

Physics Benchmarks and Global Performance

Mingshui Chen
for Physics & Performance group

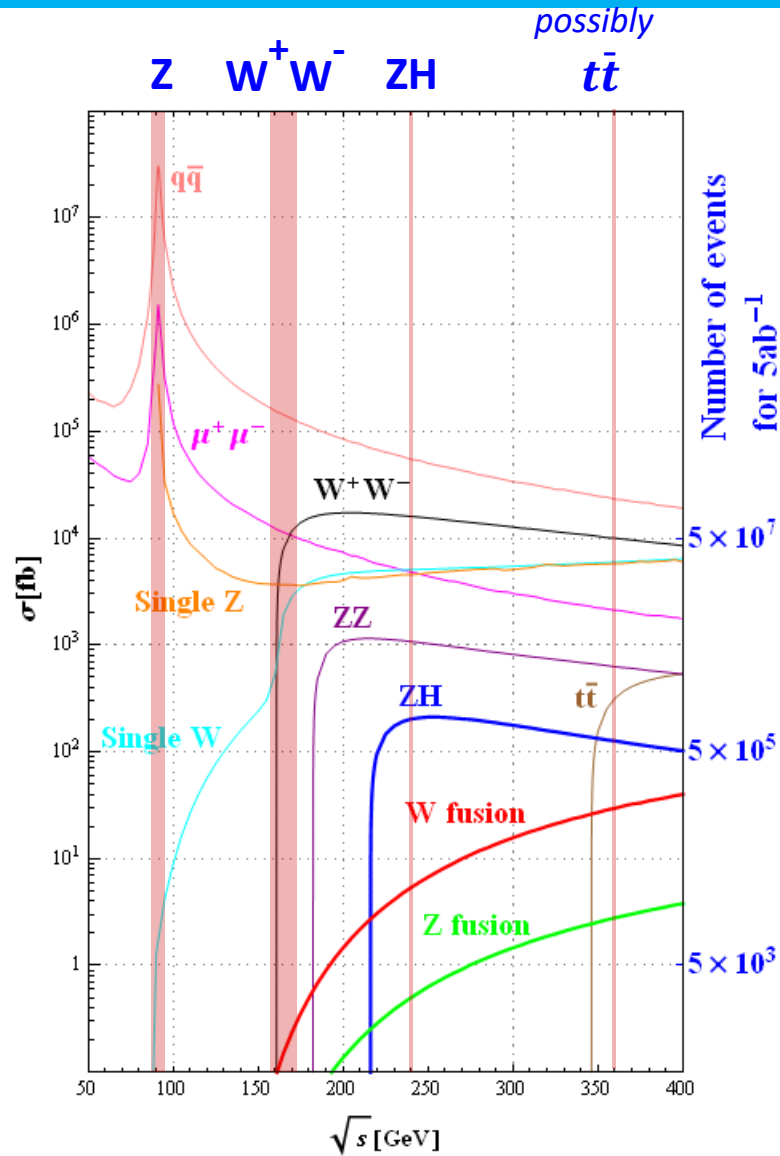


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Operation Plan from Acc. TDR



Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
\sqrt{s} [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	5
30 MW	L / IP [$\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	5.0	115	16	0.5
	$\int L dt$ [ab^{-1} , 2 IPs]	13	60	4.2	0.65
	Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
50 MW	L / IP [$\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	8.3	192	26.7	0.8
	$\int L dt$ [ab^{-1} , 2 IPs]	21.6	100	6.9	1
	Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

CEPC accelerator TDR (Xiv:2312.14363)

While aiming to meet the needs of the whole energy range, emphasizes more on the Higgs operation mode.

CEPC physics

Higgs

m_H, σ, Γ_H
self-coupling
 $H \rightarrow bb, cc, ss, gg$
 $H \rightarrow \text{inv}, H \rightarrow sb, \dots$

Flavor

CKM matrix
CPV measurements
LFV, LUV
 τ properties (lifetime, BRs...)
 $B_c \rightarrow \tau \nu, B_s \rightarrow D_s K/\pi$
 $B_s \rightarrow K^* \tau \tau, B \rightarrow K^* \nu \nu$
 $B_s \rightarrow \phi \nu \nu \dots$

Top

$m_{\text{top}}, \Gamma_{\text{top}},$
top quark coupling,
...

4 million Higgs
4 trillion Z bosons
200 million W pairs
600 k ttbar

BSM

Heavy Neutral Leptons
Dark Photons Z_D
Axion Like Particles
Exotic Higgs decays
...

EWK/QCD

$m_Z, \Gamma_Z, \Gamma_{\text{inv}}$
 $\sin^2\theta_W, m_W, \Gamma_W,$
 $A_{\text{FB}}^{b,c}, \tau \text{ pol.}$
 α_S, \dots

CEPC physics

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Precision Higgs physics at the CEPC*

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CEPC Detector Requirements

Excellent tracking resolution/
Jet energy resolution
Impact parameter resolution
for b,c,s tagging

Higgs
 m_H, σ, Γ_H
self-coupling
 $H \rightarrow bb, cc, ss, gg$
 $H \rightarrow inv, H \rightarrow sb, \dots$

Flavor
CKM matrix
CPV measurements
LFV, LUV
 τ properties (lifetime, BRs...)
 $B_c \rightarrow \tau \nu, B_s \rightarrow D_s K/\pi$
 $B_s \rightarrow K^* \tau \tau, B \rightarrow K^* \nu \nu$
 $B_s \rightarrow \phi \nu \nu \dots$

Superior impact parameter resolution
for vertices, tagging;
Energy resolution for π^0 or γ reco;
PID: K/ π separation over wide
momentum range for b and τ physics

Top
 $m_{top}, \Gamma_{top},$
top quark coupling,
...

4 million Higgs
4 trillion Z bosons
200 million W pairs
600 k ttbar

BSM
Heavy Neutral Leptons
Dark Photons Z_D
Axion Like Particles
Exotic Higgs decays
...

LLP sensitivity via far
detached vertices (mm \rightarrow m):
Tracking, Calorimetry, Muon

EWK/QCD
 $m_Z, \Gamma_Z, \Gamma_{inv}$
 $\sin^2\theta_W, m_W, \Gamma_W,$
 $A_{FB}^{b,c}, \tau$ pol.
 α_S, \dots

Small systematics:
Absolute normalisation (luminosity, 10^{-4})
Momentum resolution

Physics Benchmarks and Requirements

	Process @ c.m.e	Domain	Relevant Det. Performance
$H \rightarrow ss/cc/sb$	$\nu\nu H$ @ 240 GeV	Higgs	PFA + Jet Origin ID (JOI)
$H \rightarrow inv$	qqH	Higgs/NP	PFA, MET
Vcb	$WW \rightarrow \ell\nu qq$ @ 240/160 GeV	Flavor	JOI + PID (lepton, tau)
W fusion Xsec	$\nu\nu H$ @ 360 GeV	Higgs	PFA + JOI
α_s	$Z \rightarrow \tau\tau$ @ 91.2 GeV	QCD	PFA, tau ID
CKM angle $\gamma - 2\beta$	$Z \rightarrow bb, B \rightarrow DK$ @ 91.2 GeV	Flavor	PFA + JOI + PID (kaon)
Weak mixing angle	Z @ 91.2 GeV	EW	JOI
Higgs recoil	$\ell\ell H$	Higgs	Lepton ID, track dP/P
$H \rightarrow bb, gg$	$\nu\nu H + qqH$	Higgs	PFA + JOI
$H \rightarrow \mu\mu$	qqH	Higgs	PFA, lepton ID, tracking
$H \rightarrow \gamma\gamma$	qqH	Higgs	PFA, photon ID, EM resolution
W mass & width	Threshold scan @ 160 GeV	EW	Beam energy
Top mass & width	Threshold scan @ 360 GeV	EW	Beam energy
$B_s \rightarrow \nu\nu\phi$	91.2 GeV	Flavor	Object (ϕ) in jets; MET
$B_c \rightarrow \tau\nu$	91.2 GeV	Flavor	Object (τ) in jets; MET
$B_0 \rightarrow 2\pi^0$	91.2 GeV	Flavor	π^0 in jets; EM resolution
$H \rightarrow LLP$	qqH	NP	Tracking in calo/muon detector
$H \rightarrow aa \rightarrow 4\gamma$	qqH	NP	EM resolution

PFA is essential for the majority of benchmarks, emphasizing **global reconstruction performance**

- **BMR < 4%** required, with a target to achieve 3% for optimal resolution
- **PID**: crucial to efficiently reconstruct and accurately identify final state particles with a one-to-one correspondence
 - ◆ **Kaon ID with eff and purity > 95%**
- Capable to find composited objects in jets

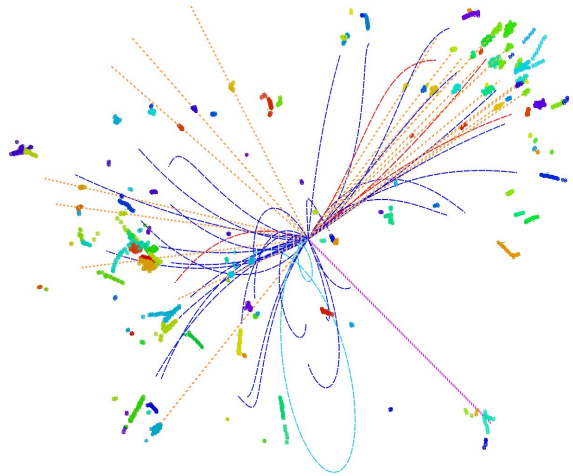
Sub-Det level performance

- **Tracking: ~0.1% momentum resolution**
- **EM resolution: ~1% level**
- **VTX: position resolution ~ 5 μm**

- **Reliance on both sub-detector performance and advanced global reconstruction algorithms is essential**
 - **CyberPFA** being developed to address the challenges of Crystal Bar ECal
 - Relying heavily on full simulation of the detector
 - New concepts emerge, such as **Jet Origin ID** and Color Singlet ID

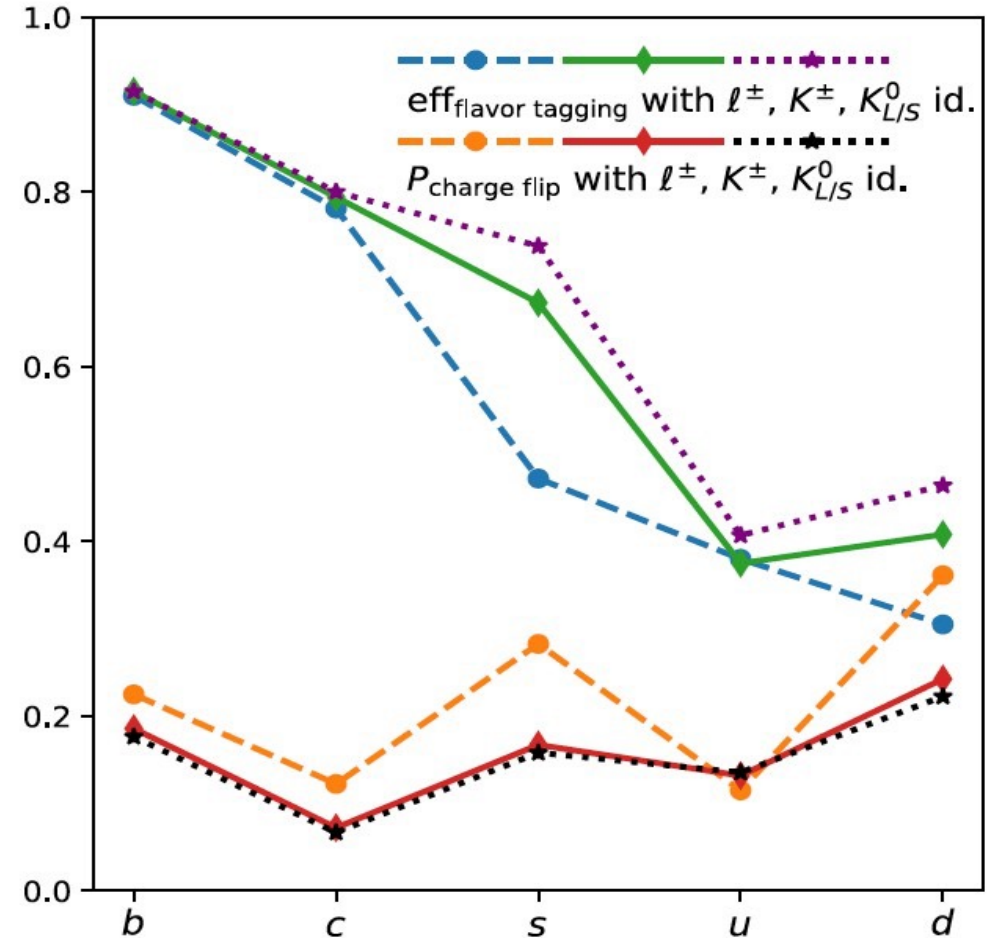
Jet Origin ID

PRL 132, 221802 (2024)



Confusion matrix M_{11}

True \ Predicted	b	\bar{b}	c	\bar{c}	s	\bar{s}	u	\bar{u}	d	\bar{d}	G
b	0.745	0.163	0.033	0.025	0.004	0.003	0.002	0.003	0.002	0.002	0.017
\bar{b}	0.170	0.737	0.026	0.033	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.014	0.743	0.055	0.036	0.031	0.025	0.009	0.009	0.018	0.043
\bar{c}	0.016	0.015	0.056	0.739	0.032	0.037	0.009	0.026	0.017	0.010	0.043
s	0.003	0.002	0.020	0.018	0.543	0.102	0.030	0.080	0.063	0.045	0.092
\bar{s}	0.003	0.003	0.018	0.020	0.102	0.542	0.084	0.028	0.045	0.062	0.094
u	0.002	0.003	0.020	0.011	0.044	0.131	0.367	0.055	0.080	0.174	0.111
\bar{u}	0.003	0.003	0.011	0.019	0.132	0.043	0.062	0.356	0.178	0.081	0.111
d	0.003	0.003	0.012	0.019	0.112	0.092	0.082	0.207	0.277	0.079	0.112
\bar{d}	0.003	0.003	0.020	0.012	0.092	0.112	0.219	0.076	0.079	0.272	0.113
G	0.015	0.014	0.024	0.024	0.052	0.052	0.043	0.041	0.034	0.034	0.667



Jet flavor tagging efficiencies and charge flip rates with perfect identifications

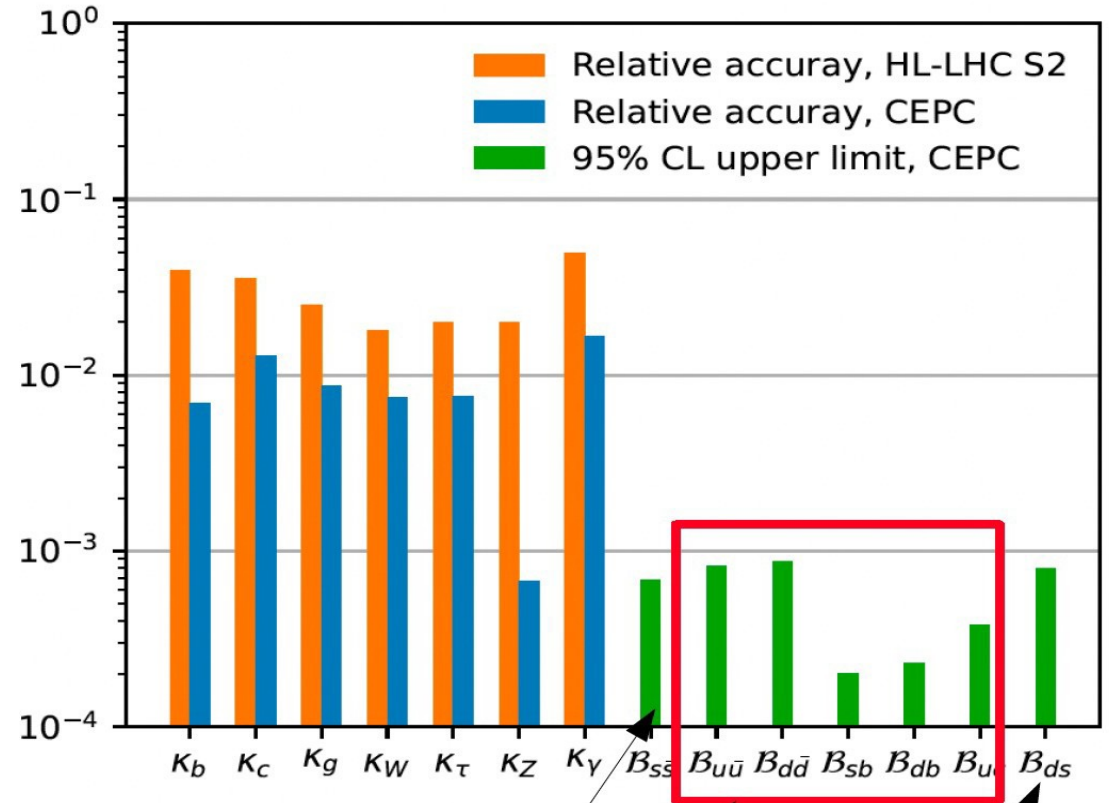
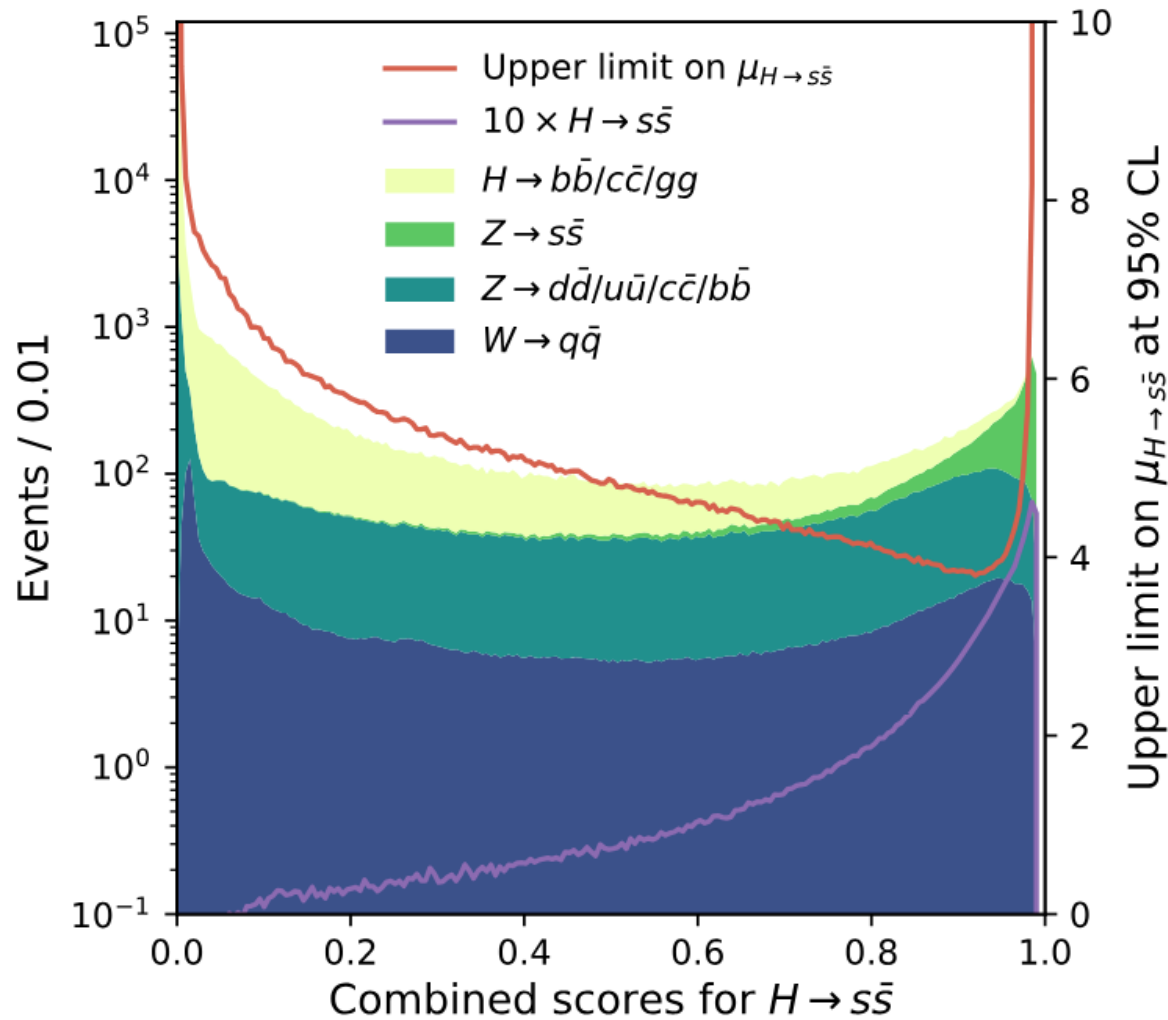
■ **Jet Origin ID: 11 categories (5 quarks + 5 antiquarks, + gluon)**

- ◆ Jet flavor (b, c, s, gluon, u & d) tagging and **charge**
- ◆ Input: PID & 4-momentum of all reconstructed particles + impact parameters for charged ones (~o(50) particles)

JOI concept successfully demonstrated using CEPC CDR baseline detector and Arbor PFA, along with perfect PID (di-jet events ($\nu\nu H(qq)$) & $Z \rightarrow qq$) simulated)

Physics Benchmarks: $H \rightarrow s\bar{s}$

PRL 132, 221802 (2024)



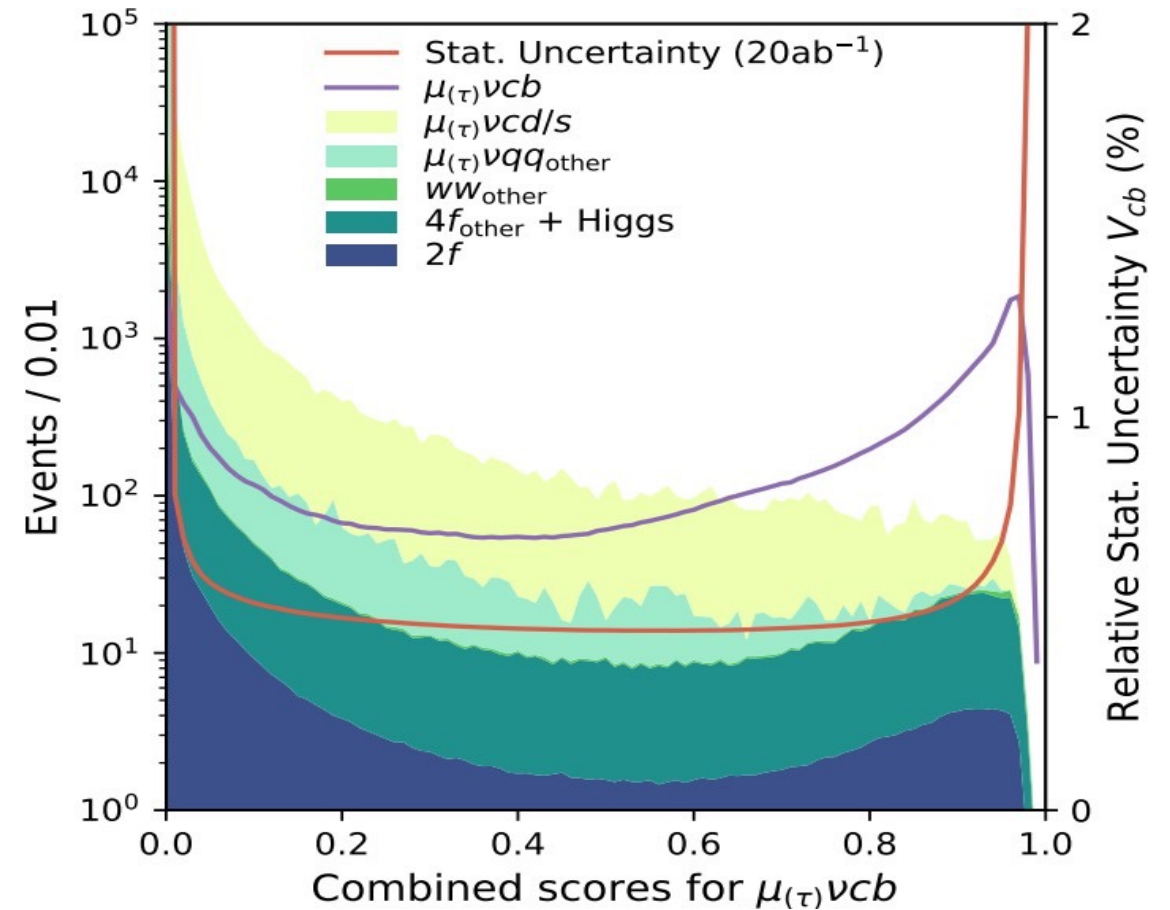
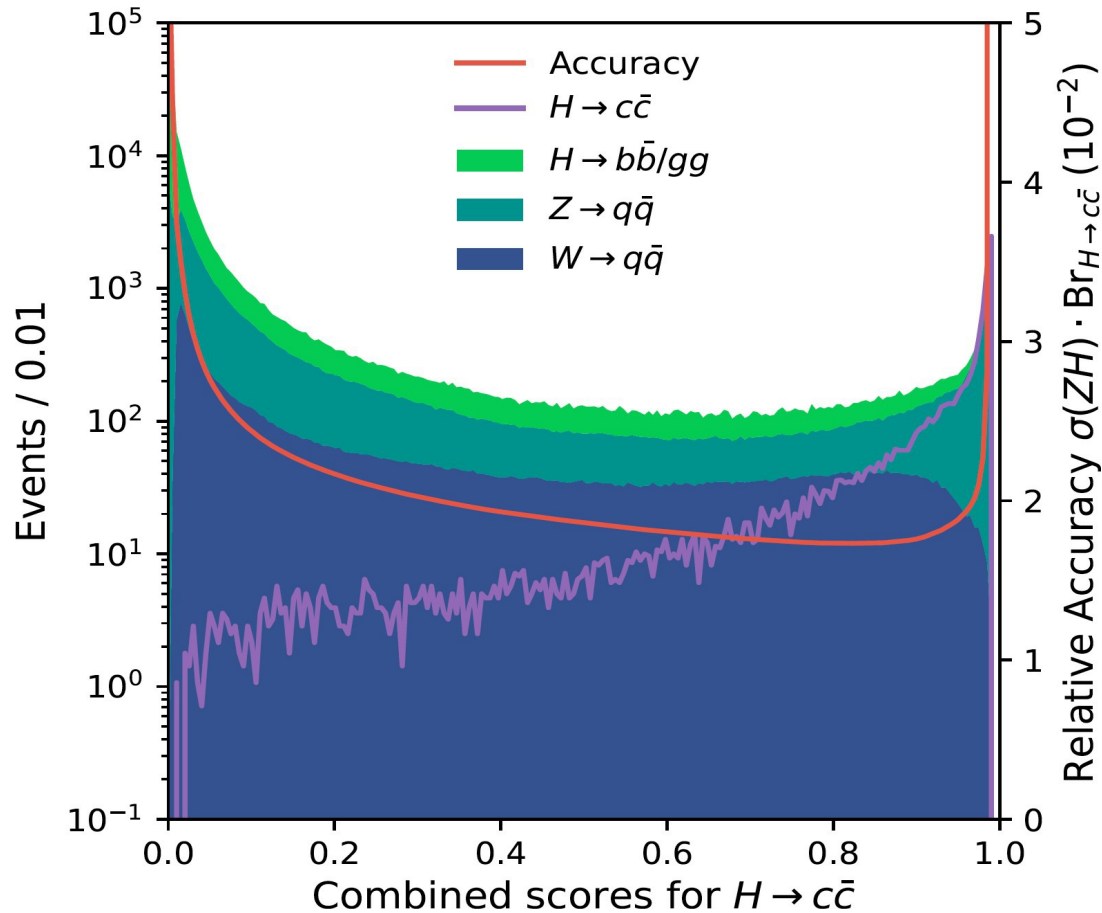
Improved by ~ 3 times

Improved by 1-2 orders of magnitudes

Presumably... firstly quantified

Physics Benchmarks: $H \rightarrow cc$ & V_{cb}

PRL 132, 221802 (2024)



■ From Jet Flavor Tagging to Jet Origin ID:

- ◆ $\nu\nu H, H \rightarrow cc$: 3% \rightarrow 1.7%
- ◆ V_{cb} : 0.75% \rightarrow 0.45% ($\mu\nu qq$ channel, $e\nu qq$: 0.6%, combined 0.4%)

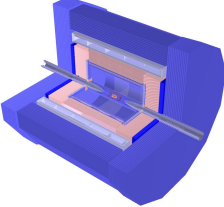
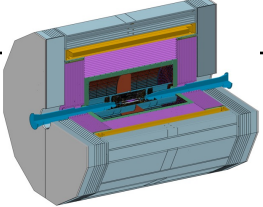
Physics Benchmarks using CDR detector and TDR lumi

	Process @ c.m.e	Domain	Sensitivities using CDR baseline detector + TDR lumi., with JOI
$H \rightarrow cc$	vvH @ 240 GeV	Higgs	1.7%
$H \rightarrow ss$ [1]			95% UL of 0.75E-3
$H \rightarrow sb$ [1]			95% UL of 0.22E-3
$H \rightarrow inv$ [2]	qqH	Higgs/BSM	95% UL of 0.13%
Vcb [3]	WW $\rightarrow\ell\nu qq$ @ 240/160 GeV	Flavor	0.4%
W fusion Xsec [2]	vvH @ 360 GeV	Higgs	1.1%
α_s	Z $\rightarrow\tau\tau$ @ 91.2 GeV	QCD	NAN
CKM angle $\gamma-2\beta$	Z $\rightarrow bb, B\rightarrow DK$ @ 91.2 GeV	Flavor	NAN
Weak mixing angle [4]	Z @ 91.2 GeV	EW	2.4E-6 using 1 month of Z pole data ($\sim 2E11 Z$)
Higgs recoil [5]	$\ell\ell H$	Higgs	$\delta m = 2.5$ MeV; $\delta\sigma/\sigma = 0.25\%/0.4\%$ (wi/wo qqH)
$H \rightarrow bb, gg$ [2]	vvH + qqH	Higgs	bb: 0.13%; gg: 0.65%
$H \rightarrow \mu\mu$ [2]	qqH	Higgs	6.4%
$H \rightarrow \gamma\gamma$ [2]	qqH	Higgs	3%
W mass & width [6]	Threshold scan @ 160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab
Top mass & width [7]	Threshold scan @ 360 GeV	EW	9 MeV & 26 MeV @ 100 ifb
Bs $\rightarrow\nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)
Bc $\rightarrow\tau\nu$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)
B ₀ $\rightarrow 2\pi^0$ [10]	91.2 GeV	Flavor	NAN
H \rightarrow LLP	qqH	BSM	NAN
H $\rightarrow aa\rightarrow 4\gamma$	qqH	BSM	NAN

1. H. Liang, et al, PHYSICAL REVIEW LETTERS 132, 221802 (2024)
2. CEPC Phy-Det Snowmass White Paper, arXiv:2205.08553v1
3. H. Liang, Ph.D thesis
4. Z. Zhao, et al., Chinese Physics C Vol. 47, No. 12 (2023) 123002
5. Z. Yang, et al., Chinese Physics C Vol. 41, No. 2 (2017) 023003
6. P. Shen, et al., Eur. Phys. J. C (2020) 80:66
7. Z. Li, et al., arXiv:2207.12177
8. Y. Wang, et al., PHYSICAL REVIEW D 105, 114036 (2022)
9. T. Zheng, et al., Chinese Physics C Vol. 45, No. 2 (2021) 023001
10. Y. Wang, et al., JHEP12(2022)135

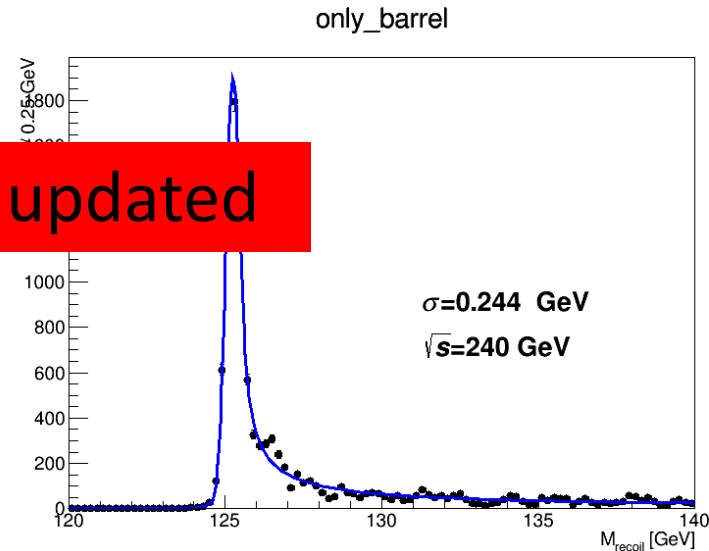
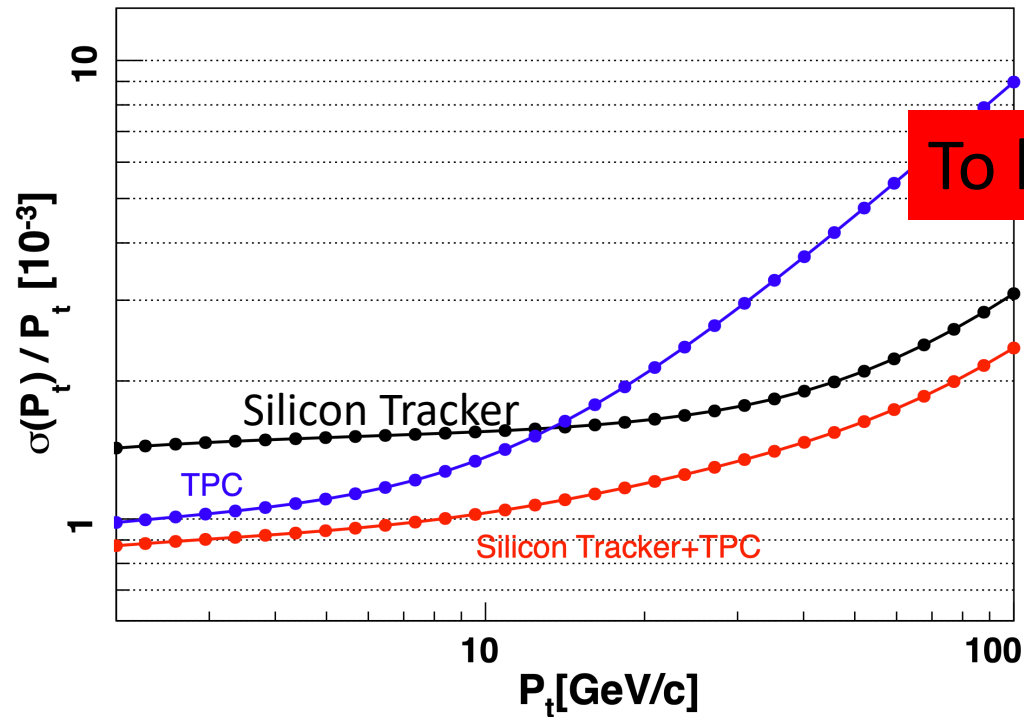
We need to demonstrate this table using RefTDR design

Detector Concepts: from CDR to refTDR

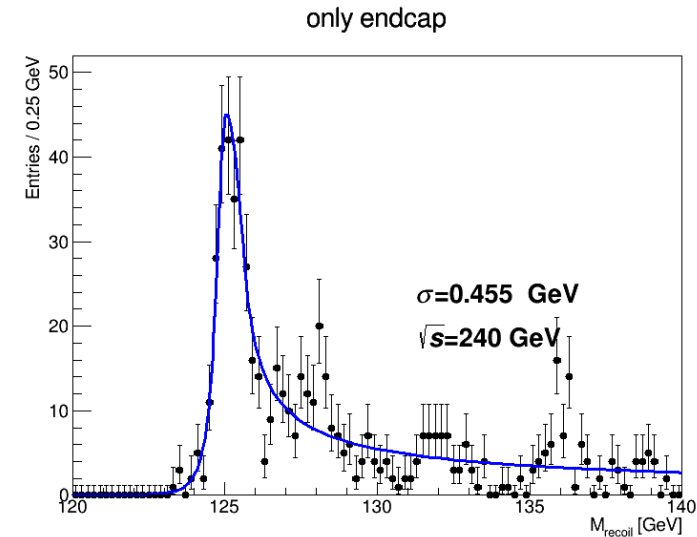
	CDR 	Ref-TDR 
VTX	Inner radius of 16 mm	Inner radius of 11 mm
	Material Budget: $0.15\% * 6 + 0.14\%(\text{beampipe}) =$ 1.05% X0	Material Budget: $0.06\% * 4(\text{inner}) + 0.25\% * 2(\text{outer}) + 0.16\%(\text{beampipe}) =$ 0.9% X0
Gaseous Tracker	TPC with 1 mm* 6 mm readout	TPC with 0.5 mm* 0.5 mm readout To have dE/dx or dN/dx resolution 3% (Drift Chamber with the capability of dN/dx as alternative)
ToF	-	AC-LGAD, with 50 ps per MIP
ECAL	Si-W-ECAL: 17%/VE \oplus 1%	Crystal Bar-ECAL: 1.5%/VE \oplus 1%
HCAL	RPC-Iron: 60%/VE \oplus 2%	Glass-Iron: 30%/VE \oplus 6%

To be updated, and also redo the extrapolation

Tracking @ simulation



Z($\mu\mu$)H – recoil mass
 $\sigma_m \sim 0.1\%$ @ Barrel



Z($\mu\mu$)H – recoil mass
 $\sigma_m \sim 0.2\%$ @ Endcap

- To be updated with full tracking system, and also versus $\cos\theta$
- $\sim 0.1\%$ achievable for the majority of tracking resolution

VTX and Jet Flavor/Charge measurement



ParticleNet and its application on CEPC jet flavor tagging

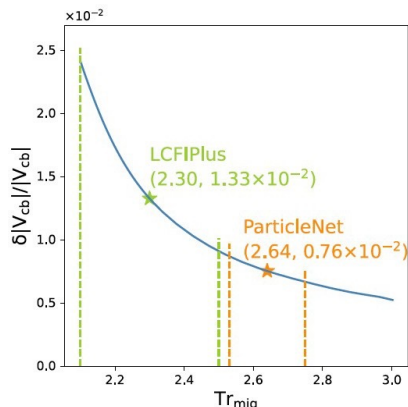
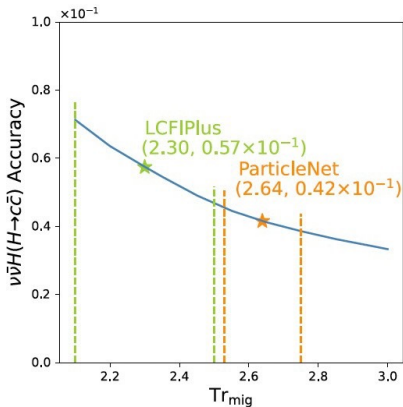
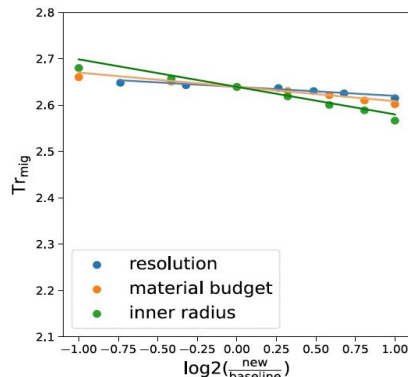
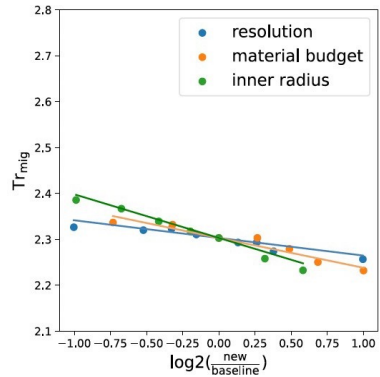
Yongfeng Zhu^{1,a}, Hao Liang^{2,3}, Yuexin Wang^{2,3}, Huilin Qu⁴, Chen Zhou^{1,b}, Manqi Ruan^{2,3,c}

¹ State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China

² Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

³ University of Chinese Academy of Sciences (UCAS), Beijing 100049, China

⁴ EP Department, CERN, 1211 Geneva 23, Switzerland



	predicted		
	b	c	uds
b	0.911	0.059	0.031
c	0.039	0.784	0.177
uds	0.005	0.051	0.944

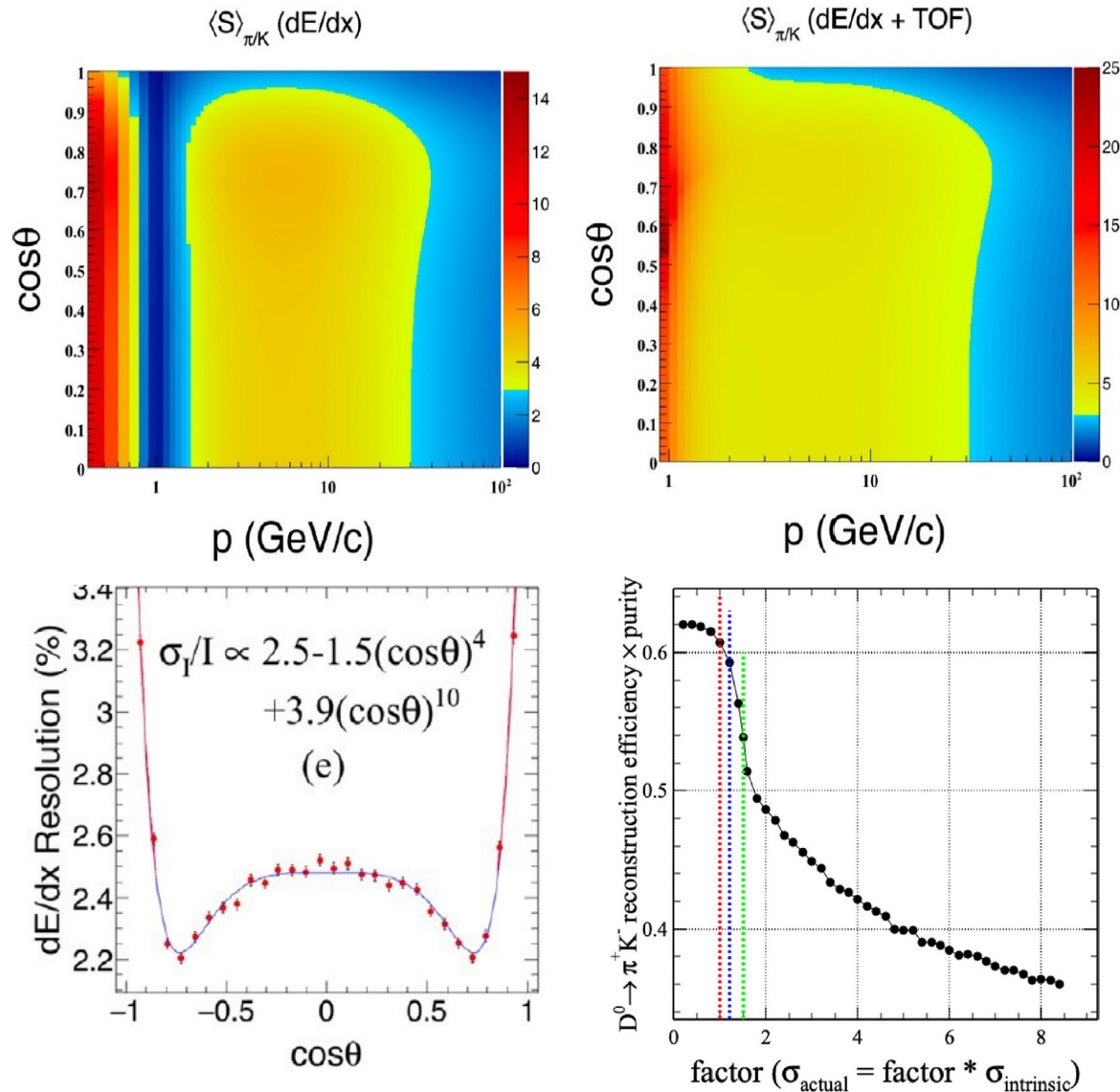
$$Tr_{mig} = 2.30 + 0.06 \cdot \log_2 \frac{R_{material}^0}{R_{material}} + 0.04 \cdot \log_2 \frac{R_{resolution}^0}{R_{resolution}} + 0.10 \cdot \log_2 \frac{R_{radius}^0}{R_{radius}} \quad (1)$$

$$Tr_{mig} = 2.64 + 0.03 \cdot \log_2 \frac{R_{material}^0}{R_{material}} + 0.02 \cdot \log_2 \frac{R_{resolution}^0}{R_{resolution}} + 0.06 \cdot \log_2 \frac{R_{radius}^0}{R_{radius}} \quad (2)$$

- Compared to the CDR, the VTX at TDR has:
 - ◆ Inner radius reduced by 40% (16 mm → 11 mm)
 - ◆ Material reduced by 10% (1.05% → 0.9% X0)
- Trace(Migration Matrix) increased from 2.64 → 2.68
 - ◆ H → cc accuracy improved by ~5%
 - ◆ Vcb accuracy improved by ~10%

PID: dE/dx or dN/dx + TOF

Nucl.Instrum.Meth.A 1047 (2023) 167835



Requirement analysis for dE/dx measurement and PID performance at the CEPC baseline detector
 Y. Zhu, S. Chen, H. Cui, M. Ruan*
 Institute of High Energy Physics, Chinese Academy of Sciences, 198 Yuqian Road, Shijingshan District, Beijing 100049, China
 University of Chinese Academy of Sciences, 19A Yuqian Road, Shijingshan District, Beijing 100049, China

Table 3

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

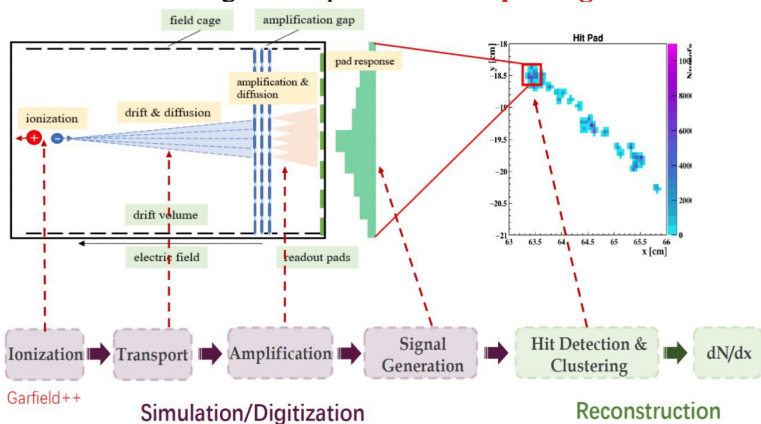
	Factor	1.	1.2	1.5	2.
dE/dx	ϵ_K (%)	95.97	94.09	91.19	87.09
	$pur_{\pi K}$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ϵ_K (%)	98.43	97.41	95.52	92.3
	$pur_{\pi K}$ (%)	97.89	96.31	93.25	87.33

- dE/dx or dN/dx with resolution of 3% + TOF of 50 ps: eff & purity of Kaon ID > 95%

dE/dx or dN/dx @ ref-TDR goal

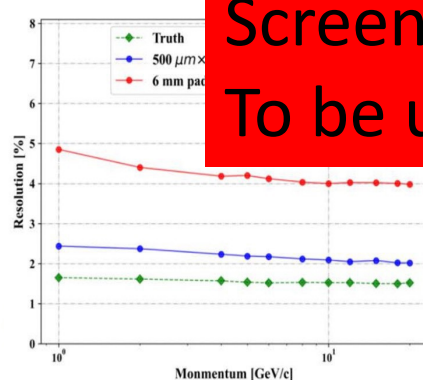
Performance from simulation

- Full simulation framework of pixelated TPC developed using Garfield++ and Geant4 at IHEP
- Investigating the π/κ separation power using reconstructed clusters, a **3 σ separation at 20GeV** with 50cm drift length can be achieved
- dN/dx has significant potential for **improving PID resolution**



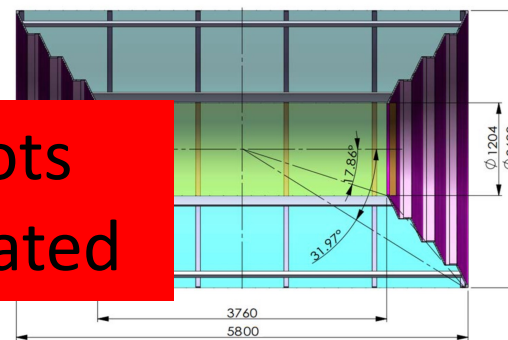
Cite#11: DOI: 10.22323/1.449.0553
Cite#12: EPS-HEP 2023 talk by Yue Chang

Simulation of TPC detector under 3T/2T and T2K mixture gas

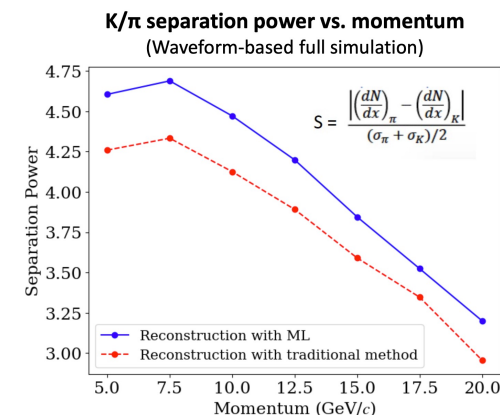


Screen shots
To be updated

Detailed design of DC for Tera-Z



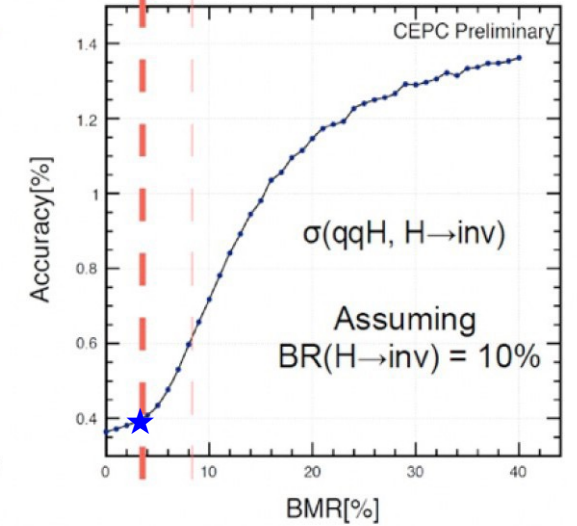
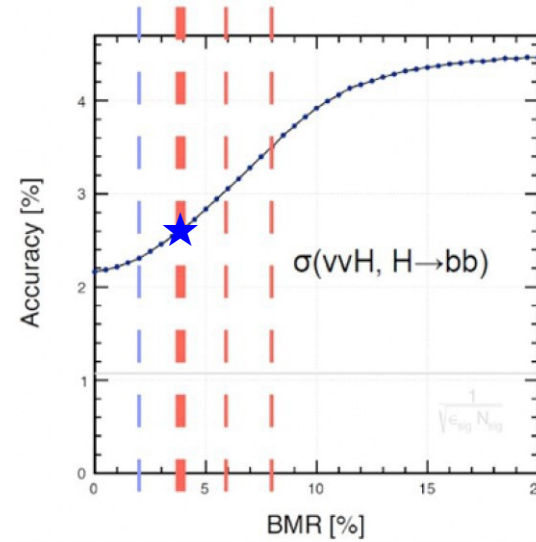
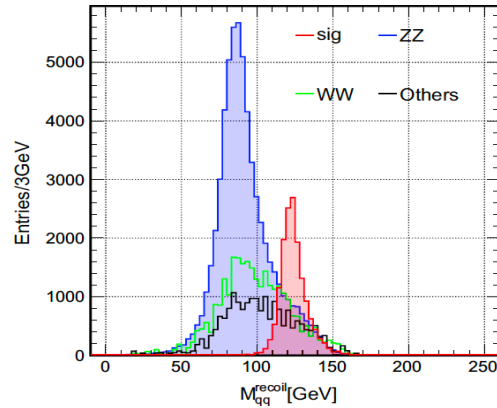
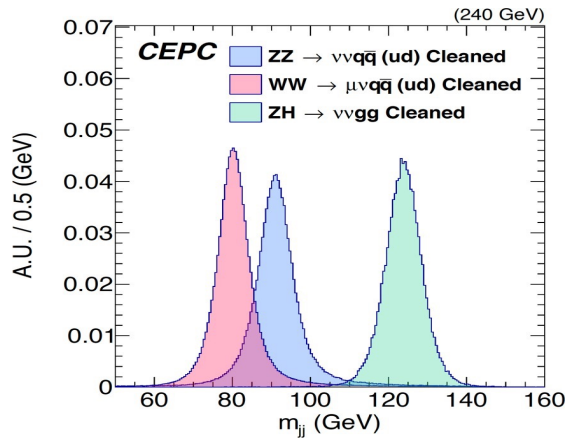
- CF frame structure
- Length: 5800 mm; Outer diameter: 3600 mm; Inner diameter: 1200 mm
- Thickness of each end plate: 20 mm, weight: 880 kg
- Gas mixture: He + iC_4H_{10} (90/10)
- Cell size: 18mm x 18mm, number of cells: 26483
- Material: 0.16% X_0 for Gas+Wires, 0.21% X_0 for inner and outer cylinders
- Finite element analysis: Endplate deformation 2.7mm, CF frame deformation 1.1mm



21

- A major goal for the Ref-TDR Gaseous Tracker is the PID: to achieve 3% dE/dx or dN/dx performance
- Initial results are promising, and will be confirmed through further studies, especially test beam
- Gaseous Tracker inner radius: to be optimized – for endcap performance

PFA Goal: BMR < 4% & pursue 3%

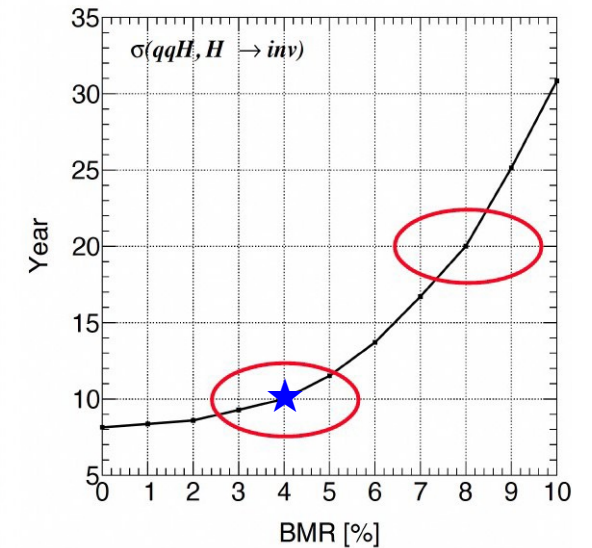
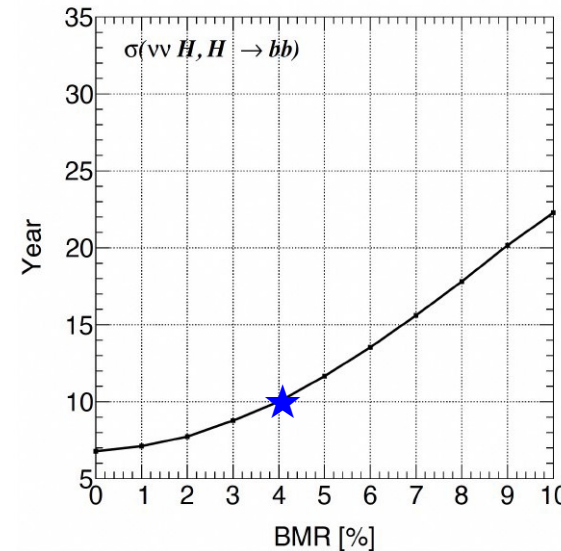


- BMR used to quantify jet reconstruction: 4% will well separate W/Z and Higgs, and separate ZH from the ZZ

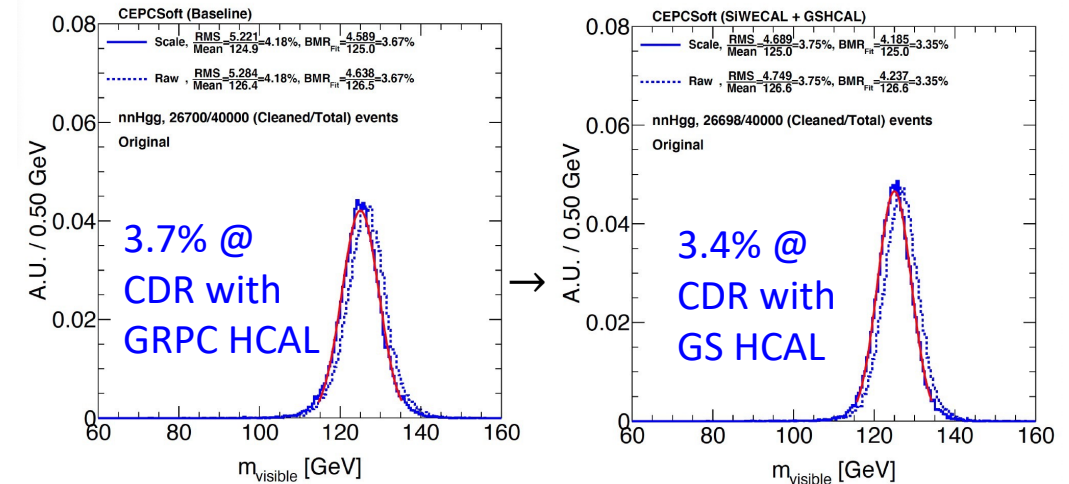
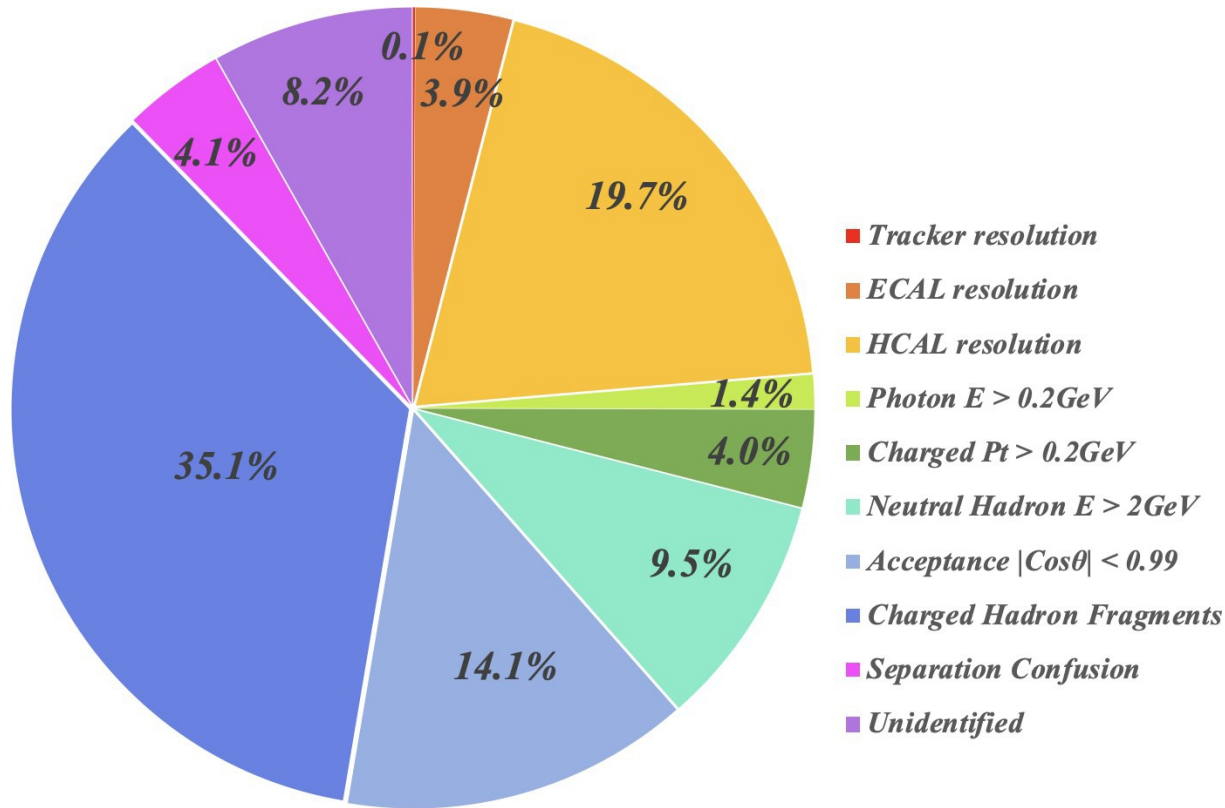
- Accuracies of different physics benchmarks as a function of the BMR show a turning point at roughly BMR of 4%

- H → inv as an example:

- BMR from 4% to 8% (typical LHC experiment performance), one need to **double the luminosity** to reach same accuracy
- BMR from 4% to 3%, **save roughly one year** of operation



BMR Decomposition



(for BMR of 3.7% at CDR)

- ~50% from confusion
- ~25% from detector resolution
- ~25% from acceptance

- HCAL resolution dominates among the uncertainties from detector resolutions:

- ◆ Using Glass Scintillator (TDR HCAL) - Iron with thickness of 6 lambda (compared to GRPC - Iron of 5 lambda) → BMR of 3.4%

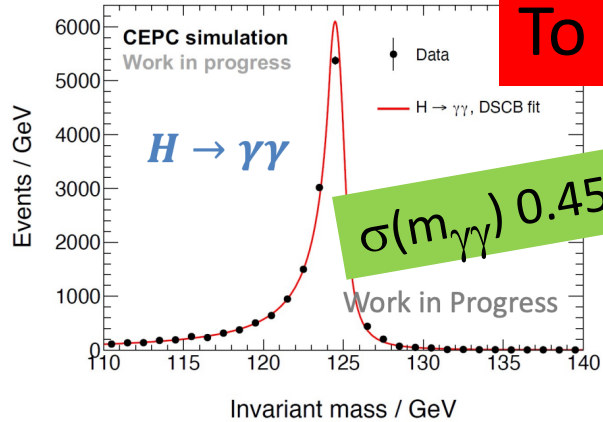
BMR of ~ 4% at refTDR

Physics performance in simulation: Higgs boson

Higgs benchmark studies at CEPC 240 GeV

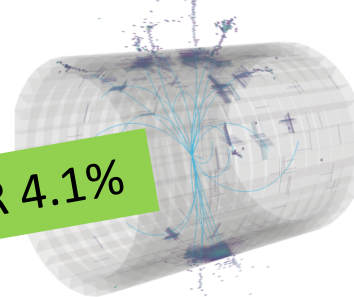
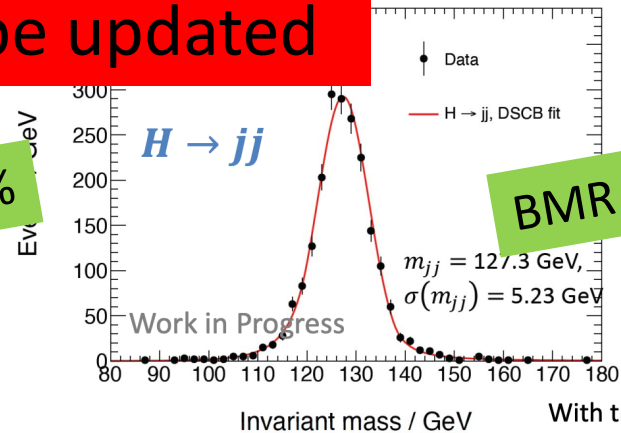
- Higgs decays to 2 photons (EM performance) and 2 gluon jets (PFA performance)

$ZH \rightarrow \nu\nu\gamma\gamma$ ($H \rightarrow \gamma\gamma$): $\sigma(m_{\gamma\gamma}) = 0.57 \text{ GeV}$



To be updated

$ZH \rightarrow \nu\nu g g$ ($H \rightarrow g g$) at 240 GeV : BMR = 4.1%



With truth tracking: **BMR 3.73%**
(comparable to CEPC CDR performance)

Reconstruction of two gluon jets in the full CEPC detector
(Vertex, Silicon + TPC tracker, crystal ECAL, ScintGlass HCAL)

Preliminary BMR at ref-TDR:
4.1%, close to the CDR value of
3.7%

Effective control of confusion
(such as fake particles) is crucial,
necessitating optimization and
further development in
reconstruction techniques

Double-side Crystal Ball fit

Long tail from lossy processes of crystal calorimeter and imperfect correction in crack region -> can be improved

Physics Benchmarks at CDR & refTDR

	Process @ c.m.e	Domain	Sensitivities using CDR det. + TDR lumi., with JOI	Prospects @ Ref-TDR
$H \rightarrow cc$	vvH @ 240 GeV	Higgs	1.7%	1.6%
$H \rightarrow ss$ [1]			95% UL of 0.75E-3	95% UL of 0.70E-3
$H \rightarrow sb$ [1]			95% UL of 0.22E-3	95% UL of 0.20E-3
$H \rightarrow inv$ [2]	qqH	Higgs/BSM	95% UL of 0.13%	Same
Vcb [3]	WW $\rightarrow\ell\nu qq$ @ 240/160 GeV	Flavor	0.4%	0.36%
W fusion Xsec [2]	vvH @ 360 GeV	Higgs	1.1%	Same
α_s	Z $\rightarrow\tau\tau$ @ 91.2 GeV	QCD	NAN	Theory Unc. Dominant
CKM angle $\gamma-2\beta$	Z $\rightarrow bb, B \rightarrow DK$ @ 91.2 GeV	Flavor	NAN	~0.1-1 degree
Weak mixing angle [4]	Z @ 91.2 GeV	EW	2.4E-6 using 1 month of Z data	tiny improvement due to VTX
Higgs recoil [5]	$\ell\ell H$	Higgs	$\delta m = 2.5$ MeV; $\delta\sigma/\sigma = 0.25\%/0.4\%$ (wi/wo qqH)	Same
$H \rightarrow bb, gg$ [2]	vvH + qqH	Higgs	bb: 0.13%; gg: 0.65%	bb: 0.12%; gg: 0.62%
$H \rightarrow \mu\mu$ [2]	qqH	Higgs	6.4%	Same
$H \rightarrow \gamma\gamma$ [2]	qqH	Higgs	3%	1.8%
W mass & width [6]	Threshold scan @ 160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab	Same
Top mass & width [7]	Threshold scan @ 360 GeV	EW	9 MeV & 26 MeV @ 100 ifb	Same
$B_s \rightarrow \nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)	Same, if object recon. ~ CDR
$B_c \rightarrow \tau\nu$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)	Same, if object recon. ~ CDR
$B_0 \rightarrow 2\pi^0$ [10]	91.2 GeV	Flavor	NAN	0.3% (need to validate photons finding)
$H \rightarrow LLP$	qqH	BSM	NAN	Work in progress
$H \rightarrow aa \rightarrow 4\gamma$	qqH	BSM	NAN	Work in progress

- Precision of $H \rightarrow \gamma\gamma$ could be improved significantly when the low mass is controlled
- Physics measurements using JOI, benefit from better VTX and have 5-10% improvements, and assuming that the TDR BMR could eventually reach 3.7%
 - ◆ If BMR of 3% achieved, precisions of most benchmarks could be further improved by 5-10%
 - ◆ Further development required for the pattern recognition capability of Crystal Bar ECAL

Physics Benchmarks at CDR & refTDR

	Sensitivities using CDR det. + TDR lumi., with JOI	Prospects @ Ref-TDR
$H \rightarrow cc$	1.7%	1.6%
$H \rightarrow ss$ [1]	95% UL of 0.75E-3	95% UL of 0.70E-3
$H \rightarrow sb$ [1]	95% UL of 0.22E-3	95% UL of 0.20E-3
$H \rightarrow inv$ [2]	95% UL of 0.13%	Same
V_{cb} [3]	0.4%	0.36%
W fusion Xsec [2]	1.1%	Same
α_s	NAN	Theory Unc. Dominant
CKM angle $\gamma - 2\beta$	NAN	$\sim 0.1-1$ degree
<hr/>		
Weak mixing angle [4]	2.4E-6 using 1 month of Z data	tiny improvement due to VTX
Higgs recoil [5]	$\delta m = 2.5$ MeV; $\delta\sigma/\sigma = 0.25\%/0.4\%$ (wi/wo qqH)	Same
$H \rightarrow bb, gg$ [2]	bb: 0.13%; gg: 0.65%	bb: 0.12%; gg: 0.62%
$H \rightarrow \mu\mu$ [2]	6.4%	Same
$H \rightarrow \gamma\gamma$ [2]	3%	1.8%

- Precision of $H \rightarrow \gamma\gamma$ could be improved significantly when the low mass is controlled
- Physics measurements using JOI, benefit from better VTX and have 5-10% improvements, and assuming that the TDR BMR could eventually reach 3.7%
 - ◆ If BMR of 3% achieved, precisions of most benchmarks could be further improved by 5-10%
 - ◆ Further development required for the pattern recognition capability of Crystal Bar ECAL

Challenges & Plans

■ Challenges:

- ◆ Impact of beam induced background
- ◆ High data rate @ Z pole: need to reconstruct in Space time (PFA in space time)
- ◆ New CyberPFA development: rely on full simulation, as it significantly impacts the final resolution on hadronic objects

■ Plans:

- ◆ Quantify the impact of beam induced background, the readout, especially at Z pole (~ Nov. 2024)
- ◆ Further develop reconstruction algorithms, and validate with full simulation (Dec. 2024)
 - PFA, smarter algorithm with AI tools
- ◆ Physics benchmarks analyses with full simulation (H measurements) + fast simulation
- ◆ Involve more efforts from theory community to ensure that theoretical uncertainties will be under control

Team

- Physics and performance team:
 - ◆ ~ 10 staff members + 4 postdocs + ~10 students, more joining
- Synergizing efforts with sub-detector teams
- Collaboration with PKU, LLR & CERN on Machine Learning algorithms
- Physics white paper efforts: IHEP team + ~ > 20 staffs from ~ 10

Universities

- ◆ Flavor Physics: Tao Liu (HKUST), Lorenzo (NKU), Shanzhen Chen(IHEP) etc
 - ◆ New Physics: Xuai Zhuang (IHEP), Mengchao Zhang (JNU)
 - ◆ EW: Zhijun Liang (IHEP), Jiayin Gu (FuDan U), Siqi Yang (USTC)
 - ◆ QCD: Zhao Li (IHEP), Meng Xiao (ZJU), Huaxing Zhu (PKU)
- Physics studies in pace with ECFA physics focus studies

Summary

■ Intensive CEPC Physics studies

- ◆ Well quantified Physics Merits
- ◆ Iterates with Detector R&D

■ CEPC Ref-TDR detector provides

- ◆ PID: critical for Higgs/Flavor physics
- ◆ Better VTX: improves precisions on benchmark analysis by 10-20%
- ◆ PFA Compatible Calorimeter with larger sampling:
 - HCAL improves the BMR by ~10%
 - Crystal Bar ECAL: improve EM resolution by an order of magnitude, but pattern recognition is challenging



CEPC



Thank you for your attention!



中國科學院高能物理研究所
Institute of High Energy Physics
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