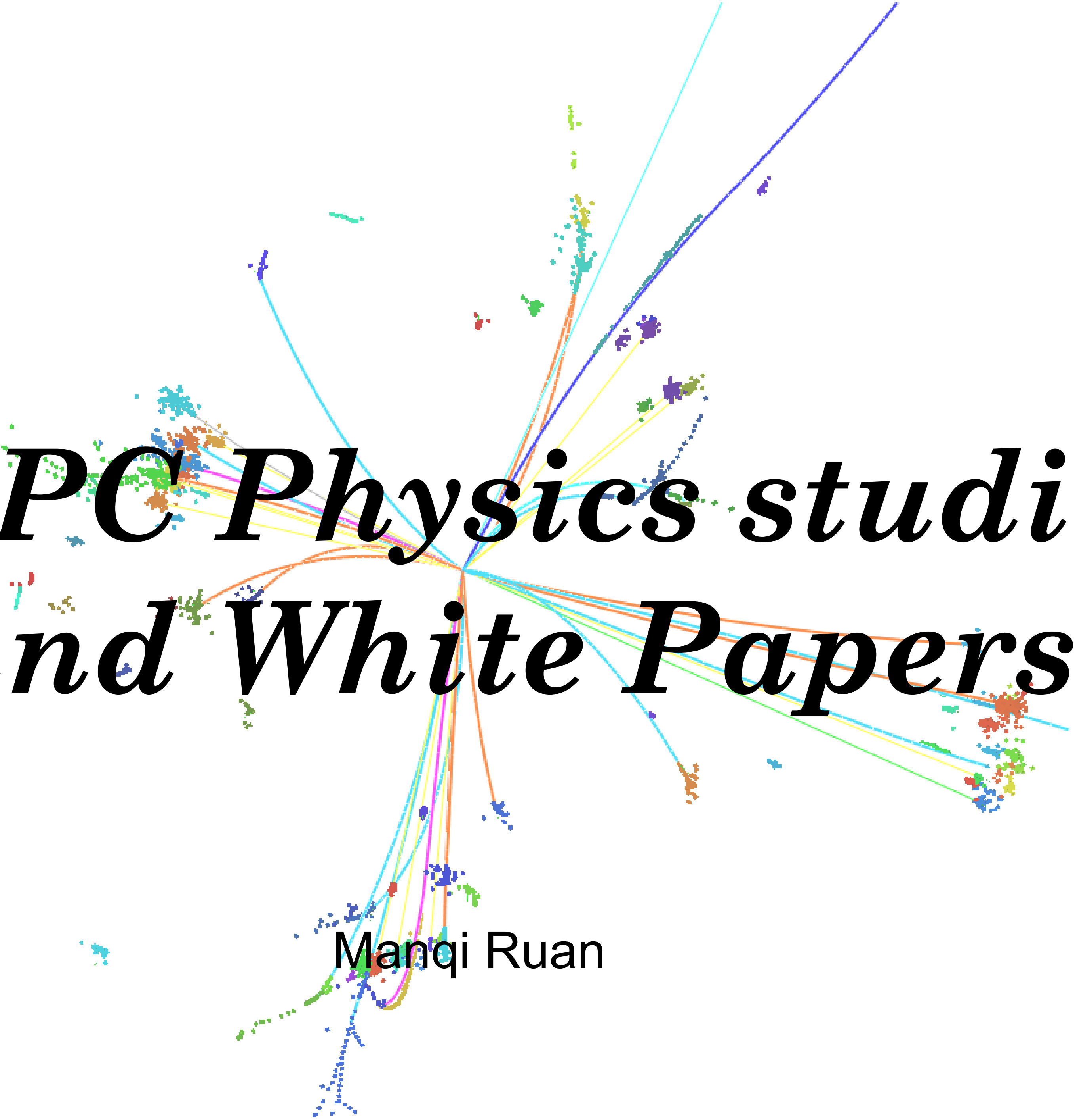


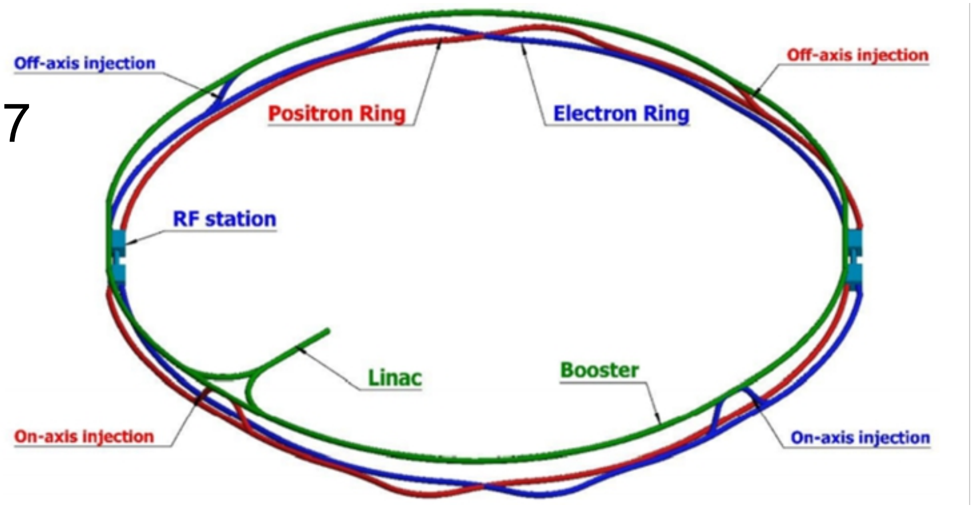
CEPC Physics studies and White Papers

Manqi Ruan

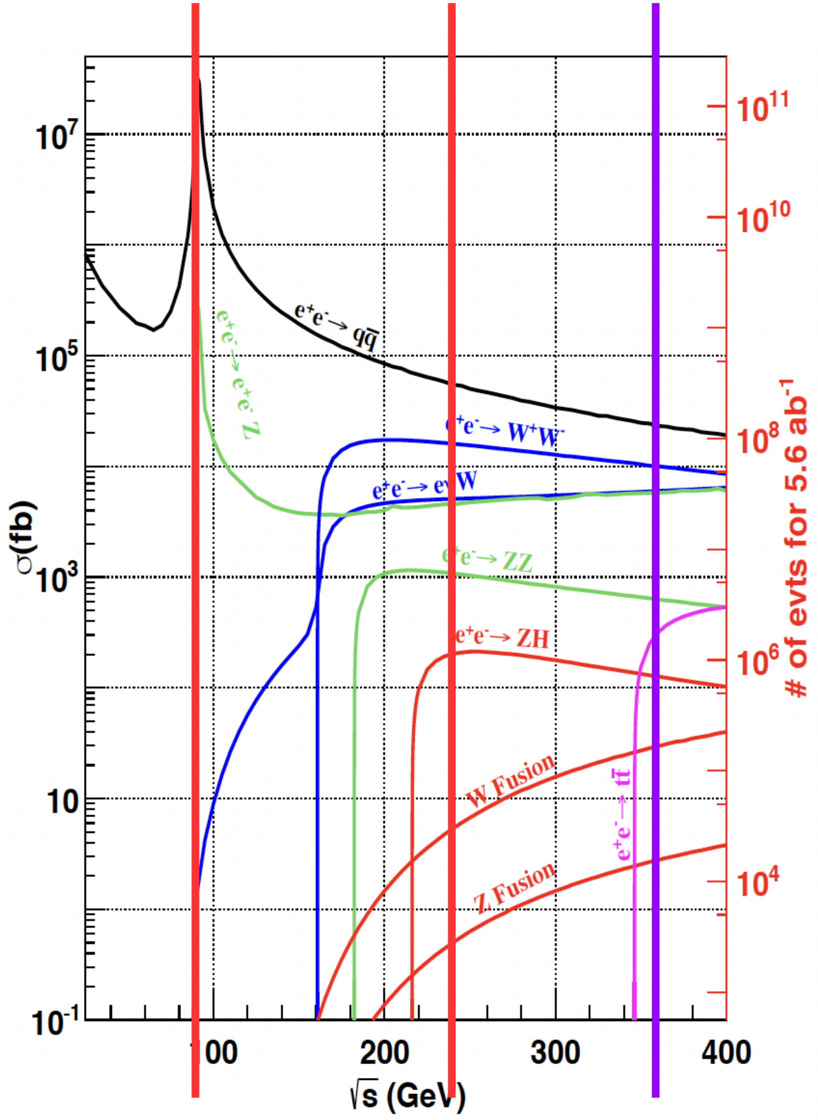
Status & Overview

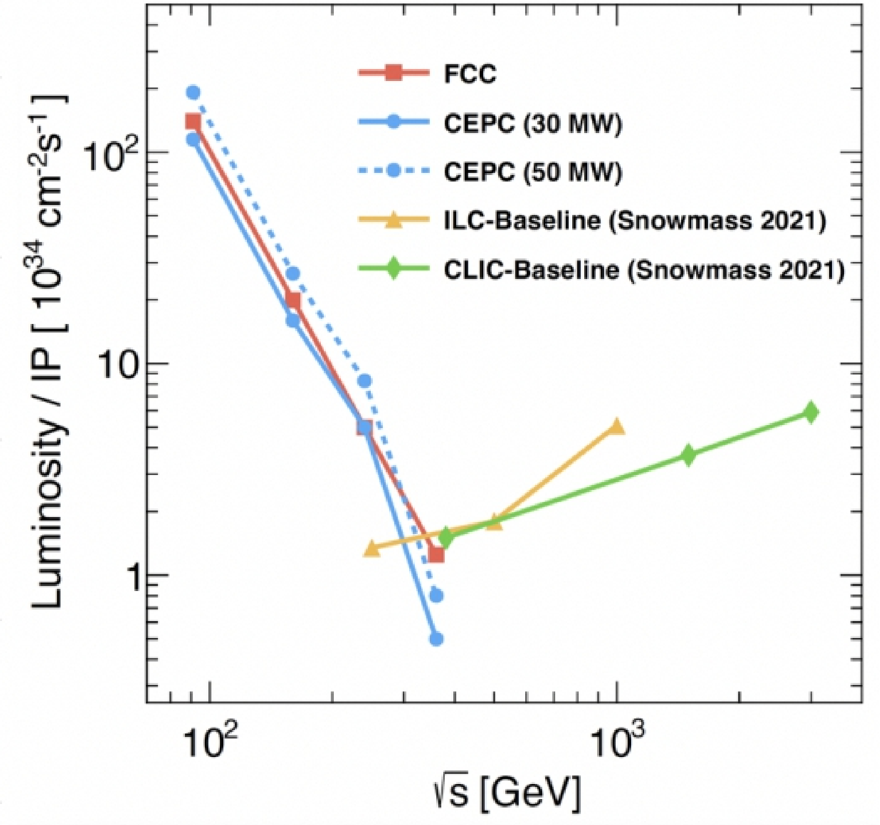
- CEPC: 100 km Higgs factory producing also huge statistic of Z, W, and potentially top quark, aiming at discovering New Physics Beyond the SM
  - 2012: Proposed right after the Higgs discovery
  - 2015: PreCDR delivered, no showstopper identified
  - 2018: CDR released
  - 2023: Acc. TDR published, Technology & Design ready for construction
  - 2025: Det Ref TDR, Physics White Papers

- Proposed to start construction in ~2027



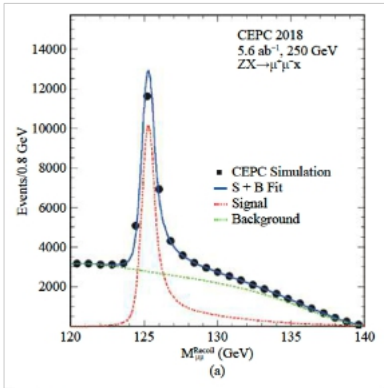
Yields ~ Xsec * Lumi * Time

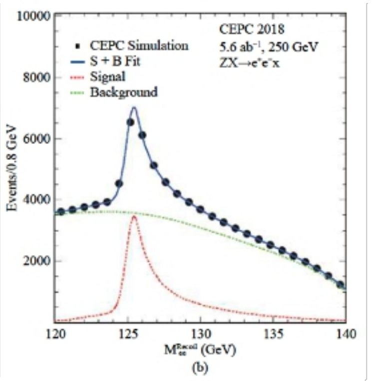


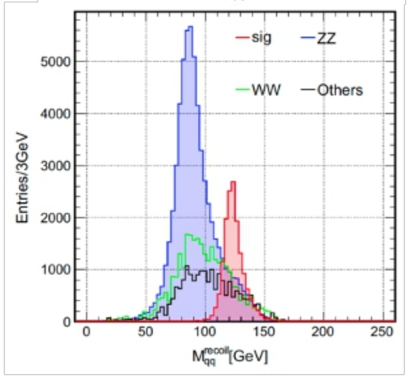


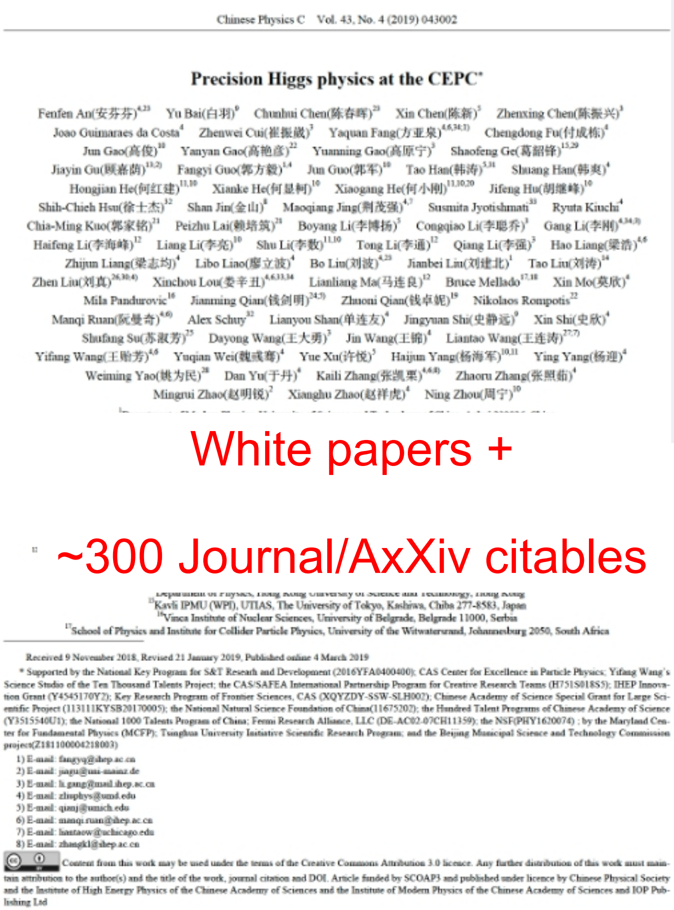
- 4 Million Higgs (10 years)
- ~ 1 Giga W (1 year) + 4 Tera Z (2 years)
- Upgradable: Top factory (500 k ttbar)

Physics study: 2024









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

Precision Higgs physics at the CEPC*

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White papers +

~300 Journal/AxXiv citables

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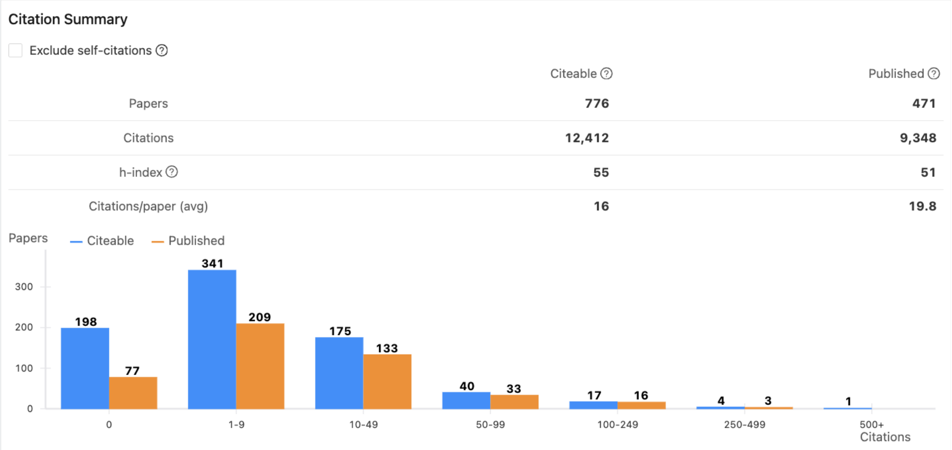


Citation Summary

☐ Exclude self-citations ⓘ

	Citeable ⓘ	Published ⓘ
Papers	776	471
Citations	12,412	9,348
h-index ⓘ	55	51
Citations/paper (avg)	16	19.8

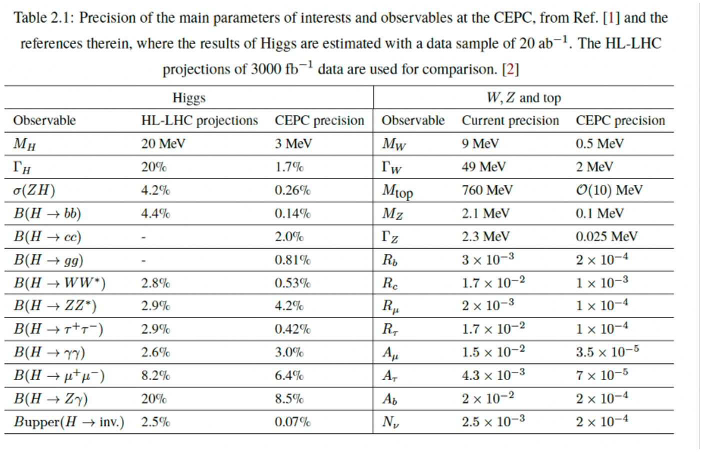


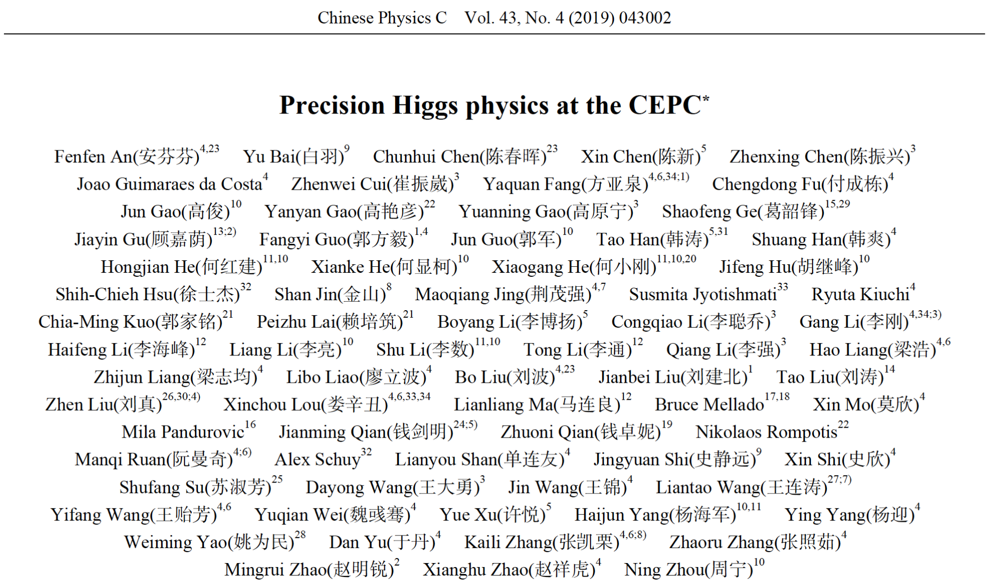
Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

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%	$M_{\rm top}$	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.
- …

Higgs + Snowmass white papers



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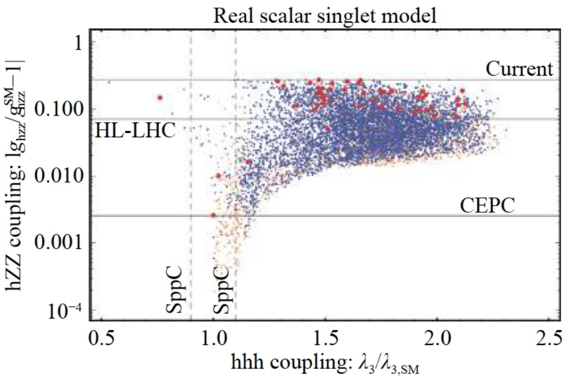

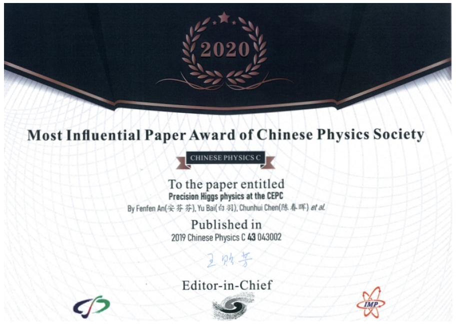

2020

Most Influential Paper Award of Chinese Physics Society

CHINESE PHYSICS C

To the paper entitled
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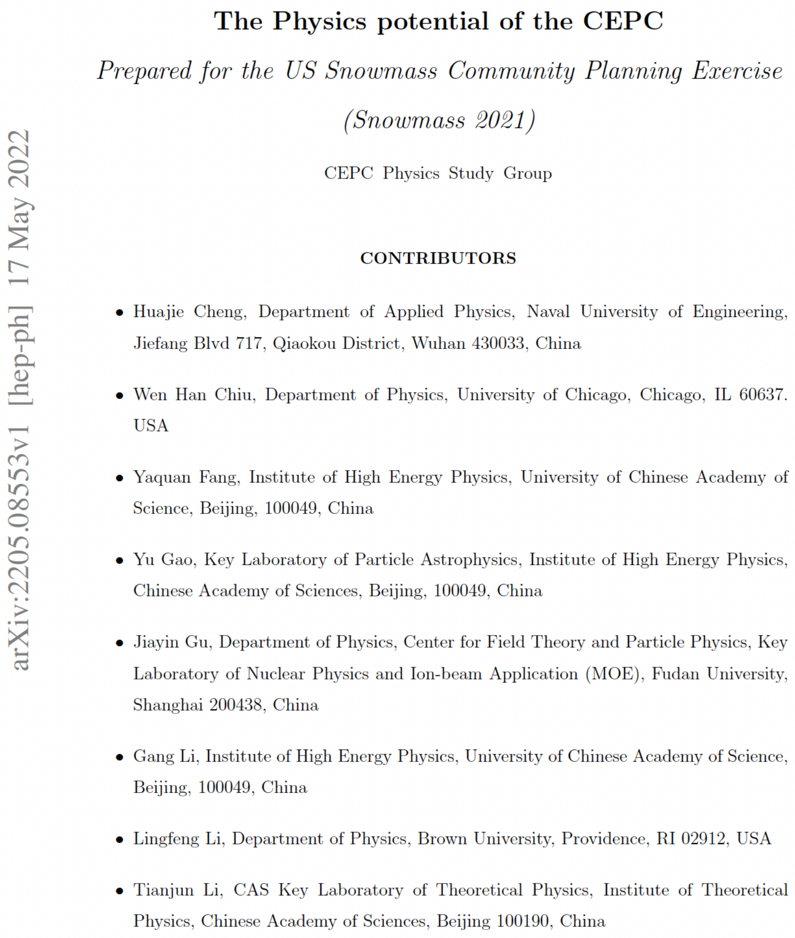
By Fenfen An(安芬芬), Yu Bai(白羽), Chunhui Chen(陈春晖) *et al.*
Published in
2019 Chinese Physics C **43** 043002
王贻芳
Editor-in-Chief



arXiv:2205.08553v1 [hep-ph] 17 May 2022

The Physics potential of the CEPC

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

CEPC Physics Study Group

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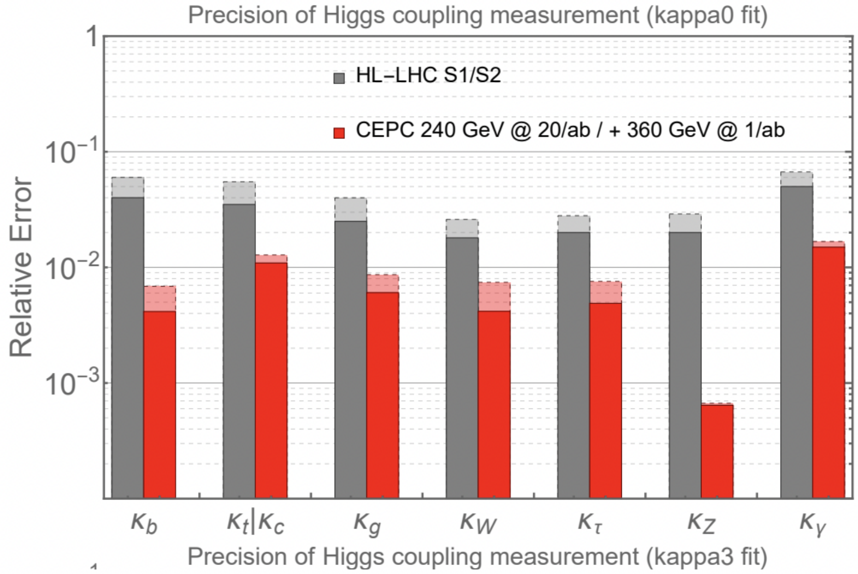
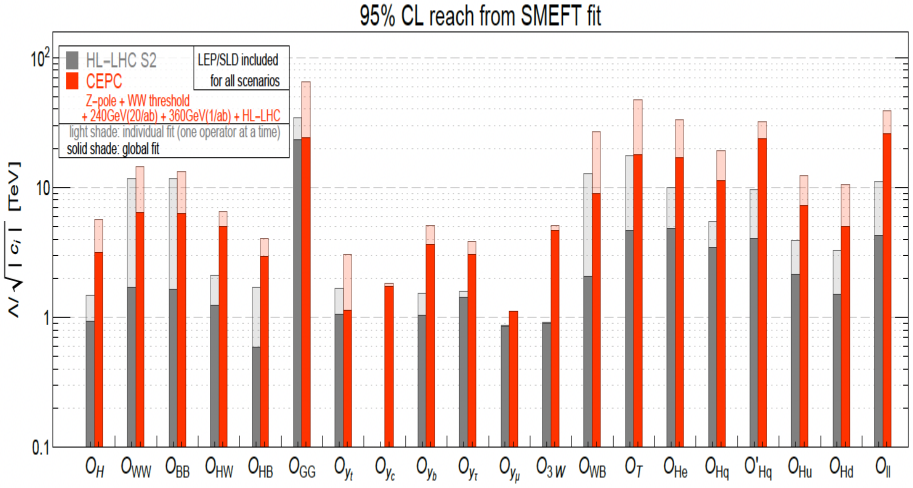
Summarize ~ 20 citables.

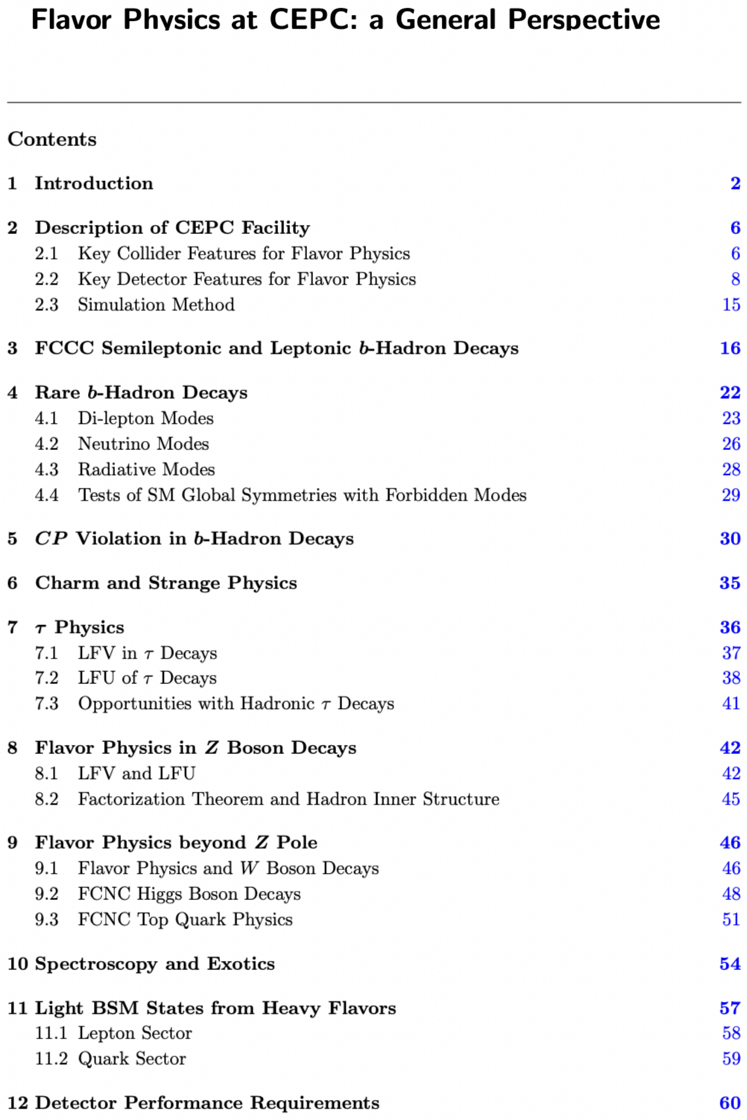
Physics reach at CEPC via Higgs, etc

	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	**vvH**	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%**
$H\to\gamma\gamma$	**3.02%**		**11%**	**16%**	
$H\to\mu\mu$	**6.36%**		**41%**	**57%**	
$H\to Z\gamma$	**8.50%**		**35%**		
$\text{Br}_{upper}(H\to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		





Flavor white paper

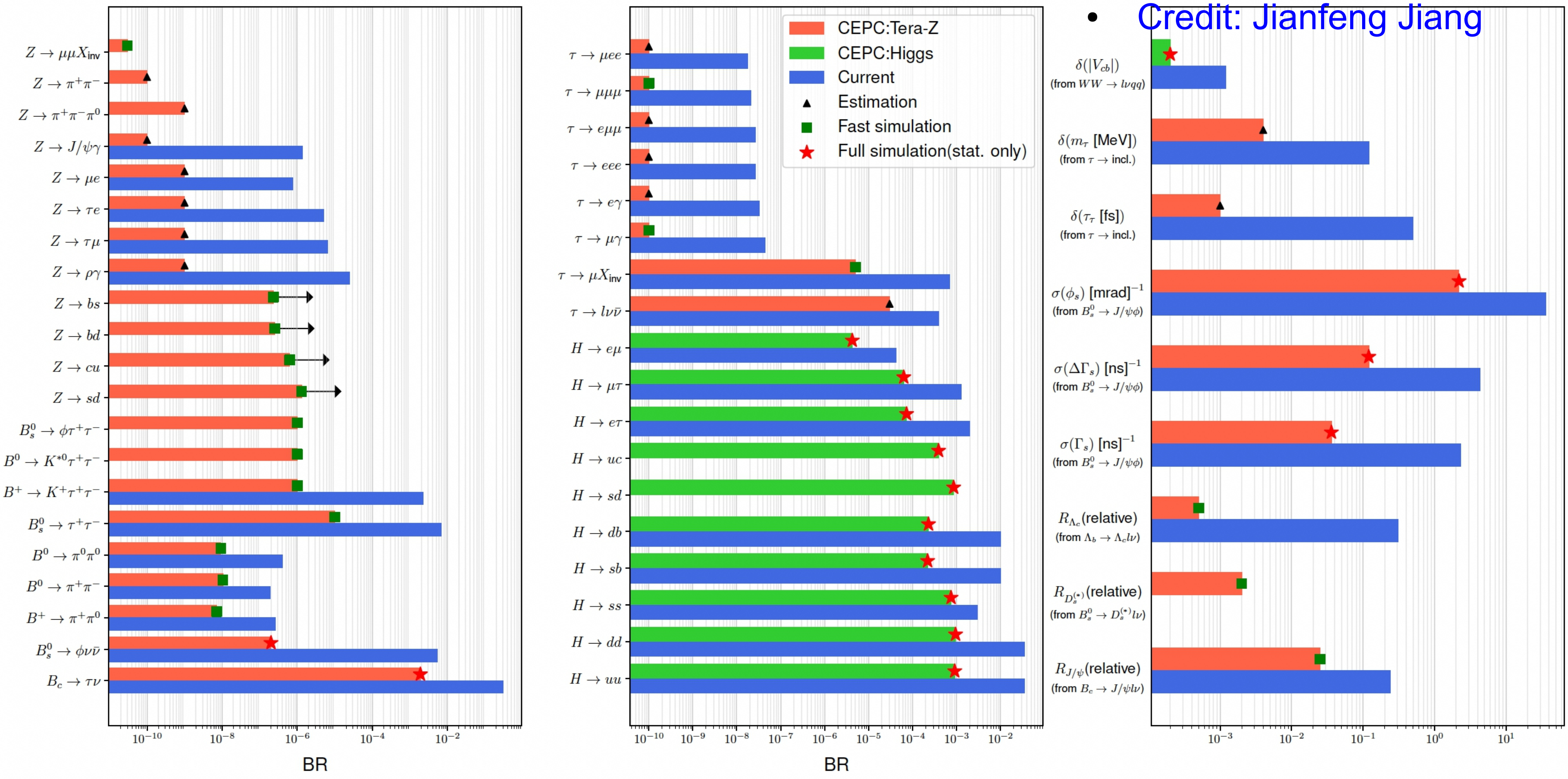


Flavor Physics at CEPC: a General Perspective

Contents

- Updates in 2024
  - Benchmark number increased from ~ 20 to ~ 50, especially with Jet Origin ID.
  - Bs-relevant CKM measurements
  - Spectroscope, LFV, LFU
  - ect

Global Impression: tentative



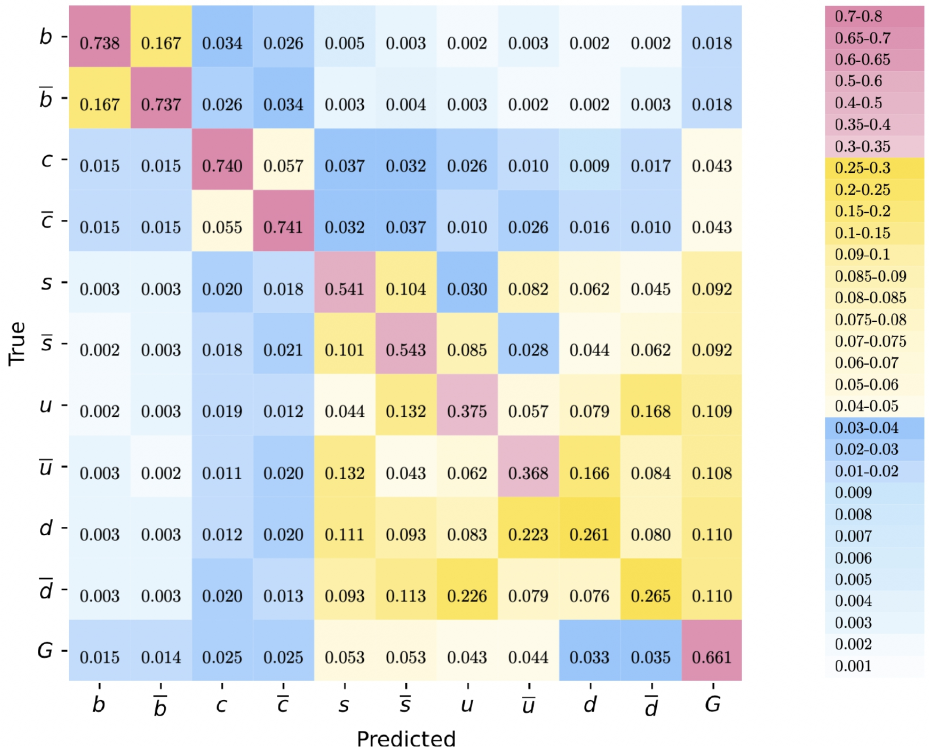
- Credit: Jianfeng Jiang

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

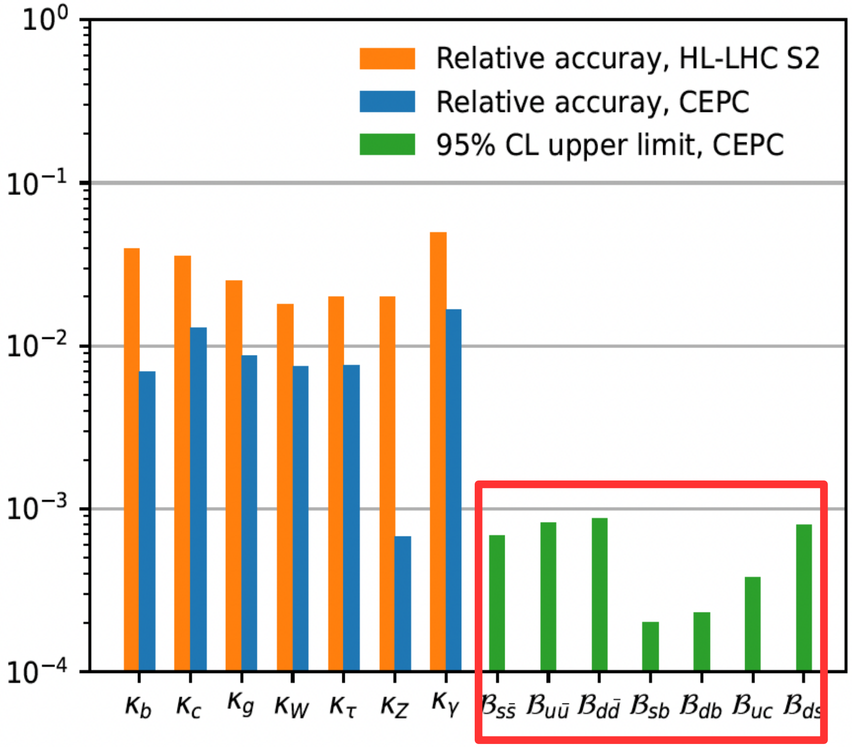
Orders of magnitudes improvements (1 – 2.5 orders...).

Many ongoing study especially towards CKM measurements (i.e. Bs→DK)

Jet origin id



	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



- 11 categories (5 quarks + 5 anti quarks + gluon) identification, realized at Full Simulated di-jet events at CEPC CDR baseline with Arbor + ParticleNet
- Improves Higgs rare/exotic hadronic decay measurements by 3 time – two orders of magnitudes
- Published in PRL. Comment from the referee: *"demonstrate the world-leading performance of tagger", "a "game changer" and opens new horizons for precision flavor studies at all future experiments."*

Vcb from semi-leptonic W decay

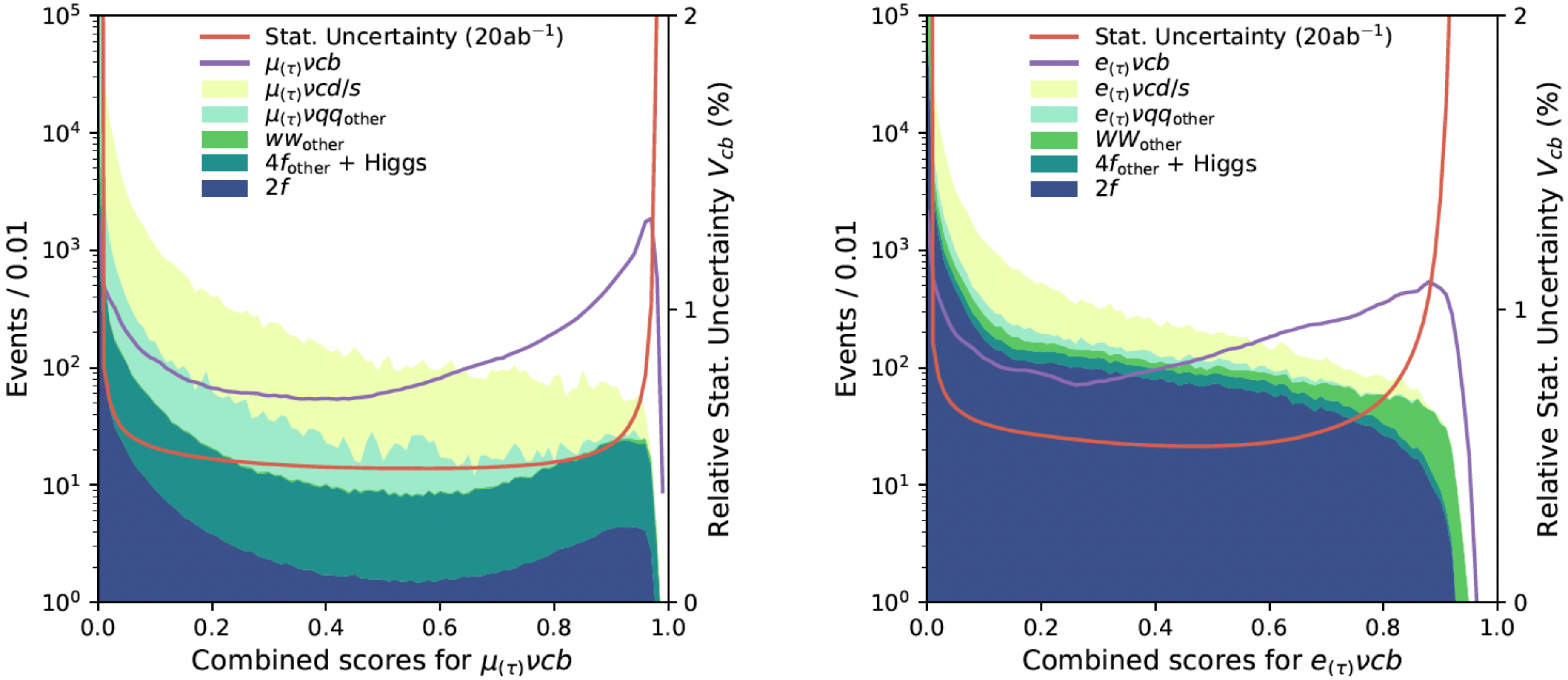
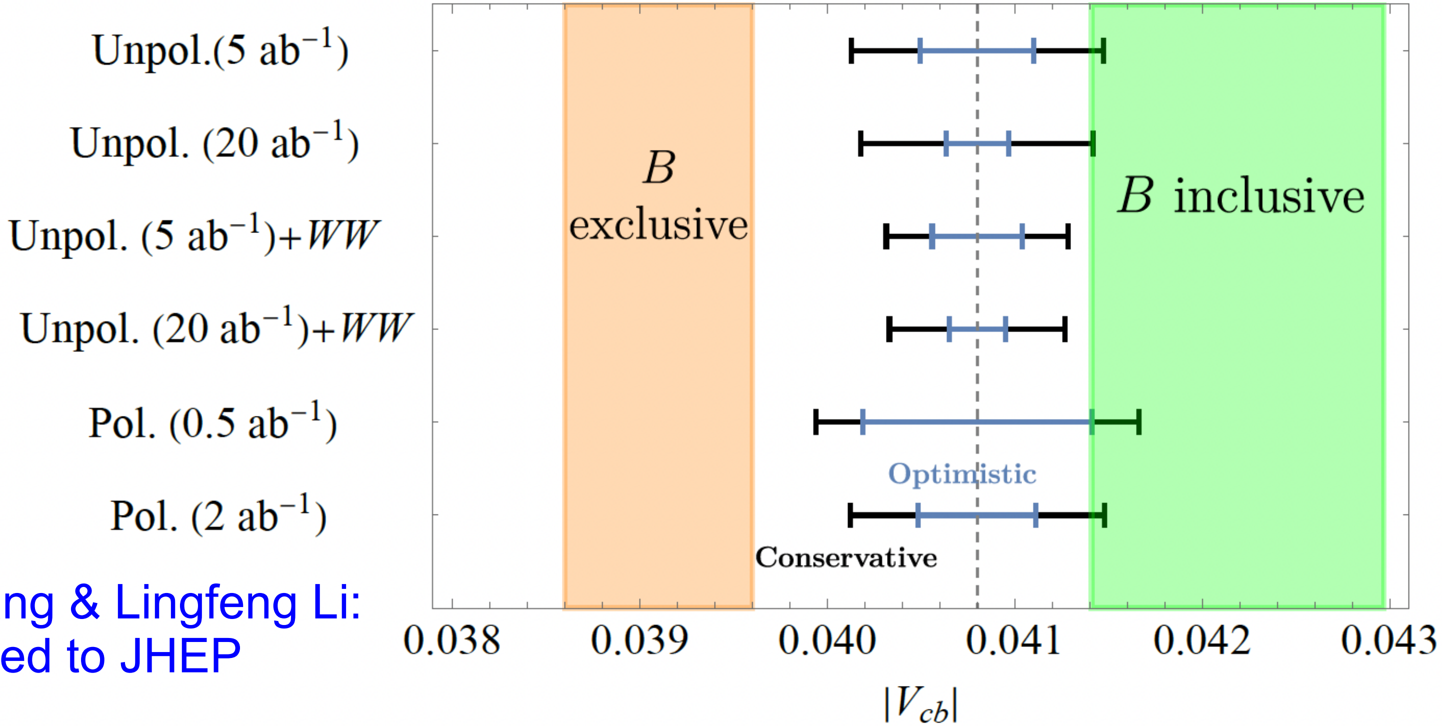


Figure 4: The BDT score distribution of signal and backgrounds in: the muon channel (left) and electron channel (right). The red curve indicates the projected statistical relative sensitivity estimated from Eq. 4.1 assuming a luminosity of 20 ab^{-1}.

Contributor: Hao Liang, Lingfeng Li, etc

Vcb: Systematic controls



- Hao Liang & Lingfeng Li: Submitted to JHEP

- Dedicated discussion on systematic, mainly dominated by jet origin id performance calibration + background yield uncertainties.

- In pace with FCC studies (estimated using full hadronic events).

- Similar method could be applied to Vcs (suggested by IDRC) and Vts (from top decay), and even Z FCNC (statistical up-limits of 1E-6 to 1E-7, while Calibration & systematic control need real breakthrough)

Lepton Flavor Violation

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

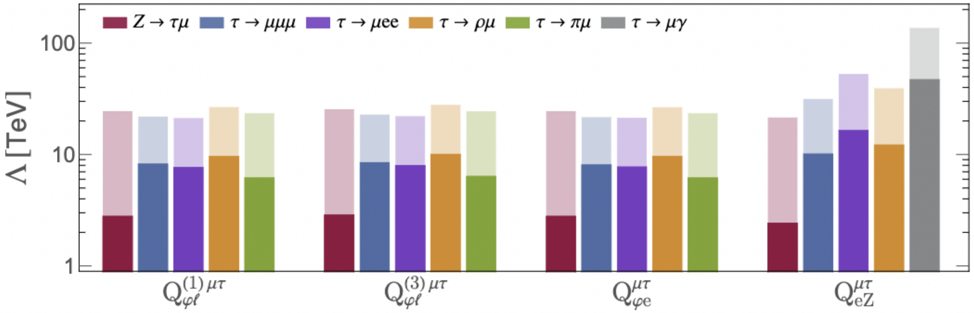


Figure 28: Sensitivity reach for probing the NP scale of the LFV operators in Eq. (8.1) and Eq. (8.2). Here the current bounds (dark-colored bars) are set by ATLAS [206] ($Z \to \tau\mu$) and B factories [149] (LFV τ decays), and the projected sensitivities (light-colored bars) are based on searches for $Z \to \tau\mu$ at the CEPC Z pole run with 100 ab^{-1} and $\tau \to \mu$ transitions at Belle II with 50 ab^{-1} [8], see Tables 7 and 8. The Wilson coefficients have been set equal to one uniformly. This plot is taken from Ref. [202]

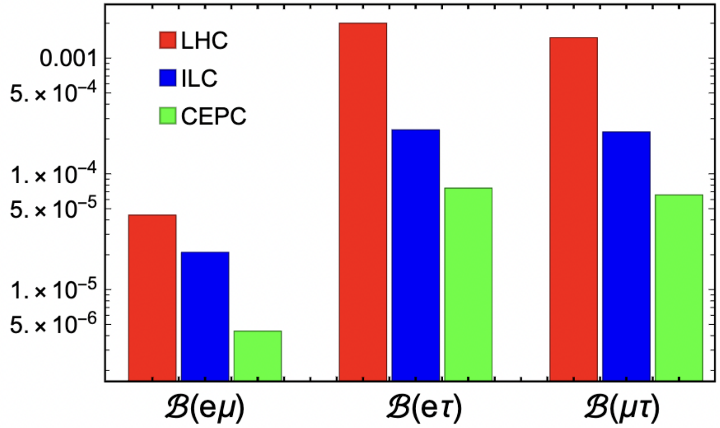
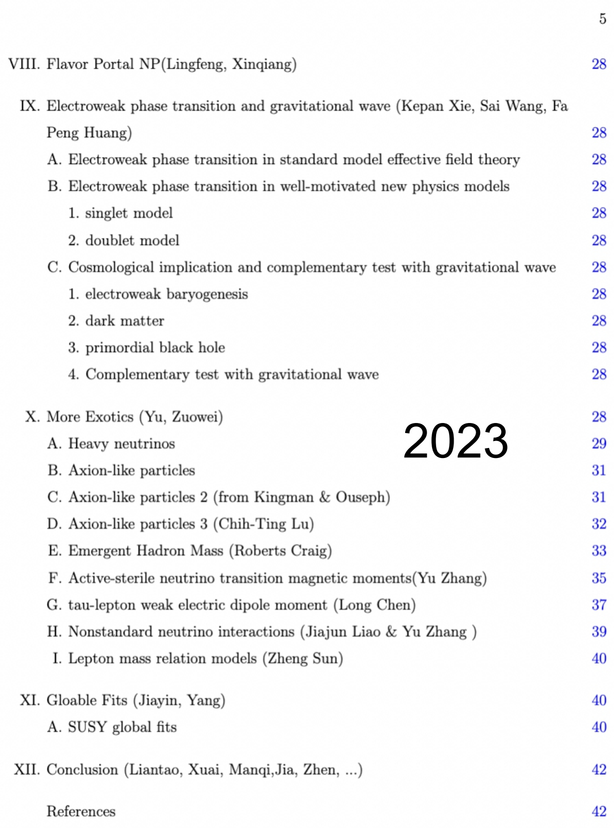


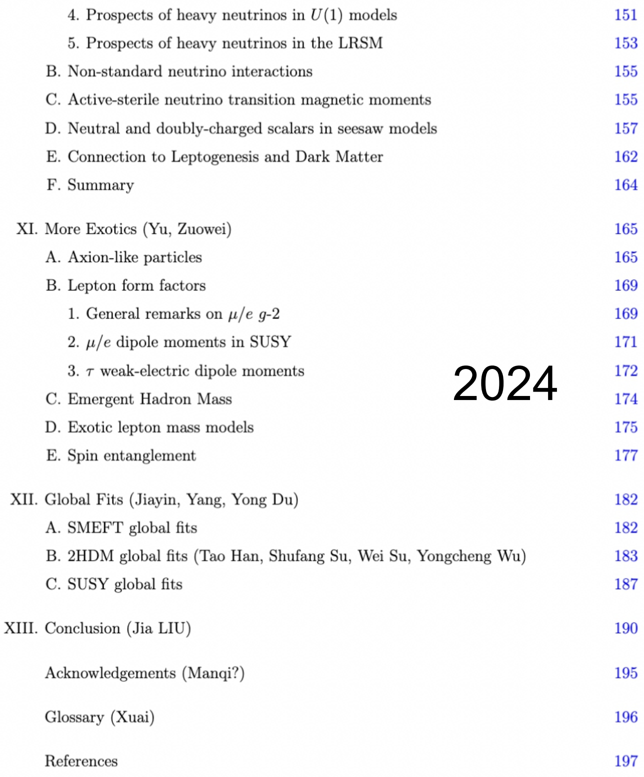
Figure 33: Anticipated upper limits on LFV Higgs decays at CEPC, ILC, and LHC. Figure updated from [231].

- Credit: Lorenzo Calibbi (Left) + Qin qin (right)

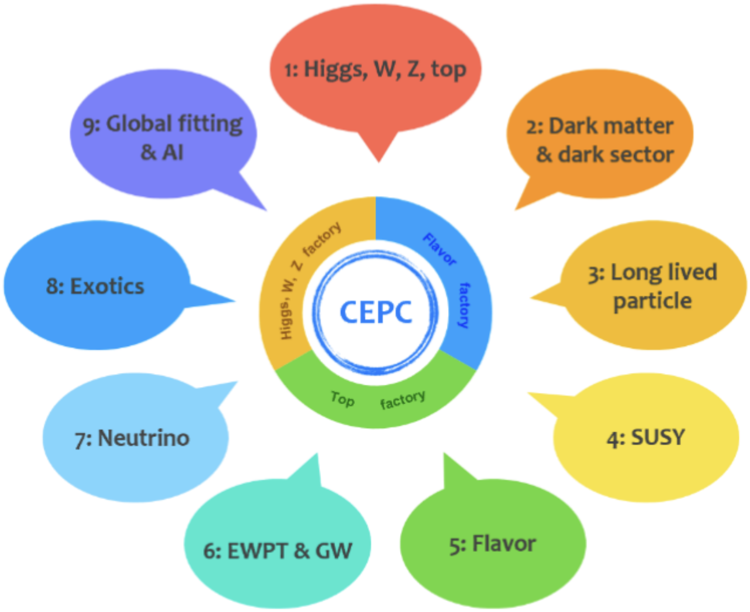
New Physics white paper



2023



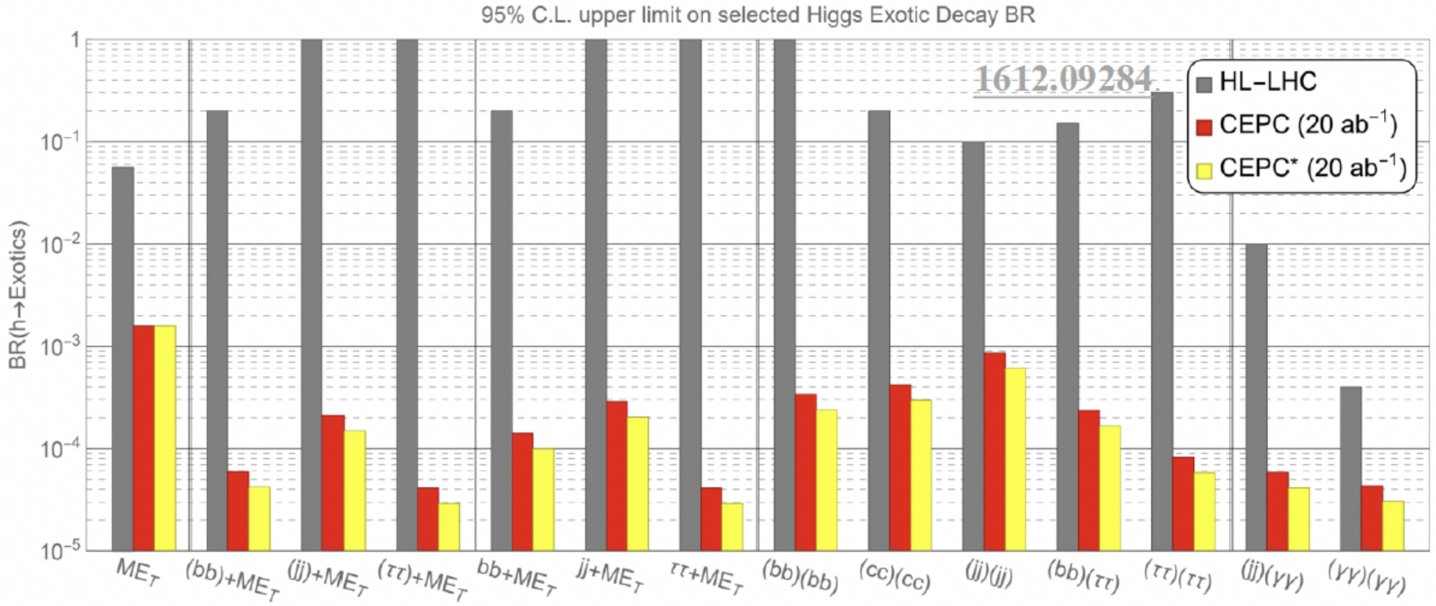
2024



- Credit: hanhua Cui, Yu Gao, Xuai Zhuang

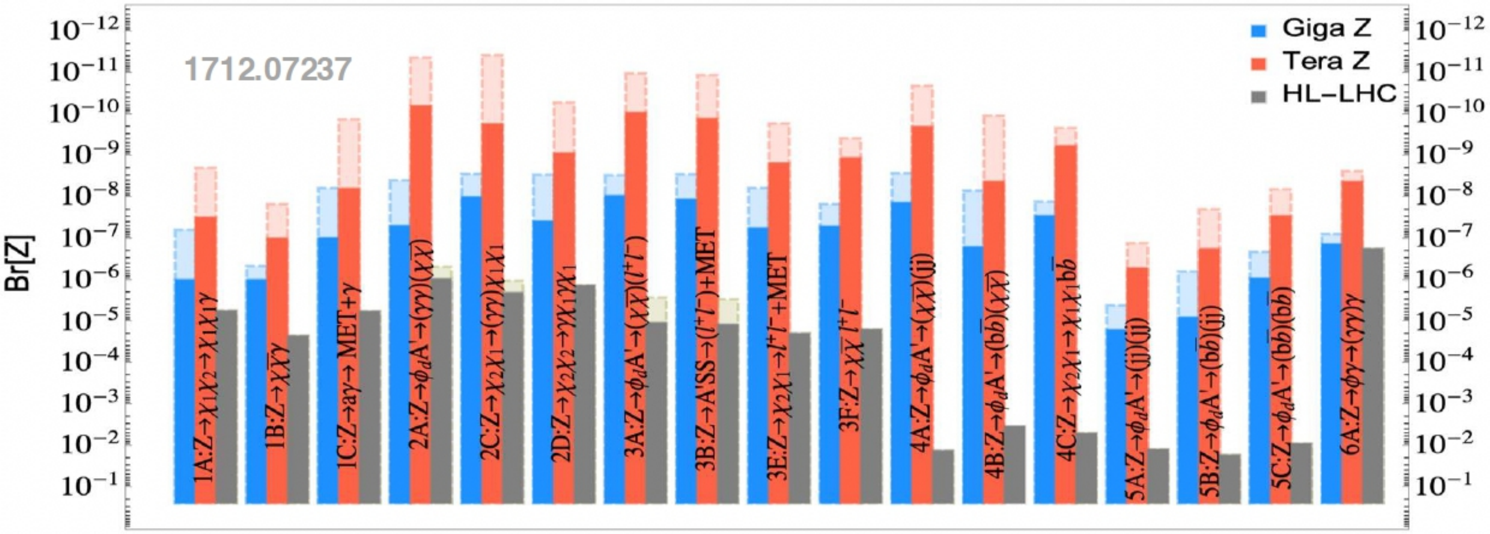
Contents extends from 40 pages → 200 pages...

Exotic decays



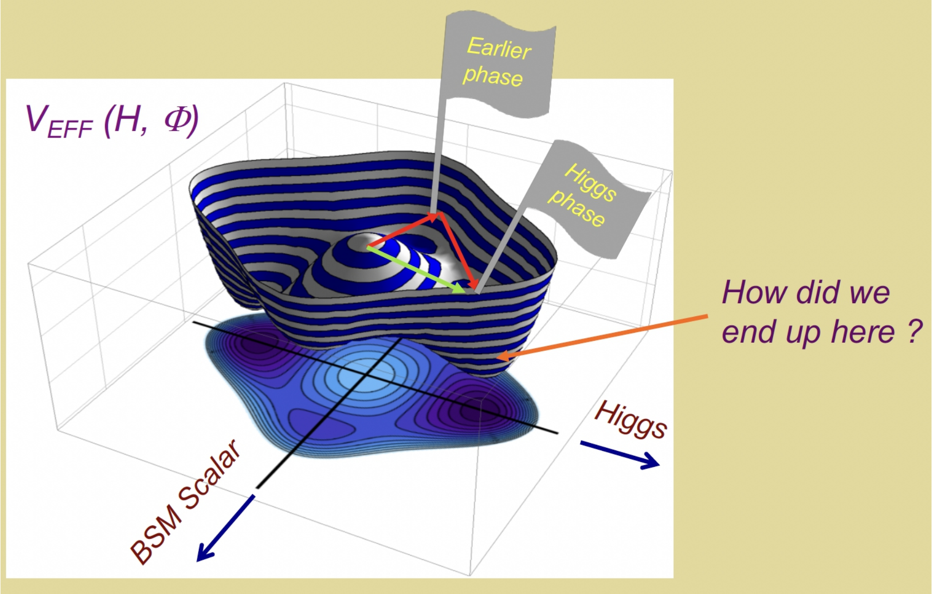
The 95% C.L. upper limit on selected Higgs exotic decay BR

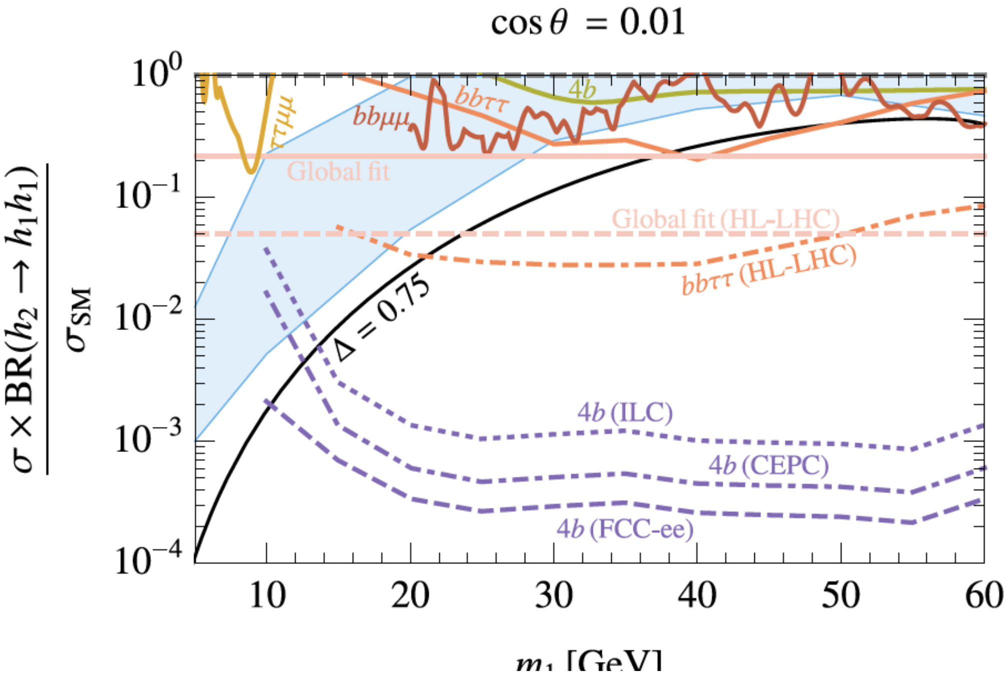
- Credit: Zhen Liu, Jia Liu, Xuai Zhuang, etc

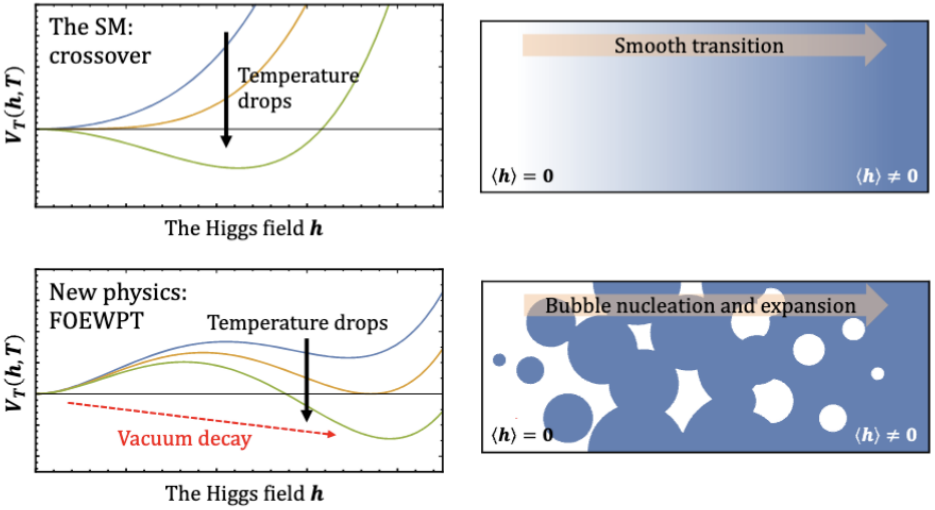


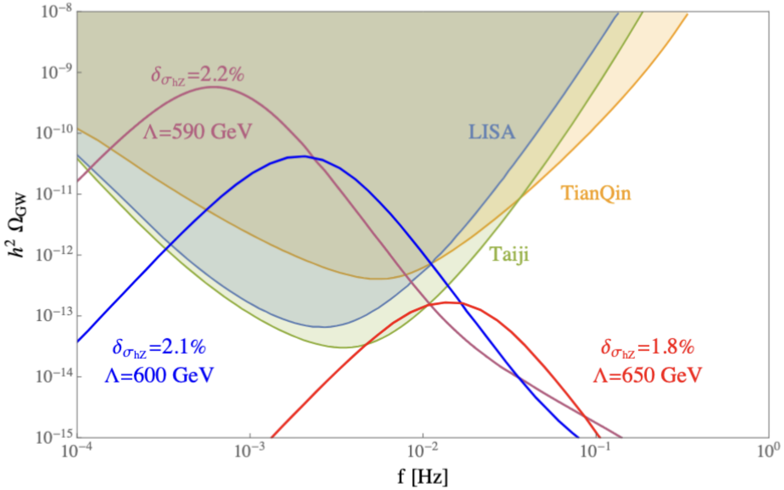
The reach for the branching ratio of various exotic Z decay modes

Phase Transition in early Universe



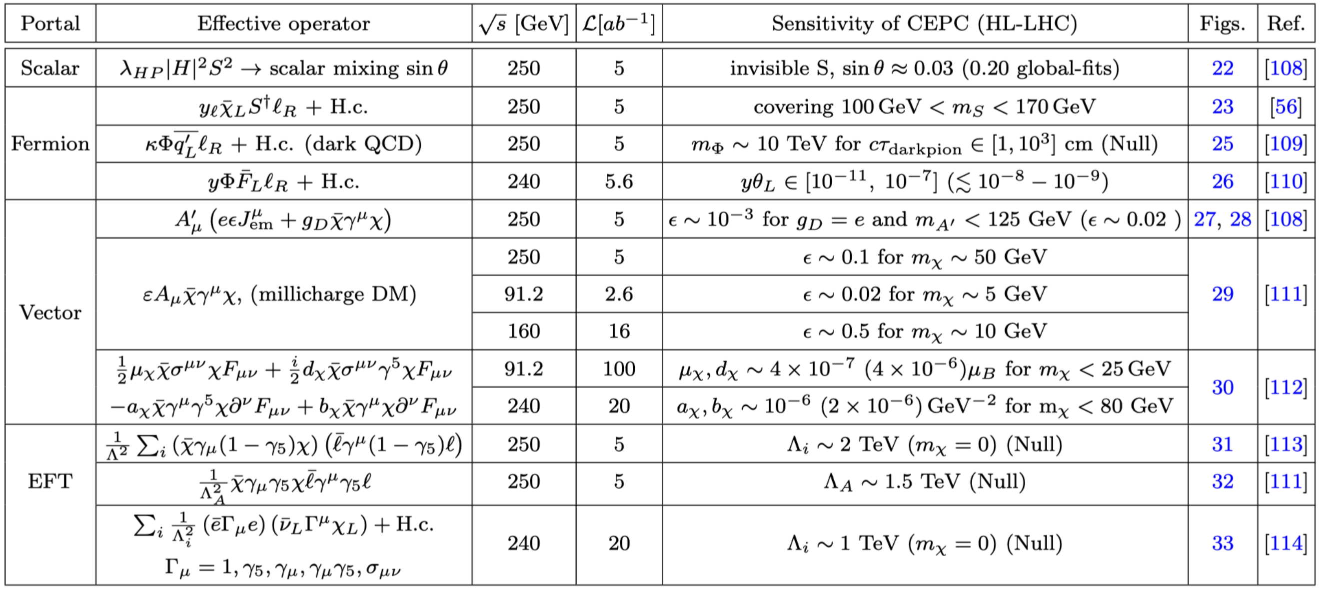




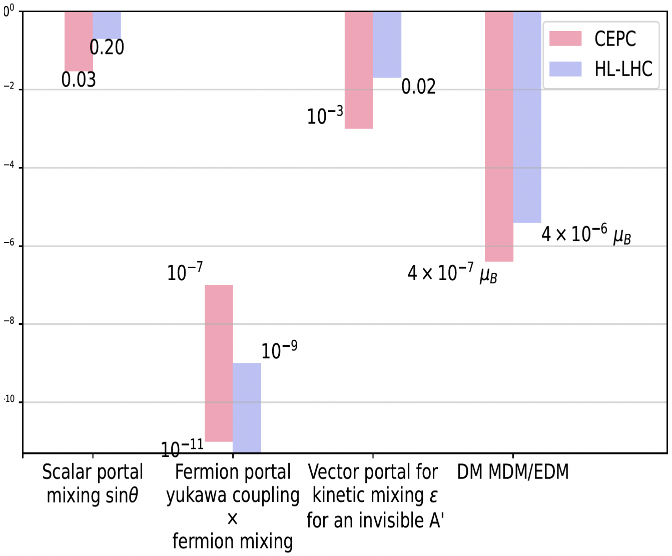


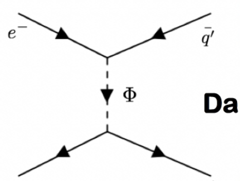
- Credit: Michael Ramse Musolfy, Kepan Xie, etc

Dark sector



Portal	Effective operator	$\sqrt{s}$ [GeV]	$\mathcal{L}[ab^{-1}]$	Sensitivity of CEPC (HL-LHC)	Figs.	Ref.
Scalar	$\lambda_{HP}\lvert H\rvert^2 S^2 \to$ scalar mixing $\sin\theta$	250	5	invisible S, $\sin\theta \approx 0.03$ (0.20 global-fits)	22	[108]
Fermion	$y_\ell \bar{\chi}_L S^\dagger \ell_R$ + H.c.	250	5	covering $100\,\text{GeV} < m_S < 170\,\text{GeV}$	23	[56]
	$\kappa\Phi\overline{q'_L}\ell_R$ + H.c. (dark QCD)	250	5	$m_\Phi \sim 10$ TeV for $c\tau_{\text{darkpion}} \in [1, 10^3]$ cm (Null)	25	[109]
	$y\Phi\bar{F}_L\ell_R$ + H.c.	240	5.6	$y\theta_L \in [10^{-11},\ 10^{-7}]$ ($\lesssim 10^{-8} - 10^{-9}$)	26	[110]
Vector	$A'_\mu\left(e\epsilon J^\mu_{\text{em}} + g_D\bar{\chi}\gamma^\mu\chi\right)$	250	5	$\epsilon \sim 10^{-3}$ for $g_D = e$ and $m_{A'} < 125$ GeV ($\epsilon \sim 0.02$)	27, 28	[108]
	$\varepsilon A_\mu\bar{\chi}\gamma^\mu\chi$, (millicharge DM)	250	5	$\epsilon \sim 0.1$ for $m_\chi \sim 50$ GeV	29	[111]
		91.2	2.6	$\epsilon \sim 0.02$ for $m_\chi \sim 5$ GeV		
		160	16	$\epsilon \sim 0.5$ for $m_\chi \sim 10$ GeV		
	$\frac{1}{2}\mu_\chi\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu} + \frac{i}{2}d_\chi\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi F_{\mu\nu}$	91.2	100	$\mu_\chi, d_\chi \sim 4\times10^{-7}$ $(4\times10^{-6})\mu_B$ for $m_\chi < 25\,\text{GeV}$	30	[112]
	$-a_\chi\bar{\chi}\gamma^\mu\gamma^5\chi\partial^\nu F_{\mu\nu} + b_\chi\bar{\chi}\gamma^\mu\chi\partial^\nu F_{\mu\nu}$	240	20	$a_\chi, b_\chi \sim 10^{-6}$ $(2\times10^{-6})\,\text{GeV}^{-2}$ for $\text{m}_\chi < 80$ GeV		
EFT	$\frac{1}{\Lambda^2}\sum_i\left(\bar{\chi}\gamma_\mu(1-\gamma_5)\chi\right)\left(\bar{\ell}\gamma^\mu(1-\gamma_5)\ell\right)$	250	5	$\Lambda_i \sim 2$ TeV $(m_\chi = 0)$ (Null)	31	[113]
	$\frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell$	250	5	$\Lambda_A \sim 1.5$ TeV (Null)	32	[111]
	$\sum_i \frac{1}{\Lambda_i^2}\left(\bar{e}\Gamma_\mu e\right)\left(\bar{\nu}_L\Gamma^\mu\chi_L\right)$ + H.c. $\Gamma_\mu = 1, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu}$	240	20	$\Lambda_i \sim 1$ TeV $(m_\chi = 0)$ (Null)	33	[114]



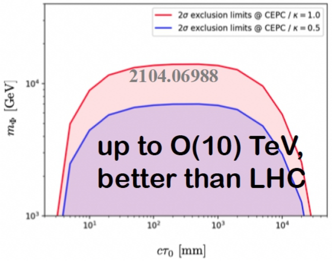


Decay to leptons

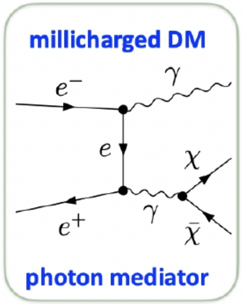
Dark quark q'

Jet-like

Signature: Lepton + jet + MET

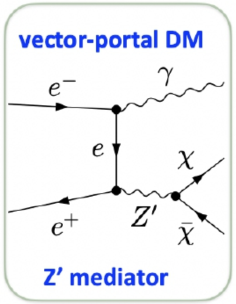


up to O(10) TeV, better than LHC



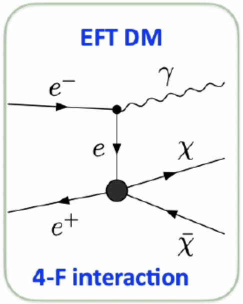
millicharged DM

photon mediator



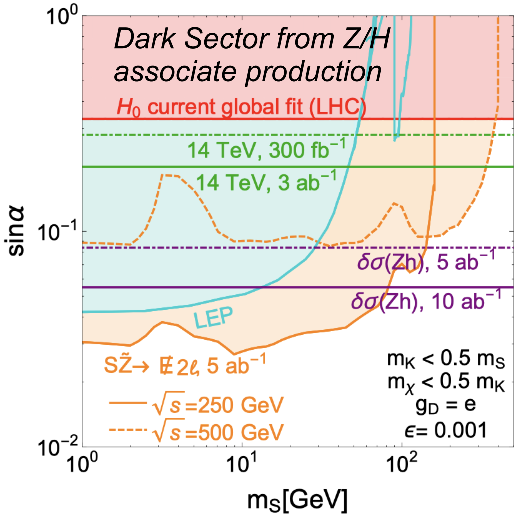
vector-portal DM

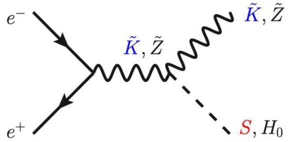
Z' mediator

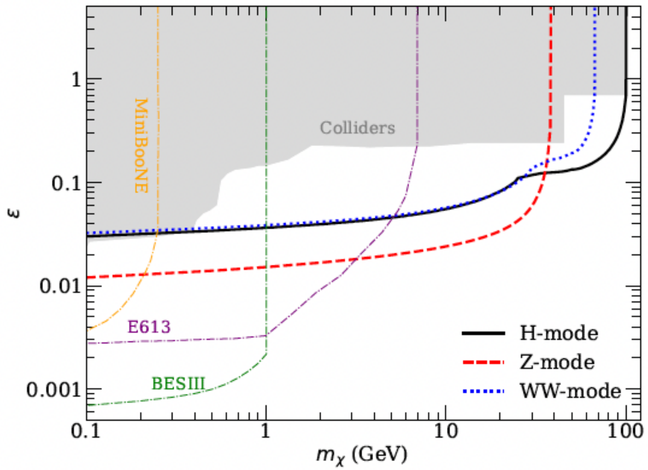


EFT DM

4-F interaction



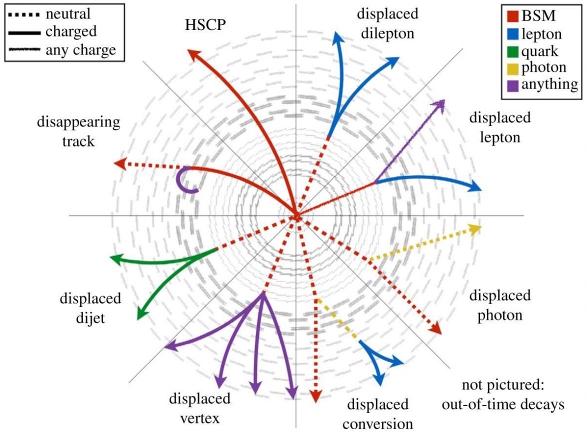


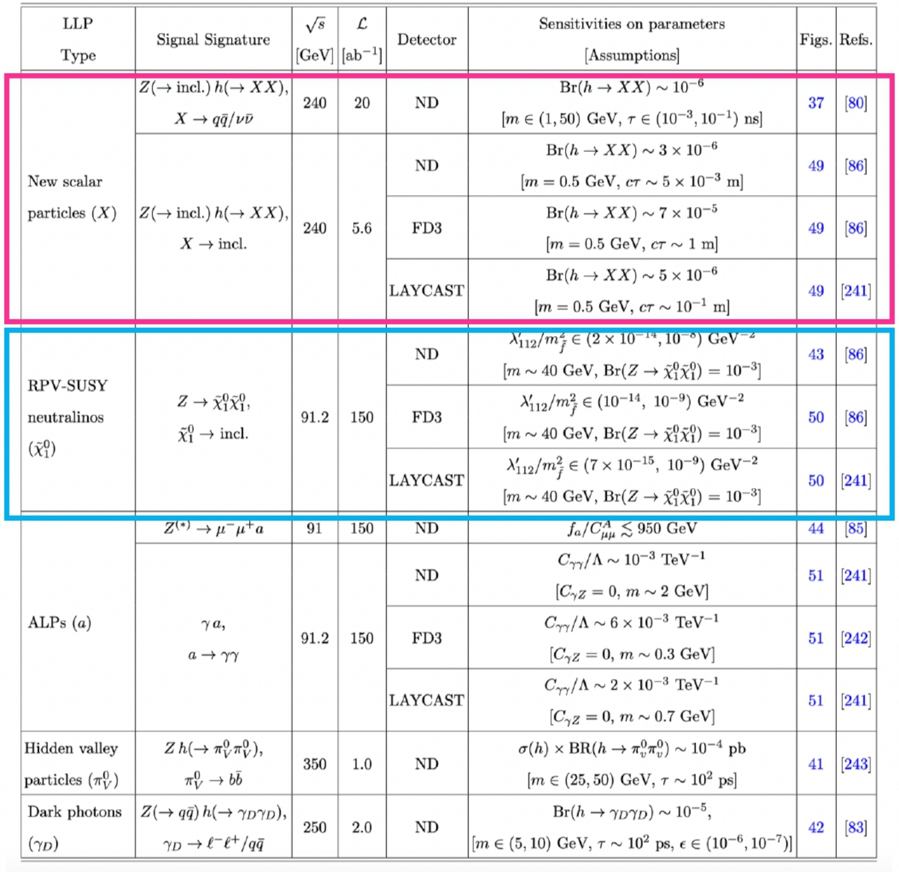


Vector portal DM

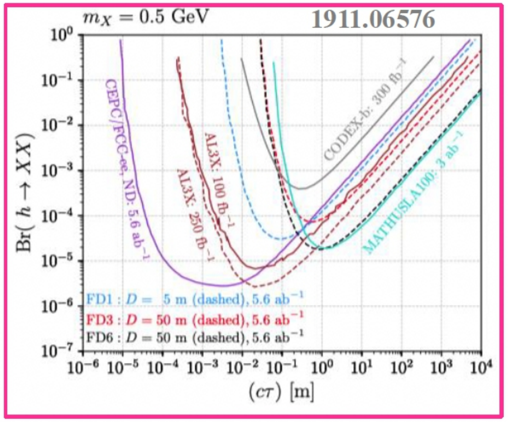
- Credit: Jia Liu, etc

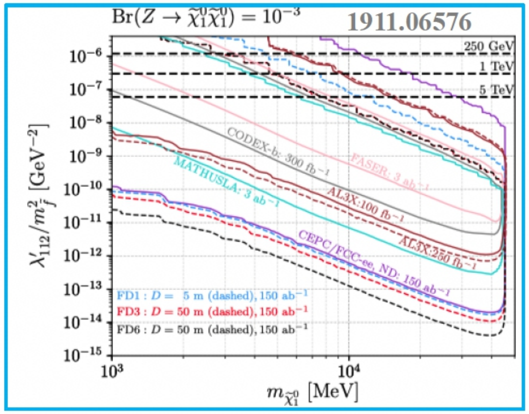
LLP, especially with Far detector

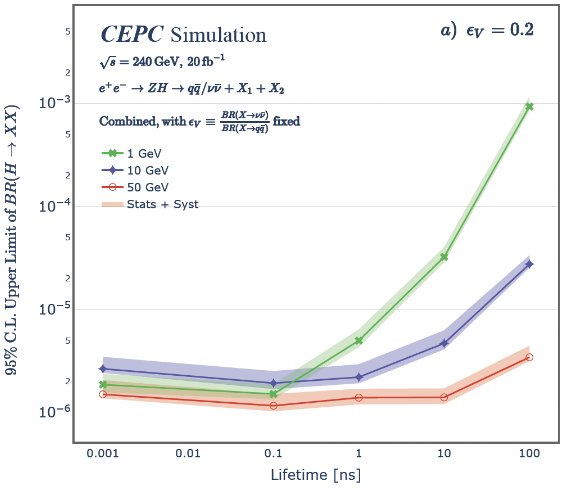




LLP Type	Signal Signature	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [ab^{-1}]	Detector	Sensitivities on parameters [Assumptions]	Figs.	Refs.
New scalar particles (X)	$Z(\to \text{incl.})\,h(\to XX)$, $X \to q\bar{q}/\nu\bar{\nu}$	240	20	ND	$\text{Br}(h \to XX) \sim 10^{-6}$ [$m \in (1,50)$ GeV, $\tau \in (10^{-3}, 10^{-1})$ ns]	37	[80]
	$Z(\to \text{incl.})\,h(\to XX)$, $X \to \text{incl.}$	240	5.6	ND	$\text{Br}(h \to XX) \sim 3 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 5 \times 10^{-3}$ m]	49	[86]
				FD3	$\text{Br}(h \to XX) \sim 7 \times 10^{-5}$ [$m = 0.5$ GeV, $c\tau \sim 1$ m]	49	[86]
				LAYCAST	$\text{Br}(h \to XX) \sim 5 \times 10^{-6}$ [$m = 0.5$ GeV, $c\tau \sim 10^{-1}$ m]	49	[241]
RPV-SUSY neutralinos ($\tilde{\chi}_1^0$)	$Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to \text{incl.}$	91.2	150	ND	$\lambda'_{112}/m_{\tilde{f}}^2 \in (2 \times 10^{-14}, 10^{-8})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0) = 10^{-3}$]	43	[86]
				FD3	$\lambda'_{112}/m_{\tilde{f}}^2 \in (10^{-14},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0) = 10^{-3}$]	50	[86]
				LAYCAST	$\lambda'_{112}/m_{\tilde{f}}^2 \in (7 \times 10^{-15},\ 10^{-9})$ GeV^{-2} [$m \sim 40$ GeV, $\text{Br}(Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0) = 10^{-3}$]	50	[241]
ALPs (a)	$Z^{(*)} \to \mu^-\mu^+a$	91	150	ND	$f_a/C_{\mu\mu}^A \lesssim 950$ GeV	44	[85]
	$\gamma\, a$, $a \to \gamma\gamma$	91.2	150	ND	$C_{\gamma\gamma}/\Lambda \sim 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 2$ GeV]	51	[241]
				FD3	$C_{\gamma\gamma}/\Lambda \sim 6 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.3$ GeV]	51	[242]
				LAYCAST	$C_{\gamma\gamma}/\Lambda \sim 2 \times 10^{-3}$ TeV^{-1} [$C_{\gamma Z} = 0$, $m \sim 0.7$ GeV]	51	[241]
Hidden valley particles (π_V^0)	$Z\,h(\to \pi_V^0\pi_V^0)$, $\pi_V^0 \to b\bar{b}$	350	1.0	ND	$\sigma(h) \times \text{BR}(h \to \pi_v^0\pi_v^0) \sim 10^{-4}$ pb [$m \in (25,50)$ GeV, $\tau \sim 10^2$ ps]	41	[243]
Dark photons (γ_D)	$Z(\to q\bar{q})\,h(\to \gamma_D\gamma_D)$, $\gamma_D \to \ell^-\ell^+/q\bar{q}$	250	2.0	ND	$\text{Br}(h \to \gamma_D\gamma_D) \sim 10^{-5}$, [$m \in (5,10)$ GeV, $\tau \sim 10^2$ ps, $\epsilon \in (10^{-6}, 10^{-7})$]	42	[83]



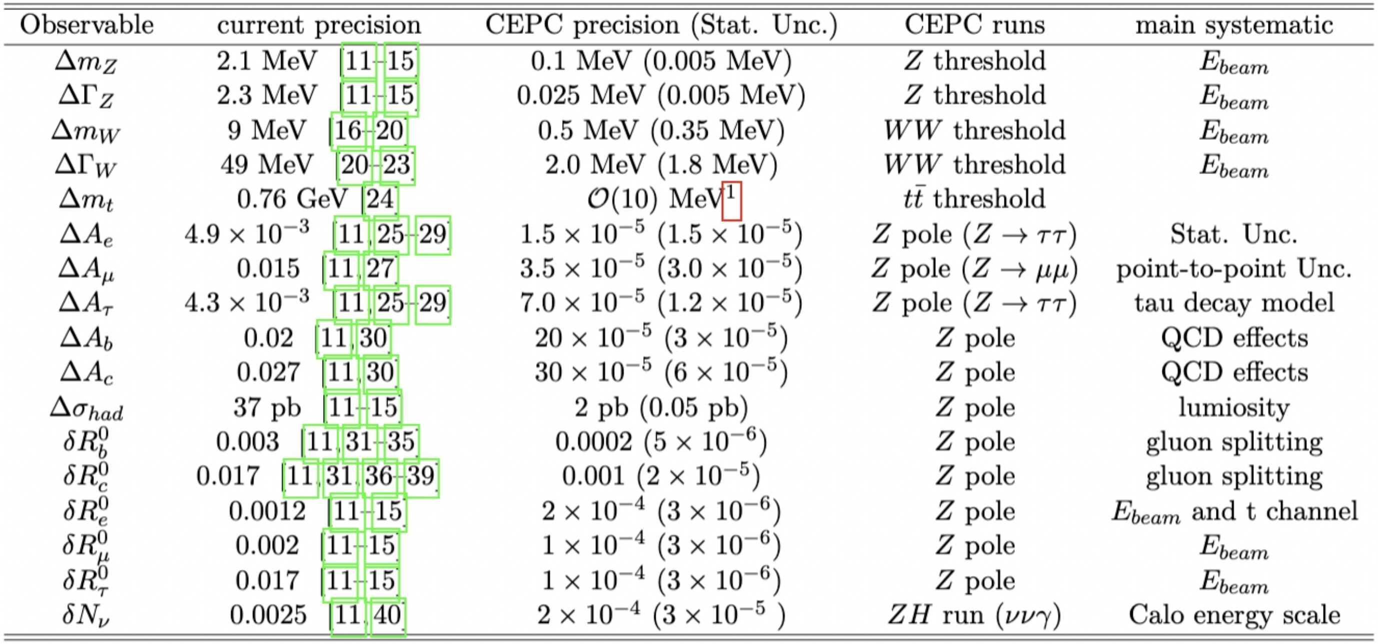




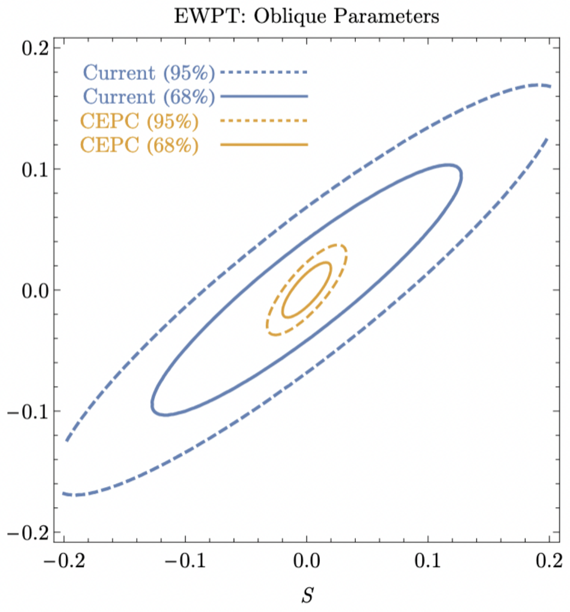
Far detector could enhance & complement the near detector (main detector) sensitivities;
While the understanding of background is the key issue.

- Credit: Kechen Wang, Yongchao Zhang, etc

Electroweak white paper

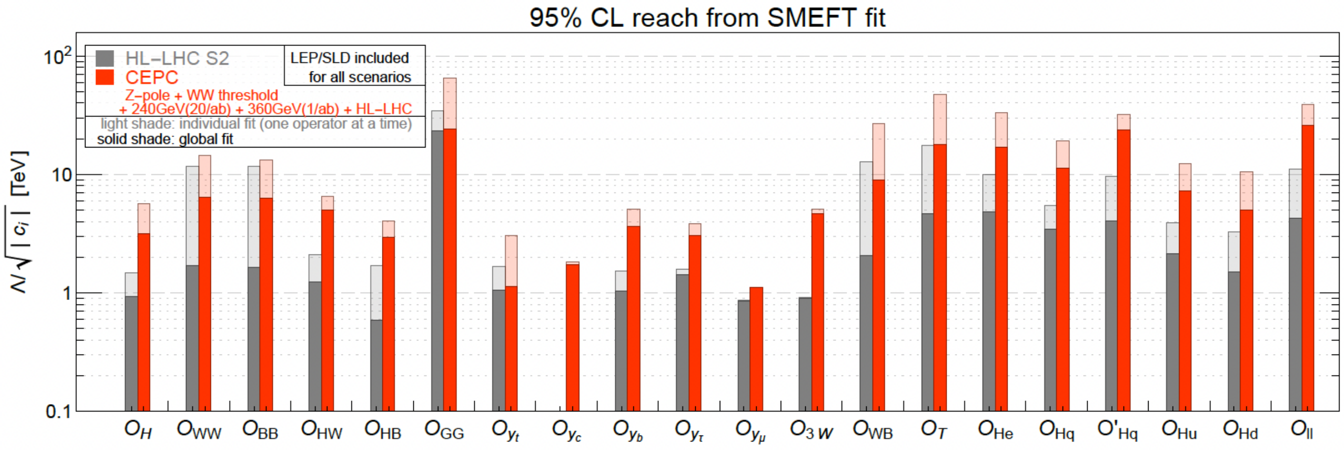


Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [11–15]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [11–15]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [16–20]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [20–23]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [24]	$\mathcal{O}(10)$ MeV[1]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [11, 25–29]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [11, 27]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [11, 25–29]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model
ΔA_b	0.02 [11, 30]	20×10^{-5} (3×10^{-5})	Z pole	QCD effects
ΔA_c	0.027 [11, 30]	30×10^{-5} (6×10^{-5})	Z pole	QCD effects
$\Delta\sigma_{had}$	37 pb [11–15]	2 pb (0.05 pb)	Z pole	lumiosity
δR_b^0	0.003 [11, 31–35]	0.0002 (5×10^{-6})	Z pole	gluon splitting
δR_c^0	0.017 [11, 31, 36–39]	0.001 (2×10^{-5})	Z pole	gluon splitting
δR_e^0	0.0012 [11–15]	2×10^{-4} (3×10^{-6})	Z pole	E_{beam} and t channel
δR_μ^0	0.002 [11–15]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δR_τ^0	0.017 [11–15]	1×10^{-4} (3×10^{-6})	Z pole	E_{beam}
δN_ν	0.0025 [11, 40]	2×10^{-4} $(3 \times 10^{-5}$)	ZH run ($\nu\nu\gamma$)	Calo energy scale



Reviewing anticipated Experimental Input,

And to include updated Higgs + top measurements



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Credit: Jiayin Gu, etc

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

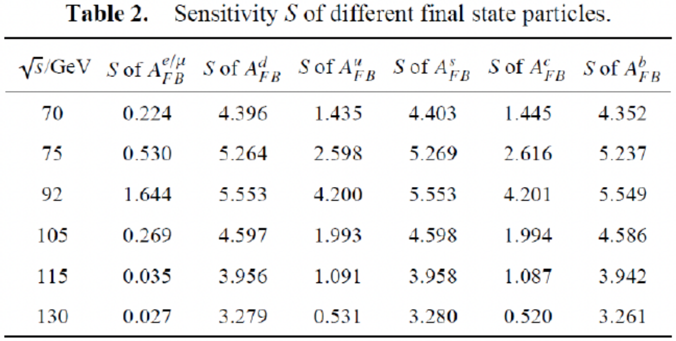


Table 2. Sensitivity S of different final state particles.

$\sqrt{s}$/GeV	S of $A_{FB}^{e/\mu}$	S of A_{FB}^{d}	S of A_{FB}^{u}	S of A_{FB}^{s}	S of A_{FB}^{c}	S of A_{FB}^{b}
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

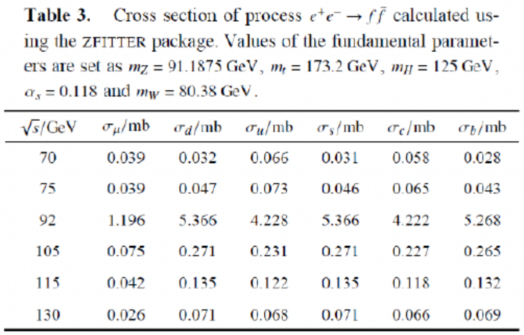


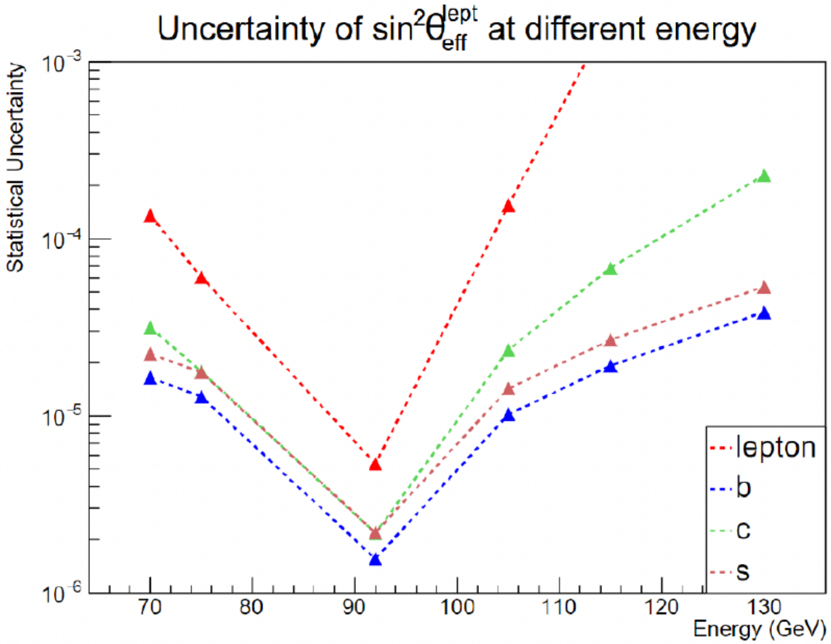
Table 3. Cross section of process $e^+e^- \to f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as $m_Z = 91.1875$ GeV, $m_t = 173.2$ GeV, $m_H = 125$ GeV, $\alpha_s = 0.118$ and $m_W = 80.38$ GeV.

$\sqrt{s}$/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 $\sin^2\theta_{eff}^{l}$ measurement.

(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)



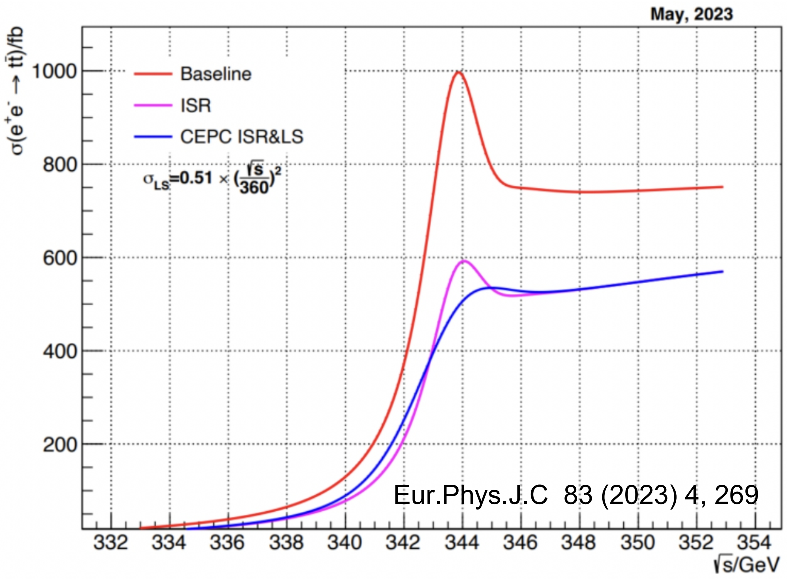
- Submitted to EPJC

$\sqrt{s}$	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}

- Credit: Zhenyu Zhao, etc

Top + differential measurements

Top quark mass measurements



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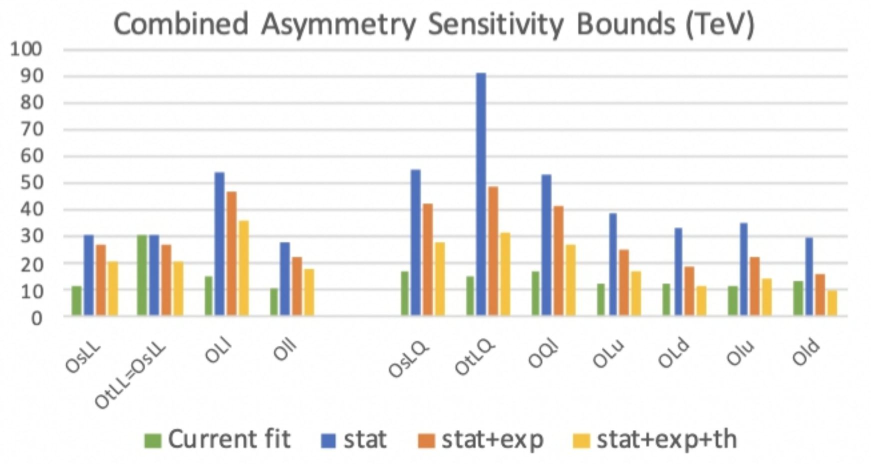
	Optimistic/MeV	Conservative/MeV
Statistics	9	9
Theory	8	24
Background	2	14
α_s	17	17
Width	10	10
Experimental Efficiency	5	44
Quick Scan	2	2
Beam	2	2
LS	3	6
Total	24	57

4-fermion interactions constrained from asymmetries (Xsec, forward-backward & polarization) at Z pole



$\mu^+\mu^-$	$q\bar{q}$
$\mathcal{O}_{LL}^{s} \equiv \frac{1}{2}(\bar{L}\gamma^{\mu}L)(\bar{L}\gamma_{\mu}L)$	$\mathcal{O}_{LQ}^{s} \equiv (\bar{L}\gamma^{\mu}L)(\bar{Q}\gamma_{\mu}Q)$
$\mathcal{O}_{LL}^{t} = \frac{1}{2}\left(\bar{L}\gamma^{\mu}\sigma^{a}L\right)\left(\bar{L}\gamma_{\mu}\sigma^{a}L\right)$	$\mathcal{O}_{LQ}^{t} = \left(\bar{L}\gamma^{\mu}\sigma^{a}L\right)\left(\bar{Q}\gamma_{\mu}\sigma^{a}Q\right)$
$\mathcal{O}_{L\ell} = \left(\bar{L}\gamma^{\mu}L\right)\left(\bar{\ell}\gamma_{\mu}\ell\right)$	$\mathcal{O}_{Q\ell} = \left(\bar{Q}\gamma^{\mu}Q\right)\left(\bar{\ell}\gamma_{\mu}\ell\right)$
$\mathcal{O}_{\ell\ell} = \frac{1}{2}\left(\bar{\ell}\gamma^{\mu}\ell\right)\left(\bar{\ell}\gamma_{\mu}\ell\right)$	$\mathcal{O}_{Lu} = \left(\bar{L}\gamma^{\mu}L\right)\left(\bar{q}_{u}\gamma_{\mu}q_{u}\right)$
	$\mathcal{O}_{Ld} = \left(\bar{L}\gamma^{\mu}L\right)\left(\bar{q}_{d}\gamma_{\mu}q_{d}\right)$
	$\mathcal{O}_{\ell u} = \left(\bar{\ell}\gamma^{\mu}\ell\right)\left(\bar{q}_{u}\gamma_{\mu}q_{u}\right)$
	$\mathcal{O}_{\ell d} = \left(\bar{\ell}\gamma^{\mu}\ell\right)\left(\bar{q}_{d}\gamma_{\mu}q_{d}\right)$

- Credit: Xiaohu Sun, Zhan Li (Left), etc; Zhuoni Qian (Right)

https://indico.ihep.ac.cn/event/22089/contributions/169056/attachments/83388/105766/202410_hz_cepc.pdf

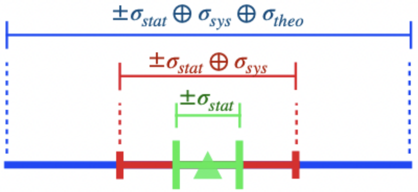
As well as top quark coupling measurements...

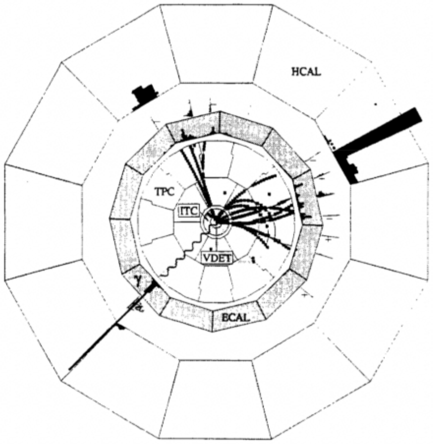
QCD: α_s measurement from tau decay

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

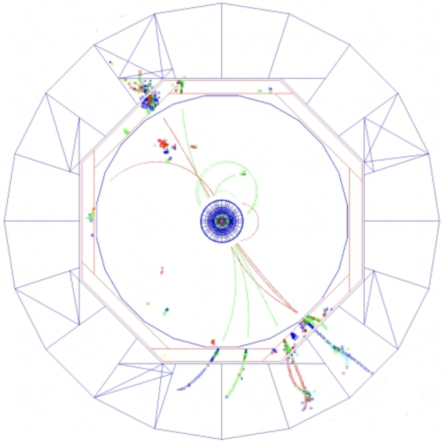
$\alpha_s(m_\tau)$

ALEPH(2014)

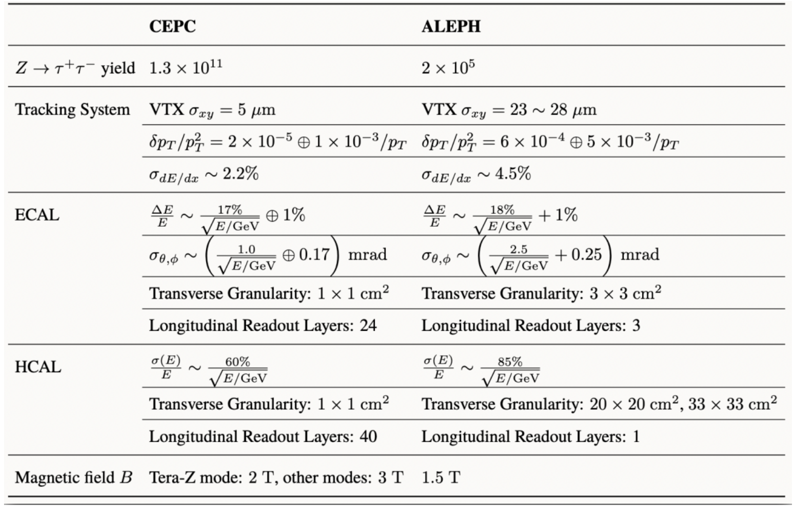




ALEPH Event display

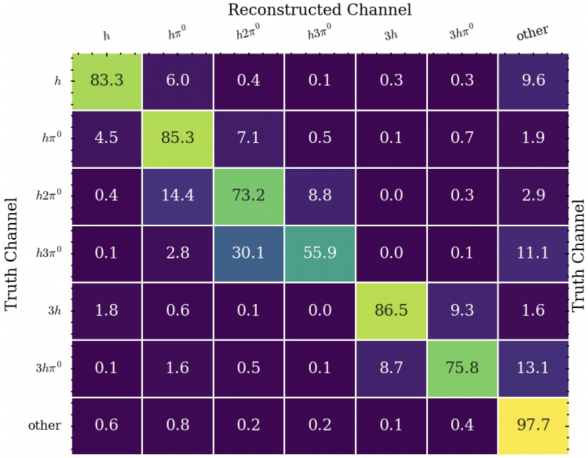


CEPC Event display



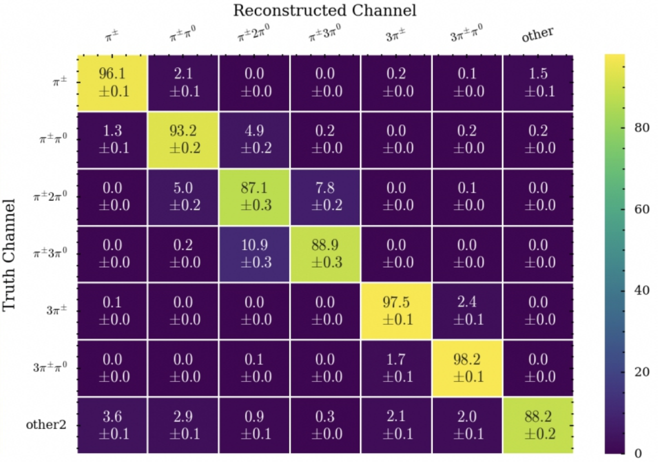
	CEPC	**ALEPH**
$Z \to \tau^+\tau^-$ yield	1.3×10^{11}	2×10^5
Tracking System	VTX $\sigma_{xy} = 5\ \mu$m	VTX $\sigma_{xy} = 23 \sim 28\ \mu$m
	$\delta p_T/p_T^2 = 2 \times 10^{-5} \oplus 1 \times 10^{-3}/p_T$	$\delta p_T/p_T^2 = 6 \times 10^{-4} \oplus 5 \times 10^{-3}/p_T$
	$\sigma_{dE/dx} \sim 2.2\%$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

ALEPH
10.1016/j.physrep.2005.06.007



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

CEPC GNN

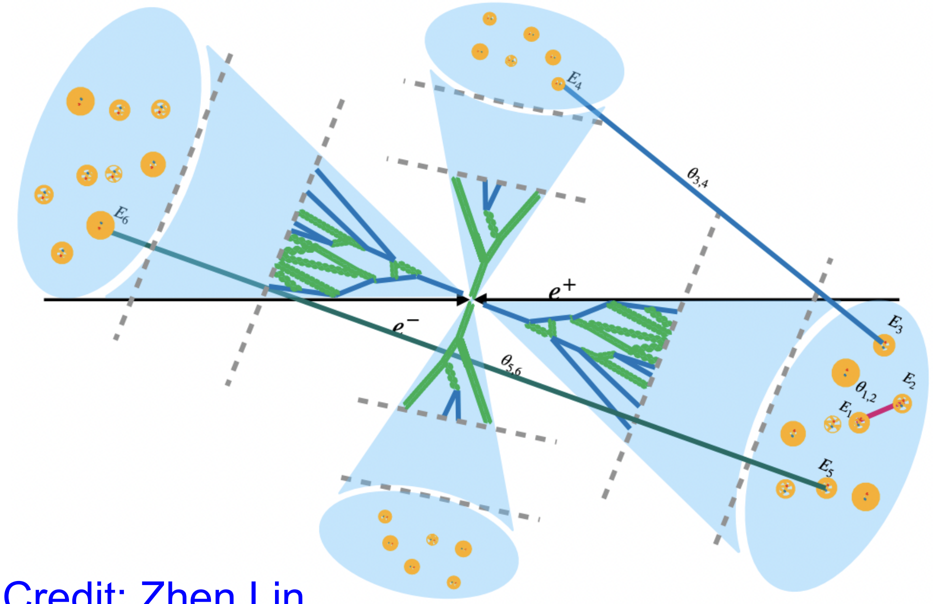


	$\pi^\pm$	$\pi^\pm\pi^0$	$\pi^\pm 2\pi^0$	$\pi^\pm 3\pi^0$	$3\pi^\pm$	$3\pi^\pm\pi^0$	other
$\pi^\pm$	96.1 ±0.1	2.1 ±0.1	0.0 ±0.0	0.0 ±0.0	0.2 ±0.0	0.1 ±0.0	1.5 ±0.1
$\pi^\pm\pi^0$	1.3 ±0.1	93.2 ±0.2	4.9 ±0.2	0.2 ±0.0	0.0 ±0.0	0.2 ±0.0	0.2 ±0.0
$\pi^\pm 2\pi^0$	0.0 ±0.0	5.0 ±0.2	87.1 ±0.3	7.8 ±0.2	0.0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

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

- Credit: Yuzhi Che

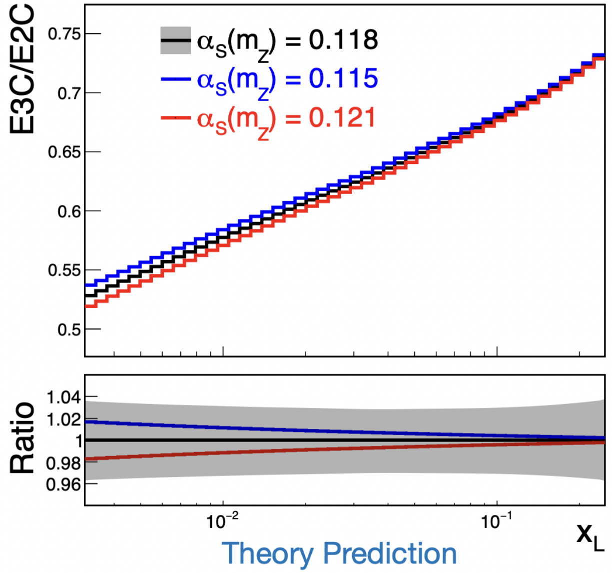
α_S from Energy Energy Correlator (EEC)



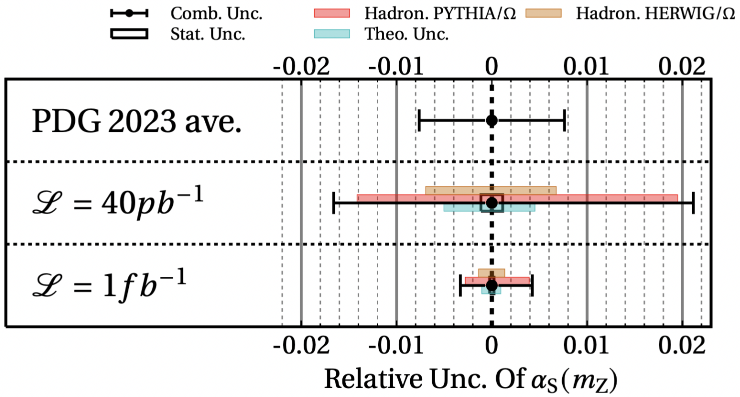
- Credit: Zhen Lin, Submitted to JHEP

$$E2C = \frac{d\sigma^{[2]}}{dx_L} = \sum_{i,j}^{n} \int d\sigma \boxed{\frac{E_iE_j}{E^2}} \delta(\chi_{ij} - \theta_{ij})$$

$$E3C = \frac{d\sigma^{[3]}}{dx_L} = \sum_{i,j,k}^{n} \int d\sigma \boxed{\frac{E_iE_jE_k}{E^3}} \delta(x_L - \max(\Delta R_{i,j}, \Delta R_{i,k}, \Delta R_{j,k}))$$



Theory Prediction



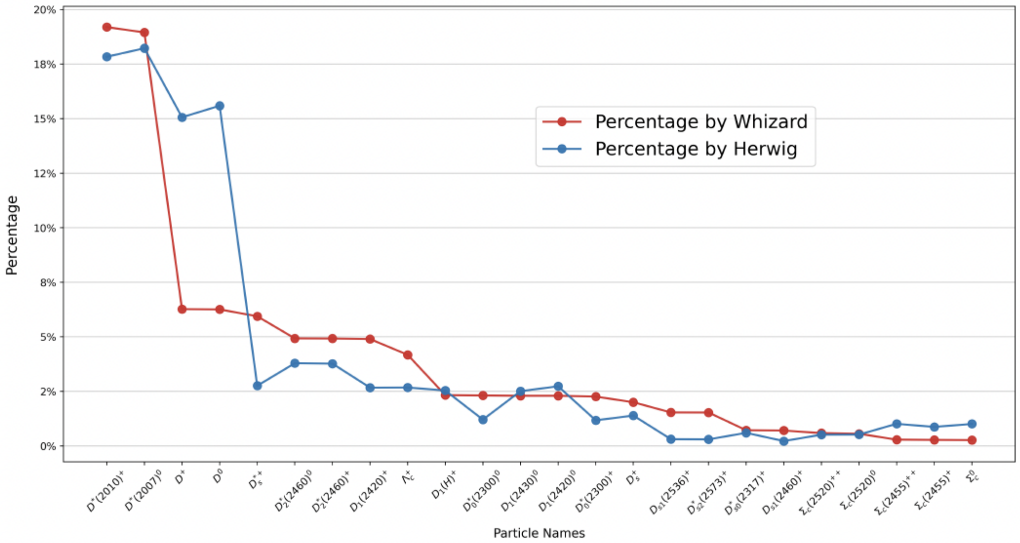
2% for $40pb^{-1}$ (1 minute)

0.4% for 1 fb^{-1} (0.5 hours)

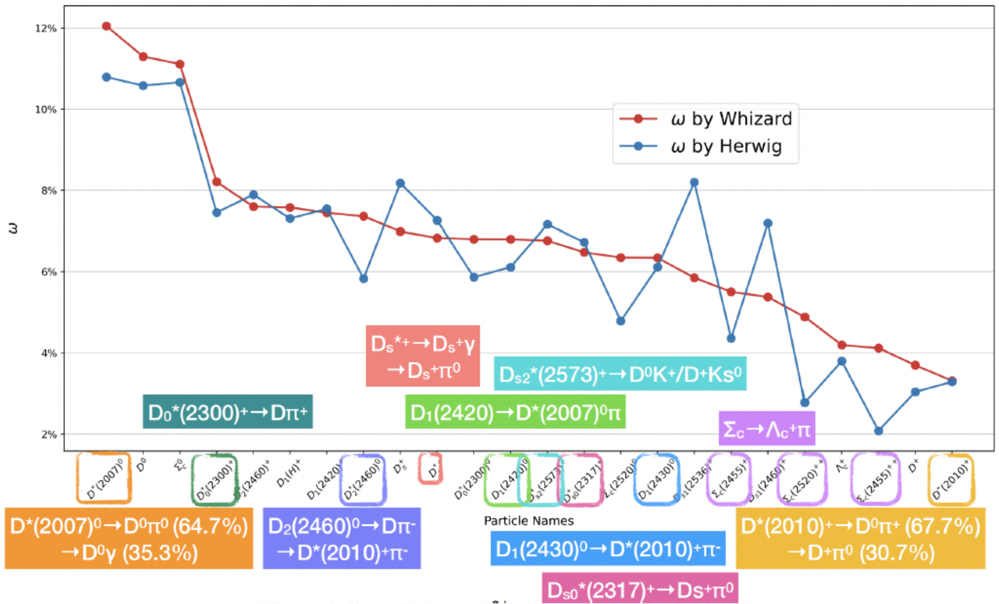
- Similar to the measurement from tau decay, sub-percentage level statistic uncertainty easily achieved, need dedicated study on theoretical & systematic uncertainty

c-jet: leading c-hadrons & flip rates

Percentage of c hadrons by Whizard & Herwig



Charge Flip Rate ω of c hadrons by Whizard & Herwig



$D_s^{*+} \to D_s^+\gamma$
$\to D_s^+\pi^0$

$D_{s2}^*(2573)^+ \to D^0K^+/D^+K_s^0$

$D_0^*(2300)^+ \to D\pi^+$

$D_1(2420) \to D^*(2007)^0\pi$

$\Sigma_c \to \Lambda_c^+\pi$

$D^*(2007)^0 \to D^0\pi^0$ (64.7%)
$\to D^0\gamma$ (35.3%)

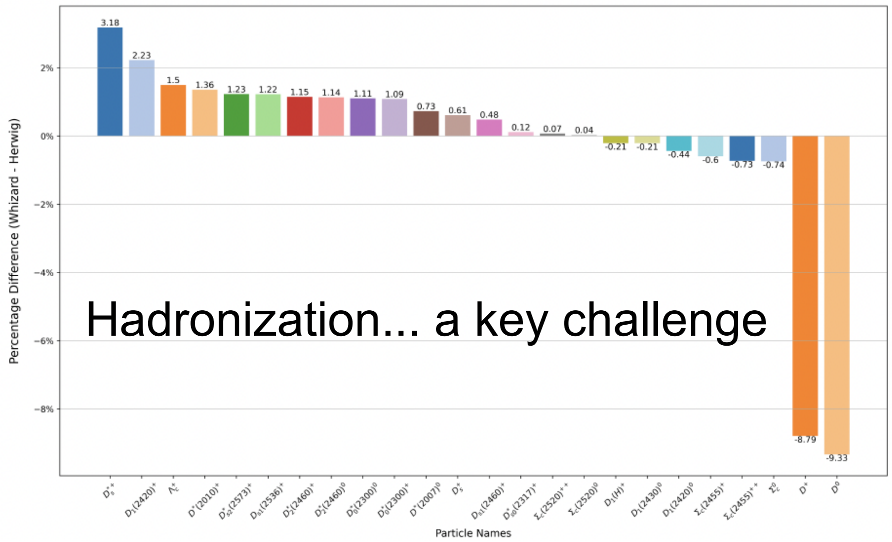
$D_2(2460)^0 \to D\pi^-$
$\to D^*(2010)^+\pi^-$

$D_1(2430)^0 \to D^*(2010)^+\pi^-$

$D^*(2010)^+ \to D^0\pi^+$ (67.7%)
$\to D^+\pi^0$ (30.7%)

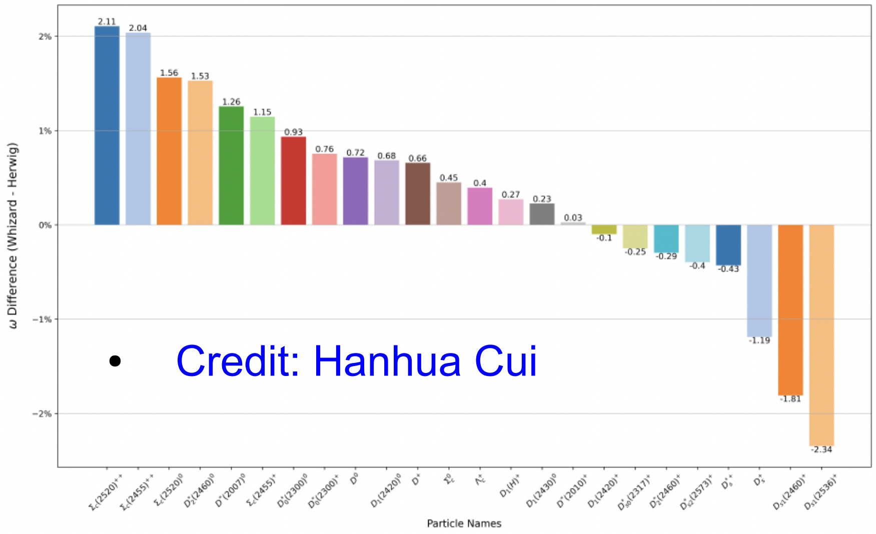
$D_{s0}^*(2317)^+ \to D_s^+\pi^0$

Difference in Percentage of c hadrons between Whizard and Herwig



Hadronization... a key challenge

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



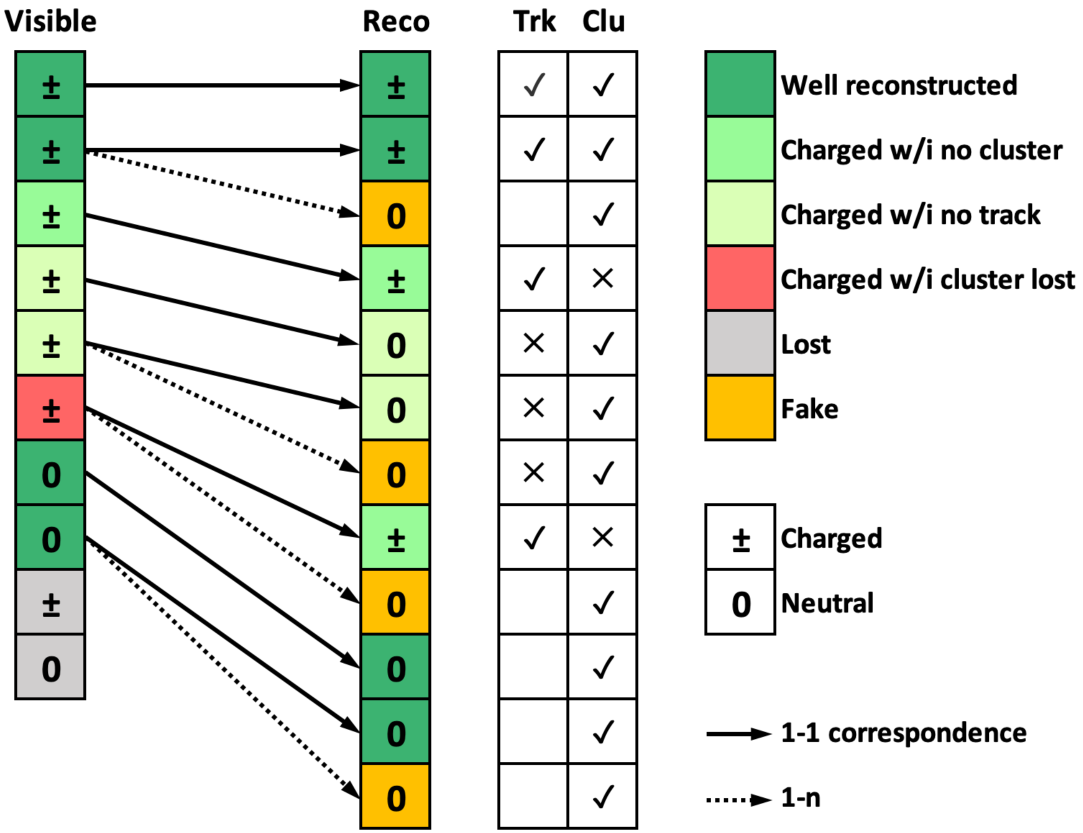
- Credit: Hanhua Cui

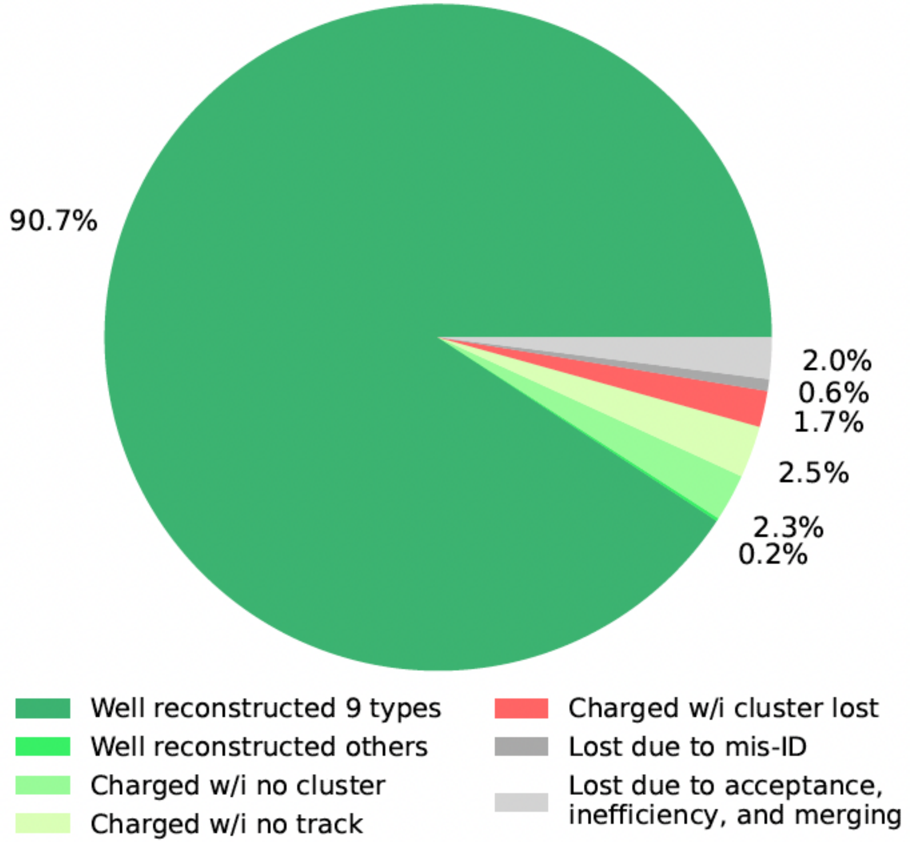
Interact with detector R&D: requirements

- BMR performance: 4% as a must, to separate qqH from qqZ bkgrd.
  - While improve to 3% could save ~ o(10%) Luminosity, benefit all measurements with hadronic final states
- Decent Pid ~ Kaon reco eff & purity > 95%
  - dE/dx or dN/dx < 3% in the barrel region + ToF with ~ 50 ps resolution
- Decent Jet origin id: PFA + VTX + Pid.
- EM resolution: ~ 3%/sqrt(E) for B_0/B_S separation with EM final states (Δm ~ 100 MeV)
- Track: dP/P ~ 0.1% for H→di muon, Flavor Physics studies, etc
- Muon Chamber: Muon-id in the fwd + LLP searches.
- Addressed by Ref-TDR studies
- **1-1 correspondence reconstruction = confusion free PFA + excellent Pid**

- *Many questions need to be addressed: impact of Beam induced background + event building*

Mapping with Arbor + AI

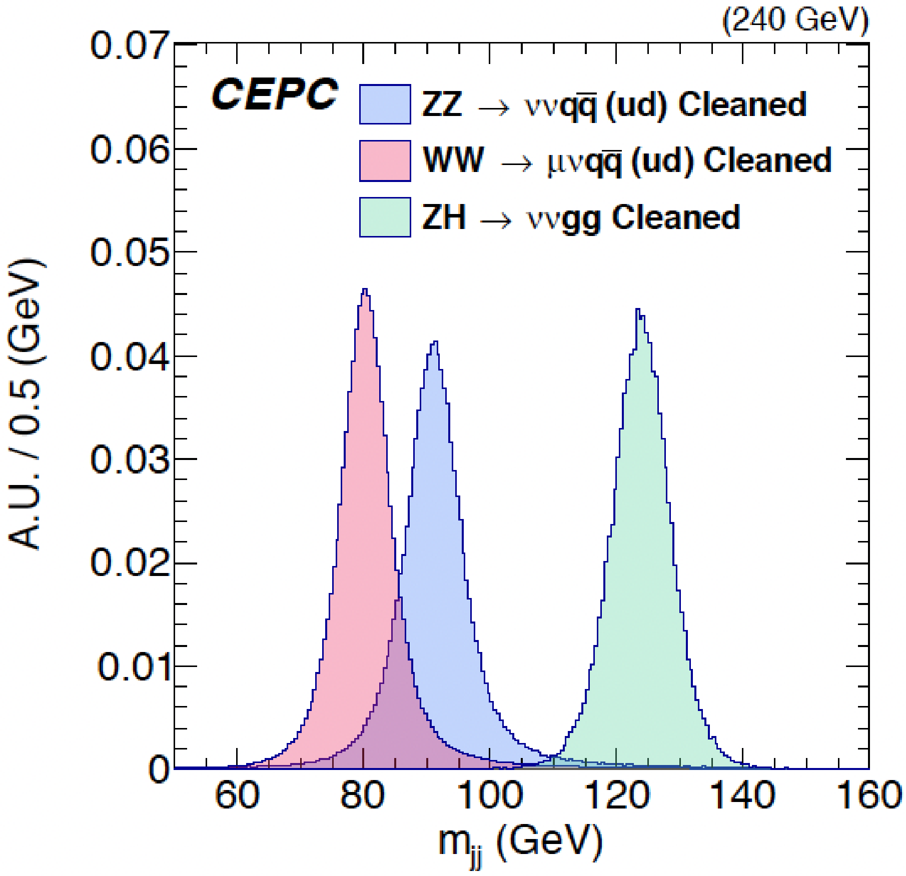


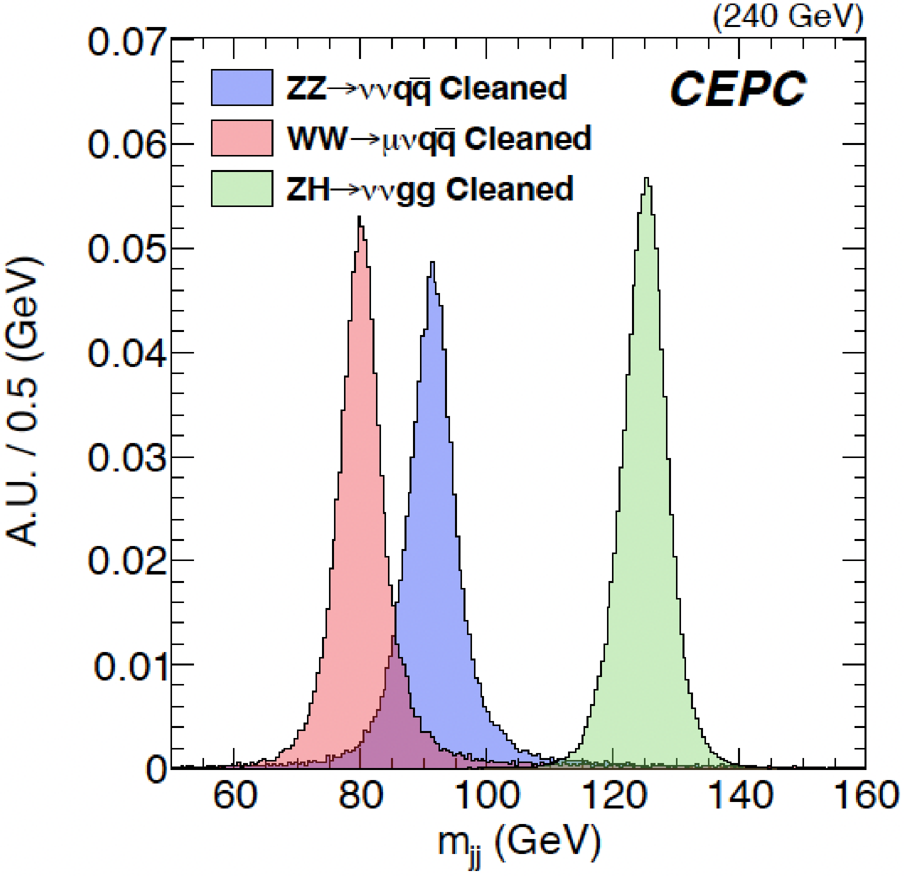


Replace HCAL in CDR baseline with a thick GS-HCAL (5λ → 6λ)

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

BMR of 2.75% reached



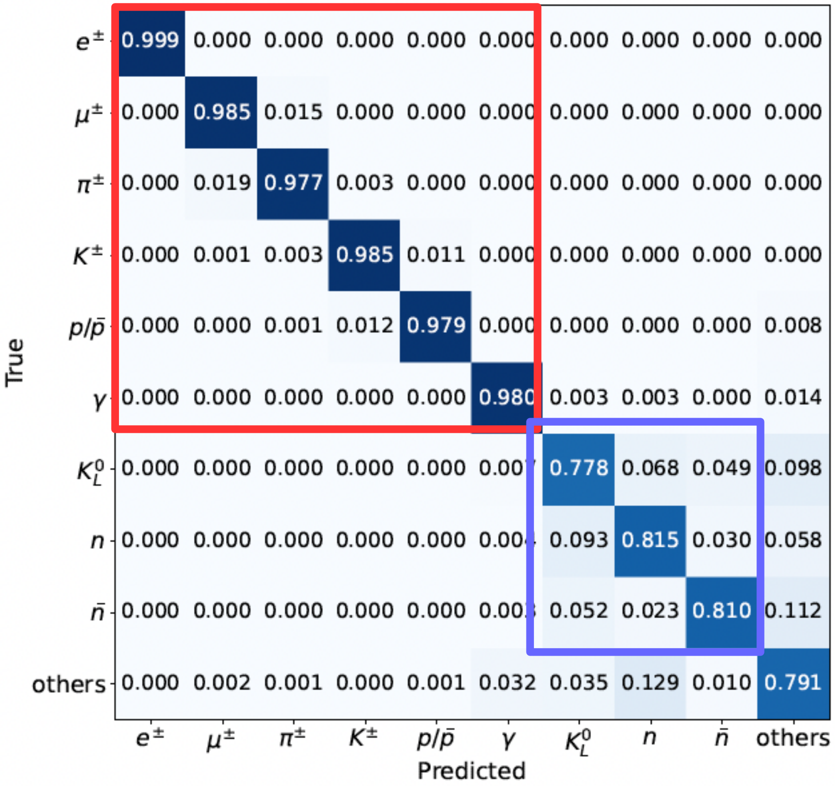


Detector change: BMR 3.7 → 3.4;

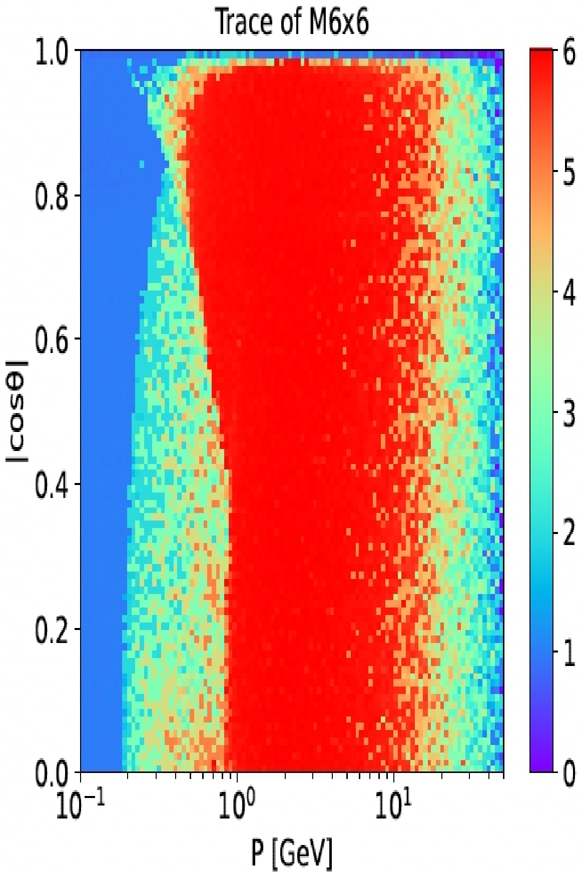
AI enhanced reconstruction: 3.4 → 2.8.

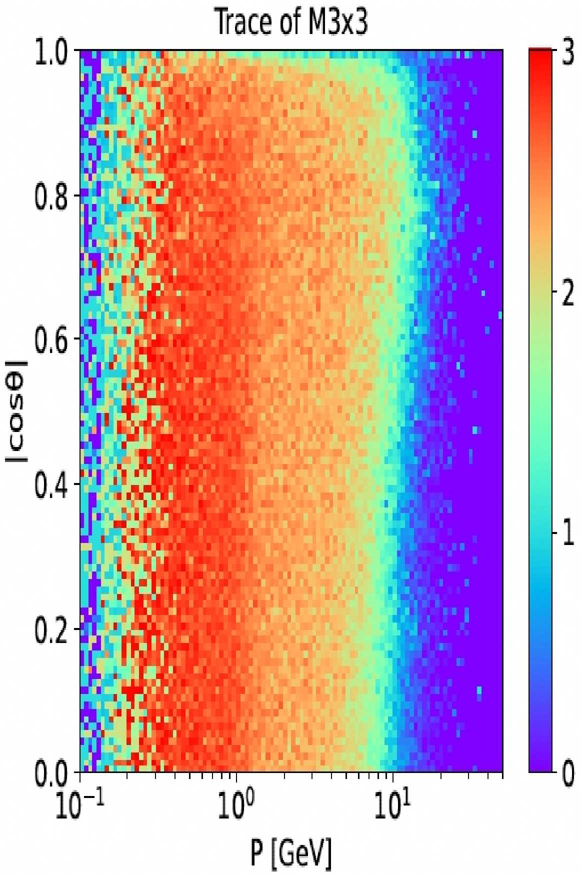
Impact from Beam induced background + impact on objects inside jet reco: to be evaluated.

Pid in the 'well reconstructed' particles category



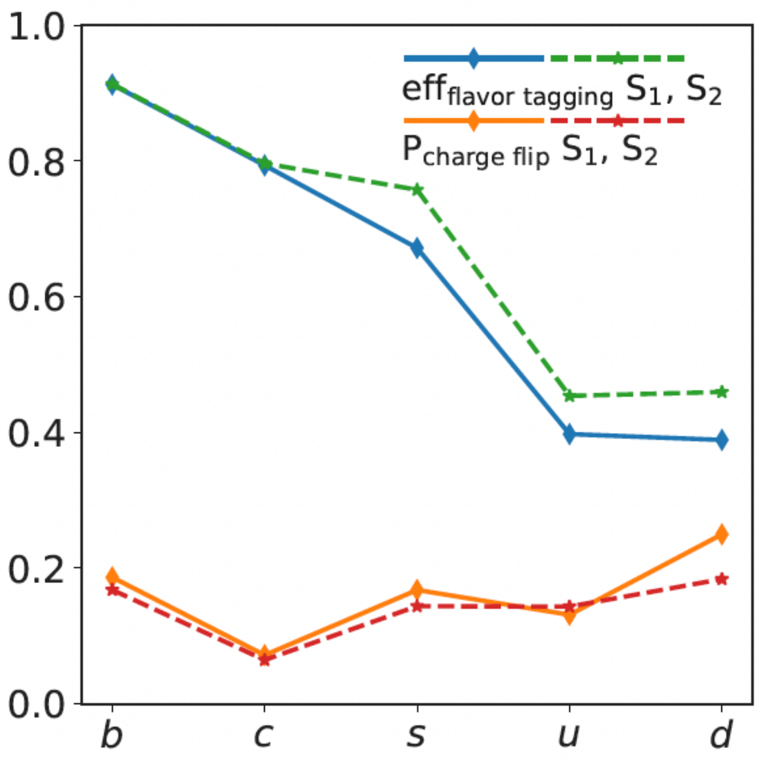
	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	0.000	0.001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

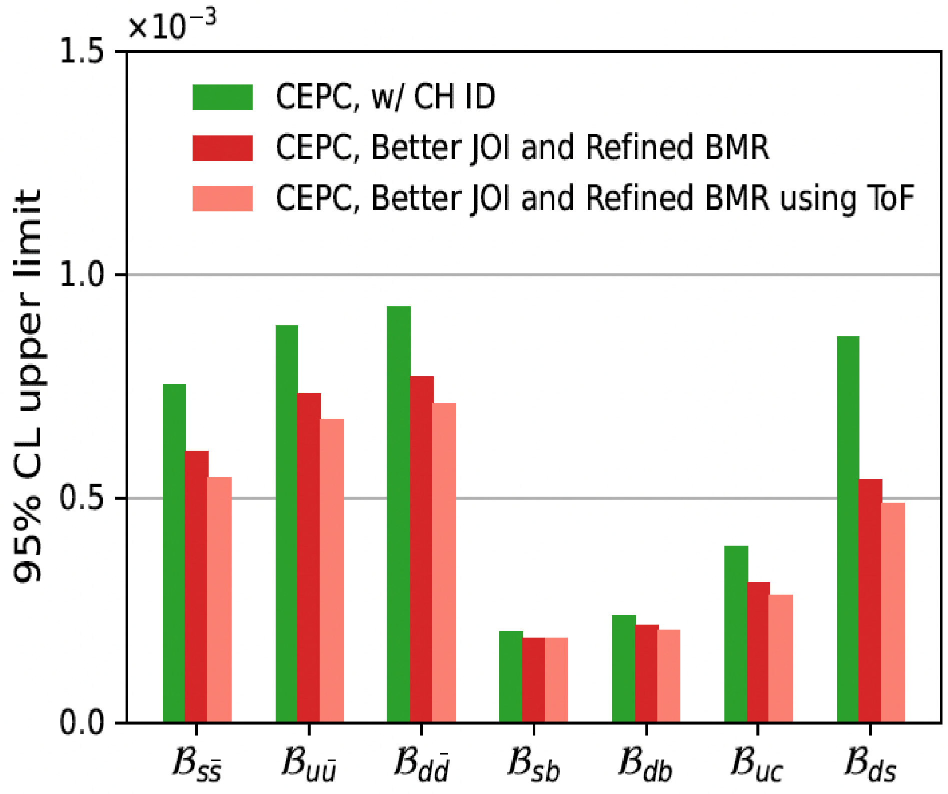




'well reconstructed' = reconstructed particle with no confusion +
both track + cluster for charged reconstructed particle
~ > 90% of total visible energy

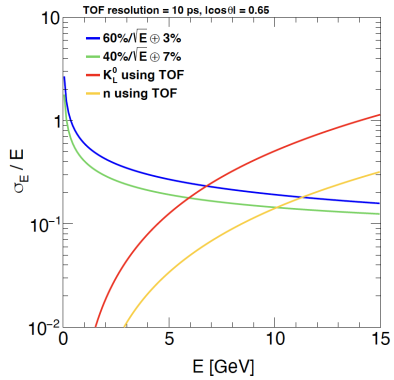
Excellent 1-1 correspondence prospective: preliminary



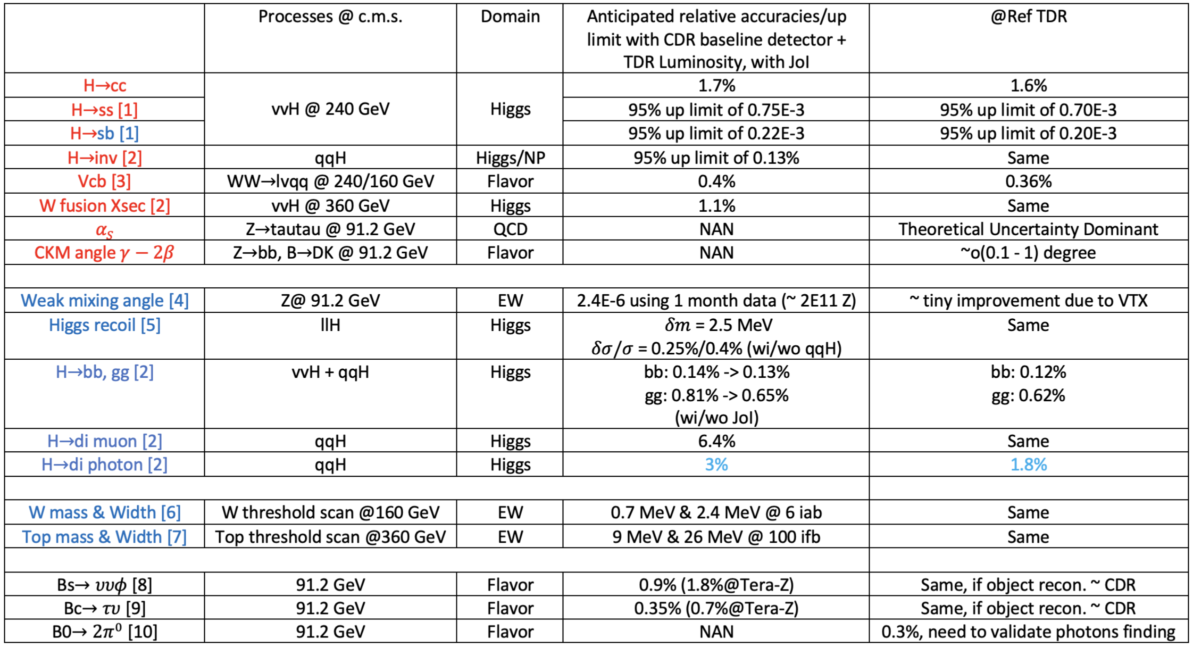


Scenario 1: Lepton + charged Kaons id, default scenario

Scenario 2: Lepton, Charged Kaons, Klong - Kshort, Neutron – Anti Neutron, Lambda/Lambda-bar



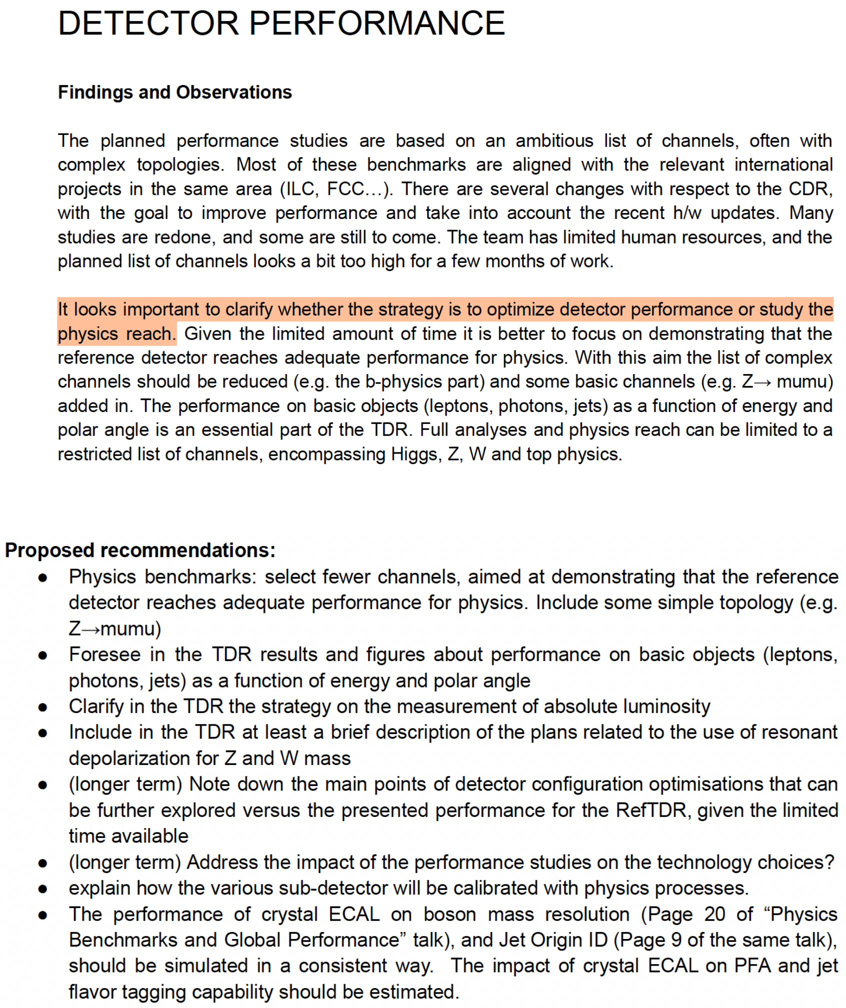
Interact with detector R&D: benchmarks



	Processes @ c.m.s.	Domain	Anticipated relative accuracies/up limit with CDR baseline detector + TDR Luminosity, with JoI	@Ref TDR
H→cc	ννH @ 240 GeV	Higgs	1.7%	1.6%
H→ss [1]			95% up limit of 0.75E-3	95% up limit of 0.70E-3
H→sb [1]			95% up limit of 0.22E-3	95% up limit of 0.20E-3
H→inv [2]	qqH	Higgs/NP	95% up limit of 0.13%	Same
Vcb [3]	WW→lvqq @ 240/160 GeV	Flavor	0.4%	0.36%
W fusion Xsec [2]	ννH @ 360 GeV	Higgs	1.1%	Same
α_S	Z→tautau @ 91.2 GeV	QCD	NAN	Theoretical Uncertainty Dominant
CKM angle $\gamma - 2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	NAN	~o(0.1 - 1) degree
Weak mixing angle [4]	Z@ 91.2 GeV	EW	2.4E-6 using 1 month data (~ 2E11 Z)	~ tiny improvement due to VTX
Higgs recoil [5]	llH	Higgs	δm = 2.5 MeV $\delta\sigma/\sigma$ = 0.25%/0.4% (wi/wo qqH)	Same
H→bb, gg [2]	ννH + qqH	Higgs	bb: 0.14% -> 0.13% gg: 0.81% -> 0.65% (wi/wo JoI)	bb: 0.12% gg: 0.62%
H→di muon [2]	qqH	Higgs	6.4%	Same
H→di photon [2]	qqH	Higgs	3%	1.8%
W mass & Width [6]	W threshold scan @160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab	Same
Top mass & Width [7]	Top threshold scan @360 GeV	EW	9 MeV & 26 MeV @ 100 ifb	Same
Bs→ $\upsilon\upsilon\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)	Same, if object recon. ~ CDR
Bc→ $\tau\upsilon$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)	Same, if object recon. ~ CDR
B0→ $2\pi^0$ [10]	91.2 GeV	Flavor	NAN	0.3%, need to validate photons finding

A shorter list...

	Process @ c.m.e	Domain	Relevant Det. Performance
Z→μμ	Z@ 91.2 GeV	Z	lepton ID, tracking
H→γγ	qqH	Higgs	photon ID, EM resolution
Higgs recoil	$\ell\ell$H	Higgs	Lepton ID, track dP/P
H→ss	ννH @ 240 GeV	Higgs	PID, Vertexing, PFA + JOI
H→inv	qqH	Higgs/NP	PFA, MET
Vcs/Vcb	WW→ℓvqq @ 240/160 GeV	Flavor	PFA, JOI + PID (lepton, tau)
H→LLP	$\ell\ell$H	NP	TPC, TOF, calo, muon detectors
H→μμ	qqH	Higgs	lepton ID, tracking, OTK
Top mass & width	Threshold scan @ 360 GeV	EW	Beam energy
Weak mixing angle	Z→bb @ 91.2 GeV	EW	JOI



DETECTOR PERFORMANCE

Findings and Observations

The planned performance studies are based on an ambitious list of channels, often with complex topologies. Most of these benchmarks are aligned with the relevant international projects in the same area (ILC, FCC…). There are several changes with respect to the CDR, with the goal to improve performance and take into account the recent h/w updates. Many studies are redone, and some are still to come. The team has limited human resources, and the planned list of channels looks a bit too high for a few months of work.

It looks important to clarify whether the strategy is to optimize detector performance or study the physics reach. Given the limited amount of time it is better to focus on demonstrating that the reference detector reaches adequate performance for physics. With this aim the list of complex channels should be reduced (e.g. the b-physics part) and some basic channels (e.g. Z→ mumu) added in. The performance on basic objects (leptons, photons, jets) as a function of energy and polar angle is an essential part of the TDR. Full analyses and physics reach can be limited to a restricted list of channels, encompassing Higgs, Z, W and top physics.

Proposed recommendations:

- Physics benchmarks: select fewer channels, aimed at demonstrating that the reference detector reaches adequate performance for physics. Include some simple topology (e.g. Z→mumu)
- Foresee in the TDR results and figures about performance on basic objects (leptons, photons, jets) as a function of energy and polar angle
- Clarify in the TDR the strategy on the measurement of absolute luminosity
- Include in the TDR at least a brief description of the plans related to the use of resonant depolarization for Z and W mass
- (longer term) Note down the main points of detector configuration optimisations that can be further explored versus the presented performance for the RefTDR, given the limited time available
- (longer term) Address the impact of the performance studies on the technology choices?
- explain how the various sub-detector will be calibrated with physics processes.
- The performance of crystal ECAL on boson mass resolution (Page 20 of “Physics Benchmarks and Global Performance” talk), and Jet Origin ID (Page 9 of the same talk), should be simulated in a consistent way. The impact of crystal ECAL on PFA and jet flavor tagging capability should be estimated.

- Recommendation From IDRC

Editors, Contributors, & Reviewers

- Flavor: submit to ArXiv in a few weeks
  - Main editors: Lingfeng Li (Brown U), TaoLiu (HKUST), Fengkun Guo (ITP), Lorenzo Calibbi (Tianjing U), Xunwu Zuo(KIT)
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  - Reviewed by: Soeren Prell (ISU), Andreas Crivellin (Zurich U), Alberto Lusiani (INFN), Haibo Li, Changzheng Yuan, Caidian LV, etc.
- EW: internal review at the end of 2024
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- NP: internal review at the end of 2024
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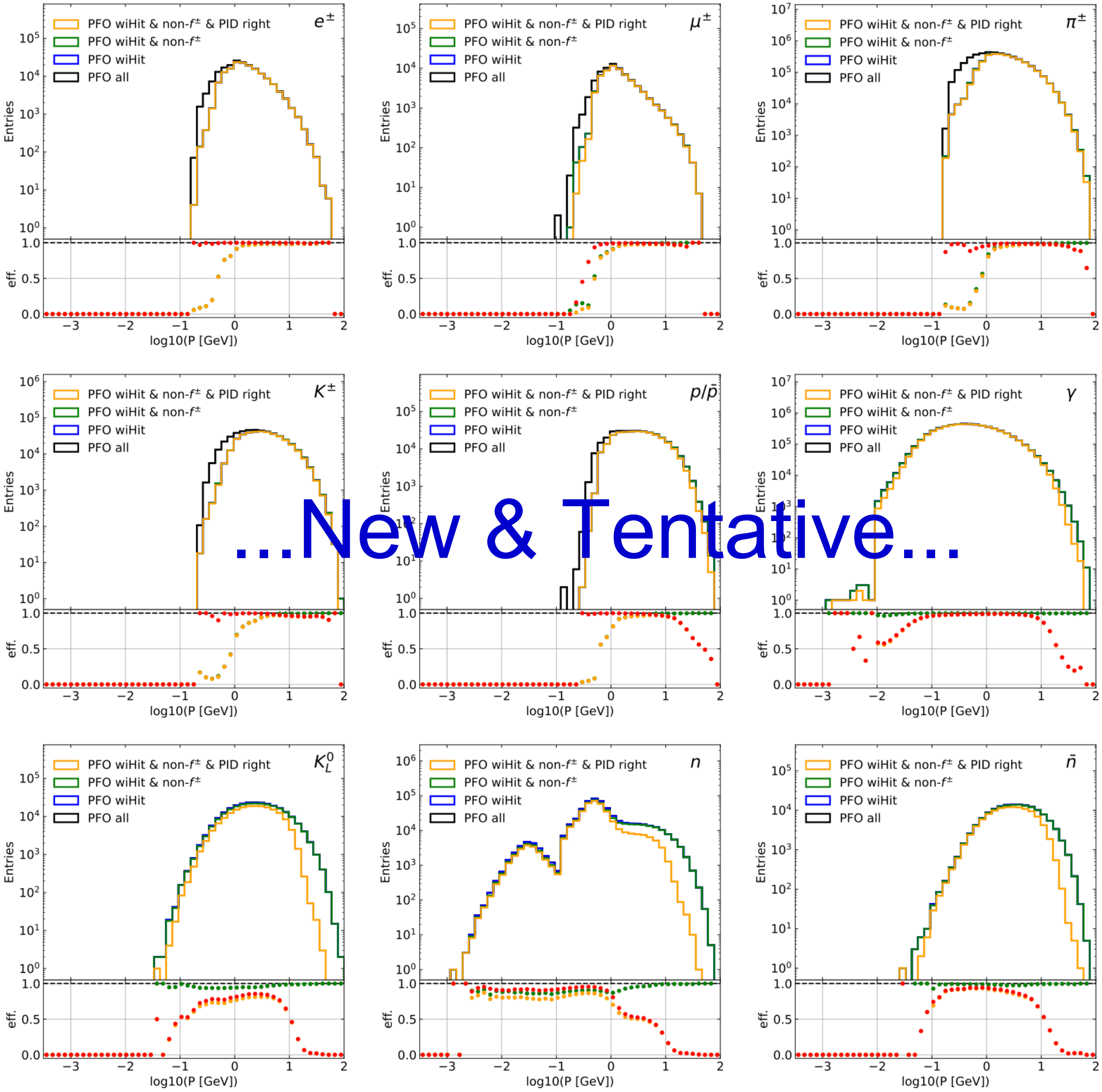
- QCD: Exploring phase, Many ppl involved in discussion:
  - Huaxing Zhu (PKU), Meng Xiao (ZJU), Jun Gao (SJTU), Zhao Li (IHEP), Yanqing Ma (PKU), Haitao Li(SDU), Yuming Wang(Nankai U), Dingyu Shao (Fudan U), etc

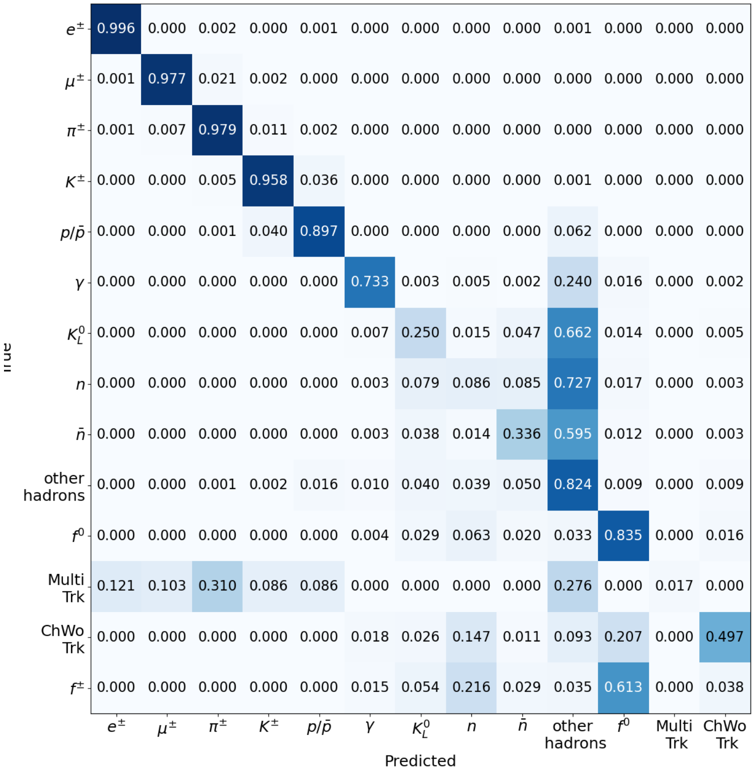
Summary

- **CEPC Physics: See the non-seen, boost our horizon by orders of magnitudes**
- Clearly... we need 2 phases of CEPC Physics study
- Phase-I: To meet the timeline of next year's project proposal
  - White papers: Lots of relevant studies collected, in synergy with international efforts especially ECFA studies
  - Visionary summarization/interpretation is needed
- Phase-II: to address the critical challenges creatively, including...
  - Detector design & Optimization
  - Reconstruction algorithm + AI, to pursue 1-1 correspondence, and to integrate into general software framework
  - Dedicated discussion/studies toward
    - QCD Phase Transition – Hadronization
    - High precision calculation.
    - Synergies with GW, Cosmology & Early Universe, and other frontiers
    - Calibration of advanced reco, i.e., JoI etc.

Back up



...New & Tentative...



	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	other hadrons	f^0	Multi Trk	ChWo Trk
$e^\pm$	0.996	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
$\mu^\pm$	0.001	0.977	0.021	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.001	0.007	0.979	0.011	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	0.000	0.000	0.005	0.958	0.036	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
$p/\bar{p}$	0.000	0.000	0.001	0.040	0.897	0.000	0.000	0.000	0.000	0.062	0.000	0.000	0.000
γ	0.000	0.000	0.000	0.000	0.000	0.733	0.003	0.005	0.002	0.240	0.016	0.000	0.002
K_L^0	0.000	0.000	0.000	0.000	0.000	0.007	0.250	0.015	0.047	0.662	0.014	0.000	0.005
n	0.000	0.000	0.000	0.000	0.000	0.003	0.079	0.086	0.085	0.727	0.017	0.000	0.003
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.003	0.038	0.014	0.336	0.595	0.012	0.000	0.003
other hadrons	0.000	0.000	0.001	0.002	0.016	0.010	0.040	0.039	0.050	0.824	0.009	0.000	0.009
f^0	0.000	0.000	0.000	0.000	0.000	0.004	0.029	0.063	0.020	0.033	0.835	0.000	0.016
Multi Trk	0.121	0.103	0.310	0.086	0.086	0.000	0.000	0.000	0.000	0.276	0.000	0.017	0.000
ChWo Trk	0.000	0.000	0.000	0.000	0.000	0.018	0.026	0.147	0.011	0.093	0.207	0.000	0.497
$f^\pm$	0.000	0.000	0.000	0.000	0.000	0.015	0.054	0.216	0.029	0.035	0.613	0.000	0.038

Predicted

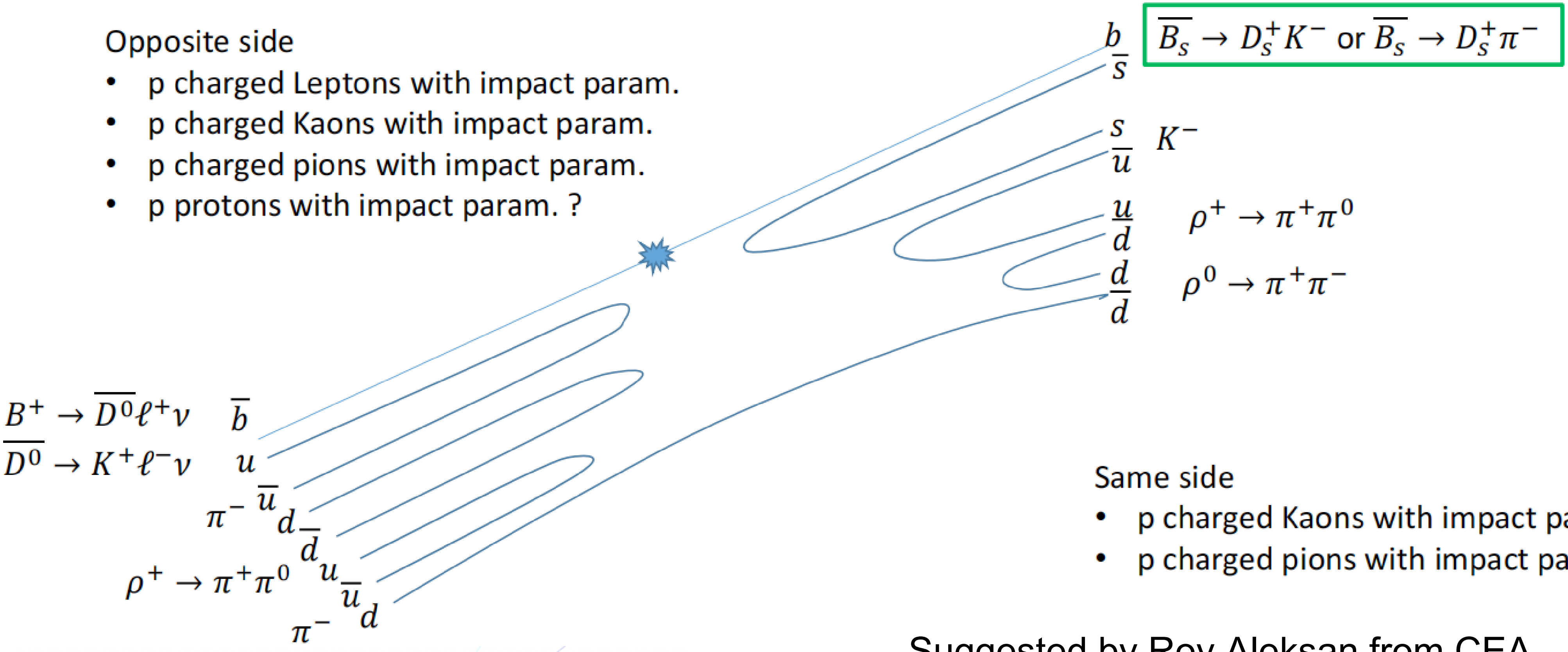
Identification of particles
With E > 10 GeV.

Many neutral particles
Mis-identified as 'others' -
consists mainly of High
energy Ks and Lambda that
not yet decayed inside
tracker volume

B-charge flip rate: Bs oscillations

Opposite side

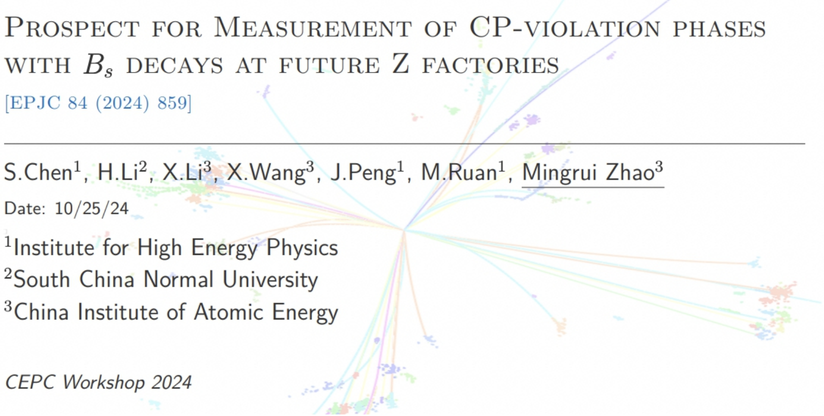
- p charged Leptons with impact param.
- p charged Kaons with impact param.
- p charged pions with impact param.
- p protons with impact param. ?



Same side

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

Suggested by Roy Aleksan from CEA


PROSPECT FOR MEASUREMENT OF CP-VIOLATION PHASES WITH B_s DECAYS AT FUTURE Z FACTORIES

[EPJC 84 (2024) 859]

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Date: 10/25/24

[1]Institute for High Energy Physics
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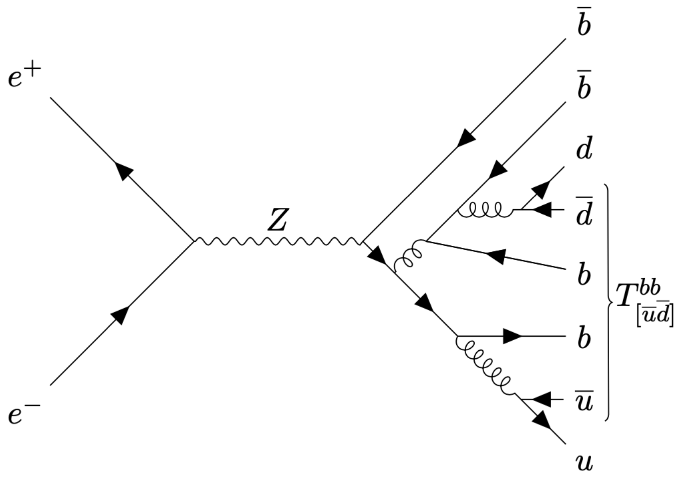
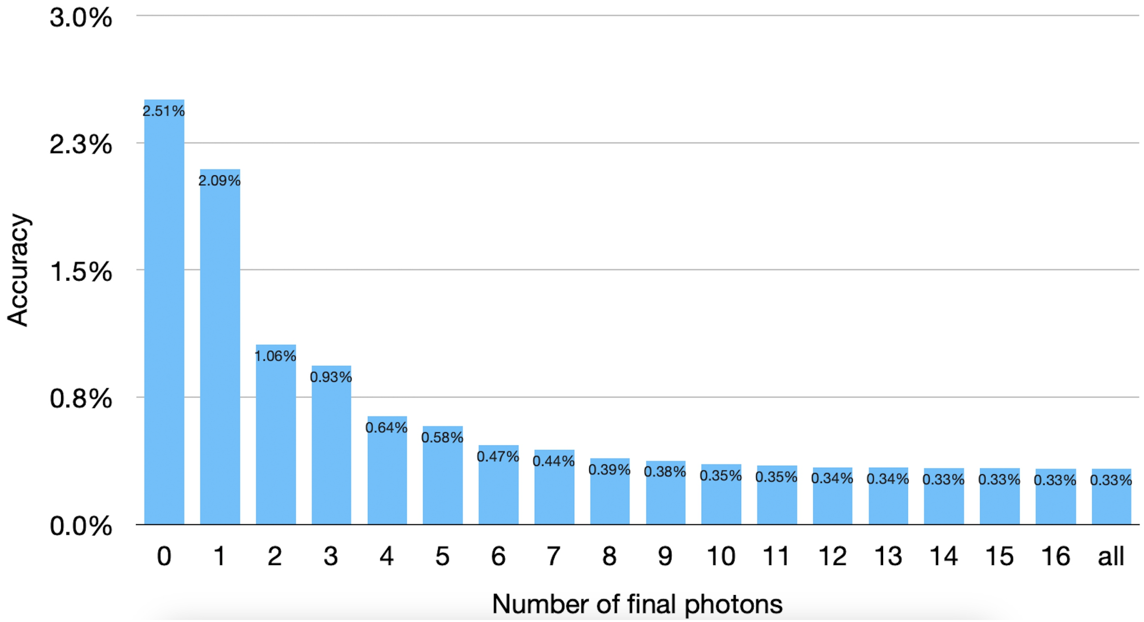
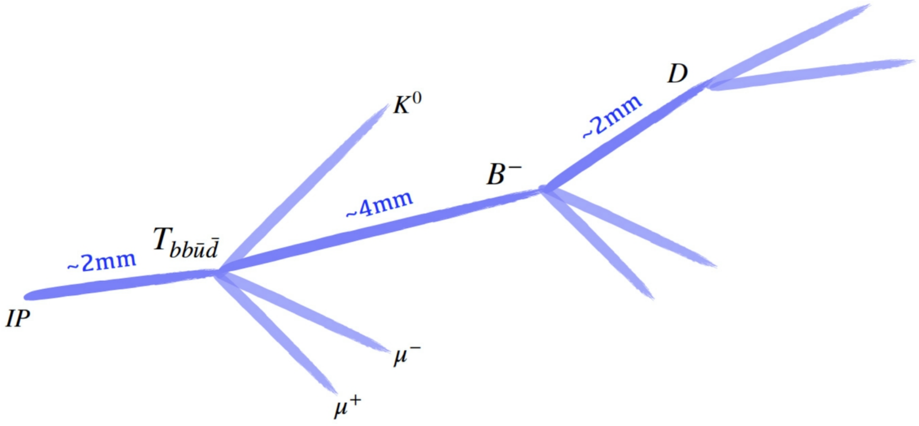
CEPC Workshop 2024

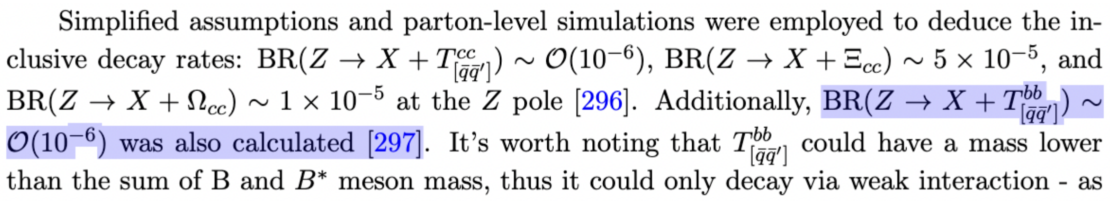
- See Mingrui's talk for more details (https://indico.ihep.ac.cn/event/22089/contributions/168047/attachments/83473/105931/slides_CEPCworkshop.pdf)

Spectroscope: T(bbud)



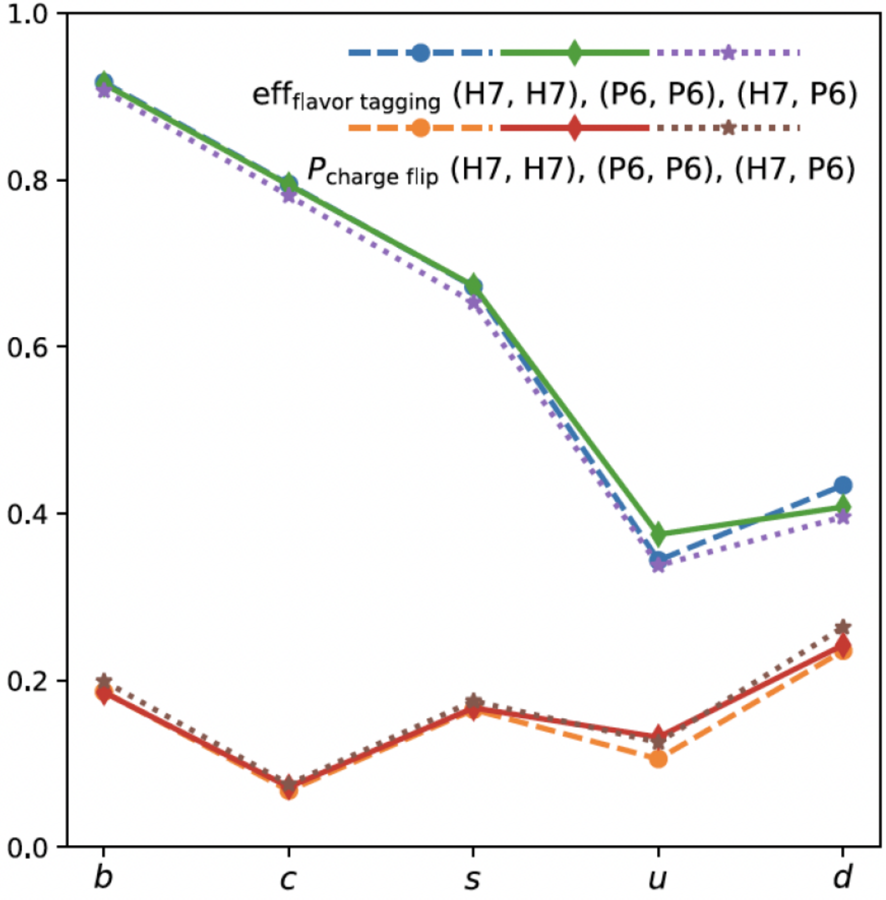


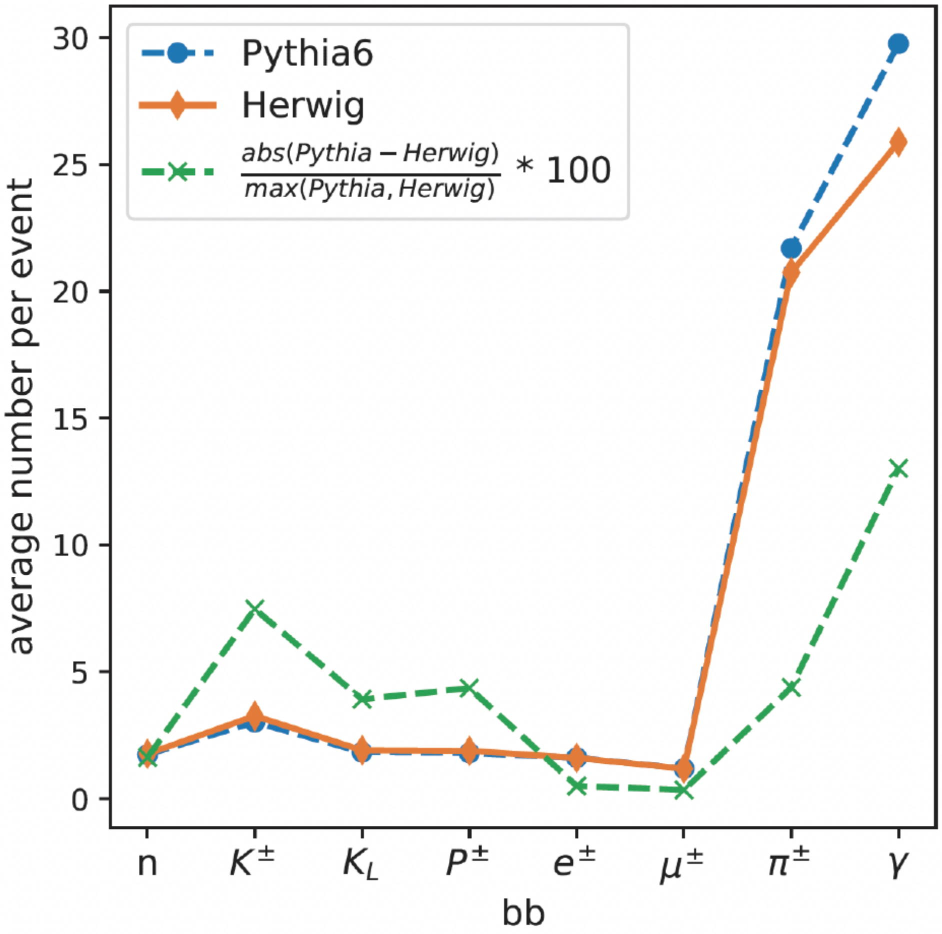




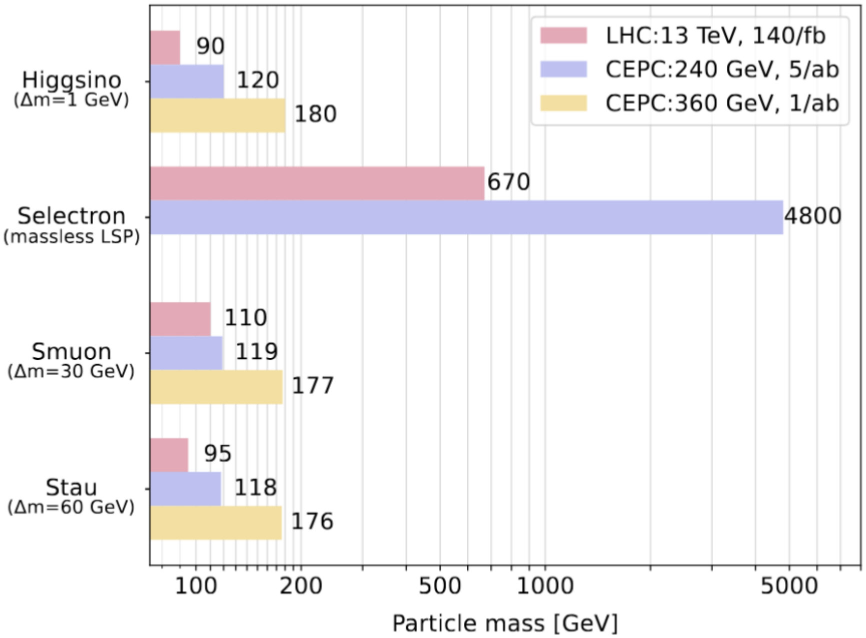
Simplified assumptions and parton-level simulations were employed to deduce the inclusive decay rates: $\mathrm{BR}(Z \to X + T^{cc}_{[\bar{q}\bar{q}']}) \sim \mathcal{O}(10^{-6})$, $\mathrm{BR}(Z \to X + \Xi_{cc}) \sim 5 \times 10^{-5}$, and $\mathrm{BR}(Z \to X + \Omega_{cc}) \sim 1 \times 10^{-5}$ at the Z pole [296]. Additionally, $\mathrm{BR}(Z \to X + T^{bb}_{[\bar{q}\bar{q}']}) \sim \mathcal{O}(10^{-6})$ was also calculated [297]. It's worth noting that $T^{bb}_{[\bar{q}\bar{q}']}$ could have a mass lower than the sum of B and B^* meson mass, thus it could only decay via weak interaction - as

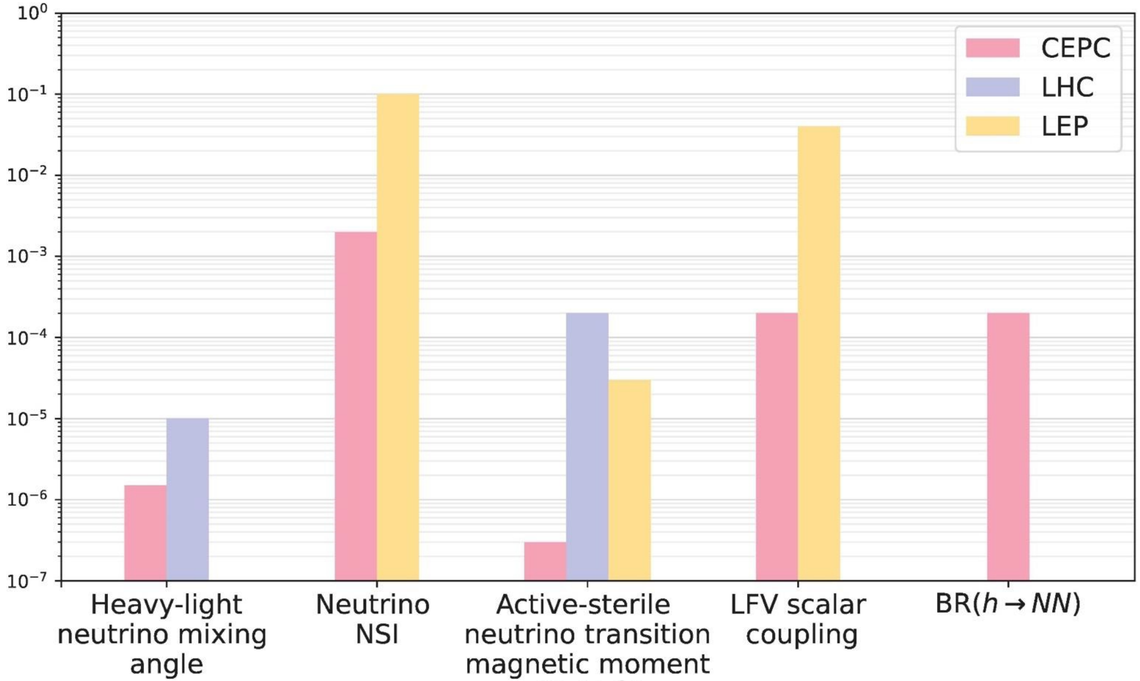
V.S. Hadronization models

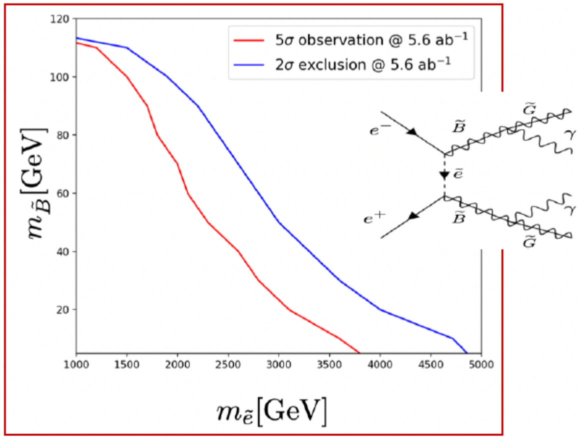


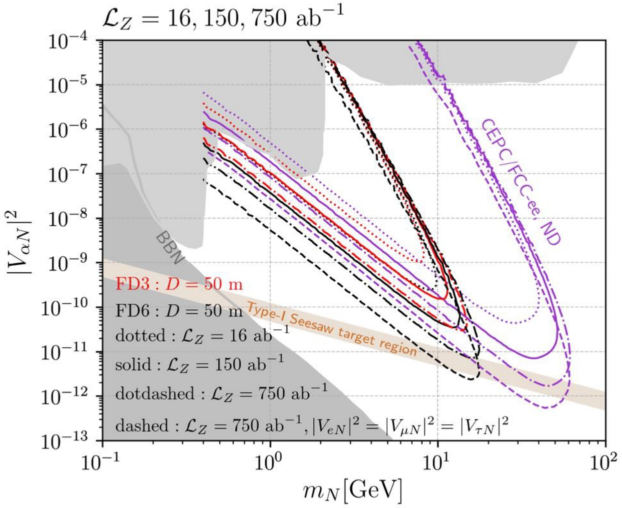


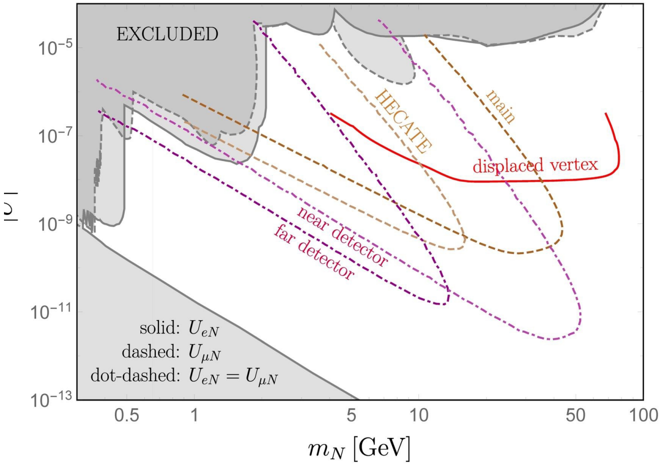
Neutrinos, SUSY











Summary

- Electron Positron Higgs factories: a gigantic boost from LHC
- CEPC physics studies: composed of physics reach/pheno and detector requirement optimization, aims at White papers to be released according to the project paces
  - Community activated, results in multiple new ideas/results
  - Good international communication/collaboration
  - Lots of raw material available, visionary summarization/interpretation is needed
    - Incentives/supports to young people, especially young PIs at China
    - Editing help from senior & visionary experts
- Extremely rich physics program results in stringent requirements on the detector performance, to be addressed by intensive study on detector design, key tech R&D, and algorithms development
  - Significant efforts towards the RDR (reference detector design TDR)
  - Manpower/resource is an issue. Especially the service & communication
- New tools, especially AI, could significantly alter the physics study/detector design.

...In principle...

Z boson FCNC

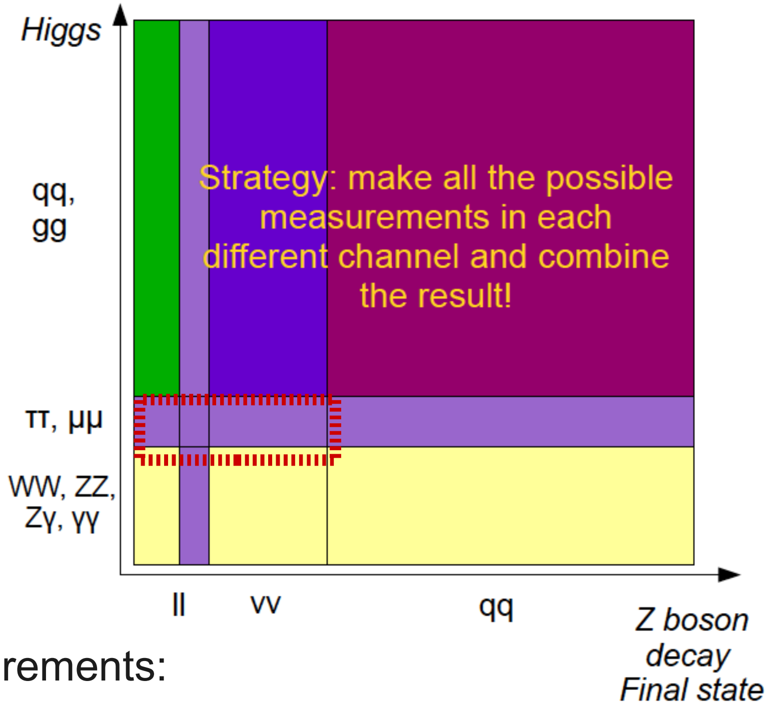
- Without considering other process other than Z
    - 1 Tera Z boson
- Confusion matrix based
    - Using 11x11 confusion matrix as template, extract signal strength of FCNC
    - Re-use confusion matrix of Higgs boson (No much difference according study of Yongfeng)
    - may not be statistically optimal
- No kinematic cut. No polar angle factors considered

	Z Br by SM (Flavor violating Higgs and Z decays at FCC-ee)	95% Upper limit on Br (statistics only)
Z->bs	4.2E-8	2.3e-07
Z->bd	1.8E-9	2.5e-07
Z->cu	1.4E-18	6.3e-07
Z->sd	-	1.3e-06

...surly the Systematic control & JoI Calibration need breakthrough method...

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 → W + b

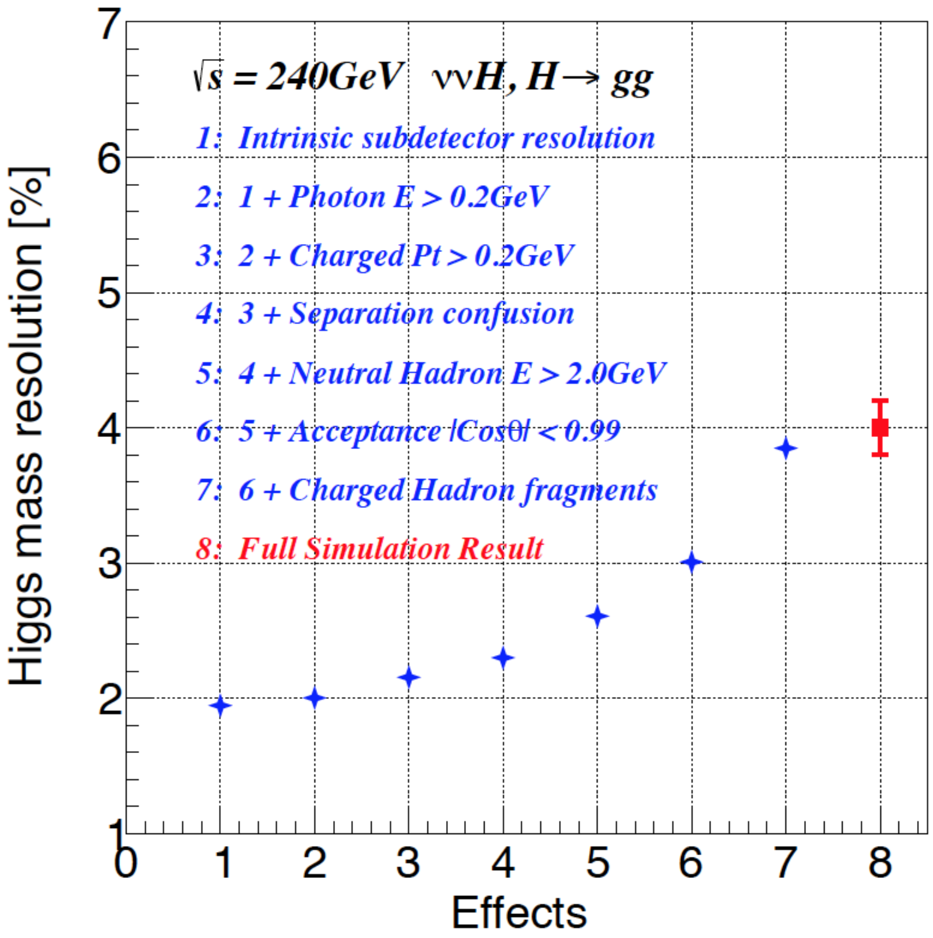


Strategy: make all the possible measurements in each different channel and combine the result!

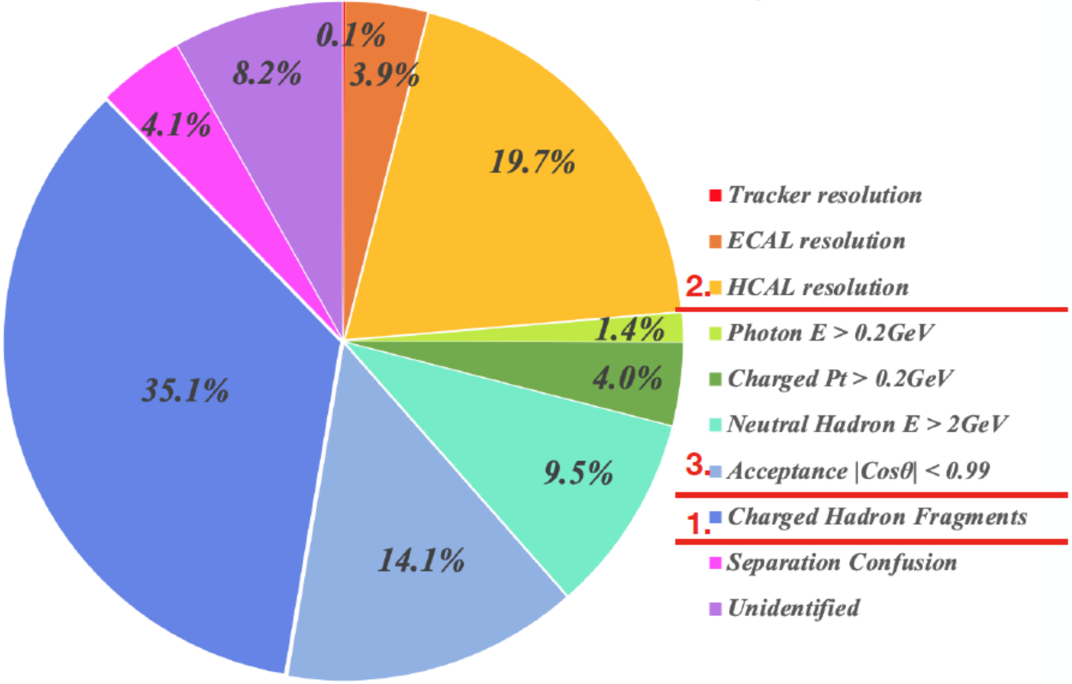
- Requirements:
  - **1-1 correspondence**

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

PFA Fast simulation



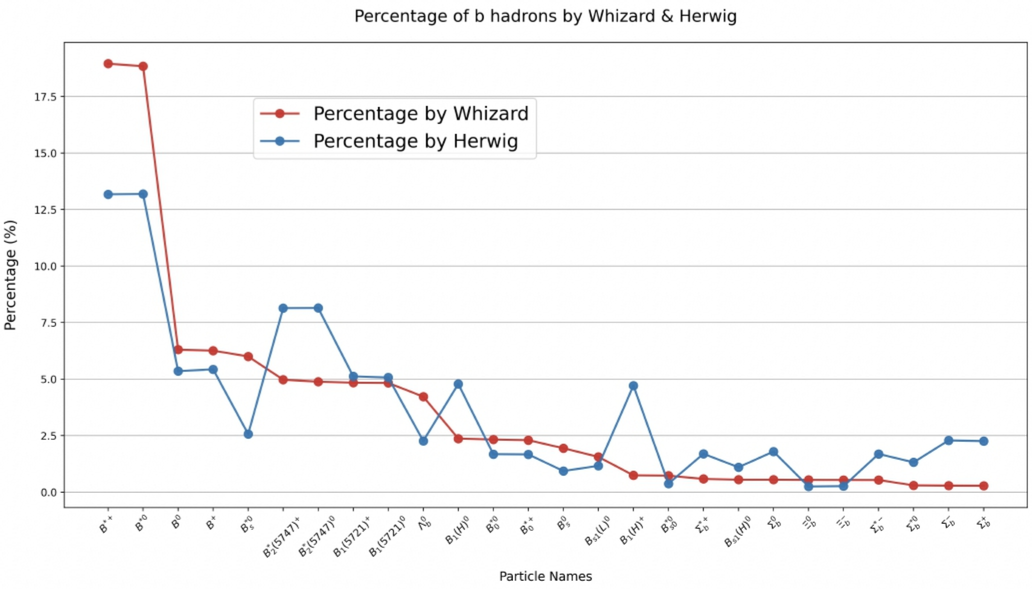
To be updated!

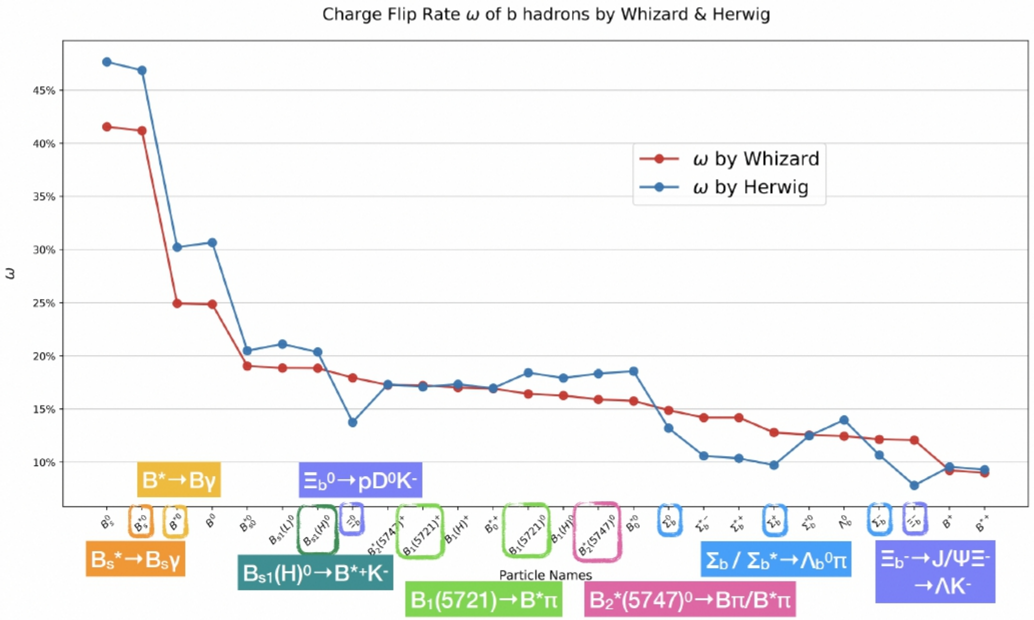


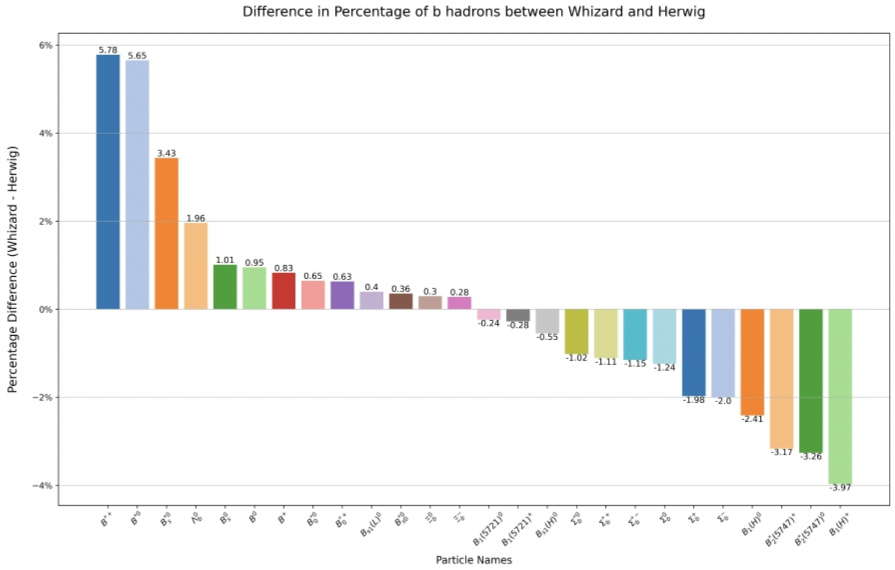
YX. Wang

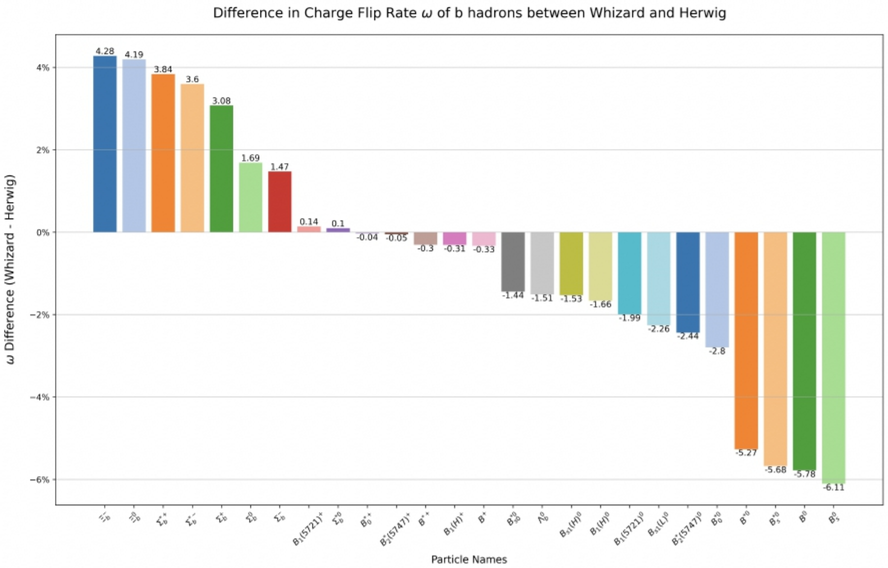
Fast simulation reproduces the full simulation results, factorize/quantifies different impacts

b-jet: leading b-hadrons & flip rates

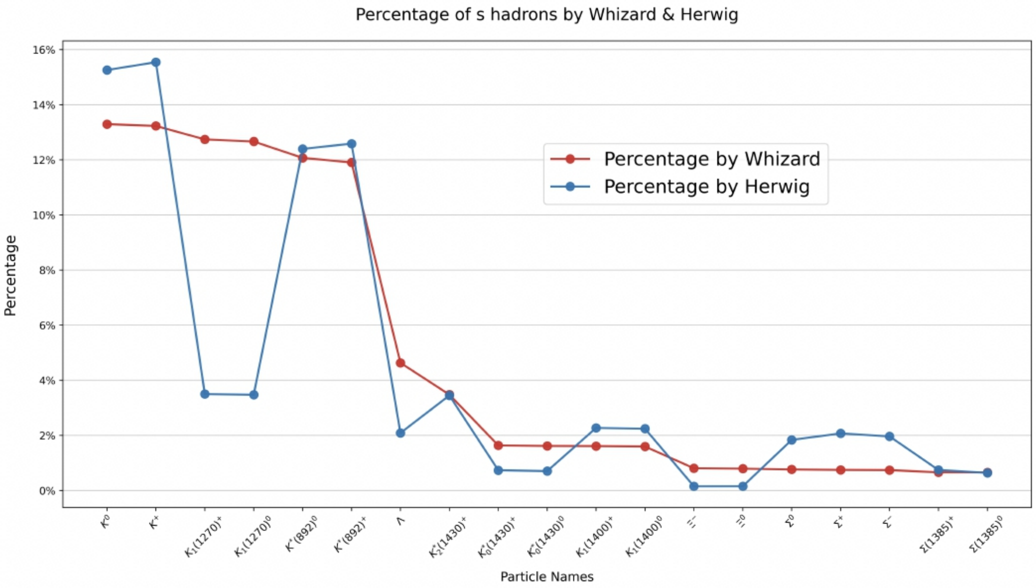

Percentage of b hadrons by Whizard & Herwig


Charge Flip Rate ω of b hadrons by Whizard & Herwig

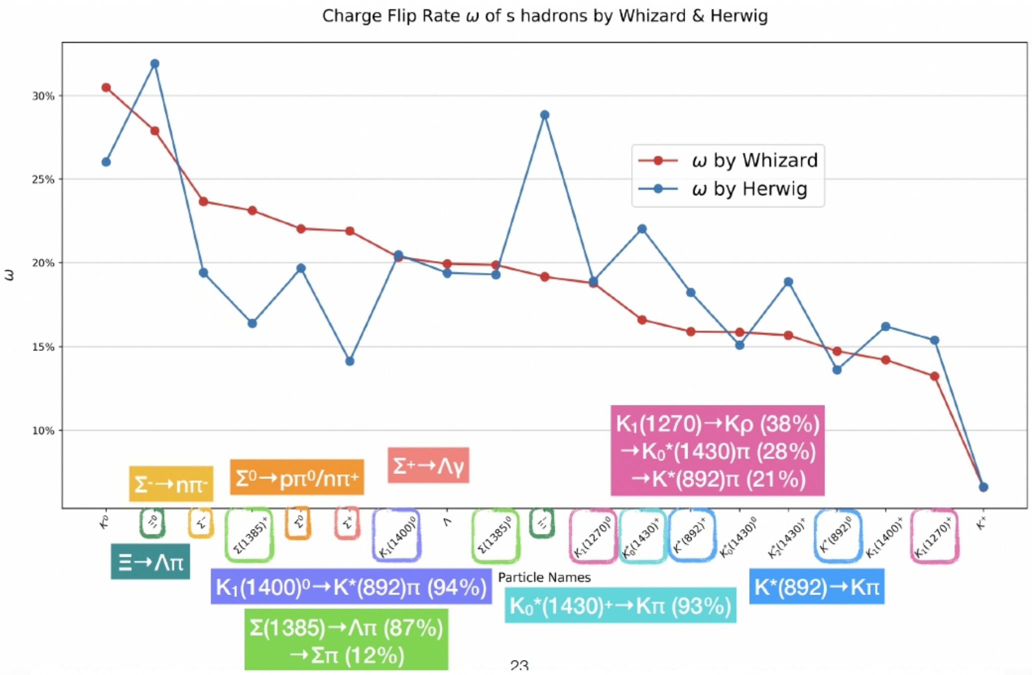

Difference in Percentage of b hadrons between Whizard and Herwig


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

s-jet: leading s-hadrons & flip rates



Percentage of s hadrons by Whizard & Herwig



Charge Flip Rate ω of s hadrons by Whizard & Herwig

$\Sigma^- \to n\pi^-$

$\Sigma^0 \to p\pi^0/n\pi^+$

$\Sigma^+ \to \Lambda\gamma$

$K_1(1270) \to K\rho$ (38%)
$\to K_0^*(1430)\pi$ (28%)
$\to K^*(892)\pi$ (21%)

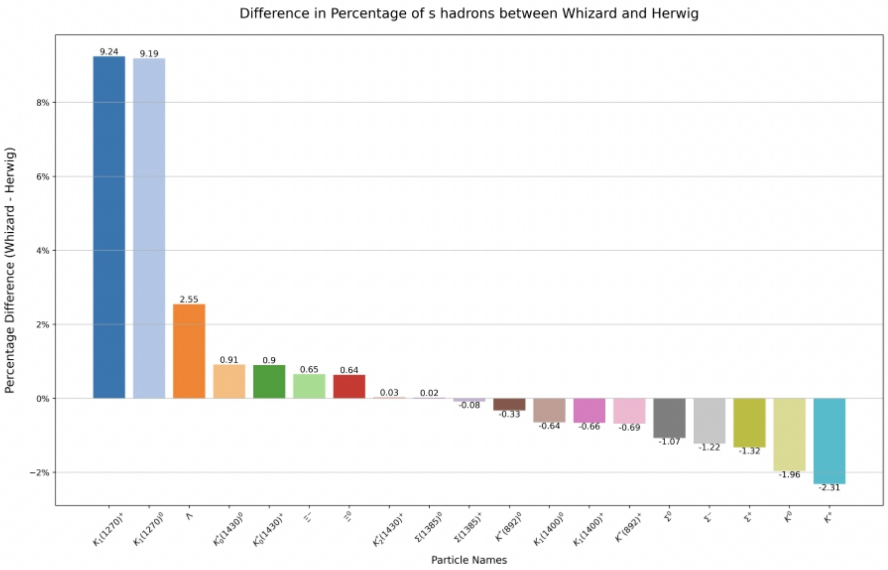
$\Xi \to \Lambda\pi$

$K_1(1400)^0 \to K^*(892)\pi$ (94%)

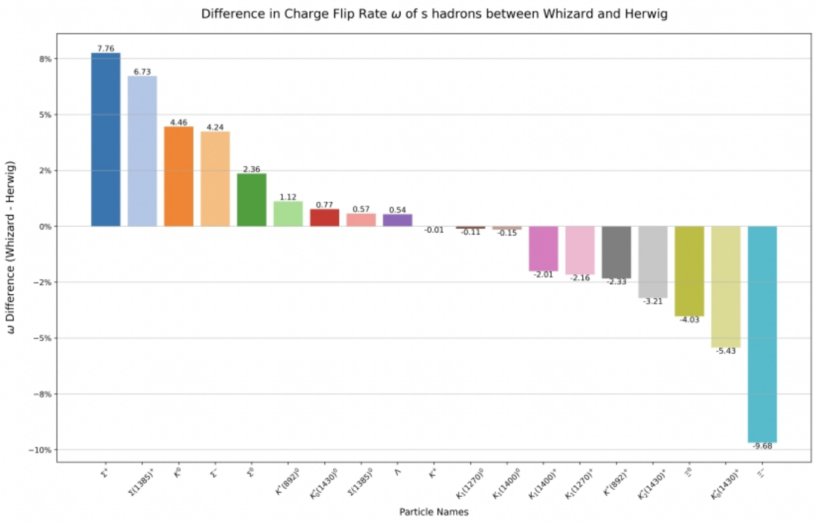
$K_0^*(1430)^+ \to K\pi$ (93%)

$K^*(892) \to K\pi$

$\Sigma(1385) \to \Lambda\pi$ (87%)
$\to \Sigma\pi$ (12%)

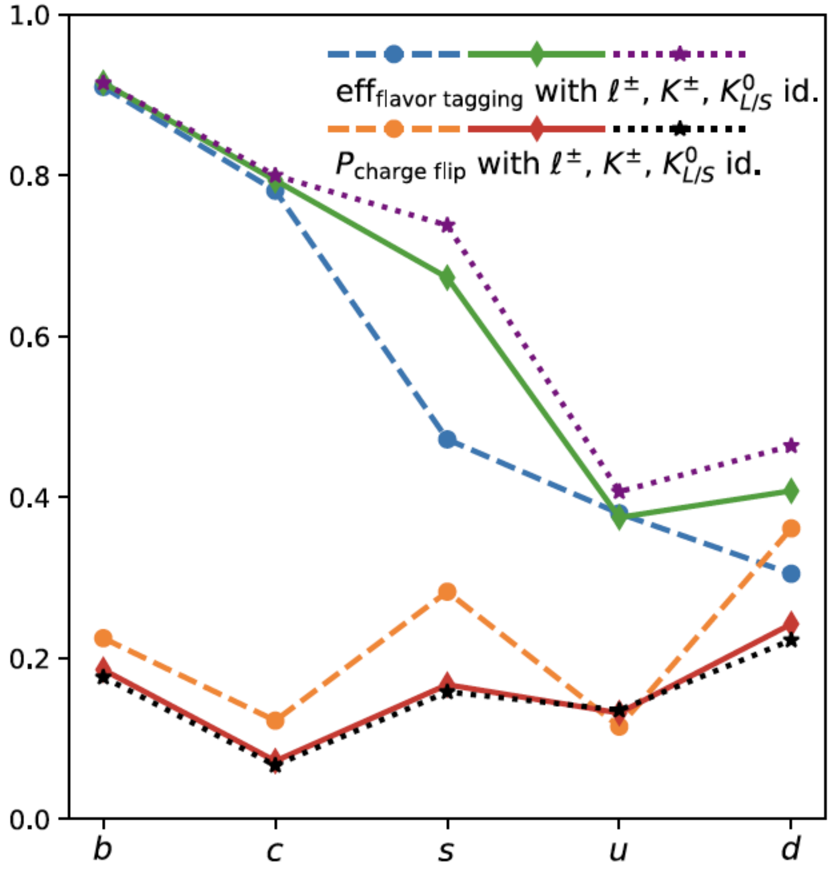


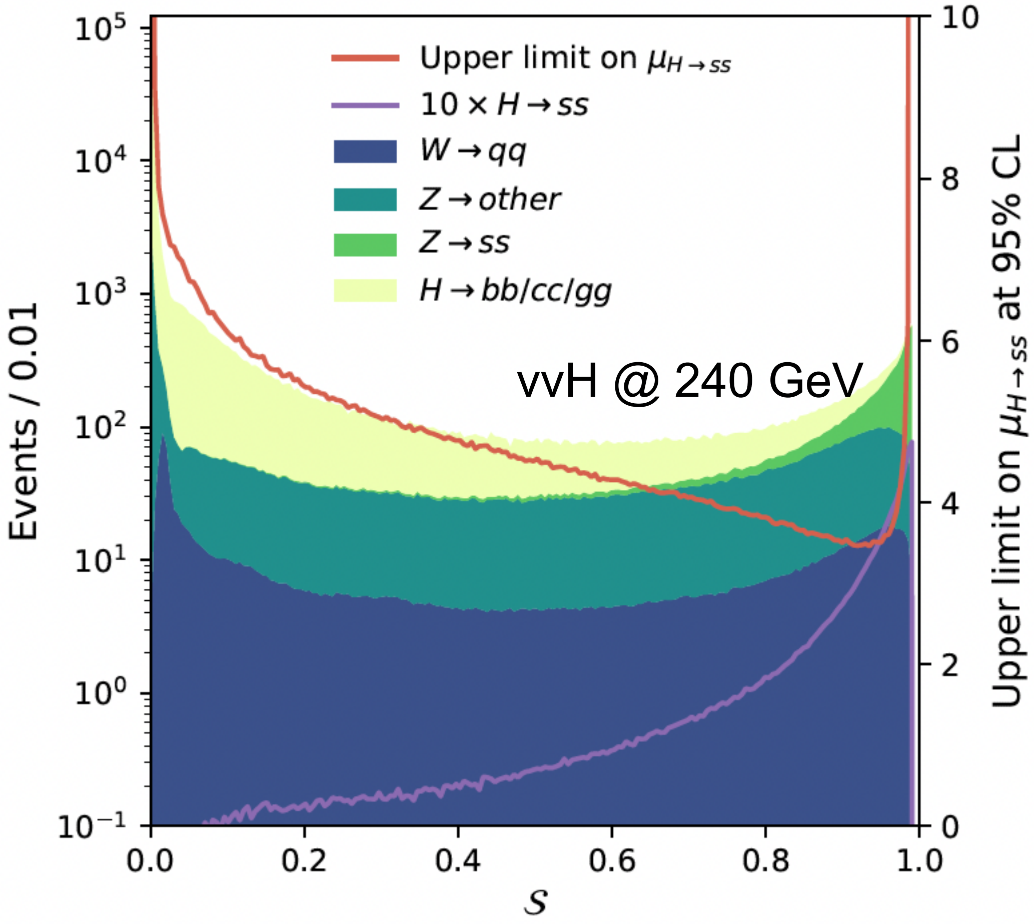
Difference in Percentage of s hadrons between Whizard and Herwig



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

Performance with different PID scenarios & H→ss measurements



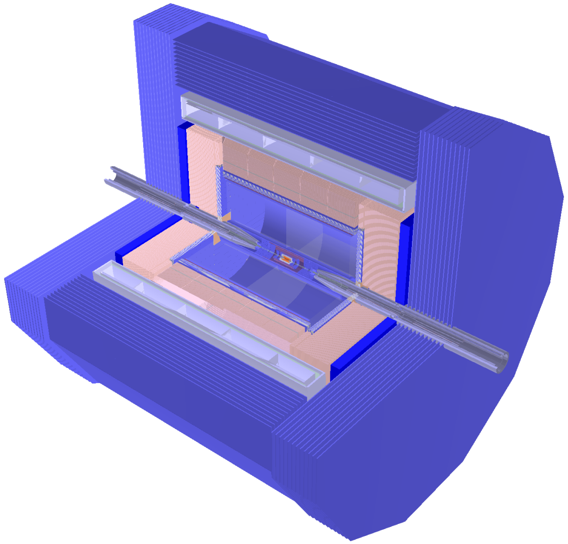


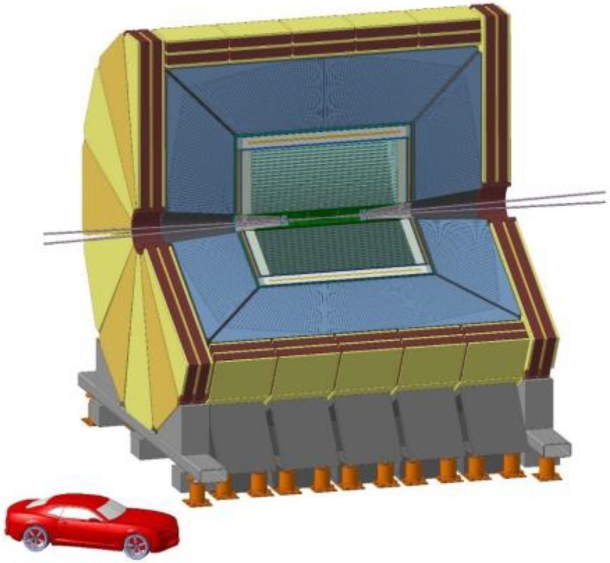
Flavor tagging: type that maximize {L_q + L_q_bar, L_g}

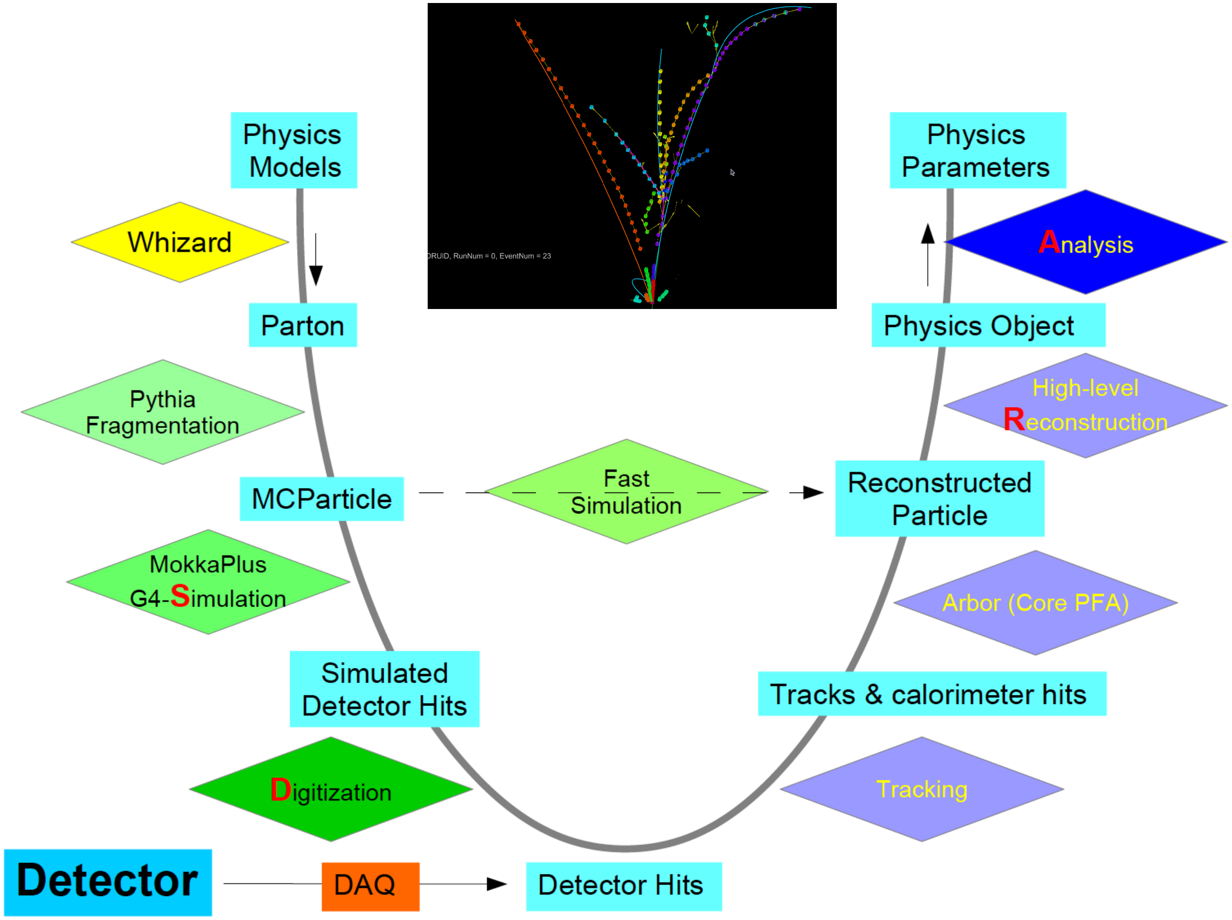
If quark jet: jet charge ~ compare {L_q, L_q_bar}

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

Detector & Software







Physics Models

Whizard

Parton

Pythia Fragmentation

MCParticle

MokkaPlus G4-Simulation

Simulated Detector Hits

Digitization

Detector

DAQ

Detector Hits

Fast Simulation

Tracking

Tracks & calorimeter hits

Arbor (Core PFA)

Reconstructed Particle

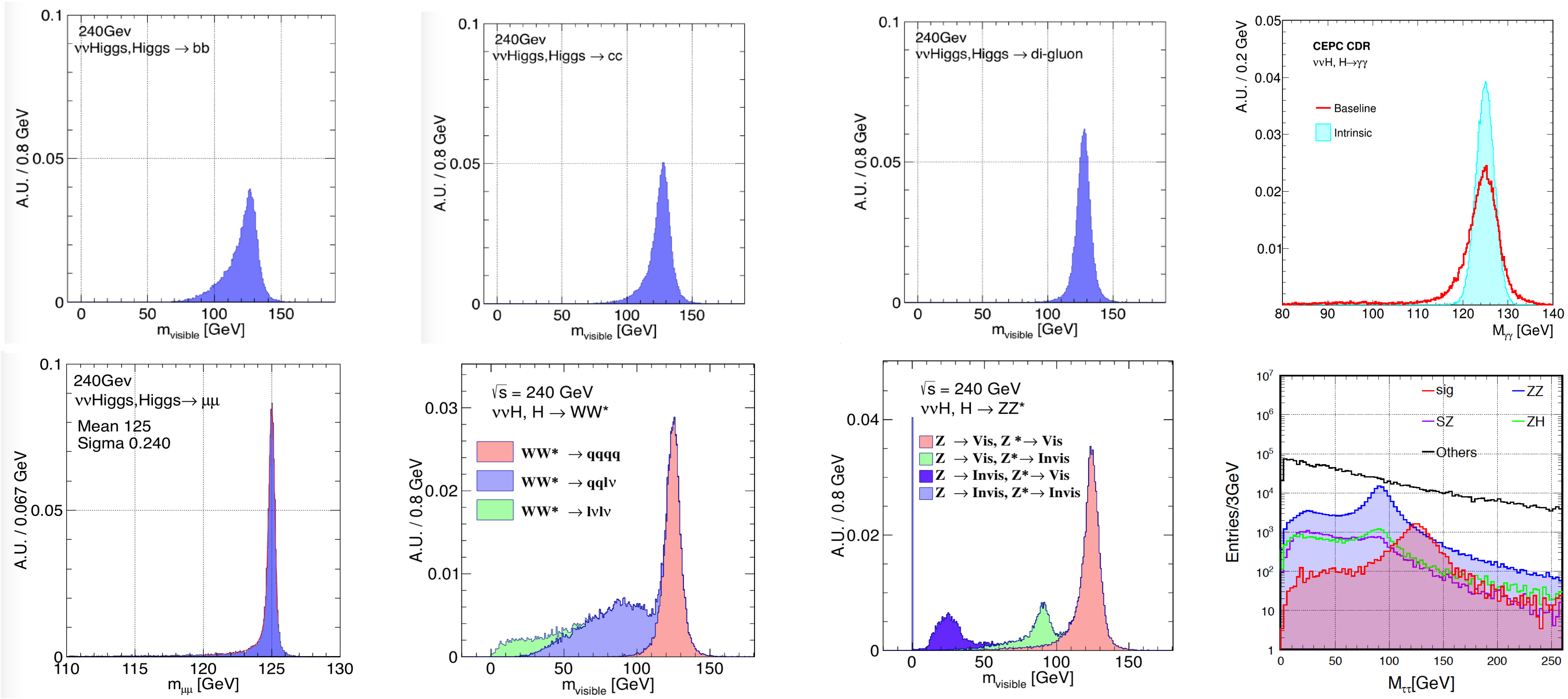
High-level Reconstruction

Physics Object

Analysis

Physics Parameters

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