Searches for heavy Higgs bosons in the framework of 2HDM model

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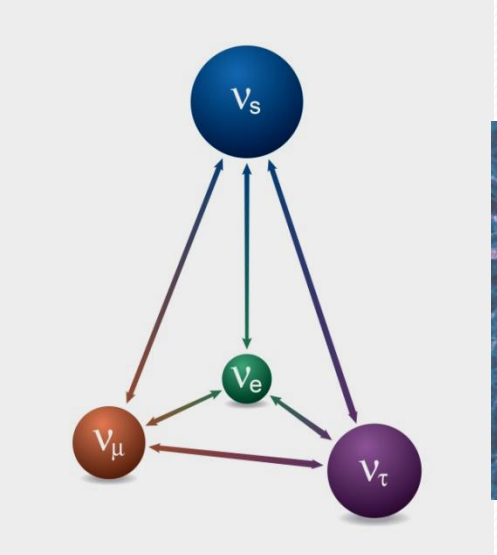
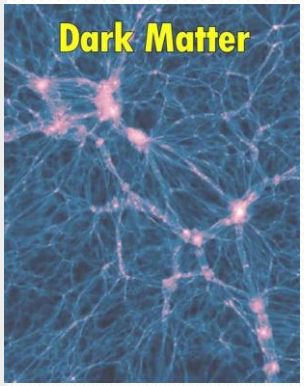
Plan of the talk

- Problems with explanations of experimental data
- Two-Higgs-Doublet Model
- Benchmark scenarios within the 2HDM model
- Calculations of Higgs boson production cross sections
  - The modifications of the SM-like Higgs couplings
  - Direct searches for BSM Higgses
- Conclusions

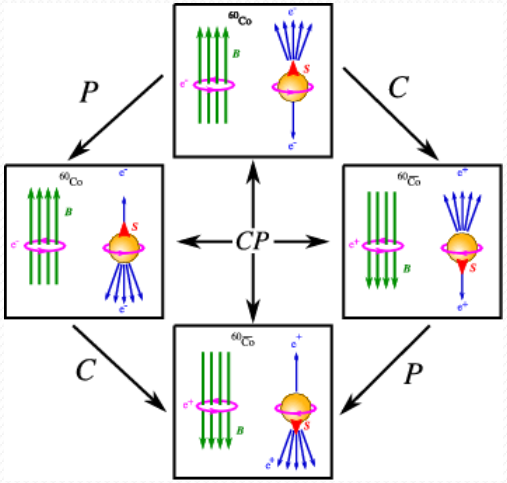
Problems with explanations of experimental data



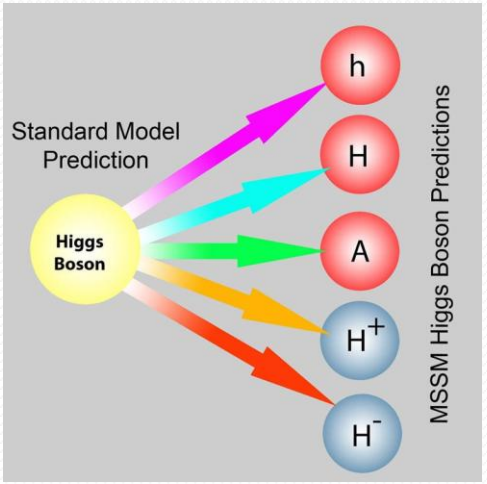
neutrino oscillations



dark matter candidate



CP-violation



Higgs boson

Two-Higgs-Doublet Model

$$V = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left(m_{12}^2 \Phi_1^\dagger \Phi_2 + h.c. \right)$$
$$+ \frac{1}{2}\lambda_1 \left(\Phi_1^\dagger \Phi_1 \right)^2 + \frac{1}{2}\lambda_2 \left(\Phi_2^\dagger \Phi_2 \right)^2 + \lambda_3 \left(\Phi_1^\dagger \Phi_1 \right) \left(\Phi_2^\dagger \Phi_2 \right) + \lambda_4 \left(\Phi_1^\dagger \Phi_2 \right) \left(\Phi_2^\dagger \Phi_1 \right)$$
$$+ \left[\frac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2) \right] \Phi^\dagger \Phi_2 + h.c. \right]$$

$$\Phi_i = \begin{pmatrix} \phi_i^+ \\ \frac{v_i + \phi_i + i\chi_i}{\sqrt{2}} \end{pmatrix}$$

$$H_1 = \Phi_1 \cos\beta + e^{-i\xi} \Phi_2 \sin\beta$$
$$H_1 = -e^{-i\xi} \Phi_1 \sin\beta + \Phi_2 \cos\beta.$$

$$H^\pm = -\sin\beta \phi_1^\pm + \cos\beta \phi_2^\pm$$
$$A = -\sin\beta \chi_1 + \cos\beta \chi_2$$
$$H = \cos\alpha \phi_1 + \sin\alpha \phi_2$$
$$h = -\sin\alpha \phi_1 + \cos\alpha \phi_2$$

Two-Higgs-Doublet Model

The 2HDM parameter space is described by six free parameters: the physical Higgs masses (m_h, m_H, m_A and $m_{H^\pm}$), the mixing angle between the two CP-even Higgses (α), and the ratio of the two vacuum expectation values ($\tan\beta = v_2/v_1$)

	Type I	Type II
ξ_h^u	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
ξ_h^d	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_h^l	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
ξ_H^u	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
ξ_H^d	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_H^l	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
ξ_A^u	$\cot\beta$	$\cot\beta$
ξ_A^d	$-\cot\beta$	$\tan\beta$
ξ_A^l	$-\cot\beta$	$\tan\beta$

Table 1: Yukawa couplings u, d, l to the neutral Higgs bosons, h, H, A

Benchmark scenarios within the 2HDM model

The new parameter space of the model is spanned by the three new Yukawa couplings, by the mass of the heavy neutral Higgs boson H and by the mixing angle $\alpha - \beta$

$$\{\bar{Y}_t, \bar{Y}_b, \bar{Y}_\tau, M_H, \sin(\alpha - \beta)\}$$

Benchmark points	$\bar{Y}_t$	$\bar{Y}_b$	$\bar{Y}_\tau$	$\sin(\alpha - \beta)$	M_H(GeV)
BP1	+1.01	-0.10	10^{-3}	+0.50	500
BP2	-1.0	+0.01	10^{-3}	-0.1	600
BP3	1.25	+0.05	10^{-3}	-0.2	680

Table 2: Sample points on parameter space

Calculations of Higgs boson production cross sections

The modifications of the SM-like Higgs couplings

- $pp \to At\bar{b}$, Fig.1;

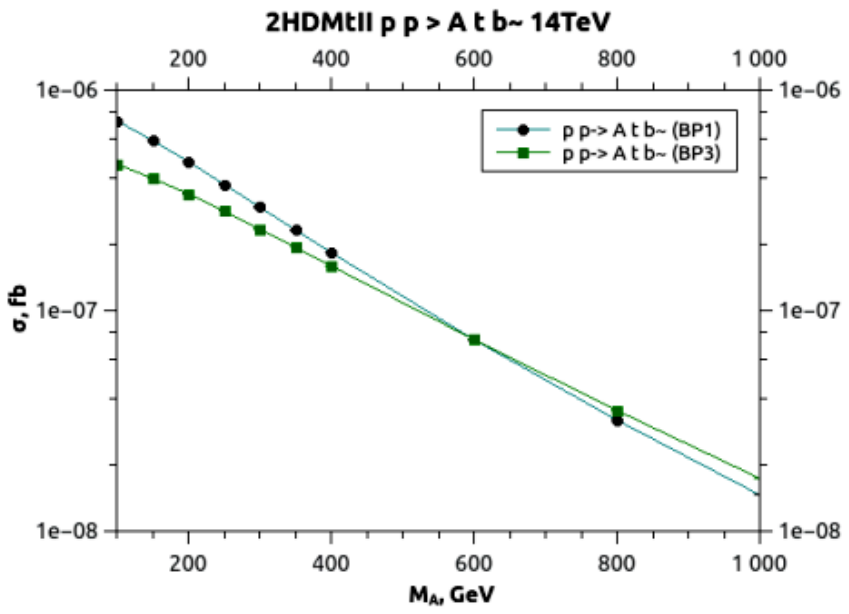


Figure 1: Production cross sections of A boson as a function of its mass M_A

- $pp \to HHZ$, Fig.2;

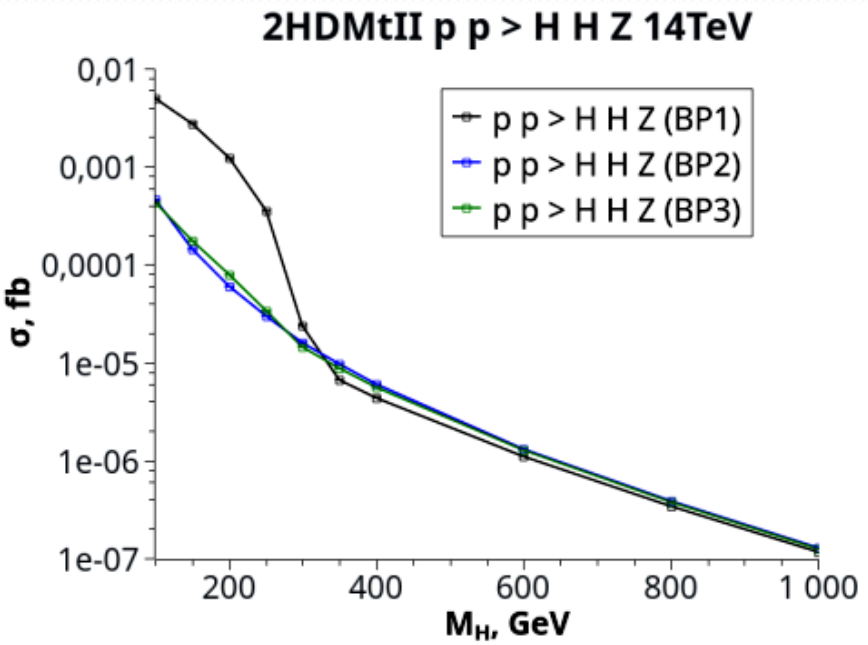


Figure 2: Production cross section of H boson as a function of mass M_H

The modifications of the SM-like Higgs couplings

- $pp \to H^+ b\bar{t}$, $pp \to H^+ t\bar{t}$, Fig.3;

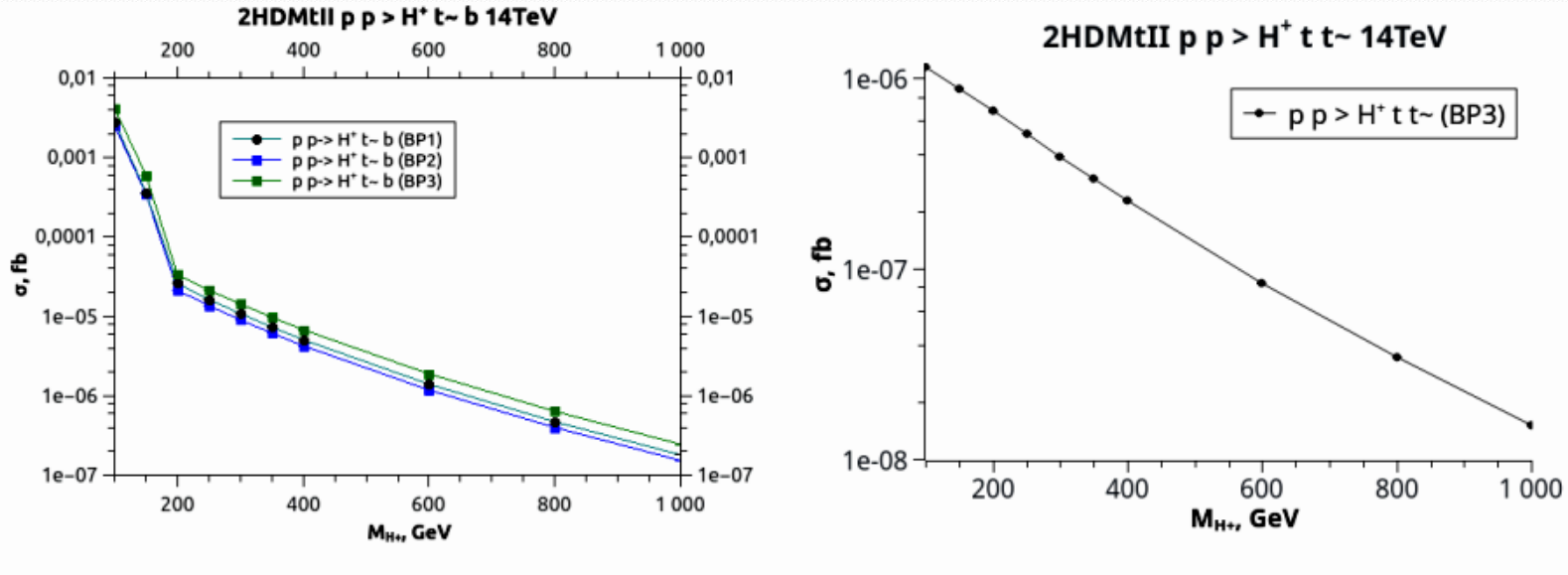


Figure 3: Production cross sections of H^+ boson as a function of its mass, M_{H^+} for left: $pp \to H^+ b\bar{t}$ process; right: $pp \to H^+ t\bar{t}$ process

Direct searches for BSM Higgses

- $pp \to At\bar{b}$, Fig.4;
- $pp \to Ht\bar{b}$, Fig.5;

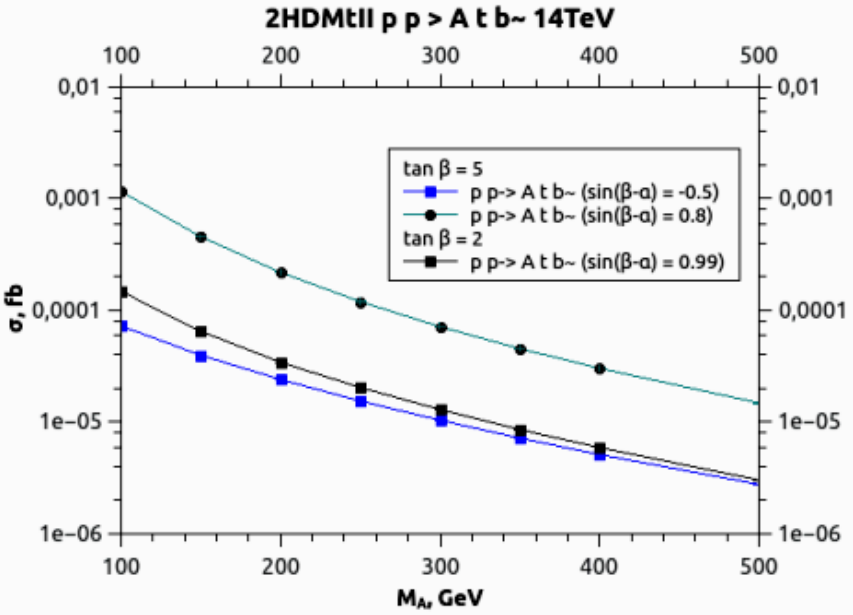


Figure 4: Production cross sections of A boson as a function of its mass, M_A

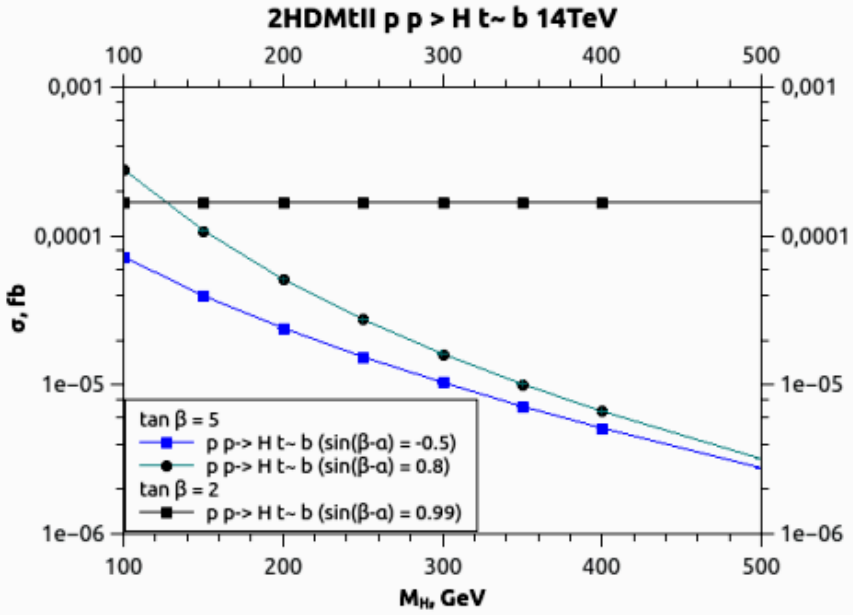


Figure 5: Production cross section of H boson as a function of mass, M_H

Conclusions

- Latest experimental data are related to the searches for additional Higgs bosons in the mass range of about 95-100 GeV, 350-400 GeV and 600-650 GeV. These searches are accompanied by severe restrictions on the parameter space. So our purpose was to take the most comprehensive parameter restrictions connected with ansatz for the Yukawa couplings and with the latest experimental parameter space from decay channels and Higgs coupling measurements.
- Our calculations were divided into two parts.
  - The calculations according to the first part connected with modification of Yukawa couplings demonstrated the clear and bright jump in production cross section of H+bt and HHZ production processes in the mass range of 100-200 GeV and 100-300 GeV accordingly at energy of 14 TeV. So, we can say about the possibility to find charged H+ and CP-even H bosons in the corresponding mass ranges.
  - As for the second part, we didn't see any essential deviations from the SM.
- The consequence of our calculations is the conclusion about the predominance of Yukawa coupling modifications over the modifications of the angles α, β in the searches for SUSY signal.

THANK YOU