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CEPC EWK white paper

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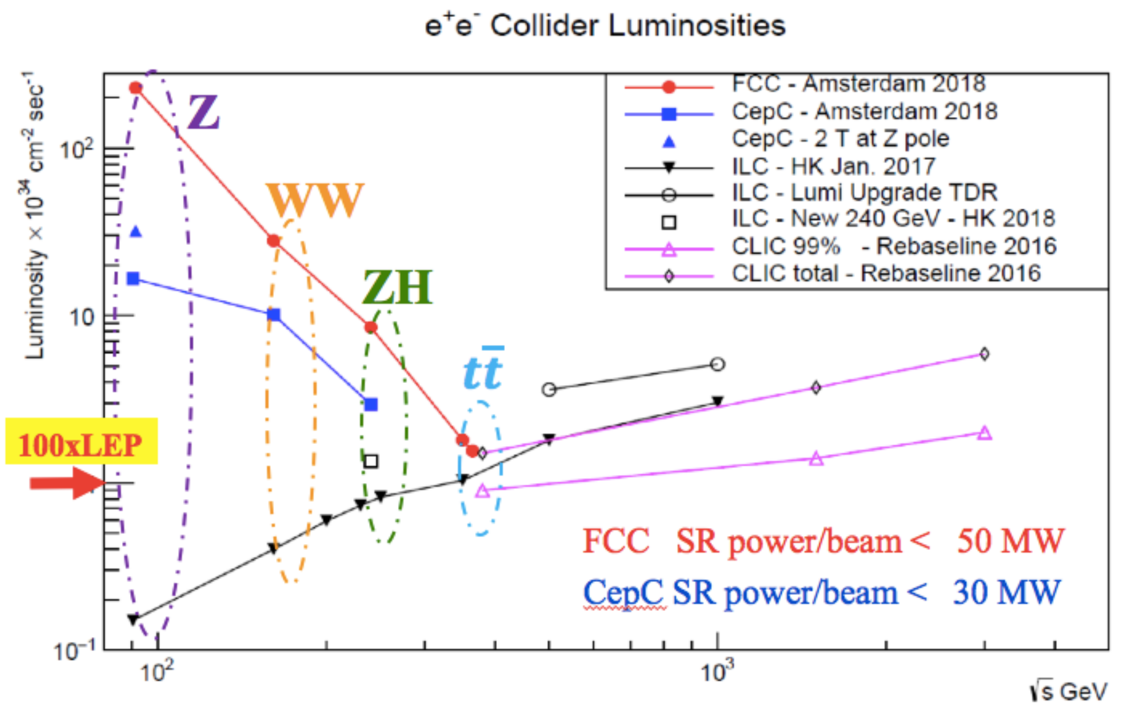
Chinese Academy of Science

Introduction to CEPC

- CEPC is Higgs Factory (E_{cms}=240GeV , 10^6 Higgs)
- CEPC is Z factory(E_{cms}~91GeV) ,electroweak precision physics at Z pole.
  - **baseline L=1.6 X 10^{35} $cm^{-2}s^{-1}$, Solenoid =3T, 3X10^{11} Z boson, two years**
  - **L= 3.2 X 10^{35} $cm^{-2}s^{-1}$, Solenoid =2T , 6X10^{11} Z boson**
- WW threshold scan runs (~160GeV) are also expected.
  - One year, Total luminosity 2.6 ab^{-1} **14M WW events**



From F. Bedeschi

Electroweak global fit

- Review of the key electroweak constant

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

From PDG2018

Summary of EWK section

- New measurements (Hao Zhang)
  - **Exotic Z-decay**
  - energy correlations measurements
- EFT (Higgs + EWK), Jiayin Gu
- New EWK fit, Top FCNC , Cen Zhang
  - Combing different experiments in different energy scale
- R_b measurement (LI Bo)
  - B tagging and Systematics study
- W mass measurement with Threshold scan (Peixun Shen , Gang Li)
- LHC EWK input and Z->4l (Yu Sheng)
- More details can be found
  - https://indico.ihep.ac.cn/event/9832/other-view?view=standard

White paper : R_b from Z->bb

- R_b
  - B tagging and systematics study
    - Correlation of b tagging systematics between two bjets
    - Good progress, toward a paper publication

Get From Mixed MC Sample

$$\frac{N_t}{2N_{had}} = R_b\varepsilon_b + R_c\varepsilon_c + (1 - R_b - R_c)\varepsilon_{uds}$$

$$\frac{N_{tt}}{N_{had}} = C_b R_b \varepsilon_b^2 + C_c R_c \varepsilon_c^2 + C_{uds}(1 - R_b - R_c)\varepsilon_{uds}^2$$

R_c, ε_c, ε_{uds}, C_b, C_c, C_{uds} Get from MC

$$C_b = \frac{\varepsilon_{2jet-tagged}}{(\varepsilon_{1jet-tagged})^2}$$

LEP like working point
60% purity

Bo Li (Yantai University)

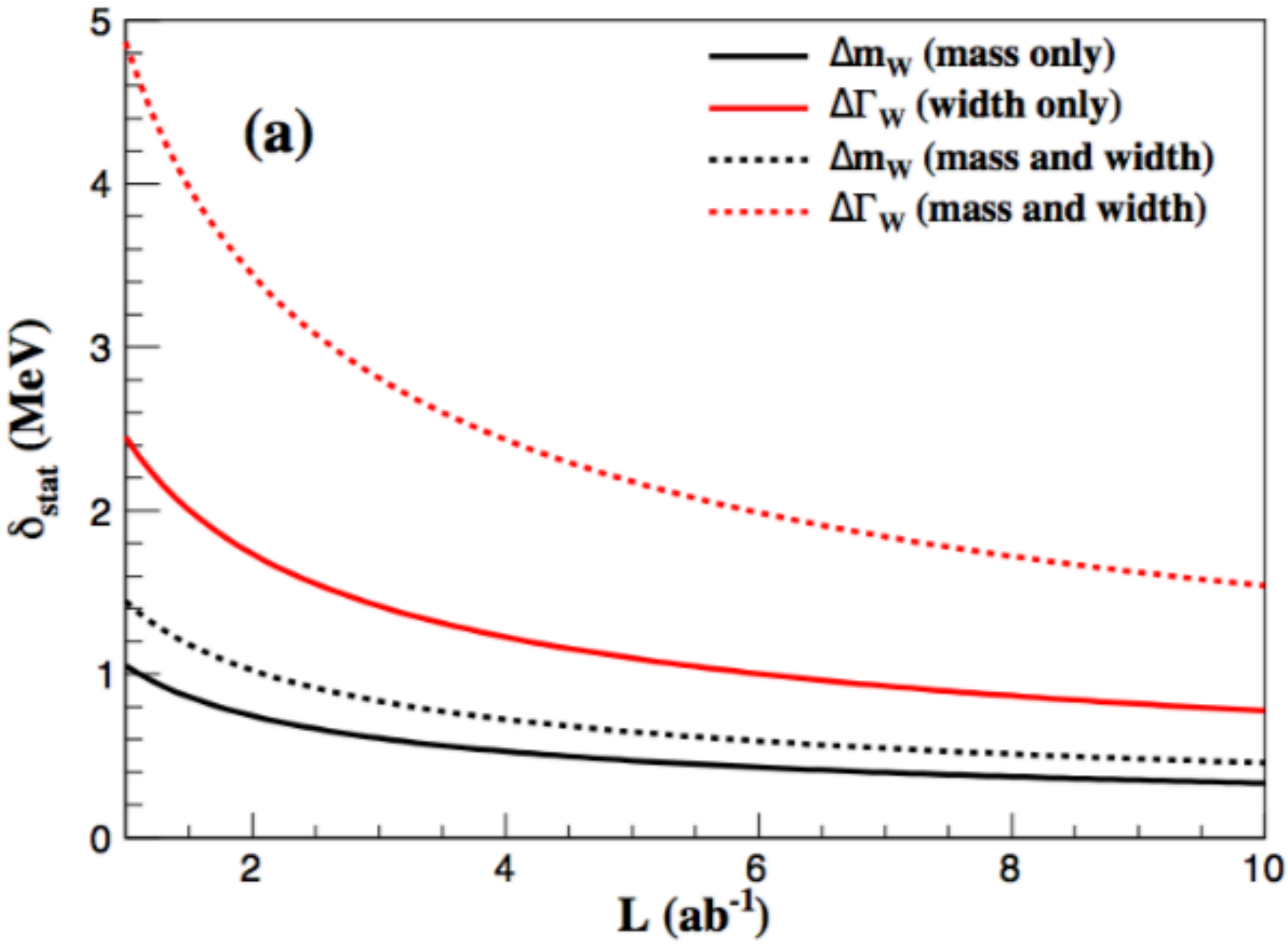
CEPC working point
99% purity

	(Measured Rb-0.2158)/0.2158					
	Prob>0.6	**Prob>0.70**	**Prob>0.80**	**Prob>0.90**	**Prob>0.95**	**Prob>0.99**
ε_c ±10%	0.55%	0.34%	0.19%	0.09%	0.05%	0.01%
ε_{uds} ±10%	0.21%	0.14%	0.10%	0.06%	0.04%	0.02%
C_b ±10%	10.12%	10.09%	10.08%	10.06%	10.06%	10.05%

Statistics error on W mass Vs Luminosity

- Paper draft ready on WW threshold scan study
  - Plan to submit to EPJC

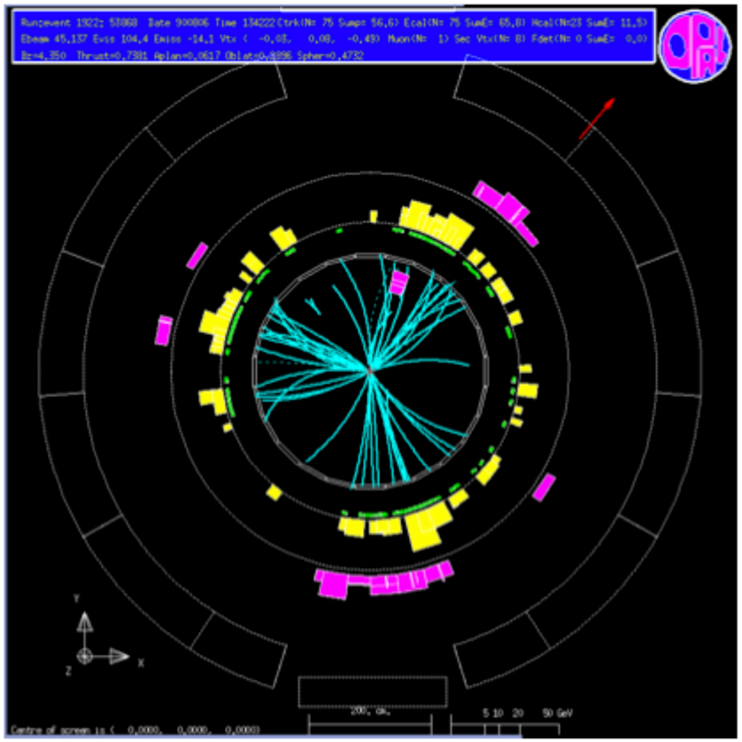
Peixun Shen (Nankai)



New idea on Z pole

- Z->γ γ search : Exotics decay search, need high statistics (TeV Z)
- Energy correlations study

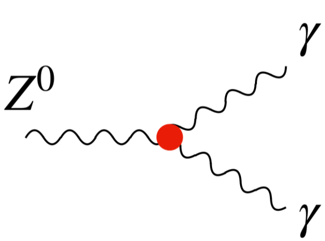
Well defined (non-artificial) quantity



Energy-Energy Correlation

$$\frac{d\Sigma}{d\cos\chi} = \sum_{i,j} \int \frac{E_i E_j}{Q^2} \delta(\vec{n}_i \cdot \vec{n}_j - \cos\chi) d\sigma,$$

Hao Zhang (IHEP)

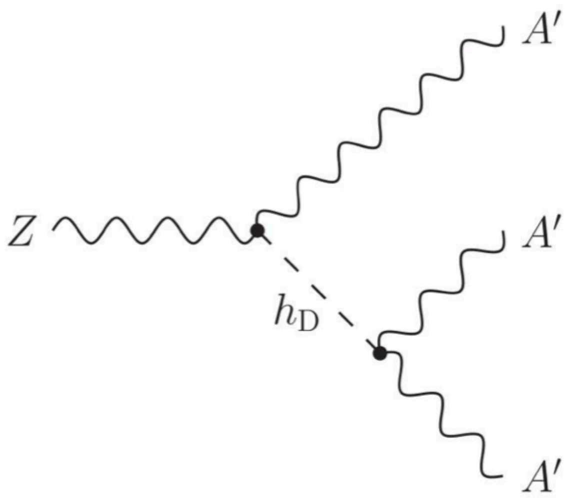


Ideas of Using Z→ 4l decays to Search for BSM

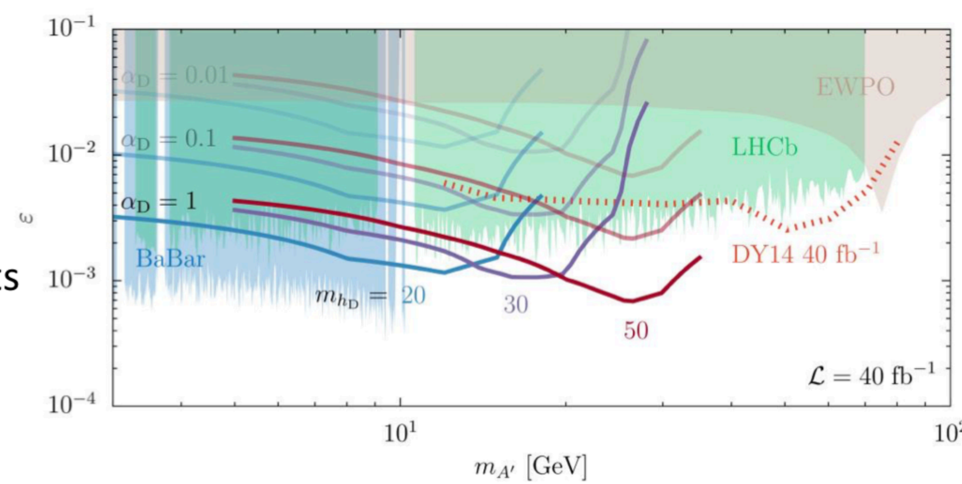
- *Z→4l, 6l* have good sensitivity to BSM physics
- *At CEPC, Z bosons are produced at rest, lepton pT would be even lower, this requires some care about low momentum measurement*

For instance arXiv:1710.07635v2

Yusheng (USTC)



Rare decays of Z to multiple leptons can have good sensitivity to its portal to dark / hidden sector



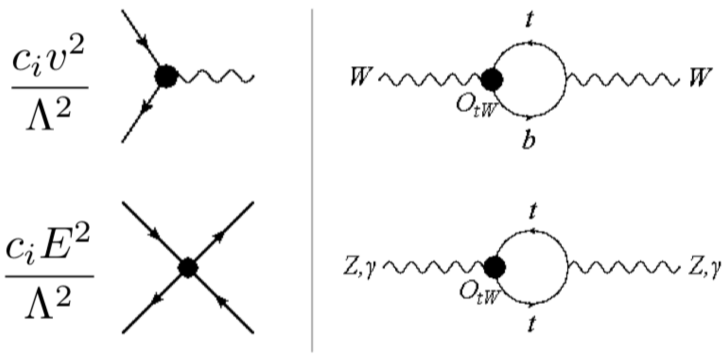
LHC could give sensitive constraints of dark photon with O(10) GeV mass range

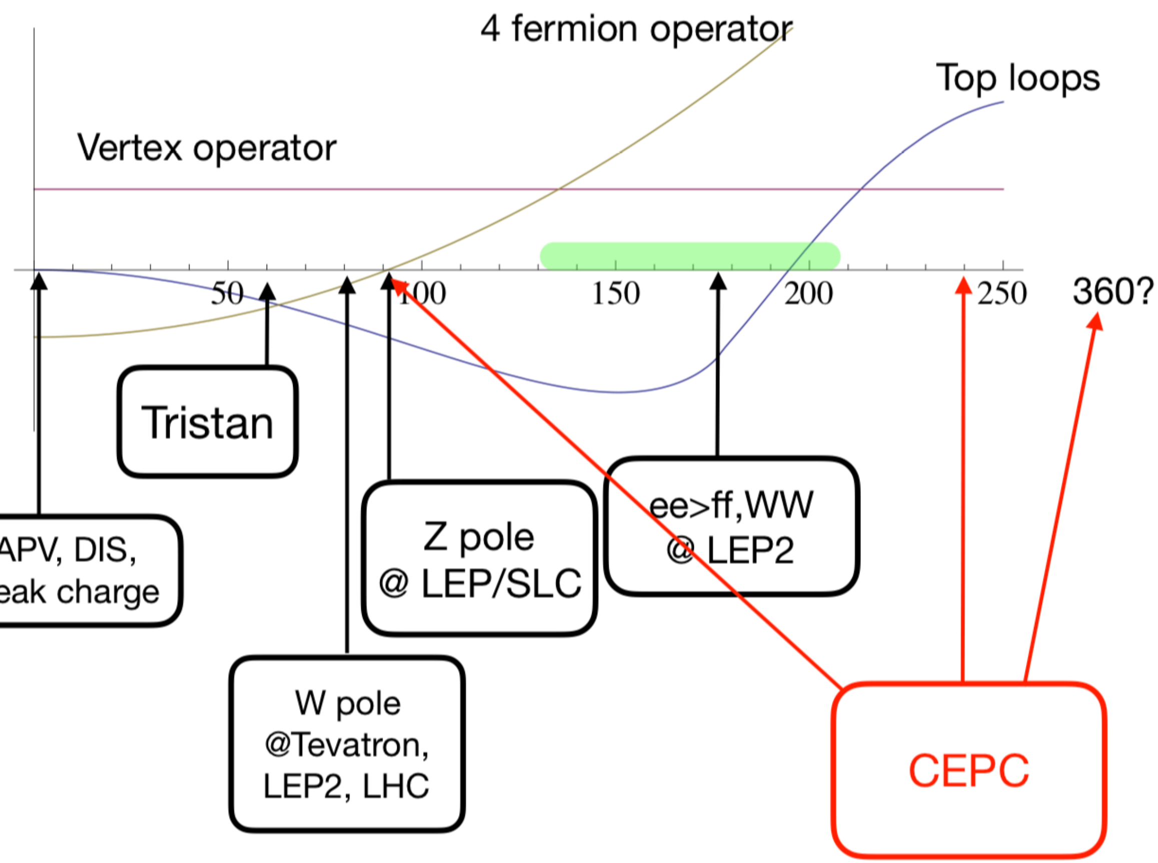
CEPC can do better with large amount of Zs and precise detector?

Top coupling in EWK fit

EW fit: top couplings enter through loops

Cen Zhang



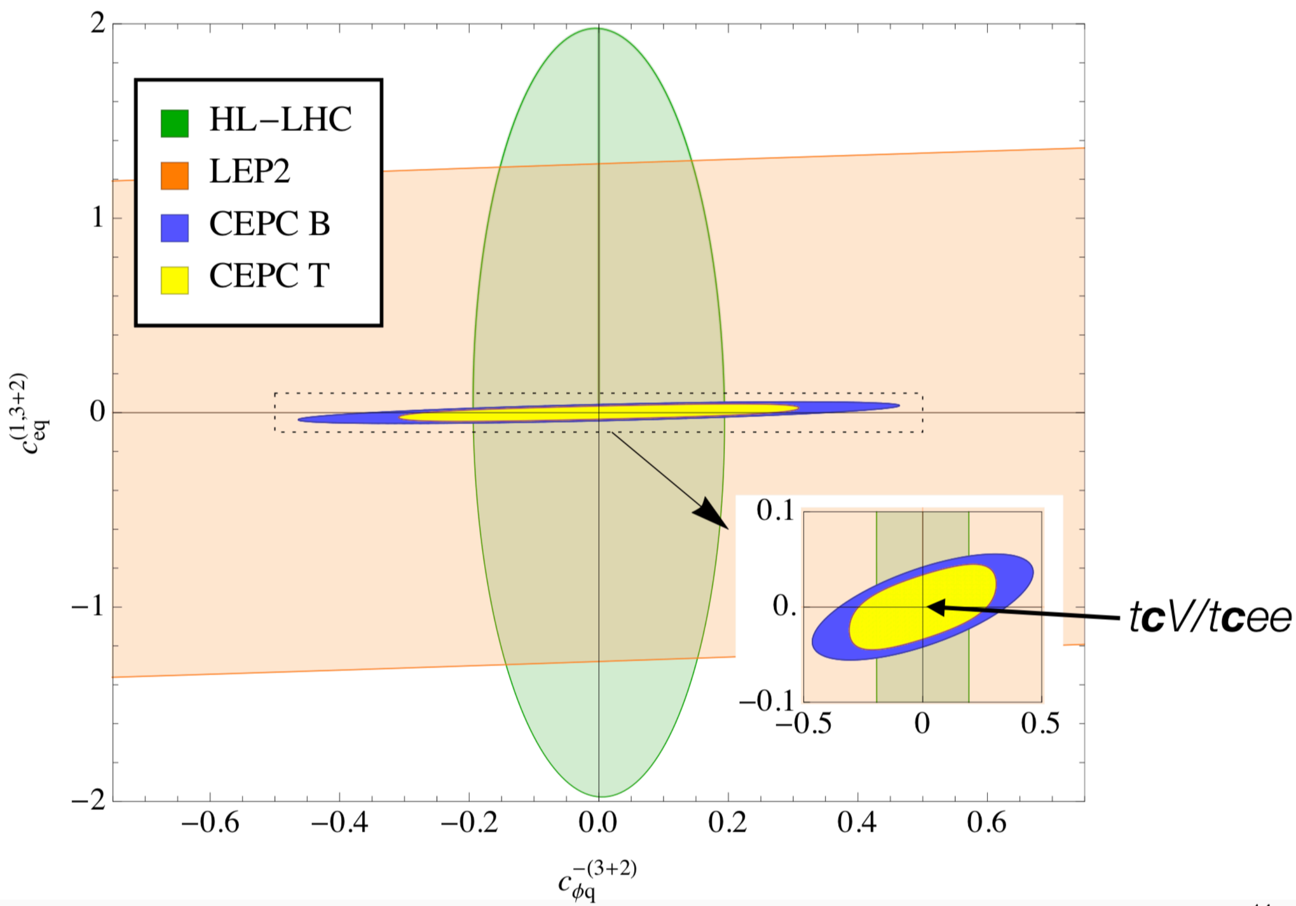


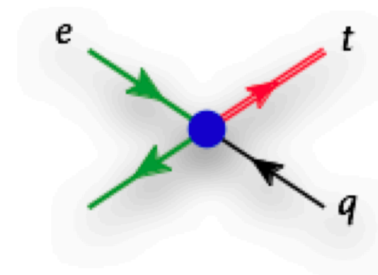
- Loop effects lead to unique energy-dependent "form factors".
- Precision EW measurements coming from very different energy scales provide a handle.

Top coupling in EWK fit

- CEPC has shown good potential in constraint top coupling
  - Without ttbar threshold runs
  - Significantly better than HL-LHC 4f coupling

Cen Zhang(IHEP)
Liaoshan Shi (IHEP)

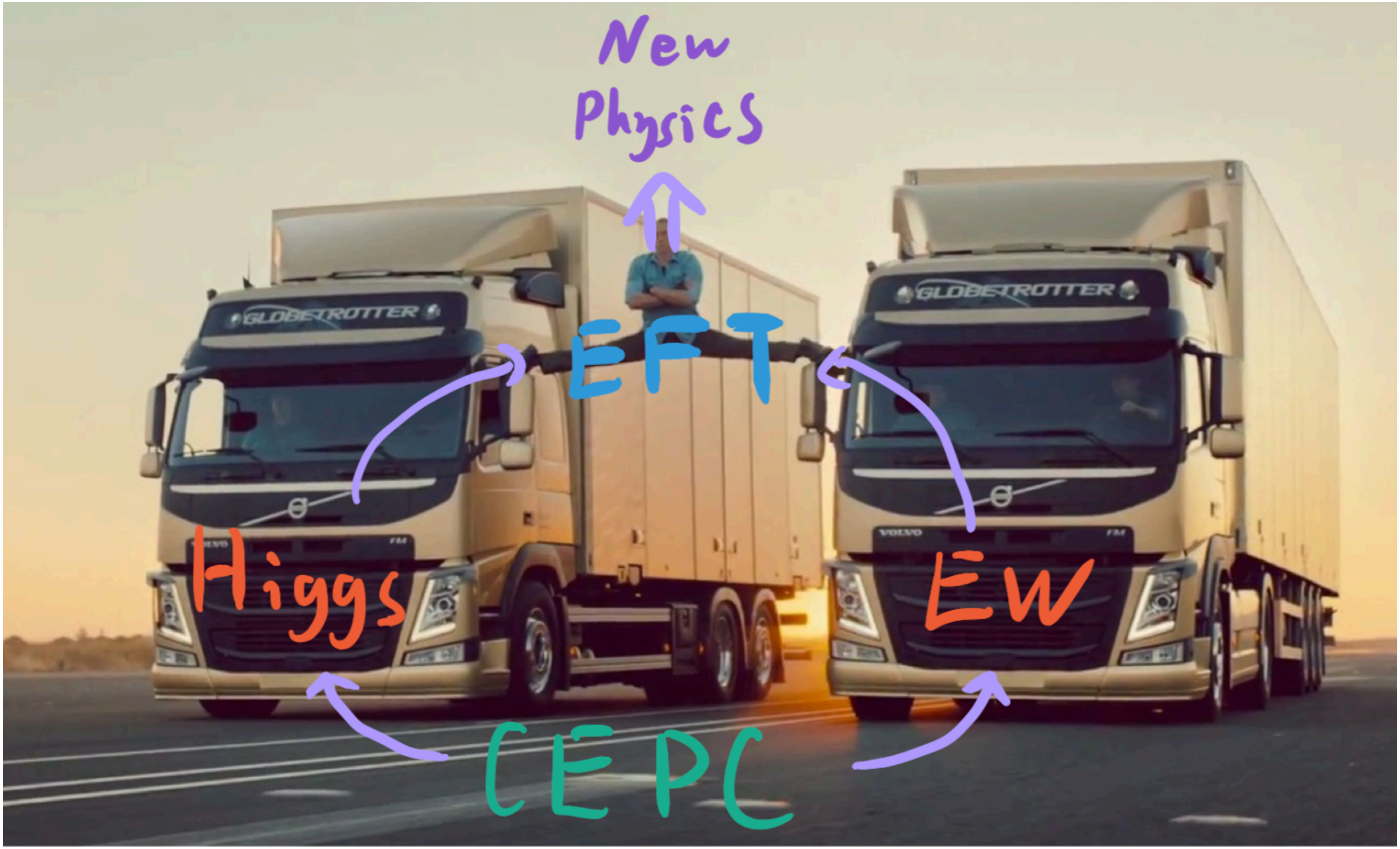




E^4/m_Z^4 scaling enhancement

4f: 120 fb 预览

EFT fit (Jiayin Gu)



EFT fit

- Higgs + aTGC + EW = **28** parameters in our framework
  - ▶ Some operators can only be probed with the **Higgs particle**.

You can't really separate Higgs from the rest of the SM!

Jiayin Gu (Mainz)

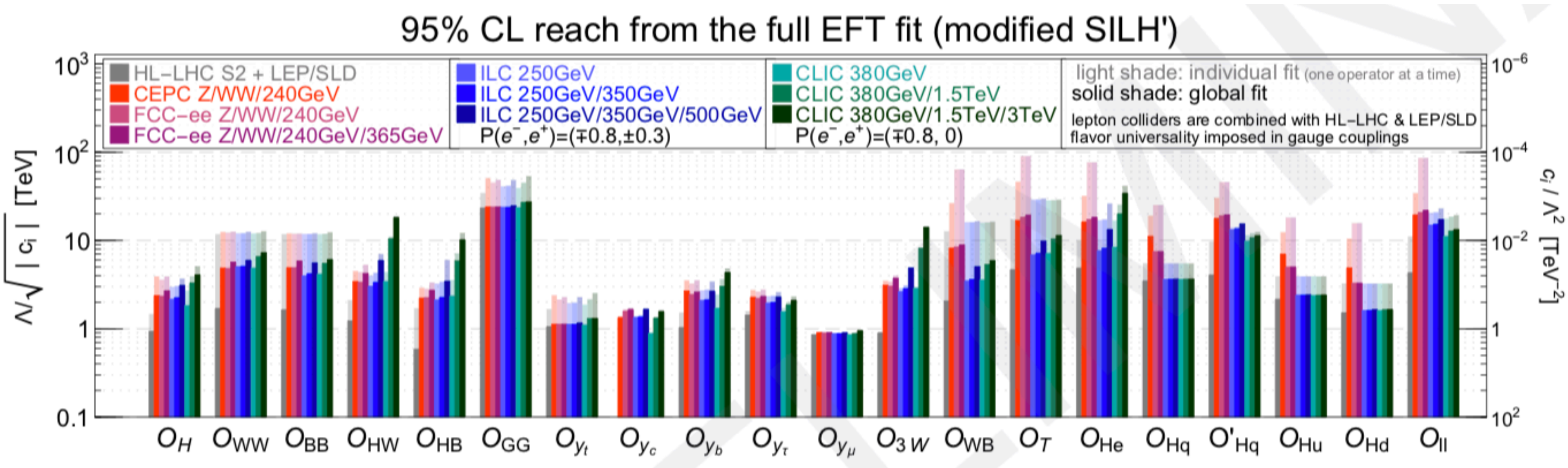
▶ $\mathcal{O}_{H\ell} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{\ell}_L \gamma^\mu \ell_L$,

$\mathcal{O}'_{H\ell} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{\ell}_L \sigma^a \gamma^\mu \ell_L$,

$\mathcal{O}_{He} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{e}_R \gamma^\mu e_R$

(or the ones with quarks)

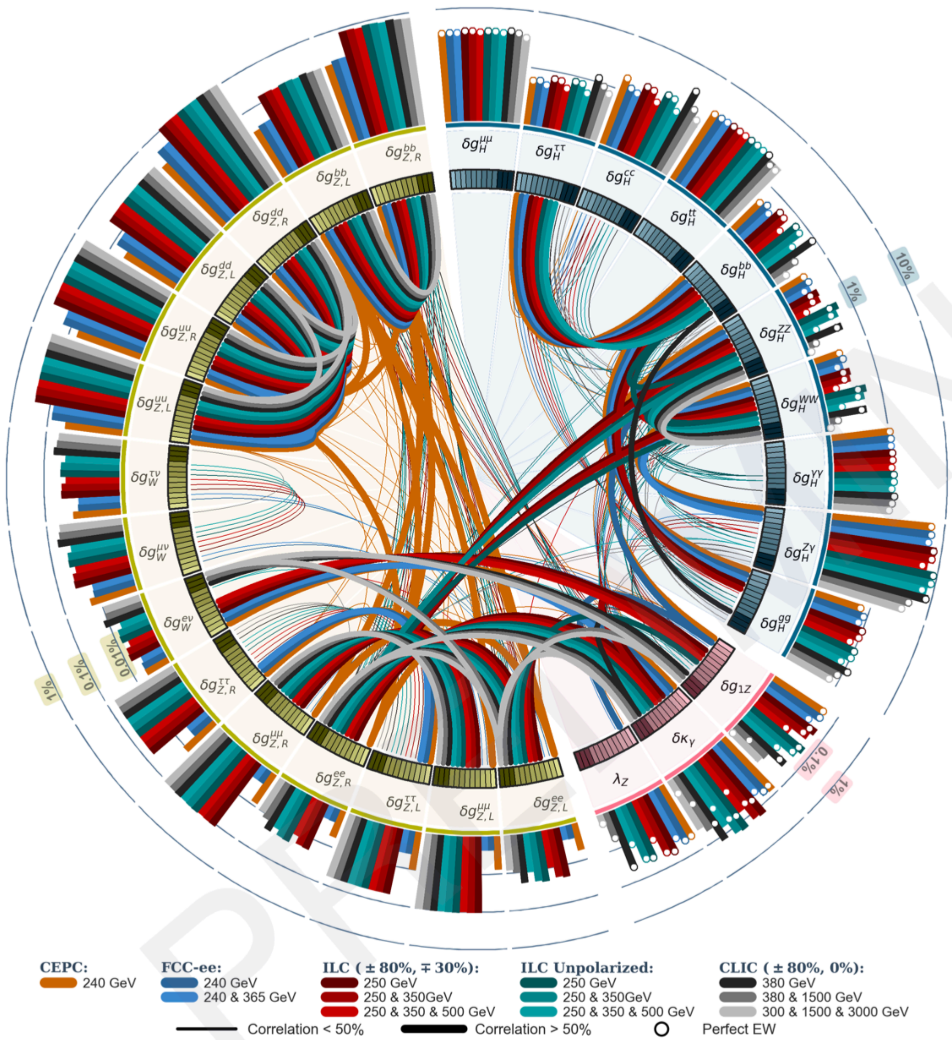
- ▶ modifies gauge couplings of fermions,
- ▶ also generates *hVff* type contact interaction.



EFT fit

- EPS2019 highlight figure
  - CEPC provide more details input
  - They can fit correlations between EFT operators

Jiayin Gu (Mainz)



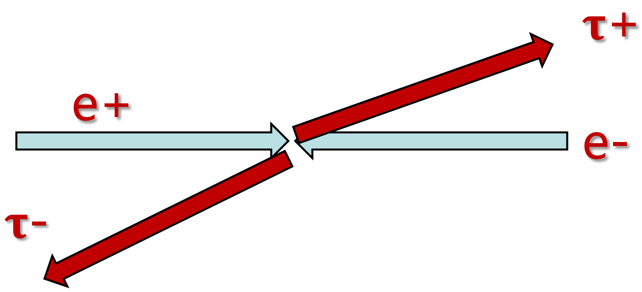
- Precision reach on the outside...
- Correlations on the inside...
- Without future *Z*-pole run ⇒ larger correlation among the *hWW*, *hZZ* couplings, aTGCs and the *Zee* couplings.

CEPC EWK input to ECFA

	Γ_Z	σ_{had}		A_e (τ pol)	A_τ (τ pol)
CEPC	0.5 MeV	0.005 nb		0.0003	0.0005
FCC-ee	0.1 MeV	0.005 nb		–	–
	R_e	R_μ	R_τ	R_b	R_c
CEPC	0.0003	0.0001	0.0002	0.0002	0.001
FCC-ee	0.0003	0.00005	0.0001	0.0003	0.0015
	$A_{\text{FB}}^{0,e}$	$A_{\text{FB}}^{0,\mu}$	$A_{\text{FB}}^{0,\tau}$	$A_{\text{FB}}^{0,b}$	$A_{\text{FB}}^{0,c}$
CEPC	0.005	0.003	0.005	0.001	0.003
FCC-ee	–	–	–	–	–
(fitted)	A_e	A_μ	A_τ	A_b	A_c
CEPC	0.0003	0.003	0.0005	0.001	0.003
FCC-ee	0.0001	0.00015	0.0003	0.003	0.008

Table 1: A comparison of CEPC and FCC-ee Z-pole inputs. All uncertainties are relative **(normalized to 1)** except for Γ_Z and σ_{had}. "τ pol" denotes that the measurement is from τ polarization in $Z \to \tau^+\tau^-$. The 5 fitted asymmetry observables ($A_{e,\mu,\tau,b,c}$) are derived from a simutanous fit of all the $A_{\text{FB}}^{0,}$ observables as well as the A_e and A_τ from τ polarization.

A_e and A_τ in Z->ττ (τ polarization)



$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \frac{1}{\langle|\mathcal{P}_e|\rangle}$$

$$A_{LRFB} = \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_F + \sigma_B)_R} \frac{1}{\langle|\mathcal{P}_e|\rangle}$$

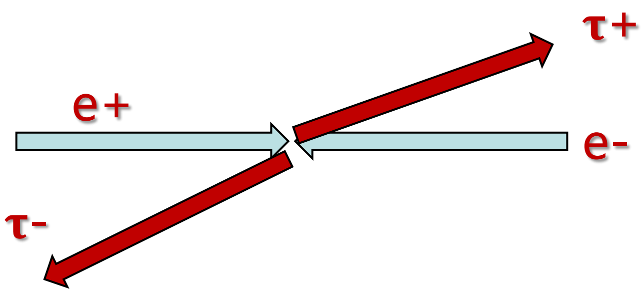
- A_e and A_τ w/o polarization info

(derived)	A_e	A_μ	A_τ	A_b	A_c
CEPC	0.0025	0.0039	0.0056	0.0027	0.0039
FCC-ee	0.0001	0.00015	0.0003	0.003	0.008

- A_e and A_τ with polarization info (from tau or from beam)

(fitted)	A_e	A_μ	A_τ	A_b	A_c
CEPC	0.0003	0.003	0.0005	0.001	0.003
FCC-ee	0.0001	0.00015	0.0003	0.003	0.008

A_e and A_τ: tau polarization



$$A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}}$$

$$A_{\mathrm{LR}} = \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} \frac{1}{\langle|\mathcal{P}_{\mathrm{e}}|\rangle}$$

$$A_{\mathrm{LRFB}} = \frac{(\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}})_{\mathrm{L}} - (\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}})_{\mathrm{R}}}{(\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}})_{\mathrm{L}} + (\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}})_{\mathrm{R}}} \frac{1}{\langle|\mathcal{P}_{\mathrm{e}}|\rangle}$$

- Weak mixing angle
  - extracted from A_e and A_τ using tau polarization: more precise

τ decay mode	Number selected decays	Purity of the samples (%)
$\tau \to e\nu_e\nu_\tau$	18434	89.4 ± 0.1
$\tau \to \mu\nu_\mu\nu_\tau$	19811	94.3 ± 0.1
$\tau \to \pi/K\nu_\tau$	14850	73.2 ± 0.1
$\tau \to \rho\nu_\tau$	26548	75.4 ± 0.1
$\tau \to a_1\nu_\tau$	9446	53.2 ± 0.2

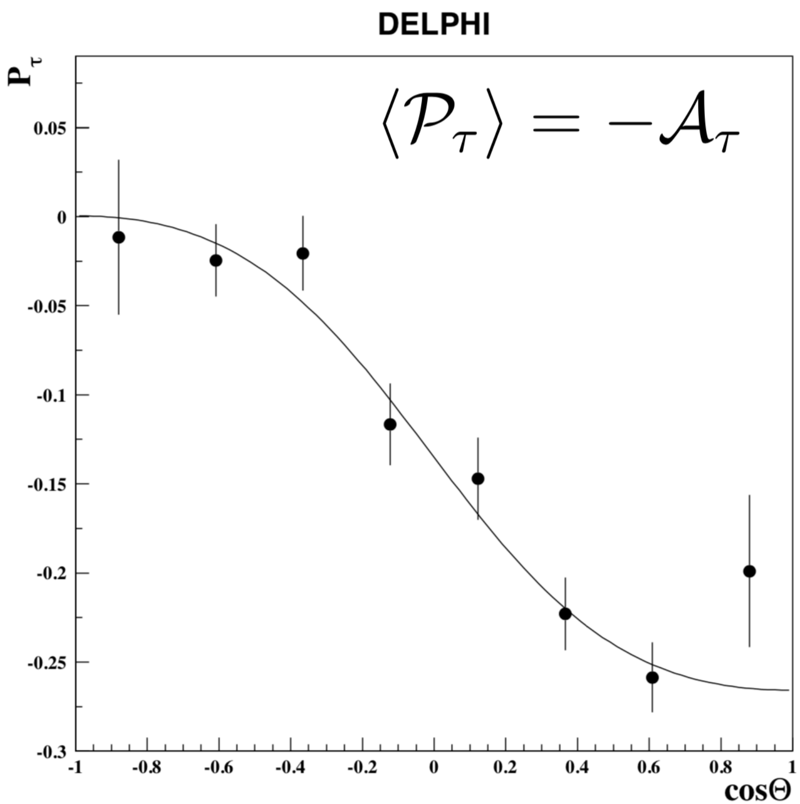
A_{LRFB}, $P_\tau(\cos\theta)$ → A_e and A_τ

A_e and A_τ in $Z \rightarrow \tau\tau$

- Tau polarization can be measured through its decay product

$$P_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta) + \mathcal{A}_e(2\cos\theta)}{(1+\cos^2\theta) + \frac{4}{3}\mathcal{A}_{fb}(2\cos\theta)}$$

A_{LRFB}, $P_\tau(\cos\theta)$ → A_e and A_τ



From DELPHI

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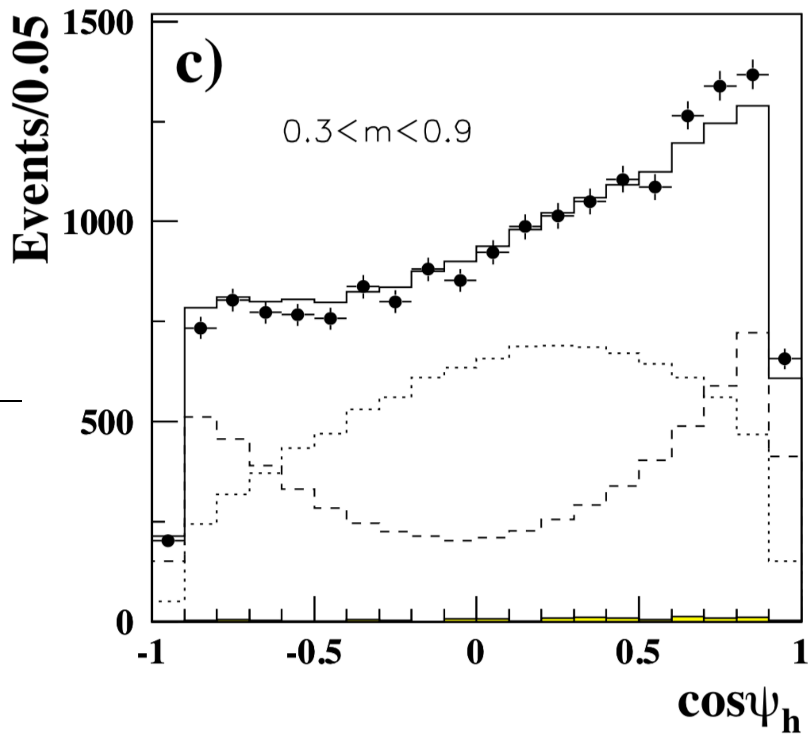


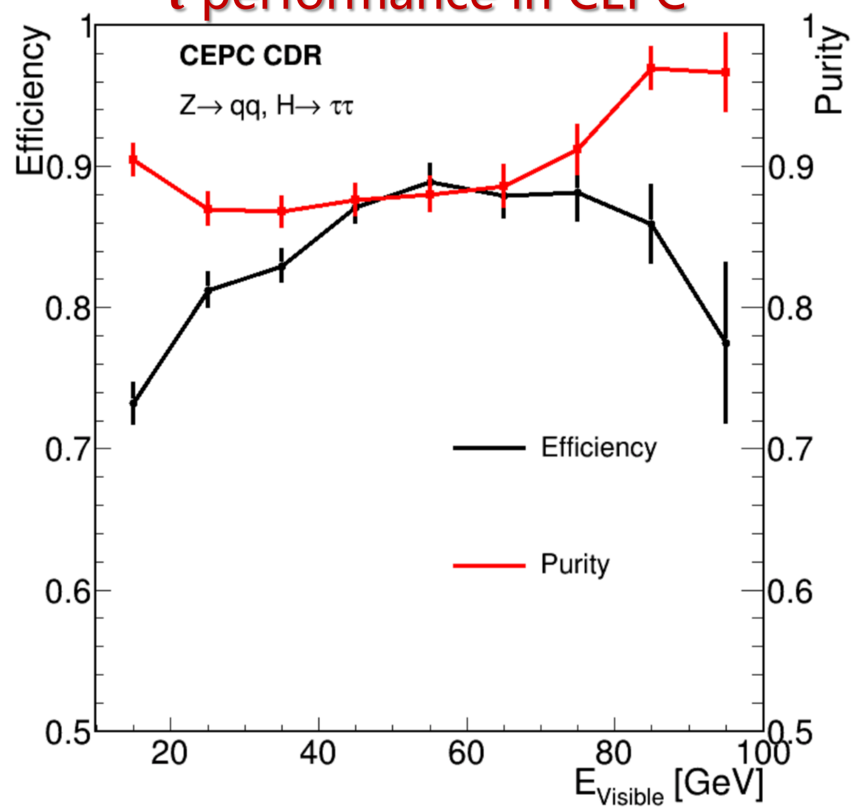
Eur. Phys. J. C 14, 585-611 (2000)

A_e and A_τ in Z →ττ: systematics

- Current precision
  - A_e : **0.1515±0.0019 (PDG)**
  - A_τ : **0.143±0.004 (PDG)**
- CEPC:
  - A_τ : Key systematics is from EM scale, and **τ** identification
  - A_e limited by statistics

CEPC precision	Rel stat unc.	Rel total unc.
A_τ	**2×10^{-4}**	**5×10^{-4}**
A_e	**3×10^{-4}**	**3×10^{-4}**

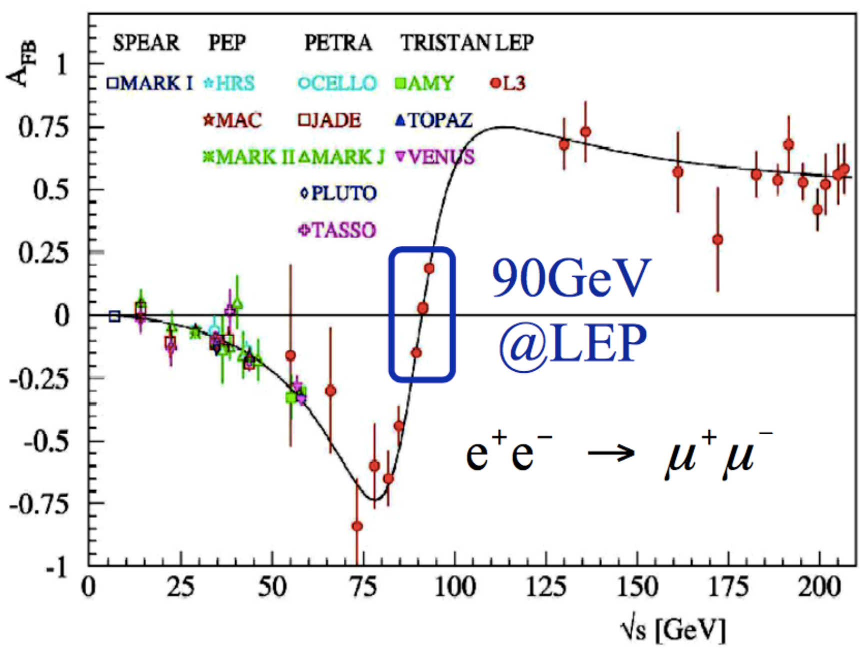
τ performance in CEPC

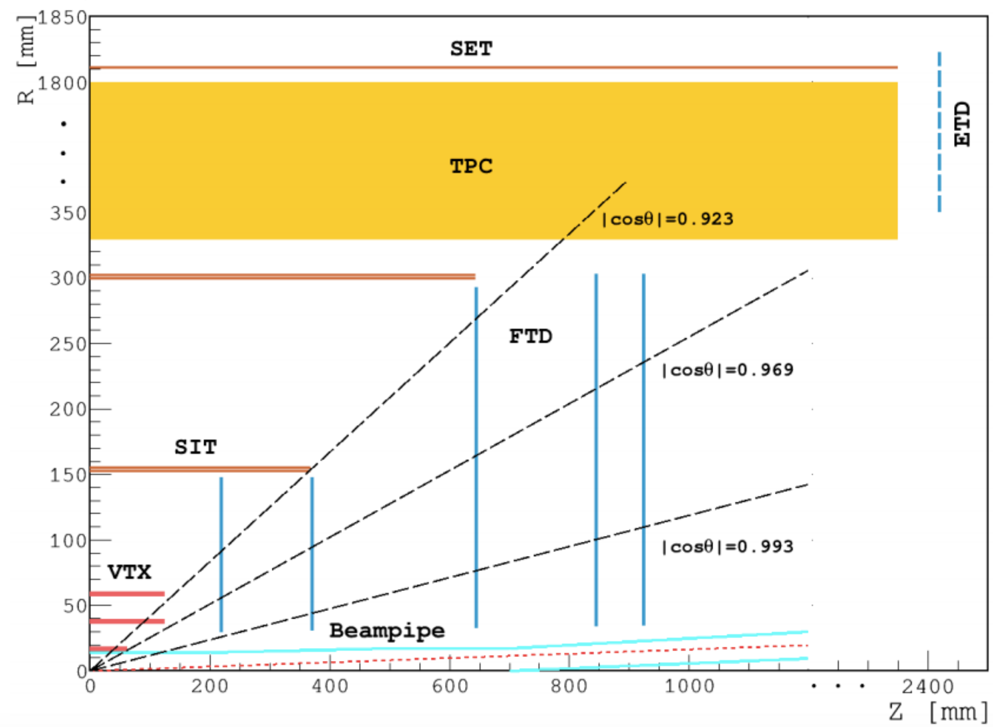


Backward-forward asymmetry in Z->μμ

$$A_{FB}^{(0,\mu)}$$

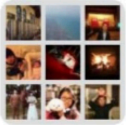
- LEP measurement : 0.0169 +-0.00130
- CEPC expected: +-0.00005
  - CEPC has potential to improve it by a factor of 20~30 .
    - Acceptance systematics (larger detector coverage, smaller syst.)
- Major systematics (absolute value.)
  - Beam energy systematics ($5e^{-5}$, assuming 500keV E_{beam} unc.)
  - Muon angular resolution ($1e^{-5}$ level)





Summary

- Welcome to join CEPC EWK study
  - Input for ECFA (to be documented in short writeup)
  - In one month timescale
  - http://cepcgit.ihep.ac.cn/CEPC-White-Paper/electroweak-physics

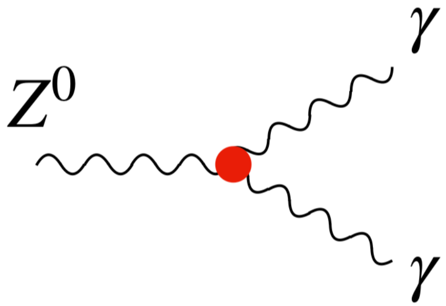


CEPC Electroweak Working Group

- Longer term goal for white paper
  - More details study on systematics in each measur
    - R_b
    - W mass
    - A_e and A_τ in Z->$\tau\tau$ (τ polarization)
  - aTGCs
  - Z rare decay (Direct search for new physics)

Backup: Summary of workshop

Exotic Z-decay



Exotic decays	Topologies	$n_{\rm res}$	Models
$Z \to \not{E} + \gamma$	$Z \to \chi_1\chi_2, \chi_2 \to \chi_1\gamma$	0	1A: $\frac{1}{\Lambda_{1A}}\bar{\chi}_2\sigma^{\mu\nu}\chi_1 B_{\mu\nu}$ (MIDM)
	$Z \to \chi\bar{\chi}\gamma$	0	1B: $\frac{1}{\Lambda_{1B}^3}\bar{\chi}\chi B_{\mu\nu}B^{\mu\nu}$ (RayDM)
	$Z \to a\gamma \to (\not{E})\gamma$	1	1C: $\frac{1}{4\Lambda_{1C}} aB_{\mu\nu}\tilde{B}^{\mu\nu}$ (long-lived ALP)
	$Z \to A'\gamma \to (\bar{\chi}\chi)\gamma$	1	1D: $\epsilon^{\mu\nu\rho\sigma}A'_\mu B_\nu \partial_\rho B_\sigma$ (Wess-Zumino terms)
$Z \to \not{E} + \gamma\gamma$	$Z \to \phi_d A', \phi_d \to (\gamma\gamma), A' \to (\bar{\chi}\chi)$	2	2A: Vector portal
	$Z \to \phi_H\phi_A, \phi_H \to (\gamma\gamma), \phi_A \to (\bar{\chi}\chi)$	2	2B: 2HDM extension
	$Z \to \chi_2\chi_1, \chi_2 \to \chi_1\phi, \phi \to (\gamma\gamma)$	1	2C: Inelastic DM
	$Z \to \chi_2\chi_2, \chi_2 \to \gamma\chi_1$	0	2D: MIDM
$Z \to \not{E} + \ell^+\ell^-$	$Z \to \phi_d A', A' \to (\ell^+\ell^-), \phi_d \to (\bar{\chi}\chi)$	2	3A: Vector portal

Summary of workshop

Loops as "direct" probes

- **Consider Z(->ll) + H**

Under T transformation without interchanging the initial and final states,

$$\frac{d^3\sigma}{d\cos\Theta d\cos\theta d\phi} \to \underbrace{F_1(1+\cos^2\theta) + F_2(1-3\cos^2\theta) + F_3\sin 2\theta\cos\phi + F_4\sin^2\theta\cos 2\phi}_{\text{T-even}}$$

$$+ \underbrace{F_5\cos\theta + F_6\sin\theta\cos\phi}_{\text{T-even}} \underbrace{-F_7\sin\theta\sin\phi - F_8\sin 2\theta\sin\phi - F_9\sin^2\theta\sin 2\phi}_{\text{T-odd}},$$

Define T-odd asymmetries (A_7, A_8, A_9) by

$$A_{(7,8,9)} \equiv \frac{F_{(7,8,9)}}{F_1}, \qquad A_7 \propto \frac{N(\sin\phi > 0) - N(\sin\phi < 0)}{N(\sin\phi > 0) + N(\sin\phi < 0)} \text{ etc}$$

8/11

You can't really separate Higgs from the rest of the SM!

- $\mathcal{O}_{H\ell} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{\ell}_L \gamma^\mu \ell_L,$
  $\mathcal{O}'_{H\ell} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{\ell}_L \sigma^a \gamma^\mu \ell_L,$
  $\mathcal{O}_{He} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{e}_R \gamma^\mu e_R$
  (or the ones with quarks)
  - modifies gauge couplings of fermions,
  - also generates $hVff$ type contact interaction.