A path to evaluating Dalitz decay contamination in $H\to ss$

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work (barely) in progress, based on discussions with Michele Selvaggi

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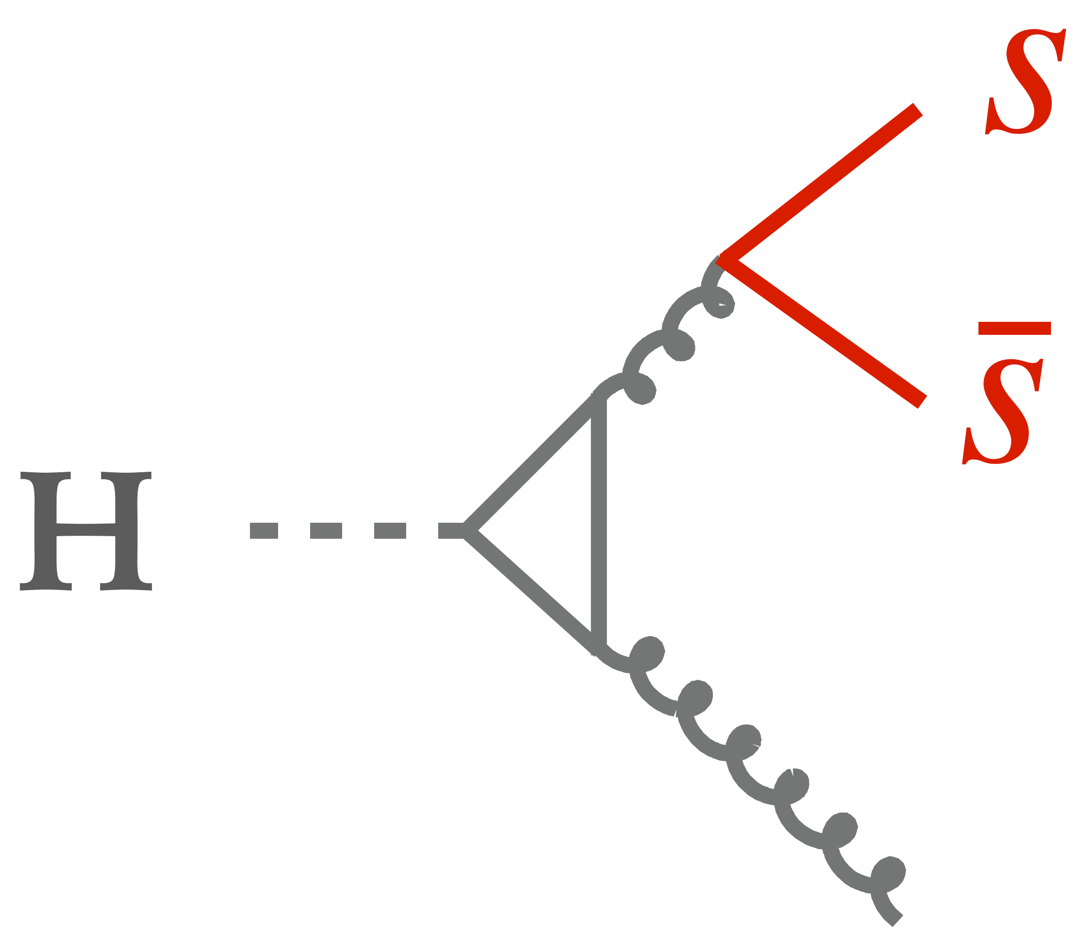
disclaimer

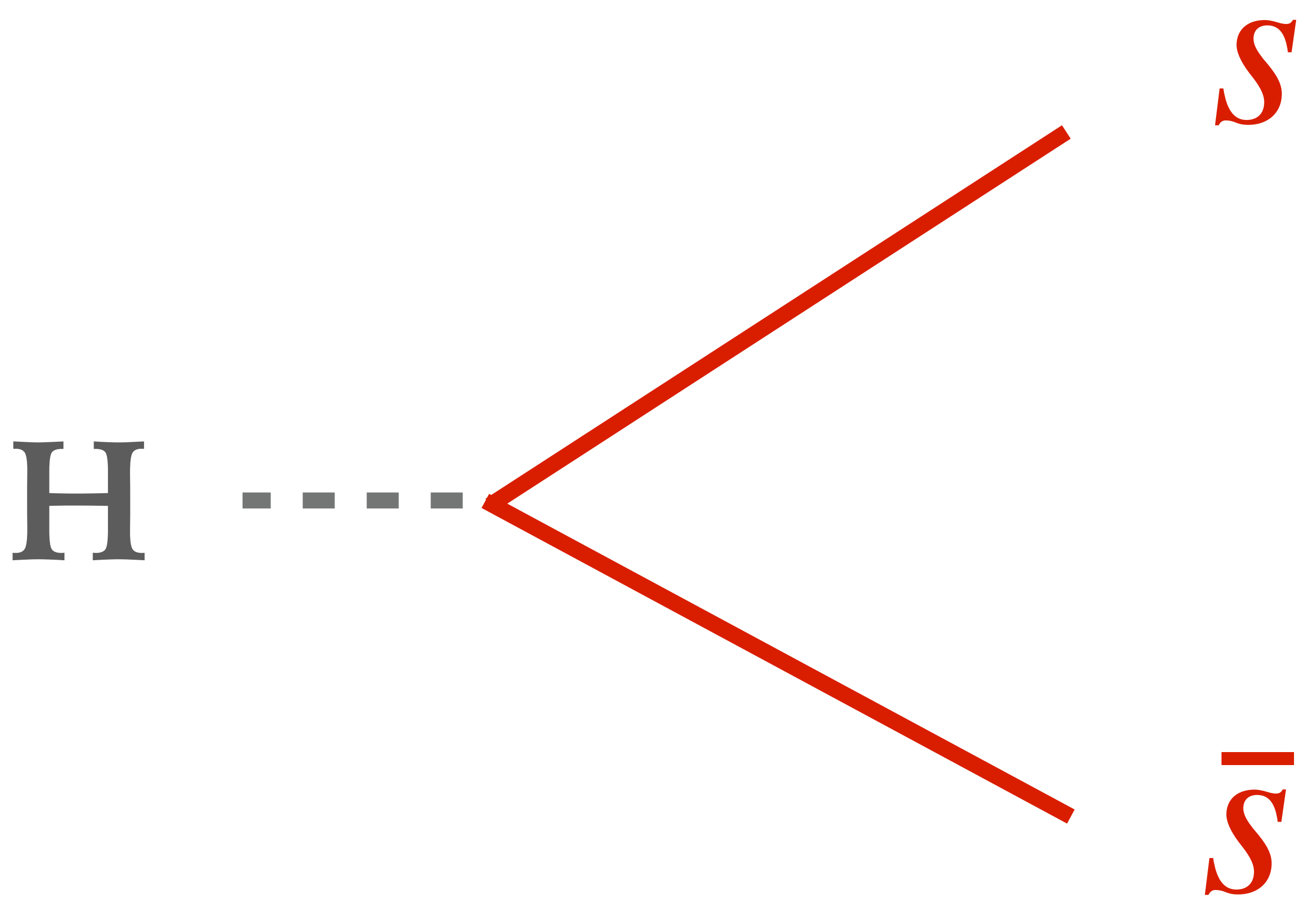
these slides are the result of $O(2–3)$ days' work

everything shown is rough

intention: maybe they can serve as a starting point for others to do a more proper job

Dalitz v. Yukawa H → ss + X





	BR
H → gg	8.1×10^{-2}
H → ss	$\sim 2 \times 10^{-4}$

Ratio is ~ 400

Dalitz decay ($\alpha_s^3 y_t^2$)

$\sim \alpha_s$ suppressed
relative to $H \to gg$

Yukawa decay (y_s^2)

What questions?

Actual experimental tagging will be based on **machine learning**, exploiting Kaon particle-ID (with various underlying experimental techniques, + maybe K_s reco, etc.)

Theorists' job: identify elements to be understood (& remaining uncertainties) for experiments to make reasonable $H \to s\bar{s}$ projections

Kinds of questions to investigate

- rates of basic decay topologies at low perturbative order
- matched parton showers' implicit higher orders in generating basic topologies
- importance of parton showers' extra $g \to s\bar{s}$
- how hadronisation rearranges & adds strangeness (see Skands @ECFA H→ss)

Parton-level studies

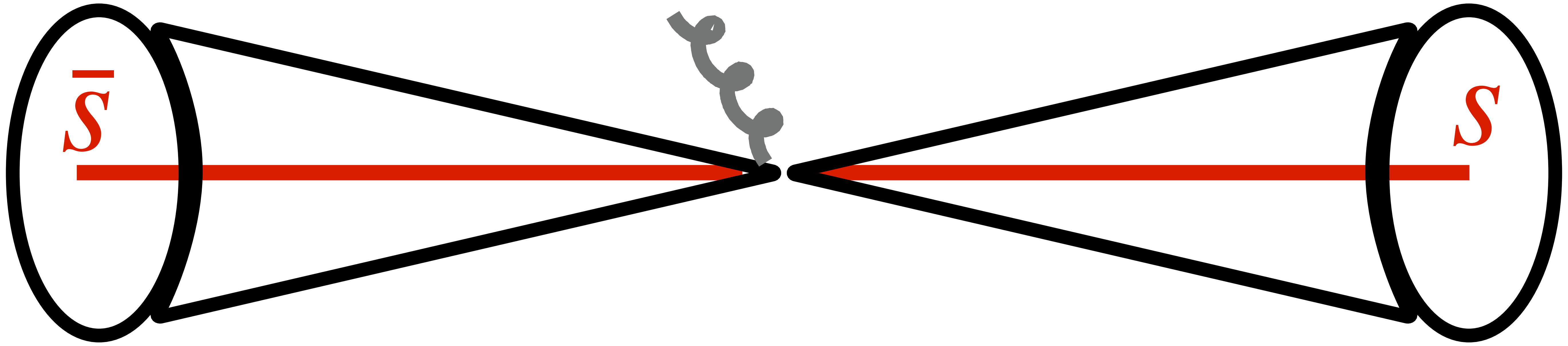
- Concentrate on parton-level to help understand the **theoretical** question of separating Yukawa and Dalitz decays
- Use the new **PanScales parton showers** (2312.13275), v0.1.2
  - still not entirely ready for phenomenology
  - they offer some (incomplete) handles for examining robustness of any conclusions (e.g. two showers, NLO matching for $H \to gg$)
- It would be interesting to also explore
  - NLO $H \to gg \to 3$ jets (or NNLO $H \to gg$)
  - more established parton showers

Melissa van Beekveld[1], Mrinal Dasgupta[2], Basem Kamal El-Menoufi[2,3], Silvia Ferrario Ravasio[4], Keith Hamilton[5], Jack Helliwell[6], Alexander Karlberg[4], Rok Medves[6], Pier Francesco Monni[4], Gavin P. Salam[6,7], Ludovic Scyboz[3,6], Alba Soto-Ontoso[4], Gregory Soyez[8], Rob Verheyen[5]

Working definition to tag H → ss topology

One approach is Sterman-Weinberg inspired:

- Work in CoM of hadronic Higgs decay
- Use a suitable jet flavour algorithm to get **inclusive flavour-safe anti-k_t jets with a small radius**, e.g. $R = 0.4$
- $H \to s\bar{s}$ flavour tagging:
  - each of the two highest-energy jets must have strange flavour
  - together they must carry most of the Higgs decay mass (e.g. > 80%)



$R \simeq 0.4$

This is almost certainly not optimal as a tagging strategy. But a decent starting point for calculations and evaluating simulation tools.

NB: Actual kinematic tagging of hadronic Higgs decay should use full hadronic mass (better resolution), not just two leading jets

Example code, based on anti-k_t + Interleaved Flavour Neutralisation (IFN)

IFN: Caola, Grabarczyk, Hutt, GPS, Scyboz, 2306.07314
https://github.com/jetflav/IFNPlugin (soon to be in FJContrib)

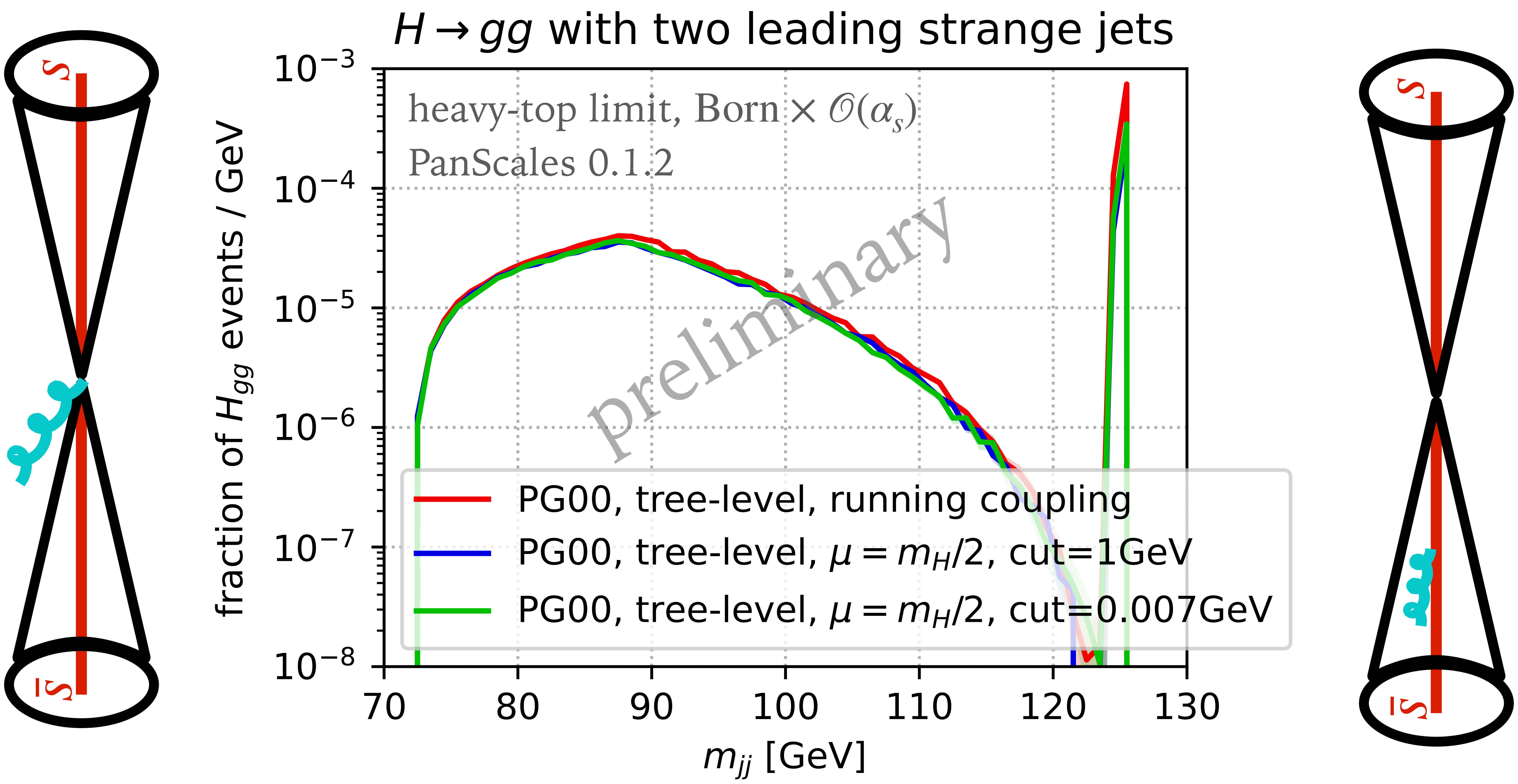
```
#include "IFNPlugin.hh"
using namespace std;
using namespace fastjet;
using namespace fastjet::contrib;
inline FlavInfo current_flav(const PseudoJet & j) {return FlavHistory::current_flavour_of(j);}

/// return true iff the event passes a simple Hss tag, based on a
/// a (Stermain-Weinberg inspired) flavour-safe anti-kt tagging
bool Hss_tag(vector<PseudoJet> & particles, const vector<int> & pdgids) {

  // set jet algorithm
  double R =  0.4;
  double p = -1.0; // anti-kt
  double IFN_alpha = 2.0;
  JetDefinition jet_def(new IFNPlugin(JetDefinition(ee_genkt_algorithm, R, p), IFN_alpha));
  jet_def.delete_plugin_when_unused();

  // assign strange flavour info to the particles
  for (size_t i = 0; i < particles.size(); i++) {
    FlavInfo * flavinfo = new FlavInfo(pdgids[i]);
    flavinfo->reset_all_but_flav(3); // ignore any non-strange flavour
    particles[i].set_user_info(flavinfo);
  }

  // get the jets (automatically sorted by energy)
  vector<PseudoJet> jets = jet_def(particles);

  // tag
  if (jets.size() < 2) return false;
  double mjj = (jets[0] + jets[1]).m();
  bool s_tag_0 = (abs(current_flav(jets[0])[3]) == 1);
  bool s_tag_1 = (abs(current_flav(jets[1])[3]) == 1);
  return (mjj > 100.0 && s_tag_0 && s_tag_1);
}
```

IFN adds flavour info to jet in an infrared safe manner (with $s + \bar{s} = g$)

For other IRC safe jet flavour algorithms, see also Czakon, Mitov, Poncelet (2205.11879) Gauld, Huss, Stagnitto (2208.11138)

NB: not quite the code used in the next slides, but should be very similar.

It's rare for Dalitz H→gg to give two leading strange jets



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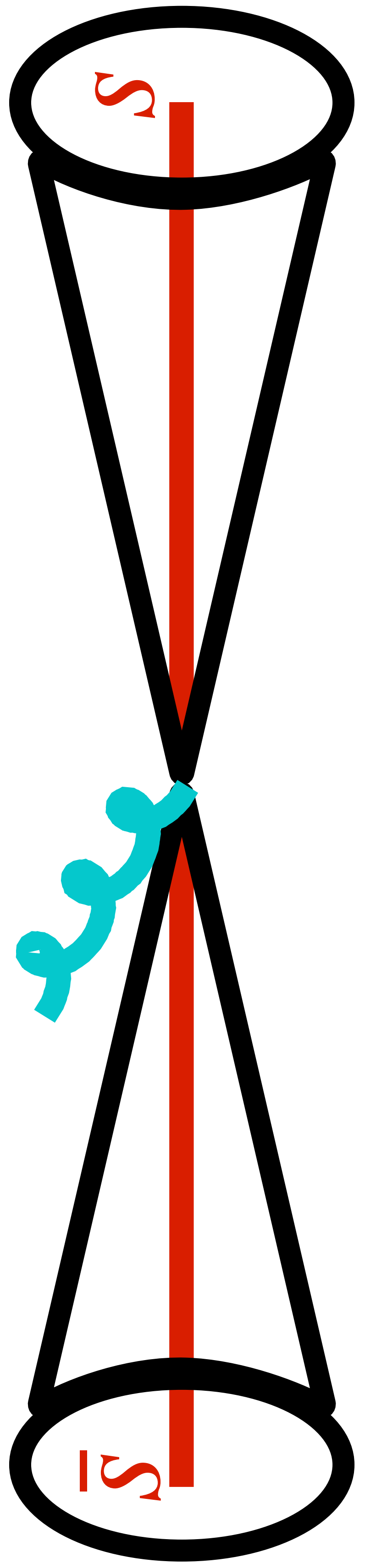
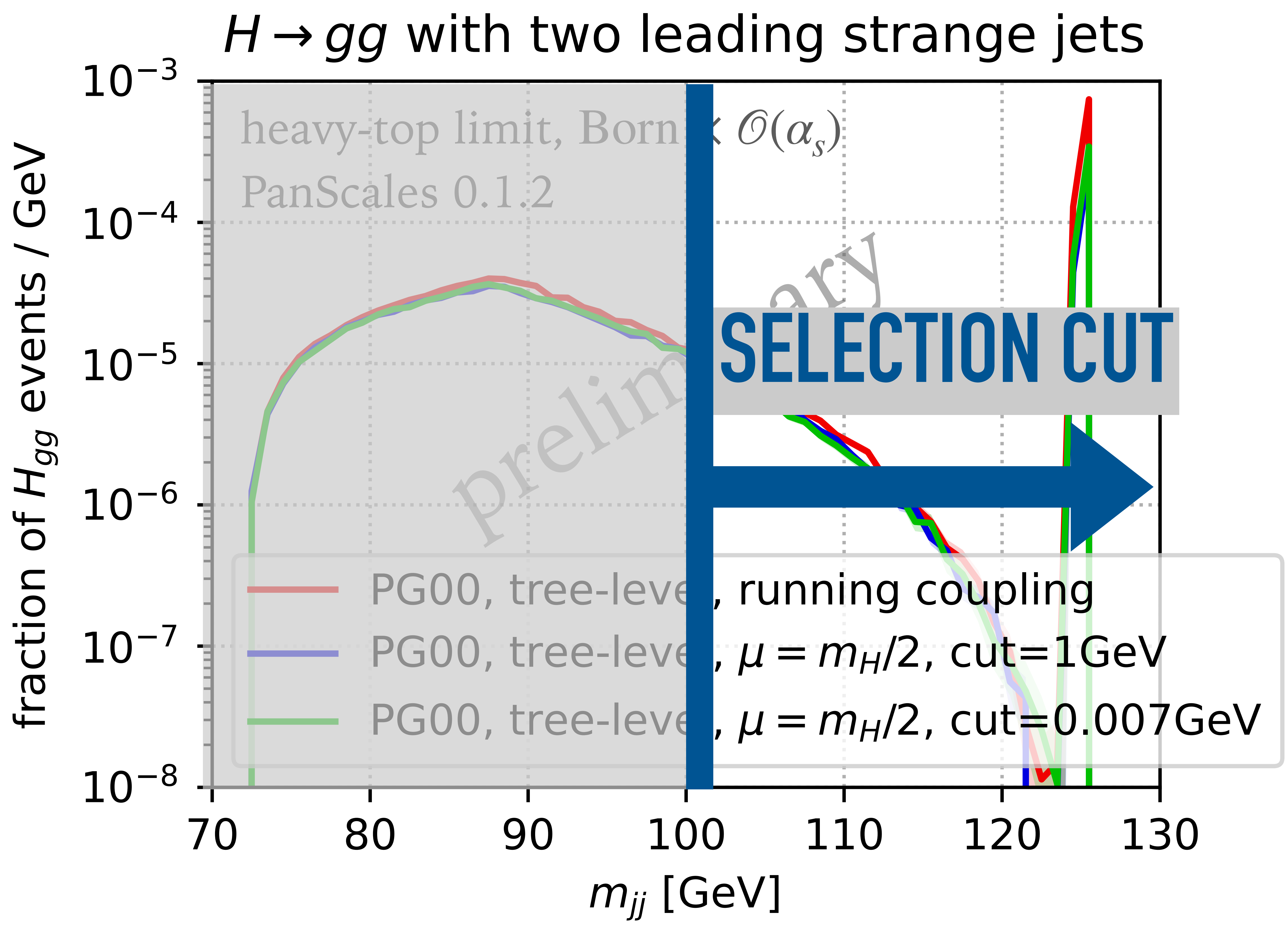
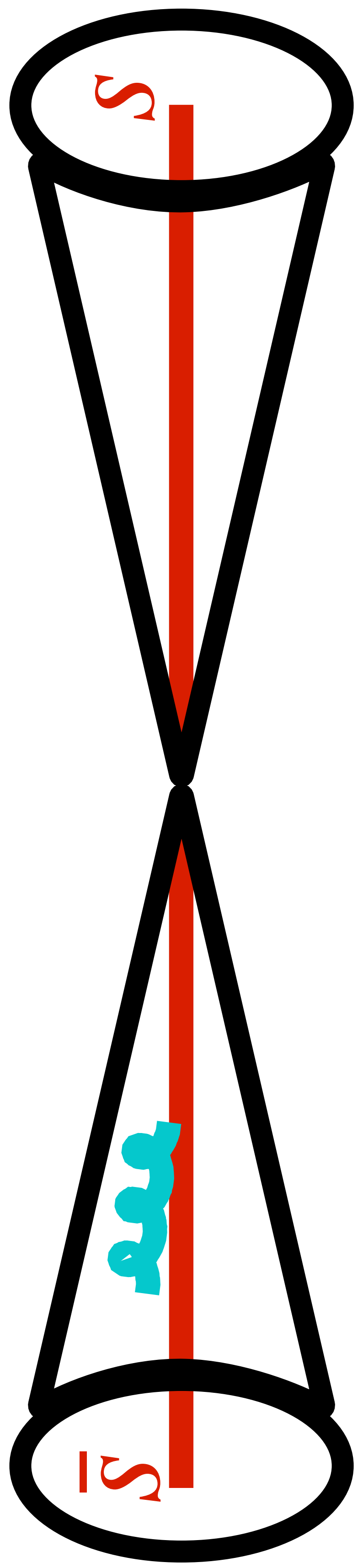
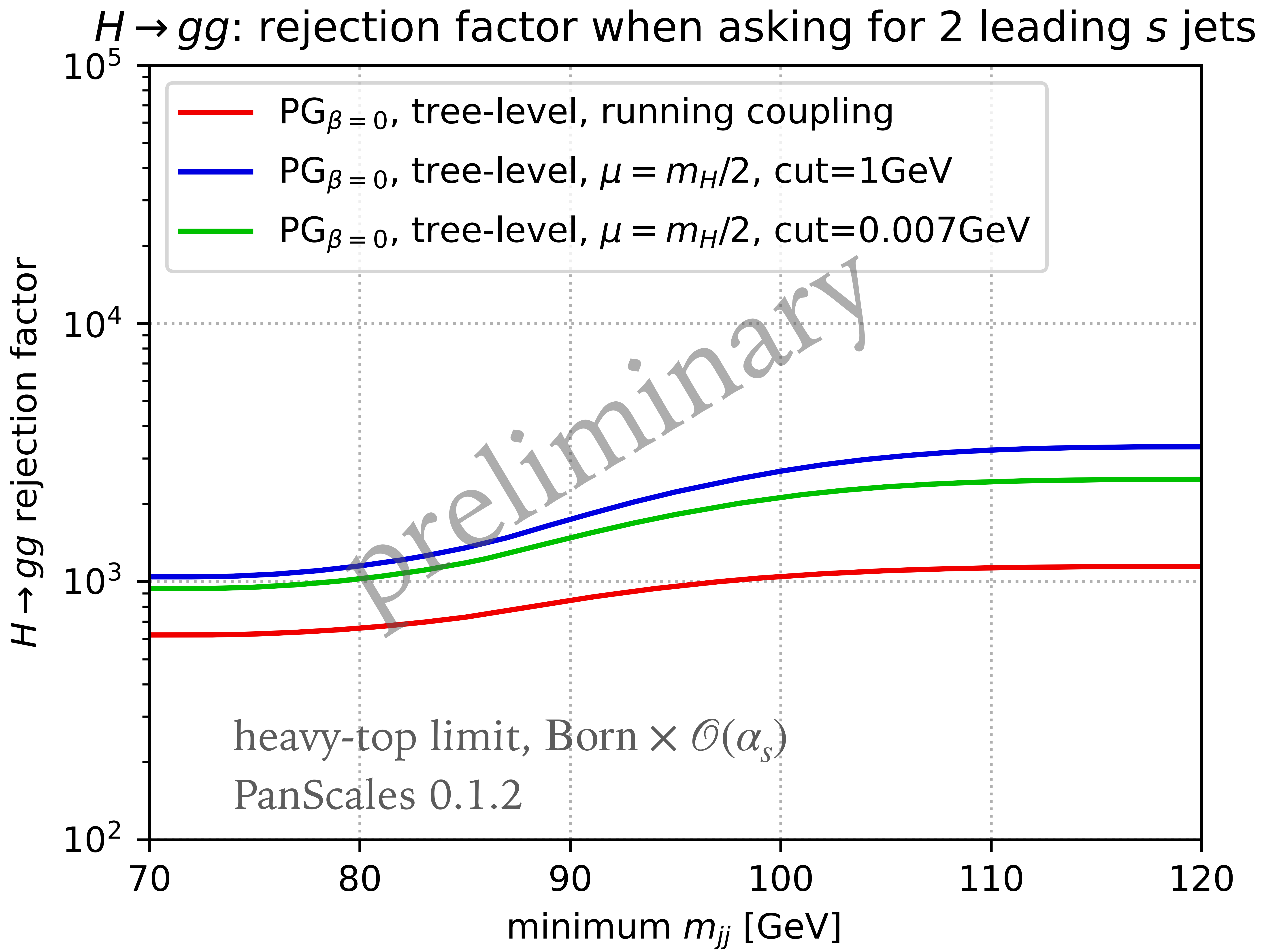






Calculate tree-level H → gg rejection factor



- Depending on cuts, rejection factor ~ few hundred to few thousand
- choice of coupling scale (running = k_t, versus fixed = $m_H/2$) effects have significant impact
- what of other higher-order effects?

Two parton showers, multiplicative NLO matching

PanGlobal ($PG_{\beta=0}$) [NLL accurate for Born-like configurations]

- k_t ordered
- global event-wide transverse recoil for each emission
- shower without matching underestimates 3-jet region

PanLocal ($PL_{\beta=0.5}$) [NLL accurate for Born-like configurations]

- $k_t\sqrt{\theta}$ ordered
- dipole-local recoil for each emission
- shower without matching overestimates 3-jet region

NLO 2-jet matching [2301.09645]

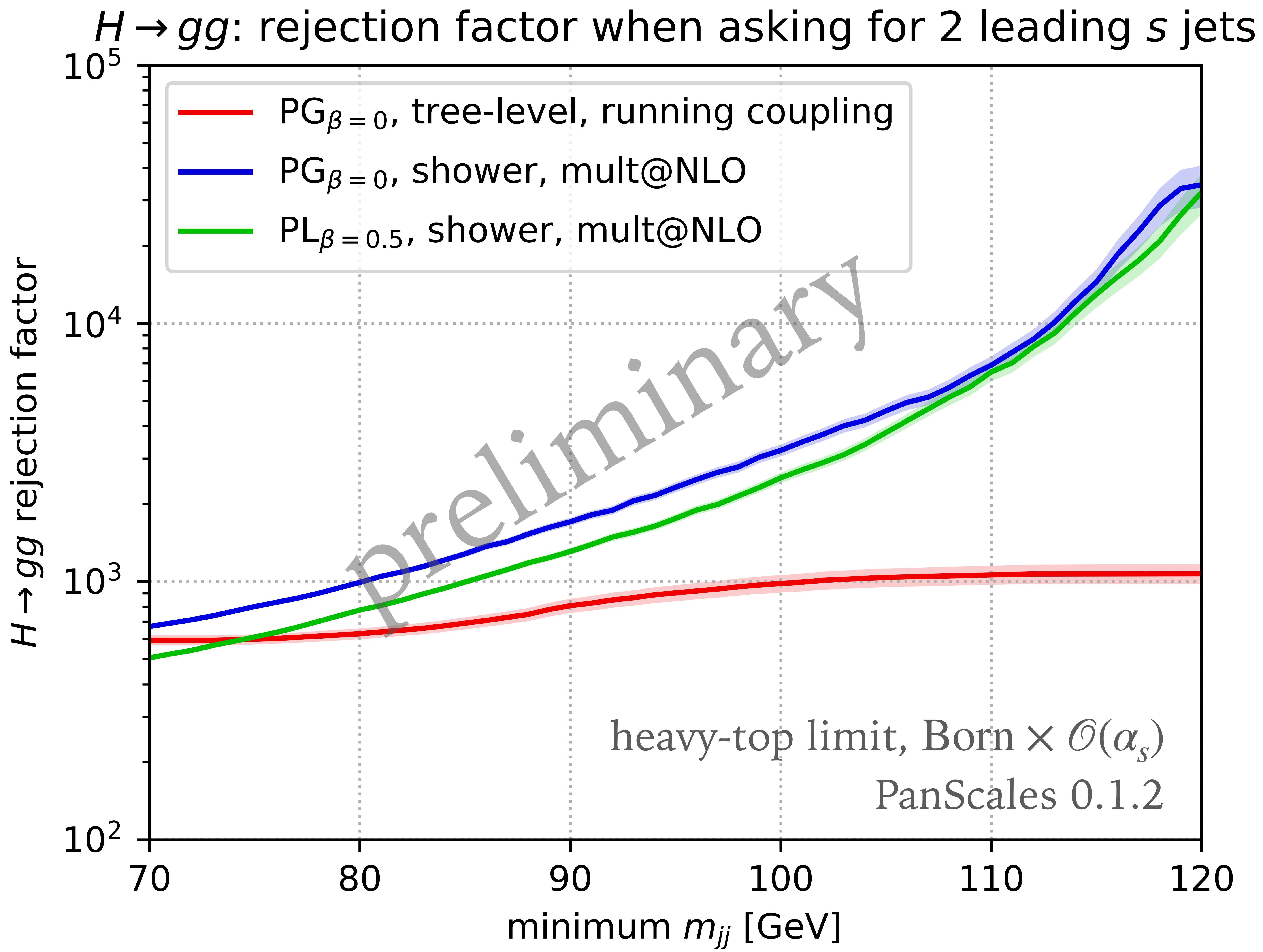
- mult@NLO: scales shower emission rate by $|ME|^2$/shower correction factor

NO HADRONISATION

H→gg→ss+X is outside any parton shower's region of validity

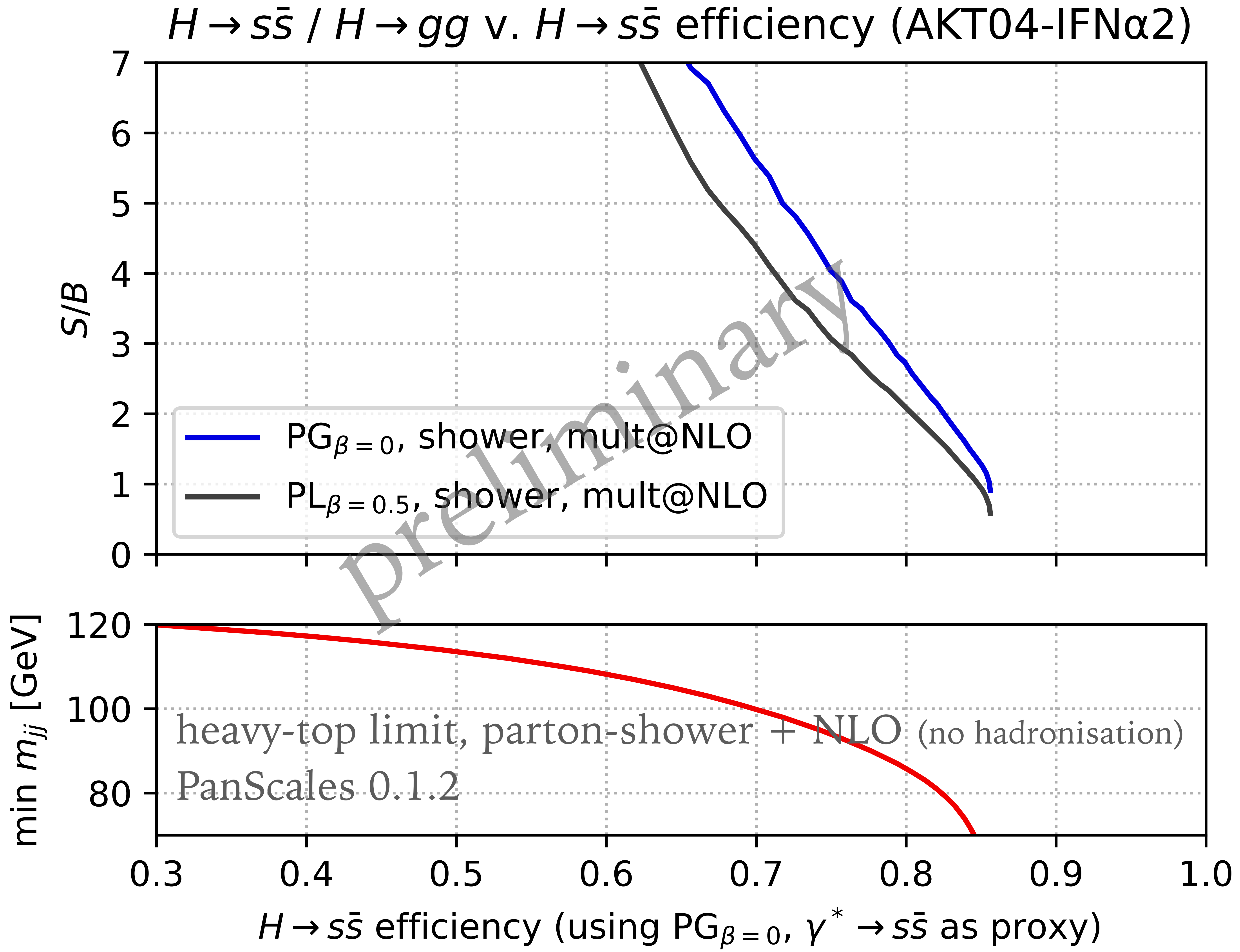
Differences between showers and matching schemes only poor indication of potential ambiguities

Calculate parton-shower H → gg rejection factor



- Large change in size & shape of rejection factor from tree-level to parton shower
- limited spread between showers probably an underestimate of uncertainty
- **need dedicated $H \to gg \to$ 3jet NLO + resummation theory to get clearer picture?**

Add ($\gamma^* \to$ ss as proxy for) H→ss to estimate S/B



This basic analysis suggests that S/B $\gtrsim$ 1 is possible in terms of theory separation of Yukawa from Dalitz decays.

This is without too much optimisation (mainly choice of R)

Likely scope for doing better, but this simple analysis is good starting point for theory calculation?

Conclusions

A simple parton-level $H \to s\bar{s}$ tagging condition is to require two leading (flavour-safe) anti-k_t jets to both have |net strangeness| of 1 and carry most of Higgs mass.

- e.g. use R=0.4 jets, two leading just should carry > 100 GeV of mass
- [or require upper limit on energy outside the jets]

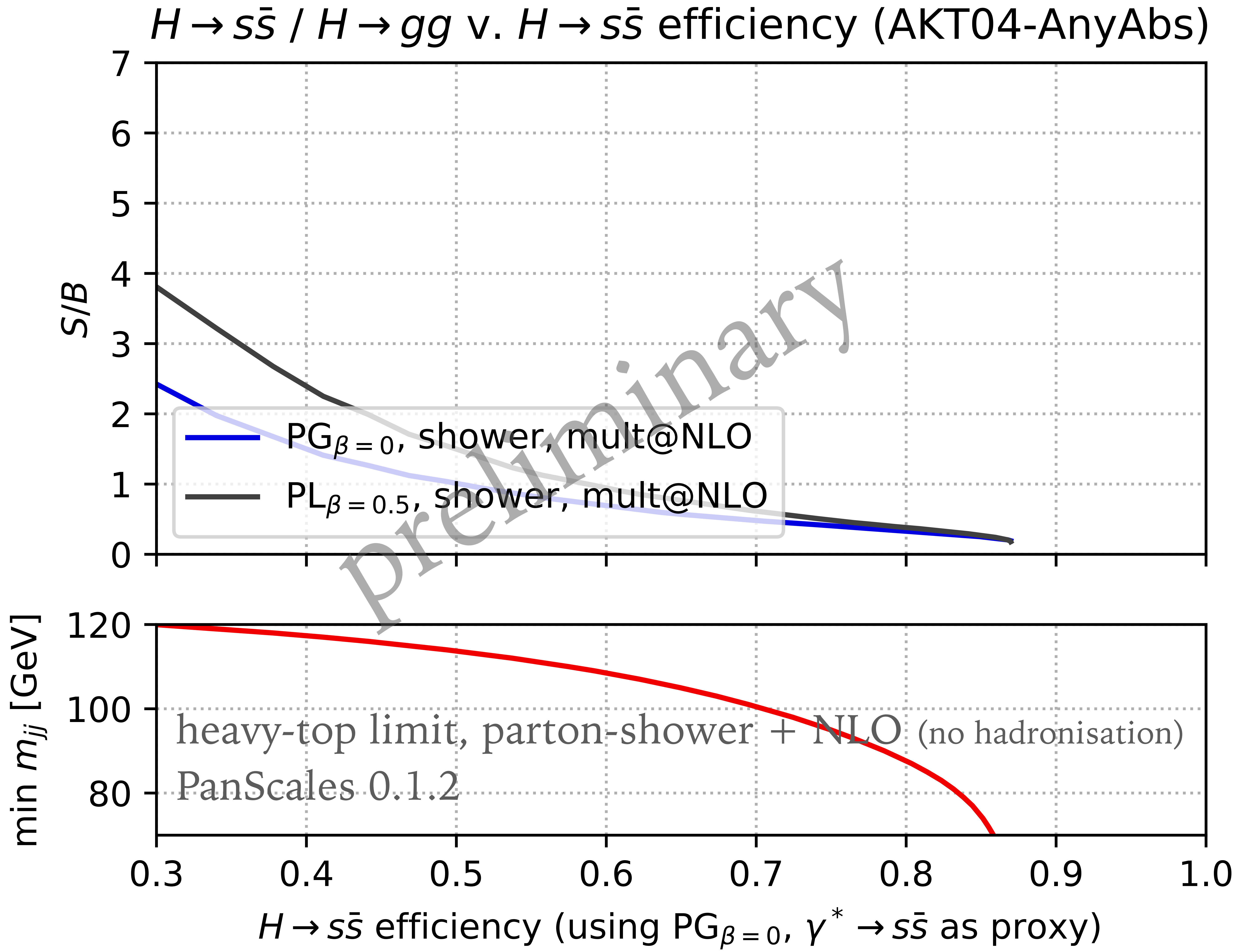
At parton level, theoretical separation of Yukawa $H \to s\bar{s}$ from Dalitz $H \to gg$ decays looks feasible with S/B ~ 2 – 3, for reasonable signal efficiency (60–80%)

Potential route to reducing (substantial) remaining uncertainties:

- dedicated $H \to gg \to$ 3jet NLO calculation could be useful
- resummation understanding & how this translates into parton shower requirements
- double-check accuracy of heavy-top limit

Note: $H \to g(\to s\bar{s})g(\to s\bar{s})$ has $H \to gg$ flavour classification in "theory-land".
Experimentally, could be difficult to distinguish

Treating $H \to g(\to s\bar{s})g(\to s\bar{s})$ as two s-tagged jets



Very considerable worsening of S/B

This is after a parton shower. Hadronisation will inject even more strangeness.

This kind of background

(a) nominally reducible

(b) reasonably well modeled in showers?