

Jet Performance at CEPC

Presented by ¹Pei-Zhu Lai (賴培築)

Supervisor: ²Man-Qi Ruan, ²Gang Li, ¹Chia-Ming Kuo

¹National Central University, Taiwan

²Institute of High Energy Physics, China

CEPC Physics Workshop, PKU, Beijing China

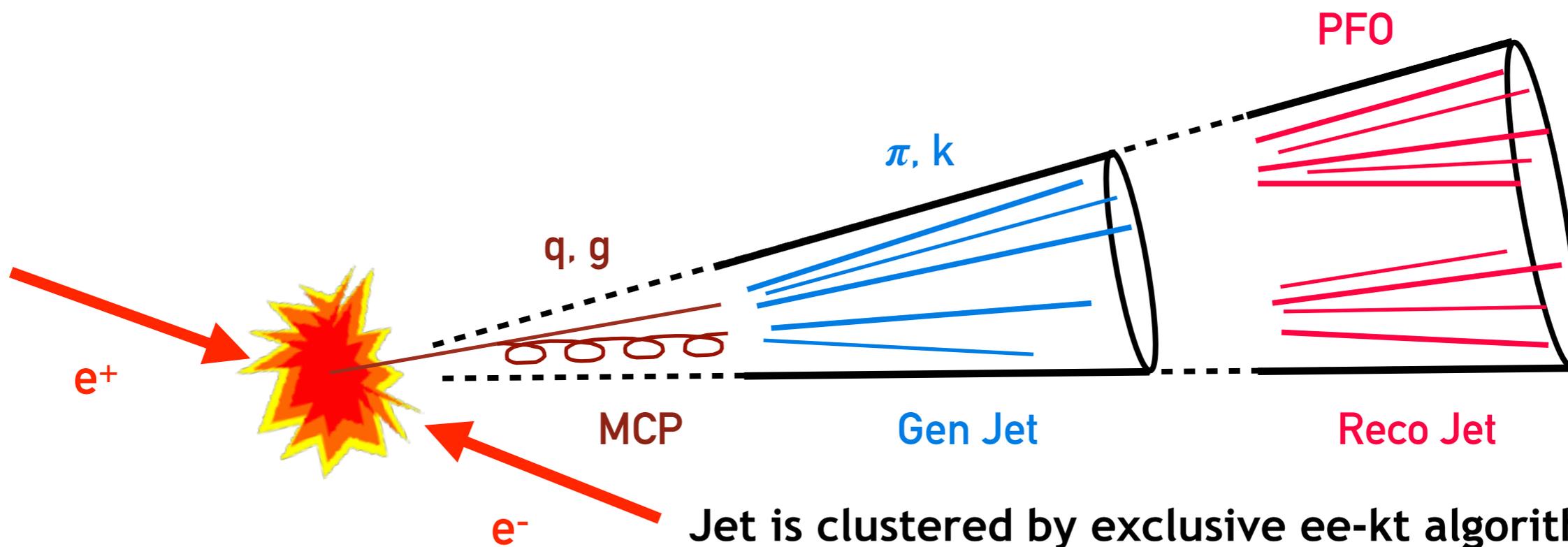
July 01-05, 2019





- Introduction
- Strategy
- Event selections
- Results
 - Angular and energy dependence of JAR/JAS (Reco-MCP)
 - The jet energy resolution and scale (Reco-Gen, Gen-MCP, Reco-MCP)
 - Angular and energy dependence of JER/JES (Reco-MCP)
 - Comparison with CMS at LHC
- Jet energy calibration
- Summary

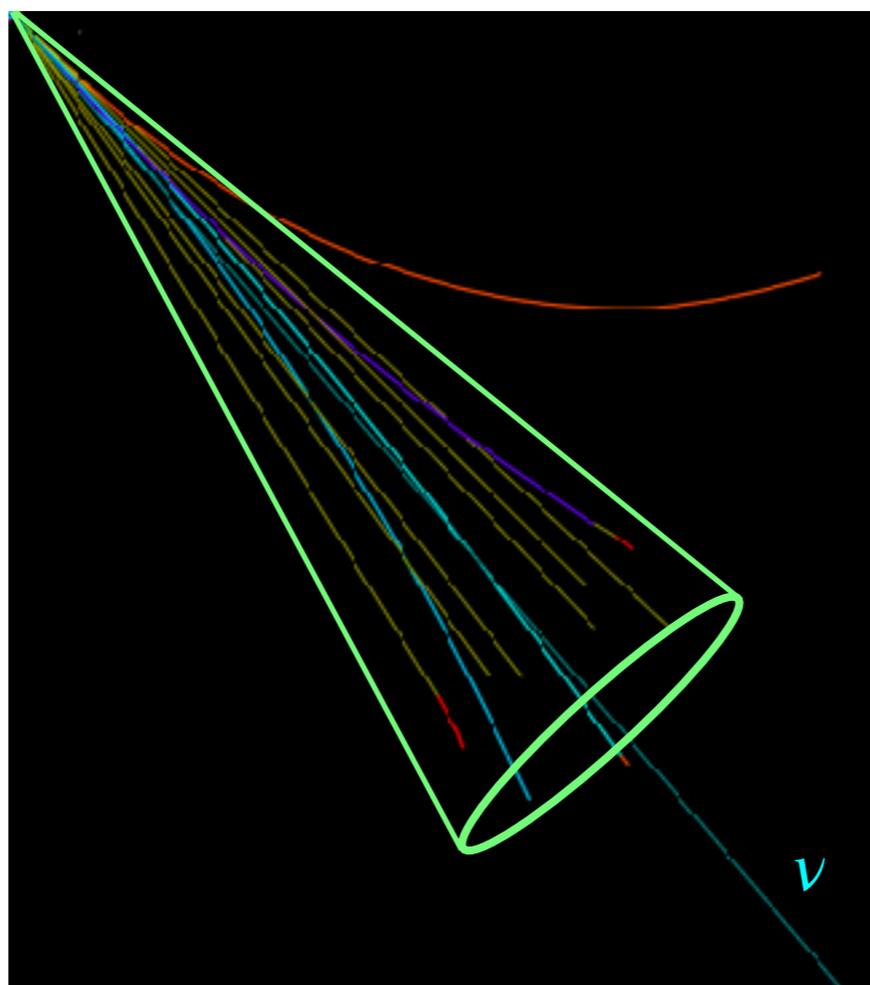
- Jet reconstruction plays an important role in particle physics. To study the performance of the jet reconstruction in CEPC, we look at the simulation which contains MC particle (MCP), particle jet (Gen Jet), and PFOs (Particle Flow Objects) jet (Reco Jet).



Difficulties in jet reconstruction

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

Wrong measurement leads to wrong physical results.

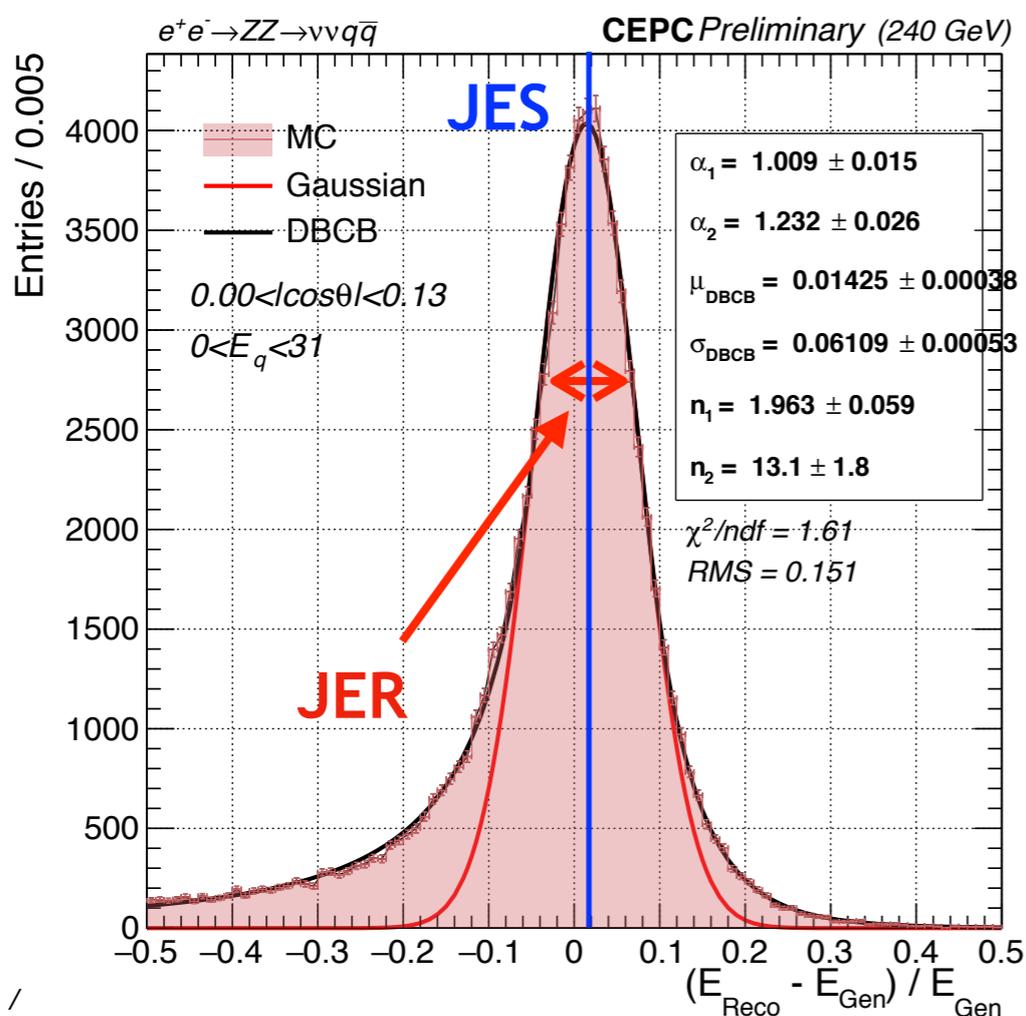


Quantify the Performance

- Double-sided crystal ball(DBCB) function is used to extract energy and angular resolution and scale.

JES = Jet Energy Scale

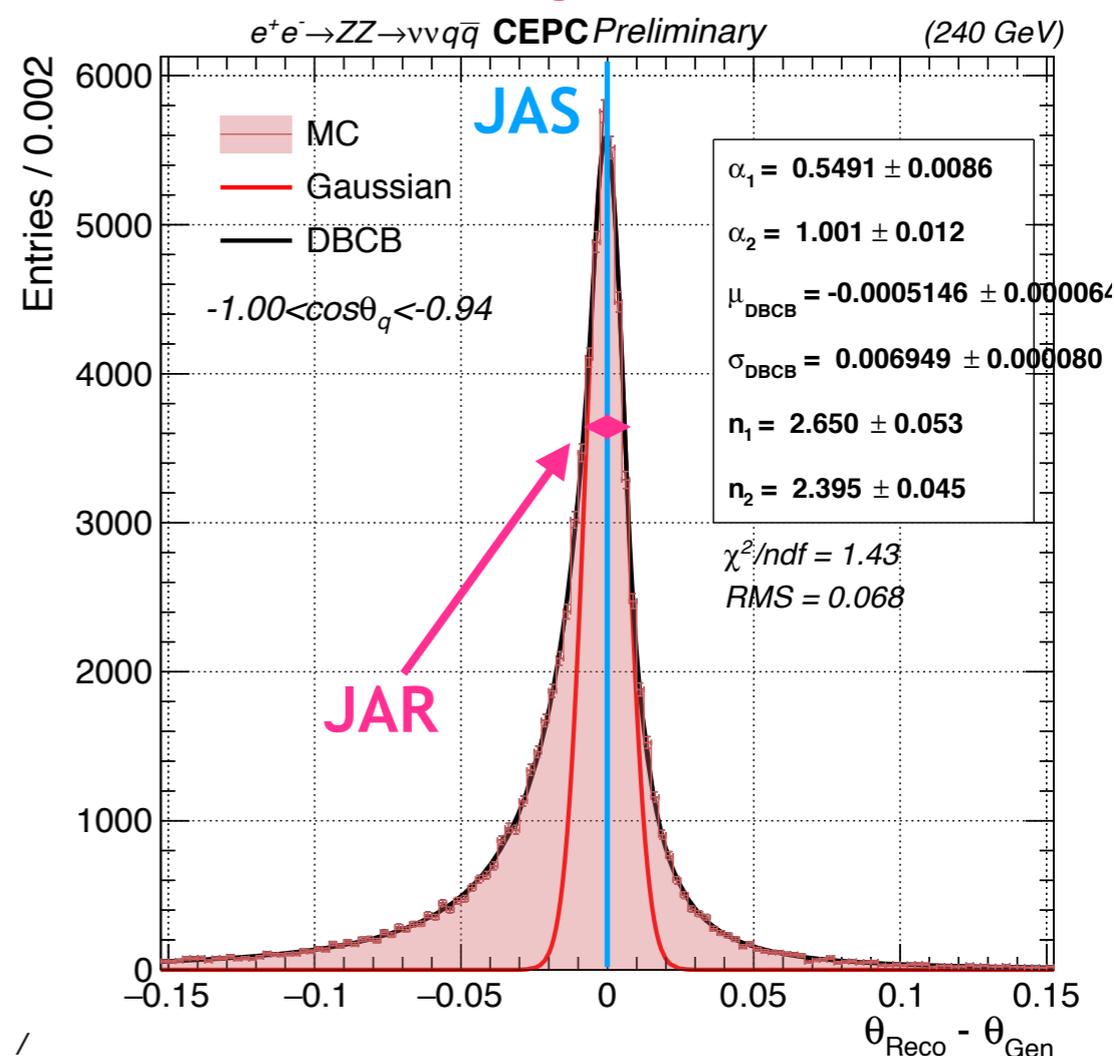
JER = Jet Energy Resolution



Relative difference :
$$\frac{E_{Reco} - E_{Gen}}{E_{Gen}}$$

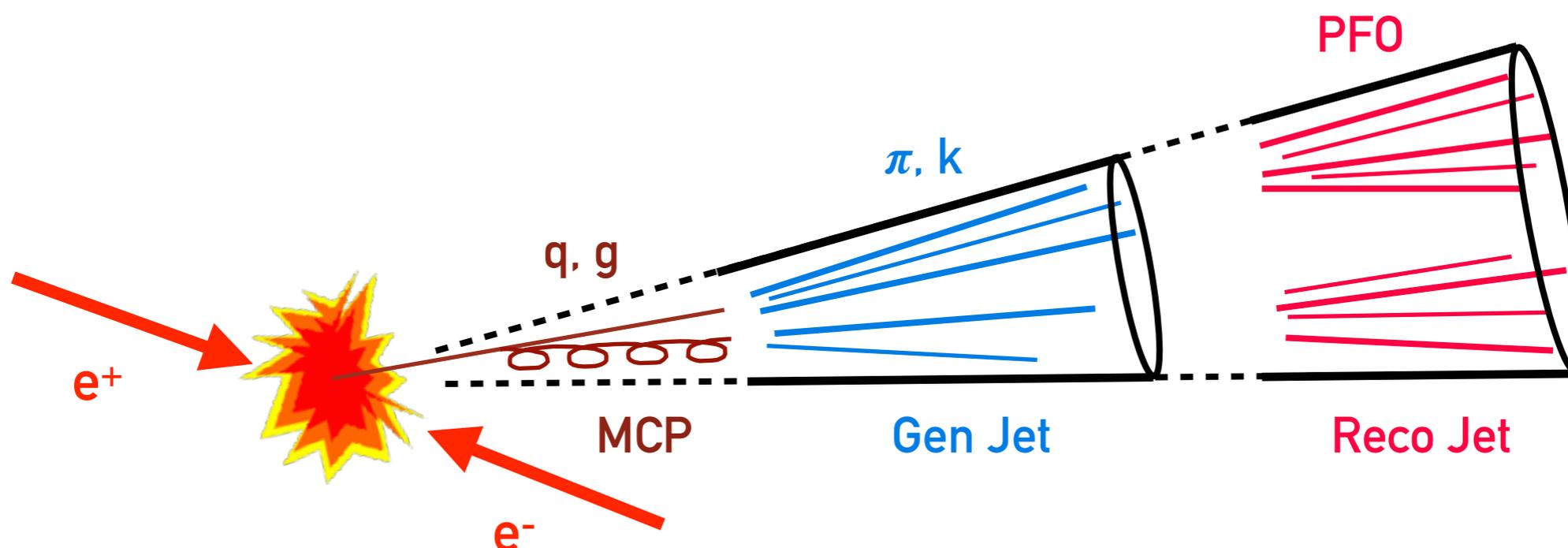
JAS = Jet Angular Scale

JAR = Jet Angular Resolution

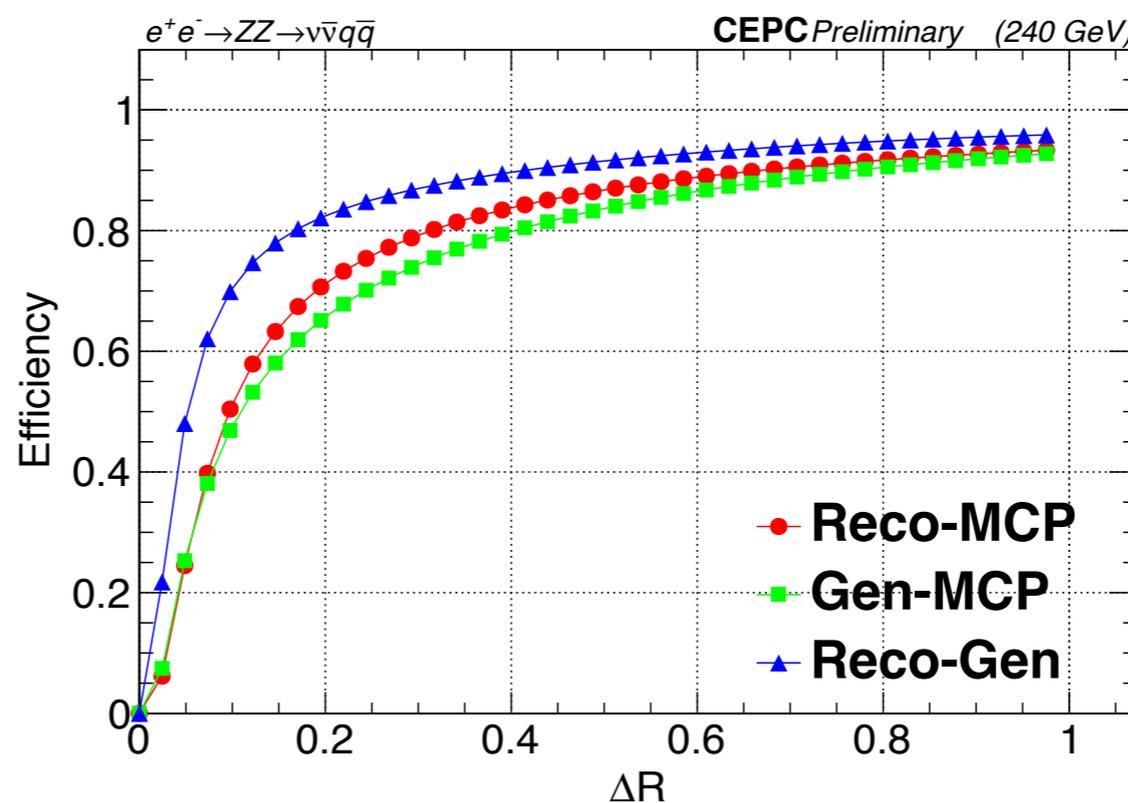
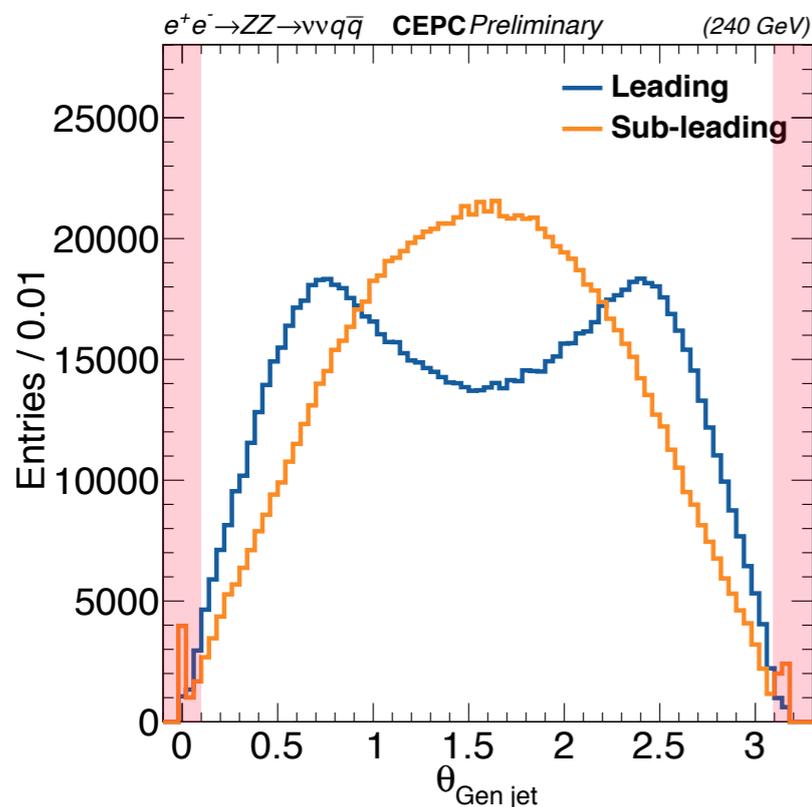


Difference :
$$\theta_{Reco} - \theta_{Gen}$$

- The jet energy resolution and scale(JER/JES), and jet angular resolution and scale(JAR/JAS) in two or four jets final state processes(ZZ, WW, and ZH) have been studied.
- To exclude the influence of jet clustering algorithm, matching reco jet and MC particle by $\Delta R < 0.1$.
- The differential JAR/JAS as the function of angle and energy; JER/JES as the function of the angle, energy and flavor. (Reco-MCP)



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



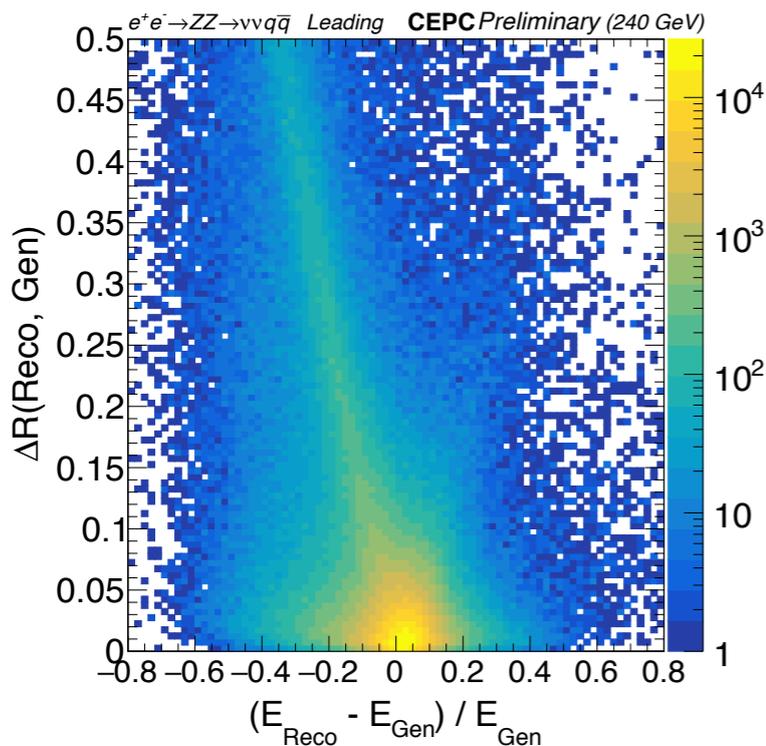
Efficiency =

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

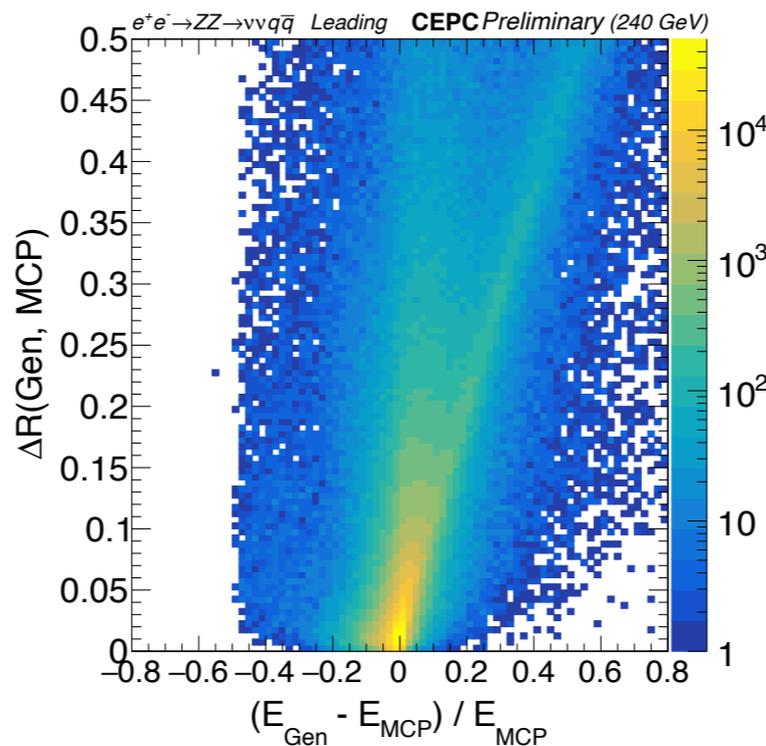
$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

ΔR as the function of ΔE

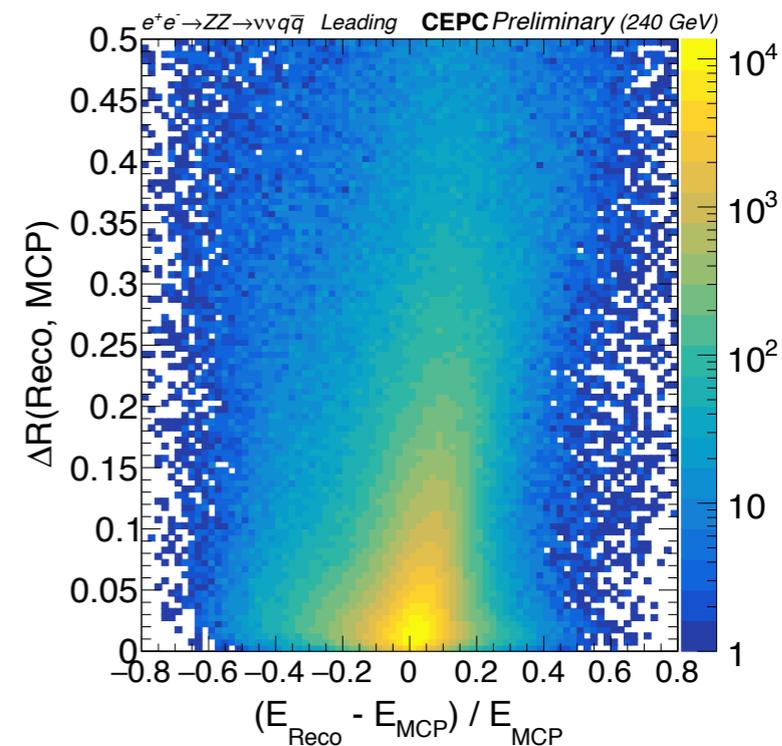
Leading, Gen-MCP



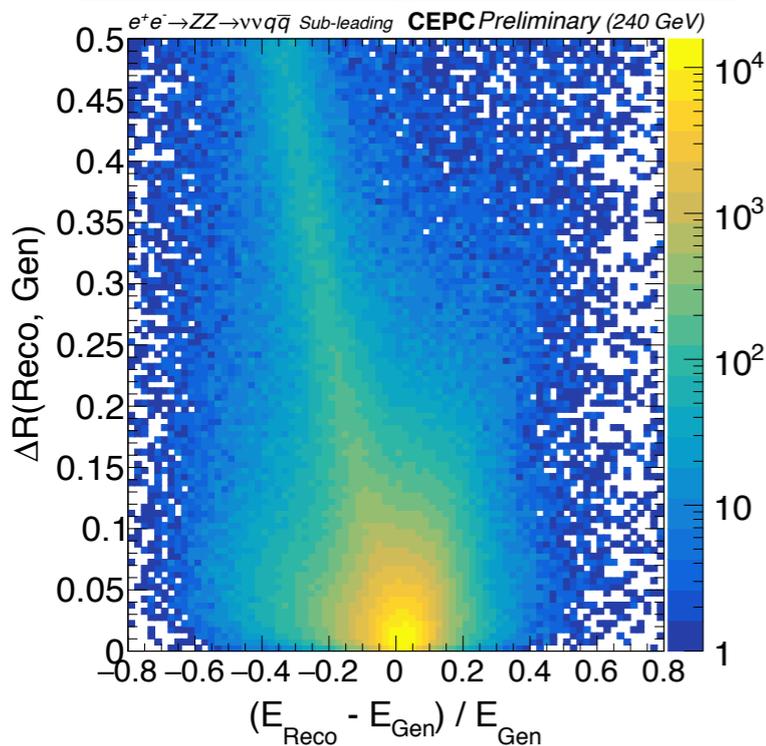
Leading, Reco-Gen



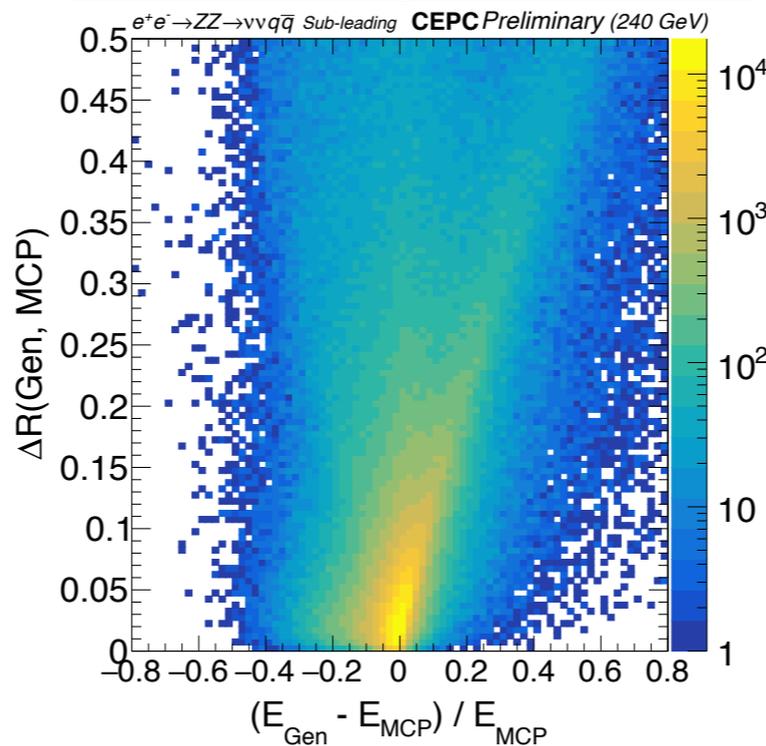
Leading, Reco-MCP



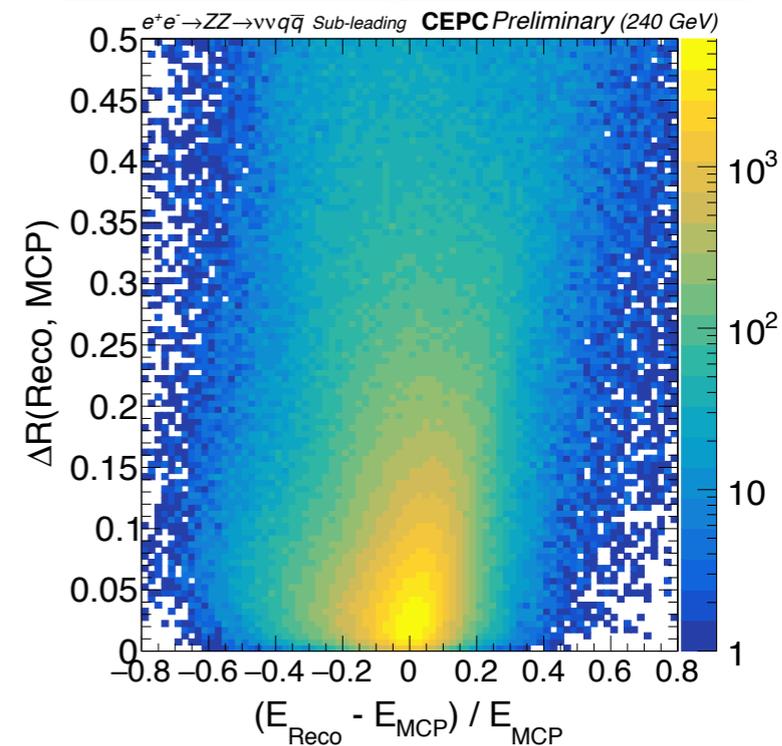
Sub-leading, Gen-MCP



Sub-leading, Reco-Gen

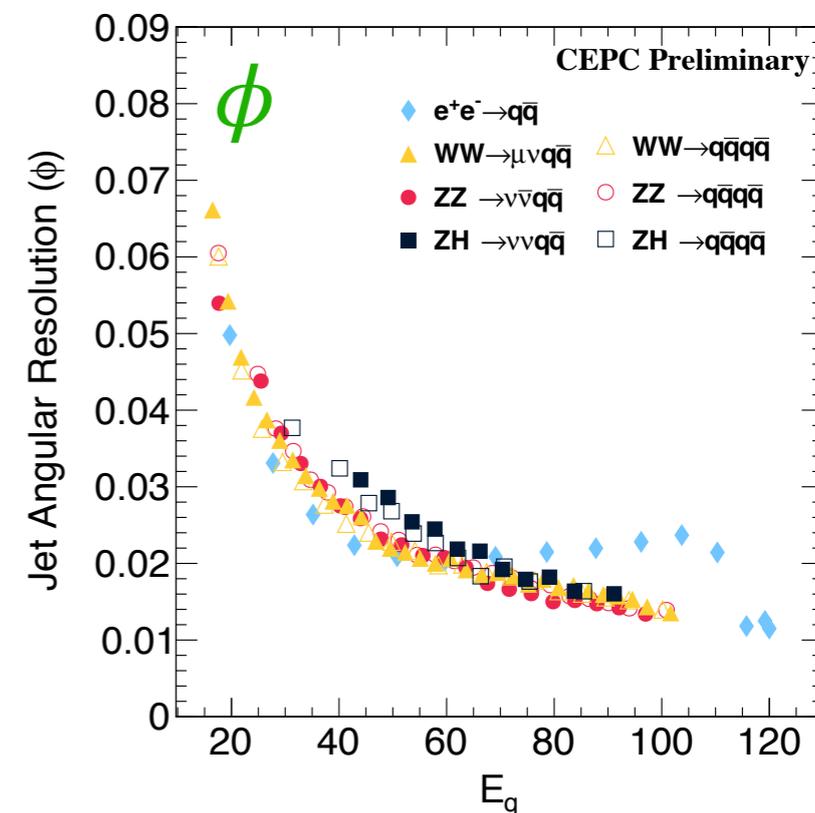
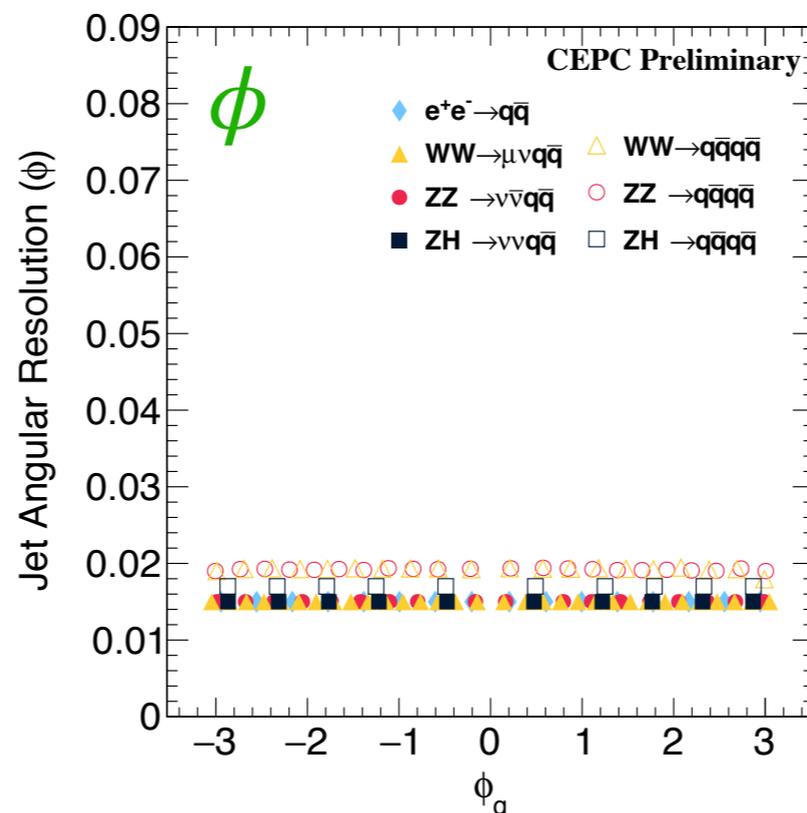
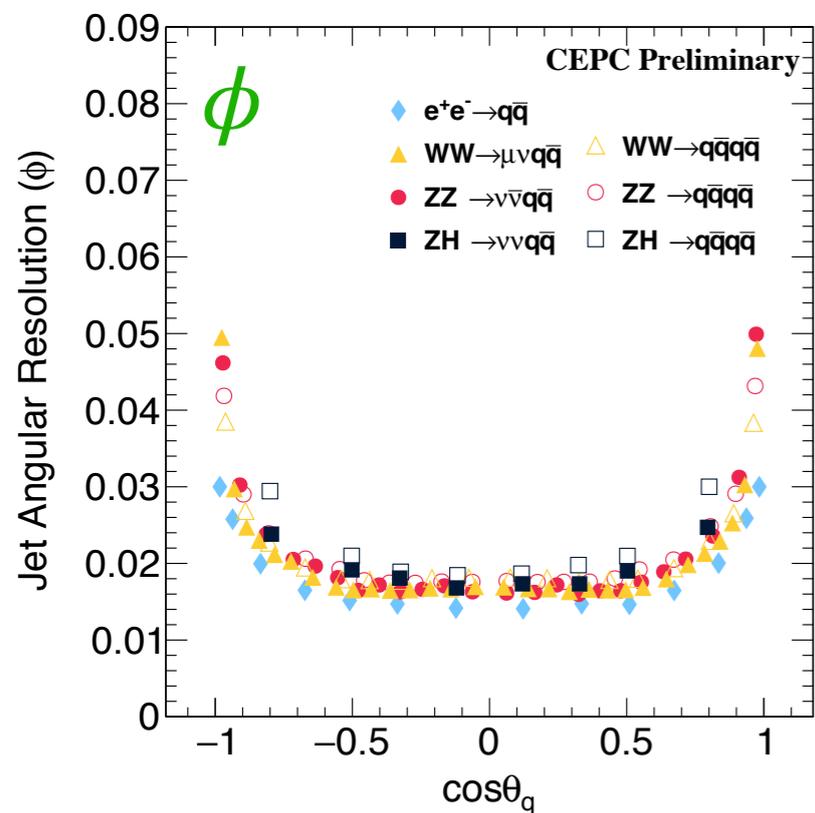
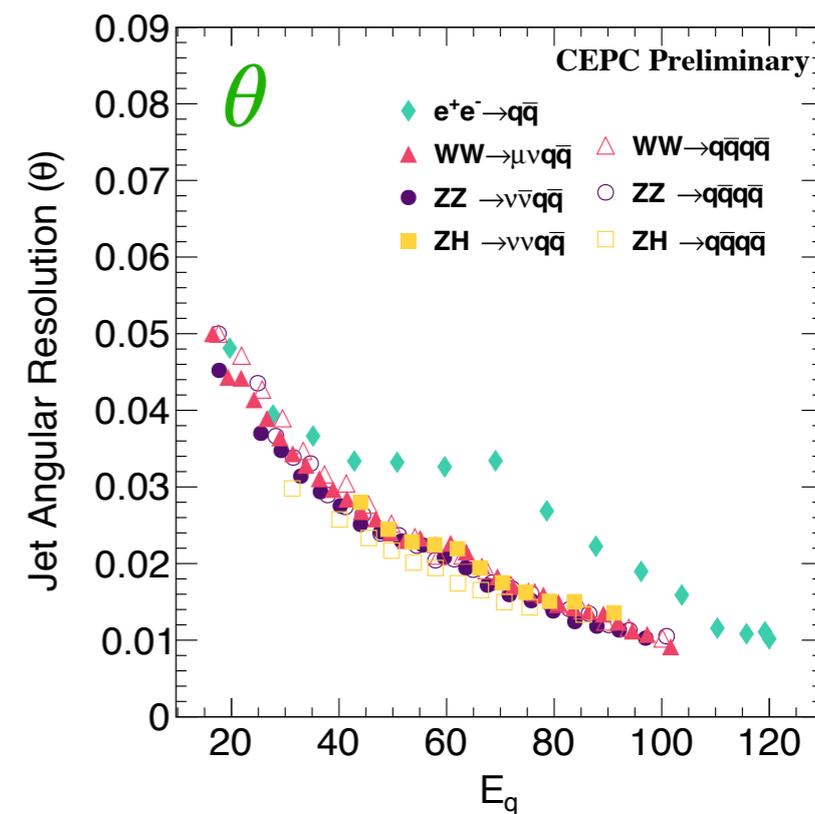
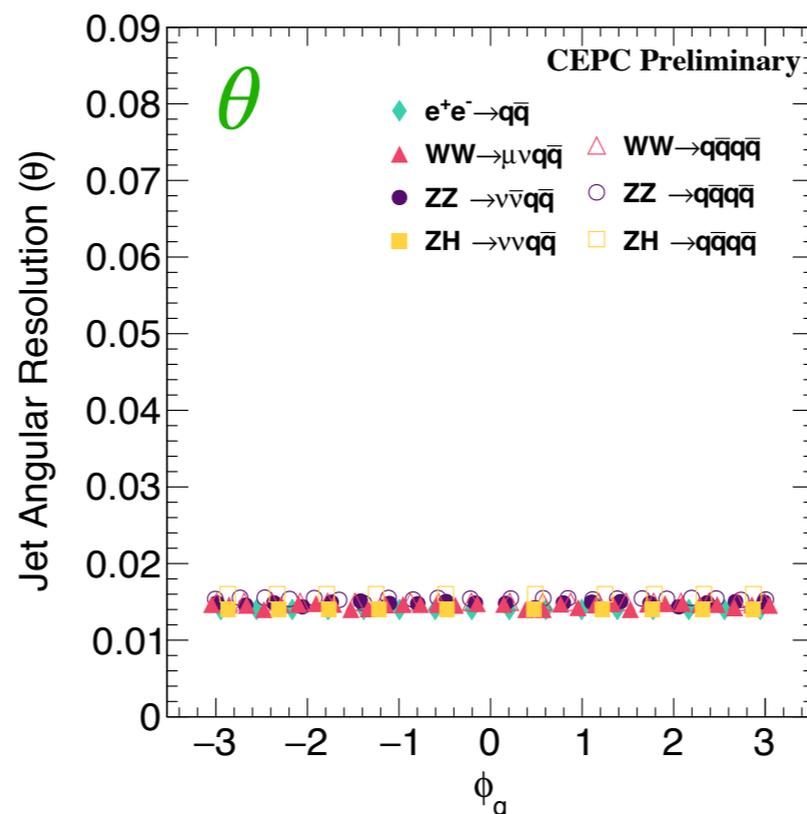
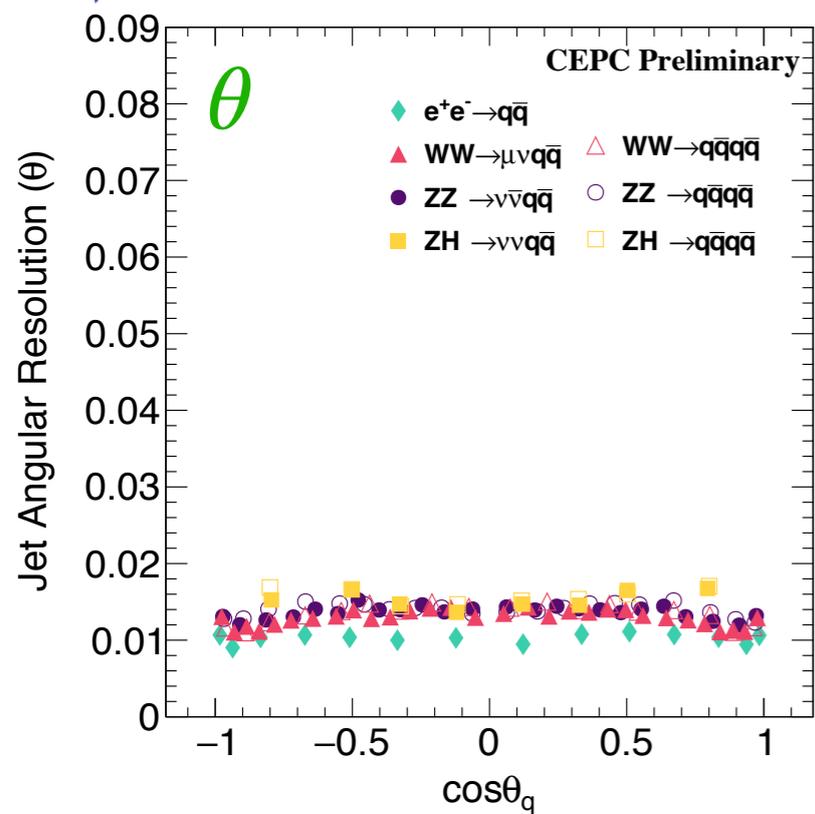


Sub-leading, Reco-MCP



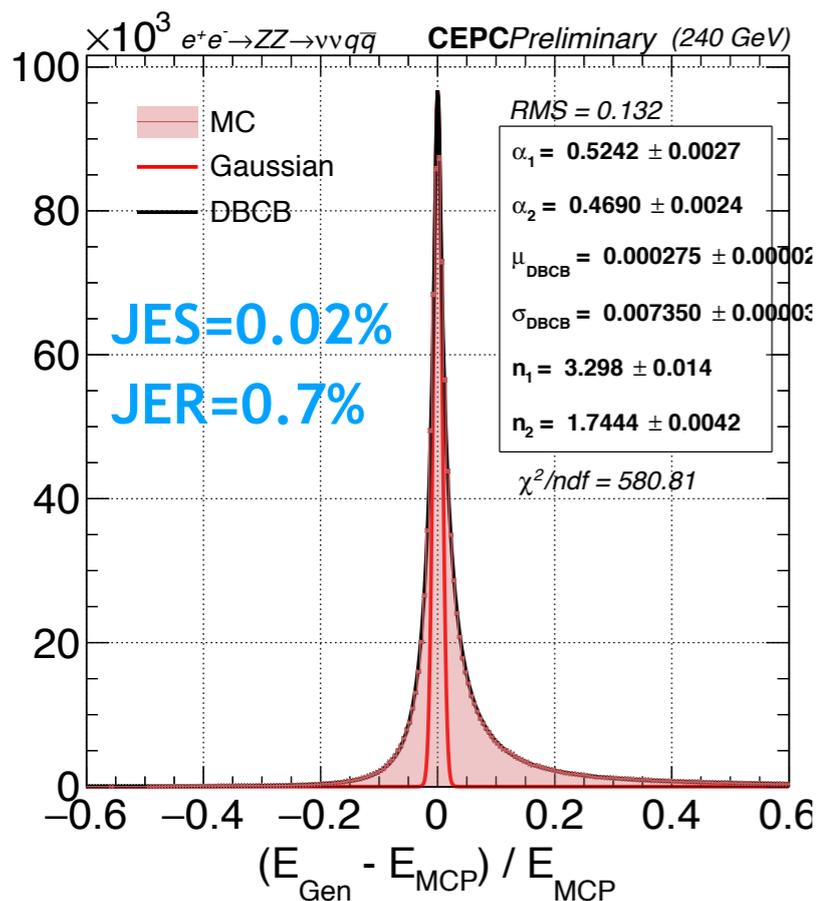
The jet clustering brings a significant uncertainty.

JAR (Reco-MCP)

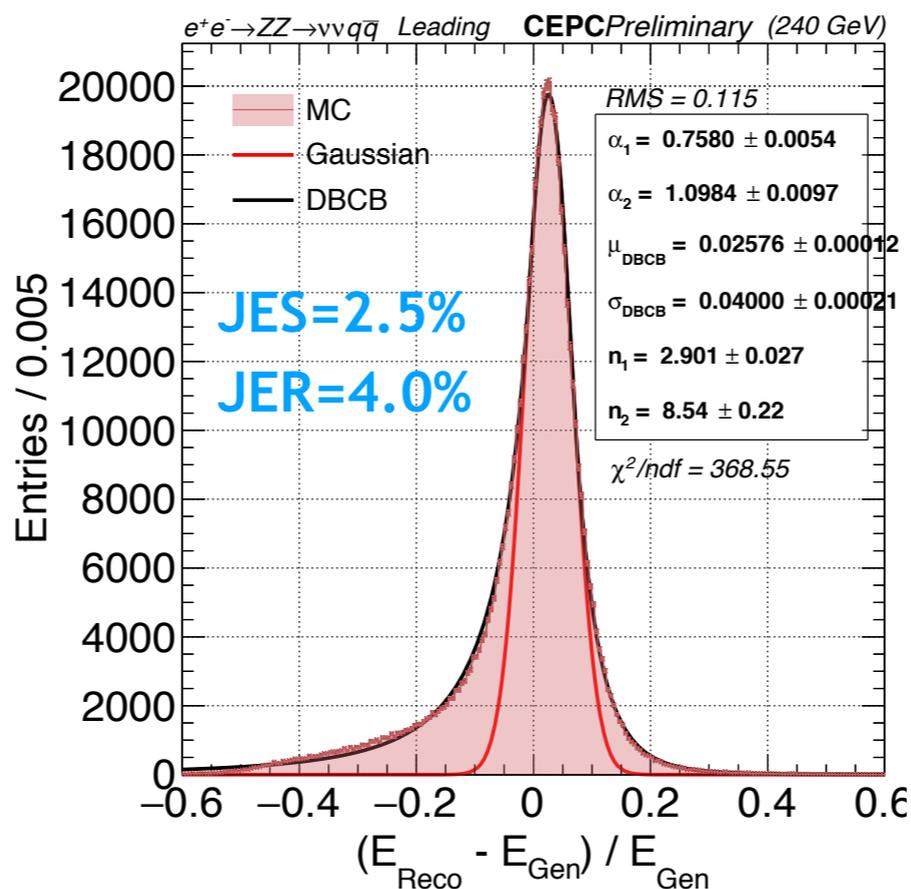


■ JAR is around **1.5%** in barrel region; JAS is **independent** of ϕ and energy.

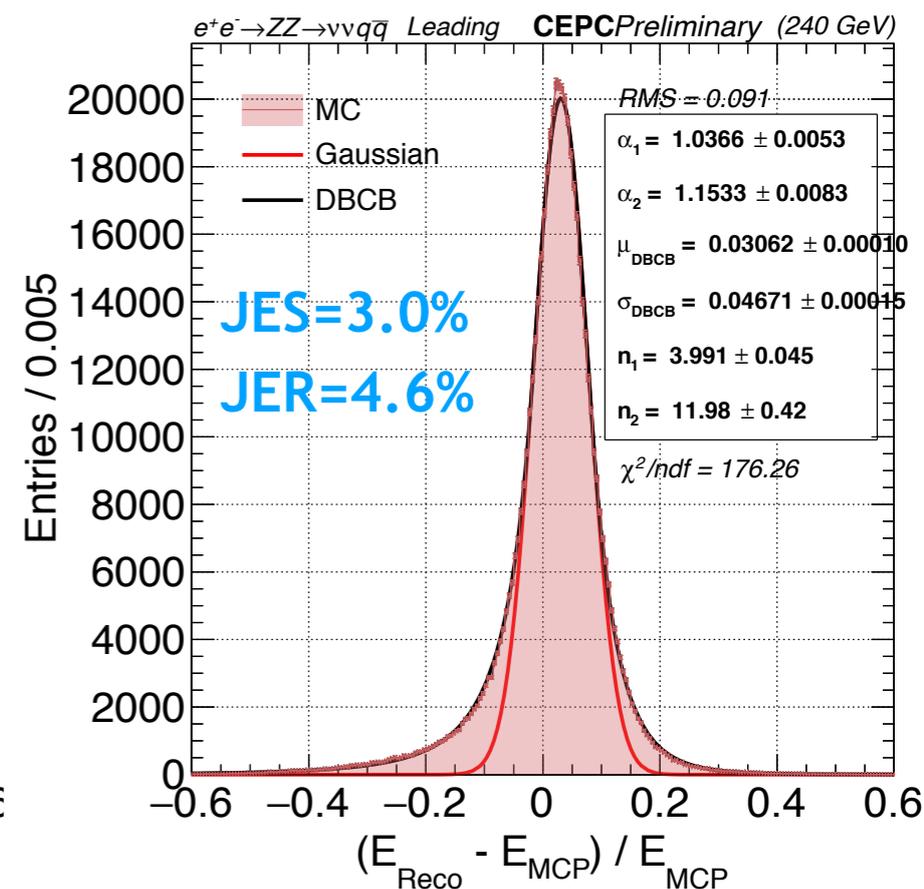
Gen-MCP



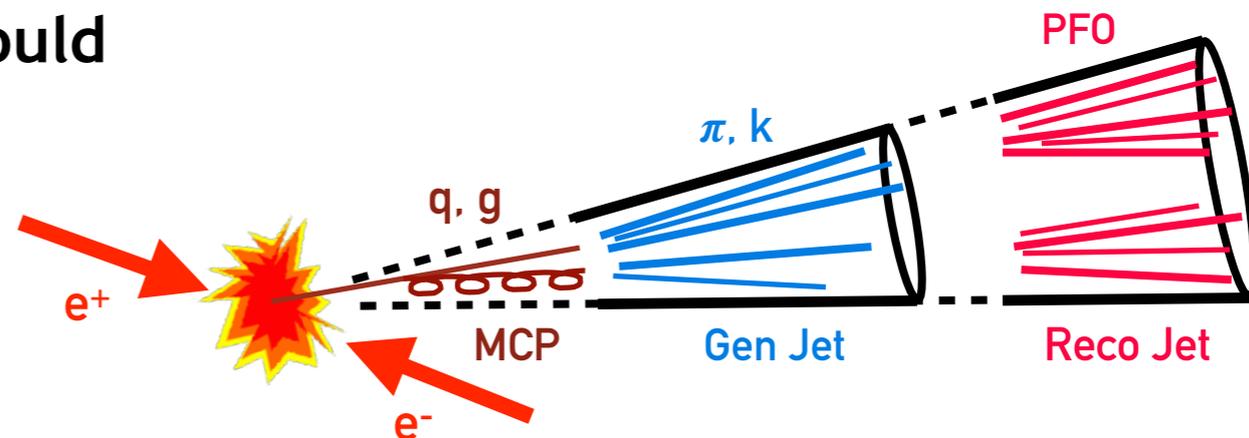
Reco-Gen



Reco-MCP

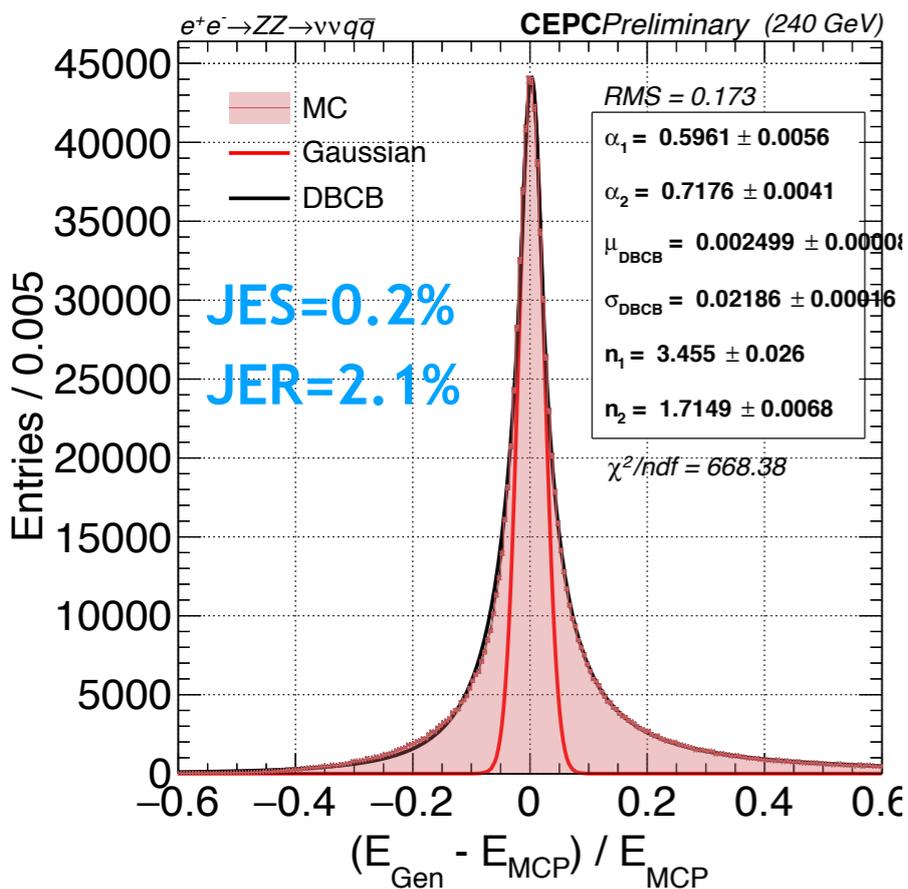


■ JER/JES between Reco jet and MCP would combine the effects of two previous stages.

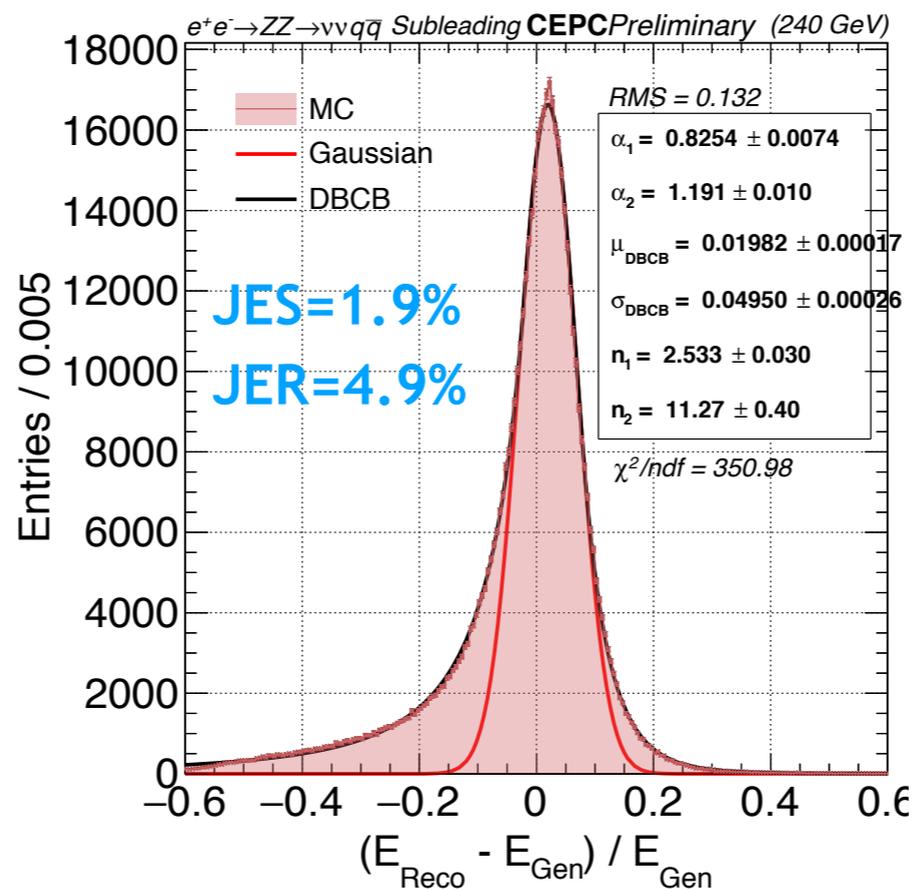


Sub-leading JER & JES

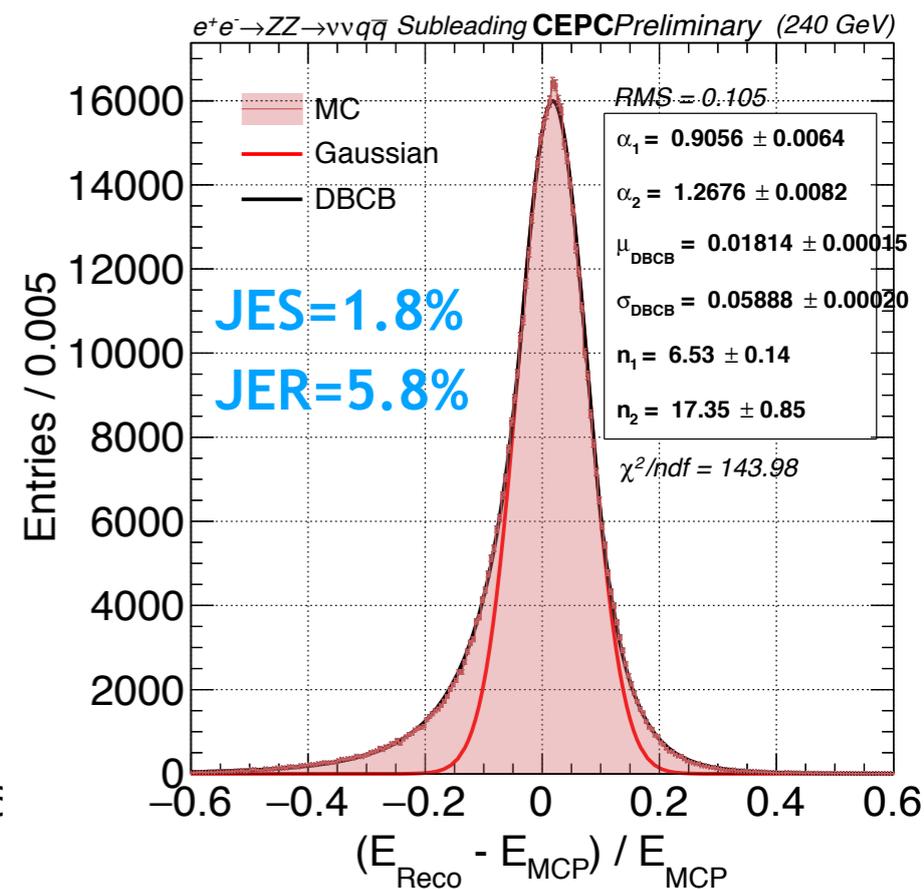
Gen-MCP



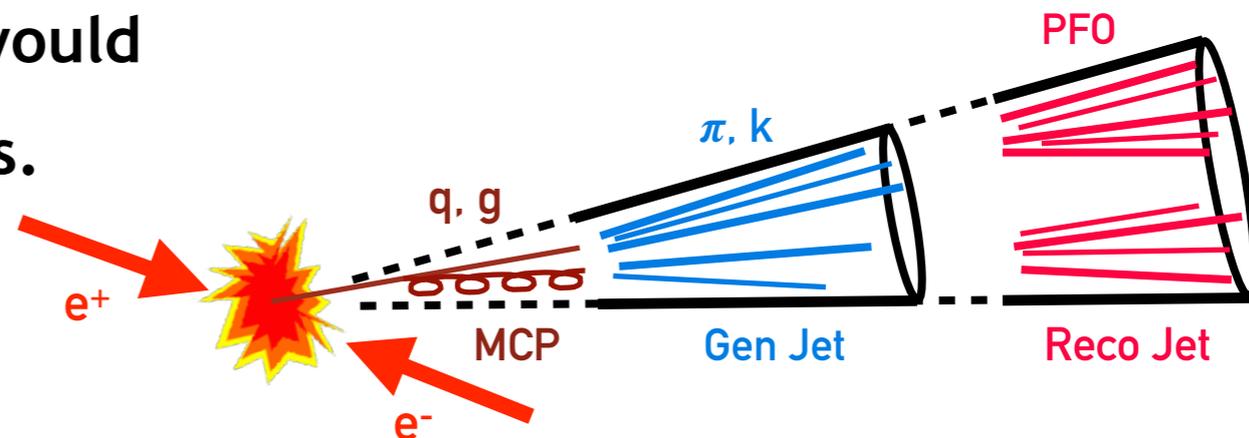
Reco-Gen



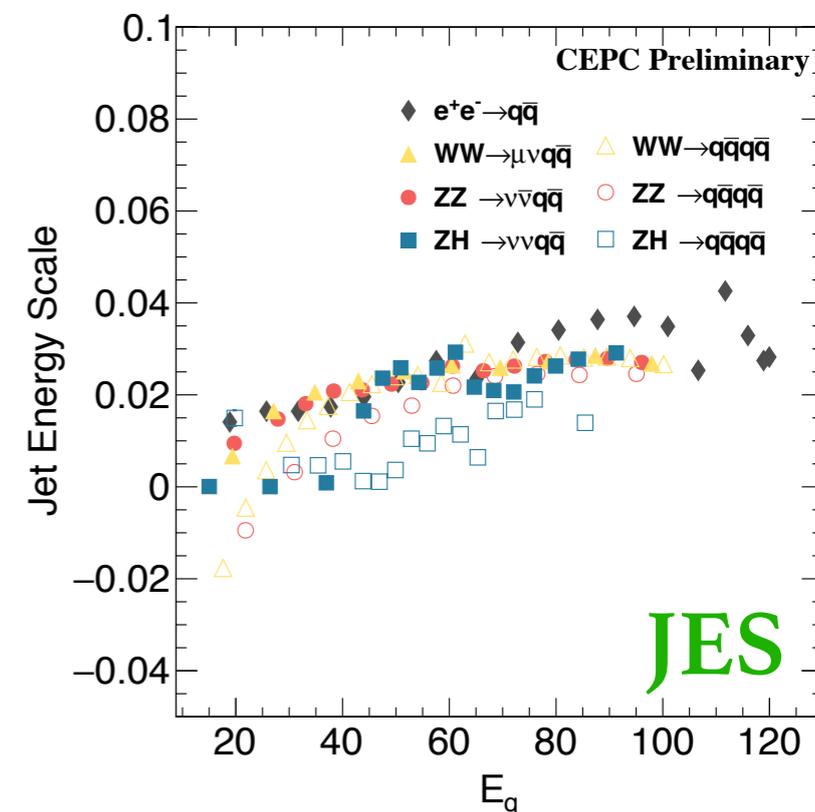
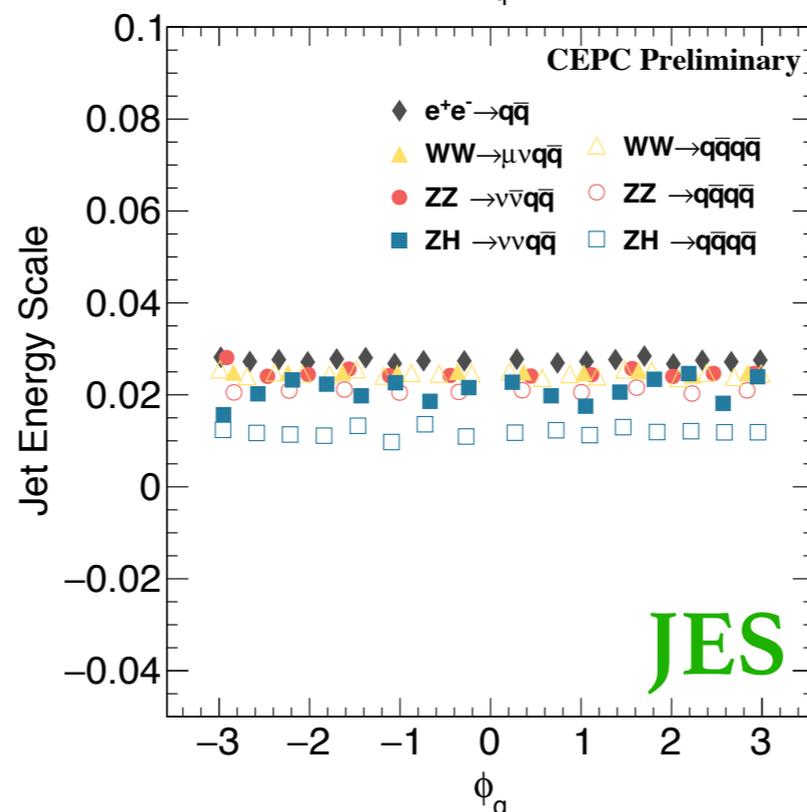
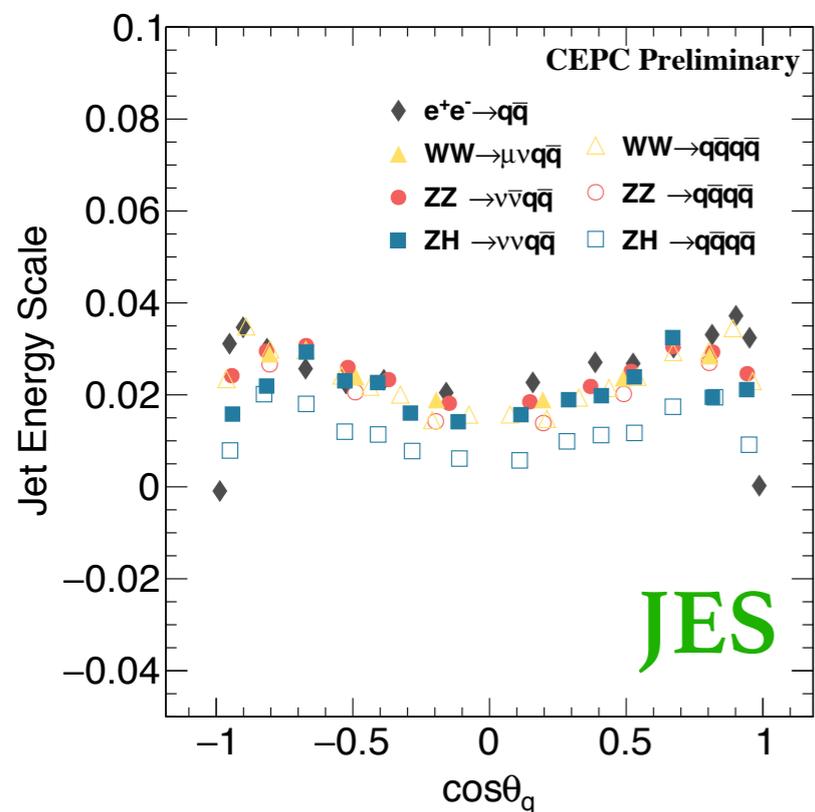
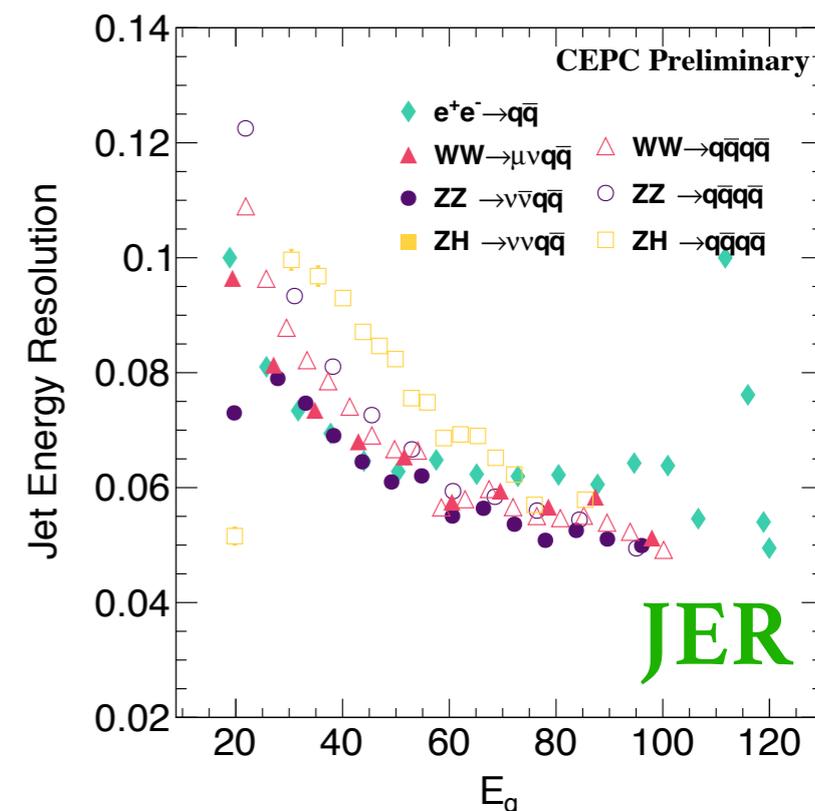
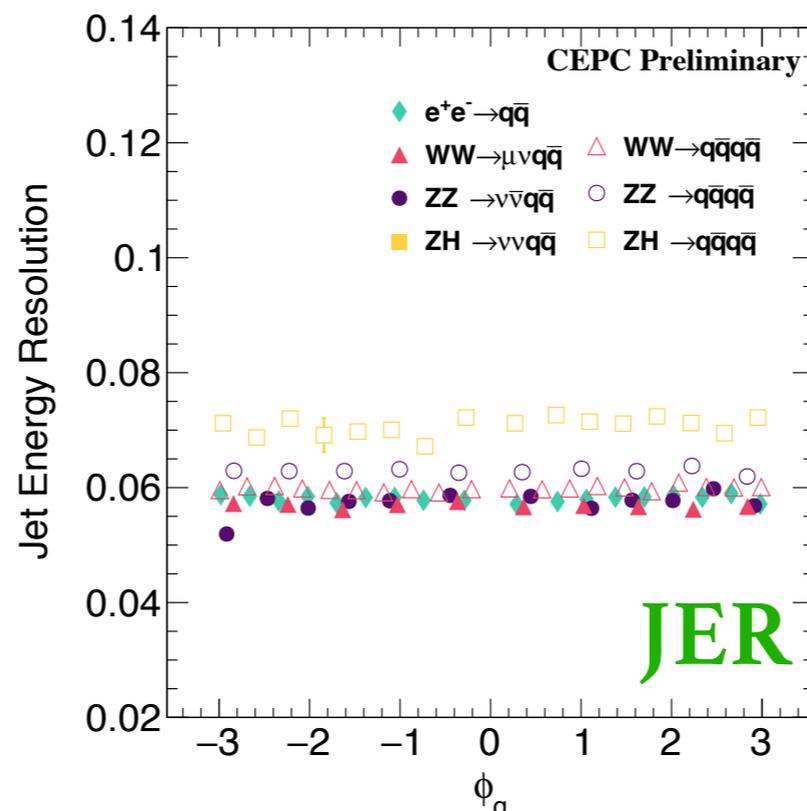
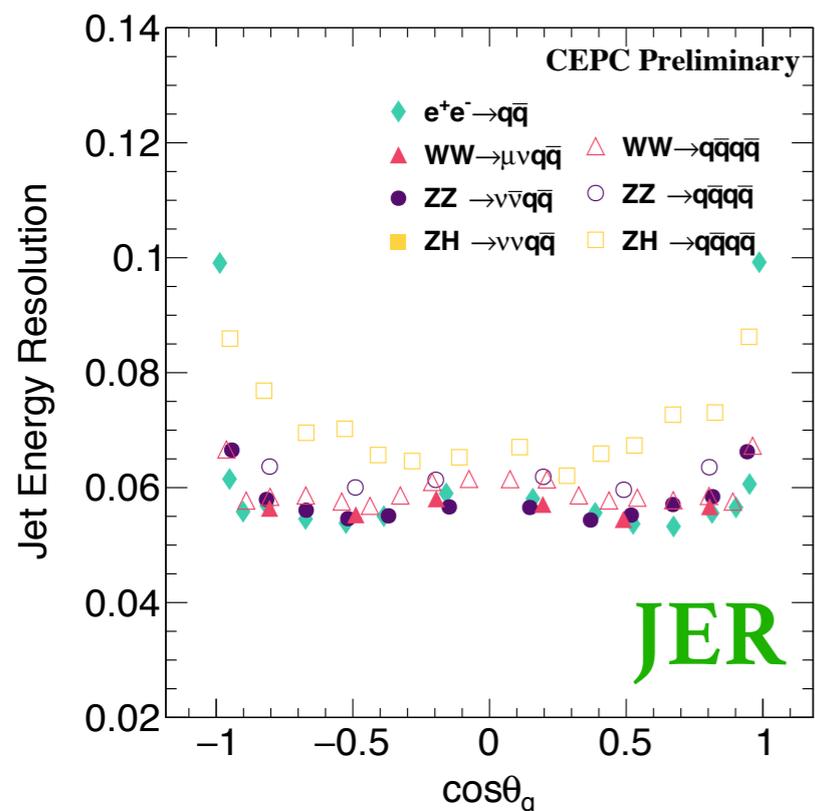
Reco-MCP



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

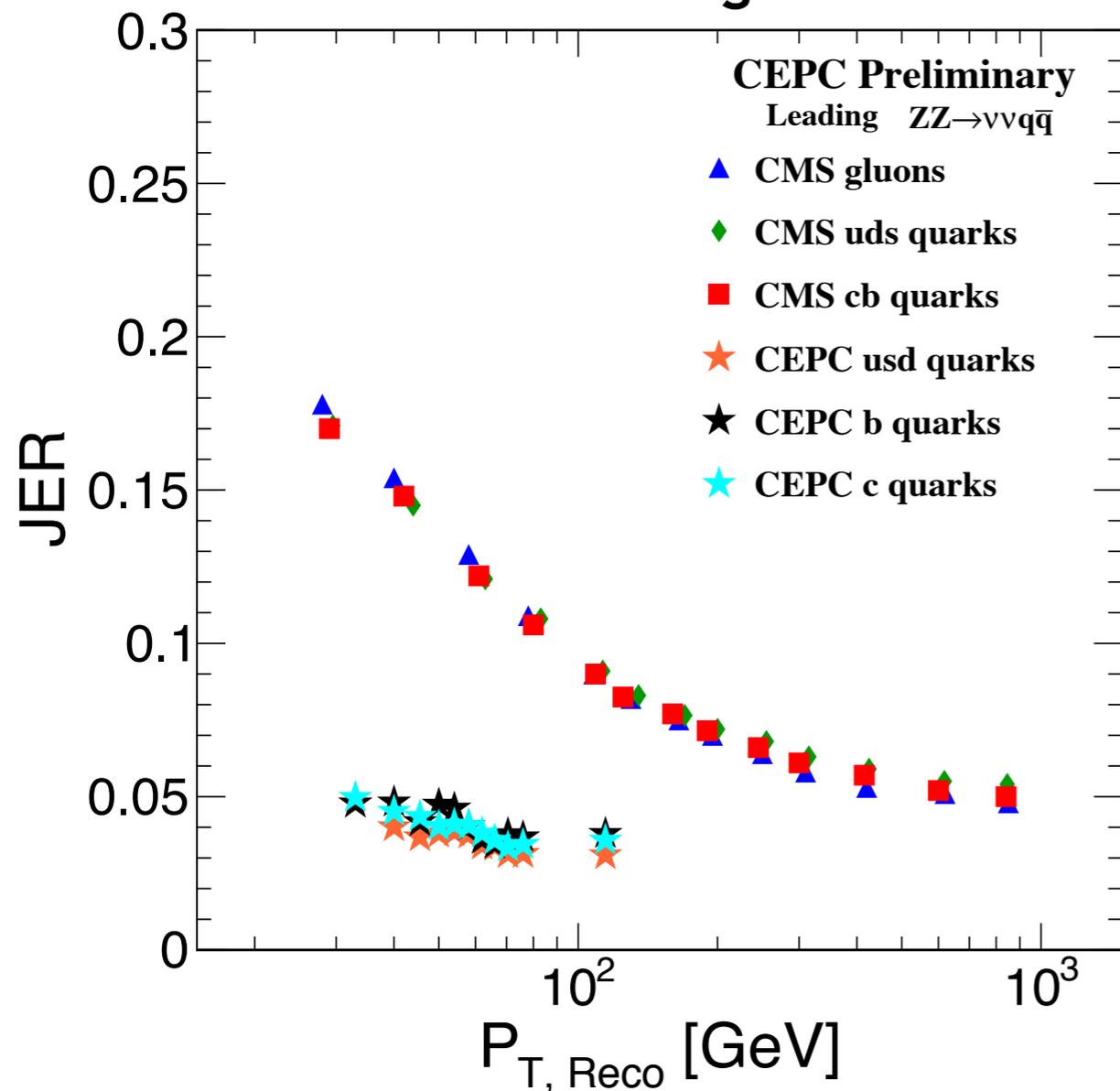


JER & JES (Reco-MCP)

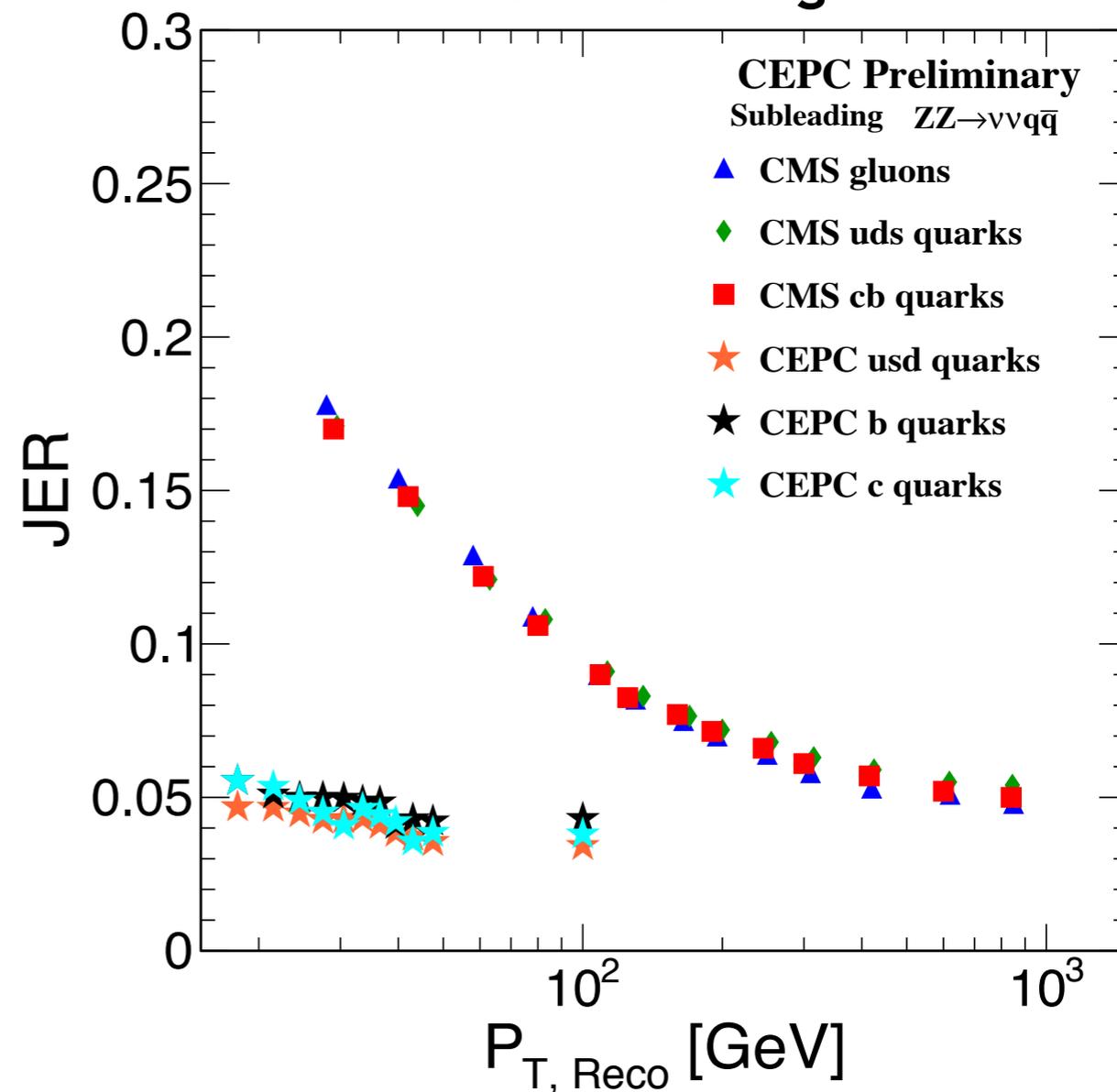


■ JER is around **6%** in barrel region; JES is around **2%**.

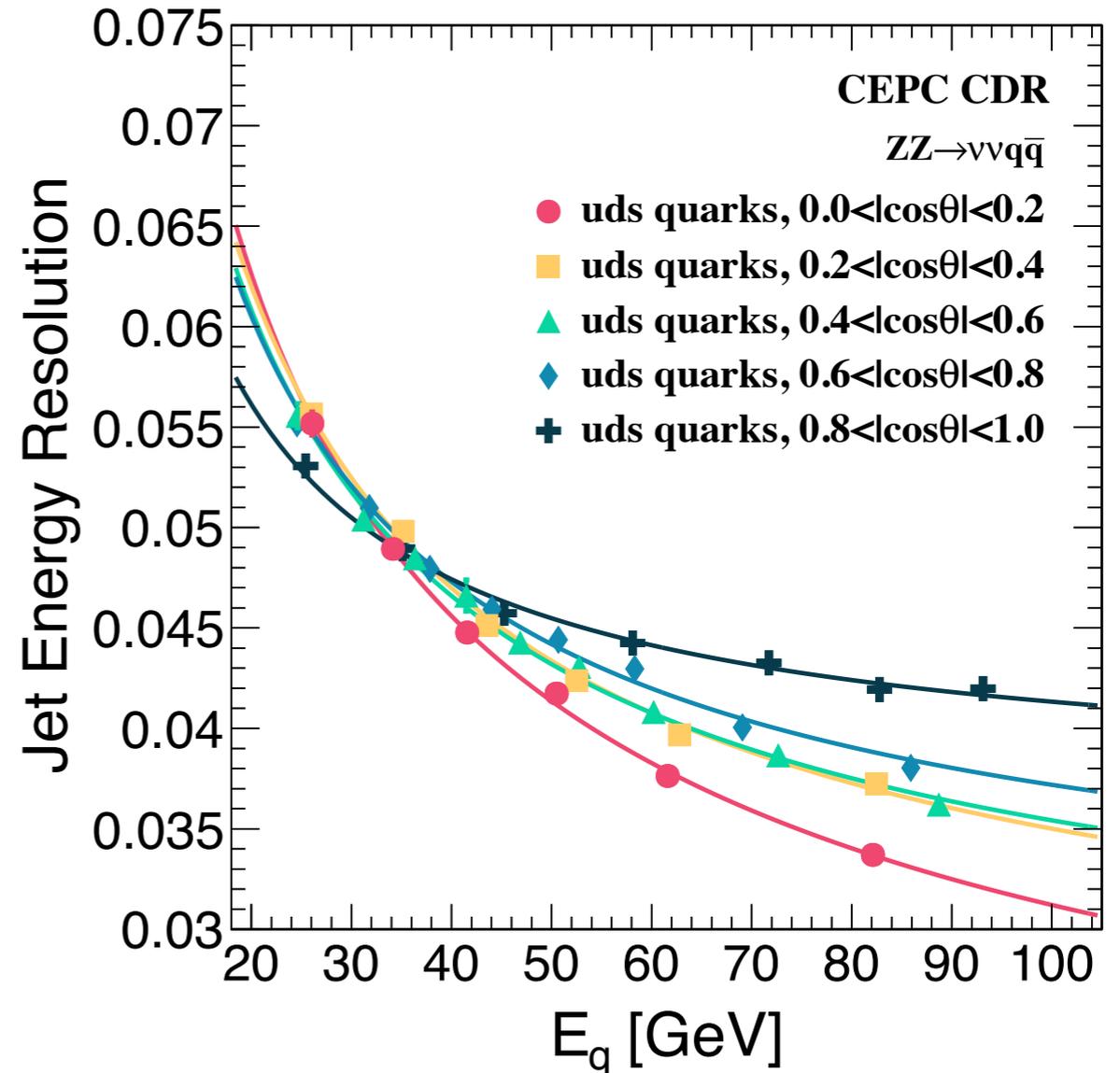
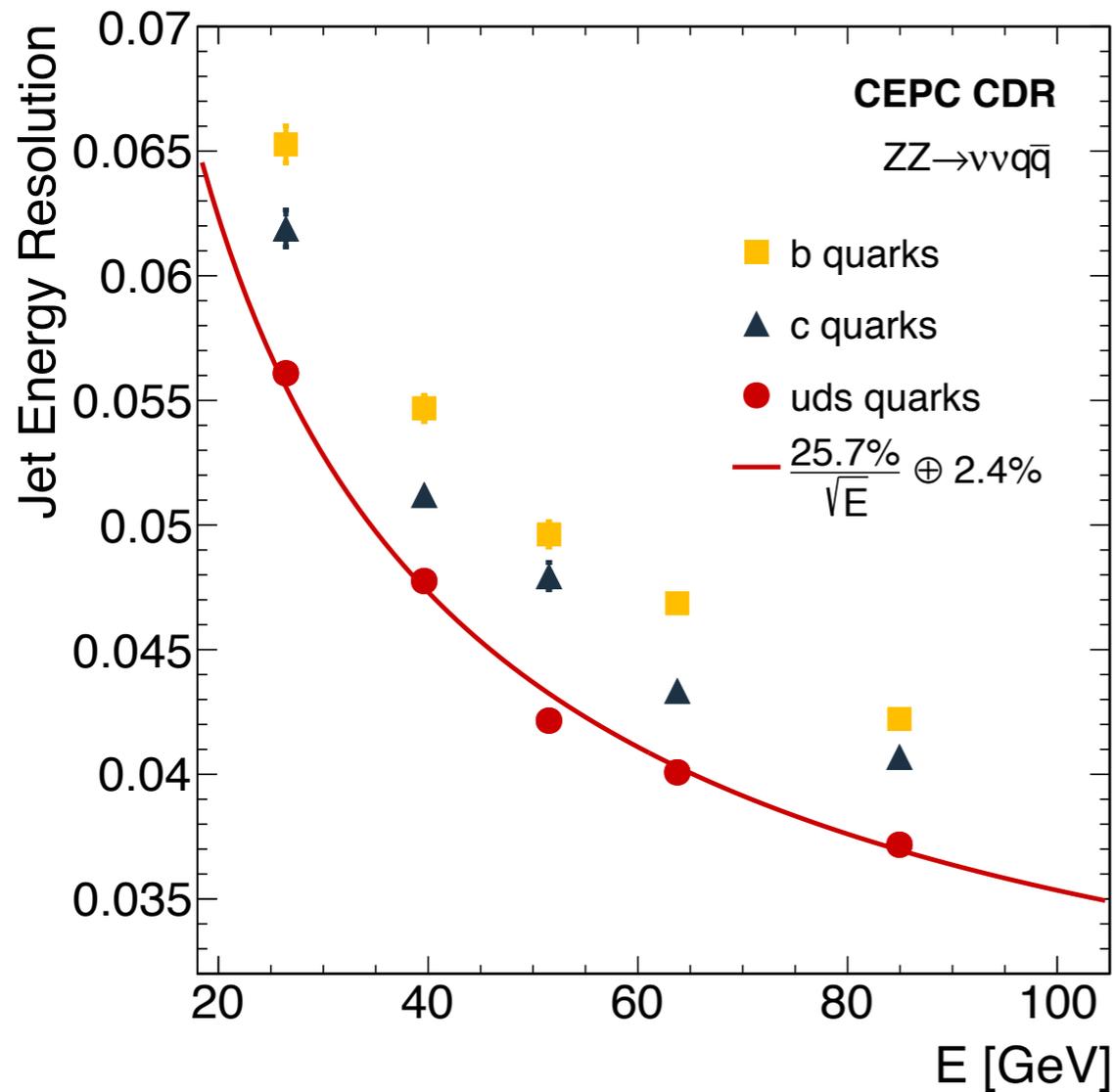
Leading



Sub-leading

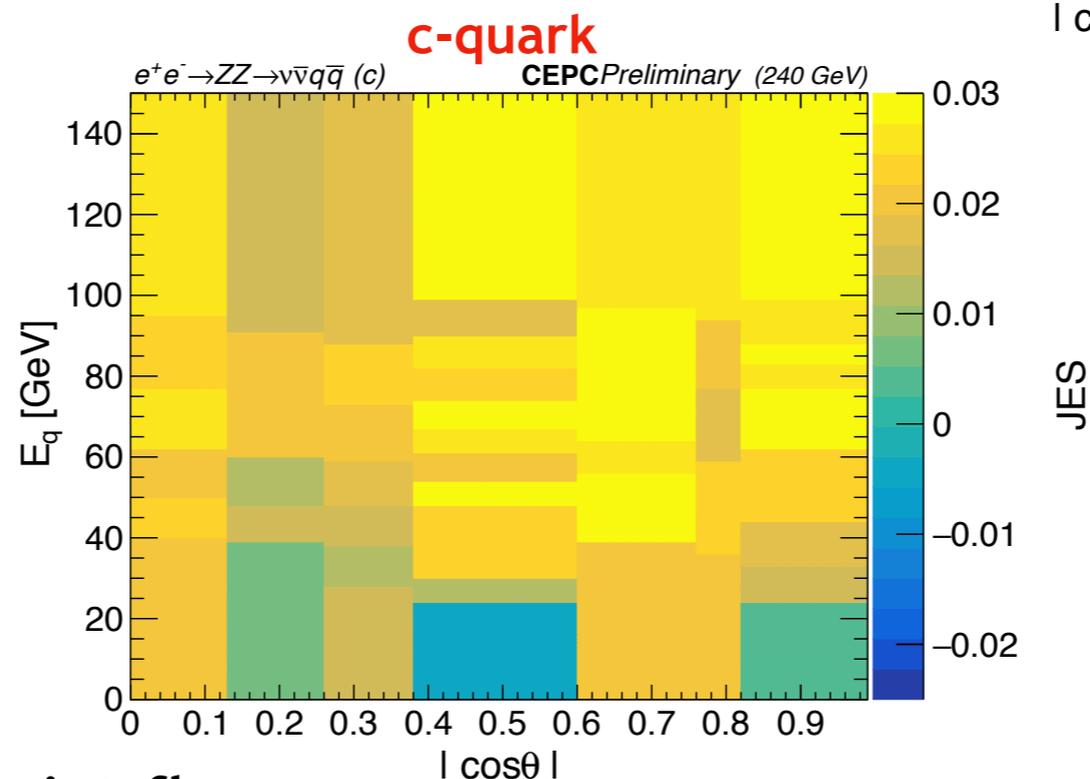
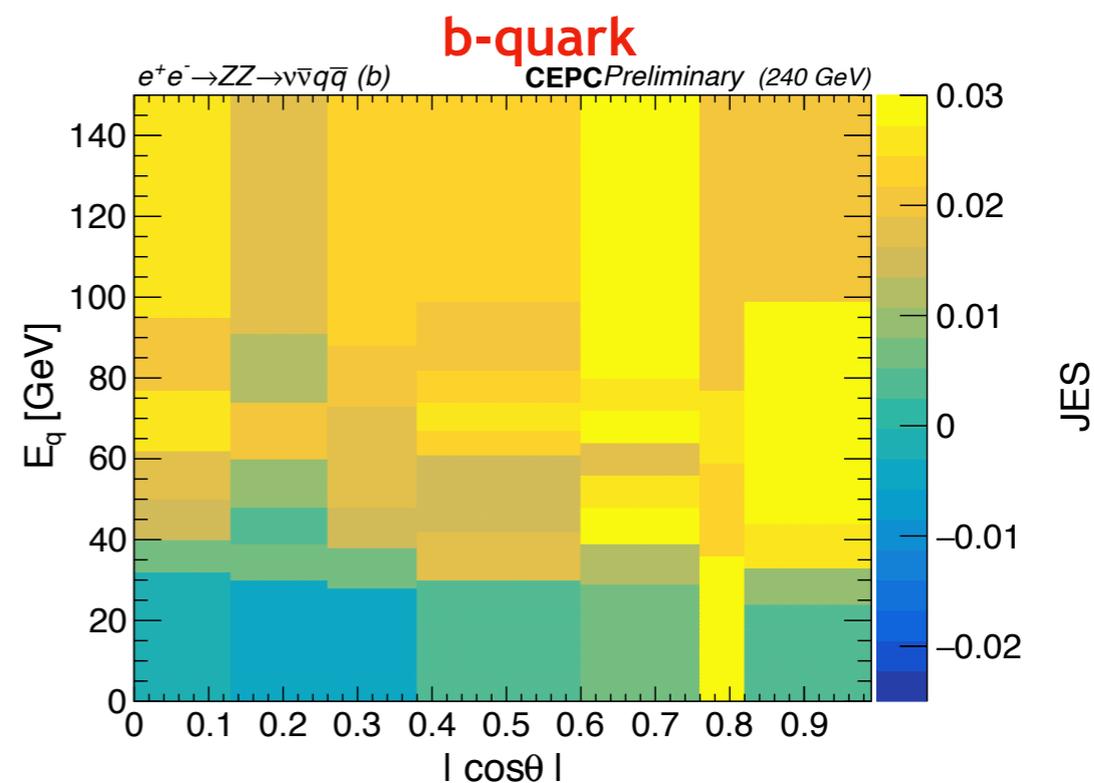
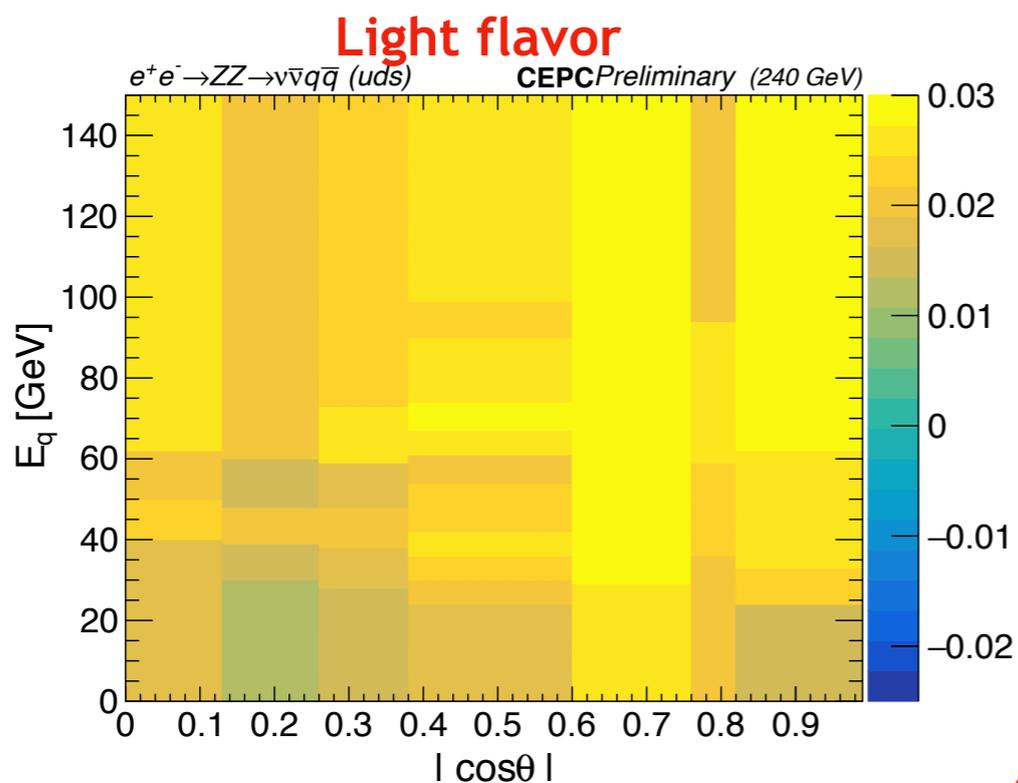


- JER at CEPC is better than CMS as it should be.
- Heavy flavors have a little bit poor JER, since its usually decays with the neutrinos.



- JER also depends on the jet flavor.
- For light-flavor jets with high energy and within central region of barrel, JER has good performance compared to LHC, **3%**.

JES in Phase Space

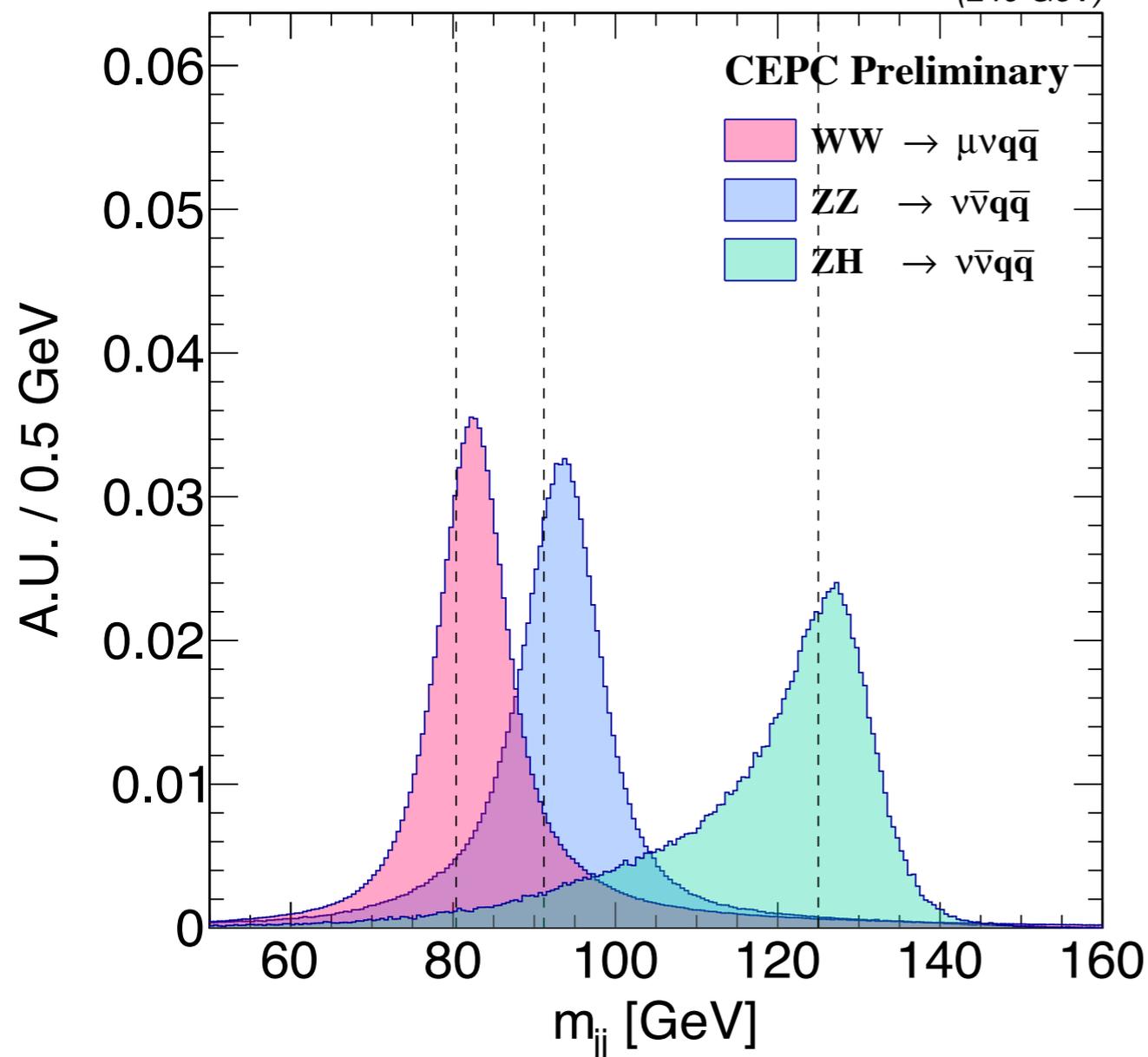


- JES also depends on the jet flavor.
- Light flavor jet has higher energy deviation.

Jet Energy Calibration

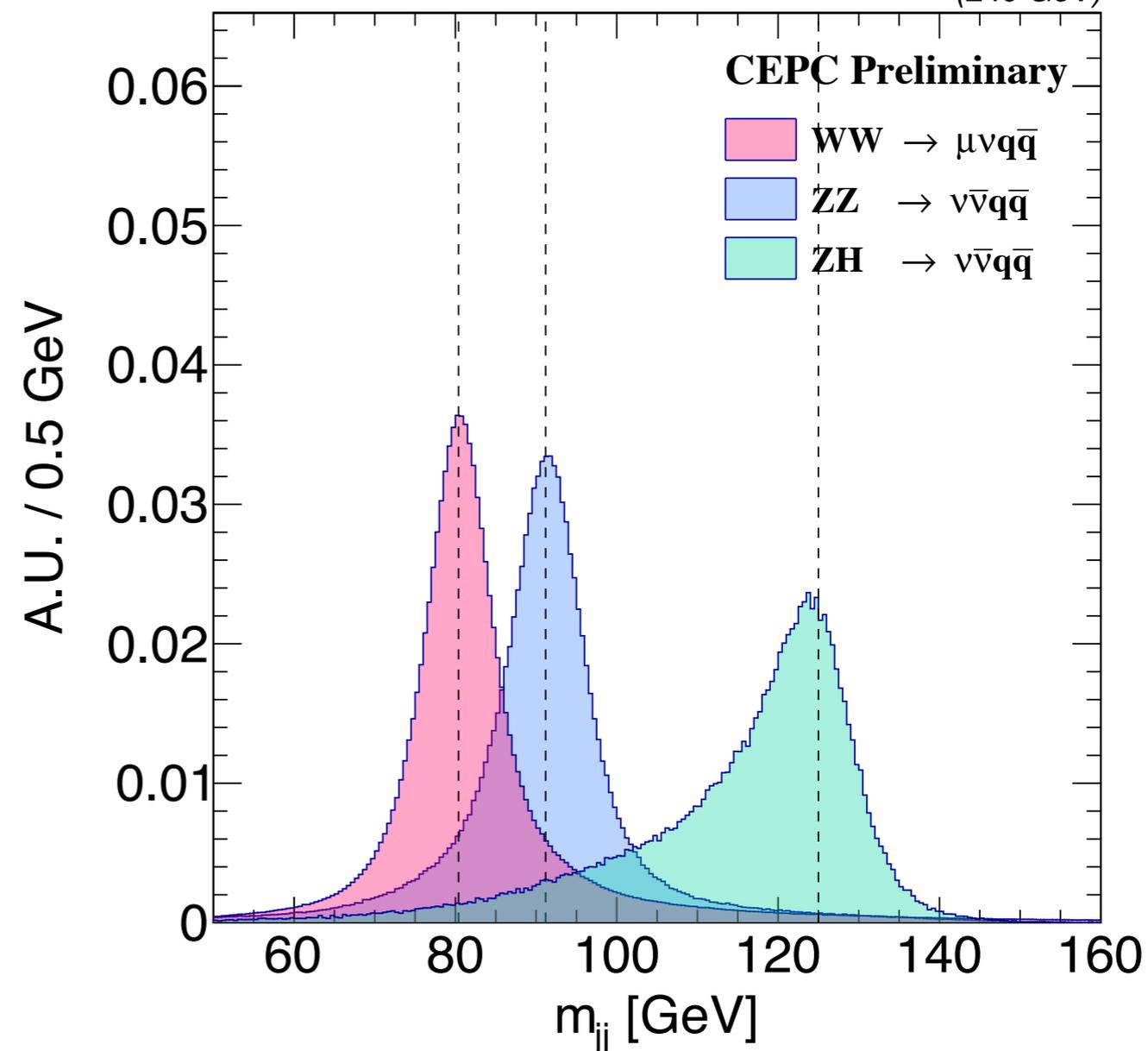
Before Calibration

(240 GeV)



After Calibration

(240 GeV)

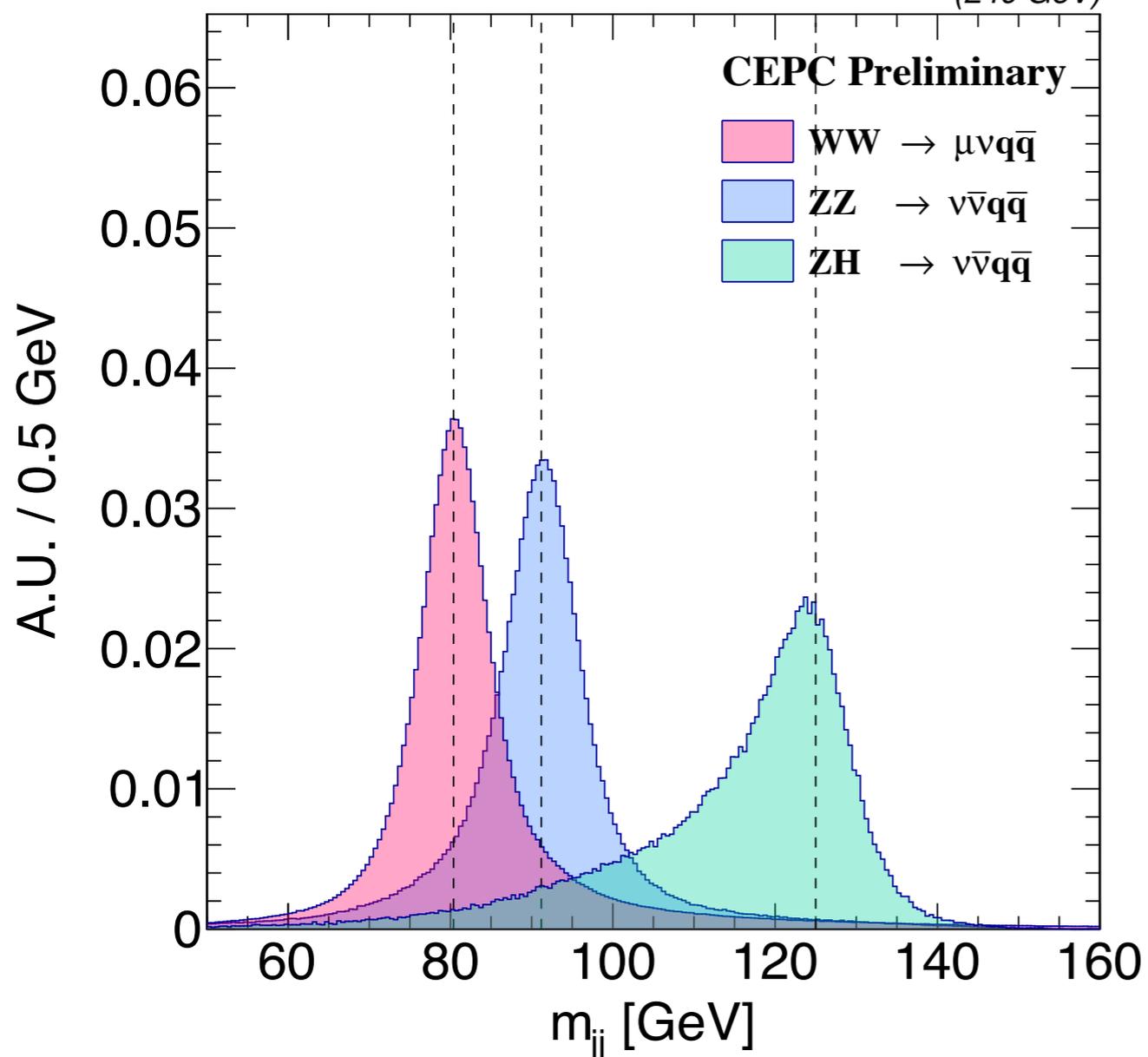


- Since the double-counting effect, jet energy would be overestimated.
- According to MC true energy and $\cos\theta$ distribution, JES can be used to calibrate the dijet invariant mass back to the value we put into simulation.
- After calibration, boson mass resolution is improved about **1%**.

Massive Boson Mass Resolution

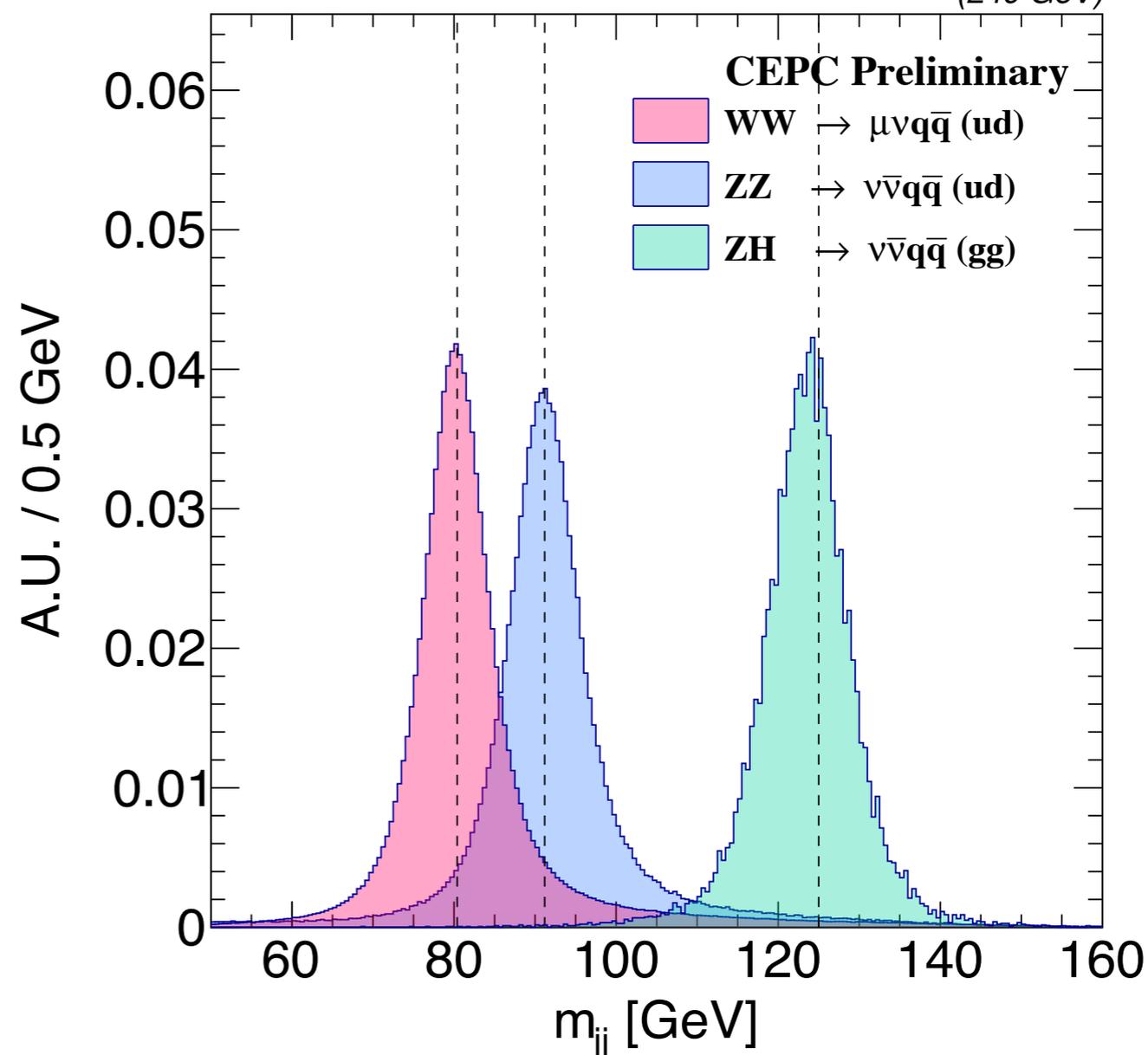
Before Cleaned

(240 GeV)



After Cleaned

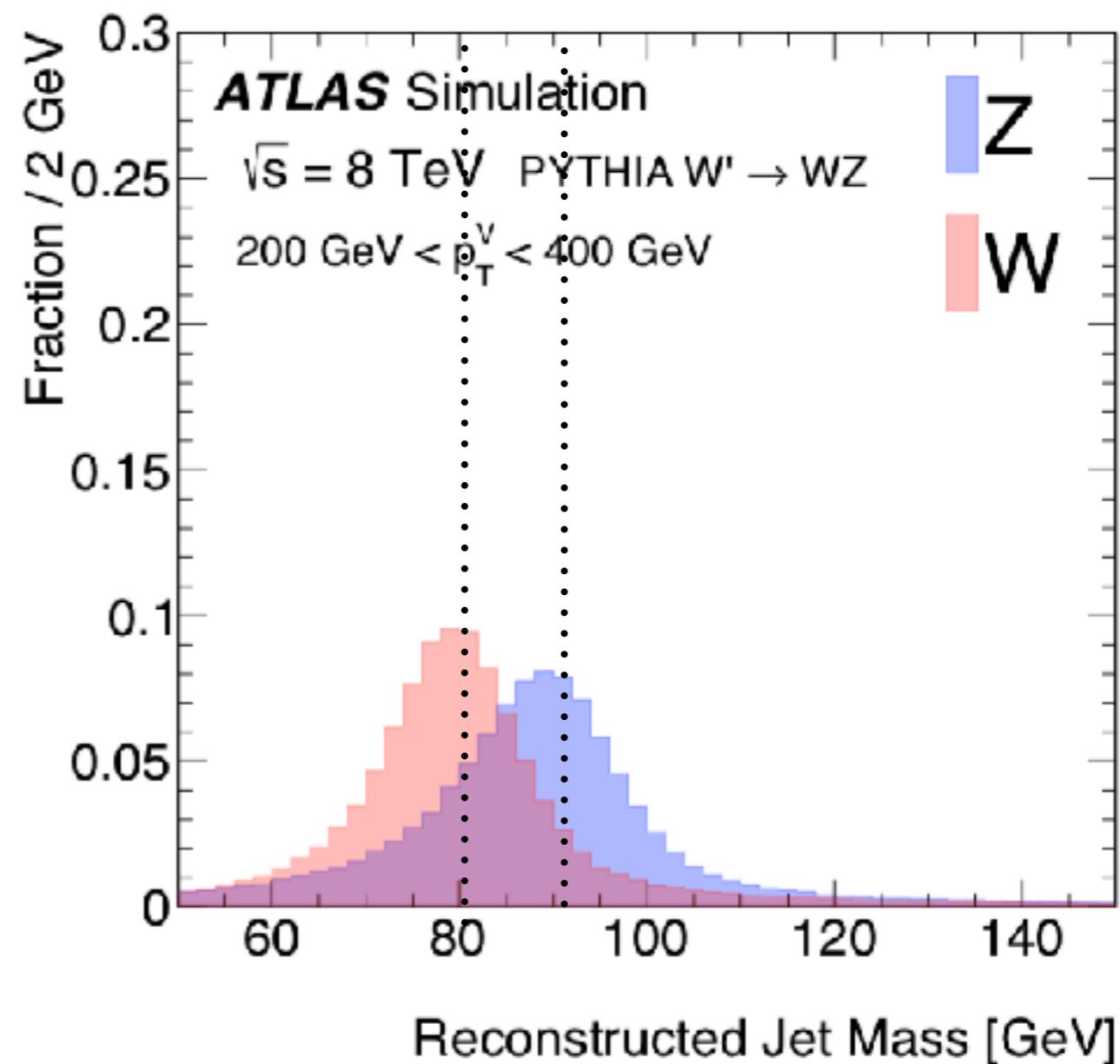
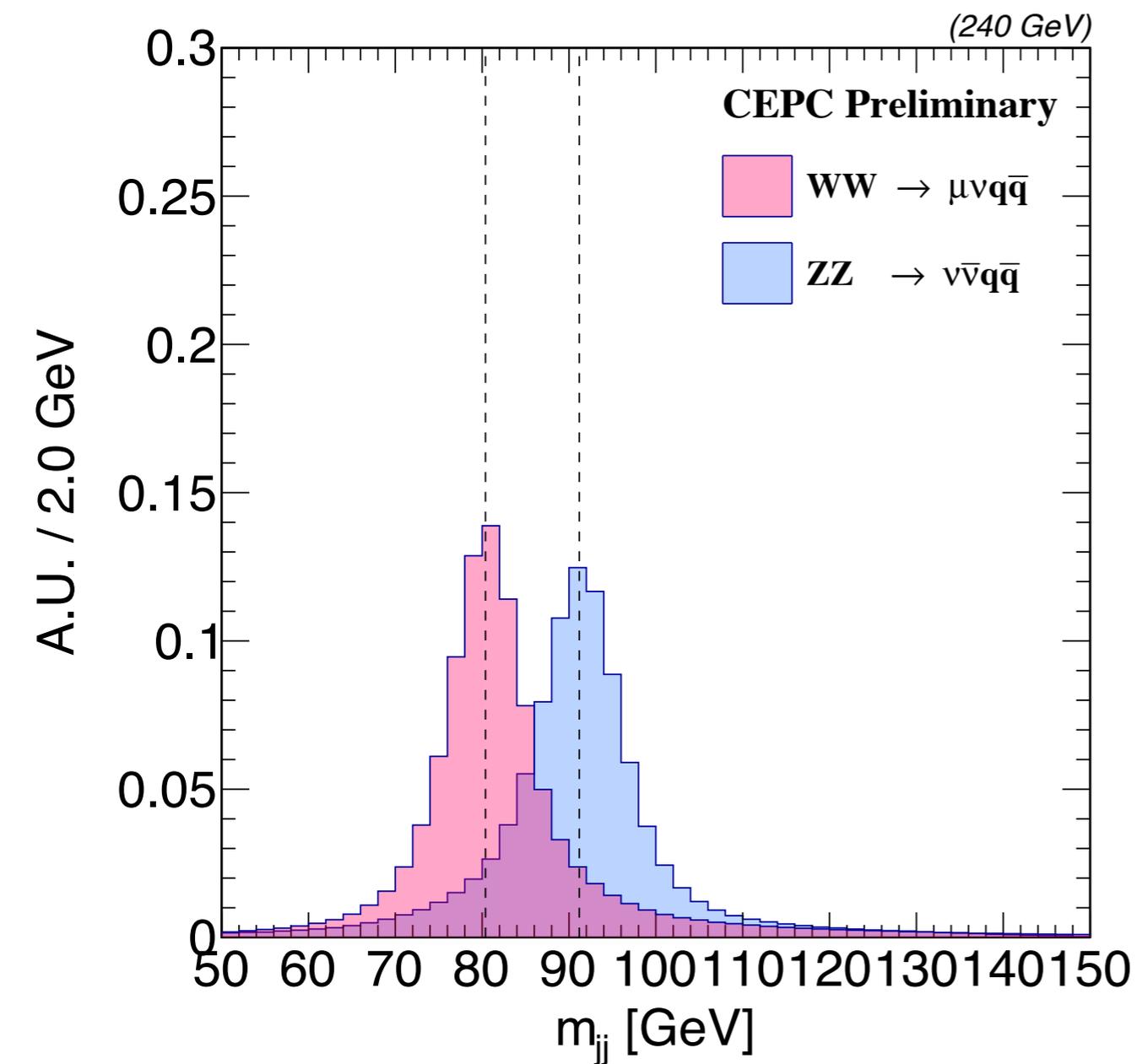
(240 GeV)



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

Cleaned: Select the light flavor jet event with low energy ISR, low energy neutrino inside jet, and within $|\cos\theta| < 0.85$.

Massive Boson Mass Resolution



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

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	

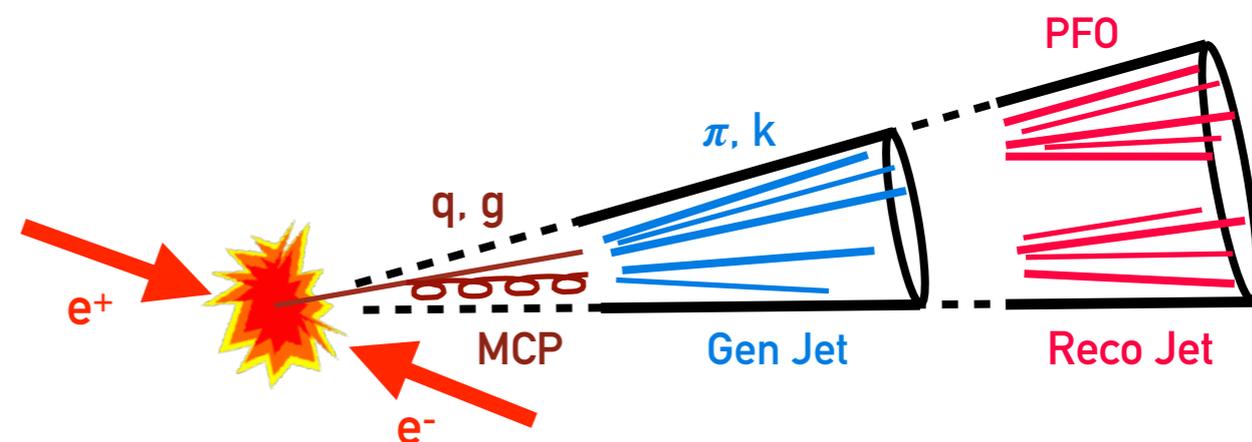
Reco-Gen

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%	

- JAR is around **1.5%** in barrel region;
JAS is **independent** of ϕ and energy.

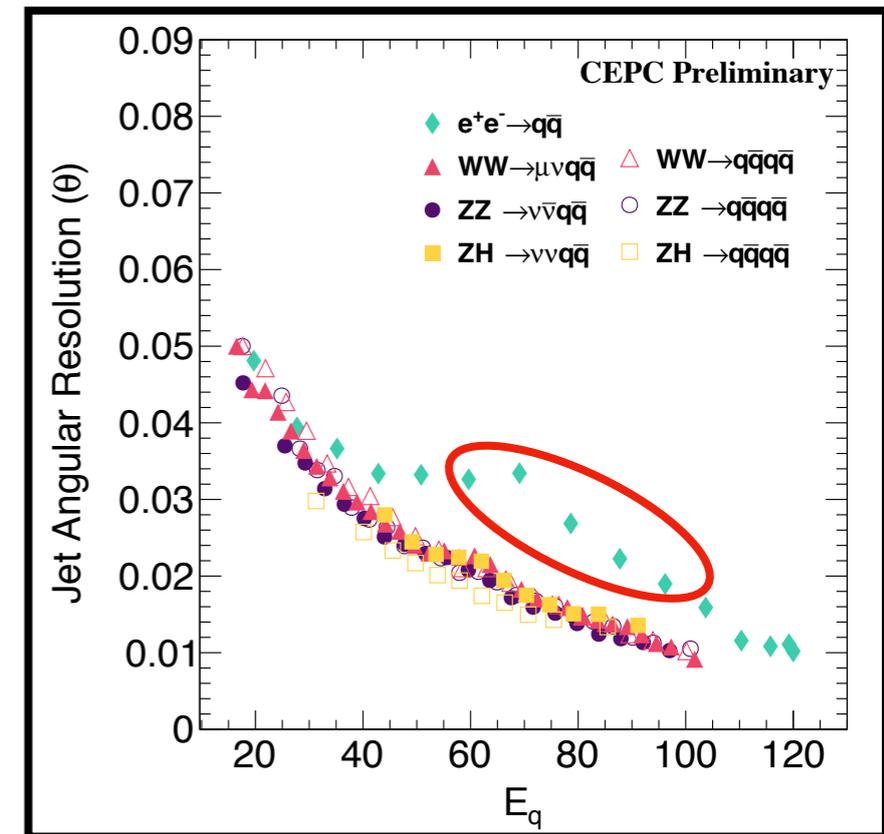
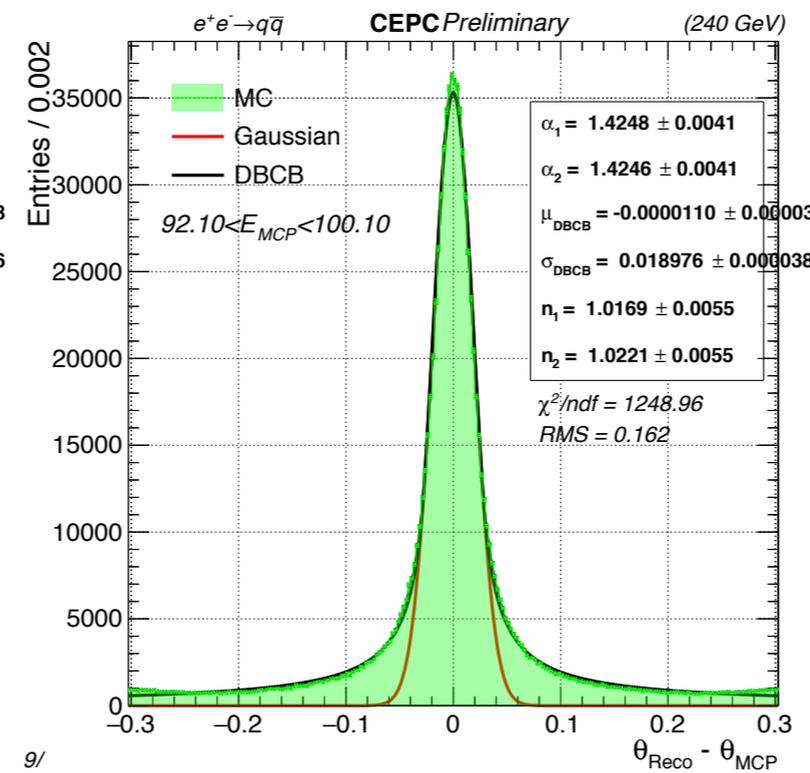
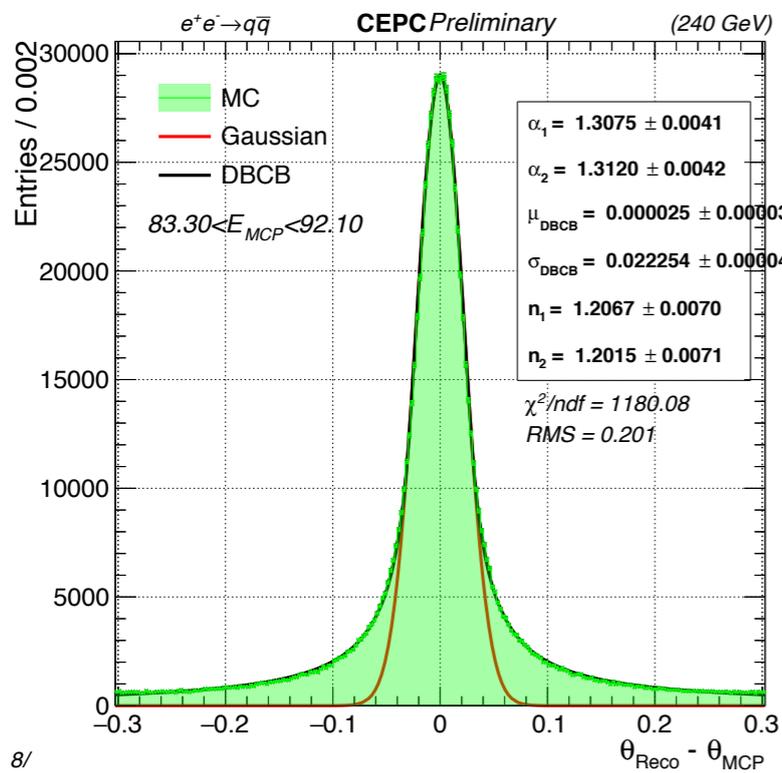
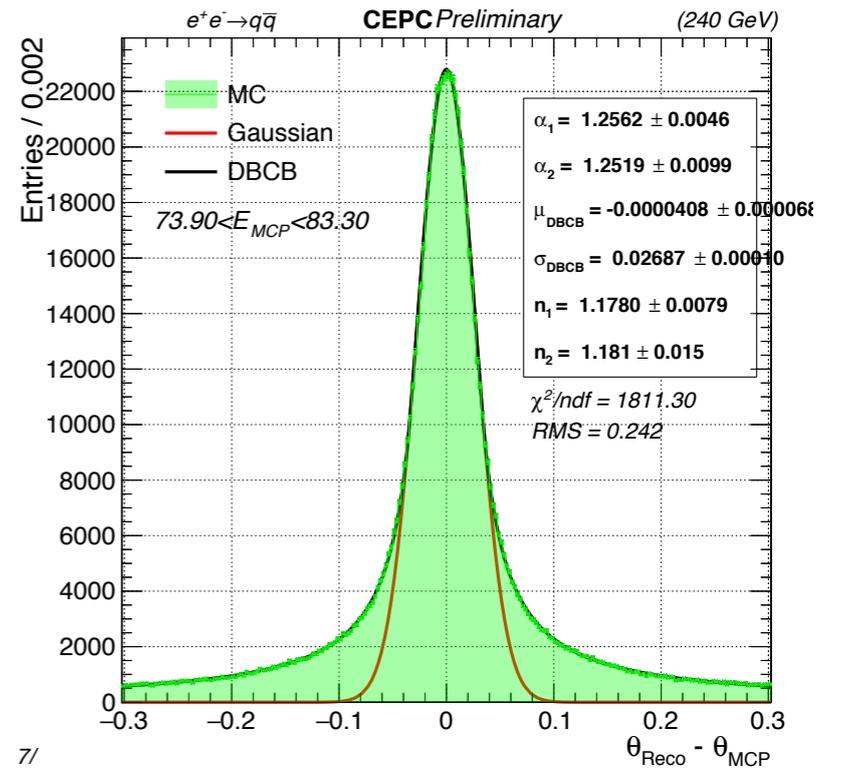
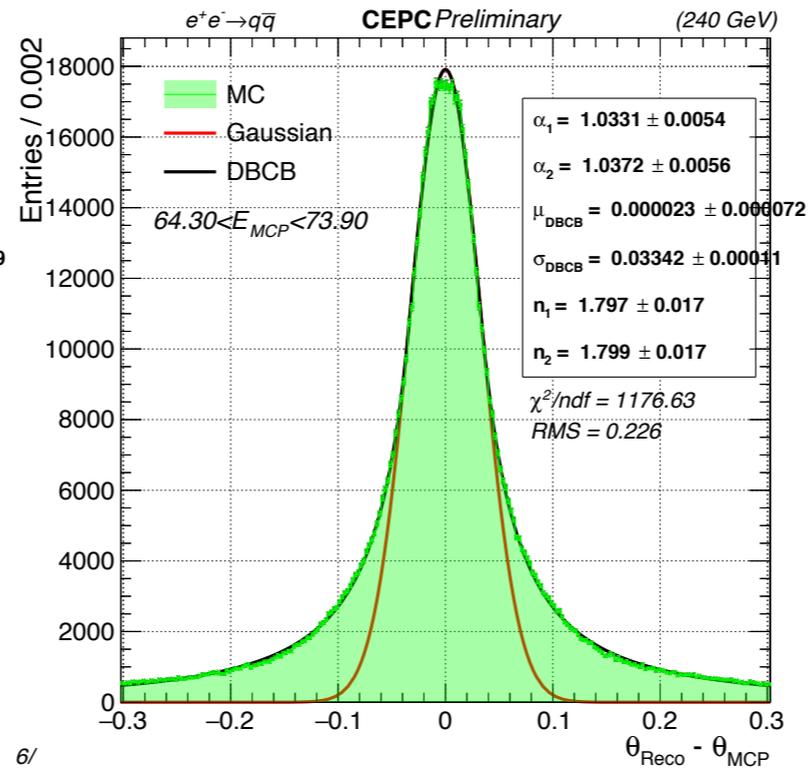
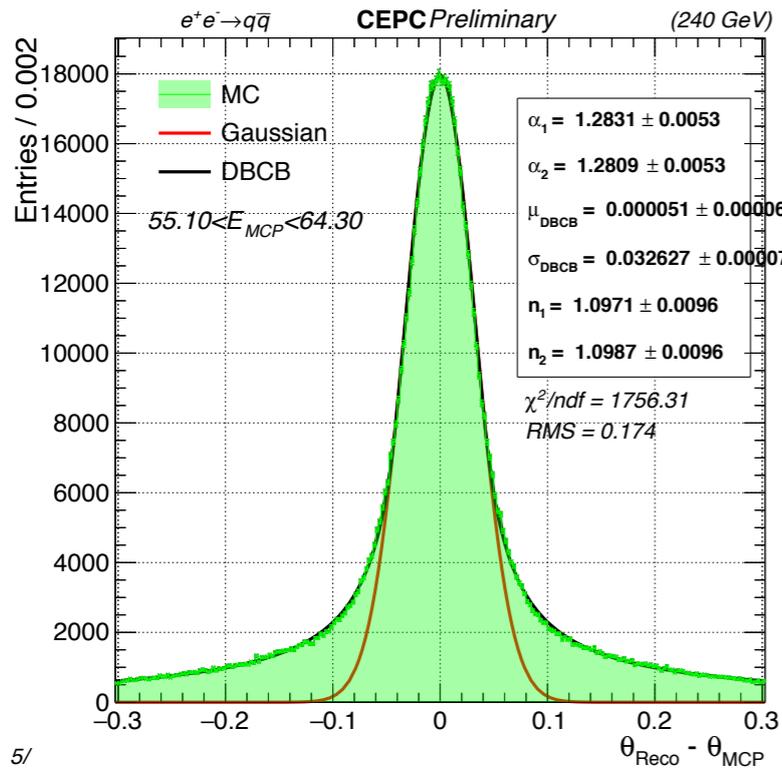


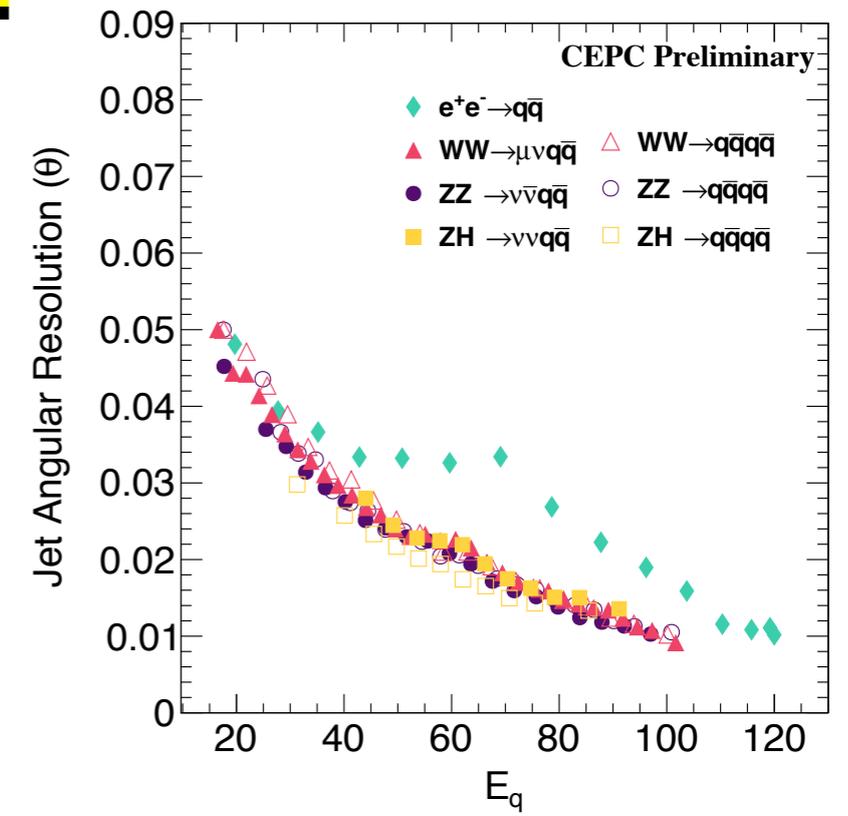
- After comparison, the CEPC detector has excellent jet energy resolution, **4%**.
- Four jet final state only has a bit poor JER than two jet final states, **1%** poorer.
- Z, W, and Higgs boson mass in dijet final state can be well separated in CEPC. **The separation of Z- and W-boson is around 2σ .**
- The jet clustering brings a significant or even leading uncertainty.
- Jet energy calibration can be used to improve the precision of boson mass measurement.
- The patterns of differential JAR are still being investigated.

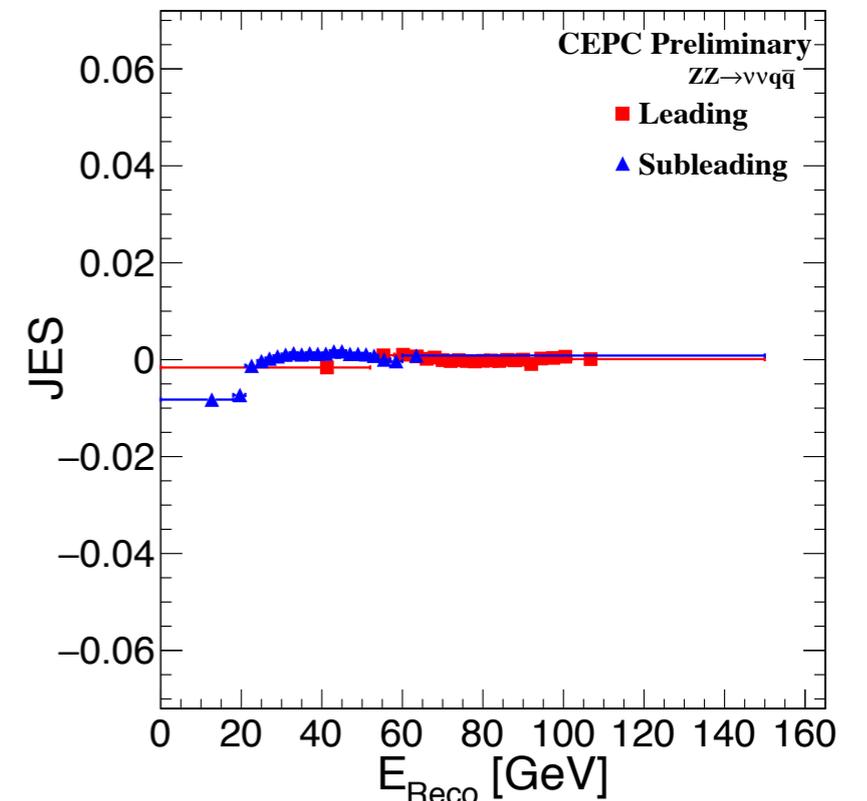
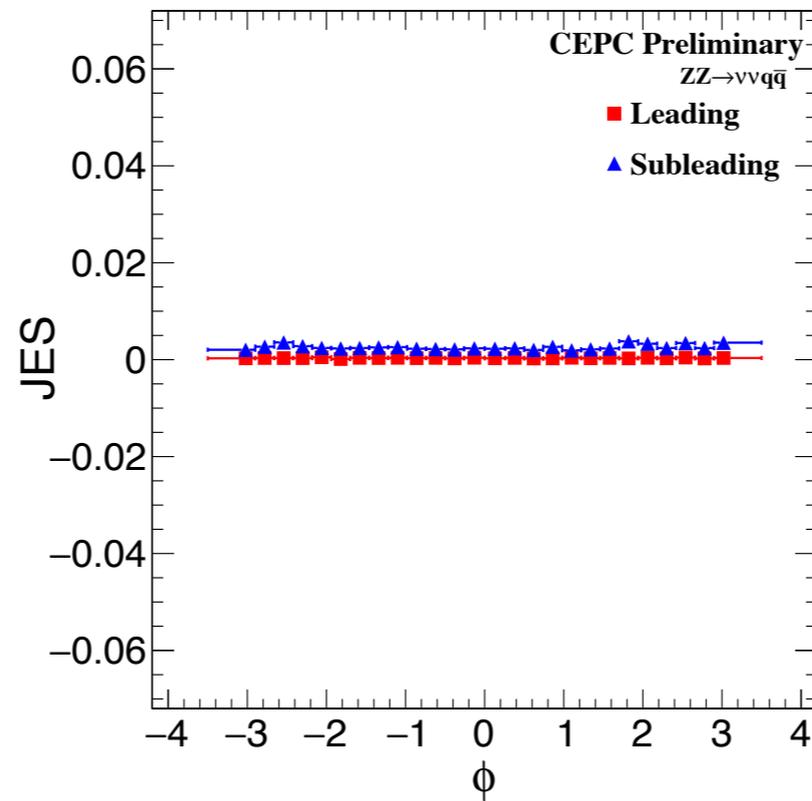
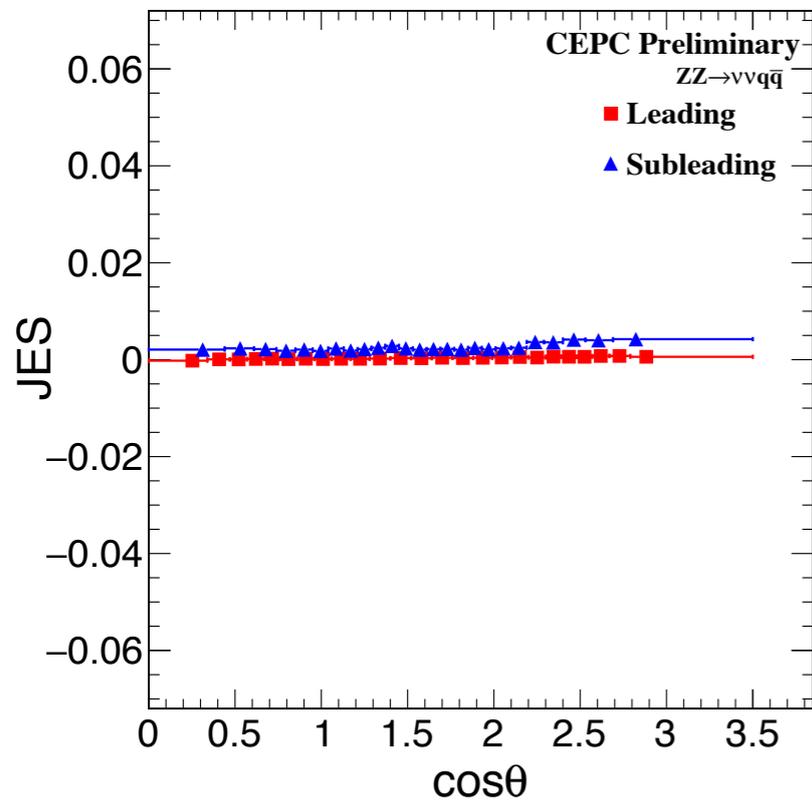
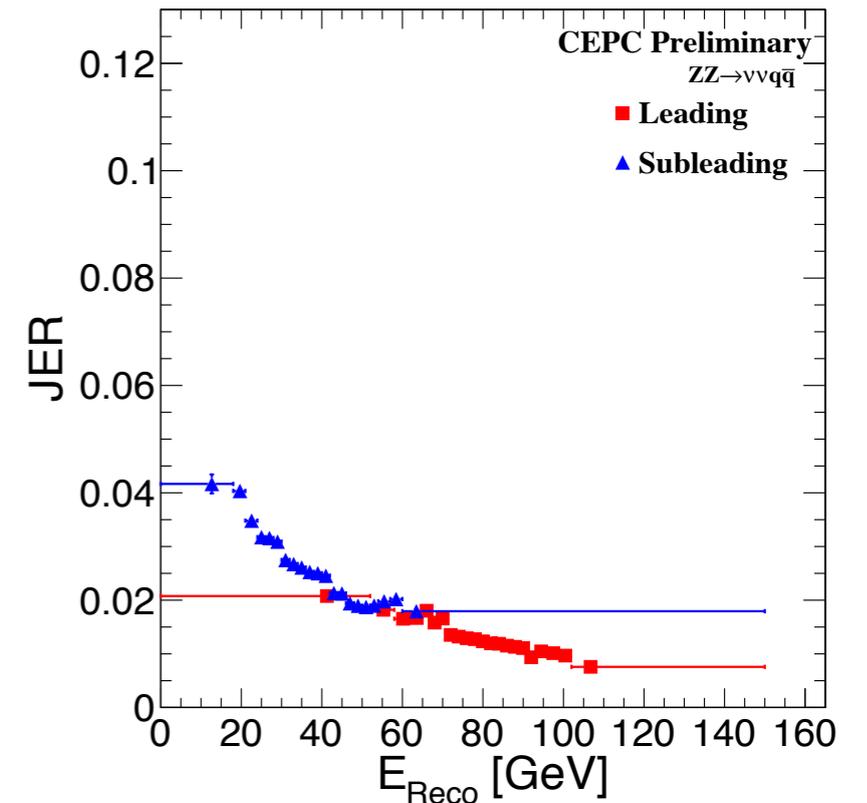
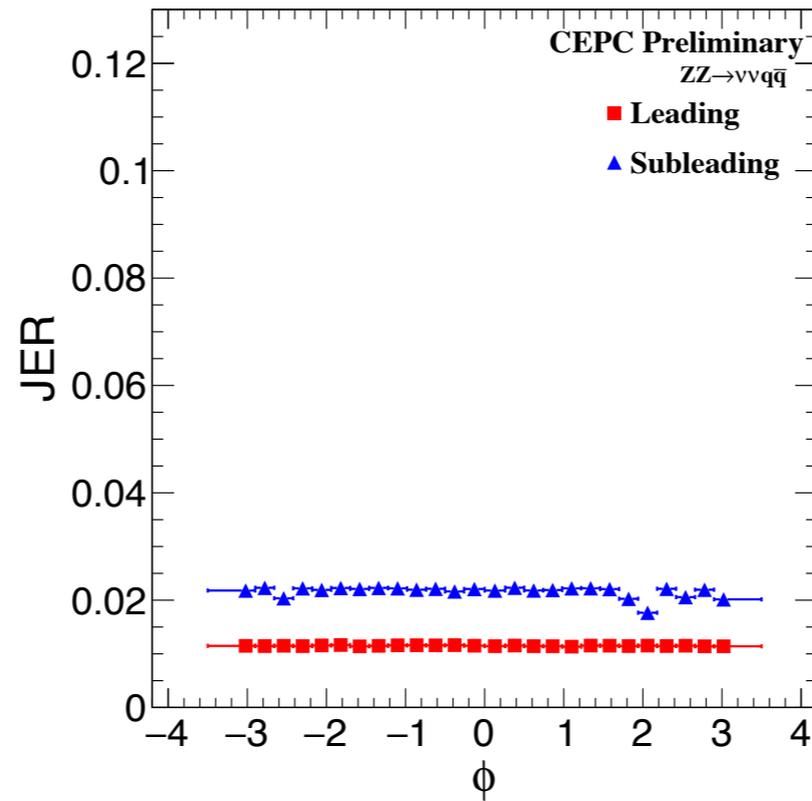
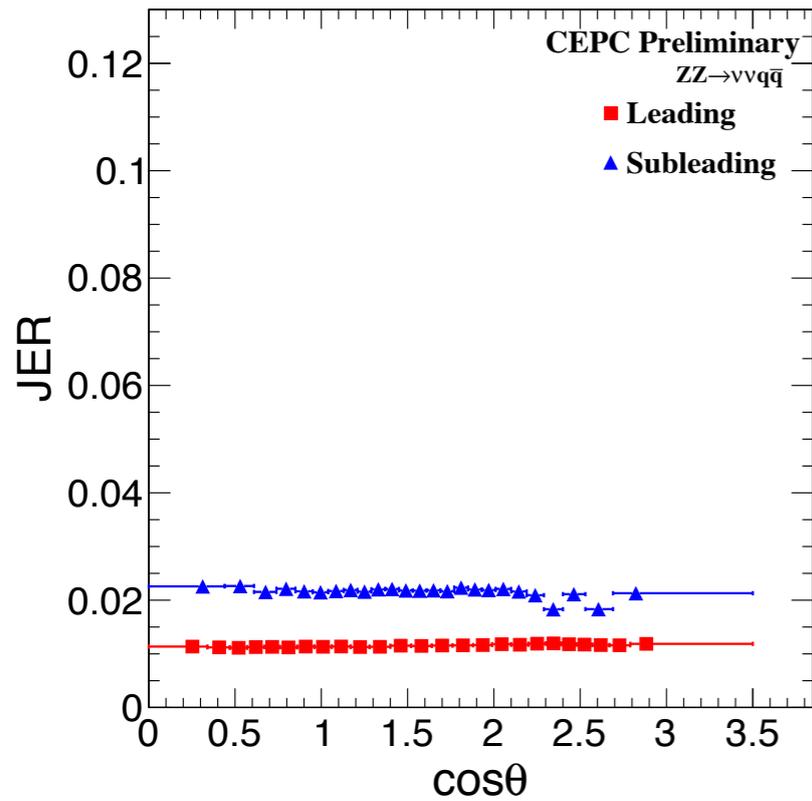
Thank for your attention

- [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

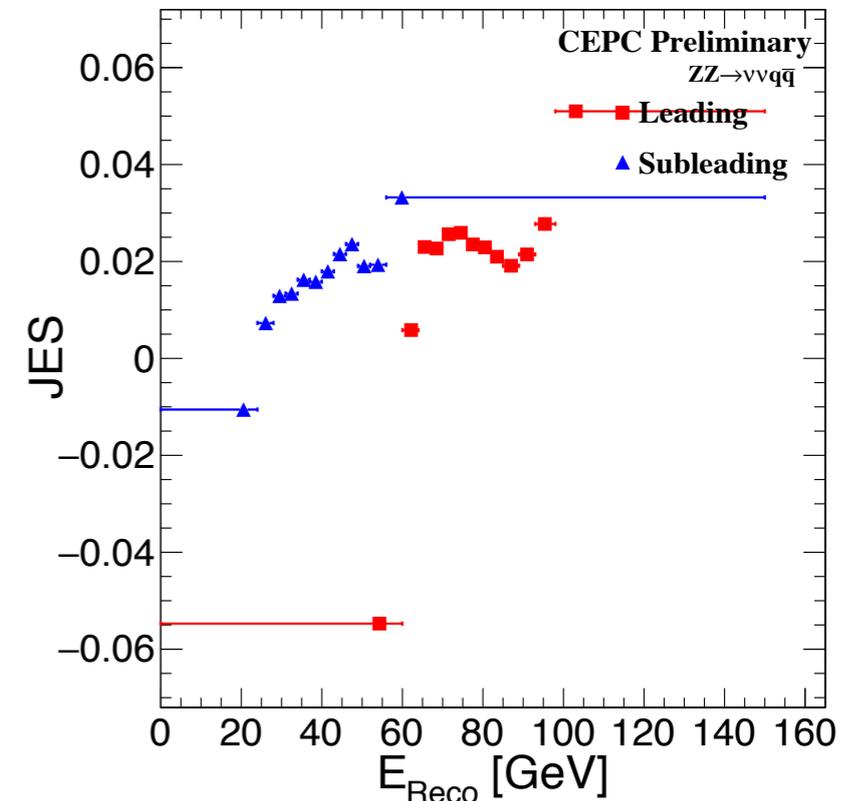
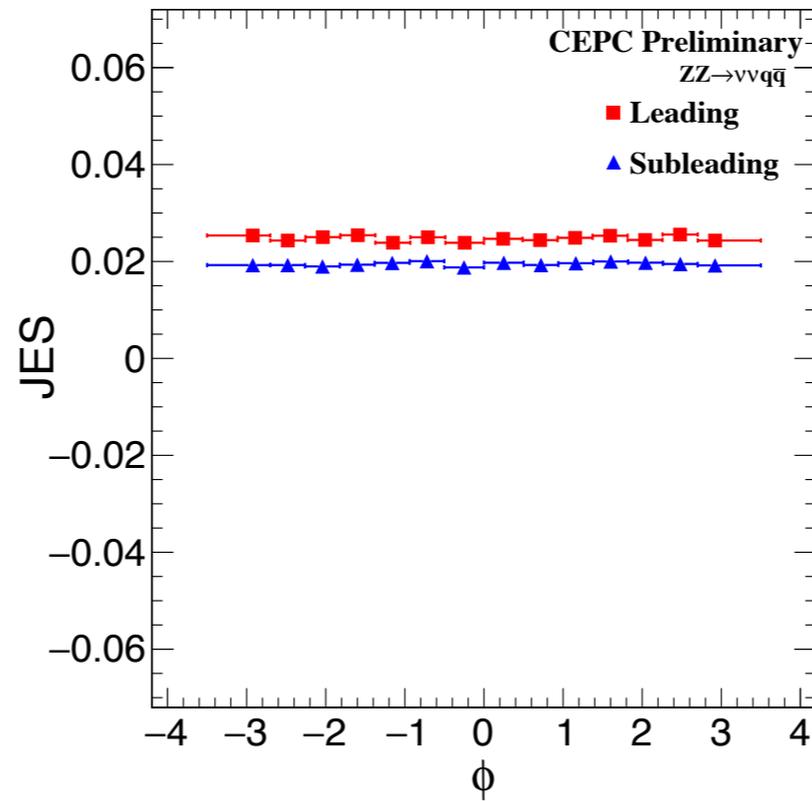
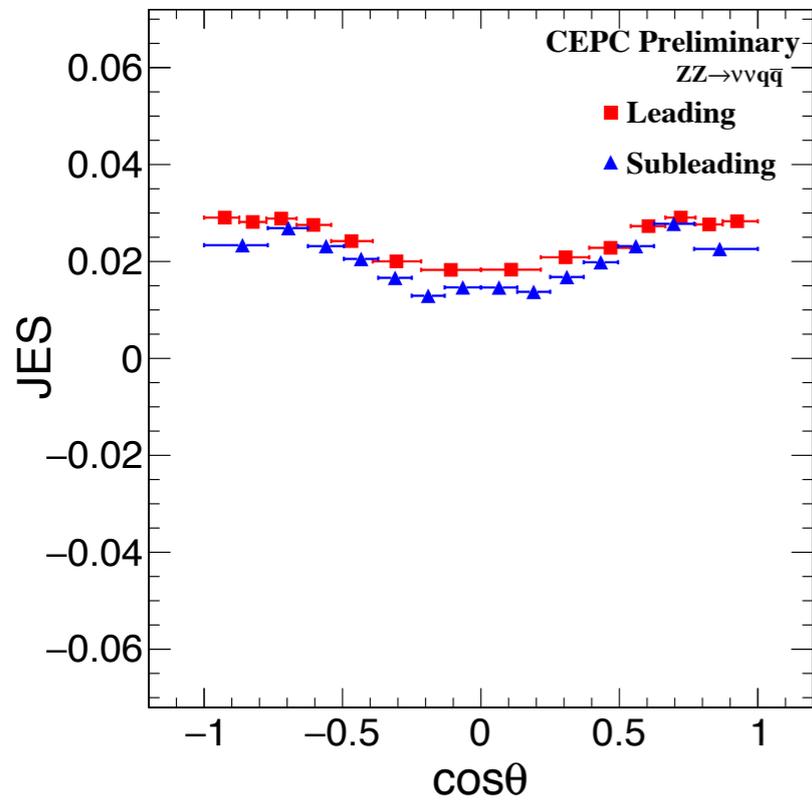
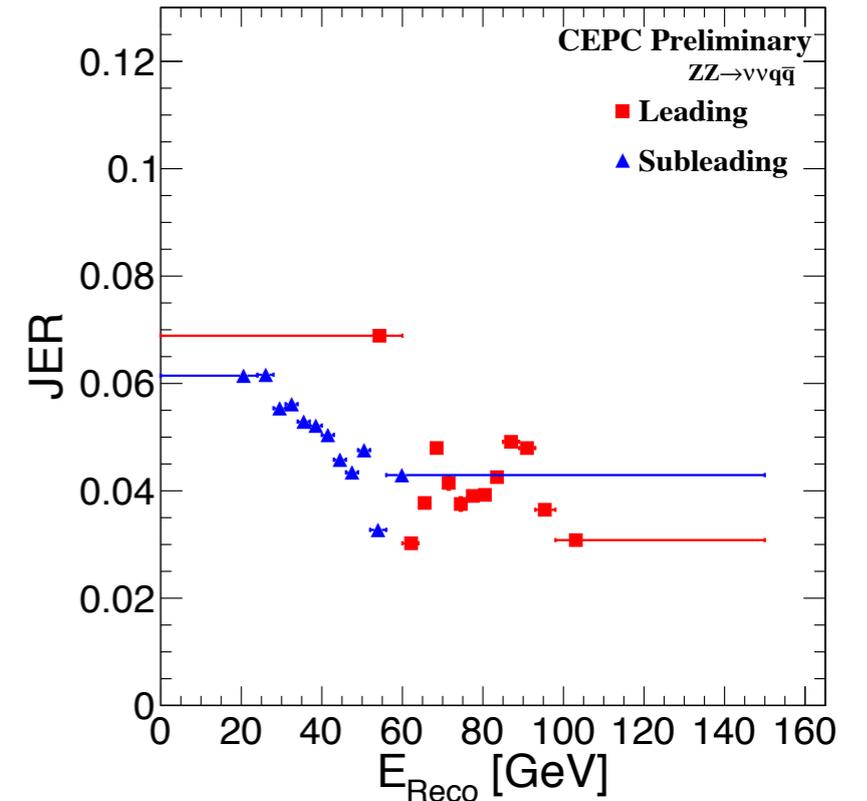
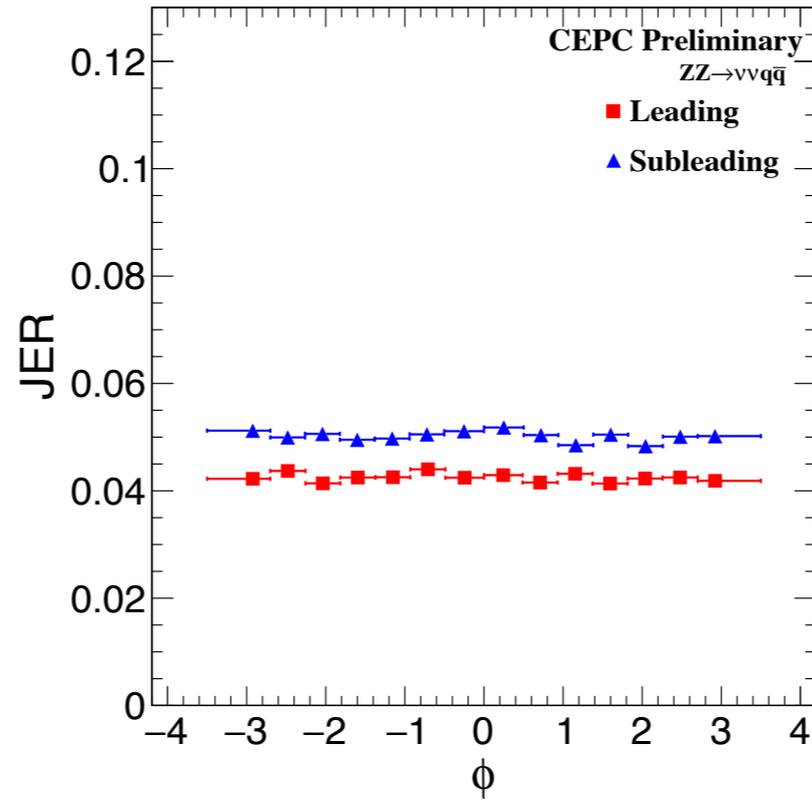
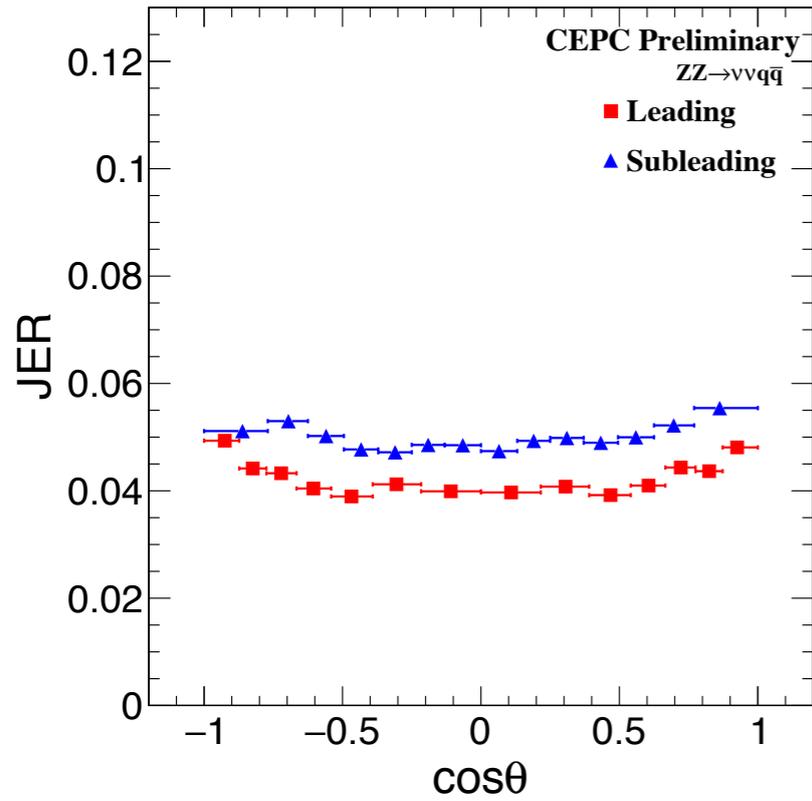
JAR(Reco-MCP)



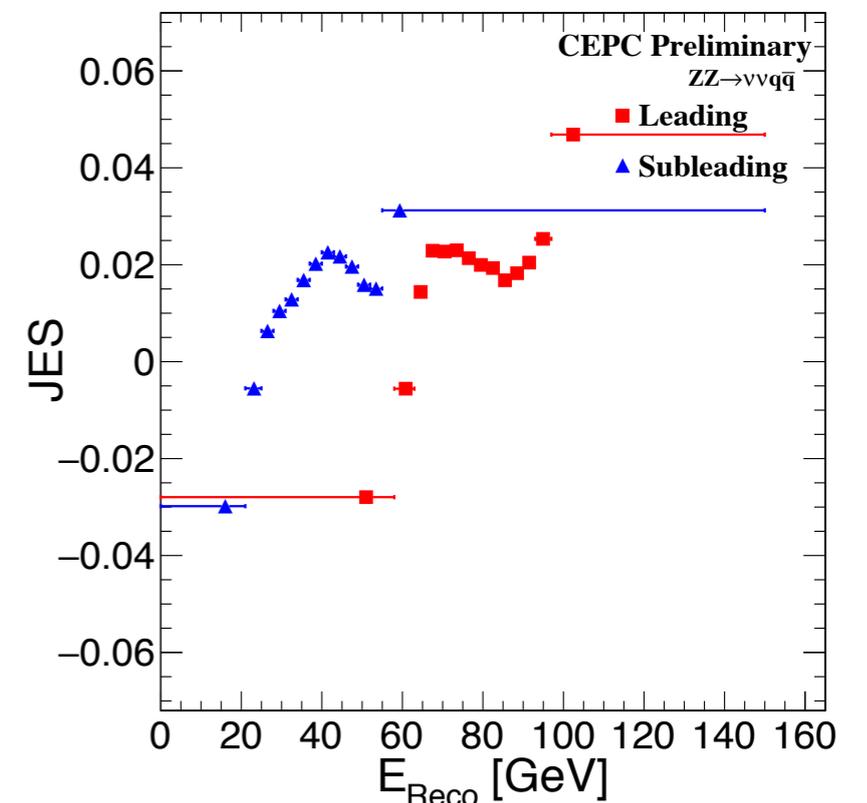
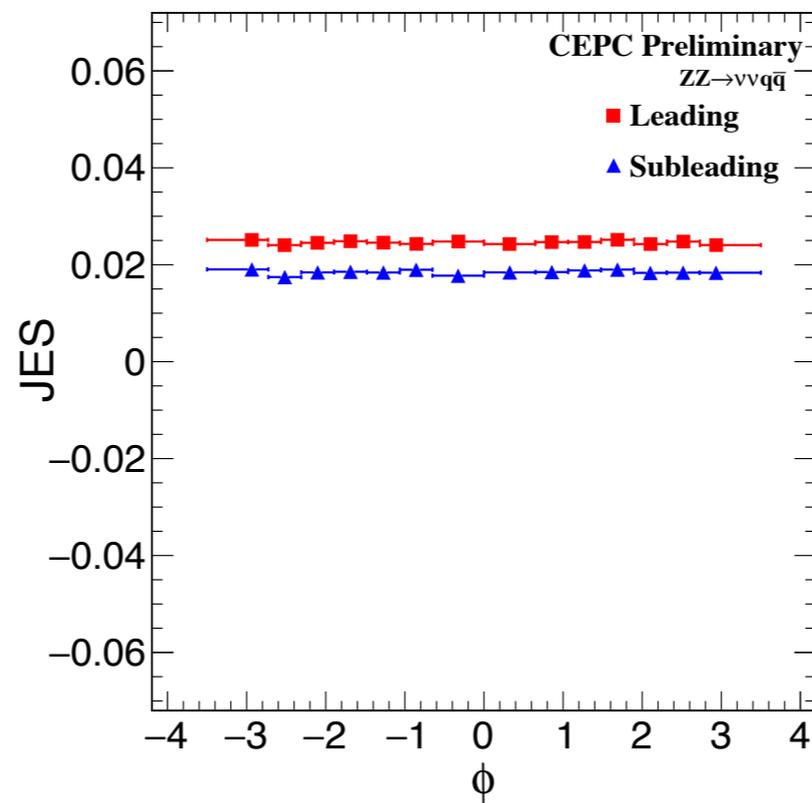
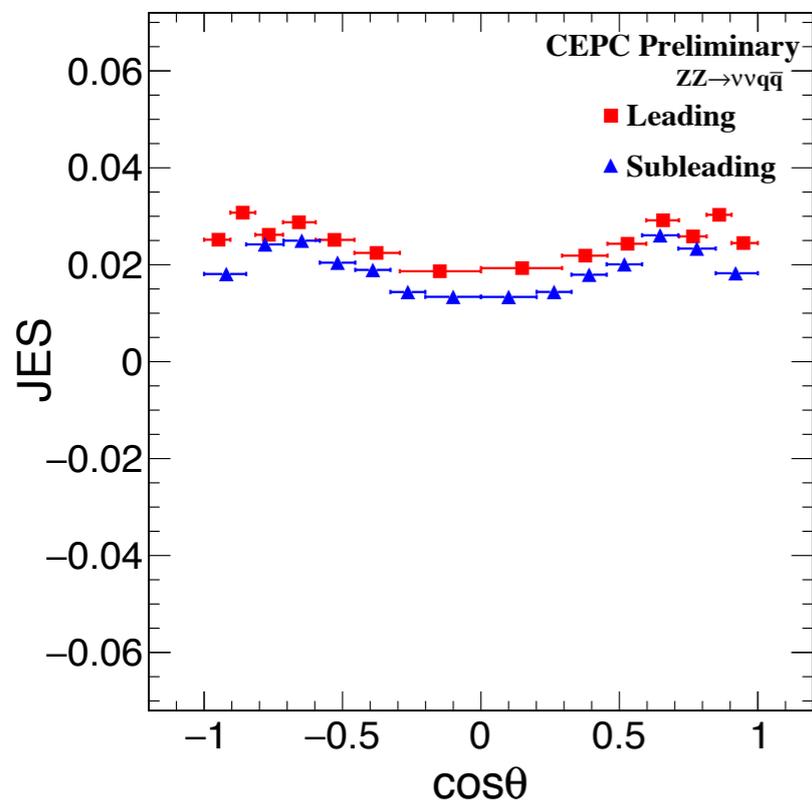
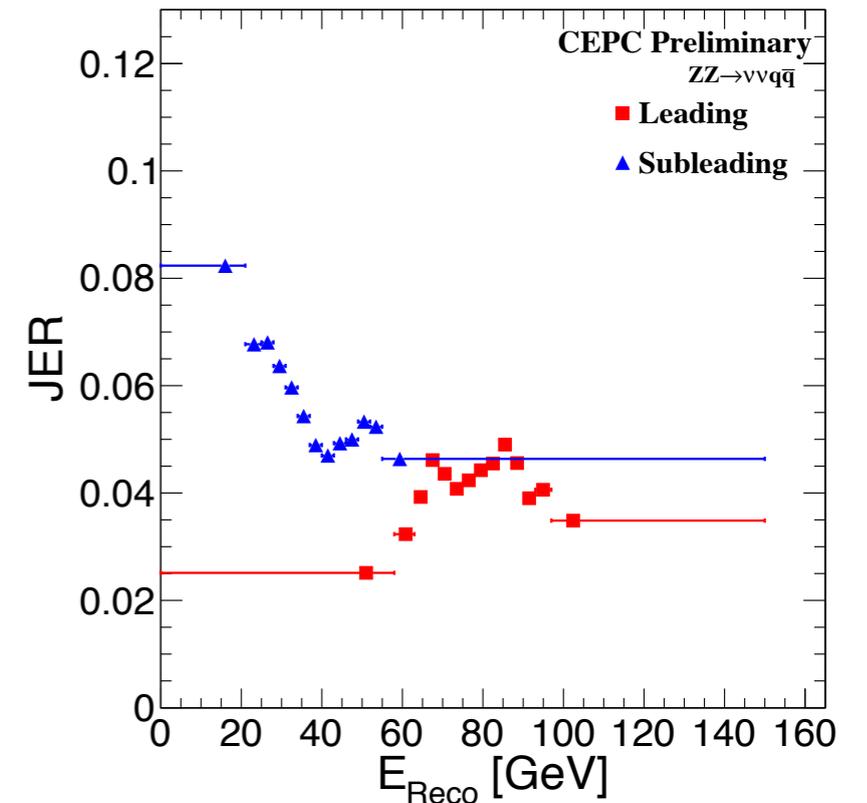
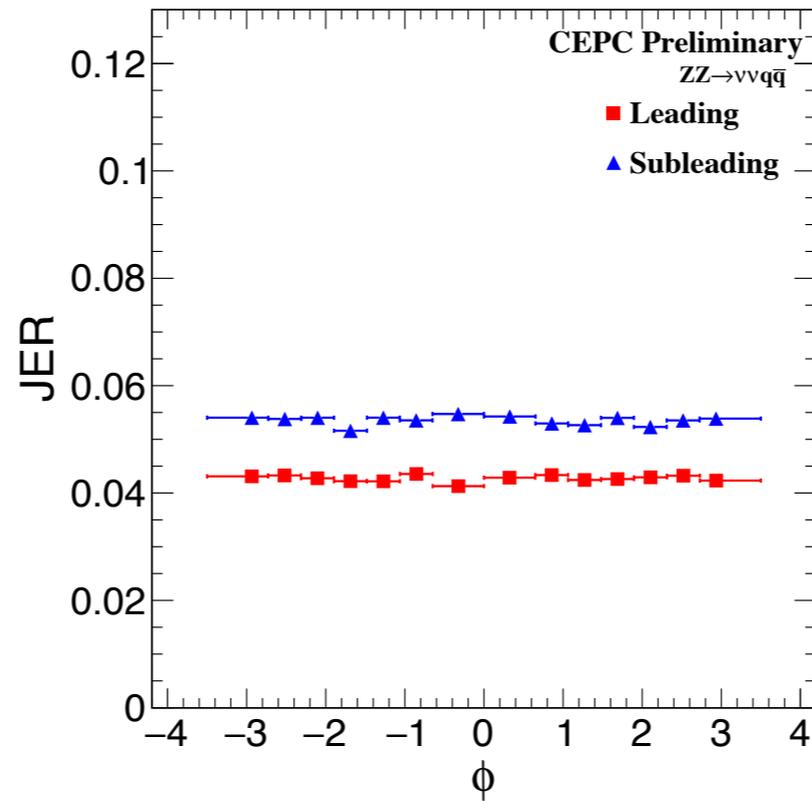
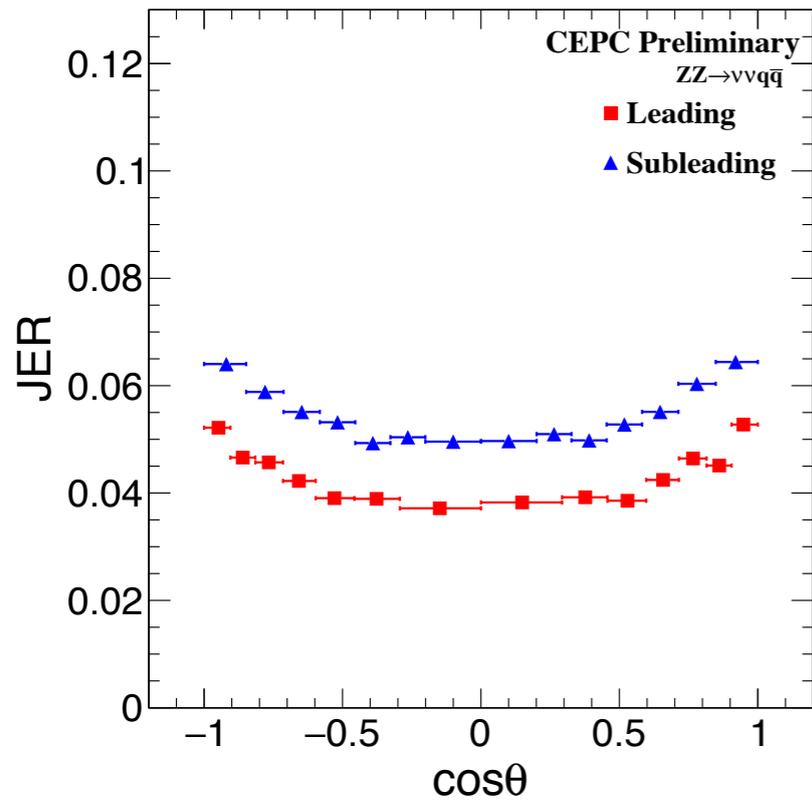




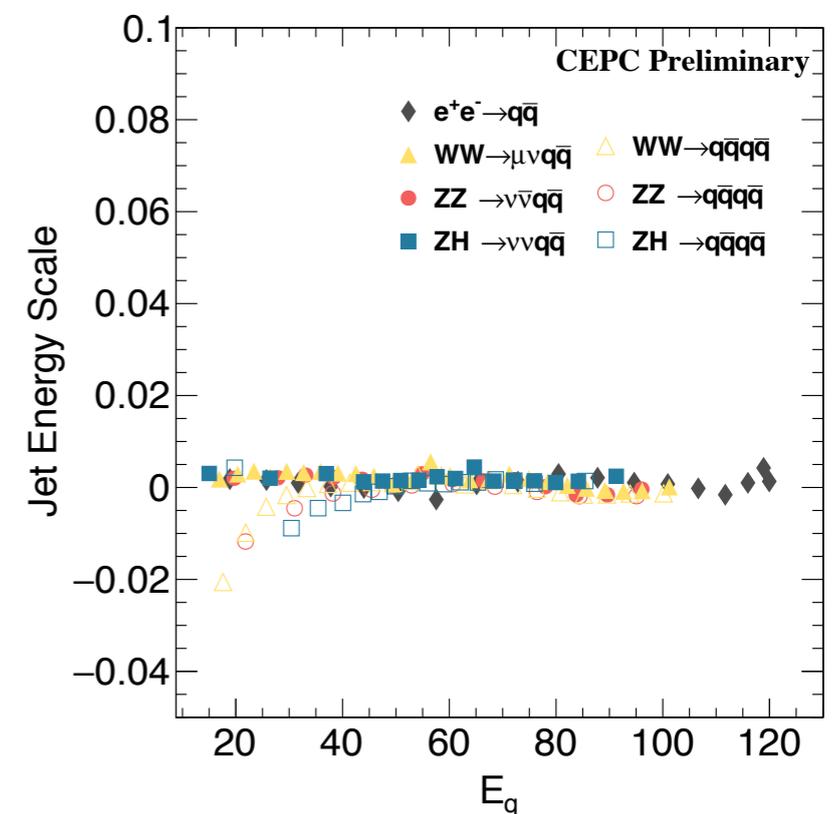
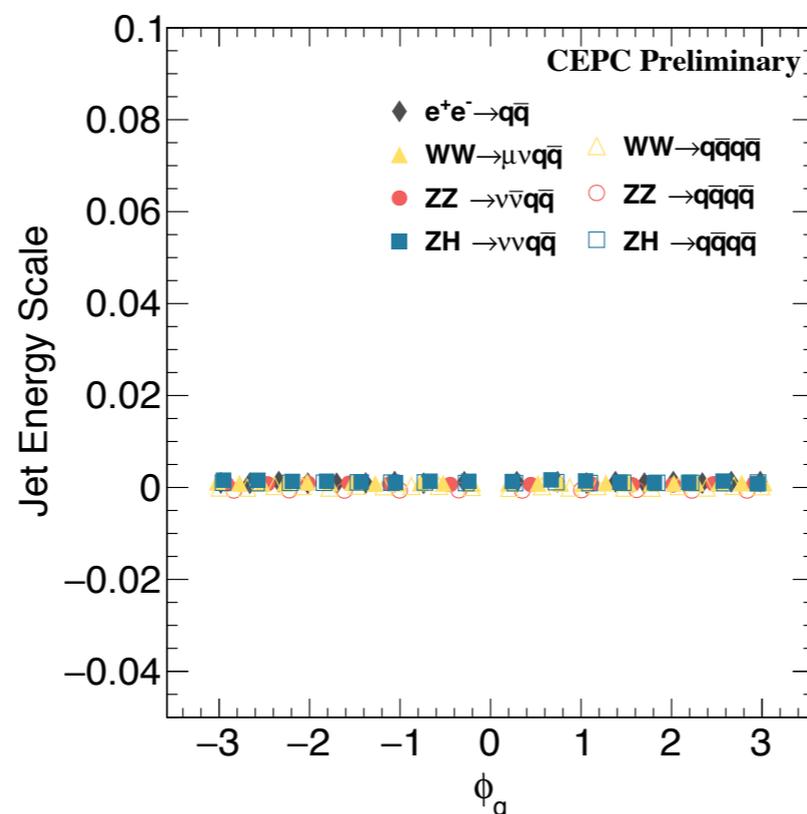
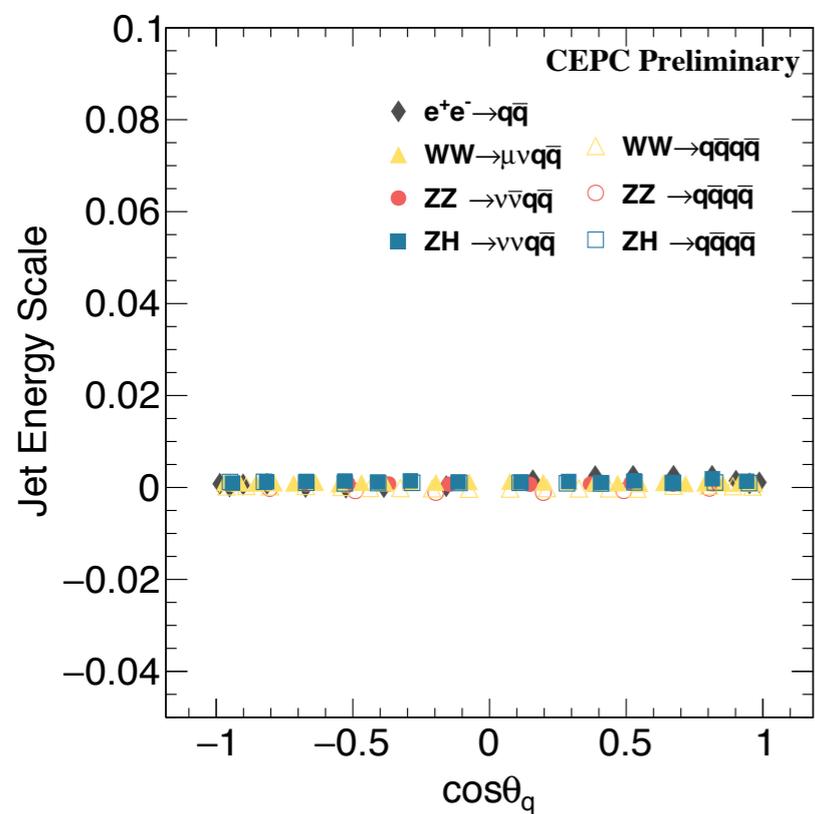
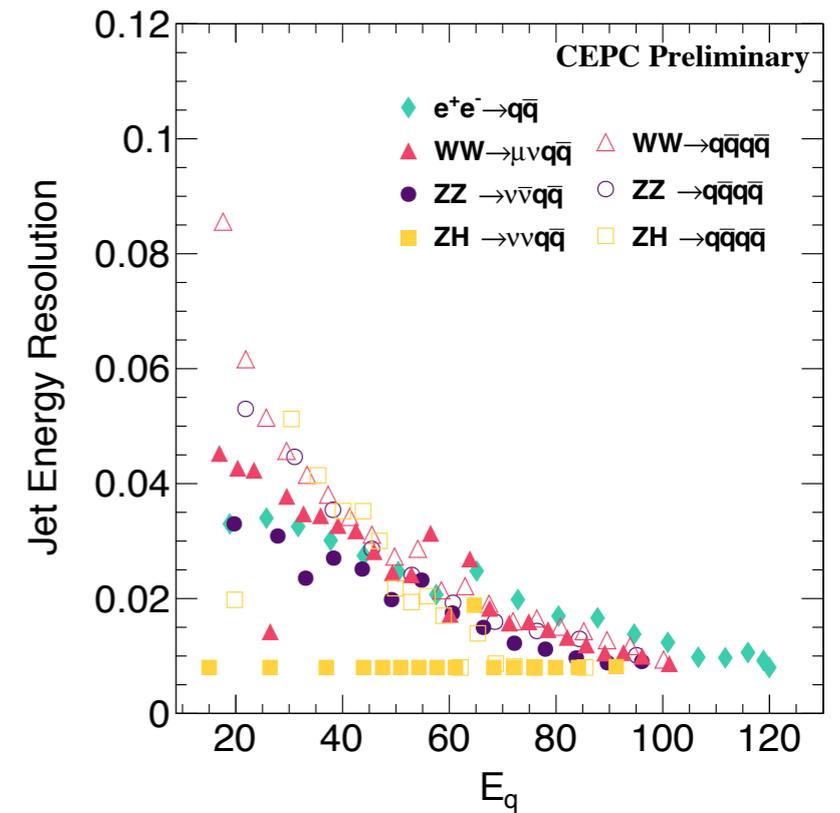
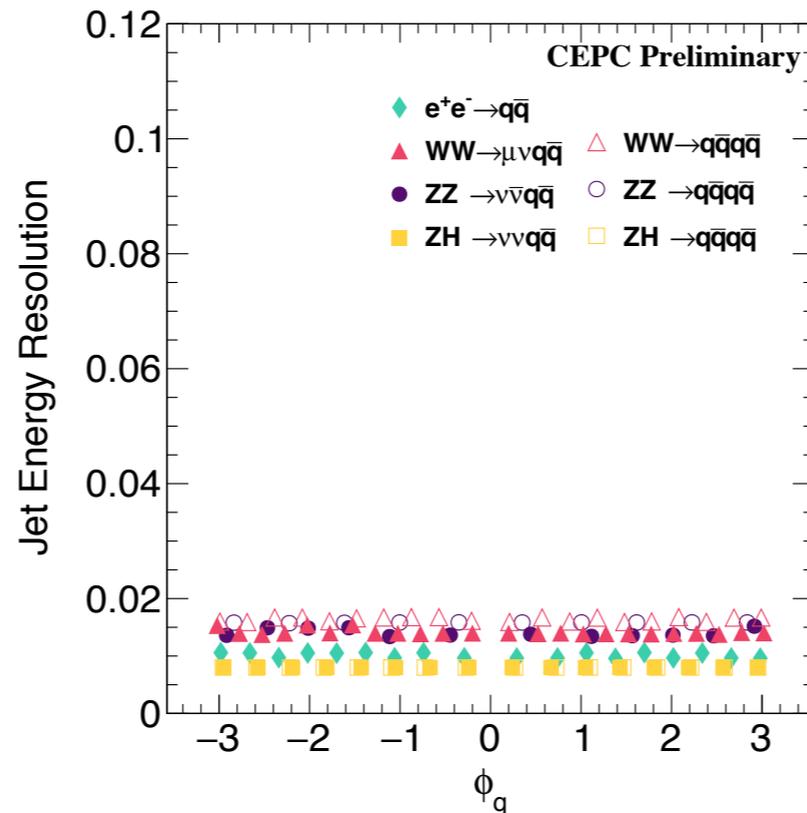
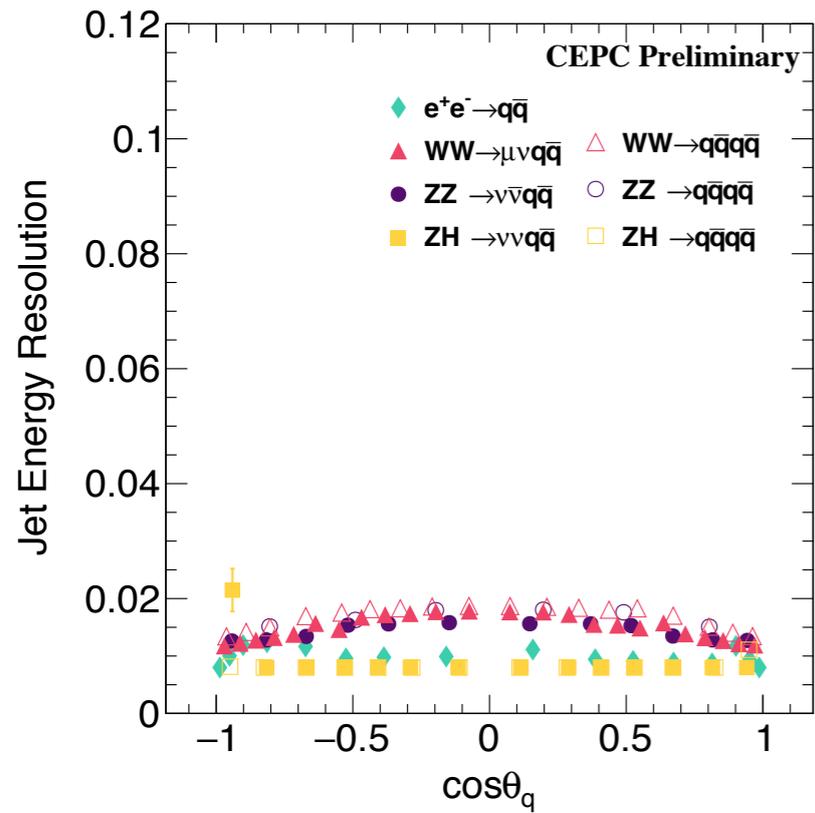
The jet clustering is independently on direction.

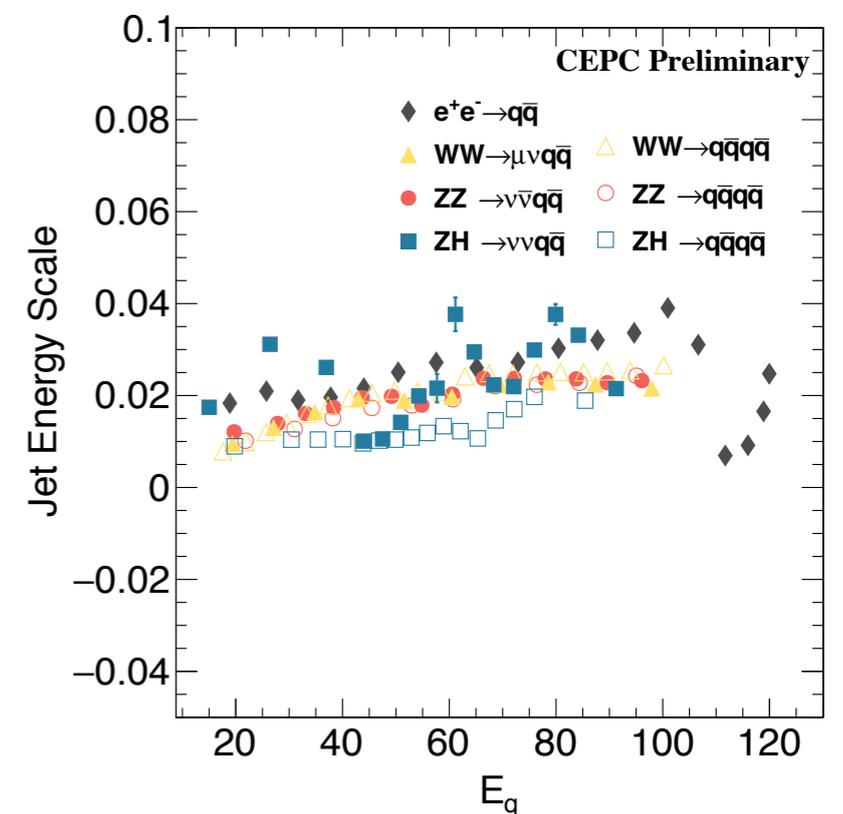
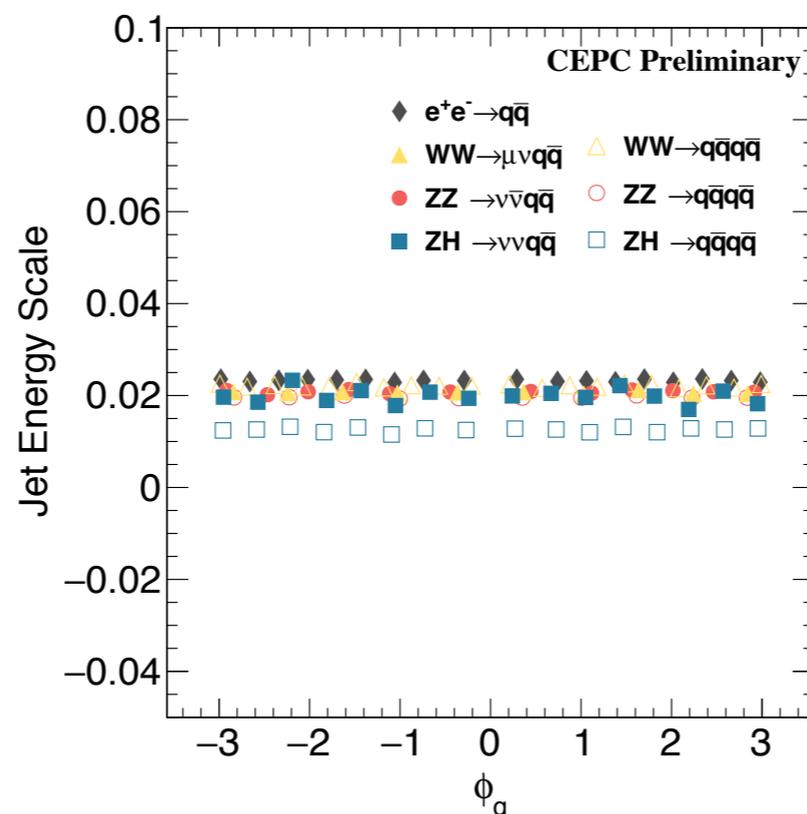
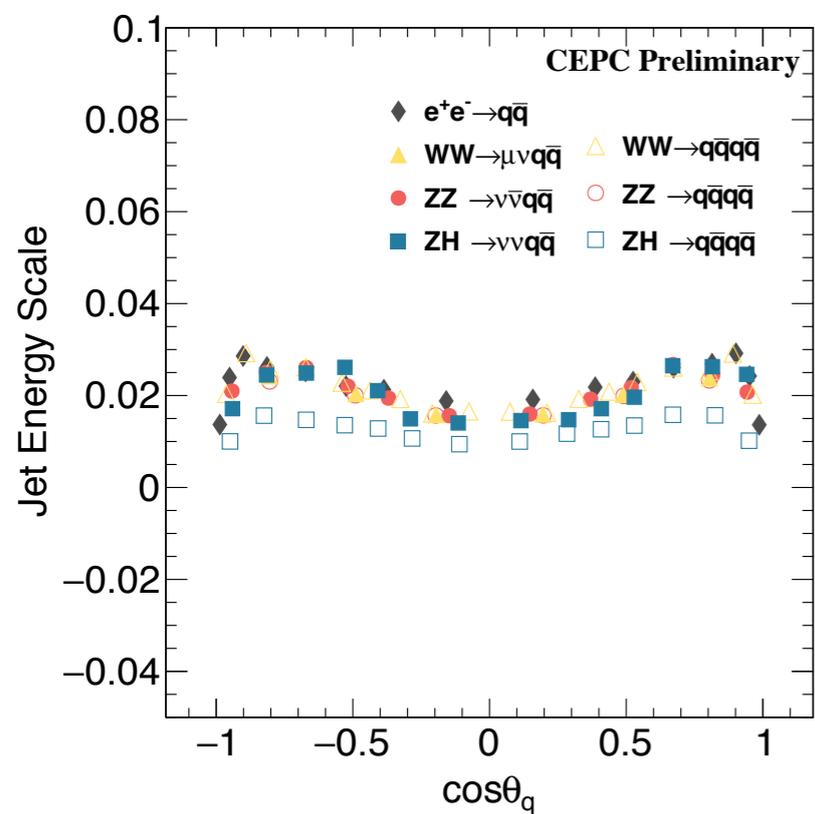
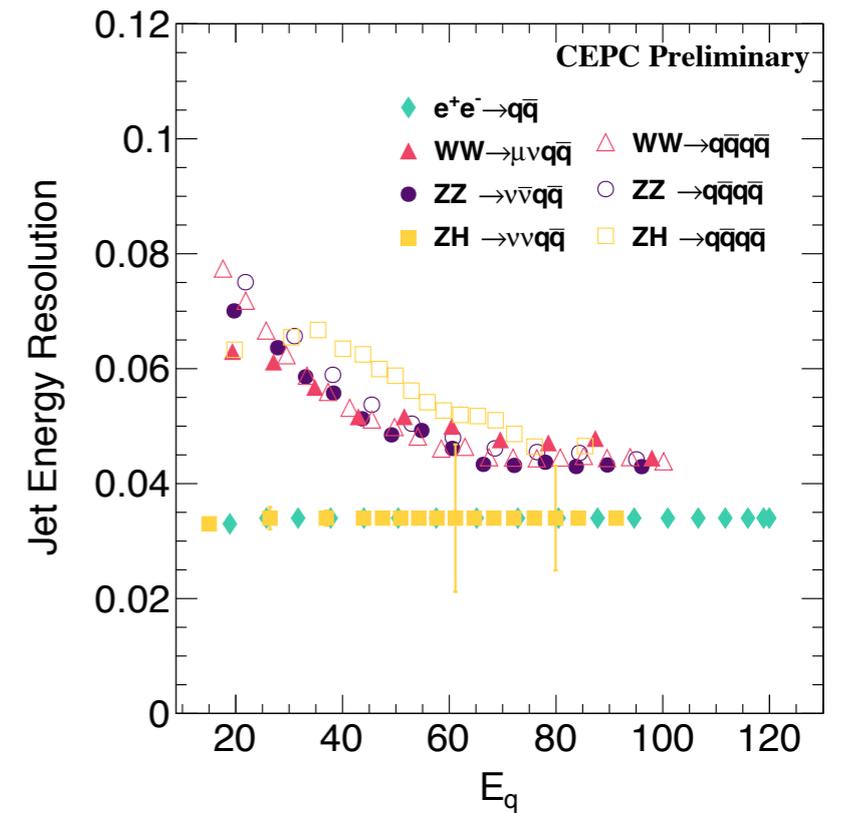
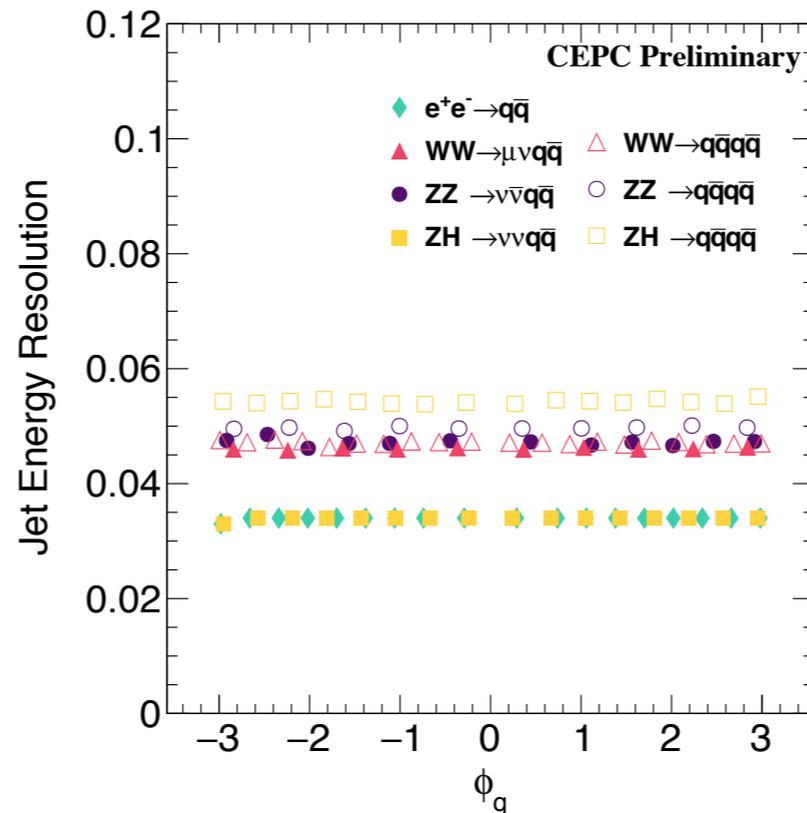
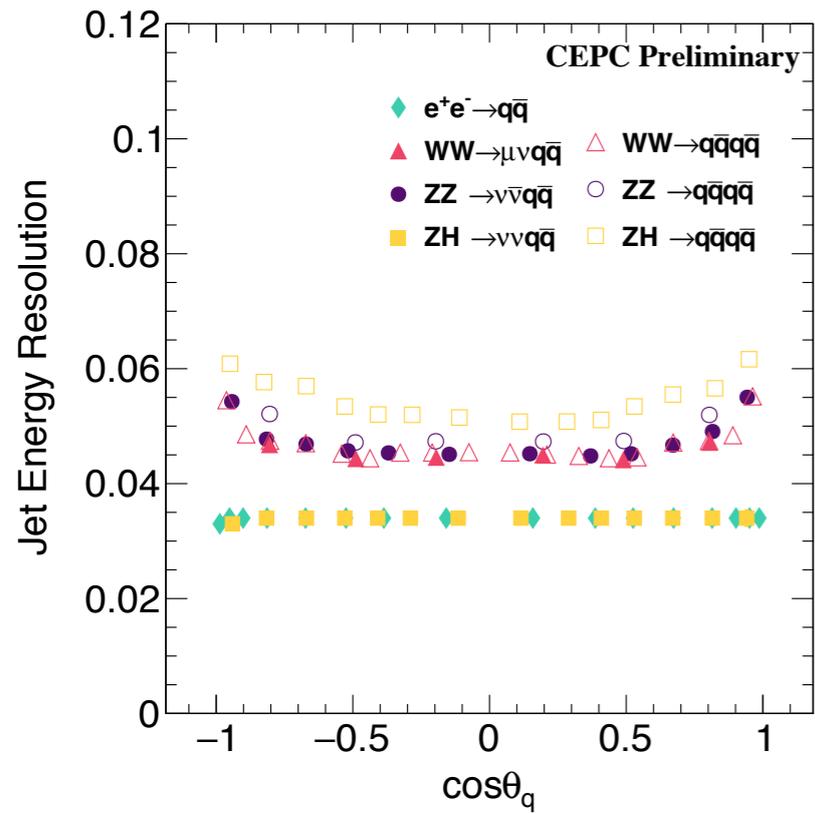


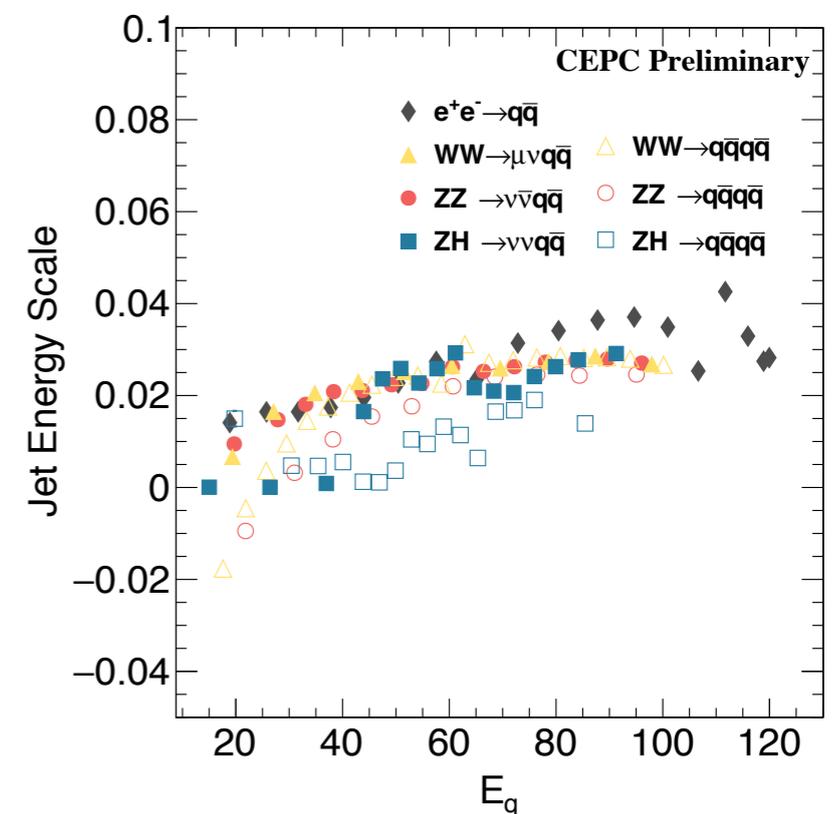
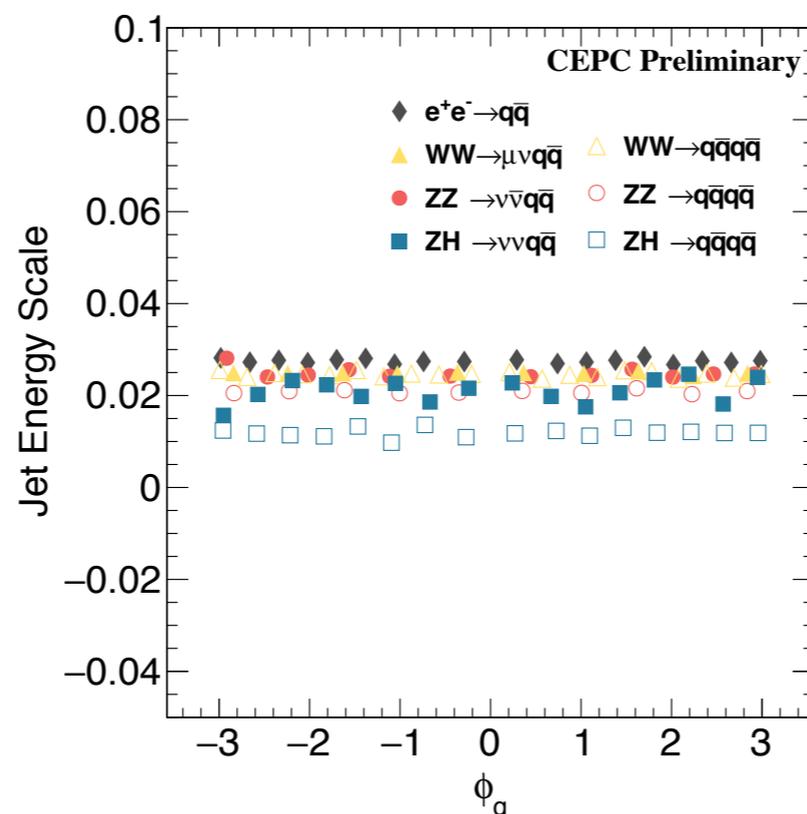
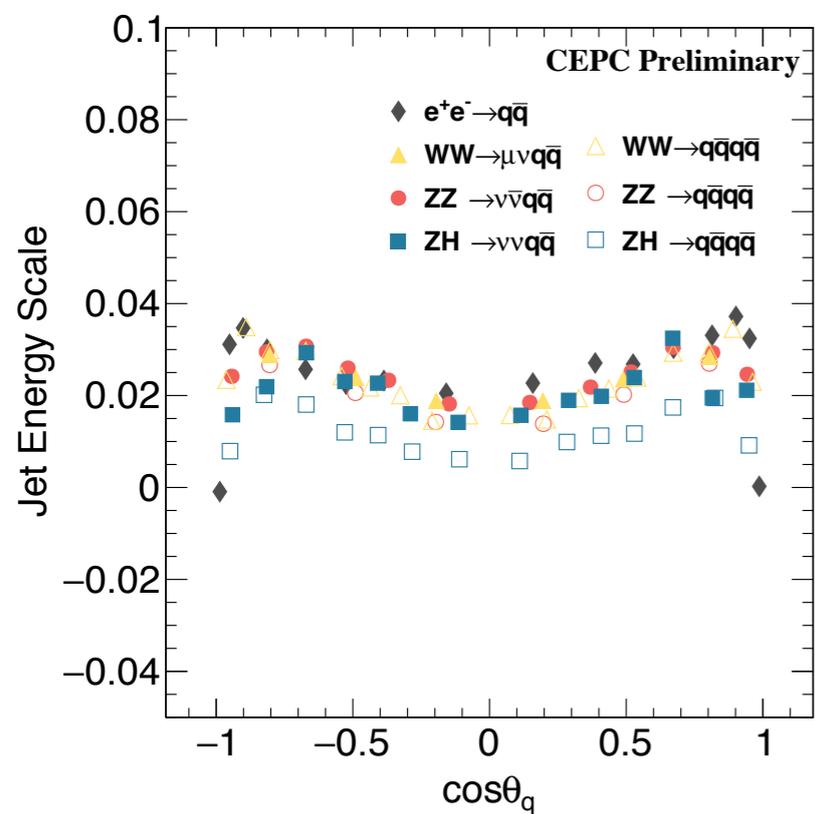
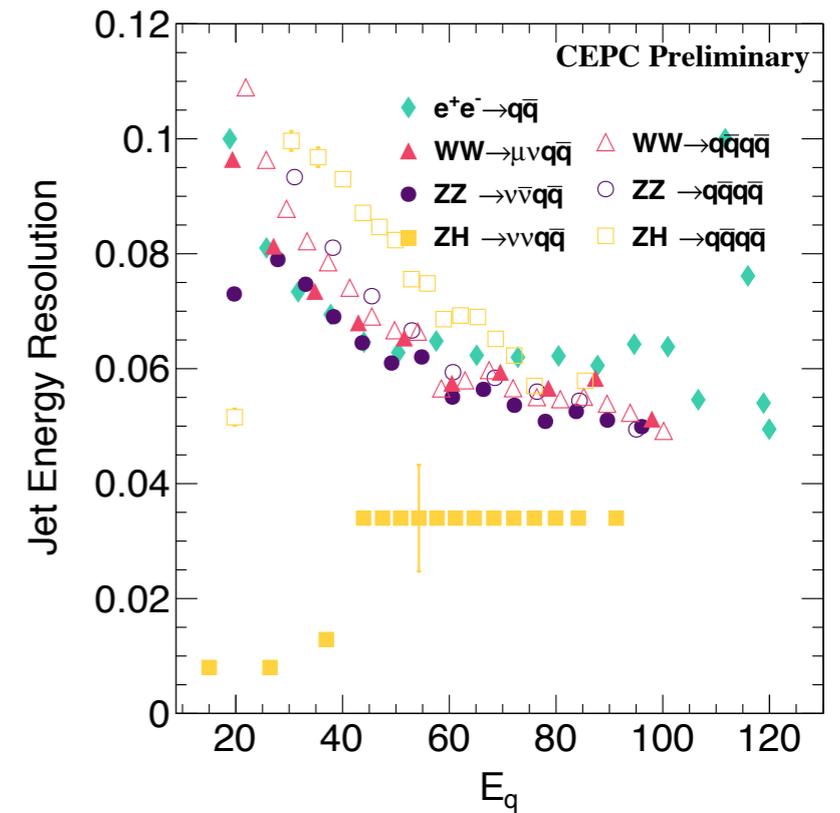
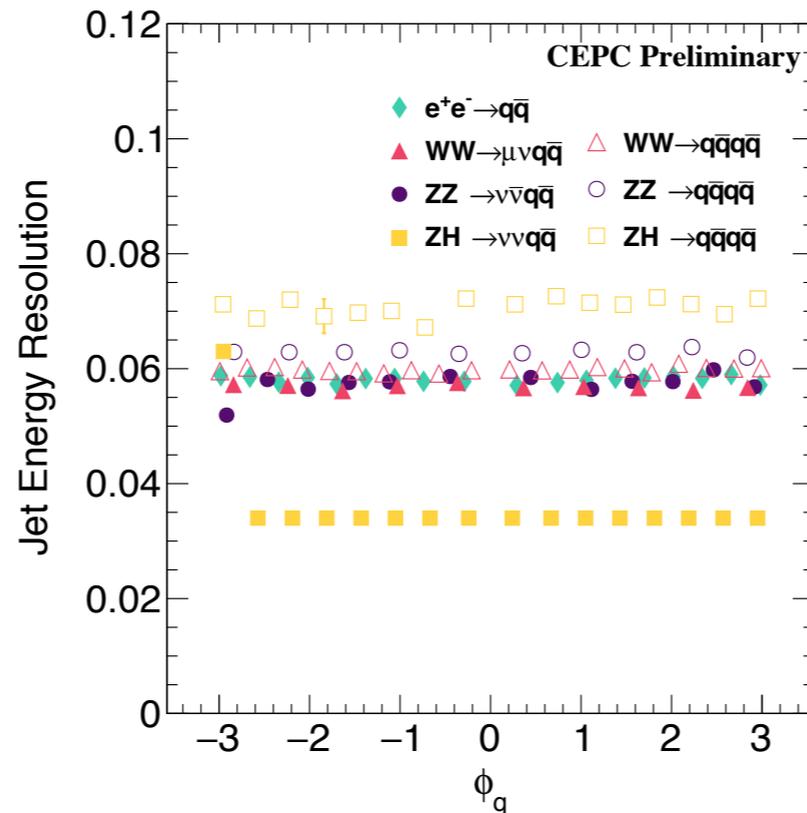
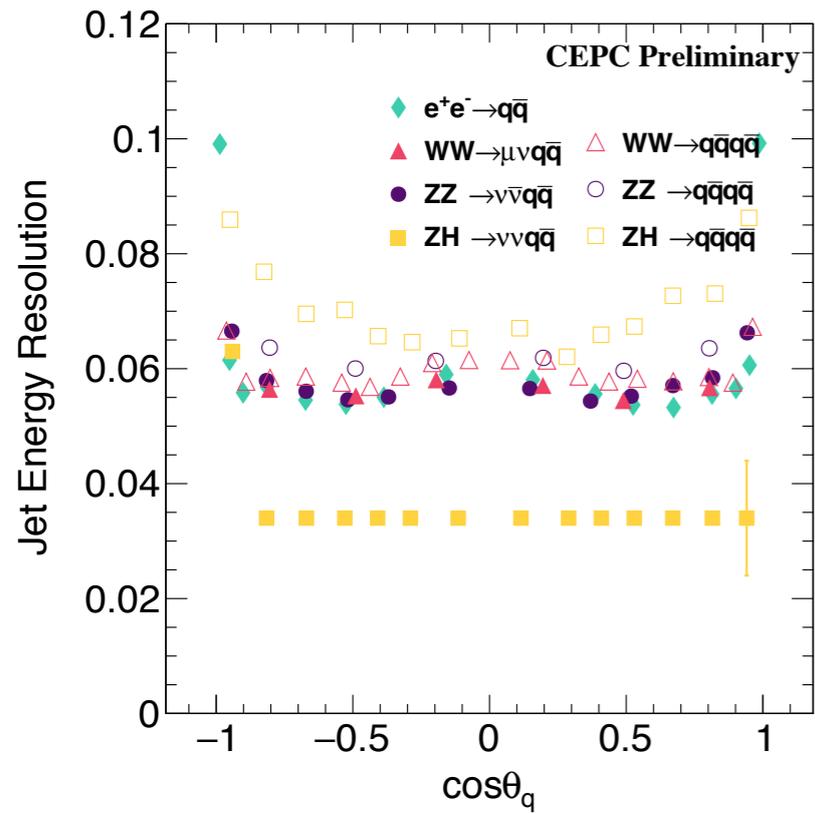
Both JER/JES slightly depend on $\cos\theta$.

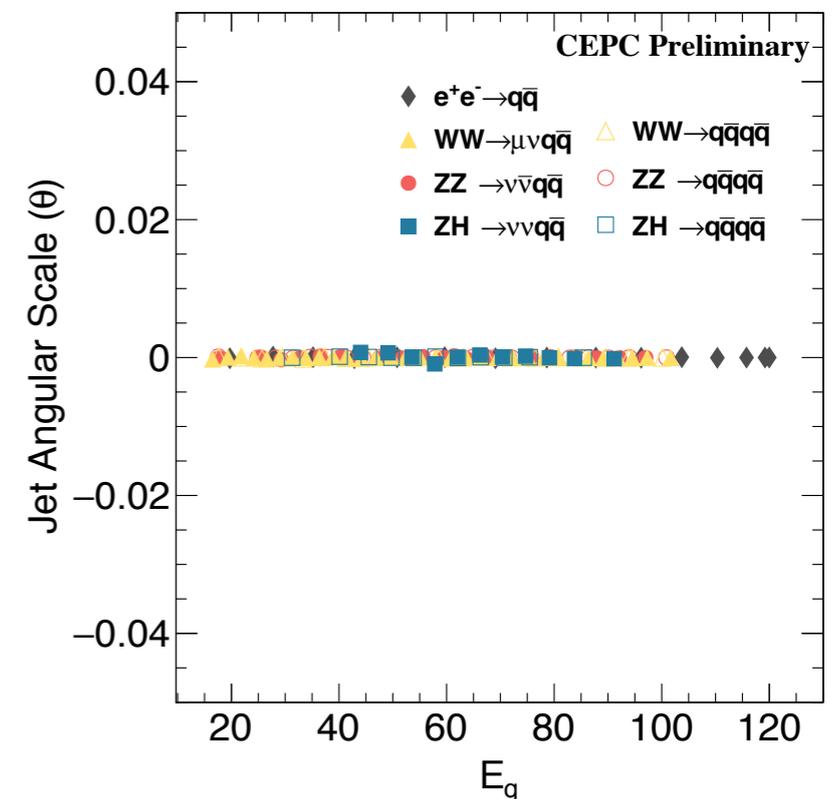
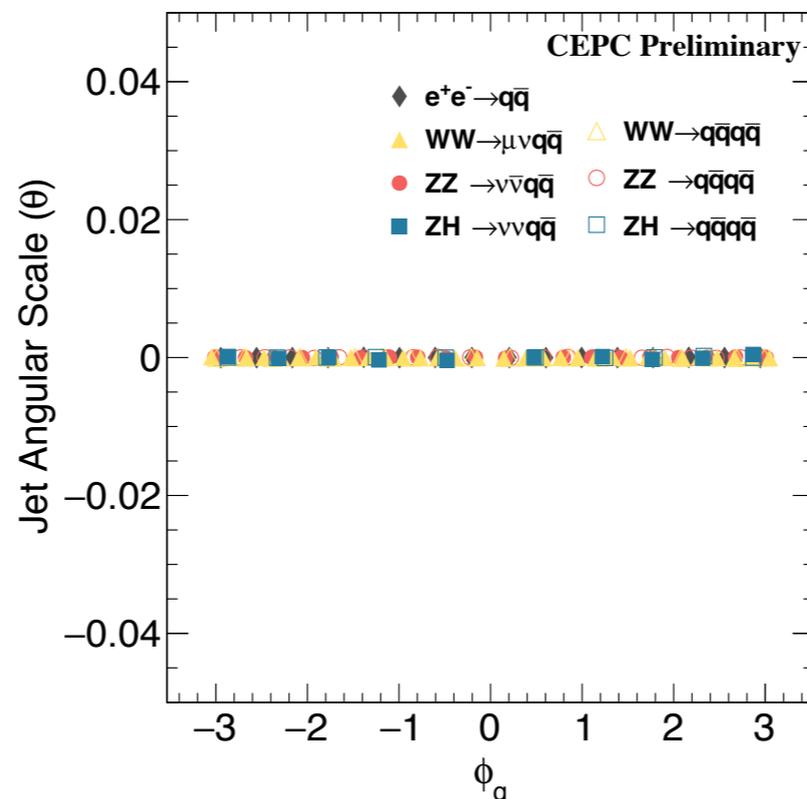
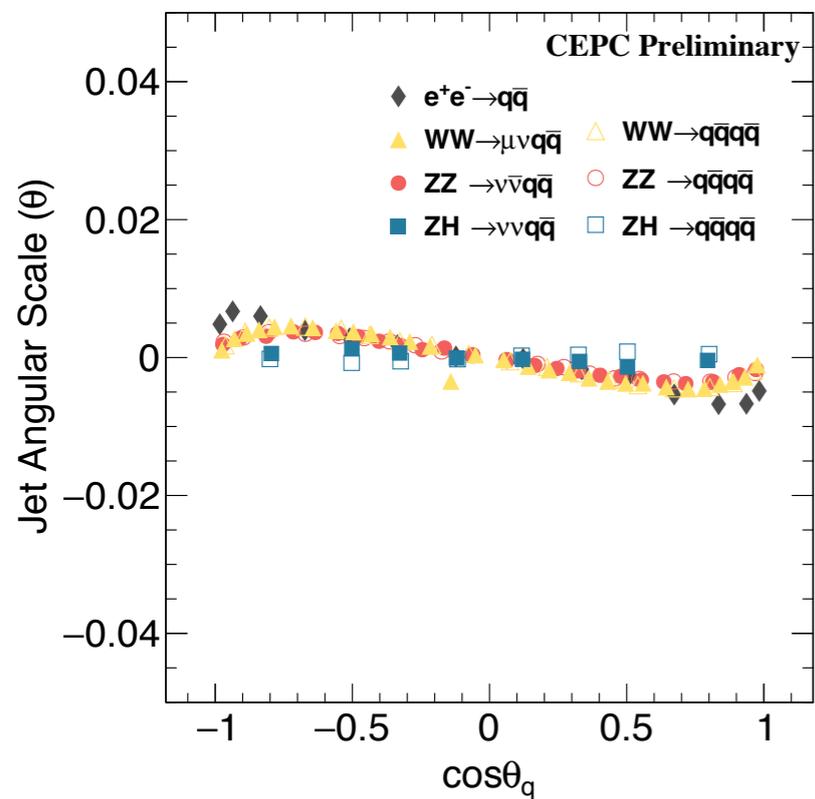
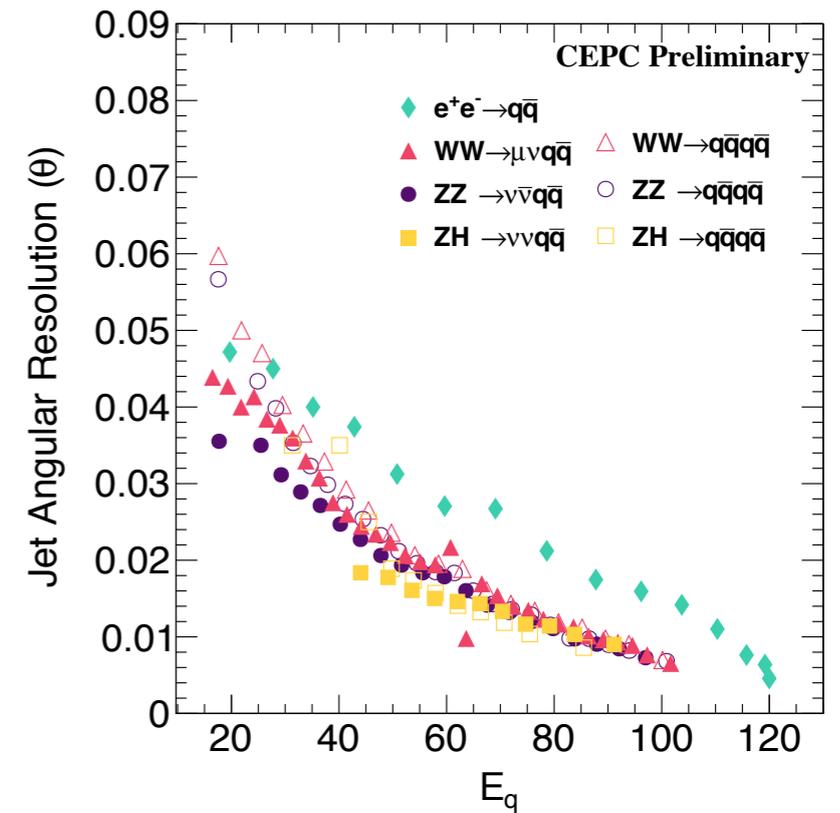
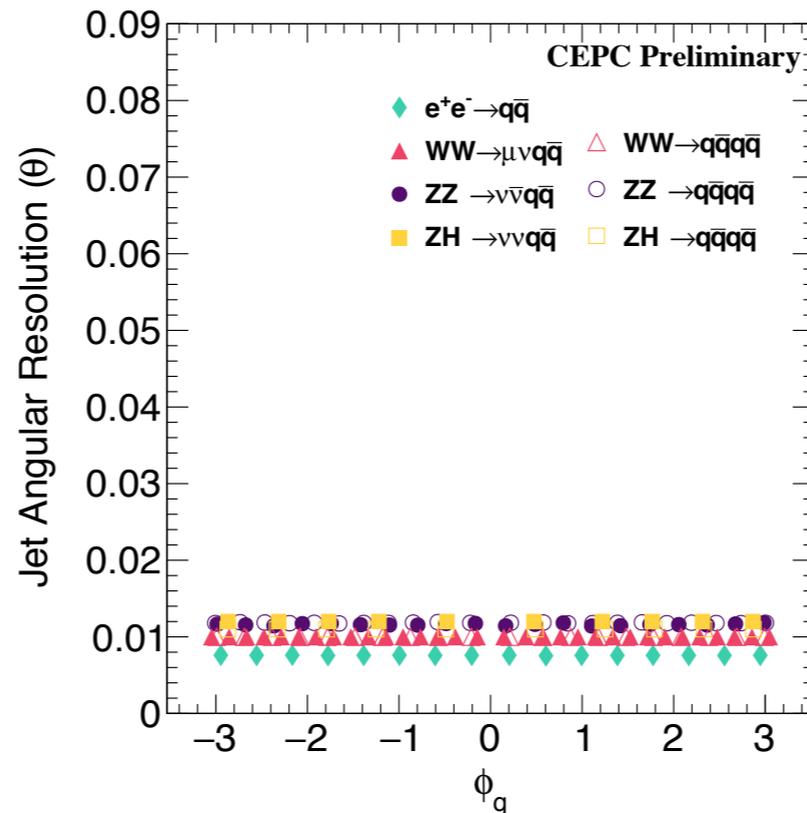
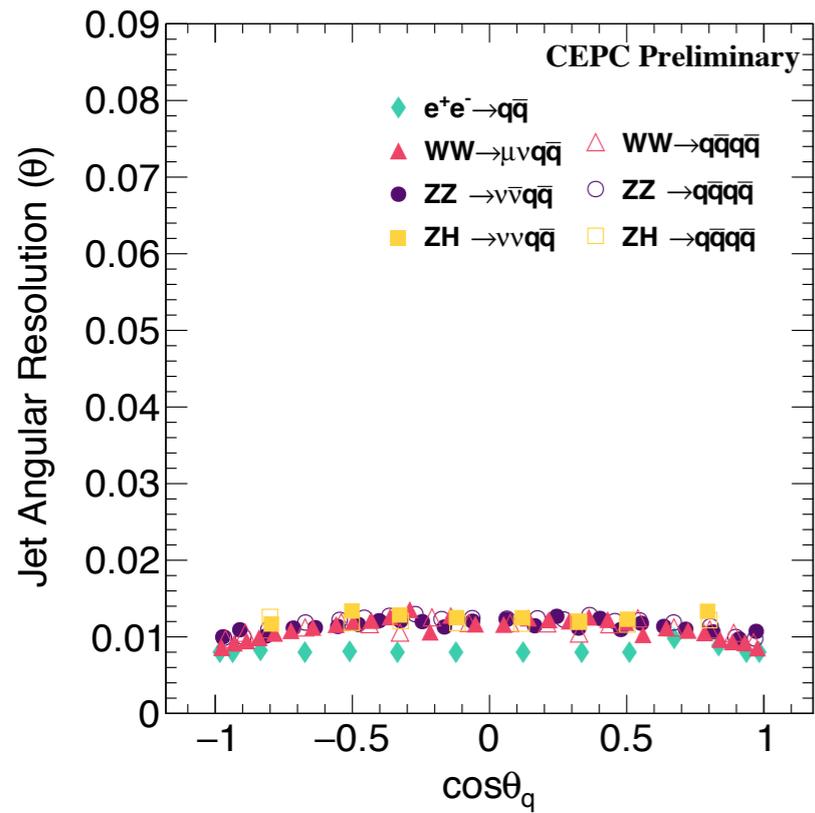


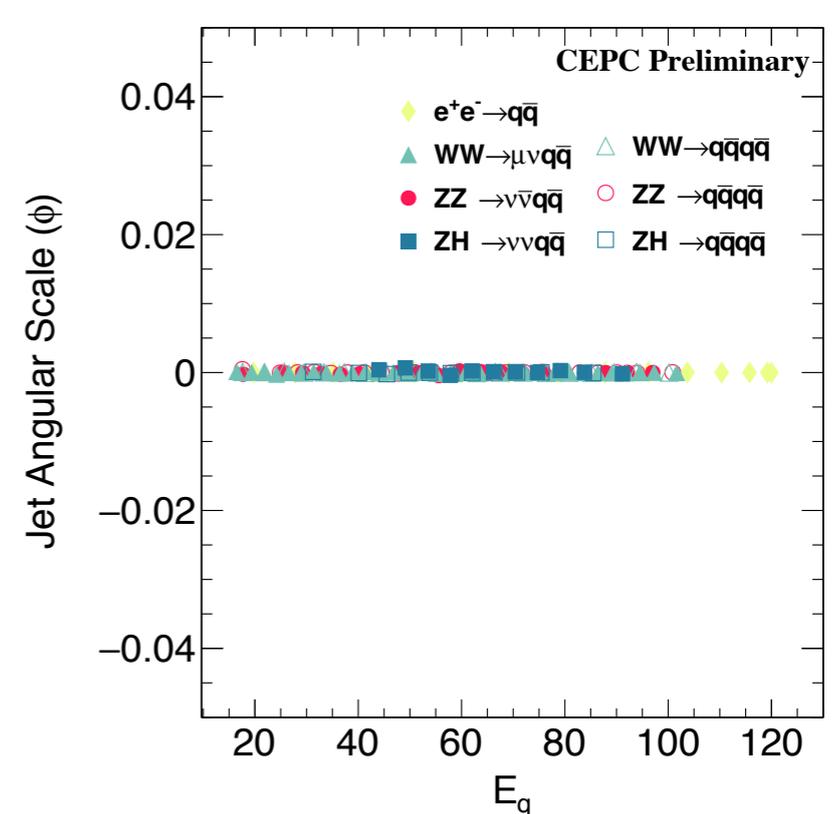
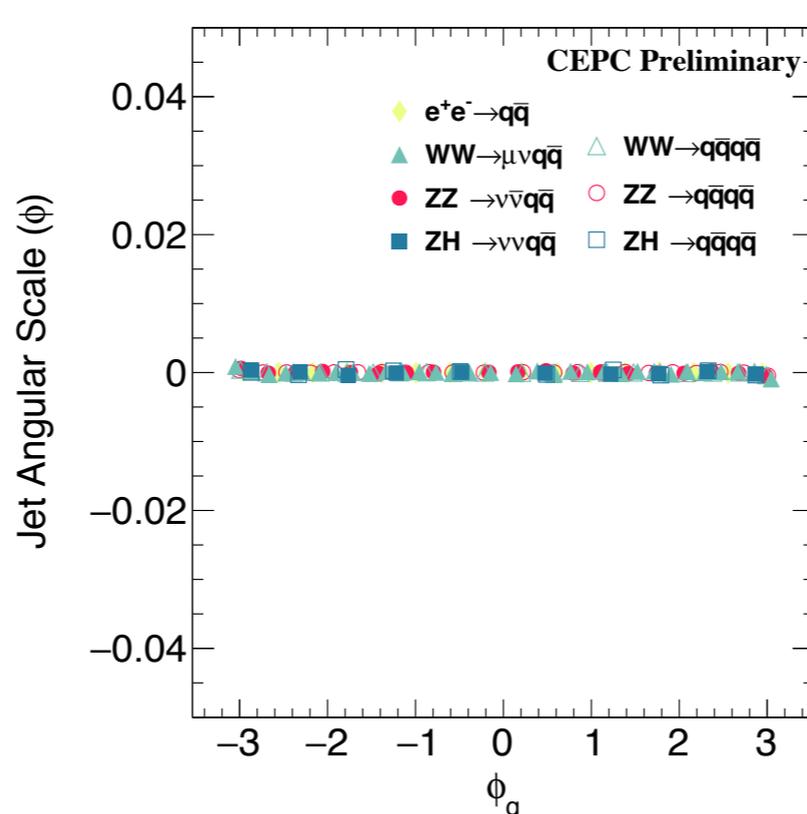
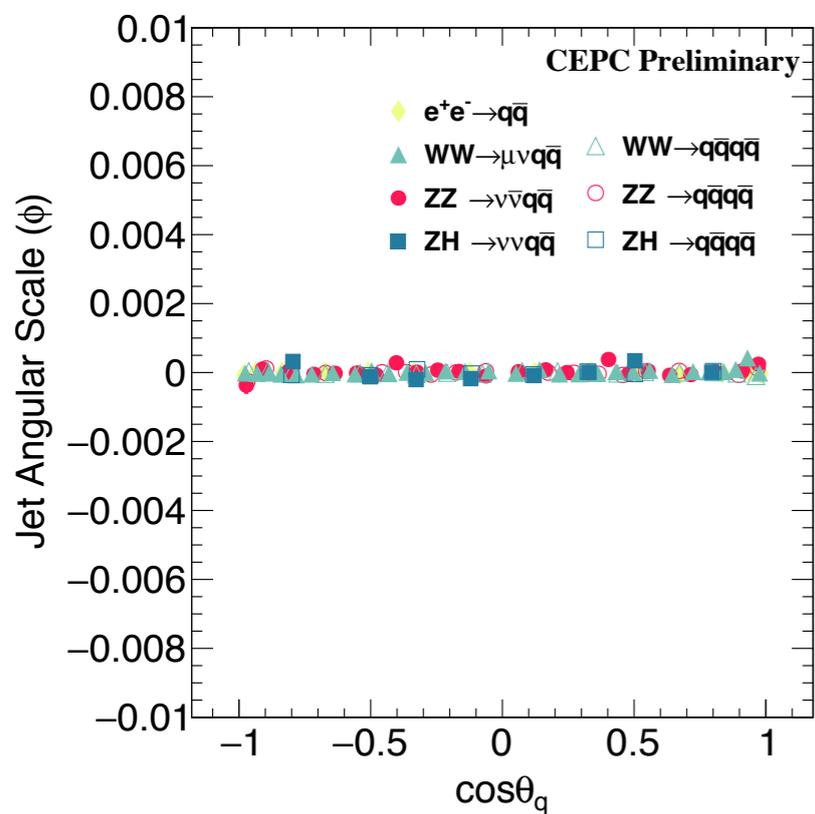
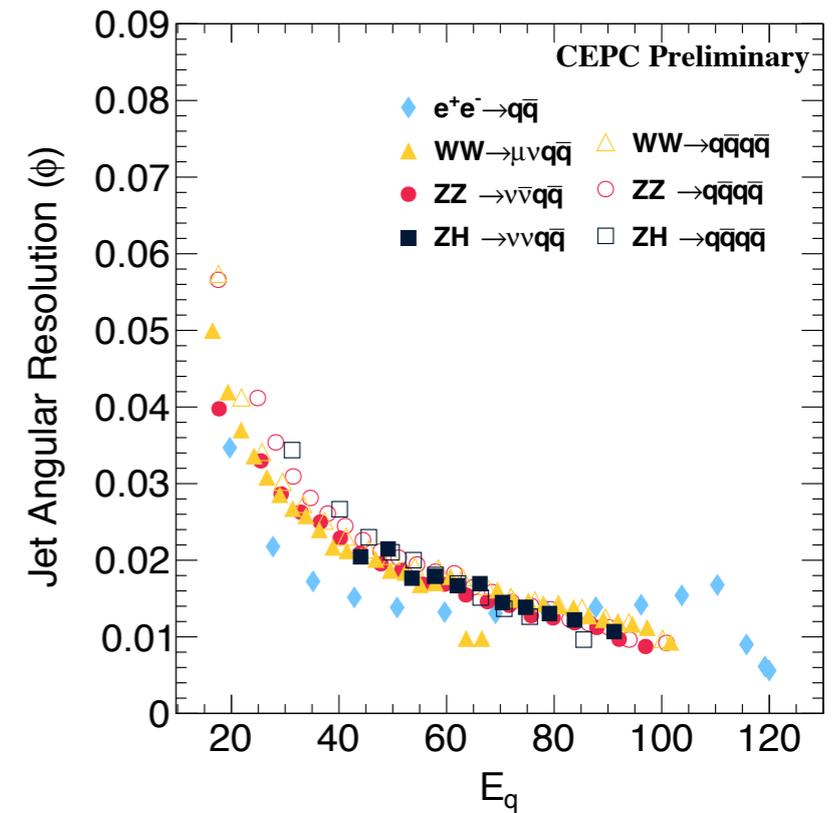
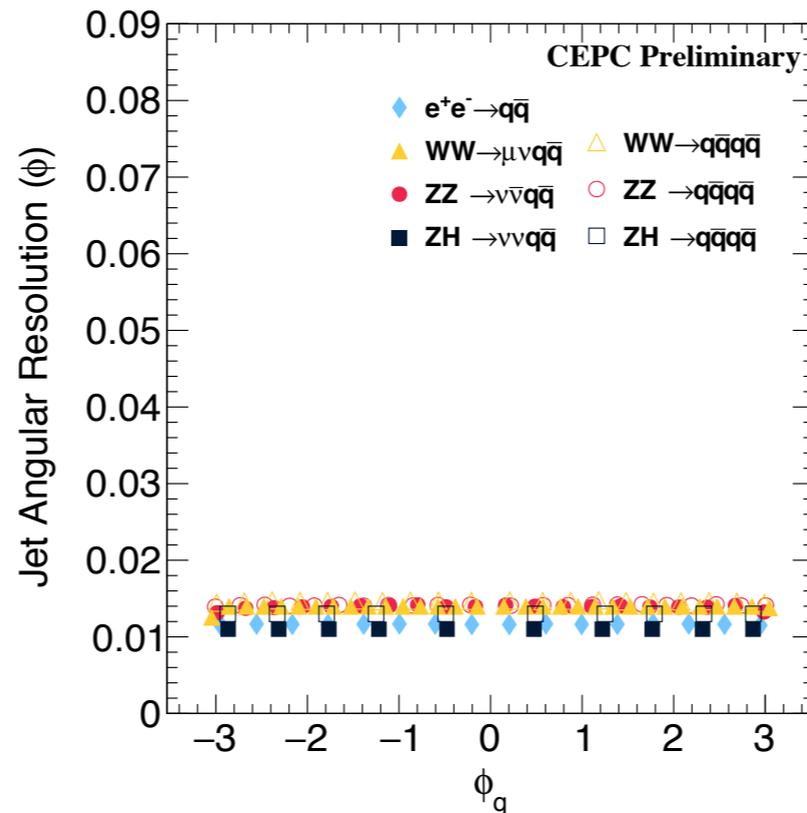
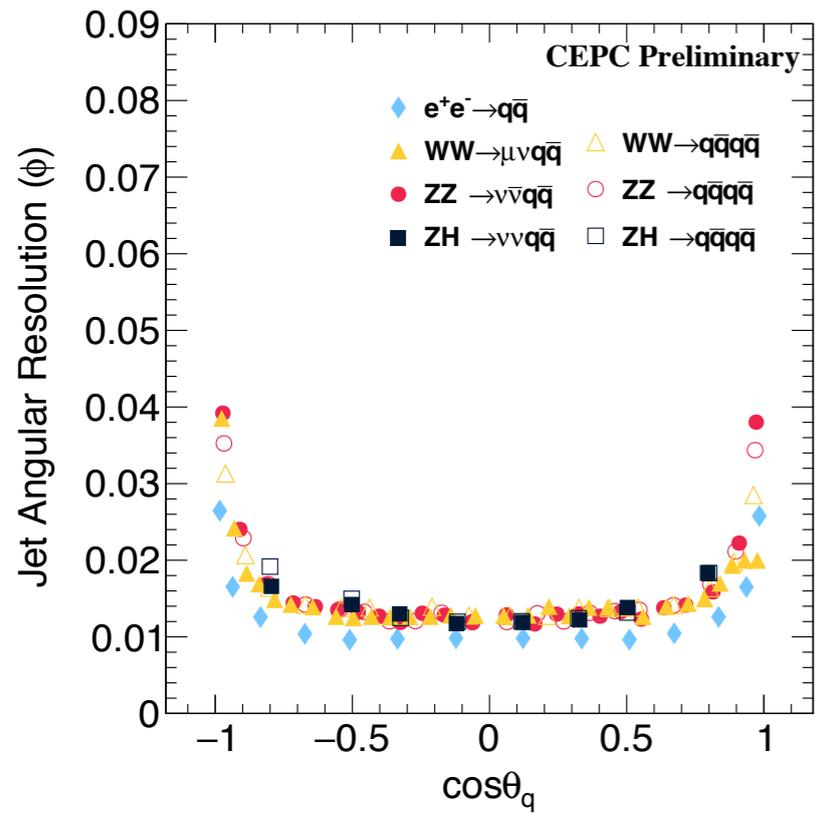
The varying of JER/JES as a function of the $\cos\theta$ is within 3%.

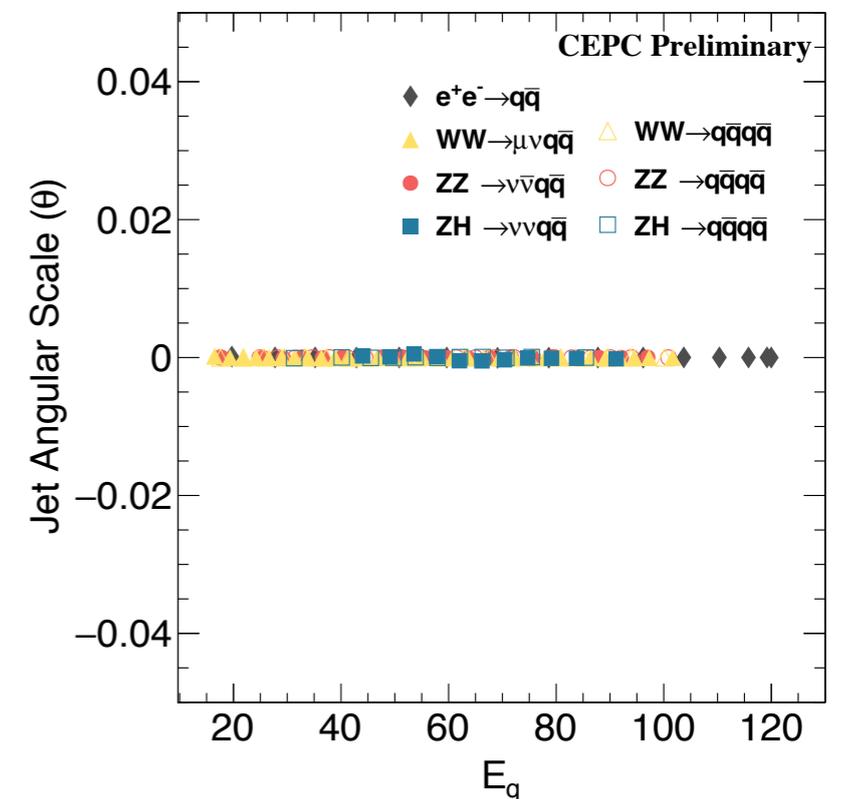
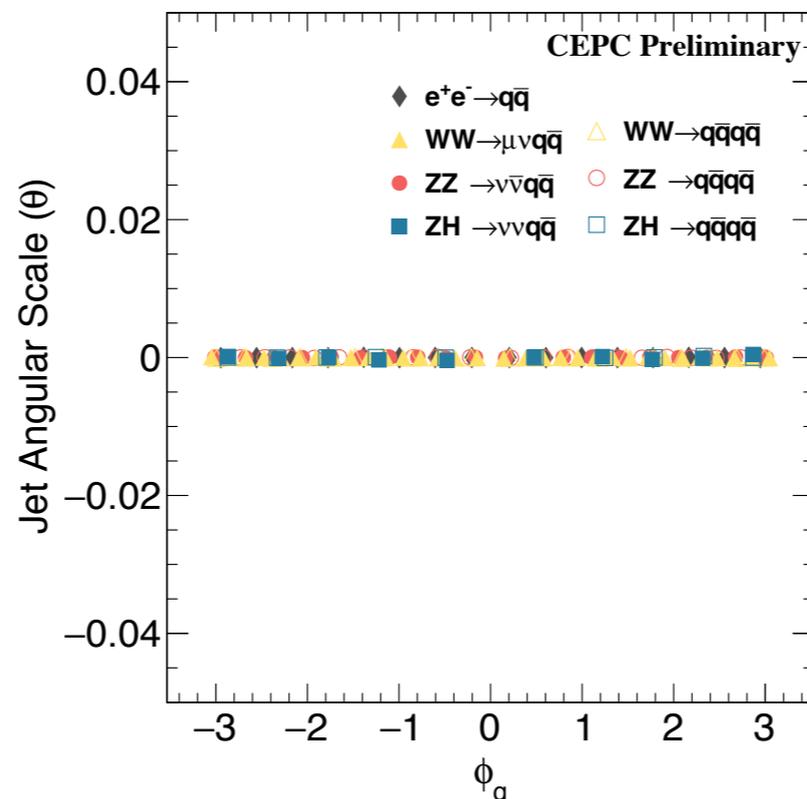
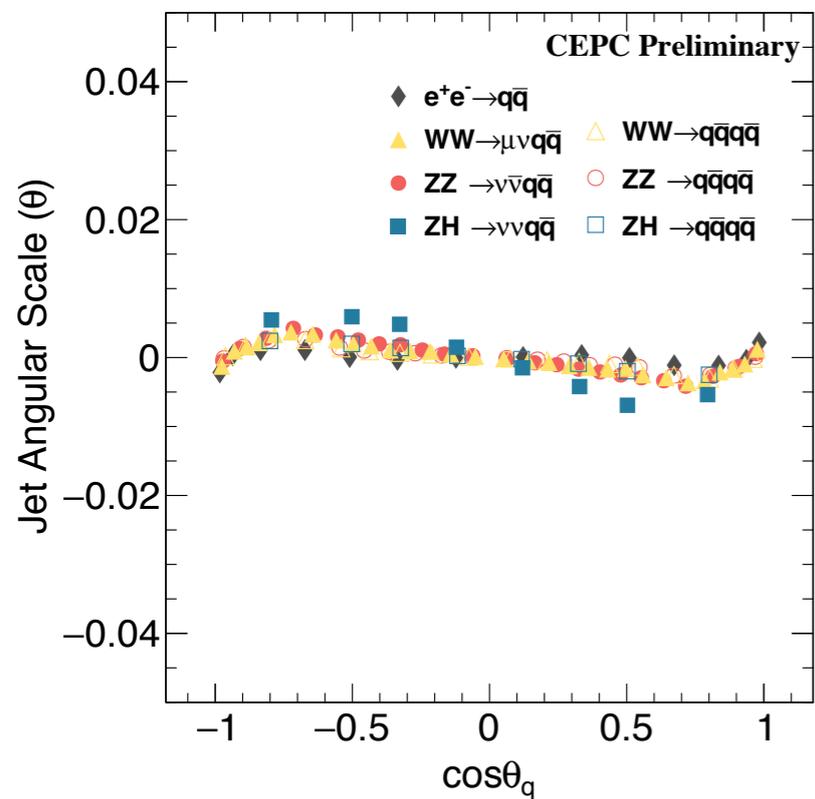
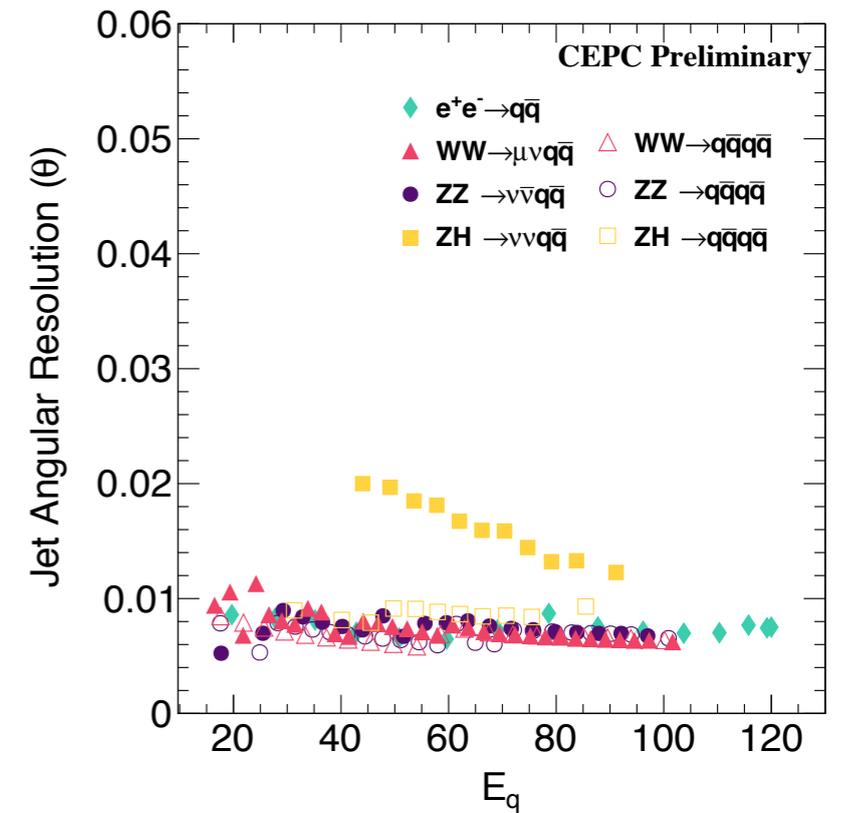
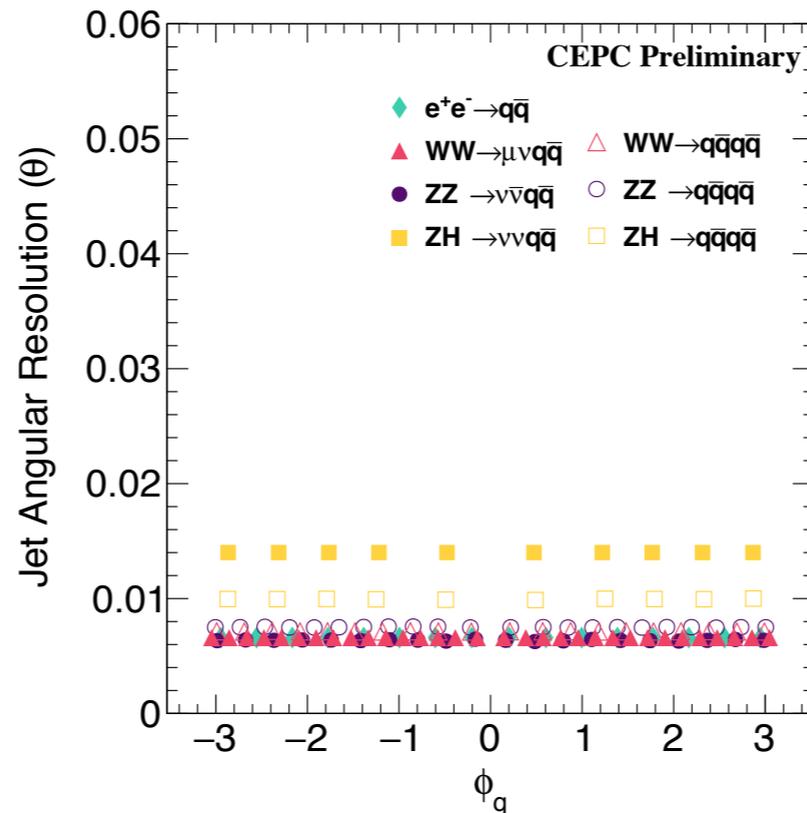
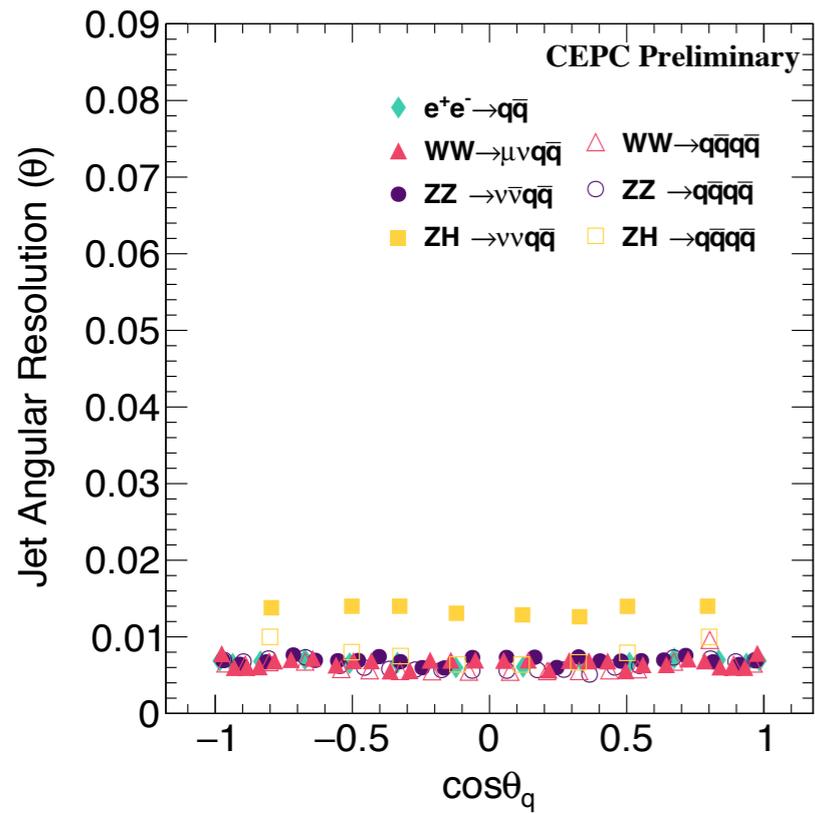


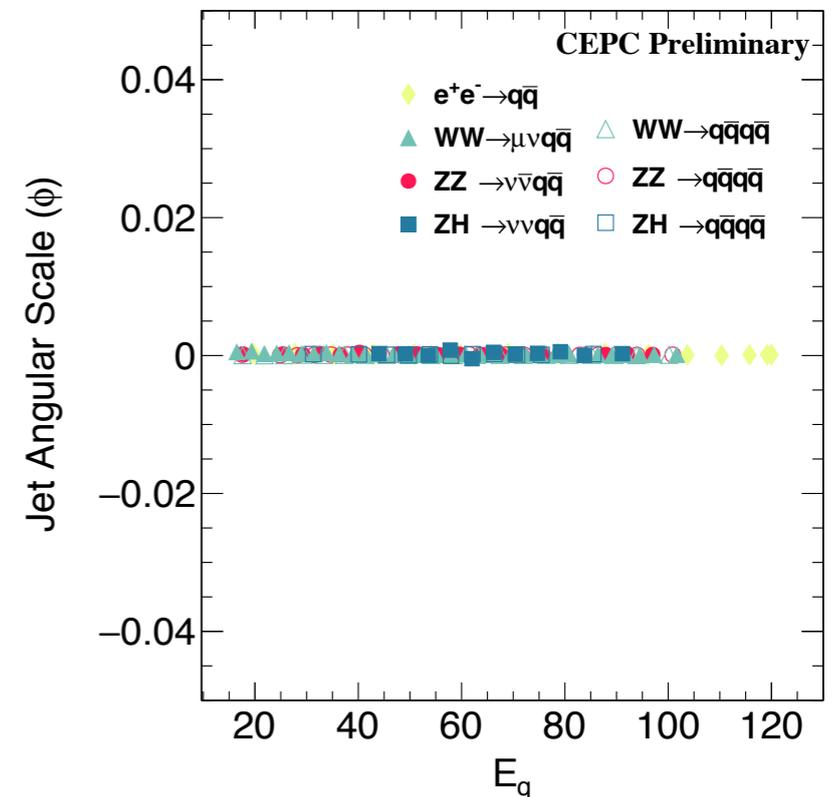
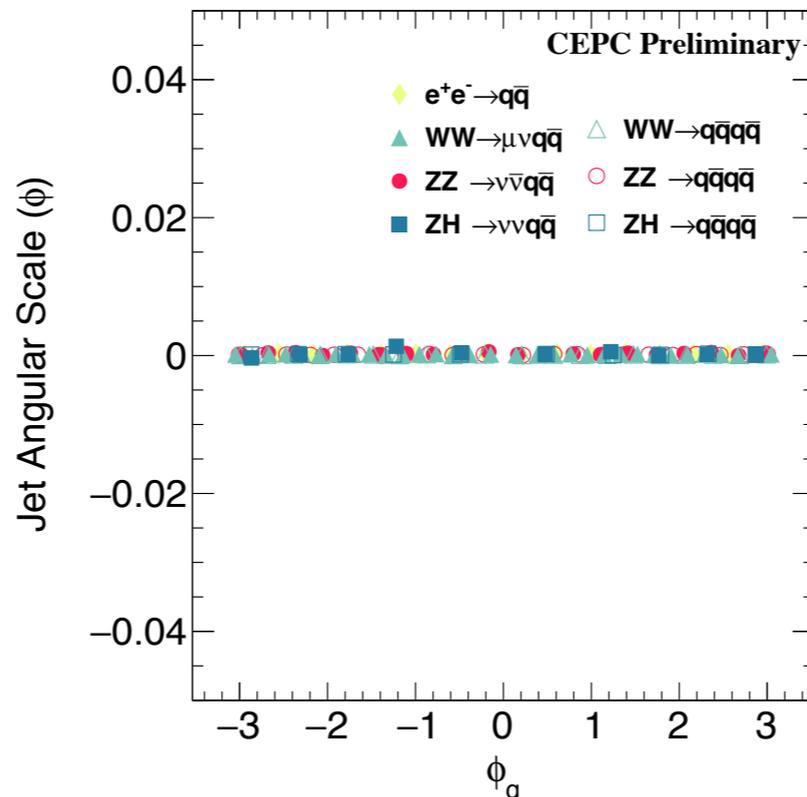
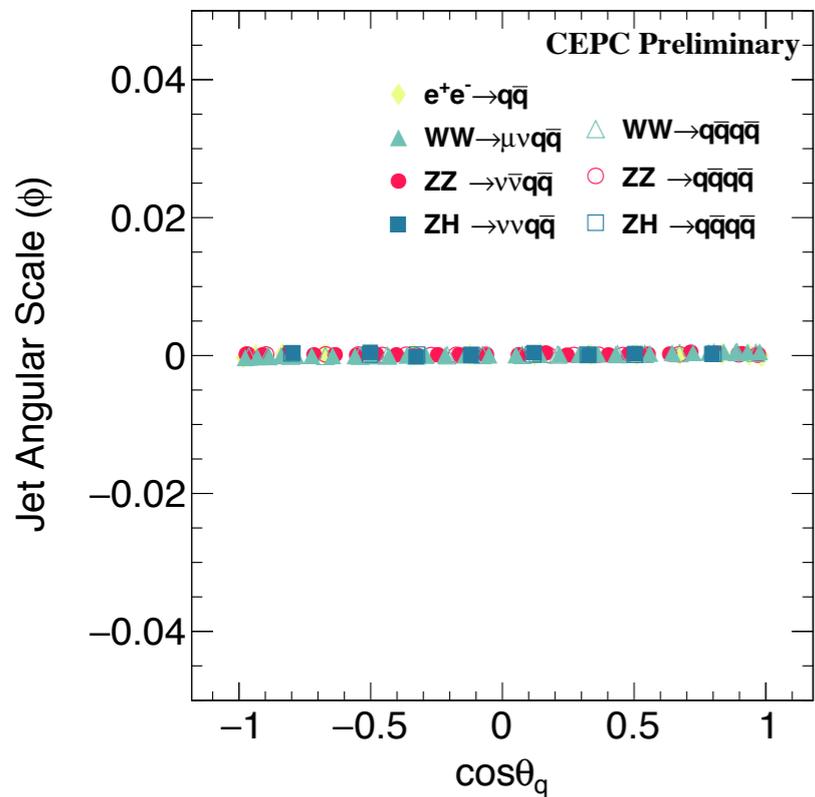
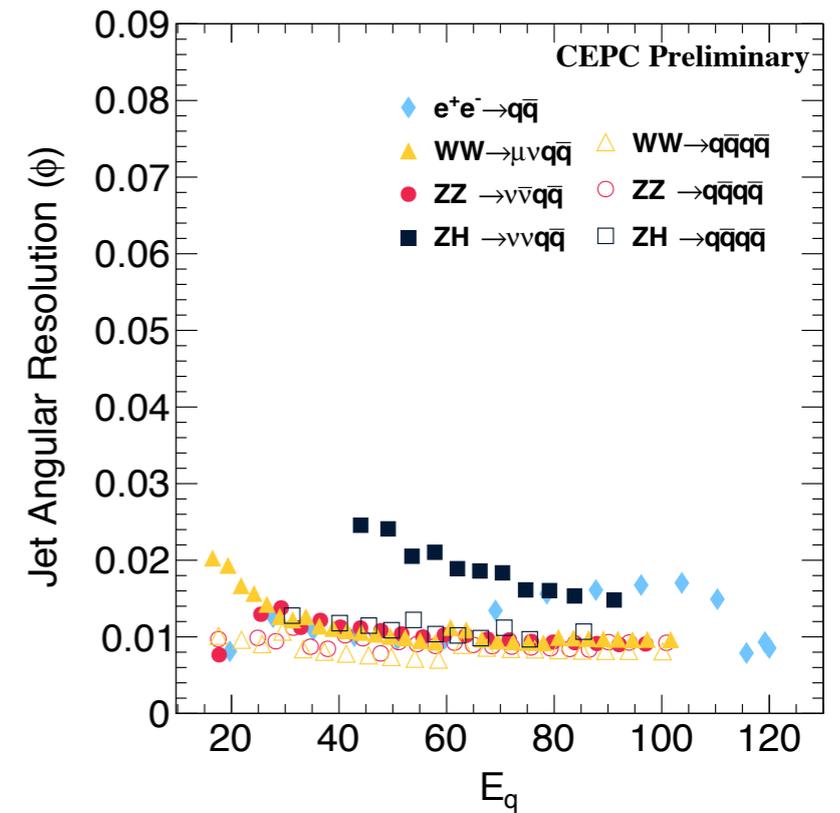
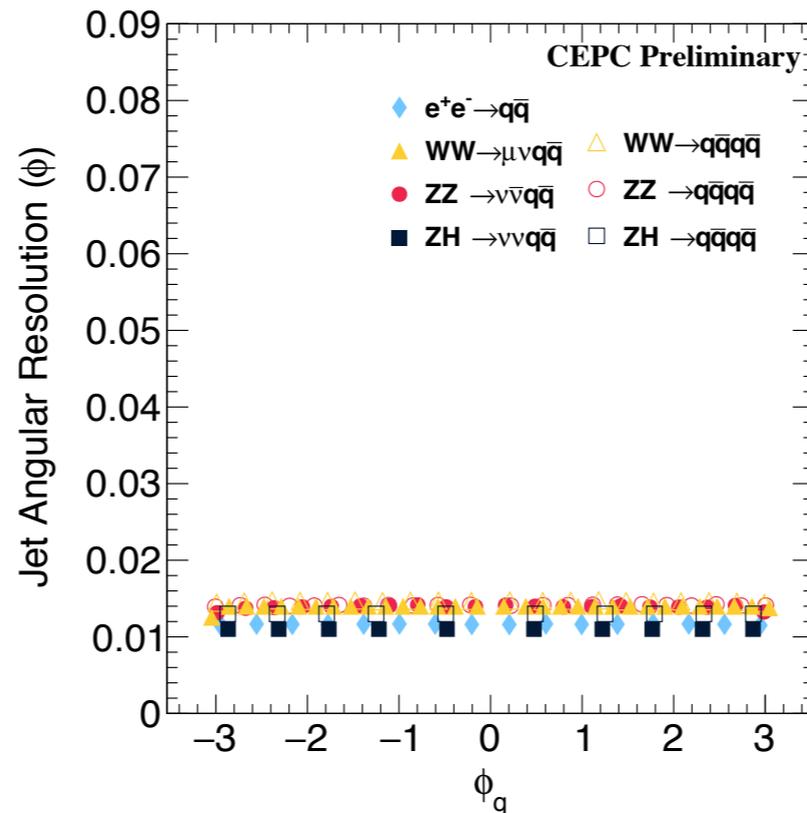
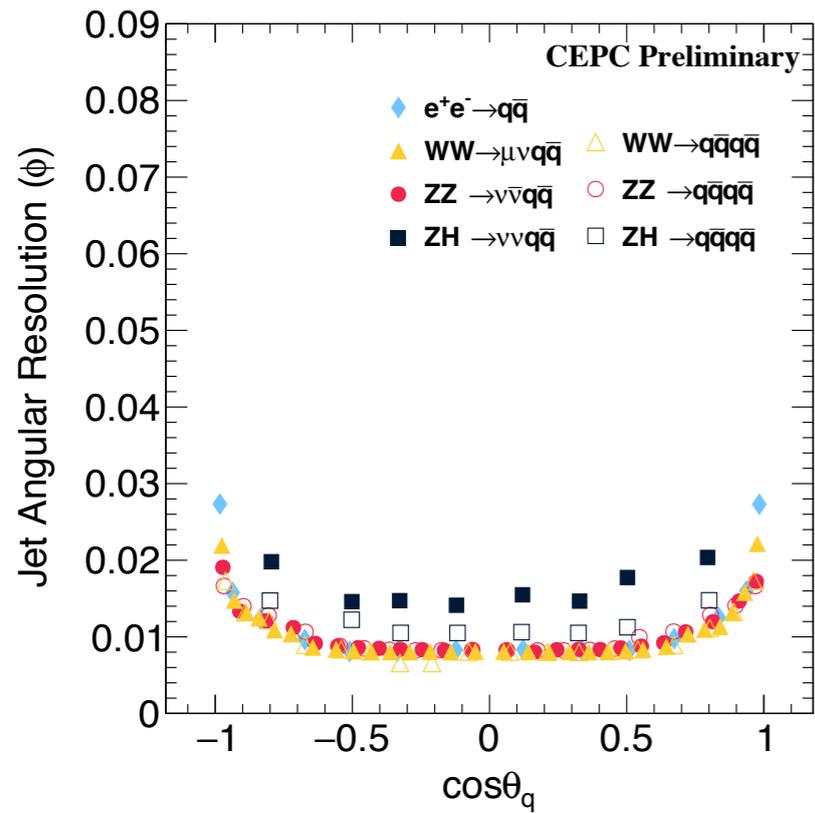


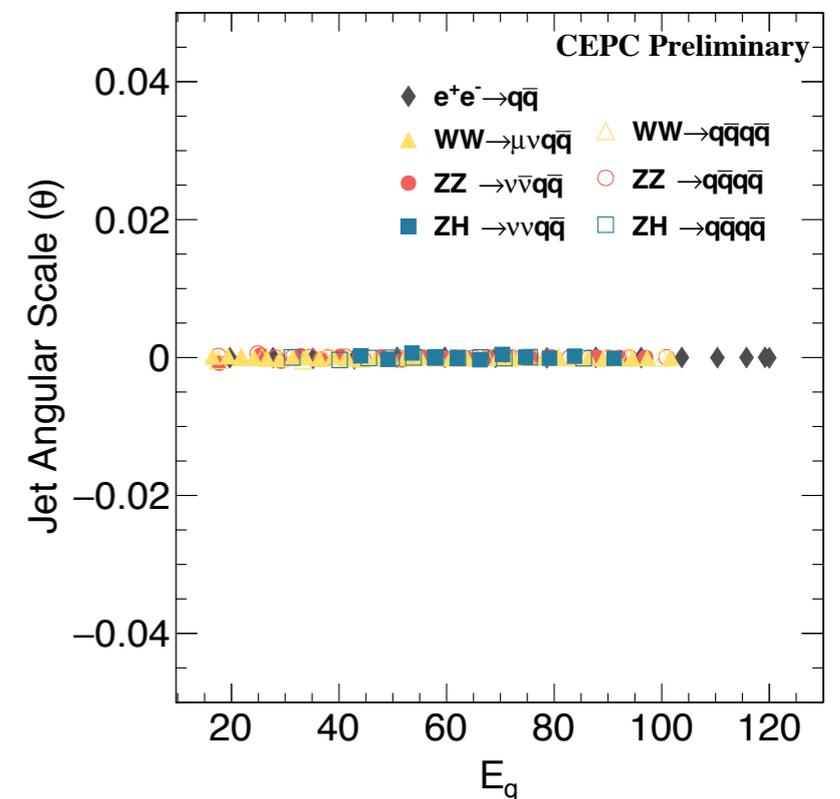
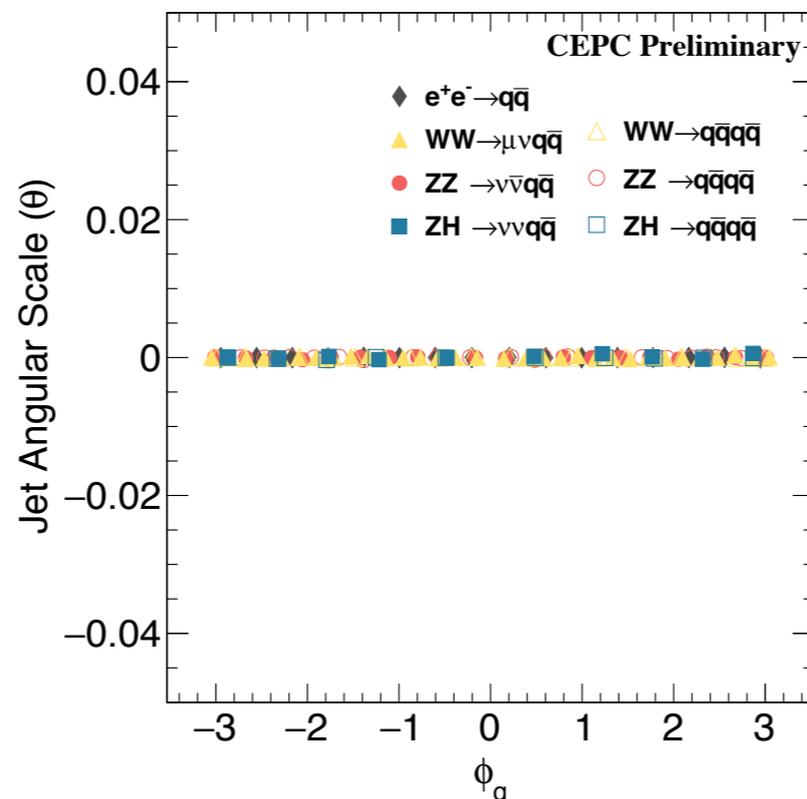
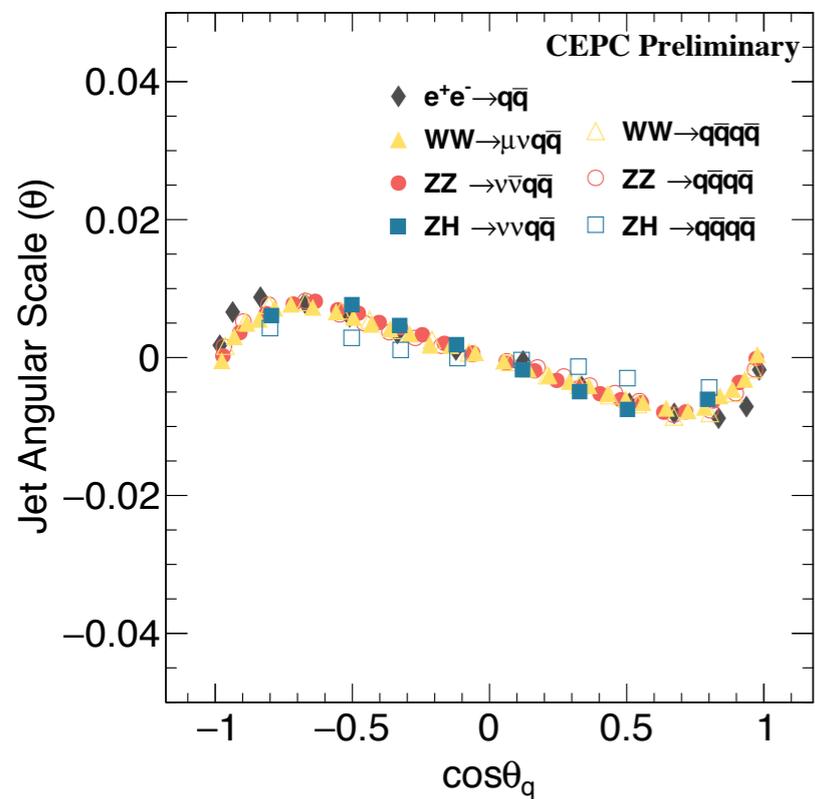
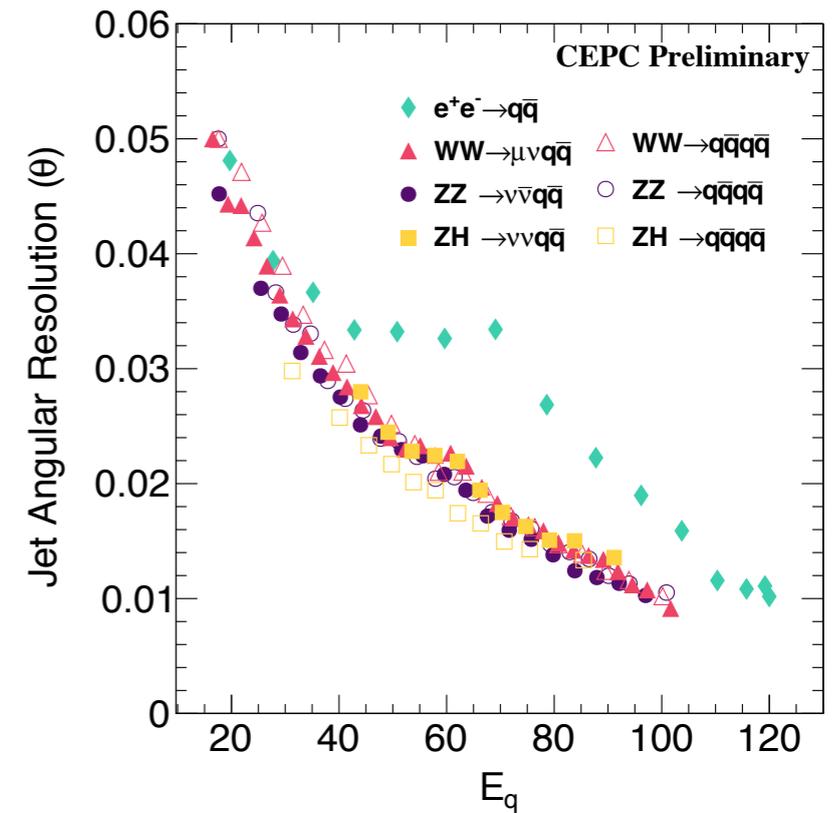
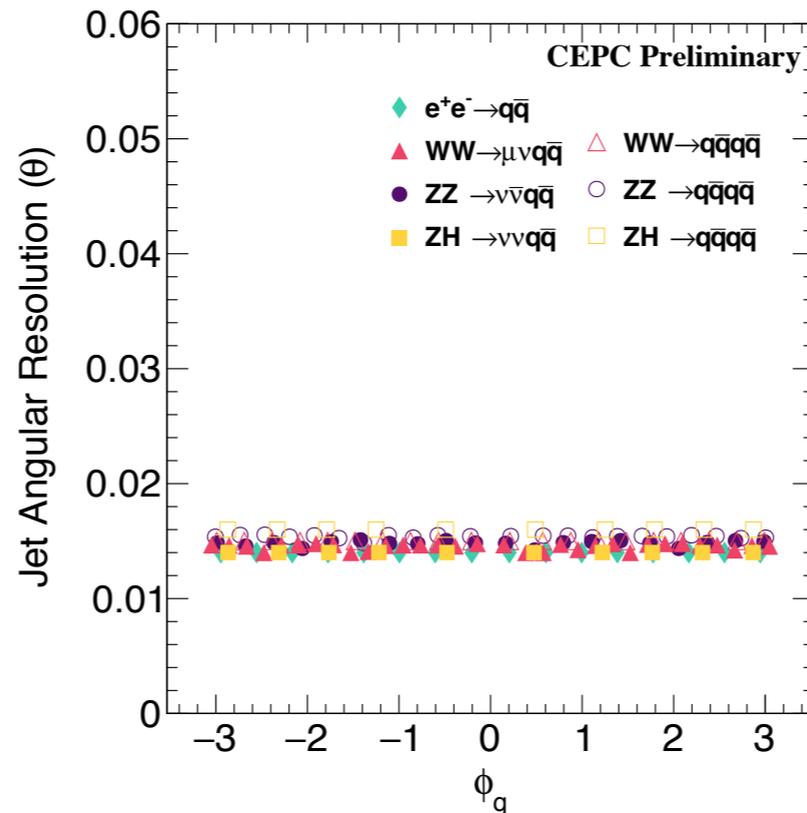
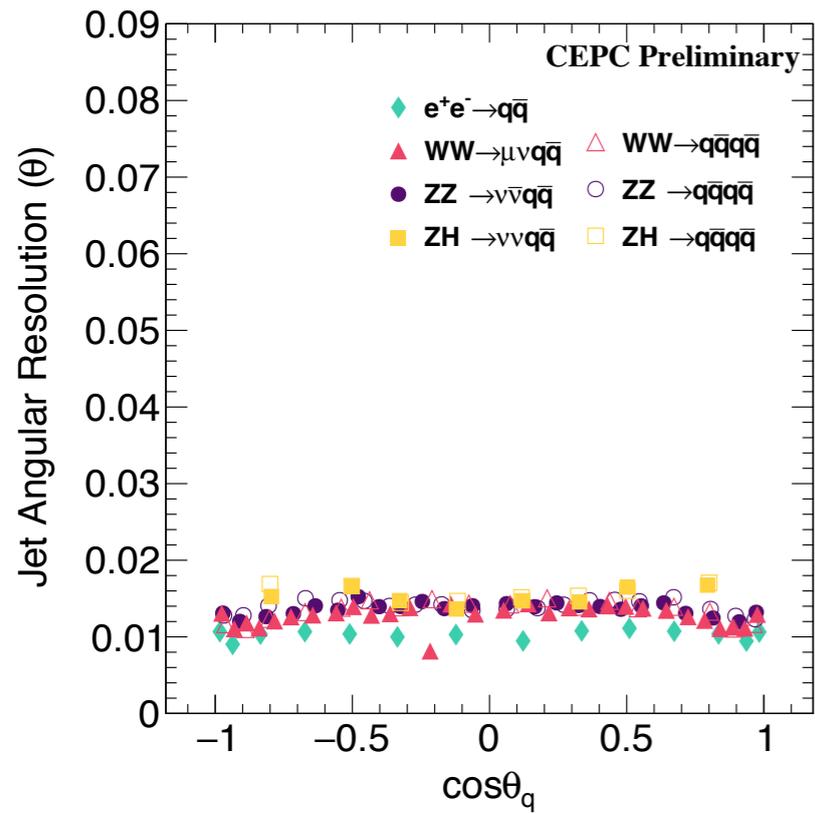


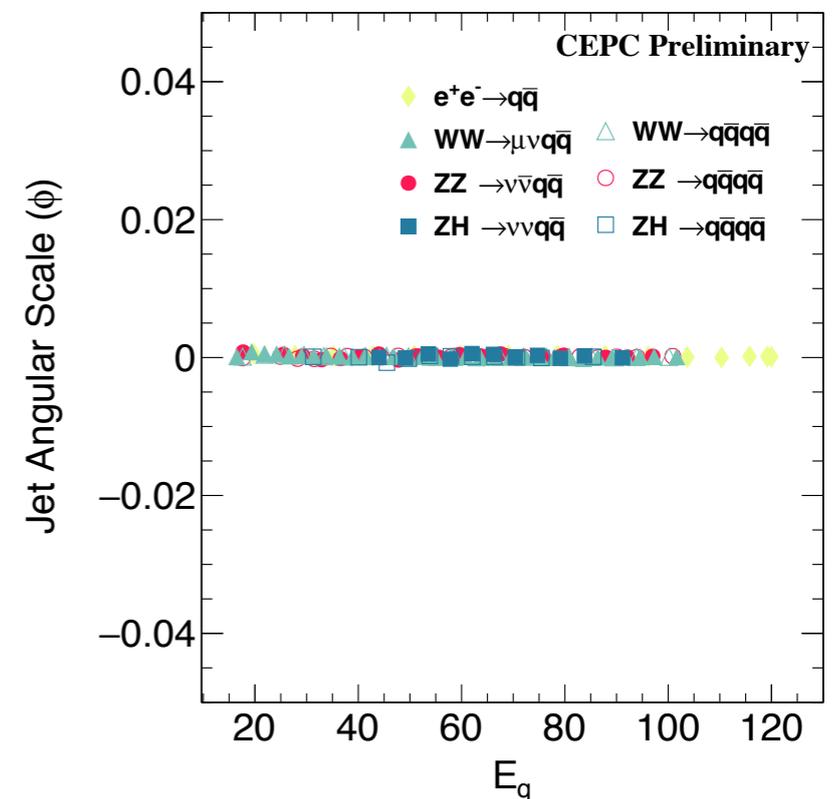
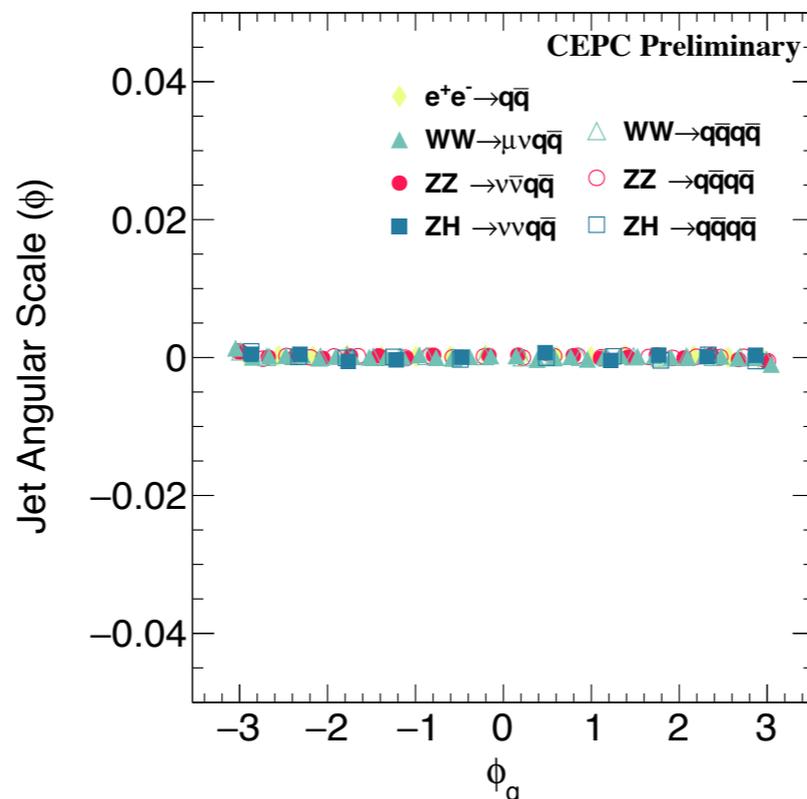
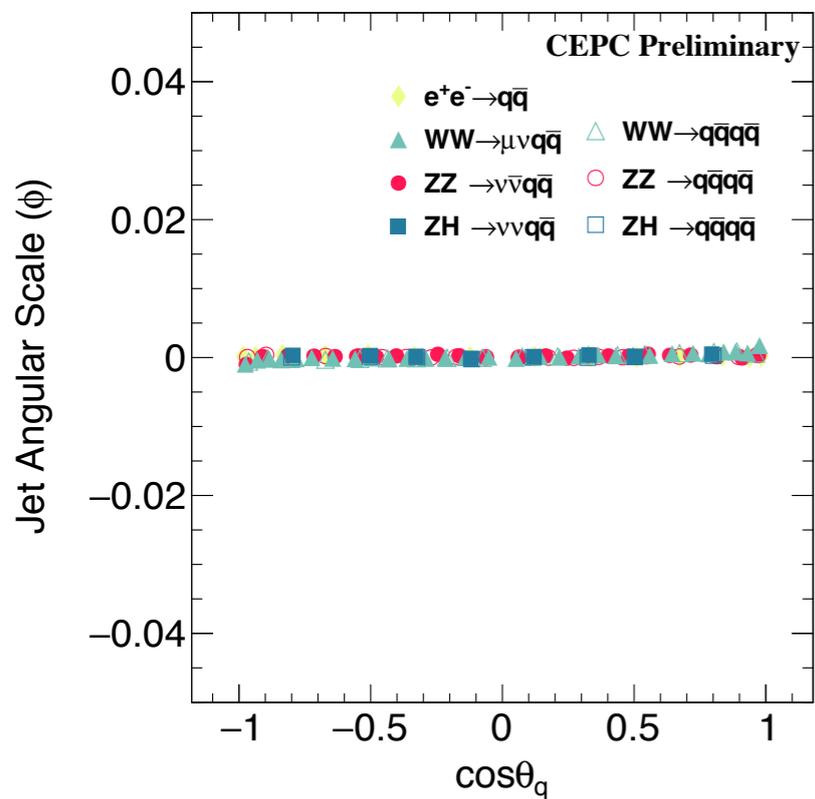
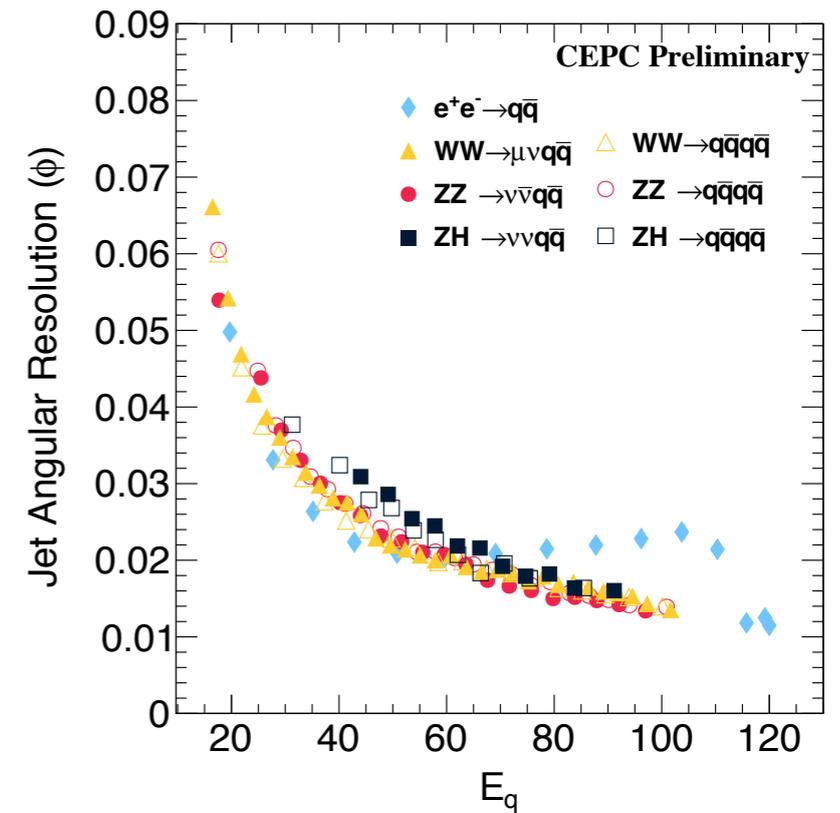
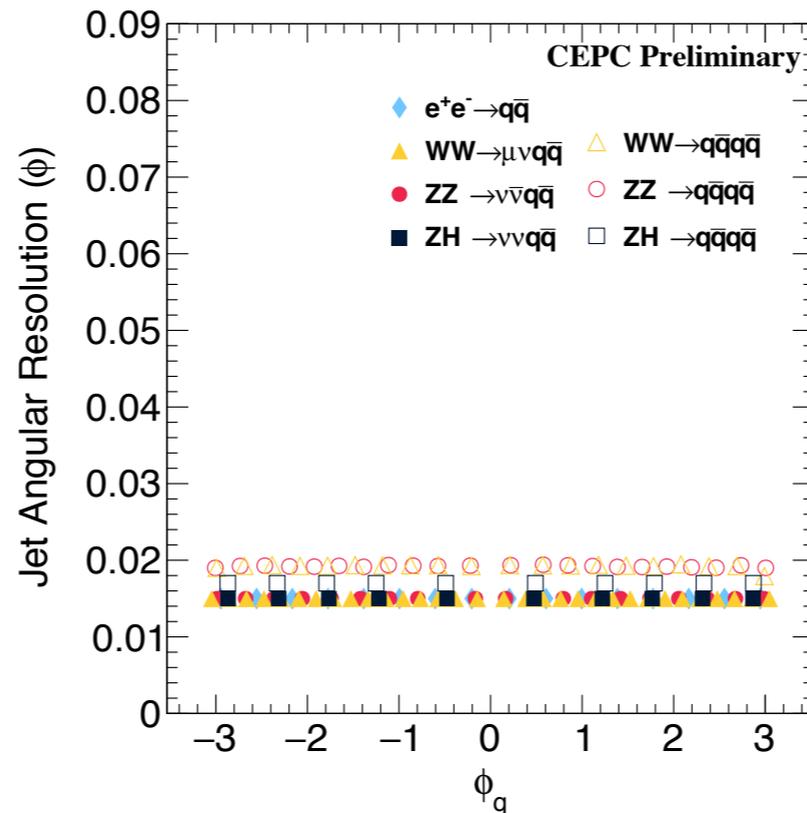
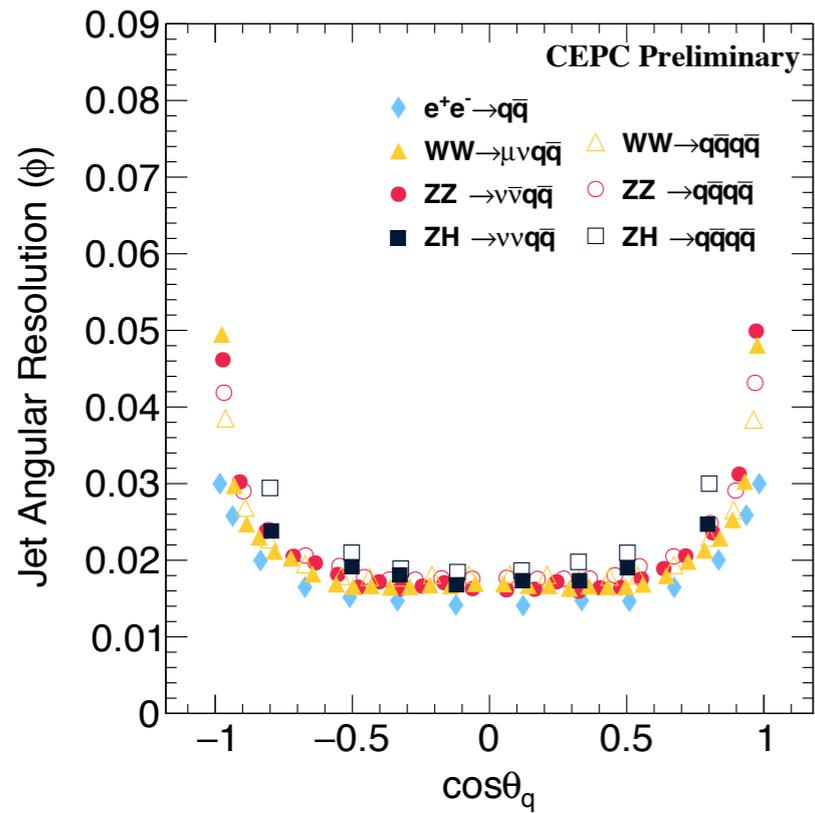


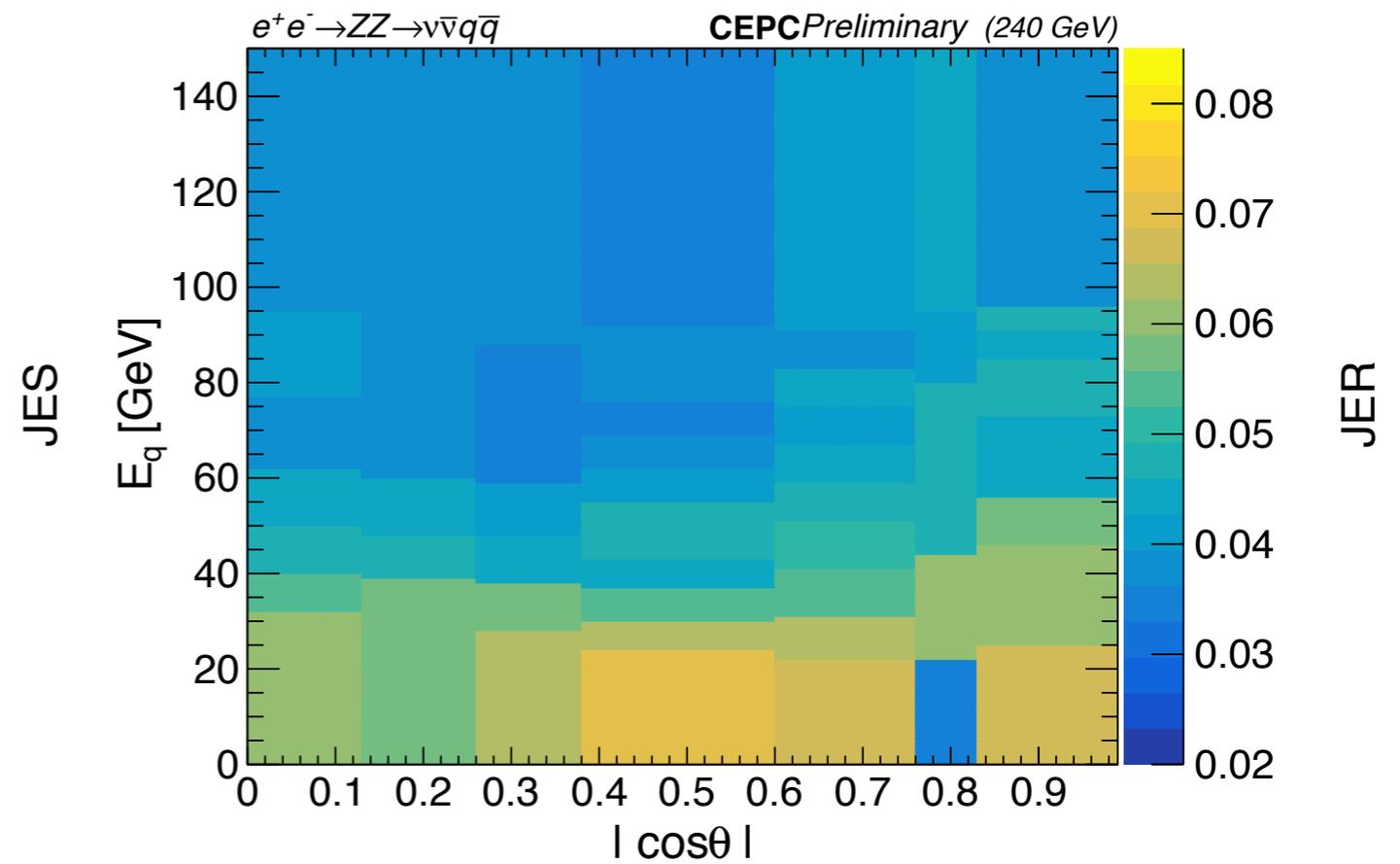
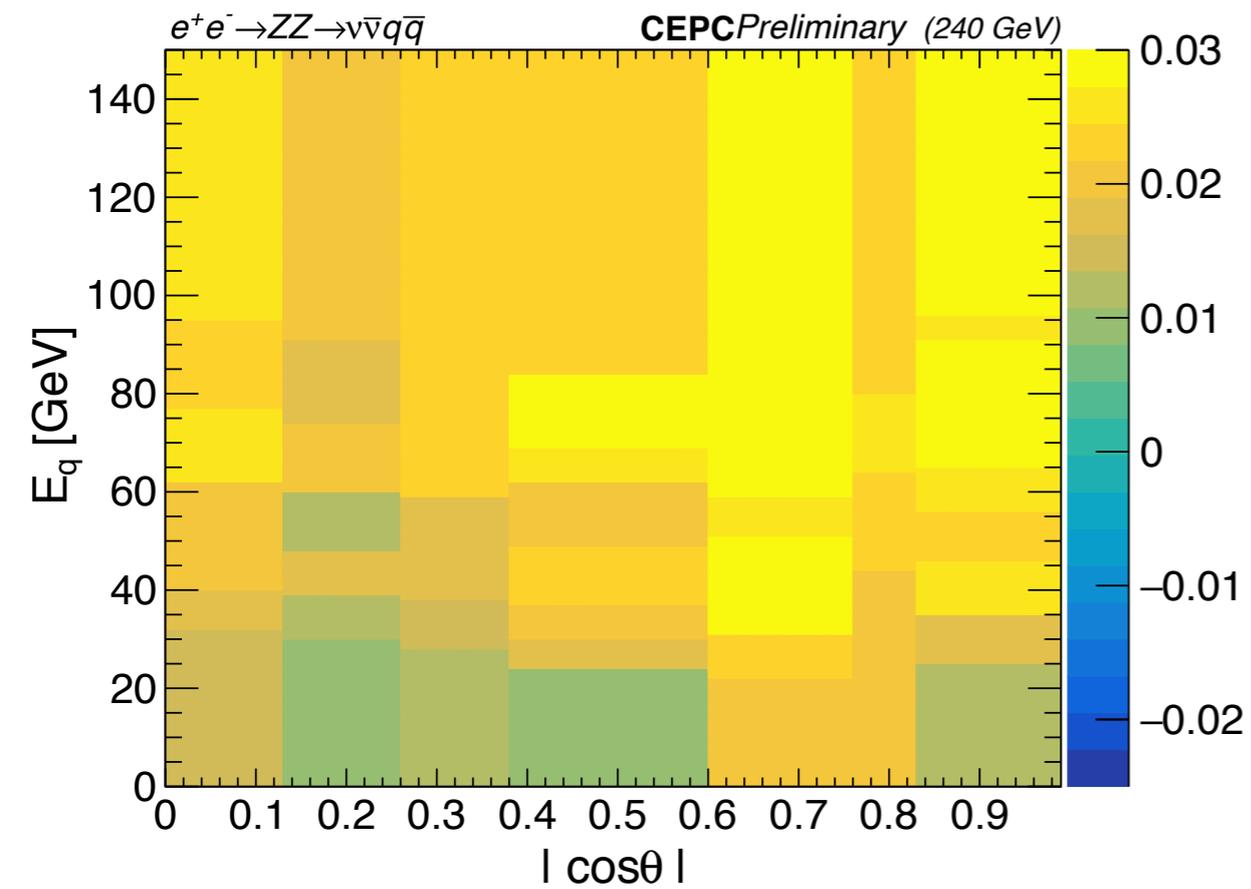


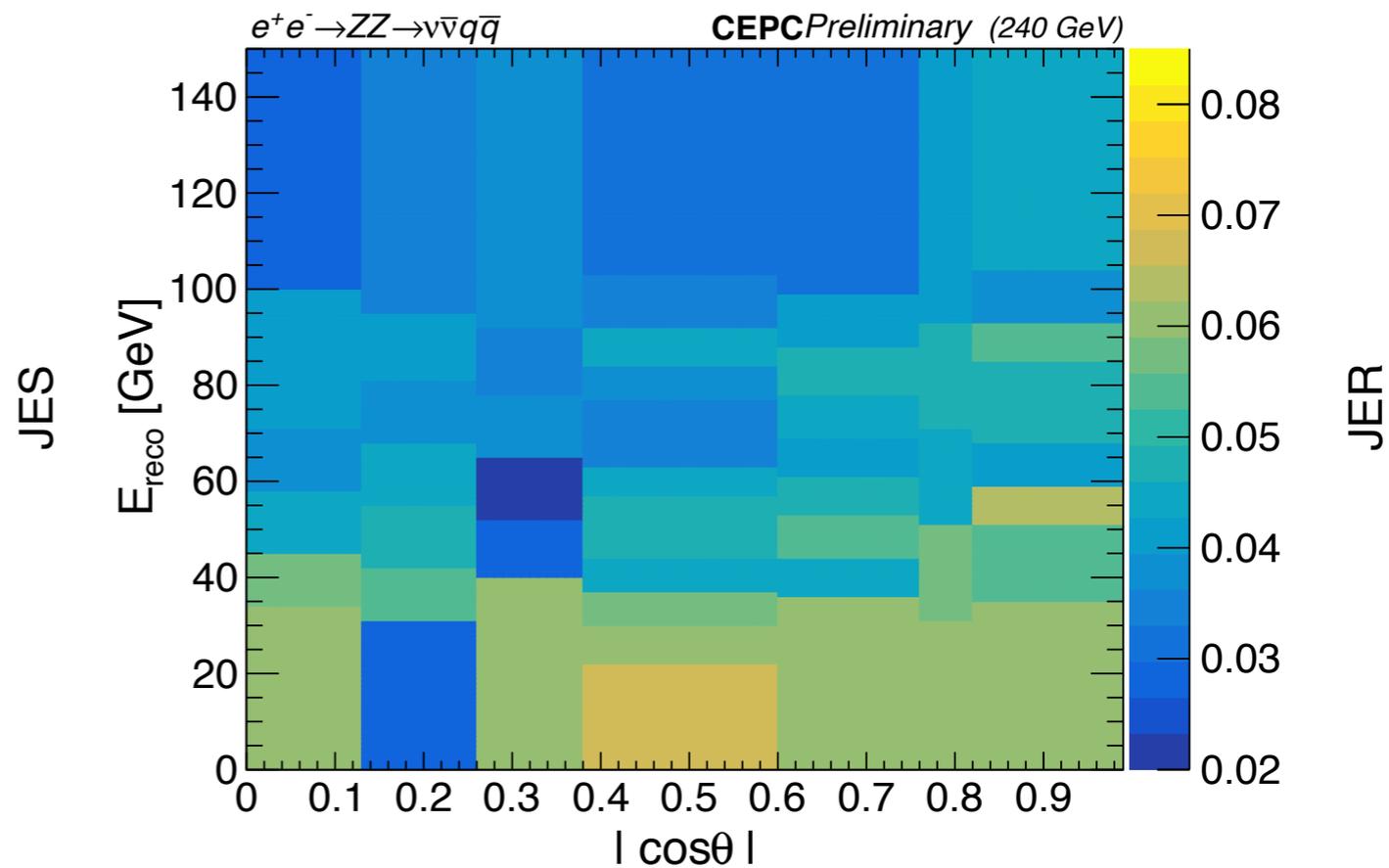
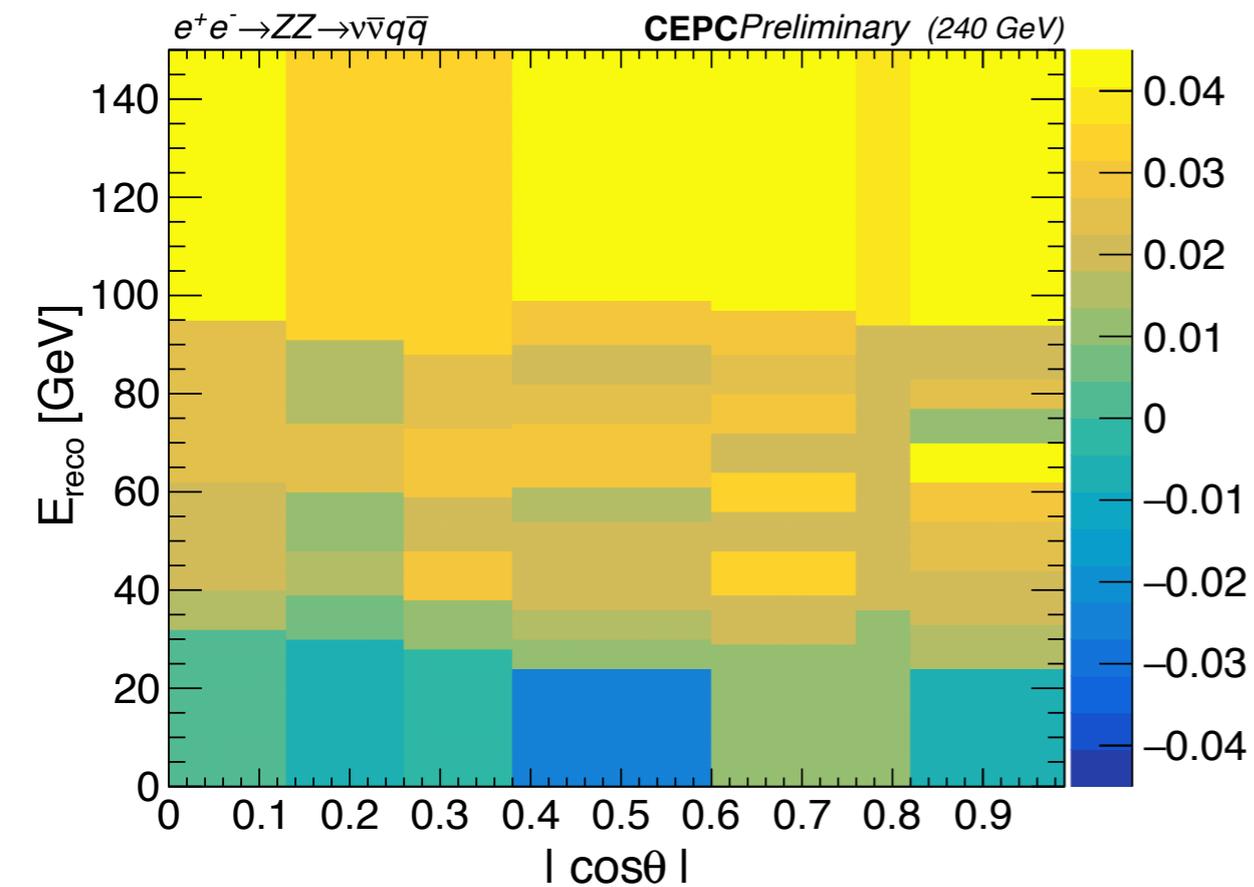


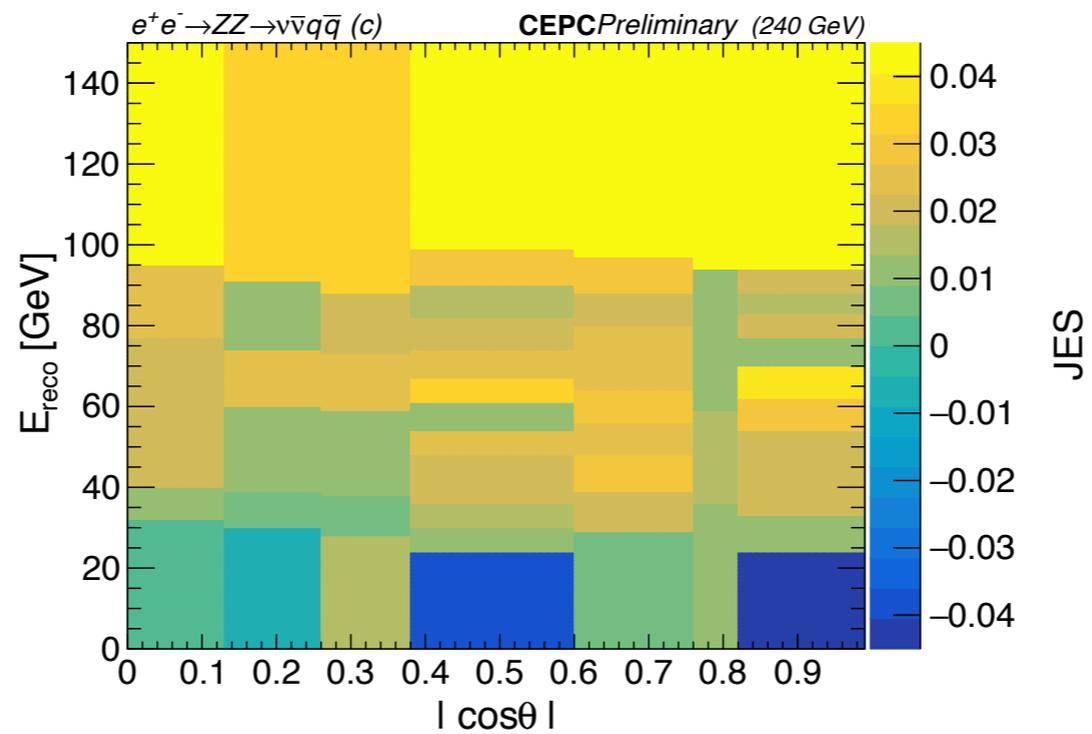
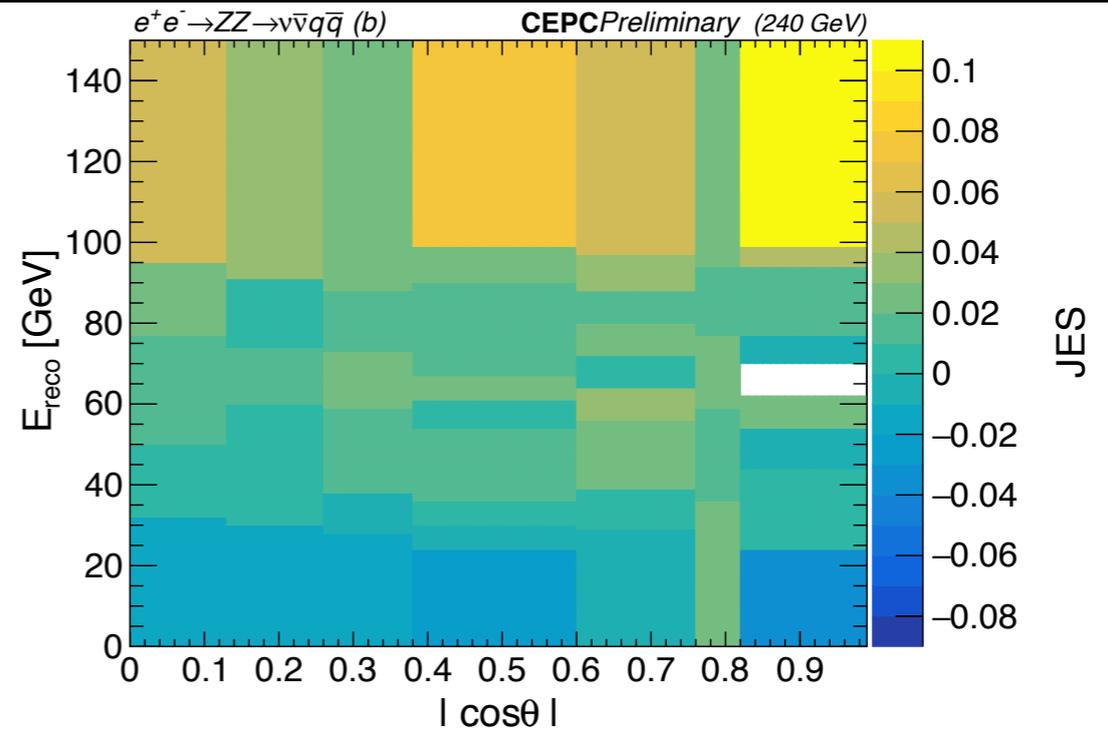
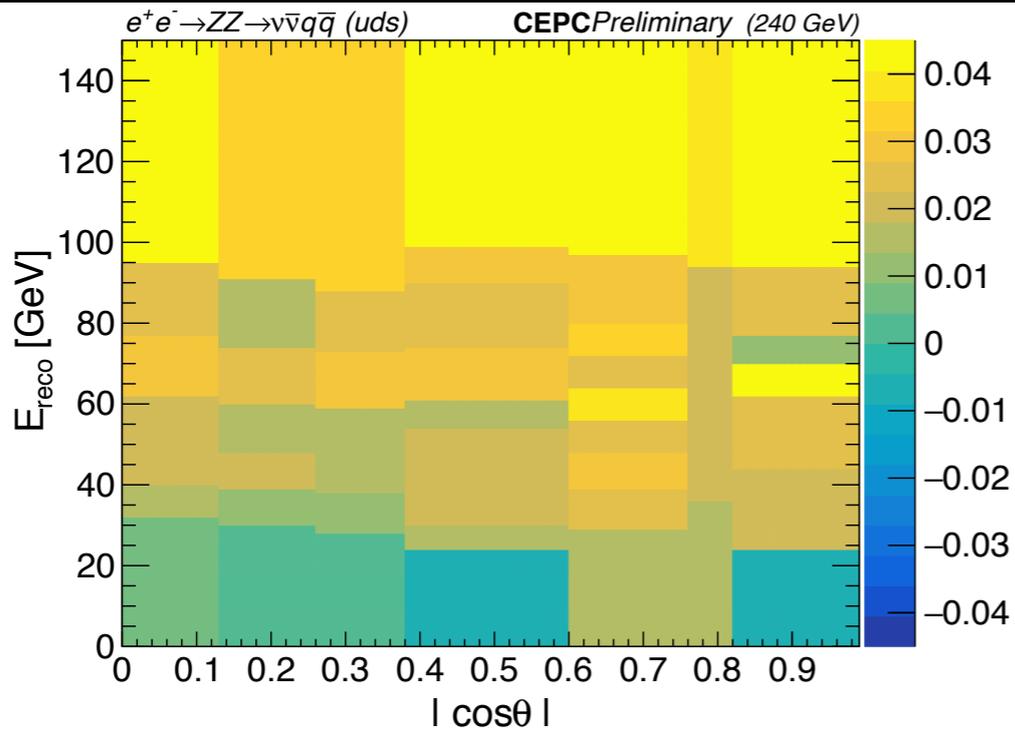


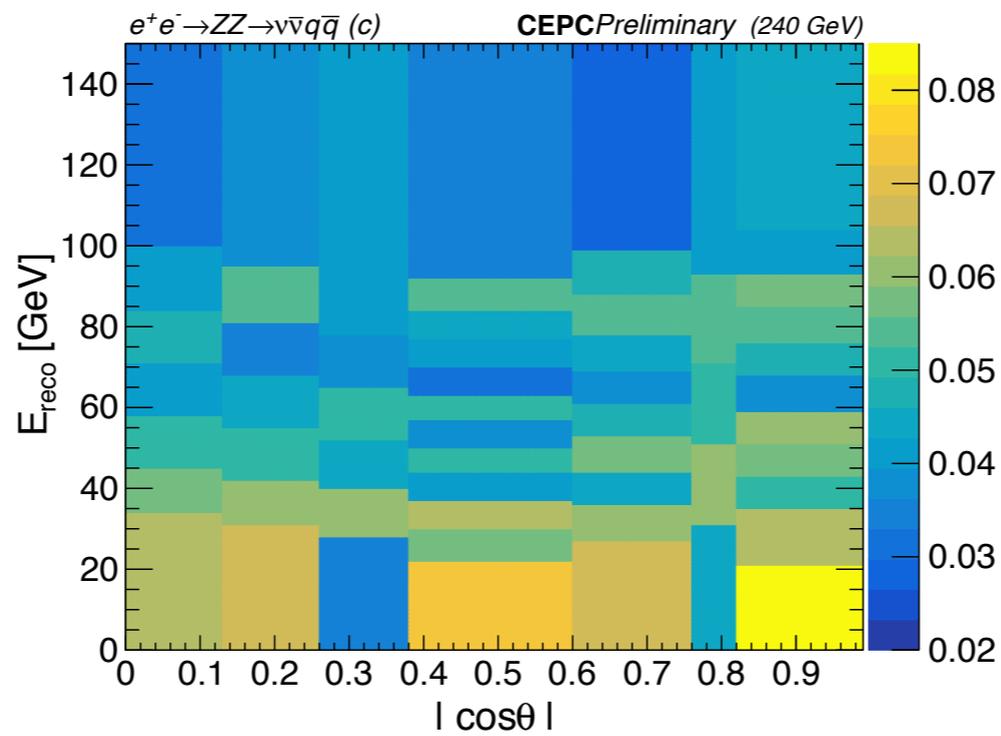
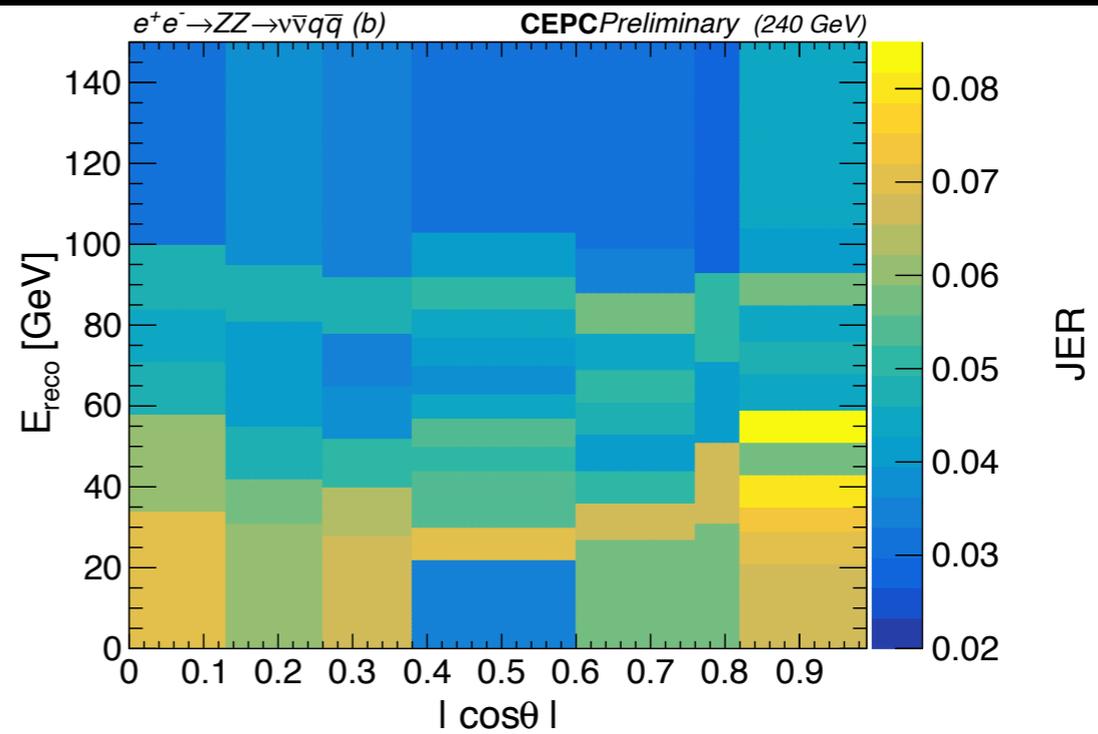
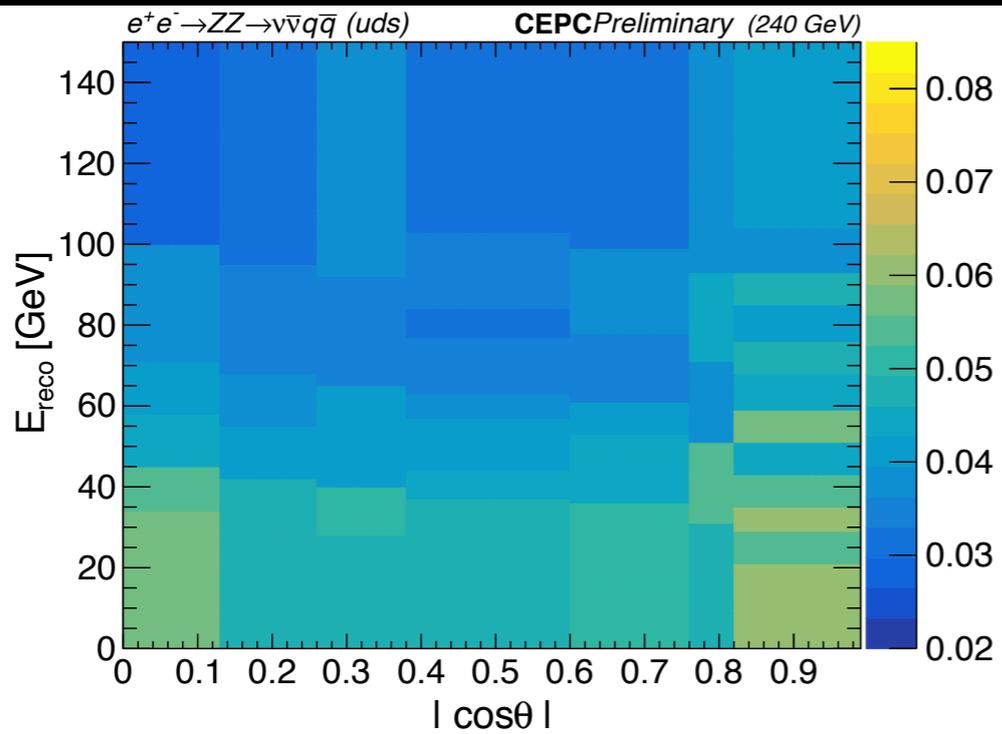


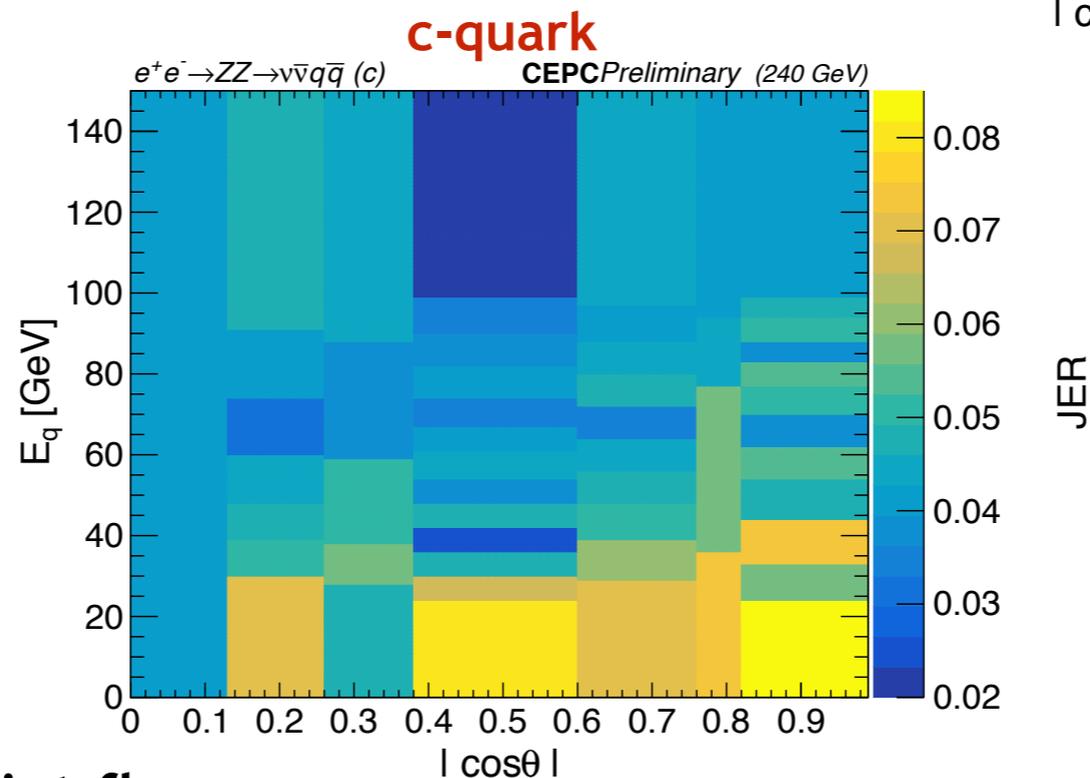
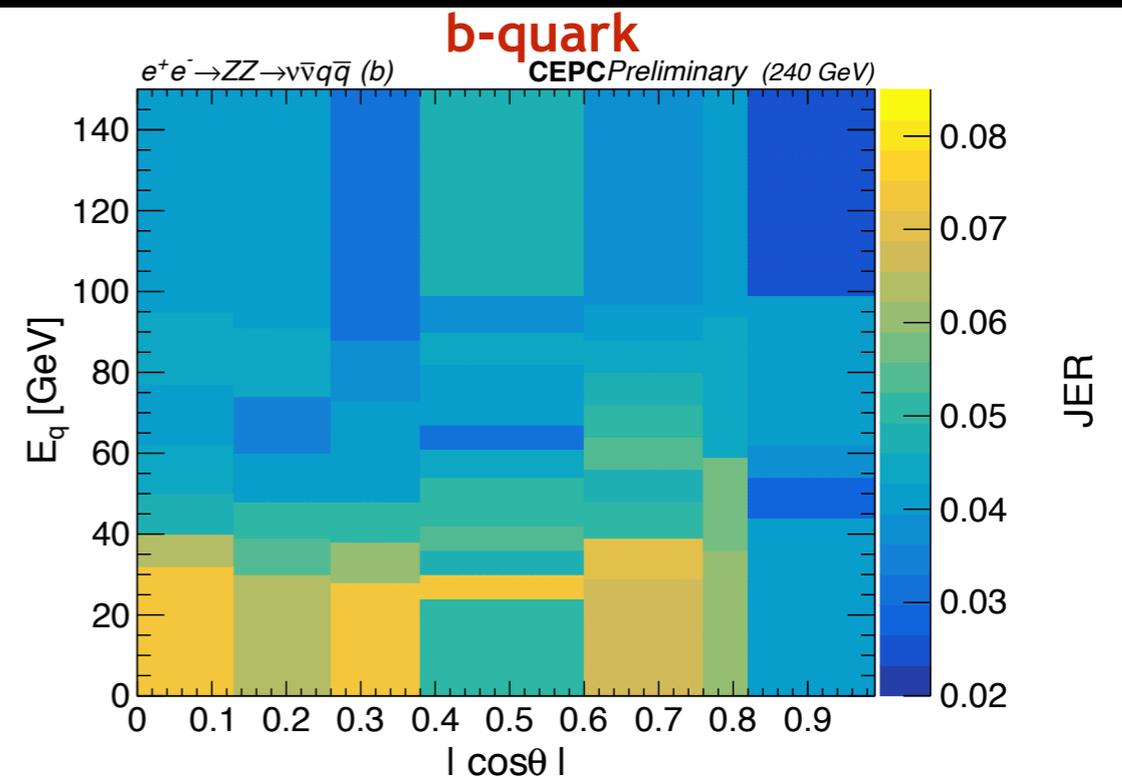
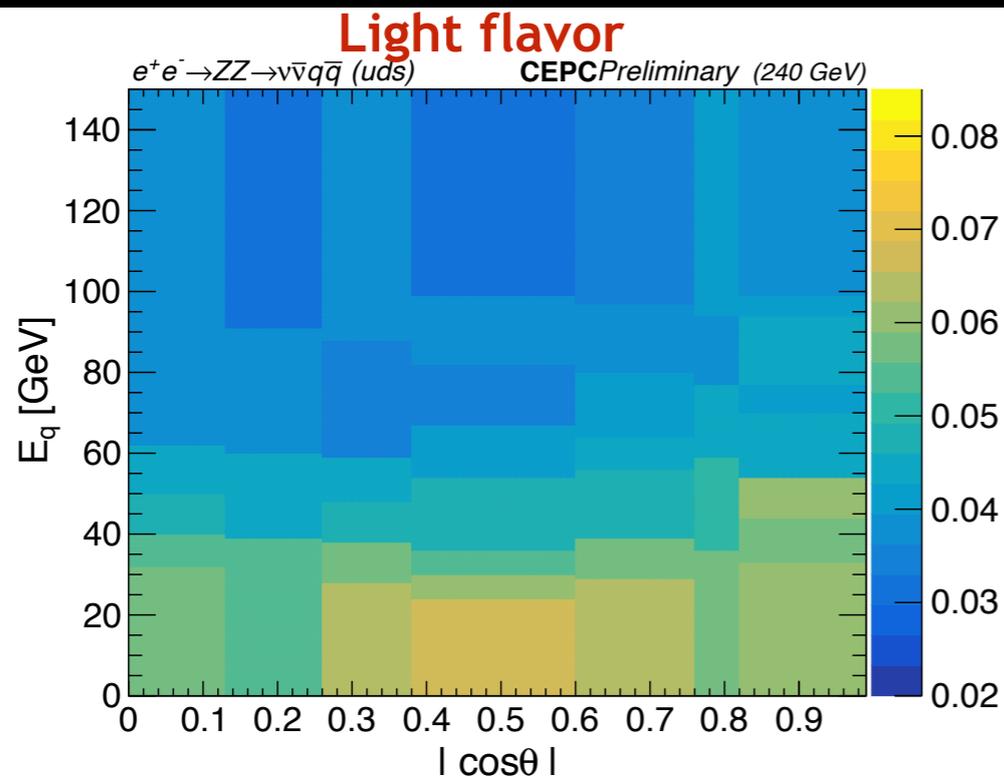








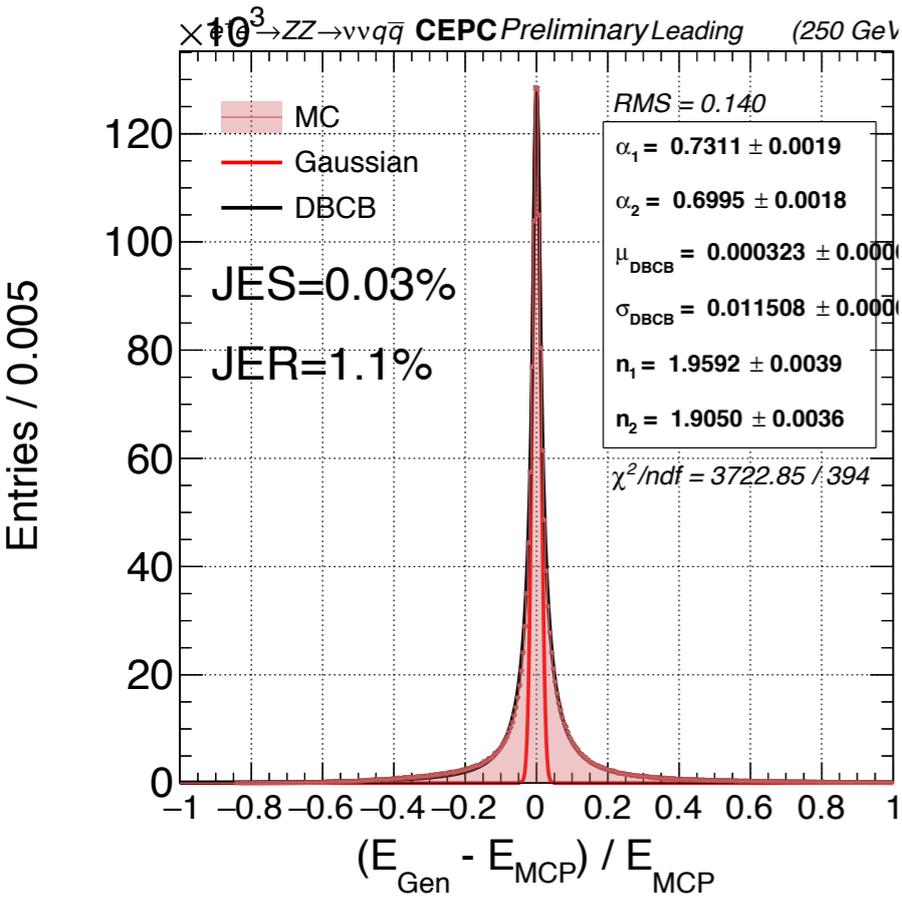




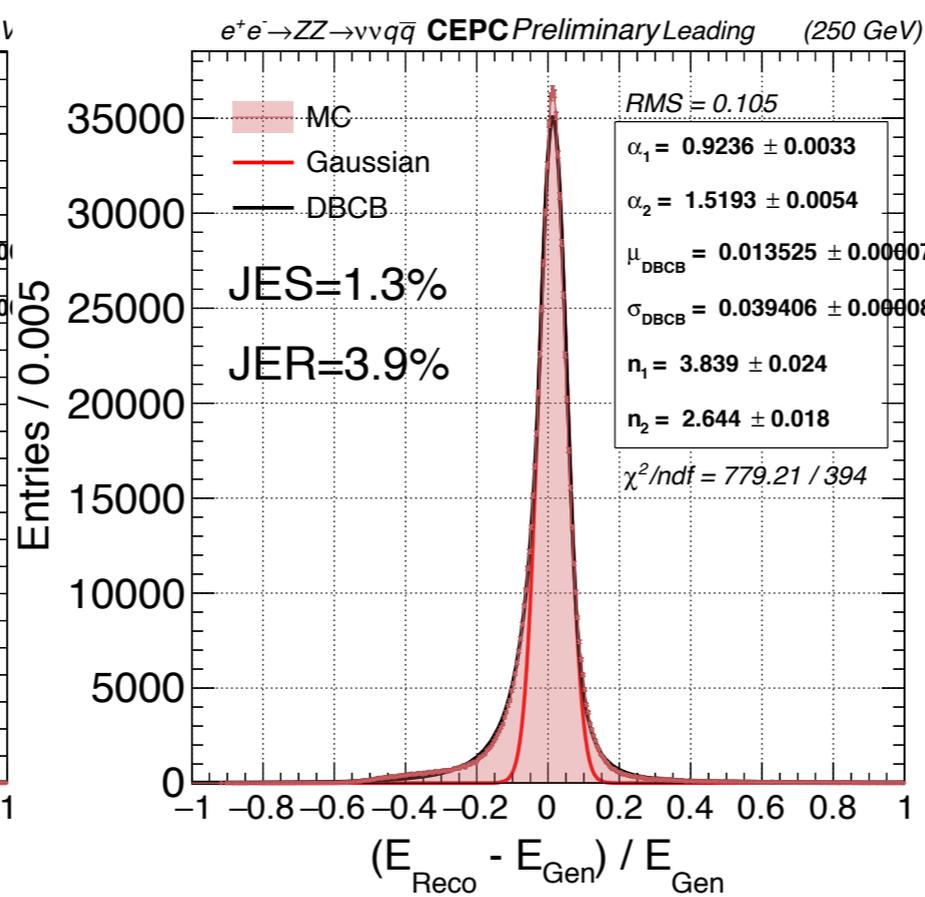
- JER also depends on the jet flavor.
- Higher jet energy and within central region of barrel, JER has impressive performance.

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

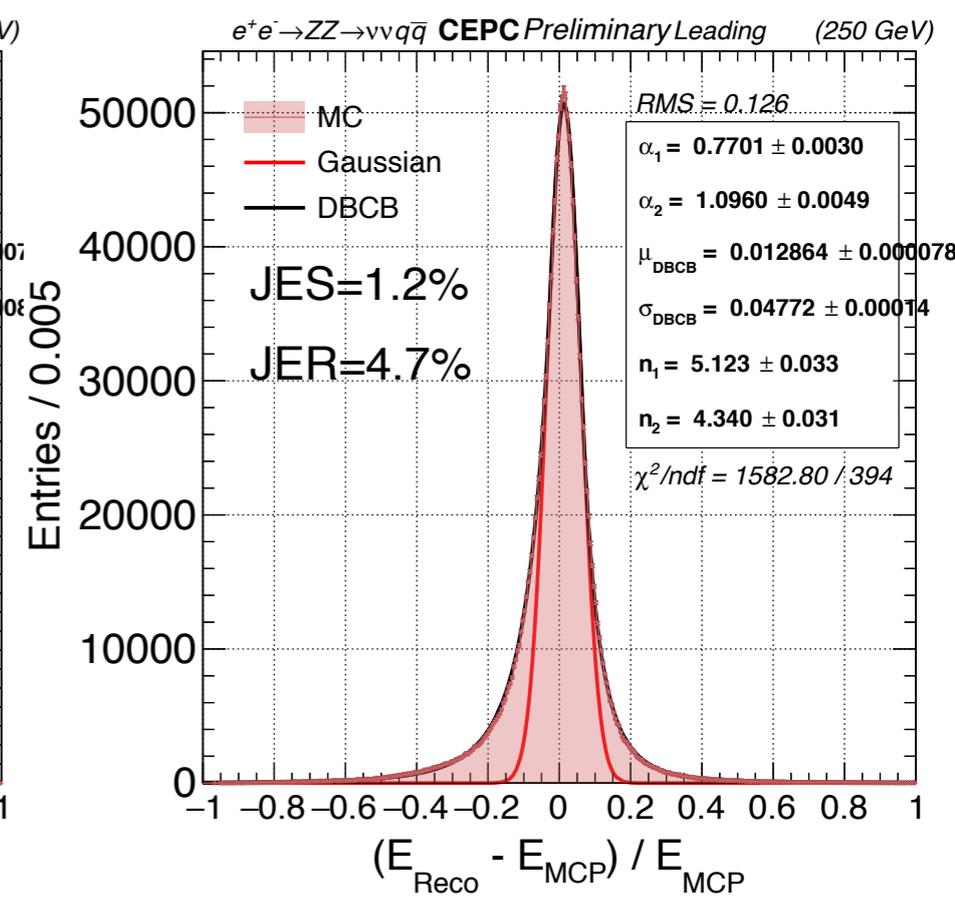
Gen-MCP



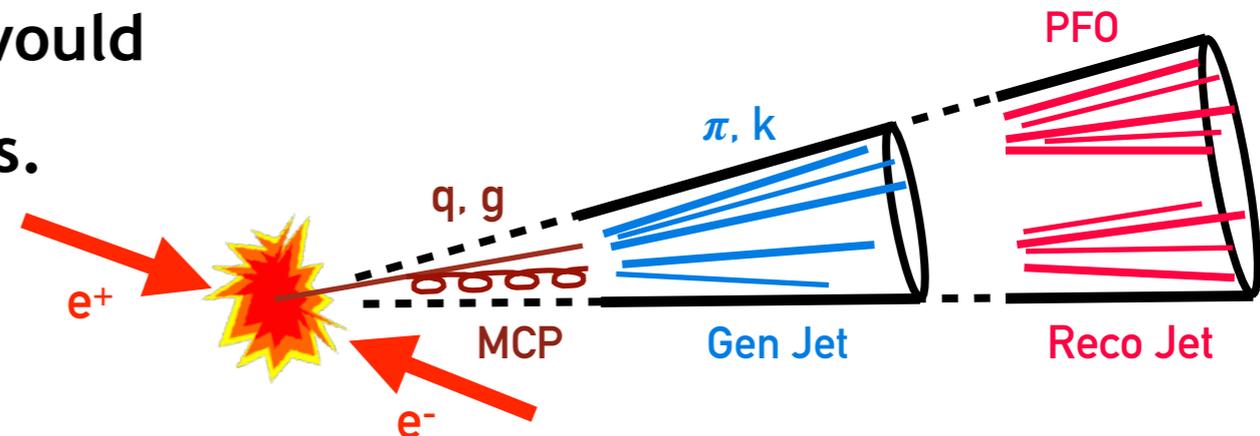
Reco-Gen



Reco-MCP

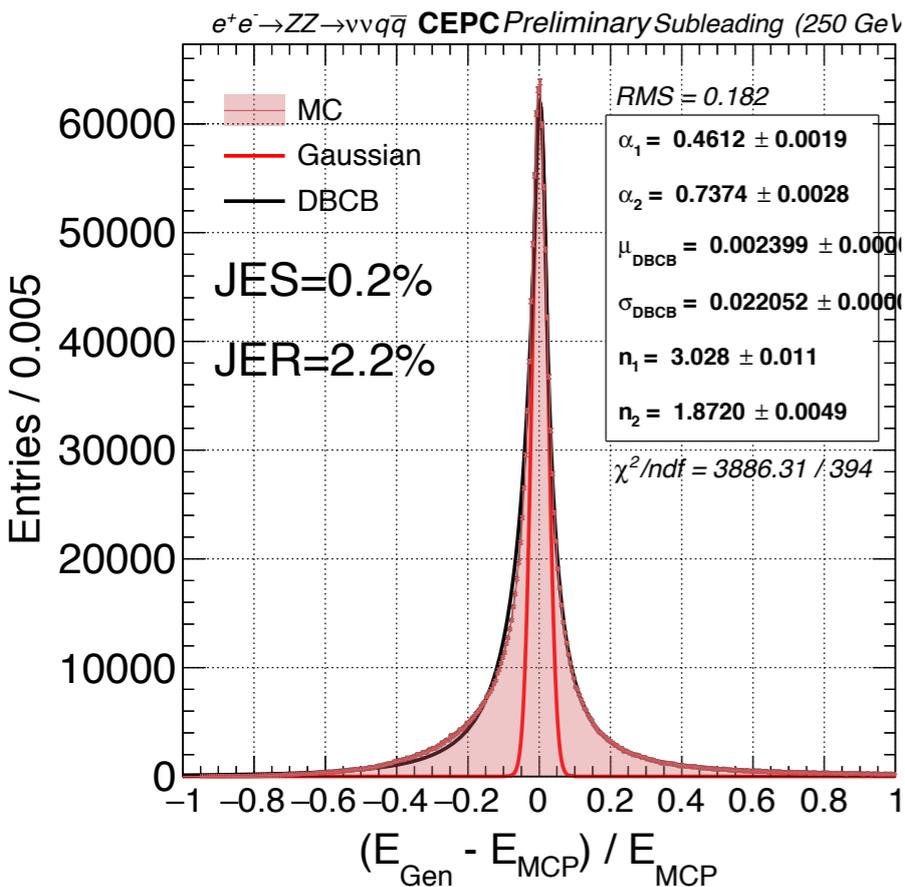


■ JER/JES between reco jet and MCP would combine the effects of two previous stages.

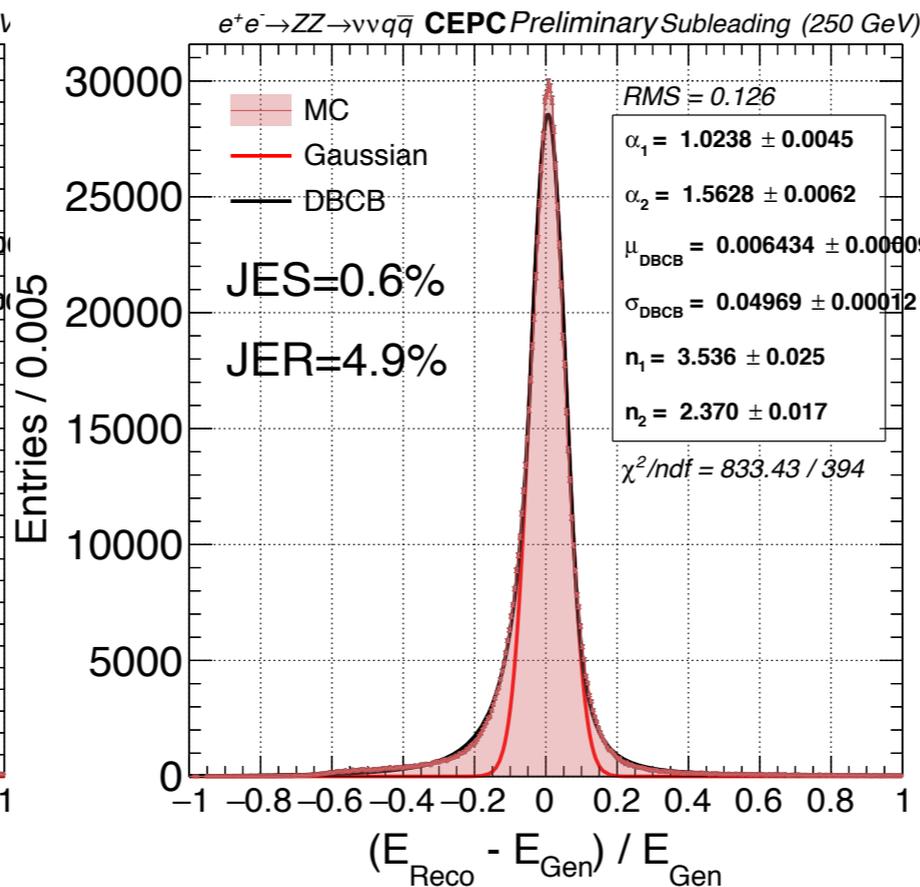


Sub-leading JER & JES V1

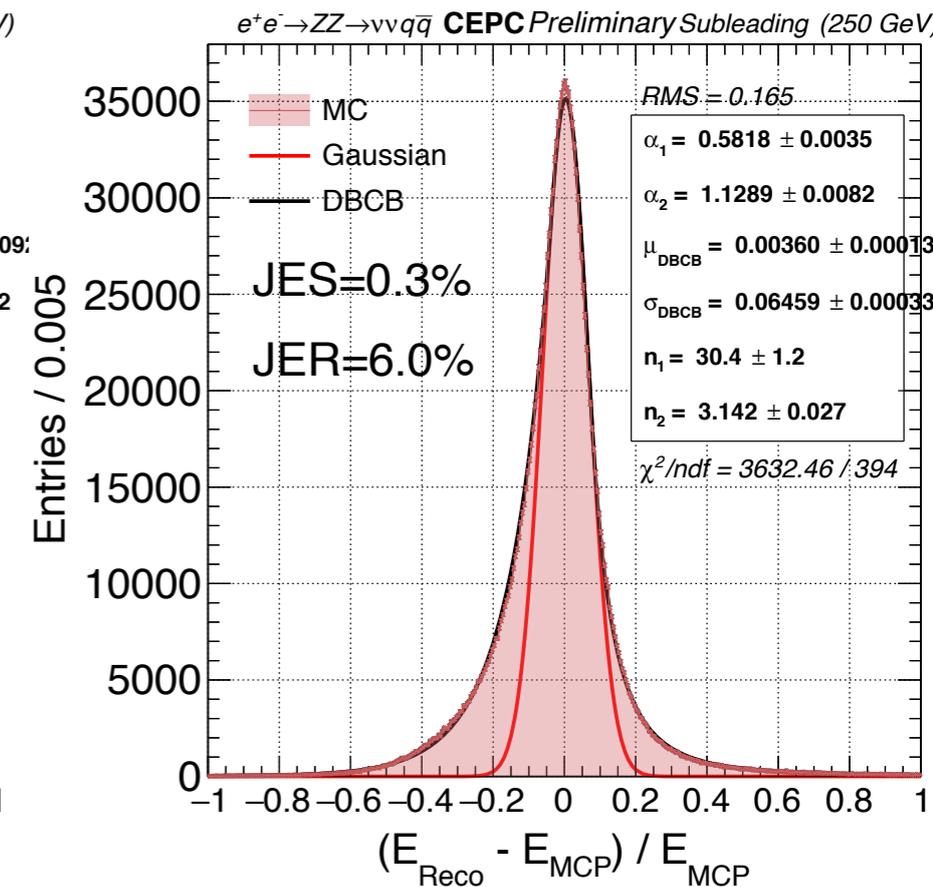
Gen-MCP



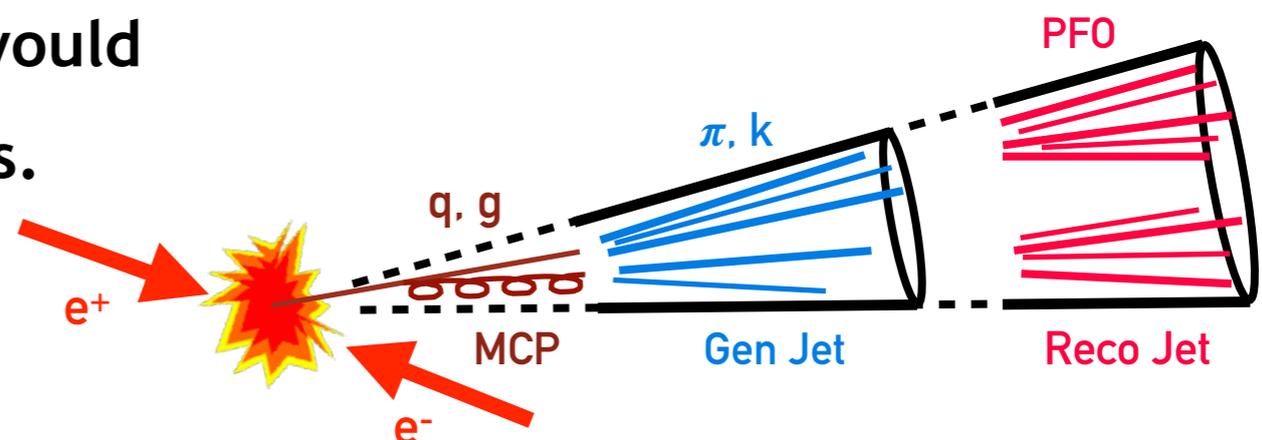
Reco-Gen



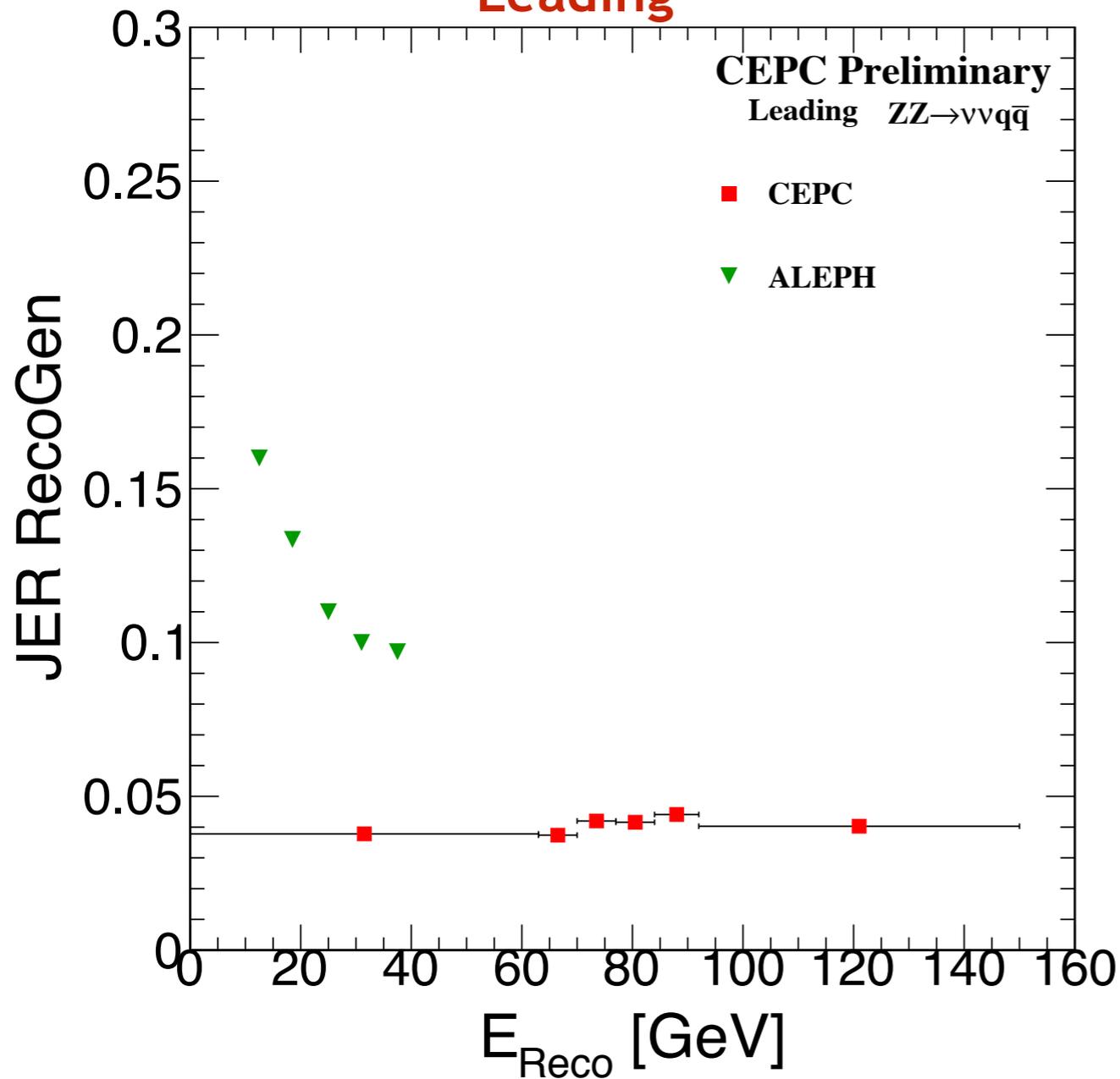
Reco-MCP



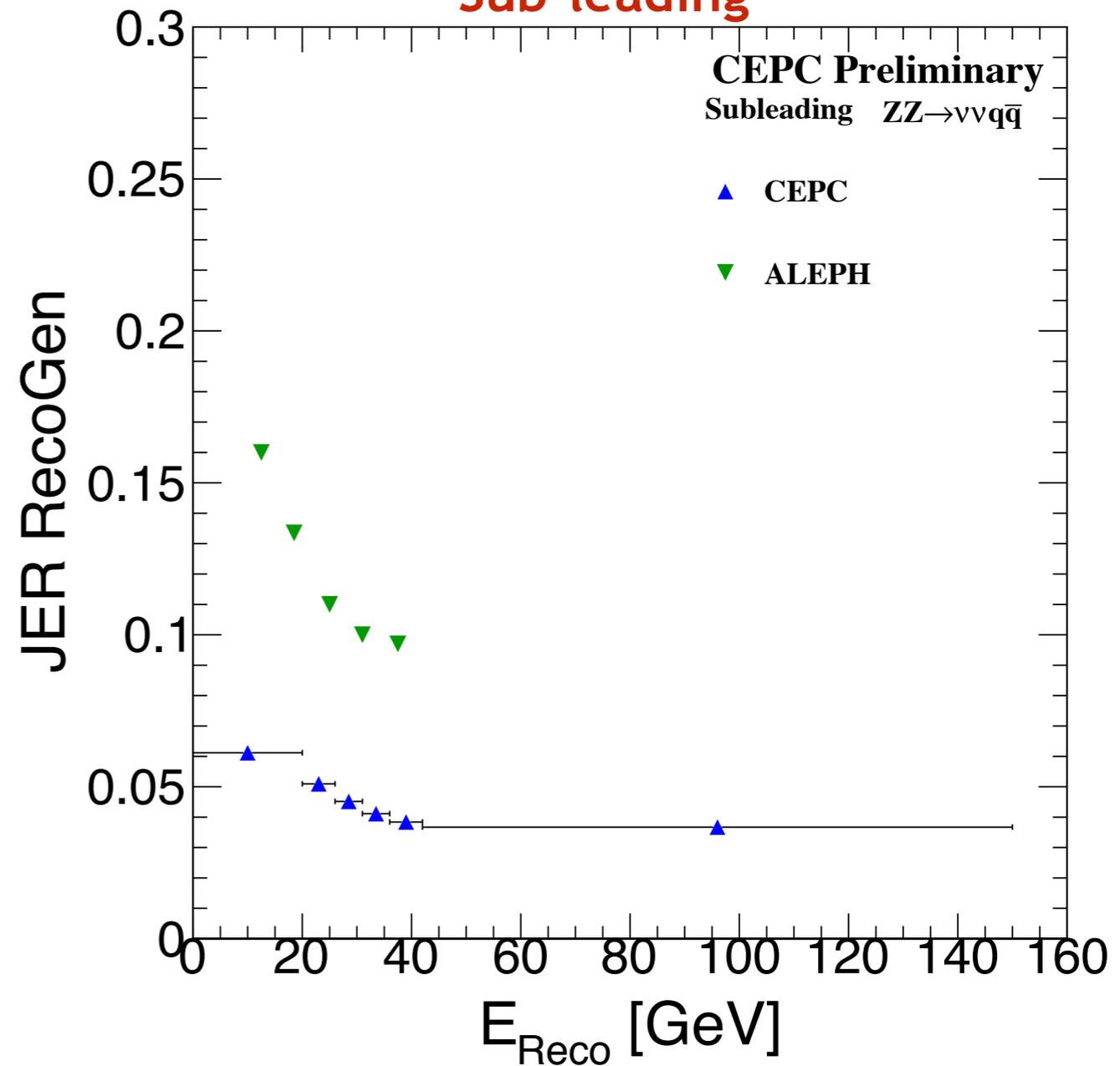
■ JER/JES between reco jet and MCP would combine the effects of two previous stages.



Leading



Sub-leading



■ Our JER is better than ALEPH.

Ref. [4]

