Phenomenology of the Wino Dark Matter

Shigeki Matsumoto (Kavli IPMU)

1. Why the wino dark matter (DM)?
2. Phenomenology of the wino DM
3. Summary

1. Why the wino dark matter?

Main results from experiments:

New scalar boson (Higgs boson) with its mass 126 GeV was discovered.
No obvious BSM signals were discovered at LHC and other experiments.
WMAP and Planck experiments (may) indicate very standard cosmology.

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Clear evidences of BSM are

1. Neutrino masses and their mixings
2. Baryon asymmetry of the universe
3. Existence of cold dark matter

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About 1st & 2nd evidences

First two evidences can be simultaneously explained by introducing heavy right-handed neutrinos. (Seesaw mechanism & Leptogenesis)

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Existence of $U(1)_{B-L}$ gauge symmetry broken at some high scale!

1. Why the wino dark matter?

About 3rd evidence

What is the dark matter? → DM will be a neutral stable particle.

Why is it stable? → Because of a **residual symmetry of $U(1)_{B-L}$**.

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Why $U(1)_{B-L}$ works?

- $U(1)_{B-L}$ can be broken with a VEV having B-L charge two.
- SM involves only B-L odd fermions and B-L even bosons,

A new fermion (boson) w/ even (odd) B-L charge is stable!

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From a minimality viewpoint

Here, we concentrate on **a fermion without B-L charge** (charge 0).

→ WIMP DM, while Asymmetric DM in other cases (charge ≠ 0).

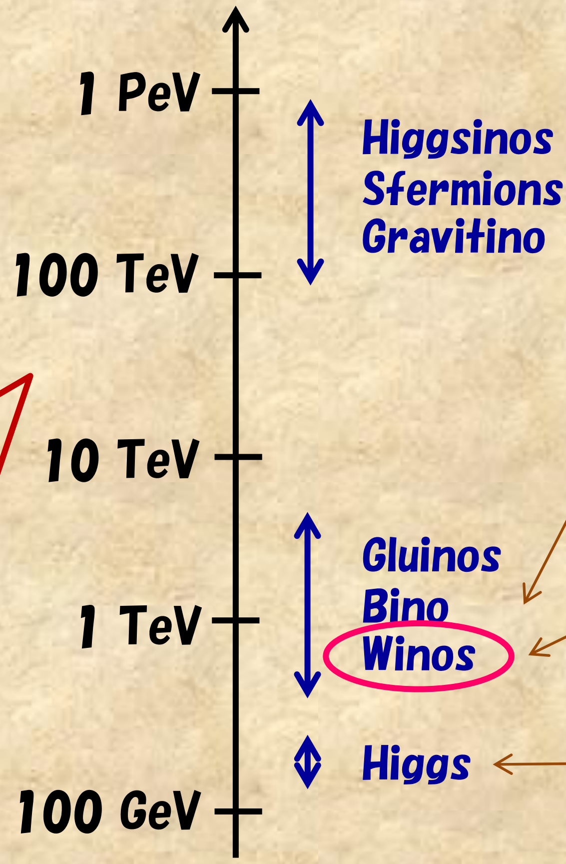
$SU(2)_L$ singlet: No renormalizable interactions with SM particles.
$SU(2)_L$ doublet: DM is a Dirac Fermion → Not favored by DD of DM.
$SU(2)_L$ triplet: Neutral component is lighter than charged ones.

1. Why the wino dark matter?

BSM which is behind the triplet DM? → MSSM with a simplest ~~SUSY~~

Higgs mass of 126 GeV
No Gravitino problem
No Polonyi problem
No FCNC problem
CP problem relaxed
No BSM @ current LHC
Consistent with GUT
Dark matter exists

MSSM — SUGRA interactions — No singlets → ~~SUSY~~



[Giudice and Masiero, (1988); Inoue, Kawasaki, Yamaguchi, Yanagida (1992)]

[Dine, MacIntire (1992); Giudice, Luty, Murayama, Rattazzi (1998); Randall , Sundrum, (1999); Bagger, Moroi, Poppitz, (2000); Binetruy, Gaillard, Nelson, (2001)]

Thermal: [Hisano, Matsumoto, Nagai, Saito, Senami (2007)]
Non-thermal: [Moroi et al (1999)]

[Okada, Yamaguchi, Yanagida (1990), Ellis et al (1990), Haber et al (1990)]

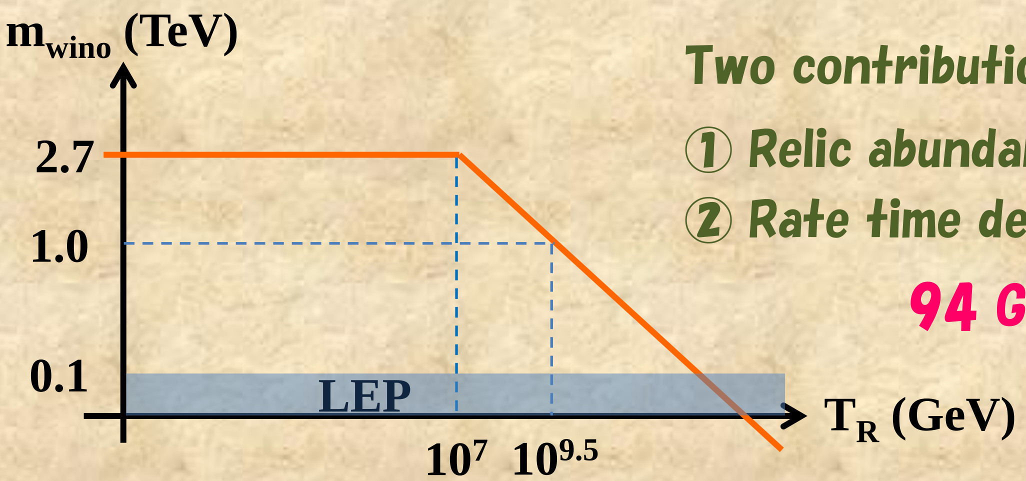
☆ Pure gravity mediation model [M. Ibe, S.M., T. Yanagida,]
☆ Strong moduli stabilization [E. Dudas, A. Linde, Y. Mambrini, A. Mustafayev, K. Olive]
☆ Gravity mediation retrofitted [M. Bose, M. Dine, 2012]
☆ Mini-split model [A. Arvanitakia, N. Craigb, S. Dimopoulos, G. Villadoroc,]
☆ Spread supersymmetry [L. Hall, Y. Nomura, Shirai]

1. Why the wino dark matter?

Physics of Wino dark matter is governed by SU(2) gauge interaction.
→ Relevant new physics parameter is only the wino mass.

Wino DM is highly degenerated with Charged wino (Δm = 160 MeV)

Limits on the mass from the LEPII and cosmology:



Two contributions to the DM abundance today

① Relic abundance from thermal decoupling

② Rate time decay of the gravitino to the DM

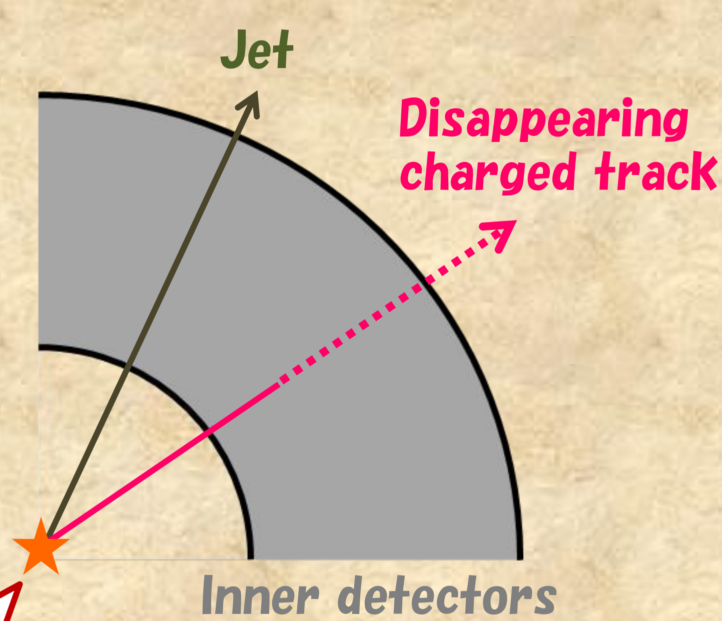
$94 \text{ GeV} < m_{wino} < 2.7 \text{ TeV}$

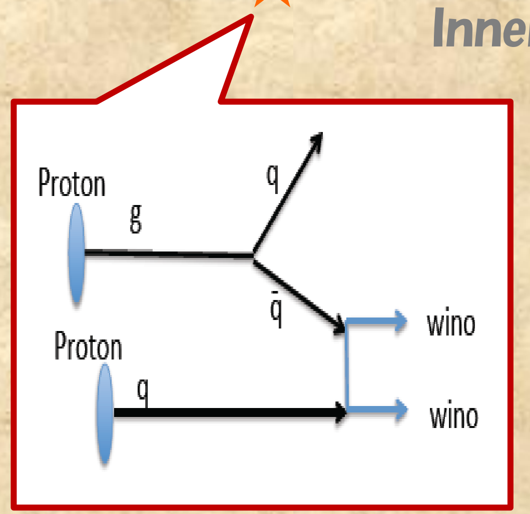
Thermal leptogenesis works when the wino mass is enough less than 1 TeV.

2. Phenomenology of the Wino DM

~ Direct (charged) wino production @ LHC ~

[Ibe, Moroi, Yanagida (2007), Asai, Moroi, Yanagida (2008)]





[ATLAS, JHEP1301 (2013)]

Decay process of charged wino

Charged wino → Neutral wino + π

Its decay width is sensitive to the mass difference between charged and neutral winos.

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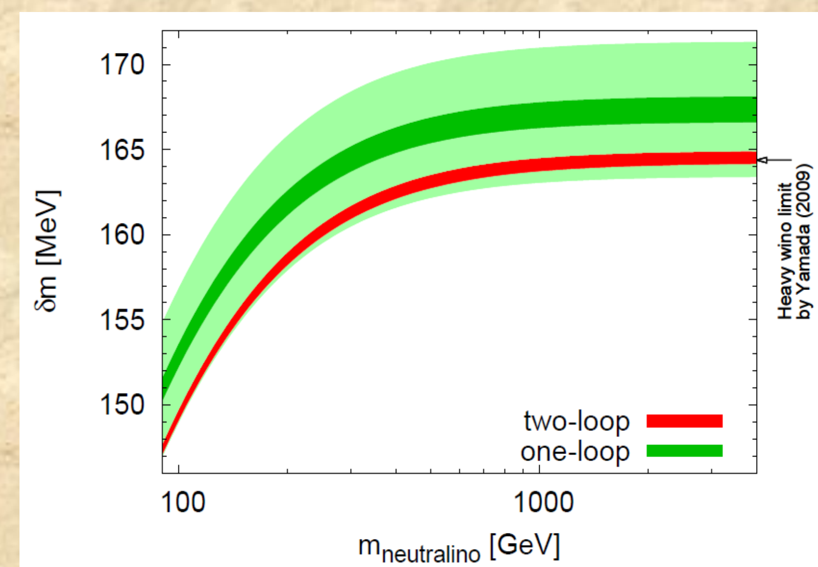
Two-loop level calculation!

[Ibe, Matsumoto, Sato (2013)]



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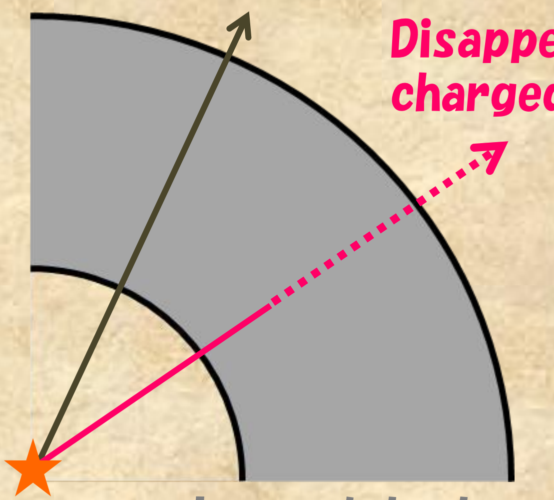

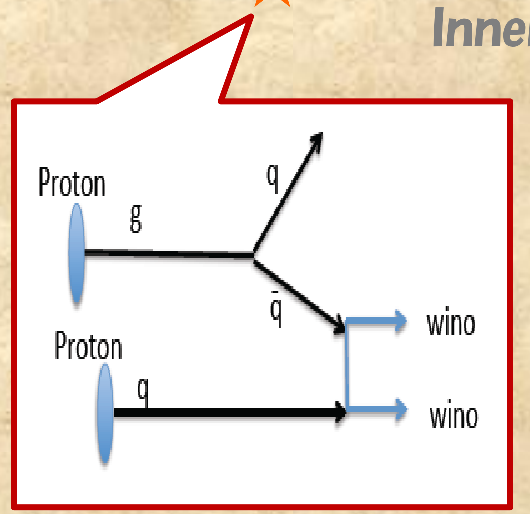

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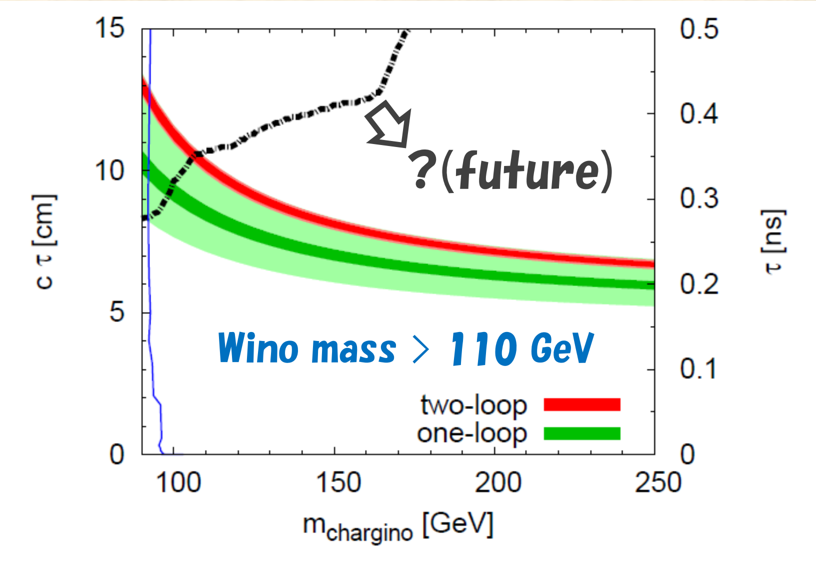
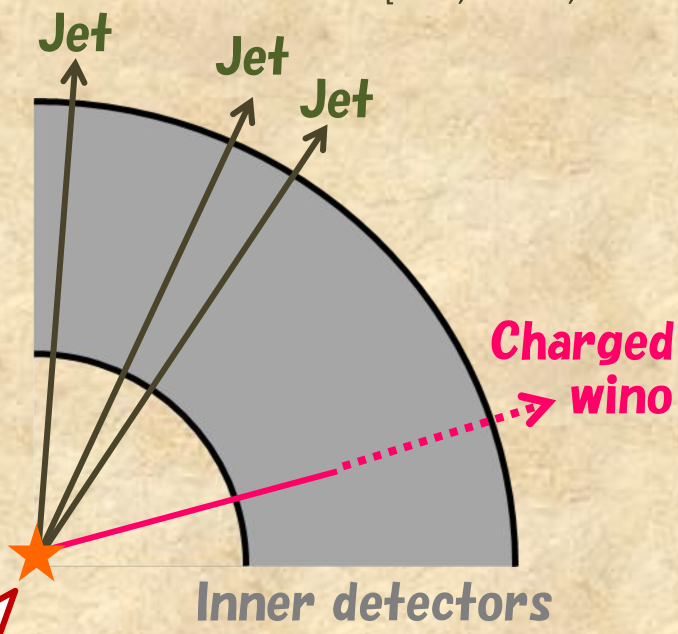
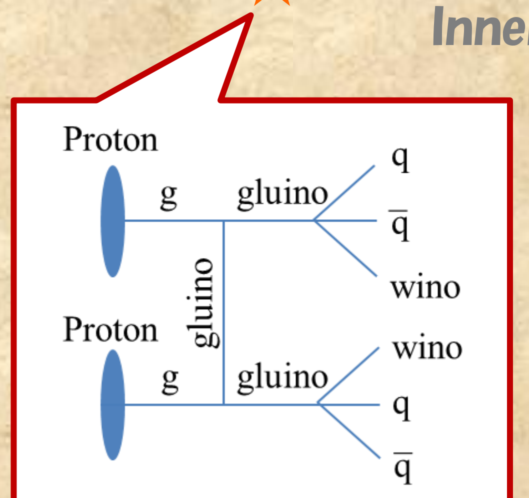


2. Phenomenology of the Wino DM

~ Gluino assisted wino production @ LHC ~

[Asai, Moroi, Ishihara, Yanagida (2007)]



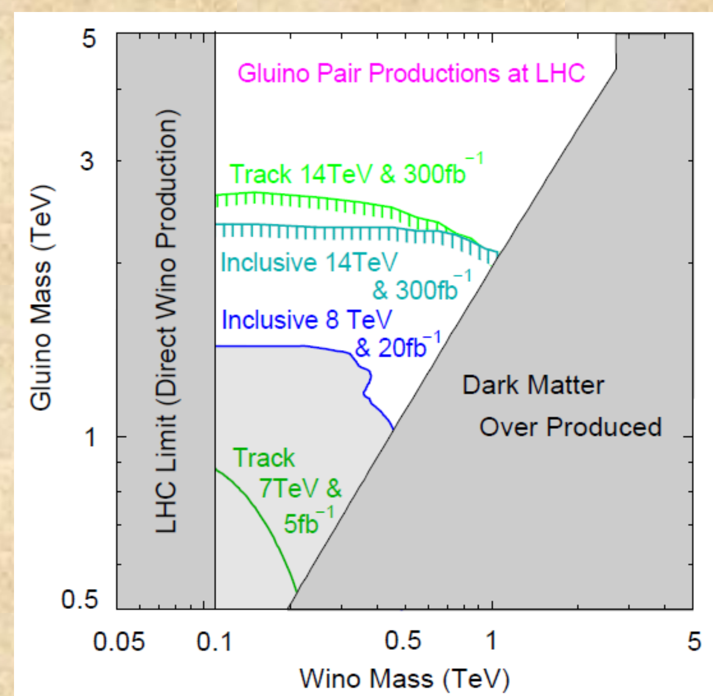


[ATLAS, Eur. Phys. J. C72 (2012)]

Two strategies to analyze the process.

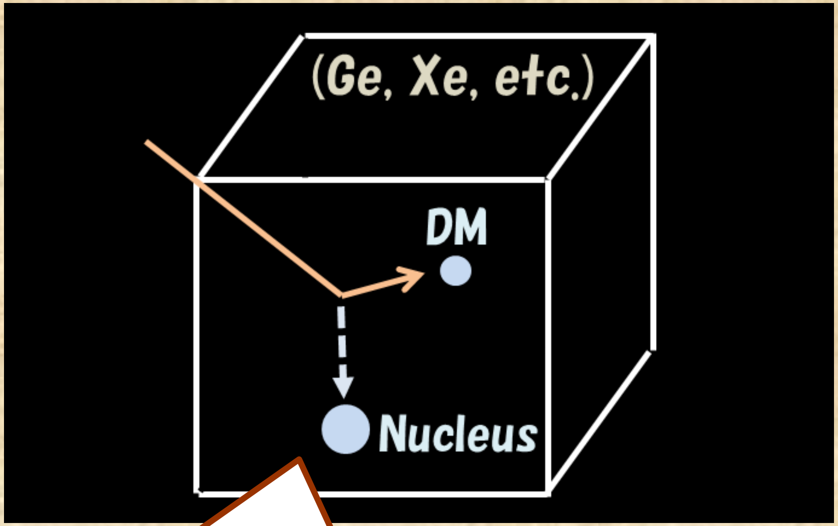
1. Inclusive channel (**Multi-jets + E_T**)
2. Inclusive channel + disappearing tracks (**Multi-jets + E_T + track**)

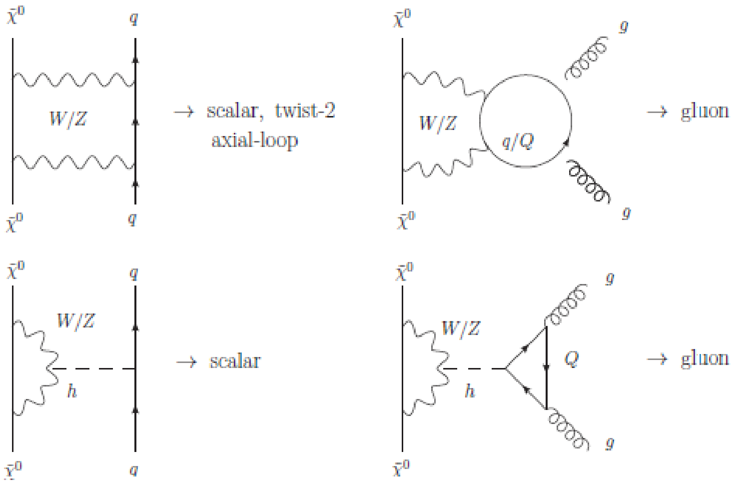
[Bhattacherjee, Feldstein, Ibe, Matsumoto, Yanagida, (2012)]



2. Phenomenology of the Wino DM

~ Direct detection of the Wino DM ~



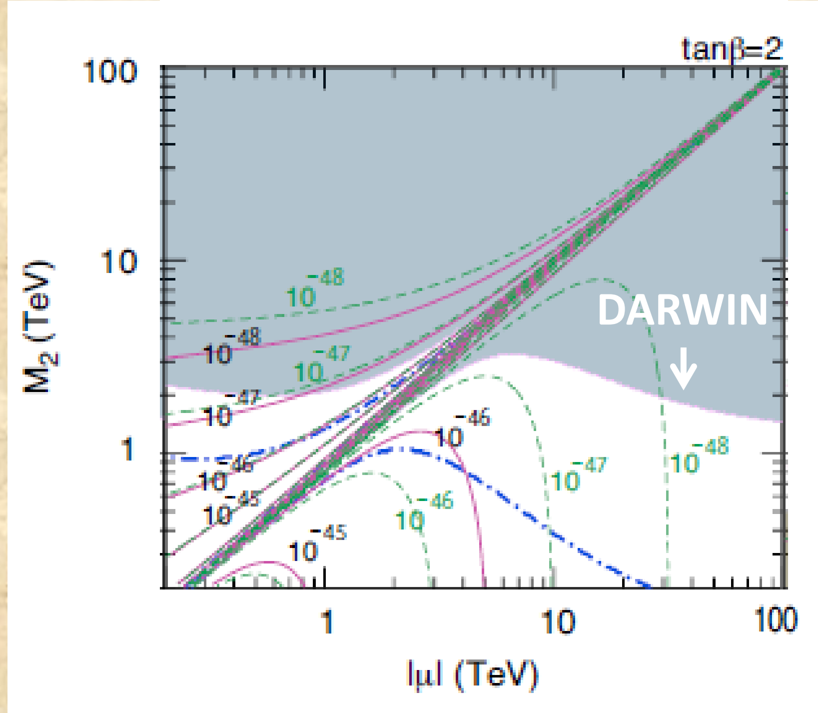


[Hisano, Matsumoto, Nojiri (2004)]

No tree-level diagrams inducing the scattering between the wino DM and Nucleon. Two-loop level calculation is needed to estimate it quantitatively.

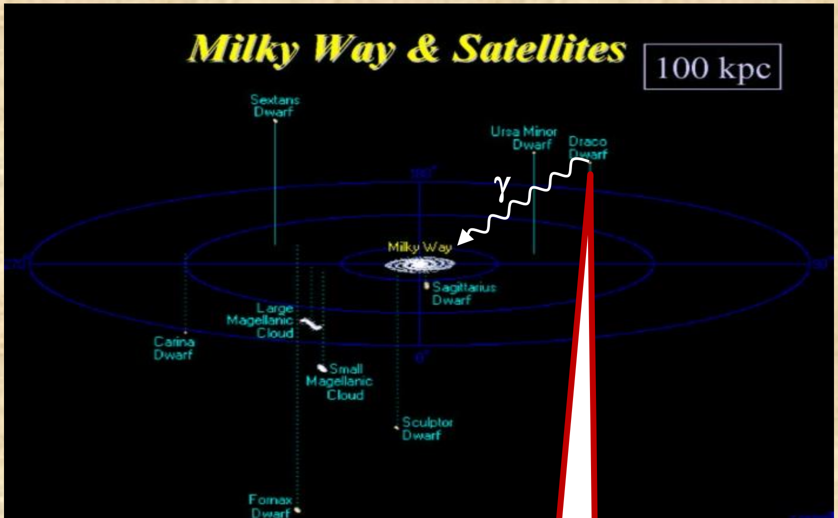
[Hisano, Ishiwata, Nagata (2012)]

DARWIN may find the signal in future.



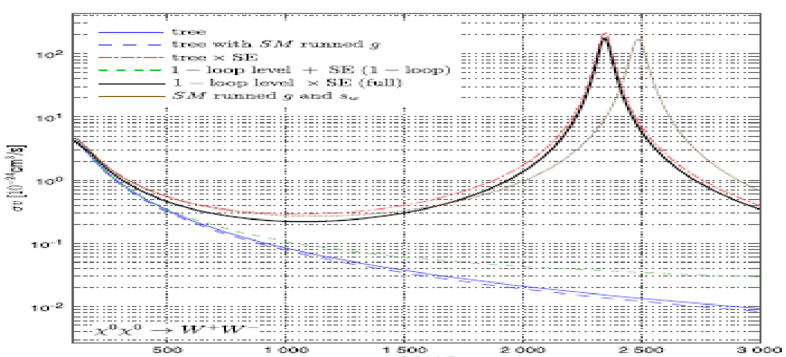
2. Phenomenology of the Wino DM

~ Indirect detection of the Wino DM ~



Wino annihilation is boosted by the Sommerfeld effect.

[Hisano, Matsumoto, Nojiri (2004)]

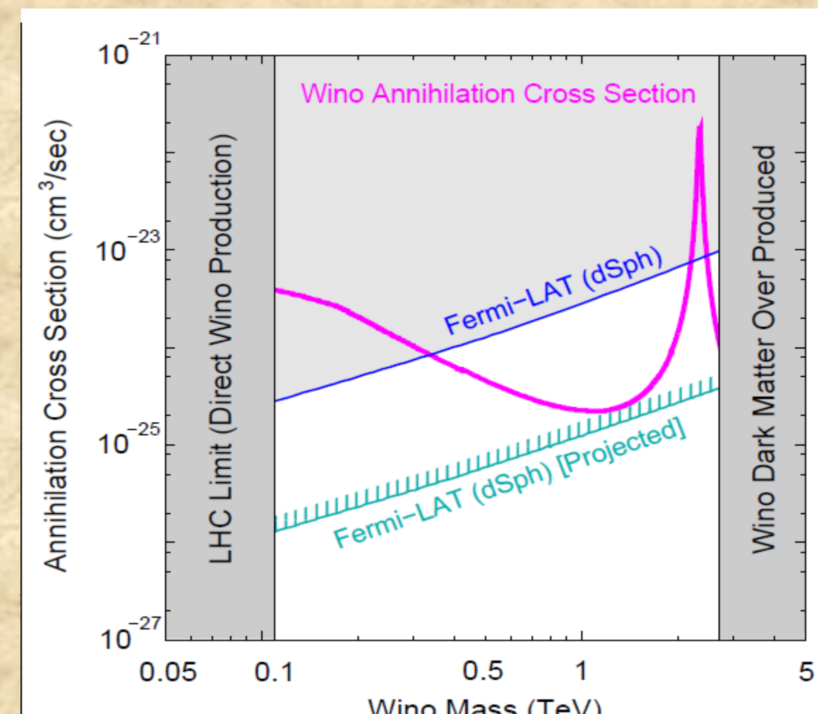


The most reliable limit is obtained by the observation of gamma-rays from milky-way satellites at Fermi-LAT.

[Fermi-LAT, PRL 107 (2011)]

We have performed dedicated analysis.

[Bhattacherjee, Ibe, Ichikawa, Matsumoto, Nishiyama (2013)]

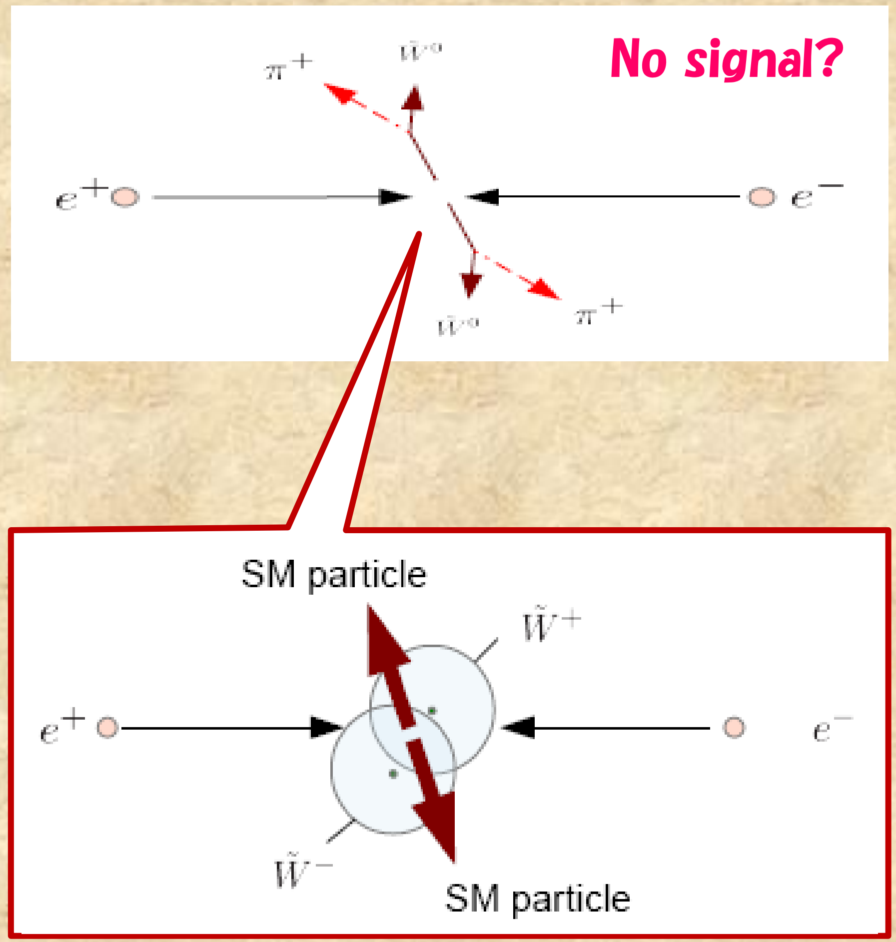


2. Phenomenology of the Wino DM

～ Threshold production of the wino DM at ILC ～

[Asai, Moroi, Ishihara, Yanagida (2007)]

Pair production of charged wino

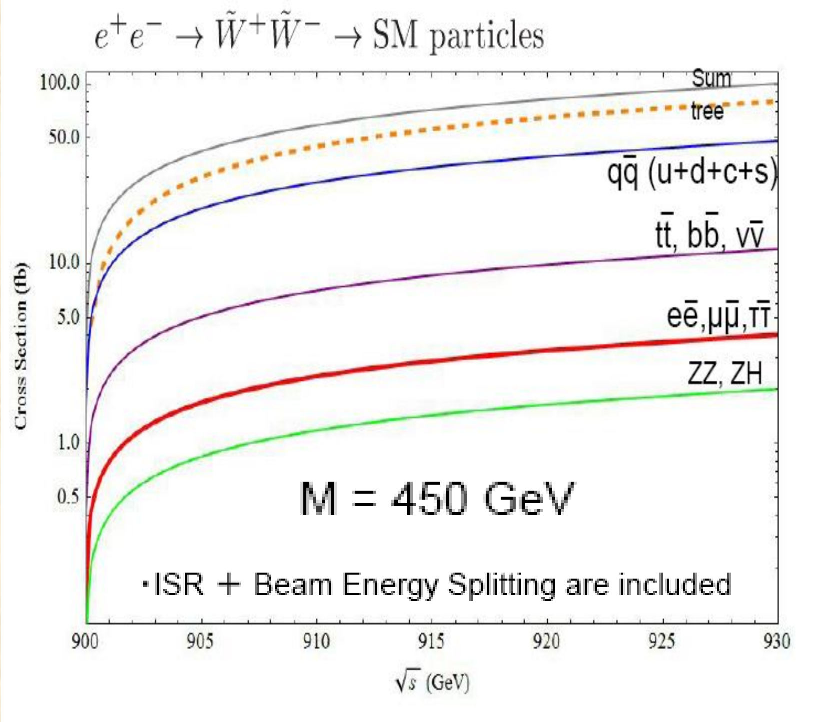


All winos annihilate before they decay.

[Ichikawa, Nojiri, and S. M.(2013)]

For 340 GeV < Wino Mass << 1 TeV, the (charged) wino will be produced in a non-relativistic way at the ILC.

At first glance, no signal can be obtained because of the final sate.



3. Summary

- SU(2) triplet fermion with a B-L charge zero is the best candidate for dark matter from the viewpoint of minimality. It is also consistent with the MSSM with the simplest SUSY breaking (AMSB/PGM).

- Before LHC starts, the limit on the wino mass was 94 GeV < Wino mass < 2.7 TeV. Now, current limit is 110 GeV < Wino mass < 2.7 TeV. When we seriously take the thermal leptogenesis, the limit should be 110 GeV < Wino mass << 1 TeV.

- Several phenomenology of the wino dark matter has been considered: expected signals at the LHC, direct detection, indirect detection, and the ILC. Whole mass range can be tested in future.