Toward a Minimum Branching for Dark Matter Annihilation into Electromagnetic Final States

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Electroweak Bremsstrahlung in Dark Matter Annihilation
Nicole F. Bell, JD, Thomas D. Jacques, Thomas J. Weiler

Outline

- Bounds on DM annihilation to Standard Model products

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- Neutrinos only model and higher order corrections from SM processes

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- Neutrinos only model and higher order corrections from SM processes
- We calculate the branching ratio to charged leptons in a neutrinos only model and show that it is typically $\gtrsim 1\%$, when the scale of the dark matter mass(es) exceeds the electroweak scale, M_W

Bounds from Disappearance and Appearance Rates

- Thermal Relic Scale: $\Omega_\chi h^2 = 0.1$ requires an annihilation cross section of approximately $\langle v\sigma \rangle \sim 3 \times 10^{-26}$ cm^3 sec^{-1}

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- Alteration of Halo density profiles

  M. Kaplinghat, L. Knox, and M.S. Turner, Phys.Rev.Lett. **85**,3335 (2000)

Bounds from Disappearance and Appearance Rates

- Assuming that DM annihilation or decay is into SM particles neutrinos can be used to set an upper bound on the cross section.

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  H. Yuksel, S. Horiuchi, J.F. Beacom, and S. Ando, Phys.Rev.D **76**, 123506 (2007)

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- Measuring ν and γ fluxes leads to bounds on the cross section
- For a $Br(\gamma\gamma)$ of 10^{-4}, the ν bounds generally provide tighter constraints than photons for large dark matter masses ($M_\chi > 100$ MeV)

Embedding Neutrinos Only into Field Theory

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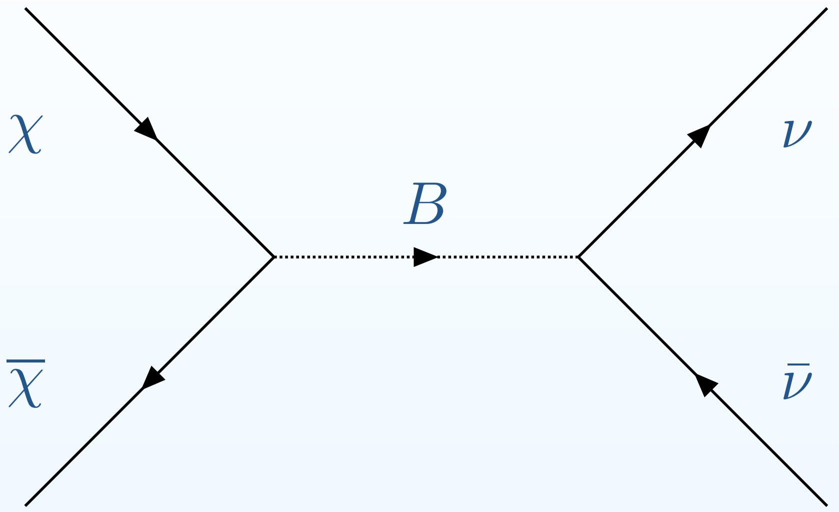
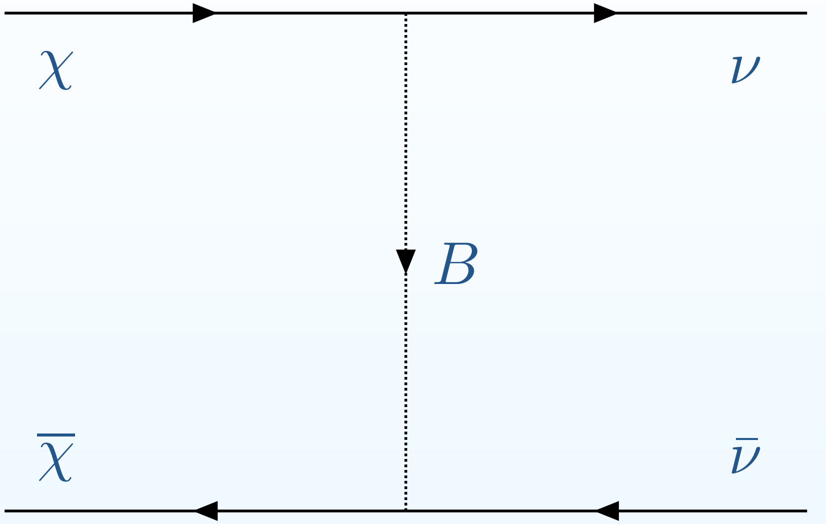
- Such an embedding proves to be unstable against higher order corrections
- Finely tuned effective theory below some scale Λ, or UV completion introduces a new spectrum at Λ

Neutrinos Only at Tree Level

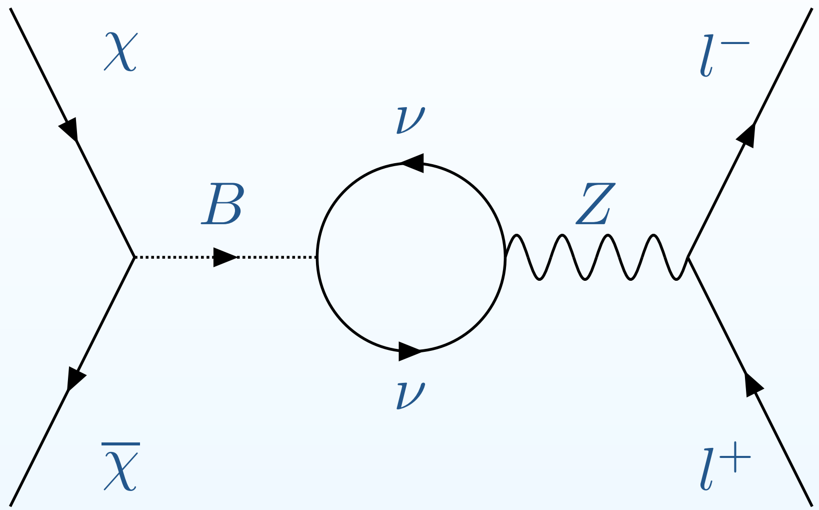


(I)

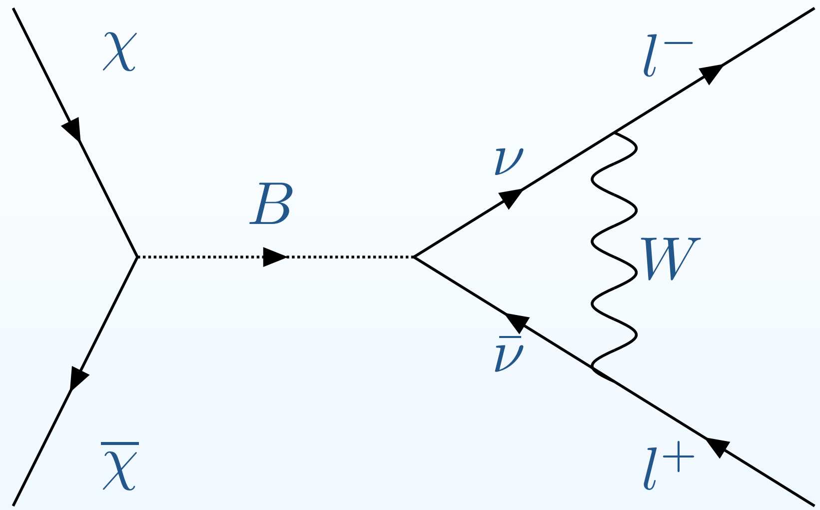


(II)

Loop Corrections

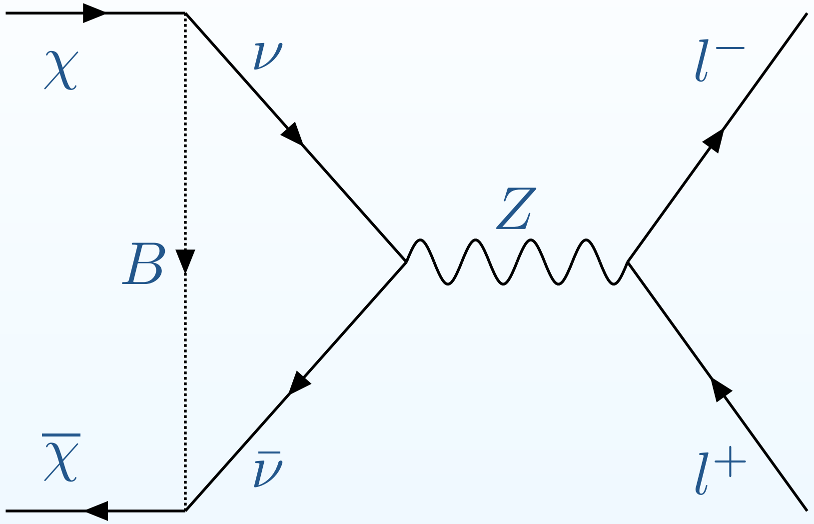


oblique correction, B-Z mixing

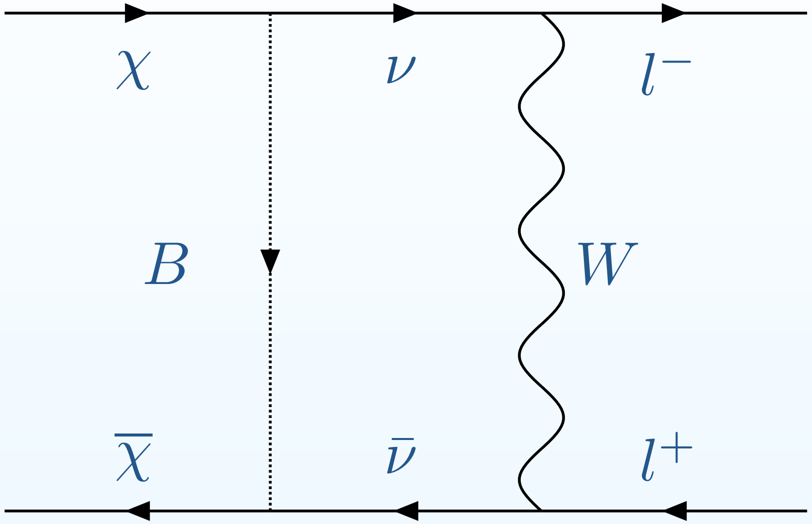


induced Bl^+l^- vertex

Loop Corrections

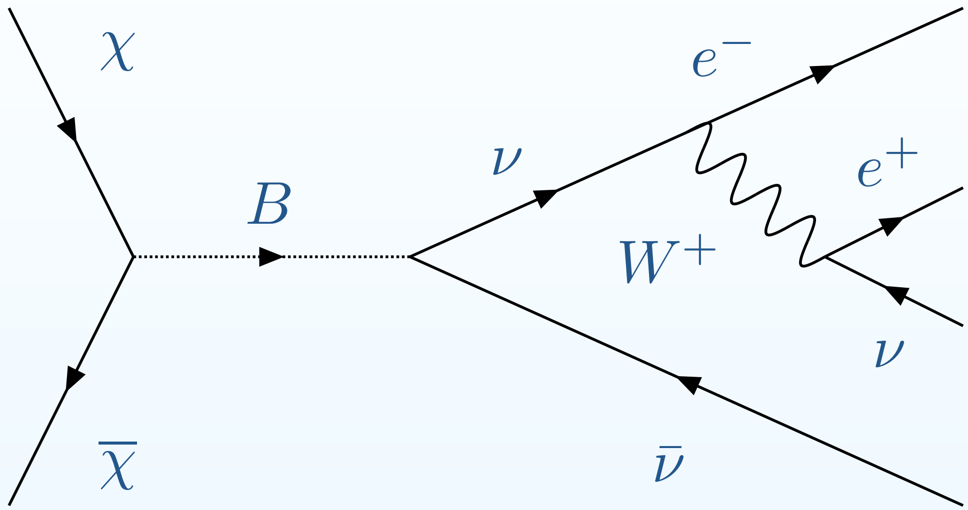


induced $Z\chi\bar{\chi}$ vertex



$\chi\bar{\chi}\nu\bar{\nu}$ box graph

Bremsstrahlung



Bremsstrahlung

first estimated by
M. Kachelriess and P.D. Serpico, Phys.Rev.D **76**, 063516 (2007).

The Box Diagram

- The (scalar) box diagram is logarithmically divergent
- There is no counterterm to suppress it
- We introduce a Pauli-Villars regulator which gives the cutoff scale Λ
- The final ratio

$$\mathcal{R} = \frac{\langle v\,\sigma(\chi\bar{\chi} \to l^+ l^-)\rangle}{\langle v\,\sigma(\chi\bar{\chi} \to \nu\,\bar{\nu}\,)\rangle}$$

will depend on three independent ratios of the four variables M_χ, M_B, Λ, and M_W.

Box Formula

We work in unitary gauge where the W propagator is given by

$$\frac{-i\,(g_{\mu\nu} - k_\mu k_\nu / M_W^2)}{k^2 - M_W^2 + i M_W \Gamma_W}$$

The overall ratio becomes

$$\mathcal{R} = \left(\frac{M_B^2 + M_\chi^2}{128 \cdot 8\pi \cdot M_W^2} \right)^2 \left[\int d\xi \, \ln \left| \frac{\Delta_\Lambda^2}{\Delta_B^2} \right| \right]^2$$

where

$$\Delta_B^2 \equiv \xi_1 \, M_B^2 + \xi_2 \, M_W^2 - (\xi_1 - \xi_1^2 - 2\xi_1\xi_2 + 4\xi_3\xi_4)\, M_\chi^2$$
$$\Delta_\Lambda^2 \equiv \xi_1 \, \Lambda^2 + \xi_2 \, M_W^2 - (\xi_1 - \xi_1^2 - 2\xi_1\xi_2 + 4\xi_3\xi_4)\, M_\chi^2$$

Range of Validity

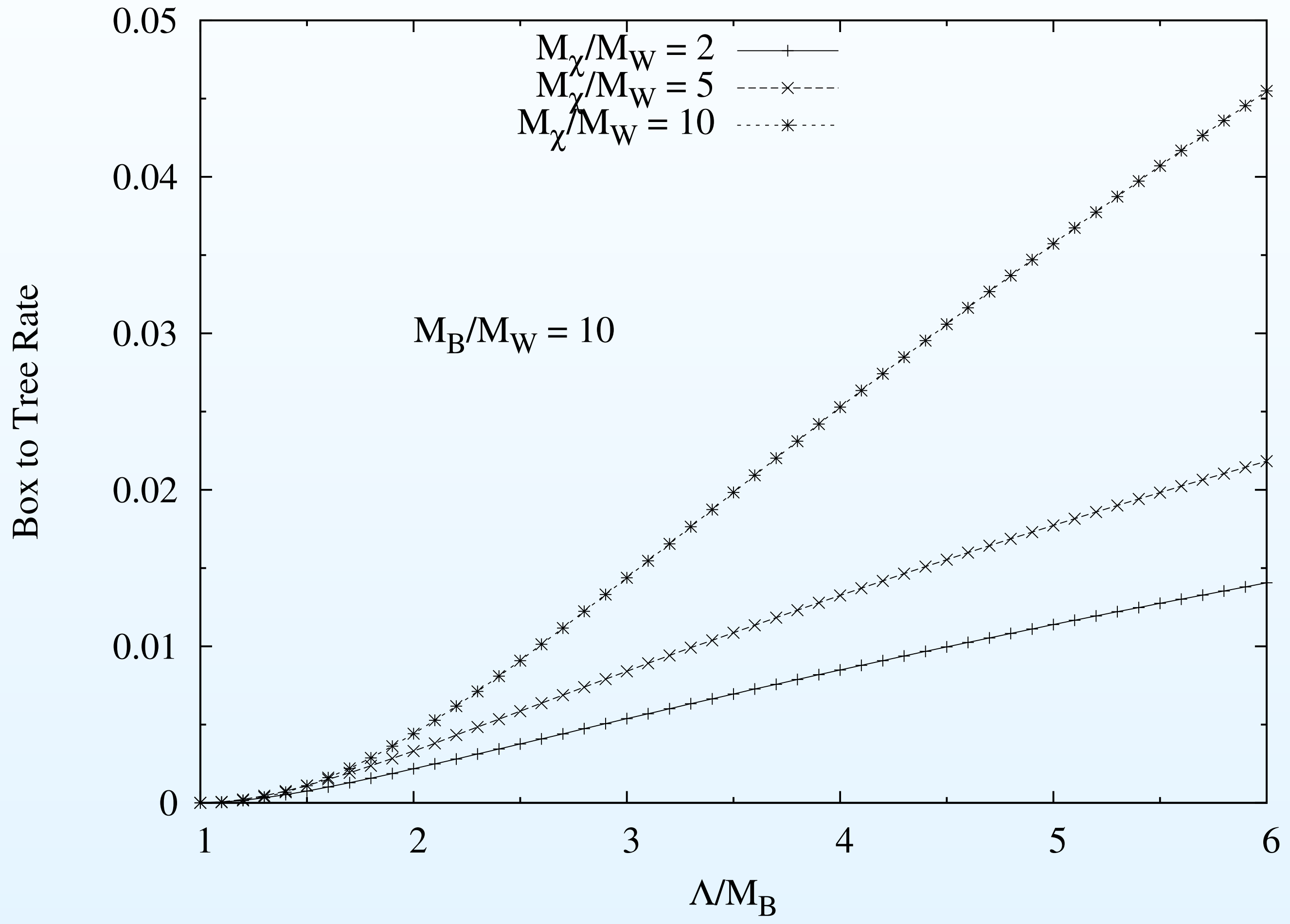
M_B and M_χ are constrained by the requirement that the value $\Omega_\chi h^2 = 0.1$ requires an annihilation cross section of $\langle v\sigma \rangle \gtrsim 3 \times 10^{-26}$ cm^3 sec^{-1}. In the model presented here, in the non-relativistic $s \sim (2\, M_\chi)^2$ and large $M_B^2 \gg s$ limits, we have

$$\langle v\, \sigma(\chi\bar{\chi} \to \nu\bar{\nu}) \rangle = \left(\frac{g_B^4}{8\pi}\right)\left(\frac{2\, M_\chi^2}{M_B^4}\right)$$

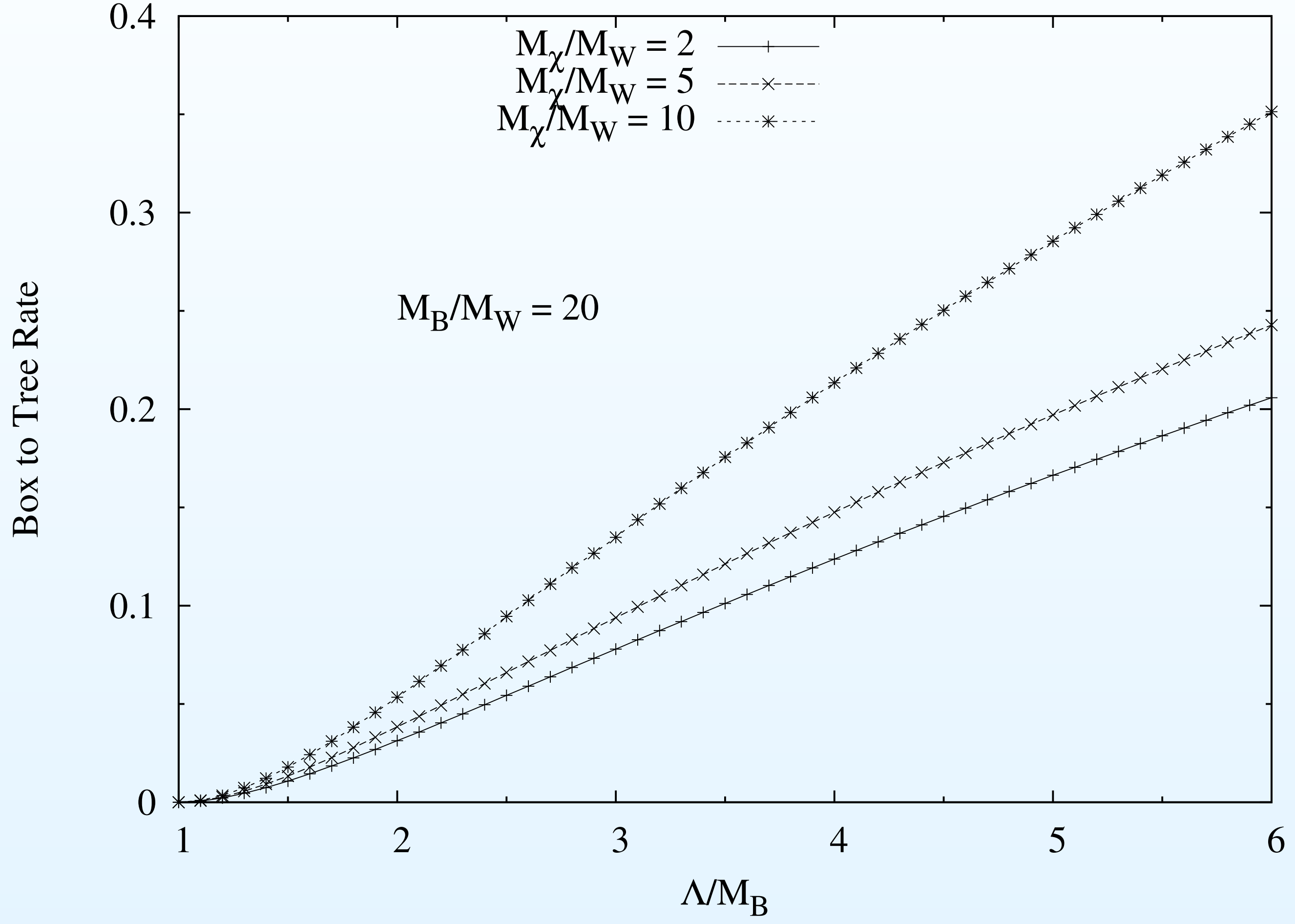
If we consider only $M_\chi > 100$ GeV, and restrict the coupling to the perturbative regime $g_B^2 \leq 4\pi$, then we obtain the bound

$$1 < \frac{M_B}{M_\chi} < 26,$$

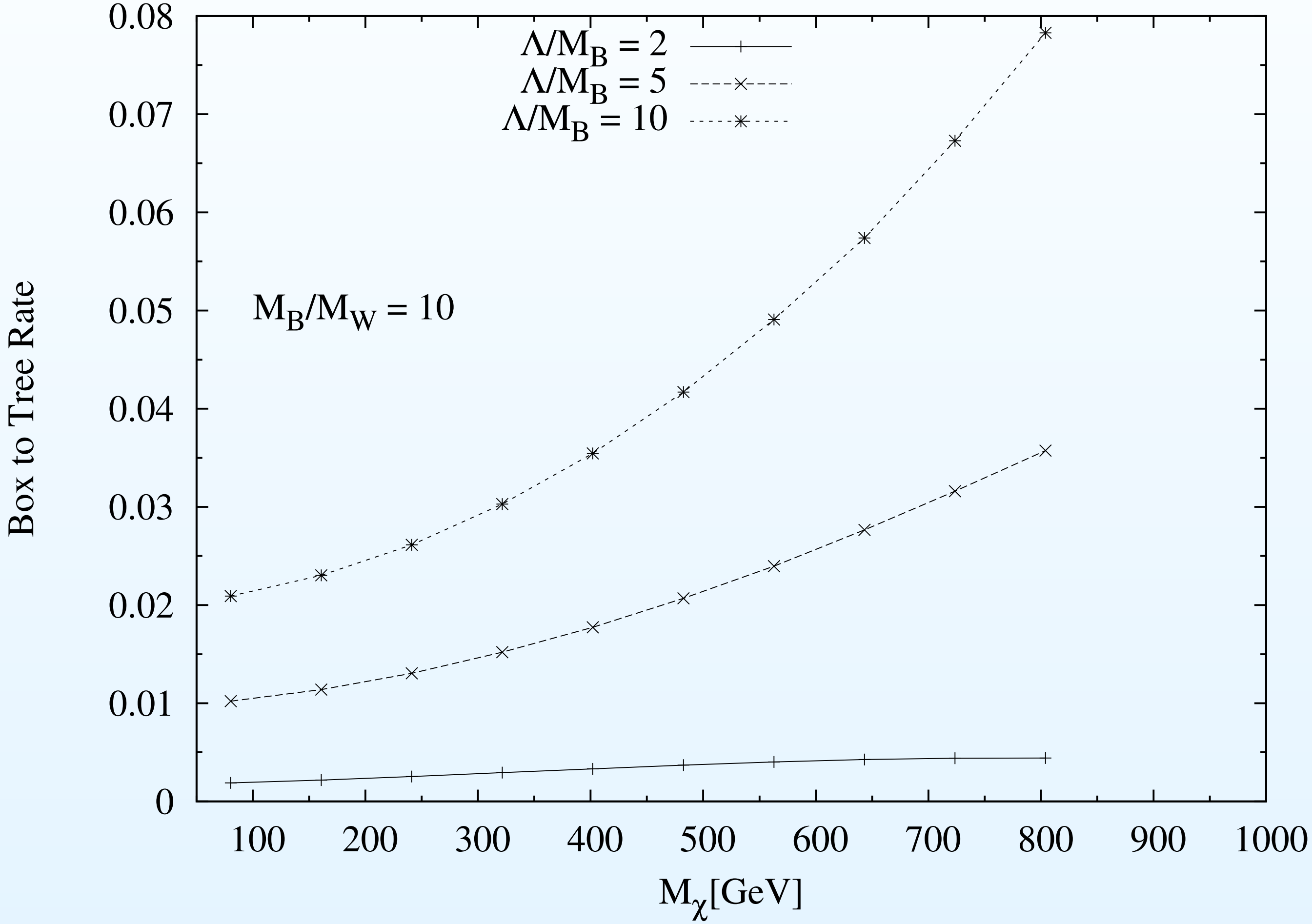
Running Λ



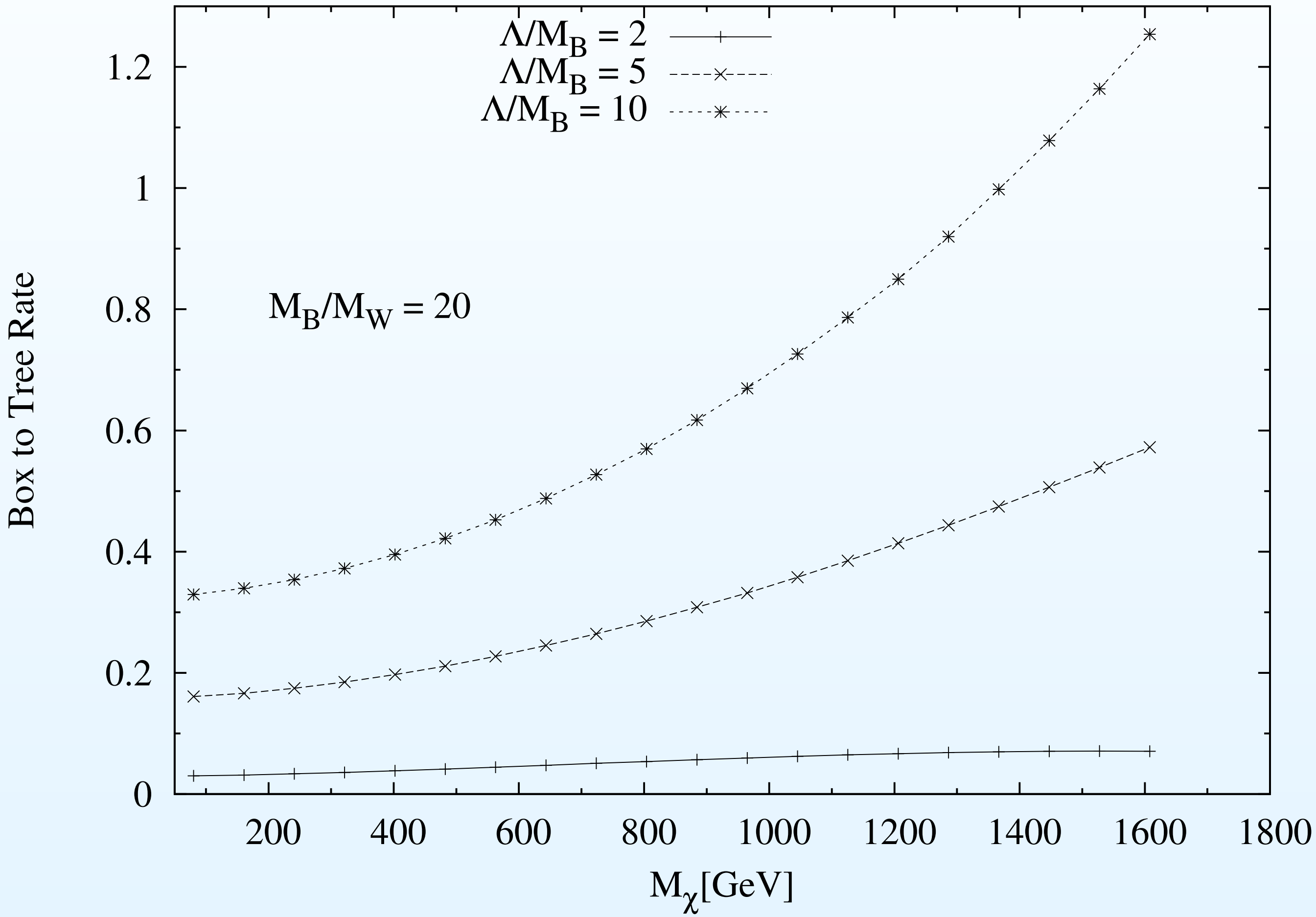
Running Λ



Running M_χ



Running M_χ



Conclusions

- Whenever neutrino-antineutrino pairs are produced in the final state, they can always be converted into l^+l^- pairs through W (or Z) exchange
- The branching ratio to charged leptons in a neutrinos only model is typically $\gtrsim 1\%$, when the scale of the dark matter mass(es) exceeds the electroweak scale, M_W
- This is true for both the box diagram as well as W or Z-strahlung.
- Neutrino and photon limits are likely to be competitive in the 100GeV to a few TeV range