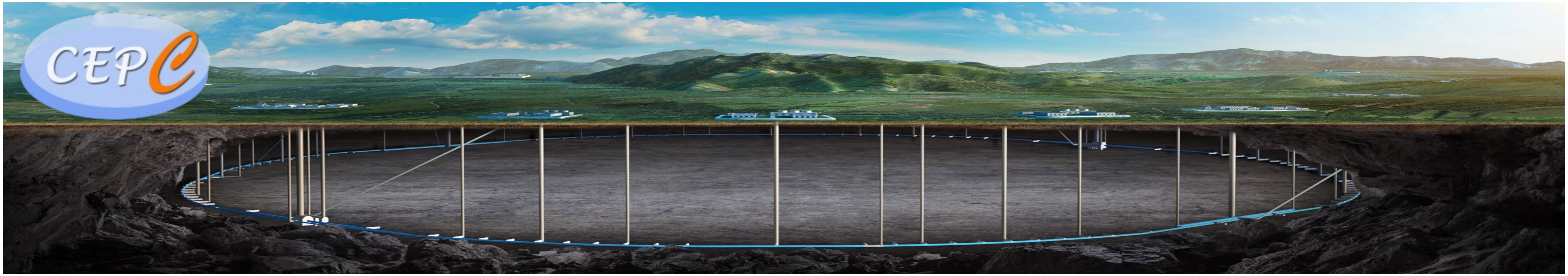
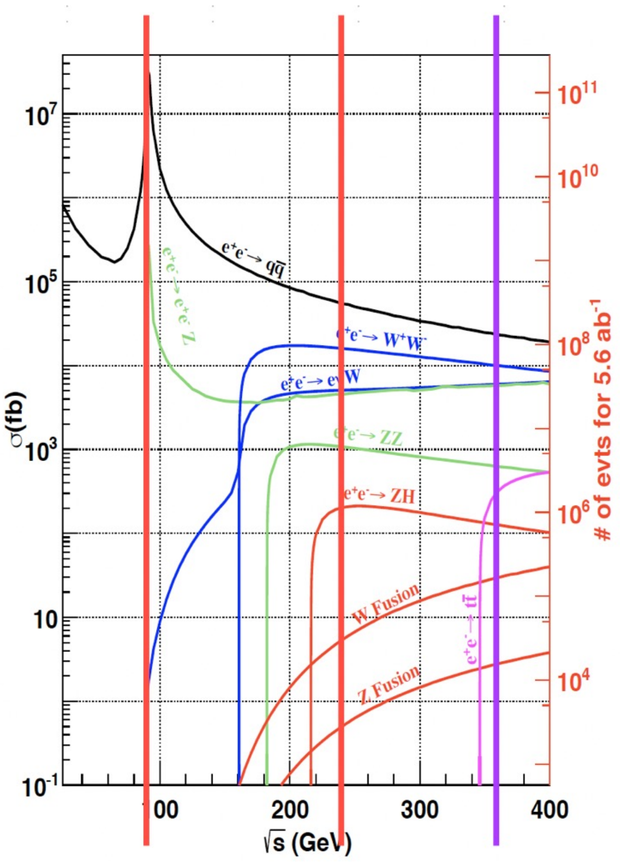


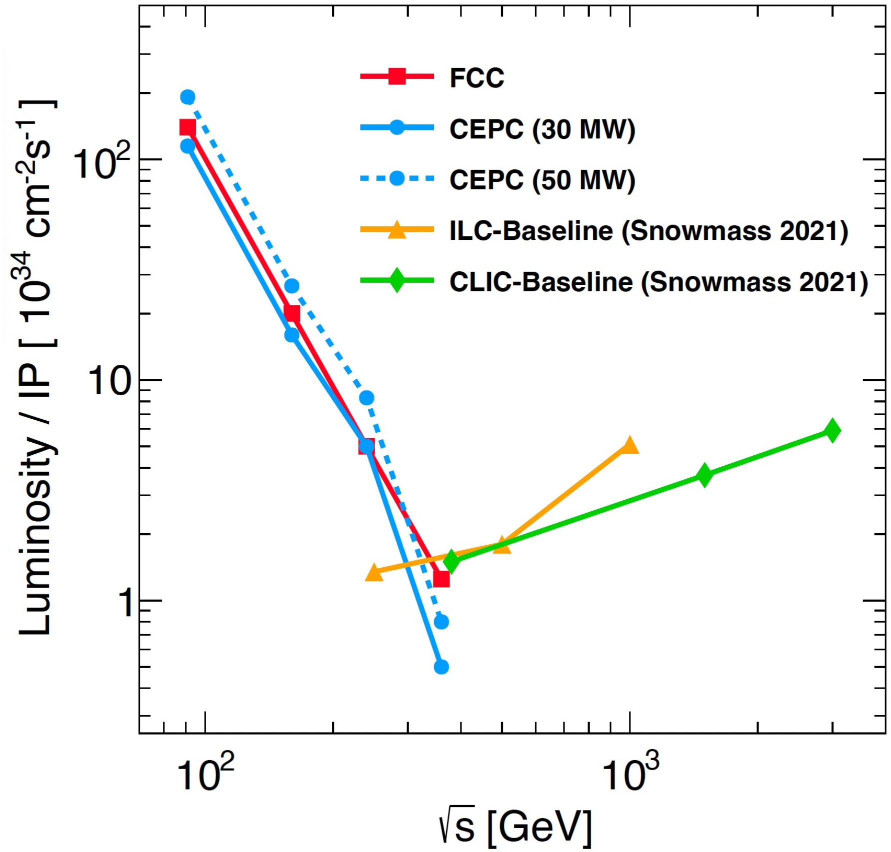
Detector & Performance

Manqi Ruan

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Physics Study : Status





CEPC TDR para & Snowmass studies

The Physics potential of the CEPC

Prepared for the US Snowmass Community Planning Exercise

(Snowmass 2021)

CEPC Physics Study Group

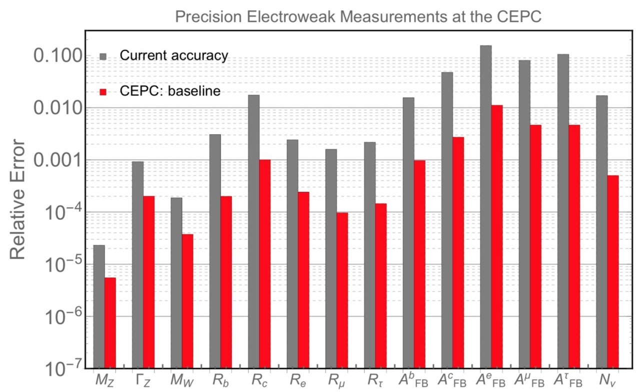
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	
$H \to \mu\mu$	6.36%		41%	57%	
$H \to Z\gamma$	8.50%		35%		
$Br_{upper}(H \to inv.)$	0.13%				
Γ_H	1.65%		1.10%		

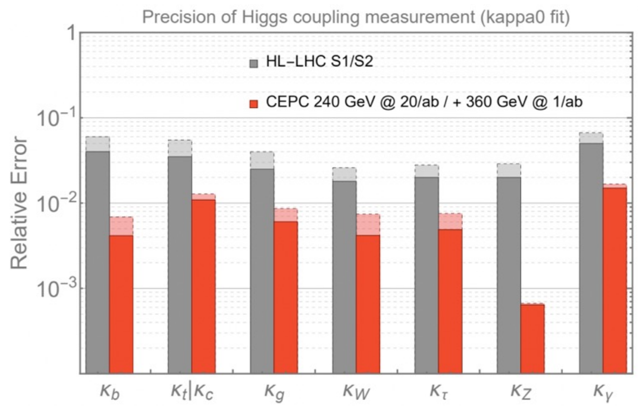
Table 3.2: CEPC operation plan (@ 50 MW)

Particle	$E_{c.m.}$ (GeV)	L per IP (10^{34} $cm^{-2}s^{-1}$)	Integrated L per year (ab^{-1}, 2 IPs)	Years	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H	240	8.3	2.2	10	21.6	4.3×10^6
Z	91	192*	50	2	100	4.1×10^{12}
W	160	26.7	6.9	1	6.9	2.1×10^8
$t\bar{t}$**	360	0.8	0.2	5	1.0	0.6×10^6

* Detector solenoid field is 2 Tesla during Z operation.
** $t\bar{t}$ operation is optional.

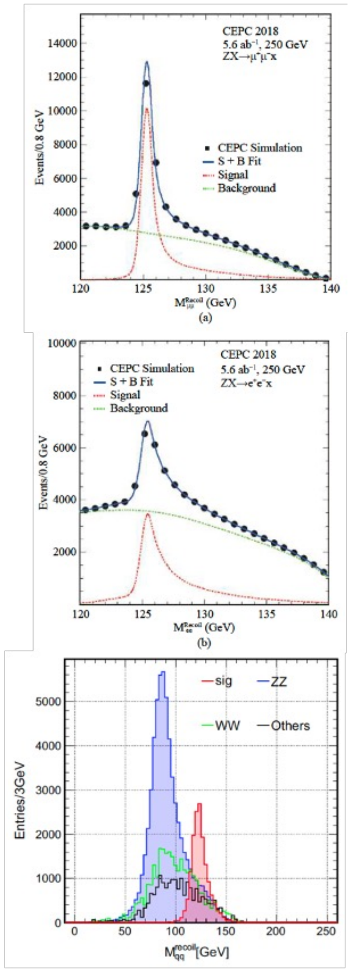
CEPC TDR





arXiv:2205.08553v1

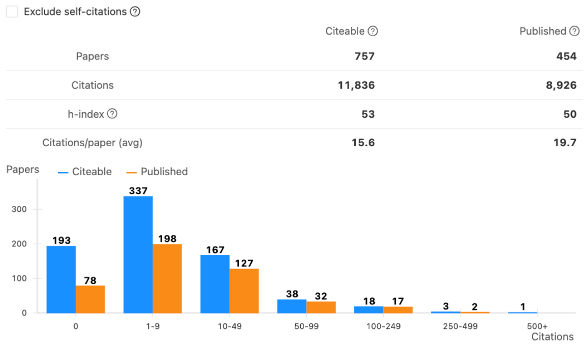
Physics Study : Status




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

Precision Higgs physics at the CEPC*

043002-1



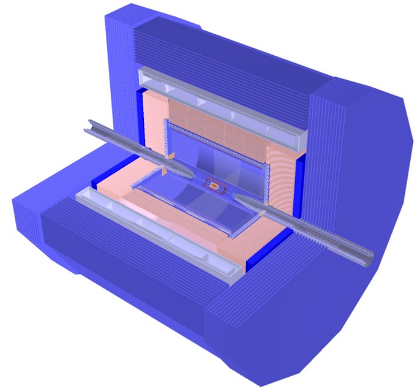
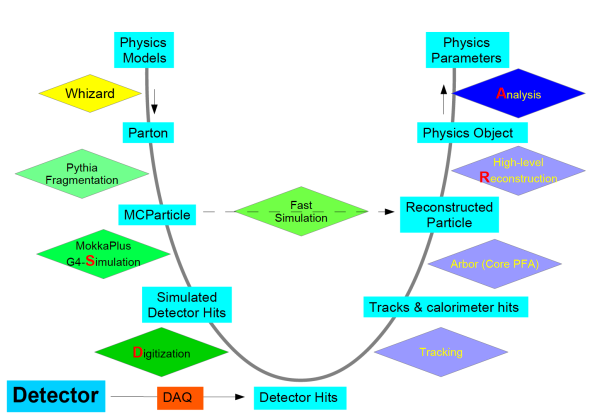


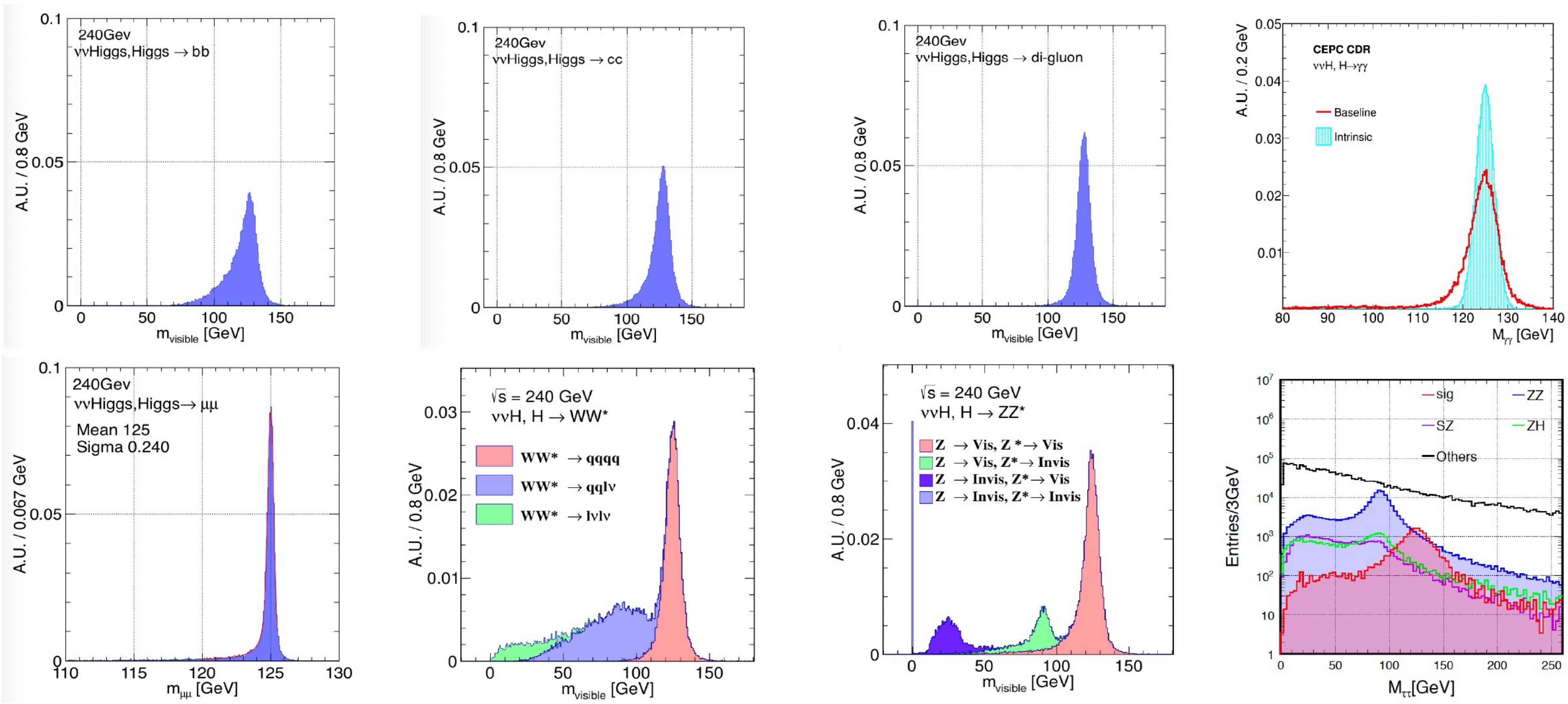
Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H\to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H\to cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H\to gg)$	-	0.81%	R_b	3×10^{-3}	2×10^{-4}
$B(H\to WW^*)$	2.8%	0.53%	R_c	1.7×10^{-2}	1×10^{-3}
$B(H\to ZZ^*)$	2.9%	4.2%	R_μ	2×10^{-3}	1×10^{-4}
$B(H\to\tau^+\tau^-)$	2.9%	0.42%	R_τ	1.7×10^{-2}	1×10^{-4}
$B(H\to\gamma\gamma)$	2.6%	3.0%	A_μ	1.5×10^{-2}	3.5×10^{-5}
$B(H\to\mu^+\mu^-)$	8.2%	6.4%	A_τ	4.3×10^{-3}	7×10^{-5}
$B(H\to Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	2×10^{-4}
Bupper($H\to$ inv.)	2.5%	0.07%	N_ν	2.5×10^{-3}	2×10^{-4}



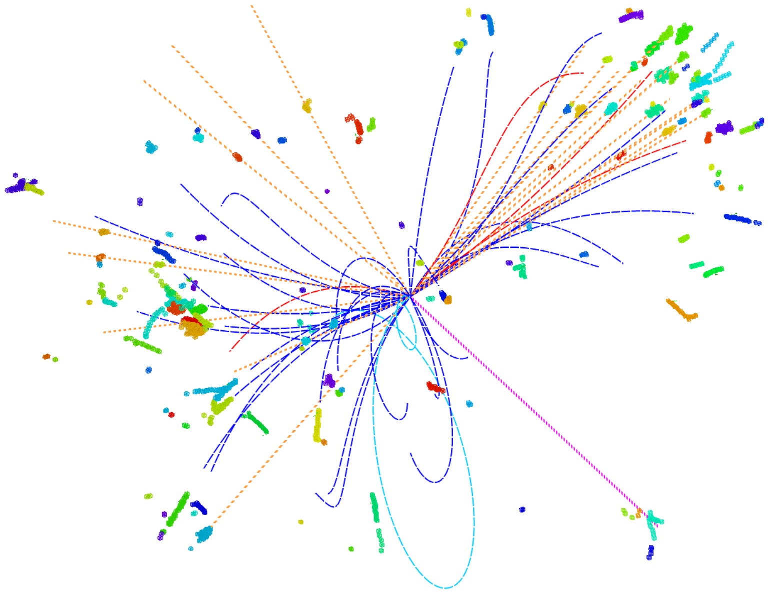
- Science Merit quantified by simulation & phenomenology studies:
  - Higgs White Paper, etc: Precisions exceed HL-LHC ~ 1 order of magnitude
  - EW: Precision improved from current limit by 1-2 orders of magnitudes
  - Flavor, sensitive to NP of energy scale of 10 TeV or above (Flavor White Paper, summarizing ~ 40 benchmarks)
  - Sensitive to varies of NP signal

Higgs signature @ CDR baseline

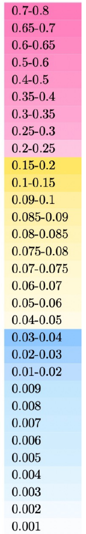


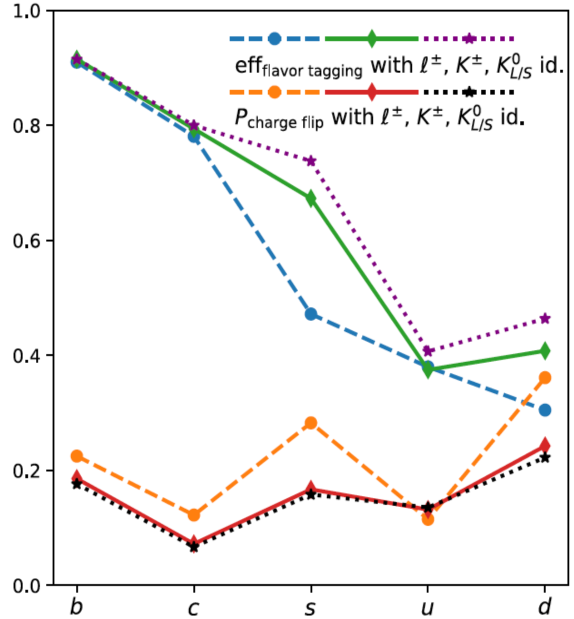
Update-1: Jet Origin identification.

Jet Origin ID



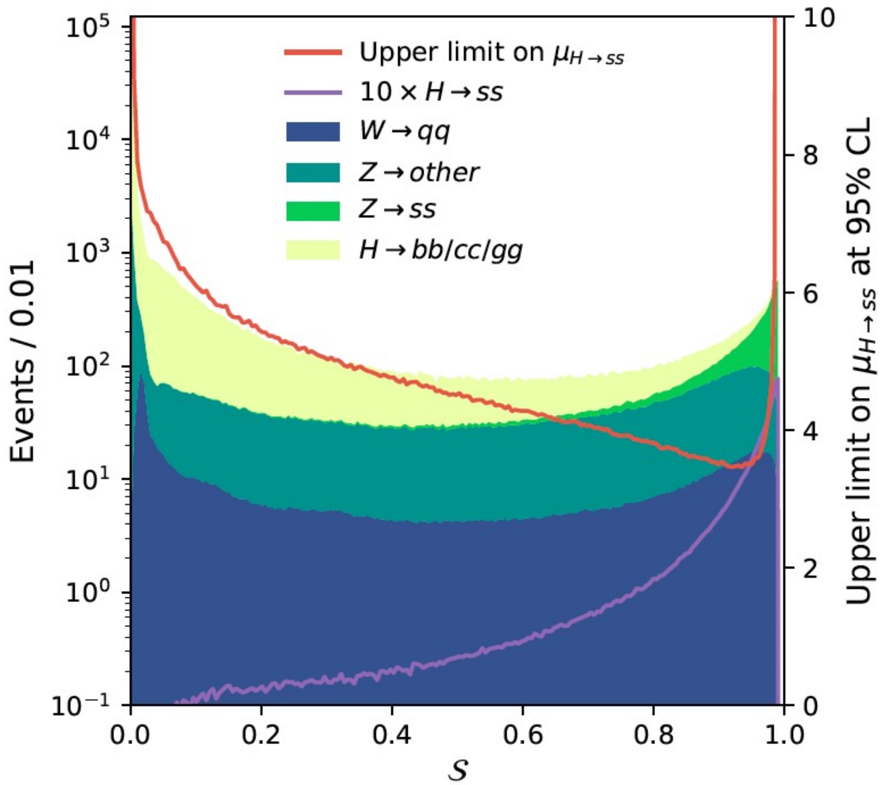
True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$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

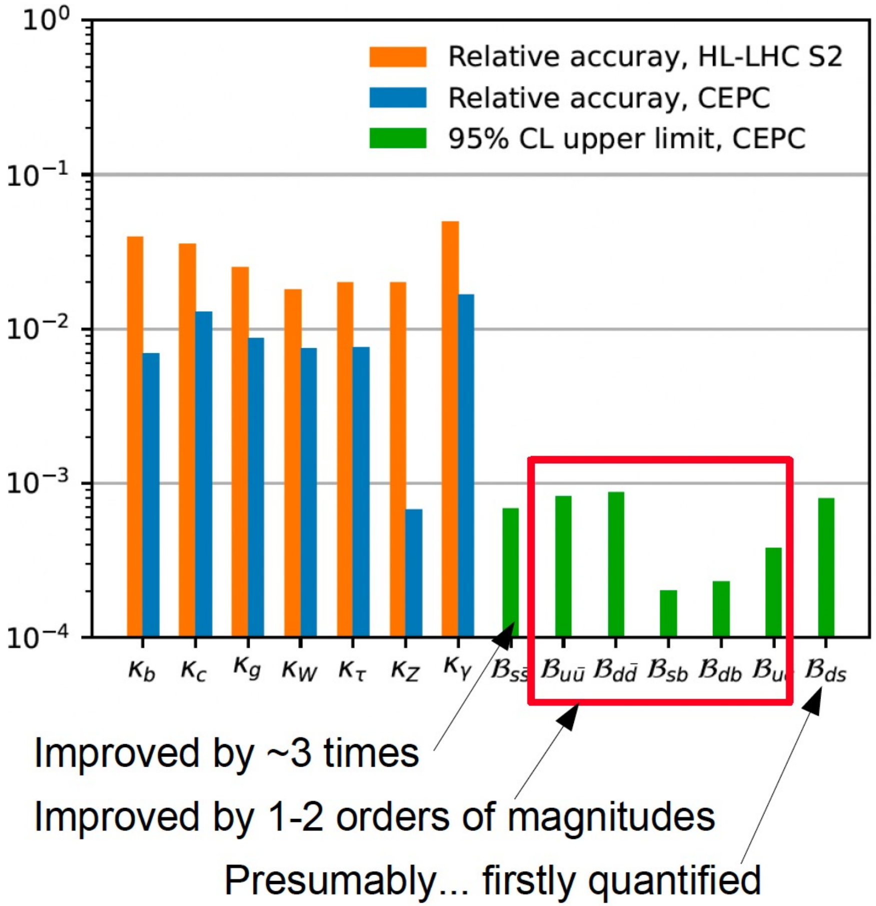




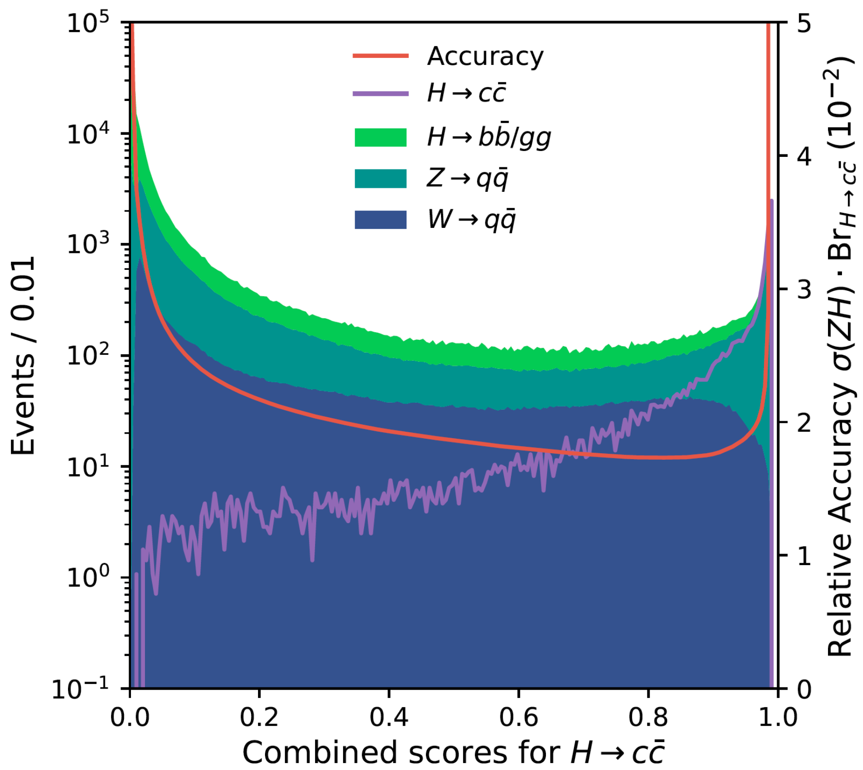
- Jet origin id: 11 categories (5 quarks + 5 antiquarks, + gluon)
  - Jet Flavor Tagging + Jet Charge measurement + s, gluon, u & d -tagging
- Di-jet events (vvH, H->2jet & Z->qq) simulated with CEPC CDR baseline & reconstructed with Arbor
- Input: Pid & 4-momentum of all reconstructed particle + impact parameters for charged ones (~o(50) reco Particles)

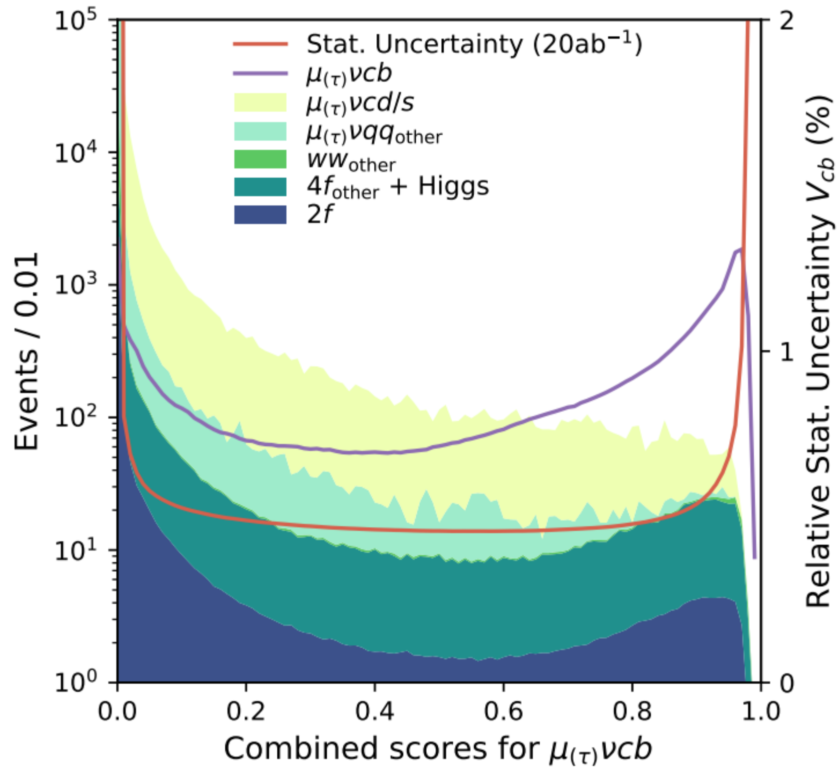
Physics benchmarks: H->ss





Physics benchmarks: H→cc & Vcb





- From Jet Flavor Tagging to Jet Origin ID:
  - vvH, H→cc: 3% → 1.7% (**Preliminary**)
  - Vcb: 0.75% → 0.45% (muvqq channel. evqq: 0.6%, combined 0.4%)

Update-2: 1-1 corresponding reco.

Reconstruct precisely all final state particle within detector acceptance (space, time, & energy)

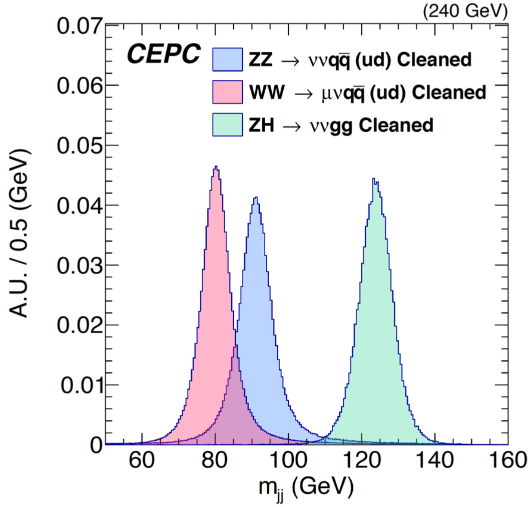
=

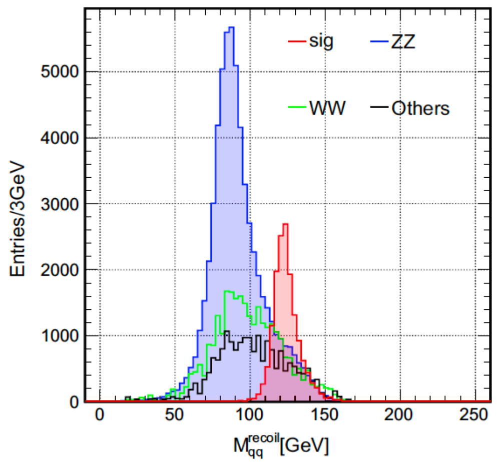
Significantly Suppress Confusion of current PFA

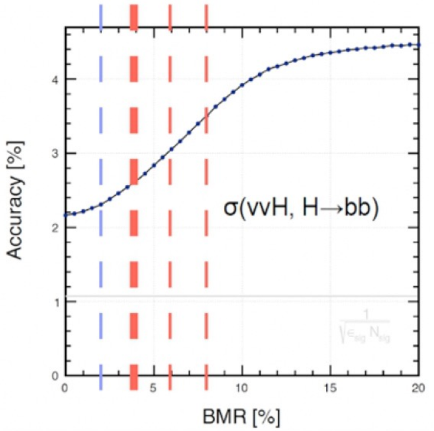
+

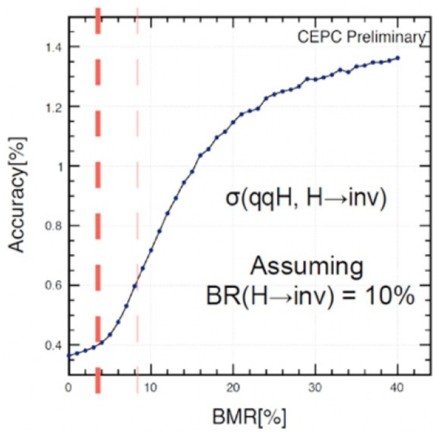
High-efficiency particle identification of reconstructed particle

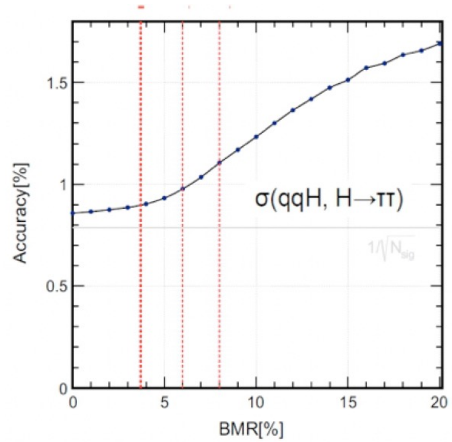
PFA Goal: BMR < 4% & pursue 3%

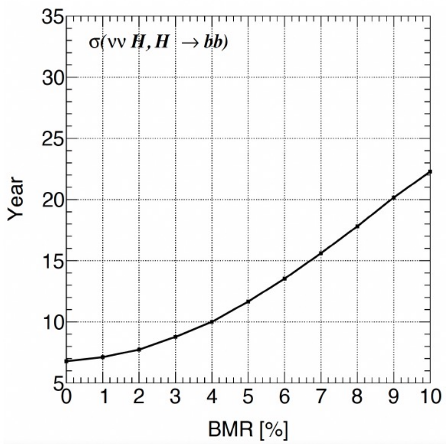


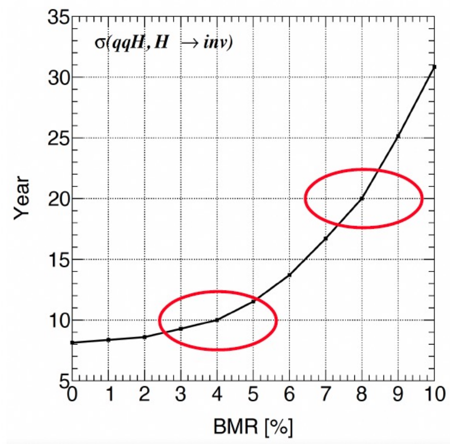


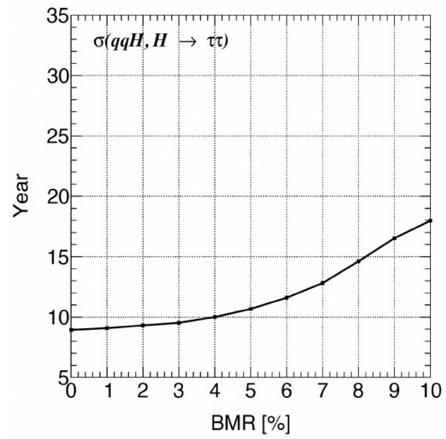




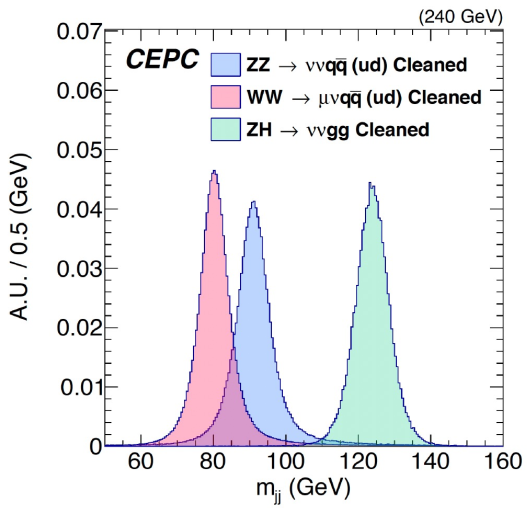


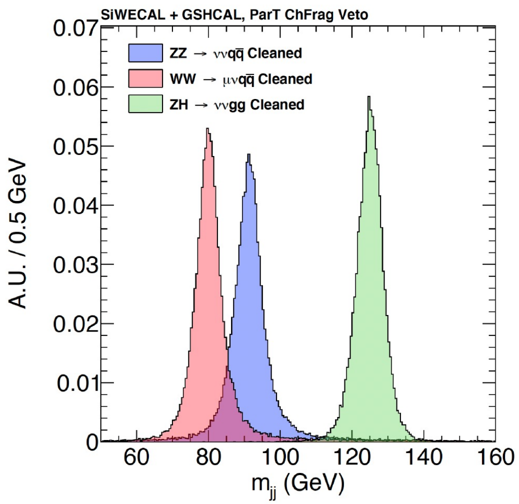


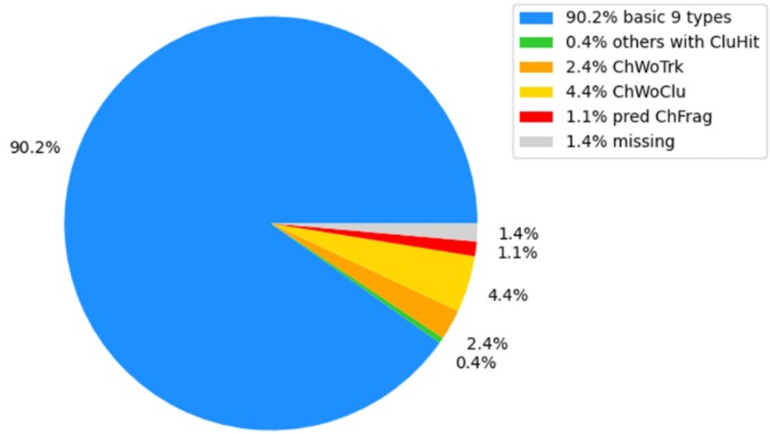


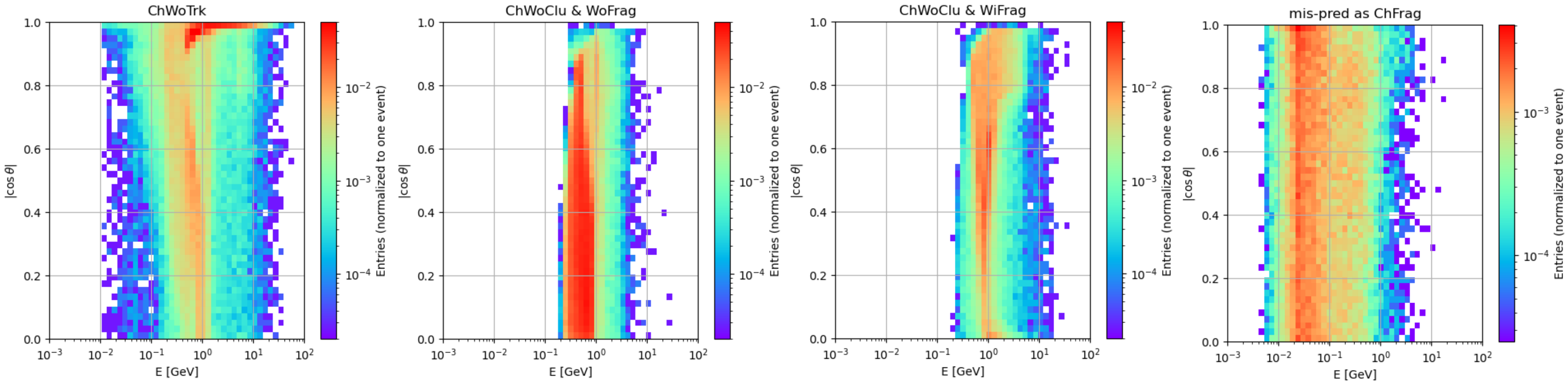


BMR @ CDR & AURORA: 3.7% & 2.9%

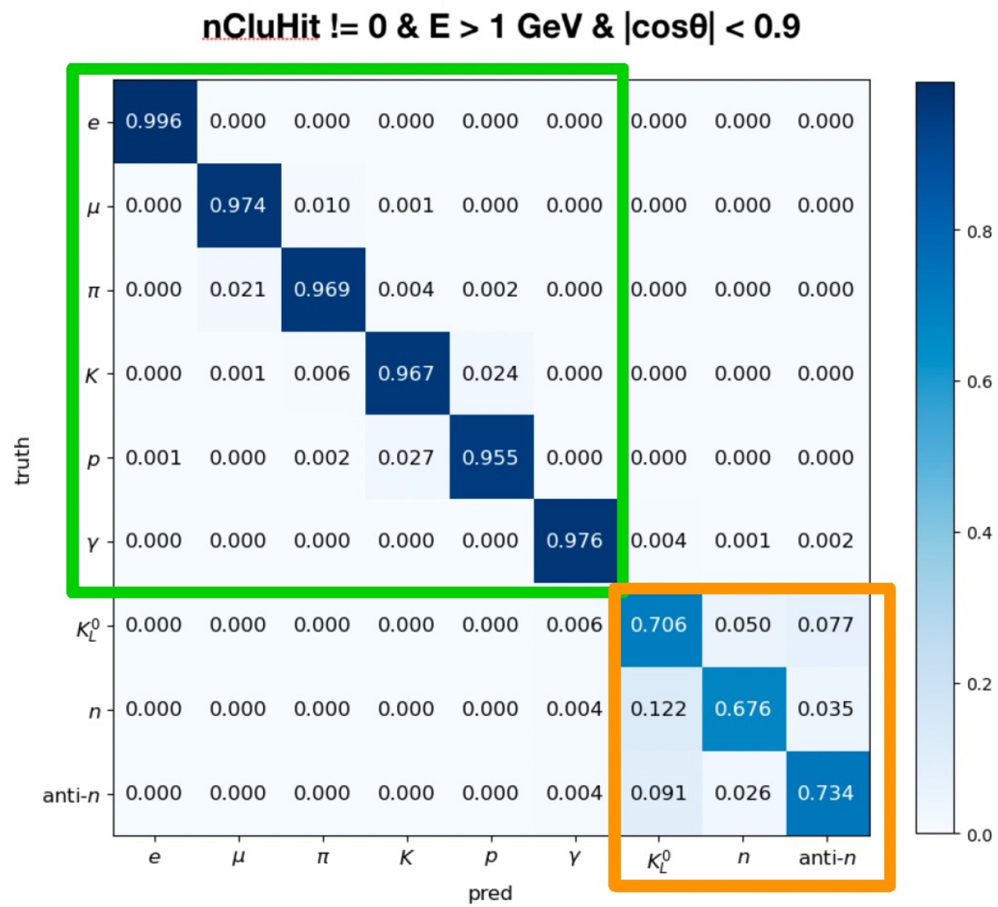


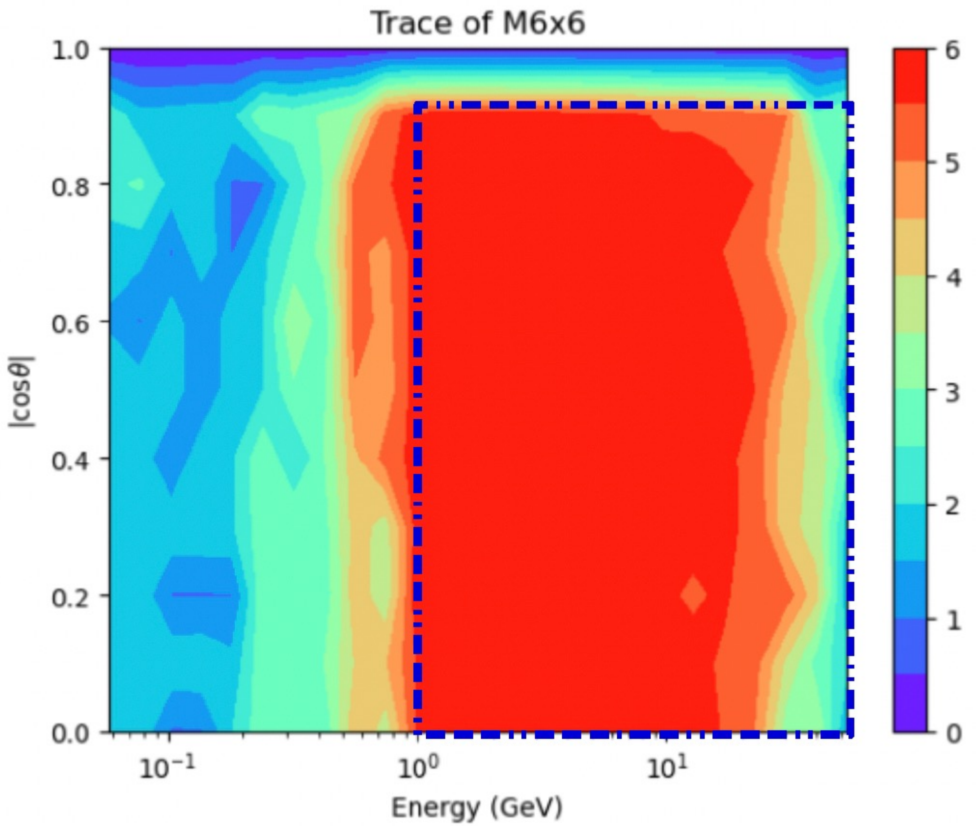






Pid of all final state particle...





At vvH, H->gg events @ 240 GeV, Using AURORA, No TPC dE/dx Digitization.

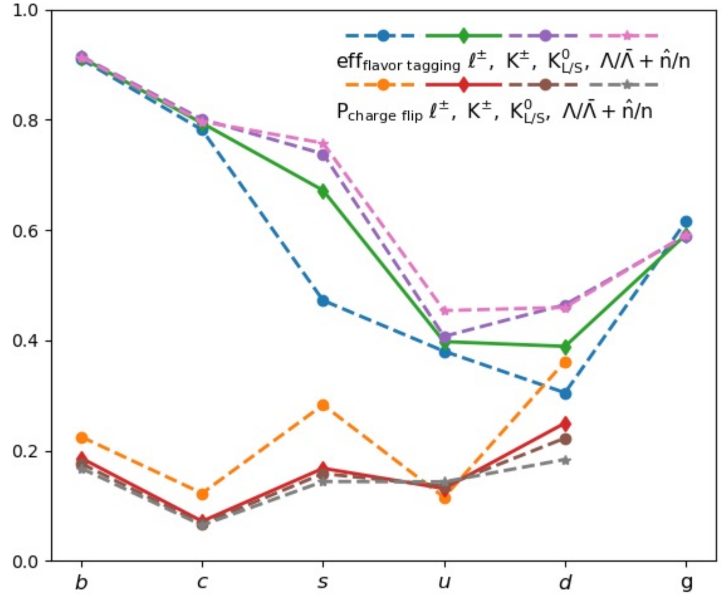
Impact on JoI

M11 2 PID $l^{\pm}$, $K^{\pm}$

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

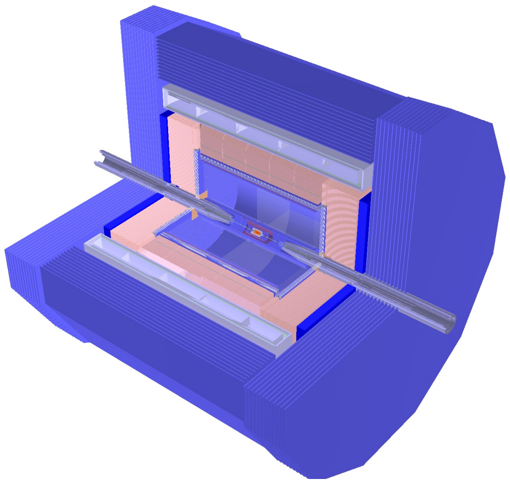
M11 4 PID $l^{\pm}$, $K^{\pm}$, K_L/K_S, $\Lambda/\bar{\Lambda}$, $n/\bar{n}$

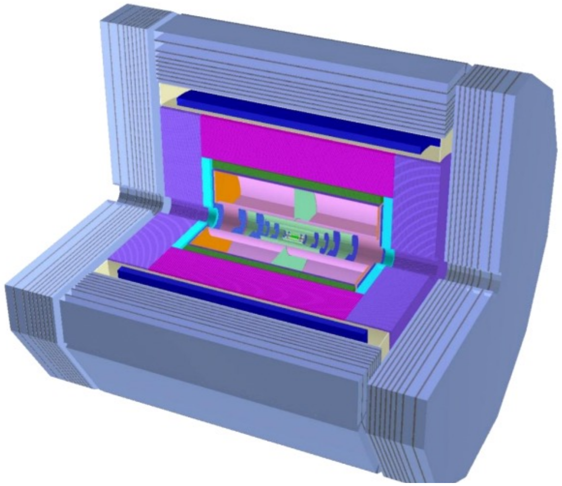
True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.761	0.146	0.034	0.022	0.005	0.003	0.002	0.003	0.003	0.002	0.018
$\bar{b}$	0.155	0.750	0.024	0.033	0.003	0.005	0.003	0.003	0.002	0.003	0.018
c	0.016	0.014	0.751	0.049	0.042	0.033	0.021	0.008	0.009	0.017	0.039
$\bar{c}$	0.015	0.017	0.051	0.745	0.034	0.044	0.008	0.022	0.016	0.010	0.039
s	0.004	0.002	0.025	0.018	0.635	0.101	0.020	0.052	0.036	0.036	0.071
$\bar{s}$	0.002	0.003	0.019	0.024	0.101	0.637	0.050	0.019	0.036	0.035	0.073
u	0.003	0.003	0.017	0.008	0.031	0.092	0.400	0.063	0.095	0.183	0.105
$\bar{u}$	0.003	0.003	0.009	0.015	0.089	0.03	0.067	0.396	0.191	0.092	0.105
d	0.003	0.003	0.01	0.015	0.068	0.065	0.097	0.195	0.365	0.073	0.105
$\bar{d}$	0.003	0.003	0.017	0.01	0.066	0.068	0.204	0.095	0.075	0.353	0.107
G	0.015	0.014	0.024	0.023	0.049	0.049	0.044	0.044	0.042	0.041	0.655



Update-3: detector

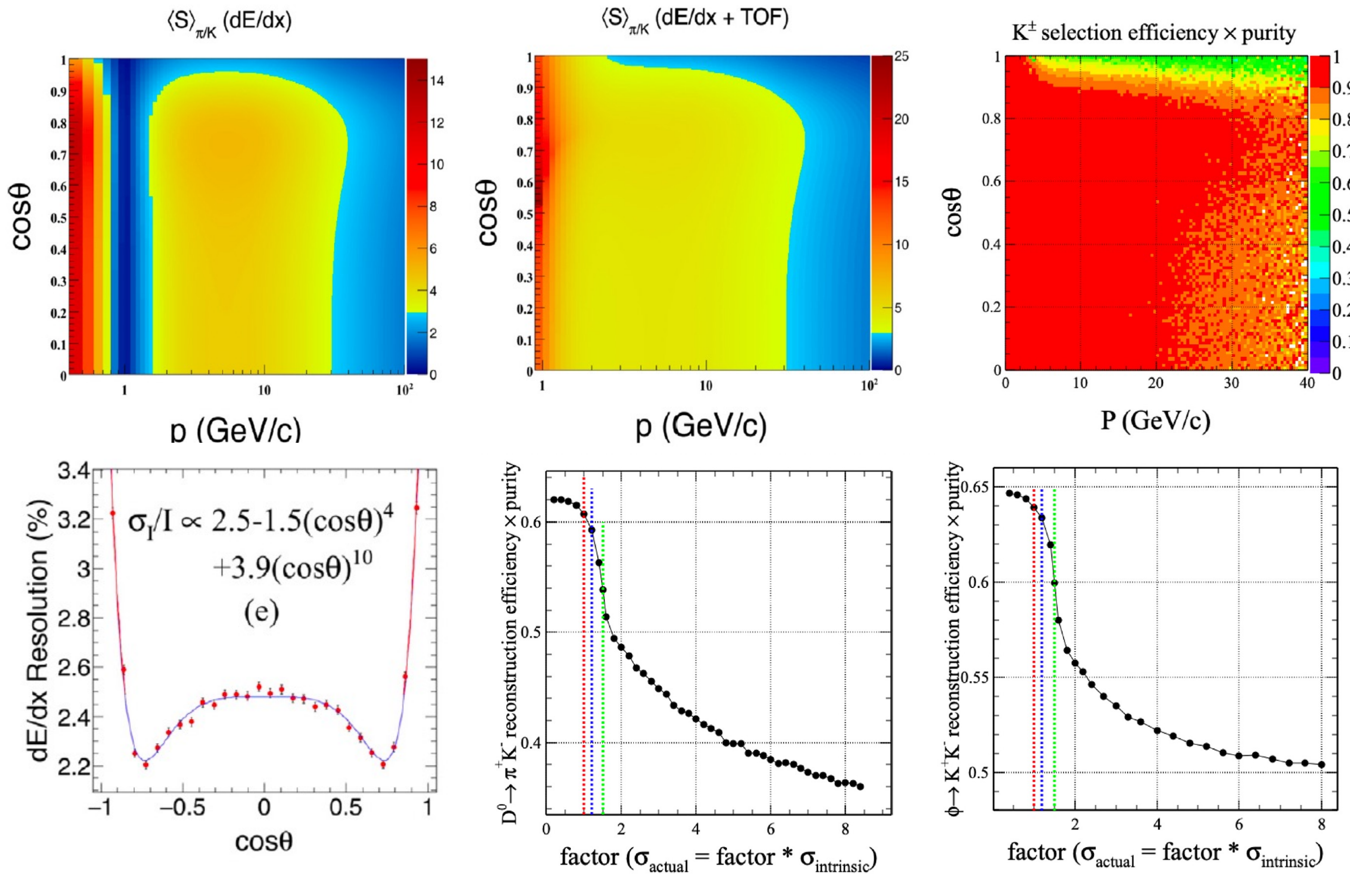
Det. Concepts: CDR to TDR





	CDR	Ref-TDR
VTX	Inner radius of 16 mm	Inner radius of 11 mm
	Material Budget: 0.15% * 6 + 0.14% (beampipe) = 1.05 X0	Material Budget: 0.06% * 4 (inner) + 0.25*2 (outer) + 0.16% (beampipe) = 0.9 X0
Main Tracker	TPC with 1 mm * 6 mm readout	TPC with 0.5 mm * 0.5 mm readout Required to have dE/dx or dN/dx with relative accuracies of 3% (Drift Chamber with the capability of dN/dx as alternative)
ToF	-	LGAD, with 50 ps per MIP
ECAL	Si-W-ECAL: $\frac{17\%}{\sqrt{E/GeV}} \oplus 1\%$	Xbar-ECAL: $\frac{3\%}{\sqrt{E/GeV}} \oplus 1\%$
HCAL	RPC-Iron: $\frac{60\%}{\sqrt{E/GeV}} \oplus 2\%$	Glass-Iron: $\frac{40\%}{\sqrt{E/GeV}} \oplus 2\%$

Pid via ToF + dE/dx or dN/dx



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

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University of Chinese Academy of Sciences, 19A Yuquan 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.

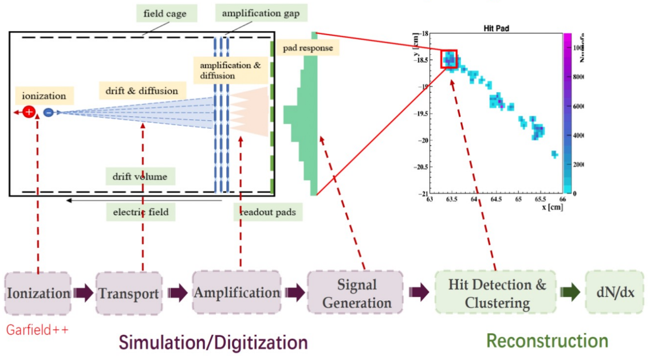
	Factor	1.	1.2	1.5	2.
dE/dx	ϵ_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ϵ_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

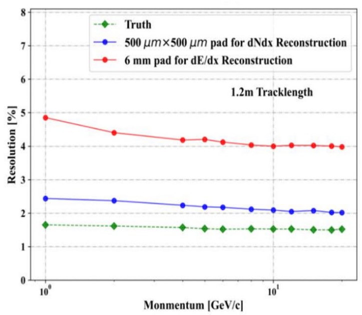
- dE/dx or dN/dx with relevant uncertainty of **3%** + ToF of 50 ps: eff & purity of Kaon id > 95%

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

Performance from simulation

- Full simulation framework of pixelated TPC developed using Garfied++ and Geant4 at IHEP
- Investigating the π/κ separation power using reconstructed clusters, **a 3σ 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

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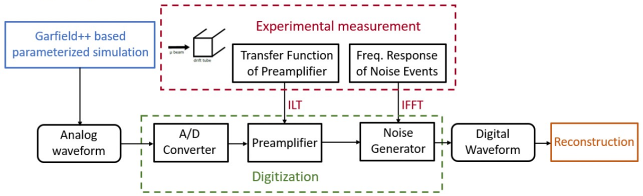
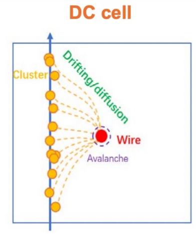
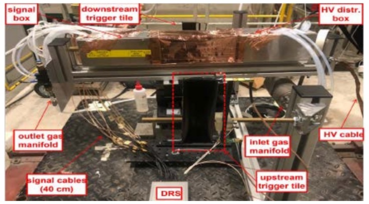
DC R&D efforts and results

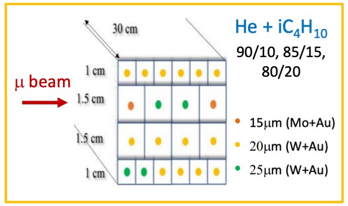
- Develop sophisticated software tools for DC PID simulation



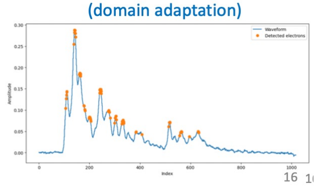


- International collaboration of the beam test





Waveform reconstruction with ML (domain adaptation)



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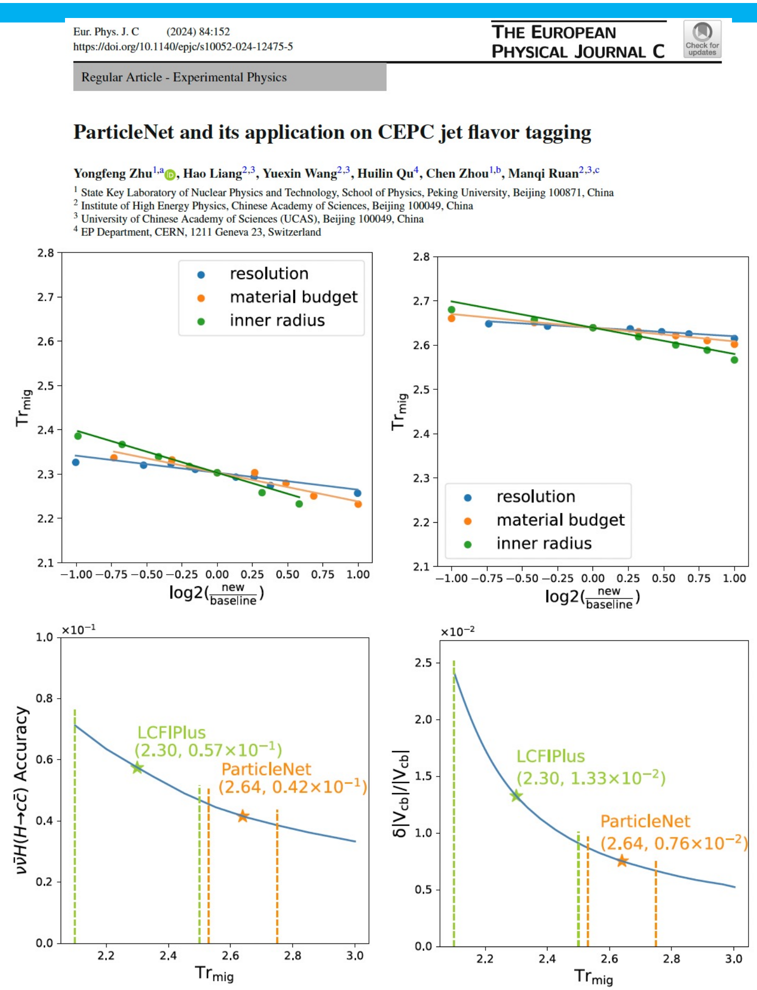
- A major goal for the Ref-TDR Gaseous Tracker is the Pid: to achieve 3% dE/dx or dN/dx performance.
- Promising results, to be validated with further studies, especially test beam.
- Gaseous Tracker inner radius: to be optimized.

VTX and Jet Flavor/Charge measurement


Eur. Phys. J. C (2024) 84:152
https://doi.org/10.1140/epjc/s10052-024-12475-5

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

ParticleNet and its application on CEPC jet flavor tagging

Yongfeng Zhu[1,a], Hao Liang[2,3], Yuexin Wang[2,3], Huilin Qu[4], Chen Zhou[1,b], Manqi Ruan[2,3,c]

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[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

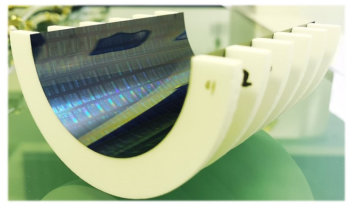
predicted

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

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

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

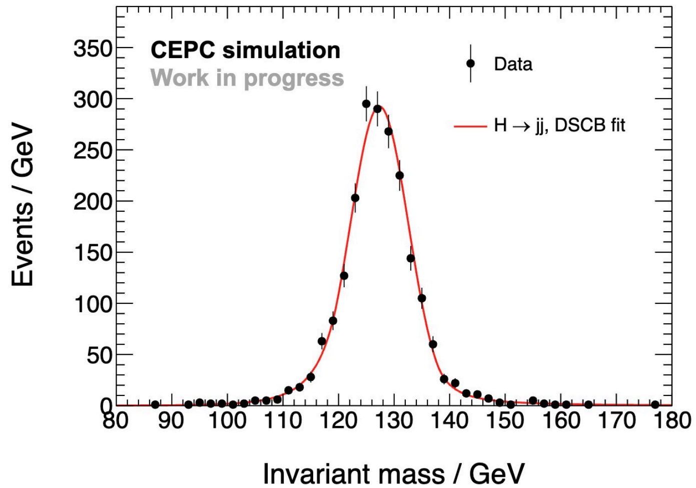
- Compared to CDR, VTX at TDR:
  - Inner radius reduced by 40% (16 mm -> 11 mm)
  - Material reduced by 10% (1.05 -> 0.9 X0)
- Tr(Mig): 2.64 -> 2.68
  - H->cc accuracy improved by ~5%
  - Vcb accuracy improved by ~10%



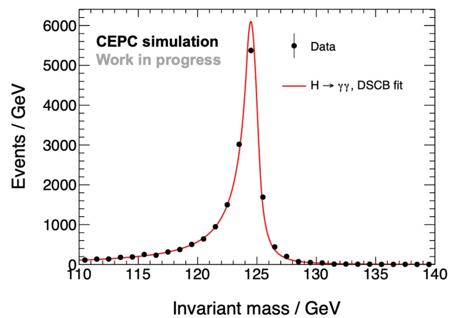
Xstal ECAL

Physics performance: $H \rightarrow gg$

- **Physics process: $ee \rightarrow ZH \rightarrow \nu\nu gg$ in $\sqrt{s} = 240$ GeV**
  - Full reconstruction in CEPC detector: Silicon + TPC tracker, crystal ECAL, glass tile HCAL.

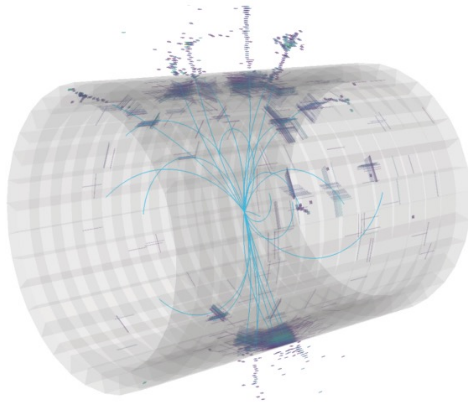


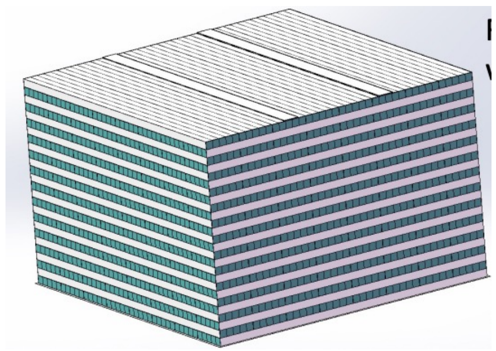
m_{jj} = 127.3 GeV, $\sigma(m_{jj})$ = 5.23 GeV
Boson mass resolution (BMR) 4.11%.
With truth track: BMR 3.73%.



Double-side CB fit, $\sigma(m_{\gamma\gamma})$ = 0.57 GeV
Long tail from
- Lossy processes of crystal calorimeter
- Imperfect correction in crack region.

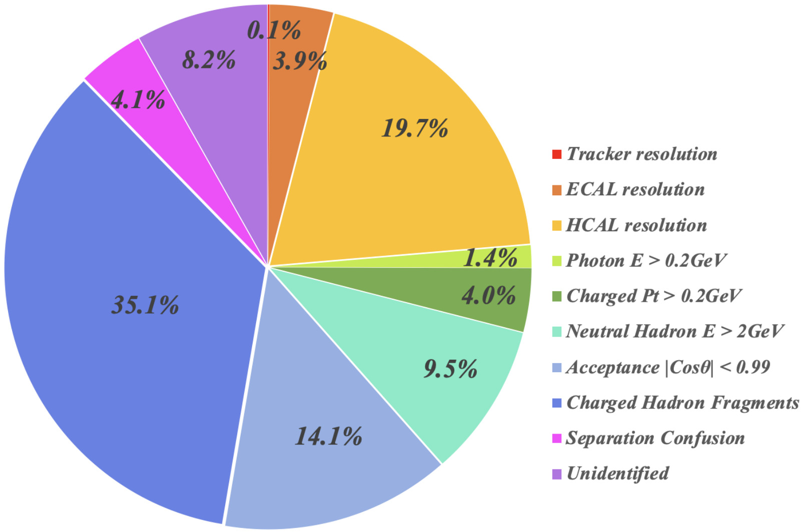
Can be fixed with better photon energy correction in the future.

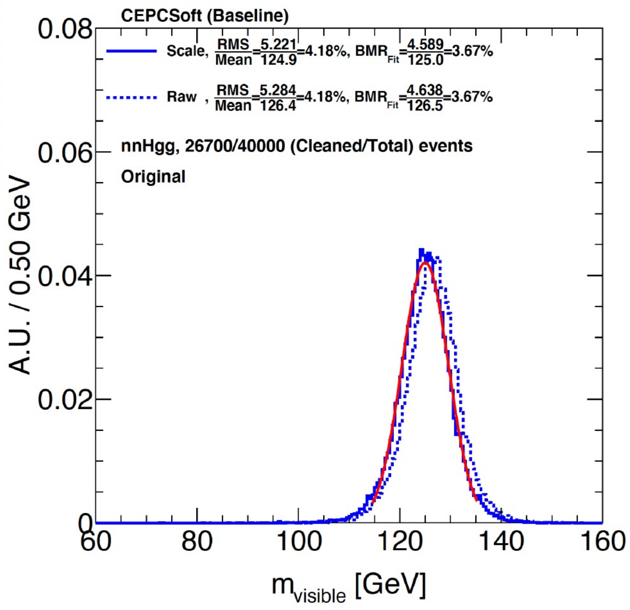


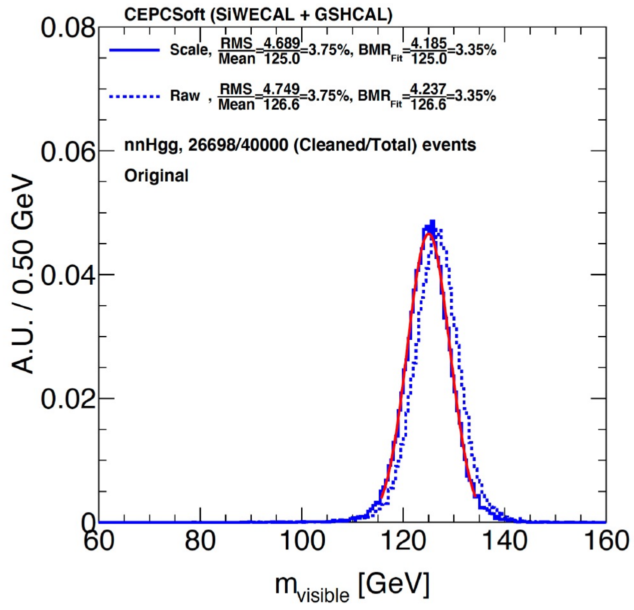


- BMR at ref-TDR: not far from CDR (BMR of 3.7%).
- To control the confusion (fake particles, etc) is the critical: Need optimization + reconstruction development.

Glass scintillator HCAL







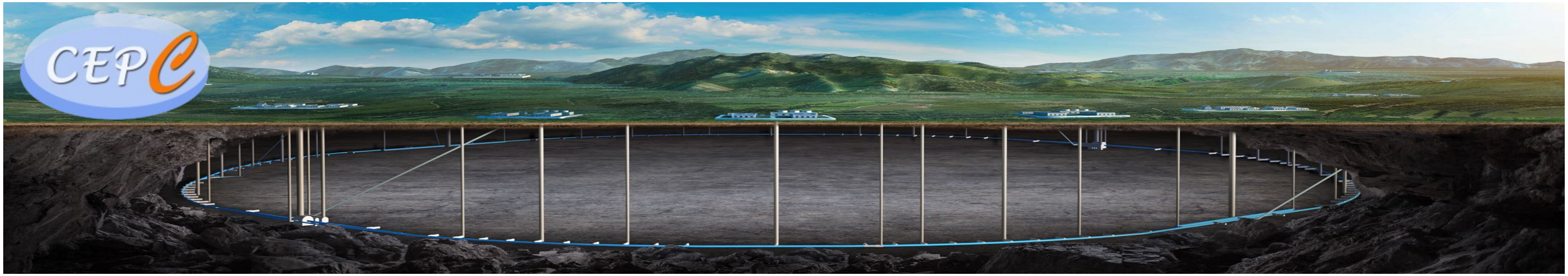
1st, 50% from Confusion, 25% from detector resolution & 25% from acceptance, for BMR of 3.7% at CDR

2nd, HCAL resolution dominant the uncertainties from detector resolution:

*TDR HCAL: Glass Scintillator - Iron with thickness of 6 lambda (compared to GRPC - Iron of 5 lambda) BMR of 3.4% (2*2 cm^2 cell) & 3.5% (4*4 cm^2 cell)*

Summary

- CEPC Physics studies: Well quantified Physics Merits
- Detector + Performance: CDR baseline has excellent performance for Higgs measurements. With Updates of:
  - Embrace AI trends: JoI & 1-1 correspondence
  - Tool: CEPC Delphes Card (see Kaili's talk)
  - Iterate with Detector R&D
  - To quantify & to ameliorate the impact of Beam induced background, the readout, especially at Z pole
- CEPC New Physics WP Study: essential to demonstrate & quantify the discover power
  - Science reach on top of anticipated reach at LHC & current boundary: Key conclusion + plots
  - Requirements on Acc. Luminosity, Polarization
  - Bottle neck of performance (identification efficiency – purity, resolution…) for your measurement
  - Experimental Systematics: Luminosity, identification
  - Theoretical Uncertainties: Model dependence, modeling & High Precision Calculation



Thank you for your attention!

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Summary

- Intensive CEPC Physics studies
  - Well quantified Physics Merits
  - Iterates with Detector R&D
- CEPC Ref-TDR detector provides
  - Pid: critical for Physics.
  - Better VTX: improves precisions on benchmark analysis by 10-20%
  - PFA Compatible Calorimeter with larger sampling:
    HCAL improves the BMR by ~10%,
    Xbar ECAL: pattern recognition is challenging.
- To do:
  - To quantify & to ameliorate the impact of Beam induced background, the readout, especially at Z pole
  - To develop Smart Reco. Algo, especially with AI tools.

Physics Benchmarks at CDR & TDR

	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→lνqq @ 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→ $\nu\nu\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)	Same, if object recon. ~ CDR
Bc→ $\tau\nu$ [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

- Higgs to di photon precisions improves significantly, if low mass tail tamed.
- Physics measurements using JoI, etc, benefit from better VTX and has 5-10% improvements
- Here we assume the TDR BMR could eventually reach ~ CDR
- If BMR of 3% achieved, precisions of most benchmarks could be further improved for 5-10%
- The Pattern reco. capability of Xbar ECAL is still a concern. Need further development & validations.

Challenges & Team

- Challenges:
  - Impact of Beam induced background (~ Nov. 2024)
  - To further validate & verify the Pattern reco. performance (~ Dec. 2024)
  - High data rate @ Z pole: need to reconstruct in Space time (PFA in space time)

- Core team: ~ 5 staffs + 3 Postdocs + 5 Students + 2 Visitors
- Performance: with sub-detector team
- Algorithms: collaboration with PKU, LLR & CERN
- Benchmark: in pace with physics white paper efforts: ~ > 20 staffs from ~ 10 Universities
  - *Higgs: Yaquan Fang (IHEP) + HEF team*
  - *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.

Physics Benchmarks & Global Performances

	Processes @ c.m.s.	Domain	Relevant Det. Performance
H→ss/cc/sb	vvH @ 240 GeV	Higgs	PFA + Jet Origin Id (JoI)
H→inv	qqH	Higgs/NP	PFA
Vcb	WW→lvqq @ 240/160 GeV	Flavor	JoI + Pid (Lepton, tau)
W fusion Xsec	vvH @ 360 GeV	Higgs	PFA + JoI
α_S	Z→tautau @ 91.2 GeV	QCD	PFA: Tau & Tau final state id
CKM angle $\gamma - 2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	PFA + JoI + Pid (Kaon)
Weak mixing angle	Z@ 91.2 GeV	EW	JoI
Higgs recoil	llH	Higgs	Pid (Lepton), track dP/P
H→bb, gg	vvH + qqH	Higgs	PFA + JoI + Color Singlet id
H→di muon	qqH	Higgs	PFA, Leptons id, Tracking
H→di photon	qqH	Higgs	PFA, Photons id, EM resolution
W mass & Width	W threshold scan @160 GeV	EW	Beam energy
Top mass & Width	Top threshold scan @360 GeV	EW	Beam energy
Bs→ $\upsilon\upsilon\phi$	91.2 GeV	Flavor	Object (ϕ) in jets; MET
Bc→ $\tau\upsilon$	91.2 GeV	Flavor	Object (τ) in jets; MET
B0→ $2\pi^0$	91.2 GeV	Flavor	π^0 in jets; EM resolution

- PFA is required by most of the benchmarks, emphasize global Detector reconstruction performance
- BMR < 4% required, to pursue 3%

- Object identification: need to efficient reconstruct and identify final state particles (1-1 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

- New concepts (Jet origin id & color singlet id) emerges, need to establish their relevance to algorithm & sub-detector configuration & performance

Physics Benchmarks using CDR baseline

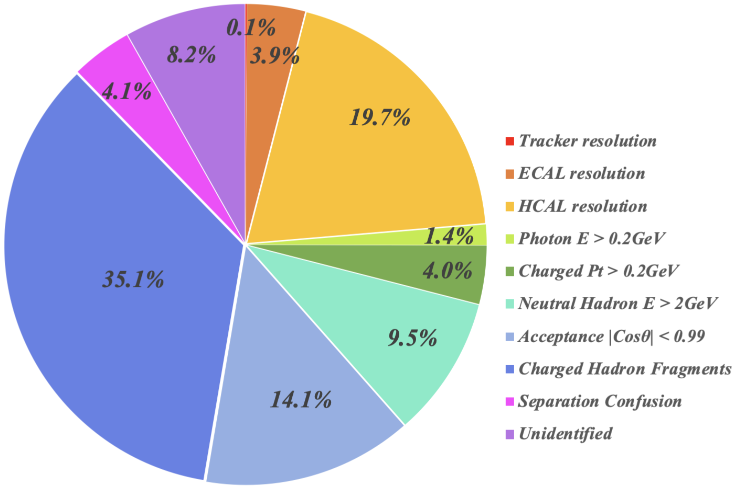
	Processes @ c.m.s.	Domain	Anticipated relative accuracies/up limit with CDR baseline detector + TDR Luminosity, with JoI
H→cc	vvH @ 240 GeV	Higgs	1.7%
H→ss [1]			95% up limit of 0.75E-3
H→sb [1]			95% up limit of 0.22E-3
H→inv [2]	qqH	Higgs/NP	95% up limit of 0.13%
Vcb [3]	WW→lvqq @ 240/160 GeV	Flavor	0.4%
W fusion Xsec [2]	vvH @ 360 GeV	Higgs	1.1%
α_S	Z→tautau @ 91.2 GeV	QCD	NAN
CKM angle $\gamma - 2\beta$	Z→bb, B→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 (~ 2E11 Z)
Higgs recoil [5]	llH	Higgs	δm = 2.5 MeV $\delta\sigma/\sigma$ = 0.25%/0.4% (wi/wo qqH)
H→bb, gg [2]	vvH + qqH	Higgs	bb: 0.14% -> 0.13% gg: 0.81% -> 0.65% (wi/wo JoI)
H→di muon [2]	qqH	Higgs	6.4%
H→di photon [2]	qqH	Higgs	3%
W mass & Width [6]	W threshold scan @160 GeV	EW	0.7 MeV & 2.4 MeV @ 6 iab
Top mass & Width [7]	Top threshold scan @360 GeV	EW	9 MeV & 26 MeV @ 100 ifb
Bs→ $\upsilon\upsilon\phi$ [8]	91.2 GeV	Flavor	0.9% (1.8%@Tera-Z)
Bc→ $\tau\upsilon$ [9]	91.2 GeV	Flavor	0.35% (0.7%@Tera-Z)
B0→ $2\pi^0$ [10]	91.2 GeV	Flavor	NAN

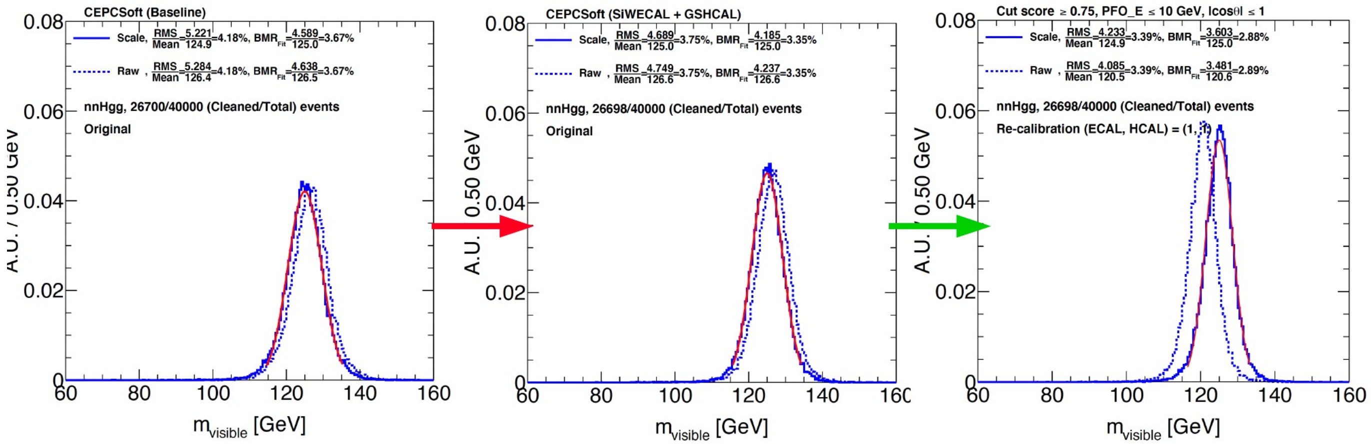
[1] H. Liang, et al, PHYSICAL REVIEW LETTERS 132, 221802 (2024)
[2] CEPC Phy-Det Snowmass White Paper, arXiv:2205.08553v1
[3] H. Liang, Ph.D thesis
[4] Z. Zhao, et al., Chinese Physics C Vol. 47, No. 12 (2023) 123002
[5] Z. Yang, et al., Chinese Physics C Vol. 41, No. 2 (2017) 023003

[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

Back Up

BMR Decomposition



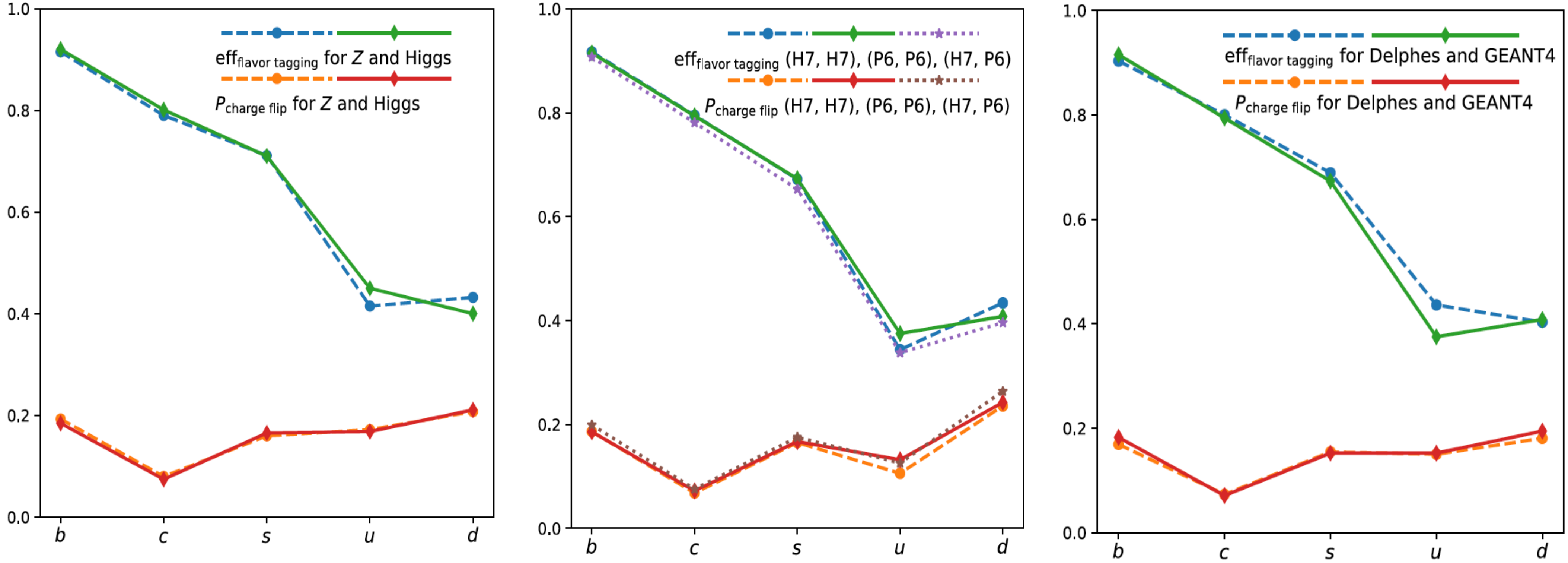


1st, 50% from Confusion, 25% from detector resolution & 25% from acceptance, for BMR of 3.7% at CDR

2nd, HCAL resolution dominant the uncertainties from detector resolution:
TDR HCAL: Glass Scintillator - Iron with thickness of 6 lambda (compared to GRPC - Iron of 5 lambda) BMR of 3.4%

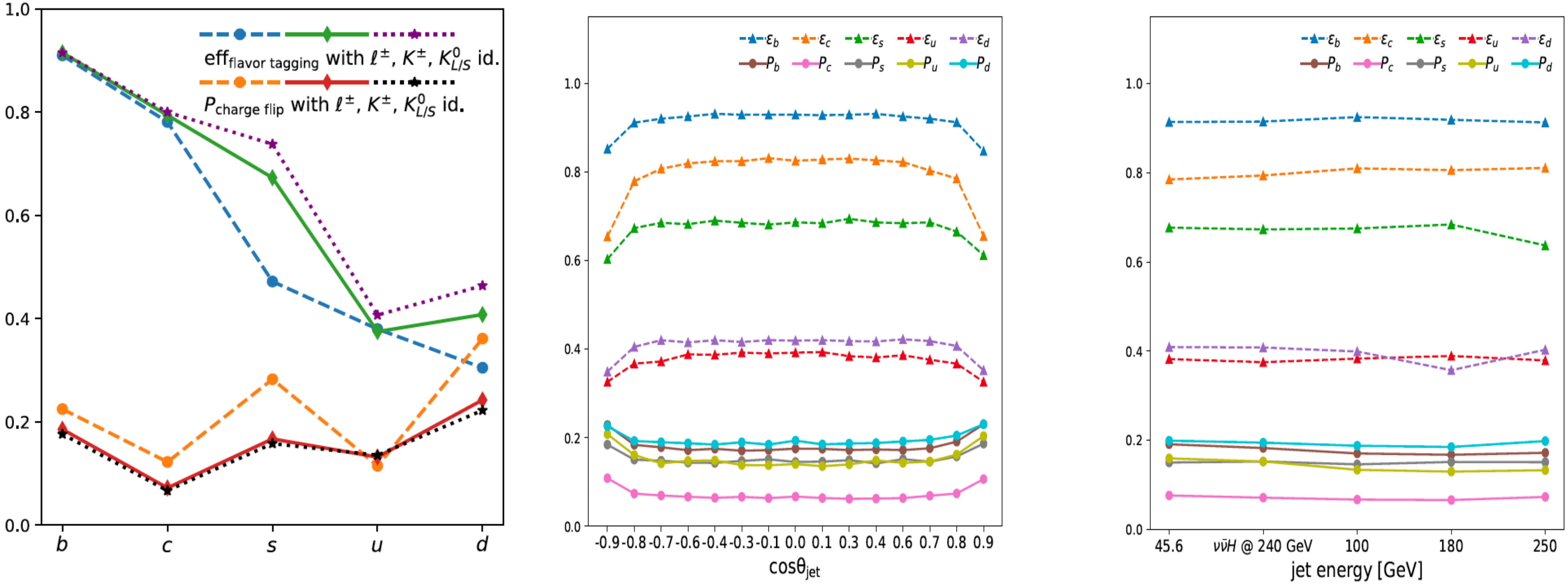
3rd, Leading contribution: Confusion from shower Fragments (fake particles), need better Pattern Reco.
Mostly can be reduced by AI enhanced Arbor at SiW ECAL + GS HCAL: BMR of 2.9%

JOI: validation & comparison



- Could be calibrated using Z->qq. (10 category id, without gluon)
- Stable at different Hadronization model, different simulation method (Geant 4 & Delphes - Fast Sim)
- *Referee: A "game changer" and opens new horizon for precise flavor studies at all future experiments*

JOI: tagging efficiency & flip rates



- Kaon id: a must
- Could be calibrated on Z->qq events, and is relatively stable VS hadronization models, etc

Challenges

- More realistic collision environments: Beam induced background, Primary IP reco, etc
  - To be addressed by a few benchmark performance study wi. Beam induced background & to be included in TDR

- Event overlap in time (Z pole):
  - To be solved by **PFA in Space time: Future Plan.**

- More Realistic Digitization, including Noise & TDAQ effects

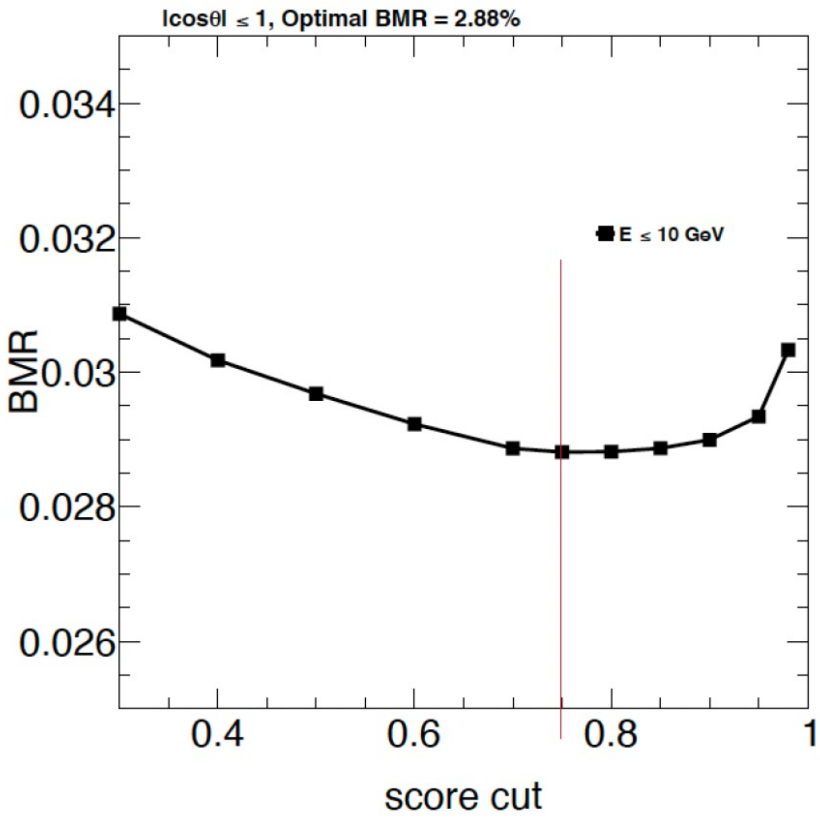
+

- Further Optimization (5D Calorimerter, Time resolution, cell configuration, etc)
  - To be addressed by joint study with Sub-detector & Software team (Long term plan)
  - AI enhanced reco. algorithm. will be the key.

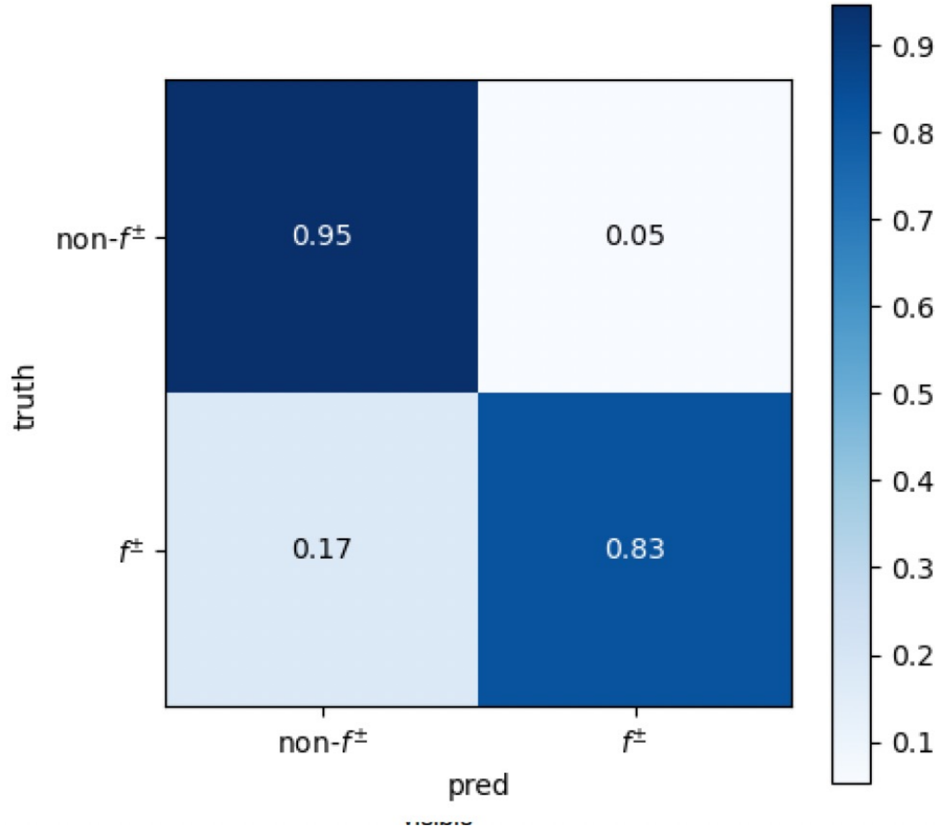
T.o.C. at Ref TDR

- Introduction: Physics requirements
- Recap of sub-detector performance, tracking, Pid, etc
- Detector global Performance:
  - BMR
  - JoI
  - Pid
  - Outlook: 1-1 correspondence reco.
- Physics Benchmarks
- Challenges & Plan
- Teams
- Summary

Fake particle veto using AI



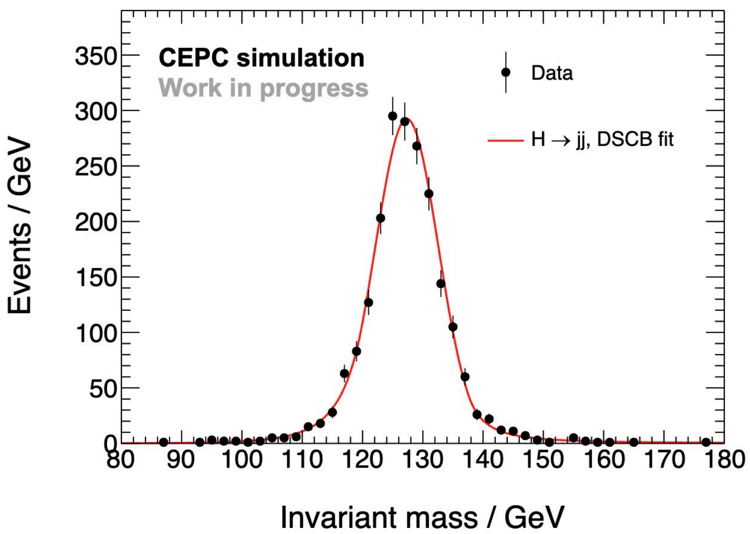
(stemmed from Charge Shower Fragments)



BMR of ~ 4% at TDR baseline

Physics performance: $H \rightarrow gg$

- **Physics process: $ee \rightarrow ZH \rightarrow \nu\nu gg$ in $\sqrt{s} = 240$ GeV**
  - Full reconstruction in CEPC detector: Silicon + TPC tracker, crystal ECAL, glass tile HCAL.



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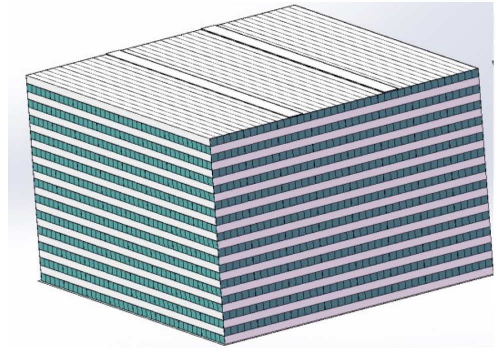

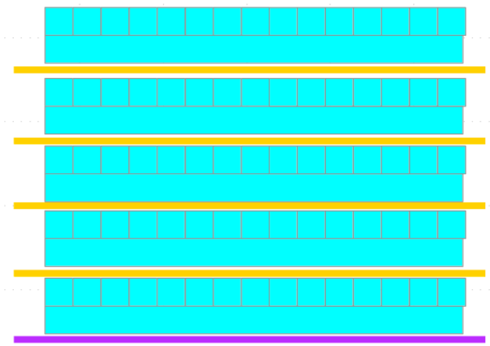

- BMR at ref-TDR: not far from CDR (BMR of 3.7%).
- To control the confusion (fake particles, etc) is the critical: Need optimization + reconstruction development.
- One solution is to add a few timing & positioning layers.