Constraining the Higgs branching ratio to jets

EF01 Working group meeting

Snowmass LOI EF01 067

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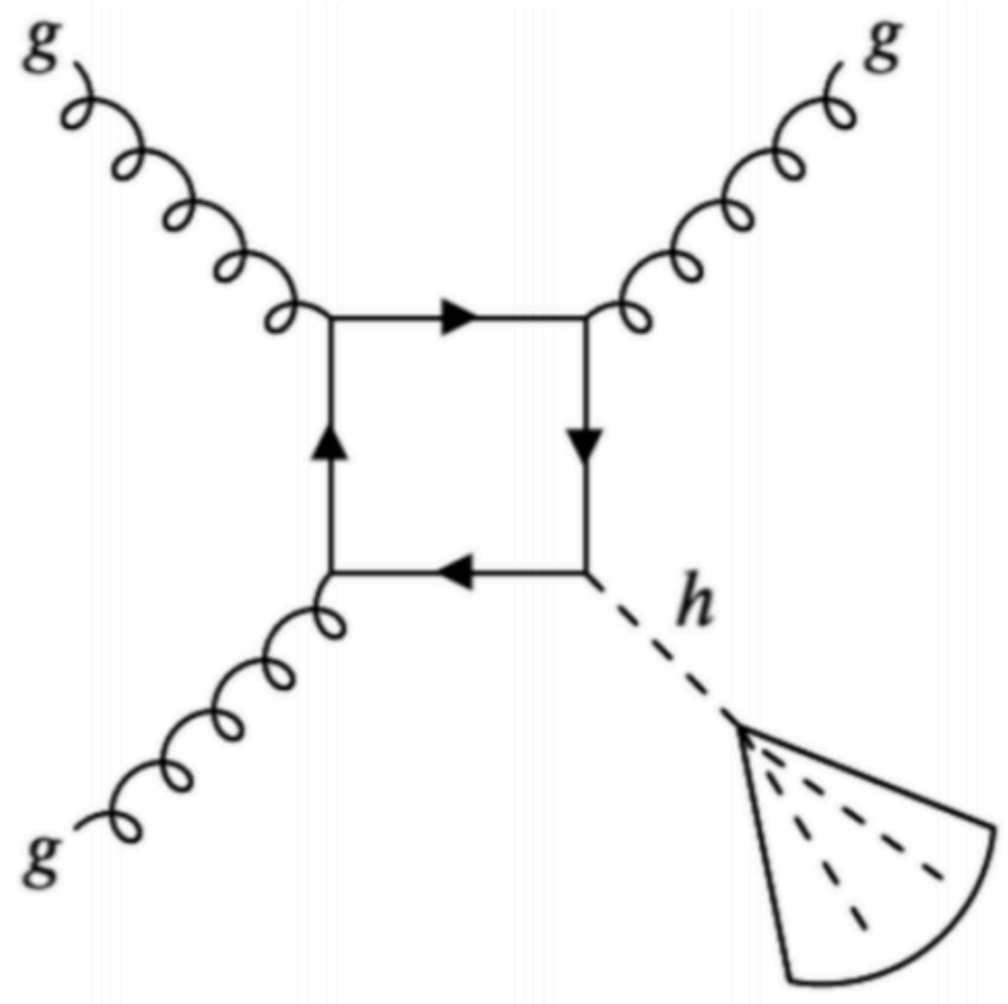
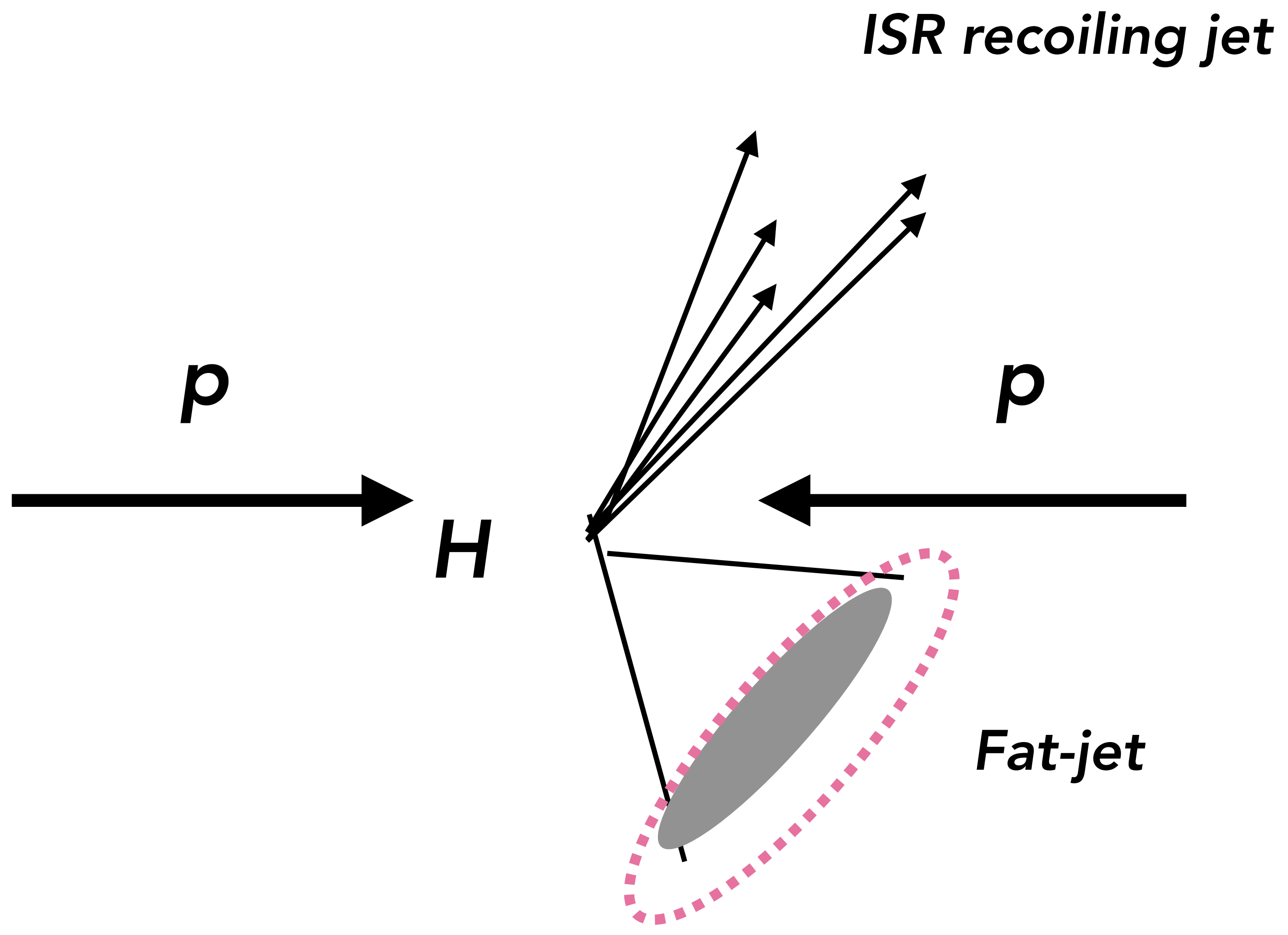
Motivation

- Higgs couplings are a crucial test of SM
- The HL-LHC has potential to test them at a higher precision
- In this talk, we will focus on **Higgs decays to hadronic final states**
  - These have high branching ratios
  - Some are still un-explored at LHC because of high background
  - High p_T reconstruction opens a window to constrain them

Can we reconstruct the Higgs decays into one single cone?

e.g. consider ggH production



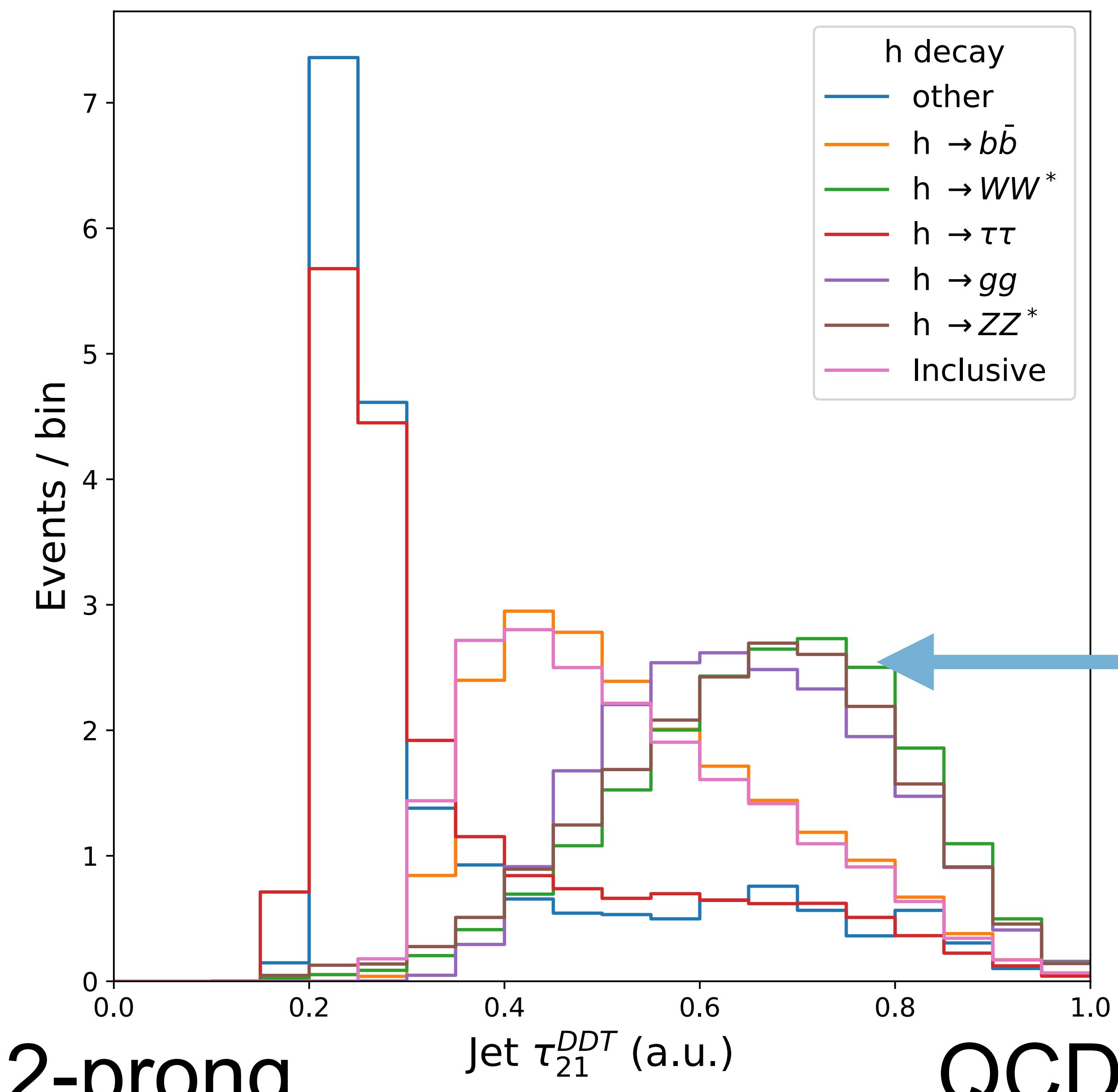


- We can reconstruct Higgs as one single large-cone jet
  - Require high-pT jet
  - Tag a Higgs jet - Main background is from QCD jets
  - Reconstruct Higgs jet mass and perform a fit

A baseline result @ 3000 fb^{-1}

With common available tools

Use jet-substructure tools (n-subjetiness) for tagging

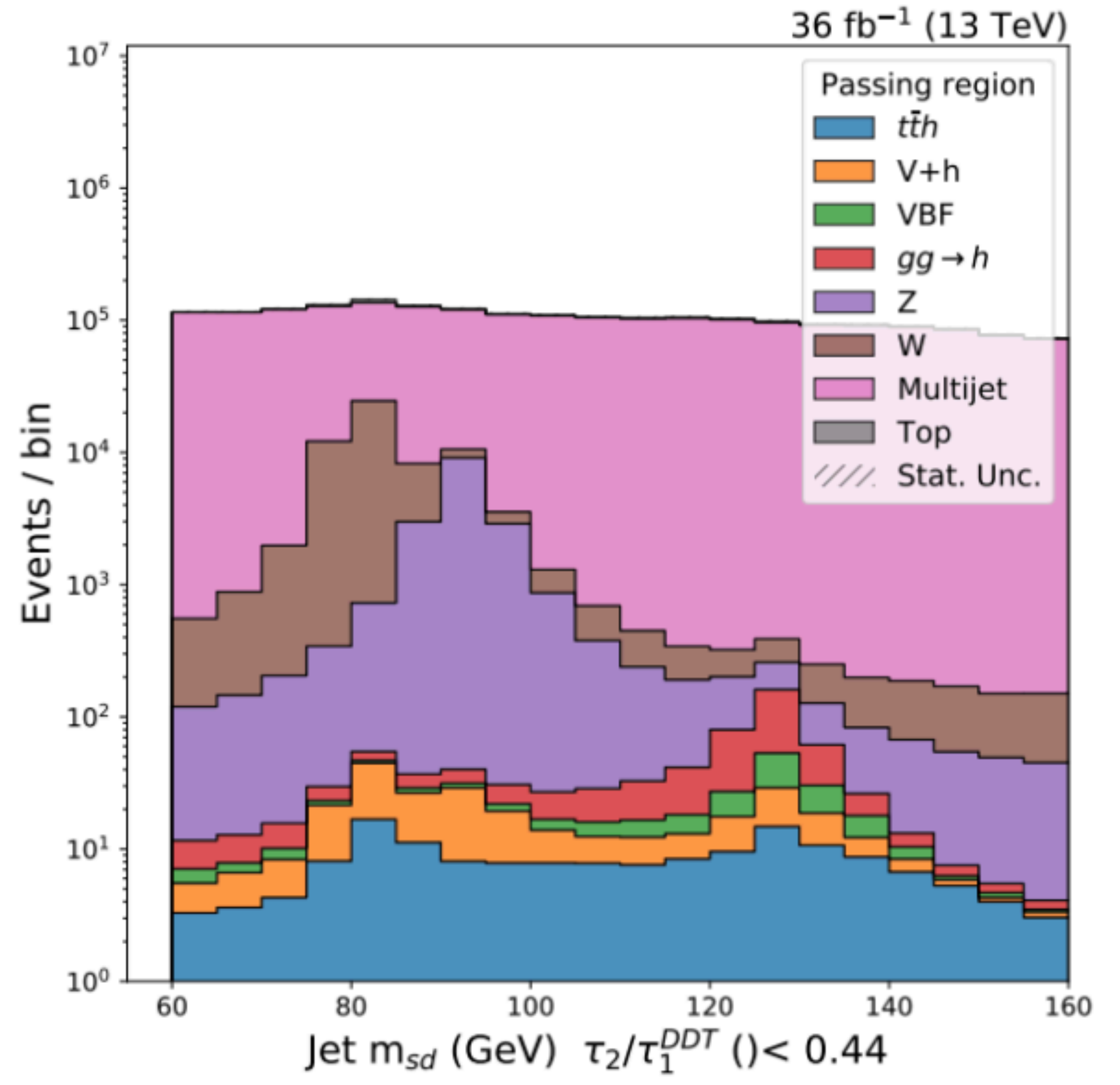


2-prong

QCD

not optimal for gg/WW/ZZ

Use jet soft-drop mass



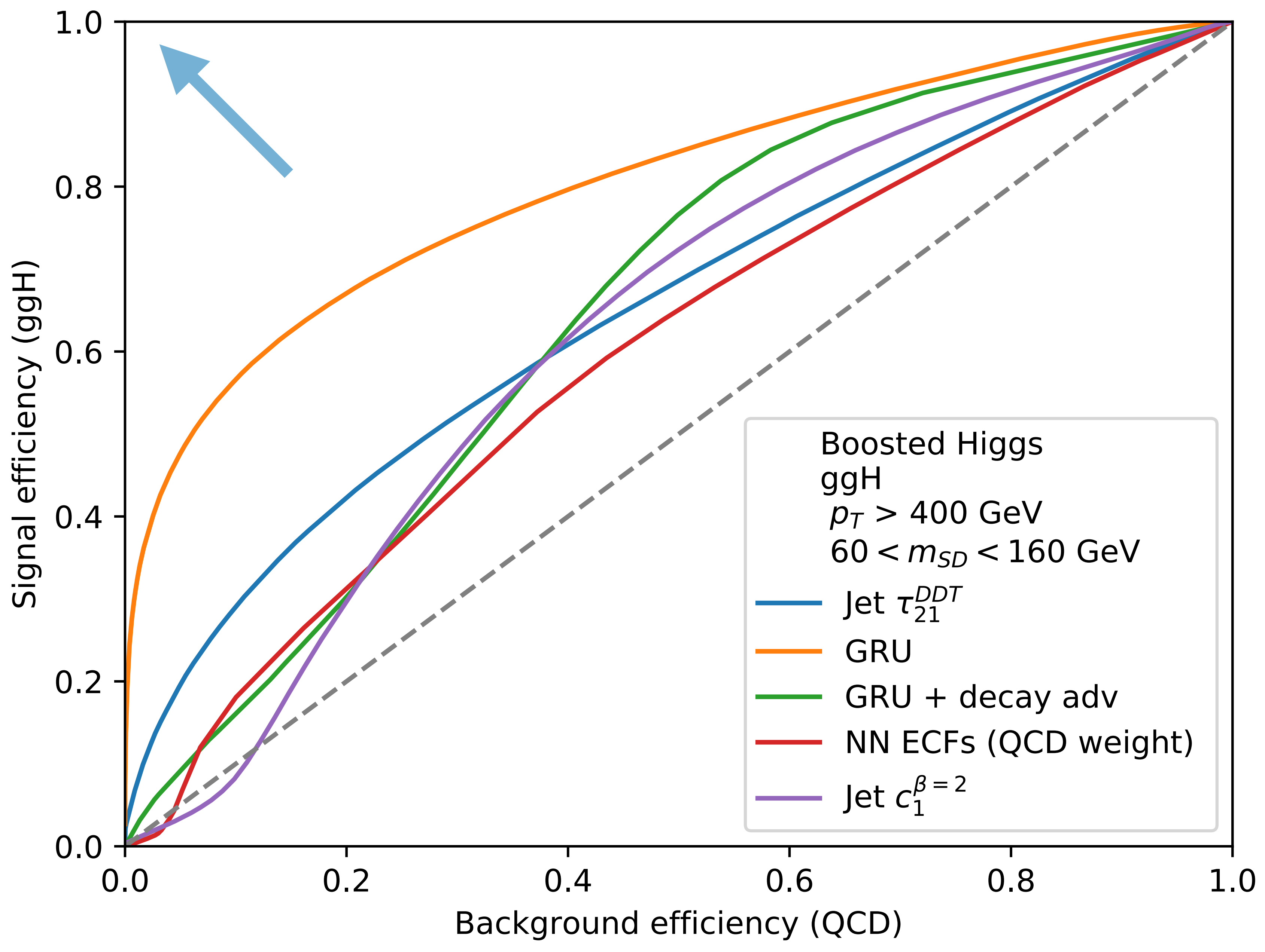
Fit for Higgs signal

Decay channel	Branching ratio	$\delta\sigma_h$
Inclusive	1	$0.46 \times \sigma$ SM
$h \to \bar{b}b$	5.84×10^{-1}	$0.16 \times \sigma$ SM
$h \to WW^*$	2.14×10^{-1}	$2.4 \times \sigma$ SM
$h \to gg$	8.19×10^{-2}	$0.7 \times \sigma$ SM
$h \to \bar{\tau}\tau$	6.27×10^{-2}	$0.44 \times \sigma$ SM
$h \to \bar{c}c$	2.89×10^{-2}	$0.13 \times \sigma$ SM
$h \to ZZ^*$	2.62×10^{-2}	$1.4 \times \sigma$ SM

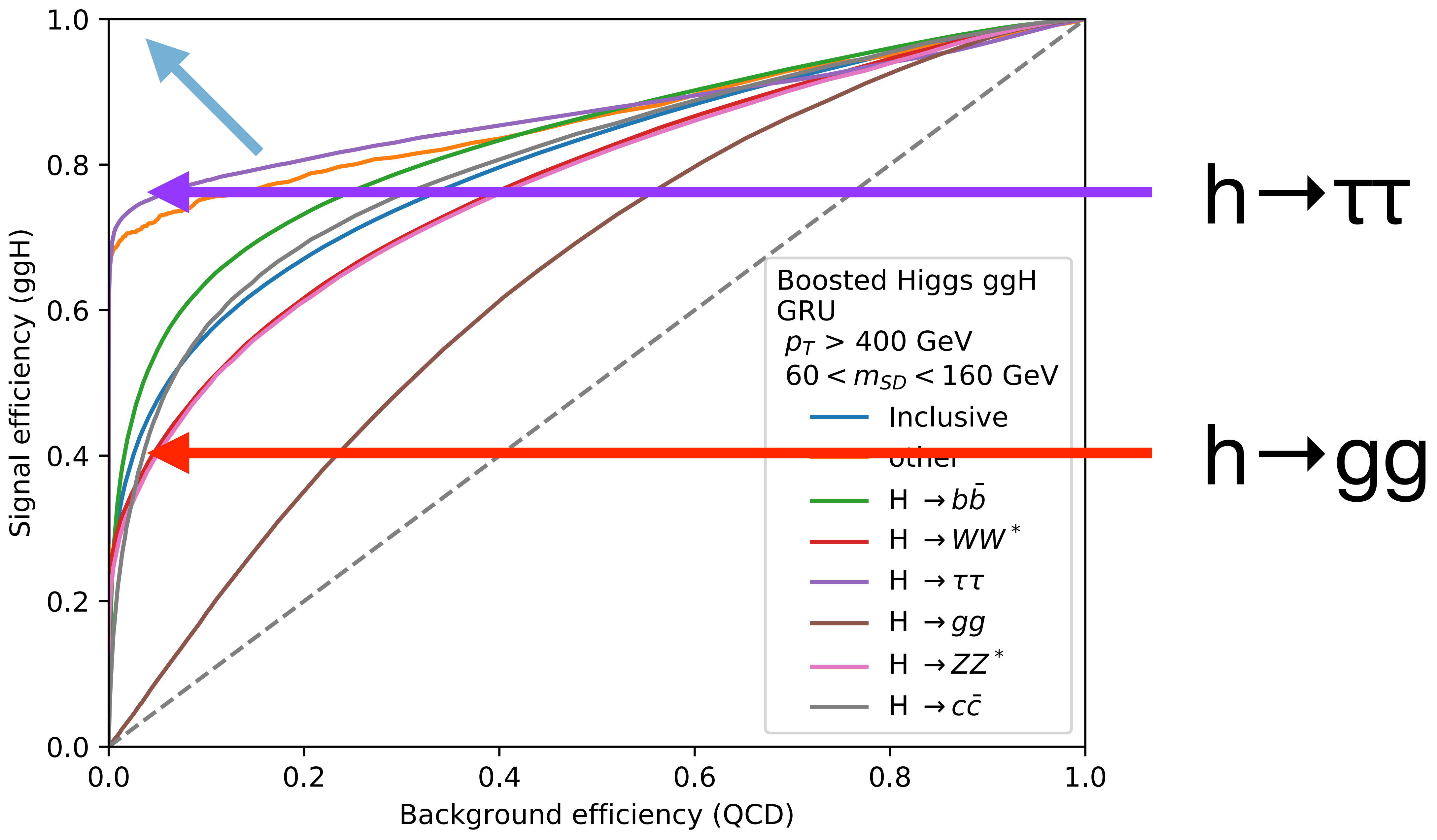
Use deep learning for tagging

How good is our discrimination against unexplored hadronic modes

Deep learning for tagging
w. jet particles (pT, η, ϕ, ID)



Performance depends on
decay channel (worse for gg)



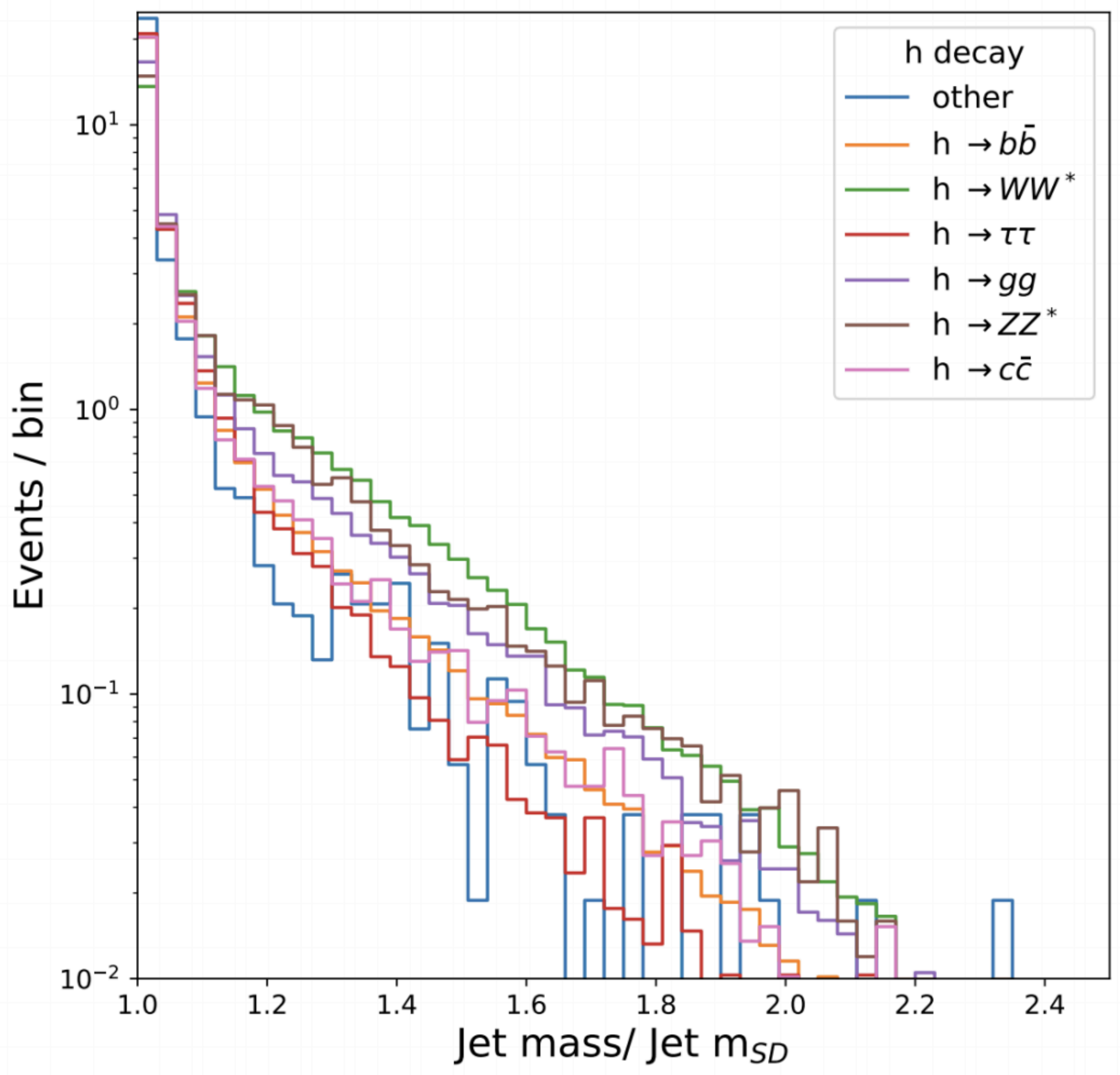
Use color singlet property for tagging

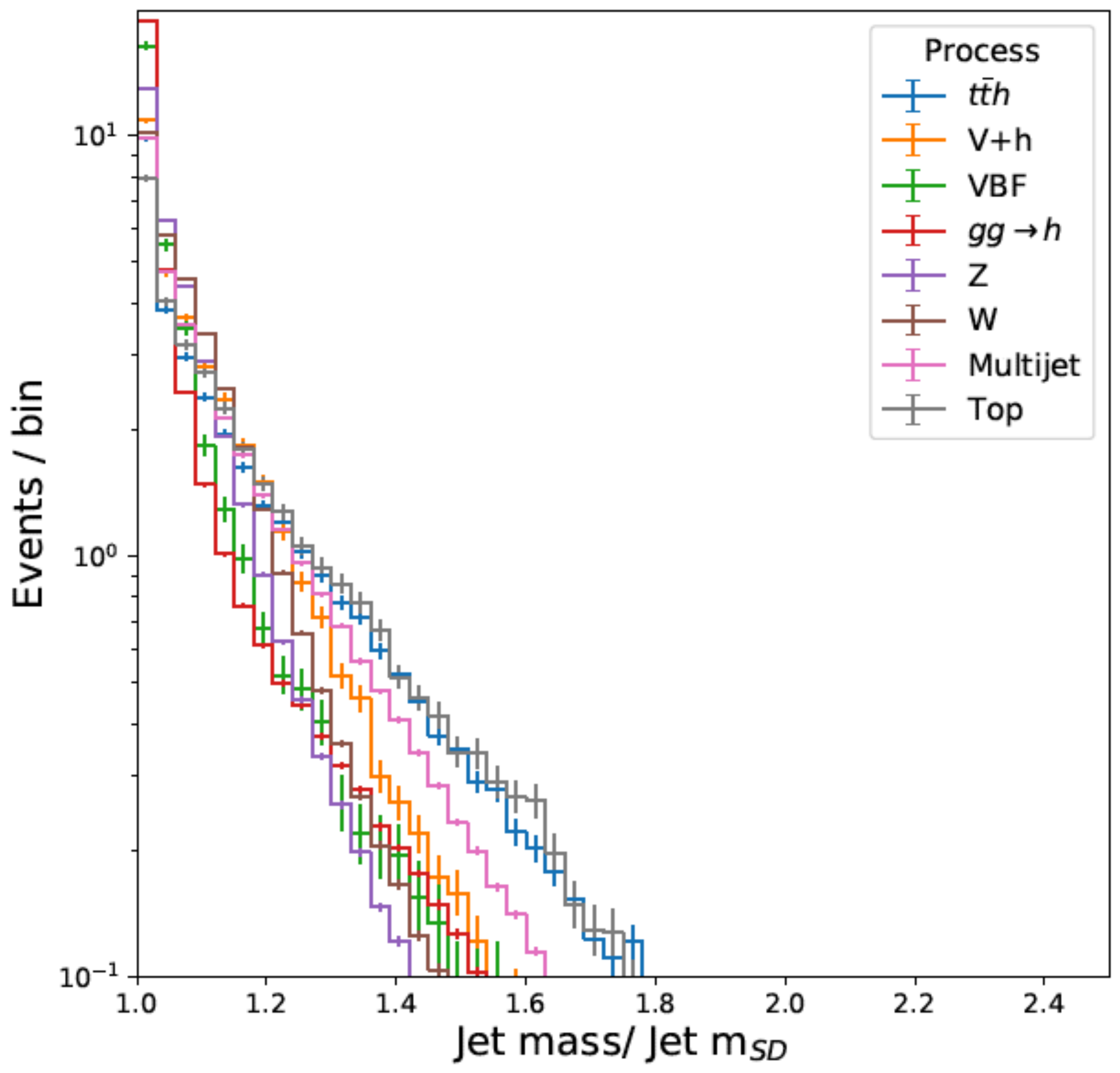
e.g. a ratio of groomed and ungroomed mass

can show differences in retaining collinear components but removing soft emissions

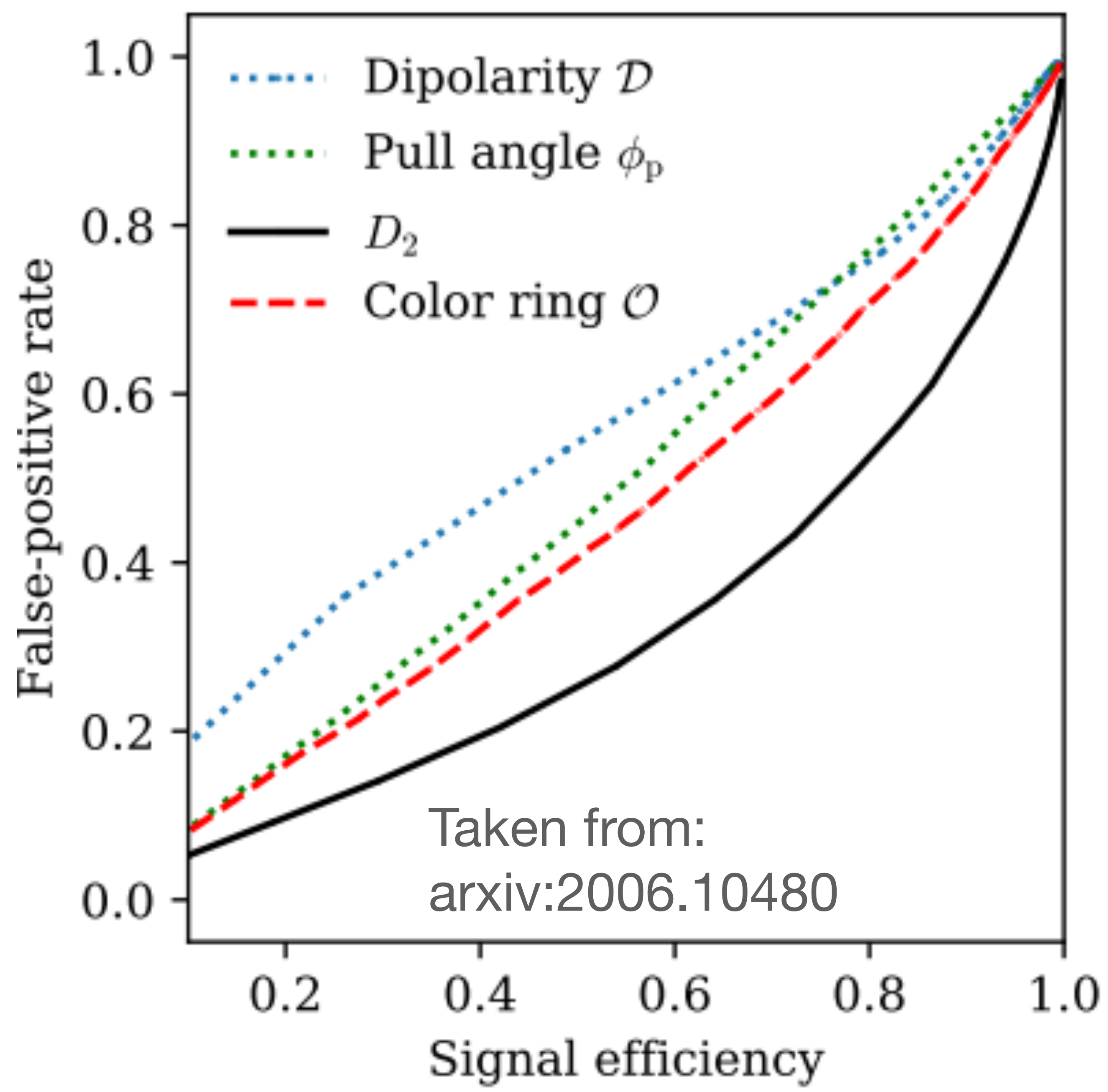
This is an idea also in development

see e.g. collinear-drop (arxiv:1907.11107.pdf) and color-singlet observables (arxiv:2006.10480)





$H \to gg$

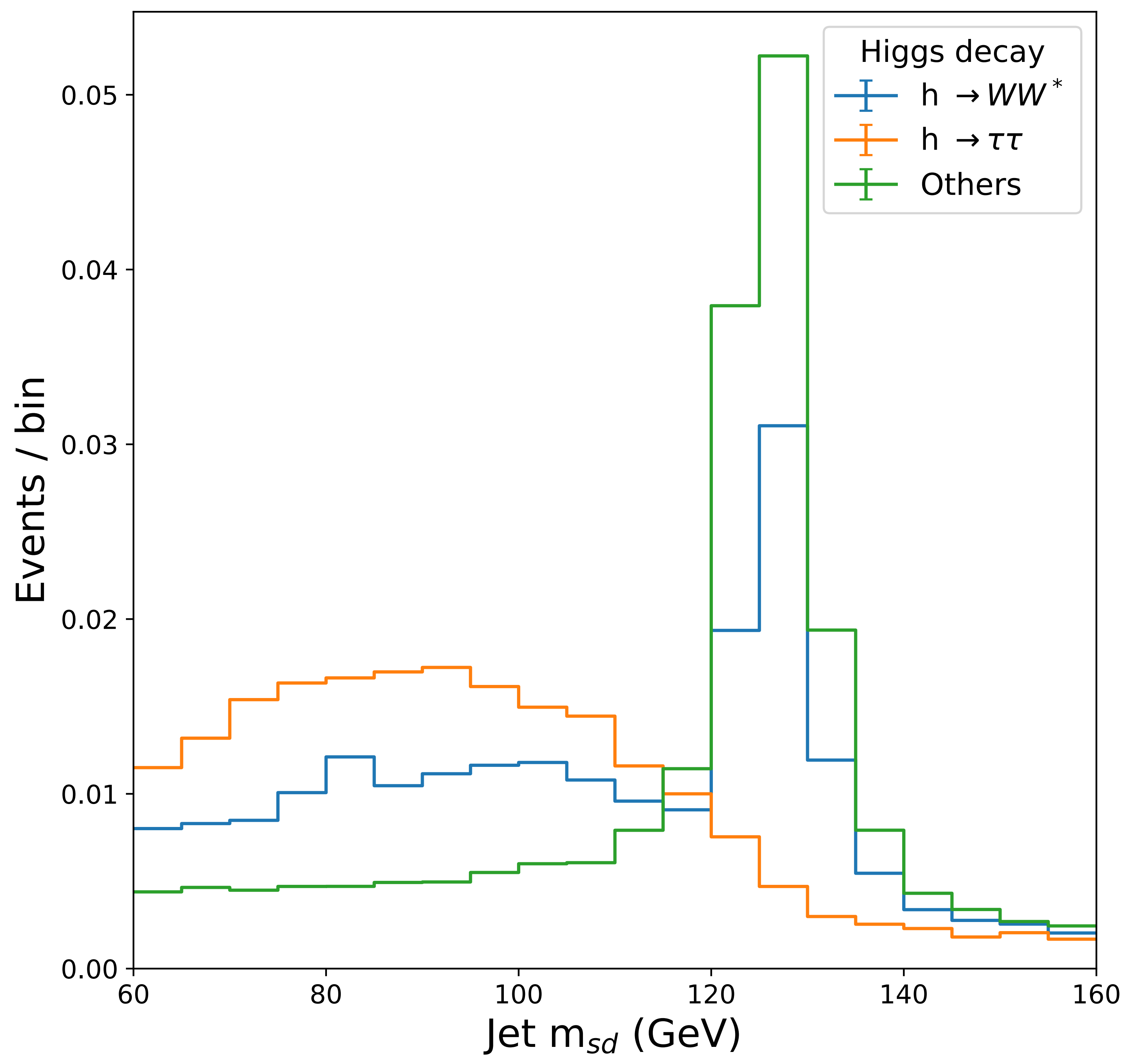


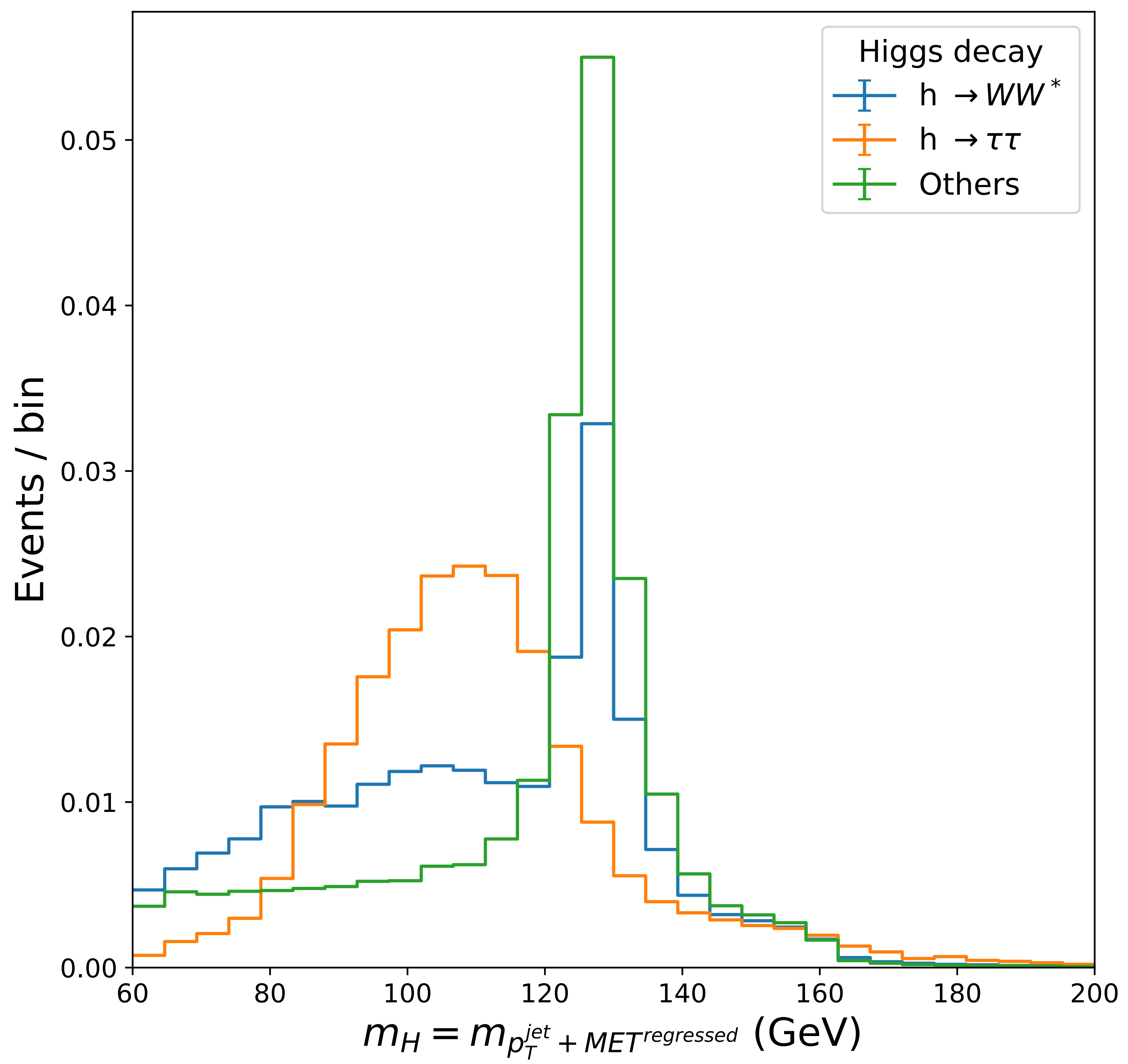
Use deep learning for mass regression

Need to find a way to include semi-visible decays in the reconstruction

Jet soft drop mass has broad peaks for h→ττ and WW

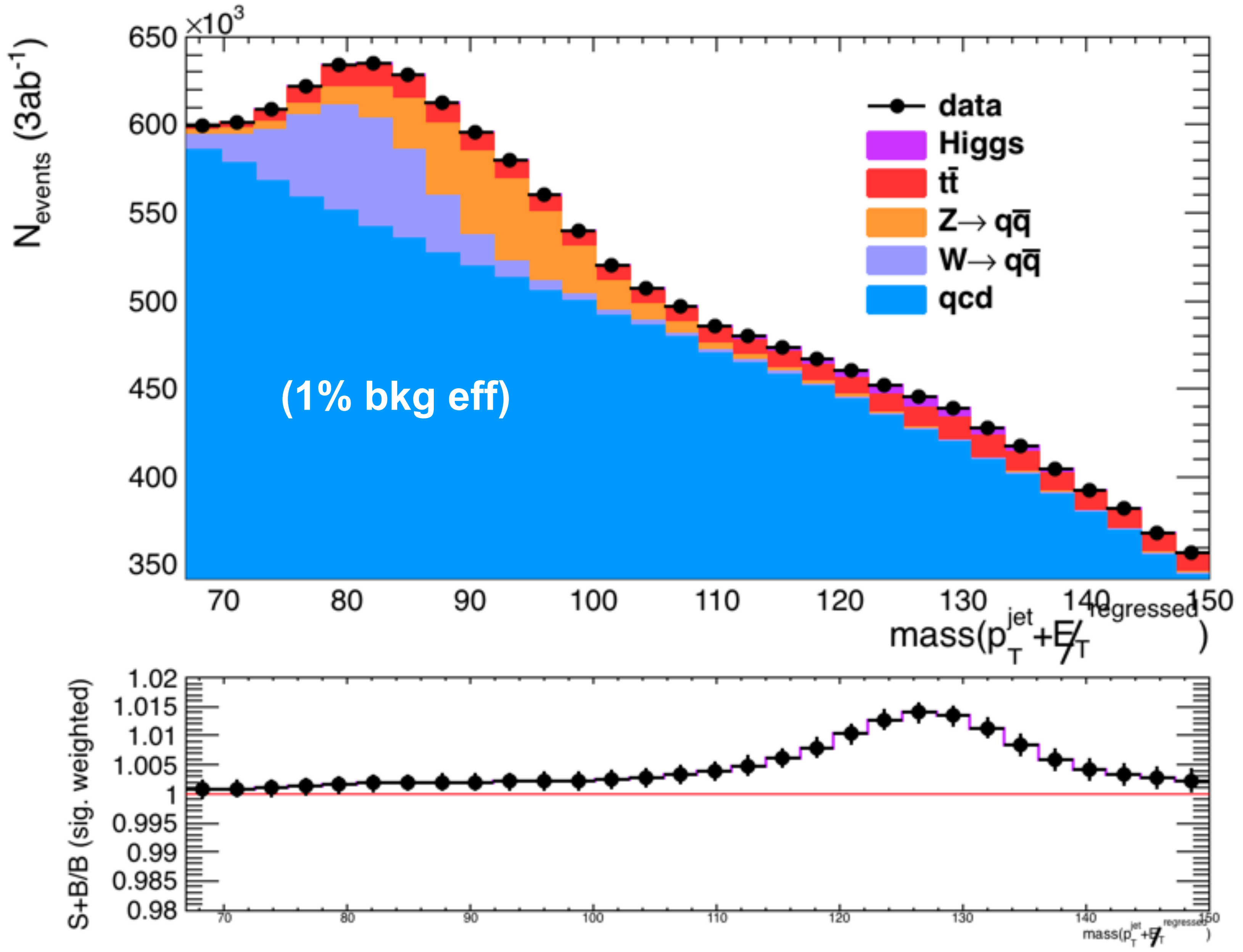
Use regressed (jet + neutrino) 4-vector





Improved performance

Fit to regressed Higgs jet mass



We are able to improve limit by almost 50%

Tagger	QCD background efficiency	$\delta\sigma_h$
$(\tau_2/\tau_1)^{\mathrm{DDT}}$	6%	$0.46 \times \sigma$ SM
$\mathrm{GRU}^{\mathrm{DDT}}$ and mass-ratios $\mathrm{DNN}^{\mathrm{DDT}}$	1%	$0.14 \times \sigma$ SM
$\mathrm{GRU}^{\mathrm{DDT}}$ and mass-ratios $\mathrm{DNN}^{\mathrm{DDT}}$	10%	$0.26 \times \sigma_{\mathrm{SM}}$
$\mathrm{GRU}^{\mathrm{DDT}}$ and mass-ratios $\mathrm{DNN}^{\mathrm{DDT}}$ $(h \rightarrow gg)$	10%	$0.41 \times \sigma_{\mathrm{SM}}$

Take h→gg as proxy for background-like decays

How can we use the constrain on cross section

from the measurement of the boosted Higgs jet

- We can assume that the limit we have obtained by reconstructing the Higgs jet is an **“inclusive” limit**
    - This **assumption has biases** (mainly from decays that are not reconstructed in the jet cone or BSM Higgs decays)
- A constraint on the inclusive cross section can lead to one on the Higgs width:

$$\Gamma_h \propto \frac{1}{\sigma(W + h \to WW)} \times \left(\sigma(gg \to h) \times \frac{\sigma(W + h \to bb)}{\sigma(gg \to h \to bb)} \right)^2$$

Our plans for Snowmass:

Investigate future directions to improve constraint

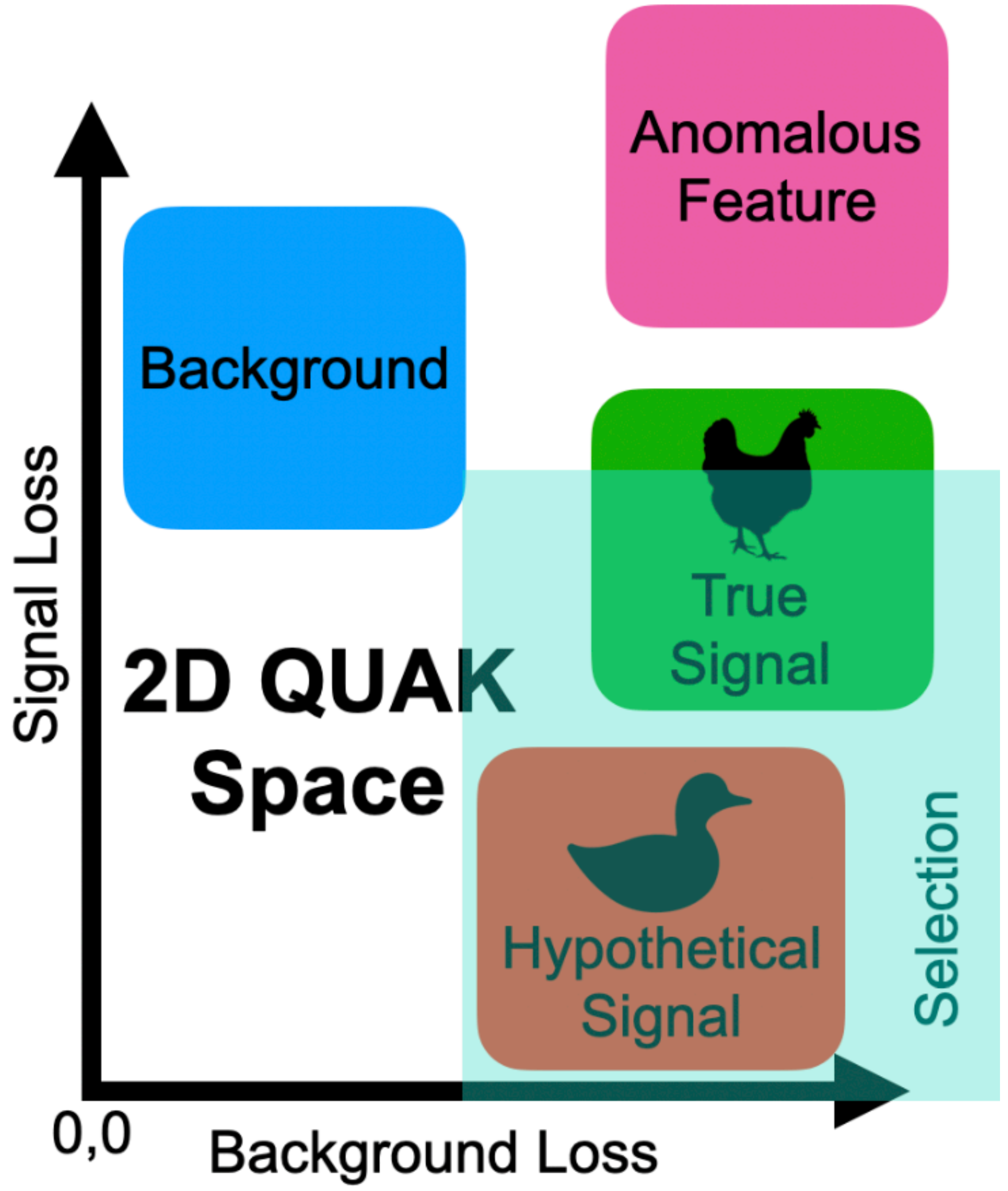
- Demonstrate the feasibility of measuring background-like decays of the Higgs boson:
    - e.g. can we improve our constraint on $h \to gg$
    - or, most importantly, can we constrain BSM Higgs decays that carry some of the SM Higgs boson features
- Study approach that leverages on a prior knowledge of well known decay modes of the Higgs boson

Our plans for Snowmass:

Investigate semi-supervised detection

- Quasi – Anomalous Knowledge approach (QUAK) - see LHC Olympics talk from S.E. Park (MIT) and arXiv to appear soon.
  - Semi-supervised Deep Learning
  - Starts w. background and approximate signal prior (SM Higgs)
  - Construct **2D loss space** to search for similar anomalous signals (from BSM Higgs decays) - these will have large signal and background loss

S.E. Park and P. Harris (MIT)



Summary

- Most results in these slides from: arxiv:1910.02082, study how to reconstruct all hadronic decays of the Higgs in one single-jet cone
- For Snowmass:
  - We want to summarize these results
  - And improve the constraint on challenging decay channels ($h \rightarrow gg$) and Higgs signals that only share certain similarities with the SM Higgs boson signal