Lepton Universality at Z pole Bo Liu IHEP

Joint Workshop of the CEPC Physics, Software and New Detector Concept, Yangzhou, April 14-17

LFU evidence in LHCb

Lepton Universality:

- In the SM, the couplings of leptons to the gauge boson are independent with their flavour except for the phase space difference.
- LHCb collaboration just report a results of evidence of Lepton non-universality with LHC data in $B^+ \rightarrow K^+ \ell \ell$



$$R_{\mathcal{K}} = \frac{\int_{1.1 \text{ GeV}^2}^{6.0 \text{ GeV}^2} \frac{\mathrm{d}\mathcal{B}\left(B^+ \to \mathcal{K}^+ \mu^+ \mu^-\right)}{\mathrm{d}q^2} \mathrm{d}q^2}{\int_{1.1 \text{ GeV}^2}^{6.0 \text{ GeV}^2} \frac{\mathrm{d}\mathcal{B}\left(B^+ \to \mathcal{K}^+ e^+ e^-\right)}{\mathrm{d}q^2} \mathrm{d}q^2} \stackrel{\mathrm{SM}}{=} 1 \pm \mathcal{O}(10^{-2}) \text{ EM correction}^1$$

R_{K} with full Run 1 and Run 2 LHCb data

The measured value of R_K is:

$$R_{K} = 0.846 \stackrel{+0.042}{_{-0.039}} (\text{stat.}) \stackrel{+0.013}{_{-0.012}} (\text{syst.})$$

- dominant systematic effect: fit model
 - effects such as calibration of trigger & kinematics are at permille-level
- *p*-value under SM hypothesis: 0.0010
- significance: 3.1 σ (evidence for LFU violation in $B^+ \rightarrow K^+ \ell^+ \ell^-$ decays)



CEPC opportunities



With 10E12 Z bosons produced, it's great opportunity to explore Lepton Flavour Universality. LFU test in flavour physics reported by Lingfeng Li

Directly LFU measure in Z→ℓℓ



Phys. Rev. Lett. 126, 141801 (2021)





- Precise measure of Br(Z→ℓℓ) is a test on mu g-2 new physics
- Potential explore tau g-2 as well

$Z \rightarrow \ell\ell$ (results from LEP and LHC)

$$\frac{\Gamma_{\mu\mu}}{\Gamma_{ee}} = \frac{B(Z \to \mu^+ \mu^-)}{B(Z \to e^+ e^-)} = 1.0009 \pm 0.0028$$
$$\frac{\Gamma_{\tau\tau}}{\Gamma_{ee}} = \frac{B(Z \to \tau^+ \tau^-)}{B(Z \to e^+ e^-)} = 1.0019 \pm 0.0032$$

Br(
$$Z \rightarrow \ell \ell$$
) 3.3632 ± 0.0042 $\mu^+ \mu^ 3.3662 \pm 0.0066$ $\tau^+ \tau^ 3.3696 \pm 0.0083$

 $\tau^+ \tau^-$

PR 427 (2006) 257 (a combined measurement from LEP) SM: $O(10^{-9})$

$$R_{Z} = \frac{\sigma_{Z \to ee}^{\text{fid},e} / E_{Z}^{\text{e}}}{\sigma_{Z \to \mu\mu}^{\text{fid},\mu} / E_{Z}^{\mu}} = \frac{\sigma_{Z \to ee}^{\text{fid}}}{\sigma_{Z \to \mu\mu}^{\text{fid}}} = \frac{BR(Z \to ee)}{BR(Z \to \mu\mu)}$$

= 1.0026 ± 0.0013 (stat) ± 0.0048 (syst)
= 1.0026 ± 0.0050.

Eur. Phys. J. C 77 (2017) 367 (measurement from ATLAS)

$$\frac{\sigma_{pp \to Z \to \tau^+ \tau^-}^{8 \text{ TeV}}}{\sigma_{pp \to Z \to \mu^+ \mu^-}^{8 \text{ TeV}}} = 1.01 \pm 0.05 \quad , \quad \frac{\sigma_{pp \to Z \to \tau^+ \tau^-}^{8 \text{ TeV}}}{\sigma_{pp \to Z \to e^+ e^-}^{8 \text{ TeV}}} = 1.02 \pm 0.06 \, , \qquad \text{JHEP 1809 (2018) 159}$$

$$\text{LHCb measurement}$$

 $Z \rightarrow \ell\ell$ (CEPC prospective)

• LFU test highly related to the measurement of $Br(Z \rightarrow \ell \ell)$

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- LEP results are dominated by statistical uncertainty
 - With~10¹² Z produced, statistical uncertainty will be neglected
- Modeling play important role on systematics uncertainty, expected to be improved at CEPC era.
- Momentum/Energy calibration and lepton identification (~0.1%)
- Tau reconstruction and selection (~0.2-0.3%)

 $\sigma(pp \rightarrow ee) = 1.0064 \pm 0.0109 \text{ nb}$ $\sigma(pp \rightarrow \mu\mu) = 1.4563 \pm 0.0142 \text{ nb}$ $\sigma(pp \rightarrow \tau\tau) = 1.5048 \pm 0.0158 \text{ nb}$

All the quoted cross sections are fiducial cross sections

Eur.Phys.J.C **19 (2001) 587-651 (OPAL measurement)** ⁶

$Z \rightarrow ee (OPAL selection)$

• Low multiplicity: $2 \le N_{\text{track}} \le 8 \text{ and } 2 \le N_{\text{cluster}} \le 8$,

 $E_1 > 0.2 \sqrt{s}$ and $E_2 > 0.1 \sqrt{s}$.

- High energy clusters:
- Total electromagnetic energy:
 - Two electrons $E_{\text{total}} \equiv \sum E_{\text{cluster}}^i > 0.80\sqrt{s}.$

High energy cluster associated with a track is treated with electron candidate. Noval Lepton indentification, like LICH

 Geometrical and kinematic acceptance: (e⁻ direction is measured from calorimeter)

 $|\cos \theta_{\rm e^-}| < 0.70$ and $\theta_{\rm acol} < 10^{\circ}$,

Particle flow algorithm to improve

We may expect a 1-2 magnitude lower than LEP for systematics, comparable with statistical $\sim\!10^{-4}$ - 10^{-5} (Current LEP $\sim\!10^{-3)}$

* θ_{acol} is the acollinearity angle of the e+e- pair, defined as $180^{\circ} - \alpha$, where α is the opening $\phi_{acop} \equiv ||\phi_{e^-} - \phi_{e^+}| - 180^{\circ}|^7$

Improve from **Track** reconstruction and high granularity calorimeter in CEPC

Better energy resolution

	1000		
	pe	ak	
	f	$\Delta f/f$	
		(%)	
Monte Carlo			
$\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}$ Monte Carlo	1.0056	0.02	
Acceptance Correction			
Electromagnetic energy	1.0009	0.10	
Electron identification	1.0025	0.08	
Acceptance definition	1.0000	0.09	
Low multiplicity	1.0001	0.01	
Other Corrections			
Four-fermion events	1.0000	0.02	
Signal Correction	1.0091	0.16	
Backgrounds			
$e^+e^- \to \tau^+\tau^-$	0.9968	0.06	
$e^+e^- \rightarrow \gamma\gamma$	0.9999	0.01	
$e^+e^- \rightarrow q\overline{q}$	0.9999	0.02	
$\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-} \ell^+ \ell^-$	1.0000	0.01	
Background Correction	0.9966	0.06	
Total Correction Factor	1.0057	0.17	

1993



 $\phi = ||\phi - \phi|| - 180$

$Z \rightarrow \mu \mu$ (OPAL selection)

• Two tracks with:

 $p_{\text{track}} > 6 \text{ GeV}, \quad |\cos \theta| < 0.95,$

- Azimuthal separation $\cos(\Delta\phi) < 0.95$,
- Muon identification:
 - At least two muon chamber hits are associated *control of accep* with the track *uncertainty expe*
 - At least four hadronic calorimeter strips associated with track
 - Track has pT>15 GeV and isolated
- Visiable energy: scaler sum of two tracks momentum and the energy of highest energy cluster found in the EM calo. (reject ee→ττ and two-photon interaction events)

 $E_{\rm vis}^{\mu} > 0.6 \sqrt{s},$

A better tracking efficiency in CEPC, and better momentum/angular measurement (*especially in forward region where OPAL uses muon chamber, a better control of acceptance uncertainty expected in CEPC*)

LICH algorithm

LICH algorithm and new tau reconstruction

	Γ	1993		
	T	peak		
	h	f	$\Delta f/f$	
			(%)	
Monte Carlo	Π			
$e^+e^- \rightarrow \mu^+\mu^-$ Monte Carlo		1.0955	0.07	
s' cut correction		0.9990	_	
Initial/final state interference		1.0002	_	
Acceptance Correction				
Tracking losses		1.0046	0.06	
Track multiplicity cuts		1.0007	0.04	
Muon identification		1.0000	0.05	
Acceptance definition		1.0000	0.10	
Other Corrections				
Trigger efficiency		1.0006	0.02	
Four-fermion events		1.0011	0.01	
Signal Correction		1.1022	0.15	
Backgrounds	Π			
$e^+e^- \to \tau^+\tau^-$		0.9914	0.02	
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$		0.9995	0.01	
Cosmic rays		0.9998	0.02	
Background Correction		0.9907	0.03	
Total Correction Factor	Π	1.0920	0.16	

8

Expect to reduce systematics by a order of magnitude, resulting XS measure at level 10^{-4} - 10^{-5} , a R_{mm/ee} at level of 10^{-5} . With PFO for both electron and muon, some systematic can be correlated and cancelled out.

$Z \rightarrow \tau \tau$ (OPAL selection)

- Multiplicity cuts: $2 \le N_{\text{track}} \le 6$ and $N_{\text{track}} + N_{\text{cluster}} \le 15$. •
- $ee \rightarrow \tau \tau$ event topology: event are reconstructed with a cone jet-finding ٠ algorithm with cone half-angle of 35°, Each cone must have summed energy>0.1 beam energy. Exactly two clusters reconstructed.
- ee \rightarrow ττ acollinearity: $\theta_{acol} < 15^{\circ}$ •
- Geometrical acceptance ٠ $|\cos \theta_{\tau}| < 0.9.$





- Orthogonal with $ee \rightarrow \mu\mu$ events ٠
- Reject ee \rightarrow ee events with:

 $E_{\text{total}} \equiv \sum E_{\text{cluster}}^i < 0.8\sqrt{s}, \quad |\cos\theta_{\tau}| < 0.7$ $E_{\text{vis}}^{\tau} < 1.05\sqrt{s}$ or $E_{\text{total}} < 0.25\sqrt{s}, \cos\theta_{\tau} > 0.7$

• Reject non-resonance $ee \rightarrow ee \ell \ell$

 $E_{\rm vis}^{\tau} > 0.18\sqrt{s}.$

Expect to reduce factor of 5-10 for systematics uncertainty, resulting a 10⁻⁵ for ratio.





Summary

- Propose measurements of $Br(Z \rightarrow \ell \ell)$ in CEPC at Z pole
 - Results can test LFU with a unprecedented precision with an simple estimation
 - A complimentary result for LHCb measurement
 - Also sensitive to potential new physics related to muon/tau g-2
- Next step will run on full/fast simulated samples