Boosted Multi-Higgs with Jets in CMS

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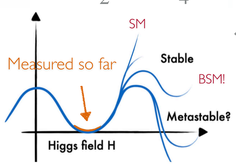
Di-Higgs

- Can characterize the Higgs potential
- Access Higgs self- and vector-boson-couplings

$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$

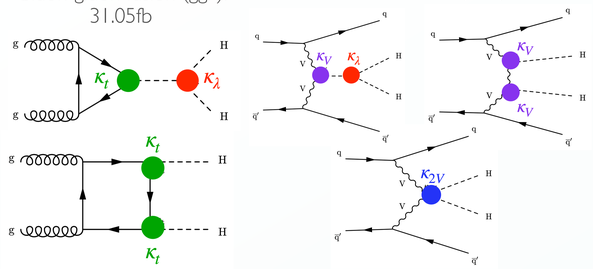


$$\mathscr{L} \supset -\frac{m_t}{v}\bar{t}tH + \frac{m_H^2}{2v}H^3 + \frac{m_H^2}{8v^2}H^4 + \delta_V\frac{2m_V^2}{v}V_\mu V^\mu H + \delta_V\frac{m_V^2}{v^2}V_\mu V^\mu H^2$$

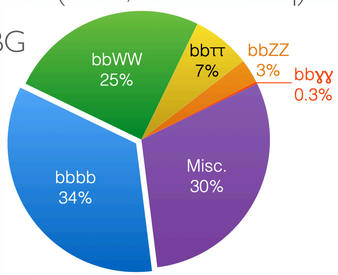
- Small SM cross sections: ~5000 total in Run 2

Gluon-gluon fusion (ggF): 31.05fb

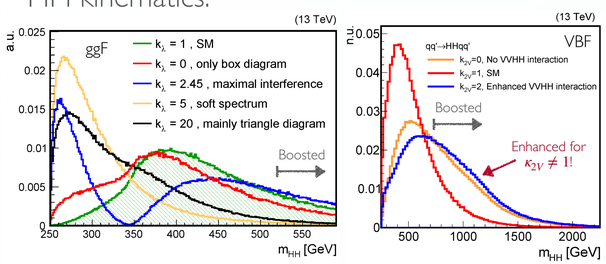
Vector-boson fusion (VBF): 1.73fb



- Top 2 BRs are hadronic (bbbb, bbVV→bb4q)
- Challenging QCD BG
- Idea: ***BOOST***
- Lower background
- Can exploit ML techniques for jets



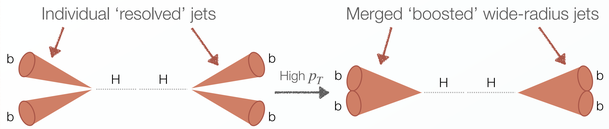
- HH kinematics:



- QCD exponentially falling for high H $p_T \Leftrightarrow m_{HH}$

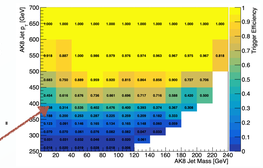
Boosted Techniques

- Select for high p_T jets ($\gtrsim$ 300 GeV)

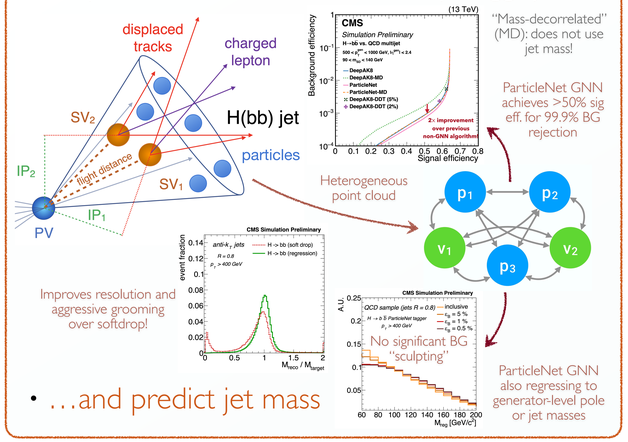


- Anti-k_T clustering with typical $R = 0.8$ (AK8)

- Missing dedicated triggers in Run 2
- "Soup" of AK8 jet triggers
- p_T, mass, single-b tagging…
- Jet p_T turn-on around 400-500 GeV



- Graph neural networks to identify Higgs jets…



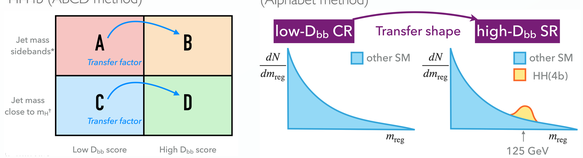
- …and predict jet mass

- Data-driven QCD/multi-jet BG estimates

Mass-decorrelated tagger is key:
Can use jet mass and tagger score (D_{bb}) as orthogonal axes for ABCD method

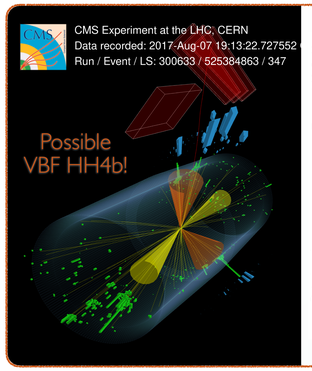
Constant transfer factor N_B/N_A for VBF HH4b (ABCD method)

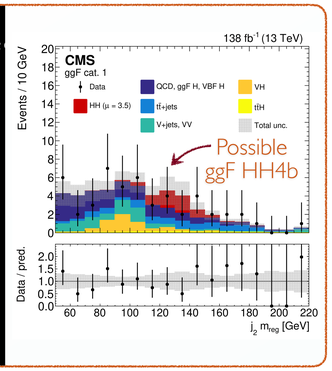
Parametric transfer factor in m_{reg} for ggF HH4b (Alphabet method)



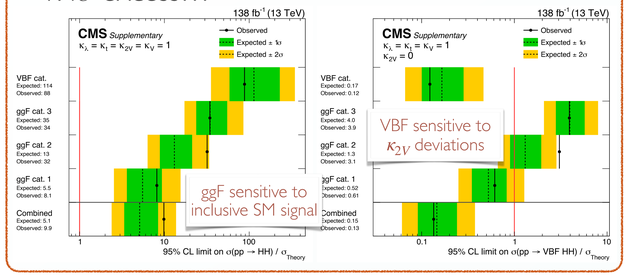
- Top quark, vector boson BGs from MC (+ corrections)

Run 2 HH4b Results

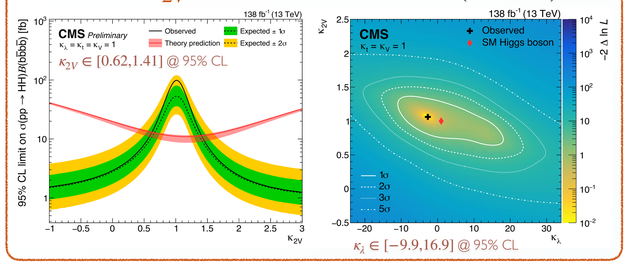




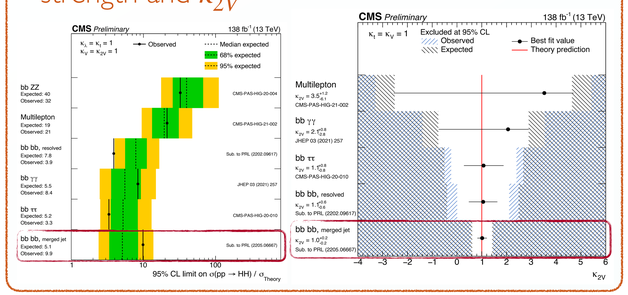
- ggF and VBF categories combined: $\mu = 3.5^{+3.3}_{-2.5}$
- 1.4σ excess…



- Excludes $\kappa_{2V} = 0$ for the first time (at 6.3σ)

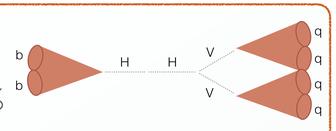


- Most sensitive in CMS to inclusive HH signal strength and κ_{2V}



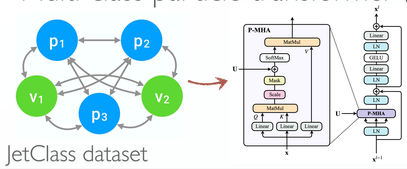
Future prospects

- bbVV→bb4q channel
- 2nd highest BR: 13.4%



- Can take advantage of boosted 4b techniques
- Expect next-best sensitivity to κ_{2V}

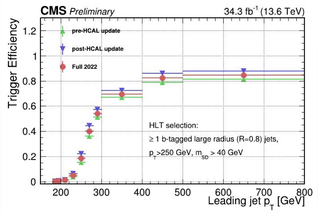
- Multi-class particle transformer (ParT)



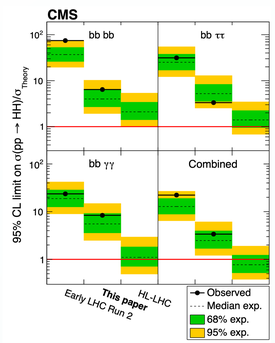
JetClass dataset

	All classes		$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to 4q$	$H \to \ell\nu qq'$	$t \to bqq'$	$t \to b\ell\nu$	$W \to qq'$	$Z \to q\bar{q}$
	Accuracy	AUC	Rej$_{50\%}$	Rej$_{50\%}$	Rej$_{50\%}$	Rej$_{50\%}$	Rej$_{99\%}$	Rej$_{50\%}$	Rej$_{99.5\%}$	Rej$_{50\%}$	Rej$_{50\%}$
PFN	0.772	0.9714	2924	841	75	198	265	797	721	189	159
P-CNN	0.809	0.9789	4890	1276	88	474	947	2907	2304	241	204
ParticleNet	0.844	0.9849	7634	2475	104	954	3339	10526	11173	347	283
ParT	**0.861**	**0.9877**	**10638**	**4149**	**123**	**1864**	**5479**	**32787**	**15873**	**543**	**402**

- ParticleNet AK8 bb tagging at HLT in Run 3
- 70% efficiency for 300-400GeV p_T jets
- 2-10x improvement over Run 2



- 4b expected to play major part in bringing HH limit <1 at HL-LHC
- Overall, exciting times ahead for boosted HH!



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