Searches of mediator to Dark sector in B-meson decay into Kaon

Aliaksei Kachanovich[1], Ulrich Nierste[1], Ivan Nišandžić[2]

[1]Karlsruhe Institute of Technology, [2]Ruđer Bošković Institute

Karlsruher Institut für Technologie

Motivation

- We consider the Higgs portal to the Dark sector, where the Standard Model-like Higgs boson mixed with light singlet boson h_2. The boson h_2 couple to Dark sector but it also decays into the Standard Model particle.
- One of the main goals of this research was to check the property of gauge cancellation. Multiplying the gauge-dependent off-shell Standard-Model b-s-Higgs vertex with the sine of the Higgs mixing angle does not give the correct b-s-h_2 vertex.
- We further advocate for using the h_2 lifetime information contained in displaced-vertex data with h_2 decaying back to Standard-Model particles to better constrain the h_2 mass or to reveal additional h_2 decay modes into long-lived particles.

Theory

- **The model**
  - The scalar potential of the model is described by

$$V = V_H + V_{H\phi} + V_\phi + \text{h.c.}$$

$$\text{with} \qquad V_H = -\mu^2 H^\dagger H + \frac{\bar{\lambda}_0}{4}(H^\dagger H)^2,$$

$$V_{H\phi} = \frac{\alpha}{2}\phi(H^\dagger H),$$

$$V_\phi = \frac{m^2}{2}\phi^2 + \frac{1}{4}\lambda_\phi \phi^4,$$

  where H is a scalar doublet, and ϕ is a singlet.
  - It is convenient to work in the mass base. Mass matrix elements defined as

$$\mu_h^2 \equiv \frac{\partial^2 V}{\partial h^2} = \frac{\bar{\lambda}_0 v^2}{2},$$

$$\mu_{h\phi}^2 \equiv \frac{\partial^2 V}{\partial h \partial \phi} = \frac{\alpha v}{2},$$

$$\mu_\phi^2 \equiv \frac{\partial^2 V}{\partial \phi^2} = 2\lambda_\phi v_\phi^2 - \frac{\alpha v^2}{4 v_\phi}.$$

  - New eigenstates defined as

$$h_1 = h\cos\theta + \phi\sin\theta\,,$$
$$h_2 = -h\sin\theta + \phi\cos\theta\,.$$

  - Vertices for the process are

$$G^+G^-h_1: \qquad -i\frac{e m_{h_1}^2 \cos\theta}{2 m_W \sin\theta_W},$$

$$G^+G^-h_2: \qquad i\frac{e m_{h_2}^2 \sin\theta}{2 m_W \sin\theta_W}.$$

  - The process is described by diagrams

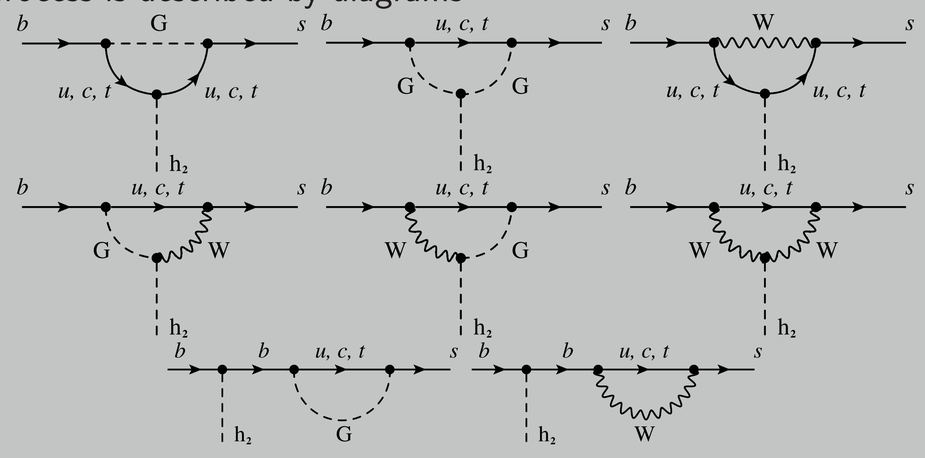
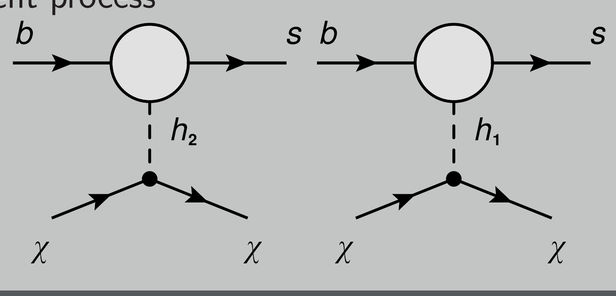


Figure 1: One-loop diagrams contributing to $b \to s h_2$ in R_ξ gauge.

- **Gauge cancellation**
  - As an example: The simplest fermion Dark Matter model is described by

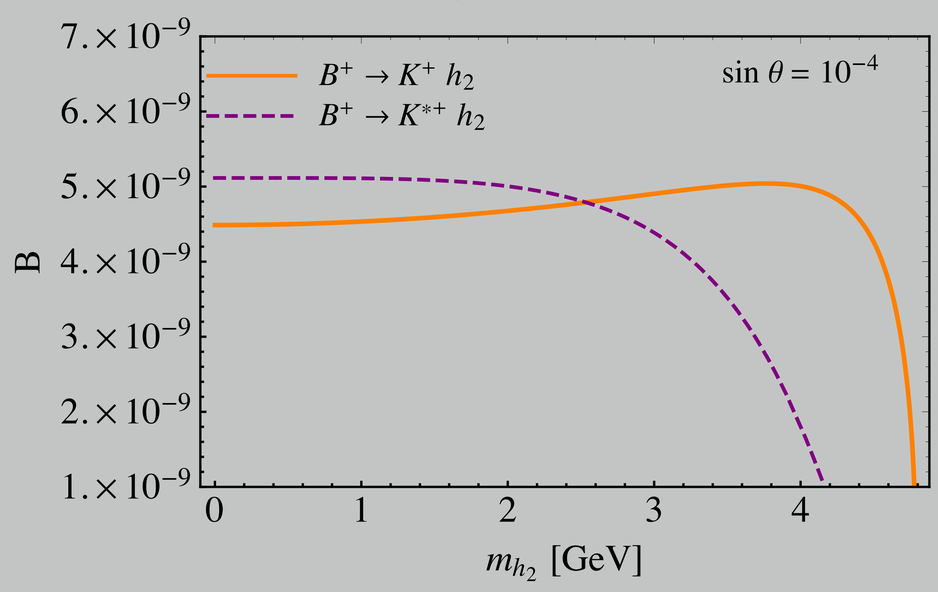
$$\mathcal{L}_\chi = \lambda_\chi \phi \bar{\chi}\chi\,.$$

  - The full set of diagrams for the process $b \to s\chi\chi$ which is needed to be gauge independent process

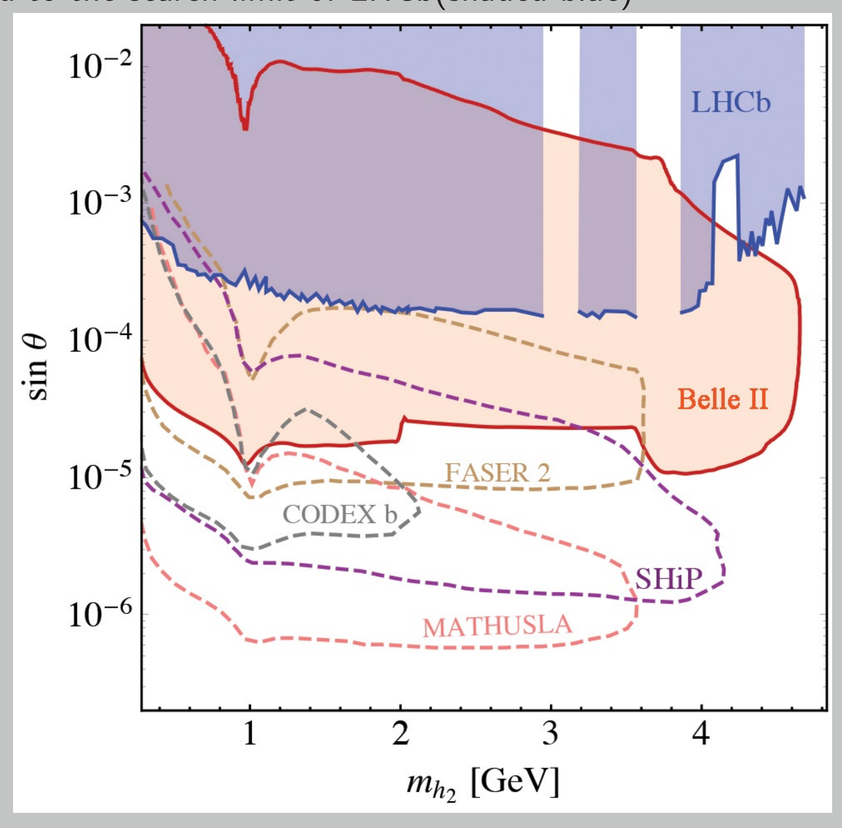


Results: Searches in the Belle II experiment

- The branching fractions of $B^+ \to K^+ h_2$ (thick orange curve) and $B^+ \to K^{\star+} h_2$ (dashed purple curve) for $\sin\theta = 10^{-4}$.



  - Sensitivity of the *Belle II* experiment to decay h_2 into the SM particles, including both $B \to K h_2$ and $B \to K^* h_2$ and decays of h_2 to $(\pi\pi + KK), \mu^+\mu^-, \tau^+\tau^-$ are shown with the filled red region, and compared to the search limit of *LHCb*(shaded blue)



  - The number of displaced vertices which can be detected in *Belle II* experiment

$$N_f^{\text{tot}} = N_{B\bar{B}} 1.93\, Br(B^\pm \to K^{(\star)\pm} h_2) Br(h_2 \to f) \times \int d\vartheta\, p(\vartheta) \frac{1}{d_L} \int_{r_{\min}(\vartheta)}^{r_{\max}(\vartheta)} dr \exp\left[-\frac{r}{d_L}\right]. \qquad (1)$$

  - Total number N_f^{tot} of displaced-vertex $B \to K^{(\star)} h_2[\to f]$ events in the detector of *Belle II* according to Eq. 1 for various values of the proper lifetime (columns) and mass (rows) of h_2. Here is taken into account all possible final state for the mesons K and $K^\star$.

m_{h_2}[GeV]	τ [ps]				
	250	500	1000	2000	4000
0.3	50204	18385	5734	1614	429
0.9	972.3	465	191.8	65.7	19.6
1.5	1634.7	815.2	382.7	152.7	50.9
2.1	334.2	167.6	82.6	36.8	13.7
2.7	115.6	58	29	13.9	5.8
3.3	56.8	28.6	14.4	7.1	3.2
3.9	58.4	29.6	14.9	7.4	3.6

Conclusions

- To use Wilson coefficient without further analysis could provide gauge dependent result.
- In wide range of parameters scalar particle can be detected in Belle II experiment.
- The results published in: Eur.Phys.J.C 80 (2020) 7, 669; e-Print: 2003.01788 [hep-ph]

Authors thank BMBF for the support, A.K. also thanks DAAD and KSETA