Higgs self-coupling @FCC-hh

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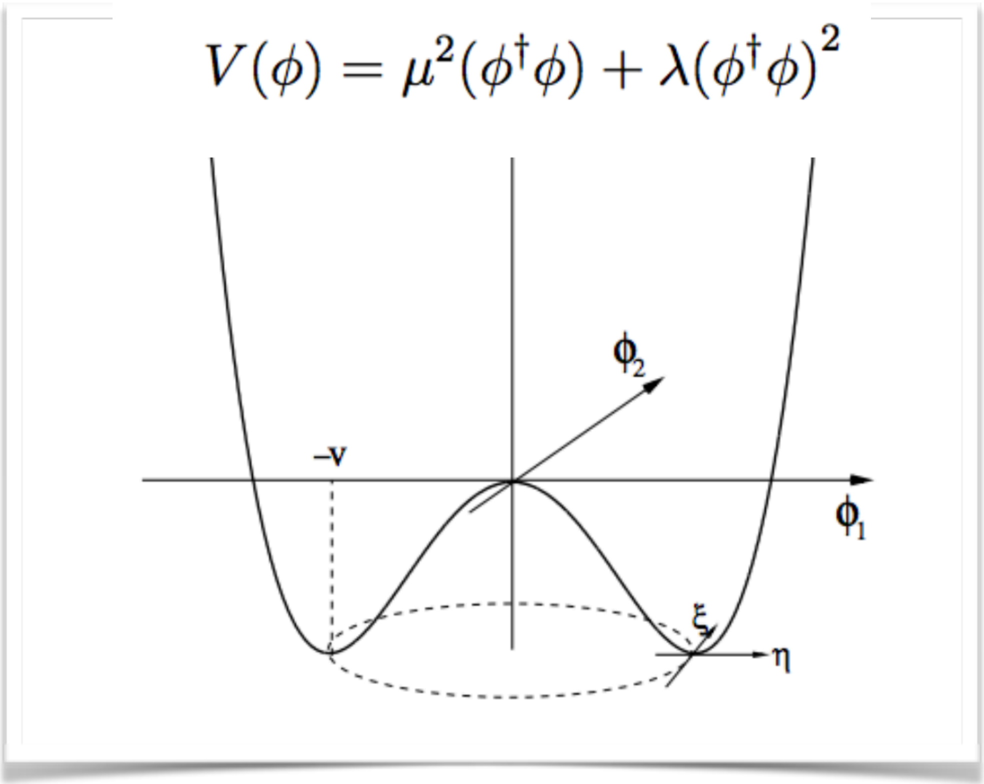
Why measure HH?

- Measure HH gives access to the magnitude of the **Higgs self-interaction**:

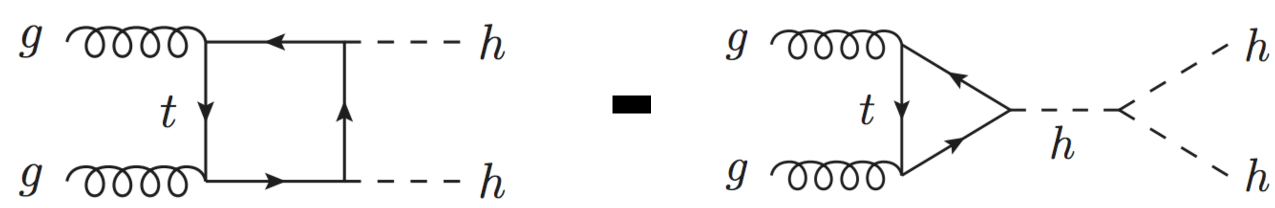
$$V = \lambda v^2 H^2 + \lambda v H^3 + \frac{\lambda}{4} H^4$$

- Shape of the **Higgs potential** is determined by the self coupling value (EWPT)

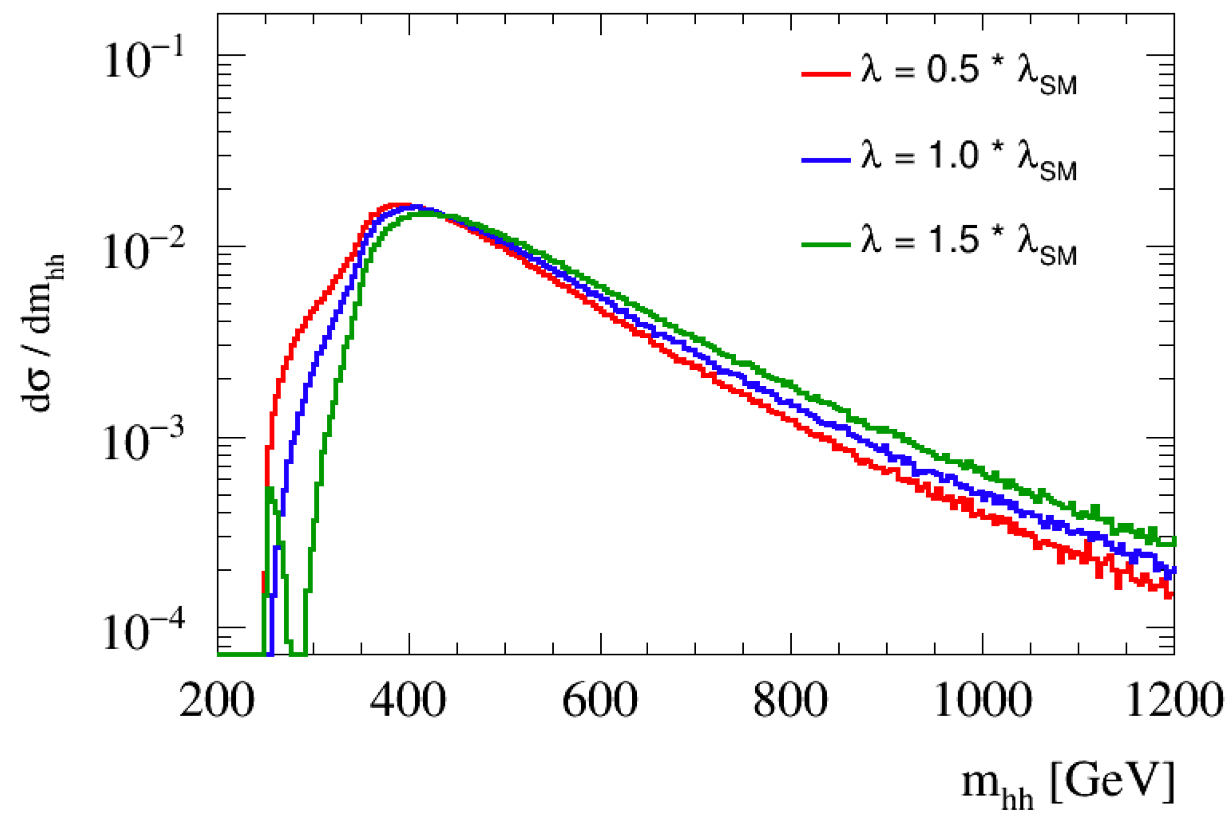


HH@ FCC-hh: production

gluon fusion:

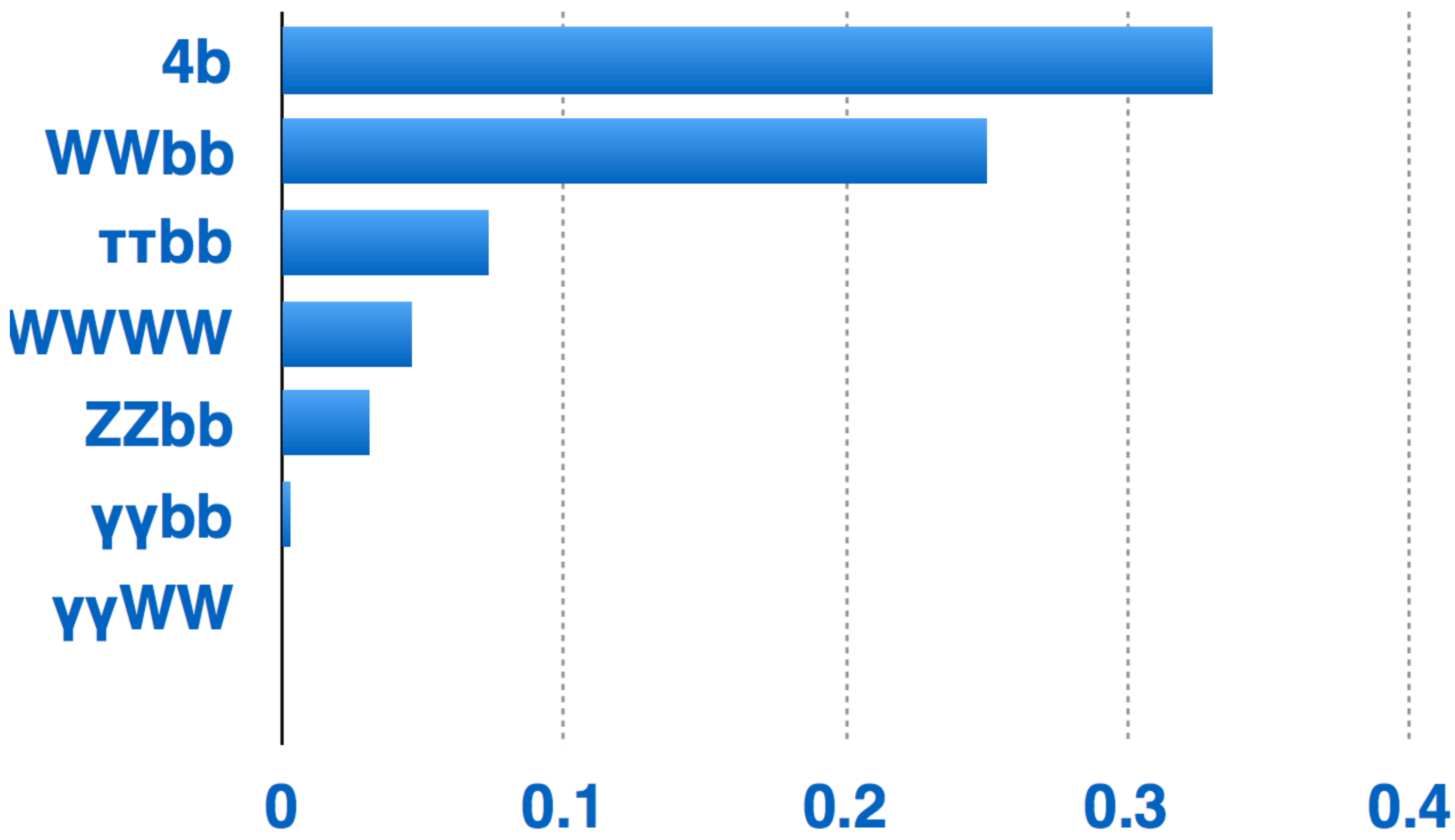


- **negative interference** between **box** and **triangle**
- **high m_{hh} region suppressed** by off-shell propagator in triangle (and dominated by box)

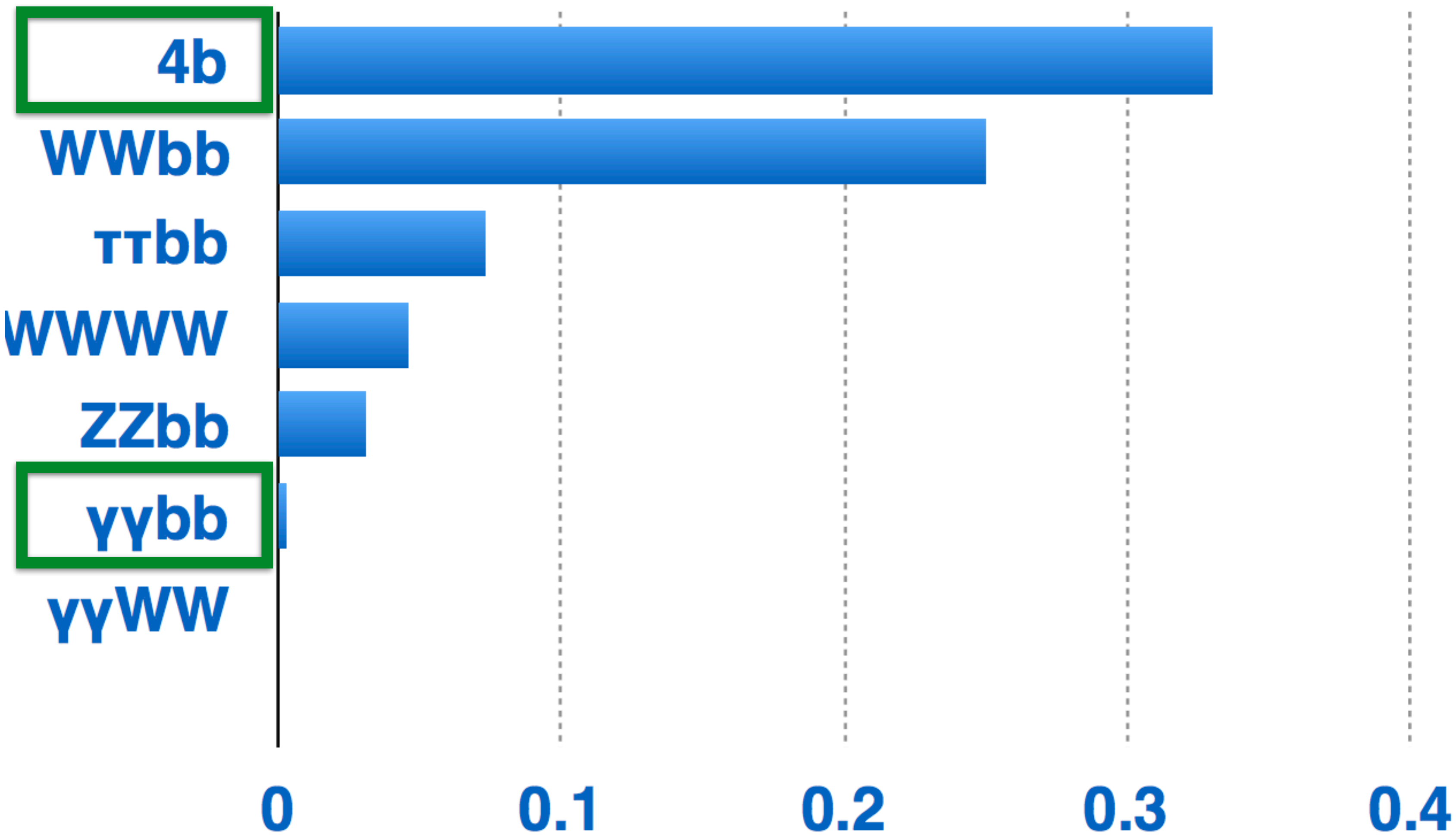


→ **sensitivity** to the self-coupling is determined by **low m_{hh} region**

HH@ FCC-hh: decay modes



HH@ FCC-hh: decay modes



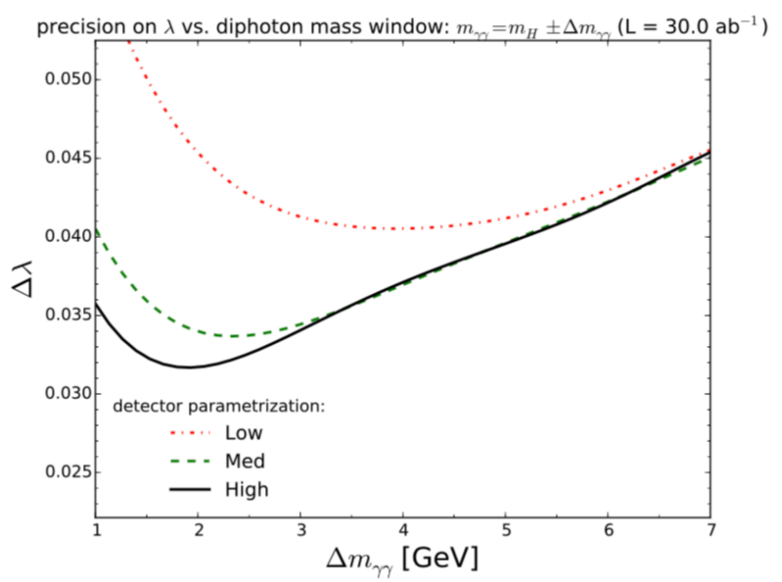
are discussed here …

bbγγ

Baseline

[R. Contino, C. Englert, G. Panico, A. Papaefstathiou, J. Ren, MS, M. Son, M. Spannowsky, W. Yao]

- Detailed analysis performed in 2016 (summarised in the Yellow Report [1606.09408])
  - **cut-based analysis**
  - reported sensitivity on **λ** after 30 ab^{-1} at 100 TeV
  - studied impact of **detector performance**, systematics, background normalisation

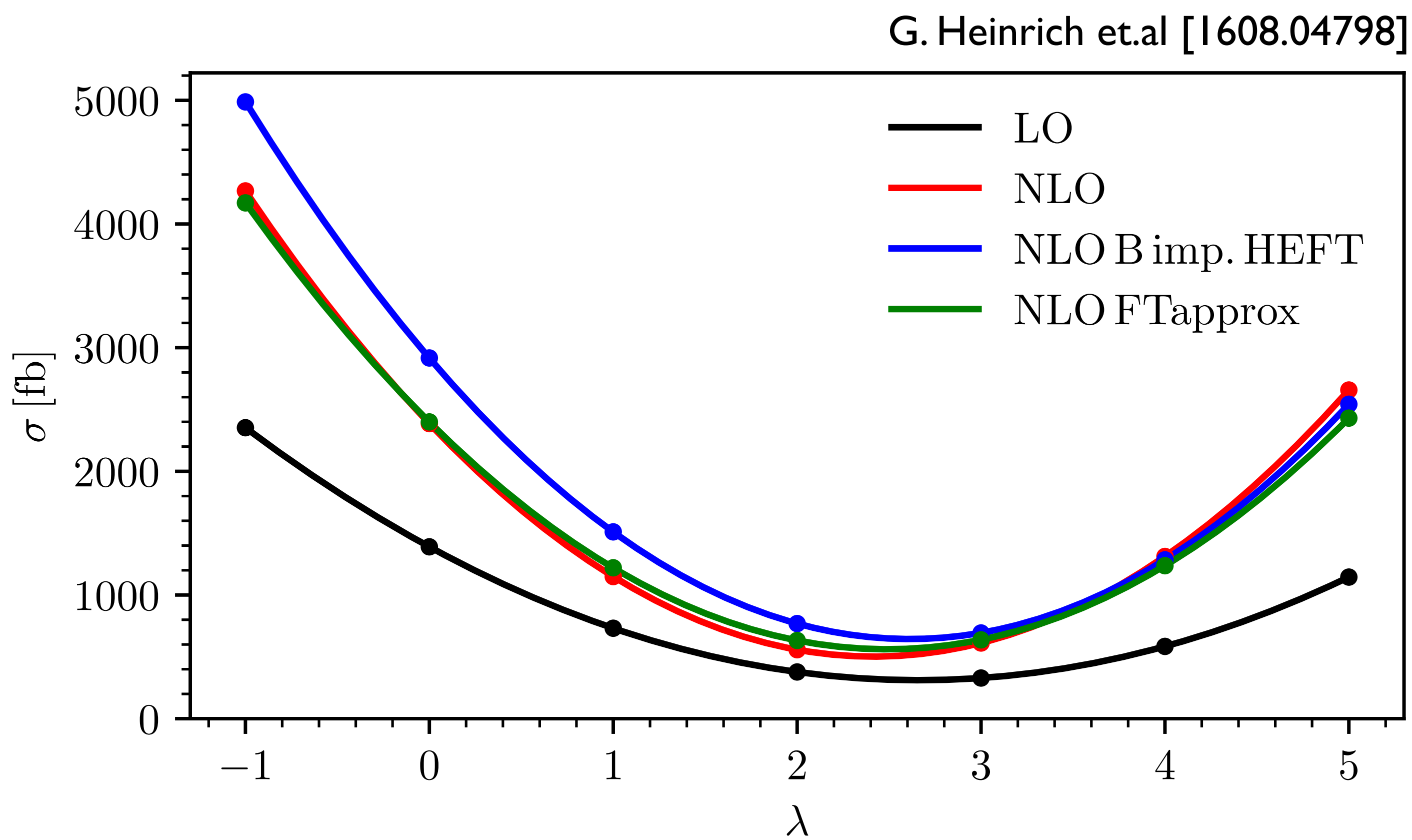


	$\Delta_S = 0.00$	$\Delta_S = 0.01$	$\Delta_S = 0.015$	$\Delta_S = 0.02$	$\Delta_S = 0.025$
$r_B = 0.5$	2.7%	3.4%	4.1%	4.9%	5.8%
$r_B = 1.0$	3.4%	3.9%	4.6%	5.3%	6.1%
$r_B = 1.5$	3.9%	4.4%	5.0%	5.7%	6.4%
$r_B = 2.0$	4.4%	4.8%	5.4%	6.0%	6.8%
$r_B = 3.0$	5.2%	5.6%	6.0%	6.6%	7.3%

To be updated:

- up-to-date parton shower/underlying event modelling (Pythia8 vs Pythia6)
- more recent FCC-hh detector description (4T vs 6T, smaller detector size)
- QCD background generation using 5f scheme (jjjɣ, jjɣɣ)
- Up-to-date k-factors for backgrounds (ttH) and signal (λ-dependent)

Production



- Higher order in QCD helps λ-dependent K-factor sensitivity (not only the rate)
  → included here!

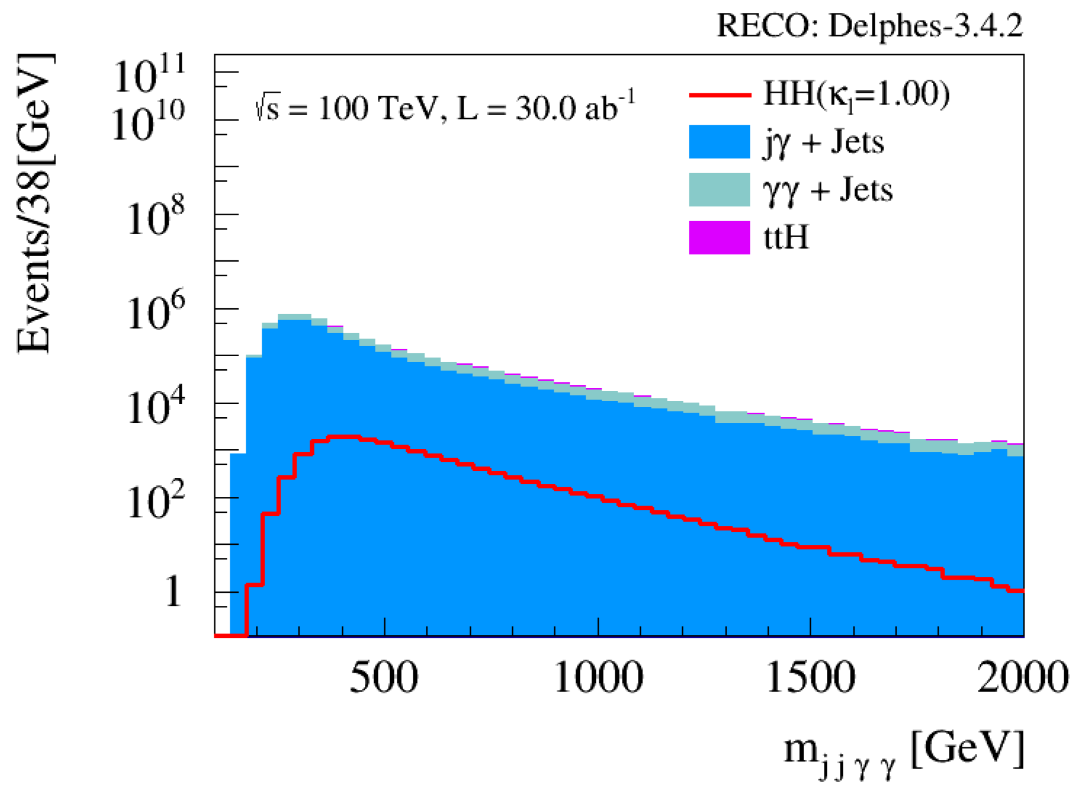
- Total rate still taken to be given by NNLL+NNLO in EFT (although known to be overshooting by 20%), but missing the following (should compensate?):
  - higher orders other channel (N^nLO, n>2)
  - VBF-HH/ttHH

Selection [1606.09408]

Acceptance cuts

γ isolation $R = 0.4$
$(p_T(had)/p_T(\gamma) < 0.15)$
jets: anti-k_T, parameter $R = 0.4$
$|\eta_{b,\gamma,j}| < 6$
$p_T(b), p_T(\gamma), p_T(j) > 35$ GeV

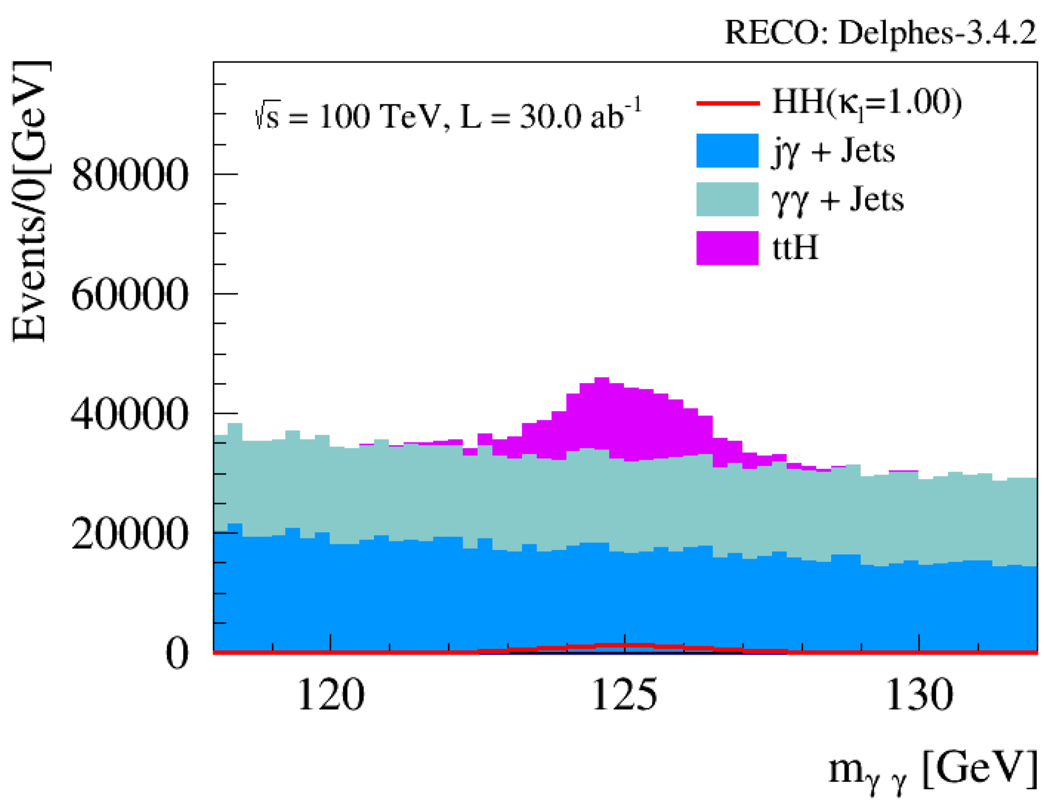
$m_{bb} \in [60, 200]$ GeV
$m_{\gamma\gamma} \in [100, 150]$ GeV

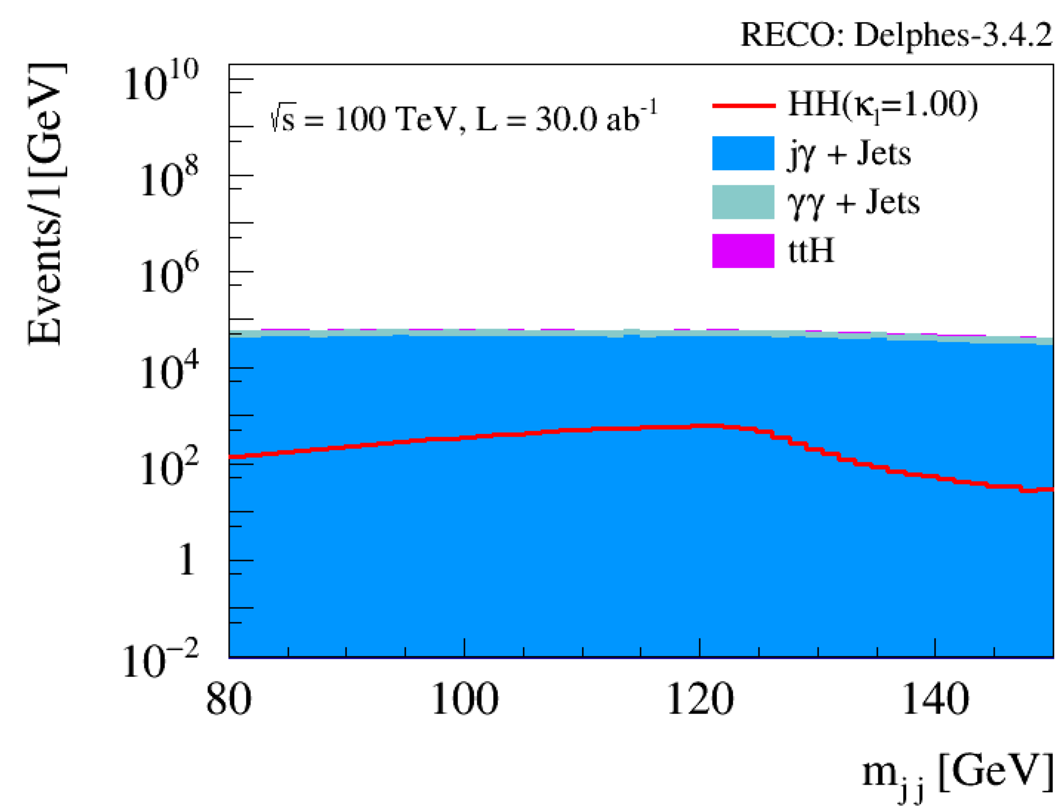


Final selection

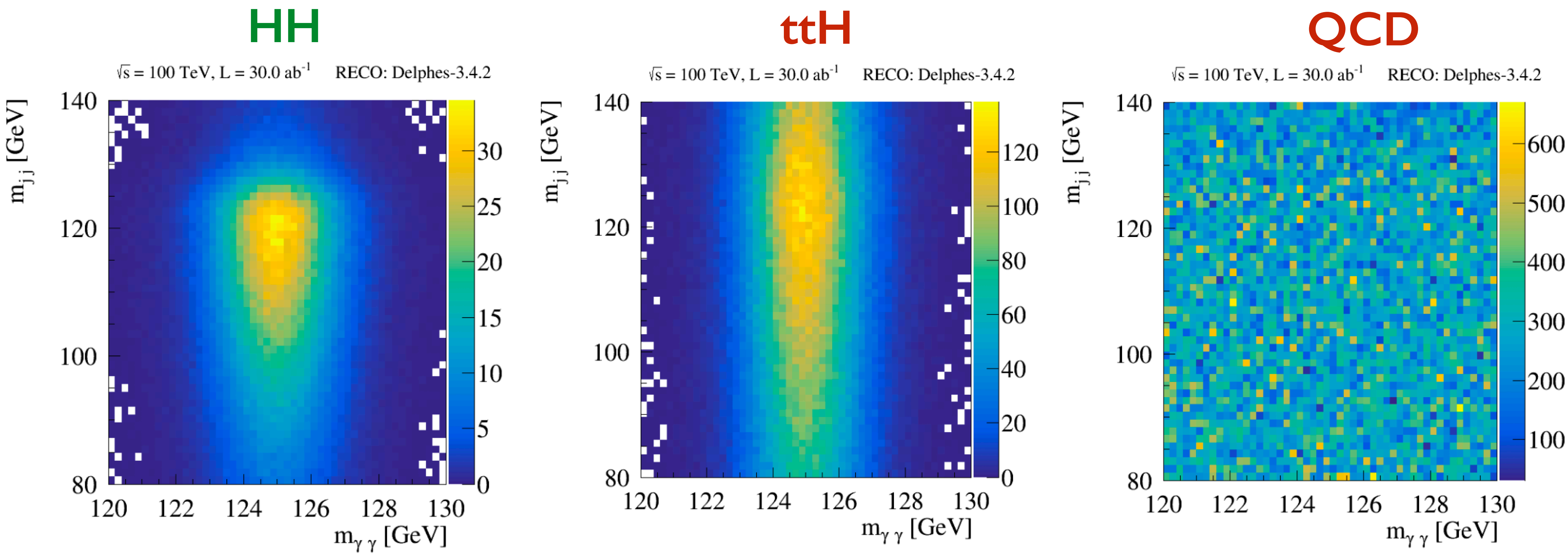
γ isolation $R = 0.4$
$(p_T(had)/p_T(\gamma) < 0.15)$
jets: anti-k_T, parameter $R = 0.4$
$|\eta_{b,\gamma}| < 4.5$
$p_T(b_1), p_T(\gamma_1) > 60$ GeV
$p_T(b_2), p_T(\gamma_2) > 35$ GeV
$m_{bb} \in [100, 150]$ GeV

$p_T(bb), p_T(\gamma\gamma) > 100$ GeV
$\Delta R(bb), \Delta R(\gamma\gamma) < 3.5$
no isolated leptons with $p_T > 25$ GeV





2D shapes

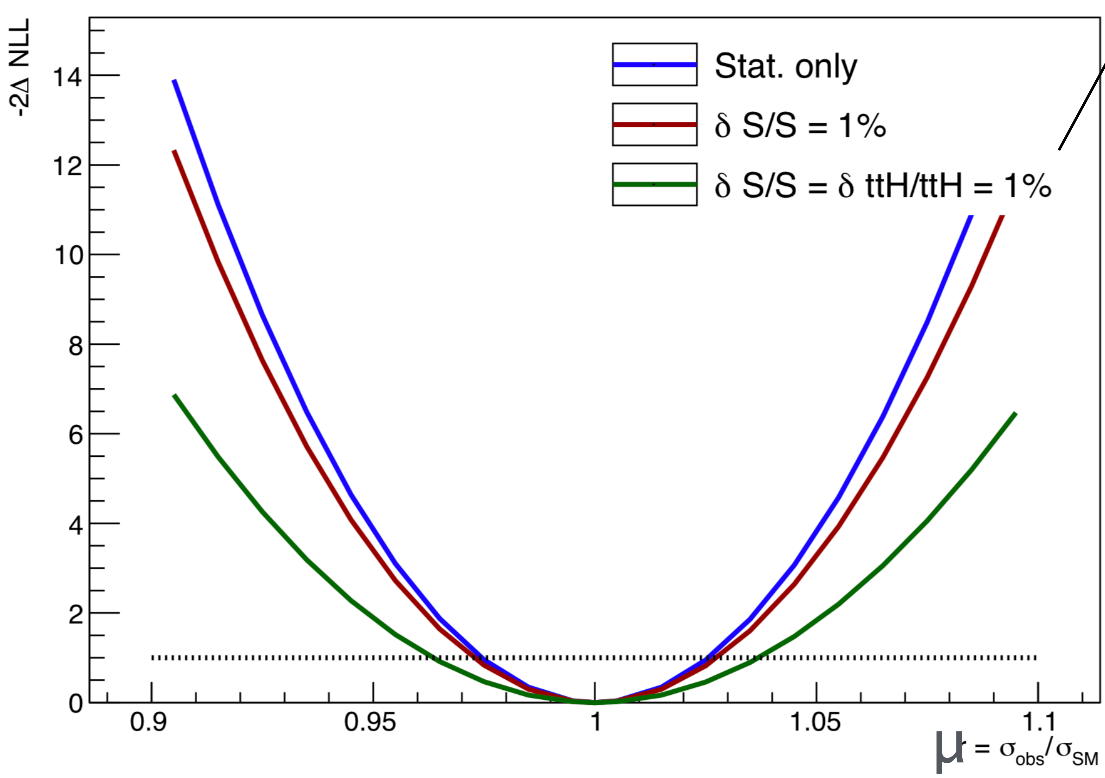


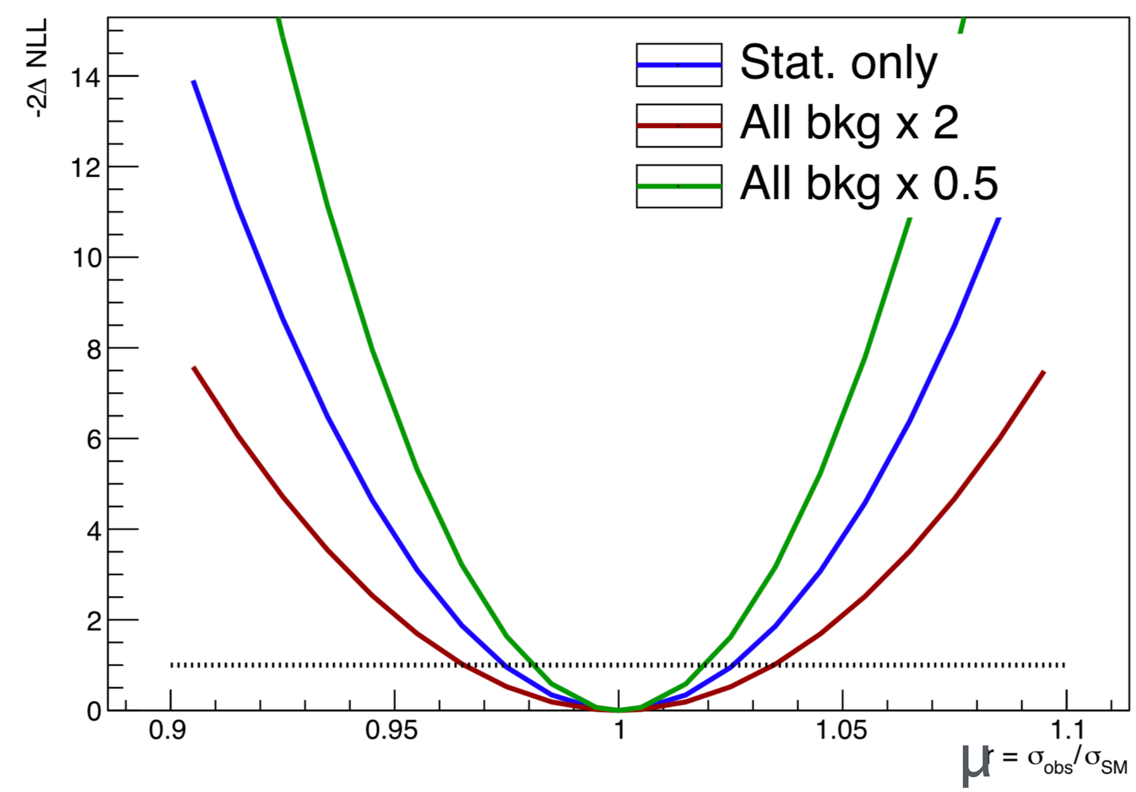
- exploit correlations of means if the signal, ex: $\mathbf{m_{\gamma\gamma}}$ **vs** $\mathbf{m_{bb}}$
- build **template model** in 2D on λ using splines (morphing)
- perform **2D Likelihood fit** on the **signal strength** and **coupling modifier:**

$\mu = \sigma_{obs}/\sigma_{SM}$ $\kappa_\lambda = \lambda_{obs}/\lambda_{SM}$

Precision on the signal strength

assuming QCD can be measured from sidebands





nominal background yields:

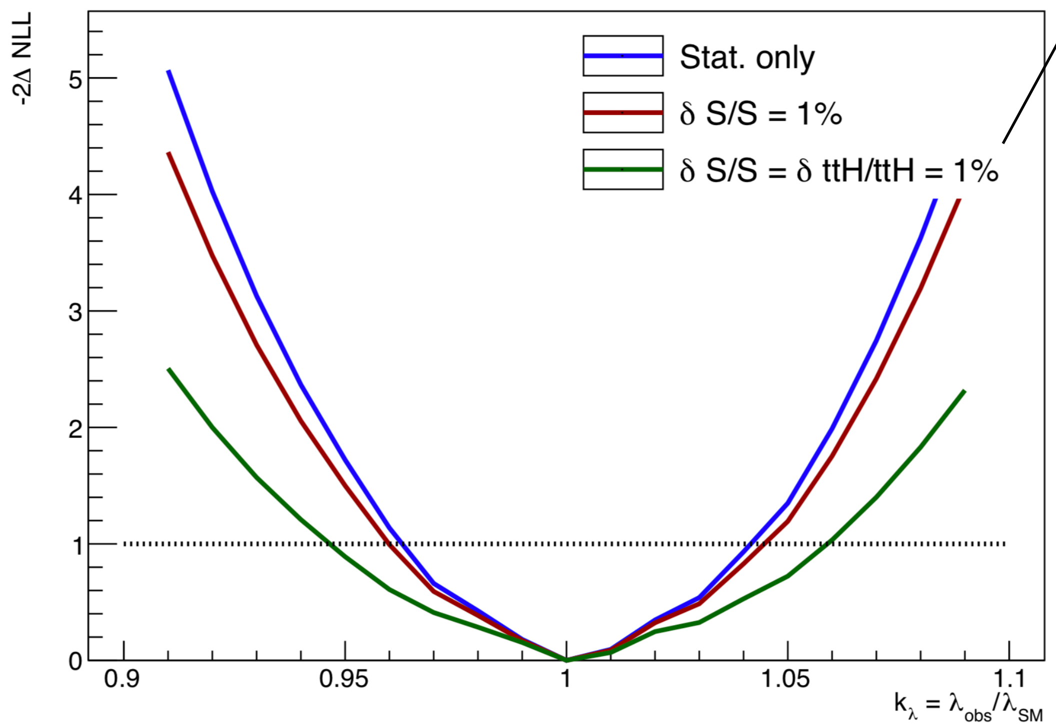
$\delta\mu(\text{stat}) \approx 2.5\ \%$
$\delta\mu(\text{stat + syst}) \approx 4\ \%$

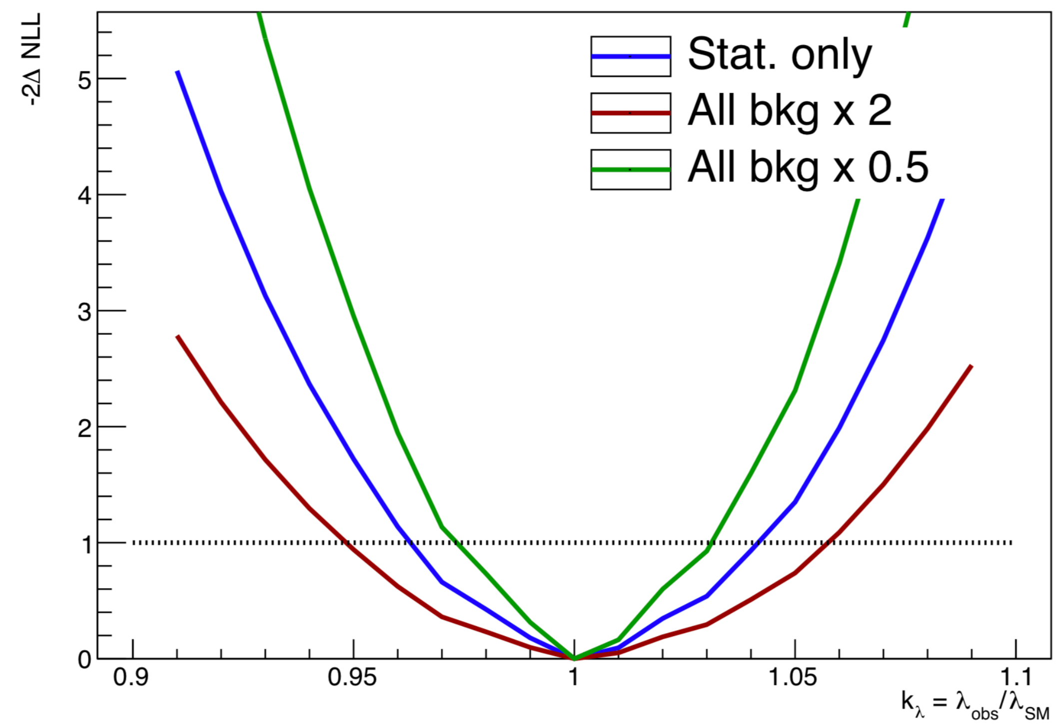
varying (0.5x-2x) background yields:

$\delta\mu(\text{stat}) \approx 2 - 4\ \%$

Precision on the self-coupling

assuming QCD can be measured from sidebands





nominal background yields:

$\delta\kappa_\lambda(\text{stat}) \approx 3.5\ \%$
$\delta\kappa_\lambda(\text{stat + syst}) \approx 6\ \%$

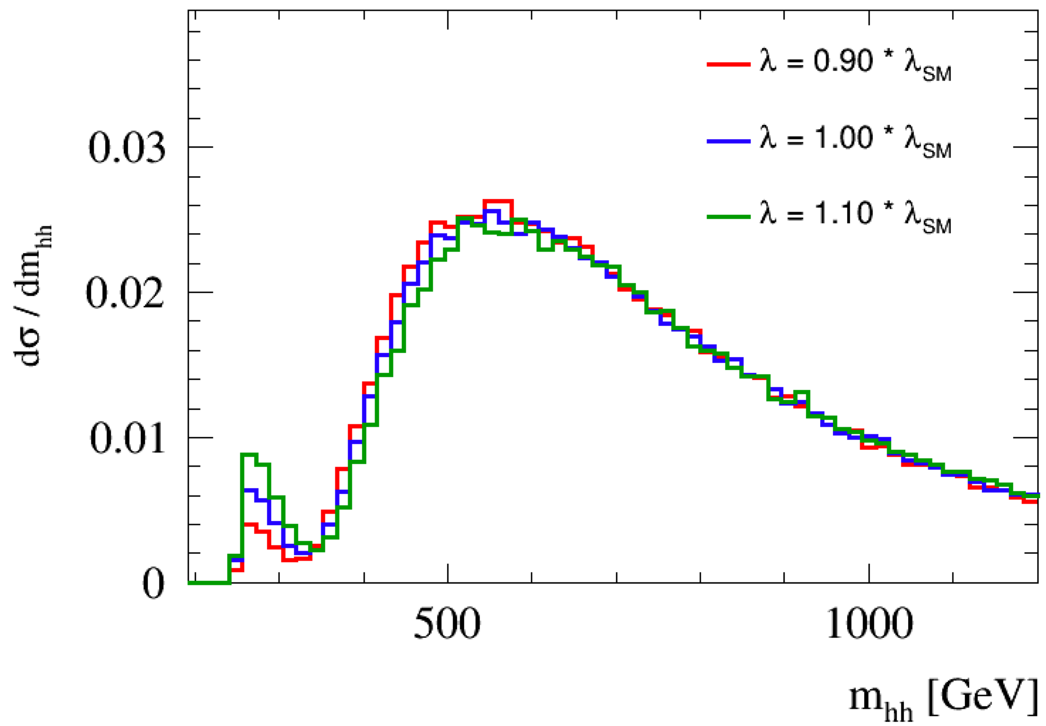
varying (0.5x-2x) background yields:

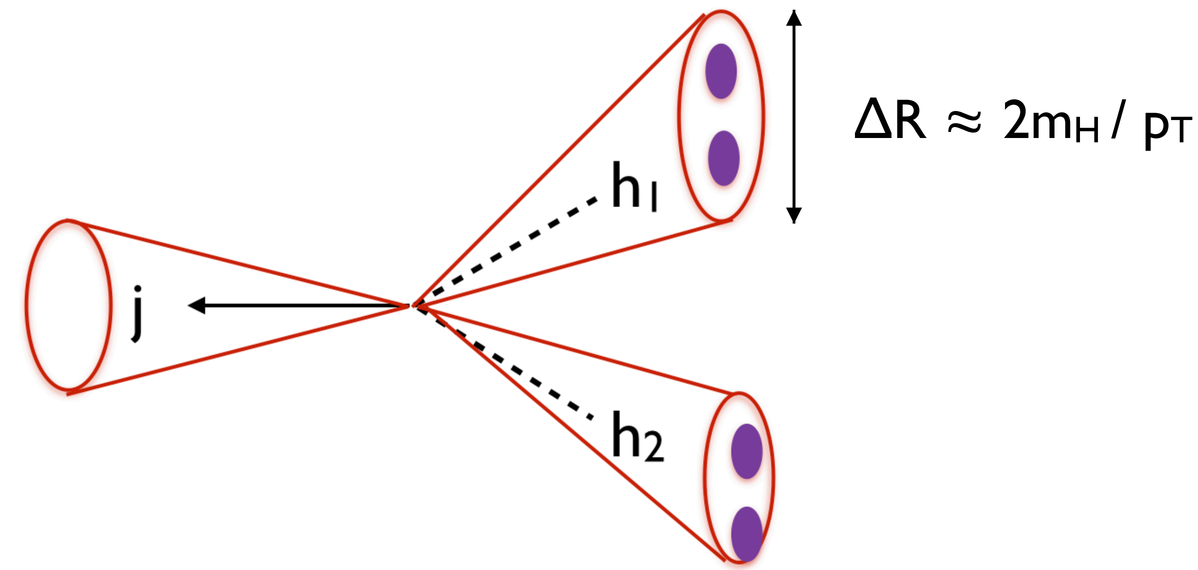
$\delta\kappa_\lambda(\text{stat}) \approx 3 - 5\ \%$

4b - boosted

PRELIMINARY!

Approach





- Exploit **large branching ratio** $BR(H\rightarrow bb)^2 \approx 0.3$
- Requiring a **boosted HH system recoiling against jet(s)**, contains the invariant mass to small values → maintain sensitivity to the self-coupling
- In practice **low mass region** ($m_{HH} \approx 200$ GeV) is **unresolvable**:

$$m_{HH} \gtrsim p_T * 2R_{jet} \quad \text{and} \quad R_{jet} \gtrsim 2m_H/p_T$$

$$\Rightarrow \quad m_{HH} \gtrsim 3\text{-}4\ m_H$$

Signal and backgrounds

Backgrounds

- QCD: (double gluon to b-bar splitting recoiling against jet)
  - $p\,p \to 4b + j$ (or simply $p\,p \to j\,g\,g$)

σ^{4b+j} (pT(j) > 500 GeV) ~ 57 pb (10^9 @ $30ab^{-1}$)

- ttbar, ZH …

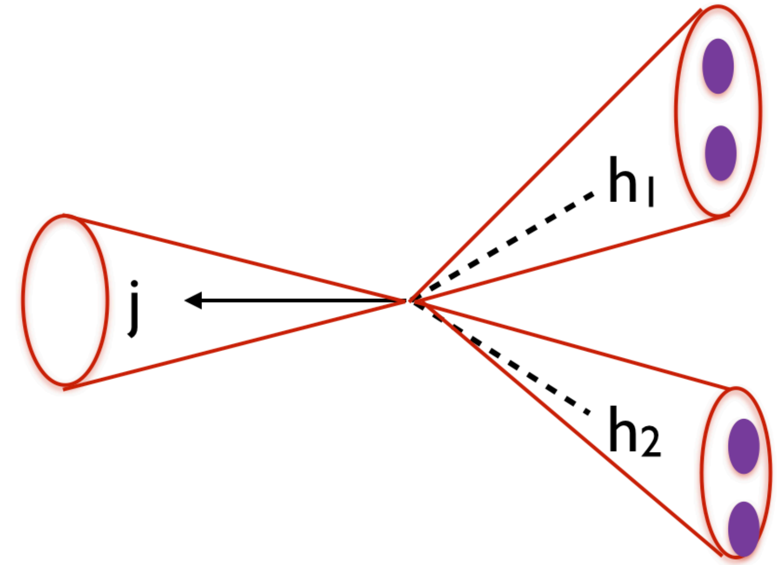
Signal

- $p\,p \to h\,h + j$

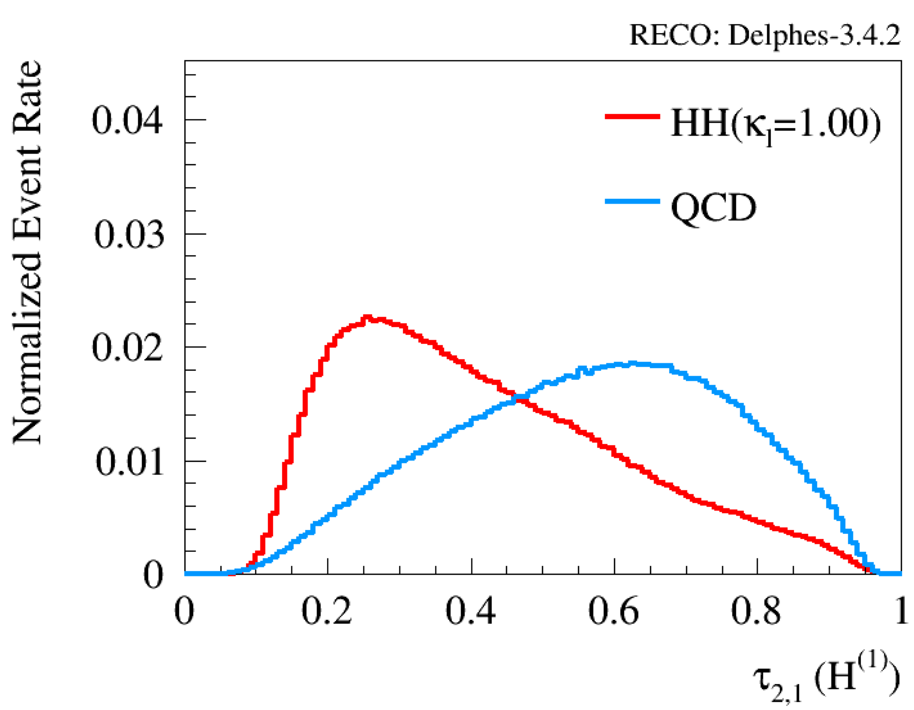
σ^{hh+j} (pT(j) > 500 GeV) ~ 4 fb (10^5 @ $30ab^{-1}$)

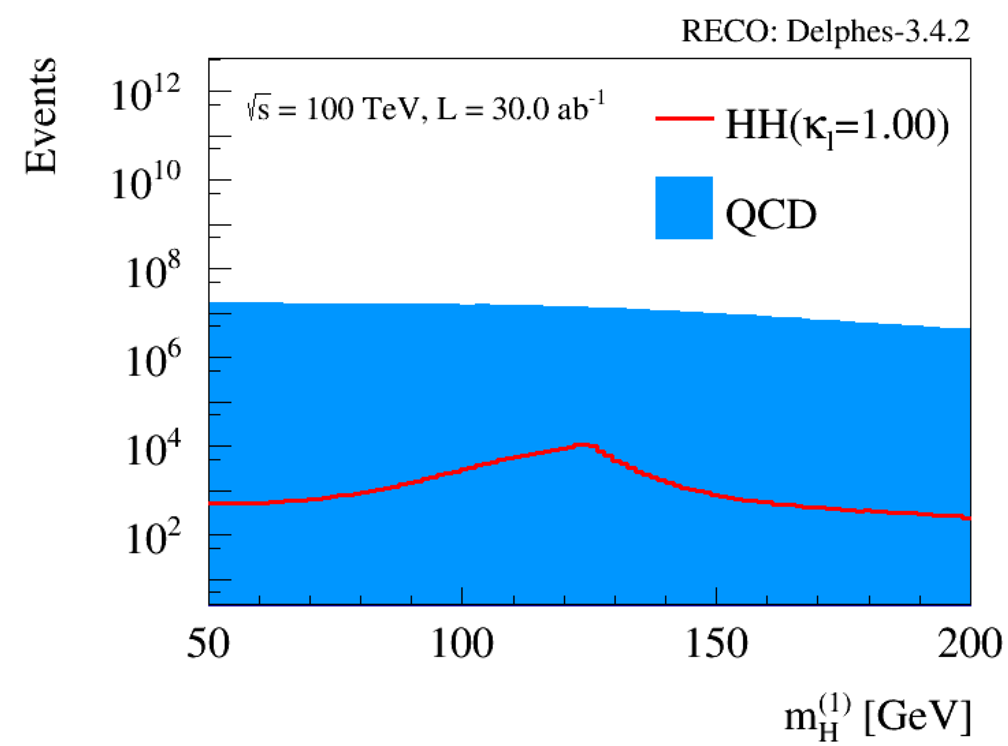
If aim for % level precision, need S,B $\gtrsim 10^4$ after cuts:
, i.e. a **factor of 10^5 in background rejection** → very hard !!
→ explore lower pT(hh) range as well ….

Selection strategy

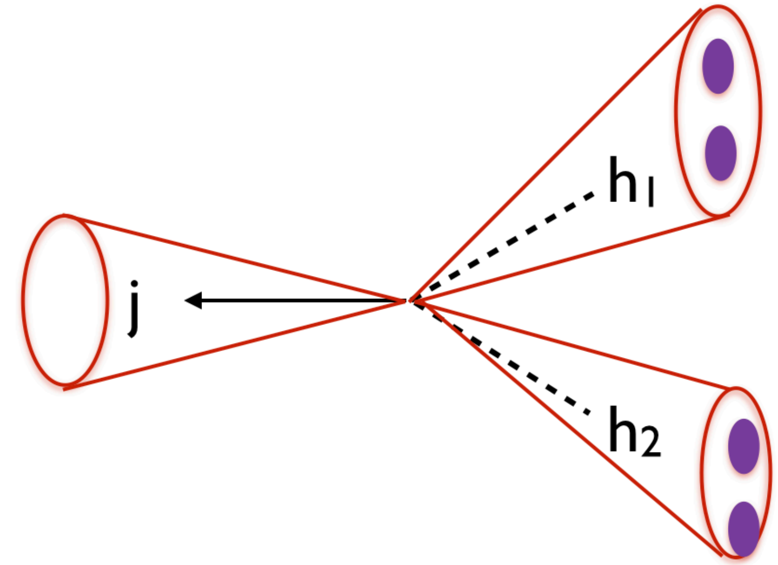


- Boost the di-Higgs system:
  - $p_T(h_1 h_2) > 400$ GeV
- Preselection: Require $\gtrsim 2$ b-tagged fatjets R = 0.8
  - $p_T(h_1) > 300$ GeV and $|\eta_1| < 3.0$
  - $p_T(h_2) > 200$ GeV and $|\eta_2| < 3.0$





Analysis strategy



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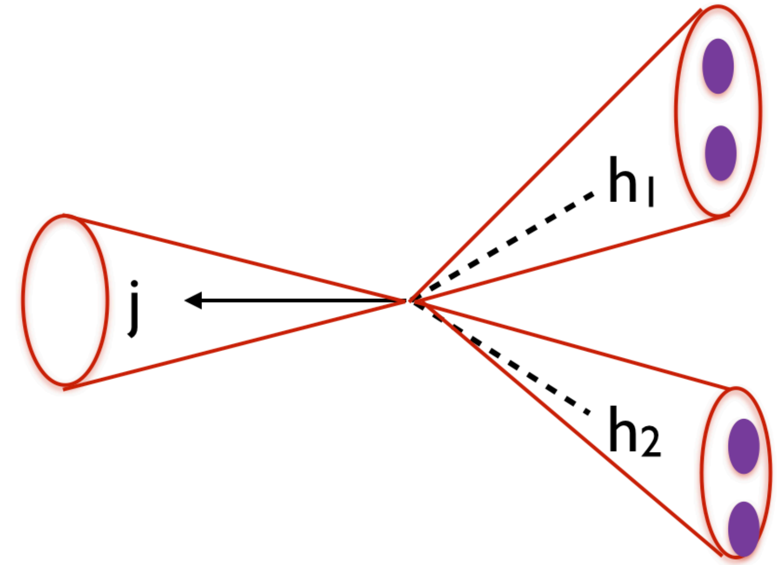
  - $p_T(h_2) > 200$ GeV and $|\eta_2| < 3.0$
- Higgs tagging:
  - $100 < m_{SD}(h_1) < 130$ and $\tau_{2,1}(h_1) < 0.4$
  - $100 < m_{SD}(h_2) < 130$ and $\tau_{2,1}(h_2) < 0.4$

Analysis strategy



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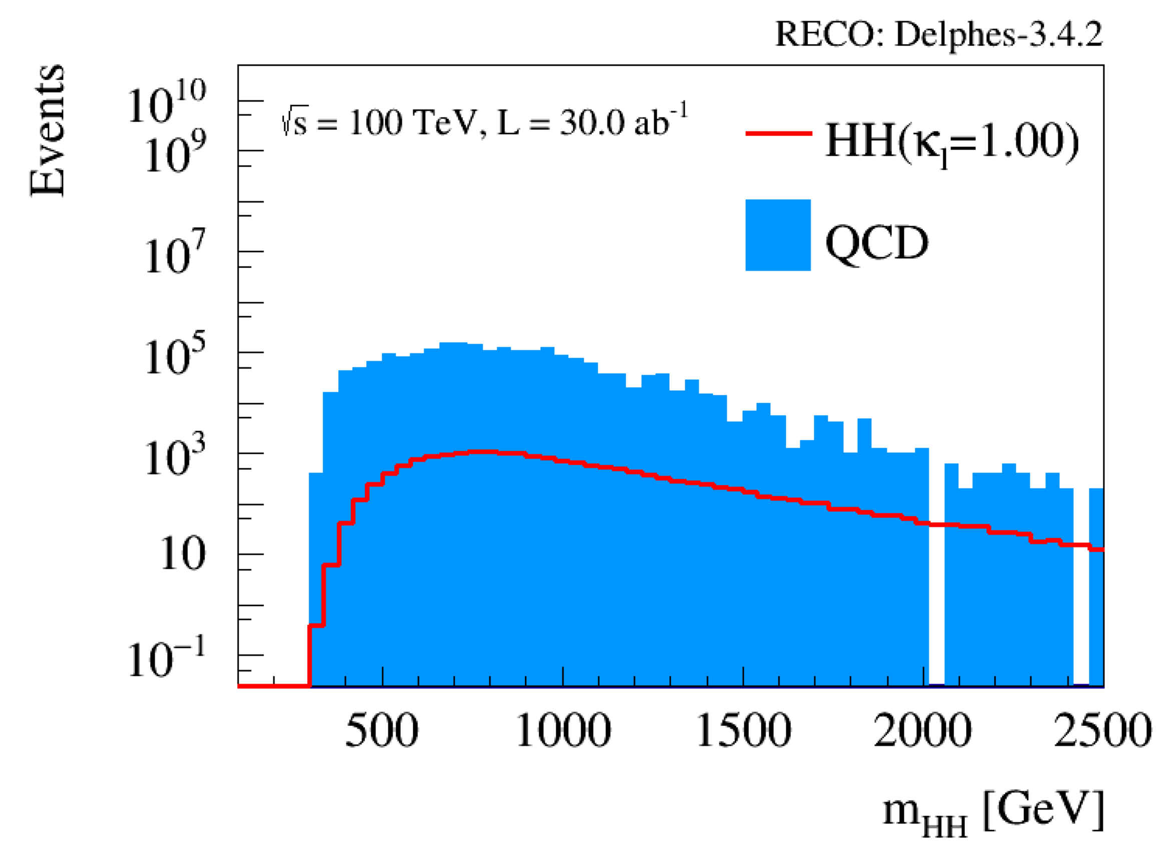
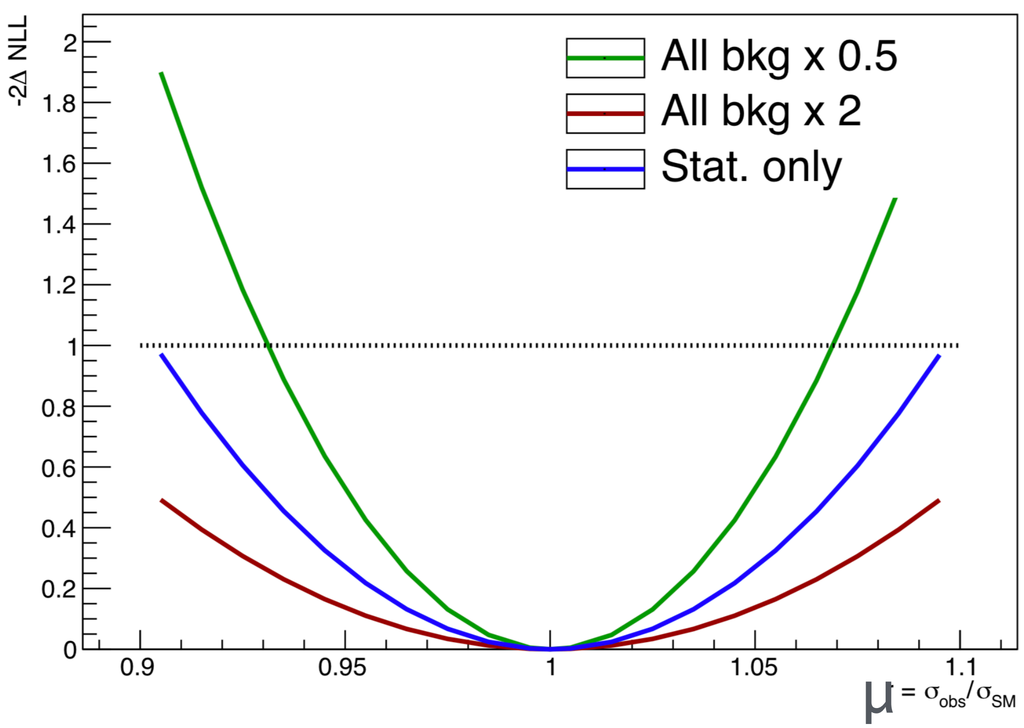
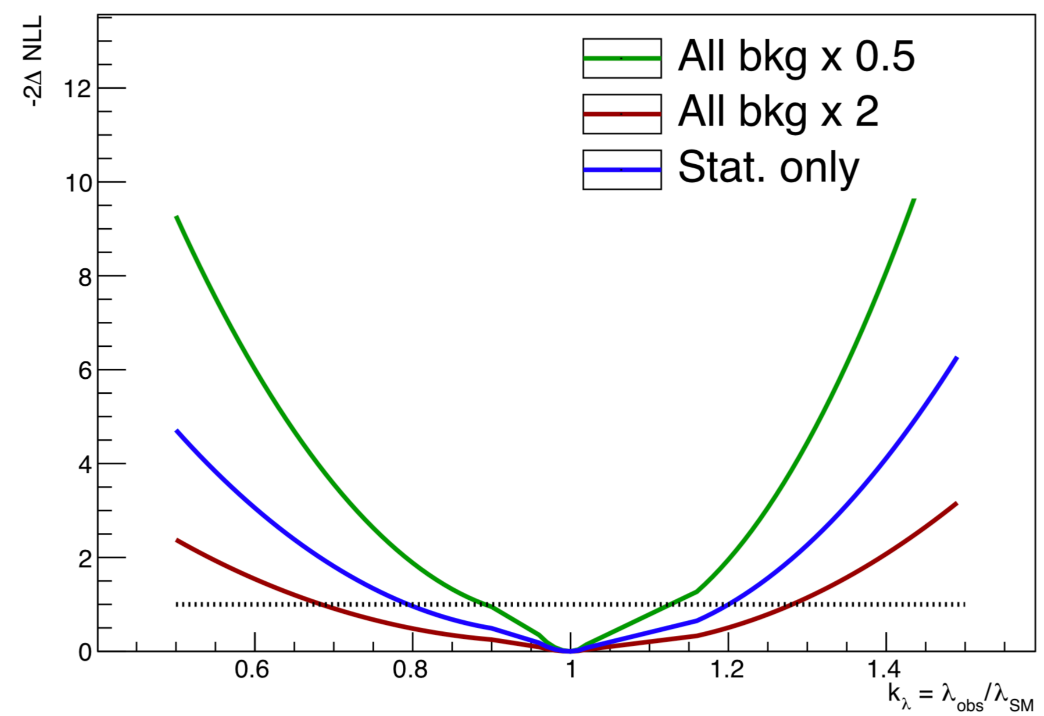
$\Rightarrow$ **fit the m_{HH} spectrum**



Expected sensitivity

varying (0.5x-2x) background yields:





$\delta\mu$(stat) ≈ 10 - 20 %

$\delta\kappa_\lambda$(stat) ≈ 15 - 30 %

Conclusions & outlook

- HH→bbɣɣ analysis has been performed with more recent detector description and new MC samples
  - small differences have been observed but overall comparable performance on sensitivity **$\delta\kappa_\lambda$(stat) ≈ 3.5 %**
- HH recoil displays lower performance due to huge QCD background
  - sensitivity found **$\delta\kappa_\lambda$(stat) ≈ 20%**
  - can definitely be further improved by using state-of-the art boosted techniques (here simple m_{SD} and $\tau_{2,1}$ cuts), optimising cone size, p_T range, etc …
- In either case, the following can help:
  - including other production channels (ttHH, VBF-HH)
  - using machine learning techniques at the preselection level
  - also higher order in QCD seem to increase sensitivity