Z pole $ee \rightarrow s\bar{s}$ forward-backward asymmetry at CEPC

Shuo Han, Minqia Li

1 IHEP

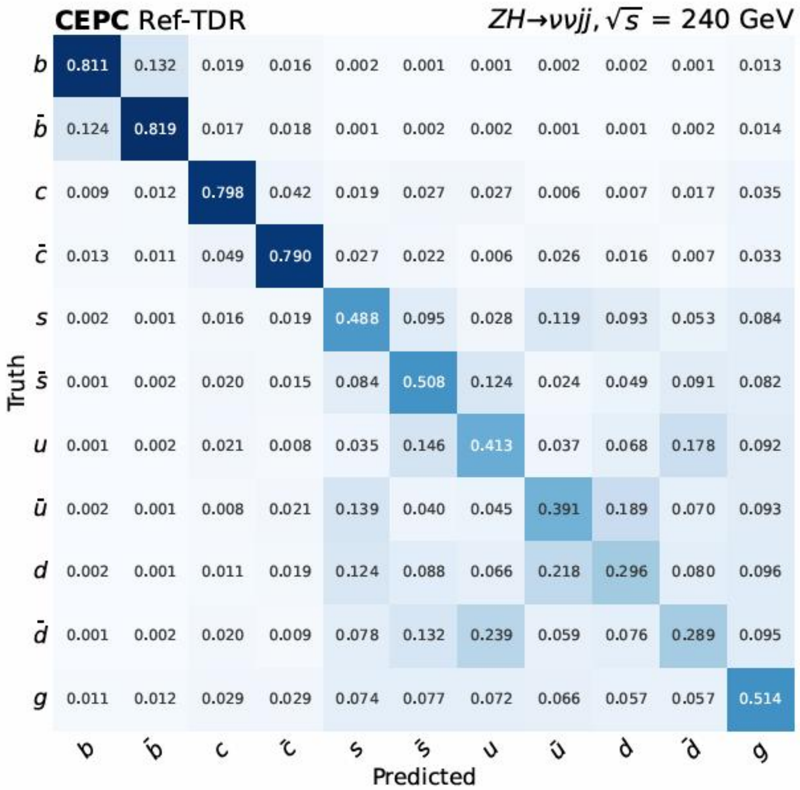
Introduction

- According to TDR(arXiv:2510.05260) of the CEPC, low-energy runs at Z pole will produce large numbers of Z boson.
- The electroweak mixing angle is extracted from the forward-backward asymmetry (AFB) of the $ee \to Z/\gamma* \to ff$ events.
- The AFB is defined by the angle θ_{CM} between the final-state quark and the initial-state e^- in the dilepton center-of-mass frame.
- $ee \to ss$ forward-backward asymmetry is one of the Benchmark Physics studies that IDRC are interested in.

Sample Production

- ee→qq events are simulated with Whizard + Phythia at LO and Z pole energy, including bb, cc, ss, uu, dd final states.
- Process the sample with the detector ref-TDR version of the CEPC software.
- Jet Origin Identification[(Phys.Rev.Lett. 132 (2024) 22, 221802)](#) are used in jet tagging.
  - Tagging model based on ParticleTransformer framework.
  - We can identify the jet by the highest score in the prediction.

Channel	$e^+e^- \to s\bar{s}$	$e^+e^- \to b\bar{b}$	$e^+e^- \to c\bar{c}$	$e^+e^- \to u\bar{u}$	$e^+e^- \to d\bar{d}$
Events	239250	199400	249500	199424	199000



[arXiv:2510.05260](#)

Event Selection and Cutflow

- Jet-level selection based on JOI: select all the jets which pass s-tagging.
- $|\cos\theta| > 0.05$: reduce the forward and backward misidentification caused by reconstruction.

Channel	$e^+e^- \to s\bar{s}$	$e^+e^- \to b\bar{b}$	$e^+e^- \to c\bar{c}$	$e^+e^- \to u\bar{u}$	$e^+e^- \to d\bar{d}$
Cross Section	6.7 nb	6.7 nb	5.0 nb	5.0 nb	6.7 nb
Expected Events	6.24×10^9	6.24×10^9	4.64×10^9	4.64×10^9	6.24×10^9
Simulated Events	239250	199400	249500	199424	199000
Pass s-tagging	55678	3	341	4428	4543
$\|\cos\theta\|>0.05$	53477	3	331	4257	4384

Calculation

● Forward and backward events are classified by the angle θ_{CM} of the s quark, which is reconstructed in the CM frame.

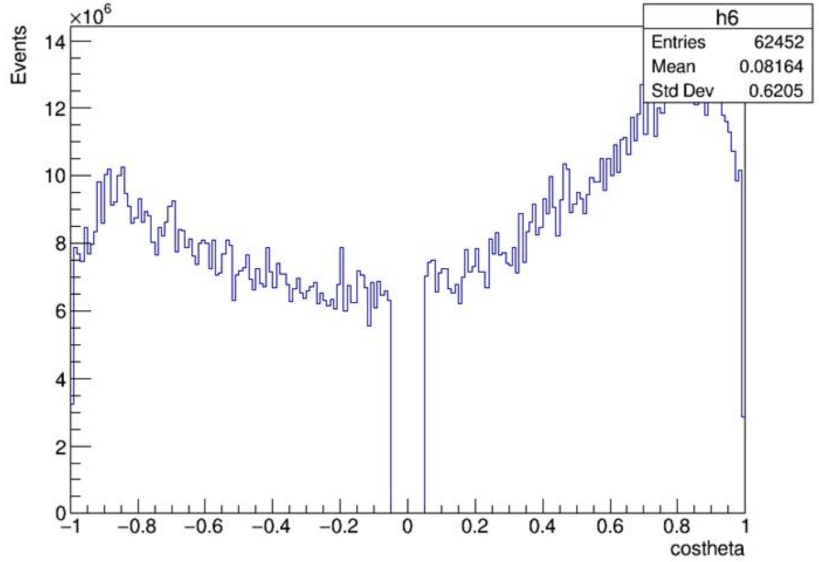
● Counting the number of forward and backward s quarks.

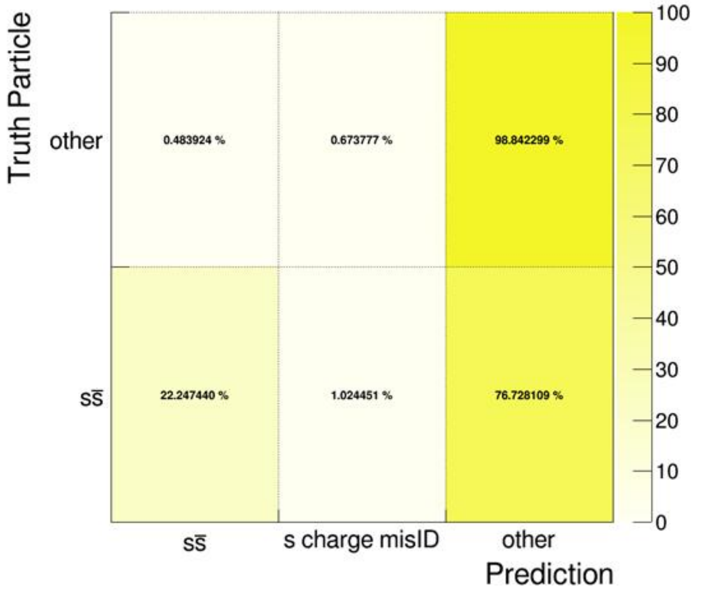
● Define the correction of charge misidentification.

○ AFB observed value contains three terms of contribution: s quark, $\bar{s}$ quark and background.

○ The fractions and AFB values of those three terms can be calculated using s-tagging confusion matrix based on simulation data.

$$AFB_s = \frac{AFB_{obs} - AFB_{\bar{s}} \cdot frac_2 - AFB_{bkg} \cdot frac_3}{frac_1}$$





Calculation

- Getting the AFB(s): A likelihood function is defined to fit the number of forward and backward s quark.
  - Likelihood function of the distribution observed in 2-bin histogram should be expressed as the product of two Poisson terms.

$$\mathcal{L}(N, A) = \mathrm{Pois}(n_F|\mu_F)\mathrm{Pois}(n_B|\mu_B)$$

  - But in AFB measurement, the function is equivalent to:

$$\mathrm{Pois}(n_F|\mu_F)\mathrm{Pois}(n_B|\mu_B) = \mathrm{Pois}(n_{\mathrm{tot}}|N)\mathrm{Binom}(n_F|n_{\mathrm{tot}}, p)$$

  - The factor of systematic uncertainty will be a Gaussion term multipled into the likelihood function:

$$\mathcal{L}(a_3, \theta, N) = \binom{n_{tot}}{n_F} p^{n_F}(1-p)^{n_B} \times \frac{N^{n_{tot}} e^{-N}}{n_{tot}!} \times \frac{1}{\sqrt{2\pi}} e^{-\theta^2/2}$$

  - p is the probability that the event has forward s quark and it is constructed by AFB.

$$p = \frac{1 + A_{\mathrm{mix}}}{2}$$

$$A_{\mathrm{mix}} = f_1 A_1 + f_2 A_2 + f_3 A_{fb}^{eff},\ \ A_{fb}^{eff} = \tanh(a + \sigma_a \theta)$$

- The fitting was performed using RooFit.

Results and Uncertainties

- Result
  - AFB(s, obs) = 0.125507 ± 0.000025.
  - AFB(s) = 0.154499 ± 0.000028.
- Statistical uncertainties.
  - One-month run @ 1 ab^{-1}: 6.24×10^9 ss quark pairs(4×10^{10} Z bosons), 2.8×10^{-5} statistical uncertainty.
- Systematic Uncertainties.
  - Detector Resolution: Uncertainty estimated to be 3.7×10^{-5}.

	Before jet reco	**No selection**	**After selections**	**Using PFO**
Forward	3.60204×10^9	3.59390×10^9	9.21455×10^8	9.21523×10^8
Backward	2.63796×10^9	2.64610×10^9	7.16071×10^8	7.16003×10^8
A_{FB}^{s} or A_{FB}^{obs}	0.154499	0.151891	0.125424	0.125507
A_{FB}^{s} after phase space correction	N/A	N/A	0.154462	0.154499

Summary

● This is the first time that AFB(s) measurements have been conducted based on the TDR software and detailed systematic error analysis.

  ○ A workflow based on statistical method has been built.
  ○ Implement s-tagging using Jet Origin Identification(JOI).

● Plan for the Next Step

  ○ Consider more sources of systematic uncertainties in the estimation.
  ○ Add more information about s-quark on track/cluster level during the JOI model training in order to improve s-tagging performance.