# DiHiggs Phenomenology *it depends on what you are asking for*

- trilinear Higgs self-coupling
- extra heavy resonances (MSSM, Higgs portals,...)
  - unboosted $m_H \sim 2m_h$
  - (un)boosted $m_H \gg 2m_h$ e.g. [Bowen, Wells, Cui `96]
- composite Higgs, top partners
  - new interactions
  - enhancement at large $p_T$

## Which final states are accessible?

# Self-coupling measurements

$$= \lambda_{\rm SM} = g^2 m_h^2/m_W^2$$

$$-\mathcal{L} \supset \frac{1}{2}m_h^2 h^2 + \sqrt{\frac{\eta}{2}} m_h h^3 + \frac{\eta}{4} h^4$$

$$- g m_V V^2 h - \frac{m_f}{v}\bar{f} f h$$

$$- \frac{\alpha_s}{12\pi} G^a_{\mu\nu} G^{a\,\mu\nu} \log(1 + h/v)$$

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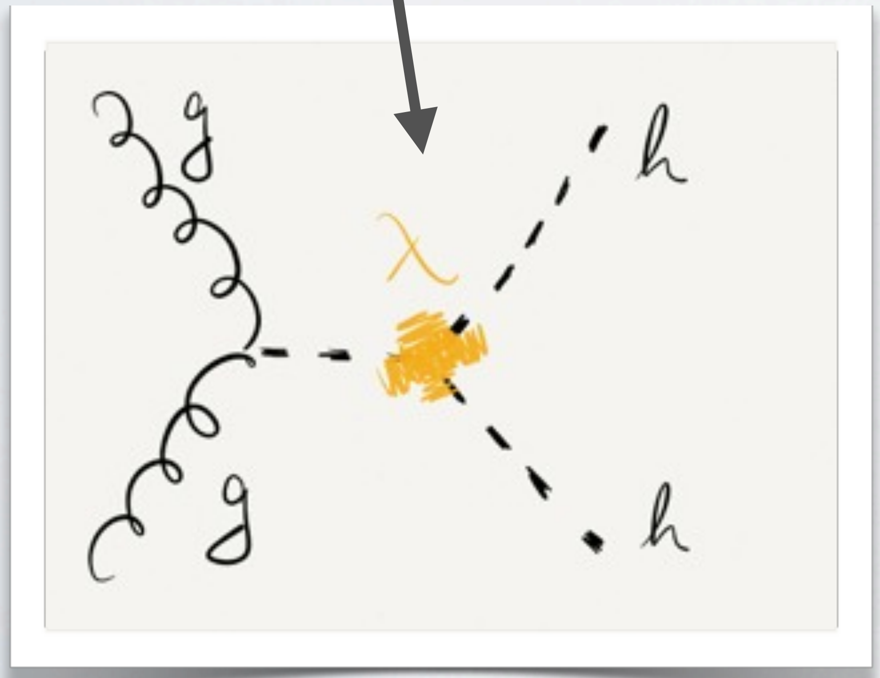

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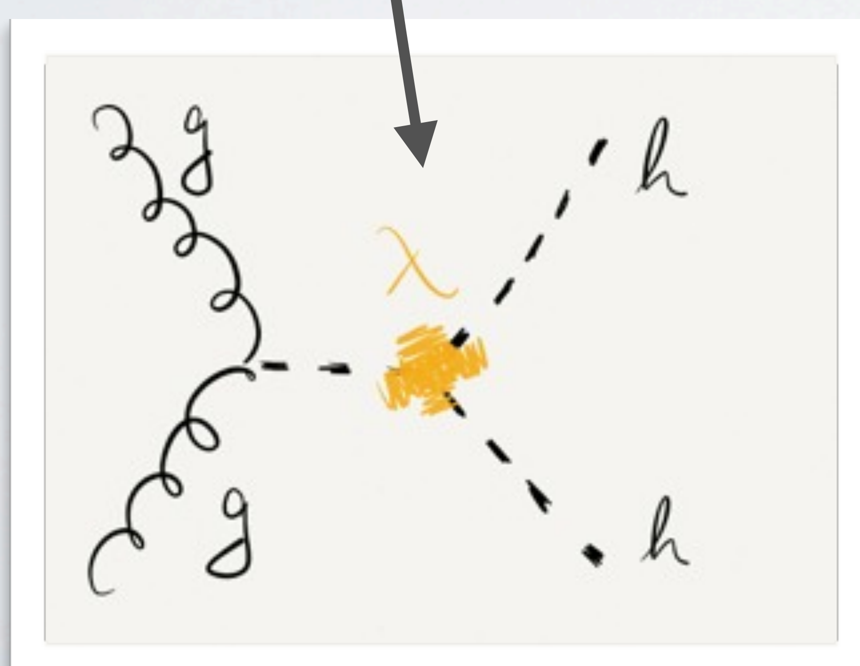


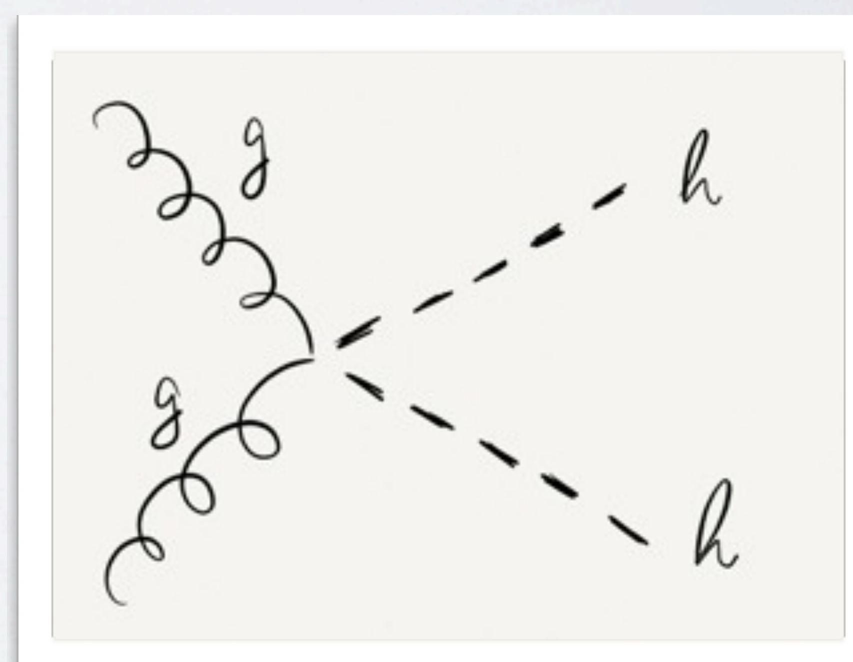

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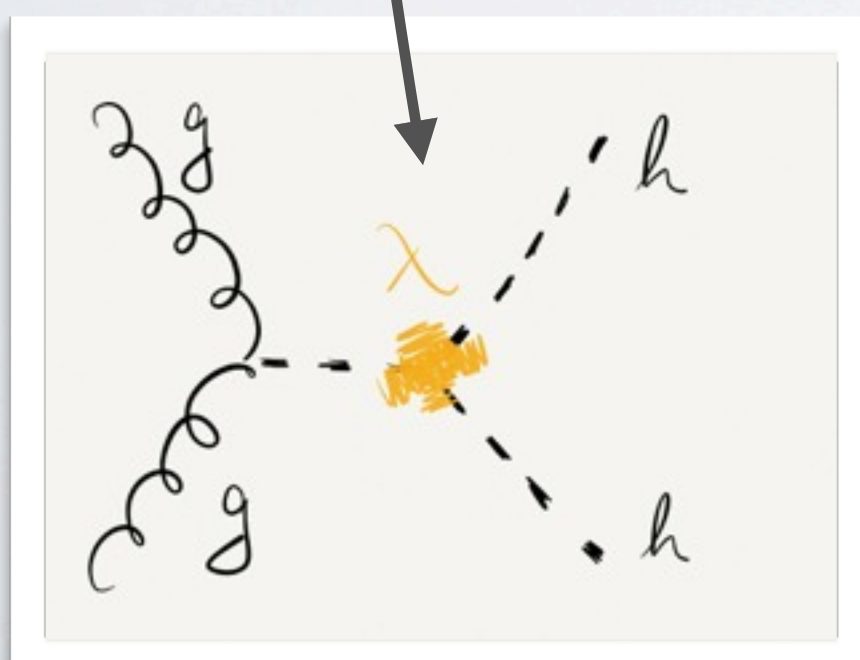


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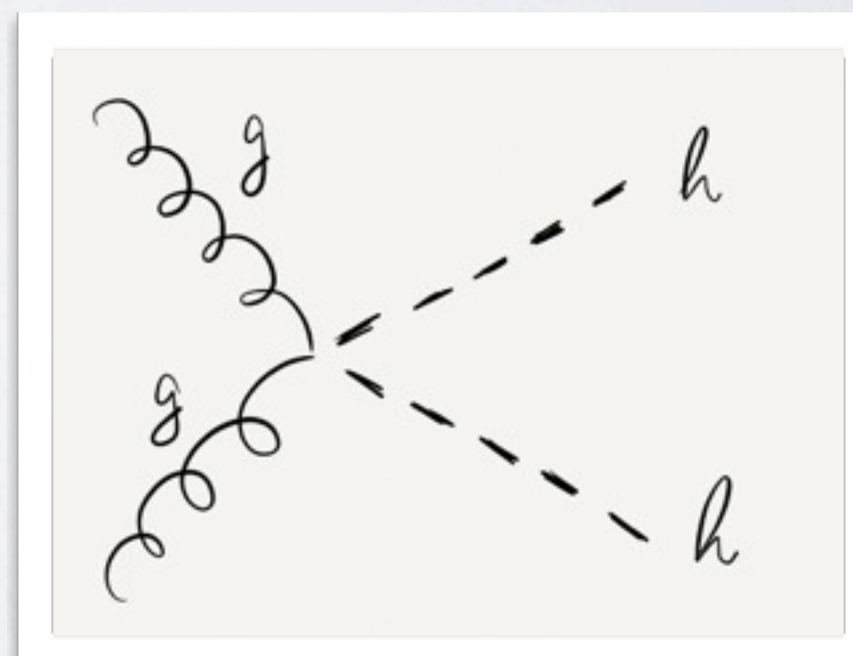

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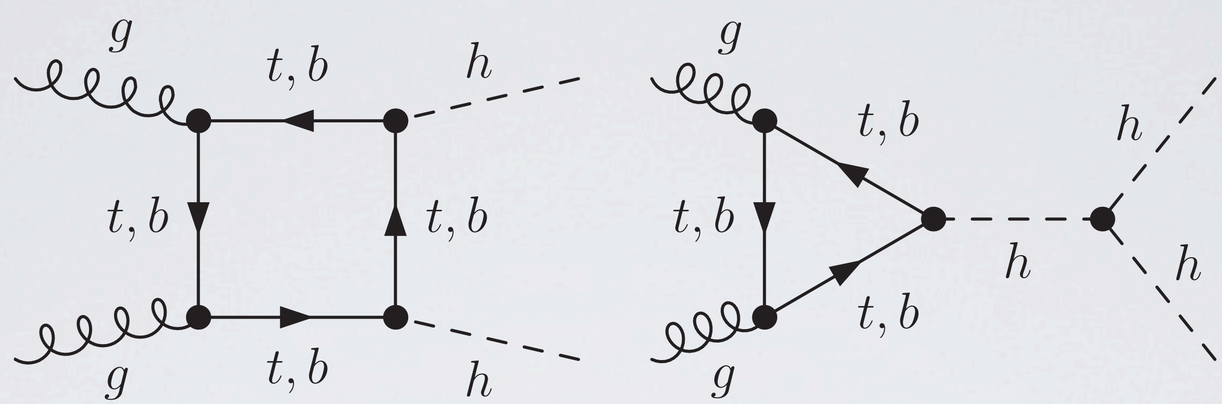
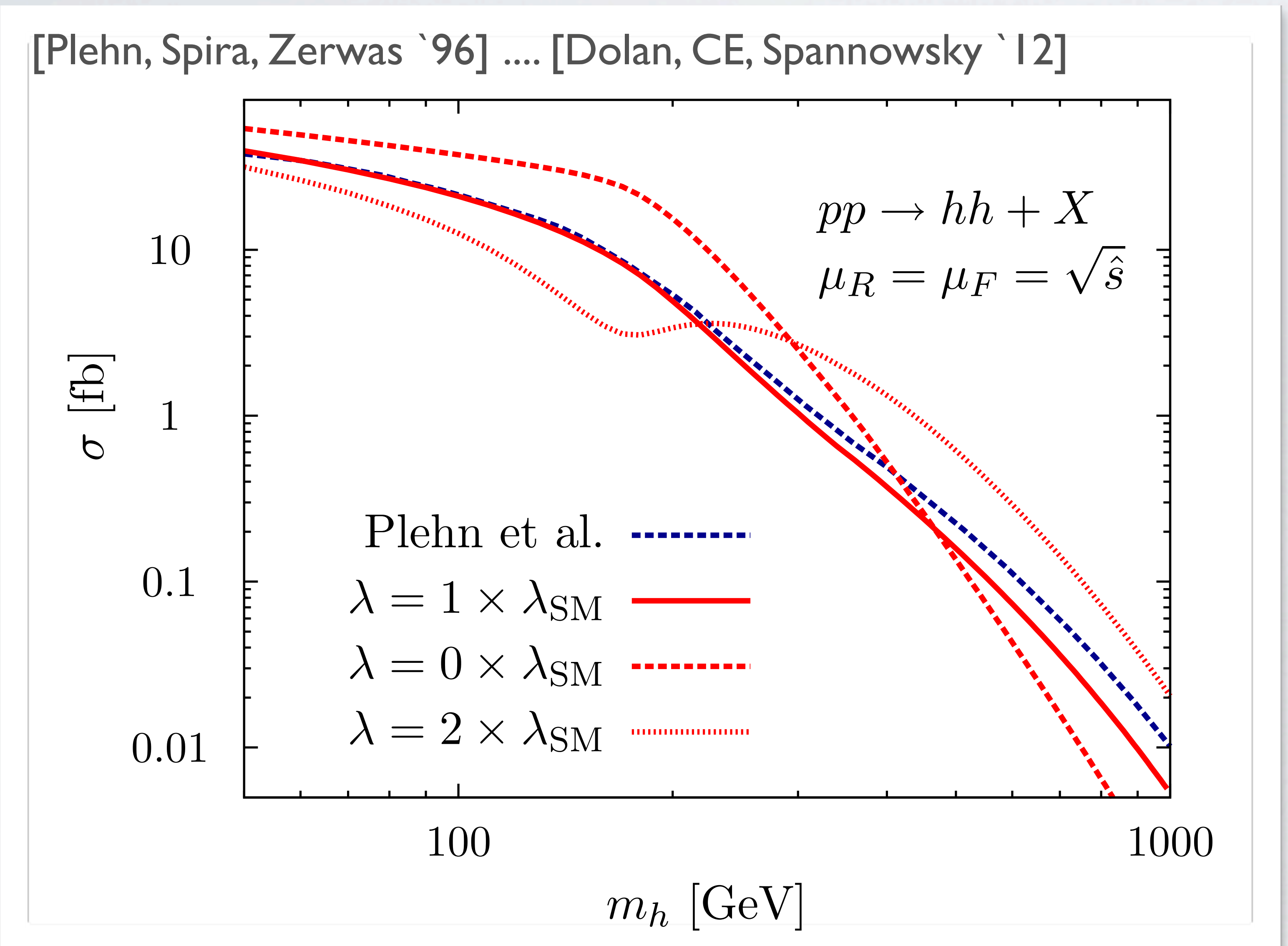



- massive quark loops are resolved for $p_{T,h} \gtrsim m_t$ forget about EFT

  [Plehn, Spira, Zerwas `96]
  [Baur, Plehn, Rainwater `03, `04]

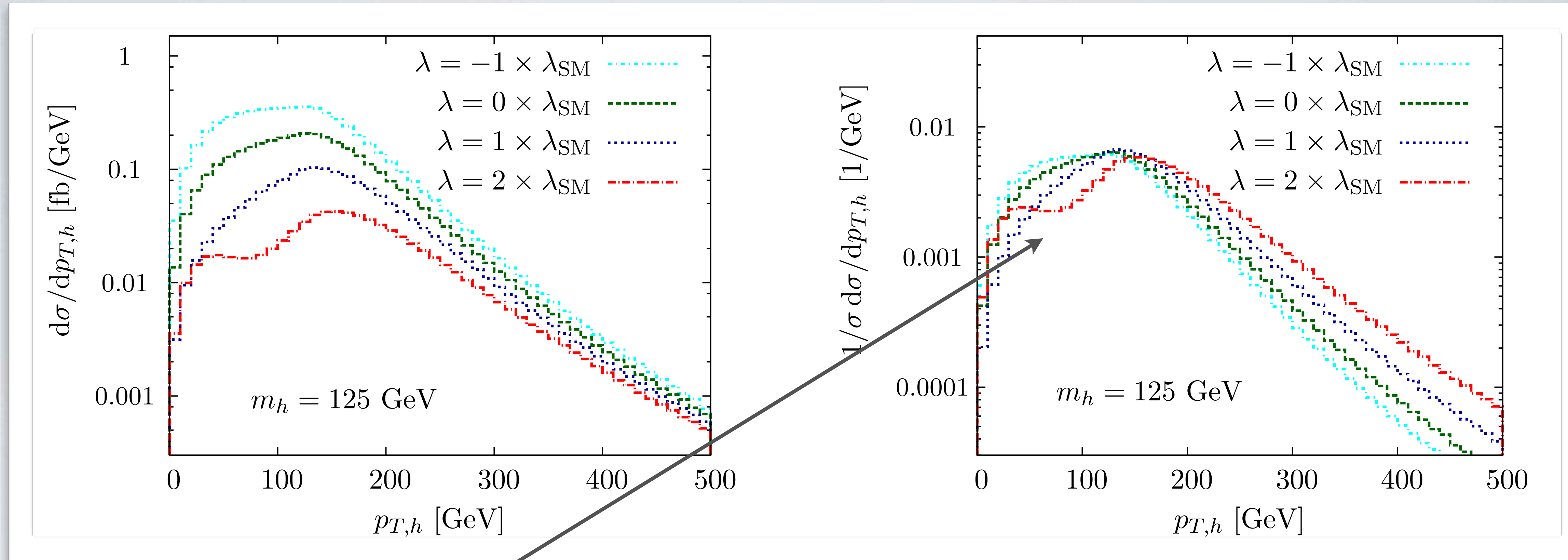
- NLO QCD corrections are large ~2

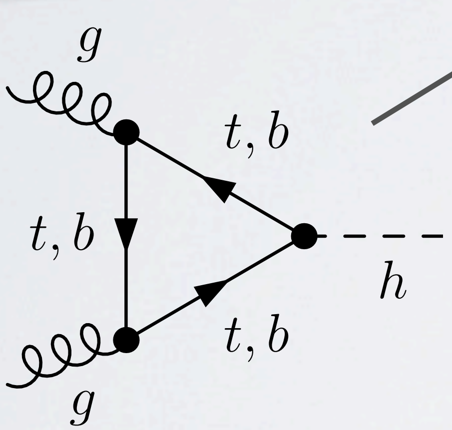
  [Dawson, Dittmaier, Spira `98]
  [Grigo et al. `13] [de Florian et al `13]

- good *a priori* sensitivity to $\lambda$ for $m_h = 125$ GeV

# Self-coupling measurements

[Dolan, CE, Spannowsky `12]



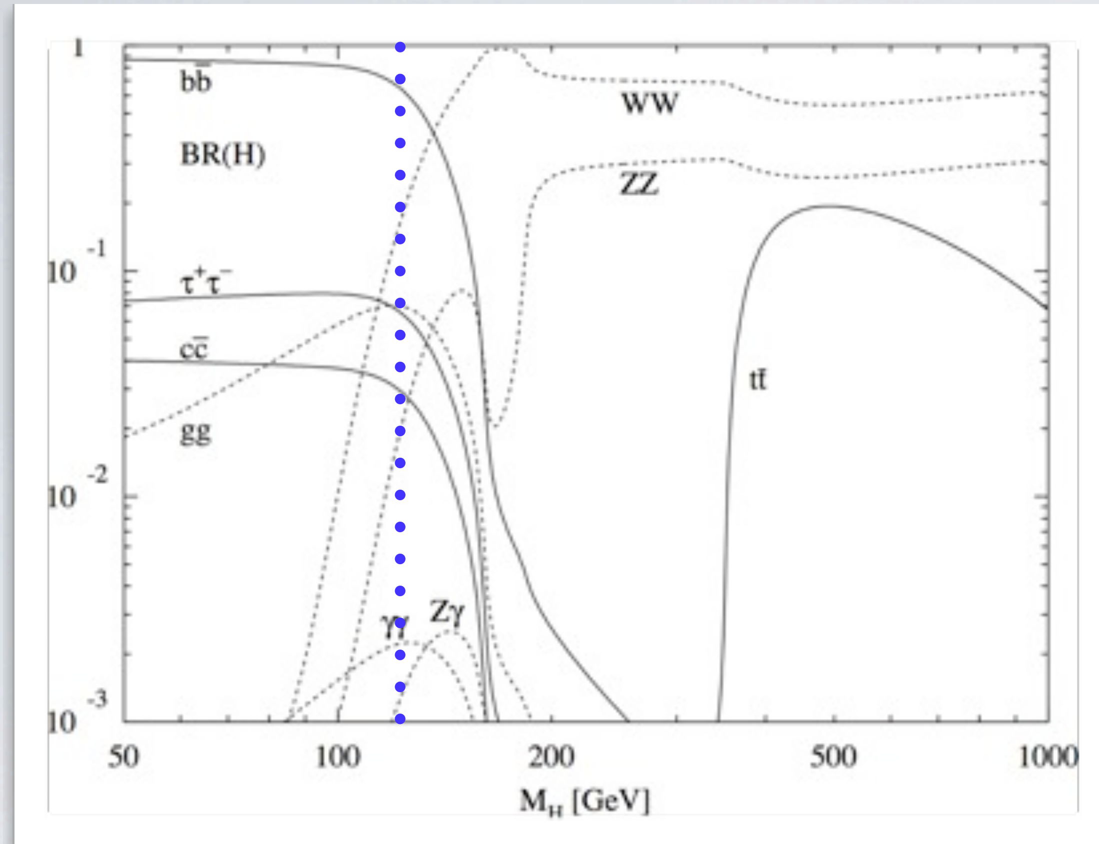

has maximum contribution for $m_h^2 = 4m_t^2$

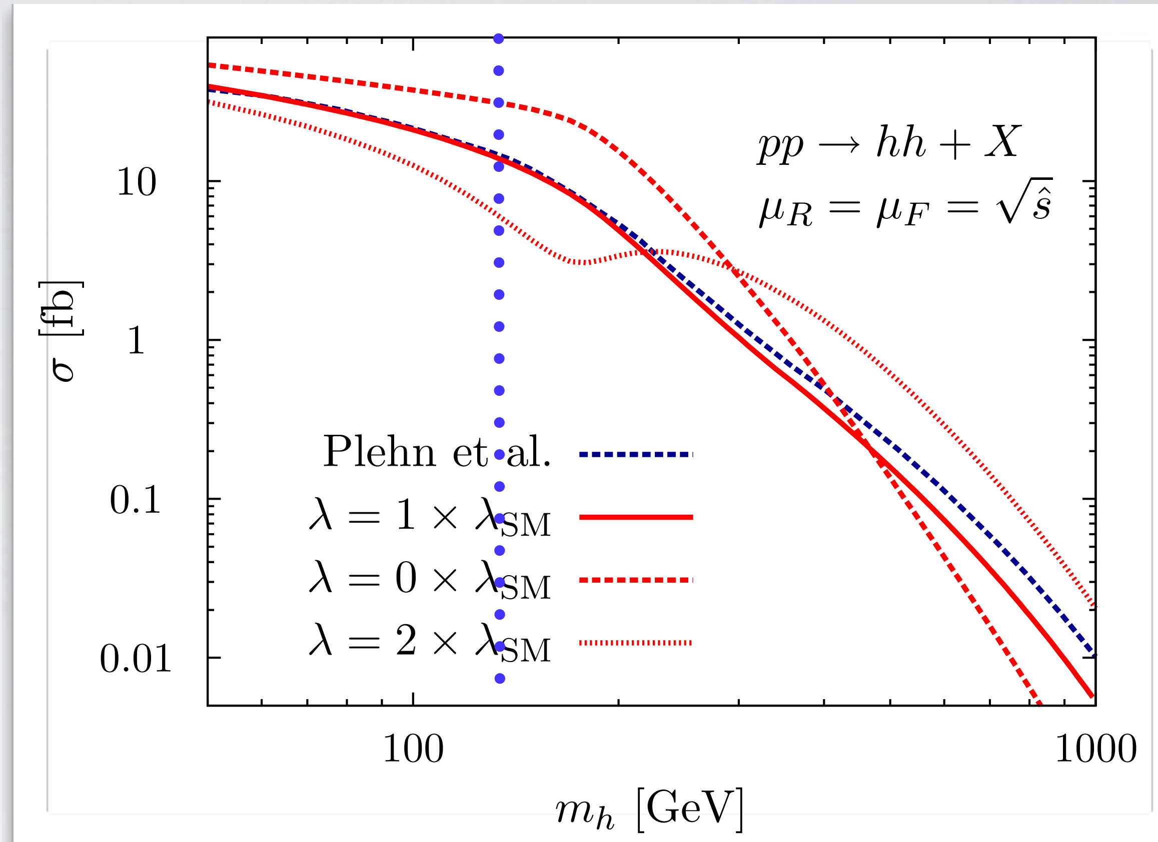
[Georgi et al. `78]

for dihiggs production this becomes $s = (p_{h,1} + p_{h,2})^2 = 4m_t^2$

sensitivity to the trilinear coupling for $m_h \simeq 125$ GeV is in the boosted regime

# Self-coupling measurements at the hadron level




- We're dealing with small xsections, hence need to look for large BRs for <u>theoretical</u> improvements: $h \longrightarrow b\bar{b}, W^+W^-, \tau^+\tau^-$

$b\bar{b}\gamma\gamma$ (fairly standard)

[Baur, Plehn, Rainwater `12]
European Strategy report

Following this selection, a signal yield of approximately 12 events is obtained, with the irreducible $\gamma\gamma b\bar{b}$ background sample of more than 300,000 events completely suppressed and the $b\bar{b}H$ contribution to a negligible level. The only significant background remaining is $t\bar{t}H$, contributing approximately 18 events. This corresponds to a $S/B$ ratio of around 0.7 ($\frac{S}{\sqrt{B}} = 2.8$).

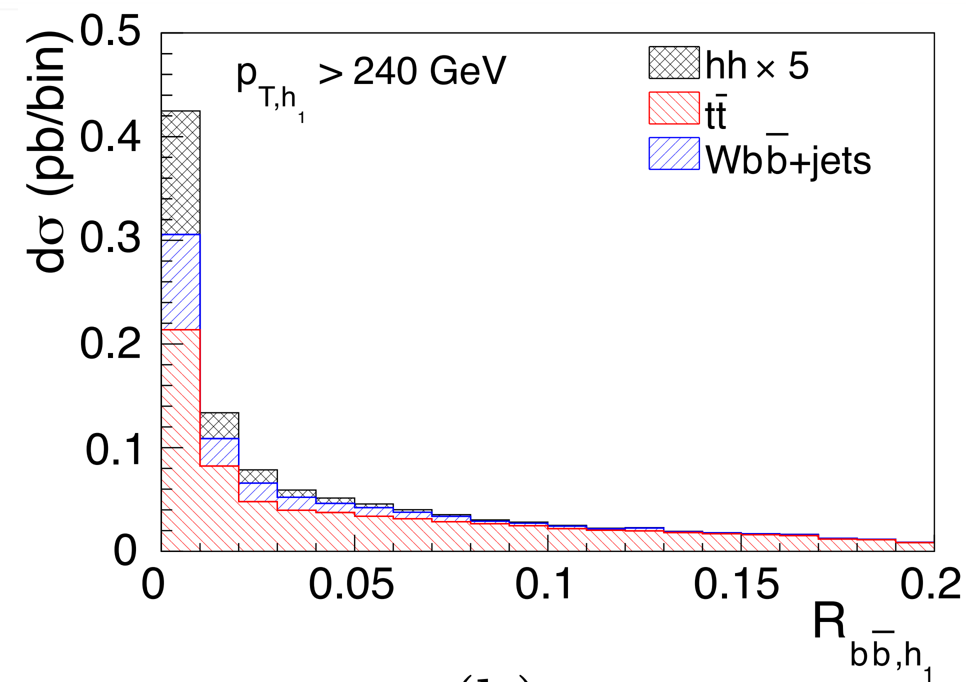
# channels

$b\bar{b}W^+W^-$ (fairly standard)

[Dolan, CE, Spannowsky `12] and European Strategy report

| | $\xi=0$ | $\xi=1$ | $\xi=2$ | $b\bar{b}WW$ | ratio to $\xi=1$ |
|---|---|---|---|---|---|
| cross section before cuts | 59.48 | 28.34 | 13.36 | 877500 | $3.2\cdot10^{-5}$ |
| 1 isolated lepton | 7.96 | 3.76 | 1.74 | 254897 | $1.5\cdot10^{-5}$ |
| MET + jet cuts | 1.54 | 0.85 | 0.44 | 66595.7 | $1.2\cdot10^{-5}$ |
| hadronic $W$ reconstruction | 0.59 | 0.33 | 0.17 | 38153.3 | $0.9\cdot10^{-5}$ |
| kinematic Higgs reconstruction | 0.028 | 0.017 | 0.007 | 205.1 | $8.3\cdot10^{-5}$ |

$b\bar{b}W^+W^-$ (BDRS-like)




(b)

[Papaefstathiou, Yang, Zurita `12]

# channels

## $b\bar{b}b\bar{b}$ (boosted)

[Dolan, CE, Spannowsky `12]

| | $\xi=0$ | $\xi=1$ | $\xi=2$ | $b\bar{b}b\bar{b}$ [QCD] | $b\bar{b}b\bar{b}$ [ELW] | $b\bar{b}b\bar{b}$ [QCD/ELW] | ratio to $\xi=1$ |
|---|---|---|---|---|---|---|---|
| cross section before cuts | 59.48 | 28.42 | 13.36 | 21165 | 16.5 | 160.35 | $1.3\cdot10^{-3}$ |
| trigger+no leptons | 17.93 | 10.21 | 5.31 | 5581.2 | 8.0 | 38.85 | $1.8\cdot10^{-3}$ |
| fatjet cuts | 13.73 | 8.23 | 4.50 | 4761.0 | 7.50 | 31.65 | $1.7\cdot10^{-3}$ |
| first Higgs rec + $2b$ | 1.55 | 1.02 | 0.60 | 235.22 | 0.75 | 1.32 | $4.2\cdot10^{-3}$ |
| second Higgs rec + $2b$ | 0.137 | 0.094 | 0.059 | 9.72 | 0.011 | 0.050 | $9.6\cdot10^{-3}$ |

## $b\bar{b}\tau^+\tau^-$ (boosted)

[Dolan, CE, Spannowsky `12]
[Baglio, Djouadi,Gröber, Mühlleitner, Quevillon, Spira `12]

| | $\xi=0$ | $\xi=1$ | $\xi=2$ | $b\bar{b}\tau\tau$ | $b\bar{b}\tau\tau$ [ELW] | $b\bar{b}W^+W^-$ | ratio to $\xi=1$ |
|---|---|---|---|---|---|---|---|
| cross section before cuts | 59.48 | 28.34 | 13.36 | 67.48 | 8.73 | 873000 | $3.2\cdot10^{-5}$ |
| reconstructed Higgs from $\tau$s | 4.05 | 1.94 | 0.91 | 2.51 | 1.10 | 1507.99 | $1.9\cdot10^{-3}$ |
| fatjet cuts | 2.27 | 1.09 | 0.65 | 1.29 | 0.84 | 223.21 | $4.8\cdot10^{-3}$ |
| kinematic Higgs reconstruction ($m_{b\bar{b}}$) | 0.41 | 0.26 | 0.15 | 0.104 | 0.047 | 9.50 | $2.3\cdot10^{-2}$ |
| Higgs with double $b$-tag | 0.148 | 0.095 | 0.053 | 0.028 | 0.020 | 0.15 | 0.48 |

# going beyond

phase space in inclusive dihiggs production is limited due to small phase space for the back-to-back configuration at rather small invariant masses $2m_t$

| | $\xi = 0$ | $\xi = 1$ | $\xi = 2$ | $b\bar{b}\tau^+\tau^- j$ | $b\bar{b}\tau^+\tau^- j$ [ELW] | $t\bar{t}j$ | ratio to $\xi = 1$ |
|---|---|---|---|---|---|---|---|
| cross section before cuts | 6.45 | 3.24 | 1.81 | 66.0 | 1.67 | 106.7 | $1.9 \cdot 10^{-2}$ |
| 2 $\tau$s | 0.44 | 0.22 | 0.12 | 37.0 | 0.94 | 7.44 | $4.8 \cdot 10^{-3}$ |
| Higgs rec. from taus + fatjet cuts | 0.29 | 0.16 | 0.10 | 2.00 | 0.150 | 0.947 | $5.1 \cdot 10^{-2}$ |
| kinematic Higgs rec. | 0.07 | 0.04 | 0.02 | 0.042 | 0.018 | 0.093 | 0.26 |
| $2b + hh$ invariant mass + $p_{T,j}$ cut | 0.010 | 0.006 | 0.004 | <0.0001 | 0.0022 | 0.0014 | 1.54 |

# going beyond

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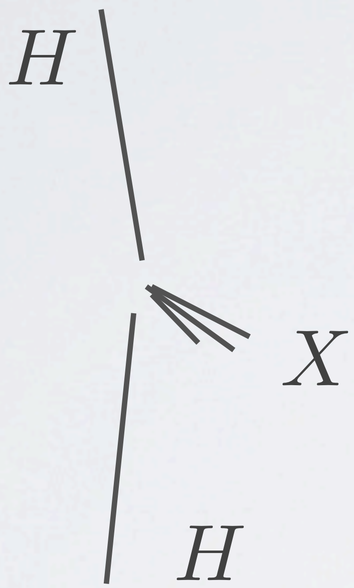
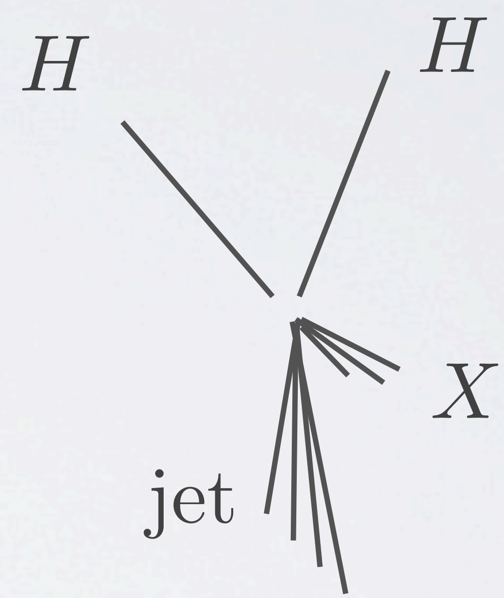
open up the phase space by accessing small invariant di-Higgs masses in collinear configurations:




add sensitivity

$+$




| | $\xi = 0$ | $\xi = 1$ | $\xi = 2$ | $b\bar{b}\tau^+\tau^- j$ | $b\bar{b}\tau^+\tau^- j$ [ELW] | $t\bar{t}j$ | ratio to $\xi = 1$ |
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