

# Light inflaton model hunting guide



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## The inflaton model

⇒ The model is extremely simple:

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

where

$$\begin{aligned}V_H &= -\mu^2 H^\dagger H + \lambda_H (H^\dagger H)^2 \\V_{\text{mix}} &= \frac{a_1}{2} (H^\dagger H) S + \frac{a_2}{2} (H^\dagger H) S^2 \\V_S &= \frac{b_2}{2} S^2 + \frac{b_3}{3} S^3 + \frac{b_4}{4} S^4\end{aligned}$$

⇒ 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):

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

# 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:

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

⇒ 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:  $h \rightarrow \sin \theta s$

⇒ For example:

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

## The inflaton model, so what?

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

$$\Gamma_{\ell\ell} = \frac{\sin^2 \theta}{8\pi\nu^2} m_\ell^2 m_S \left(1 - \frac{4m_\ell^2}{m_S^2}\right)^{\frac{3}{2}}$$
$$c\tau_S \approx 60 \times \left(\frac{0.01}{\sin \theta}\right)^2 \left(\frac{500}{m_S}\right)^3 [\text{mm}]$$

⇒ 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:

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

and: "where  $X_s$  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  $B \rightarrow K^* \xi$  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:

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

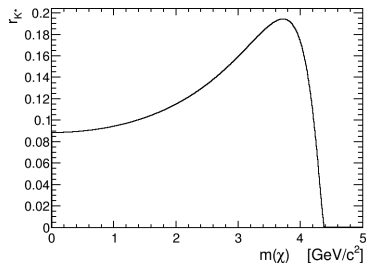
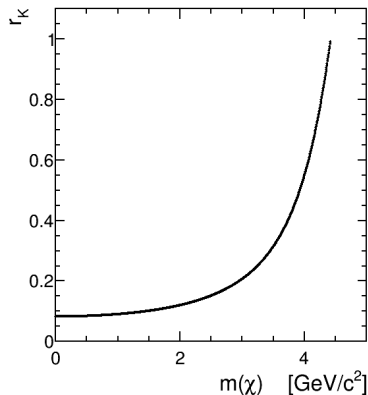
$$\Gamma_{B \rightarrow K^* \chi} = \frac{c_h\theta^2}{64\pi}\lambda^{1/2}\left(1, \frac{M_K^2}{M_B^2}, \frac{M_S^2}{M_B^2}\right)f_0(m_S^2)\frac{(M_B^2 - M_K^2)}{M_B(m_b - m_s)^2}$$

⇒ 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:

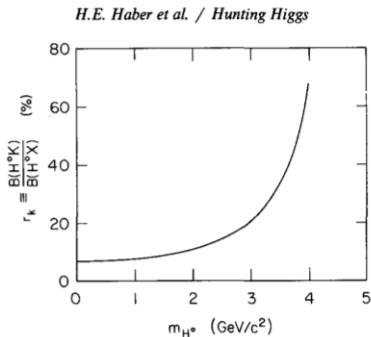
$$r_K = \frac{B \rightarrow K\chi}{B \rightarrow X_s\chi} \quad r_{K^*} = \frac{B \rightarrow K^*\chi}{B \rightarrow X_s\chi}$$



⇒ So the assumption about 33 % was generous assumption.

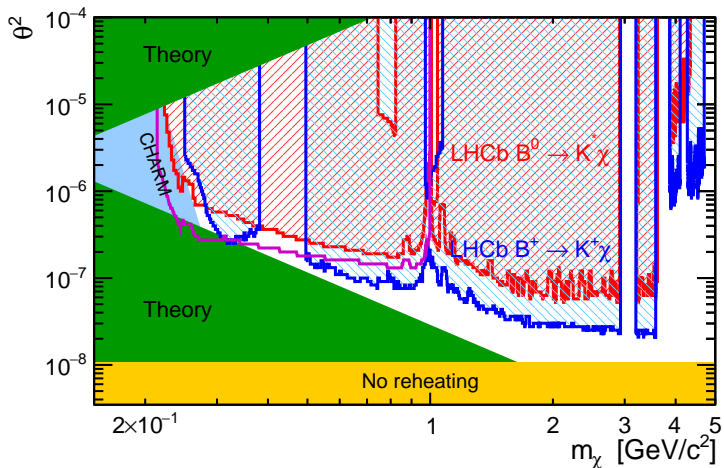
# Cross check of the calculations

- ⇒ So we have cross-checked this calculations with old Higgs papers.
- ⇒ In the 80s they thought that Higgs might be light enough that it can be produced in  $B$  decays.
- ⇒ From Haber, et al.:



- ⇒ So everything is consistent.

# The result





⇒ ves:

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

⇒ Minimalization:

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

# 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:

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

⇒ 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 125GeV then  $m_S \sim \mathcal{O}(1)$