Investigating Higgs self-interaction through di-Higgs plus jet production

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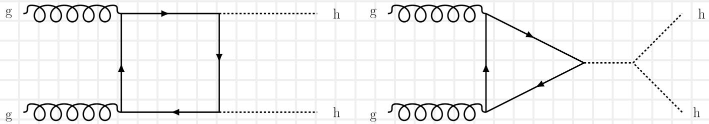
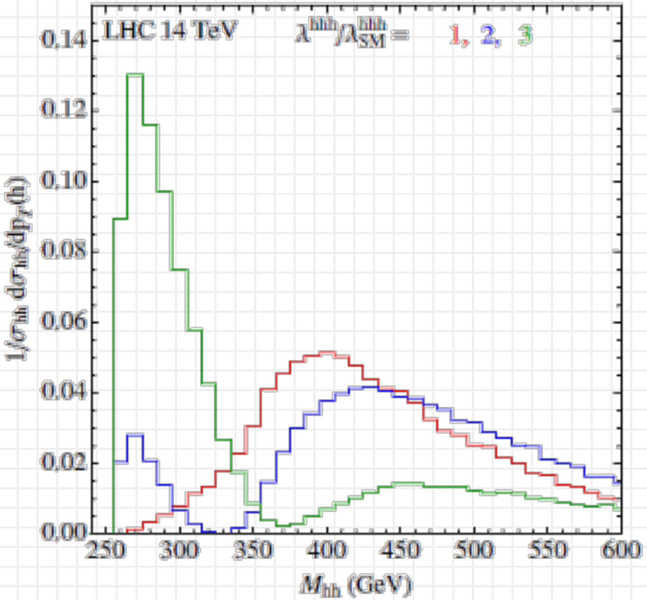
Motivation

- The Higgs self-couplings is crucial to several fundamental questions: the nature of the Higgs boson, electroweak symmetry breaking and electroweak baryogenesis etc.
- This measurement remains challenging: For trilinear Higgs self-coupling, at the LHC, the 95% confidence interval is $-1.5 < \kappa_\lambda < 6.7$ (arXiv:2112.11876 [hep-ex]).

Phenomenology of Higgs pair plus jet production at hadron collider

Higgs pair production



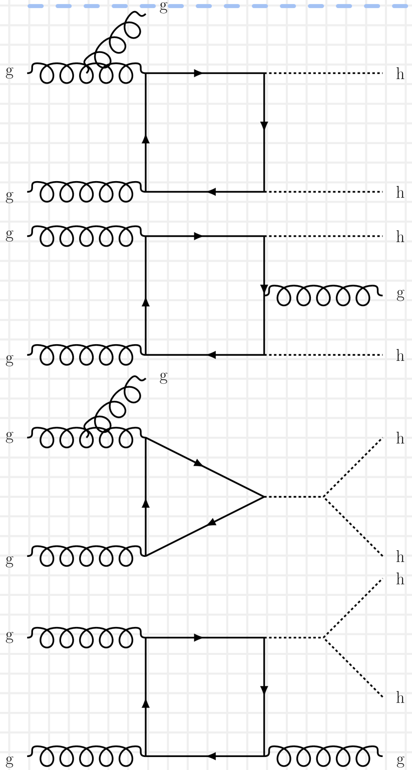


- Threshold $m_{hh} \approx 2m_h$:

$$\mathcal{M} \simeq \frac{\alpha_s}{12\pi v}\left(\frac{\kappa_\lambda \lambda_{\rm SM}}{s-m_h^2} - \frac{1}{v}\right) \to \frac{\alpha_s}{12\pi v^2}(\kappa_\lambda - 1) \overset{\rm SM}{=} 0$$

- Top mass effect $m_{hh} \approx 2m_t$.
- Large m_{hh} region: dominated by box diagram.
- The m_{hh} region between 250 GeV and 400 GeV is the most sensitive to κ_λ.
- Current experimental cuts, such as $p_T^h > 150\ GeV$, usually excludes this region.

Why additional jet?



- ✗ No need of p_T^h cuts: the large p_T cut over the additional jet could largely suppress the SM background in small m_{hh} region.
- ✗ When the jet p_T is large, the m_{hh} tend to be small.
- ✗ Drawbacks: the total cross section would be much smaller.

Simulations

Parton-level analysis

- Signal:

$$pp \to hh + jet \to b\bar{b}\gamma\gamma + jet$$

- Background

$$pp \to t\bar{t}\,(h \to \gamma\gamma)$$
$$pp \to t\bar{t}\,(h \to \gamma\gamma)\,j$$
$$pp \to b\bar{b}\gamma\gamma j$$
$$pp \to b\bar{b}\gamma jj$$
$$pp \to bj\gamma\gamma j$$

- Pre-selection cuts:

$$\Delta R_{j\gamma,jj,\gamma\gamma} > 0.3, \quad |\eta_{b,\gamma}| < 3, \quad |\eta_i| < 5$$
$$p_T^{\gamma} > 10\text{GeV}, \quad p_T^{j} > 20\text{GeV}, \quad p_T^{leading-jet} > 80\text{GeV}$$
$$75\text{GeV} < m_{bb} < 175\text{GeV}, \quad 100\text{GeV} < m_{\gamma\gamma} < 150\text{GeV}$$

- Kinematical cuts

$$\Delta R_{bb,\gamma\gamma,b\gamma} < 0.4, \; p_T^{b} > 30\text{GeV}, \; p_T^{\gamma} > 30\text{GeV}$$
$$|\eta_b| < 2.5, \; |\eta_\gamma| < 2.5, \; p_T^{leading-jet} > 150\text{GeV}$$
$$120\text{GeV} < m_{\gamma\gamma} < 130\text{GeV}, \; 80\text{GeV} < m_{bb} < 160\text{GeV}$$

- Smearing effect and mis-tagging rate

$$\sigma(m_{\gamma\gamma}) = 1.52\text{GeV}, \quad \sigma(m_{bb}) = 12.6\text{GeV}$$
$$\epsilon_{\gamma\to\gamma} = 0.863 - 1.07 \cdot e^{-p_{T,\gamma}/34.8\text{GeV}}$$
$$\epsilon_{j\to\gamma} = \begin{cases} 5.3 \times 10^{-4} \exp\left(-6.5\left(\frac{p_{T,j}}{60.4\text{GeV}} - 1\right)^2\right), & p_{T,j} < 65\text{GeV} \\ 0.88 \times 10^{-4}\left[\exp\left(-\frac{p_{T,j}}{943\text{GeV}}\right) + \frac{248\text{GeV}}{p_{T,j}}\right], & p_{T,j} >= 65 \end{cases}$$
$$\epsilon_b = 0.7, \epsilon_{c\to b} = 0.15, \epsilon_{light-jet\to b} = 0.003$$

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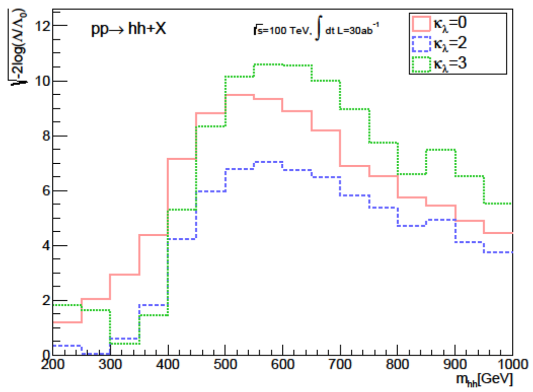
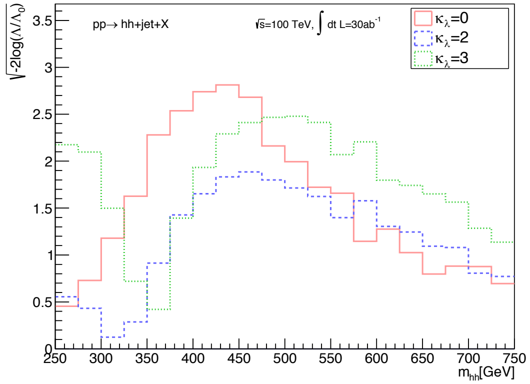
Parton-level analysis: the significance distributions.





- Significance distributions: likelihood ratio for each m_{hh} bin.
- Only give better sensitivity in small m_{hh} region.

Detector-level analysis

- All jets were reconstructed with anti-k_T algorithm with the parameter $R = 0.4$
- Detector parameters: $\epsilon_\gamma = 0.9, \epsilon_b = 0.8, \epsilon_{c\to b} = 0.1, \epsilon_{light-jet\to b} = 0.01, \epsilon_{j\to\gamma} = 0.0005$
- Exactly two b-tagged jets, two photons and at least one additional jet with the following Kinematical cuts:

$$p_T > 30\text{GeV}, |\eta_j| < 2.5, \quad |\eta_\gamma| < 1.37 \ or \ 1.52 < |\eta_\gamma| < 2.5$$

$$122\text{GeV} < m_{\gamma\gamma} < 128\text{GeV}, \quad 95\text{GeV} < m_{bb} < 155\text{GeV},$$

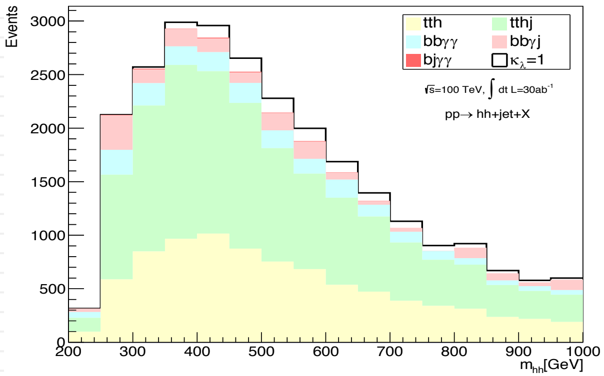
$$p_T^{leading-jet} > 150\text{GeV}$$

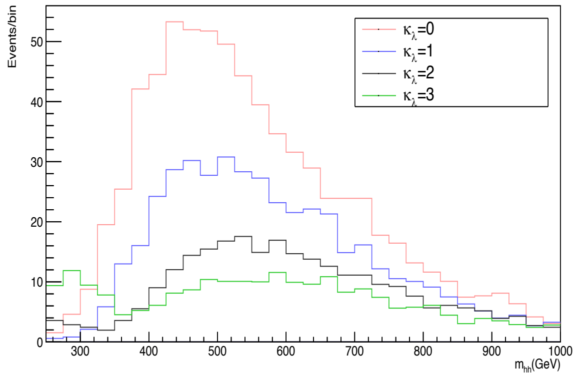
- Top rejection (the largest background is tth):

$$\chi^2 = \min\left\{\frac{(m_W - m_{i_1 i_2})^2}{\sigma_W^2} + \frac{(m_t - m_{i_1 i_2 j_1})^2}{\sigma_t^2} + \frac{(m_W - m_{i_3 i_4})^2}{\sigma_W^2} + \frac{(m_t - m_{i_3 i_4 j_2})^2}{\sigma_t^2}\right\}$$

$$\chi^2 > 6 \quad and\ lepton\ veto$$

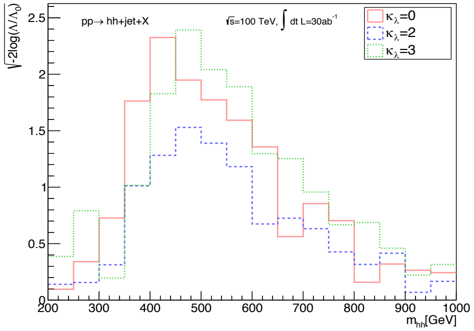
Results: m_{hh} distributions of signal and background events

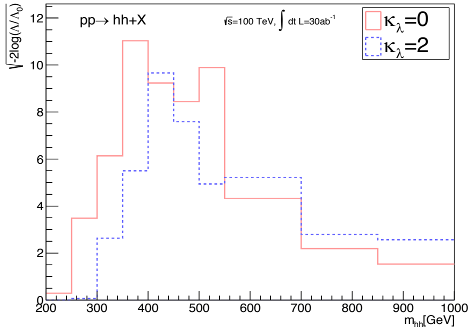




- Small m_{hh} region is more sensitive to κ_λ.
- We also analyzed our events with the current experimental cuts: $p_T^{\gamma\gamma} > 150\mathrm{GeV}, \mathrm{p_T^{b\bar{b}}} > 150\mathrm{GeV}$. Results shows that 23% of the signal events which passes our cuts can not pass the current experimental cuts. And for $m_{hh} < 400\ GeV$ region, this number is 67%.

Results: the significance distributions





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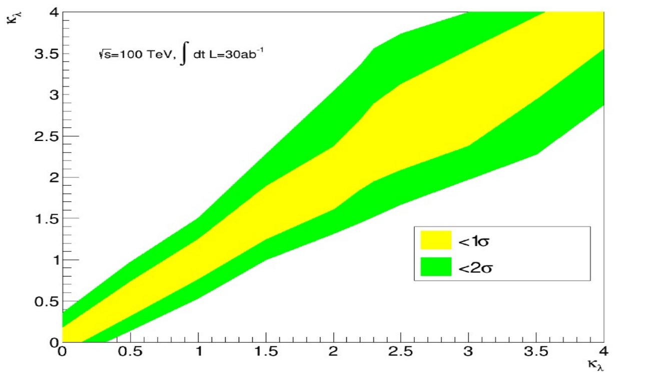
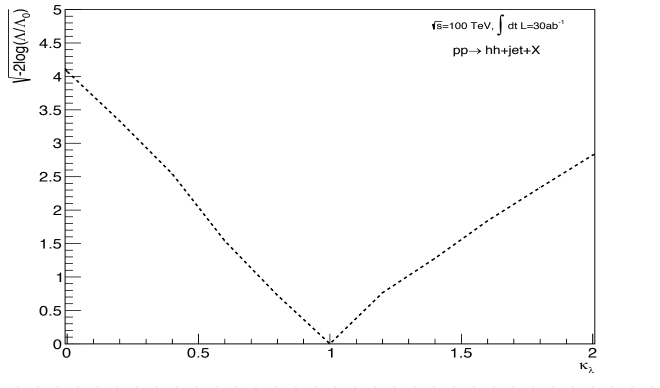
- For small m_{hh} region, our channel could give comparable significance, and it is largely independent to $pp \to hh + X$ channel.

Results: the confidence intervals





- The 2σ allowed interval is $0.51 < \kappa_\lambda < 1.65$
- A combined analysis with Higgs pair production could give a better result.

Thank you!