Effective mixing angle($\sin^2\theta_W^{eff}$) measurement at CEPC

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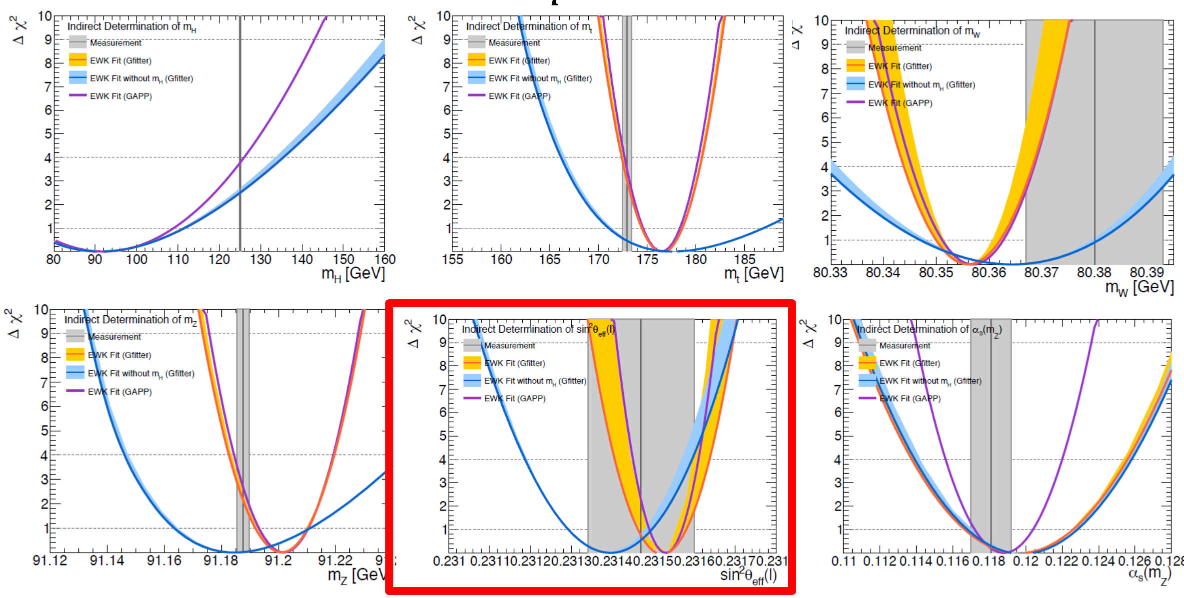
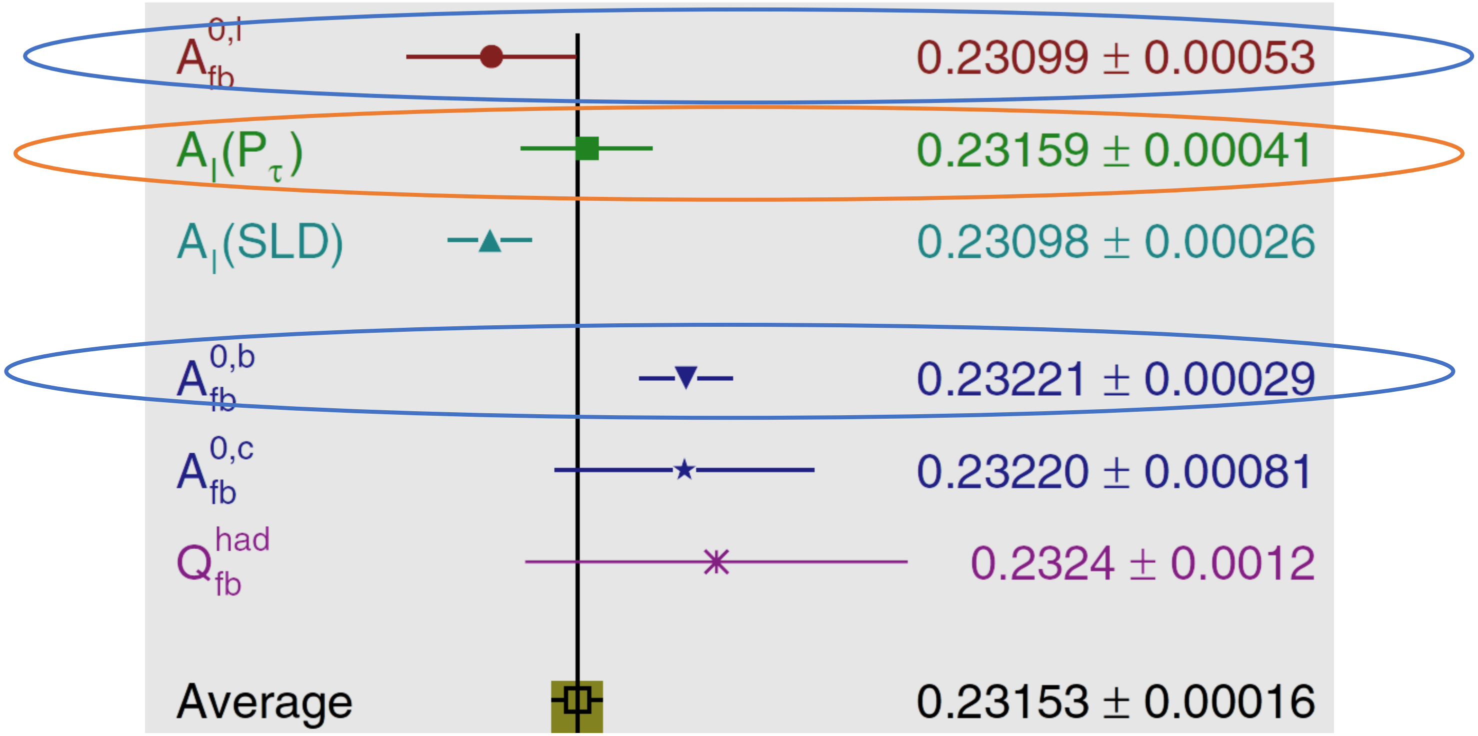
Weak mixing angle ($\sin^2\theta_W^{eff}$) (stw)

- Key parameter in electroweak sector:
  - $\alpha, G_\mu, M_Z, M_W, \mathbf{\sin^2\theta_W}, M_H, M_{top}$



- Current theoretical calculation error: **1e-5**
  - Consider all two-loop corrections and partly three-loop/four-loop corrections
- LEP's results: error~1e-4

Stw measurement in LEP&SLC



Feature:

1. A_{FB} measurements(lepton, b quark) give the most precise result
2. P_τ measurement also gives a great result(better than A_{FB}^{l})

1. AFB method — theory

- In theory, $A_{FB} = A_{FB}(\sin^2\theta_{eff})$, so one can derive $\sin^2\theta_{eff}$ by measuring A_{FB}(software ZFITTER can be used for calculation)

- Error propagation:

$$sensitivity = S_{phy} := \frac{\Delta A_{FB}}{\Delta \sin^2\theta_{eff}}$$

- Error estimation for stw

$$\Delta sin^2\theta_{eff}(stat.) = \sqrt{\frac{1-(A_{FB}^{measure})^2}{N \cdot \epsilon_{tagging}}} \cdot \frac{\sqrt{1-2f+2f^2}}{1-2f} \cdot \frac{1}{S_{phy}}$$

Tagging efficiency ($\epsilon_{tagging}$) — Charge mis-id rate (f)

1. AFB method -- results

Consider 1 month statistics ($\sim 3e11/24\ Z\ events$ at Z pole)

- Lepton case($ee + \mu\mu + \tau\tau$):
  - Efficiency ~ 100%   mis-id rate ~ 0

Energy	70 GeV	75 GeV	91.19 GeV	115 GeV	130 GeV	155 GeV
$\sin^2\theta_W^{eff}$	0.23140	0.23136	0.23123	0.23128	0.23136	0.23152
Error(stw)	0.00042	0.00017	0.00001	0.00328	0.00636	0.00796

We can get precise stw measurement , but cannot see running effect of it

- B quark case:
  - (LEP's performance) efficiency~20%
    - 5% : leptonic decay, charge mis-ID 5%
    - 15%: those with good jet charge tagging, charge mis-ID 10%

Energy	70 GeV	75 GeV	91.19 GeV	115 GeV	130 GeV	155 GeV
$\sin^2\theta_W^{eff}$	0.23159	0.23149	0.23123	0.23097	0.23084	0.23065
Error(stw)	0.00012	0.00009	<0.00001	0.00009	0.00016	0.00032

We can get precise stw measurement AND see running effect of it

2. P_τ method — theory

$\sigma^{\pm}$: cross section of τ in helicity positive/negative

- Definition:

$$P_\tau := \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{N_+ - N_-}{N_+ + N_-}$$

θ: polar angle of τ

- $P(\cos\theta)$@Z pole:

$$P(\cos\theta) = -\frac{A_\tau(1+\cos^2\theta) + 2A_e\cos\theta}{1+\cos^2\theta + 2A_\tau A_e\cos\theta}$$

- Relationship with stw:

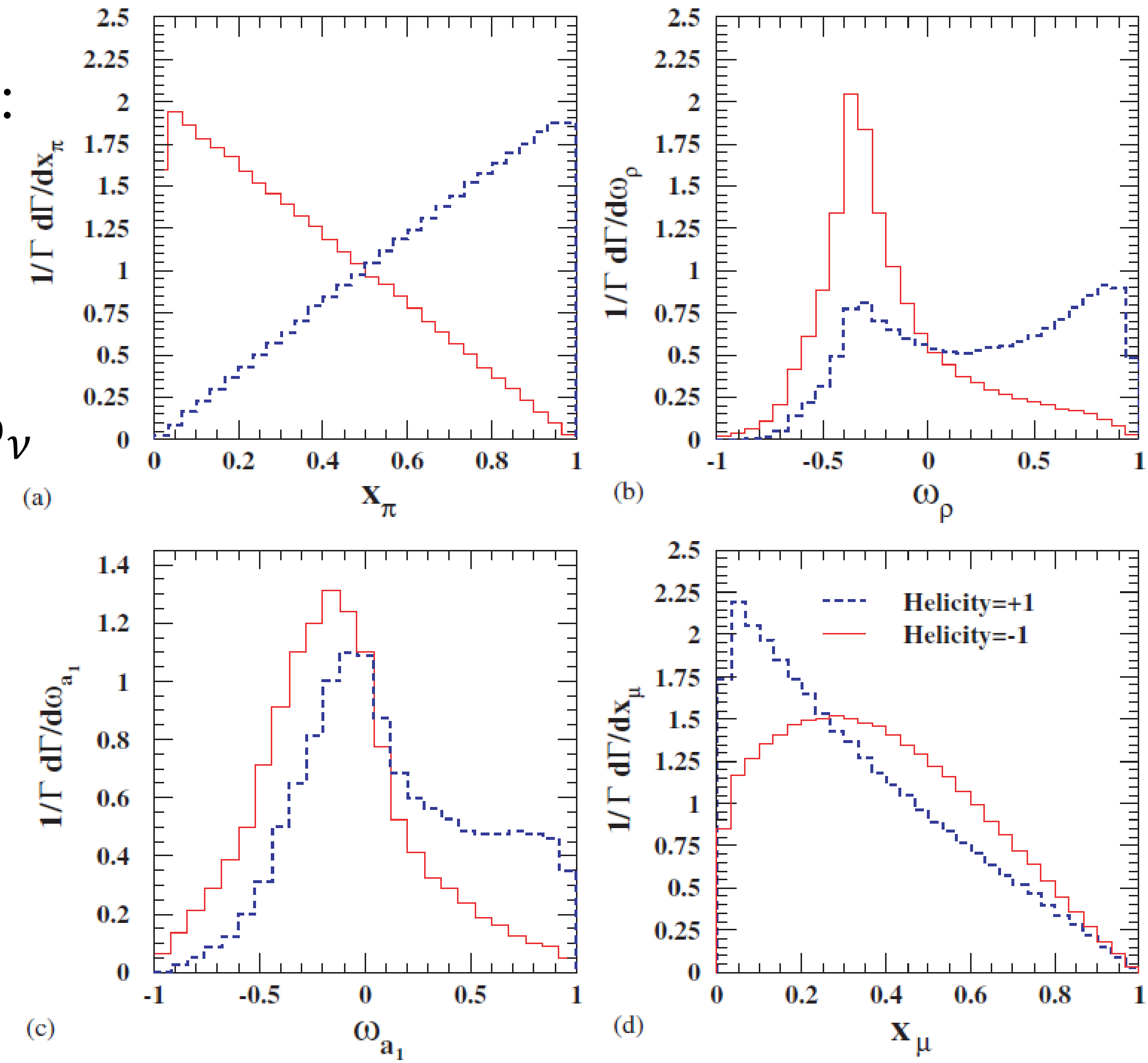
$$A_l = \frac{2g_V^l g_A^l}{\left(g_V^l\right)^2 + \left(g_A^l\right)^2} \qquad \frac{g_V^l}{g_A^l} = 1 - 4\sin^2\theta_W^{eff}$$

- Note:
  - Compare A_τ with A_e, one can test lepton universality.
  - If lepton universality assumed, one can get stw directly from A_l

2.How to get P_τ — kinematic spectrum

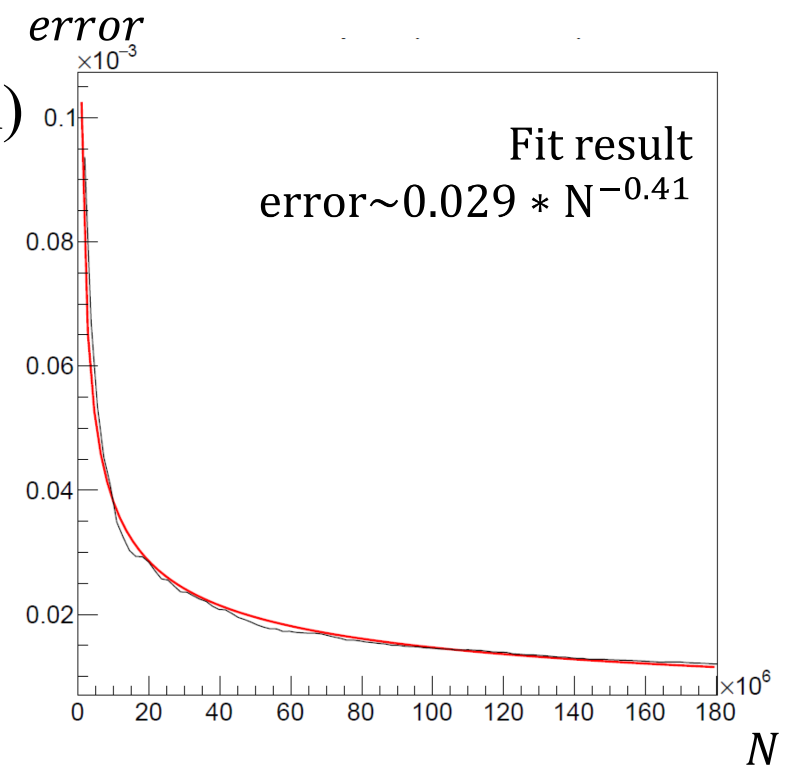
- 5 leading τ decay modes:
  - $\tau \to \pi\nu$
  - $\tau \to \rho\nu$,
    - ➢ $\rho \to \pi\pi^0$
  - $\tau \to a_1\nu$,
    - ➢ $a_1 \to \pi\pi\pi\nu$ or $\pi\pi^0\pi^0\nu$
  - $\tau \to \mu\nu\bar{\nu}$
  - $\tau \to e\nu\bar{\nu}$
- Kinematic variable ω

mode1	mode2
mode3	mode4/5



2. P_τ method — results

- Measured stw value:
  - 100million $Z \to \tau\tau$ events:
  - $\sin^2\theta_W^{eff} = 0.231566 \pm 0.000012$(statistical error only)
- One month's statistic(3e11/24 Z boson)
  - Statistical error ~ $0.82e-5$
  - Not so big compared to $1e-5$
- Statistical error is not very crucial to the measurement



2. P_τ method —Systematic error

- ECAL scale
  - Affect p_i&E_i, thus affect ω, and kinematic spectrum
- Photon(fake photon)
  - Mainly about PID, especially id of π^0(efficiency)
    - Affect statistics
    - Cause bkg. from different mode(misclassification)
- Non-tau bkg.
  - E.g., electron from $Z \to ee$ can be bkg. of $\tau \to e\nu\nu$
  - Hard to estimate at present.
  - Not dangerous to neglect.

What we further need

- AFB method:
  - Hope for further results of b quark tagging performance
    - Tagging efficiency $\epsilon_{tagging}$
    - Charge mis-id rate f and error of f
- P_τ method:
  - Need:
    - ECAL: error of 4-momentum of: $\pi^{\pm}; \pi^0; e; \mu; \tau$
    - Efficiency: ϵ and $\Delta\epsilon$ of: $\pi^{\pm}; \pi^0$
  - Plan:
    - Study systematic error and get final results
    - Study the energy running effect of P_τ method

Summary

- $\sin^2\theta_W^{eff}$ is one of key parameters in electroweak section
  - Theoretical calculation error: ~1e-5
  - LEP's error: ~1e-4
- AFB method:
  - Lepton case: precise at Z pole
  - B quark case: precise at Z pole and off-peak
- P_τ method:
  - Measure procedure:
    - Different mode → kinematic spectrum → fit to get $P_\tau(\cos\theta)$ → get stw
  - Statistical error: not very crucial
  - Systematic error:
    - Error of 4-momentum of : $\pi^\pm$、π^0、e、μ、τ
    - Efficiency and error of efficiency of : $\pi^\pm$、π^0

Thanks