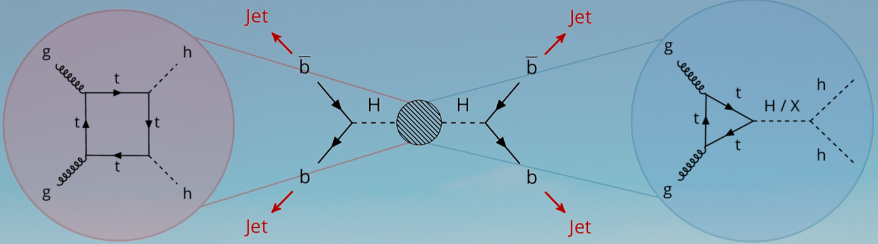


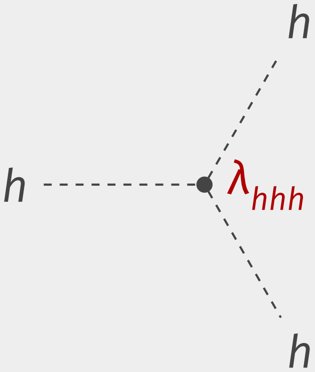
A New Jet Pairing Algorithm for the ATLAS HH → 4b Analysis

Beojan Stanislaus

IOP HEPP Conference

9th April 2019

Measure Higgs self-coupling λ_{hhh}



Motivation for di-Higgs

Additional HH production $\Longrightarrow$ New Physics

Motivation for HH → 4b

Data from LHCHXSWG (arXiv:1201.3084)

	$b\bar{b}$	W^+W^-	gg	$\tau^+\tau^-$	$c\bar{c}$	ZZ	$\gamma\gamma$	$Z\gamma$	$\mu^+\mu^-$
$\mu^+\mu^-$									< 0.1%
$Z\gamma$								< 0.1%	< 0.1%
$\gamma\gamma$							< 0.1%	< 0.1%	< 0.1%
ZZ						< 0.1%	< 0.1%	< 0.1%	< 0.1%
$c\bar{c}$					< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
$\tau^+\tau^-$				0.4%	0.2%	0.2%	< 0.1%	< 0.1%	< 0.1%
gg			0.7%	0.5%	0.2%	0.2%	< 0.1%	< 0.1%	< 0.1%
W^+W^-		4.6%	1.8%	1.4%	0.6%	0.6%	< 0.1%	< 0.1%	< 0.1%
$b\bar{b}$	**33.3%**	12.4%	4.9%	3.6%	1.7%	1.5%	0.1%	< 0.1%	< 0.1%

HH → 4b has highest branching ratio

Analysis Strategy from 30,000 Feet

1. Consider only jets with $p_T \geq 40$ GeV, $|\eta| < 2.5$
2. Choose events with four b-tagged jets

   Events with two b-tagged jets used for background estimation
3. Pair jets into two Higgs candidates

   Randomly selecting two additional jets if event has only two b-tagged jets
4. Apply background suppression cuts:
   - ΔR between each pair of jets
   - p_T of each Higgs candidate
   - $\Delta\eta$ between Higgs candidates
   - Veto $t\bar{t}$

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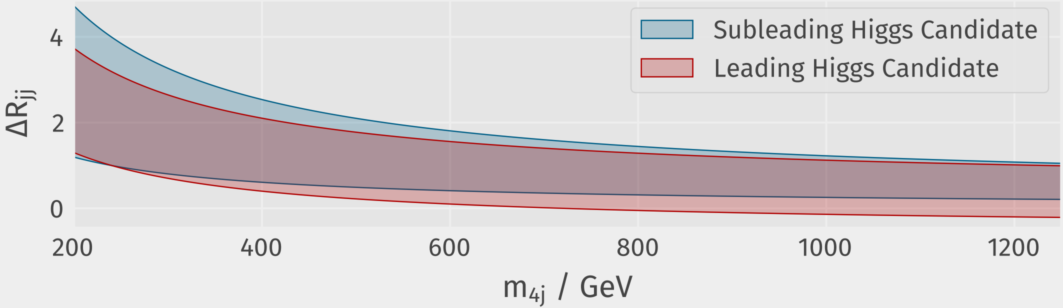
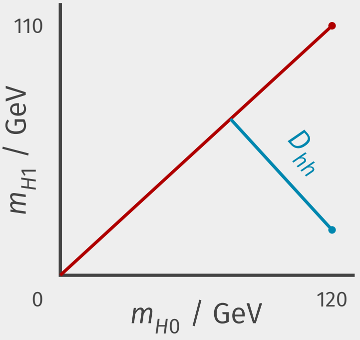
Discard pairings that fail ΔR_{jj} condition



See JHEP 01 (2019) 030 for details

Select pairing that minimizes D_{hh}



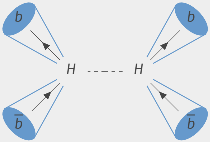
See JHEP 01 (2019) 030 for details

Jet Pairing Performance Study — Strategy

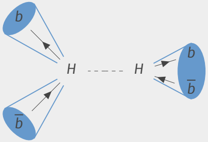
- Use simulated HH events
  Standard Model and G $\rightarrow$ HH decays
- Considering only
  - Jets with $p_T \geq 40$ GeV, $|\eta| < 2.5$
  - Events with 4 b-tagged jets
- Assign each b-quark its closest jet (in ΔR)
  Jet need not be b-tagged
- Separate into categories — study performance in Good category

Categories

Good Each b-quark assigned a distinct $R = 0.4$ jet



Category 1 One Higgs assigned two distinct $R = 0.4$ jets

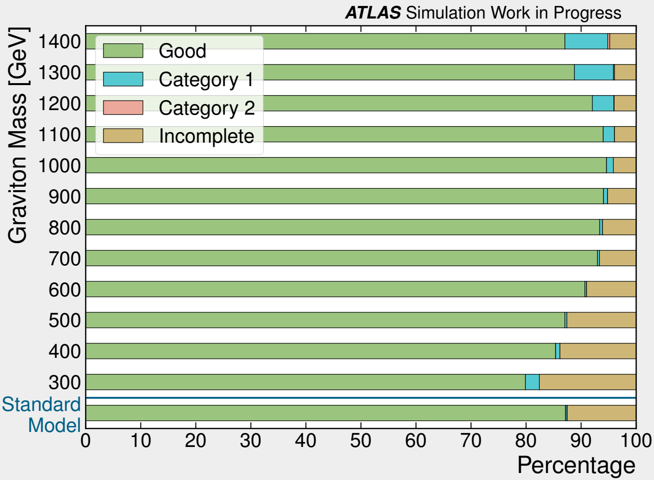


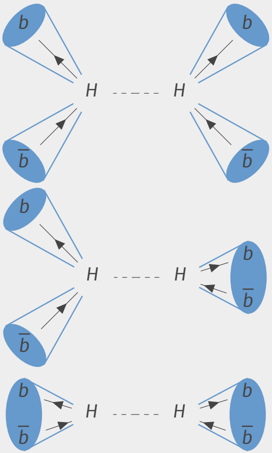
Category 2 Each Higgs assigned one $R = 0.4$ jet

Incomplete At least one b-quark has $\Delta R > 0.4$ from assigned jet

Indicates missing jet

Category Composition





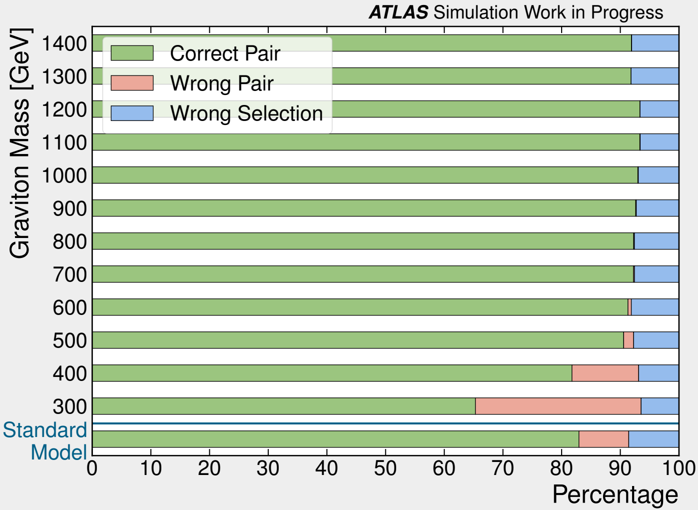
Mostly in the “Good” category

Pairing

Correct Pair	Correct four jets selected and paired correctly
Wrong Pair	Correct four jets selected, but paired incorrectly
Wrong Selection	At least one selected jet is incorrect

Considering Good category only

Pairing

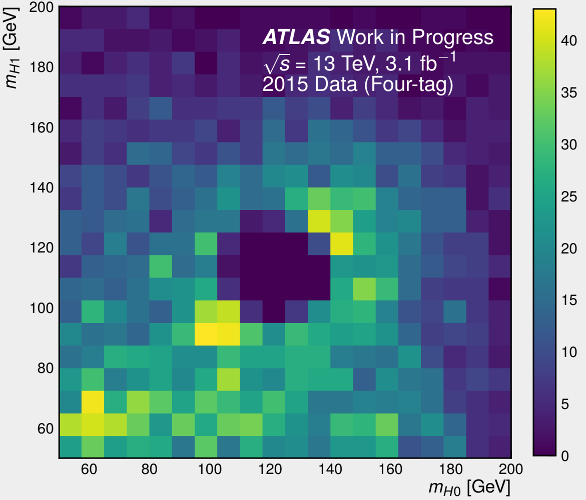


Very impressive performance

Background Sculpting

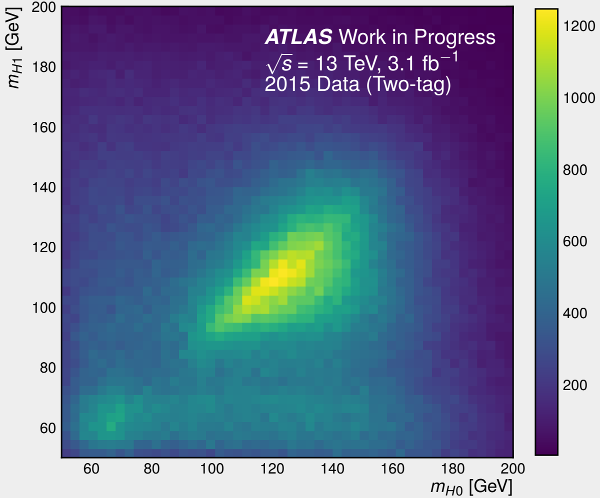
- Seen impressive efficiency of old pairing algorithm
- Unfortunately, it severely sculpts the background

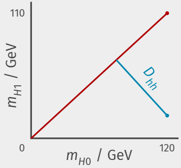
Sculpting in Data



Periphery of peak visible around blinded signal region.

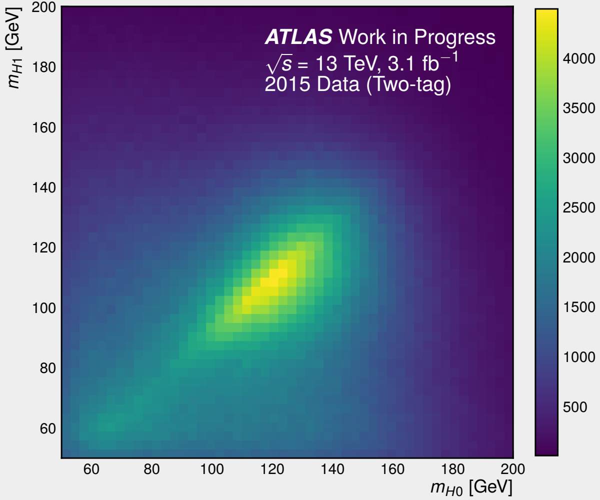
Sculpting in Data (Two b-tagged Jets)

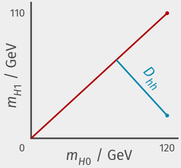




Peak clearer with only two b-tagged jets.

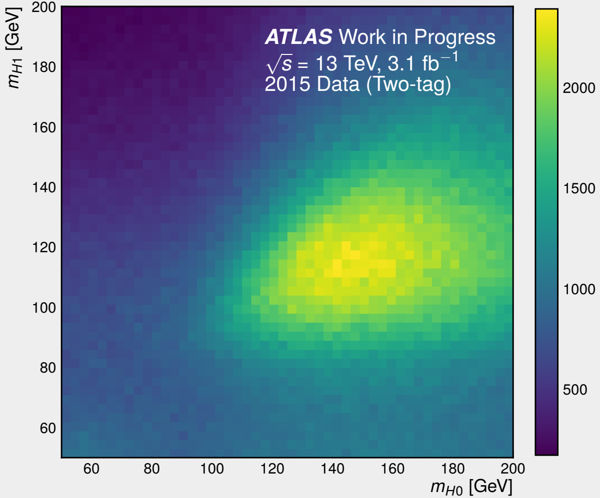
Sculpting in Data (Before Background Suppression Cuts)





Peak still present with no cuts.

Sculpting in Data (Random Pairing)

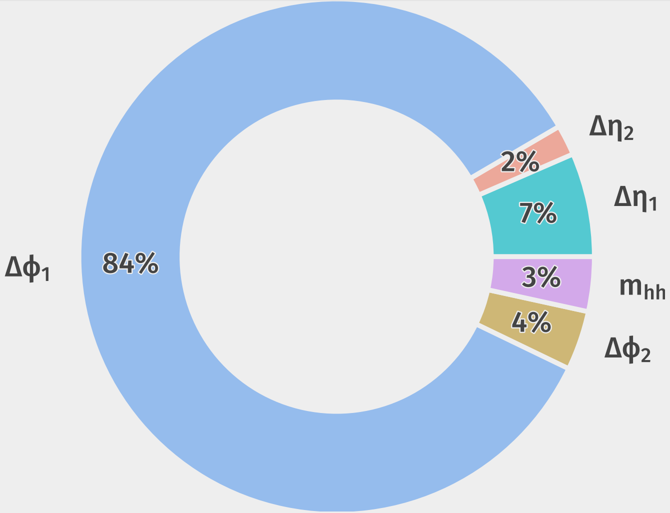


Far less severe with random pairing.

Boosted Decision Tree Jet Pairing Algorithm

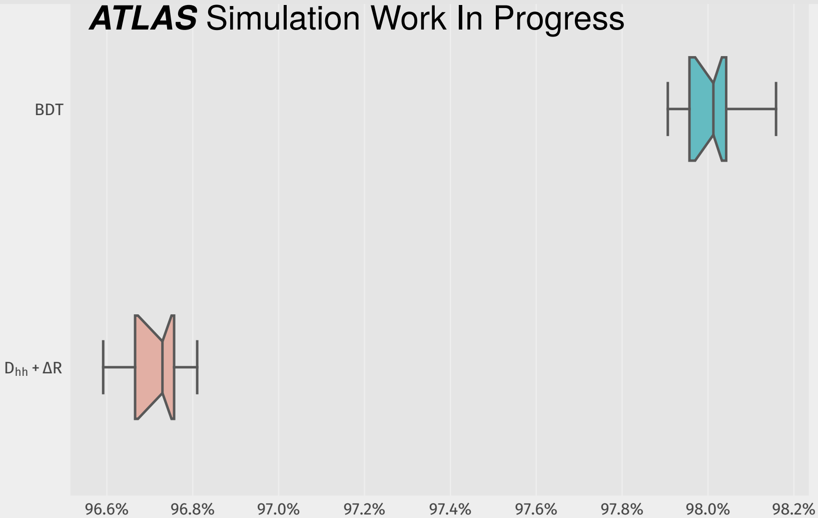
- Train BDT to distinguish correct from incorrect pairings
- Choose pairing with highest BDT score for each event
- Use $\Delta\eta_1$, $\Delta\eta_2$, $\Delta\phi_1$, and $\Delta\phi_2$
- Also use HH invariant mass (m_{hh}) to tune BDT
- New algorithm does not use Higgs candidate masses

Feature Importance Chart



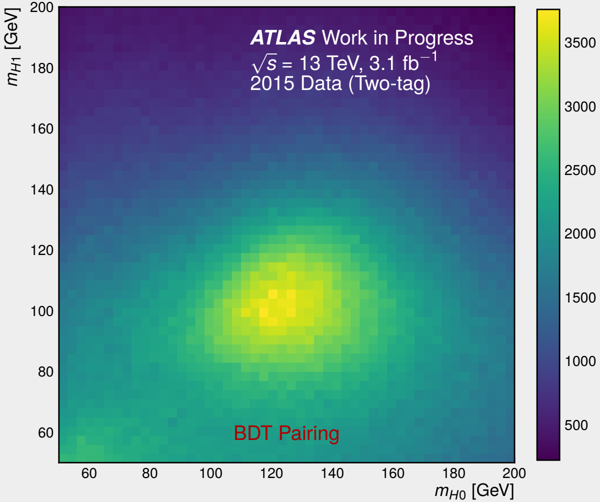
Mostly uses one angular separation

Results — Efficiency



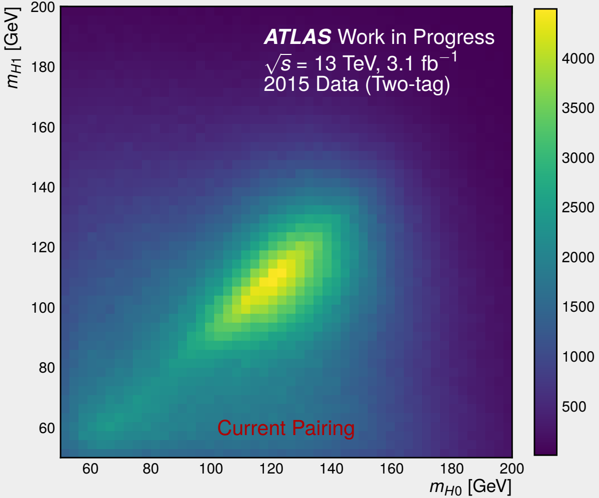
Statistically significantly higher efficiency

Results — Background Distribution



Less severe sculpting

Results — Background Distribution



Less severe sculpting

Conclusion

- Current pairing algorithm:
  impressive performance, but sculpts background
- Developed new algorithm using angular separations only
  - Higher efficiency — 96.7% → 98%
  - Less severe background sculpting

Backup

Current Jet Pairing Algorithm — Details

1. Discard pairings that fail ΔR_{jj} condition

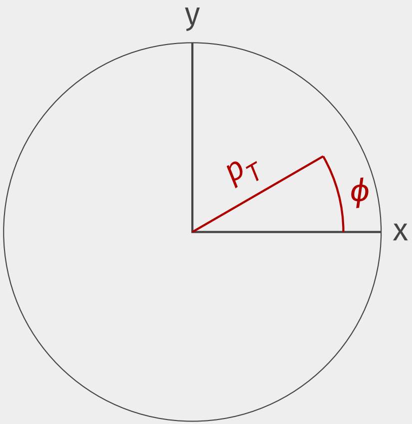
$$\frac{360}{m_{4j}/\text{GeV}} - 0.5 < \Delta R_{jj}^{\text{leading}} < \frac{653}{m_{4j}/\text{GeV}} + 0.47$$

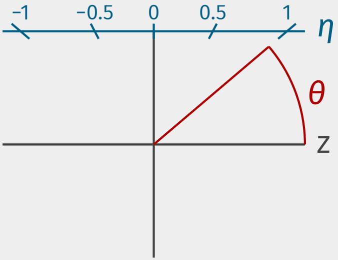
$$\frac{235}{m_{4j}/\text{GeV}} + 0.02 < \Delta R_{jj}^{\text{subleading}} < \frac{875}{m_{4j}/\text{GeV}} + 0.35$$

2. Select pairing that minimizes D_{hh}

$$D_{hh} = \frac{\left|110 m_{H0} - 120 m_{H1}\right|}{\sqrt{120^2 + 110^2}\ \text{GeV}}$$

ATLAS Coordinate System





$$\eta = -\ln\tan\left(\frac{\theta}{2}\right)$$