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

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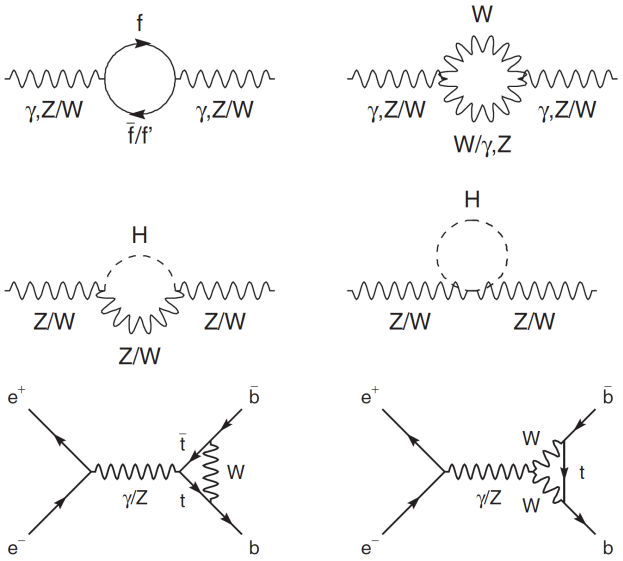
Electroweak Precision measurements and $\sin^2\theta^f_{eff}$

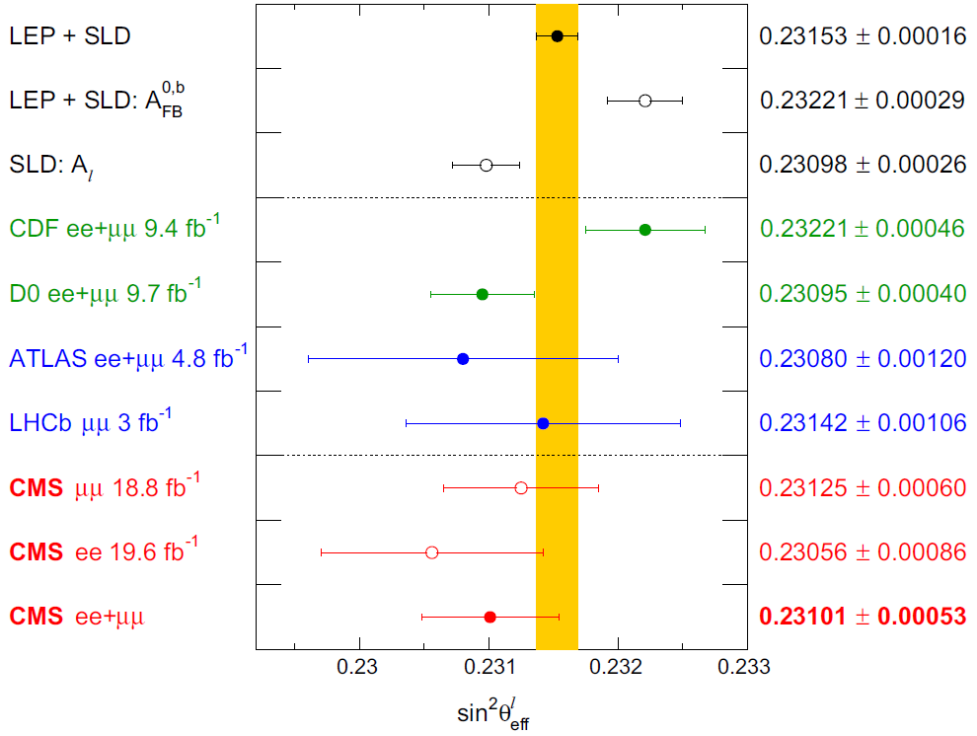
- Key parameter in electroweak sector:
  - $\alpha, G_\mu, M_Z, M_W, \mathbf{\sin^2\theta_W}$
- Effective weak mixing angle:
  - $\sin^2\theta^f_{eff} = (1 - m_W^2/m_Z^2) * (1 + \Delta\kappa)$
  - $\Delta\kappa$ absorb higher order corrections

Physical constants	Experimental uncertainty (relative)
Fermi Constant (G_F)	10^{-7}
Mass of Z (m_Z)	10^{-5}
Mass of W (m_W)	10^{-4}
Effective Weak mixing angle ($\sin^2\theta_{eff}$)	10^{-3}



$\sin^2\theta^l_{eff}$ 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 ± 0.00033 (DØ+CDF)
  - Statistic & PDF dominant
- LHC
  - PDF, QCD & systematic dominant
  - Aiming for ~0.00010 in the future



Tevatron:

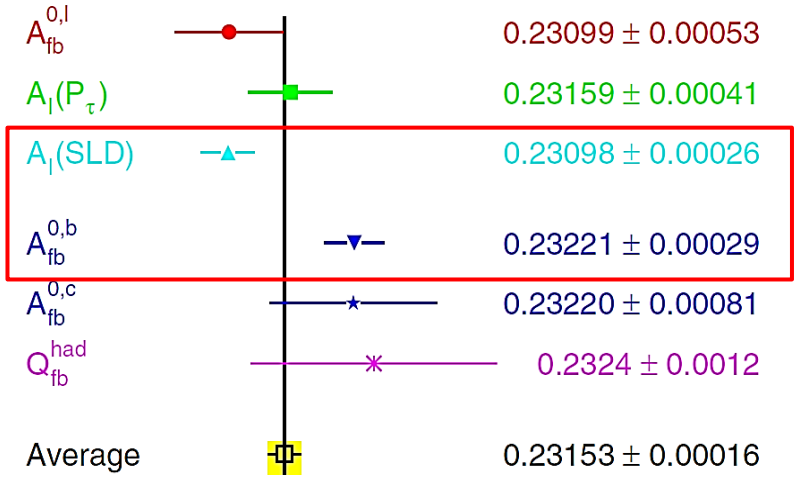
$$\sin^2\theta^l_{eff} = 0.23148 \pm 0.00027(stat.) \pm 0.00005(syst.) \pm 0.00018(PDF)$$

CMS 8TeV:

$$\sin^2\theta^l_{eff} = 0.23101 \pm 0.00036(stat.) \pm 0.00018(syst.) \pm 0.00016(theo.) \pm 0.00031(PDF)$$

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

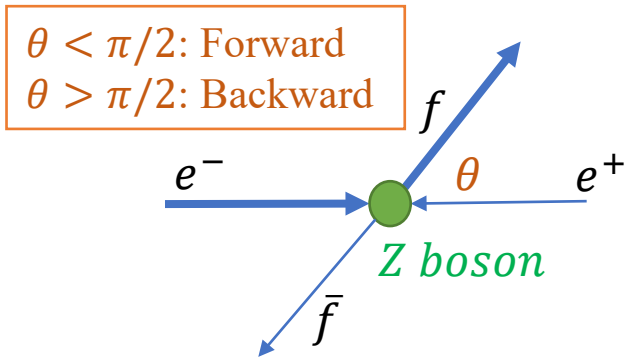
- Measurement before Higgs discovery
  - world average under SM assumption
  - ~0.1% precision good enough for Higgs mass prediction
- Measurement in the future
  - Global test of SM & search for new physics.
  - From O(0.1%) to O(0.01%), comparable to current theoretical calculation.
  - Direct comparison between different progresses (leptons, light quarks, heavy quarks ...)
  - Next 10~15 years: LHC, $\Delta\sin^2\theta^l_{eff}$ ~10^{-4}. Limited by PDF, QCD and experimental systematics.



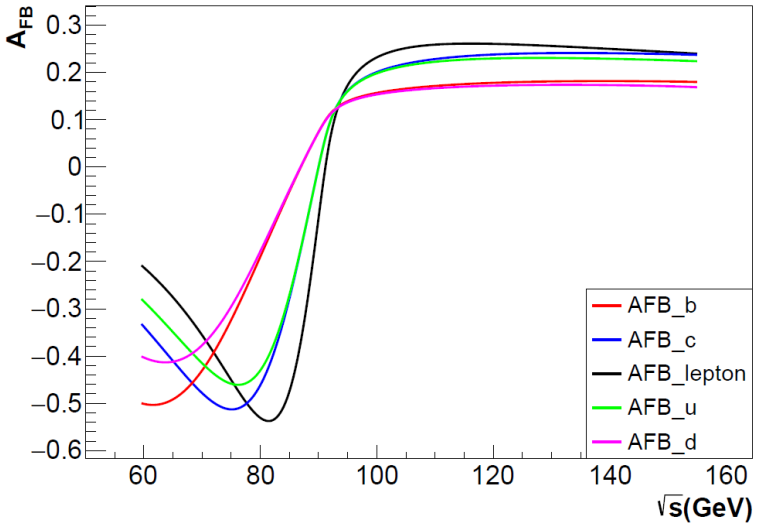
Experimental uncertainty	Theoretical calc. error
~0.00030	~0.00004

$\sin^2\theta^f_{eff}$ measurement at the CEPC

- $A_{FB} = \frac{N_F - N_B}{N_F + N_B} = A_{FB}(\sin^2\theta_{eff})$
- $A_{FB} = A_{FB}(\sqrt{s})$
- Flavor dependent

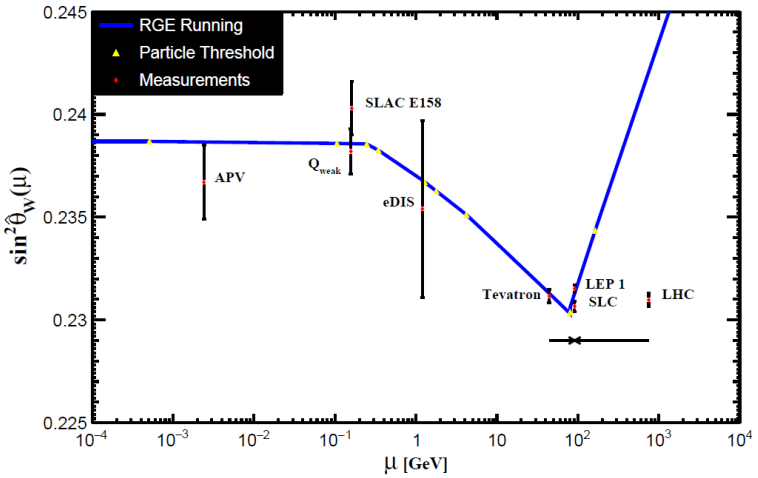


- High luminosity at the CEPC
  - CEPC: 4 trillion Z in 2 years (Z period, 100ab^{-1})
- Low systematics



$\sin^2\theta^f_{eff}$ measurement at the CEPC

- High precision measurement
  - Final precision expected to be $\Delta \sin^2\theta_{eff} \sim \mathcal{O}(10^{-5})$
- Independent measurement via different final states:
  - 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

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

$$S^{phy} = \frac{\partial A_{FB}^{phy}}{\partial \sin^2 \theta_{eff}}$$

$$Det = \frac{1}{1-2f} \cdot \sqrt{\frac{1}{\epsilon_{tagging}}}$$

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

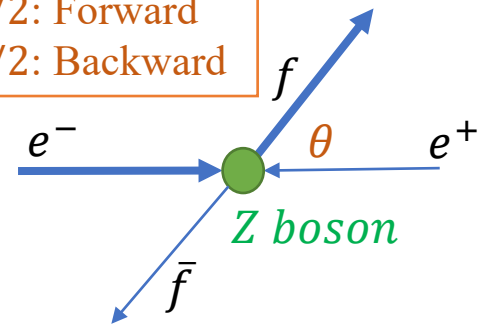
Lepton	Quarks
ϵ~100% f~0	tagging power: $\epsilon * (1-2f)^2$ $= 0.088$ (for b quarks)

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 data-driven method
- Other systematics (from LEP):
  - Electron channel: t-channel & s-t interference (0.00085)
  - Lepton channel: QED calculation (0.00006)
  - B quark channel: QCD calculation (0.00007)

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

$\theta < \pi/2$: Forward
$\theta > \pi/2$: Backward



- B quark systematics: Preliminary study found it may significantly reduce

Results: A_{FB} measurement

Consider 1 month statistics at each energy point ($\sim 4e12/24\ Z\ events$ at Z pole)

Only statistical uncertainty considered

Table 1. Expected statistical uncertainties on $\sin^2\theta^{\ell}_{\rm eff}$. Results are estimated according to one month data collection.

collision energy/GeV	$\delta\sin^2\theta^{\ell}_{\rm eff}$ in lepton final state	$\delta\sin^2\theta^{\ell}_{\rm eff}$ in b quark final state
70	1.5×10^{-4}	4.1×10^{-5}
75	6.8×10^{-5}	3.3×10^{-5}
92	4.9×10^{-6}	3.5×10^{-6}
105	1.7×10^{-4}	2.7×10^{-5}
115	2.0×10^{-3}	4.8×10^{-5}
130	4.0×10^{-3}	9.8×10^{-5}

Supplementary result from P_τ measurement

- The only channel for which the polarization can be determined

$$P_\tau = \frac{\mathrm{d}(\sigma_r - \sigma_l)}{\mathrm{d}\cos\theta} \Big/ \frac{\mathrm{d}(\sigma_r + \sigma_l)}{\mathrm{d}\cos\theta}$$

- $P_\tau = P_\tau(\cos\theta\,, \sin^2\theta_{eff})$

- Measurement of P_τ rely on the kinematic spectrum of different tau decay modes.

- Statistical: 2.15×10^{-6} (one month data)
- Systematic: $\mathcal{O}(10^{-4})$ for LEP

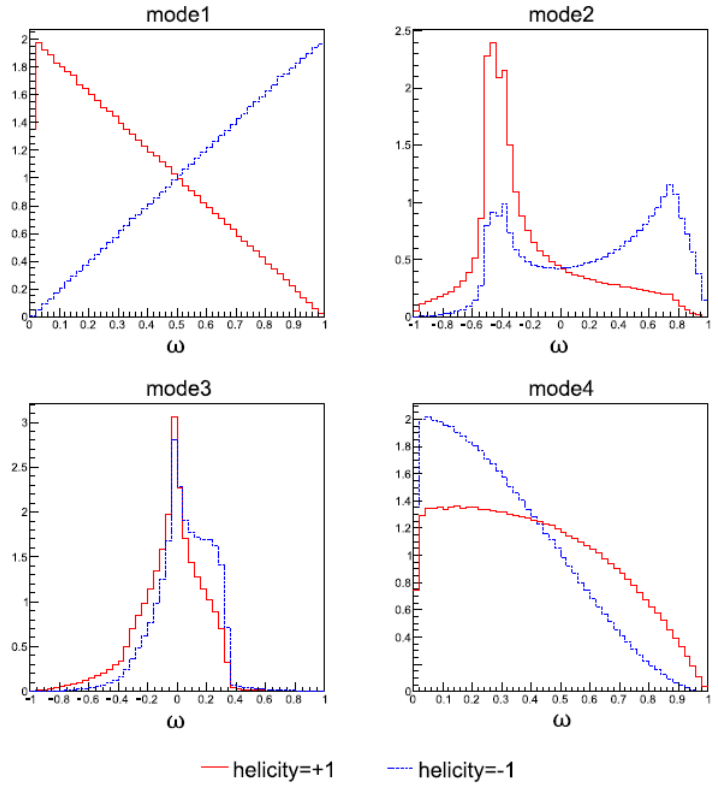


Fig. 5. (color online) Kinematic spectrum of different tau decay modes. The red solid line and blue dashed line represent the kinematic spectrum of taus with *helicity* = +1 and −1, respectively. All the spectra are generated using PYTHIA8 generator and tauola interface.

Summary

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

Overall precision at Z pole	Lepton/quark comparison	Precision at off Z pole
$\Delta\sin^2\theta_{eff} \sim \mathcal{O}(10^{-5})$	$\Delta\sin^2\theta_{eff} \sim \mathcal{O}(10^{-5})$ Able to make comparison	$\Delta\sin^2\theta_{eff} \sim \mathcal{O}(10^{-4})$

- CEPC features
  - Large statistics
  - Low systematics

https://iopscience.iop.org/article/10.1088/1674-1137/acf91f
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Thanks