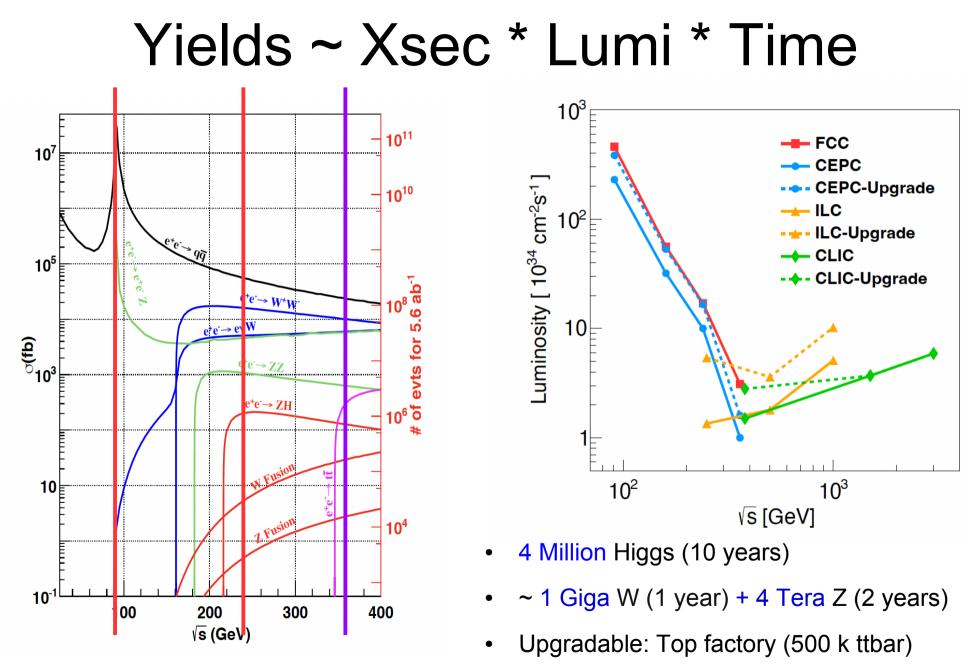
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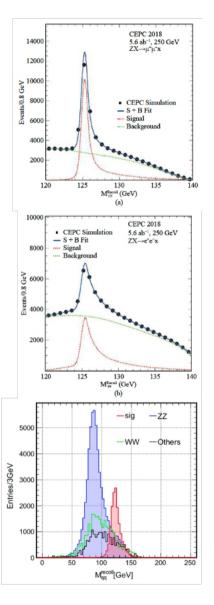
Its Impact on CEPC Physics

N

Manqi Ruan



Physics study: 2023



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

Precision Higgs physics at the CEPC'

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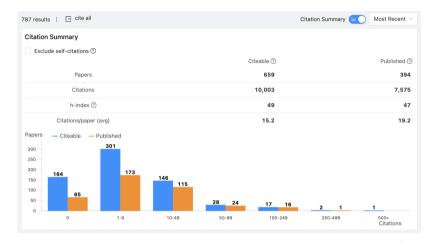


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1} . The HL-LHC precision of 2000 bb^{-1} data are used for comparison [2]

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

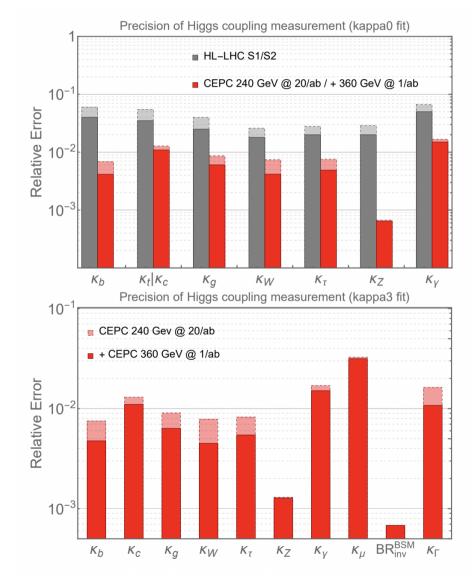
Scientific Significance quantified by CEPC physics studies, via full simulation/phenomenology studies:

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

07/01/2004

Physics reach via Higgs at CEPC

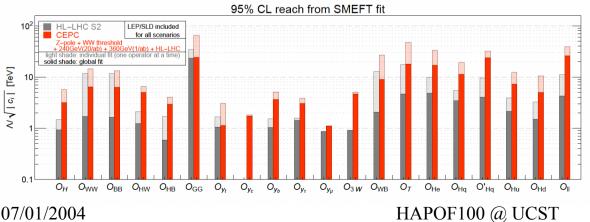
	$240{ m GeV},20{ m ab}^{-1}$		360 0	ab^{-1}	
	\mathbf{ZH}	\mathbf{vvH}	\mathbf{ZH}	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau \tau$	0.42%		2.10%	4.20%	7.50%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

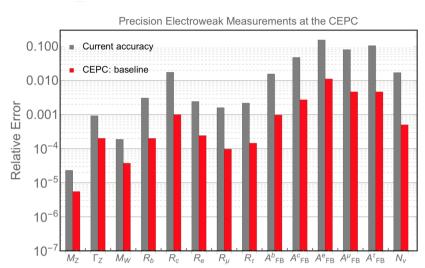


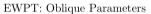
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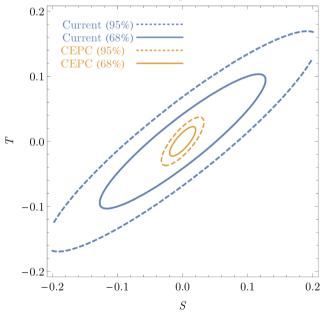
EW measurements & SMEFT

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









07/01/2004

Flavor Physics

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Flavor Physics at CEPC: a General Perspective

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07/01/2004

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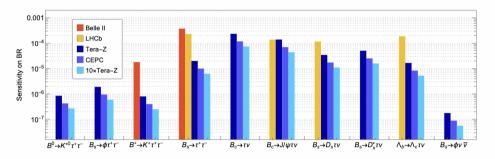
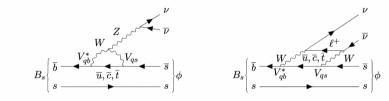
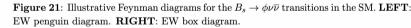
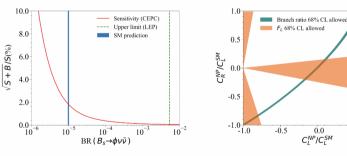


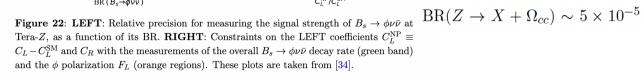
Figure 18: Projected sensitivities of measuring the $b \to s\tau\tau$ [70], $b \to s\nu\bar{\nu}$ [34] and $b \to c\tau\nu$ [35, 62] transitions at the Z pole. The sensitivities at Belle II @ 50 ab⁻¹ [6] and LHCb Upgrade II [17, 71] have also been provided as a reference. Note, the LHCb sensitivities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

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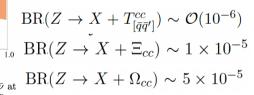






$$e^+$$

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



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

New Physics White paper

5

ABSTRACT (TO BE UPDATED)

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

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G. The 95 GeV Higgs boson at the CEPC

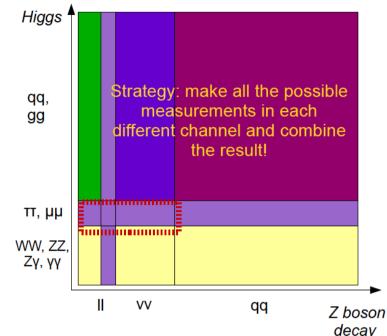
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07/01/2004

Performance requirements

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



• Requirements:

decay Final state

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

Jet origin id

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

PHYSICAL REVIEW LETTERS 132, 221802 (2024)

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

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

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

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

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Regular Article - Experimental Physics

ParticleNet and its application on CEPC jet flavor tagging

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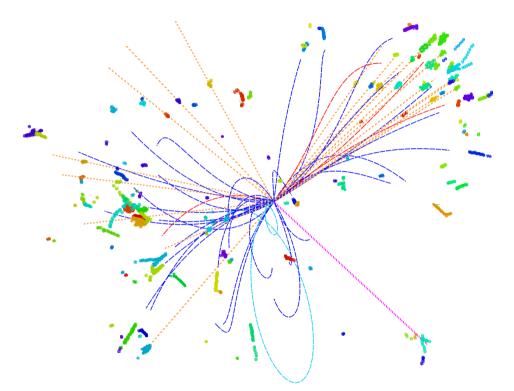
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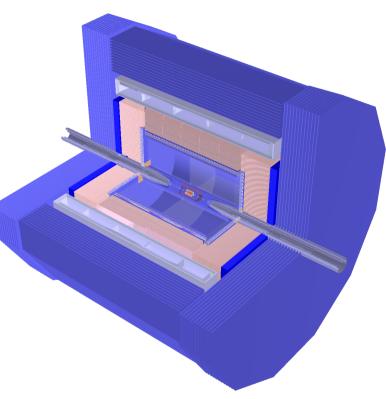
Received: 15 November 2023 / Accepted: 23 January 2024 © The Author(s) 2024

https://arxiv.org/abs/2310.03440

https://arxiv.org/abs/2309.13231

Detector & Sample





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

Particle Net: IO

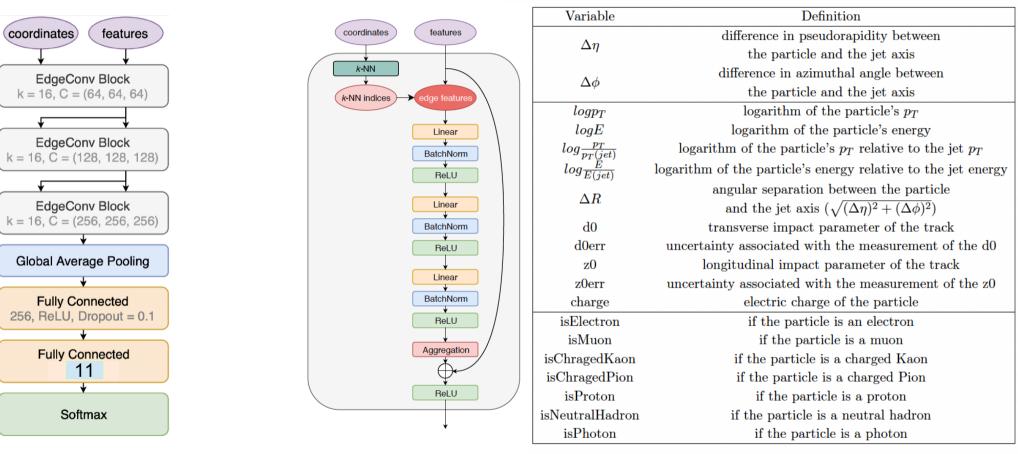


Table 3. The input variables used in ParticleNet for jet flavor tagging at the CEPC.

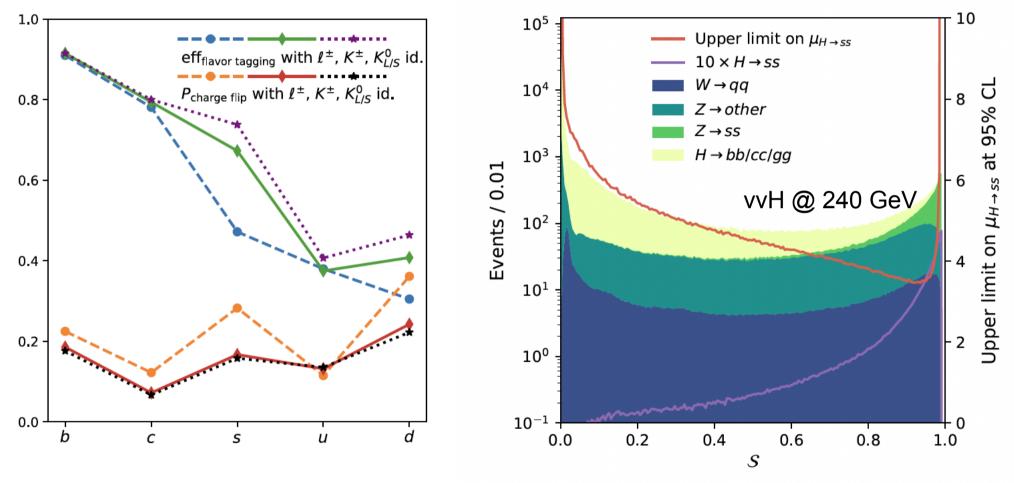
- Input: measurable of all reconstructed jet particles ~ 500 input numbers
- Output: 10(11)-likelihoods to different categories
 HAPOF100 @ UCST

11-dim migration behavior

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

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

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



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

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

13

Benchmark analyses: Higgs rare/FCNC

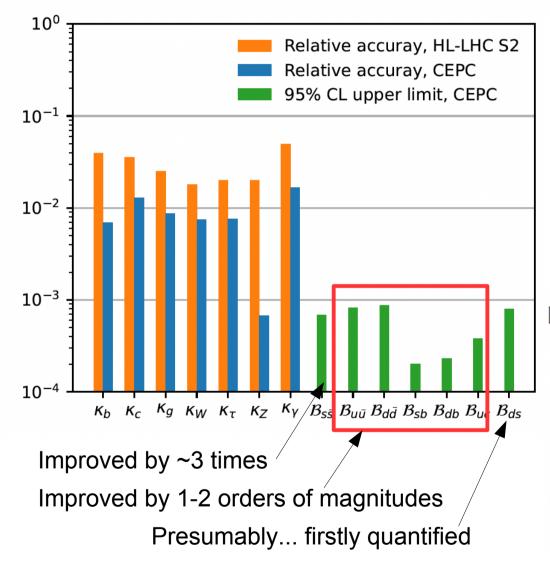
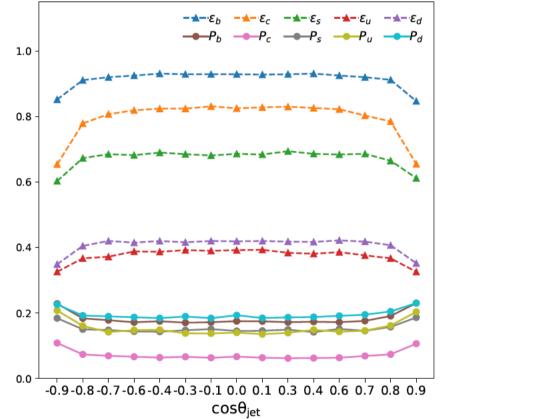


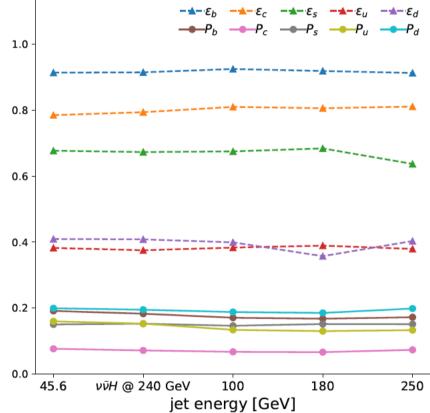
TABLE I: Summary of background events of $H \rightarrow b\bar{b}/c\bar{c}/gg$, Z, and W prior to flavor-based event selection, along with the expected upper limits on Higgs decay branching ratios at 95% CL. Expectations are derived based on the background-only hypothesis.

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

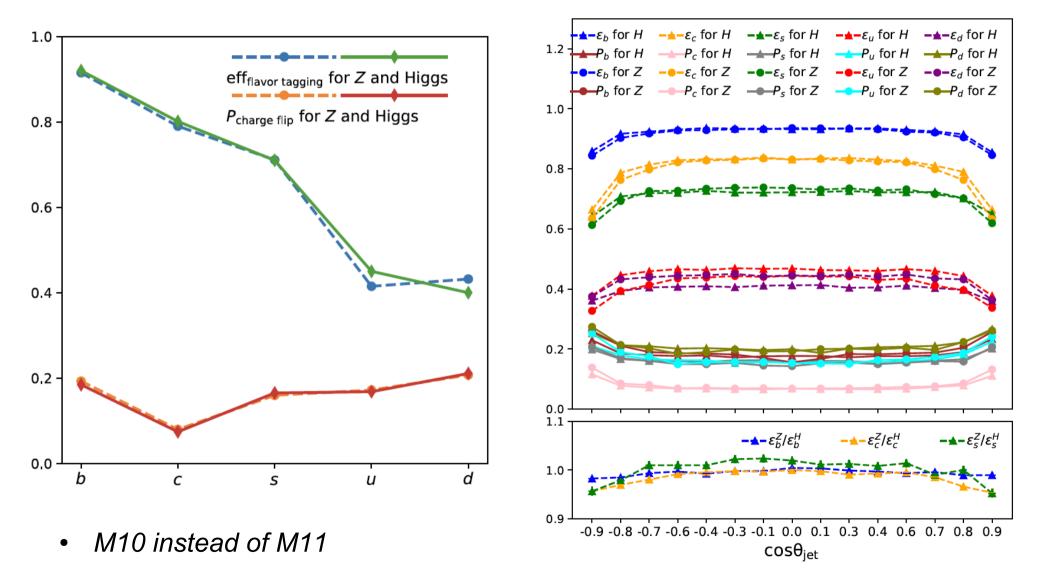
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Performance V.S. Jet Kinematics

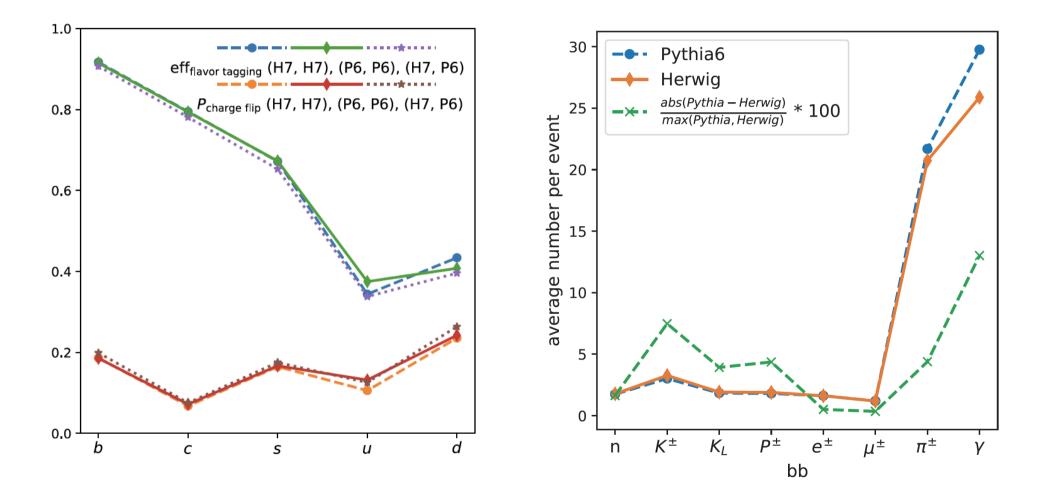




Performance @ Z and Higgs

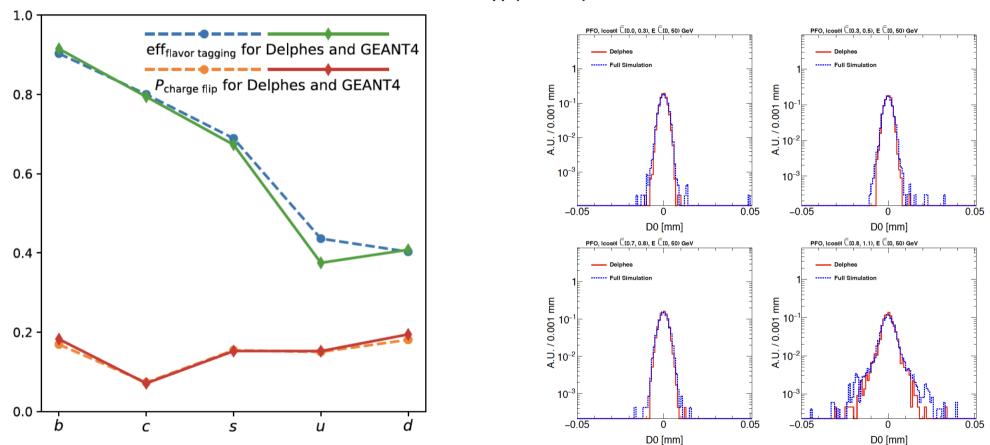


V.S. Hadronization models



07/01/2004

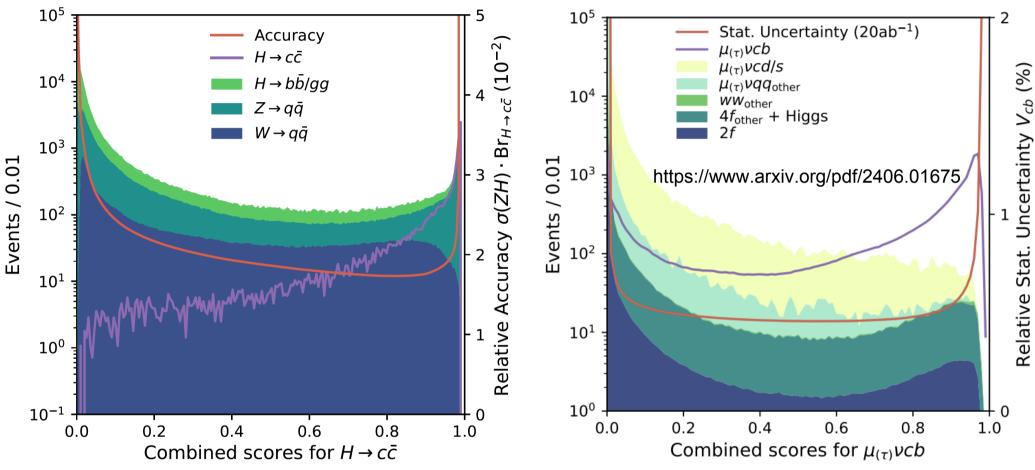
Fast/Full Simulation



Z->μμ (91.2 GeV)

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

Recent update at more benchmarks



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

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

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

 Table 2.
 Sensitivity S of different final state particles.

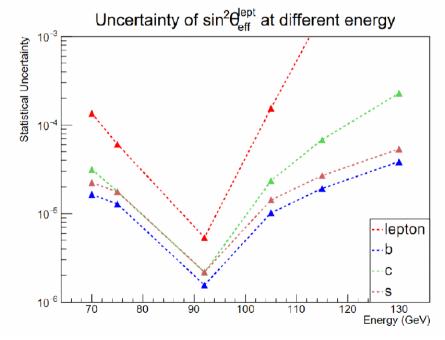
√s/GeV	S of $A_{FB}^{e/\mu}$	$S ext{ of } A^d_{FB}$	$S ext{ of } A^u_{FB}$	S of A^s_{FB}	S of A^c_{FB}	S of A^b_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958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

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

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

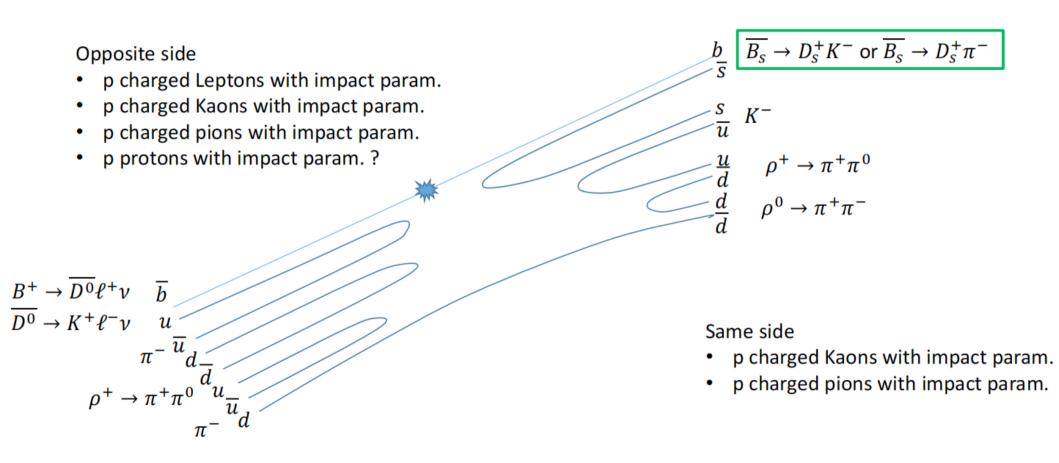
Verify the RG behavior... using ~1 month of data taking

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



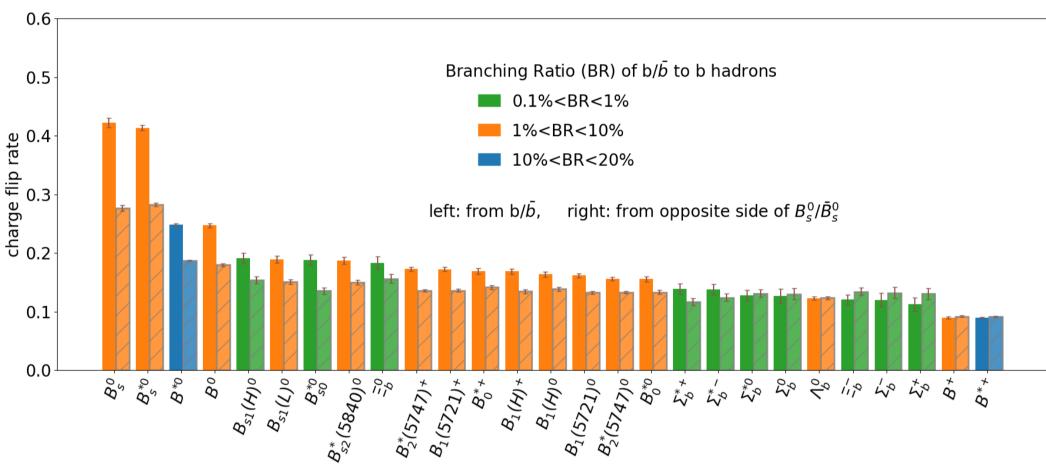
\sqrt{s}	b	С	S
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

B-charge flip rate: Bs oscillations



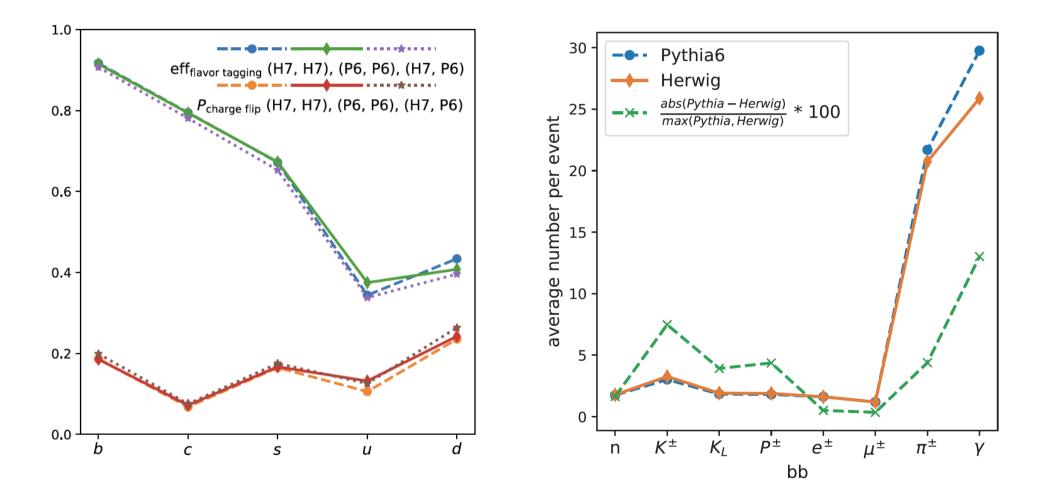
Roy. Aleksan, et. al @ CEA Saclay

B-charge flip rate: Bs oscillations

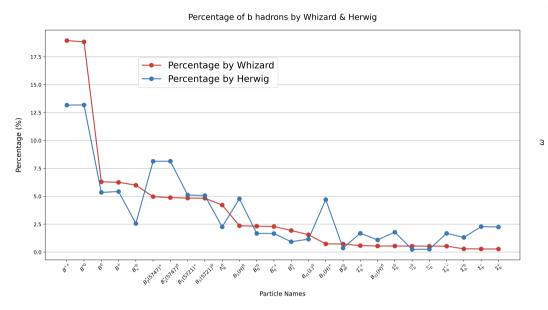


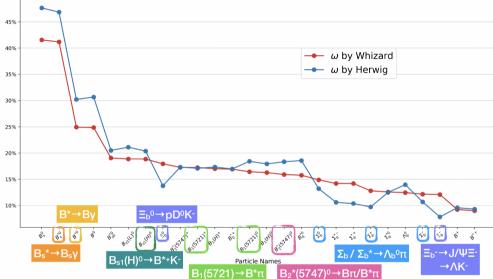
• Flip rate ~ 15%, Eff. Tagging power > 40%

V.S. Hadronization models



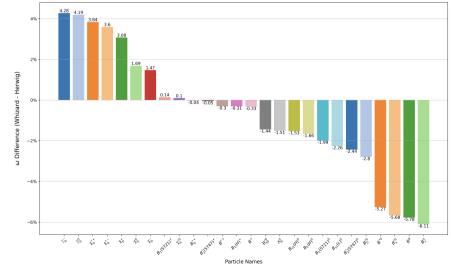
b-jet: leading b-hadrons & flip rates



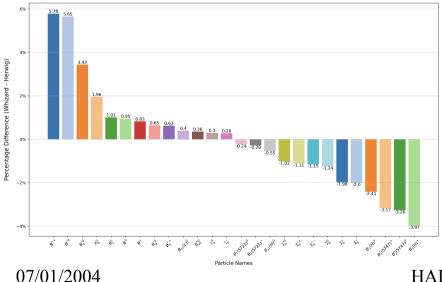


Charge Flip Rate ω of b hadrons by Whizard & Herwig

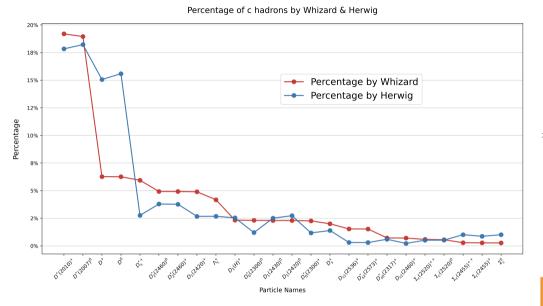
Difference in Charge Flip Rate ω of b hadrons between Whizard and Herwig



Difference in Percentage of b hadrons between Whizard and Herwig



c-jet: leading c-hadrons & flip rates



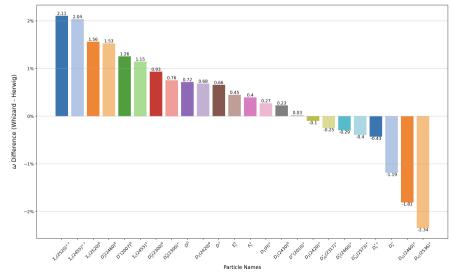
Difference in Percentage of c hadrons between Whizard and Herwig

07/01/2004

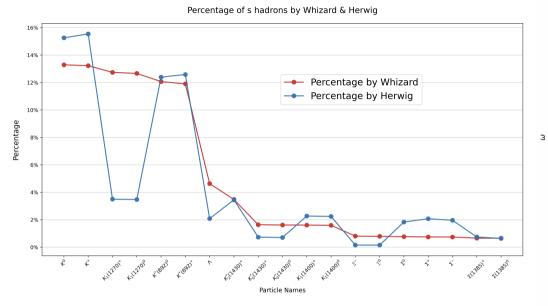
12% 10% - ω by Whizard ω by Herwig З 69 4% →D_s+π⁰ $D_{s2}^{*}(2573)^{+} \rightarrow D^{0}K^{+}/D^{+}Ks^{0}$ D₀*(2300)+→Dπ+ D₁(2420)→D*(2007)⁰I Particle Names D₂(2460)⁰→Dπ D*(2007)⁰→D⁰π⁰ (64.7%) D*(2010)+→D⁰π+ (67 D₁(2430)⁰→D*(2010)+π⁻ →D*(2010)+π[.] →D⁰v (35.3%) D_{s0}*(2317)+→Ds+π⁰

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

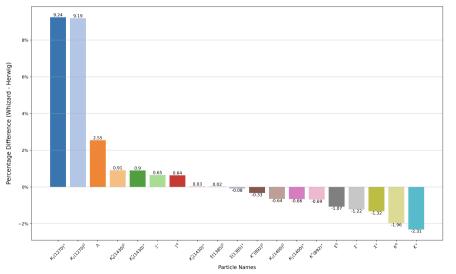
Charge Flip Rate ω of c hadrons by Whizard & Herwig



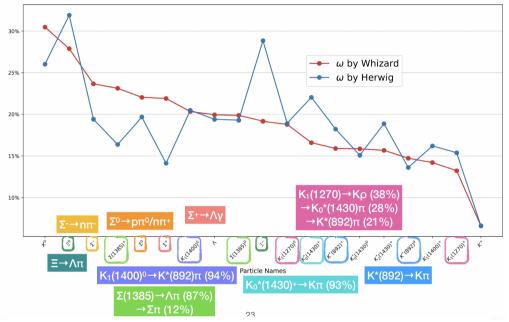
s-jet: leading s-hadrons & flip rates



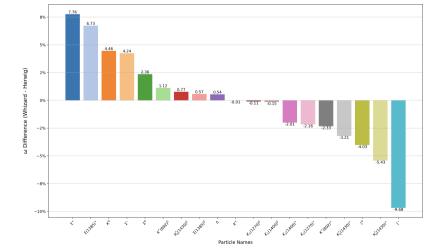
Difference in Percentage of s hadrons between Whizard and Herwig



Charge Flip Rate ω of s hadrons by Whizard & Herwig

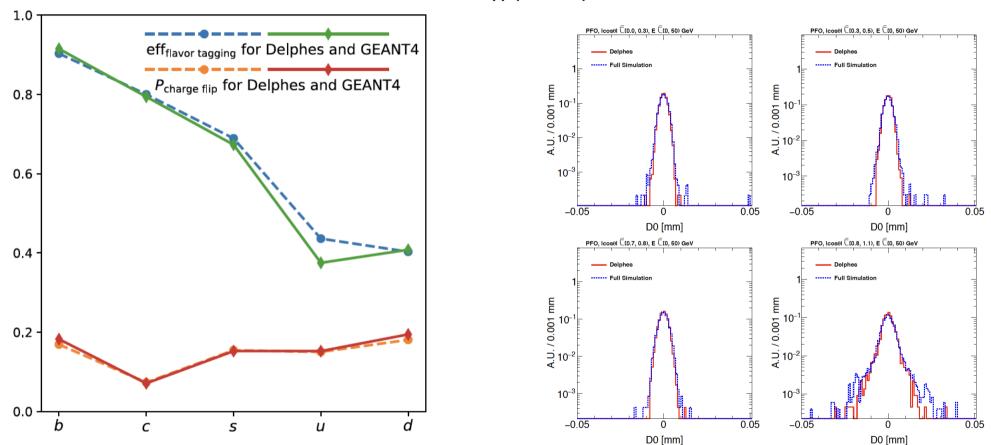


Difference in Charge Flip Rate ω of s hadrons between Whizard and Herwig



07/01/2004

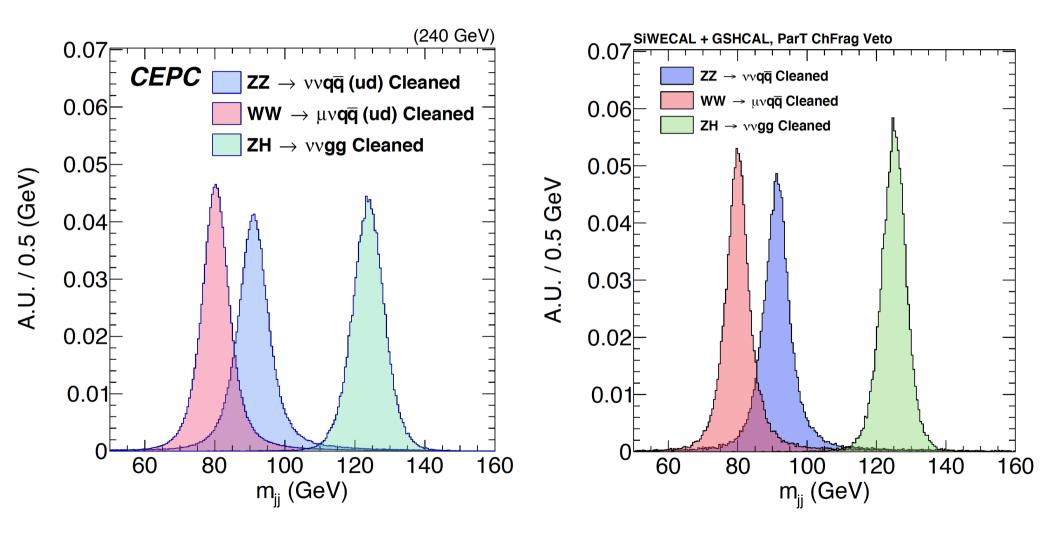
Fast/Full Simulation



Z->μμ (91.2 GeV)

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

... At Bosons Mass resolution...

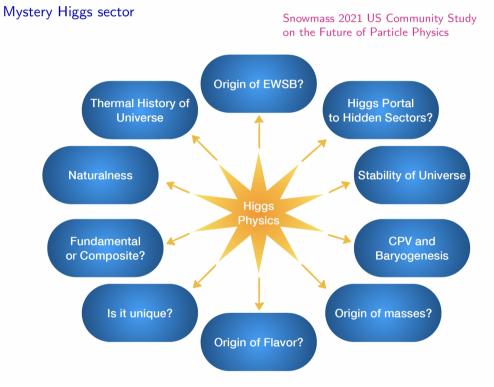


Summary

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

Back up

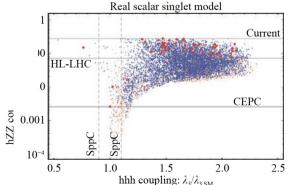
Higgs white paper

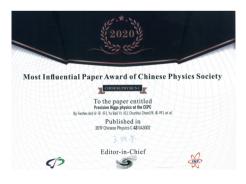


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Precision Higgs physics at the CEPC*

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Snowmass White Paper

ABSTRACT

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

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Summarize ~ 20 citables for CEPC Snowmass studies •

17 May 2022

arXiv:2205.08553v1 [hep-ph]

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The Physics potential of the CEPC

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

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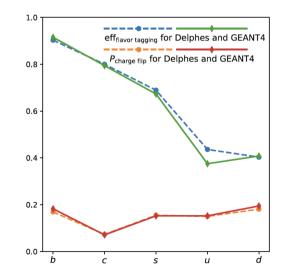
M11 3 with charged hadron and K_L K_S

												0.							
0.748	0.159	0.034	0.024	0.004	0.003	0.002	0.003	0.002	0.002	0.018		0. 0.							
												0.							
0.158	0 740	0.025	0.034	0.003	0.005	0.003	0.002	0.002	0.003	0.017		0.							
0.150	0.143	0.025	0.034	0.005	0.005	0.005	0.002	0.002	0.005	0.017		0.							
												0.							
0.016	0.014	0.752	0.053	0.040	0.034	0.020	0.008	0.008	0.017	0.038		0.							
												0.							
												0.							
0.015	0.016	0.053	0.749	0.034	0.041	0.008	0.020	0.017	0.009	0.039		0.							
												0.							
0.002	0.002	0.021	0.010	0.607	0.110	0.020	0.056	0.044	0.041	0.077		0.							
0.005	0.002	0.021	0.019	0.007	0.110	0.020	0.050	0.044	0.041	0.077		0.							
												0.							
0.003	0.003	0.019	0.023	0.107	0.609	0.057	0.019	0.041	0.043	0.078		0.							
0.000	5.000	5.020	5.025		51000		5.020			5.0.0		0.							
												0.							
0.002	0.003	0.016	0.009	0.032	0.104	0.378	0.057	0.093	0.197	0.108		0.							
																			0.
			0.01.0		0.000	0.000	0.071	0.000	0.00.1	0.100		0.							
0.003	0.002	0.009	0.016	0.102	0.032	0.062	0.371	0.202	0.094	0.108		0.							
												0.							
0.003	0.002	0.010	0.016	0.076	0.074	0.087	0.201	0 335	0.086	0 1 1 0		0. 0.							
0.003	0.002	2 0.010	0.010	0.070	0.074	0.087	0.201	0.000	0.000	0.110		0.							
												0.							
0.003	0.003	0.016	0.009	0.075	0.076	0.210	0.083	0.086	0.330	0.110		0.							
				0.010	0.010	0.210	5.000		2.000	0.210		0.							
												0							
0.015	0.015	0.024	0.024	0.051	0.050	0.042	0.042	0.040	0.041	0.657		0							
1	<u> </u>	I.	<u> </u>	I.	1	I.	I	1	1	I									
b	\overline{b}	С	\overline{c}	5	ŝ	и	\overline{u}	d	d	G									
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0.003 0.003 0.016 0.009 0.032 0.003 0.002 0.010 0.016 0.102 0.003 0.002 0.010 0.016 0.102 0.003 0.002 0.010 0.016 0.076 0.003 0.003 0.016 0.009 0.075 0.003 0.015 0.024 0.024 0.021 0.015 0.015 0.024 0.024 0.051 b b c c c c	0.1100 0.1000 0.0011 0.0021 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0031 0.0110 0.0331 0.0141 0.003 0.003 0.012 0.013 0.013 0.010 0.0131 0.110 0.0101 0.003 0.003 0.016 0.019 0.023 0.104 0.032 0.1104 0.003 0.003 0.016 0.003 0.016 0.016 0.012 0.032 0.003 0.002 0.016 0.016 0.016 0.017 0.016 0.003 0.003 0.016 0.016 0.017 0.016 0.017 0.016 0.003 0.015 0.024 0.024 0.051 0.050 0.51 <td>0.1100 0.1001 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 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M11 2 with charged hadron

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

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





Arbor Tree topology of particle shower

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

Special Article - Tools for Experiment and Theory

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

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

¹ Institute of High Energy Physics, Beijing, China

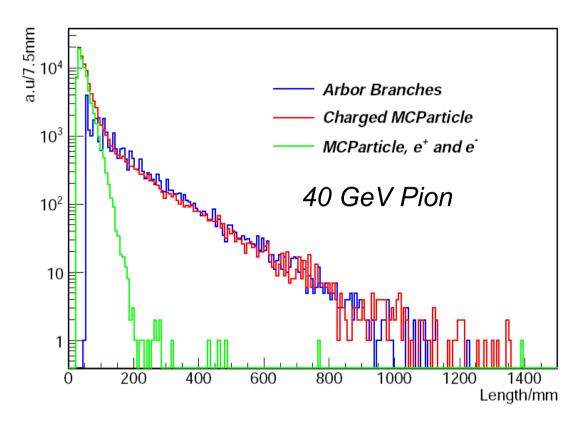
- ² Laboratoire Leprince-Ringuet, Ecole Polytechnique, Palaiseau, France
- ³ Department of Physics and Center of high energy and high field physics, National Central University, Taoyuan City, Taiwan
- ⁴ Iowa State University, Ames, USA
- ⁵ Institute de Physique Nucleaire de Lyon, Lyon, France
- ⁶ Institute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

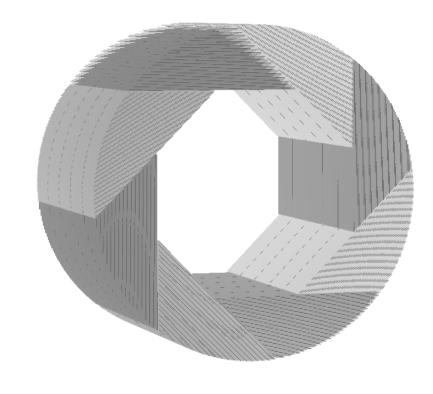
15cm

6.5

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

Validation: Arbor Branch Length Vs MC Truth

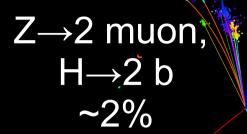




Arbor: successfully tag sub-shower structure

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

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



Z→2 jet, \checkmark H→2 tau \sim 5%

ZH \rightarrow 4 jets ~50%

Z→2 muon H→WW*→eevv ~1%

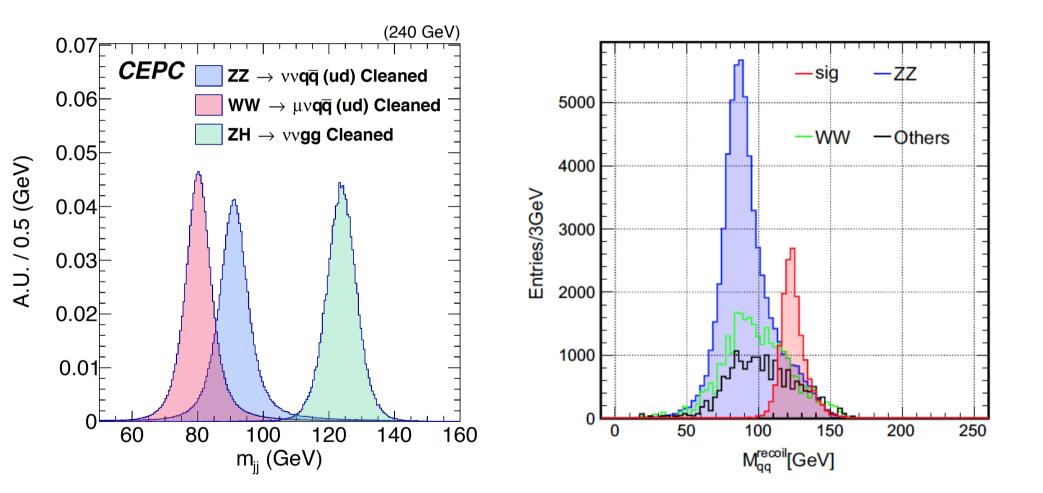
07/01/2004



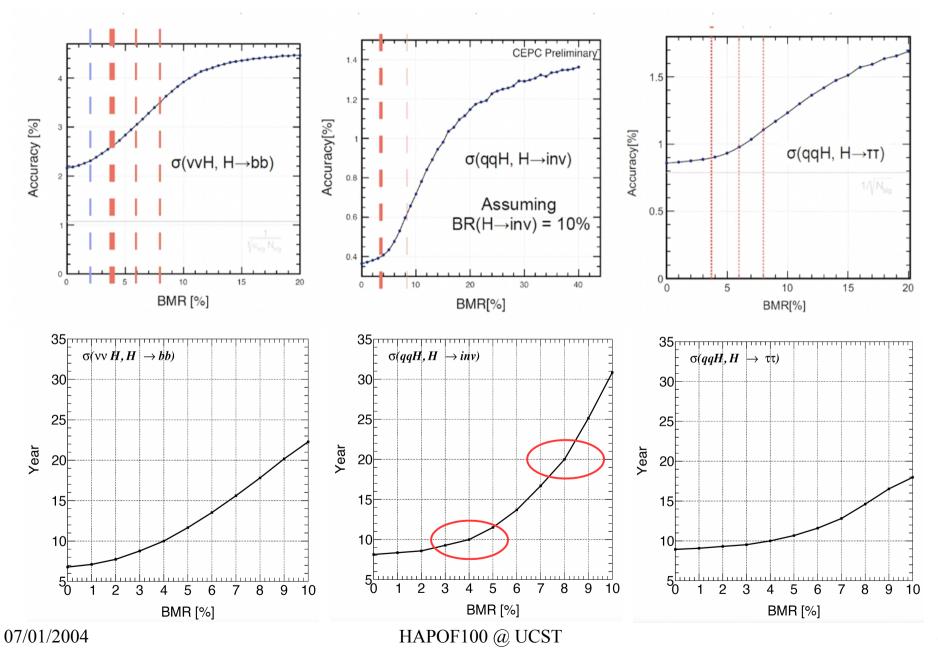
CMS Experiment at LHC, CERN Data recorded: Thu Jan 1 01:00:00 1970 CEST Run/Event: 1 / 1201 Lumi section: 13

k

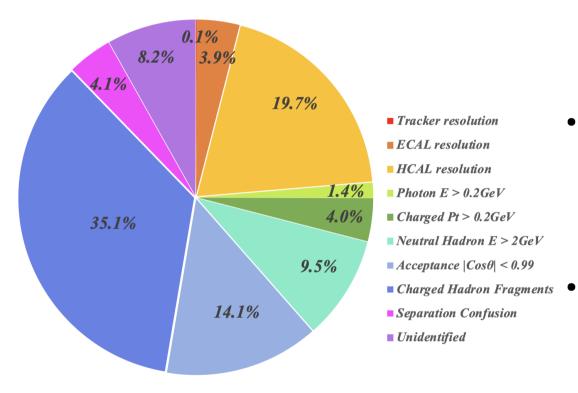
Boson Mass Resolution: Key Per. Para



BMR: impact on critical measurements



BMR decomposition @ CDR baseline



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

Improving HCAL: RPC Digital HCAL \rightarrow GSHCAL

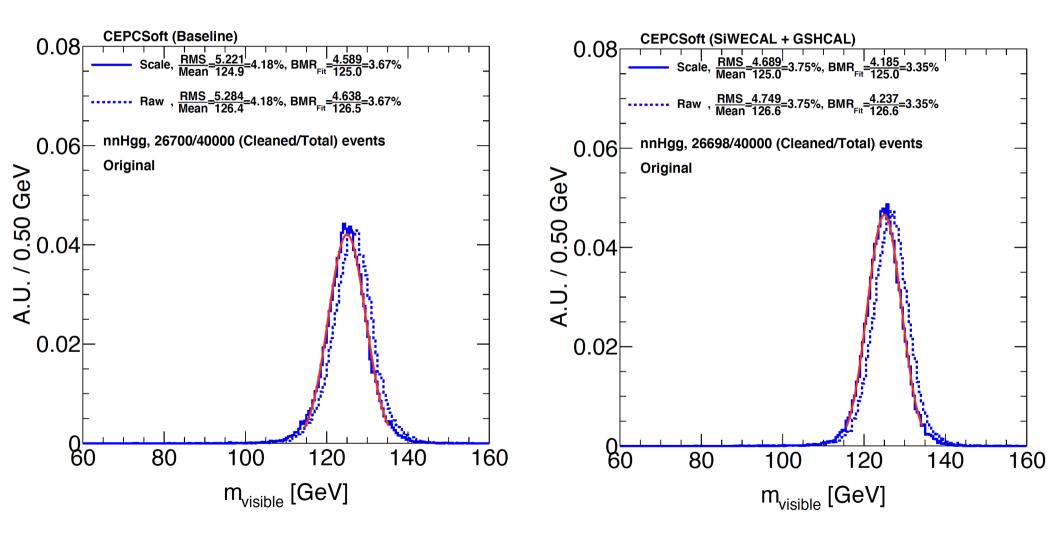
Remarks:

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

Three detector models

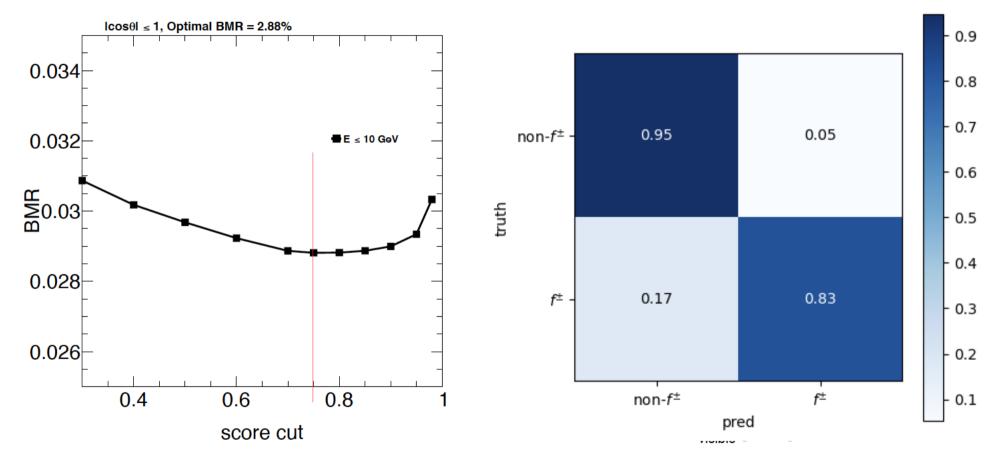
Parameters	SiWECAL + SDHCAL (Baseline)	SiWECAL + GSHCAL	CSECAL + GSHCAL
ECAL Material	Si + W	Si + W	BGO (Homogeneous)
ECAL Transverse cell size	$1 \times 1 \ \mathrm{cm}^2$	$1 \times 1 \text{ cm}^2$	$1 imes 1~{ m cm}^2$
ECAL Number of layers	30	30	27
ECAL Total thickness	$24 X_0$	$24 X_0$	$24 X_0$
ECAL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

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



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

Preliminary: Identify & veto charged shower fragments using AI

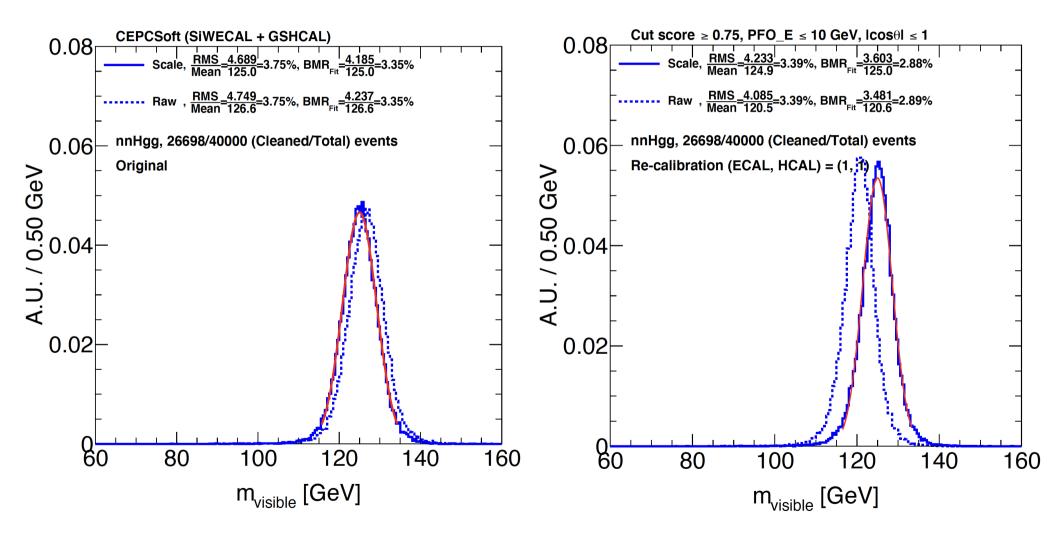


Trained at 12E4 events,

Test & Applied at 4E4 events

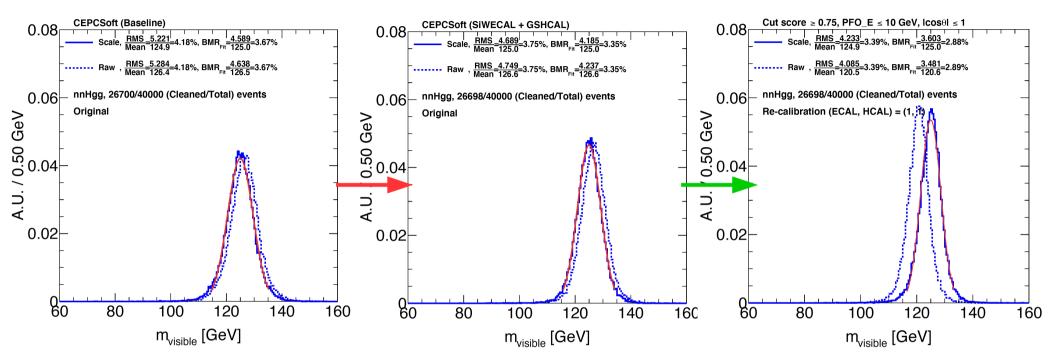
score > 0.75 efficiency ~83% purity ~95%

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



Truth level veto prediction: 3.32 -> 2.98%

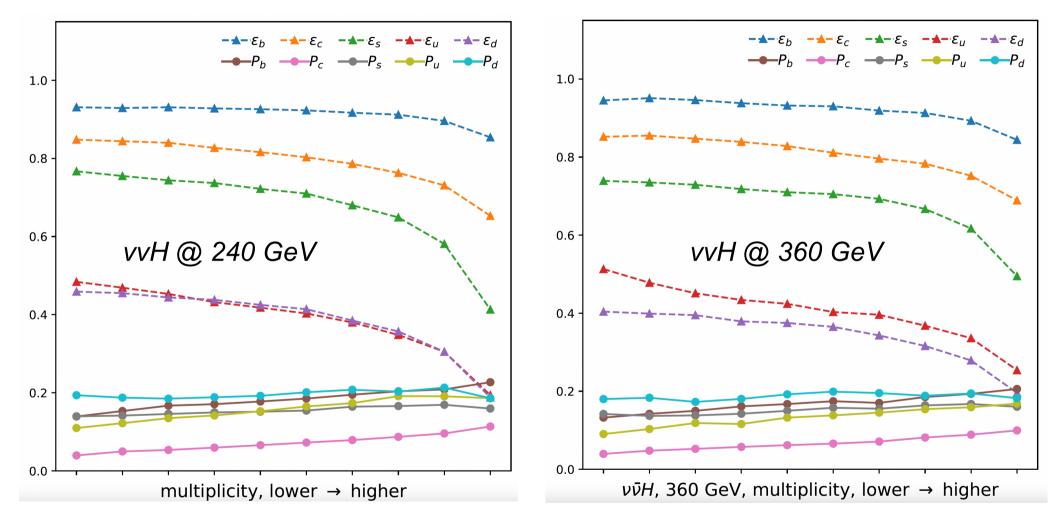
BMR Comparison



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

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

V.S. Multiplicity



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

Particle identification



week ending 10 JANUARY 2014

PRL 112, 012001 (2014)

DOI: 10.1103/PhysRevLett.112.012001

07/01/2004

PHYSICAL REVIEW LETTERS

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

Fractal Dimension of Particle Showers Measured in a Highly Granular Calorimeter

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

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



journal homepage: www.elsevier.co

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

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

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HAPOF100 @ UCST





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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Cluster time measurement with CEPC calorimeter

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

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



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

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

THE EUROPEAN	CrossMark
PHYSICAL JOURNAL C	

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

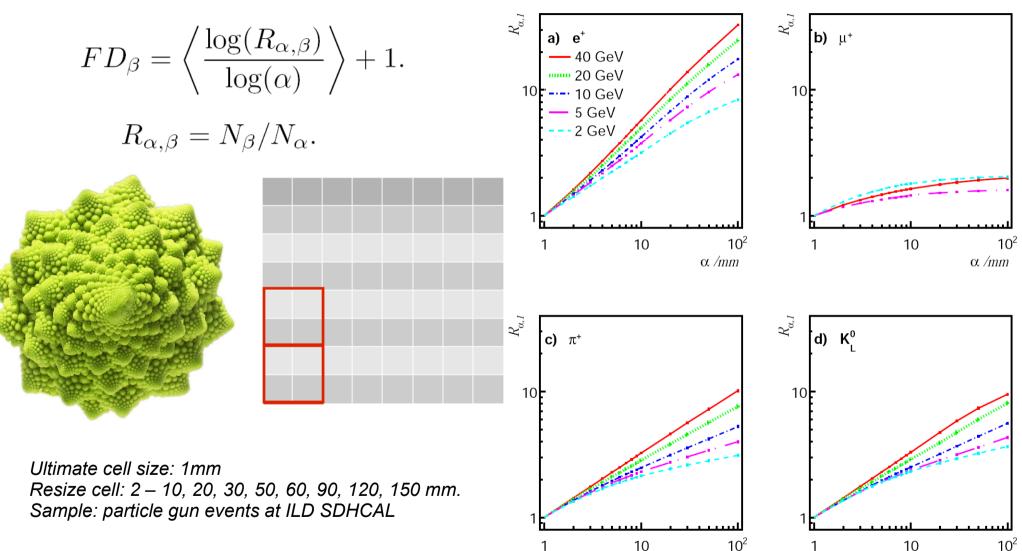
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Fractal dimension of particle shower





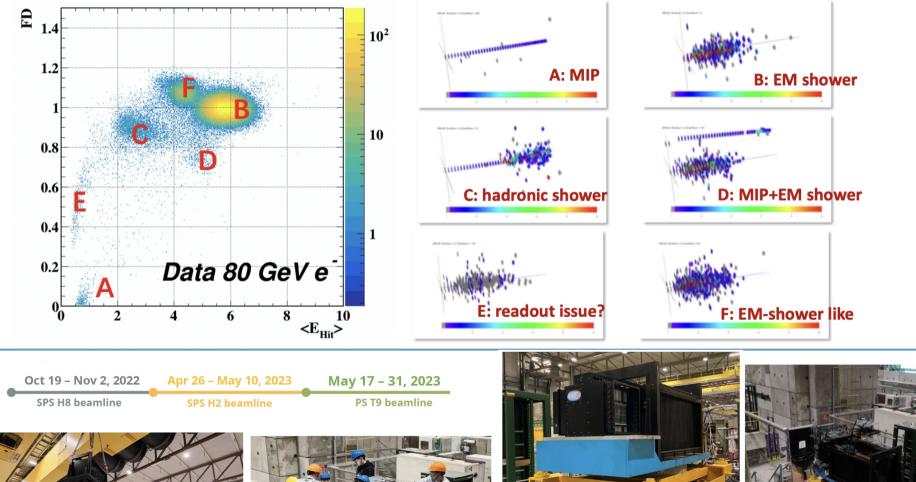
HAPOF100 @ UCST

 α /mm

 α /mm



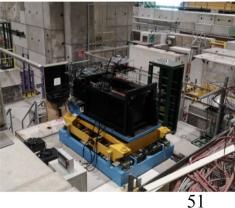
- FD characteristics of different beam particles
 - Imaging capability of high granularity calorimeter ()







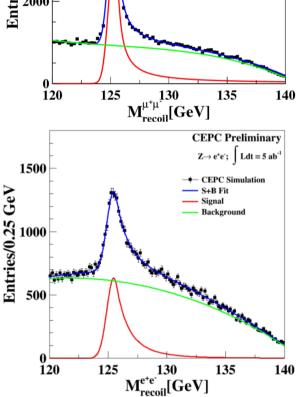




Lepton: isolated **CEPC** Preliminary $Z \rightarrow \mu^+ \mu^-$; Ldt = 5 ab⁻¹ **~102** CEPC Simulation log10(ELike) agged eff(%) Entries/0.25 GeV 4000 S+B Fit Signal Background 100 98 2000 -electron 96 muon 94 - pion -10 Electron $M_{recoil}^{\mu^{+}\mu^{1}}[GeV]$ 125 120 135 • Muon 92 × Pion 90 -15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

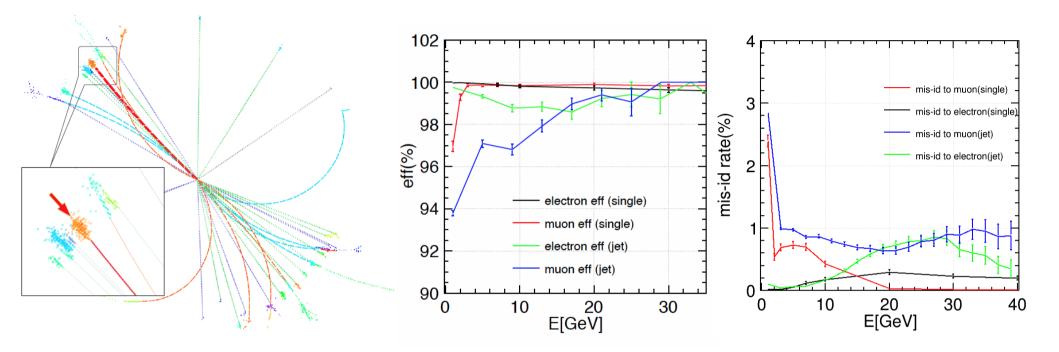
BDT method using 4 classes of 24 input discrimination variables.

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



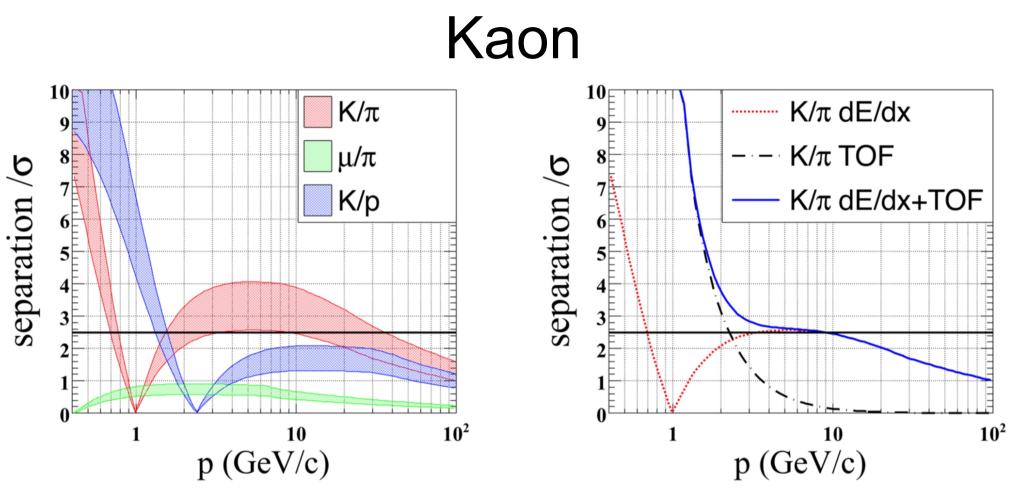
https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5 CEPC-DocDB-id:148, Eur. Phys. J. C (2017) 77: 591 HAPOF100 @ UCST 52

Lepton: inside jet



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

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



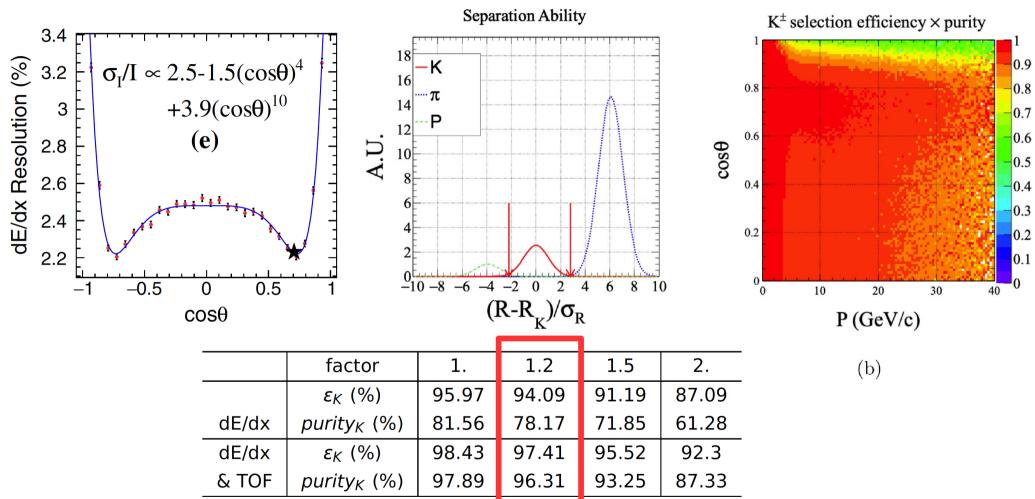
Highly appreciated in flavor physics @ CEPC Z pole TPC dEdx + ToF of 50 ps

At inclusive Z pole sample:

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

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Pid performance

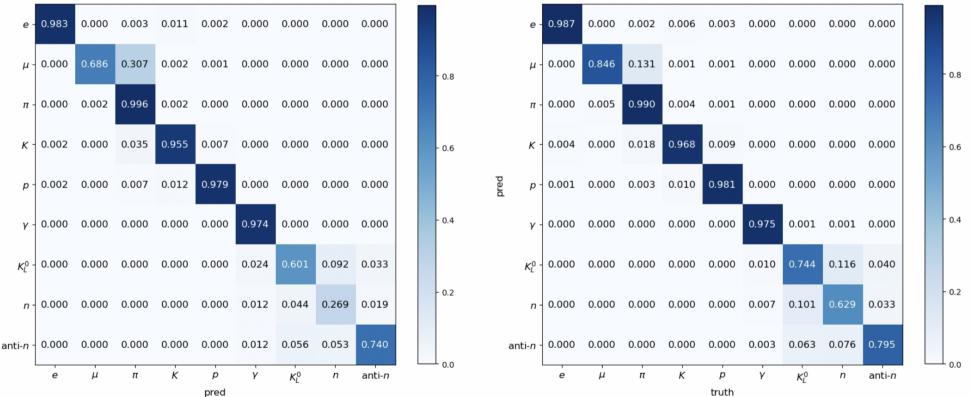


3% of dE/dx & dN/dx + 50 ps ToF: eff/purity of Kaon reco > 95%

Inc. Reco. Particle id: Preliminary & in progress

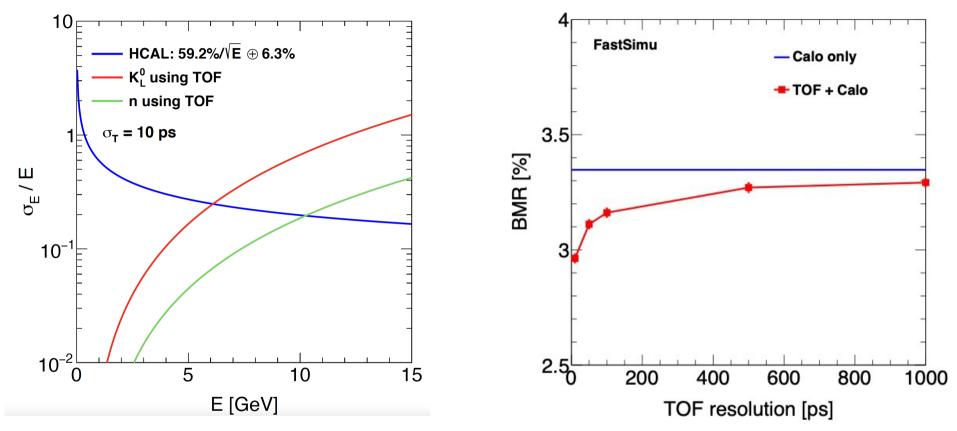
purity

efficiency



truth

Neutral Particle id: Very Preliminary



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

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

2-body decay particles and tau leptons

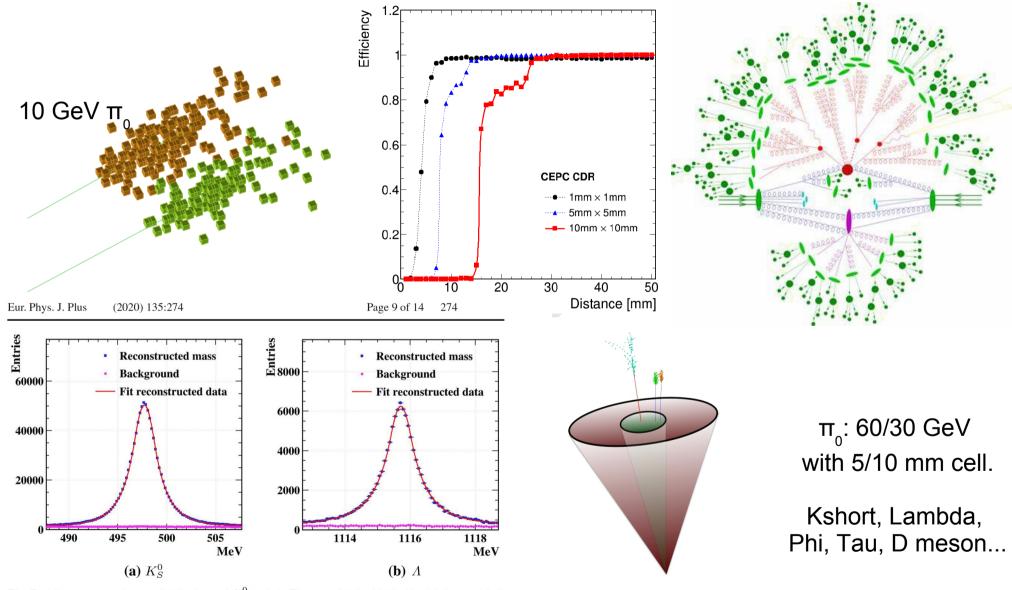


Fig. 7 All reconstructed mass distributions of K_S^0 and Λ . They are fitted with double-sided crystal ball functions

07/01/2004

Summary

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

Summary

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

One to one correspondence reco. at Higgs factory

The should, and we could

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



Key figures of the CEPC-SPPC

- Tunnel ~ 100 km
- CEPC (90 240 GeV)
 - Higgs factory: 4M Higgs boson
 - Absolute measurements of Higgs boson width and couplings
 - Searching for exotic Higgs decay modes (New Physics)
 - Z & W factory: ~ 4 Tera Z boson, Booster(7.2Km)
 - Precision test of the SM Medium Energy Booster(4.5Km)
 - Rare decay
 - Flavor factory: b, c, tau
 - QCD studies
- Upgradable to ttbar threshold (360 GeV)
- SPPC (~ 100 TeV)

CEPC Collider Ring(50Km) IP2

Low Energy Booster(0.4Km)

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

- ...

Heavy ion, e-p collision...

TP4

IP3

LTB

e+ e- Linac

(240m)