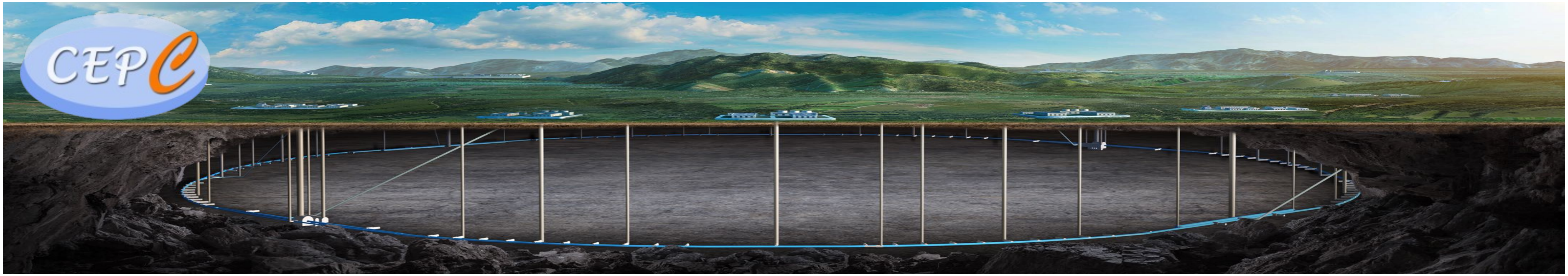

Physics Benchmarks & Global Performance

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Aug. 7th, 2024, CEPC Detector Ref-TDR Review

Content

- Introduction: Physics benchmarks & relevant Global performance
- Status of CEPC Physics Studies
  - Snowmass studies
  - Key technologies: Jet origin id & its application
- Physics benchmarks at CDR detector
- Comparison between CDR and Ref-TDR detector: Pid, VTX & PFA.
- Physics benchmarks at Ref-TDR
- Challenges and team
- Summary

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→ $\nu\nu\phi$	91.2 GeV	Flavor	Object (ϕ) in jets; MET
Bc→ $\tau\nu$	91.2 GeV	Flavor	Object (τ) in jets; MET
B0→ $2\pi^0$	91.2 GeV	Flavor	π^0 in jets; EM resolution

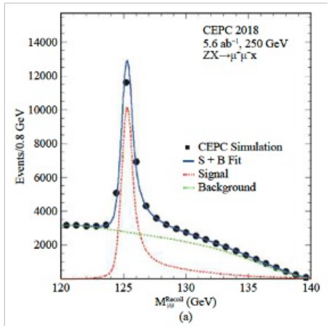
- PFA is required by most of the benchmarks, emphasize global Detector reconstruction performance
- BMR < 4% required, to pursue 3%

- 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.

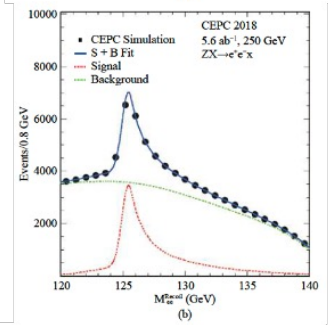
- Sub-Det level performance
- Tracking: ~0.1% momentum resolution
- EM resolution: ~1% level
- VTX: position resolution ~ 5 μm

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

Physics Study : Status



(a)



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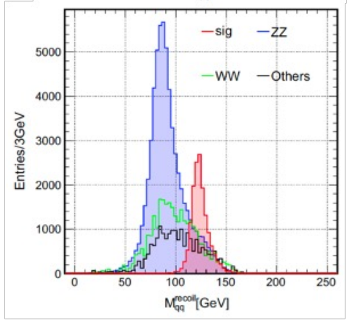

Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

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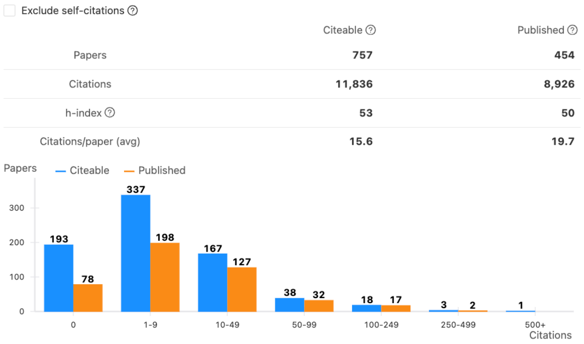

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	Citeable	Published
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Citations	11,836	8,926
h-index	53	50
Citations/paper (avg)	15.6	19.7

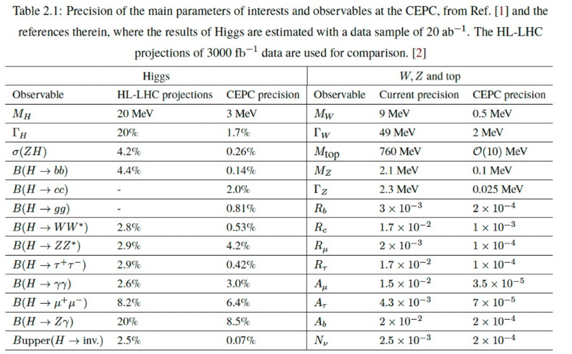
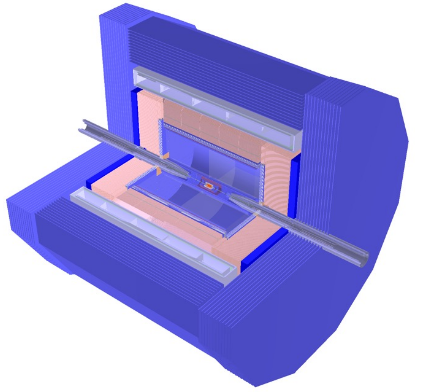
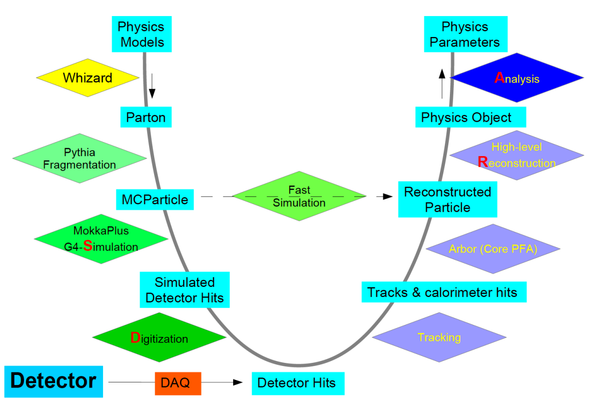


Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2]

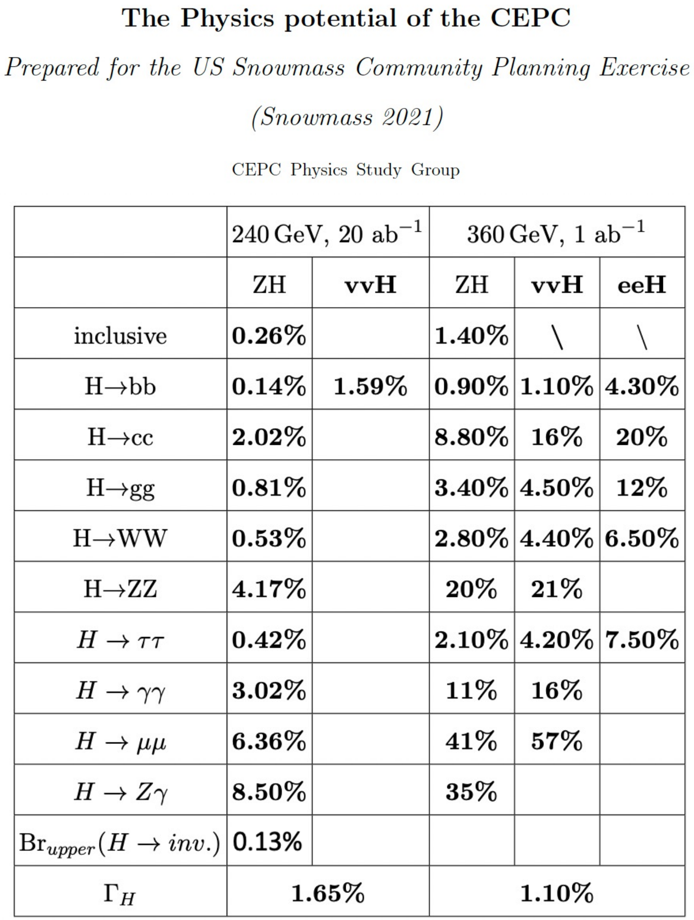
Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H \to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \to cc)$	-	2.0%	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$(H \to \mathrm{inv.})$	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

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%**		

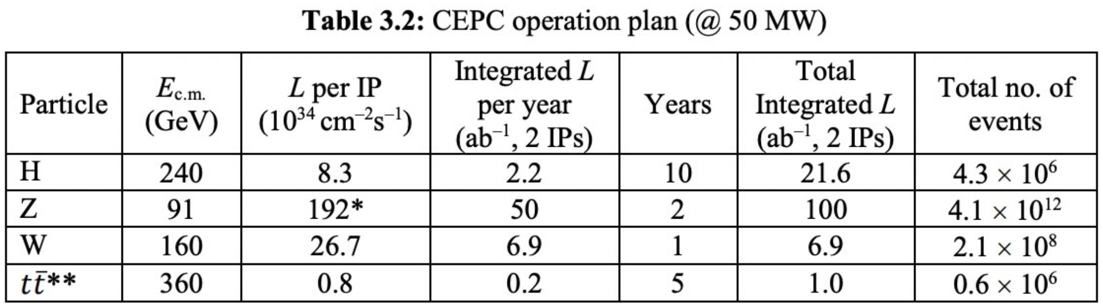
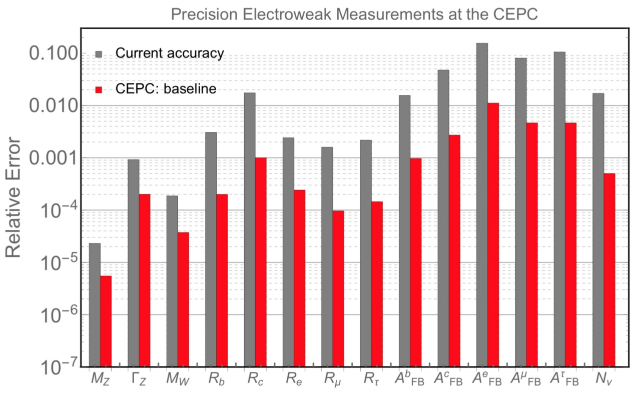


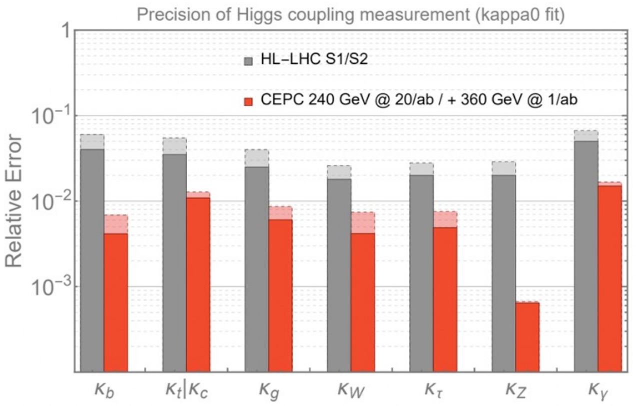
Table 3.2: CEPC operation plan (@ 50 MW)

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.

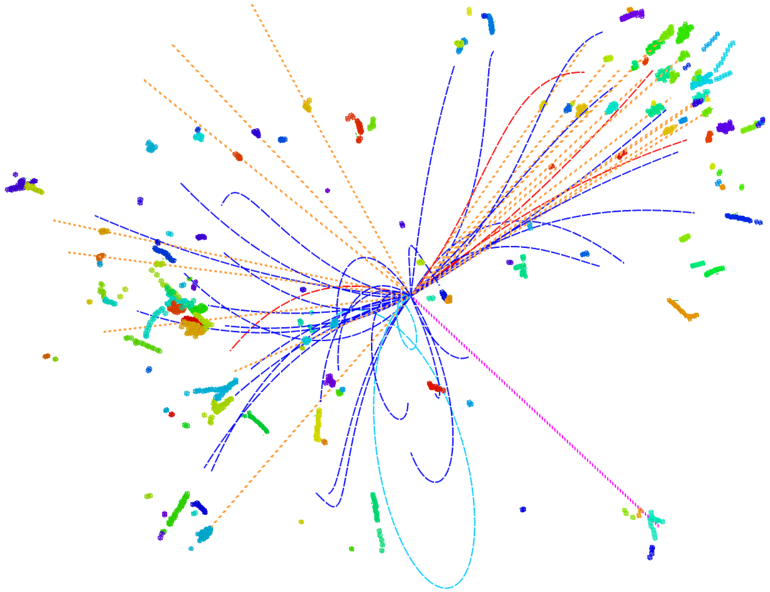
CEPC TDR

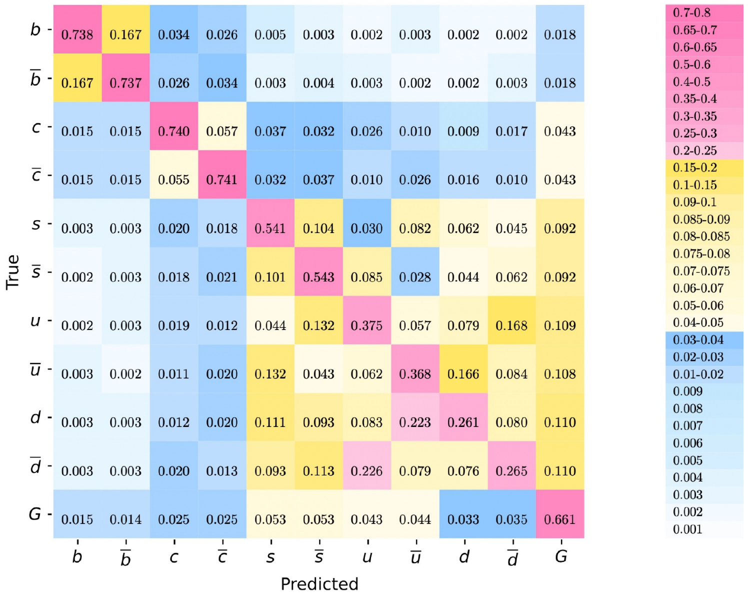




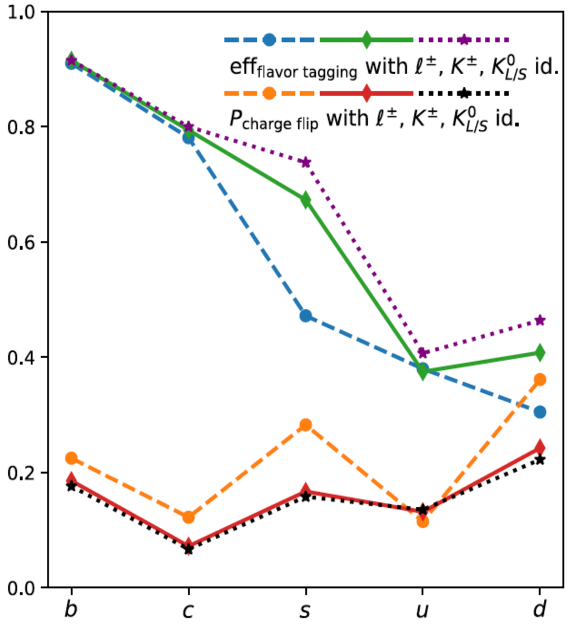
arXiv:2205.08553v1

Jet Origin ID



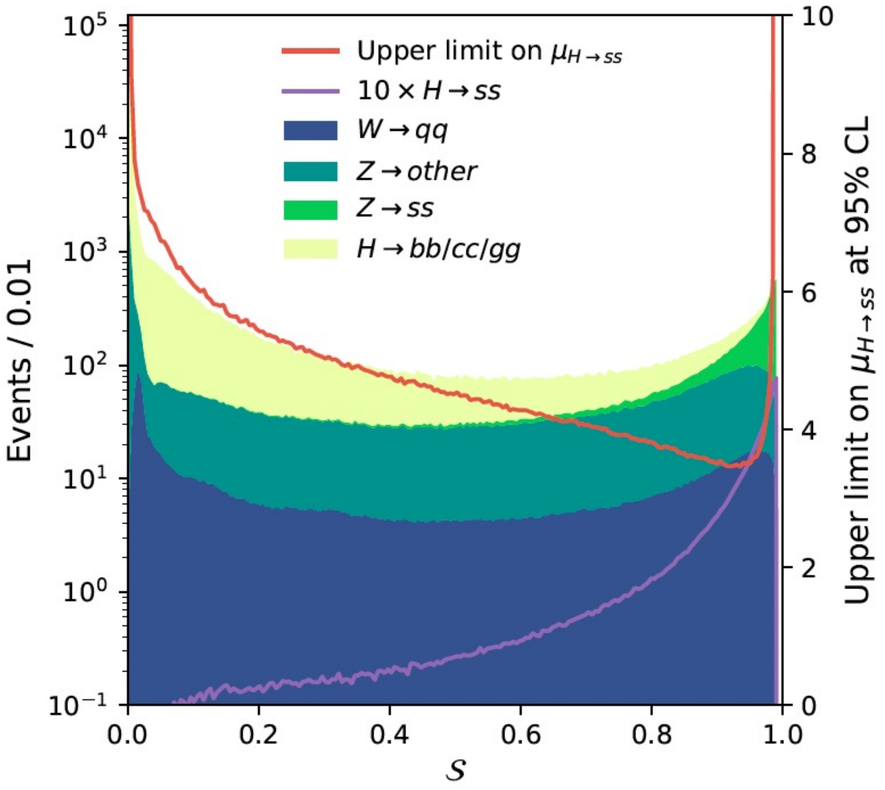


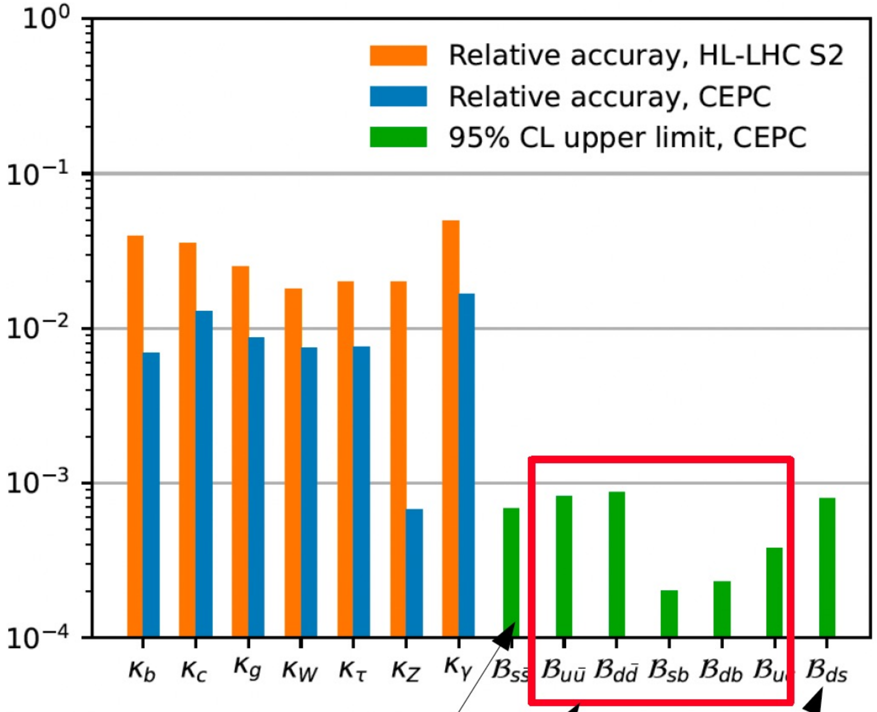
True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$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



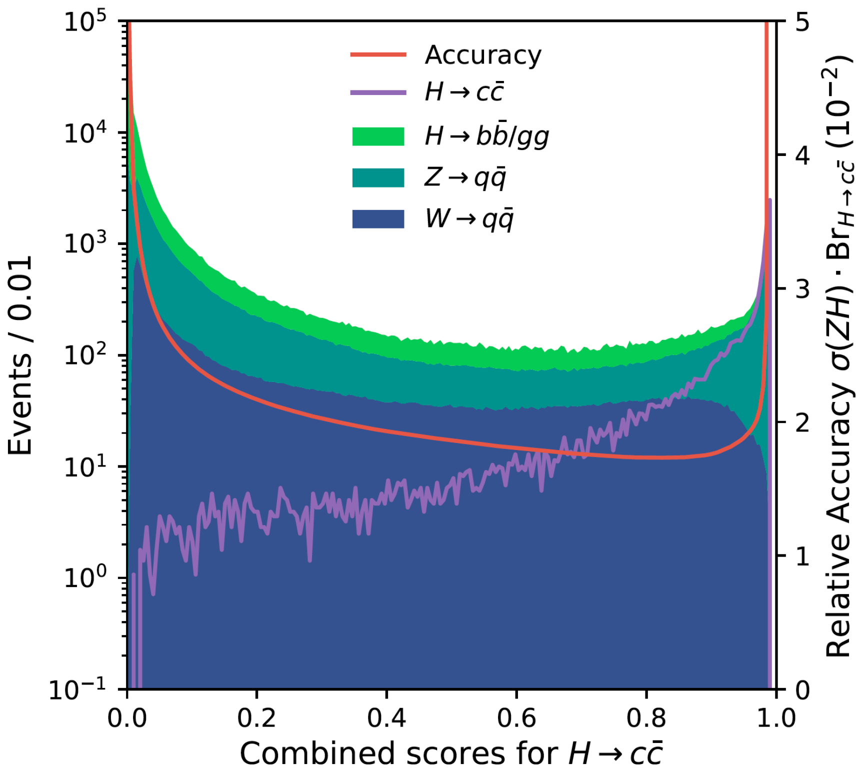


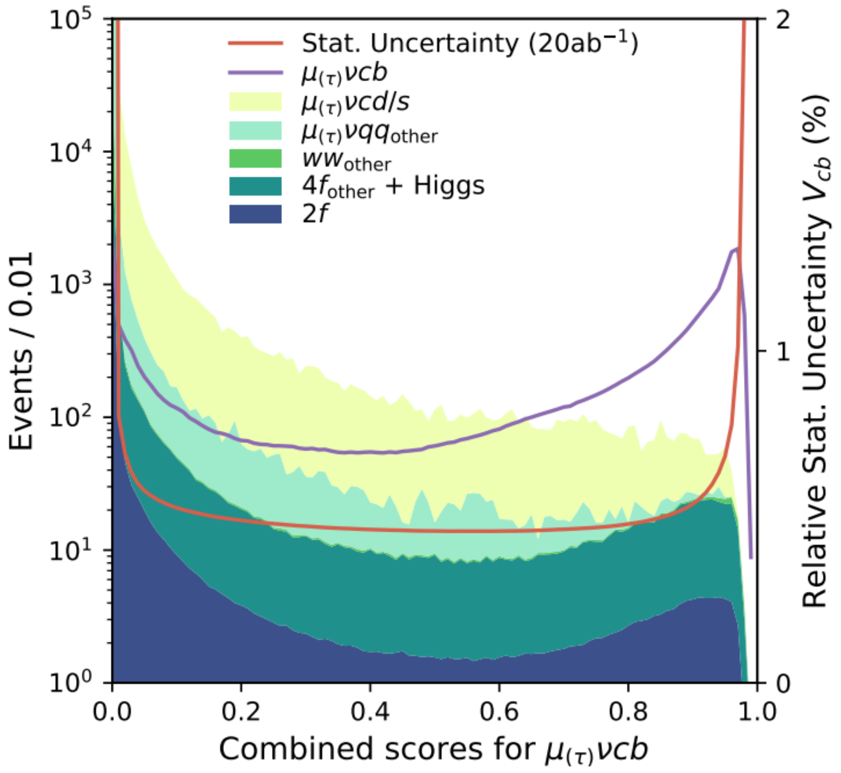
Improved by ~3 times

Improved by 1-2 orders of magnitudes

Presumably... firstly quantified

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%)

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

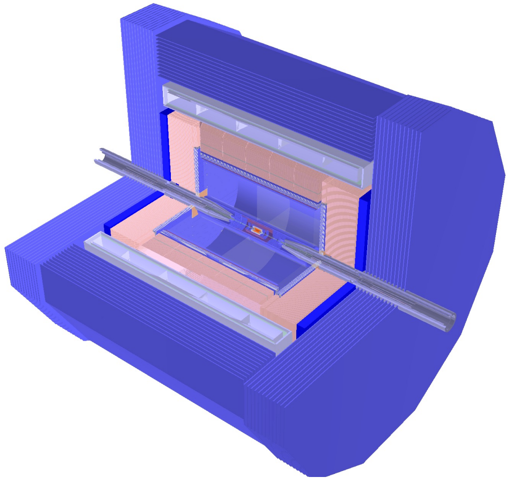
[7] Z. Li, et al., arXiv:2207.12177

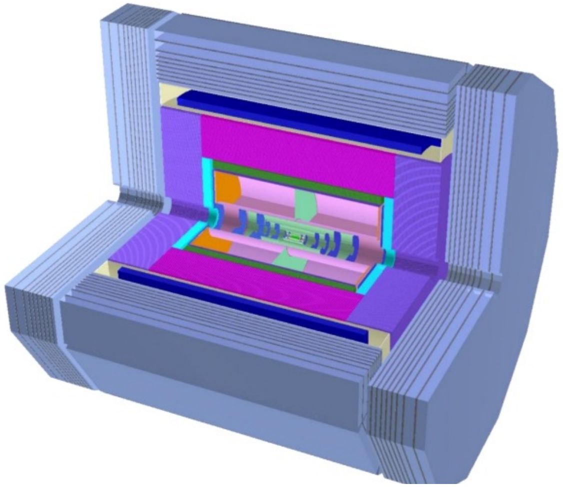
[8] Y. Wang, et al., PHYSICAL REVIEW D 105, 114036 (2022)

[9] T. Zheng, et al., Chinese Physics C Vol. 45, No. 2 (2021) 023001

[10] Y. Wang, et al., JHEP12(2022)135

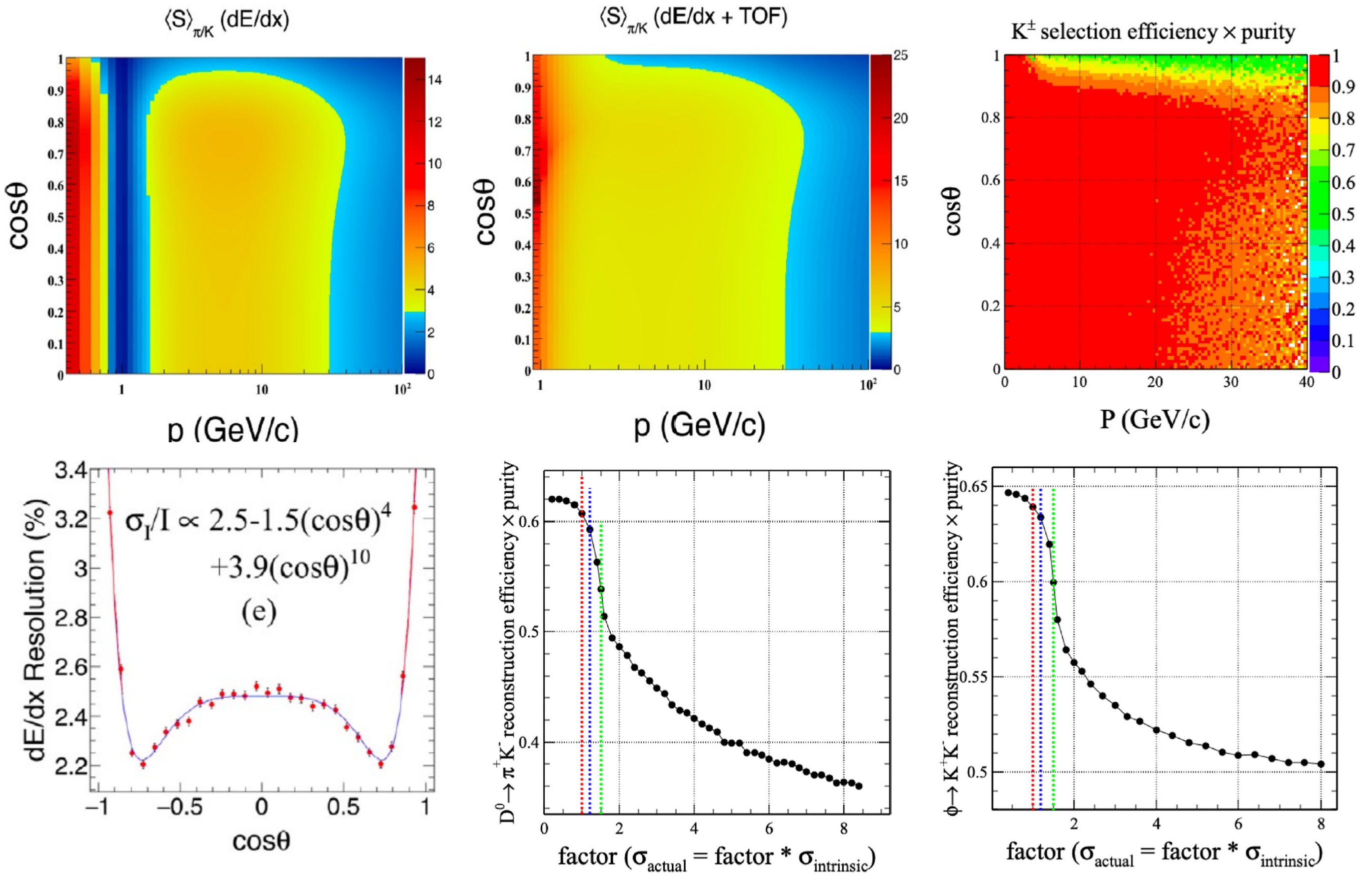
Det. Concepts: CDR to TDR

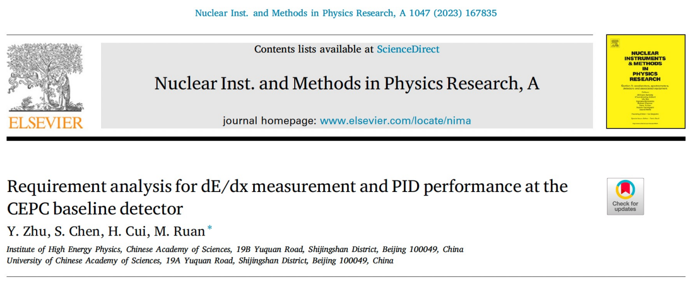




	CDR	Ref-TDR
VTX	Inner radius of 16 mm	Inner radius of 11 mm
	Material Budget: 0.15% * 6 + 0.14% (beampipe) = 1.05 X0	Material Budget: 0.06% * 4 (inner) + 0.25*2 (outer) + 0.16% (beampipe) = 0.9 X0
Main Tracker	TPC with 1 mm * 6 mm readout	TPC with 0.5 mm * 0.5 mm readout Required to have dE/dx or dN/dx 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





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

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

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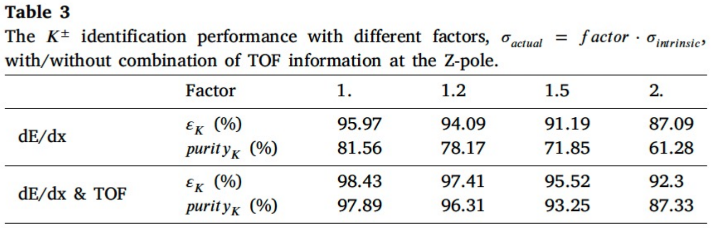


Table 3
The $K^{\pm}$ identification performance with different factors, $\sigma_{actual} = factor \cdot \sigma_{intrinsic}$, with/without combination of TOF information at the Z-pole.

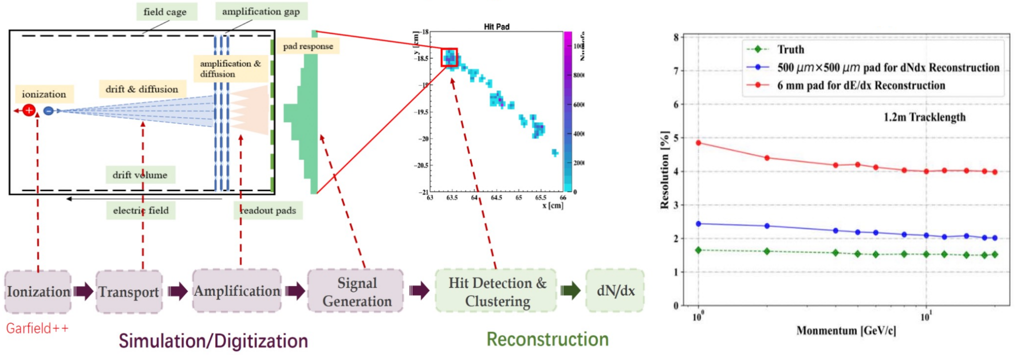
	Factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ε_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

- 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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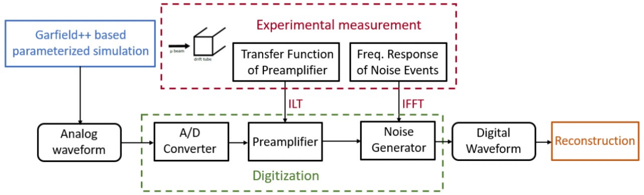
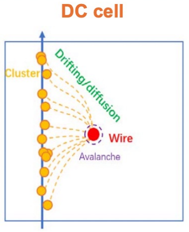
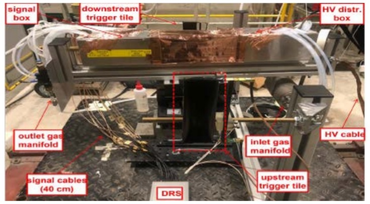
DC R&D efforts and results

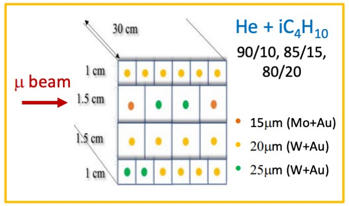
- Develop sophisticated software tools for DC PID simulation



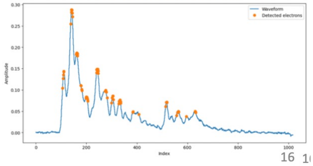


- International collaboration of the beam test





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

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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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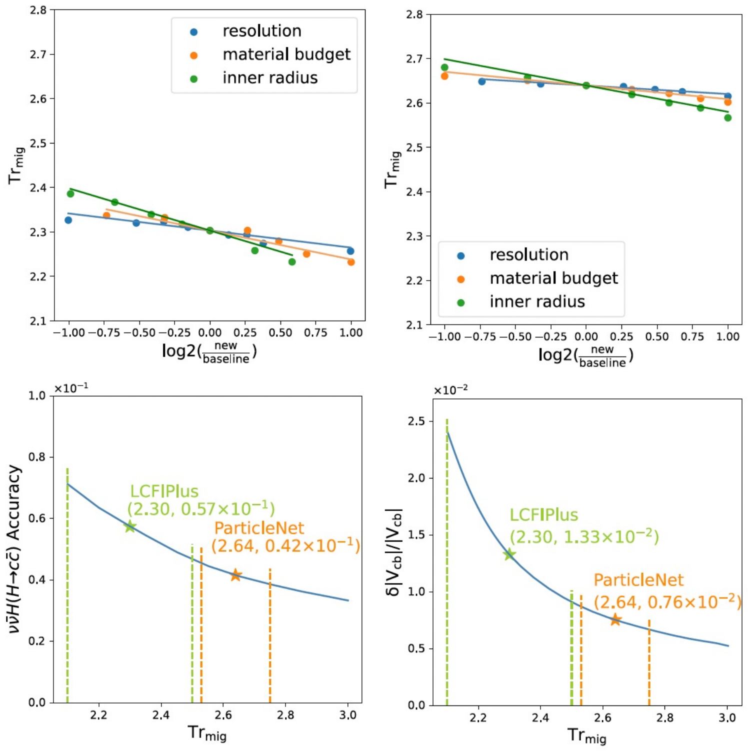
[2] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[3] University of Chinese Academy of Sciences (UCAS), Beijing 100049, China
[4] EP Department, CERN, 1211 Geneva 23, Switzerland



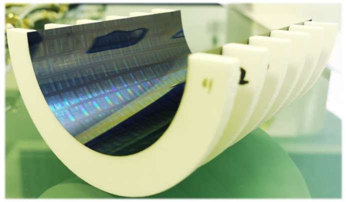
predicted

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

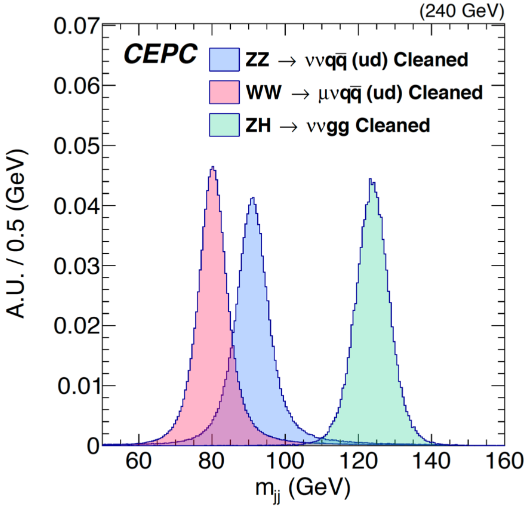
$$\mathrm{Tr}_{\mathrm{mig}} = 2.30 + 0.06 \cdot \log_2 \frac{\mathrm{R}^0_{material}}{\mathrm{R}_{material}} + 0.04 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{resolution}}}{\mathrm{R}_{\mathrm{resolution}}} + 0.10 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{radius}}}{\mathrm{R}_{\mathrm{radius}}} \tag{1}$$

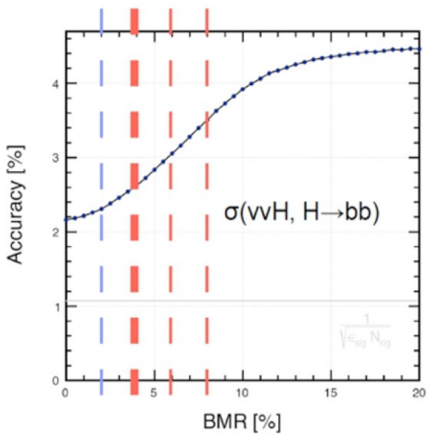
$$\mathrm{Tr}_{mig} = 2.64 + 0.03 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{material}}}{\mathrm{R}_{\mathrm{material}}} + 0.02 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{resolution}}}{\mathrm{R}_{\mathrm{resolution}}} + 0.06 \cdot \log_2 \frac{\mathrm{R}^0_{\mathrm{radius}}}{\mathrm{R}_{\mathrm{radius}}}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

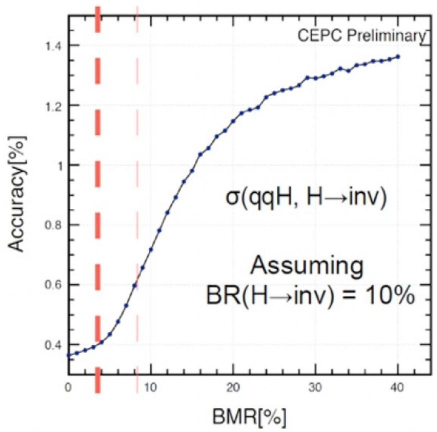
- Compared to CDR, VTX at TDR:
  - Inner radius reduced by 40% (16 mm -> 11 mm)
  - Material reduced by 10% (1.05 -> 0.9 X0)
- Tr(Mig): 2.64 -> 2.68
  - H->cc accuracy improved by ~5%
  - Vcb accuracy improved by ~10%

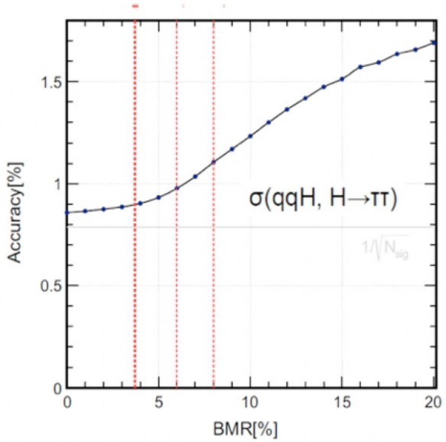


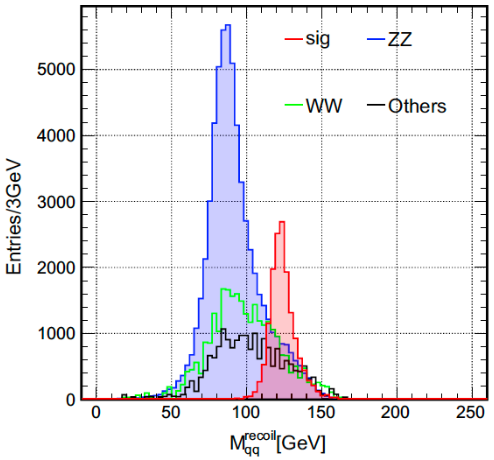
PFA Goal: BMR < 4% & pursue 3%

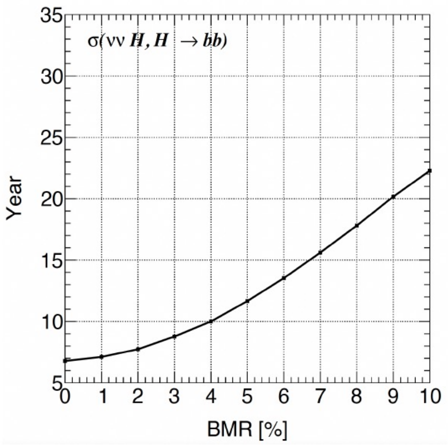


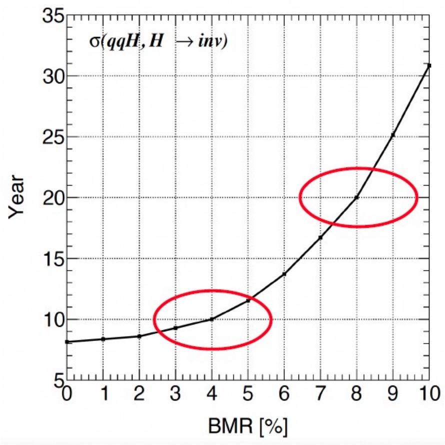


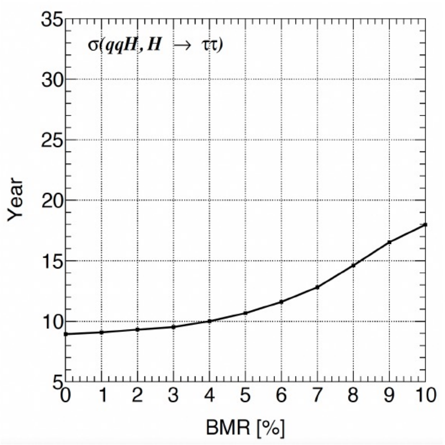




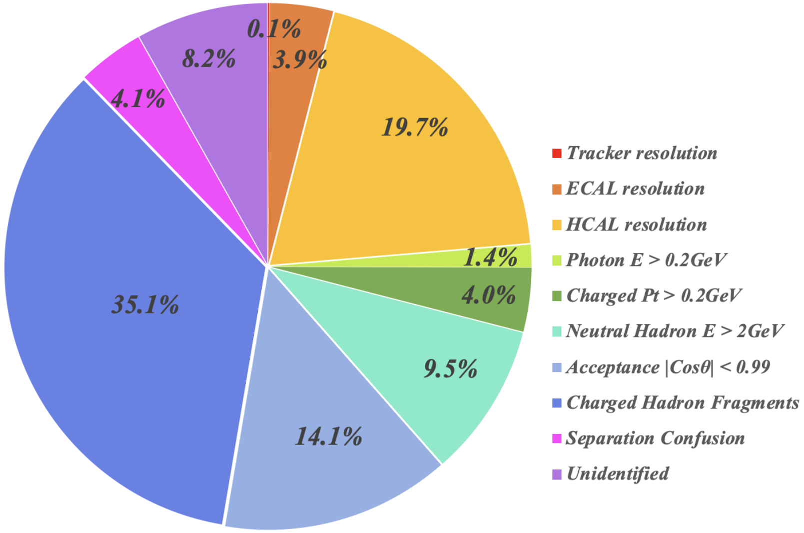


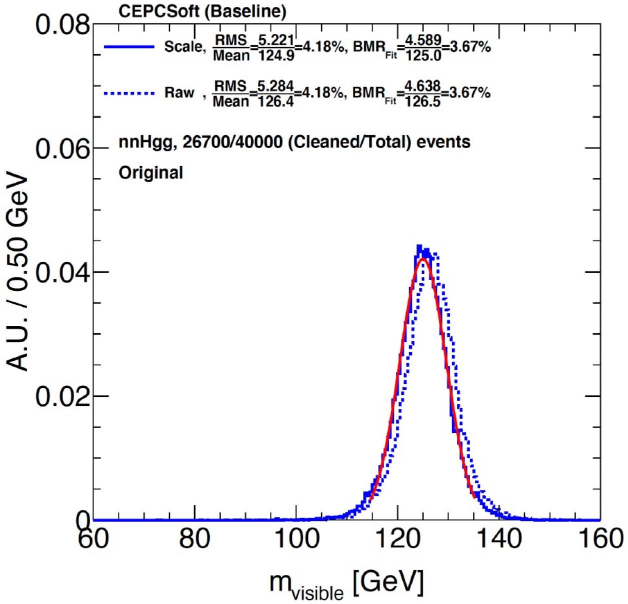


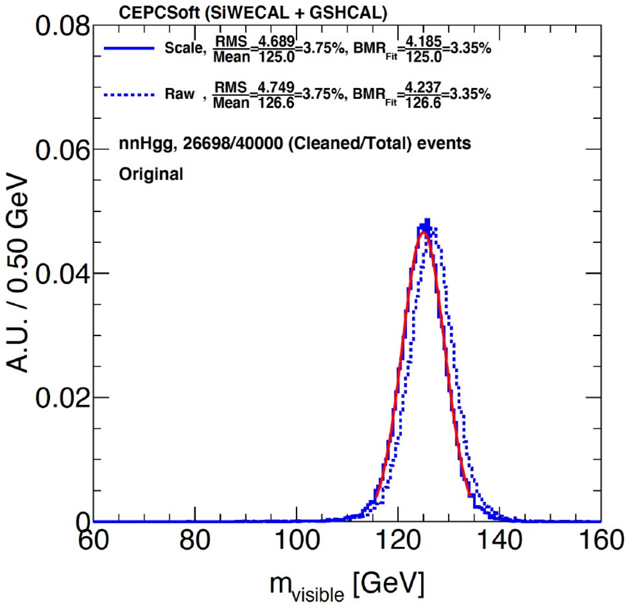




BMR Decomposition







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

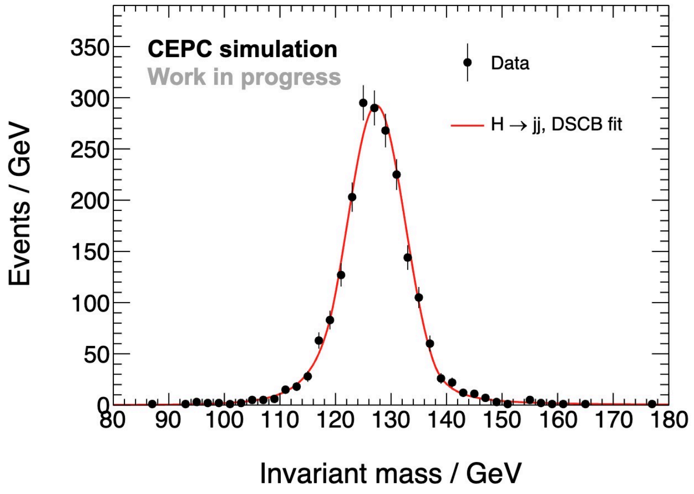
2nd, HCAL resolution dominant the uncertainties from detector resolution:

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

BMR of ~ 4% at TDR baseline

Physics performance: $H \rightarrow gg$

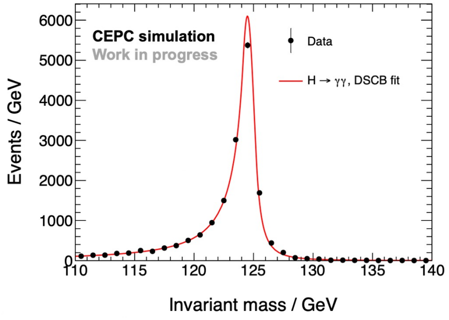
- **Physics process: $ee \rightarrow ZH \rightarrow \nu\nu gg$ in $\sqrt{s} = 240$ GeV**
  - Full reconstruction in CEPC detector: Silicon + TPC tracker, crystal ECAL, glass tile HCAL.



$m_{jj} = 127.3$ GeV, $\sigma(m_{jj}) = 5.23$ GeV

Boson mass resolution (BMR) 4.11%.

With truth track: BMR 3.73%.

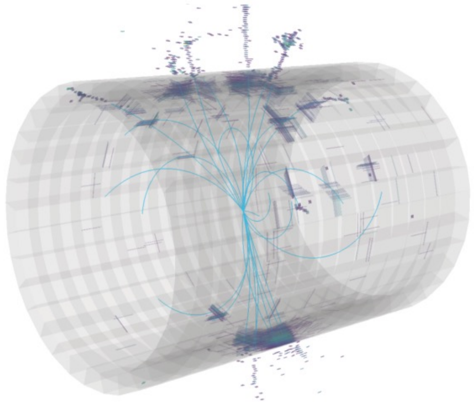


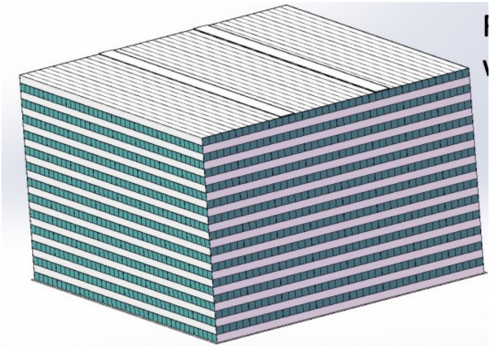
Double-side CB fit, $\sigma(m_{\gamma\gamma}) = 0.57$ GeV

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.

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	vvH @ 240 GeV	Higgs	1.7%	1.6%
H→ss [1]			95% up limit of 0.75E-3	95% up limit of 0.70E-3
H→sb [1]			95% up limit of 0.22E-3	95% up limit of 0.20E-3
H→inv [2]	qqH	Higgs/NP	95% up limit of 0.13%	Same
Vcb [3]	WW→lvqq @ 240/160 GeV	Flavor	0.4%	0.36%
W fusion Xsec [2]	vvH @ 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]	vvH + 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.

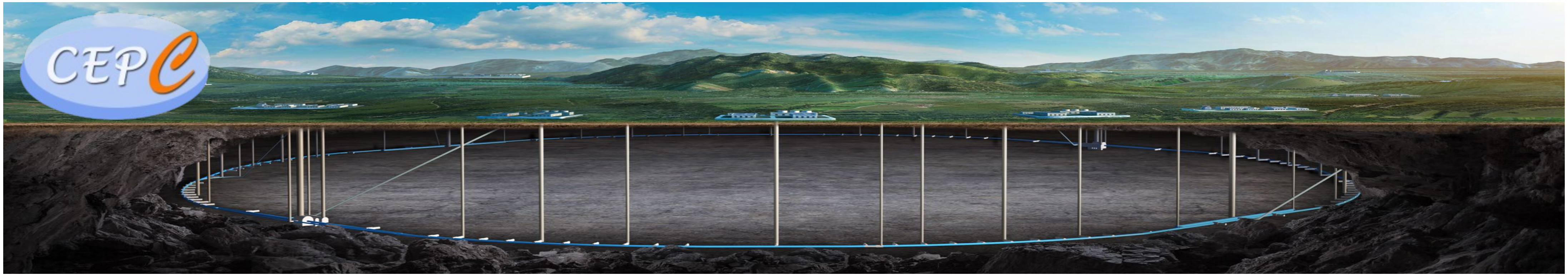
Challenges & Team

- 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.

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.

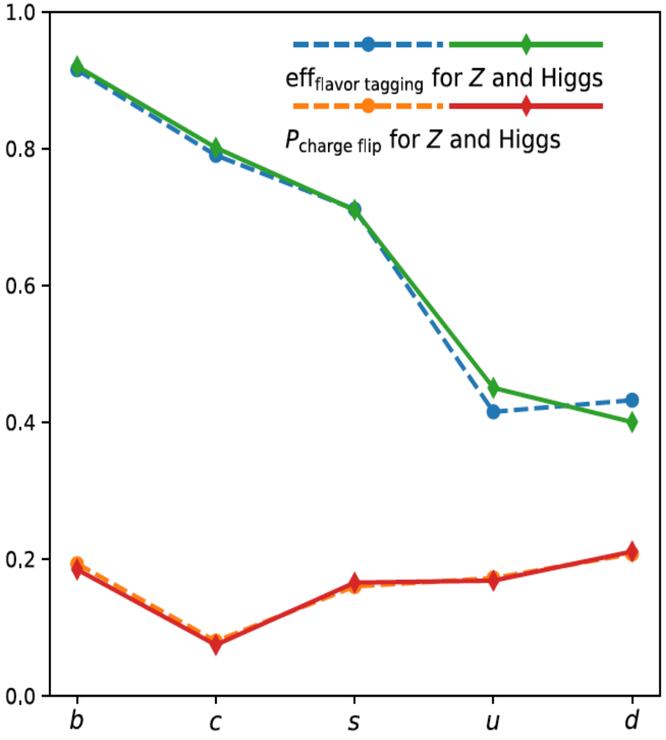


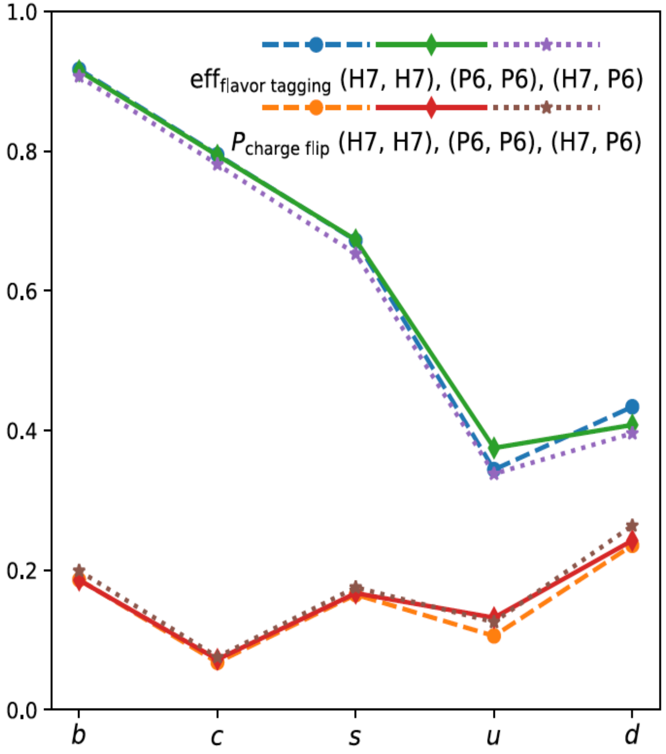
Thank you for your attention!

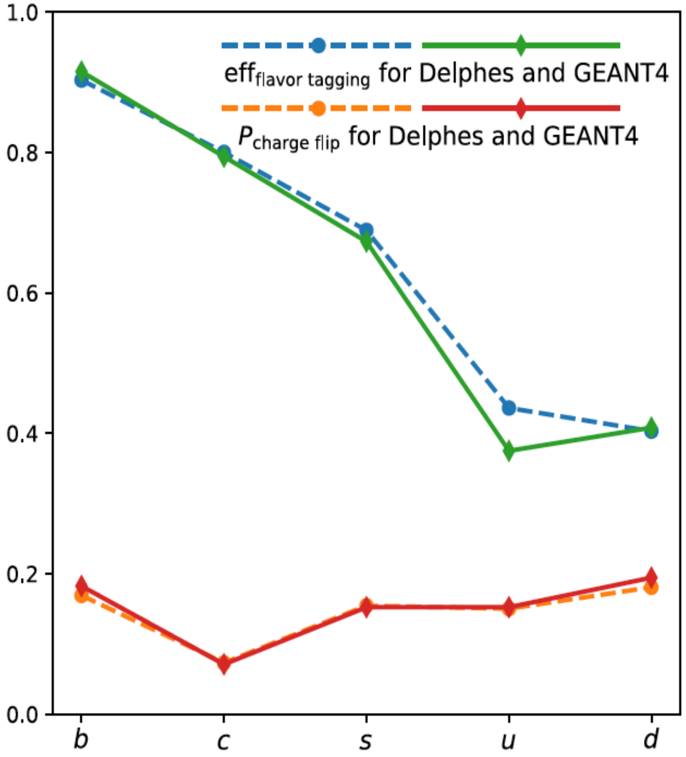
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Back Up

JOI: validation & comparison

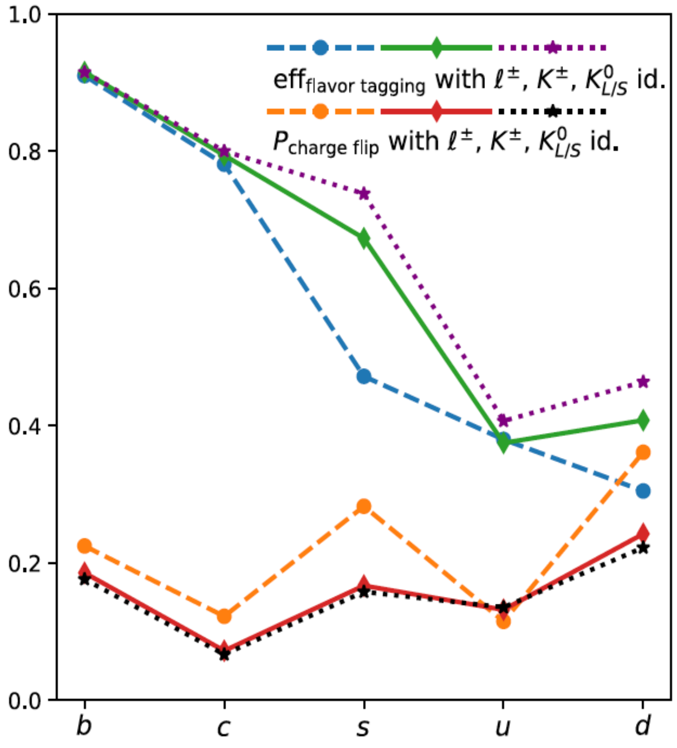


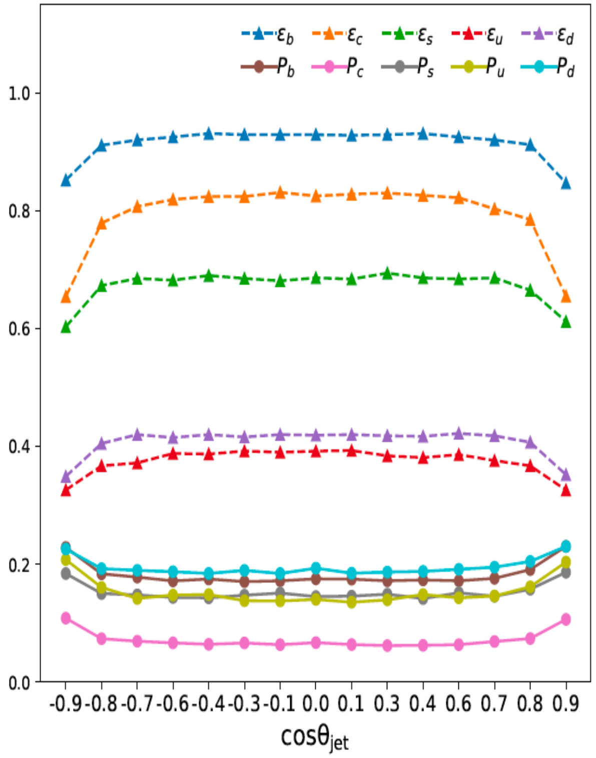


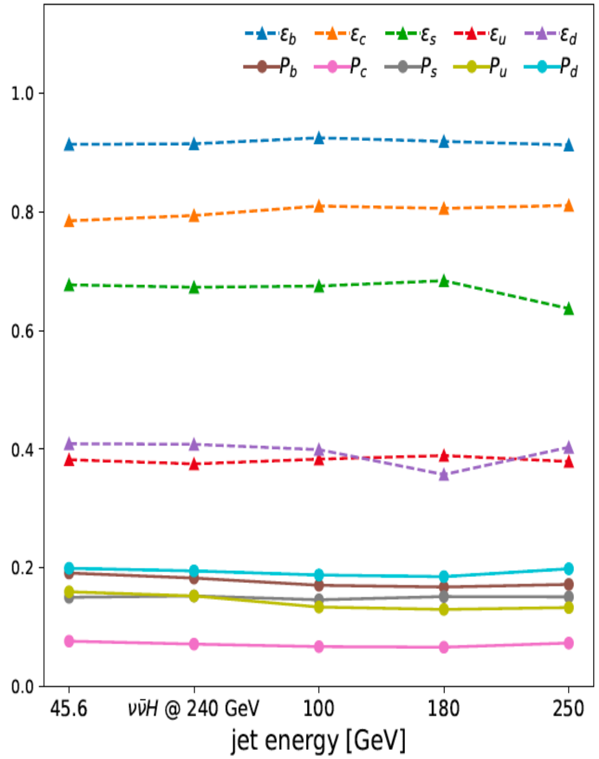


- Could be calibrated using Z->qq. (10 category id, without gluon)
- Stable at different Hadronization model, different simulation method (Geant 4 & Delphes - Fast Sim)
- *Referee: A “game changer” and opens new horizon for precise flavor studies at all future experiments*

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

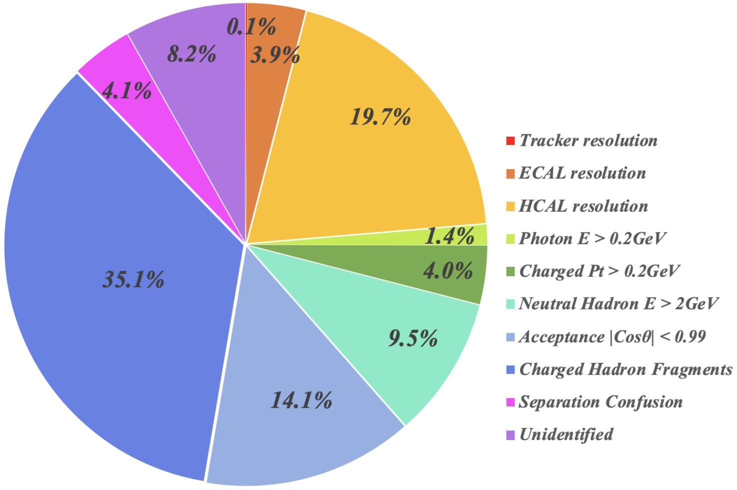
+

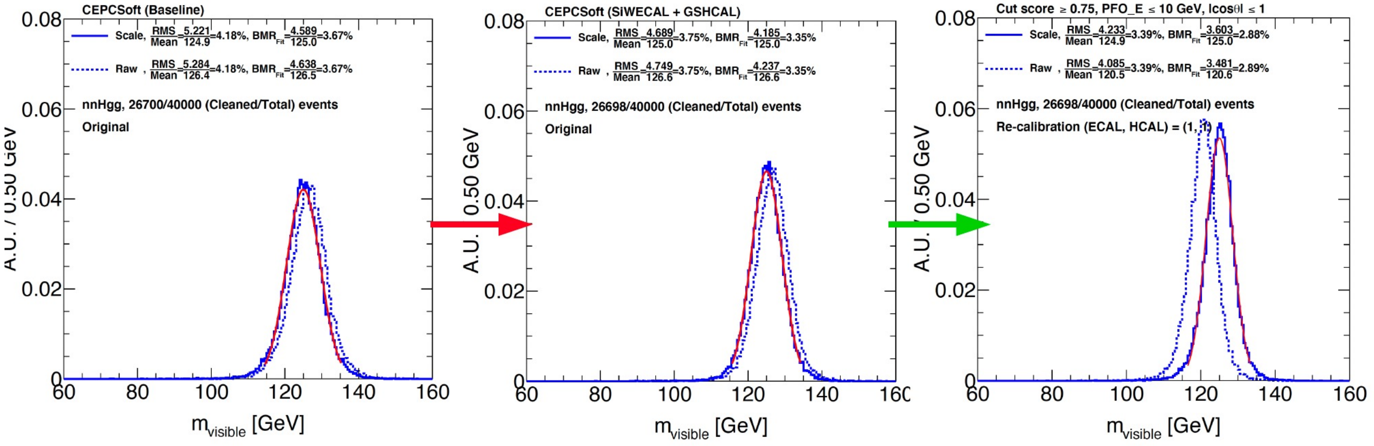
- Further Optimization (5D Calorimerter, Time resolution, cell configuration, etc)
  - To be addressed by joint study with Sub-detector & Software team (Long term plan)
  - AI enhanced reco. algorithm. will be the key.

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

BMR Decomposition



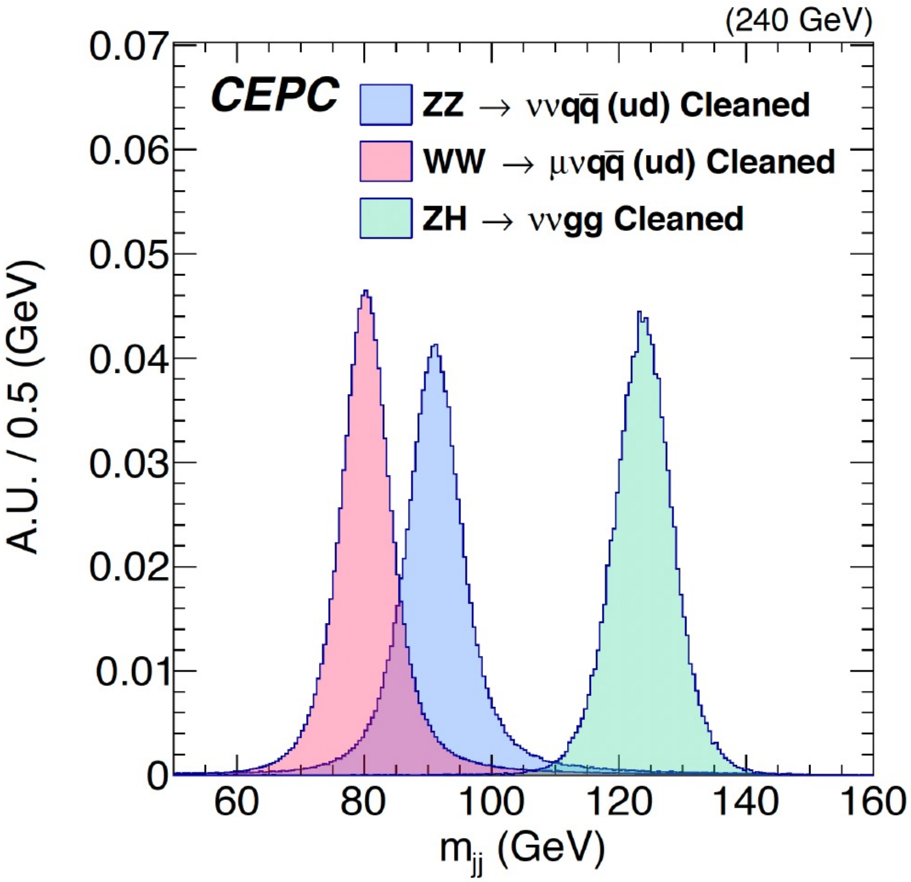


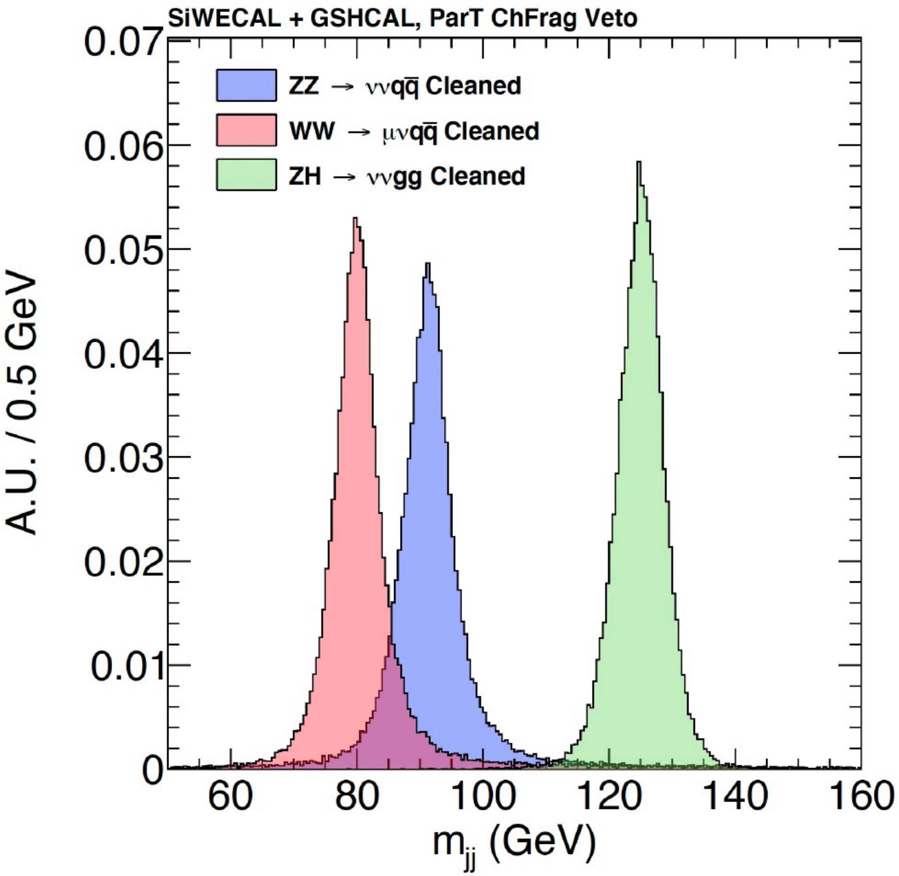
1st, 50% from Confusion, 25% from detector resolution & 25% from acceptance, for BMR of 3.7% at CDR

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%

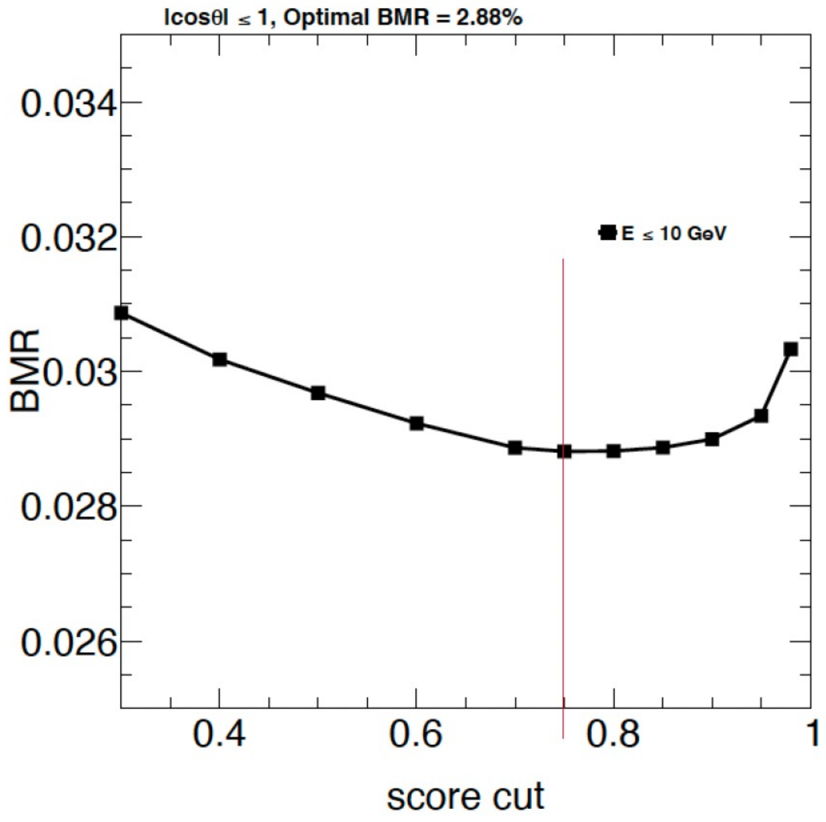
3rd, Leading contribution: Confusion from shower Fragments (fake particles), need better Pattern Reco.
Mostly can be reduced by AI enhanced Arbor at SiW ECAL + GS HCAL: BMR of 2.9%

BMR @ CDR & AURORA: 3.7% & 2.9%

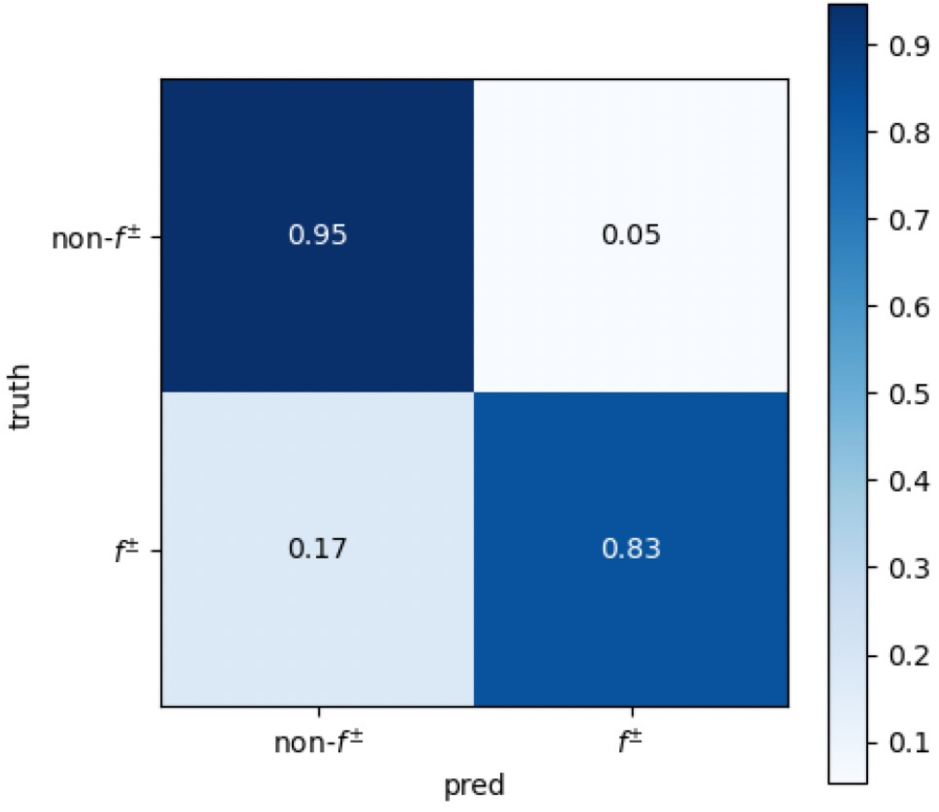




Fake particle veto using AI



(stemmed from Charge Shower Fragments)

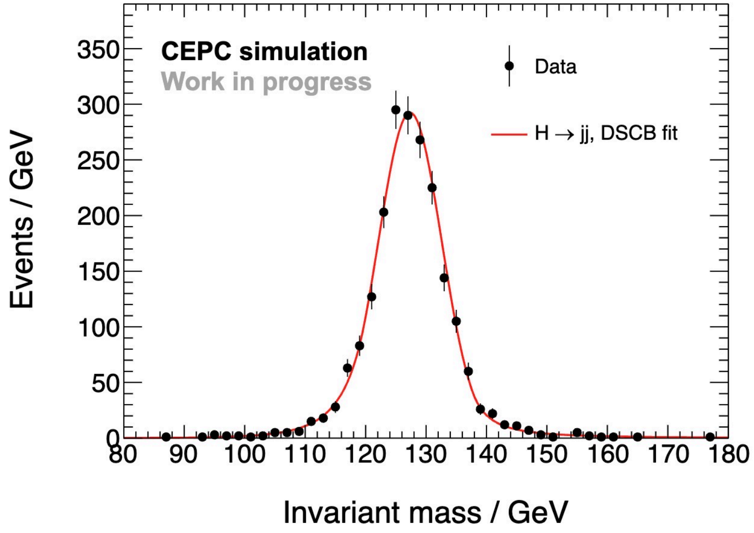


truth \ pred	non-$f^{\pm}$	$f^{\pm}$
non-$f^{\pm}$	0.95	0.05
$f^{\pm}$	0.17	0.83

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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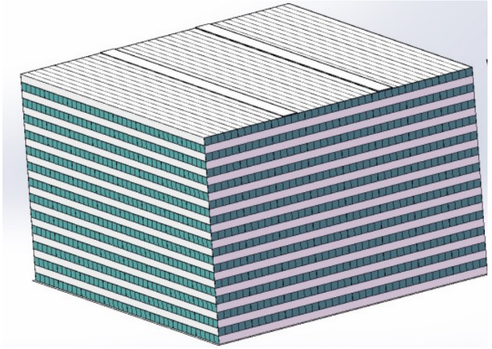
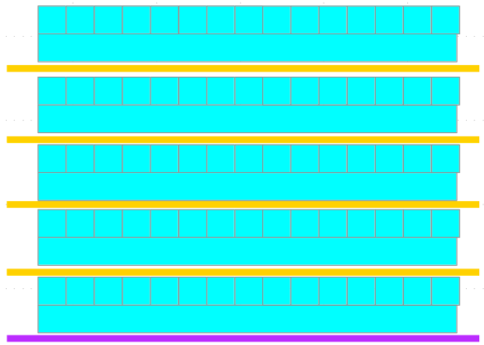
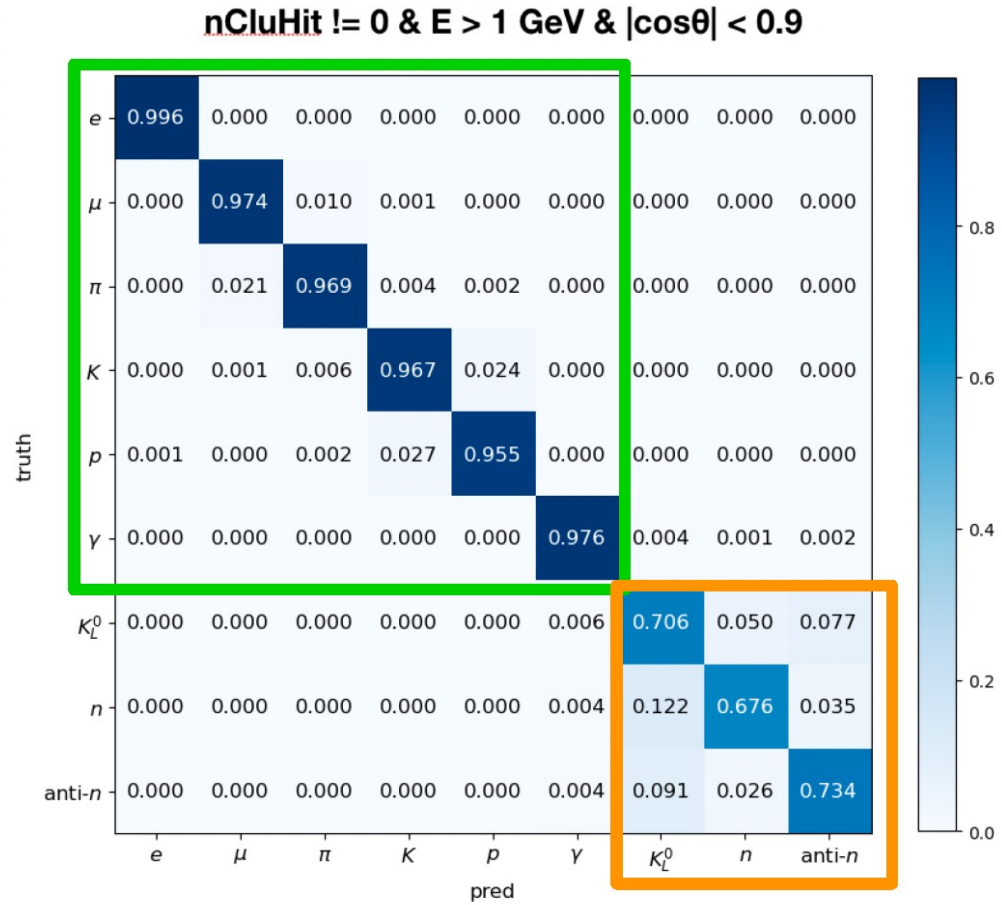


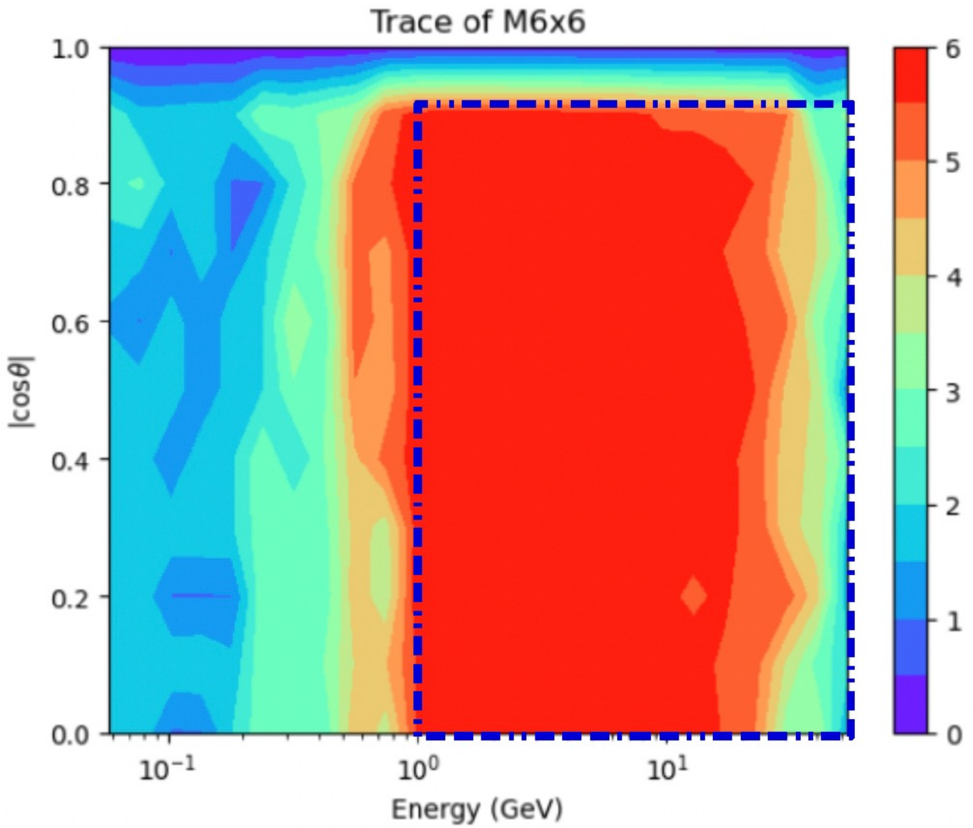


- BMR at ref-TDR: not far from CDR (BMR of 3.7%).
- To control the confusion (fake particles, etc) is the critical: Need optimization + reconstruction development.
- One solution is to add a few timing & positioning layers.

Pid of all final state particle...


nCluHit != 0 & E > 1 GeV & |cosθ| < 0.9

	e	μ	π	K	p	γ	K_L^0	n	anti-n
e	0.996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
μ	0.000	0.974	0.010	0.001	0.000	0.000	0.000	0.000	0.000
π	0.000	0.021	0.969	0.004	0.002	0.000	0.000	0.000	0.000
K	0.000	0.001	0.006	0.967	0.024	0.000	0.000	0.000	0.000
p	0.001	0.000	0.002	0.027	0.955	0.000	0.000	0.000	0.000
γ	0.000	0.000	0.000	0.000	0.000	0.976	0.004	0.001	0.002
K_L^0	0.000	0.000	0.000	0.000	0.000	0.006	0.706	0.050	0.077
n	0.000	0.000	0.000	0.000	0.000	0.004	0.122	0.676	0.035
anti-n	0.000	0.000	0.000	0.000	0.000	0.004	0.091	0.026	0.734

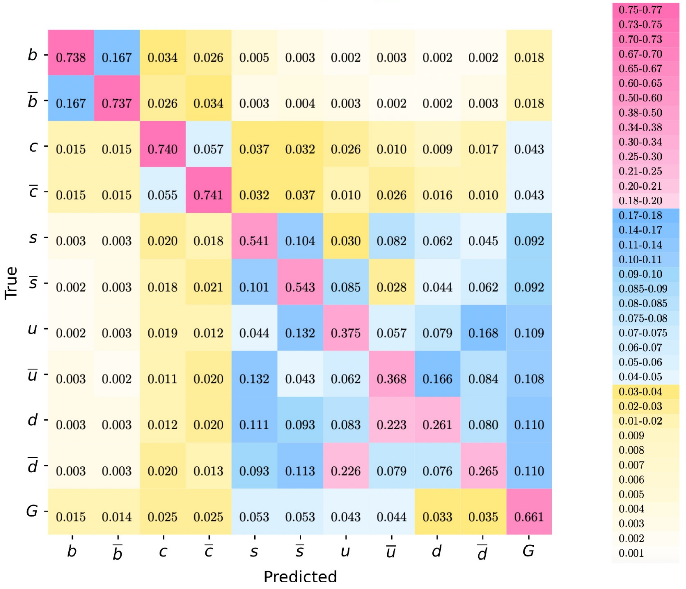


At vvH, H->gg events @ 240 GeV, Using AURORA, No TPC dE/dx Digitization.

Impact on JoI

M11 2

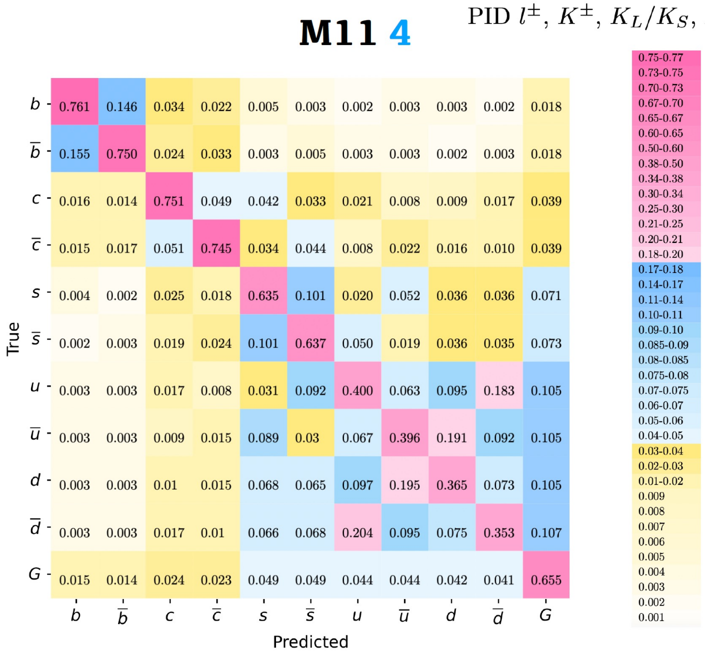
PID $l^{\pm}$, $K^{\pm}$



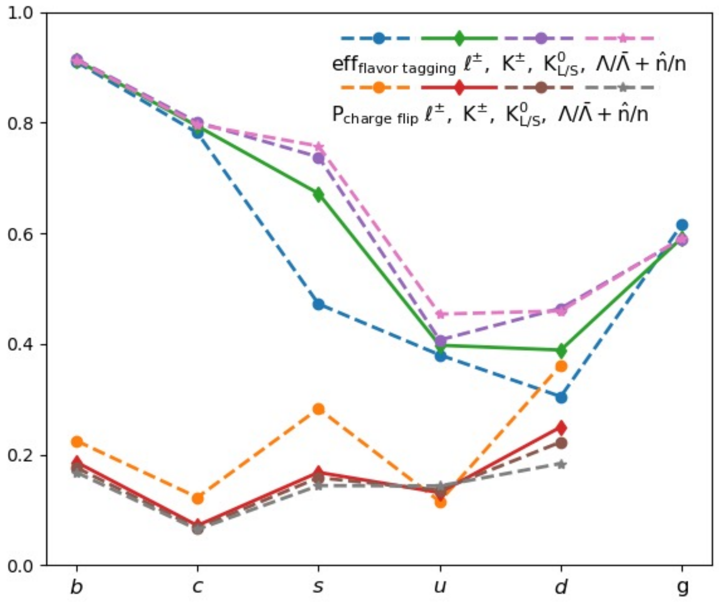
True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$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

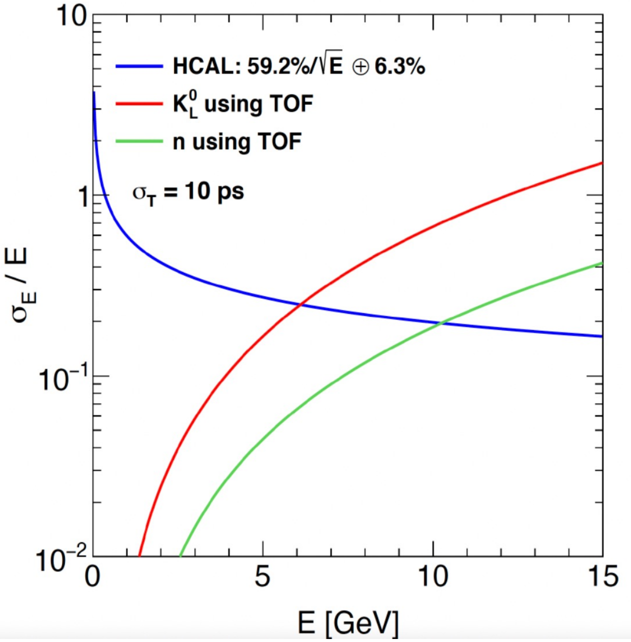
PID $l^{\pm}$, $K^{\pm}$, K_L/K_S, $\Lambda/\bar{\Lambda}$, $n/\bar{n}$

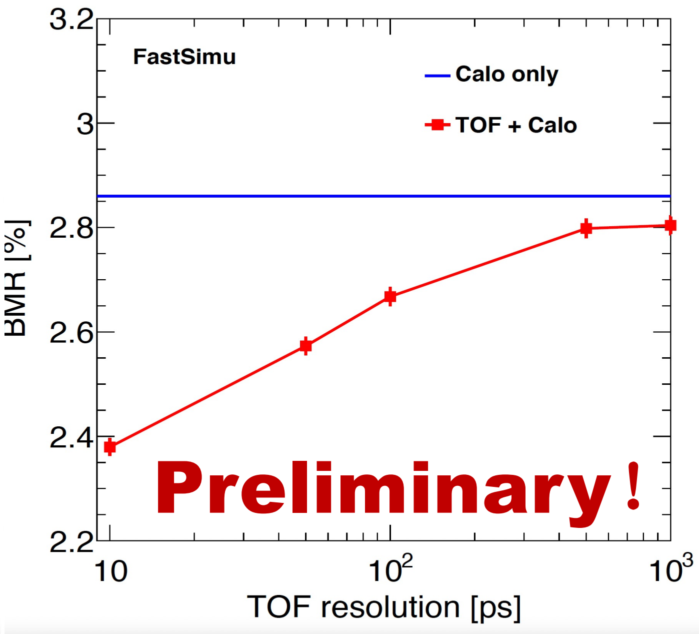


True \ Predicted	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.761	0.146	0.034	0.022	0.005	0.003	0.002	0.003	0.003	0.002	0.018
$\bar{b}$	0.155	0.750	0.024	0.033	0.003	0.005	0.003	0.003	0.002	0.003	0.018
c	0.016	0.014	0.751	0.049	0.042	0.033	0.021	0.008	0.009	0.017	0.039
$\bar{c}$	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



BMR with perfect Neutral hadron id

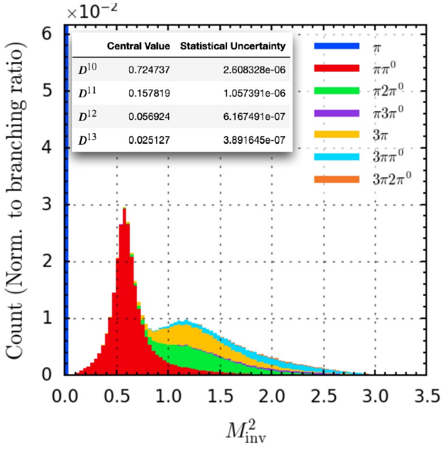




	Charged	Neutral
Non-PFA	Calorimeter	
PFA	Track + Calo (Calo for Pid & Energy matching)	Calorimeter
Future (1-1)	Track + Calo with Time (ToF)	Calo with Time (5D Calo.)

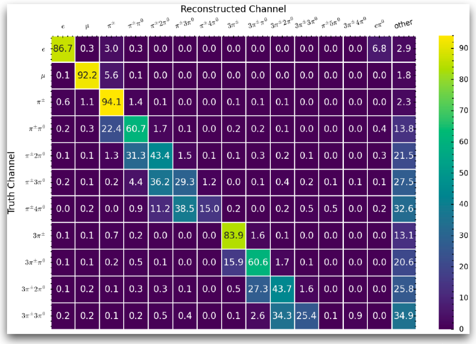
- 5D Calorimeter is essential for
  - Pid, including neutral hadron (~ o(10 ps))
  - PFA Confusion id & Control (~ ns)
  - Event Overlap at Z pole (~ ns)

Physics benchmarks: alpha-s



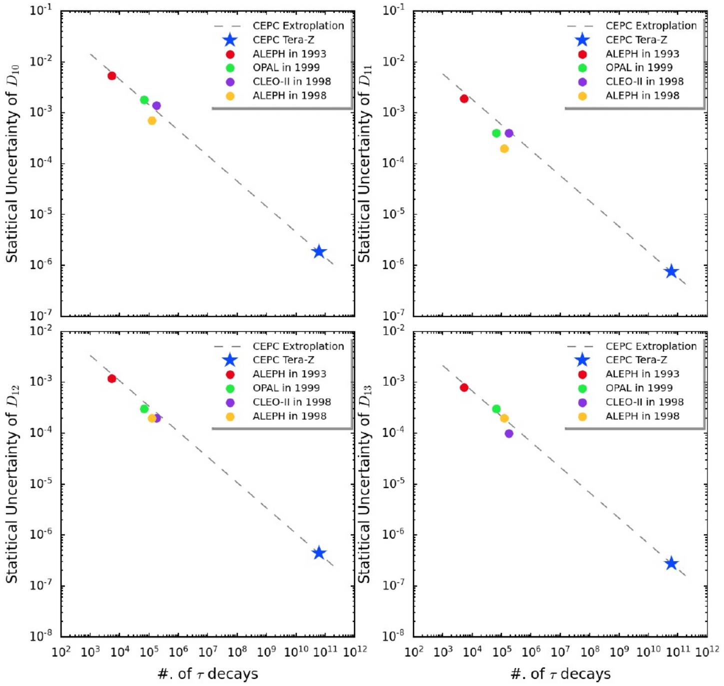
	Central Value	Statistical Uncertainty
D^{10}	0.724737	2.608328e-06
D^{11}	0.157819	1.057391e-06
D^{12}	0.056924	6.167491e-07
D^{13}	0.025127	3.891645e-07

Inclusive $M^2_{\rm inv}$ spectrum merged from exclusive ture $M^2_{\rm inv}$ spectra by associated branching ratio.



	e	μ	$\pi^\pm$	$\pi^\pm\pi^0$	$\pi^\pm 2\pi^0$	$\pi^\pm 3\pi^0$	$\pi^\pm 4\pi^0$	$3\pi^\pm$	$3\pi^\pm\pi^0$	$3\pi^\pm 2\pi^0$	$3\pi^\pm 3\pi^0$	$\pi^\pm 5\pi^0$	$3\pi^\pm 4\pi^0$	$e\pi^0$	other
e	86.7	0.3	3.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	2.9
μ	0.1	92.2	5.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
$\pi^\pm$	0.6	1.1	94.1	1.4	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	2.3
$\pi^\pm\pi^0$	0.2	0.3	22.4	60.7	1.7	0.1	0.0	0.2	0.2	0.1	0.0	0.0	0.0	0.4	13.8
$\pi^\pm 2\pi^0$	0.1	0.1	1.3	31.3	43.4	1.5	0.1	0.1	0.3	0.2	0.1	0.0	0.0	0.3	21.5
$\pi^\pm 3\pi^0$	0.2	0.1	0.2	4.4	36.2	29.3	1.2	0.0	0.1	0.4	0.2	0.1	0.1	0.1	27.5
$\pi^\pm 4\pi^0$	0.0	0.2	0.0	0.9	11.2	38.5	15.0	0.2	0.0	0.2	0.5	0.5	0.0	0.2	32.6
$3\pi^\pm$	0.1	0.1	0.7	0.2	0.0	0.0	0.0	83.9	1.6	0.1	0.0	0.0	0.0	0.0	13.1
$3\pi^\pm\pi^0$	0.1	0.1	0.2	0.5	0.1	0.0	0.0	15.9	60.6	1.7	0.1	0.0	0.0	0.0	20.6
$3\pi^\pm 2\pi^0$	0.1	0.2	0.1	0.3	0.3	0.1	0.0	0.5	27.3	43.7	1.6	0.0	0.0	0.0	25.8
$3\pi^\pm 3\pi^0$	0.2	0.2	0.1	0.2	0.5	0.4	0.0	0.1	2.6	34.3	25.4	0.1	0.9	0.0	34.9

Confusion matrix of leptonic and pionic τ decay modes. The migration chance are normalized to truth channel.



Extracting α_S at future e^+e^- Higgs factory with energy correlators

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ABSTRACT: The prospected sensitivity in α_S determination using an event shape observable, ratio of energy correlators at future electron-positron collider is presented. The study focuses on the collinear region which has suffered from large theoretical and hadronization uncertainty in the past. The ratio effectively reduces the impacts of the uncertainties. With the amount of data that future electron-positron collider could produce in 1 minute (40 pb^{-1}) and 0.5 hour (1 fb^{-1}), a 1% and 0.2% precision of α_S could be reached.

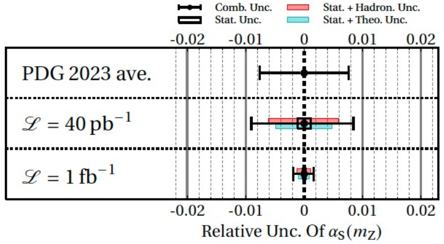
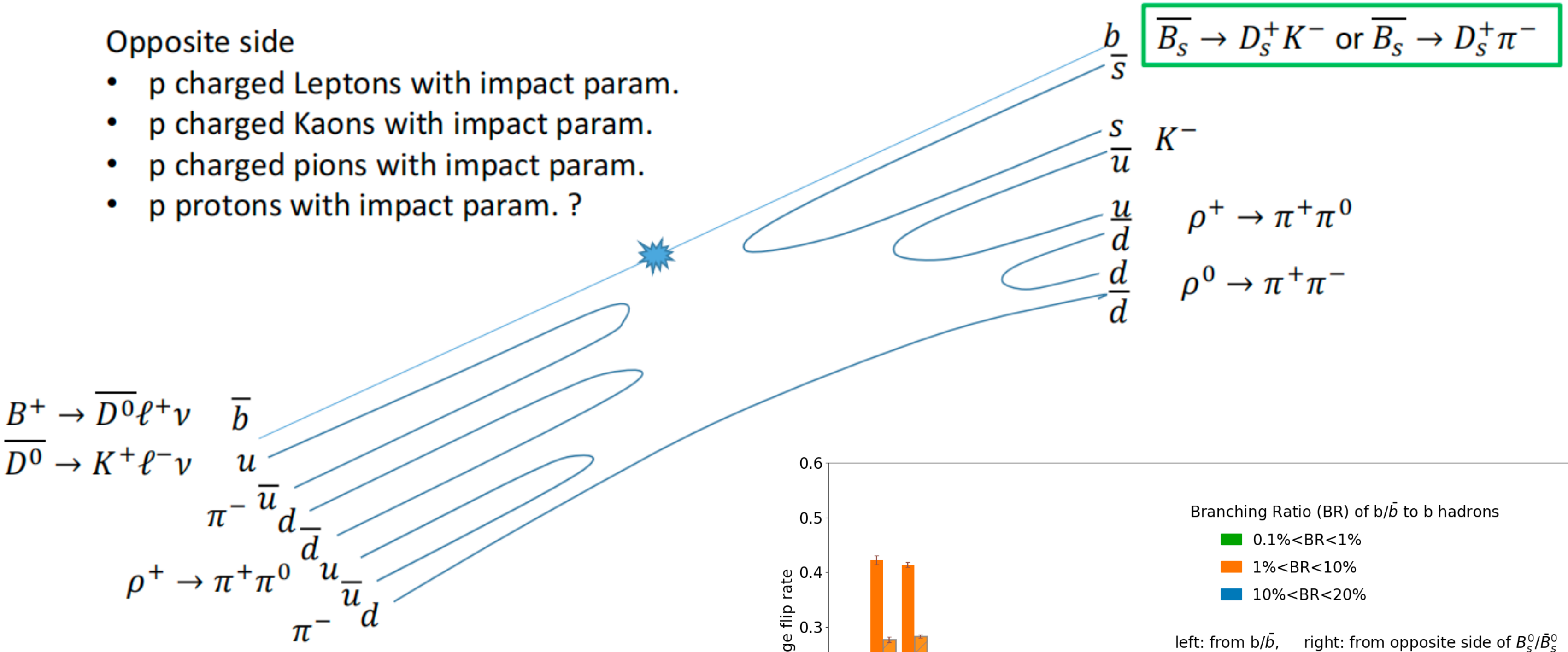


Figure 3: The expected sensitivity to $\alpha_S(m_Z)$ using E3C/E2C at CEPC in different luminosity scenarios. The world average precision for α_S extraction is shown for a comparison [1]. The breakdown of statistical, hadronization, and theoretical uncertainties is shown.

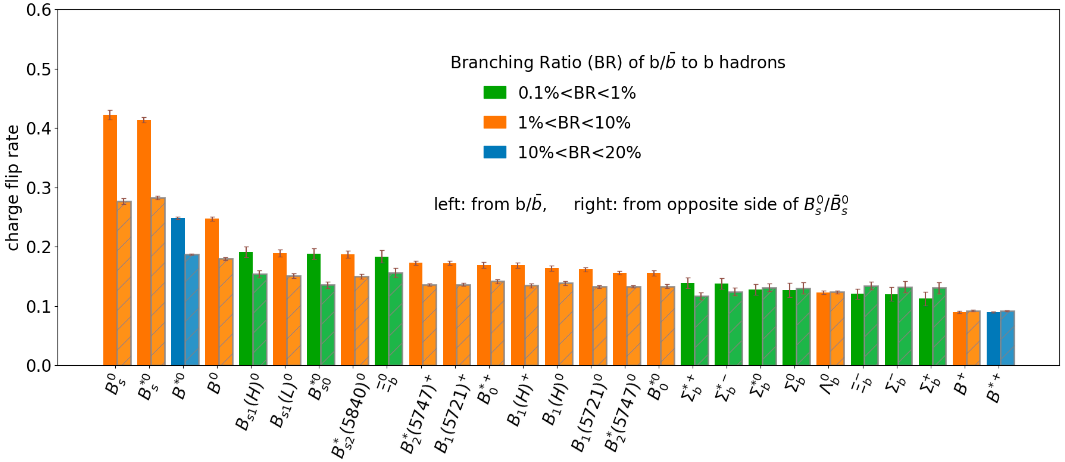
Physics benchmarks: Bs oscillation

Opposite side

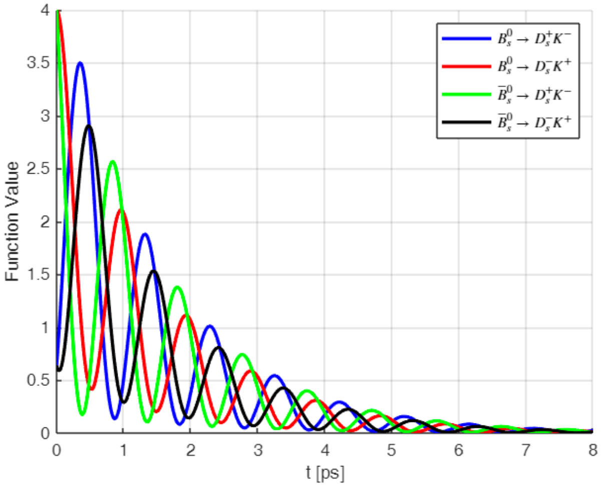
- p charged Leptons with impact param.
- p charged Kaons with impact param.
- p charged pions with impact param.
- p protons with impact param. ?

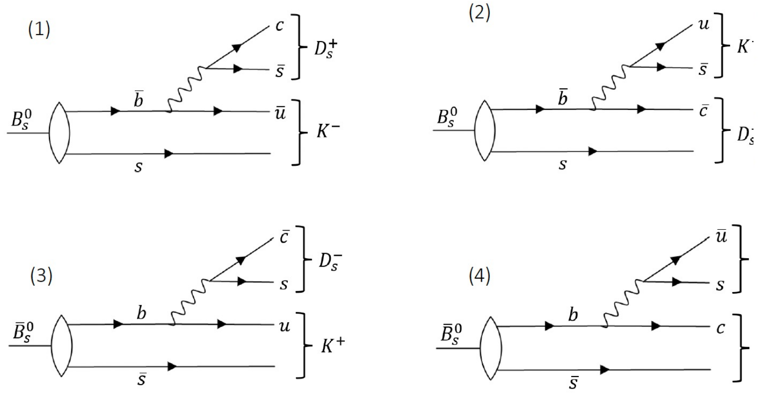


Effective tagging power (eff*(1-2*ω)^2) ~ 40%, one order of magnitude better than LHCb



Physics benchmarks: Bs oscillation





$$P_{++} \propto e^{-\Gamma t}\left(\cosh\left(\frac{\Delta\Gamma}{2}t\right) - C\cos(\Delta m t) + D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma}{2}t\right) - S_{\bar{f}}\sin(\Delta m t)\right) \quad (19)$$

$$P_{+-} \propto e^{-\Gamma t}\left(\cosh\left(\frac{\Delta\Gamma}{2}t\right) + C\cos(\Delta m t) + D_{f}\sinh\left(\frac{\Delta\Gamma}{2}t\right) - S_{f}\sin(\Delta m t)\right) \quad (20)$$

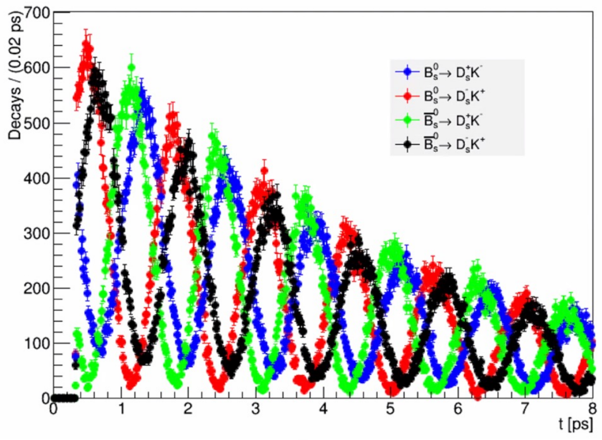
$$P_{-+} \propto e^{-\Gamma t}\left(\cosh\left(\frac{\Delta\Gamma}{2}t\right) + C\cos(\Delta m t) + D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma}{2}t\right) + S_{\bar{f}}\sin(\Delta m t)\right) \quad (21)$$

$$P_{--} \propto e^{-\Gamma t}\left(\cosh\left(\frac{\Delta\Gamma}{2}t\right) - C\cos(\Delta m t) + D_{f}\sinh\left(\frac{\Delta\Gamma}{2}t\right) + S_{f}\sin(\Delta m t)\right) \quad (22)$$

$$C = \frac{1-r^2}{1+r^2}, \quad (23)$$

$$D_f = \frac{-2r\cos(\delta-(\gamma-2\beta_s))}{1+r^2}, \qquad D_{\bar{f}} = \frac{-2r\cos(\delta+(\gamma-2\beta_s))}{1+r^2}, \quad (24)$$

$$S_f = \frac{2r\sin(\delta-(\gamma-2\beta_s))}{1+r^2}, \qquad S_{\bar{f}} = \frac{-2r\sin(\delta+(\gamma-2\beta_s))}{1+r^2}. \quad (25)$$



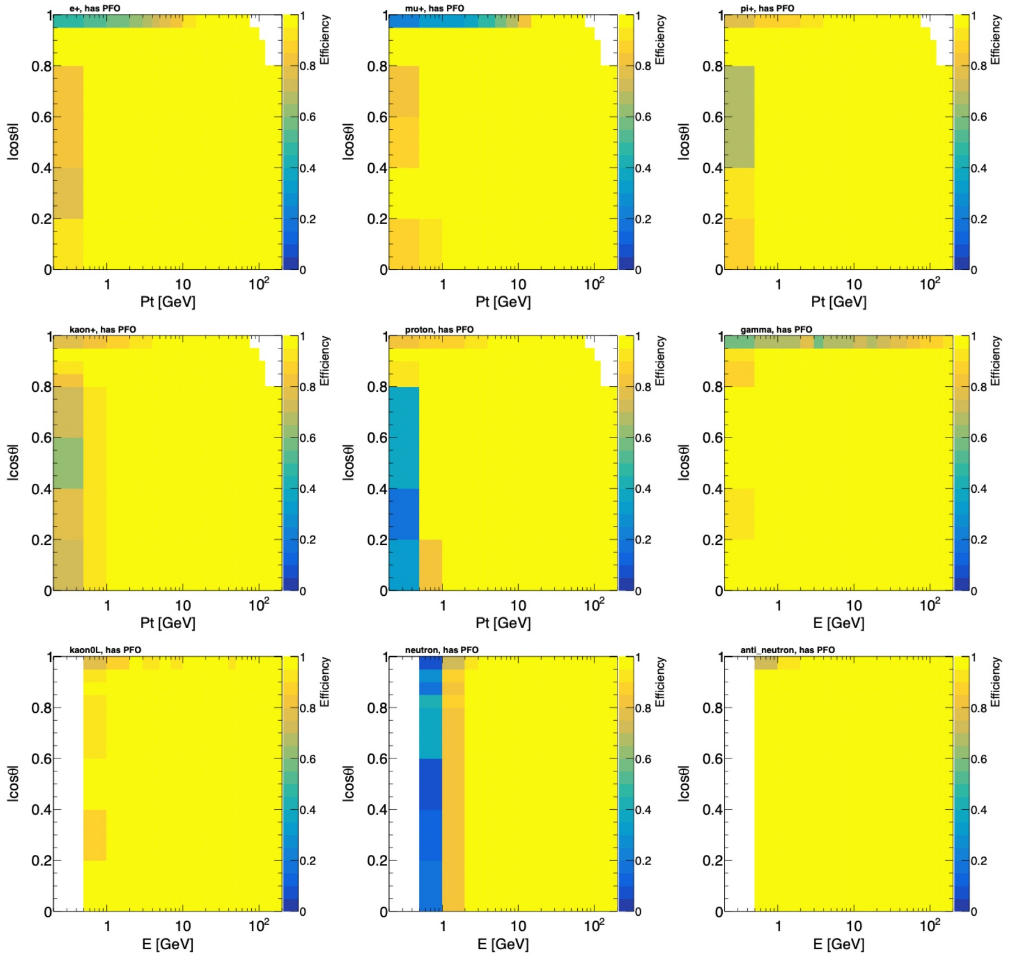
From Peng Ji (IHEP), Xiaoling Wang (SCNU), Mingrui Zhao (CIAE), etc

Preliminary Estimation based on Yield & Key Performance comparison:

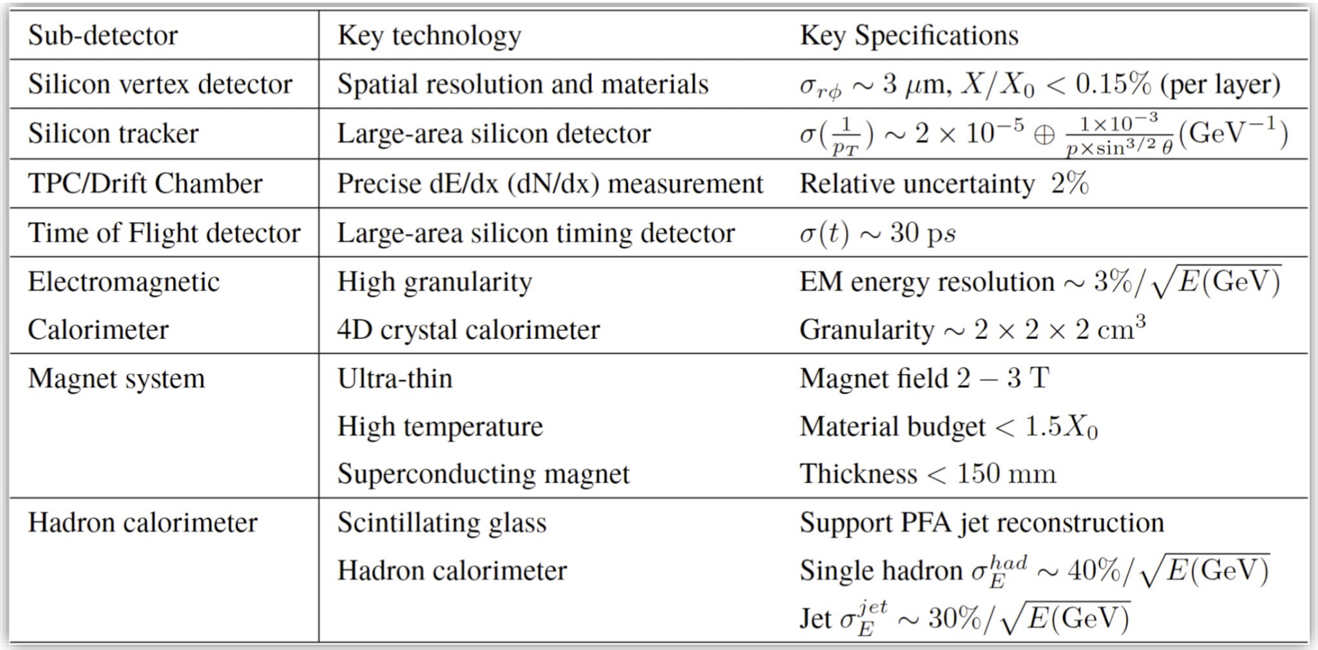
measure $\gamma - 2\beta_s$ to precision of o(0.1 degree)

~ 20 times better than current precision…
~ 4 times better than LHCb @ HL-LHC

Single Particle: differential efficiency

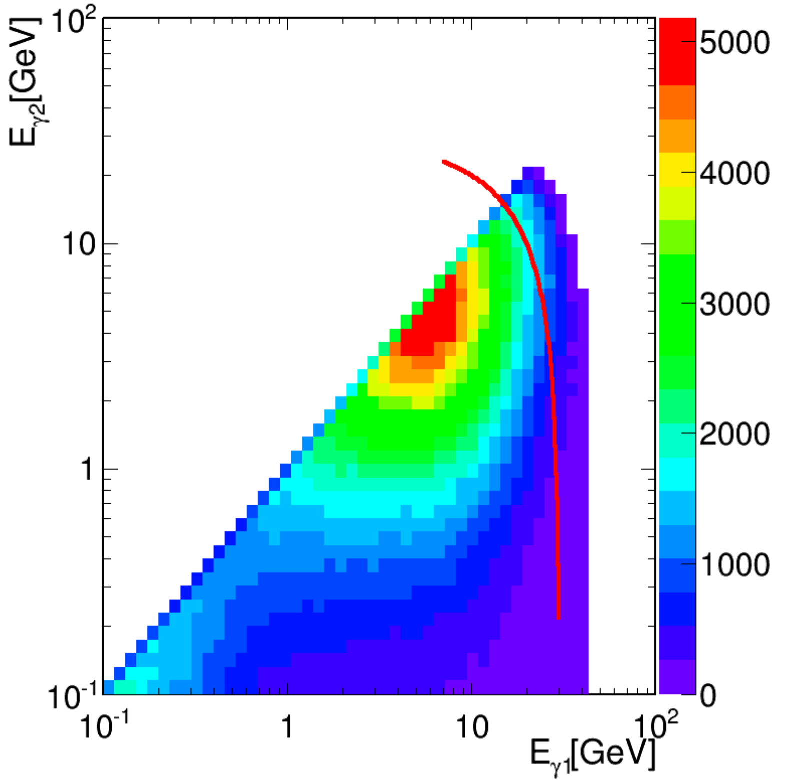


Sep. power.



Sub-detector	Key technology	Key Specifications
Silicon vertex detector	Spatial resolution and materials	$\sigma_{r\phi} \sim 3\ \mu\mathrm{m}$, $X/X_0 < 0.15\%$ (per layer)
Silicon tracker	Large-area silicon detector	$\sigma(\frac{1}{p_T}) \sim 2 \times 10^{-5} \oplus \frac{1\times10^{-3}}{p\times\sin^{3/2}\theta}(\mathrm{GeV}^{-1})$
TPC/Drift Chamber	Precise dE/dx (dN/dx) measurement	Relative uncertainty 2%
Time of Flight detector	Large-area silicon timing detector	$\sigma(t) \sim 30$ ps
Electromagnetic Calorimeter	High granularity 4D crystal calorimeter	EM energy resolution $\sim 3\%/\sqrt{E(\mathrm{GeV})}$ Granularity $\sim 2 \times 2 \times 2\ \mathrm{cm}^3$
Magnet system	Ultra-thin High temperature Superconducting magnet	Magnet field 2 – 3 T Material budget $< 1.5X_0$ Thickness < 150 mm
Hadron calorimeter	Scintillating glass Hadron calorimeter	Support PFA jet reconstruction Single hadron $\sigma_E^{had} \sim 40\%/\sqrt{E(\mathrm{GeV})}$ Jet $\sigma_E^{jet} \sim 30\%/\sqrt{E(\mathrm{GeV})}$

These specifications continue to be optimized



Pi0 energies at Z->tautau events at Z pole.

Sep power ~ 1.6 cm ~ 30 GeV Pi0

Sub D recap

- Tracking: efficiency & resolutions as a function of cos(theta) & Pt
- Calorimeter: efficiency & resolution – linearity of photon, neutral hadron
- Pid relevant: ToF, dE/dx, dN/dx, etc.