

Performance of **Jets** at CEPC

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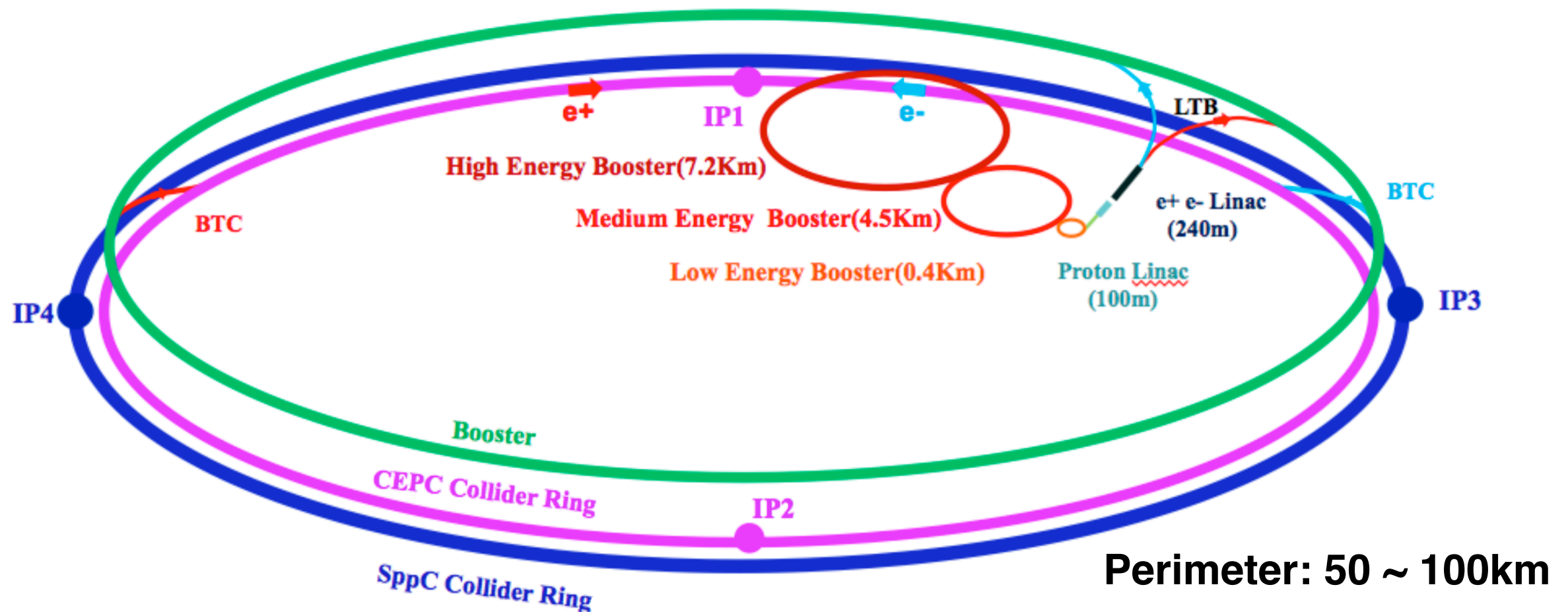
KR x TW Joint Workshop, NCU, Taiwan

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- **Introduction**
- **Strategy**
- **Event selections**
- **Results**
 - **The total jet energy resolution and scale (Reco-Gen, Gen-MCP, Reco-MCP)**
 - **JER/JES depend on angle and energy (Reco-Gen, Gen-MCP, Reco-MCP)**
 - **Compare the results with CMS and ALEPH**
 - **Boson mass resolution in dijet final state**
- **Summary**

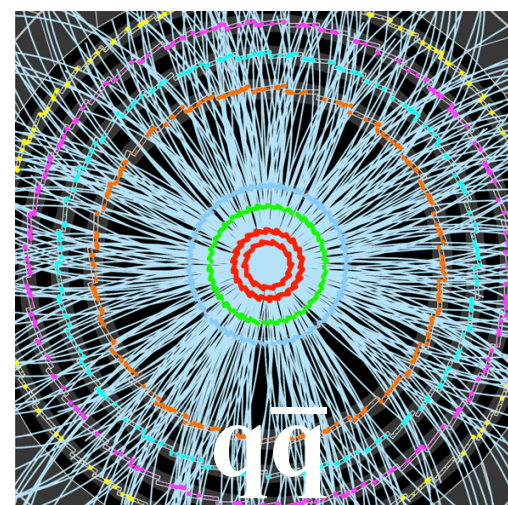
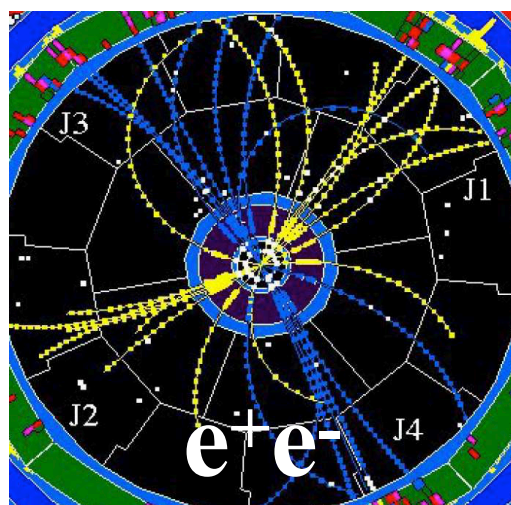
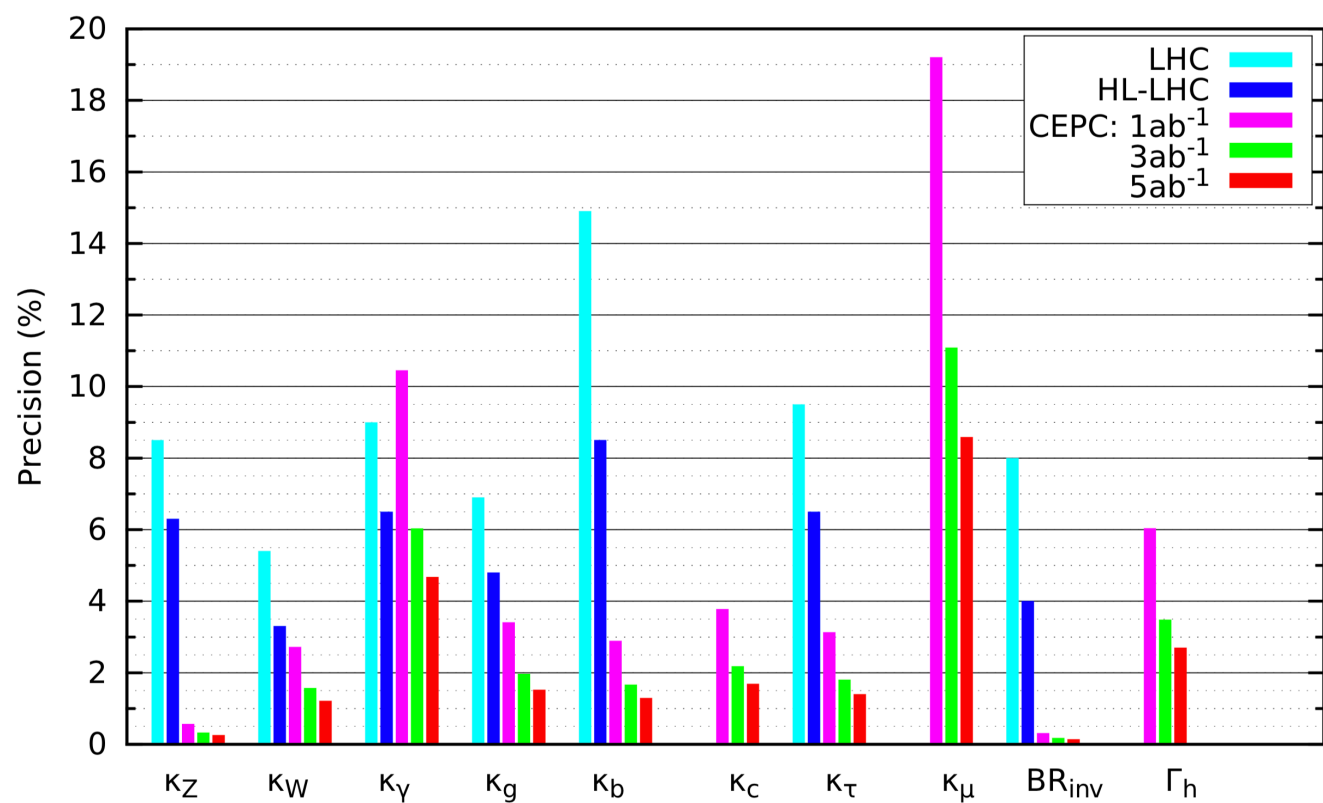
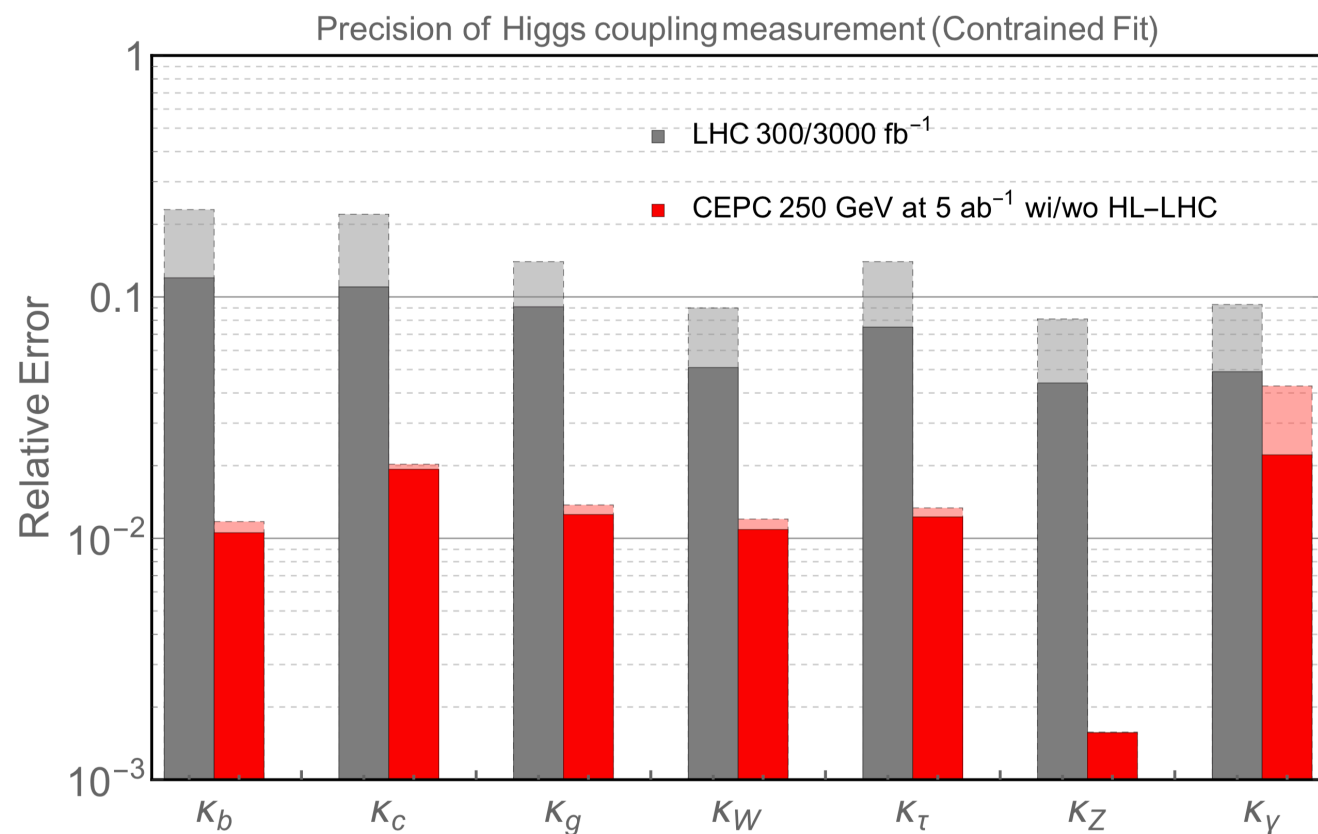
- Higgs mass ~ 125 GeV, it is possible to build a Circular e^+e^- Higgs factory(CEPC), followed by a proton collider (SPPC) in the same tunnel
- Looking for Hints (from Higgs) at CEPC $\rightarrow$ direct search at SPPC



Circular Electron-Positron Collider(CEPC), $\sqrt{s} = 90 \sim 250$ GeV
 Super Proton-Proton Collider(SPPC), $\sqrt{s} = 70 \sim 140$ TeV

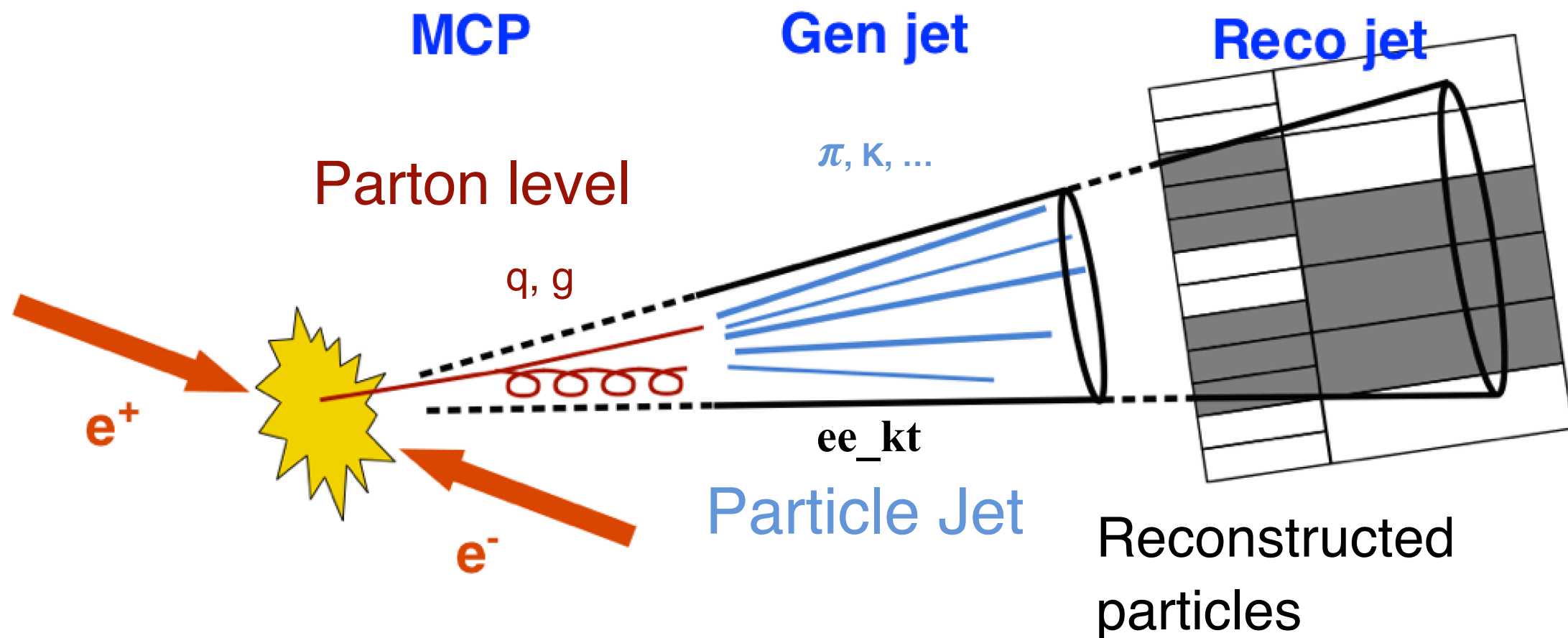
Ref. [1]

- * Higgs factory: 1M Higgs boson
 - * Absolute measurements of Higgs boson width and couplings
 - * Searching for exotic Higgs decay modes (New Physics)
- * Flavor factory: b, c, τ , and QCD studies (Highly correlate with jet)



Ref. [1-3]

- 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), Gen jet, Reco jet.

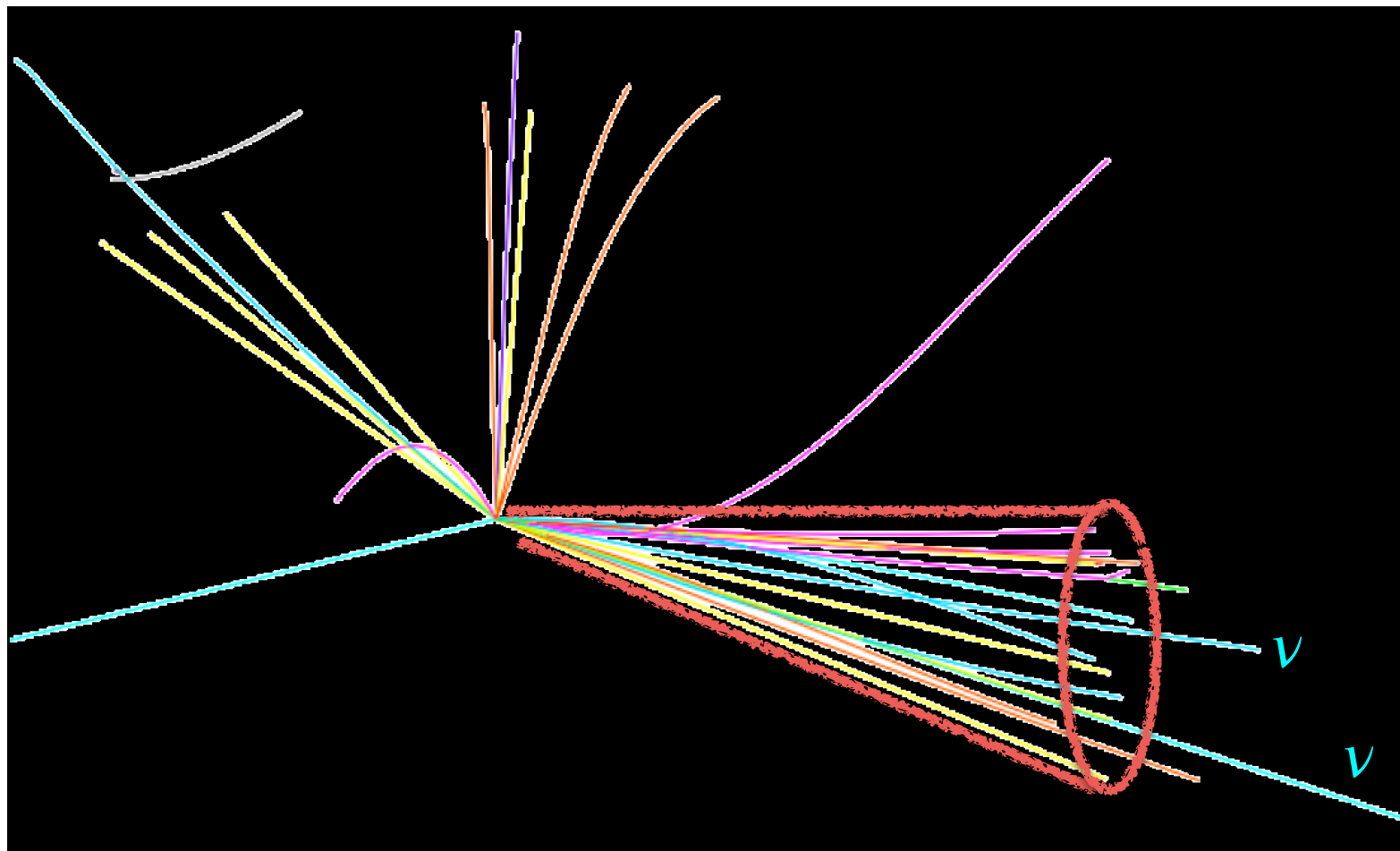


Ref. [2]

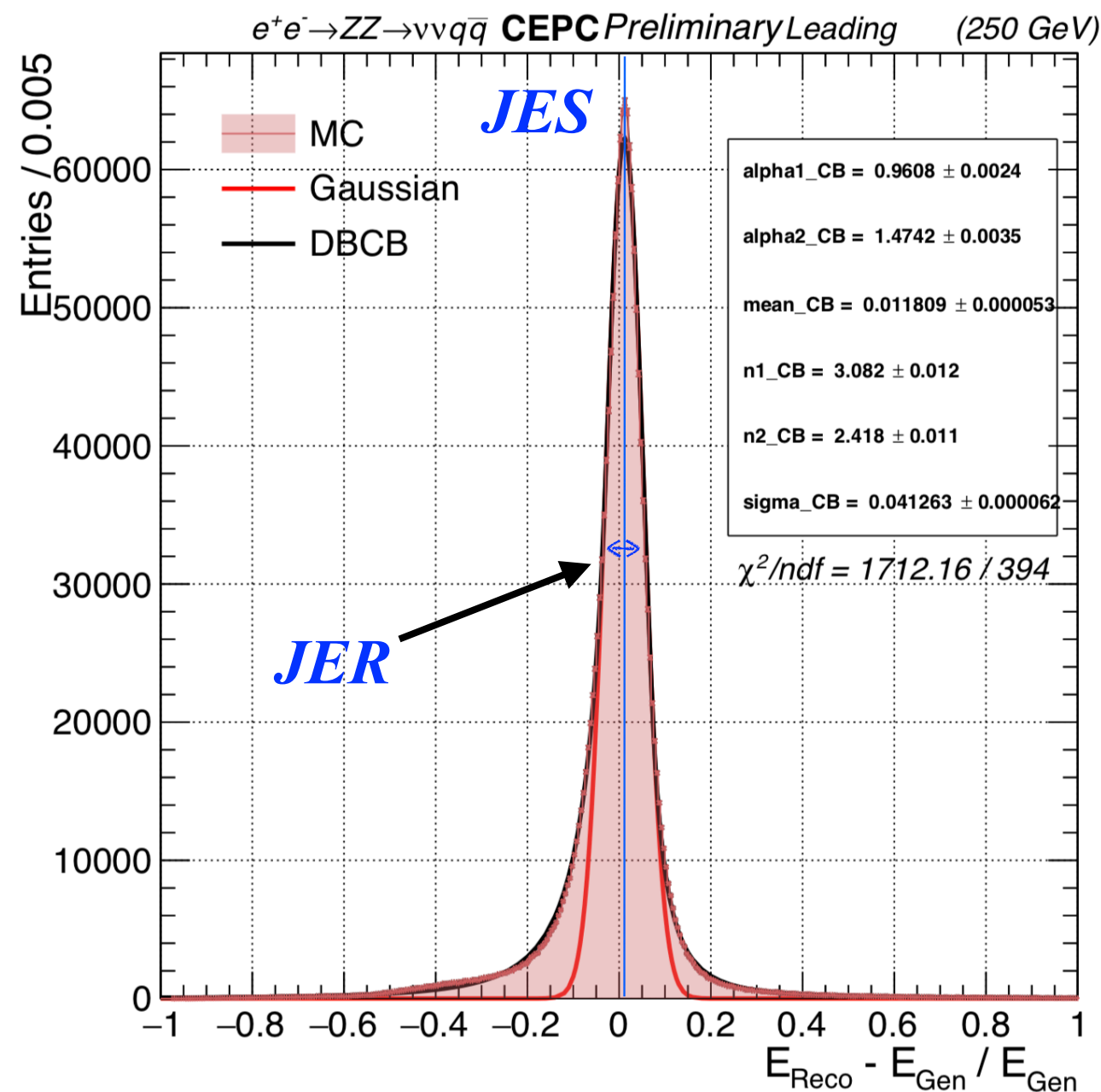
Difficulties in jet reconstruction

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

Wrong measurement leads to wrong physical results!



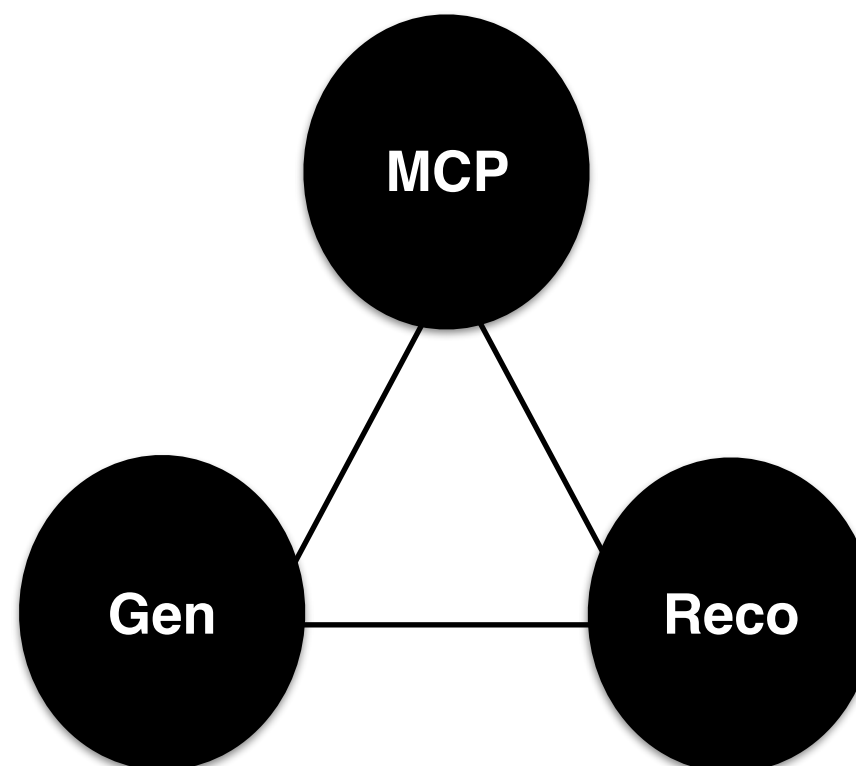
- Double-sided crystal ball(DBCB) function are used to extract energy resolution.
- The bin size of histogram is 0.5%.



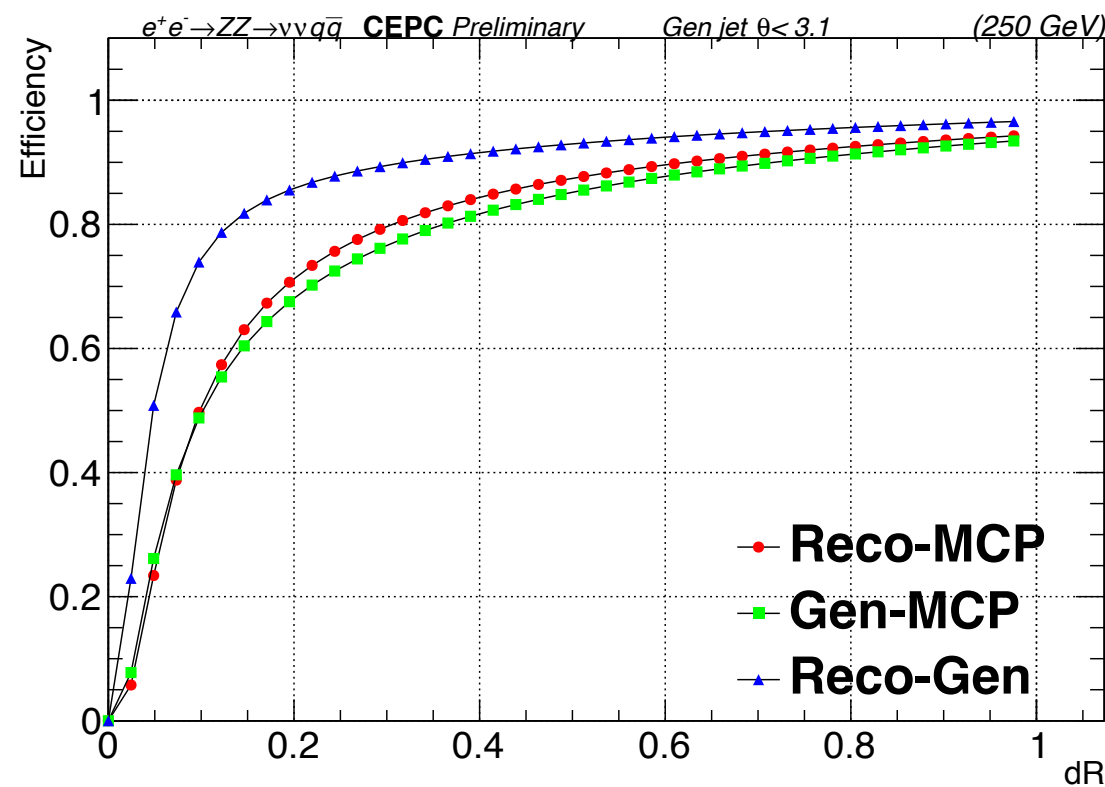
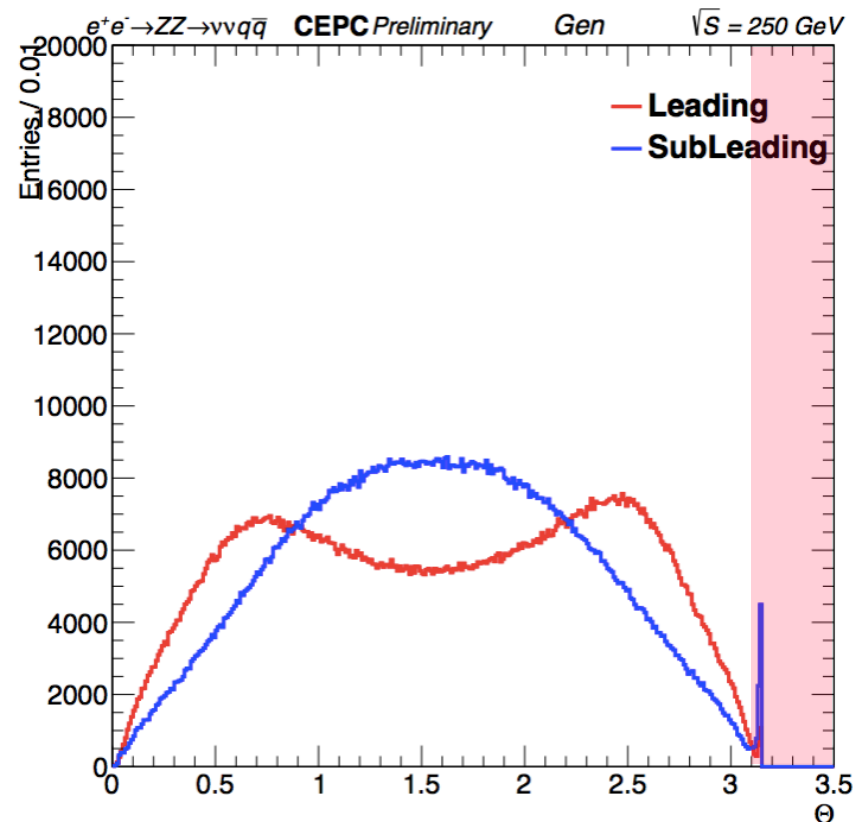
Relativity difference

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

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



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

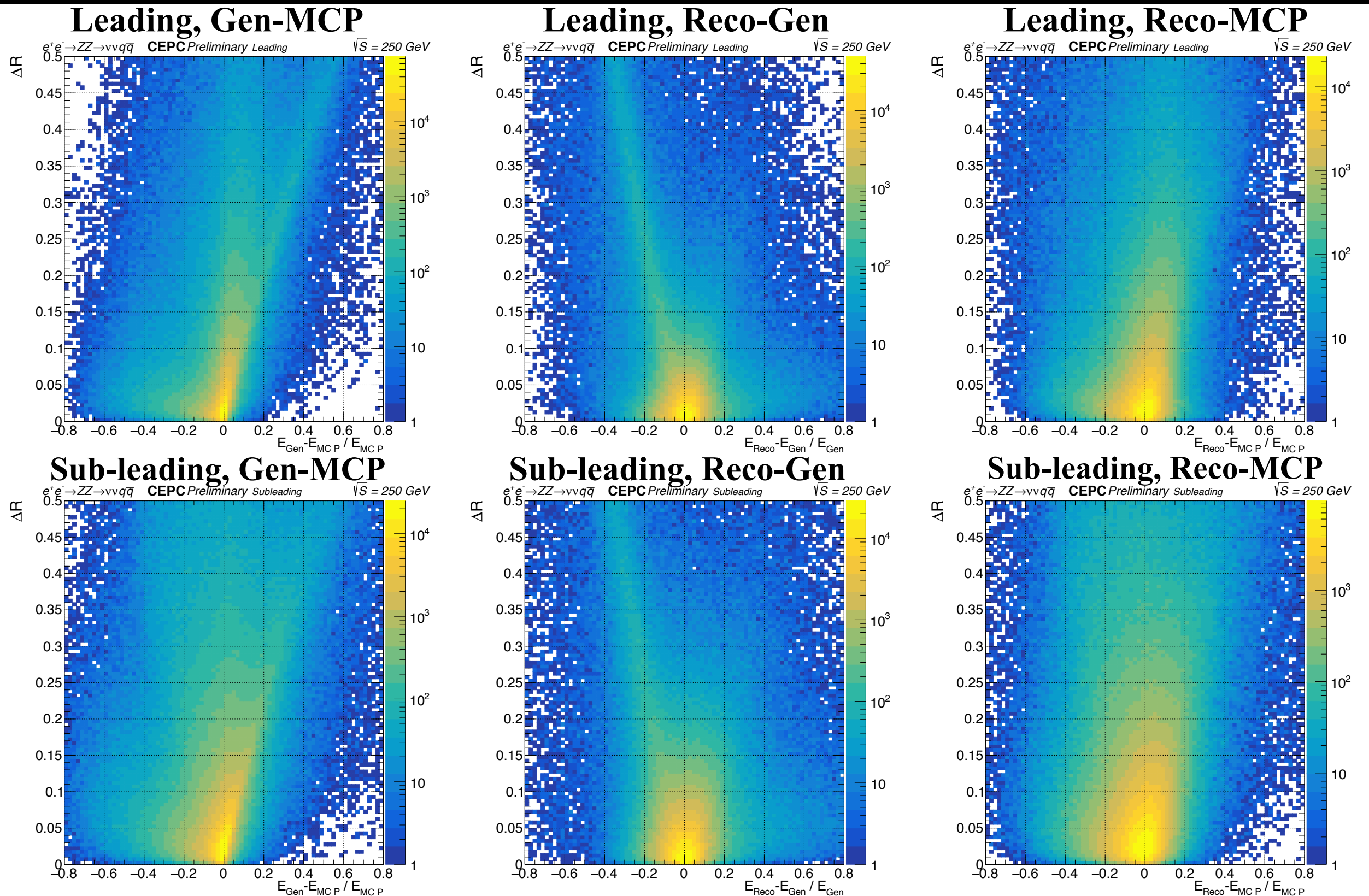


Efficiency =

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

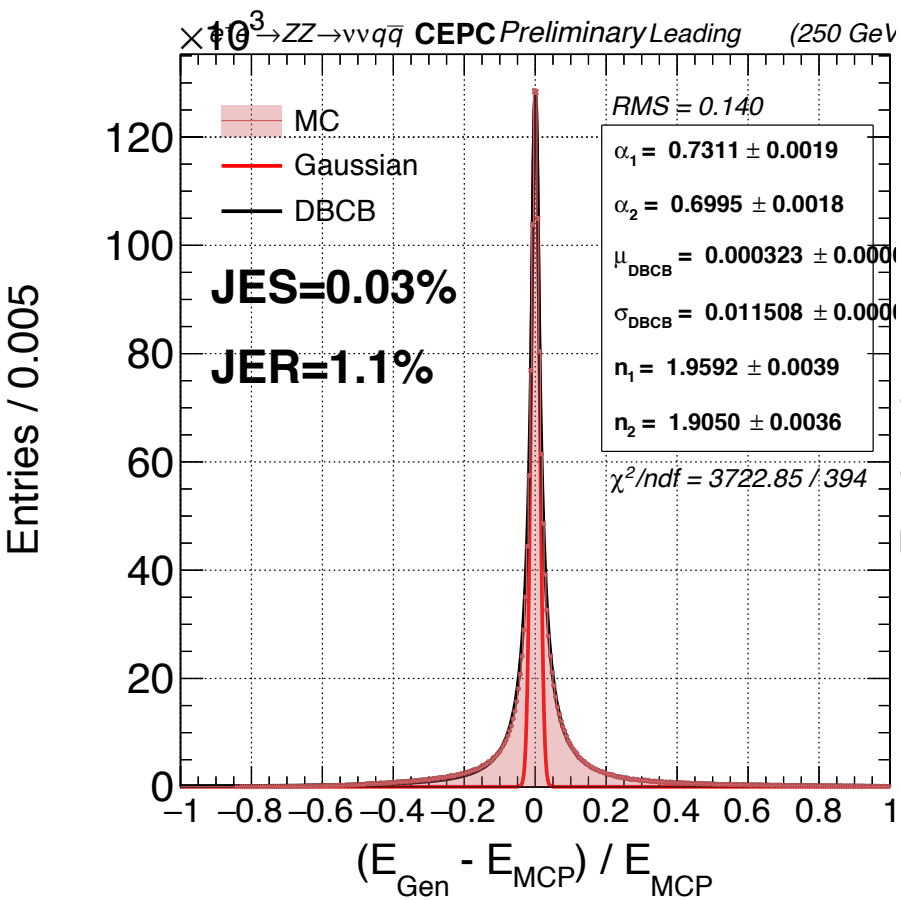
$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

The Reason for ΔR Cut

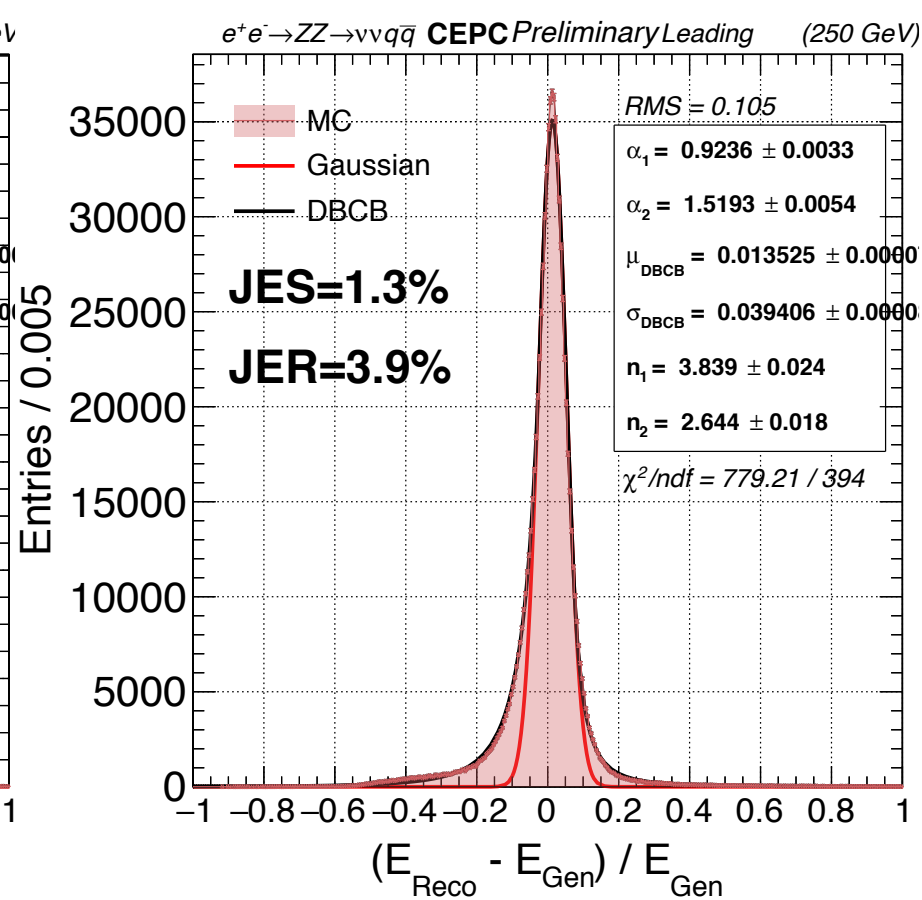


The jet clustering bring a significant uncertainty.

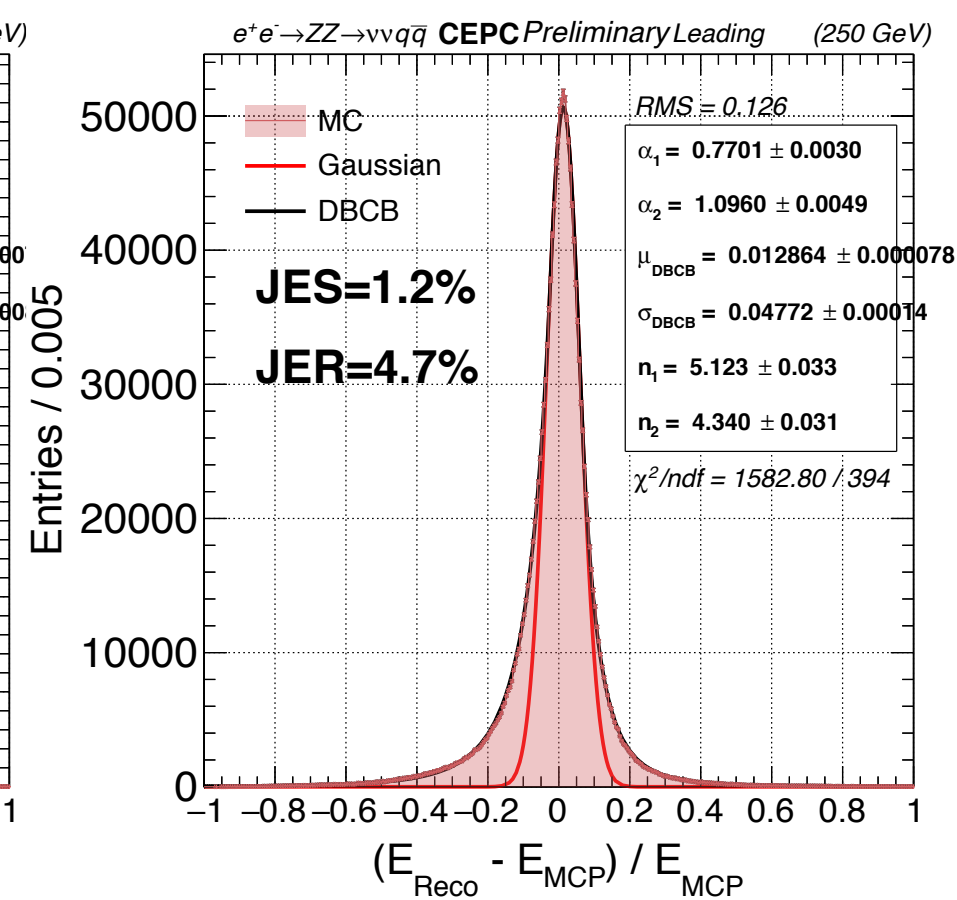
Gen-MCP



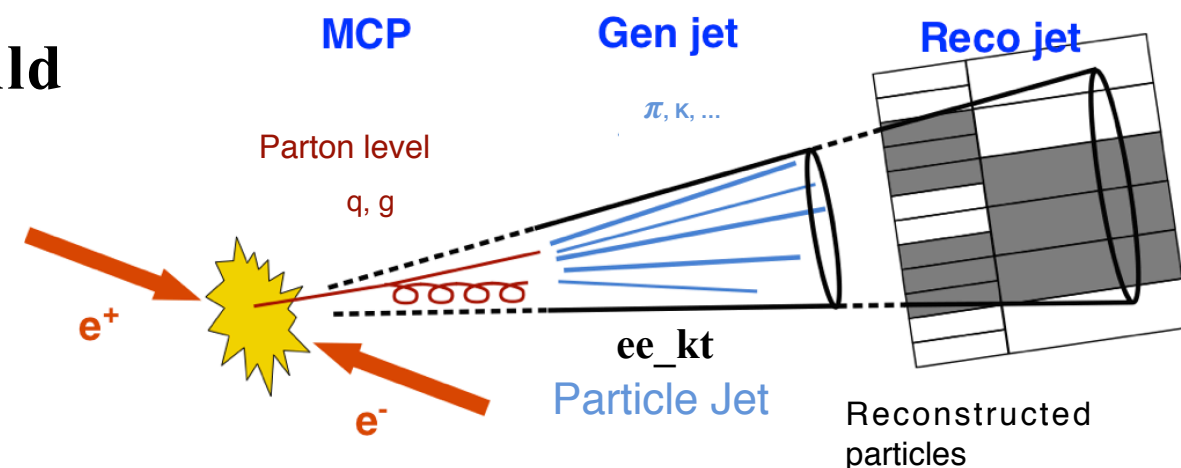
Reco-Gen



Reco-MCP

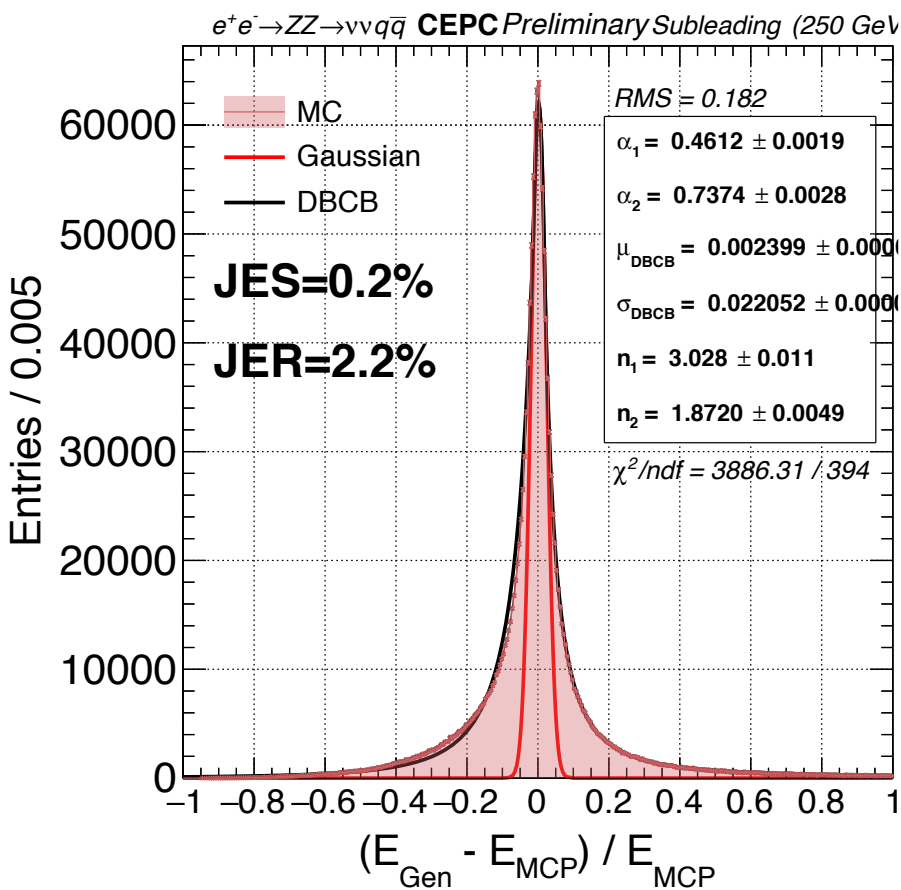


- JER/JES between reco jet and MCP would combine the effects of two previous stages.

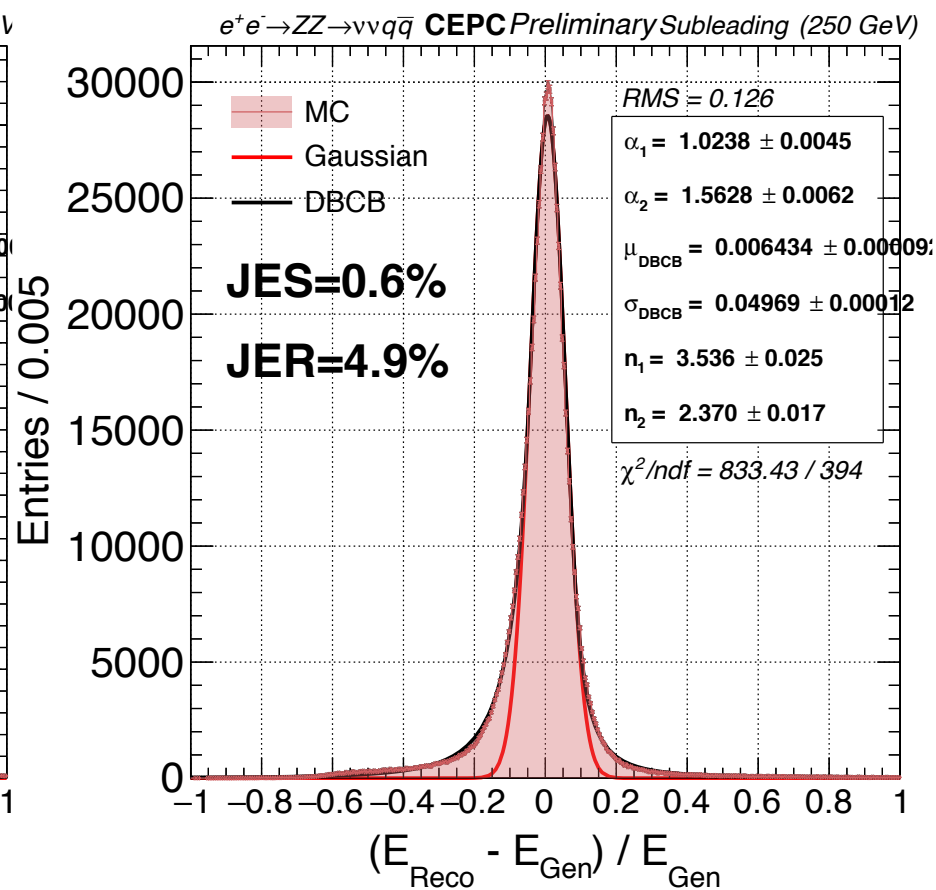


Sub-leading JER & JES

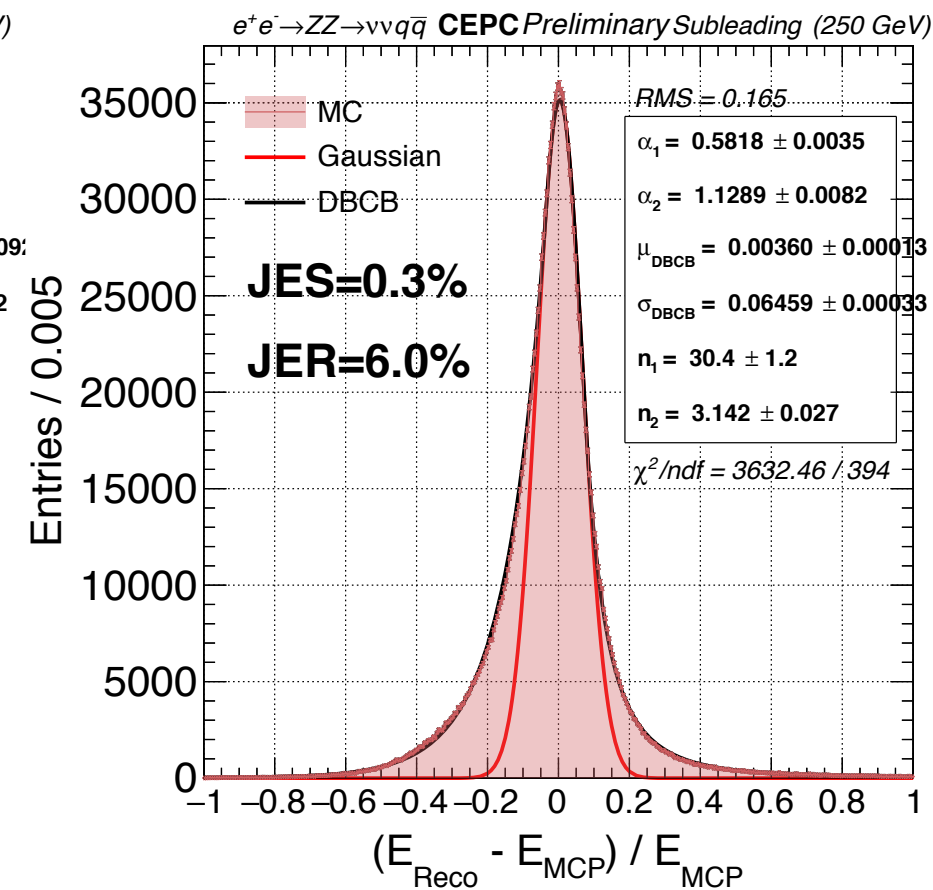
Gen-MCP



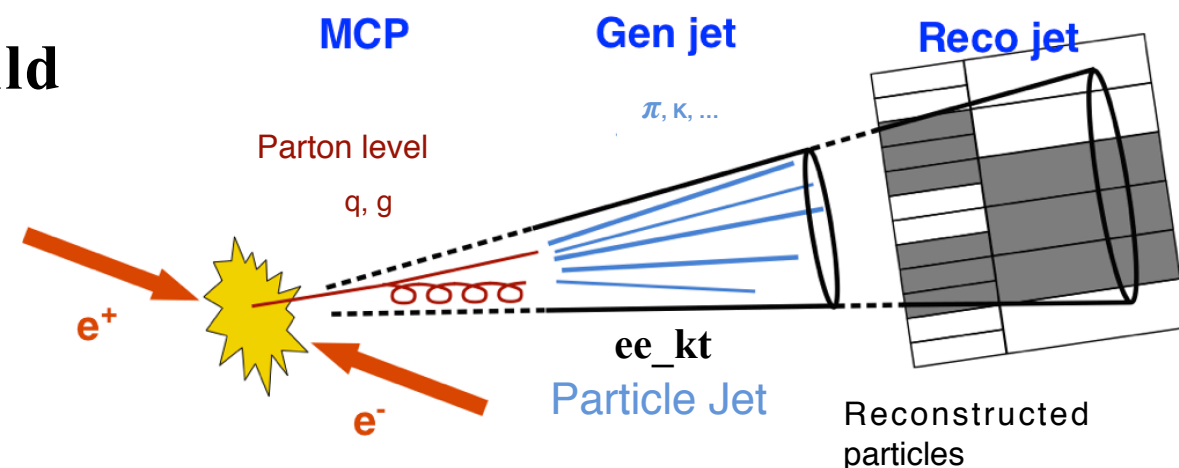
Reco-Gen

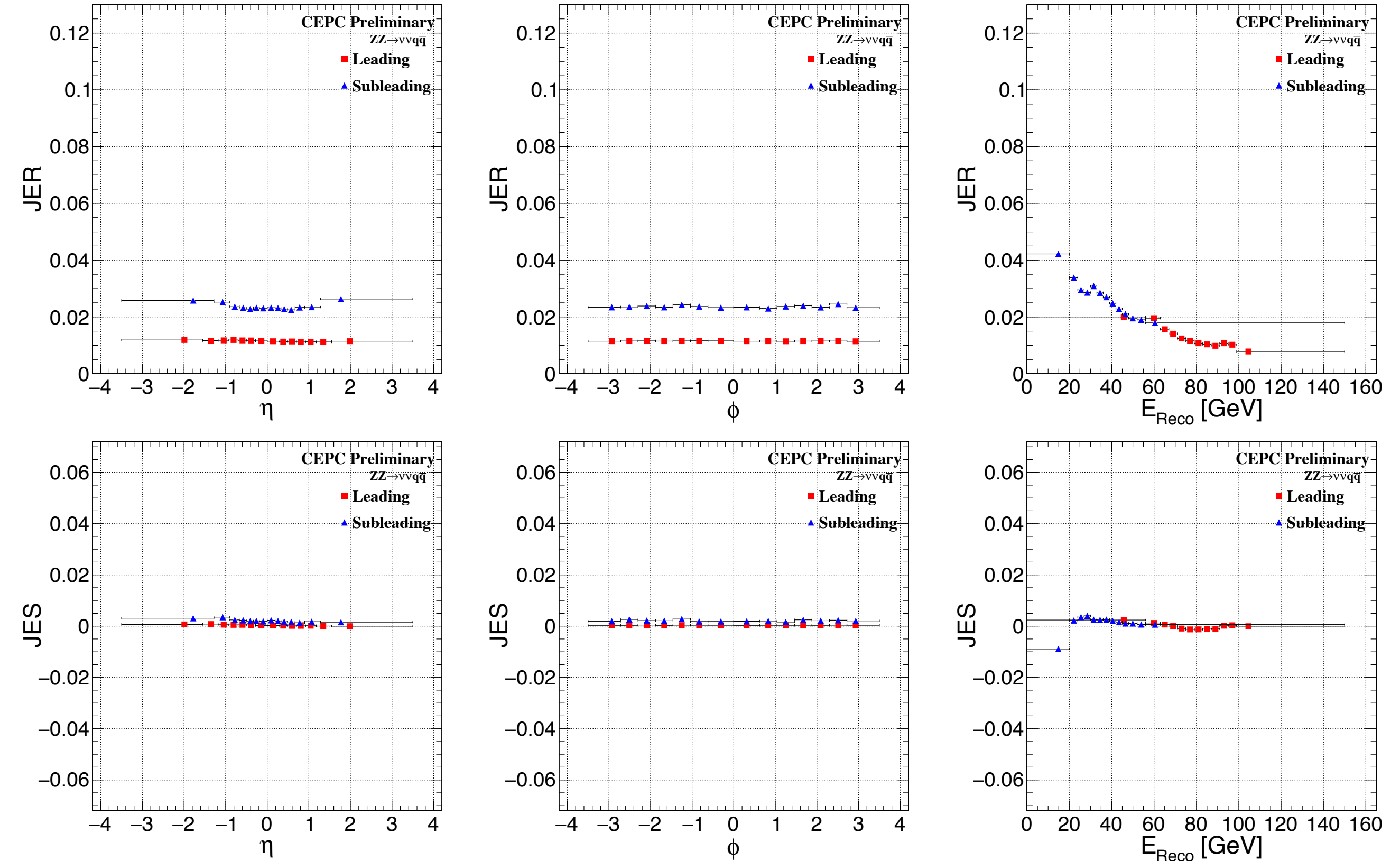


Reco-MCP

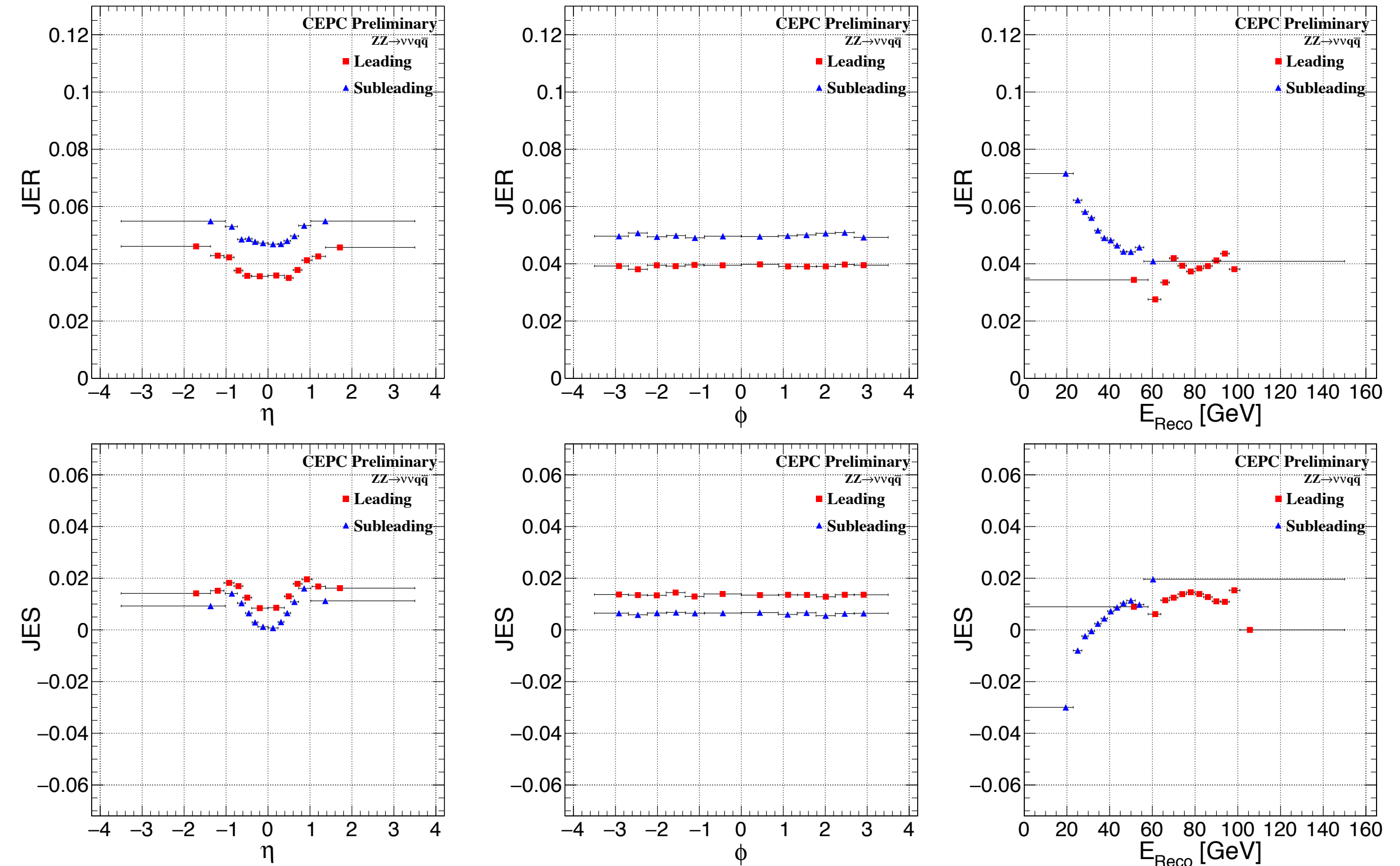


- JER/JES between reco jet and MCP would combine the effects of two previous stages.

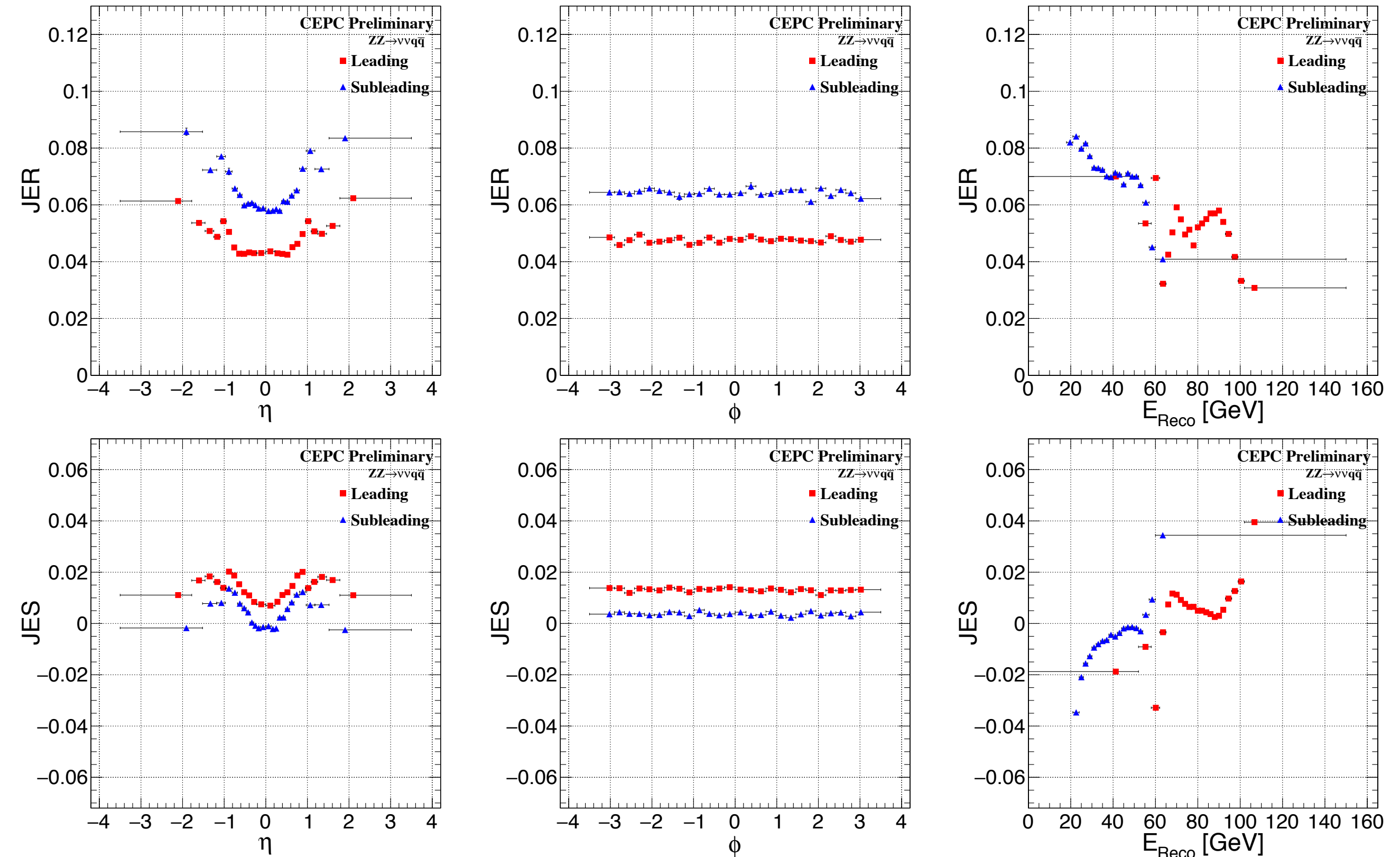




The jet clustering is independently on direction.

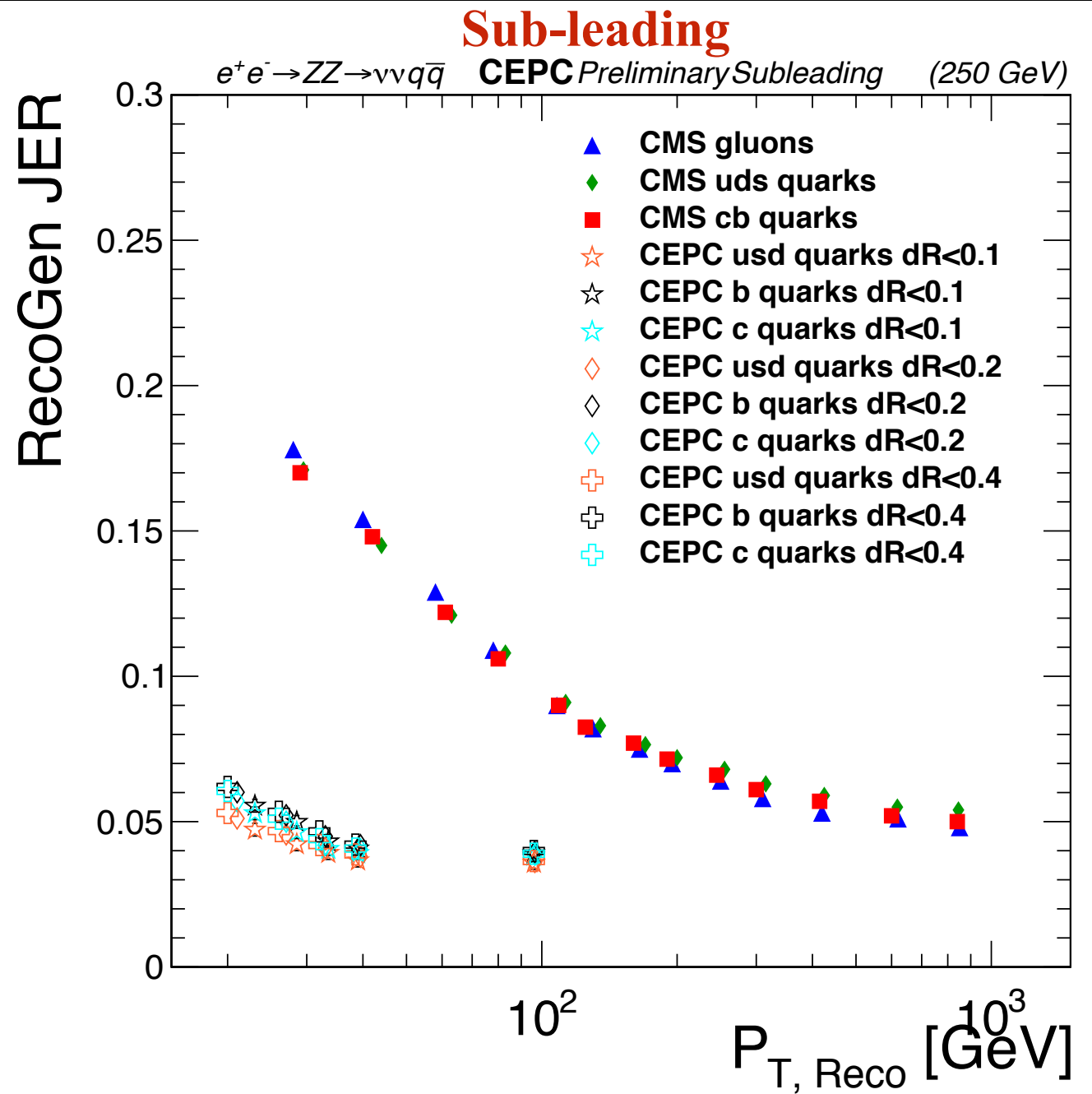
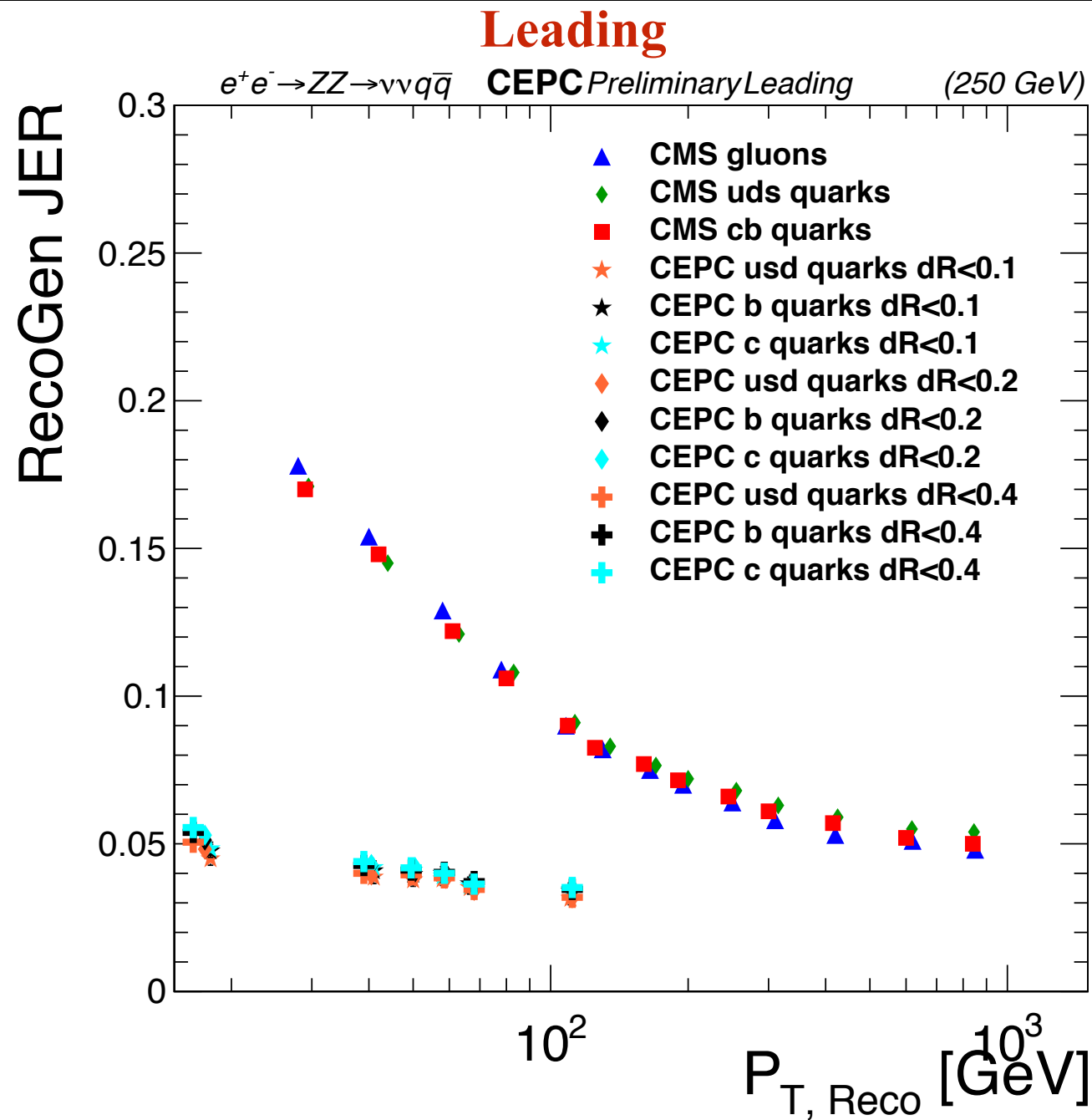


Both JER/JES are slightly depend on Eta.



Both JER/JES depend on Eta within 2%.

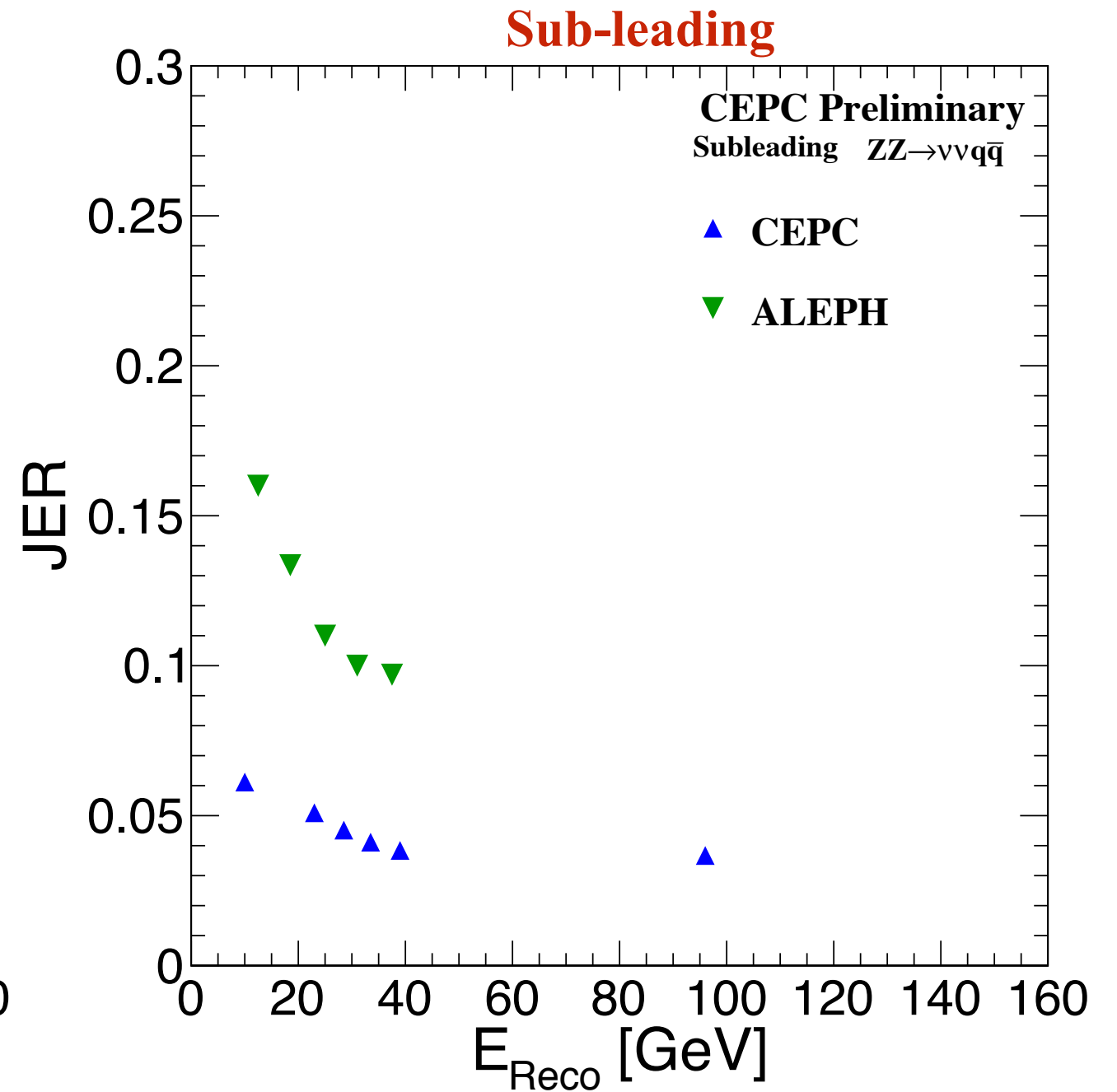
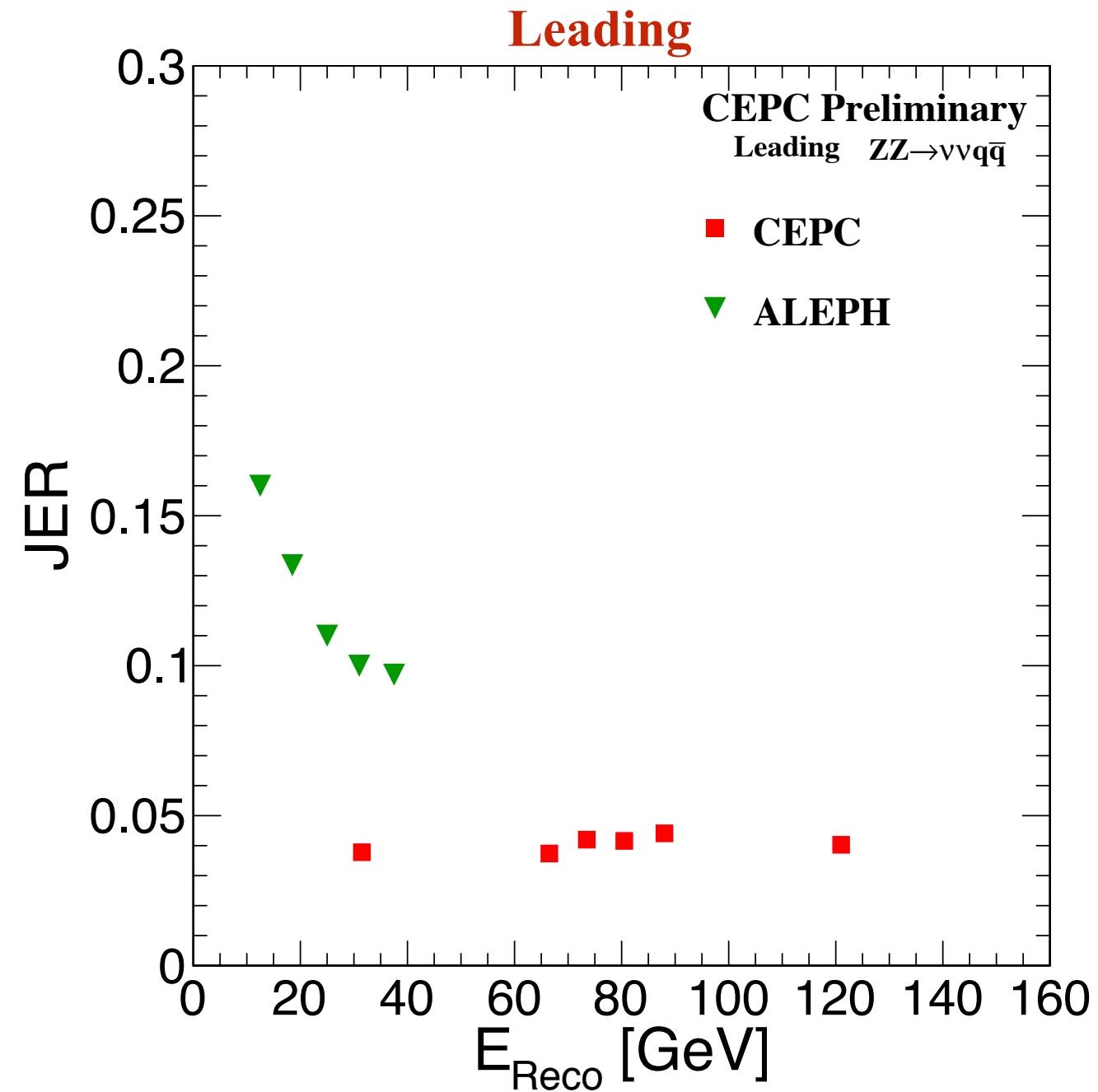
Compare with CMS at LHC



- Our JER is better than CMS.
- Heavy flavors have a little poor JER.
- Different matching criteria only improve JER a little bit.

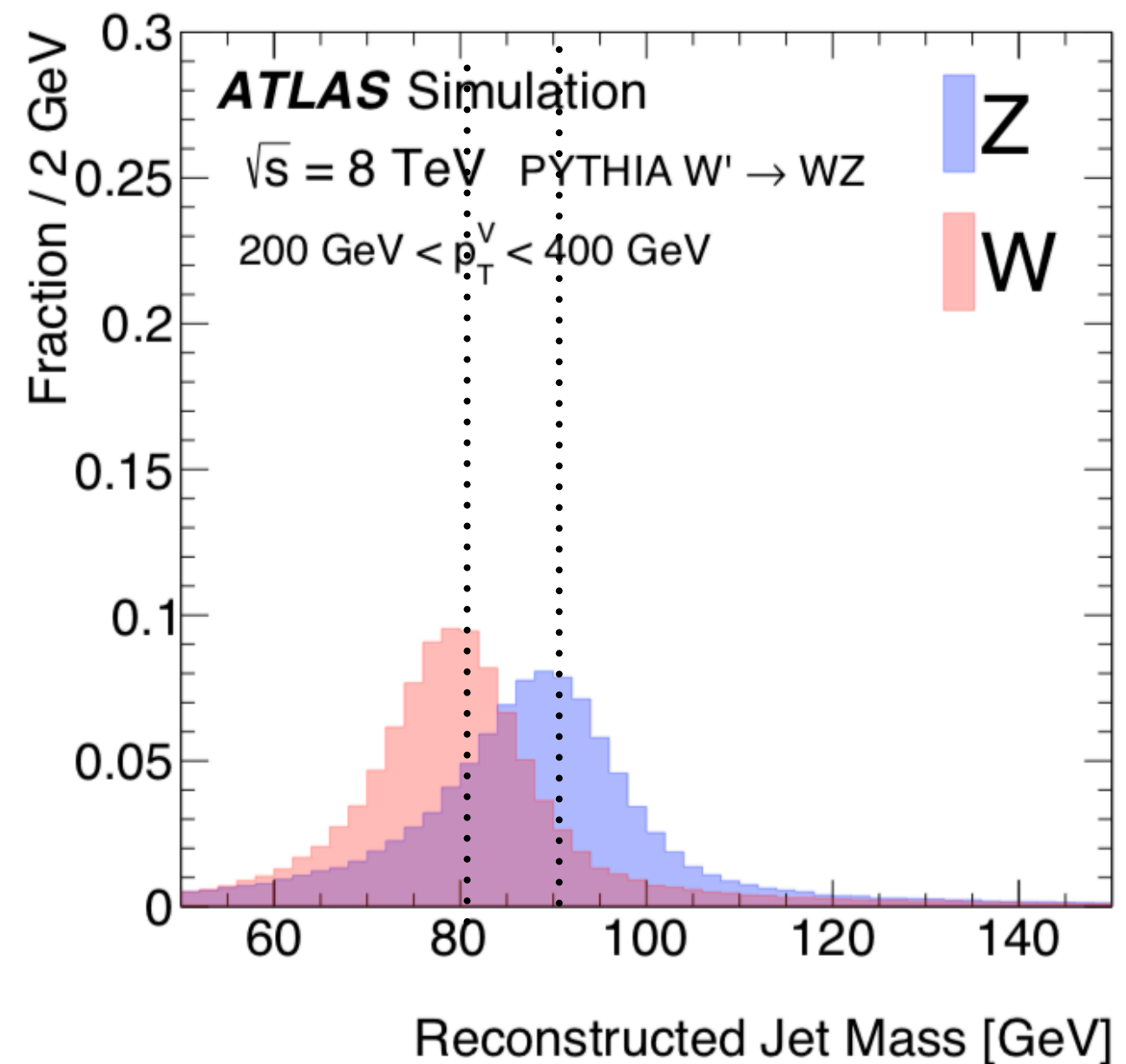
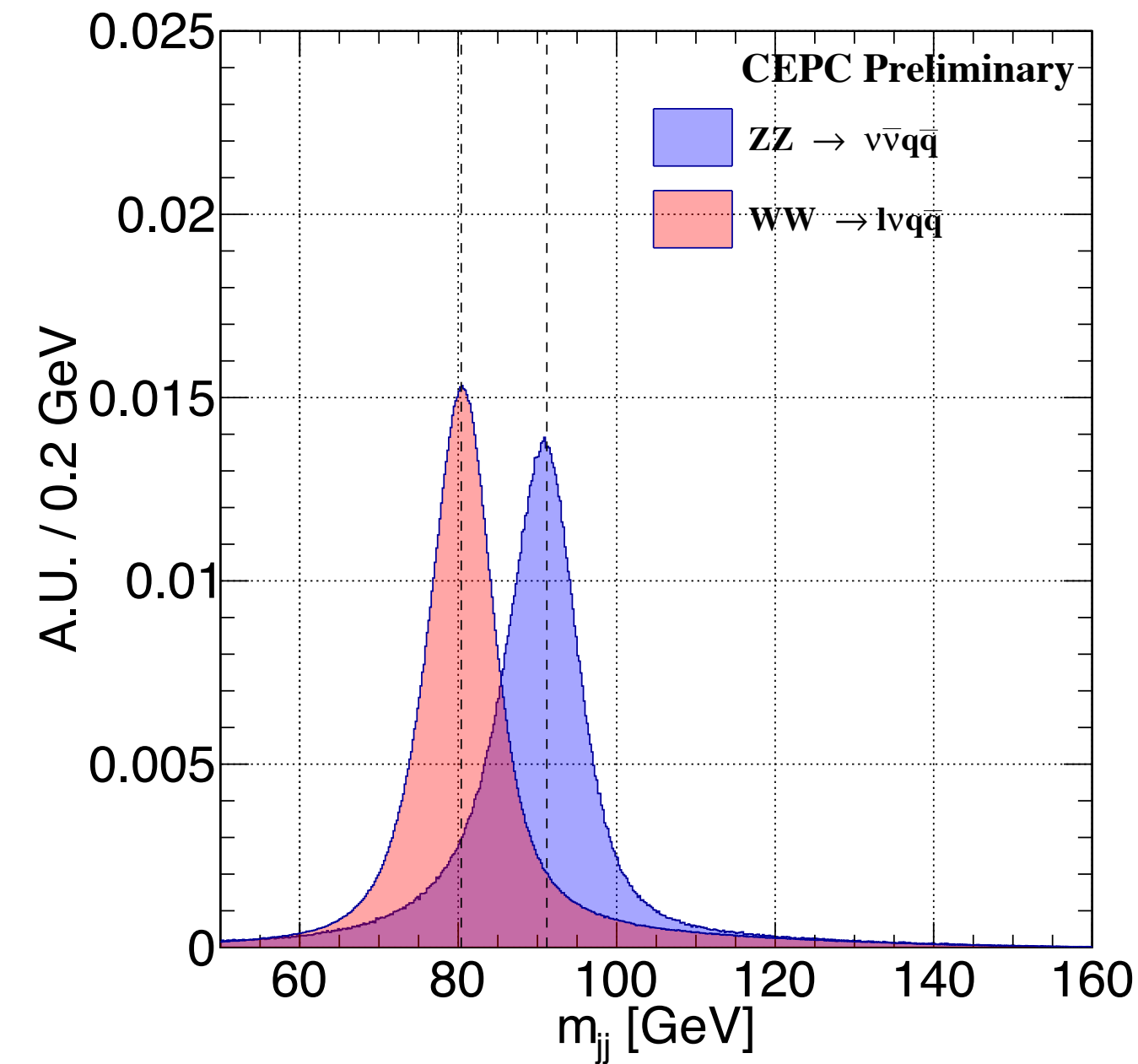
Ref. [3]

Compare with ALEPH at LEP



■ Our JER is better than ALEPH.

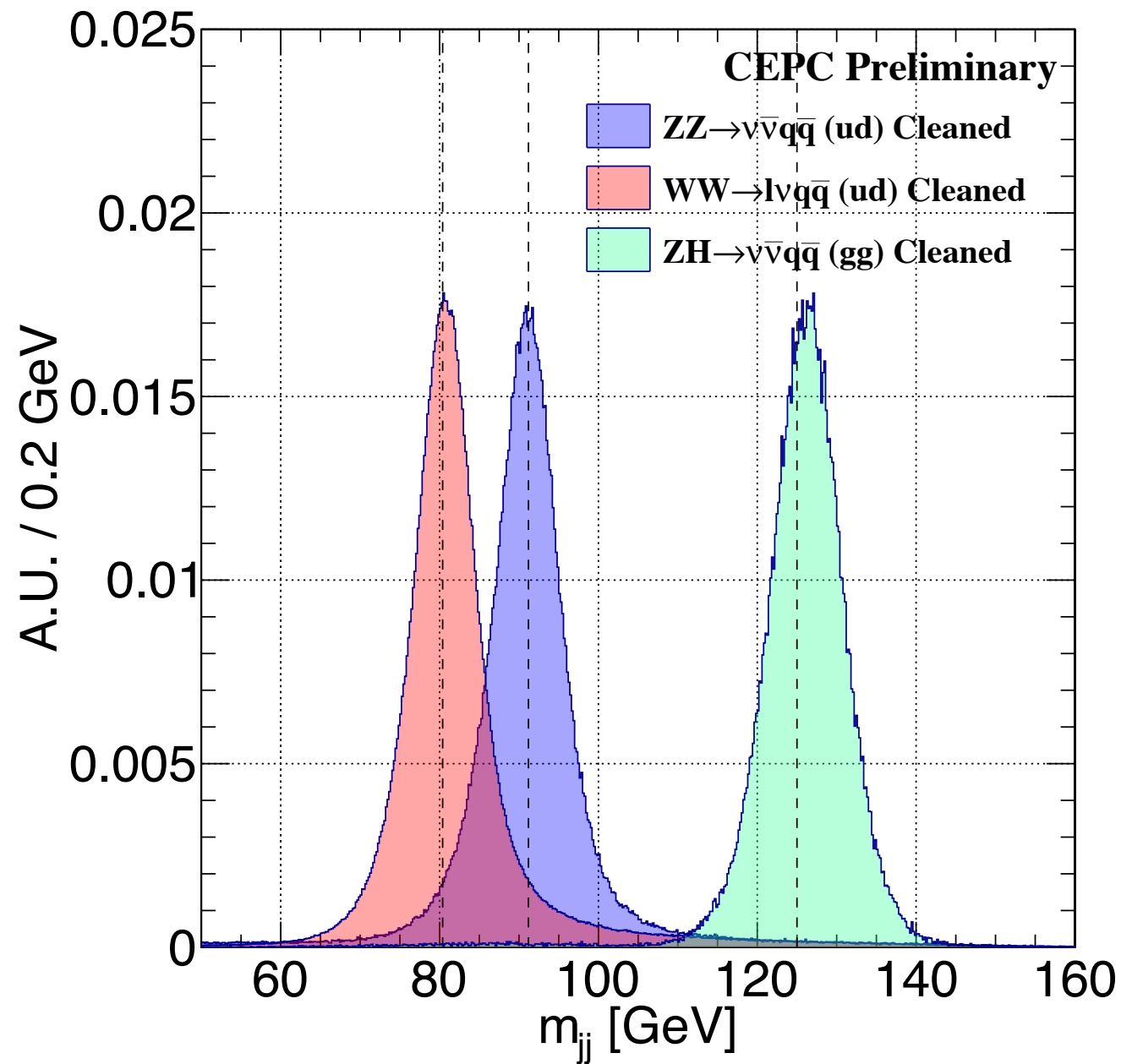
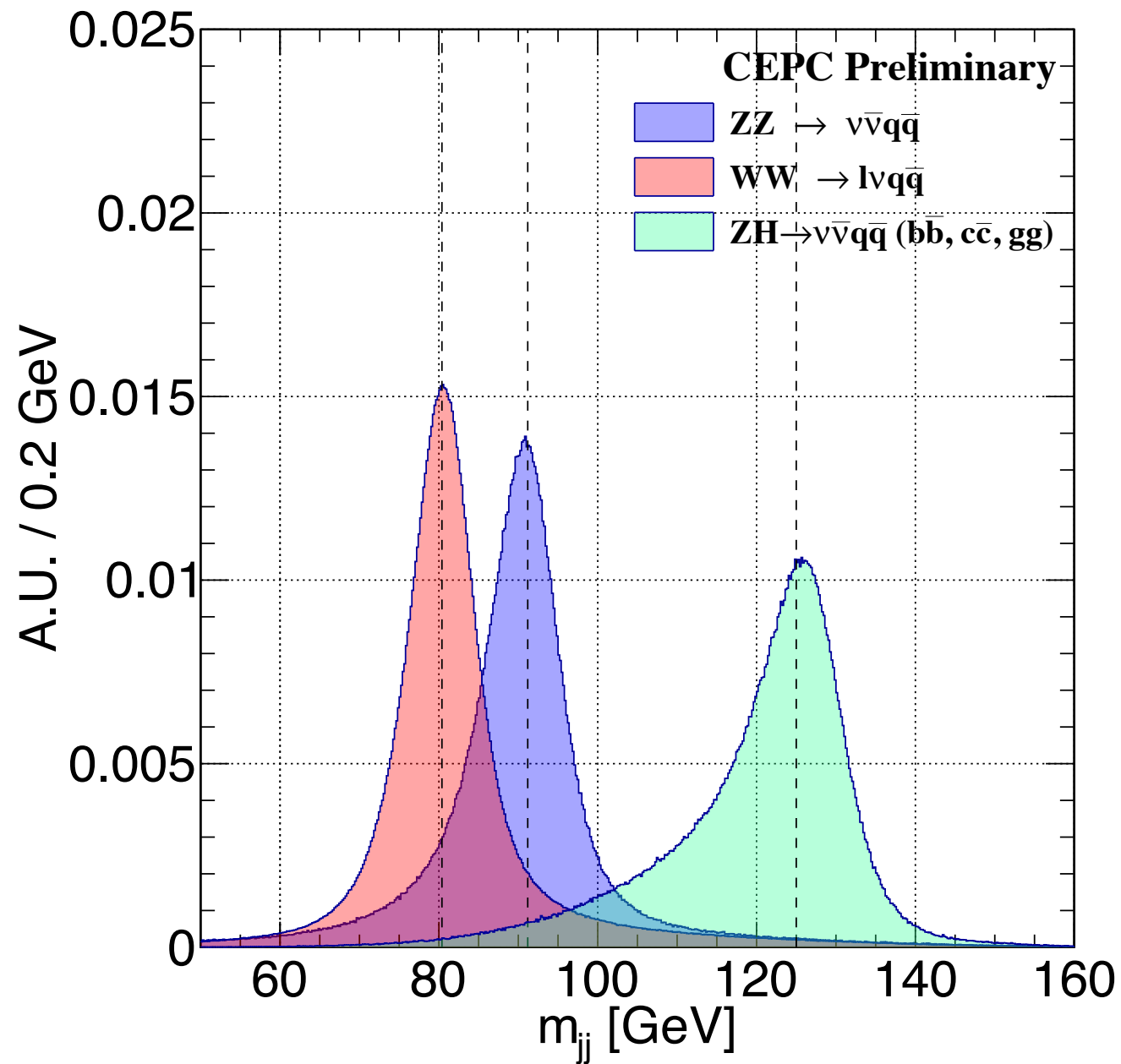
Ref. [4]



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

Ref. [5]

Massive Boson Separation



The Z, W, and Higgs bosons can be well separated in CEPC.

Gen-MCP

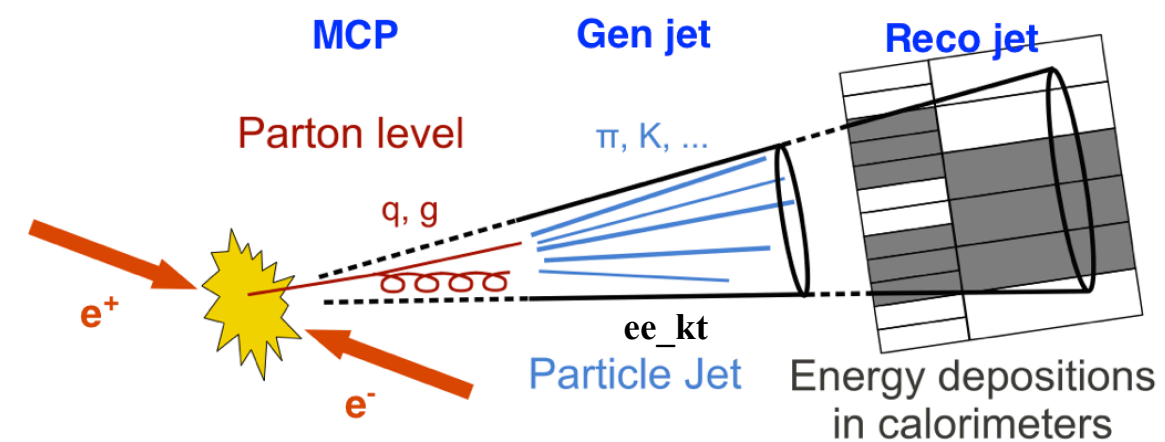
Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	1%	2%	0	0
Endcaps	1%	2%	0	0
En > 60 GeV	1%	2%	0	0

Reco-Gen

Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	3.5%	4.5%	1%	0
Endcaps	4%	5%	1.5%	0.5%
En > 60 GeV	4%	4.5%	1%	1.5%

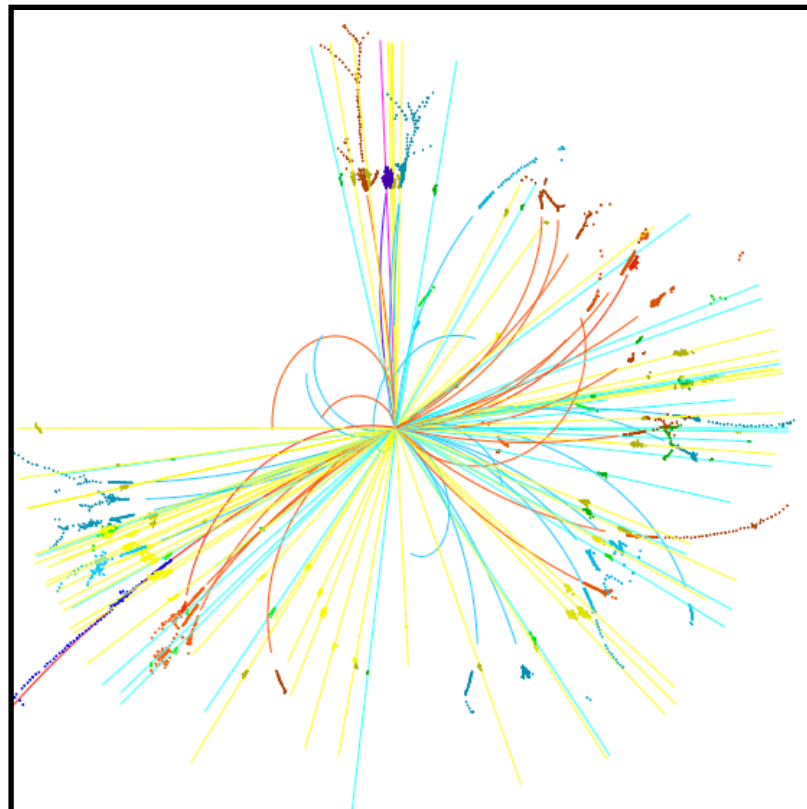
Reco-MCP

Type	JER		JES	
	Lead	Sub-Lead	Lead	Sub-Lead
Barrel	4.5%	6%	1%	0
Endcaps	5%	6.5%	1.5%	0.5%
En > 60 GeV	5%	6%	0.5%	1.5%



- The jet clustering brings a significant or even leading uncertainty.
- After comparison, the CEPC detector has excellent jet energy resolution.
- **Z, W, Higgs boson mass can be well separated in CEPC.**
- **These results have been accepted by EPJC.**
- Study the performance of different jet clustering algorithms and try to find out the best one for CEPC.
- Apply the best one to multi-jet processes ($ee \rightarrow ZH \rightarrow 4b$) to promote precision.

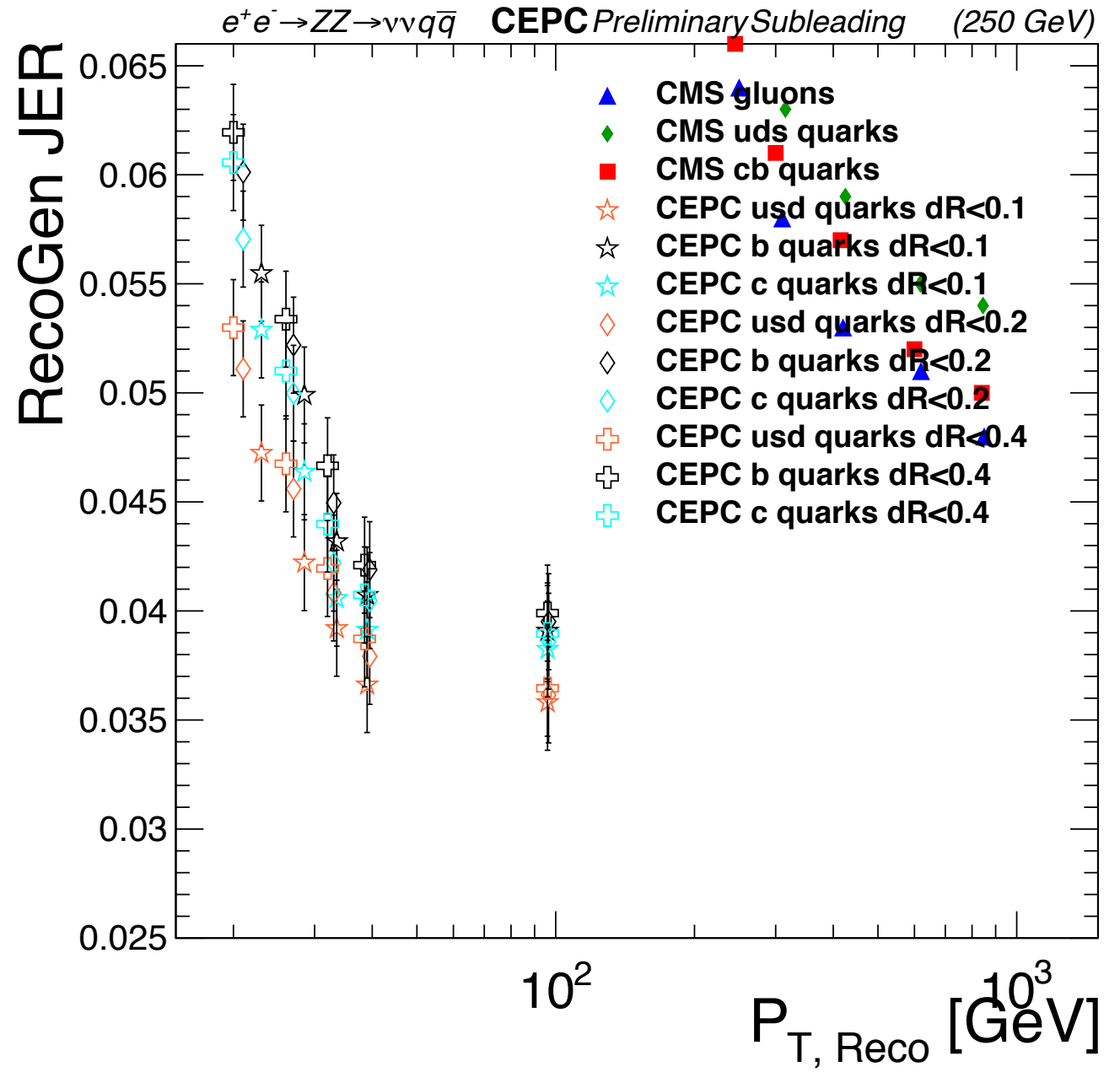
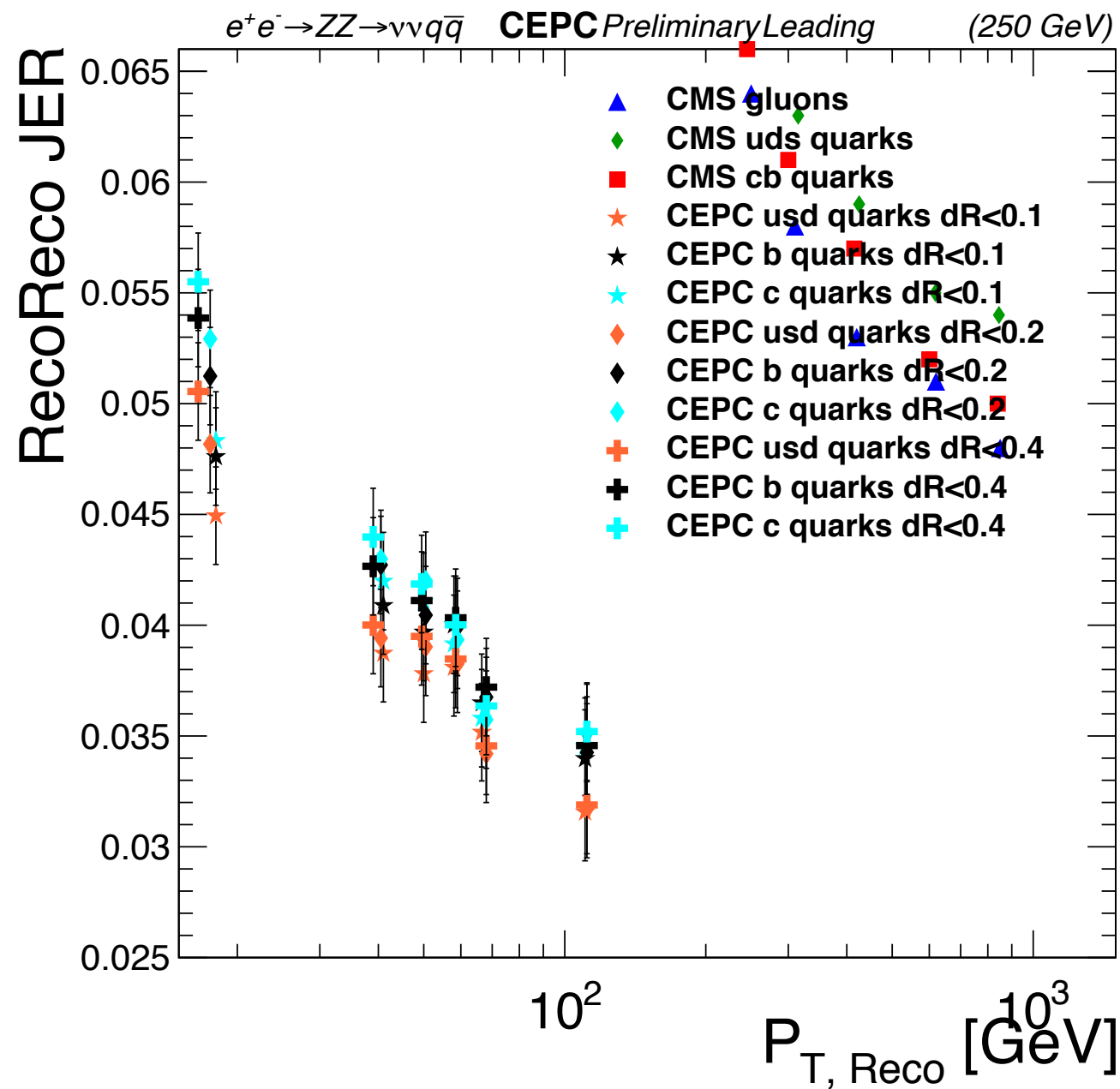
$ee \rightarrow ZH \rightarrow 4b$



Thank for your attention

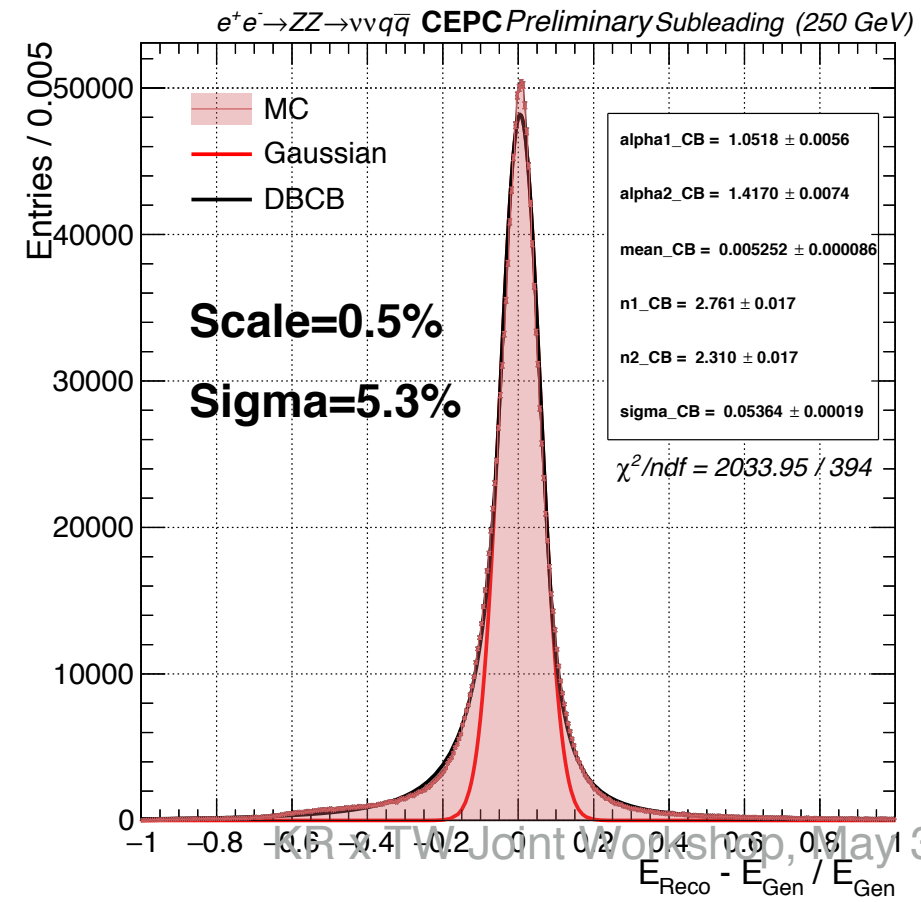
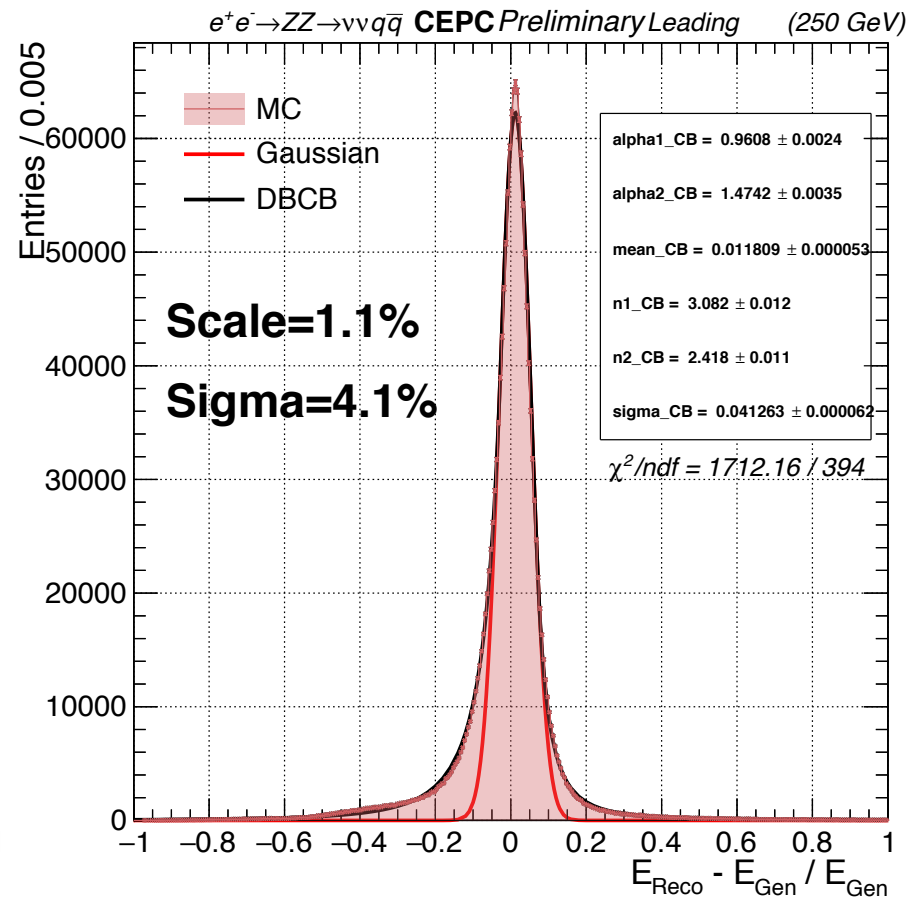
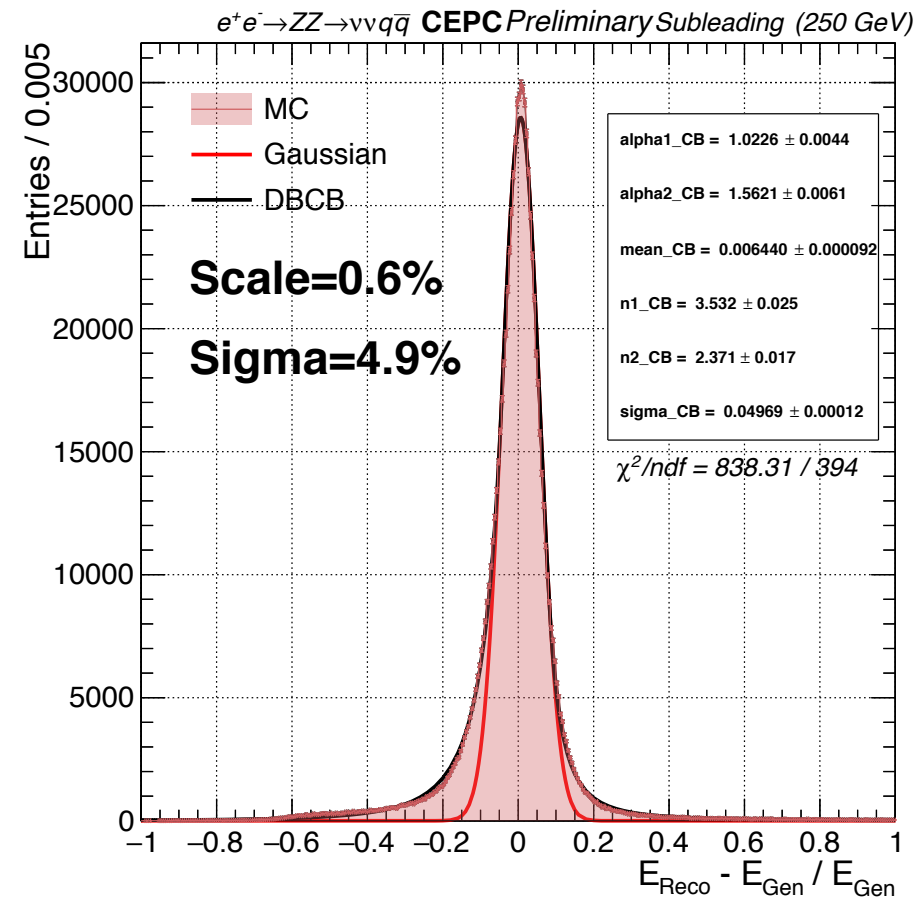
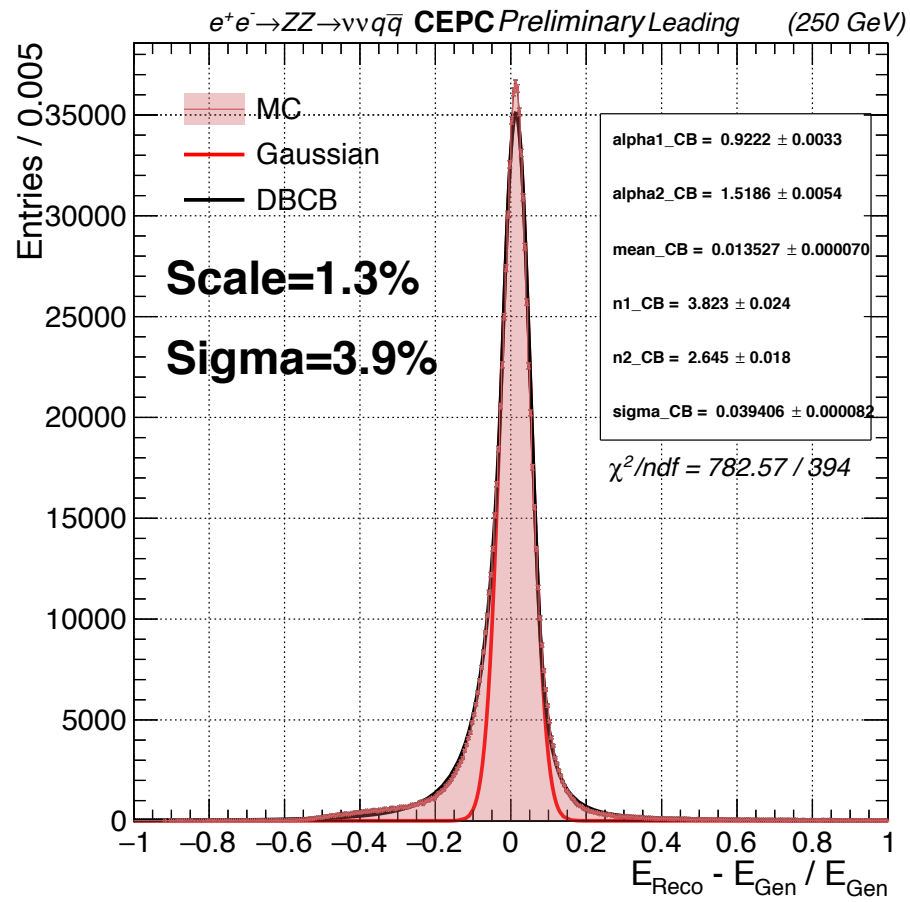
- [1] CMS-Physics-Technical-Design-Report-2006-001**
- [2] <http://cms.web.cern.ch/tags/particle-jet>**
- [3] CMS-JME-13-004, CERN-PH-EP “Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV”**
- [4] <https://goo.gl/ZvTvoy> // ALEPH**
- [5] CERN-PH-2015-194**

JER with Different dR



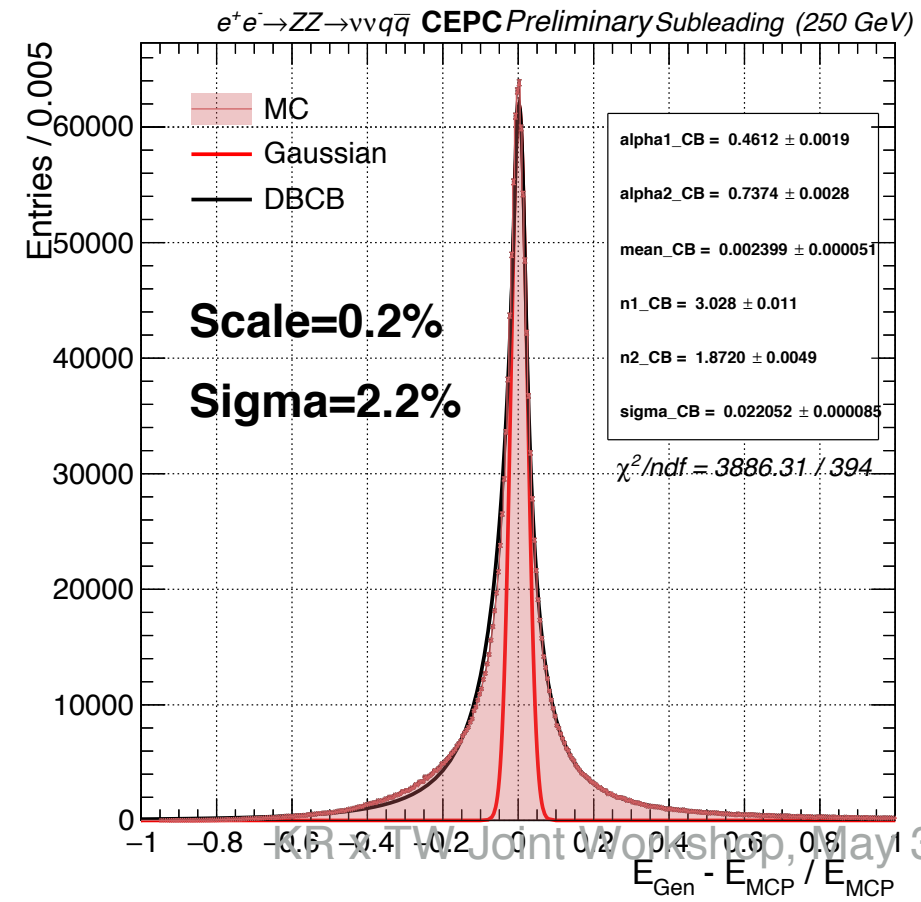
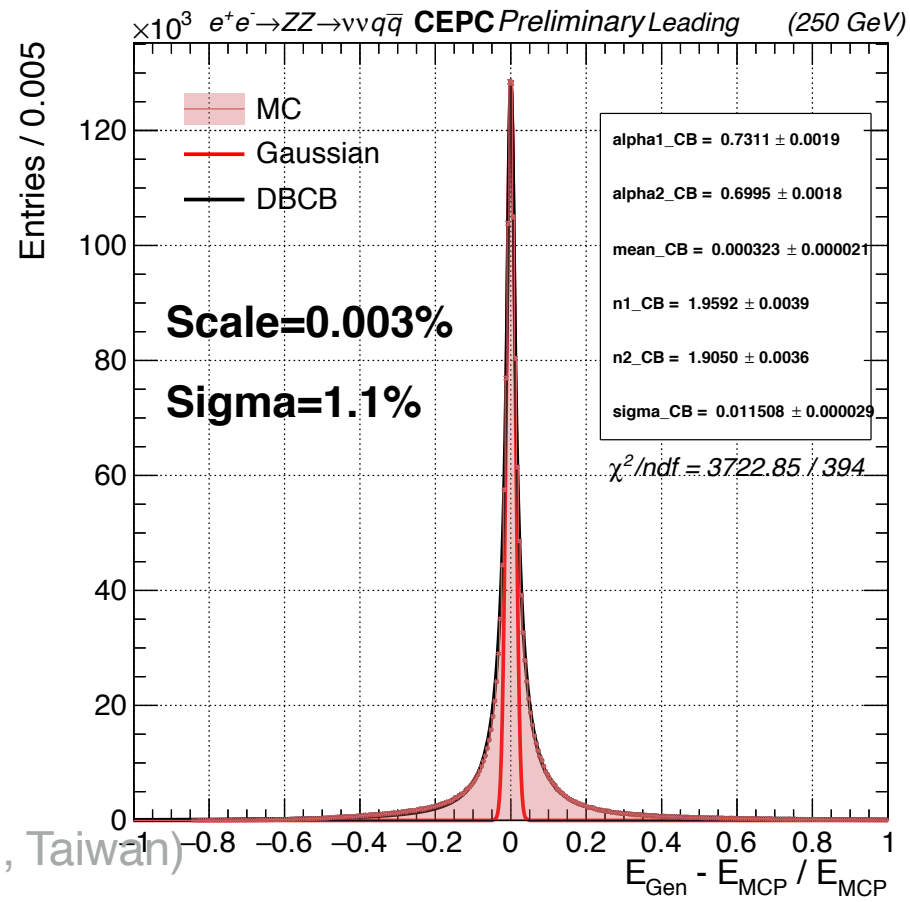
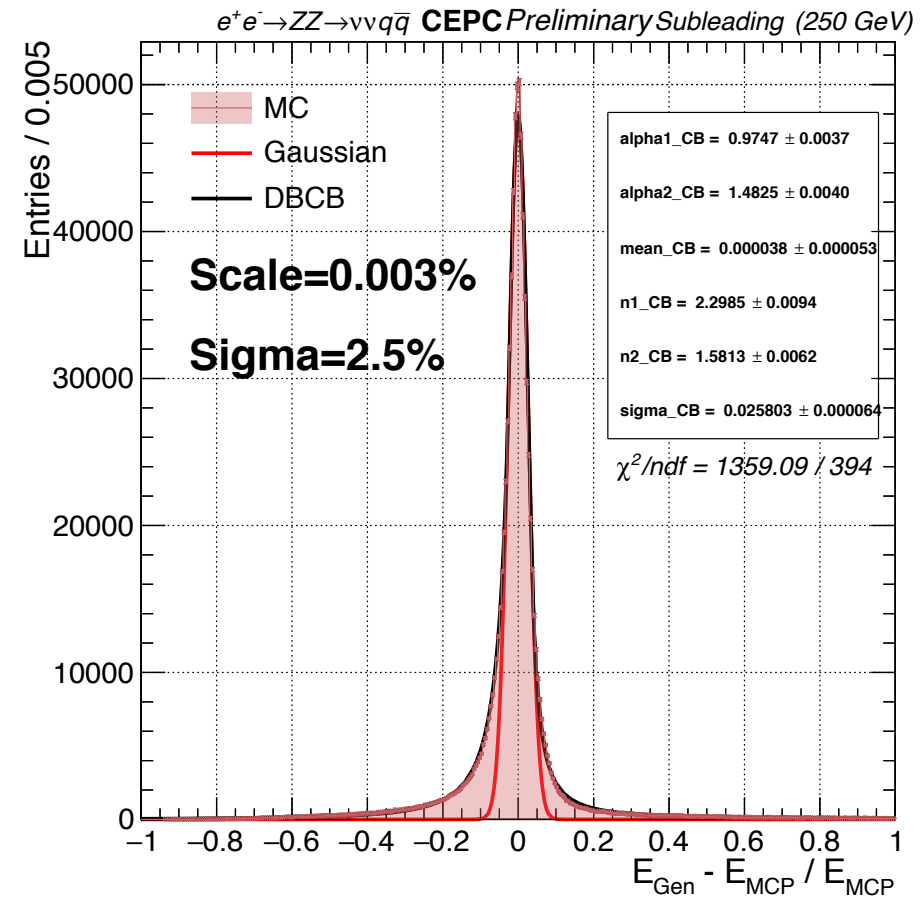
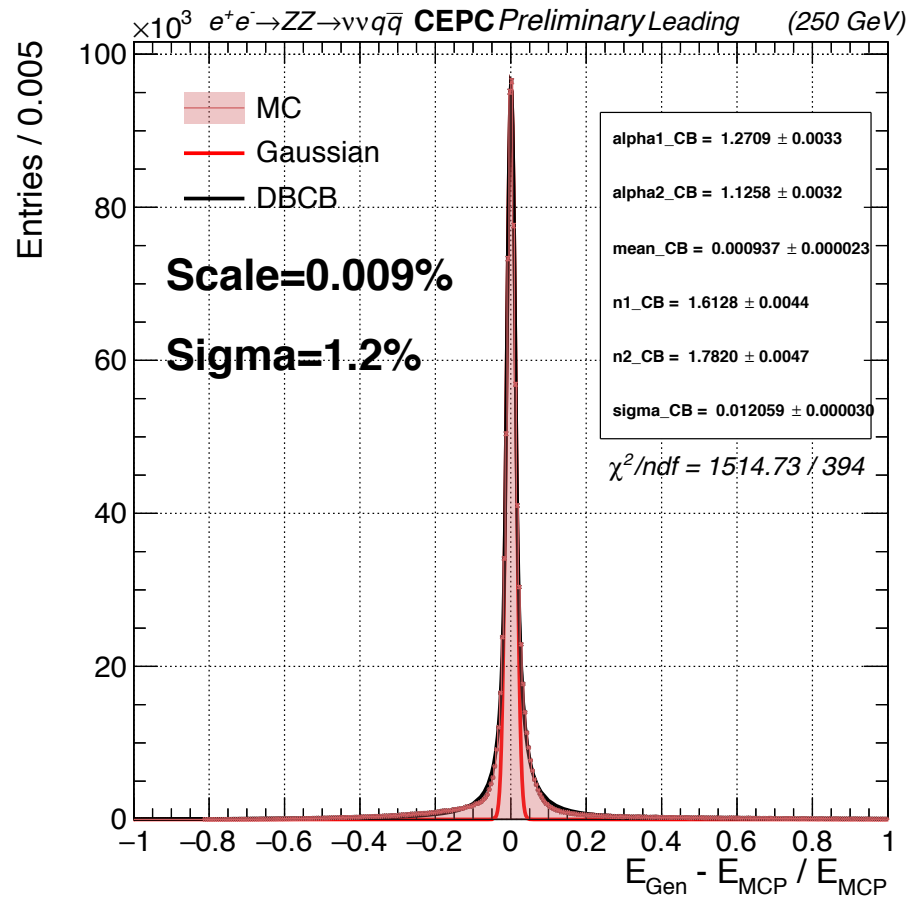
Compare the Results Whether with dR Cut (Reco-Gen)

dR < 0.1



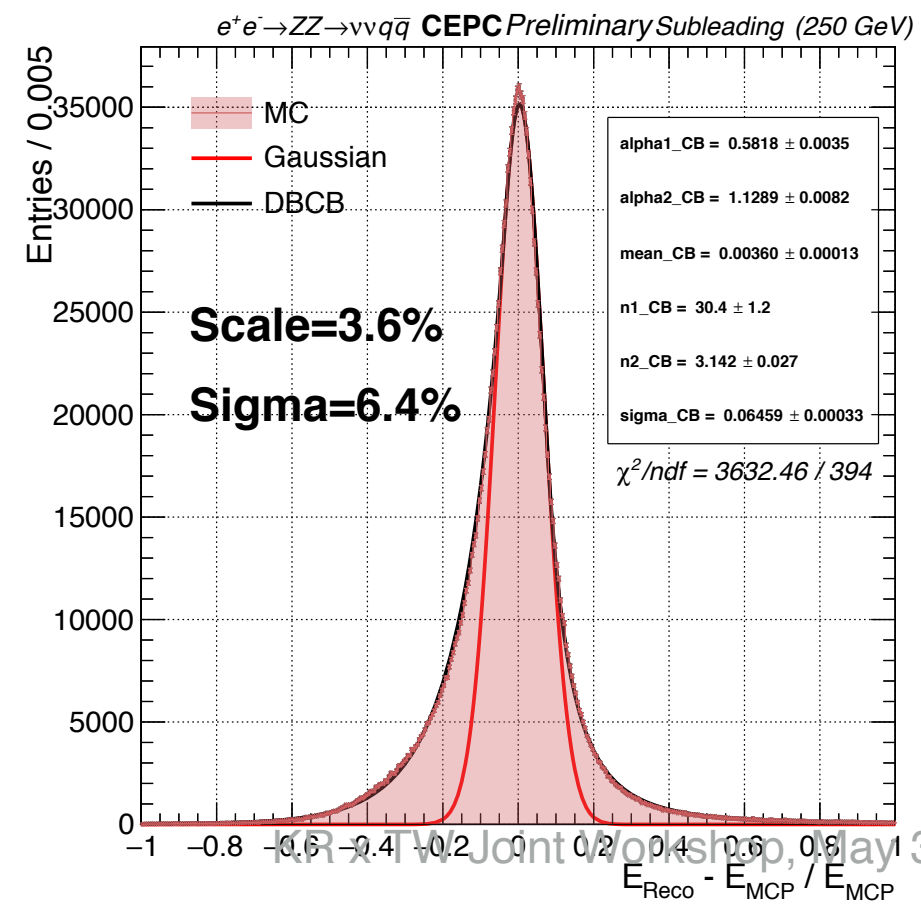
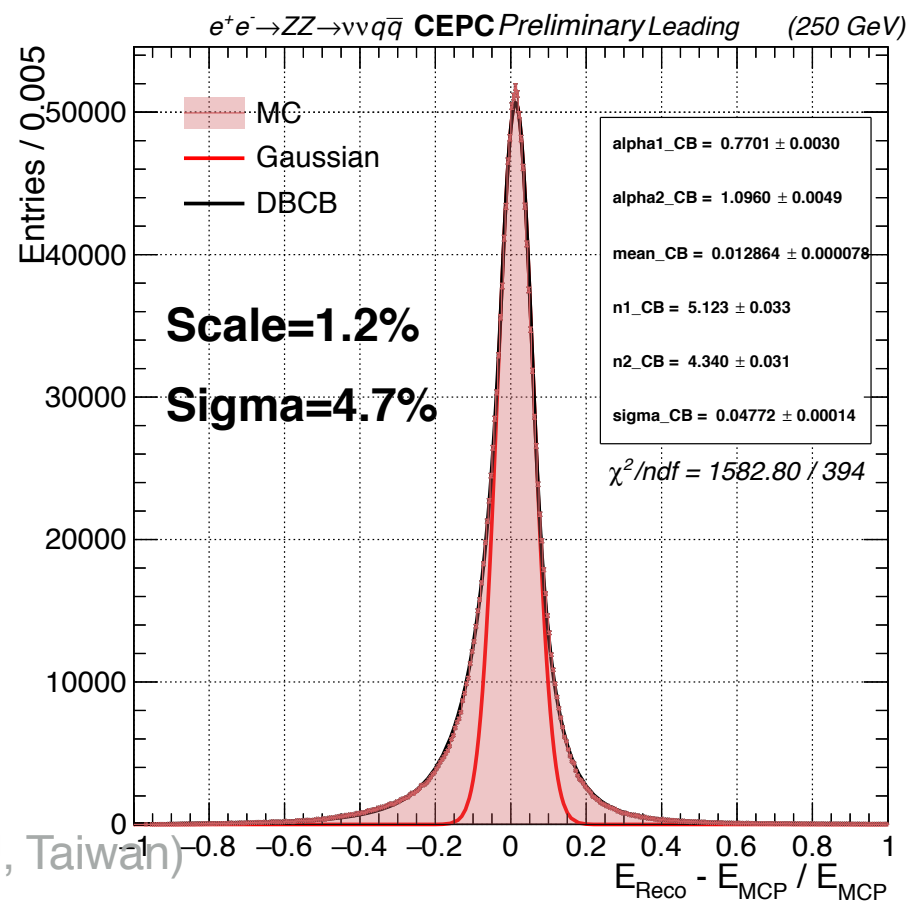
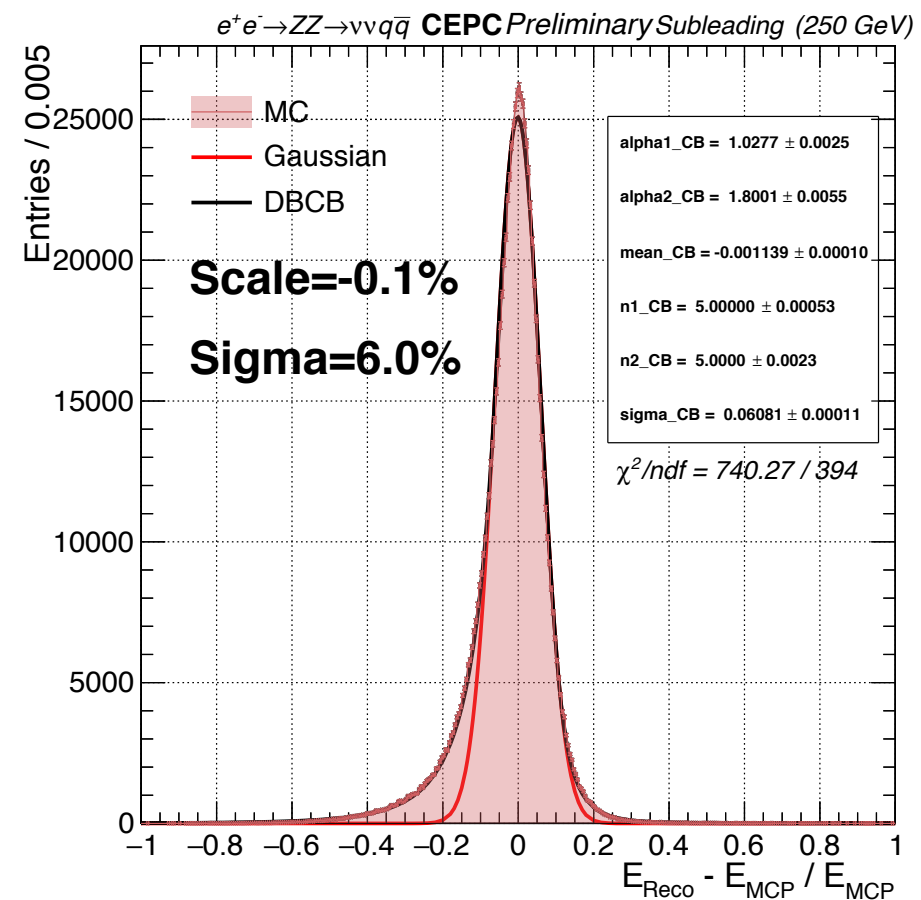
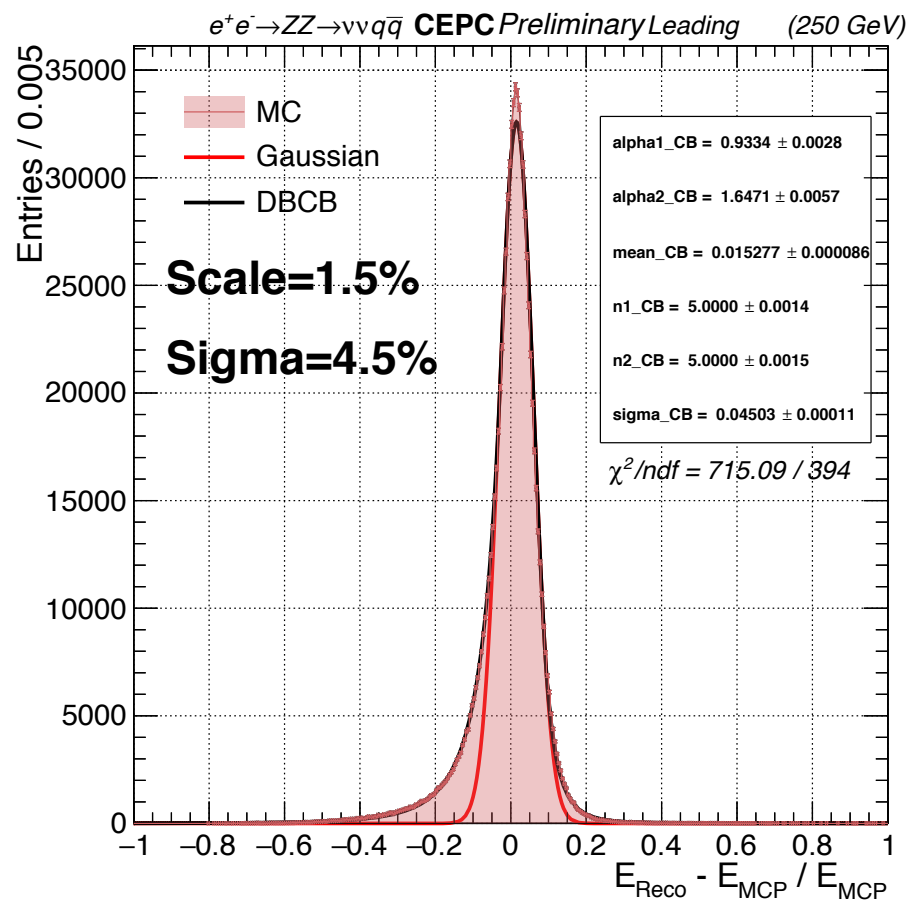
Compare the Results Whether with dR Cut (Gen-MCP)

dR < 0.1

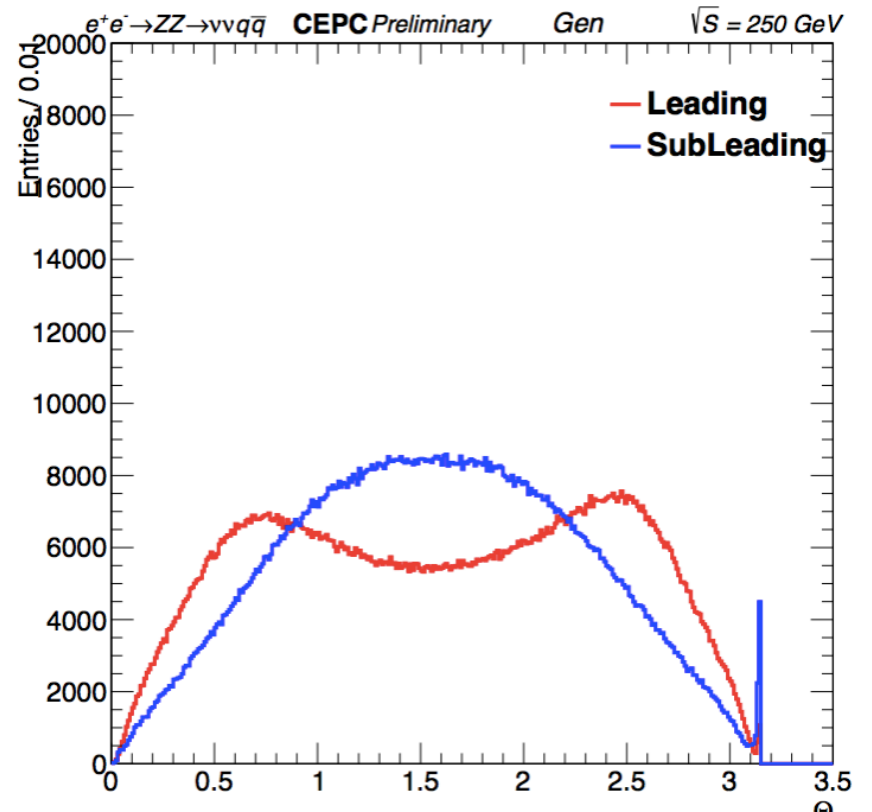
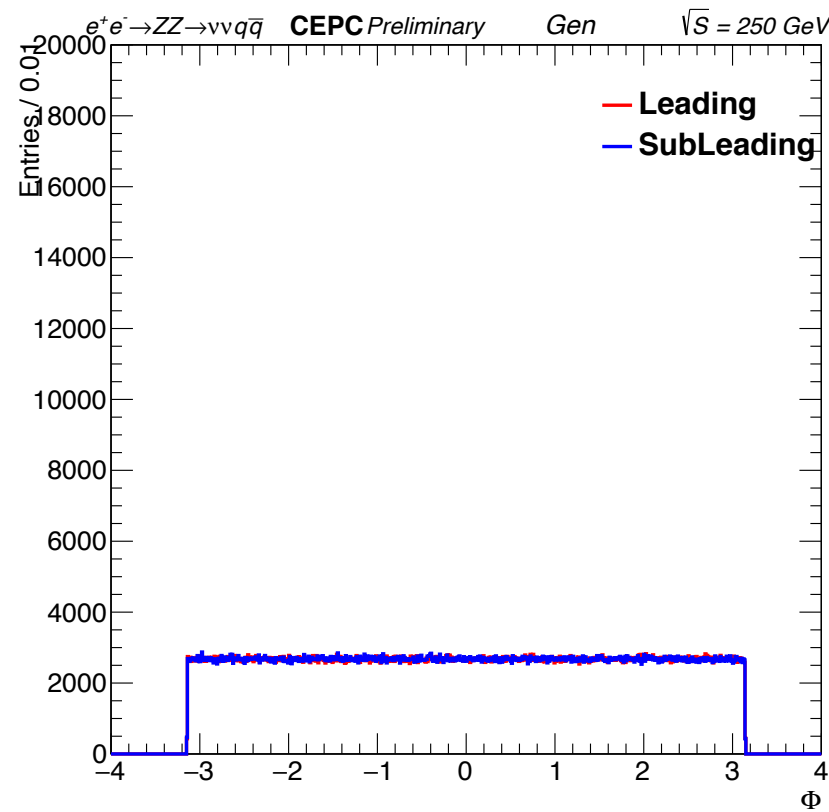
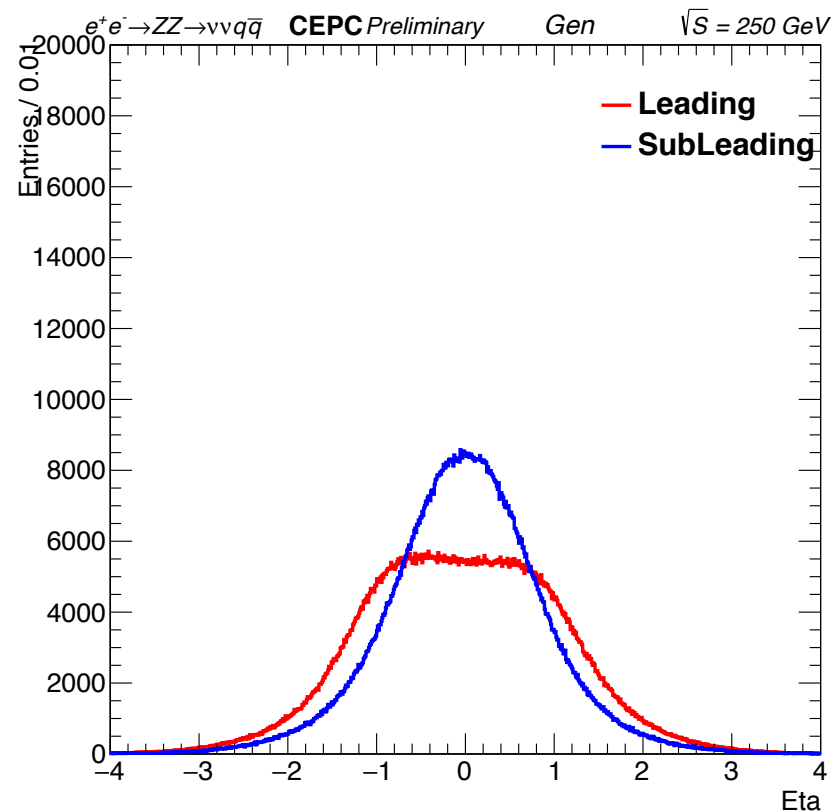
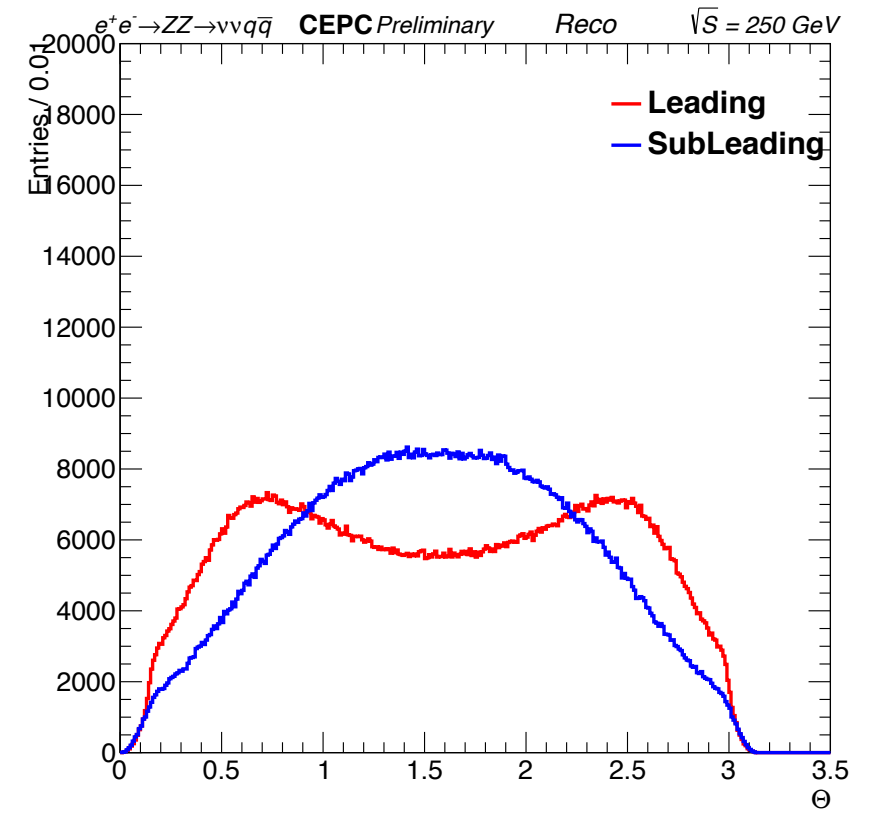
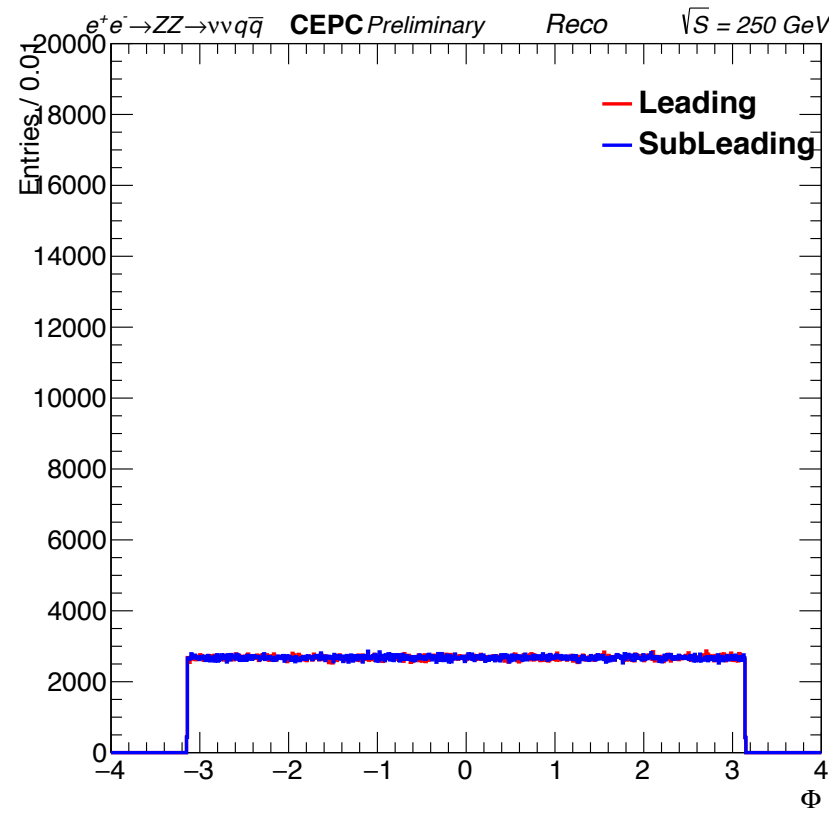
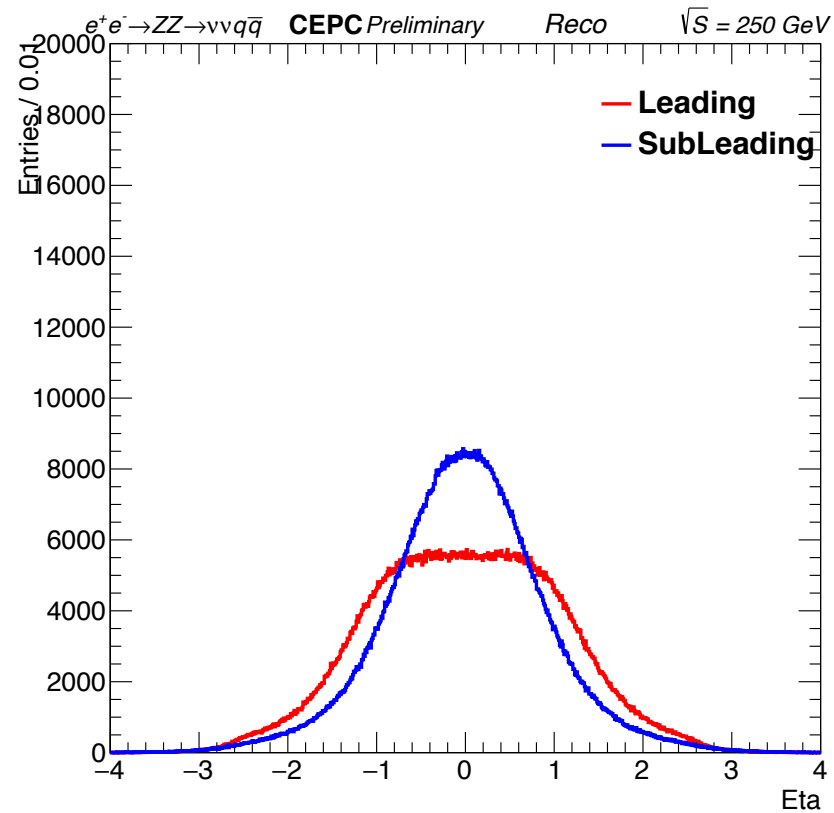


Compare the Results Whether with dR Cut (Reco-MCP)

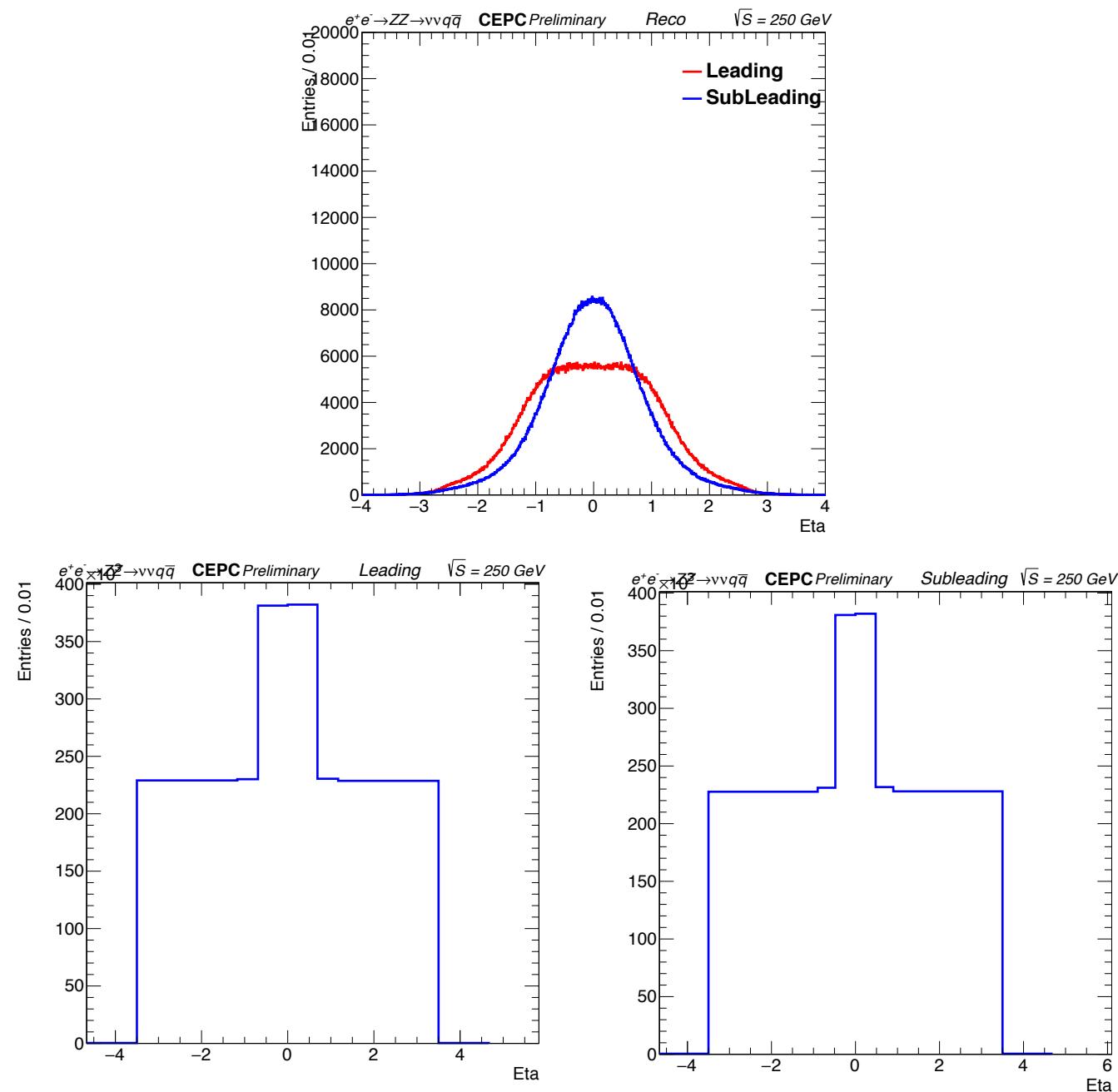
dR < 0.1



Angular Distribution of Gen and Reco

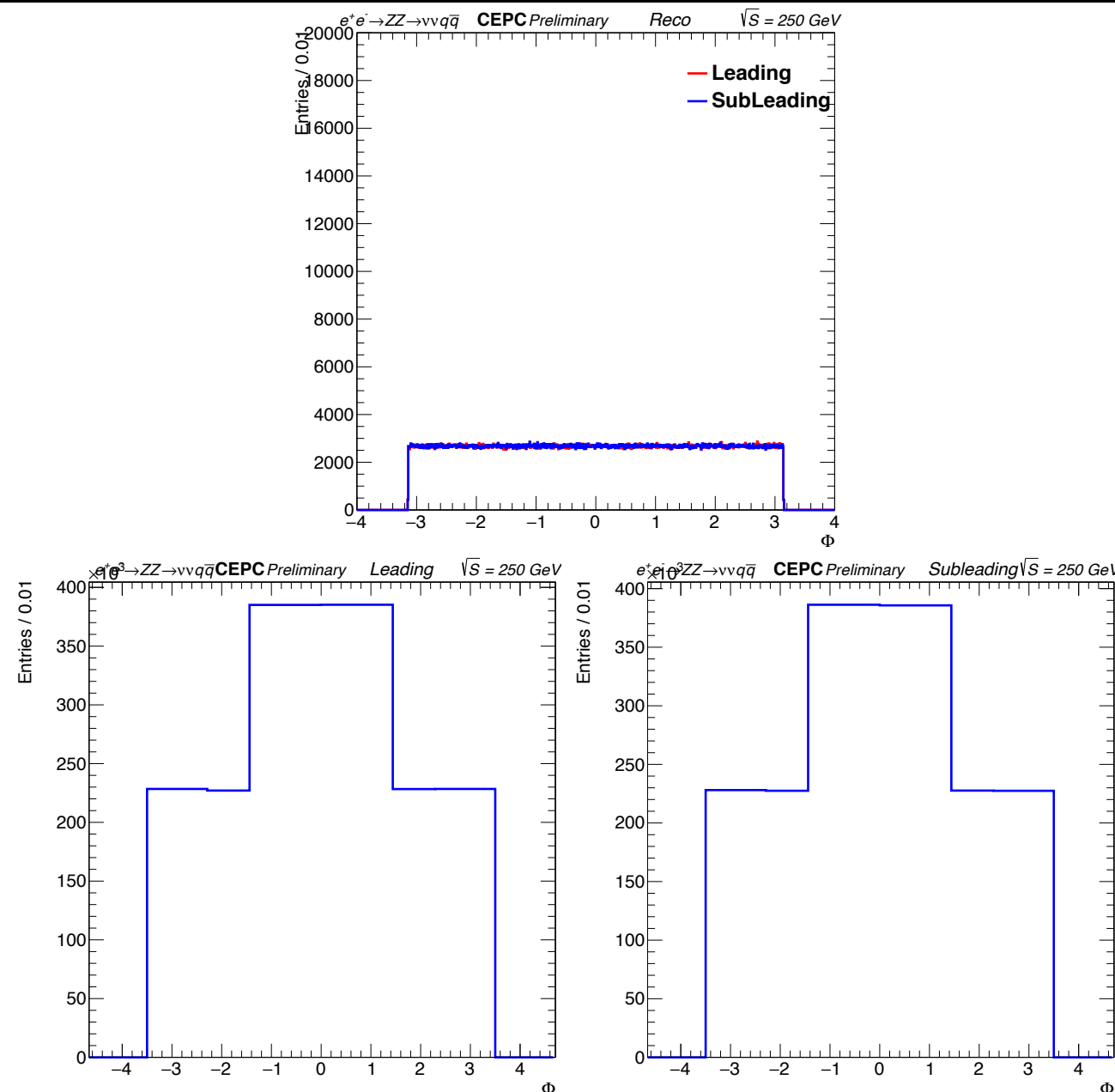


The Distribution of Unequal Eta Bin



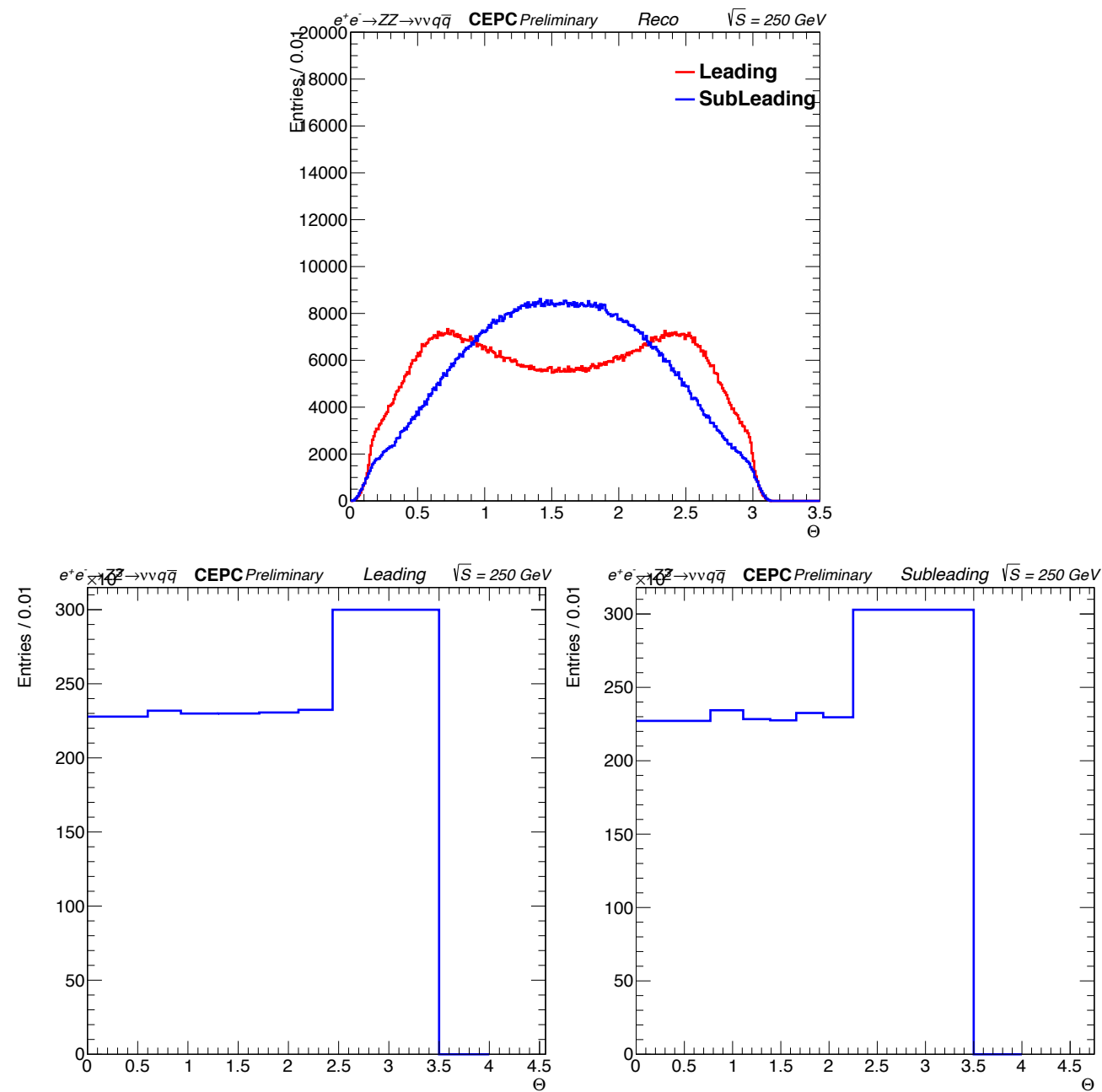
- When divided the angular bin, I have required the statistical uncertainty should less than 0.21% for each angular bin I also sorted the jet by energy. I want the unequal angular symmetry on zero. Therefore, the bin around zero with more the number of events.

The Distribution of Unequal Phi Bin

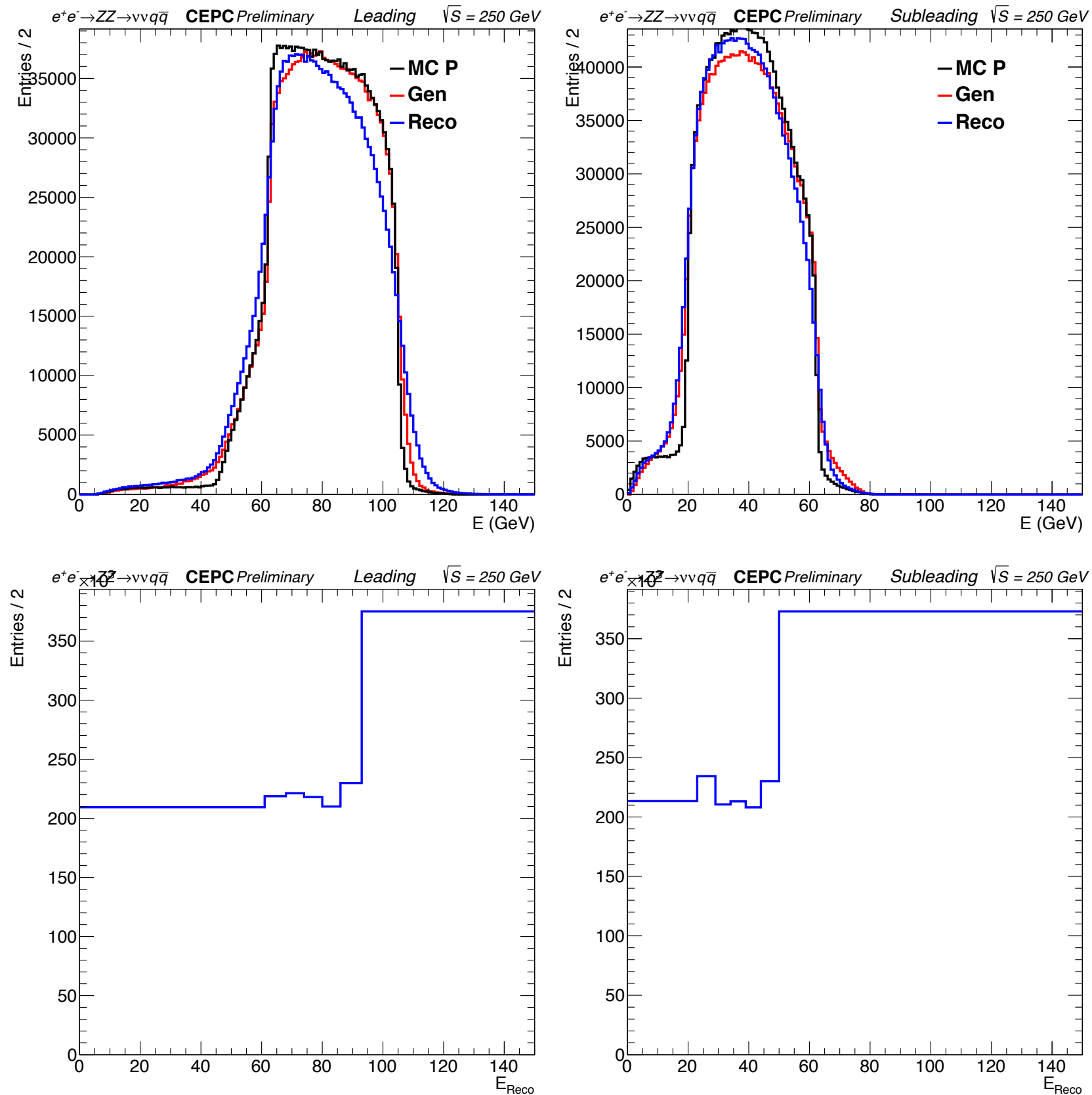


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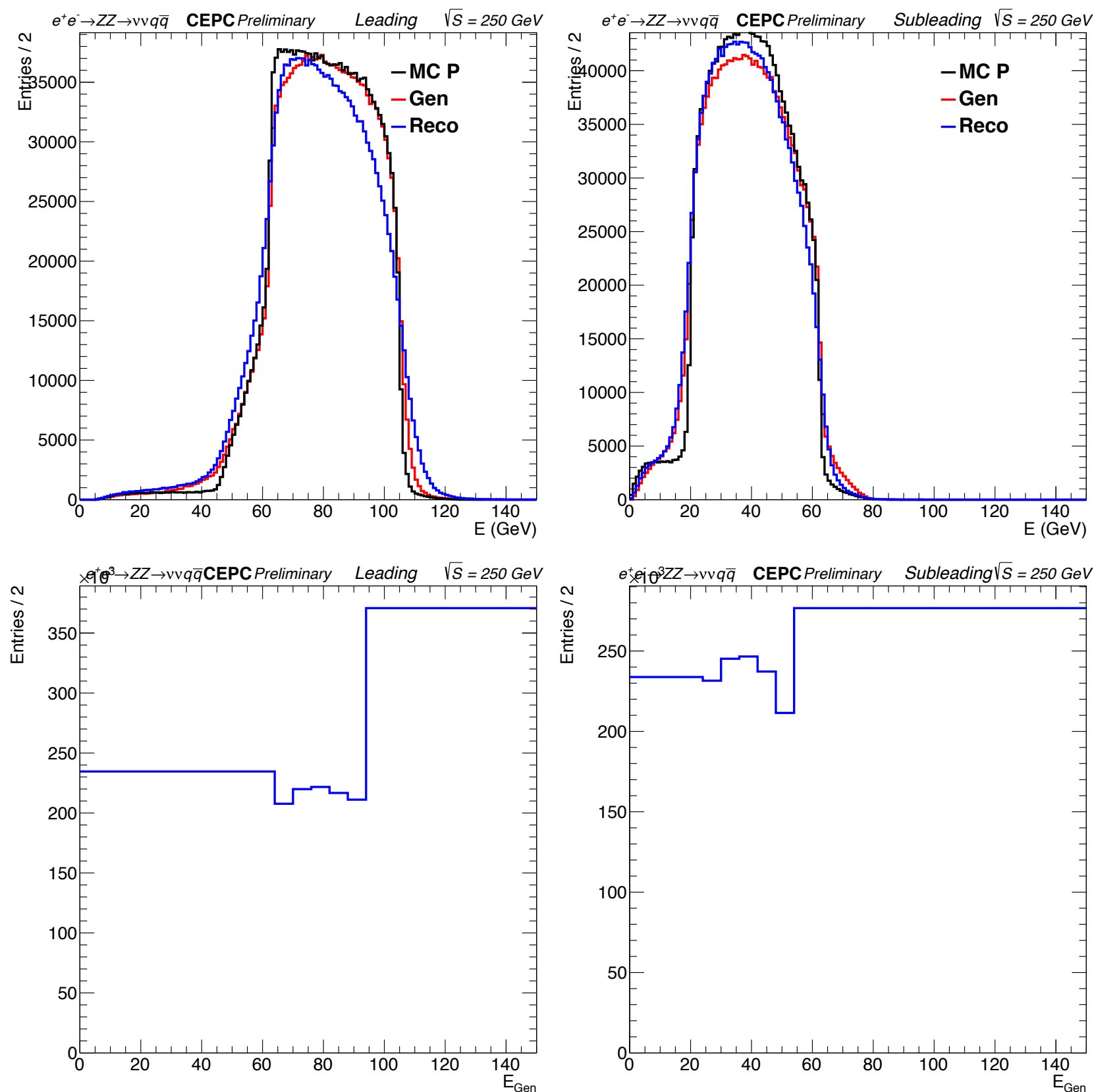
The Distribution of Unequal Theta Bin



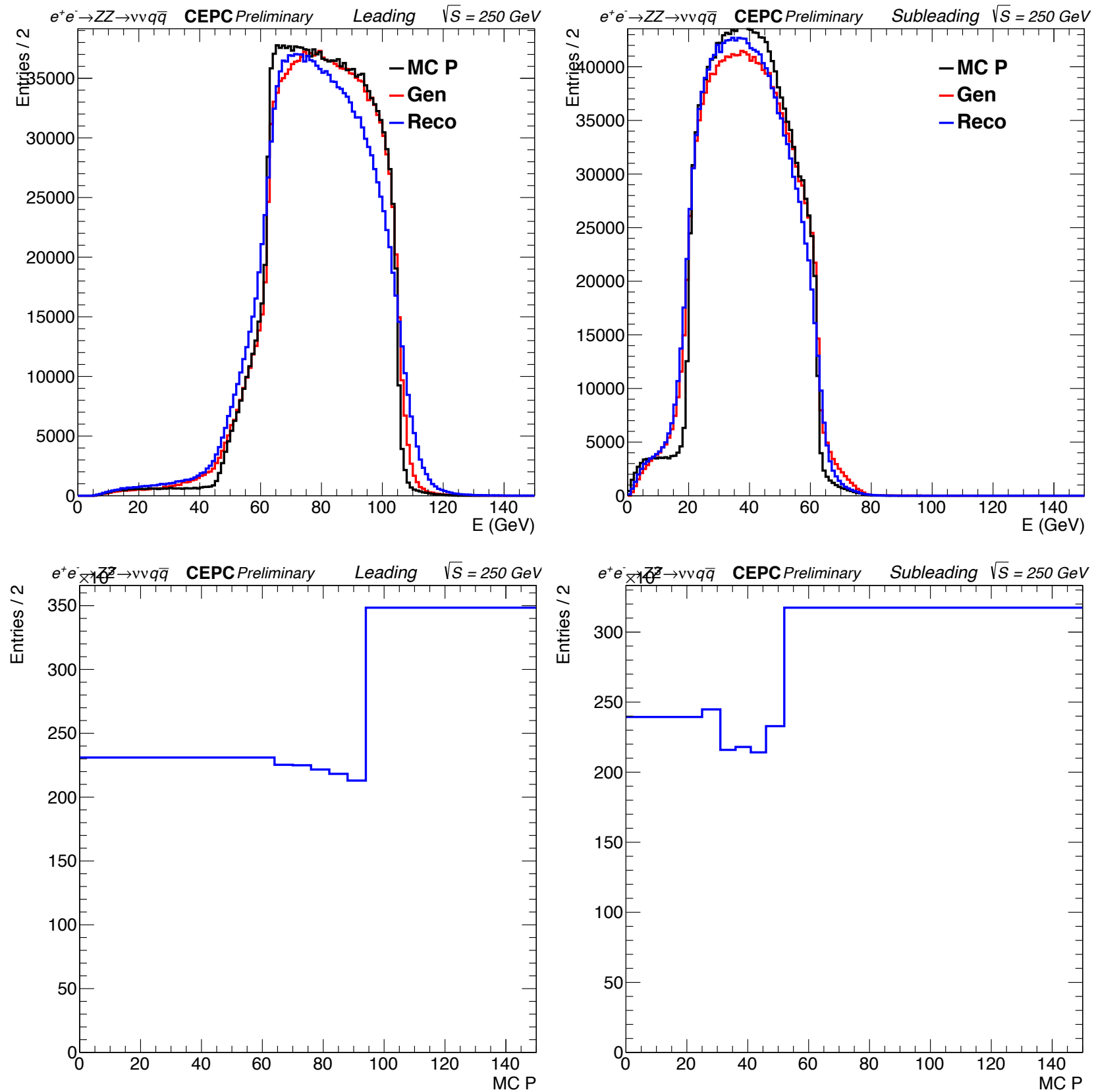
The Distribution of Unequal Reco Energy Bin



The Distribution of Unequal Gen Energy Bin



The Distribution of Unequal MCP Energy Bin



Gen-MCP

	JER		JES	
Type	Lead	Sub-Lead	Lead	Sub-Lead
Eta	1% Stable	2% Stable	0 Stable	0 Stable
Phi	1% Stable	2% Stable	0 Stable	0 Stable
Theta	1% Stable	2% Stable	0 Stable	0 Stable
Reco	1.5-0.5% ↘	4.5-2% ↘	0 Stable	0 Stable
Gen	2-1% ↘	5-2.5% ↘	0 Stable	0 Stable
MCP	1.5-1% ↘	4-2% ↘	0 Stable	0 Stable

Reco-Gen

	JER		JES	
Type	Lead	Sub-Lead	Lead	Sub-Lead
Eta	4.5-3.5-4.5	5.5-4.5-5.5	1.5-1-1.5	1-0-1
Phi	4% Stable	5% Stable	1.5 Stable	0.5 Stable
Theta	4.5-3.5-4.5	5.5-4.5-5.5	1.5-1-1.5	1.5-1-1.5
Reco	4-4.5%	6.5-4.5% ↘	0.5-2% ↗	-1.5-1.5% ↗
Gen	4-3.5%	6.5-4% ↘	1.5% Stable	0-0.5% ↗
MCP	4-4.3%	6.5-4.5% ↘	1.5% Stable	0-0.5% ↗

Reco-MCP

	JER		JES	
Type	Lead	Sub-Lead	Lead	Sub-Lead
Eta	5.5-4.5-5.5	7.5-6-7.5	1.5-1-1.5	0.5-0-0.5
Phi	5% Stable	6.5% Stable	1.5 Stable	0.5 Stable
Theta	5.5-4.5-5.5	7.5-6-7.5	1.5-1-1.5	0.5-0-0.5
Reco	6-5% ↘	10-6% ↘	-1.5-2.5% ↗	-7-1.5% ↗
Gen	6-5%	13-6.5% ↘	1.5% Stable	-6.5-0.5% ↗
MCP	5-5.3%	10-6% ↘	1.5% Stable	-1.5-0.5% ↗

■ Gen-MCP

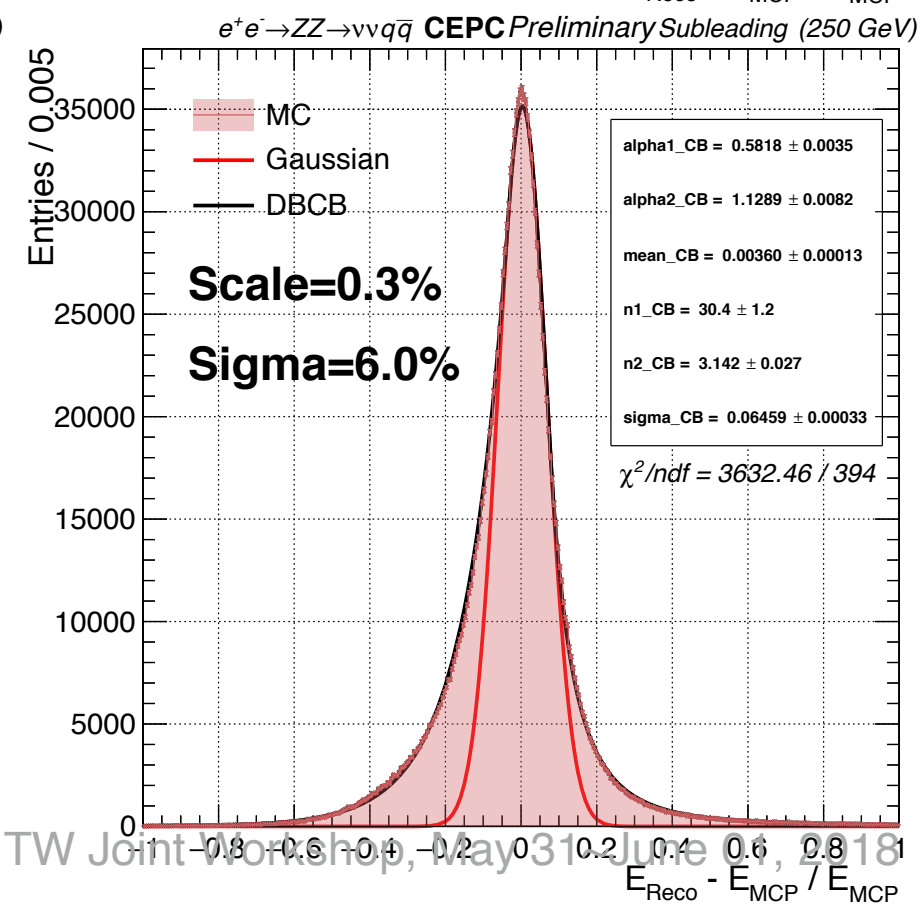
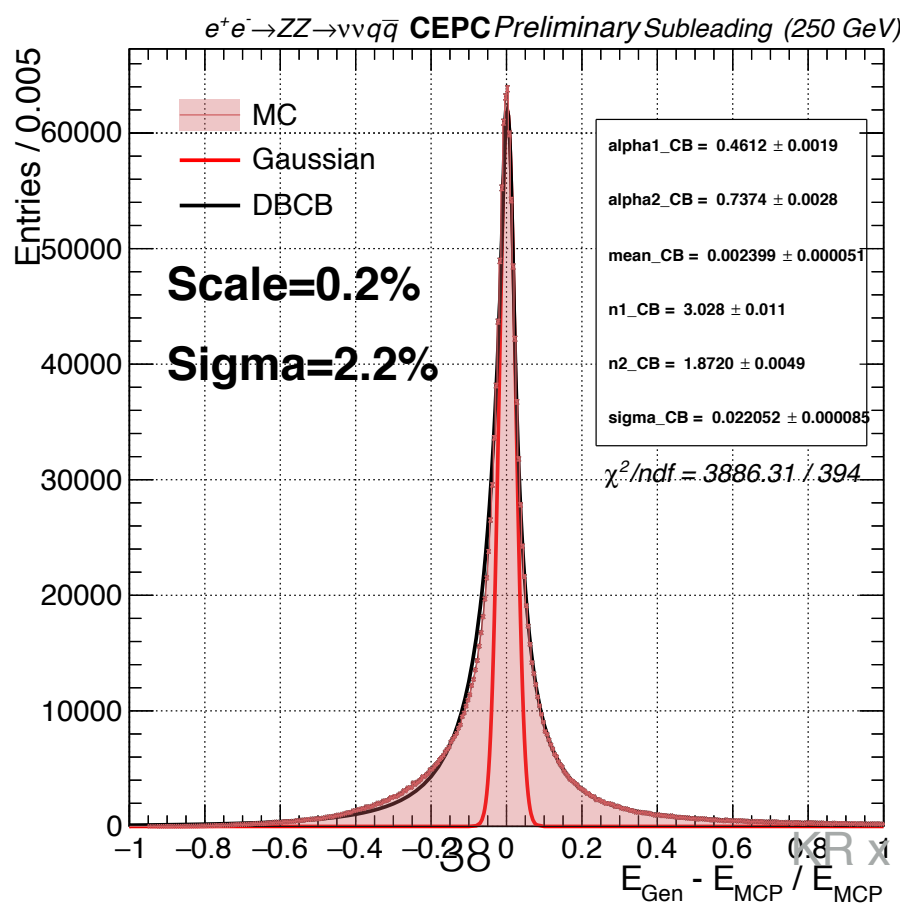
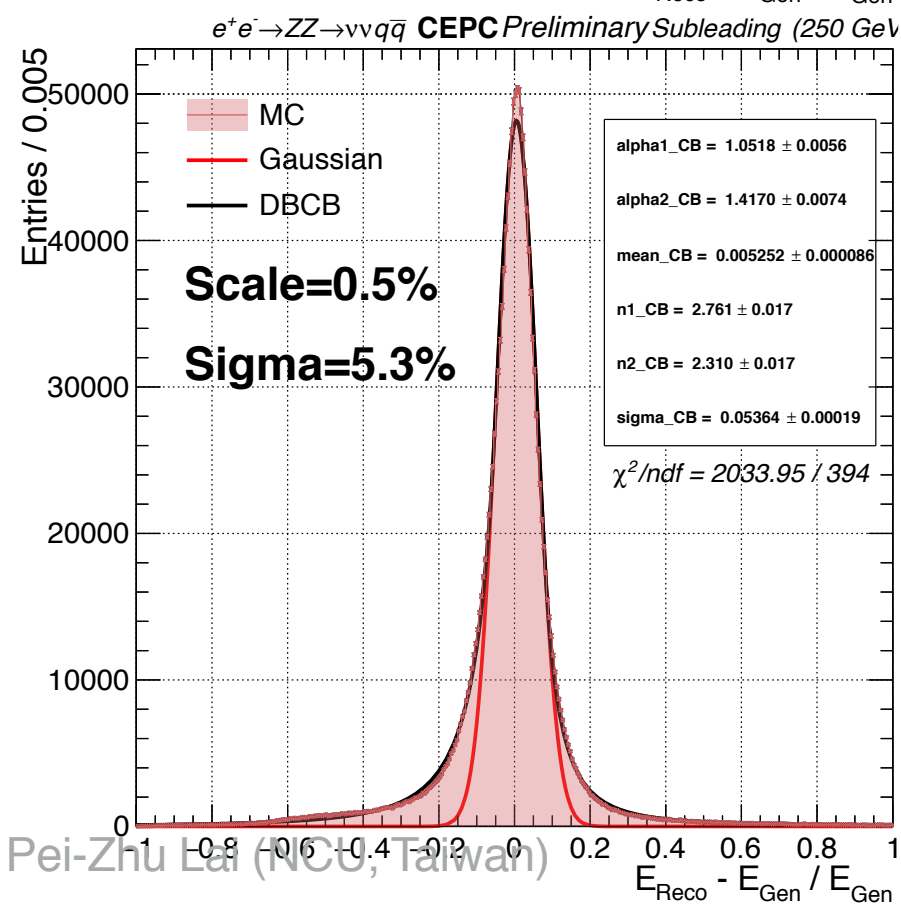
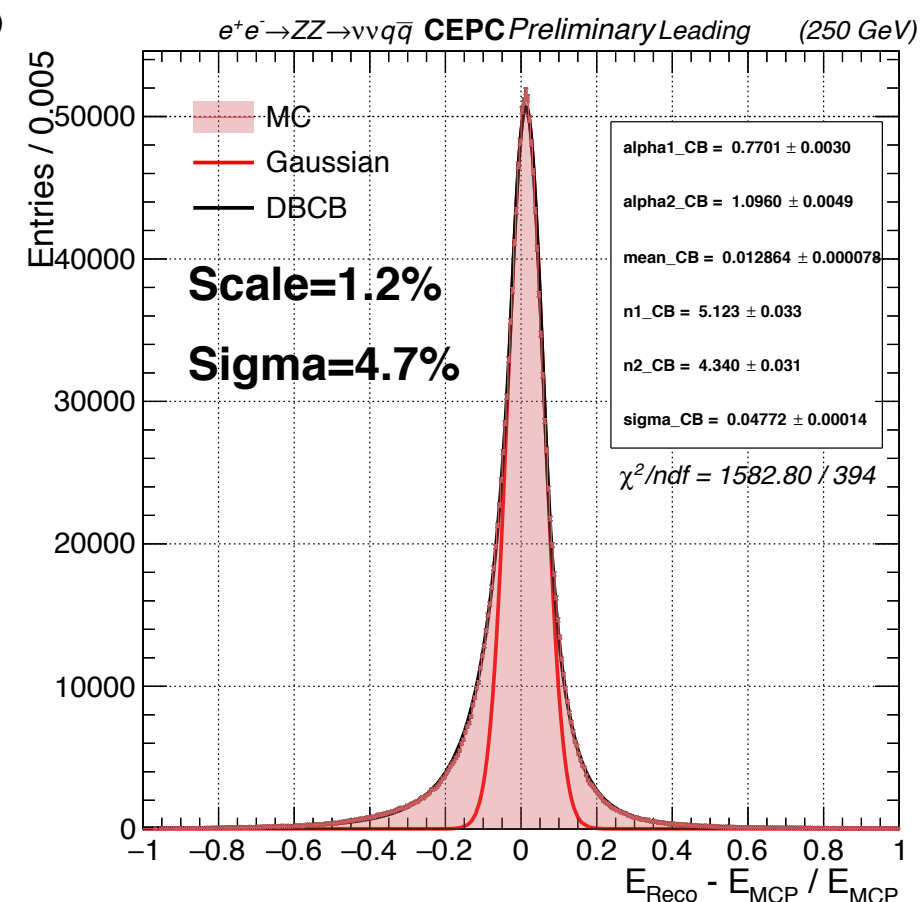
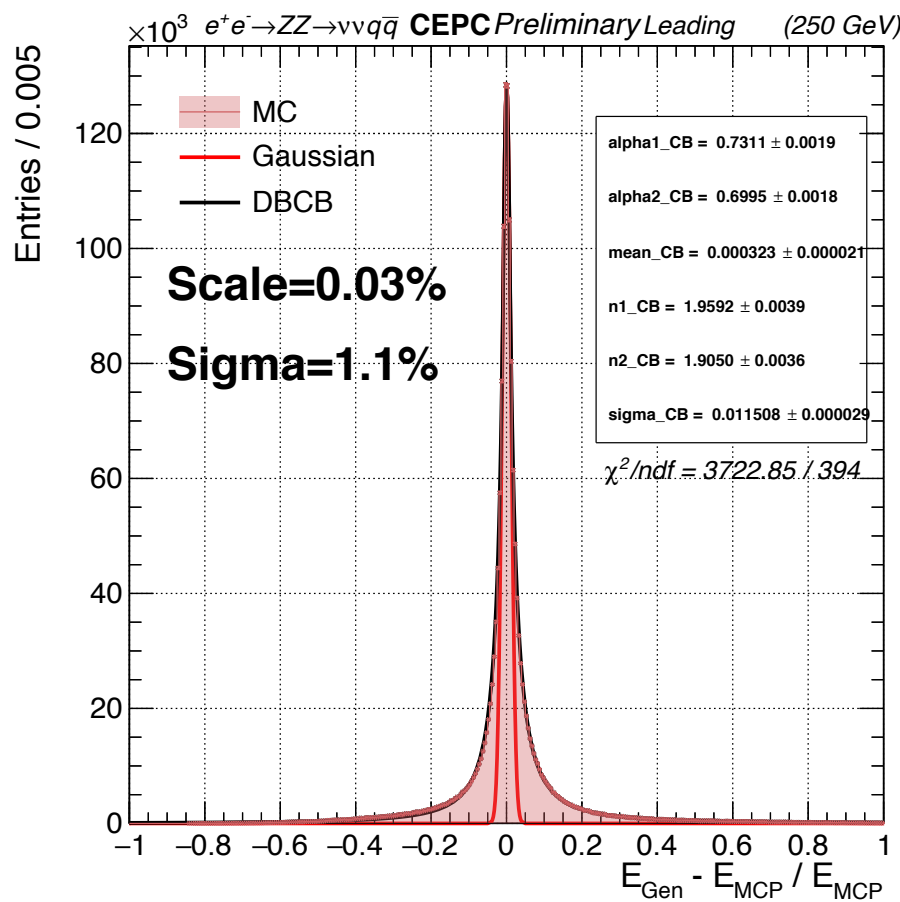
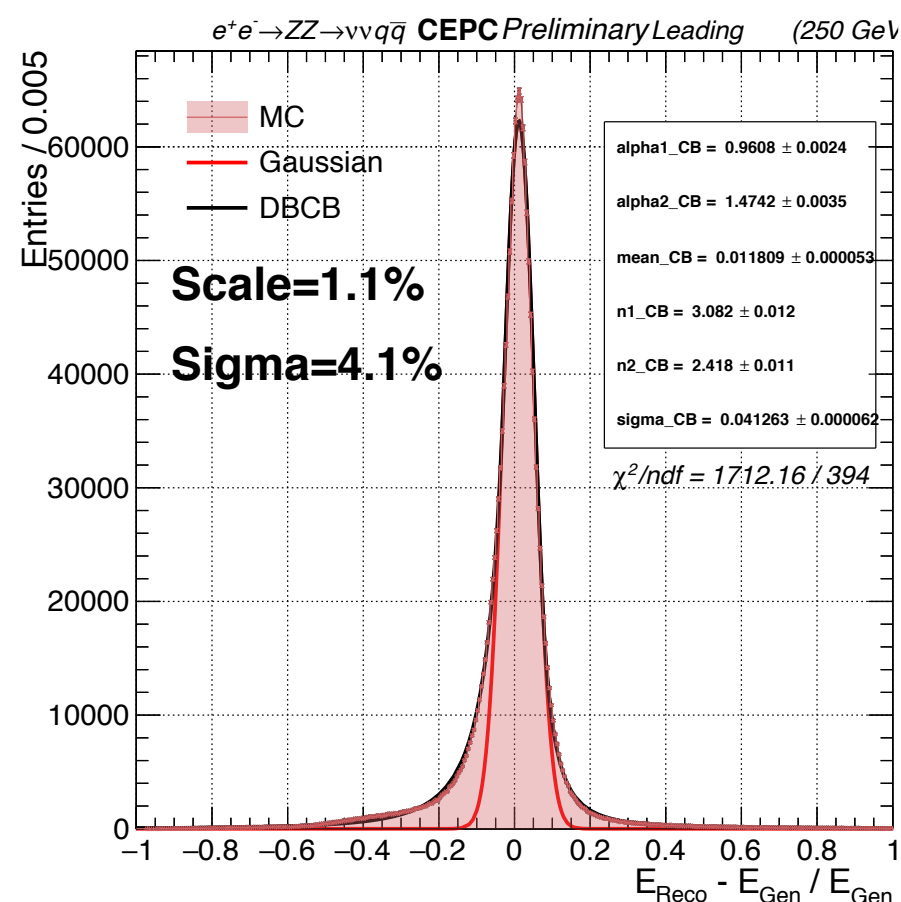
- JES is about “Zero” and stable in both angular and energy bin.
- JER is stable as the function of the angular. Leading is 1% and Sub-leading is 2%.
- For leading JER is 1.5-0.5% as the function of the energy of reco jet and for sub-leading JER is 4.5-2%.

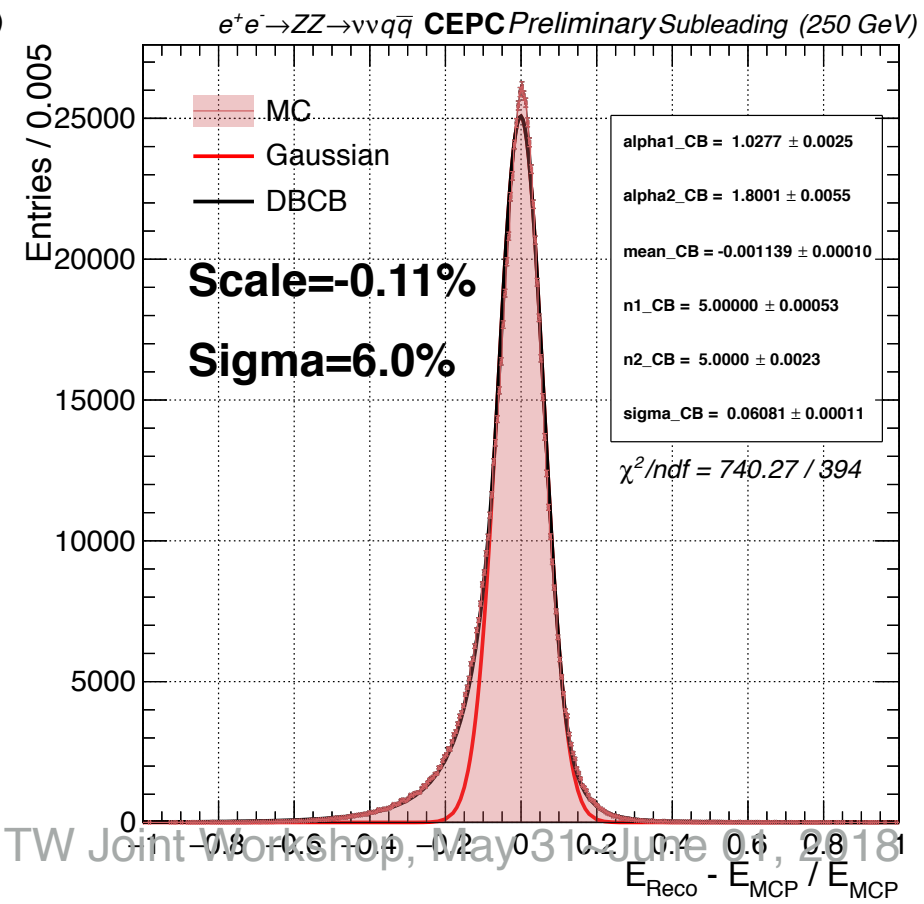
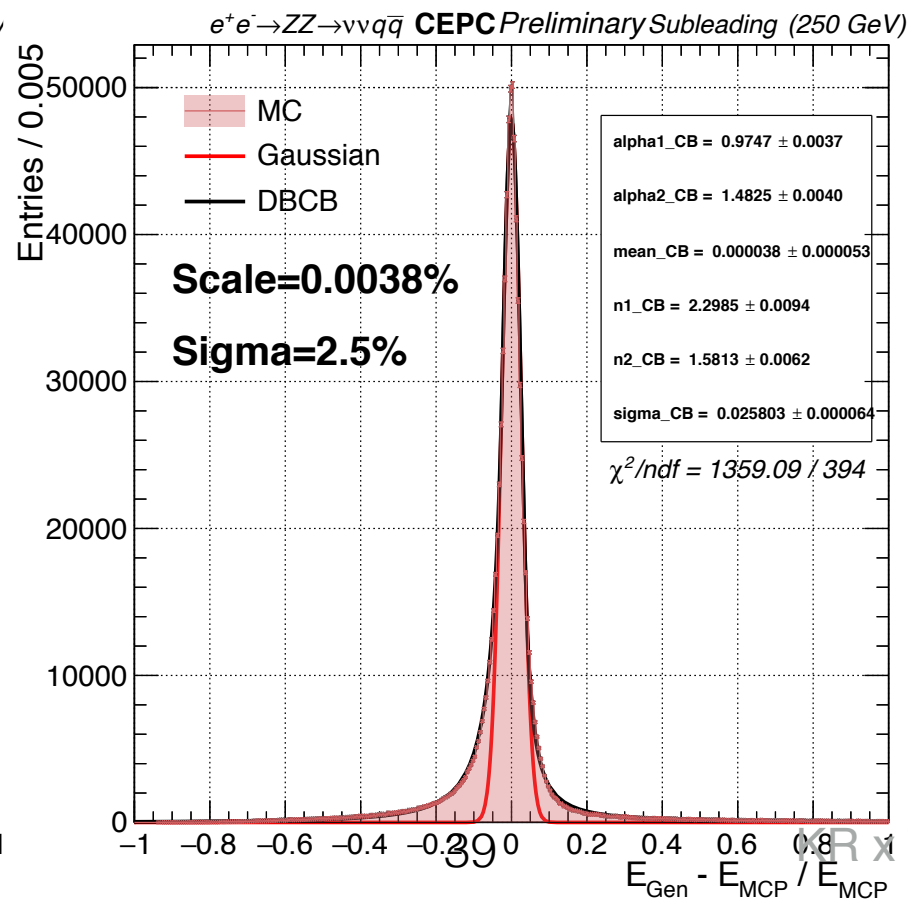
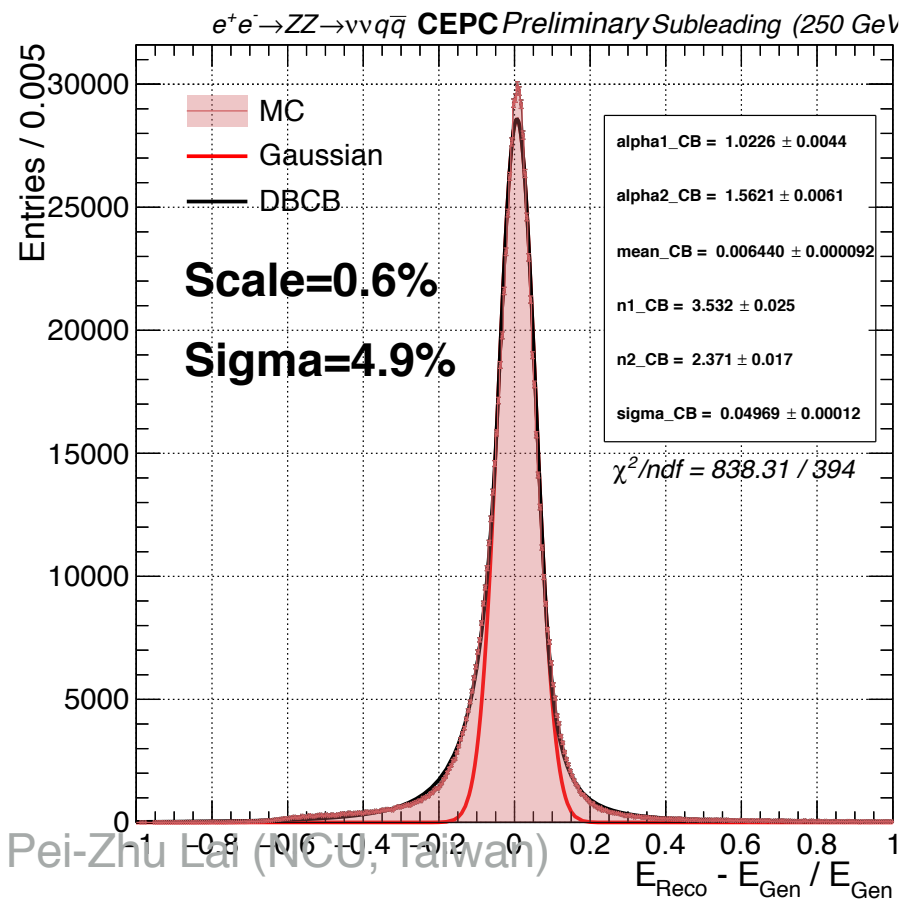
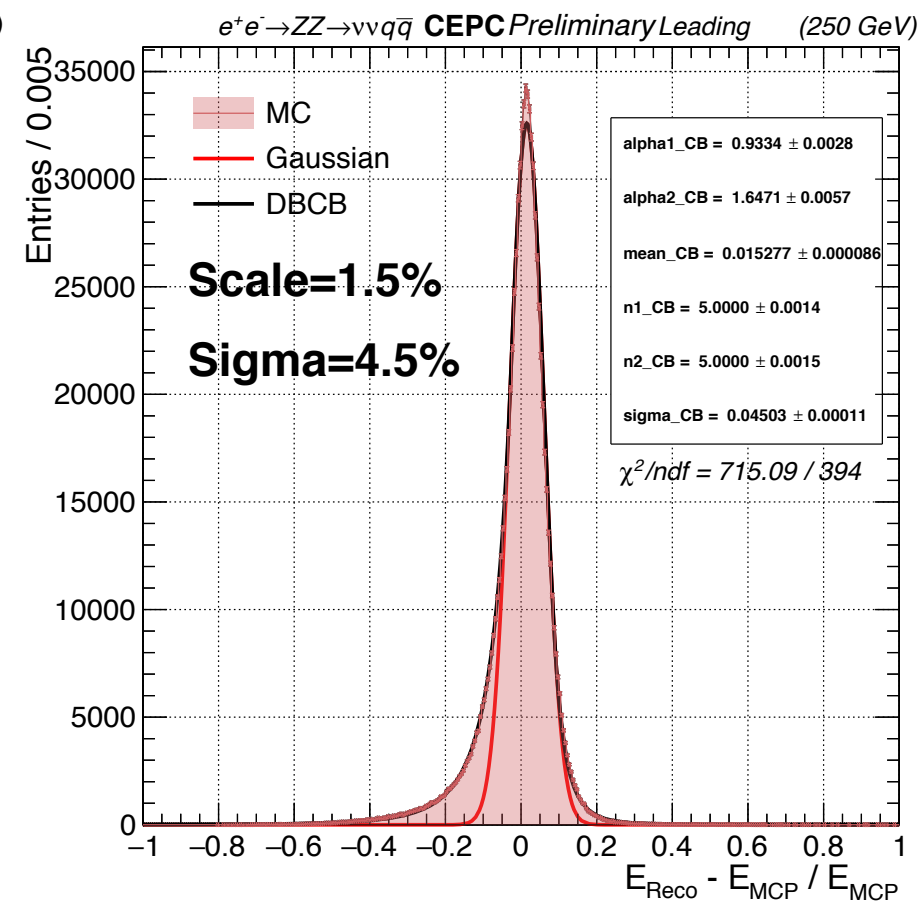
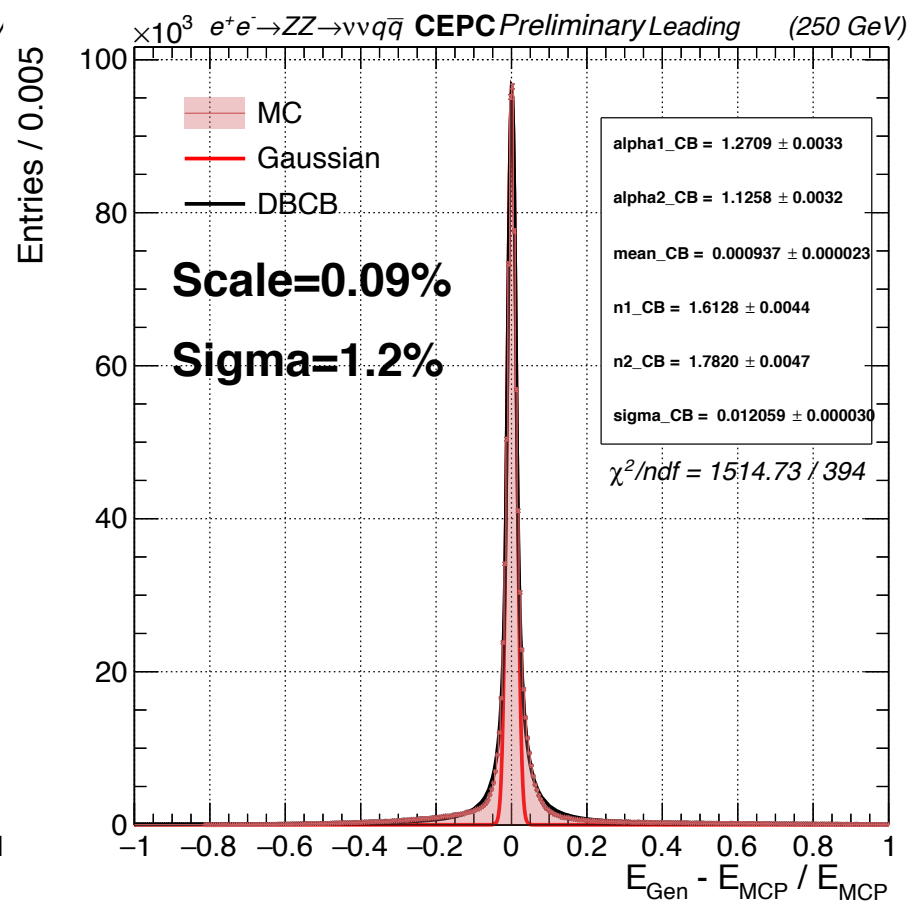
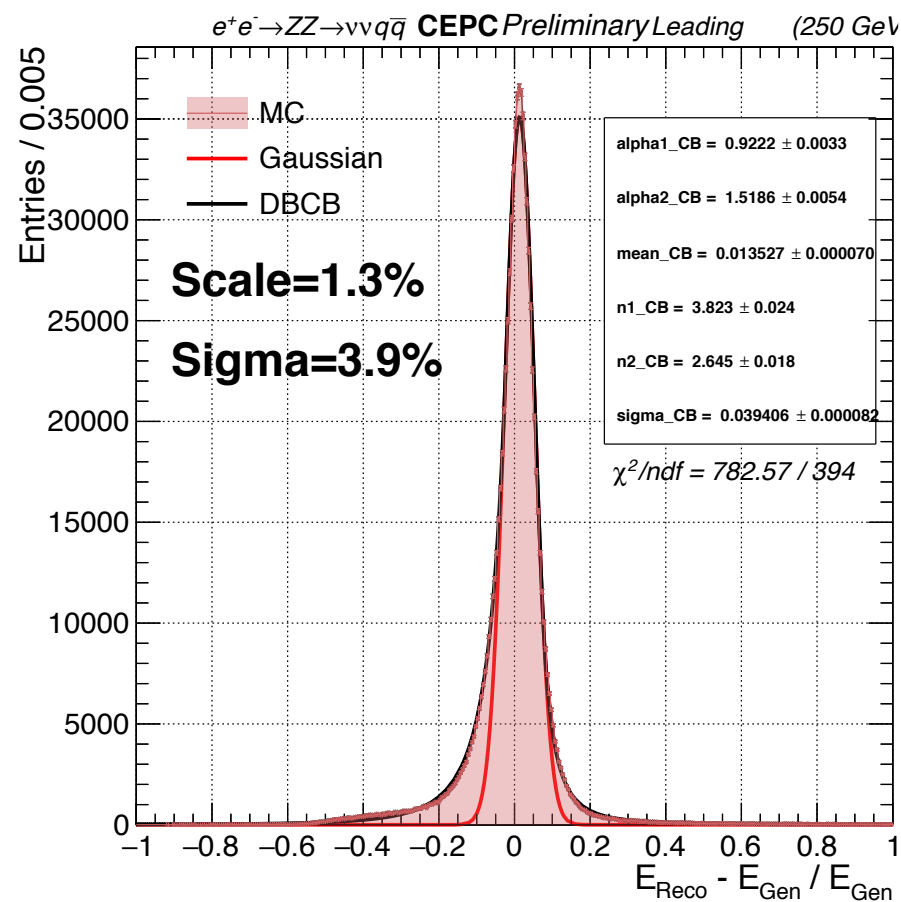
■ Reco-Gen

- Both JER/JES are independent of the Φ .
- In the barrel region, leading JER is 3.5% and sub-leading JER is 4.5%. Leading JES is about 1%. Sub-leading JES is about zero.
- In the 60-100 GeV region, leading and sub-leading JER is 4%, JES is 1.5%.

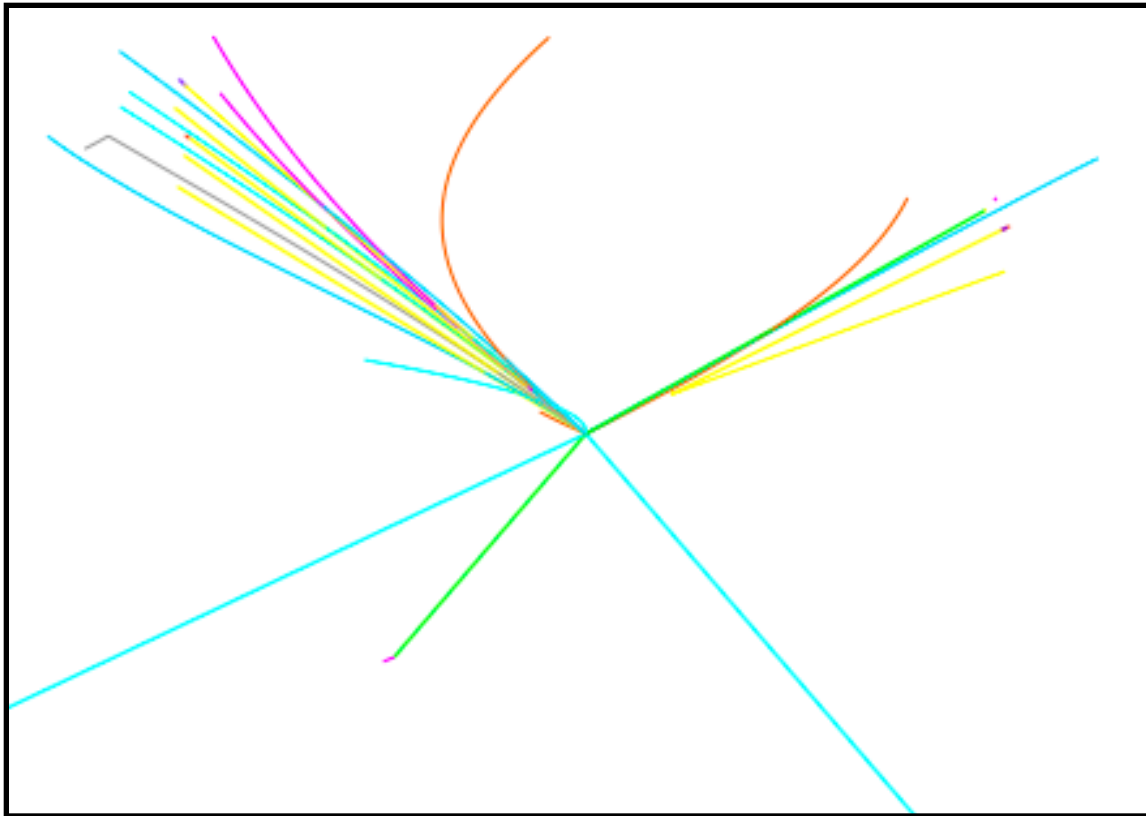
■ Reco-MCP

- Both JER/JES are stable as the function of the Φ .
- In the barrel region, leading JER is 4.5%, JES is 1%; sub-leading JER is 6%, JES is zero.
- In the 60-100 GeV region, leading and sub-leading JER is 5%, JES is 1%.

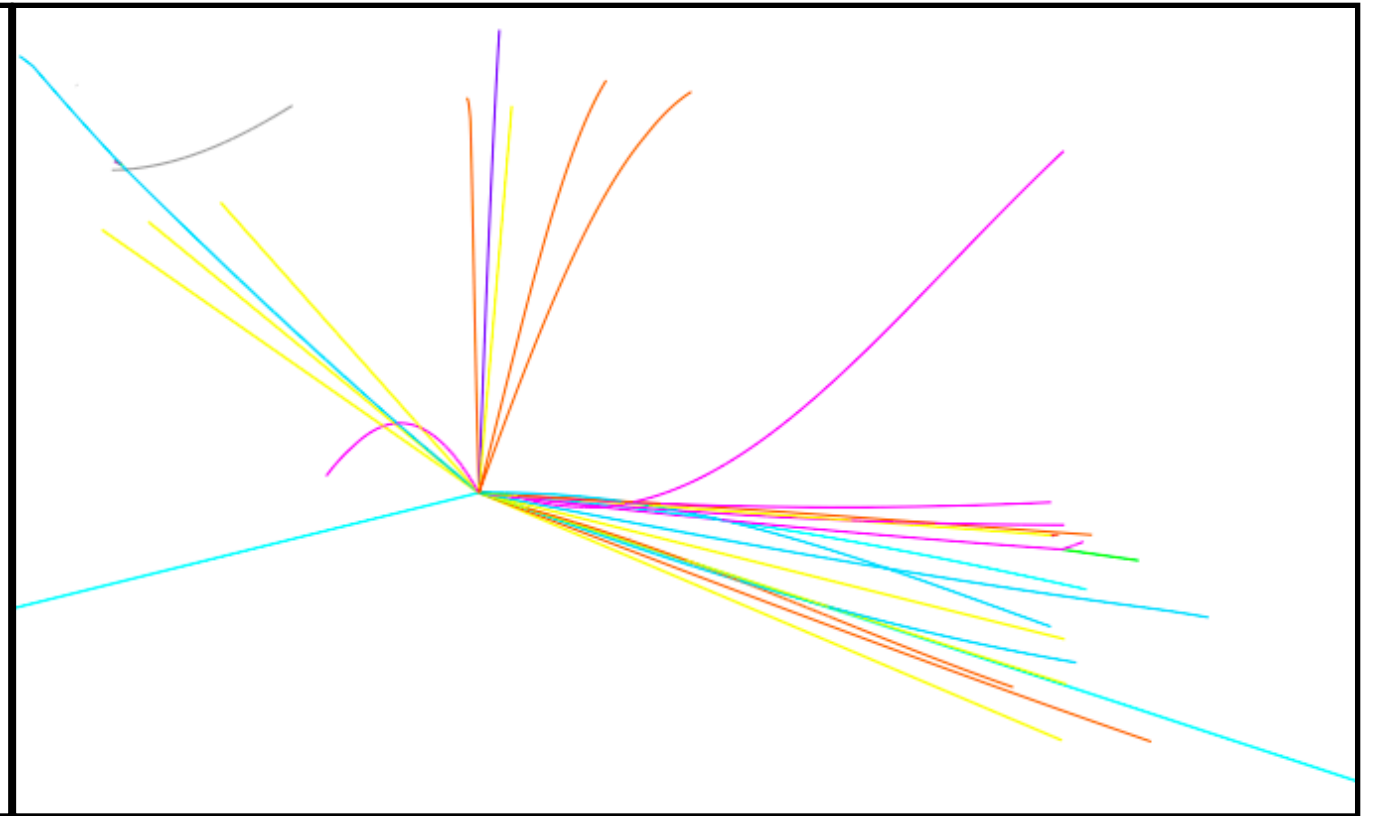


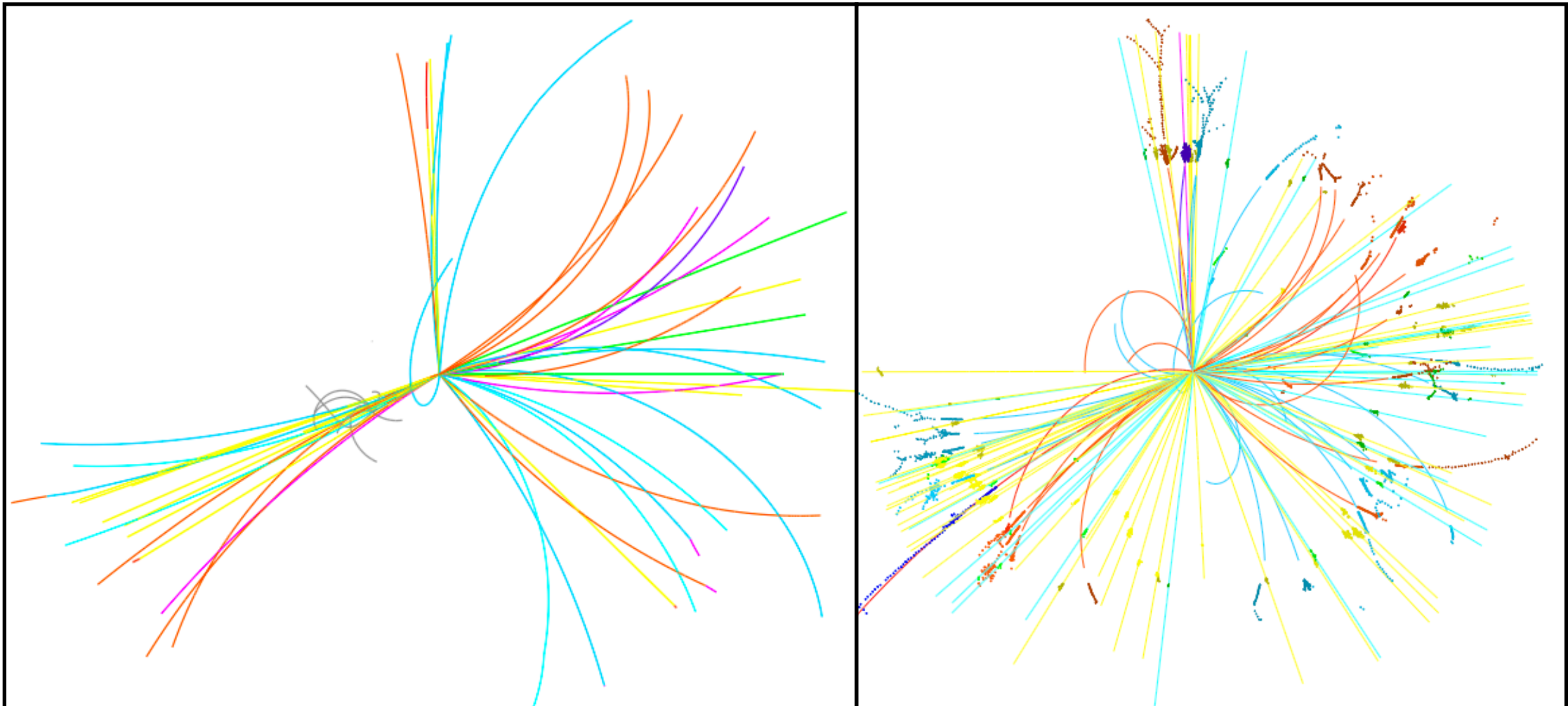


$vvH \rightarrow vv\gamma\gamma$



$vvH \rightarrow vv\gamma\gamma$

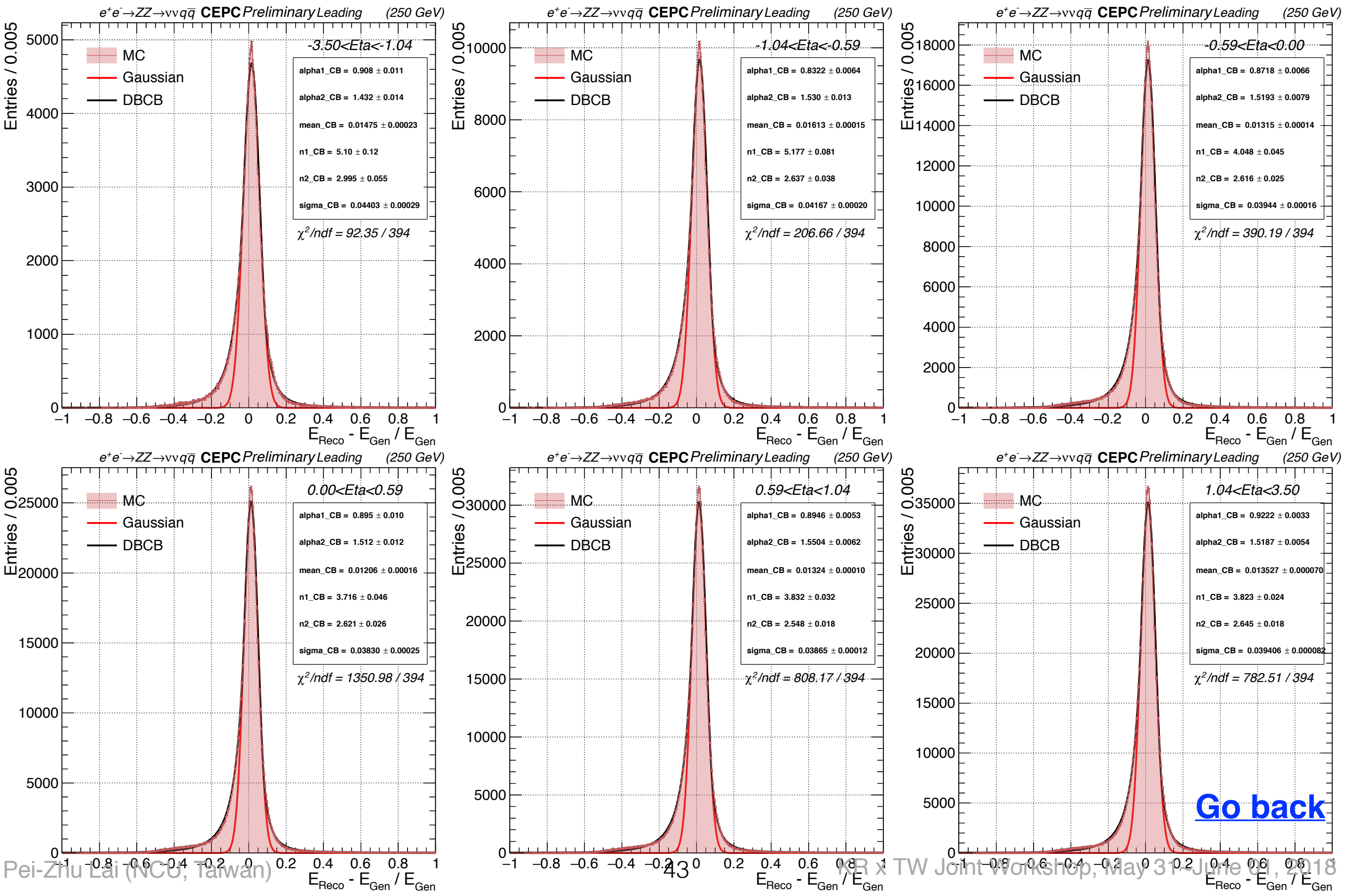




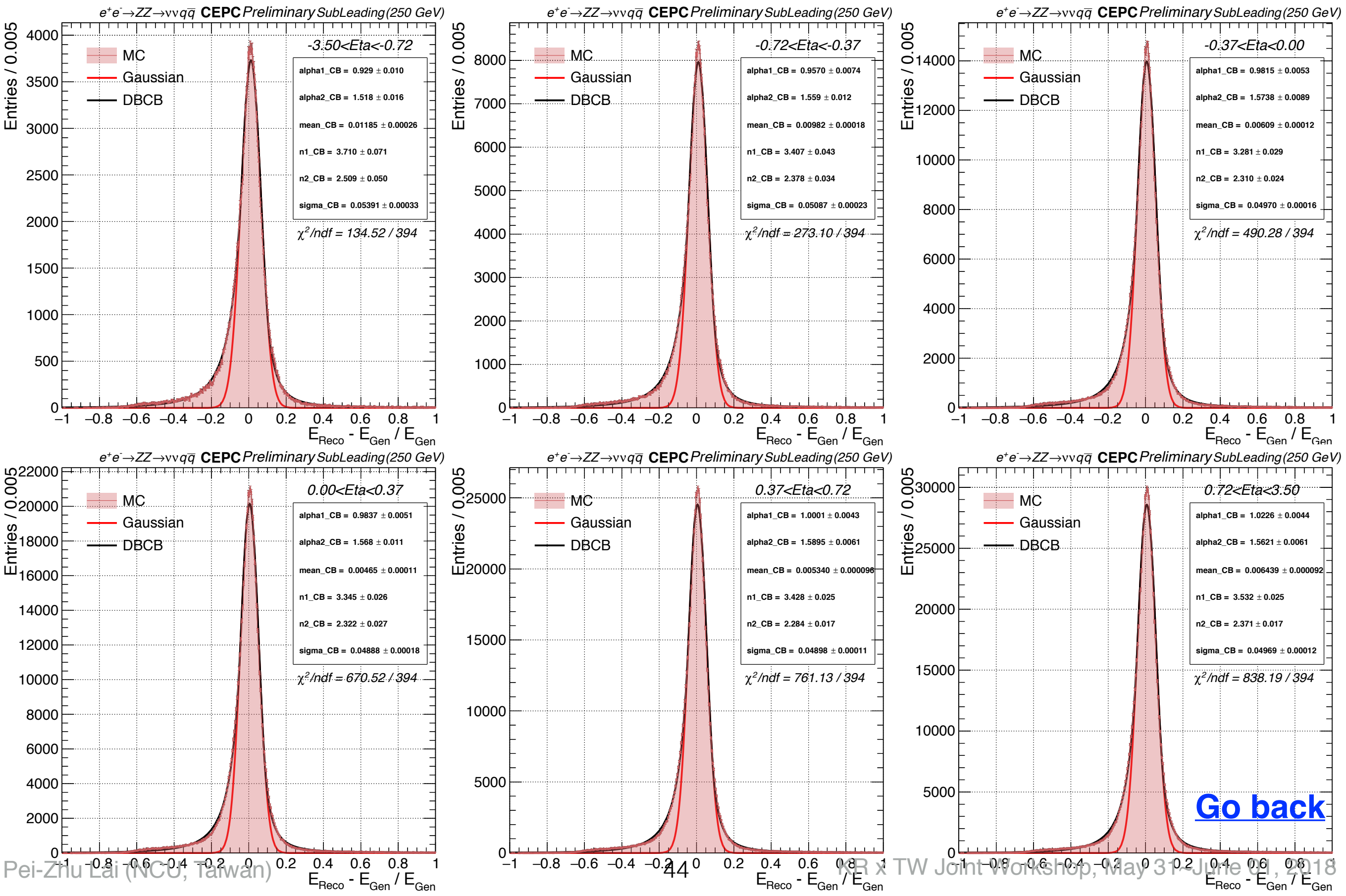
Each Angular Bin with dR Cut
(Reco-Gen)



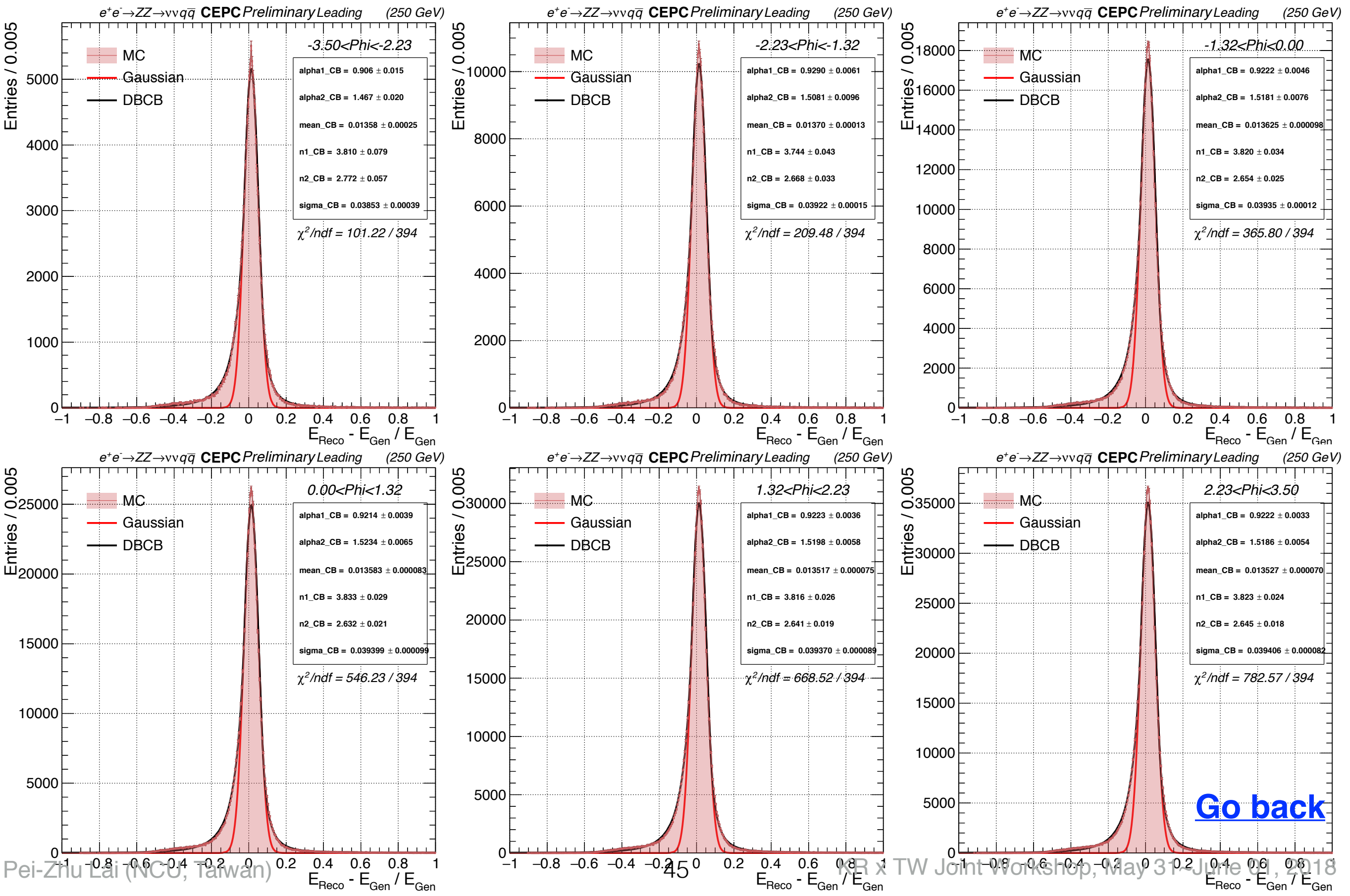
The Eta Bin Leading JER & JES with dR Cut (Reco-Gen)



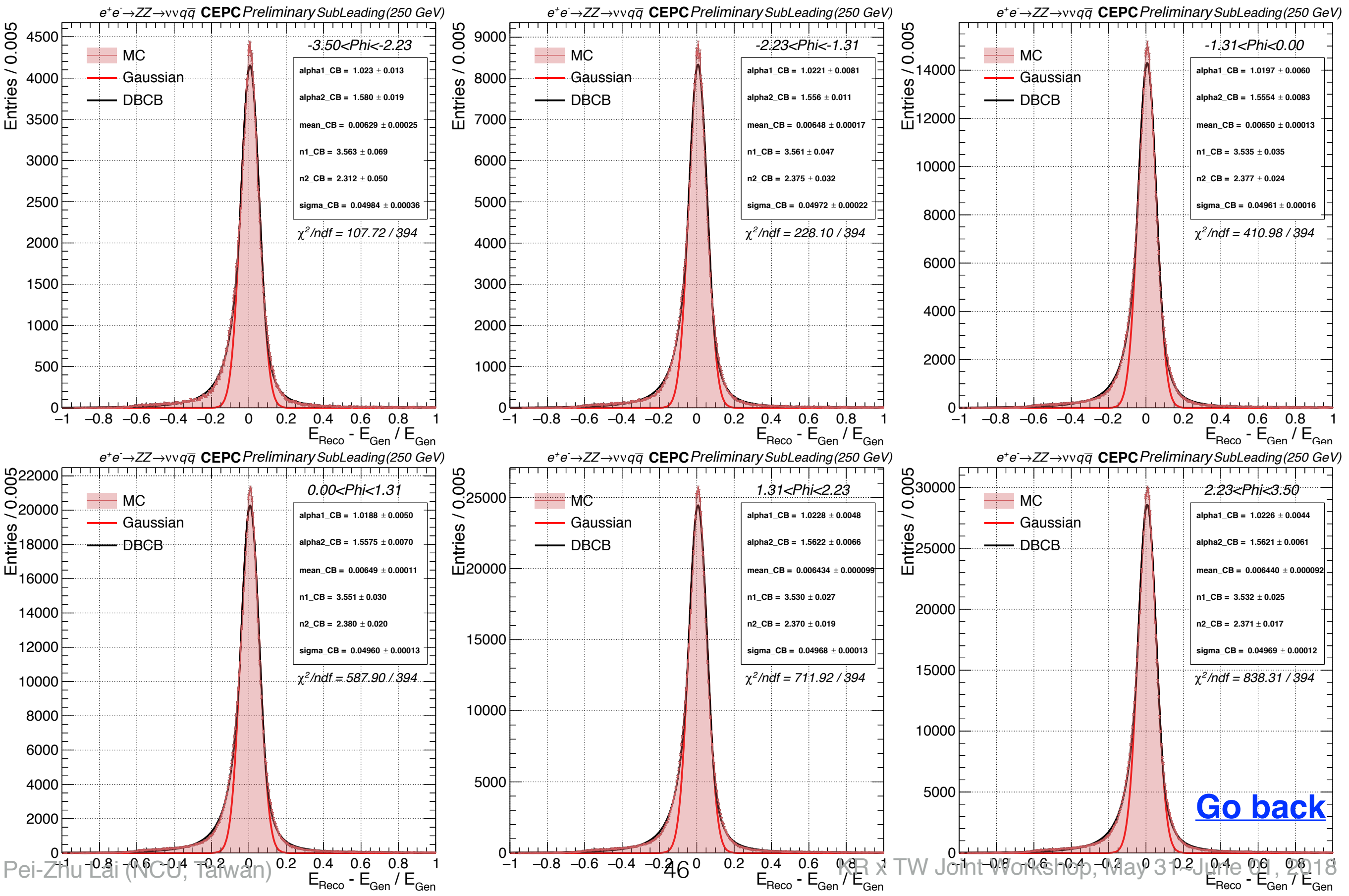
The Eta Bin Sub-leading JER & JES with dR Cut (Reco-Gen)



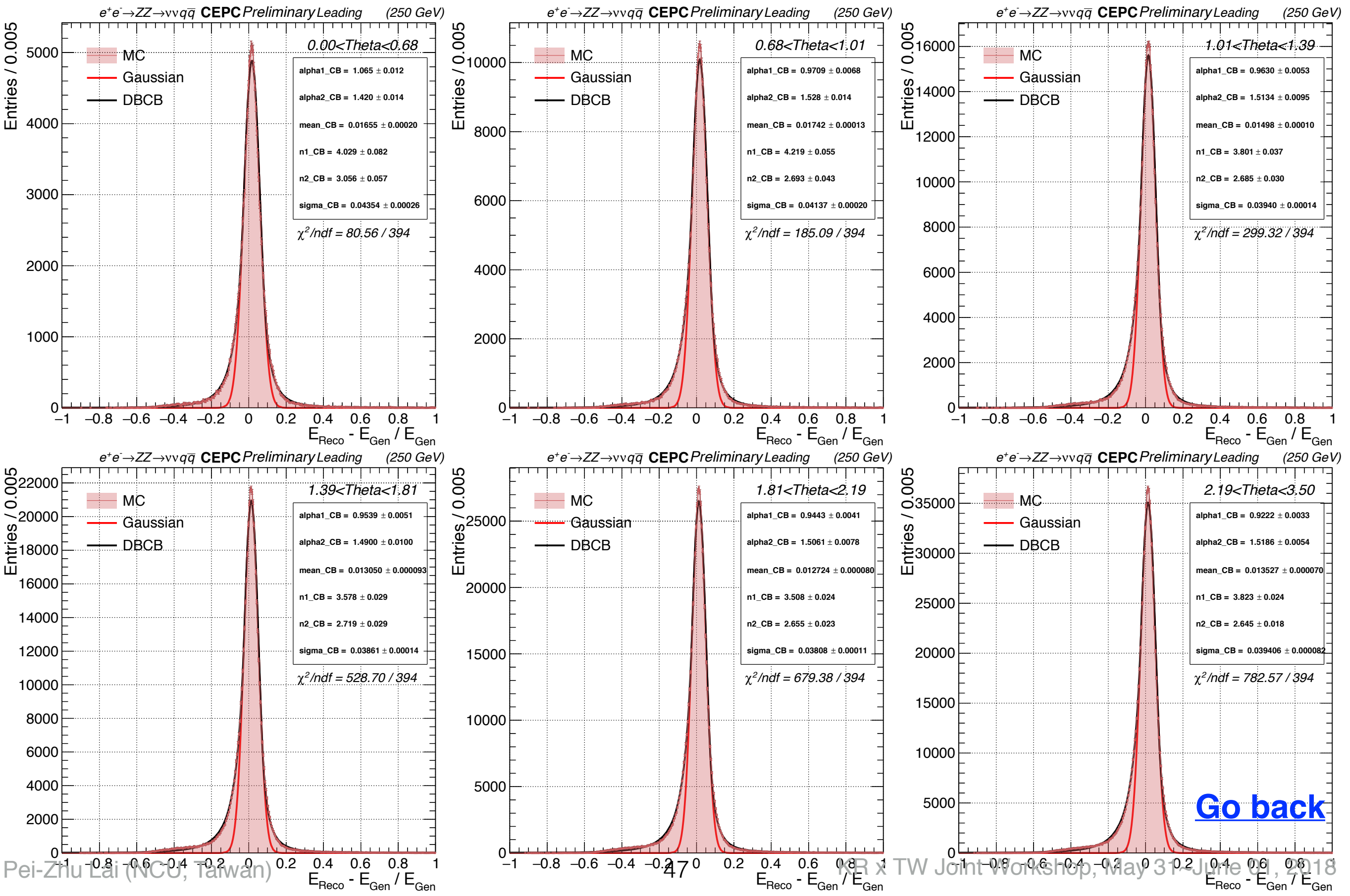
The Phi Bin Leading JER & JES with dR Cut (Reco-Gen)



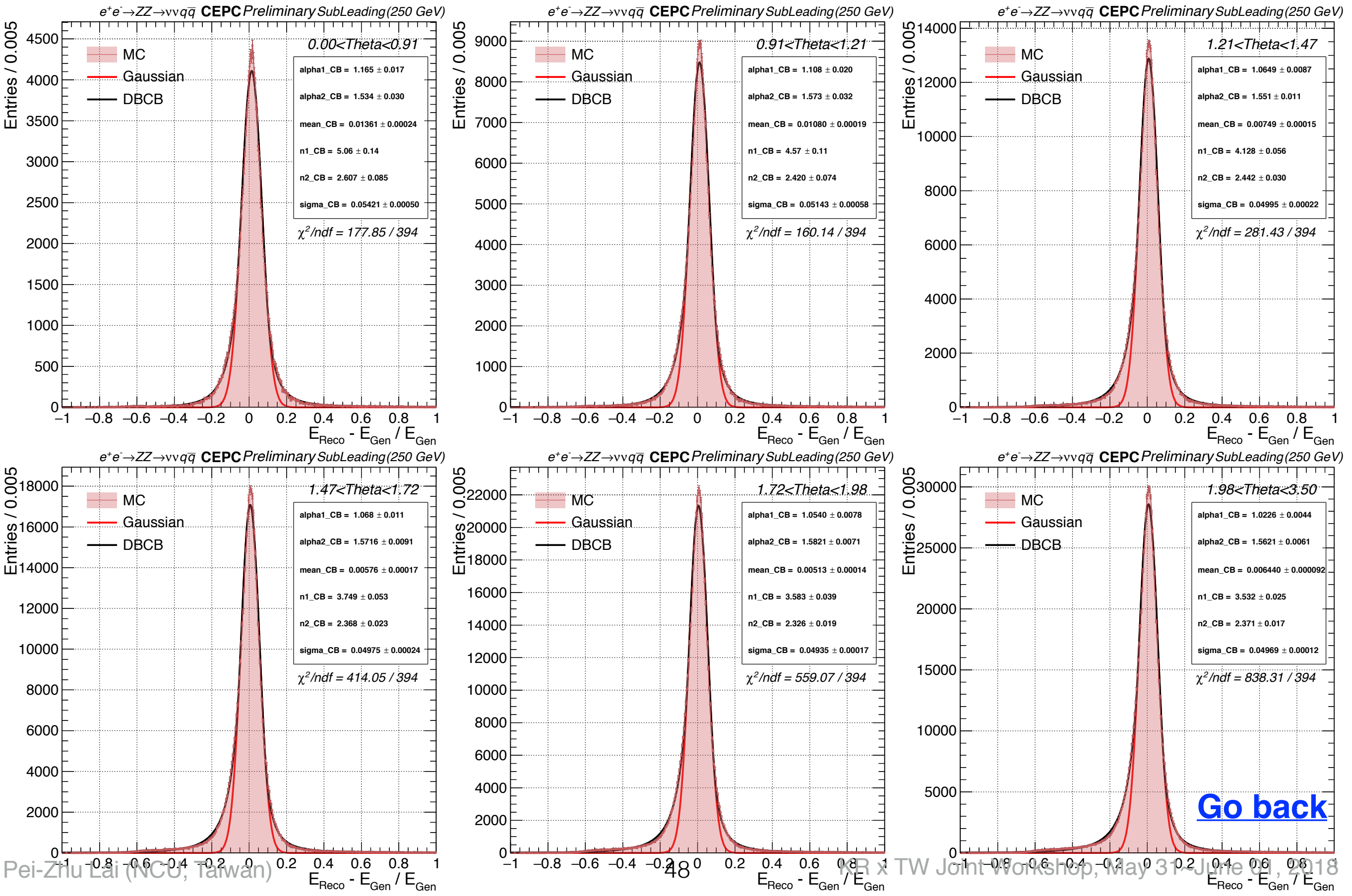
The Phi Bin Sub-leading JER & JES with dR Cut (Reco-Gen)



The Theta Bin Leading JER & JES with dR Cut (Reco-Gen)



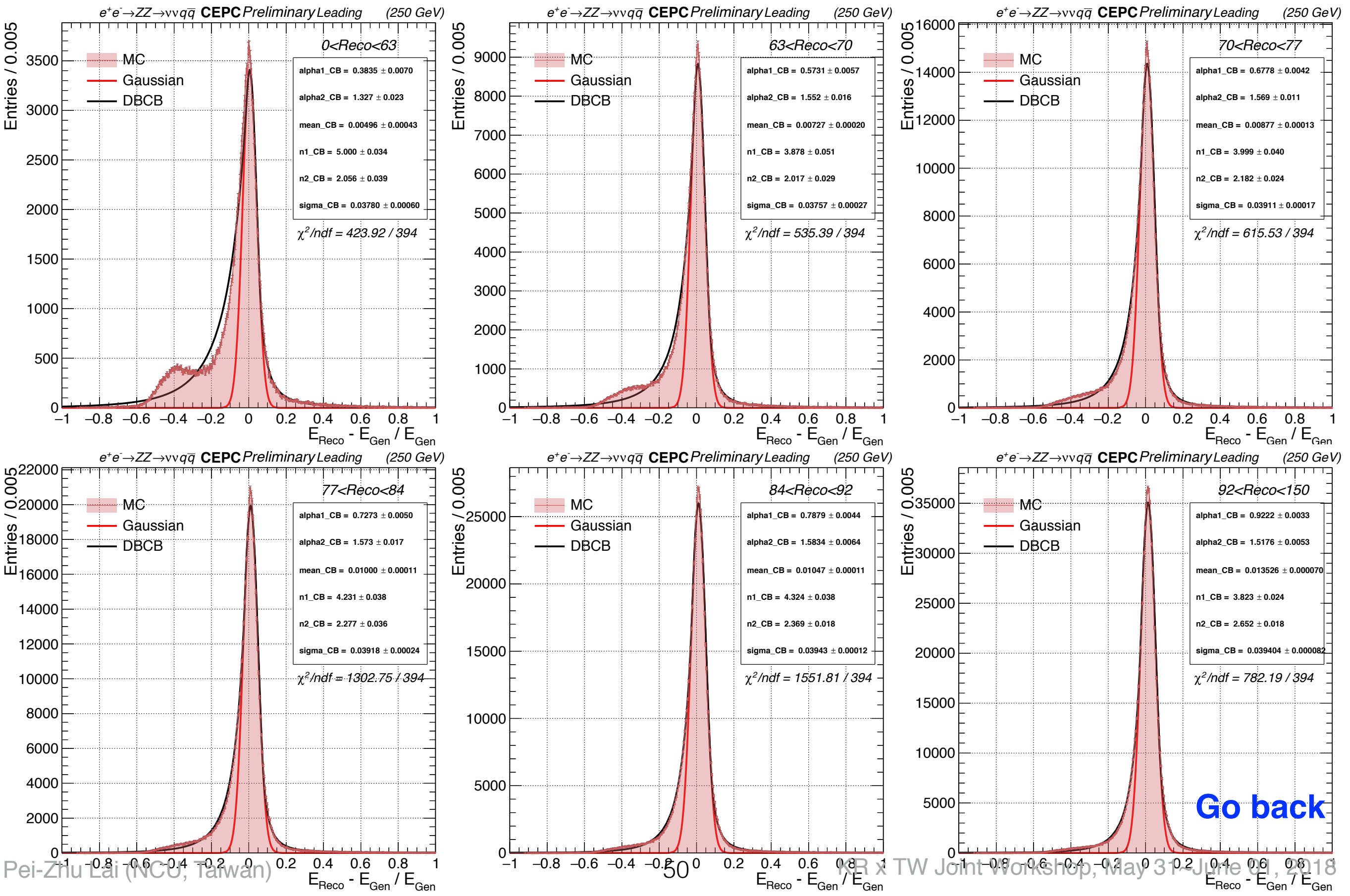
The Theta Bin Sub-leading JER & JES with dR Cut (Reco-Gen)



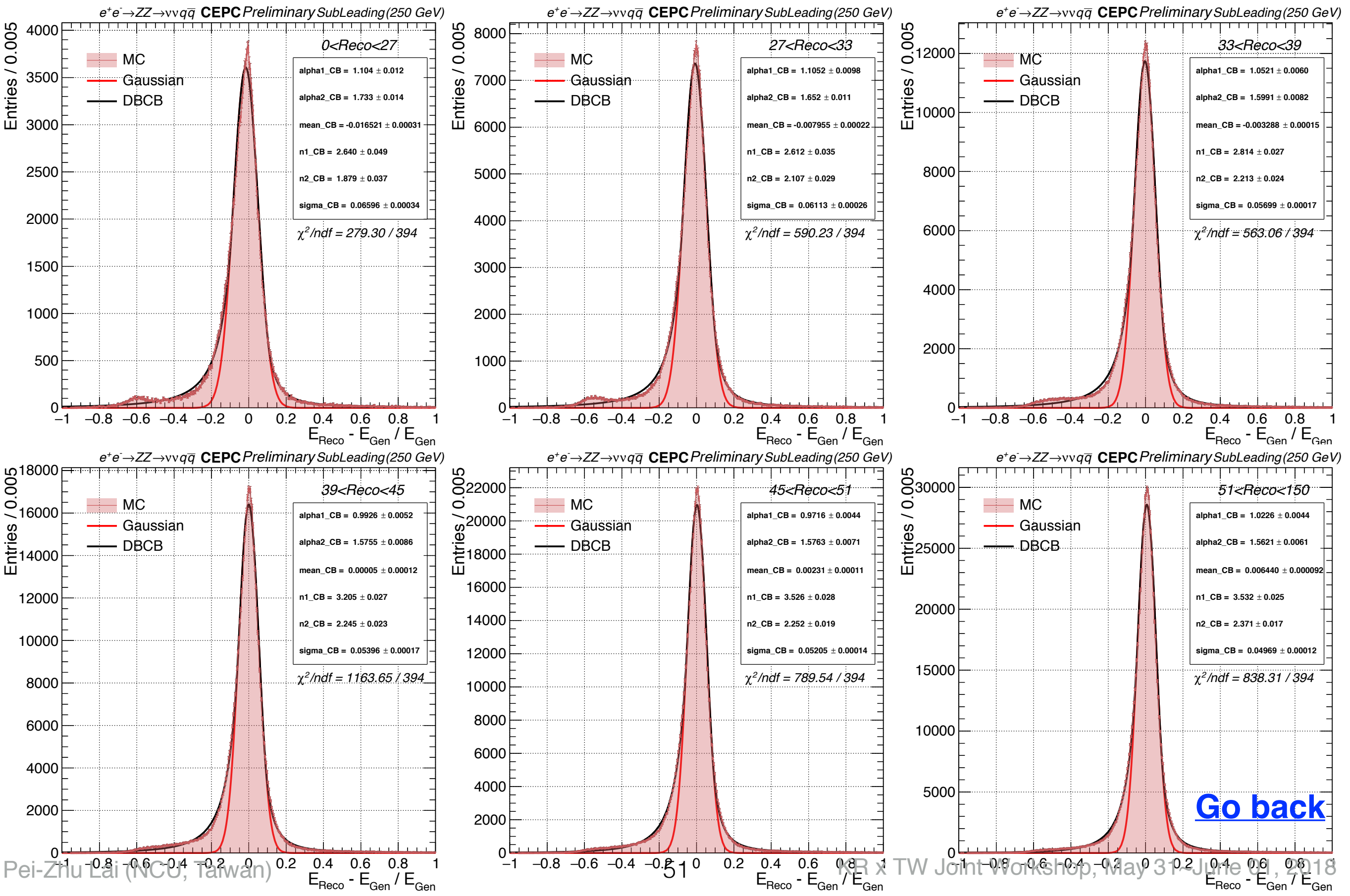
Each Energy Bin with dR Cut
(Reco-Gen)



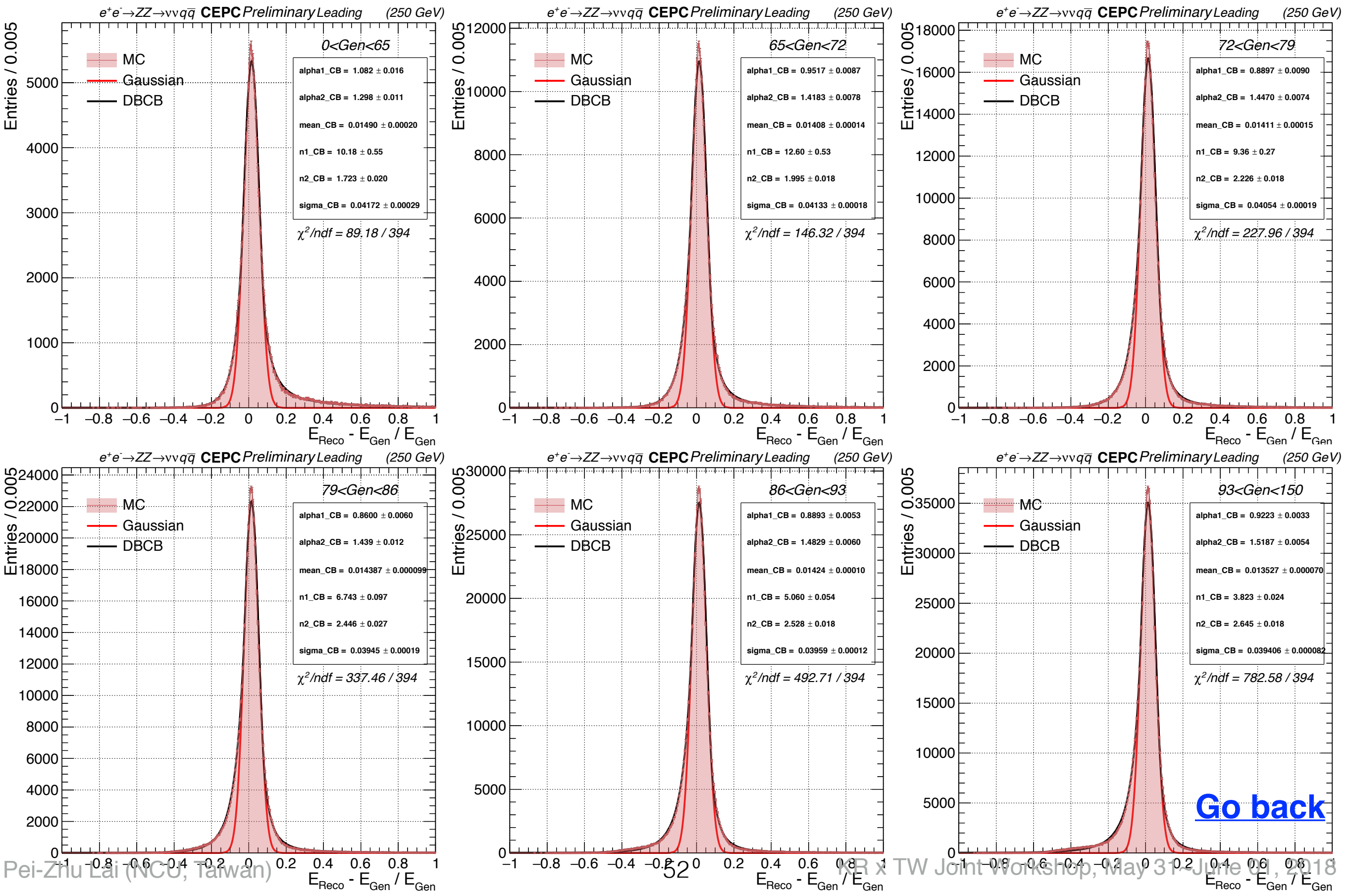
The Reco Bin Leading JER & JES with dR Cut (Reco-Gen)



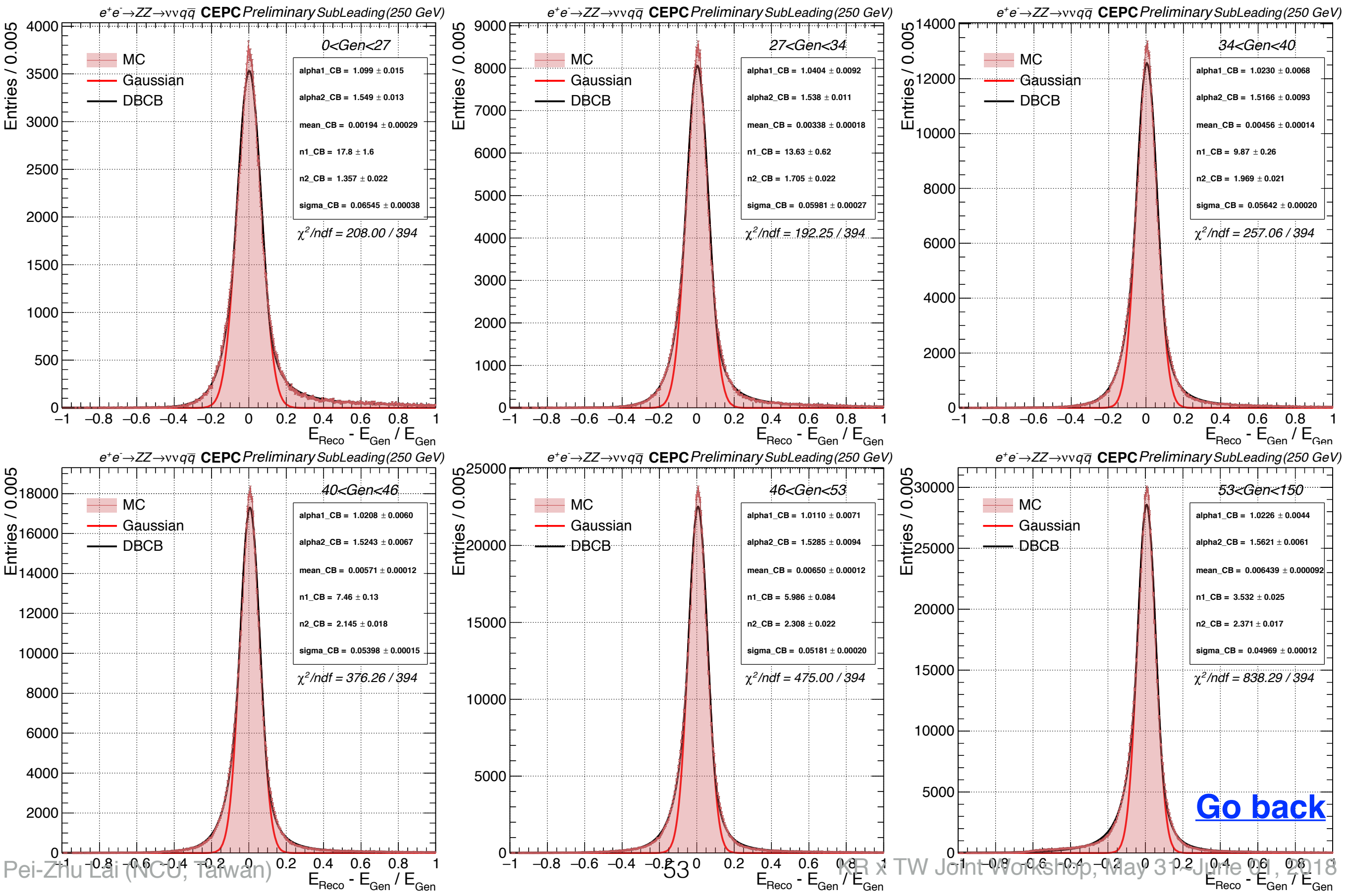
The Reco Bin Sub-leading JER & JES with dR Cut (Reco-Gen)



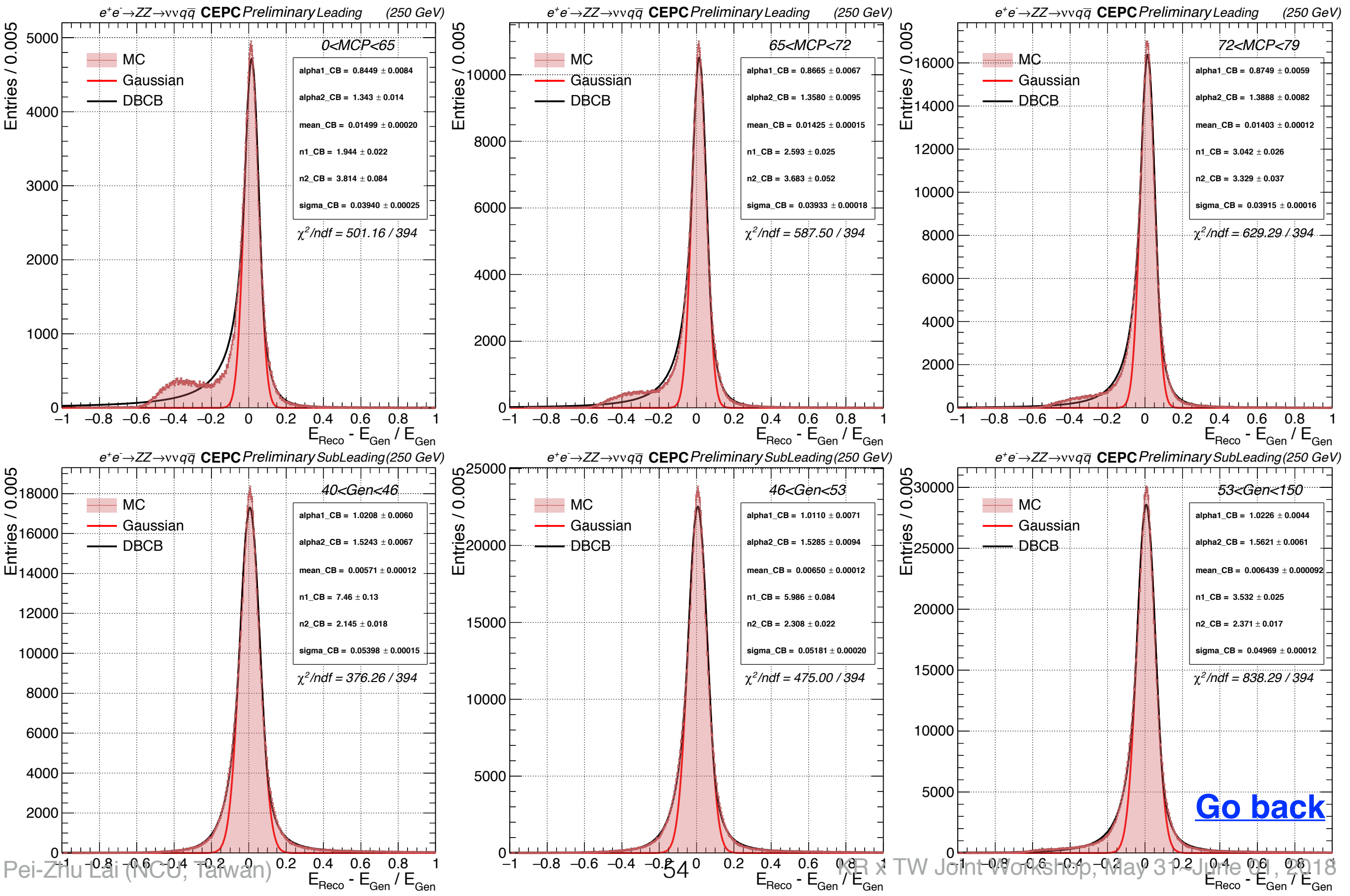
The Gen Bin Leading JER & JES with dR Cut (Reco-Gen)



The Gen Bin Sub-leading JER & JES with dR Cut (Reco-Gen)



The MCP Bin Leading JER & JES with dR Cut (Reco-Gen)



The MCP Bin Sub-leading JER & JES with dR Cut (Reco-Gen)

