

Precise Measurement of Higgs Hadronic Decay at CEPC

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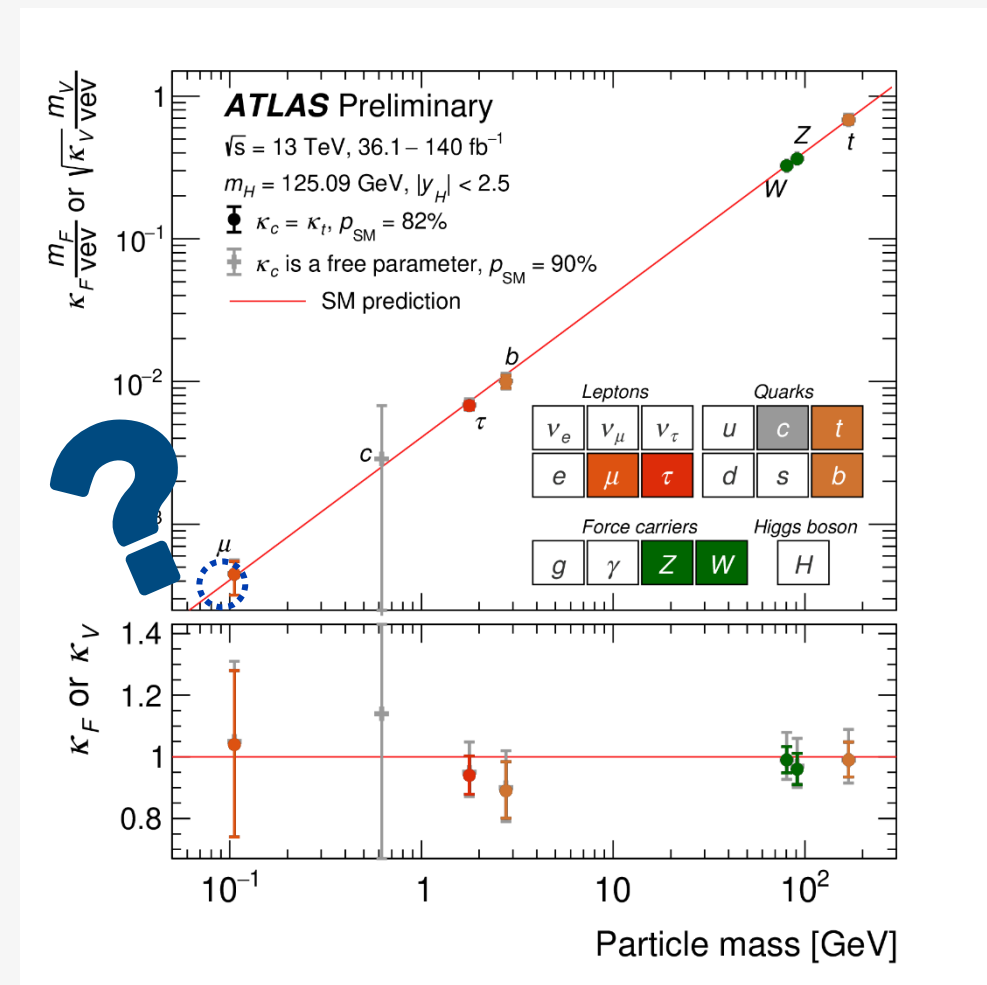
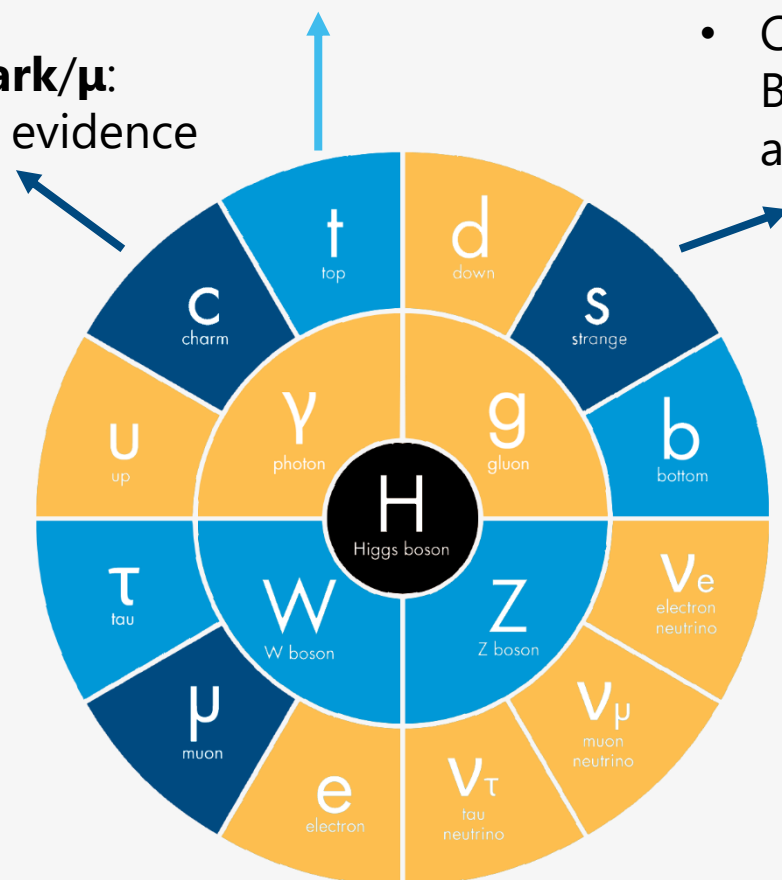


What's Next?



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- **3rd generation fermions & vector bosons:** observed
- **c quark/ μ :** towards evidence
- **s quark:** the next one?
- Challenge: small BR($\sim 10^{-4}$), QCD bkg at LHC



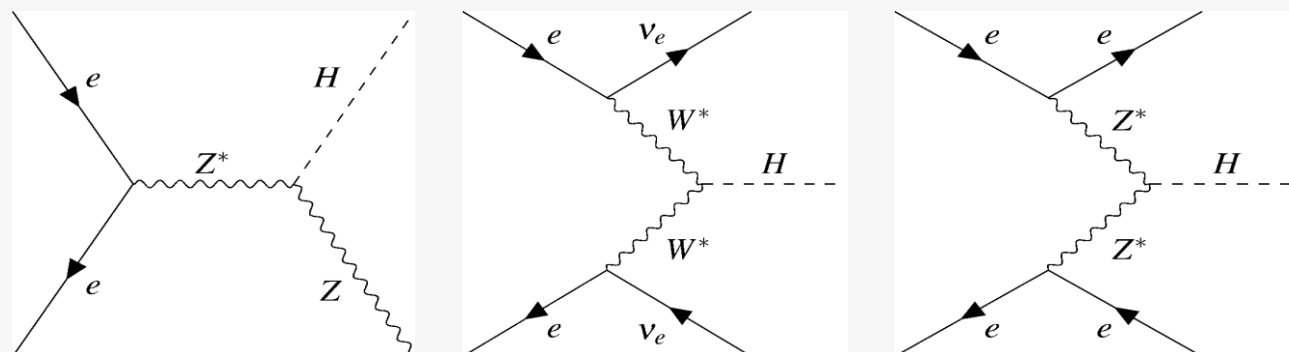
Nature volume 607, 52–59

CEPC: New Opportunity for Higgs Physics

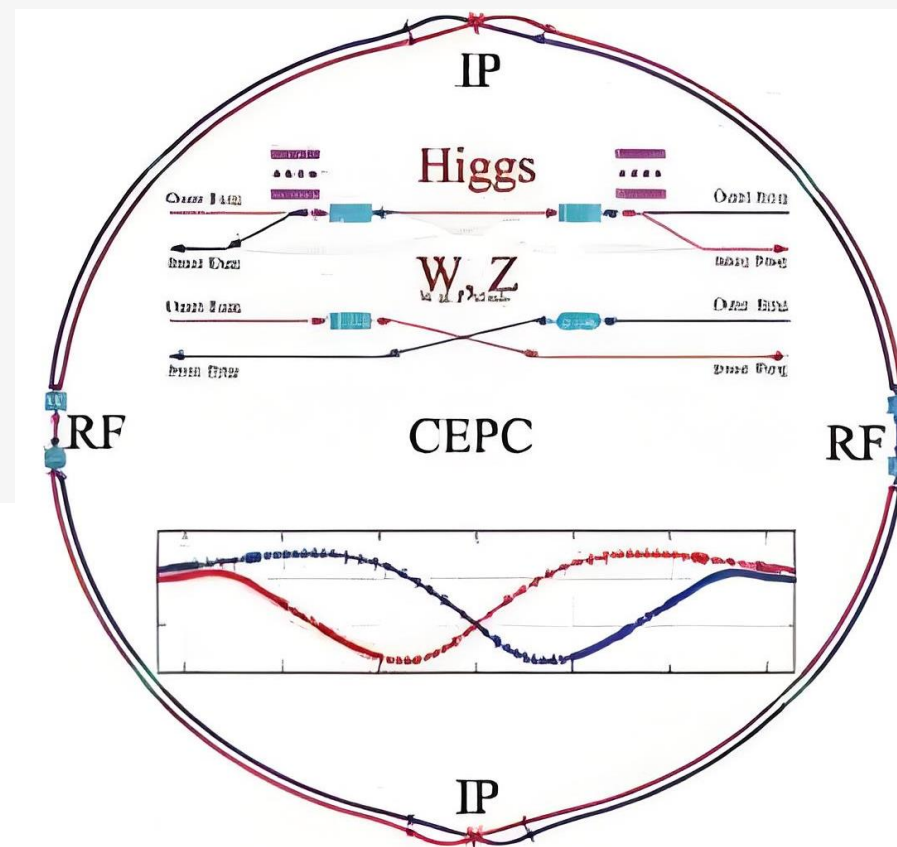


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- Lepton colliders like CEPC may provide opportunities for even more precise measurements of Higgs physics
 - ~4M Higgs events within 10 years
 - Clean jet environment from e^-e^+ collisions

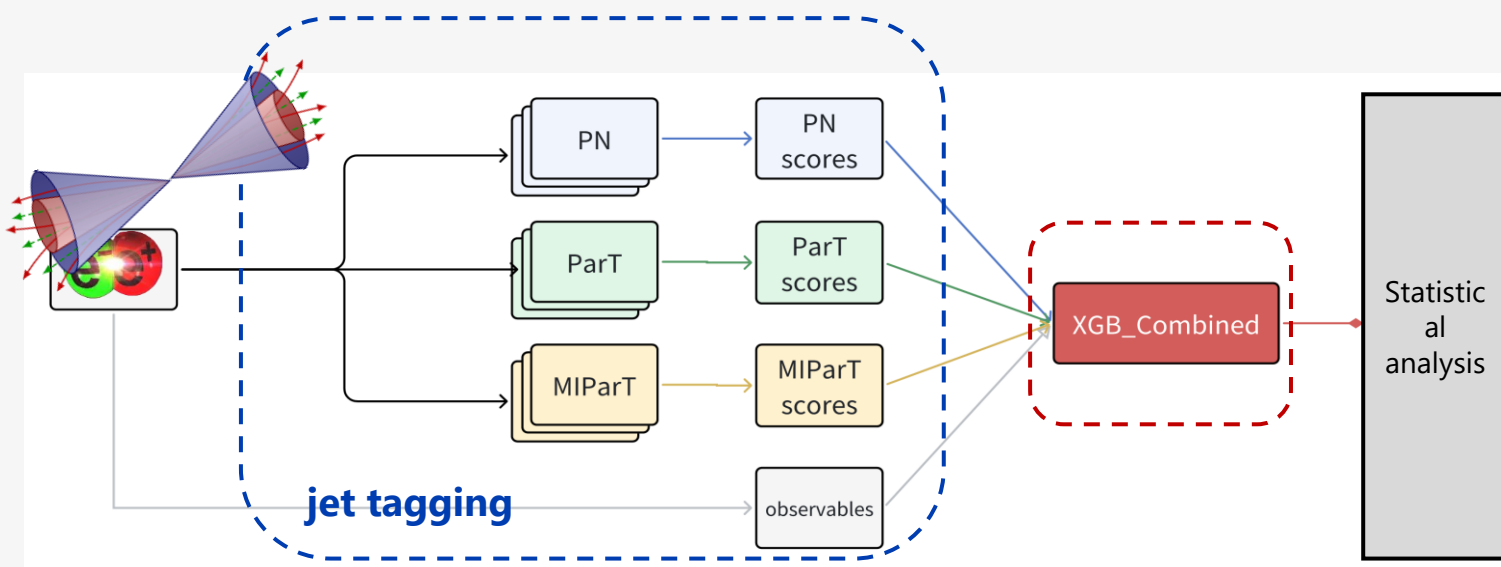


Operation mode	$\sqrt{s}$ (GeV)	SR power (MW)	$\mathcal{L}$ ($10^{34} \text{ cm}^{-2}\text{s}^{-1}$)	$\int \mathcal{L}/\text{year}$ (ab^{-1} , 2 IPs)	Years	Total $\int \mathcal{L}$ (ab^{-1} , 2 IPs)	Event yields
H	240	50	8.3	2.2	10	21.6	4.3×10^6
Z	91	50	192(*)	50	2	100	4.1×10^{12}
W^+W^-	155-170	50	26.7	6.9	1	6.9	5.5×10^7
$t\bar{t}$	360	50	0.8	0.2	5	1.0	0.6×10^6



H $\rightarrow$ ss based on Particle Info from Jet Tagging

- At event level, **combining jet scores** with other observables
 - Jet scores encode **information of jet sub-structures** while remain **traditional jet object**
 - 3 $\times$ 3 tagging models -> uncertainties from models
- 10M events from Delphes for each Higgs final state and SM bkg

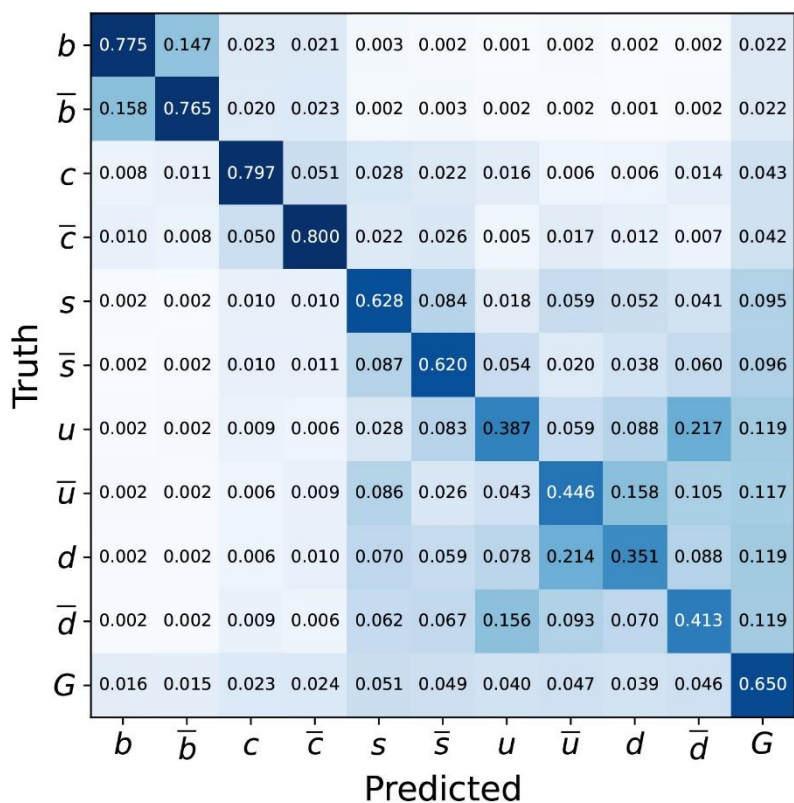


Category	Features
Single-jet kinematics	$p_T, p_z, \eta, \theta, \phi, \text{energy}$
Jet shape and composition	$n_{\text{particles}}, \Delta R, \Delta p_T$
Dijet kinematics	$m_{jj}, \Delta\eta_{jj}, \Delta\theta_{jj}, \Delta\phi_{jj}$
Missing energy	$\text{MET}, \eta_{\text{ME}}, \theta_{\text{ME}}, \phi_{\text{ME}}, \text{MEZ}, \text{MET}/p_T^{\text{otherobjects}}$
Jet-MET correlations	$\Delta\eta, \Delta\phi, \Delta\theta$ between each jet and MET
Jet flavor tagging scores	outputs from ParticleNet, ParT, and MIParT

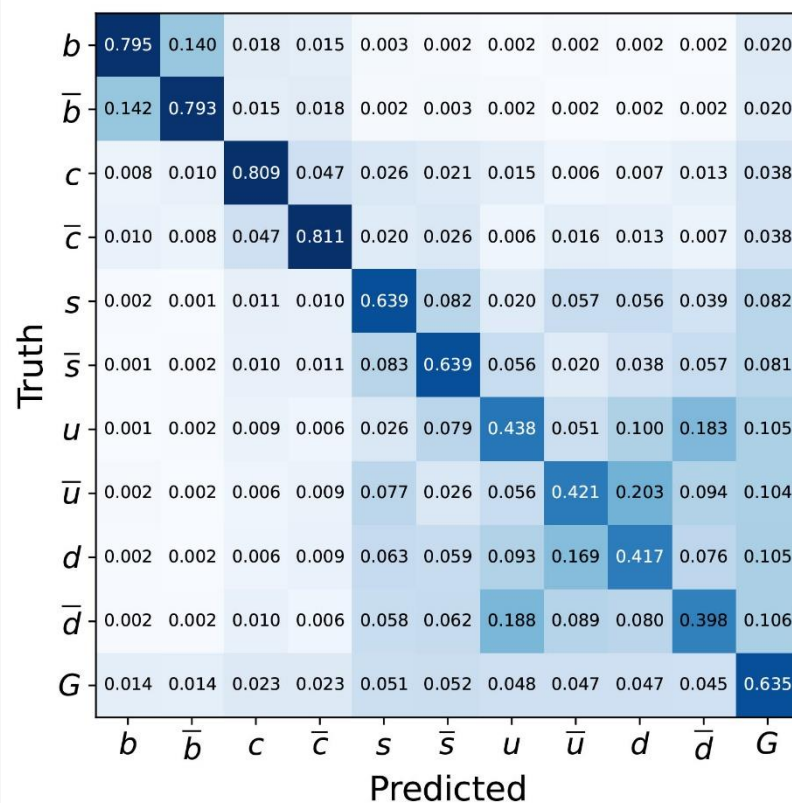
BDT inputs

Jet Tagging at CEPC

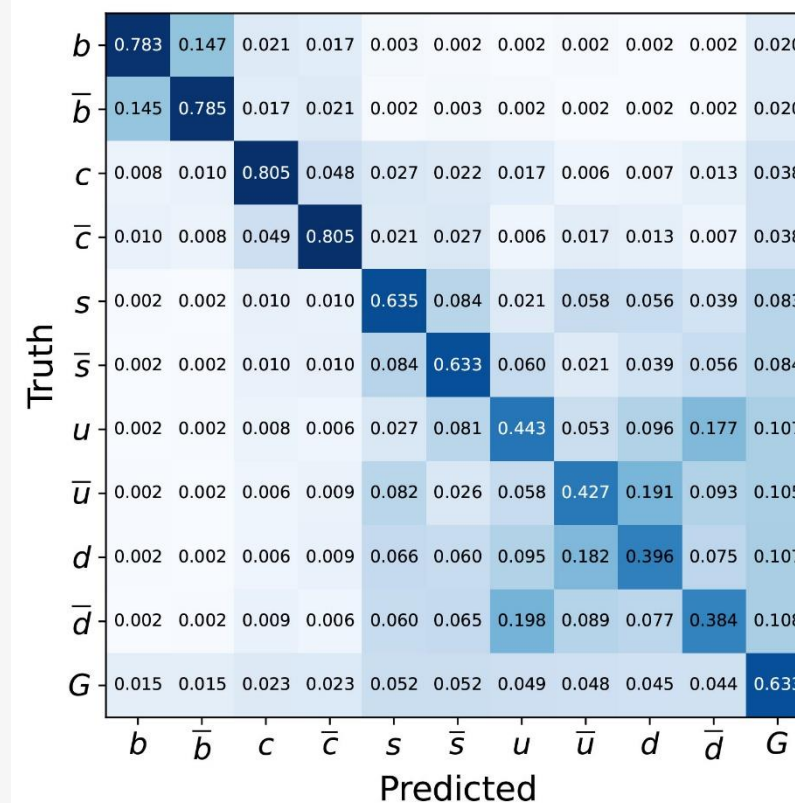
- Possibility to tag s-jets at CEPC



PN



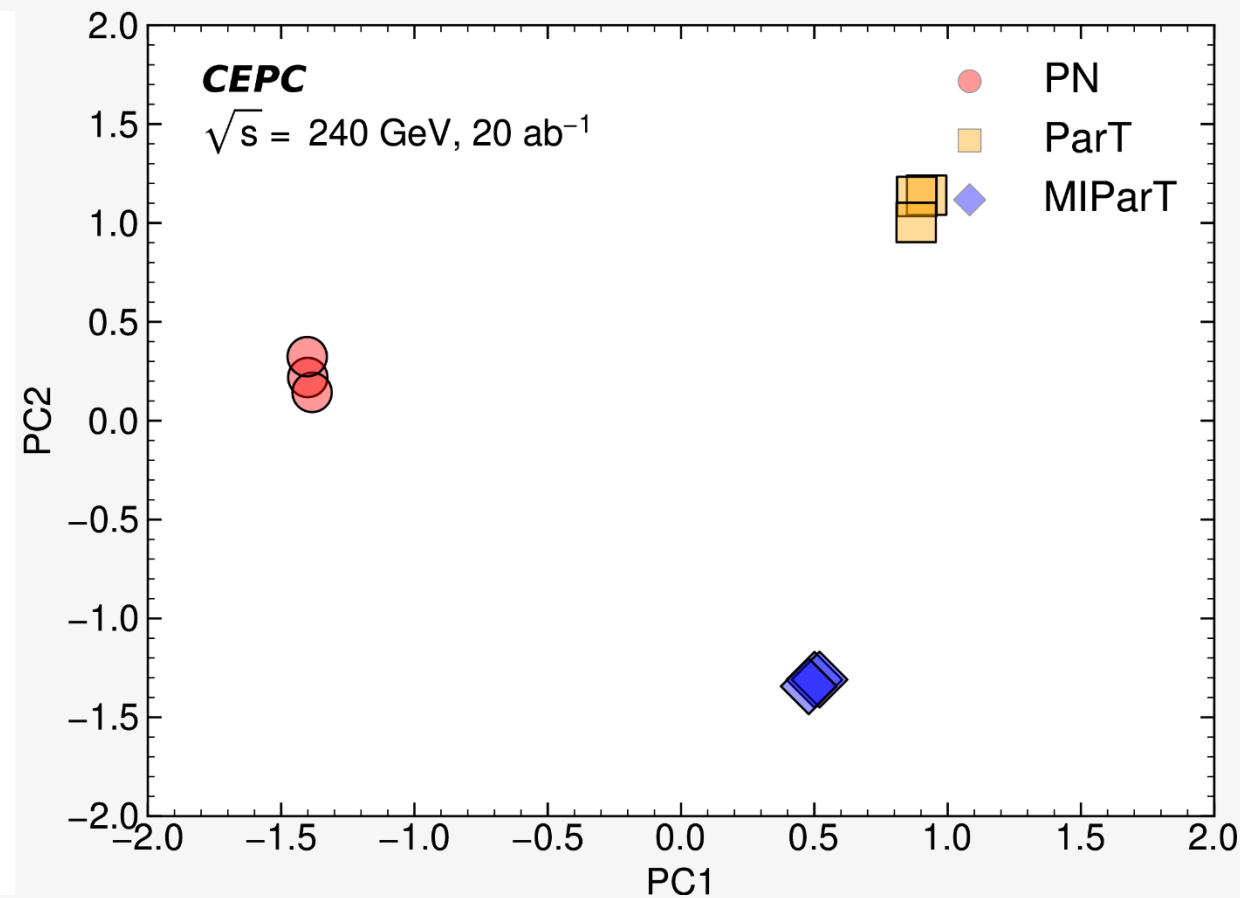
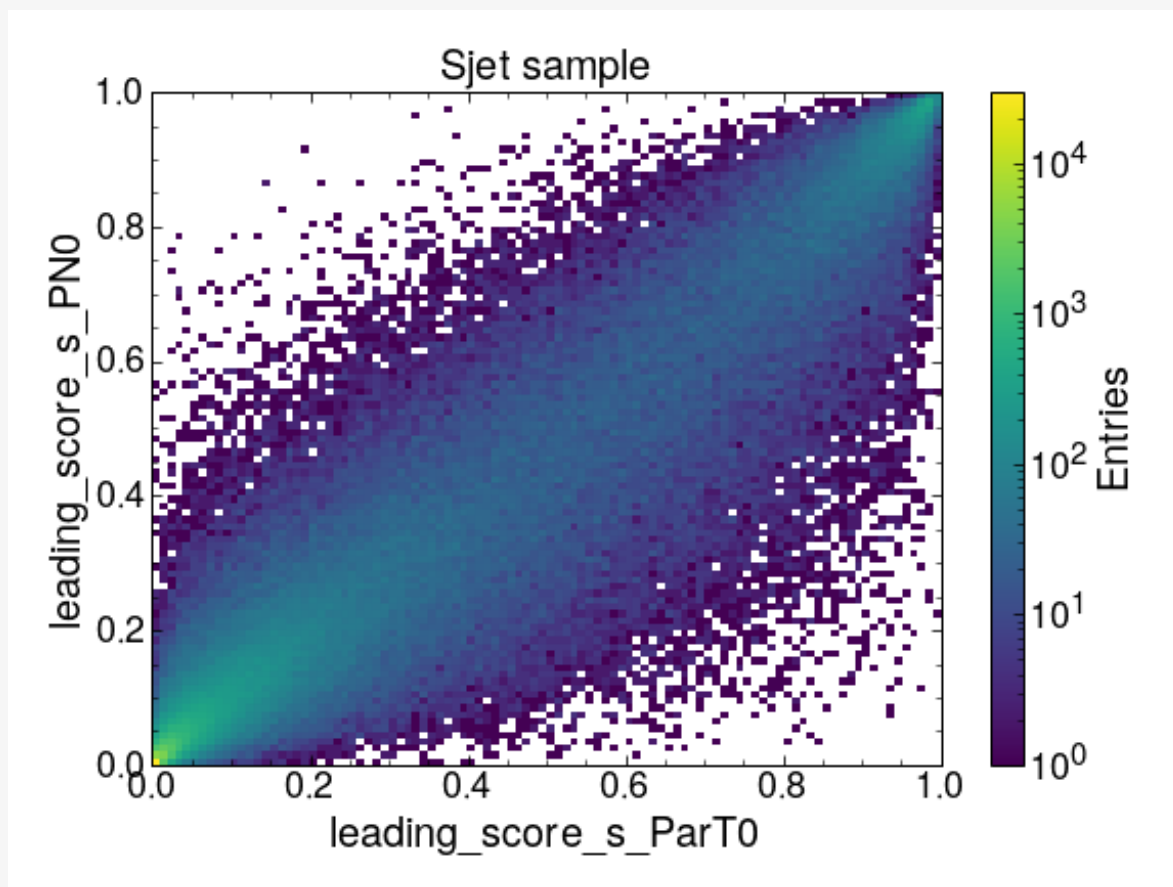
ParT



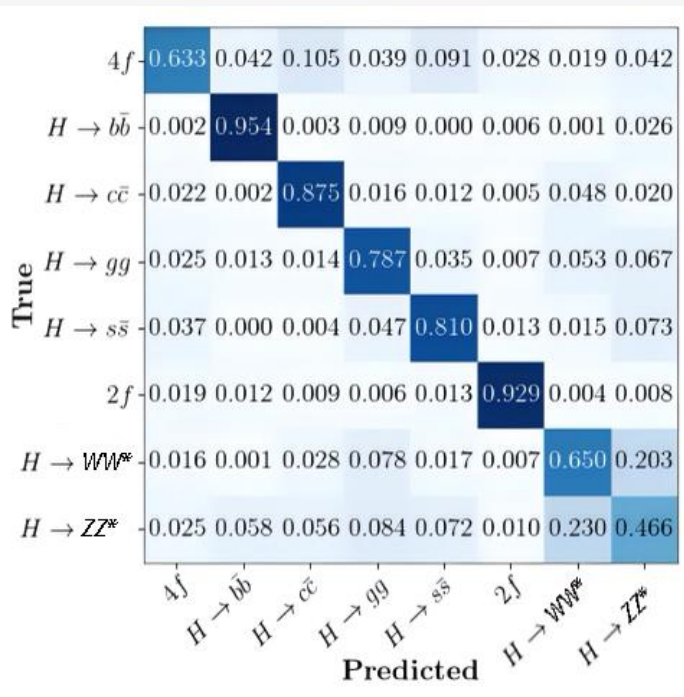
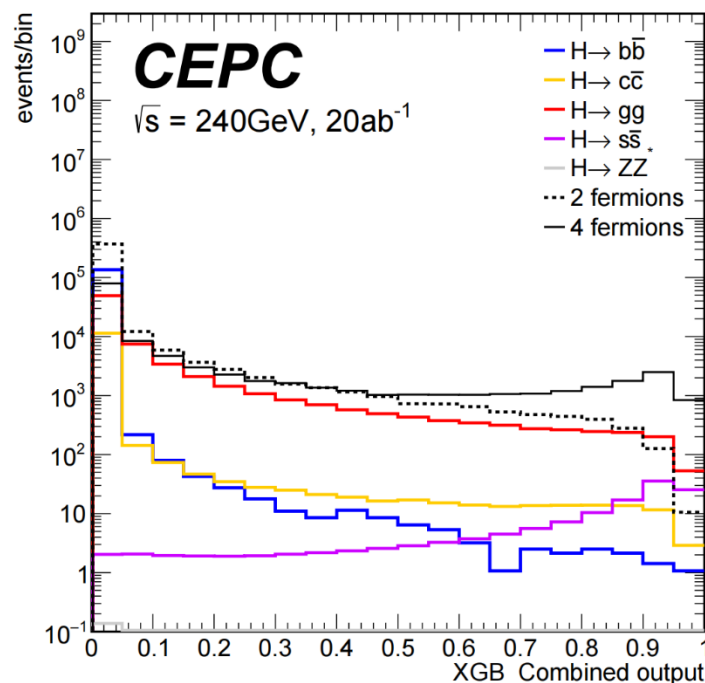
MIParT

Correlations of Models

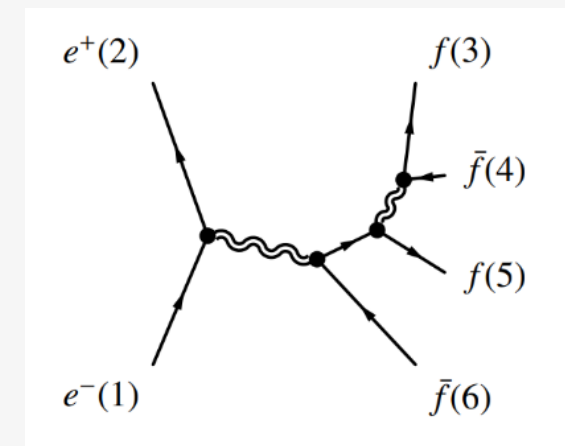
- Do different models extract different info in a jet?



H→ss Results



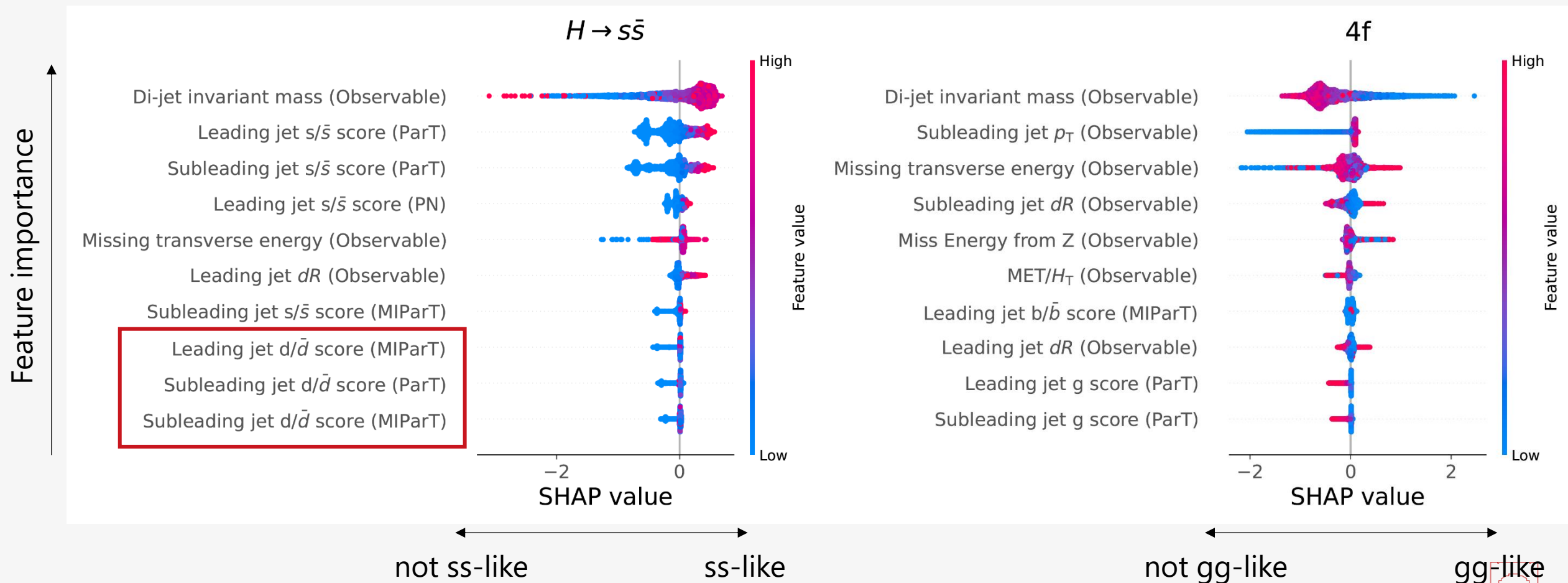
- Good classification performance among the channels
- $\sim 1.5\sigma$ (statistical only) for H→ss search
- Leading bkg: 4f



Channels	H->bb	H->cc	H->gg	H->ss	H->ZZ	4f	2f
Efficiency [%]	6.00E-04	0.07	0.44	45.99	0.00	0.04	8.00E-04
Event Yields [20/ab]	3.21	20.05	346.85	91.97	0.00	3288.52	211.25

Interpretations of the Results

- **SHapley Additive exPlanations**: how features contribute to the results event by event
- **d-tagging** plays an important role in identifying $H \rightarrow s\bar{s}$

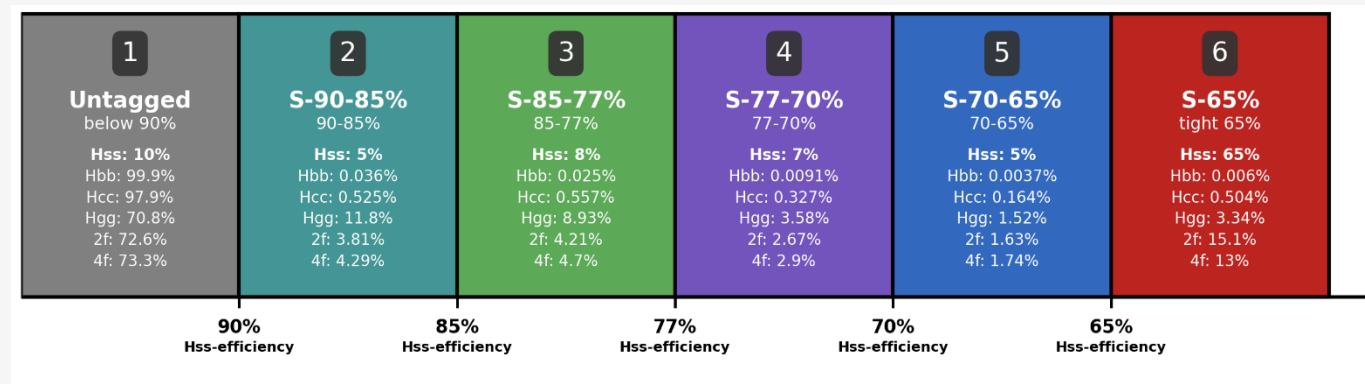


Do Jet Scores Really Carry More Information?



- Define s-tagging WPs in a traditional way
 - Select 2 s-tagged jets @ 85 WP and retrain the event classifier

- Using tagging scores directly improved the significance
- Underlying information, especially **correlations between jet constituents** are carried by the **shape of the tagging scores**



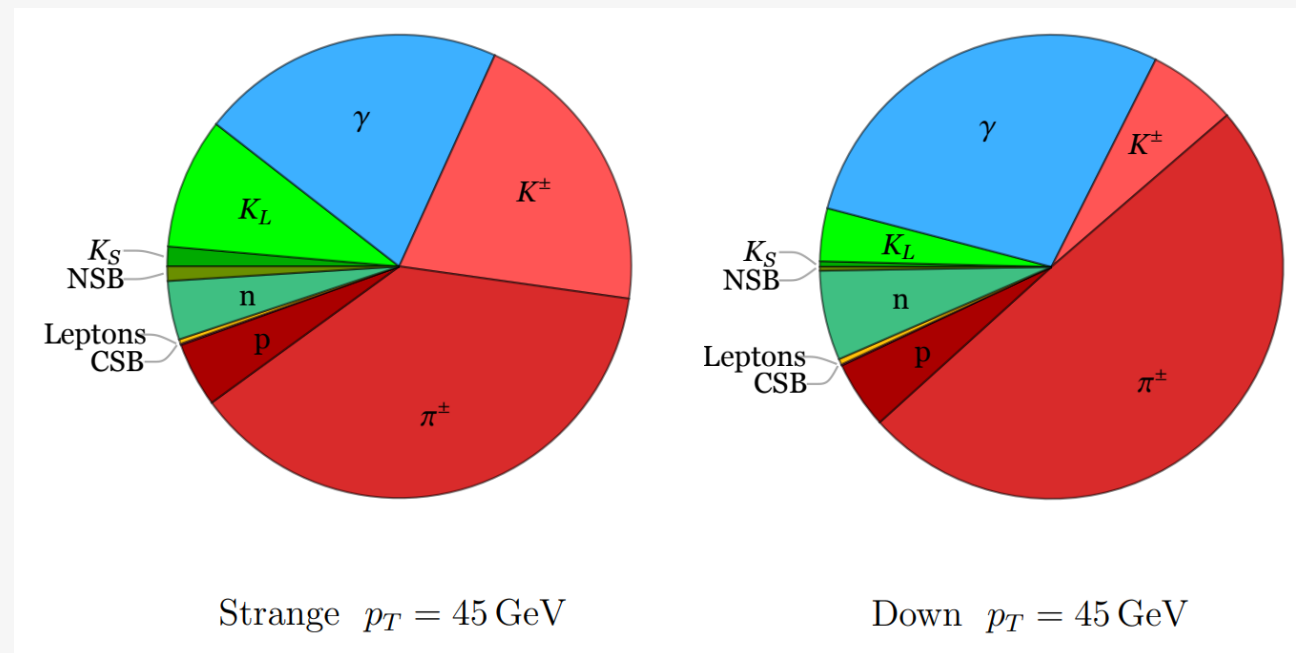
Scheme	S	B	significance [σ]	precision
Our work	91.97	3869.88	1.48	68%
No s-tagging	83.06	33412.41	0.45	220%
N s-jet>2 @ 85 WP	82.12	6147.38	1.05	96%

From Pheno to Realistic

- Various uncertainties are considered
 - **PID** plays a leading role in tagging s and light jets -> signal loss considering realistic PID in current CEPC design
 - Other systematic sources at ~1% or negligible

True	$H \rightarrow b\bar{b}$	0.971	0.011	0.000	0.017
	$H \rightarrow c\bar{c}$	0.009	0.922	0.026	0.043
	$H \rightarrow s\bar{s}$	0.001	0.018	0.826	0.155
	$H \rightarrow gg$	0.023	0.043	0.141	0.793
		$H \rightarrow b\bar{b}$	$H \rightarrow c\bar{c}$	$H \rightarrow s\bar{s}$	$H \rightarrow gg$

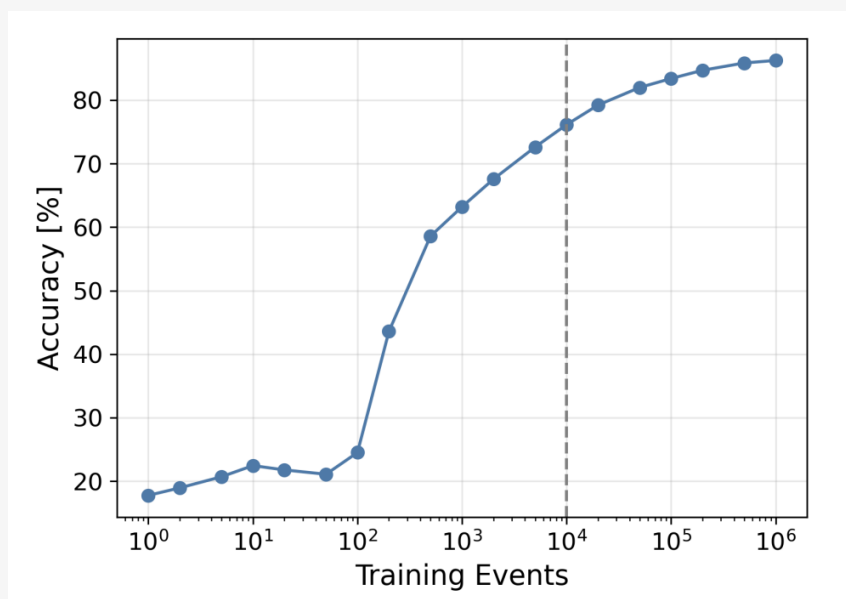
Full simulation matrix Predicted



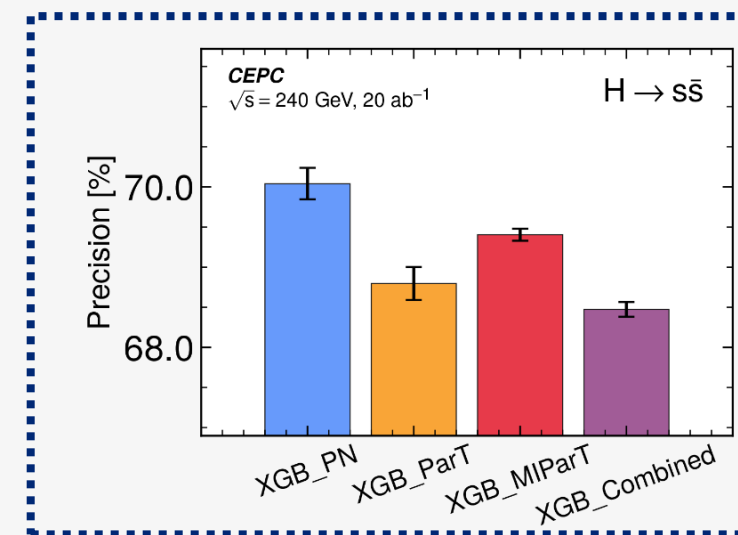
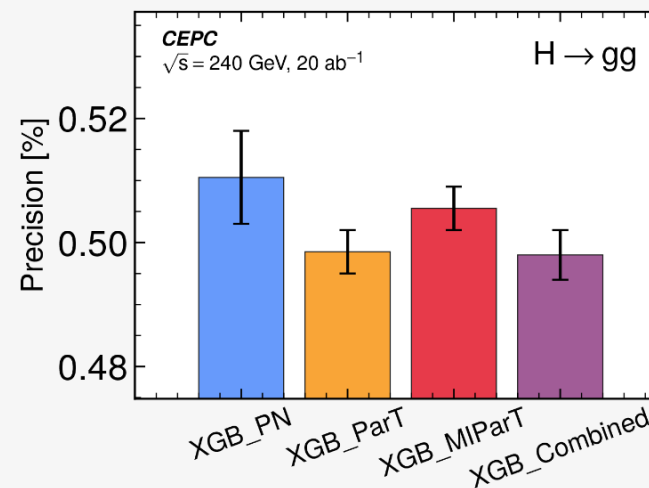
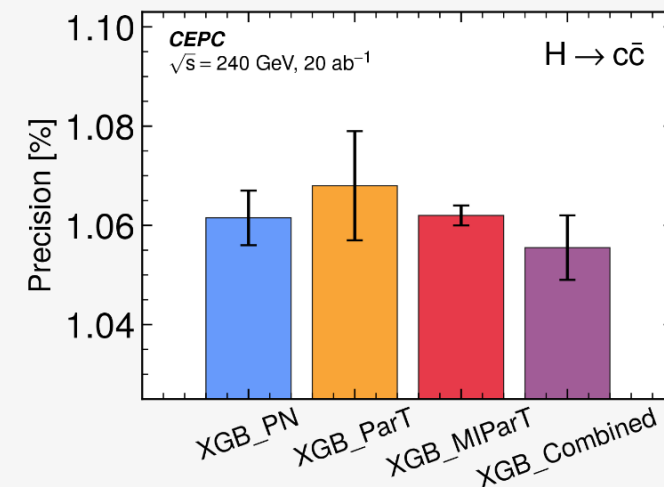
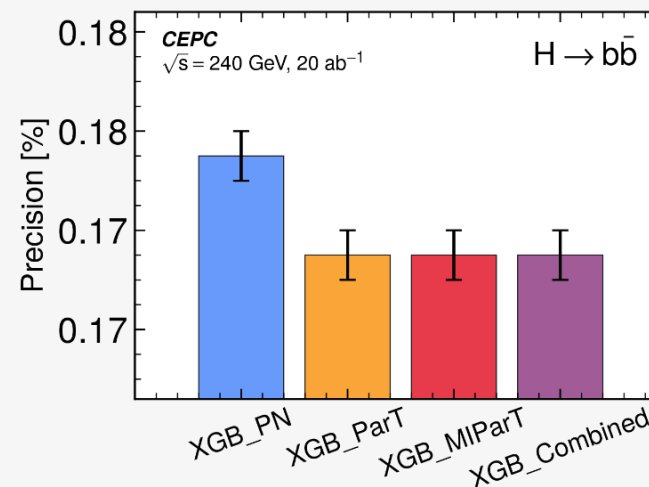
[arxiv:2003.09517](https://arxiv.org/abs/2003.09517)

What Beyond Our Knowledge

- Only $H \rightarrow ss$ precision improved from multiple jet experts?
 - Scaling law: will the sensitivity be further improved with $> 10M$ evts?



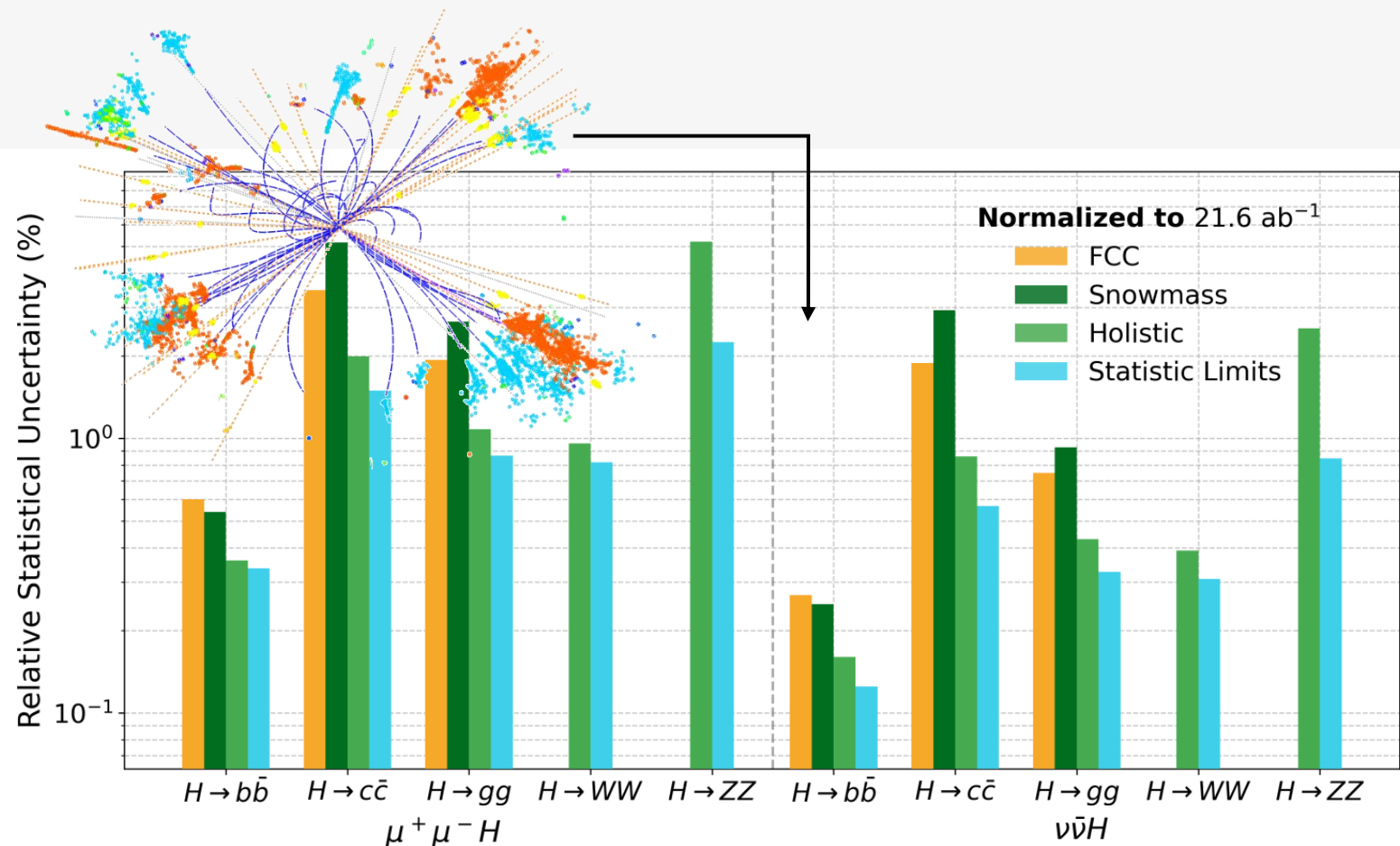
HiHEP 2026, 2 (1), 5



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Even More Particle Level Information?

- While indirect info from jet tagging boosts sensitivity, **how about using particles directly?**
- “Holistic”** approach: event classifier from particles to events **w/o jets**



Channel	This work	Holistic
$Z \rightarrow \nu\bar{\nu}, H \rightarrow b\bar{b}$	0.17%	0.14%
$Z \rightarrow \nu\bar{\nu}, H \rightarrow c\bar{c}$	0.78%	0.72%
$Z \rightarrow \nu\bar{\nu}, H \rightarrow gg$	0.46%	0.46%
$Z \rightarrow \nu\bar{\nu}, H \rightarrow s\bar{s}$	23%	29%

- Now jet scores + jets show competitive performance
- Many questions to be answered: SM bkg? $Z(qq)H$? theo. unc. ? ...

Conclusions

- We explore the limit of Higgs couplings to quarks in a combined approach
 - Jet level tagging -> jet scores in event-level classification

Channels	CEPC	FCC-ee	Ours JHEP	Improvement vs CEPC
$Z \rightarrow \nu\nu, H \rightarrow bb$	0.20%	0.28%	0.17%	15%
$Z \rightarrow \nu\nu, H \rightarrow cc$	1.85%	1.95%	1.06%	43%
$Z \rightarrow \nu\nu, H \rightarrow gg$	0.70%	0.78%	0.50%	29%
$Z \rightarrow \nu\nu, H \rightarrow ss$	—	117%	68%	—

- Interpretations of the results
- Systematics estimate
- Even more exciting: holistic approach?



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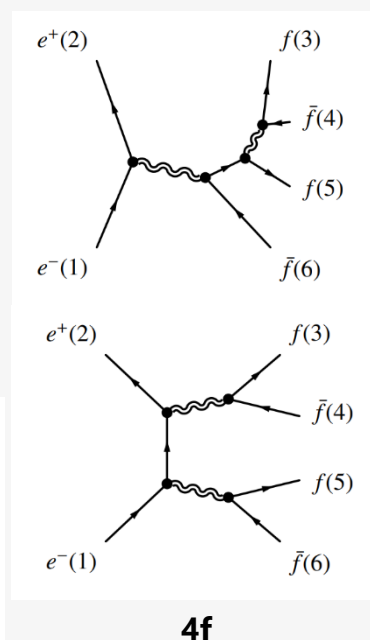
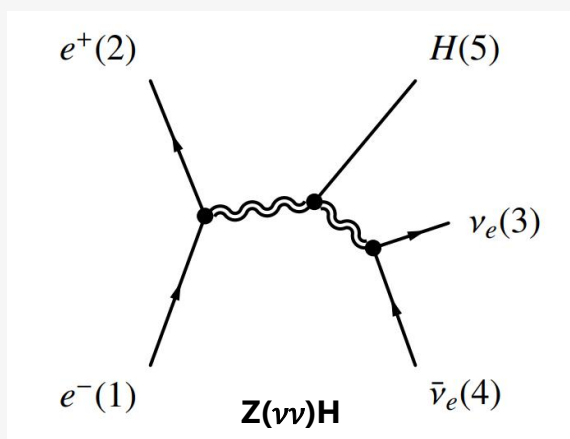
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Thank You!

飲水思源 愛國榮校

Samples

- **10M** Delphes events generated for each process
- **Signal:** $ee \rightarrow ZH$, $Z \rightarrow \nu\nu$, $H \rightarrow qq/gg$ @ 240GeV
- **Backgrounds:** Dominated by $H \rightarrow ZZ$, 2 fermions and 4 fermions

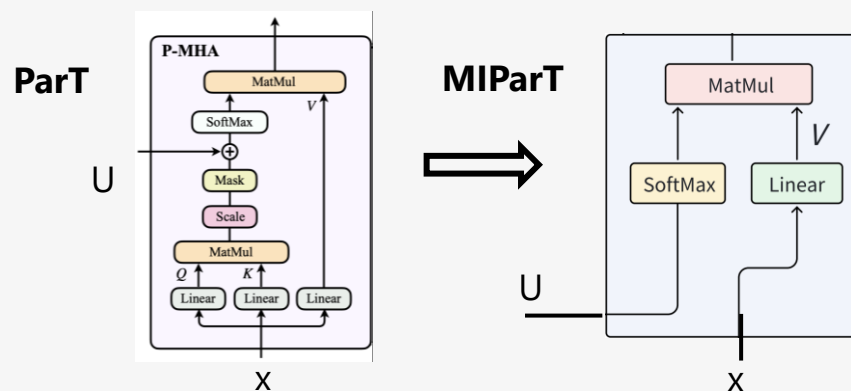
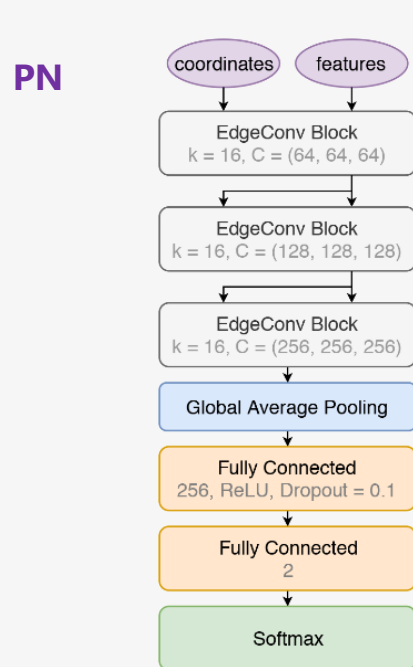


Category	Channel	Cross Section [fb]	Expected Events [M]	Simulated Events [M]
Signal	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow bb$	26.71	0.5342	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow cc$	1.35	0.027	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow ss$	0.01	0.0002	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow gg$	3.97	0.0794	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow ZZ$; $Z \rightarrow \nu\nu$, $Z \rightarrow qq$	0.34	0.0068	10
Background	4f	369.71	7.3942	44
	2f	54106.86 1213.25	1082.1372 24.2650	6

2f

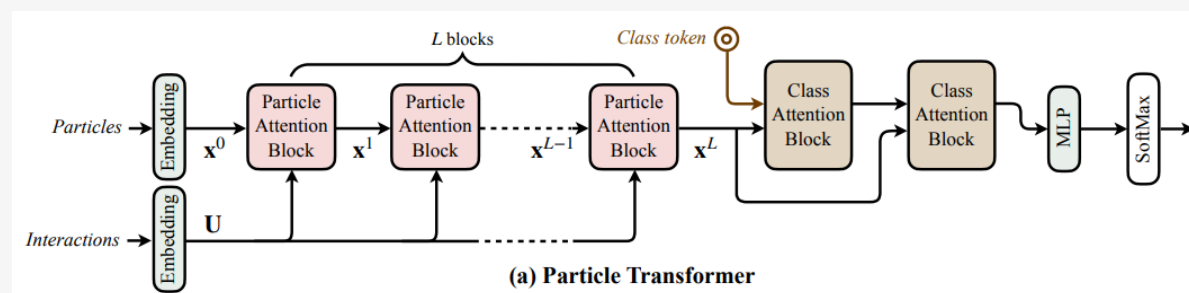
Jet Tagging at CEPC

- 3 advanced taggers
 - ParticleNet (PN)**: Use dynamic graph convolutions to learn local & global jet substructure
 - Particle Transformer (ParT)**: Based on attention, capturing long-range correlations among jet constituents
 - More-Interaction Particle Transformer (MIParT)**: reduced ParT



Model	Params
ParticleNet	370k
ParT	2.14M
MIParT	720.9k

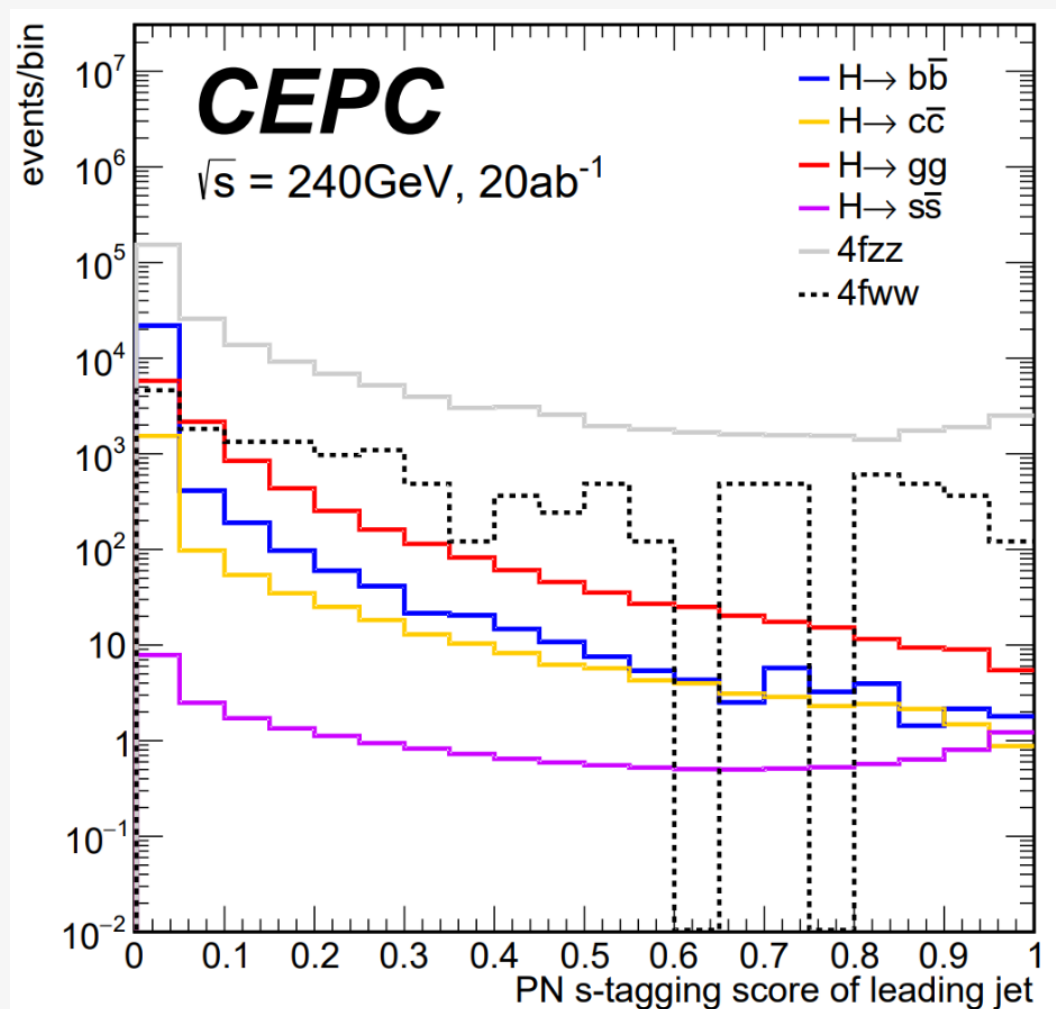
0.3x



Jet Tagging at CEPC

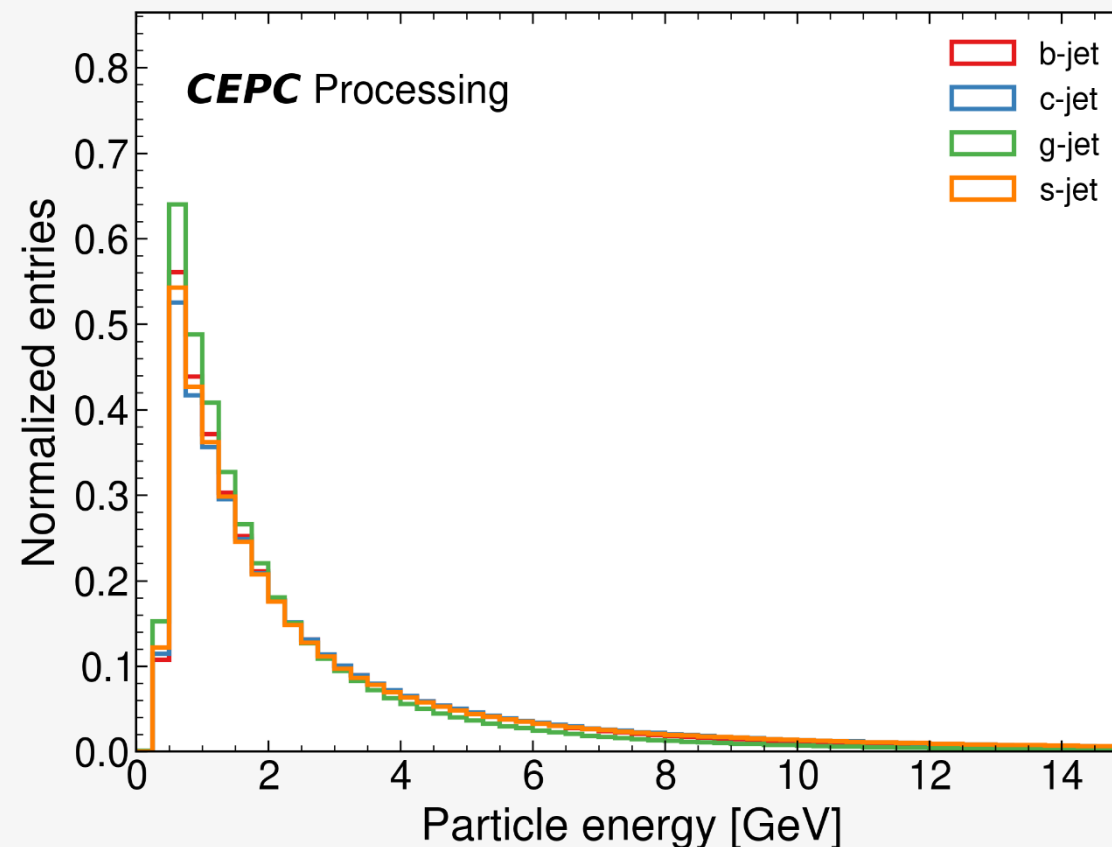
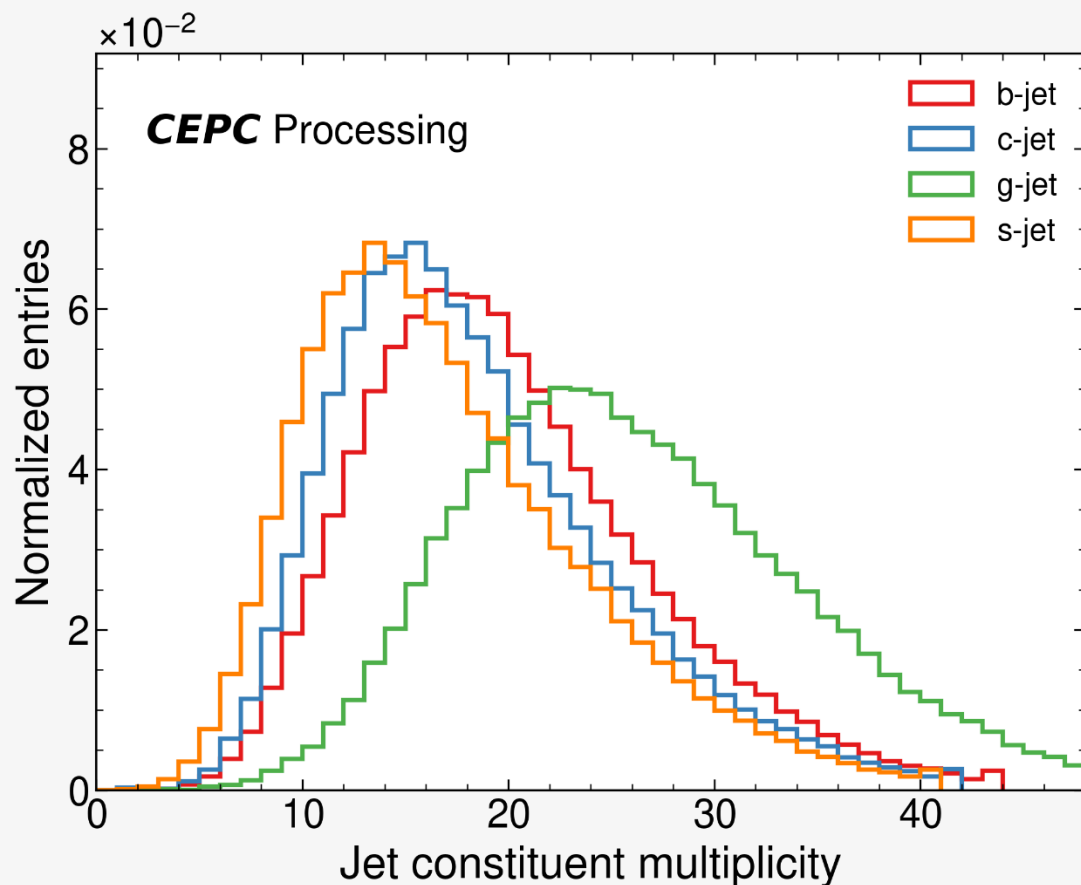


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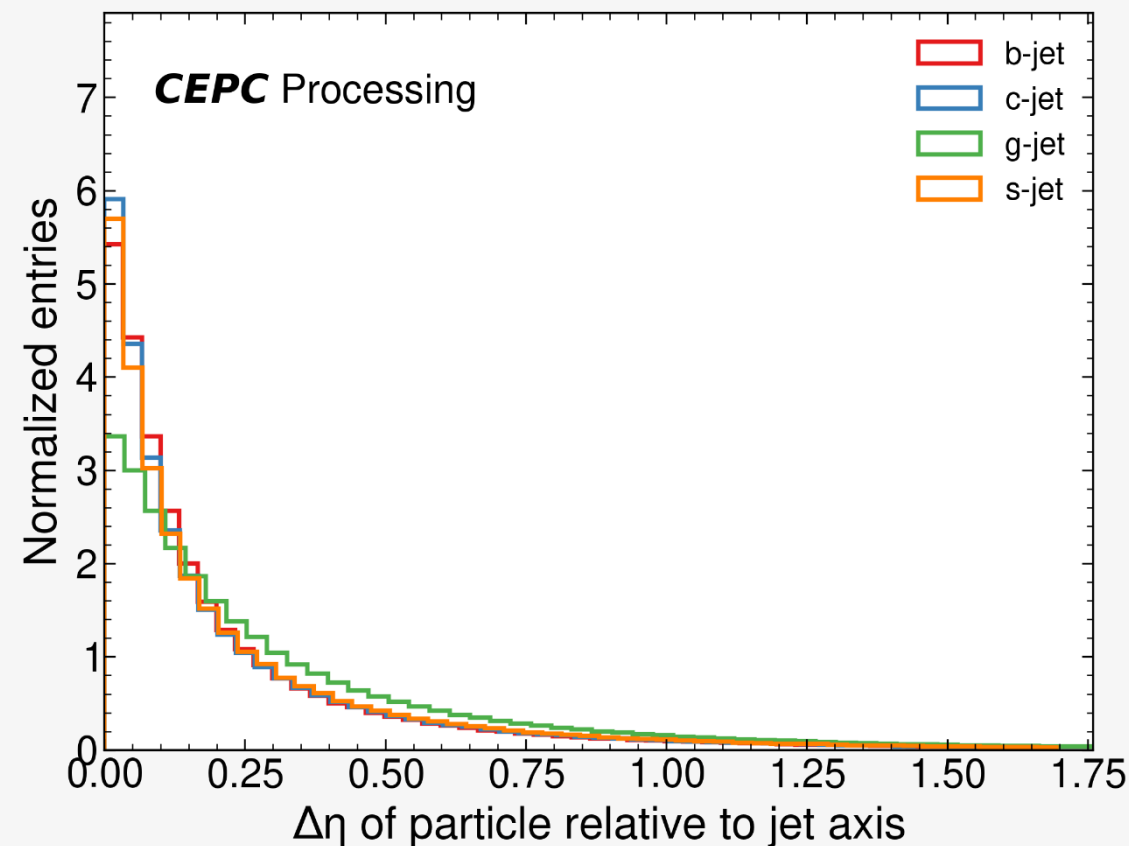
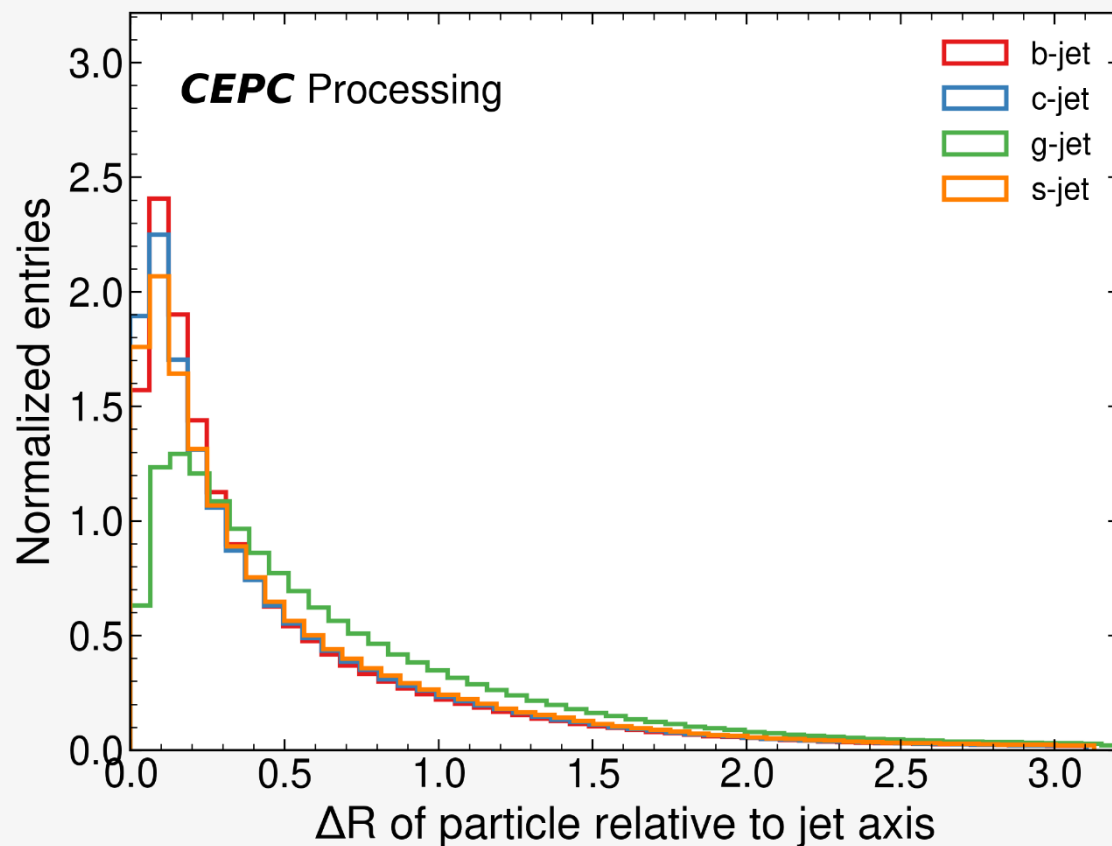


- Underlying information, especially correlations between jet constituents are carried by the shape of the tagging scores

Some Characteristic Distributions for Jet Classifier



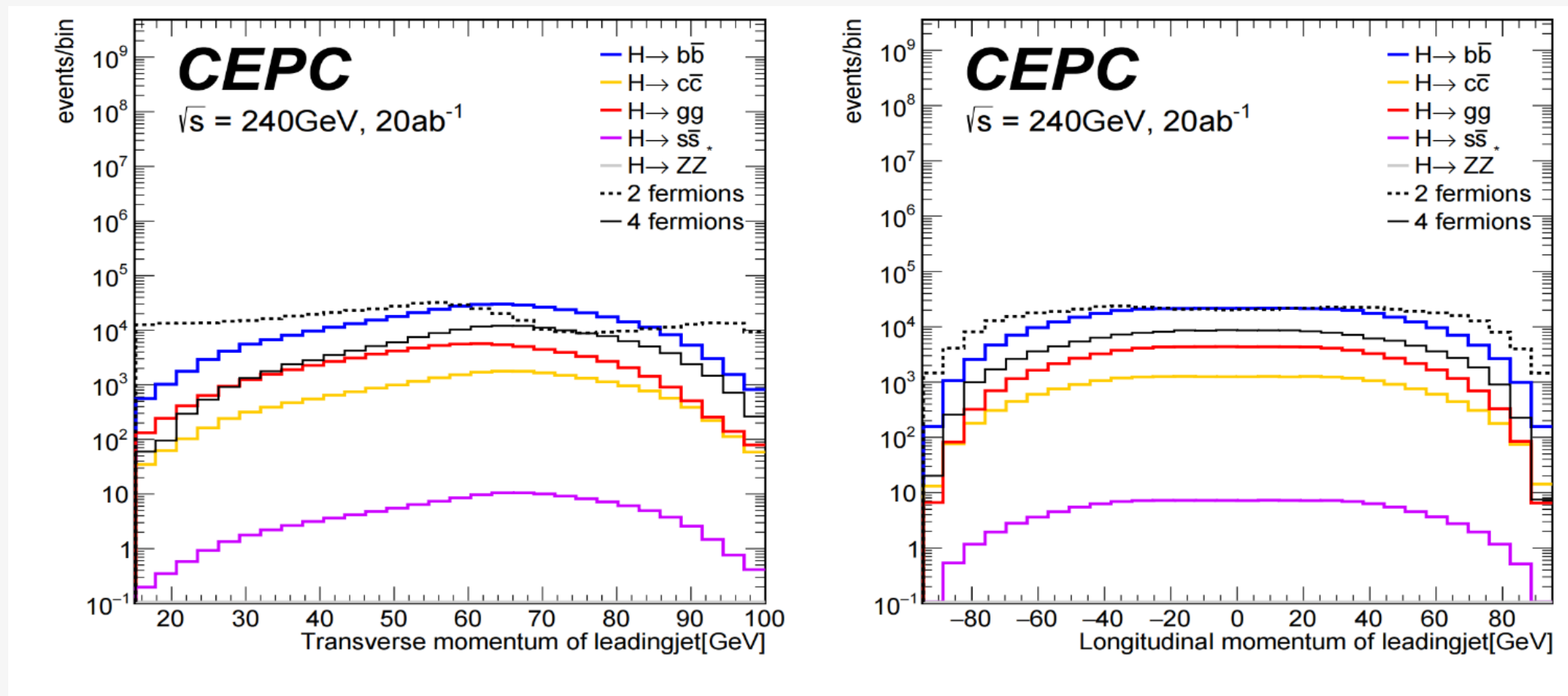
Some Characteristic Distributions for Jet Classifier



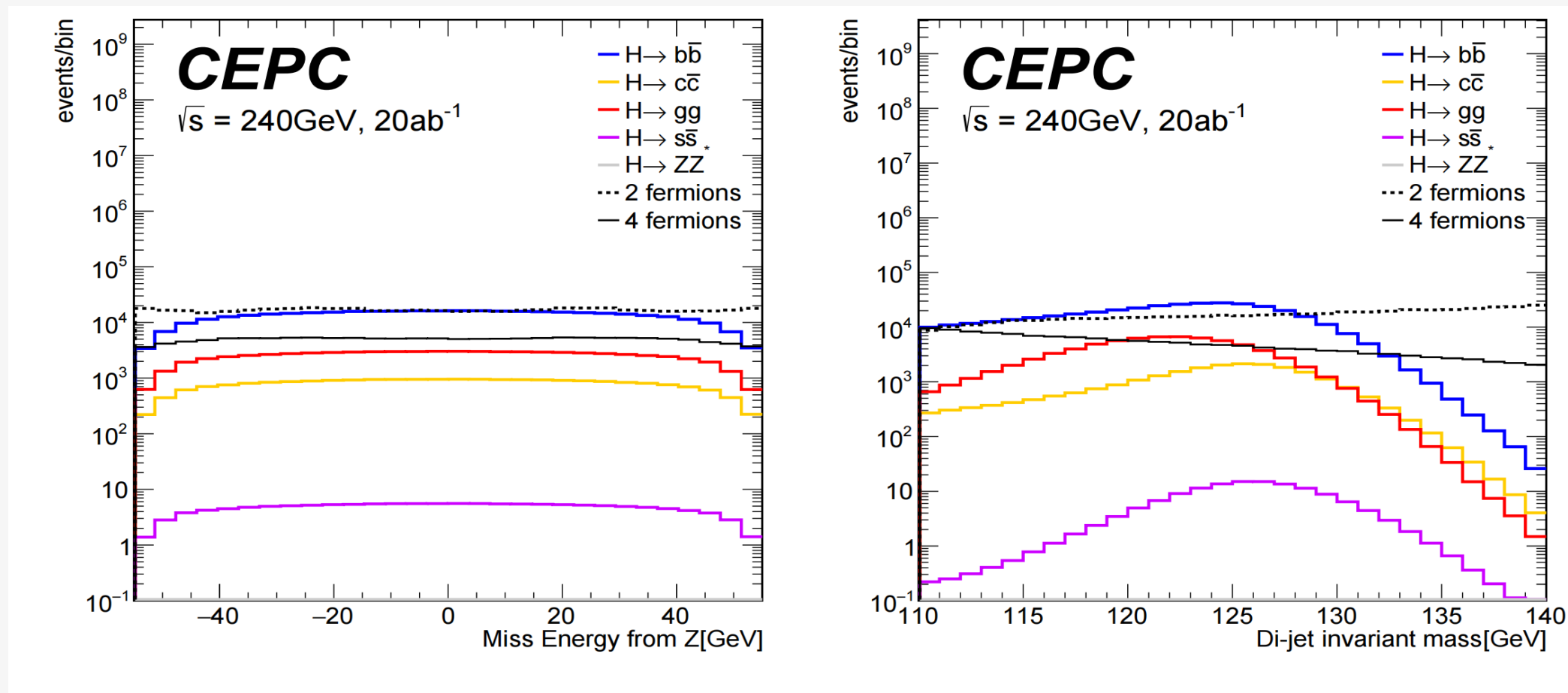
Some Characteristic Distributions for Event Classifier



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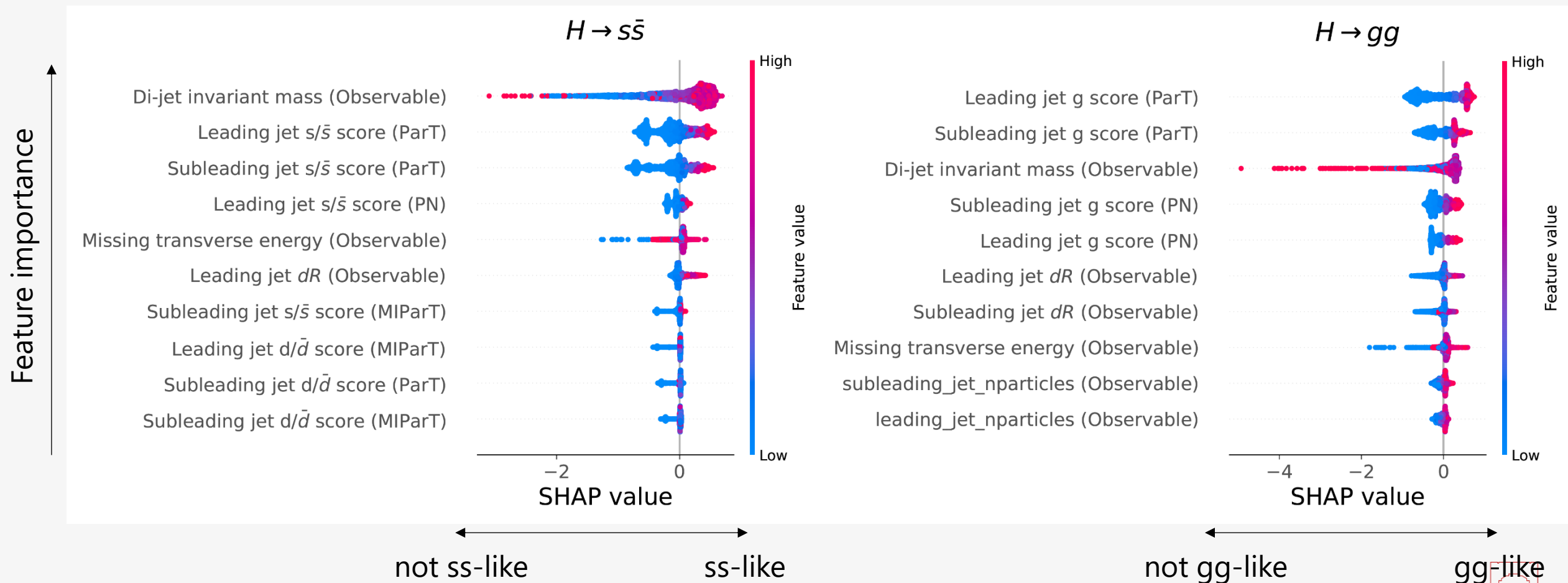


Some Characteristic Distributions for Event Classifier



Interpretations of the Results

- **SHapley Additive exPlanations**: how features contribute to the results event by event
- m_{jj} , jet ΔR and **tagging scores** dominate the **Higgs processes** classification



Interpretations of the Results

- **2f bkg**: suppressed by event level features
- **4f bkg**: no features with good discriminative ability, can be explained from the diagrams

