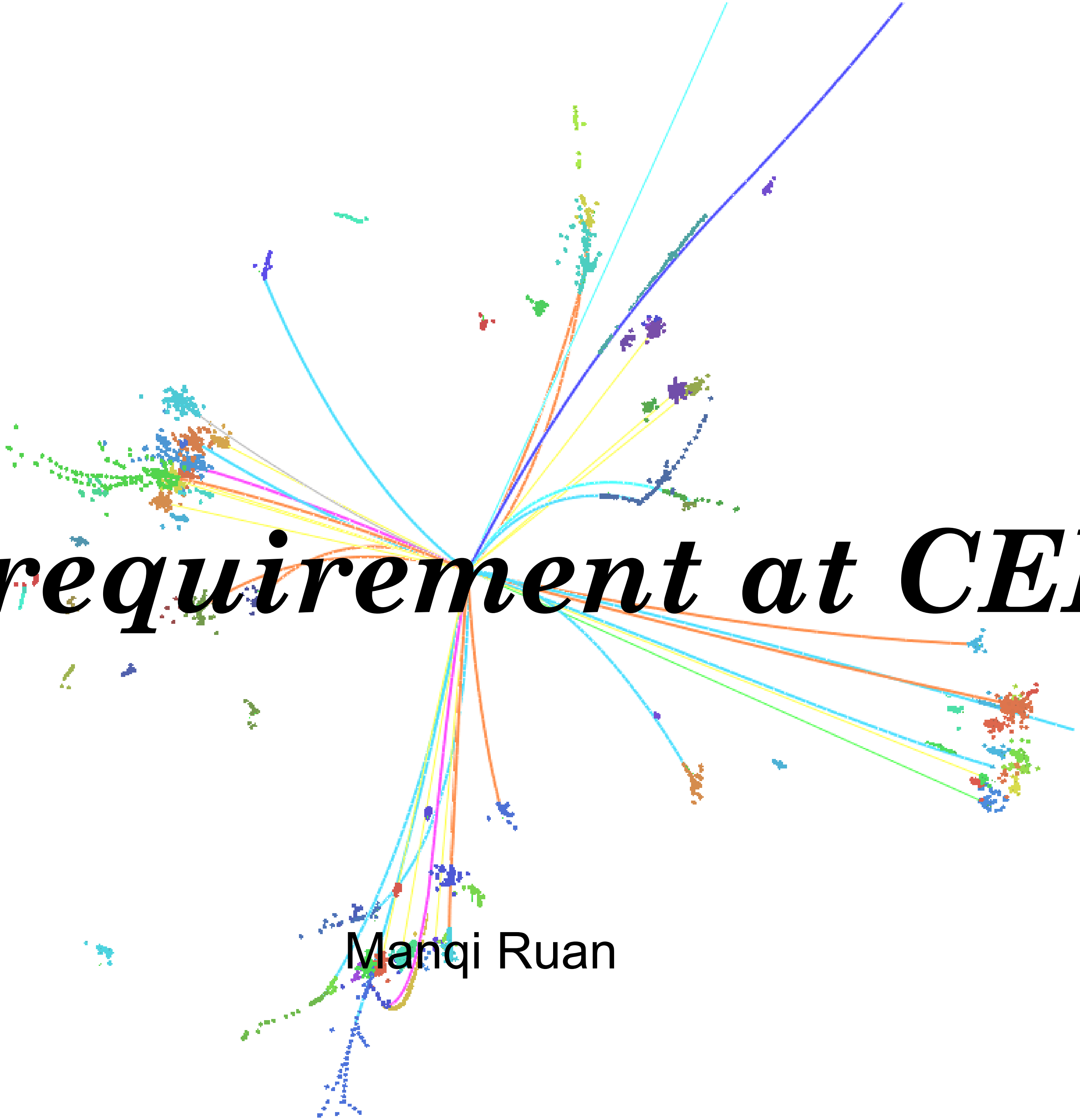
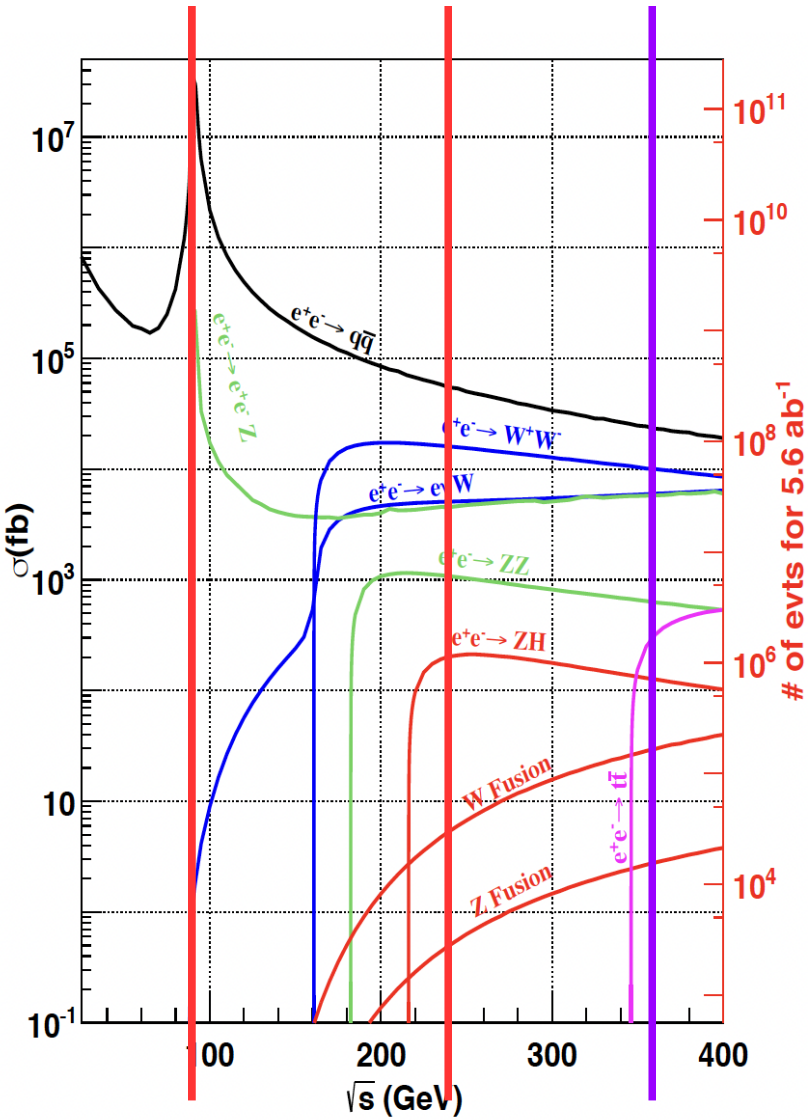
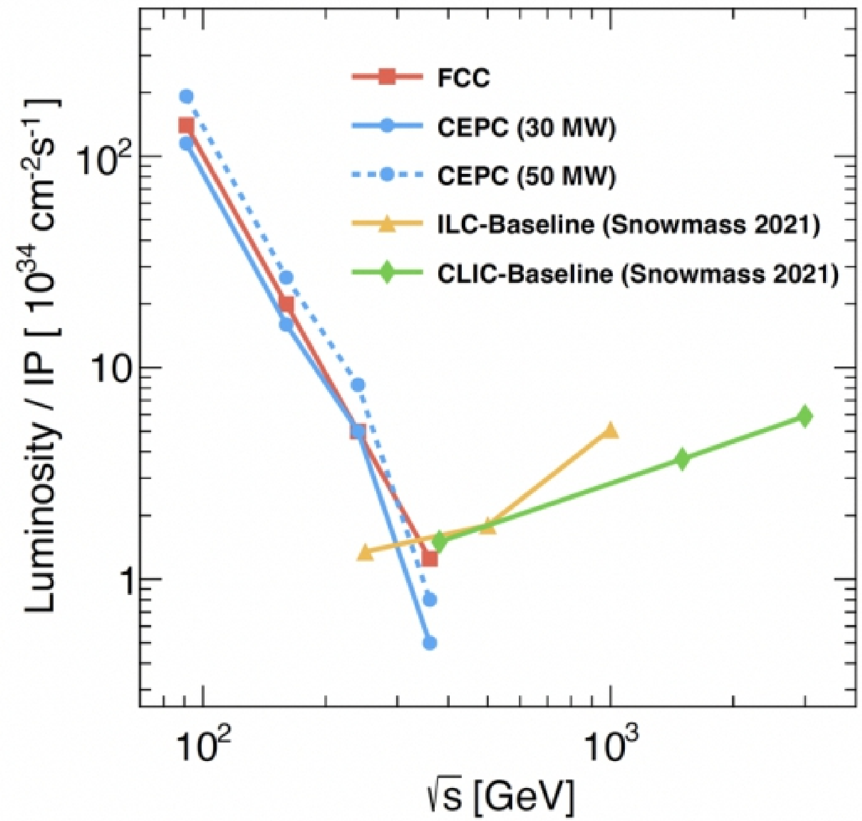
Pid requirement at CEPC



Manqi Ruan

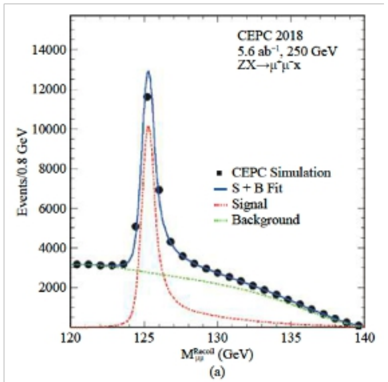
Yields ~ Xsec * Lumi * Time

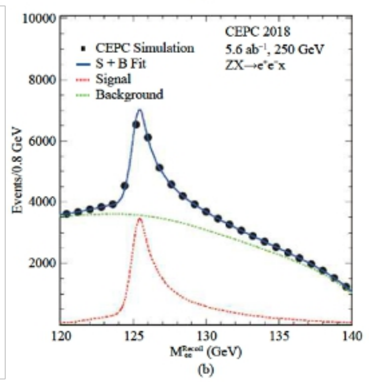


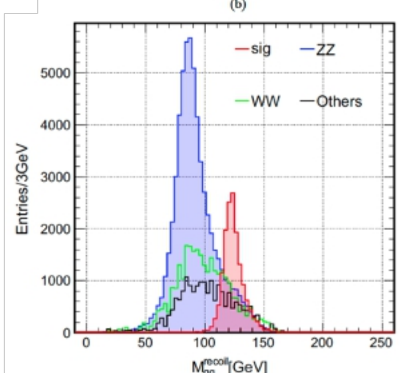


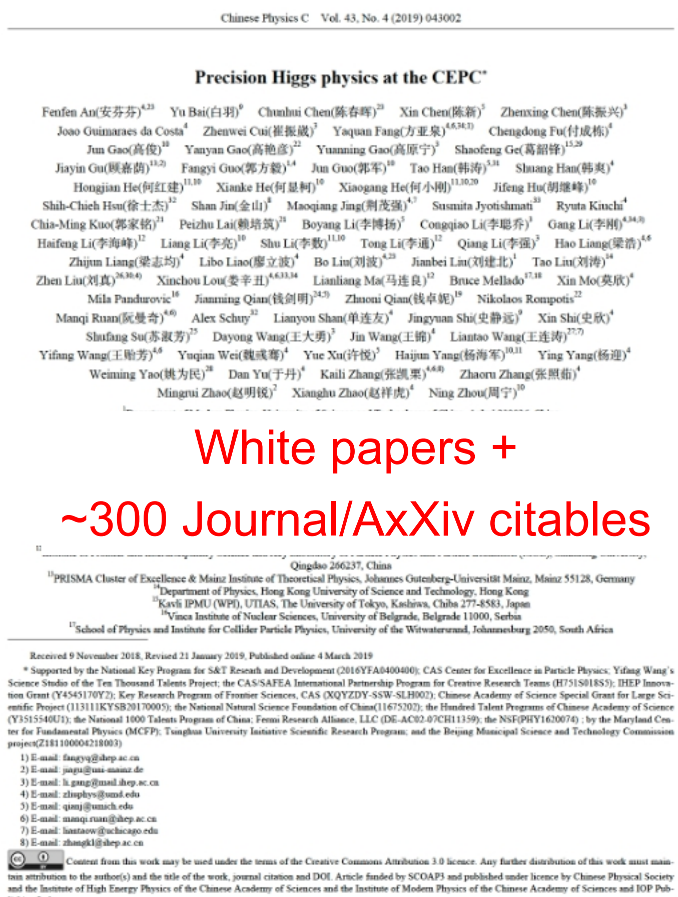
- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

CEPC Physics study








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

Precision Higgs physics at the CEPC*

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

White papers +

~300 Journal/AxXiv citables

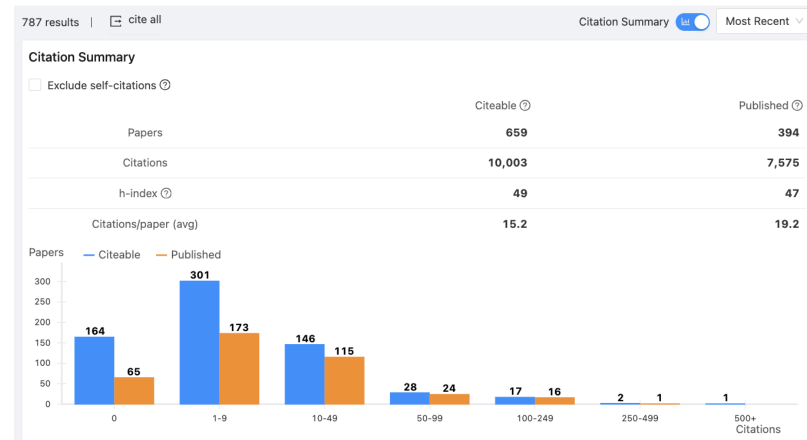


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

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}

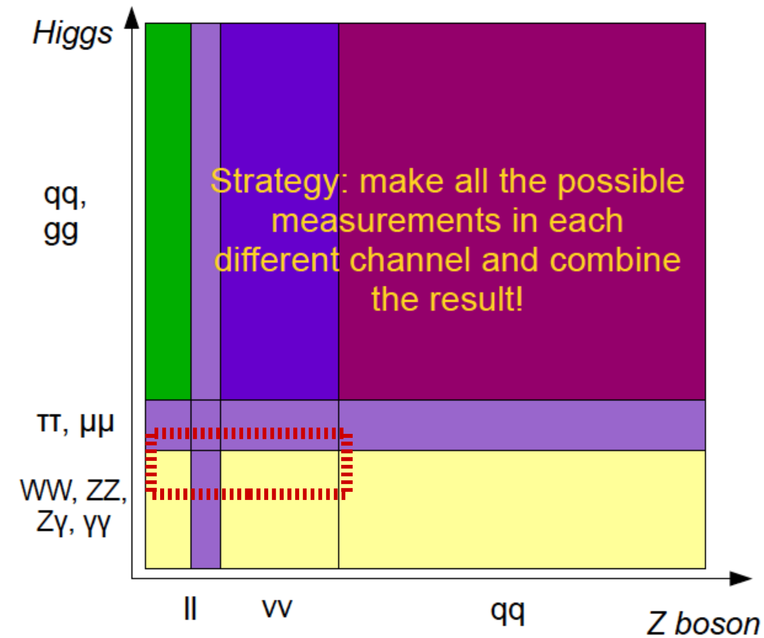
Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

- 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

- 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:
  - **1-1 correspondence**

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

Flavor Physics

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}	8.3×10^{11}
$D^\pm$	1.2×10^8	4.8×10^{10}	6×10^{14}	4.9×10^{11}
$D_s^\pm$	1×10^7	1.6×10^{10}	2×10^{14}	1.8×10^{11}
$\Lambda_c^\pm$	0.3×10^7	1.6×10^{10}	2×10^{14}	6.2×10^{10}
$\tau^+\tau^-$	3.6×10^8	4.5×10^{10}		1.2×10^{11}

Flavor Physics @ Z pole

- Extremely rich physics & strong competition from Belle-II & LHCb
- Comparative advantages of a Tera-Z
  - V.S. BelleII, Access to particles heavier than Bs, large boost
  - V.S. LHCb, much lower yields (2 orders of magnitudes) Better Acceptance, better reconstruction of neutral final state (photon, missing energy, and even Klong, neutron) and Jet Charge – Jet Origin

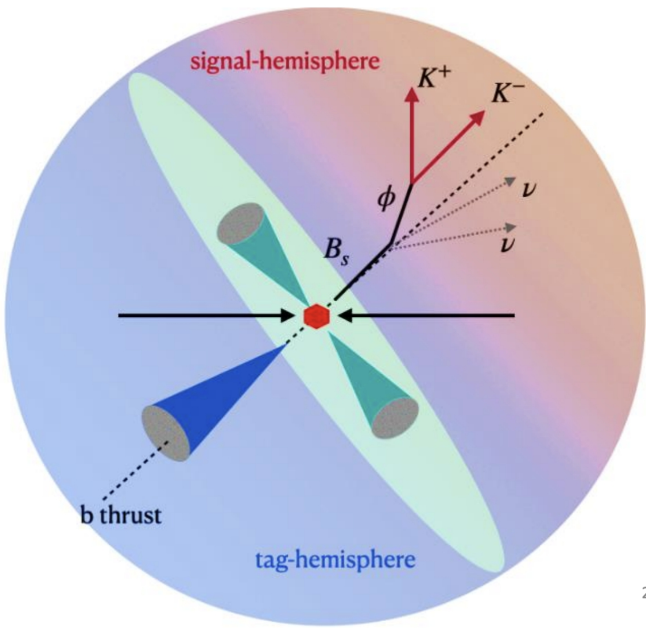
Contents

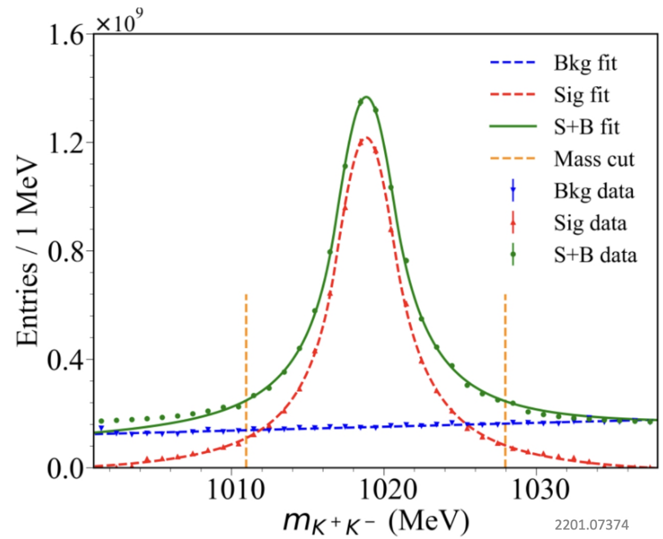
~ 40 benchmarks

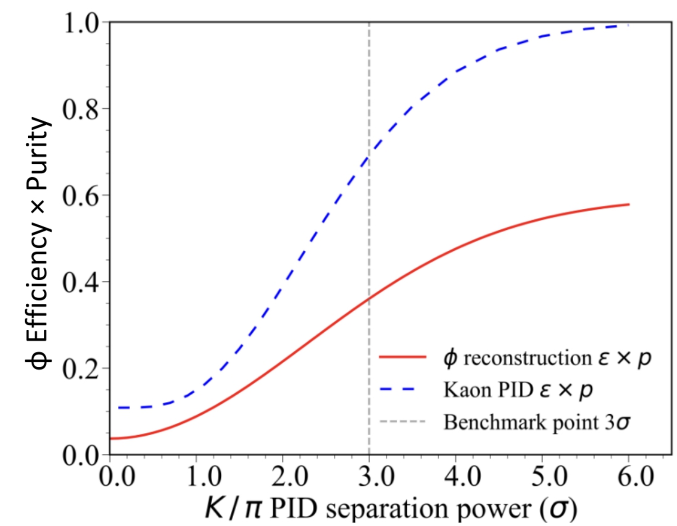
No.	Process	$\sqrt{s}$ (GeV)	Parameter of interest	Observable	Current precision	CEPC Precision	Estimation method	Key detector performance	Relevant Section
1	$Z \to \mu\mu a$	91.2	-	BR upper limit	-	$\lesssim 3 \times 10^{-11}$ [251]	Fast simulation	Tracker Missing energy	12
2	$B \to K\hat{\pi}(\to \mu\mu)$	91.2	-	BR upper limit	-	$\lesssim 10^{-10}$ [261]	Fast simulation	Tracker Vertex	12
3	$Z \to \pi^+\pi^-$	91.2	-	BR upper limit	-	$\mathcal{O}(10^{-10})$ [109]	Guesstimate	Tracker PID	9
4	$Z \to \pi^+\pi^-\pi^0$	91.2	-	BR upper limit	-	$\mathcal{O}(10^{-9})$ [109]	Guesstimate	Tracker PID ECAL	9
5	$b \to s\tau^+\tau^-$	91.2	-	BR upper limit	-	$B^0 \to K^{*0}\tau^+\tau^- \sim \mathcal{O}(10^{-6})$ $B_s \to \phi\tau^+\tau^- \sim \mathcal{O}(10^{-6})$ $B^+ \to K^+\tau^+\tau^- \sim \mathcal{O}(10^{-6})$ $B_s \to \tau^+\tau^-\ \mathcal{O}(10^{-5})$ [71]	Fast simulation	Tracker Vertex Jet origin ID	4
6	$Z \to \rho\gamma$	91.2	-	BR upper limit	$< 2.5 \times 10^{-5}$ [150]	$\mathcal{O}(10^{-9})$ [109]	Guesstimate	Tracker PID ECAL	9
7	$Z \to J/\psi\gamma$	91.2	-	BR upper limit	$< 1.4 \times 10^{-6}$ [150]	$10^{-9} - 10^{-10}$ [109]	Guesstimate	Tracker PID ECAL	9
8	$Z \to \tau\mu$ $Z \to \tau e$ $Z \to \mu e$	91.2	-	BR upper limit	$< 6.5 \times 10^{-6}$ $< 5.0 \times 10^{-6}$ $< 7.5 \times 10^{-7}$ [105–107]	$\mathcal{O}(10^{-9})$ [108, 109] $\mathcal{O}(10^{-9})$ [108, 109] 1×10^{-9} [110]	Guesstimate	E_{beam} Tracker PID	6
9	$\tau \to \mu a$	91.2	-	BR upper limit	$\lesssim 7 \times 10^{-4}$ [259]	$\lesssim$ 3–5 $\times 10^{-6}$	Fast simulation	Tracker Missing energy	12
10	$\tau \to \mu\mu\mu$ $\tau \to eee$ $\tau \to e\mu\mu$ $\tau \to \mu ee$	91.2	-	BR upper limit	$< 2.1 \times 10^{-8}$ $< 2.7 \times 10^{-8}$ $< 2.7 \times 10^{-8}$ $< 1.8 \times 10^{-8}$ [150]	$\mathcal{O}(10^{-10})$ [108, 109]	Guesstimate	Tracker Lepton ID	8
11	$\tau \to \mu\gamma$ $\tau \to e\gamma$	91.2	-	BR upper limit	$< 4.4 \times 10^{-8}$ $< 3.3 \times 10^{-8}$ [150]	$\mathcal{O}(10^{-10})$ [108, 109]	Guesstimate	Tracker Lepton ID ECAL	8
12	$B_c \to \tau\nu$	91.2	$\lvert V_{cb}\rvert$	$\sigma(\mu)/\mu$	BR$\lesssim$ 30% [267]	$\mathcal{O}(1\%)$ [63]	Full simulation	Tracker Lepton ID Missing energy Jet origin ID	3
13	$B_s \to \phi\nu\bar{\nu}$	91.2	-	$\sigma(\mu)/\mu$	BR $< 5.4 \times 10^{-3}$ [150]	$\lesssim$ 2% [35]	Full simulation	Tracker Vertex Missing energy PID	4
14		91.2		τ_τ (s) lifetime	$\pm 5 \times 10^{-16}$ [150]	$\pm 1 \times 10^{-18}$ [108]	Guesstimate	-	8
15		91.2		m_τ (MeV)	± 0.12 [150]	$\pm 0.004 \pm 0.1$ [108]	Guesstimate	-	8
16	$\tau \to \ell\nu\bar{\nu}$	91.2	-	BR	$\pm 4 \times 10^{-4}$ [150]	$\pm 3 \times 10^{-5}$ [108]	Guesstimate	Tracker Lepton ID Missing energy	8
17	$b \to c\ell\nu$	91.2	-	R_{H_c}	$R_{J/\psi} = 0.71 \pm 0.17 \pm 0.18$ [268] $R_{\Lambda_c} = 0.242 \pm 0.076$ [269]	relative (stat. only) $R_{J/\psi} \lesssim 5\%$ $R_{D_s^{(*)}} \lesssim 0.4\%$ $R_{\Lambda_c} \sim 0.1\%$ [38]	Fast simulation	Tracker Vertex	3
18	$B_s \to J/\psi\phi$	91.2	ϕ_s (= $-2\beta_s$)	Γ_s, $\Delta\Gamma_s$	$\Gamma_s = 657.3 \pm 2.3$ ns^{-1} [150] $\Delta\Gamma_s = 65.7 \pm 4.3 \pm 3.7$ ns^{-1} [270] $\phi_s = -87 \pm 36 \pm 21$ mrad [270]	$\sigma(\Gamma_s) = 0.072$ ns^{-1} $\sigma(\Delta\Gamma_s) = 0.24$ ns^{-1} $\sigma(\phi_s) = 4.3$ mrad [45]	Full simulation	Tracker Vertex Lifetime resolution Jet origin ID	5
19	$B^0 \to \pi^0\pi^0$ $B^0 \to \pi^+\pi^-$ $B^+ \to \pi^+\pi^0$	91.2	α	BR, A_{CP}	$BR^{00} = (1.59 \pm 0.26) \times 10^{-6}$ (16%) $BR^{+0} = (5.5 \pm 0.4) \times 10^{-6}$ (7%) $BR^{+-} = (5.12 \pm 0.19) \times 10^{-6}$ (4%) $C_{CP}^{00} = -0.33 \pm 0.22$ $C_{CP}^{+-} = -0.314 \pm 0.030$ $S_{CP}^{+-} = -0.670 \pm 0.030$ [150]	$\sigma(BR)/BR^{00} = 0.45\%$ $\sigma(BR)/BR^{+0} = 0.19\%$ $\sigma(BR)/BR^{+-} = 0.18\%$ $\sigma(a_{CP}^{00}) = \pm$ (0.014–0.018) $\sigma(C_{CP}^{+-}) = \pm$ (0.004–0.005) $\sigma(S_{CP}^{+-}) = \pm$ (0.004–0.005) [31]	Fast simulation	ECAL Tracker Vertex Jet origin ID	5
20	$H \to sb, sd, db, uc$	240	-	BR upper limit	-	0.02%—0.1% [32]	Full simulation	Jet origin ID	10
21	$H \to ss, uu, dd$	240	-	BR upper limit	-	0.1% [32]	Full simulation	Jet origin ID	10
22	$e^+e^- \to t(\bar{t})j$	240	-	FCNC constraint coefficients	two-fermion, LHC [199–203] four-fermion, LEP2 [204, 205]	1–2 orders of magnitude improvement compared to LEP2 [198]	Fast simulation	Tracker Missing energy Jet origin ID	10
23	$WW \to \mu\nu qq$ $WW \to \tau(\to \mu\nu\nu)\nu qq$	240	$\lvert V_{cb}\rvert$	$\lvert V_{cb}\rvert$	$(38.9 \pm 0.53) \times 10^{-3}$ relative $\sim 1.4\%$ [9]	$\lesssim 0.5\%$ [194]	Full simulation	Jet origin ID	10

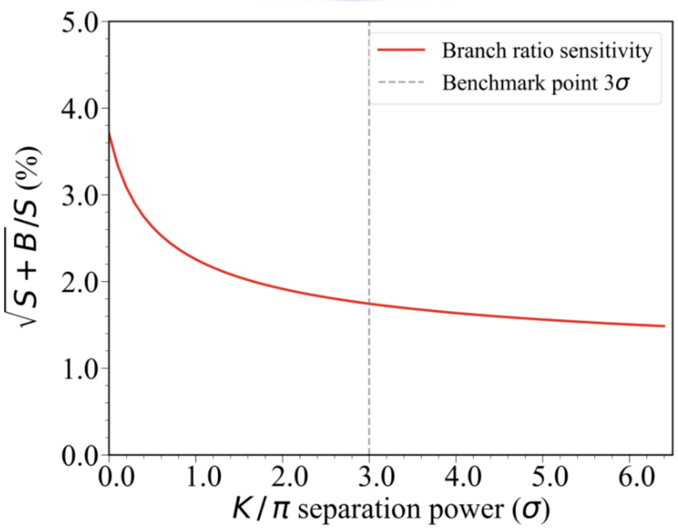
- Access to non-seen
- Orders of magnitudes improvements
- Multiple sqrt(s)
- Non-inclusive + long wishlist -> to be addressed in phase II flavor WP study

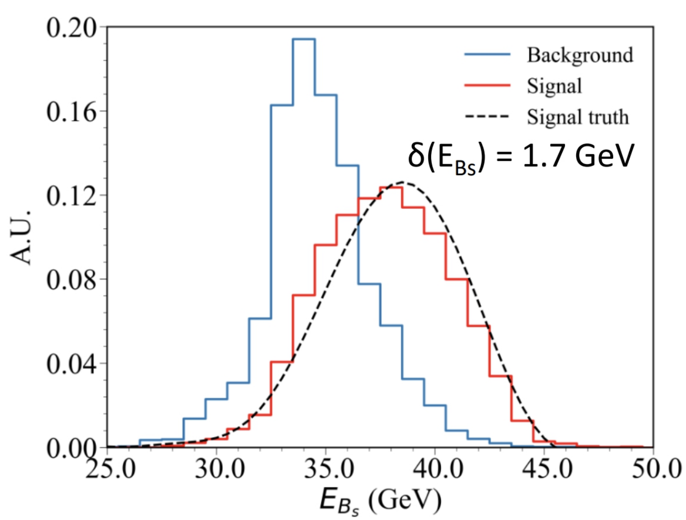
Bs→Phi νν

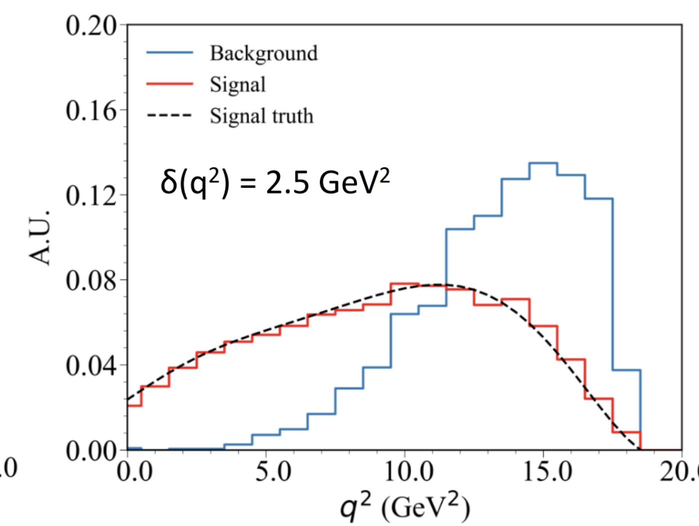












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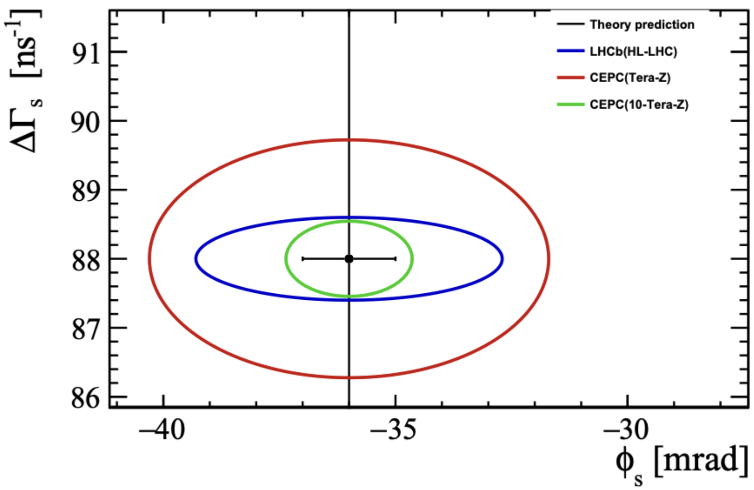
CP measurement with Bs→J/psi Phi

$\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H, \phi_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$

SM: small CPV phase ϕ_s

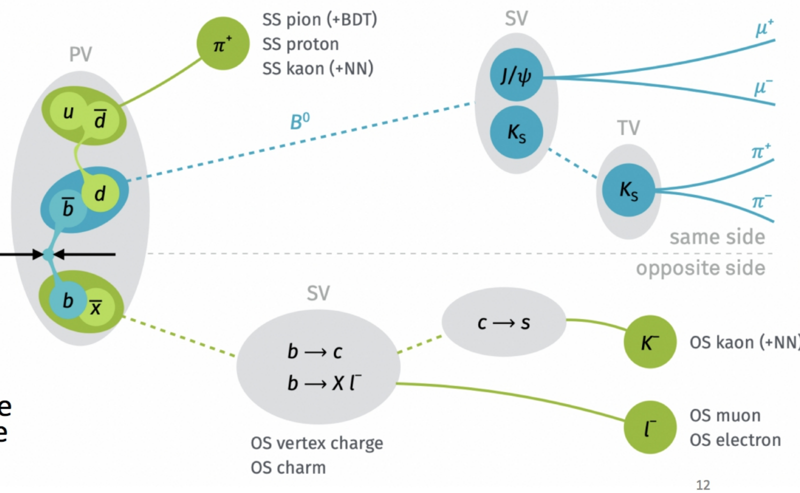
Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

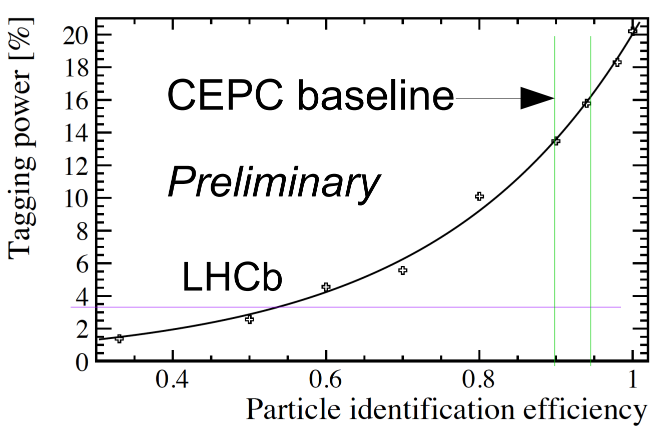


Flavour tagging power

- LHCb: 3~4%
- CEPC: 15% (Previous estimation)
- B factory: ~30%

- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation





- With a decent Pid, the effective tagging power on jet Charge can be 5-6 times better than LHCb, which can compensate the statistic difference between LHCb & CEPC.
- Strong motivation to higher Luminosity at Z pole

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 Liang,[1,2,*] Yongfeng Zhu,[3,*] Yuexin Wang,[1,4] Yuzhi Che,[1,2] Manqi Ruan,[1,2,†]
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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 $\nu\bar{\nu}H, H \to jj$ 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 $H \to s\bar{s}, u\bar{u}, d\bar{d}$ and $H \to sb, db, uc, ds$ can be determined to 2×10^{-4} to 1×10^{-3} at 95% confidence level. The derived upper limit for $H \to s\bar{s}$ decay is approximately 3 times the prediction of the standard model.

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https://doi.org/10.1140/epjc/s10052-024-12475-5

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

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 Qu[4], Chen Zhou[1,b], Manqi Ruan[2,3,c]

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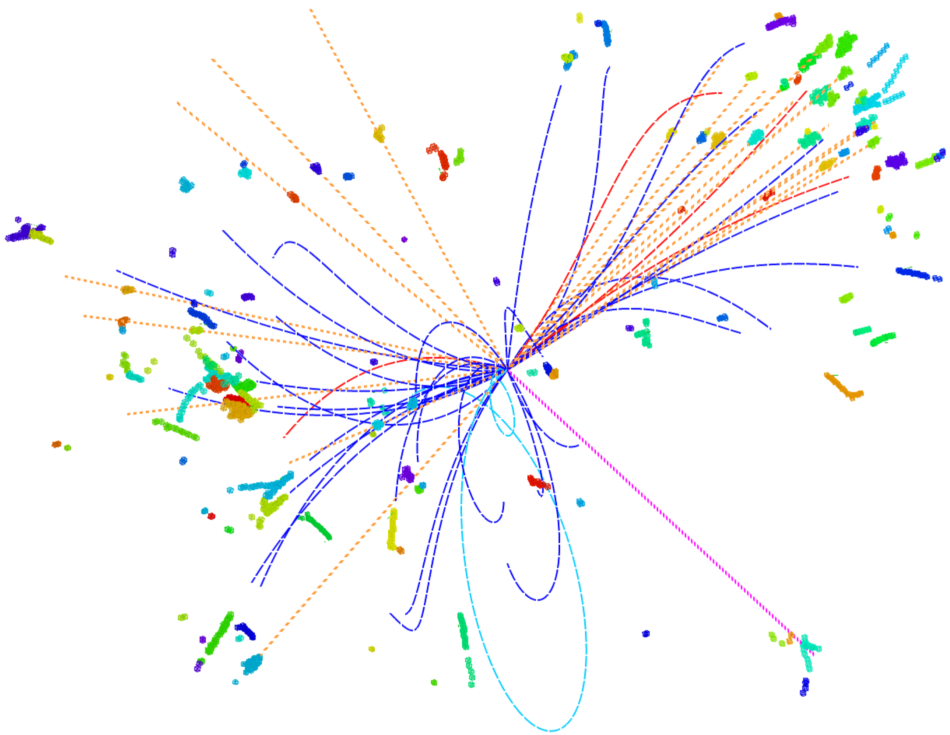
Received: 15 November 2023 / Accepted: 23 January 2024

https://arxiv.org/abs/2310.03440

https://arxiv.org/abs/2309.13231

Geo. & Tools

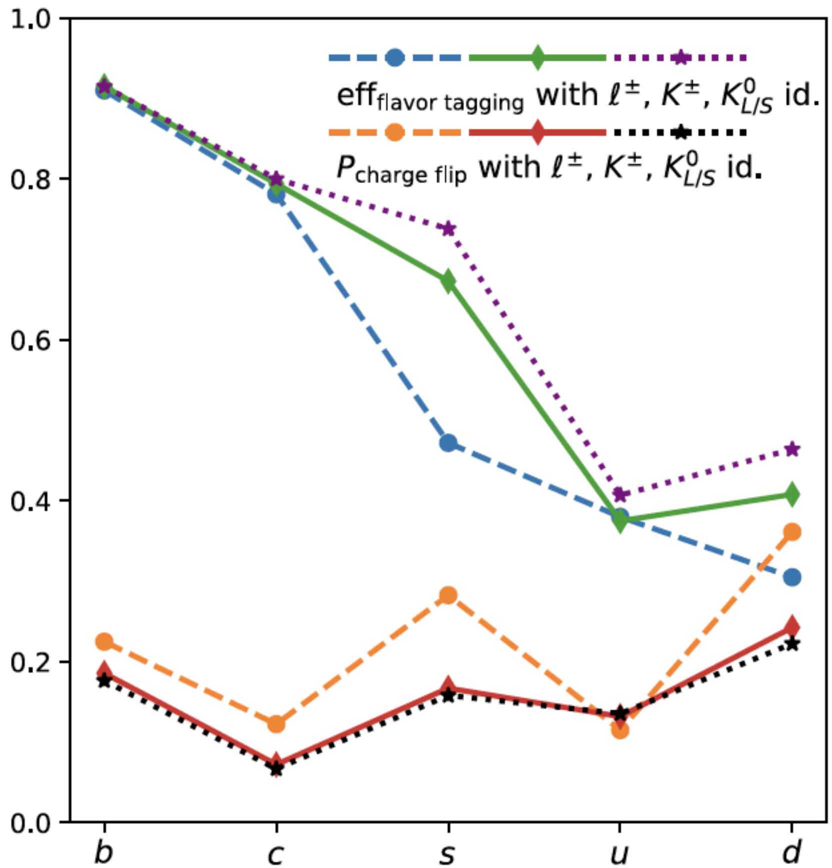


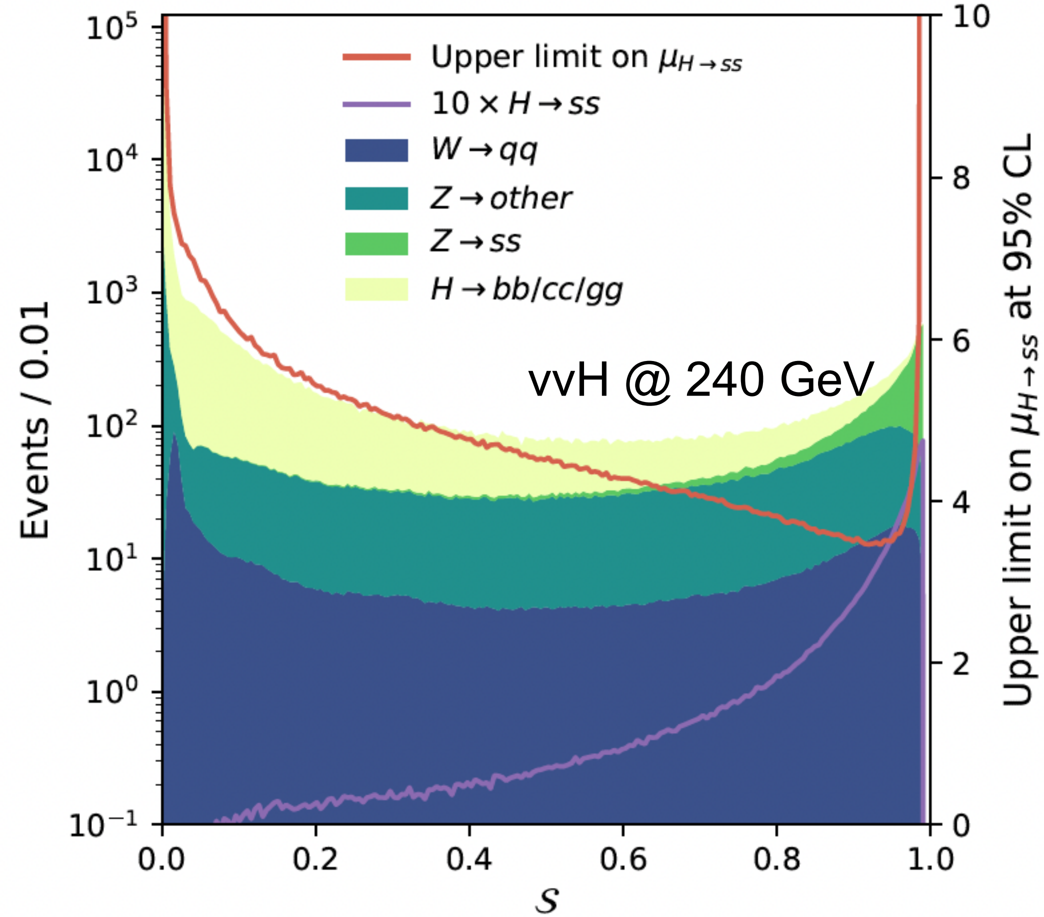
True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$	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
$\bar{s}$	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
$\bar{u}$	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
$\bar{d}$	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

0.7-0.8
0.65-0.7
0.6-0.65
0.5-0.6
0.4-0.5
0.35-0.4
0.3-0.35
0.25-0.3
0.2-0.25
0.15-0.2
0.1-0.15
0.09-0.1
0.085-0.09
0.08-0.085
0.075-0.08
0.07-0.075
0.06-0.07
0.05-0.06
0.04-0.05
0.03-0.04
0.02-0.03
0.01-0.02
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001

- **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

Performance with different PID scenarios & H→ss measurements



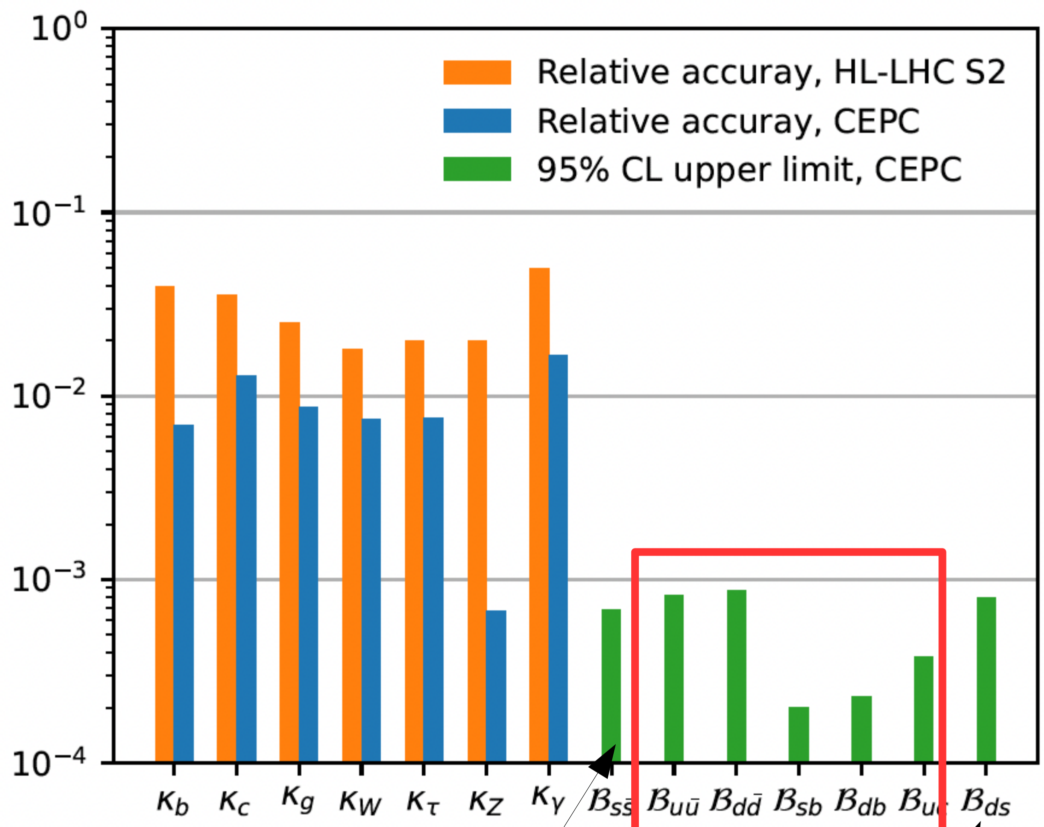


Flavor tagging: type that maximize {L_q + L_q_bar, L_g}

If quark jet: jet charge ~ compare {L_q, L_q_bar}

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

Benchmark analyses: Higgs rare/FCNC



Improved by ~3 times

Improved by 1-2 orders of magnitudes

Presumably... firstly quantified

TABLE I: Summary of background events of $H \to b\bar{b}/c\bar{c}/gg$, 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})						
	H	Z	W	$s\bar{s}$	$u\bar{u}$	$d\bar{d}$	sb	db	uc	ds
$\nu\bar{\nu}H$	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
Comb.	-	-	-	0.75	0.91	0.95	0.22	0.23	0.39	0.86

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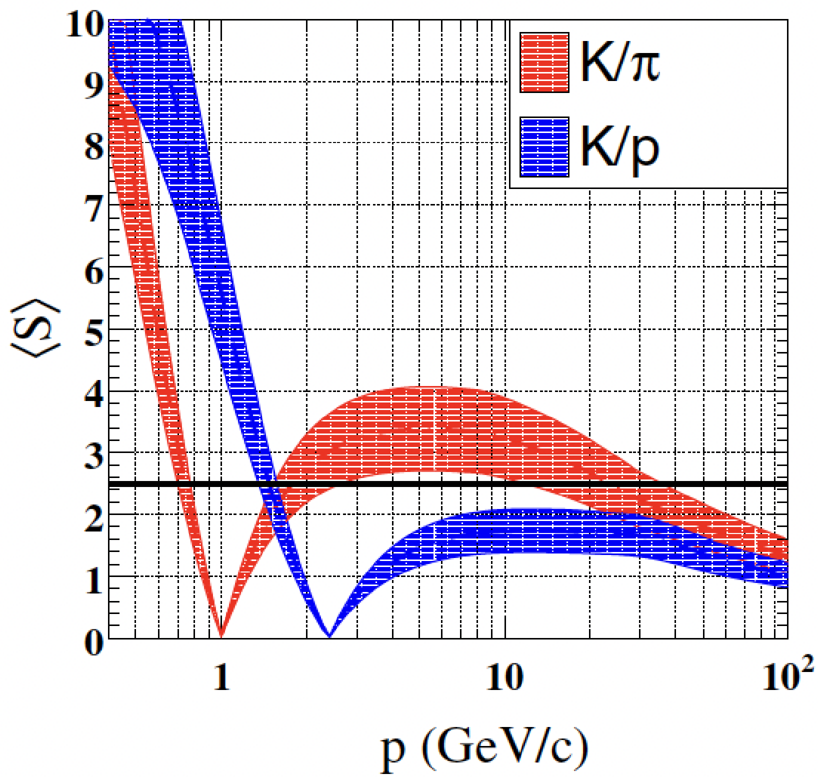
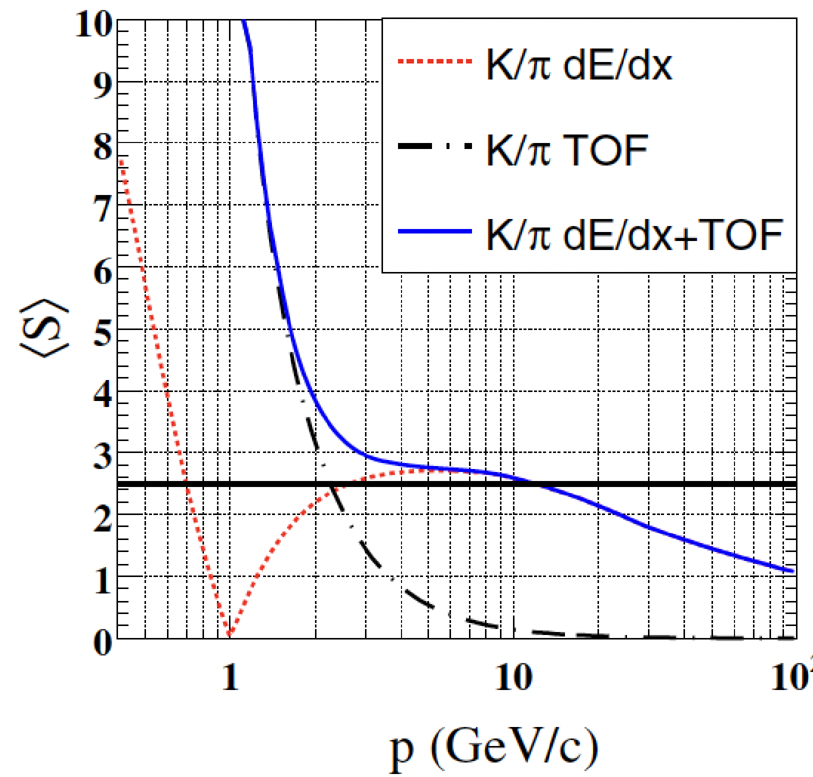
Particle id with dE/dx + ToF





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Regular Article - Experimental Physics

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

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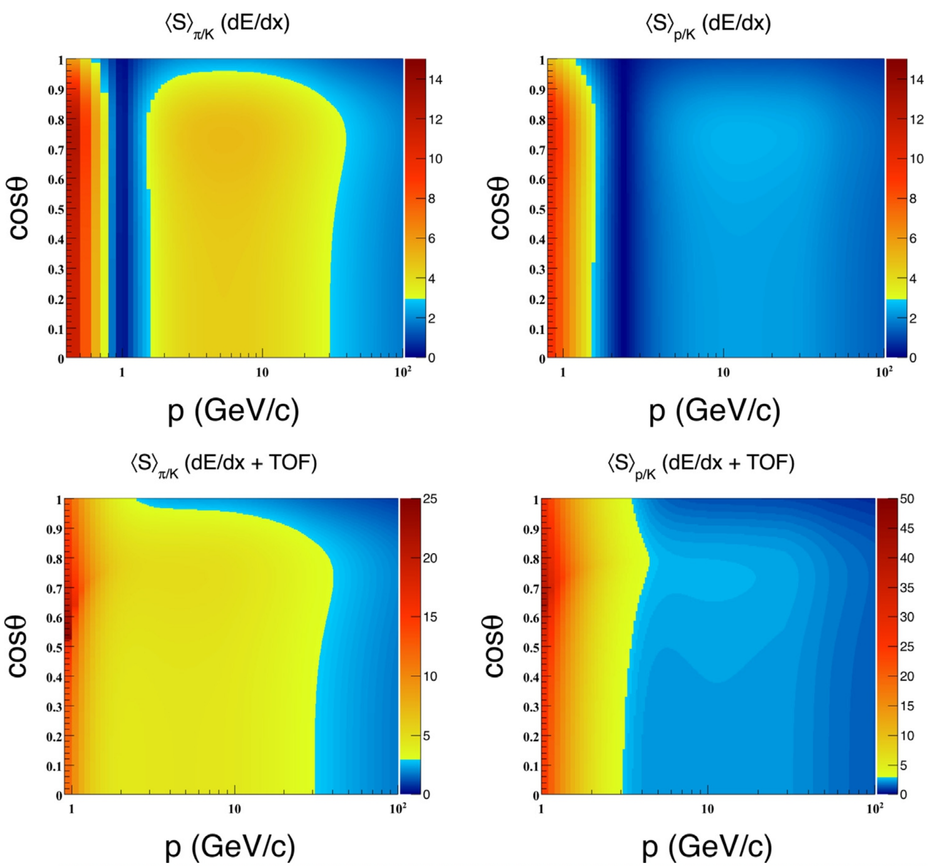
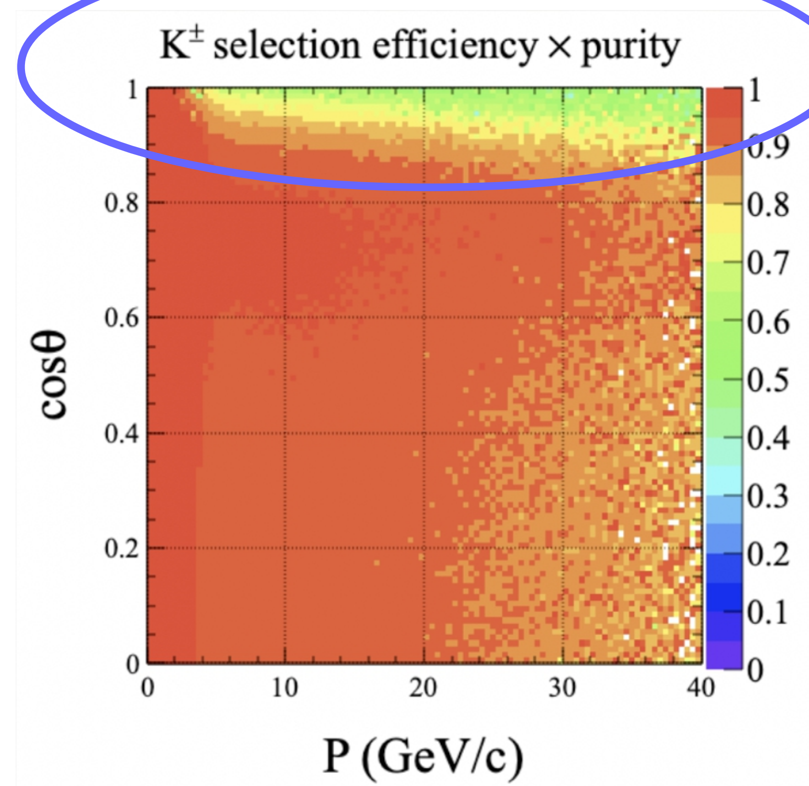
Sep. power





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

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Requirement analysis for dE/dx measurement and PID performance at the CEPC baseline detector

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Table 3
The $K^{\pm}$ identification performance with different factors, $\sigma_{actual} = factor \cdot \sigma_{intrinsic}$, with/without combination of TOF information at the Z-pole.

	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

Requirement on dE/dx & dN/dx

Y. Zhu, S. Chen, H. Cui et al. *Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167835*

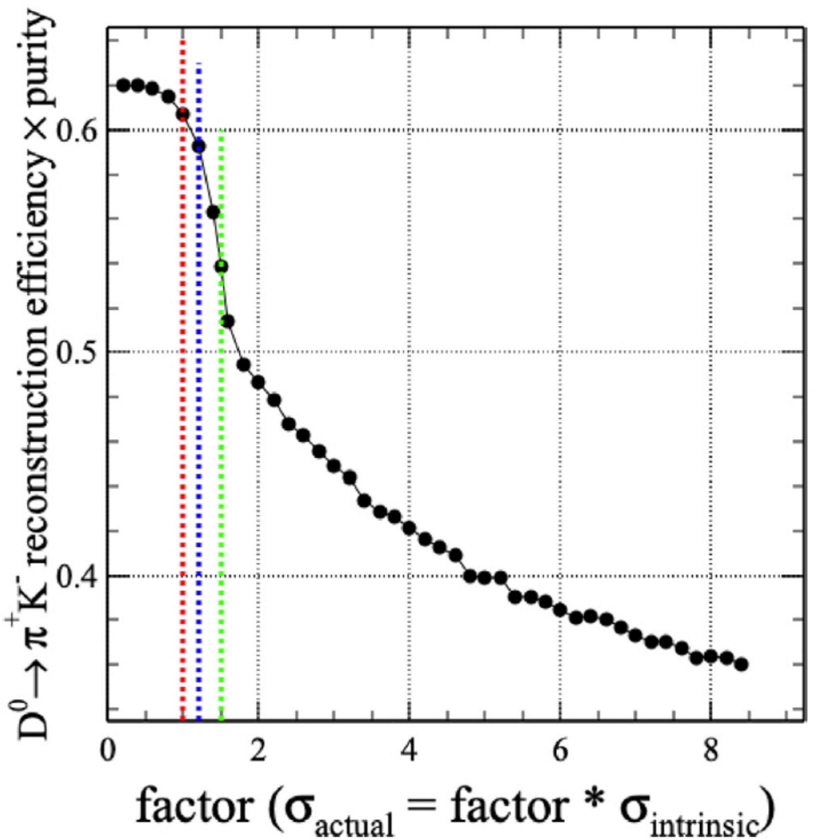


Fig. 12. The distribution of $D^0 \to \pi^+ K^-$ reconstruction performance as a function of the factor defined in $\sigma_{actual} = factor \cdot \sigma_{intrinsic}$. The red/blue/green line corresponds to the 0%/20%/50% degradation of dE/dx resolution.

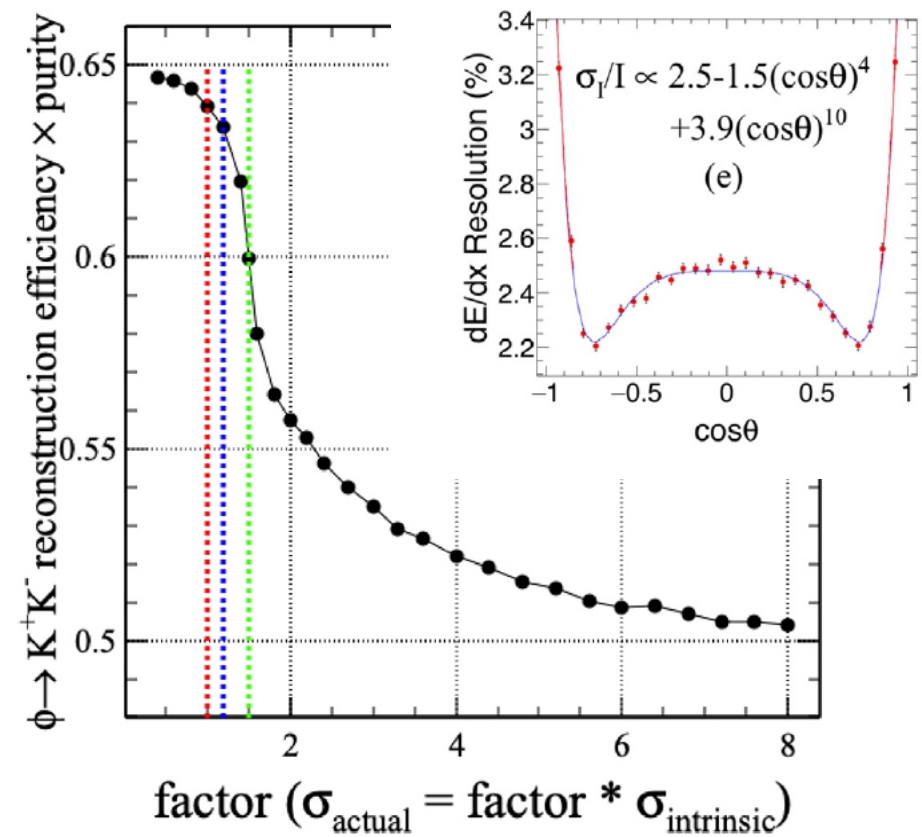
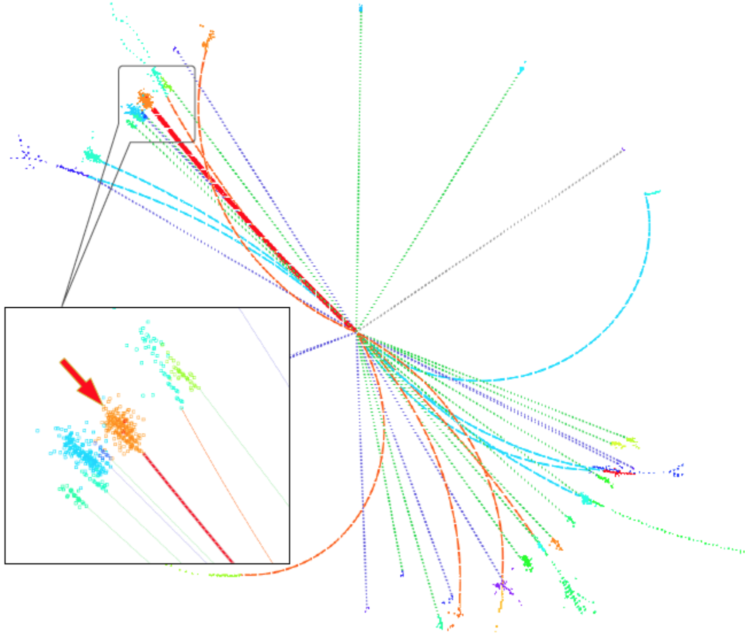
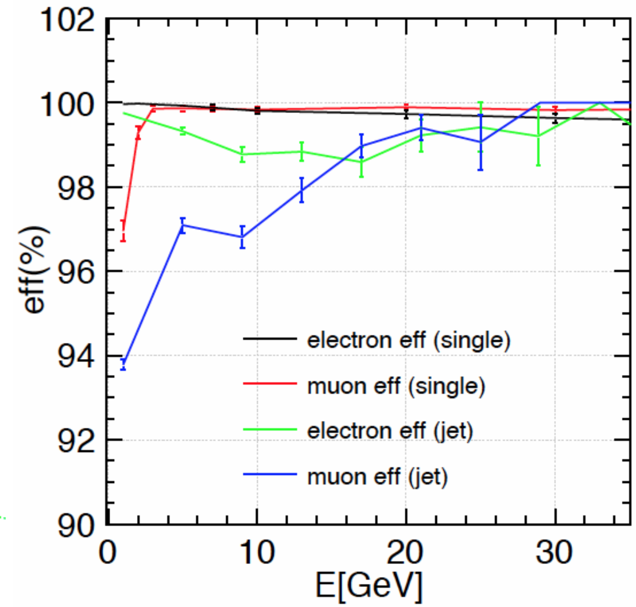


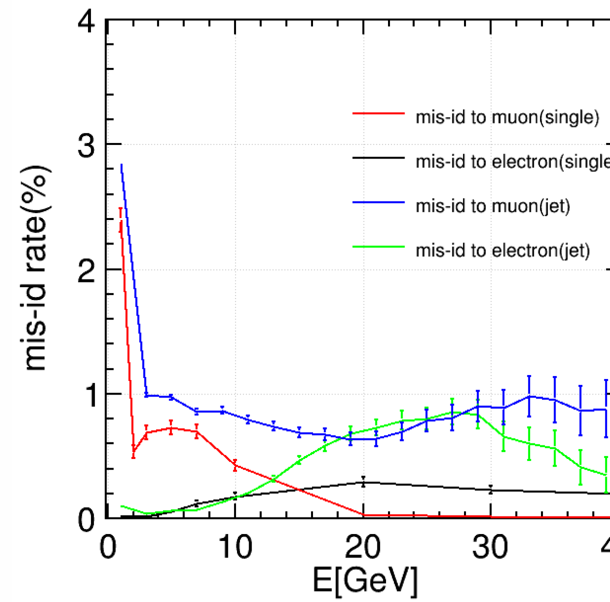
Fig. 13. The distribution of $\phi \to K^+ K^-$ reconstruction as a function of the factor defined in $\sigma_{actual} = factor \cdot \sigma_{intrinsic}$. The red/blue/green line corresponds to the 0%/20%/50% degradation of the dE/dx resolution.

→ 3% dE/dx resolution in the barrel for E > 2 GeV tracks

Lepton: inside jet

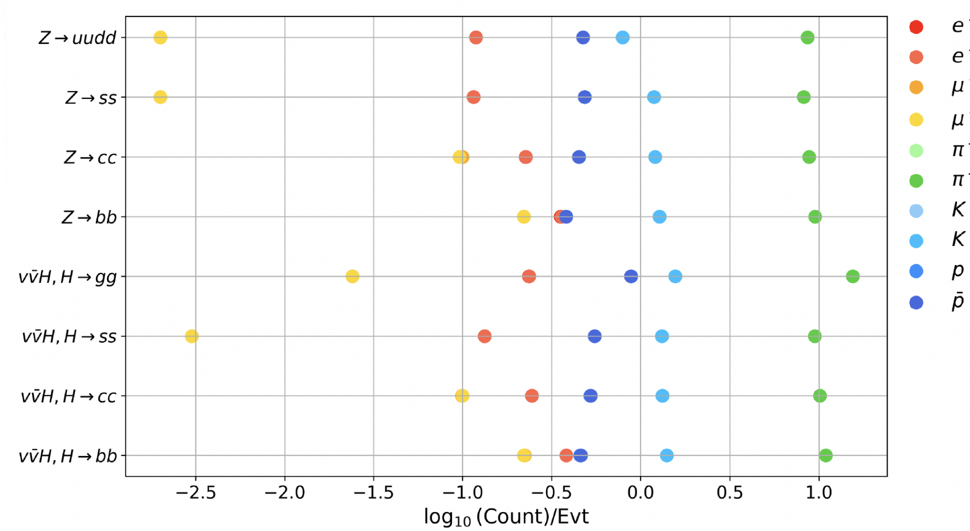






- Compared to isolated lepton, the jet lepton id performance is slightly degraded (percentage level)

- Giving the large hadron/lepton ratio in jet, It would be beneficial to further improve the jet lepton identification performance, while identifying hadron decay (kink finding) + converted photon are critical



Summary

- Decent Pid is required
  - For Flavor Physics, especially those with B/D measurements...
  - For identification of Jet Origin, which will influence all physics measurement with hadronic final state
  - 3 sigma separation – 95% eff/purity in identifying the charged Kaons
- Need Pid could be achieved using dE/dx (dN/dx) + ToF measurement
  - ~ 50 ps time resolution
  - 3% dE/dx in the barrel region...
  - Address the forward region which is current bottleneck
- Alternative choices are welcome – while we need to understand the impact on other performance especially PFA recon.
  - i.e., Silicon sensor with Pid??

Back up

Updated result on $\sin^2\theta^l_{eff}$ measurement

Table 2. Sensitivity S of different final state particles.

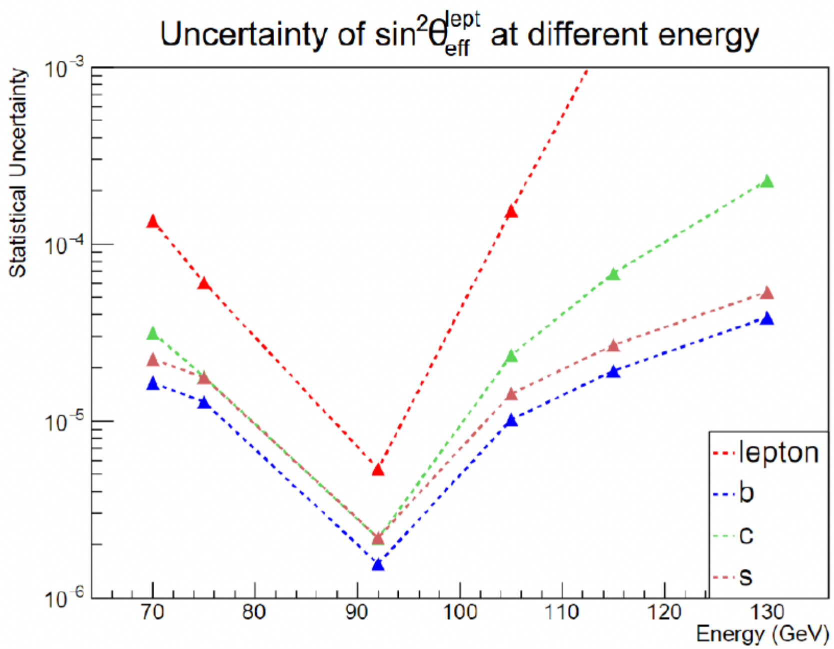
$\sqrt{s}$/GeV	S of $A^{e/\mu}_{FB}$	S of A^{d}_{FB}	S of A^{u}_{FB}	S of A^{s}_{FB}	S of A^{c}_{FB}	S of A^{b}_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958	1.087	3.942
130	0.027	3.279	0.531	3.280	0.520	3.261

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

$\sqrt{s}$/GeV	σ_μ/mb	σ_d/mb	σ_u/mb	σ_s/mb	σ_c/mb	σ_b/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 $\sin^2\theta^l_{eff}$ measurement.
(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)

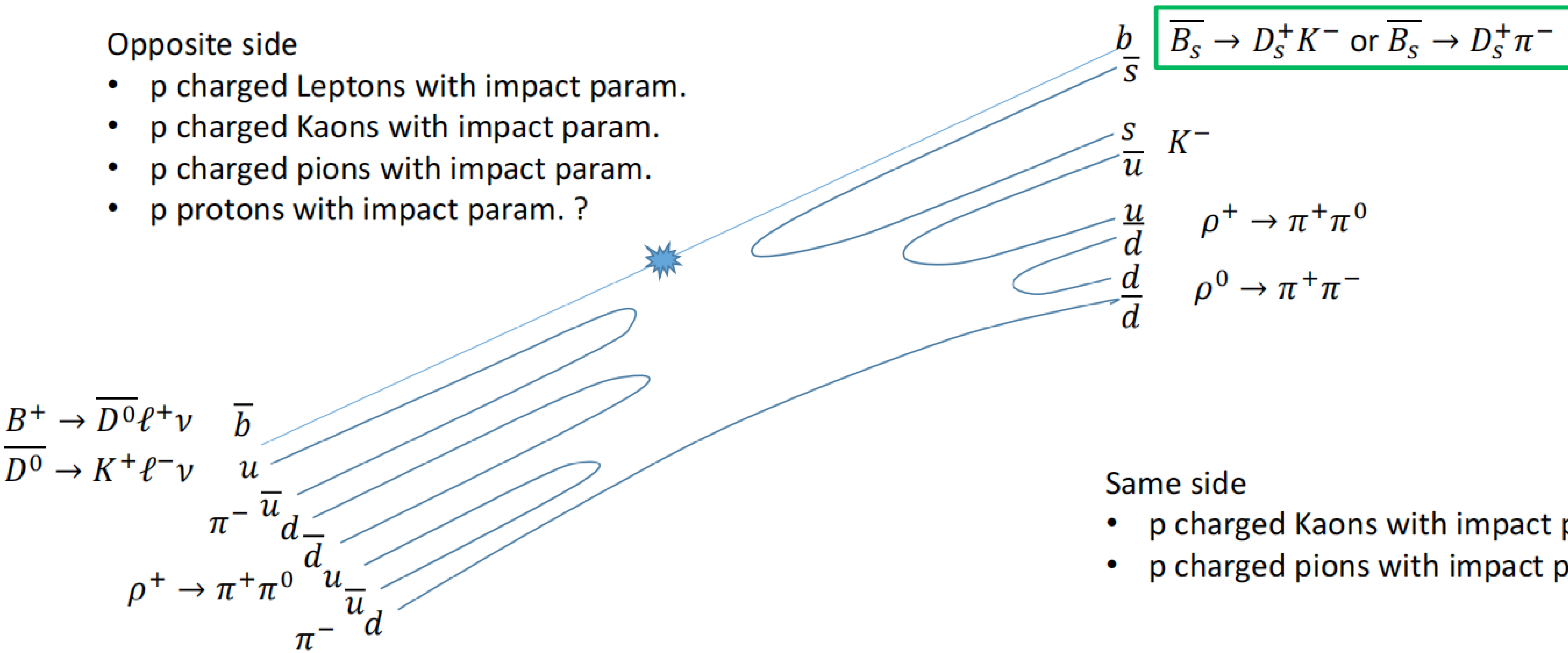


$\sqrt{s}$	b	c	s
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

B-charge flip rate: Bs oscillations

Opposite side

- p charged Leptons with impact param.
- p charged Kaons with impact param.
- p charged pions with impact param.
- p protons with impact param. ?

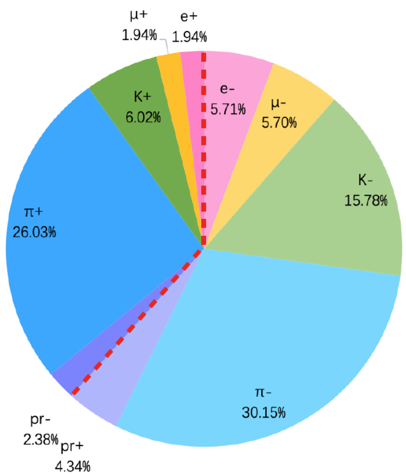


Same side

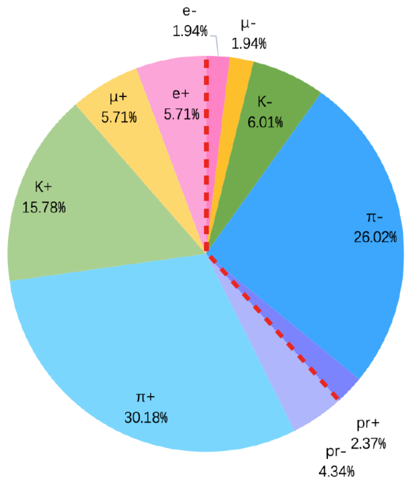
- p charged Kaons with impact param
- p charged pions with impact param.

Jet Charge reconstruction

$Z \to b\bar{b}$ **Percent of final charged leading particles of b jet and $\bar{b}$ jet**



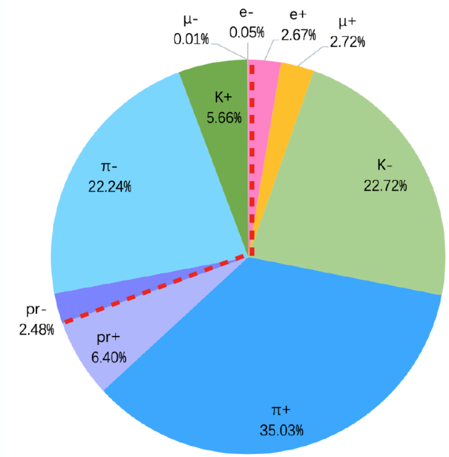
b jet



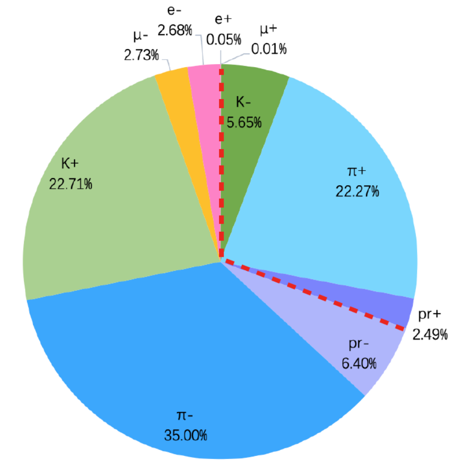
$\bar{b}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

$Z \to c\bar{c}$ **Percent of final charged leading particles of c jet and $\bar{c}$ jet**



c jet



$\bar{c}$ jet

☞ *The distribution of each charged particle of two jets is asymmetry*

percent bbar jet → b jet ↓	B^0	B^+	B_s^0	B_c^+	$\Lambda_b$bar	others	all
B^0bar	17.360%	17.350%	3.369%	0.022%	2.759%	0.688%	41.548%
B^-	17.350%	17.359%	3.364%	0.022%	2.765%	0.689%	41.550%
B_s^0bar	3.355%	3.362%	0.652%	0.004%	0.545%	0.144%	8.062%
B_c^-	0.022%	0.022%	0.004%	0.00003%	0.004%	0.001%	0.052%
Λ_b	2.762%	2.762%	0.543%	0.004%	0.451%	0.121%	6.644%
others	0.653%	0.655%	0.136%	0.001%	0.119%	0.579%	2.144%
all	41.503%	41.511%	8.068%	0.053%	6.641%	2.225%	100%

Effective tagging power:

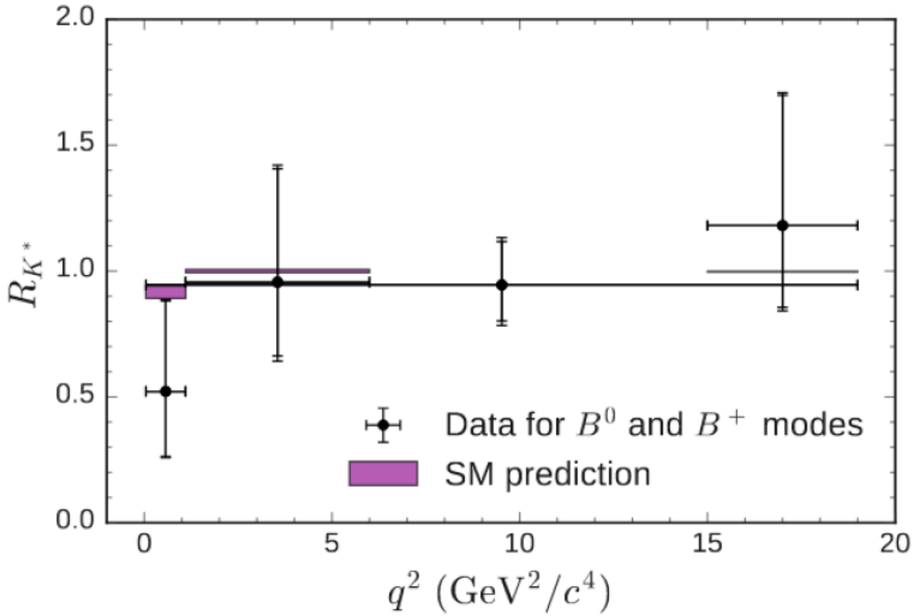
A straight forward, leading particle based algorithm leads to effective tagging power of 10%/20% for b/c-jet
(... we understand how the jet charge information eventually incarnated into Leading final state particles...)

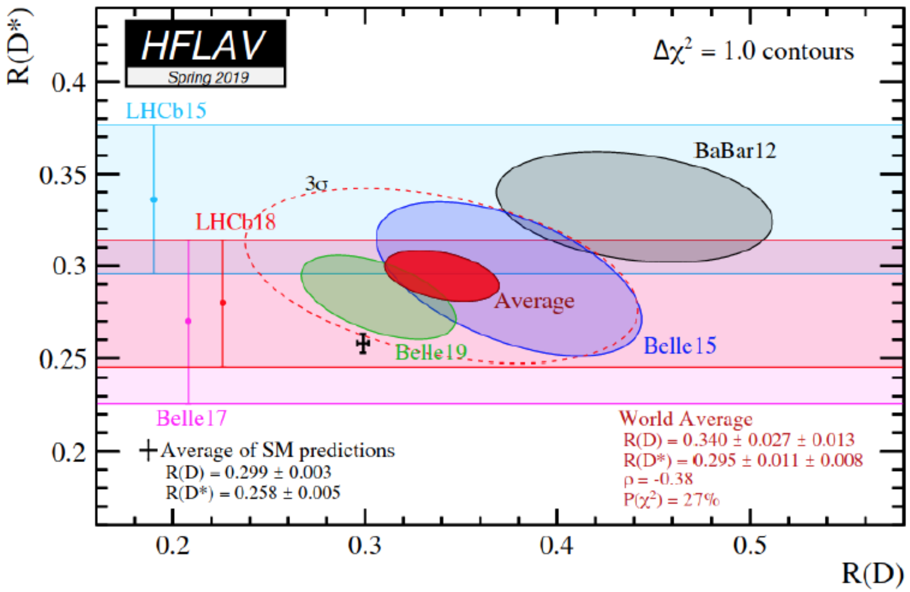
Can be significantly enhanced using Pt weighted, VTX charge, Kaon information, etc

Physics benchmarks

- CP measurement via Bs→Jpsi + Φ: detector acceptance, VTX, tracker momentum, Jet charge
  - Accuracy comparable to LHCb – strong motivation to go beyond Tera Z.
- Addressing Flavor Anomaly
  - Bs→Φvv: Pid, momentum and missing energy resolution
    - Percentage level accuracy anticipated
  - Bc→Tauv: Tau inside jet, missing energy
    - 1 order of magnitude better than current accuracy.
- CKM measurements
  - B0/Bs→2 pi0/eta; EM resolution, Pi0 reconstruction
    - 1 order of magnitude better than Belle II, or discovered for the first time, dependence on detector performance quantified.
    - Key input for alpha measurement -> need also Jet charge measurement
- Multiple studies on LFV, LFU, Tau related. Exotic...
- ...

B Anomalies Indicating LFUV

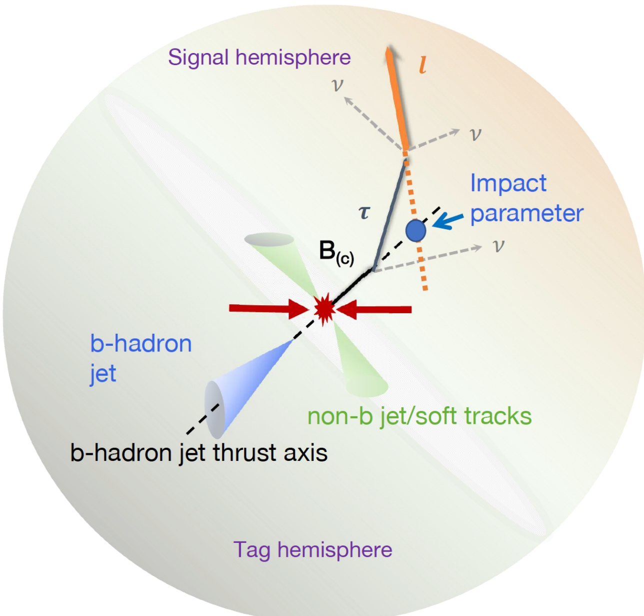


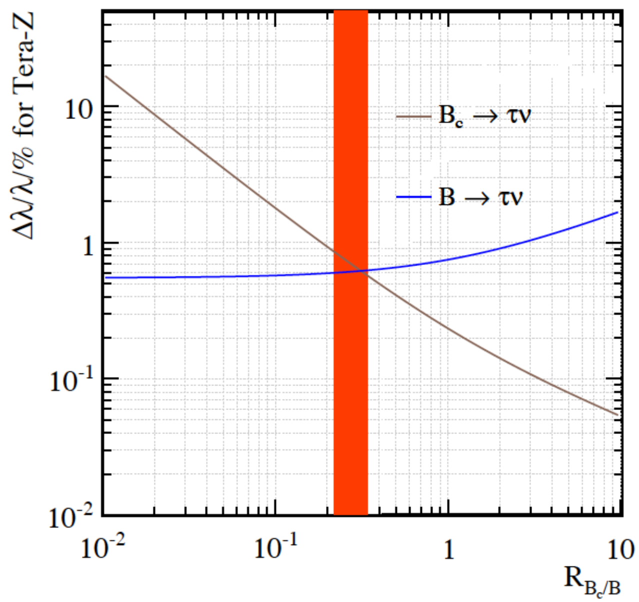


	Experimental	SM Prediction	Comments
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.00 ± 0.01	$m_{\ell\ell} \in [1.0, 6.0]$ GeV^2, via $B^\pm$.
R_{K^*}	$0.69^{+0.12}_{-0.09}$	0.996 ± 0.002	$m_{\ell\ell} \in [1.1, 6.0]$ GeV^2, via B^0.
R_D	0.340 ± 0.030	0.299 ± 0.003	B^0 and $B^\pm$ combined.
R_{D^*}	0.295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

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

Bc→Tauv





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

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

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

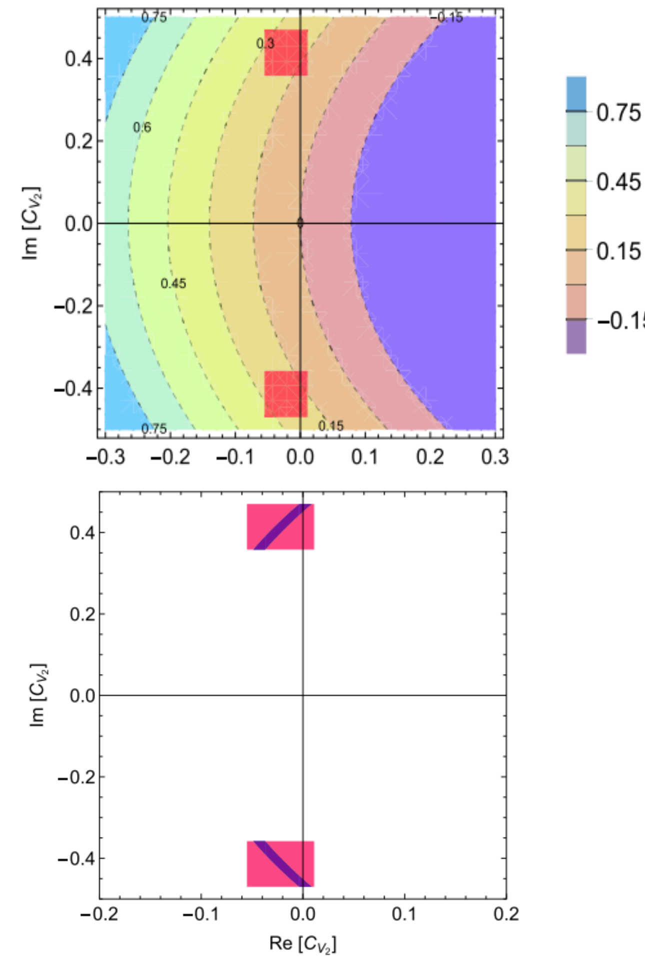

Fig. 10. (color online) Constraints on the real and imaginary parts of C_{V_2}. The red shaded area corresponds to the current constraints using available data on $b \to c\tau\nu$ decays. If the central values in Eq. (9) remain while the uncertainty in $\Gamma(B_c^+ \to \tau^+\nu_\tau)$ is reduced to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

Taifan, etc, Published by CPC.
Collaborate with Wei Wang, et.al.