

Flavor Physics Program at the CEPC

Towards the CEPC White Paper

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Aug. 17, 2021

Outline

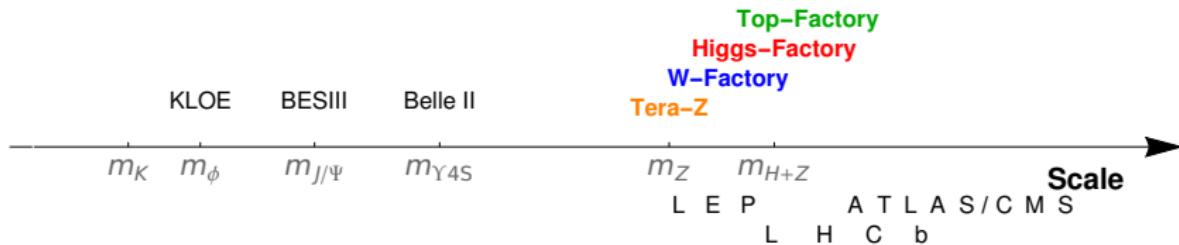
- ▶ Why CEPC is the ideal machine to study flavor physics?
- ▶ How shall we contribute to flavor physics @ CEPC?
- ▶ Recent highlights
- ▶ The current status of the CEPC flavor physics white paper.

Flavor Physics at CEPC

Z Factory \supseteq Flavor Factory

Particle-ID \supseteq Flavor-ID!

Channel	Belle II	LHCb	Giga-Z	CEPC (Tera-Z)
B^0, \bar{B}^0	5.3×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}
B^\pm, \bar{B}^\pm	5.6×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}
B_s, \bar{B}_s	5.7×10^8	$\sim 2 \times 10^{13}$	3.2×10^7	3.2×10^{10}
B_c^\pm	-	$\sim 4 \times 10^{11}$	2.2×10^5	2.2×10^8
$\Lambda_b, \bar{\Lambda}_b$	-	$\sim 2 \times 10^{13}$	1.0×10^7	1.0×10^{10}
c, \bar{c}	2.6×10^{11}	$\gtrsim 10^{14}$	2.4×10^8	2.4×10^{11}
τ^+, τ^-	9×10^{10}	-	7.4×10^7	7.4×10^{10}



VS. B Factories

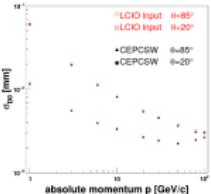
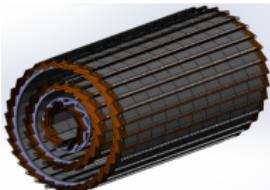
- ▶ Much higher b quark boost
- ▶ Abundant heavy b hadron

VS. Hadron Colliders

- ▶ Clean environment
- ▶ Direct missing momenta measurement

Key Detector Features for Flavor Physics

Materials from the CEPC April meeting

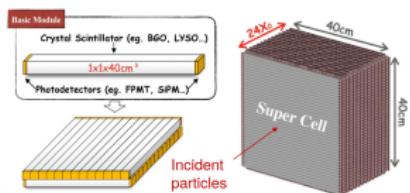
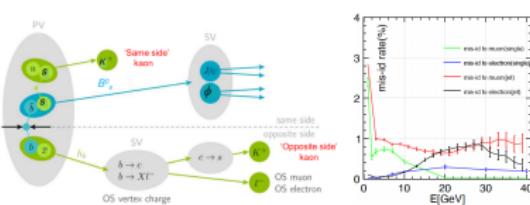


Tracking sys, grants $\mathcal{O}(10)$ fs sensitivity.

- ▶ High time precision for CPV measurements.
- ▶ Authentic c/τ reconstruction inside a jet.
- ▶ Greater acceptance for displaced signals.

Advanced PID coming from the combination of $dE(N)/dx$ method, time resolution and calorimetry:

- ▶ Flavor tagging for everything.
- ▶ Suppressing backgrounds in general.
- ▶ Clean leptonic/baryonic modes.



Calorimetry gives neutral energy and angular resolution.

- ▶ Better ϕ measurement for neutrinos.
- ▶ Excited states such as D_s^* and radiative decays.
- ▶ Distinguishing $\pi^0/\eta\dots$, allowing $h^0 X$ modes.

See also:[Shen et al., 2019, Yu et al., 2020, Zheng et al., 2020a, Yu et al., 2021]

White Paper

- To quantify CEPC flavor physics potential with benchmark analyses, and global interpretation.
- To guide the design/optimization of the facility & maximize the physics output: to quantify the requirements on luminosity, beam quality, & detector performance.

Precision Higgs Physics at the CEPC *

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Zhenwei Cui³ Yaquan Fang^{4,6,34} Chengdong Fu⁴ Jun Gao¹⁰ Yanyan Gao²² Yuanning Gao³
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Hong-Jian He^{11,10} Xianke He¹⁰ Xiao-Gang He^{11,10,20} Jifeng Hu¹⁰ Shih-Chieh Hsu³² Shan Jin⁸
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White paper (II)

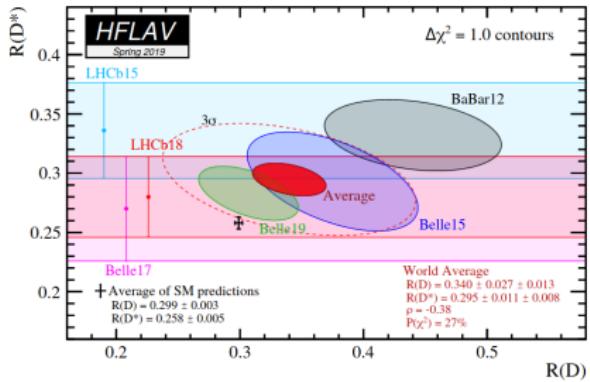
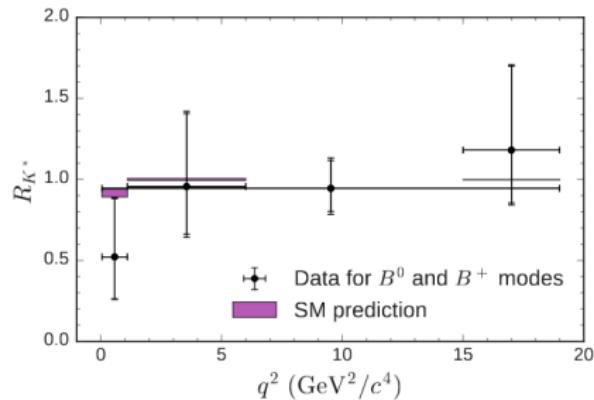
Our job is to feed materials
to this table of content:

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- ▶ (Semi)leptonic b decays.
- ▶ EW penguin b rare decays.
- ▶ CKM matrix element measurements.
- ▶ Lepton Flavor Violation in τ and Z decays.
- ▶ Exclusive Z hadronic decays.
- ▶ Detector benchmark studies.
- ▶ Hadronic spectroscopy and exotic states.
- ▶ Flavorful $\gamma\gamma$ fusion.

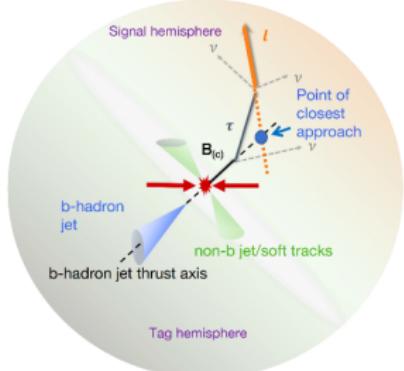
B Anomalies Indicating LFUV



	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0] \text{ GeV}^2$, via B^\pm .
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0] \text{ GeV}^2$, via B^0 .
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and B^\pm combined.
R_{D^*}	0.295 ± 0.014	0.258 ± 0.005	B^0 and B^\pm combined.
$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.18$	$0.25-0.28$	

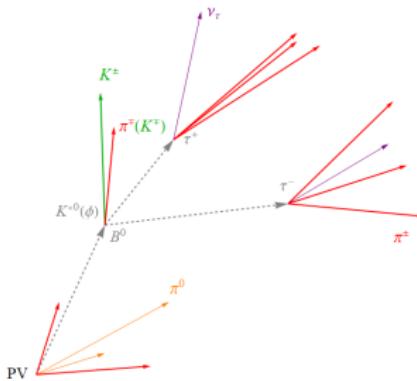
[Tanabashi et al., 2018][Altmannshofer et al., 2018].

Current Progress in LFU Tests



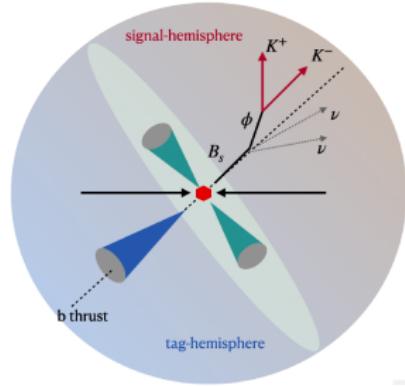
Charged current $B_c \rightarrow \tau\nu$ decays [Zheng et al., 2020b].

Absolute precision $\sim 10^{-4}$.



Neutral current $b \rightarrow s\tau\tau$ decays [Li and Liu, 2020].

Absolute precision $\lesssim 10^{-6}$:
 $\sim 10^3 - 10^4$ improvement from current limits.

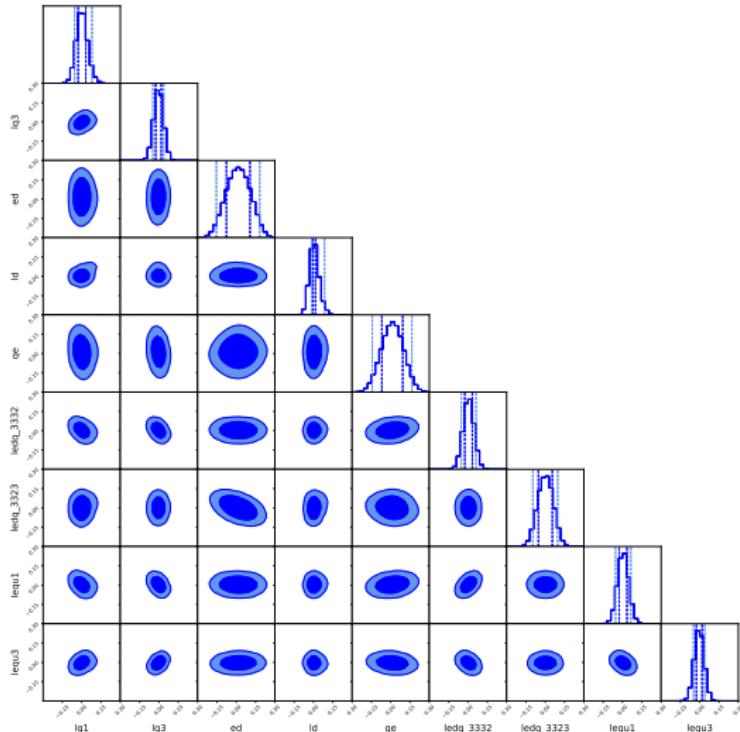


Neutral current $B_s \rightarrow \phi\nu\bar{\nu}$ decay [In preparation]

Absolute precision $\sim 10^{-7}$.

Unique opportunities at the Z -pole

Current Progress in LFU Tests (II)



Preliminary: 9 effective channels: ($R_{J/\psi}$, R_{D_s} , $R_{D_s^*}$, R_{Λ_c} , $B_c \rightarrow \tau\nu$, $B \rightarrow K\nu\bar{\nu}$, $B_s \rightarrow \phi\nu\bar{\nu}$, $B^0 \rightarrow K\tau\tau$, $B^+ \rightarrow K^+\tau\tau$, $B_s \rightarrow \tau\tau\dots$)

Dim-6 SMEFT basis at NP scale $\Lambda=3$ TeV.

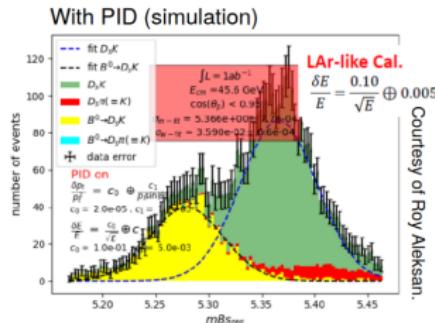
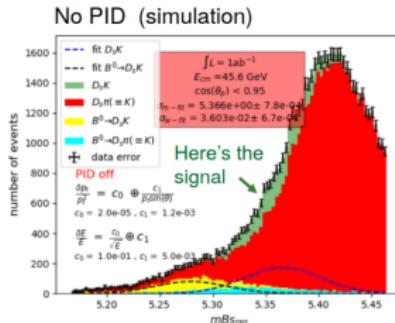
CKM Measurements

FCC-*ee* proposed target [Abada et al., 2019]:

Observable / Experiments	Current W/A	Belle II (50 /ab)	LHCb-U1 (23/fb)	FCC- <i>ee</i>
CKM inputs				
γ (uncert., rad)	$1.296^{+0.087}_{-0.101}$	1.136 ± 0.026	1.136 ± 0.025	1.136 ± 0.004
$ V_{ub} $ (precision)	5.9%	2.5%	6%	1%
Mixing-related inputs				
$\sin(2\beta)$	0.691 ± 0.017	0.691 ± 0.008	0.691 ± 0.009	0.691 ± 0.005
ϕ_s (uncert. rad 10^{-2})	-1.5 ± 3.5	n/a	-3.65 ± 0.05	-3.65 ± 0.01
Δm_d (ps^{-1})	0.5065 ± 0.0020	same	same	same
Δm_s (ps^{-1})	17.757 ± 0.021	same	same	same
a_{fs}^d (10^{-4} , precision)	23 ± 26	-7 ± 15	-7 ± 15	-7 ± 2
a_{fs}^s (10^{-4} , precision)	-48 ± 48	n/a	0.3 ± 15	0.3 ± 2

The goal at CEPC shall be similar, but validation is necessary.

CKM Measurements (II)



FCC preliminary study for
 γ
measurement [Aleksan, 2020]

Using $B_s \rightarrow D_s K^\pm$

Expected $\sigma_\gamma \lesssim 7 \times 10^{-3}$

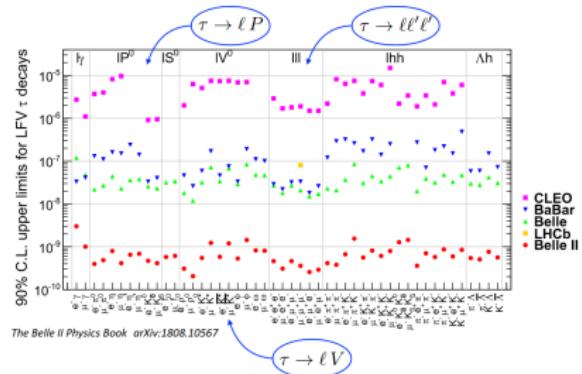
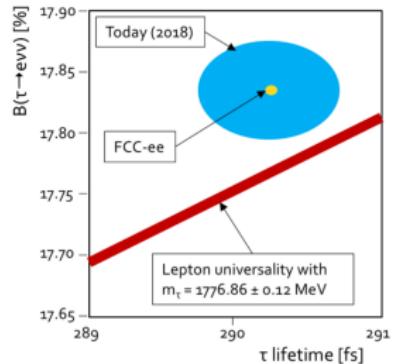
CEPC preliminary study for ϕ_s
measure-
ment [Mingrui Zhao, 2021]

Using $B_s \rightarrow \phi J/\psi$

Can outperform LHCb
 (300 fb^{-1})

	LHCb	CEPC	LHCb(Run 1)
$b\bar{b}$ statics	$43.2 * 10^{12}$	$0.152 * 10^{12}$	$26.64 * 10^9$
Acceptance * trigger * Reconstruction	5%	100%	5%
$\text{Br}(b\bar{b} \rightarrow B_s)$	$10\% * 2$ (b and anti-b)	$10\% * 2$	$10\% * 2$
$\text{Br}(B_s \rightarrow J\psi \text{ Phi})$	0.001	0.001	0.001
* $\text{Br}(J\psi \rightarrow ll)$	* 0.06	* 0.12 (ee channel)	* 0.06
* $\text{Br}(\Phi \rightarrow KK)$	* 0.5	* 0.5	* 0.5
$B_s \rightarrow J\psi(-ll)\Phi(-KK)$ stat			8000 consist with paper
Flavour tagging	4%	15%	4%
Time resolution	0.67	1	0.67
Total effective statics	$0.23 * 10^6$	$0.27 * 10^6$	144

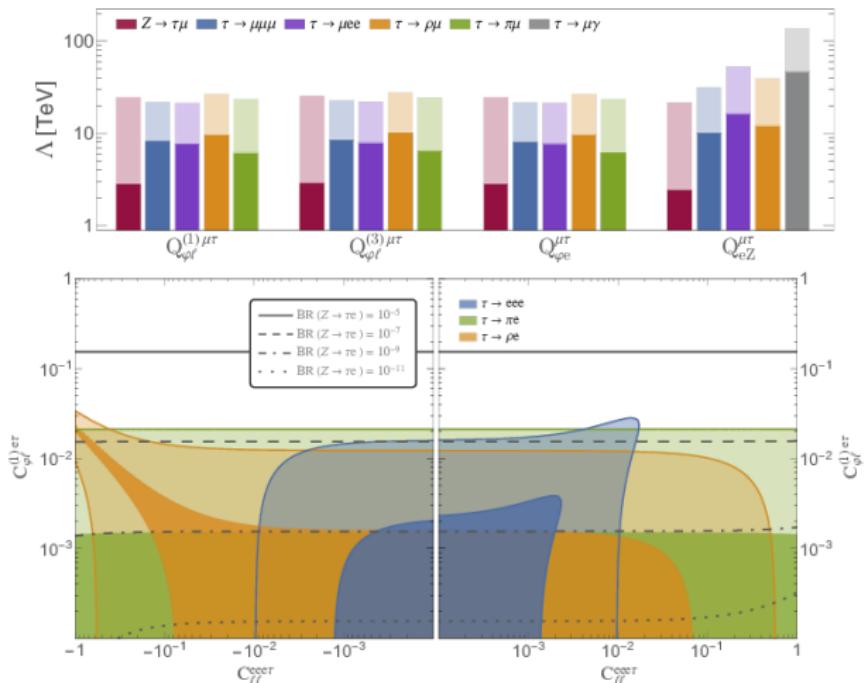
Lepton Flavor Violation



Measurement	Current	FCC Projection	Comments
Lifetime [sec]	$\pm 5 \times 10^{-16}$	$\pm 1 \times 10^{-18}$	3-prong decays, stat. limited
$BR(\tau \rightarrow \ell\nu\bar{\nu})$	$\pm 4 \times 10^{-4}$	$\pm 10^{-6} \pm 3 \times 10^{-5}$	Assumed $0.1 \times$ syst.(ALEPH)
$m(\tau)$ [MeV]	± 0.12	$\pm 0.004 \pm 0.1$	$\sigma(\vec{p}_{\text{track}})$ limited
$BR(\tau \rightarrow 3\mu)$	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	bkg free
$BR(\tau \rightarrow 3e)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	bkg free
$BR(\tau^\pm \rightarrow e\mu\mu)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	bkg free
$BR(\tau^\pm \rightarrow \mu ee)$	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$	bkg free
$BR(\tau \rightarrow \mu\gamma)$	$< 4.4 \times 10^{-8}$	$\sim 2 \times 10^{-9}$	$Z \rightarrow \tau\tau\gamma$ bkg , $\sigma(p_\gamma)$ limited
$BR(\tau \rightarrow e\gamma)$	$< 3.3 \times 10^{-8}$	$\sim 2 \times 10^{-9}$	$Z \rightarrow \tau\tau\gamma$ bkg, $\sigma(p_\gamma)$ limited

[Altmannshofer et al., 2018, Dam, 2019]

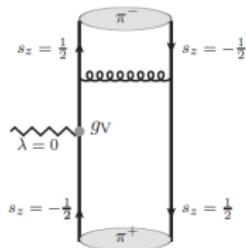
Lepton Flavor Violation (II)



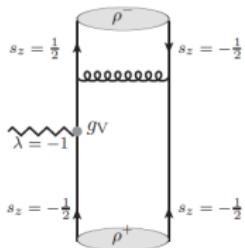
[Calibbi et al., 2021]

Exclusive Z Hadronic Decays

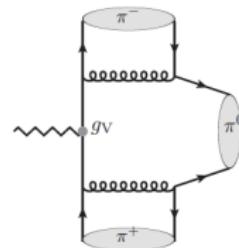
Channel	Theoretical BR	Current Limit	CEPC Goal (Optimistic)
$Z \rightarrow \pi^+ \pi^-$	0.83×10^{-12}	/	$\mathcal{O}(10^{-11})$
$Z \rightarrow \pi^+ \pi^- \pi^0$	$[10^{-8}, 10^{-5}]$	/	Vary
$Z \rightarrow J/\psi \gamma$	8.02×10^{-8}	1.4×10^{-6}	$\mathcal{O}(10^{-9})$
$Z \rightarrow D_s^\pm W^\mp$	6×10^{-10}	/	$\mathcal{O}(10^{-10})$



(a) $Z \rightarrow \pi^+ \pi^-$



$$(b) Z_\perp \rightarrow \rho_\perp^+ \rho_L^-$$



$$(c) Z \rightarrow \pi^+ \pi^- \pi^0$$

- ▶ Testing the highly suppressed Sudakov effect at small $-x$ region.
 - ▶ MC simulations are necessary and currently in the early stage.

Summary

- ▶ CEPC is a powerful machine to study flavor physics.
- ▶ Flavor studies at CEPC benefit from:
 - ① Large luminosity (from accelerator physics)
 - ② Clean environment and moderate energy (from m_Z)
 - ③ Good or even revolutionary detectors (from detector R&D)
- ▶ We need a white paper to form the consensus about what should be done, what should be done, and what we have done.

CEPC Flavor Physics Discussion

Wednesday, July 21, 2021 from 14:00 to 16:00 (Asia/Shanghai)

Description ZOOM 会议链接
Meeting ID: 89678431034
Meeting URL: https://keep-ac.cn/econ.com.cn/j/89678431034/
pwd=3f9d13169c0cf0efwN2hvn3Oa09
Password: 80808 37451



Wednesday, July 21, 2021

14:00 - 14:30 White Paper Scratch 30' Speaker: Dongling Li (KAOS) Material: [Slides](#)

14:30 - 14:45 CP measurement with $B_s \rightarrow J/\psi \ell \bar{\nu}$ process at the CEPC JS' Speaker: Mengtao Zhao (China Institute of Atomic Energy) Material: [Slides](#)

14:45 - 15:00 Updates of $B_s \rightarrow \rho \gamma$ vs J/ψ Speaker: WANG Yaqing Material: [Slides](#)

15:00 - 15:30 Discussion

Welcome to join our monthly discussion!

-  Abada, A. et al. (2019).
FCC Physics Opportunities.
Eur. Phys. J., C79(6):474.
-  Aleksan, R. (2020).
Constraints on calorimetry from (some) cp violation and
electroweak physics.
Technical report, IRFU, Saclay.
-  Altmannshofer, W. et al. (2018).
The Belle II Physics Book.
-  Calibbi, L., Marcano, X., and Roy, J. (2021).
Z lepton flavour violation as a probe for new physics at
future e^+e^- colliders.
-  Dam, M. (2019).
Tau-lepton Physics at the FCC-ee circular e^+e^- Collider.
SciPost Phys. Proc., 1:041.

- Li, L. and Liu, T. (2020).
 $b \rightarrow s\tau^+\tau^-$ Physics at Future Z Factories.
- Mingrui Zhao, M. R. (2021).
Cp-violating phase ϕ_s measurement $b_s^0 \rightarrow \phi j/\psi$ at cepc.
Technical report, IHEP, CAS.
- Shen, Y., Xiao, H., Li, H., Qin, S., Wang, Z., Wang, C., Zhang, D., and Ruan, M. (2019).
Photon Reconstruction Performance at the CEPC baseline detector.
- Tanabashi, M. et al. (2018).
Review of Particle Physics.
Phys. Rev., D98(3):030001.
- Yu, D., Ruan, M., Boudry, V., Videau, H., Brient, J.-C., Wu, Z., Ouyang, Q., Xu, Y., and Chen, X. (2020).
The measurement of the $H \rightarrow \tau\tau$ signal strength in the future e^+e^- Higgs factories.

-  Yu, D., Zheng, T., and Ruan, M. (2021).
Lepton identification performance in Jets at a future electron positron Higgs Z factory.
-  Zheng, T., Wang, J., Shen, Y., Cheung, Y.-K. E., and Ruan, M. (2020a).
Reconstructing K_S^0 and Λ in the CEPC baseline detector.
Eur. Phys. J. Plus, 135(3):274.
-  Zheng, T., Xu, J., Cao, L., Yu, D., Wang, W., Prell, S., Cheung, Y.-K. E., and Ruan, M. (2020b).
Analysis of $B_c \rightarrow \tau \nu_\tau$ at CEPC.