

Jet Energy Scale & Jet Calibration Study



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CEPC Workshop, Beijing, China

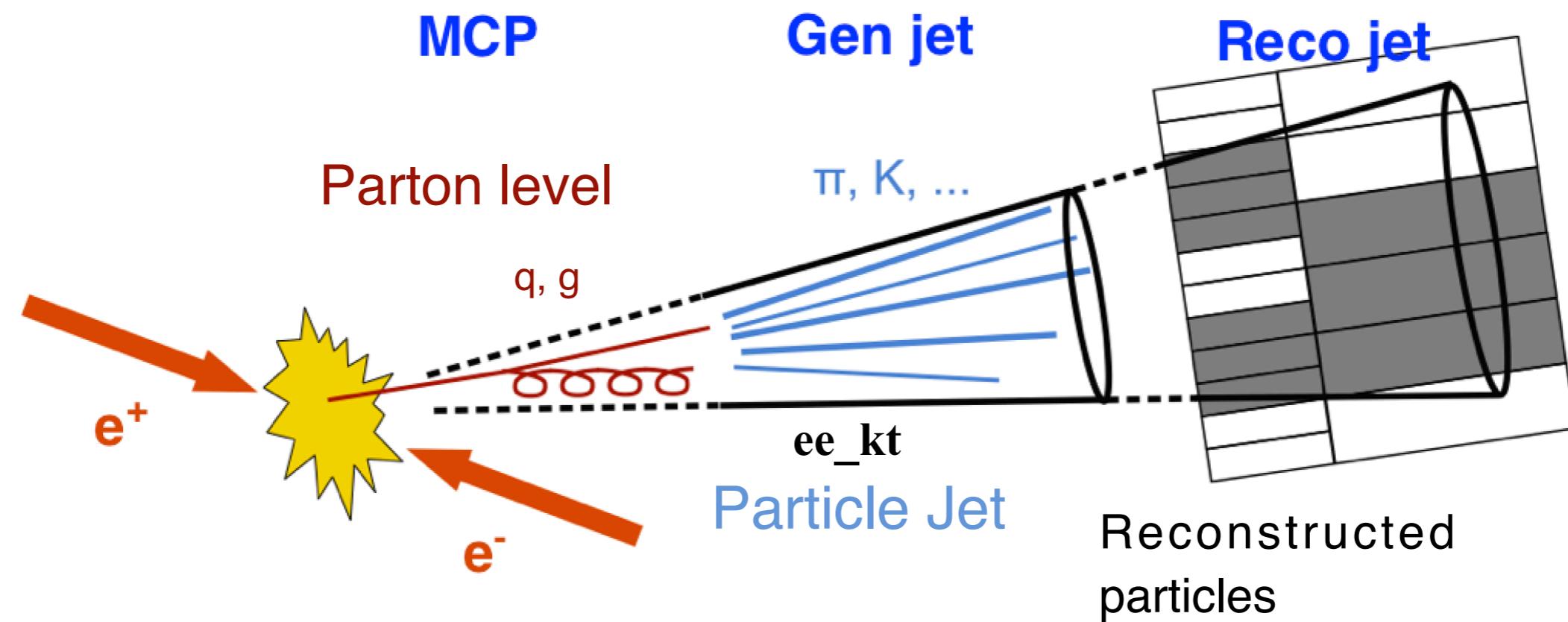
Nov 12-14, 2018



- **Introduction**
- **Strategy**
- **Event selections**
- **Results**
 - The total jet energy resolution and scale (Reco-Gen, Gen-MCP, Reco-MCP)
 - JER/JES depend on angel and energy (Reco-Gen, Gen-MCP, Reco-MCP)
 - Compare the results with CMS at LHC
- **Jet energy calibration**
- **Summary**

Introduction

- Jet reconstruction plays an important role in particle physics. To study the performance of the jet reconstruction in CEPC, we look at the simulation which contains MC particle(MCP), particle jet(Gen jet), and PFOs(Particle Flow Objects) jet(Reco jet).

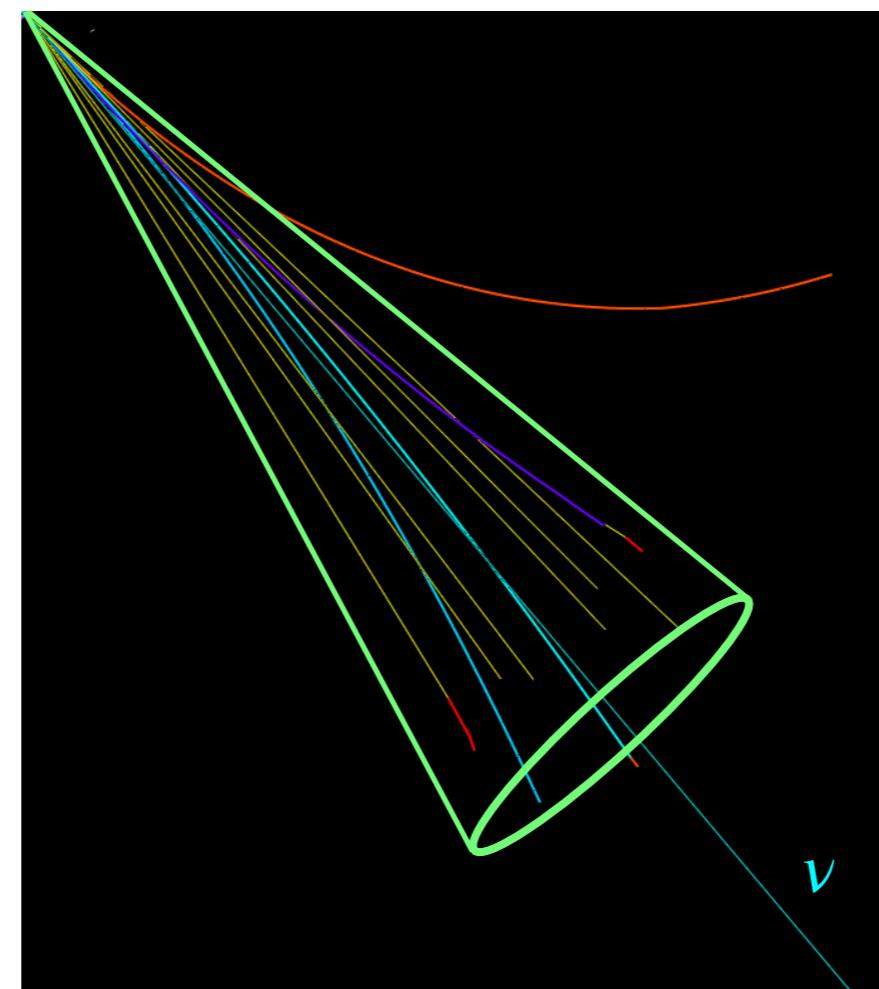


Ref. [2]

Difficulties in jet reconstruction

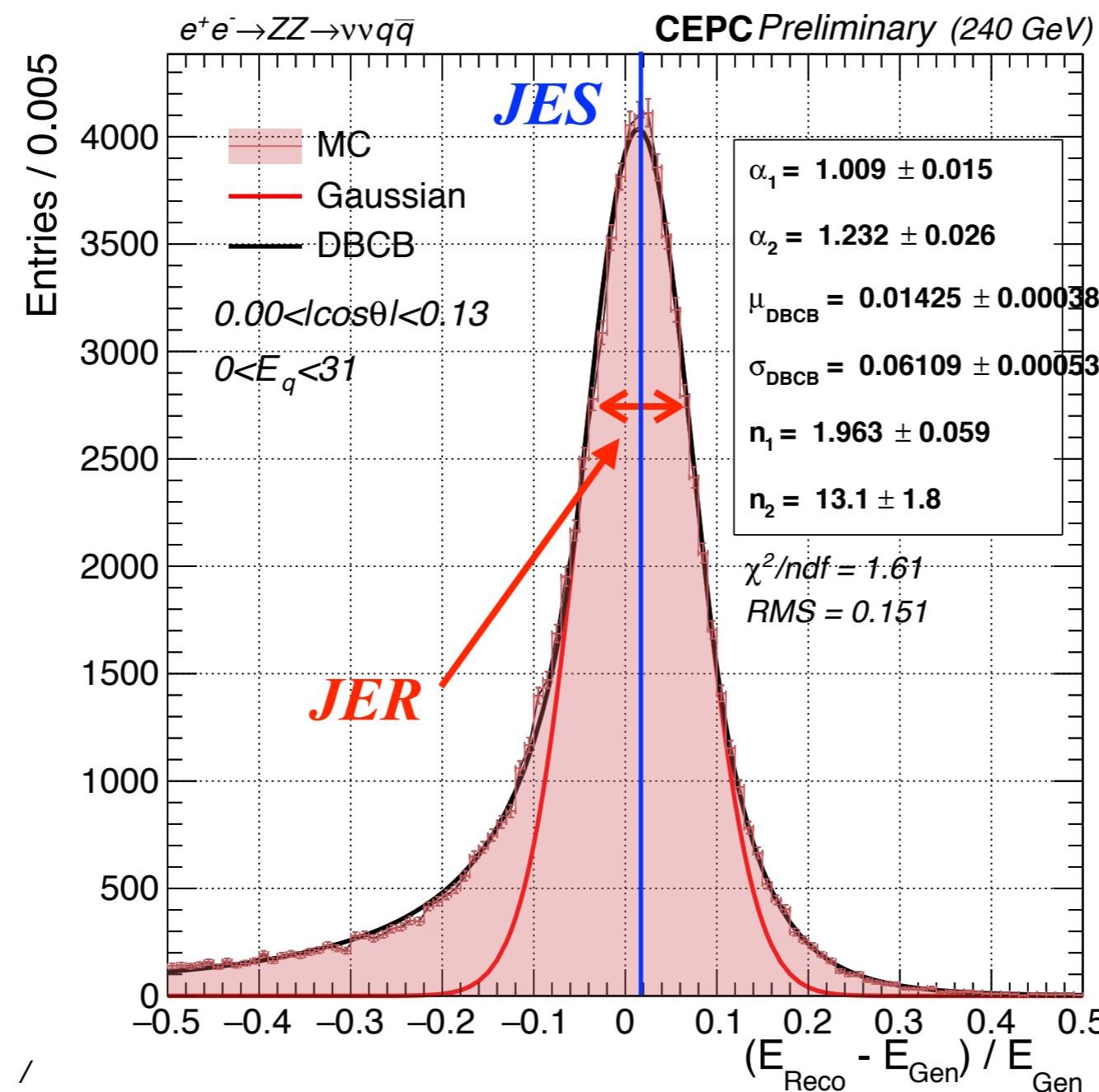
- Poor clustering
- Neutrinos cannot be detected
- The detector responses(i.e. energy threshold)

Wrong measurement leads to wrong physical results.



Quantify the Performance

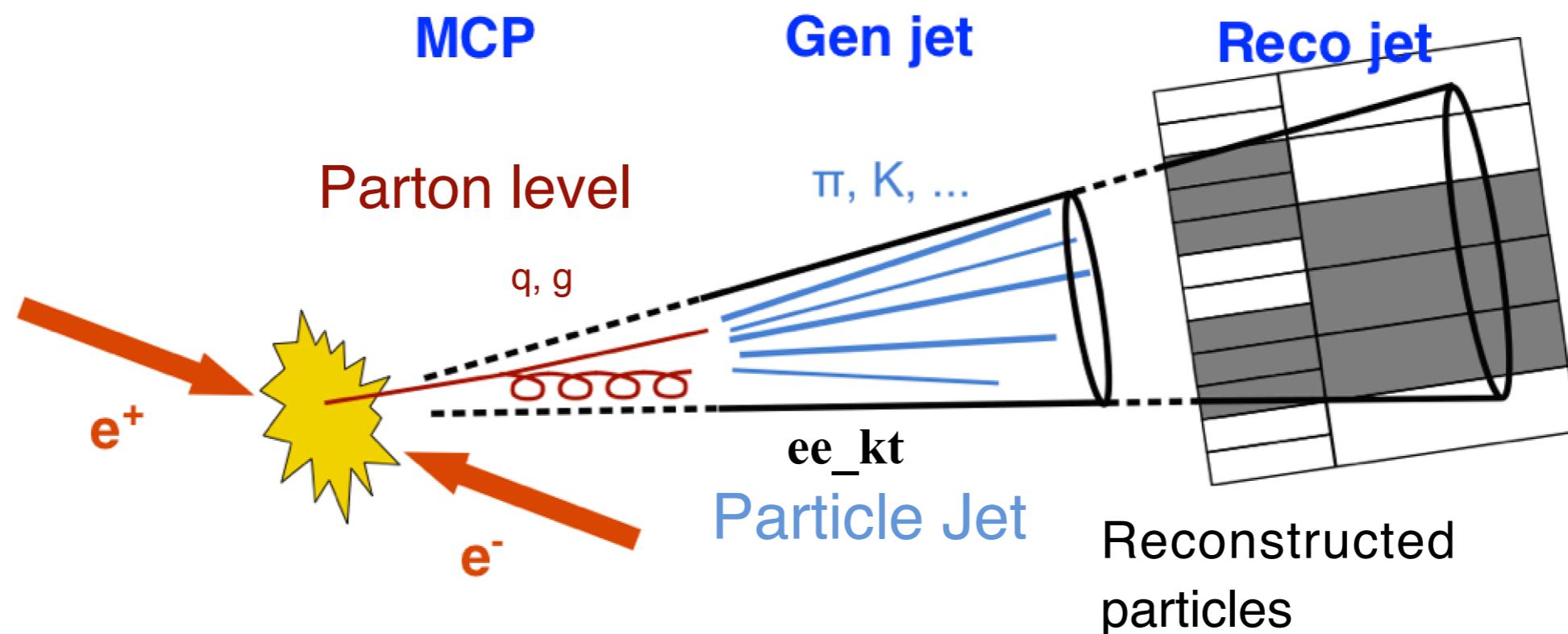
- Double-sided crystal ball(DBCB) function are used to extract energy resolution.
- The bin size of histogram is 0.5%.



Relativity difference

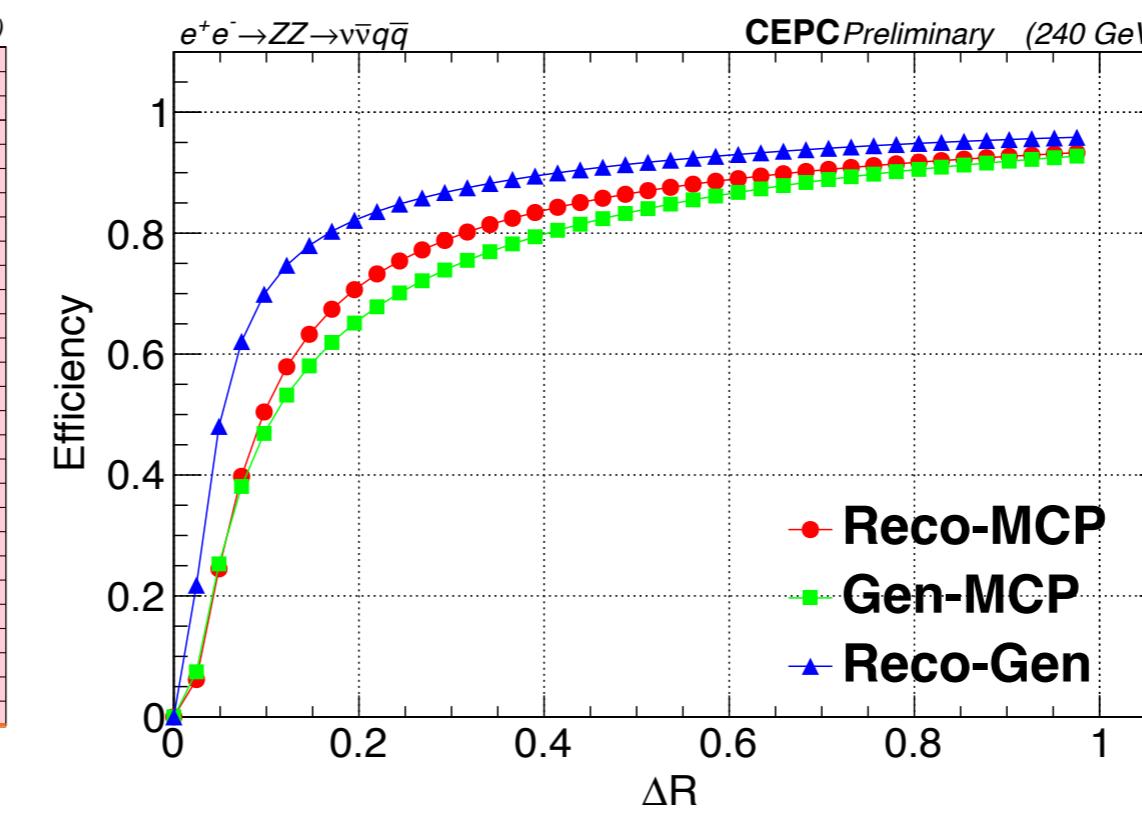
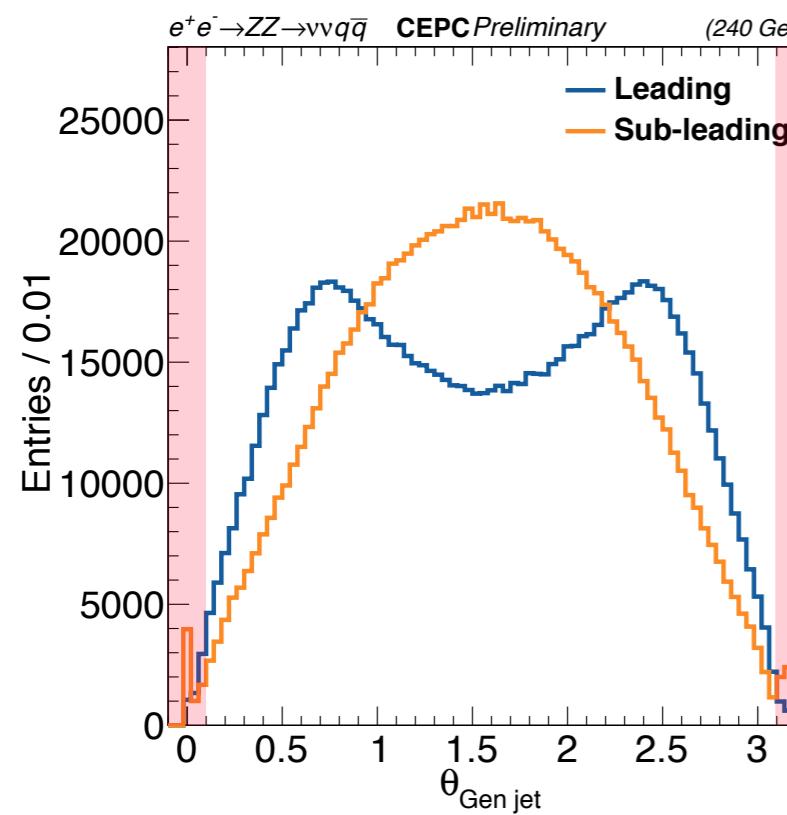
$$\frac{E_{Reco} - E_{Gen}}{E_{Gen}}$$

- The jet energy resolution and scale(JER/JES) in $e^+e^- \rightarrow ZZ \rightarrow v\bar{v}q\bar{q}$ process have been studied.
- The JER/JES relation between each simulation stage(Gen-MCP, Reco-Gen, and Reco-MCP).
- Angular, energy, and flavor dependence of JER/JES.
- To exclude the influence of jet clustering algorithm, matching reco jet and MC particle by $\Delta R < 0.1$.



Event Selection

Items	JER/JES(Reco-Gen)	JER/JES(Gen-MCP)
$\theta_{\text{Gen jet}} > 0.1 \text{ } \& \text{ } \theta_{\text{Gen jet}} < 3.1$	✓	✓
$\Delta R(\text{Reco-MCP}) < 0.1$	✓	✗

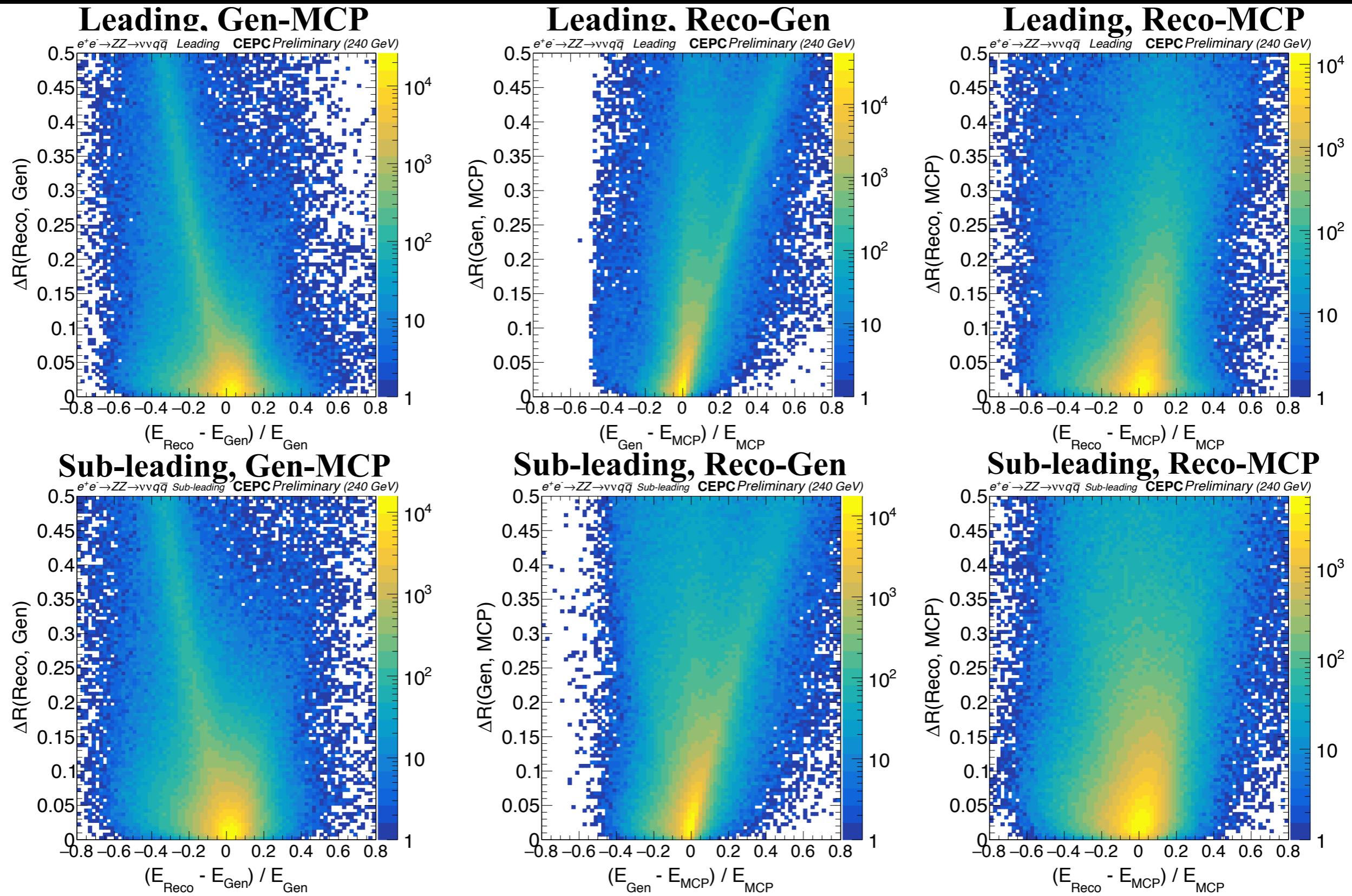


Efficiency =

$$\frac{\# \text{ of leftover event}}{\# \text{ of total event}}$$

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

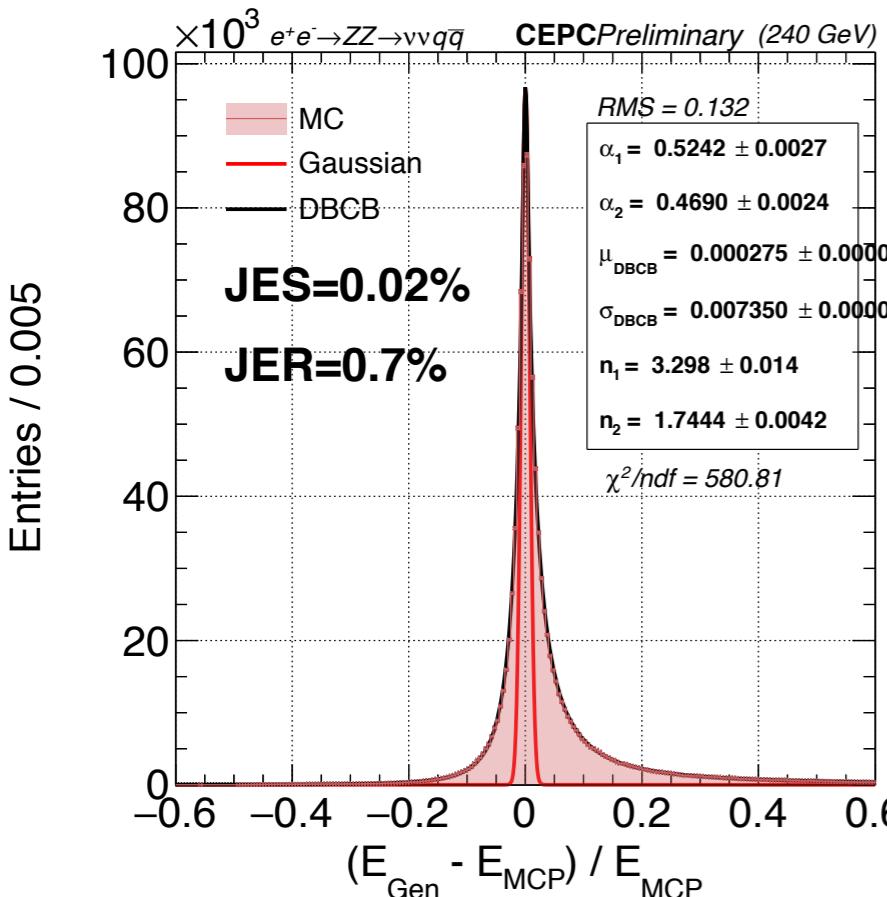
The Reason for ΔR Cut



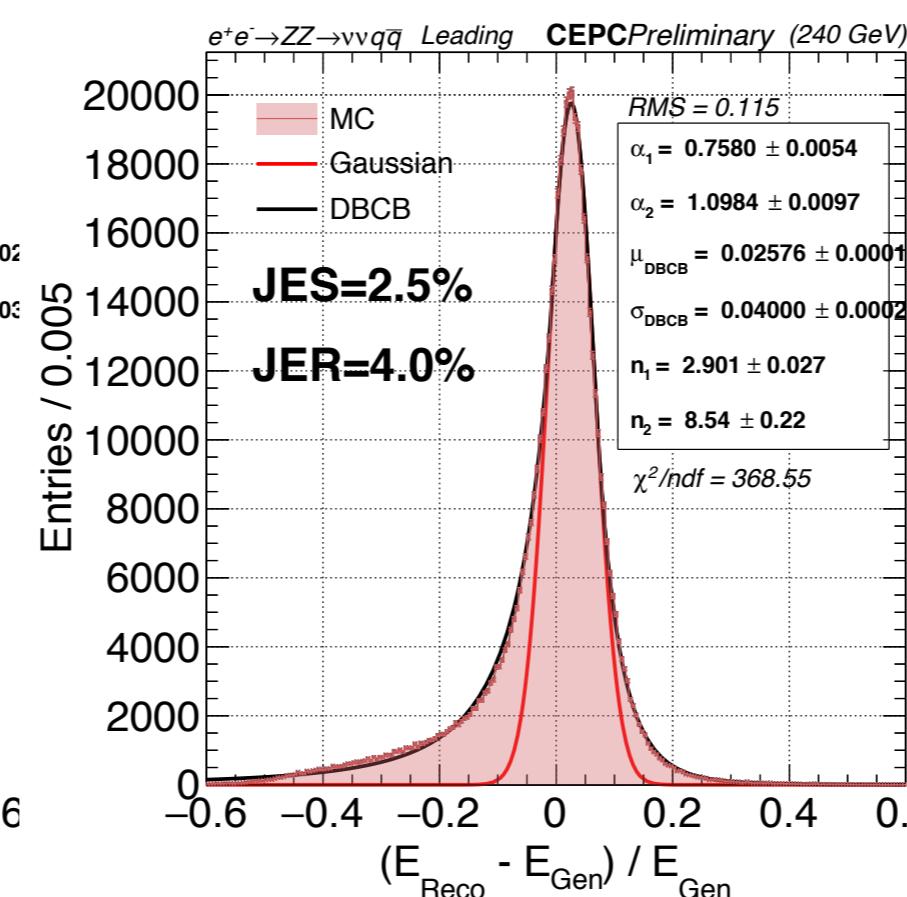
The jet clustering brings a significant uncertainty.

Leading JER & JES

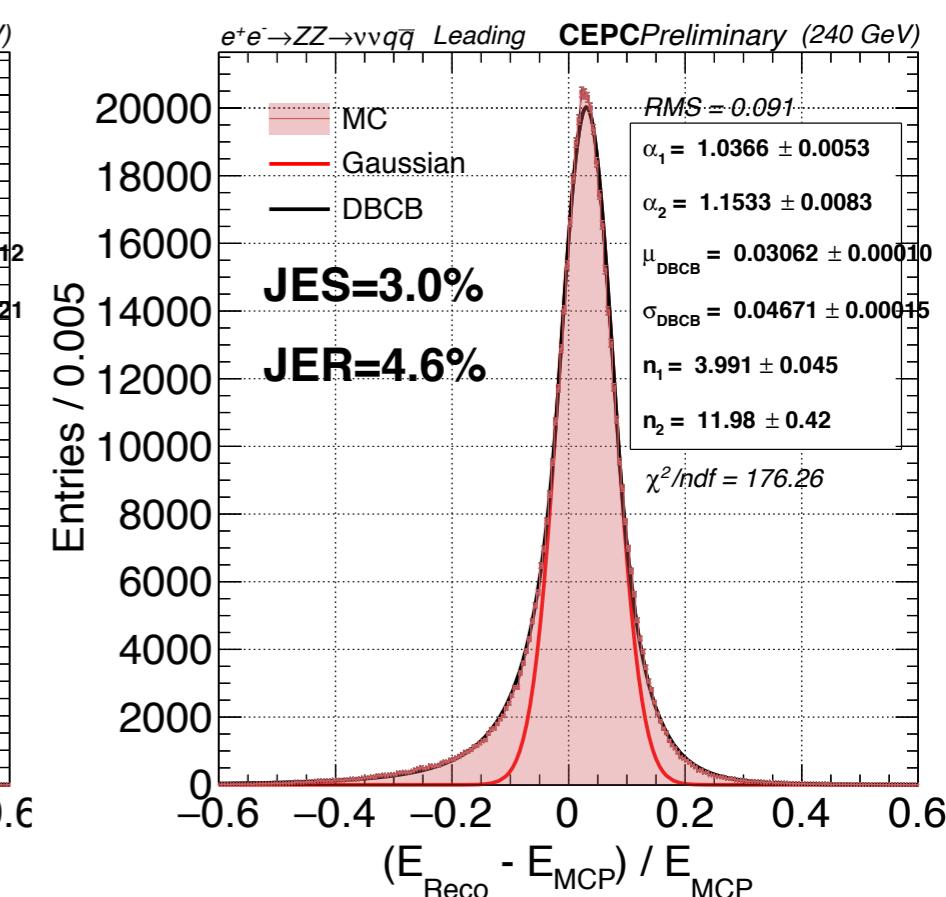
Gen-MCP



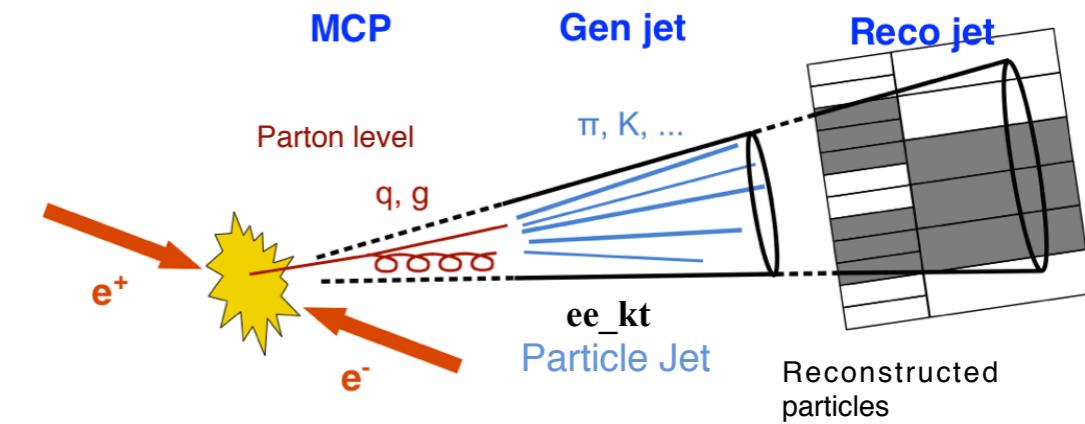
Reco-Gen



Reco-MCP

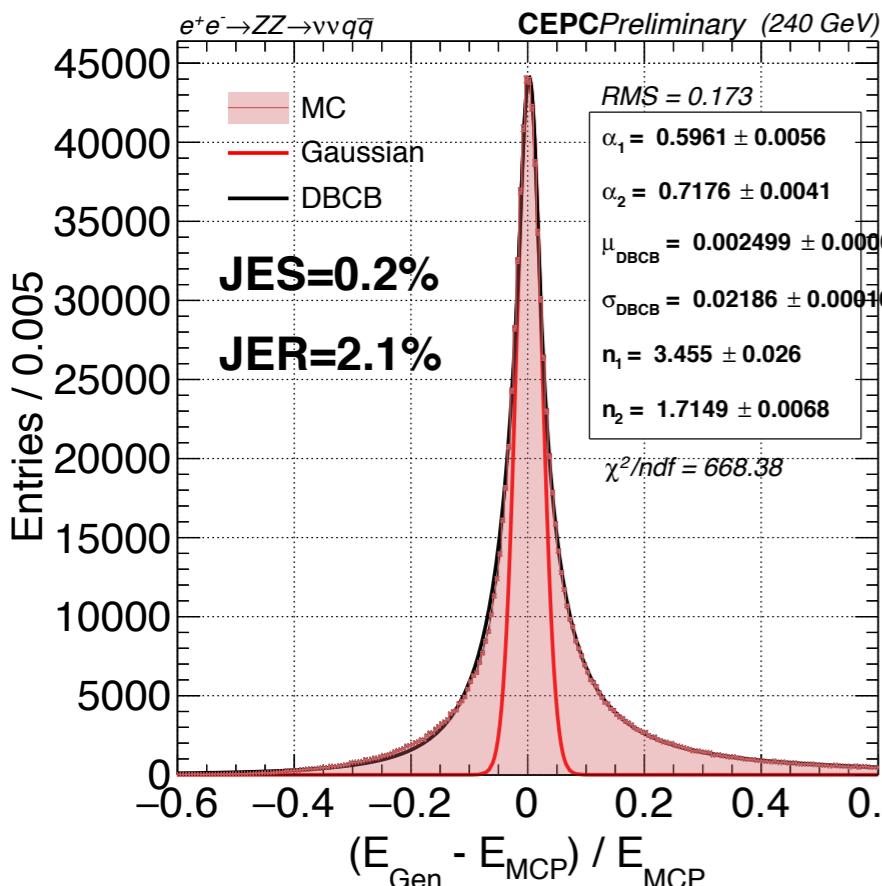


- JER/JES between Reco jet and MCP would combine the effects of two previous stages.

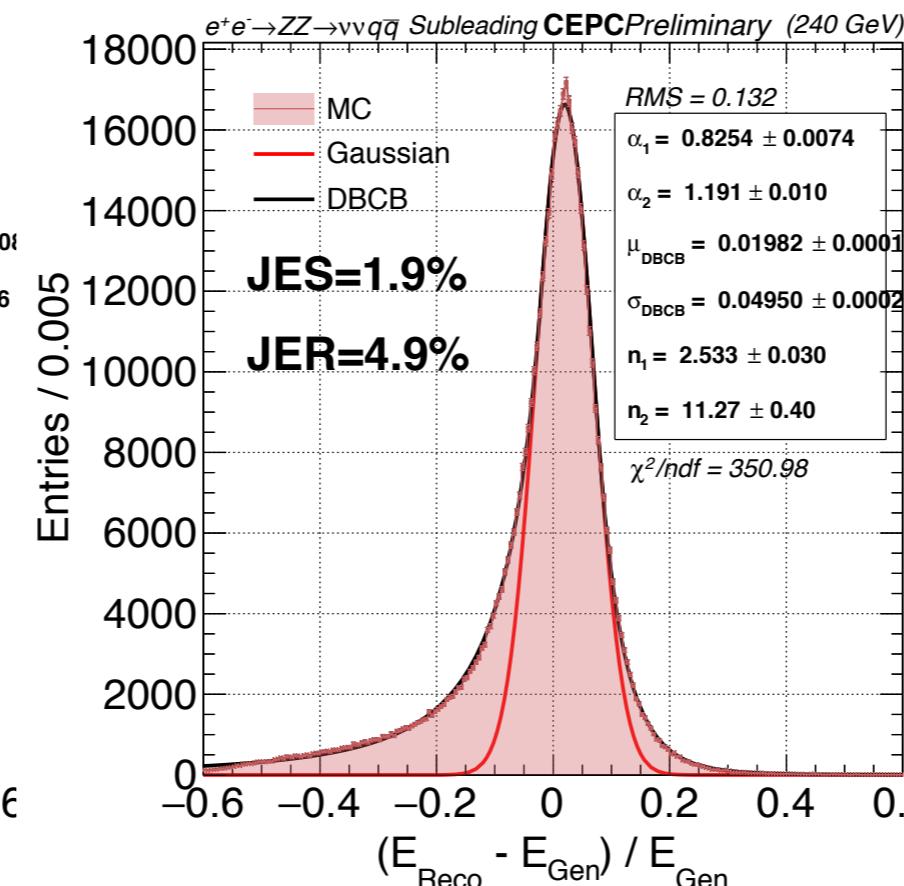


Sub-leading JER & JES

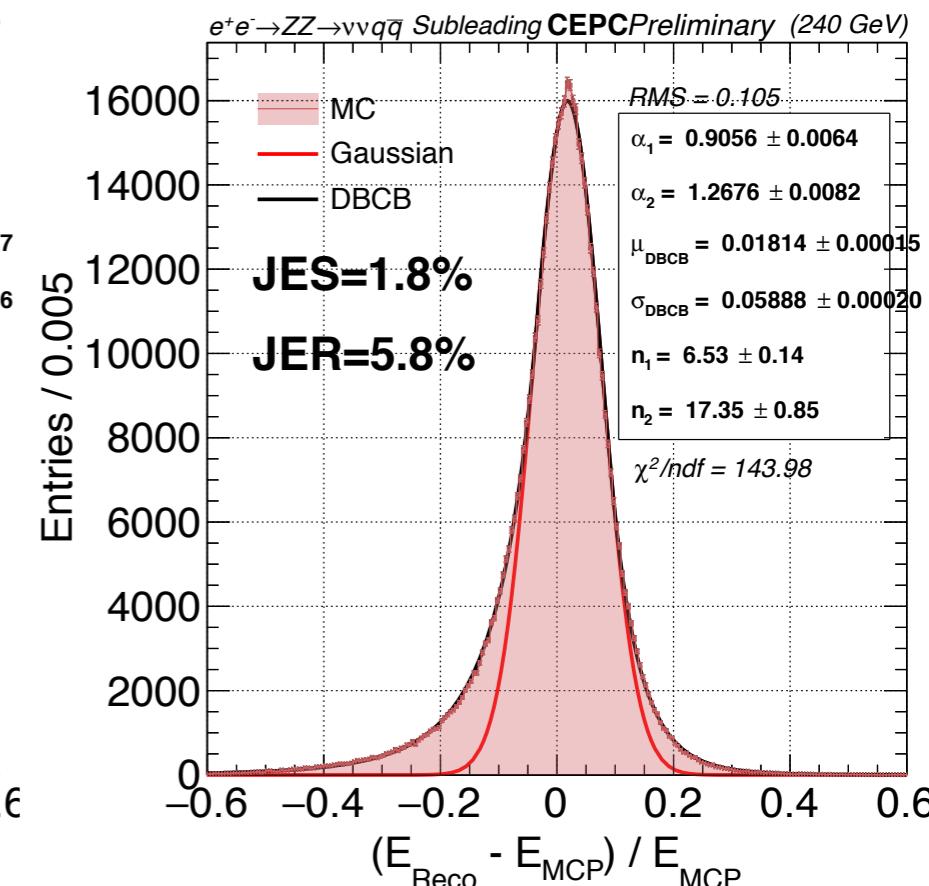
Gen-MCP



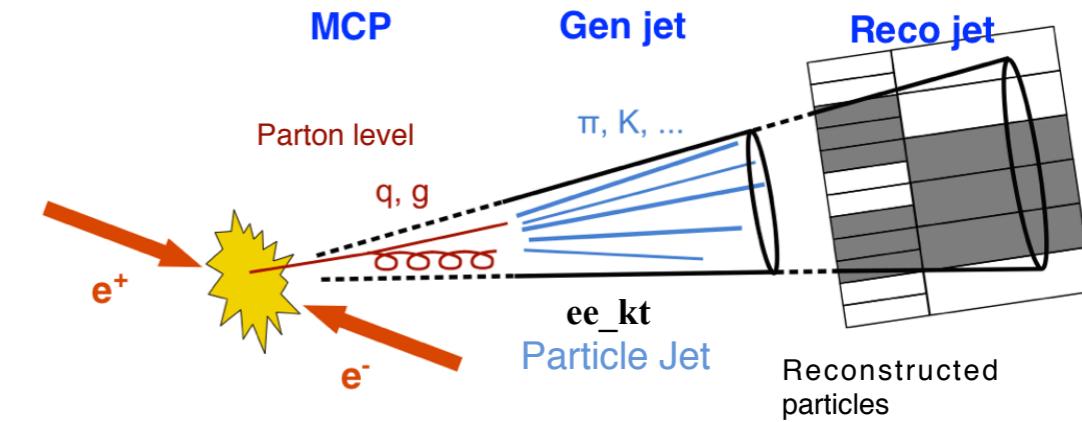
Reco-Gen



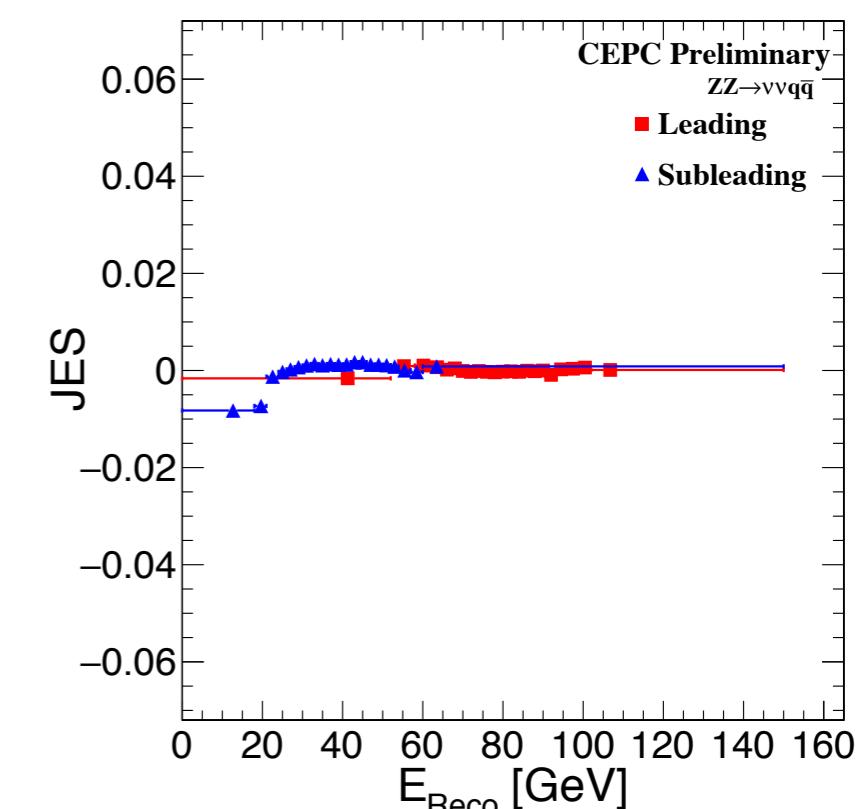
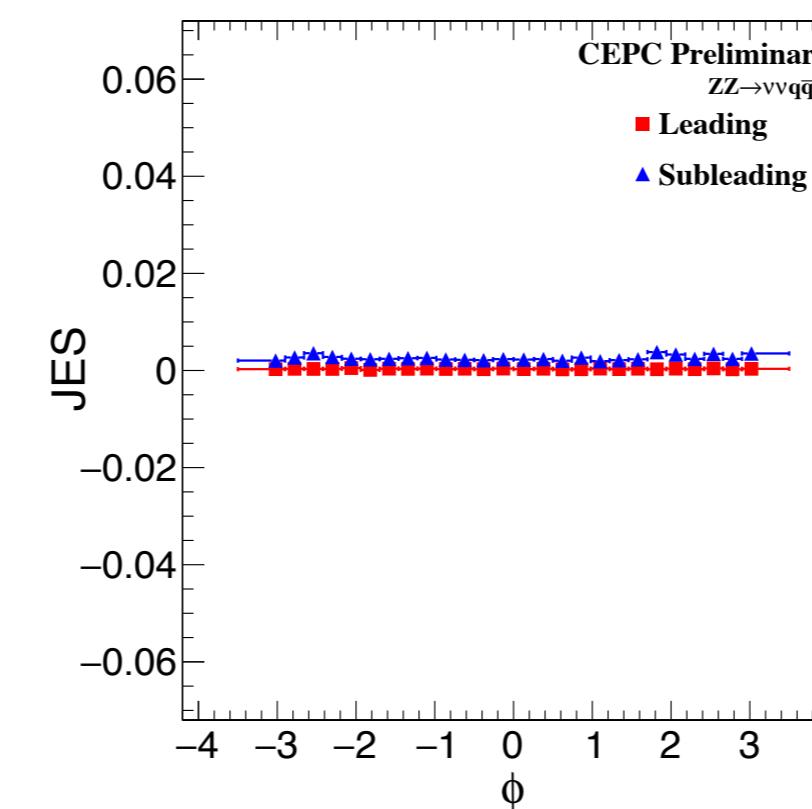
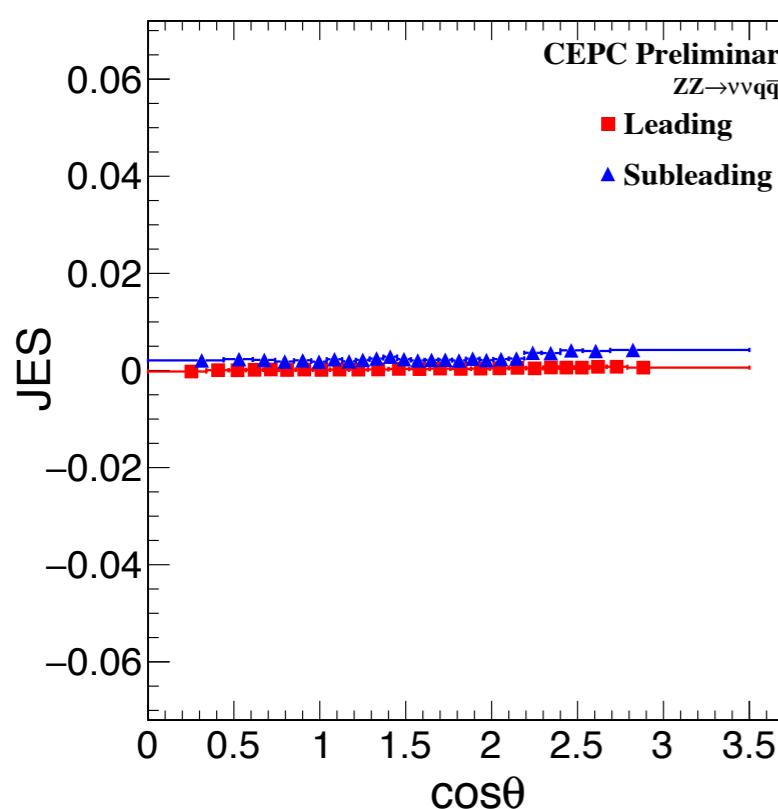
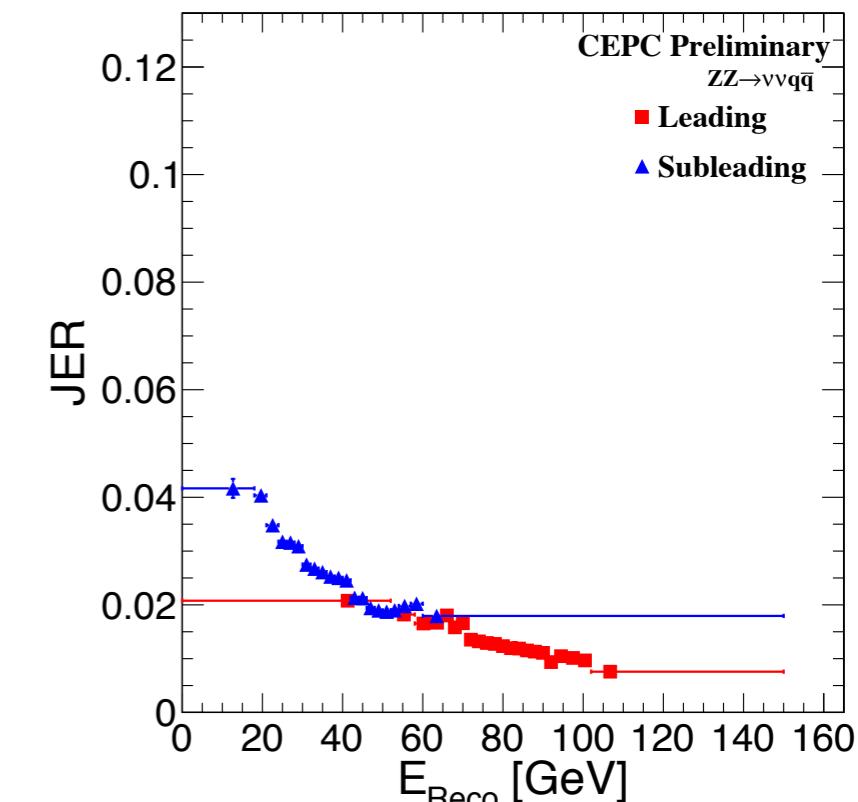
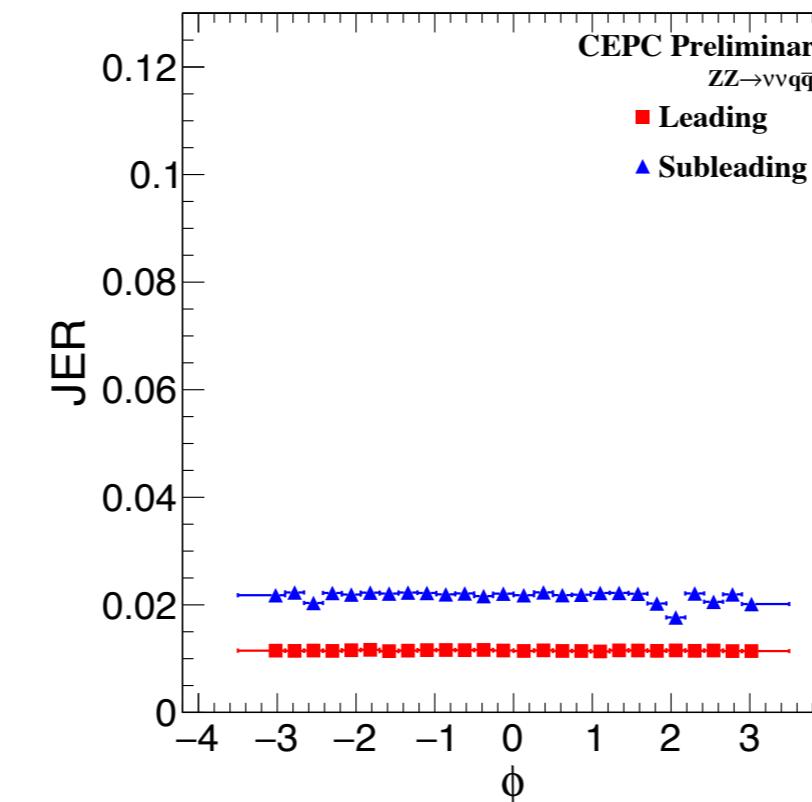
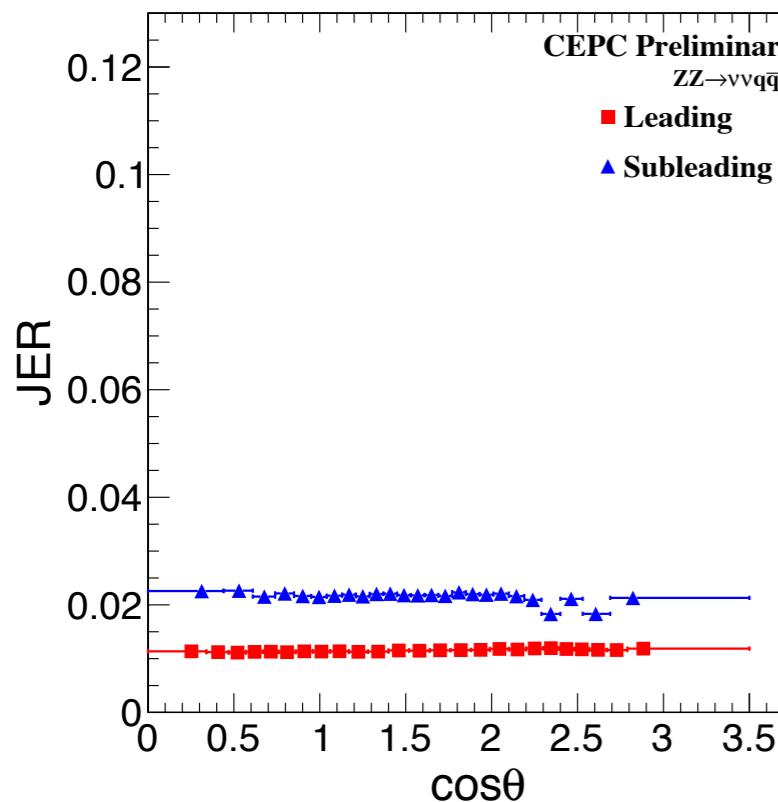
Reco-MCP



- JER/JES between Reco jet and MCP would combine the effects of two previous stages.

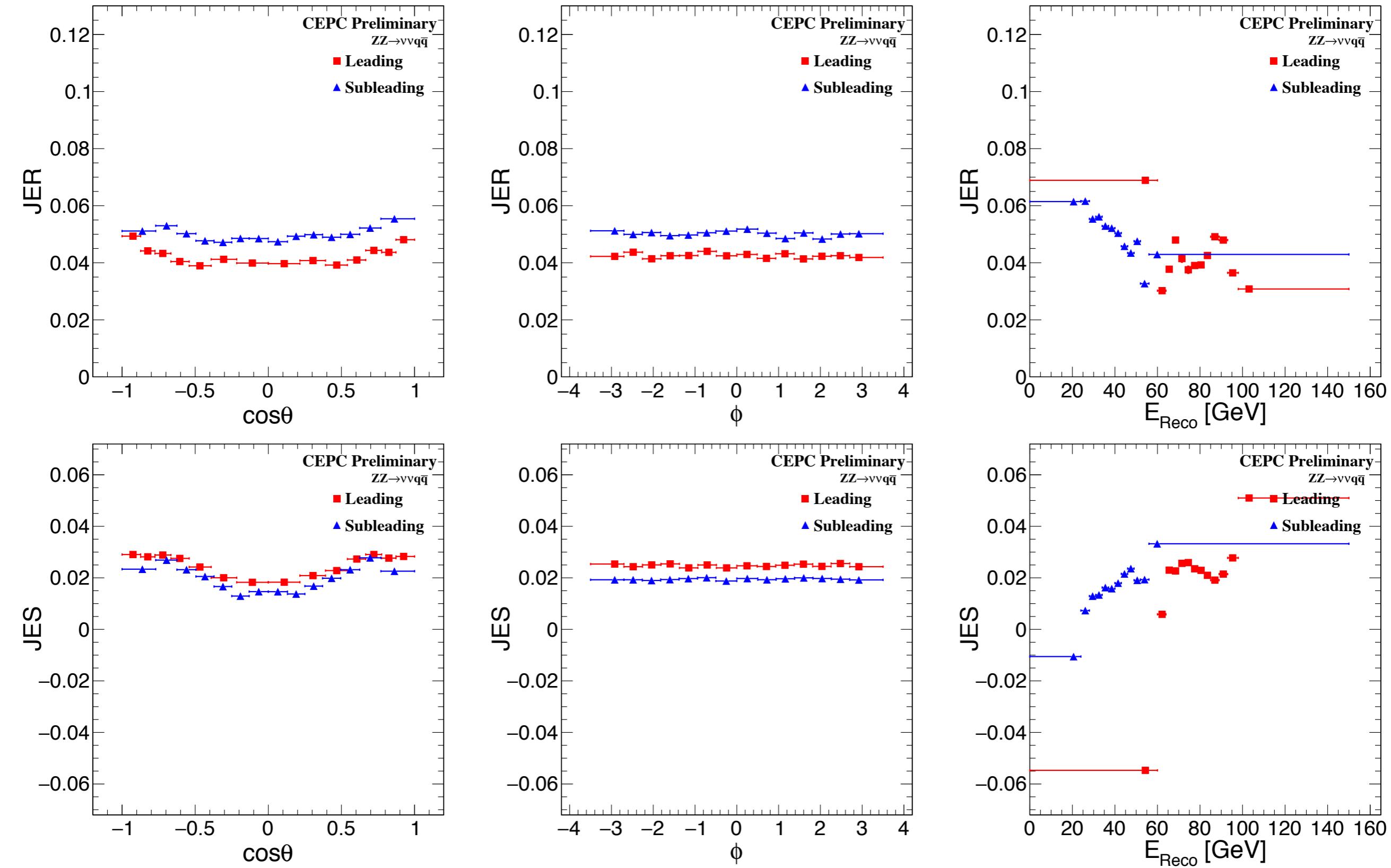


JER & JES(Gen-MCP)



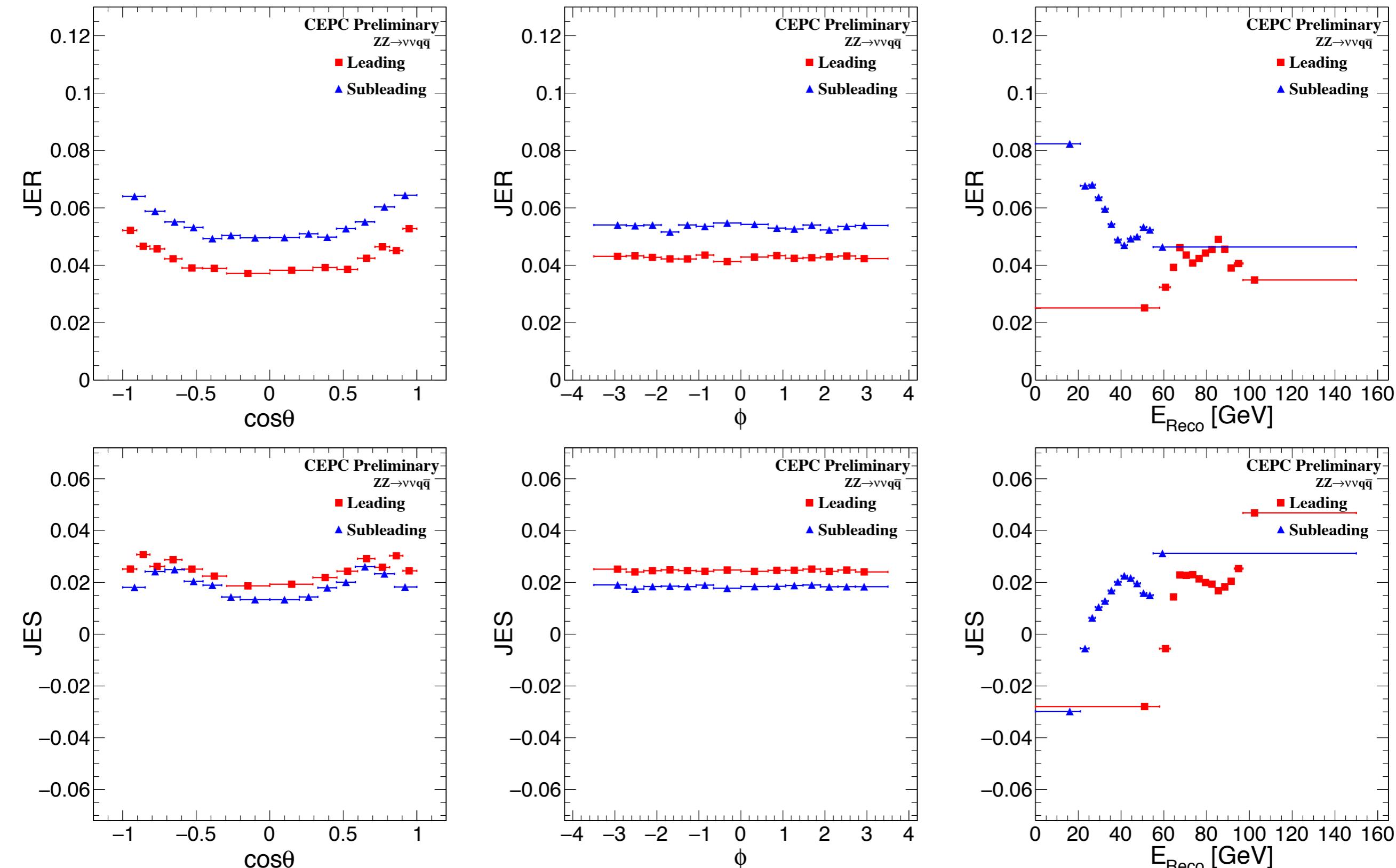
The jet clustering is independently on direction.

JER & JES(Reco-Gen)



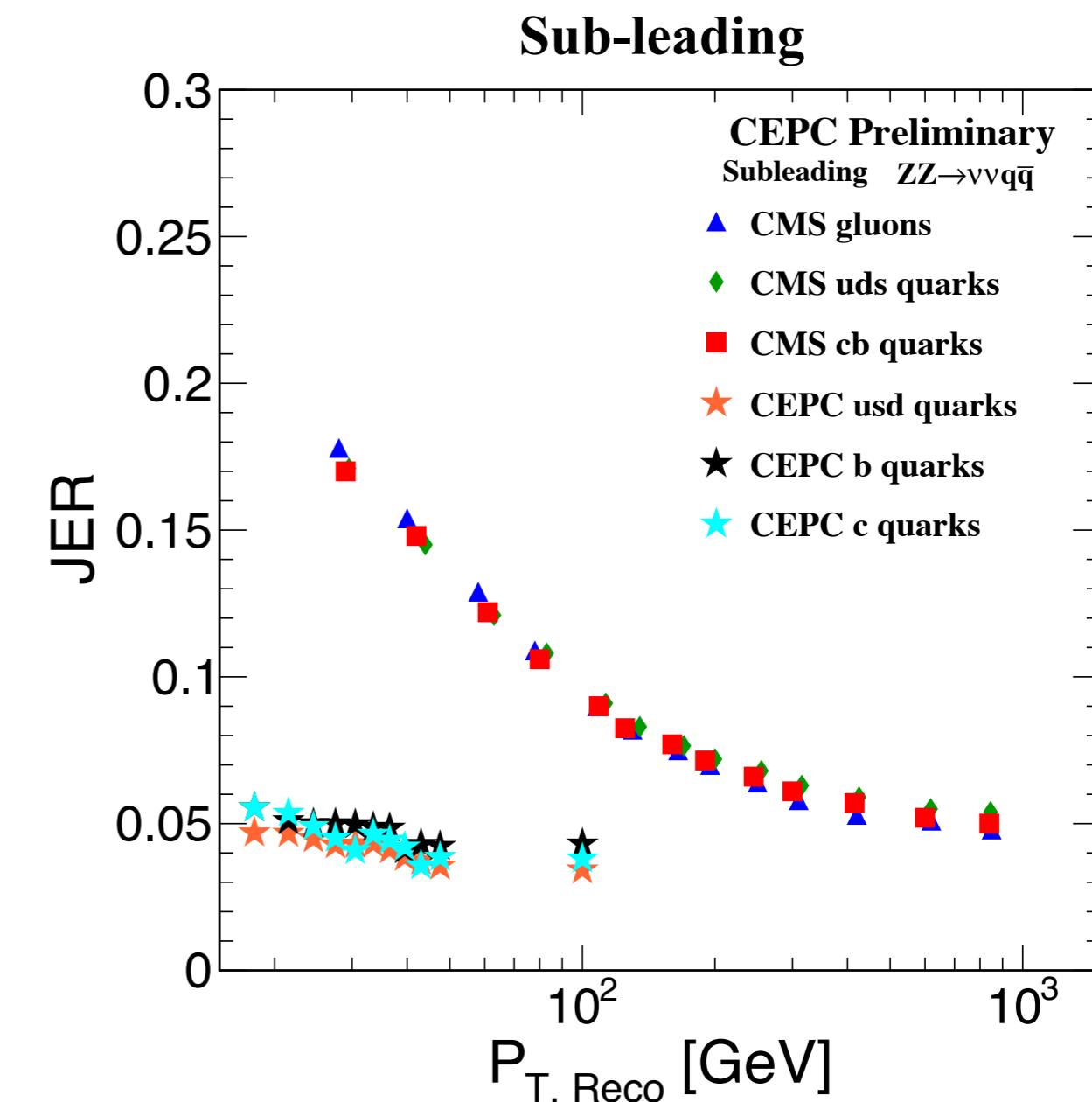
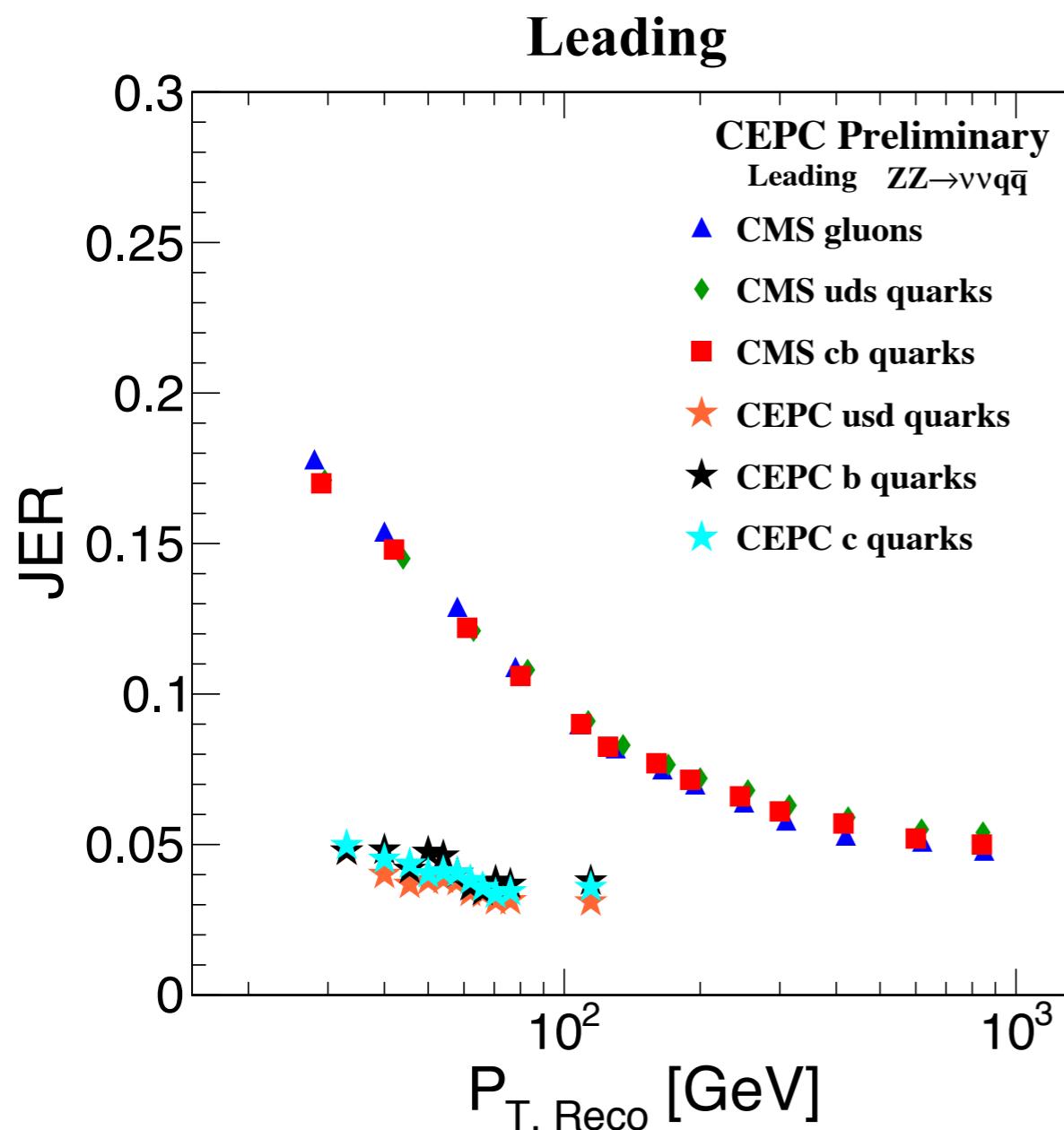
Both JER/JES slightly depend on $\cos\theta$.

JER & JES(Reco-MCP)



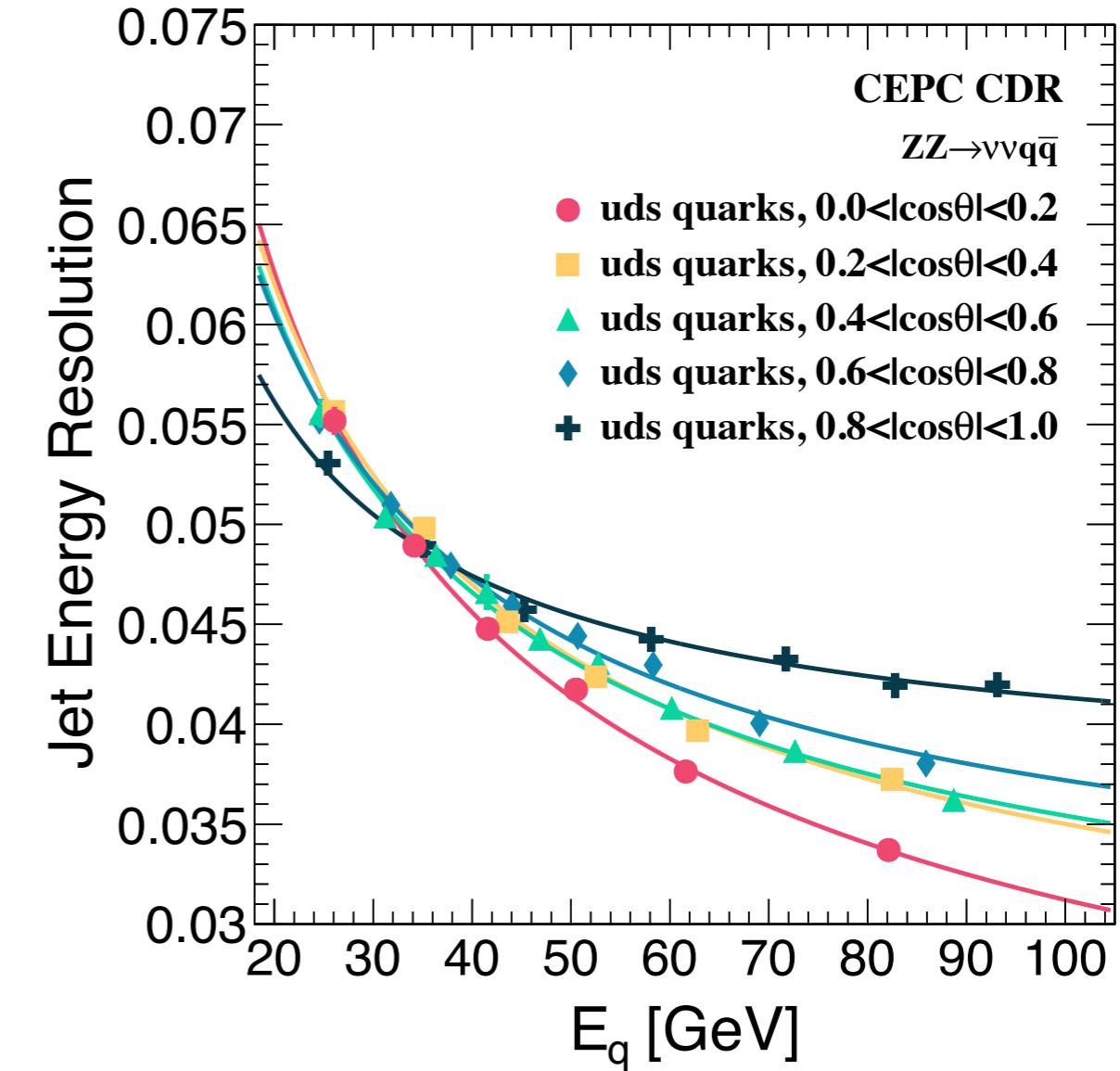
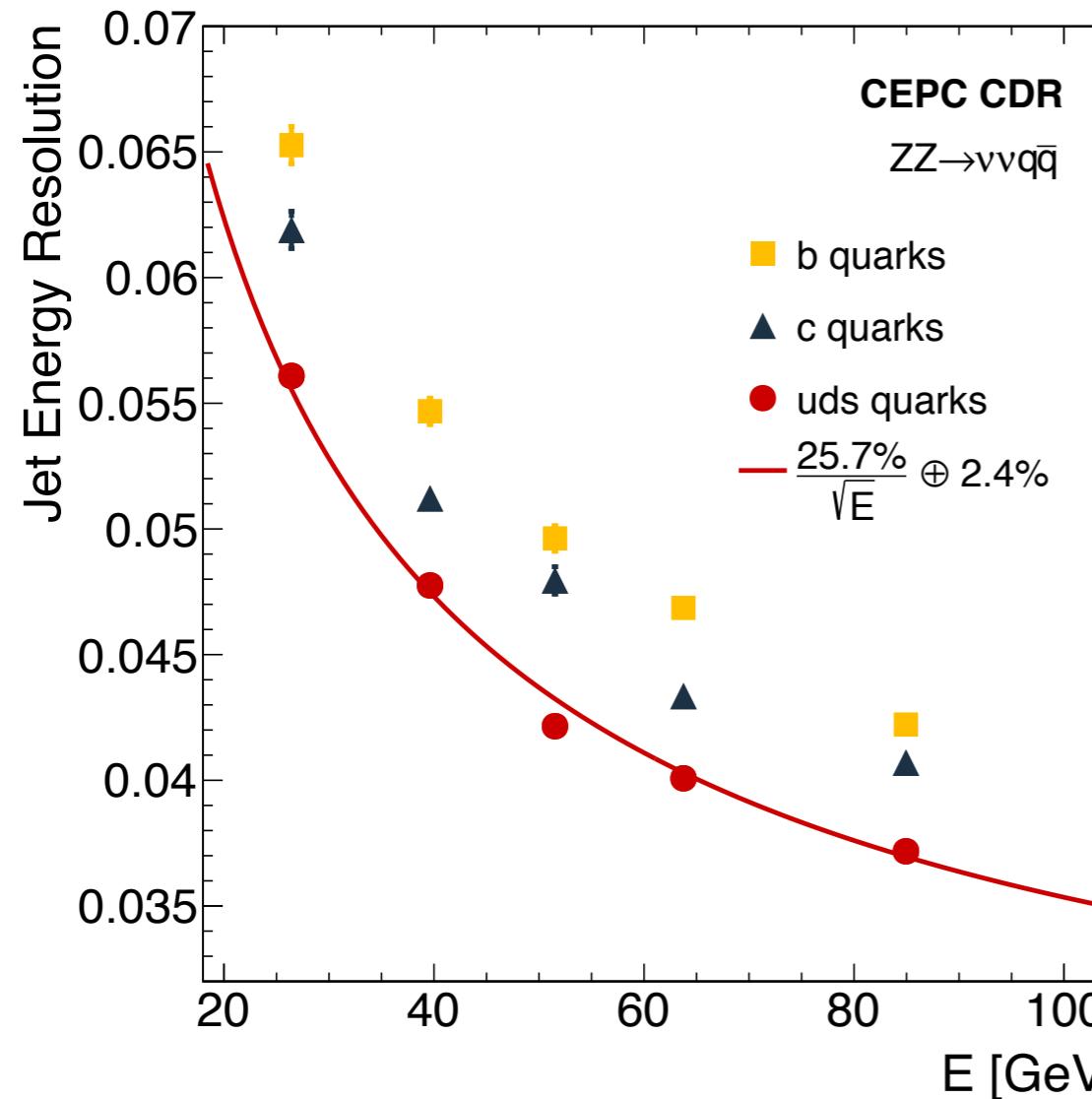
The varying of JER/JES as a function of the $\cos\theta$ is within 3%.

Compare to CMS at LHC



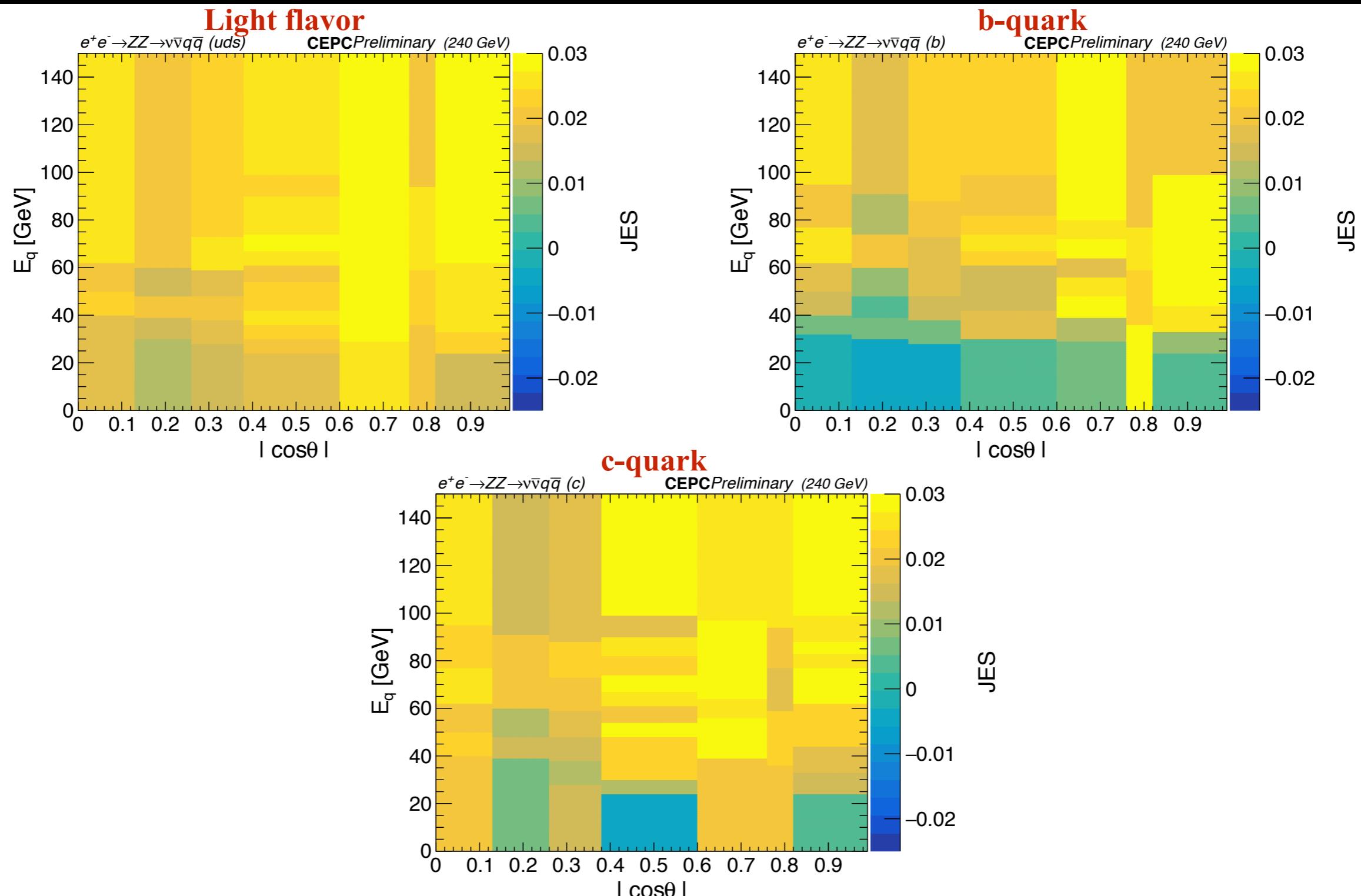
- Our JER is better than CMS as it should be.
- Heavy flavors have a little poor JER.

Ref. [3]



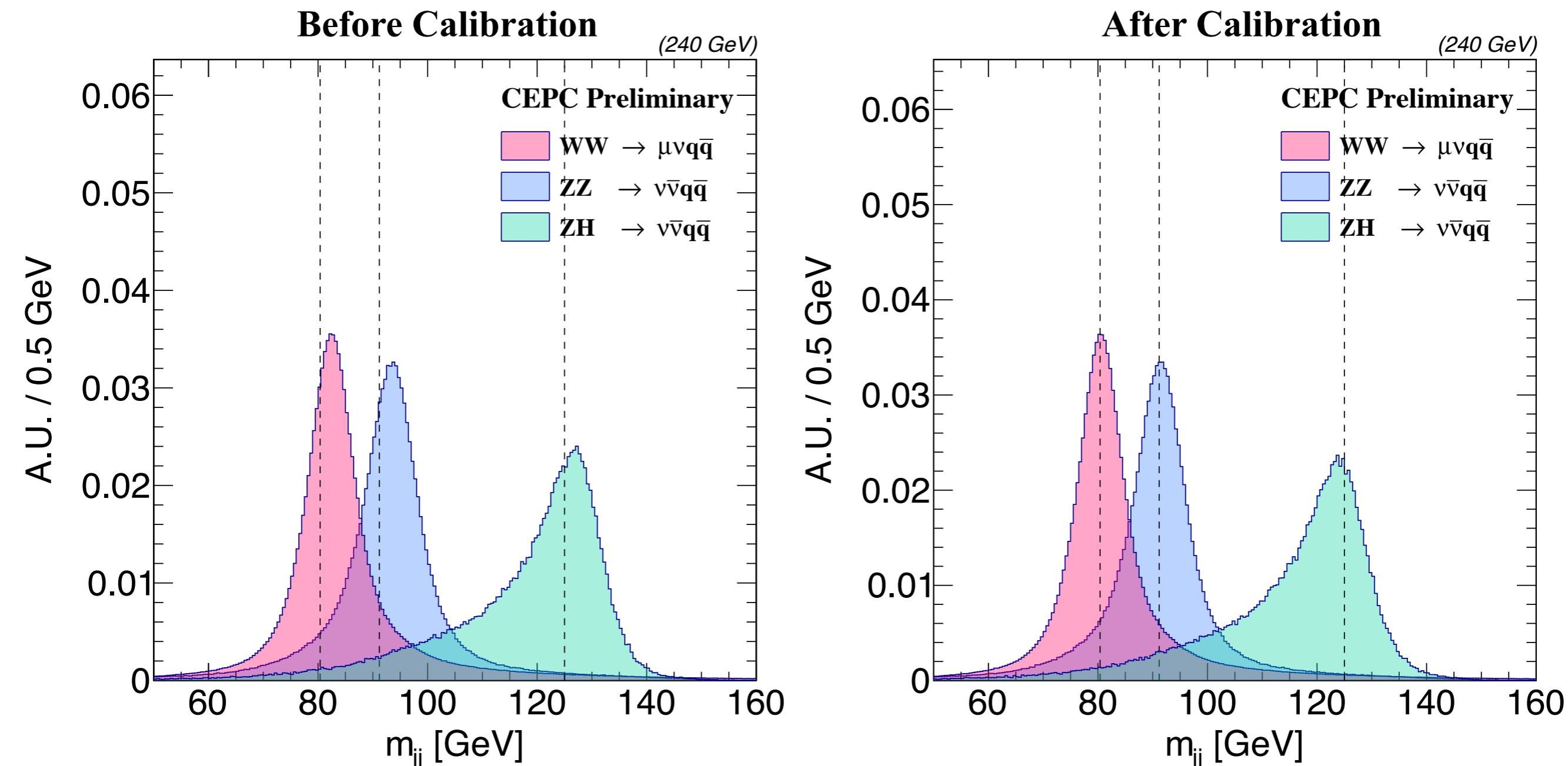
- JER also depends on the jet flavor.
- Higher jet energy and within central region of barrel, JER has impressive performance.

JES in Phase Space



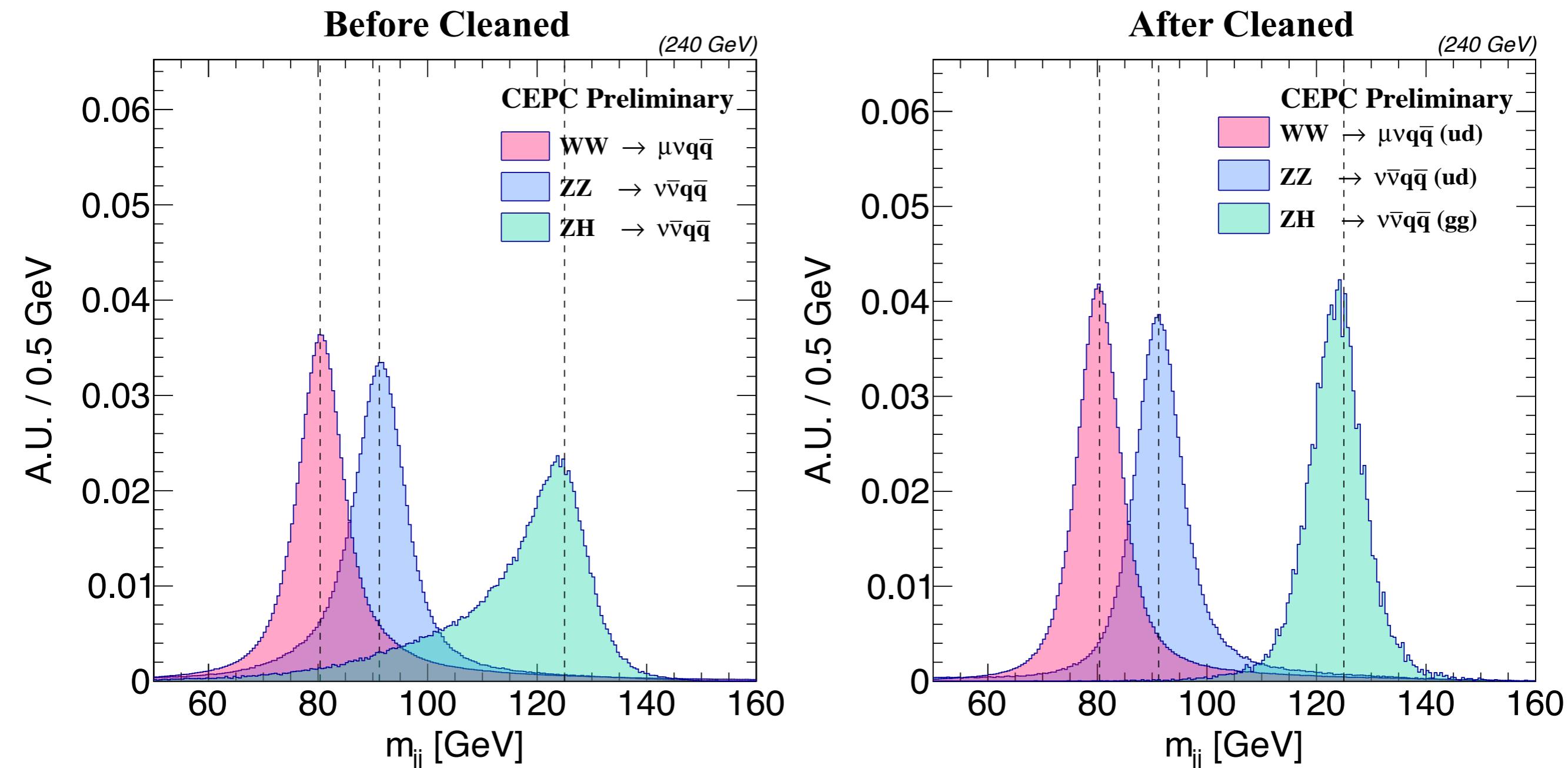
- JES also depends on the jet flavor.
- Light flavor jet has higher energy deviation.

Jet Energy Calibration



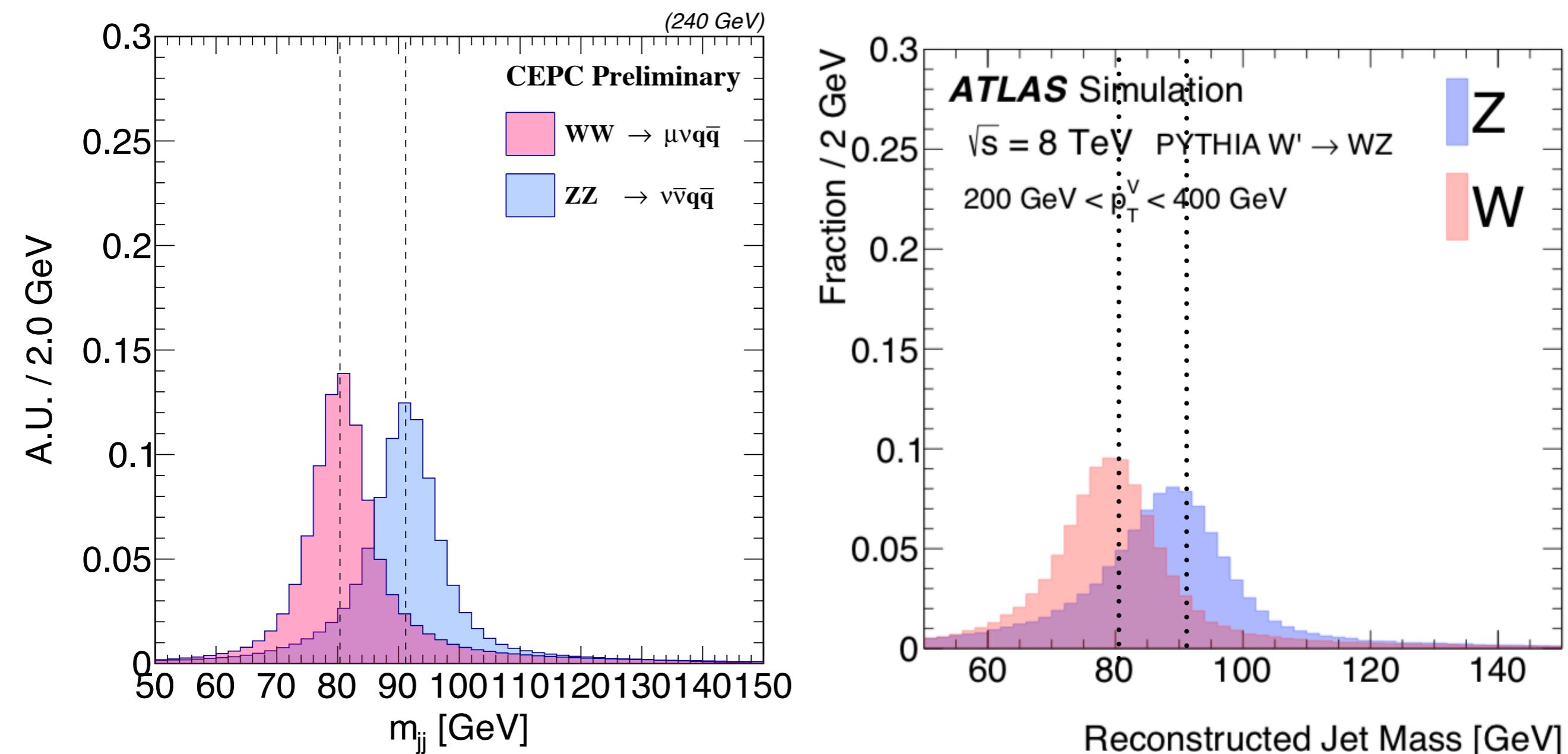
- According to MC true energy and $\cos\theta$ distribution, JES can calibrate the dijet invariant mass back to the value we put into simulation.
- After calibration, boson mass resolution is improved about 1%.

Boson Mass Resolution



Z, W, and Higgs boson masses in dijet final state can be well separated in CEPC.

Boson Mass Resolution



- The separation of Z and W at CEPC is much better than ATLAS as it should be, because we have better jet energy resolution.

Ref. [4]

Gen-MCP

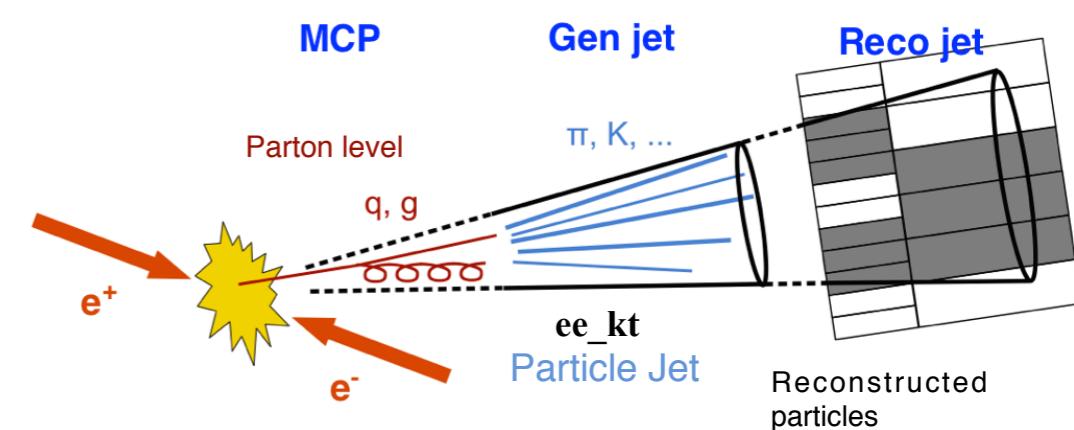
Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	1%	2%	0	0
Endcaps	1%	2%	0	0
En > 60 GeV	1%		0	

Reco-Gen

Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	4%	5%	2%	1.5%
Endcaps	5%	5.5%	3%	2.5%
En > 60 GeV		4%		2.5%

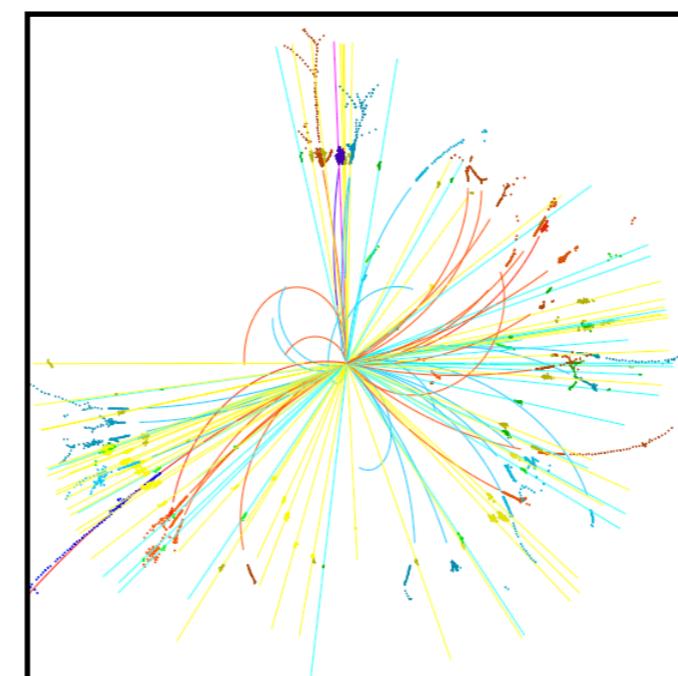
Reco-MCP

Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	4%	5.5%	2.5%	1.5%
Endcaps	5%	6.5%	3%	2.5%
En > 60 GeV	4.5%		2.5%	



- After comparison, the CEPC detector has excellent jet energy resolution.
- Z, W, and Higgs boson mass in dijet final state can be well separated in CEPC.
- The jet clustering brings a significant or even leading uncertainty.
- Jet energy calibration can be used to improve the precision of boson mass measurement.
- Base on reconstruction level and $Z\gamma$ process to do calibration.
- Study the performance of different jet clustering algorithms to promote precision in multi-jet processes measurements. (e.g., $e^+e^- \rightarrow ZH \rightarrow 4b$)

$e^+e^- \rightarrow ZH \rightarrow 4b$



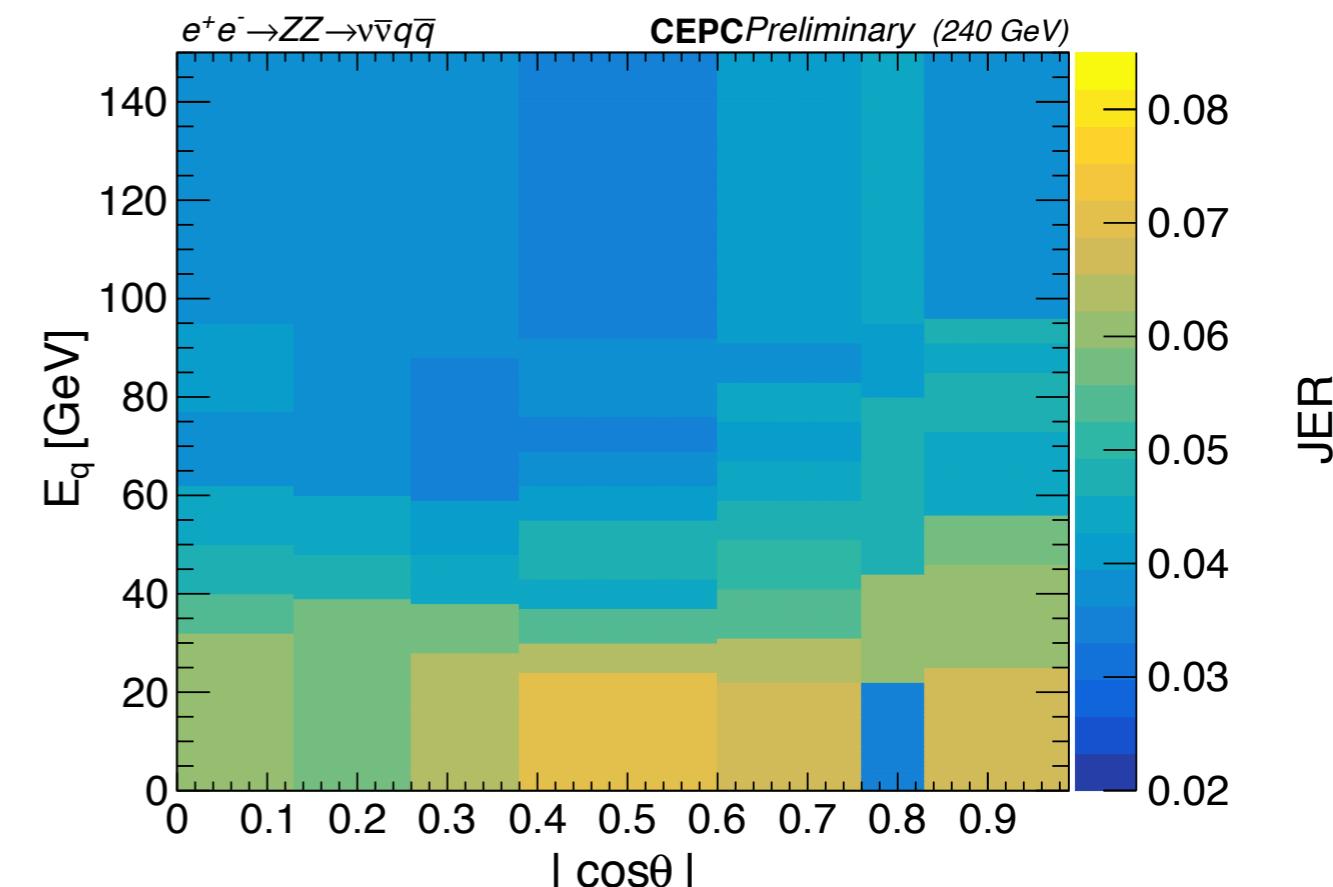
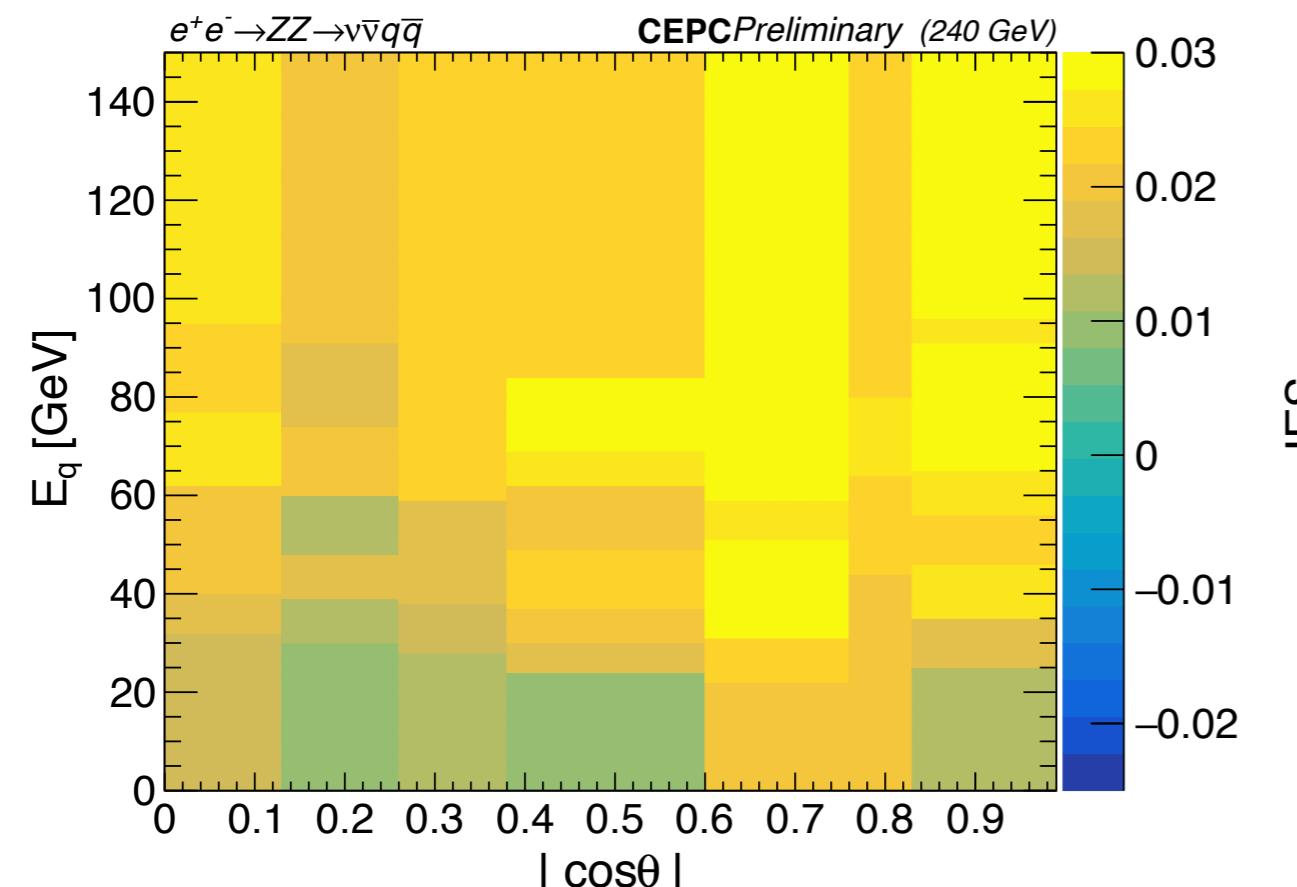
Thank for your attention

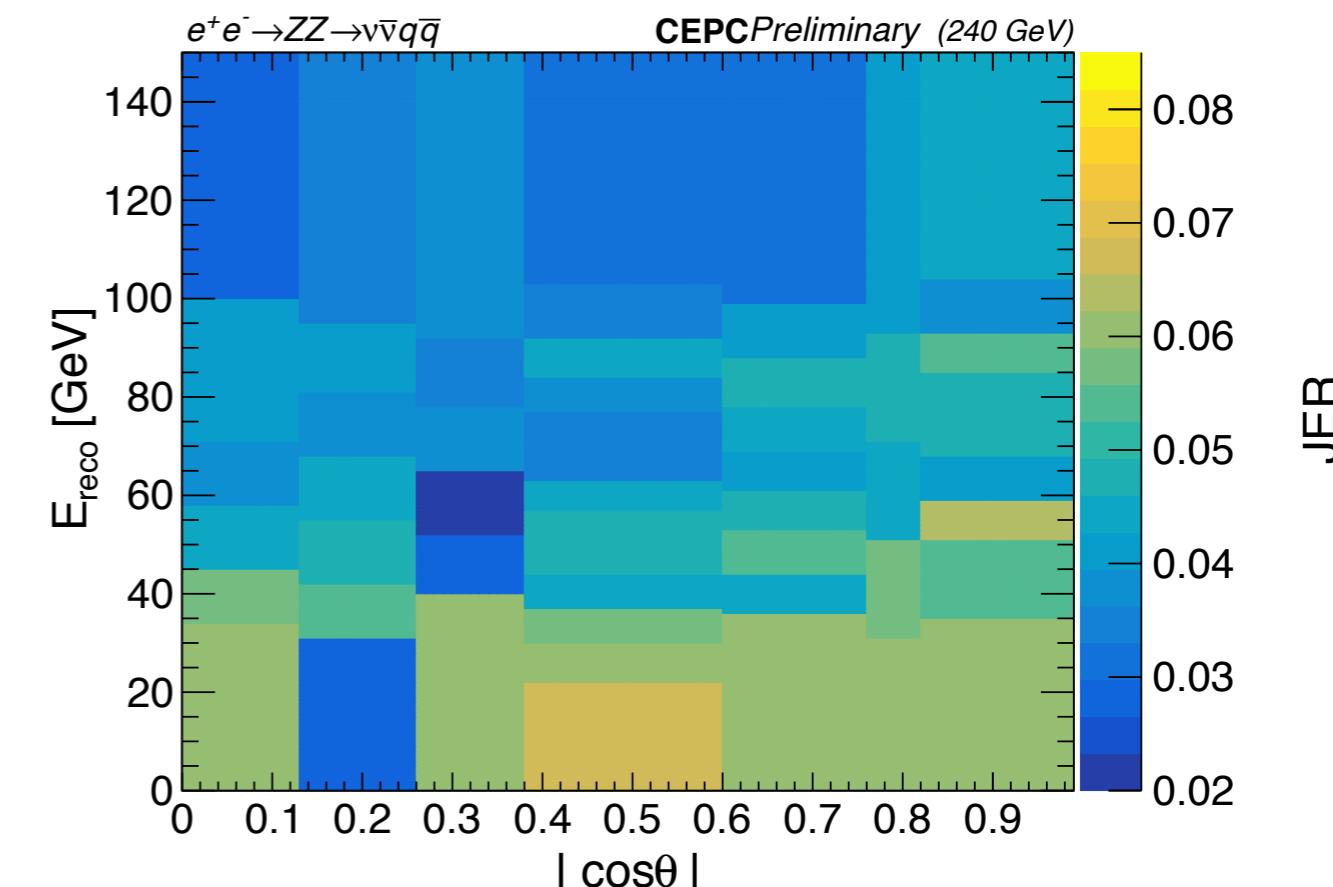
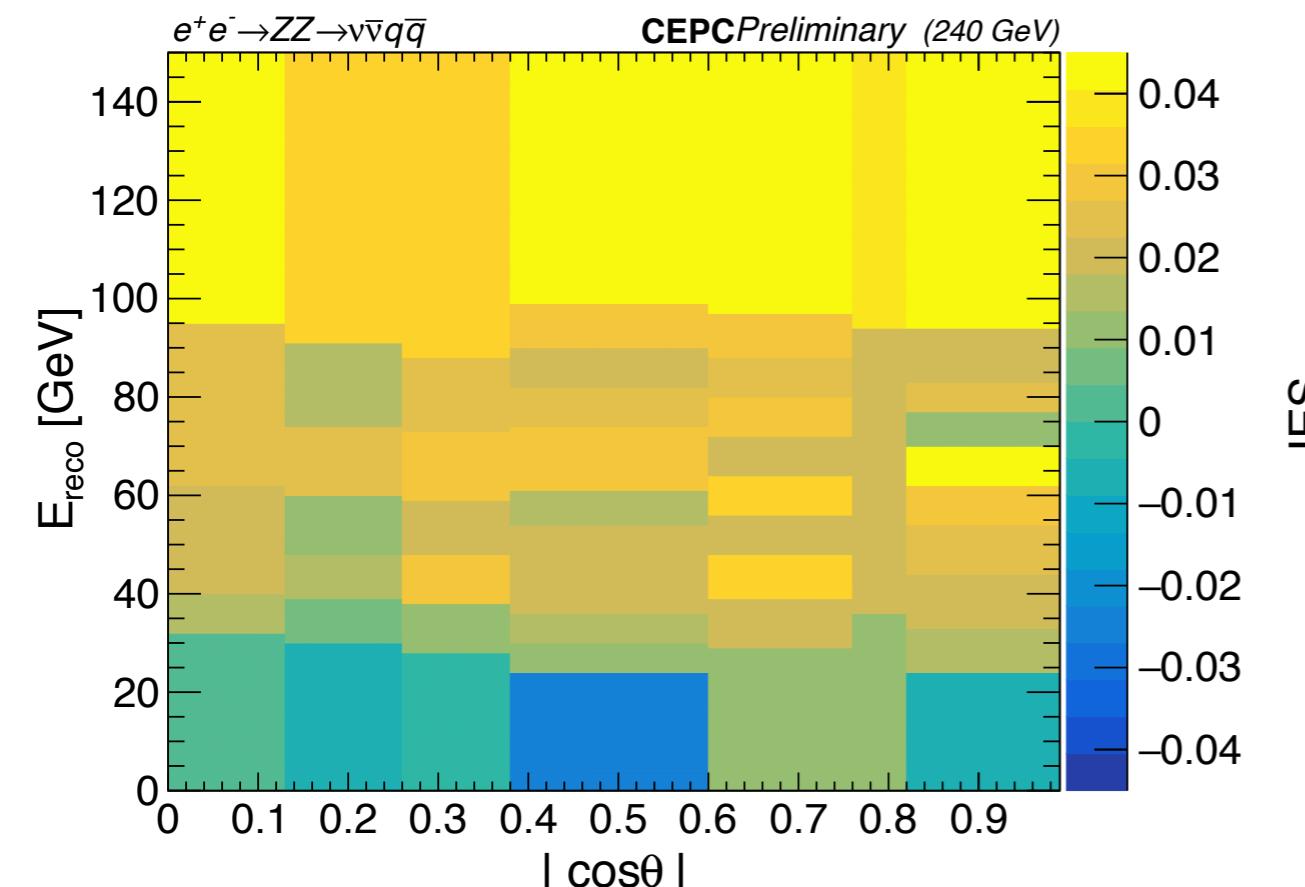




- [1] CMS-Physics-Technical-Design-Report-2006-001
- [2] <http://cms.web.cern.ch/tags/particle-jet>
- [3] CMS-JME-13-004, CERN-PH-EP “**Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV**”
- [4] **A new method to distinguish hadronically decaying boosted Z bosons from W bosons using the ATLAS detector**, CERN-PH-EP-2015-194

Back up

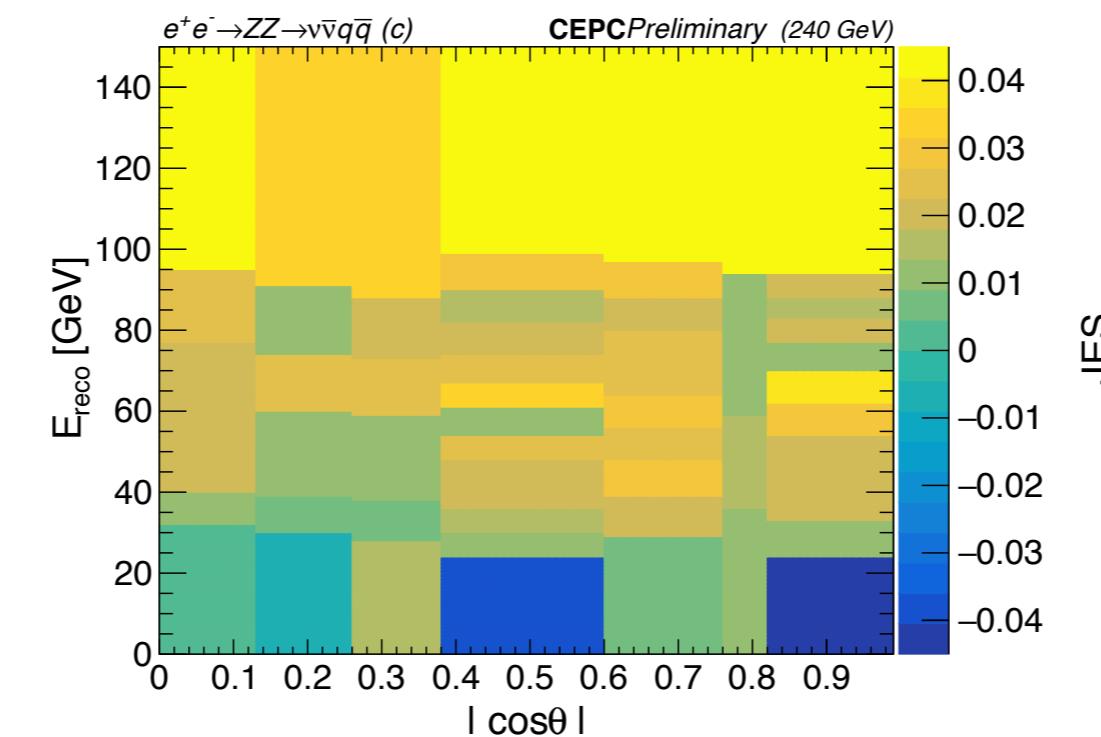
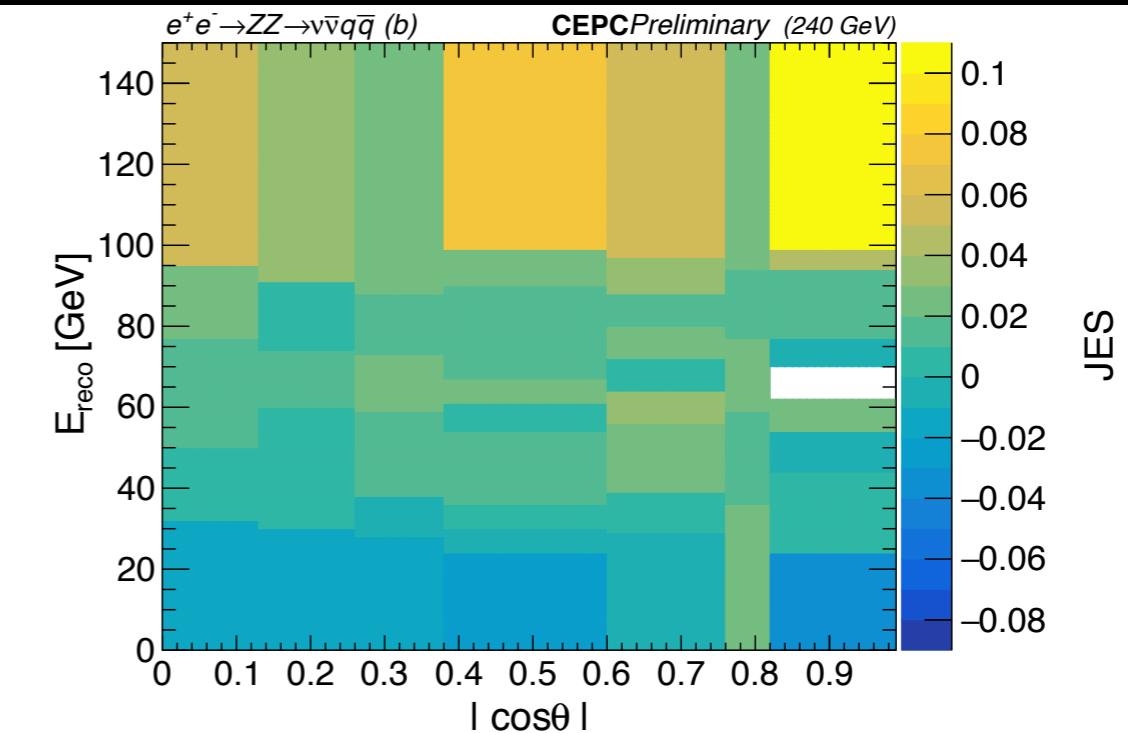
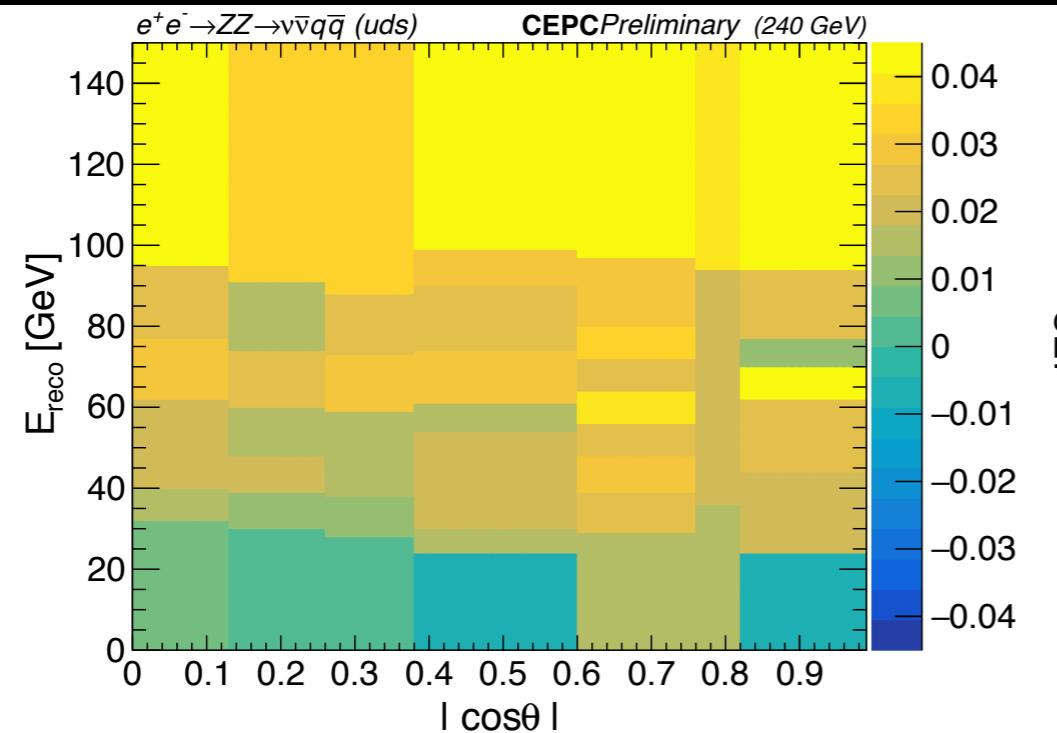






CEPC

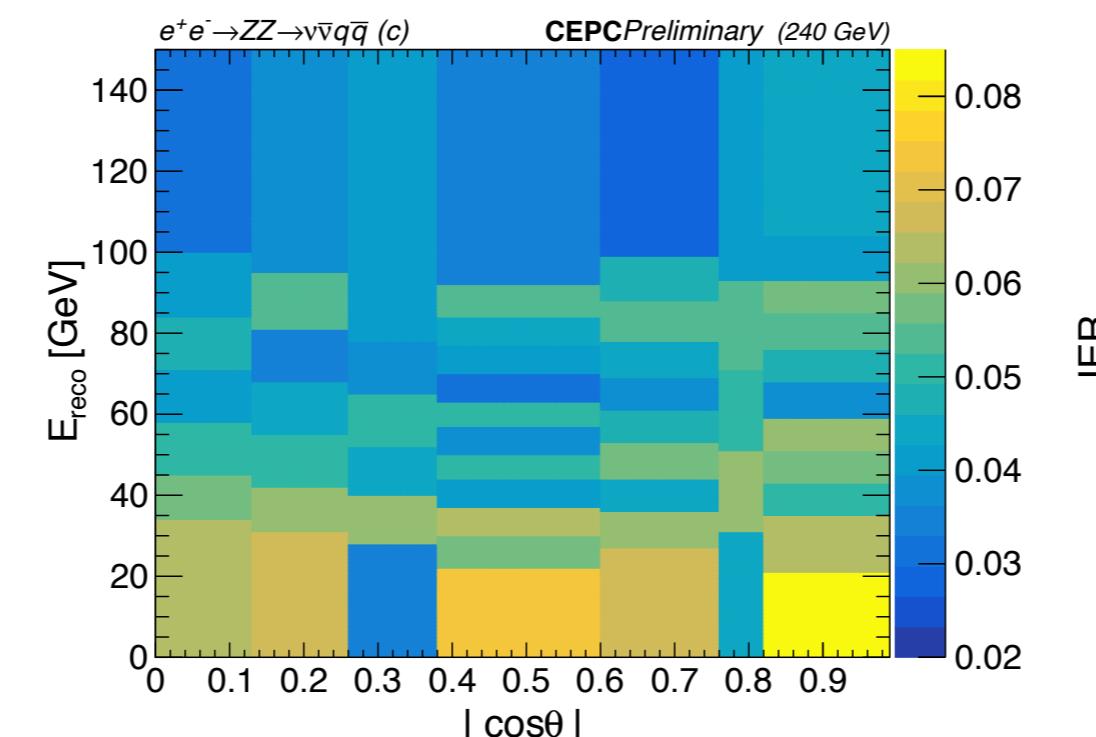
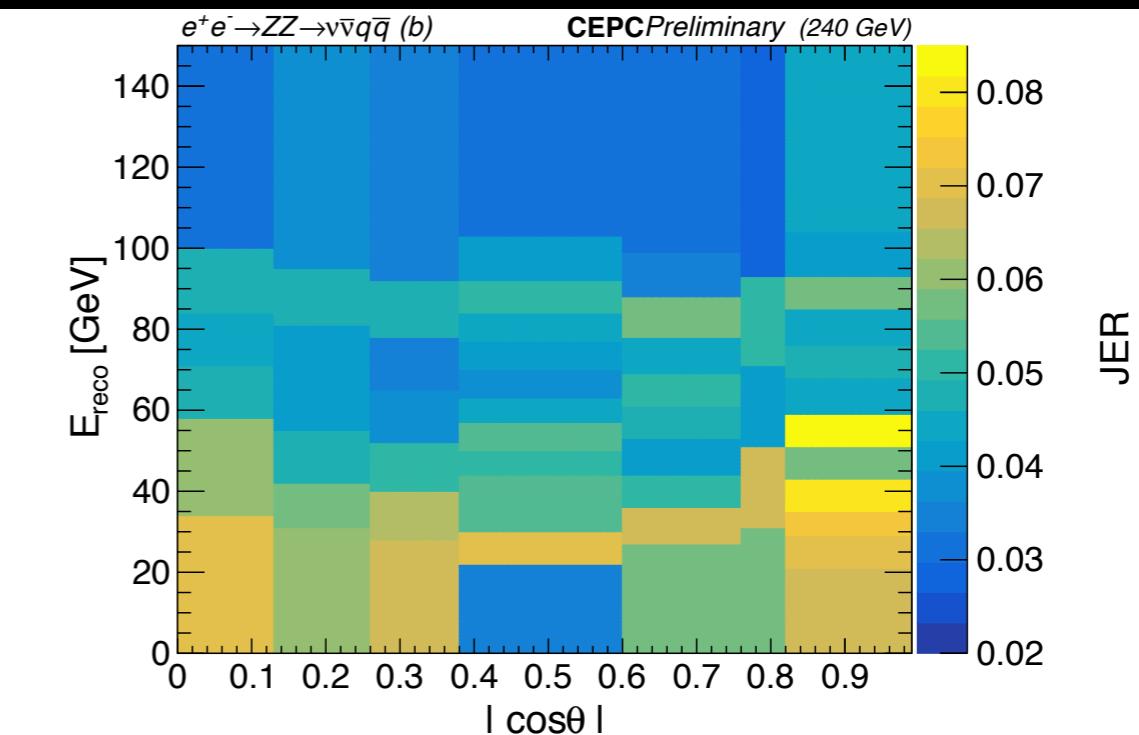
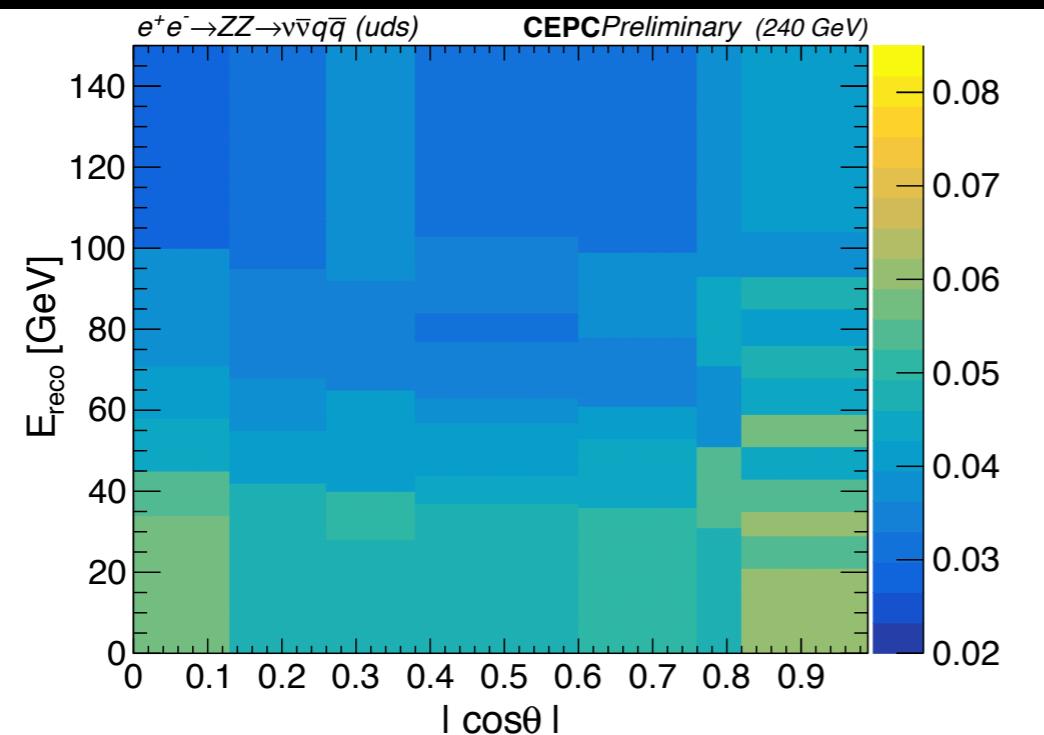
JES



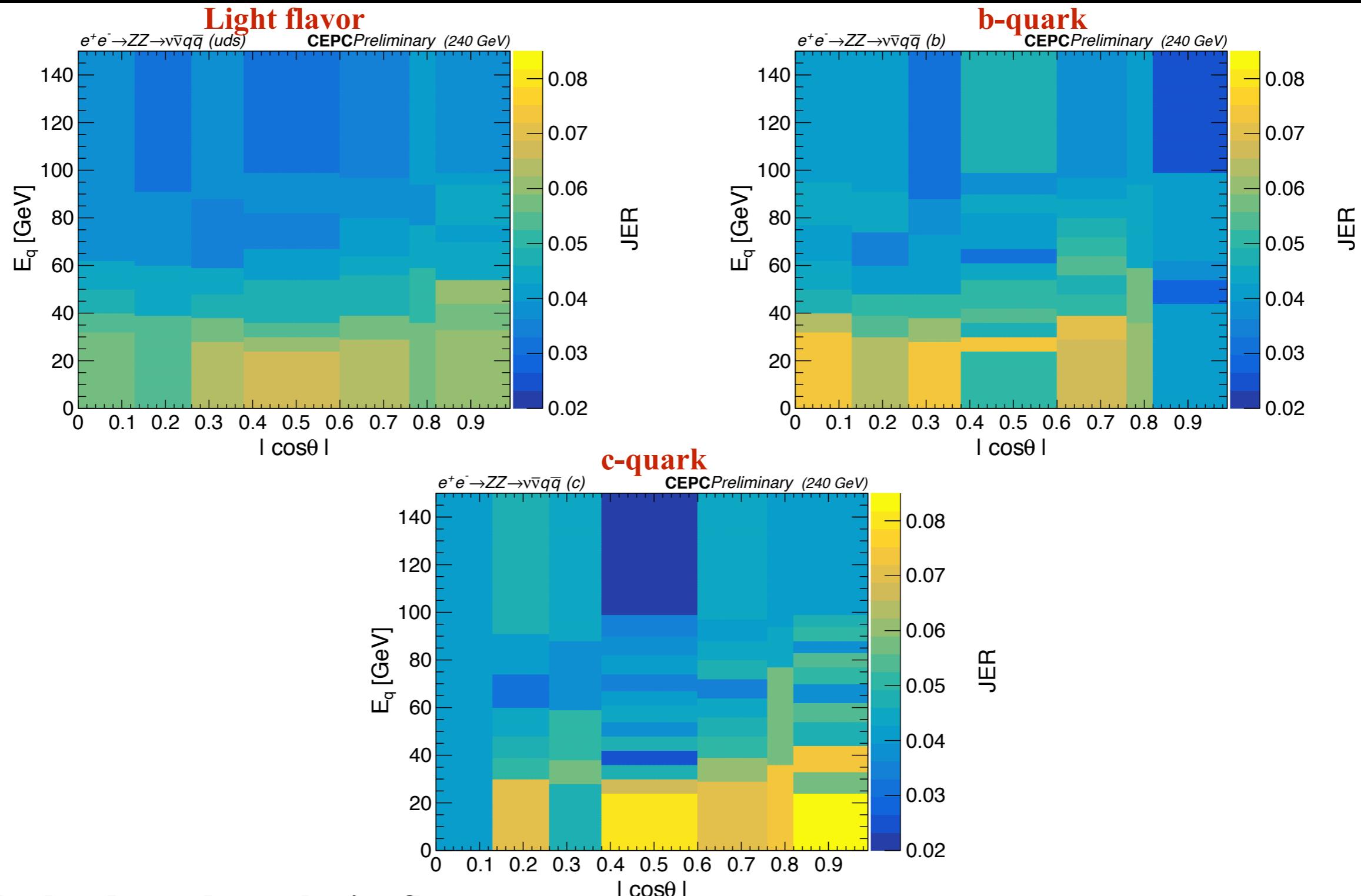


CEPC

JER



JER in Phase Space

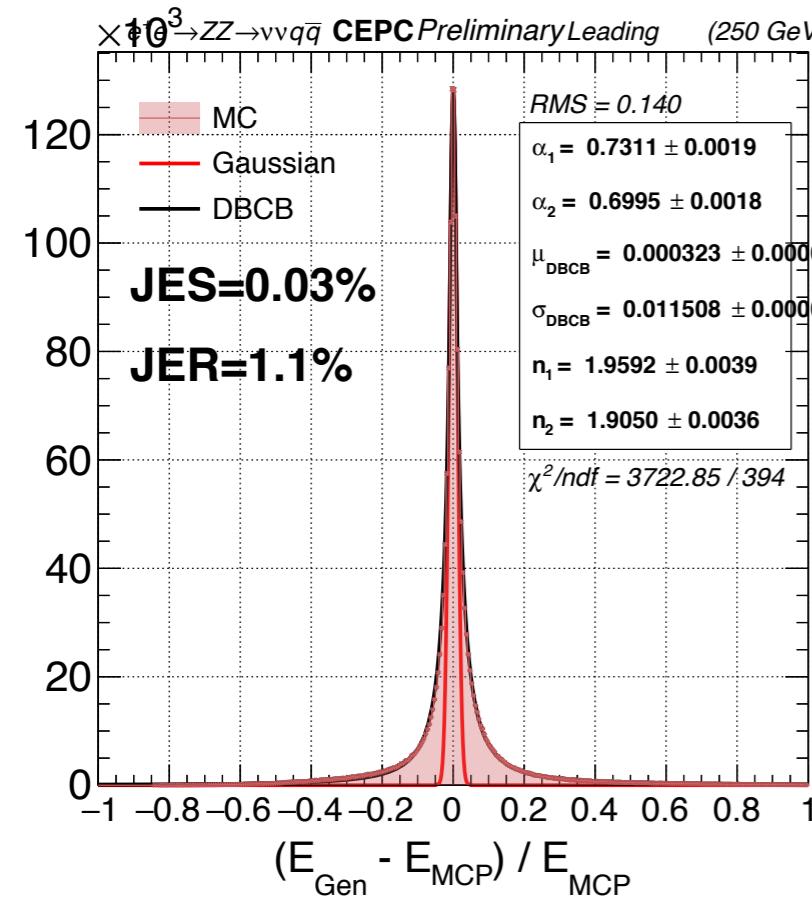


- JER also depends on the jet flavor.
- Higher jet energy and within central region of barrel, JER has impressive performance.

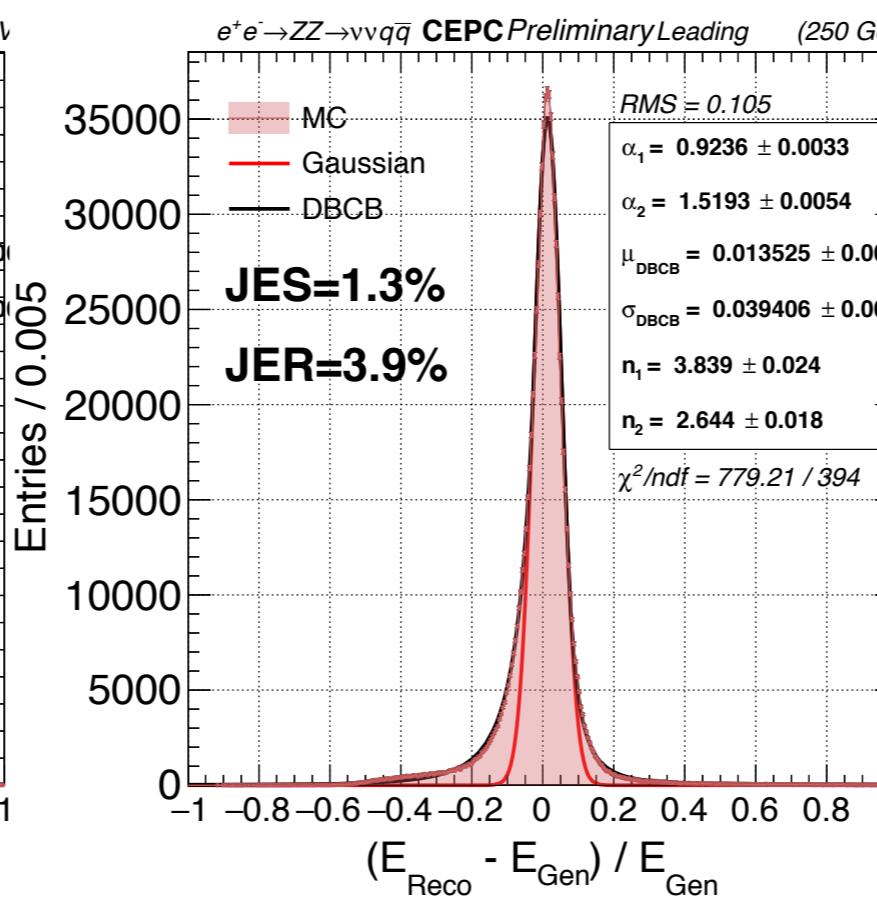
m_W (GeV)	m_Z (GeV)	m_H (GeV)	Jets / PFOs	wi/wo Clean	wi/wo Cali
82.66 ± 3.54	93.69 ± 3.89	127.48 ± 4.93	Jets	0	0
82.79 ± 3.34	93.95 ± 3.48	127.31 ± 4.54	Jets	1	0
80.72 ± 3.46	91.67 ± 3.77	125.02 ± 5.11	Jets	0	1
80.82 ± 3.23	91.76 ± 3.39	124.39 ± 4.39	Jets	1	1
82.63 ± 3.53	93.69 ± 3.89	127.57 ± 4.80	PFOs	0	0
82.77 ± 3.32	93.90 ± 3.54	127.83 ± 4.50	PFOs	1	0

Leading JER & JES V1

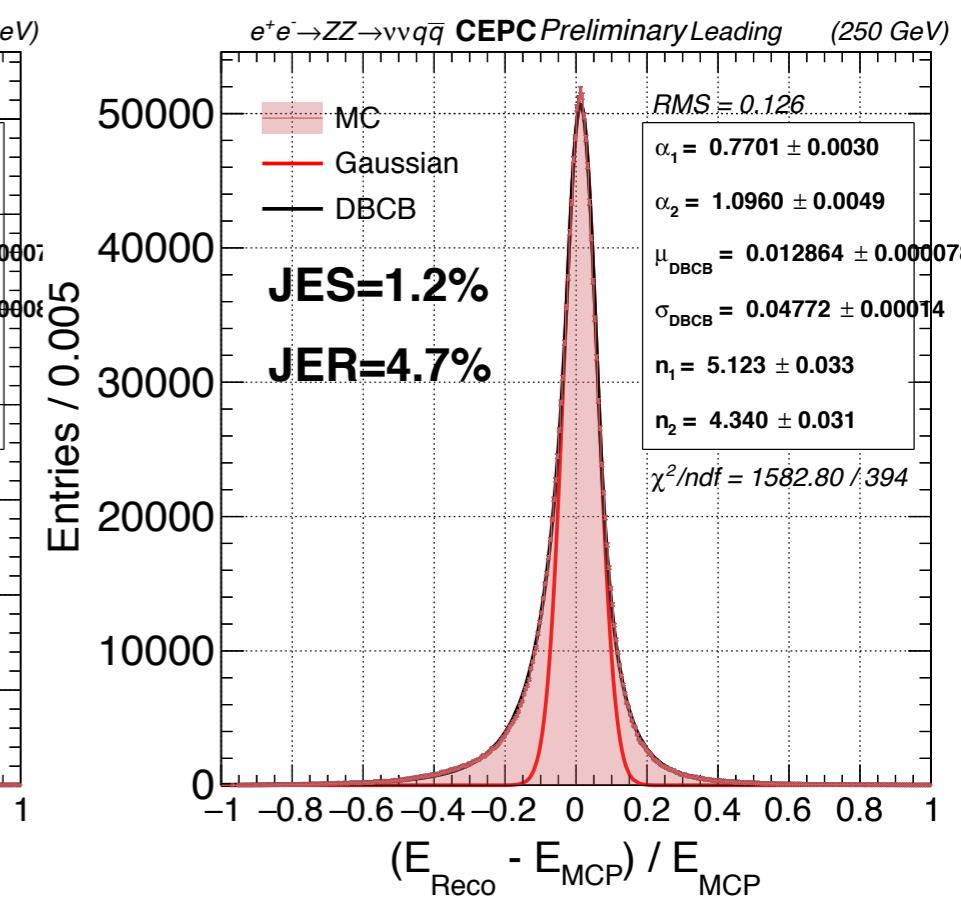
Gen-MCP



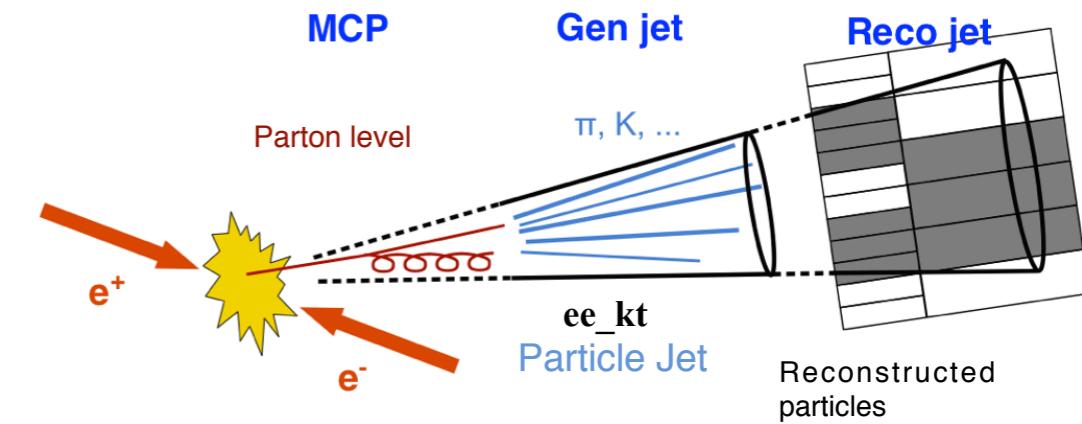
Reco-Gen



Reco-MCP

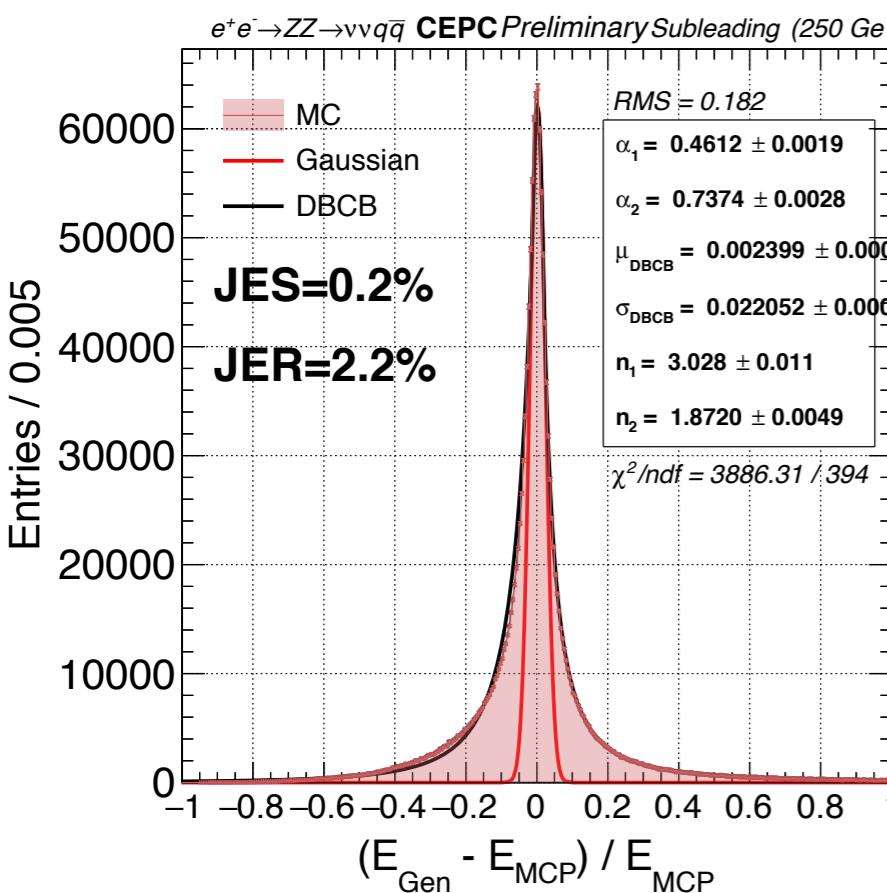


- JER/JES between reco jet and MCP would combine the effects of two previous stages.

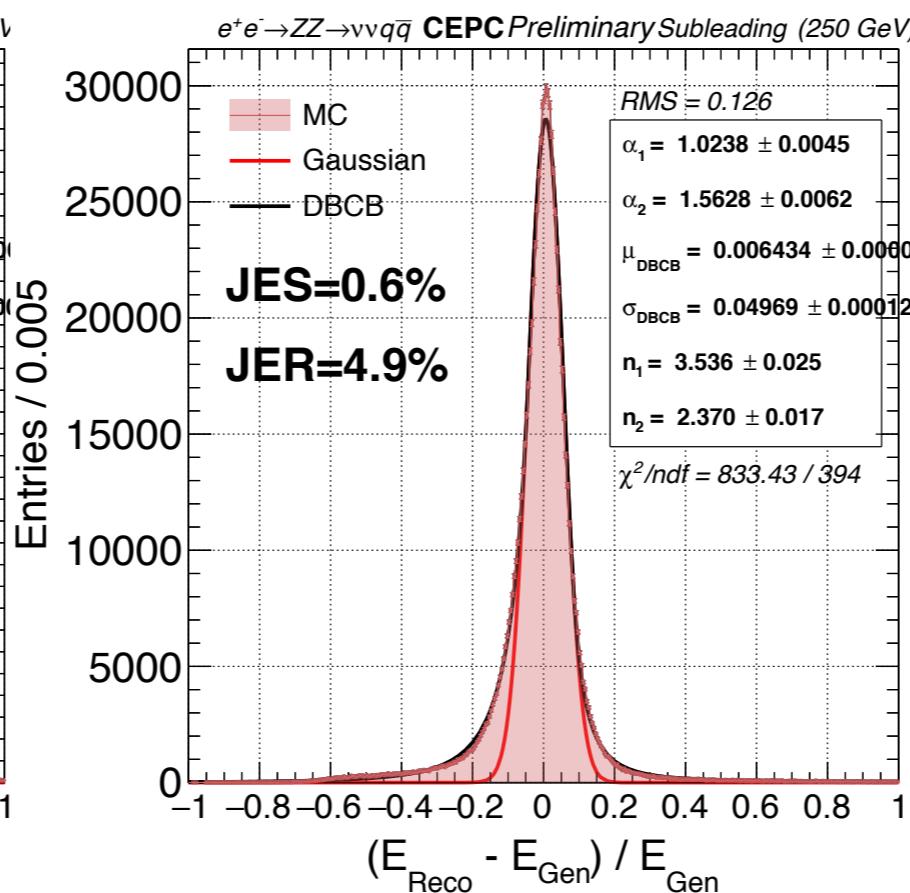


Sub-leading JER & JES V1

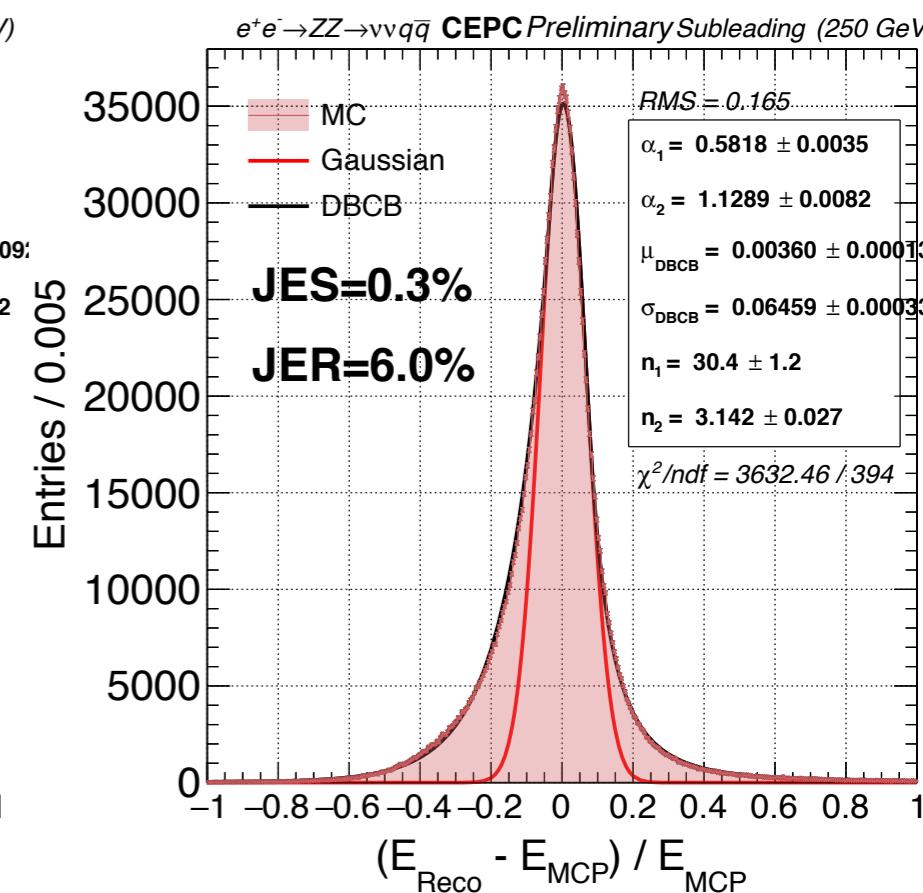
Gen-MCP



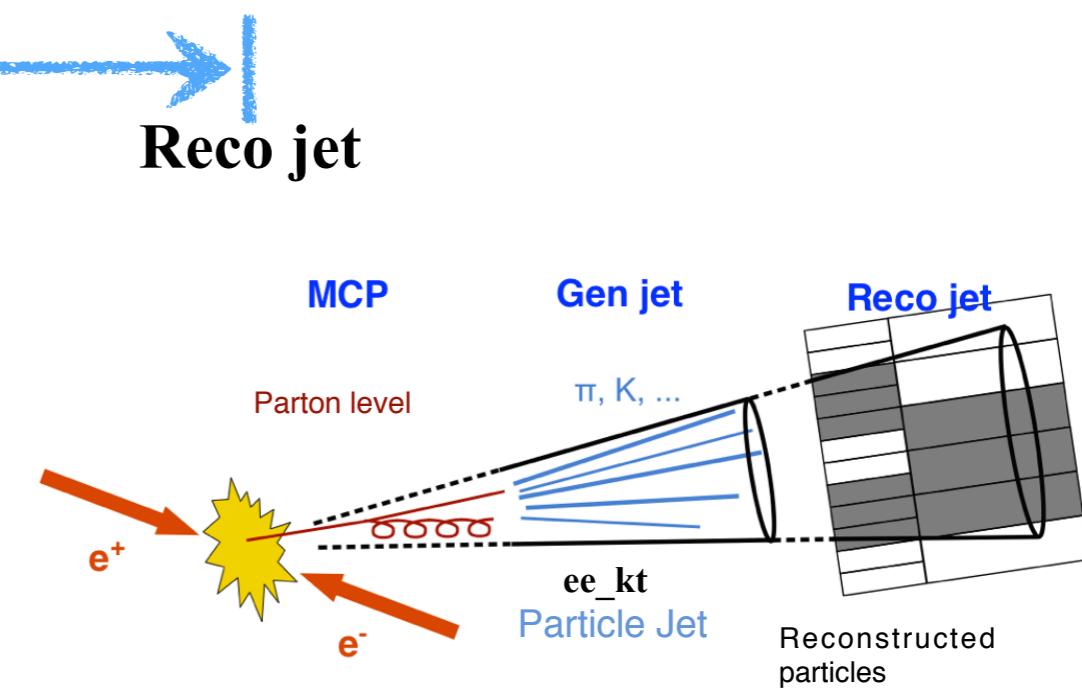
Reco-Gen



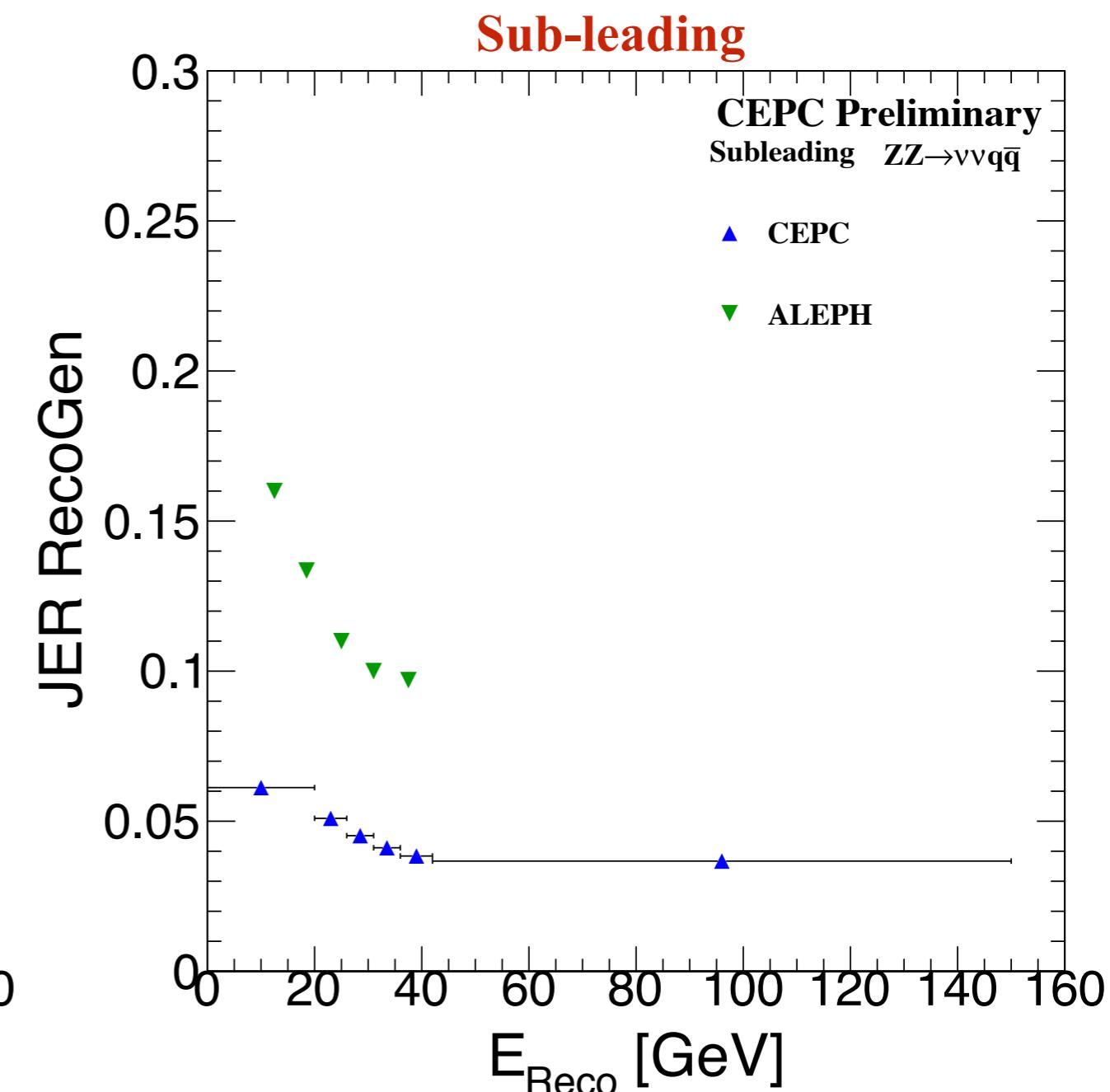
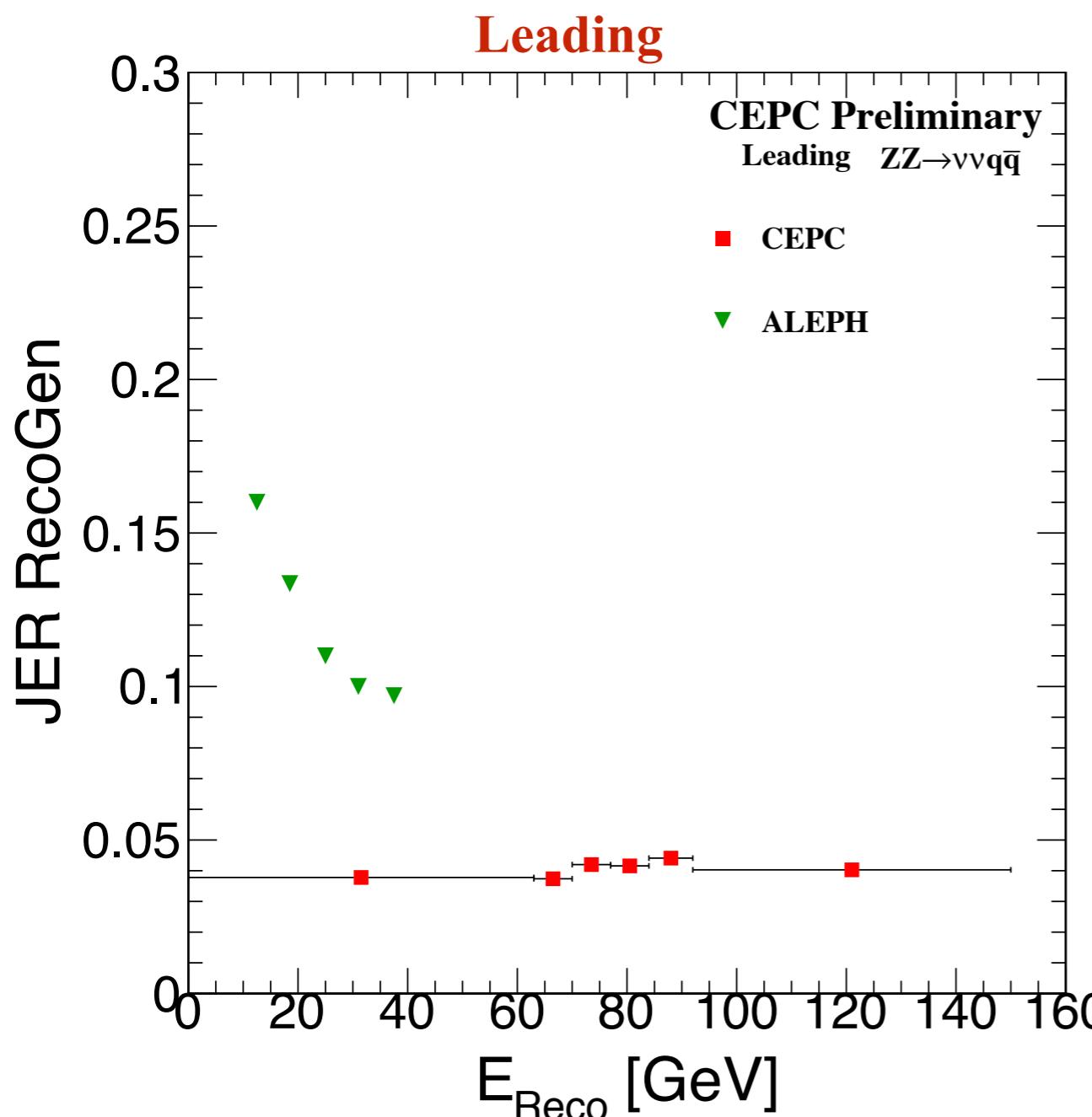
Reco-MCP



- JER/JES between reco jet and MCP would combine the effects of two previous stages.



Compare with ALEPH at LEP



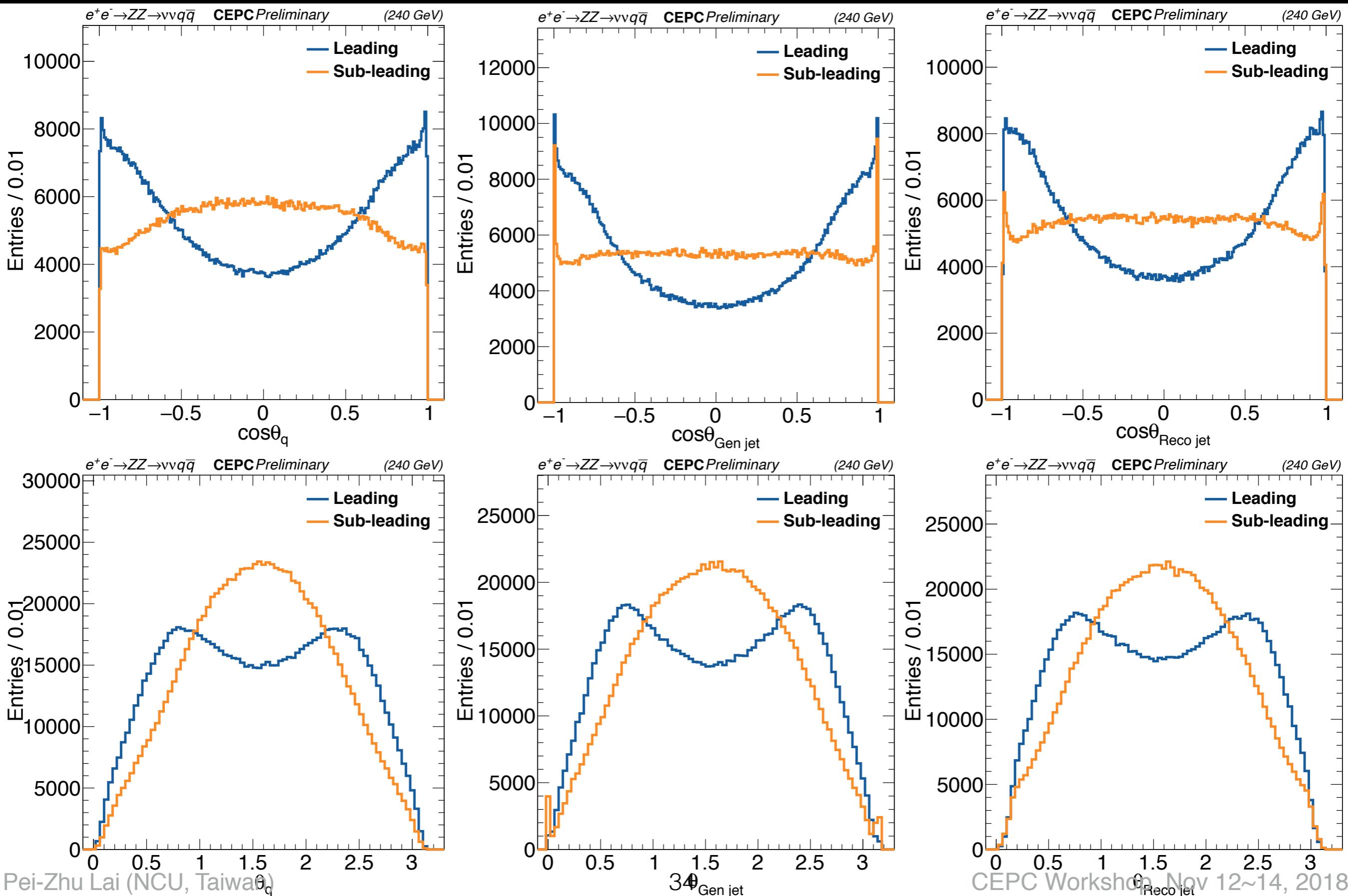
■ Our JER is better than ALEPH.

Ref. [4]



CEPC

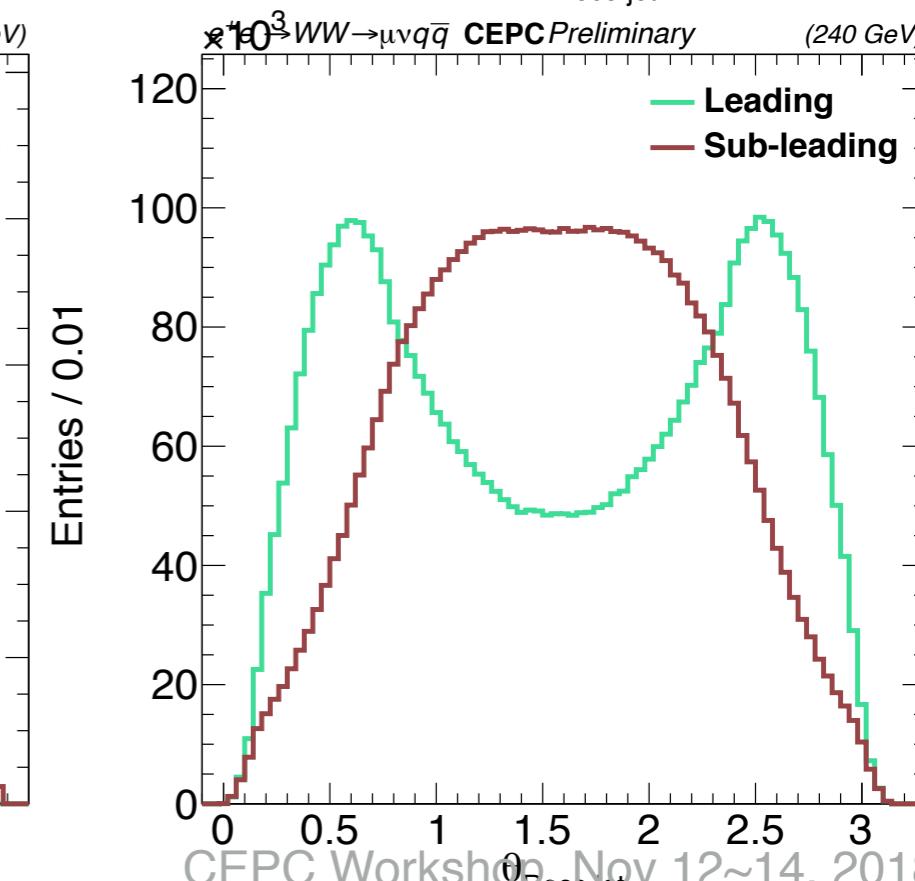
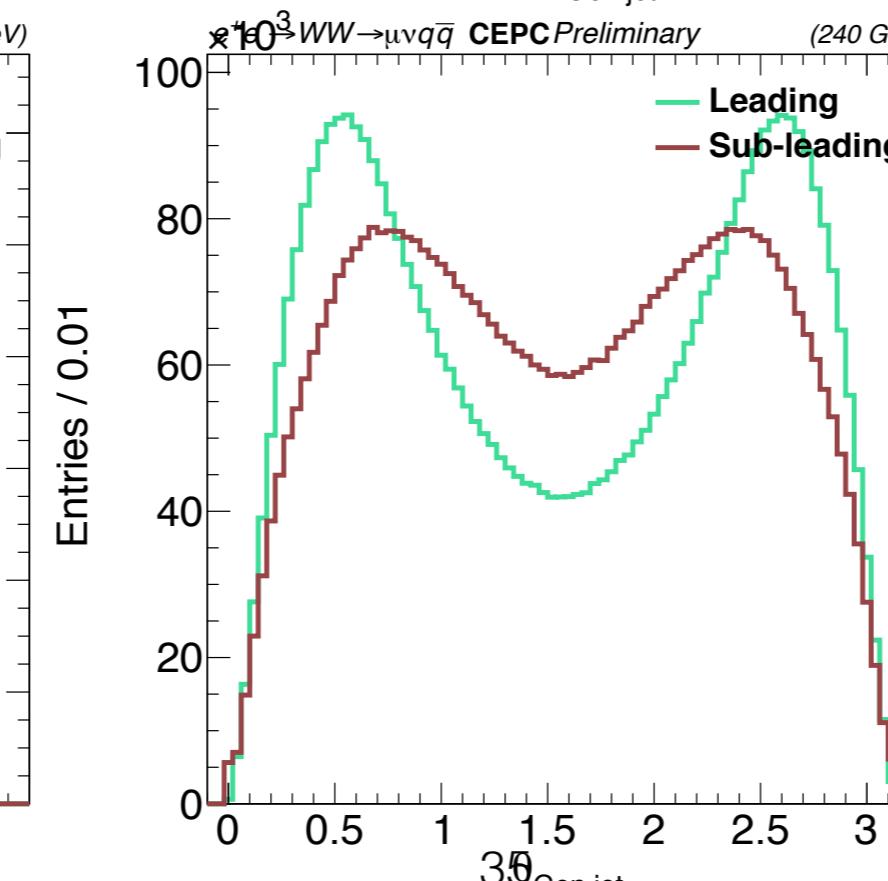
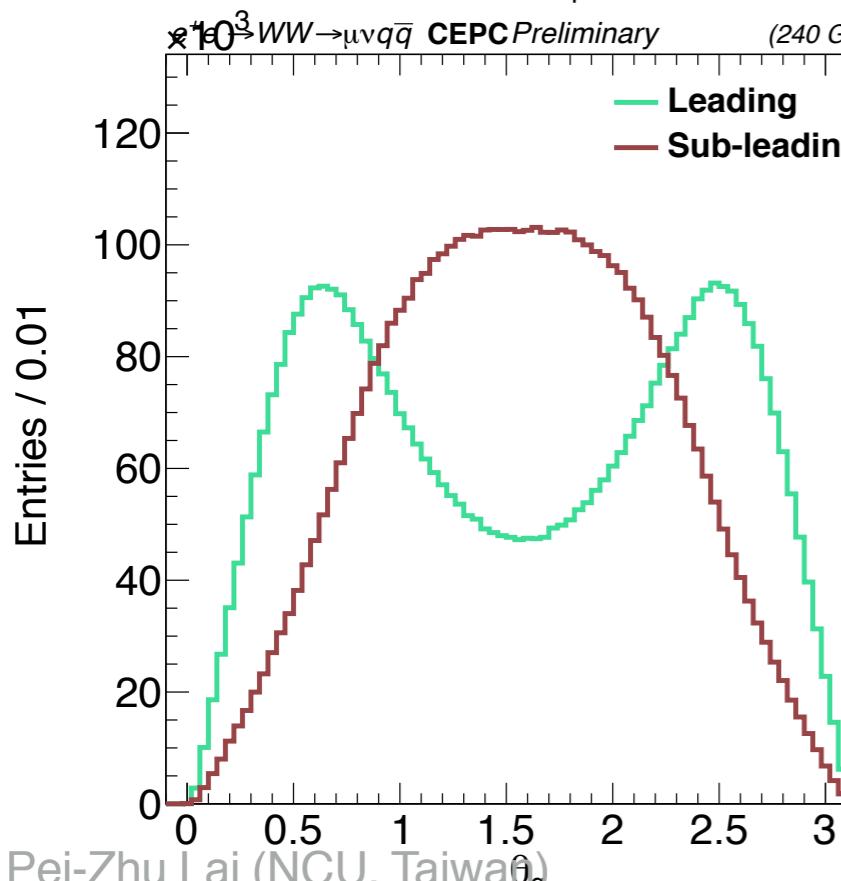
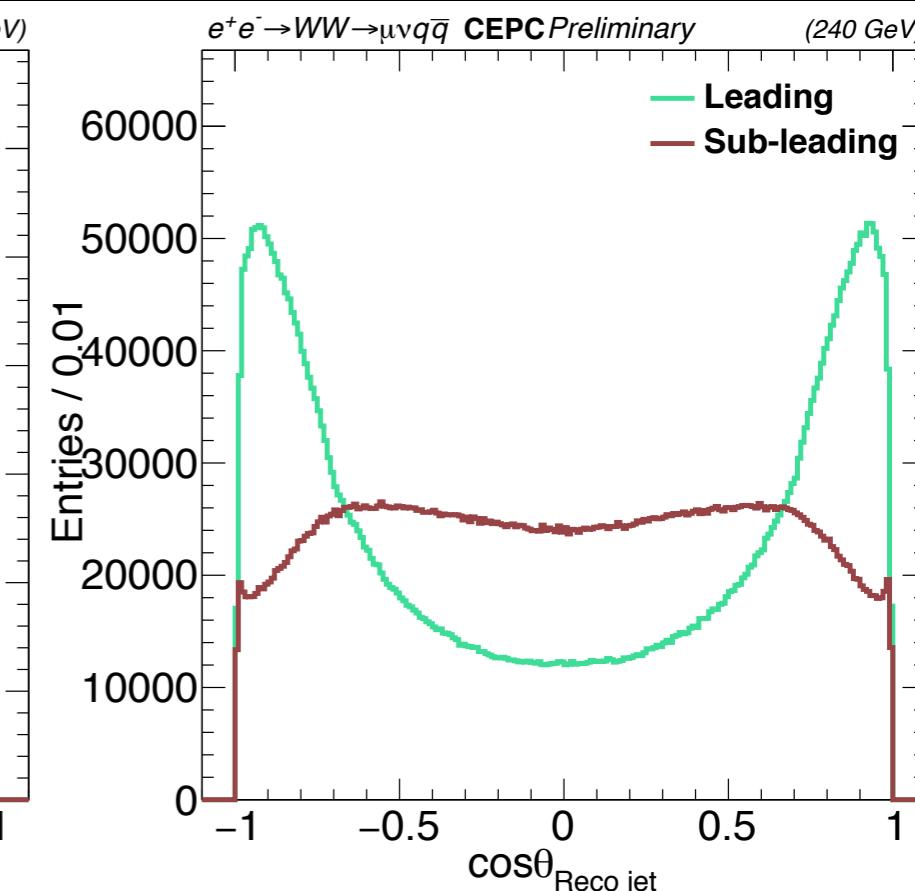
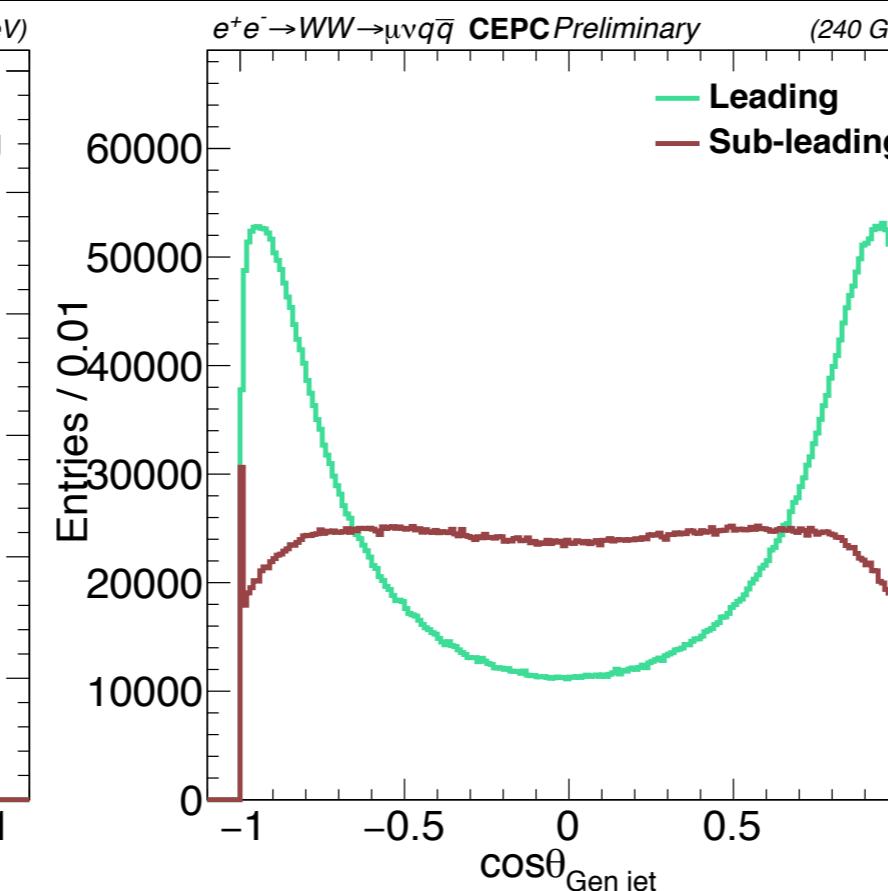
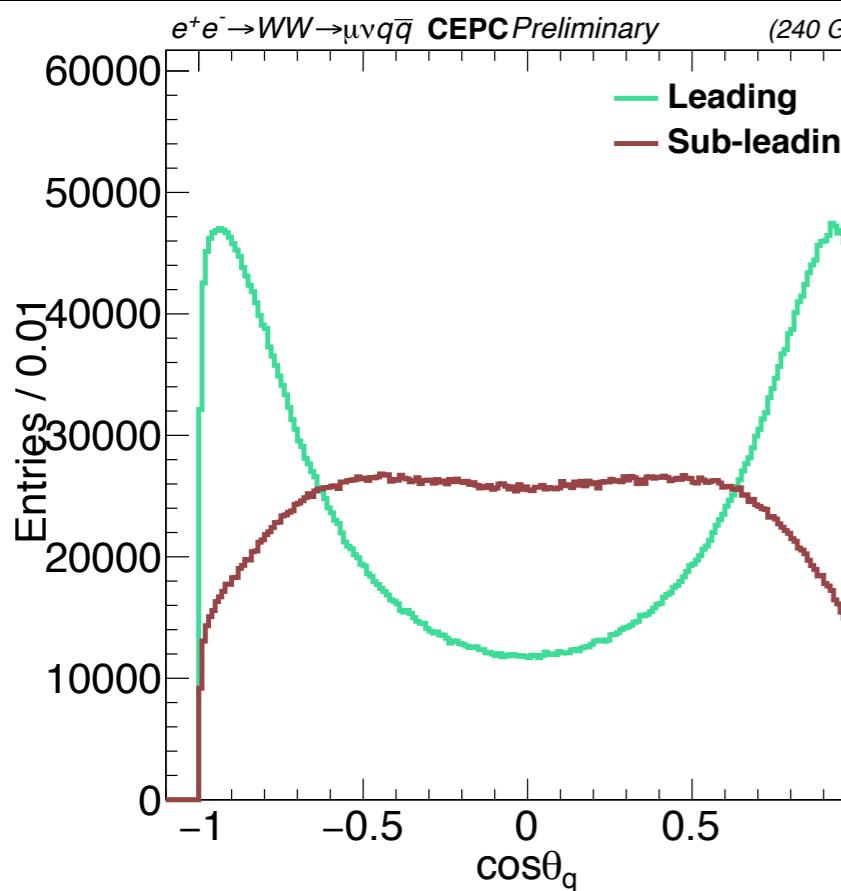
$ZZ \rightarrow \nu\nu q\bar{q}$





CEPC

WW $\rightarrow \mu\nu q\bar{q}$





$ZH \rightarrow \nu\nu q\bar{q}$

