arXiv:0712.0016v2

Light Higgses and Dark Matter at Bottom and Charm Factories

XIAO Suyu from IHEP

20180615

Introduction

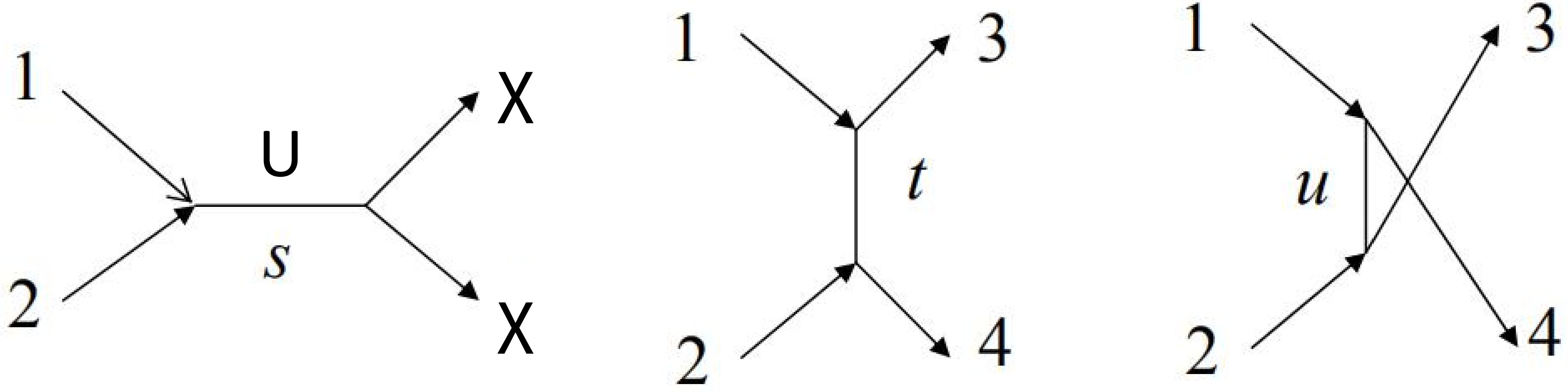
- Two major new particles expected at colliders are Dark Matter and the Higgs boson.
- While some models are now ruled out at energies accessible to bottom and charm factories, it is by no means proven that these cannot be light.
- The problem of light Dark Matter and light Higgses are related, as light Dark Matter particle X requires a new light particle U with $m_U \cong 2m_\chi$ to serve as an s-channel annihilation mediator.
- A promising possibility for U is that it is a pseudo-scalar higgs, which can be naturally light due to new symmetries which can protect its small mass.

Introduction

- Question from Yuhang:

  What's the relationship between U and X?

  Are they similar to $\Gamma(H \to \chi\chi) = f_H^2 M_H \sigma(q\bar{q} \to \chi\chi)$?



Dark Matter

- Dark Matter must have been non-relativistic at a temperature of about 0.3eV, therefore the smallest possible mass consistent with the Standard Cosmological Model is about 0.3eV.
- This means that bottom and charm factories are capable of exploring 10 orders of magnitude in the Dark Matter mass.
- Treating the relic density as a constraint, acceptable models are achieved for(at least) two values of the Dark Matter mass as a function of the mediator's mass, $M_\chi = M_U / 2 \pm \varepsilon$, in Fig.1.

Dark Matter

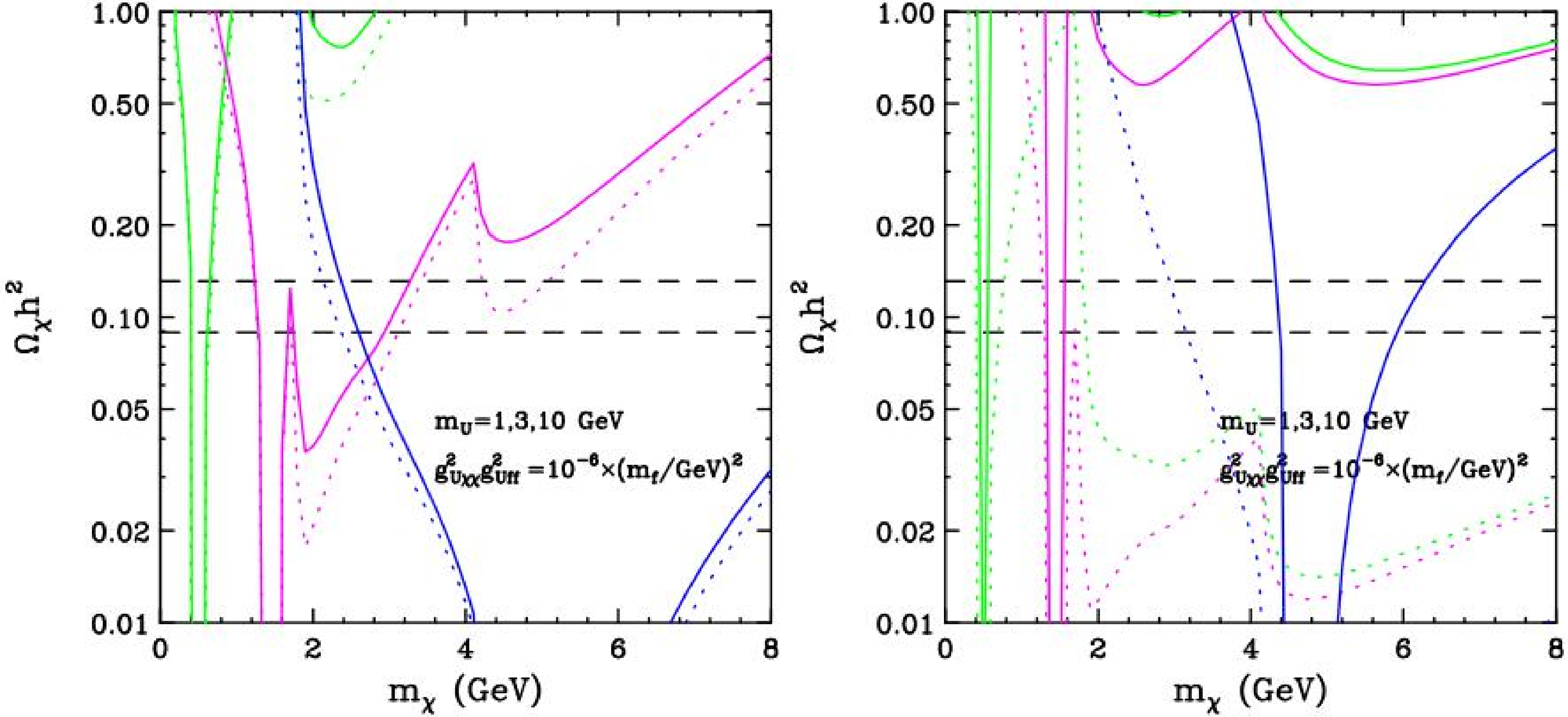


Figure 1: The relic density $\Omega_\chi h^2$ vs the Dark Matter mass M_χ for masses of the mediator $M_U = 1, 3, 10$ GeV. In the left (right) panel, χ is a scalar (fermion). In both panels, U is a scalar (solid) or pseudo-scalar (dotted). These curves move vertically as the free-parameter couplings g_{Uff} and $g_{U\chi\chi}$ are changed. We thank Dan Hooper for his contribution in creating these figures.

Dark Matter

- There is experimental evidence that Dark Matter may be light from the INTEGRAL satellite, which has detected an anomalously large population of positrons in the galactic center. If this is from Dark Matter annihilation, it requres .
- Another source of evidence is from the DAMA annual modulation signal. This is consistent with light Dark Matter due to the lower threshold of Sodium, as compared to heavier elements such as gallium(CDMS) and xenon(XENON).
- There are two major modes of discovery for light Dark Matter: invisible meson decay and rediative decay. Here we'll learn some details of invisible one.

Invisible Quarkonium Decay

- In invisible meson decay, we can get an order of magnitude estimate for the annihilation cross section using

$\Omega_X = \rho_X / \rho_c$, the relic density for species X relative to the critical density ρ_c

$$\boxed{\Omega_X h^2} \cong \frac{0.1 pb \cdot c}{< \sigma \upsilon >} \quad \Rightarrow \quad < \sigma \upsilon >= 0.88 pb \cdot c$$

Hubble constant

thermally averaged annihilation cross section of the DM into SM particles

central value of WMAP result 0.113

Invisible Quarkonium Decay

- By approximating that $<\sigma\upsilon>=\sigma\sqrt{<\upsilon_{rel}^{2}>}$ we can remove the kinematic velocity factor, assuming that the per-particle energy is given by the average energy of the gas $\frac{3}{2}kT$.
- Expand $<\sigma\upsilon>$ in the velocity at freeze-out to seperate s-wave and p-wave components, $<\sigma\upsilon>=a+b\upsilon^{2}$.

$$\sigma(\chi\chi \to SM) = a/v_{\rm rel} \simeq 1.8\,{\rm pb}, \qquad ({\rm s-wave})$$
$$\sigma(\chi\chi \to SM) = b/v_{\rm rel} \simeq 7.5\,{\rm pb}. \qquad ({\rm p-wave})$$

Invisible Quarkonium Decay

- Question from Yuhang:

  How to distinguish s-wave and p-wave when analysing J/psi->XX?

  If they cannot be distinguished, then how to deal with s-p?

Assuming time-reversed reaction is the same:

$$\sigma(f\bar{f} \to \chi\chi) \simeq \sigma(\chi\chi \to f\bar{f})$$

The invisible width of a hadron composed dominantly of $q\bar{q}$ is given approximately by:

$$\Gamma(H \to \chi\chi) = \underbrace{f_H^2}_{\text{hadronic from factor}} \underbrace{M_H}_{\text{hadronic's mass}} \sigma(q\bar{q} \to \chi\chi)$$

Invisible Quarkonium Decay

mode	s-wave	p-wave
$\mathrm{BR}(\Upsilon(1S) \to \chi\chi)$	4.2×10^{-4}	1.8×10^{-3}
$\mathrm{BR}(\Upsilon(1S) \to \nu\bar{\nu})$	9.9×10^{-6}	
$\mathrm{BR}(J/\Psi \to \chi\chi)$	2.5×10^{-5}	1.0×10^{-4}
$\mathrm{BR}(J/\Psi \to \nu\bar{\nu})$	2.7×10^{-8}	
$\mathrm{BR}(\eta \to \chi\chi)$	3.4×10^{-5}	1.4×10^{-4}
$\mathrm{BR}(\eta' \to \chi\chi)$	3.7×10^{-7}	1.5×10^{-6}
$\mathrm{BR}(\eta_c \to \chi\chi)$	1.3×10^{-7}	5.3×10^{-7}
$\mathrm{BR}(\chi_{c0}(1P) \to \chi\chi)$	2.7×10^{-8}	1.2×10^{-7}
$\mathrm{BR}(\phi \to \chi\chi)$	1.9×10^{-8}	7.8×10^{-8}
$\mathrm{BR}(\omega \to \chi\chi)$	7.2×10^{-8}	3.0×10^{-8}

Table I Estimated branching ratios for the narrowest mesons. The two columns correspond to the assumption that the Dark Matter annihilation in the early universe occurs in either the s-wave or p-wave. Neutrino branching ratios are from Ref.[17]. All mesons have a branching ratio (even if tiny) to neutrinos.

Summary

- This is only an order-of-magnitude calculation. A more precise calculation requires inclusion of kinematic and spin factors, as well as consideration of which fermions the mediator U couples to.
- The freeze-out of light Dark Matter occurs in the middle of the QCD phase transition, and is much more sensitive to uncertainties due to QCD than heavier Dark Matter.
- Several of these measurements have now been performdd including $\Upsilon(1S) \to \chi\chi$; $\eta \to \chi\chi$ and $\eta' \to \chi\chi$; and now $J/\Psi \to \chi\chi$.

Thanks!