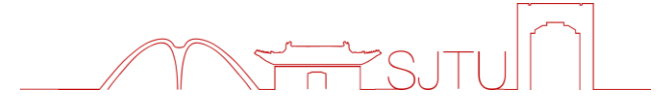




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JOI on vertex detector optimization

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饮水思源 · 爱国荣校

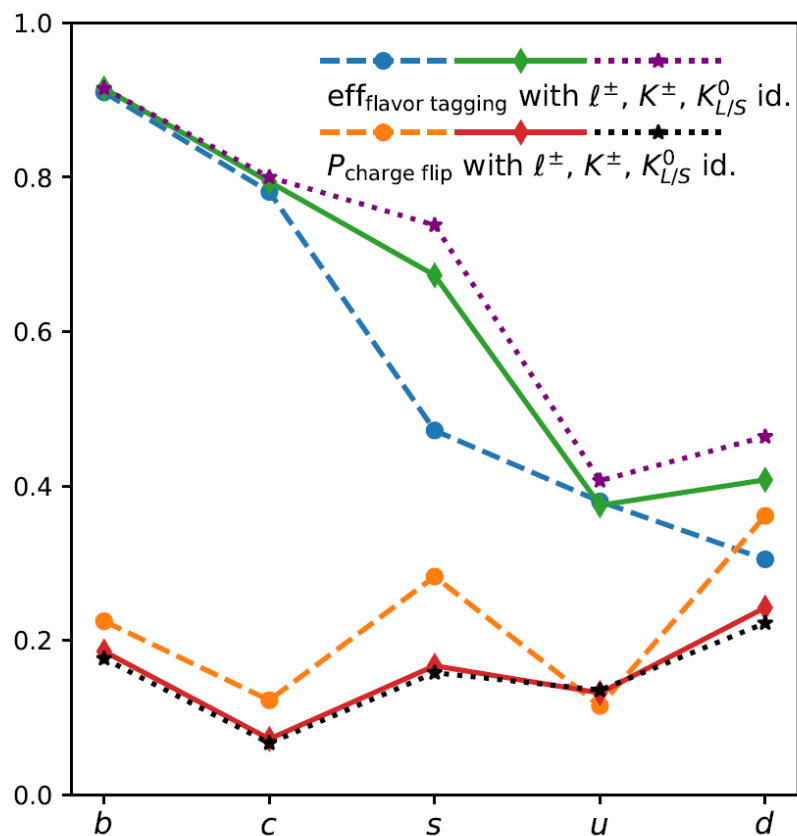


Introduction

🌀 Jet Origin Identification(JOI): determine from which colored particle a jet is generated.

➤ 11 classes: b , \bar{b} , c , \bar{c} , s , \bar{s} , u , \bar{u} , d , \bar{d} , Gluon

🌀 Test the performance of JOI and the measurement of $H \rightarrow CC/SS$ in different CEPC vertex detector parameters.





Setup

- ⊗ Baseline: CEPC_CDR
- ⊗ Generator: Whizard + Pythia6 + Fast simulation(Delphes)
- ⊗ Training: ParN
- ⊗ Parameters: inner radius(**R**) and resolution(**δ**) range [0.5, 2] vs baseline

$$R_{rad} = \frac{R_{inner}}{R_{baseline}}, R_{res} = \frac{\delta_{inner}}{\delta_{baseline}}$$

	R (mm)	$ z $ (mm)	$ \cos \theta $	σ (μm)
Layer 1	16	62.5	0.97	2.8
Layer 2	18	62.5	0.96	6
Layer 3	37	125.0	0.96	4
Layer 4	39	125.0	0.95	4
Layer 5	58	125.0	0.91	4
Layer 6	60	125.0	0.90	4

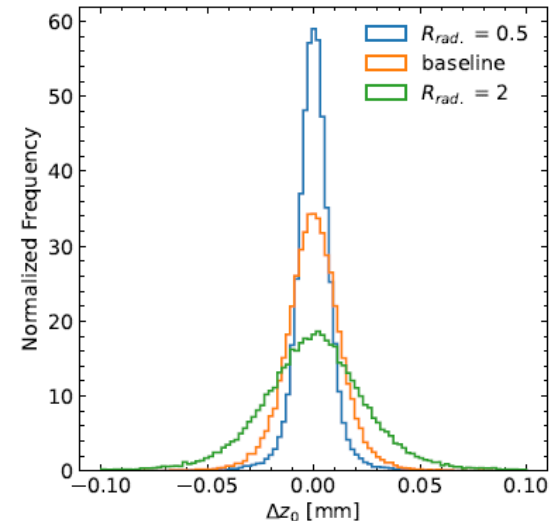
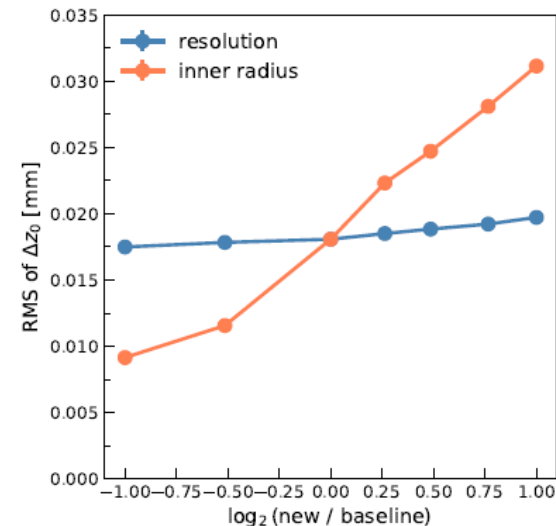
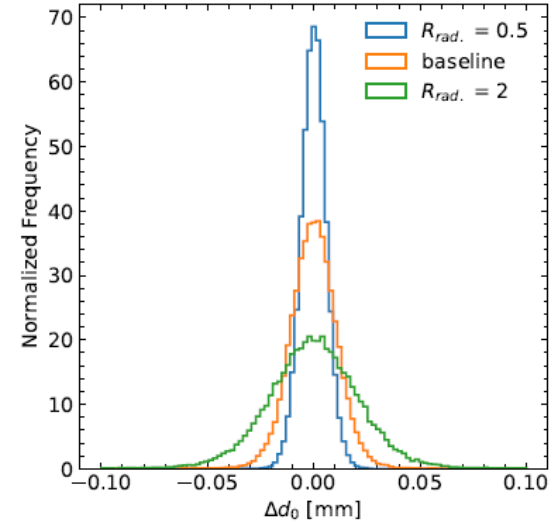
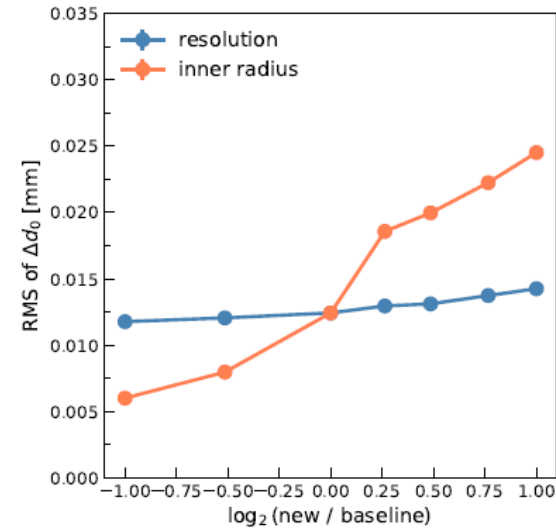




Effect on impact parameter



- Both d_0 and z_0 resolutions increase linearly with smaller inner radius and worse spatial resolution.
- Inner radius has a much stronger impact than resolution.
- Distributions show narrower peaks for smaller R_{rad} (right panel), confirming improved tracking precision.



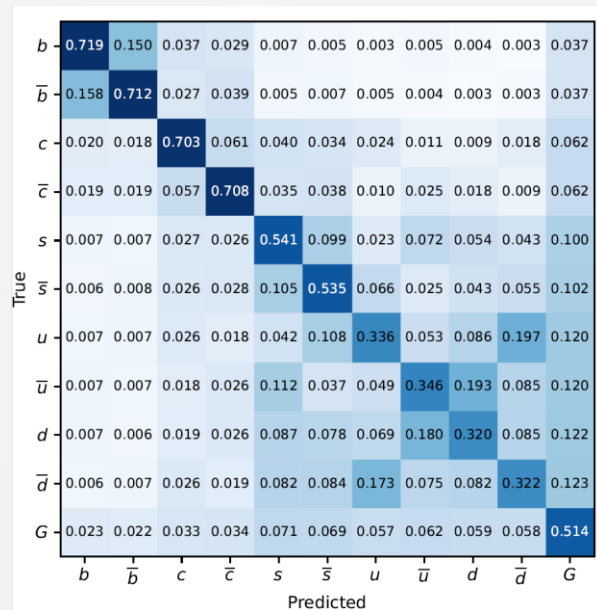


JOI Confusion matrix of Rrad

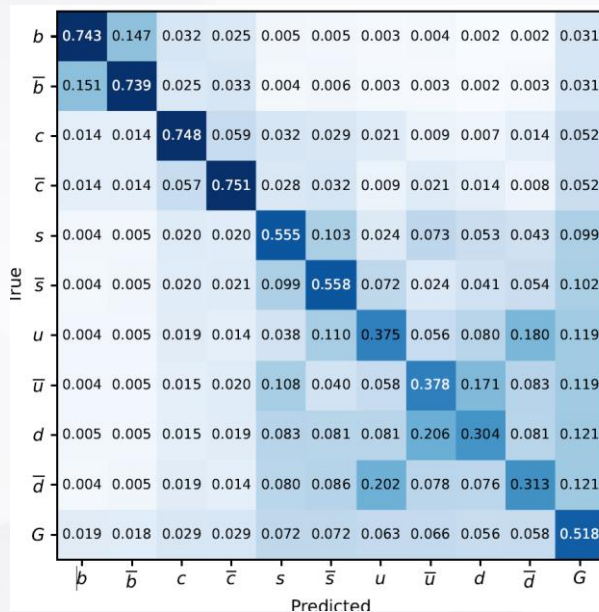
0.5ir : 0.5*baseline inner radius

Trace: 5.76, 5.98, 6.20, 6.35

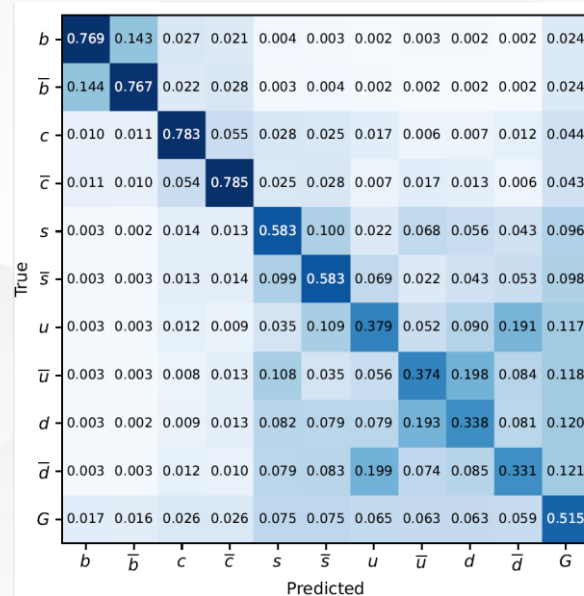
2ir



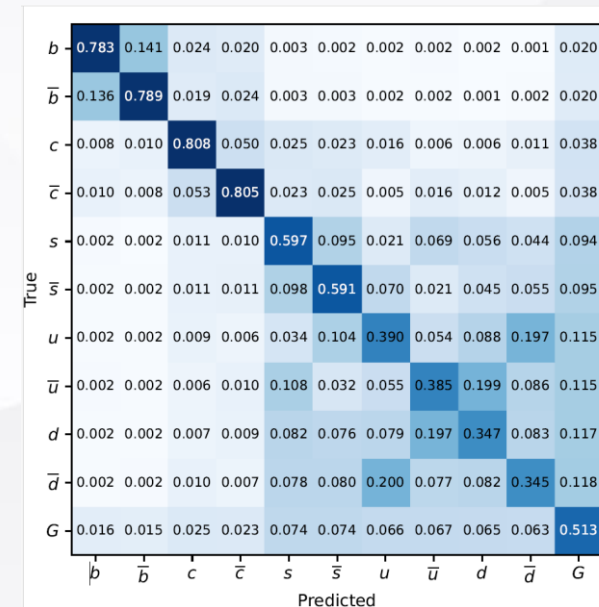
Baseline



0.7ir



0.5ir

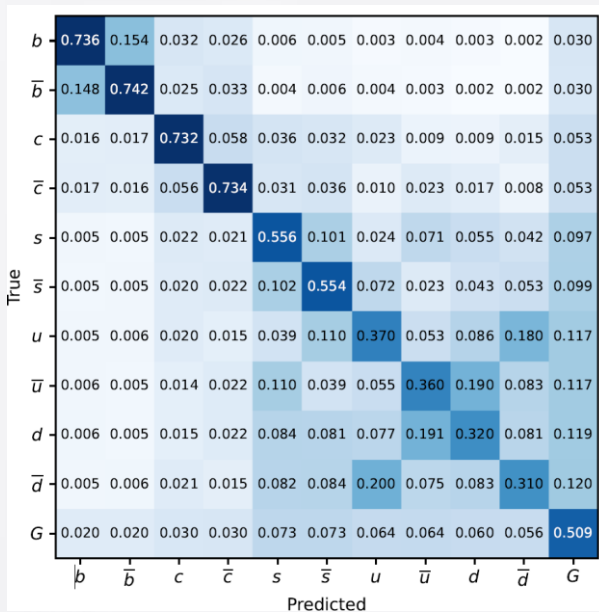




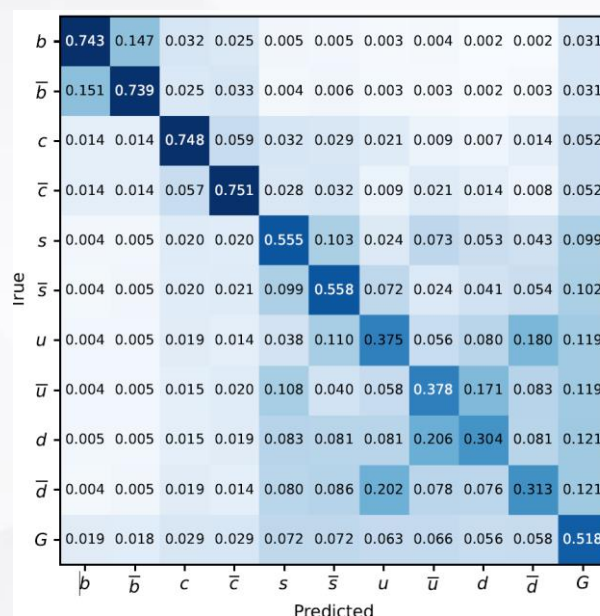
JOI Confusion matrix of Res

Trace: 5.92, 5.98, 6.00, 6.01

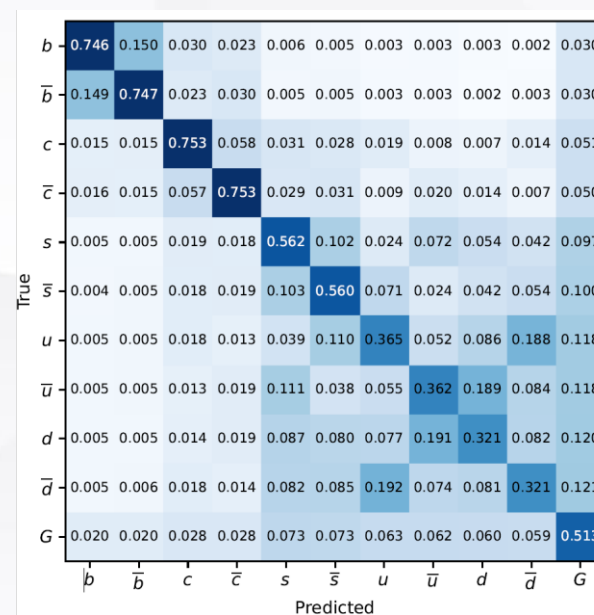
2vtx



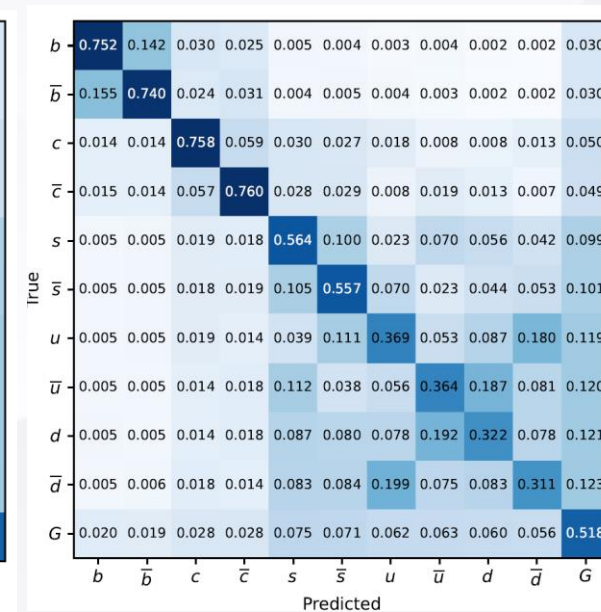
Baseline



0.7 vtx



0.5 vtx





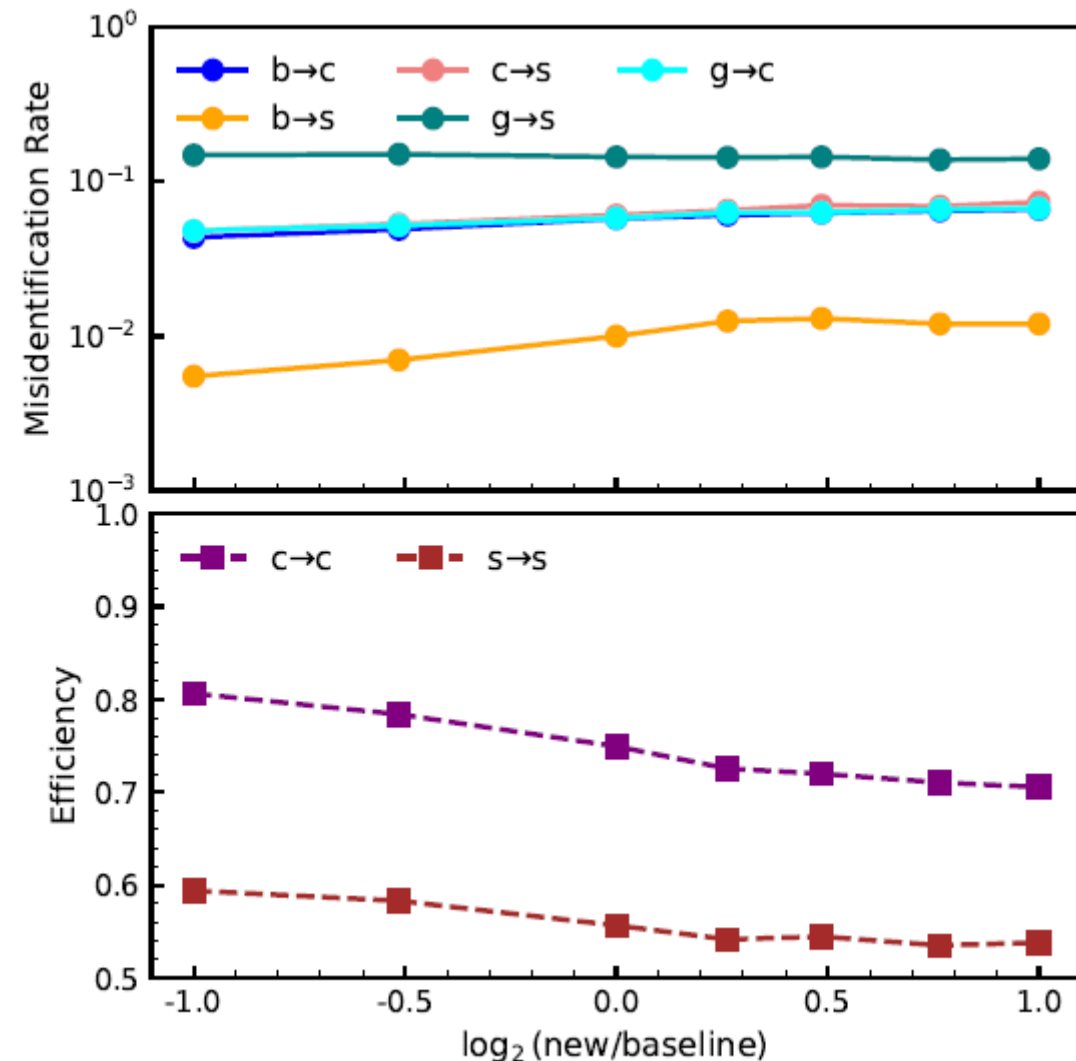
Tagging Efficiency and mis-id rate

Misidentification rates (top):

- $b \rightarrow s$ increases significantly with larger inner radius;
- $g \rightarrow s$ stay stable. Gluon originate from the primary vertex; the misidentification is unaffected clear.

Efficiency (bottom):

- c-jet and s-jet tagging efficiencies drop as radius increases.



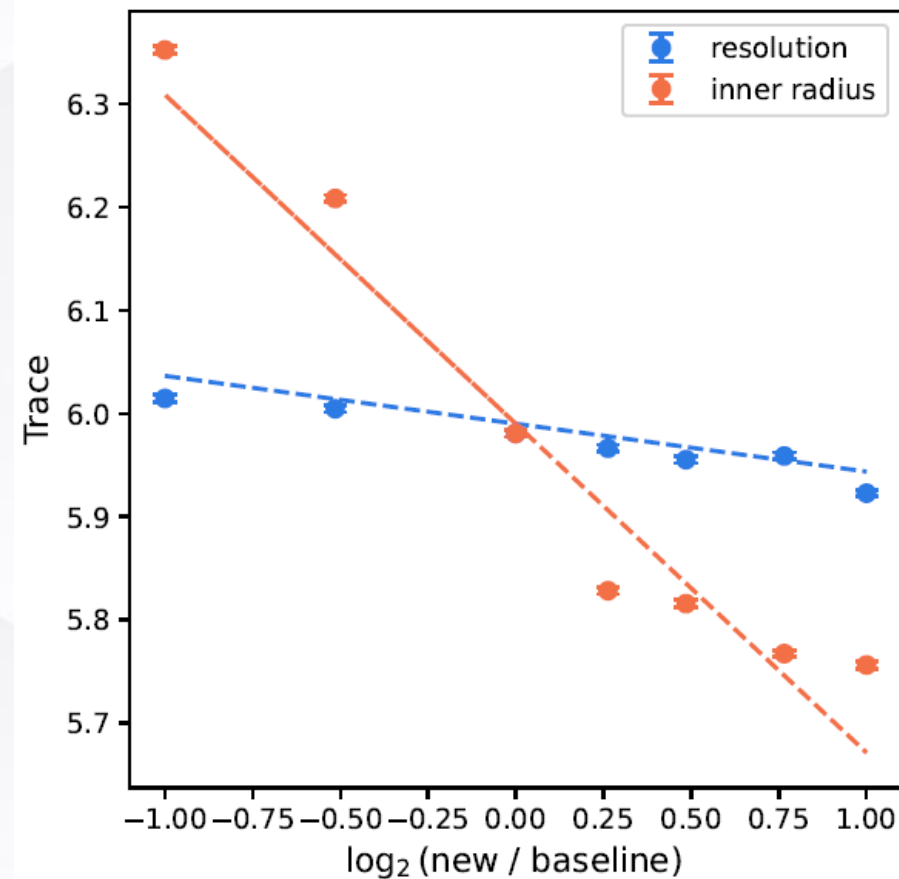


Trace of JOI

vtx: $5.98 - 0.05 * \log_2\left(\frac{new}{baseline}\right)$

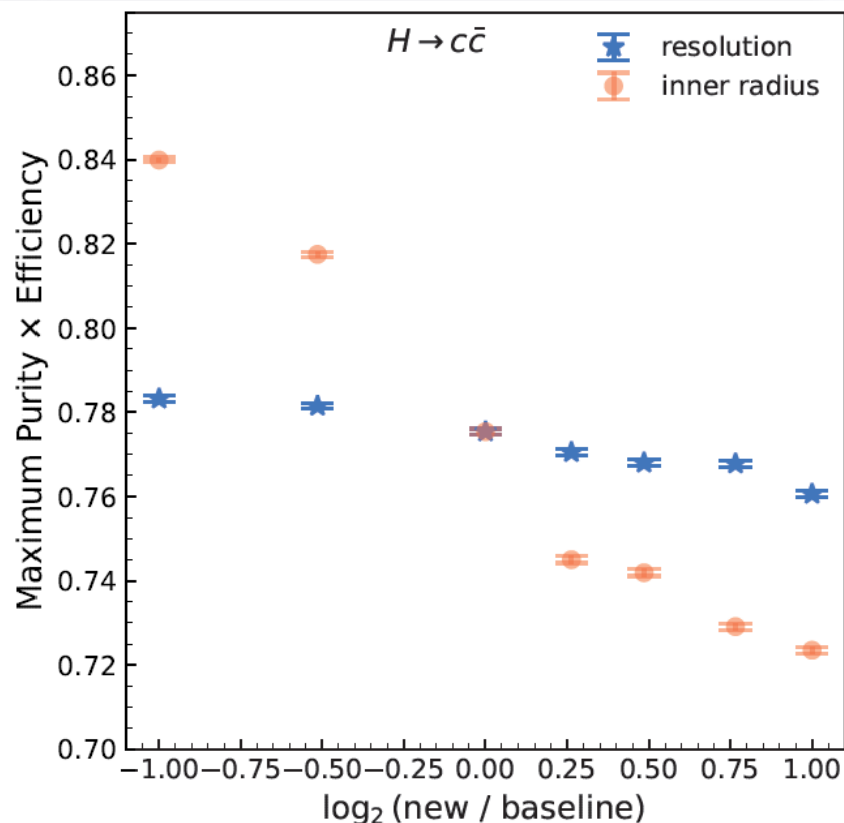
ir: $5.98 - 0.27 * \log_2\left(\frac{new}{baseline}\right)$

Orange line drops sharply with increasing R_{rad} confirming radius dominance. (5 times of R_{res})



Measurement of $H \rightarrow c\bar{c}$

- Inner radius has a greater impact than spatial resolution.
- The best configuration improves the branching ratio uncertainty by **~3.8%**, while the worst worsens it by **~3.5%** compared to baseline.

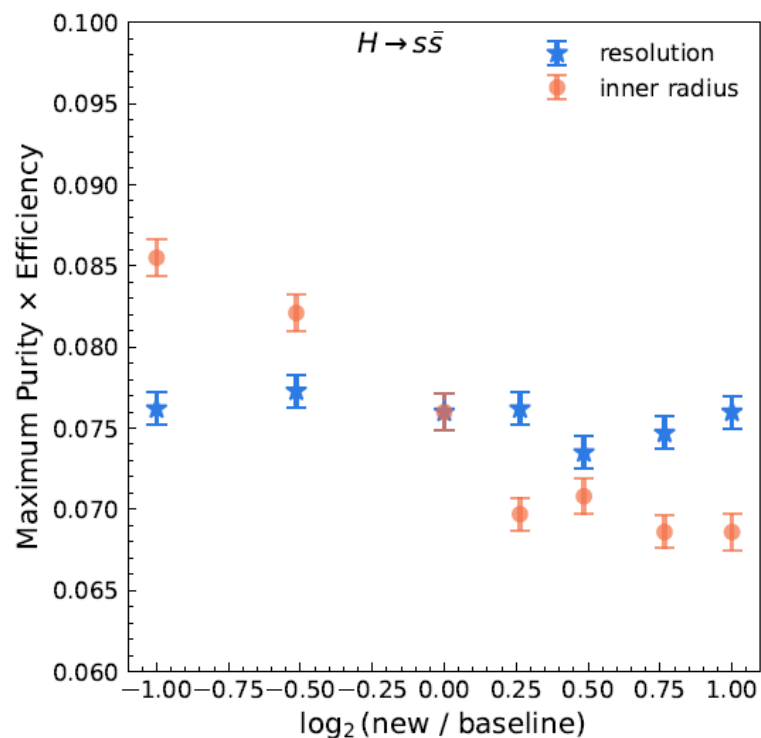


$$\frac{\delta \mathcal{B}}{\mathcal{B}} = \frac{\sqrt{s + b}}{s}$$

Configuration	$c\bar{c} (10^3)$	$b\bar{b} (10^3)$	$s\bar{s}$	$gg (10^3)$	Uncertainty(10^{-3})
baseline	24.4	1.26	11.0	1.92	6.81
$R_{\text{res}} = 0.5$	24.5	1.21	8.95	1.85	6.78
$R_{\text{res}} = 2$	24.0	1.21	12.9	1.99	6.88
$R_{\text{rad}} = 0.5$	25.6	0.75	5.54	1.75	6.55
$R_{\text{rad}} = 2$	23.2	1.54	1.61	2.04	7.05

Measurement of $H \rightarrow S\bar{S}$

- Backgrounds (especially gg) dominate.
- Significance reaches 4.76σ with $R_{\text{rad}}=0.5$
- The best configuration enhances the significance by $\sim 7.7\%$, while the worst reduces it by $\sim 4.3\%$ relative to baseline.



$$S = \sqrt{2 \left((s + b) \ln \left(1 + \frac{s}{b} \right) - s \right)}$$

Configuration	$s\bar{s}$	$b\bar{b}$	$c\bar{c}$	gg	Significance
baseline	70.9	0	10.0	224.6	4.42σ
$R_{\text{res}} = 0.5$	64.1	0	7.6	179.4	4.45σ
$R_{\text{res}} = 2$	64.4	0	10.3	181.4	4.41σ
$R_{\text{rad}} = 0.5$	70.2	0	6.2	189.4	4.76σ
$R_{\text{rad}} = 2$	64.8	0	11.5	203.2	4.23σ



Best result @kaili



- Setup: TDR+Fast+P8+ParT
- Trace is 6.834
- 14% improvement vs. my baseline and 7% vs. my best result(0.5ir)

CEPC					TDR Fast Pythia ParT TruthID						
Truth	b	\bar{b}	c	\bar{c}	s	\bar{s}	u	\bar{u}	d	\bar{d}	g
	0.798	0.139	0.020	0.016	0.003	0.001	0.001	0.002	0.001	0.001	0.017
	0.147	0.790	0.015	0.021	0.002	0.003	0.002	0.001	0.001	0.002	0.016
	0.008	0.009	0.809	0.045	0.029	0.021	0.017	0.006	0.007	0.013	0.037
	0.009	0.009	0.042	0.811	0.021	0.028	0.006	0.017	0.013	0.007	0.037
	0.002	0.001	0.013	0.012	0.646	0.077	0.021	0.058	0.053	0.037	0.080
	0.001	0.002	0.011	0.013	0.079	0.644	0.057	0.020	0.037	0.054	0.081
	0.001	0.002	0.010	0.006	0.024	0.075	0.442	0.053	0.098	0.185	0.103
	0.002	0.001	0.006	0.010	0.076	0.024	0.054	0.440	0.187	0.097	0.102
	0.002	0.002	0.007	0.011	0.062	0.056	0.092	0.180	0.408	0.077	0.104
	0.001	0.002	0.011	0.007	0.056	0.061	0.181	0.091	0.077	0.407	0.105
	0.013	0.013	0.023	0.024	0.051	0.050	0.050	0.049	0.045	0.044	0.639
Predicted											





Conclusion and Next plan (submitted to JHEP)



- Vertex detector parameters, especially inner radius, play a critical role in flavor tagging performance.
- For $H \rightarrow c\bar{c}$: Best setup improves branching ratio uncertainty by $\sim 3.8\%$, Worst case worsens it by $\sim 3.5\%$, compared to baseline.
- For $H \rightarrow s\bar{s}$: Best configuration yields $\sim 7.7\%$ gain in significance, Worst case results in $\sim 4.3\%$ loss.
- 4.76σ for $H \rightarrow s\bar{s}$ brings CEPC closer to discovering this rare Higgs decay mode.
- According to Kaili's latest results, the improvement of JOI suggests that $H \rightarrow s\bar{s}$ measurement may achieve $\geq 5\sigma$ significance.

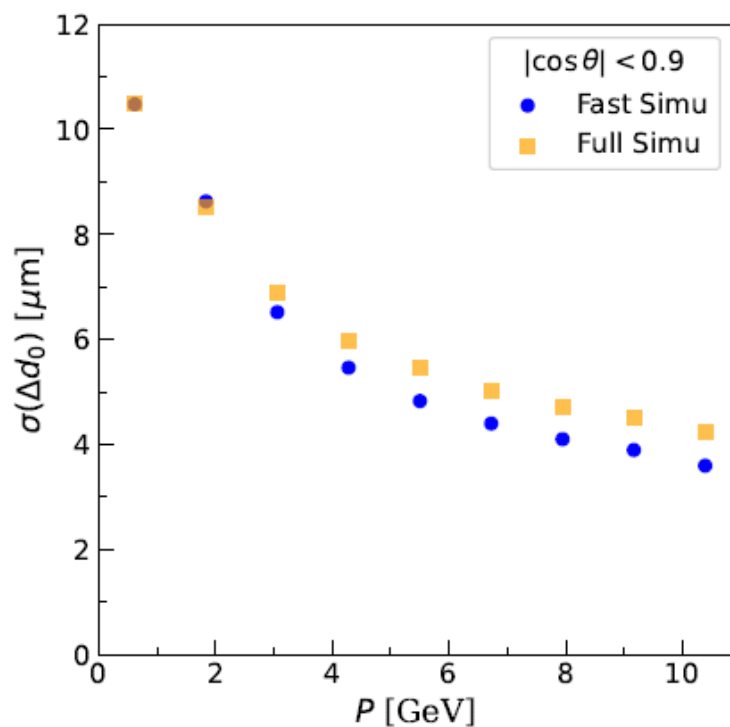


Backup

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Simulation Validation (Delphes vs. Geant4)



True	b	0.732	0.173	0.034	0.026	0.004	0.003	0.002	0.003	0.002	0.001	0.021
	\bar{b}	0.160	0.744	0.026	0.034	0.003	0.004	0.003	0.002	0.001	0.002	0.020
	c	0.015	0.015	0.736	0.057	0.036	0.030	0.025	0.008	0.009	0.016	0.052
	\bar{c}	0.014	0.016	0.055	0.737	0.030	0.036	0.009	0.025	0.016	0.009	0.052
	s	0.003	0.003	0.022	0.019	0.544	0.099	0.029	0.079	0.063	0.042	0.097
	\bar{s}	0.002	0.004	0.020	0.022	0.099	0.544	0.082	0.027	0.044	0.059	0.098
	u	0.002	0.003	0.021	0.012	0.042	0.130	0.375	0.053	0.085	0.163	0.114
	\bar{u}	0.003	0.003	0.011	0.021	0.130	0.041	0.060	0.356	0.184	0.075	0.115
	d	0.003	0.003	0.013	0.021	0.109	0.090	0.083	0.210	0.281	0.072	0.117
	\bar{d}	0.002	0.003	0.020	0.013	0.090	0.109	0.229	0.076	0.082	0.258	0.117
	G	0.021	0.023	0.034	0.034	0.075	0.075	0.065	0.064	0.052	0.050	0.507
	Predicted											

True	b	0.743	0.147	0.032	0.025	0.005	0.005	0.003	0.004	0.002	0.002	0.031
	\bar{b}	0.151	0.739	0.025	0.033	0.004	0.006	0.003	0.003	0.002	0.003	0.031
	c	0.014	0.014	0.748	0.059	0.032	0.029	0.021	0.009	0.007	0.014	0.052
	\bar{c}	0.014	0.014	0.057	0.751	0.028	0.032	0.009	0.021	0.014	0.008	0.052
	s	0.004	0.005	0.020	0.020	0.555	0.103	0.024	0.073	0.053	0.043	0.099
	\bar{s}	0.004	0.005	0.020	0.021	0.099	0.558	0.072	0.024	0.041	0.054	0.102
	u	0.004	0.005	0.019	0.014	0.038	0.110	0.375	0.056	0.080	0.180	0.119
	\bar{u}	0.004	0.005	0.015	0.020	0.108	0.040	0.058	0.378	0.171	0.083	0.119
	d	0.005	0.005	0.015	0.019	0.083	0.081	0.081	0.206	0.304	0.081	0.121
	\bar{d}	0.004	0.005	0.019	0.014	0.080	0.086	0.202	0.078	0.076	0.313	0.121
	G	0.019	0.018	0.029	0.029	0.072	0.072	0.063	0.066	0.056	0.058	0.518
	Predicted											



3*3 Full simu

$$\begin{aligned} Tr_{mig} = & 2.64 + 0.03 \cdot \log_2 \frac{R_{material}^0}{R_{material}} \\ & + 0.02 \cdot \log_2 \frac{R_{resolution}^0}{R_{resolution}} + 0.06 \cdot \log_2 \frac{R_{radius}^0}{R_{radius}} \end{aligned}$$

