Published for SISSA by Springer

Received: May 25, 2023
Accepted: May 29, 2023
Published: June 13, 2023

Erratum: Searching for dark radiation at the LHC

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Erratum to: JHEP08(2022)169

Keywords: Early Universe Particle Physics, New Light Particles, Cosmology of Theories BSM

ArXiv ePrint: 2204.01759

https://doi.org/10.1007/JHEP06(2023)071

JHEP06(2023)071

In the published version there was a small mistake in eq. (2.15), leading to errors also in eqs. (2.16) and (2.18). The corrected expression should read

$$
\begin{aligned}
I =& 8\pi^2 \int dE\, E^3 \int d\eta\, \sinh^2\eta \int d\cos\theta \frac{2E(\cosh\eta + \sinh\eta\cos\theta)}{m_B} f_B(2E\cosh\eta)\delta(E - m_B/2) \\
&\times \left[1 - \frac{f_\chi\left(E(\cosh\eta + \sinh\eta\cos\theta)\right)}{f_\chi^{\rm eq}\left(E(\cosh\eta + \sinh\eta\cos\theta)\right)}\right] , \qquad (1)
\end{aligned}
$$

which directly implies

$$
\begin{aligned}
I =& \pi^2 m_B^3 \int d\eta\, \sinh^2\eta \int d\cos\theta (\cosh\eta + \sinh\eta\cos\theta) f_B(m_B\cosh\eta) \\
&\times \left[1 - \frac{f_\chi\left(\frac{m_B}{2}(\cosh\eta + \sinh\eta\cos\theta)\right)}{f_\chi^{\rm eq}\left(\frac{m_B}{2}(\cosh\eta + \sinh\eta\cos\theta)\right)}\right] . \qquad (2)
\end{aligned}
$$

This then leads to

$$
\begin{aligned}
\tilde{H} x s^{4/3}(x) \frac{\mathrm{d}Z_\chi}{\mathrm{d}x} =& \frac{m_B^4 \Gamma_B}{8\pi^2} \int_{-1}^{1} \mathrm{d}\cos\theta \int_1^\infty \mathrm{d}w \sqrt{w^2-1} f_B^{eq}(w;T)(w + \sqrt{w^2-1}\cos\theta) \\
&\times \left[1 - r_\chi\left(w + \sqrt{w^2-1}\cos\theta; T, \epsilon\right)\right] . \qquad (3)
\end{aligned}
$$

We note that in the absence of backreaction (setting $r_\chi = 0$) the integral over $\cos\theta$ can be performed analytically, giving

$$
I = 2\pi^2 m_B^3 \int \mathrm{d}w \sqrt{w^2-1}\, w f_B(m_B w) = \frac{\pi}{2} \int \mathrm{d}^3 p_B f_B(E_B) = 4\pi^4 n_B , \qquad (4)
$$

where we have introduced $E_B = m_B w$ in the second line. In other words, the relativistic corrections for freeze-in from decays cancel out, and the integrated collision operator is simply given by $m_B \Gamma_B n_B/2$.

The correction leads to a slightly enhanced production of dark radiation at high temperatures, leading to a slight increase in the predicted value of $\Delta N_{\rm eff}$ for a given model parameter point. The mistake therefore affects all figures shown in the published version. We include the corrected versions below.

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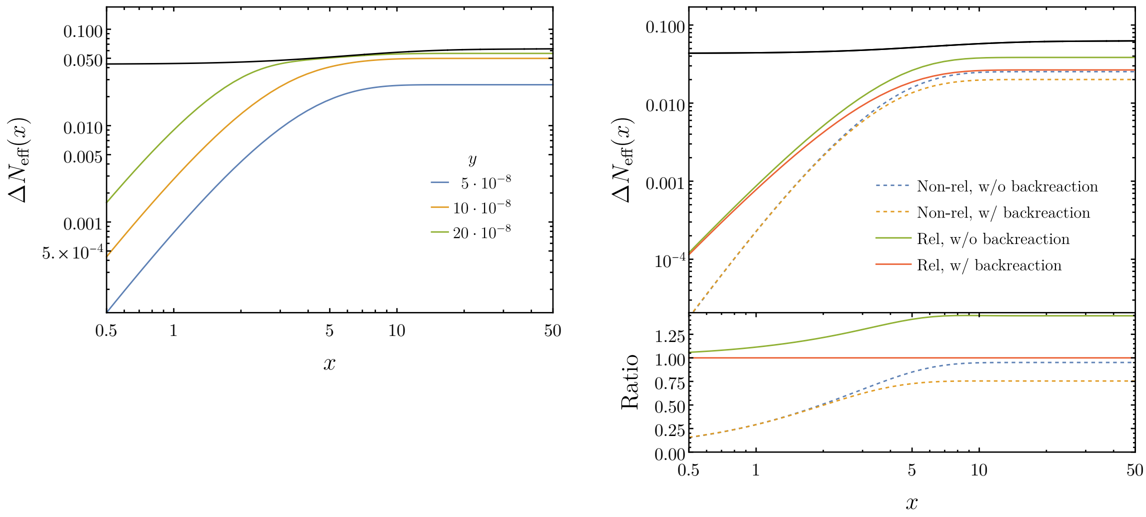

Figure 1. Shift in the effective number of relativistic species as defined in eq. (2.5) as a function of time for a benchmark mass value of $m_B = 300\,\text{GeV}$. The left panel shows how increasing the coupling increases ΔN_{eff}, but the increase becomes milder for large couplings due to the backreaction effect. The right panel illustrates the importance of the various effects included in our analysis compared to simpler approximations (non-relativistic decays, no backreaction).

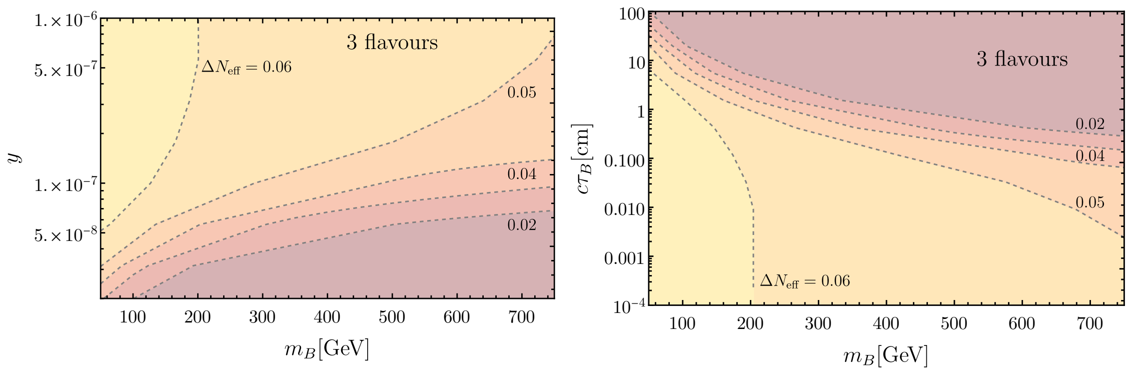

Figure 2. Shift in the effective degrees of freedom as a function of the mass and coupling (*left*) or proper decay length (*right*). Shorter lifetimes correspond to larger coupling and for short enough lifetimes we reach the equilibrium densities and the upper bound on ΔN_{eff}.

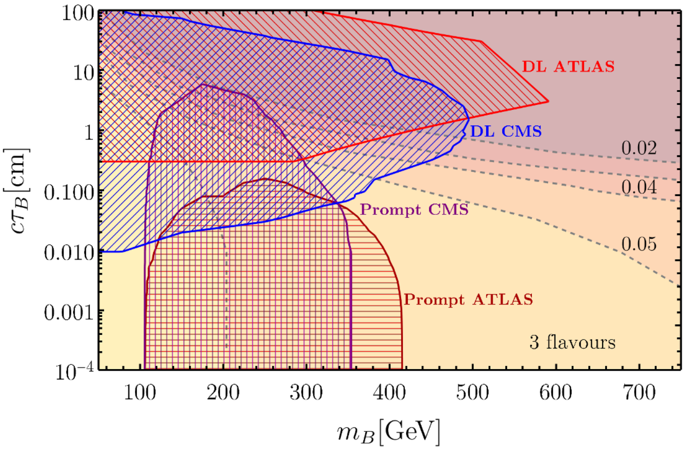

Figure 3. LHC constraints on the parameter space of interest for the 3-flavour case ($y_e = y_\mu = y_\tau = y$). Note that for short lifetimes and $m_B \lesssim 100\,\text{GeV}$ the parameter space is at least partially excluded by LEP searches [1].

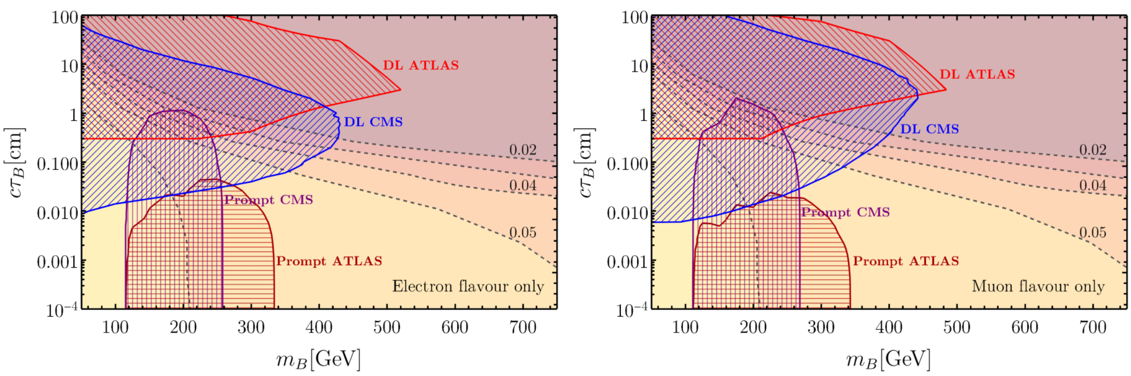

Figure 4. LHC constraints on the parameter space of interest in the case of B only coupling to a single flavour. On the left for coupling to electrons only ($y_e = y$, $y_\mu = y_\tau = 0$), on the right for coupling to muons only ($y_\mu = y$, $y_e = y_\tau = 0$). Also in this case LEP excludes partner masses $m_B \leq 104\,\text{GeV}$.

References

[1] DELPHI collaboration, *Searches for supersymmetric particles in e+ e- collisions up to 208-GeV and interpretation of the results within the MSSM*, *Eur. Phys. J. C* **31** (2003) 421 [hep-ex/0311019] [INSPIRE].

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