Mass splitting between charged and neutral winos at two-loop level

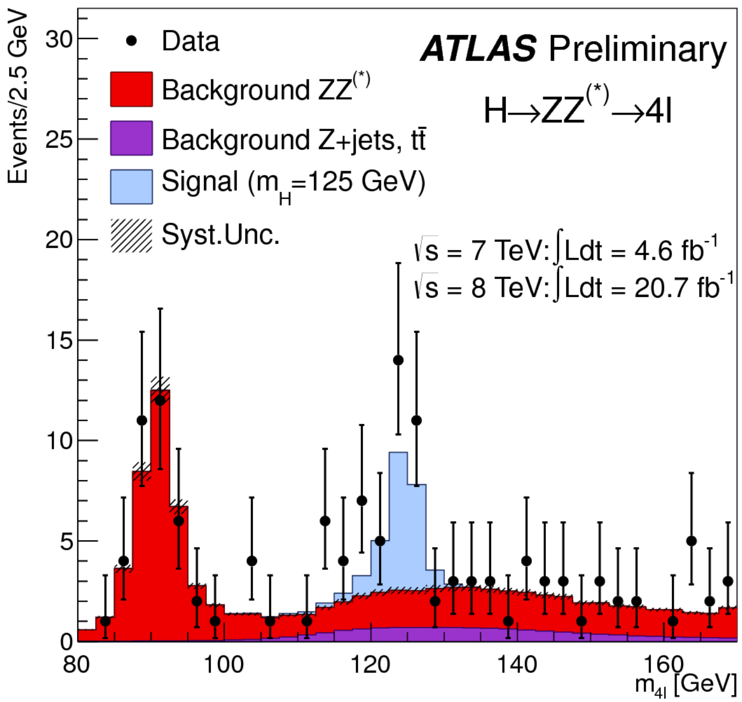
Ryosuke Sato（KEK）

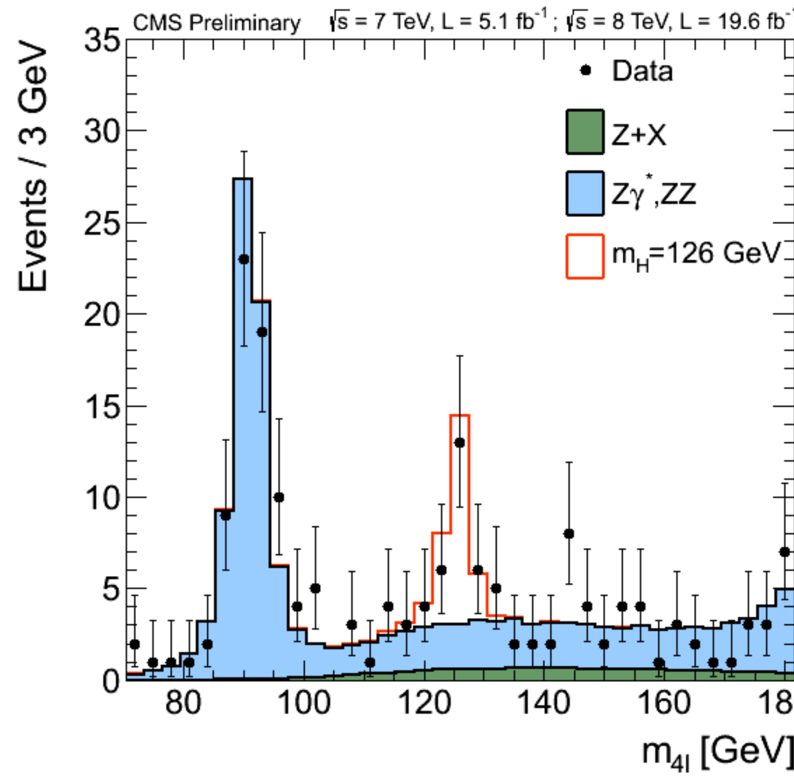
“Mass Splitting between Charged and Neutral Winos at Two-Loop Level”,
M. Ibe, S. Matsumoto and RS,

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

2013. 8. 29 @ SUSY 2013

Discovery of the Higgs boson





LHC 7 TeV & 8 TeV data gives,

$$125.5 \ \pm 0.2(\text{stat.}) \ ^{+0.5}_{-0.6}(\text{sys.}) \ \text{GeV}$$ [ATLAS-CONF-2013-014]

$$125.7 \ \pm 0.3(\text{stat.}) \ \pm 0.3(\text{sys.}) \ \text{GeV}$$ [CMS PAS HIG-13-005]

125 GeV Higgs in Supersymmetry

SM-like Higgs boson mass in MSSM is given by,

$$m_h^2 \sim m_Z^2 \cos^2 2\beta + \frac{3 G_F m_t^4}{\sqrt{2}\pi^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2} - \frac{X_t^4}{12 m_{\tilde{t}}^4}\right]$$

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How to get 125 GeV Higgs :

- heavy stop
- Large left-right mixing
- Non-minimal SSM

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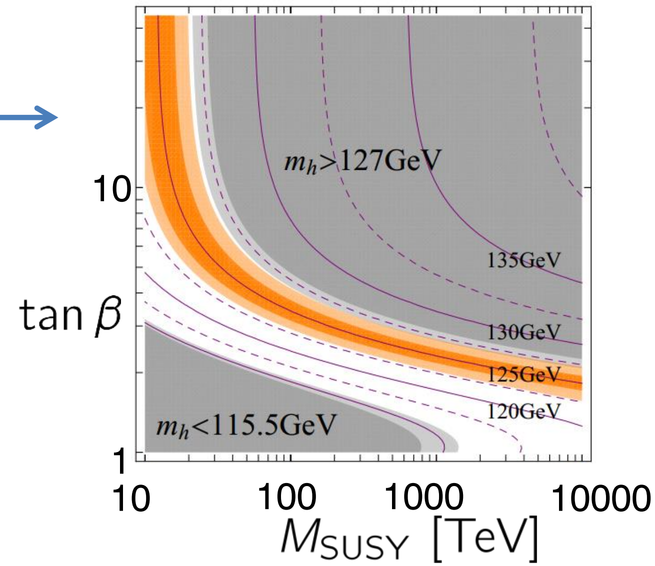

[Ibe, Matsumoto, Yanagida (2012)]

High scale SUSY

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

O(100) TeV $\tilde{q}, \ \tilde{\ell}, \ \tilde{H}, \ H, \ \tilde{G}$

O(1) TeV $\tilde{g}$

$\tilde{B}$

$\tilde{W}^0, \ \tilde{W}^{\pm}$

125 GeV h_0

Anomaly Mediation

[Giudice, Luty, Murayama, Rattazzi (1998)]
[Randall, Sundrum (1998)]

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

- At tree level

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

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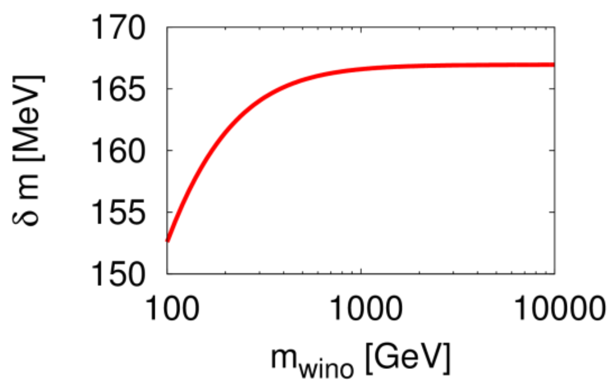
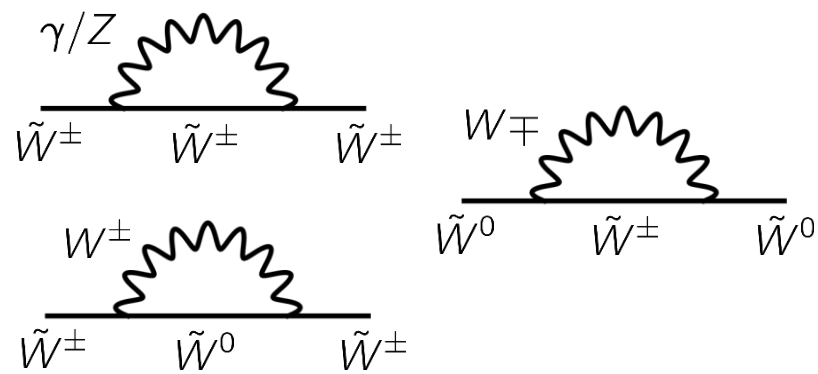
- At one-loop level

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





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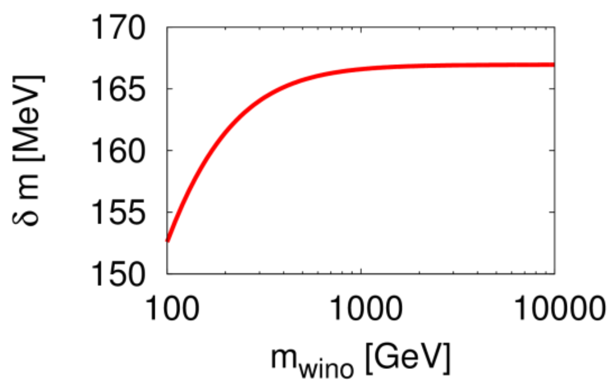
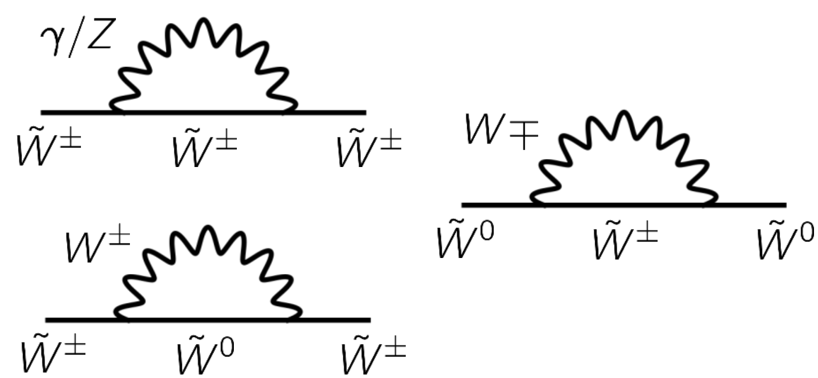


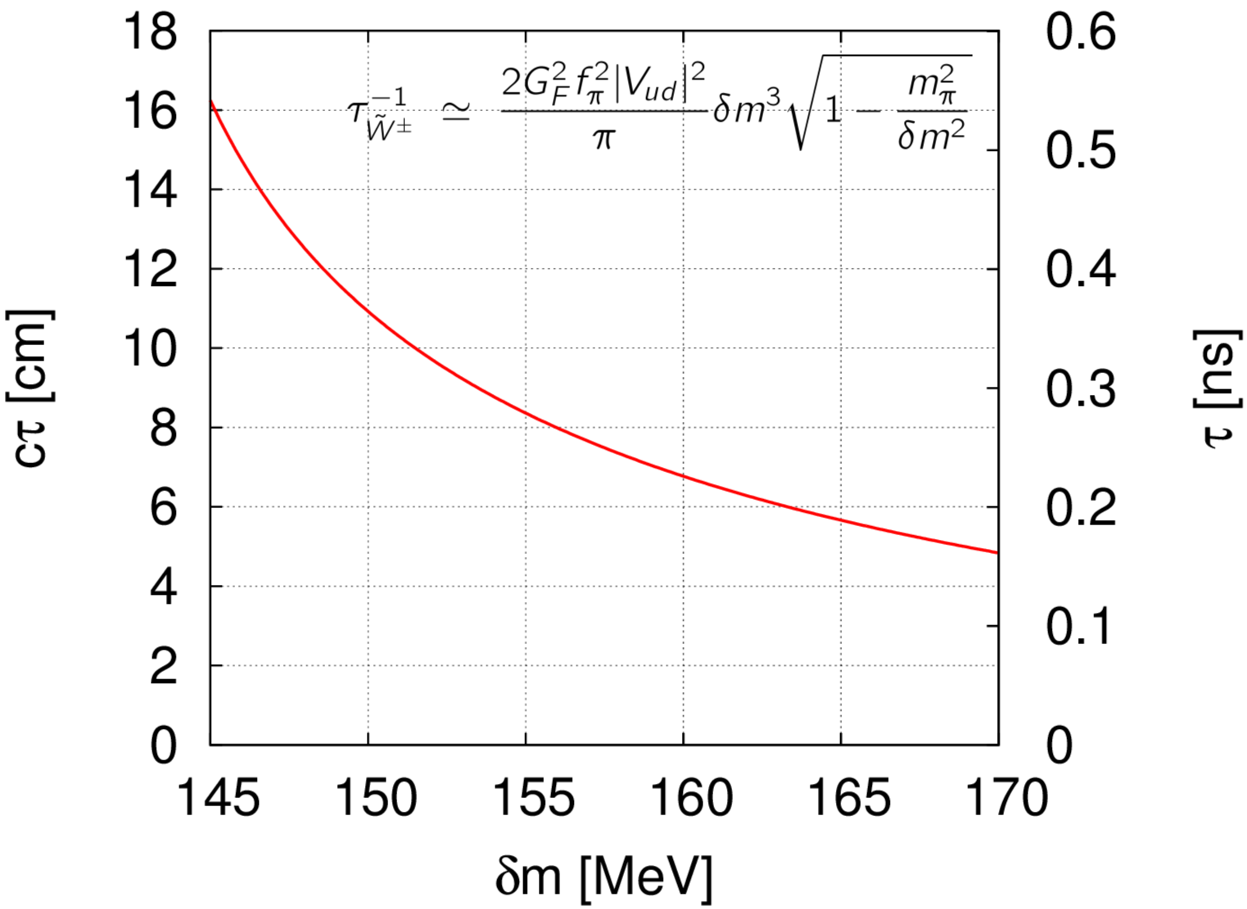


- Uncertainty of one-loop calculation (naïve estimation of two-loop contribution)

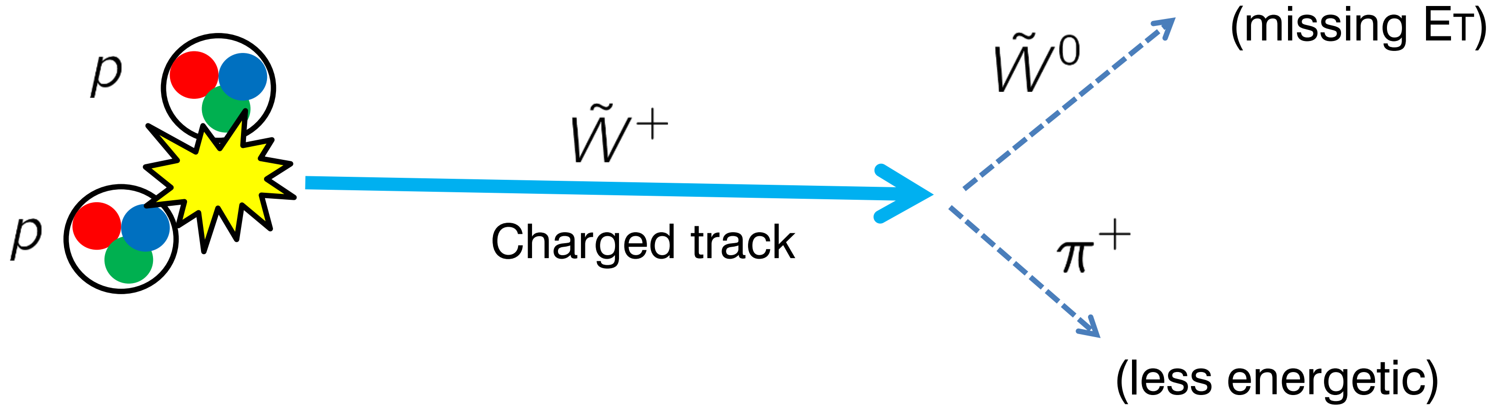
$$\Delta_{2-\text{loop}}\delta m = \left(\frac{\alpha_2}{4\pi}\right)^2 \pi m_t \simeq 3.9\ \text{MeV}$$

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

- Main decay mode : $\tilde{W}^\pm \to \tilde{W}^0 \pi^\pm$
- Life-time is strongly depends on $\delta m = m_{\tilde{W}^\pm} - m_{\tilde{W}^0}$



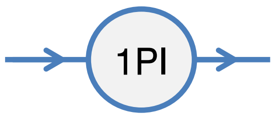
Decay of charged wino at LHC



To get the accuracy of life-time,
We need the accuracy of mass splitting.

Two-loop calculation

- We calculate 1PI self-energy.



$$= \Sigma_K(p^2)\not p + \Sigma_M(p^2) \longrightarrow M_{\rm pole} = {\rm Re}\left[\frac{M_0 - \Sigma_M(M_{\rm pole}^2)}{1+\Sigma_K(M_{\rm pole}^2)}\right]$$

Pole mass can be expanded as a series of loop-order :

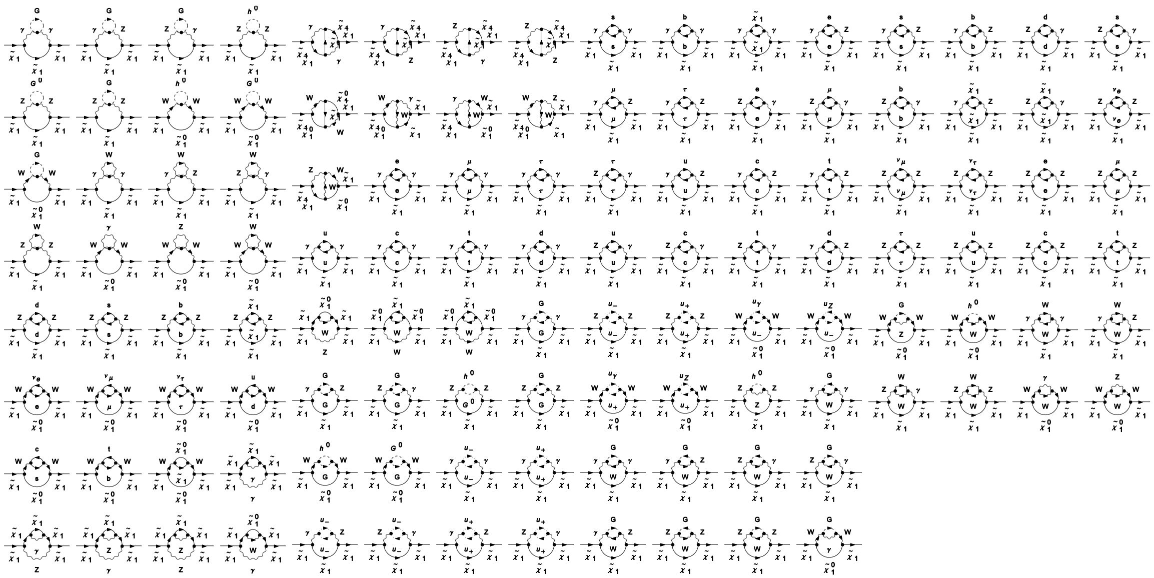
$$M_{\rm pole} = M_0 + M^{(1)} + M^{(2)} + \cdots .$$

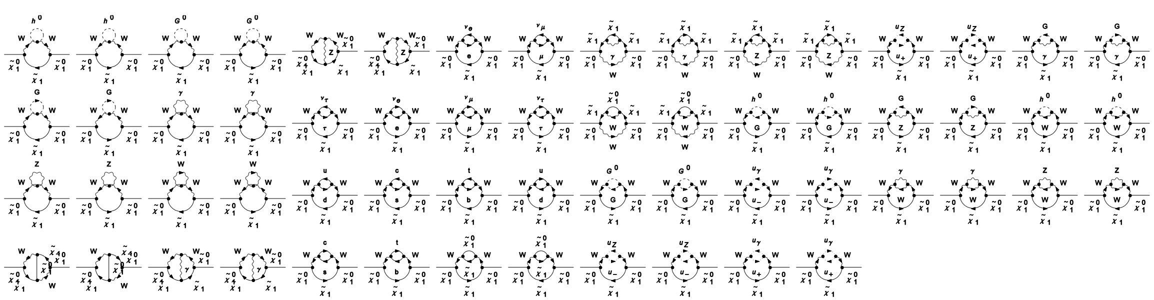
- We use an effective theory (SM + winos)

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

  - Heavy particles (sfermions, Higgsino, heavy Higgses) can be neglected.
  - Bino and gluino does not contribute at two-loop order.

Diagrams to evaluate





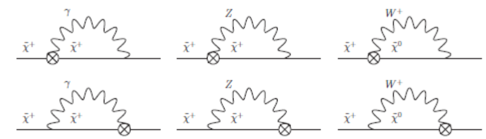


Figure D.7: Charged wino self-energy (group A)

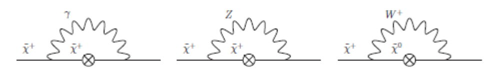


Figure D.8: Charged wino self-energy (group B)

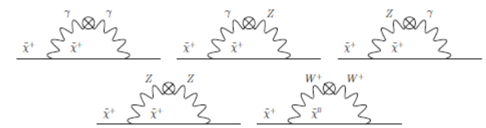


Figure D.9: Charged wino self-energy (group C)

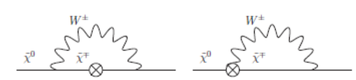


Figure D.1: Neutral wino self-energy (group A)

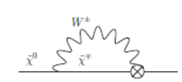


Figure D.2: Neutral wino self-energy (group B)

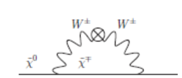


Figure D.3: Neutral wino self-energy (group C)

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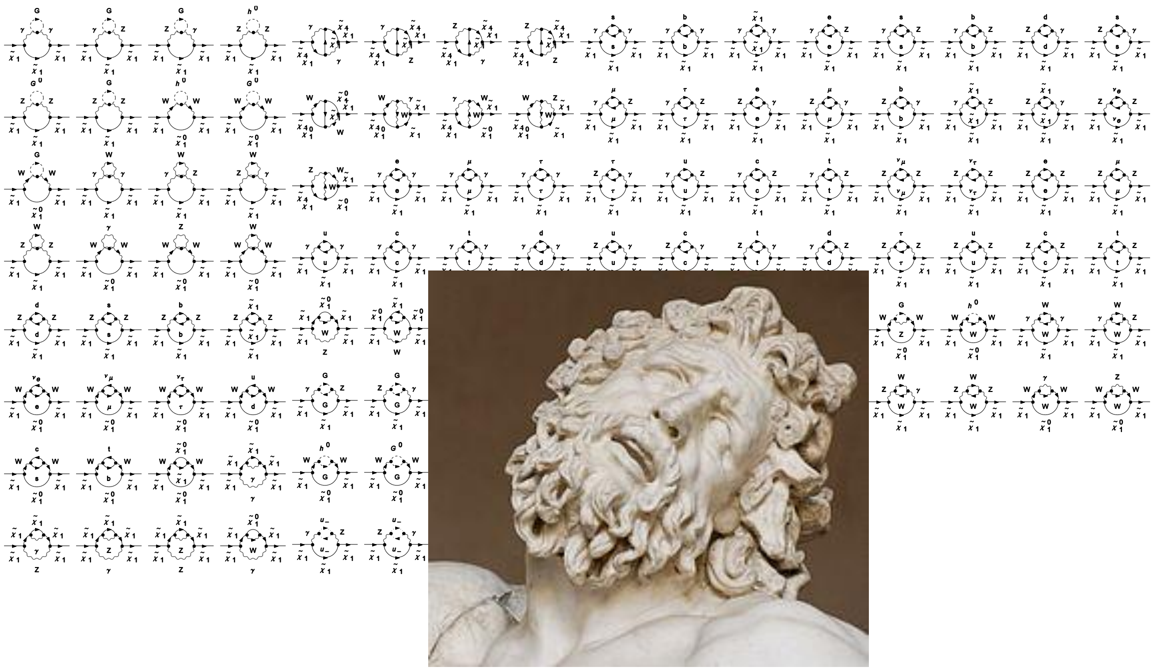

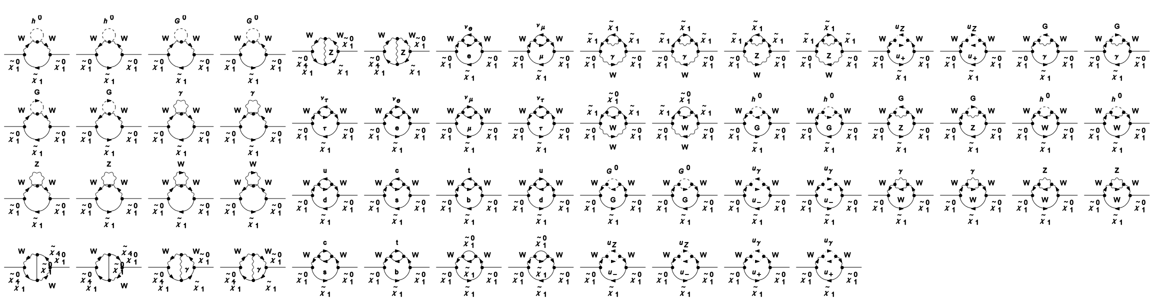

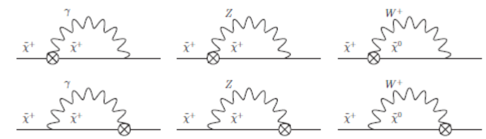

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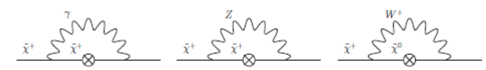

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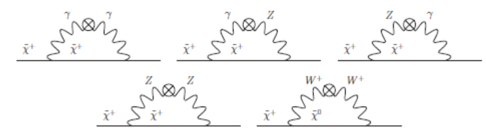

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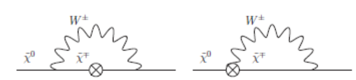

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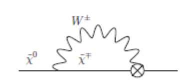
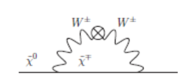


Figure D.2: Neutral wino self-energy (group B)



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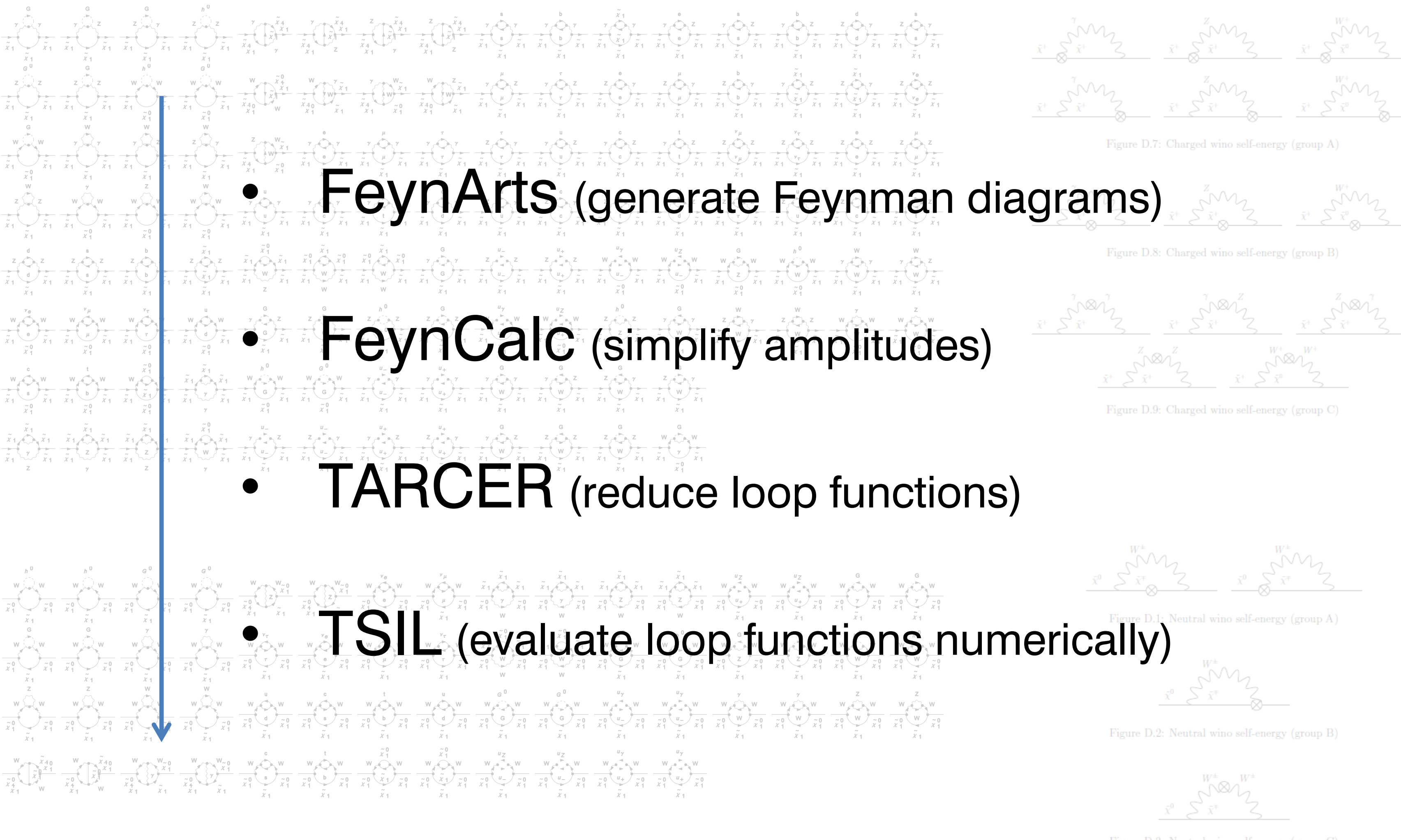
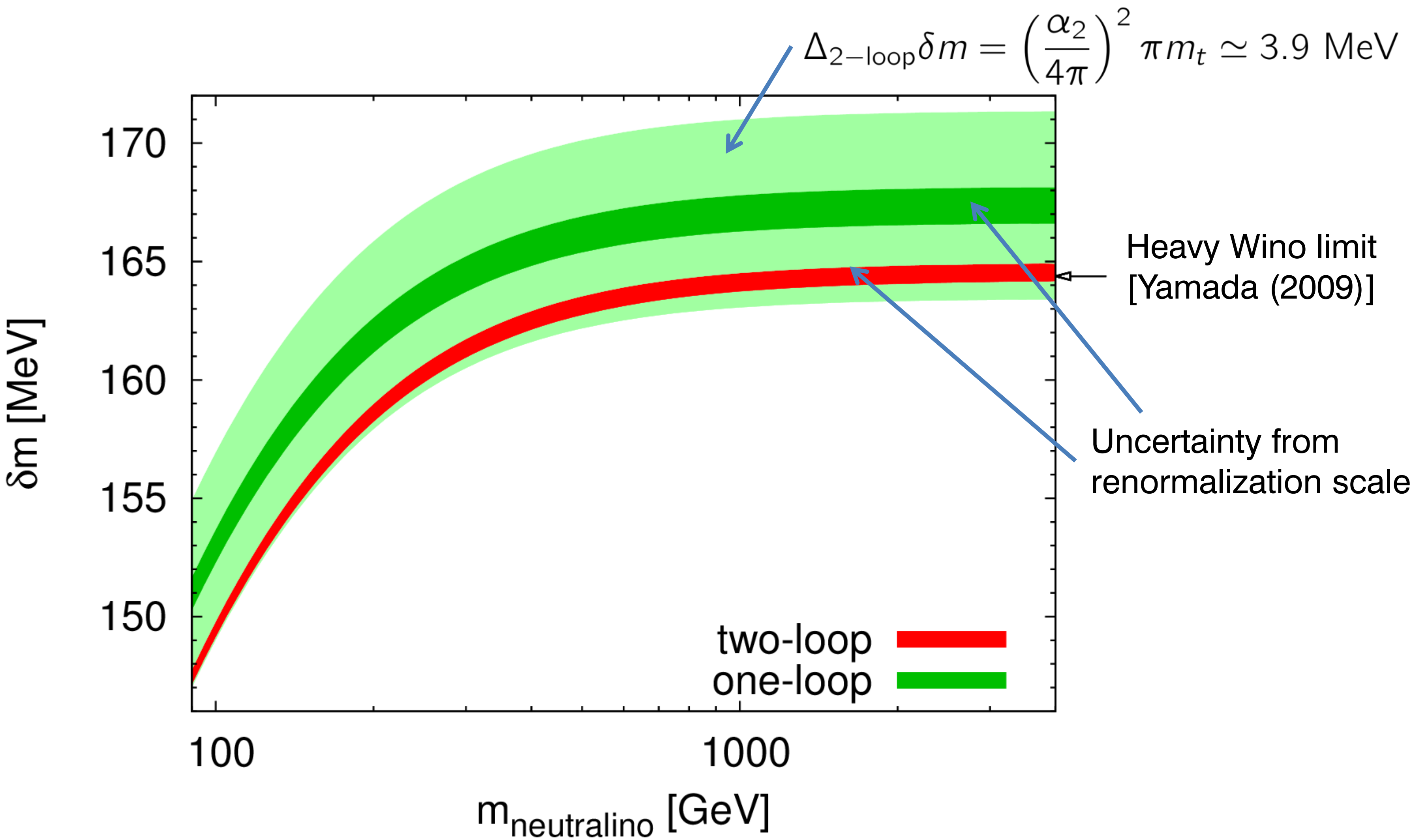


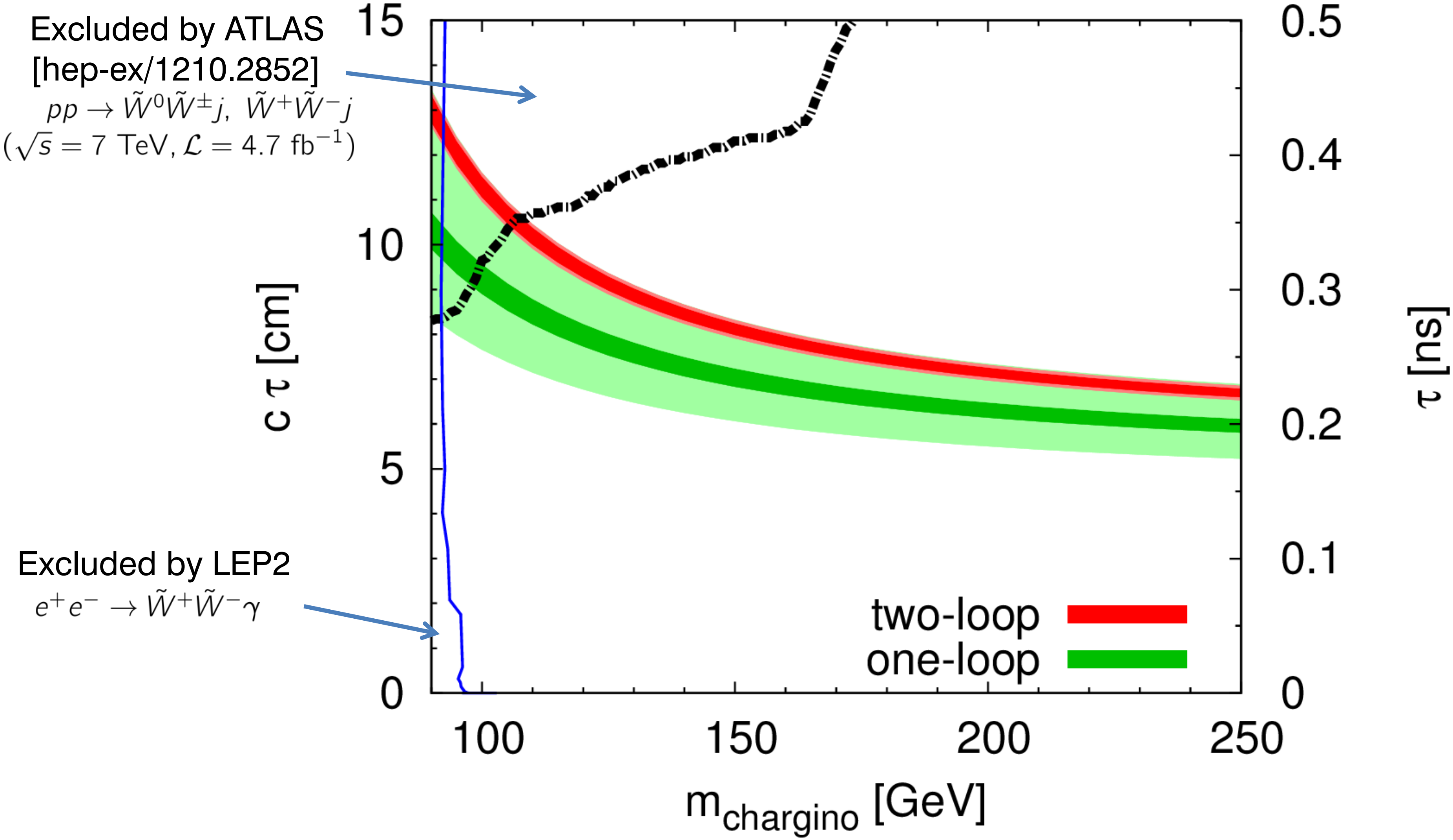
- FeynArts (generate Feynman diagrams)
- FeynCalc (simplify amplitudes)
- TARCER (reduce loop functions)
- TSIL (evaluate loop functions numerically)

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



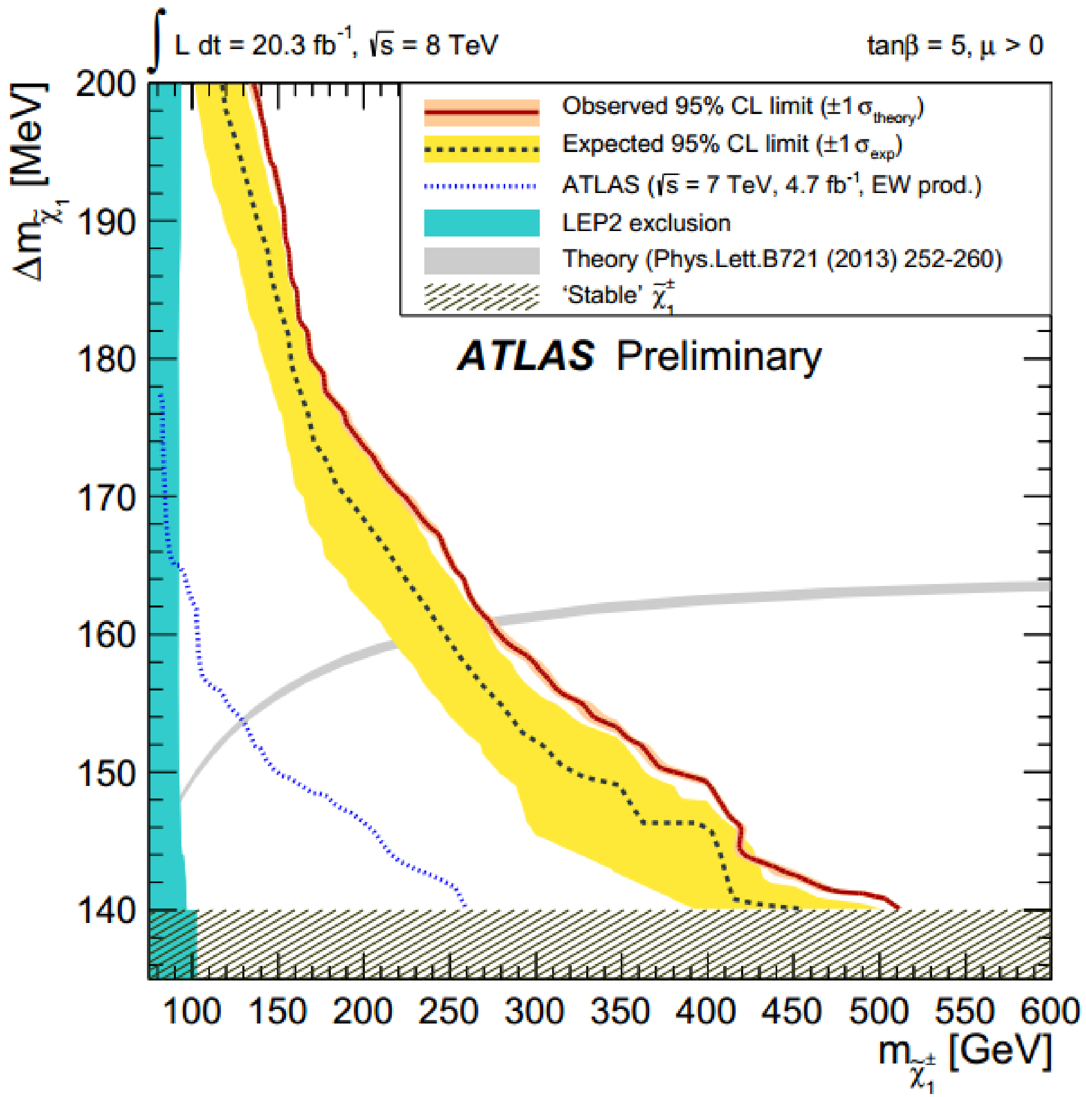
[Ibe, Matsumoto, RS (2012)]

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



[Ibe, Matsumoto, RS (2012)]

Latest result (2013 July)



$m_{\tilde{W}} \lesssim 250$ GeV

is excluded!

[ATLAS-CONF-2013-069]

Summary

- 125 GeV Higgs motivates wino LSP.
- Lifetime of charged wino is very sensitive to mass splitting within Winos.
- We calculated the mass splitting at two-loop level.
- Our result is available as the following fitting formula. (see arXiv:1212.5989)

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

$$(100\ \mathrm{GeV} < m_{\tilde{W}^0} < 4000\ \mathrm{GeV})$$

Mass correction as a Coulomb energy

[Cirelli, Fornengo, Strumia (2005)]

Coulomb Potential of massive vector boson:

$$\phi(r) = \frac{g}{4\pi}\frac{e^{-M_V r}}{r} \quad \Rightarrow \quad E_{\text{coul.}} = \int d^3x \left(\frac{1}{2}(\nabla\phi)^2 + \frac{m_V^2}{2}\phi^2\right)$$

Coulomb Energy of massive vector boson:

$$\delta m_{\tilde{W}^+}(W^+) = \frac{g^2\Lambda}{8\pi} - \frac{g^2 m_W}{8\pi} + \cdots$$

$$\delta m_{\tilde{W}^+}(\gamma) = \frac{g^2 s_W^2\Lambda}{8\pi}$$

$$\delta m_{\tilde{W}^+}(Z) = \frac{g^2 c_W^2\Lambda}{8\pi} - \frac{g^2 c_W^2 m_Z}{8\pi} + \cdots$$

$$\delta m_{\tilde{W}^0}(W^\pm) = \frac{2g^2\Lambda}{8\pi} - \frac{2g^2 m_W}{8\pi} + \cdots$$

Λ : cut off scale