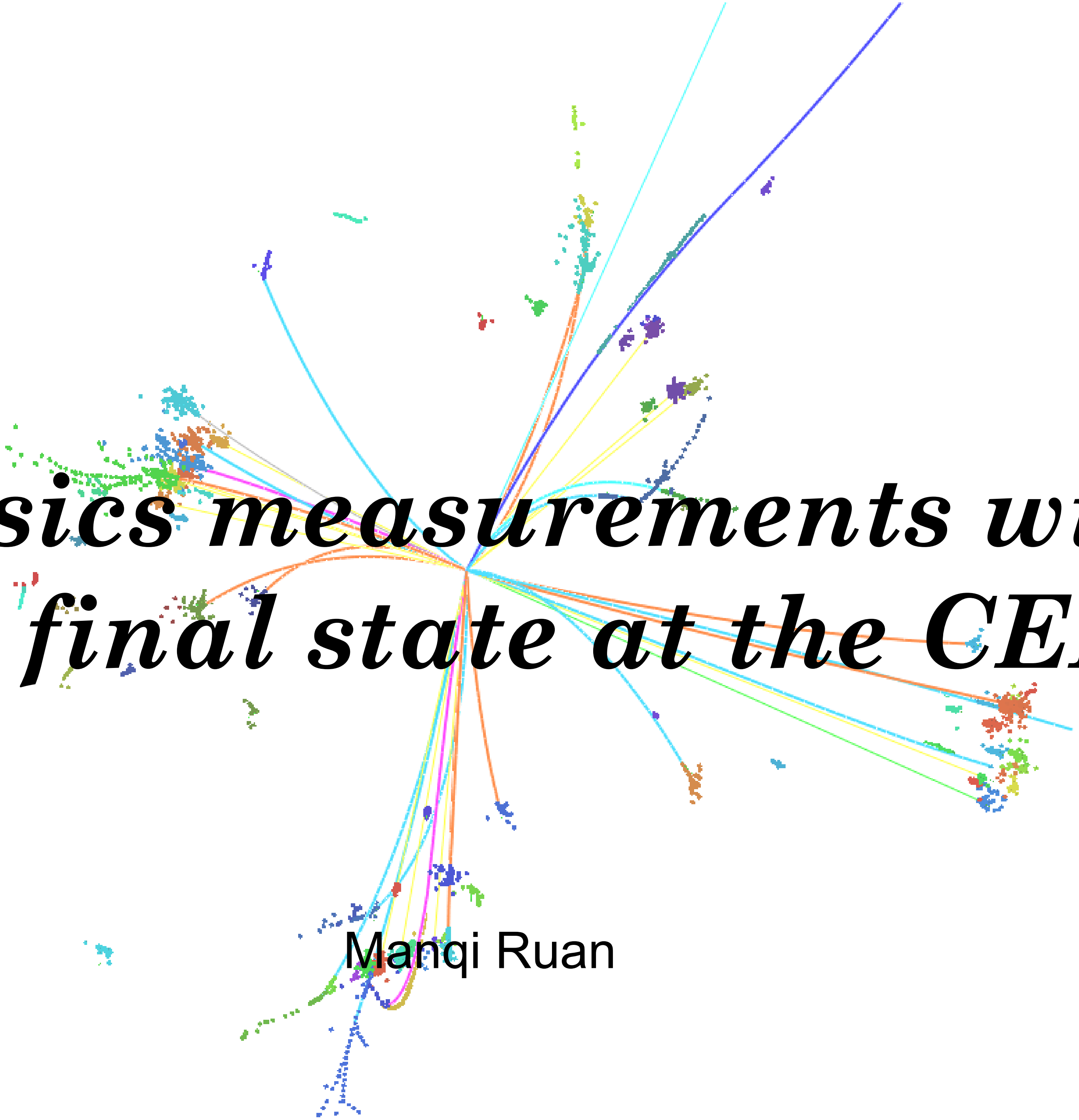
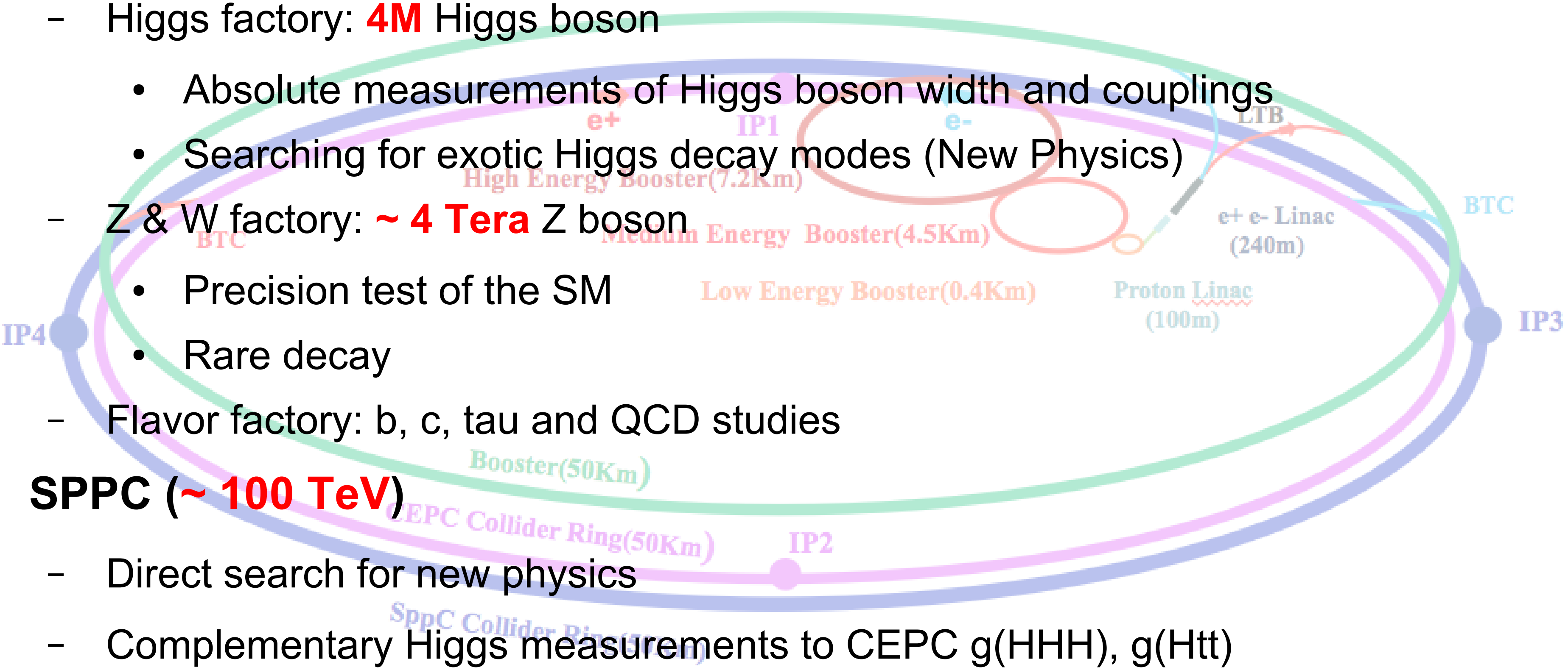


Physics measurements with Tau final state at the CEPC

Manqi Ruan

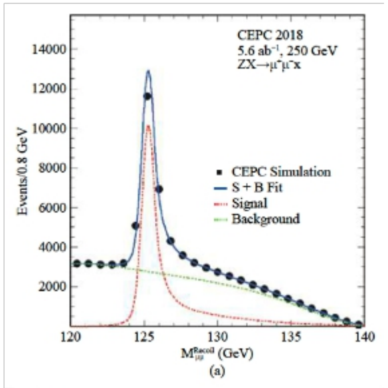
Key figures of the CEPC-SPPC



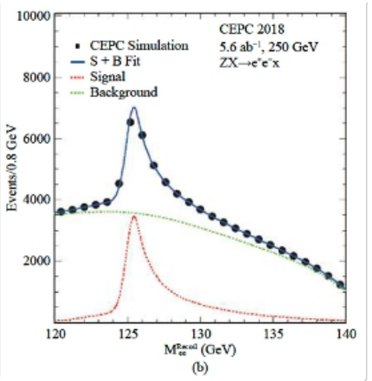
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **4M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 4 Tera** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

Complementary

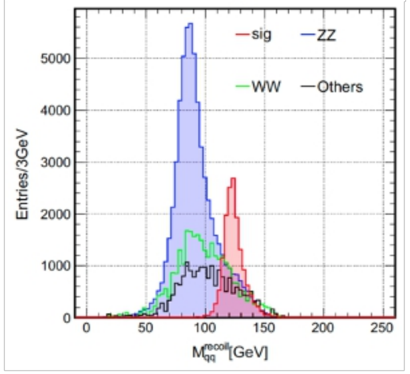
CEPC Physics



(a)



(b)



Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

Fenfen An(安芬芬)[4,23] Yu Bai(白羽)[9] Chunhui Chen(陈春晖)[23] Xin Chen(陈新)[5] Zhenxing Chen(陈振兴)[3]
Joao Guimaraes da Costa[4] Zhenwei Cui(崔振崴)[3] Yaquan Fang(方亚泉)[4,6,34,1)] Chengdong Fu(付成栋)[4]
Jun Gao(高俊)[10] Yanyan Gao(高艳彦)[22] Yuanning Gao(高原宁)[3] Shaofeng Ge(葛韶锋)[15,29]
Jiayin Gu(顾嘉荫)[13,2)] Fangyi Guo(郭方毅)[1,4] Jun Guo(郭军)[10] Tao Han(韩涛)[5,31] Shuang Han(韩爽)[4]
Hongjian He(何红建)[11,10] Xianke He(何显柯)[10] Xiaogang He(何小刚)[11,10,20] Jifeng Hu(胡继峰)[10]
Shih-Chieh Hsu(徐士杰)[32] Shan Jin(金山)[8] Maoqiang Jing(荆茂强)[4,7] Susmita Jyotishmati[33] Ryuta Kiuchi[4]
Chia-Ming Kuo(郭家铭)[21] Peizhu Lai(赖培筑)[21] Boyang Li(李博扬)[5] Congqiao Li(李聪乔)[3] Gang Li(李刚)[4,34,3)]
Haifeng Li(李海峰)[12] Liang Li(李亮)[10] Shu Li(李数)[11,10] Tong Li(李通)[12] Qiang Li(李强)[3] Hao Liang(梁浩)[4,6]
Zhijun Liang(梁志均)[4] Libo Liao(廖立波)[4] Bo Liu(刘波)[4,23] Jianbei Liu(刘建北)[1] Tao Liu(刘涛)[14]
Zhen Liu(刘真)[26,30,4)] Xinchou Lou(娄辛丑)[4,6,33,34] Lianliang Ma(马连良)[12] Bruce Mellado[17,18] Xin Mo(莫欣)[4]
Mila Pandurovic[16] Jianming Qian(钱剑明)[24,5)] Zhuoni Qian(钱卓妮)[19] Nikolaos Rompotis[22]
Manqi Ruan(阮曼奇)[4,6)] Alex Schuy[32] Lianyou Shan(单连友)[4] Jingyuan Shi(史静远)[9] Xin Shi(史欣)[4]
Shufang Su(苏淑芳)[25] Dayong Wang(王大勇)[3] Jin Wang(王锦)[4] Liantao Wang(王连涛)[27,7)]
Yifang Wang(王贻芳)[4,6] Yuqian Wei(魏彧骞)[4] Yue Xu(许悦)[5] Haijun Yang(杨海军)[10,11] Ying Yang(杨迎)[4]
Weiming Yao(姚为民)[28] Dan Yu(于丹)[4] Kaili Zhang(张凯栗)[4,6,8)] Zhaoru Zhang(张照茹)[4]
Mingrui Zhao(赵明锐)[2] Xianghu Zhao(赵祥虎)[4] Ning Zhou(周宁)[10]

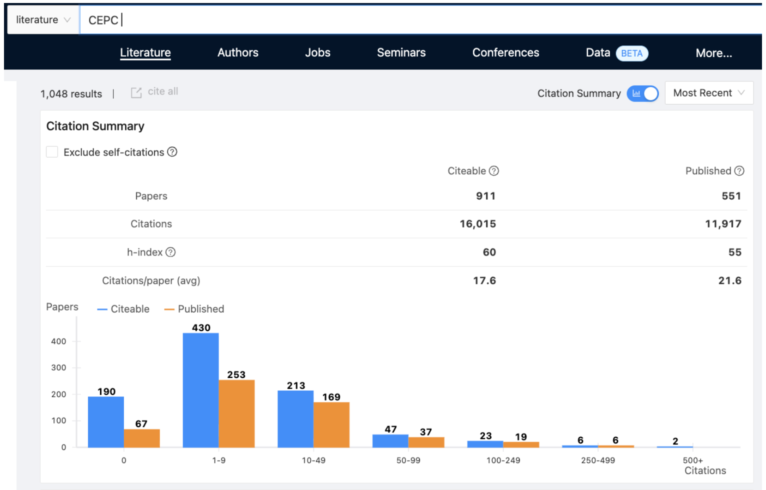
[1]Department of Modern Physics, University of Science and Technology of China, Anhui 230026, China
[2]China Institute of Atomic Energy, Beijing 102413, China
[3]School of Physics, Peking University, Beijing 100871, China
[4]Institute of High Energy Physics, Beijing 100049, China
[5]Department of Engineering Physics, Physics Department, Tsinghua University, Beijing 100084, China
[6]University of Chinese Academy of Science (UCAS), Beijing 100049, China
[7]School of Nuclear Science and Technology, University of South China, Hengyang 421001, China
[8]Department of Physics, Nanjing University, Nanjing 210093, China
[9]Department of Physics, Southeast University, Nanjing 210096, China
[10]School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai 200240, China
[11]Tsung-Dao Lee Institute, Shanghai 200240, China
[12]Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao 266237, China
[13]PRISMA Cluster of Excellence & Mainz Institute of Theoretical Physics, Johannes Gutenberg-Universität Mainz, Mainz 55128, Germany
[14]Department of Physics, Hong Kong University of Science and Technology, Hong Kong
[15]Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan
[16]Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade 11000, Serbia
[17]School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg 2050, South Africa

---

Received 9 November 2018, Revised 21 January 2019, Published online 4 March 2019

* Supported by the National Key Program for S&T Research and Development (2016YFA0400400); CAS Center for Excellence in Particle Physics; Yifang Wang's Science Studio of the Ten Thousand Talents Project; the CAS/SAFEA International Partnership Program for Creative Research Teams (H751S018S5); IHEP Innovation Grant (Y4545170Y2); Key Research Program of Frontier Sciences, CAS (XQYZDY-SSW-SLH002); Chinese Academy of Science Special Grant for Large Scientific Project (113111KYSB20170005); the National Natural Science Foundation of China(11675202); the Hundred Talent Programs of Chinese Academy of Science (Y3515540U1); the National 1000 Talents Program of China; Fermi Research Alliance, LLC (DE-AC02-07CH11359); the NSF(PHY1620074) ; by the Maryland Center for Fundamental Physics (MCFP); Tsinghua University Initiative Scientific Research Program; and the Beijing Municipal Science and Technology Commission project(Z181100004218003)

1) E-mail: fangyq@ihep.ac.cn
2) E-mail: jiagu@uni-mainz.de
3) E-mail: li.gang@mail.ihep.ac.cn
4) E-mail: zliuphys@umd.edu
5) E-mail: qianj@umich.edu
6) E-mail: manqi.ruan@ihep.ac.cn
7) E-mail: liantaow@uchicago.edu
8) E-mail: zhangkl@ihep.ac.cn



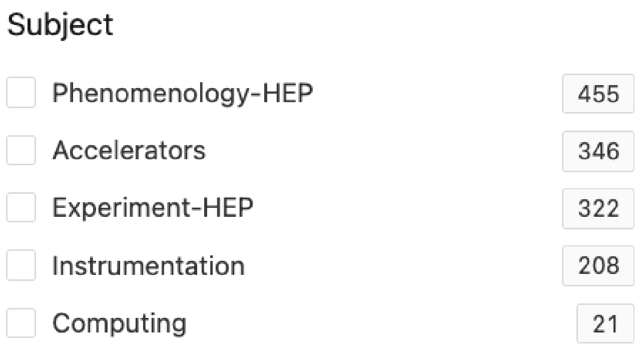
1,048 results

Citation Summary

Citation Summary

☐ Exclude self-citations

	Citeable	Published
Papers	911	551
Citations	16,015	11,917
h-index	60	55
Citations/paper (avg)	17.6	21.6



Subject

☐	Phenomenology-HEP	455
☐	Accelerators	346
☐	Experiment-HEP	322
☐	Instrumentation	208
☐	Computing	21

Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude.
- EW: Precision improved from current limit by 1-2 orders.
- Flavor Physics, sensitive to NP of 10 TeV or even higher.
- Sensitive to varies of NP signal.
- …

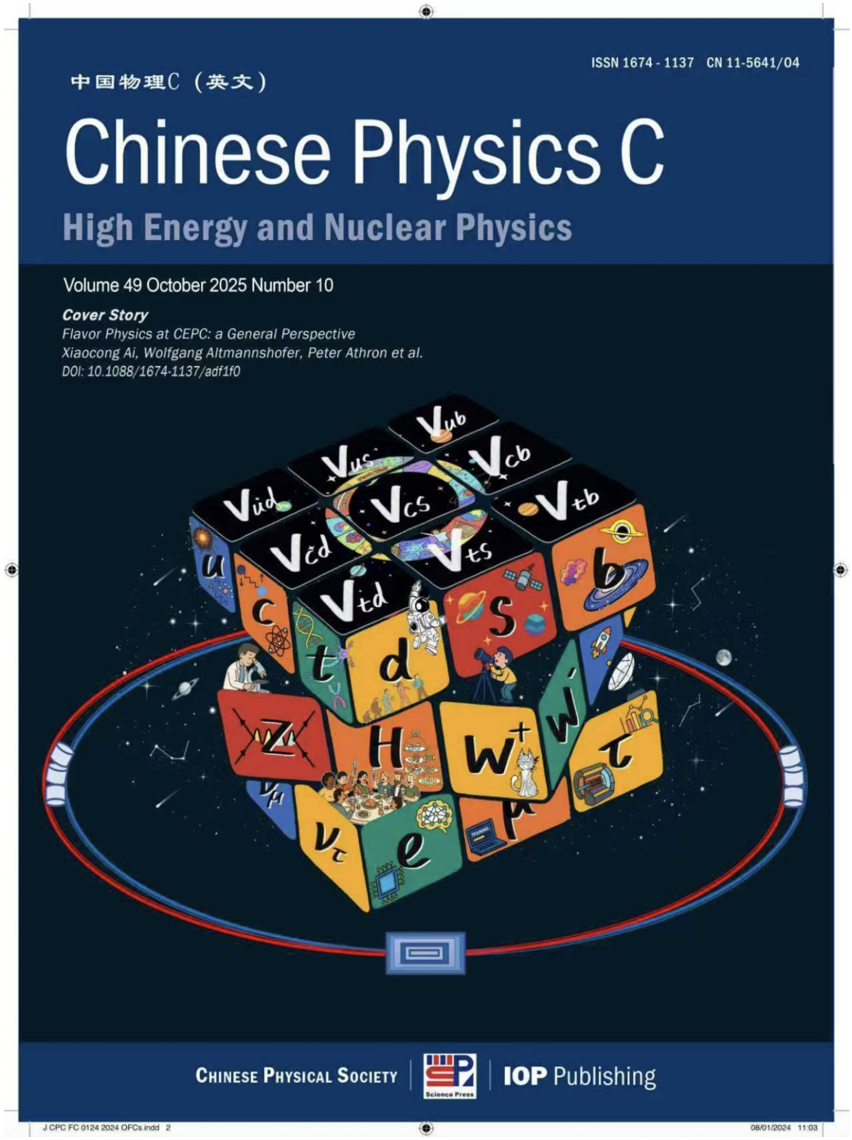
~ 500 Physics citables

Physics reaches

- Higgs: 2019, CPC
- ESPPU input: 2019 ArXiv
- Snowmass input: 2022 ArXiv

- **Flavor physics: 2025, CPC**
- **New physics: CPC, CPC**

- **Current focus**
  - **EW White paper**
  - **QCD studies**
  - Reco & Det. Optimization
  - …


中国物理C（英文）

ISSN 1674 - 1137 CN 11-5641/04

Chinese Physics C

High Energy and Nuclear Physics

Volume 49 October 2025 Number 10

Cover Story

Flavor Physics at CEPC: a General Perspective

Xiaocong Ai, Wolfgang Altmannshofer, Peter Athron et al.

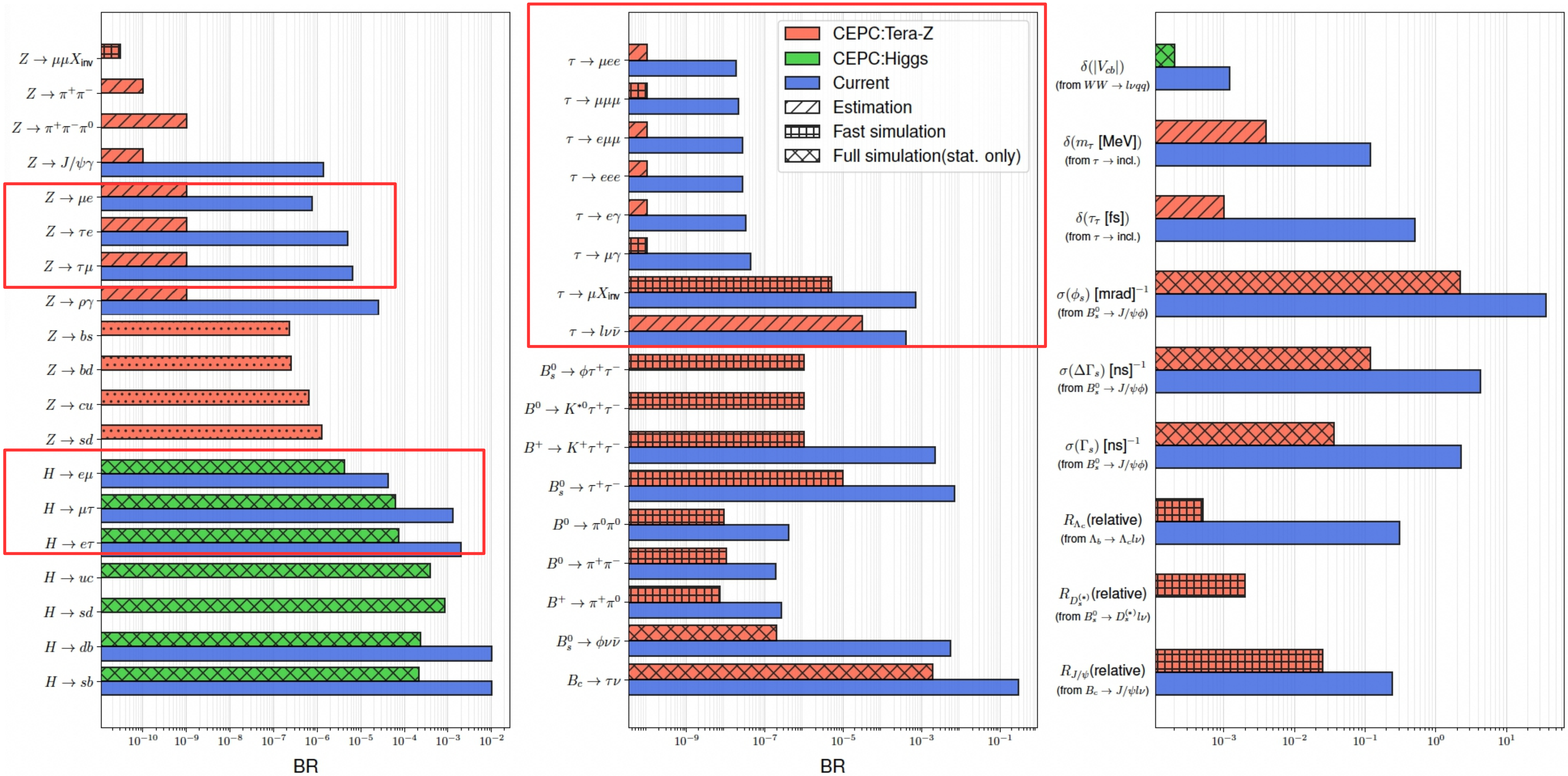
DOI: 10.1088/1674-1137/adf1f0

CHINESE PHYSICAL SOCIETY

IOP Publishing

J CPC FC 0124 2024 OFCs.indd 2 08/01/2024 11:03

Flavor Physics

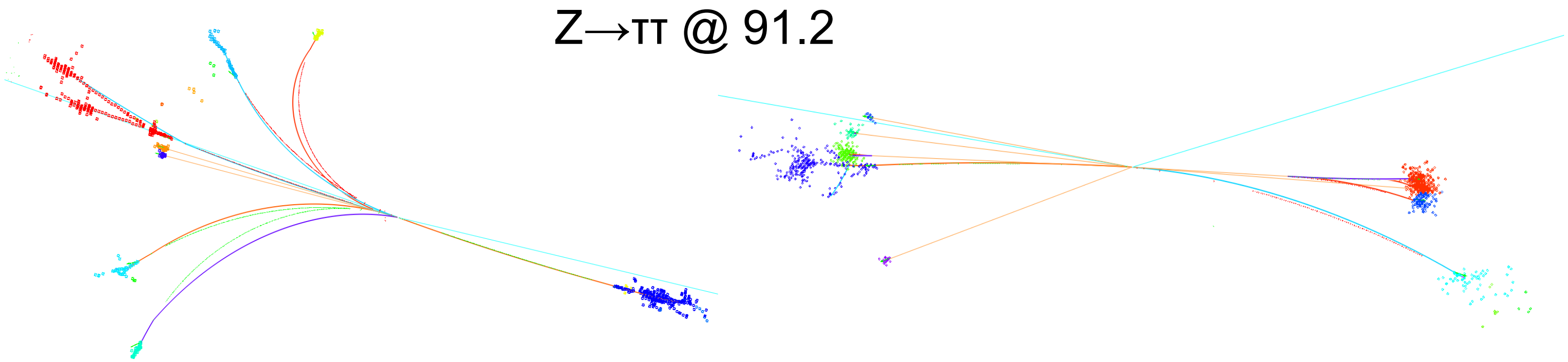


See the non-seen: i.e, Bc→tauv, Bs→Phivv

Orders of magnitudes improvements (1 – 2.5 orders...).

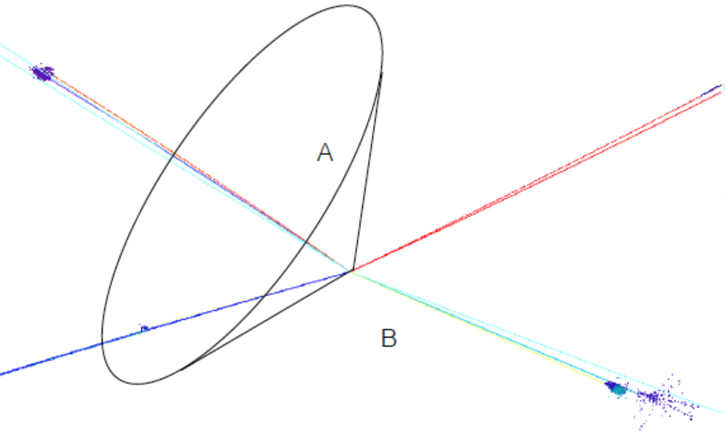
Access New Physics with energy scale of 10 TeV, or even above

Taus at the CEPC

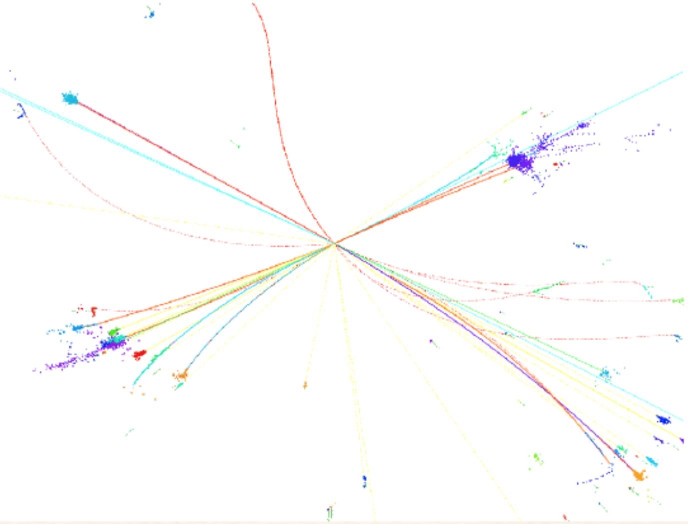


Z→ττ @ 91.2

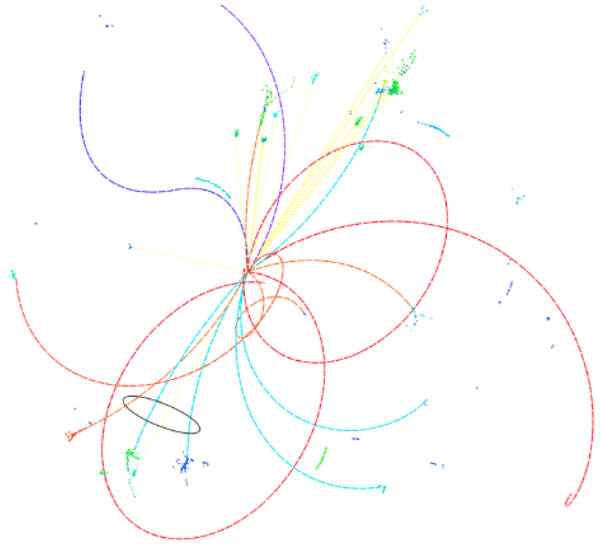
- Finding Tau
- Identify tau decay product



Leptonic:
ZH, Z→ll/vv, H→ττ
Z→ττ

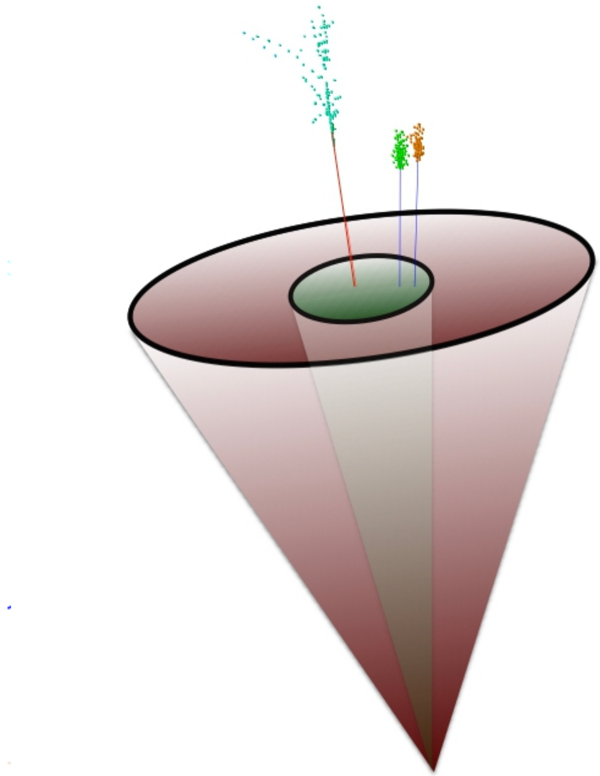


Semi-Leptonic:
ZH, Z→qq, H→ττ
WW→τvqq

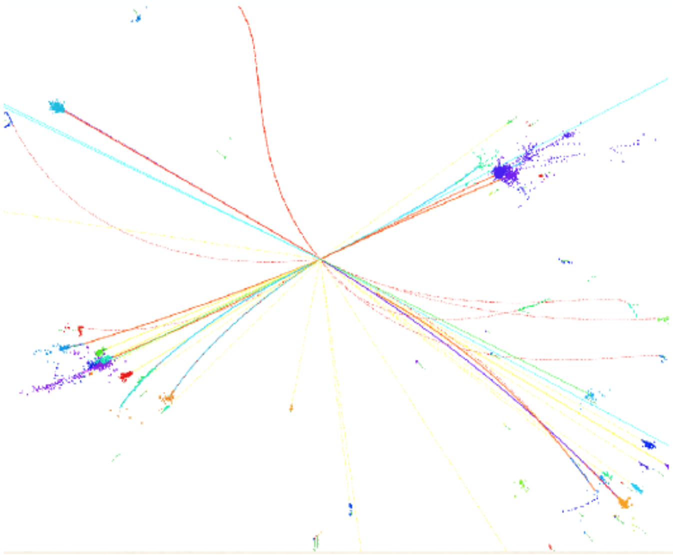


Full-Hadronic:
Z→qq→τ + X

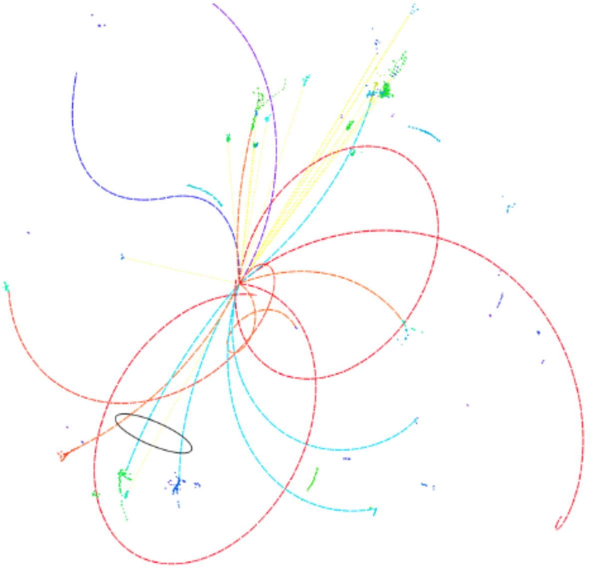
Taus at the CEPC



Semi-Leptonic:
ZH, Z→qq, H→ττ
WW→τνqq



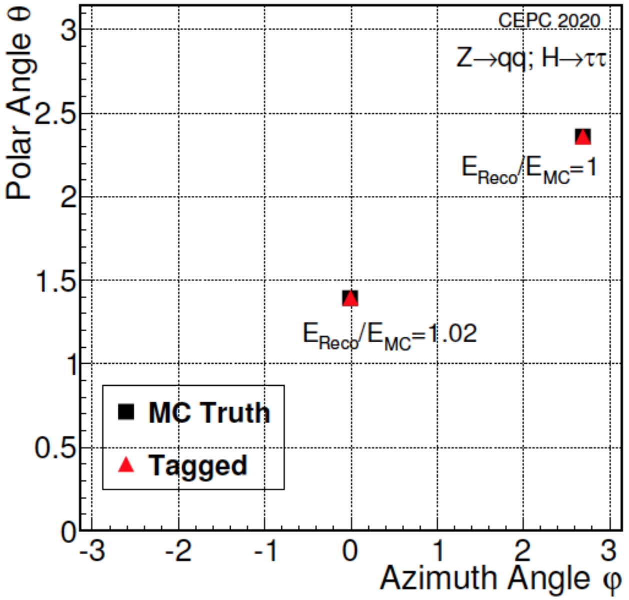
Full-Hadronic:
Z→qq→τ + X



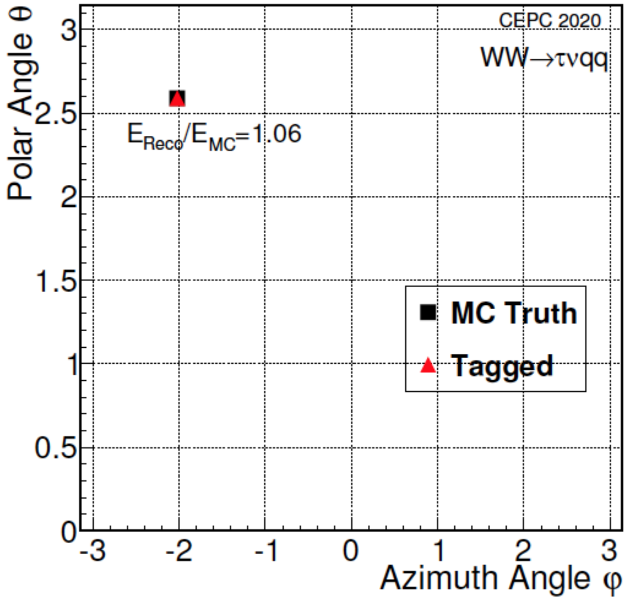
TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for qqττ, and qqτν events

TAURUS/Specify Tau decay product

Eff ~ 80%
Purity ~ 85%



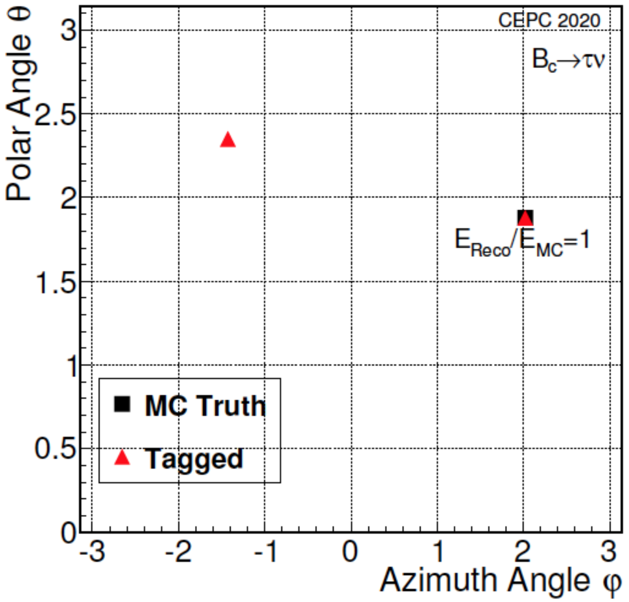
(a) $Z \to qq, H \to \tau\tau$, efficiency=1, purity=1



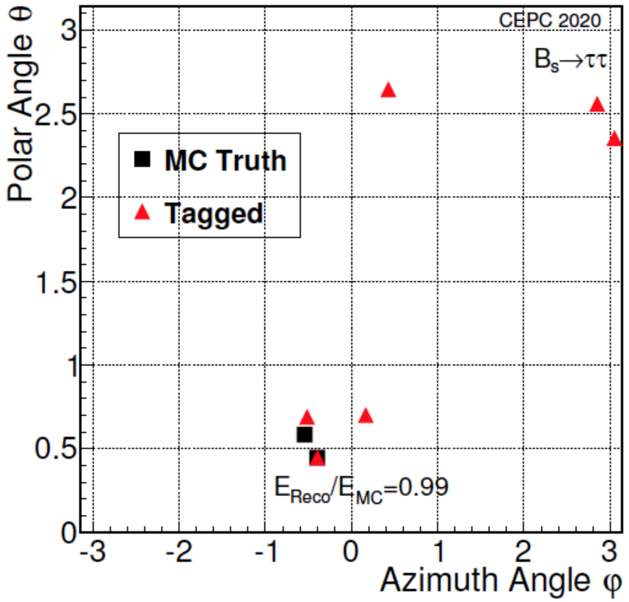
(b) $WW \to \tau\nu qq$, efficiency=1, purity=1

Eff ~ 80%
Purity ~ 85%

Eff ~ 60%
Purity ~ 75%



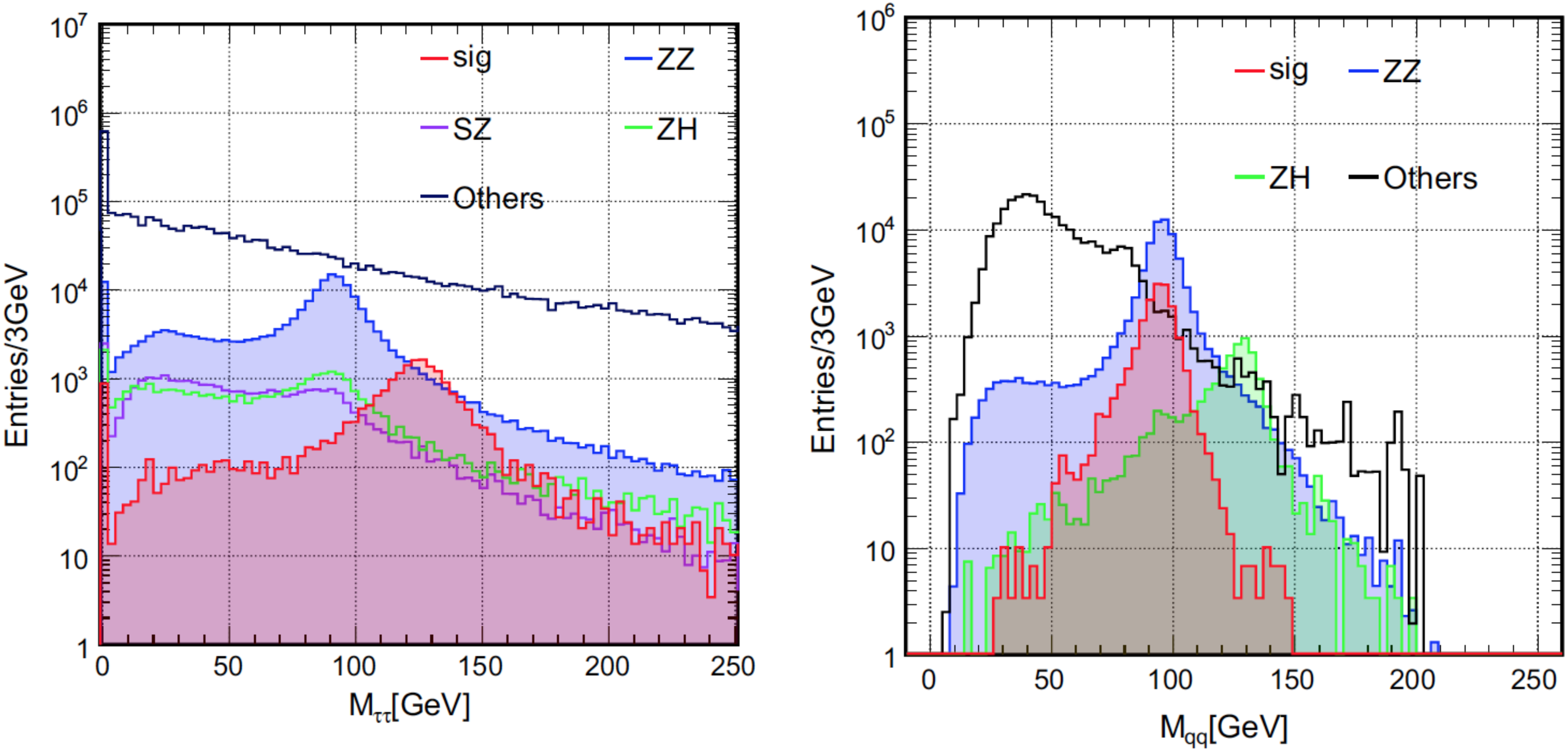
(c) $Z \to b\overline{b}, B_c \to \tau\nu$, efficiency=1, purity=0.5



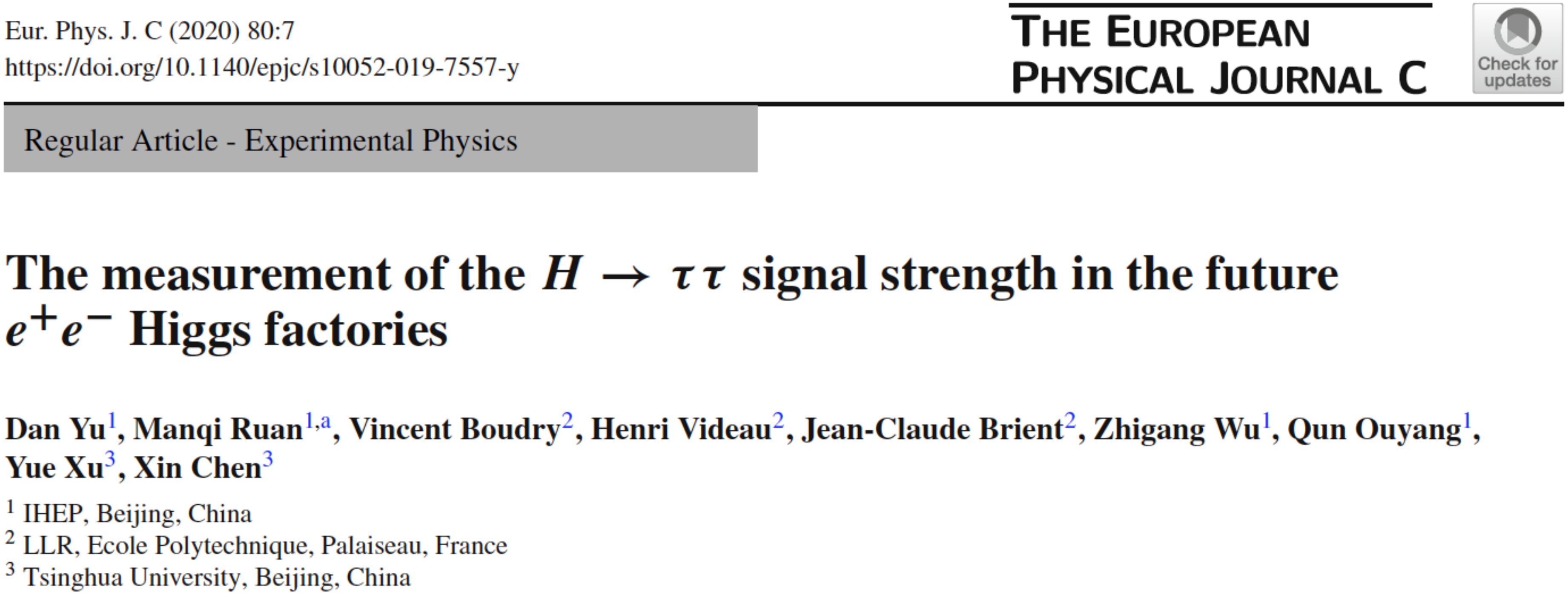
(d) $Z \to b\overline{b}, B_s \to \tau\tau$, efficiency=0.5, purity=0.167

Eff ~ 25%
Purity ~ 30%

Signal strength measurement of qqH, H→ττ @ 240 GeV



Invariant mass of di-tau: collinear approximation that assumes the neutrinos aligns with the direction of visible tau decay product



Eur. Phys. J. C (2020) 80:7
https://doi.org/10.1140/epjc/s10052-019-7557-y

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

The measurement of the $H \to \tau\tau$ signal strength in the future e^+e^- Higgs factories

Dan Yu[1], **Manqi Ruan**[1,a], **Vincent Boudry**[2], **Henri Videau**[2], **Jean-Claude Brient**[2], **Zhigang Wu**[1], **Qun Ouyang**[1], **Yue Xu**[3], **Xin Chen**[3]

[1] IHEP, Beijing, China
[2] LLR, Ecole Polytechnique, Palaiseau, France
[3] Tsinghua University, Beijing, China

Received: 22 July 2019 / Accepted: 12 December

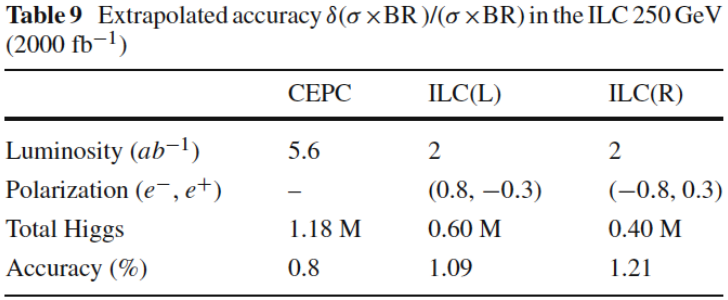
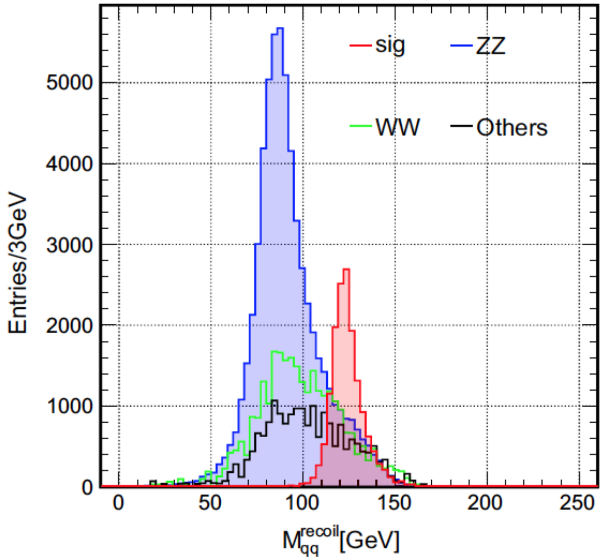
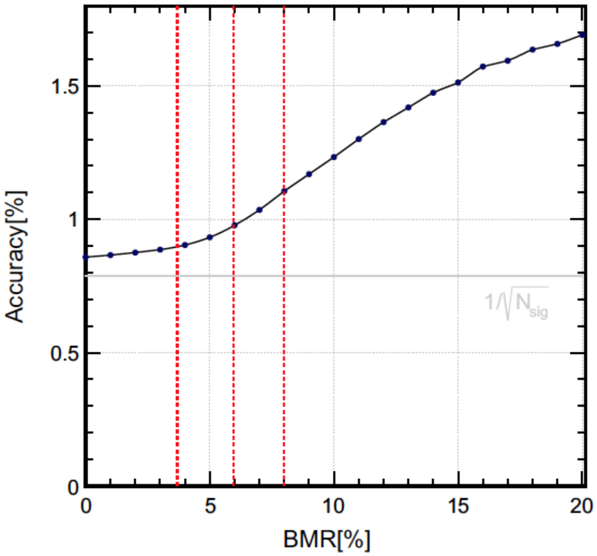


Table 9 Extrapolated accuracy $\delta(\sigma \times \mathrm{BR})/(\sigma \times \mathrm{BR})$ in the ILC 250 GeV (2000 fb^{-1})

	CEPC	ILC(L)	ILC(R)
Luminosity (ab^{-1})	5.6	2	2
Polarization (e^-, e^+)	–	(0.8, −0.3)	(−0.8, 0.3)
Total Higgs	1.18 M	0.60 M	0.40 M
Accuracy (%)	0.8	1.09	1.21





LFV Higgs decays

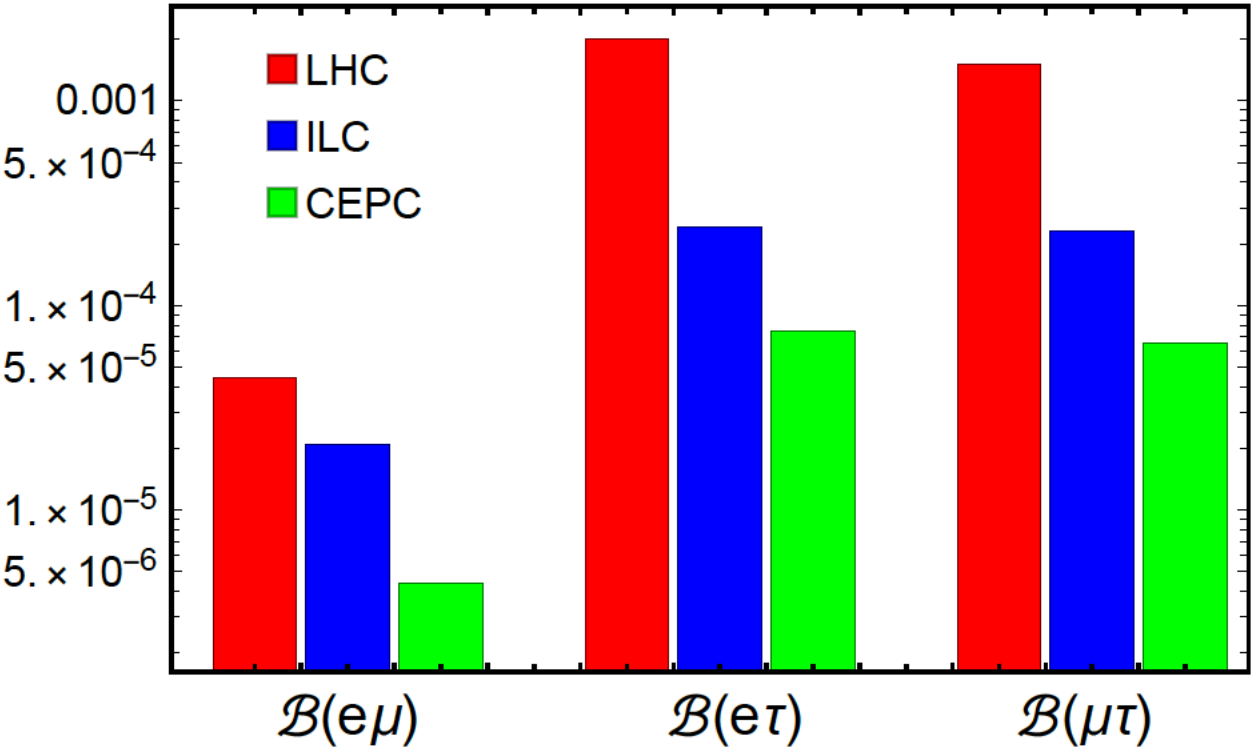
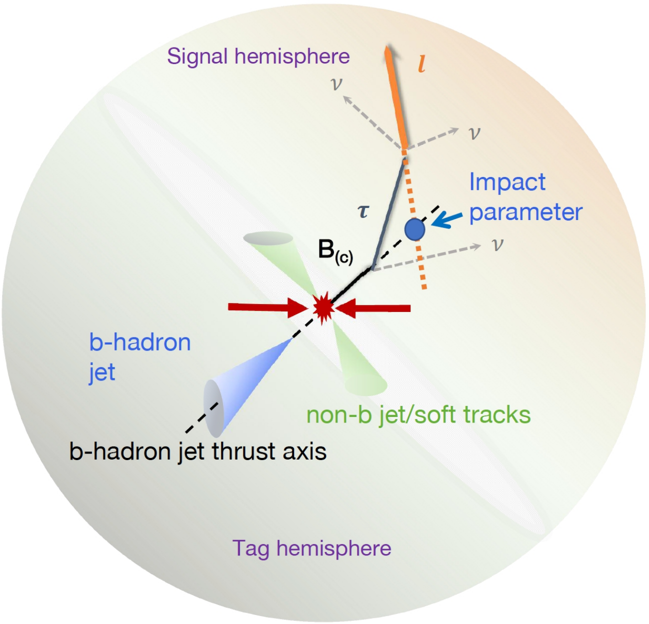
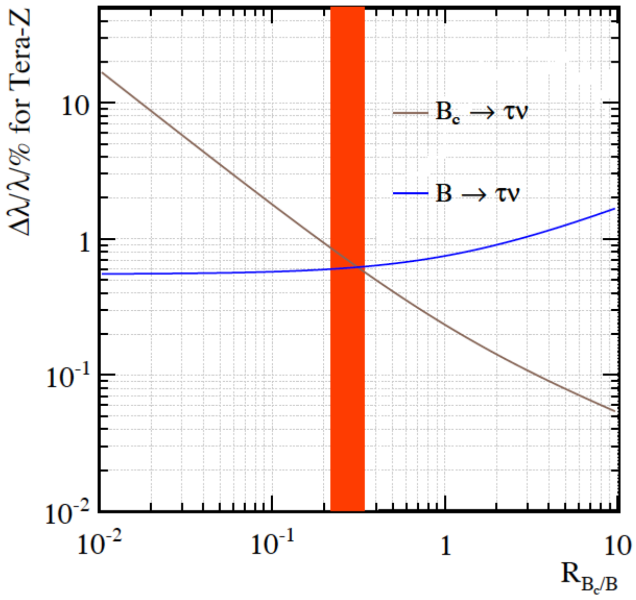
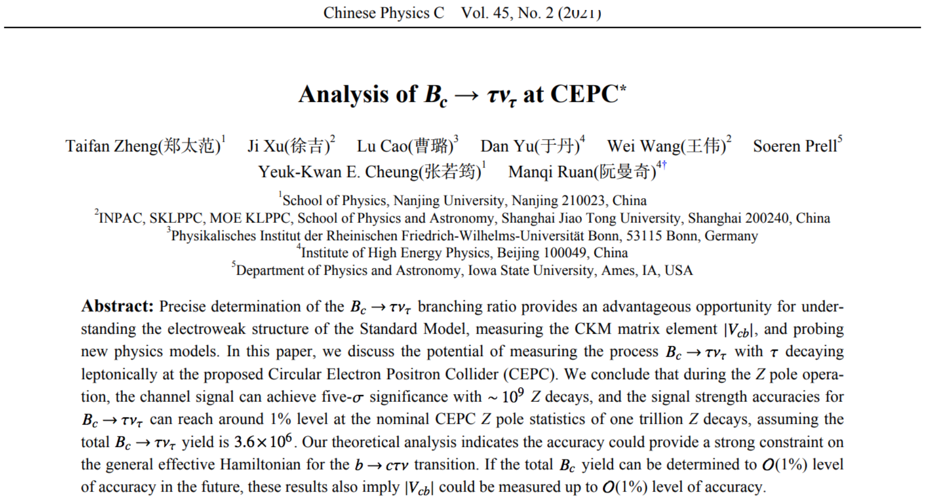


Figure 33: Projected upper limits on the LFV Higgs decays at the LHC, ILC and CEPC. The figure is updated from [250].

Bc->Tauv







Chinese Physics C Vol. 45, No. 2 (2021)

Analysis of $B_c \to \tau\nu_\tau$ at CEPC*

Taifan Zheng(郑太范)[1] Ji Xu(徐吉)[2] Lu Cao(曹璐)[3] Dan Yu(于丹)[4] Wei Wang(王伟)[2] Soeren Prell[5]
Yeuk-Kwan E. Cheung(张若筠)[1] Manqi Ruan(阮曼奇)[4†]

[1]School of Physics, Nanjing University, Nanjing 210023, China
[2]INPAC, SKLPPC, MOE KLPPC, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China
[3]Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany
[4]Institute of High Energy Physics, Beijing 100049, China
[5]Department of Physics and Astronomy, Iowa State University, Ames, IA, USA

Abstract: Precise determination of the $B_c \to \tau\nu_\tau$ branching ratio provides an advantageous opportunity for understanding the electroweak structure of the Standard Model, measuring the CKM matrix element $|V_{cb}|$, and probing new physics models. In this paper, we discuss the potential of measuring the process $B_c \to \tau\nu_\tau$ with τ decaying leptonically at the proposed Circular Electron Positron Collider (CEPC). We conclude that during the Z pole operation, the channel signal can achieve five-σ significance with $\sim 10^9$ Z decays, and the signal strength accuracies for $B_c \to \tau\nu_\tau$ can reach around 1% level at the nominal CEPC Z pole statistics of one trillion Z decays, assuming the total $B_c \to \tau\nu_\tau$ yield is 3.6×10^6. Our theoretical analysis indicates the accuracy could provide a strong constraint on the general effective Hamiltonian for the $b \to c\tau\nu$ transition. If the total B_c yield can be determined to $O(1\%)$ level of accuracy in the future, these results also imply $|V_{cb}|$ could be measured up to $O(1\%)$ level of accuracy.

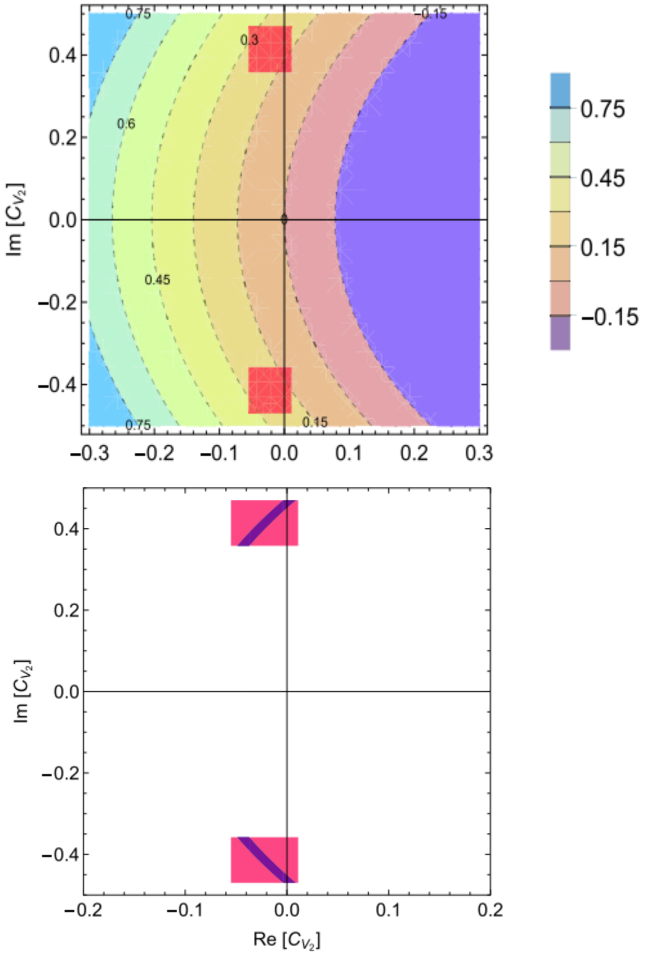
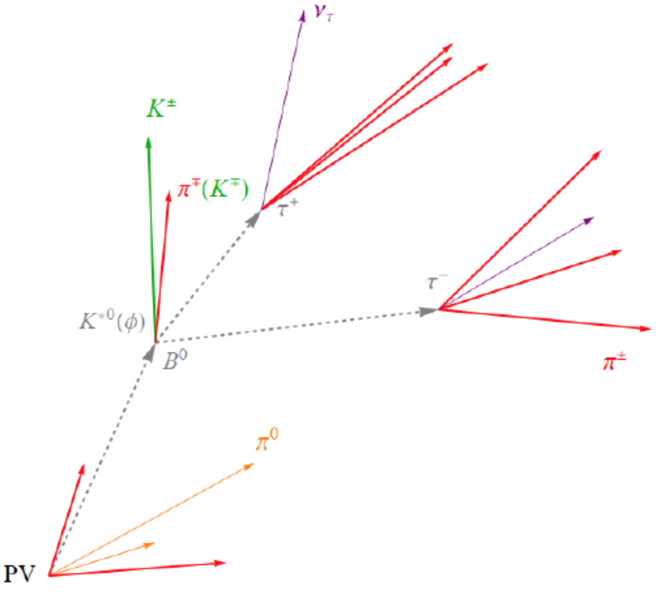


Fig. 10. (color online) Constraints on the real and imaginary parts of C_{V_2}. The red shaded area corresponds to the current constraints using available data on $b \to c\tau\nu$ decays. If the central values in Eq. (9) remain while the uncertainty in $\Gamma(B_c^+ \to \tau^+\nu_\tau)$ is reduced to 1%, the allowed region for C_{V_2} shrinks to the dark-blue regions.

LFU Test with $b \to s\tau\tau$ Measurements

More details in the published work (arXiv:2012.00665) [Li and Liu(2020)]

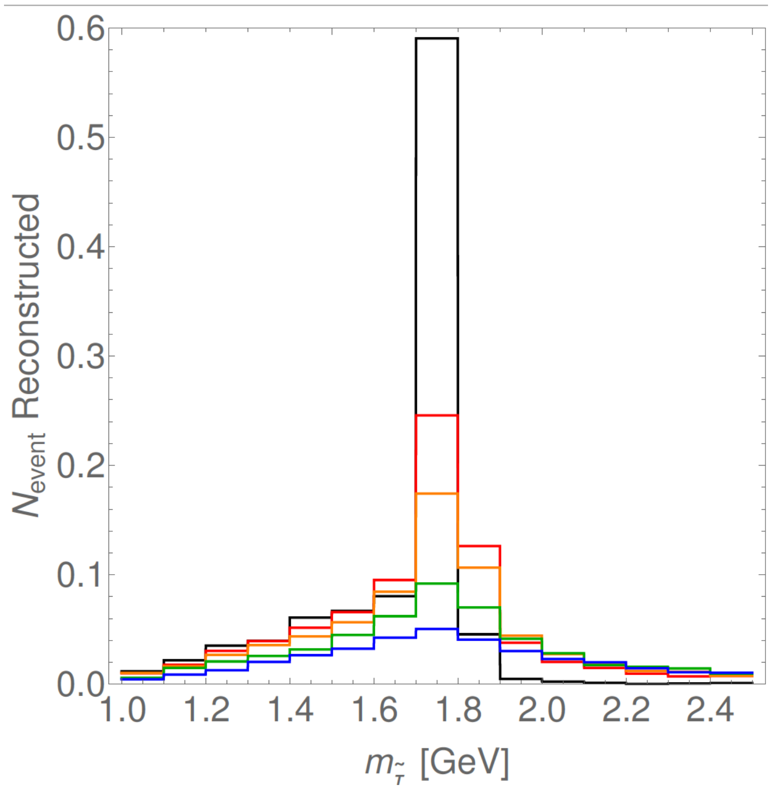


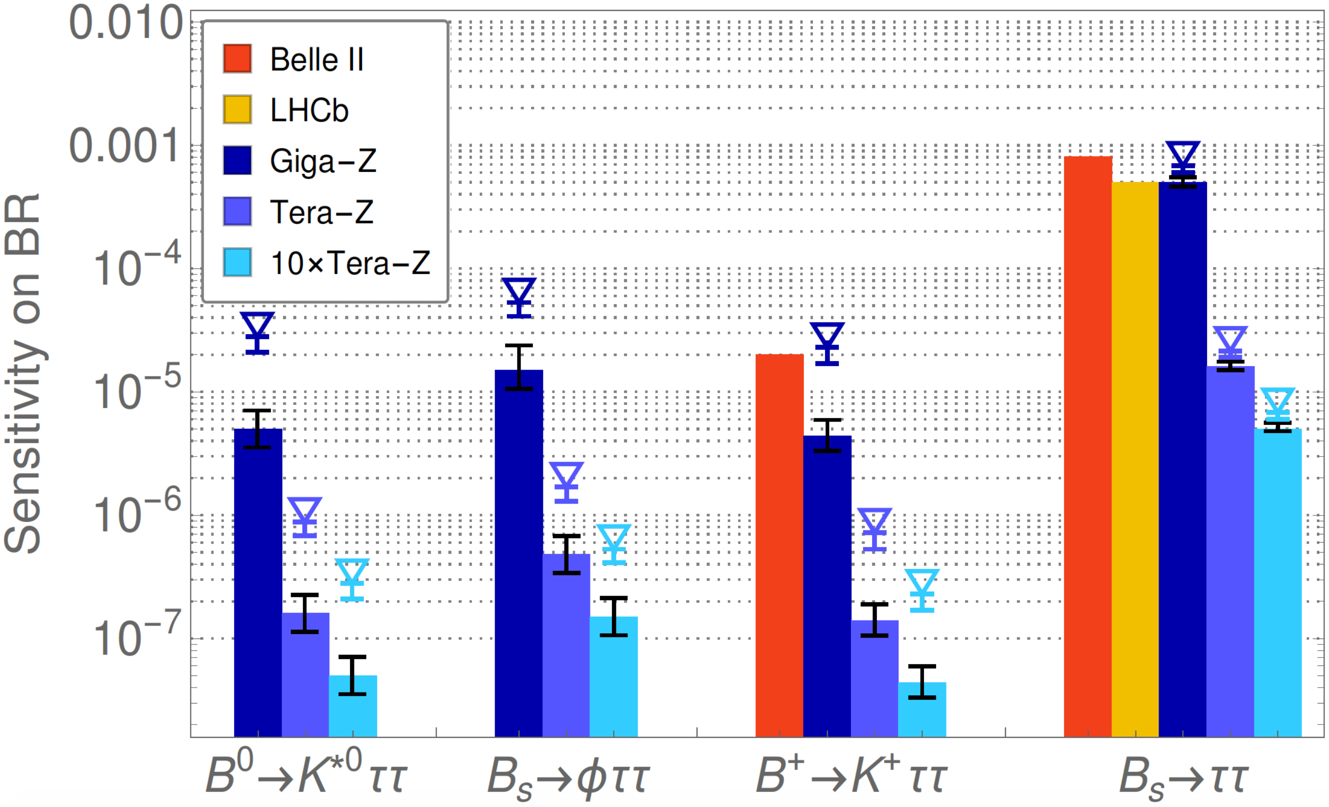
Use $\tau \to \pi^\pm\pi^\pm\pi^\mp\nu$ decay to locate each vertex

Fake 3π vertex from $D^\pm_{(s)} \to \pi^\pm\pi^\pm\pi^\mp + X$ decays:

	Properties	Decay Mode	BR
$\tau^\pm$	$m = 1.777$ GeV $c\tau = 87.0$ μm	$\pi^\pm\pi^\pm\pi^\mp\nu$	9.3%
		$\pi^\pm\pi^\pm\pi^\mp\pi^0\nu$	4.6%
$D_s^\pm$	$m = 1.968$ GeV $c\tau = 151$ μm	$\tau^\pm\nu$	5.5%
		$\pi^\pm\pi^\pm\pi^\mp\pi^0$	0.6%
		$\pi^\pm\pi^\pm\pi^\mp 2\pi^0$	4.6%
		$\pi^\pm\pi^\pm\pi^\mp K_S^0$	0.3%
		$\pi^\pm\pi^\pm\pi^\mp\phi$	1.2%
$D^\pm$	$m = 1.870$ GeV $c\tau = 311$ μm	$\tau^\pm\nu$	$< 0.12\%$
		$\pi^\pm\pi^\pm\pi^\mp\pi^0$	1.1%
		$\pi^\pm\pi^\pm\pi^\mp K_S^0$	3.0%

Sensitive to VTX Performance





LINGFENG @ HKIAS

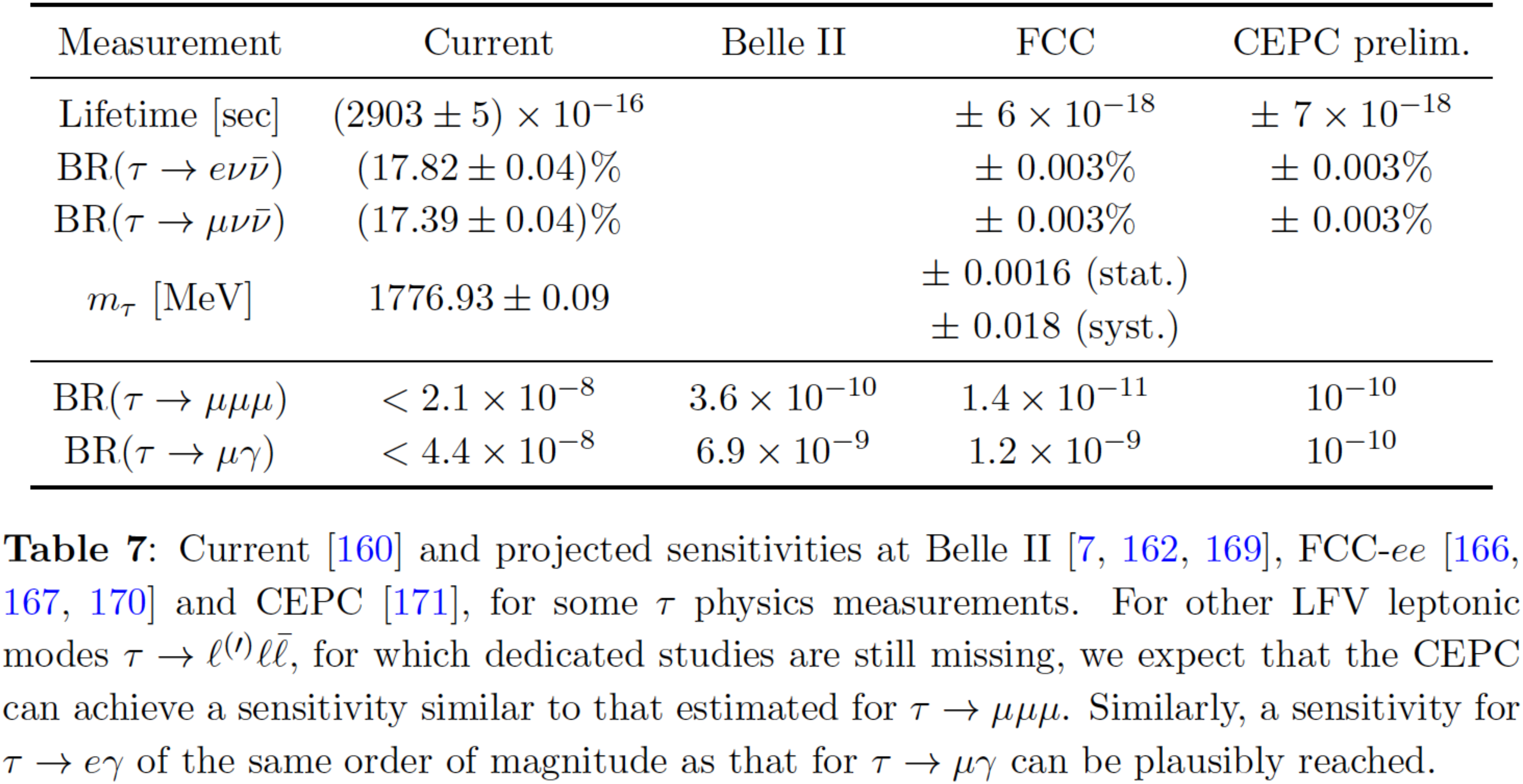
...

Contamination of D decay that mimics tau 3-prong decay;

reconstruction accuracy V.S final accuracy: ideal, 1, 2, 5, 10μm resolution

...

Tau decay: SM & BSM



Measurement	Current	Belle II	FCC	CEPC prelim.
Lifetime [sec]	$(2903 \pm 5) \times 10^{-16}$		$\pm\ 6 \times 10^{-18}$	$\pm\ 7 \times 10^{-18}$
$\mathrm{BR}(\tau \to e\nu\bar{\nu})$	$(17.82 \pm 0.04)\%$		$\pm\ 0.003\%$	$\pm\ 0.003\%$
$\mathrm{BR}(\tau \to \mu\nu\bar{\nu})$	$(17.39 \pm 0.04)\%$		$\pm\ 0.003\%$	$\pm\ 0.003\%$
m_τ [MeV]	1776.93 ± 0.09		$\pm\ 0.0016$ (stat.) $\pm\ 0.018$ (syst.)	
$\mathrm{BR}(\tau \to \mu\mu\mu)$	$< 2.1 \times 10^{-8}$	3.6×10^{-10}	1.4×10^{-11}	10^{-10}
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	6.9×10^{-9}	1.2×10^{-9}	10^{-10}

Table 7: Current [160] and projected sensitivities at Belle II [7, 162, 169], FCC-*ee* [166, 167, 170] and CEPC [171], for some τ physics measurements. For other LFV leptonic modes $\tau \to \ell^{(\prime)}\ell\bar{\ell}$, for which dedicated studies are still missing, we expect that the CEPC can achieve a sensitivity similar to that estimated for $\tau \to \mu\mu\mu$. Similarly, a sensitivity for $\tau \to e\gamma$ of the same order of magnitude as that for $\tau \to \mu\gamma$ can be plausibly reached.

Z decay: SM & BSM with tau

Measurement	Current	HL-LHC	FCC	CEPC prelim.
BR$(Z \to \tau\mu)$	$< 6.5 \times 10^{-6}$	1.4×10^{-6}	10^{-9}	10^{-9}
BR$(Z \to \tau e)$	$< 5.0 \times 10^{-6}$	1.1×10^{-6}	10^{-9}	
BR$(Z \to \mu e)$	$< 2.62 \times 10^{-7}$	5.7×10^{-8}	$10^{-8} - 10^{-10}$	10^{-9}

Table 8: Current 95% CL limits on LFV in Z decays [225, 226] and projected sensitivities at HL-LHC and the FCC-*ee* [166] and CEPC [171] Z factories (see also [222]). For HL-LHC, we naively scaled the current limits, which were obtained by ATLAS employing 139 fb^{-1} of data [225, 226], to the target luminosity 3000 fb^{-1}.

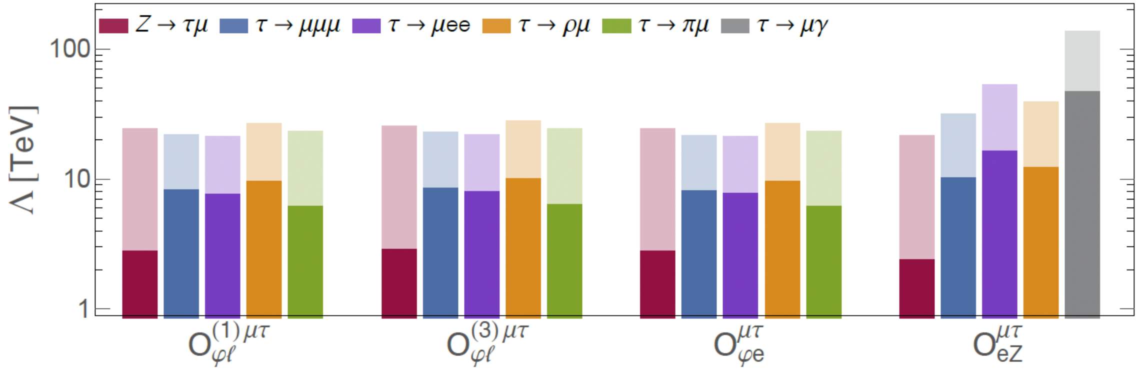


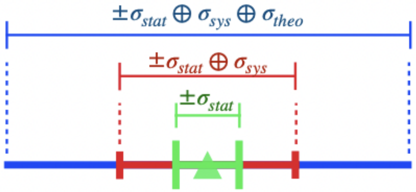
Figure 28: Sensitivity reach for probing the NP scale of the LFV operators in Eq. (8.1) and Eq. (8.2). Here the current bounds (dark-colored bars) are set by ATLAS [225] ($Z \to \tau\mu$) and B factories [160] (LFV τ decays), and the projected sensitivities (light-colored bars) are based on searches for $Z \to \tau\mu$ at the CEPC Z pole run with 100 ab^{-1} and $\tau \to \mu$ transitions at Belle II with 50 ab^{-1} [7], see Tables 7 and 8. The Wilson coefficients have been set equal to one uniformly. This plot is taken from Ref. [221].

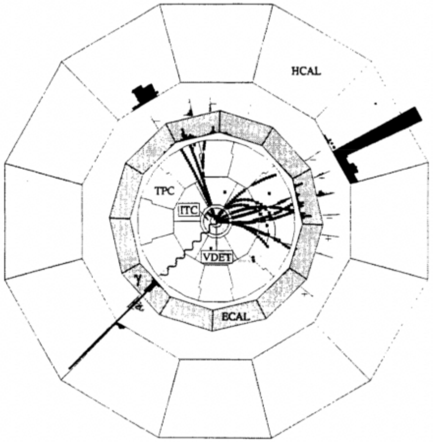
QCD: α_s measurement from tau decay

$$\pm 0.4\%_{stat} \pm 1.4\%_{sys} \pm 3.3\ \%_{theo}$$

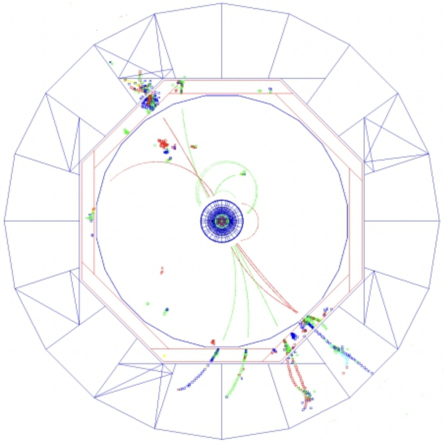
$\alpha_s(m_\tau)$

ALEPH(2014)

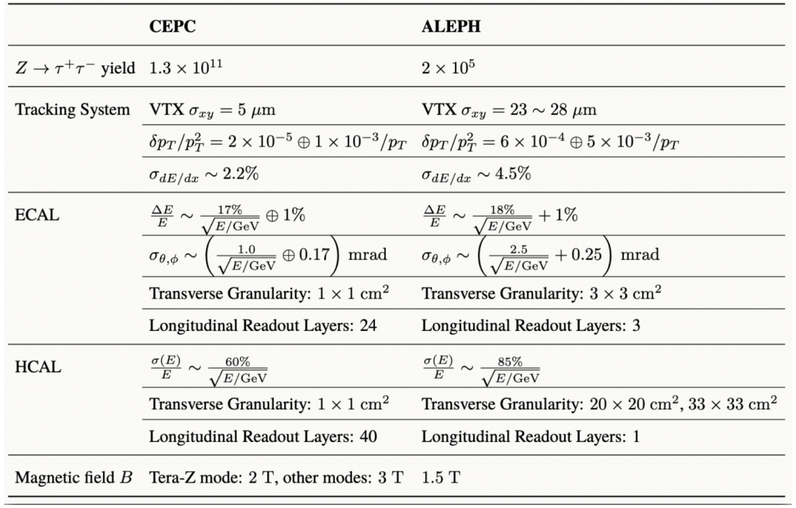




ALEPH Event display



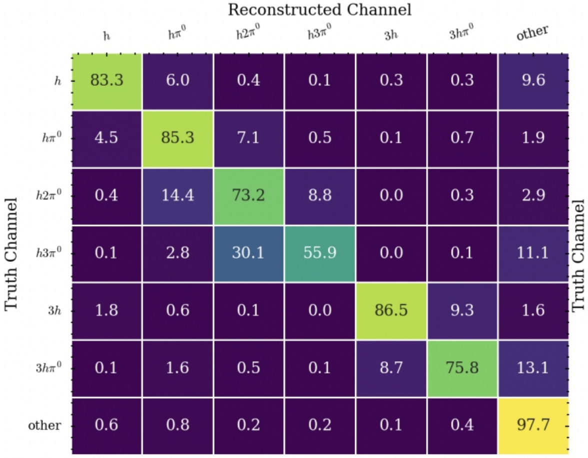
CEPC Event display



	CEPC	ALEPH
$Z \to \tau^+\tau^-$ yield	1.3×10^{11}	2×10^5
Tracking System	VTX $\sigma_{xy} = 5\ \mu\text{m}$	VTX $\sigma_{xy} = 23 \sim 28\ \mu\text{m}$
	$\delta p_T/p_T^2 = 2 \times 10^{-5} \oplus 1 \times 10^{-3}/p_T$	$\delta p_T/p_T^2 = 6 \times 10^{-4} \oplus 5 \times 10^{-3}/p_T$
	$\sigma_{dE/dx} \sim 2.2\%$	$\sigma_{dE/dx} \sim 4.5\%$
ECAL	$\frac{\Delta E}{E} \sim \frac{17\%}{\sqrt{E/\text{GeV}}} \oplus 1\%$	$\frac{\Delta E}{E} \sim \frac{18\%}{\sqrt{E/\text{GeV}}} + 1\%$
	$\sigma_{\theta,\phi} \sim \left(\frac{1.0}{\sqrt{E/\text{GeV}}} \oplus 0.17\right)$ mrad	$\sigma_{\theta,\phi} \sim \left(\frac{2.5}{\sqrt{E/\text{GeV}}} + 0.25\right)$ mrad
	Transverse Granularity: $1 \times 1\ \text{cm}^2$	Transverse Granularity: $3 \times 3\ \text{cm}^2$
	Longitudinal Readout Layers: 24	Longitudinal Readout Layers: 3
HCAL	$\frac{\sigma(E)}{E} \sim \frac{60\%}{\sqrt{E/\text{GeV}}}$	$\frac{\sigma(E)}{E} \sim \frac{85\%}{\sqrt{E/\text{GeV}}}$
	Transverse Granularity: $1 \times 1\ \text{cm}^2$	Transverse Granularity: $20 \times 20\ \text{cm}^2$, $33 \times 33\ \text{cm}^2$
	Longitudinal Readout Layers: 40	Longitudinal Readout Layers: 1
Magnetic field B	Tera-Z mode: 2 T, other modes: 3 T	1.5 T

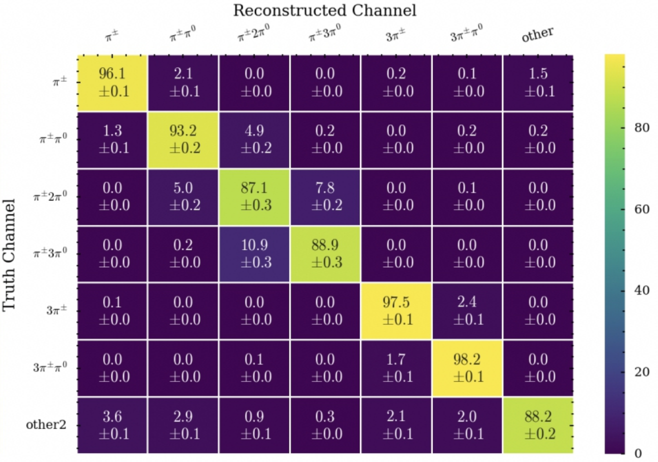
ALEPH

10.1016/j.physrep.2005.06.007



	h	$h\pi^0$	$h2\pi^0$	$h3\pi^0$	$3h$	$3h\pi^0$	other
h	83.3	6.0	0.4	0.1	0.3	0.3	9.6
$h\pi^0$	4.5	85.3	7.1	0.5	0.1	0.7	1.9
$h2\pi^0$	0.4	14.4	73.2	8.8	0.0	0.3	2.9
$h3\pi^0$	0.1	2.8	30.1	55.9	0.0	0.1	11.1
$3h$	1.8	0.6	0.1	0.0	86.5	9.3	1.6
$3h\pi^0$	0.1	1.6	0.5	0.1	8.7	75.8	13.1
other	0.6	0.8	0.2	0.2	0.1	0.4	97.7

CEPC GNN



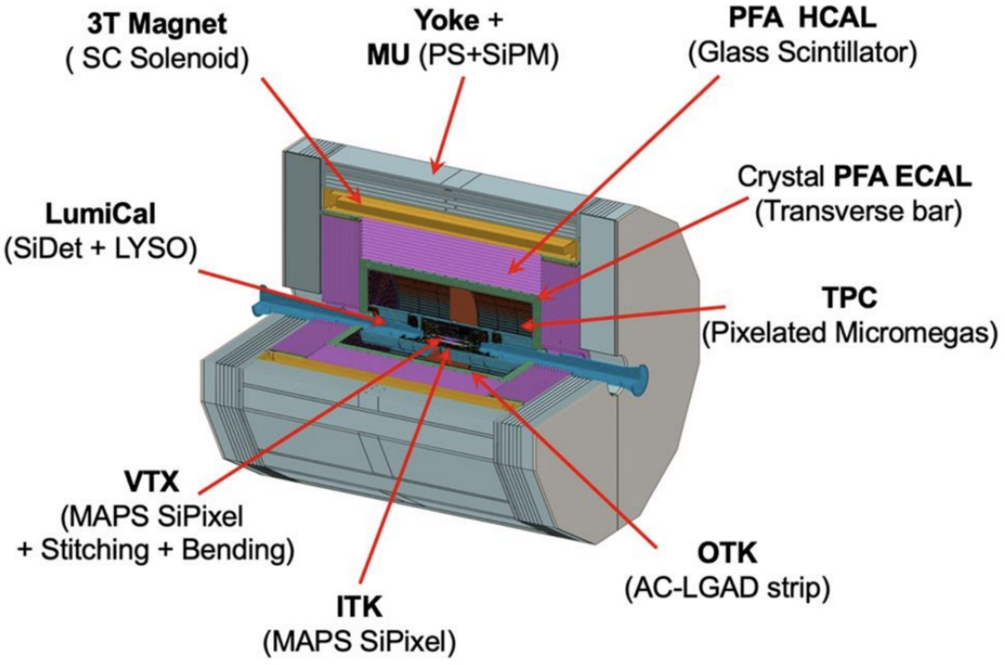
	$\pi^\pm$	$\pi^\pm\pi^0$	$\pi^\pm 2\pi^0$	$\pi^\pm 3\pi^0$	$3\pi^\pm$	$3\pi^\pm\pi^0$	other
$\pi^\pm$	96.1 $\pm$0.1	2.1 $\pm$0.1	0.0 $\pm$0.0	0.0 $\pm$0.0	0.2 $\pm$0.0	0.1 $\pm$0.0	1.5 $\pm$0.1
$\pi^\pm\pi^0$	1.3 $\pm$0.1	93.2 $\pm$0.2	4.9 $\pm$0.2	0.2 $\pm$0.0	0.0 $\pm$0.0	0.2 $\pm$0.0	0.2 $\pm$0.0
$\pi^\pm 2\pi^0$	0.0 $\pm$0.0	5.0 $\pm$0.2	87.1 $\pm$0.3	7.8 $\pm$0.2	0.0 $\pm$0.0	0.1 $\pm$0.0	0.0 $\pm$0.0
$\pi^\pm 3\pi^0$	0.0 $\pm$0.0	0.2 $\pm$0.0	10.9 $\pm$0.3	88.9 $\pm$0.3	0.0 $\pm$0.0	0.0 $\pm$0.0	0.0 $\pm$0.0
$3\pi^\pm$	0.1 $\pm$0.0	0.0 $\pm$0.0	0.0 $\pm$0.0	0.0 $\pm$0.0	97.5 $\pm$0.1	2.4 $\pm$0.1	0.0 $\pm$0.0
$3\pi^\pm\pi^0$	0.0 $\pm$0.0	0.0 $\pm$0.0	0.1 $\pm$0.0	0.0 $\pm$0.0	1.7 $\pm$0.1	98.2 $\pm$0.1	0.0 $\pm$0.0
other2	3.6 $\pm$0.1	2.9 $\pm$0.1	0.9 $\pm$0.1	0.3 $\pm$0.0	2.1 $\pm$0.1	2.0 $\pm$0.1	88.2 $\pm$0.2

- Statistic uncertainty reduced by 2-3 orders of magnitude – systematic & theoretical uncertain dominants.

- Credit: Yuzhi Che

AGORA as a Reference Detector for CEPC - TDR

- **CEPC reference detector TDR:** Demonstrate readiness for construction of detector for baseline scenario. A detector that could be constructed and commissioned within a decade.
- **After CEPC project approval:** Two CEPC detectors will be selected among international proposals. International collaborations will lead those detector designs and produce corresponding TDRs adapted to the final operational scenarios.



$10\times10\times12$ m^3,
~5000 ton

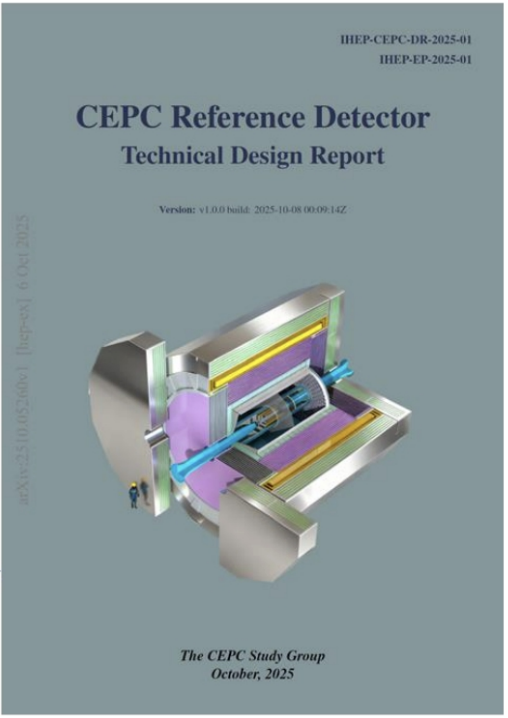
19 chapters

669 pages

1474 authors

383 institutes

43 countries



IHEP-CEPC-DR-2025-01
IHEP-EP-2025-01

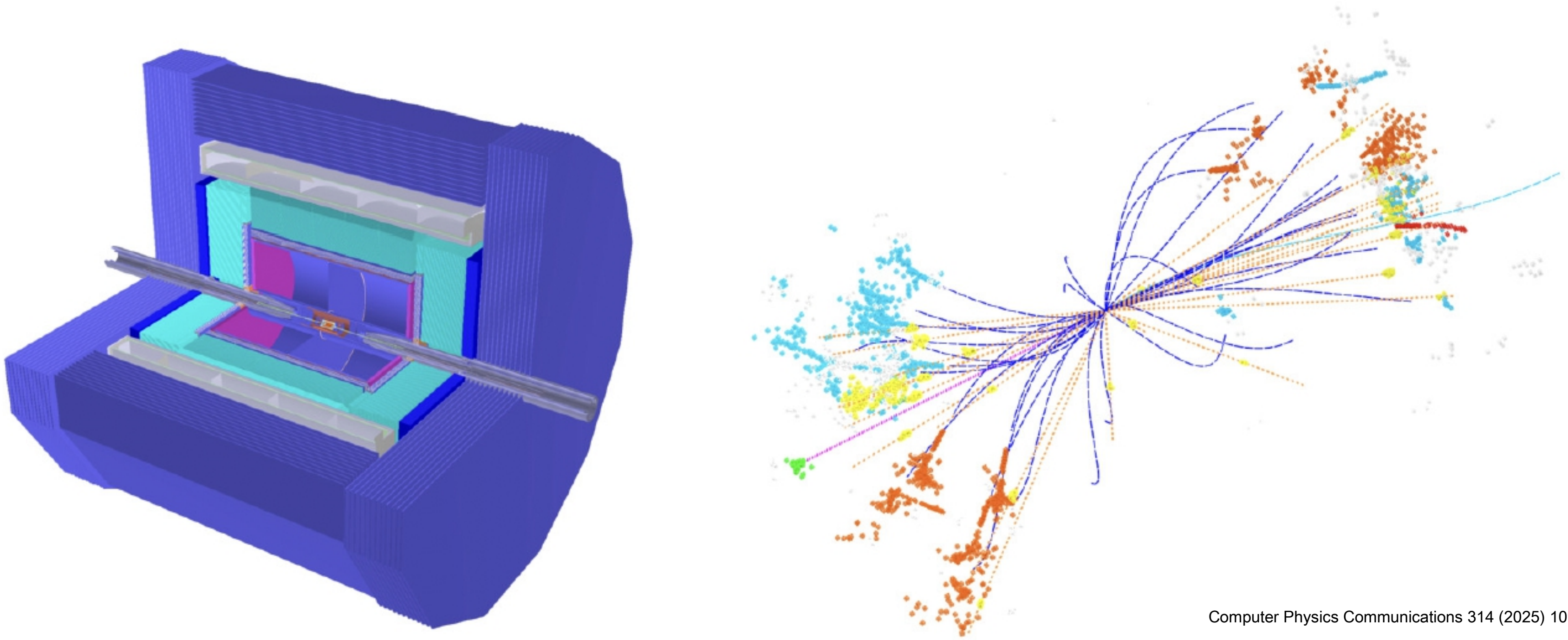
CEPC Reference Detector
Technical Design Report

Version: v1.0.0 build: 2025-10-08 00:09:14Z

arXiv:2510.05260v1 [hep-ex] 6 Oct 2025

The CEPC Study Group
October, 2025

An alternative design: AURORA

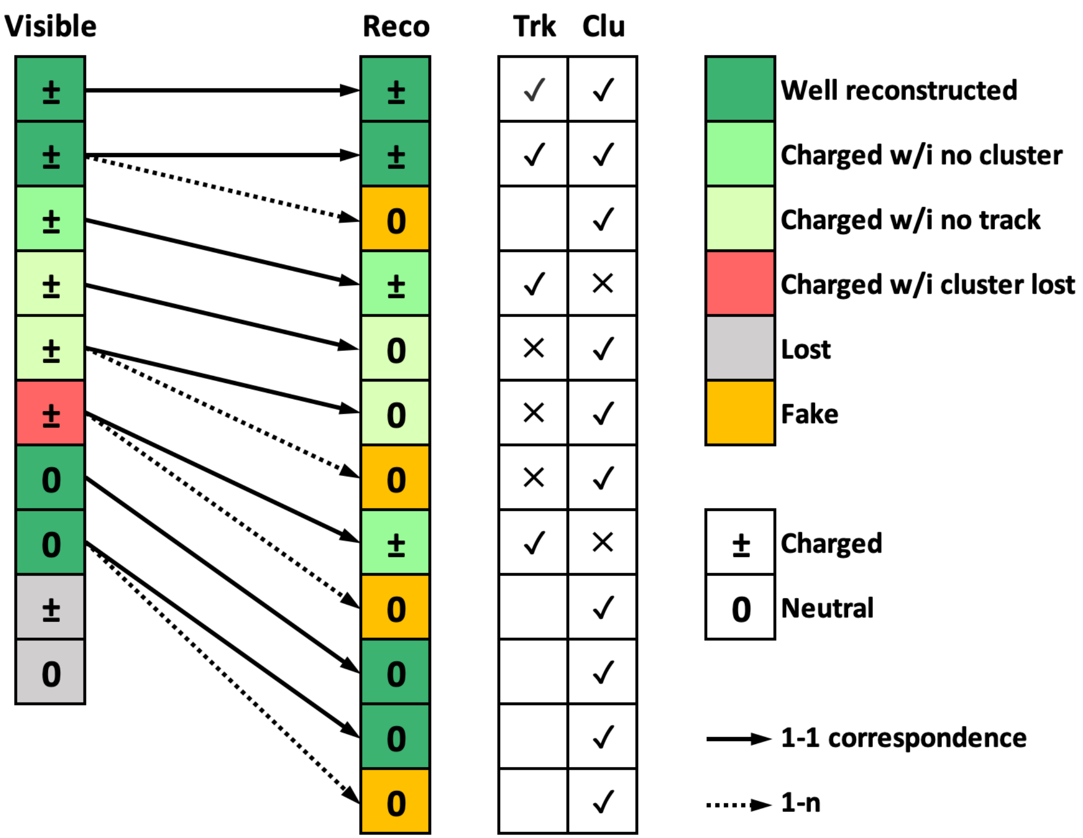


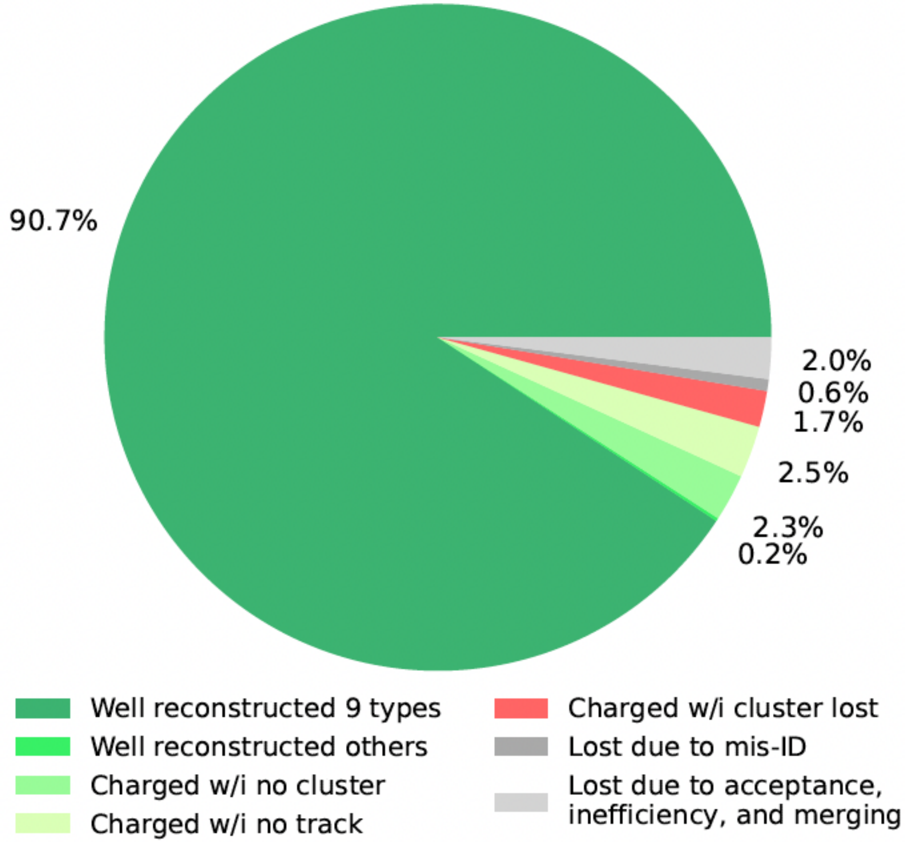
Computer Physics Communications 314 (2025) 109661

Fig. 1. AURORA detector geometry and an event display of a reconstructed $e^+e^- \to Z(\to \nu\bar{\nu})H(\to gg)$ ($\sqrt{s}$ = 240 GeV) event.

- Demonstrate the idea of 1-1 correspondence reco.

Mapping with Arbor + AI

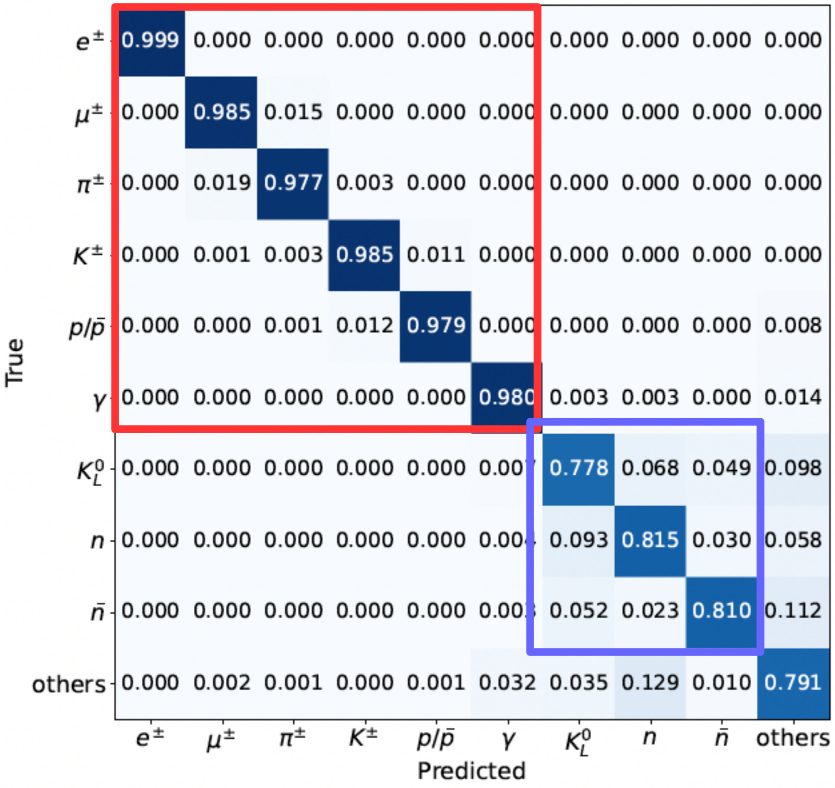




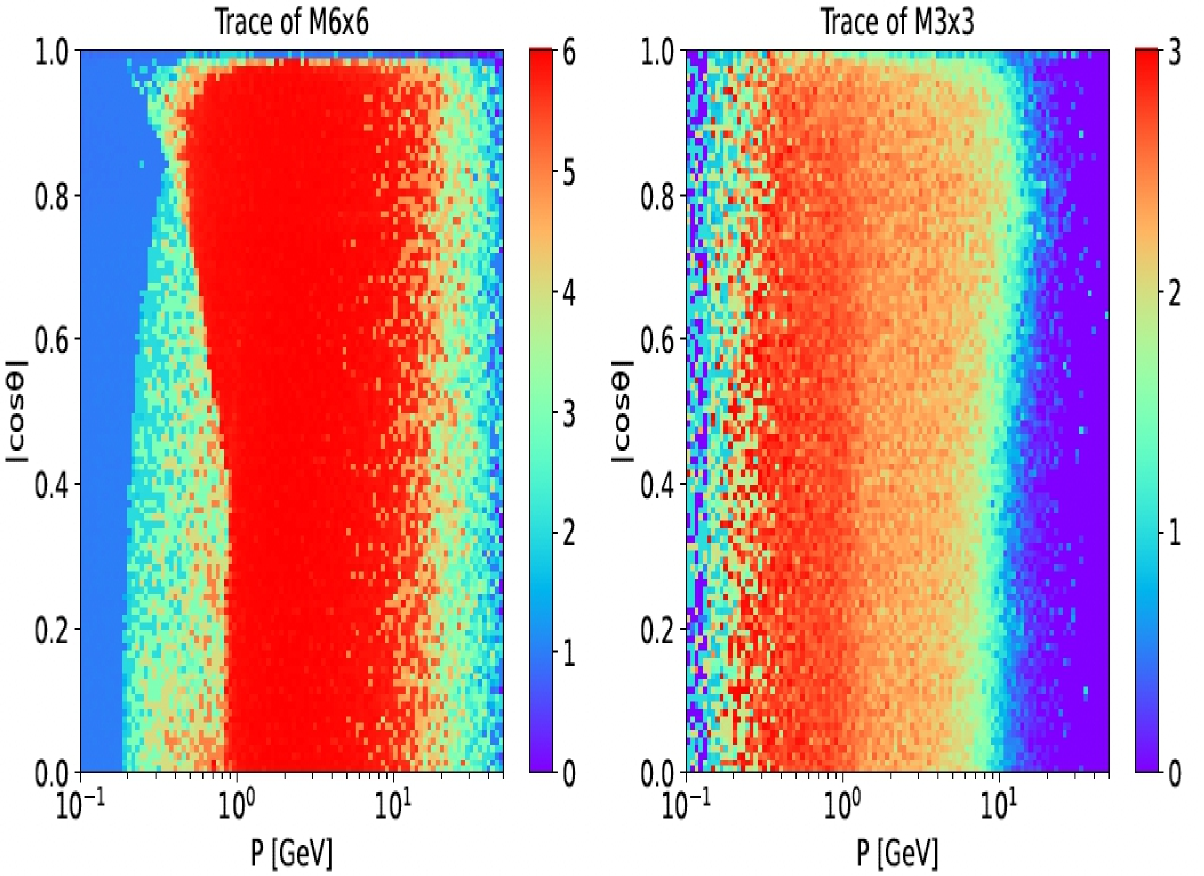
Replace HCAL in CDR baseline with a thick GS-HCAL (5λ → 6λ)

~ 95% of the visible energy is mapped to reco-particle with 1-1 correspondency.
~ 90% are well reconstructed: has the right composition of clusters & tracks.

Pid in the 'well reconstructed' particles category

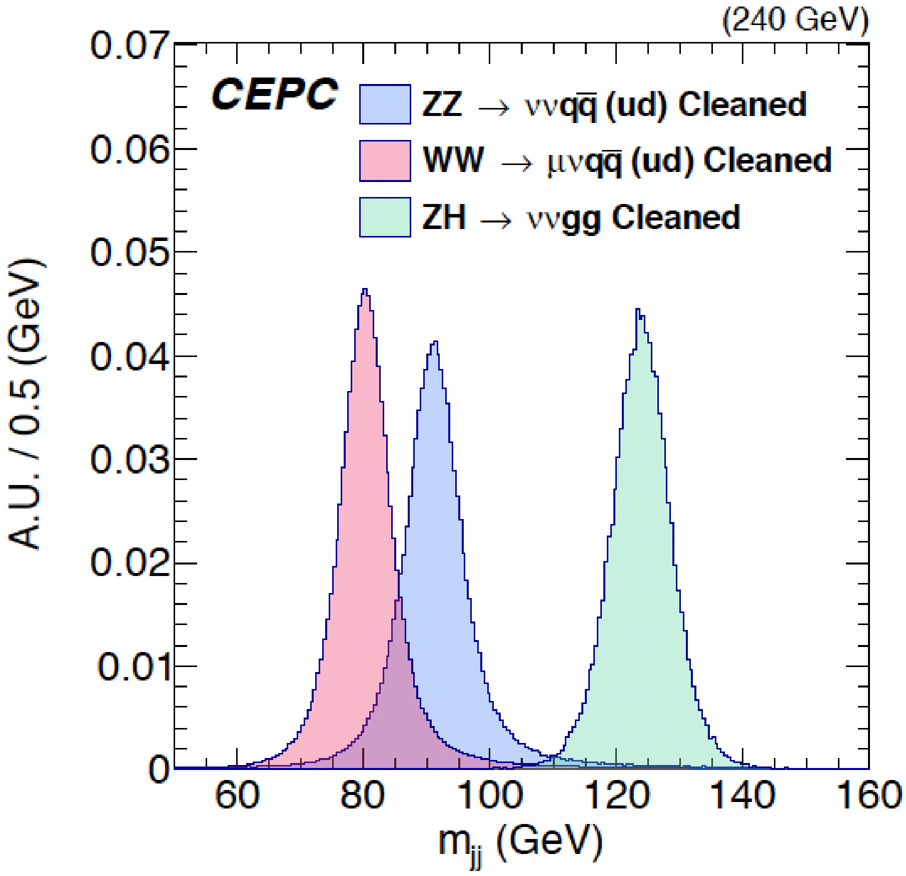


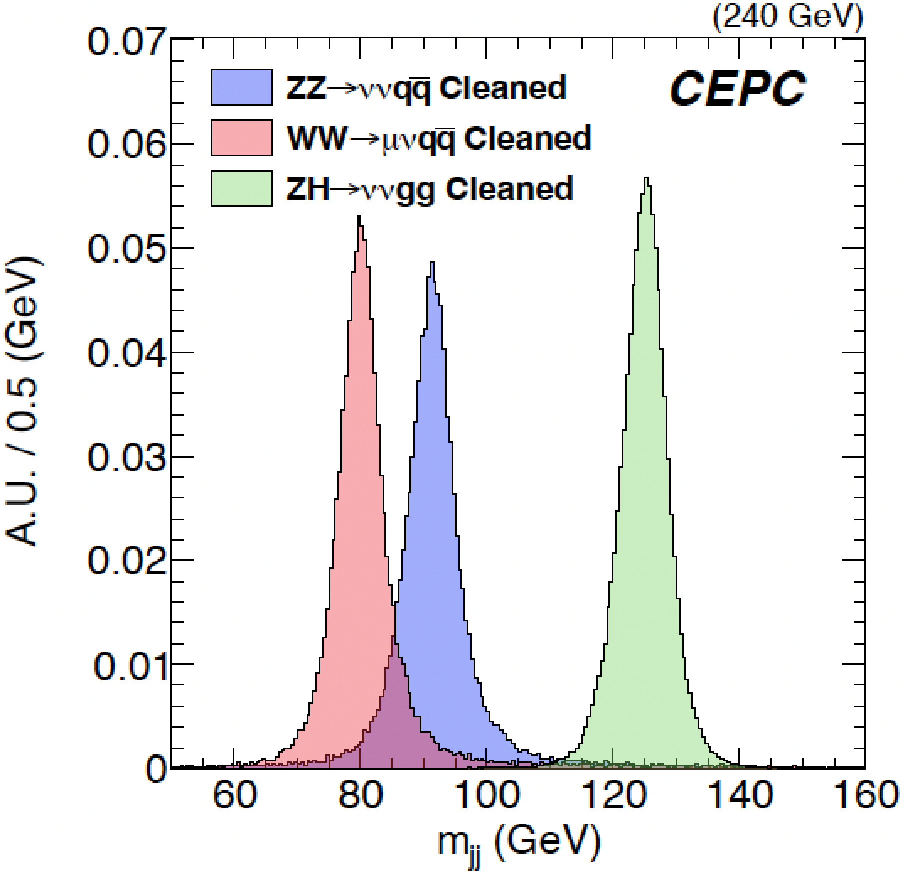
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	0.000	0.001	0.003	0.985	0.011	0.000	0.000	0.000	0.000	0.000
$p/\bar{p}$	0.000	0.000	0.001	0.012	0.979	0.000	0.000	0.000	0.000	0.008
γ	0.000	0.000	0.000	0.000	0.000	0.980	0.003	0.003	0.000	0.014
K_L^0	0.000	0.000	0.000	0.000	0.000	0.007	0.778	0.068	0.049	0.098
n	0.000	0.000	0.000	0.000	0.000	0.004	0.093	0.815	0.030	0.058
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.003	0.052	0.023	0.810	0.112
others	0.000	0.002	0.001	0.000	0.001	0.032	0.035	0.129	0.010	0.791



'well reconstructed' = reconstructed particle with no confusion +
both track + cluster for charged reconstructed particle
~ > 90% of total visible energy

BMR of 2.75% reached



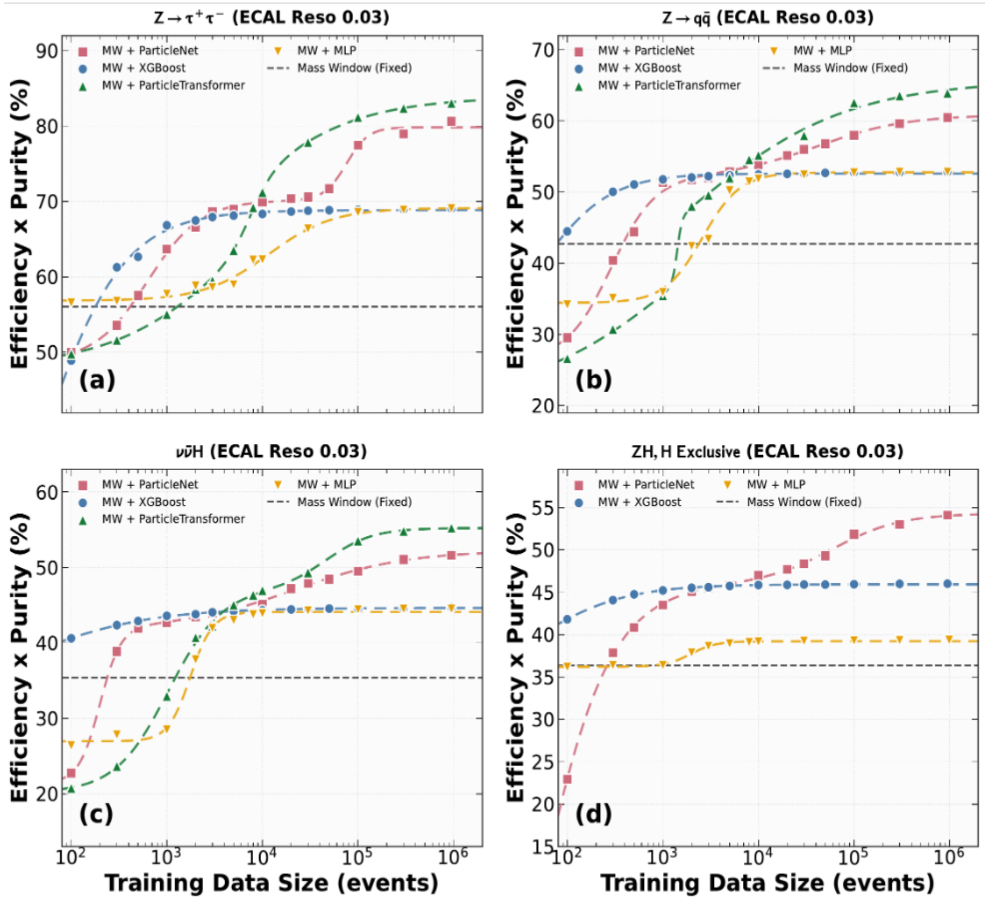


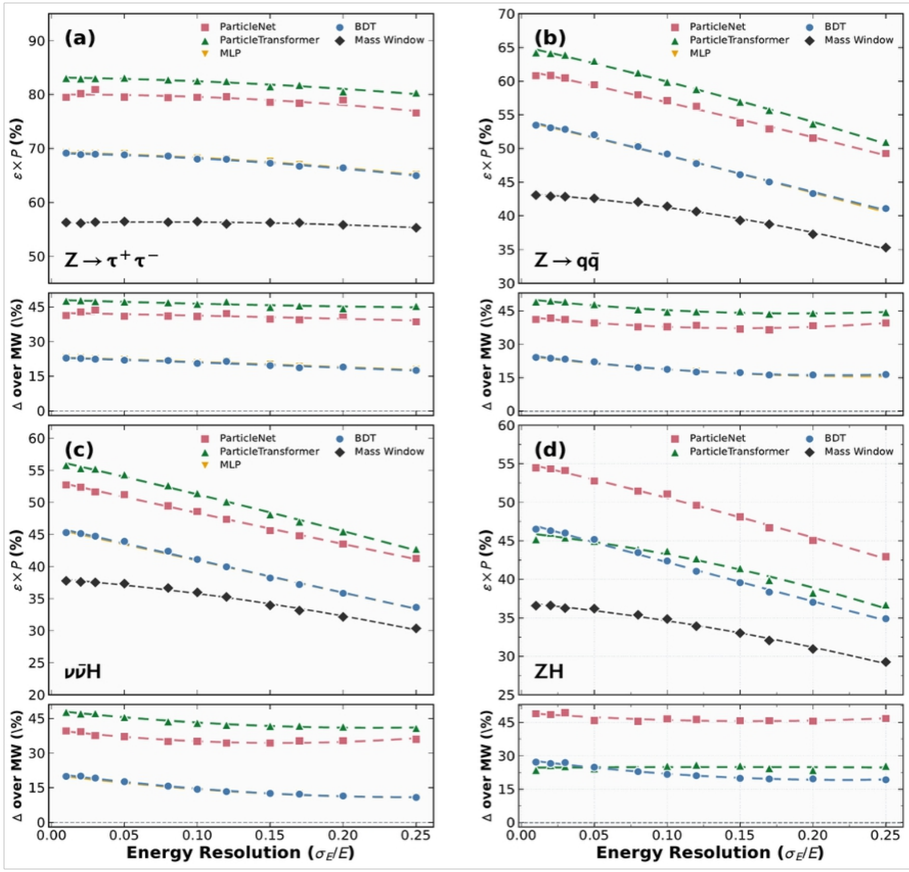
Detector change: BMR 3.7 → 3.4;

AI enhanced reconstruction: 3.4 → 2.8.

Impact from Beam induced background + impact on objects inside jet reco: to be evaluated.

From leaves to the tree: pi0 for reco





Summary

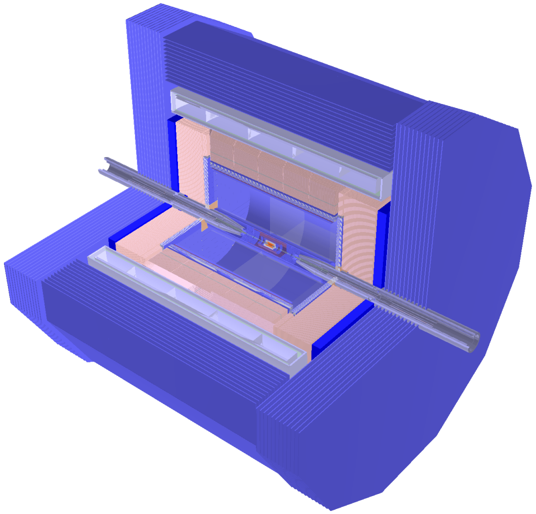
- CEPC, a precision & upgradable Higgs/W/Z factory, and a Discover machine!
  - Boost the Higgs/EW precision by ~ 10 times w.r.t HL-LHC/current boundary
  - Huge potential on QCD, Flavor, BSM

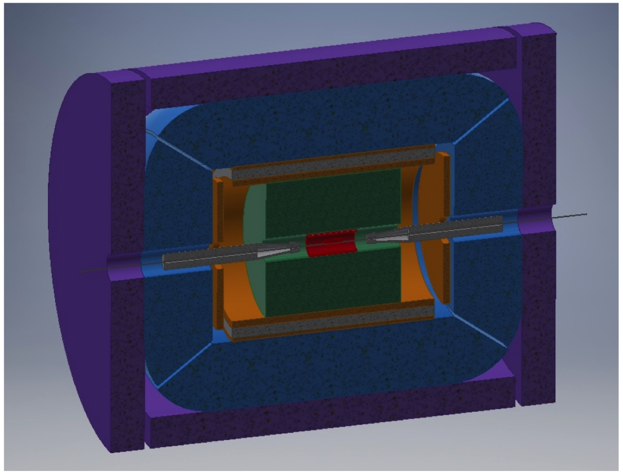
- Tau is critical for CEPC physics: we estimated the accuracy for multiple physics benchmarks with tau in their final states
  - Higgs→tautau; relative accuracy of 0.8%
  - Z→bb, Bc→Tauv; relative accuracy of o(1%)
  - Z→bb, b→stautau; sensitive to Br ~ 1E-6
  - ...

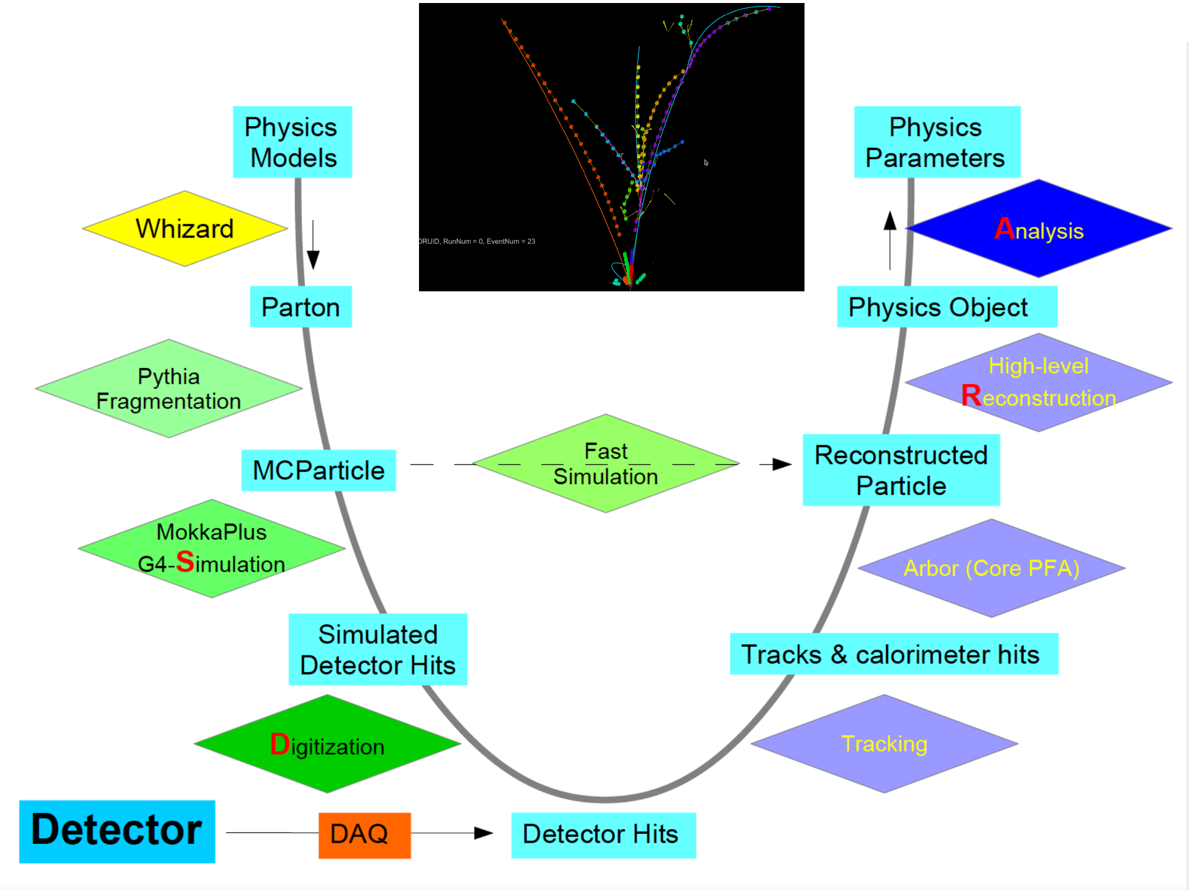
- Novel detector design + technologies & AI enhanced reconstruction are expected to strongly boost the physics reach of Higgs factory, including the tau relevant physics.
  -

Backup

Detector & Software







Physics Models

Whizard

Parton

Pythia Fragmentation

MCParticle

MokkaPlus G4-Simulation

Simulated Detector Hits

Digitization

Detector

DAQ

Detector Hits

Fast Simulation

Tracking

Tracks & calorimeter hits

Arbor (Core PFA)

Reconstructed Particle

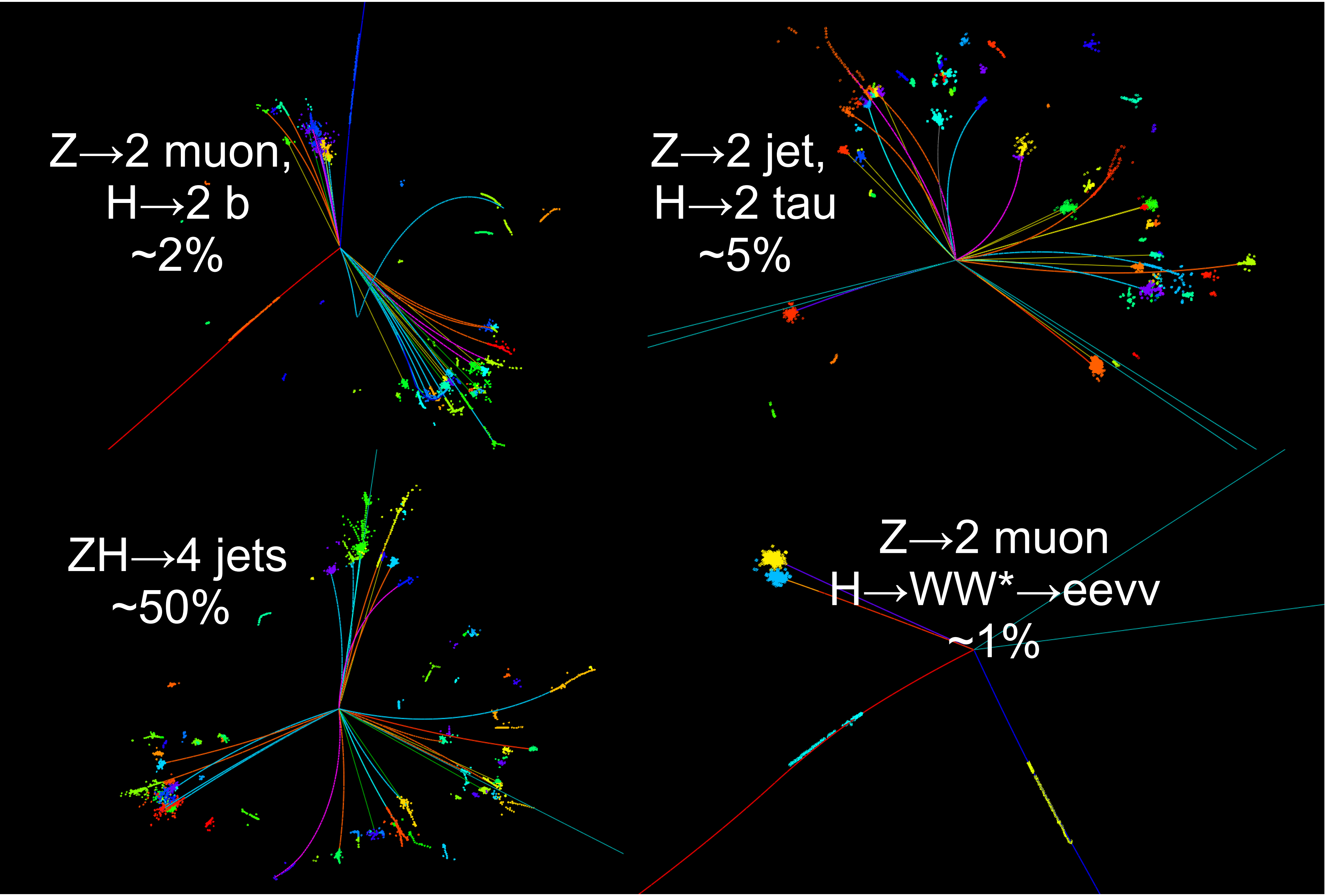
High-level Reconstruction

Physics Object

Analysis

Physics Parameters

Full simulation reconstruction Chain functional, iterating/validation with hardware studies



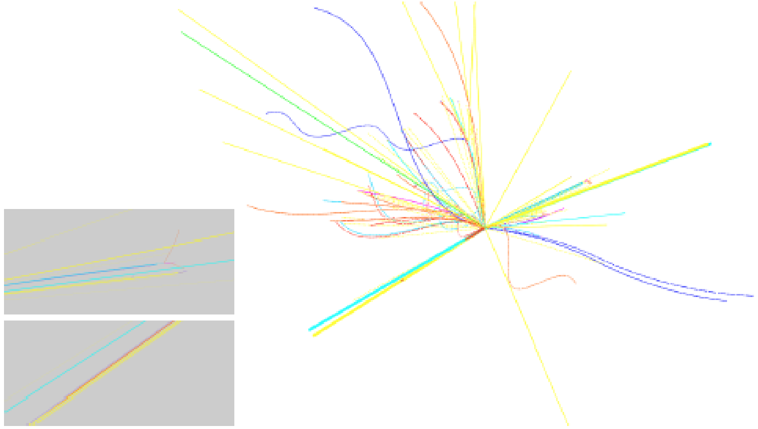
Z→2 muon,
H→2 b
~2%

Z→2 jet,
H→2 tau
~5%

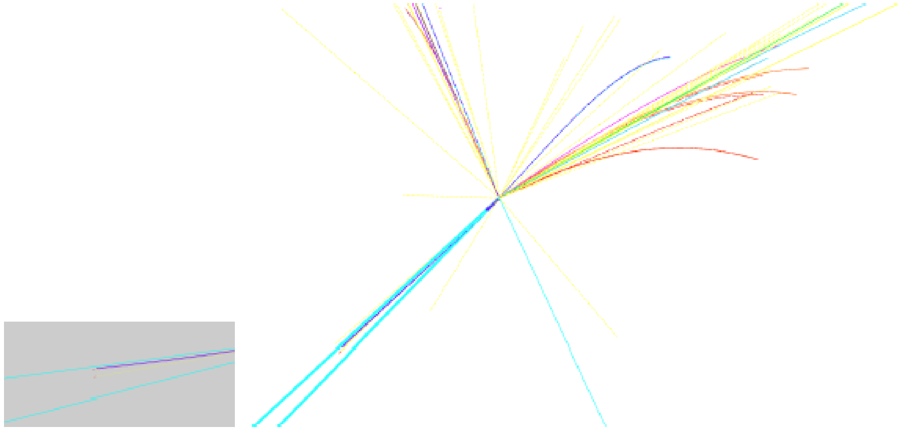
ZH→4 jets
~50%

Z→2 muon
H→WW*→eeνν
~1%

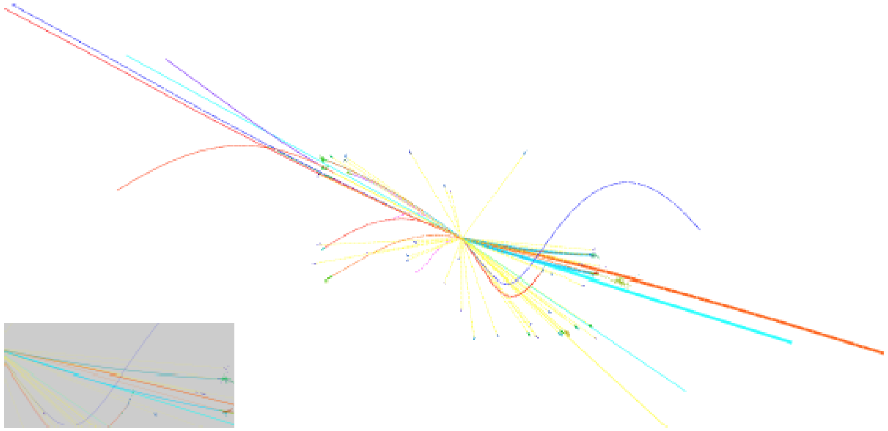
Benchmarks



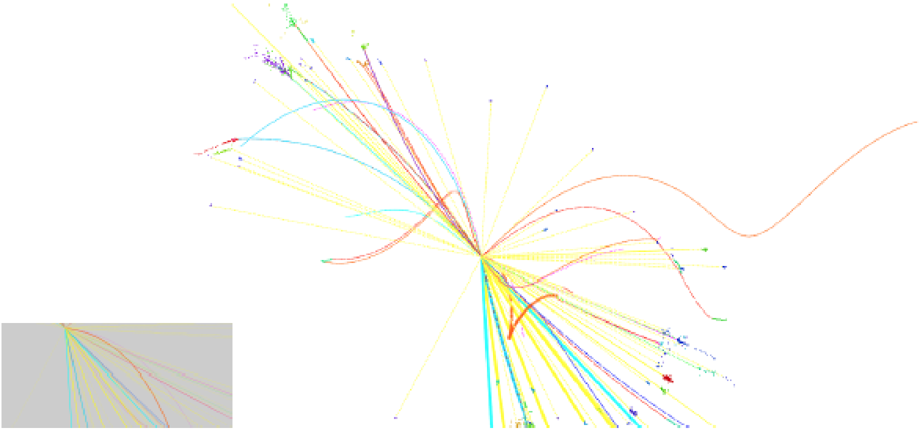
(a) $Z \to qq, H \to \tau\tau$ with two hadronic decay.



(b) $WW \to \tau\nu qq$ with one leptonic decay.

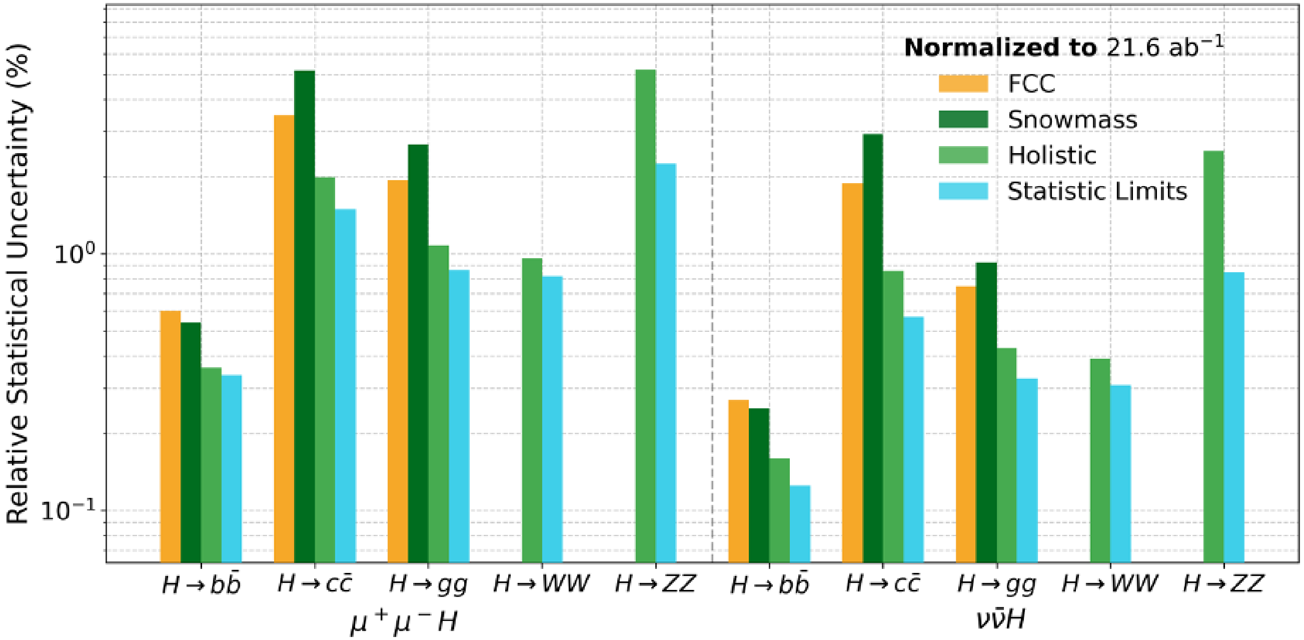


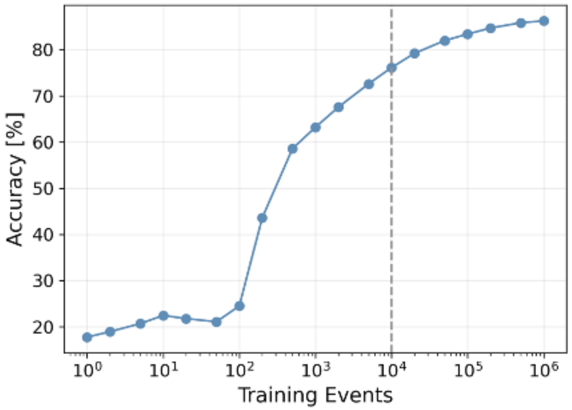
(c) $Z \to b\overline{b}, B_c \to \tau\nu$ with one hadronic dacay.

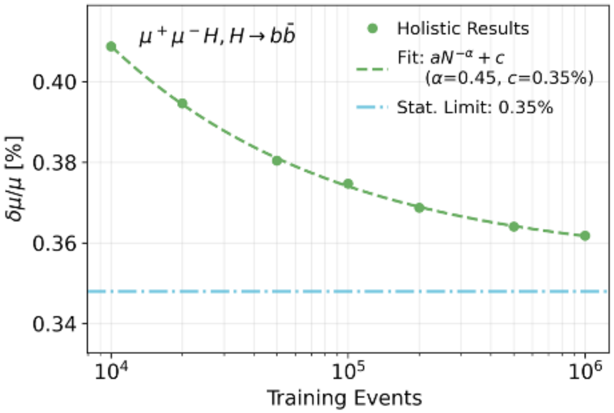


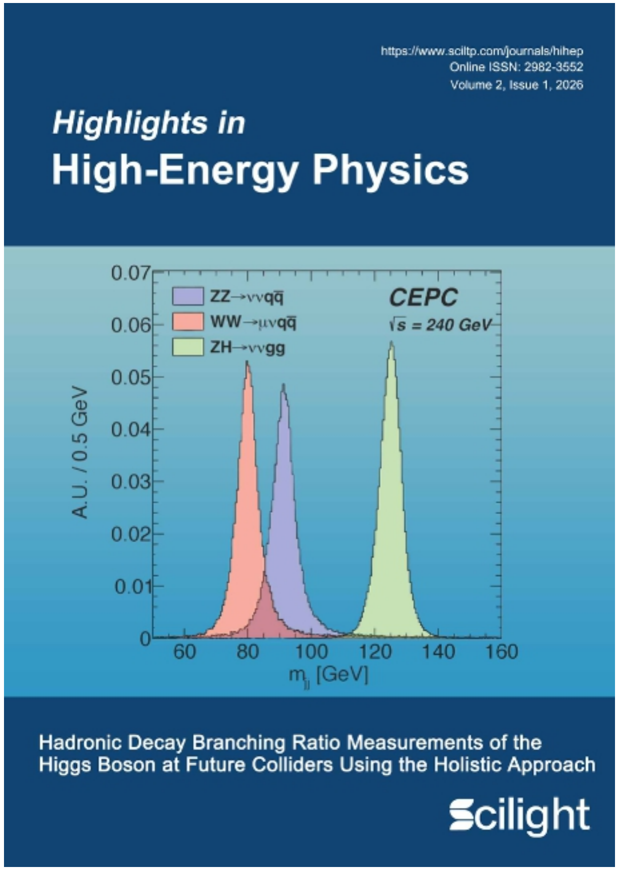
(d) $Z \to b\overline{b}, B_s \to \tau\tau$ with two hadronic decay mixed together.

Application at Higgs measurements







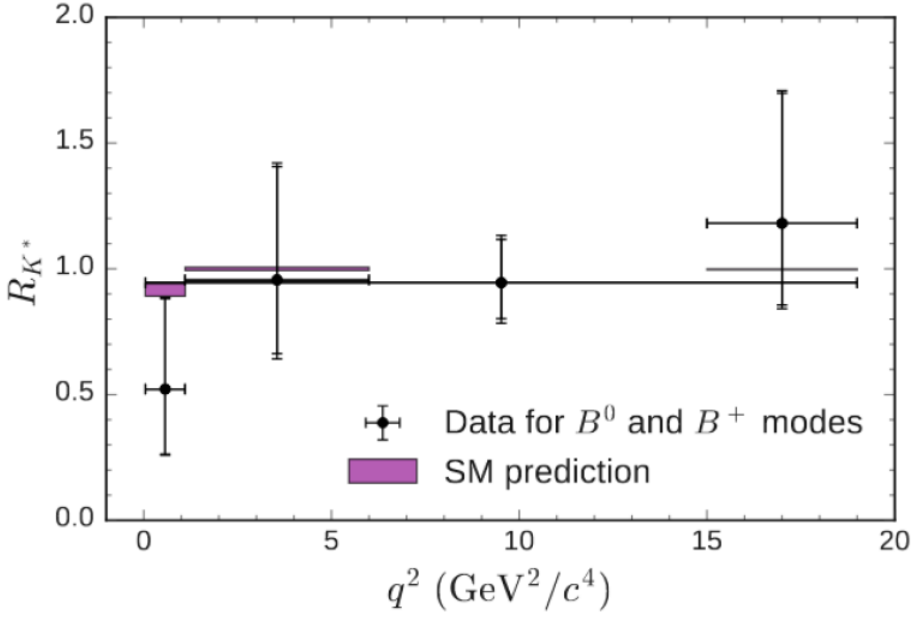

https://www.sciltp.com/journals/hihep
Online ISSN: 2982-3552
Volume 2, Issue 1, 2026

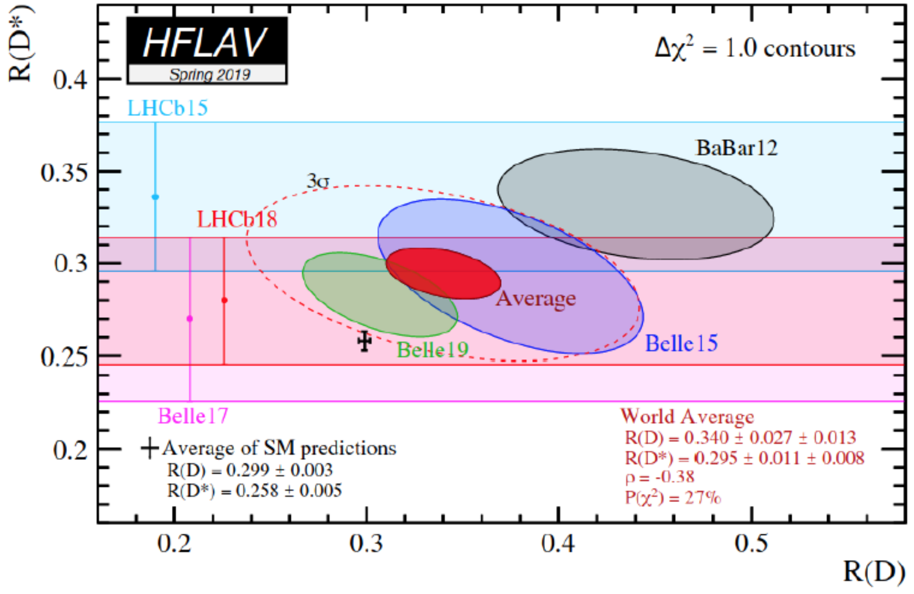
Highlights in
High-Energy Physics

Hadronic Decay Branching Ratio Measurements of the Higgs Boson at Future Colliders Using the Holistic Approach

Scilight

B Anomalies Indicating LFUV

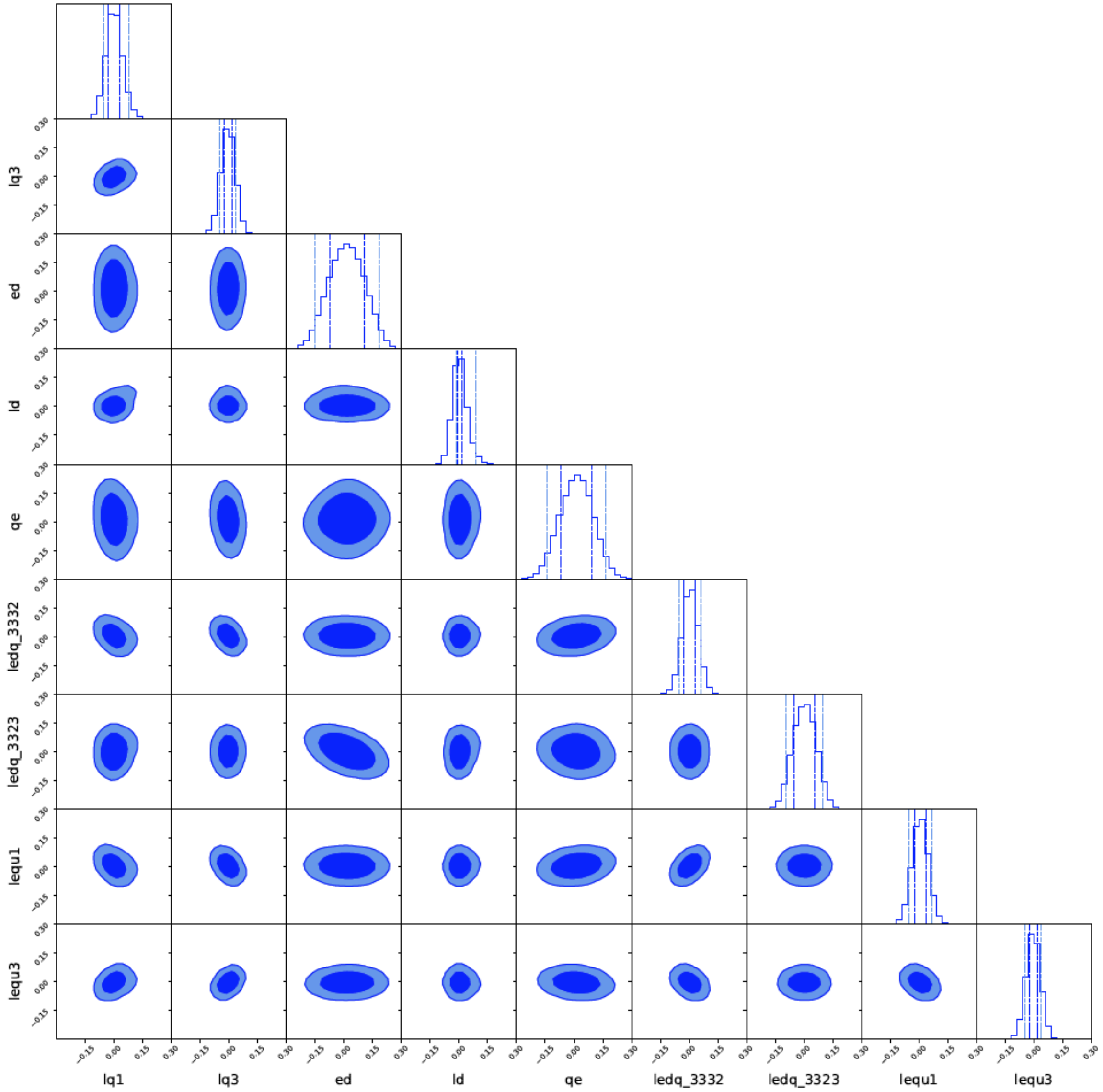




	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295 ± 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 (II)

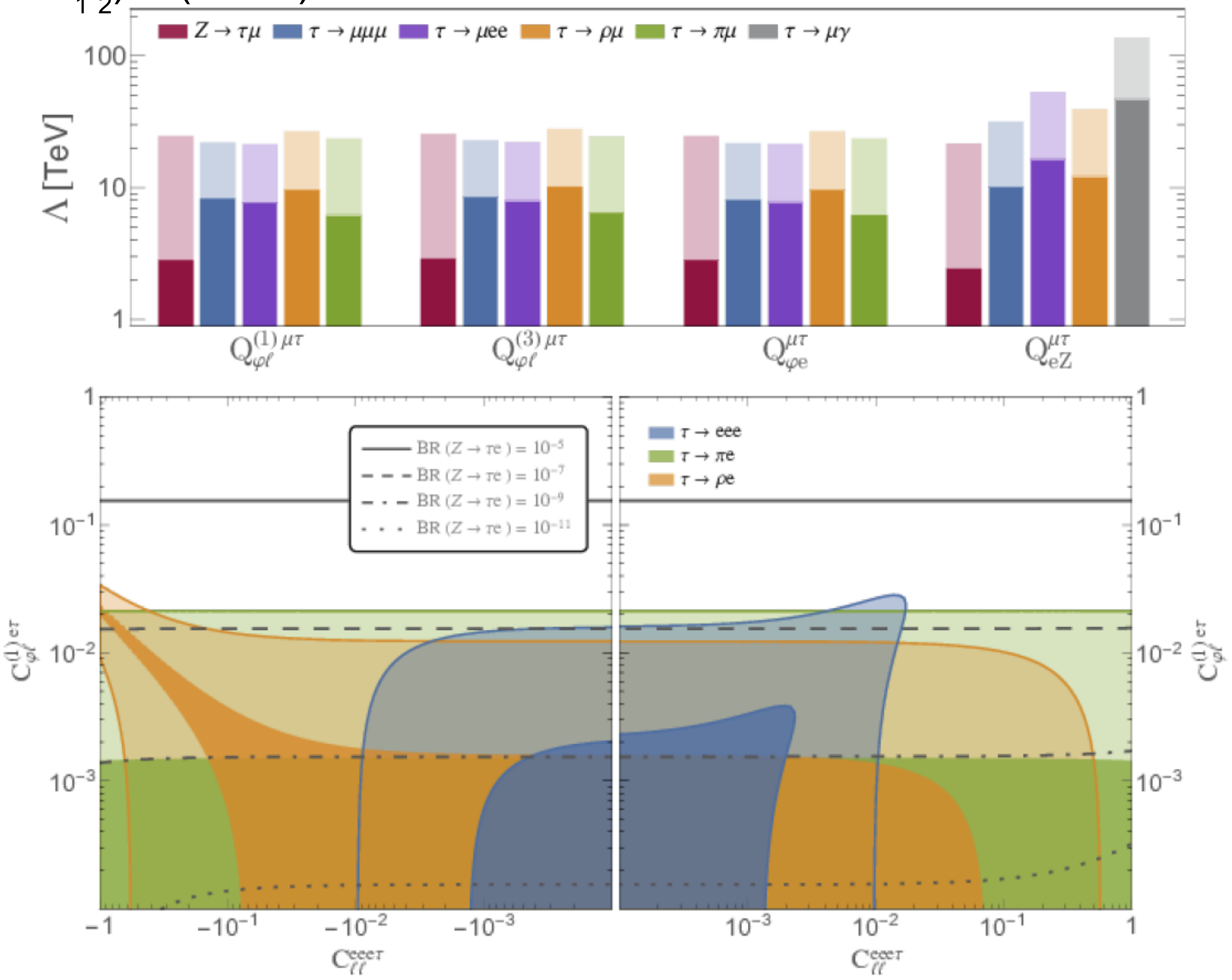


Preliminary: 9 effective channels:($R_{J/\psi}$, R_{D_s}, $R_{D_s^*}$, R_{Λ_c}, $B_c \to \tau\nu$, $B \to K\nu\bar{\nu}$, $B_s \to \phi\nu\bar{\nu}$, $B^0 \to K\tau\tau$, $B^+ \to K^+\tau\tau$, $B_s \to \tau\tau$...)

Dim-6 SMEFT basis at NP scale Λ=3 TeV.

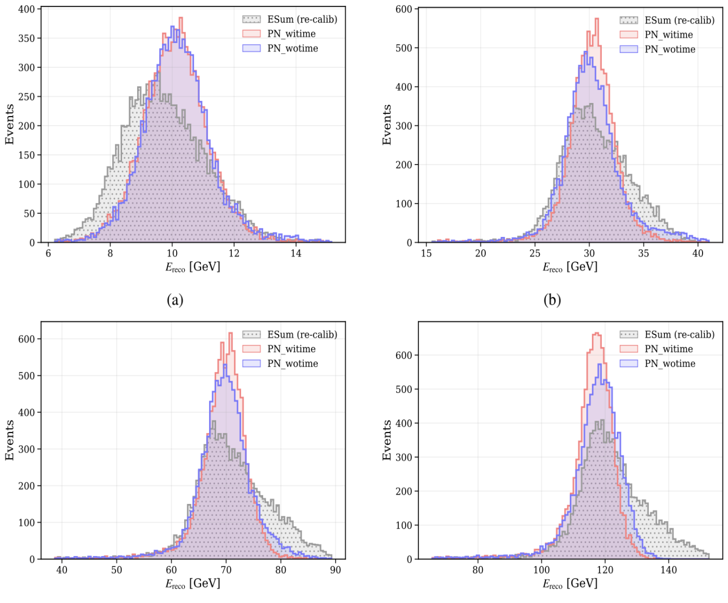
Lepton Flavor Violation (II)

Up limit of Br(Z→$l_1 l_2$)~o(1E-9)



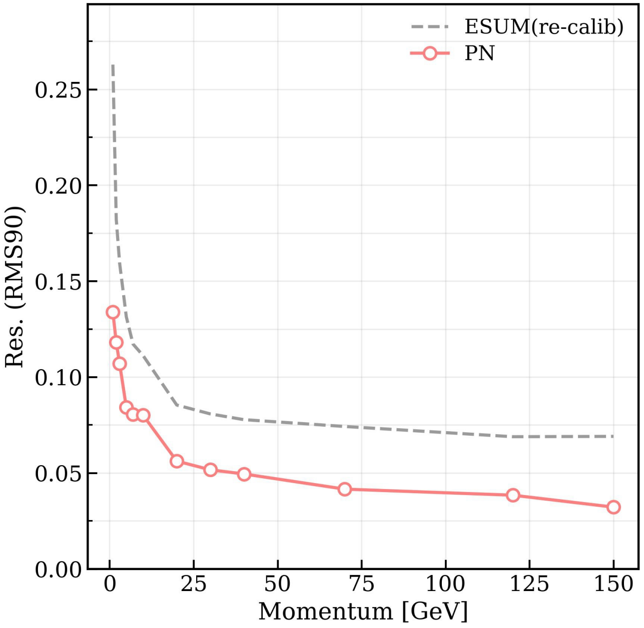
[Calibbi et al., 2021] 2107.10273

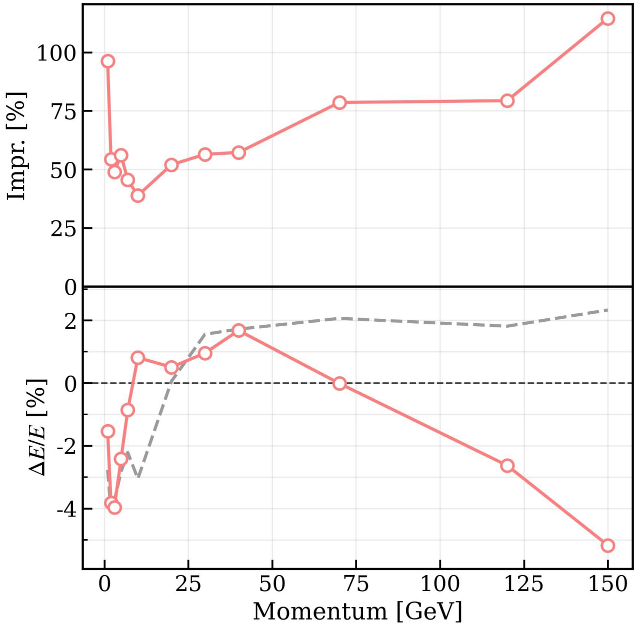
Regression: energy measurements

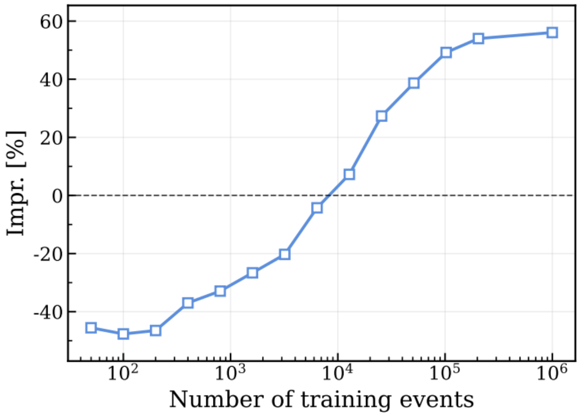


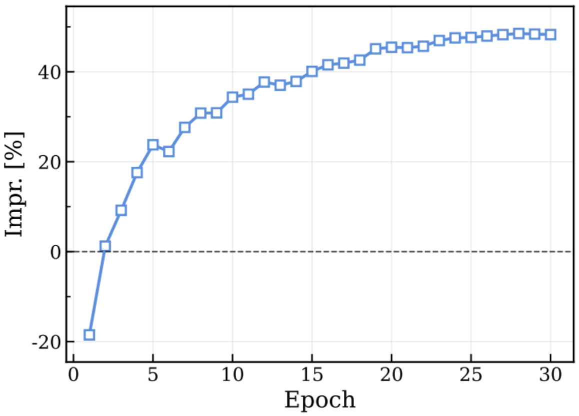
(a) (b)

(c) (d)









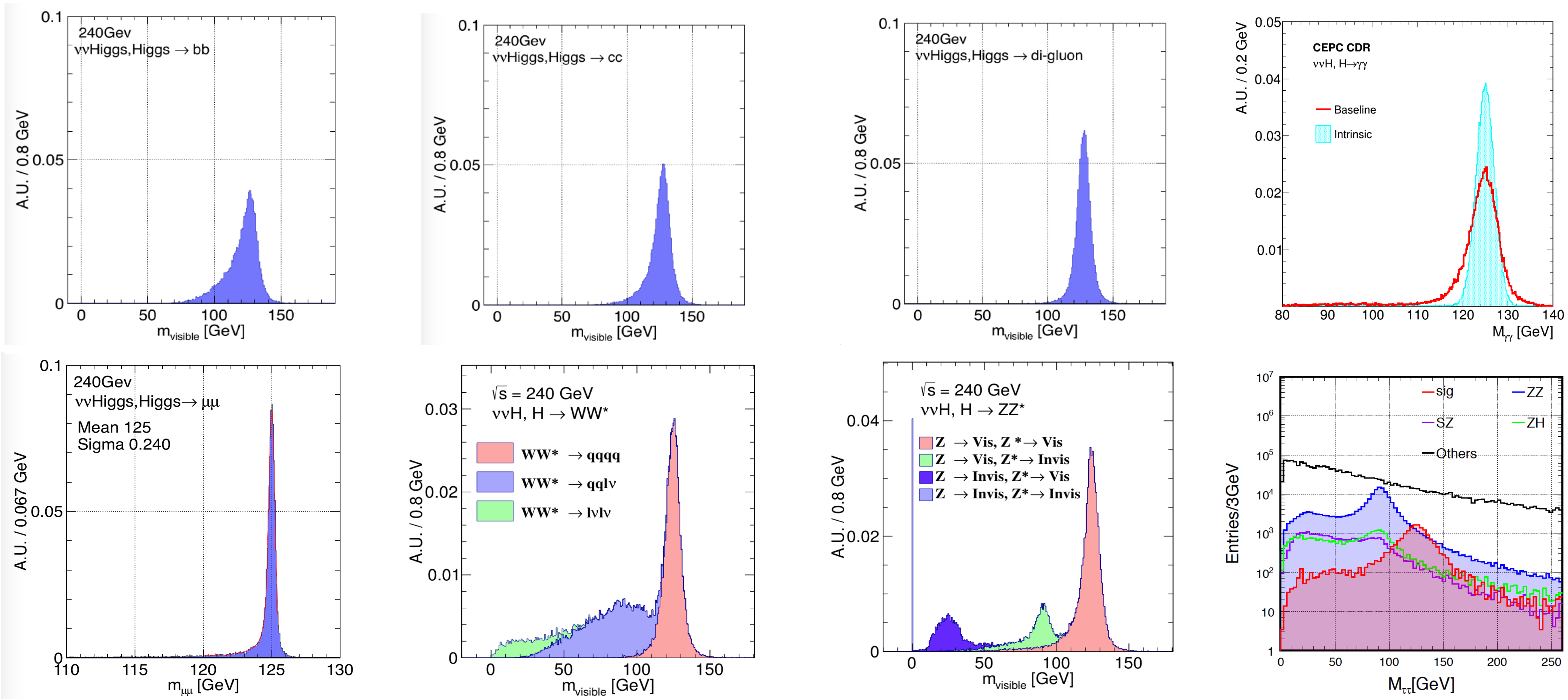
Preliminary

Current Best BMR: ~ 2.5%

Latent uncertainties:

Upstream materials.

Reconstructed Higgs Signatures

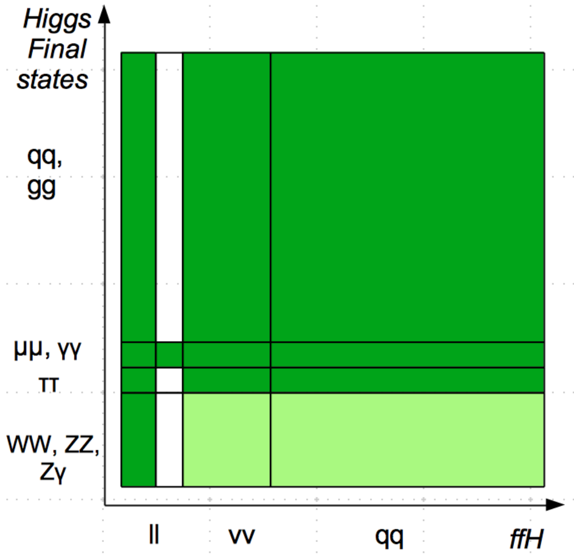


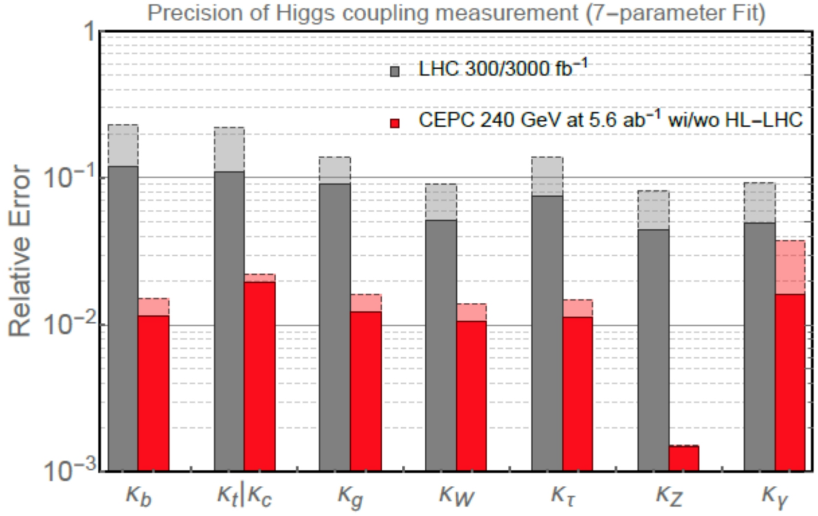
Clear Higgs Signature in all SM decay modes

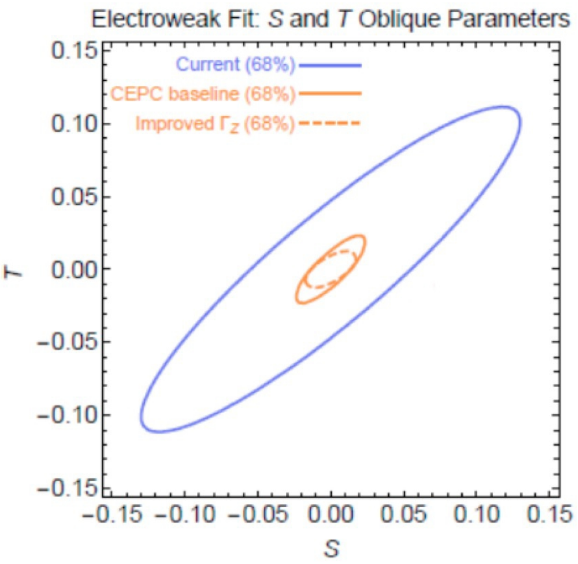
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

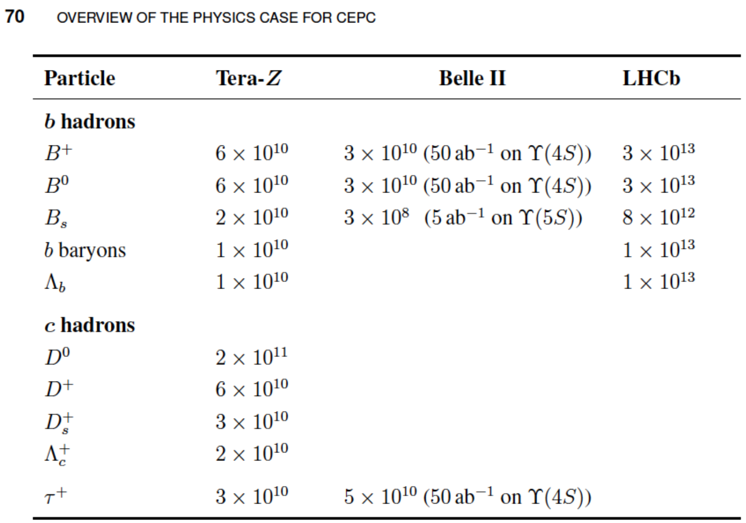
Right corner: di-tau mass distribution at qqH events using collinear approximation

Quantify the physics potential



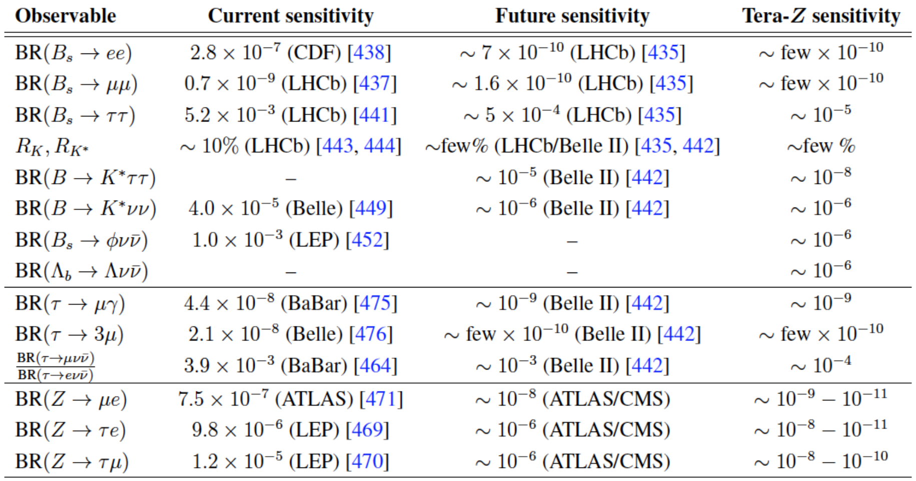






70 OVERVIEW OF THE PHYSICS CASE FOR CEPC

Particle	Tera-Z	Belle II	LHCb
***b* hadrons**			
B^+	6×10^{10}	3×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} (5 ab^{-1} on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b	1×10^{10}		1×10^{13}
***c* hadrons**			
D^0	2×10^{11}		
D^+	6×10^{10}		
D_s^+	3×10^{10}		
Λ_c^+	2×10^{10}		
τ^+	3×10^{10}	5×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	



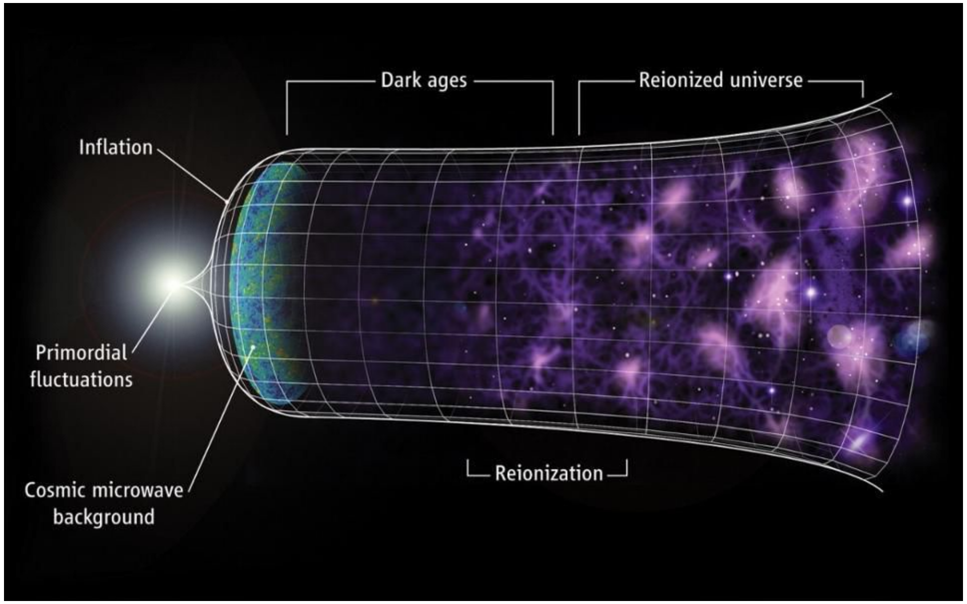
Observable	Current sensitivity	Future sensitivity	Tera-Z sensitivity
$\mathrm{BR}(B_s \to ee)$	2.8×10^{-7} (CDF) [438]	$\sim 7 \times 10^{-10}$ (LHCb) [435]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \mu\mu)$	0.7×10^{-9} (LHCb) [437]	$\sim 1.6 \times 10^{-10}$ (LHCb) [435]	$\sim$ few $\times 10^{-10}$
$\mathrm{BR}(B_s \to \tau\tau)$	5.2×10^{-3} (LHCb) [441]	$\sim 5 \times 10^{-4}$ (LHCb) [435]	$\sim 10^{-5}$
R_K, R_{K^*}	$\sim 10\%$ (LHCb) [443, 444]	$\sim$few% (LHCb/Belle II) [435, 442]	$\sim$few %
$\mathrm{BR}(B \to K^*\tau\tau)$	–	$\sim 10^{-5}$ (Belle II) [442]	$\sim 10^{-8}$
$\mathrm{BR}(B \to K^*\nu\nu)$	4.0×10^{-5} (Belle) [449]	$\sim 10^{-6}$ (Belle II) [442]	$\sim 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	1.0×10^{-3} (LEP) [452]	–	$\sim 10^{-6}$
$\mathrm{BR}(\Lambda_b \to \Lambda\nu\bar{\nu})$	–	–	$\sim 10^{-6}$
$\mathrm{BR}(\tau \to \mu\gamma)$	4.4×10^{-8} (BaBar) [475]	$\sim 10^{-9}$ (Belle II) [442]	$\sim 10^{-9}$
$\mathrm{BR}(\tau \to 3\mu)$	2.1×10^{-8} (Belle) [476]	$\sim$ few $\times 10^{-10}$ (Belle II) [442]	$\sim$ few $\times 10^{-10}$
$\frac{\mathrm{BR}(\tau \to \mu\nu\bar{\nu})}{\mathrm{BR}(\tau \to e\nu\bar{\nu})}$	3.9×10^{-3} (BaBar) [464]	$\sim 10^{-3}$ (Belle II) [442]	$\sim 10^{-4}$
$\mathrm{BR}(Z \to \mu e)$	7.5×10^{-7} (ATLAS) [471]	$\sim 10^{-8}$ (ATLAS/CMS)	$\sim 10^{-9} - 10^{-11}$
$\mathrm{BR}(Z \to \tau e)$	9.8×10^{-6} (LEP) [469]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-11}$
$\mathrm{BR}(Z \to \tau\mu)$	1.2×10^{-5} (LEP) [470]	$\sim 10^{-6}$ (ATLAS/CMS)	$\sim 10^{-8} - 10^{-10}$

Table 2.5: Order of magnitude estimates of the sensitivity to a number of key observables for which the tera-Z factory at CEPC might have interesting capabilities. The expected future sensitivities assume luminosities of 50 fb^{-1} at LHCb, 50 ab^{-1} at Belle II, and 3 ab^{-1} at ATLAS and CMS. For the tera-Z factory of CEPC we have assumed the production of 10^{12} Z bosons.

Higgs: linked to many known unknowns of the SM

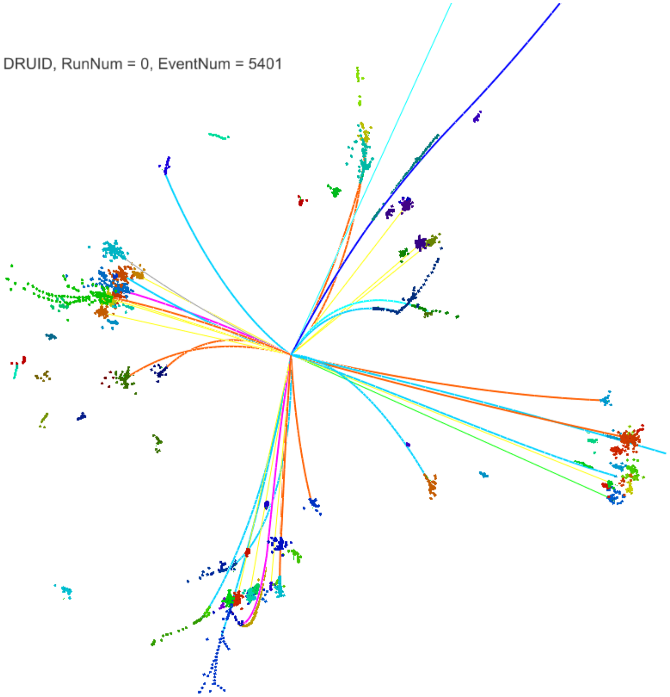
- Hierarchy: From neutrinos to the top mass, masses differs by 13 orders of magnitude
- Naturalness: Fine tuning of the Higgs mass
- Masses of Higgs and top quark: meta-stable of the vacuum
- Unification?
- Dark matter candidate?
- Not sufficient CP Violation for Matter & Antimatter asymmetry

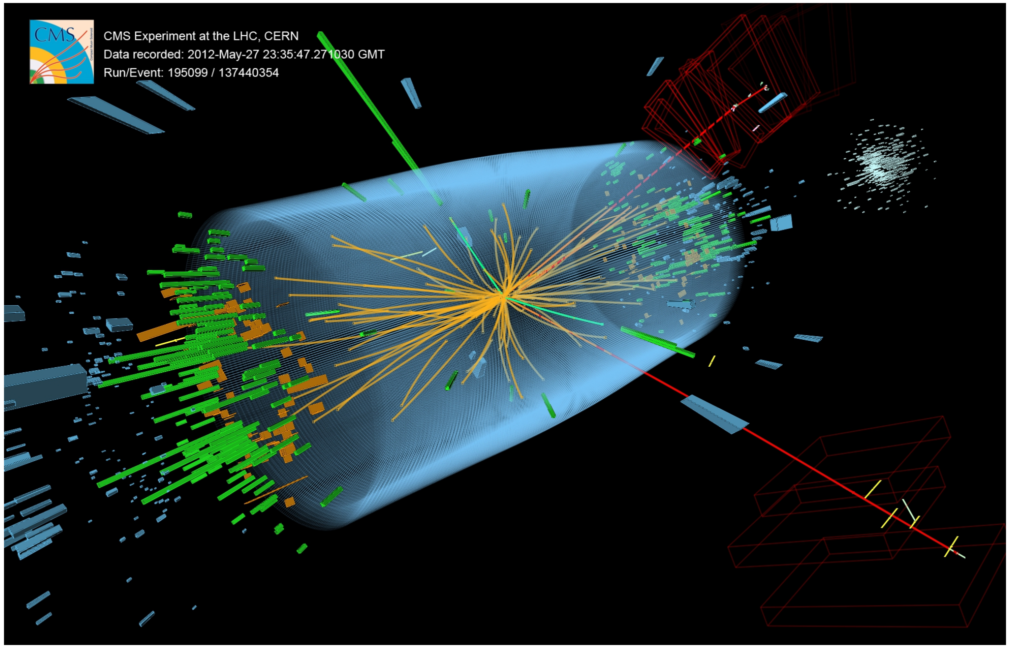
$$\begin{aligned} m_H^2 &= 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023 \\ &\quad -36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398 \\ &= (125\ \mathrm{GeV})^2\ !\ ? \end{aligned}$$



- **Most issues related to Higgs**

Higgs measurement at e+e- & pp





	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: 10^{7-8}	~o(10^{-3})	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	~o(1)	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

Complementary

Electron Positron Higgs factories

High-priority future initiatives

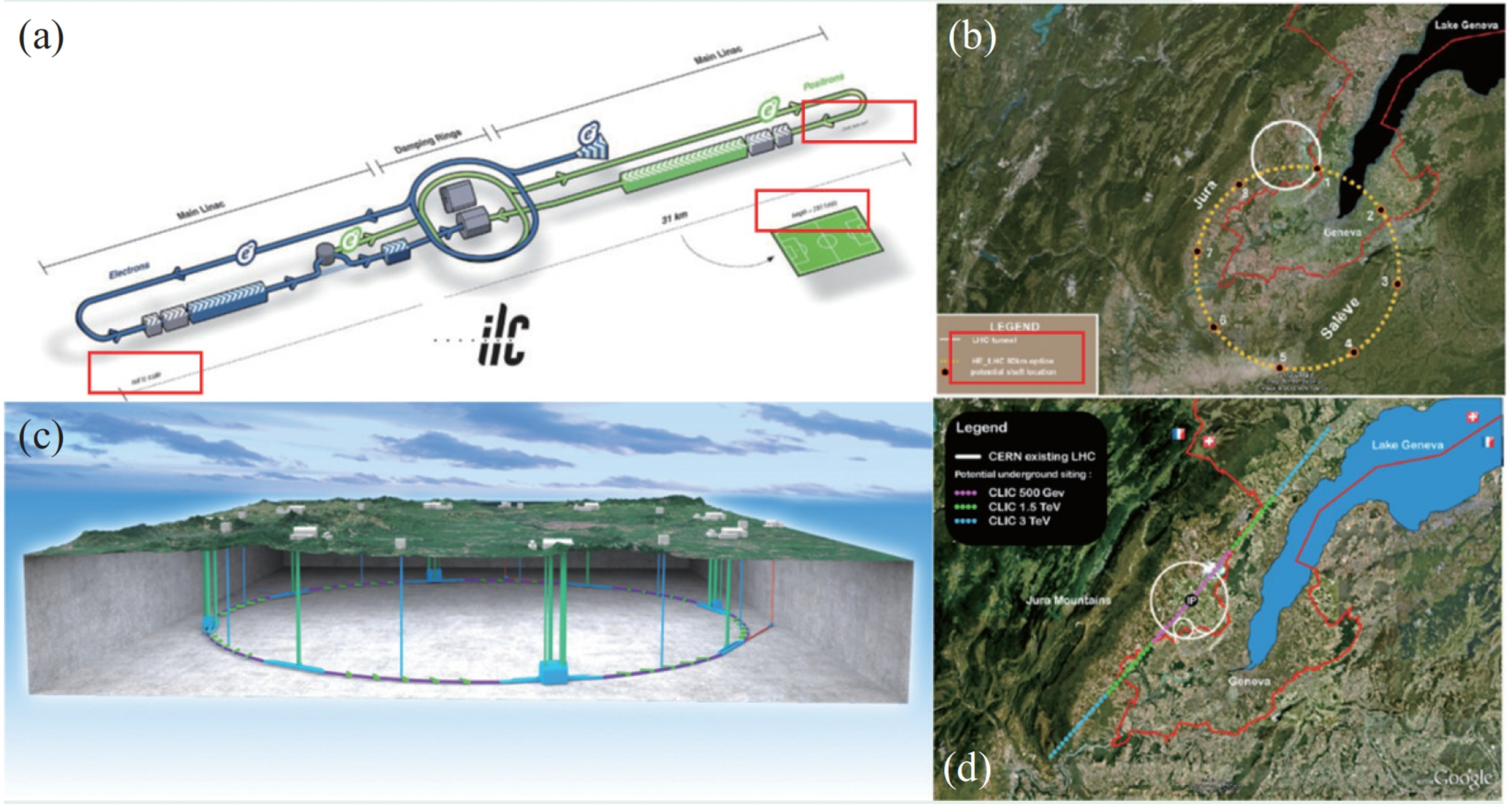
An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

ILC (a):	TDR @ 2013
FCC (b):	CDR @ 2019
CEPC (c):	CDR @ 2018
CLIC (d):	CDR @ 2013

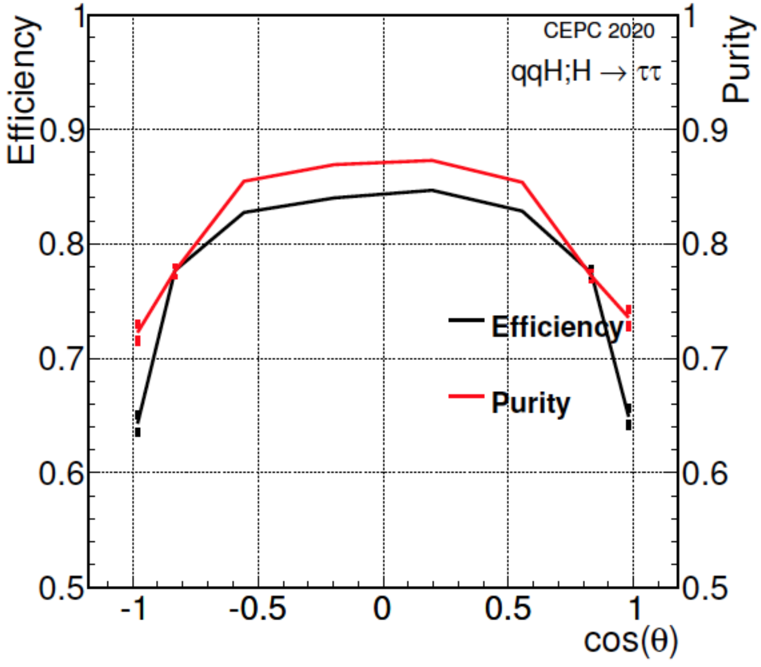
DELIBERATION DOCUMENT
ON THE 2020 UPDATE OF THE EUROPEAN STRATEGY
FOR PARTICLE PHYSICS

The European Strategy Group

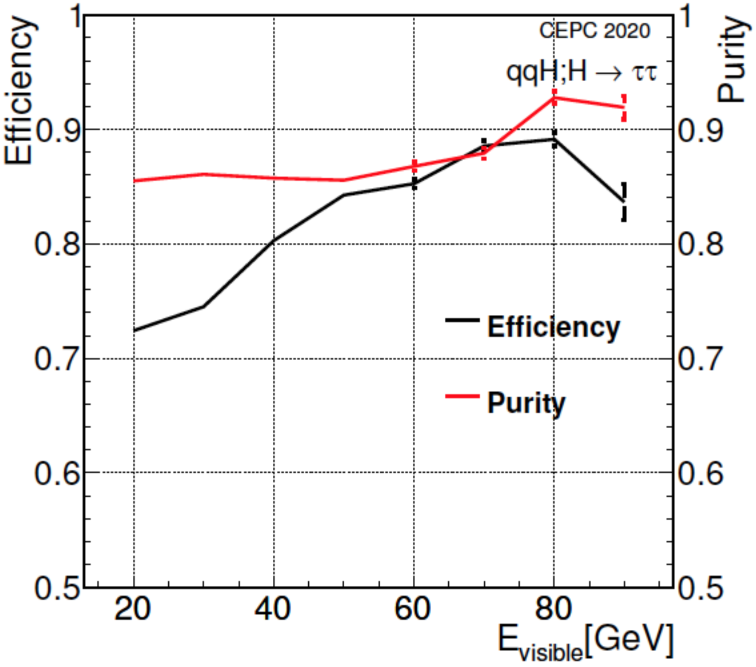
European Strategy
Update



qqH, H→ττ @ 240GeV: eff ~ 80%, purity ~ 85%

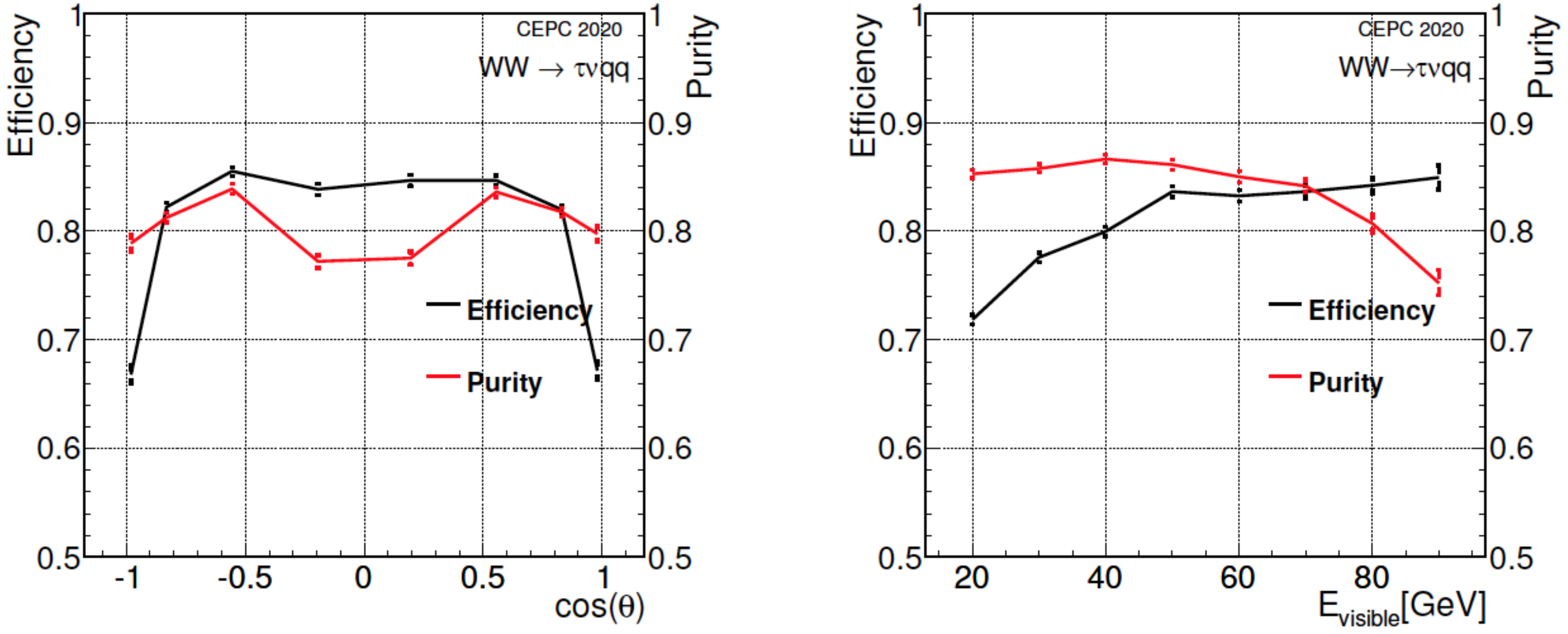


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



(b) Efficiency and purity performance along with visible energy. The performance above 80 GeV falls as a result of stringent cone selection.

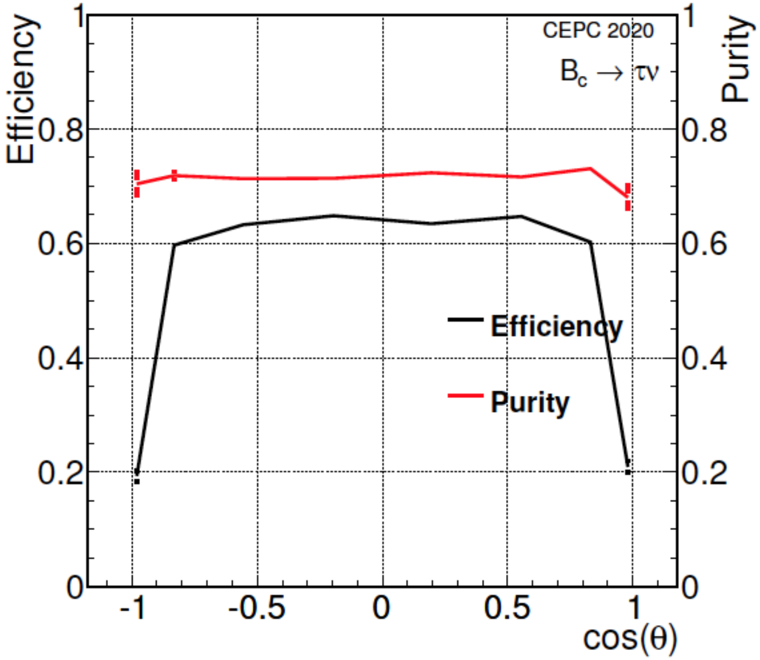
WW→τνqq @ 240GeV: eff ~ 80%, purity ~ 85%



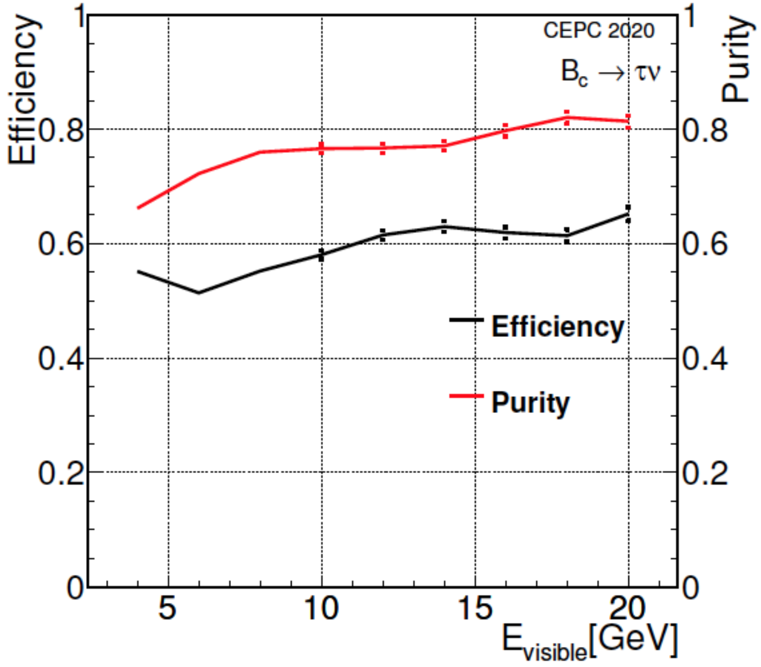
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

(b) Efficiency and purity performance along with visible energy

Z→bb, Bc→τν @ 91.2 GeV: eff ~ 60%, purity ~ 75%

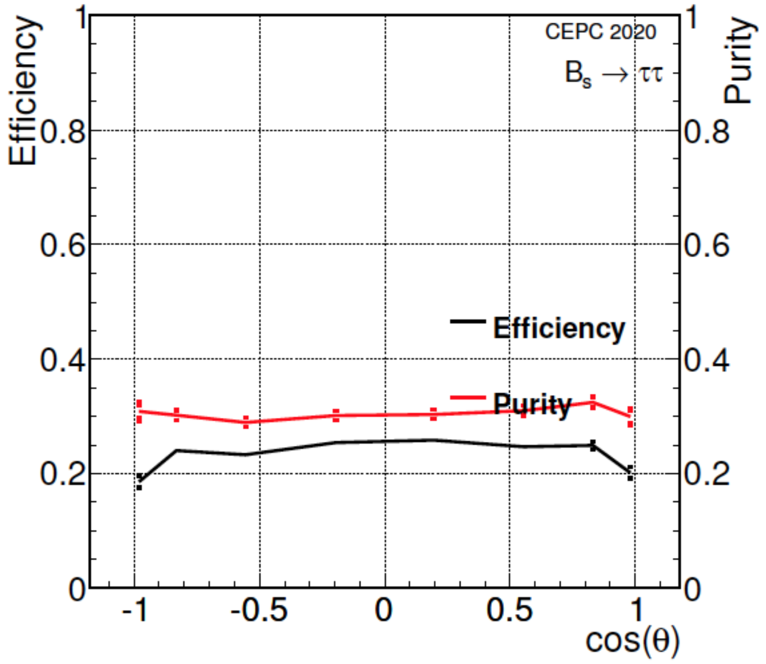


(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

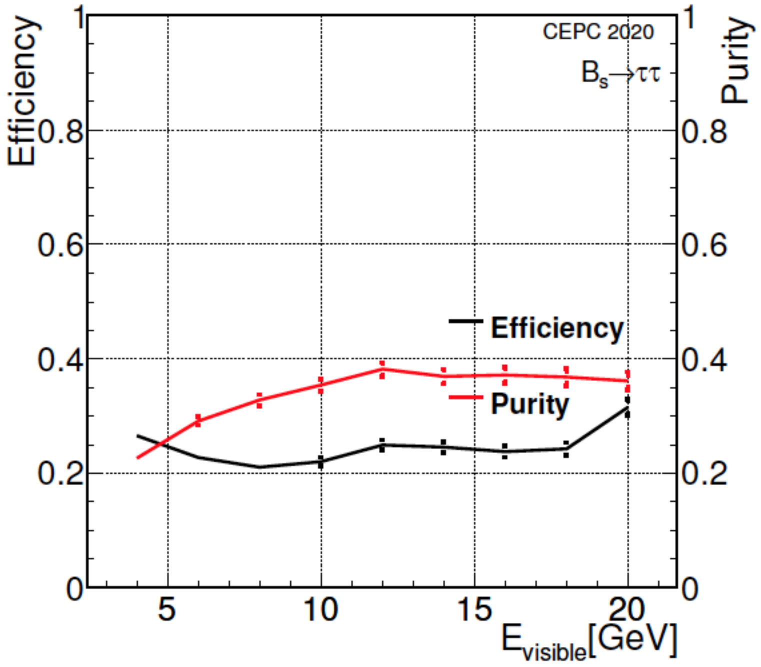


(b) Efficiency and purity performance along with visible energy

Z→bb, B_s→ττ @ 91.2 GeV: eff ~ 25%, purity ~ 30%



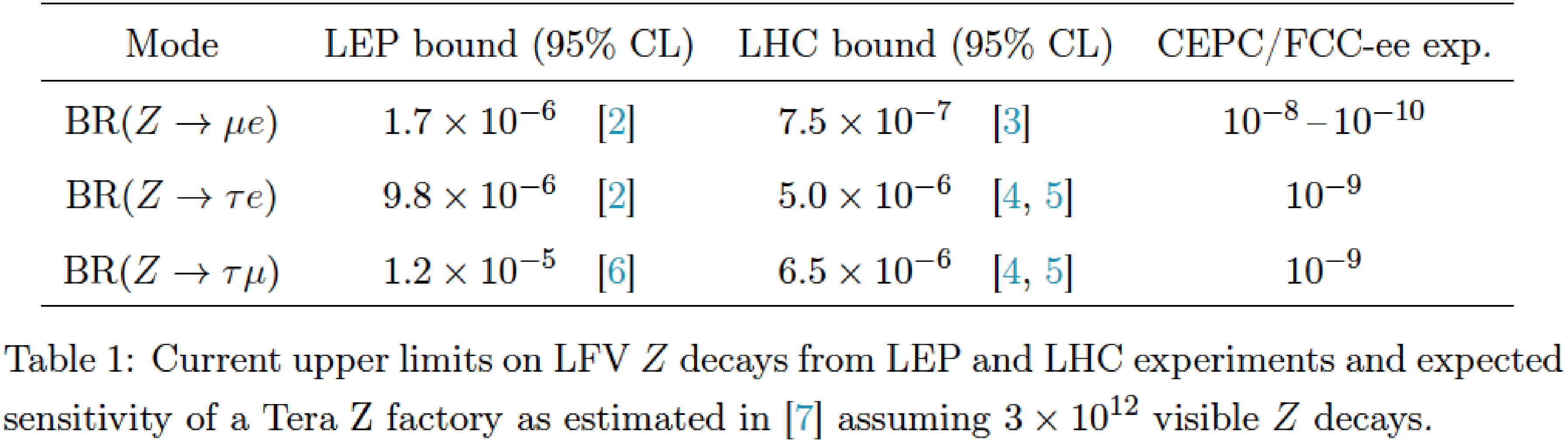
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.



(b) Efficiency and purity performance along with visible energy

LFV from Z & Tau decays

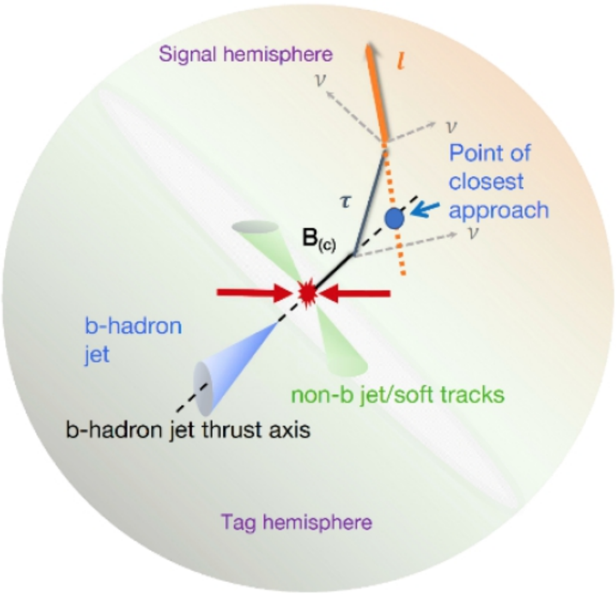
Lorenzo Calibbi, 2107.10273



Mode	LEP bound (95% CL)	LHC bound (95% CL)	CEPC/FCC-ee exp.
$\mathrm{BR}(Z \to \mu e)$	1.7×10^{-6} [2]	7.5×10^{-7} [3]	10^{-8} – 10^{-10}
$\mathrm{BR}(Z \to \tau e)$	9.8×10^{-6} [2]	5.0×10^{-6} [4, 5]	10^{-9}
$\mathrm{BR}(Z \to \tau \mu)$	1.2×10^{-5} [6]	6.5×10^{-6} [4, 5]	10^{-9}

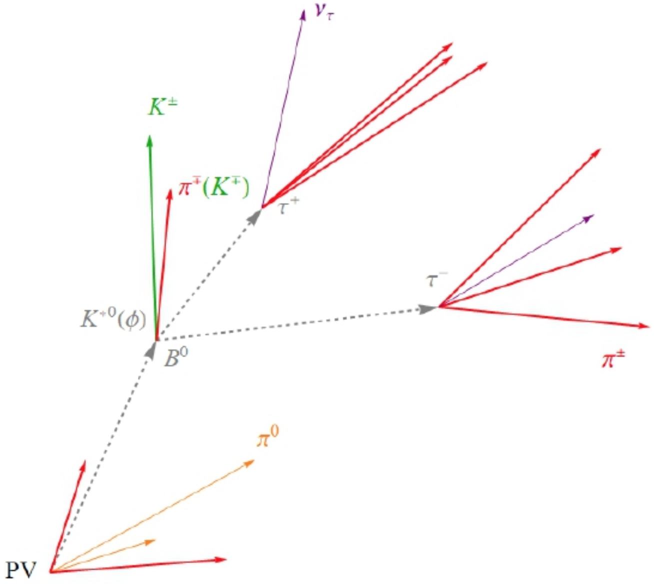
Table 1: Current upper limits on LFV Z decays from LEP and LHC experiments and expected sensitivity of a Tera Z factory as estimated in [7] assuming 3×10^{12} visible Z decays.

Current Progress in LFU Tests



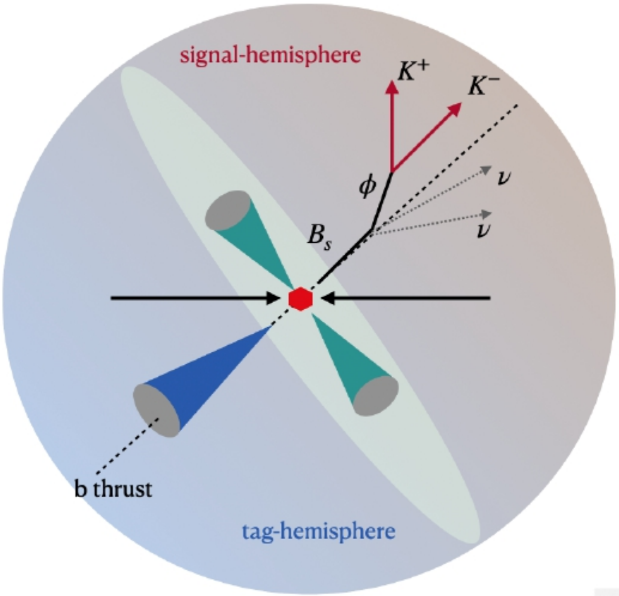
Charged current $B_c \to \tau\nu$ decays [Zheng et al., 2020b].

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



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

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

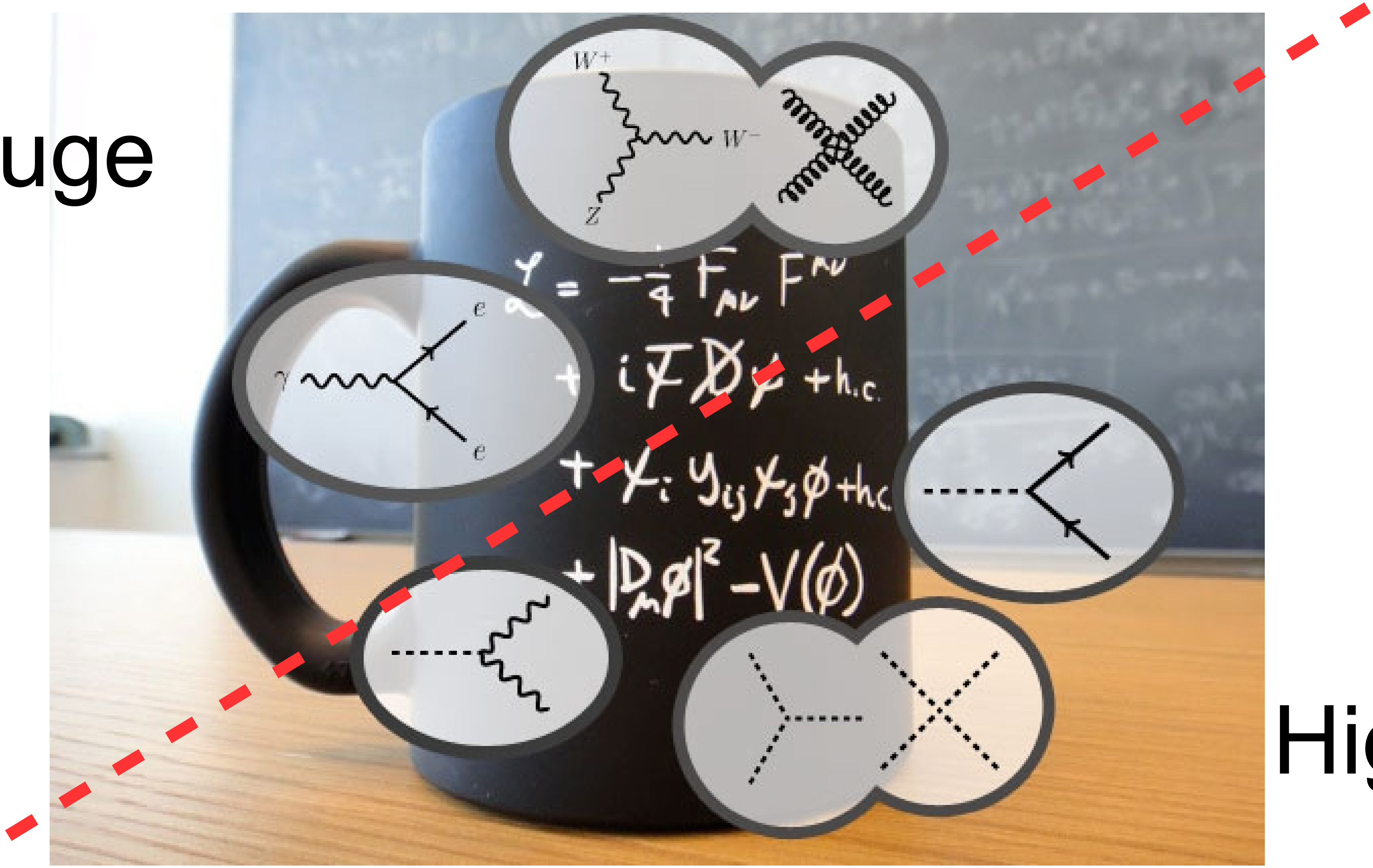


Neutral current $B_s \to \phi\nu\bar{\nu}$ decay [In preparation]

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

Unique opportunities at the Z-pole

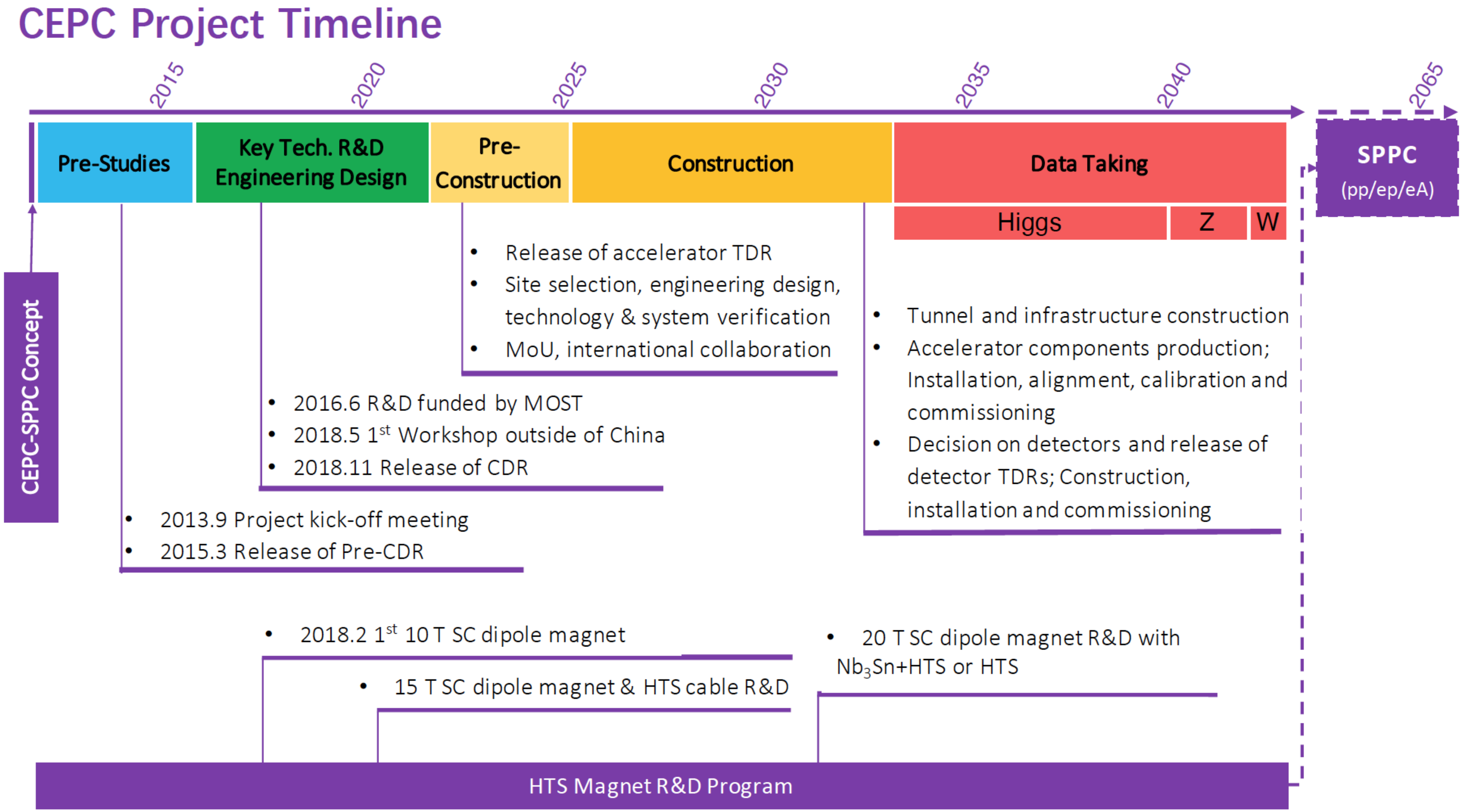
The Higgs field: one of the two pillars of the SM



Gauge

Higgs

Timeline



CEPC Project Timeline

2015 2020 2025 2030 2035 2040 2065

CEPC-SPPC Concept

Pre-Studies | **Key Tech. R&D Engineering Design** | **Pre-Construction** | **Construction** | **Data Taking** (Higgs, Z, W) | **SPPC** (pp/ep/eA)

- 2013.9 Project kick-off meeting
- 2015.3 Release of Pre-CDR

- 2016.6 R&D funded by MOST
- 2018.5 1st Workshop outside of China
- 2018.11 Release of CDR

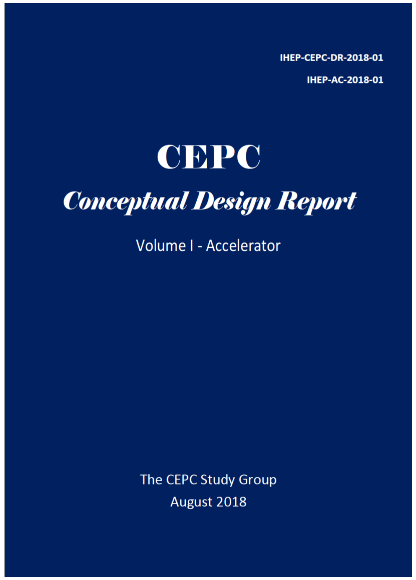
- Release of accelerator TDR
- Site selection, engineering design, technology & system verification
- MoU, international collaboration

- Tunnel and infrastructure construction
- Accelerator components production; Installation, alignment, calibration and commissioning
- Decision on detectors and release of detector TDRs; Construction, installation and commissioning

- 2018.2 1st 10 T SC dipole magnet
- 15 T SC dipole magnet & HTS cable R&D
- 20 T SC dipole magnet R&D with Nb_3Sn+HTS or HTS

HTS Magnet R&D Program

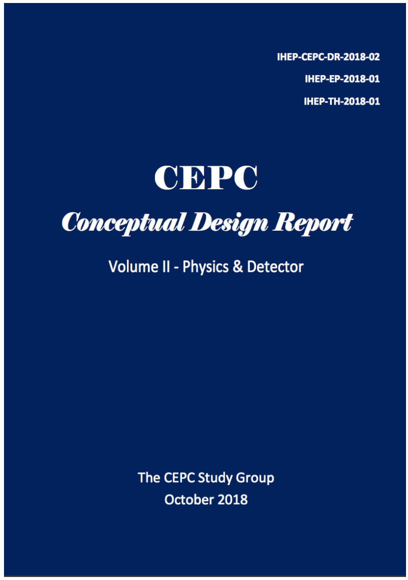
CDR released in Nov. 2018



IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC
Conceptual Design Report
Volume I - Accelerator

The CEPC Study Group
August 2018



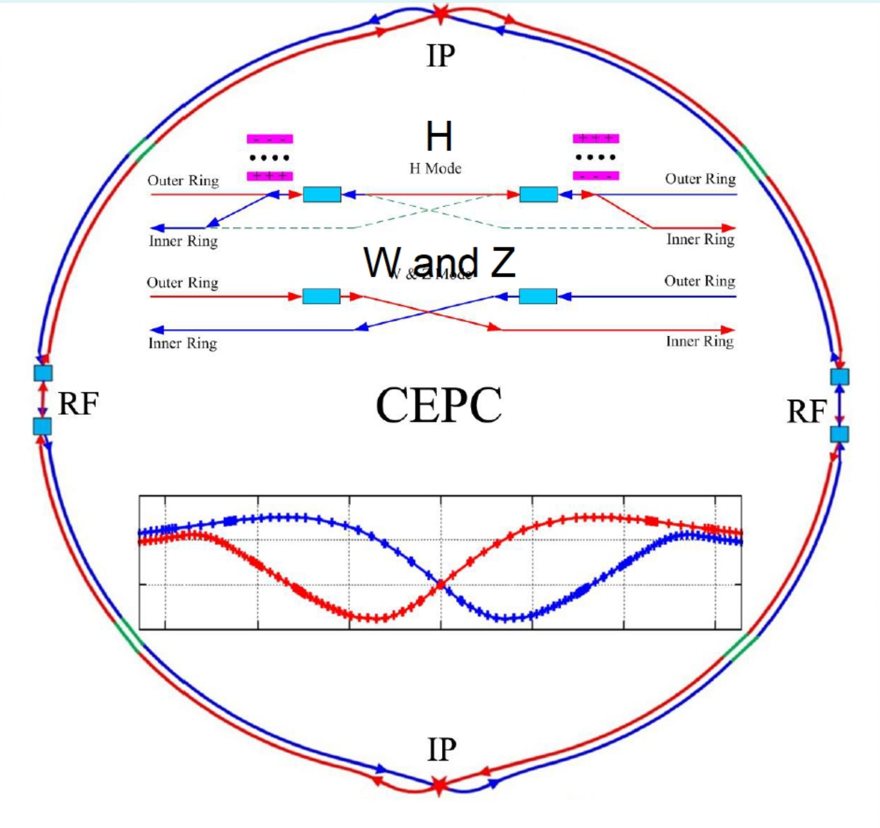
IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC
Conceptual Design Report
Volume II - Physics & Detector

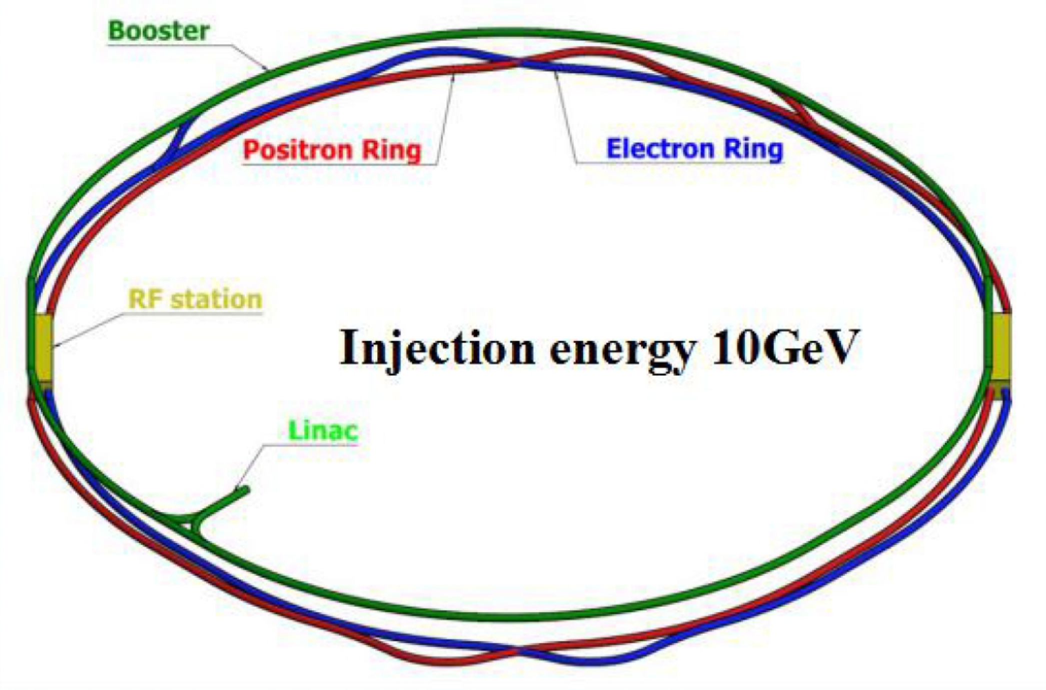
The CEPC Study Group
October 2018

- Baseline designs for the Accelerator, Detector & Software
  - Subsystems' designs supported with Prototype construction & test
- Physics potential

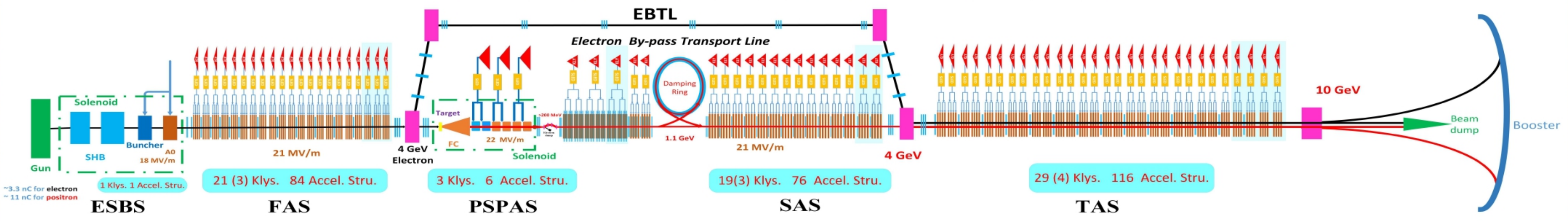
CEPC Accelerator Baseline Layout



CEPC collider ring (100km)



CEPC booster ring (100km)



CEPC CDR Parameters

D. Wang

	Higgs	*W*	*Z*（*3T*）	*Z*（*2T*）
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	1.94	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP L (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

Recent Progresses

- Pursue higher luminosity... and develop upgrading plan to 360 GeV center of mass energies
- Accelerator Critical R&D
  - SRF
  - Klystron
  - High Temperature Iron Based Super Conductor & Magnets
- Detector & Software innovative R&D
- Physics studies: white papers, etc