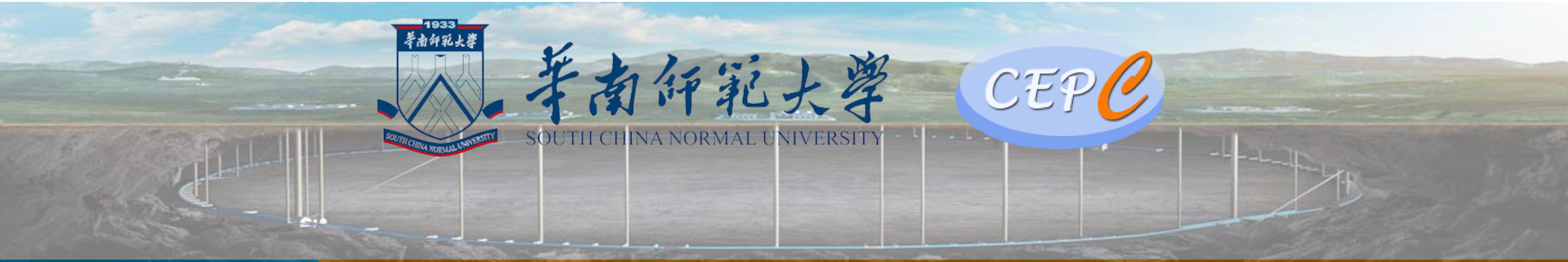
2025 European Edition of the International Workshop on the Circular Electron-Positron Collider (CEPC), Barcelona, Spain

16 Jun 2025, 08:00 → 19 Jun 2025, 14:10 UTC

EW Physics at the CEPC

Hengne Li (SCNU)

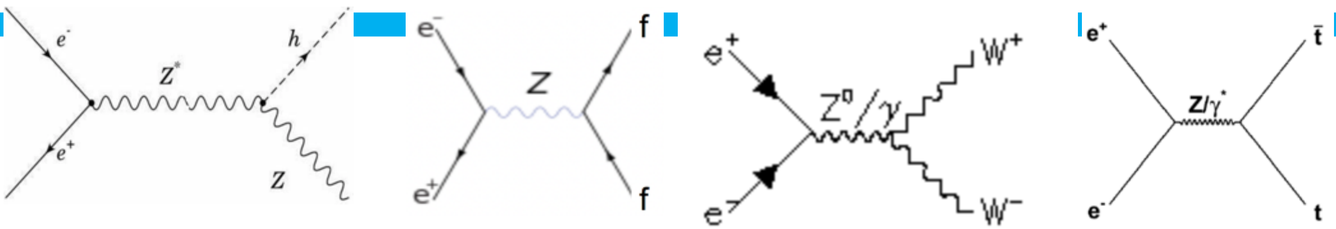
on behalf of the CEPC physics and detector group



CEPC physics program

An extremely versatile machine with a broad spectrum of physics opportunities

→ Far beyond a Higgs factory



Operation mode			ZH	Z	W⁺W⁻	$t\bar{t}$
$\sqrt{s}$ [GeV]			~240	~91.2	~160	~360
Run time [years]			10	2	1	5
CDR (30 MW)		L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**3**	**32**	**10**	-
		$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	~5
TDR	30 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**
	50 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**8.3**	**191.7**	**26.6**	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
		Event yields [2 IPs]	4×10^6	4×10^{12}	5×10^7	5×10^5

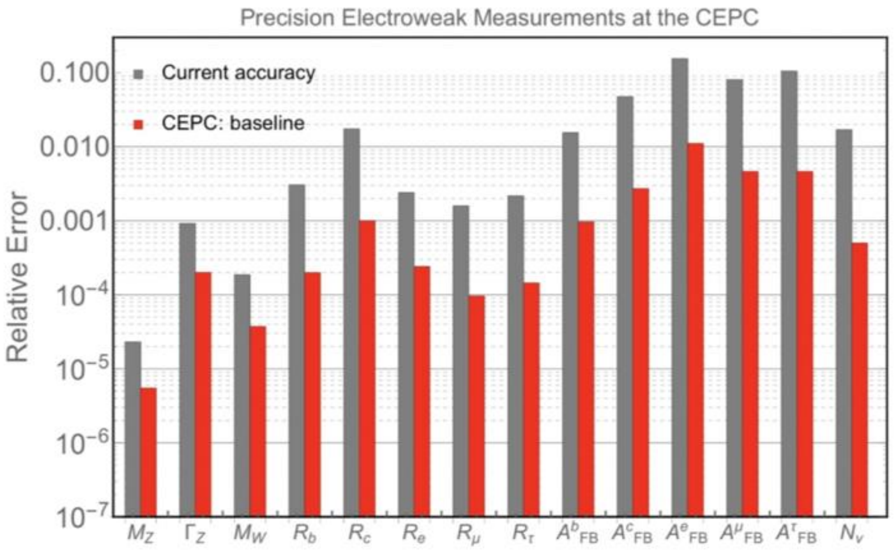
CEPC accelerator TDR (arXiv:2312.14363)

- First 10 year operation
  - **Higgs factory**
  - **low-lumi Z (20% of high-lumi Z)**
    - **Detector calibration and alignment**
    - **Physics with Giga-Z**
- 2 year of high-lumi Z factory operation
- 1 year of WW threshold scan
- 5 year of ttbar runs

Both 50 MW and $t\bar{t}$ modes are currently considered as CEPC upgrades.

EWK precision measurements (ZH, Z pole, WW runs)

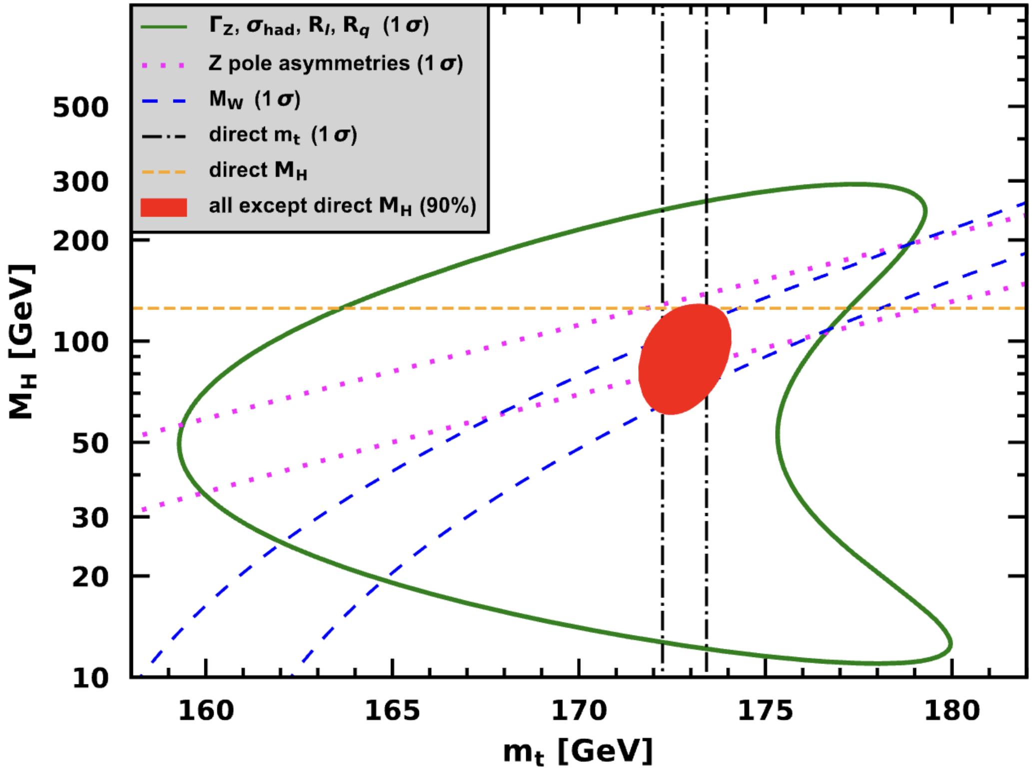
Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta \Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta \Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [37, 56]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [37, 56]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta \sigma_{had}$	37 pb [37–41]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [37, 57, 62–65]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [37–41]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [37–41]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [37, 66]	2×10^{-4} (3×10^{-5})	ZH run ($\nu\nu\gamma$)	Calo energy scale



CEPC is expected to improve the current precision by 1-2 orders of magnitude, offering a great opportunity to test the consistency of the SM.

The status of electroweak global fit

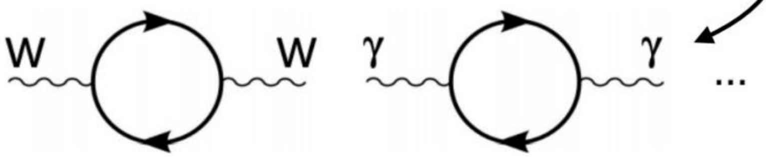
- 7 key observables in electroweak global fit
  - Consistency study of the standard model electroweak section
  - Need CEPC Z pole and WW runs : Precise measurements on EWK observables.



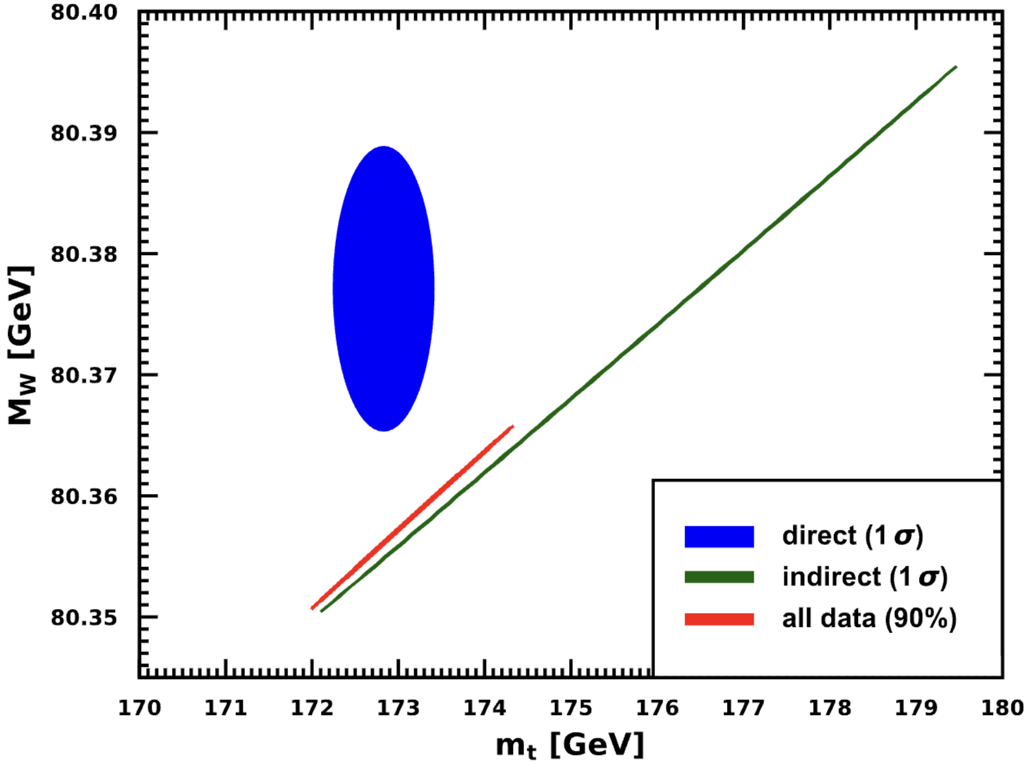
Fundamental constant	δx/x	measurements
$\alpha = 1/137.035999139\,(31)$	1×10^{-10}	$e^{\pm}\ g_2$
$G_F = 1.1663787\,(6) \times 10^{-5}\ \mathrm{GeV}^{-2}$	1×10^{-6}	$\mu^{\pm}$ lifetime
$M_Z = 91.1876 \pm 0.0021$ GeV	1×10^{-5}	LEP
$M_W = 80.379 \pm 0.012$ GeV	1×10^{-4}	LEP/Tevatron/LHC
$\sin^2\theta_W = 0.23152 \pm 0.00014$	6×10^{-4}	LEP/SLD
$m_{top} = 172.74 \pm 0.46$ GeV	3×10^{-3}	Tevatron/LHC
$M_H = 125.14 \pm 0.15$ GeV	1×10^{-3}	LHC

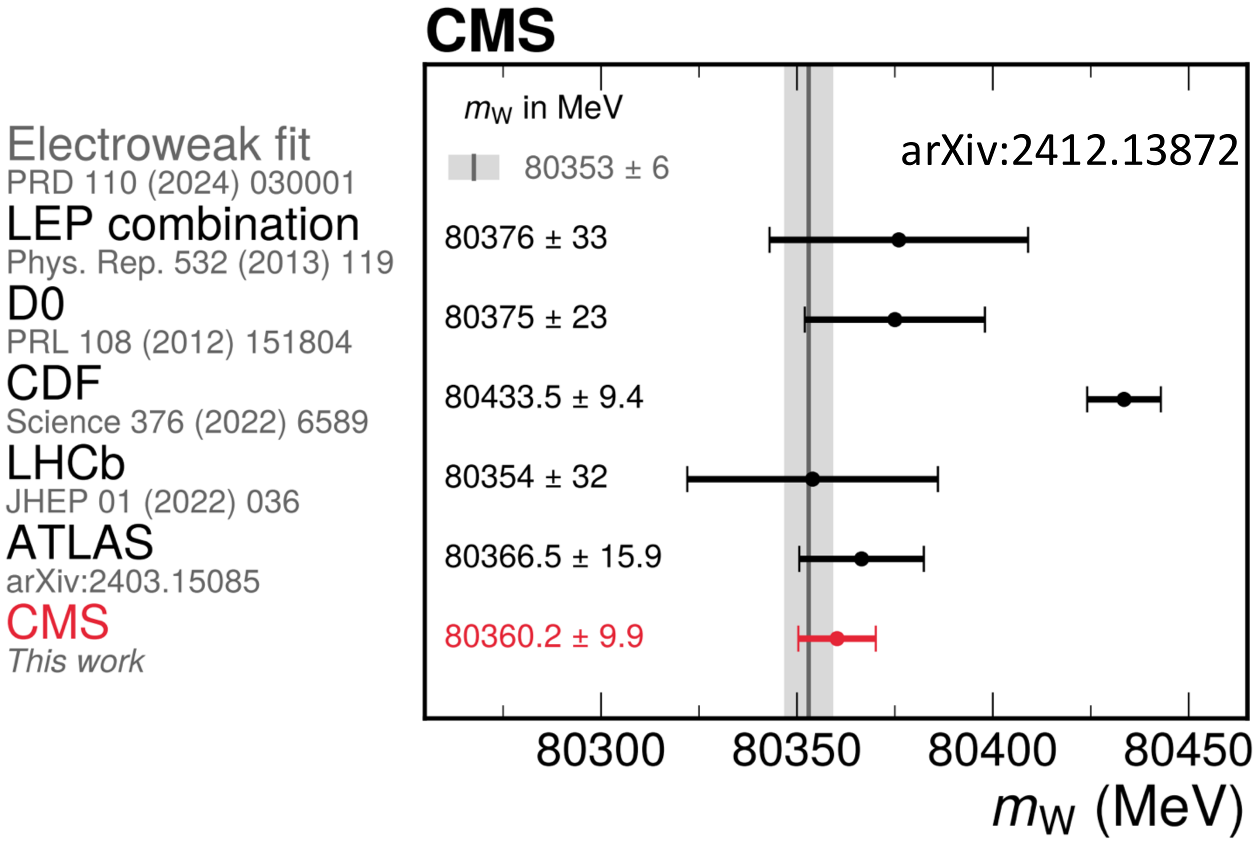
W mass measurement

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta)$$



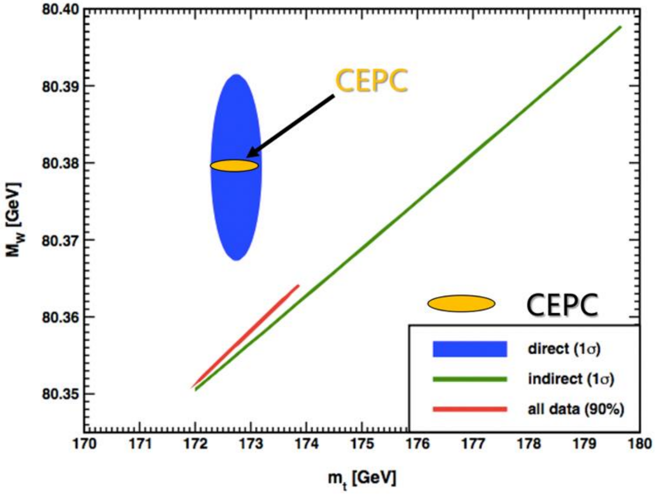
- mW is a key observable to test SM consistency
  - Latest CMS result in tension with CDF
  - mW Measurement at future collider is essential





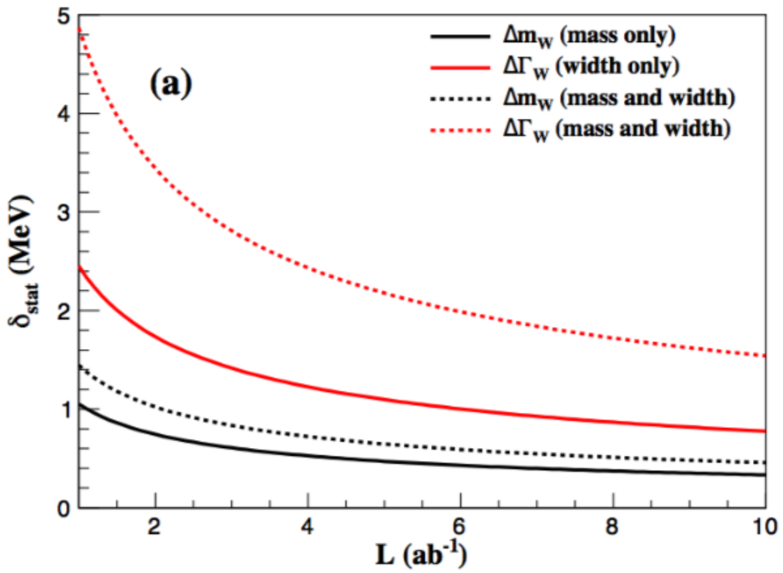
W mass measurement at CEPC

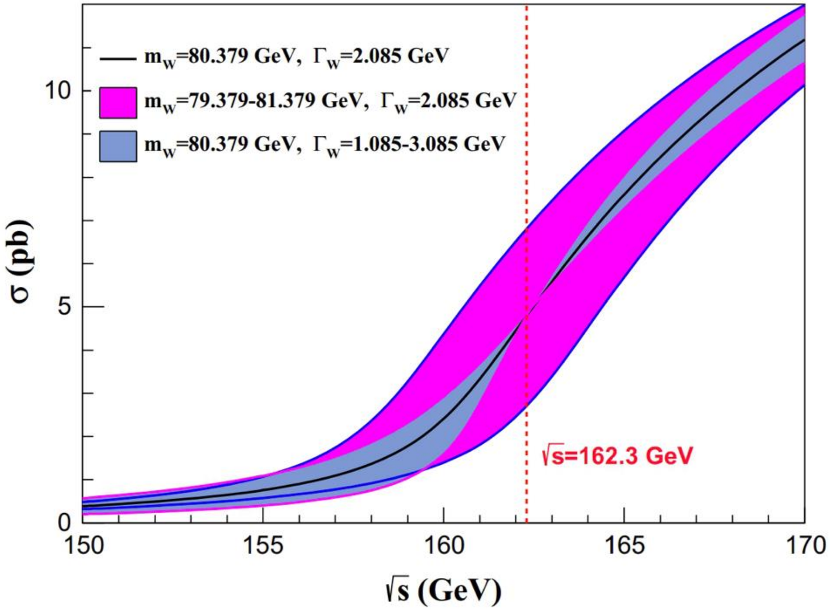
- Expect to reach below 1MeV precision on W mass
  - 1 year of WW threshold scan, 4 energy scan points:
    - 157.5, 161.5, 162.5 GeV: W mass, W width
    - 172.0 GeV: αQCD (mW), Br (W->had) , CKM |Vcs|



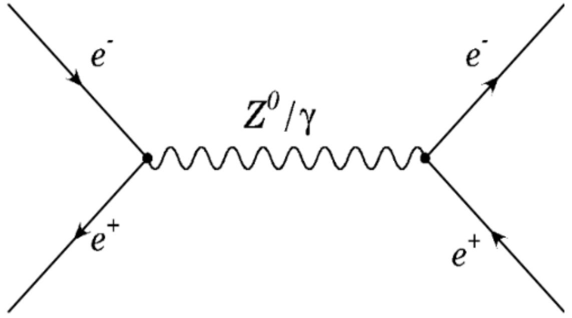
P.X.Shen, P.Azzuri , G.Li et,al,
Eur.Phys.J.C 80 (2020) 1, 66
Joint study of CEPC/Fcc-ee

Observable	m_W	Γ_W
Source	Uncertainty (MeV)	
Statistics	0.8	2.7
Beam energy	0.4	0.6
Beam spread	–	0.9
Corr. syst.	0.4	0.2
Total	1.0	2.8



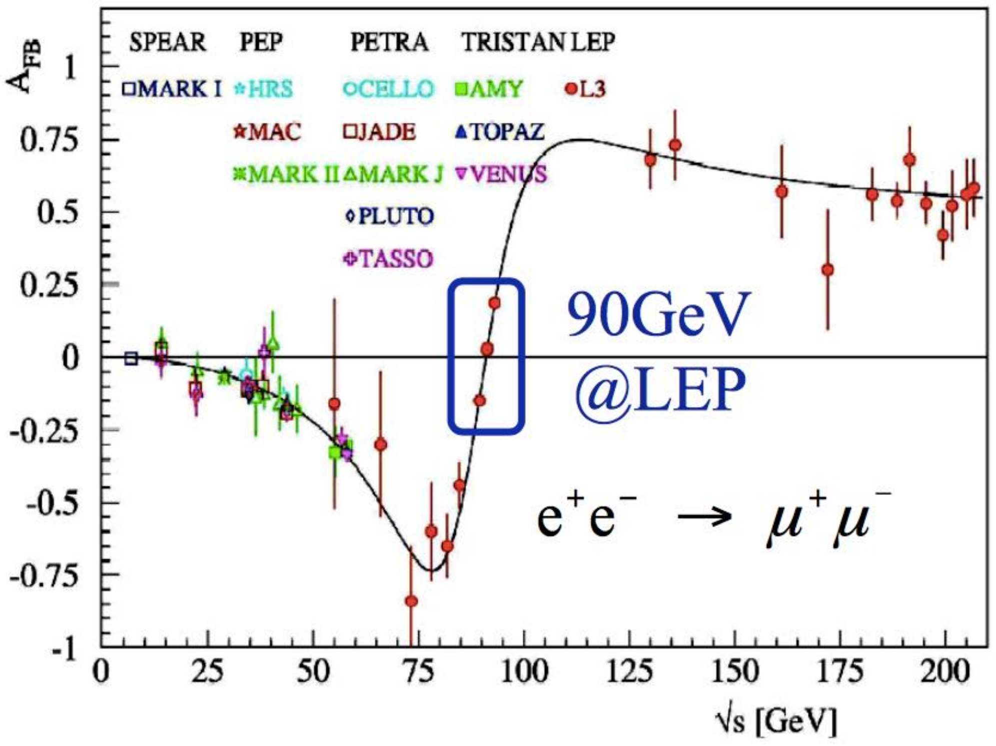


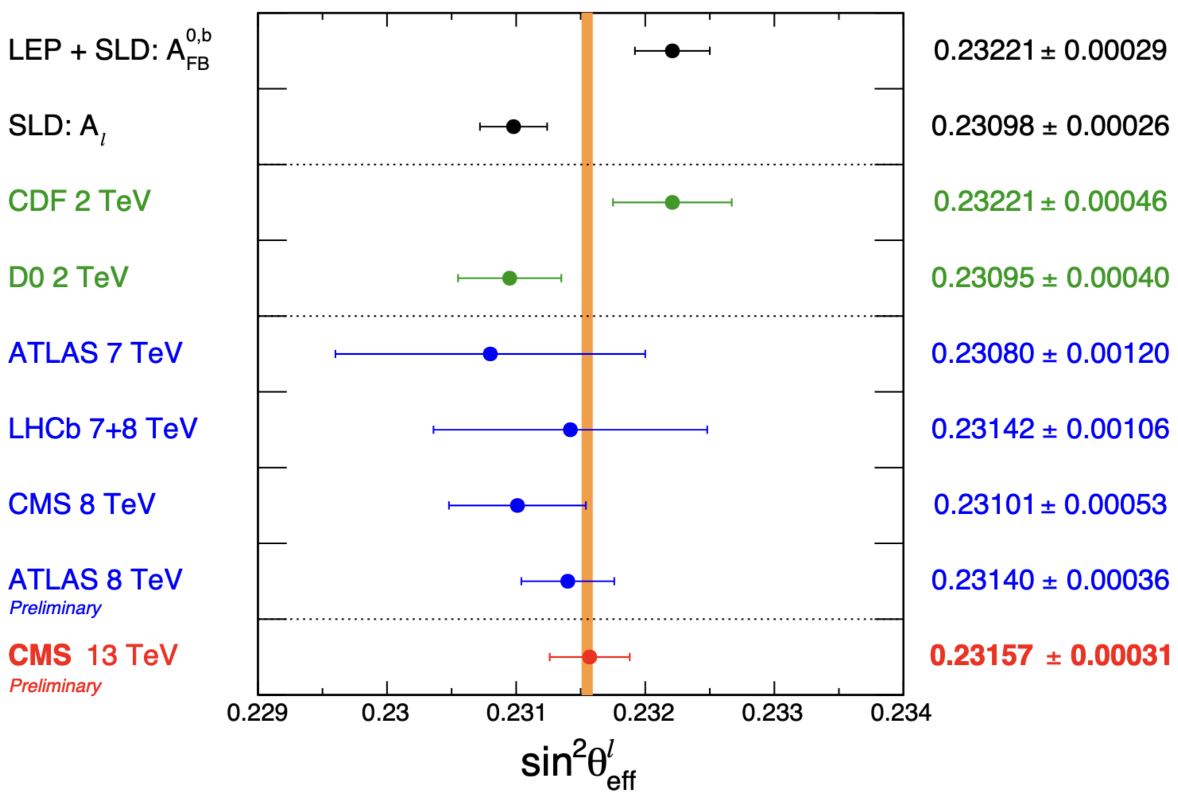
Weak mixing angle measurements ($Sin^2\theta_W$)



- Weak mixing angle measurement is well motivated
  - ~3σ tension between LEP and SLC measurements
  - LHC results can reach similar precision level now

Phys. Lett. B 866 (2025) 139526





Weak mixing angle measurements at CEPC (AFB)

- Study of off-peak runs for weak mixing angle measurements.

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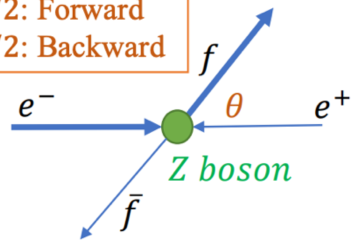
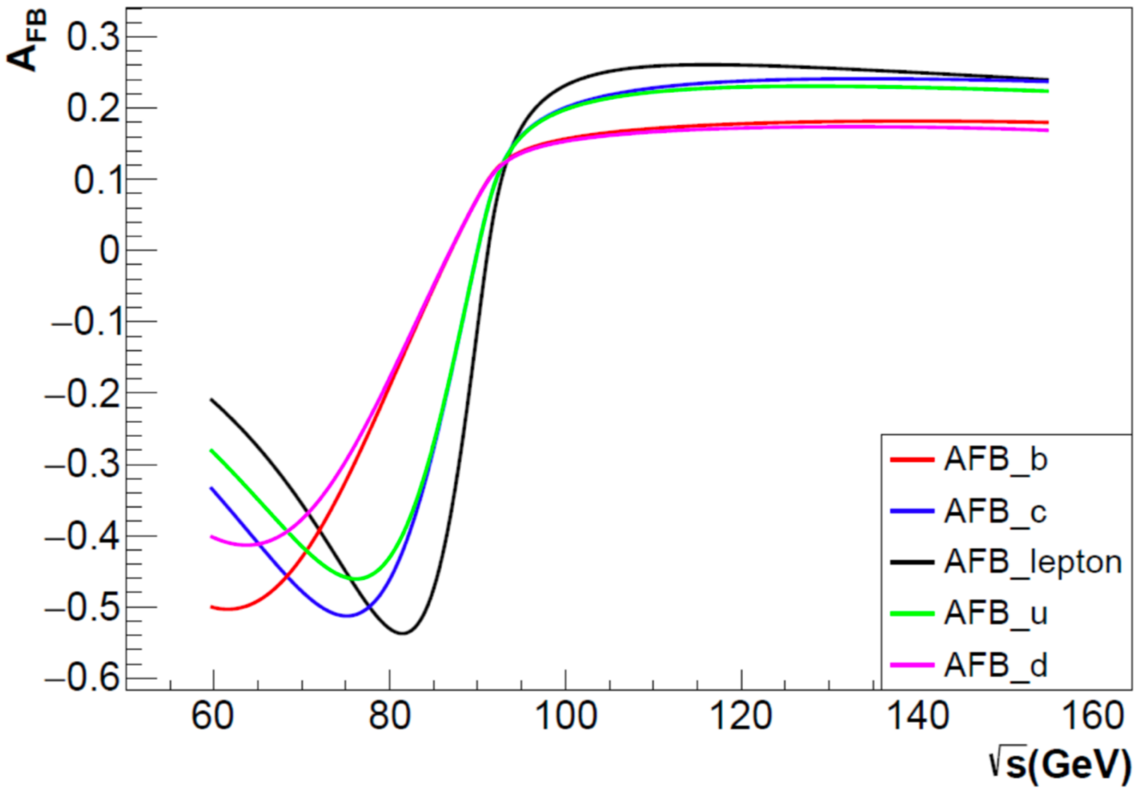
Table 2. Sensitivity S of different final state particles.

$\sqrt{s}$/GeV	S of $A_{FB}^{e/\mu}$	S of A_{FB}^{d}	S of A_{FB}^{u}	S of A_{FB}^{s}	S of A_{FB}^{c}	S of A_{FB}^{b}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958	1.087	3.942
130	0.027	3.279	0.531	3.280	0.520	3.261

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

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





Weak mixing angle measurements at CEPC (AFB)

- Tau channel can help to reduce systematic due to beam polarization

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- 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

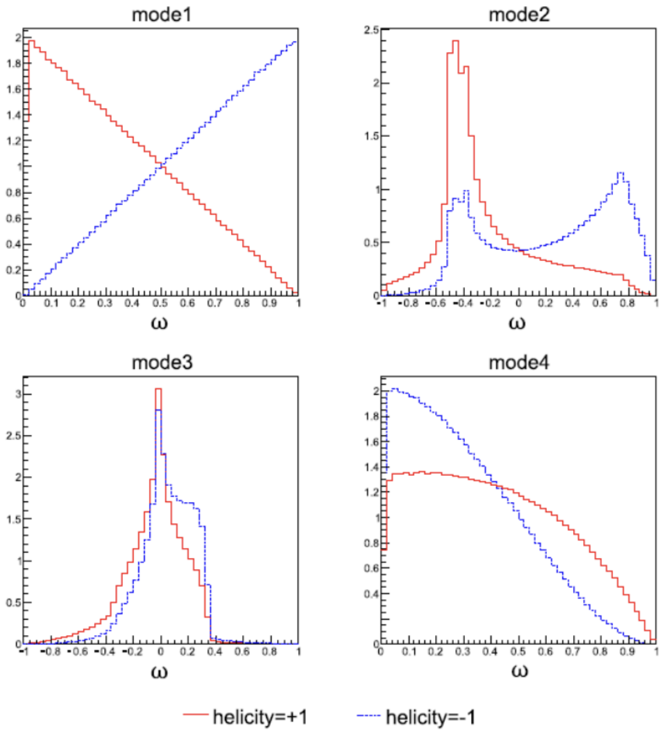


Fig. 5. (color online) Kinematic spectrum of different tau decay modes. The red solid line and blue dashed line represent the kinematic spectrum of taus with *helicity* = +1 and −1, respectively. All the spectra are generated using PYTHIA8 generator and tauola interface.

Weak mixing angle measurements (Sin2θW)

- CEPC has potential to improve it by two order of magnitudes

Experiment	Stat. (10^{-5})	Syst. (10^{-5})	Theory unc. (PDF+QCD) (10^{-5})	Total unc. (10^{-5}) $\delta \sin^2\theta_W$
LEP	29	~ 1	~0	29
Tevatron	27	5	18	33
ATLAS 8TeV (ATL-CONF-2018-037)	21	16	24	36
CMS 13TeV (SMP-22-01)	10	15	9	27
CEPC (2205.08553)	~0.2	~0.2	~0	~0.3
New: results confirmed by recent Ref-TDR studies. (Shuo Han, Jiawei Wan, Lei Zhang)				
Theory prediction			~4	~4

Rb measurement

$$\frac{\Gamma(\mathrm{Z} \to \mathrm{b\bar{b}})}{\Gamma(\mathrm{Z} \to \mathrm{had})}$$

- At LEP measurement 0.21594 ±0.00066
- CEPC aim to improve the precision by a factor 10~20 (0.02%)
- Rb measurement is sensitive to New physics models (SUSY)
  - SUSY predicts corrections to Z→ bb vertex
  - Through gluino and chargino loop …

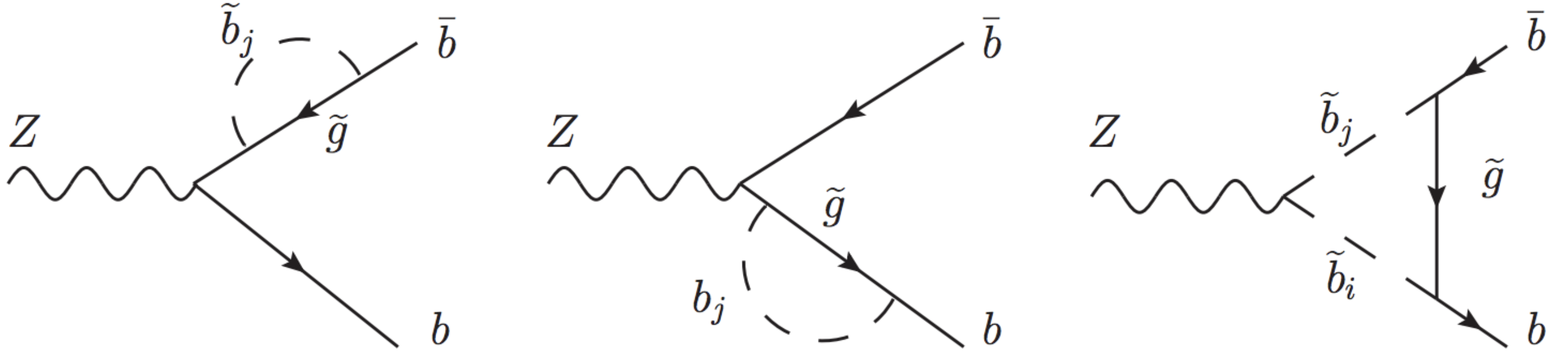


FIG. 1: One-loop Feynman diagrams of gluino correction to $Z \to \bar{b}b$

1601.07758

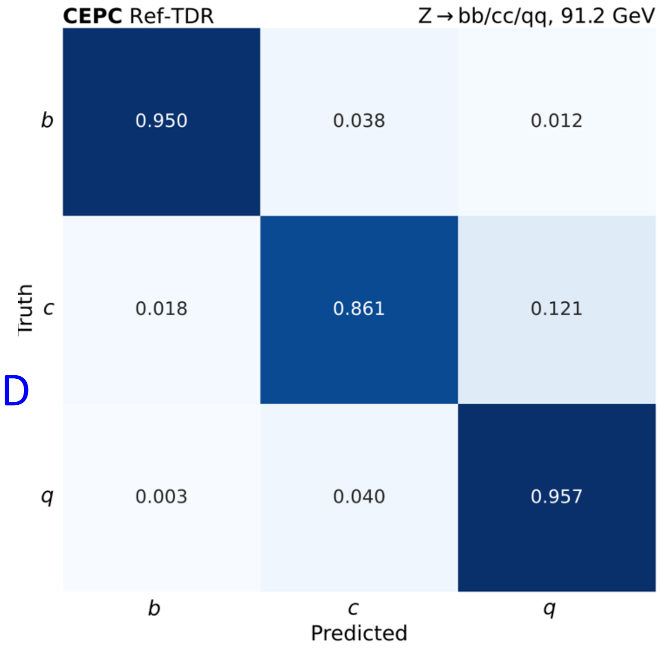
Rb measurement (2)

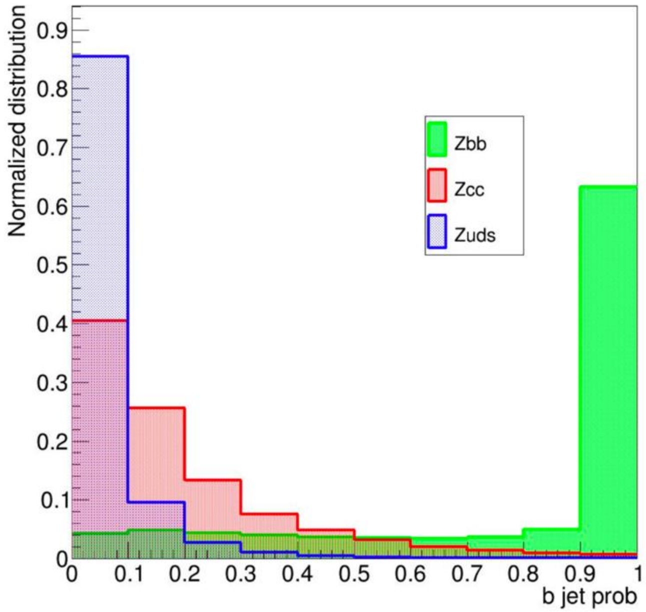
New: method verified by recent Ref-TDR studies. (Bo Liu, Hancen Lu, et.al.,)

- Expected to be 20~50 times better than LEP measurements
  - With 95% purity working points, efficiency > 70% in CEPC (~30% for LEP)
  - 1D and 2D template fit for b tagging probability
- A global analysis method is developed to reduce impact from correlations between jet pairs.

Eur. Phys. J. Plus 136, 1 (2021)

New:
Ref-TDR
Based on
Jet-Origin ID

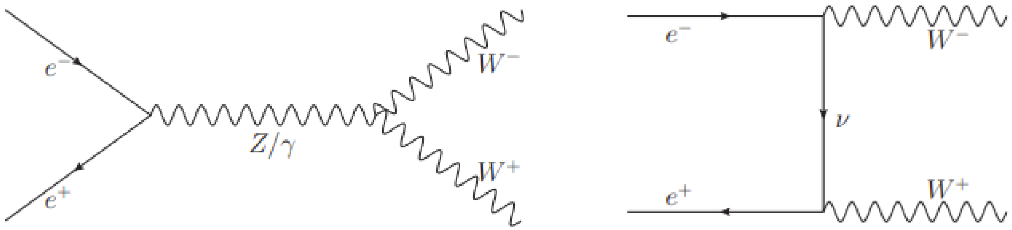




Error source	ΔR^b (10^{-5})
Statistics	1
Tracking resolution	1
Charm modeling	3
Gluon spliting	1
Hemisphere correlation	6
Total	7

Search for aTGCs with ee→WW

- Measurement of ee→WW process provides important constraints c various new physics contributions
- 7 parameters considered for further EFT studies

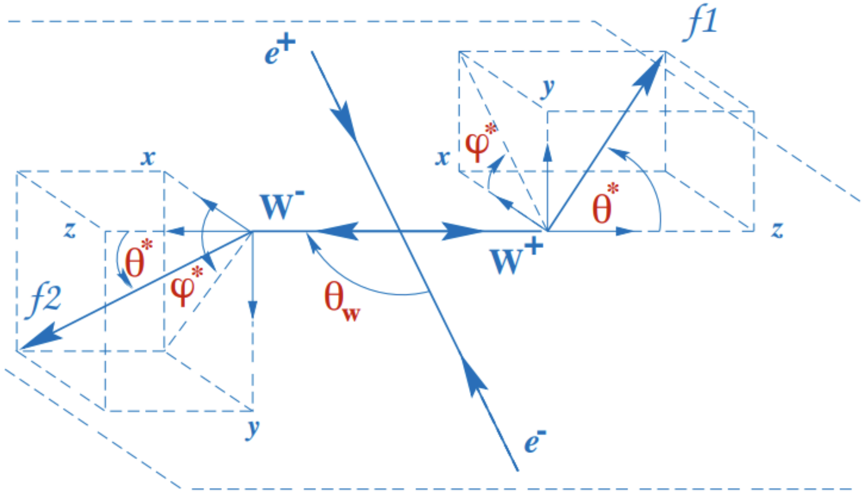


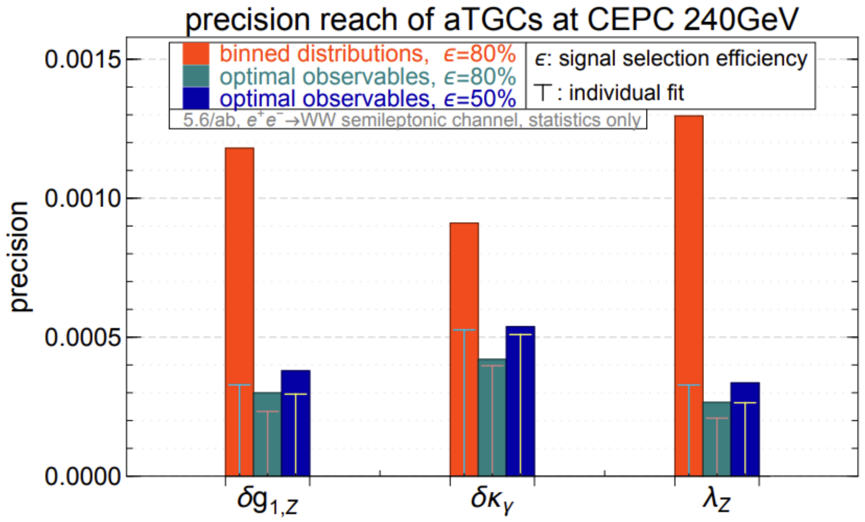
$$\boxed{\delta g_{1,Z}\,,\quad \delta\kappa_\gamma\,,\quad \lambda_Z\,,}\quad \delta g^{ee}_{Z,L}\,,\quad \delta g^{ee}_{Z,R}\,,\quad \delta g^{e\nu}_{W}\,,\quad \delta_{m_W}$$

aTGC couplings

gauge couplings modifier

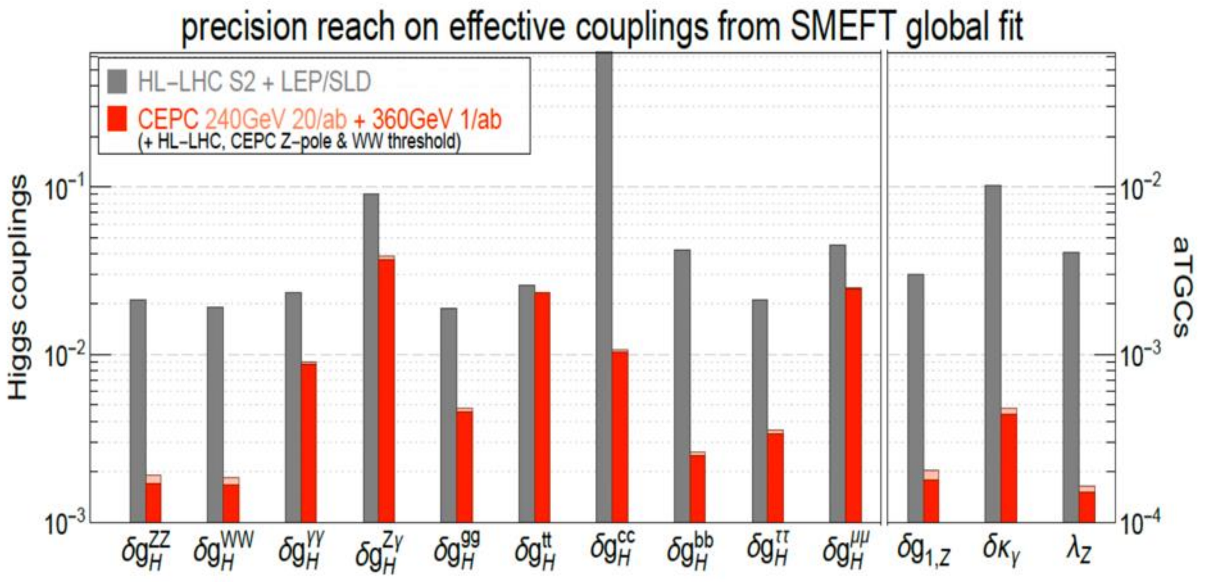
- The optimal observable method explore for this search (Z. Phys. C 62 (1994) 397–412)

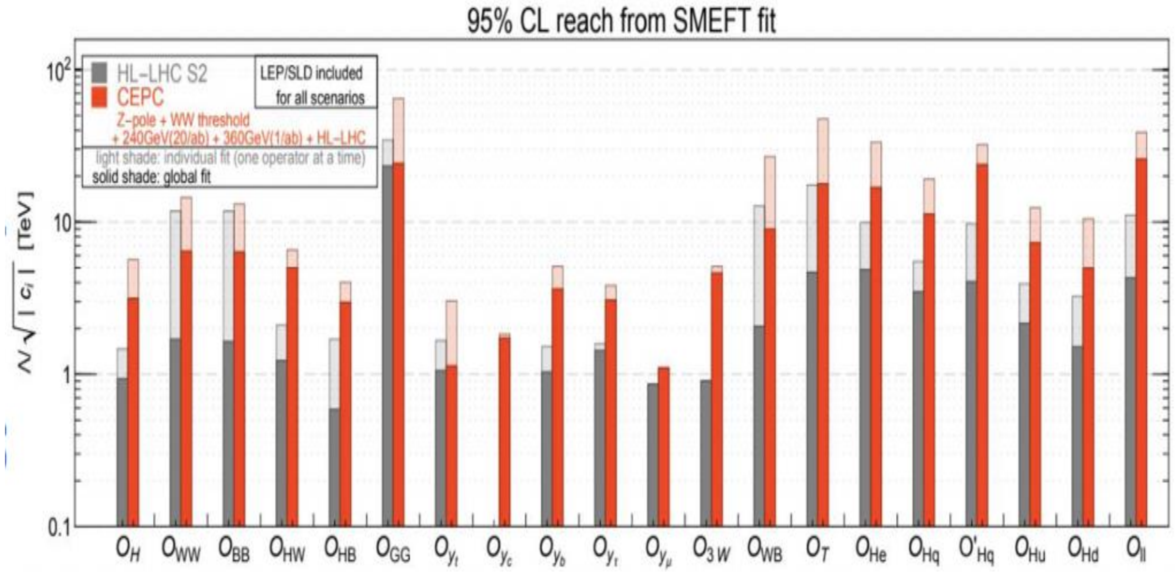




Global fit with SMEFT: new physics constrains

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$





CEPC has potential to reveal new physics @10 TeV by combining Higgs, EWK and top measurements → power of precision

Global fit with SMEFT: new physics constrains

- **Oblique parameters S, T: measure new physics effects in electroweak loops, see Peskin-Takeuchi [PRD 46 (1992) 381]**

CEPC projected sensitivity on oblique parameters from the EW fit

		Current	CEPC
individual	ΔT	0.020	0.0030
	ΔS	0.025	0.0046
marginalized	ΔT	0.049	0.0062
	ΔS	0.063	0.0094

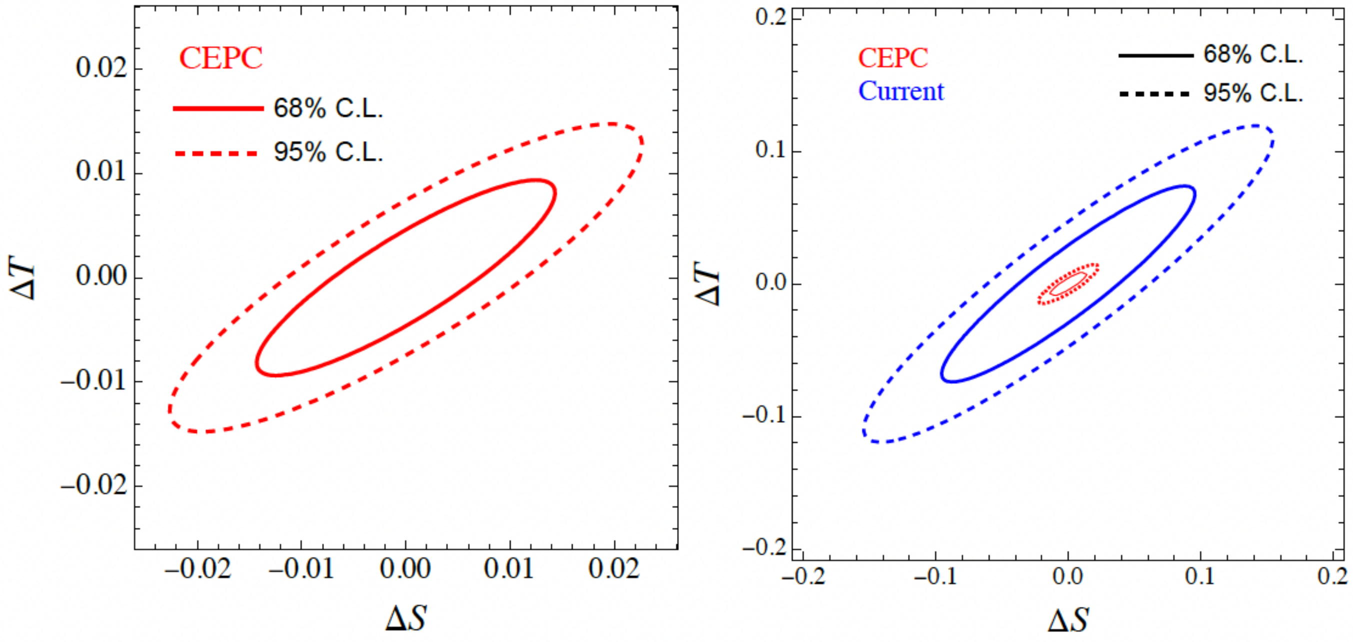


Figure 4: The projected CEPC precision on the oblique parameters ΔS and ΔT, compared to the current constraints. All the contours are shifted to be centered at the SM prediction, *i.e.* $\Delta S = \Delta T = 0$.

Status and plan for the EW white paper

- A draft is under preparation
- Aiming at a complete draft for review in this summer (in two months)

Electroweak precision measurements at the CEPC

June 16, 2025

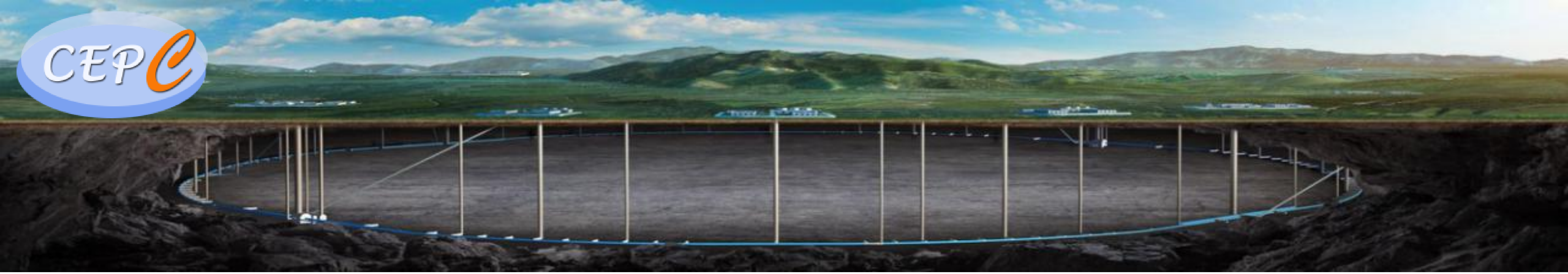
Abstract

The Circular Electron Positron Collider (CEPC) is expected to deliver 4 million Higgs bosons, 4 trillion Z boson, approximately one Giga of W bosons, and potentially one million top quarks, in roughly 15 years of operation. It will be able to perform many important electroweak measurements with an unprecedented level of precision, providing important probes to the new physics beyond the Standard Model. In this document, we report the projected reaches of the electroweak precision measurements at the CEPC based on the most recent scenarios and discuss their physics implications.

Contents

Summary

- Unprecedented luminosity in CEPC provides chance to test the SM EWK sector in a more precise way
  - Expected 1-2 order of magnitude better than current precision
  - Would help to solve puzzles in current measurements
- CEPC Electroweak white paper preparation is on-going
  - Aiming to have a complete draft for review this summer
  - Your input is important, please consider to join us
- For the first 10 years CEPC operation, especially low-lumi Z runs
  - Physics goal needs to be refined.



Thanks for your attention!