

Separation of 2 fermions, 4 fermions and 6 fermions at the CEPC with event-shape variables

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IHEP

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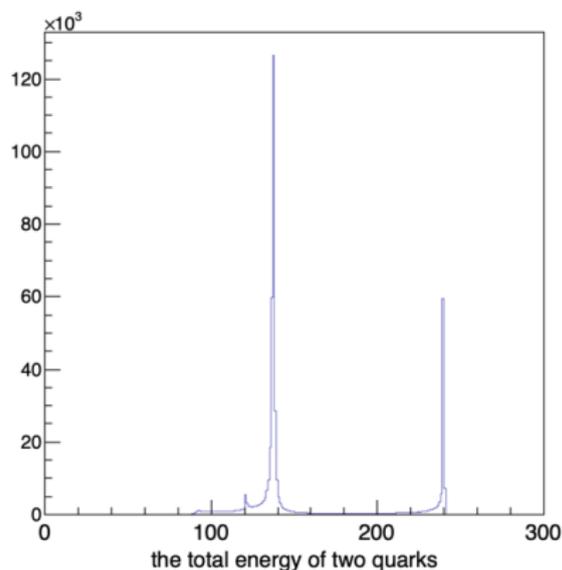
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- Sample
- Separation of 2 fermions from 4 fermions
- Event-shape Variables
 - thrust
 - heavy jet mass
 - wide jet broadening
 - total jet broadening
 - C parameter and D parameter
- Separation of 6 fermions from 4 fermions

Motivation:

- Finding 2 fermions signal with 4 fermions background. The 2 fermions finding is important at CEPC.
- Finding 6 fermions signal with 4 fermions background. The 6 fermions channel is important to measure $\sigma(H \rightarrow WW^*) + \sigma(H \rightarrow ZZ^*)$.

Sample

- $e^+e^- \rightarrow 2$ quarks(inclusive)
- $e^+e^- \rightarrow 4$ quarks(inclusive, $e^+e^- \rightarrow WW \rightarrow 4$ quarks, $e^+e^- \rightarrow ZZ \rightarrow 4$ quarks, $e^+e^- \rightarrow ZH \rightarrow 4$ quarks)
- $e^+e^- \rightarrow 6$ quarks($e^+e^- \rightarrow ZH, Z \rightarrow qq$ and $H \rightarrow WW^*(ZZ^*), WW^*(ZZ^*) \rightarrow 4$ quarks)



statistics:

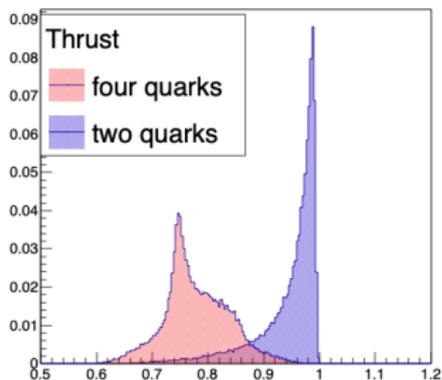
$$\frac{\text{two}}{\text{four}} = 12.195$$

$$\frac{\text{four}}{\text{six}} = 293.218$$

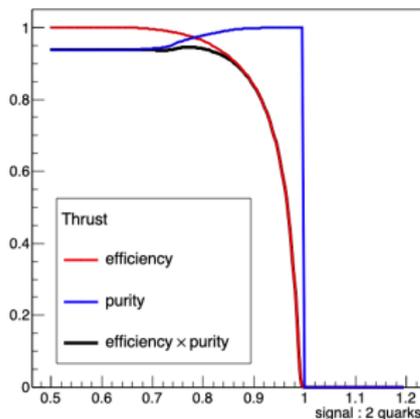
separation of 2 fermions from 4 fermions

Thrust

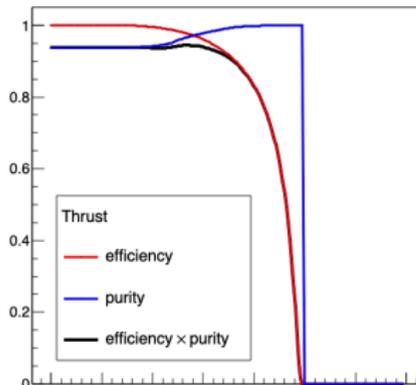
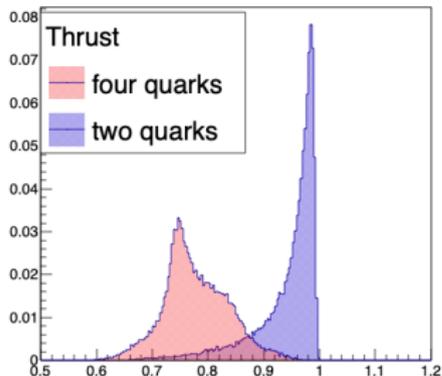
- $T = \max_{n_T} \left(\frac{1}{\sum_{j=1}^{N_{particles}} |P_j|} \sum_{i=1}^{N_{particles}} |P_i \cdot n_T| \right)$
 P_i : 3-momentum
 n_T : a unit vector
- The direction of n_T : the thrust axis.



normalized to one



normalized to luminosity

MCTruth:
0.9454Reconstruction:
0.9442

Hemisphere masses



$$M_1^2/s = \frac{1}{E_{vis}^2} \left(\sum_{i=1, P_i \cdot n_T > 0}^{N_{particles}} P_i \right)^2$$

$$M_2^2/s = \frac{1}{E_{vis}^2} \left(\sum_{i=1, P_i \cdot n_T < 0}^{N_{particles}} P_i \right)^2$$

E_{vis} : total energy of final state particles

P_i : 4-momentum

- heavy jet mass : $M_h^2/s = \max(M_1^2/s, M_2^2/s)$

MCTruth: 0.9372

Reconstruction: 0.9372

Jet broadening

$$B_1 = \frac{1}{2 \sum_{j=1}^{N_{particles}} |P_j|} \sum_{i=1, P_i \cdot n_T > 0}^{N_{particles}} |P_i \times n_T|$$
$$B_2 = \frac{1}{2 \sum_{j=1}^{N_{particles}} |P_j|} \sum_{i=1, P_i \cdot n_T < 0}^{N_{particles}} |P_i \times n_T|$$

P_j : 3-momentum

- total jet broadening : $B_T = B_1 + B_2$
- wide jet broadening : $B_W = \max(B_1, B_2)$

max efficiency × purity	MCTruth	Reconstruction
max jet broadening	0.9372	0.9372
total jet broadening	0.9482	0.9472

C parameter and D parameter

$$L^{ab} = \frac{1}{\sum_{j=1}^{N_{\text{particles}}} |P_j|^2} \sum_{i=1}^{N_{\text{particles}}} \frac{P_i^a P_i^b}{|P_i|}$$

P_j : **3-momentum**

P_i^a : the component a of the **3-momentum** of the particle i

- C parameter : $C = 3(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3)$
 λ : the eigenvalue of L^{ab} .
- D parameter : $D = 27 \times \lambda_1 \times \lambda_2 \times \lambda_3$

max <i>efficiency</i> × <i>purity</i>	MCTruth	Reconstruction
C Parameter	0.9468	0.9462
D Parameter	0.9473	0.9464

max efficiency \times purity

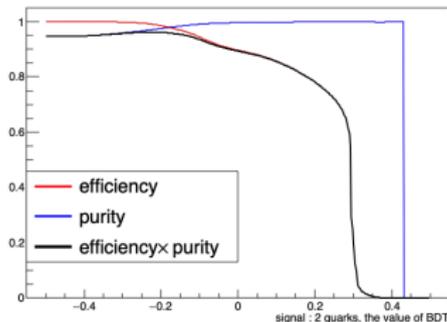
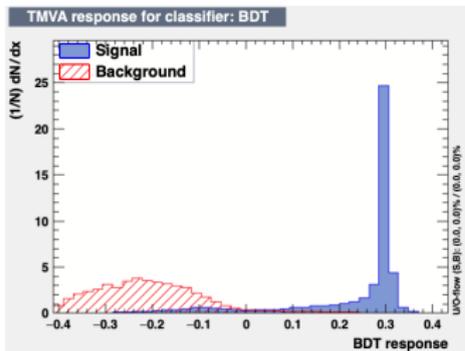
before normalizing according to luminosity

		T	Heavy Mass	Max Broadening	Total Broadening	C	D
MC	bkg : 4	0.8463	0.8068	0.7772	0.8289	0.8402	0.8405
	signal : 2	0.8379	0.7905	0.7592	0.8157	0.8294	0.8296
Reco	bkg : 4	0.8416	0.8019	0.7755	0.8236	0.8353	0.8358
	signal : 2	0.8318	0.7850	0.7574	0.8105	0.8248	0.8251

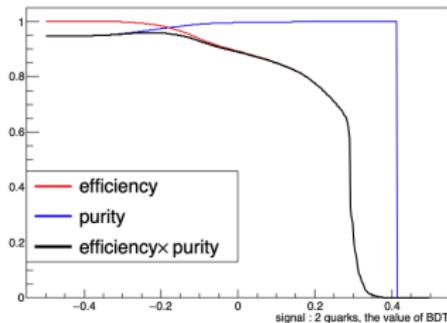
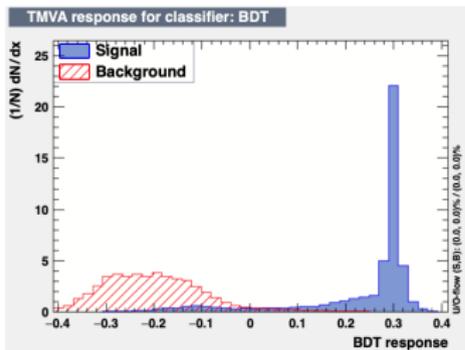
after normalizing according to luminosity

		T	Heavy Mass	Max Broadening	Total Broadening	C	D
MC	bkg : 4	0.3842	0.3106	0.2891	0.3529	0.3792	0.3816
	signal : 2	0.9454	0.9372	0.9372	0.9482	0.9468	0.9473
Reco	bkg : 4	0.3779	0.3057	0.2850	0.3471	0.3727	0.3747
	signal : 2	0.9442	0.9372	0.9372	0.9472	0.9462	0.9464

BDT Results



MCTruth:
0.9628



Reconstruction:
0.9597

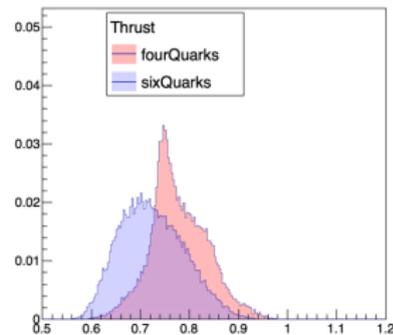
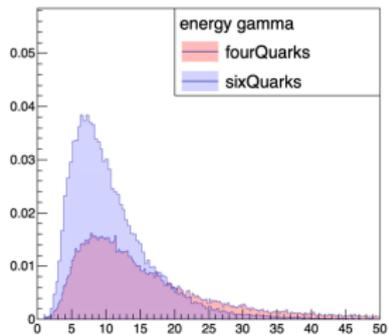
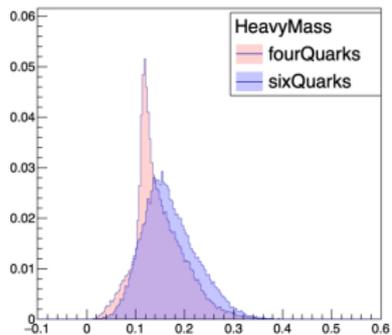
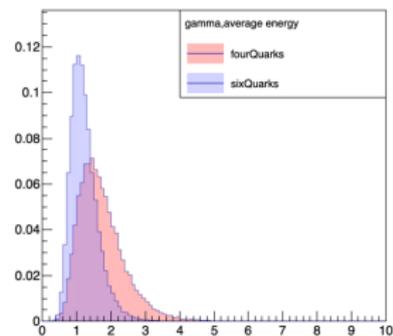
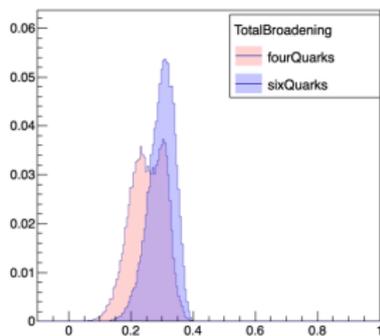
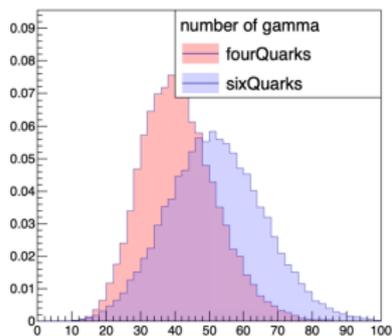
	T	Heavy Mass	Max Broadening	Total Broadening	C	D
importance factor	0.172	0.174	0.186	0.173	0.150	0.145

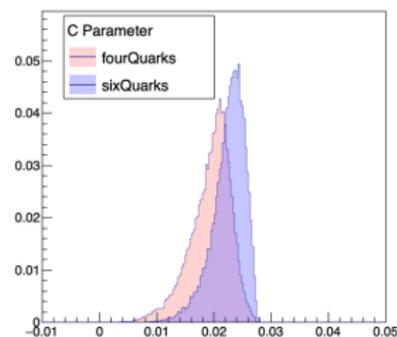
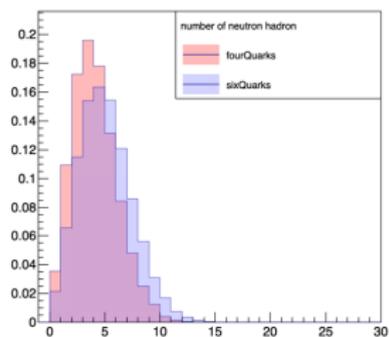
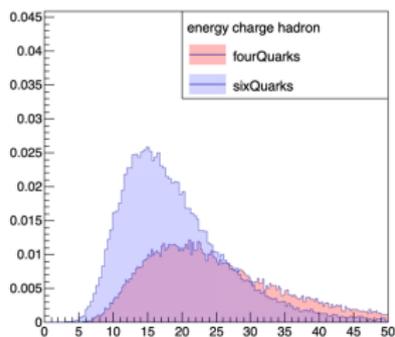
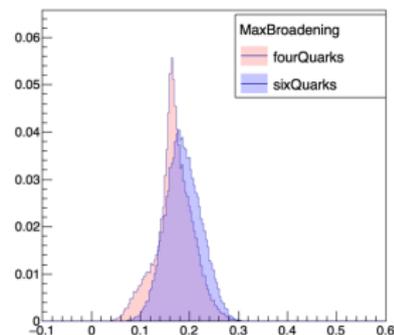
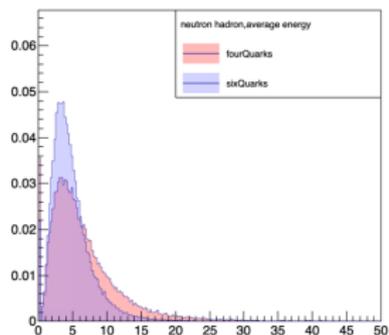
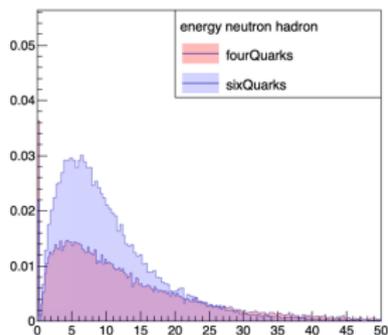
separation of 6 fermions from 4 fermions

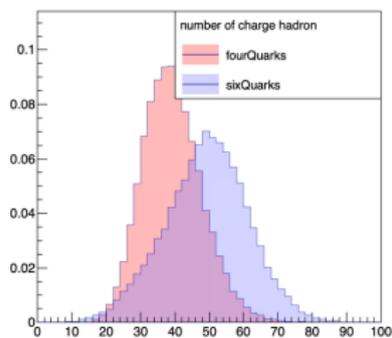
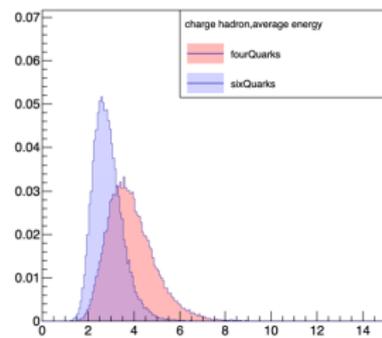
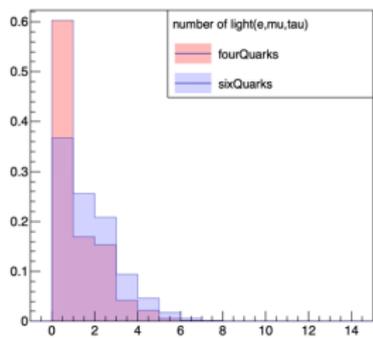
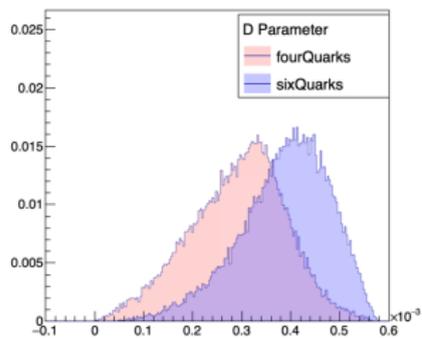
Sample:

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- $e^+e^- \rightarrow 6$ quarks ($e^+e^- \rightarrow ZH, Z \rightarrow qq$ and $H \rightarrow WW^*(ZZ^*), WW^*(ZZ^*) \rightarrow 4$ quarks)

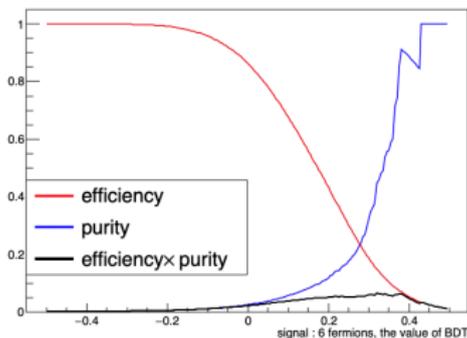
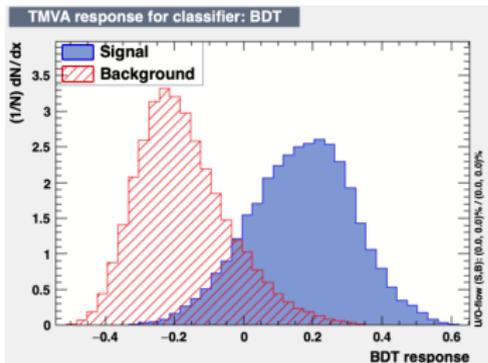
- energetic charge hadron
- average energy of charge hadron
- number of charge hadron
- energetic neutron hadron
- average energy of neutron hadron
- number of neutron hadron
- energetic gamma
- average energy of gamma
- number of gamma
- number of light(e, mu, tau)







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MCTruth:
0.066485

Summary:

- Event-shape variables can efficiently separate 2 fermions from 4 fermions.
- Event-shape variables plus multiplex variables can separate 6 fermions from 4 fermions to some extent.
- Next step, we will apply energy energy correlation to this analysis and find more effective variables to separate 6 fermion from 4 fermions.

Thank you!

Back up

Rank	Variable	Variable Importance
1	avChargeHad	8.389e-02
2	numChargeHad	8.175e-02
3	numGamma	7.869e-02
4	totalBroadening	7.281e-02
5	avGma	6.928e-02
6	HeavyMass	6.887e-02
7	energyGma	6.598e-02
8	thrust	6.007e-02
9	energyNeuHad	5.923e-02
10	avNeuHad	5.711e-02
11	WideBroadening	5.408e-02
12	energyChargeHad	5.351e-02
13	numNeuHad	5.053e-02
14	CParameter	4.874e-02
15	DParameter	4.785e-02
16	numchgLight	4.761e-02
