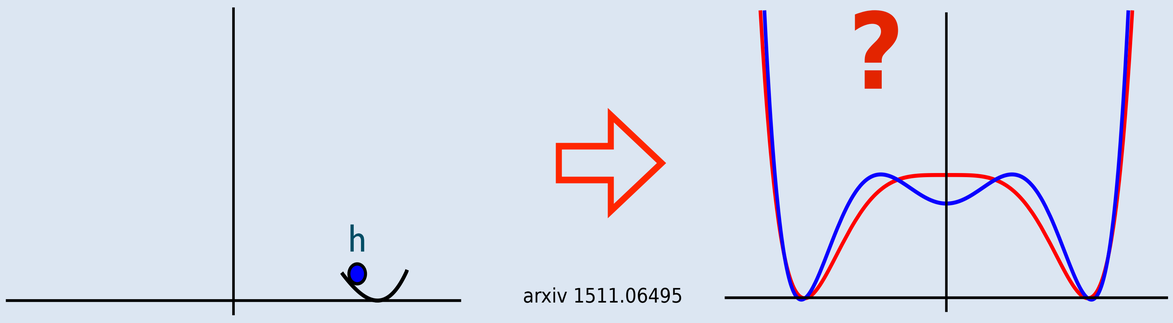
Boosting Higgs-Pair Production in the $b\bar{b}b\bar{b}$ Final State With Multivariate Techniques

J. K. Behr [1] D. Bortoletto[2] J. Frost[2] N. P. Hartland[2] C. Issever[2] J. Rojo[2]
[1]DESY [2]University of Oxford

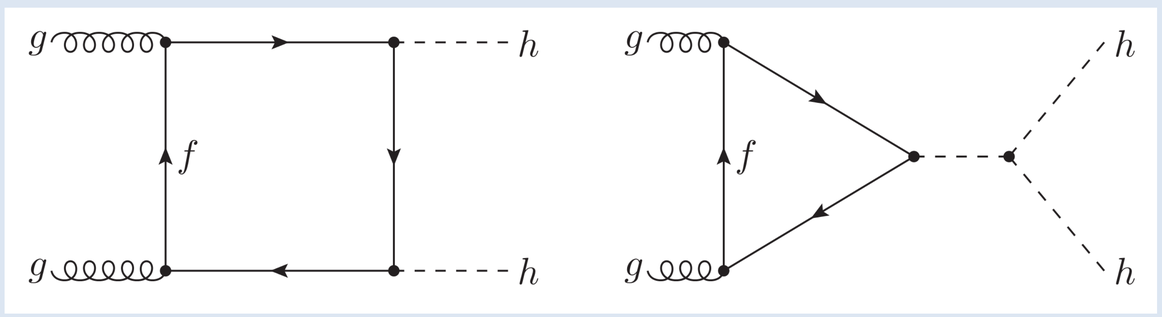
PROBING THE HIGGS POTENTIAL

- Shape of Higgs potential postulated ad-hoc, not derived from first principles
- Current measurements only probe potential around minimum
- Full potential accessible via Higgs self-couplings

Current measurements



- Trilinear coupling accessible via Higgs pair production
- Provides test of EWSB mechanism
- Sensitive to BSM physics



A central physics goal of the LHC, HL-LHC and future colliders

THE CHALLENGE

- HH cross-section is tiny in the SM: $\sigma^{\text{SM-LO}} \approx 3\text{-}4 \times 10^{-2}$ pb
- The largest Higgs decay mode is $b\bar{b}$: BR(H→ $b\bar{b}$) ≈ 0.57
- But $HH \to b\bar{b}b\bar{b}$ suffers overwhelming QCD multi-jets background

Process	Generator	N_{evt}	σ_{LO} (pb)	K-factor
$pp \to hh \to 4b$	MG5_aMC@NLO	1M	$6.2 \cdot 10^{-3}$	2.4 (NNLO+NNLL)
$pp \to b\bar{b}b\bar{b}$	SHERPA	3M	$1.1 \cdot 10^{3}$	1.6 (NLO)
$pp \to b\bar{b}jj$	SHERPA	30M	$2.7 \cdot 10^{5}$	1.3 (NLO)
$pp \to jjjj$	SHERPA	30M	$9.7 \cdot 10^{6}$	0.6 (NLO)

- LHC Run 2 and 3: $\int \mathcal{L}$ =300 fb^{-1} and pile-up between 40-60
- HL-LHC: $\int \mathcal{L}$ = 3000 fb^{-1} and levelled pile-up of ≈ 140
- Previous studies for $b\bar{b}b\bar{b}$ final state pessimistic: S/√B ≈ 2 @ HL-LHC
  - Not including pile-up and some relevant backgrounds
  - 2b2j background is not negligible w.r.t. 4b after applying b-tagging

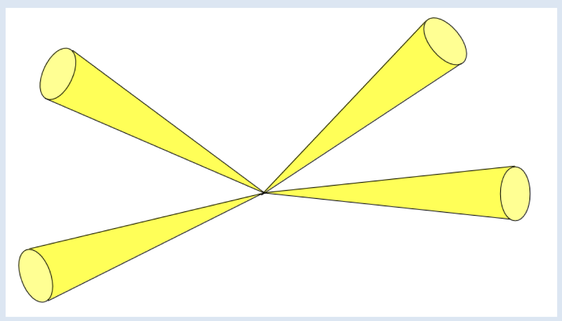
$$\frac{\text{EFF}_{\text{b-tag}}[2b2j]}{\text{EFF}_{\text{b-tag}}[4b]} \simeq \left(\frac{f_l}{f_b}\right)^2 \simeq 1.5 \cdot 10^{-4} \quad \Rightarrow \quad \frac{\text{EFF}_{\text{b-tag}}[2b2j]}{\text{EFF}_{\text{b-tag}}[4b]} \simeq 5 \cdot 10^{-3}$$

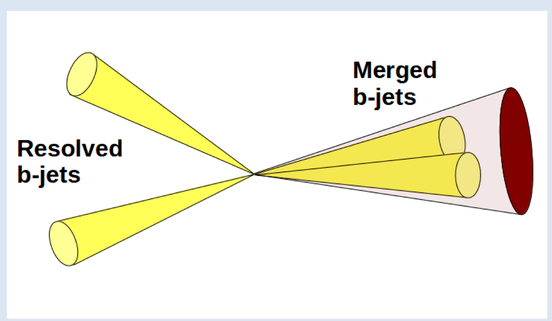
b-quark radiation in parton shower and additional light jets

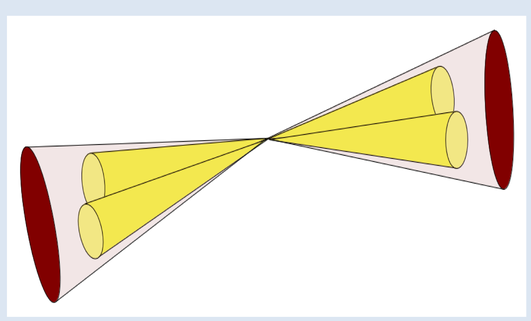
INCLUDE PILE-UP AND PILE-UP MITIGATION TOOLS

- PU simulation: Overlay Pythia8 events (< μ >= 80 or 150)
- PU mitigation with SoftKiller [arXiv:1407.0408]
- PU mitigation with trimming for large-R jets

STRATEGY: OPTIMIZE AND COMBINE ALL DECAY TOPOLOGIES







RESOLVED

- 4 b-tagged anti-k_T R = 0.4 (small-R) jets with p_T > 40 GeV and $|\eta^{\text{jet}}|$< 2.5
- Higgs reconstruction from leading 4 jets choosing combinations that minimises di-jet mass difference

INTERMEDIATE

- 1 large-R jet (Higgs-tagged + b-tagged)
- 2 b-tagged small-R jets, ΔR > 1.2 w.r.t. large-R jet

BOOSTED

- 2 large-R jets (Higgs-tagged + b-tagged) with p_T > 200 GeV and $|\eta^{\text{jet}}|$< 2.0
- Leading jets taken as Higgs candidates

For all categories:

- Loose Higgs mass window cut: $|m_{h,j}$-125 GeV|< 40 GeV; j = 1, 2
- Rank categories by S/√B to make them exclusive:

Higgs-tagging:

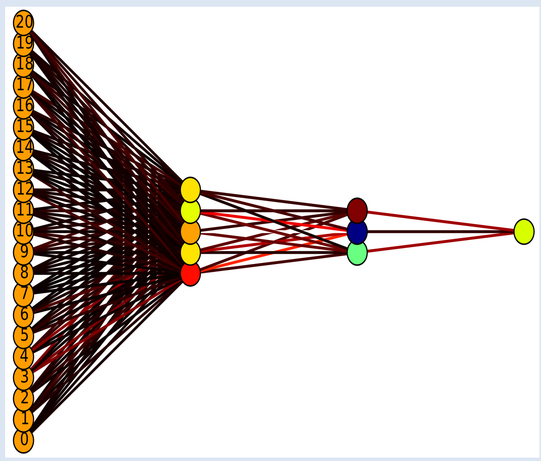
- Trimmed anti-k_T R = 1.0 jet
- BDRS mass-drop tagged [arxiv:0802:2470]
- 2 matched b-tagged anti-k_T R = 0.3 jet

b-tagging

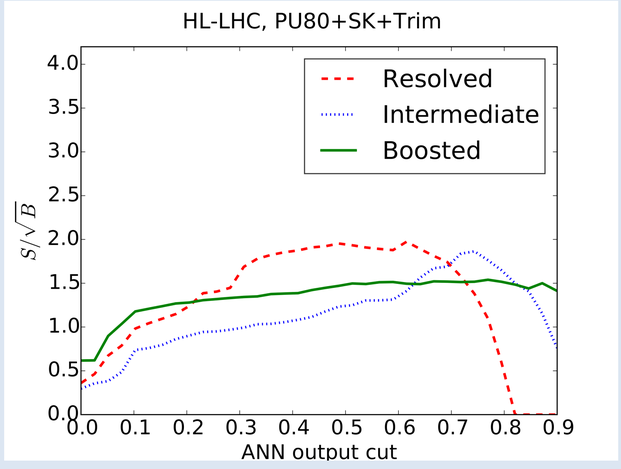
- b-jet: f_b = 0.8
- c-jet: f_c = 0.1
- light jet: f_l = 0.01

STRATEGY: MULTIVARIATE ANALYSIS

- Multi-layer feed-forward Artificial Neural Net - perceptron
- Architecture: $N_{\text{var}} \times 5 \times 3 \times 1$
- Trained separately for each category on the signal nd background distributions of 21 input variables: m_H, $p_{T,H}$, m_{HH}, $p_{T,HH}$, R_{HH}, substructure, ...



RESULTS



- $HH \to b\bar{b}b\bar{b}$ could provide sufficient sensitivity to claim evidence for HH production

Combination yields:

S/√B≃3.1 with $\int \mathcal{L}$ =3000 fb^{-1}

- Result is not sensitive to pile-up if pile-up reduction tools are used (S/√B≃4)
- Key issues:
  - Reduce light- and charm-mistag rates
  - Optimise PU mitigation techniques
  - Improve jet mass resolution
  - Keep trigger thresholds low to maintain efficiency in resolved channel

European Research Council
Science & Technology Facilities Council
HELMHOLTZ ASSOCIATION

Behr, J.K., Bortoletto, D., Frost, J.A. et al.
Eur. Phys. J. C (2016) 76: 386. doi:10.1140/epjc/s10052-016-4215-5