Measurement of forward-backward asymmetry (A_{FB}) and effective weak mixing angle at the CEPC

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Z pole physics from LEP to CEPC

LEP in 1990s

- First time that experimental precision is high enough to constrain loop effect from weak interactions
- A_{FB} and weak mixing angle at Z pole: precision ~0.1%
- Known loop corrections to the weak mixing angle: ~4%

CEPC

- In general, CEPC has the capability to improve precision of Z pole physics to 0.01%

Is this important? Yes!

- 0.1% uncertainty is as large as the effect from 2-loop contribution, and one order magnitude larger than the theoretical uncertainty
- EW global fitting is limited by the experimental results

Weak mixing angle

Key parameter in electroweak sector

- **Observation on fundamental paramaters**
  - **α, G_μ, M_Z, M_W, $\sin^2\theta_W$, M_H, M_{top}**

$$\sin^2\theta^f_{\text{eff}} = \frac{1}{4|Q_f|}\left(1 - \frac{g^f_V}{g^f_A}\right)$$

The relative fraction between vector and axial-vector contributions in electrweak interactions

In general, it reflects the overall spatial asymmetry of the entire physics

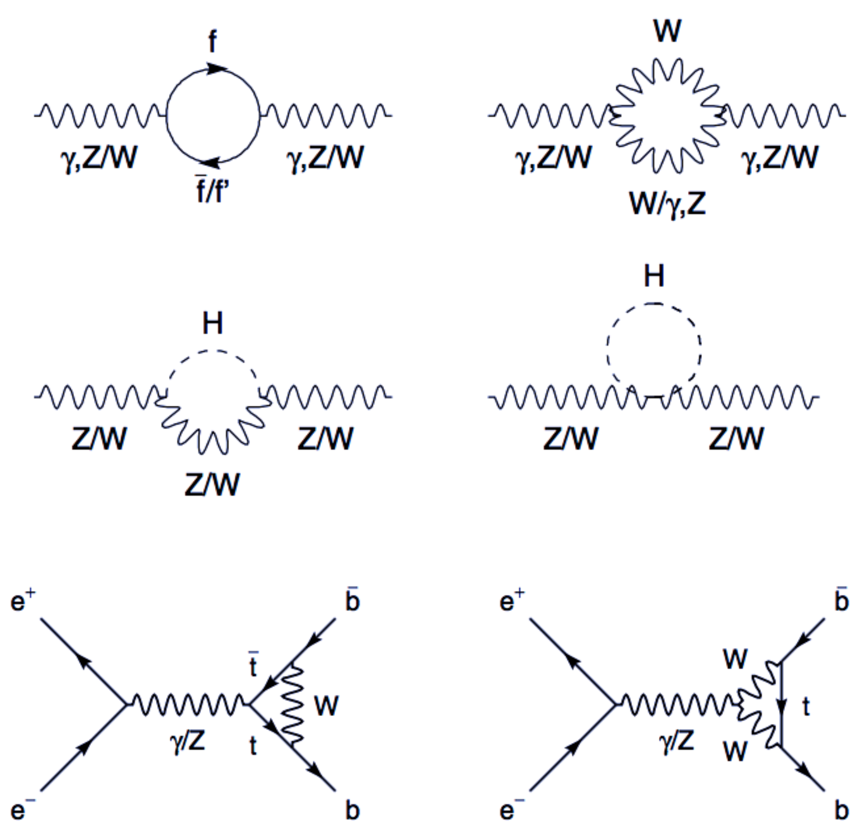
	experimental precision
Fine structure constant： α	10^{-9}
Fermi constant： G_μ	10^{-7}
Mass of Z boson： M_Z	10^{-5}
Mass of W boson： M_W	10^{-4}
Effective weak mixing angle： $\sin^2\theta_{\text{eff}}$	10^{-3}

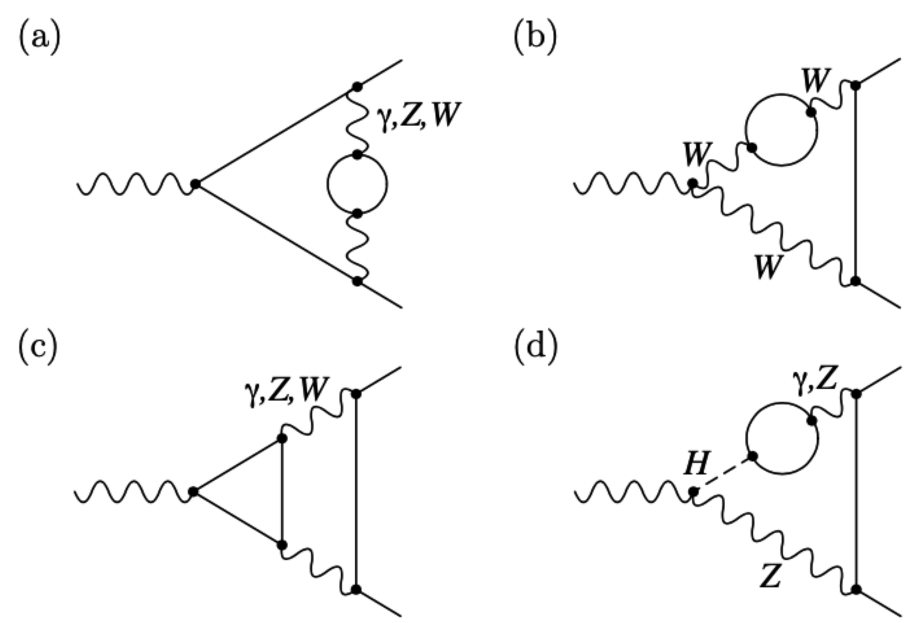
Weak mixing angle is important. But it has the worst precision among fundamental parameters

Loop corrections

Uncertainties on $\sin^2\theta_{eff}$

- By 2006, we can make complete 2-loop calculations, with uncertainty 4 MeV on M_W and 0.00005 on $\sin^2\theta_{eff}$
- Experimental uncertainty: 0.00026/0.00029 from SLC/LEP

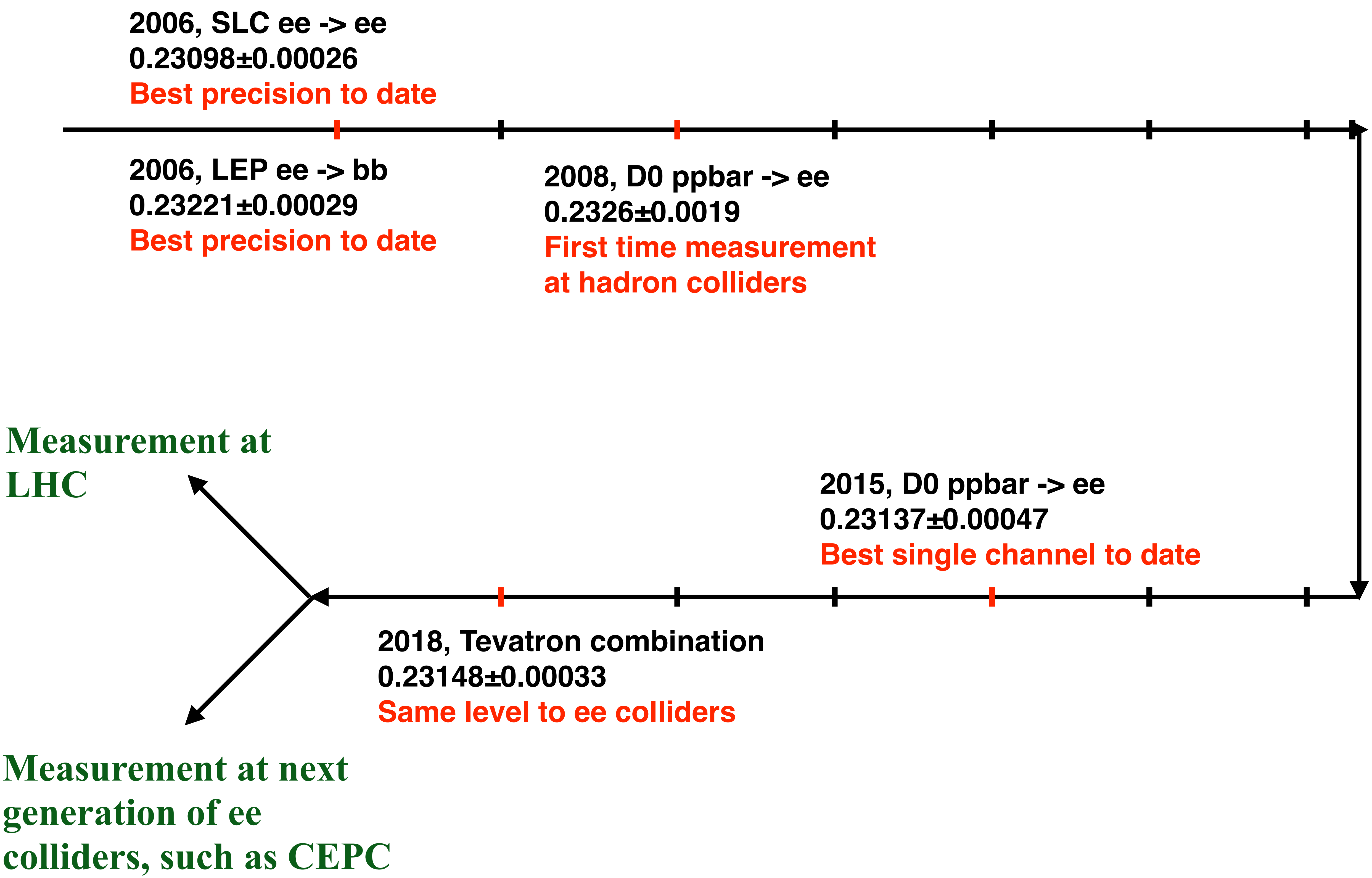




1-loop diagrams contribute to $\sin^2\theta_{eff}$, shifting its value by 3.7%

2-loop diagrams contribute to $\sin^2\theta_{eff}$, shifting its value by ~0.2%

History of weak mixing ange measurement



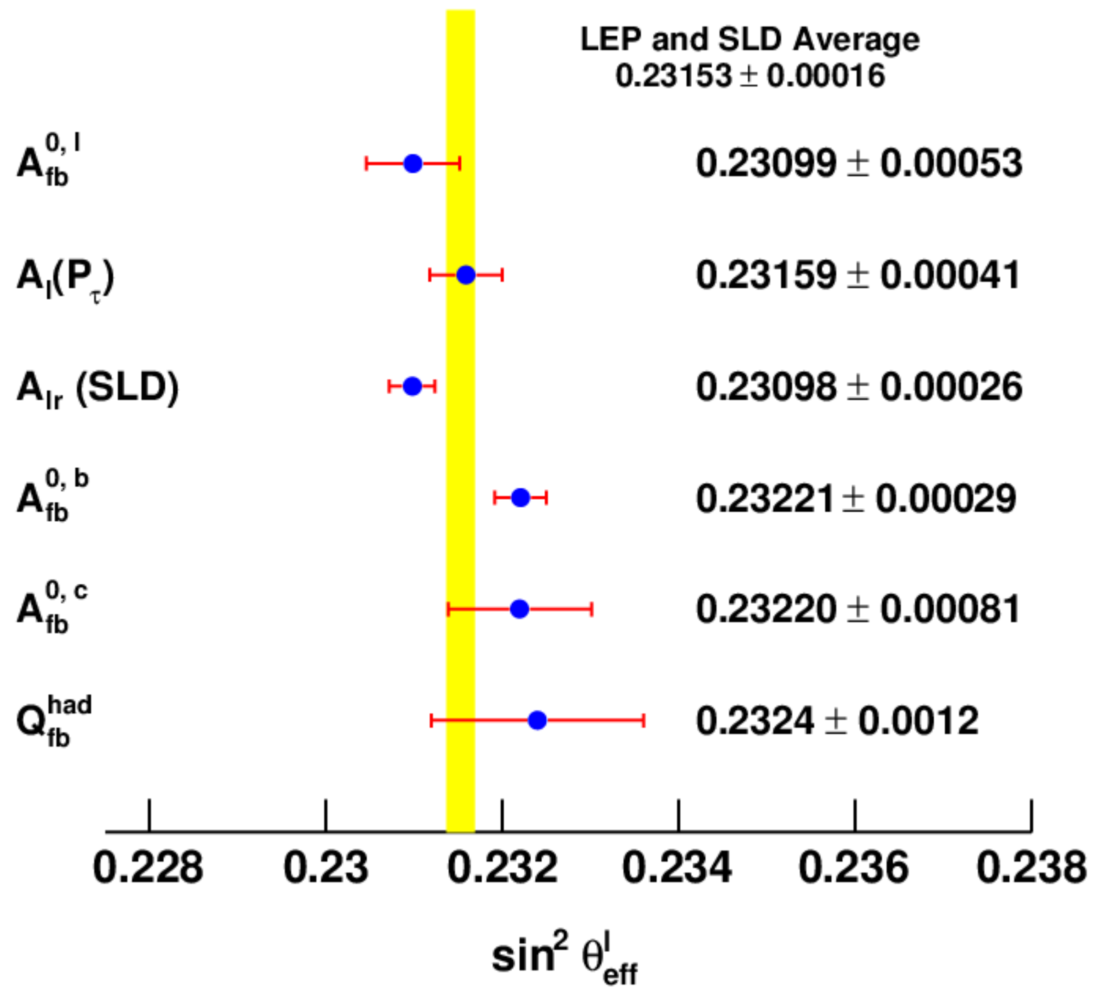
What can CEPC do?

Precise determination of A_{FB} and $\sin^2\theta_{eff}$

- At least one order magnitude better than LEP/SLC

Additional 1: flavor comparison

- In the future, measurements and comparisons between different flavor channels are important. Combination for average $\sin^2\theta_{eff}$ is no longer meaningful



LEP ee-bb result is 3.2 sigma different from SLC ee-ee result

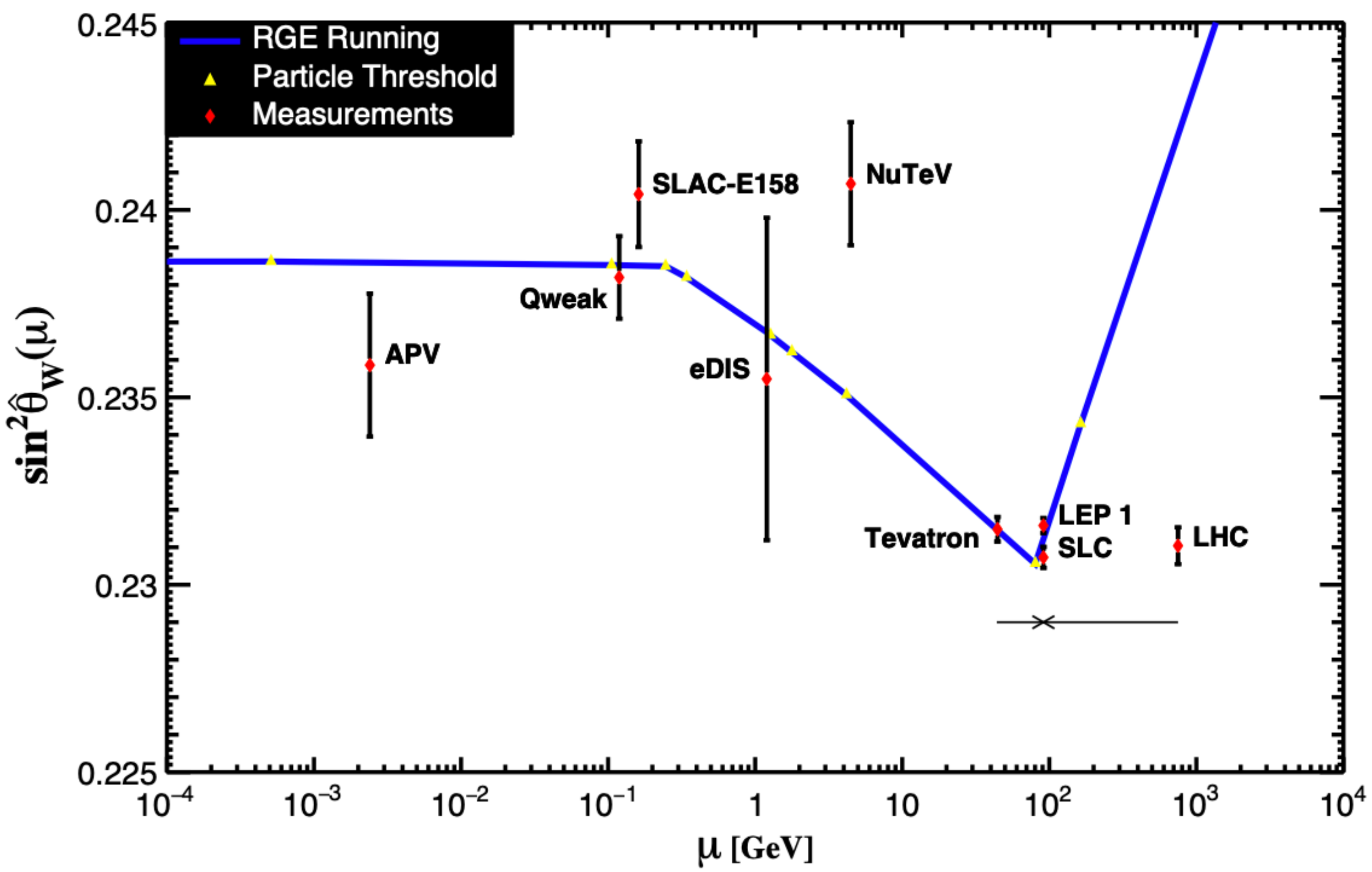
Actually, LEP ee-qq results are in general larger than the lepton results itself

Flavor-dependence is one of the important things we need to test, and contains possible information of new physics

What can CEPC do?

Additional 2: $\sin^2\theta_W$ vs energy scale

- All precision measurement is determined at Z-pole
- We already have some lower energy measurement, but not a single higher energy measurement.



For a long time, people want to have a measurement of $\sin^2\theta_W$ in high mass region, to test the running effect to higher energy scale.

CEPC could be the first one that makes it clear

NOTE: this is MSbar scheme defined weak mixing angle.

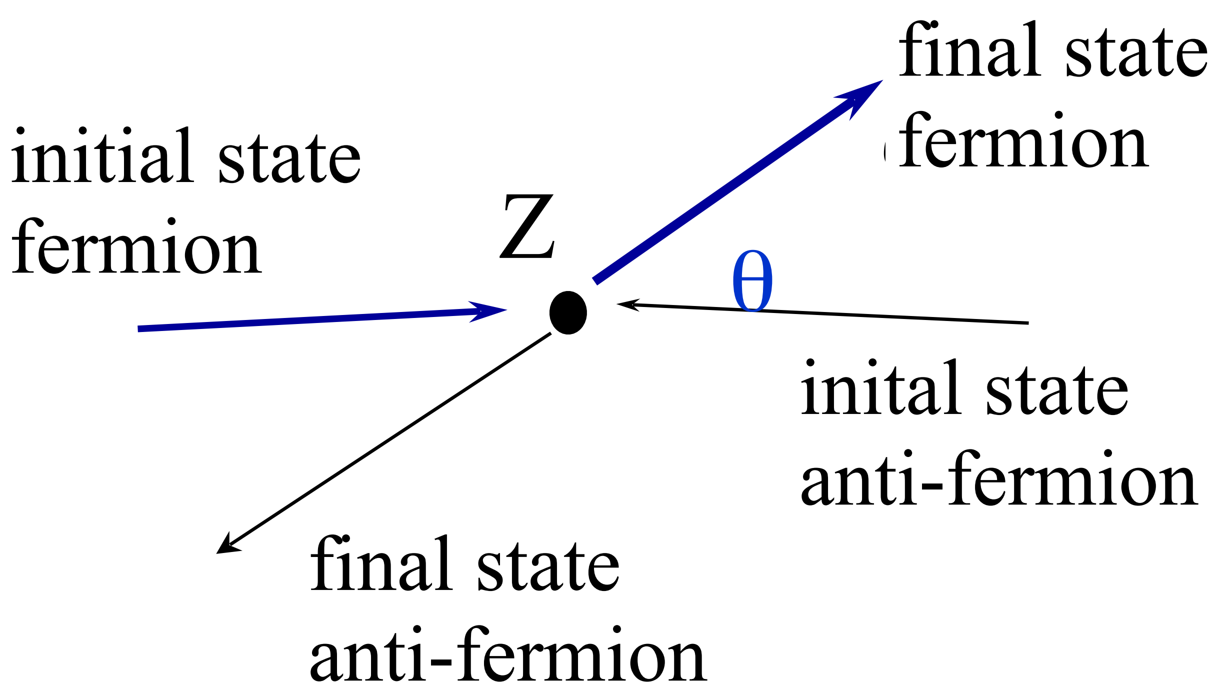
Measurement: $\sin^2\theta_{eff}$ and AFB

Asymmetry at Z pole

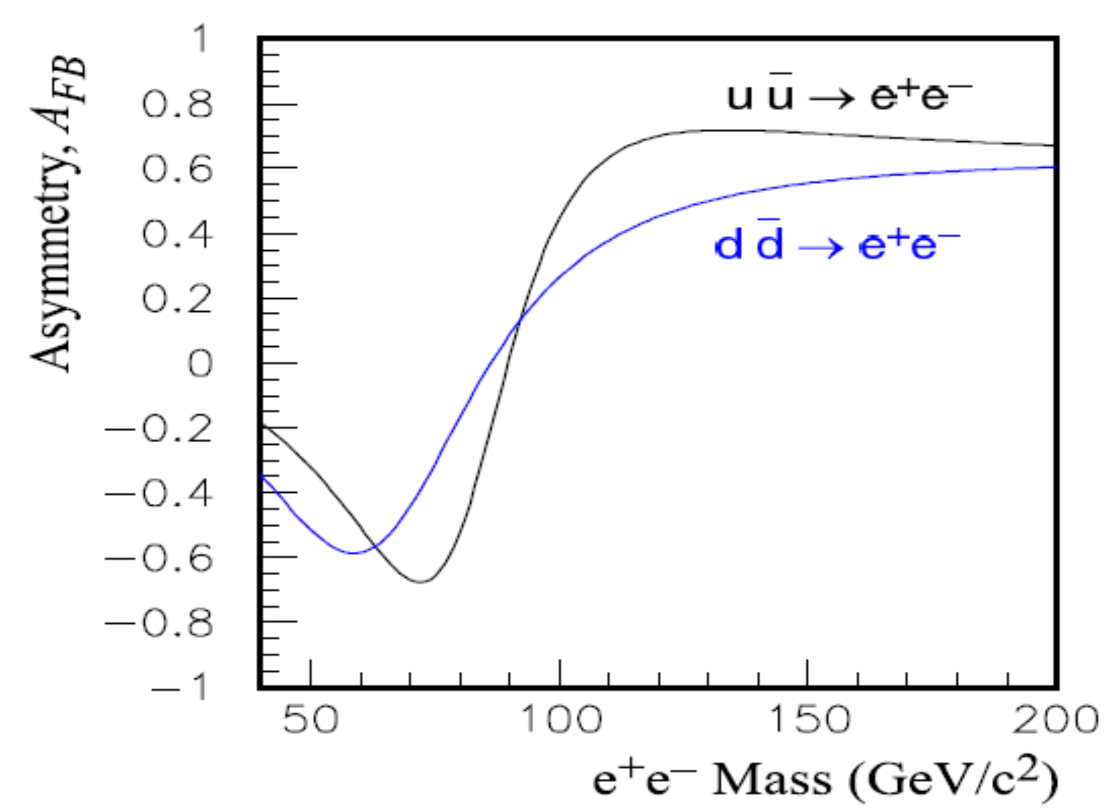
- **Forward-Backward Asymmetry (A_{FB})**
- **A function of invariant mass**

$\cos\theta>0$, forward

$\cos\theta<0$, backward



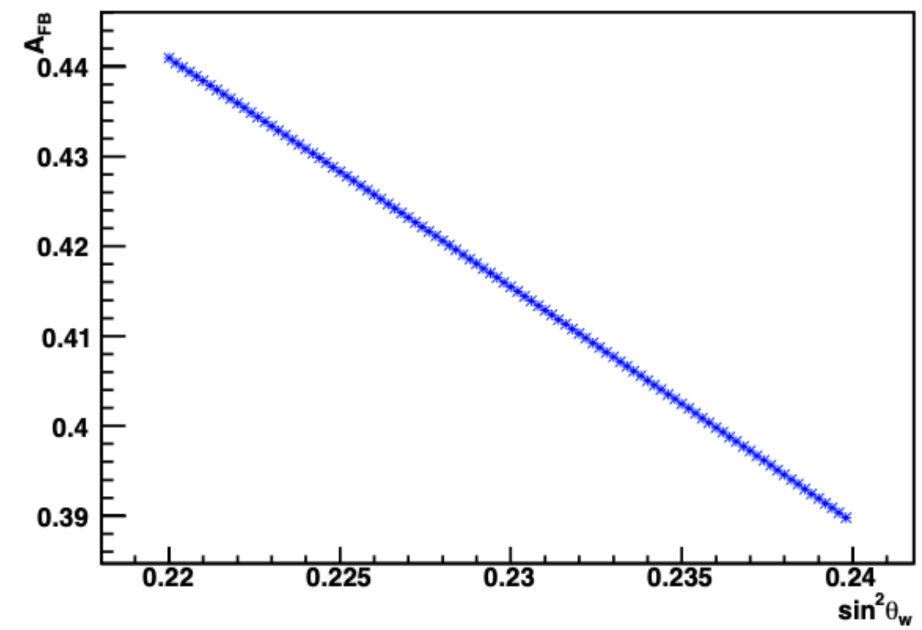
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = A_{FB}(\sin^2\theta^f_{\text{eff}})$$



NOTE! θ is defined as between the fermions in the initial and final state. So, we need to know the charge of particles in order to judge fermions and anti-fermions

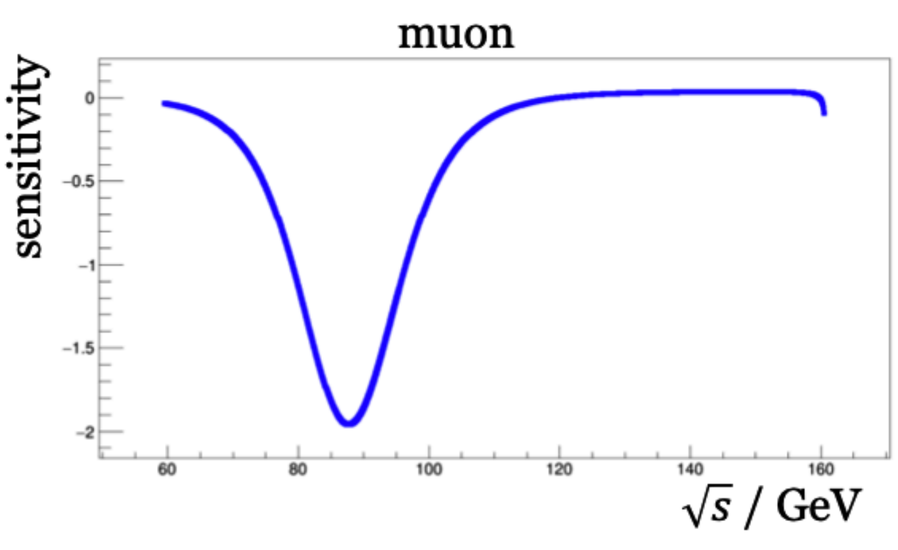
Measurement: $\sin^2\theta_{eff}$ and A_{FB}

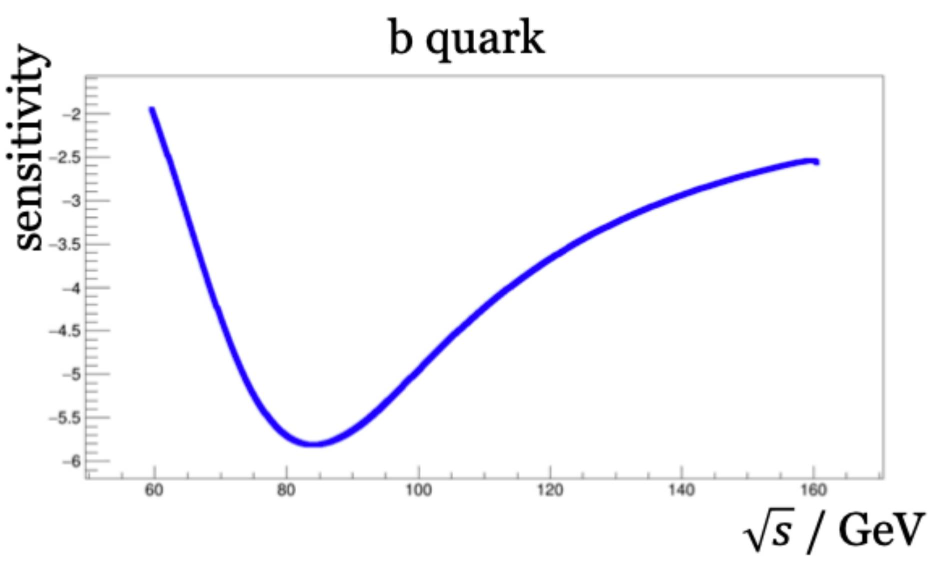
A_{FB} has roughly a linear relationship to $\sin^2\theta_{eff}$. Right plot is the average A_{FB} at Z pole, as a function of $\sin^2\theta_{eff}$ for e+e- → Z → uubar events, for example.



This relationship, or sensitivity of AFB to $\sin^2\theta_{eff}$, depends on collision energy and particle flavors

$$\text{sensitiviy} = \frac{\Delta \sin^2 \theta^{\ell}_{\text{eff}}}{\Delta A_{FB}}$$





Uncertainties

Statistical uncertainty

- Counting forward (N_F) and backward (N_B) events
- Branching ratio, acceptance and efficiency affect the final sample size

Systematic uncertainties

- Negligible effect from direction, energy, momentum and efficiency determination
- Only one thing: charge mis-identification

$$A_{FB}^{\text{obs}} = \frac{1-2f}{(1-f)^2+f^2} A_{FB}^{\text{true}}$$

Note: efficiency simply affects the data sample size. It doesn't change the value of AFB, thus no uncertainty extrapolation.

Charge mis-ID changes the AFB values. So it not only affects the sensitivity, but also extrapolate as a systematic uncertainty.

Statistical uncertainties

Previous results from LEP, SLC and Tevatron

- All previous results are statistical uncertainty dominant
- For LEP/SLC: 0.00026/0.00029 completely from statistics

Estimation for CEPC

- 3 x 10^{11} single Z boson events including all final states at Z pole in 2 years
- Different final states:
  - branching ratio makes statistics different
  - acceptance and efficiency (for quark final states) makes statistics different
  - different sensitivity
- Different collision energy:
  - luminosity changes (~ΔL^3)
  - sensitivity changes

$$\Delta \sin^2\theta_{\mathrm{eff}}(\mathrm{stat.}) = \sqrt{\frac{1-(A_{FB}^{\mathrm{obs}})^2}{N\cdot\epsilon}} \cdot \sqrt{\frac{1-2f+2f^2}{(1-2f)^2}} \cdot \mathrm{sensitivity}$$

Lepton cases (ee + μμ + ττ)

Consider 1 month data taken at a given energy point:

- **acceptance set to 100%**
- **efficiency set to 100%**
- **charge mis-ID set to 0**

Collision Energy	70 GeV	75 GeV	91.18 GeV	115 GeV	130 GeV	155 GeV
$\sin^2\theta_{eff}$ in prediction	0.23140	0.23136	0.23123	0.23128	0.23136	0.23152
statistical uncertainty	0.00042	0.00019	0.00001	0.00328	0.00636	0.00796

- **Lepton channels can provide very precise measurement at Z pole**
- **However it cannot measure the running $\sin^2\theta_W$**

b quark cases

Consider 1 month data taken at a given energy point:

- **No study yet, estimation based on LEP performance (we should be better)**
- **efficiency set to 20% (select those b quarks that we can measure charge)**
  - **5%: leptonic decay, charge mis-ID 5%**
  - **15%: those with good jet charge tagging, charge mis-ID 10%**

Collision Energy	70 GeV	75 GeV	91.18 GeV	115 GeV	130 GeV	155 GeV
$\sin^2\theta_{eff}$ in prediction	0.23159	0.23149	0.23123	0.23097	0.23084	0.23058
statistical uncertainty	0.00012	0.00009	<0.00001	0.00009	0.00016	0.00032

- **b quark channel can provide not only precise measurement at Z pole, but also a running $\sin^2\theta_W$**

What we further need

Efficiency (tagging) and charge mis-ID

- for tau, b quark, c quark, and light quark (u and d)

In principle

- We don’t go for a high efficiency (since we anyway have a large data sample)
- We need a low charge mis-ID
- So, if needed, we can determine a tagging algorithm with relatively low efficiency, but high purity and charge accuracy
- We also need an uncertainty on the charge mis-ID probability

Summary

A first estimation on CEPC asymmetry measurement

- Total uncertainty of $\sin^2\theta_{eff}$ can easily be at 0.00001 level, for each single final state (except light quar finals)
- Which means an accurate flavor comparison is possible
- Energy-running $\sin^2\theta_W$ measurement can be achieved at heavy quark channels (uncertainty / running effect ~ 1/3 or 1/4)
- Better give more time running on off Z pole point

To finish further works

- Efficiency (particle tagging) and charge mis-ID estimation are needed
  - We now estimate using LEP's performance. We should be better
- Further calculation from $\sin^2\theta_{eff}$ to MSbar $\sin^2\theta_W$, for energy-running measurement