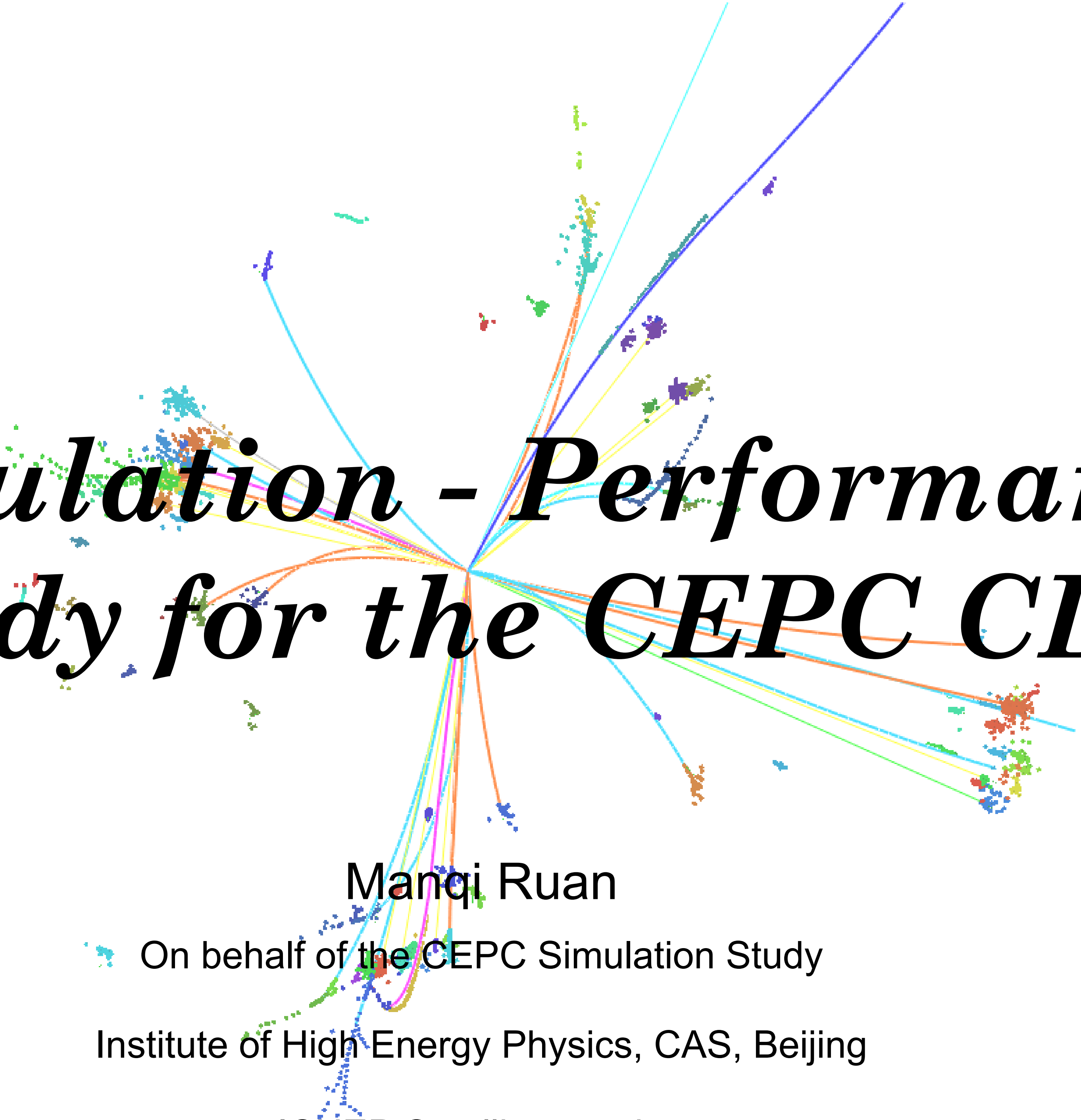


Simulation - Performance Study for the CEPC CDR

Manqi Ruan

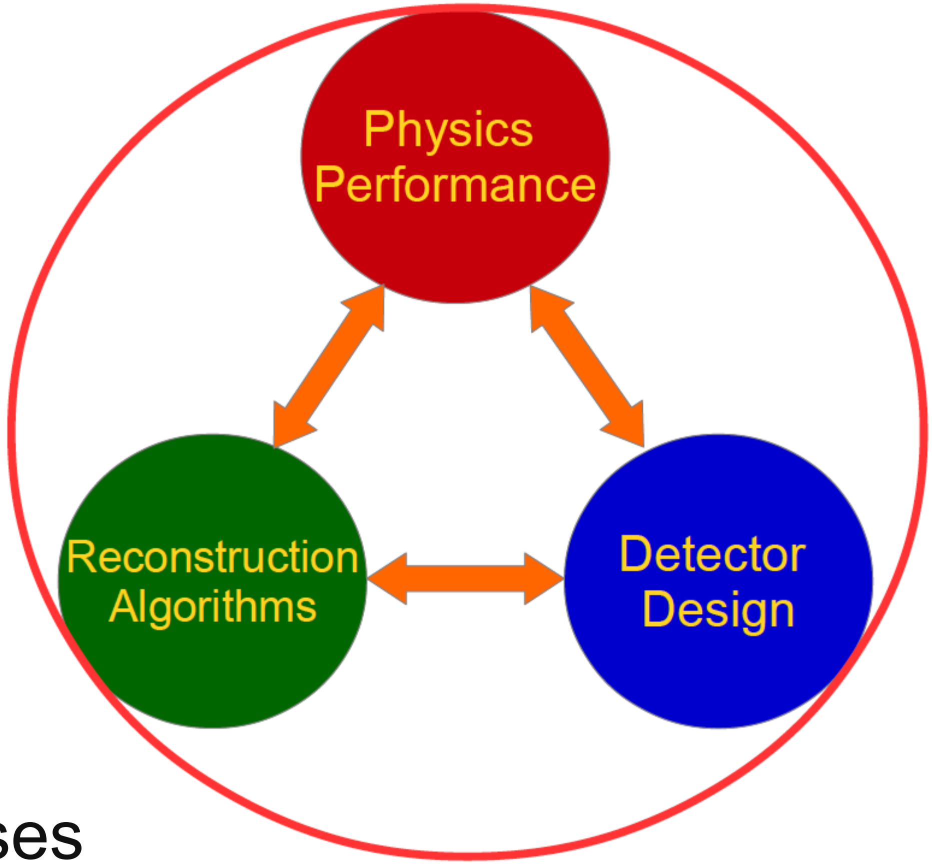
On behalf of the CEPC Simulation Study

Institute of High Energy Physics, CAS, Beijing

ICHEP Satellite meeting

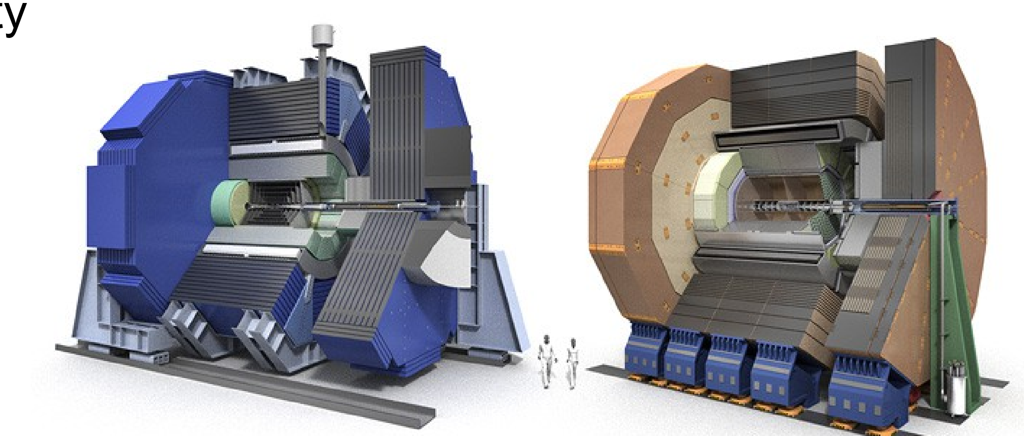
Basic ingredients

- **Performance**
  - Determined by
    - Detector geometry
    - Reconstruction algorithm
  - Characterized at
    - **Physics Objects**
    - **Higgs Signal**
    - Benchmark Physics Analyses

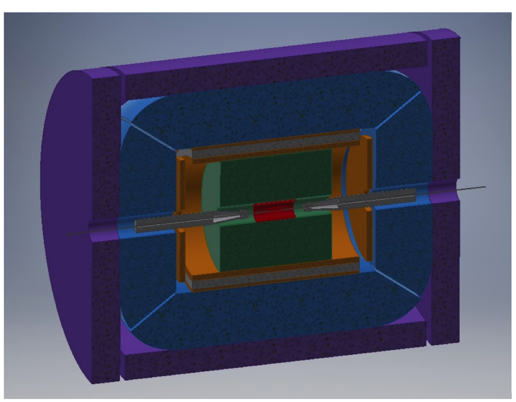


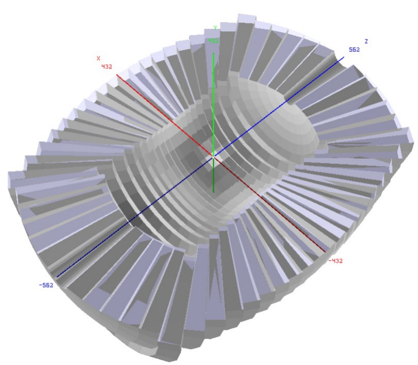
Two classes of Concepts

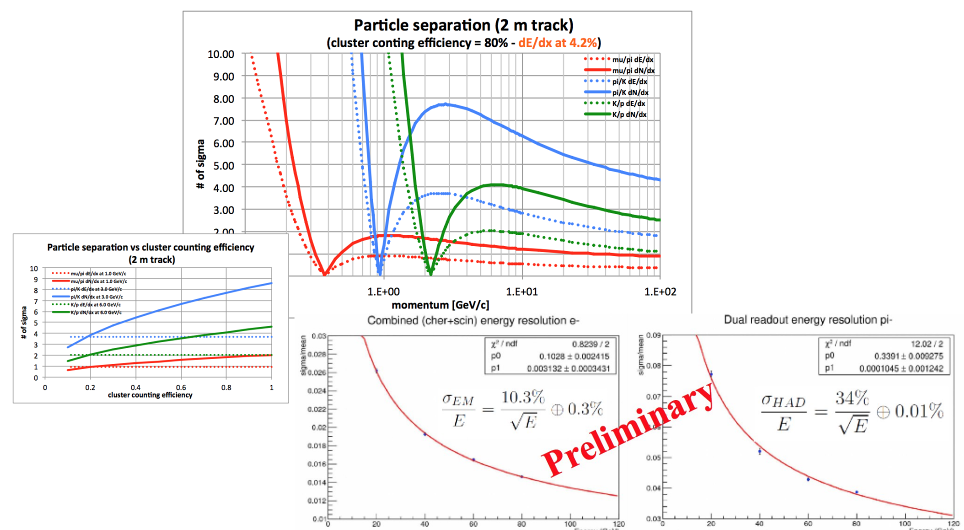
- PFA Oriented concept using High Granularity Calorimeter
  - + TPC (ILD-like, **Baseline**)
  - + Silicon tracking (SiD-like)



- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter







https://indico.ihep.ac.cn/event/6618/

https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

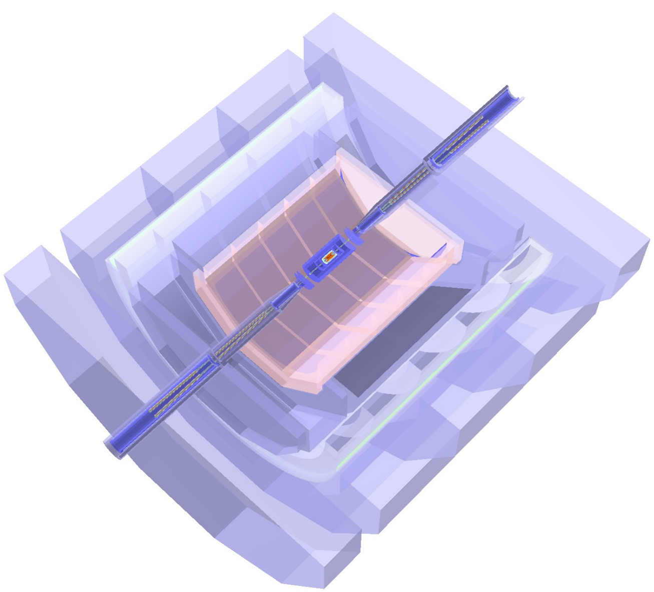
Geometry: APODIS (A PFA Oriented Detector for HIggS factory)

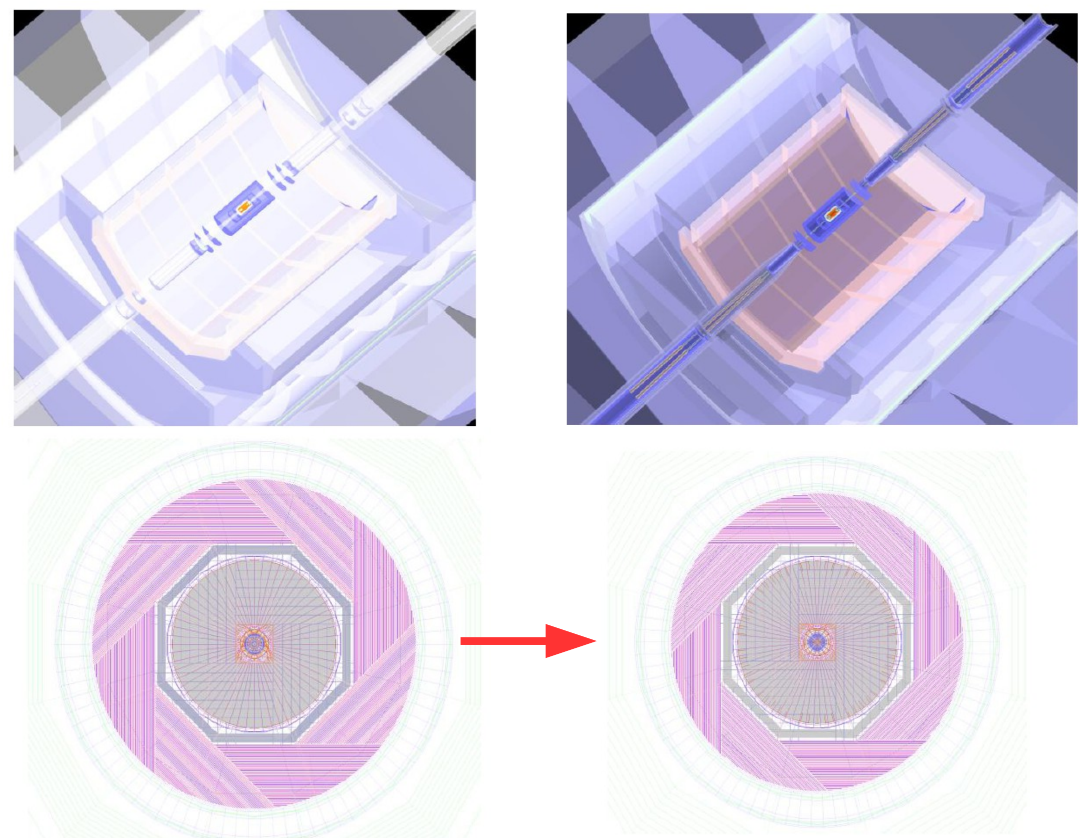
Feasibility analysis: TPC is OK for CEPC (2017 JINST 12 P07005)

	CEPC_v1 (~ ILD)	APODIS (Optimized)	Comments
Track Radius	1.8 m	>= 1.8 m	Requested by Br(H->di muon) measurement
B Field	**3.5 T**	**3 T**	**Requested by MDI**
ToF	**-**	**50 ps**	**Requested by pi-Kaon separation at Z pole**
ECAL Thickness	84 mm	84(90) mm	Optimized on Br(H->di photon) at 250 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm is required for EW measurements
ECAL NLayer	30	30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs mass resolution with jet final states

APODIS

- Operational at CEPC Collision environment & Geometry parameter Optimized
- Significantly reduced Cost/Energy Consumption
  - ECAL power: 75 - 80%
  - Yoke weight: 60 -70%
  - Construction cost: 30%

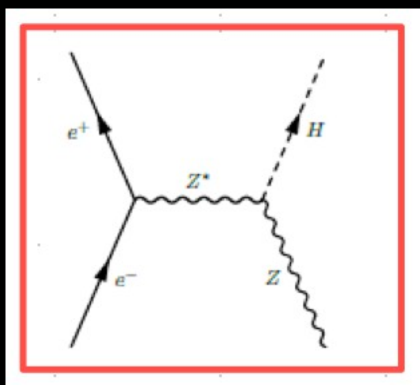


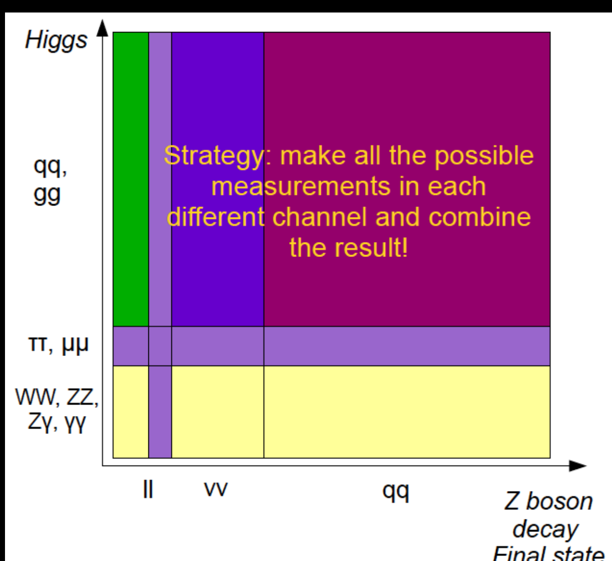


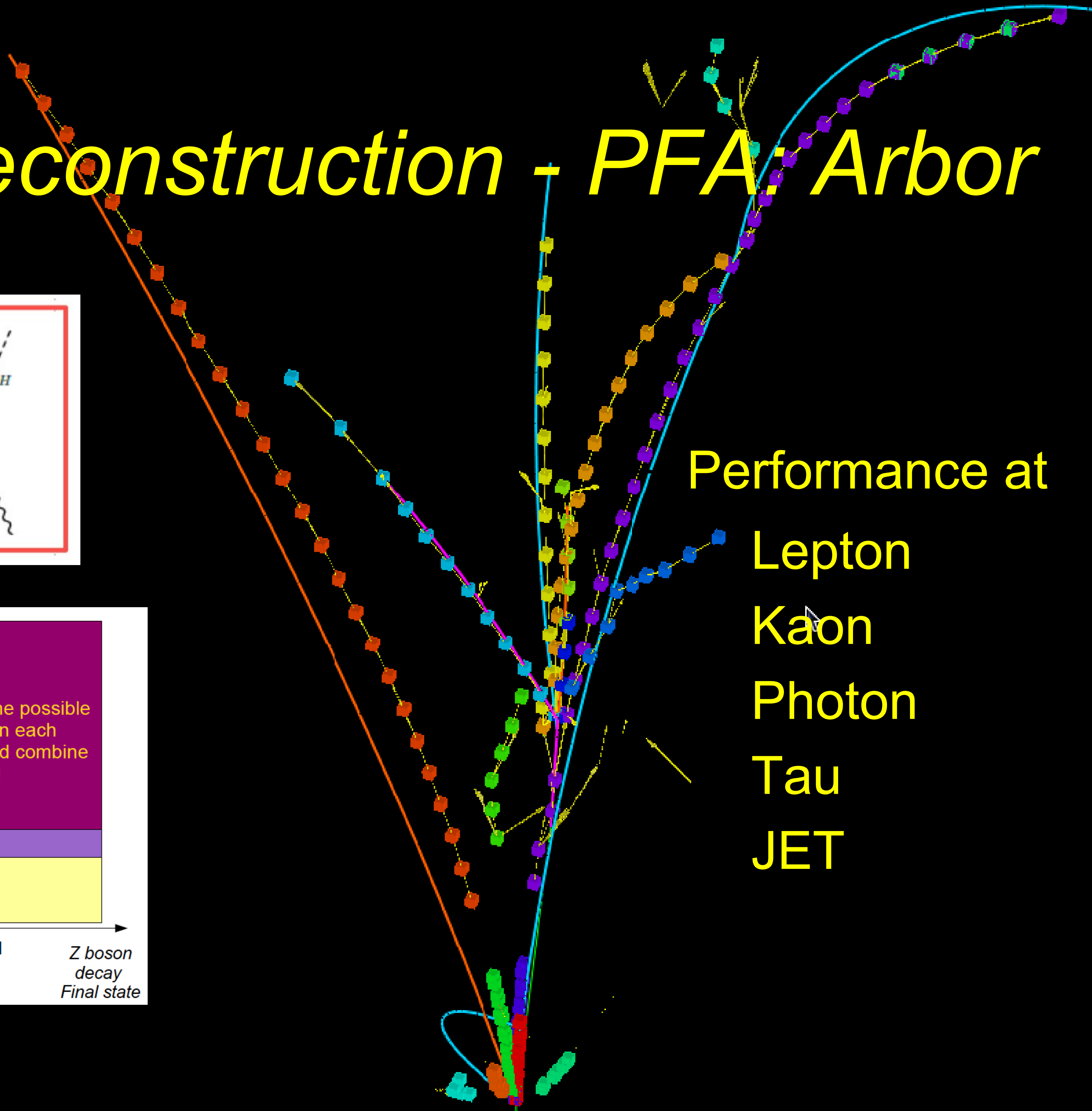
2015 PreCDR　　2017 CDR

See Joao's talk for details...

Reconstruction - PFA: Arbor



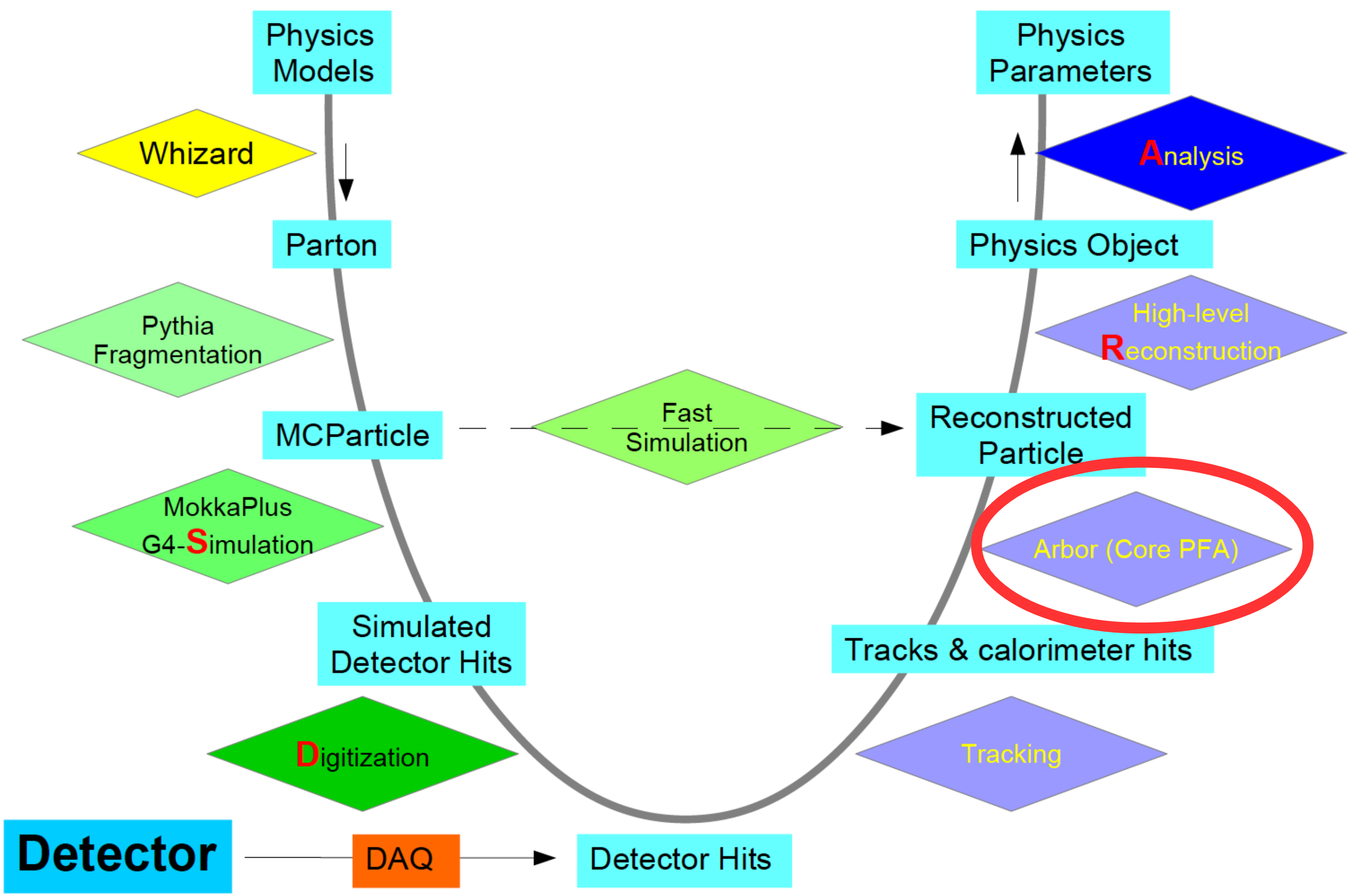




Performance at

- Lepton
- Kaon
- Photon
- Tau
- JET

Simulation-Reconstruction Chain with Arbor



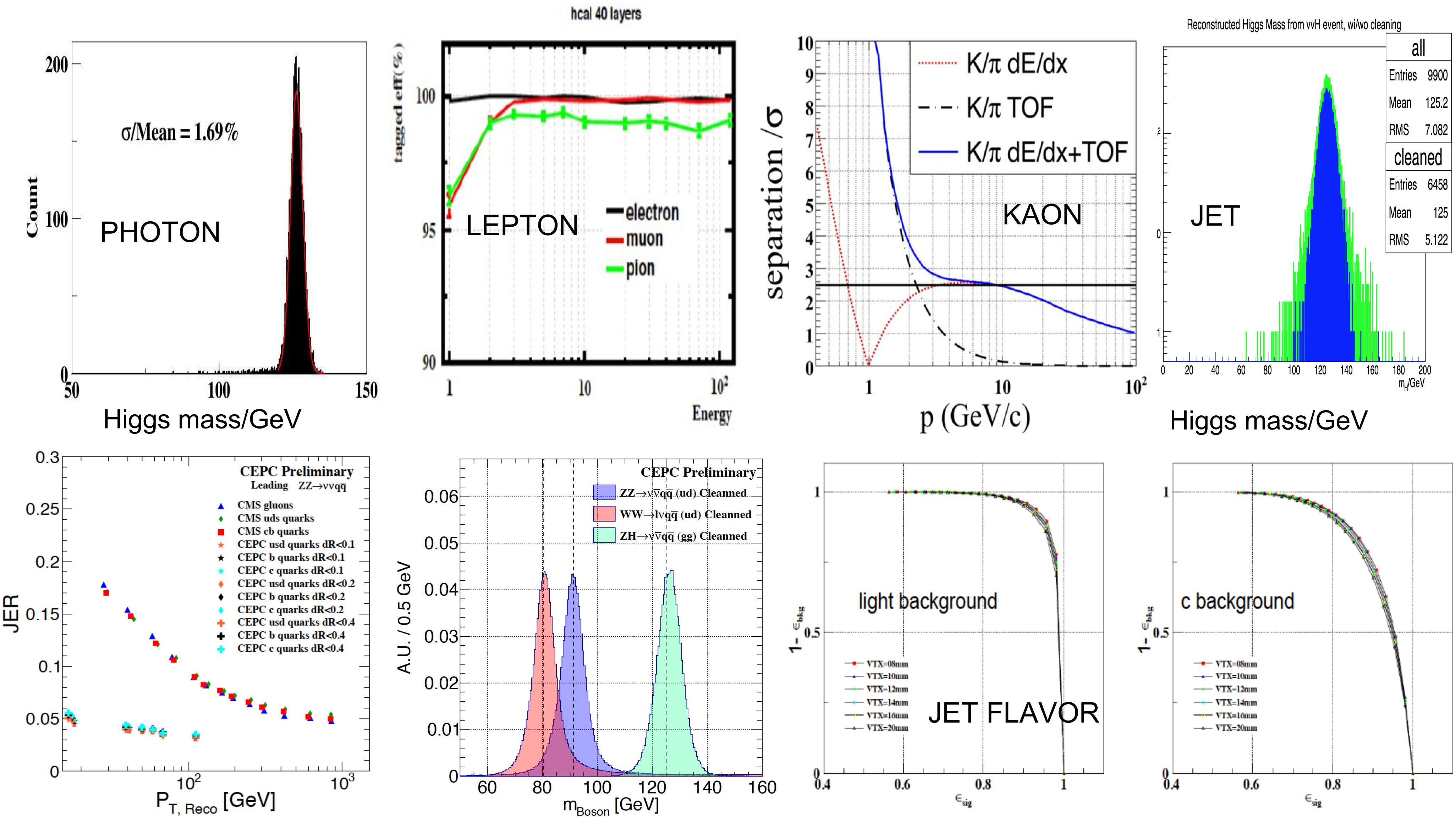
- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder (Coral)
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display (Druid)
- General Analysis Framework (FSClasser)
- Fast Simulation (Delphes + FSClasser)

CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

http://cepcsoft.ihep.ac.cn/

General tool | ILC soft | ILC Soft + New developments | New developments

Performance at Physics Objects



Eur. Phys. J. C (2018) 78:426

https://doi.org/10.1140/epjc/s10052-018-5876-z

Performance at Higgs Signal: total visible mass at ννH events

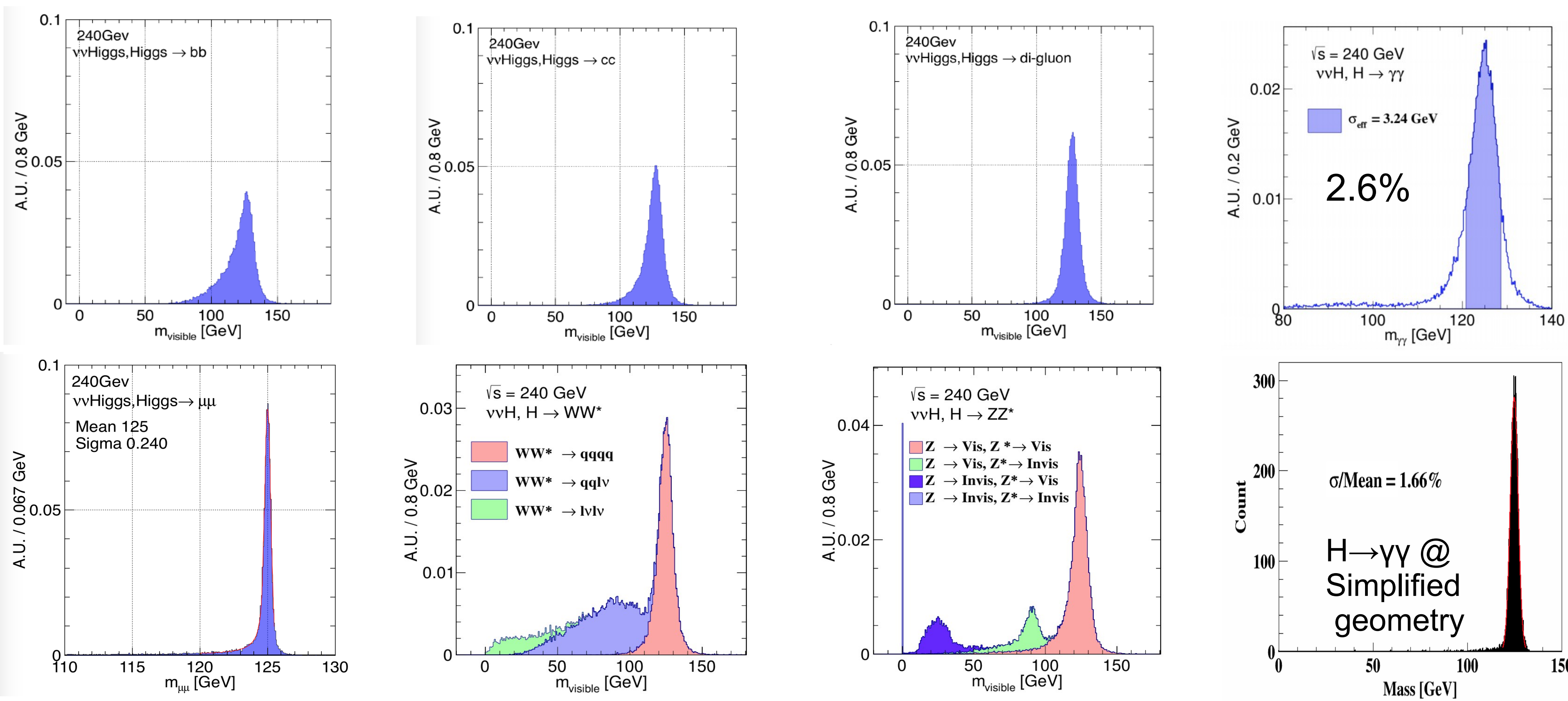


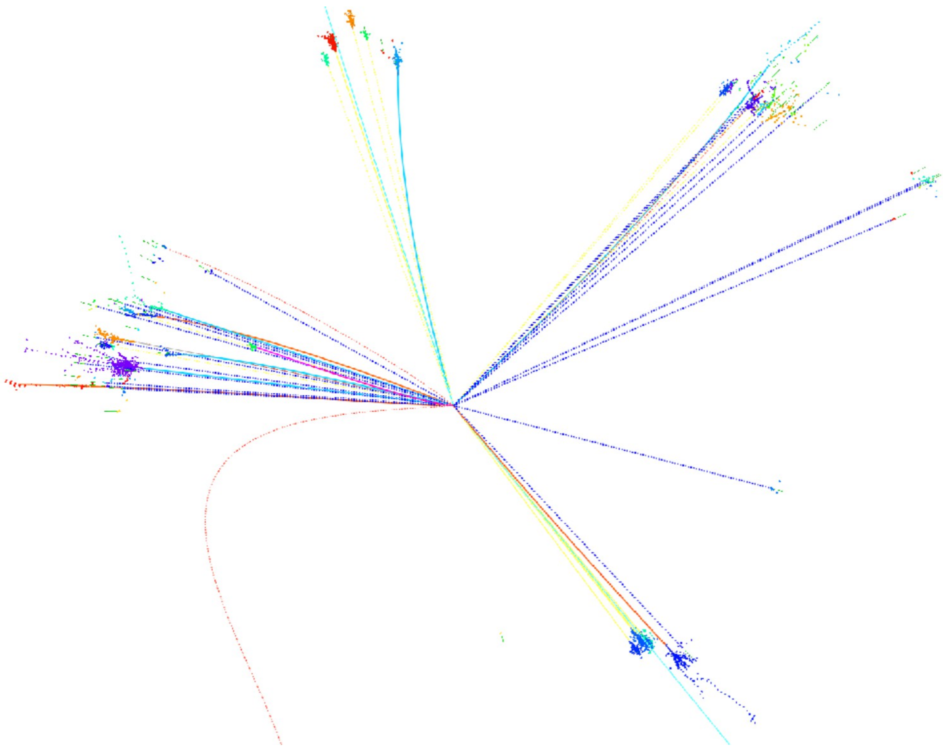
Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

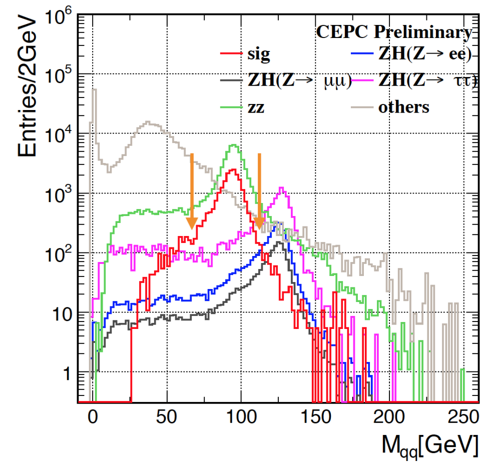
	Higgs→ $\mu\mu$	Higgs→ $\gamma\gamma$.	Higgs→bb
CEPC (APODIS)	0.20%	2.59%[1]	3.63%
LHC (CMS, ATLAS)	~2% [19, 20]	~1.5% [21, 22]	~10% [23, 24]

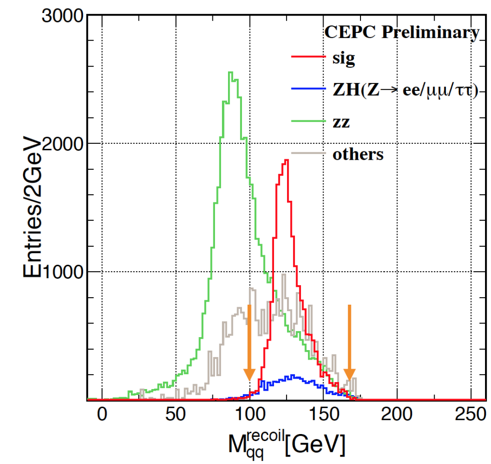
[1] primary result without geometry based correction and fine-tuned calibration.

https://arxiv.org/abs/1806.04992

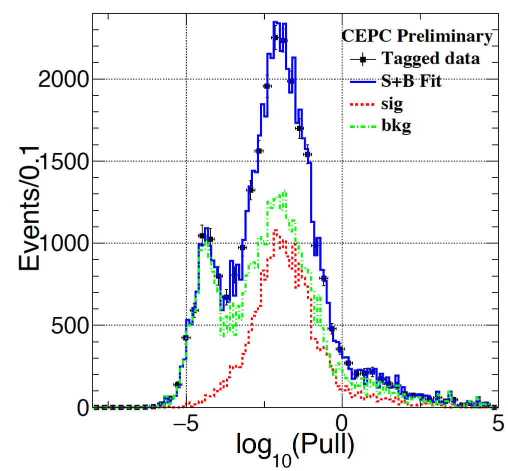
An analysis example: *g(Hττ)* via qqH







	m_{jj}	$m_{jj\text{-}recoil}$
Signal: Z(qq)H(ττ)	91.2	125
Z(ττ)H(qq)	125	91.2
ZZ	91.2	91.2

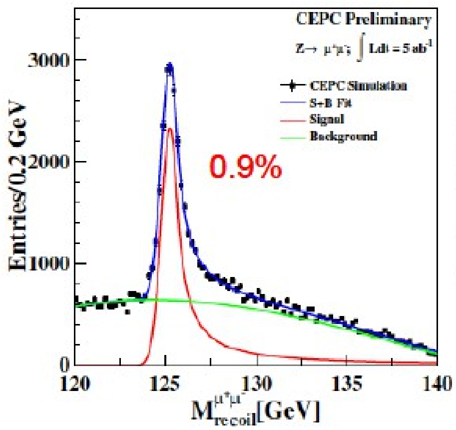


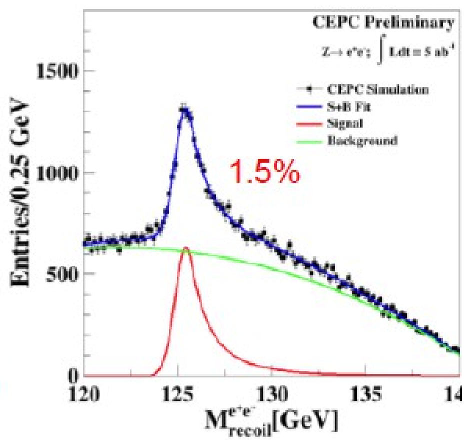
- Tau finding: di-tau system (double cone algorithm)
- The remaining particles → di-jet system: invariant/recoil mass information
- Isolated tracks → tau candidate: be distinguished by the VTX
- Final Accuracy: 0.9% (with total 46k signal events)

Ph.D thesis of D. Yu

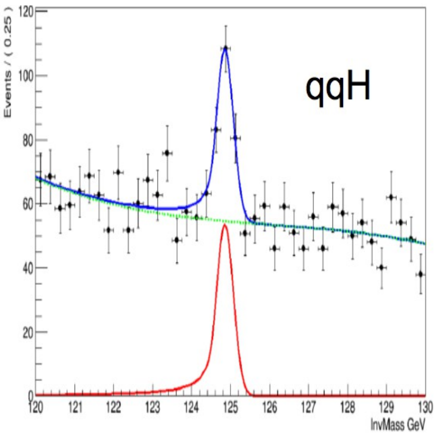
Higgs benchmark analyses...

Mostly done with CEPC-v1 geometry @ 250 GeV c.m.s...

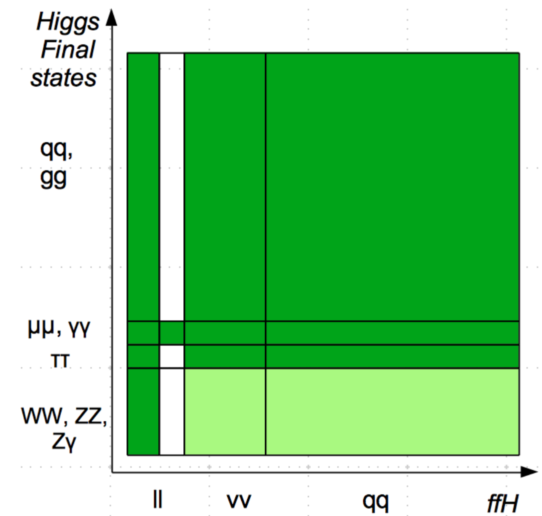


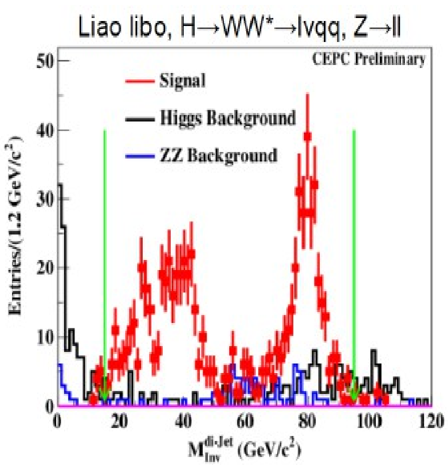


σ(ZH) measurements

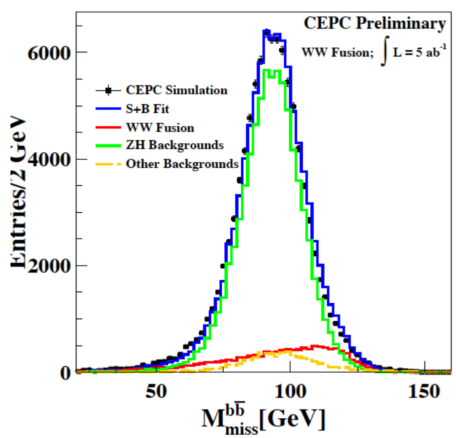


Br(H→μμ)

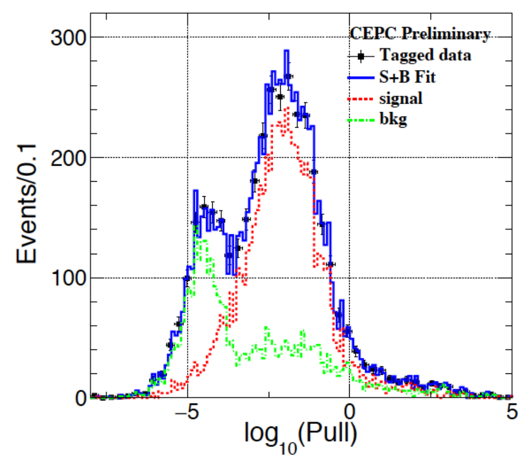




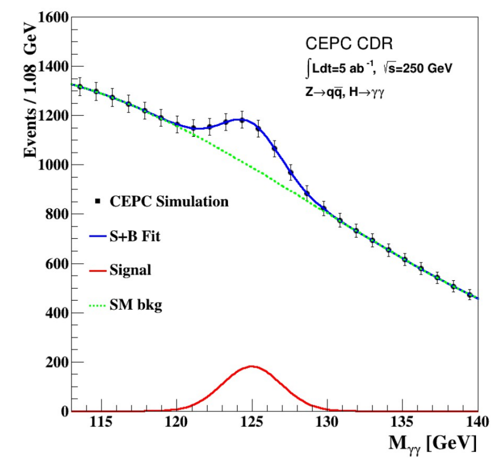
Br(H→WW)



σ(vvH)*Br(H→bb)



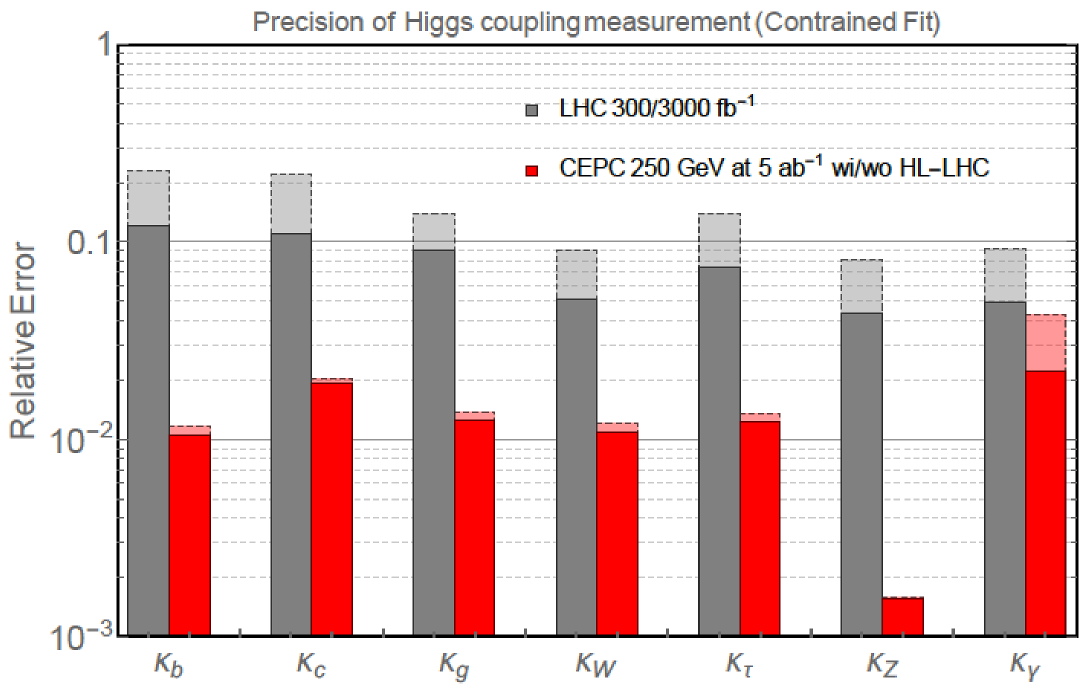
Br(H→ττ)

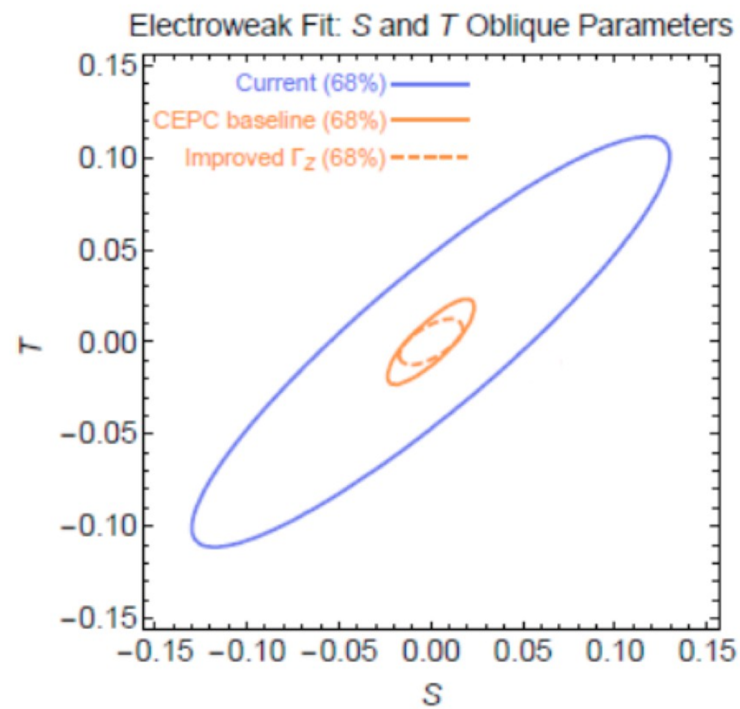


Br(H→γγ) (Asimov)

CEPC Higgs White Paper – be available soon

Physics Potential



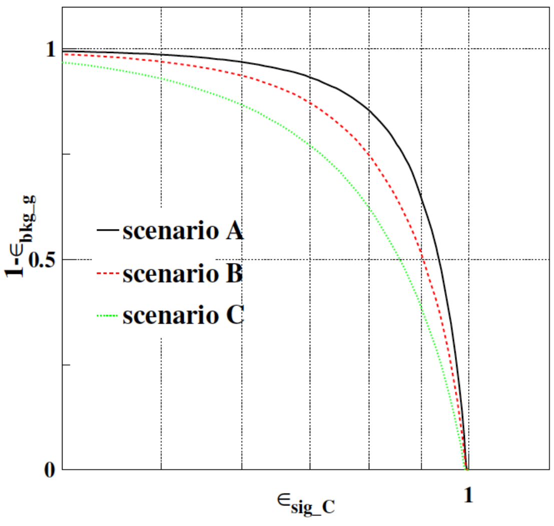


- The nature of Higgs boson & EWSB, flavor physics...
  - Higgs signal strengths (In κ-framework): roughly 1 order of magnitude better than HL-LHC
  - Absolute measurement to the Higgs boson: Γ_H~3%, Br(H→exotic, invisible) ~ 10^{-3} - 10^{-5}
  - Improve EW measurement precision by at least 1 order of magnitude
  - Significant potential in flavor physics: Bs, Bc, ...

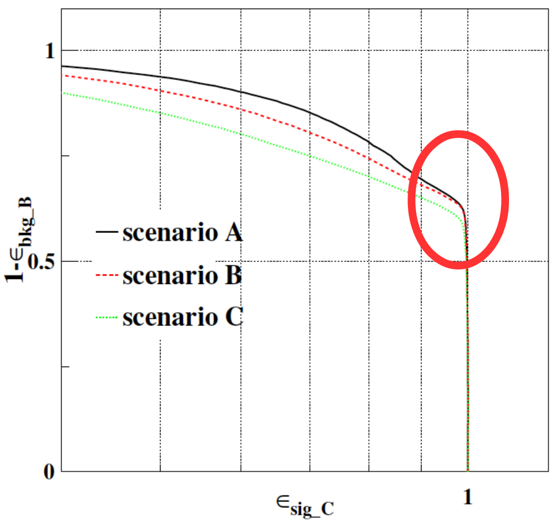
PreCDR results – to be updated (CDR) soon

To do (personal wish list)

- Detector optimization:
  - New ideas: Time information...
  - Integration (DAQ, Trigger, Cooling, Mechanism)
  - Systematic understanding & control
  - Sub detector – modeling & requirements
- Better reconstruction & Software
  - Identification of c-jets, gluon jets, and color singlets
  - Deep learning
  - Data preservation/framework, Parallel computing
- Analysis – Phenomenology/theory:
  - EW, Differential, Flavor...
  - Theoretical uncertainties
  - New observables
- **Synergies**: physics potential & ongoing studies...



(b) g background



(a) b background

Summary

- **Multiple IP** - two sets of detector concepts
- Particle Flow oriented design: the baseline for the CEPC CDR
  - High efficiency/accuracy reconstruction of all key **physics objects**
  - Clear **Higgs signature** in all SM Higgs decay mode
  - **Mature software/reconstruction tool/team (thanks to linear collider studies)**
- APODIS, Optimized for the CEPC collision environments
  - Significantly reduced B-Field (15%), #readout channels (75% in ECAL) & HCAL layer-thickness (20%), Yoke thickness & cost (15%/30% w.r.t CEPC-v1/ILD)
  - Same Higgs performance & enhanced Pid Performance
  - Iterate with hardware studies
- Todo:
  - A **LOOOOOOOOOT** interesting/exciting topic!
  - **Your support/participation is crucial & more than welcome!**

Manqi.ruan@ihep.ac.cn

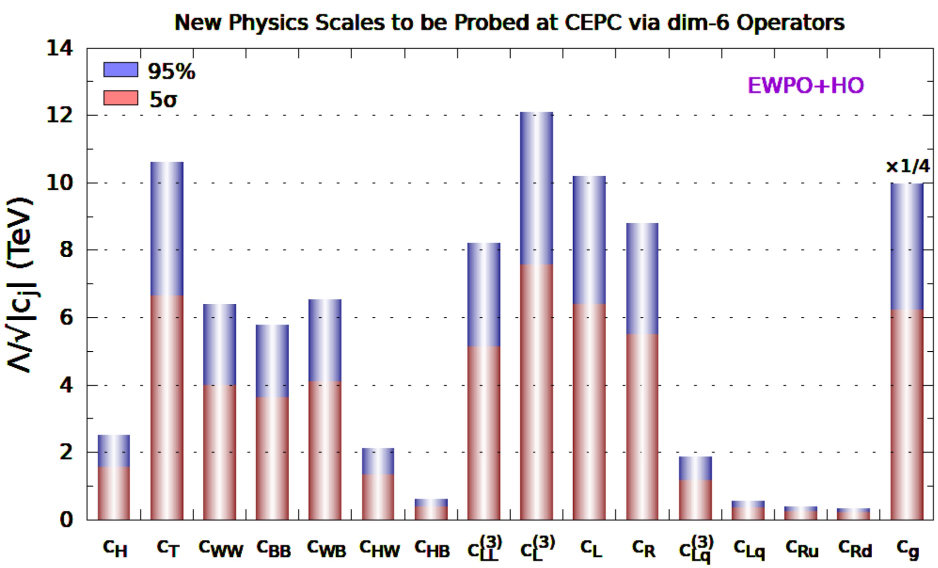
Thank you!

Example Working Points & Performance for Object identification (Preliminary)

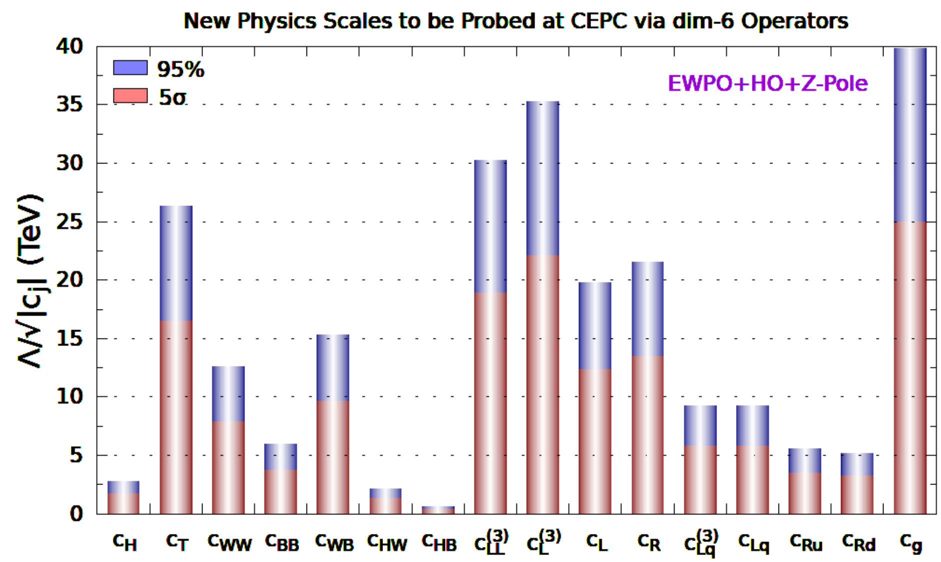
	Efficiency	Purity	Mis-id Probability from Main Background
Leptons	99.5 – 99.9%	99.5 – 99.9% at Higgs Runs(c.m.s = 240 GeV), Energy dependent	$P(\pi^{\pm} \rightarrow leptons) < 1\%$
Photons*	99.3 – 99.9%	99.5 – 99.9% at Higgs Runs Energy Dependent	P(Neutron → γ) = 1- 5%
Charged Kaons**	86 – 99%	90 – 99% at Z pole Runs (c.m.s = 91.2GeV, Track Momentum 2- 20 GeV)	$P(\pi^{\pm} \rightarrow K^{\pm})$ = 0.3 – 1.1%
b-jets	80%	90% at Z pole runs ($Z \rightarrow qq$)	P(uds → b) = 1% P(c → b) = 10%
c-jets	60%	60% at Z pole runs	P(uds → c) = 5% P(b → c) = 15%

New Physics Reach via dim-6 operators

Sensitivities from Existing EWPO & Future HO



Sensitivity from EWPO+HO+Z-Pole

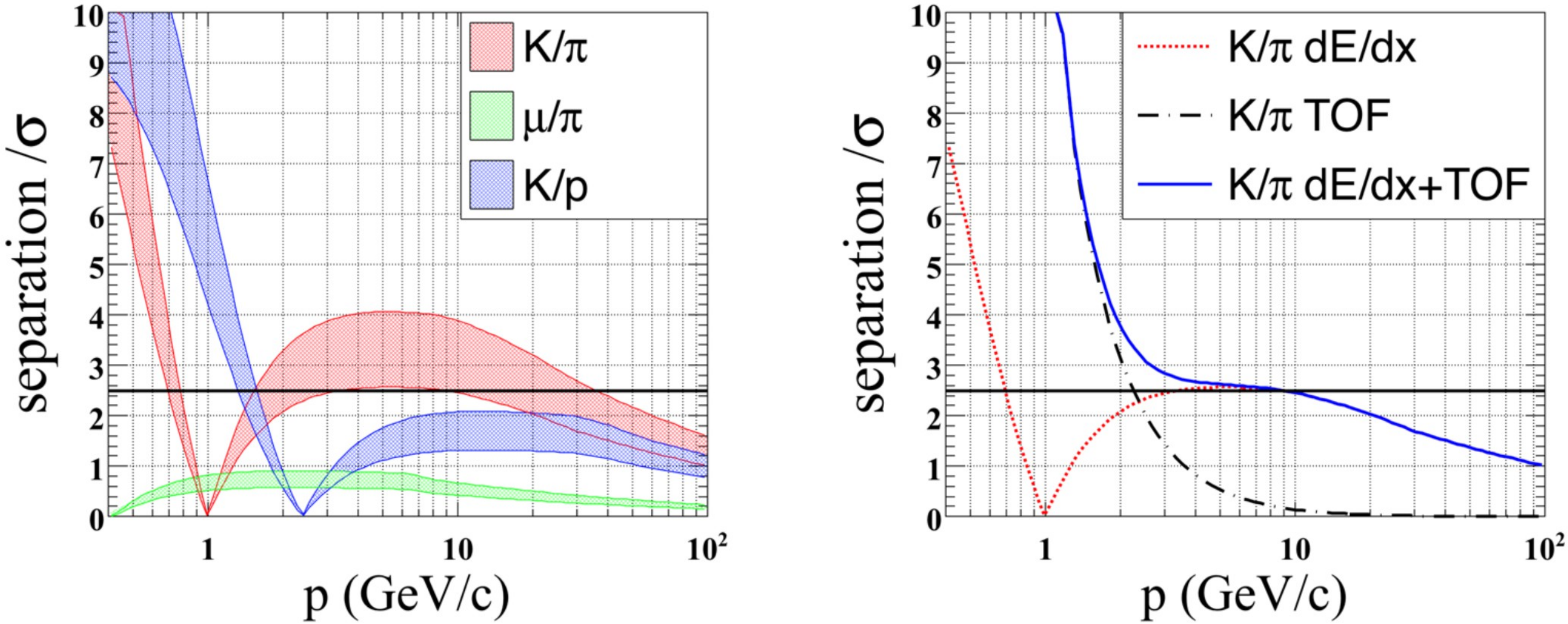


1603.03385

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_{ij} \frac{y_{ij}}{\Lambda \sim 10^{14}\,{\rm GeV}} (\bar{L}_i \tilde{\mathbf{H}})(\tilde{\mathbf{H}}^\dagger L_j) + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i \,.$$

Higgs	EW Gauge Bosons	Fermions
$\mathcal{O}_{\rm H} = \frac{1}{2}(\partial_\mu \lvert\mathbf{H}\rvert^2)^2$	$\mathcal{O}_{\rm WW} = g^2 \lvert\mathbf{H}\rvert^2 W^a_{\mu\nu} W^{a\mu\nu}$	$\mathcal{O}_{\rm L}^{(3)} = (i\mathbf{H}^\dagger \sigma^a \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
$\mathcal{O}_{\rm T} = \frac{1}{2}(\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})^2$	$\mathcal{O}_{\rm BB} = g'^2 \lvert\mathbf{H}\rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\rm LL}^{(3)} = (\overline{\Psi}_L \gamma_\mu \sigma^a \Psi_L)(\overline{\Psi}_L \gamma^\mu \sigma^a \Psi_L)$
	$\mathcal{O}_{\rm WB} = g g' \mathbf{H}^\dagger \sigma^a \mathbf{H} W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\rm L} = (i\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\Psi}_L \gamma^\mu \Psi_L)$
Gluon	$\mathcal{O}_{\rm HW} = i g (D^\mu \mathbf{H})^\dagger \sigma^a (D^\nu \mathbf{H}) W^a_{\mu\nu}$	$\mathcal{O}_{\rm R} = (i\mathbf{H}^\dagger \overleftrightarrow{D}_\mu \mathbf{H})(\overline{\psi}_R \gamma^\mu \psi_R)$
$\mathcal{O}_{\rm g} = g_s^2 \lvert\mathbf{H}\rvert^2 G^a_{\mu\nu} G^{a\mu\nu}$	$\mathcal{O}_{\rm HB} = i g' (D^\mu \mathbf{H})^\dagger (D^\nu \mathbf{H}) B_{\mu\nu}$	

Kaon

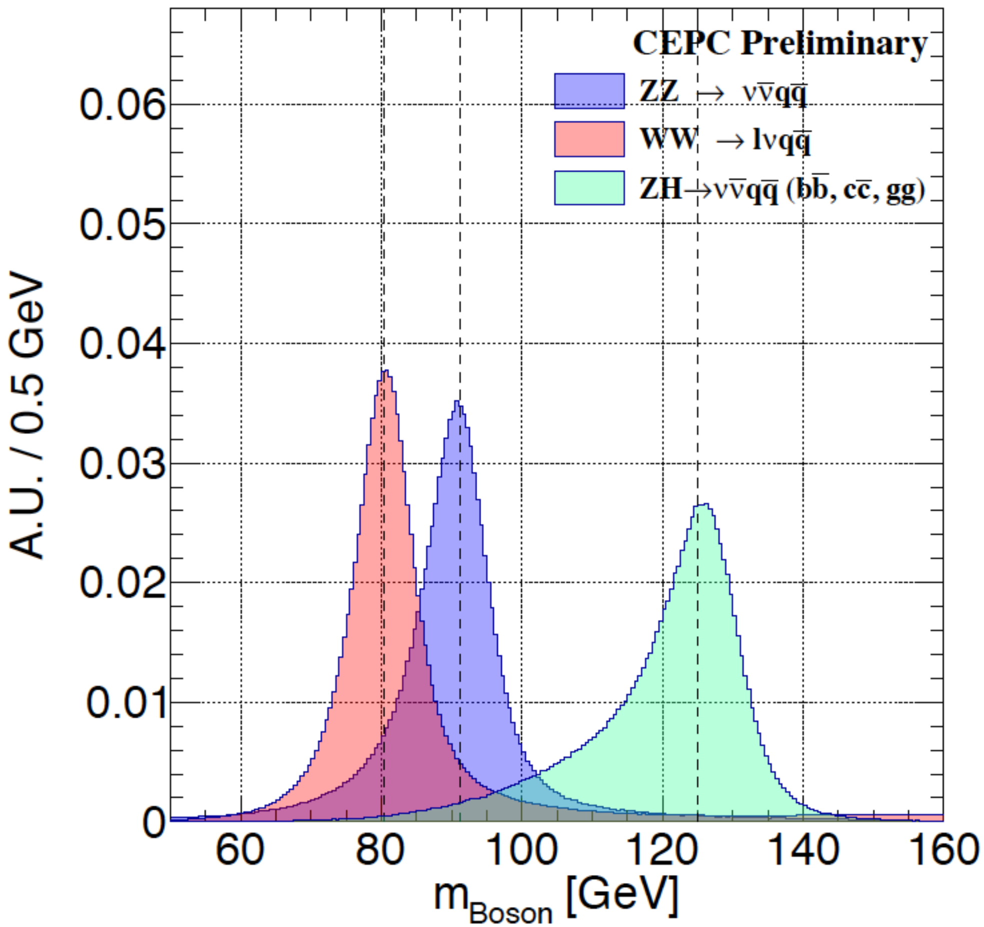


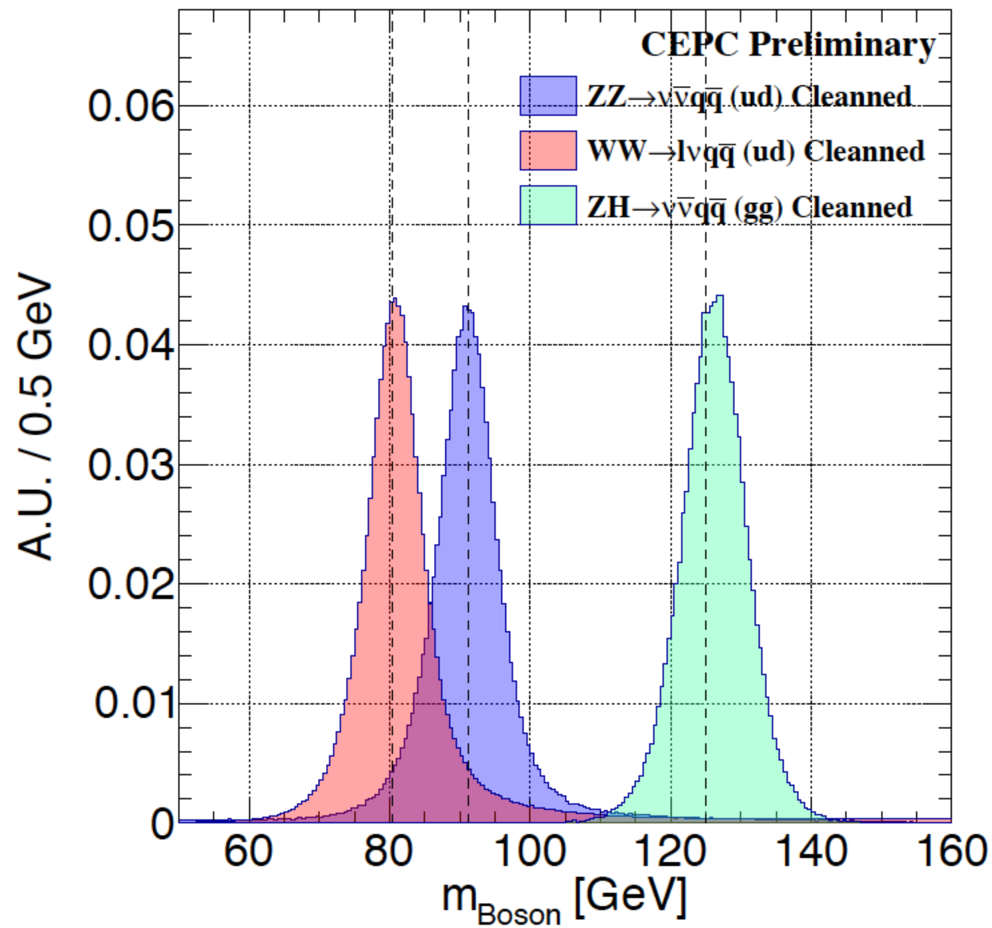
Highly appreciated in flavor physics @ CEPC Z pole
- TPC dEdx + ToF of 50 ps

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

CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464

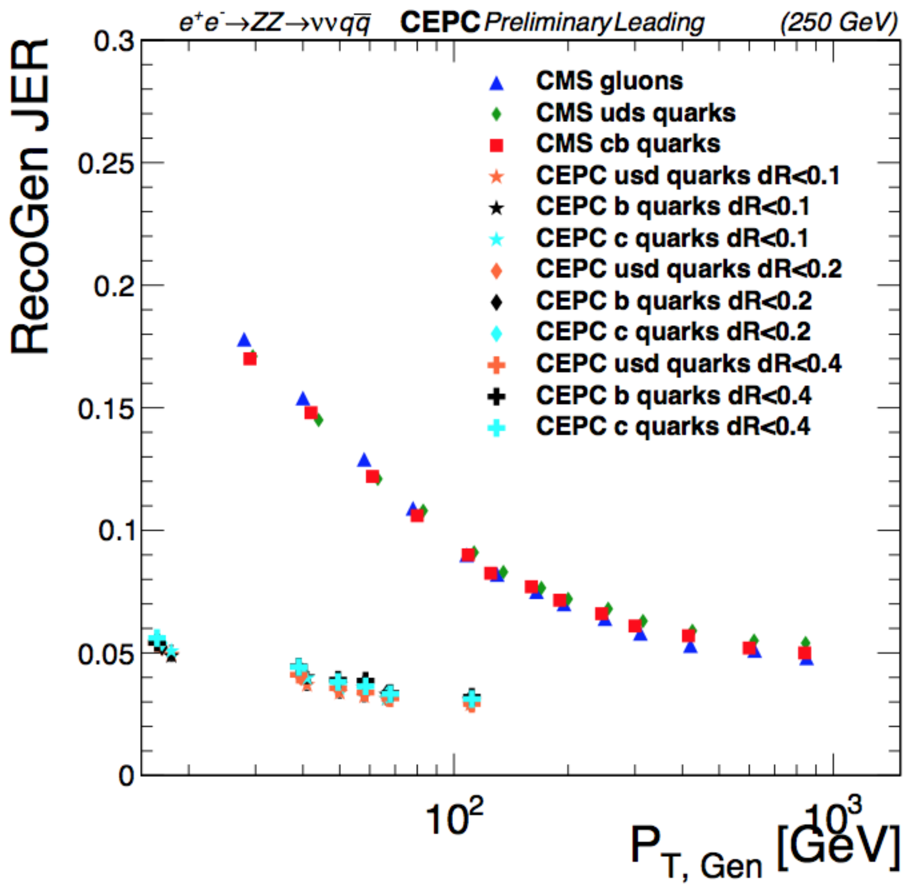
Massive Boson Separation

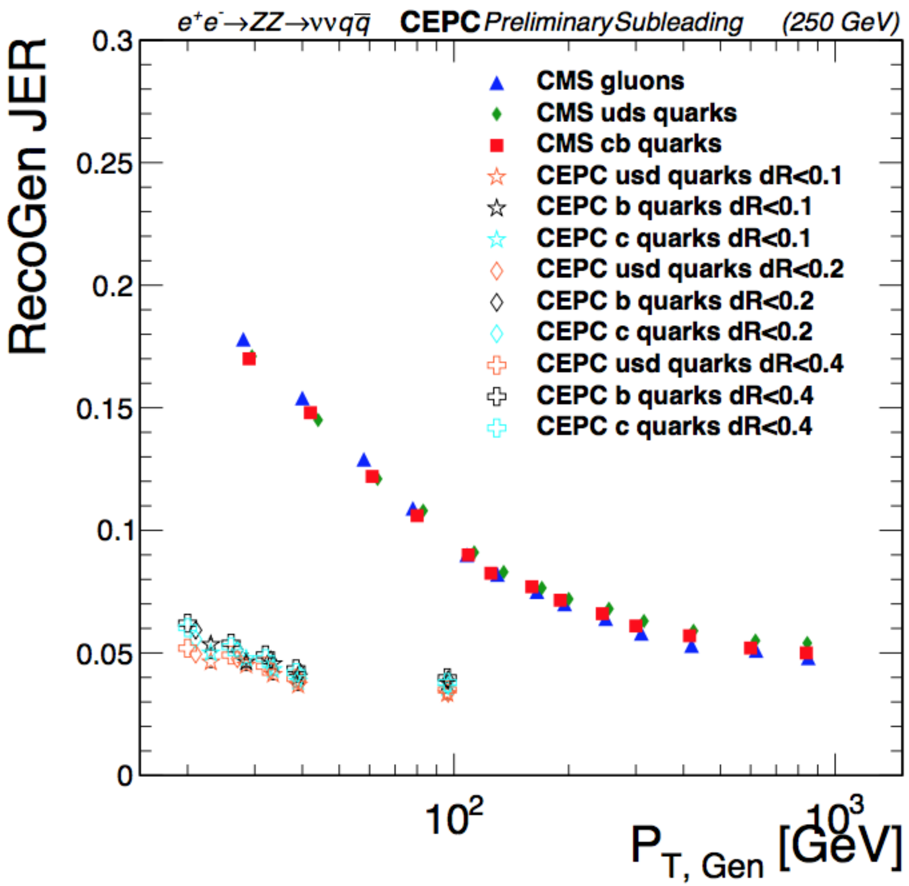




CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),
Eur.Phys.J. C78 (2018) no.5, 426

Jet Energy Resolution

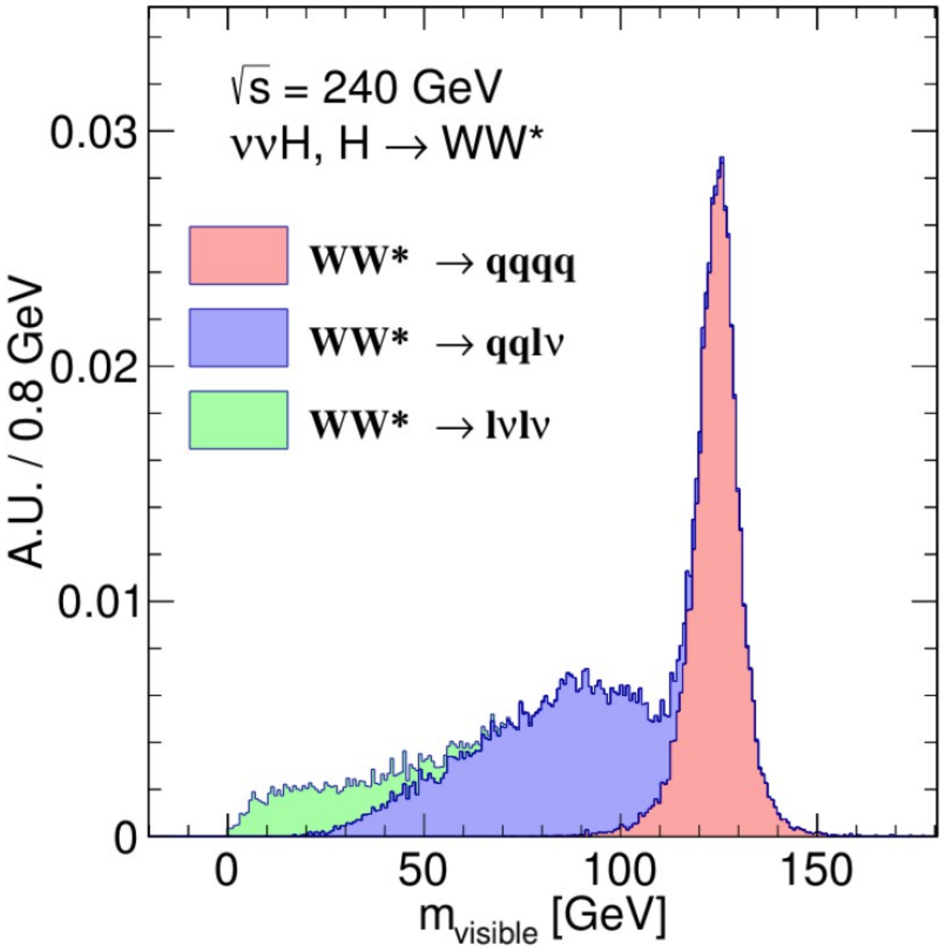




CMS Reference: CMS-JME-13-004,

Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV

Higgs to WW, ZZ



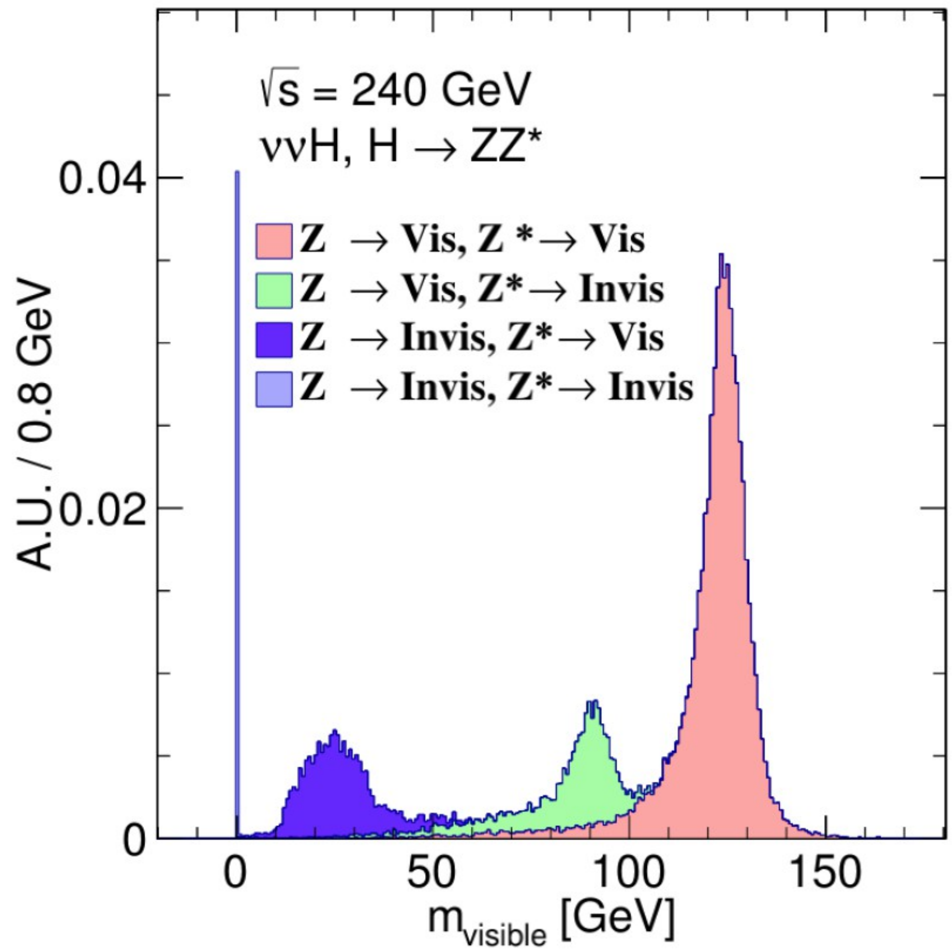


Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

	Higgs→ $\mu\mu$	Higgs→ $\gamma\gamma$.	Higgs→bb
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LHC (CMS, ATLAS)	~2% [19, 20]	~1.5% [21, 22]	~10% [23, 24]

[1] primary result without geometry based correction and fine-tuned calibration. https://arxiv.org/abs/1806.04992

H to gluons: total visible mass

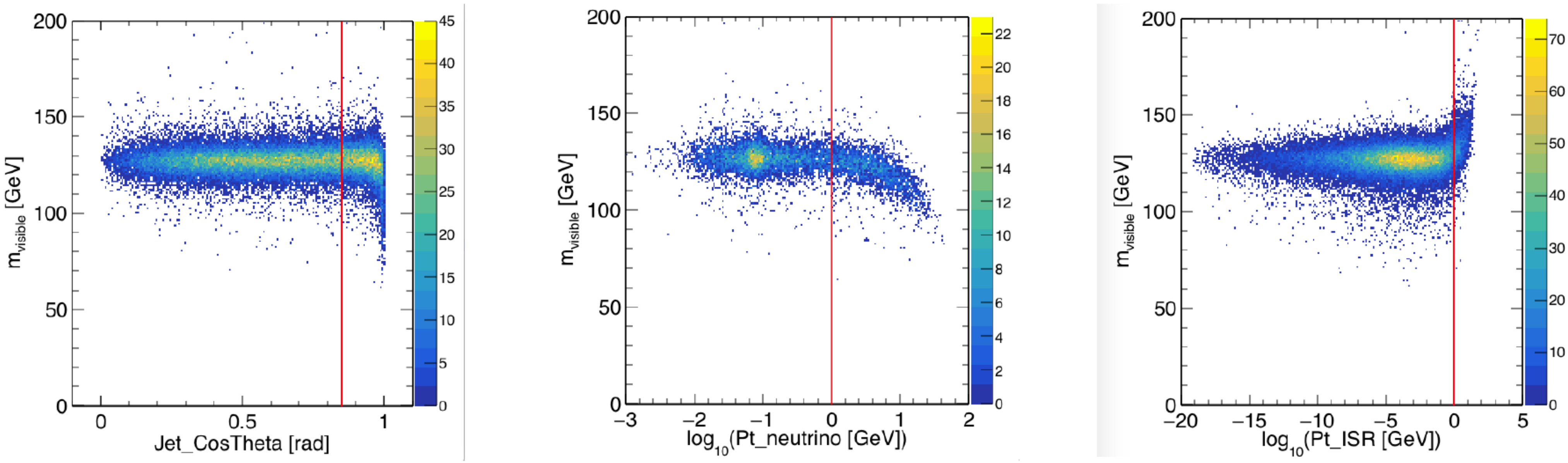
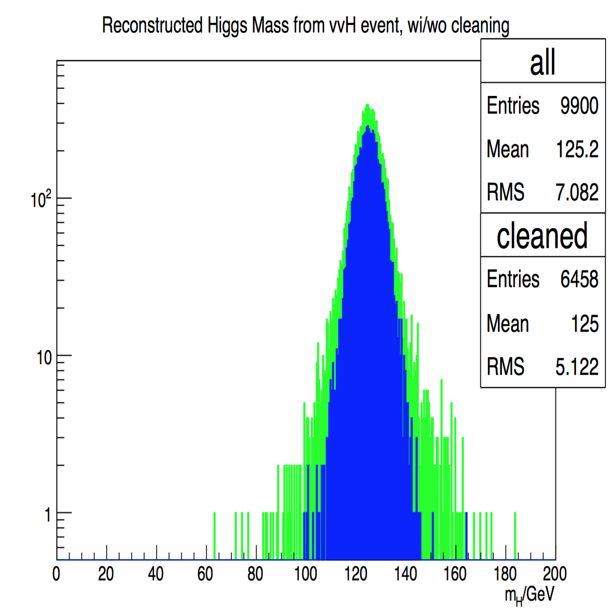


Table 1. Event selection efficiency for Higgs boson exclusive decay at CEPC with $\sqrt{s} = 240$ GeV.

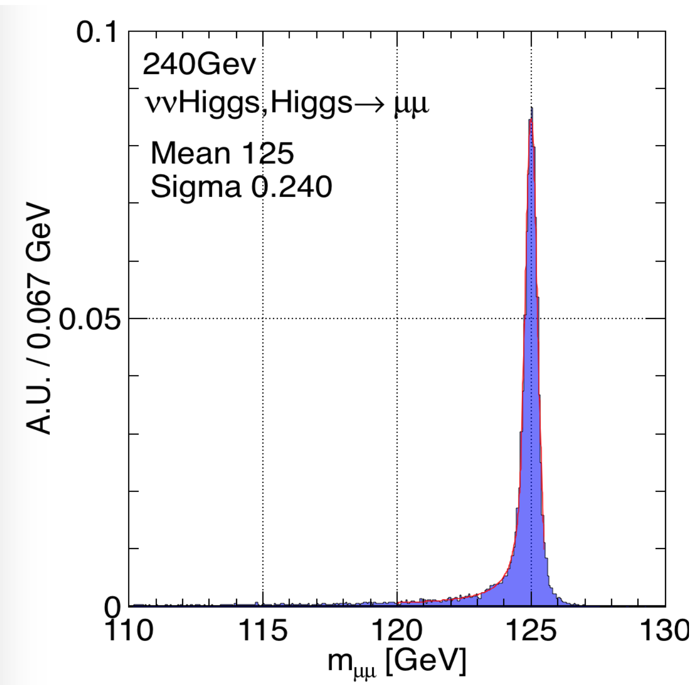
	$\mu\mu$	$\gamma\gamma$	*di_gluon*	bb	cc	WW^*	ZZ^*
Total	45000	48000	48000	45000	46000	47000.	45000
$Pt\_ISR < 1GeV$	-	95.52%	95.14%	95.37%	95.27%	95.19%	95.22%
$Pt\_neutrino < 1GeV$	-	-	89.35%	39.00%	66.30%	37.41%	41.42%
$\lvert costheta \rvert < 0.85$	-	-	67.27%	28.58%	49.23%	37.03%	40.91%

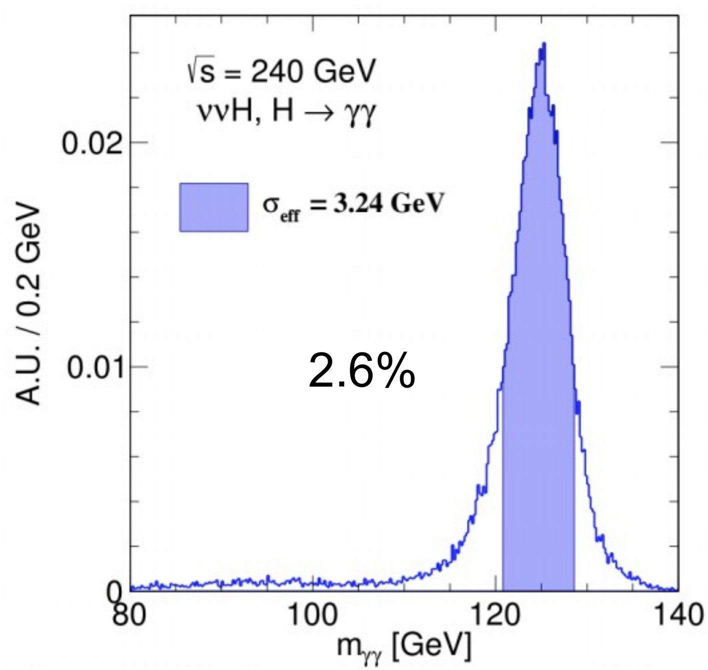


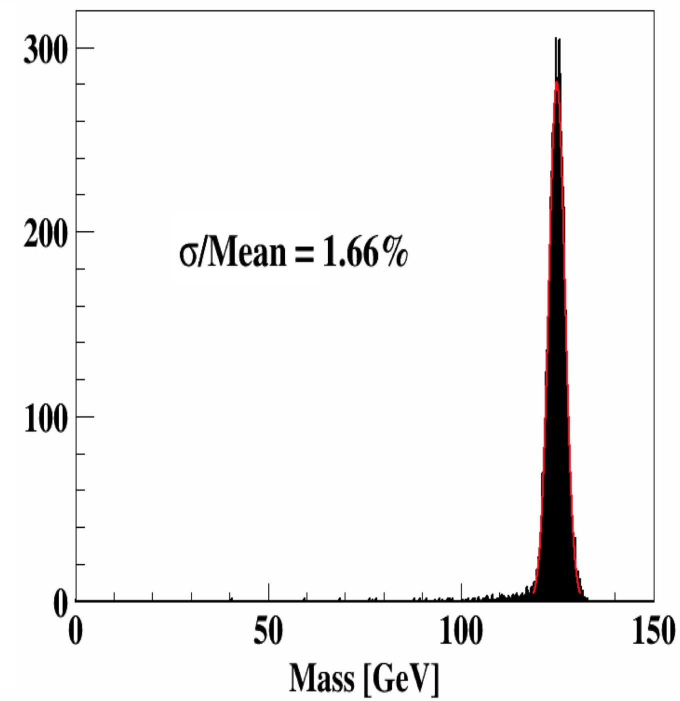
06/07/2018

Higgs Signal at APODIS

- Tracks - Leptons & Photons







H→γγ at CEPC-v4/Simplified geometry

CEPC-RECO-2018-002
CEPC-Doc id 174, 175

Asymmetric tails in CEPC-v4 induced by geometry defects need careful geometry corrections

Higgs to bb, cc, gg