University of Glasgow

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Higgs Boson Boosted Topologies

Higgs Couplings 2015

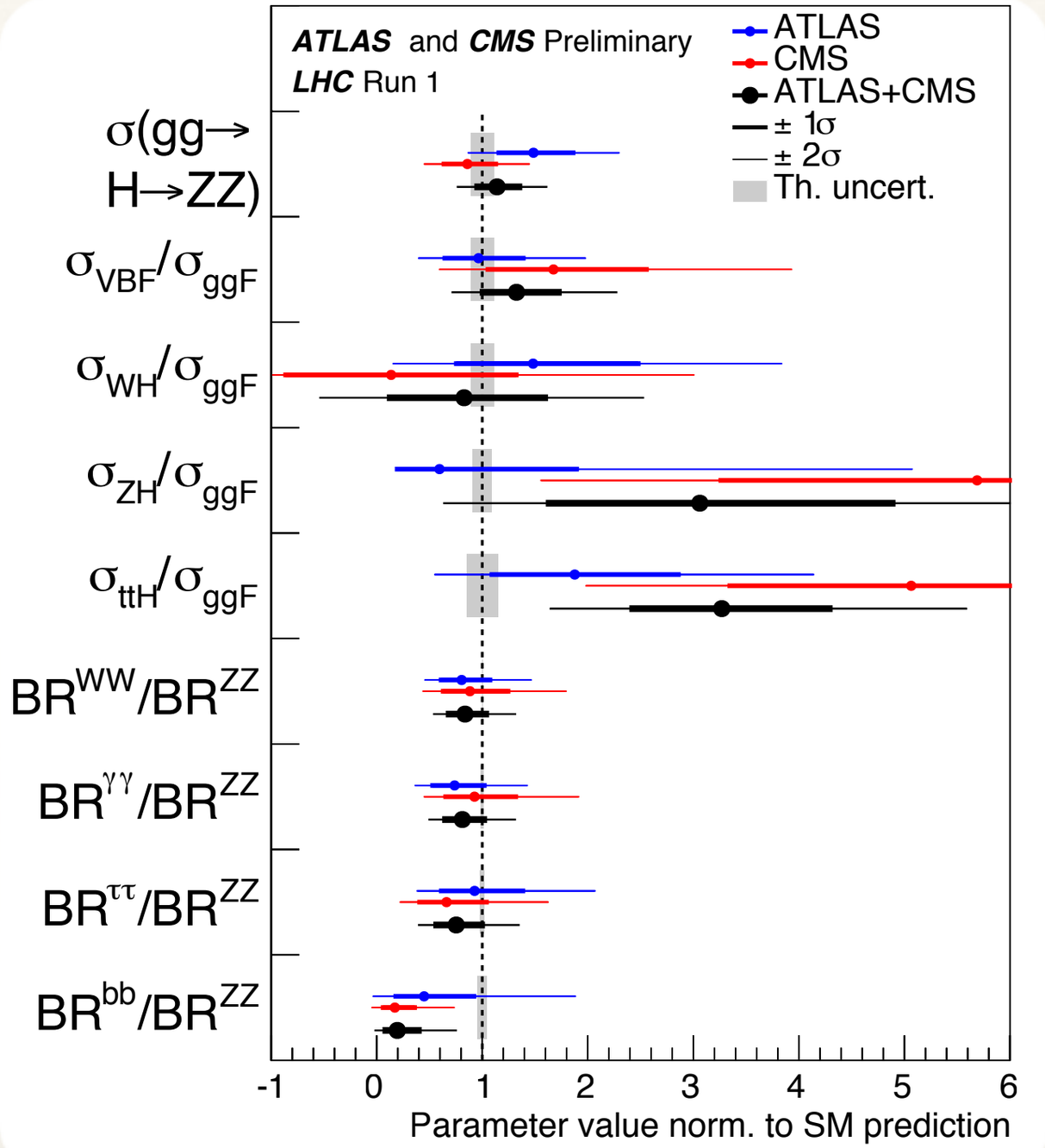
Lumley Castle
October 13, 2015

Boosting the Higgs

- Currently everything looks like the SM within (big statistical) errors
- Most 7+8 TeV measurements are rather inclusive
- Where is new physics?

Effective Field Theory?

concrete models?



[ATLAS-CONF-2015-044]

Boosting the Higgs

BSM physics in the Higgs sector

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

[Buchmüller, Wyler `87] [Hagiwara, Peccei, Zeppenfeld, Hikasa`87]
[Giudice, Grojean, Pomarol, Rattazzi `07]
[Grzadkowski, Iskrzynski, Misiak, Rosiek `10]

Michael Trott, this workshop

concrete models

- (N)MSSM
- Higgs portals
- compositeness
- …

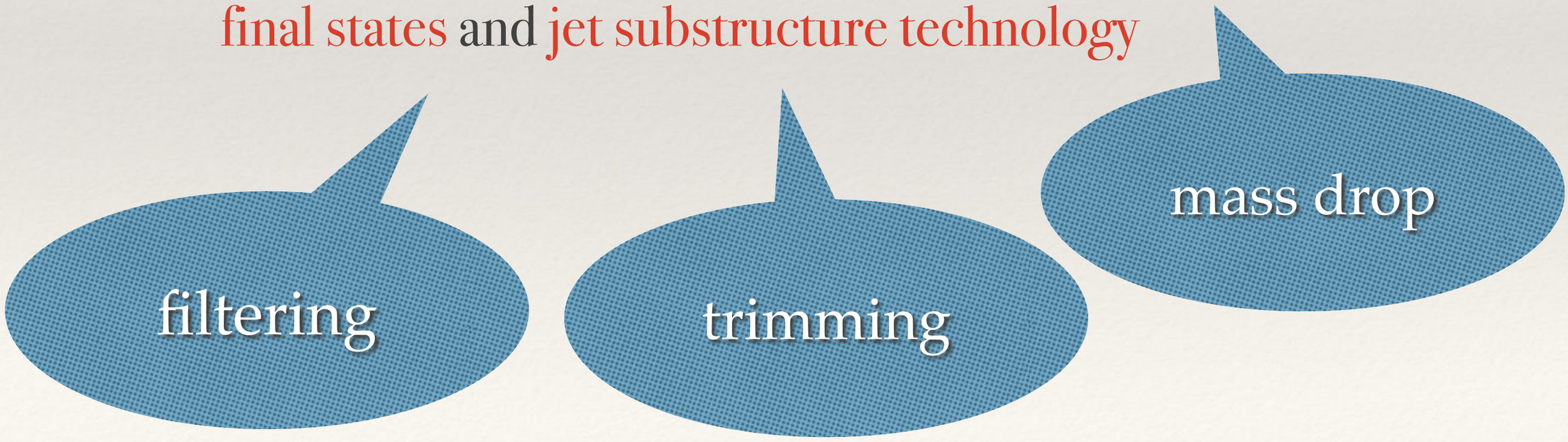
Nausheen Shah, Brian Batell this workshop

Benefits of boosted Higgs final states

- contd. Higgs characterisation (spin & CP measurements)
- EFT
  - access VH production mechanisms
  - break degeneracies in the dim 6 coupling fit
  - access sensitivity in rare final states
- concrete models
  - extended Higgs sector exotics (light and heavy)

Tools & Developments

- 1994: boosted hadronic W's and tops [Seymour `94]
- 2002: boosted hadronic W's from strongly interacting WW systems [YSplitter: Butterworth, Cox, Forshaw `2002]
- 2008: boosted Higgs to bottoms [Butterworth, Davison, Rubin, Salam `08]
  - Higgs discovery in associated production feasible and crucially relies on background rejection based on boosted final states and jet substructure technology



Tools & Developments

- **since then rapid developments within the BOOST community**

- jet "grooming" methods (inverted jet algorithms + extras)
  - filtering [Butterworth, Davison, Rubin, Salam `08]
  - pruning [Ellis, Vermillion, Walsh `09]
  - trimming [Krohn, Thaler, Wang `10]

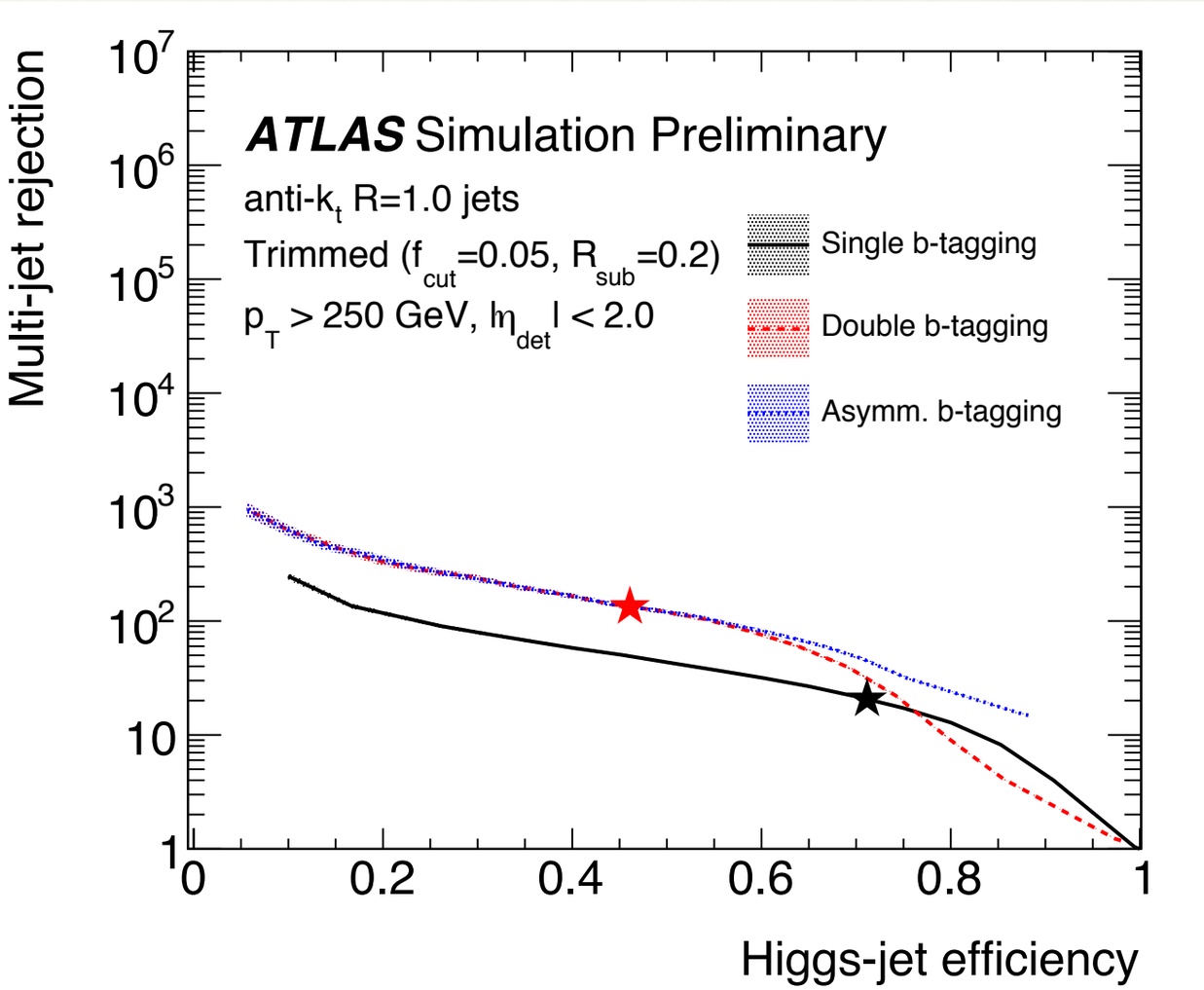
} capture complementary complementary information [Soper, Spannowsky `10]

- subjet techniques well understood in QCD
  - resummed calcuations for filtering, trimming, pruning
  - QCD-improved definitions of (soft) mass drop

[Dasgupta, Fregoso, Marzani, Salam `13]

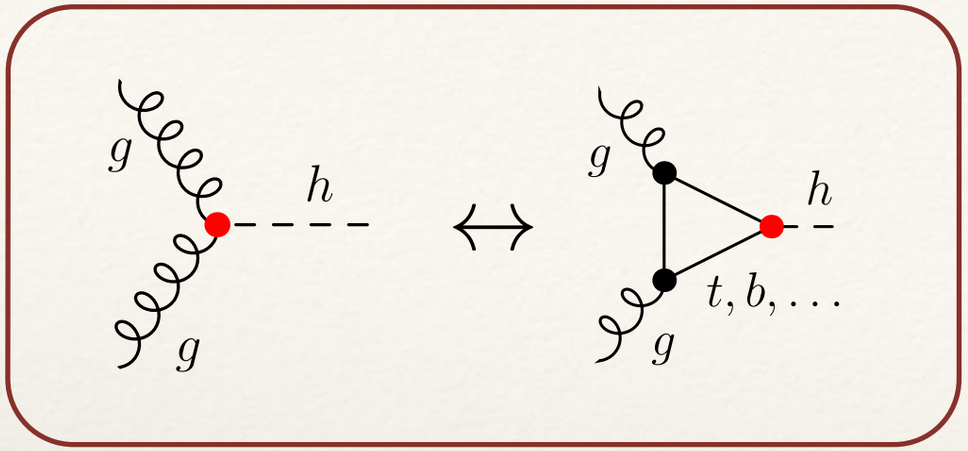
Tools & Developments

- **since then rapid developments within the BOOST community**
- plethora of jet substructure techniques on the market
  - BDRS (with modifications)
    [ATLAS-PHYS-PUB-2015-035]
  - template overlap method
    [Almeida et al. `08]
  - shower/event deconstruction
    [Soper, Spannowsky `11, `14]
  - QJets
    [Ellis et al. `12]
  - multivariate techniques,
    matrix element method....

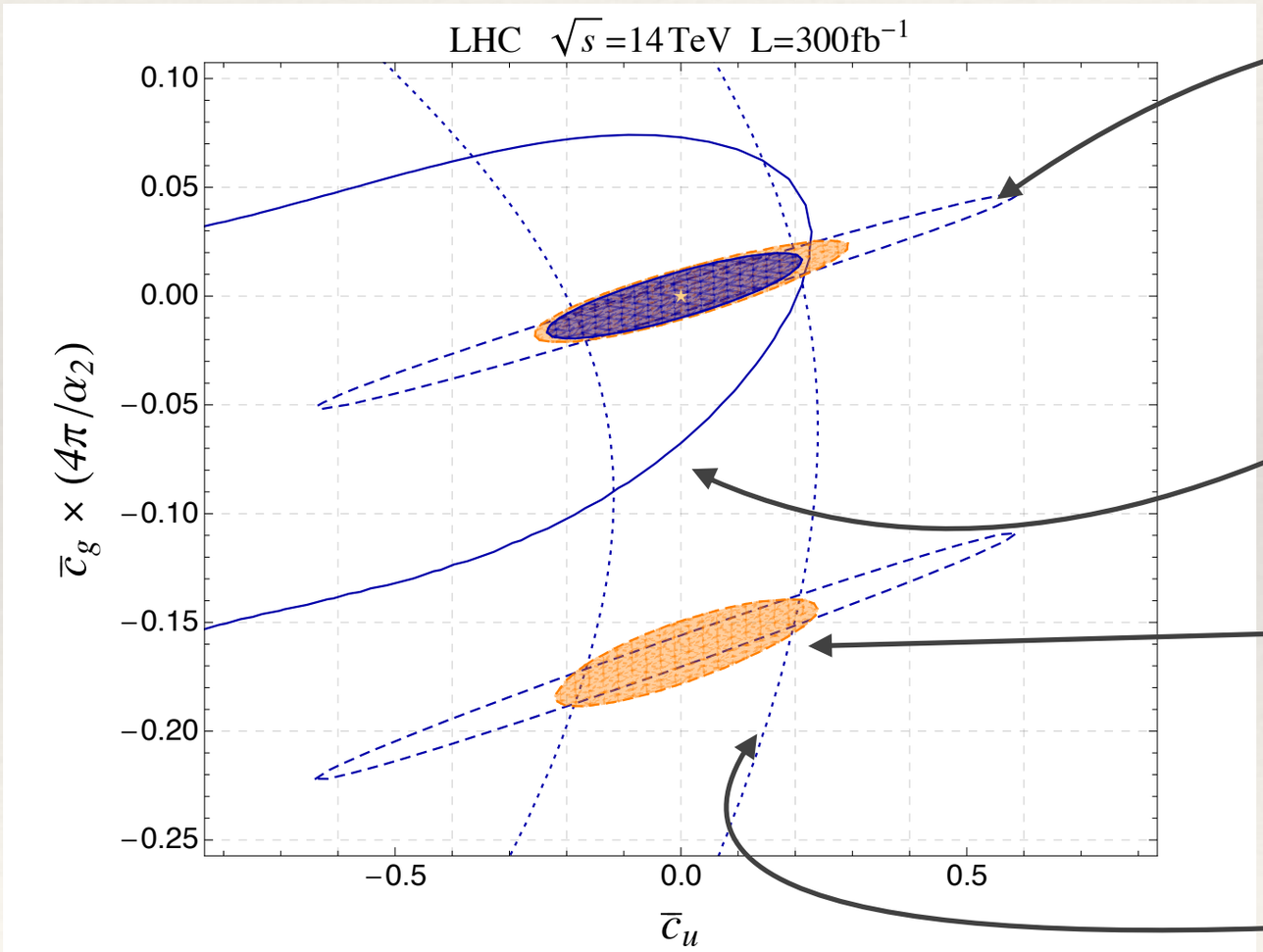


[ATL-PHYS-PUB–2015-035]

Boosted Higgs EFT



☛ Standard searches leave degeneracies in the Higgs coupling fit



all couplings without ttH

double Higgs production

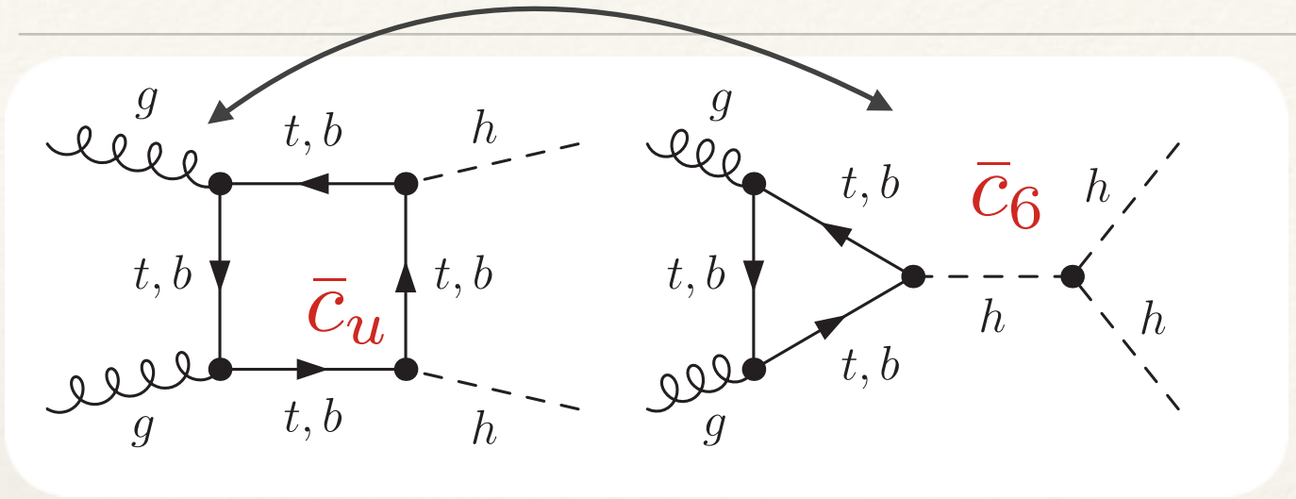
all couplings including ttH

ttH

[Azatov, Contino, Panico, Son `15]

HH: a case for boosted Higgs

destructive interference



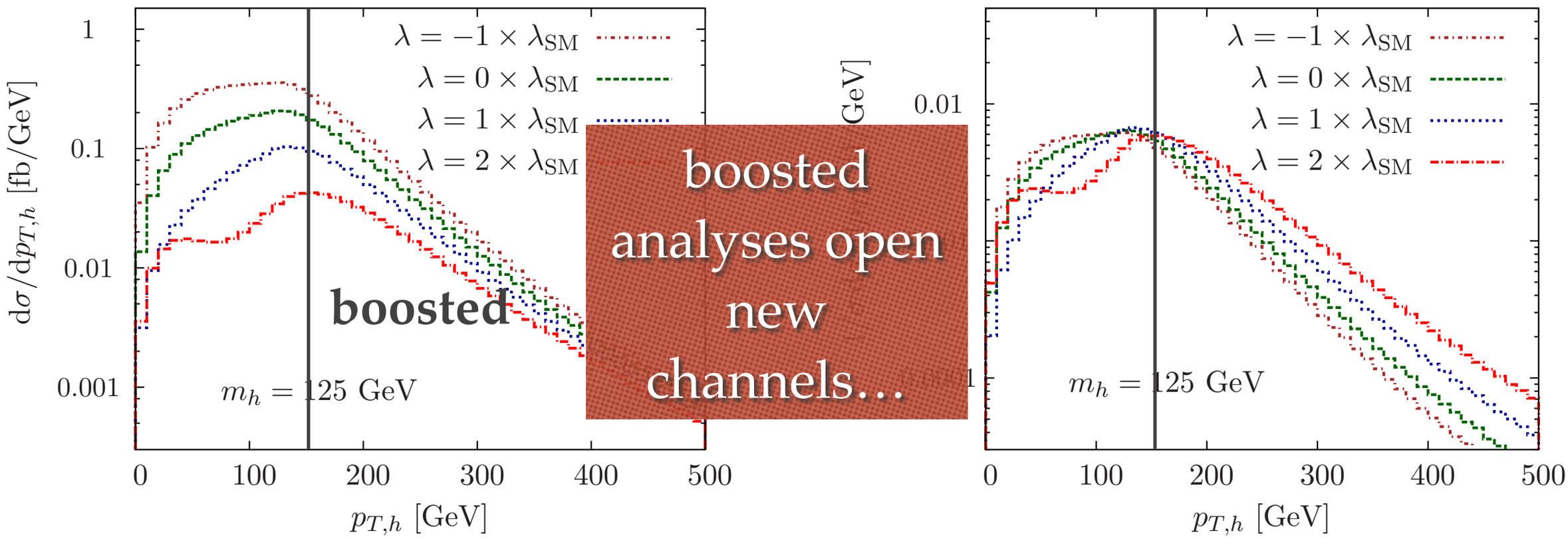
$b\bar{b}\gamma\gamma$: 1.3σ at 3/ab, limited statistics

[ATLAS PHYS-PUB 2014-19]

[Glover, van der Bij `87]
[Plehn, Spira, Zerwas `96]
[Djouadi, Killian, Mühlleitner, Zerwas `99]

[Plehn, Baur, Rainwater `03]
[Dolan, CE, Spannowsky `12]
[Papaefstathiou, Yang, Zurita `12]
[Barr, Dolan, CE, Spannowsky `13]
.....

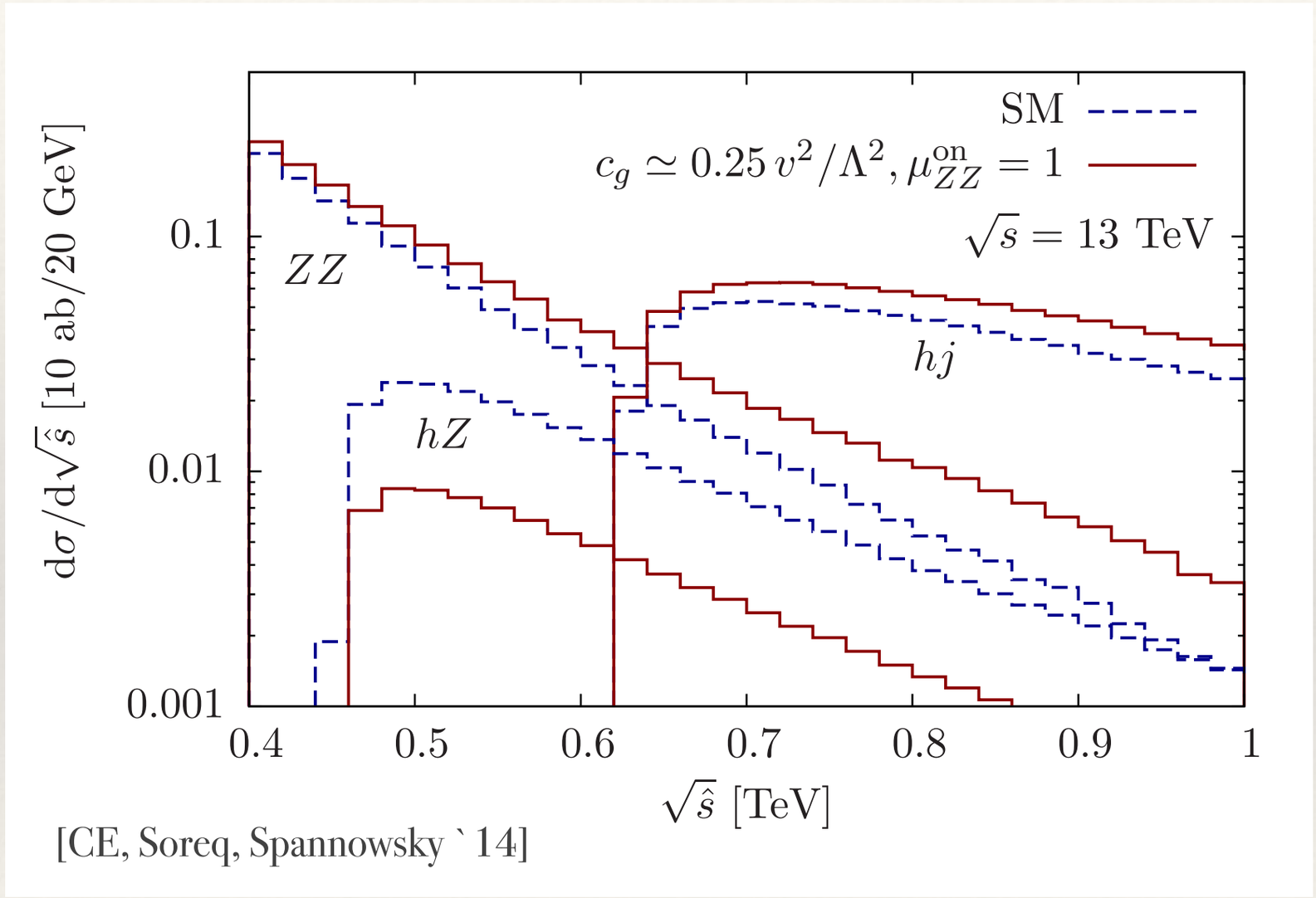
Michael Spannowsky, this workshop



overconsrtaining the Higgs system

- Can replace HH with off-shell and H+jet measurements to break degeneracies

[Grojean et al `13] [Schlaffer et al `14] [Buschmann et al `14, `14]



[CE, Soreq, Spannowsky `14]

typical S/B thresholds motivate the boosted regime, but do not forget background systematics ….

Litmus test in Higgs physics

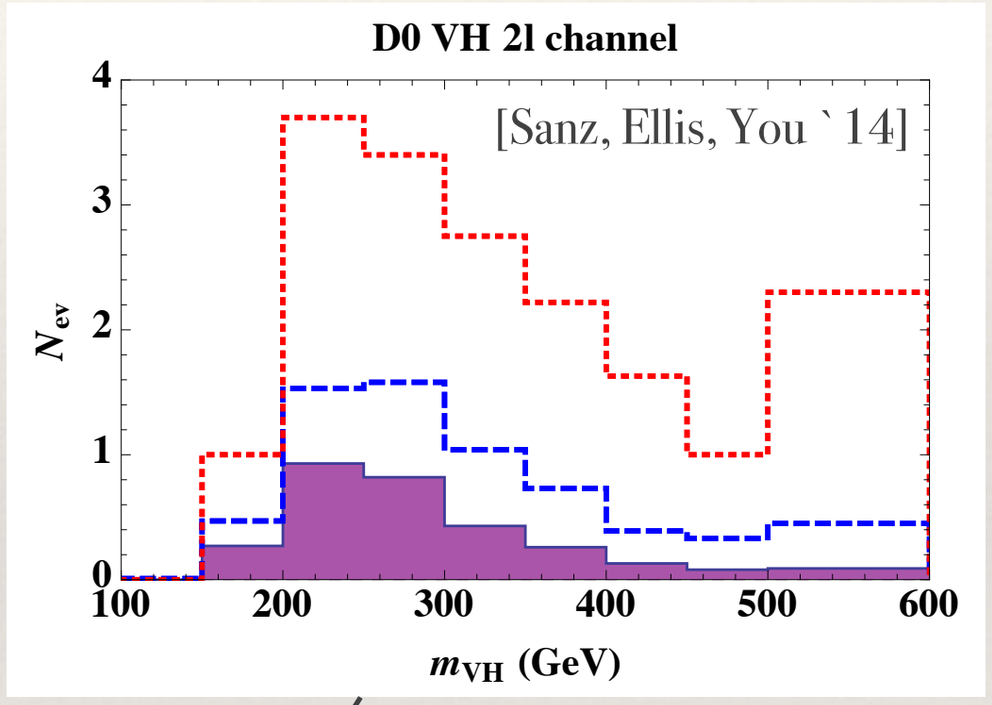
- Higgs discovery in VH, H >bottoms feasible and relies on background rejection based on boosted final states and subject technology

[Butterworth, Davison, Rubin, Salam `08]

$S/\sqrt{B}$, $L = 3000(150)$ fb^{-1}

$p_T(W)$ [GeV]	Resolved	Substructure	Unique Substructure
$200 - 400$	20.6 (4.6)	20.8 (4.7)	4.7 (1.1)
$400 - 600$	9.2 (2.1)	8.9 (2.0)	1.6 (0.4)
> 600	2.7 (0.6)	4.1 (0.9)	3.4 (0.8)
> 200	22.7 (5.1)	23.0 (5.1)	5.9 (1.3)

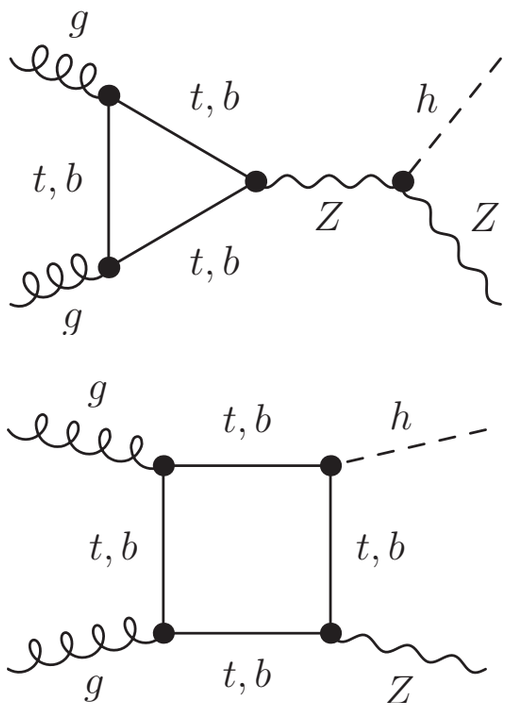
[Butterworth, Ochoa, Scanlon `15]

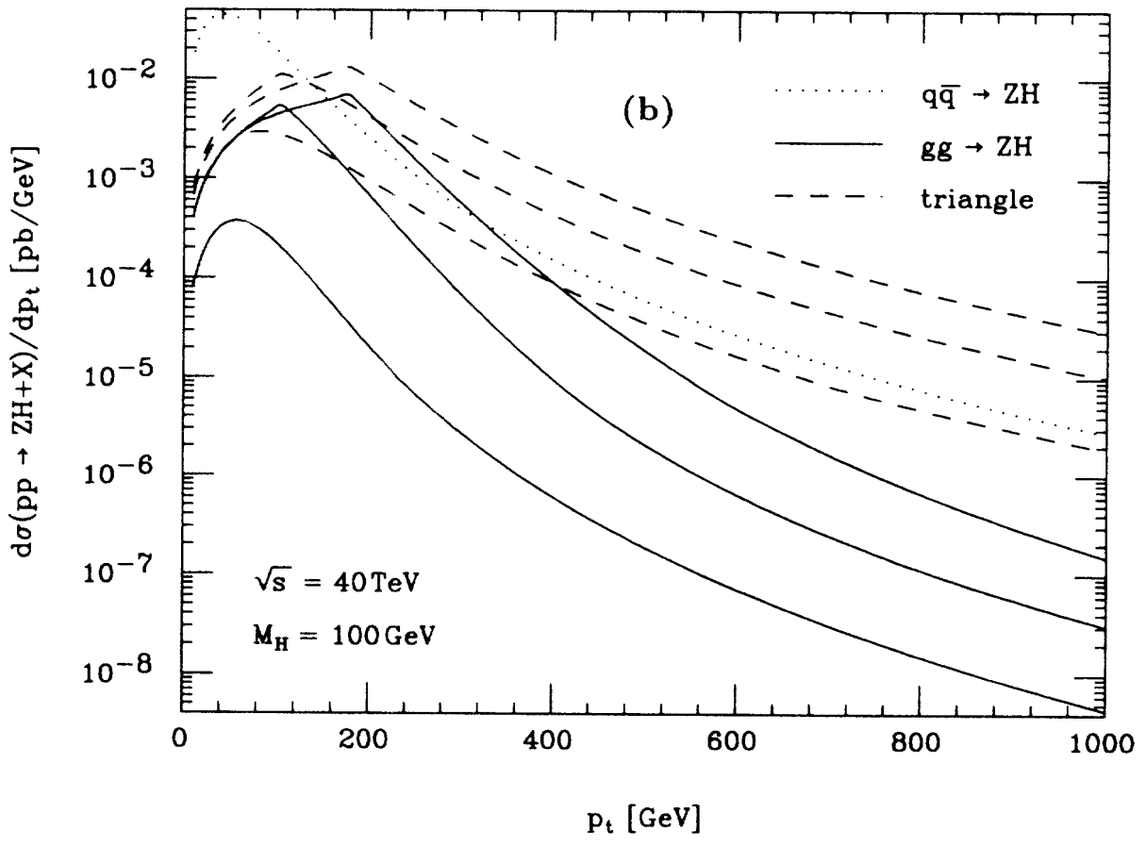


Boosted Higgs searches remains superb Higgs BSM spectroscopy tools

Thresholds = boost

- thresholds can render subdominant contributions relevant at high luminosity & energy
- interference of contributions non-negligible and important for BSM





[Kniehl `90] [Matsuura, Hamberg, van Neerven `90]

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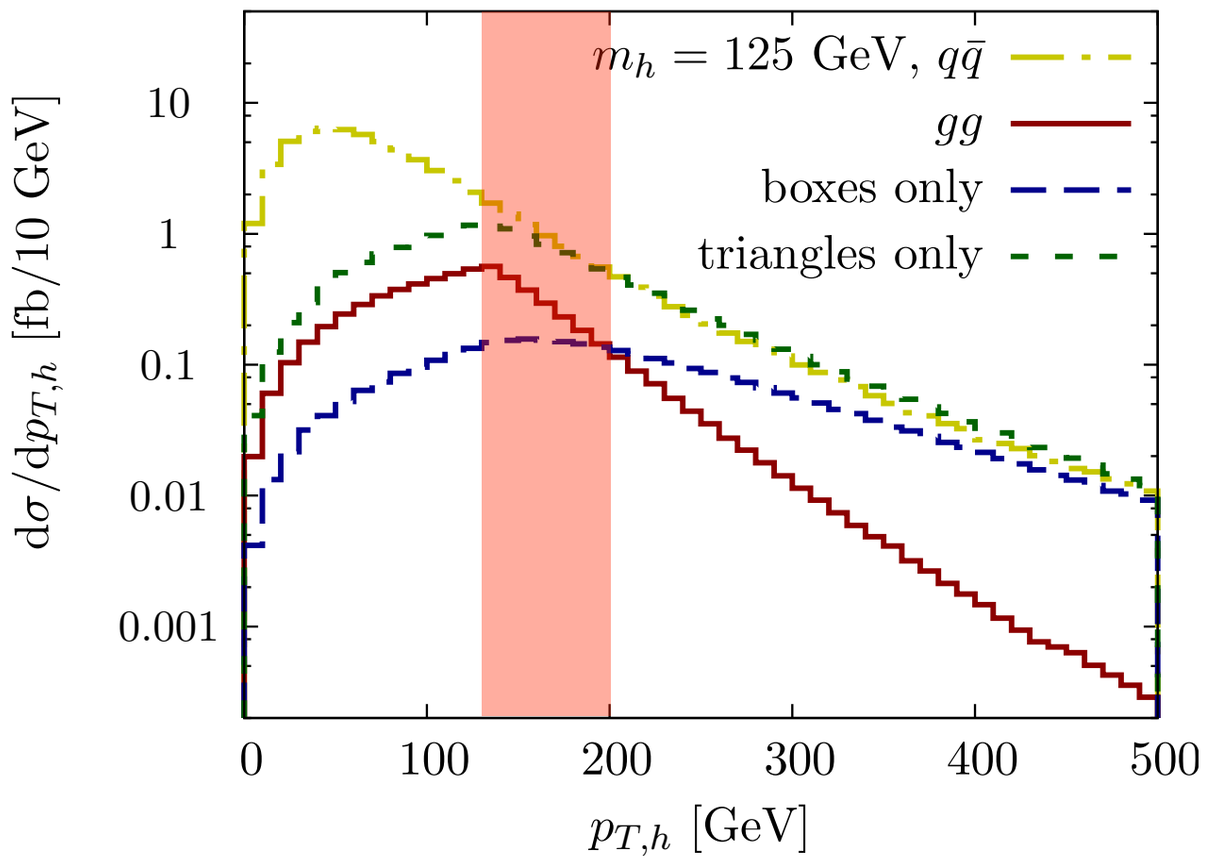
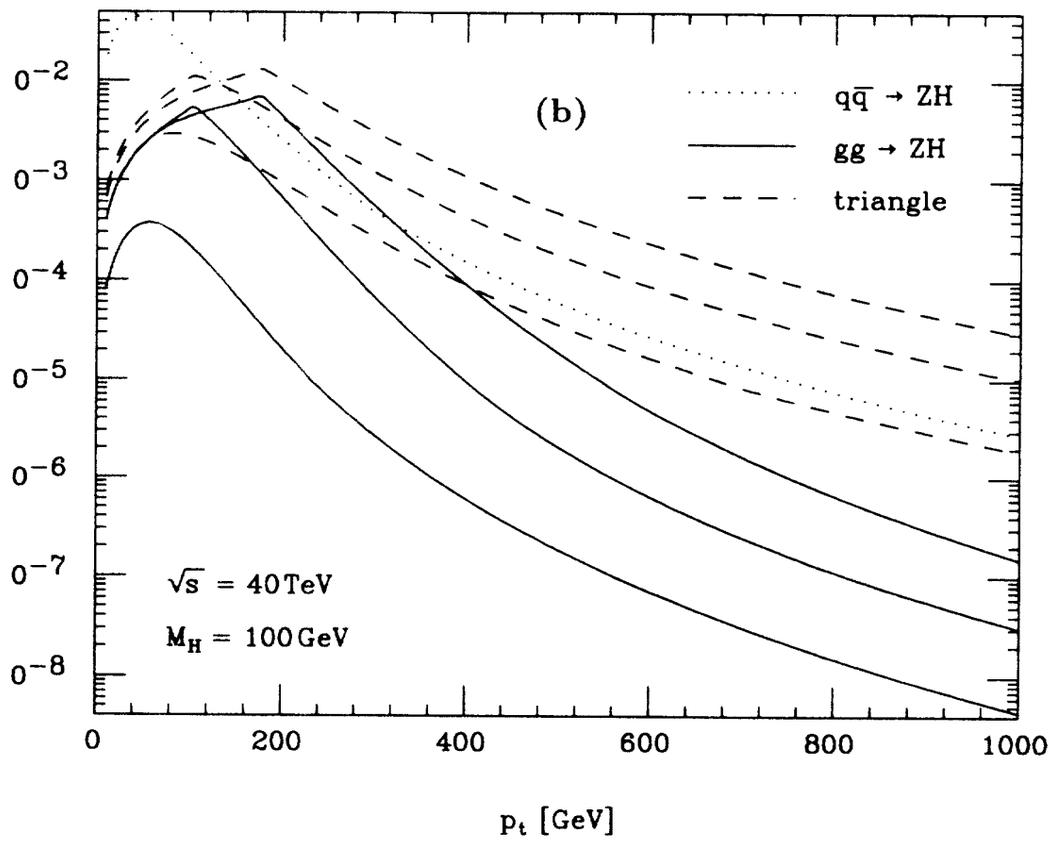


[CE, McCullough, Spannowsky `13]



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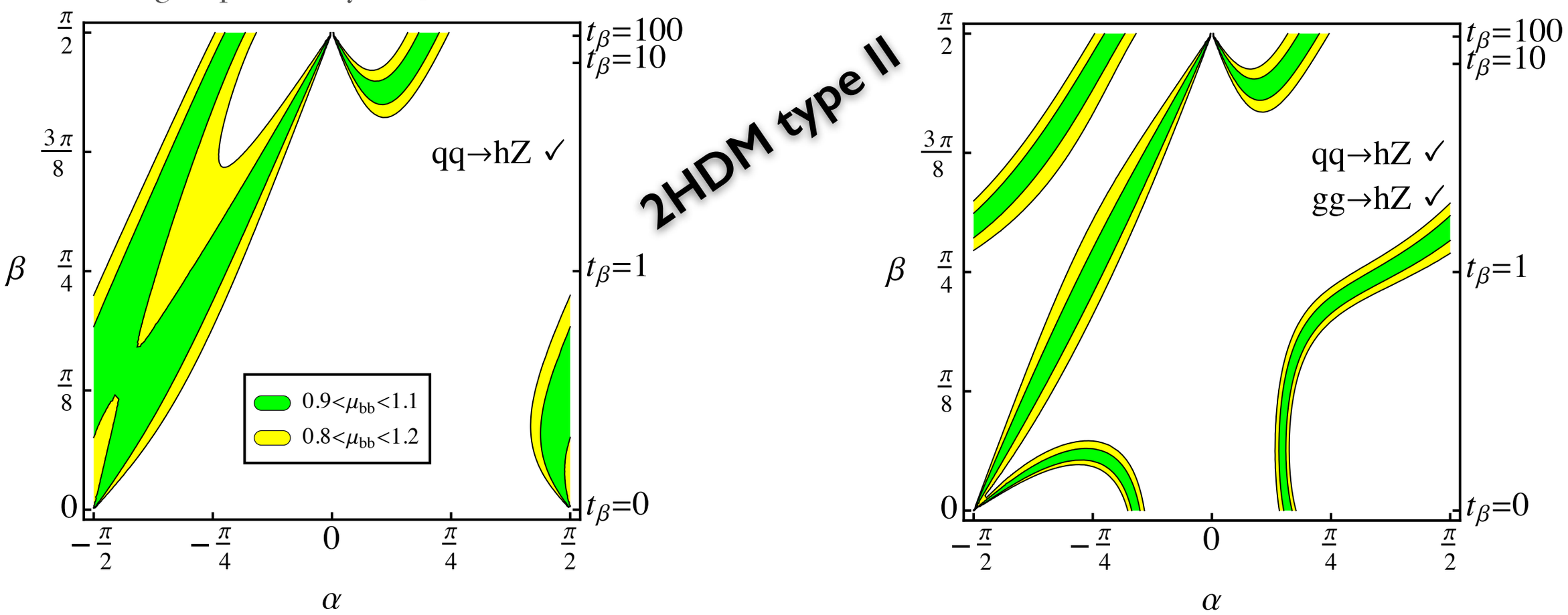


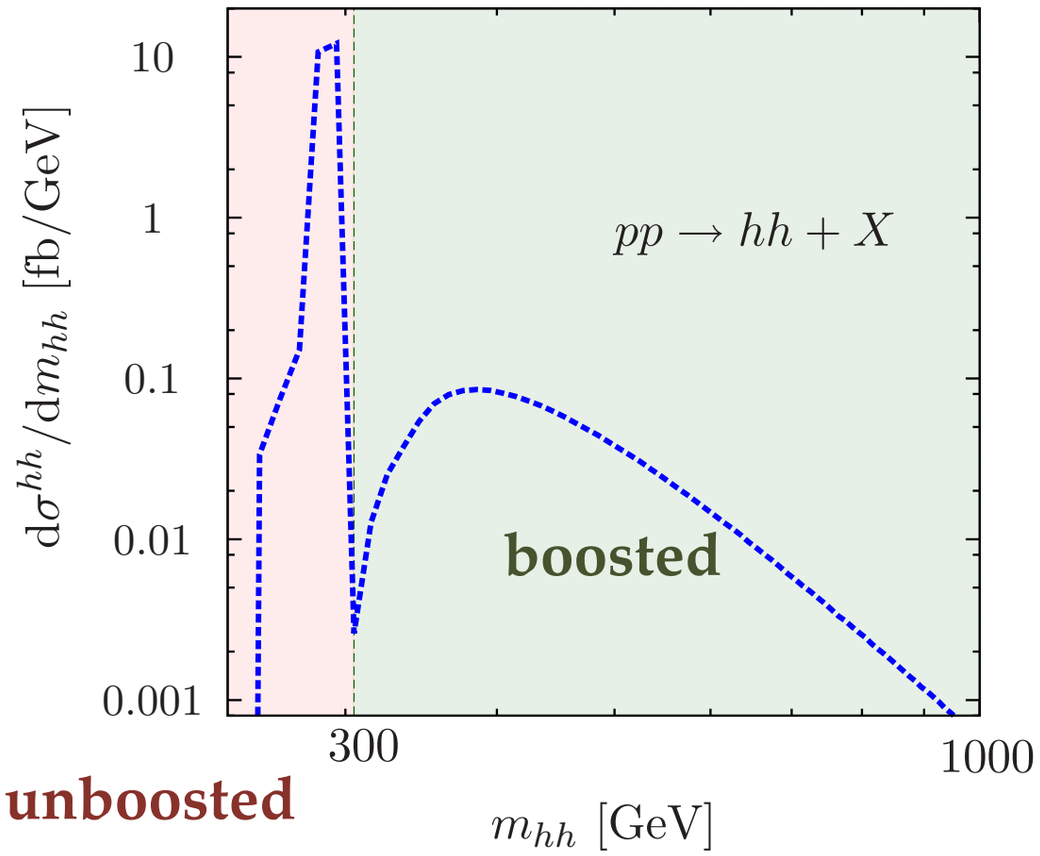
exotics: NMSSM

[King, Mühlleitner, Nevzorv, Walz `14]

B.3 (Point ID 210)	Scenario		
M_h, M_{H_s}, M_H	124.1 GeV	184.3 GeV	463.1 GeV
M_{A_s}, M_A	133.4 GeV	457.2 GeV	

B.3 (Point ID 210)	Signal Rates
$\sigma(ggH_s)$	390.38 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to b\bar{b})$	160.37 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to \tau\tau)$	18.46 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to WW)$	176.63 fb
$\sigma(ggH_s)\mathrm{BR}(H_s \to ZZ)$	29.00 fb
$\sigma(ggH)$	1.326 pb
$\sigma(ggH)\mathrm{BR}(H \to tt)$	684.96 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s)$	184.85 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to bb + bb)$	50.46 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to bb + \tau\tau)$	11.08 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to \tau\tau + \tau\tau)$	0.61 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to bb + \gamma\gamma)$	0.24 fb

typical Higgs pair spectrum with resonances
(mini-split SUSY, portals, …)



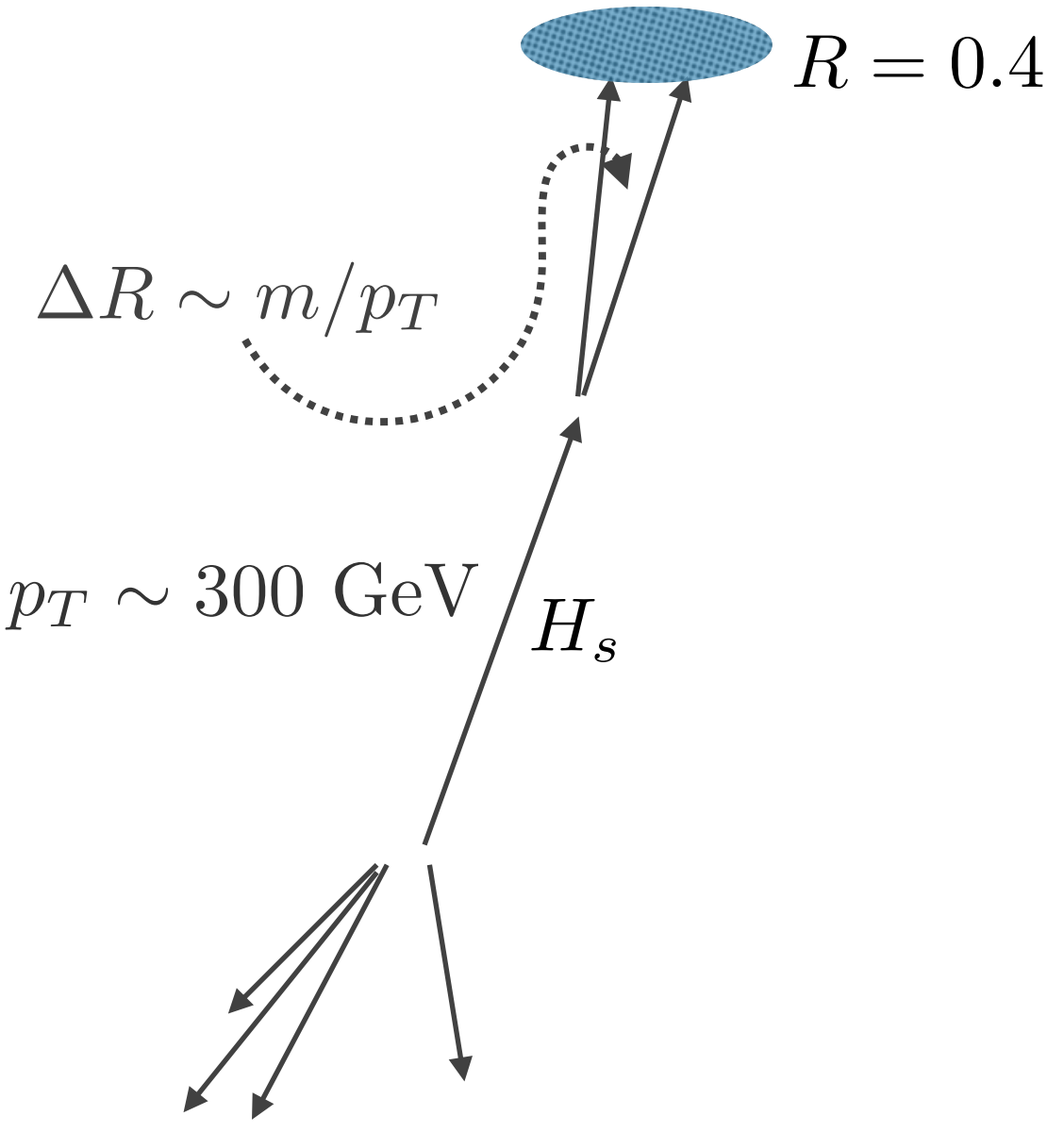
[Dolan, CE, Spannowsky `12]

- correlation of on- and off-shell regions can provide complementary yet highly non-linear information to constrain model parameters
- strong case for boosted Higgs final states, validation of new substructure techniques necessary

[King, Mühlleitner, Nevzorv, Walz `14]

exotics: NMSSM

ditaus decay leptonically 12.25%,
ditaus decay semi-leptonically 45.5%,
ditaus decay hadronically 42.25%.



exotics reconstruction, e.g. ditau jets, double b jets, ... **jet substructure**

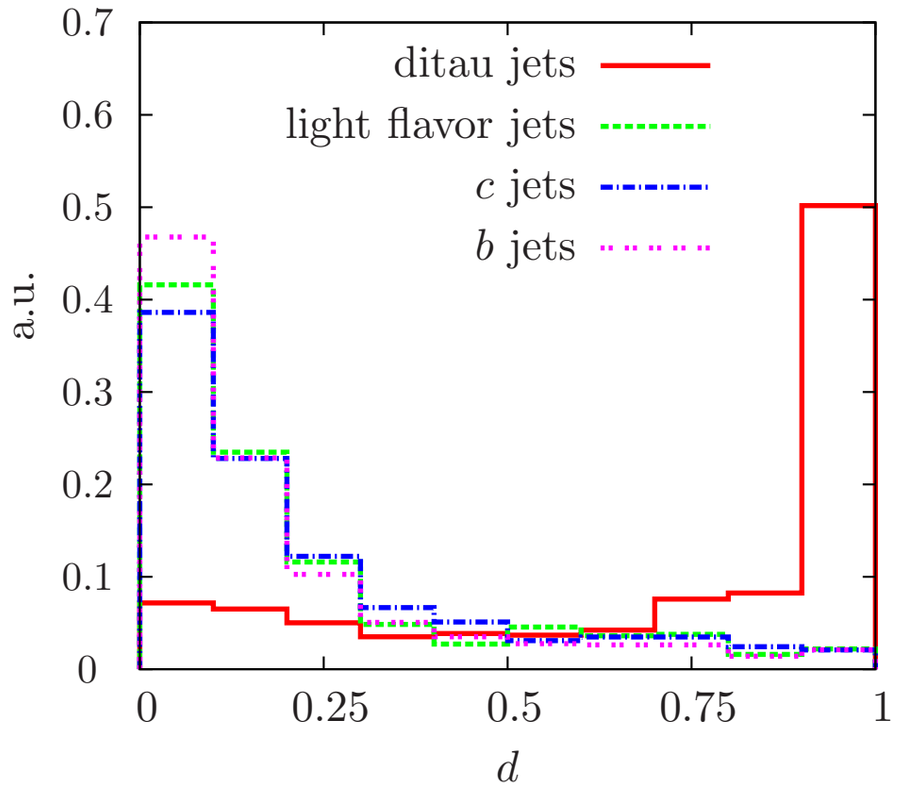
D.1 (Point ID 5416)	Scenario		
M_{H_s}, M_h, M_H	9.6 GeV	124.2 GeV	793.4 GeV

D.1 (Point ID 5416)	Signal Rates
$\sigma(ggh)$	44.28 pb
$\sigma(ggh)\mathrm{BR}(h \to H_sH_s)$	4.22 pb
$\sigma(ggh)\mathrm{BR}(h \to H_sH_s \to \tau\tau+\tau\tau)$	3.58 pb
$\sigma(ggh)\mathrm{BR}(h \to H_sH_s \to \tau\tau+\mu\mu)$	31.64 fb
$\sigma(ggH_s)$	439.80 pb
$\sigma(ggH_s)\mathrm{BR}(H_s \to \mu\mu)$	1.79 pb
$\sigma(ggH_s)\mathrm{BR}(H_s \to \tau\tau)$	405.09 pb
$\sigma(ggH_s)\mathrm{BR}(H_s \to c\bar{c})$	5.17 pb
$\sigma(ggH_s)\mathrm{BR}(H_s \to s\bar{s})$	7.24 pb
$\sigma(ggH_s)\mathrm{BR}(H_s \to \gamma\gamma)$	7.95 fb
$\sigma(ggH)$	38.72 fb
$\sigma(ggH)\mathrm{BR}(H \to t\bar{t})$	9.80 fb
$\sigma(ggH)\mathrm{BR}(H \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$	5.73 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s)$	8.08 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to bb+\tau\tau)$	4.26 fb
$\sigma(ggH)\mathrm{BR}(H \to hH_s \to \tau\tau+\tau\tau)$	0.45 fb

☛ light exotics: “new” boosted strategies need to be validated

[King, Mühlleitner, Nevzorv, Walz `14]

exotics: NMSSM



high discrimination taggers available from substructure developments

- pile-up & underlying event at LHC 13?
- general feasibility for model-dependent cross sections after fits?

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☛ light exotics: “new” boosted strategies need to be validated

Summary

- LHC run II will bring Higgses at high pT with reasonable statistics

- Boosted Higgs final states are crucial tools if the new physics scale is well separated from the electroweak scale

- top (partner) thresholds can populate the boosted Higgs pT regime addining additional sensitivity

- Boosted Higgs final states can be “make-or-break” final states for extended Higgs sectors with new light degrees of freedom