Higgs Self-Coupling Measurements at the LHC

Matthew Dolan

IPPP
University of Durham

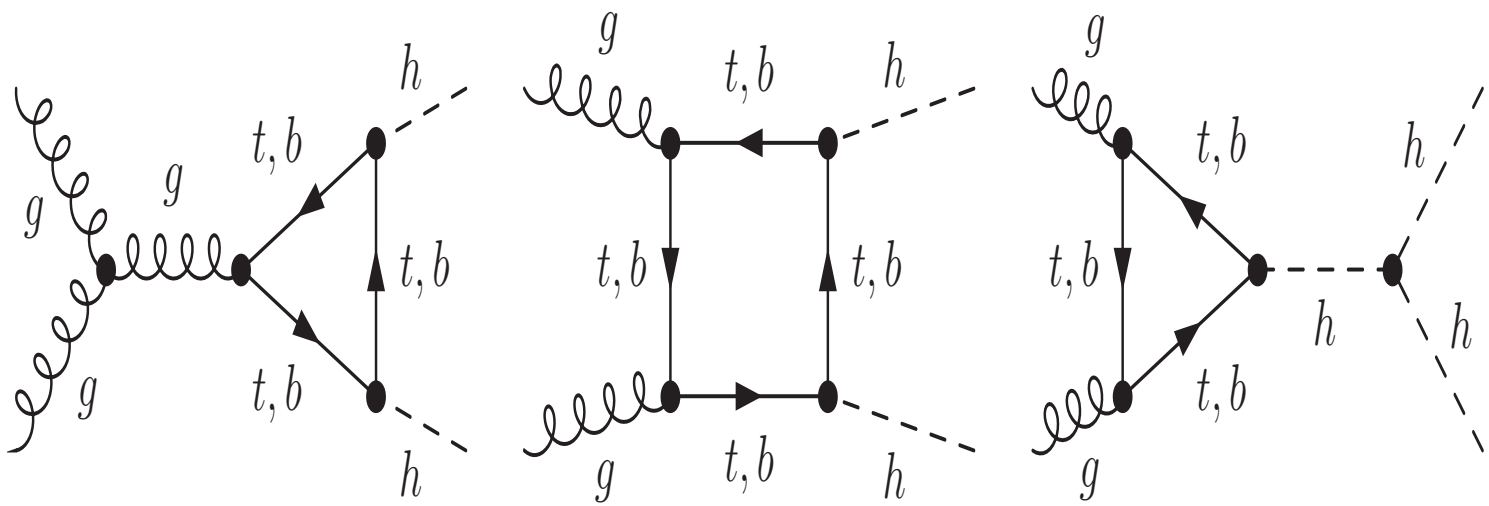
Double Higgs Production

- Can we measure the Higgs self-coupling at the LHC?[1]
- Can we measure double Higgs production at the LHC?

[1] MD,Englert,Spannowsky: 1206.5001

Double Higgs Production

- Can we measure the Higgs self-coupling at the LHC?[2]
- Can we measure double Higgs production at the LHC?



(a) (b) (c)

[2]MD,Englert,Spannowsky: 1206.5001

Higgs pair production

Effective Lagrangian

- Heavy top quark limit

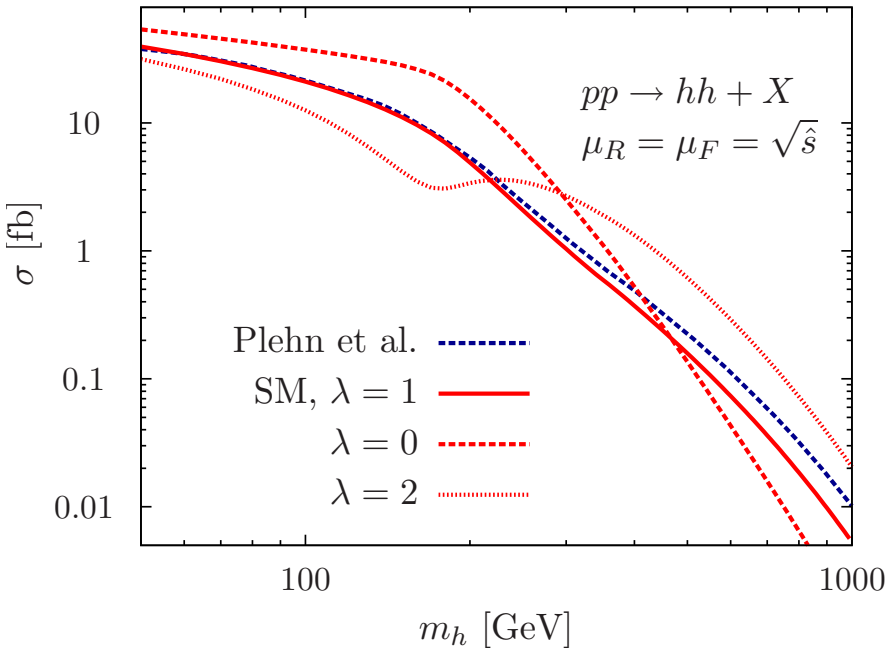
$$\mathcal{L}_{\text{eff}} = \frac{1}{4}\frac{\alpha_s}{3\pi} G^a_{\mu\nu} G^{a\,\mu\nu} \log(1 + h/v)$$

- Expanding gives

$$\mathcal{L} \supset + \frac{1}{4}\frac{\alpha_s}{3\pi v} G^a_{\mu\nu} G^{a\,\mu\nu} h - \frac{1}{4}\frac{\alpha_s}{6\pi v^2} G^a_{\mu\nu} G^{a\,\mu\nu} h^2$$

- Interference effects important!
- Fails to reproduce full kinematics when $Q^2 \gtrsim m_t^2 \implies$ need to implement full matrix element.

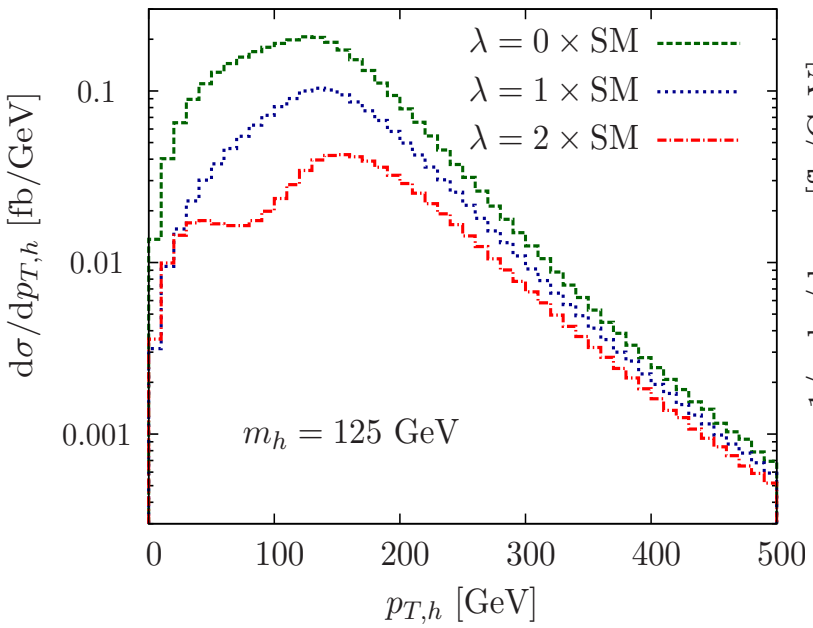
Cross-sections

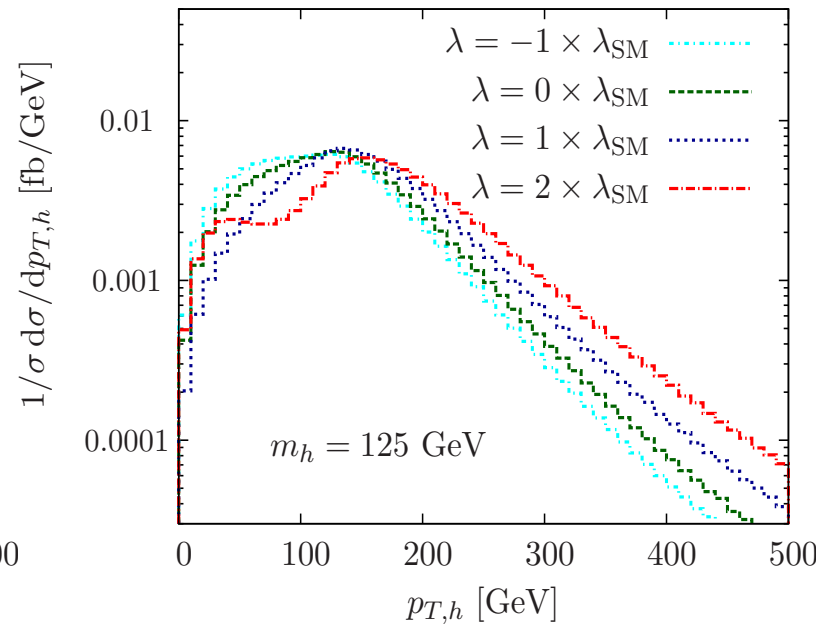


Comments

- Relatively large dependence on λ at $m_h \approx 125$
- Diagram (c) resonantly enhanced when $s \simeq 4m_t^2$
- Ameliorates s-channel suppression.

p_T distributions





- Naturally boosted $p_{T,h} \gtrsim 100$ GeV
- Max sensitivity at $p_{T,h} \sim 100$ GeV
- Triangles decouple at large s

Unboosted and Boosted searches

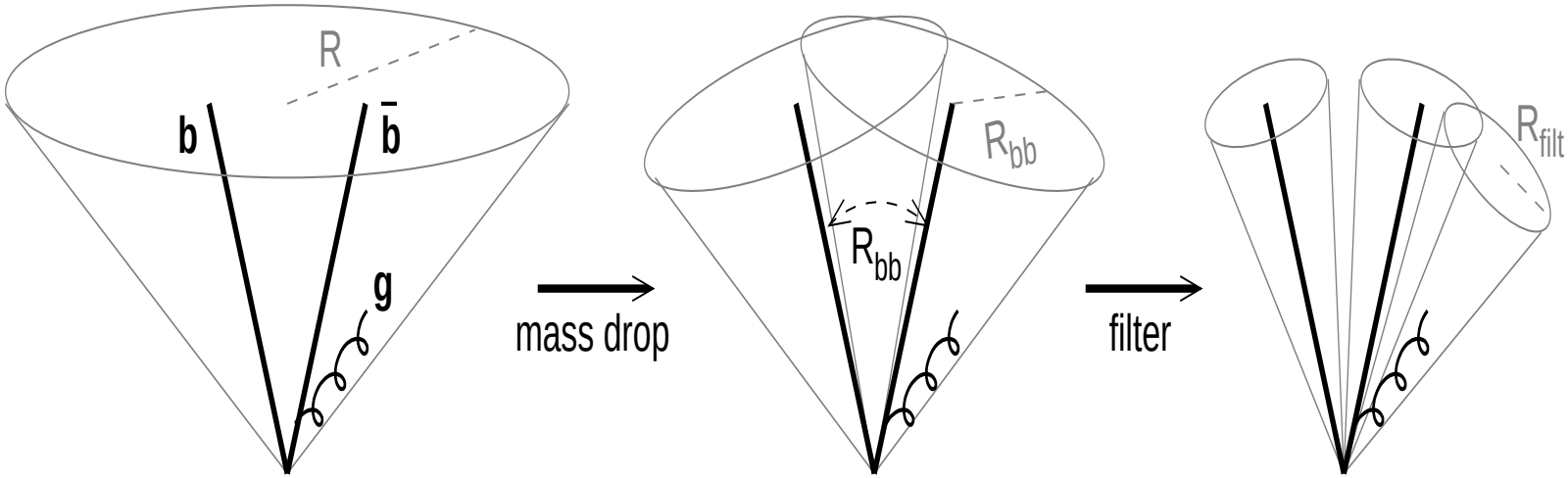
Strategy

- Small cross-section: $\sigma^{NLO}(hh) = 28.4$ fb.
- So focus on largest branching ratios: bb (60%), WW (20%), $\tau\tau$ (6%).
- Unboosted $bbbb$, $bbWW$: Not possible due to $4b$ and $t\bar{t}$ backgrounds.

	$\xi = 1$	$b\bar{b}WW$	ratio to $\xi = 1$
1 isolated lepton	3.76	254897	$1.5 \cdot 10^{-5}$
MET + jet cuts	0.85	66595.7	$1.2 \cdot 10^{-5}$
had-W recon	0.33	38153.3	$0.9 \cdot 10^{-5}$
kinematic Higgs recon	0.017	205.1	$8.3 \cdot 10^{-5}$

Substructure techniques: Quick BDRS

- Look for C/A fatjets with $R \approx 1.5$
- Undo clustering and look for subjets and mass-drop
- Reduce R to R_{filt} to filter away UE



Boosted Kinematics: $(\text{BDRS})^2$

Comments

- Can gain sensitivity in main decay channels.
- But lose sensitivity to modifications of trilinear coupling.

	$\xi = 1$	$b\bar{b}b\bar{b}$ [QCD]	ratio to $\xi = 1$
x-sec pre-cuts	28.42	21165	$1.3 \cdot 10^{-3}$
trigger+no lep	10.21	5581.2	$1.8 \cdot 10^{-3}$
fatjet cuts	8.23	4761.0	$1.7 \cdot 10^{-3}$
1^{st} Higgs rec+2b	1.02	235.22	$4.2 \cdot 10^{-3}$
2^{nd} Higgs rec+2b	0.094	9.72	$9.6 \cdot 10^{-3}$

Boosted regime: $bb\tau\tau$

Consider $bb\tau\tau$

- Two hadronic taus reconstructing m_h
- One fatjet with BDRS cuts.

	$\xi = 1$	$b\bar{b}W^+W^-$	ratio to $\xi = 1$
x-section pre-cuts	28.34	873000	$3.2 \cdot 10^{-5}$
Higgs from τs	1.94	1507.99	$1.9 \cdot 10^{-3}$
fatjet cuts	1.09	223.21	$4.8 \cdot 10^{-3}$
Higgs-rec($m_{b\bar{b}}$)	0.26	9.50	$2.3 \cdot 10^{-2}$
double b-tag	0.095	0.15	0.49

Boosted regime: $bb\tau\tau$

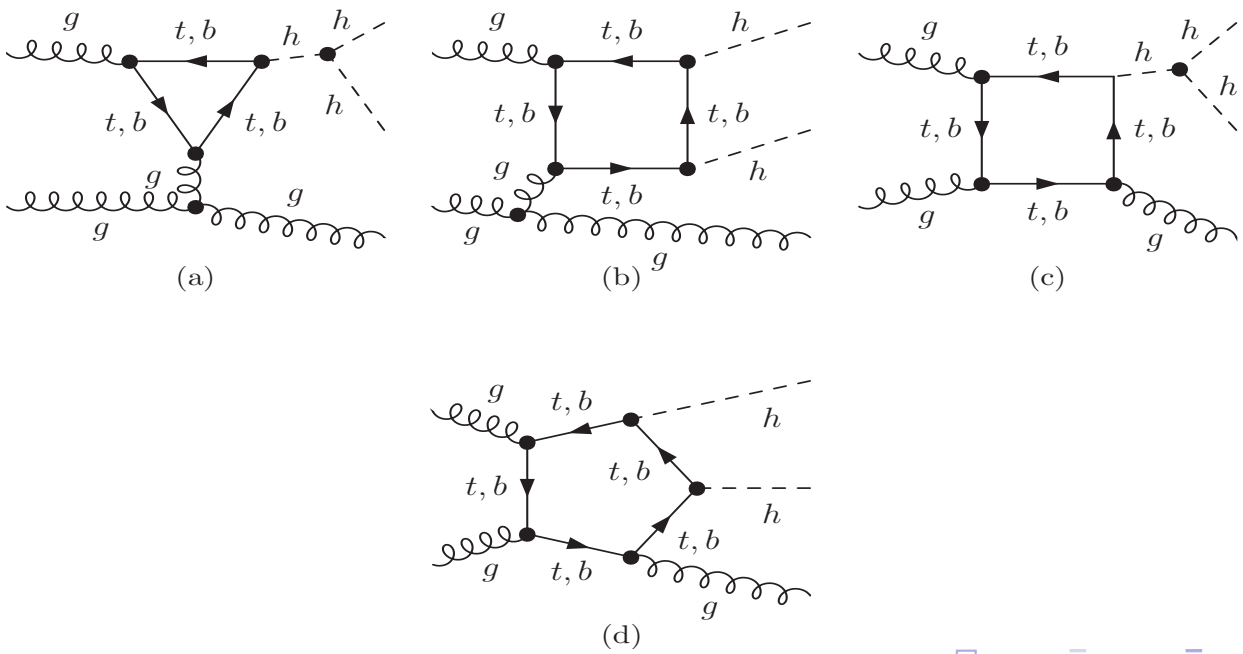
Consider $bb\tau\tau$

- Expect 95 signal events with 1000fb^{-1} in SM.
- Expect 148 events for $\xi = 0$; 53 events for $\xi = 2$.

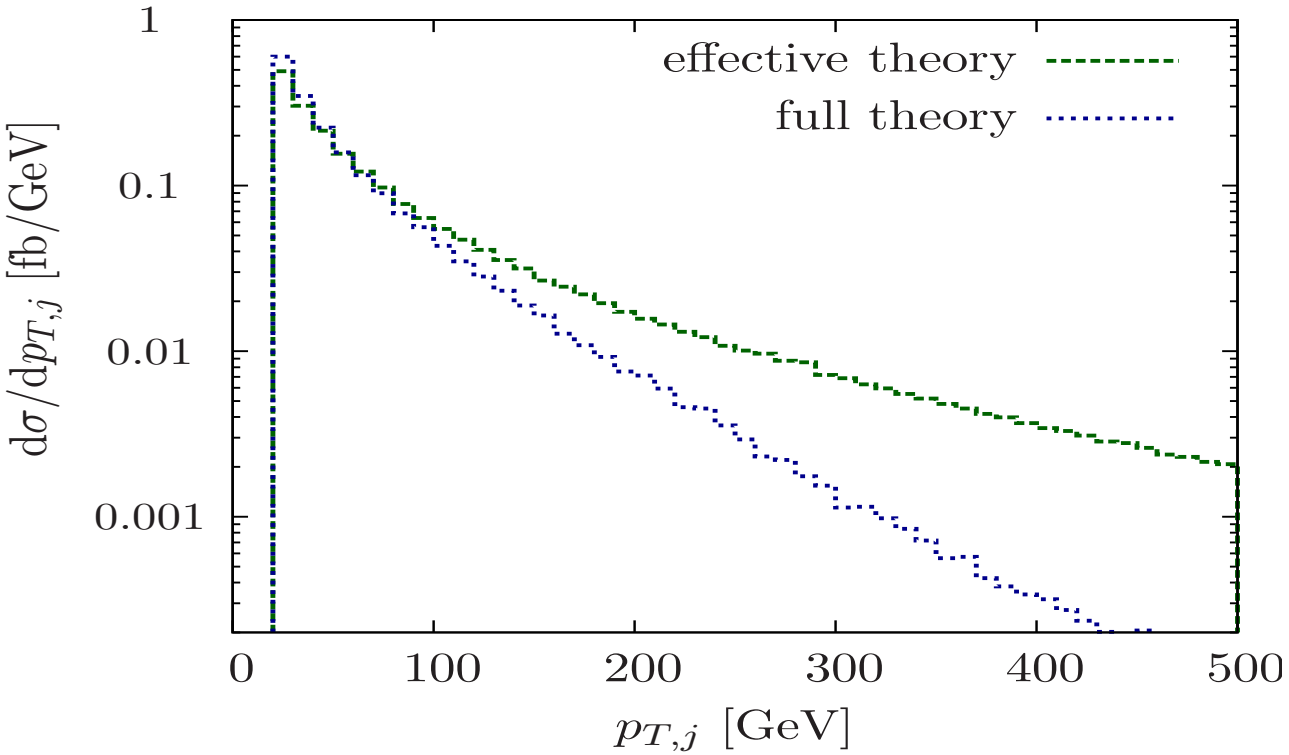
	$\xi = 1$	$b\bar{b}W^+W^-$	ratio to $\xi = 1$
x-section pre-cuts	28.34	873000	$3.2 \cdot 10^{-5}$
Higgs from τs	1.94	1507.99	$1.9 \cdot 10^{-3}$
fatjet cuts	1.09	223.21	$4.8 \cdot 10^{-3}$
Higgs-rec($m_{b\bar{b}}$)	0.26	9.50	$2.3 \cdot 10^{-2}$
double b-tag	0.095	0.15	0.49

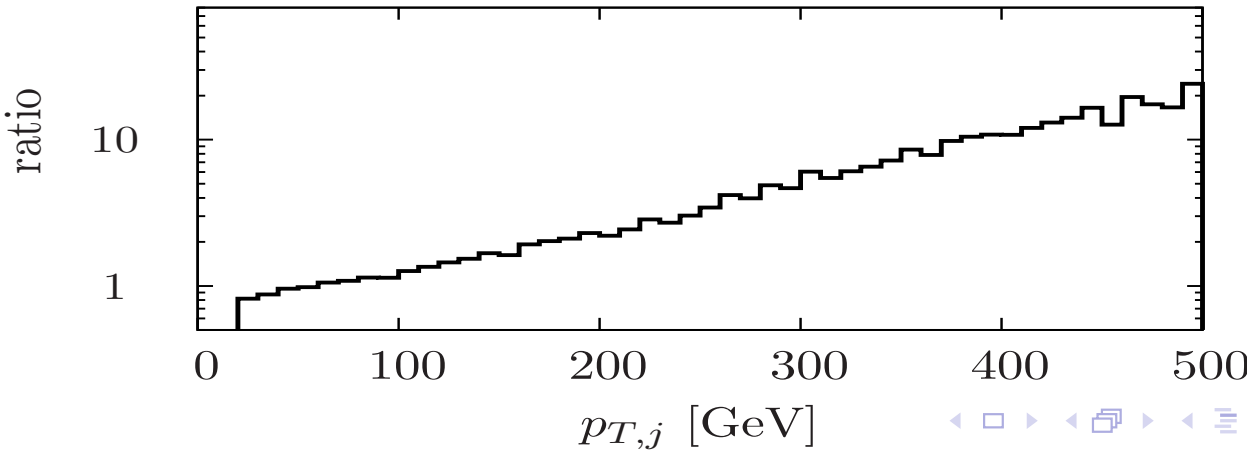
Higgs production with a hard hadronic jet

- Want to decorrelate $p_{T,h}$ with suppression of triangle diagram
- Motivates studying $pp \to hh + j$

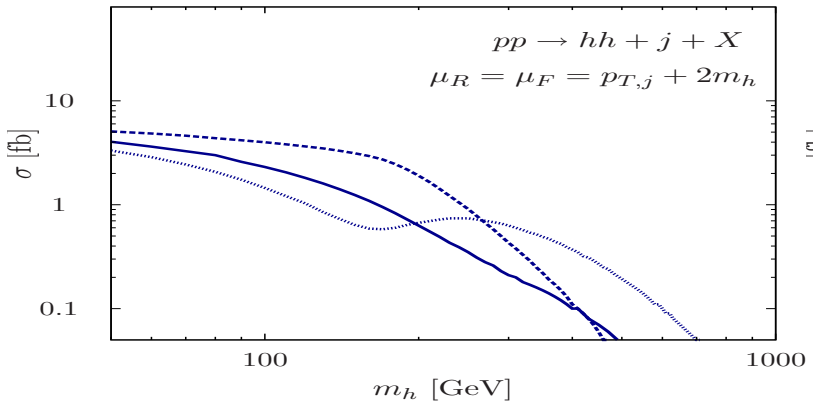


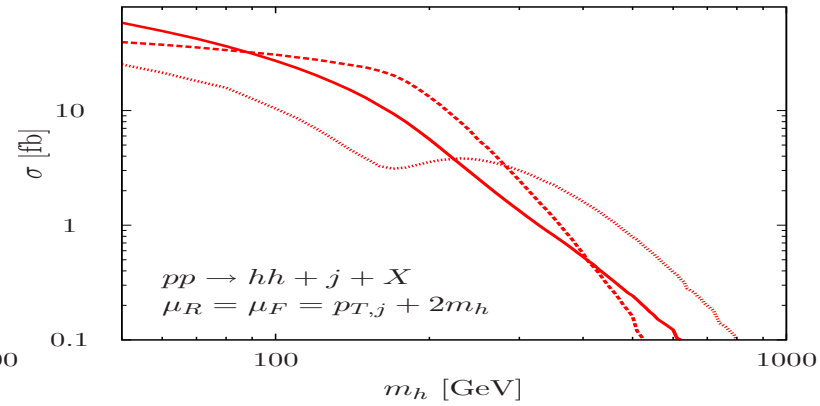
Effective theory vs full theory for *hhj*.

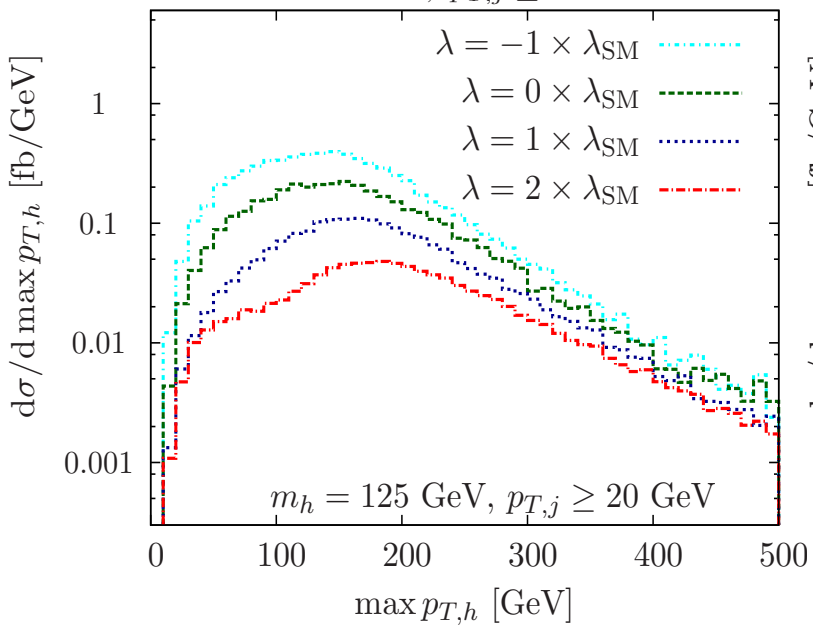


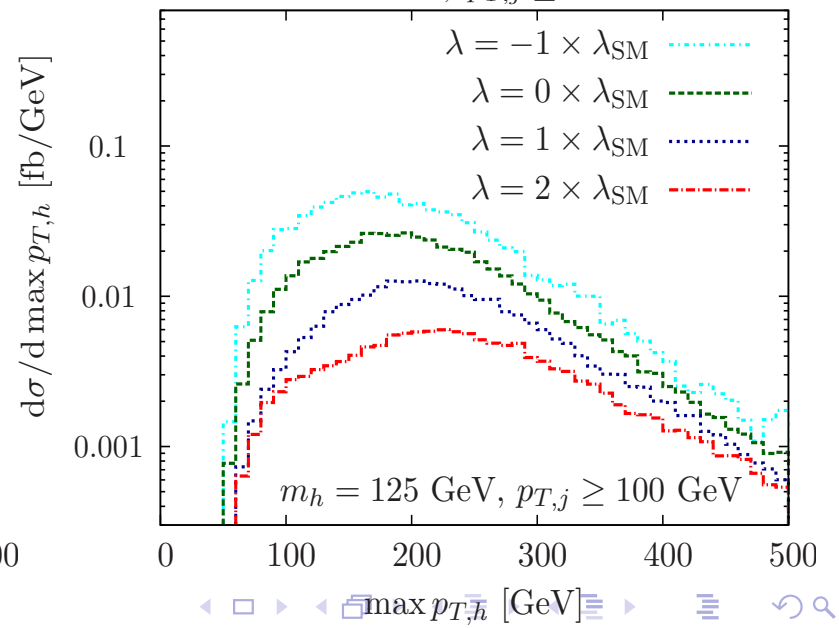


$\sigma(pp \to hh + j)$









Comments on $pp \to hh + j$

- Large dependence on λ: $\Delta\sigma/\sigma_{SM} \simeq 100\%$ for $\lambda \in [0, 2\lambda_{SM}]$
- Compare $\Delta\sigma/\sigma_{SM} \simeq 45\%$ for $pp \to hh$.

- Sensitivity to λ comes from configs with two Higgs bosons close to each other and central.
- Hadronic decay products likely to overlap $\to$ to reconstruct hh system rely on substructure techniques.
- Cost in cross-section: $\sigma(pp \to hh + j) \simeq$ few fb^{-1}

Analysis details

- Two τ-jets with $100 < m_{\tau\tau} < 150$ + 1-fatjet
- Apply Higgs-tagger and require $115 < m_{h-jet} < 135$, $p_{T,h} > 150$ GeV.
- $m_{hh} > 400$ GeV for rejecting $t\bar{t}$ background.

Higgs-tagger

- Modify BDRS similar to 0910.5472[3]

[3] Plehn,Salam,Spannowsky

Modified tagger

- Hadronically more active final state
- Undo clustering, if $m_{j_1} > 0.8 m_j$ discard m_{j_2}, else keep both.
- If $m_{j_i} < 30$ GeV, add to list of substructures, else further decompose.

- Do filtering
- Keep three hardest filtered subjets.
- Call two hardest filtered subjets with mass closest to 125 GeV a Higgs candidate and b-tag

Results for $b\bar{b}\tau\tau j$ and $b\bar{b}b\bar{b}j$

- S/B improves relative to $bb\tau\tau$
- But cross-section very small.
- $b\bar{b}b\bar{b}j$: S/B still $\sim 10^{-3}$

	$\xi = 1$	$b\bar{b}\tau^+\tau^- j$ [ELW]	ratio to $\xi = 1$
x-sec precuts	3.24	1.67	$1.9 \cdot 10^{-2}$
2 τs	0.22	0.94	$4.8 \cdot 10^{-3}$
$m_{\tau\tau} \approx m_h$ + fatjets	0.16	0.150	$5.1 \cdot 10^{-2}$
kin. Higgs rec.	0.04	0.018	0.26
$2b + hh$ inv. mass + $p_{T,j}$ cuts	0.006	0.0022	1.54

Summary

- Trilinear coupling an important measurement of EWSB (and possibly signal of new physics).
- $bbbb$, $bbWW$, $bbbbj$ not promising.
- Prospects interesting in boosted $bb\tau\tau$ final state
- In $pp \to hh + j$: boosted $bb\tau\tau j$ final state.