The decay $A^0 \to h^0 Z^*$ in the inverted hierarchy and the production for A^0 at the LHC in normal hierarchy in 2HDM.

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Outline

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Motivation

Investigating the decay $A^0 \to h^0 Z^{(*)}$ in 2HDM Type I in the inverted hierarchy scenario ($m_{H^0} = 125\,GeV > m_{h^0}$), arXiv:2301.00728 (to appear in J.Phys.G).

Why?

- No experimental results by ATLAS and CMS in this scenario.
- Has not been studied by Monte Carlo Simulation.
- Promising for new physics.

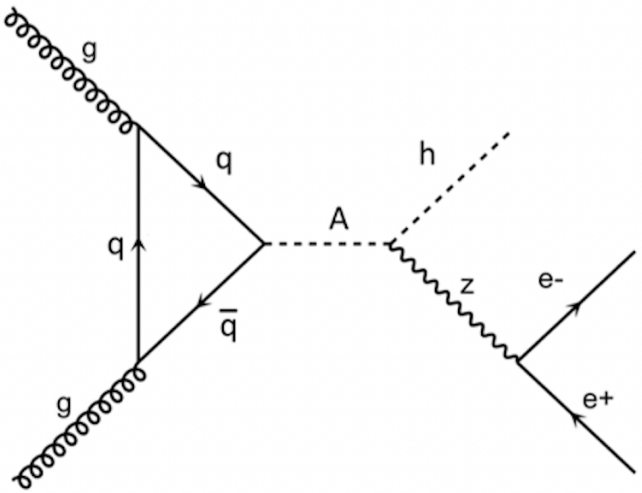


Figure: Feynman diagram for the process $gg \to A^0 \to h^0 l^+ l^-$.

Outline

Two Higgs Doublet Model (2HDM)

- Two-Higgs-doublet model (2HDM)
  1. A simple extension of the SM
  2. Contains 4 more scalars CP-even (H^0), CP-odd (A^0) and charged Higgs bosons ($H^{\pm}$)
  3. Leads to some interesting properties, such as Flavour Changing Neutral Currents (FCNCs)
     - Avoided if all fermions with the same quantum number interact with no more than one Higgs doublet.
     - Produce 4 types: type I, type II, type X and type Y.

Types	$y^d_{A^0}$	$y^u_{A^0}$	$y^l_{A^0}$
I	$-cot\beta$	$cot\beta$	$-cot\beta$
II	$tan\beta$	$cot\beta$	$tan\beta$
X	$-cot\beta$	$cot\beta$	$tan\beta$
Y	$tan\beta$	$cot\beta$	$-cot\beta$

Inverted hierarchy

- Inverted hierarchy
  1. The SM Higgs boson is measured to be CP-even, so either h^0 or H^0 can be interpreted as the observed 125 GeV boson ($m_{H^0} > m_{h^0}$).
  2. Normal hierarchy:$cos(\beta - \alpha) \rightarrow 0$, $H^0_{SM} \equiv h^0$.
  3. Inverted hierarchy: $sin(\beta - \alpha) \rightarrow 0$, $H^0_{SM} \equiv H^0$.

Outline

Searches for $A^0 \to h^0 Z$ at the LHC

- The ATLAS and CMS investigated the decay channel $A^0 \to h^0 Z$ on the Normal Hierarchy (NH) scenario ($m_{h^0} = 125 GeV$) and an on-shell Z boson, arXiv:1712.06518, arXiv:1903.00941 and arXiv:1910.11634.
- These searches primarily explore the region of parameter space where $m_{A^0} > 225$ GeV.
- In this study, we investigate the decay process $A^0 \to h^0 Z^{(*)}$ in the scenario of inverted hierarchy and it includes the possibility of an off-shell Z boson (130 GeV $\leq m_{h^0} + m_{A^0} \leq$ 400 GeV).

Outline

Results

1. Determining suitable regions: The parameter space must respect all theoretical and experimental constraints.
   - 2HDMC.
   - HiggsBounds and HiggsSignal.
   - SuperIso.
2. Calculating the signal cross section in IH Type I.

$$\sigma(gg \to A^0) \times BR(A^0 \to h^0 Z^*) \times BR(h^0 \to b\bar{b}). \quad (1)$$

3. Comparing the magnitude with the corresponding cross section in the NH scenario. arXiv:1903.00941.

Components	$\sigma(gg \to A^0)$	$BR(A^0 \to h^0 Z^*) = \frac{\Gamma(A^0 \to h^0 Z^{(*)})}{\Gamma^{total}_{A^0}}$	$BR(h^0 \to b\bar{b}) = \frac{\Gamma(h^0 \to b\bar{b})}{\Gamma^{total}_{h^0}}$
Parameters	m_{A^0} and $tan\beta$	m_{A^0}, m_{h^0} and $cos^2(\beta - \alpha)$	m_{h^0}, $tan\beta$ and $cos^2(\beta - \alpha)$

Table: The components and the parameters they depend on.

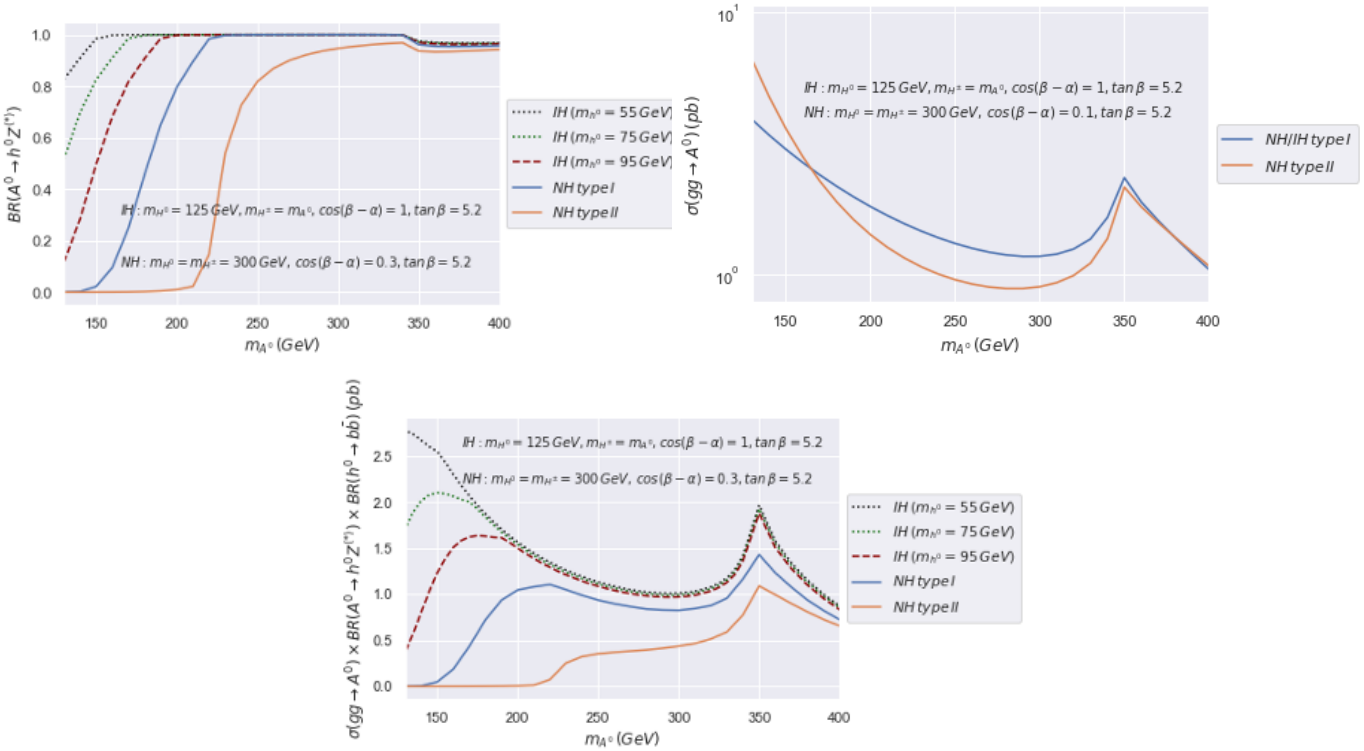


Figure: The $BR(A^0 \to h^0 Z^*)$, $(gg \to A^0)$ and the $\sigma(gg \to A^0) \times BR(A^0 \to h^0 Z^*) \times BR(h^0 \to b\bar{b})$ as functions of m_{A^0} for NH with Type I and Type II and for IH with Type I.

The results demonstrate that:

1. the decay $A^0 \to h^0 Z$ in IH has very little suppression from the coupling $A^0 h^0 Z$, in contrast to the case of NH.
2. the cross section for signal events in the Two Higgs Doublet Model (Type I) can be as high as a few pb in IH for the experimentally unexplored region of $m_{A^0} < 225\,GeV$. These cross sections are significantly higher than those in NH.

Outline

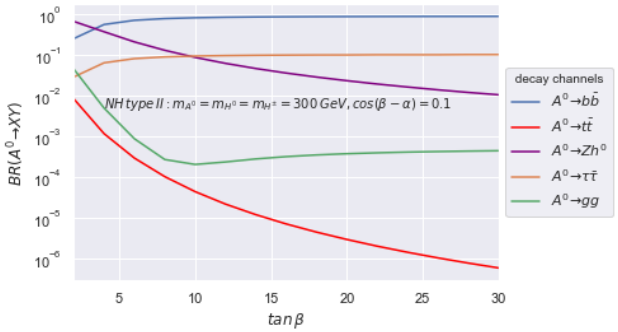
Conclusion

- A search for $A^0 \to h^0 Z^*$ in the 2HDM type I inverted hierarchy has not been done experimentally.
- In inverted hierarchy, there can be significantly larger cross sections for $A^0 \to h^0 Z^*$ events than in the normal hierarchy case.

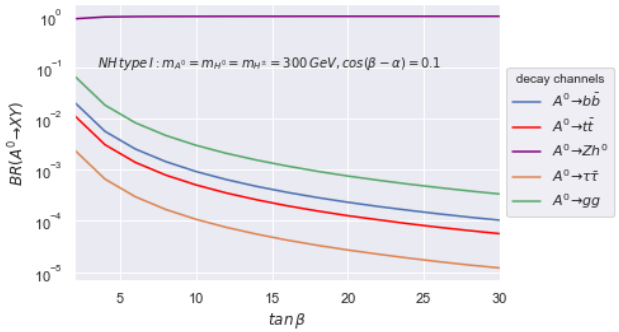
Thanks for listening

Backup

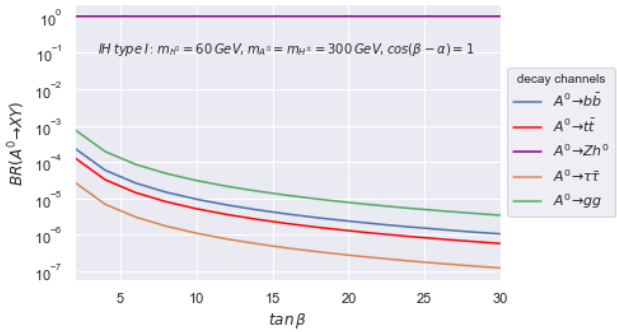
$$\Gamma(A^0 \to h^0 Z^*) = \frac{m_{A^0}^3 cos^2(\beta-\alpha)\lambda^{3/2}}{v^2}\left(\frac{m_{h^0}^2}{m_{A^0}^2}, \frac{m_Z^2}{m_{A^0}^2}\right) \quad (2)$$



(a) The BRs of A^0 in the 2HDM (Type II) as a function of $tan\beta$ in the NH.



(b) The BRs of A^0 in the 2HDM (Type I) as a function of $tan\beta$ in the NH.



(c) The BRs of A^0 in the 2HDM (Type I) as a function of $tan\beta$ in the IH.

Figure: The BRs of A^0 in the 2HDMs as functions of $tan\beta$.

Backup

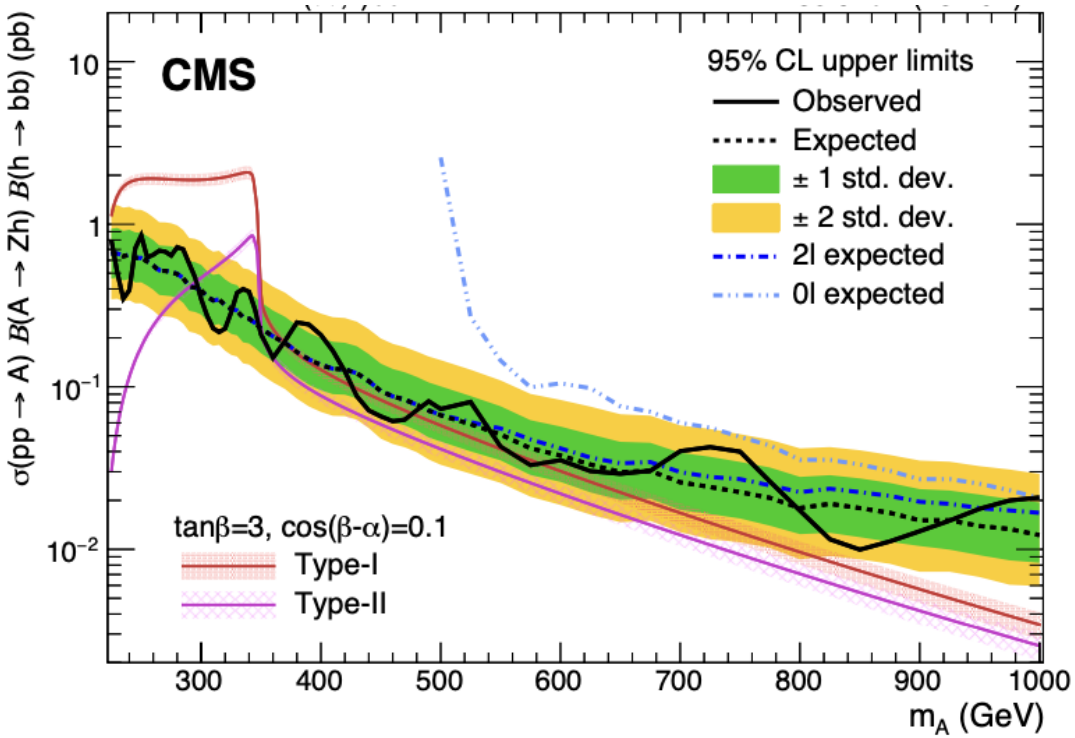


Figure: Observed and expected upper limits on $\sigma(gg \to A^0)B(A^0 \to h^0 Z)B(h^0 \to b\bar{b})$, arXiv:1903.00941.