Searching Invisible Higgs with Jet Flavor Tagging

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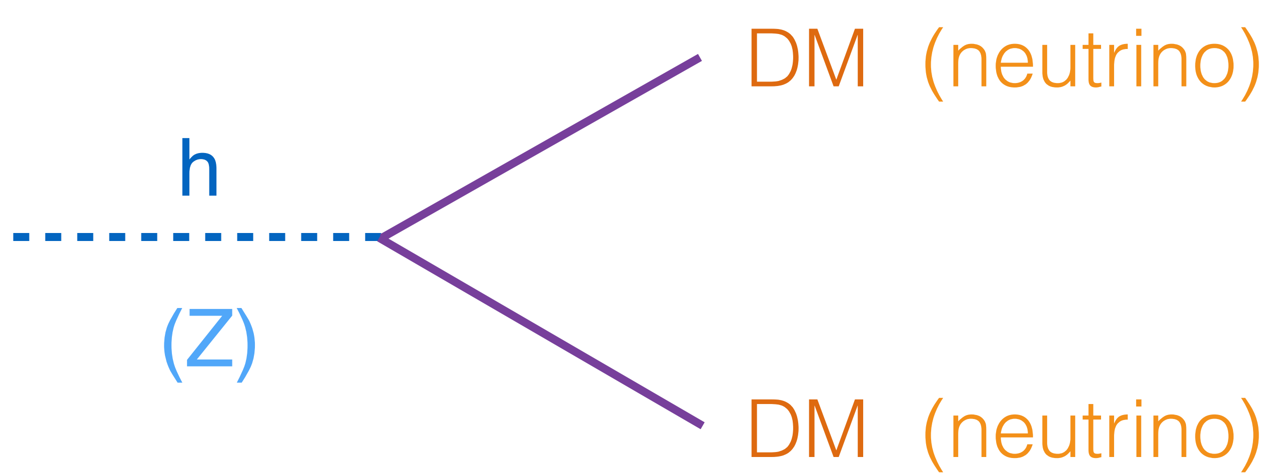
Invisible Higgs Decay



assuming SM production

$$\sigma_{\rm prod} \times \frac{\Gamma_{\rm vis}}{\Gamma_{\rm total}}$$

$$\Gamma_{\rm total} = \Gamma_{\rm visible} + \Gamma_{\rm invisible}$$

To measure the invisible branching ratio of Higgs
is crucial for precision measurement of Higgs couplings

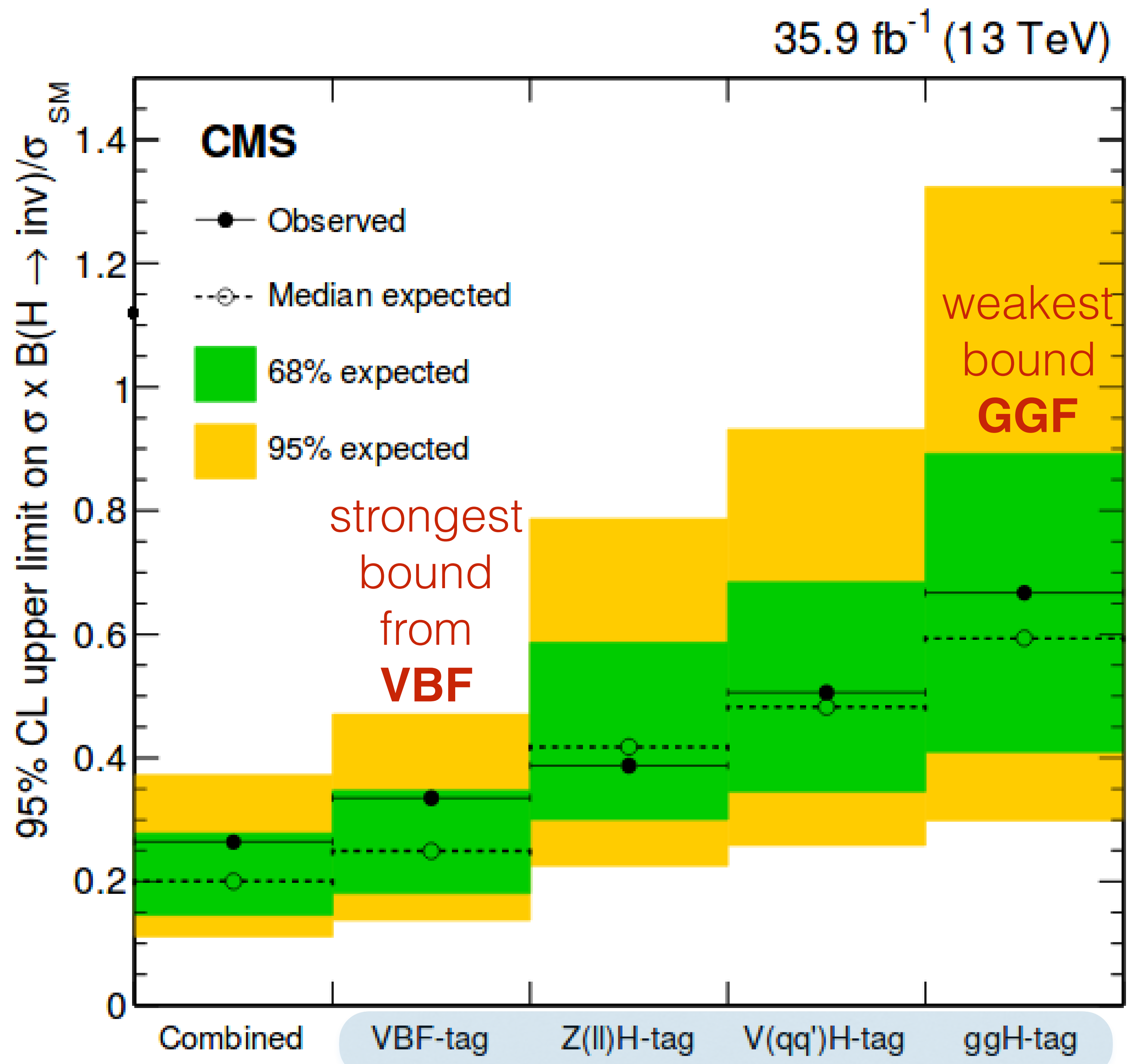
The signal has missing transverse energy:
Z to neutrinos are irremovable backgrounds

Higgs produced from vector boson fusion
is the most useful constraining the invisible Br

2 forward jets
as a tagger

Current Limits on Higgs Invisible Branching Ratio

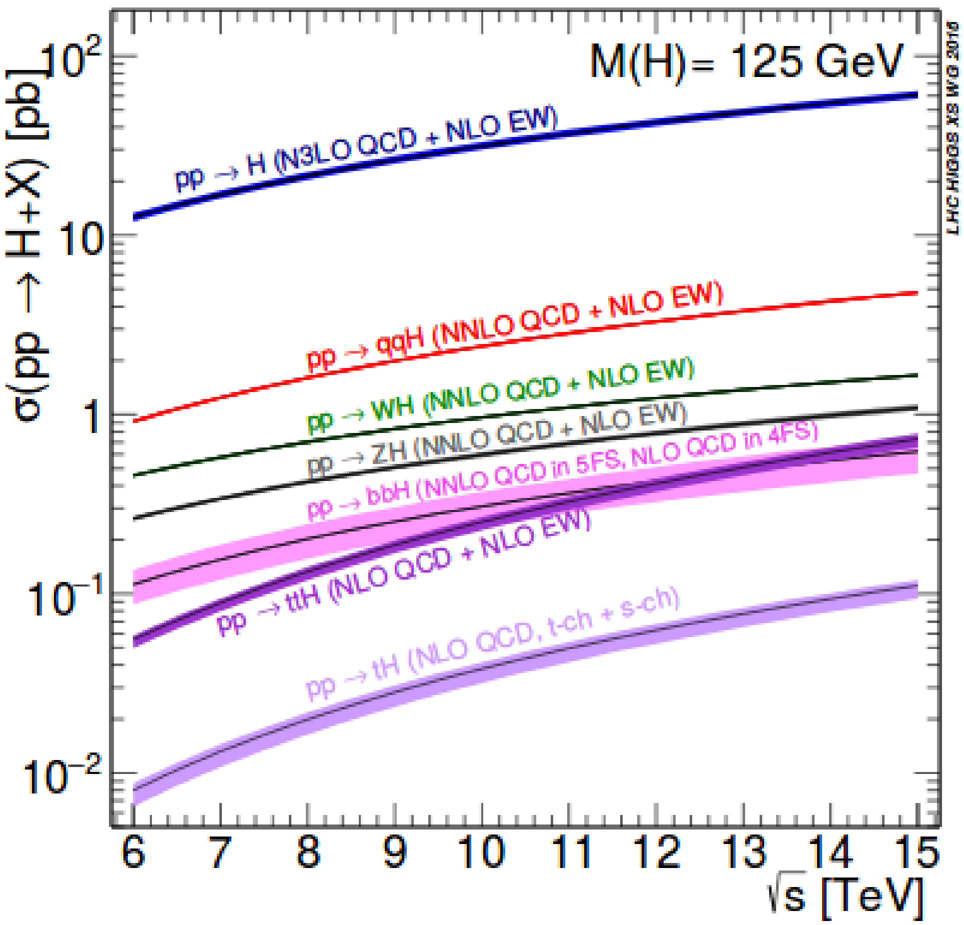
CMS 2018 result



VBF, VH, ggH overlap is removed
in order to avoid double counting
in the combined analysis

Analysis	Final state	Signal composition	Observed limit	Expected limit
VBF-tag	VBF-jet + p_T^{miss}	52% VBF, 48% ggH	0.33	0.25
VH-tag	$Z(\ell\ell) + p_T^{miss}$ [72]	79% qqZH, 21% ggZH	0.40	0.42
	$V(qq') + p_T^{miss}$ [73]	39% ggH, 6% VBF, 33% WH, 22% ZH	0.50	0.48
ggH-tag	jets + p_T^{miss} [73]	80% ggH, 12% VBF, 5% WH, 3% ZH	0.66	0.59

Higgs Invisible Branching Ratio from Gluon Fusion Production



From arXiv:1610.07922

Production Cross Section

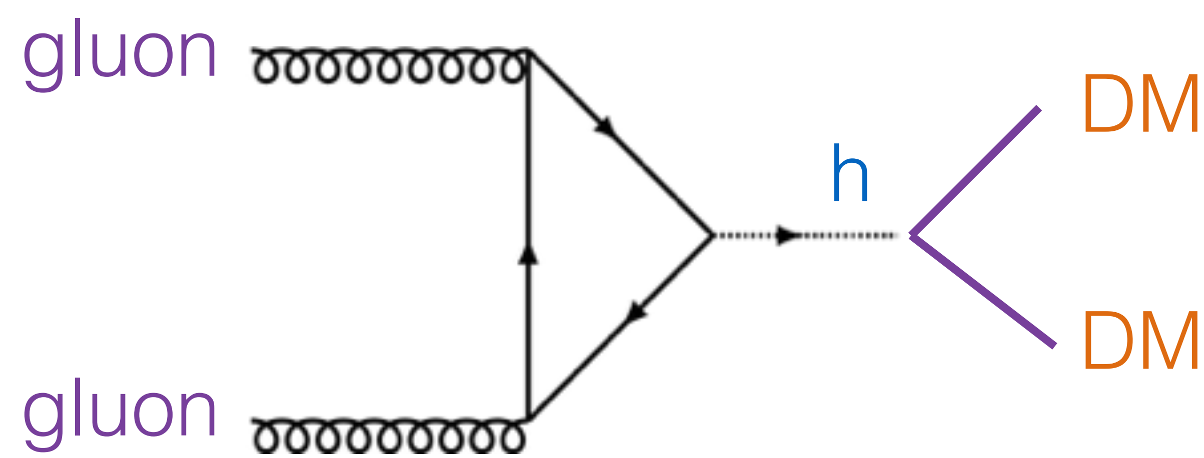
ggH > VBF > VH

Invisible Br limit (strongest)

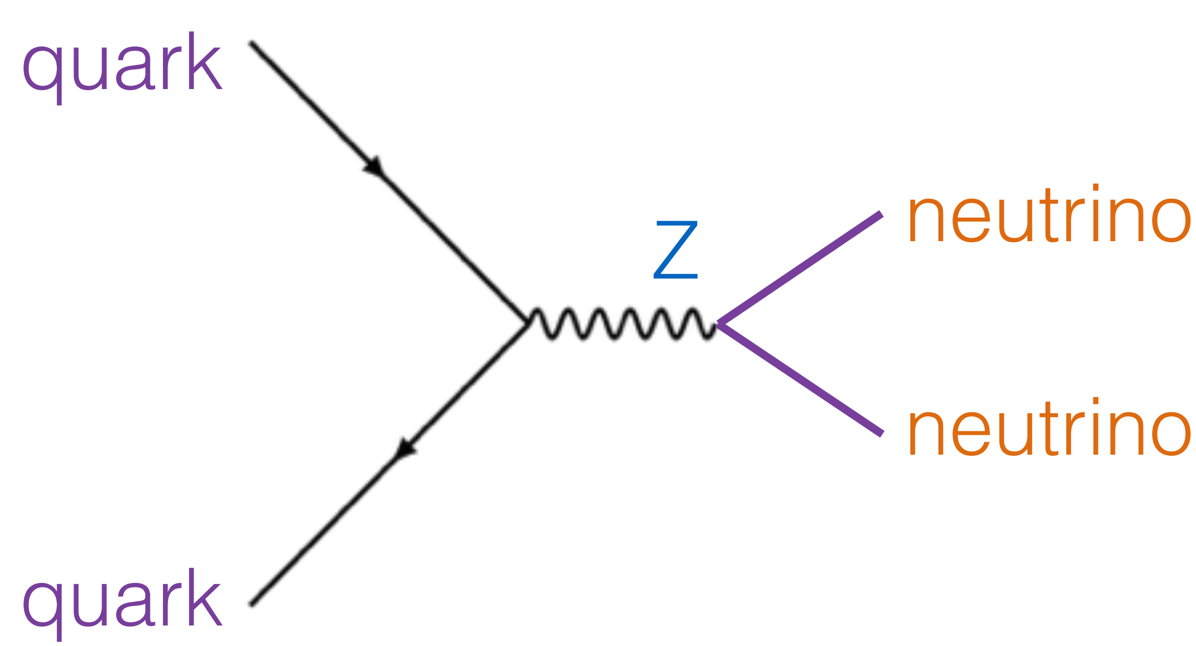
VBF > VH > ggH

ISR + MET for **ggH,**
same for **Z to neutrinos**

Signal : Higgs production from gluon fusion



Background : Z to neutrinos from Drell-Yan



Main Backgrounds for Higgs Invisible Br from ggH

Selection Criteria (arXiv:1610.09218)

- $E_T^{\text{miss}} \geq 200\text{GeV}$
- $p_T^{\text{jet}} \geq 100\text{GeV}$
- $|\eta^{\text{jet}}| \leq 2.5$
- $\min\Delta\phi(\vec{p}_T^{\,\text{miss}}, \vec{p}_T^{\,\text{jet}}) > 0.5$

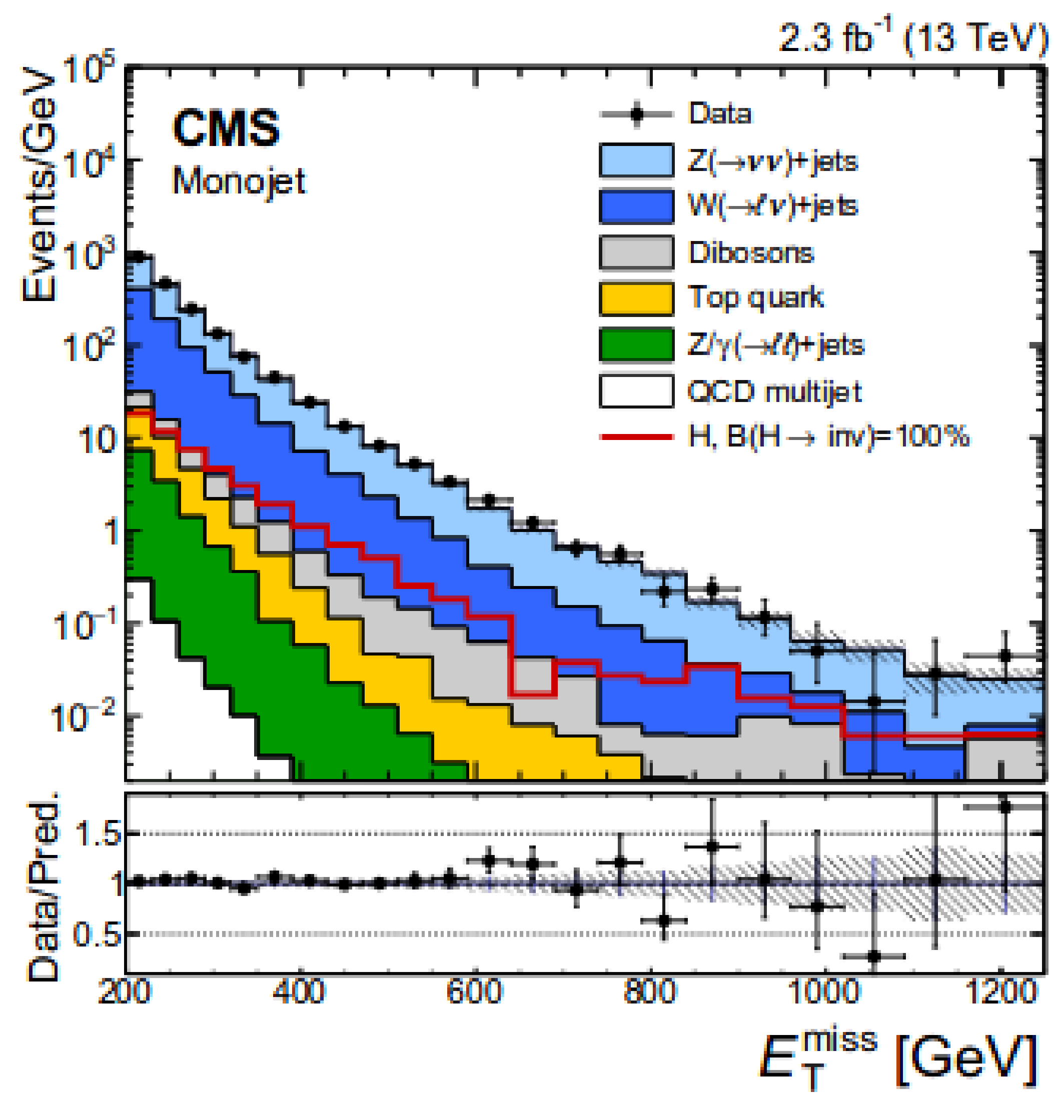
Background processes

- $Z \rightarrow \nu\bar{\nu}$
- $W \rightarrow l\nu$
- di-boson
- SM top

Mainly qq-initiated

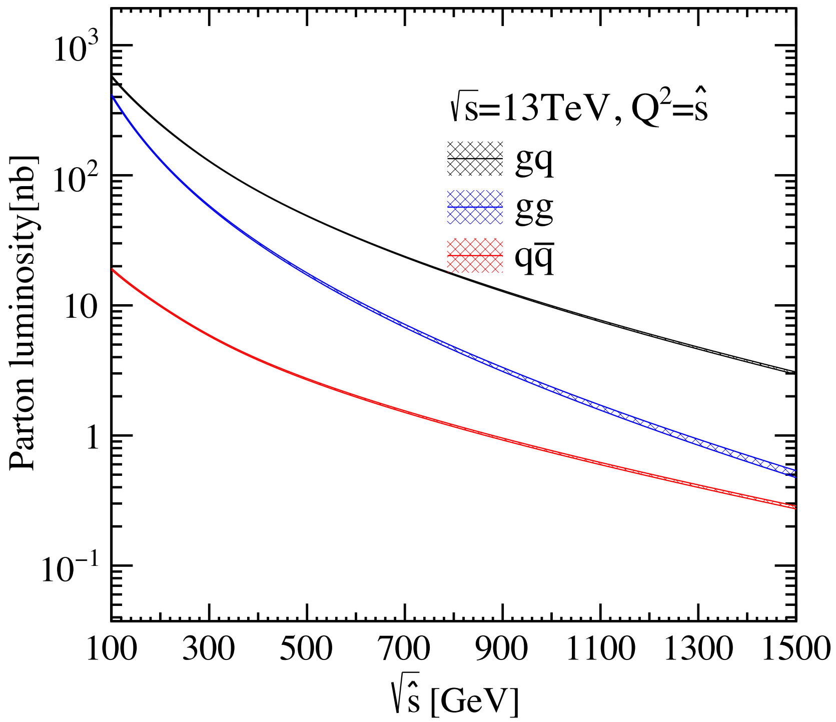
- QCD multi-jet

Mainly gg-initiated

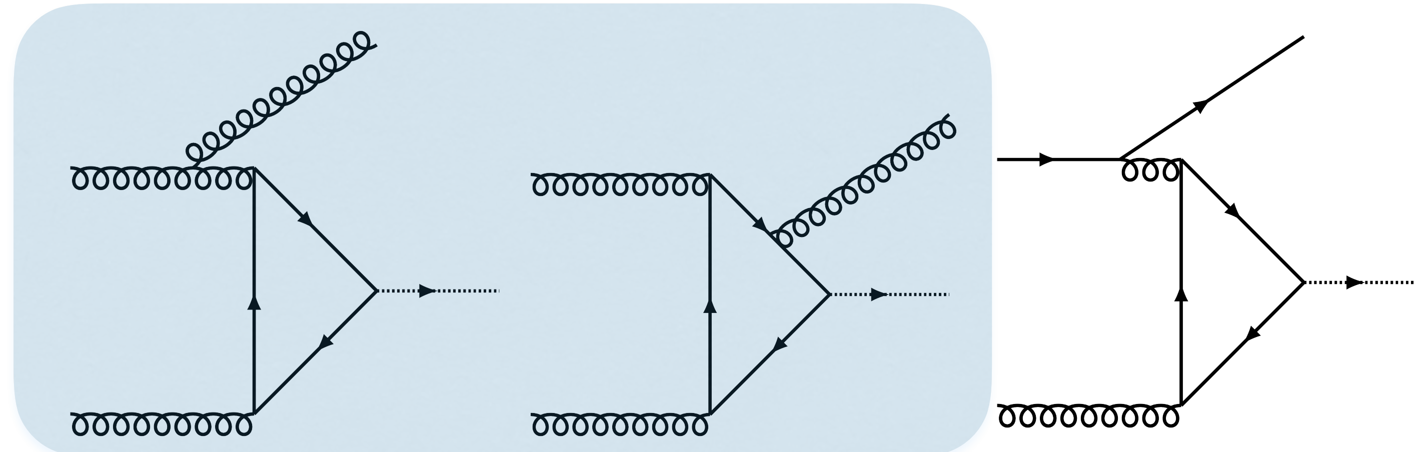


ISR for the **signal** and **background**

qg > gg > qqbar



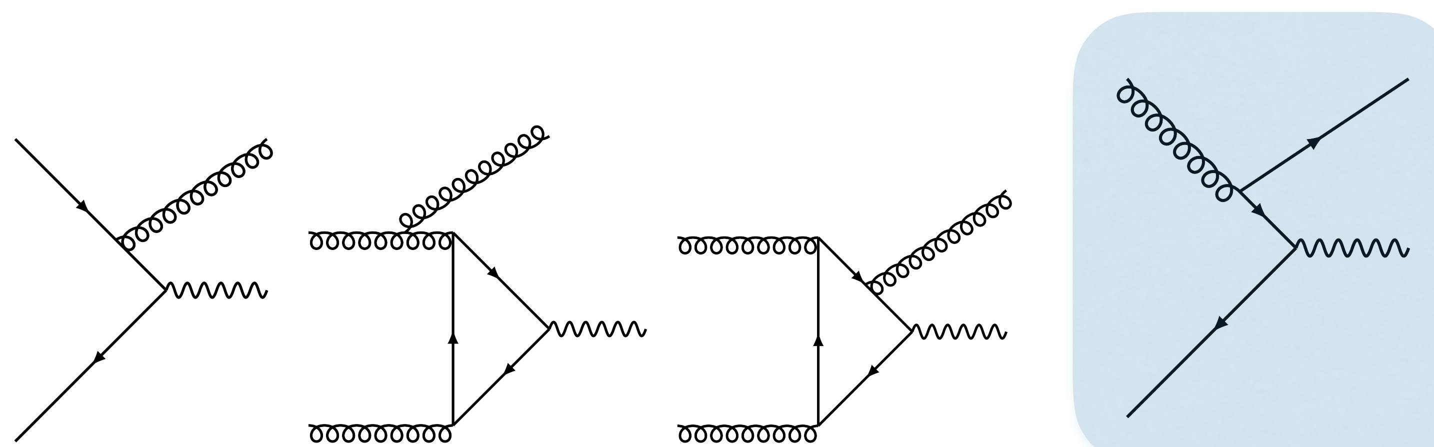
Parton Luminosity
13 TeV LHC



(a) ggH with g-jet

(b) ggH with q-jet

more **gluon** ISR from **ggH**

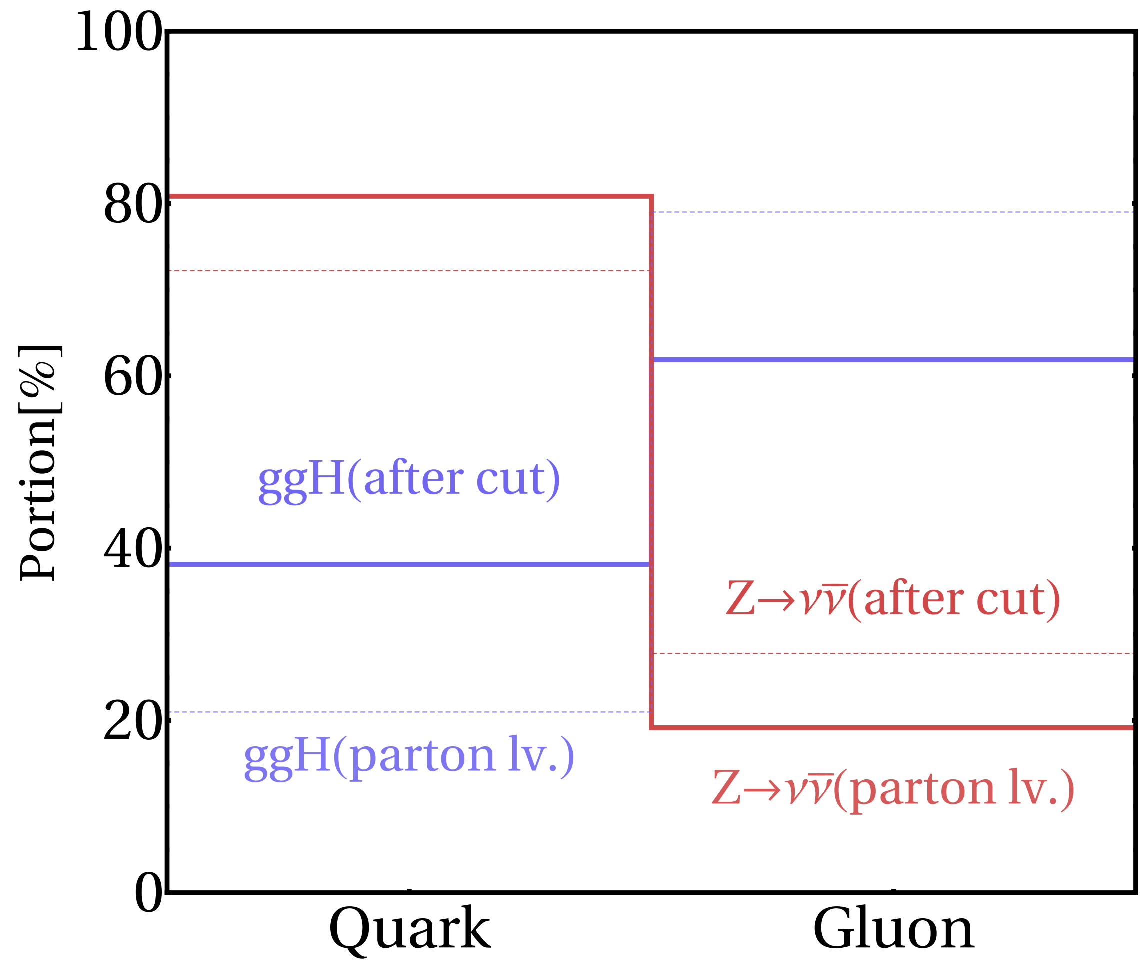


(c) Z with g-jet

(d) Z with q-jet

more **quark** ISR from **Znunu**

FIG. 3: Parton contents(initial particle) of jets associated to ggH and $Z \to \nu\bar{\nu}$ process.



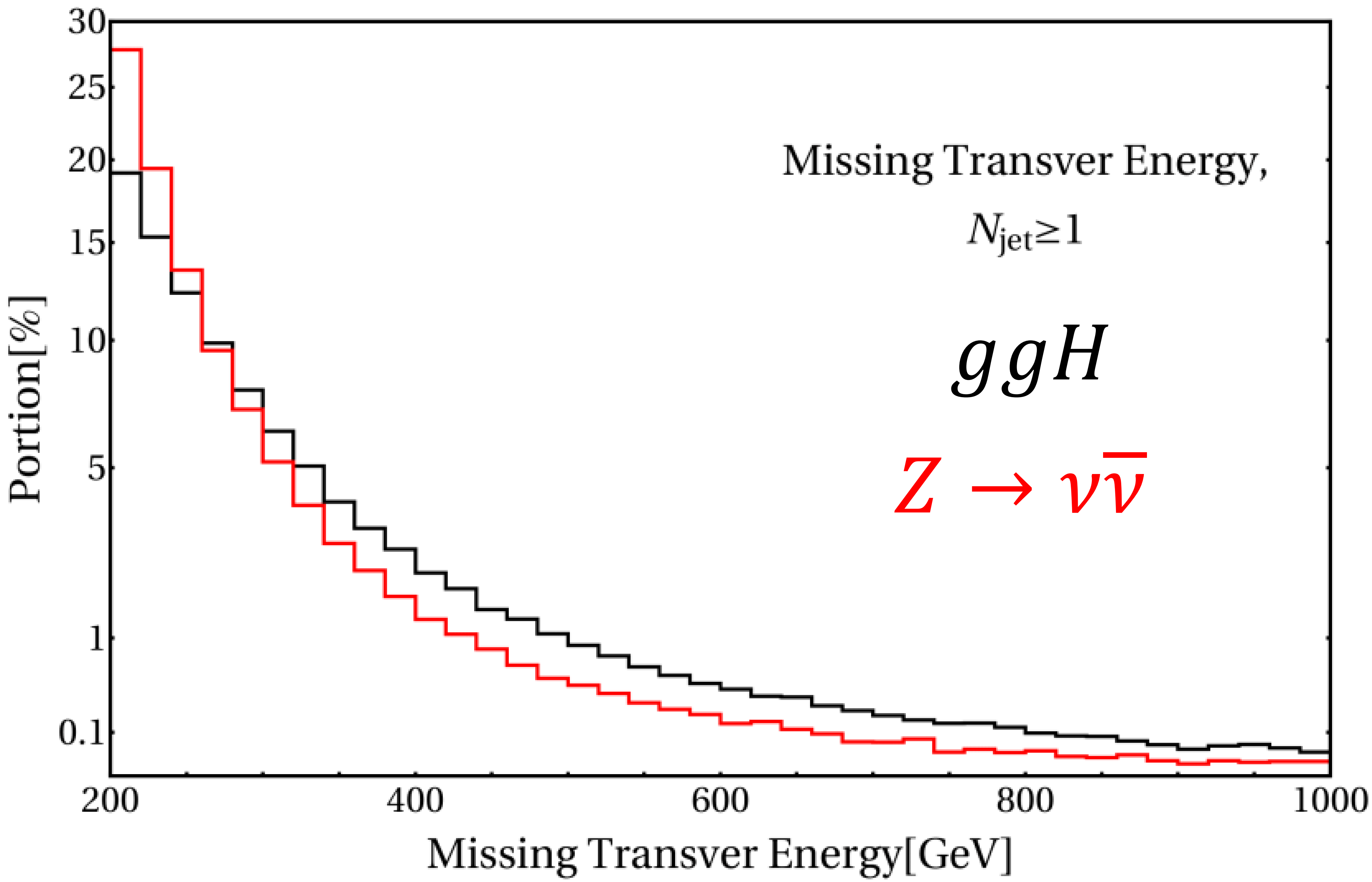
The number in the parenthesis ( ) shows the ratio before applying the cuts

Cuts eliminates more gluon jets than quark jets

Sig(**ggH**)	4(2)	:	**6(8)**
Bg(**Znunu**)	**8(7)**	:	2(3)

Conventional invisible Higgs search from ggH

MET is harder for ggH compared to bg(Znunu)

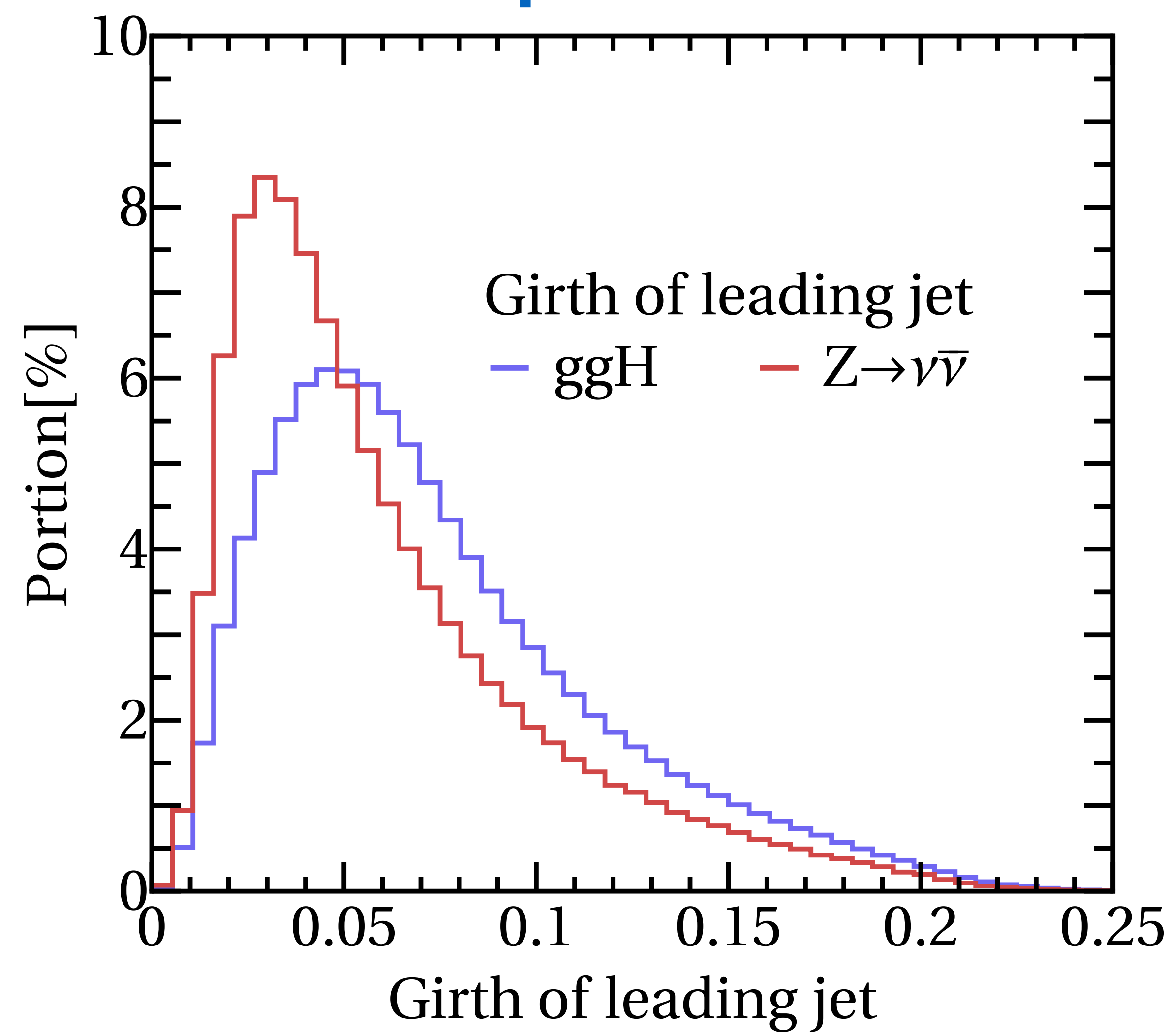


Quark Jet vs Gluon Jet

Jet substructure variables can distinguish quark and gluon jets

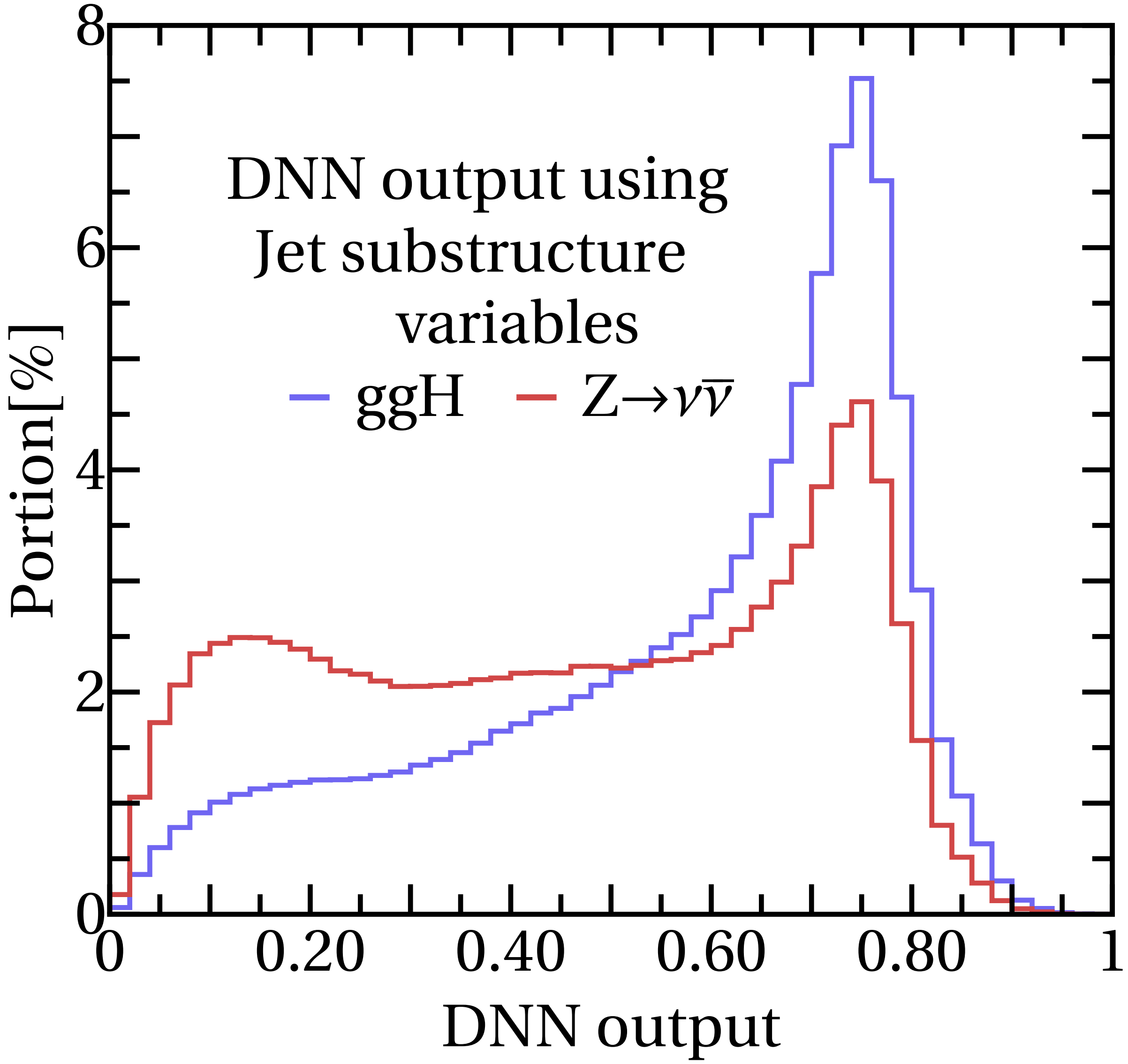
- n_{tk}[8] : Track multiplicity(the number of charged tracks in jet)
- Girth[8, 9] : $\frac{1}{p_T^{\mathrm{jet}}} \sum_{i \in \{\mathrm{const.}\}} p_T^i \left|\Delta \vec{R}_i\right|$
- Broadening[10] : $\frac{1}{\sum_i |\vec{p}^i|} \sum_i \left|\vec{p}^i \times \hat{p}^{\mathrm{jet}}\right|$
- EEC[1][11] : $C_1^\beta = \frac{1}{(\sum_i p_T^i)^2} \sum_{i<j} p_T^i p_T^j (\Delta R_{ij})^\beta$
- RMS-p_T[8] : $\sqrt{\frac{1}{p_T^{\mathrm{jet}} \sum_i} \sum_i \left(p_T^i\right)^2}$

Example : Girth

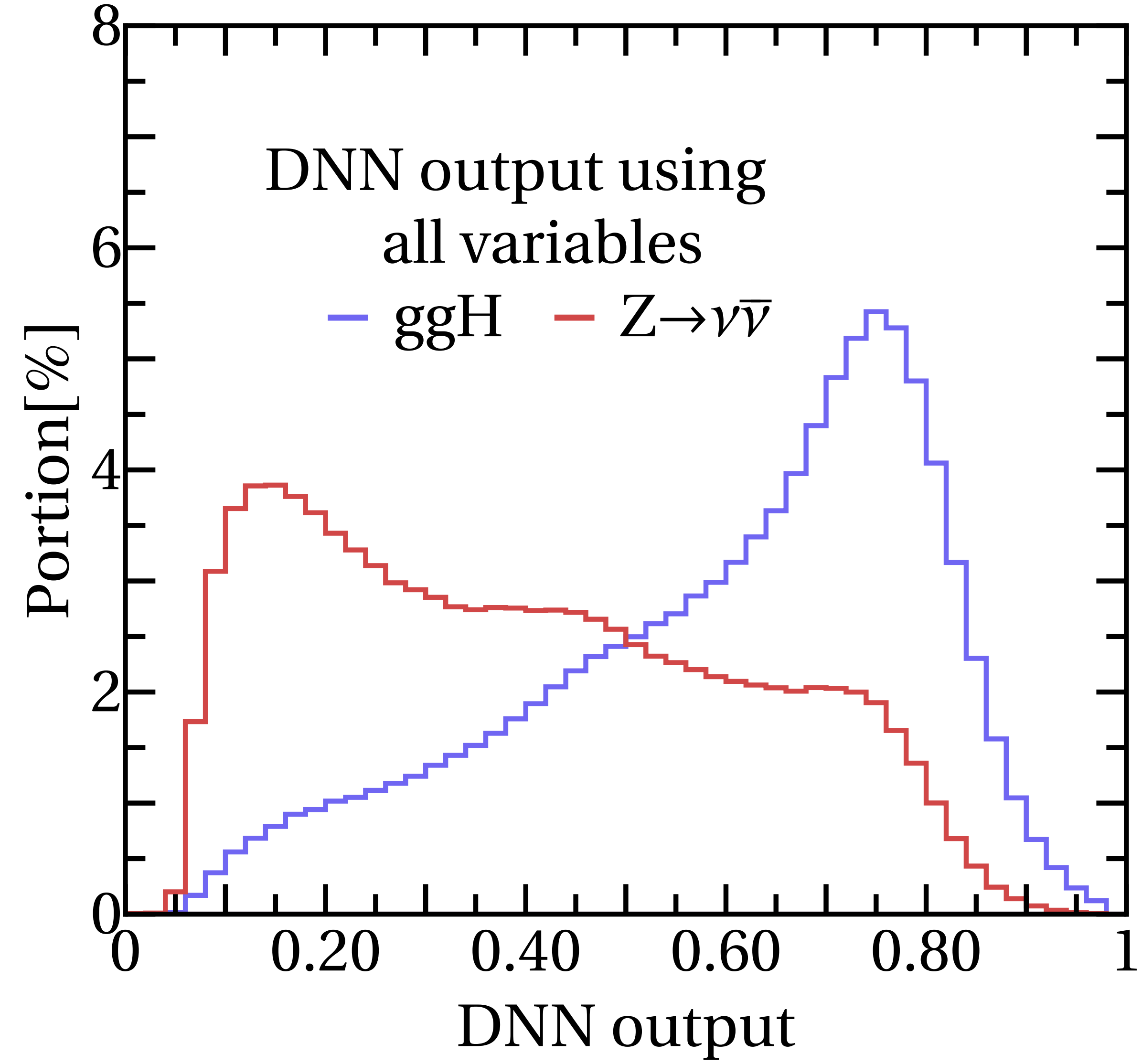


Girth(gluon) > Girth(quark)
&
More gluons from ggH

New Ingredients : Jet Substructures

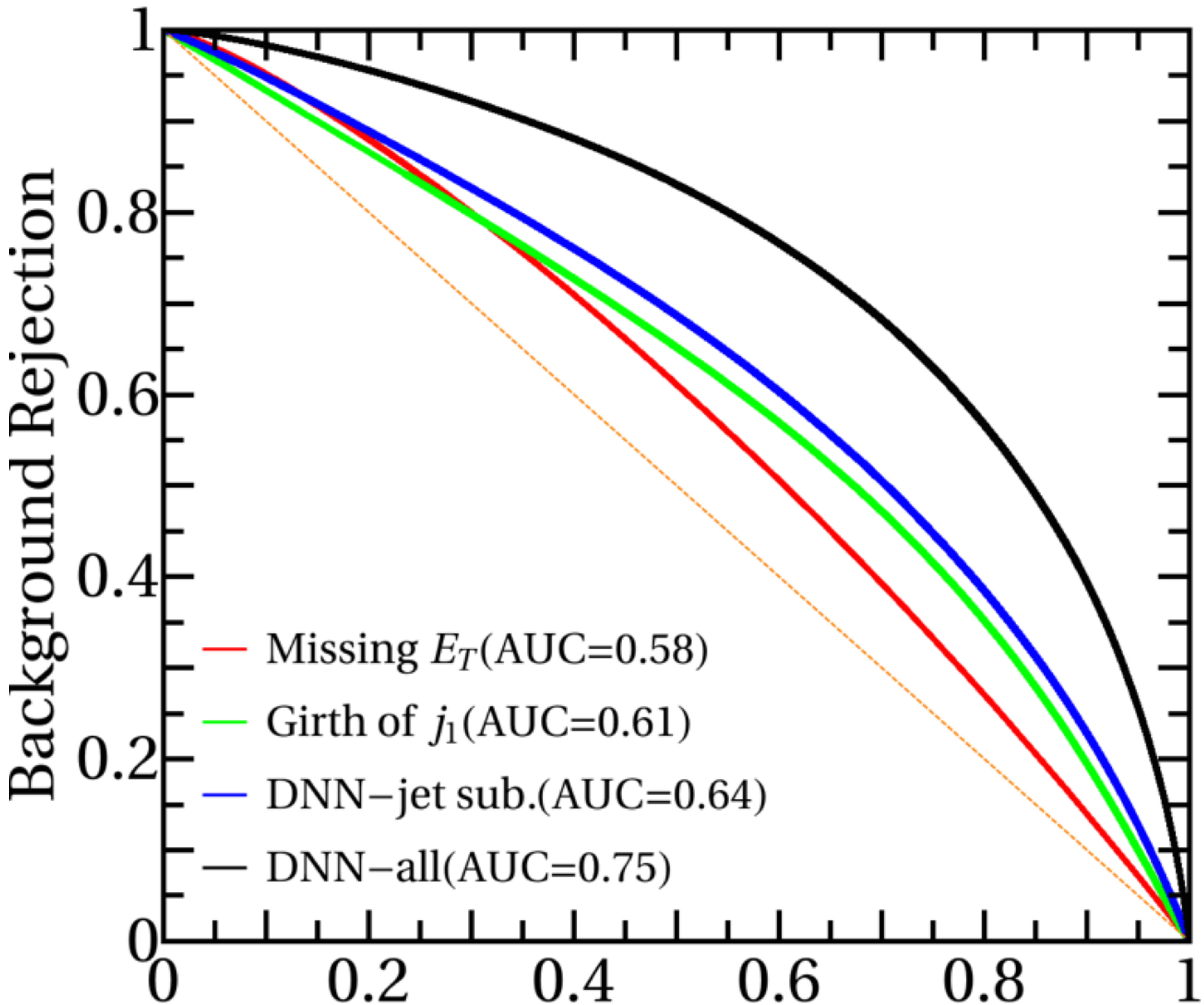


Scores using Jet Substructure Variables



Scores using Jet Substructure & MET

Receiver Operating Characteristics (ROC) Curve



Likelyhood Fitting

Likelihood fitting using ‘Scores’ as probability distribution fuction(pdf)

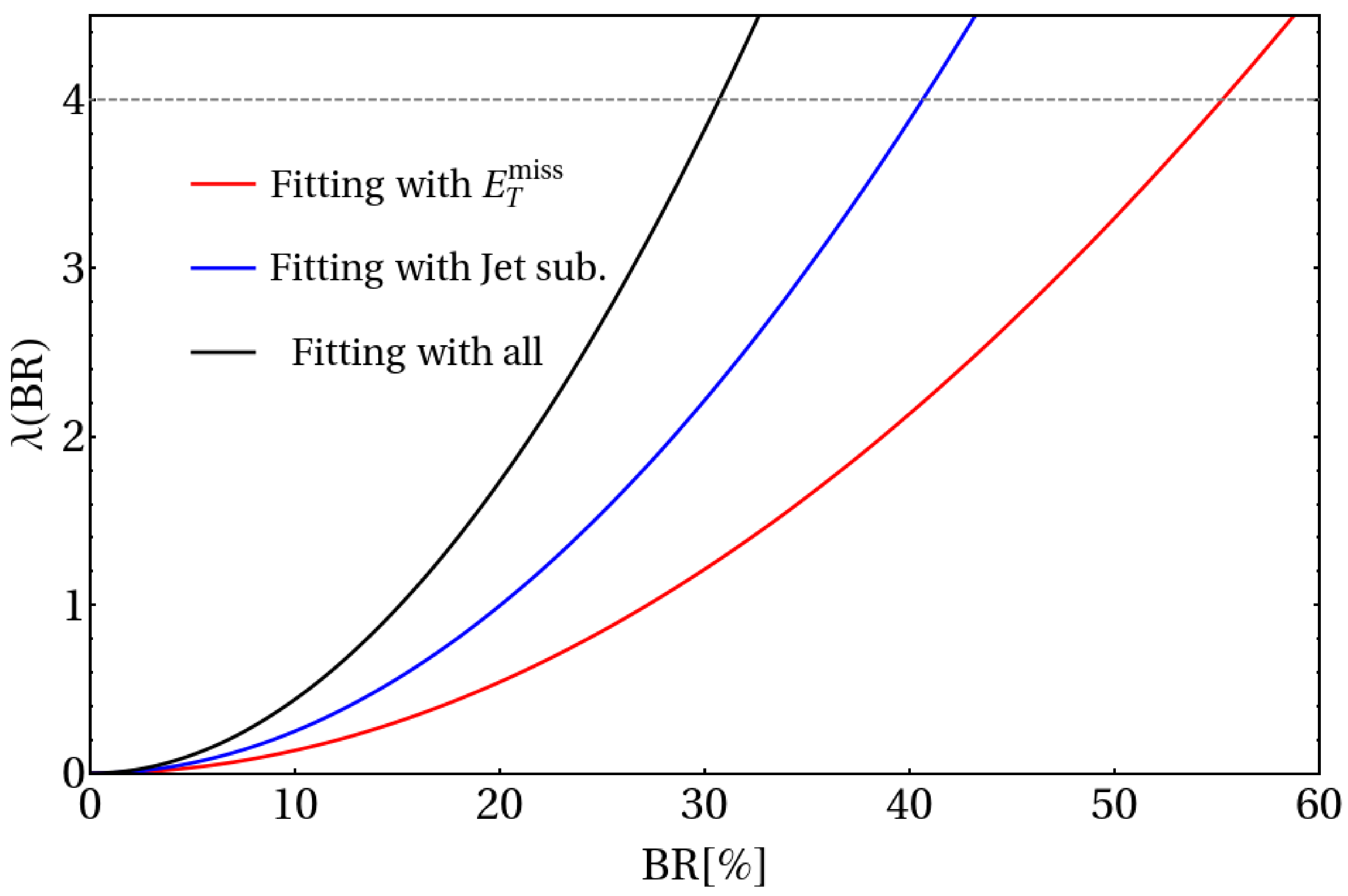
Integrated luminosity : 36 fb^-1

Ensemble : 5,000

Systematic uncertainty : 10%

Test statistics

$$\lambda(BR) = -2\ln\frac{\mathcal{L}(\mathrm{Data}|BR, f)}{\max\mathcal{L}}$$



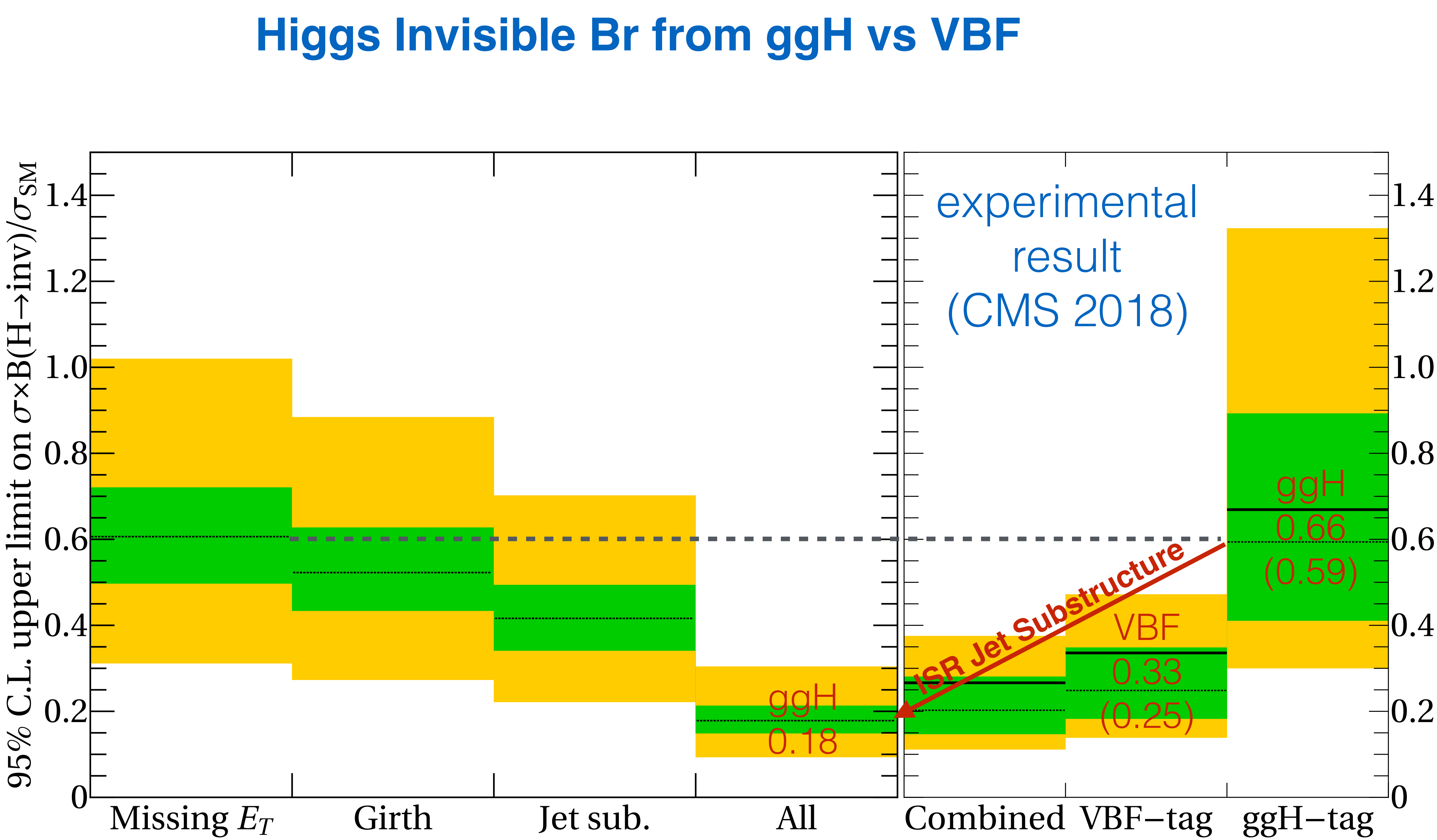
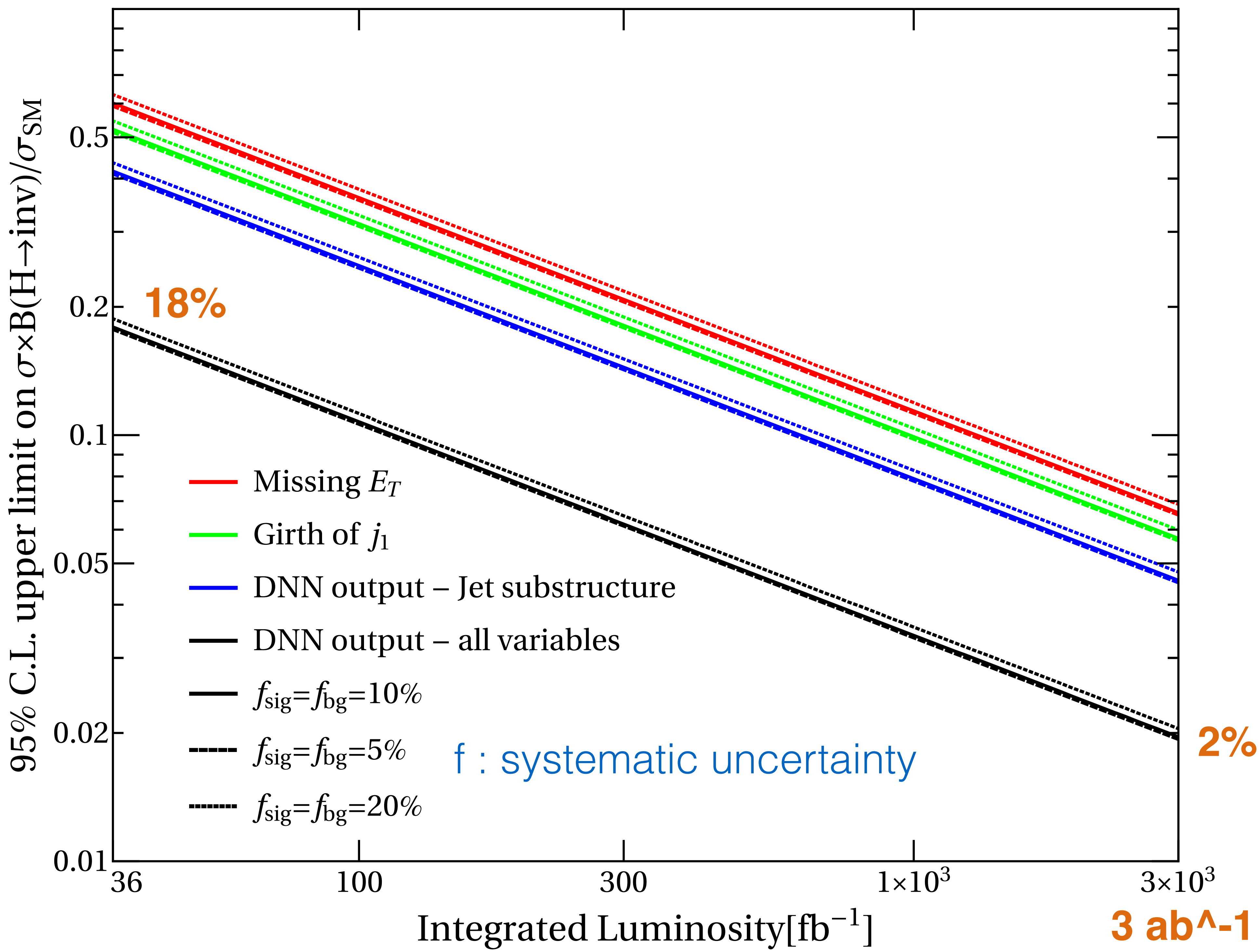


FIG. 4: Result with 36fb^{-1} with 5K ensembles.

Expected Sensitivity for Higgs Invisible Br from ggH



Combining with VBF, the limit can be stronger by 20~30%

Conclusion

Using jet substructure variables and machine learning, it was demonstrated that the strongest bound on **Higgs invisible branching ratio** can be obtained from **gluon fusion produced Higgs(ggH)** signals.

Different composition of quark and gluon jets in ISR from signal and backgrounds can be used to enhance the signal to background ratio in the analysis.

The idea can be generalized and applied in many processes including Higgs to dimuons(working in progress).