

HH measurements at HL-LHC

Michael Spannowsky

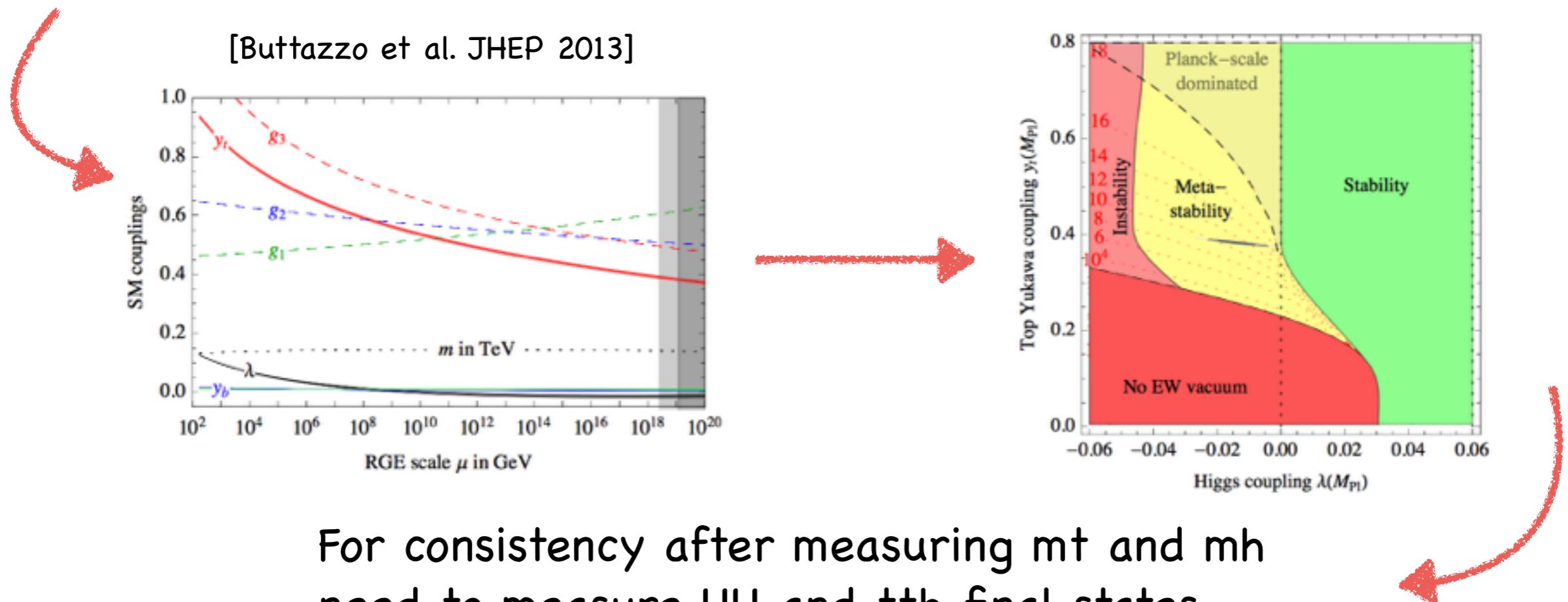
IPPP, Durham University

Motivation

HH final states directly linked to fundamental questions

Measurement of Higgs potential

- We found remnant of symmetry breaking but need to know mechanism
- Shape of potential (stable, meta-stable)



Motivation

[Contino, et al (2012)]

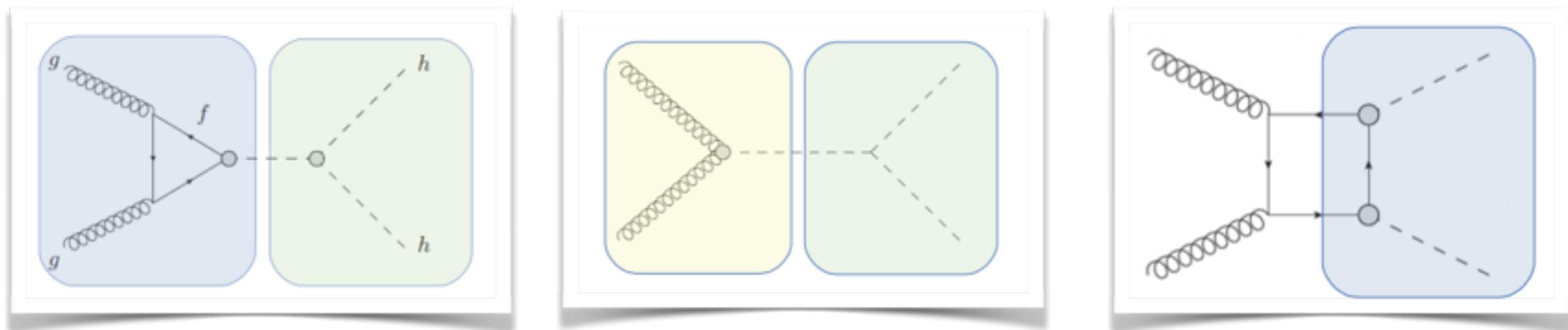
Constrain/discover new physics

[Goertz, et al (2014)]

- If new physics heavy can parametrise effect using EFT

$$\begin{aligned}\mathcal{L}_{\text{Dim6}} \supset & c_H \partial^\mu (\Phi^\dagger \Phi) \partial_\mu (\Phi^\dagger \Phi) - c_6 (\Phi^\dagger \Phi)^3 \\ & + (c_y \Phi^\dagger \Phi \bar{Q}_L \Phi q_R + h.c.) + c_g \Phi^\dagger \Phi G_{\mu\nu}^a G^{a\mu\nu}\end{aligned}$$

- c_6 can only be constrained in HH production
- Non-resonant loop-induced HH production affected



Motivation

Matter-/Anti-matter asymmetry

[Morrissey, Ramsey-Musolf (2012)]

[Curtin, Meade, Yu (2014)]

- First-order phase transition for Baryogenesis
- Need additional scalars \rightarrow resonant HH production
- Generic also in Higgs-portal models, multi-HDM models, ...

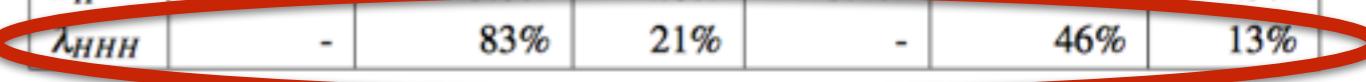
[Blinov, et al. (2015)]

Not more promising at FCC-ee or ILC

[Tian, Fujii 1311.6528]

- WBF most sensitive channel for large energies > 500 GeV
- Decay via $H \rightarrow bb$
- Unless 1 TeV ILC precision low
- How about FCC-hh?
Ongoing studies...

$\Delta g/g$	Baseline			LumiUP		
	250 GeV	+ 500 GeV	+ 1 TeV	250 GeV	+ 500 GeV	+ 1 TeV
g_{HZZ}	1.3%	1.0%	1.0%	0.61%	0.51%	0.51%
g_{HWW}	4.8%	1.2%	1.1%	2.3%	0.58%	0.56%
g_{Hbb}	5.3%	1.6%	1.3%	2.5%	0.83%	0.66%
g_{Hcc}	6.8%	2.8%	1.8%	3.2%	1.5%	1.0%
g_{Hgg}	6.4%	2.3%	1.6%	3.0%	1.2%	0.87%
$g_{H\tau\tau}$	5.7%	2.3%	1.7%	2.7%	1.2%	0.93%
$g_{H\gamma\gamma}$	18%	8.4%	4.0%	8.2%	4.5%	2.4%
$g_{H\mu\mu}$	-	-	16%	-	-	10%
g_{Htt}	-	14%	3.1%	-	7.8%	1.9%
Γ_H	11%	5.0%	4.6%	5.4%	2.5%	2.3%
λ_{HHH}	-	83%	21%	-	46%	13%



Higgs self-coupling measurements in the Standard Model

$$-\mathcal{L} \supset \frac{1}{2}m_h^2 h^2 + \sqrt{\frac{\eta}{2}}m_h h^3 + \frac{\eta}{4}h^4 - gm_V V^2 h - \frac{m_f}{v}\bar{f}fh - \frac{\alpha_s}{12\pi}G_{\mu\nu}^a G^{a\mu\nu} \log(1+h/v)$$

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

Potential needs at least dihiggs production!

Higgs self-coupling measurements in the Standard Model

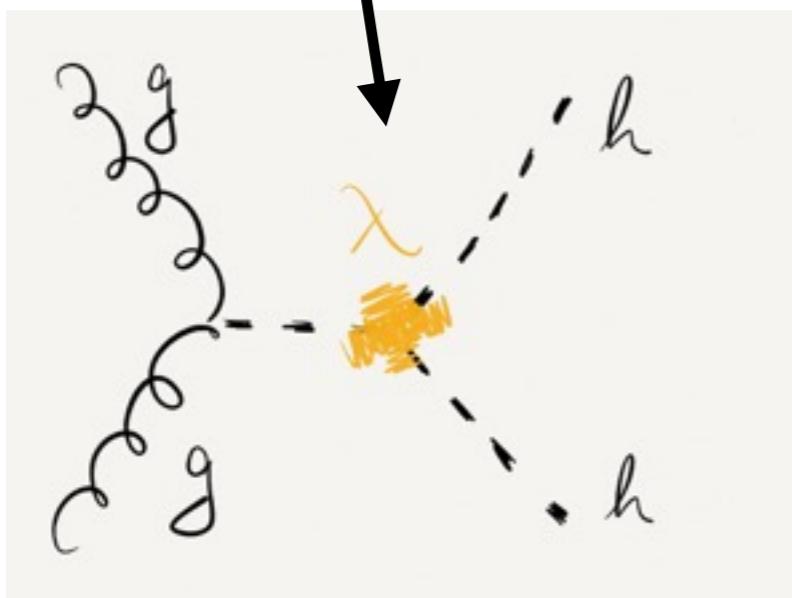
$$\begin{aligned}
 -\mathcal{L} \supset & \frac{1}{2}m_h^2 h^2 + \sqrt{\frac{\eta}{2}}m_h h^3 + \frac{\eta}{4}h^4 \xrightarrow{= \lambda_{\text{SM}}} g^2 m_h^2 / m_W^2 \\
 & - gm_V V^2 h - \frac{m_f}{v} \bar{f} f h \\
 & - \frac{\alpha_s}{12\pi} G_{\mu\nu}^a G^{a\mu\nu} \log(1 + h/v) \\
 \Delta & = -\frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} h + \frac{\alpha_s}{24\pi v^2} G_{\mu\nu}^a G^{a\mu\nu} h^2 + \dots
 \end{aligned}$$

Potential needs at least dihiggs production!

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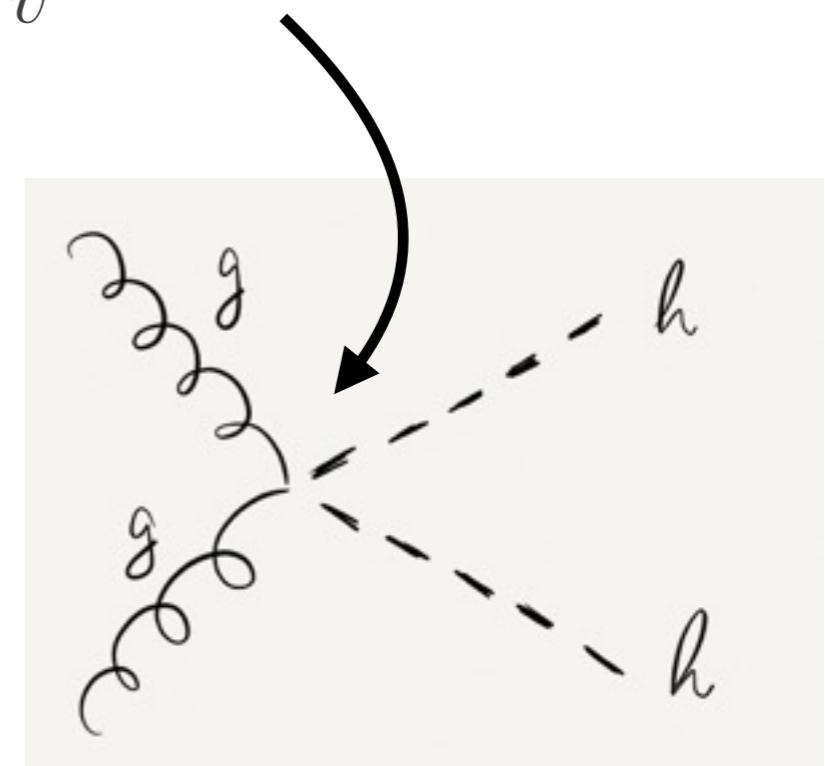
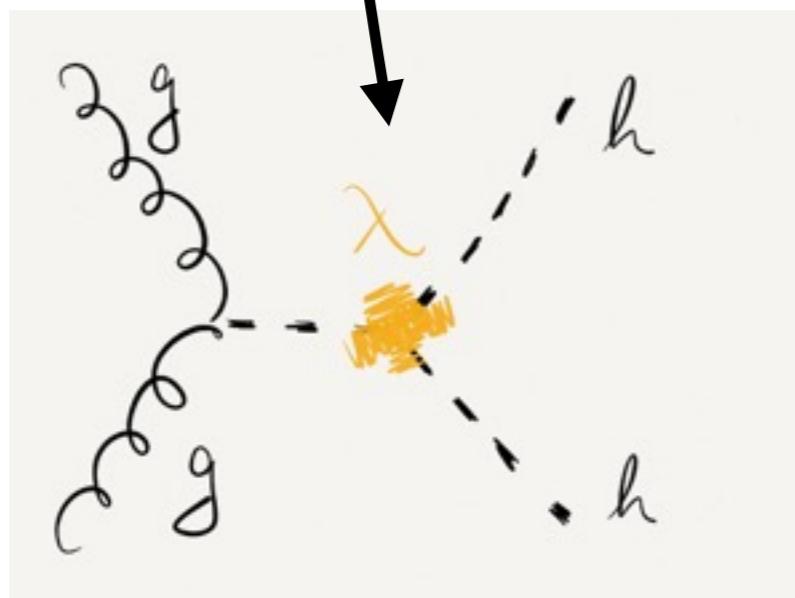
$= \lambda_{\text{SM}} = g^2 m_h^2 / m_W^2$

Potential needs at least dihiggs production!

Δ

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

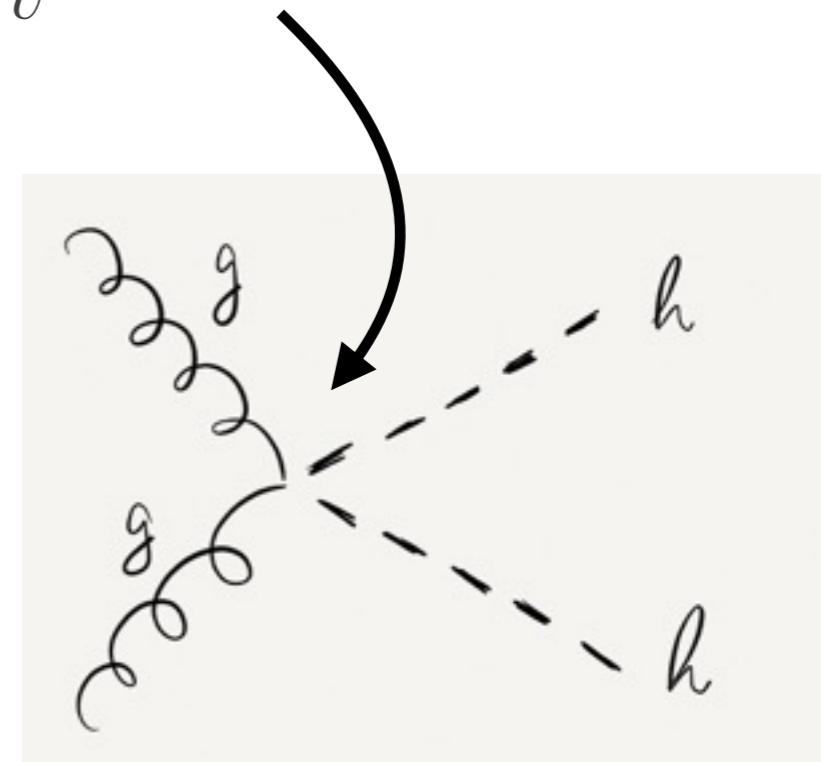
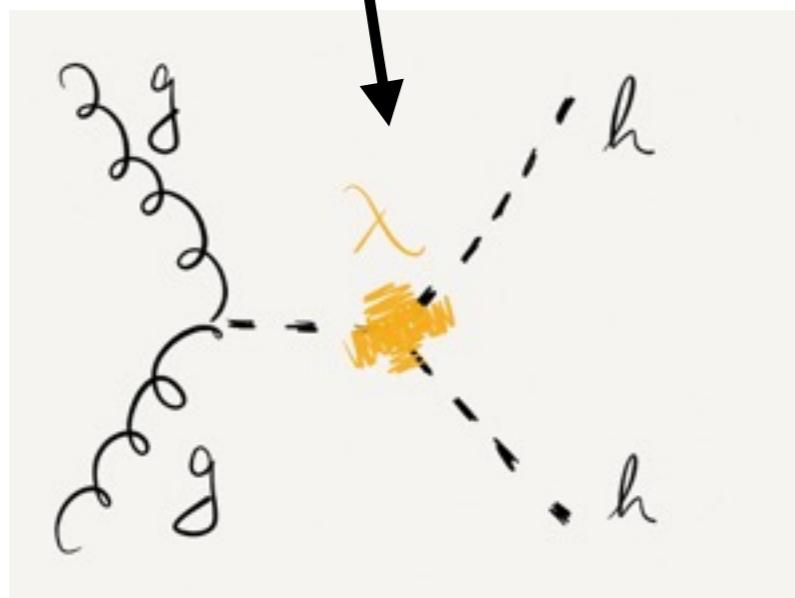
$$= -\frac{\alpha_s}{12\pi v} G_{\mu\nu}^a G^{a\mu\nu} h + \frac{\alpha_s}{24\pi v^2} G_{\mu\nu}^a G^{a\mu\nu} h^2 + \dots$$



Higgs self-coupling measurements in the Standard Model

$$\begin{aligned}
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$\lambda_{\text{SM}} = g^2 m_h^2 / m_W^2$
 Potential needs at least dihiggs production!

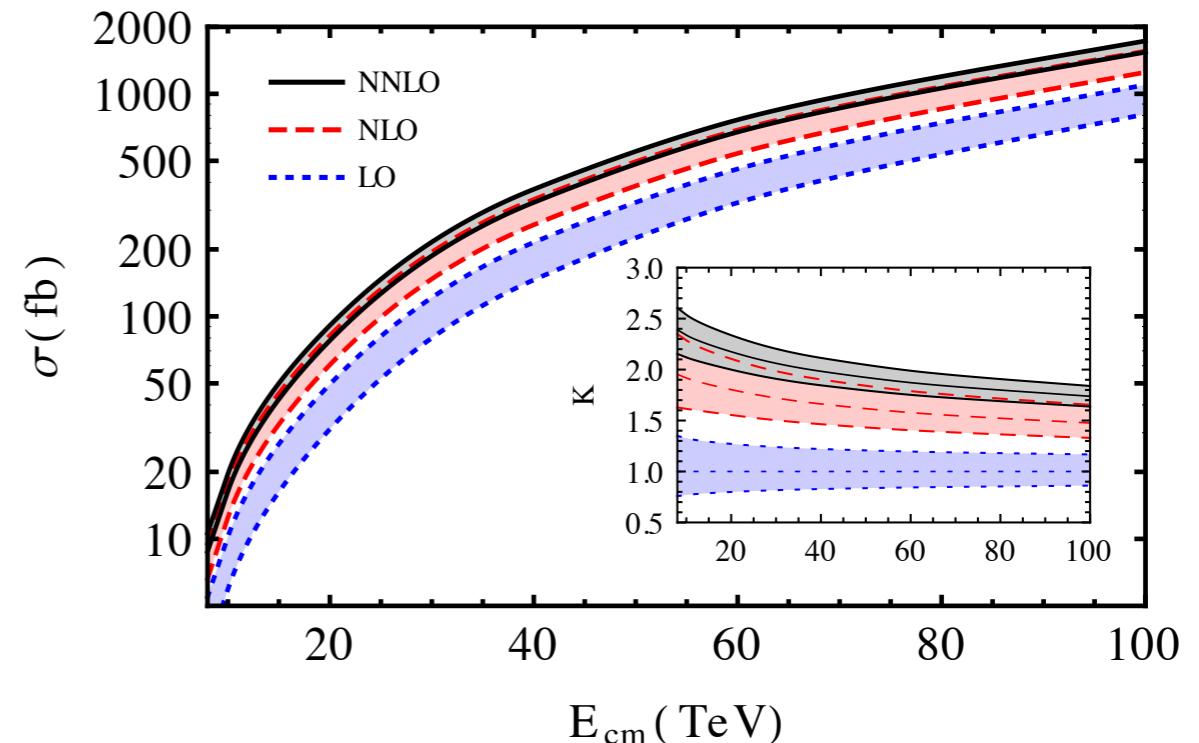
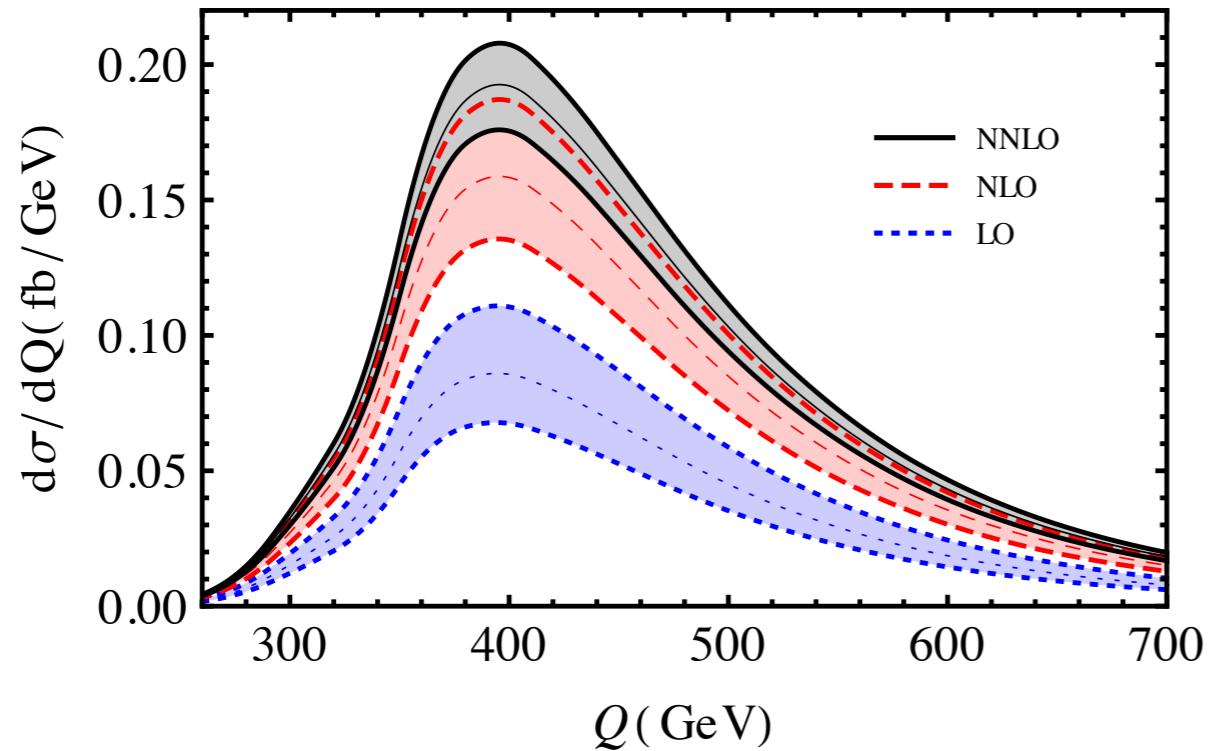


Recent progress in HH cross section calculations

HH	LO full mt	[Glover, van der Bij '88] [Plehn, Spira, Zerwas Nucl. Phys. B479, hep-ph 9603205] many others...
	NLO eff. mt	[Dawson, Dittmaier, Spira PRD 58 1998] implemented in HPair http://people.web.psi.ch/spira/hpair/
	NLO with 1/mt exp	[Grigo, Hoff, Melnikov, Steinhauser 1311.7425]
	NNLO eff. mt	[De Florian, Mazzitelli PRL 111, 1309.6594] [Grigo, Melnikov, Steinhauser]
	Full NLO	GoSam team - prop. this summer see talk by G. Heinrich, HH Workshop MIAPP
HHj	LO full mt,mb	[Dolan, Englert, MS JHEP 1210, 1206.5001] [Li, Yan, Zhao 1312.3830] [Maierhoefer, Papaefstathiou 1401.0007]
HHjj	LO full mt,mb (reweighted)	[Dolan, Englert, Greiner, MS 1310.1084]

Higgs selfcoupling in $\text{H}\bar{\text{H}}+\text{X}$

[De Florian, Mazzitelli PRL 111, 1309.6594]

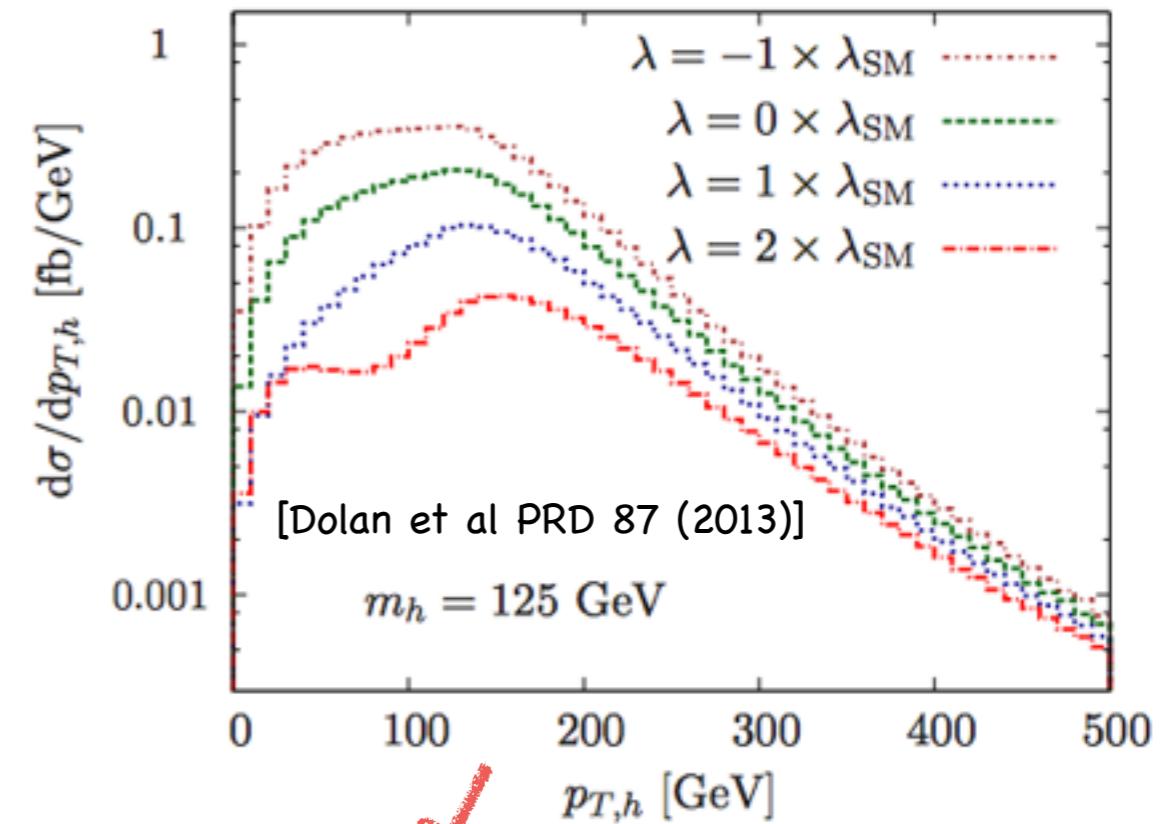
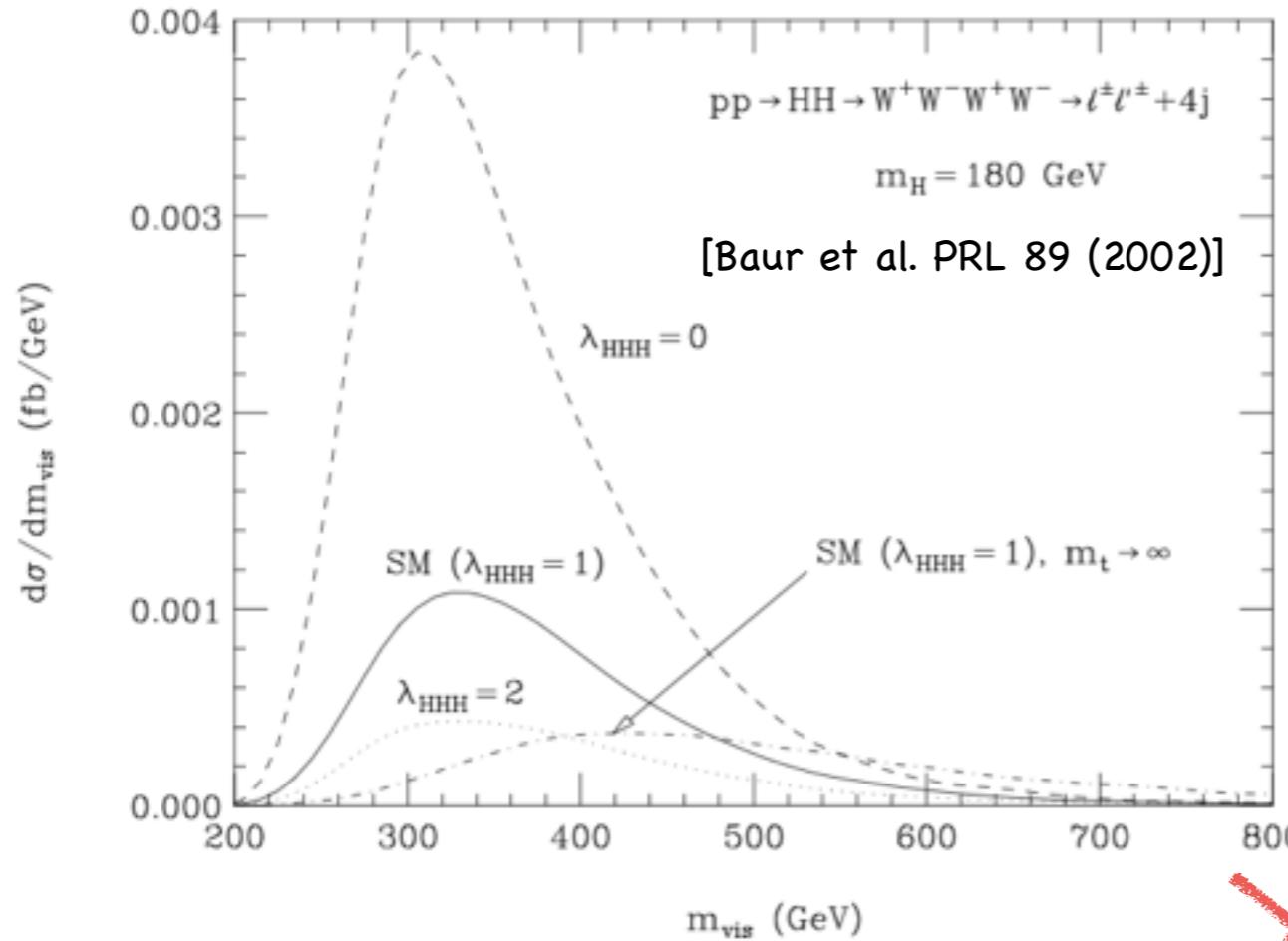


E_{cm}	8 TeV	14 TeV	33 TeV	100 TeV
σ_{NNLO}	9.76 fb	40.2 fb	243 fb	1638 fb
Scale [%]	+9.0 – 9.8	+8.0 – 8.7	+7.0 – 7.4	+5.9 – 5.8
PDF [%]	+6.0 – 6.1	+4.0 – 4.0	+2.5 – 2.6	+2.3 – 2.6
PDF+ α_S [%]	+9.3 – 8.8	+7.2 – 7.1	+6.0 – 6.0	+5.8 – 6.0

- NNLO in effective ggH
- Very large k-factors

Kinematics for $gg \rightarrow HH$

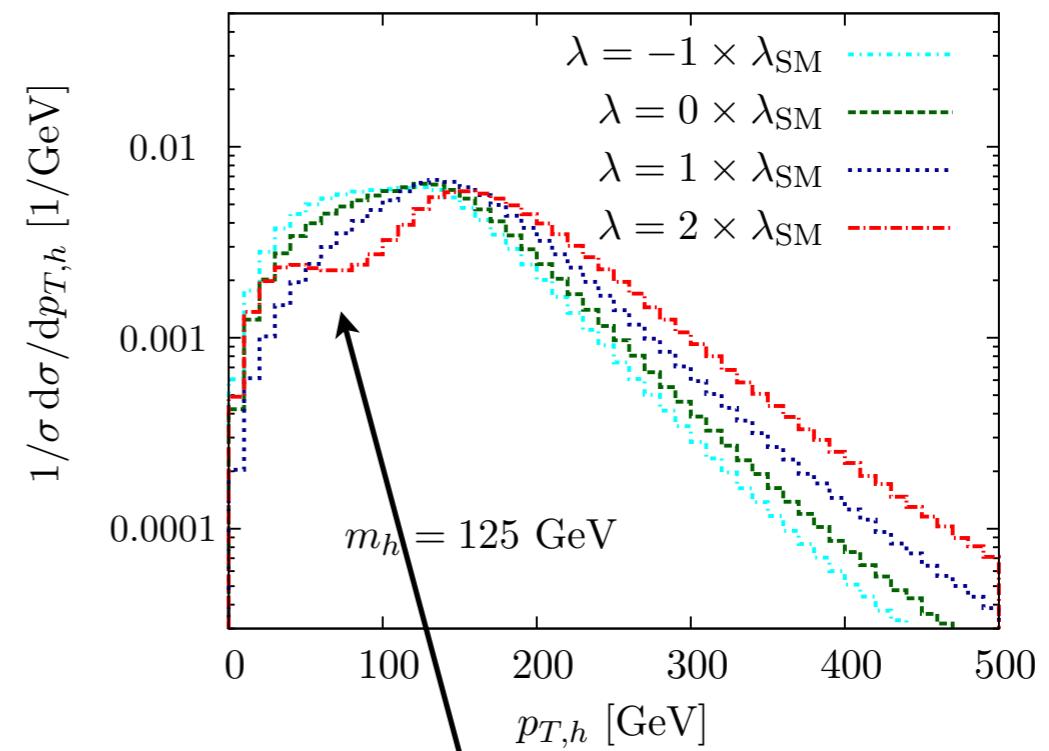
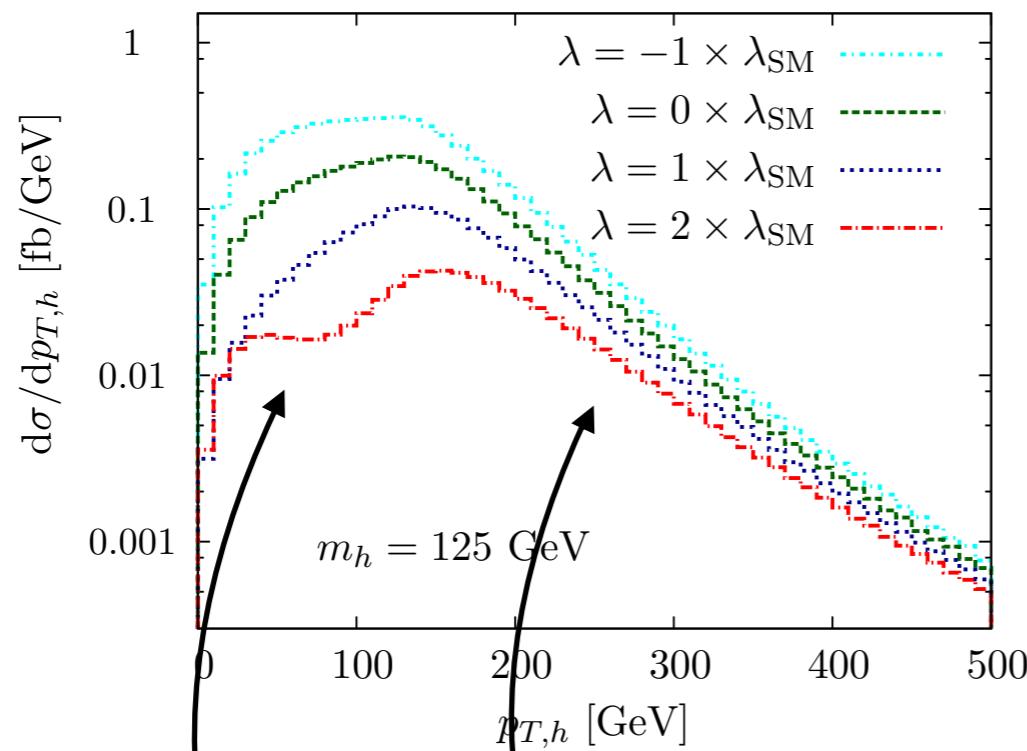
2 \rightarrow 2 scattering process completely determined by 2 variables,
e.g. S and T, E and scattering angle



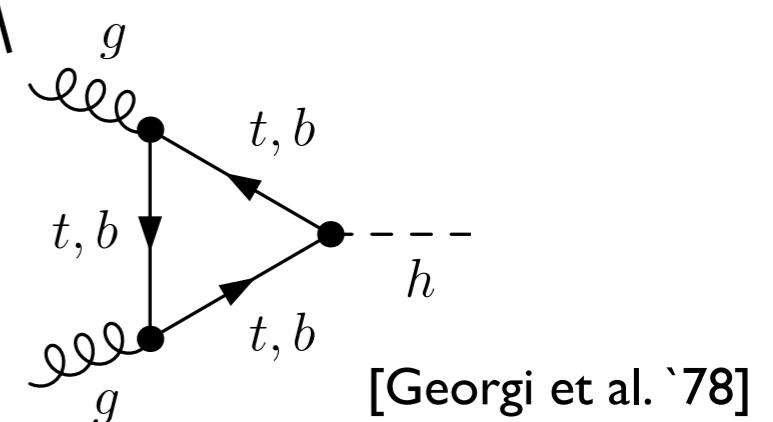
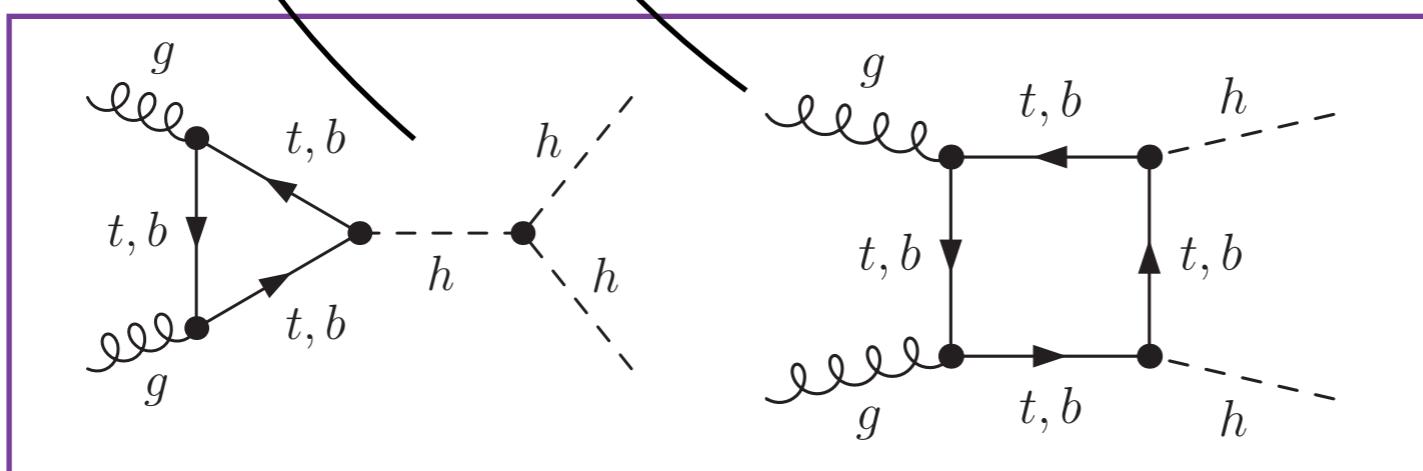
variables more close to reconstructed objects: m_{HH} and $p_{T,H}$

- All SM and BSM effects covered by double-differential measurement of two variables
- Whether possible depends on signal rate and sensitivity in phase space (backgrounds)

Higgs selfcoupling in $\text{HH}+\text{X}$



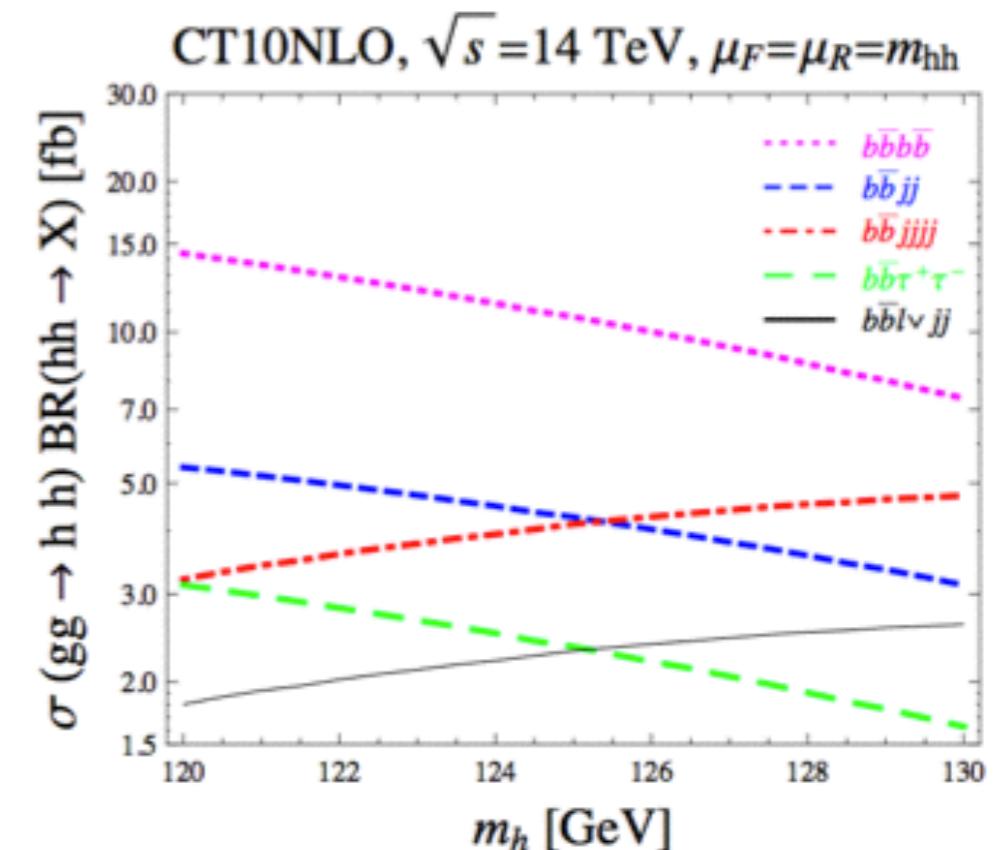
has maximum contribution for
 $s = (p_{h,1} + p_{h,2})^2 = 4m_t^2$



Where is sensitivity located?

Measuring this small cross section in an inclusive search is very challenging at the HL-LHC: compromise between branching ratio and cleanliness of the signal

Channel	BR (%)	Events/3 ab
$bbWW$	24.7	30000
$bb\tau\tau$	7.3	9000
$WWWW$	4.3	5200
$bb\gamma\gamma$	0.27	330
$bbZZ(\rightarrow e^+e^- \mu^+\mu^-)$	0.015	19
$\gamma\gamma\gamma\gamma$	0.00052	1



Several channels are currently under study by the collaborations

Decay	Issues	Expectation 3000 ifb	References
$b\bar{b}\gamma\gamma$	<ul style="list-style-type: none"> • Signal small • BKG large & difficult to asses • Simple reconst. 	$S/B \simeq 1/3$ $S/\sqrt{B} \simeq 2.5$	[Baur, Plehn, Rainwater] [Yao 1308.6302] [Baglio et al. JHEP 1304]
$b\bar{b}\tau^+\tau^-$	<ul style="list-style-type: none"> • tau rec tough • largest bkg $t\bar{t}$ • Boost+MT2 might help 	differ a lot $S/B \simeq 1/5$ $S/\sqrt{B} \simeq 5$	[Dolan, Englert, MS] [Barr, Dolan, Englert, MS] [Baglio et al. JHEP 1304]
$b\bar{b}W^+W^-$	<ul style="list-style-type: none"> • looks like $t\bar{t}$ • Need semilep. W to rec. two H • Boost + BDT proposed 	differ a lot best case: $S/B \simeq 1.5$ $S/\sqrt{B} \simeq 8.2$	[Dolan, Englert, MS] [Baglio et al. JHEP 1304] [Papaefstathiou, Yang, Zurita 1209.1489]
$b\bar{b}b\bar{b}$	<ul style="list-style-type: none"> • Trigger issue (high pT kill signal) • 4b background large difficult with MC • Subjets might help 	$S/B \simeq 0.02$ $S/\sqrt{B} \leq 2.0$	[Dolan, Englert, MS] [Ferreira de Lima, Papaefstathiou, MS] [Wardrope et al, 1410.2794]
others	<ul style="list-style-type: none"> • Many taus/W not clear if 2 Higgs • Zs, photons no rate 		



- Rate small for creative reconstruction ~ 300 events with 3 iab
- While side-band for photons clear, bump from $b\bar{b}$ very broad and background biased

Baur, Plehn, Rainwater (2003)

W. Yao (2013)

Baglio et al (2012)

Barger, Everett, Jackson, Shaughnessy (2013)

Azatov, Contino, Panico, Son (2015)

For 3 iab:

$$S/\sqrt{B} \simeq 3$$

$$S/\sqrt{B} \simeq 6.46$$

$$S/\sqrt{B} \simeq 2.3$$

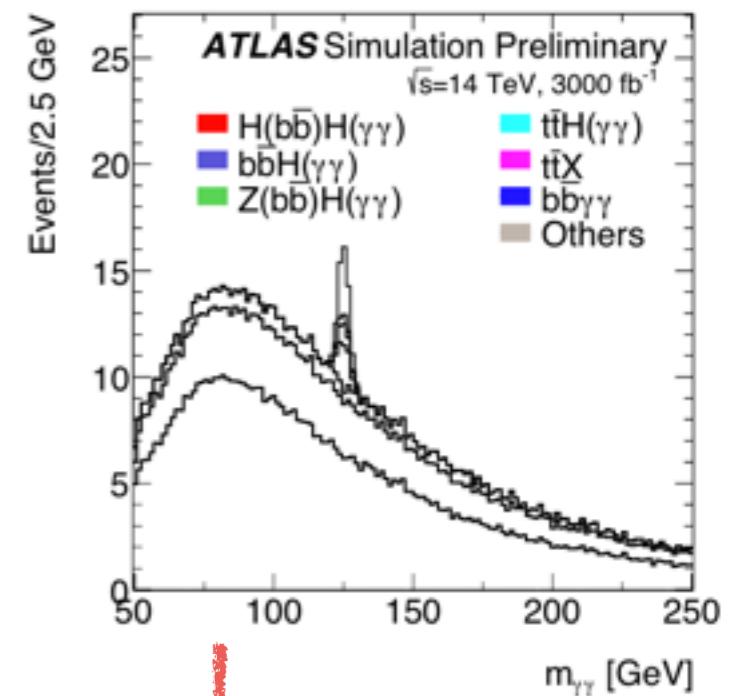
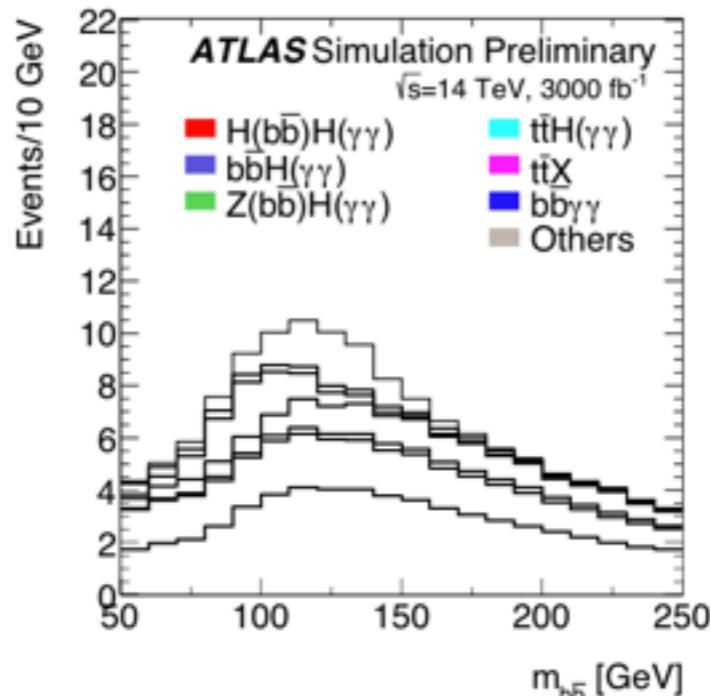
$$S/\sqrt{B} \simeq 2.1$$

Difficulties: • Need to include hadronisation and parton shower
 \rightarrow changes mass windows, # jets, fake rates

- Need to include reducible backgrounds
- Need exp. input on fake-rates and mass windows
- Need multi-jet merging for (ir)reducible backgrounds

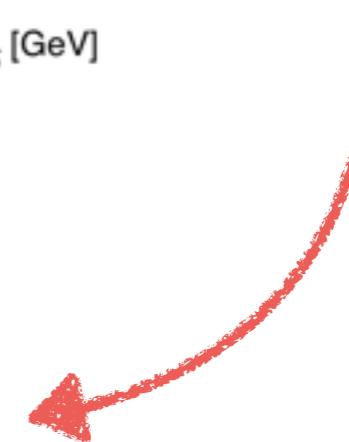
→ Reliable background simulation and fake rates
true challenge for sensitivity estimate

- Estimates from experiments far worse than theory estimates
- Background estimates between both experiments quite different

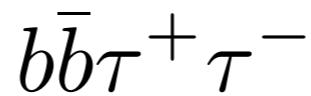


process	ATLAS	CMS
SM $HH \rightarrow b\bar{b}\gamma\gamma$	8.4 ± 0.1	9.9
$b\bar{b}\gamma\gamma$	9.7 ± 1.5	$\gamma\gamma + \text{jets}$
$cc\gamma\gamma, b\bar{b}\gamma j, b\bar{b}jj, jj\gamma\gamma$	24.1 ± 2.2	$\gamma + \text{jets}, \text{jets}$
top background	3.4 ± 2.2	1.1
$t\bar{t}H(\gamma\gamma)$	6.1 ± 0.5	1.5
$Z(b\bar{b})H(\gamma\gamma)$	2.7 ± 0.1	3.3
$bbH(\gamma\gamma)$	1.2 ± 0.1	0.8
Total background	47.1 ± 3.5	22.6
S/\sqrt{B} (barrel+endcap)	1.2	
S/\sqrt{B} (split barrel and endcap)	1.3	

BKG quite different!



CMS gives 60% uncertainty on signal CS measurement

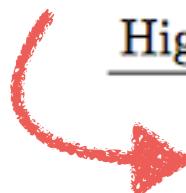


[Dolan, Englert, MS (2012)]

[Baglio et al (2012)]

- Inclusive rate 9000 events for 3 iab [Barr, Dolan, Englert, MS (2013)]
- Rate can be used for advanced reconstruction (jet substructure, MT2)
- b and tau most complicated objects to reliably simulate

	$\xi = 0$	$\xi = 1$	$\xi = 2$	$b\bar{b}\tau\tau$	$b\bar{b}\tau\tau$ [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	$3.2 \cdot 10^{-5}$
reconstructed Higgs from τs	4.05	1.94	0.91	2.51	1.10	1507.99	$1.9 \cdot 10^{-3}$
fatjet cuts	2.27	1.09	0.65	1.29	0.84	223.21	$4.8 \cdot 10^{-3}$
kinematic Higgs reconstruction ($m_{b\bar{b}}$)	0.41	0.26	0.15	0.104	0.047	9.50	$2.3 \cdot 10^{-2}$
Higgs with double b-tag	0.148	0.095	0.053	0.028	0.020	0.15	0.48



For 3 iab:

$$S/\sqrt{B} \simeq 11.70$$

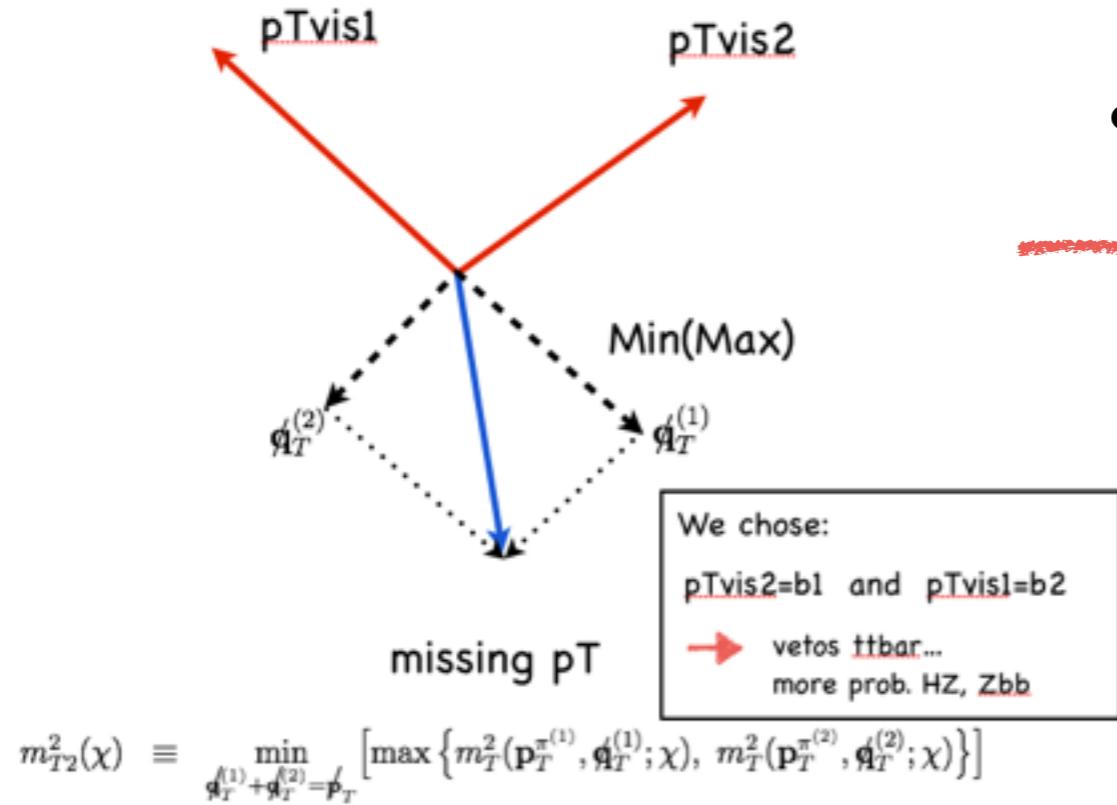
$$S/\sqrt{B} \simeq 9.37$$

$$S/\sqrt{B} \simeq 5.94 - 2.71$$

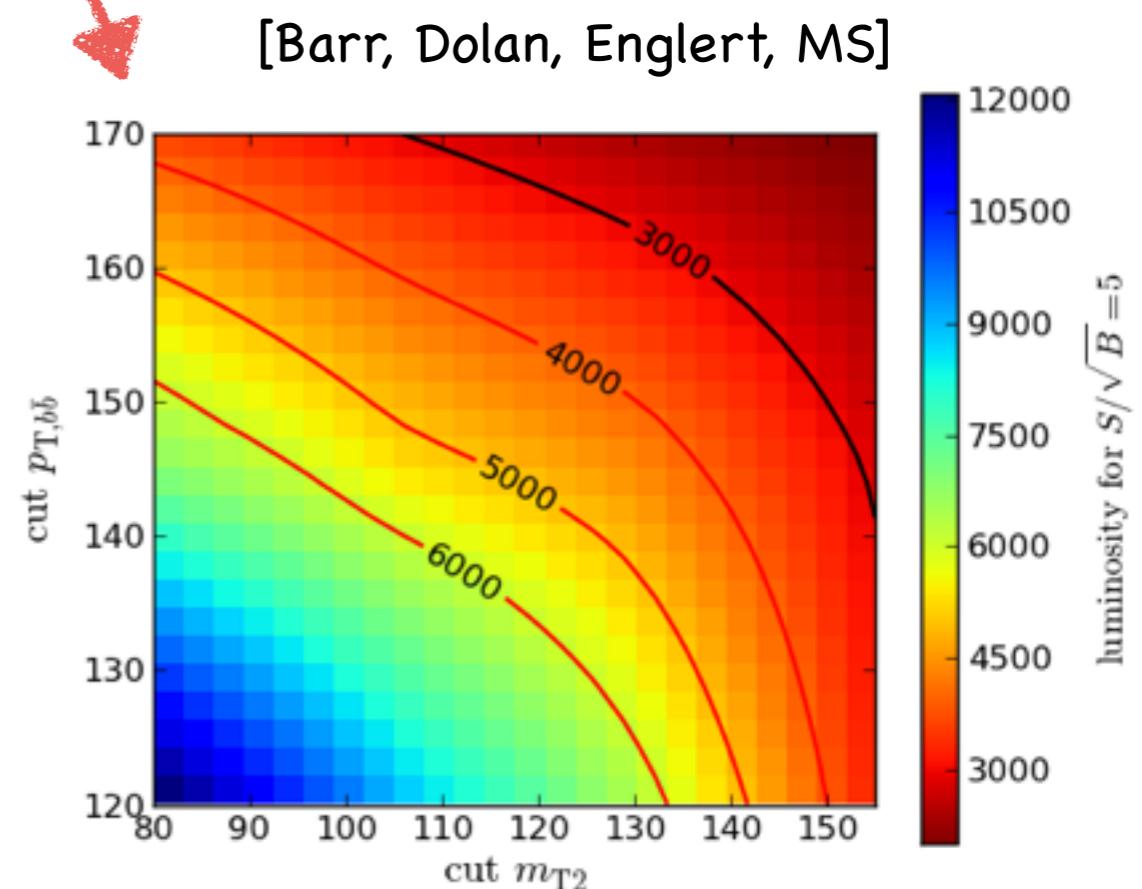
- Some studies tau efficiency/fake over optimistic
- Need better simulation of tau decays
- Need detailed sensitivity study of hadronic, semilep, leptonic taus
- Need hadronic backgrounds for hadronic tau decays
- Need JES uncertainties for subjets

$b\bar{b}\tau^+\tau^-$

- Here, major background $t\bar{t}$ can change that
- Handles to suppress background: leptons, b-jets and MET



- Jet substructure can help in addition to $mT2$ known to go very well together



- $MT2$ distribution discriminates between HH and $t\bar{t}$
- Without jet substructure we find $S/B \sim 1/5$

Exclusion at 95% CL: $\lambda > \lambda_{95\% \text{ CL}}^{3000/\text{fb}} \simeq 3.0 \times \lambda_{\text{SM}}$

$$hh \rightarrow b\bar{b}W^+W^- \rightarrow b\bar{b}\ell\nu jj$$

- Fully reconstructable final state
- Triggering easy due to lepton
- But looks like ttbar...
- Resolved analysis considered hopeless, but how about boosting?

Process	σ_{initial} (fb)	σ_{basic} (fb)
$hh \rightarrow b\bar{b}\ell\nu jj$	2.34	0.134
$t\bar{t} \rightarrow b\bar{b}\ell\nu jj$	240×10^3	15.5
$W(\rightarrow \ell\nu)b\bar{b}+\text{jets}$	2.17×10^3	0.97
$W(\rightarrow \ell\nu)+\text{jets}$	2.636×10^6	$\mathcal{O}(0.01)$
$h(\rightarrow \ell\nu jj)+\text{jets}$	36.11	$\mathcal{O}(0.0001)$
$h(\rightarrow \ell\nu jj)b\bar{b}$	6.22	$\mathcal{O}(0.001)$
$h(\rightarrow b\bar{b}) + WW(\rightarrow \ell\nu jj)$	0.0252	-

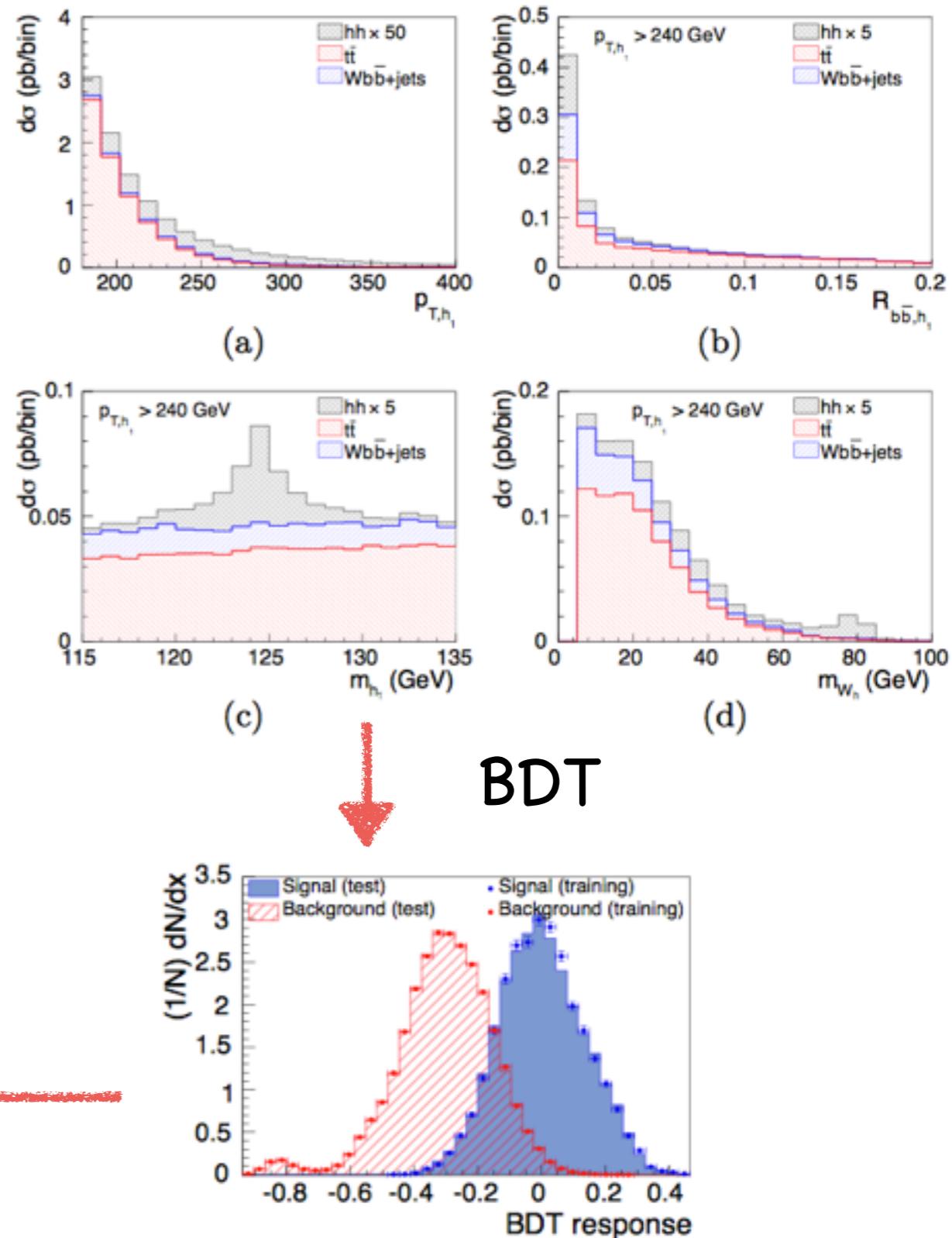
For SM coupling \downarrow
 $S/\sqrt{S+B} \sim 2.4 \quad 3.1\sigma$
with $S=9$ and $B=6$ after 600 ifb

$$\bar{b}bW^+W^-$$

[Dolan, Englert, MS (2012)]

[Baglio et al (2012)]

[Papaefstathiou, Yang, Zurita (2012)]



Search for $HH \rightarrow bb^-WW \rightarrow bb^-l\nu l\nu$

CMS feasibility study for ECFA

Event preselection:

- ♦ 2 b-jets Medium WP, $pT > 30$ GeV
- 2 leptons, muons: $pT > 20$ GeV, electrons: $pT > 25$ GeV
- ♦ MET > 20 GeV
- Clean up cuts (m_{jj} , m_{ll} , ΔR_{jj} , ΔR_{ll} , $\Delta\phi_{jj,ll}$)

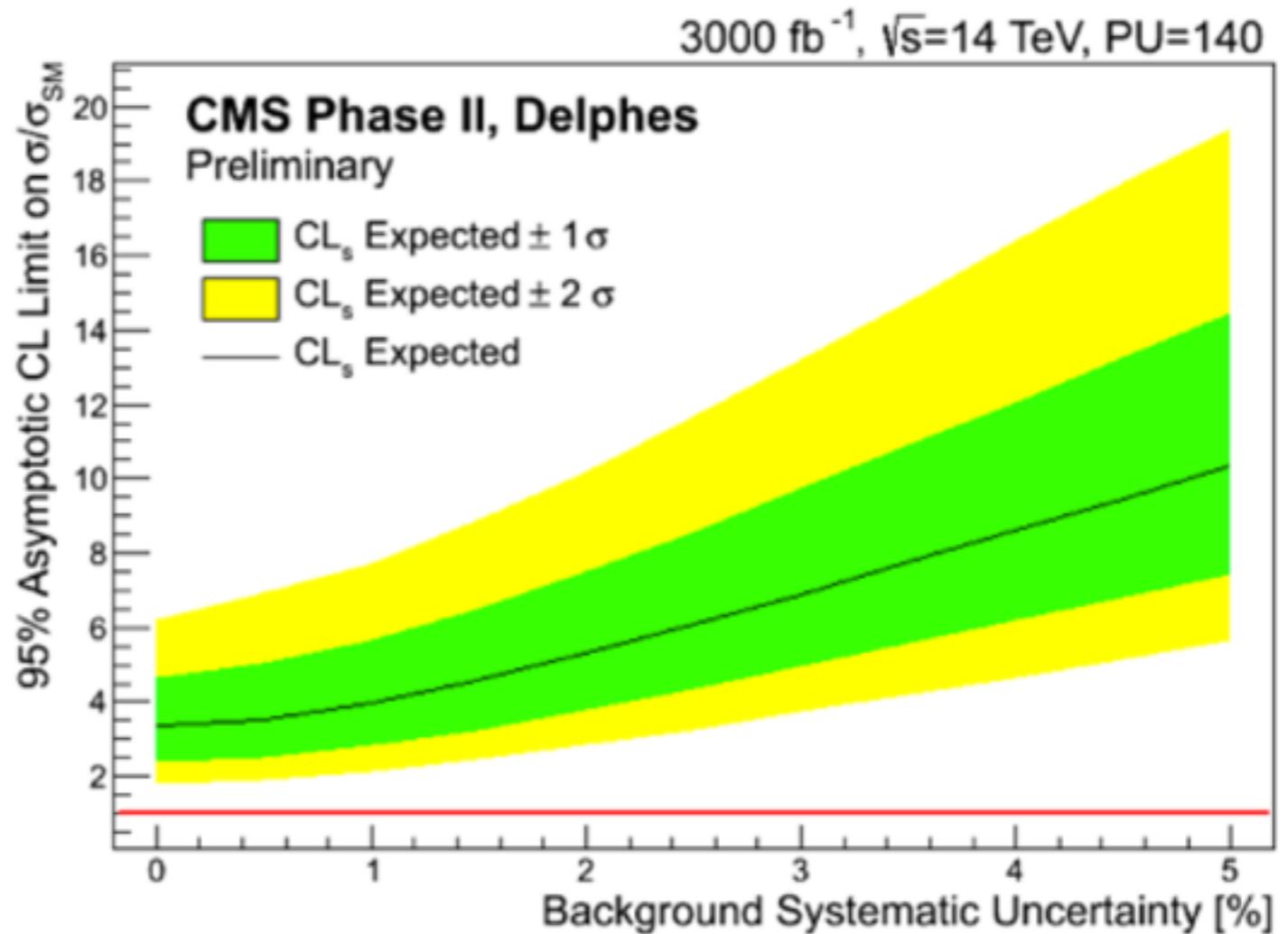
Analysis Optimization:

- ♦ Neural network discriminant from kinematic variables
- ♦ Variables: M_{ll} , M_{jj} , ΔR_{ll} , ΔR_{jj} , ΔR_{jl} , MET, $\Delta\phi_{ll,jj}$, p_{jj} , and MT

Analysis Setup:

- ♦ Phase II scenario Assuming $3000 / fb$
- ♦ Based on Delphes reconstruction
- ♦ Considering only the main background: t^+t^-
- ♦ The rest of the SM processes are negligible

Very large uncertainties in fit
Huge systematic uncertainties



$\bar{b}b\bar{b}b$

[Baur, Plehn, Rainwater]

[Dolan, Englert, MS]

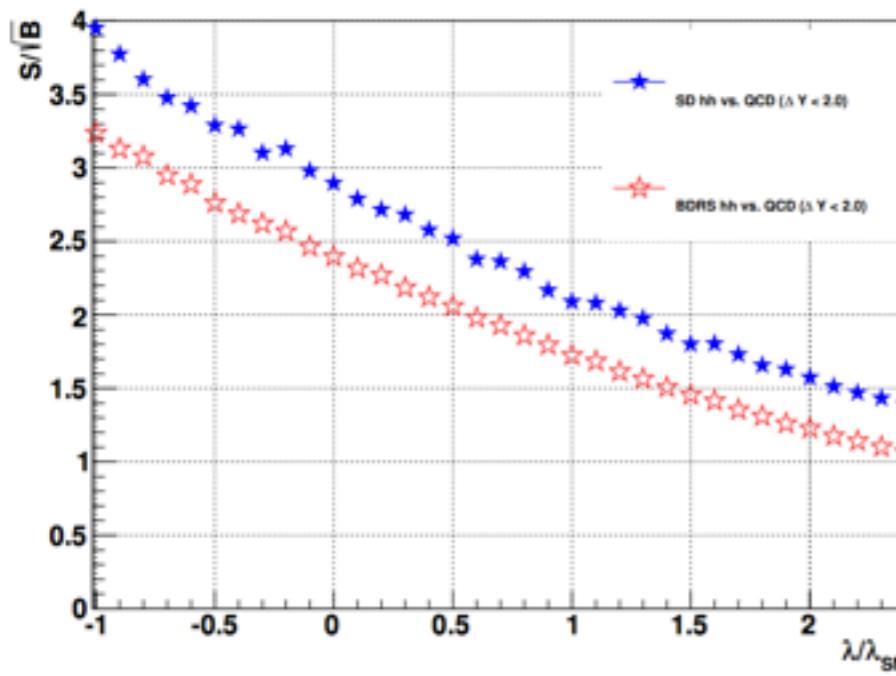
[Papaefstathiou, Ferreira, MS]

[Wardrope, Jansen, Konstantinidis,
Cooper, Falla, Norjoharudeen]

- Difficult to trigger (requires large pT cuts or fat jet)
- Huge QCD backgrounds
- Can try to use jet substructure techniques to overcome large backgrounds
- Maybe sideband possible?
- After reconstruction and 3000 ifb:
- S/B $\sim 1/20$

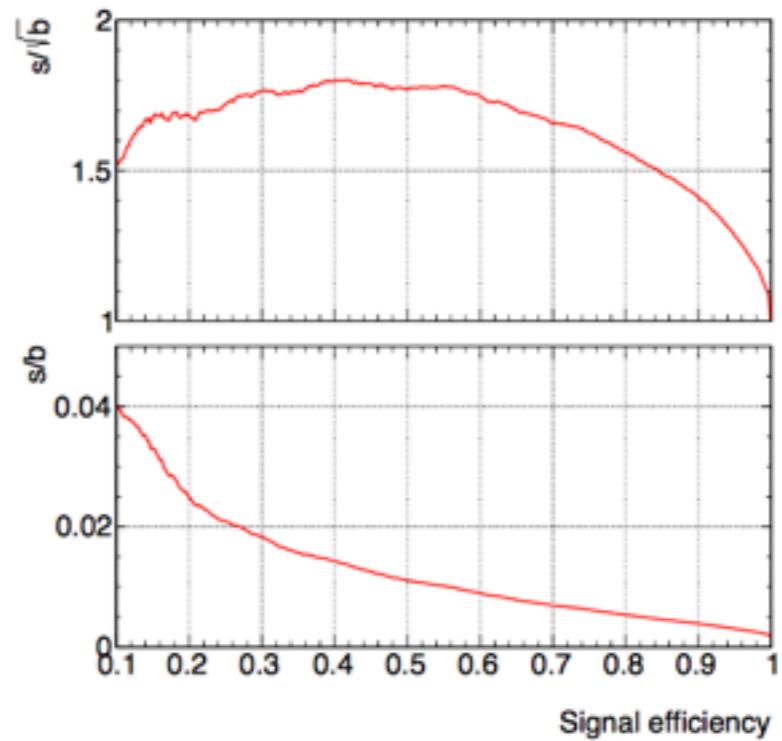
sample	$\sigma_{\text{initial}} (\text{fb})$
$hh, h \rightarrow b\bar{b}$ (SM)	10.7
QCD ($b\bar{b}$)($b\bar{b}$)	151.1×10^3
$Zb\bar{b}, Z \rightarrow b\bar{b}$	8.8×10^3
$hZ, h \rightarrow b\bar{b}, Z \rightarrow b\bar{b}$	70.0
$hW, h \rightarrow b\bar{b}, W \rightarrow c\bar{b}(c\bar{b})$	96.4

Boosted + Jet substructure



↔
consistent

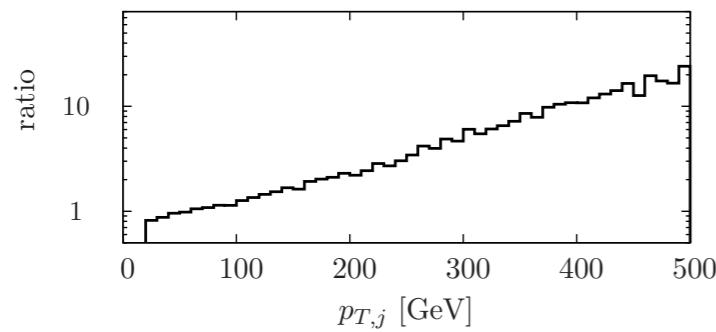
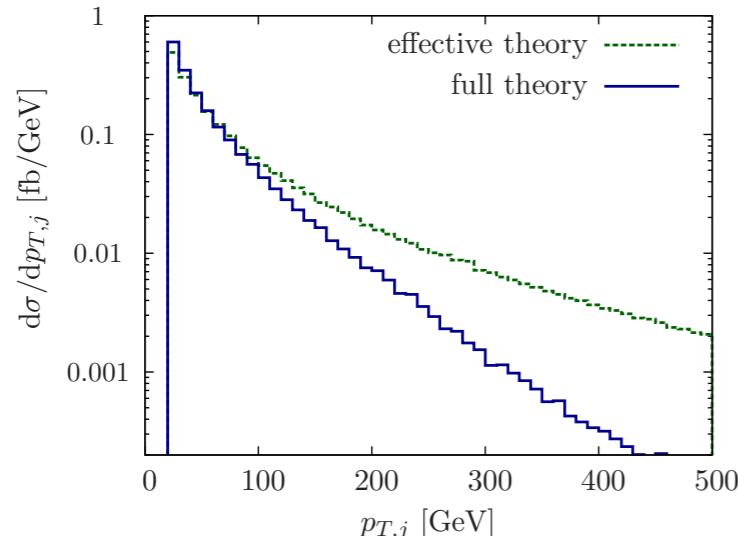
Resolved + BDT (incl. ttbar BKG)



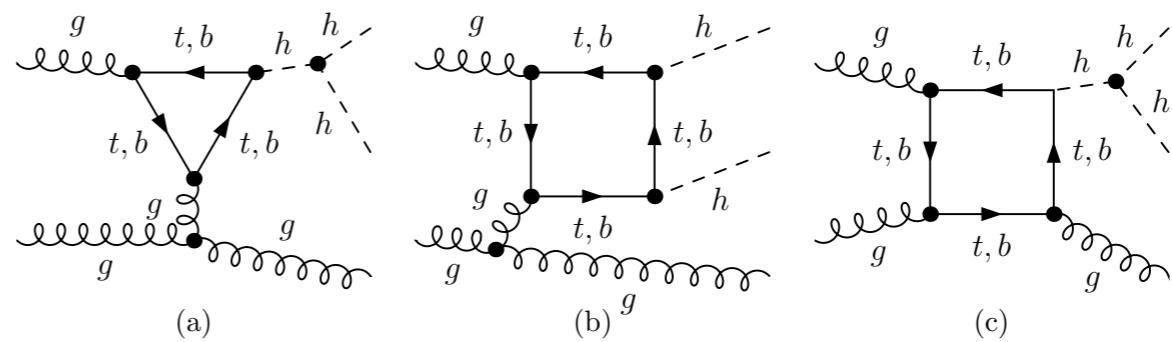
More jets can keep m_{inv} small and pT, H large

- need to work a little harder

Eff. theory breaks down quickly

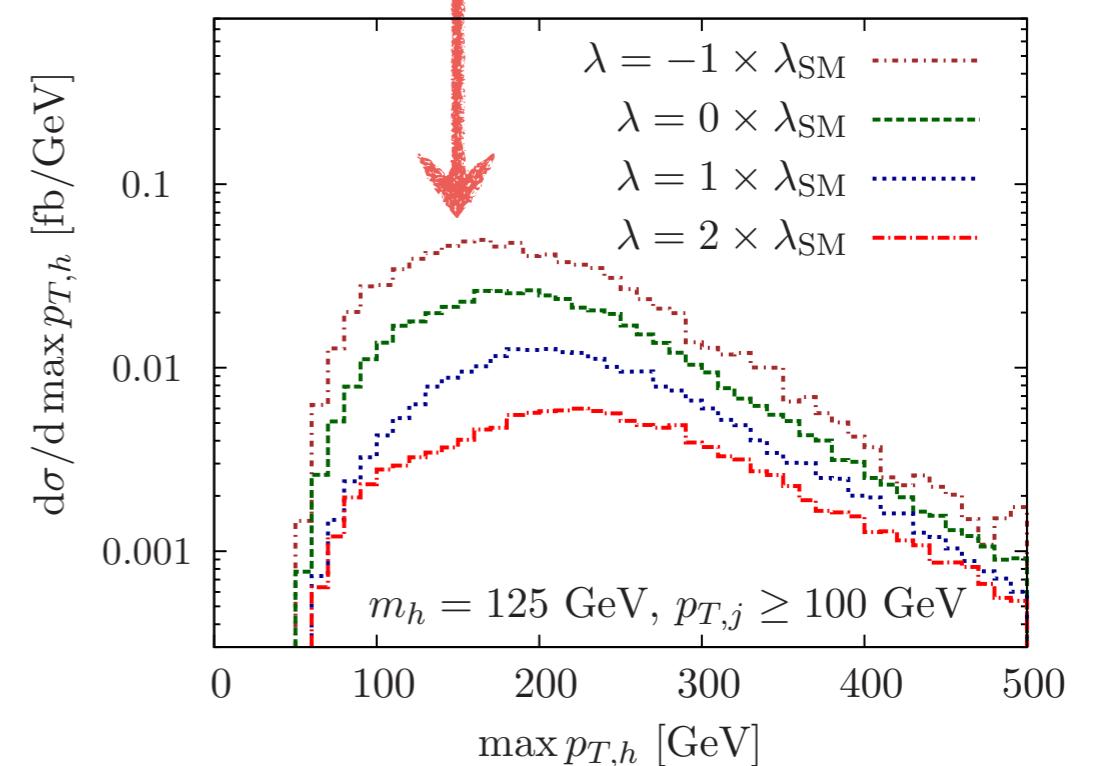


[Dolan, Englert, MS]



+ quark & gluon induced

retain sensitivity for boosted Higgs



Additional jet can help to suppress backgrounds:

$$hhj \rightarrow b\bar{b}\tau^+\tau^- j \quad S/B \sim 3/2$$

$$hh \rightarrow b\bar{b}\tau^+\tau^- \quad S/B \sim 1/2$$

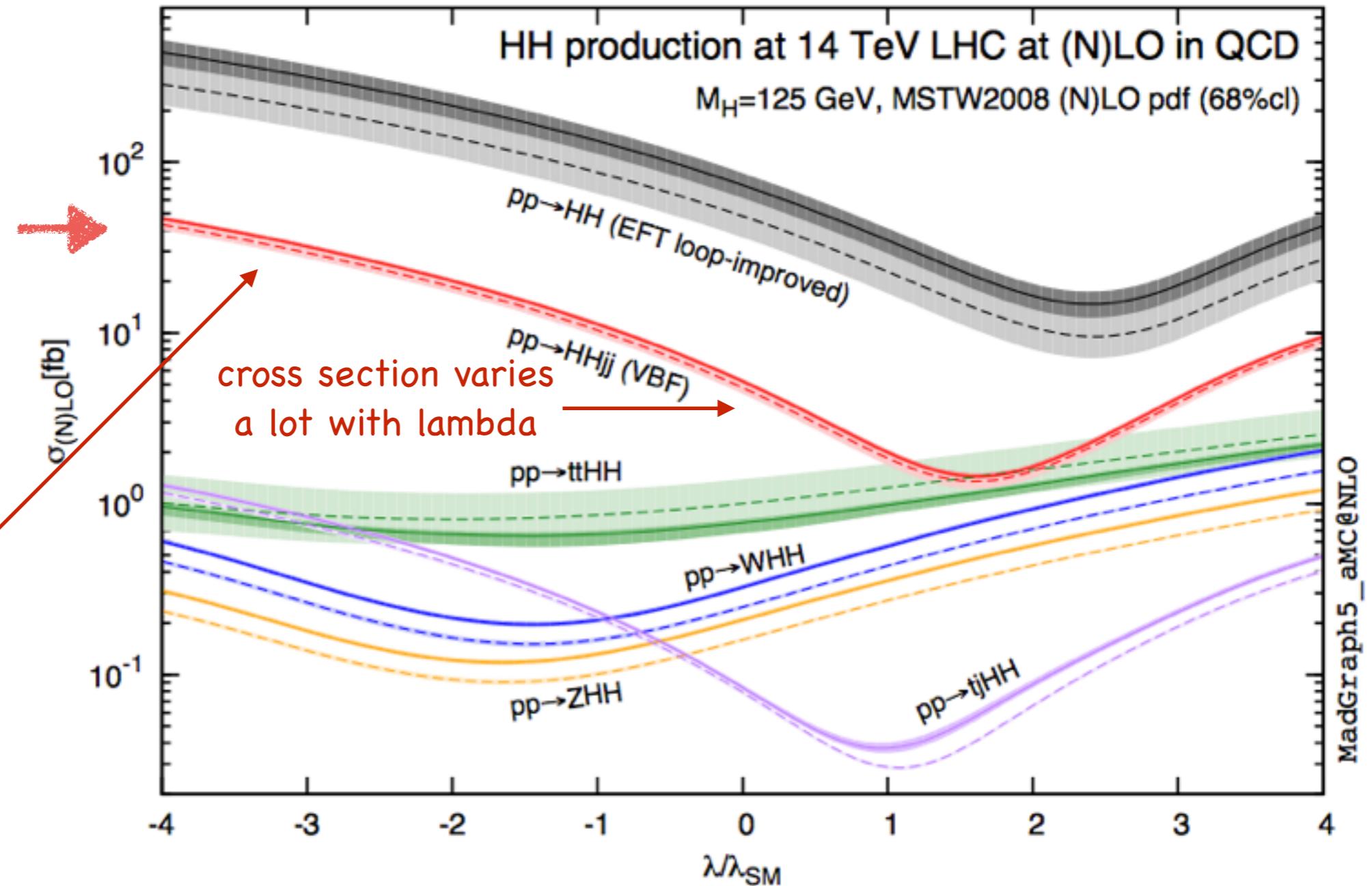
However rate after reconstruction too small for LHC $\sim 0.03 \text{ fb}$ - better at FCC-hh

Other HH production channels

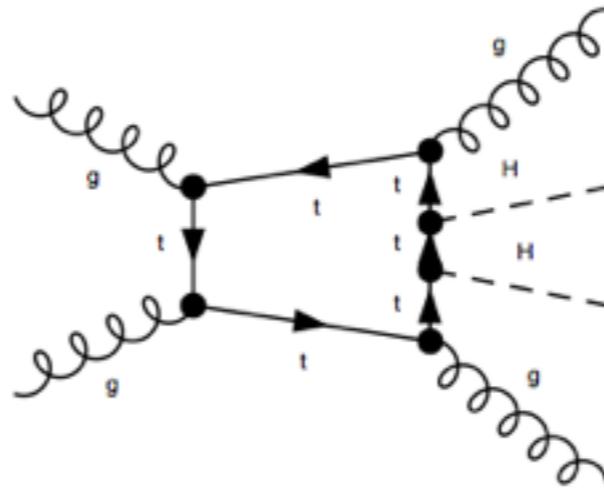
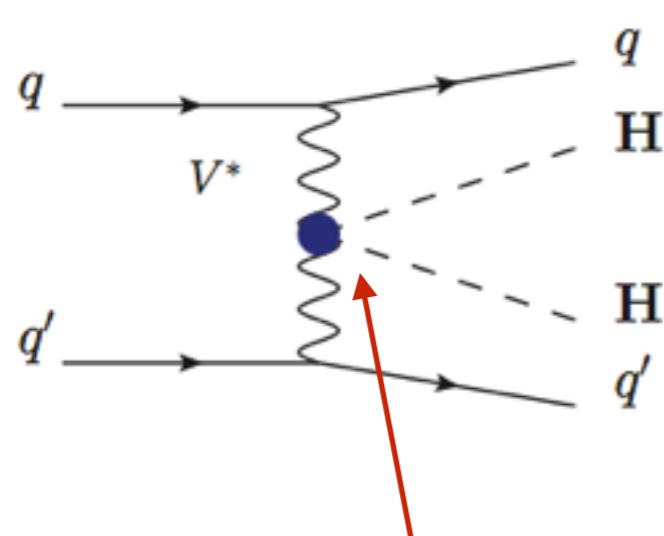
[Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Torielli, Vryonidou, Zaro '14]

Second largest
production process

small
uncertainties



Higgs selfcoupling in $\text{HHjj}+\chi$



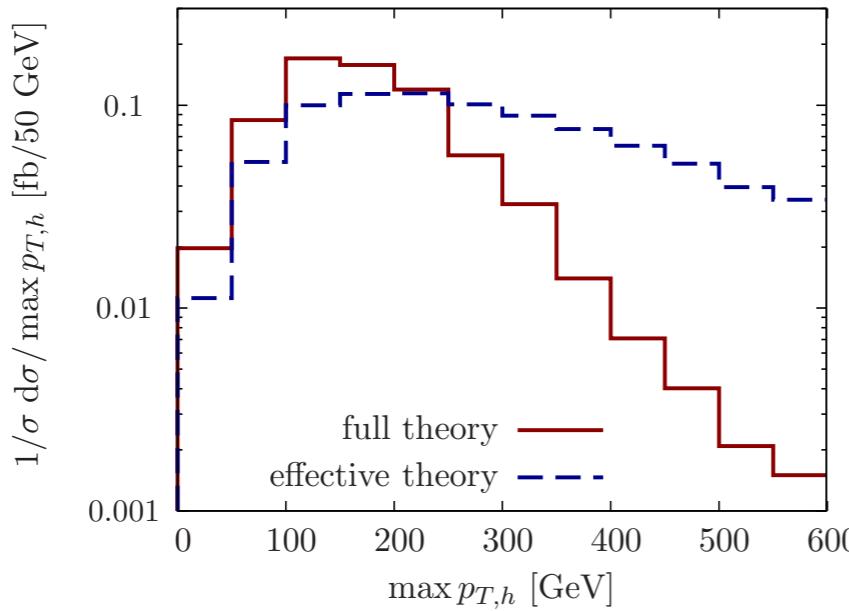
[Contino et al. JHEP 1005]

[Baglio et al. JHEP 1304]

[Dolan, Englert, Greiner, MS]

- Want to study $VVHH$
Directly related to long. gauge boson scattering $V_L V_L \rightarrow hh$
- In SM fixed: $g_{WWhh} = e^2/(2s_w^2)$ $g_{ZZhh} = e^2/(2c_w^2 s_w^2)$
- However in BSM models, e.g. composite (strongly coupled light) Higgs models, can be strongly modified
- Higher-dim operators momentum dependent \rightarrow enhanced in high-pT region
- Separation of WBF and gluon fusion channel non-trivial

Higgs selfcoupling in $\text{HH}jj+\chi$



- For kinematic distributions full loop recommended in gluon fusion
- Analysis in $\bar{b}b\tau^+\tau^-$
- Very bad S/B, but expected to improve easily...

So far very rudimentary analysis:

[Dolan, Englert, Greiner, MS]

	Signal with $\xi \times \lambda$			Background		S/B ratio to $\xi = 1$
	$\xi = 0$	$\xi = 1$	$\xi = 2$	$t\bar{t}jj$	Other BG	
tau selection cuts	0.212	0.091	0.100	3101.0	57.06	0.026×10^{-3}
Higgs rec. from taus	0.212	0.091	0.100	683.5	31.92	0.115×10^{-3}
Higgs rec. from b jets	0.041	0.016	0.017	7.444	0.303	1.82×10^{-3}
2 tag jets	0.024	0.010	0.012	5.284	0.236	1.65×10^{-3}
incl. GF after cuts/re-weighting	0.181	0.099	0.067	5.284	0.236	1/61.76

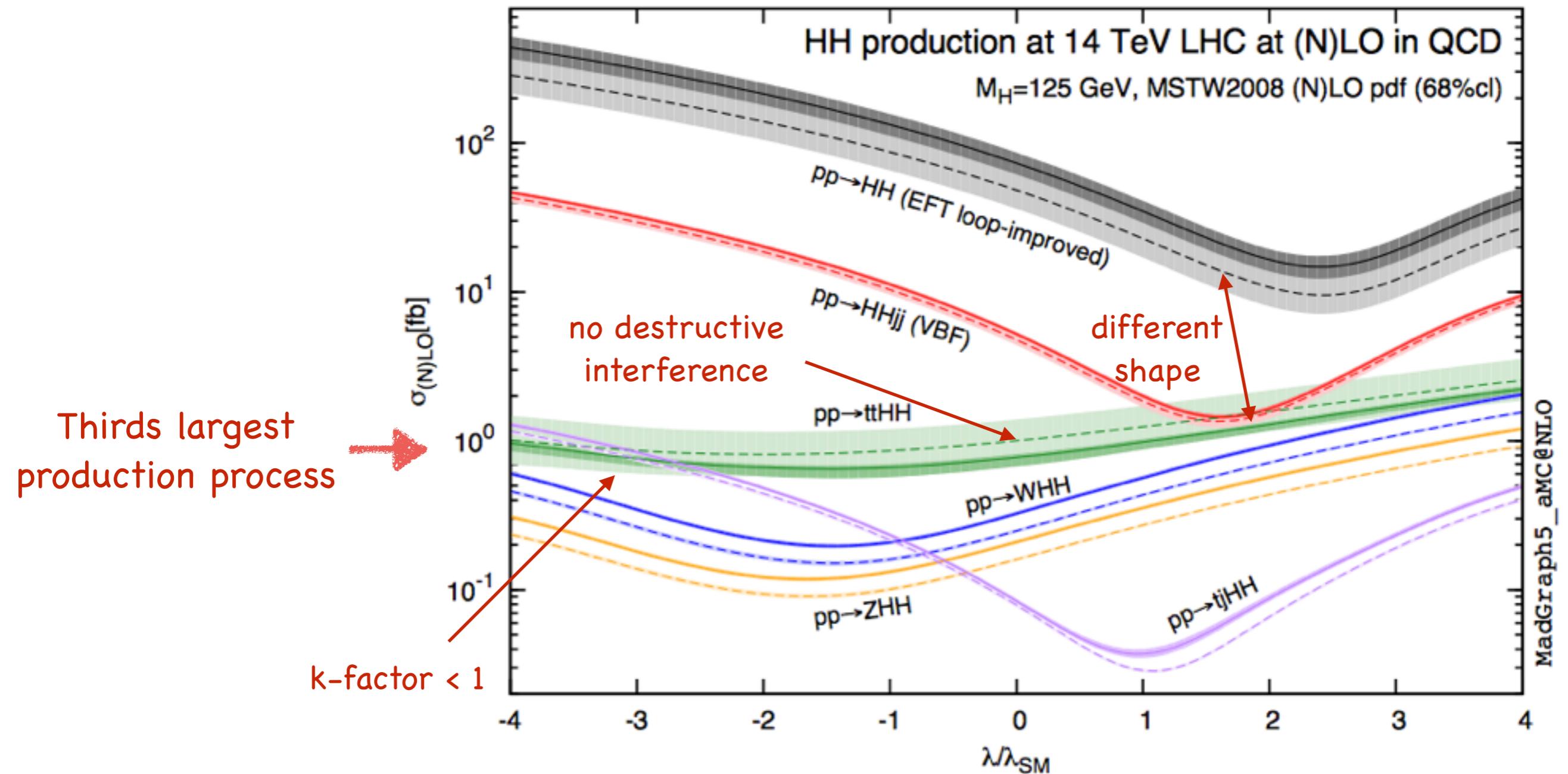
WBF only

GF+WBF

	Signal with $\zeta \times \{g_{WWhh}, g_{ZZhh}\}$			Background	
	$\zeta = 0$	$\zeta = 1$	$\zeta = 2$	$t\bar{t}jj$	Other BG
tau selection cuts	1.353	0.091	0.841	3101.0	57.06
Higgs rec. from taus	1.352	0.091	0.840	683.5	31.92
Higgs rec. from b jets	0.321	0.016	0.207	7.444	0.303
2 tag jets/re-weighting	0.184	0.010	0.126	5.284	0.236
incl. GF after cuts/re-weighting	0.273	0.099	0.214	5.284	0.236

Other HH production channels

[Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Torielli, Vryonidou, Zaro '14]



Higgs selfcoupling in $t\bar{t}HH$

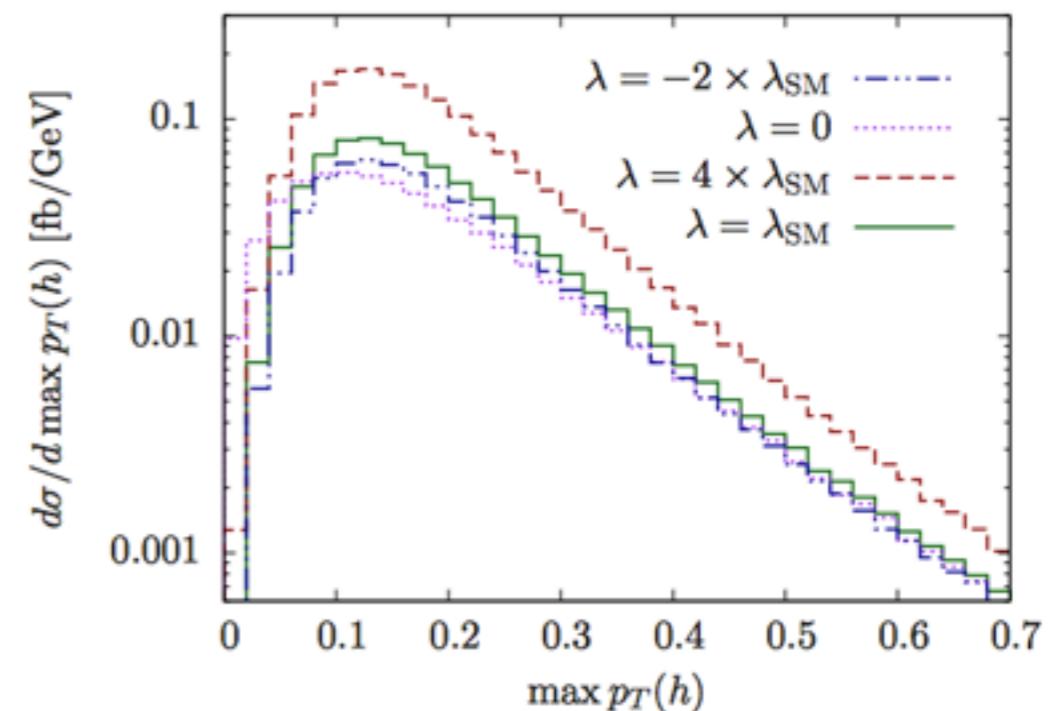
[Englert, Krauss, MS, Thompson]

[Liu, Zhang]

	signal		backgrounds					
	$\xi = 1$	$\xi = 4$	$t\bar{t}bbbb$	$t\bar{t}hbb$	$t\bar{t}hZ$	$t\bar{t}Zbb$	$t\bar{t}ZZ$	$Wbbb$
trigger	0.10	0.23	4.75	1.38	0.64	1.37	1.36×10^{-2}	1.33
jet cuts	7.40×10^{-2}	0.17	1.44	0.76	0.40	0.65	8.74×10^{-3}	7.46×10^{-2}
5 b tags	1.23×10^{-2}	2.83×10^{-2}	4.46×10^{-2}	6.19×10^{-2}	7.24×10^{-3}	4.43×10^{-2}	1.25×10^{-3}	5.35×10^{-4}
$2 \times h \rightarrow b\bar{b}$	7.33×10^{-3}	1.69×10^{-2}	1.59×10^{-2}	2.71×10^{-2}	3.41×10^{-3}	1.56×10^{-2}	4.28×10^{-4}	$< 1 \times 10^{-4}$
lep./had. t	5.04×10^{-3}	1.12×10^{-2}	9.50×10^{-3}	1.66×10^{-2}	2.29×10^{-3}	9.42×10^{-3}	2.69×10^{-4}	$< 1 \times 10^{-4}$
lep. t only	2.33×10^{-3}	5.29×10^{-3}	5.03×10^{-3}	9.36×10^{-3}	1.14×10^{-3}	4.90×10^{-3}	1.39×10^{-4}	$< 1 \times 10^{-4}$
had. t only	2.71×10^{-3}	5.93×10^{-3}	4.47×10^{-3}	7.20×10^{-3}	1.16×10^{-3}	4.44×10^{-3}	1.30×10^{-4}	$< 1 \times 10^{-4}$
6 b tags	2.21×10^{-3}	4.97×10^{-3}	3.80×10^{-3}	8.01×10^{-3}	9.57×10^{-4}	5.10×10^{-3}	1.86×10^{-4}	$< 1 \times 10^{-4}$
$2 \times h \rightarrow b\bar{b}$	1.81×10^{-3}	5.94×10^{-3}	2.01×10^{-3}	5.47×10^{-3}	6.60×10^{-4}	3.28×10^{-3}	1.11×10^{-4}	$< 1 \times 10^{-4}$

- Signal rate too small for inventive reconstruction
- Though Backgrounds for 5+ b-tags already small
- 13-22 signal event with 3000 ifb

$\lambda \lesssim 2.51 \lambda_{SM}$ at 95% CLs.

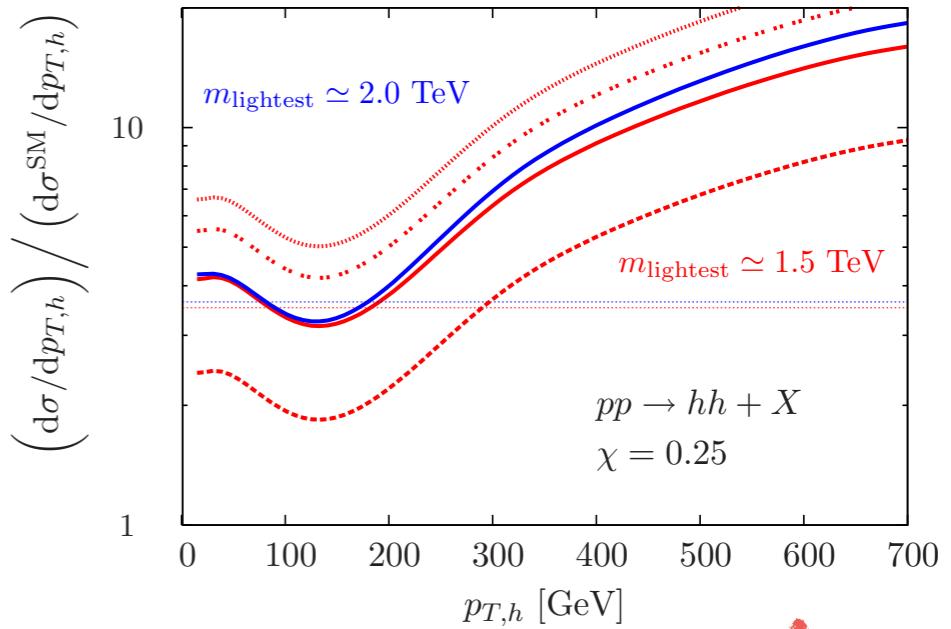
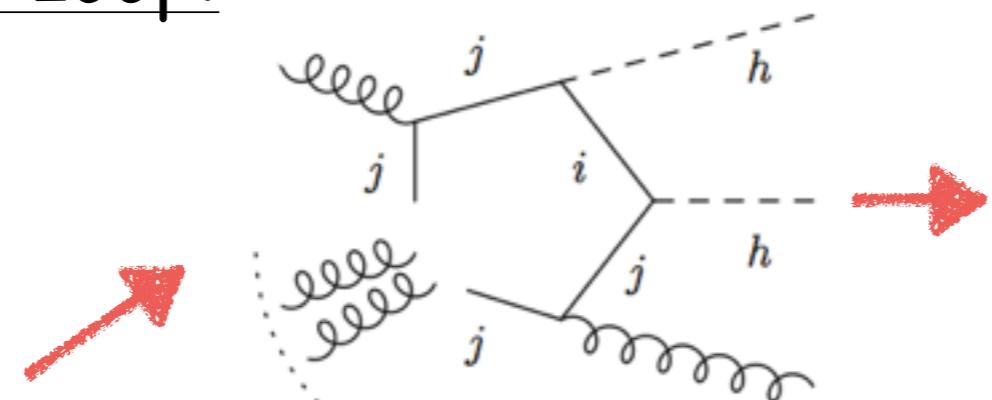


Brief comment on New Physics searches beyond EFT

Increase in CS great help

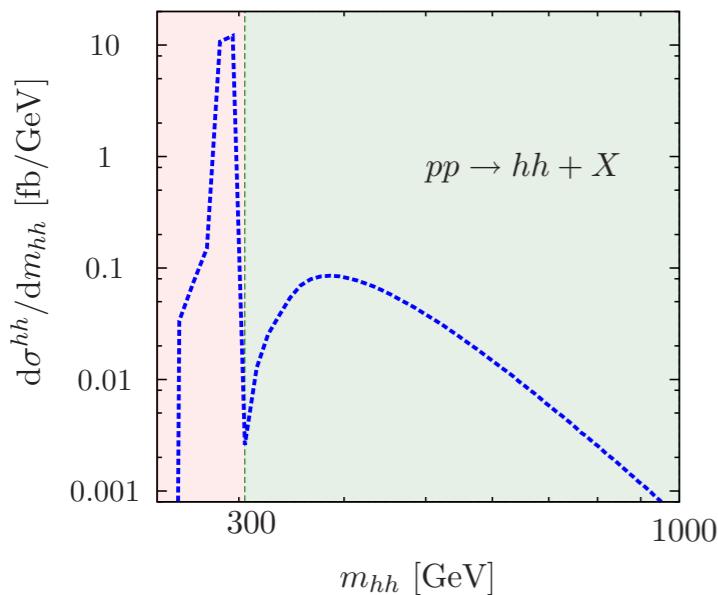
New physics in Loop:

- Composite Higgs
- 4th generation
- Other theories modifying $hht_i t_j$ or $h\bar{t}_i t_j$



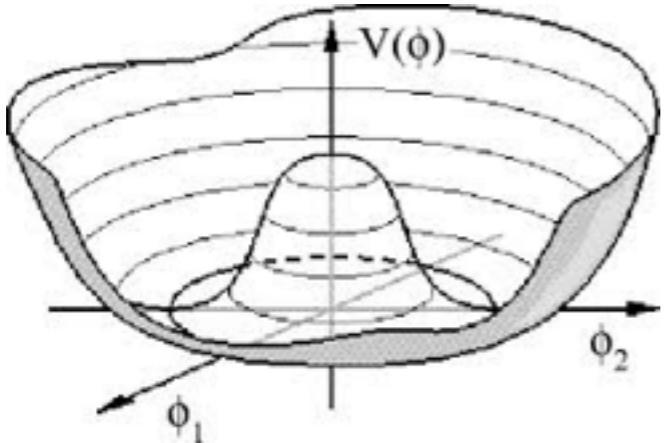
Resonant new physics:

- Very heavy resonance decay \rightarrow extreme boosts
 \rightarrow exploit kinematics

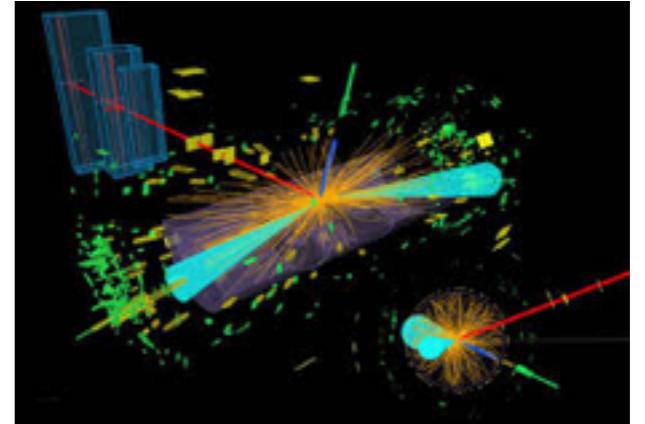


[Gouzevitch et al. 1303.6636]
[Cooper et al 1307.0407]
[No, Ramsey-Musolf 1310.6035]

- However, often in singlet, NHDM, multi-scalar extensions cross section enhancement in small m_{hh} region
 \rightarrow small or no boost \rightarrow exploit rate



Summary



HH final state at core of fundamental questions

- SM:
- Separation of signal and background most limiting factor to measure Higgs selfcoupling at LHC
 - Still reconstruction bigger issue than normalisation of S
 - Still not clear what HL-LHC can do
 - Need FINALLY input from experimentalists
 - However, sensitivity in individual channels expected to be low
Combination of many channels necessary

- BSM:
- Many BSM models enhance HH cross section
 - Working on HH = no-lose situation for experimentalists