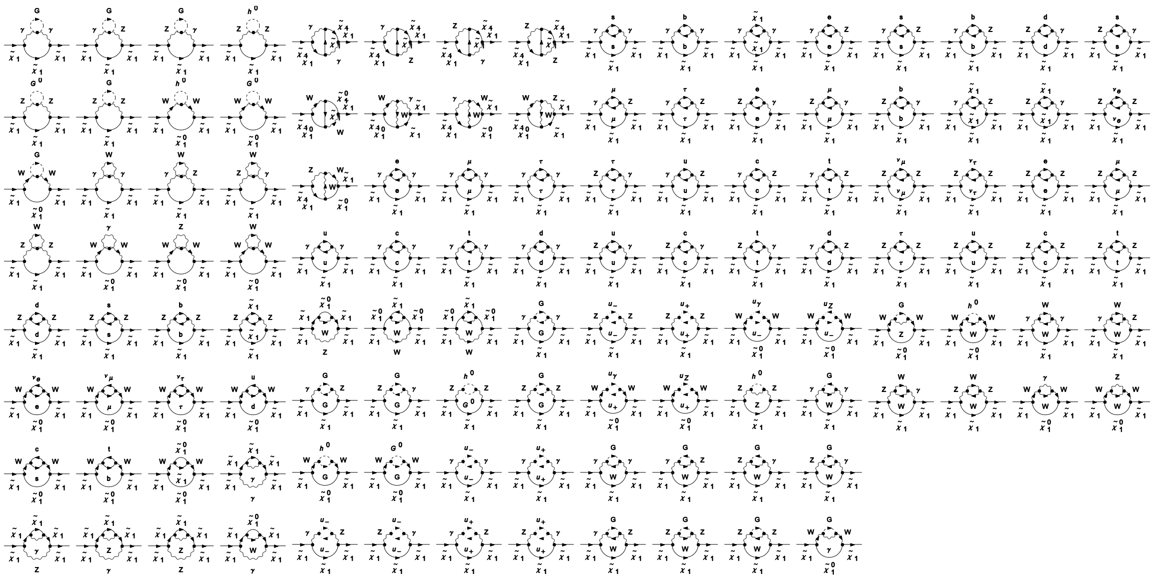
- Standard model + Winoの有効理論で計算。

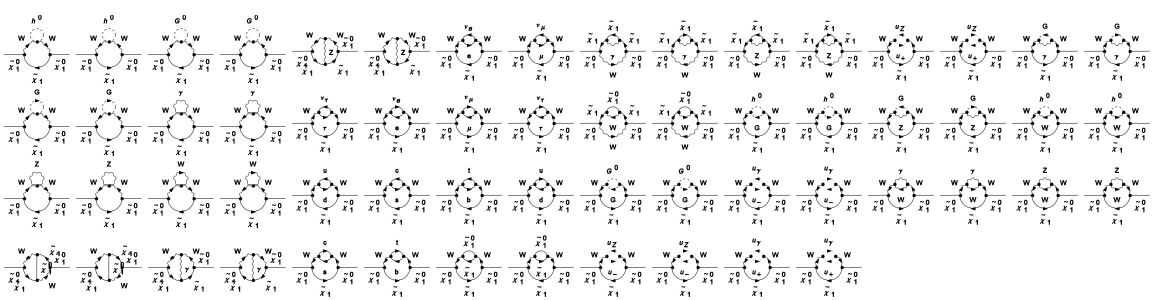
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + i\tilde{W}^{a\dagger}(\not{\partial}\delta_{ac} - \epsilon_{abc}\not{W}^{b})\tilde{W}^{c} - \frac{M_2}{2}(\tilde{W}^{a}\tilde{W}^{a} + h.c.)$$

Numerical Calculation !

- FeynArts
- FeynCalc
- TARCER
- TSIL

Diagrams





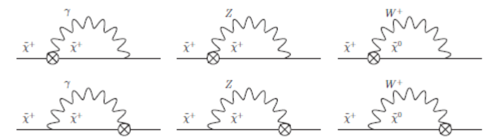


Figure D.7: Charged wino self-energy (group A)

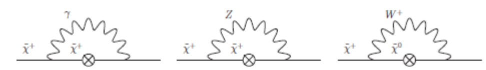


Figure D.8: Charged wino self-energy (group B)

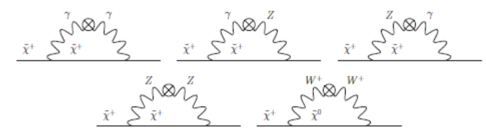


Figure D.9: Charged wino self-energy (group C)

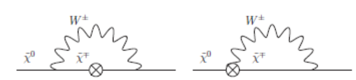


Figure D.1: Neutral wino self-energy (group A)

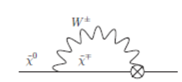


Figure D.2: Neutral wino self-energy (group B)

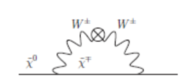
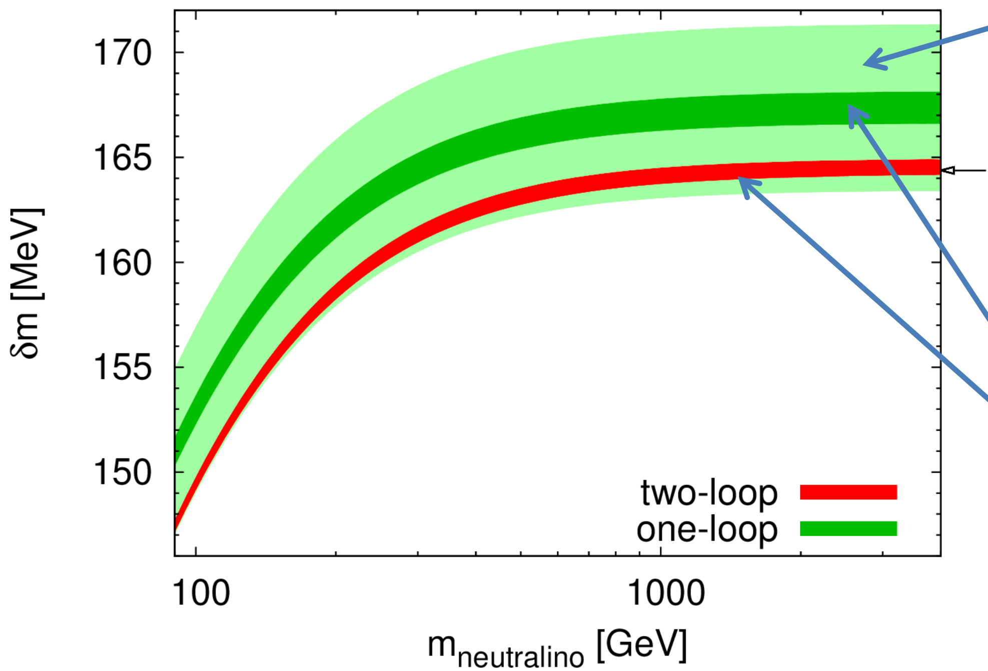


Figure D.3: Neutral wino self-energy (group C)

[9]

Mass splitting: $\delta m = m_{\tilde{W}^\pm} - m_{\tilde{W}^0}$



$$\Delta_{2-\mathrm{loop}}\delta m = \left(\frac{\alpha_2}{4\pi}\right)^2 \pi m_t \simeq 3.9\ \mathrm{MeV}$$

Heavy Wino limit
[Yamada (2009)]

くりこみスケール依存性に
由来する不定性

[Ibe, Matsumoto, Sato (2012)]

$$\frac{\delta m}{1\ \mathrm{MeV}} = -413.315 + 305.383\left(\log\frac{m_{\tilde{\chi}^0}}{1\ \mathrm{GeV}}\right) - 60.8831\left(\log\frac{m_{\tilde{\chi}^0}}{1\ \mathrm{GeV}}\right)^2$$
$$+5.41948\left(\log\frac{m_{\tilde{\chi}^0}}{1\ \mathrm{GeV}}\right)^3 - 0.181509\left(\log\frac{m_{\tilde{\chi}^0}}{1\ \mathrm{GeV}}\right)^4. \qquad (100\ \mathrm{GeV} < m_{\tilde{\chi}^0} < 4000\ \mathrm{GeV})$$

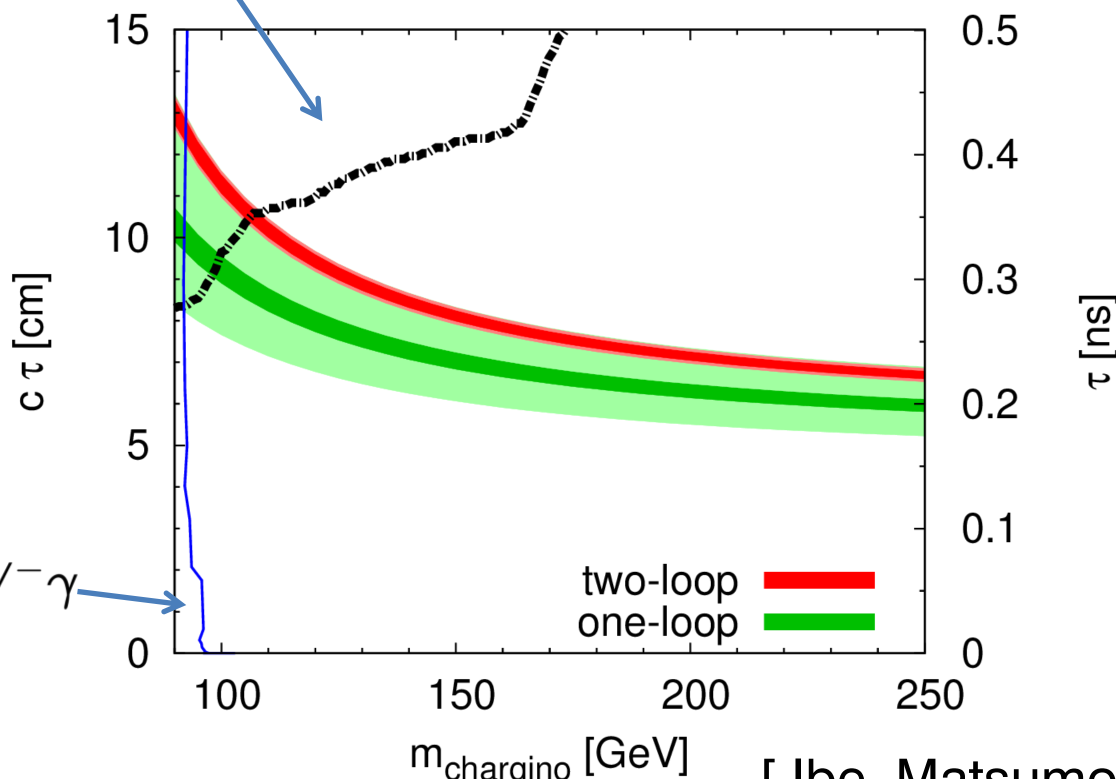
Lifetime of charged wino: $\tau_{\tilde{W}^\pm}$

Excluded by ATLAS [hep-ex/1210.2852]

$$pp \to \tilde{W}^0 \tilde{W}^\pm j,\ \tilde{W}^+ \tilde{W}^- j \quad (\sqrt{s} = 7\ \text{TeV}, \mathcal{L} = 4.7\ \text{fb}^{-1})$$

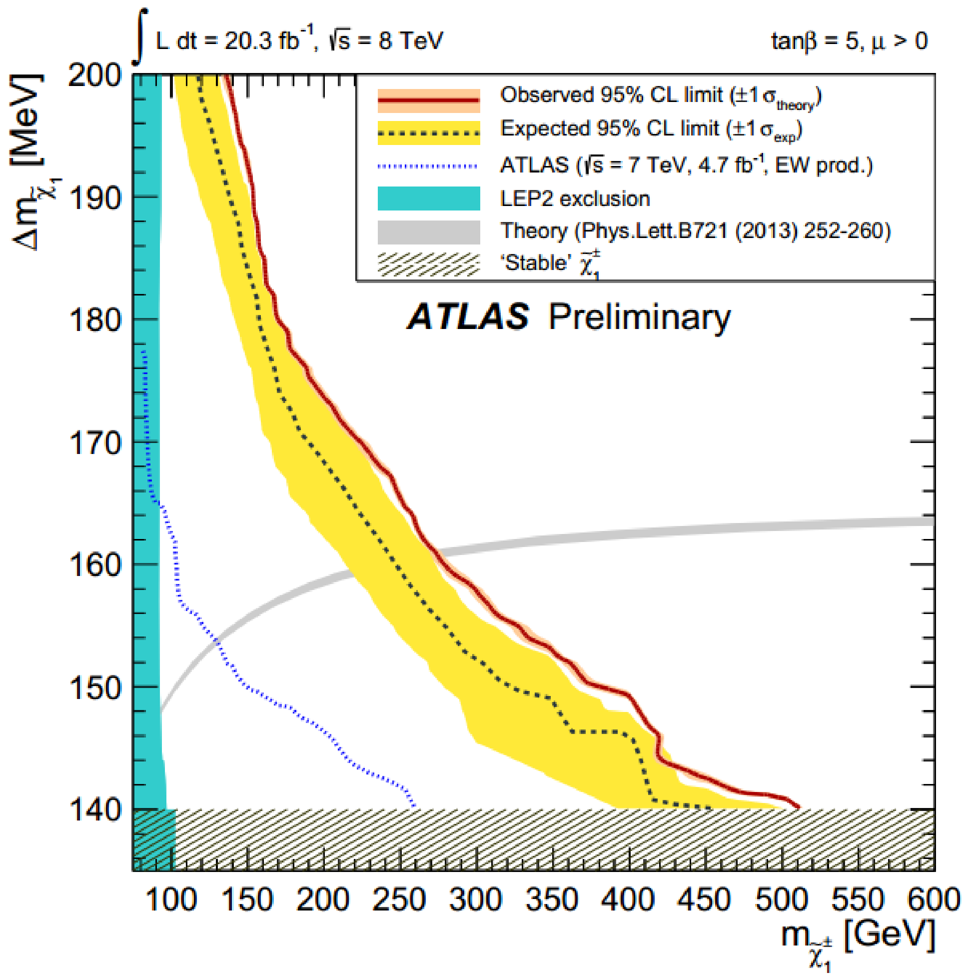
Excluded by LEP2

$$e^+ e^- \to \tilde{W}^+ \tilde{W}^- \gamma$$



[Ibe, Matsumoto, Sato (2012)]

Latest result (2013 July)



[ATLAS-CONF-2013-069]

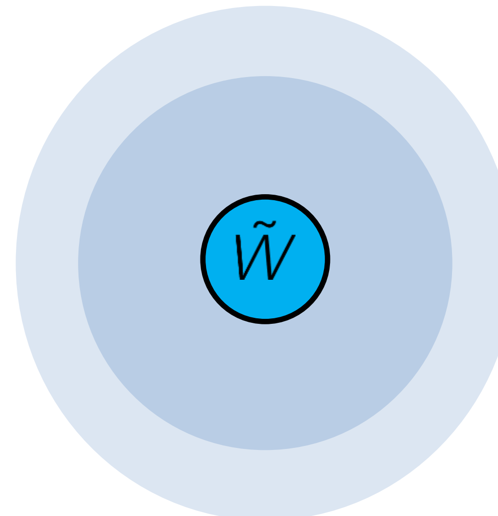
最新の結果で

$m_{\tilde{W}} < 270$ GeV は棄却。

Why non-decoupling?

- It's Coulomb energy!

[Cirelli, Fornengo, Strumia (2005)]



Coulomb Potential of massive vector boson:

$$\phi(r) = \frac{g}{4\pi}\frac{e^{-M_V r}}{r}$$

Coulomb Energy of massive vector boson:

$$E = \int d^3x \left(\frac{1}{2}(\nabla\phi)^2 + \frac{m_V^2}{2}\phi^2\right) = \frac{g^2 M_V}{8\pi} + (UV\ div.)$$

$$\Rightarrow \begin{cases} \delta m_{\tilde{W}^+} = \dfrac{g^2 m_W}{8\pi} + \dfrac{g^2 c_W^2 m_Z}{8\pi} + (UV\ div.) \\ \delta m_{\tilde{W}^0} = \dfrac{g^2 m_W}{4\pi} + (UV\ div.) \end{cases}$$