Big Bang Nucleosynthesis constraints on resonant DM annihilations

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BBN & photodisintegration

During Big Bang nucleosynthesis (BBN) the lightest elements (Helium, Lithium, Beryllium) are formed

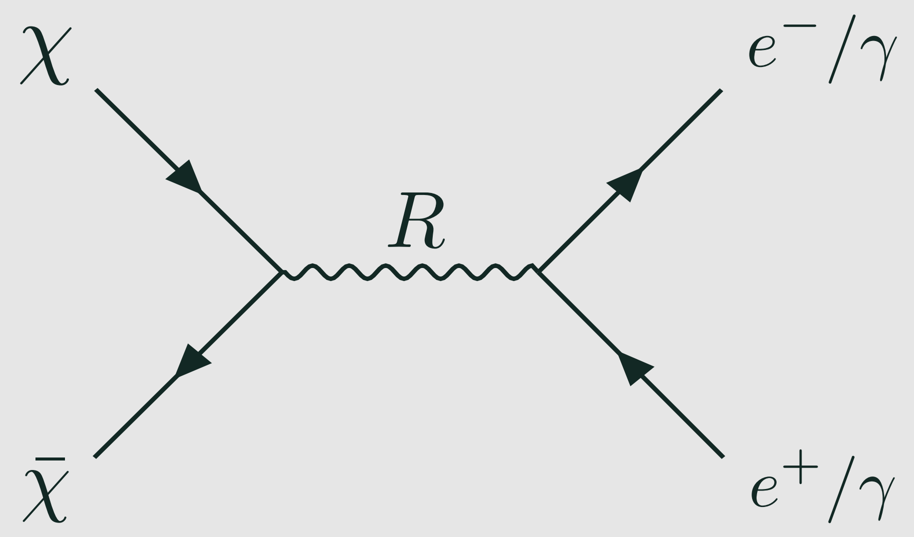
Observed values match predictions

$$\mathcal{Y}_p = 0.245 \pm 0.003$$
$$\mathrm{D}/^1\mathrm{H} = (25.47 \pm 0.25) \times 10^{-6}$$

PDG (2022)

$\Longrightarrow$ Can use observations to constrain new physics

Exotic EM energy injection can destroy the formed elements after BBN, e.g. DM annihilations



Light element abundances $N \in \{n, p, \mathrm{D}, {}^3\mathrm{H}, {}^3\mathrm{He}, {}^4\mathrm{He}, {}^7\mathrm{Li}, {}^7\mathrm{Be}\}$ are tracked via

$$\frac{dT}{dt}\frac{dY_N}{dT} = \underbrace{\sum_{N_i} Y_{N_i} \int_0^\infty dE\, f_\gamma(E)\sigma_{\gamma+N_i\to N}(E)}_{\text{creation}} \underbrace{- Y_N \sum_{N_f} \int_0^\infty dE\, f_\gamma(E)\sigma_{\gamma+N\to N_f}(E)}_{\text{destruction}}$$

In principle complicated system —> ACROPOLIS

Depta, Hufnagel, Schmidt-Hoberg (2021)

Photodisintegration is sensitive to specific temperature range

$T \in [10^{-7}, 10^{-2}]\ \mathrm{MeV}$: well after standard BBN has ended

Why resonant annihilations?

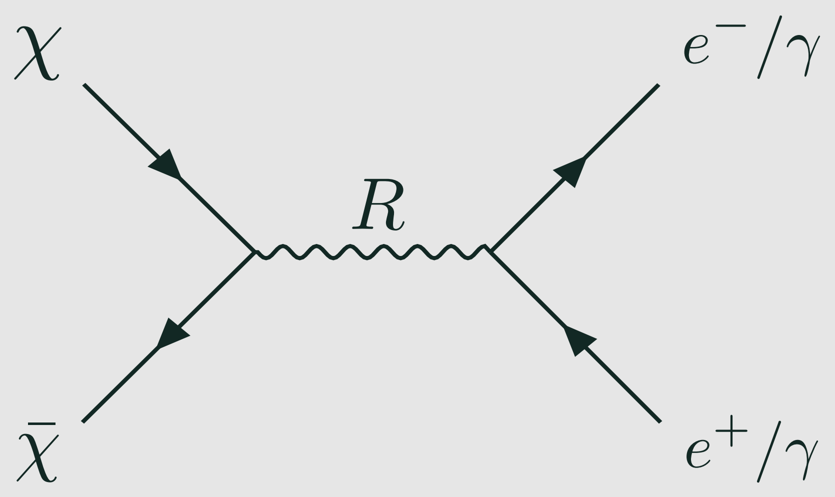
Consider dark sector with resonance

$$m_R \equiv m_\chi(2+\delta_R), \quad \delta_R \ll 1$$

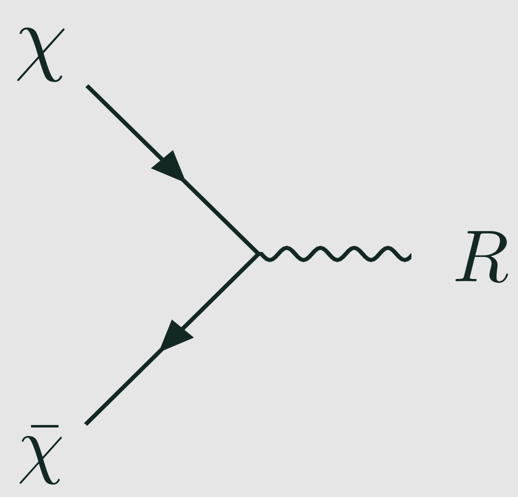
For MeV scale DM, annihilations peak in photodisintegration window!

We can write the annihilation cross section as

$$\sigma_{\rm ann}^{\rm res} = \frac{4\pi S}{m_\chi E(v)} \frac{\Gamma_d(v)\Gamma_v(v_f)/4}{(E(v)-E(v_R))^2 + \Gamma(v)^2/4}, \quad v_R \equiv 2\sqrt{\delta_R}$$

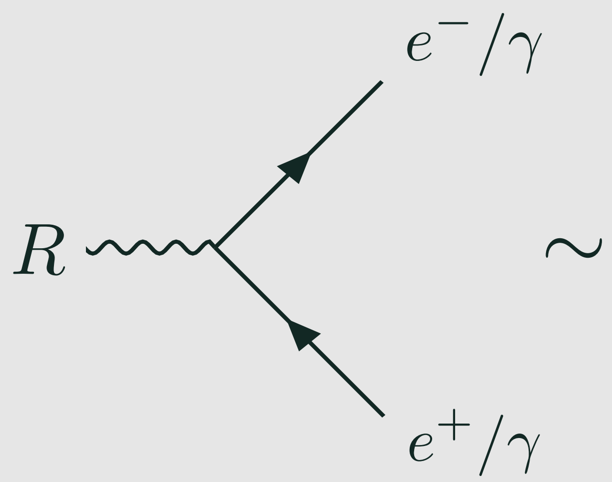


$\sim$



$$\sim \gamma_d m_R \frac{p^{2n_d+1}}{m_\chi^{2n_d+1}}$$

$\times$



$$\sim \gamma_v m_R \frac{p^3}{m_\chi^3}$$

γ_d : dark coupling

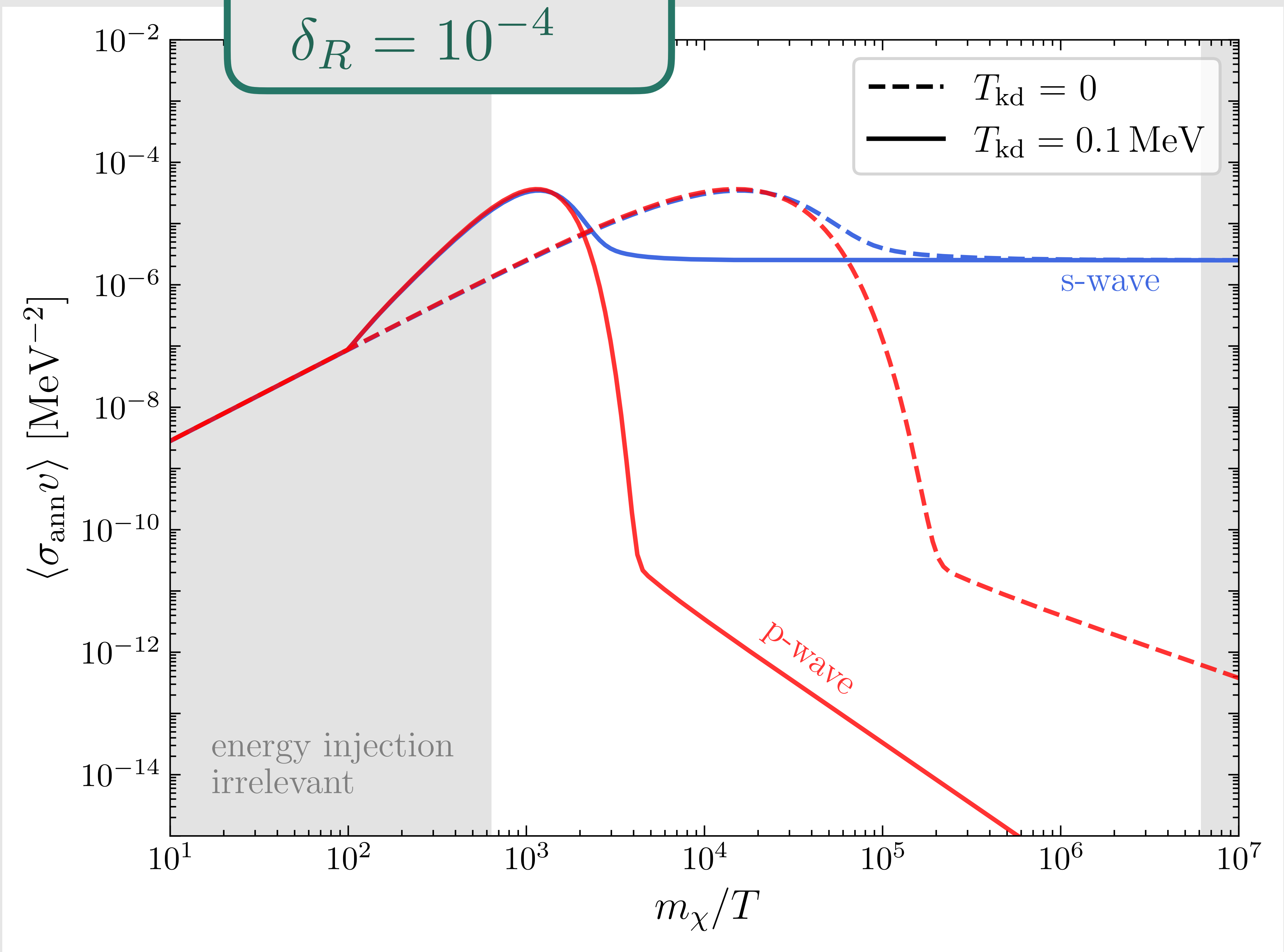
γ_v : visible coupling

$n_d = 0 \quad s-$wave

$n_d = 1 \quad p-$wave

$$m_\chi = 10\,\mathrm{MeV}$$
$$\delta_R = 10^{-4}$$

Injected power



Time

Model independent setup!

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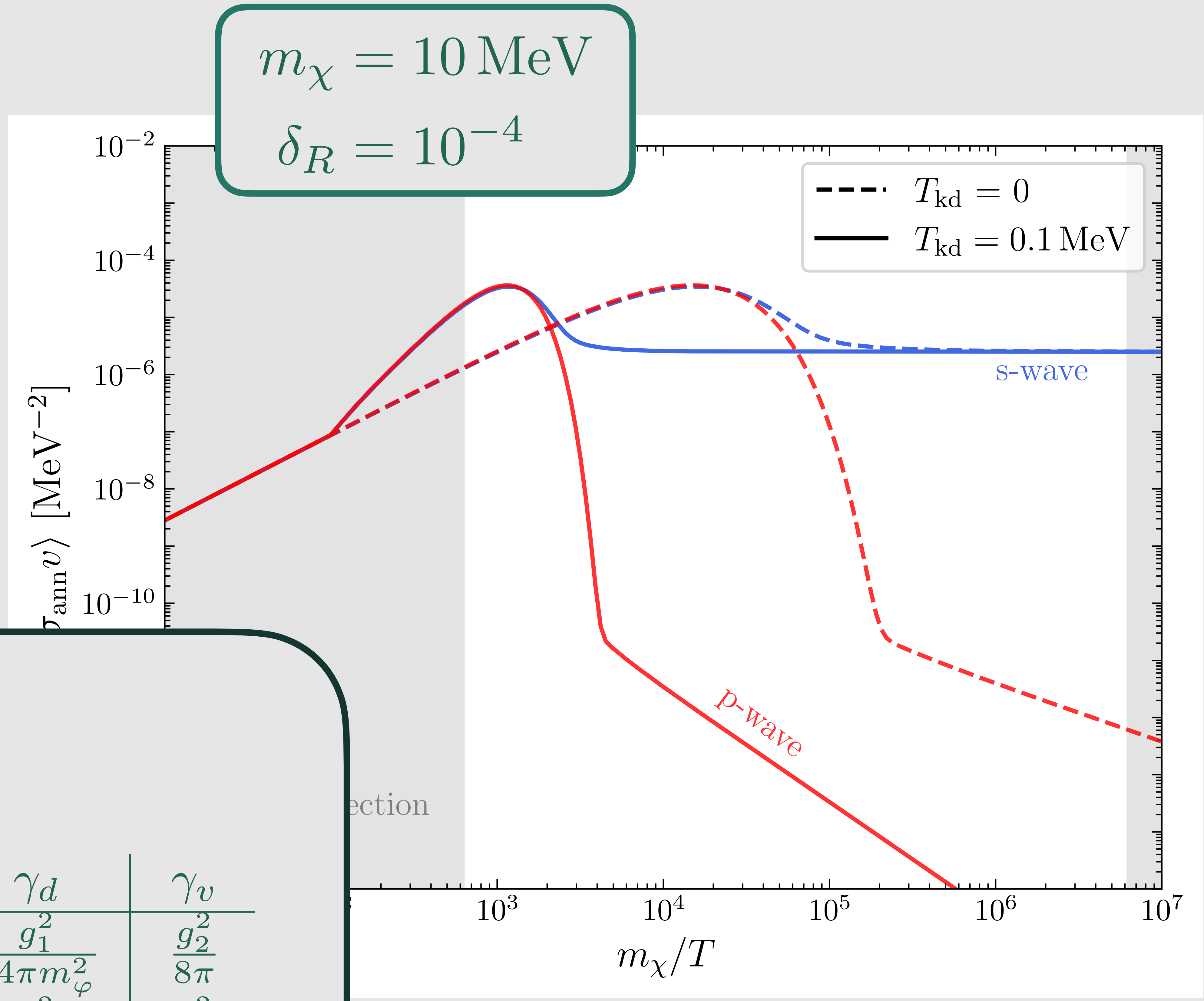
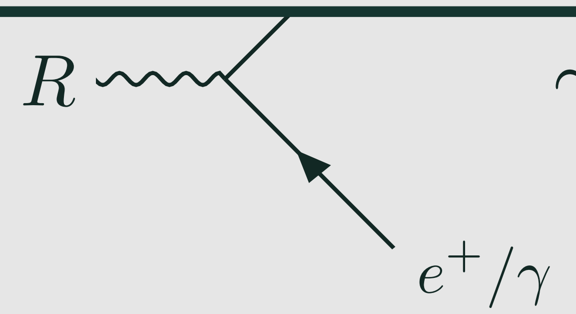


Time

Benchmark models

model	χ	R	Lagrangian	n_d	γ_d	γ_v
2 Scalars $(\varphi + \Phi)$	φ	Φ	$g_1\varphi\varphi\Phi + g_2\bar{e}e\Phi$	0	$\frac{g_1^2}{64\pi m_\varphi^2}$	$\frac{g_2^2}{8\pi}$
Fermion (ψ) + Vector (A'_μ)	ψ	A'_μ	$g_1\bar{\psi}\gamma^\mu\psi A'_\mu + g_2\bar{e}\gamma^\mu e A'_\mu$	0	$\frac{g_1^2}{8\pi}$	$\frac{g_2^2}{12\pi}$
Scalar (φ) + Vector (A'_μ)	φ	A'_μ	$g_1\varphi^\dagger \overleftrightarrow{\partial}_\mu\varphi A'^\mu + g_2\bar{e}\gamma^\mu e A'_\mu$	1	$\frac{g_1^2}{48\pi}$	$\frac{g_2^2}{12\pi}$

$\times$ 

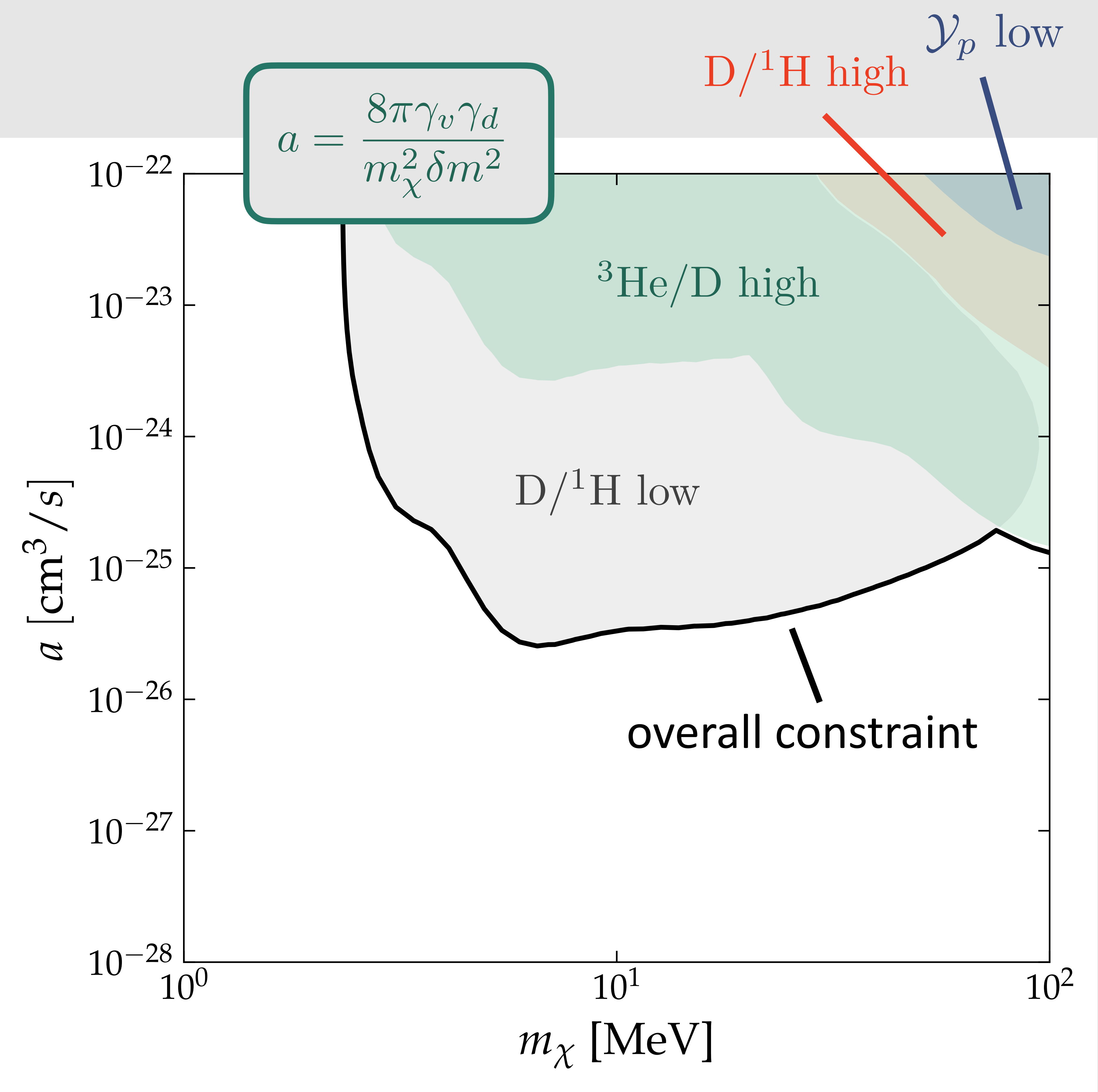
$\sim \gamma_v m_R \frac{p}{m_\chi^3}$

$n_d = 0 \quad s-$wave

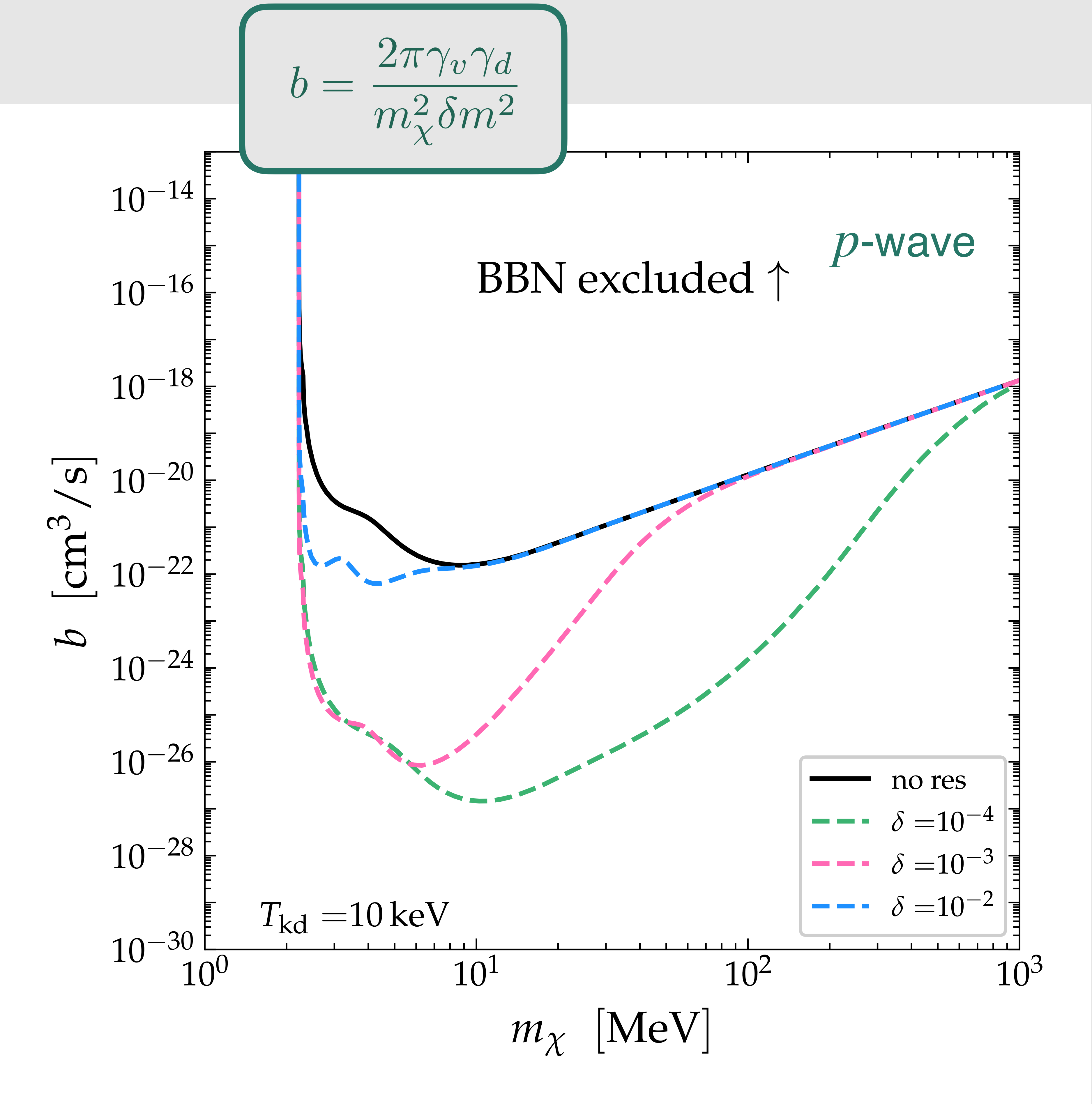
$n_d = 1 \quad p-$wave

Model independent setup!

Results



Deuterium abundance is most sensitive to the photodisintegration



For p-wave, resonance models are significantly more constrained!

Curious about s-wave?

Come talk to me at my poster!