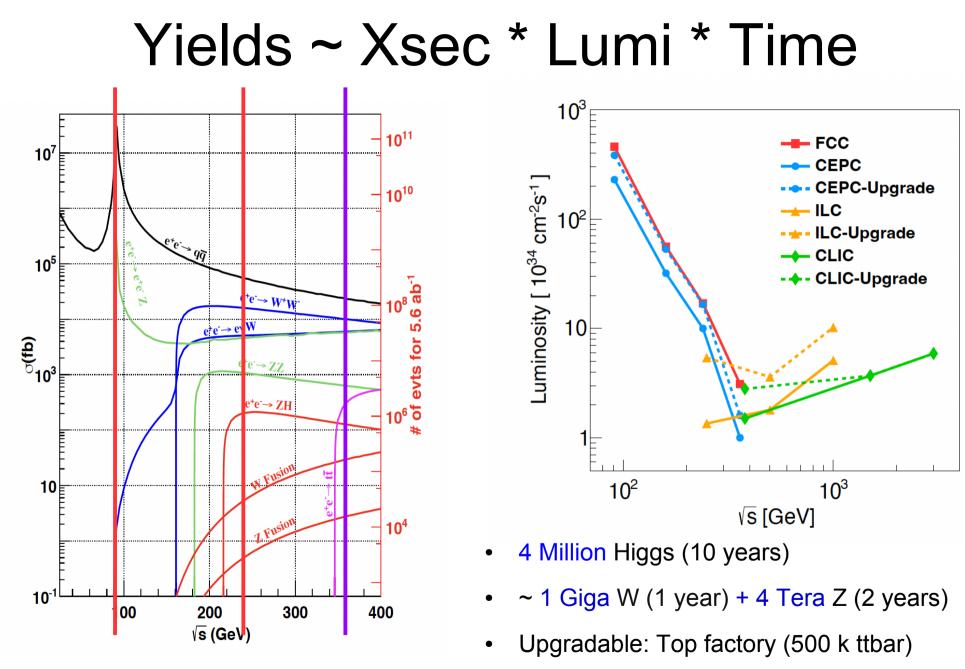
Jet origin identification

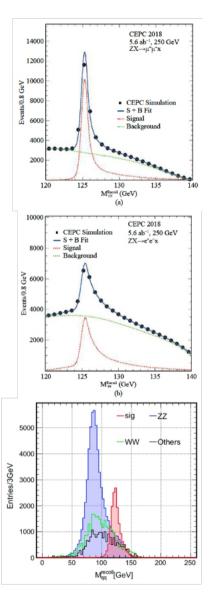
Its Impact on CEPC Physics

N

Manqi Ruan



Physics study: 2023



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

Precision Higgs physics at the CEPC'

Fenfen An(安芬芬)⁴³³ 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 Costa⁴ Zhenwei Cui(崔振儀)³ Yaquan Fang(方亚泉)^{4,6,34,3)} 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(葛韶铎)^{15,2} Jiavin Gu(顾嘉荫)^{13,2)} Fangyi Guo(郭方毅)^{1,4} Jun Guo(郭军)¹⁰ Tao Han(韩海)^{5,31} Shuang Han(韩夷)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)¹² Shan Jin(金山)⁸ Maogiang Jing(荆茂强)^{4,7} Susmita Jyotishmati³³ Ryuta Kinchi Chia-Ming Kuo(郭家铭)²¹ Peizhu Lai(赖培策)²¹ Boyang Li(李博扬)⁵ Congqiao Li(李聪乔)³ Gang Li(李明)^{4,34,5} 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)⁴⁴ 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(刘清)⁵ Zhen Liu(刘武)^{2638,4)} Xinchou Lou(娄辛丑)^{4,633,34} Lianliang Ma(马连良)¹² Bruce Mellado^{17,18} Xin Mo(莫欣) Mila Pandurovic¹⁶ Jianming Qian(钱剑明)^{24,3)} Zhuoni Qian(钱卓妮)¹⁹ Nikolaos Rompotis²¹ Manqi Ruan(阮曼奇)⁴⁶⁾ Alex Schuy³² 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(王節)4 Liantao Wang(王连涛)2 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(她为民)²⁸ Dan Yu(于丹)⁴ Kaili Zhang(张凯栗)^{4,6,8)} Zhaoru Zhang(张照载)⁴ Mingrui Zhao(赵明锐)² Xianghu Zhao(赵祥虎)⁴ Ning Zhou(周宁)¹⁰

Ninigroi Zano(42.9719.) Annigro Zano(42.1719.) Ning Zano(74.17.)

White papers + ~300 Journal/AxXiv citables

¹¹PRISMA Cluster of Excellence & Maine Institute of Park 206237, China Gurenberg-Universitä Maine, Mainez 55128, Germany ¹¹PRISMA Cluster of Excellence & Maine Institute of Parkies, Heng Kerett Urbysis, A Science and Technology Heng Keret Brand, Science and Technology Heng Keret Parkies, Parkies De University of Techno, Kathian, Cathian 274-588, Japan ¹¹Kuch Parkies, Balance Berger, Balance A, Balance B, Bardet 1900, Stehla ¹¹School B Parkies and Institute of Parkies Parkies Parkies and Braham for Collidor Parkies Parkies of the Winsterman, Johannesburg 2069, South Africa

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

* Supported by the National Key Piogram for S&T Reseath and Development (2016/YEA040040); CAS Center for Excellence in Particle Physics: Yifing Wang's Science Studio of the Ten Thomsond Talents Project, the CAS/SATEA International Parturenting Program for Centure Research Tenus (FT)3011537; JEEP Internation Gram (Y4551077); Key Research Program of Tomice Science, CAS SQUZZYU-X5533-XEB00; Clanese Academy of Science Special Grant In Large Scientific Program (13111KYSB3)10000); the National Natural Science Foundation of Clanual (167300); the Hendmeir Talent Pregram of Grantese Academy of Science (Y3555400); the National 1000 Talentes Program Grantese LLQ (DE-ACQ207EH1135); the SHOPHYI (100070); by the Mayland Crater for Fundamental Physics (MCFP); Tanghan University Institute Sciencific Research Program; and the Briging Manicipal Science and Technology Commission project(2111)0002(1100))

1) E-mail: fangyq@ihep.ac.cn 2) E-mail: jagu@uni-mainz.de 3) E-mail: jagu@uni-mainz.de 4) E-mail: jagug@unich.edu 5) E-mail: qianj@unich.edu 6) E-mail: quanj.gunich.edu 6) E-mail: mang-transfithep.ac.cn 2) E-mail: mang-transfithep.ac.cn

• ...

 B E mail: shangki@hep.a.c.m
 Consent from this work may be used under the terms of the Creative Commons Attribution 10 Scence: Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal criterion and DOI. Article funded by SCOAP3 and published under licence by Clause Physical Sciences and IOP Pubterior and the lostitute of Hydro Physical Sciences and IOP Pub-

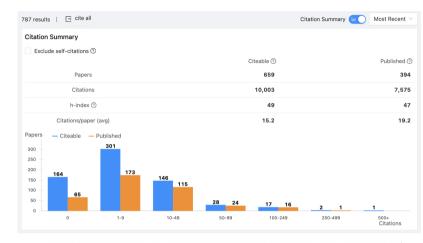


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1} . The HL-LHC precision of 2000 bb^{-1} data are used for comparison [2]

	Higgs			W, Z and top	
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precisior
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M _{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H \rightarrow bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \rightarrow cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H \rightarrow gg)$	-	0.81%	R _b	$3 imes 10^{-3}$	$2 imes 10^{-4}$
$B(H \rightarrow WW^*)$	2.8%	0.53%	R _c	$1.7 imes 10^{-2}$	1×10^{-3}
$B(H \rightarrow ZZ^*)$	2.9%	4.2%	R_{μ}	$2 imes 10^{-3}$	$1 imes 10^{-4}$
$B(H \rightarrow \tau^+ \tau^-)$	2.9%	0.42%	R_{τ}	$1.7 imes 10^{-2}$	$1 imes 10^{-4}$
$B(H ightarrow \gamma \gamma)$	2.6%	3.0%	A_{μ}	$1.5 imes 10^{-2}$	$3.5 imes 10^{-5}$
$B(H \rightarrow \mu^+ \mu^-)$	8.2%	6.4%	A_{τ}	$4.3 imes 10^{-3}$	7×10^{-5}
$B(H \rightarrow Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	$2 imes 10^{-4}$
$Bupper(H \rightarrow inv.)$	2.5%	0.07%	N_{ν}	$2.5 imes 10^{-3}$	2×10^{-4}

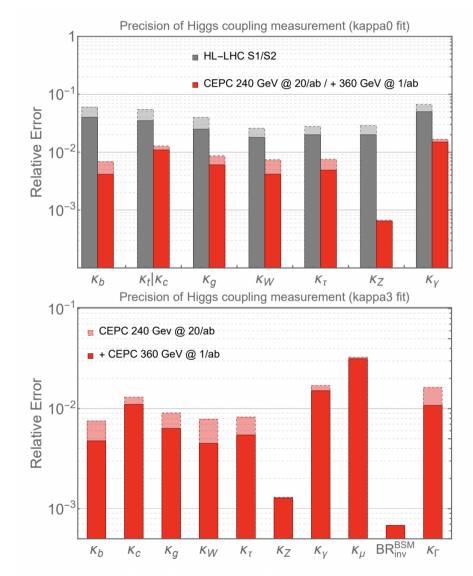
Scientific Significance quantified by CEPC physics studies, via full simulation/phenomenology studies:

- 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.

07/01/2004

Physics reach via Higgs at CEPC

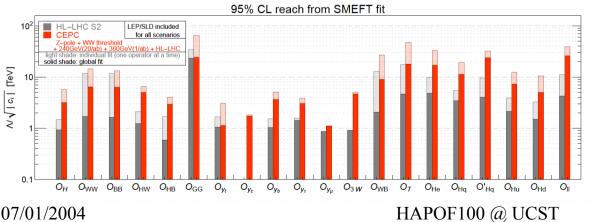
	$240{ m GeV},20{ m ab}^{-1}$		360 0	ab^{-1}	
	\mathbf{ZH}	\mathbf{vvH}	\mathbf{ZH}	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau \tau$	0.42%		2.10%	4.20%	7.50%
$H \rightarrow \gamma \gamma$	3.02%		11%	16%	
$H ightarrow \mu \mu$	6.36%		41%	57%	
$H \rightarrow Z\gamma$	8.50%		35%		
$Br_{upper}(H \to inv.)$	0.07%				
Γ_H	1.	65%		1.10%	

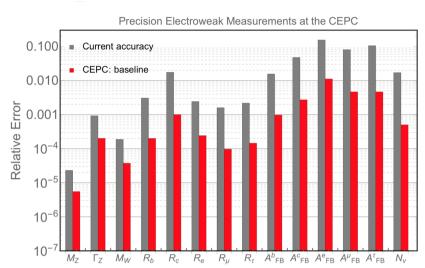


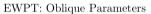
07/01/2004

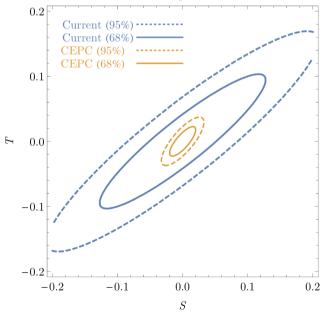
EW measurements & SMEFT

Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	$2.1 \ { m MeV} \ [37-41]$	$0.1 { m MeV} (0.005 { m MeV})$	${\cal Z}$ threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	$0.025 {\rm ~MeV} (0.005 {\rm ~MeV})$	Z threshold	E_{beam}
Δm_W	$9 { m MeV}$ [42–46	$0.5 { m ~MeV} (0.35 { m ~MeV})$	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	$2.0 { m ~MeV} (1.8 { m ~MeV})$	WW threshold	E_{beam}
Δm_t	$0.76 {\rm ~GeV} [50]$	$\mathcal{O}(10) \ \mathrm{MeV^{a}}$	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	$1.5 \times 10^{-5} \ (1.5 \times 10^{-5})$	Z pole $(Z \to \tau \tau)$	Stat. Unc.
ΔA_{μ}	$0.015 \ [37, 53]$	$3.5\times 10^{-5}~(3.0\times 10^{-5})$	Z pole $(Z \to \mu \mu)$	point-to-point Unc.
ΔA_{τ}	4.3×10^{-3} [37, 51–55]	$7.0\times 10^{-5}~(1.2\times 10^{-5})$	Z pole $(Z \to \tau \tau)$	tau decay model
ΔA_b	$0.02 \ [37, 56]$	$20 \times 10^{-5} \ (3 \times 10^{-5})$	Z pole	QCD effects
ΔA_c	$0.027 \ [37, 56]$	$30\times 10^{-5}~(6\times 10^{-5})$	Z pole	QCD effects
$\Delta \sigma_{had}$	37 pb [37–41]	$2~\mathrm{pb}~(0.05~\mathrm{pb})$	Z pole	lumiosity
δR_b^0	0.003 [37, 57–61]	$0.0002 (5 \times 10^{-6})$	Z pole	gluon splitting
δR_c^0	$0.017 \ [37, 57, 6265]$	$0.001~(2\times 10^{-5})$	Z pole	gluon splitting
δR_e^0	$0.0012 \ [37-41]$	$2\times 10^{-4}~(3\times 10^{-6})$	Z pole	E_{beam} and t channel
δR^0_μ	0.002 [37-41]	$1\times 10^{-4}~(3\times 10^{-6})$	Z pole	E_{beam}
δR_{τ}^0	$0.017 \ [37-41]$	$1\times 10^{-4}~(3\times 10^{-6})$	Z pole	E_{beam}
δN_{ν}	$0.0025 \ [37, \ 66]$	$2\times 10^{-4}~(3\times 10^{-5}$)	ZH run $(\nu\nu\gamma)$	Calo energy scale









07/01/2004

Flavor Physics

 $\mathbf{51}$

Flavor Physics at CEPC: a General Perspective

\sim					
С	0	\mathbf{n}	te	\mathbf{n}	\mathbf{ts}

07/01/2004

1	Introduction
2	Description of CEPC Facility 2.1 Key Collider Features for Flavor Physics 2.2 Key Detector Features for Flavor Physics 2.3 Simulation Method
3	FCCC Semileptonic and Leptonic b-Hadron Decays
4	Rare and Forbidden b-Hadron Decays 4.1 Di-lepton Modes 4.2 Neutrino Modes 4.3 Radiative Modes 4.4 Null Tests with Forbidden Modes
5	CP Violation in b-Hadron Decays
6	Charm and Strange Physics
7	$\begin{array}{ll} \tau \ {\bf Physics} \\ \hline 7.1 & {\rm LFV \ in \ } \tau \ {\rm Decays} \\ \hline 7.2 & {\rm LFU \ of \ } \tau \ {\rm Decays} \\ \hline 7.3 & {\rm Opportunities \ in \ Hadronic \ } \tau \ {\rm Decays} \\ \hline 7.4 & CP \ {\rm Violation \ in \ Hadronic \ } \tau \ {\rm Decays} \\ \hline \end{array}$
8	Flavor Physics in Z Boson Decays 8.1 LFV and LFU 8.2 Factorization Theorem and Hadron Inner Structure
9	Flavor Physics beyond Z Pole 9.1 Flavor Physics and W Boson Decays 9.2 FCNC Higgs Boson Decays 9.3 FCNC Top Quark Physics
10	Spectroscopy and Exotics
	Light BSM States from Heavy Flavors 11.1 Lepton Sector 11.2 Quark Sector Detector Performance Requirements

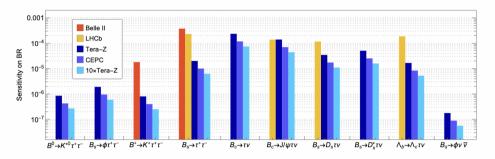
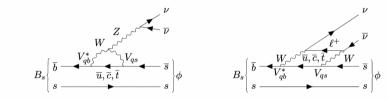
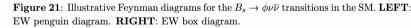
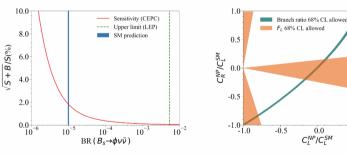


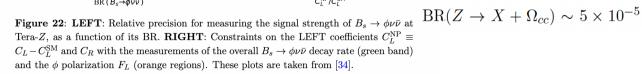
Figure 18: Projected sensitivities of measuring the $b \to s\tau\tau$ [70], $b \to s\nu\bar{\nu}$ [34] and $b \to c\tau\nu$ [35, 62] transitions at the Z pole. The sensitivities at Belle II @ 50 ab⁻¹ [6] and LHCb Upgrade II [17, 71] have also been provided as a reference. Note, the LHCb sensitivities are generated by combining the analyses of $\tau^+ \to \pi^+\pi^-\pi^-(\pi^0)\nu$ and $\tau \to \mu\nu\bar{\nu}$.

0.5



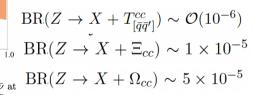






$$e^+$$

 Z
 e^-
 \overline{b}
 \overline{b}
 \overline{d}
 \overline{d}
 $T^{bb}_{[ud]}$
 \overline{u}



~ 40+ benchmarks + ... Access to NP at 10 TeV or higher

New Physics White paper

5

ABSTRACT (TO BE UPDATED)

4

1

10

16

16

17

26

26

28

30

32

32

34

35

36

36

39

The Circular Electron Positron Collider (CEPC) is a large-scale collider facility that can serve as a factory of the Higgs, Z, and W bosons and is upgradable to run at the $t\bar{t}$ threshold. This document describes the latest CEPC nominal operation scenario and particle vields and updates the corresponding physics potential. A new detector concept is also briefly described. This submission is for consideration by the Snowmass process.

CONTENTS
Contributors (to be updated)
Abstract (to be updated)
I. Executive Summary (Liantao, Xuai, Manqi, Jia, Zhen, Zhao, Yu)
II. Introduction(Liantao, Xuai, Manqi,Jia, Zhen,Zhao, Yu)
III. Description of CEPC facility, nominal luminosity and Typical Detector Performance (Manqi)A. Key Collider FeaturesB. Key Detector Features
 IV. Exotic Higgs potential and Exotic Higgs/Z/top decays (Yaquan, Zhao) A. Model-independent Sensitivity to Exotic Higgs decays B. Exotic Higgs potential C. Higgs exotic decays in supersymmetry D. Exotic Decays via Dark Sector Higgs Exotic Decays via Dark Sector Z Exotic Decays via Dark Sector E. Higgs exotic invisible decays F. Decays into Long Lived Particles Higgs exotic decays into Long Lived Particles
G. The 95 GeV Higgs boson at the CEPC

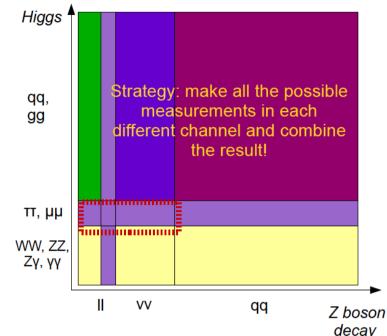
2. Z exotic decays into Long Lived Particles	38
H. Top quark exotic decays	41
V. Supersymmetry (Tianjun, Lei, Xuai, Da)	42
A. Light electroweakino searches	43
B. Light slepton searches	45
C. Input from the European Strategy	49
VI. Dark Matter and Dark Sector (Jia, Xiaoping, Yongchao, Bhupal)	50
A. Lepton portal DM	52
B. Interplay of dark particles with neutrinos	53
C. Leptophilic DM	54
D. Dark particles from exotic Z decays	55
E. DM with millicharge & the effective theory of DM	57
F. Dark particles with electromagnetic form factors	59
G. Asymmetric DM	60
H. Long-lived VLL	62
VII. Long-lived Particle Searches (Liang Li, Ying-nan Mao, Kechen Wang, Zeren	
Simon Wang)	65
A. Computation of LLP signal-event rates	66
B. Studies with near detectors	70
B. Studies with near detectors1. Higgs boson decays	70 71
1. Higgs boson decays	71
 Higgs boson decays Z-boson decays 	71 81
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) 	71 81 83
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar 	71 81 83 84
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar Studies with far detectors 	71 81 83 84 85
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar Studies with far detectors Far detectors at hadron colliders 	71 81 83 84 85 86
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar Studies with far detectors Far detectors at hadron colliders Proposed far detectors at lepton colliders 	71 81 83 84 85 86 88
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar Studies with far detectors Far detectors at hadron colliders Proposed far detectors at lepton colliders Higgs boson decays 	71 81 83 84 85 86 88 90
 Higgs boson decays Z-boson decays Supersymmetry (SUSY) Vector-like leptons with scalar Studies with far detectors Far detectors at hadron colliders Proposed far detectors at lepton colliders Higgs boson decays Z-boson decays 	71 81 83 84 85 86 88 90 91

6 1. ALPs and new scalar particles 95 2. New neutral gauge bosons 97 E. Summary and Discussion 99 VIII. Flavor Portal NP(Lingfeng, Xinqiang) 102 A. cLFV processes 104 B. Decays of b and c hadrons 105 C. Light BSM degrees of freedom from flavor transitions 106 IX. Electroweak phase transition and gravitational waves (Ke-Pan Xie, Sai Wang, Fa Peng Huang, Bruce) 108 A. Probing the nature of electroweak phase transition at the colliders 109 B. Higgs precision measurements 111 C. Higgs exotic decay 114 X. Neutrino Physics (Bhupal, Wei, Yongchao) 117 A. Motivation 117 B. Connection to Leptogenesis and Dark Matter 118 C. Prospects of heavy neutrinos 121 1. heavy neutrinos at the near detector 121 2. Heavy neutrinos at far detectors 124 3. Heavy neutrinos at beam dump experiments 126 4. SM Higgs decay $h \to NN$ 129 5. Prospects of heavy neutrinos in U(1) models 133 6. Prospects of heavy neutrinos in the LRSM 137 D. Prospects of long-lived doubly-charged scalars in seesaw models 138 E. Active-sterile neutrino transition magnetic moments 138 F. Non-standard neutrino interactions 141 XI. More Exotics (Yu, Zuowei) 141 A. Axion-like particles 142 B. Lepton form factors 144 1. General remarks on μ/e g-2 145 2. μ/e dipole moments in SUSY 148 3. τ weak-electric dipole moments 149 C. Emergent Hadron Mass 150 D. Exotic lepton mass models 152 XII. Global Fits (Jiayin, Yang, Yong Du) 154 A. SMEFT global fits 154 B. 2HDM global fits (Tao Han, Shufang Su, Wei Su, Yongcheng Wu) 157C. SUSY global fits 160 XIII. Conclusion (Liantao, Xuai, Manqi, Jia, Zhen, Zhao, Yu...) 163 Acknowledgements 164 7 164 References

07/01/2004

Performance requirements

- To reconstruct all kinds of Physics Object
 - Identification & Measurements
 - Objects:
 - Lepton, Photons, Kaon,
 - pi-0, Tau, Lambda, Kshort,
 - Heavy flavor hadrons,
 - Jets
 - Missing energy/momentum
 - Exotics...
- Massive Four in Standard Model:
 - Z & W: ~ 70% goes to a pair of jets
 - Higgs: ~90% final state with jets (ZH events)
 - Top: $t \rightarrow W + b$



• Requirements:

decay Final state

- Excellent pattern. Reco. & Object id
- Larger acceptance...
- Excellent intrinsic resolutions
- Extremely stable...
- Be addressed by state-of-art detector design, technology, and reconstruction algorithm!

Jet origin id

Hao Liang, Yongfeng Zhu, Yuzhi Che, Yuexin Wang, Huiling Qu, Cen Zhou, etc

PHYSICAL REVIEW LETTERS 132, 221802 (2024)

Jet-Origin Identification and Its Application at an Electron-Positron Higgs Factory

Hao Liang⁰,^{1,2,*} Yongfeng Zhu⁰,^{3,*} Yuexin Wang⁰,^{1,4} Yuzhi Che⁰,^{1,2} Manqi Ruan⁰,^{1,2,†} Chen Zhou^{0,3,‡} and Huilin Qu^{5,§} ¹Institute of High Energy Physics, Chinese Academy of Sciences, 19B Yuquan Road, Shijingshan District, Beijing 100049, China ²University of Chinese Academy of Sciences, 19A Yuquan Road, Shijingshan District, Beijing 100049, China ³State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China ⁴China Center of Advanced Science and Technology, Beijing 100190, China ⁵CERN, EP Department, CH-1211 Geneva 23, Switzerland

(Received 16 October 2023; revised 26 April 2024; accepted 1 May 2024; published 31 May 2024)

To enhance the scientific discovery power of high-energy collider experiments, we propose and realize the concept of jet-origin identification that categorizes jets into five quark species (b, c, s, u, d), five antiquarks $(\bar{b}, \bar{c}, \bar{s}, \bar{u}, \bar{d})$, and the gluon. Using state-of-the-art algorithms and simulated $\nu \bar{\nu} H, H \rightarrow j \bar{j}$ events at 240 GeV center-of-mass energy at the electron-positron Higgs factory, the jet-origin identification simultaneously reaches jet flavor tagging efficiencies ranging from 67% to 92% for bottom, charm, and strange quarks and jet charge flip rates of 7%-24% for all quark species. We apply the jet-origin identification to Higgs rare and exotic decay measurements at the nominal luminosity of the Circular Electron Positron Collider and conclude that the upper limits on the branching ratios of $H \rightarrow s\bar{s}, u\bar{u}, d\bar{d}$ and $H \rightarrow sb, db, uc, ds$ can be determined to 2×10^{-4} to 1×10^{-3} at 95% confidence level. The derived upper limit for $H \rightarrow s\bar{s}$ decay is approximately 3 times the prediction of the standard model.

Eur. Phys. J. C (2024) 84:152 https://doi.org/10.1140/epic/s10052-024-12475-5 THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

ParticleNet and its application on CEPC jet flavor tagging

Yongfeng Zhu^{1,a}, Hao Liang^{2,3}, Yuexin Wang^{2,3}, Huilin Qu⁴, Chen Zhou^{1,b}, Manqi Ruan^{2,3,c}

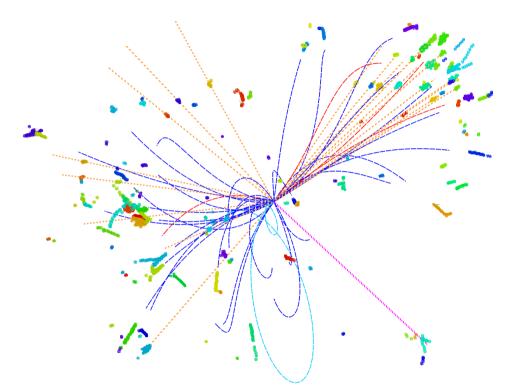
¹ State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China ² Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China ³ University of Chinese Academy of Sciences (UCAS), Beijing 100049, China ⁴ EP Department, CERN, 1211 Geneva 23, Switzerland

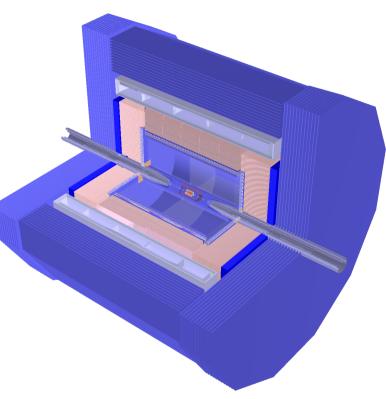
Received: 15 November 2023 / Accepted: 23 January 2024 © The Author(s) 2024

https://arxiv.org/abs/2310.03440

https://arxiv.org/abs/2309.13231

Detector & Sample





- Jet origin identification: 11 categories (5 quarks + 5 anti quarks + gluon)
 - Jet Flavor Tagging + Jet Charge measurements + s-tagging + gluon tagging...
- Full Simulated vvH, Higgs to two jets sample at CEPC baseline configuration: CEPC-v4 detector, reconstructed with Arbor + ParticleNet (Deep Learning Tech.)
- 1 Million samples each, 60/20/20% for training, validation & test

Particle Net: IO

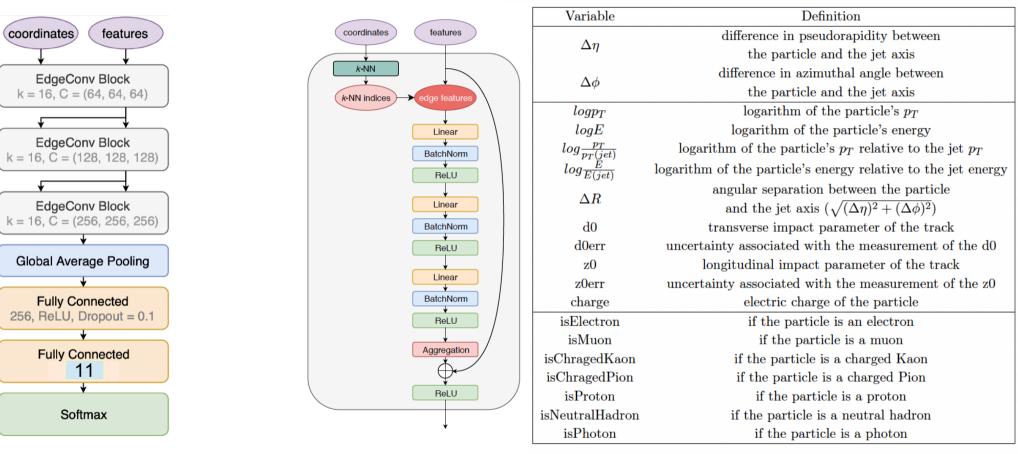


Table 3. The input variables used in ParticleNet for jet flavor tagging at the CEPC.

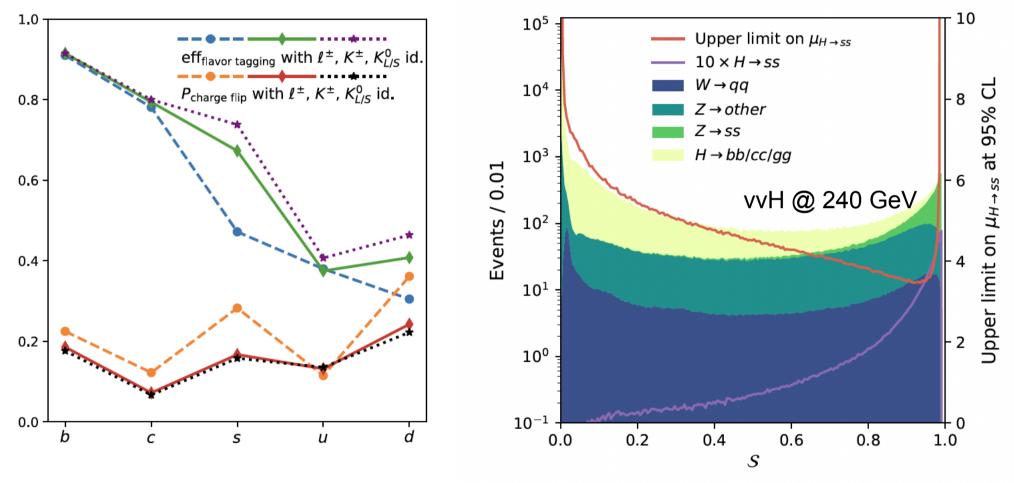
- Input: measurable of all reconstructed jet particles ~ 500 input numbers
- Output: 10(11)-likelihoods to different categories
 HAPOF100 @ UCST

11-dim migration behavior

- Let the jet be identified as the category with highest likelihood:
- Pid: ideal Pid three categories
 - Lepton identification
 - Charged Kaon identification
 - Neutral Kaon identification
- Patterns:
 - ~ Diagonal at quark sector...
 - $P(g \rightarrow q) < P(q \rightarrow g)...$
 - Light jet id...

												_	
b-	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018		0.7
	0.750	0.107	0.034	0.020	0.005	0.005	0.002	0.005	0.002	0.002	0.018		0.6
_													0.5
b -	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018		0.4
													0.3
													0.3
с-	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043		0.2
													0.2
ō-													0.1
C	0.015	0.015	0.055	0.741	0.032	0.037	0.010	0.026	0.016	0.010	0.043		0.1
													0.0
s-	0.003	0.003	0.020	0.018	0.541	0.104	0.030	0.082	0.062	0.045	0.092		0.0
-	0.003	0.003	0.020	0.018	0.541	0.104	0.030	0.082	0.062	0.045	0.092		0.0
Ð													0.0
ırue ∎	0.002	0.003	0.018	0.021	0.101	0.543	0.085	0.028	0.044	0.062	0.092		0.0
_													0.0
													0.0
<i>u</i> -	0.002	0.003	0.019	0.012	0.044	0.132	0.375	0.057	0.079	0.168	0.109		0.0
													0.0
													0.0
\overline{u} -	0.003	0.002	0.011	0.020	0.132	0.043	0.062	0.368	0.166	0.084	0.108		0.0
													0.0
d-	0.003	0.003	0.012	0.020	0 111	0.002	0.002	0 999	0.961	0.090	0.110		0.0
-	0.003	0.003	0.012	0.020	0.111	0.093	0.083	0.223	0.261	0.080	0.110		0.0
_													0.0 0.0
d -	0.003	0.003	0.020	0.013	0.093	0.113	0.226	0.079	0.076	0.265	0.110		0.0
													0.0
~													0.0
G ·	0.015	0.014	0.025	0.025	0.053	0.053	0.043	0.044	0.033	0.035	0.661		0.0
	-				1				-	1			0.0
	b	b	С	\overline{c}	S	5	u	ū	d	d	G		
					Dr	odict	bd						
Predicted													

Performance with different PID scenarios & $H \rightarrow ss$ measurements



Flavor tagging: type that maximize {L_q + L_q_bar, L_g} R je If quark jet: jet charge ~ compare {L_q, L_q_bar} 1 07/01/2004 HAPOF100 @ UCST

Remark: current jet flavor tagging efficiency & jet charge flip rates are projections of the 11-dim arrays produced by Jet origin id

13

Benchmark analyses: Higgs rare/FCNC

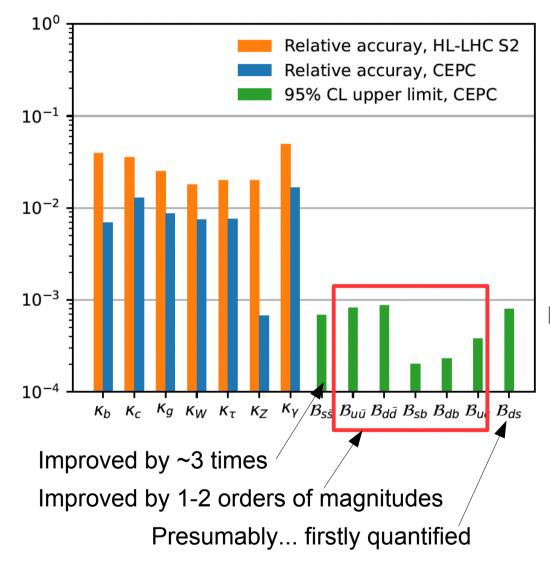
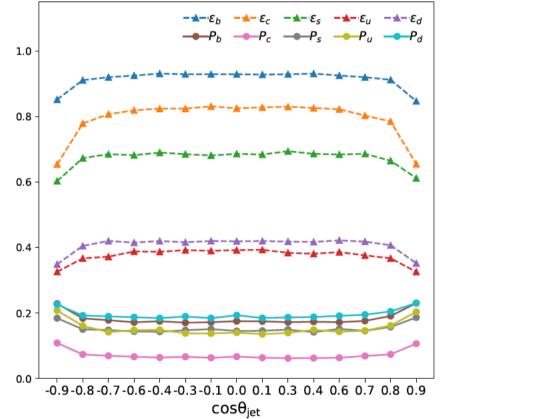


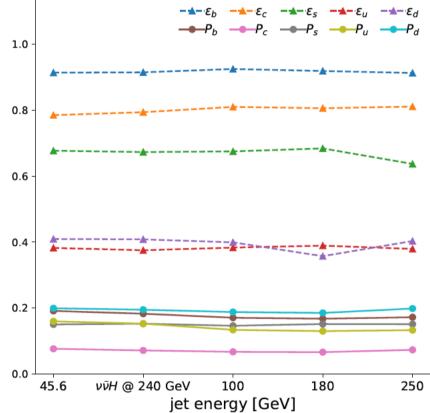
TABLE I: Summary of background events of $H \rightarrow b\bar{b}/c\bar{c}/gg$, Z, and W prior to flavor-based event selection, along with the expected upper limits on Higgs decay branching ratios at 95% CL. Expectations are derived based on the background-only hypothesis.

	Bkg. (10^3)			Upper limit (10^{-3}) $s\bar{s}$ $u\bar{u}$ $d\bar{d}$ sb db uc ds						
	H	Z	W	$s\bar{s}$	$u ar{u}$	$dar{d}$	sb	db	uc	ds
$ u \bar{ u} H$	151	20	2.1	0.81	0.95	0.99	0.26	0.27	0.46	0.93
$\mu^+\mu^-H$	50	25	0	2.6	3.0	3.2	0.5	0.6	1.0	3.0
e^+e^-H	26	16	0	4.1	4.6	4.8	0.7	0.9	1.6	4.3
$ \frac{\nu\bar{\nu}H}{\mu^+\mu^-H} \\ e^+e^-H \\ \text{Comb.} $	-	-	-	0.75	0.91	0.95	0.22	0.23	0.39	0.86

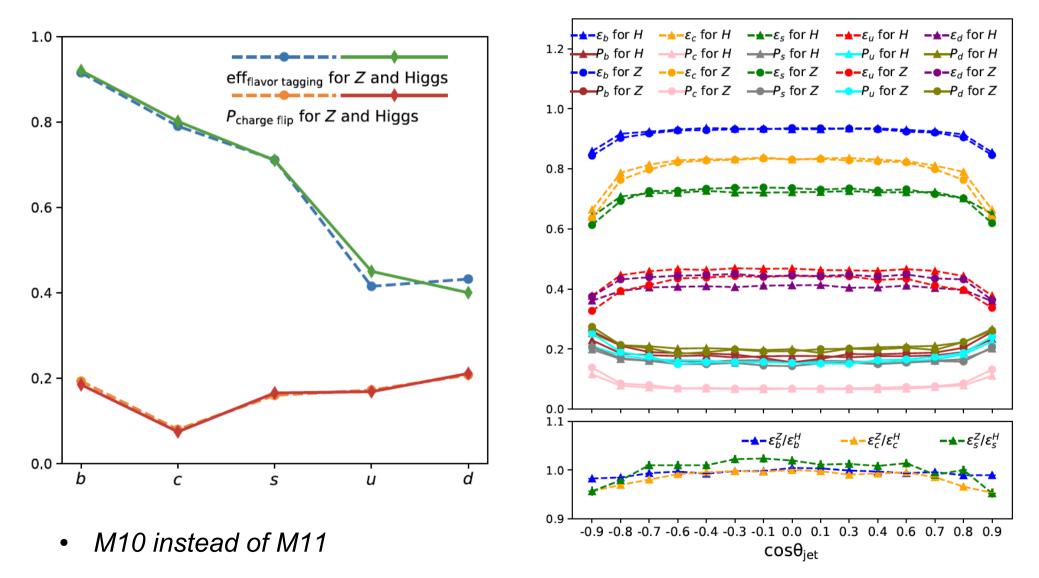
- [28] J. Duarte-Campderros, G. Perez, M. Schlaffer, and A. Soffer. Probing the Higgs–strange-quark coupling at e^+e^- colliders using light-jet flavor tagging. *Phys. Rev.* D, 101(11):115005, 2020.
- [50] Alexander Albert et al. Strange quark as a probe for new physics in the Higgs sector. In *Snowmass 2021*, 3 2022.
- [59] J. de Blas et al. Higgs Boson Studies at Future Particle Colliders. JHEP, 01:139, 2020.
- [60] Jorge De Blas, Gauthier Durieux, Christophe Grojean, Jiayin Gu, and Ayan Paul. On the future of Higgs, electroweak and diboson measurements at lepton colliders. *JHEP*, 12:117, 2019.

Performance V.S. Jet Kinematics

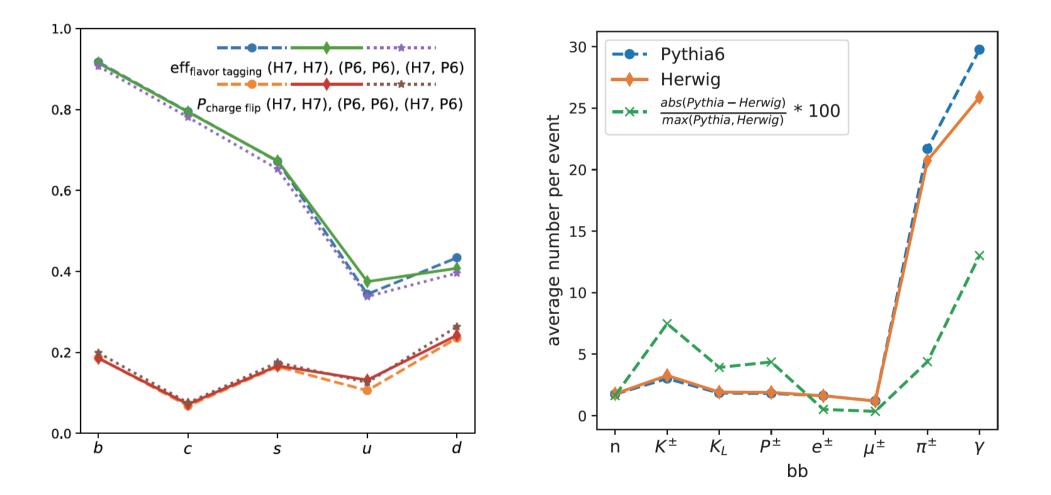




Performance @ Z and Higgs

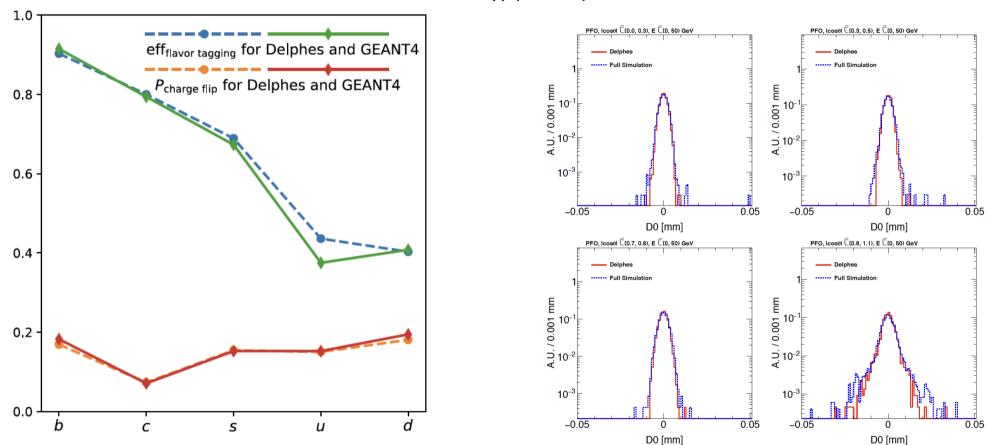


V.S. Hadronization models



07/01/2004

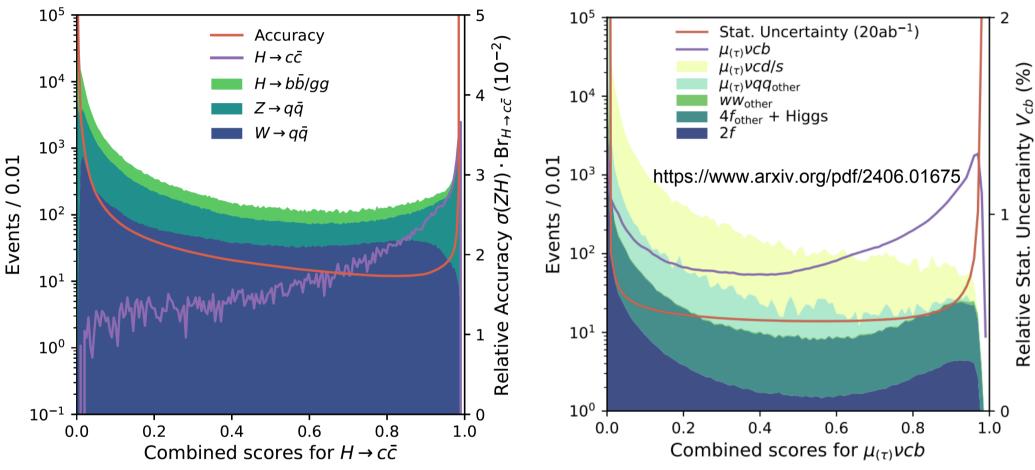
Fast/Full Simulation



Z->μμ (91.2 GeV)

Delphes ~ Perfect PFA (1 – 1 correspondence..)

Recent update at more benchmarks



- From Jet Flavor Tagging to Jet Origin ID:
 - vvH, H \rightarrow cc: 3% \rightarrow 1.7% (**Preliminary**)

- Vcb: $0.75\% \rightarrow 0.45\%$ (muvqq channel. evqq: 0.6%, combined 0.4%) 07/01/2004 HAPOF100 @ UCST

Updated result on $\sin^2 \theta_{eff}^l$ measurement

 Table 2.
 Sensitivity S of different final state particles.

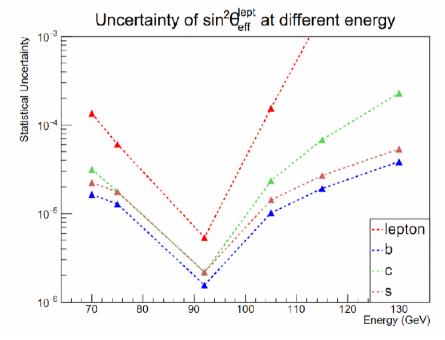
√s/GeV	S of $A_{FB}^{e/\mu}$	$S ext{ of } A^d_{FB}$	$S ext{ of } A^u_{FB}$	S of A^s_{FB}	S of A^c_{FB}	S of A^b_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958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

Table 3. Cross section of process $e^+e^- \rightarrow f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as $m_Z = 91.1875$ GeV, $m_t = 173.2$ GeV, $m_{II} = 125$ GeV, $\alpha_s = 0.118$ and $m_W = 80.38$ GeV.

\sqrt{s}/GeV	$\sigma_{\mu}/{ m mb}$	$\sigma_d/{ m mb}$	$\sigma_u/{ m mb}$	$\sigma_{\rm s}/{ m mb}$	$\sigma_c/{ m mb}$	$\sigma_b/{ m mb}$
70	0.039	0.032	0.066	0.031	0.058	0.028
75	0.039	0.047	0.073	0.046	0.065	0.043
92	1.196	5.366	4.228	5.366	4.222	5.268
105	0.075	0.271	0.231	0.271	0.227	0.265
115	0.042	0.135	0.122	0.135	0.118	0.132
130	0.026	0.071	0.068	0.071	0.066	0.069

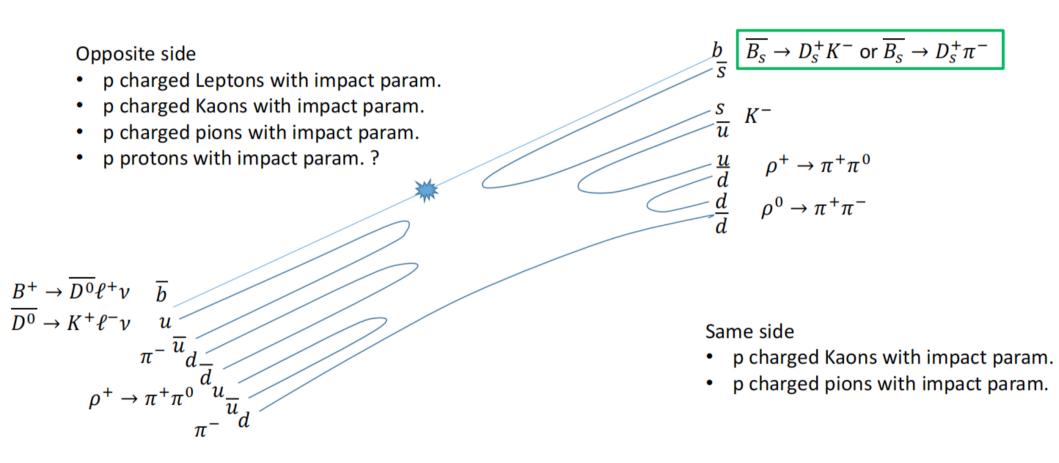
Verify the RG behavior... using ~1 month of data taking

Expected statistical uncertainties on $\sin^2 \theta_{eff}^l$ measurement. (Using one-month data collection, ~ 4e12/24 Z events at Z pole)



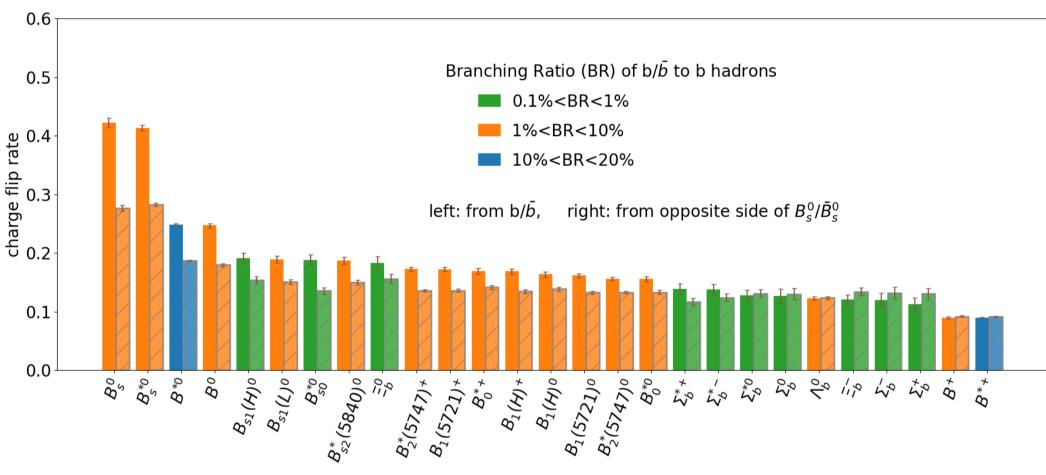
\sqrt{s}	b	С	S
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

B-charge flip rate: Bs oscillations



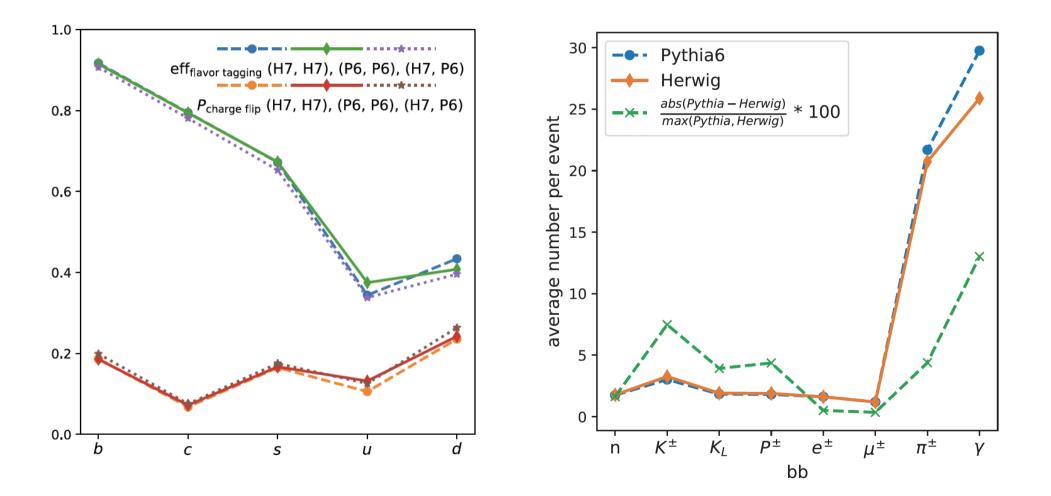
Roy. Aleksan, et. al @ CEA Saclay

B-charge flip rate: Bs oscillations

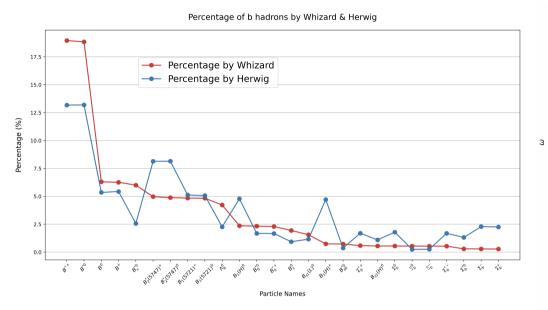


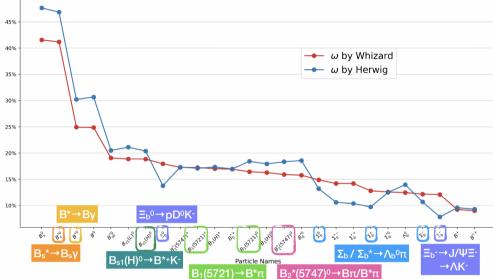
• Flip rate ~ 15%, Eff. Tagging power > 40%

V.S. Hadronization models



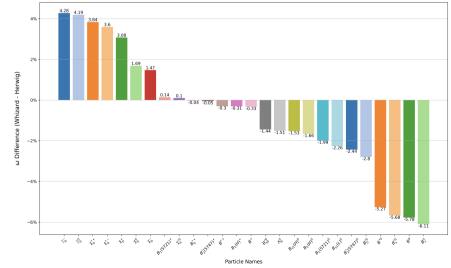
b-jet: leading b-hadrons & flip rates



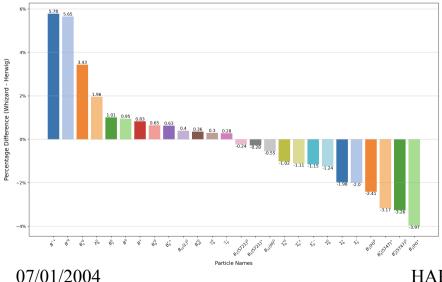


Charge Flip Rate ω of b hadrons by Whizard & Herwig

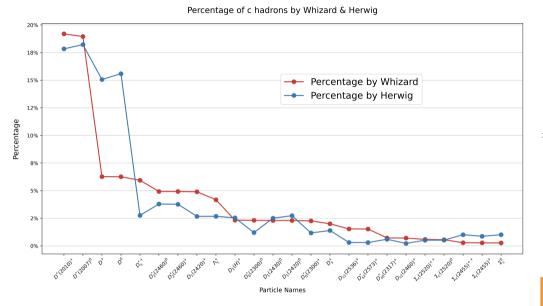
Difference in Charge Flip Rate ω of b hadrons between Whizard and Herwig



Difference in Percentage of b hadrons between Whizard and Herwig



c-jet: leading c-hadrons & flip rates



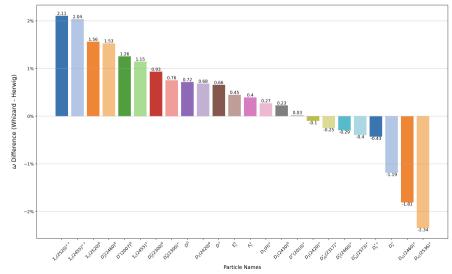
Difference in Percentage of c hadrons between Whizard and Herwig

07/01/2004

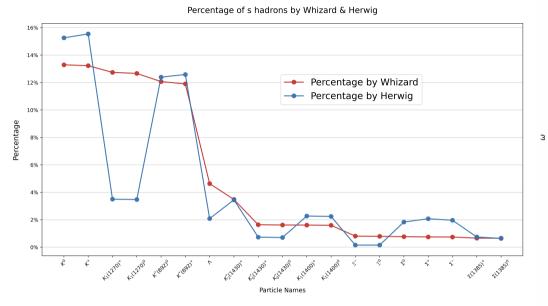
12% 10% - ω by Whizard ω by Herwig З 69 4% →D_s+π⁰ $D_{s2}^{*}(2573)^{+} \rightarrow D^{0}K^{+}/D^{+}Ks^{0}$ D₀*(2300)+→Dπ+ D₁(2420)→D*(2007)⁰I Particle Names D₂(2460)⁰→Dπ D*(2007)⁰→D⁰π⁰ (64.7%) D*(2010)+→D⁰π+ (67 D₁(2430)⁰→D*(2010)+π⁻ →D*(2010)+π[.] →D⁰v (35.3%) D_{s0}*(2317)+→Ds+π⁰

Difference in Charge Flip Rate ω of \hat{c} hadrons between Whizard and Herwig

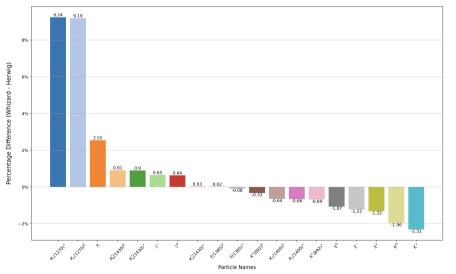
Charge Flip Rate ω of c hadrons by Whizard & Herwig



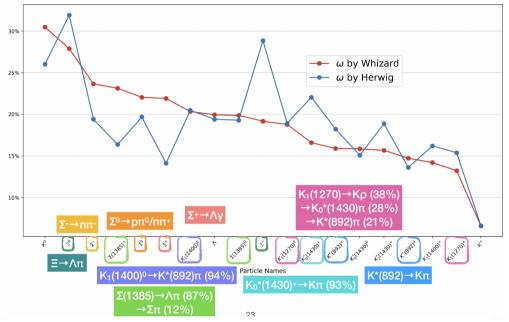
s-jet: leading s-hadrons & flip rates



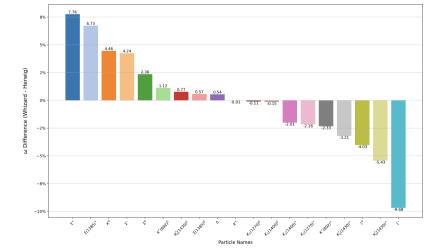
Difference in Percentage of s hadrons between Whizard and Herwig



Charge Flip Rate ω of s hadrons by Whizard & Herwig

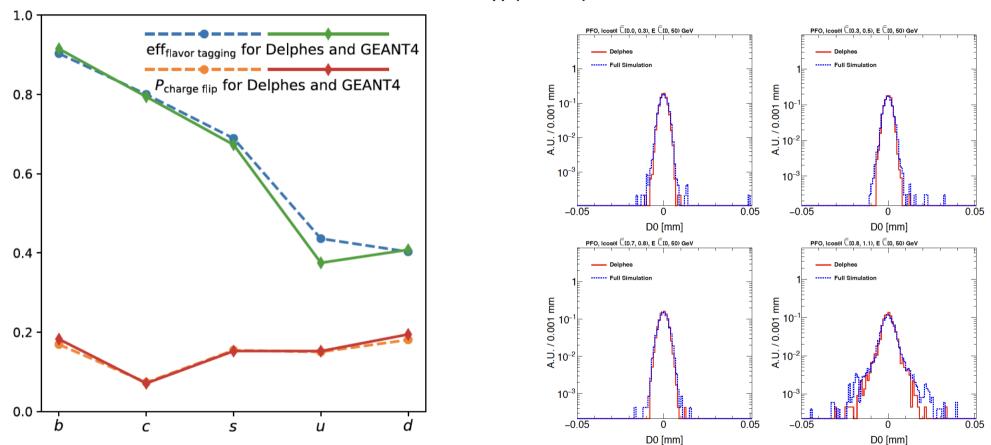


Difference in Charge Flip Rate ω of s hadrons between Whizard and Herwig



07/01/2004

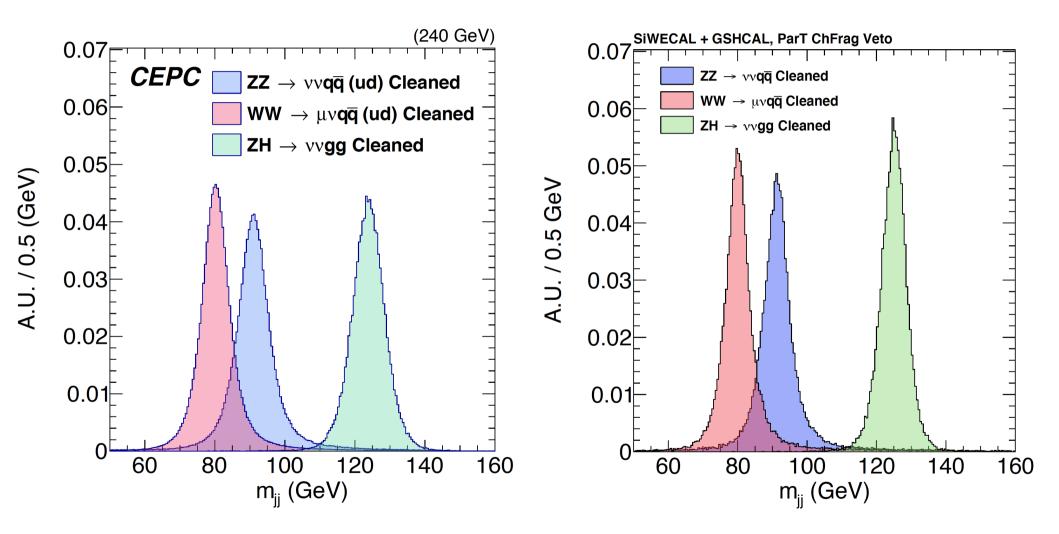
Fast/Full Simulation



Z->μμ (91.2 GeV)

Delphes ~ Perfect PFA (1 – 1 correspondence..)

... At Bosons Mass resolution...

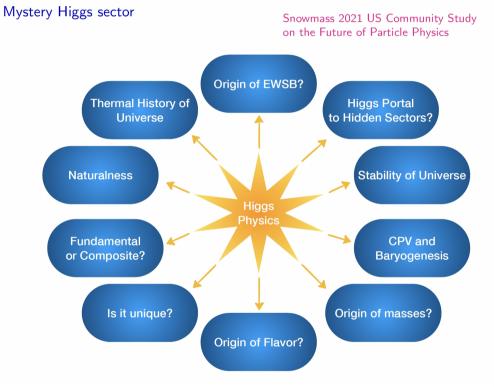


Summary

- CEPC: immense physics opportunities! Require excellent detector & reconstruction
- Jet origin id: efficiently separate different species of colored SM particle
 - A "game changer" and opens new horizon for precise flavor studies at all future experiments
- Significantly impact on physics
 - Higgs: improve H \rightarrow ss, uu, dd, sb, uc, sd, db by 3-100 times, and H \rightarrow cc by 2 times
 - Flavor: Improve Vcb precision by ~50%, effective tagging power for b-jet > 40%...
 - EW: Weak mixing angle...
 - QCD: Fragmentation, etc...
 - NP:...
- Jet Fragmentation : highly relevant,
 - Road Map wanted: towards better hadronization models + experimental validation (from both current data + GigaZ + TeraZ) + applications
- Long term version: 'see' gluon + quarks, as we see photon + leptons

Back up

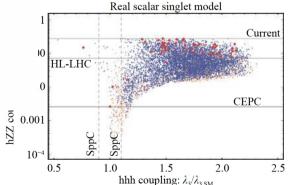
Higgs white paper

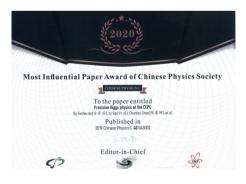


Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

Fenfen An(安芬芬)⁴²³ 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 Costa⁴ 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 Jyotishmati³³ Ryuta Kiuchi⁴ 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)^{4,633,34} Lianliang Ma(马连良)¹² Bruce Mellado^{17,18} Xin Mo(莫欣)⁴ Mila Pandurovic¹⁶ Jianming Qian(钱剑明)^{24;5)} Zhuoni Qian(钱卓妮)¹⁹ Nikolaos Rompotis²² Manqi Ruan(阮曼奇)^{4:6)} Alex Schuy³² 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





Snowmass White Paper

ABSTRACT

The Circular Electron Positron Collider (CEPC) is a large-scale collider facility that can serve as a factory of the Higgs, Z, and W bosons and is upgradable to run at the $t\bar{t}$ threshold. This document describes the latest CEPC nominal operation scenario and particle yields and updates the corresponding physics potential. A new detector concept is also briefly described. This submission is for consideration by the Snowmass process.

CONTENTS

Contributors	1
Abstract	4
I. Executive Summary	6
II. Introduction	8
III. Higgs, EW and top physics	11
A. Measurements of the SM Higgs processes	12
B. Higgs coupling determination	13
C. CP violation in the Higgs couplings	18
D. W, Z electroweak precision measurements at the CEPC	18
E. Measurement of the $e^+e^- \rightarrow WW$ process	21
F. SMEFT global fit of Higgs and electroweak processes	21
IV. Flavor Physics	23
A. Precise Measurements of Flavor Physics Parameters	24
B. (Semi)leptonic and Rare Decays	25
C. Low multiplicity and τ Physics	26
V. Beyond the Standard Model Physics	28
A. Higgs Exotic Decays	28
B. Supersymmetry	30
1. Light electroweakino and slepton searches	31

	5
2. SUSY global fits	33
C. Dark Matter and Dark Sector	35
1. Lepton portal Dark Matter	35
2. Asymmetric Dark Matter	36
3. Dark sector from exotic Z decay	37
D. Long-lived Particle Searches	40
1. Results with Near Detectors	40
2. Results with FADEPC	41
E. A couple more examples of exotics	44
1. Heavy neutrinos	45
2. Axion-like particles	47
I. Detector requirements and R&D activities	48
II. Message to the Snowmass	52
References	52

Summarize ~ 20 citables for CEPC Snowmass studies •

17 May 2022

arXiv:2205.08553v1 [hep-ph]

CONTRIBUTORS

The Physics potential of the CEPC

Prepared for the US Snowmass Community Planning Exercise (Snowmass 2021)

CEPC Physics Study Group

- Huajie Cheng, Department of Applied Physics, Naval University of Engineering, Jiefang Blvd 717, Qiaokou District, Wuhan 430033, China
- Wen Han Chiu, Department of Physics, University of Chicago, Chicago, IL 60637. USA
- Yaquan Fang, Institute of High Energy Physics, University of Chinese Academy of Science, Beijing, 100049, China
- Yu Gao, Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, China
- Jiayin Gu, Department of Physics, Center for Field Theory and Particle Physics, Key Laboratory of Nuclear Physics and Ion-beam Application (MOE), Fudan University, Shanghai 200438, China
- Gang Li, Institute of High Energy Physics, University of Chinese Academy of Science, Beijing, 100049, China
- Lingfeng Li, Department of Physics, Brown University, Providence, RI 02912, USA
- Tianjun Li, CAS Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China

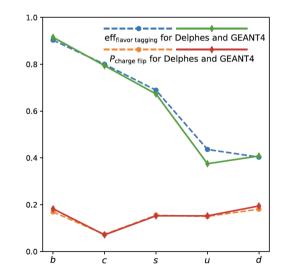
M11 3 with charged hadron and K_L K_S

												0.							
0.748	0.159	0.034	0.024	0.004	0.003	0.002	0.003	0.002	0.002	0.018		0. 0.							
												0.							
0.158	0 740	0.025	0.034	0.003	0.005	0.003	0.002	0.002	0.003	0.017		0.							
0.150	0.143	0.025	0.034	0.005	0.005	0.005	0.002	0.002	0.005	0.017		0.							
												0.							
0.016	0.014	0.752	0.053	0.040	0.034	0.020	0.008	0.008	0.017	0.038		0.							
												0.							
												0.							
0.015	0.016	0.053	0.749	0.034	0.041	0.008	0.020	0.017	0.009	0.039		0.							
												0.							
0.002	0.002	0.021	0.010	0.607	0.110	0.020	0.056	0.044	0.041	0.077		0.							
0.005	0.002	0.021	0.019	0.007	0.110	0.020	0.050	0.044	0.041	0.077		0.							
												0.							
0.003	0.003	0.019	0.023	0.107	0.609	0.057	0.019	0.041	0.043	0.078		0.							
0.000	5.000	5.020	5.025		51000		5.020			5.0.0		0.							
												0.							
0.002	0.003	0.016	0.009	0.032	0.104	0.378	0.057	0.093	0.197	0.108		0.							
																			0.
			0.01.0		0.000	0.000	0.071	0.000	0.00.1	0.100		0.							
0.003	0.002	0.009	0.016	0.102	0.032	0.062	0.371	0.202	0.094	0.108		0.							
												0.							
0.003	0.002	0.010	0.016	0.076	0.074	0.087	0.201	0 335	0.086	0 1 1 0		0. 0.							
0.003	0.002	2 0.010	0.010	0.070	0.074	0.087	0.201	0.000	0.000	0.110		0.							
												0.							
0.003	0.003	0.016	0.009	0.075	0.076	0.210	0.083	0.086	0.330	0.110		0.							
				0.010	0.010	0.210	5.000		2.000	0.210		0.							
												0							
0.015	0.015	0.024	0.024	0.051	0.050	0.042	0.042	0.040	0.041	0.657		0							
1	<u> </u>	I.	<u> </u>	I.	1	I.	I	1	1	I									
b	\overline{b}	С	\overline{c}	5	ŝ	и	\overline{u}	d	d	G									
				Dr	edicte	he													
	 0.158 0.016 0.015 0.003 0.002 0.003 0.003 0.003 0.003 0.003 0.003 0.003 	 0.113 0.113 0.113 0.113 0.113 0.016 0.014 0.015 0.003 0.003 0.003 0.003 0.002 0.003 0.002 0.003 0.003 0.002 0.003 	0.1100 0.1100 0.001 0.158 0.749 0.025 0.016 0.014 0.752 0.015 0.016 0.053 0.003 0.002 0.021 0.003 0.003 0.019 0.003 0.002 0.009 0.003 0.002 0.009 0.003 0.002 0.010 0.003 0.002 0.010 0.003 0.003 0.016	0.1160 0.1160 0.1001 0.021 0.158 0.749 0.025 0.034 0.016 0.014 0.752 0.053 0.015 0.016 0.053 0.749 0.015 0.016 0.053 0.749 0.003 0.002 0.021 0.019 0.003 0.003 0.016 0.009 0.003 0.002 0.009 0.016 0.003 0.002 0.010 0.016 0.003 0.002 0.010 0.016 0.003 0.002 0.010 0.016 0.003 0.002 0.010 0.016 0.003 0.003 0.016 0.009 0.003 0.003 0.016 0.009 0.015 0.015 0.024 0.024	0.1100 0.1000 0.0011 0.0021 0.0031 0.1158 0.749 0.025 0.034 0.003 0.016 0.014 0.752 0.053 0.040 0.015 0.016 0.053 0.749 0.034 0.015 0.016 0.053 0.749 0.034 0.015 0.016 0.025 0.019 0.034 0.003 0.002 0.021 0.019 0.607 0.003 0.003 0.019 0.023 0.107 0.003 0.003 0.016 0.009 0.032 0.003 0.002 0.010 0.016 0.102 0.003 0.002 0.010 0.016 0.102 0.003 0.002 0.010 0.016 0.076 0.003 0.003 0.016 0.009 0.075 0.003 0.015 0.024 0.024 0.021 0.015 0.015 0.024 0.024 0.051 b b c c c c	0.1100 0.1000 0.0011 0.0021 0.0031 0.0110 0.0331 0.0141 0.003 0.003 0.012 0.013 0.013 0.010 0.0131 0.110 0.0101 0.003 0.003 0.016 0.019 0.023 0.104 0.032 0.1104 0.003 0.003 0.016 0.003 0.016 0.016 0.012 0.032 0.003 0.002 0.016 0.016 0.016 0.017 0.016 0.003 0.003 0.016 0.016 0.017 0.016 0.017 0.016 0.003 0.015 0.024 0.024 0.051 0.050 0.51 <td>0.1100 0.1001 0.0011</td> <td>0.1100 0.1001 0.0011 0.0011 0.0001 0.0001 0.0002 0.0001 0.0002 0.0001 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0003 0.0010 0.002 0.0003 0.0010 0.0034 0.0011 0.0003 0.0002 0.0010 0.0010 0.0110 0.0010 0.0010 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0111</td> <td>0.1100 0.1001 0.0011 0.0021 0.0031 0.0031 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0011 0.0021 0.0021 0.0031 0.0011 0.0021 0.0031 0.0011 0.0031 0.0021 0.0011</td> <td>0.1100 0.1001 0.0011 0.0012 0.0012 0.0011 0.0011 0.0011 0.0012 0.0012 0.0011 0.0011 0.0011 0.0011 0.0011</td> <td>0.110 0.101 0.001 0.001 0.001 0.001 0.002 0.002 0.002 0.002 0.002 0.002 0.001 0.011 0.158 0.749 0.025 0.034 0.003 0.005 0.003 0.002 0.002 0.003 0.017 0.003 0.016 0.014 0.752 0.053 0.040 0.034 0.020 0.008 0.008 0.017 0.038 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.009 0.039 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.009 0.039 0.003 0.002 0.021 0.019 0.019 0.017 0.101 0.020 0.056 0.044 0.041 0.077 0.003 0.003 0.019 0.023 0.101 0.378 0.057 0.093 0.197 0.108 0.003 0.004 0.016 0.102 0.032 0.062 0.371 0.202 0.944</td> <td>0.110 0.101 0.021 0.001 0.002 0.002 0.002 0.002 0.003 0.017 0.158 0.749 0.025 0.034 0.003 0.005 0.003 0.002 0.002 0.003 0.017 0.016 0.014 0.752 0.053 0.040 0.034 0.020 0.008 0.008 0.009 0.017 0.038 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.039 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.039 0.003 0.002 0.021 0.019 0.041 0.020 0.056 0.044 0.041 0.077 0.003 0.003 0.016 0.009 0.032 0.101 0.378 0.019 0.041 0.043 0.078 0.003 0.003 0.016 0.002 0.032 0.062 0.371 0.202 0.994 0.108 0.003 0.003 0.016 0.076 0.76</td>	0.1100 0.1001 0.0011	0.1100 0.1001 0.0011 0.0011 0.0001 0.0001 0.0002 0.0001 0.0002 0.0001 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0003 0.0010 0.002 0.0003 0.0010 0.0034 0.0011 0.0003 0.0002 0.0010 0.0010 0.0110 0.0010 0.0010 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0110 0.0111	0.1100 0.1001 0.0011 0.0021 0.0031 0.0031 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0021 0.0021 0.0031 0.0011 0.0021 0.0021 0.0031 0.0011 0.0021 0.0031 0.0011 0.0031 0.0021 0.0011	0.1100 0.1001 0.0011 0.0012 0.0012 0.0011 0.0011 0.0011 0.0012 0.0012 0.0011 0.0011 0.0011 0.0011 0.0011	0.110 0.101 0.001 0.001 0.001 0.001 0.002 0.002 0.002 0.002 0.002 0.002 0.001 0.011 0.158 0.749 0.025 0.034 0.003 0.005 0.003 0.002 0.002 0.003 0.017 0.003 0.016 0.014 0.752 0.053 0.040 0.034 0.020 0.008 0.008 0.017 0.038 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.009 0.039 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.009 0.039 0.003 0.002 0.021 0.019 0.019 0.017 0.101 0.020 0.056 0.044 0.041 0.077 0.003 0.003 0.019 0.023 0.101 0.378 0.057 0.093 0.197 0.108 0.003 0.004 0.016 0.102 0.032 0.062 0.371 0.202 0.944	0.110 0.101 0.021 0.001 0.002 0.002 0.002 0.002 0.003 0.017 0.158 0.749 0.025 0.034 0.003 0.005 0.003 0.002 0.002 0.003 0.017 0.016 0.014 0.752 0.053 0.040 0.034 0.020 0.008 0.008 0.009 0.017 0.038 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.039 0.015 0.016 0.053 0.749 0.034 0.041 0.008 0.020 0.017 0.039 0.003 0.002 0.021 0.019 0.041 0.020 0.056 0.044 0.041 0.077 0.003 0.003 0.016 0.009 0.032 0.101 0.378 0.019 0.041 0.043 0.078 0.003 0.003 0.016 0.002 0.032 0.062 0.371 0.202 0.994 0.108 0.003 0.003 0.016 0.076 0.76							

M11 2 with charged hadron

	b -	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
	- -	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
	с -	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
	. -	0.015	0.015	0.055	0.741	0.032	0.037	0.010	0.026	0.016	0.010	0.043
	s -	0.003	0.003	0.020	0.018	0.541	0.104	0.030	0.082	0.062	0.045	0.092
True	<u>s</u> -	0.002	0.003	0.018	0.021	0.101	0.543	0.085	0.028	0.044	0.062	0.092
	u -	0.002	0.003	0.019	0.012	0.044	0.132	0.375	0.057	0.079	0.168	0.109
	<u>u</u> -	0.003	0.002	0.011	0.020	0.132	0.043	0.062	0.368	0.166	0.084	0.108
	d -	0.003	0.003	0.012	0.020	0.111	0.093	0.083	0.223	0.261	0.080	0.110
	d -	0.003	0.003	0.020	0.013	0.093	0.113	0.226	0.079	0.076	0.265	0.110
	G -	0.015	0.014	0.025	0.025	0.053	0.053	0.043	0.044	0.033	0.035	0.661
		b	$\frac{1}{b}$	C	$\frac{1}{C}$	s	$\frac{1}{S}$	u	$\frac{1}{u}$	d	$\frac{1}{d}$	Ġ
	Predicted											

Arbor PFA: Towards one-to-one correspondence (Totoro)





Arbor Tree topology of particle shower

Eur. Phys. J. C (2018) 78:426 https://doi.org/10.1140/epjc/s10052-018-5876-z THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

Reconstruction of physics objects at the Circular Electron Positron Collider with Arbor

Manqi Ruan^{1,a}, Hang Zhao¹, Gang Li¹, Chengdong Fu¹, Zhigang Wang¹, Xinchou Lou^{6,7,8}, Dan Yu^{1,2}, Vincent Boudry², Henri Videau², Vladislav Balagura², Jean-Claude Brient², Peizhu Lat³, Chia-Ming Kuo³, Bo Liu^{1,4}, Fenfen An^{1,4}, Chunhui Chen⁴, Soeren Prell⁴, Bo Li⁵, Imad Laketineh⁵

¹ Institute of High Energy Physics, Beijing, China

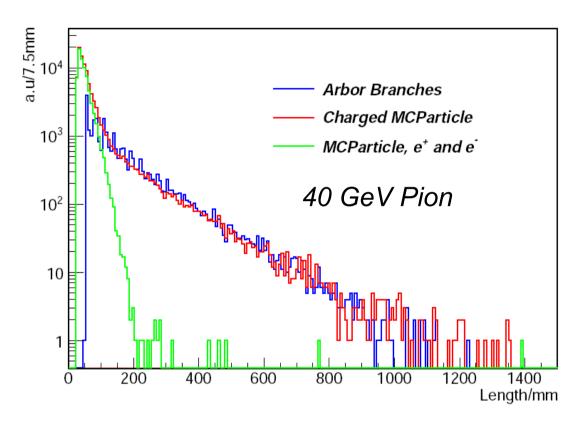
- ² Laboratoire Leprince-Ringuet, Ecole Polytechnique, Palaiseau, France
- ³ Department of Physics and Center of high energy and high field physics, National Central University, Taoyuan City, Taiwan
- ⁴ Iowa State University, Ames, USA
- ⁵ Institute de Physique Nucleaire de Lyon, Lyon, France
- ⁶ Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China 7 Physics, Department of High Energy Physics, Chinese Academy of Sciences, Beijing, China
- ⁷ Physics Department, University of Texas at Dallas, Richardson, TX, USA
- ⁸ University of Chinese Academy of Sciences (UCAS), Beijing, China

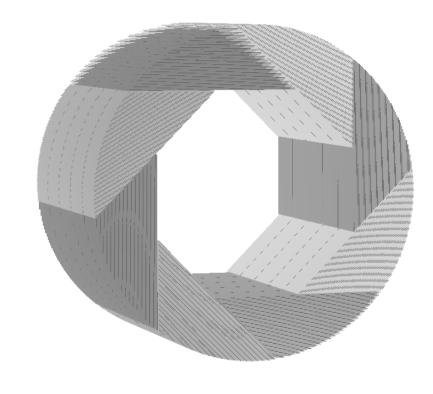
15cm

6.5

20 GeV Klong reconstructed @ ILD Calo Curves indicating expected particle trajectories (from MC-truth)

Validation: Arbor Branch Length Vs MC Truth

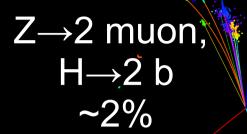




Arbor: successfully tag sub-shower structure

Samples: Particle gun event at ILD HCAL (readout granularity 1cm² & layer thickness 2.65cm) Length:

Charged MCParticle: spatial distance between generation/end points Arbor branch: sum of distance between neighboring cells



Z→2 jet, \checkmark H→2 tau \sim 5%

ZH \rightarrow 4 jets ~50%

Z→2 muon H→WW*→eevv ~1%

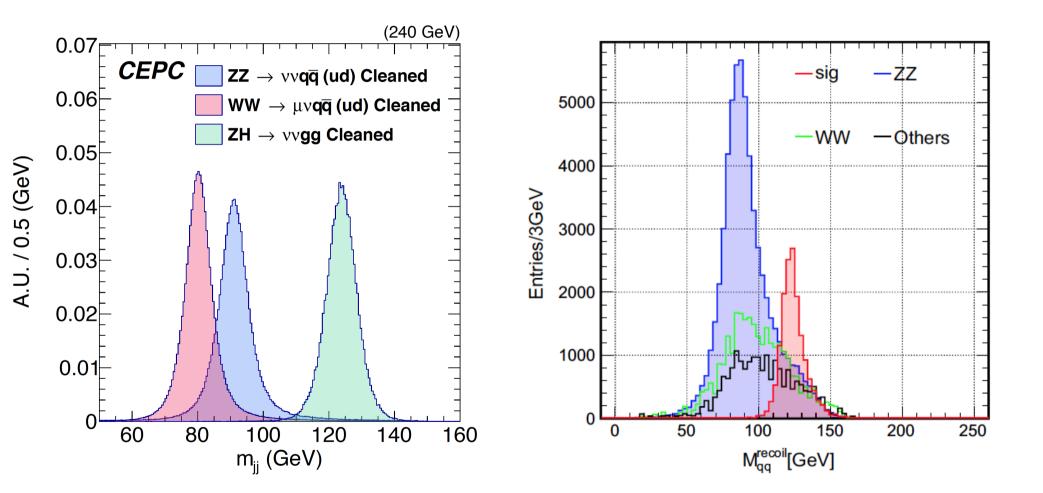
07/01/2004



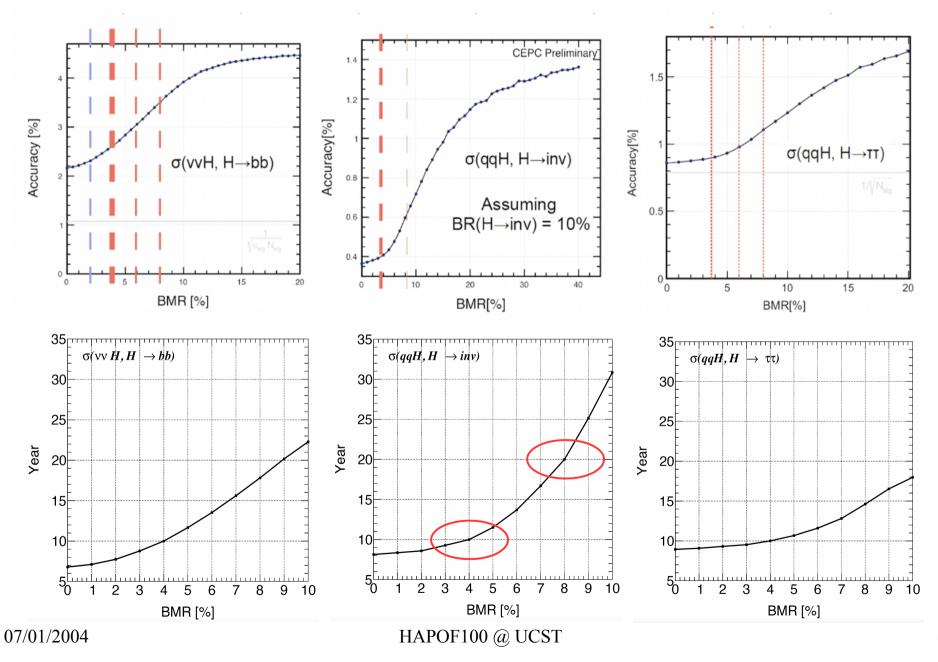
CMS Experiment at LHC, CERN Data recorded: Thu Jan 1 01:00:00 1970 CEST Run/Event: 1 / 1201 Lumi section: 13

k

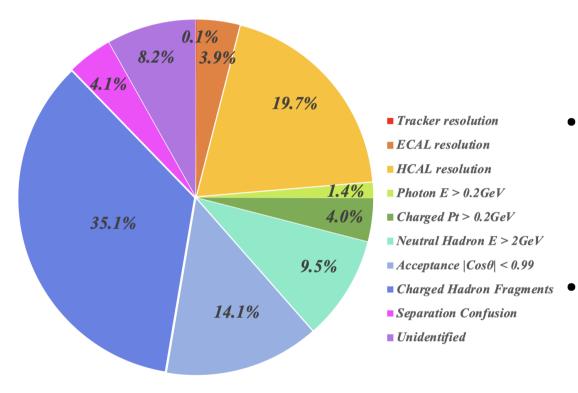
Boson Mass Resolution: Key Per. Para



BMR: impact on critical measurements



BMR decomposition @ CDR baseline



- 1st, Ultimate Precision ~ 2.8 with CDR baseline3rd, HCAL
- 2nd, HCAL resolution dominant the uncertainties from intrinsic detector resolution: need better HCAL
 - 3rd Leading contribution:
 Confusion from shower
 Fragments (fake particles),
 need better Pattern Reco.

Improving HCAL: RPC Digital HCAL \rightarrow GSHCAL

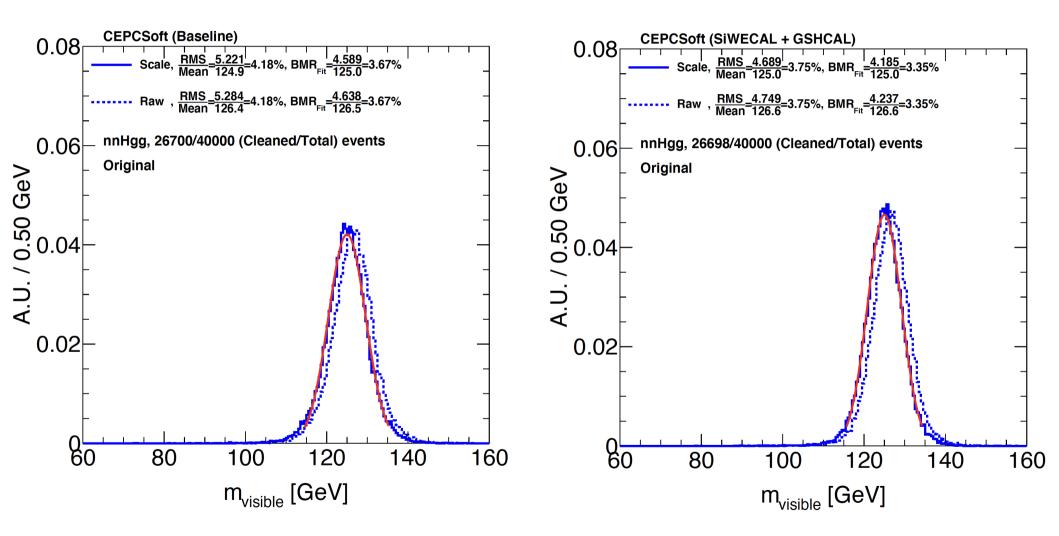
Remarks:

- 1st, what matters is not only intrinsic HCAL resolution... but hadron resolution at ECAL + HCAL: Dedicated development towards shower energy estimator is needed
- 2nd, performance dependents on Energy threshold, timing cut, etc: digitization study need to be enhanced

Three detector models

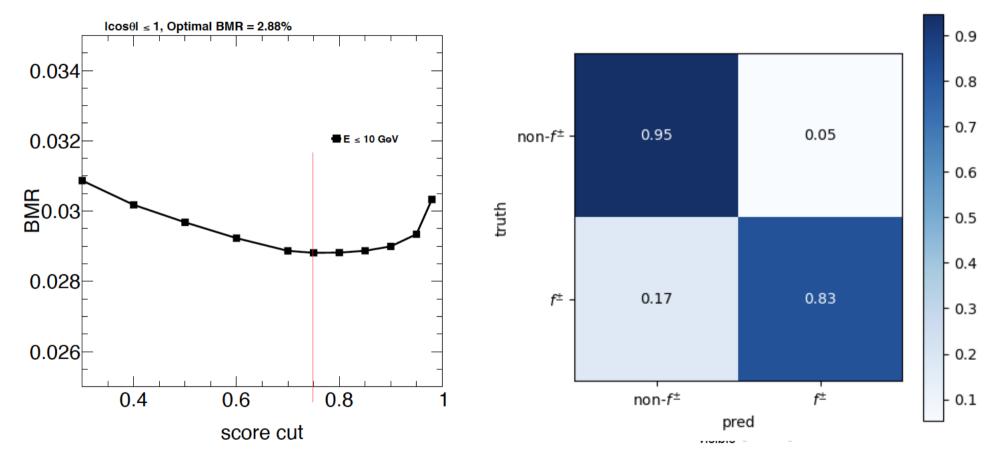
Parameters	SiWECAL + SDHCAL (Baseline)	SiWECAL + GSHCAL	CSECAL + GSHCAL
ECAL Material	Si + W	Si + W	BGO (Homogeneous)
ECAL Transverse cell size	$1 \times 1 \ \mathrm{cm}^2$	$1 \times 1 \text{ cm}^2$	$1 imes 1~{ m cm}^2$
ECAL Number of layers	30	30	27
ECAL Total thickness	$24 X_0$	$24 X_0$	$24 X_0$
ECAL Thickness/layer	Si 0.5 mm (30 layers) W 2.1 mm (20 layers) W 4.2 mm (10 layers)	Si 0.5 mm (30 layers) W 2.1 mm (20 layers) W 4.2 mm (10 layers)	$10 \mathrm{mm}$
HCAL Material	GRPC	Glass + Steel	Glass + Steel
HCAL Transverse cell size	$1 \times 1 \text{ cm}^2$	$2 imes 2~{ m cm^2}$	$2 imes 2 \ { m cm}^2$
HCAL Number of layers	40	48	48
HCAL Total thickness	5λ	6λ	6λ
HCAL Thickness/layer	0.125λ 3 mm GRPC + 3 mm Electronics + 20 mm Steel	0.125λ 10 mm Glass + 13.85 mm Steel	$\begin{array}{c} 0.125 \ \lambda \\ 10 \ \mathrm{mm \ Glass} \ + \\ 13.85 \ \mathrm{mm \ Steel} \end{array}$
HCAL Glass density	-	$6~{ m g/cm^3}$	$6 \mathrm{g/cm^3}$

Baseline \rightarrow M1: BMR 3.67% \rightarrow 3.35%



Reminder: Not only larger sampling (0.2)... but also thicker (0.1)!HAPOF100 @ UCST44

Preliminary: Identify & veto charged shower fragments using AI

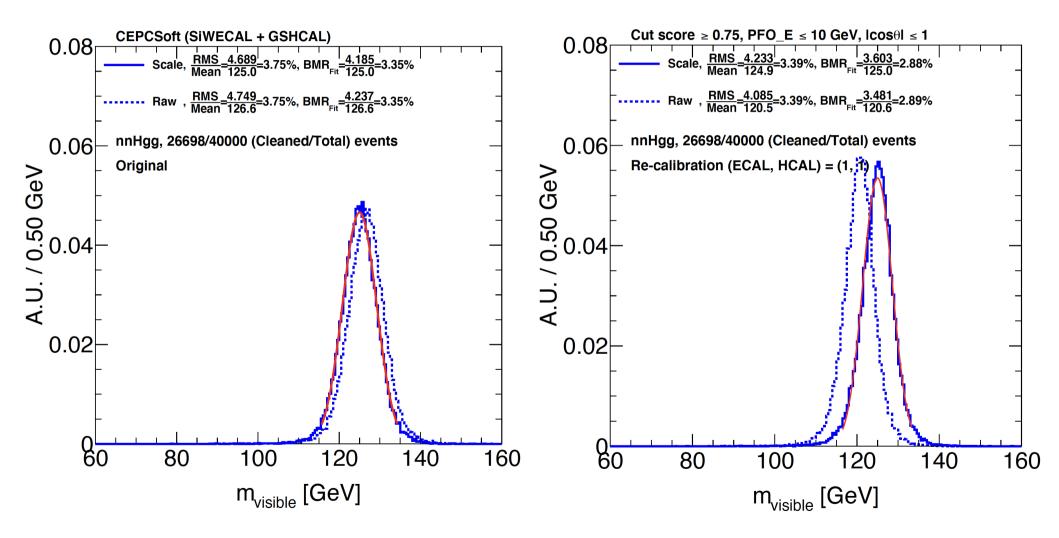


Trained at 12E4 events,

Test & Applied at 4E4 events

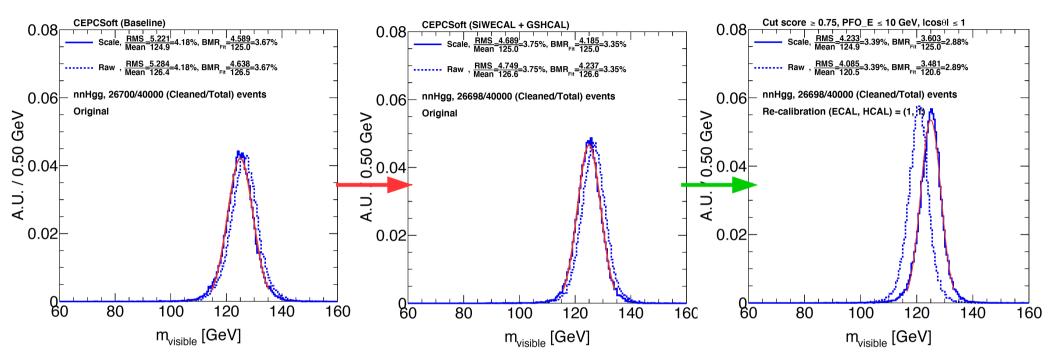
score > 0.75 efficiency ~83% purity ~95%

M1(SiW + GS): BMR $3.35 \rightarrow 2.89\%$



Truth level veto prediction: 3.32 -> 2.98%

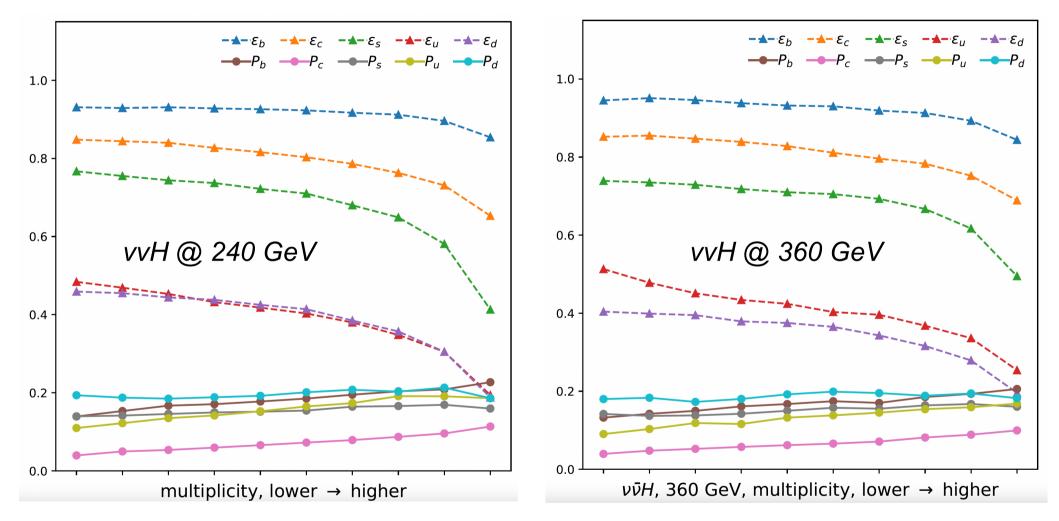
BMR Comparison



Detector	Arbor	A4: AI Assistant Arbor	Improvement
SiW ECAL + RPC DHCAL	3.67	3.31	0.4
SiW ECAL + GSHCAL	3.35 💆 🗕	2.88	0.5
Xstal ECAL + GSHCAL	3.53	3.27	0.3

@ Xstal ECAL: ...to be optimized...

V.S. Multiplicity



• ...many patterns need further understanding & towards further optimization...

Particle identification



week ending 10 JANUARY 2014

PRL 112, 012001 (2014)

DOI: 10.1103/PhysRevLett.112.012001

07/01/2004

PHYSICAL REVIEW LETTERS

PACS numbers: 13.85-t. 07.20.Fw. 13.40-f

Fractal Dimension of Particle Showers Measured in a Highly Granular Calorimeter

Manqi Ruan,12.* Daniel Jeans,13 Vincent Boudry,1 Jean-Claude Brient,1 and Henri Videau1 ¹ Juans, Jours Jeans, Vinkein Douoly, Jean-Chauo Diffelin, and Henri V ¹ Laboratoric Legistrice-Ringuet, Ecole polytechnique, CNKS/N27-3, Palaiseau, France ² Institute of High Energy Physics, Beijing 100049, China ³ Department of Physics, University of Oxfox, Oxfox) 113-3003, Japan (Received 24 May 2013; published 8 January 2014)

We explore the fractal nature of particle showers using Monte Carlo simulation. We define the fractal dimension of showers measured in a high granularity calorimeter designed for a future lepton collider. The shower fractal dimension reveals detailed information of the spatial configuration of the shower. It is found to be characteristic of the type of interaction and highly sensitive to the nature of the incident particle. Using the shower fractal dimension, we demonstrate a particle identification algorithm that can efficiently separate electromagnetic showers, hadronic showers, and nonshowering tracks. We also find a logarithmic dependence of the shower fractal dimension on the particle energy.



journal homepage: www.elsevier.co

Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167835

Requirement analysis for dE/dx measurement and PID performance at the CEPC baseline detector Y Zhu S Chen H Cui M Ruan*

Institute of High Energy Physics, Chinese Academy of Sciences, 198 Yuquan Road, Shijingshan District, Beijing 100049, China University of Chinese Academy of Sciences, 19A Yuquan Road, Shijingshan District, Beijing 100049, China

HAPOF100 @ UCST





NUCLEAR INSTRUMENTS A NETHODS IN INSTRUMENTS INSTRUMENTS

Eur. Phys. J. C (2023) 83:93 https://doi.org/10.1140/epjc/s10052-023-11221-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Cluster time measurement with CEPC calorimeter

Yuzhi Che¹, Vincent Boudry², Henri Videau², Muchen He¹, Manqi Ruan^{1,a} ¹ IHEP, Beijing, China ² LLR, Ecole Polytechnique, Palaiseau, France

Received: 21 September 2022 / Accepted: 11 January 2023 / Published online: 30 January 2023 © The Author(s) 2023

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB RECEIVED: December 8, 2020 REVISED: February 2, 2021 ACCEPTED: April 1, 2021 PUBLISHED: June 16, 2021

Lepton identification performance in jets at a future electron positron Higgs Z factory

D. Yu,^a T. Zheng^b and M. Ruan^{a,*} aIHEP, Beijing, China ^bNanjing University, Nanjing, China E-mail: ruanmg@ihep.ac.cn

inst

Eur. Phys. J. C (2017) 77:591	THE
DOI 10.1140/epjc/s10052-017-5146-5	PHY:
Regular Article - Experimental Physics	



Lepton identification at particle flow oriented detector for the future e^+e^- Higgs factories

Dan Yu^{1,2}, Manqi Ruan^{1,a}, Vincent Boudry², Henri Videau ¹ IHEP, Beijing, China ² LLR, Ecole Polytechnique, Palaiseau, France

Eur. Phys. J. C (2018) 78:464 https://doi.org/10.1140/epjc/s10052-018-5803-3 Regular Article - Experimental Physics

THE EUROPEAN	CrossMark
PHYSICAL JOURNAL C	

Monte Carlo study of particle identification at the CEPC using TPC dE/dx information

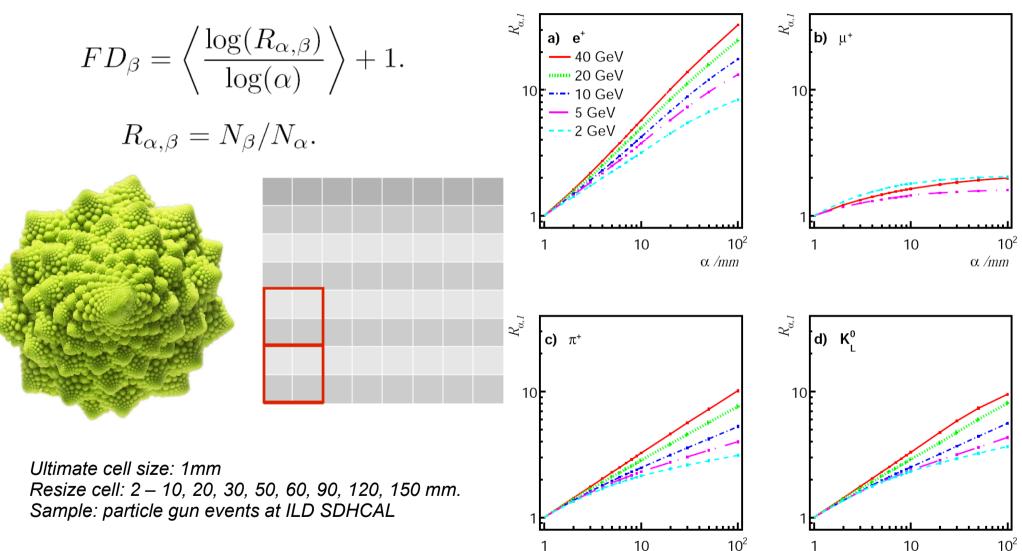
F. An^{1,2,a}, S. Prell², C. Chen², J. Cochran², X. Lou^{1,3,4}, M. Ruan^{1,b} Institute of High Energy Physics, Chinese Academy of Science, Beijing, China
 Department of Physics and Astronomy, Iowa State University, Ames, IA, USA
 Physics Department, University of Texas at Dallas, Richardson, TX, USA
 University of Chinese Academy of Science (UCAS), Beijing, China

49



Fractal dimension of particle shower





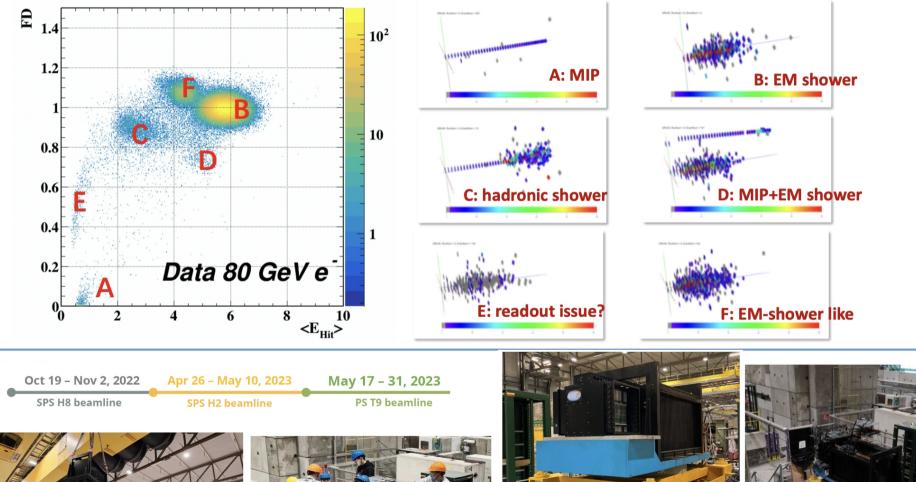
HAPOF100 @ UCST

 α /mm

 α /mm



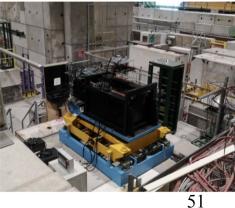
- FD characteristics of different beam particles
 - Imaging capability of high granularity calorimeter ()







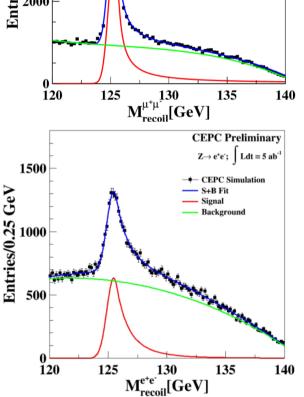




Lepton: isolated **CEPC** Preliminary $Z \rightarrow \mu^+ \mu^-$; Ldt = 5 ab⁻¹ **~102** CEPC Simulation log10(ELike) agged eff(%) Entries/0.25 GeV 4000 S+B Fit Signal Background 100 98 2000 -electron 96 muon 94 - pion -10 Electron $M_{recoil}^{\mu^{+}\mu^{1}}[GeV]$ 125 120 135 • Muon 92 × Pion 90 -15 10² -10 1500 -5 -15 10 log10(MuLike) GeV Energy +B Fit Signal Background

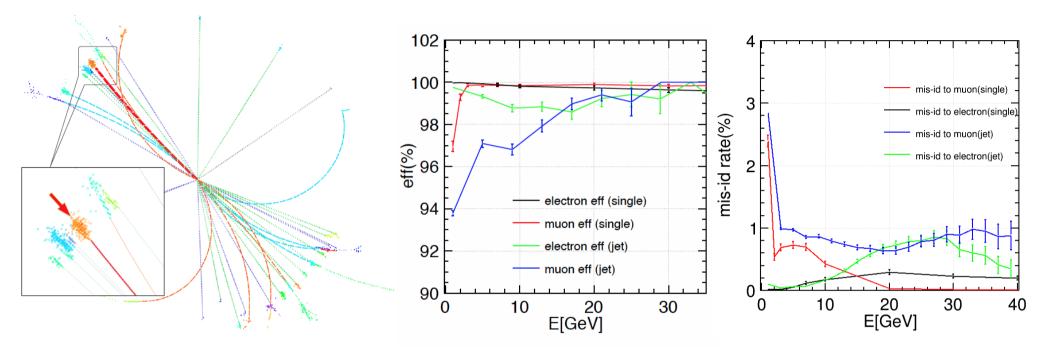
BDT method using 4 classes of 24 input discrimination variables.

Test performance at: Electron = E likeness > 0.5; Muon = Mu likeness > 0.5Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate $\sim 1\%$



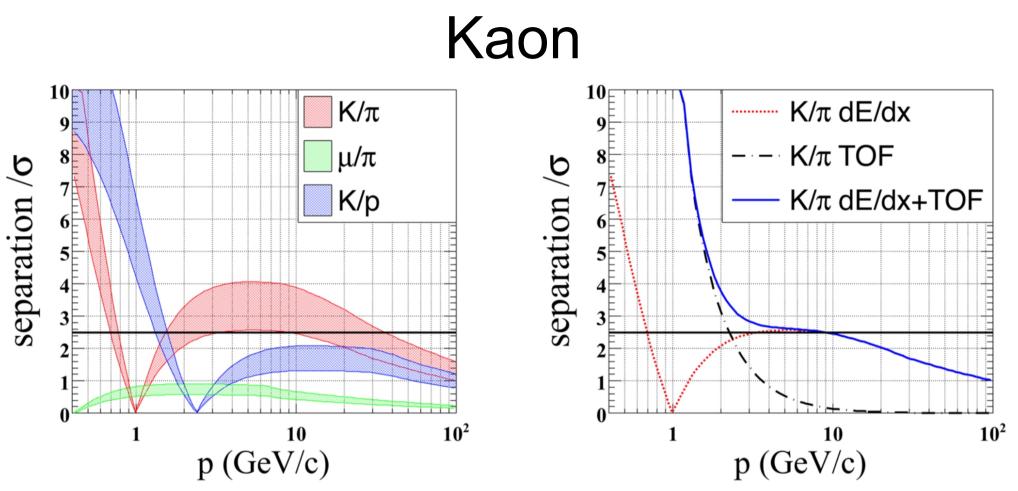
https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5 CEPC-DocDB-id:148, Eur. Phys. J. C (2017) 77: 591 HAPOF100 @ UCST 52

Lepton: inside jet



Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & contaimination).

At the same working point, the efficiency can be reduced by up to 3%; while mis-id rate increases up to 1%. Marginal Impact on Flavor Physics measurements as Bc->tauv.



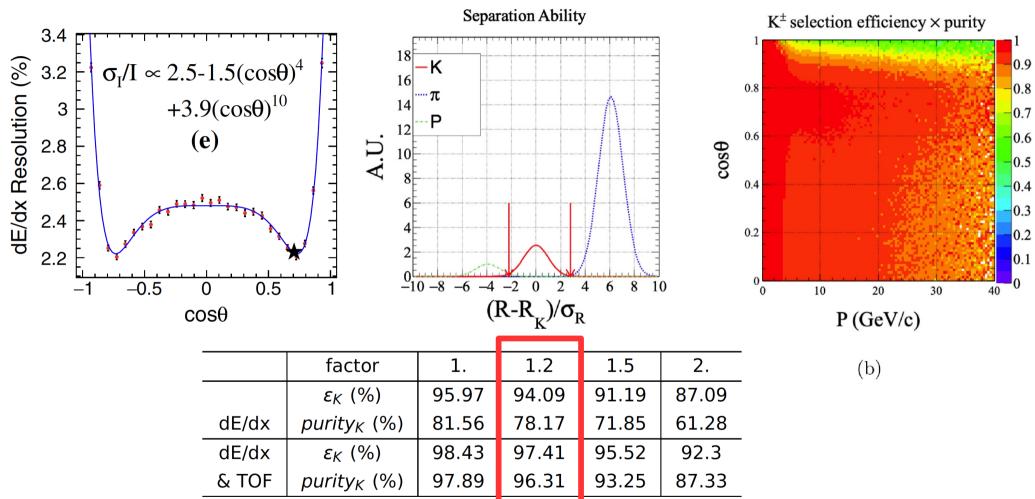
Highly appreciated in flavor physics @ CEPC Z pole TPC dEdx + ToF of 50 ps

At inclusive Z pole sample:

Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF) Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

HAPOF100 @ UCST Eur. Phys. J. C (2018) 78:464

Pid performance

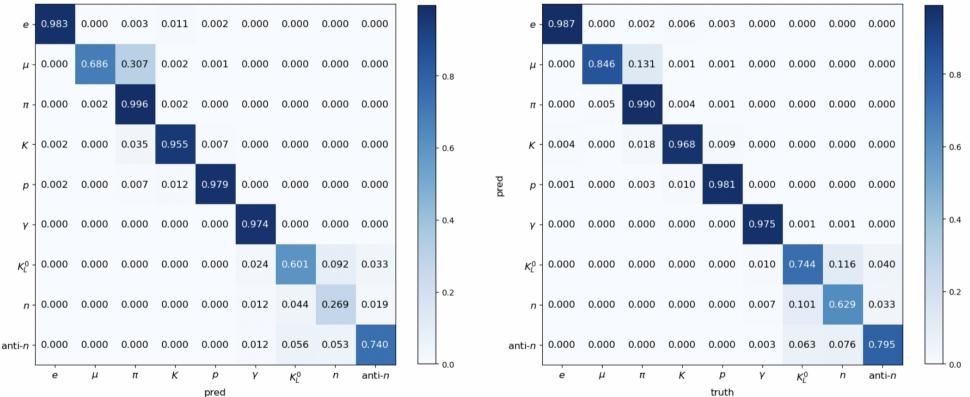


3% of dE/dx & dN/dx + 50 ps ToF: eff/purity of Kaon reco > 95%

Inc. Reco. Particle id: Preliminary & in progress

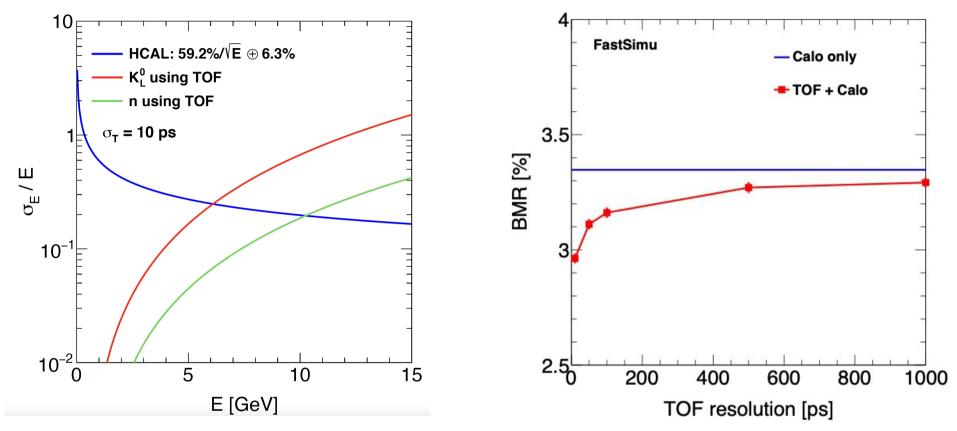
purity

efficiency



truth

Neutral Particle id: Very Preliminary



• Fast Sim Prediction: BMR: $2.9 \rightarrow 2.6$

- Need excellent CALO + ToF ~ o(10 ps)
- Need high efficiency neutral hadron reco (1-1 correspondence)

2-body decay particles and tau leptons

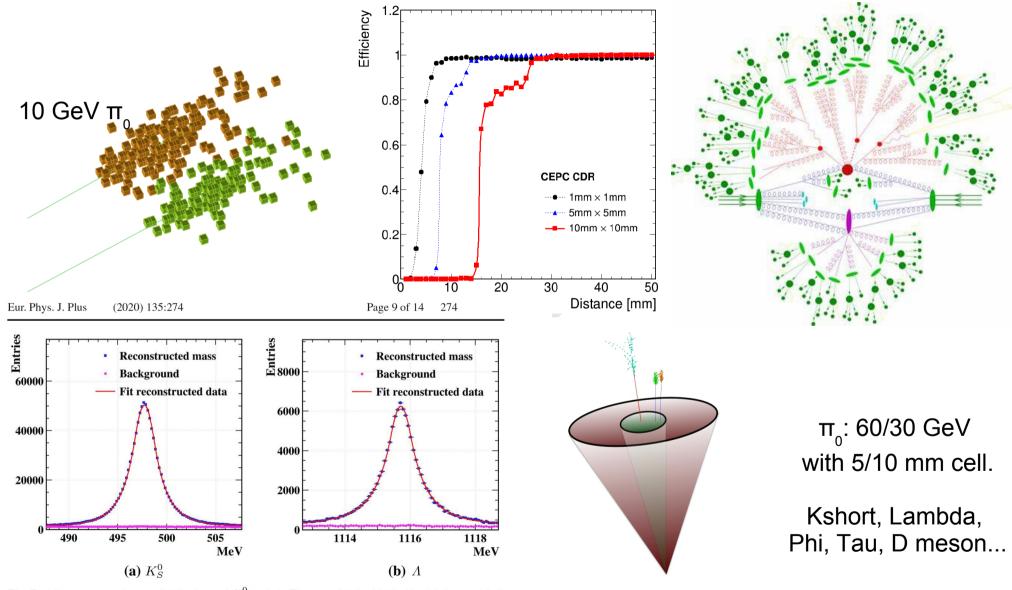


Fig. 7 All reconstructed mass distributions of K_S^0 and Λ . They are fitted with double-sided crystal ball functions

07/01/2004

Summary

- Jet origin id: efficiently separate different species of colored SM particle
 - Stable & Smooth...
 - World leading performance of the tagger with strongest expected constrains...
 - A "game changer" and opens new horizon for precise flavor studies at all future experiments
- Significantly impact on physics
 - Higgs: Boost the access to g(Hss) and Higgs exotic/FCNC with jet final state (3 100 times), and H→cc precision by 2 times
 - Flavor: Improve Vcb precision by \sim 50%, effective tagging power for b > 40%...
 - EW: Weak mixing angle
 - Reach 1E-6 level precision (at 92 GeV) using 1 month data taking with different flavors.
 - Verify RG behavior
 - QCD: Fragmentation, etc.
 - NP:...
- Long term version: 'see' gluon + quarks, as we see photon + leptons

Summary

- Arbor + AI: Towards Toolkits of One To One correspondence RecOnstruction: TOTORO
- BMR of 2.9% reached:
 - Using A4 (AI Assistant Arbor Algorithm) + SiW ECAL + GS HCAL
 - Compared to 4% BMR, BMR ~ 3% saves ~ 10% machine time for key physics benchmarks... benefit all physics measurements
- A4 significantly eliminates the shower fragment confusions: Transformer provides unprecedented identification capability (same methodology as Jet Origin ID)
 - SiW ECAL + GS HCAL: BMR ~ 2.5% @ no confusion limit
 - Similar improvements observed at other geometry
- High Granularity Calorimeter with high precision timing: Further improvements anticipated

One to one correspondence reco. at Higgs factory

The should, and we could

Via state-of-art det. Design & technology + Al enhanced algorithms



Key figures of the CEPC-SPPC

- Tunnel ~ 100 km
- CEPC (90 240 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, Booster(7.2Km)
 - Precision test of the SM Medium Energy Booster(4.5Km)
 - Rare decay
 - Flavor factory: b, c, tau
 - QCD studies
- Upgradable to ttbar threshold (360 GeV)
- SPPC (~ 100 TeV)

CEPC Collider Ring(50Km) IP2

Low Energy Booster(0.4Km)

- Direct search for new physics
- Complementary Higgs measurements to CEPC g(HHH), g(Htt)

- ...

Heavy ion, e-p collision...

TP4

IP3

LTB

e+ e- Linac

(240m)