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Effective weak mixing angle($\sin^2 \theta_{eff}^f$) measurement at the CEPC

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Electroweak Precision measurements and $\sin^2 \theta_{eff}^{f}$

- Key parameter in electroweak sector:
 - α , G_{μ} , M_Z , M_W , $\sin^2 \theta_W$
- Effective weak mixing angle:
 - $\sin^2 \theta_{eff}^f = \left(1 m_W^2 / m_Z^2\right) * (1 + \Delta \kappa)$
 - $\Delta \kappa$ absorb higher order corrections

Physical constants	Experimental uncertainty (relative)
Fermi Constant	10-7
Mass of Z	10-5
Mass of W	10-4
Effective Weak mixing angle	10-3

$\sin^2 \theta_{eff}^{f}$ measurement at lepton/hadron collider

- LEP&SLAC (precision~0.1%)
 - LEP: 0.23188 ± 0.00021
 - SLAC: 0.23098 ± 0.00026
 - Statistical dominant
- Tevatron
 - $0.23148 \pm 0.00033 (DØ+CDF)$
 - Statistic & PDF dominant
- LHC
 - PDF, QCD & systematic dominant
 - Aiming for ~0.00010 in the future

Tevatron: $\sin^2 \theta_{eff}^l = 0.23148 \pm 0.00027(stat.)$ $\pm 0.00005(syst.)$ $\pm 0.00018(PDF)$



 ± 0.00016 (theo.)

 $\pm 0.00031(PDF)$

measurement of $\sin^2 \theta^f_{eff}$ in the future

- Measurement before Higgs discovery
 - world average under SM assumption
 - ~0.1% precision good enough for Higgs mass prediction
- Measurement in the future
 - Global test of SM & search for new physics.
 - From O(0.1%) to O(0.01%), comparable to current theoretical calculation.
 - Direct comparison between different progresses (leptons, light quarks, heavy quarks ...)
 - Next 10~15 years: LHC, $\Delta \sin^2 \theta_{eff}^l \sim 0.00010$. Limited by PDF, QCD and experimental systematics.



Experimental	Theoretical calc.
uncertainty	error
~0.00030	~0.00005

$\sin^2 \theta_{eff}^f$ measurement at the CEPC

•
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} = A_{FB}(\sin^2\theta_{eff})$$



- High luminosity at the CEPC
 - CEPC: 600 billion Z in 2 years (Z period)
- Low systematics



$\sin^2 \theta_{eff}^{f}$ measurement at the CEPC

- High precision measurement
 - Final precision expected to be $\Delta \sin^2 \theta_{eff} \sim 0.00001$
- Independent measurement via different final states:
 - Each lepton channel, b, c, u+d (light)
- Running weak mixing angle with energy scale($\sin^2 \theta_w(\mu)$)
 - Make measurement at energy scale higher than Z pole for the first time.



NOTE: this is \overline{MS} scheme defined weak mixing angle.

Estimation on experimental sensitivity

sensitivity: $S = S^{phy} * Det$

$$S^{phy} = \frac{\partial A_{FB}^{phy}}{\partial \sin^2 \theta_{eff}}$$
$$Det = \frac{1}{1 - 2f} \cdot \sqrt{\frac{1}{\epsilon_{tagging}}}$$

- nhu

- $\epsilon_{tagging}$: overall efficiency of events observation
- *f*: charge mis-identification probability

Lepton	Quarks
ε~100% f~0	tagging power: $\epsilon \times (1 - 2f)^2$ =0.138 (for b quarks) =0.283 (for c quarks)

Estimation on experimental systematics

- Systematics from efficiency determination:
 - Cancelled out in the ratio-type definition of AFB, no propagation
- Systematics from charge mis-ID estimation:
 - Can be precisely measured from datadriven method

• Systematics can be well controlled at 0.00001 level

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



Results: A_{FB} measurement

Consider 1 month statistics at each energy point (~ 6e11/24 Z events at Z pole)

Only statistical uncertainty considered



Energy scale	70 GeV	75 GeV	91.19 GeV	105 GeV	115 GeV	130 GeV
from lepton final state	0.00028	0.00013	0.00001	0.00033	0.00385	0.00766
from b quark final state	0.00008	0.00006	< 0.00001	0.00005	0.00009	0.00018

Summary

• Estimation on effective weak mixing angle according to 1 month data collection

Overall precision at Z pole	Precision in lepton/quark comparison	Precision at off Z pole
$\Delta \sin^2 \theta_{eff} \sim 0.00001$	$\Delta \sin^2 \theta_{eff} \sim 0.00001$	$\Delta \sin^2 \theta_{eff} \sim 0.00010$

• CEPC features

- Large statistics
- Low systematics
- A good plan
 - 1~2 months data taken at Z pole
 - data taken at 2~3 high-mass points (>100 GeV), with 1~2 month for each

Additional discussion: EW, PDF and QCD

Why we need EW precision measurement at CEPC?
It is an PDF-QCD independent determination on EW
At the LHC, EW, PDF and QCD are strongly correlated



Constraining PDF using AFB at the LHC

 Introducing AFB to the PDF global fitting: provide unique information for q/qbar relative difference dominant unc.: independent measurement of sin²θ_W



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Bias in the PDF global fitting



Updating on the PDFs when introducing an LHC-measured AFB (pseudo-data) with weak mixing angle varied according to its experimental precision (from LEP or Tevatron)

Additional discussion: EW, PDF and QCD

- Constraining on PDF (especially at high-Q scale) needs independent EW precision measurements as input
- Dealing with PDF-EW correlation in the PDF global fitting: very difficult to consistently analysis for all data results used in PDF
- CEPC independent measurement: the ideal way to probe this

Thanks

Backups



Measurement for Tau: polarization $P_{\tau} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$

- Tau polarization method
 - Extract weak mixing angle from polarization asymmetry
 - Tau is the only lepton that can measure the polarization
- Theory of the measurement
 - For different tau decay mode, define a kinematic variable ω .
 - Fit spectrum to get P_{τ} .
 - $P_{\tau} = P_{\tau}(\cos\theta) = P_{\tau}(\sin^2\theta_{eff}, \cos\theta)$ (θ is the scattering angle of tau)



Results: P_{τ} measurement

- One month's statistics at Z pole
 - (3e11/24 Z boson)
 - Statistical error $\sim 0.5 * 0.01\%$

• Systematical error needs to be estimated in the future.

