Gravitational Leptogenesis and Primordial Gravitational Waves during PBH-induced reheating

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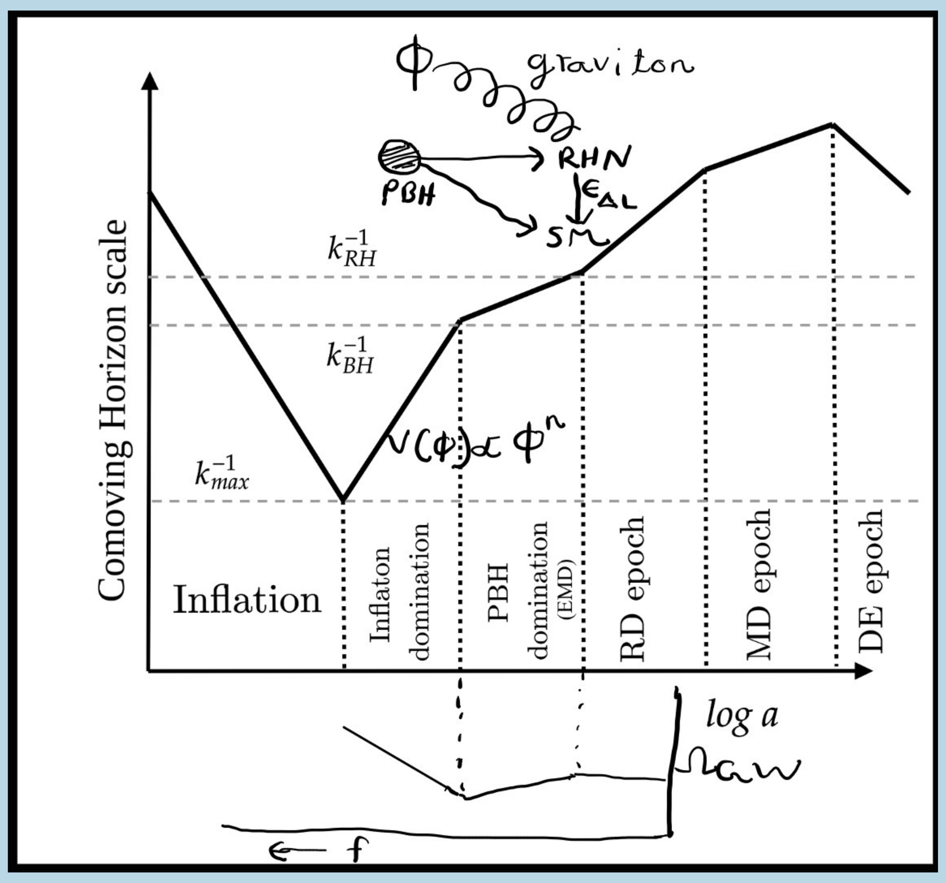
Motivation

- How to test leptogenesis ($M_N \gtrsim 10^9$ GeV)?
- Non-thermal source based on gravity?

The idea

- PBH formation and evaporation during reheating, $V(\phi) \propto \phi^n$.
- Leptogenesis from PBH evaporation and graviton mediated scatterings of inflaton.
- Imprints on *primordial gravitational waves*.

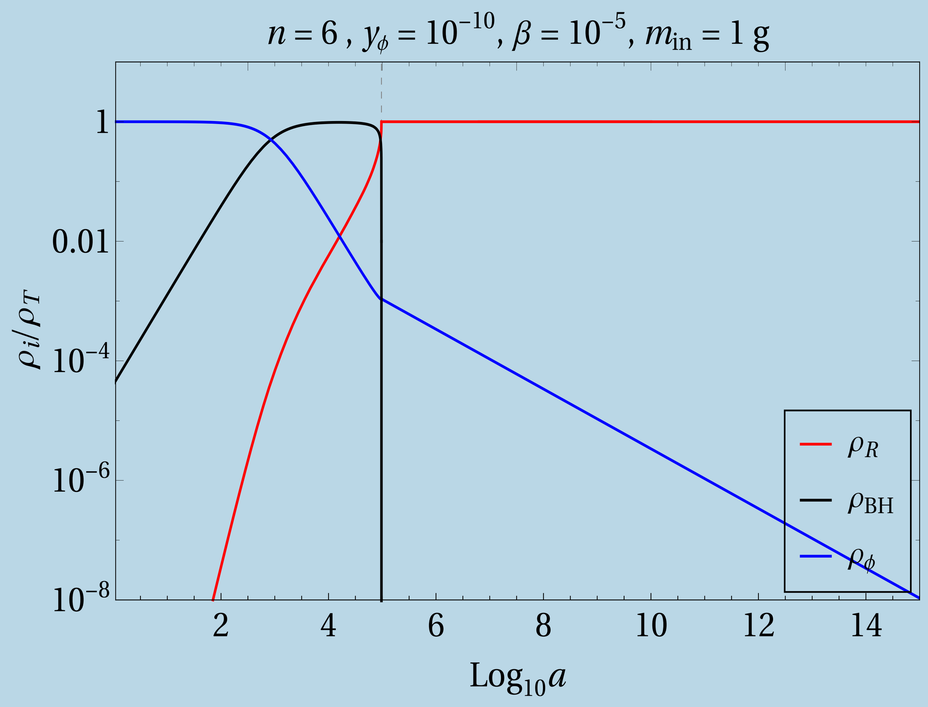


PBH during reheating era

- PBH mass at formation ($w_\phi = \frac{n-2}{n+2}$):

$$M_{\rm in} = \frac{4}{3}\pi\gamma(n) H_{\rm in}^{-3}\rho_\phi(a_{\rm in}) = 4\pi\gamma M_P^2 H_{\rm in}^{-1}\,. \quad (1)$$

- PBH domination if $\beta = \frac{\rho_{\rm PBH}}{\rho_\phi}\big|_{a_{\rm in}} > \beta_c(w_\phi)$, with $T_{\rm RH} = T_{\rm ev}(M_{\rm in})$.



Evolution of energy densities

- Even for $\beta < \beta_c$, PBH can reheat with $T_{\rm RH}(m_{\rm in}, w_\phi)$ for small inflaton coupling y_ϕ if $w_\phi > 1/3$.

Leptogenesis from PBH

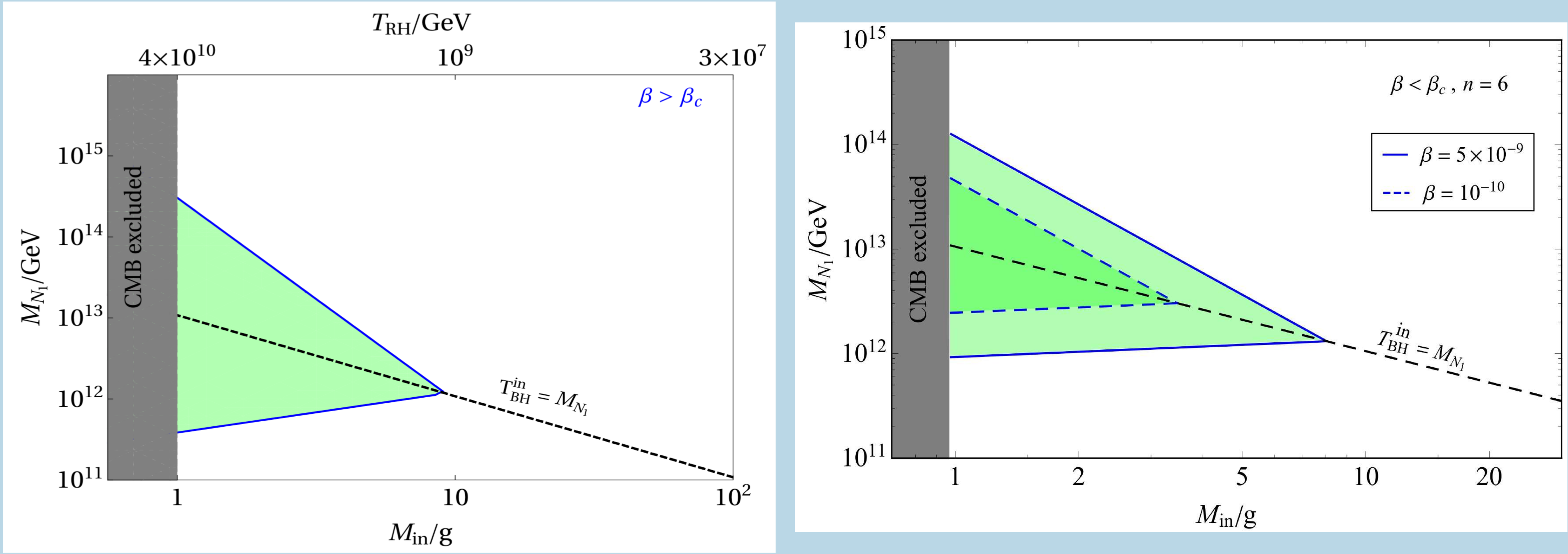
- RHNs from PBH:

$$\mathcal{N}_i \sim \frac{g_X}{g_\star}\begin{cases}\left(\frac{M_{\rm in}}{M_P}\right)^2, & M_N < T_{\rm BH}^{\rm in}\,,\\ \left(\frac{M_P}{M_N}\right)^2, & M_N > T_{\rm BH}^{\rm in}\,,\end{cases} \quad (2)$$

- Baryon Asymmetry:

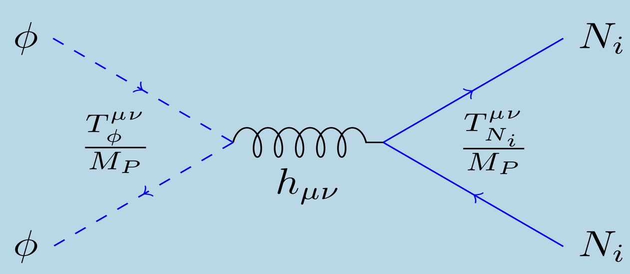
$$Y_B(T_0) = \frac{n_B}{s}\Big|_{T_{\rm ev}} = \mathcal{N}_{N_1}\,\varepsilon_{\Delta L}\,a_{\rm sph}\,\frac{n_{\rm BH}(T_{\rm ev})}{s(T_{\rm ev})} \quad (3)$$

Allowed parameter space for PBH leptogenesis



Left: PBH domination, Right: No PBH domination.

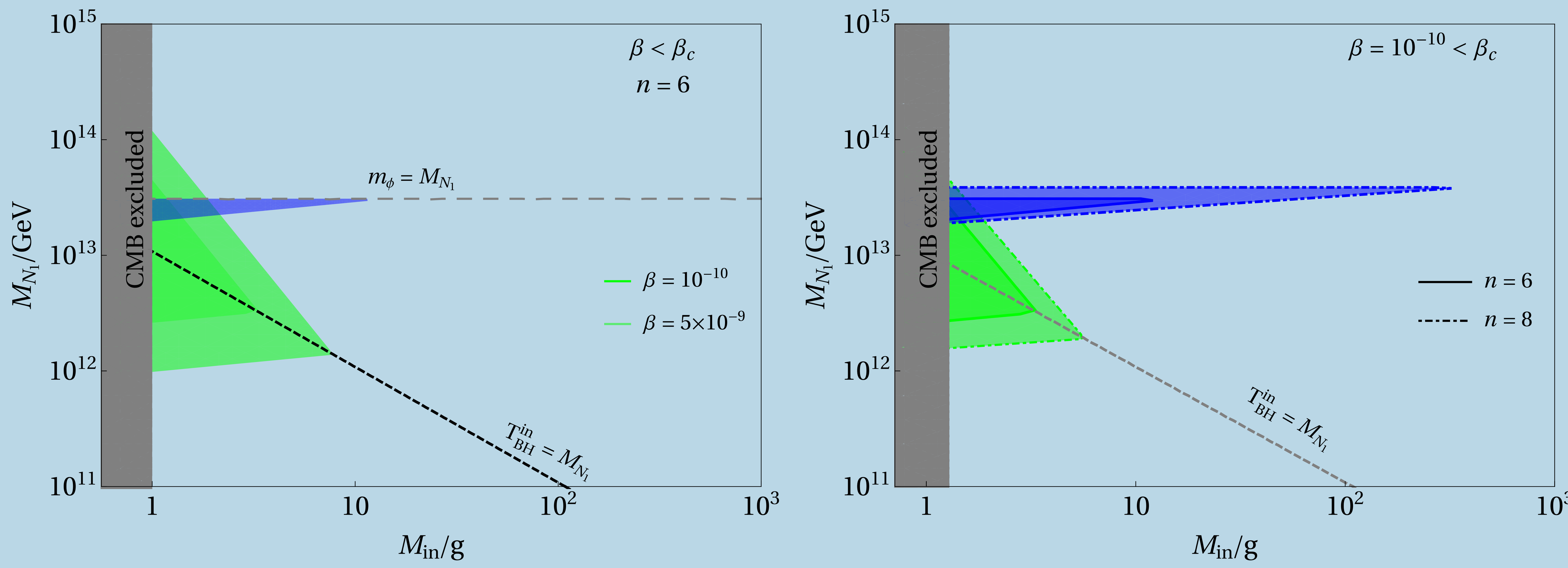
Leptogenesis from graviton mediation



$$\sqrt{-g}\,\mathscr{L}_{\rm int} = -\frac{1}{M_P}h_{\mu\nu}\left(T^{\mu\nu}_{\rm SM} + T^{\mu\nu}_\phi + T^{\mu\nu}_X\right) \quad (4)$$

- Production of N_1:

$$\frac{dn_{N_i}}{dt} + 3H\,n_{N_i} = R^{\phi^n}_{N_i} \longrightarrow \text{Production rate for } N_1 \quad (5)$$



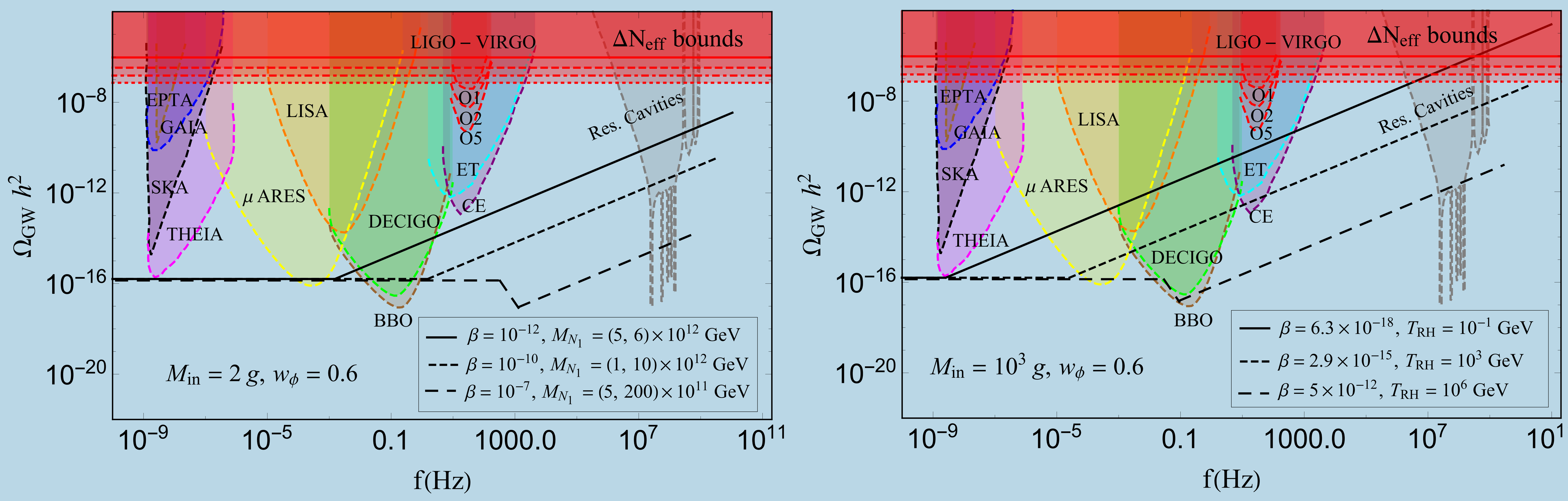
Leptogenesis parameter space for graviton mediation.

Gravitational wave signatures

$$\Omega_{\rm GW}(k) = \frac{1}{12H_0^2}\left(\frac{k}{a_0}\right)^2 T_T^2(\tau_0,k)P_T(k), \quad (6)$$

Cosmic History

$$\Omega^{(0)}_{\rm GW} \simeq \Omega^{(0)}_{\rm GW,rad}\begin{cases}1 & k < k_{\rm RH}\\ c_1\left(\frac{k}{k_{\rm RH}}\right)^{-2} & k_{\rm BH} < k < k_{\rm RH}\\ c_2\left(\frac{k}{k_{\rm BH}}\right)^{\frac{6w_\phi-2}{1+3w_\phi}} & k_{\rm BH} < k < k_{\rm max}\end{cases} \quad (7)$$



GW probe of leptogenesis (left panel) and PBH-reheating (right panel).

- Additional constraints (lower-bound on β) from $\Delta N_{\rm eff}$ contribution of GW.

Takeaways

- PBH are enough to reheat the Universe.
- Gravity-only leptogenesis: from ultralight PBH & graviton mediated scatterings.
- Primordial GW from inflation modified and detectable across several bands of frequencies, with probable $\Delta N_{\rm eff}$ by future experiments.