Light inflaton model hunting guide

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The inflaton model

⇛ The model is extremely simple:

$$V(H,S) = V_H + V_{\rm mix} + V_S,$$

where

$$V_H = -\mu^2 H^\dagger H + \lambda_H (H^\dagger H)^2$$
$$V_{\rm mix} = \frac{a_1}{2}\left(H^\dagger H\right) S + \frac{a_2}{2}\left(H^\dagger H\right) S^2$$
$$V_S = \frac{b_2}{2} S^2 + \frac{b_3}{3} S^3 + \frac{b_4}{4} S^4$$

⇛ Now the Lagrangian needs to be written in physical degrees of freedom:

- You start by minimizing the scalar potential.
- Then you expand the group states (linear terms in h, s expansion vanish).
- Then you generate the mass is given(see backup for details):

$$\mathcal{L}_{mass} = -\frac{1}{2}\begin{pmatrix} h \\ s \end{pmatrix}^T \begin{pmatrix} A & C \\ C & B \end{pmatrix} \begin{pmatrix} s' \\ h' \end{pmatrix}$$

The inflaton model

⇛ You can diagonalize the matrix by orthogonal transformation:

$$\begin{pmatrix} h \\ s \end{pmatrix} = \begin{pmatrix} \sin\theta & \cos\theta \\ \cos\theta & \sin\theta \end{pmatrix} \begin{pmatrix} s' \\ h' \end{pmatrix}$$

where

$$\cos\theta = 1 + \mathcal{O}(y^2), \quad \sin\theta = y + \mathcal{O}(y^3) \quad y = \frac{2C}{A-B}$$

⇛ For small mixing:

$$m^2_{S'} \sim B - \frac{1}{4}(A-B)y^2$$

⇛ So now comes something that is the most important; all the interaction with the SM is done just by assuming it's Higgs and inserting: $h \to \sin\theta s$

⇛ For example:

$$\mathcal{L}_Y = -m_f h \bar{\psi}_f \psi_f + \text{h.c.} \qquad \mapsto \mathcal{L}_{S'ff} = -m_f \sin\theta s \bar{\psi}_f \psi_f + \text{h.c.}$$

The inflaton model, so what?

⇛ For a given mixing angle $\sin\theta$ and the inflaton mass we can calculate it's width:

$$\Gamma_{\ell\ell} = \frac{\sin^2\theta}{8\pi\nu^2} m_\ell^2 m_S \left(1 - \frac{4m_\ell^2}{m_S^2}\right)^{\frac{3}{2}}$$

$$c\tau_S \approx 60 \times \left(\frac{0.01}{\sin\theta}\right)^2 \left(\frac{500}{m_S}\right)^3 [\mathrm{mm}]$$

⇛ Since in experiment we set limits in 2D space: $(m_S, c\tau_S)$ we can map it to: $(m_S, \sin\theta)$.

⇛ Now the misunderstanding started with "Light inflaton Hunter's Guide" D. Gorbunov:

$$\mathrm{Br}(B \to \chi X_s) \sim 10^{-6} \left(1 - \frac{m_\chi^2}{m_b^2}\right) \left(\frac{\beta}{\beta_0}\right) \left(\frac{300\mathrm{MeV}}{m_\chi}\right) \quad (1)$$

and: "where Xs stands for strange meson channel mostly saturated by a sum of pseudoscalar and vector kaons."

The inflaton model, so what?

⇛ In the interpretation of the $B \to K^* \xi$ they followed Gorbunov and assumed that the 33% of X_s are a K^* and used the above formula.
⇛ We followed a different approach and calculated the exclusive widths:

$$\mathcal{M} = -\frac{1}{2} c_h \theta \langle K | \bar{s} b | B \rangle = -\frac{1}{2} c_h \theta \frac{M_B^2 - M_K^2}{m_b - m_s} f_0(m_s^2)$$

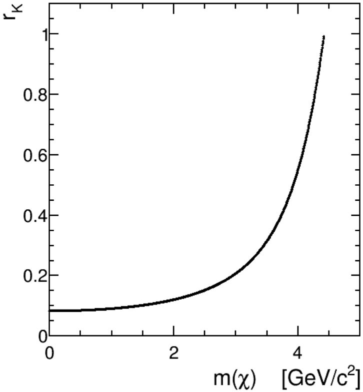
$$\Gamma_{B \to K^* \chi} = \frac{c_h \theta^2}{64\pi} \lambda^{1/2}(1, \frac{M_K^2}{M_B^2}, \frac{M_S^2}{M_B^2}) f_0(m_S^2) \frac{(M_B^2 - M_K^2)}{M_B (m_b - m_s)^2}$$

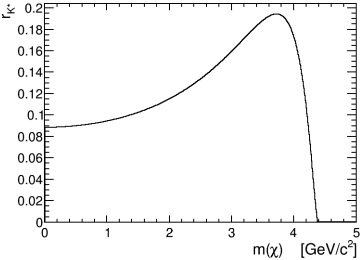
⇛ Now after we calculate this our self we found the solution in the literature B.Batel et. al

The inflaton model, so what?

⇛ Now if we look how many of the X_s are K and K^* we define the variables:

$$r_K = \frac{B \to K\chi}{B \to X_s\chi} \quad r_{K^*} = \frac{B \to K^*\chi}{B \to X_s\chi}$$





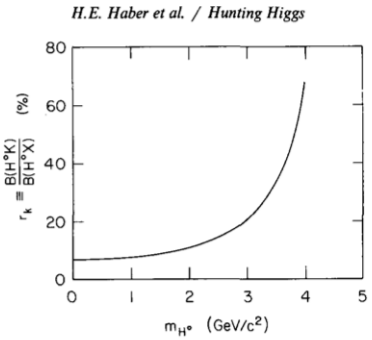
⇛ So the assumption about $33\ \%$ was generous assumption.

Cross check of the calculations

⇛ So we have cross-checked this calculations with old Higgs papers.

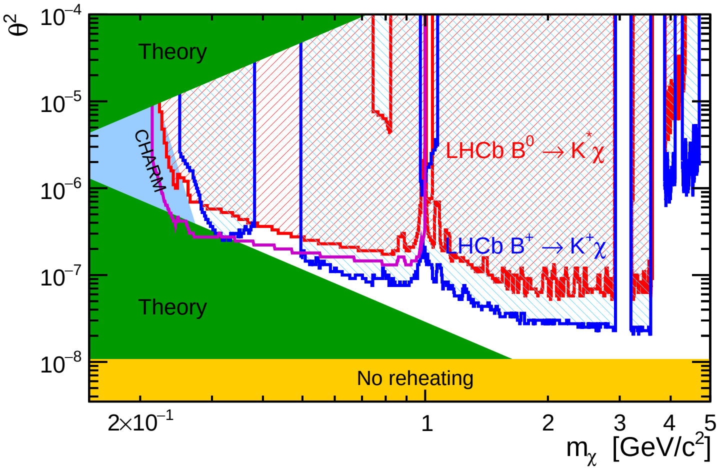
⇛ In the 80s they thought that Higgs might he light enough that it can be produced in B decays.

⇛ From Haber, et al.:



⇛ So everything is consistent.

The result



θ^2
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Theory
Theory
CHARM
LHCb $B^0 \to K^* \chi$
LHCb $B^+ \to K^+ \chi$
No reheating
2×10^{-1}
1
2
3
4
5
m_χ [GeV/c^2]

Backup

⇛ ves:

$$\langle H \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \nu \end{pmatrix}$$
$$\langle S \rangle = x.$$

⇛ Minimalization:

$$0 = -\mu^2 + \lambda_H \nu^2 + a_1 x^2 + \frac{1}{2} x^2$$
$$0 = b_2 + b_3 x + b_4 x^2 + \frac{a_1 \nu^2}{4 x_0} + \frac{a_2 \nu_0^2}{2}$$

Backup

⇛ generate the mass:

$$\mathcal{L}_{mass} = -\frac{1}{2}\begin{pmatrix} h \\ s \end{pmatrix}^T \begin{pmatrix} A & C \\ C & B \end{pmatrix} \begin{pmatrix} s' \\ h' \end{pmatrix}$$

$$\cos\theta = 2(1 + y^{-2}(1 - \sqrt{1+y^2}))^{-0.5}$$
$$\sin\theta = 2(1 + y^{-2}(1 + \sqrt{1+y^2}))^{-0.5}$$
$$y = \frac{2C}{A-B}$$

⇛ Mass eigenvalues:

$$m^2_{h'/s'} = \frac{1}{2}\left[A + B \pm (A-B)\sqrt{1+y^2}\right]$$

Naturalnes

⇛ If the $\sin\theta \ll 1$

$$m_{h'}^2 \sim 2\lambda_H \nu^2$$

$$m_{s'}^2 \sim b_3 x + 2b_4 x^2 - \frac{a_1 \nu^2}{4x}$$

⇛ Since Higgs is $125\mathrm{GeV}$ then $m_S \sim \mathcal{O}(1)$