Higgs to two spin-zero particles with a 4b final state in vector boson fusion plus a photon

Stephen Roche[1*]
Ben Carlson[1,2]
Chris Hayes[3]
Tae Min Hong[1]

[1]University of Pittsburgh
[2]Westmont College
[3]University of Michigan

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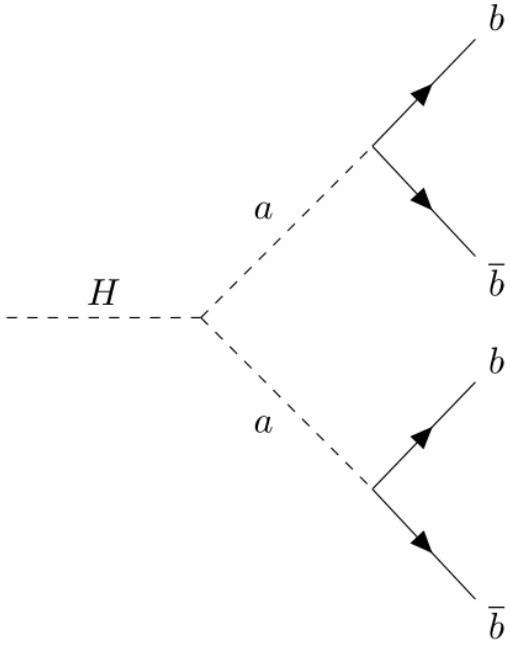
BSM Higgs decay to pseudoscalars

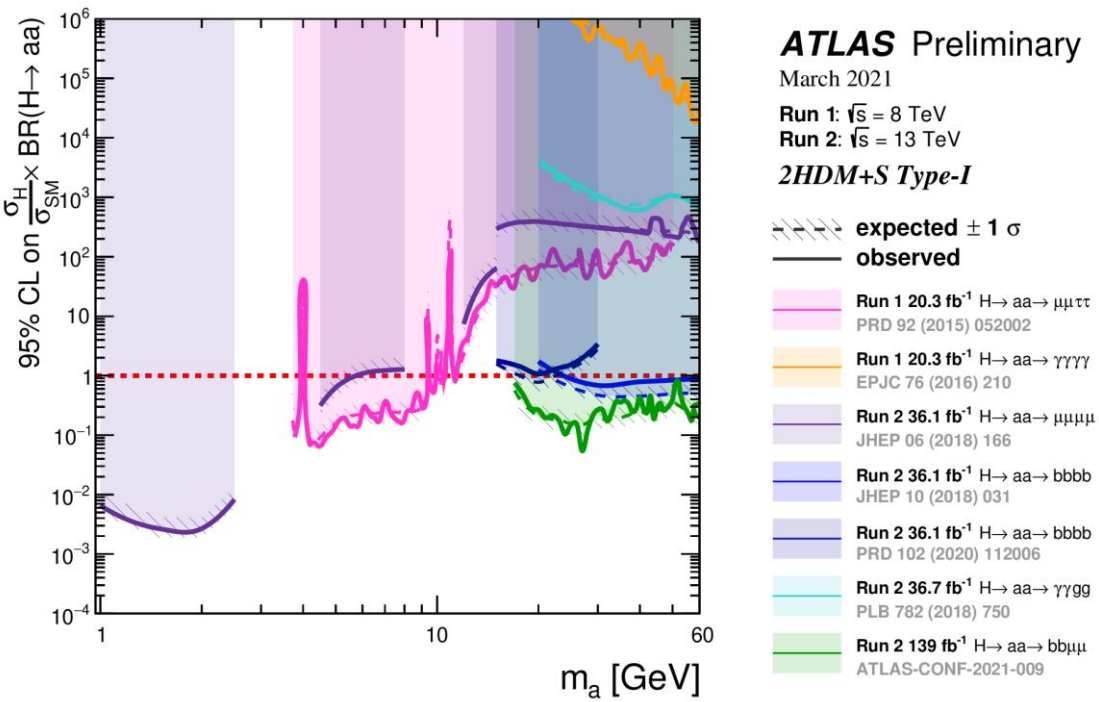
Stephen Roche

Some BSM models such as the 2HDM and MSSM predict a Higgs decay to two pseudoscalar a-bosons

- This talk: Monte Carlo based sensitivity study for H→aa→4b with VBF + photon Higgs production
- Feasibility study for what could be done now: 13 TeV, 150 fb^{-1}

Other searches have been done for pseudoscalars with different decay products and Higgs production modes





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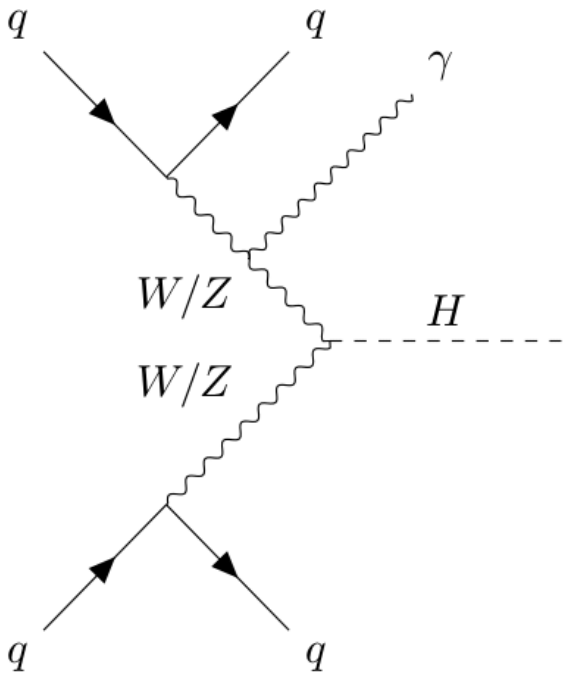
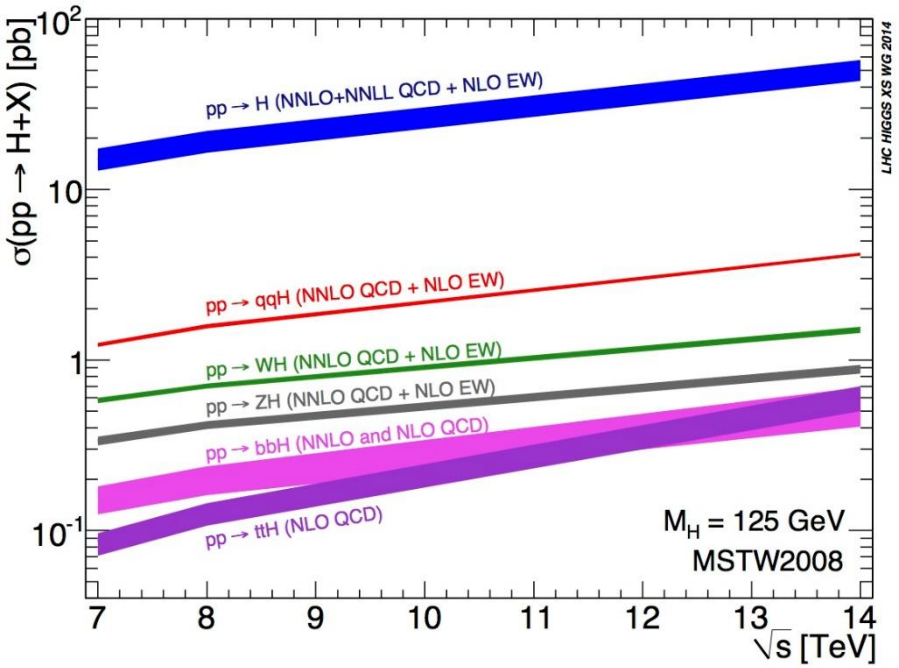
VBF + photon production mode

Stephen Roche

Vector boson fusion (VBF) is a common Higgs production mechanism

- Second most common production mechanism after ggF





LHC Higgs Cross Section Working Group

VBF + photon is a relatively easy Higgs production mechanism to trigger on

VBF + photon production mode

Stephen Roche

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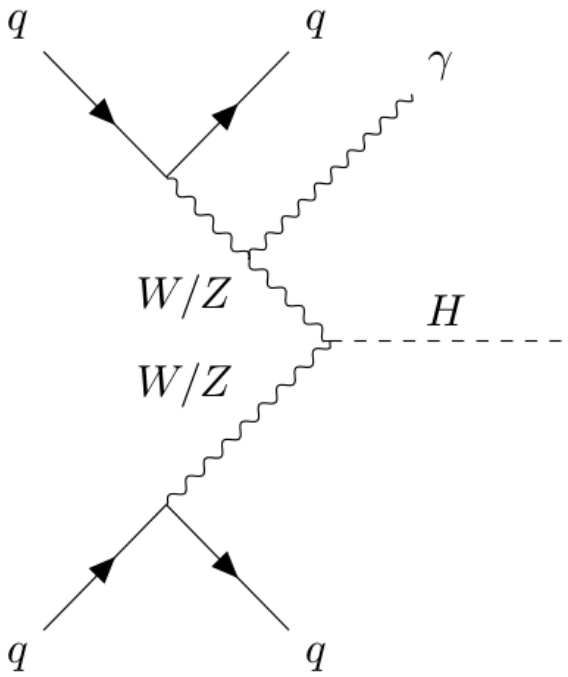

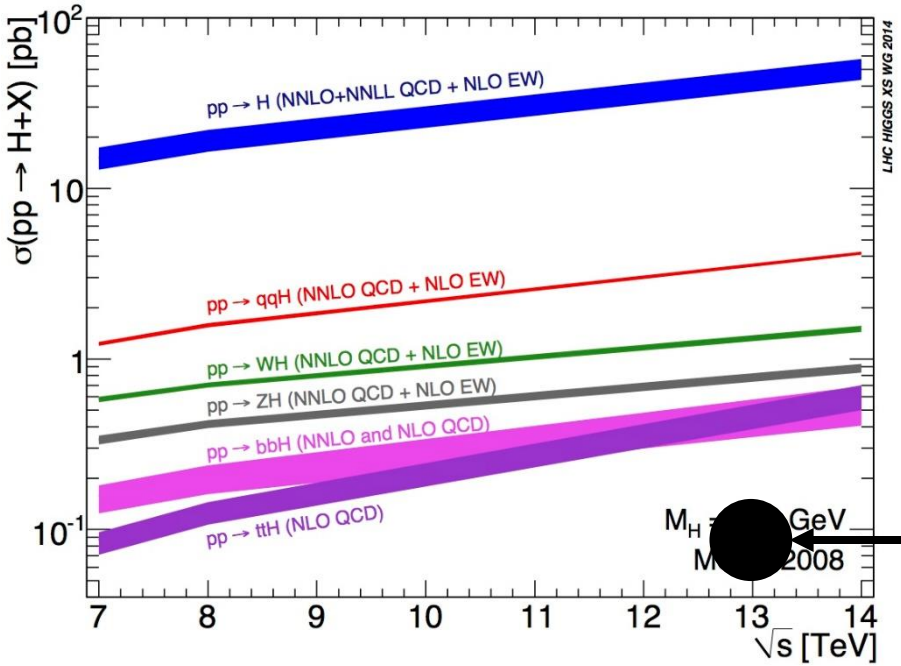

VBF+photon

[LHC Higgs Cross Section Working Group]

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VBF + photon production mode

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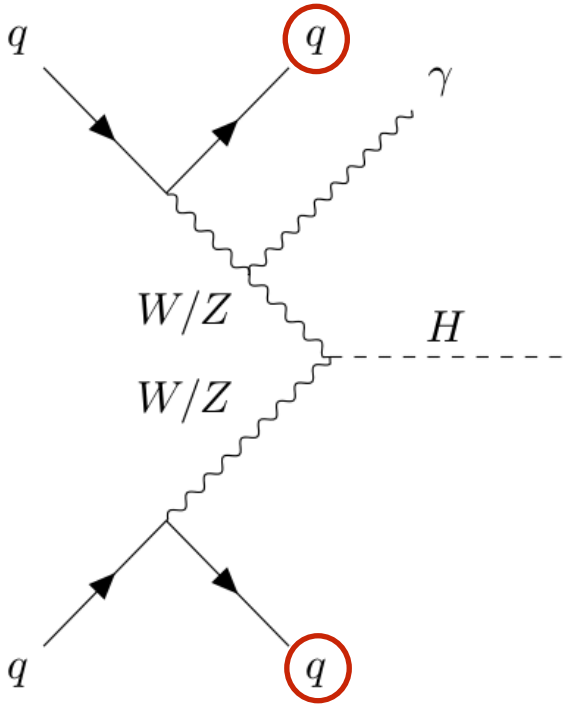

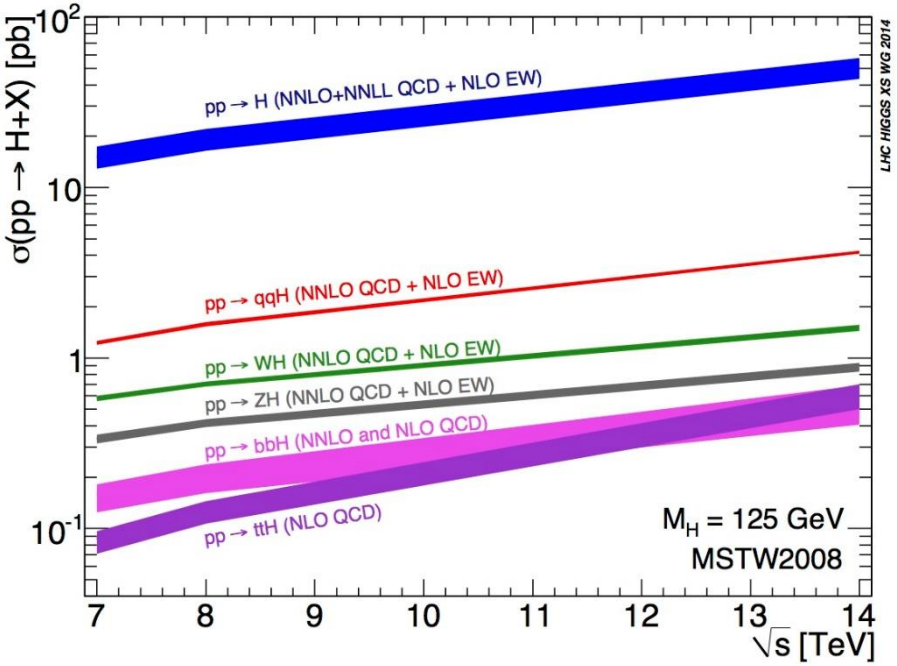

LHC Higgs Cross Section Working Group

VBF + photon is a relatively easy Higgs production mechanism to trigger on

- VBF jets have a distinct kinematic signature

VBF + photon production mode

Stephen Roche

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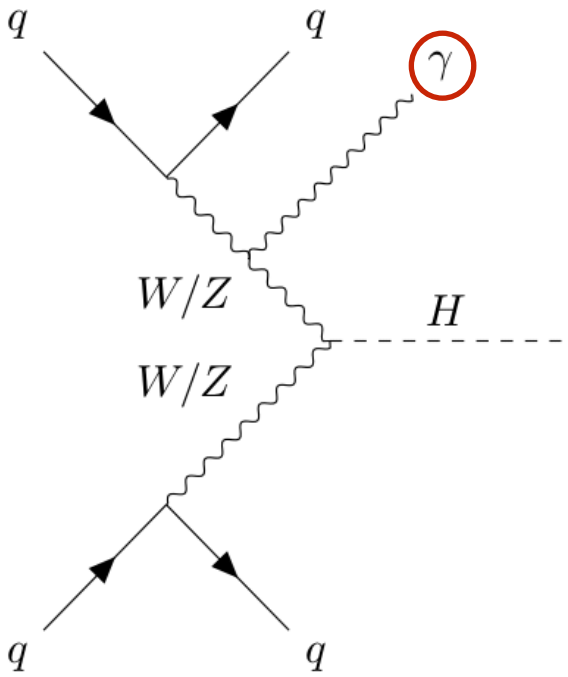
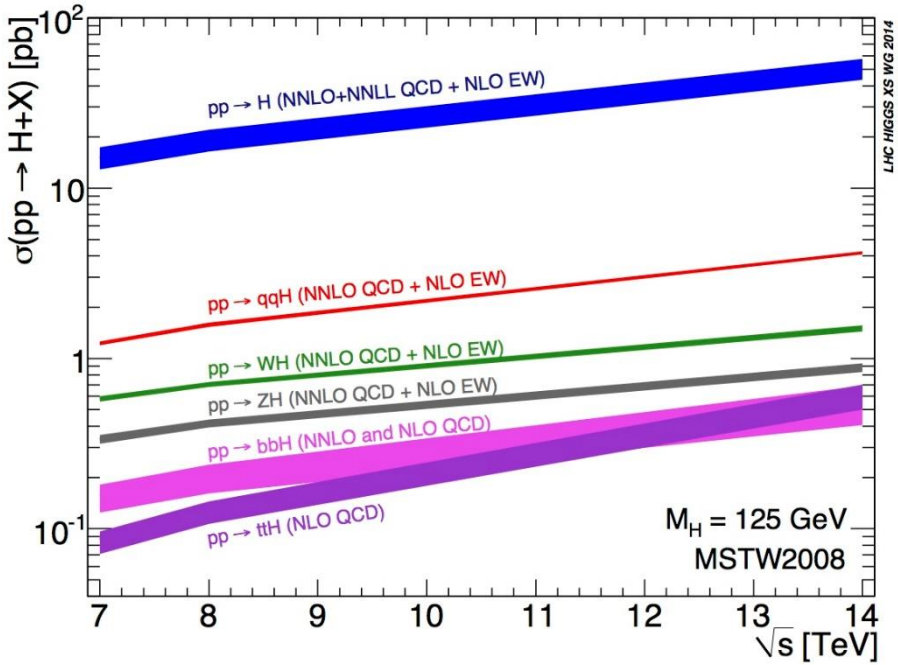




LHC Higgs Cross Section Working Group

VBF + photon is a relatively easy Higgs production mechanism to trigger on

- VBF jets have a distinct kinematic signature
- Presence of high-p_T photon suppresses background (> 25 GeV photons already triggered on)

Monte Carlo simulation

Stephen Roche

Signal and background

- Signal is MSSM VBF H→aa→4b (Branching ratio = 1)
- m_H = 125 GeV, m_a = 50 GeV
- Background is QCD multijet with a high multiplicity of b-jets and a photon

Generator

- Madgraph5 used at leading order
- Generator-level cuts: jet p_T >= 20 GeV, separated by ΔR = 0.4

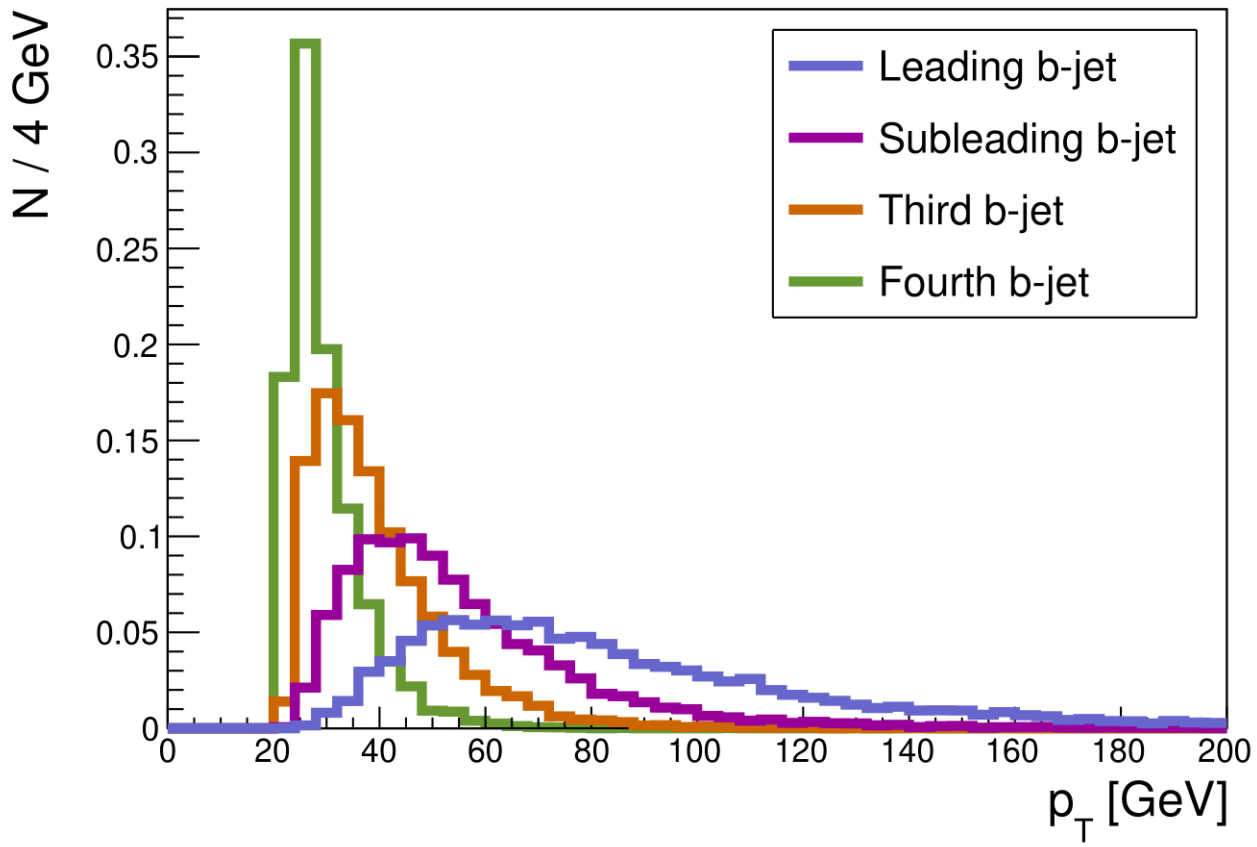
Parton hadronization and event reconstruction

- Pythia with the ATLAS AZ 17 tune used for hadronization and parton showering
- Detector simulation performed with Delphes using CMS card
- Anti-kT jet reconstruction for p_T >= 20 GeV

Final states

4b and 3b final states considered

- Possible that lowest-pT b-jet lost to reconstruction, or two b-jets merged
- First cut: 6 total jets for 4b case (2 VBF, 4 decay)
- First cut: 5 total jets for 3b case (2 VBF, 3 decay)



b-jet cuts

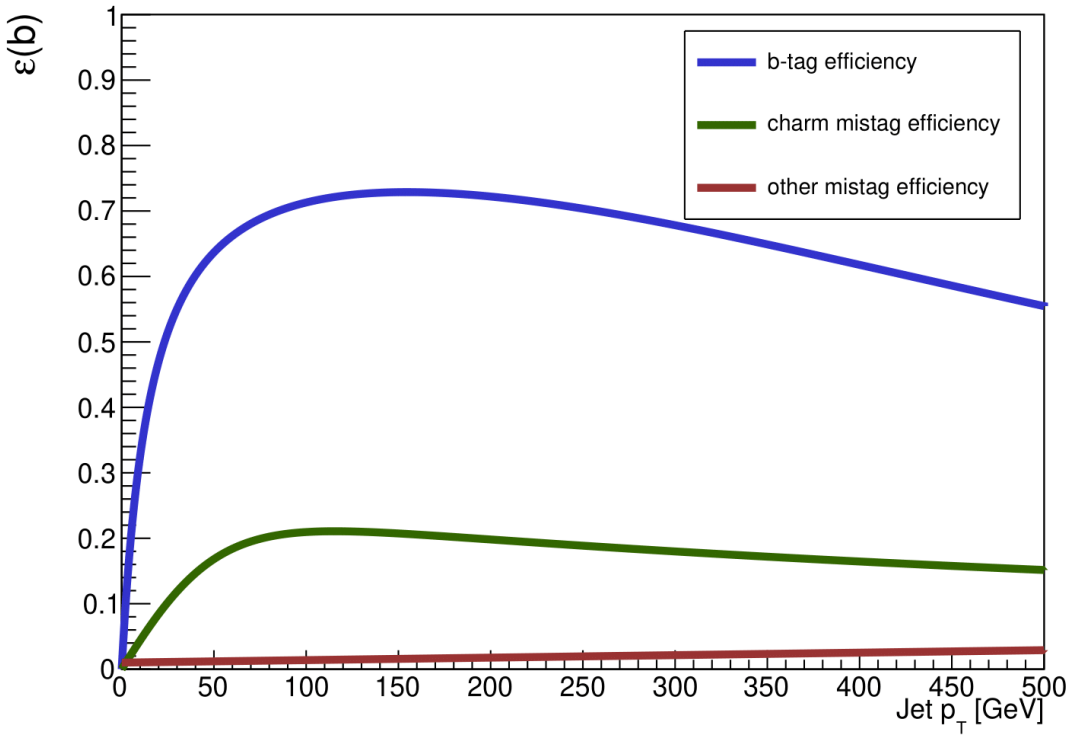
Stephen Roche

All non-VBF jets should arise from Higgs decay

- Therefore, all should be b-tagged
- b-tagging is about 75% efficient at best; requiring 4(3) b-tags would negatively impact MC statistics

Solution:

- Events weighted by probability that all 4 (3) non-VBF jets will be b-tagged
- Allows for increased statistics by not removing events with mis-tagged jets



Delphes CMS b-tagging efficiencies based on [arXiv:1211.4462]

Higgs production cuts

Stephen Roche

VBF and photon cuts used to identify signal events

- Jet pair with highest m_{jj} assumed to be VBF pair
- Production cuts remove overwhelming majority of background
- All event counts per 150 fb^{-1}

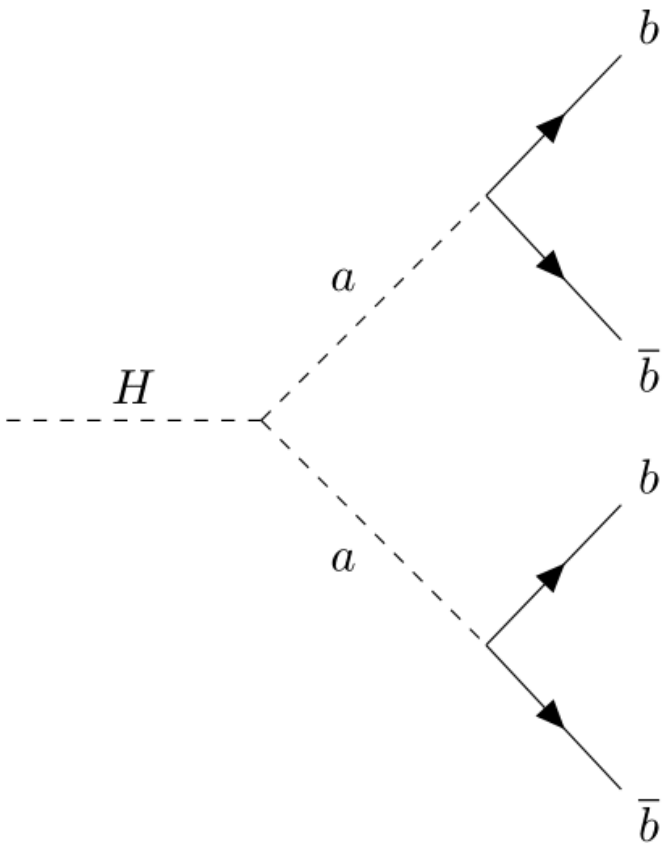
	Cuts	3b		4b	
		S	B	S	B
Pre-cut	-6 (5) total jets -Weighted to b-tagging	276	5.27×10^7	68.28	2.87×10^6
Only VBF	$p_{T1} > 50$ GeV $p_{T2} > 50$ GeV $m_{jj} > 1$ TeV $\|\Delta\eta\| > 3.0$ $\|\Delta\varphi\| < 2.0$	36.67	7.85×10^5	12.27	7.70×10^4
Only Photon	$p_T > 30$ GeV $\|\eta\| < 2.5$	107.11	1.02×10^5	27.22	6615
VBF & Photon	All above	14.85	751	4.88	65

Final state analysis – 4b

Stephen Roche

Given 4 b-jets, want to pair them up by which a-boson they come from

- b-jets paired to minimize difference in invariant mass between pairs



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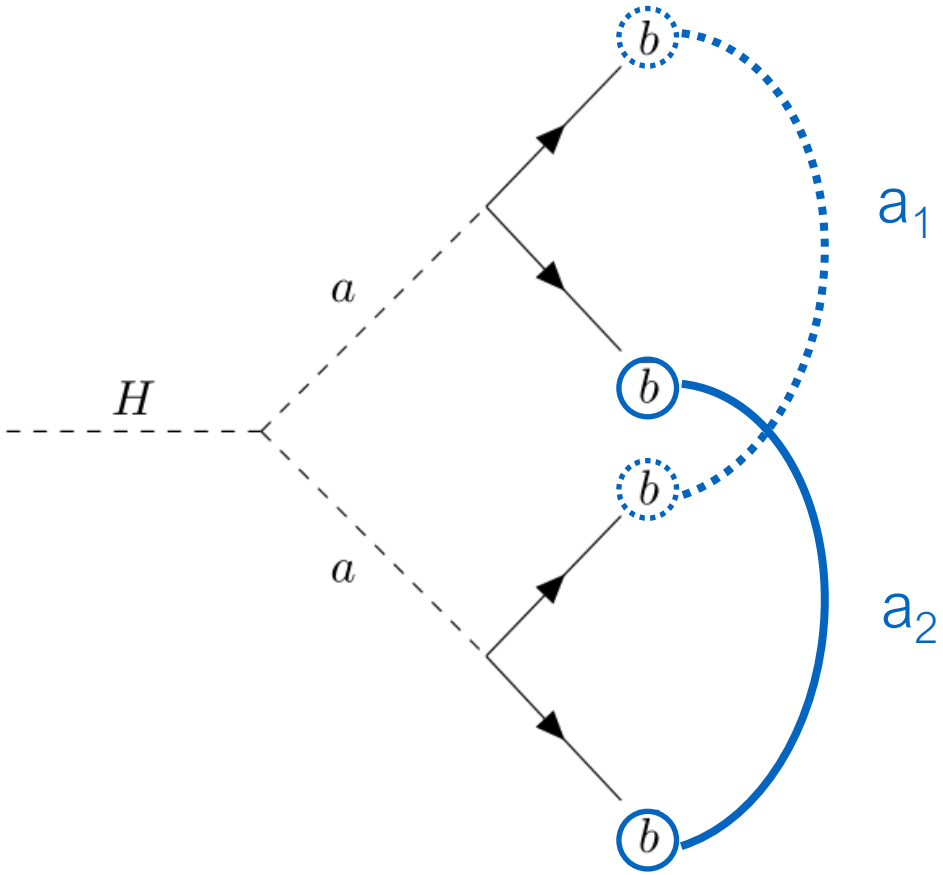

Pairing 1: High $\Delta m_{a1,a2}$

Final state analysis – 4b

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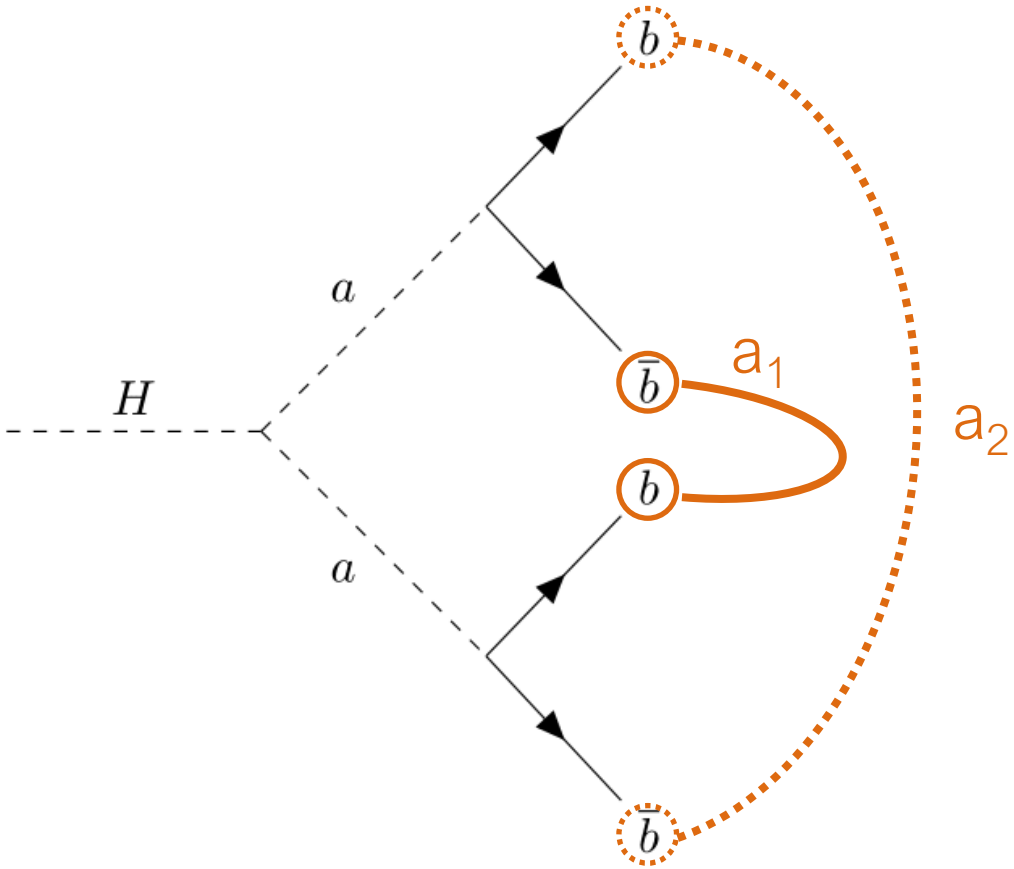

Pairing 1: High $\Delta m_{a1,a2}$

Pairing 2: High $\Delta m_{a1,a2}$

Final state analysis – 4b

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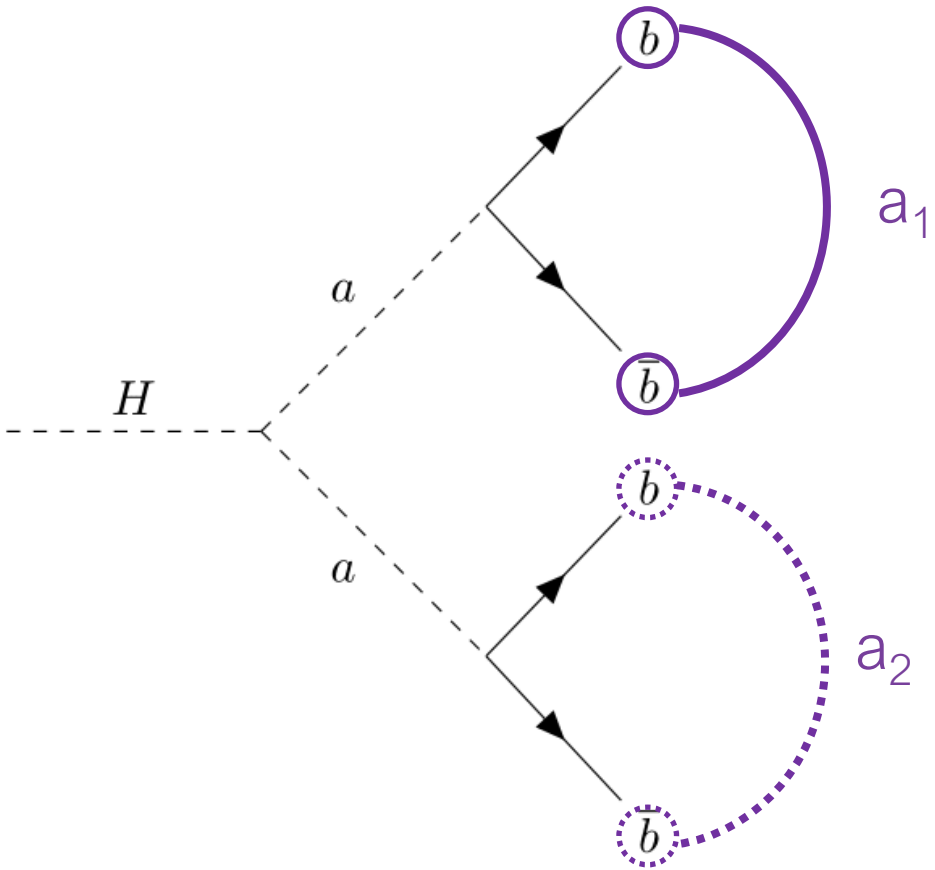

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Pairing 2: High $\Delta m_{a1,a2}$

Pairing 3: Low $\Delta m_{a1,a2}$

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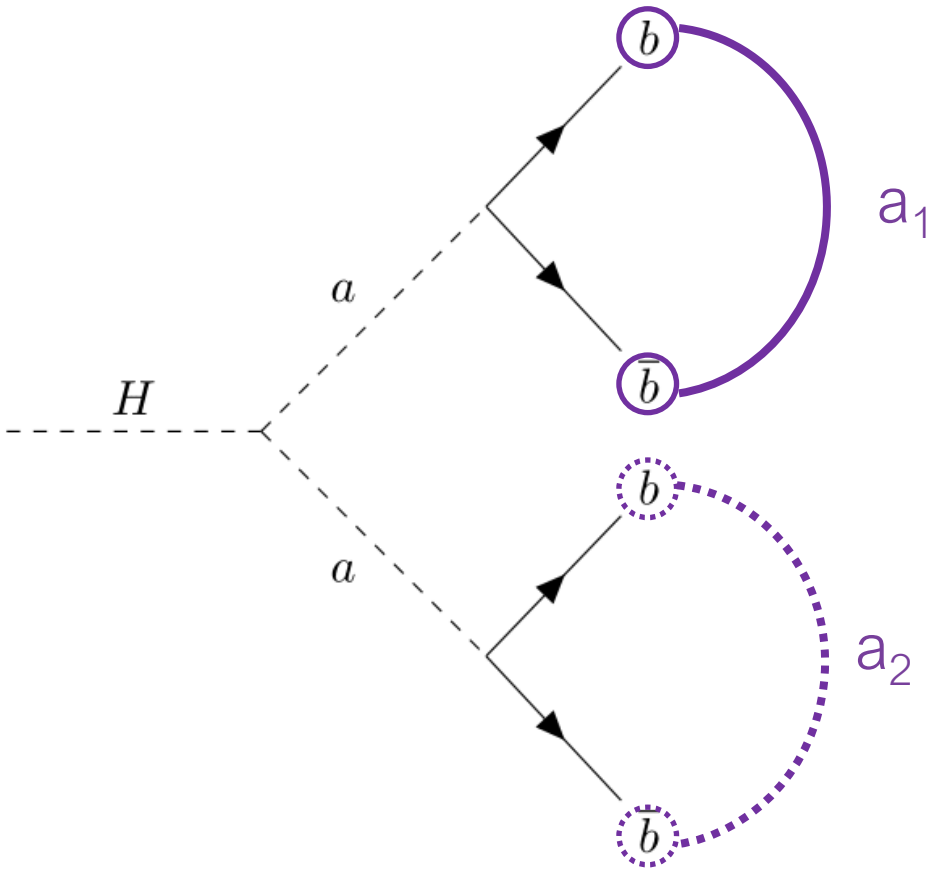


Pairing 1: High $\Delta m_{a1,a2}$

Pairing 2: High $\Delta m_{a1,a2}$

Pairing 3: Low $\Delta m_{a1,a2}$

Winner!

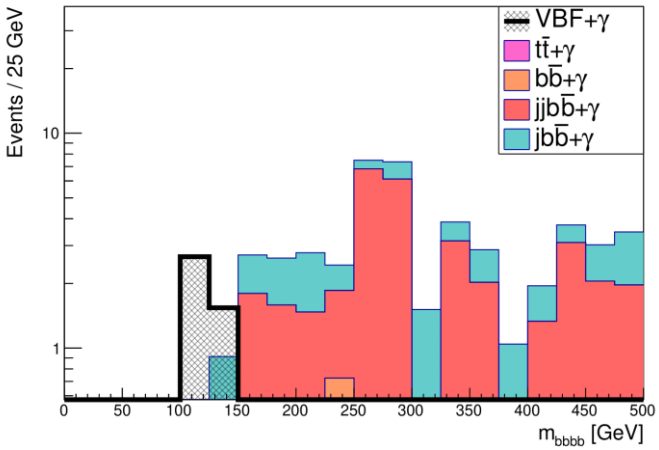
Note: This method is independent of the a-boson mass

Final state analysis – 4b

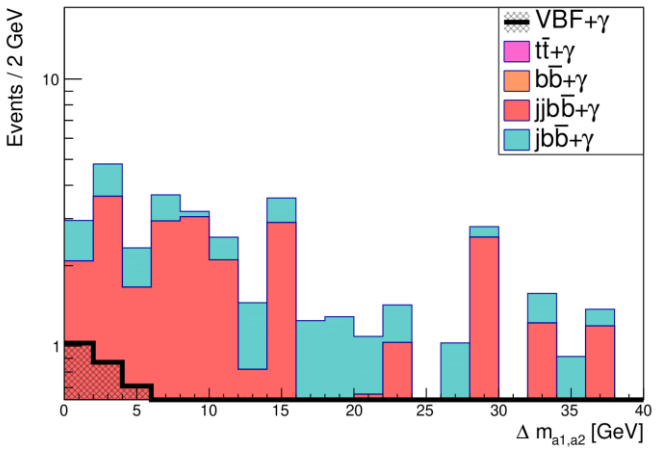
Stephen Roche

Cut-based analysis performed using three variables

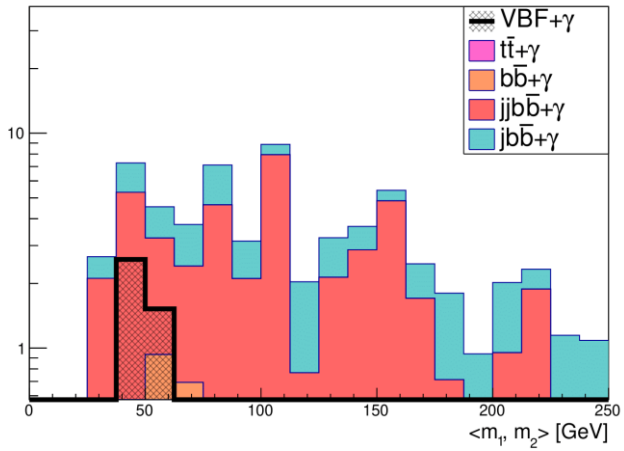
Before cuts



Invariant mass of 4 b-jets
Cut: < 180 GeV



Difference between b-pair masses
Cut: < 10 GeV



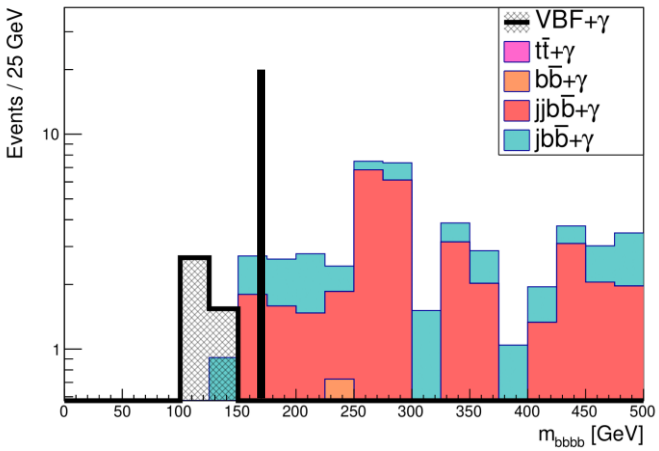
Average mass of b-jet pairs
Cut: 20 – 80 GeV

Final state analysis – 4b

Stephen Roche

Cut-based analysis performed using three variables

Before cuts



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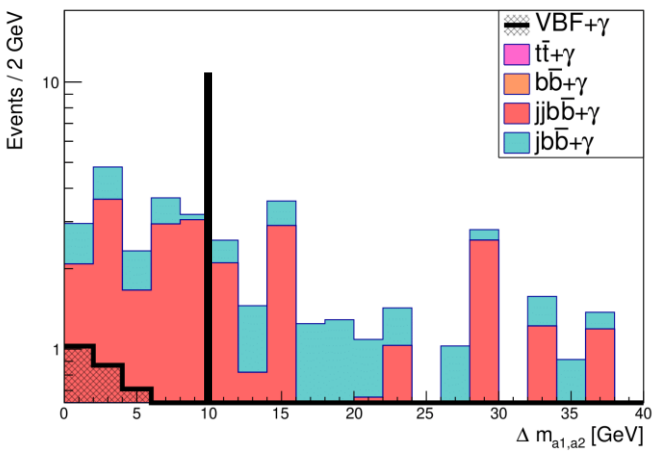

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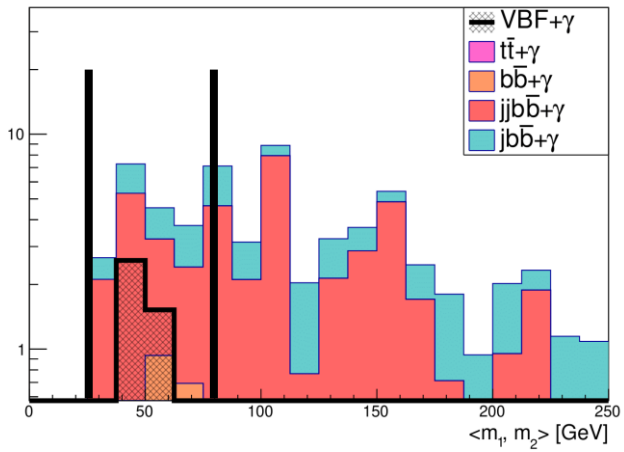

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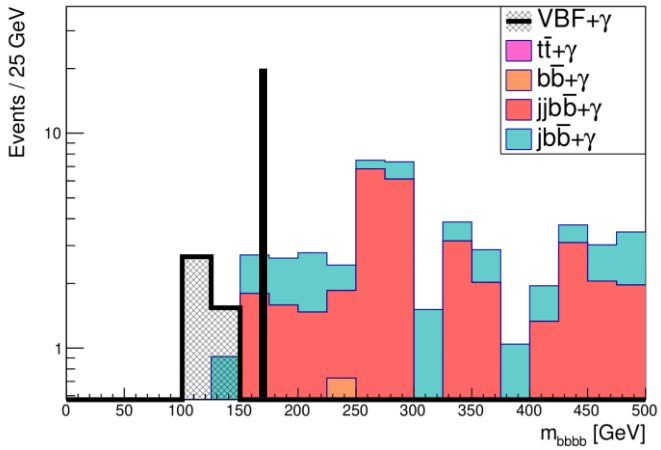

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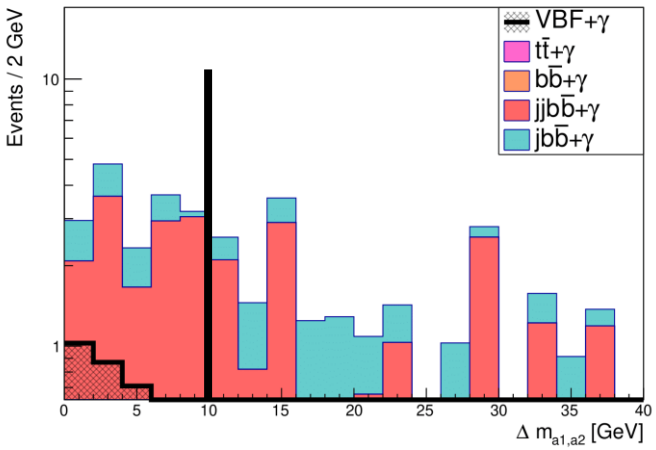

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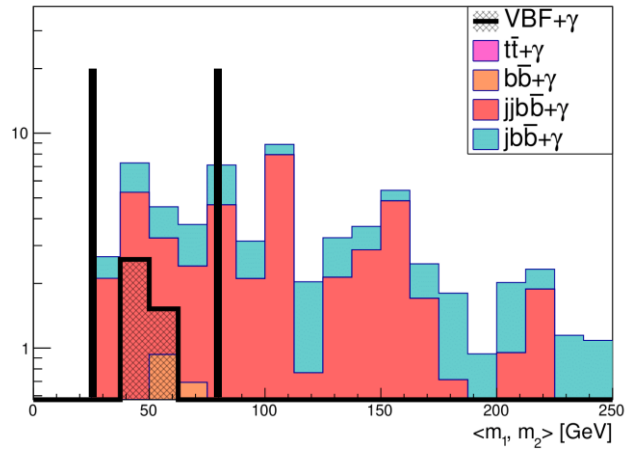

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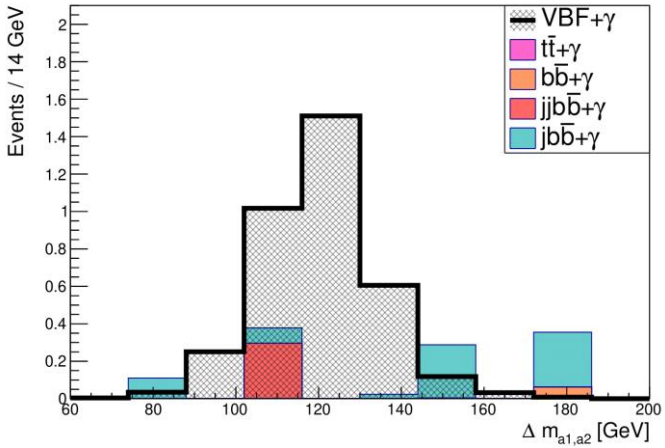
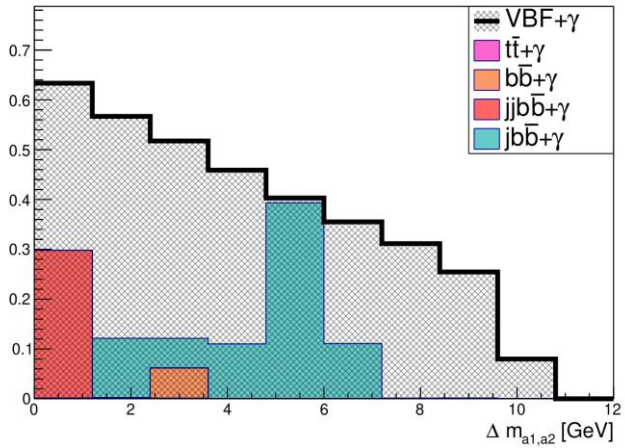
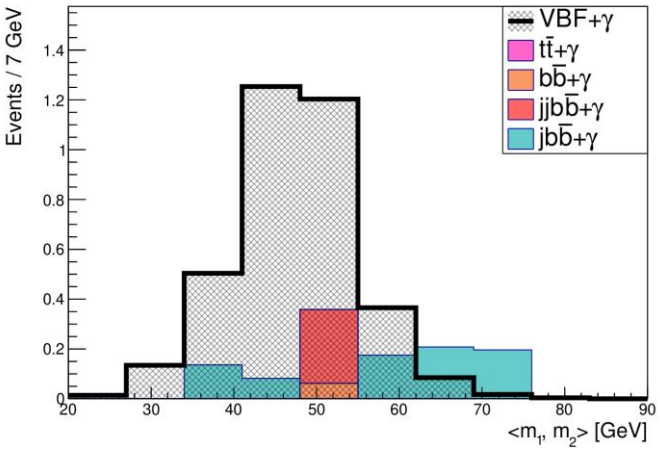




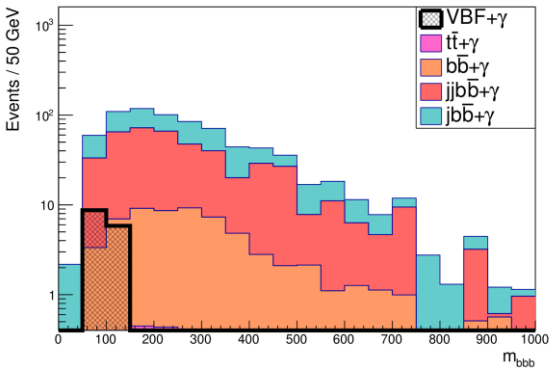


Final state analysis – 3b

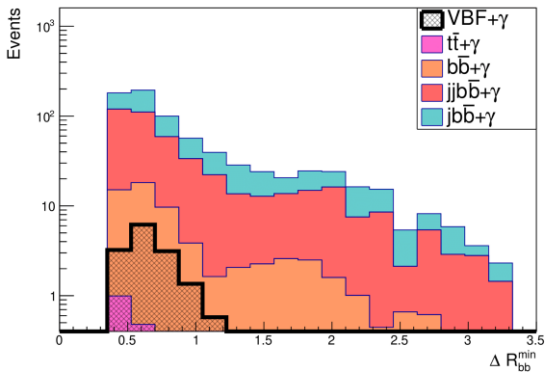
Stephen Roche

Cut-based analysis also used on 3b case

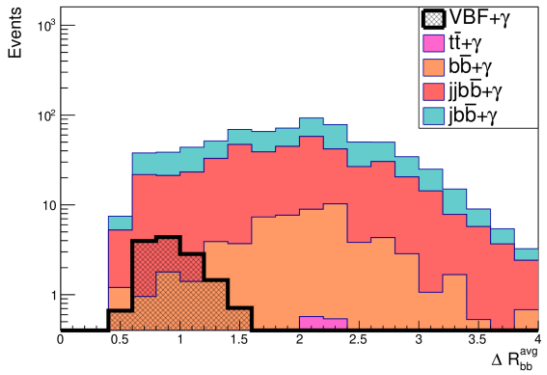
- 6 input variables chosen



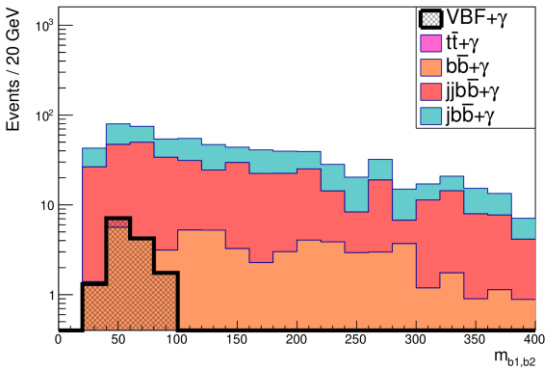
Invariant mass of 3 b-jets
Cut: 60 – 150 GeV



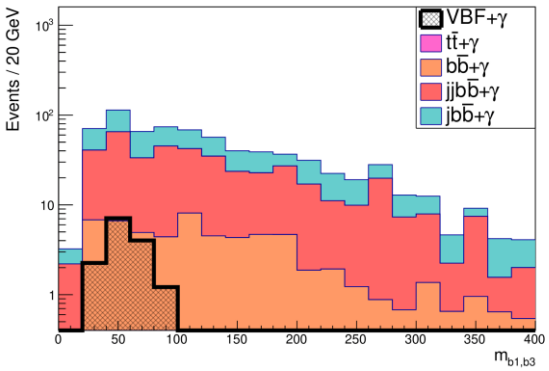
Distance between 2 closest b-jets
Cut: < 1.3



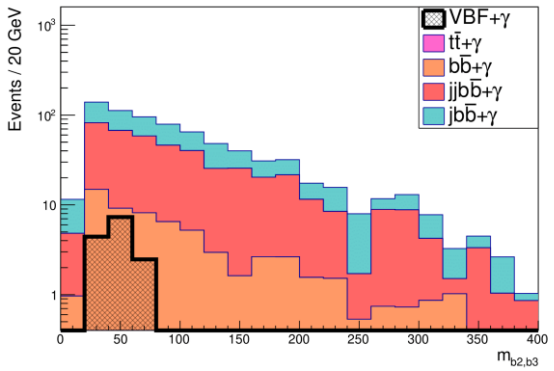
Average distance between b-jets
Cut: < 1.5



Invariant mass of b1 and b2
Cut: 30 – 90 GeV



Invariant mass of b1 and b3
Cut: 30 – 90 GeV



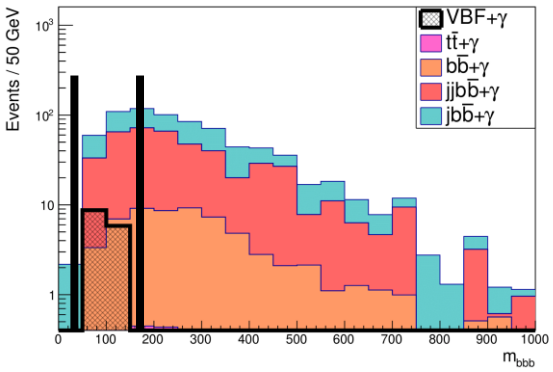
Invariant mass of b2 and b3
Cut: 20 – 80 GeV

Final state analysis – 3b

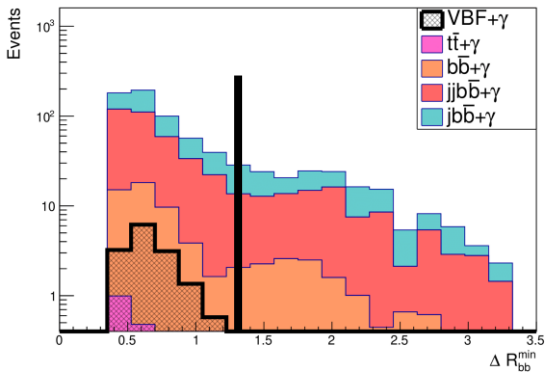
Stephen Roche

Cut-based analysis also used on 3b case

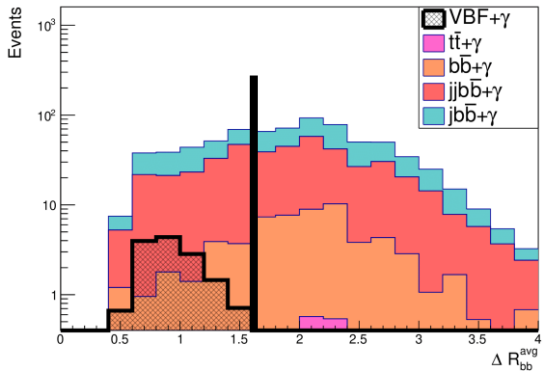
- 6 input variables chosen



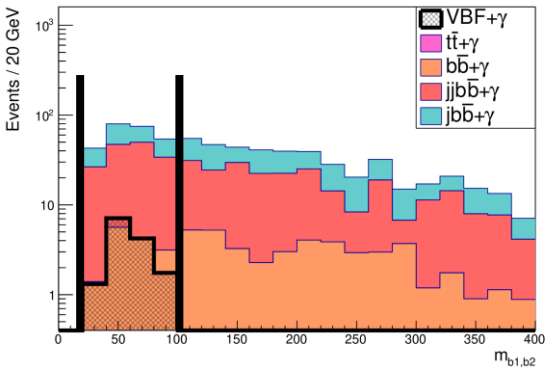
Invariant mass of 3 b-jets
Cut: 60 – 150 GeV



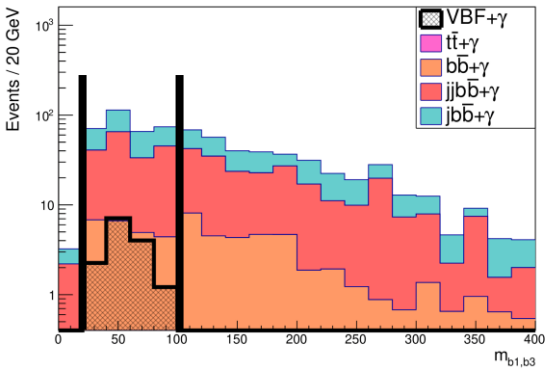
Distance between 2 closest b-jets
Cut: < 1.3



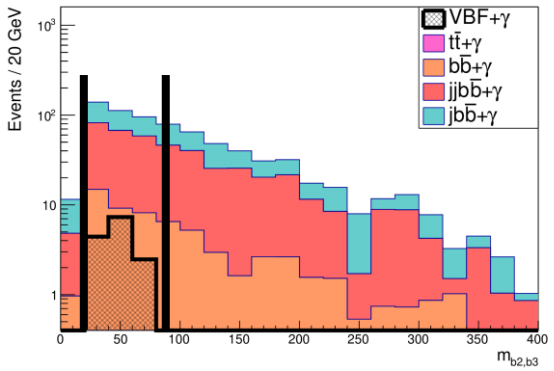
Average distance between b-jets
Cut: < 1.5



Invariant mass of b1 and b2
Cut: 30 – 90 GeV



Invariant mass of b1 and b3
Cut: 30 – 90 GeV



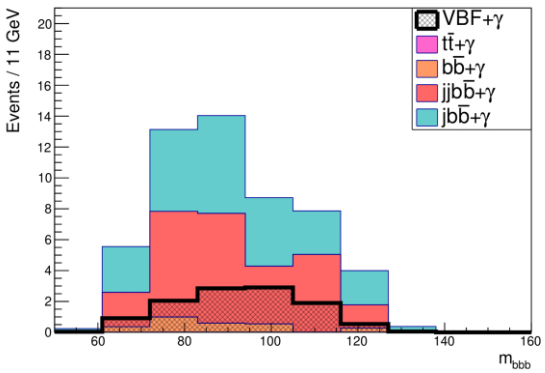
Invariant mass of b2 and b3
Cut: 20 – 80 GeV

Final state analysis – 3b

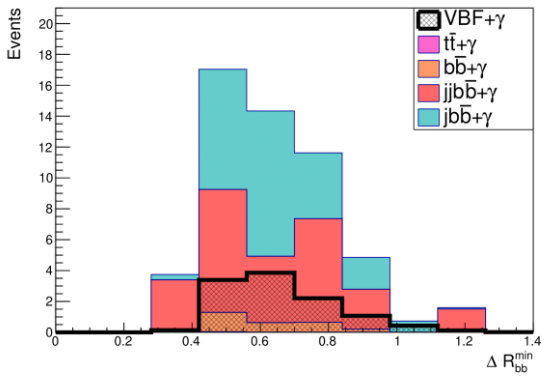
Stephen Roche

After applying cuts, background reduced by a factor of ~ 15

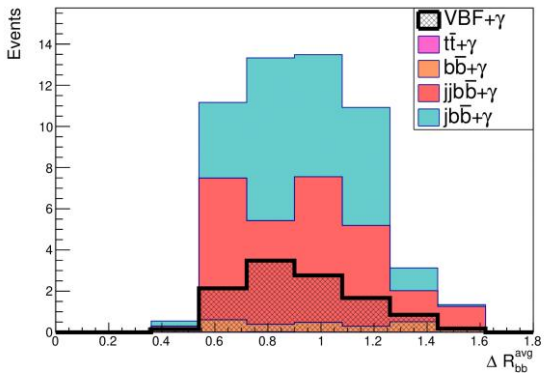
- Very little effect on signal
- Note these plots are no longer have a logarithmic y-axis



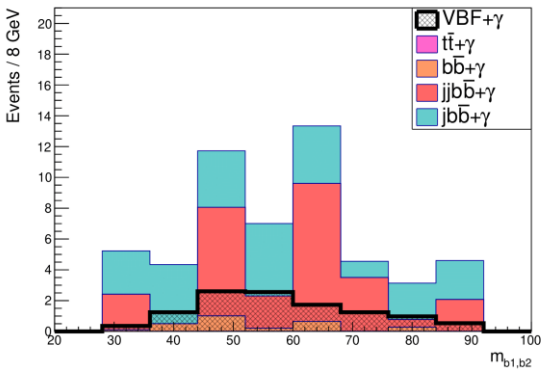
Invariant mass of 3 b-jets



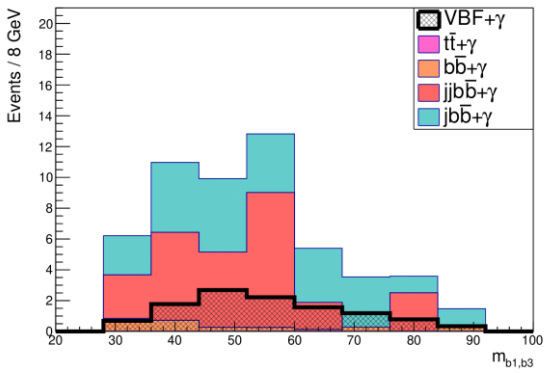
Distance between 2 closest b-jets



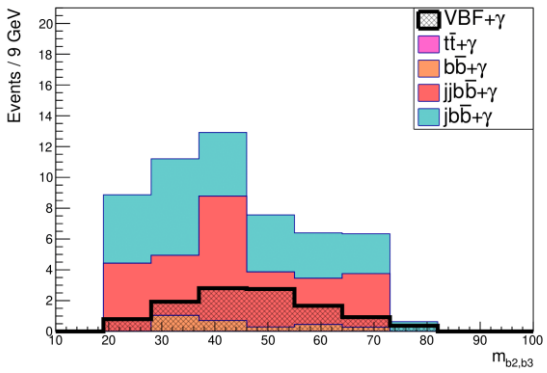
Average distance between b-jets



Invariant mass of b1 and b2



Invariant mass of b1 and b3



Invariant mass of b2 and b3

Sensitivity

Using both 3b and 4b states improves sensitivity

- Best case scenario: signal significance of 3.6
- Sensitive to branching ratio of ~ 50%
- Caveat: S and B both small, so S/√B may not be a perfect estimate of signal strength

	4b final state		3b final state	
	S	B	S	B
Higgs production cuts (VBF & photon)	4.88	65	14.85	751
S/√B	0.61		0.54	
Final state cuts	3.58	1.16	11.24	59.93
S/√B	3.32		1.45	
Combined S/√B	3.62			

Integrated luminosity: 150 fb^{-1}

Conclusions

The search is on for Higgs-like scalar bosons

- VBF + photon is a useful Higgs production mechanism for identifying difficult final states
- The 4b final state is difficult, but potentially promising

Ongoing work

- Further sample generation for improved statistical strength
- Investigating multivariate techniques for signal and background discrimination in 3b case such as BDT
- More in-depth statistical analysis

Thank you!

Any questions?