Searching for dark radiation at LHC

Based on 2204.01759

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A loving relationship...

LHC: power and versatility

↓

LHC can look for DM

DM hints to new physics

↓

DM can guide LHC

...with some LLP issues

Simple observation:
$H(T_{\mathsf{EW}}) \leftrightarrow$ LHC length

Interactions effective at the EW scale lead to macroscopic decay lengths!

But Ωh^2_{DM} is not compatible with that...

But there are other cosmological observations!

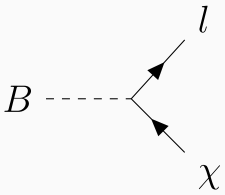
ΔN_{eff} in the near future: $\sigma_{\mathsf{CMB\text{-}S4}} = 0.03$

Model

New particle content: B, χ

B decays into almost massless χ

$B^T = (B_e, B_\mu, B_\tau)$ charged under SM



$$\mathcal{L}_{\text{NP}} \supset B^T \cdot y_l \cdot (\bar{l}_R\,\chi) + h.c.$$

$$y_l = \begin{pmatrix} y & 0 & 0 \\ 0 & y & 0 \\ 0 & 0 & y \end{pmatrix} \qquad \text{with } y \lesssim 10^{-6}$$

Calculating ΔN_{eff} (standard)

ΔN_{eff} is the extra radiation added on top of SM

$$\Delta N_{\text{eff}}(x) = \frac{\rho_\chi(x)}{\rho_{1\nu}(x)} = \frac{Z_\chi(x)\, s_0^{4/3}}{\frac{7}{8}\left(\frac{4}{11}\right)^{4/3} \rho_{\gamma,0}}, \tag{1}$$

$$Z_\chi(x) \equiv \frac{\rho_\chi(x)}{s^{4/3}(x)} \tag{2}$$

$Z(x)$ can be derived by Boltzmann equation!

IR freeze-in via parent decay: pretty easy!

Calculating ΔN_{eff} (refined calculation)

Usual assumptions:

- B decays while non-relativistic
- Backreaction $\chi\,\text{SM} \to B$ is negligible

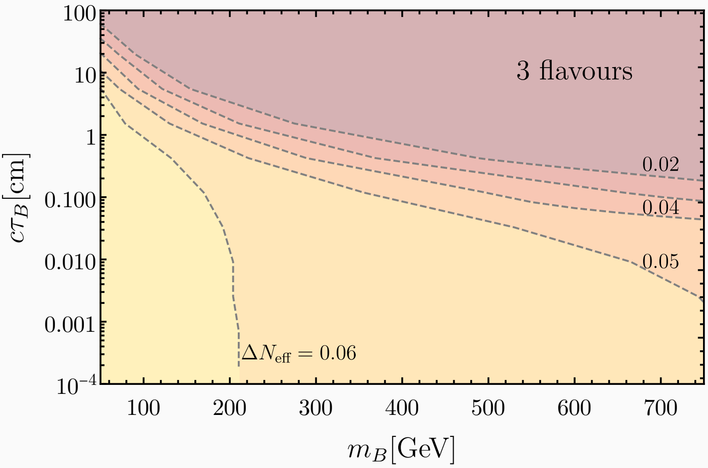
We relax these assumptions to get a better determination of the parameter space!

$$\tilde{H} x s^{4/3}(x) \frac{\mathrm{d}Z_\chi}{\mathrm{d}x} = \frac{m_B^4 \Gamma_B}{8\pi^2} \mathcal{I}(x, T_\chi, \text{spins}) \quad (3)$$

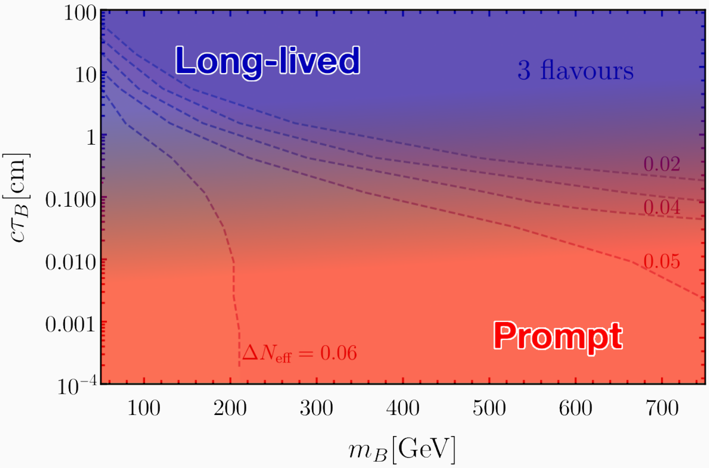
Also here there are some simplifications...

$\mathcal{I}$ can be tabulated and is provided at the arXiv link.

ΔN_{eff} result and LHC parameter space



ΔN_{eff} result and LHC parameter space



Prompt searches

Recast SUSY searches for $l\,l + \not{E}_T$
1908.08215, 2012.08600

Lifetime effect enters in the impact parameter cuts:
different for ATLAS and CMS!

ATLAS: $|d_0| < 3(5)\ \sigma(d_0)$ for electrons (muons)
CMS: $|d_0| < 0.5$mm for electrons and muons

Trick: the cut on d_0 can be extrapolated for different lifetimes without re-simulating every time!

LLP searches

"Recast" SUSY searches for displaced leptons
2011.07812, 2110.04809

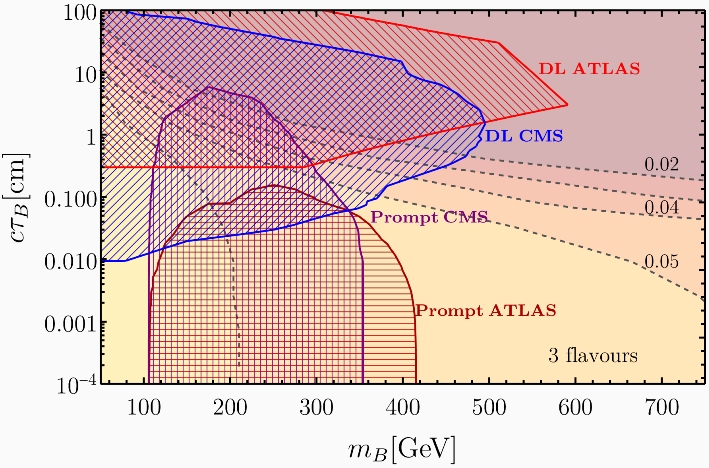
Limits provided as function of m_B and $c\tau_B$

Still different cuts for ATLAS and CMS on the impact parameter

ATLAS: $|d_0| \in [3\text{mm}, 300\text{mm}]$
CMS: $|d_0| \in [0.1\text{mm}, 100\text{mm}]$

Warning: recasting here is more complicated for the single-flavour scenario

LHC constraints on ΔN_{eff}

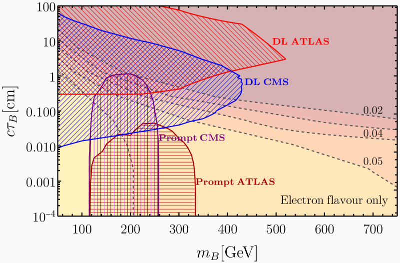


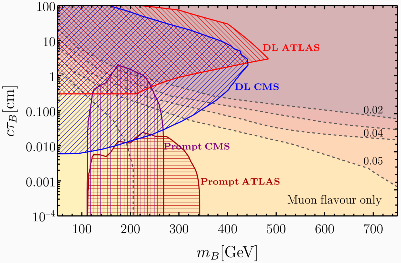
Conclusions

- Calculations of ΔN_{eff} has been improved to better determine the decay lengths
- The interesting parameter space lies at the boundary of prompt and long-lived searches $\rightarrow$ complementarity!
- ATLAS and CMS have different cuts which result in differences in parameter space probed

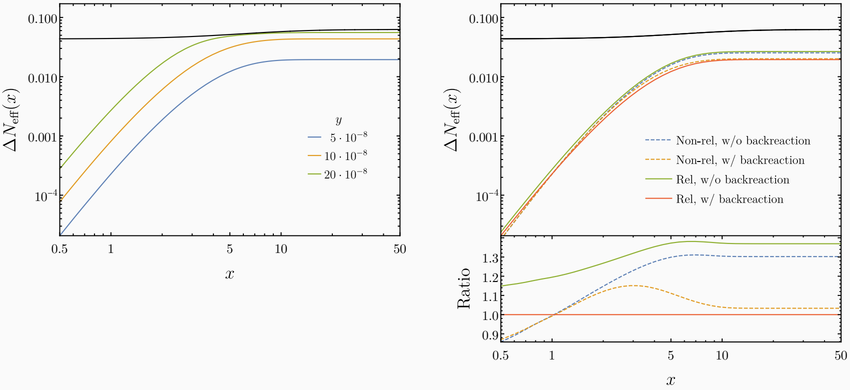
BACKUP

Single flavour case



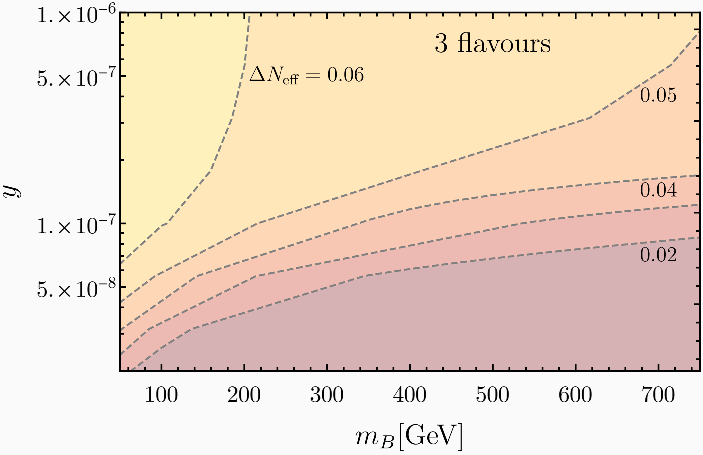


Effect of approximations



Not portrayed here: magnitude of corrections depends sensitively on the parameters!

Coupling parameter space



Other ATLAS-CMS differences

Prompt ATLAS:
bins in m_{T2}, $e\mu$ as signal region

Prompt CMS:
bins in p_T^{miss}, $e\mu$ as control region

LLP CMS does not provide limits on $\sigma(m_B, c\tau_B)$ for the single flavour scenario, so an approximation on the mass dependence is used.