Probing Wino Dark Matter at ILC

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with
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  - Why wino dark matter?
  - AMSB
- Current Experimental Limit
  - From Colliders, Astronomical observations
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  - Solution
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- Summary, Future Directions

SUSY

- The Higgs UV divergences is cancelled by the sparticle loops
- Dark matter candidates exist
- Unification of the gauge coupling constants

- Minimal extention of SM contents

  →Minimal Supersymmetric Standard Model (MSSM)

Favored parameter region of MSSM 1

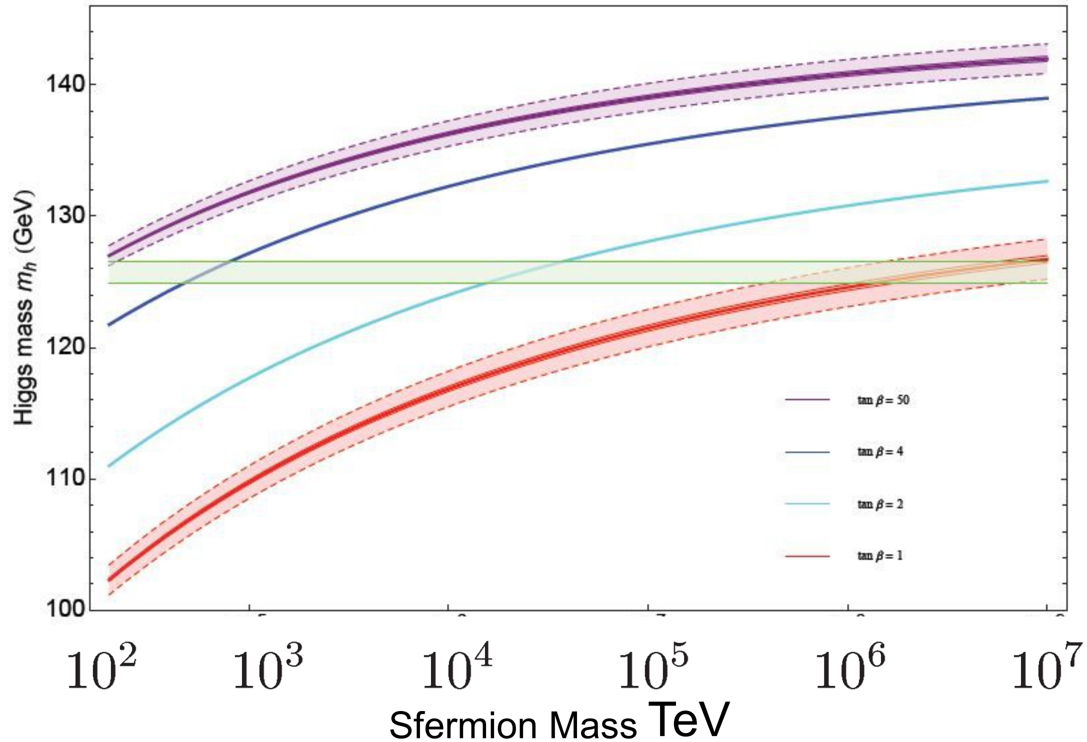
- No BSM signal → $M_{\rm SUSY} \gtrsim {\rm O(1)TeV}$
- Higgs mass ~126GeV

$$\rightarrow M_{\rm SUSY} >> {\rm O(1)TeV}\ ?$$

Large radiative correction
(Okada, Yamaguchi, Yanagida Prog.Theor.Phys85(1991))

→ High scale SUSY?

Arkani-Hamed et al :hep-ph 1212.6971
$m_{\rm h} 125.7 \pm 0.8{\rm GeV}$
$m_{\rm t} 173.2 \pm 0.9{\rm GeV}$



Favored parameter region of MSSM 2

- High scale SUSY（e.g mSUGRA ）

  →DM mass >>O（1）TeV

  →Too much DM relic density

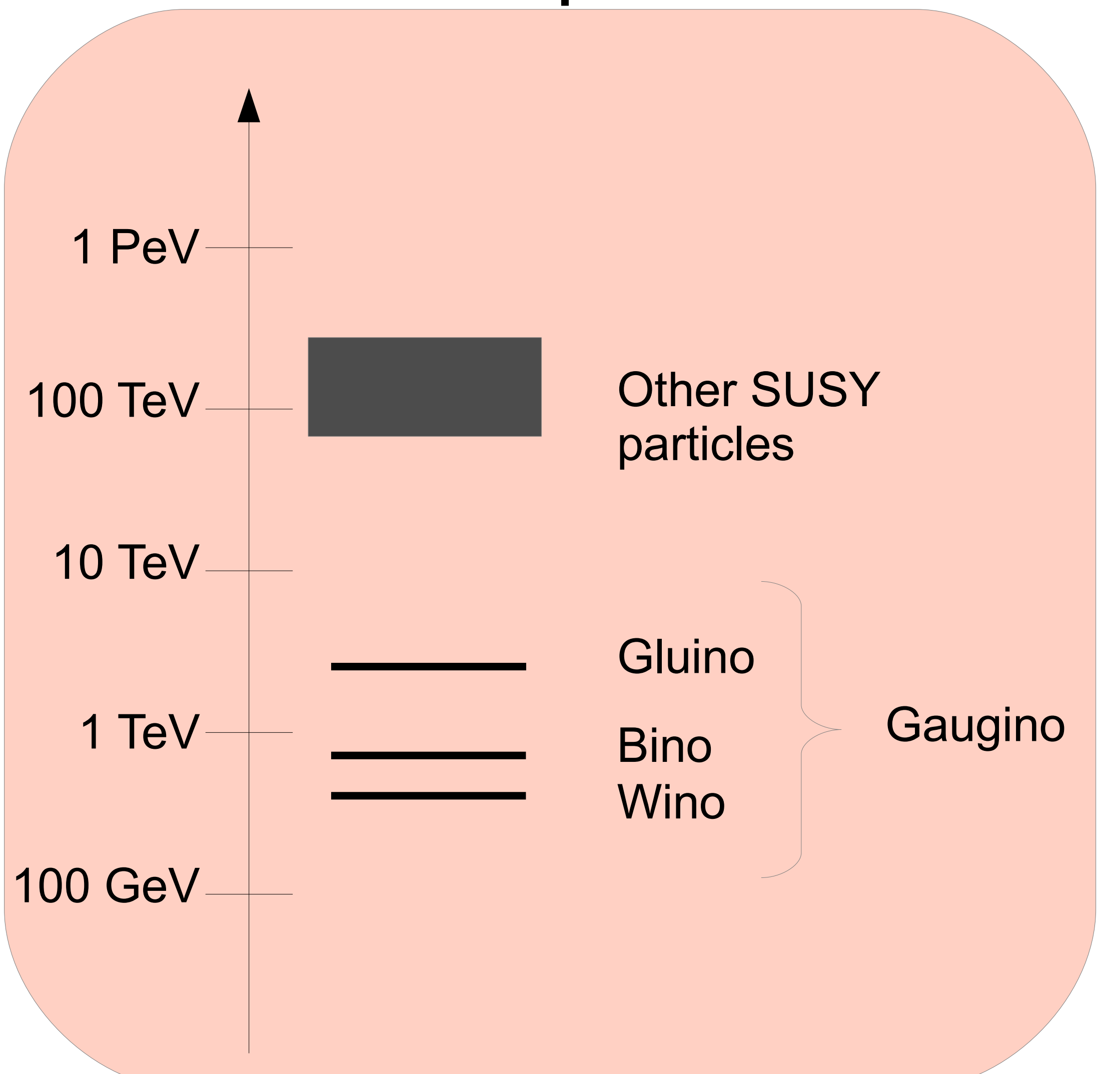
- Large sfermion mass and small DM mass seems to be favored.

Does such a model exist ? → AMSB

Anomaly Mediation Scenario

Giudice, Luty, Murayama, Rattazzi, JHEP9812(1998)

- The Mass Spectrum



- Sfermion : Tree (SUGRA)

  Gaugino : 1 loop

  $\rightarrow M_{\tilde{q}}/M_{\tilde{g}} \sim 100$

- Merit
  - FCNC constraints are relaxed
  - No gravitino problem
- Characteristics

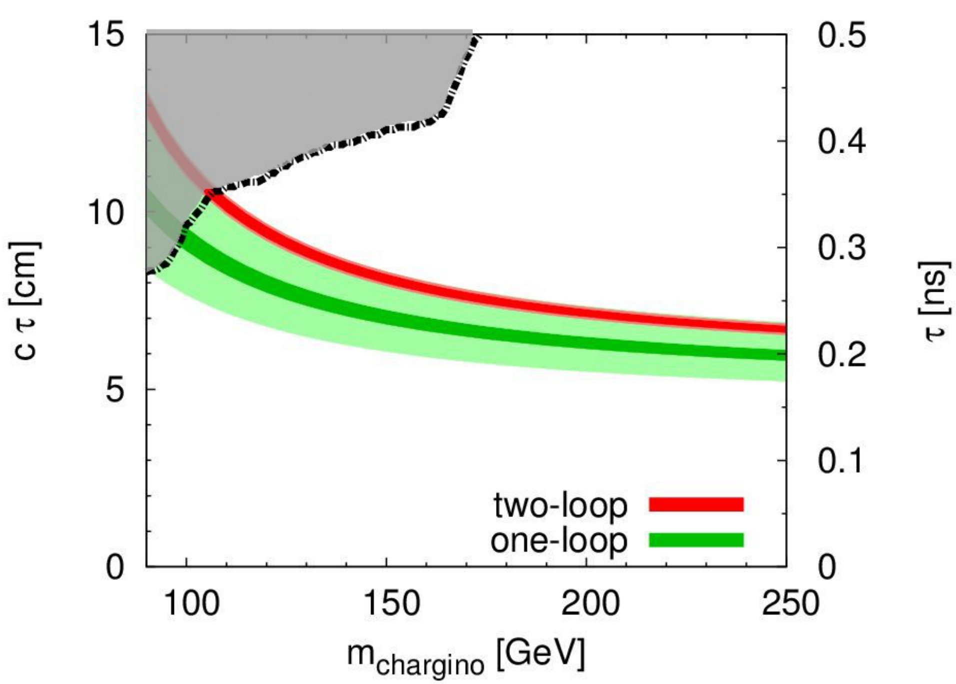
  Neutral wino is the lightest SUSY particle

  →How to probe the wino?

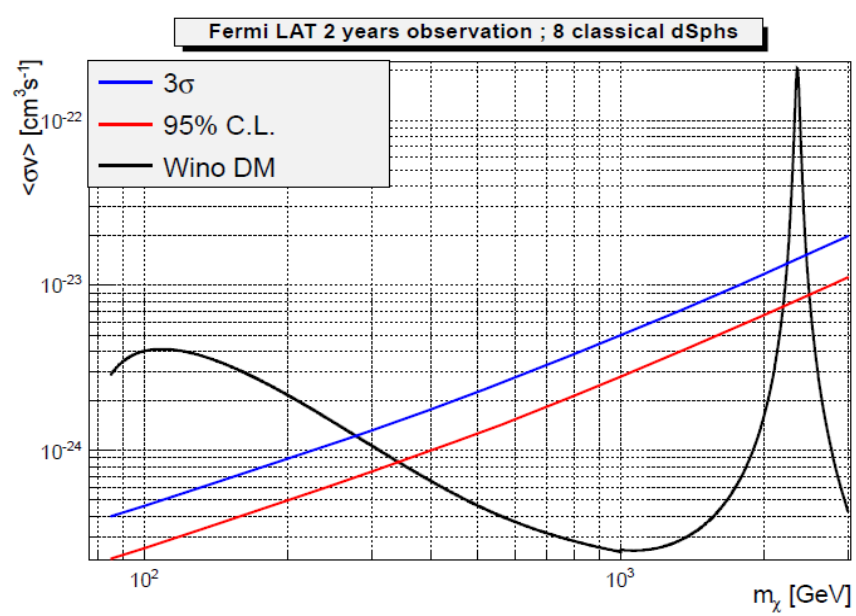
  Especially at ILC?

Wino DM: observational limit

- Collider→LHC bound $M_{\rm wino} \gtrsim 110{\rm GeV}$ (95 % CL)
- Astro→γ-ray observation from the milky way satellite galaxies $M_{\rm wino} \gtrsim 340{\rm GeV}$
  For two years observation (95 % CL)
- DM relic abundance $M_{\rm wino} \lesssim 2.7{\rm TeV}$ M. Ibe, et al, PLB709, (2012)



Ibe,Matsumoto,Sato:hep-ph1212.5989

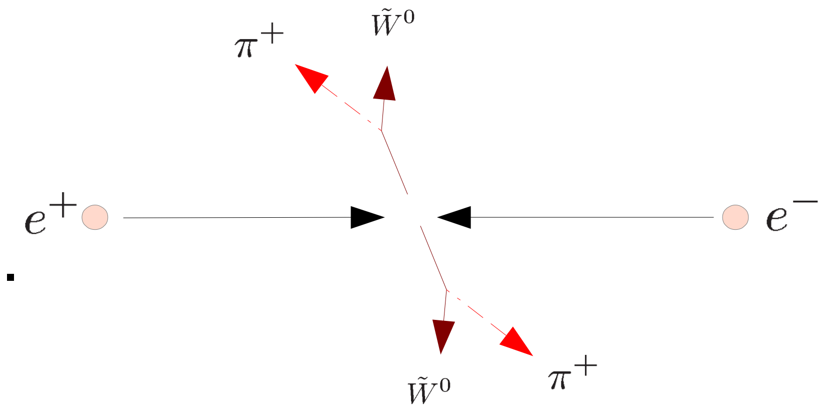


Nishiyama et al

ILC : How to probe the heavy wino?

- <u>Direct production</u> :

  There seems to be problems below...



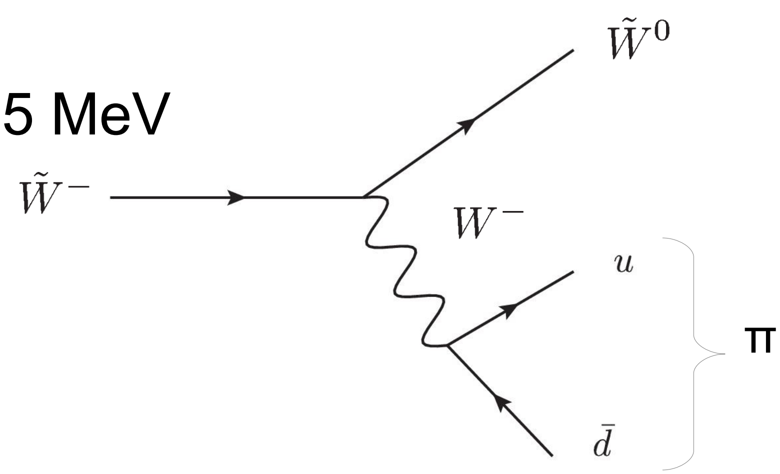
1. Charged winos are created non-relativistically

→They decay before detectors

2. Mass defference between

charged wino and neutral wino～165 MeV

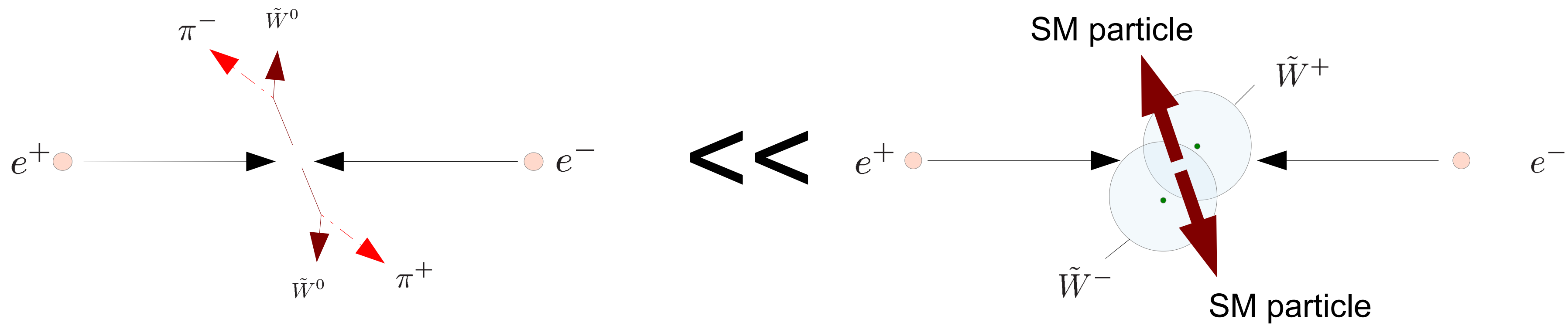
→Soft pion emmition (～20MeV)



ILC : How to probe the heavy wino?

In fact, no problem because

Created Winos annihilate into SM particles



Chargino Decay << Pair Annihilation

non-relativistic creation + attractive force + long lifetime

- ☐ There are "Charged winos ⇒ SM particles" reactions

→SM particles have the wino creation signal

- ☐ The annihilation effect can be estimated by NR quantum field theory.

We also obtain

- the annihilation branching ratio
- the cross section around the threshold energy

Set Up

- Model: SM + Wino
- Wino mass: 450 GeV

$$L_{\text{eff}} = L_{\text{SM}} + L_{\text{Wino}}$$

$$L_{\text{Wino}}^{\text{kin}} = i\bar{\tilde{W}}^- \not{\partial} \tilde{W}^- - m_c \bar{\tilde{W}}^- \tilde{W}^- + \frac{i}{2} \bar{\tilde{W}}^0 \not{\partial} \tilde{W}^0 - m_n \bar{\tilde{W}}^0 \tilde{W}^0$$

$$L_{\text{Wino}}^{\text{int}} = -g\bar{\tilde{W}}^- \not{W}^- \tilde{W}^0 - g\bar{\tilde{W}}^0 \not{W}^+ \tilde{W}^- - g\bar{\tilde{W}}^- \left(c_w \not{Z} + s_w \not{A}\right) \tilde{W}^-$$

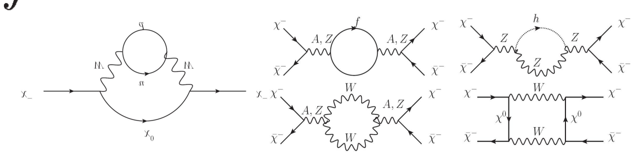
Calculation Flow

SM + Wino Lagrangian

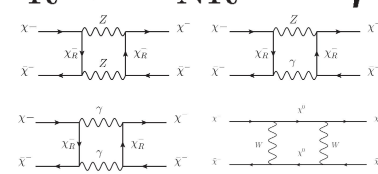
$$L = L_{\rm SM} + L_{\rm Wino}$$
$$L^{\rm kin}_{\rm Wino} = i\bar{\tilde{W}}^{-}\not{\partial}\tilde{W}^{-} - m_c\bar{\tilde{W}}^{-}\tilde{W}^{-} + \frac{i}{2}\bar{\tilde{W}}^{0}\not{\partial}\tilde{W}^{0} - m_n\bar{\tilde{W}}^{0}\tilde{W}^{0}$$
$$L^{\rm int}_{\rm Wino} = -g\bar{\tilde{W}}^{-}\not{W}^{-}\tilde{W}^{0} - g\bar{\tilde{W}}^{0}\not{W}^{+}\tilde{W}^{-} - g\bar{\tilde{W}}^{-}\left(c_w\not{Z} + s_w\not{A}\right)\tilde{W}^{-}$$

Integration of the fields except wino + **Integration of the high momentum wino**

$$\int \mathscr{D}A\mathscr{D}Z\mathscr{D}W^{\pm}\mathscr{D}G\mathscr{D}\psi\mathscr{D}\bar{\psi}...$$



$$\tilde{W} = \tilde{W}_{\rm R} + \tilde{W}_{\rm NR} \;\rightarrow \int \mathscr{D}\tilde{W}_{\rm R}$$



Effective action for a composite field of the 2 body winos(Winonium)

$$S^{\rm kin}_{\rm eff} = \int dR^4 d\mathbf{r}^3 \phi^{i\dagger}_C(\mathbf{r},R)\left[i\partial_{R^0} + \frac{\nabla^2_{\mathbf{R}}}{4m} + \frac{\nabla^2_{\mathbf{r}}}{m} + \frac{\alpha + \alpha_2 c_W^2 e^{-m_z r}}{r} + i\Gamma + 2i\gamma\delta^3(\boldsymbol{r})\right]\phi^i_C(\mathbf{r},R)$$

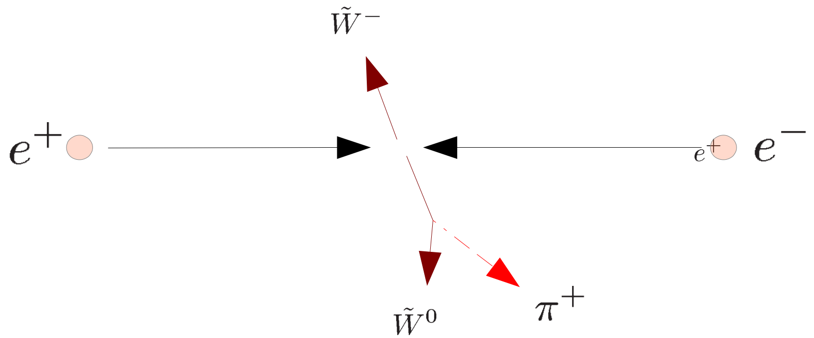
2 body state for thecharged winos (Spin 1)

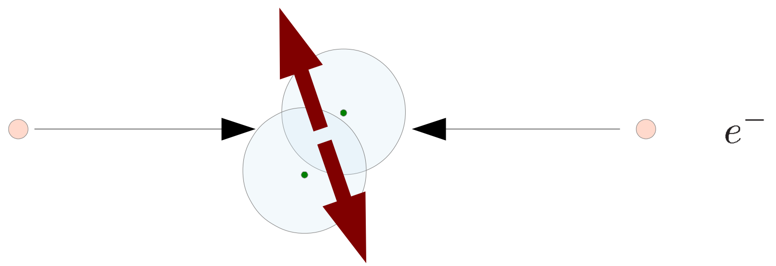
Coulomb,Yukawa Potential

Charged wino decay

Annihilation

Chargino decay VS Annihilation





$\Gamma_{\text{Decay}} \sim 2.7 \times 10^{-15}\text{GeV}$ **<<** $\Gamma_{\text{Ann}} \sim 10^{-4}\text{GeV}$

$$\Gamma_{\text{Ann}} = 4\gamma m|\psi(\mathbf{0})|^2$$

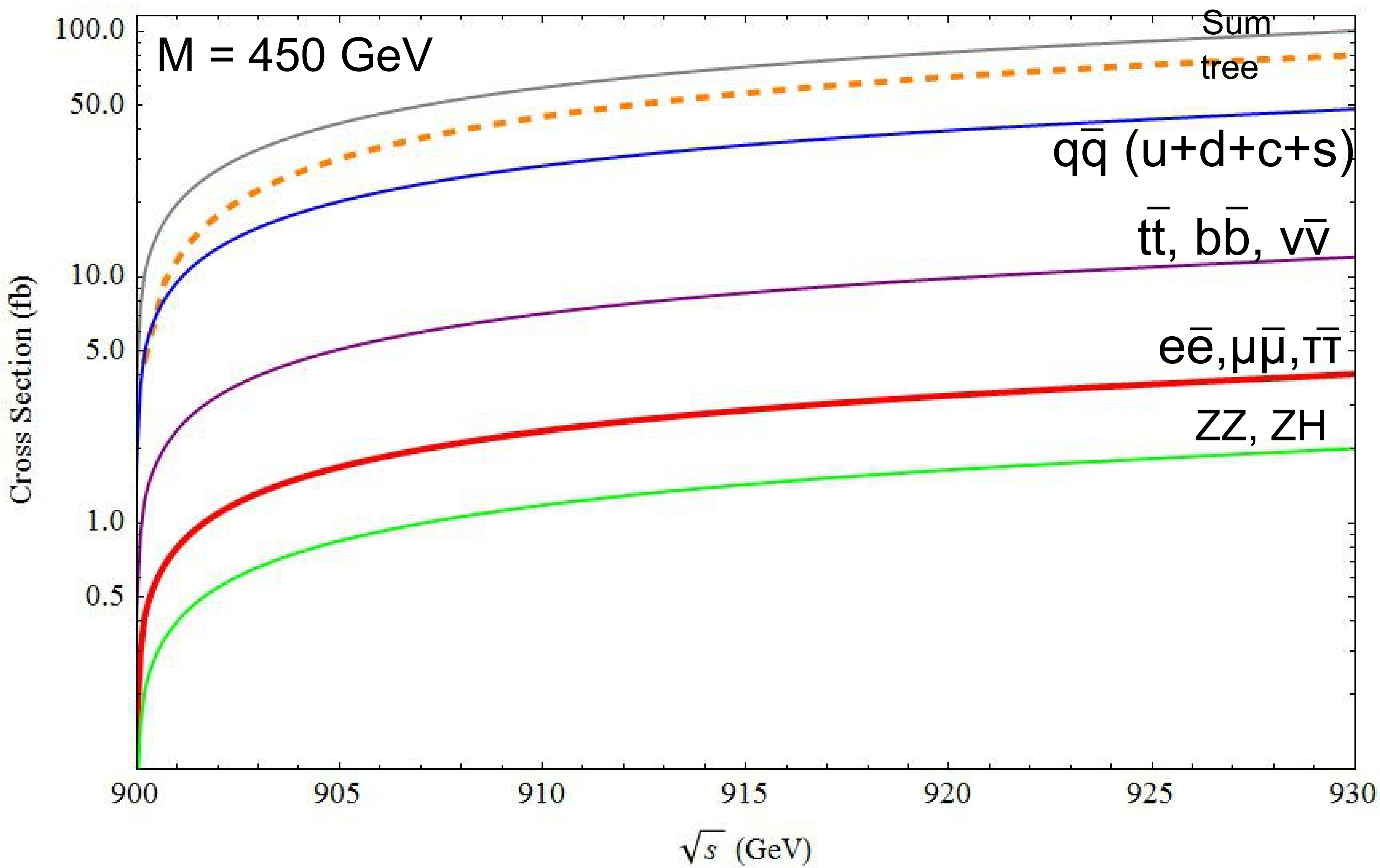
$$\left(\frac{\nabla_{\boldsymbol{r}}^2}{m} - V(\boldsymbol{r}) + \frac{k^2}{m}\right)\psi(\boldsymbol{r}) = 0,$$

$$k \equiv \sqrt{m(\sqrt{s} - 2m)}$$

Annihilation effect is dominated

The numerical result @ M = 450 GeV

$$e^+e^- \to \tilde{W}^+\tilde{W}^- \to \text{SM particles}$$



- ISR ＋ Beam Energy Splitting are included

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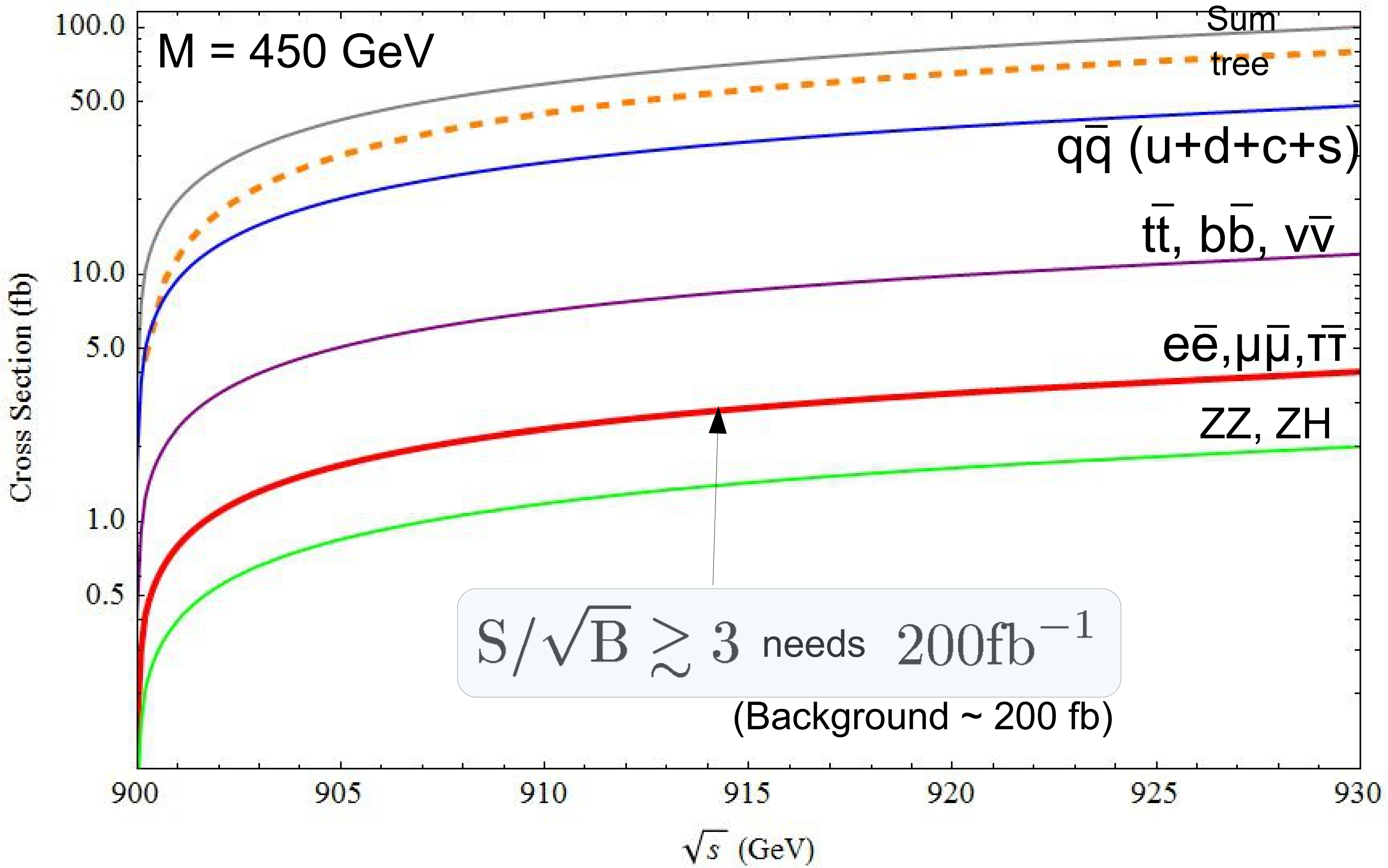


・ISR ＋ Beam Energy Splitting are included

Summary and Future directons

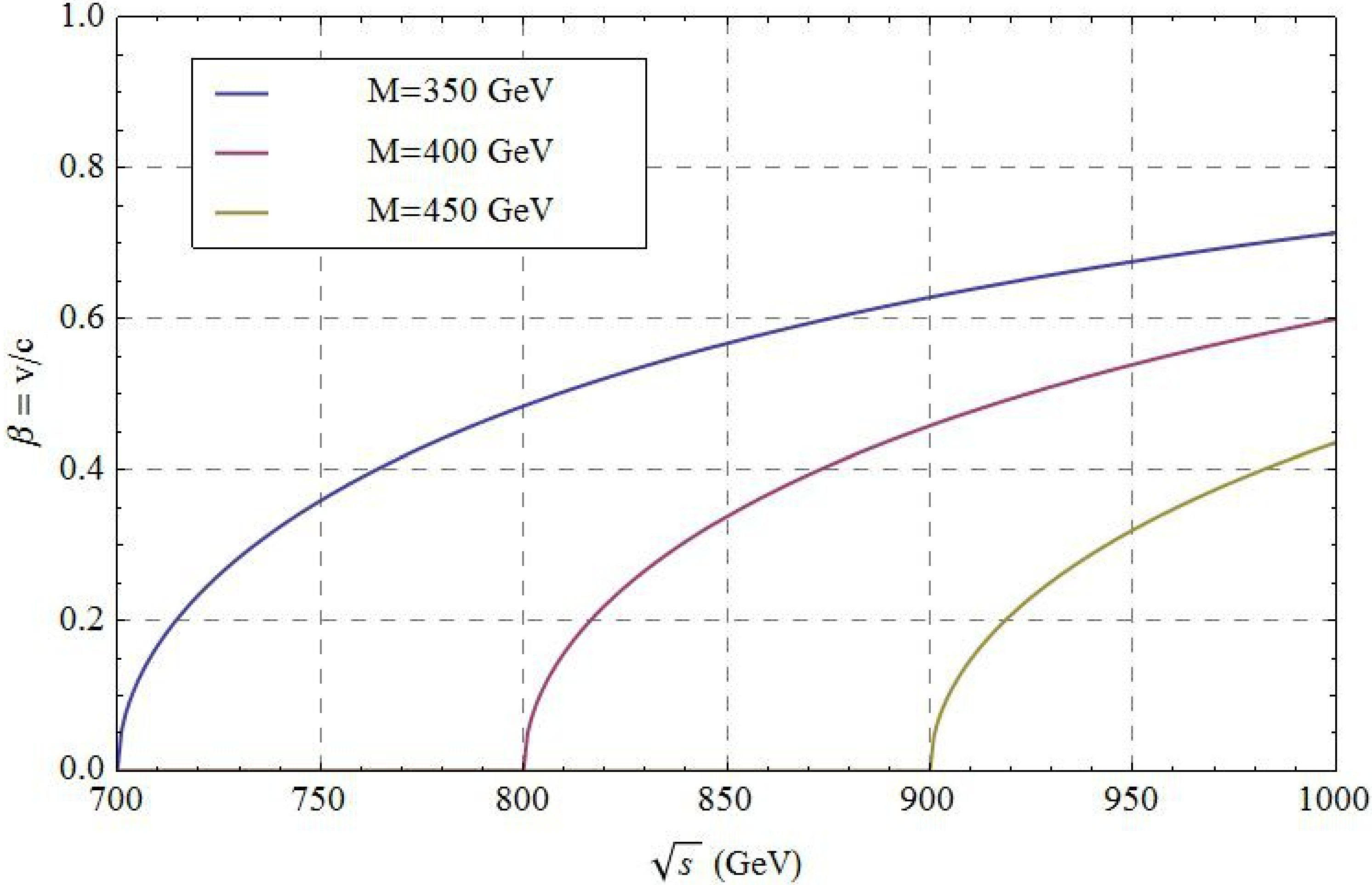
- NR charged wino pair production at ILC
  - Created wino pair annihilate before they decay
  - The wino signals can be probed through the SM excess if Mwino < 500 GeV

- Future directions:
  - A more detailed estimation for the cross section and the background.
  - Application to Higgsino LSP model
  - Higher order corrections

Thank you very much

Koji Ichikawa

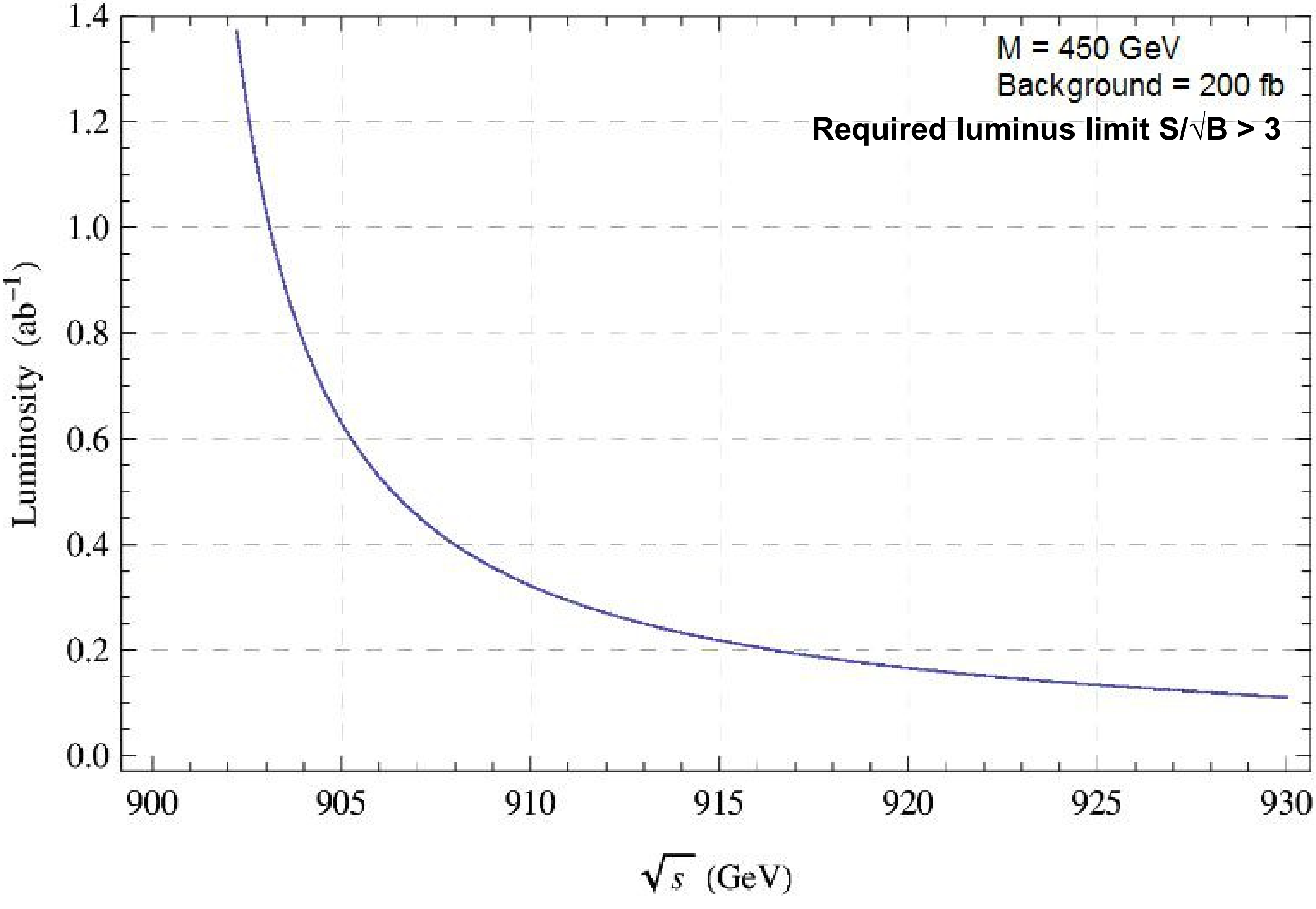
Back up

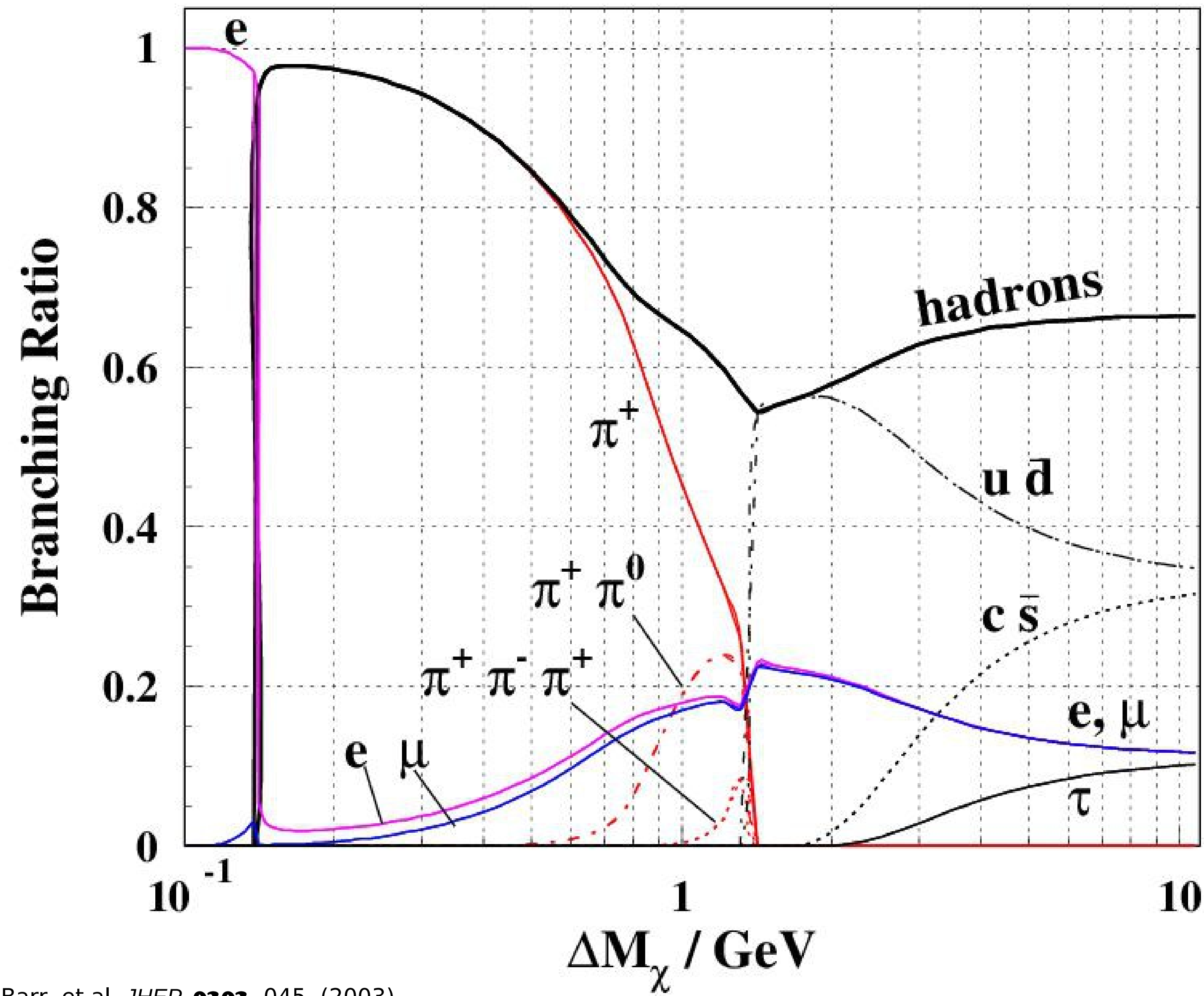


M=350 GeV
M=400 GeV
M=450 GeV
β = v/c
√s (GeV)
0.0
0.2
0.4
0.6
0.8
1.0
700
750
800
850
900
950
1000

The numerical result 3

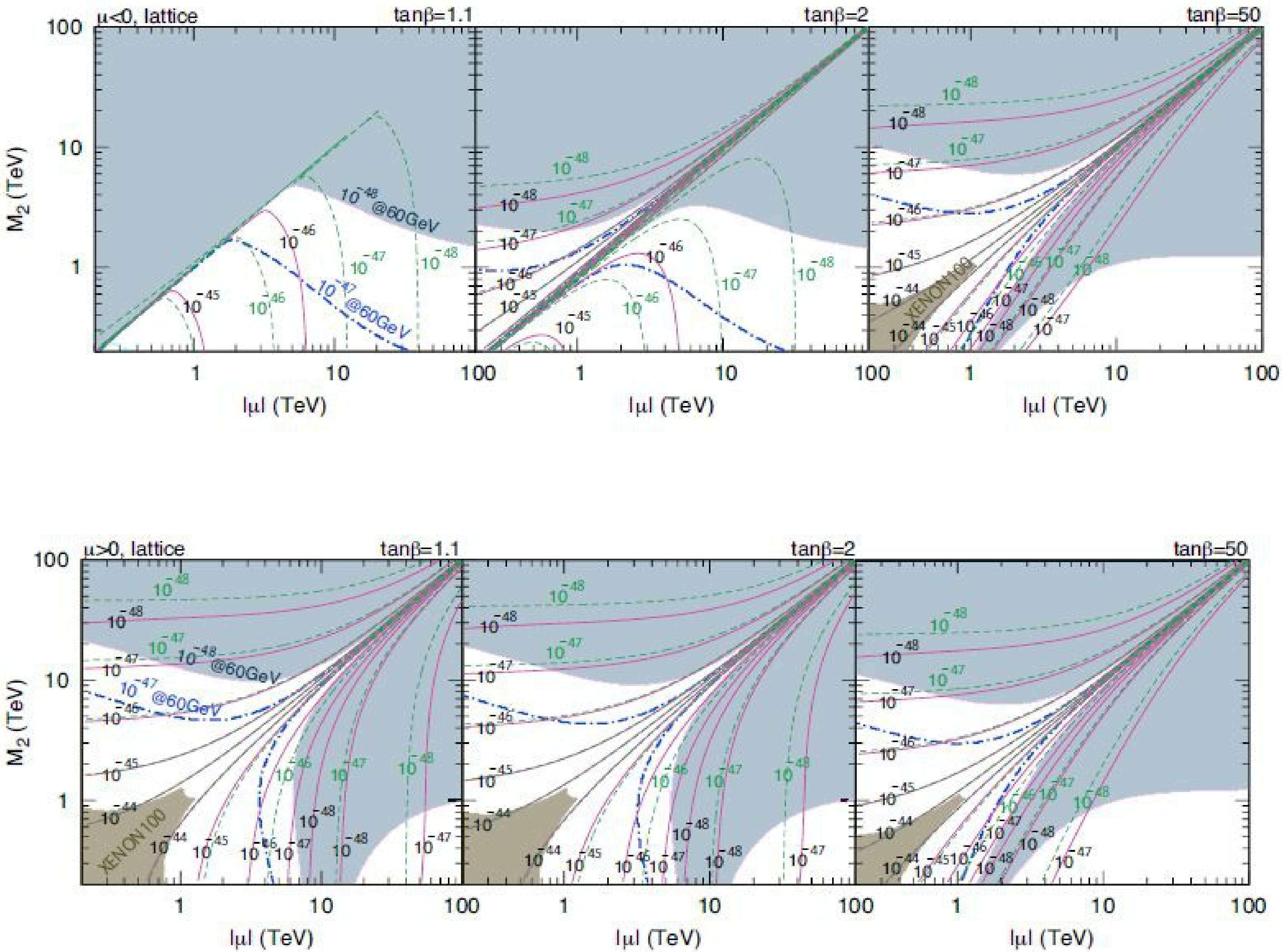
$$e^+e^- \to \tilde{W}^+\tilde{W}^- \to \mu^+\mu^- \text{ VS } \sqrt{\text{Background}}$$





A.J. Barr, et al, *JHEP*, **0303**, 045, (2003)

Direct Detection for Wino



Purple : Numerical Result

Dark Shaded: Exclusion resion by XENON100

Blue Dashed: Future Prospect (a ton-year Xenon target exp)

Hisano et al: hep-ph 1210.5985