
Precise Measurement of Higgs Hadronic Decay at CEPC

Zhu Yifan,

Wang Xinzhu, Zhu Chunxiang, Wang Kun, Yang Haijun



上海交通大学
SHANGHAI JIAO TONG UNIVERSITY



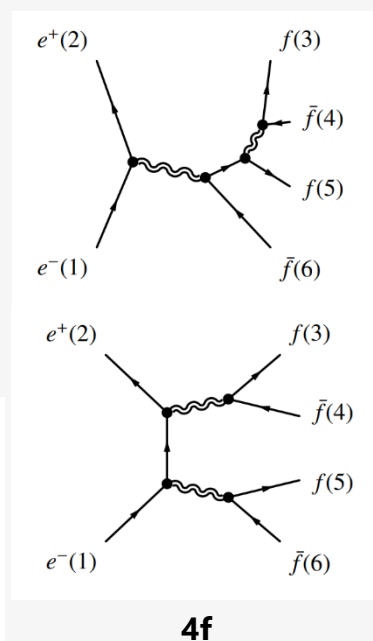
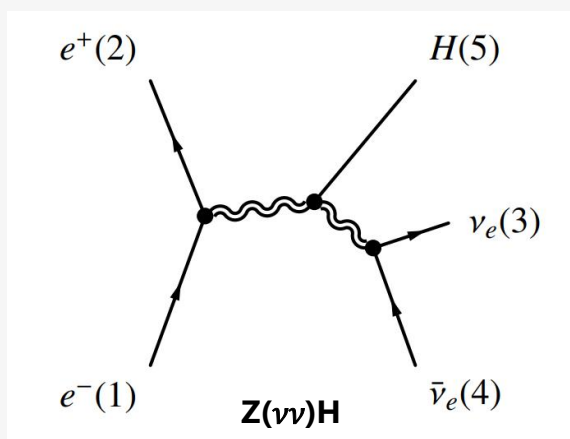
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DARK
SHINE

H→ss Pheno Search based on Advanced Jet Tagging

- **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

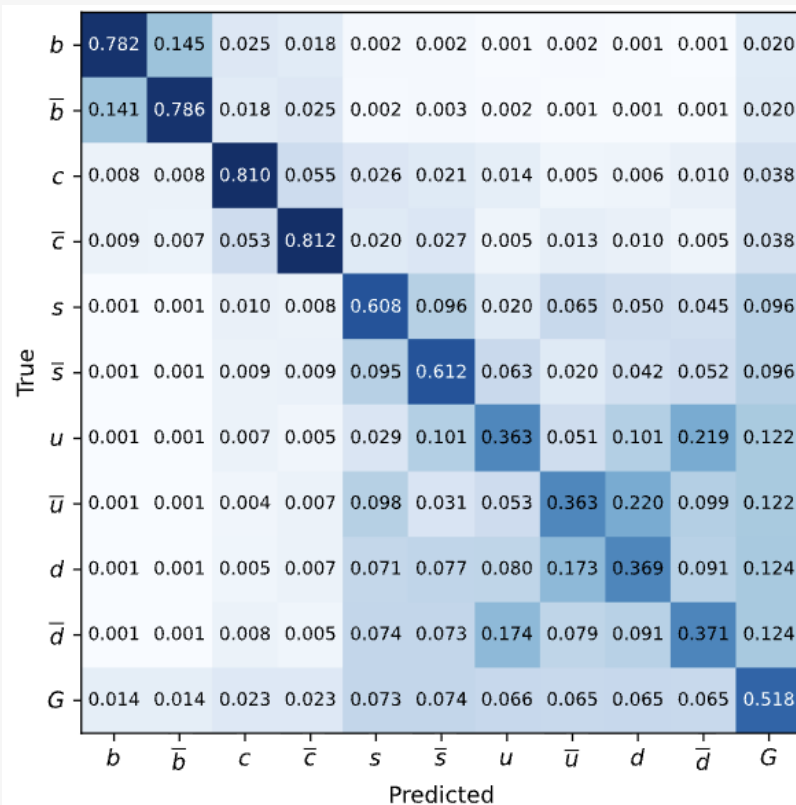


Category	Channel	Cross Section [fb]	Expected Events [M]	Simulated Events [M]
Signal	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow bb$	26.71	0.5342	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow cc$	1.35	0.027	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow ss$	0.01	0.0002	10
	ZH, $Z \rightarrow \nu\nu$, $H \rightarrow gg$	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

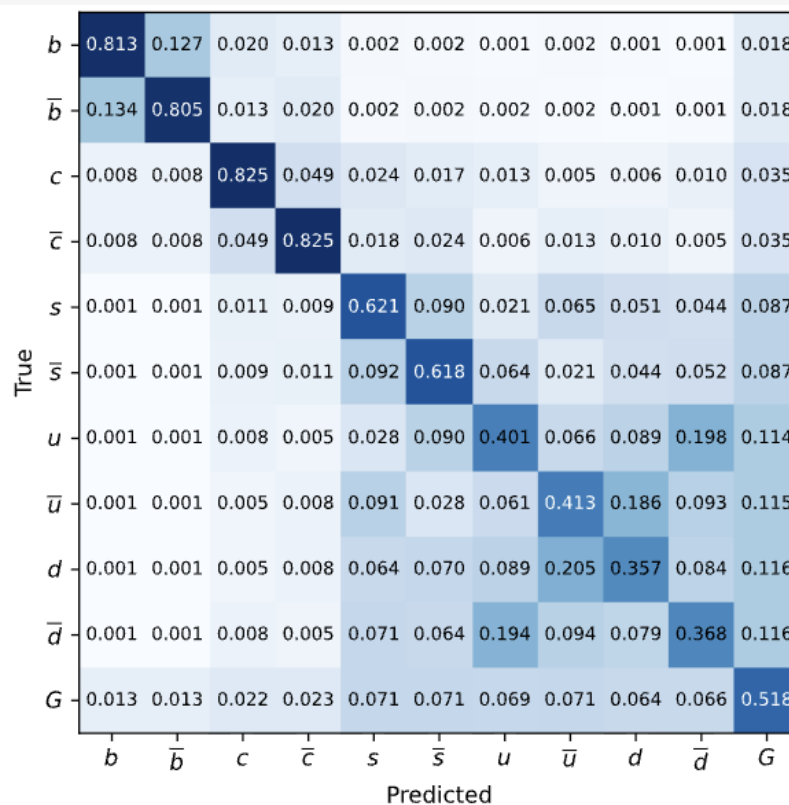
2f

Jet Tagging at CEPC

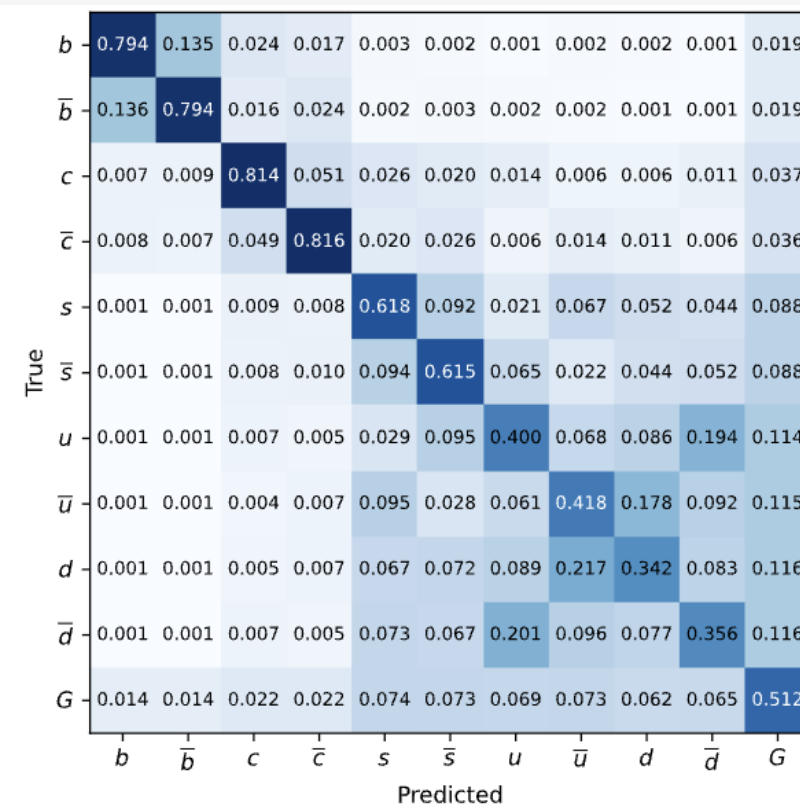
- Possibility to tag s/jets at CEPC



PN

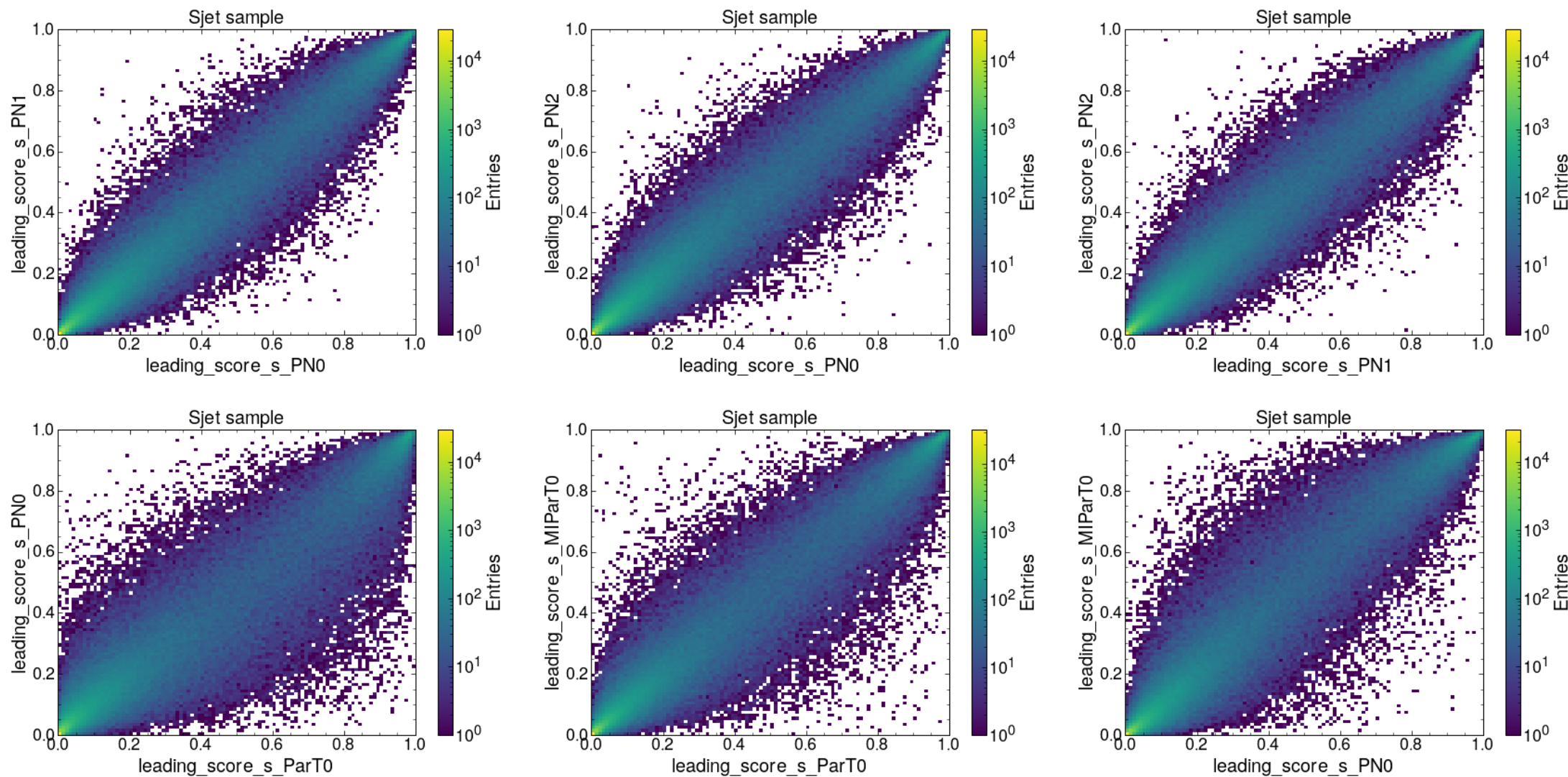


ParT



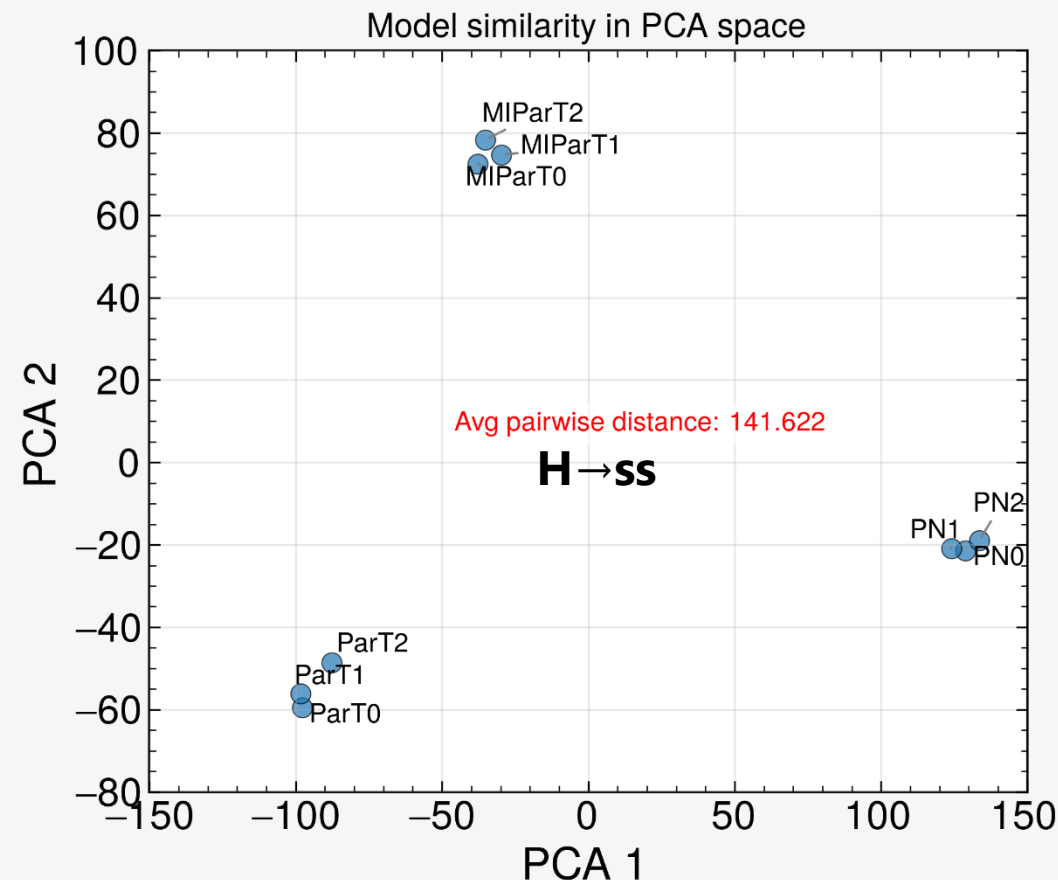
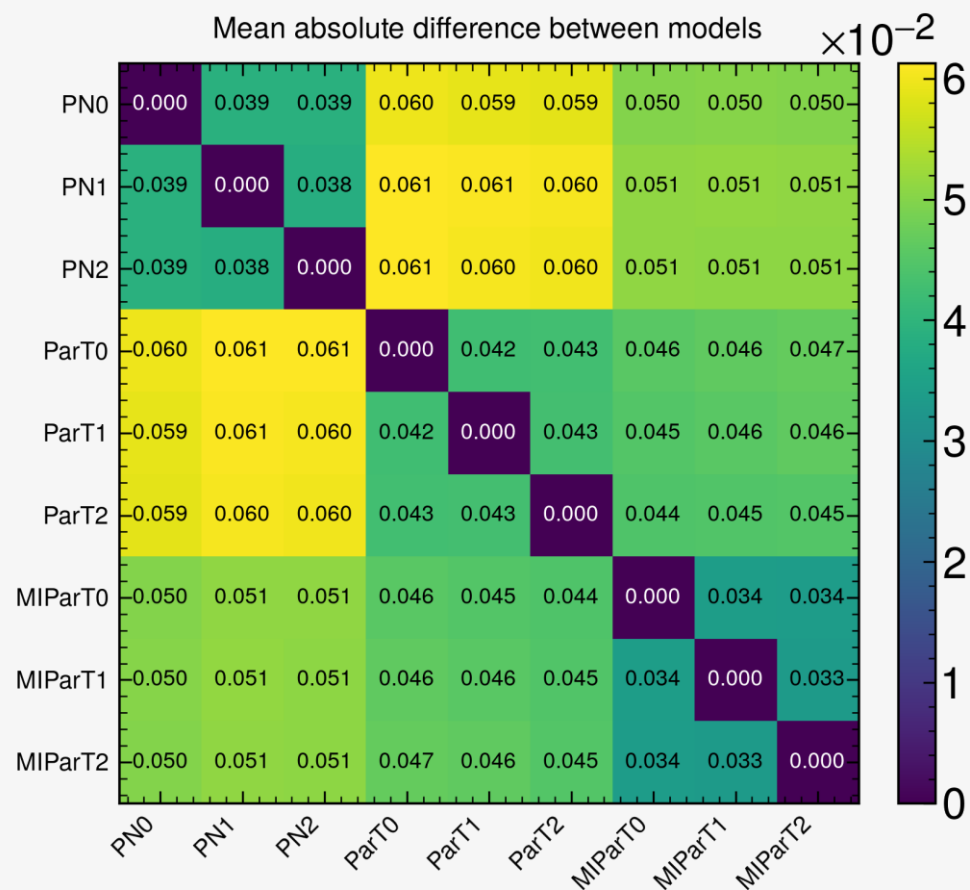
MIParT

Correlations of Models



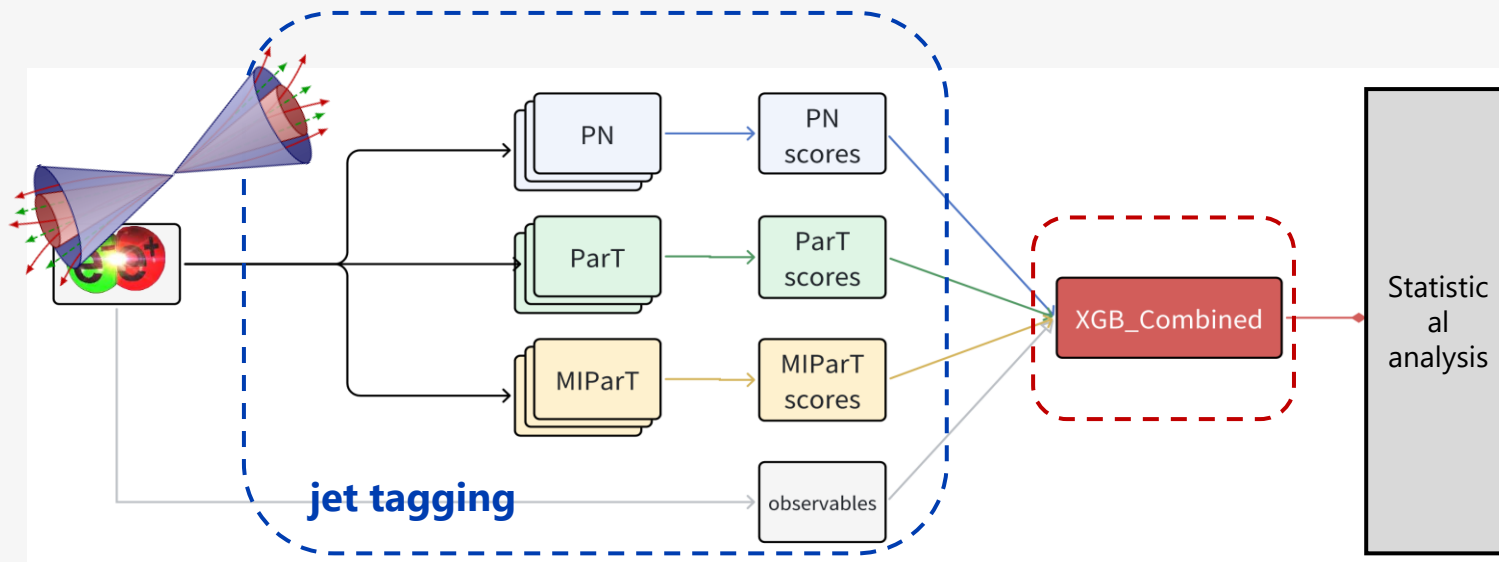
Correlation of Models

- PCA inputs: tagging scores from individual models
- Do different models focus on different features in a jet?



H→ss Pheno Search based on Advanced Jet Tagging

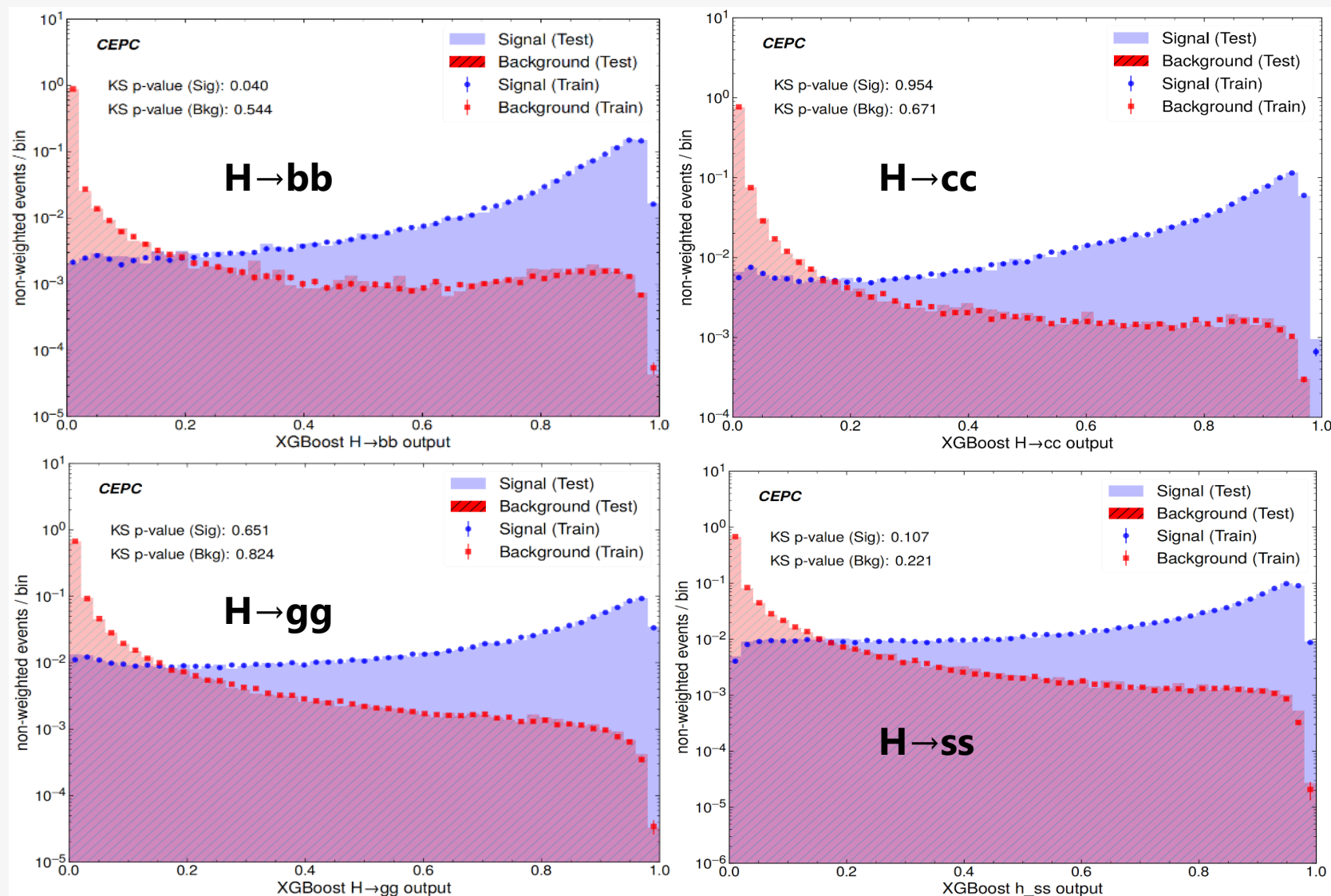
- At event level, train an XGBoost multi-class classifier combining jet scores with other observables
 - > 200 input features
 - 3×3 tagging models -> estimate uncertainties from models
- A bb/cc/gg region + a dedicated ss region



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

BDT outputs

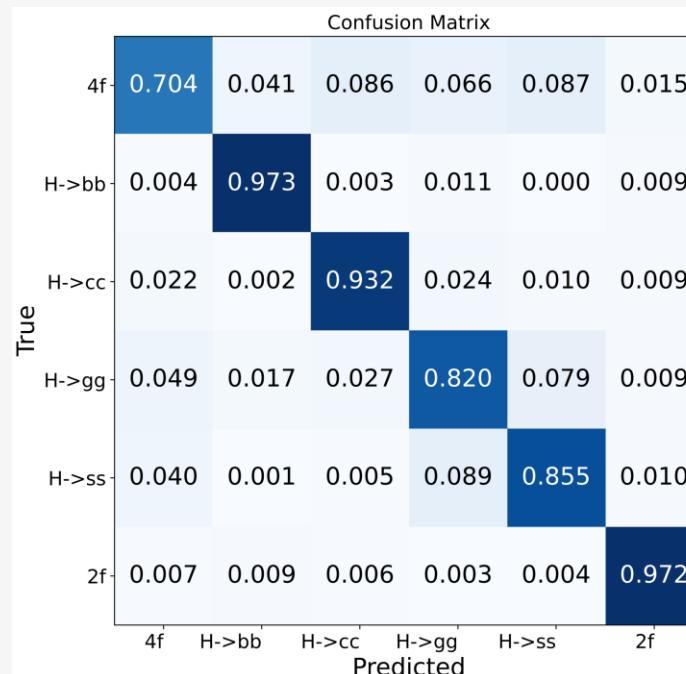
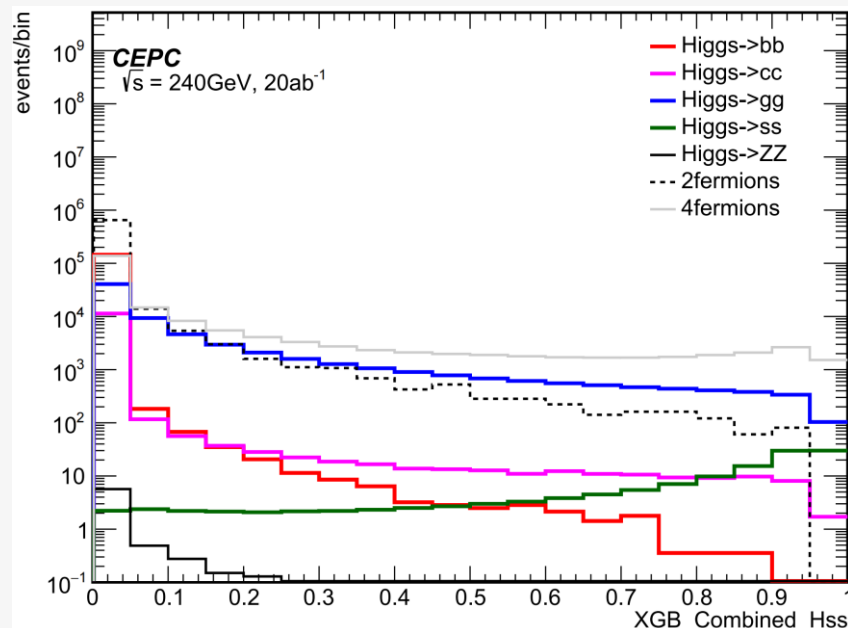


H→bb/cc/gg Results

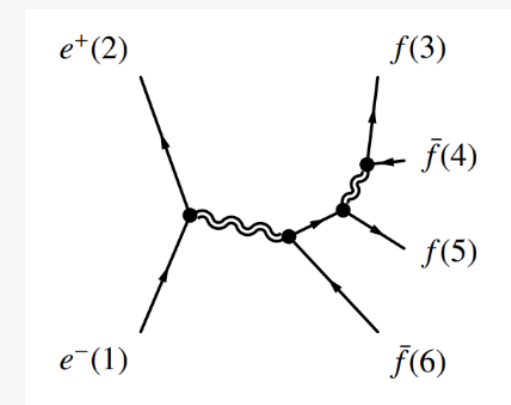
- Promising performance in bb/cc/gg measurement (statistical only)
 - Observation of H→gg at CEPC?

Target Channel	Channels	H->bb	H->cc	H->gg	H->ss	H->ZZ	4f	2f
H->bb	Efficiency [%]	63.90	1.27E-02	0.76	4.87E-03	1.73E-03	0.14	4.75E-03
	Event Yields [20/ab]	341333.70	3.44	604.07	0.01	0.12	10573.73	1151.89
H->cc	Efficiency [%]	2.10E-02	54.38	0.56	1.30E-02	9.44E-04	0.12	8.33E-04
	Event Yields [20/ab]	112.17	14681.52	441.79	0.03	0.06	8770.43	202.09
H->gg	Efficiency [%]	0.16	0.41	51.15	1.82	4.72E-04	4.50E-02	1.08E-03
	Event Yields [20/ab]	880.28	110.98	40611.67	3.63	0.03	3329.96	262.71

H→ss Results



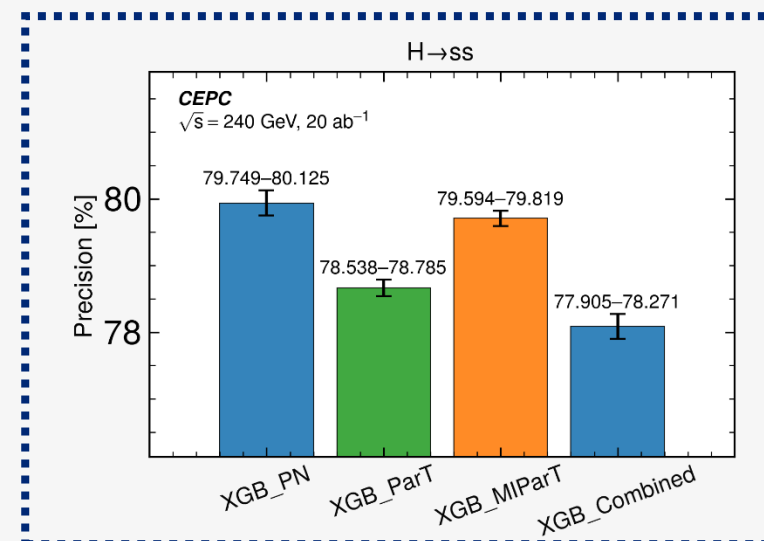
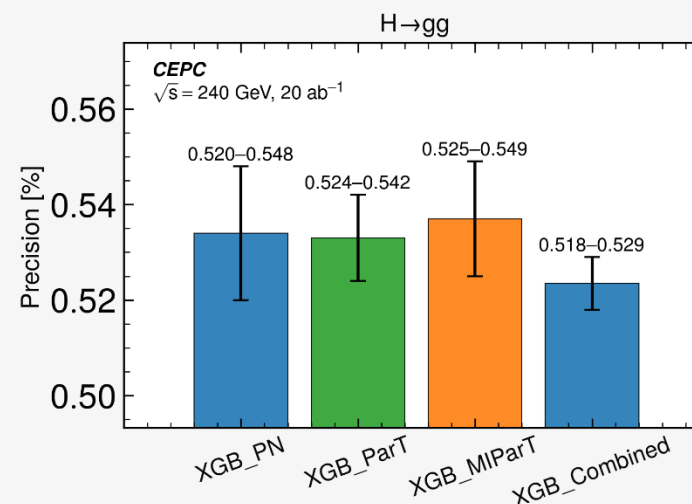
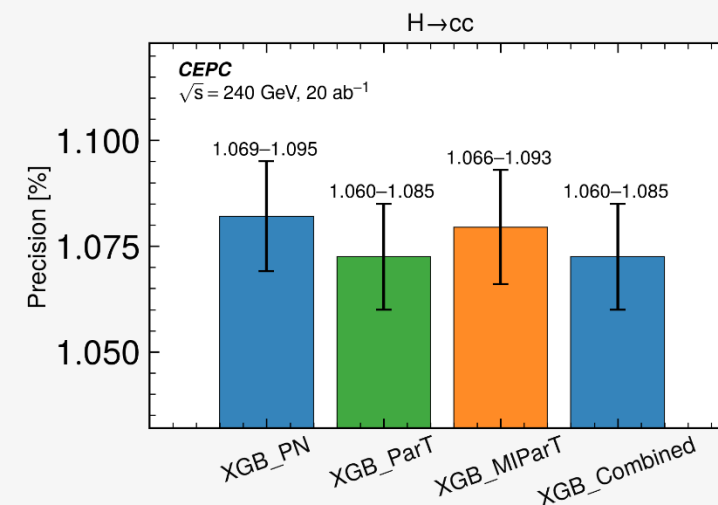
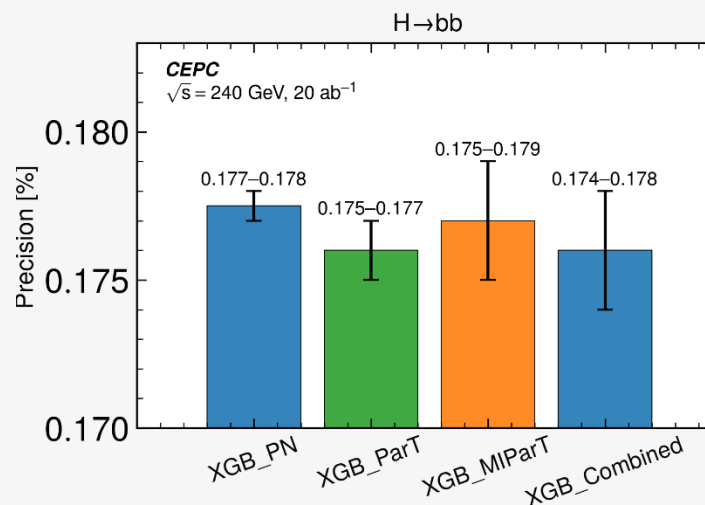
- Good classification performance among the channels
- $\sim 1.3\sigma$ (statistical only) for H→ss search
- Leading bkg: 4f



Channels	H->bb	H->cc	H->gg	H->ss	H->ZZ	4f	2f
Efficiency [%]	6.67E-05	4.95E-02	0.74	44.62	2.20E-04	5.55E-02	3.33E-04
Event Yields [20/ab]	0.36	13.37	588.86	89.24	0.01	4106.20	80.84

What Beyond Our Knowledge

- **Stable** results from all the scenarios
- **Slightly improved precision** from combination of different deep learning models in $H \rightarrow gg/ss$
- Close performance among models from $H \rightarrow gg$, **why?**



Comparison of Holistic Approach

- Comparison between our results and the holistic approach
 - Bkg free estimate

	$\nu\bar{\nu}H$			
	$H \rightarrow b\bar{b}$	$H \rightarrow c\bar{c}$	$H \rightarrow gg$	$H \rightarrow s\bar{s}$
cut + BDT	0.26% [21]	3.04% [21]	0.96% [21]	190.00% [19]
holistic	0.14%	0.72%	0.46%	29.34%
holistic with CSI	-	-	-	-
holistic with ideal CSI	-	-	-	-
statistical limit	0.14%	0.61%	0.36%	6.91%

Channels	$Z \rightarrow \nu\nu, H \rightarrow b\bar{b}$ %	$Z \rightarrow \nu\nu, H \rightarrow c\bar{c}$ %	$Z \rightarrow \nu\nu, H \rightarrow gg$ %	$Z \rightarrow \nu\nu, H \rightarrow s\bar{s}$ %
Stat. Unc.	0.17	0.77	0.47	28.54%

Conclusions

- We explore the limit of Higgs couplings to quarks in a more “traditional” approach
 - Jet level tagging -> event level classification

Channels	Published*	Ours	Improvement
$Z \rightarrow \nu\nu, H \rightarrow bb$	0.20%	0.18%	10%
$Z \rightarrow \nu\nu, H \rightarrow cc$	1.85%	1.06%	43%
$Z \rightarrow \nu\nu, H \rightarrow gg$	0.70%	0.52%	26%
$Z \rightarrow \nu\nu, H \rightarrow ss$	—	78%	—

* Precision Higgs Physics at CEPC (2018)

- There remains many questions as well
 - Impacts from theory (generators), further improve the separation performance, better understanding of models, ...



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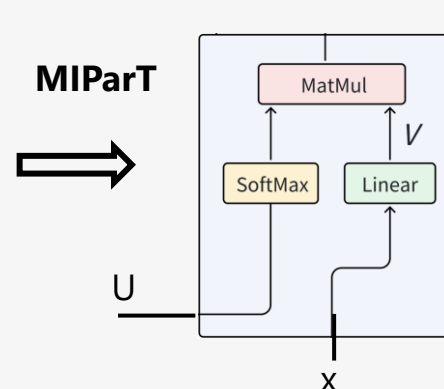
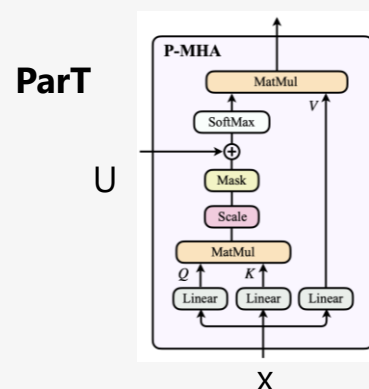
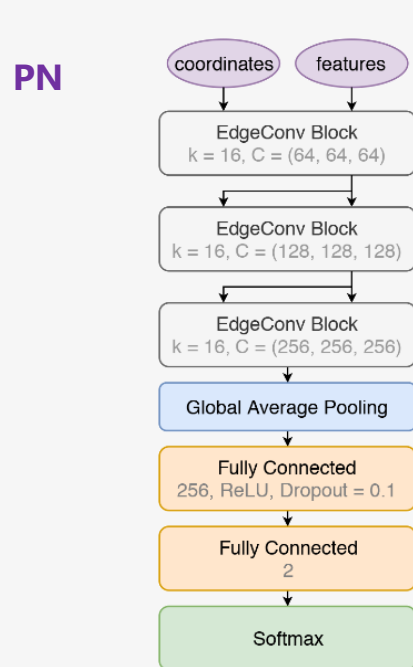
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Thank You!

饮水思源 爱国荣校

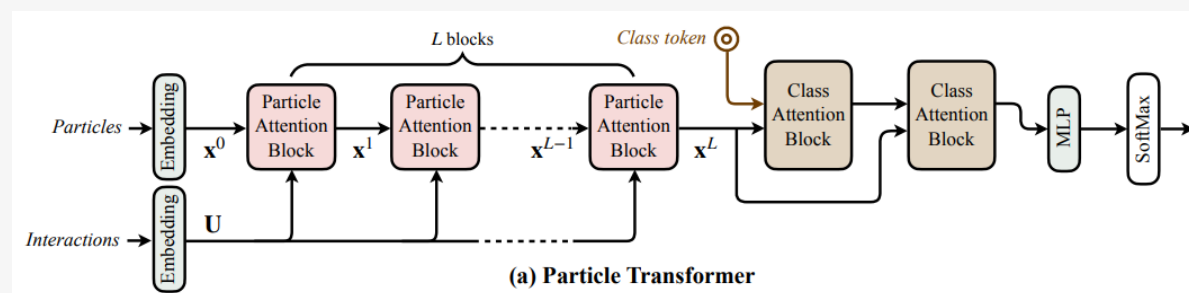
Jet Tagging at CEPC

- 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



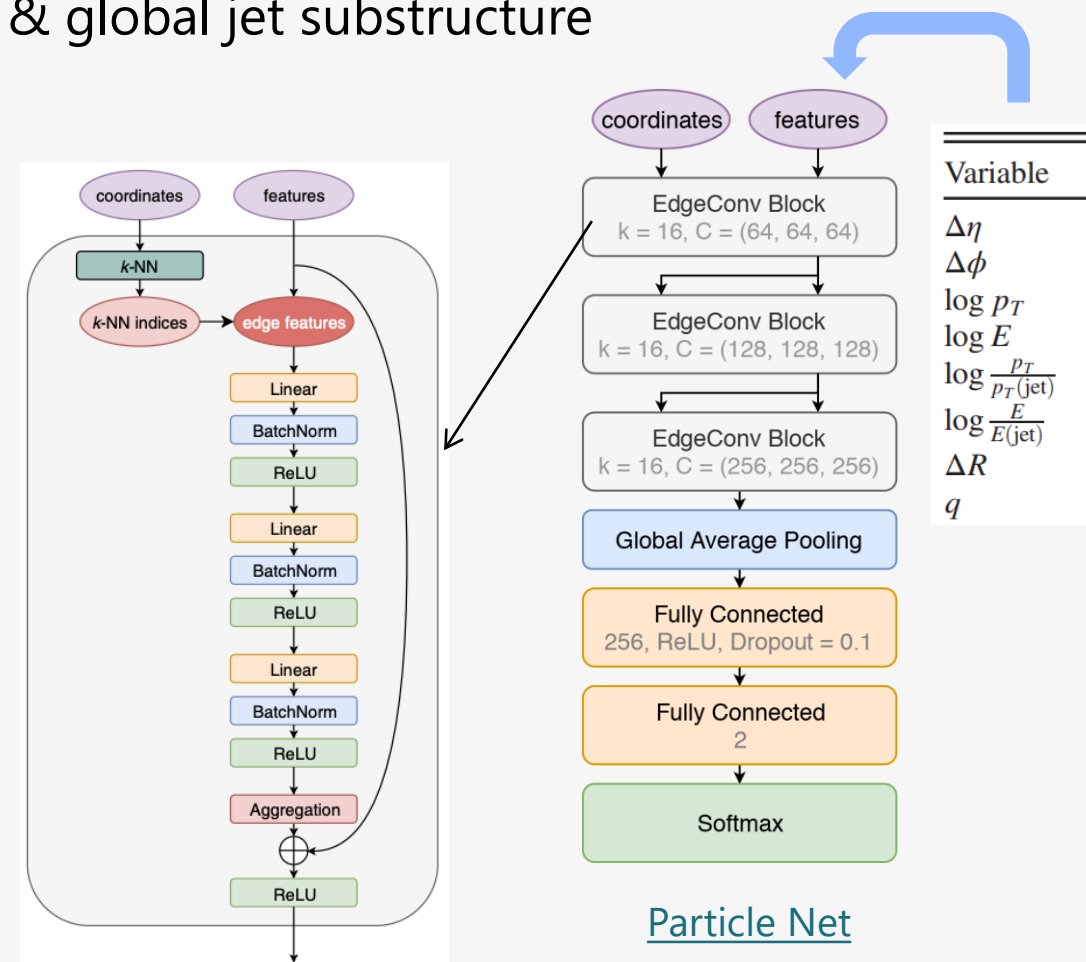
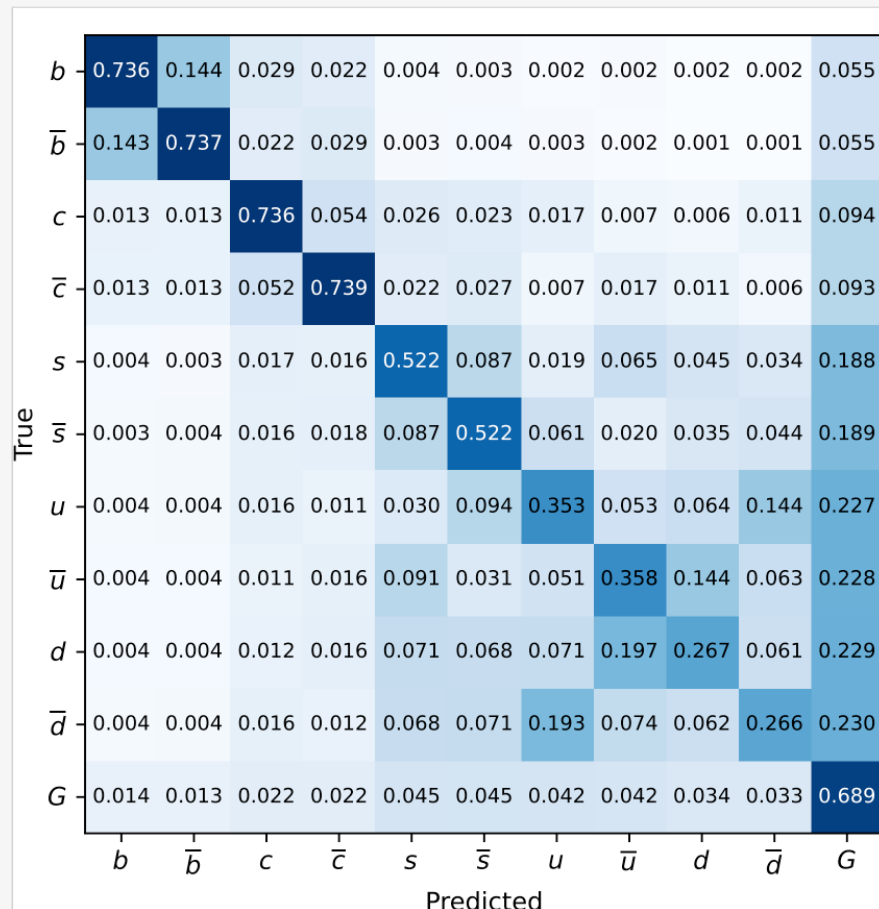
Model	Params
ParticleNet	370k
ParT	2.14M
MIParT	720.9k

0.3x



ParticleNet

- Treat a jet as a particle cloud
 - Use dynamic graph convolutions to learn local & global jet substructure



ParT & MI-ParT

- Attention on particle and their “interactions”
 - Particle attention: particle $\leftrightarrow$ particle
 - Class attention: particles $\leftrightarrow$ class/jet flavor
 - More-Interaction attention: reduces model complexity compared with ParT

$$\Delta = \sqrt{(y_a - y_b)^2 + (\phi_a - \phi_b)^2},$$

$$k_T = \min(p_{T,a}, p_{T,b}) \Delta,$$

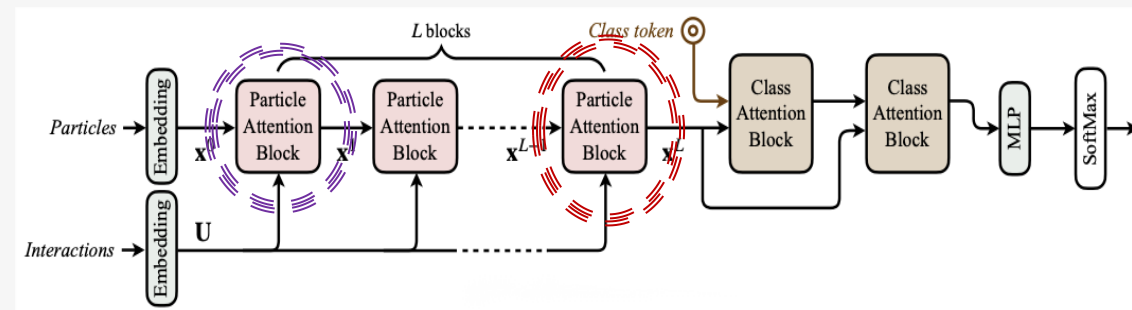
$$z = \min(p_{T,a}, p_{T,b}) / (p_{T,a} + p_{T,b}),$$

$$m^2 = (E_a + E_b)^2 - \|\mathbf{p}_a + \mathbf{p}_b\|^2,$$

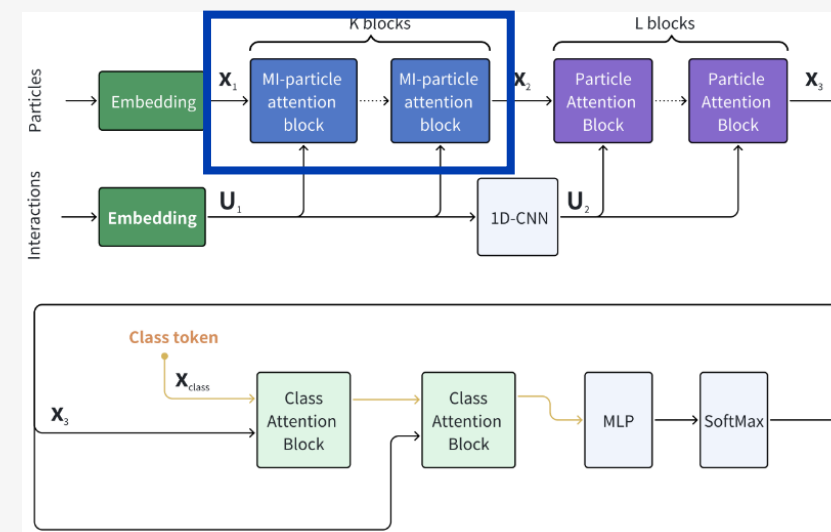
“interactions”

model	Params
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0.3x

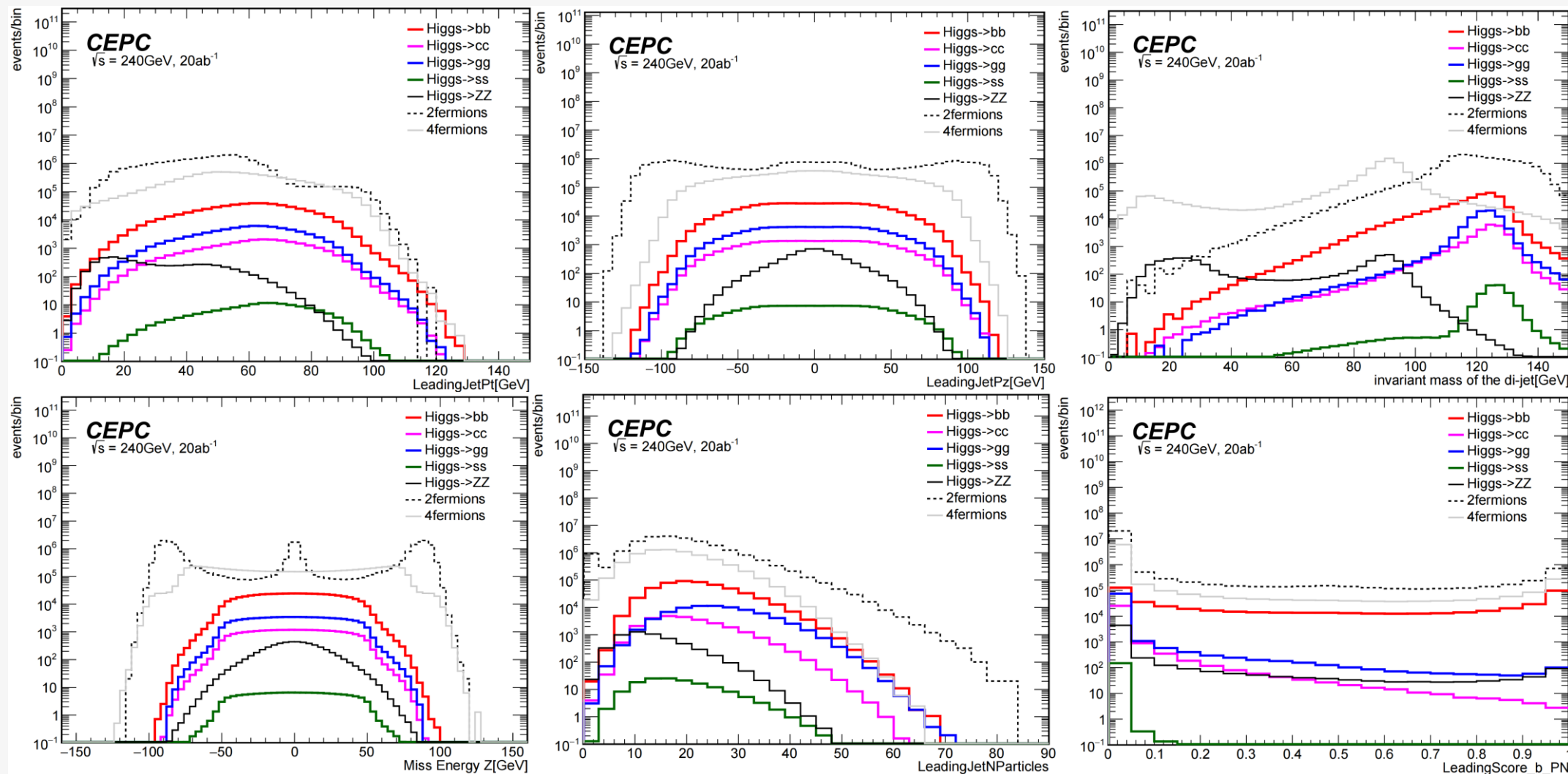


Particle Transformer



More-Interaction Particle Transformer

Some Characteristic Distributions



Some Characteristic Distributions

