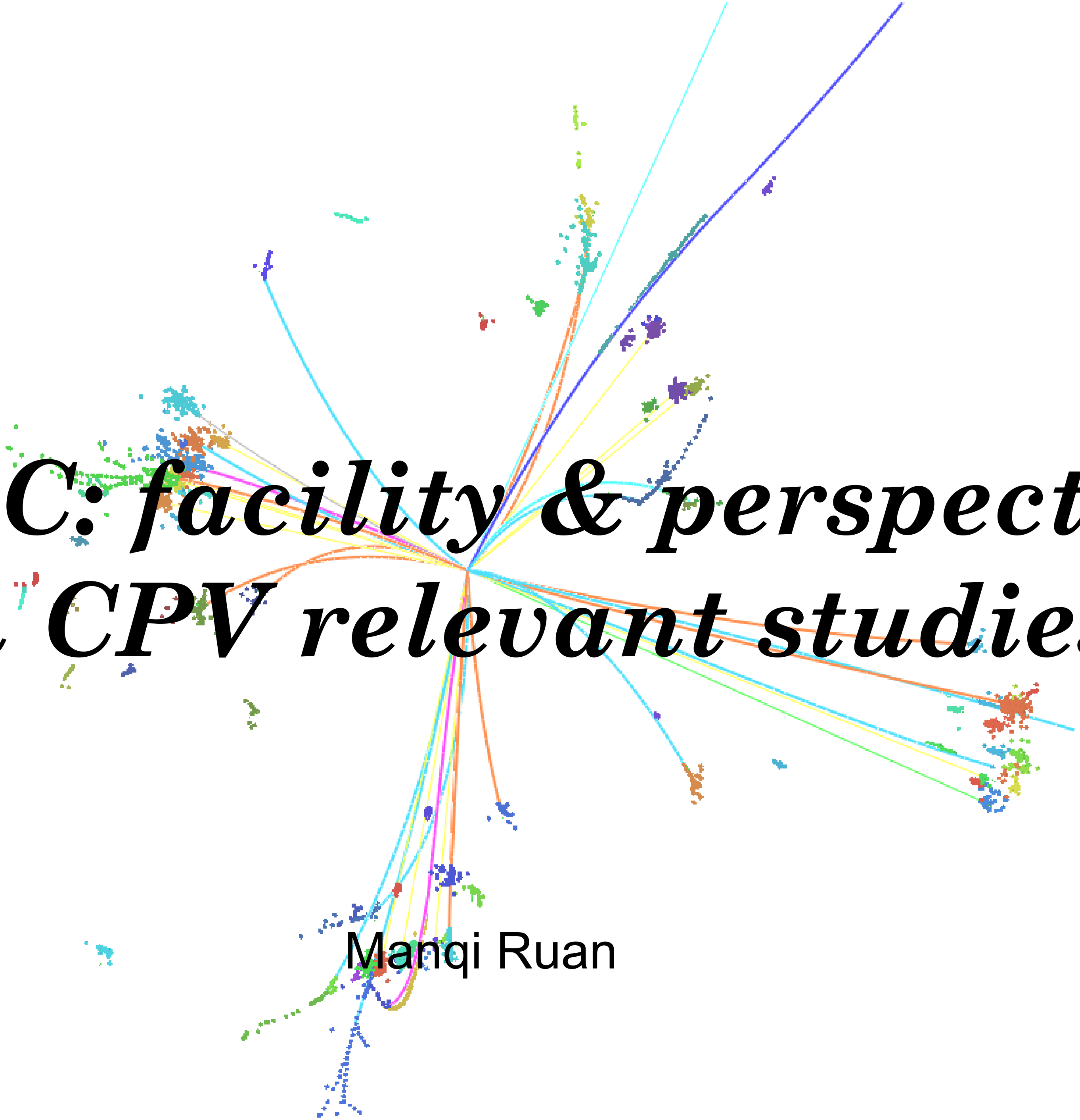
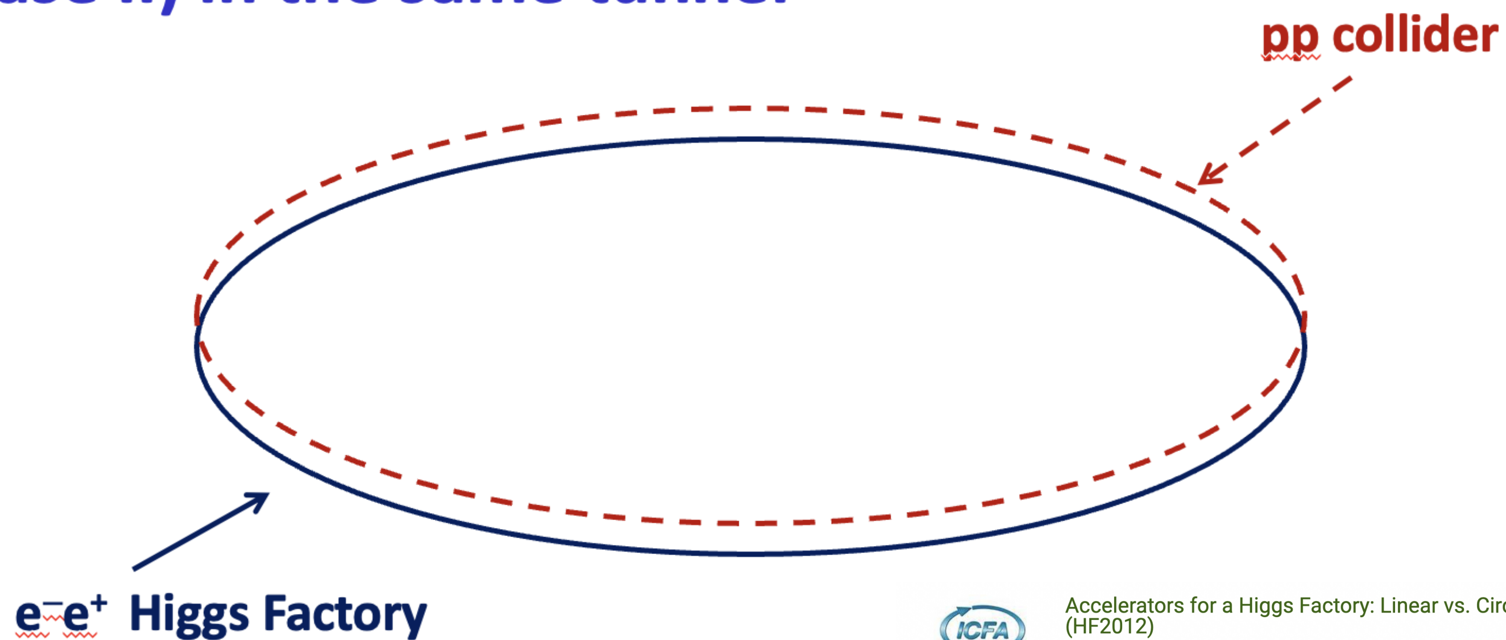


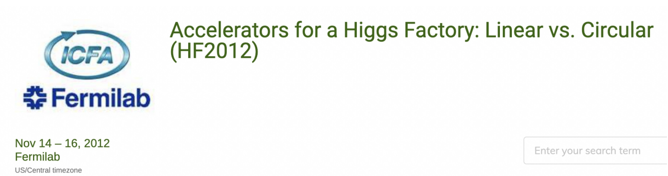
CEPC: facility & perspective on CPV relevant studies

Manqi Ruan

What is a (CHF + SppC)

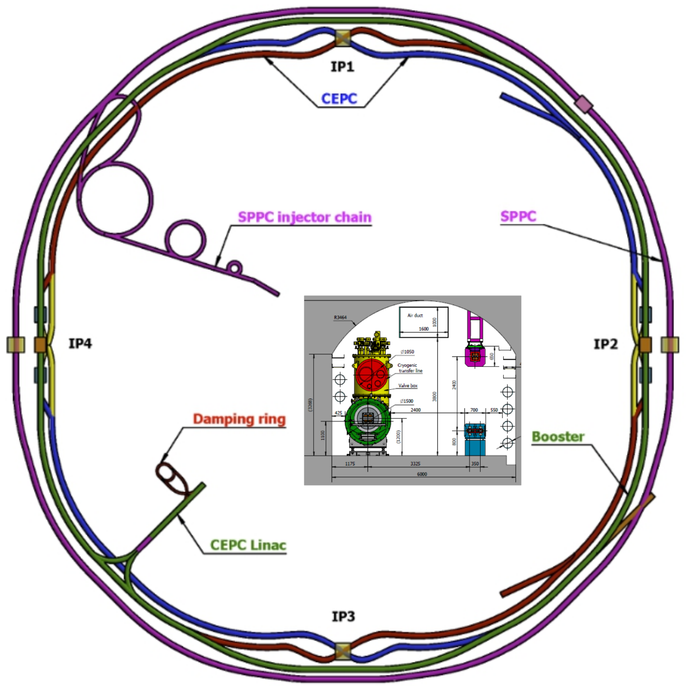
- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel

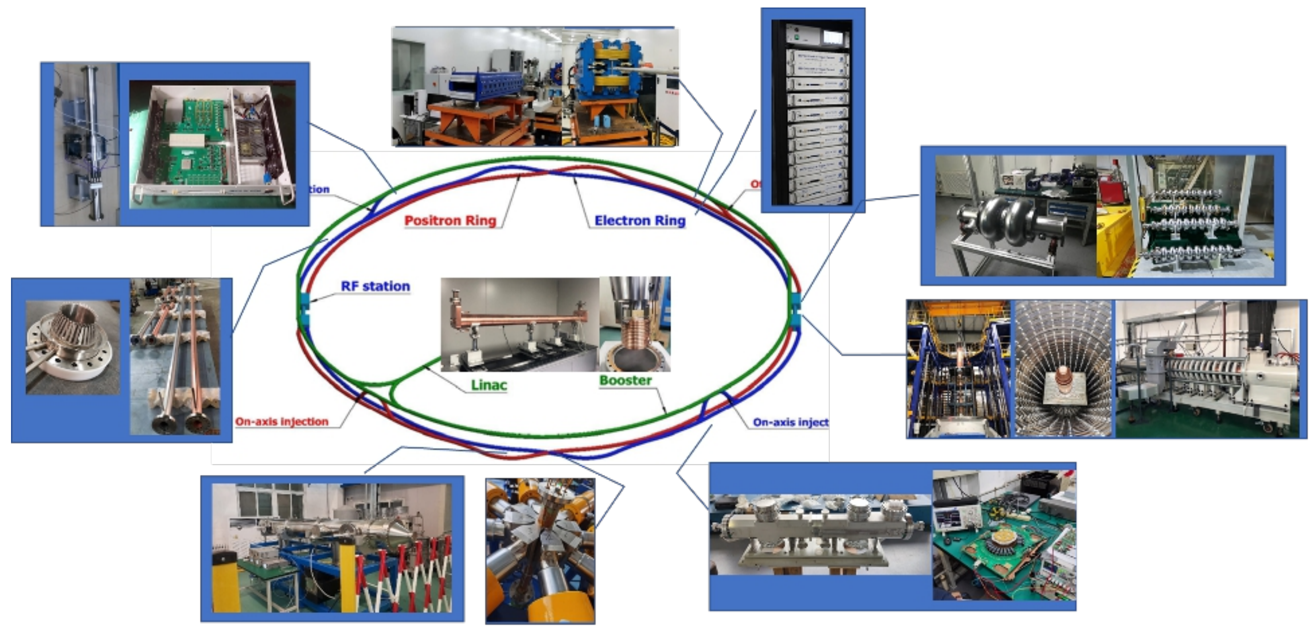


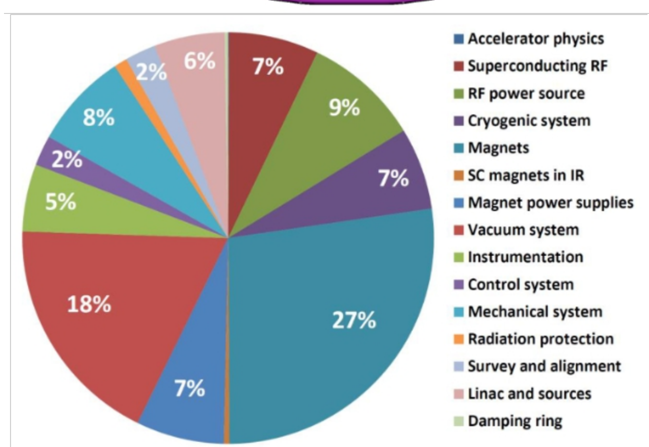


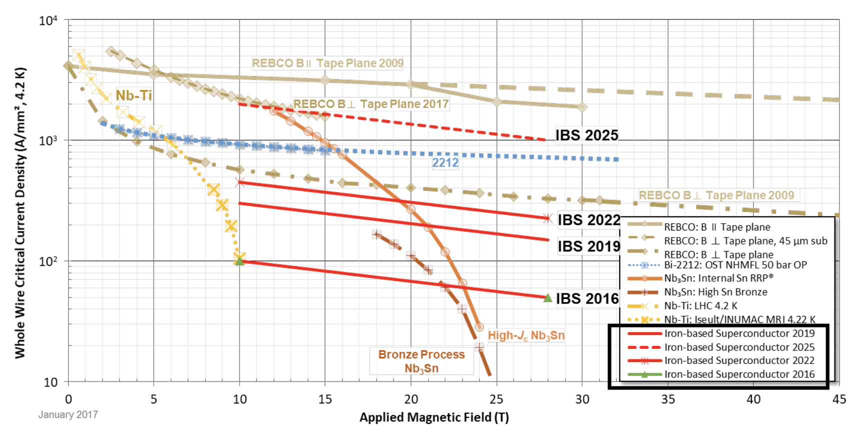
2012-11-15 HF2012 中国科学院高能物理研究所 Institute of High Energy Physics 6

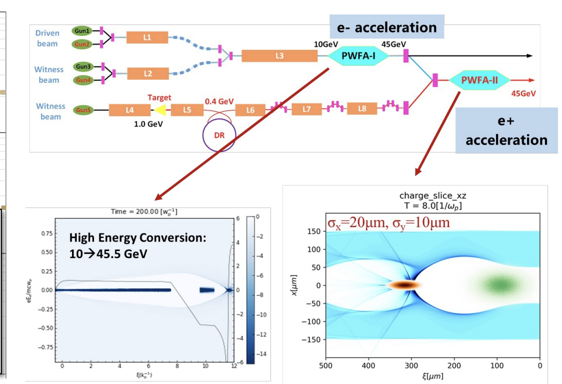
Accelerator at 2023



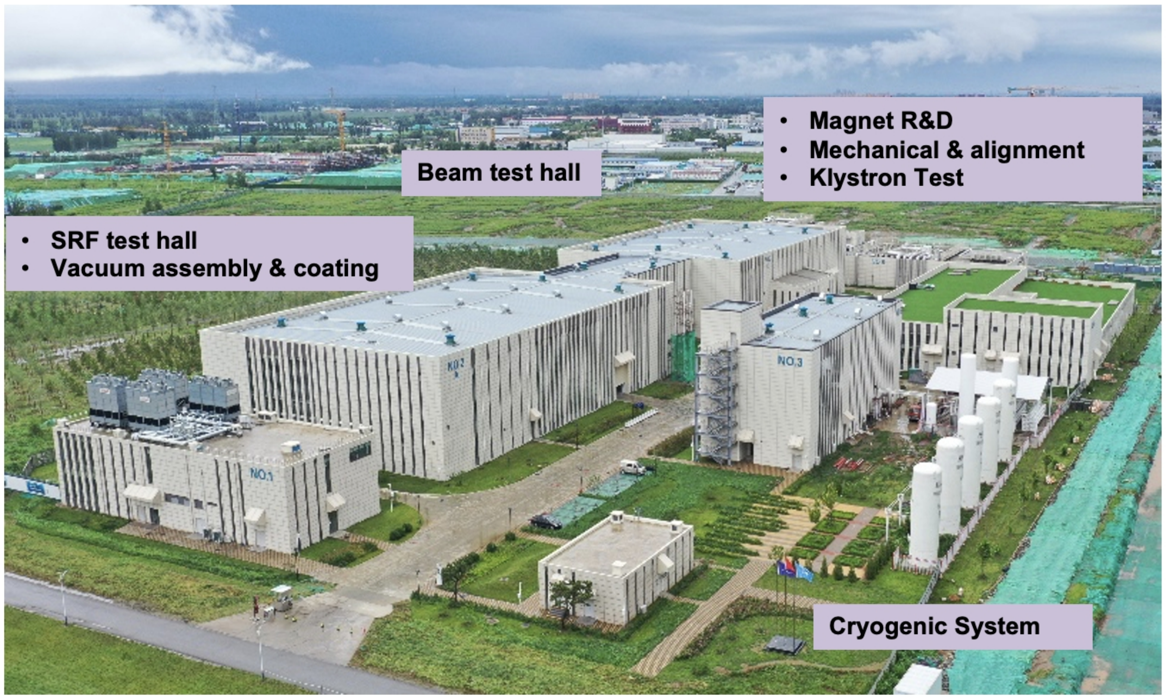








Platform for key technology R&D



Accelerator key technology R&D platform was established:

- SRF cavity and module
- High precision magnet
- Vacuum assembly & coating
- High efficiency Klystron
- Mechanics and alignment
- Beam test facility

TDR review: HK June 2023

1 Executive Summary

Five years after the completion of the CDR, the draft TDR for the CEPC accelerator has been prepared. The TDR will be completed taking into account the feedback from this Committee. The key technologies for CEPC have been developed. Prototypes meeting or exceeding the specifications are available. The CEPC team is on track to launch an engineering-design effort. After a site has been selected, the construction of the CEPC could start in 2027 or 2028. The Committee endorses this plan.

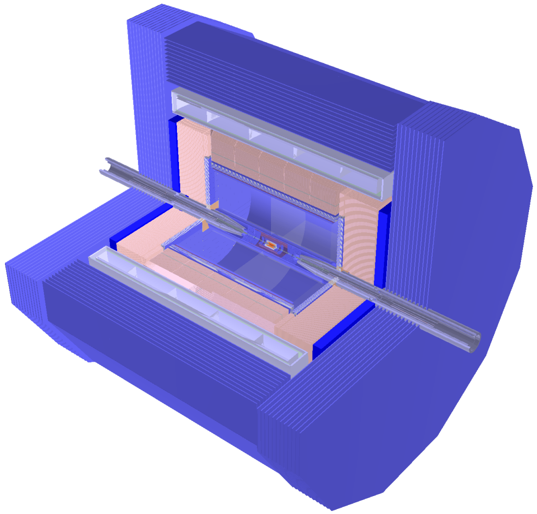
The Committee wishes to congratulate the CEPC team on the excellent progress. The Committee is impressed by the amount and quality of the work performed and presented.

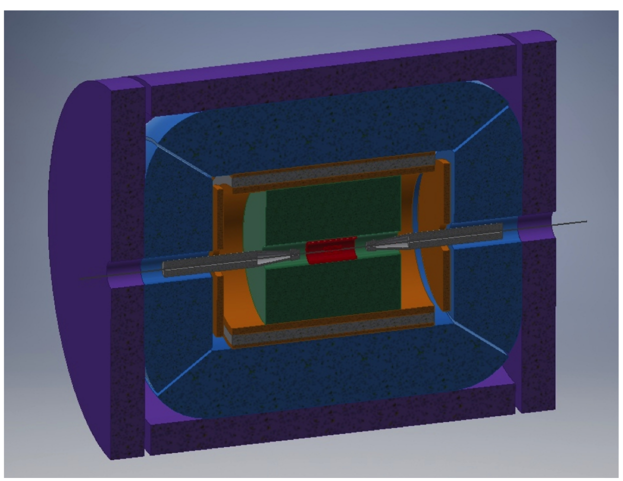
The next section provides answers to the different charge questions, the following sections contain comments and recommendations related to the individual presentations.

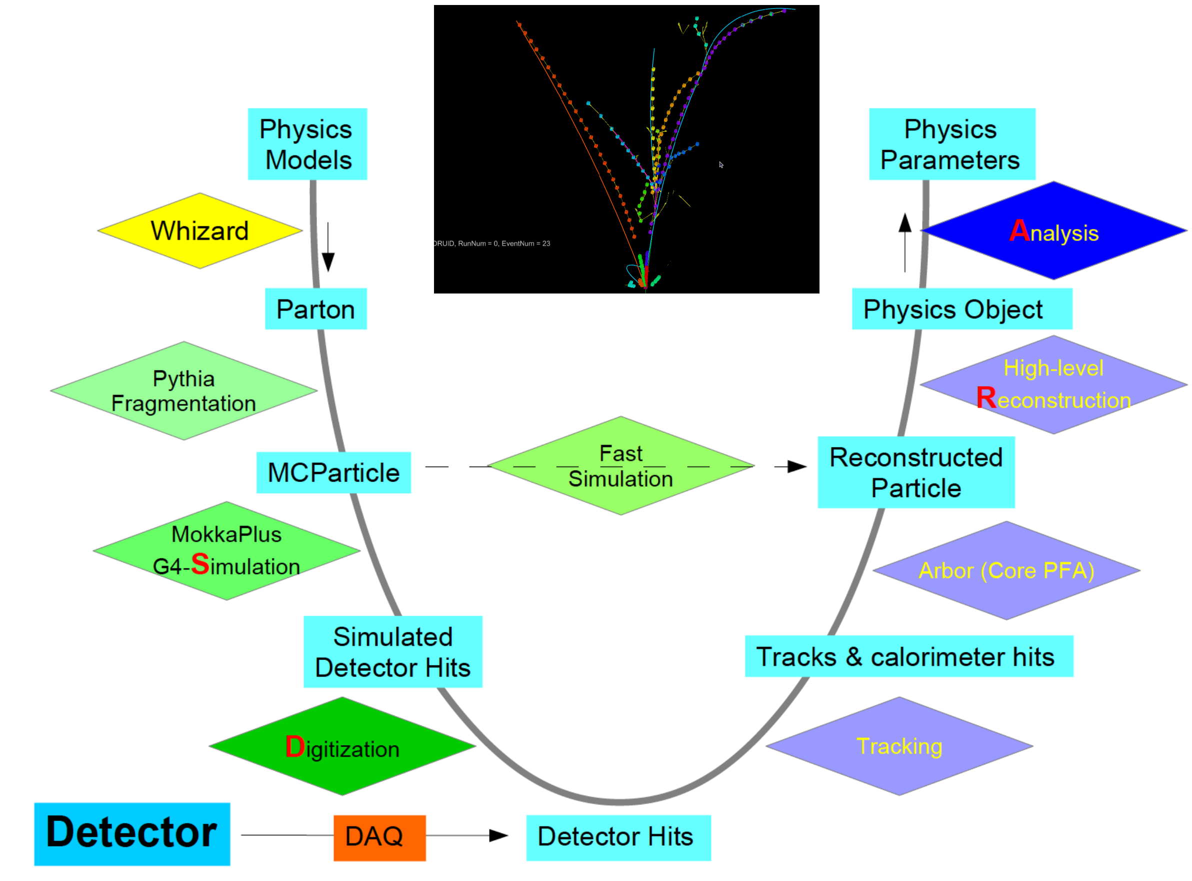
Key figures of the CEPC-SPPC

- **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
    - Precision test of the SM
    - Rare decay
    - Flavor factory: b, c, tau
    - QCD studies
- **Upgradable to ttbar threshold (360 GeV)： 1 M t/t-bar**
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

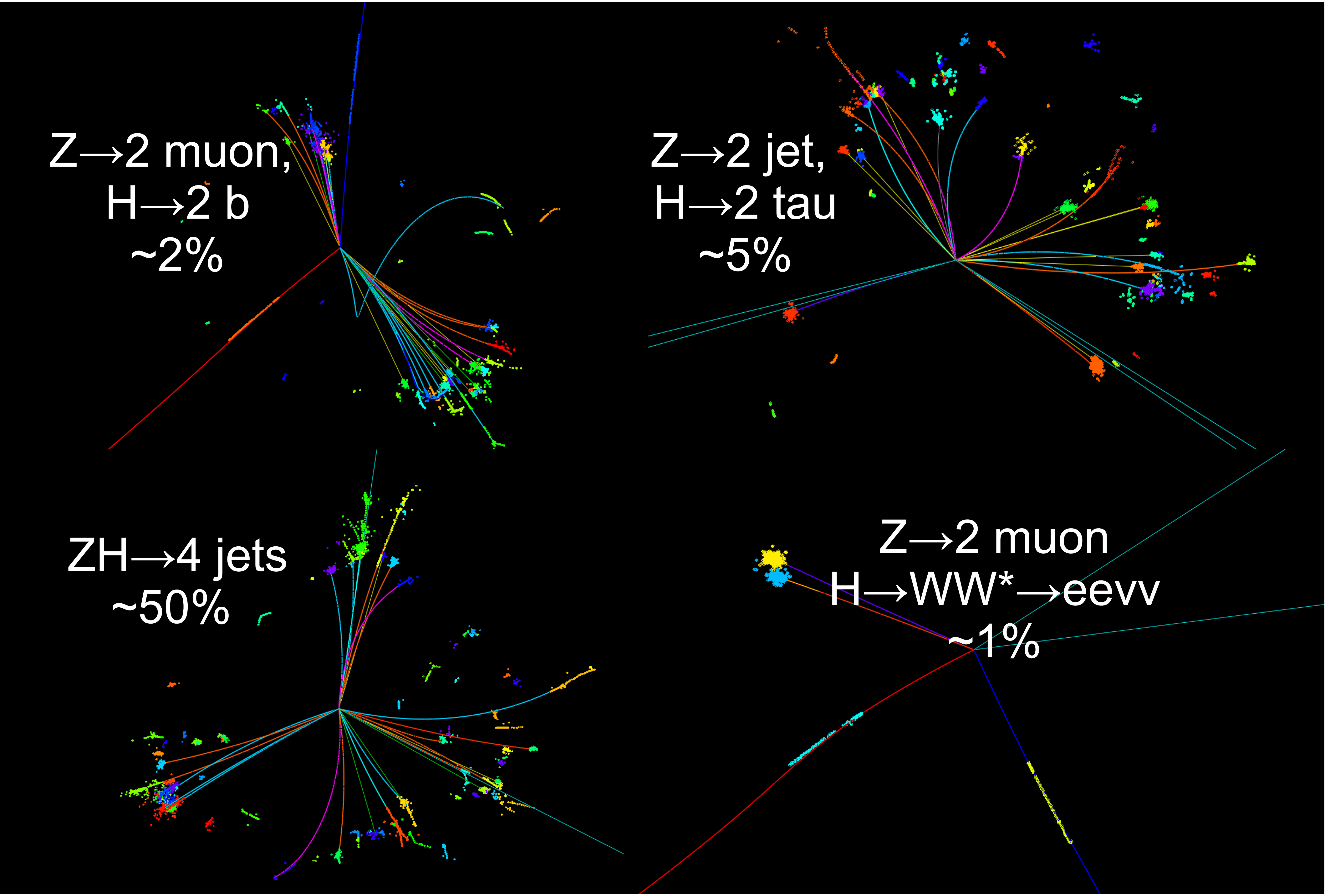
Detector & Software



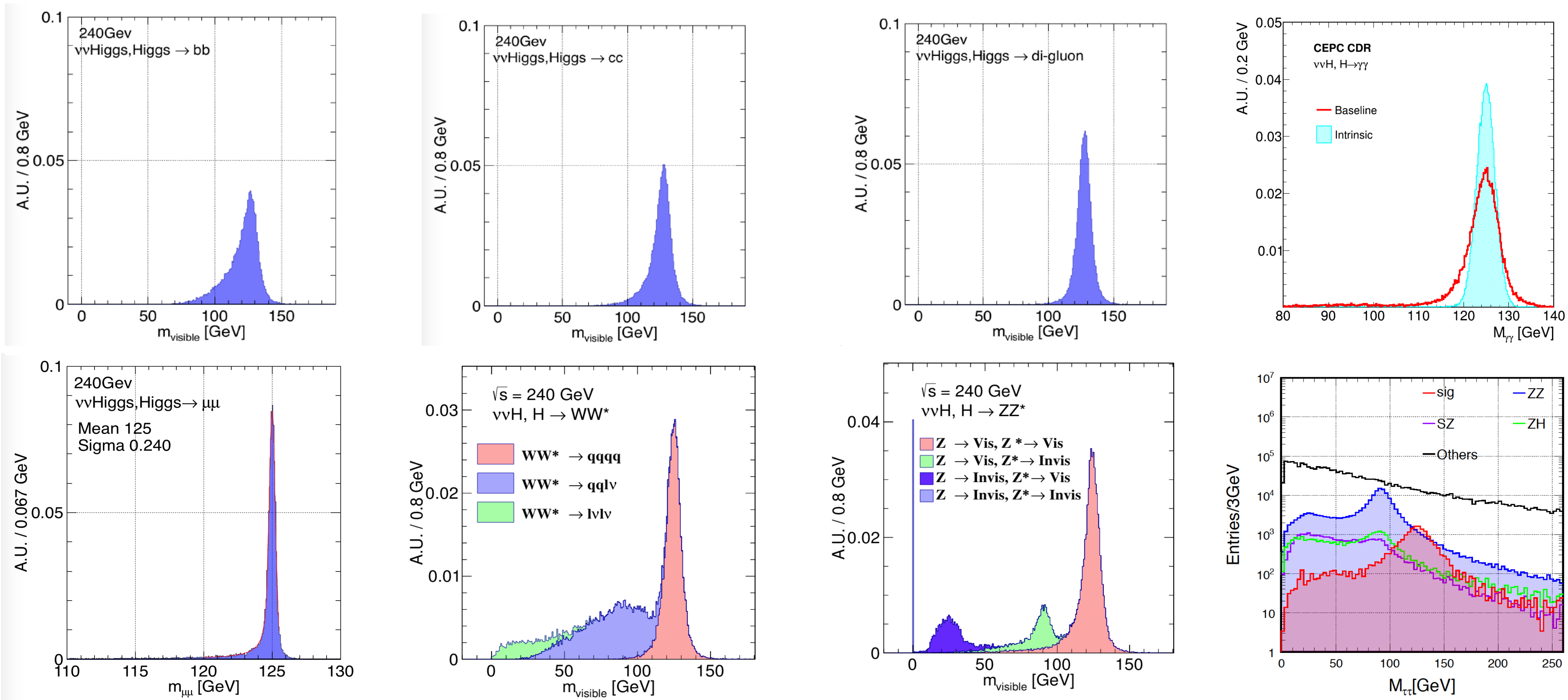




Full simulation reconstruction Chain with Arbor, iterating/validation with hardware studies


Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

Reconstructed Higgs Signatures

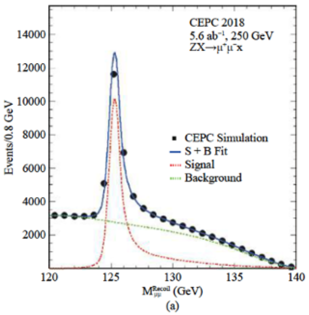


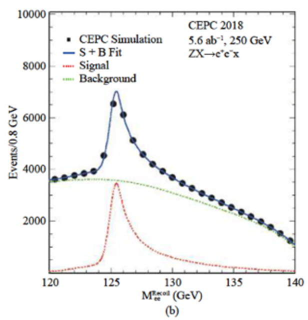
Clear Higgs Signature in all SM decay modes

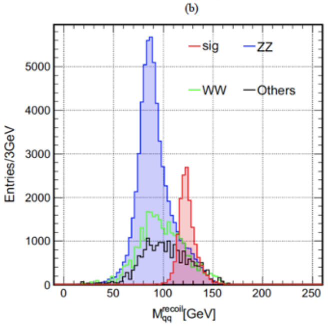
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

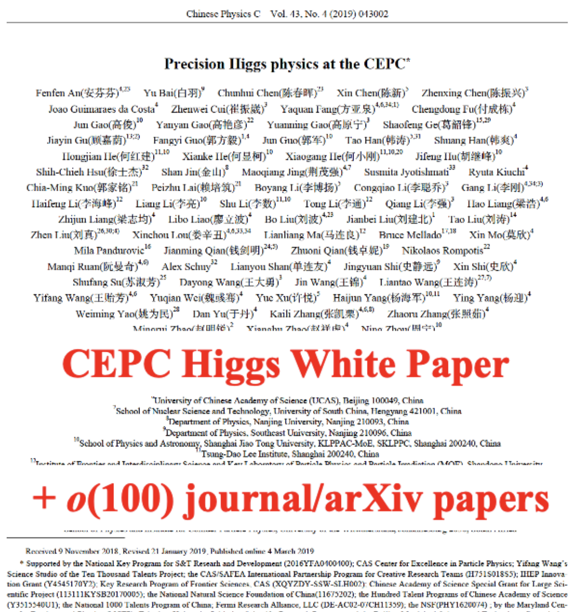
Right corner: di-tau mass distribution at qqH events using collinear approximation

Physics study: 2023








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] Minoru Zhao(赵明锐)[2] Xianghu Zhao(赵祥虎)[4] Ning Zhou(周宁)[10]

CEPC Higgs White Paper

[1]University of Chinese Academy of Science (UCAS), Beijing 100049, China
[2]School of Nuclear Science and Technology, University of South China, Hengyang 421001, China
[3]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

+ $o(100)$ journal/arXiv papers

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

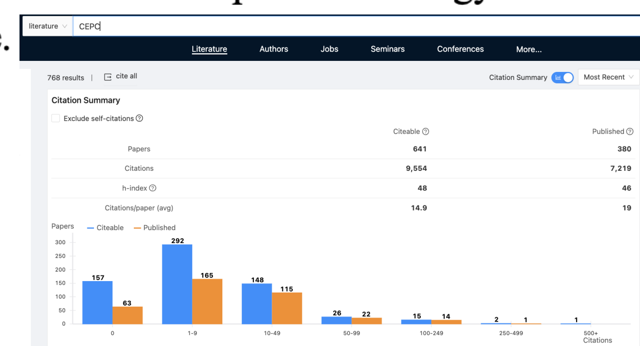
* Supported by the National Key Program for S&T Research and Development (2016YFA0400400); CAS Center for Excellence in Particle Physics; Yifang Wang's Science Studio of the Ten Thousand Talents Project; the CAS/SAFEA International Partnership Program for Creative Research Teams (H751S018S5); IHEP Innovation 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

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 projections of 3000 fb^{-1} data are used for comparison. [2]

Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
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
$B(H \to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \to cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H \to gg)$	-	0.81%	R_b	3×10^{-3}	2×10^{-4}
$B(H \to WW^*)$	2.8%	0.53%	R_c	1.7×10^{-2}	1×10^{-3}
$B(H \to ZZ^*)$	2.9%	4.2%	R_μ	2×10^{-3}	1×10^{-4}
$B(H \to \tau^+\tau^-)$	2.9%	0.42%	R_τ	1.7×10^{-2}	1×10^{-4}
$B(H \to \gamma\gamma)$	2.6%	3.0%	A_μ	1.5×10^{-2}	3.5×10^{-5}
$B(H \to \mu^+\mu^-)$	8.2%	6.4%	A_τ	4.3×10^{-3}	7×10^{-5}
$B(H \to Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	2×10^{-4}
Bupper($H \to$ inv.)	2.5%	0.07%	N_ν	2.5×10^{-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.
- …



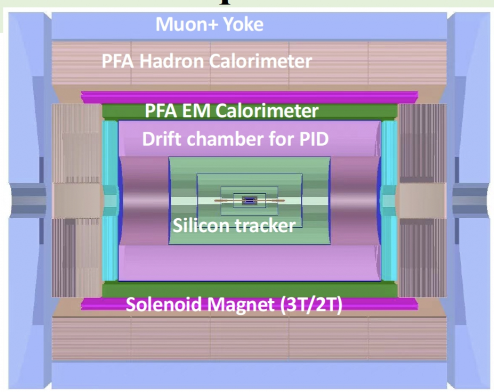
Performance requirements

- A clear separation of the final state particles
  - Identification of Physics Objects, isolated & inside jet
    - Single final state particle object, i.e., Leptons
    - Composited objects:
      - Two/three final state particles: Pi-0, K-short, Lambda, Phi,Tau, D meson...
      - Jets
  - Improving the E/P resolution for composited objects, especially jets
- BMR (Boson Mass Resolution)
  - < 4% for Higgs measurements
  - Much demanding for Flavor/New Physics Measurements
- Pid: Pion & Kaon separation > 3 σ ~ (3% dE/dx (dN/dx) + 50 ps ToF)
- Jet: Flavor Tagging & Charge Reconstruction
- Flavor Physics: EM resolution, momentum resolution...

Detector study: 2023

Design of experimental facility and technical requirements

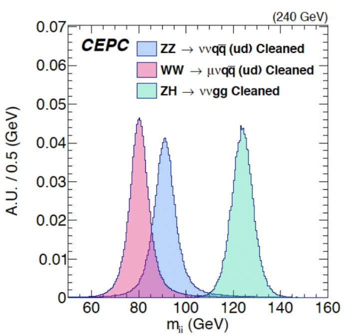
Detector



Requirements
boson mass resolution (BMR ~3%)

→

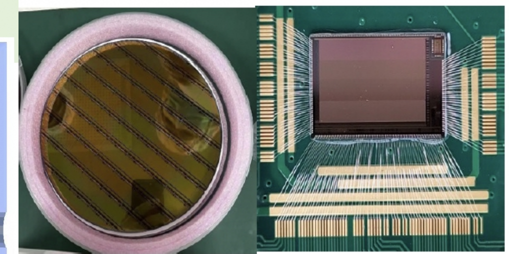
Challenges
- Support Particle flow with
  - High granularity
  - High precision

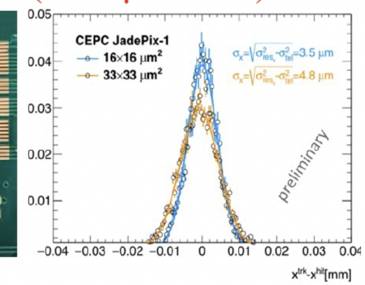


Novel detector design based on PFA calorimeter. Aim at improving BMR from 4% to 3%

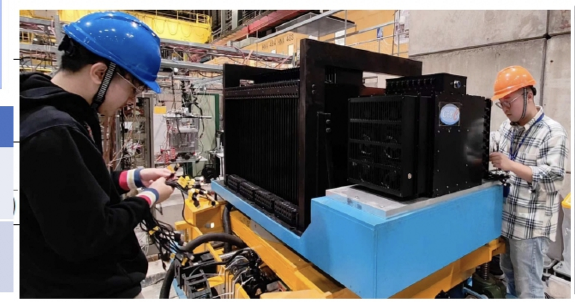
Detector	Key parameter	World-class level	CEPC design
PFA based EM calorimeter	EM shower E resolution	~20%/√E	<3%/√E
PFA based Hadron calorimeter	Single hadron E resolution	~50%/√E	~40%/√E

Vertex detector R & D (3- 5 μm reso.)

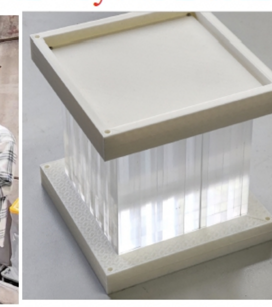


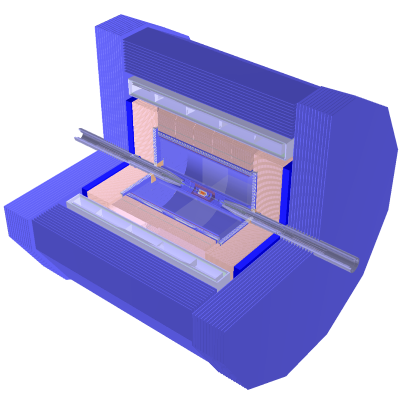


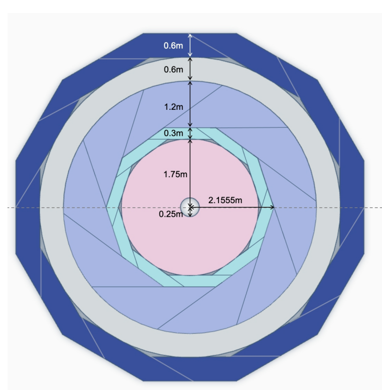
PFA scintillator-W ECAL

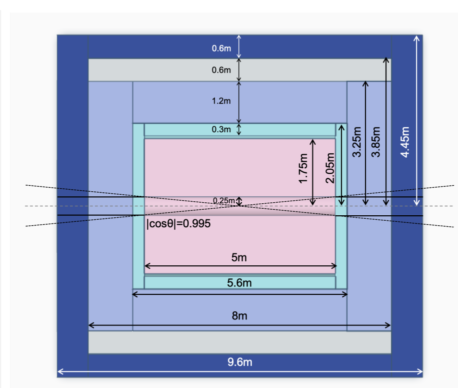


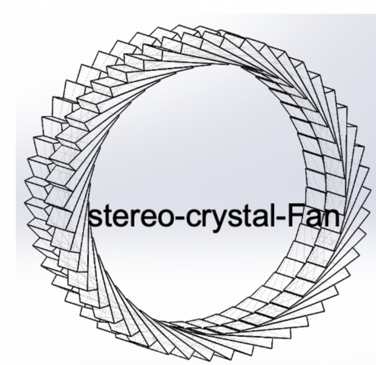
4D crystal ECAL

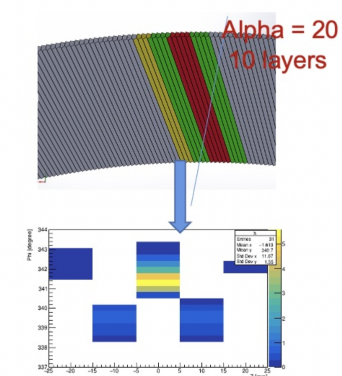












Hadron Yields

Particle	BESIII	Belle II (50 ab^{-1} on $\Upsilon(4S)$)	LHCb (300 fb^{-1})	CEPC (4×Tera-Z)
B^0, $\bar{B}^0$	-	5.4×10^{10}	3×10^{13}	4.8×10^{11}
$B^\pm$	-	5.7×10^{10}	3×10^{13}	4.8×10^{11}
B_s^0, $\bar{B}_s^0$	-	6.0×10^8 (5 ab^{-1} on $\Upsilon(5S)$)	1×10^{13}	1.2×10^{11}
$B_c^\pm$	-	-	1×10^{11}	7.2×10^8
Λ_b^0, $\bar{\Lambda}_b^0$	-	-	2×10^{13}	1×10^{11}
D^0, $\bar{D}^0$	1.2×10^8	4.8×10^{10}	1.4×10^{15}	5.2×10^{11}
$D^\pm$	1.2×10^8	4.8×10^{10}	6×10^{14}	2.2×10^{11}
$D_s^\pm$	1×10^7	1.6×10^{10}	2×10^{14}	8.8×10^{10}
$\Lambda_c^\pm$	0.3×10^7	1.6×10^{10}	2×10^{14}	5.5×10^{10}
$\tau^\pm$	3.6×10^8	4.5×10^{10}		1.2×10^{11}

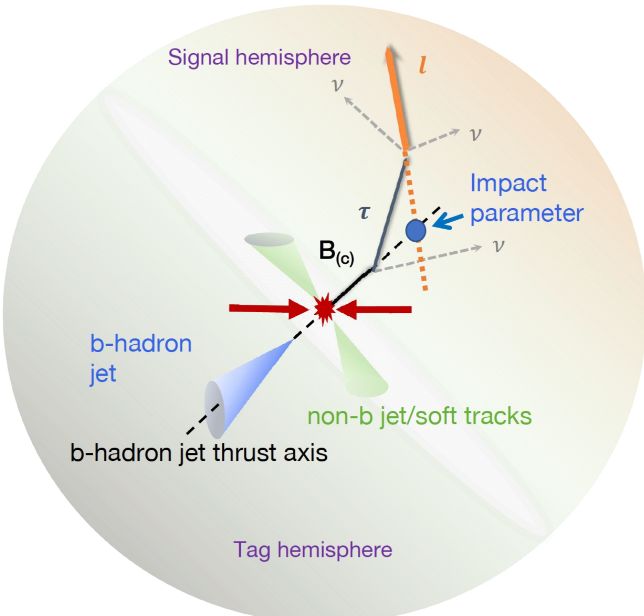
STCF ~ 100 * BES III

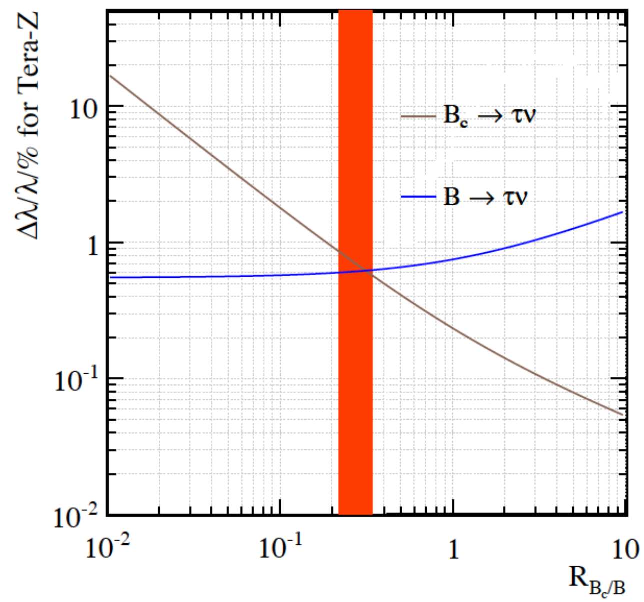
CPV at Higgs/Z factory – Comparative advantages

- V.S. B/C-Factory (Belle II, STCF, BES III)
  - Larger Boost
  - Precise Vertex reconstruction
  - Abundant heavy hadrons: Bs, Bc, Lambda_b
  - Access to high mass exotica...

- V.S. LHCb, etc
  - Cleaner collision environment ~ much lower background
  - Much better detector performance
    - Neutral Final State: Photon, Pi-0, Missing energy, etc
    - Jet Flavor & Jet Charge
    - Acceptance...

Bc → τν





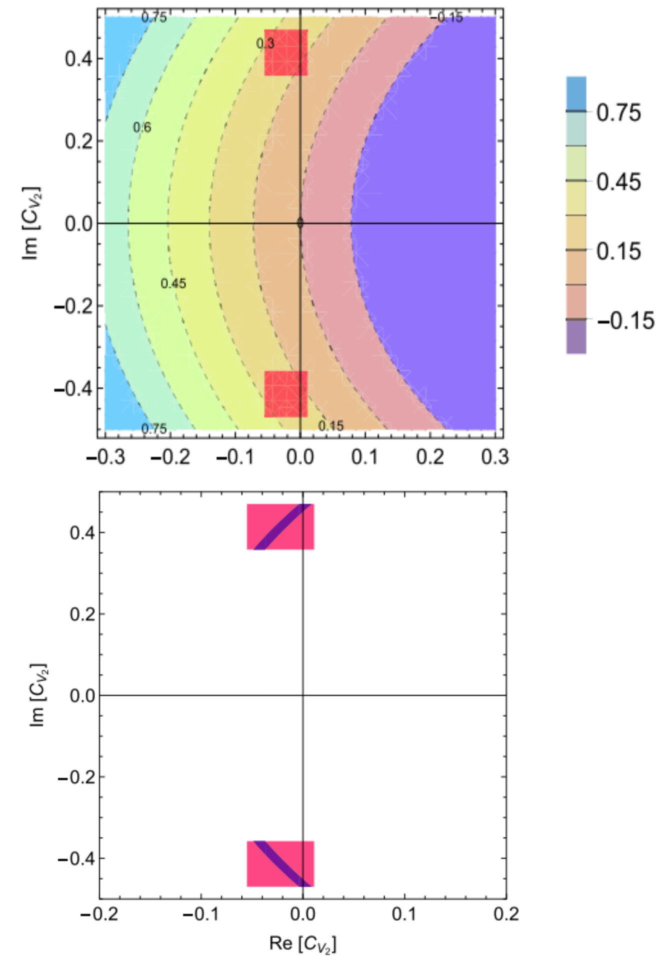


Fig. 10. (color online) Constraints on the real and imaginary parts of C_{V_2}. The red shaded area corresponds to the current constraints using available data on $b \to c\tau\nu$ decays. If the central values in Eq. (9) remain while the uncertainty in $\Gamma(B_c^+ \to \tau^+\nu_\tau)$ is reduced to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

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.

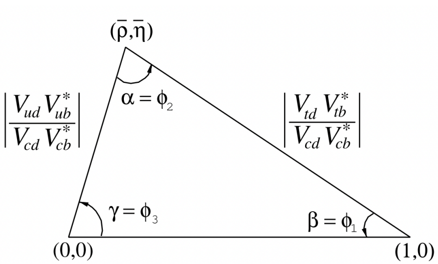
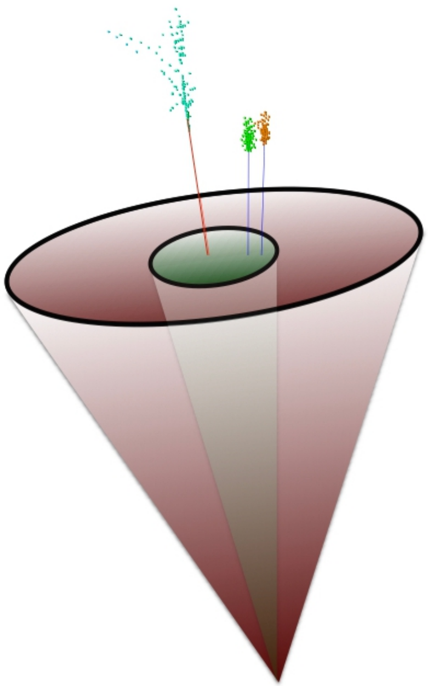
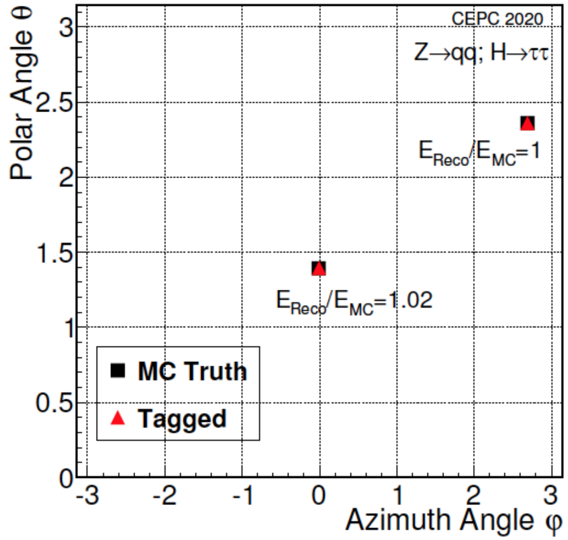
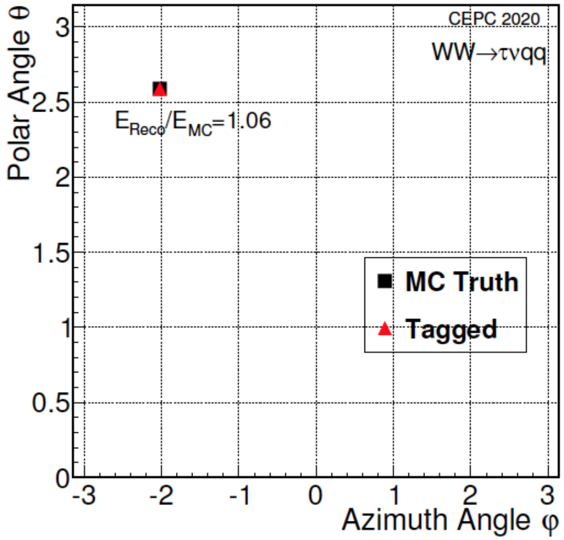


Figure 12.1: Sketch of the unitarity triangle.

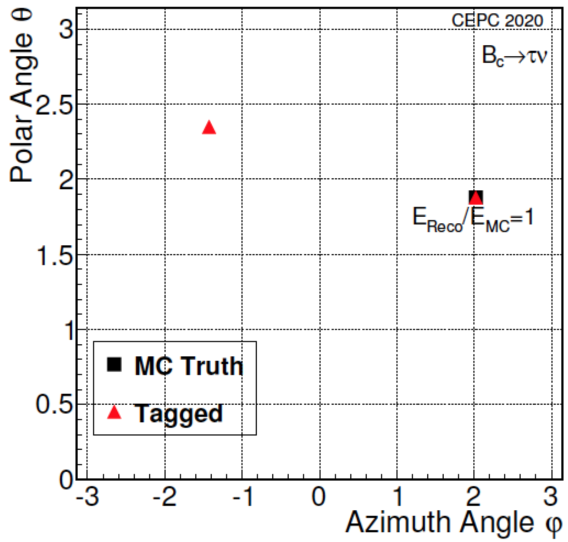




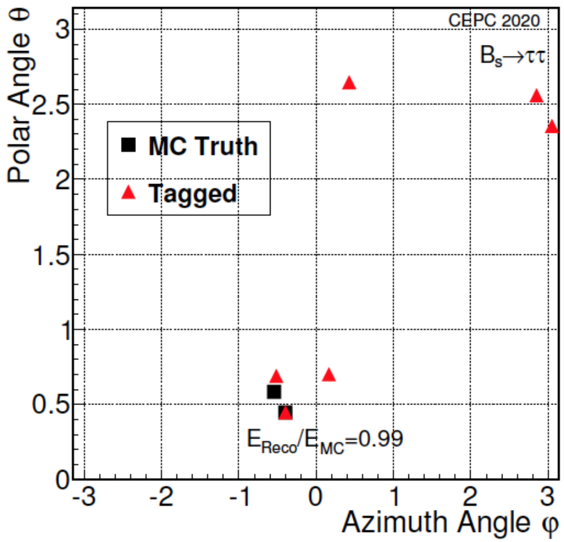
(a) $Z \to qq, H \to \tau\tau$, efficiency=1, purity=1



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

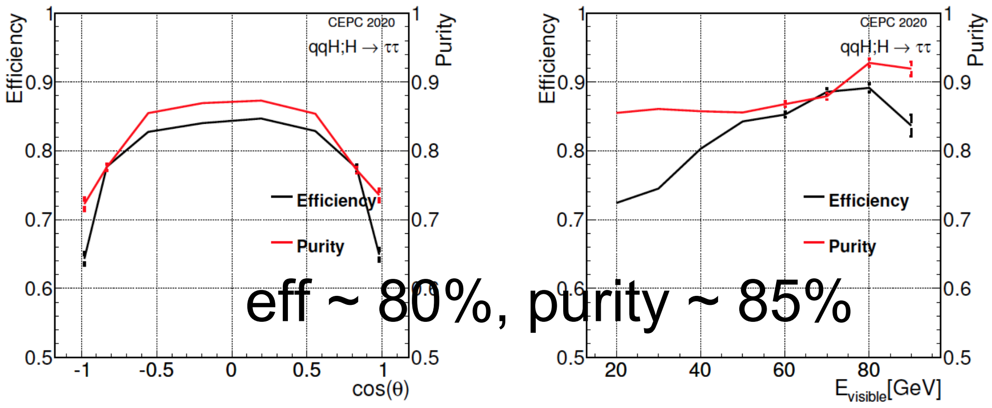


(c) $Z \to b\overline{b}, B_c \to \tau\nu$, efficiency=1, purity=0.5



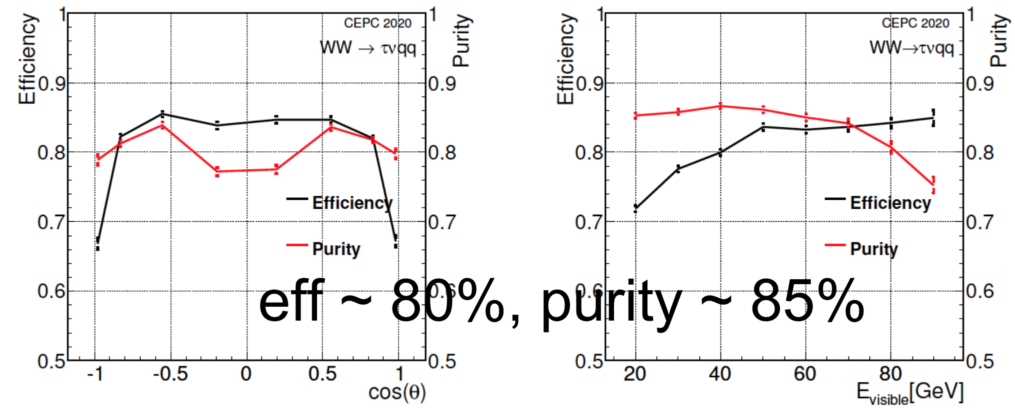
(d) $Z \to b\overline{b}, B_s \to \tau\tau$, efficiency=0.5, purity=0.167

Tau id



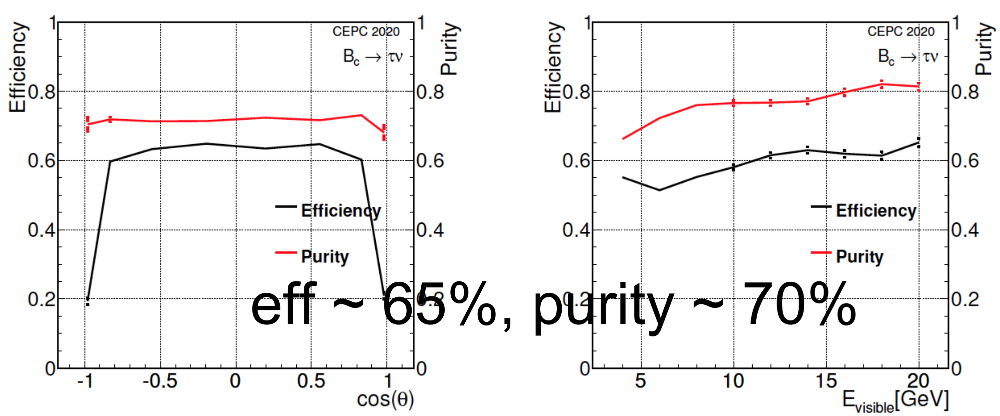
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

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



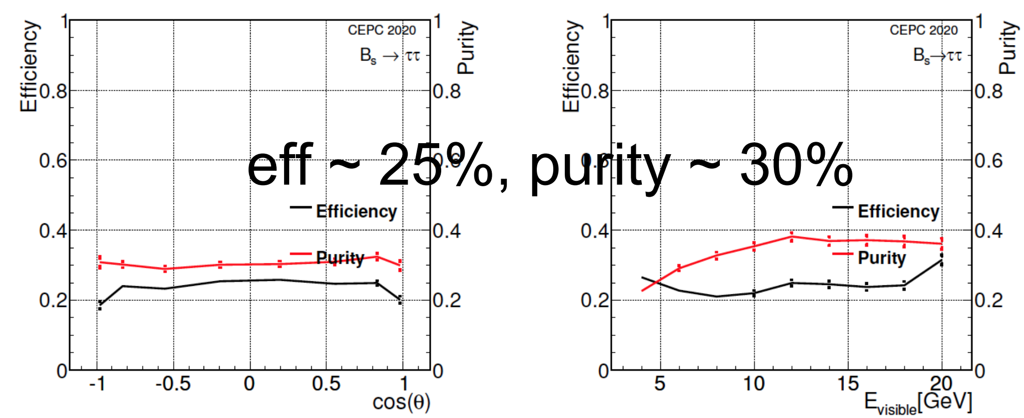
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

(b) Efficiency and purity performance along with visible energy



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

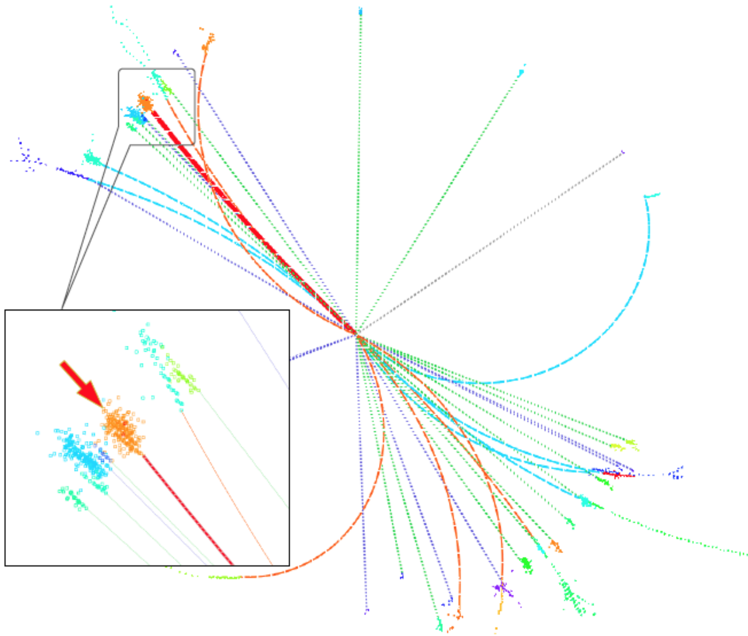
(b) Efficiency and purity performance along with visible energy

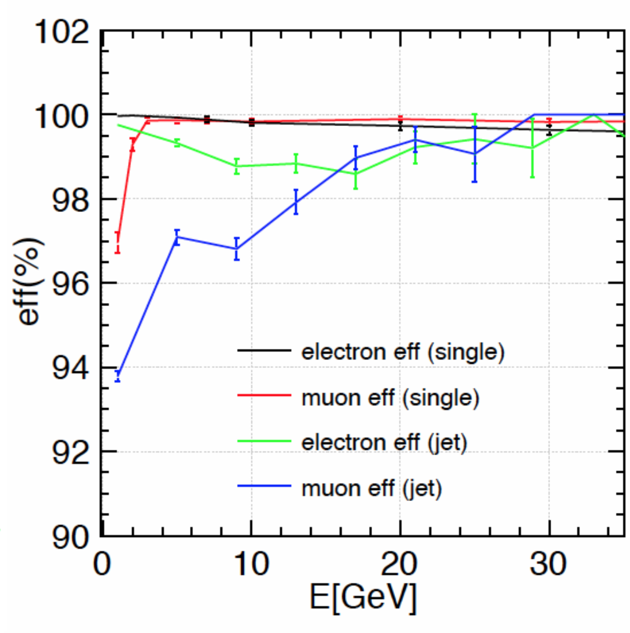


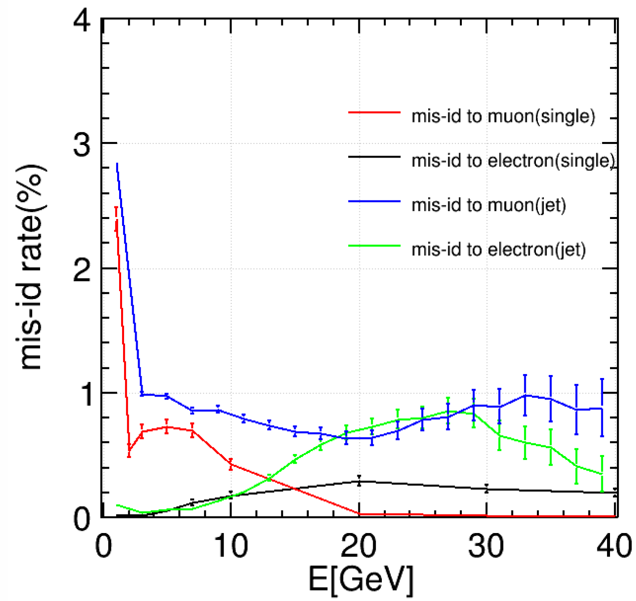
(a) Efficiency and purity performance along with polar angle θ, parameters fixed.

(b) Efficiency and purity performance along with visible energy

Lepton: inside jet



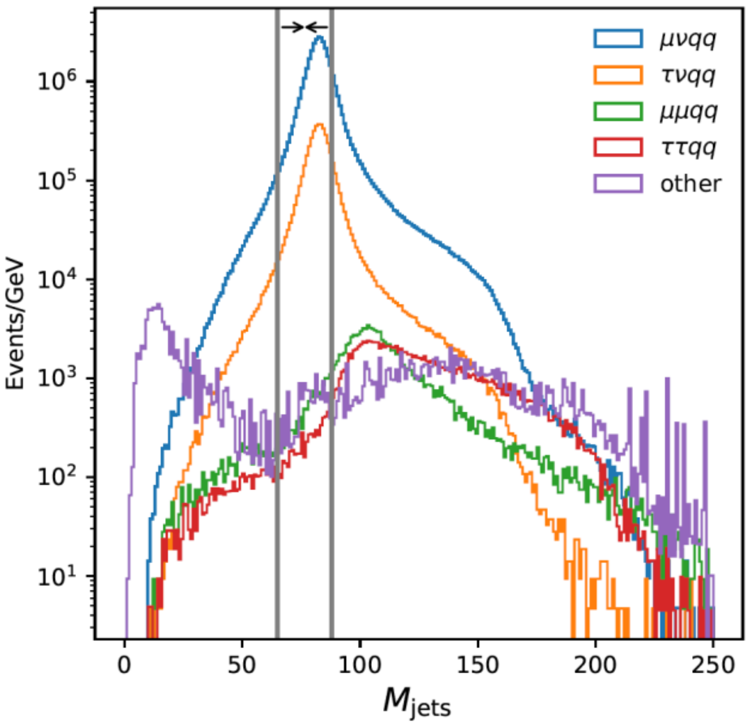




Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded – Due to the limited clustering performance (splitting & containimation).

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.

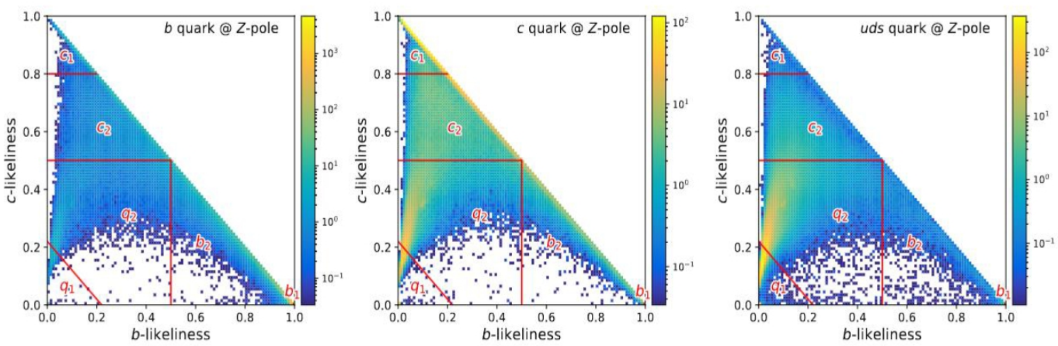
Vcb from W decay



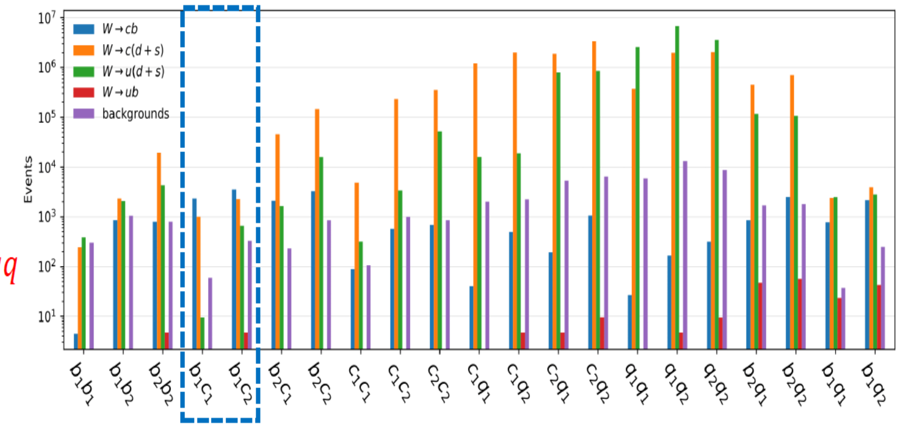
	$\mu\nu W, W \to$				$\tau(\mu\nu)\nu_\tau W, W \to$				$\tau\nu_\tau qq, \tau \to$					
	cb	ub	$c(d/s)$	$u(d/s)$	cb	ub	$c(d/s)$	$u(d/s)$	$e2\nu$	had.ν_τ	$\tau\tau qq$	$\mu\mu qq$	Higgs	others
w/o slections	40.3K	363	24.2M	24.2M	7.73K	74	4.2M	4.2M	8.66M	31.4M	2.18M	4.47M	4.07M	2.06G
$E_{\mathrm{L}\mu} > 12$GeV	37.9K	330	22.6M	22.6M	5.59K	56	2.98M	2.97M	133K	687K	422K	2.82M	645K	186.3M
$R_{\mathrm{L}\mu} > 0.85$	35.3K	302	21.1M	21.1M	5.01K	46	2.73M	2.73M	1.55K	43.2K	266K	1.82M	308K	128.8M
$\cos(\theta_{\mathrm{L}\mu})$	35.3K	302	21.1M	21.1M	5.01K	46	2.73M	2.73M	1.55K	43.2K	266K	1.82M	308K	128.8M
$q_{\mathrm{L}\mu} \cos(\theta_{\mathrm{L}\mu}) < 0.20$	32.8K	283	19.6M	19.6M	4.7K	42	2.57M	2.57M	1.26K	39.9K	156K	1.03M	183K	92.6M
2nd isolation ℓ veto	32.8K	283	19.5M	19.6M	4.7K	42	2.57M	2.57M	1.26K	39.9K	154K	526K	138K	43.9M
multiplicity ≥ 15	32.8K	283	19.5M	19.4M	4.7K	42	2.56M	2.55M	1.23K	39.6K	153K	522K	118K	185K
Missing $P_T > 9.5$ GeV/c	31.5K	264	18.7M	18.6M	4.38K	37	2.4M	2.39M	1.18K	37.2K	136K	118K	92.6K	97.7K
$M_{\text{jets}} > 65$ GeV/c^2	29.4K	254	18.1M	18.3M	4.15K	32	2.33M	2.35M	978	36.0K	132K	112K	85.3K	24.5K
$M_{\text{jets}} < 88$ GeV/c^2	24.1K	193	14.3M	14.1M	3.49K	23	1.87M	1.85M	641	24.7K	5.62K	11.5K	6.76K	4.31K
$M_{\text{jets,recoil}} < 115$ GeV/c^2	20.2K	184	13.0M	13.1M	2.96K	23	1.72M	1.73M	505	22.6K	3.57K	6.86K	536	3.02K
$M_{\mathrm{L}\mu\mathrm{S}\mu} < 75$ GeV/c^2	19.6K	184	12.9M	13.0M	2.95K	23	1.72M	1.73M	505	22.6K	3.56K	5.78K	414	3.0K
$M_{\ell\nu} > 12$ GeV/c^2	19.6K	184	12.9M	13.0M	2.7K	18	1.54M	1.55M	416	19.5K	2.08K	5.16K	390	1.81K
ϵ_{kin} (%)	48.8	50.6	53.5	53.7	34.9	25.0	36.7	36.9	0.0	0.1	0.1	0.1	0.0	0.0
	(0.7)	(8.1)	(0.0)	(0.0)	(1.5)	(12.5)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
$b_1 c_{1,2}$	5.14K	4	2.79K	571	632	0	407	65	0	14	67	228	0	0
$\epsilon_{b_1 c_{1,2}}$ (%)	12.8	1.3	0.0	0.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(0.4)	(1.3)	(0.0)	(0.0)	(0.7)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

- Purity > 99.5% at Eff. 50% for $\mu\nu qq$ and 34% for $\tau(\mu 2\nu)\nu qq$
- Main backgrounds include:
  - $W \to c(d/s)$
  - $\mu\mu qq$

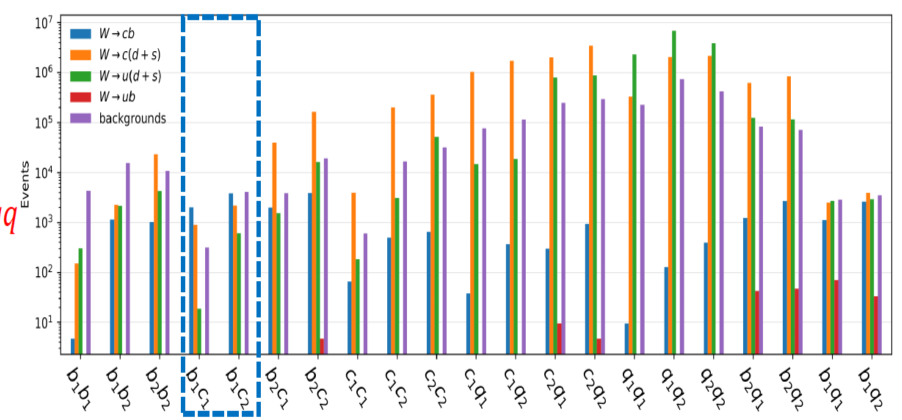
Vcb from W decay



$\mu\nu qq$



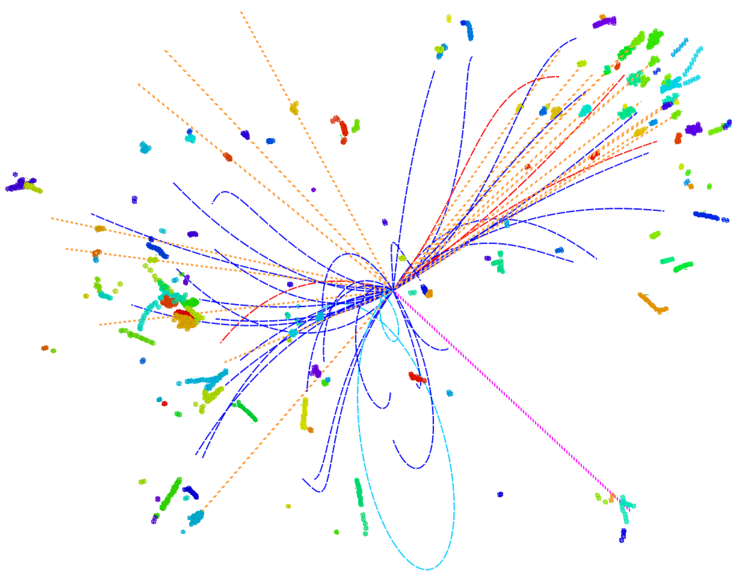
$e\nu qq$

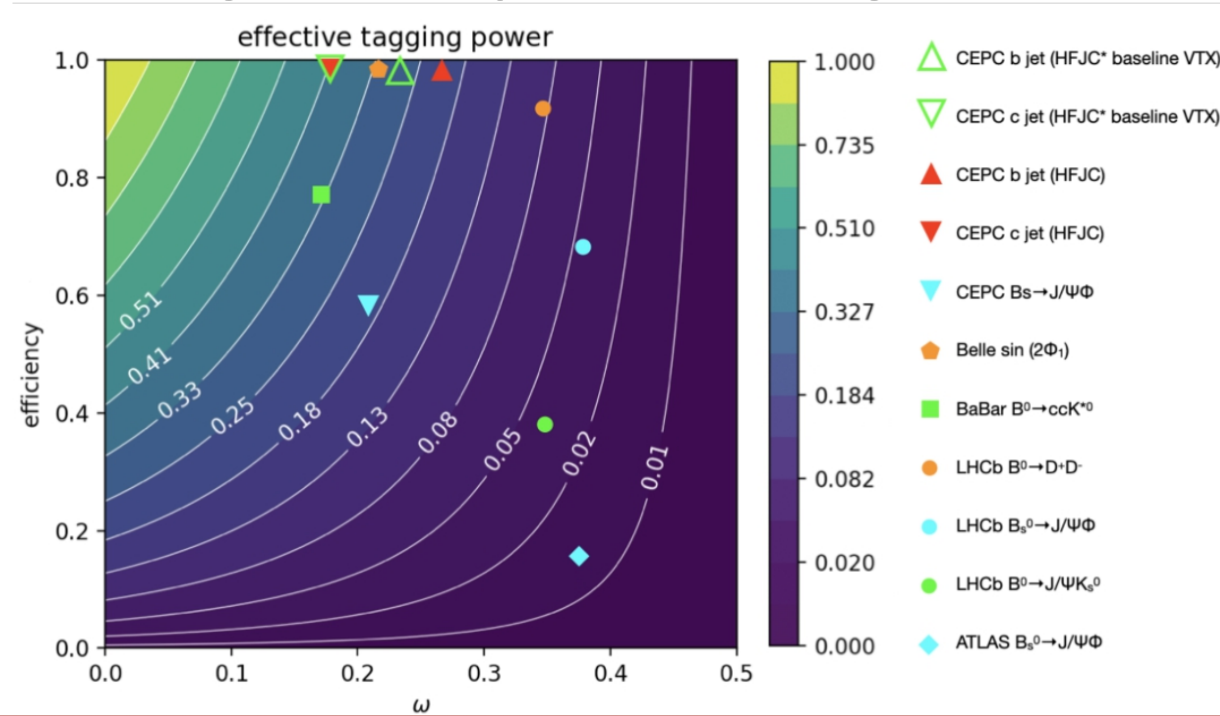


quark \ tag	b_1	b_2	c_1	c_2	q_1	q_2
b	0.47	0.378	0.0197	0.0965	0.00397	0.0315
c	0.00042	0.078	0.298	0.373	0.0682	0.182
uds	0.000104	0.00477	0.00145	0.054	0.538	0.401

- $\mu\nu qq$
  - Statistical (relative) error: 1.5%, 3.4E-4, 3.4E-4
  - $|V_{cb}|$ Statistical error: 0.75%
- $e\nu qq$
  - statistical (relative) error: 1.7%, 3.7E-4, 3.7E-4
  - $|V_{cb}|$ Statistical error: 0.85%

Jet charge measurement using Leading jet particle & weighted jet charge





Eff. Tag. Power:
~ 40%/20% for c/b jet
with 45 GeV energy

arXiv > hep-ex > arXiv:2306.14089

High Energy Physics – Experiment

[Submitted on 25 Jun 2023 (v1), last revised 13 Jul 2023 (this version, v3)]

Jet charge identification in ee→Z→qq process at Z pole operation

Hanhua Cui, Mingrui Zhao, Yuexin Wang, Hao Liang, Manqi Ruan

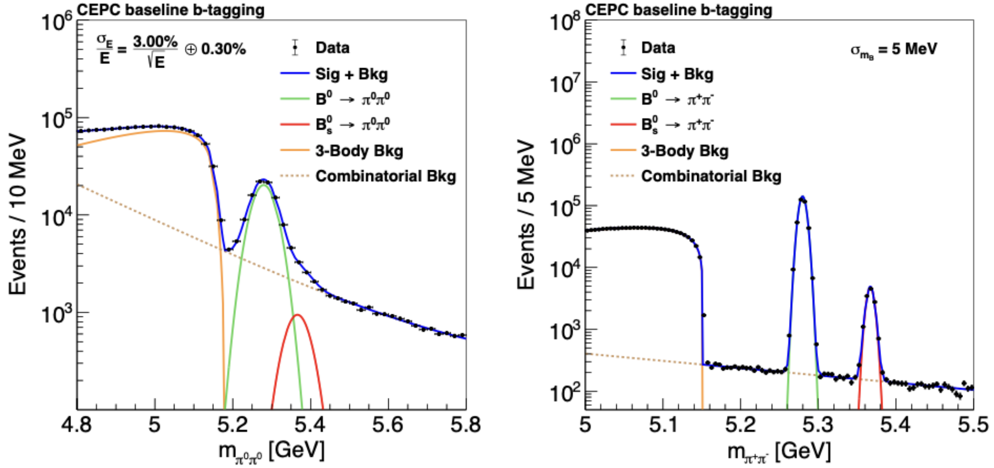
Accurate jet charge identification is essential for precise electroweak and flavor measurements at the high-energy frontier. We propose a novel method called the Leading Particle Jet Charge method (LPJC) to determine the jet charge based on information about the leading charged particle. Tested on Z → bb and Z → cc samples at a center-of-mass energy of 91.2GeV, the LPJC achieves an effective tagging power of 20%/9% for the c/b jet, respectively. Combined with the Weighted Jet Charge method (WJC), we develop a Heavy Flavor Jet Charge method (HFJC), which achieves an effective tagging power of 39%/20% for c/b jet, respectively. This paper also discusses the dependencies between jet charge identification performance and the fragmentation process of heavy flavor jets, and critical detector performances.

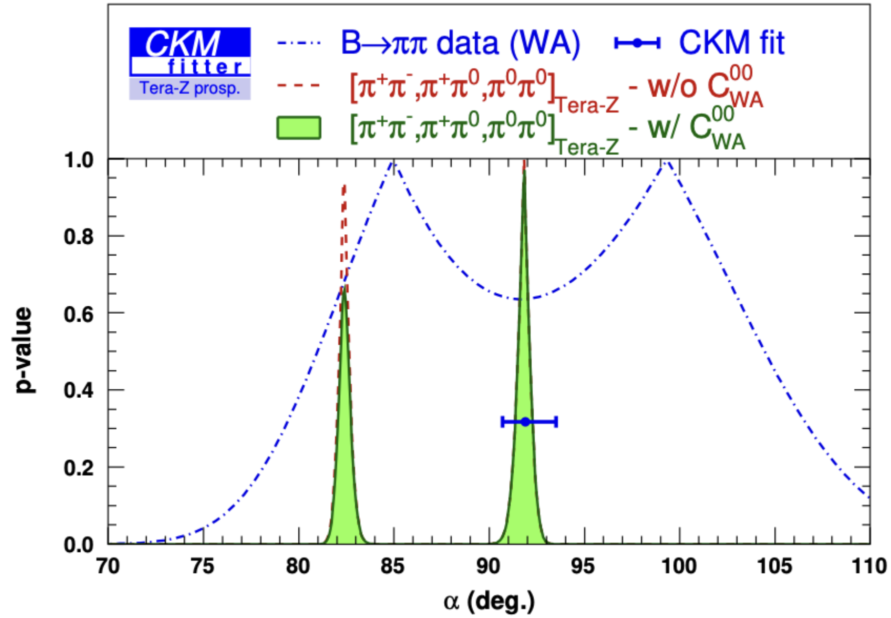
Measurement of α using B0 → 2pi0

- $B \to \pi\pi$ [JHEP12(2022)135]
  - Z-factory advantages
    - Lower bkg level & better Neutral final state reconstruction (vs LHC)
    - Larger boost of b-hadrons (vs B-factory)
    - Complementary with B-factory in
      - extracting S_{CP}^{00}
      - reducing mirror solutions in α
  - Tera-Z precisions

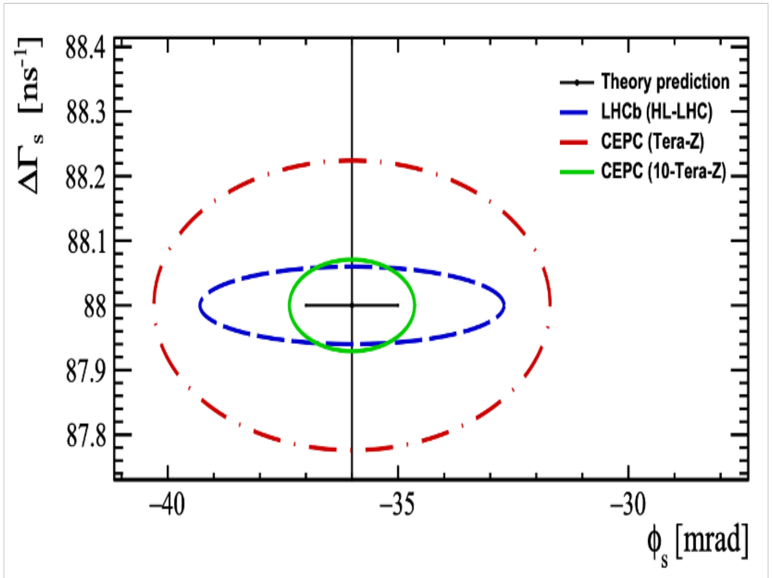
Parameters	Tera-Z Projection
$\sigma_{\mathcal{B}^{00}}/\mathcal{B}^{00}$	0.45%
$\sigma_{\mathcal{B}^{+0}}/\mathcal{B}^{+0}$	0.19%
$\sigma_{\mathcal{B}^{+-}}/\mathcal{B}^{+-}$	0.18%
$\sigma_{a_{CP}^{00}}$	$\pm$ (0.014–0.018)
$\sigma_{C_{CP}^{+-}}$	$\pm$ (0.004–0.005)
$\sigma_{S_{CP}^{+-}}$	$\pm$ (0.004–0.005)

  - σ(α) ≈ 0.4°
  - Prospects
    - Direct extraction of $S_{\pi\pi}^{00}$ via π^0 Dalitz decay or photon conversion

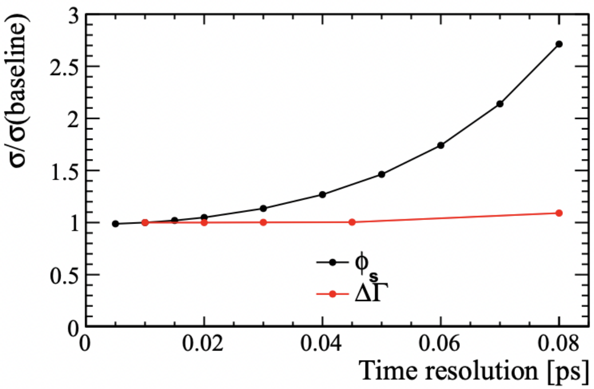


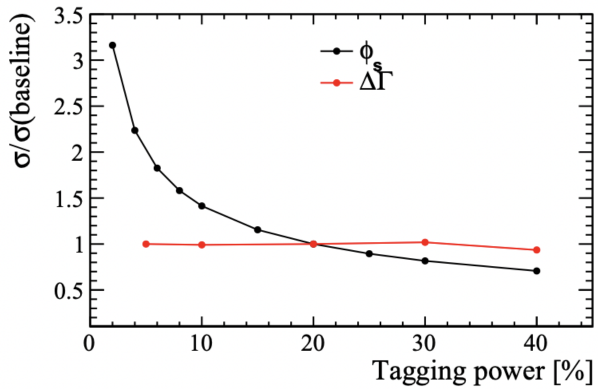


Bs→J/ψϕ



	LHCb(HL-LHC)	CEPC(Tera-Z)	CEPC/LHCb
$b\bar{b}$ statics	43.2×10^{12}	0.152×10^{12}	1/284
Acceptance×efficiency	7%	75%	10.7
Br	6×10^{-6}	12×10^{-6}	2
Flavour tagging	4.7%	20%	4.3
Time resolution $(\exp(-\frac{1}{2}\Delta m_s^2 \sigma_t^2)^2)$	0.52	1	1.92
scaling factor ξ	0.0014	0.0019	0.8
$\sigma(\phi_s)$	3.3 mrad	4.3 mrad	

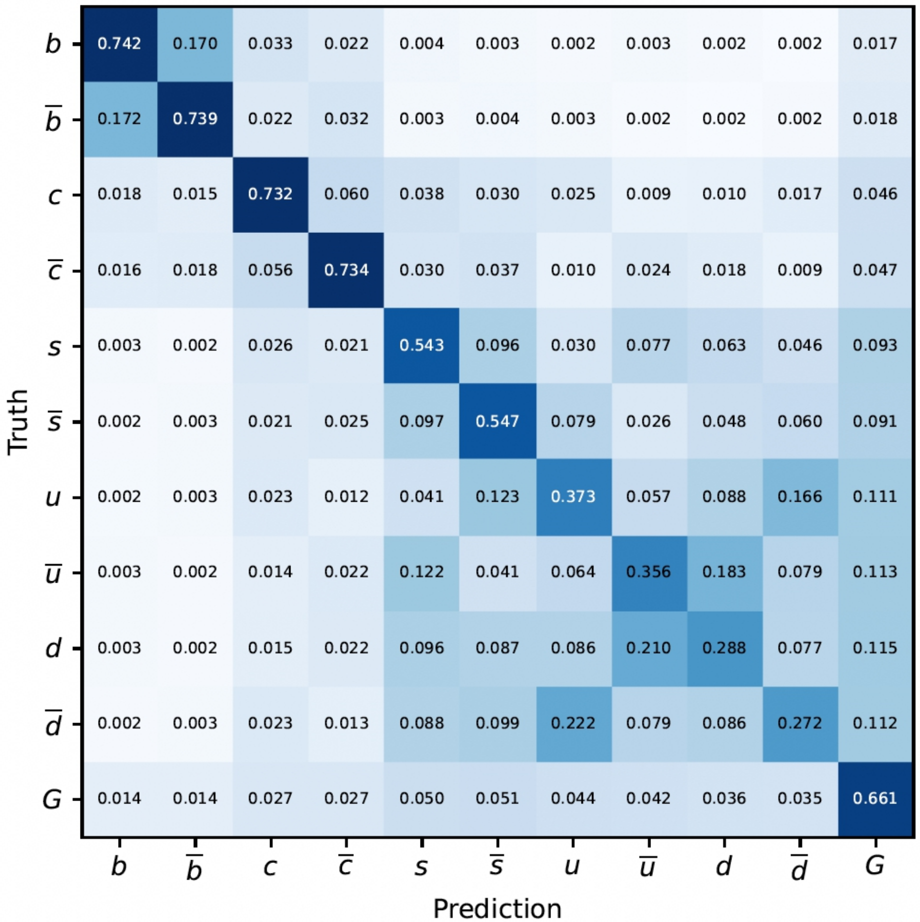


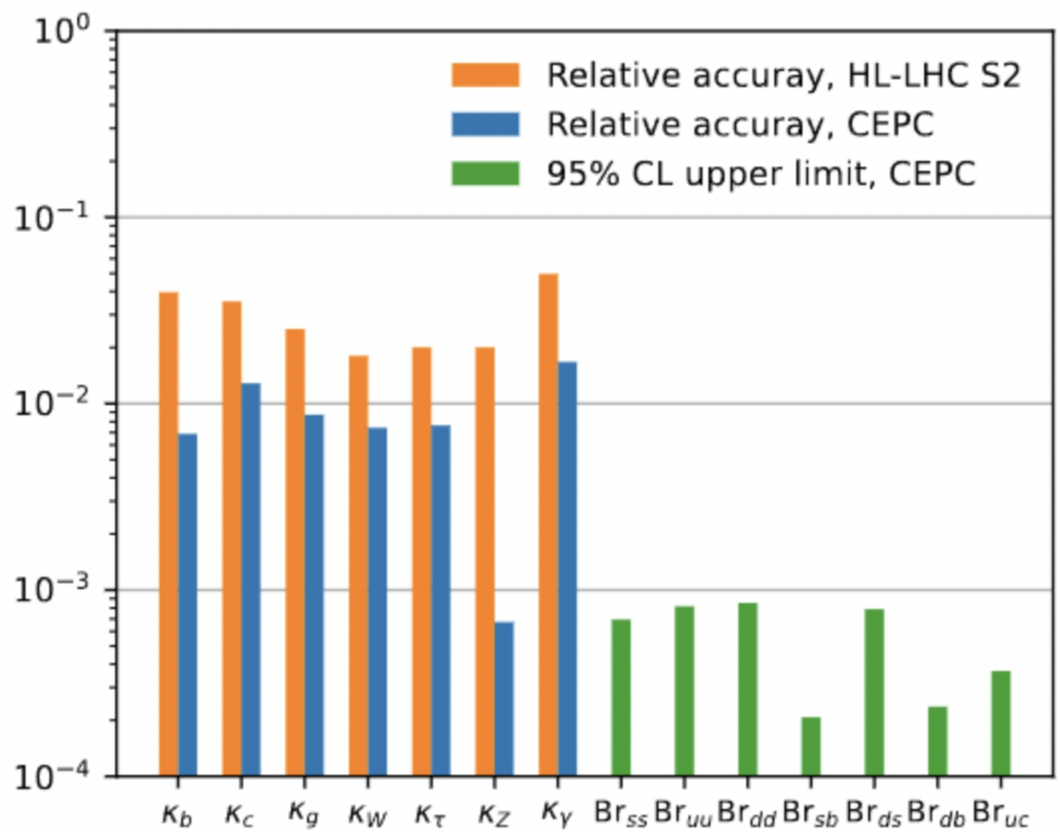


- $B_s \to J/\psi\phi \to \mu\mu KK$ [2205.10565]
  - $\phi_s = -2\beta_s$
  - $\sigma(\phi_s)$ = 4.3 mrad
  - $\sigma(\Delta\Gamma_s)$ = 0.24 ns^{-1}
  - $\sigma(\Gamma_s)$ = 0.072 ns^{-1}

Time resolution ~ o(10) fs

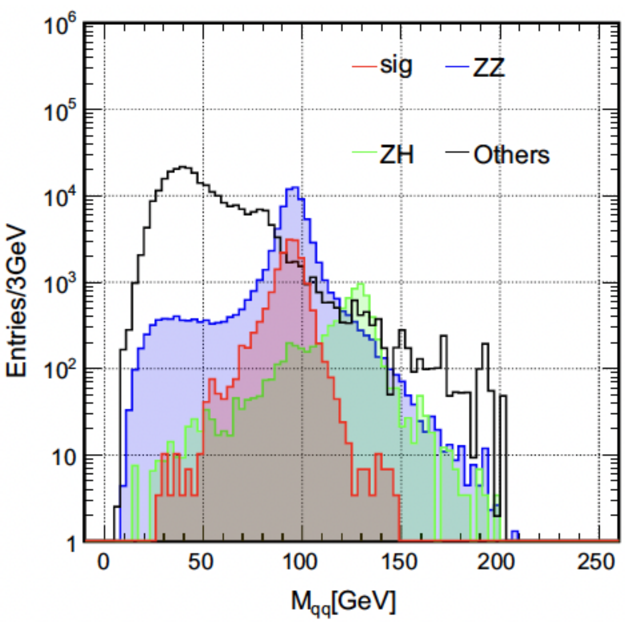
Jet origin id using Particle Net

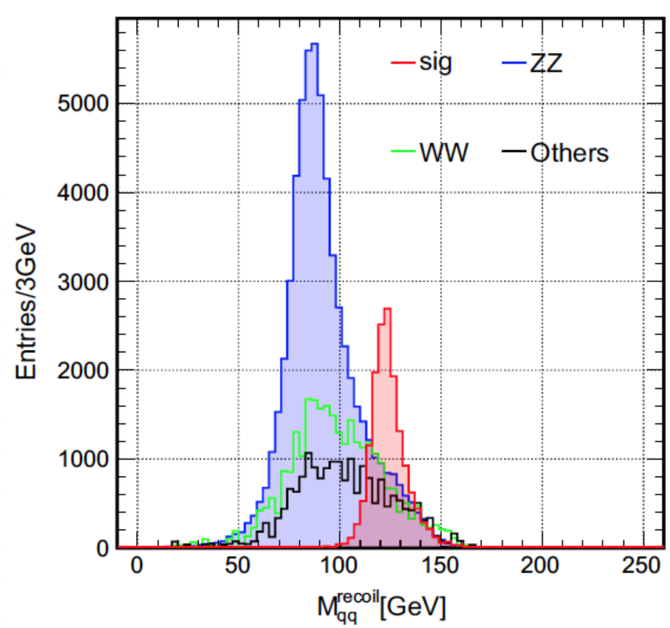




H → ss: be limited to 3*SM using vvH + llH at 20 iab

Higgs to di-tau measurements





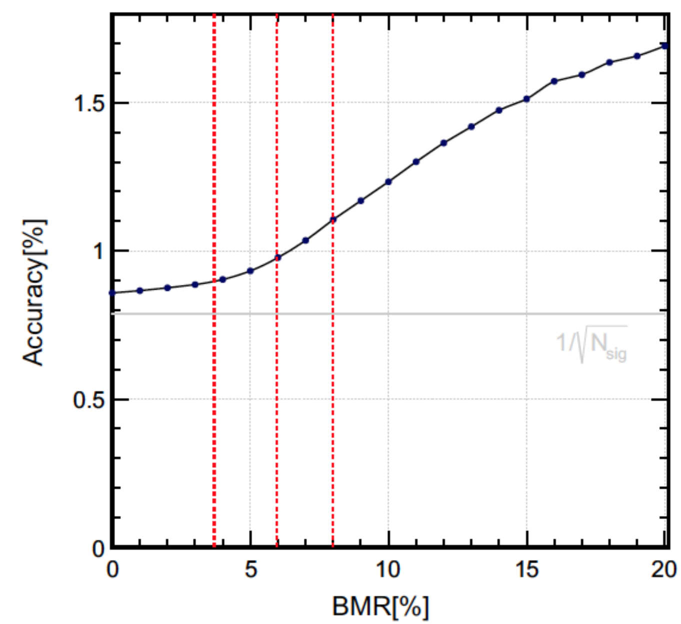


Table 8 Combined signal strength accuracy

	$\delta(\sigma \times BR)/(\sigma \times BR)$ (%)
$\mu\mu H$	2.8
eeH	5.1
$\nu\nu H$	7.9
qqH	0.9
Combined	0.8

Table 9 Extrapolated accuracy $\delta(\sigma \times BR)/(\sigma \times BR)$ 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

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

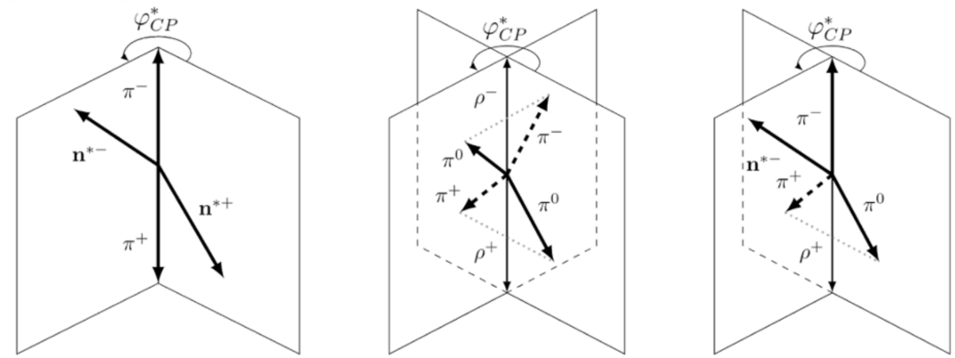
Dan Yu[1], Manqi Ruan[1,a], Vincent Boudry[2], Henri Videau[2], Jean-Claude Brient[2], Zhigang Wu[1], Qun Ouyang[1], Yue Xu[3], Xin Chen[3]

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

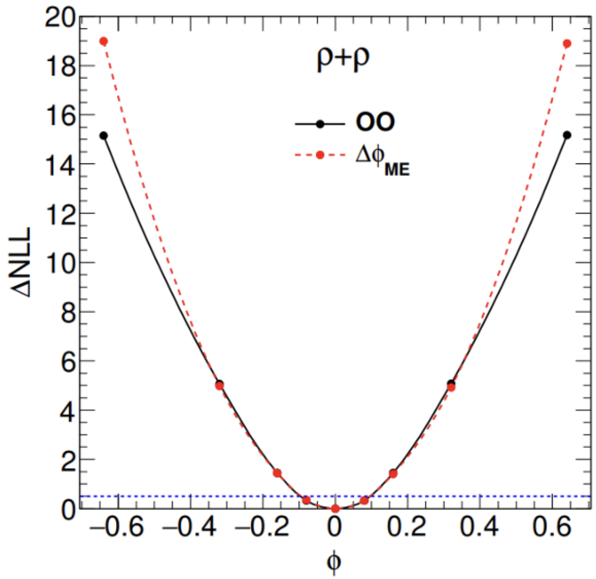
Received: 22 July 2019 / Accepted: 12 December 2019 / Published online: 3 January 2020

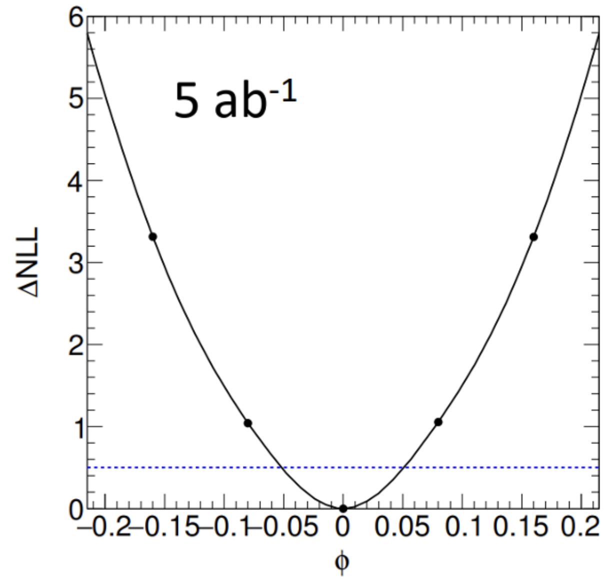
CP violation in Higgs sector

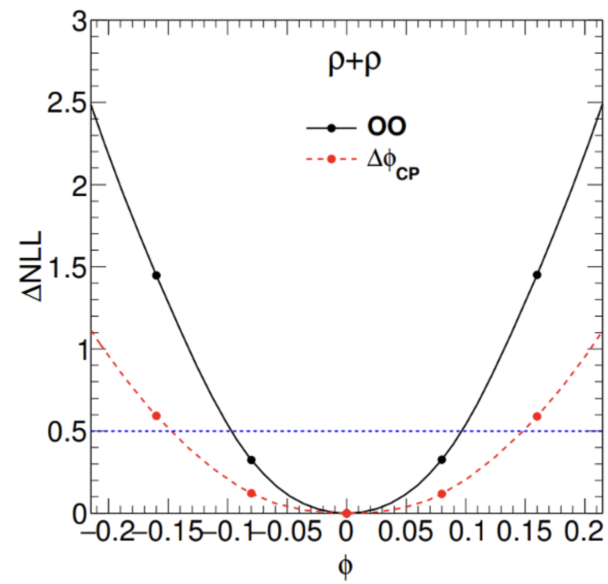
- $H \to \tau^+\tau^-$ [Y.C. Wu 2023]
  - With 5 (2) ab^{-1}, 2.9° (5.2°) can be reached



(a) $H \to \tau^+\tau^- \to \pi^+\pi^- + 2\nu$ (b) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\pi^0\nu$ (c) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\nu$





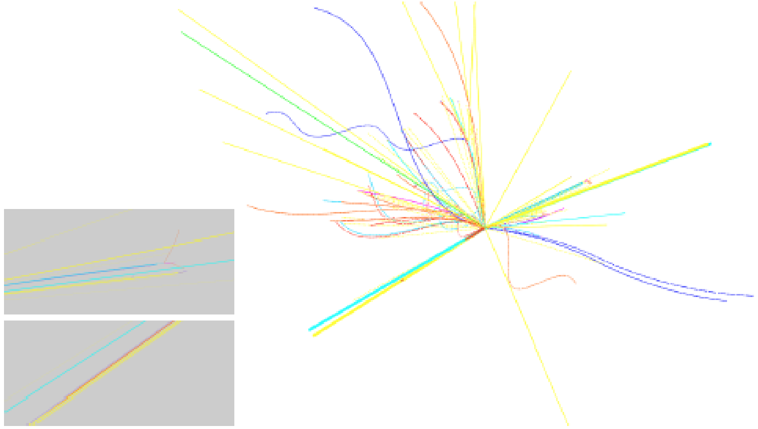


Summary

- CEPC, especially its Z pole operation, provide excellent opportunities for CPV
  - 1% level Vcb measurements;
  - Alpha angle be determined to 0.4 degree;
  - Comparable performance on Bs->J/psi Phi;
  - Higgs CP measurements;
  - ...
- Highly complementary to LHCb & B-factories
- PFA oriented detector design + Innovative algorithm leads to excellent detector performance, which is critical for CPV relevant measurements
  - PFA oriented design -> Object (Tau, lepton) finding inside Jet
  - Particle identification
  - Excellent EM resolution
  - Jet origin determination
- A lot more to explore

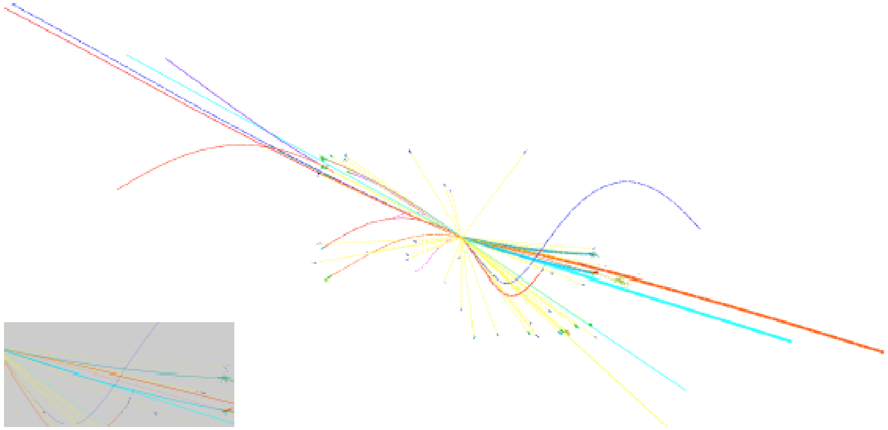
Backup

Taus: isolated or inside jets

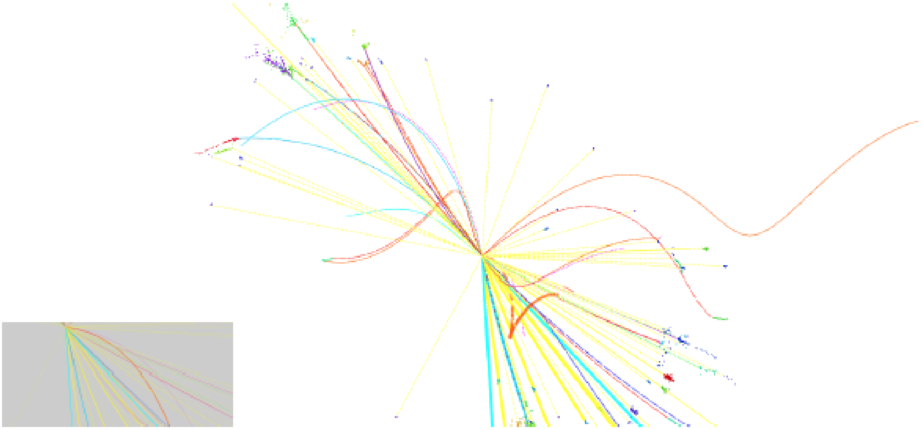


(a) $Z \to qq, H \to \tau\tau$ with two hadronic decay.

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

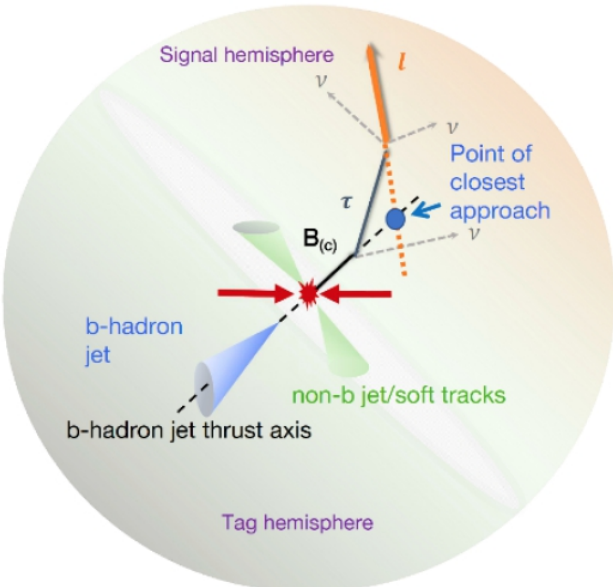


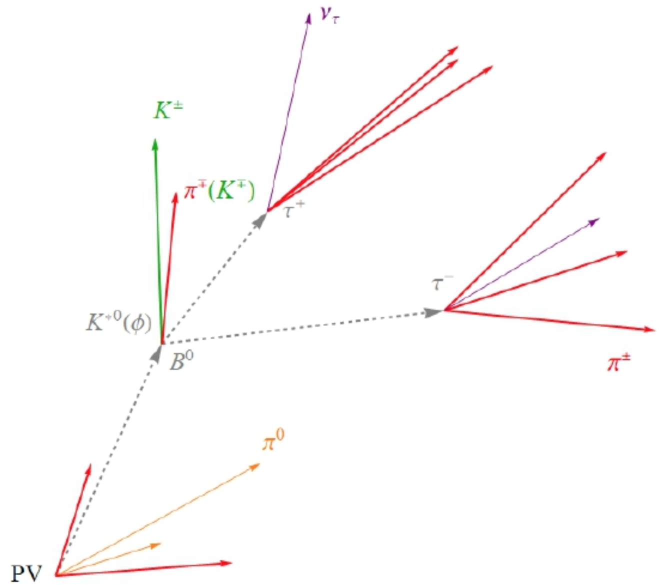
(c) $Z \to b\overline{b}, B_c \to \tau\nu$ with one hadronic dacay.

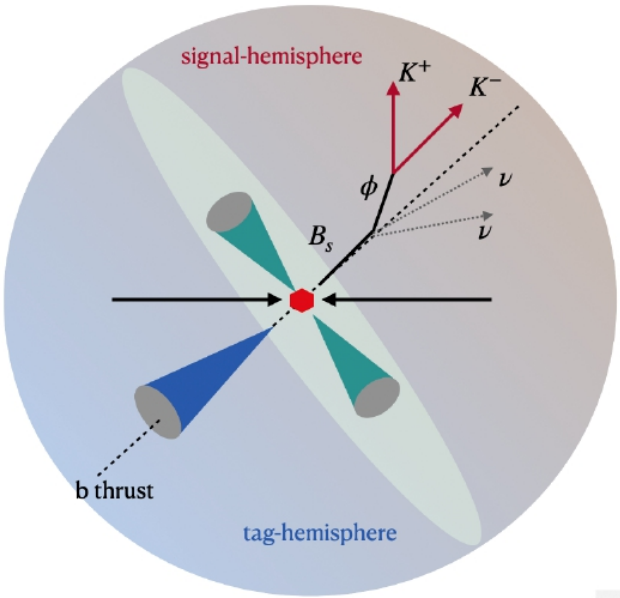


(d) $Z \to b\overline{b}, B_s \to \tau\tau$ with two hadronic decay mixed together.

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

Bs→Phi vv

https://arxiv.org/pdf/2201.07374.pdf

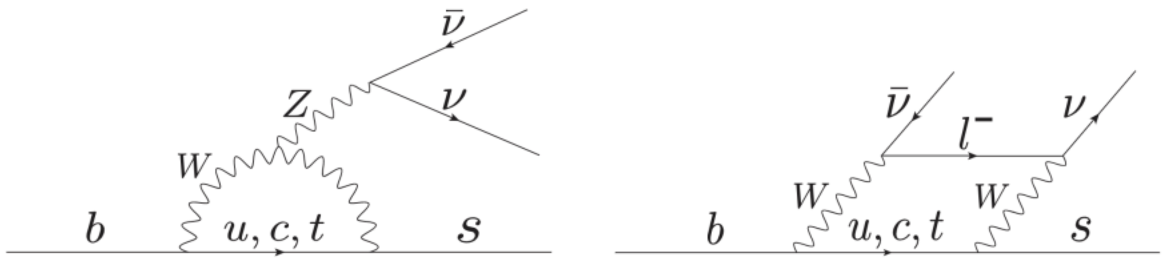
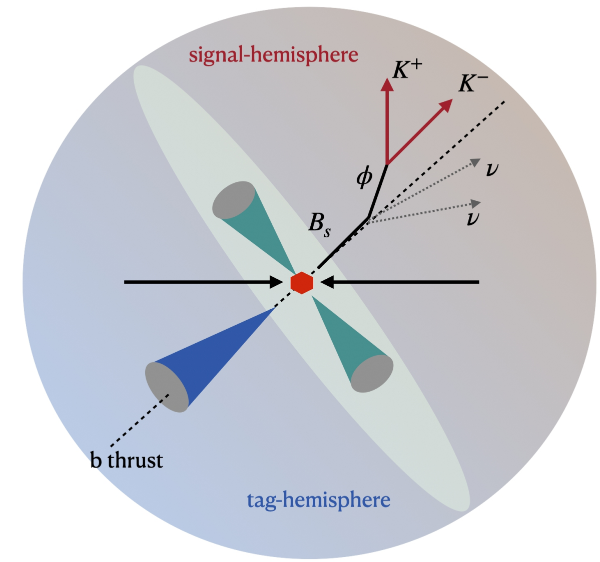
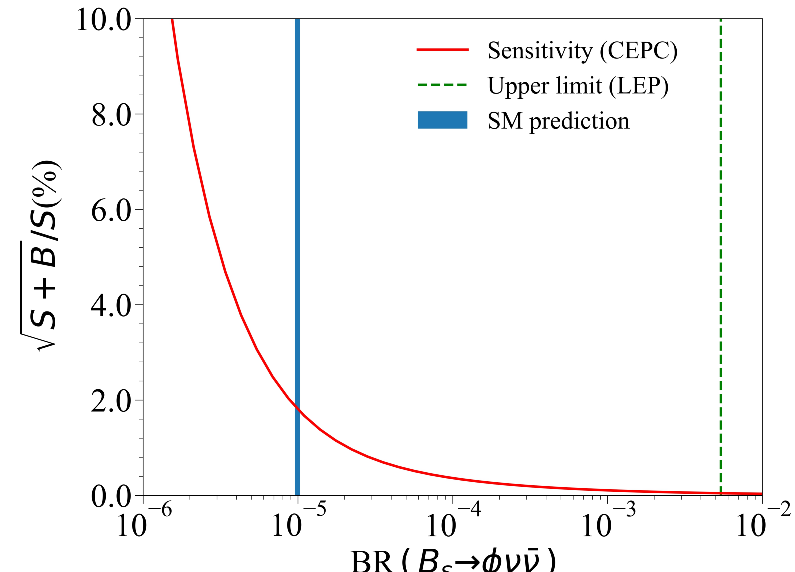


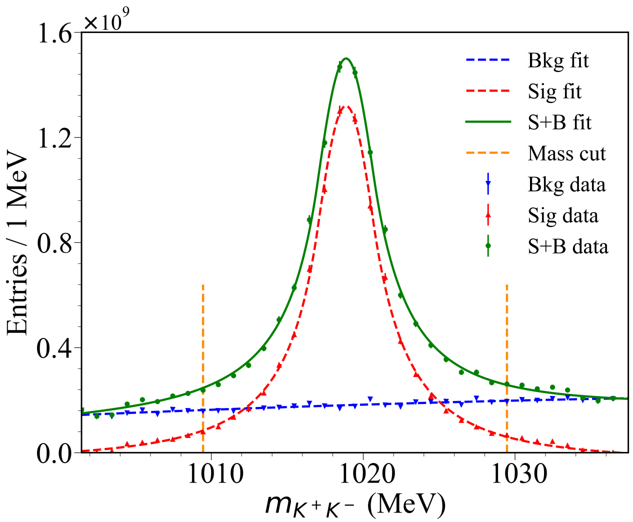
FIG. 1. The penguin and box diagrams of $b \to s\nu\bar{\nu}$ transition at the leading order.

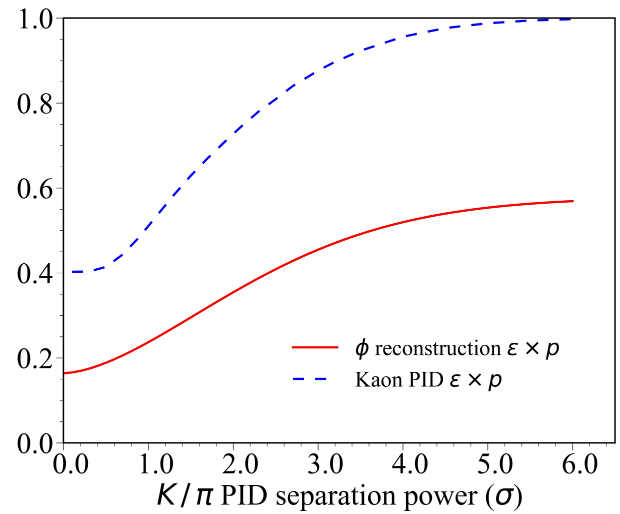


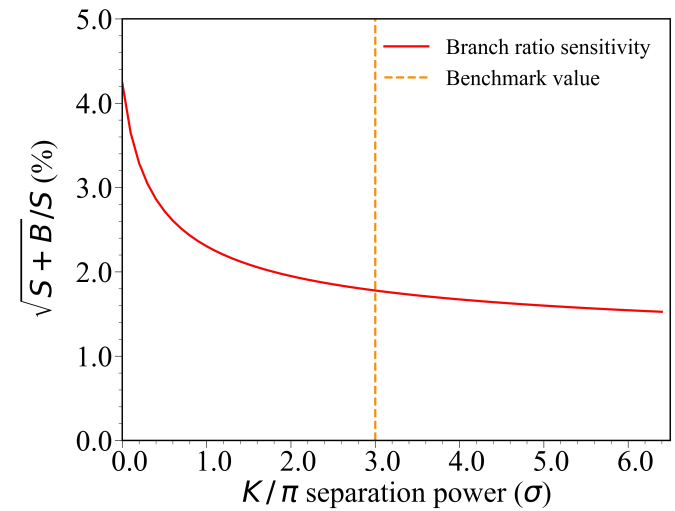
- Key ingredient to understand FCNC anomaly...
- Critical Physics Objects: Phi (and charged Kaon), 2nd VTX, Missing E/P, b-jet at opposite side
- Percentage level accuracy anticipated at Tera-Z

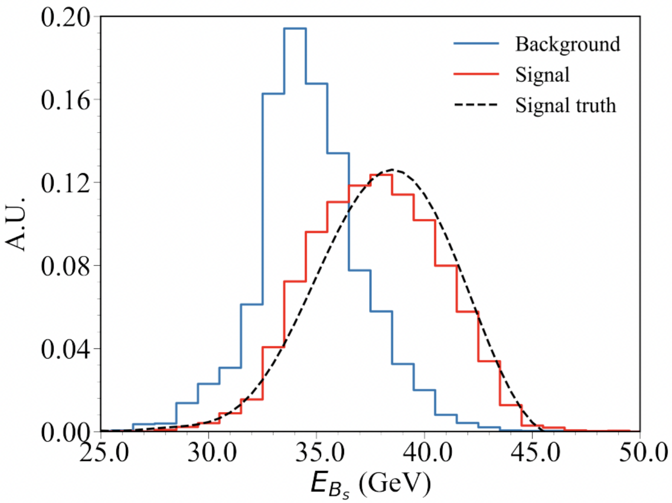


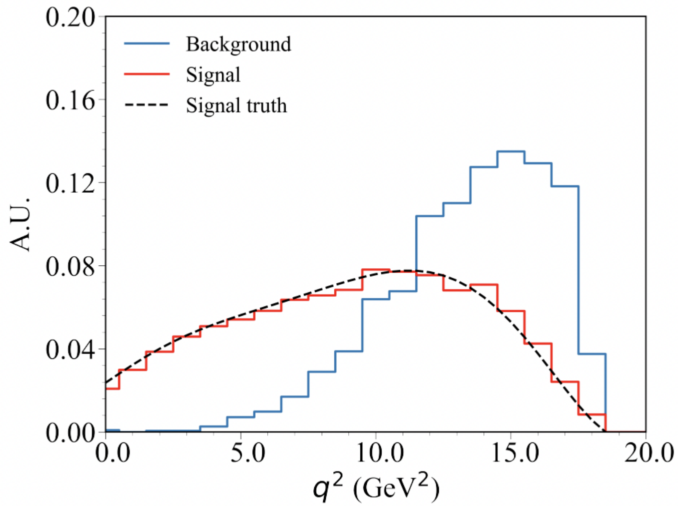
Bs→Phi νν











$$M_{\rm tag} = \sqrt{\left(\sum p_{\rm tag}^{\rm vis}\right)^2}\,,$$

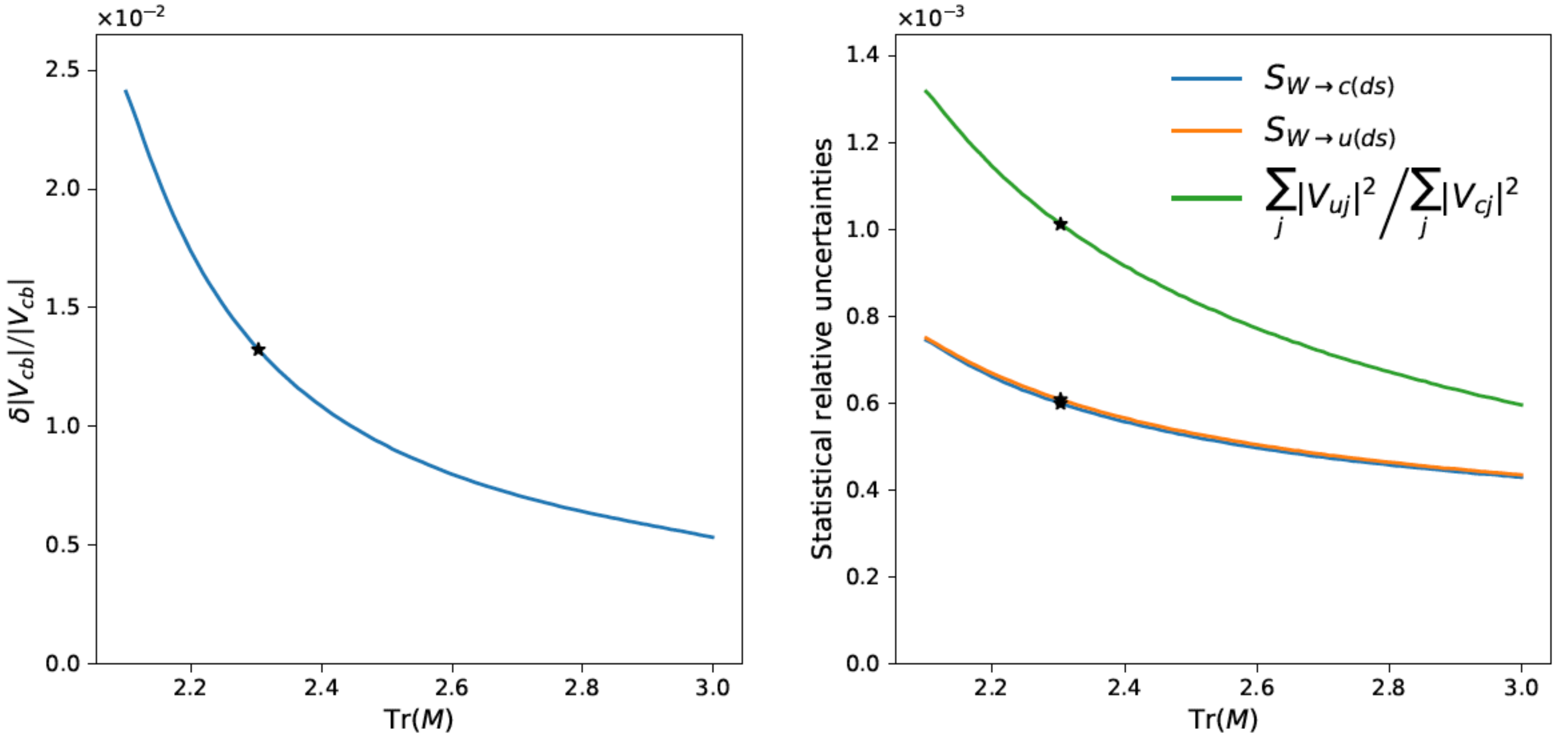
$$M_{\rm sig}^{(i)} = \sqrt{\left(\sum p_{\rm sig}^{\rm vis} + p_{B_s}^{(i-1)} - p_\phi\right)^2}\,,$$

$$E_{B_s}^{(i)} = \frac{s + (M_{\rm sig}^{(i-1)})^2 - M_{\rm tag}^2}{2\sqrt{s}} - E_{\rm sig} + E_\phi\,,$$

$$(q^2)^{(i)} = (p_{B_s}^{(i-1)} - p_\phi)^2\,,$$

The separation power is defined as $2|\mu_\pi - \mu_K|/(\sigma_\pi + \sigma_K)$. Without loss of generality, we set $\sigma_\pi = \sigma_K$. Com-

Vertex

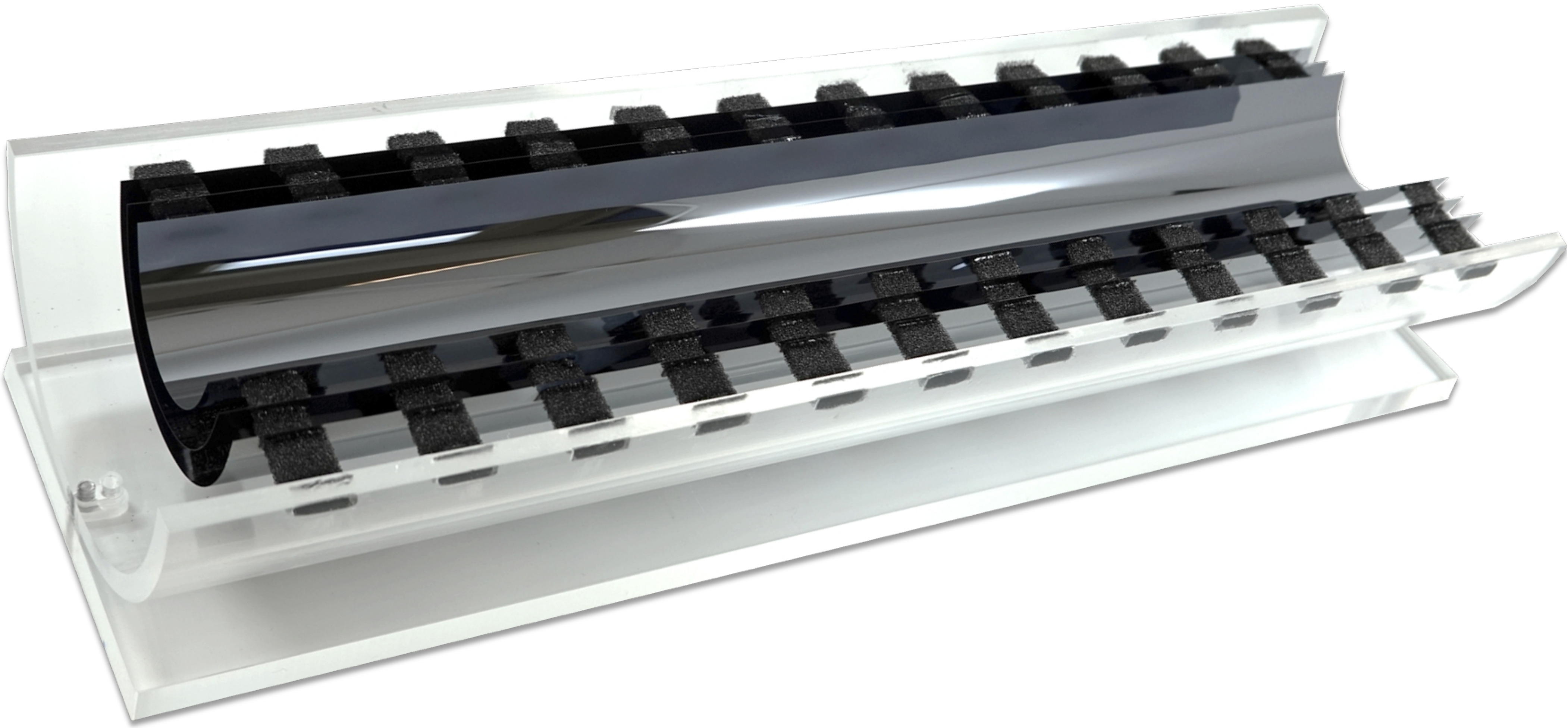


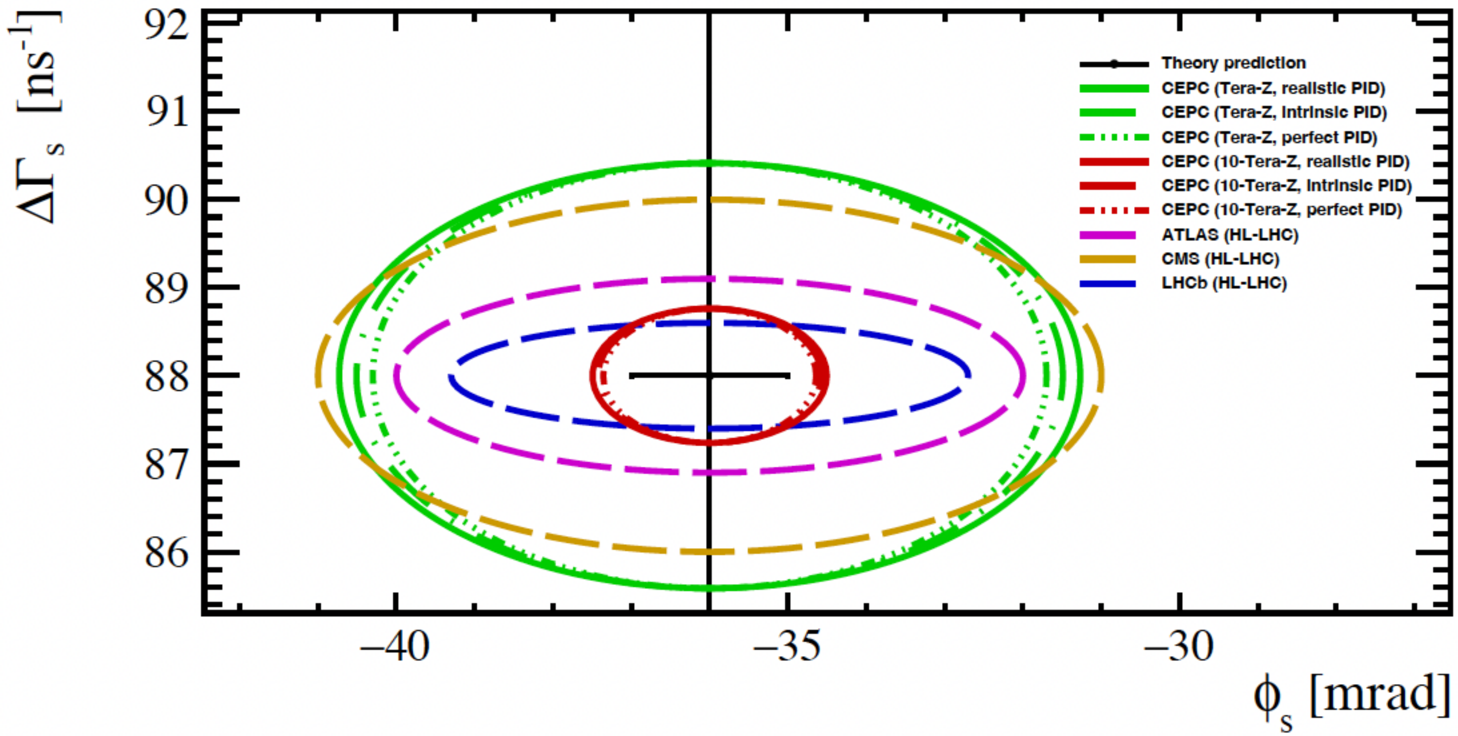
Similar performance dependence on CKM measurements at 240 GeV using semi-leptonic WW events

CPV relevant measurements

- Vcb:
  - Bc → tau v
  - W decay
- Bs → J/psi Phi
- Bs → 2 pi0, to determine alpha angle
- Bs → Phi vv
- Higgs measurements
- ...

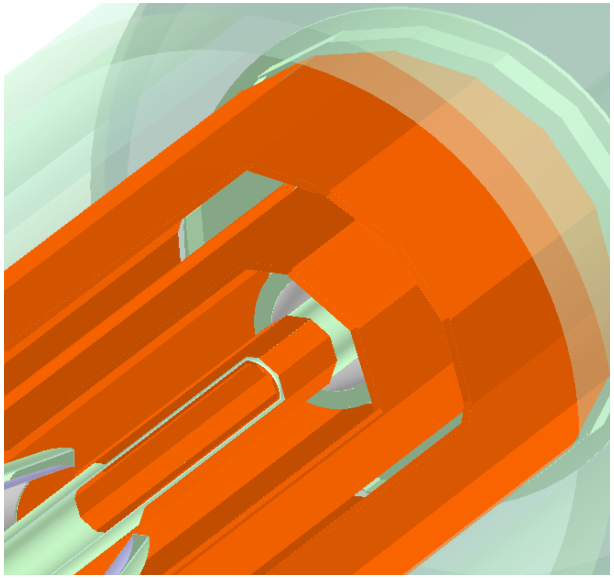
...ALICE ITS3...

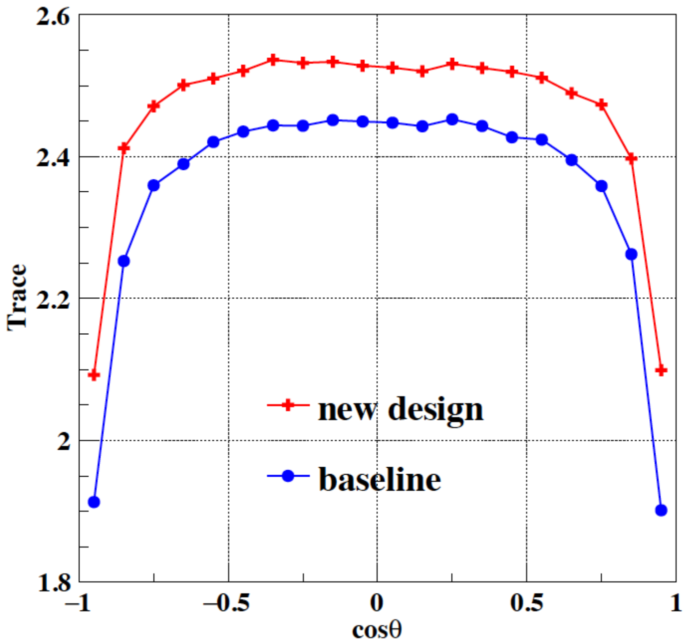



Theory prediction
CEPC (Tera-Z, realistic PID)
CEPC (Tera-Z, intrinsic PID)
CEPC (Tera-Z, perfect PID)
CEPC (10-Tera-Z, realistic PID)
CEPC (10-Tera-Z, intrinsic PID)
CEPC (10-Tera-Z, perfect PID)
ATLAS (HL-LHC)
CMS (HL-LHC)
LHCb (HL-LHC)
$\Delta\Gamma_s$ [ns^{-1}]
92
91
90
89
88
87
86
−40
−35
−30
ϕ_s [mrad]

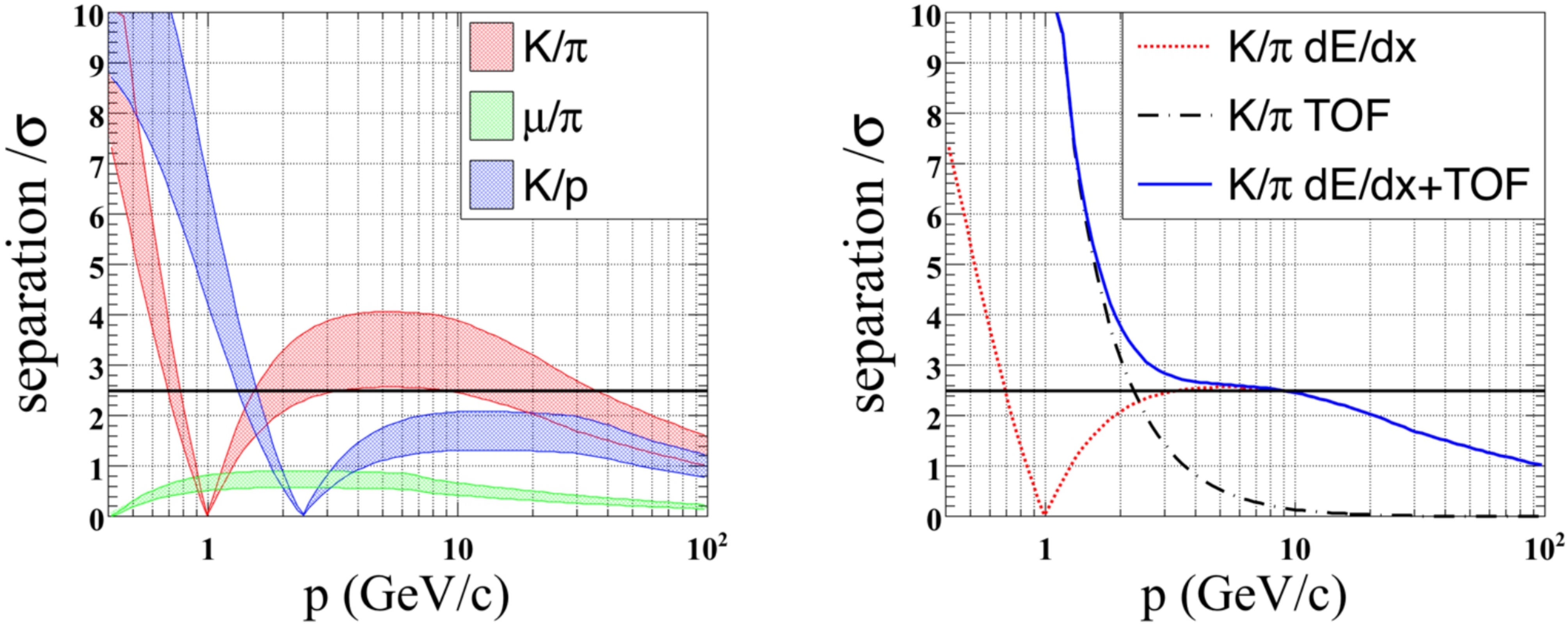
Vin

- Tr(MM) in the barrel
  - 2.45 for baseline (?)
  - 2.55 for 8 mm inner radius (9 mm)
- Compared to Baseline:
  - 10 mm beam pipe with silicon outside/inside improves the accuracy of g(Hcc) and |Vcb| measurement by ~20%
- Vin:
  - Pro:
    - Closer to the IP with same beam pipe radius
    - No multiple scattering to the 1st layer
    - Loose the material constrain of beam pipe: more efficient cooling, etc
  - Challenges:
    - Vacuum level
    - Radiation tolerance
    - Power & Signal → Wireless?





Kaon

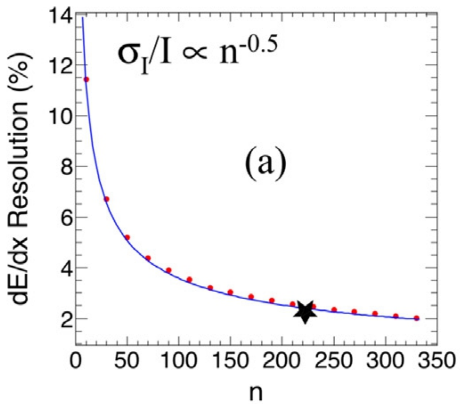


Highly appreciated in flavor physics @ CEPC Z pole
TPC dEdx + ToF of 50 ps

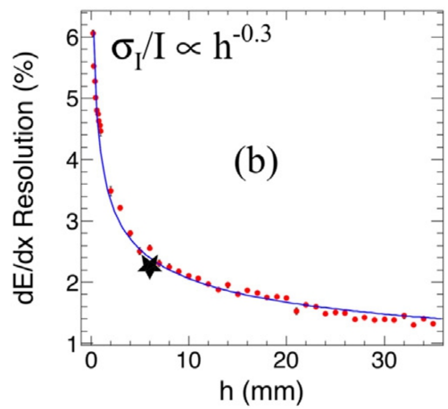
At inclusive Z pole sample:
- Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
- Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

Eur. Phys. J. C (2018) 78:464

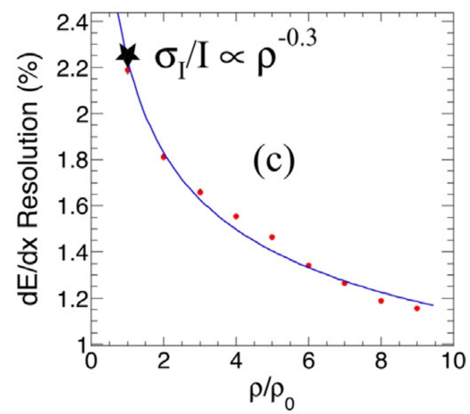
Dedx at truth level: Differential



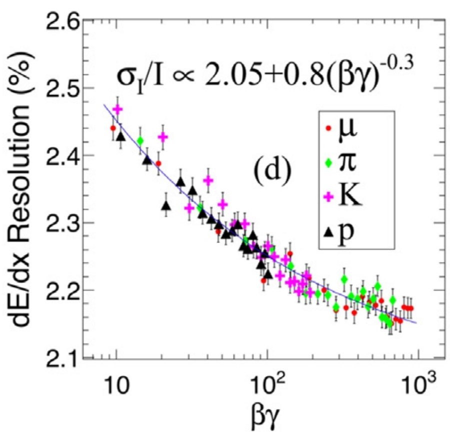
(a)



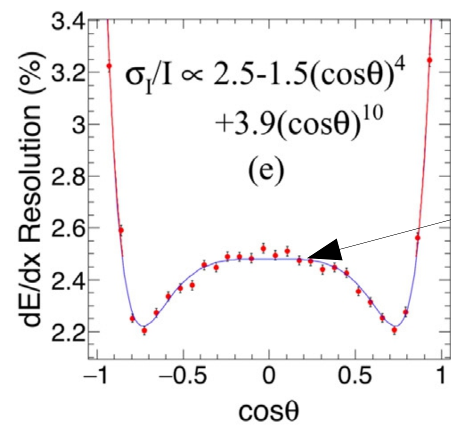
(b)



(c)



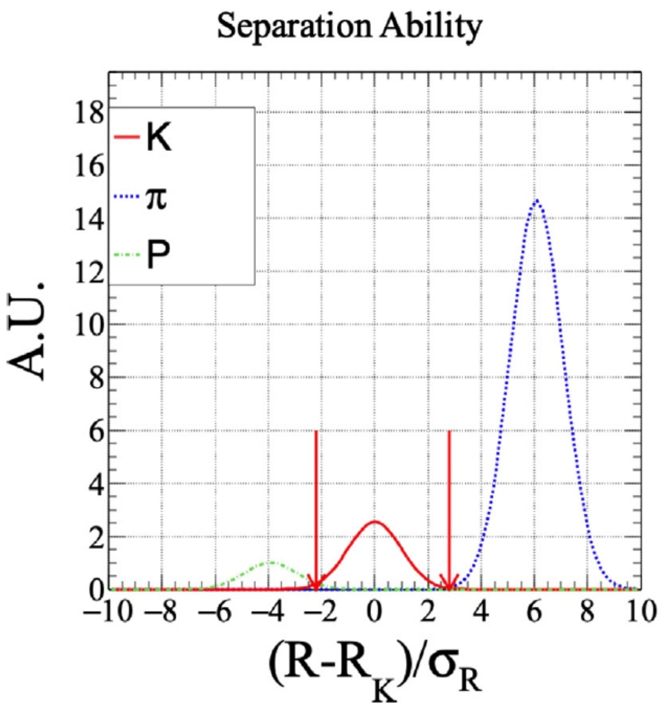
(d)

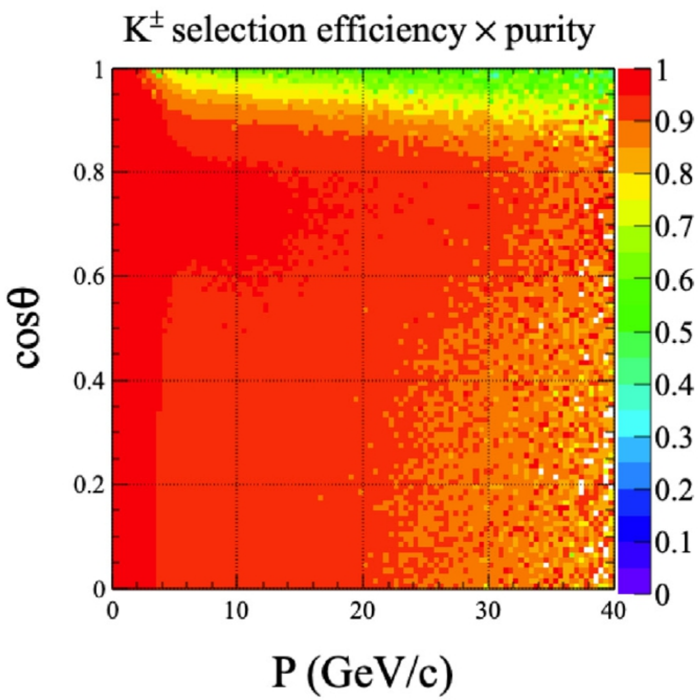


(e)

2.5% relative accuracy of dE/dx at truth level, in barrel

Pid performance



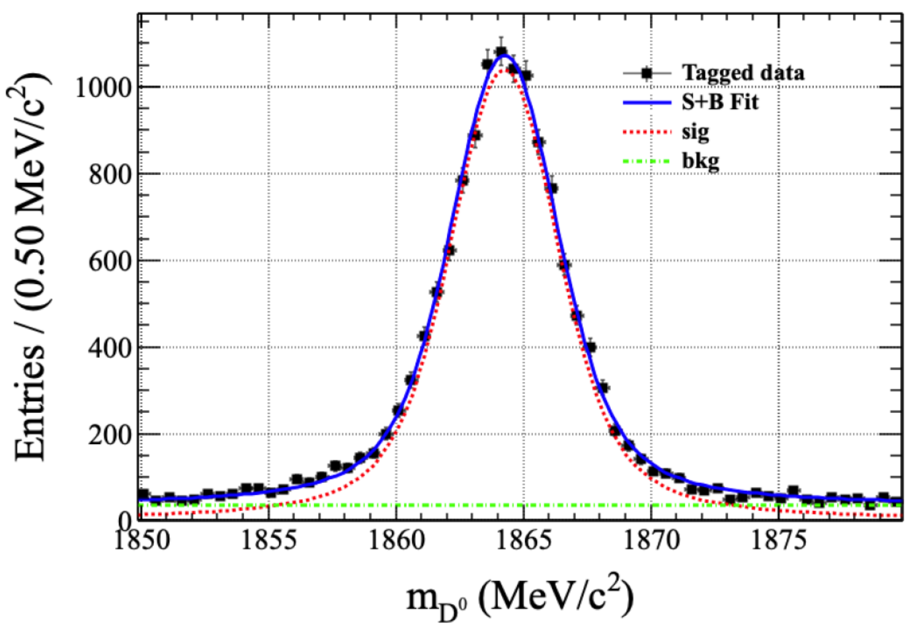


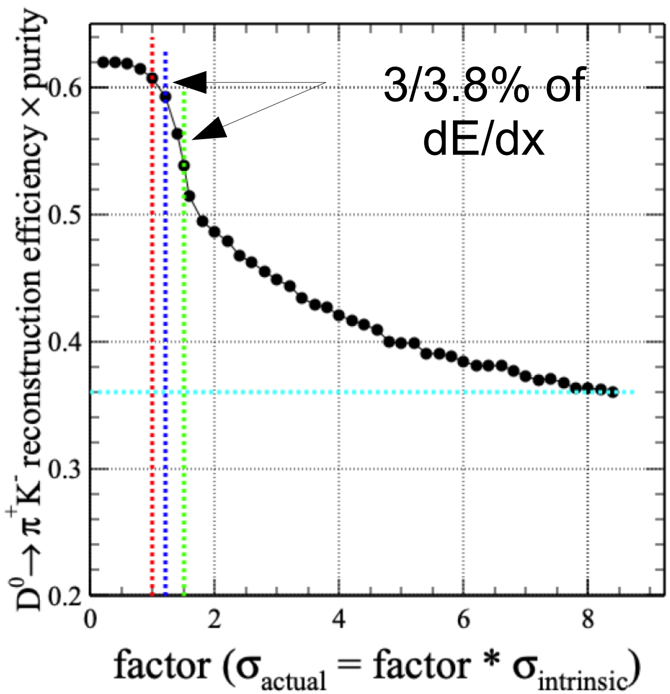
	factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ε_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

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

$D^0 \to \pi^+ K^-$ reconstruction

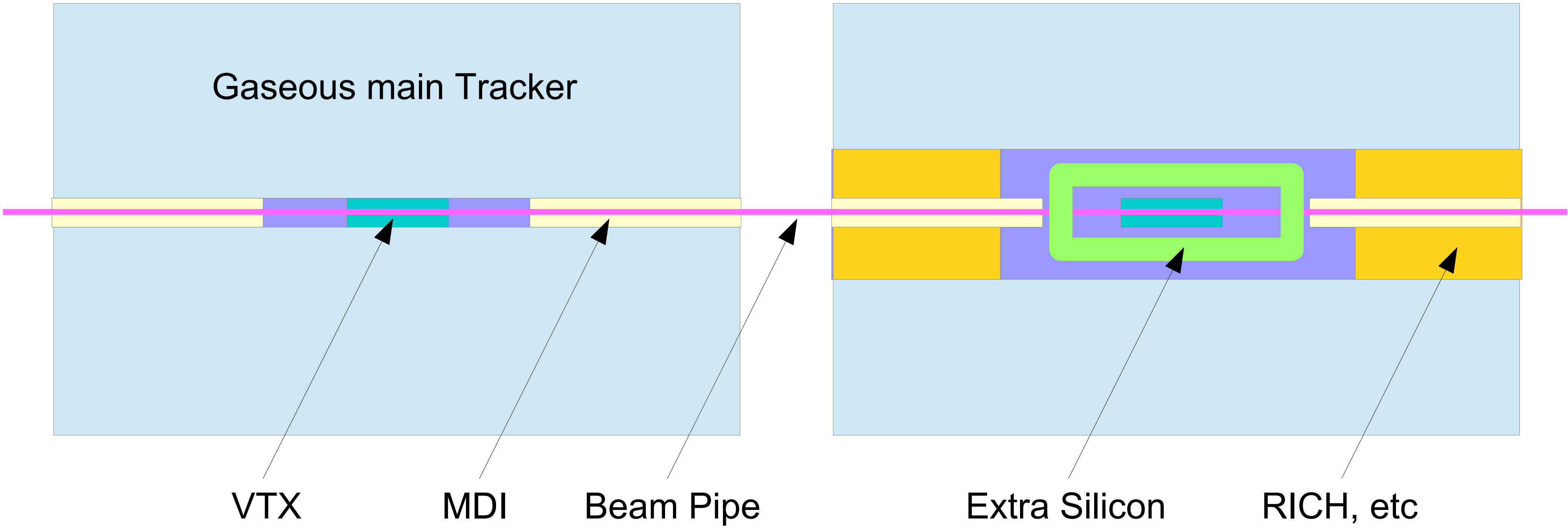
	ϵ (%)	p (%)
$\|mass - mass_{D0}\| < 0.01\, GeV/c^2$	90.39	2.16
IMP $> 0.02\, mm^2$	79.12	5.04
vertex fitted $\chi^2 < 5.15$	72.62	15.36
dis of vertex to IP $> 0.305\, mm$	69.24	28.41
PID	68.19	89.05





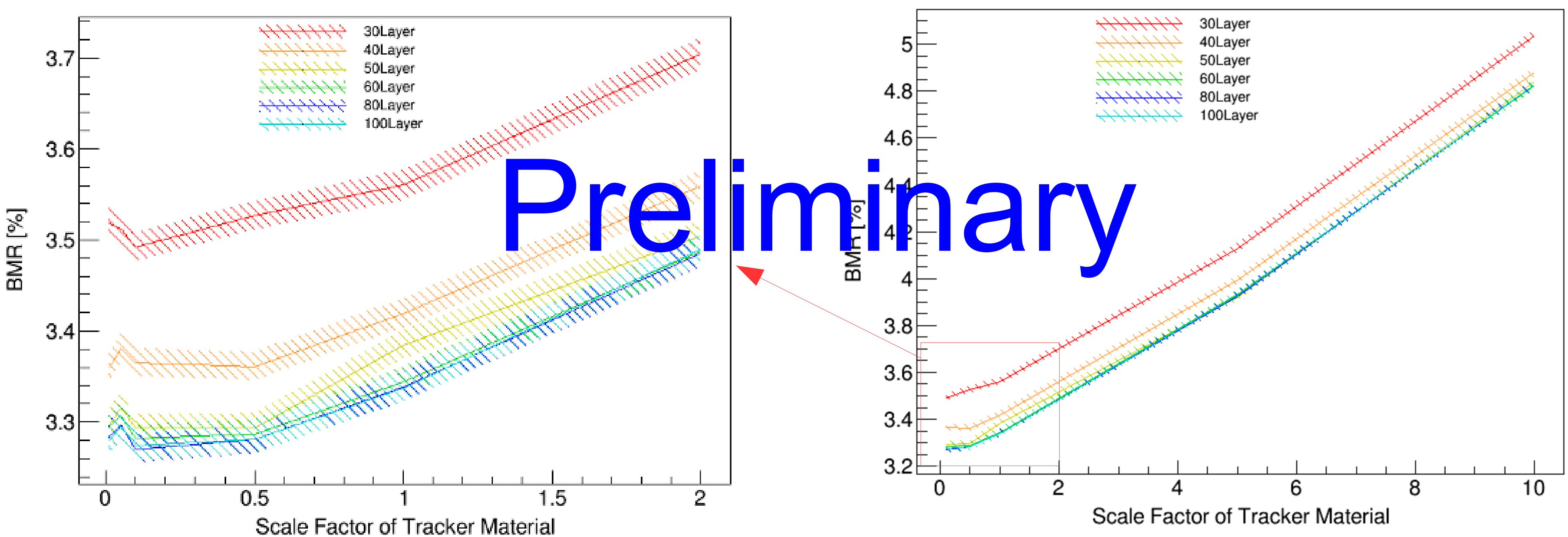
fitted mass : $1864.259 \pm 0.025\, \mathrm{MeV/c^2}$

2.5 Tracker Scenarios

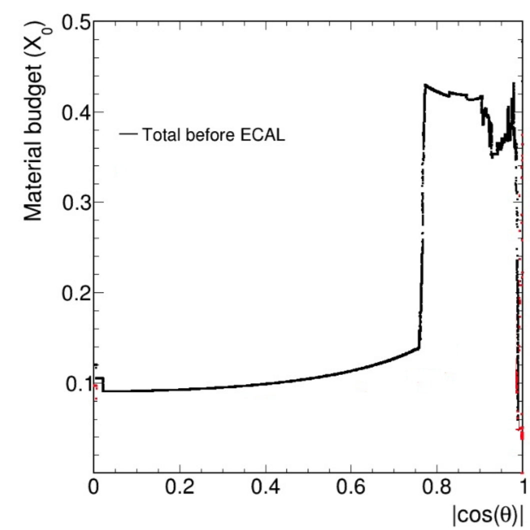


- Our understanding to Beam background & MDI design not fully converged
  - Beamstrahlung background seems to be very challenge to gaseous tracker
- I will discuss mainly the 1st scenario (Left)：
  - Tracker inner radius of 25 cm to have good Pid in fwd region
- The 2.5 scenario: Silicon Tracker with Pid (like AMS, with much better precision...)

BMR VS upstream material



- Baseline: 10% X0 material in the barrel region.
- Would be great to half the upstream material.



Kshort & Lambda

Eur. Phys. J. Plus (2020) 135:274
https://doi.org/10.1140/epjp/s13360-020-00272-4

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Check for updates

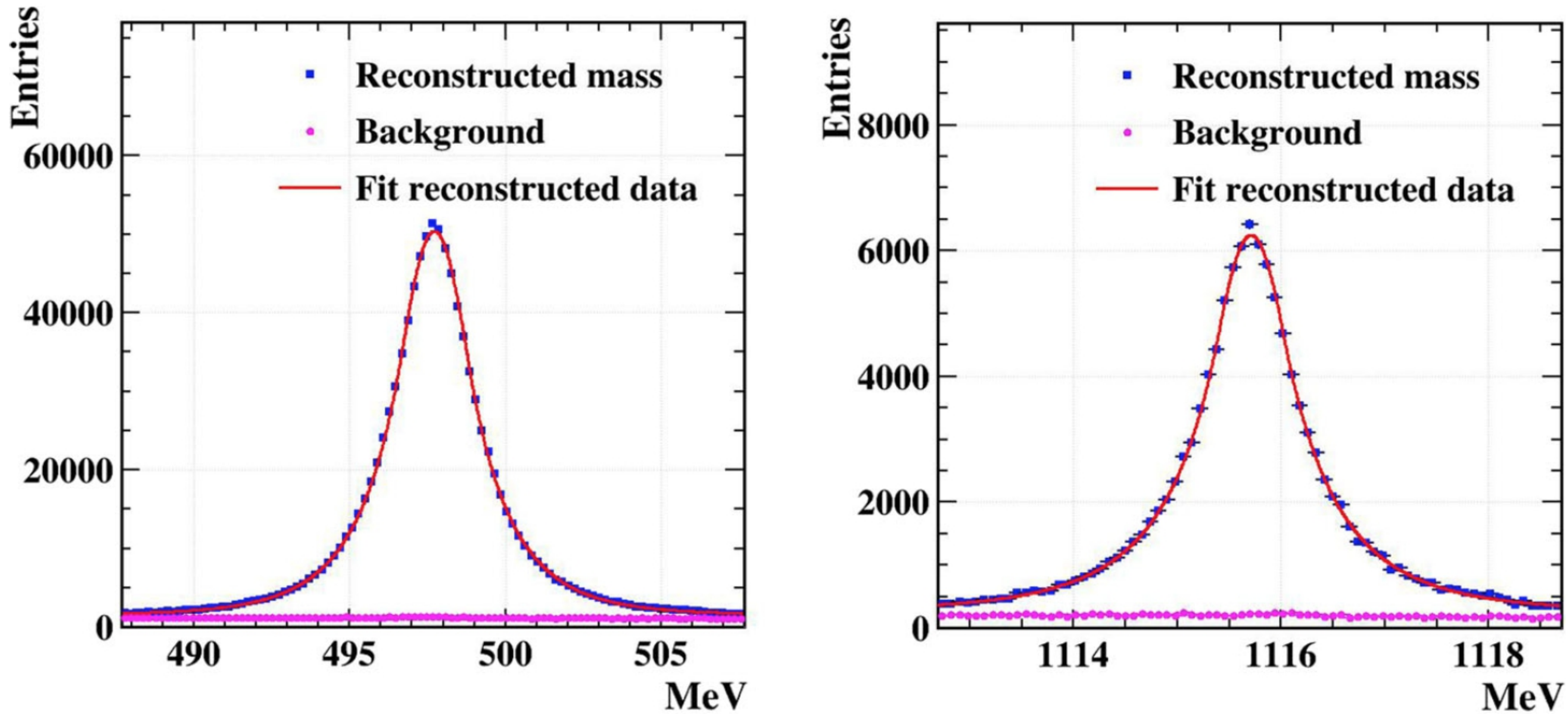
Reconstructing K_S^0 and Λ in the CEPC baseline detector

Taifan Zheng[1], Jike Wang[2], Yuqiao Shen[3], Yeuk-Kwan E. Cheung[1], Manqi Ruan[4,a]

[1] School of Physics, Nanjing University, Nanjing, China
[2] The Institute for Advanced Studies, Wuhan University, Wuhan, China
[3] Changzhou Institute of Technology, Changzhou, Jiangsu, China
[4] Institute of High Energy Physics, Beijing, China

Kshort & Lambda

Eur. Phys. J. Plus (2020) 135:274 Page 9 of 14 274



(a) K_S^0 **(b)** Λ

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

Kshort & Lambda

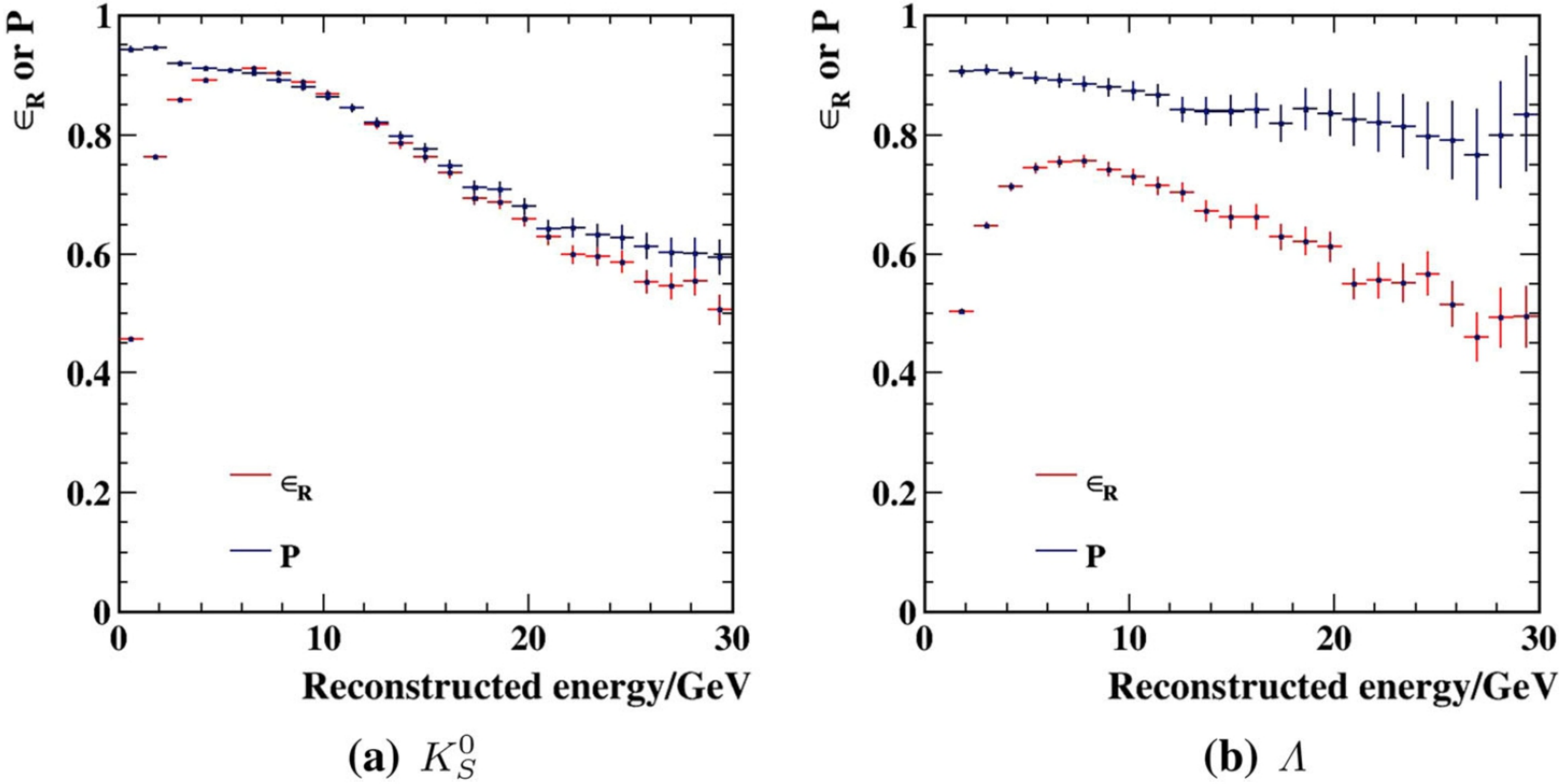


Fig. 9 Energy dependence of ϵ_R and P

Kshort & Lambda

Table 3 K_S^0 and Λ reconstruction performance

Particle	K_S^0 (%)	Λ (%)
ϵ_R	81.3	70.1
ϵ_T	40.6	27.3
P	92.4%	86.4%
$\epsilon_R \cdot P$	0.751	0.606
$\epsilon_T \cdot P$	0.375	0.236

Table 4 Estimation of K_S^0 and Λ reconstruction performance assuming ideal PID

Particle	K_S^0	Λ
ϵ_R	82.4%	89.1%
ϵ_T	41.2%	34.7%
P	97.2%	94.6%
$\epsilon_R \cdot P$	0.801	0.843
$\epsilon_T \cdot P$	0.400	0.327

eff_T = eff_R*Br(X->all tracks)

Yields ~ Xsec * Lumi