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# Physics at Z pole

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# Introduction

- CEPC have good potential in electroweak precision physics at Z pole.
  - Latest design in CEPC Z pole accelerator
  - $L=1.6 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$  (one order of magnitude larger than pre-CDR)
  - Aim to have  $10^{11}$  Z boson for electroweak precision physics
- The accelerator design for WW threshold scan runs are also updated
  - Total luminosity  $3.2 \text{ ab}^{-1}$
  - Aim to have 1 MeV level precision for W mass measurement
  - More details in Hengne and Peixun's talk

# Status of W/Z physics study in CEPC

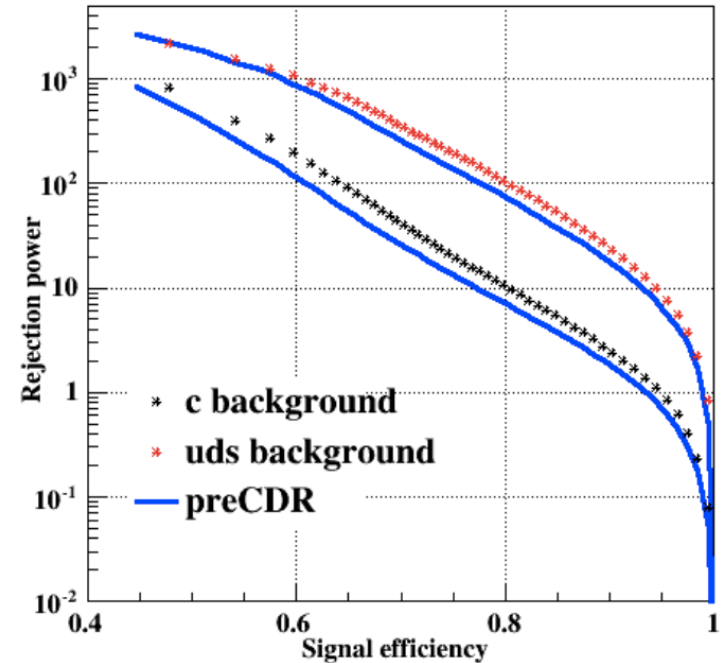
- The prospect of W/Z physics study in CEPC are under study
  - New full simulation with latest detector geometry and magnetic field (3T)

Observable	LEP precision	CEPC precision	CEPC runs
$m_Z$	2 MeV	0.5 MeV	Z threshold scan
$A_{FB}^b$	1.7%	0.1%	Z threshold scan
$\sin^2 \theta_W^{\text{eff}}$	0.07%	0.002%	Z threshold scan
$R_b$	0.3%	0.02%	Z pole
$R_\mu$	0.2%	0.01%	Z pole
$N_\nu$	1.7%	0.05%	ZH runs
$m_W$	33 MeV	2-3 MeV	ZH runs
$m_W$	33 MeV	1 MeV	WW threshold

# Branching ratio ( $R^b$ )

$$\frac{\Gamma(Z \rightarrow b\bar{b})}{\Gamma(Z \rightarrow \text{had})}$$

- LEP measurement  $0.21594 \pm 0.00066$  ( $\sim 0.3\%$ )
  - Stat unc and Systematics Unc. Have similar contribution
- CEPC
  - Expected Stat Unc. Is neglectable
  - Expected Syst error (0.02%)
  - Expect to use 80% working points
    - 15% higher efficiency than SLD
    - 20-30% higher in purity than SLD



Uncertainty	LEP	CEPC	Thing to improve
hemisphere tag correlations for b events	0.2%	0.02%	B tagging performance, pixel
gluon splitting	$\sim 0.15\%$	0.01%	Better granularity in Calo

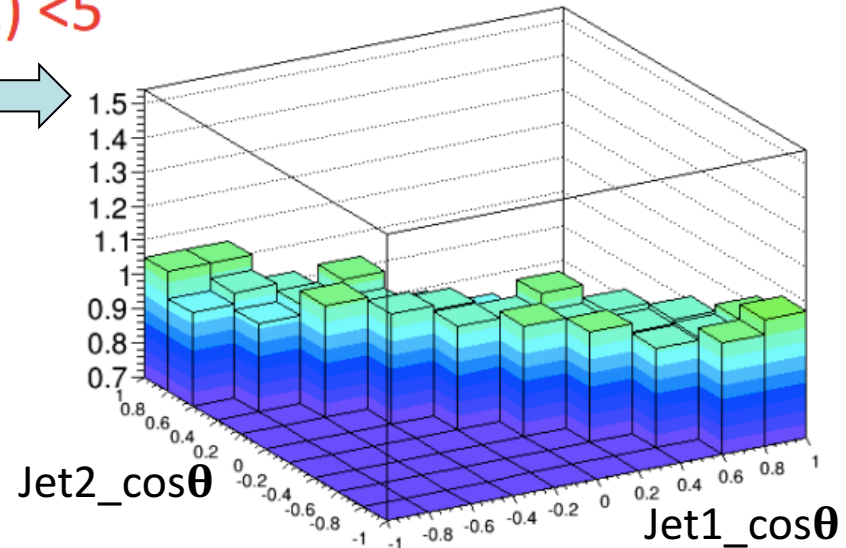
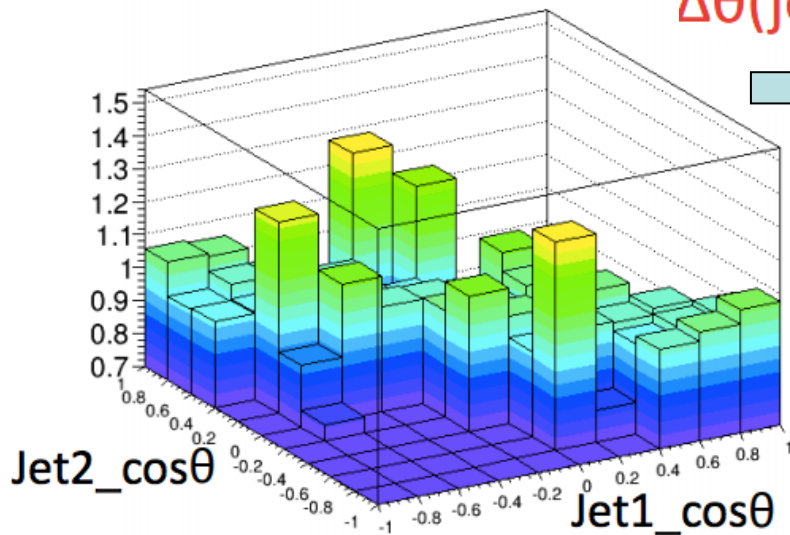
# $R^b$ : hemisphere tag correlations

- Study hemisphere b tag correlations systematics with full simulation
- Two ways to reduce correlations factor -> **reducing systematics**
  - Using higher efficiency b tagging working points
  - Using tighter cuts to choose Z->bb events
  - Correlations factors  $c_b$  need to be reduced below 0.01% (systematics 0.02%)

By Bo Li (Yantai University )

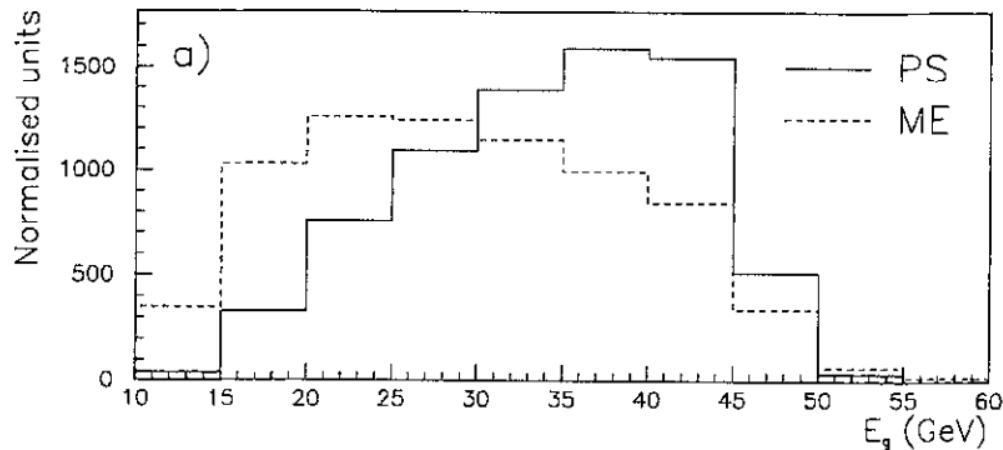
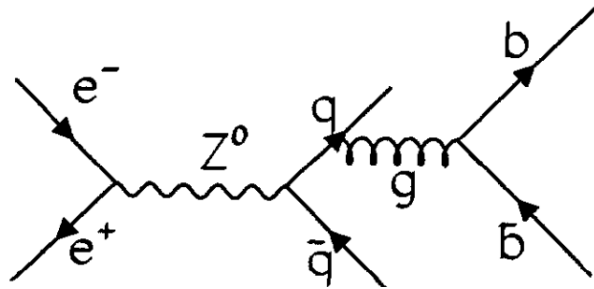
$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

$\Delta\theta(\text{jet1}, \text{jet2}) < 5^\circ$

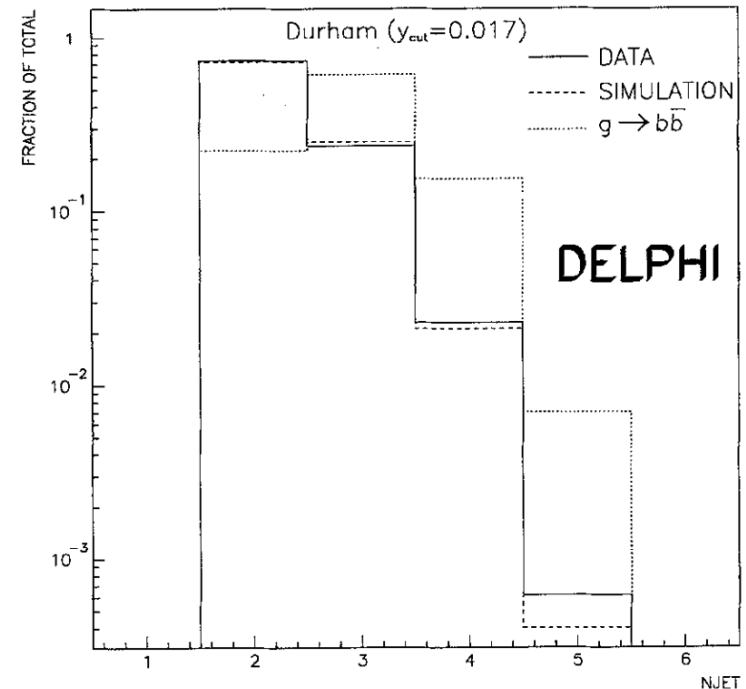


# Branching ratio ( $R^b$ ): gluon splitting

- To reduce the  $R_b$  systematics
  - Another task is to measure gluon splitting
  - plan to setup dedicated analysis for gluon splitting measurement

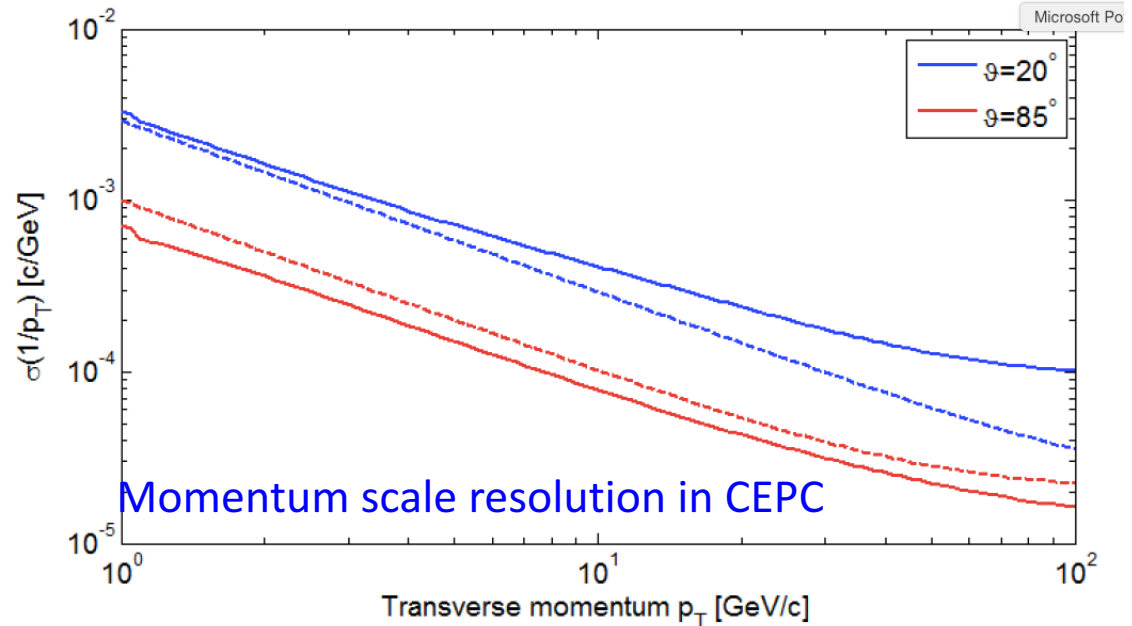


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# Branching ratio ( $R^\mu$ )

- LEP result: 0.2% total error (Stat : 0.15%, Syst : 0.1%)
- CEPC : 0.01% total error expected
  - Higher granularity and better resolution in EM calorimeter is the key



Systematics source	LEP	CEPC
Radiative events ( $Z \rightarrow \mu\mu\gamma$ )	0.05%	0.01%
Muon Momentum scale	0.009%	<0.005%

# Weak mixing angle

$$\sin^2 \theta_{\text{eff}}^{\text{lept}}$$

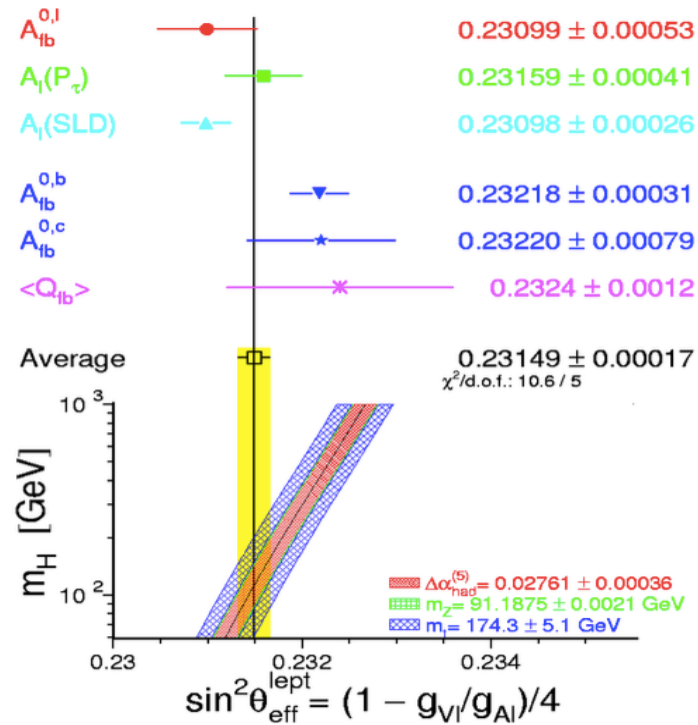
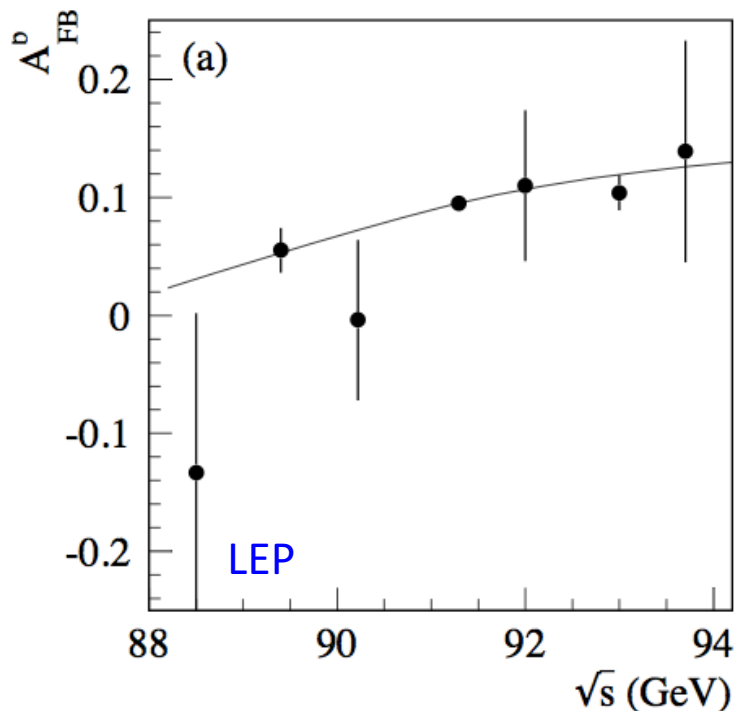
- LEP/SLD:  $0.23153 \pm 0.00016$

–  $\sim 0.07\%$  precision. (Stat error is limiting factor.)

- CEPC

- Aim for 0.002% precision

- Input from Backward-forward asymmetry measurement of  $Z \rightarrow b\bar{b}$  and  $Z \rightarrow \mu\bar{\mu}$
- $Z \rightarrow e\bar{e}$ ,  $Z \rightarrow \tau\bar{\tau}$  have not been studied yet.



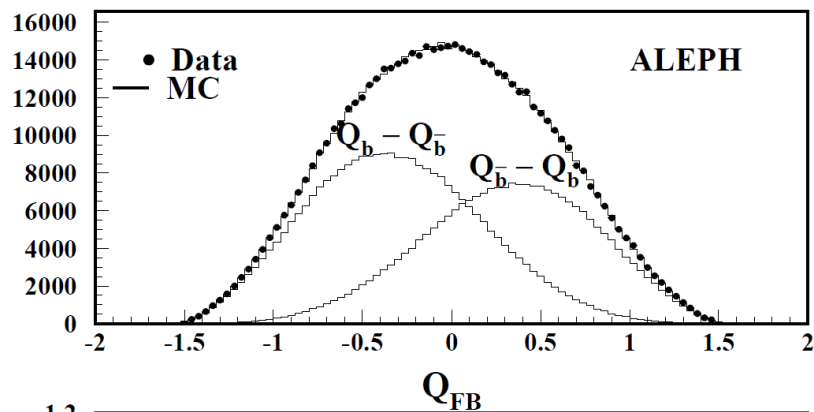


# Backward-forward asymmetry

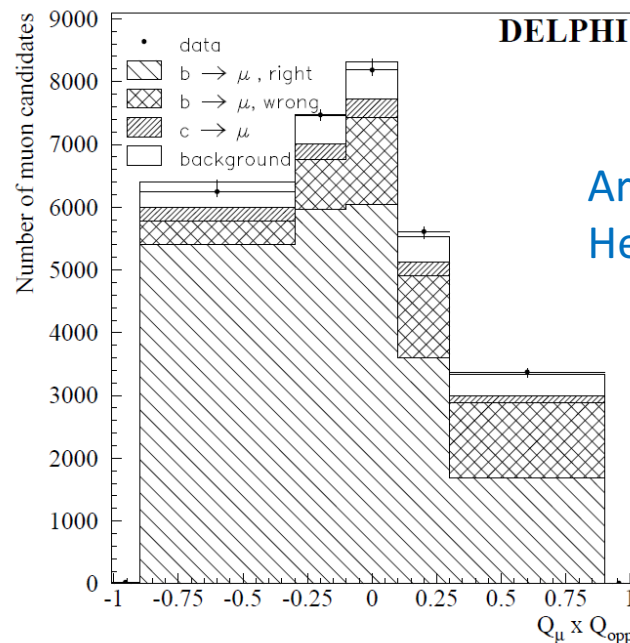
- LEP measurement :  $0.1000 \pm 0.0017$  (Z peak)
  - Method 1: Soft lepton from b/c decay ( $\sim 2\%$ )
    - Select one lepton from b/c decay, and one b jets
    - Select lepton charge ( $Q_{\text{lepton}}$ ) and jet charge ( $Q_{\text{jet}}$ )
  - Method 2: jet charge method using Inclusive b jet ( $\sim 1.2\%$ )
    - Select two b jets
    - use event Thrust to define the forward and background
    - Use jet charge difference ( $Q_F - Q_B$ )

Arxiv:Hep-ex/0107033

$Q_F - Q_B$  in method 2



$Q_{\text{lepton}} - Q_{\text{jet}}$  in method 1



Arxiv:  
Hep-ex/0403041

# Backward-forward asymmetry

$$A_{FB}^{b\bar{b}}(0)$$

- LEP measurement : 0.1000+-0.0017 (Z peak)
  - Method 1: Soft lepton from b/c decay (~2%)
  - Method 2: jet charge method using Inclusive b jet (~1.2%)
  - Method 3: D meson method (>8%, method)
- CEPC
  - Focus more on method 2 (inclusive b jet measurement)
  - Expected Systematics (0.15%) :

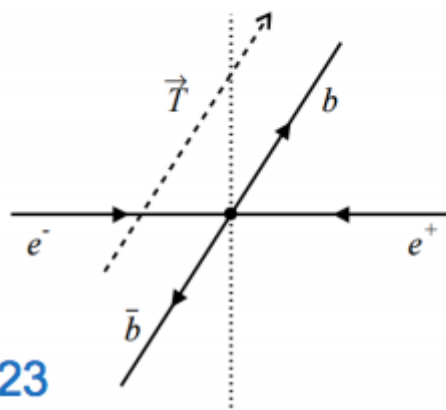
Uncertainty	LEP	CEPC	Things to improve
hemisphere tag correlations for b events	1.2%	0.1%	Higher b tagging efficiency
QCD and thrust axis correction	0.7%	0.1%	

# Backward-forward asymmetry

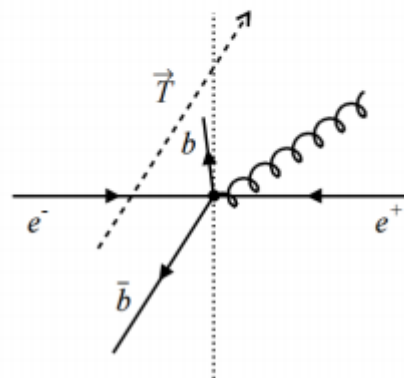
$$A_{FB}^{b\bar{b}}(0)$$

- Uncertainty  $A_{fb\_b}$  due to QCD correction to Thrust
  - Higher order QCD effect is major systematics

CERN-EP/98-23



(a) No gluon



(d) Thrust forward, quark backward

Error source	$C_{\text{QCD}}^{\text{quark}}$ (%)		$C_{\text{QCD}}^{\text{part},T}$ (%)	
	$b\bar{b}$	$c\bar{c}$	$b\bar{b}$	$c\bar{c}$
Theoretical error on $m_b$ or $m_c$	0.23	0.11	0.15	0.08
$\alpha_s(m_Z^2)$ ( $0.119 \pm 0.004$ )	0.12	0.16	0.12	0.16
Higher order corrections	0.27	0.66	0.27	0.66
Total error	0.37	0.69	0.33	0.68

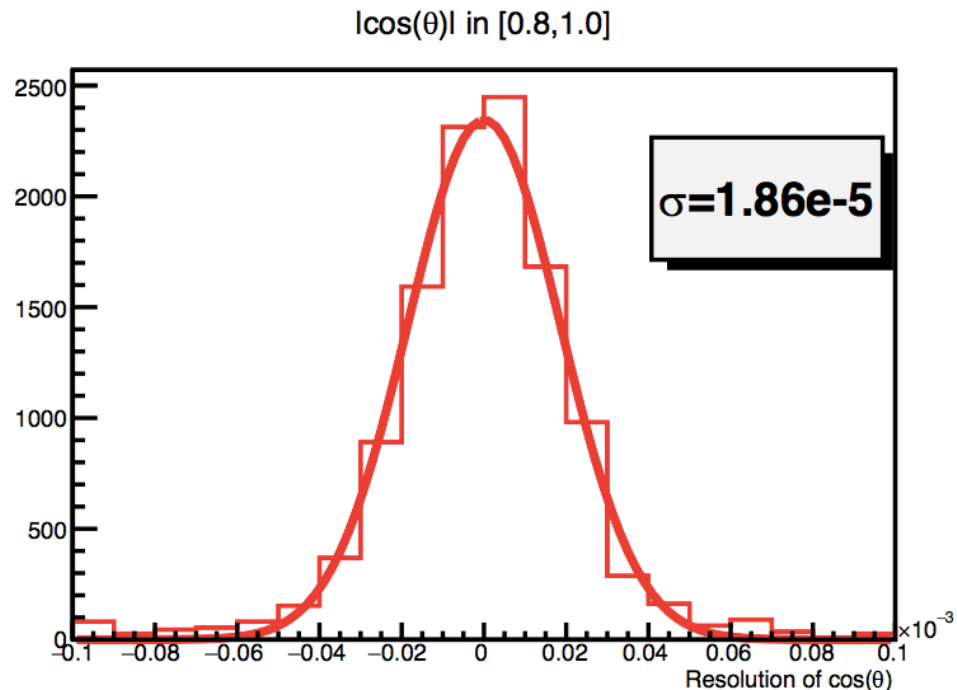
# Backward-forward asymmetry in $Z \rightarrow \mu\mu$

- LEP measurement : 1.69%  $\pm$  0.13% (PDG fit)
- CEPC aim to improve it by a factor of 20~30 .

$$A_{FB}^{(0,\mu)}$$

- muon angular resolution and acceptance
- the precision of beam energy measurement
- Full simulation studies to understand muon angular resolution
  - Muon angular resolution can reach  $1e^{-4}$  to  $1e^{-5}$  level

By Mengran Li (IHEP)



# Weak mixing angle (2)

- Comparison with Fcc-ee on weak mixing angle measurement
  - Expect 1~2 order magnitude better than LEP results

Improvement compared to LEP results	CEPC	FCC-ee (from Paolo's talk)
AFB (Z- $\rightarrow$ ee)	NA	50
AFB (Z- $\rightarrow$ $\mu\mu$ )	20-30	30
AFB (Z- $\rightarrow$ $\tau\tau$ )	NA	15
AFB (Z- $\rightarrow$ bb)	10	5
Weak mixing angle	30	100

# Summary

- CEPC electroweak physics community is working on in Conceptual Design Report.
  - updated in CEPC accelerator design on Z pole and WW threshold runs
  - one order of magnitude larger than pre-CDR
  - Prospect of CEPC W/Z physics improved benefitted from higher design luminosity
  - More details about W physics in Hengne and Peixun's talk
- Welcome to join this effort
  - Lots of work needed to understand the systematics