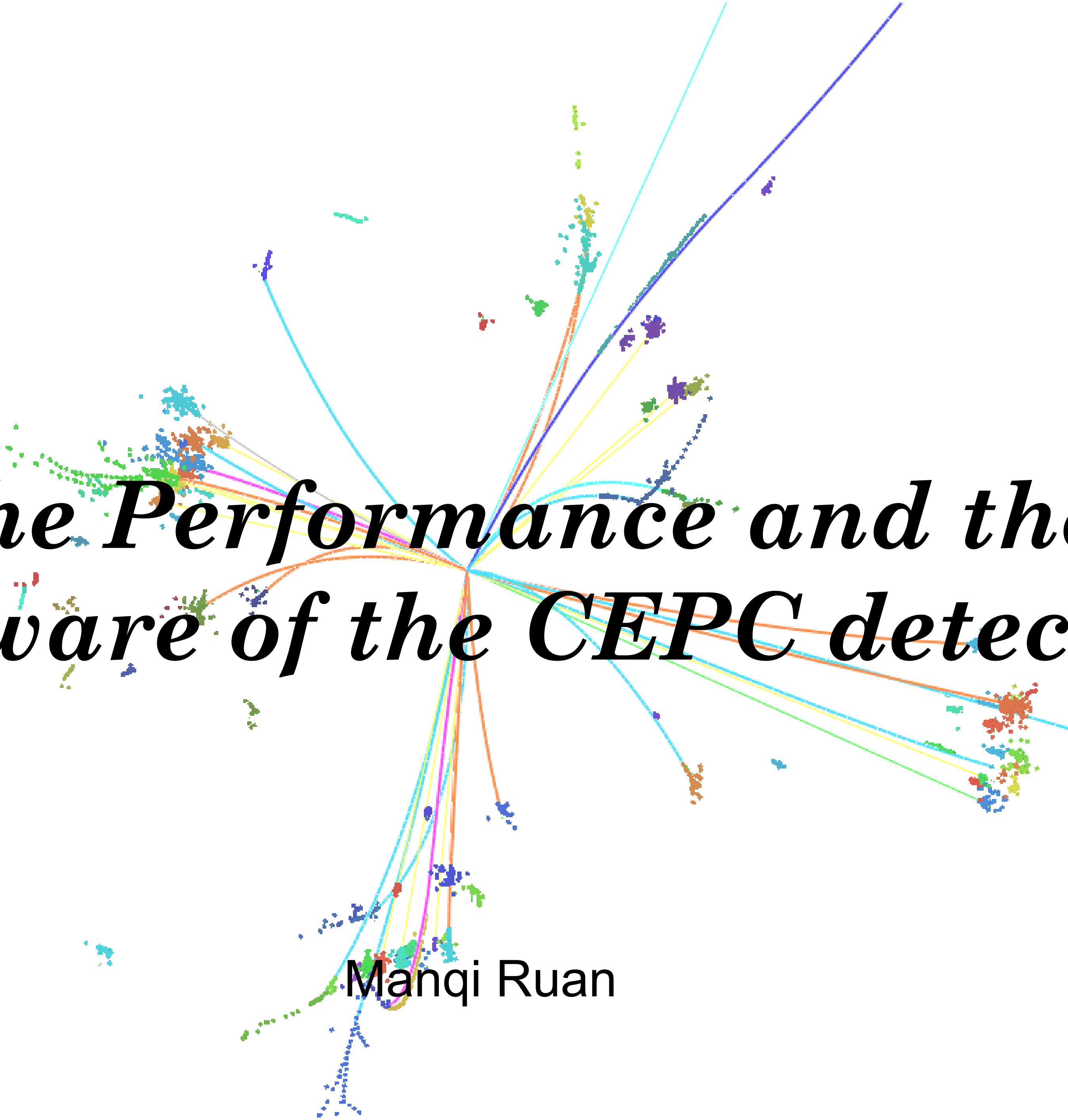
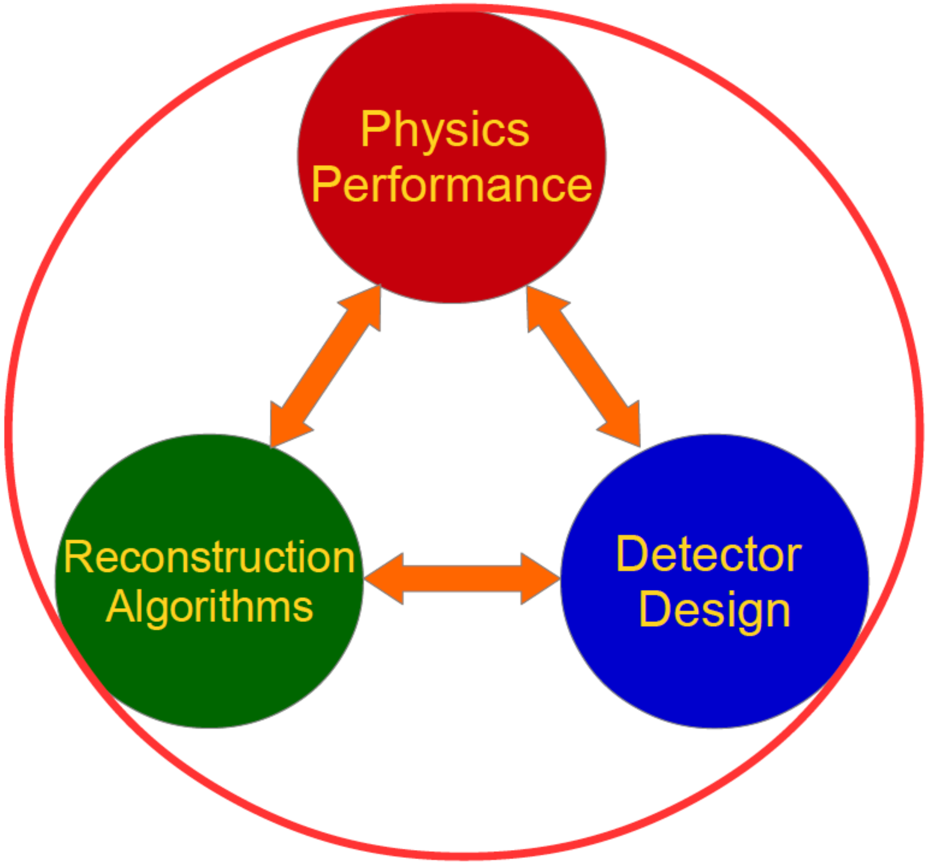


The Performance and the software of the CEPC detector

Manqi Ruan

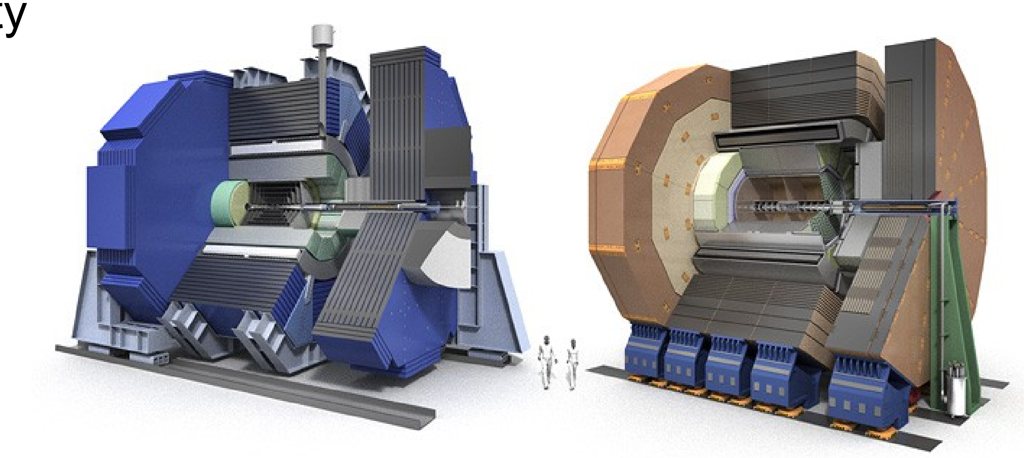
Performance

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

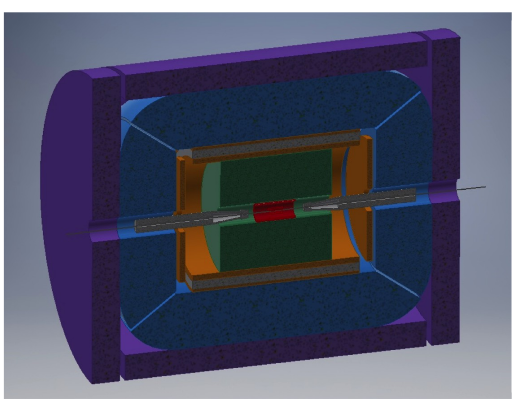


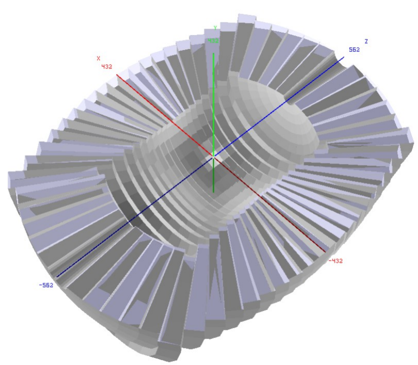
Two classes of Concepts

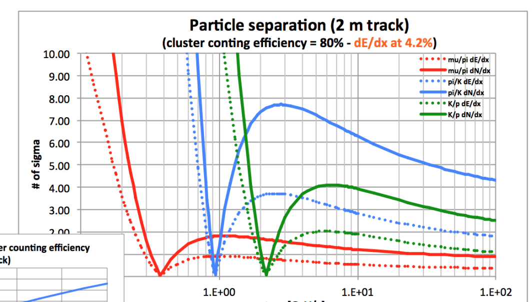
- PFA Oriented concept using High Granularity Calorimeter
  - **+ TPC (ILD-like, Baseline)**
  - + Silicon tracking (SiD-like)

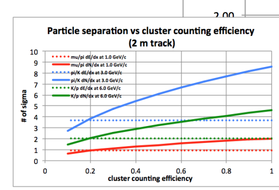


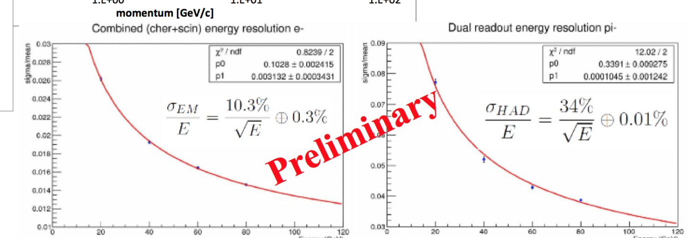
- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter







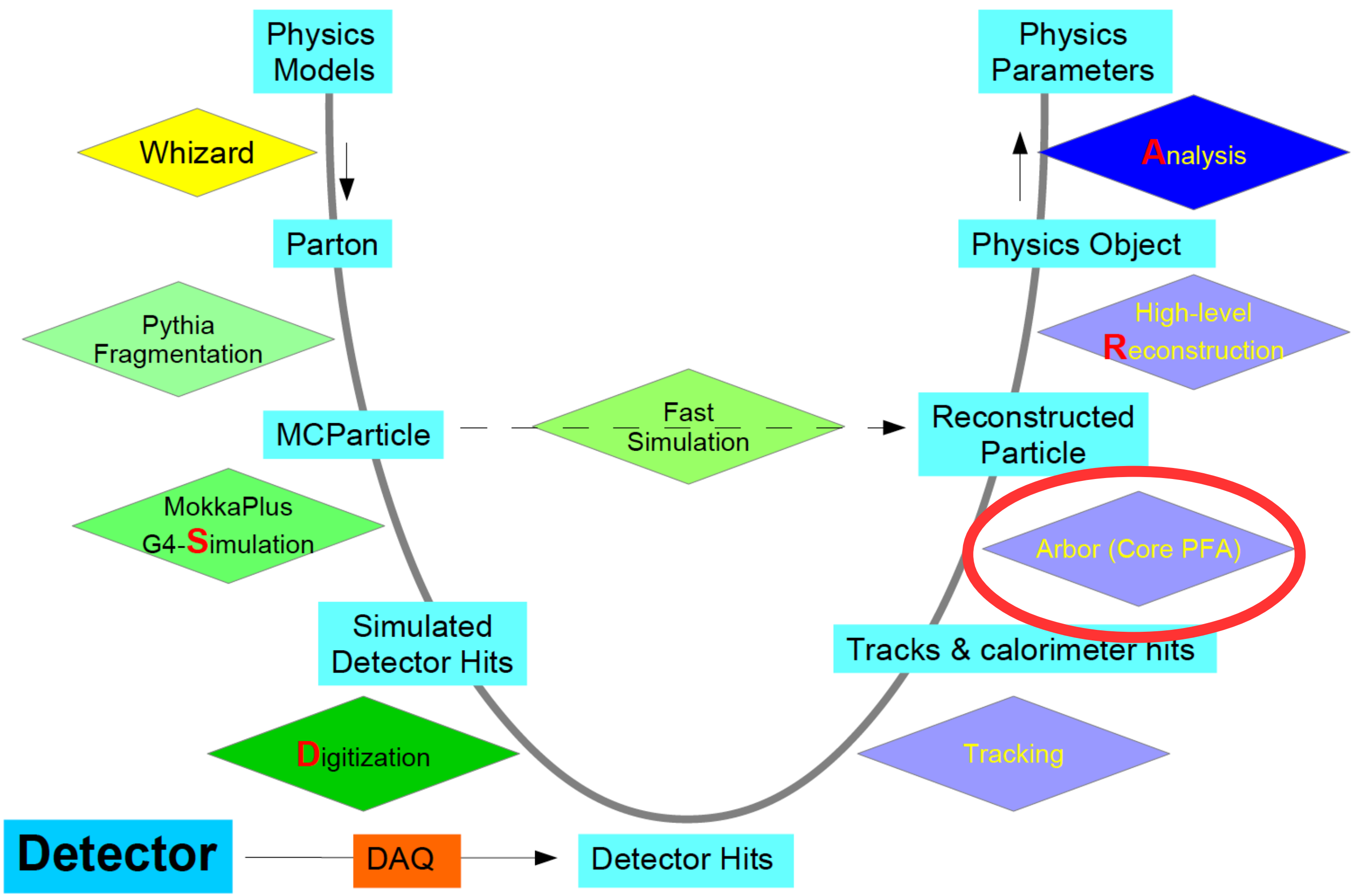




https://indico.ihep.ac.cn/event/6618/

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

CEPC Baseline Software

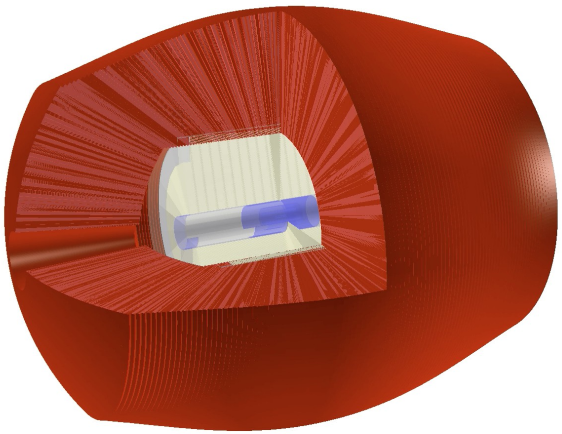


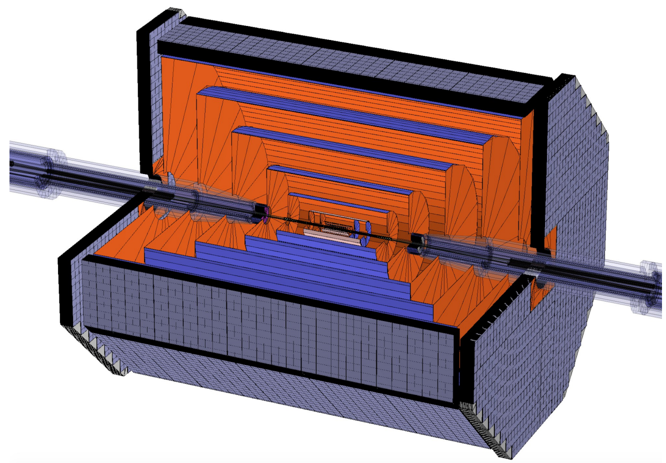
- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder (Coral)
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display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

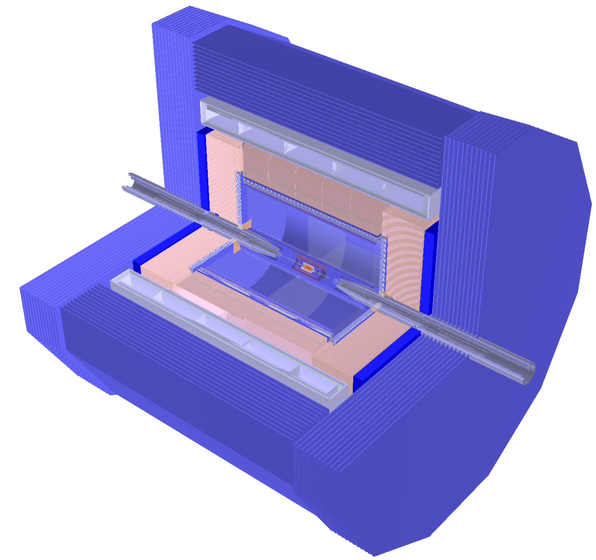
CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

General Software | ILCSoft | ILCSoft + Development | Developments

Status of simulation-performance study



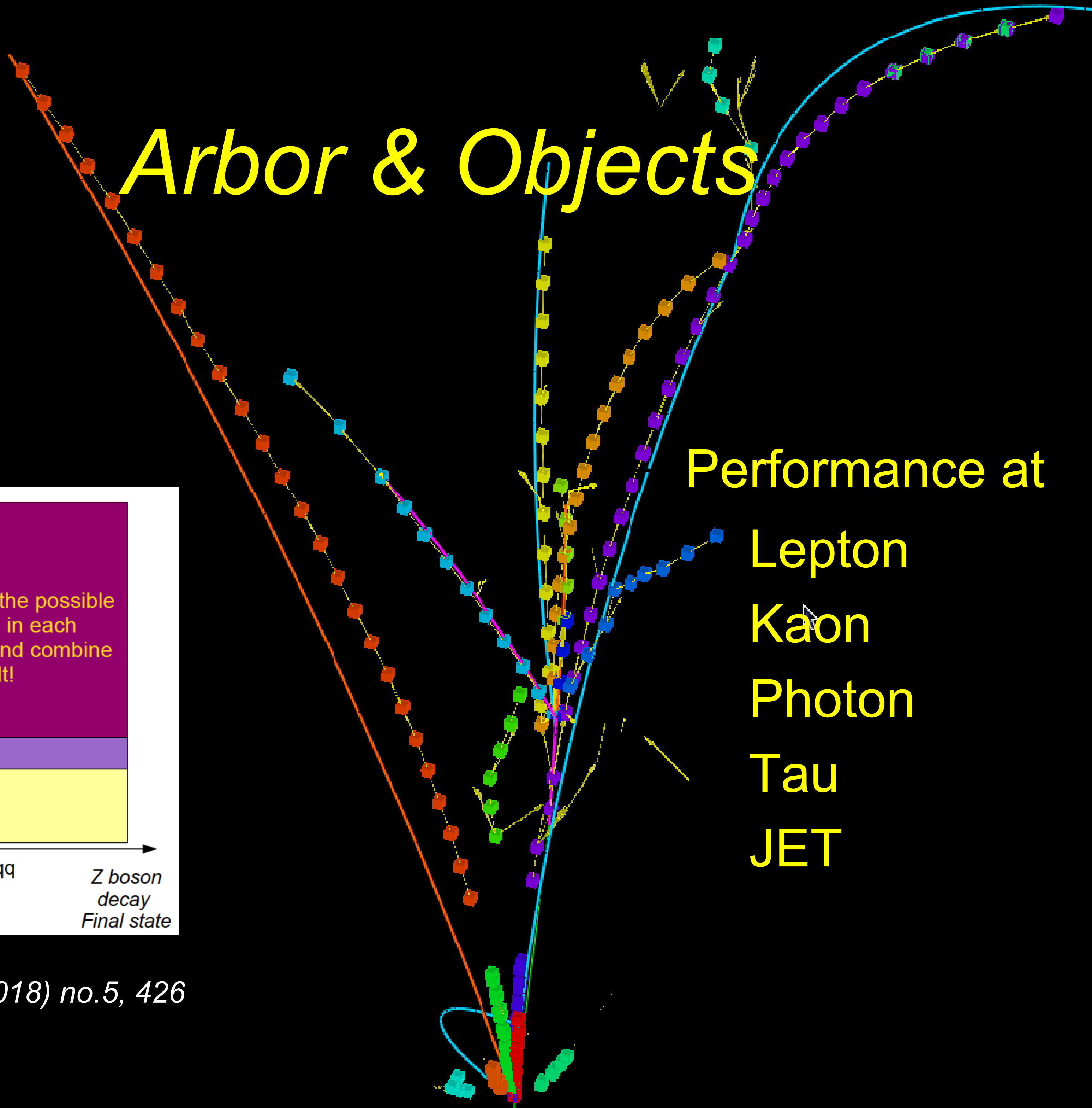




	Geant4-Simulation	Digitization	Reconstruction	Performance-Object	Performance-Benchmark
IDEA					
Full-Silicon					
APODIS					

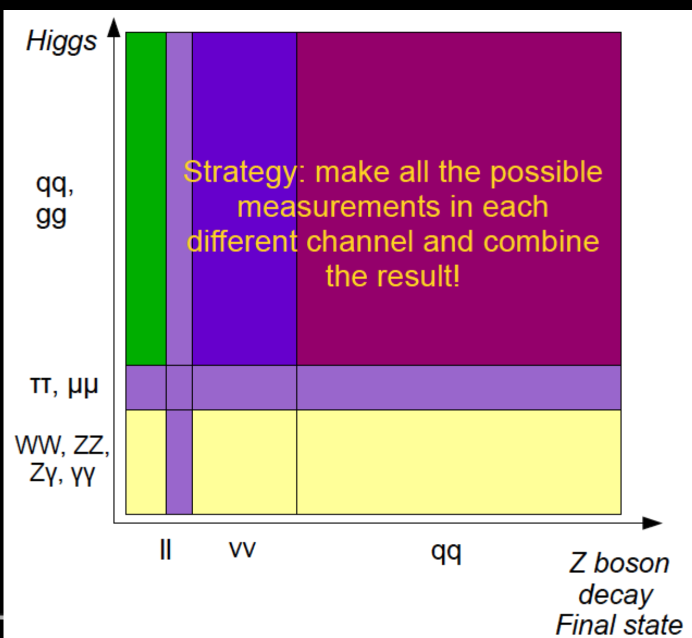
See Chengdong Fu's talk

Arbor & Objects



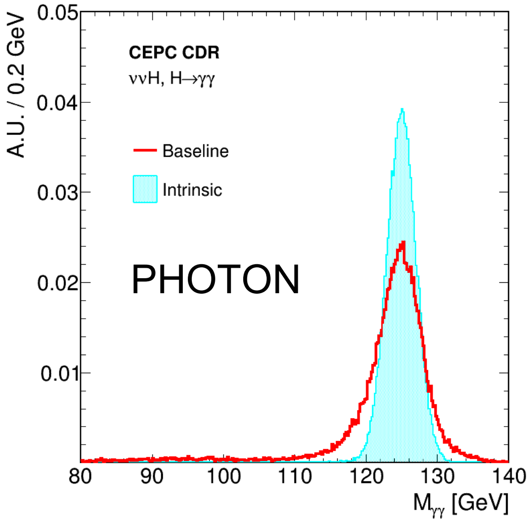
Performance at

- Lepton
- Kaon
- Photon
- Tau
- JET

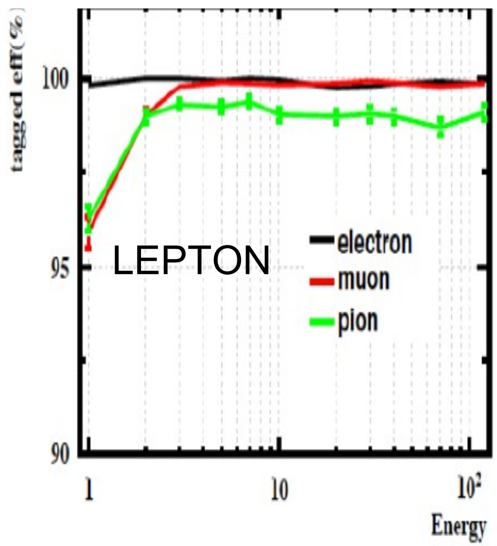


Eur. Phys. J. C78 (2018) no.5, 426

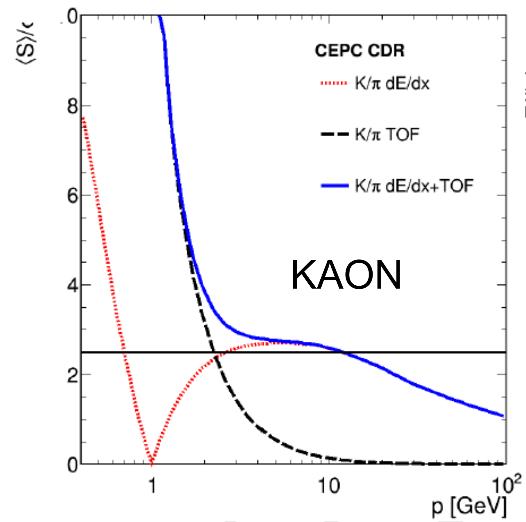
Physics Objects

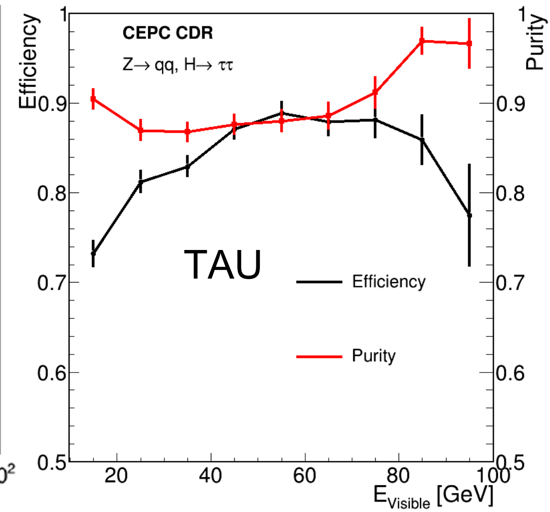


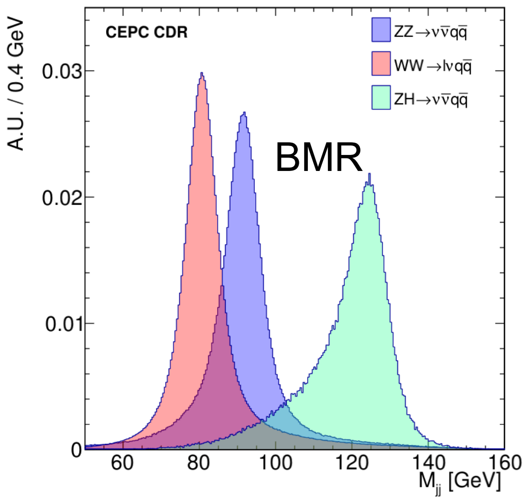
Eur. Phys. J. C (2017) 77: 591

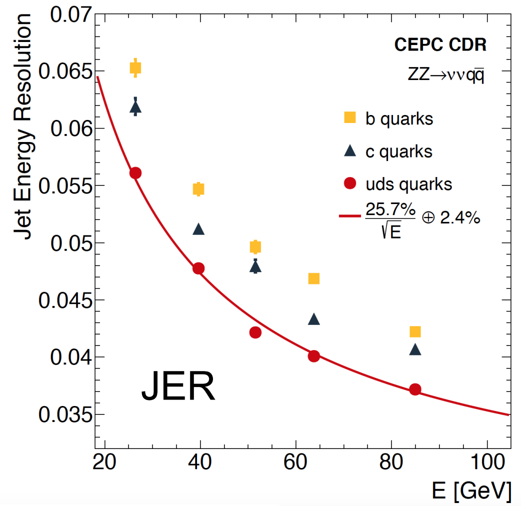


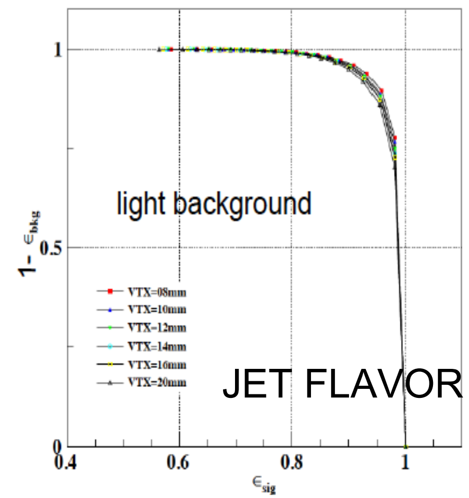
Eur. Phys. J. C (2018) 78:464

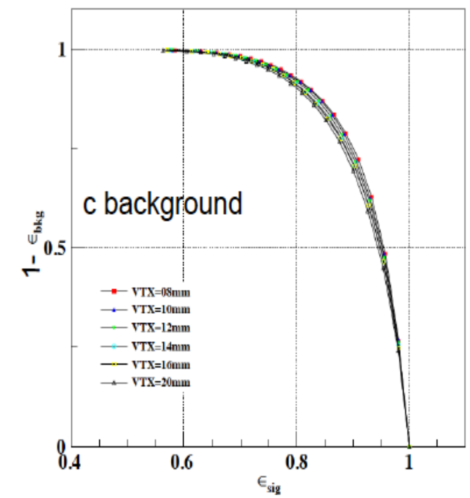






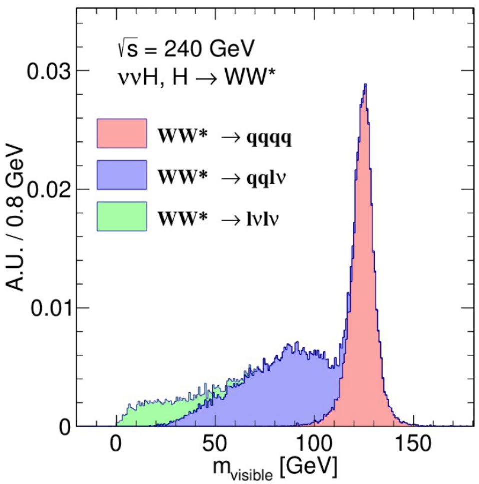


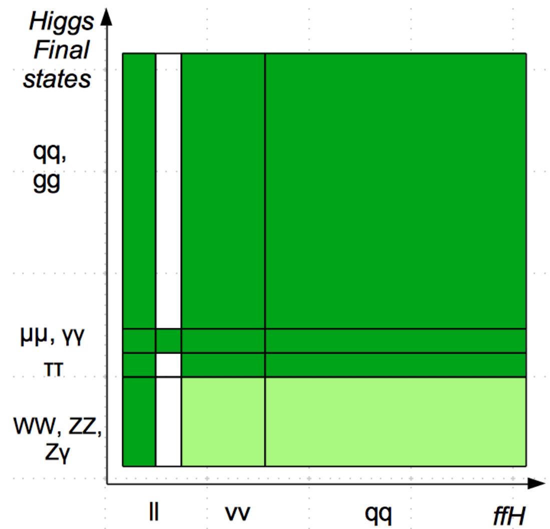


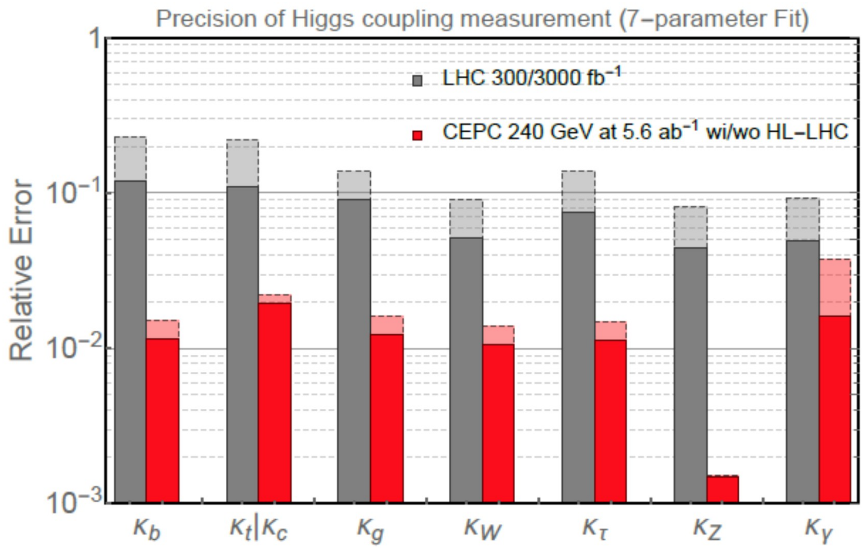


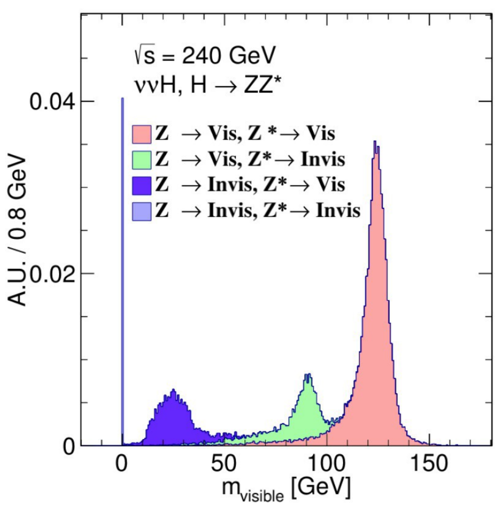
Eur. Phys. J. C (2018) 5: 426

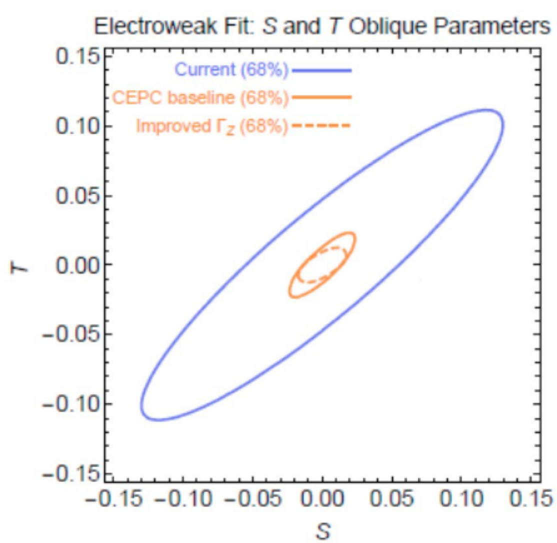
Applied on Higgs physics, et.al











Precision Higgs Physics at CEPC

Initial assessments of Higgs physics potential at the CEPC based on the white paper (to be submitted)

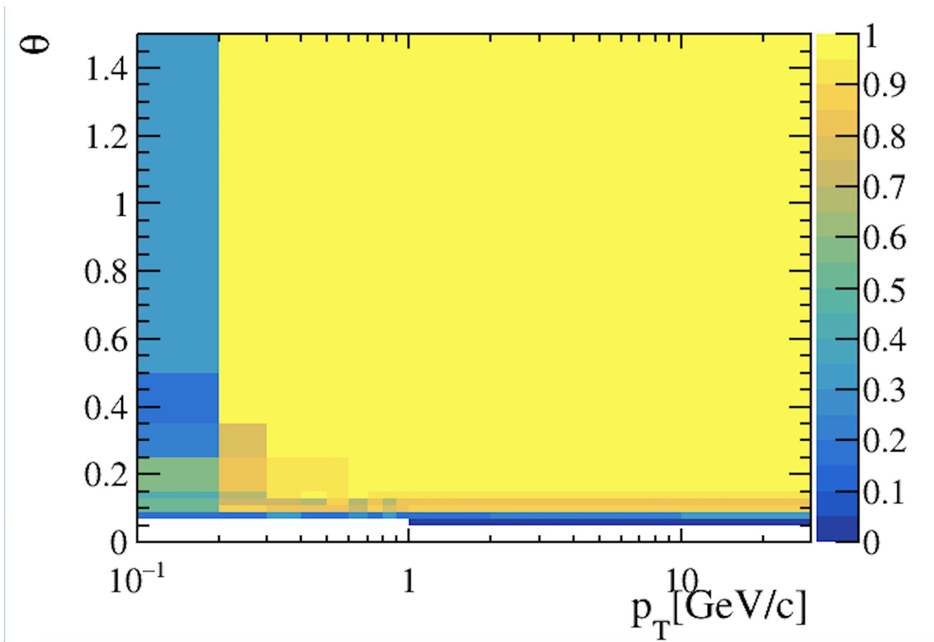
Chinese Physics C Vol. XX, No. X (201X) 010201

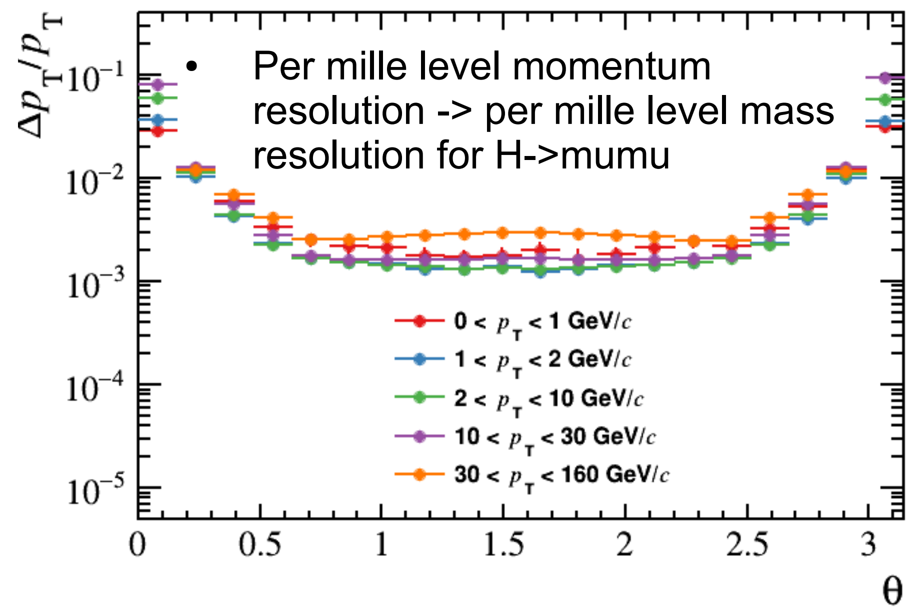
Precision Higgs Physics at the CEPC*

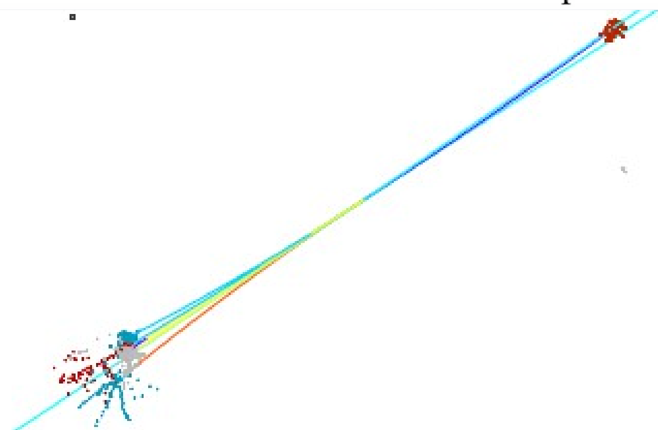
Fenfen An[4,21] Yu Bai[9] Chunhui Chen[21] Xin Chen[5] Zhenxing Chen[3] Joao Guimaraes da Costa[4]
Zhenwei Cui[3] Yaquan Fang[4,6] Chengdong Fu[4] Jun Gao[10] Yanyan Gao[20] Yuanning Gao[5]
Shao-Feng Ge[15,27] Jiayin Gu[13] Fangyi Guo[1,4] Jun Guo[10,11] Tao Han[5,29] Shuang Han[4]
Hong-Jian He[10,11] Xianke He[10] Xiao-Gang He[10,11] Jifeng Hu[10] Shih-Chieh Hsu[30] Shan Jin[8]
Maoqiang Jing[4,7] Ryuta Kiuchi[4] Chia-Ming Kuo[19] Pei-Zhu Lai[19] Boyang Li[5] Congqiao Li[3] Gang Li[4]
Haifeng Li[12] Liang Li[10] Shu Li[10,11] Tong Li[12] Qiang Li[3] Hao Liang[4,6] Zhijun Liang[4]
Libo Liao[4] Bo Liu[4,21] Jianbei Liu[1] Tao Liu[14] Zhen Liu[24,28] Xinchou Lou[4,6,31] Lianliang Ma[12]
Bruce Mellado[17] Xin Mo[4] Mila Pandurovic[16] Jianming Qian[22] Zhuoni Qian[18]
Nikolaos Rompotis[20] Manqi Ruan[4] Alex Schuy[30] Lian-You Shan[4] Jingyuan Shi[9] Xin Shi[4]
Shufang Su[23] Dayong Wang[3] Jing Wang[4] Lian-Tao Wang[25] Yifang Wang[4,6] Yuqian Wei[4]
Yue Xu[5] Haijun Yang[10,11] Weiming Yao[26] Dan Yu[4] Kaili Zhang[4,6] Zhaoru Zhang[4]
Mingrui Zhao[2] Xianghu Zhao[4] Ning Zhou[10]

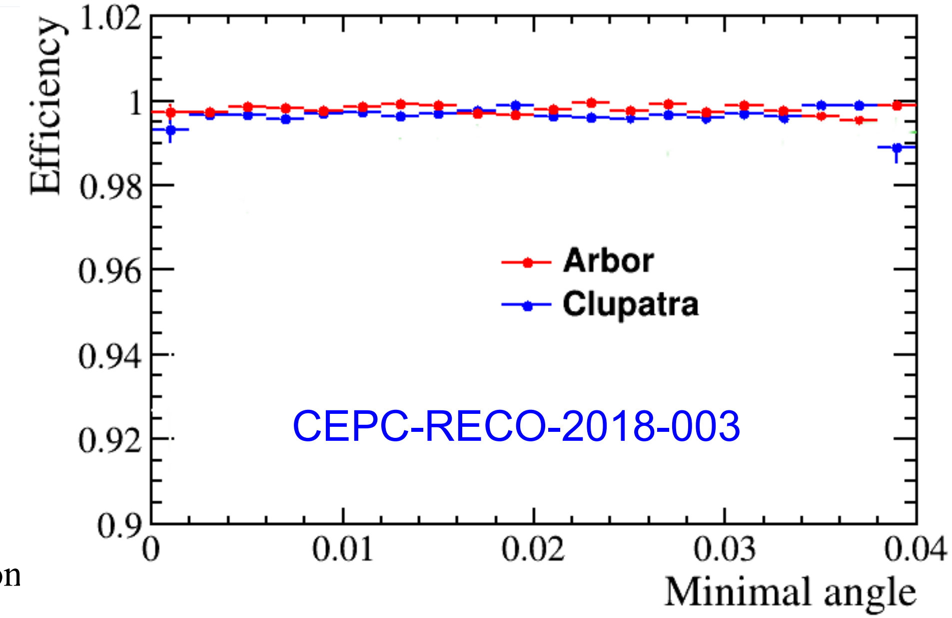
https://arxiv.org/pdf/1810.09037.pdf

Tracking



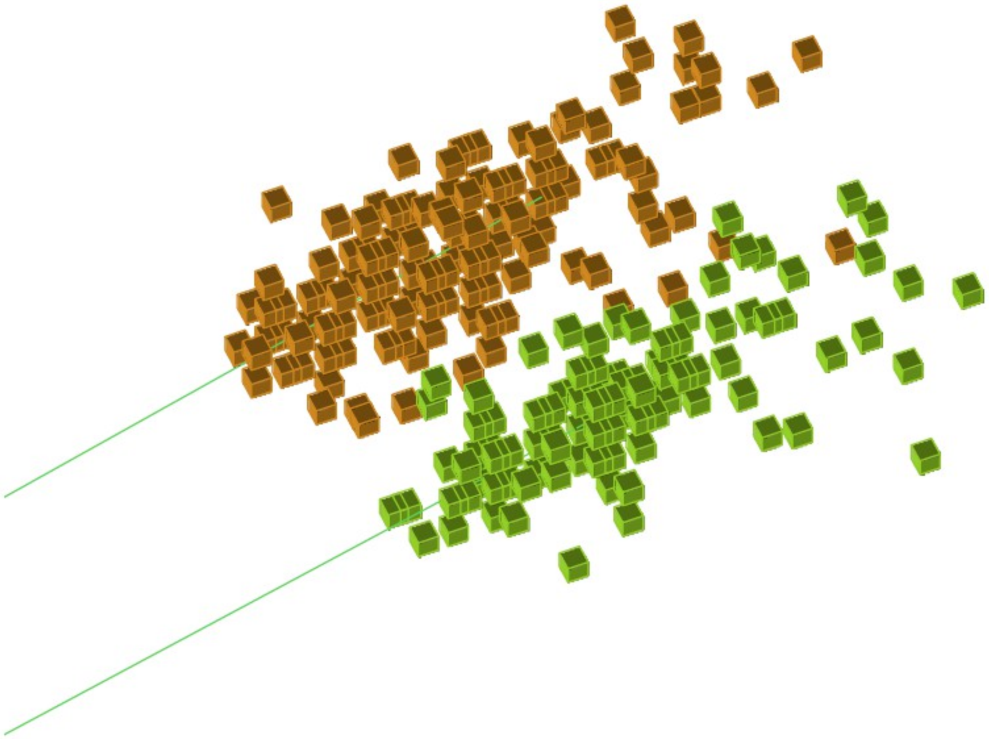


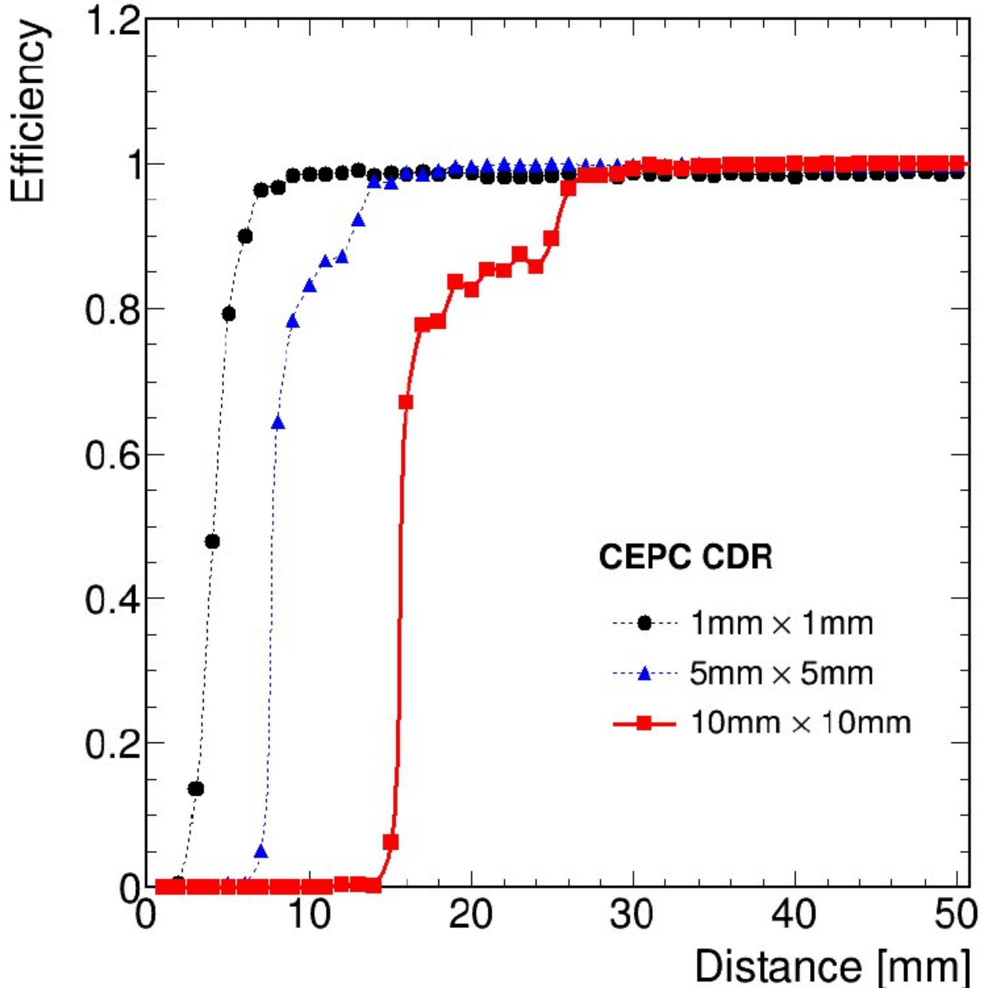




See Mingrui Zhao's talk

Clustering

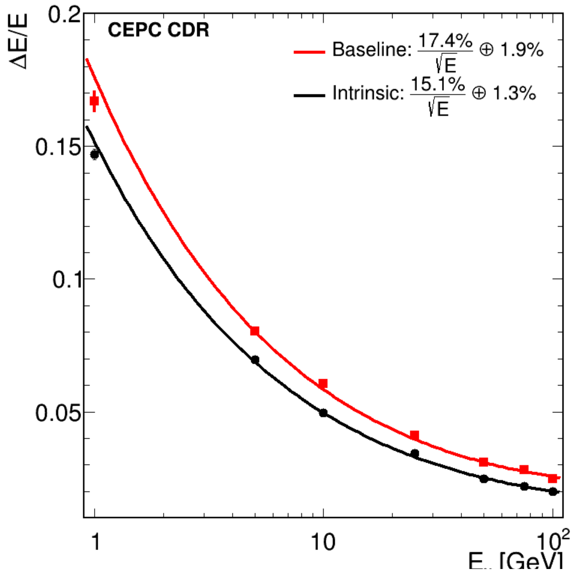


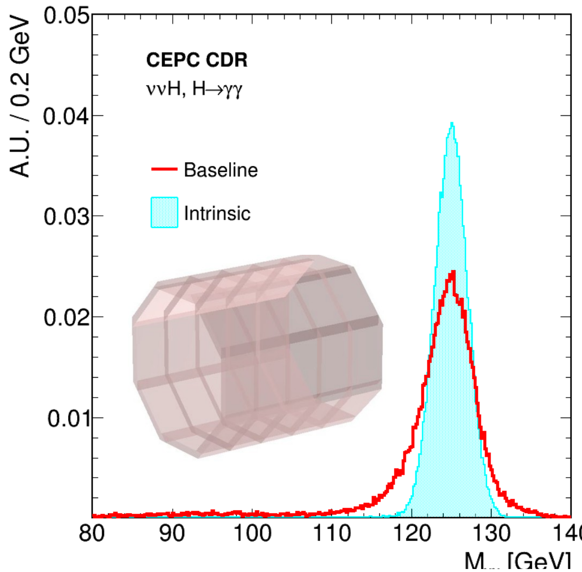


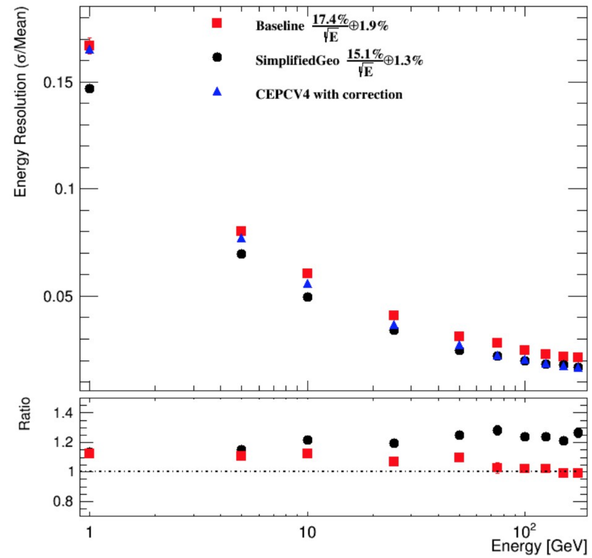
Critical energy to separate an evenly decay π_0: 30 GeV

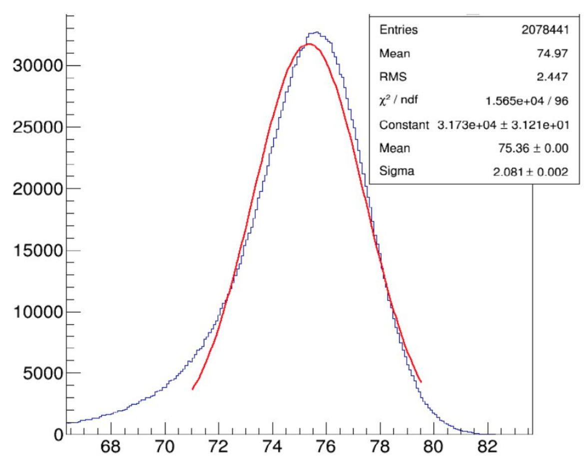
See Hang Zhao's talk

Photon: resolution

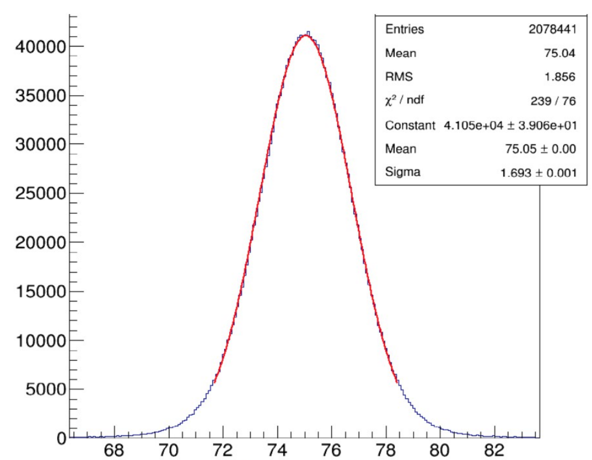








Before correction

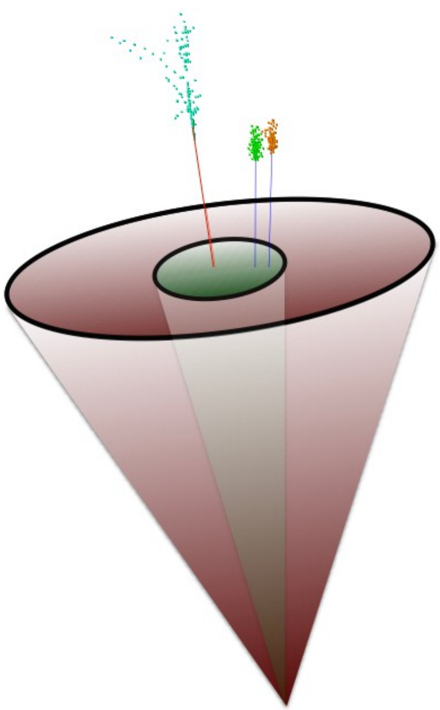


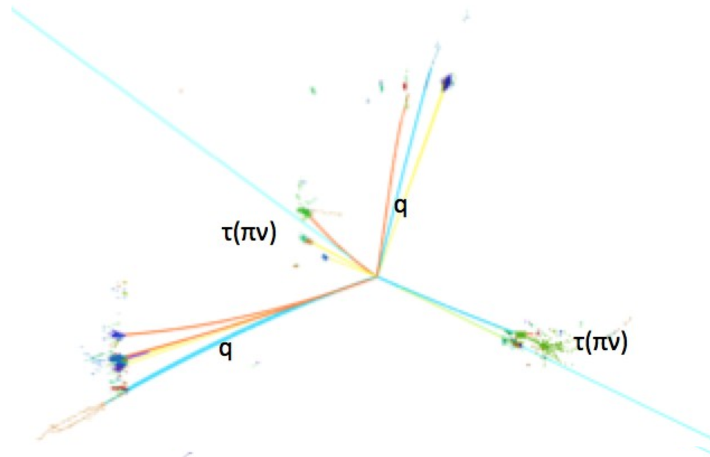
After correction

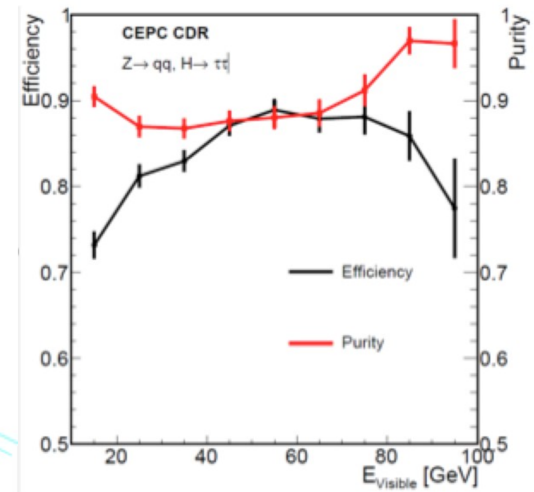
- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/baseline geometry
- The geometry defects correction could be efficiently corrected (Preliminary)

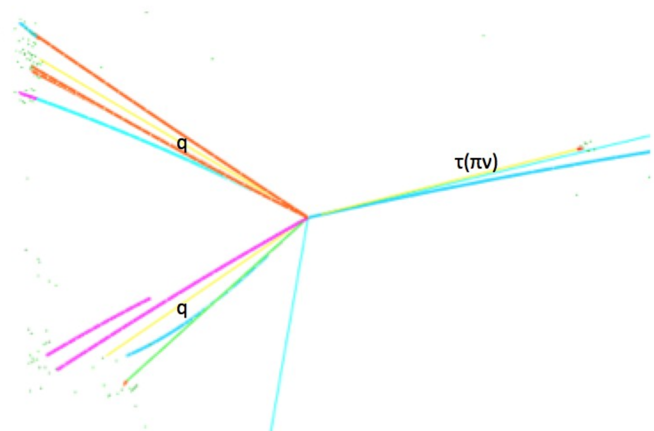
See Yuqiao Shen's talk

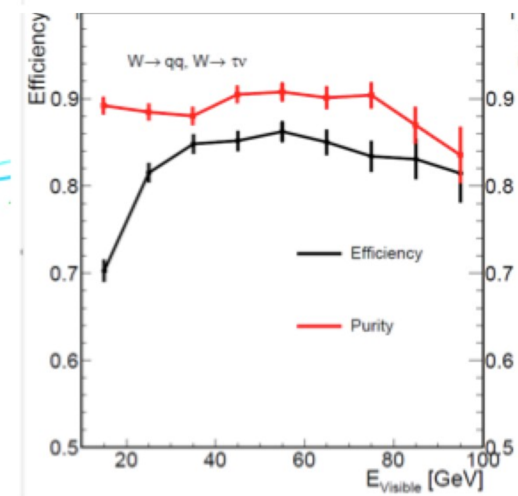
Tau finding at hadronic events











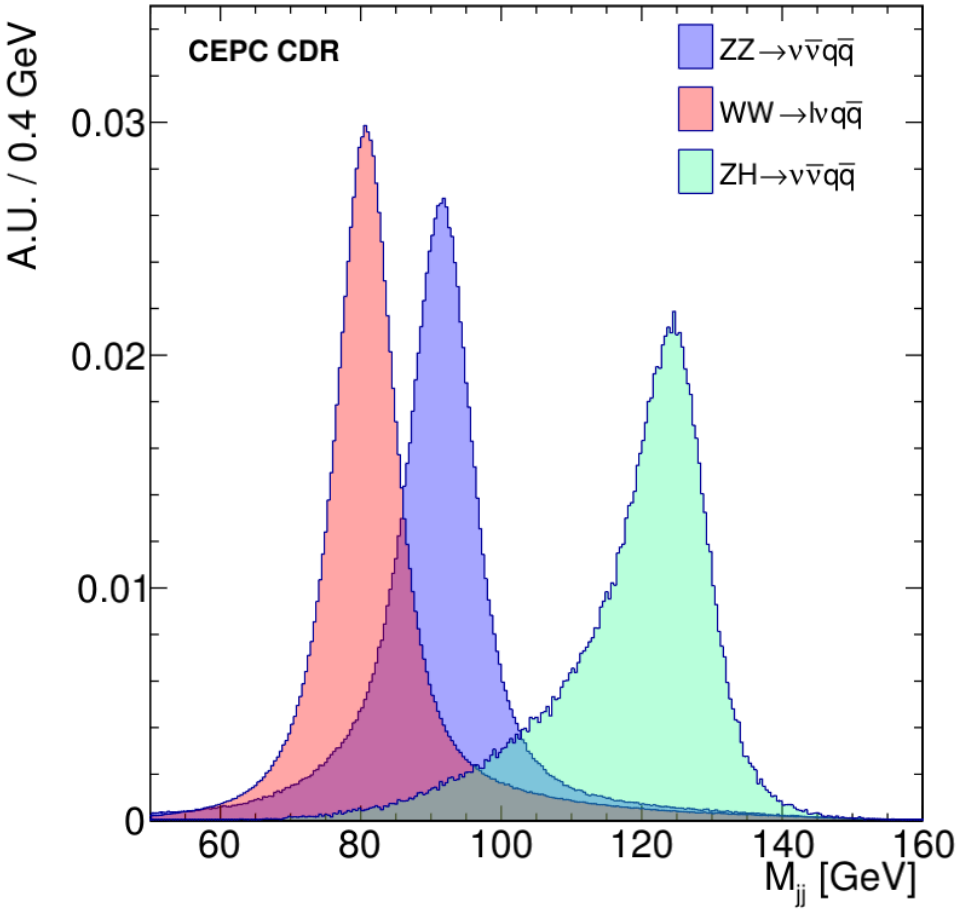
TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for qqττ, and qqτν events

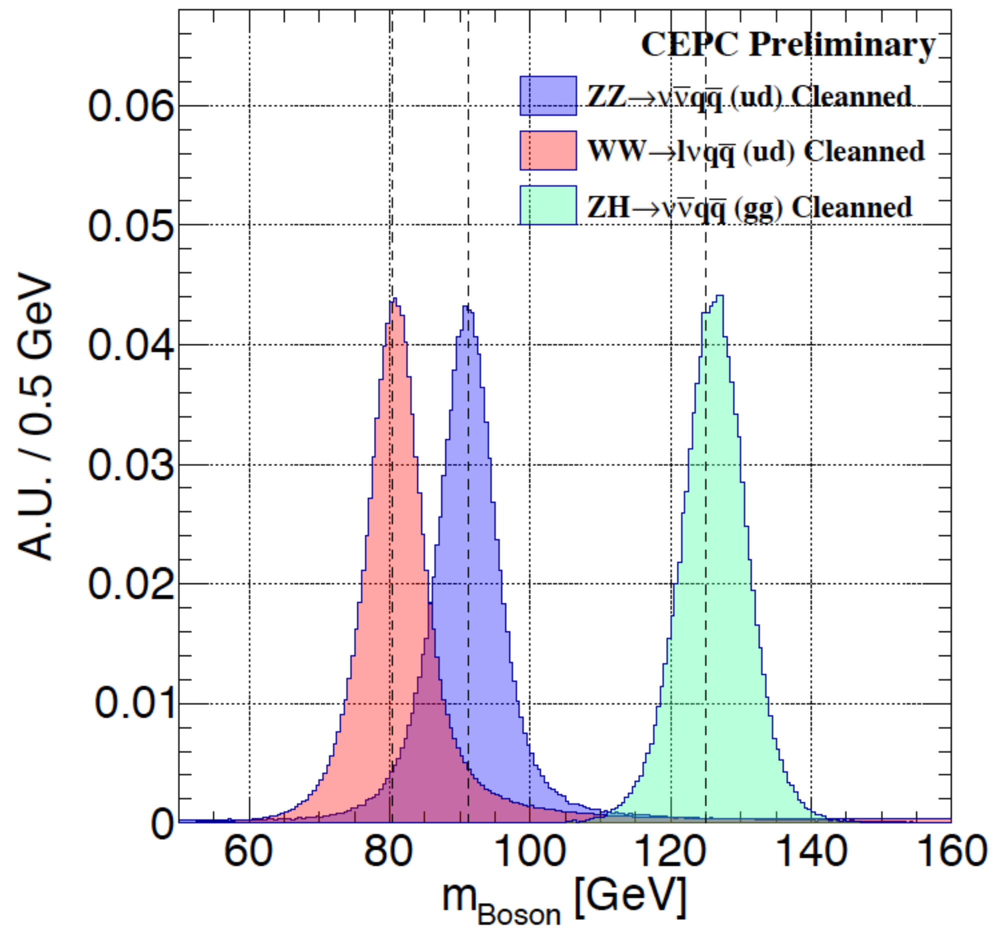
See Zhigang Wu's talk

Jets

- Boson Mass Resolution: Total reconstructed mass of hadronic events
  - 3.8% at baseline (benchmarked with vvH, H→gluons process)
  - Be applied directly to event with one color singlet
    - W, Z, H signal separation at lvqq, ll(vv)+qq events (Appreciated in Triplet Gauge Boson Coupling measurements)
    - Analysis of qqH, Higgs decays into non-jet final states, for example, qqH, H→taus, inv, photons, muons...
    - ...
- Jet Clustering: Single jet response (Jet energy scale/resolution)
  - Differential measurements with jet directions
  - Events with more than one color singlet:
    - WW/ZZ/ZH event separation in 4-jet final state
    - ...

Massive Boson Separation





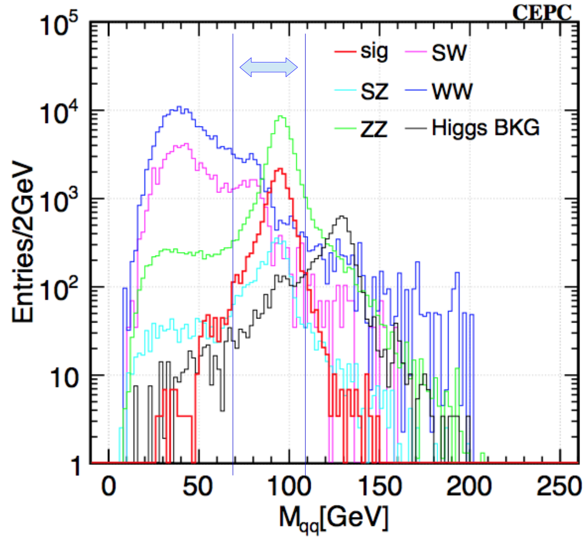
See Peizhu Lai's talk

WW sample: using μνqq sample,
Plot: the visible mass without the muon

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

An Analysis Example: *g(Hττ)* at qqH

- TAURUS: di-tau system
- The rest particles are identified as the di-jet: to distinguish the ZZ/ZH background & **Improves the accuracy by more than a factor of 2**
- Isolated tracks are intensionally defined as tau candidate: be distinguished by the VTX



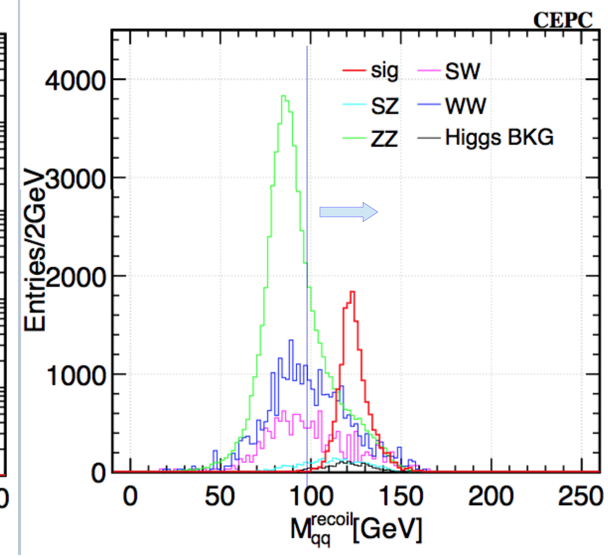


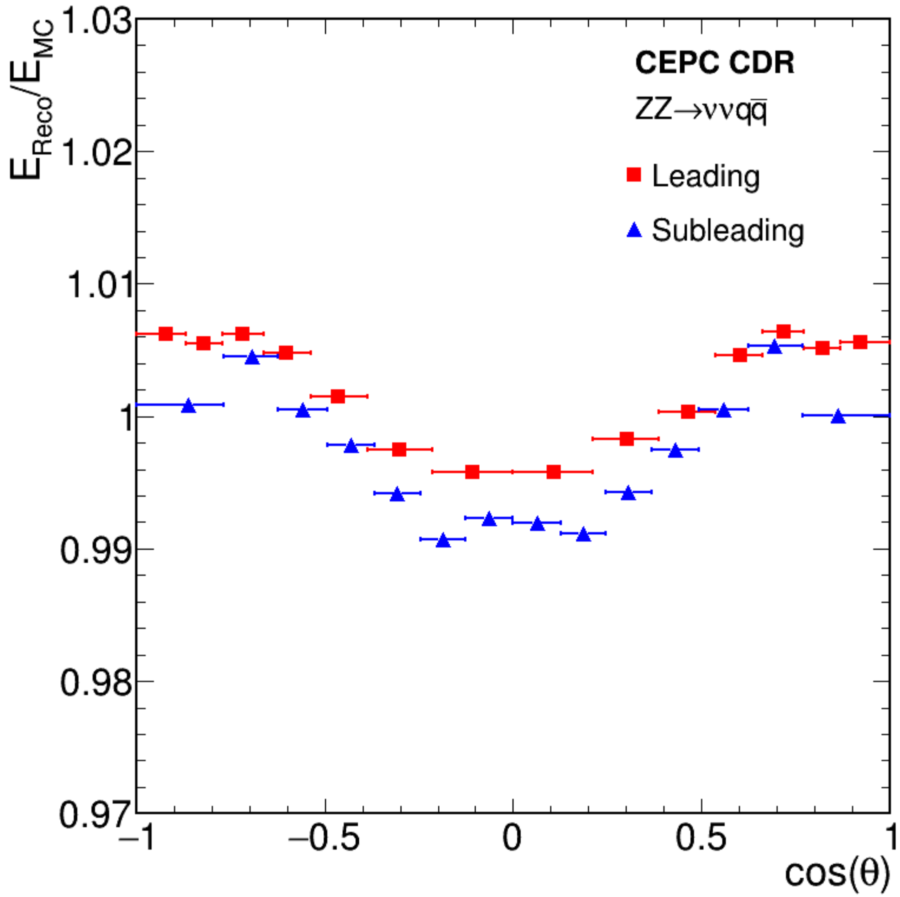
Table 6 Cut Flow of MC sample for qqH→ $\tau\tau$ selection on signal and inclusive SM backgrounds, $E_{Le}/E_{L\mu}$ represents the energy of the leading election or muon, $M_{\tau\tau}^{col}$ is the $\tau\tau$ mass calculated with collinear approximation, Pull1 and Pull2 are the pulls of the leading τ pairs.

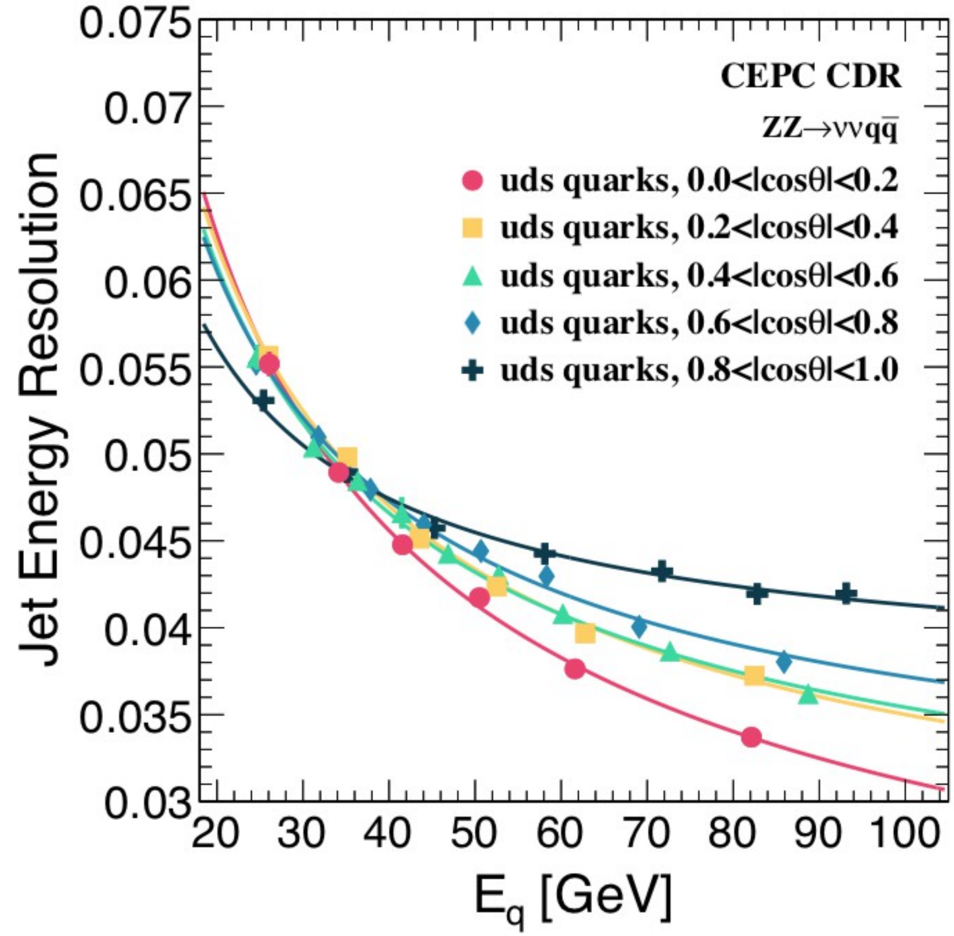
	2f	sw	sz	WW	ZZ	$qqH\tau\tau$	total Bkg	$\sqrt{S+B}/S\,(\%)$
Total Statistic	722467499	17600512	8181853	45834351	5552013	43526	799636228	64.96
NCh>10	246181175	12413358	1776493	42431059	4996124	42697	307798209	41.09
$110GeV < E_{tot} < 235GeV$	156540856	11866685	850064	28223344	2736725	41647	200217674	33.97
$E_{Le} < 45GeV, E_{L\mu} < 65GeV$	152933720	3078507	637585	20225454	2464417	39762	179339683	33.68
$N_{\tau^+} > 0, N_{\tau^-} > 0$	361749	191343	12624	1018569	105854	20212	1690139	6.47
$90GeV < M_{\tau\tau}^{col} < 160GeV$	8762	19373	1521	122226	36453	15489	188335	2.91
$70GeV < M_{qq} < 110GeV$	1439	3715	912	24188	31244	14660	61498	1.88
$M_{qq}^{rec}(GeV) > 100GeV$	0	1319	573	9983	8424	14619	20299	1.27
$Pull1 > 0, Pull2 > 0$	0	590	238	3426	6266	12402	10520	1.22

See Dan Yu's Poster

BMR < 4% (baseline of 3.8%) is crucial

Jet Energy Scale & Resolution

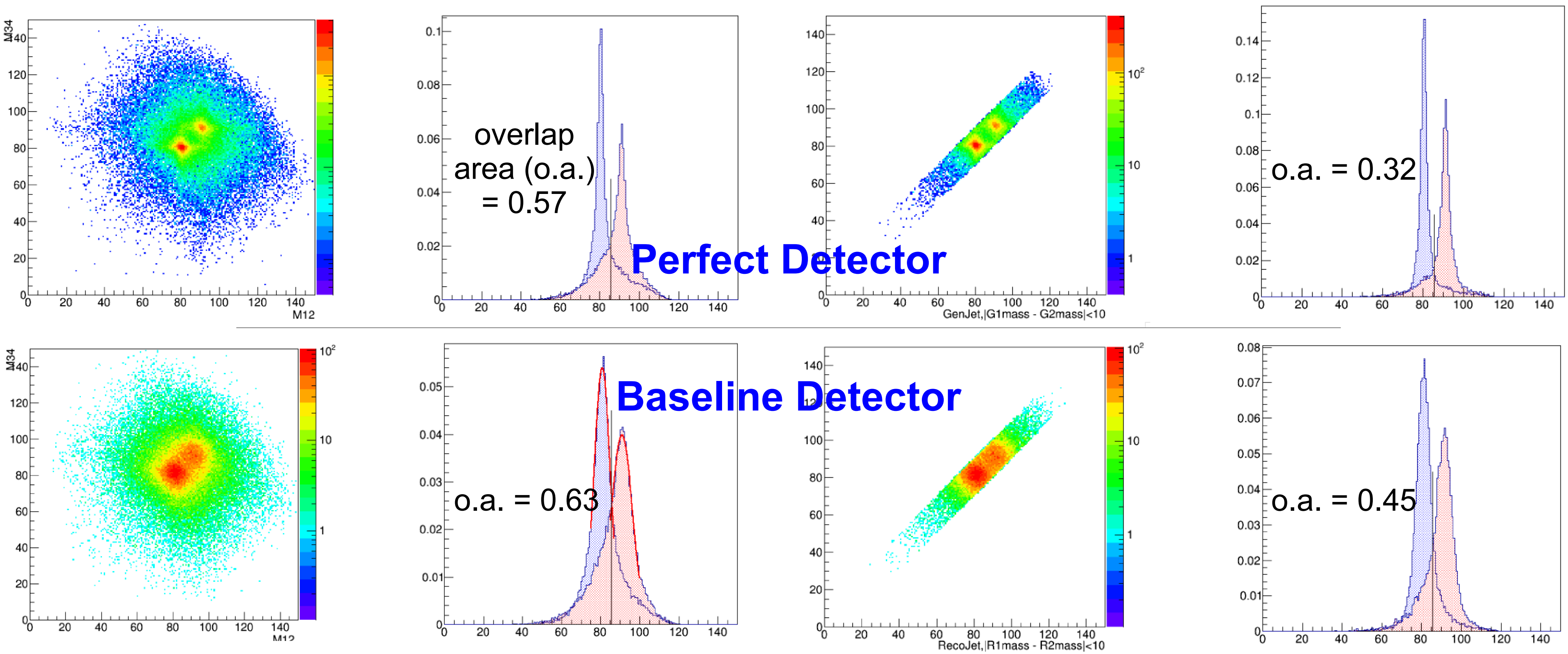




- JES ~ with 1% of the unity (without correction)
- JER ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
- **Both Superior to LHC experiments by 3-4 times**

See Peizhu Lai's talk

Can we separate the full hadronic WW/ZZ events: Yes!...



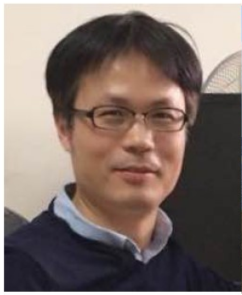
- Force all reconstructed particles into 4 jets, identify the event with minimal chi-2. Preliminary Jet clustering optimization is performed to minimize Overlap Area
- Separation power is mainly limited by the Jet-Clustering

See YongFeng Zhu's talk

Summary

- CEPC, a super Higgs/W/Z factory, requests high **efficiency, purity,** and **precision** reconstruction of all key physics objects
  - Tracker & Calorimeter intrinsic resolution: better is better!
  - BMR < 4% is crucial
- Performance at the baseline (APODIS + Arbor) fulfills the physics requirements
  - All key physics objects tamed
  - Clear Higgs signature in all SM Higgs decay modes
  - Clear distinguish between the Signal and SM backgrounds → 0.1% – 1% relative error in Higgs coupling measurements
- To do
  - Reconstruction - Optimization, iterate with detector design: to address the challenges at TDR
  - Identification of jet, jet flavor, gluon jet, and **color singlet**
  - Data preservation, deep learning, parallel computing
  - Lots of challenges & excitements

Many Thanks to


C. Fu, Geant 4 & Tracking


X. Zhao, Software & production


Dan, Lepton ID, Tau, PFA

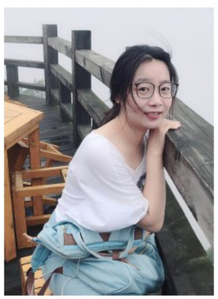

P. Lai, Jet Calibration


F. An, Pid & Flavor


Z. Wu, VTX Optimization


H. Liang, Generator


Y. Wang, Calo optimization


Y. Shen, Photon


M. Zhao, Tracking, TPC,


G. Li, Generator & Flavor tagging


H. Zhao, Calo Optimization & PFA


Y. Zhu, Jet Clustering


T. Zhen, K_short & Lambda

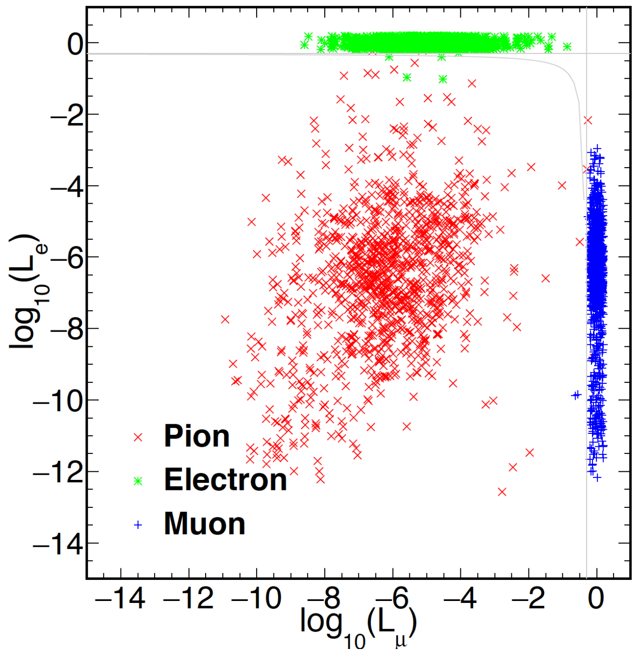

M. Ruan, PFA, Object,...

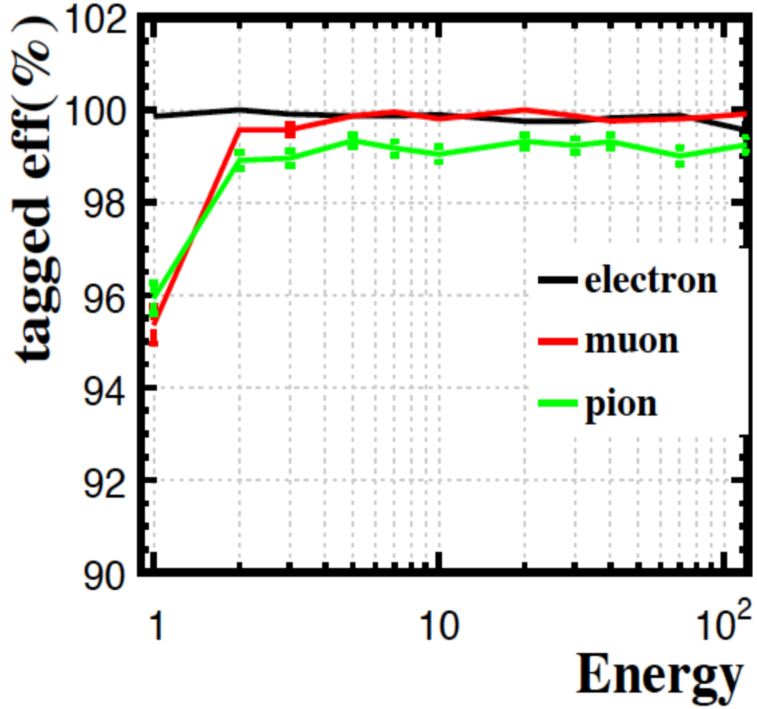
See also:

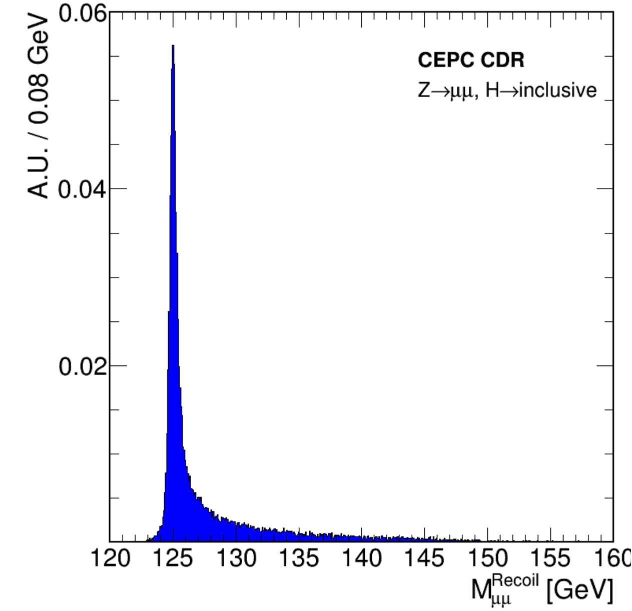
Xianghu Zhao & Mingrui Zhao's talks on Software/production
Taifan Zhen's talk on Ks & Λ reconstruction
Hao Liang & Fenfen An's talks on Higgs/Flavor benchmark analysis
YueXin Wang's Poster on Alternative Calorimeter study

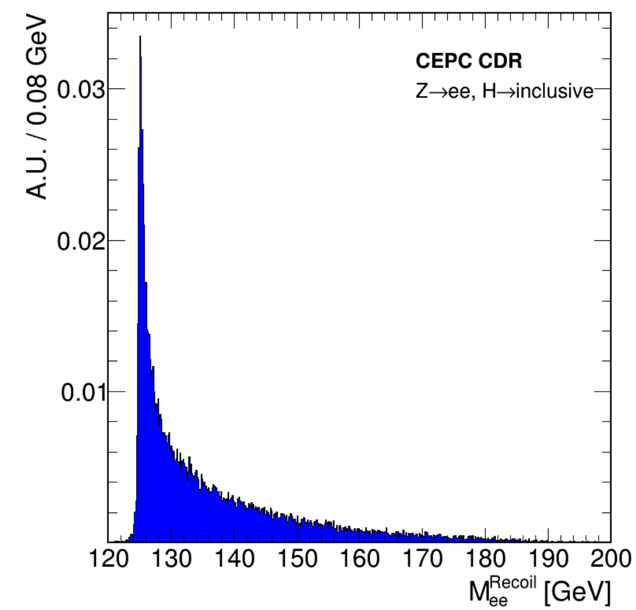
backup

Leptons









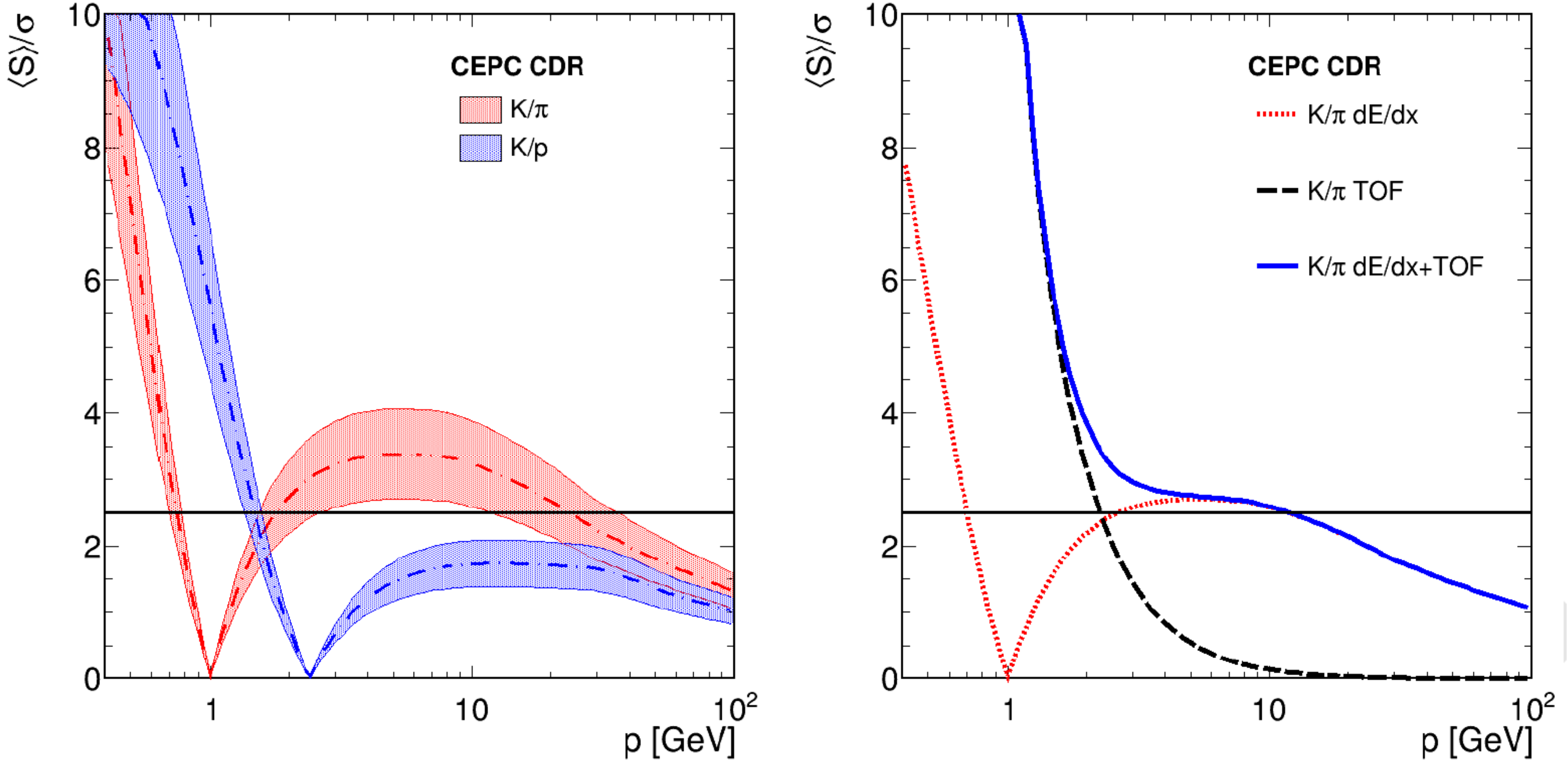
BDT method using 4 classes of 24 input discrimination variables.

Test performance at: Electron = E_likeness > 0.5 ; Muon = Mu_likeness > 0.5

Single charged reconstructed particle, for E > 2 GeV: lepton efficiency > 99.5% && Pion mis id rate ~ 1%

Eur. Phys. J. C (2017) 77: 591

Kaon



Highly appreciated in flavor physics @ CEPC Z pole

TPC dEdx + ToF of 50 ps

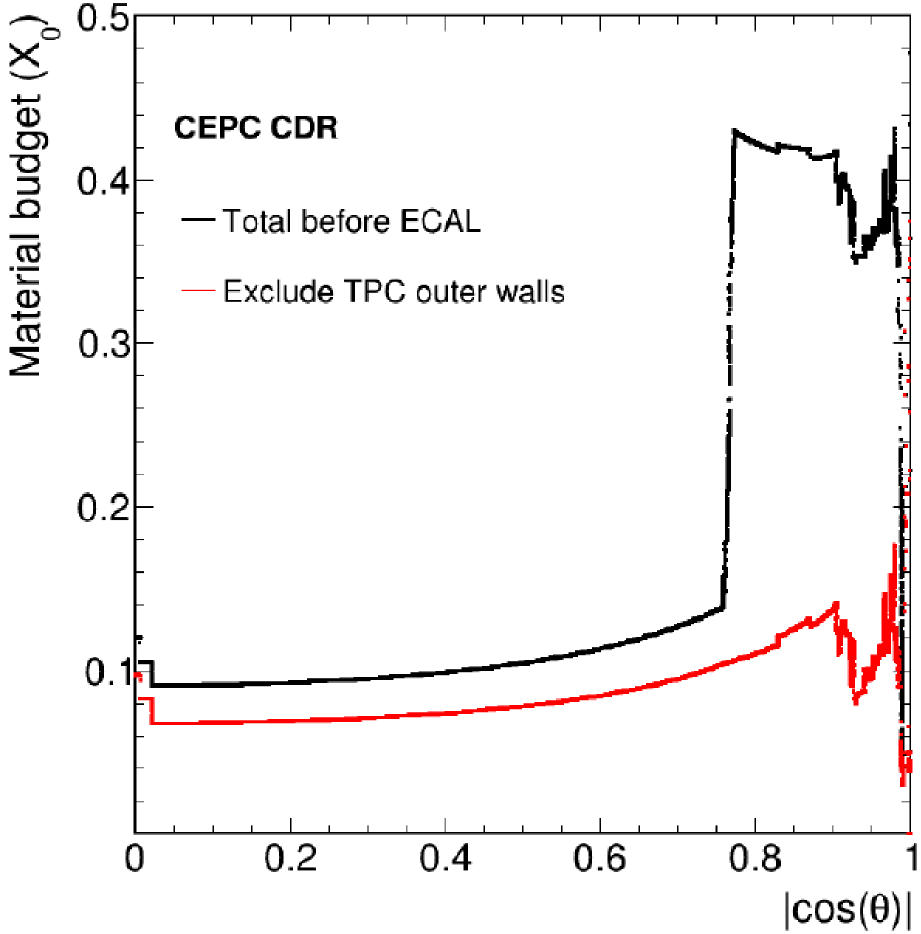
Eur. Phys. J. C (2018) 78:464

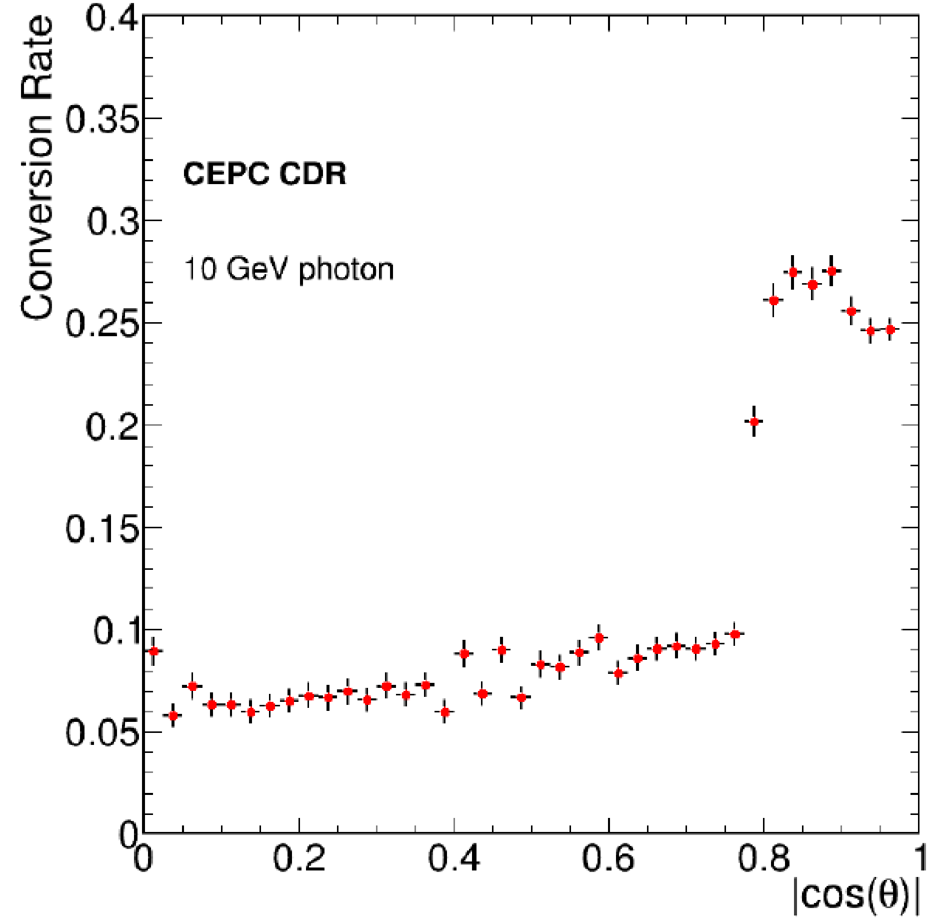
At inclusive Z pole sample:

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)

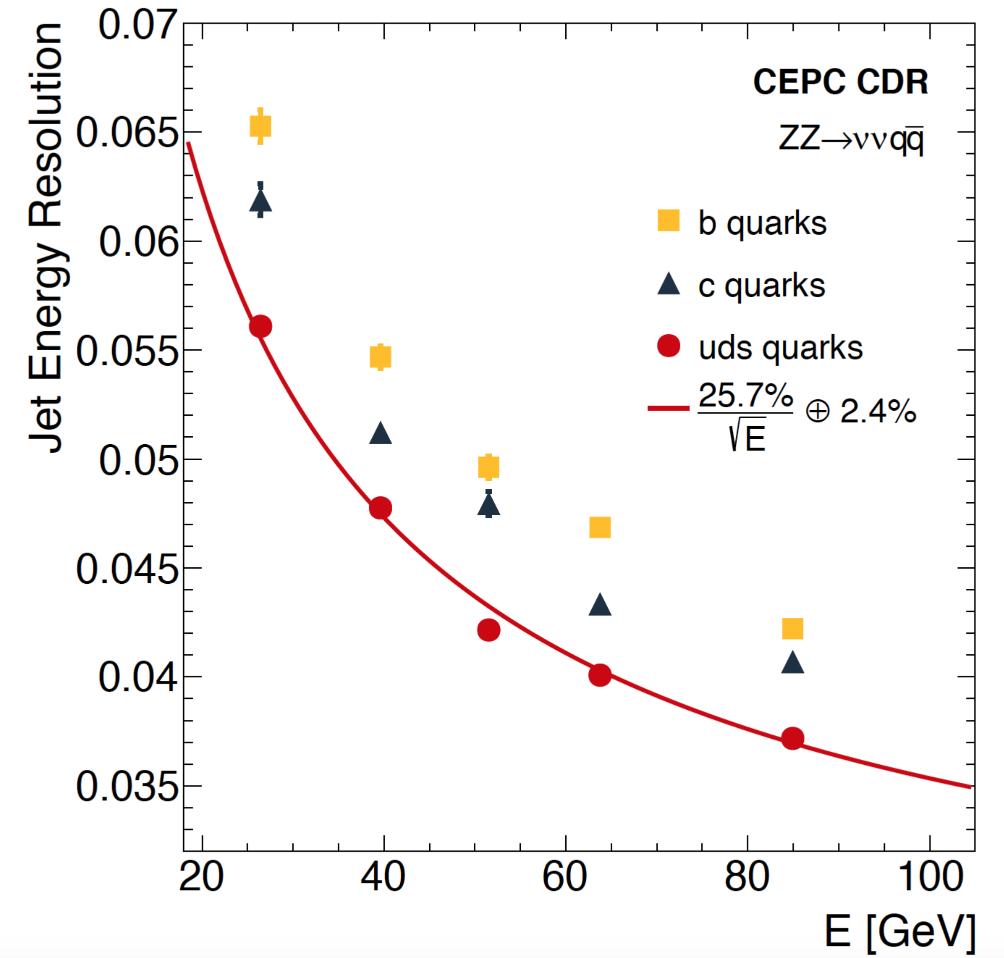
Photons - conversion

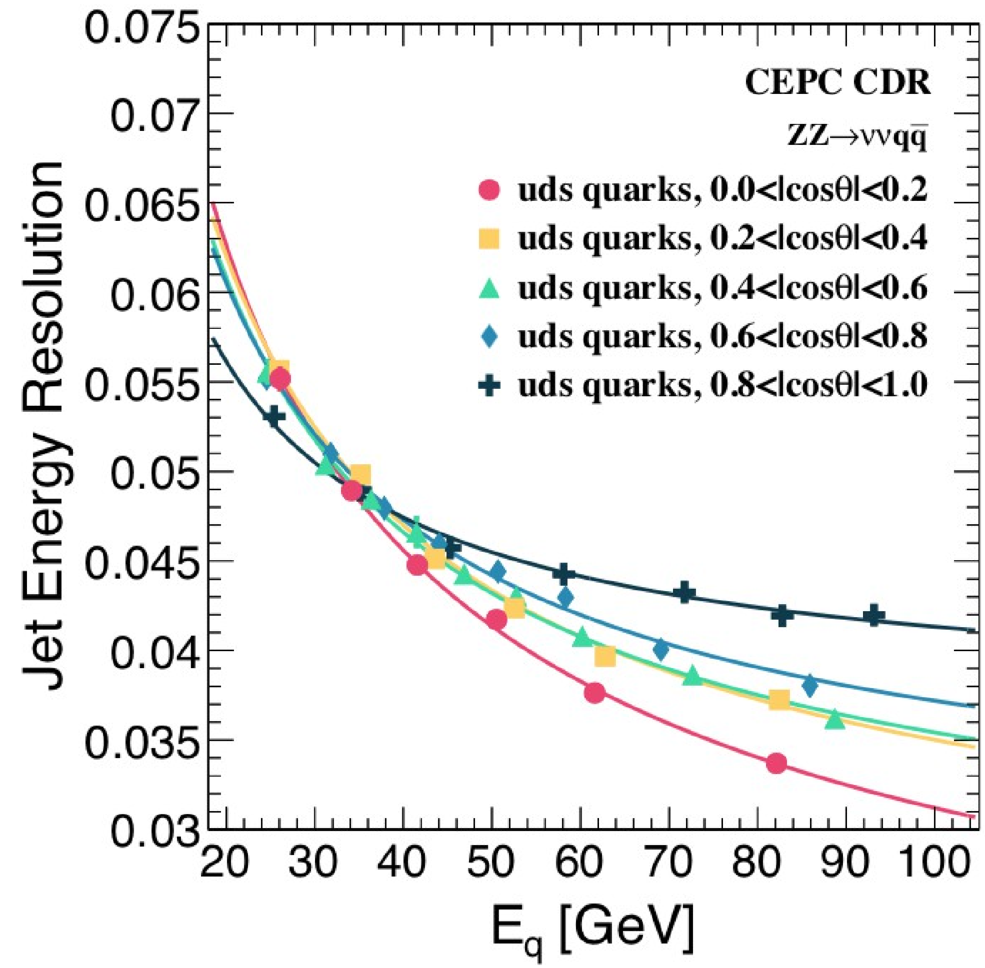




In the barrel region: Roughly 6-10% of the photons converts before reaching the Calorimeter.

Jet Energy Resolution

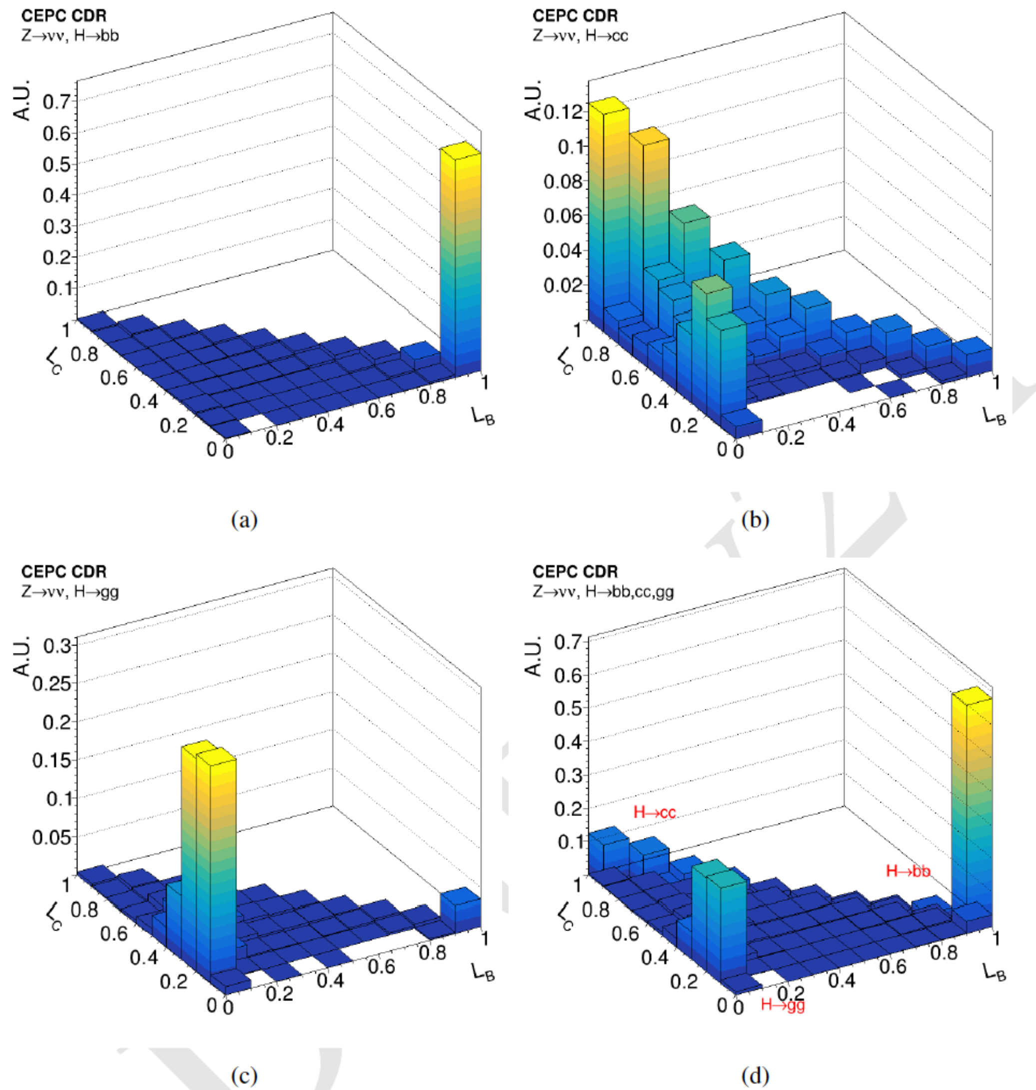




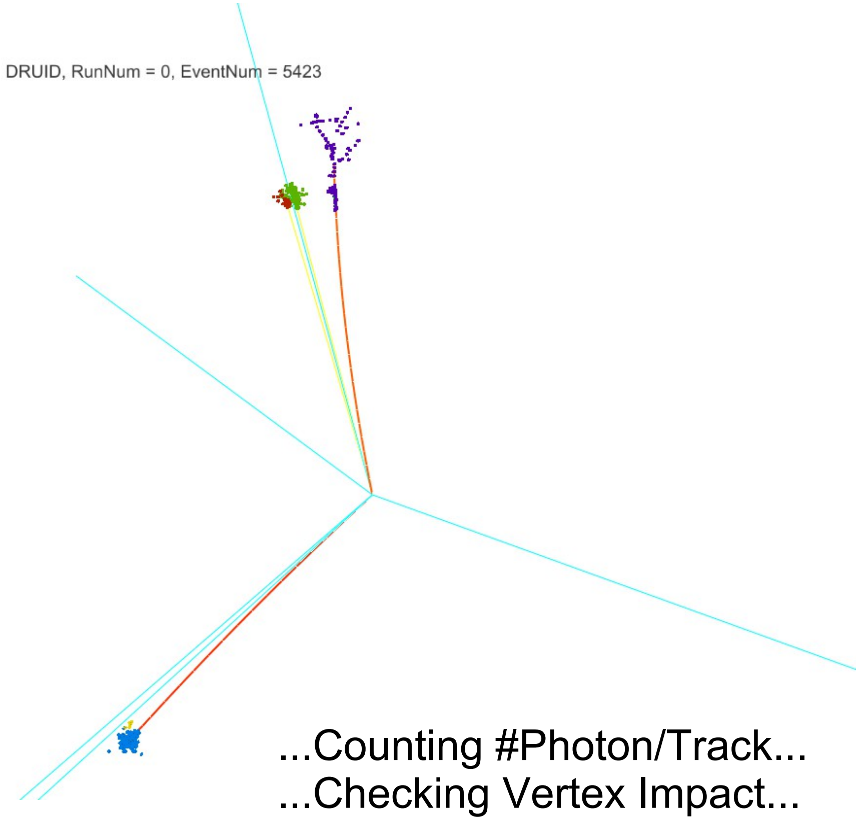
Amplitude ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
Depends on the Flavor, direction and jet energy
Superior to LHC experiments by 3-4 times

Flavor Tagging

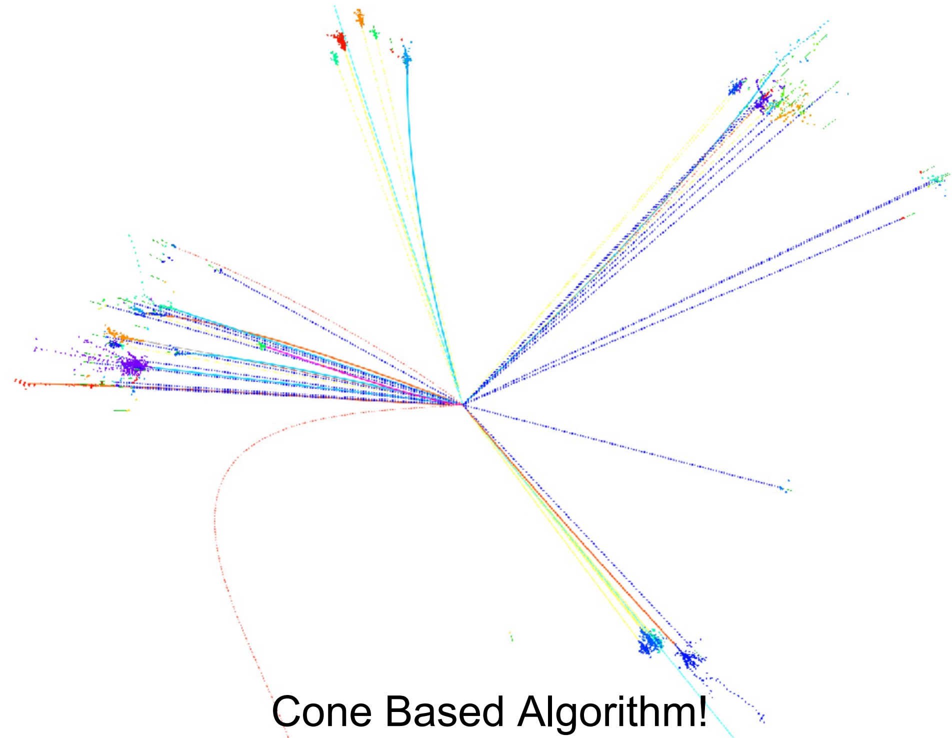
- Using LCFIPlus Package from ilcsoft
- At Higgs->2 jet samples:
  - *Clear separation between different decay modes*
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*



Tau



...Counting #Photon/Track...
...Checking Vertex Impact...

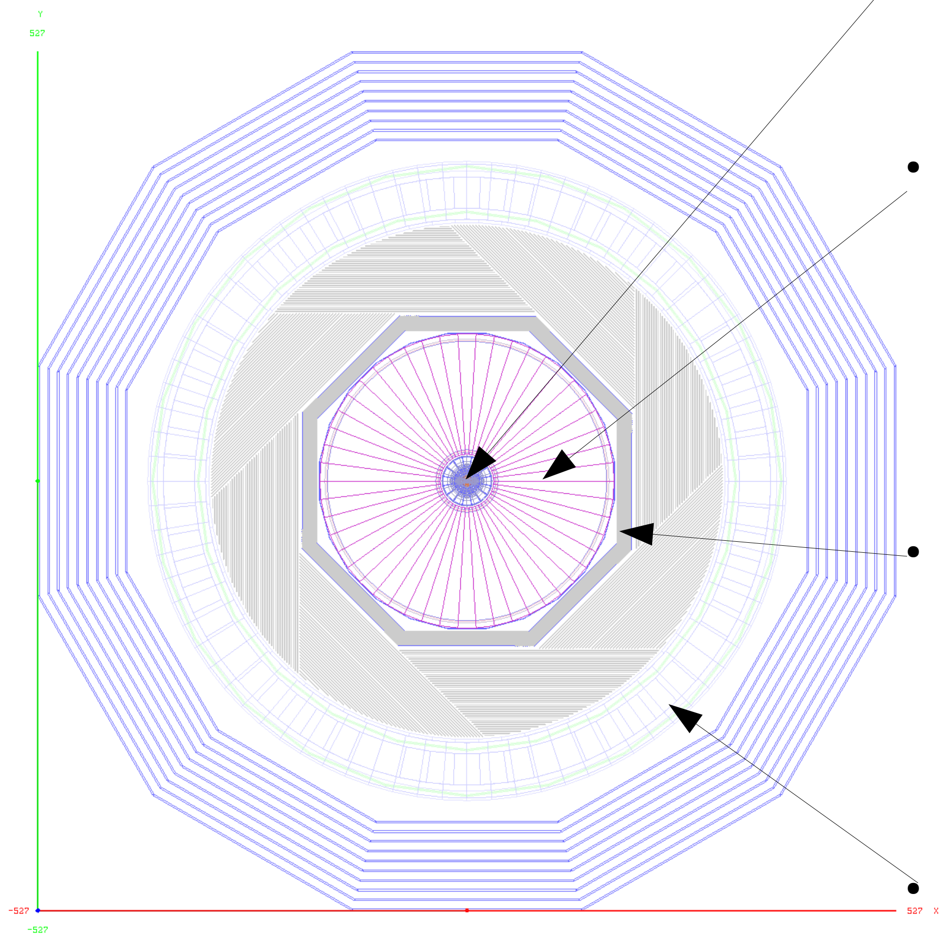


Cone Based Algorithm!
Para. Optimization

- Two catalogues:
  - Leptonic environments: i.e, llττ(ZZ/ZH), ννττ(ZZ/ZH/WW), Z→ττ;
  - Jet environments: i.e, ZZ/ZH→qqττ, WW→qqντ;

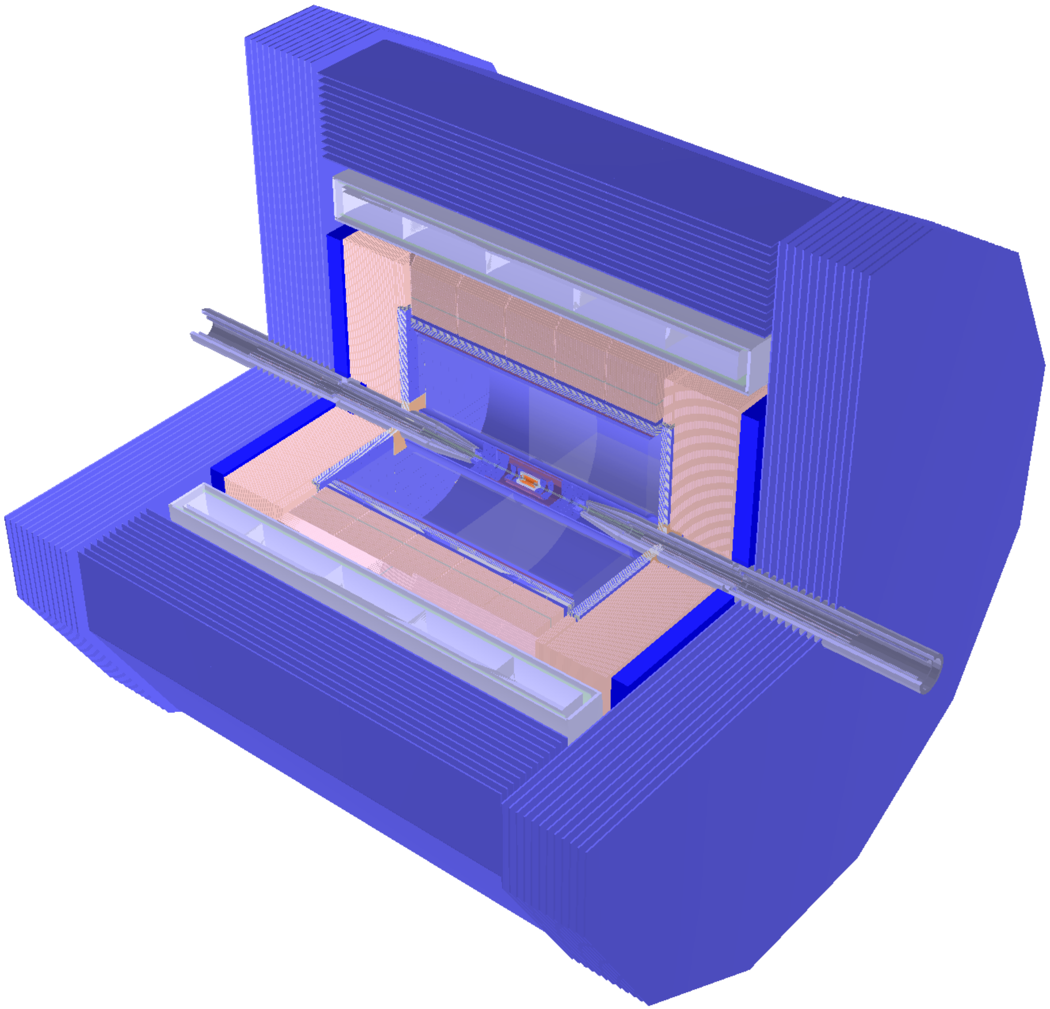
Ph.D thesis: D. Yu, reconstruction of leptonic objects at e+e- Higgs factory

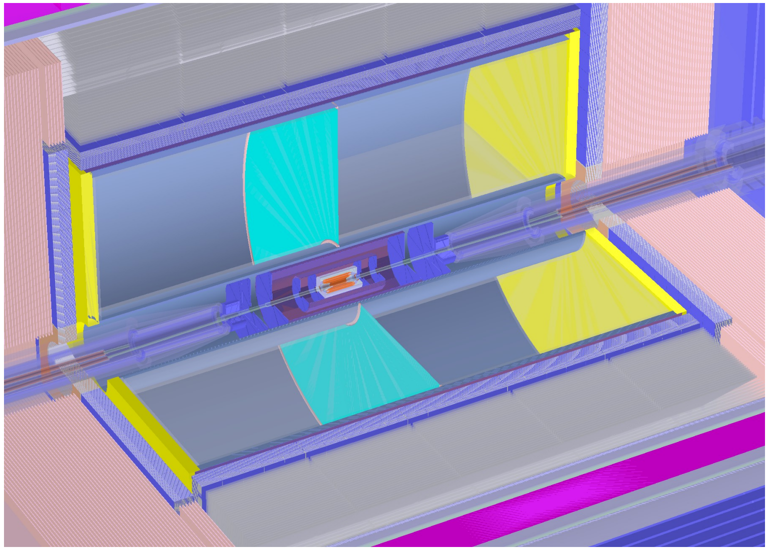
An ILD-like detector at the CEPC

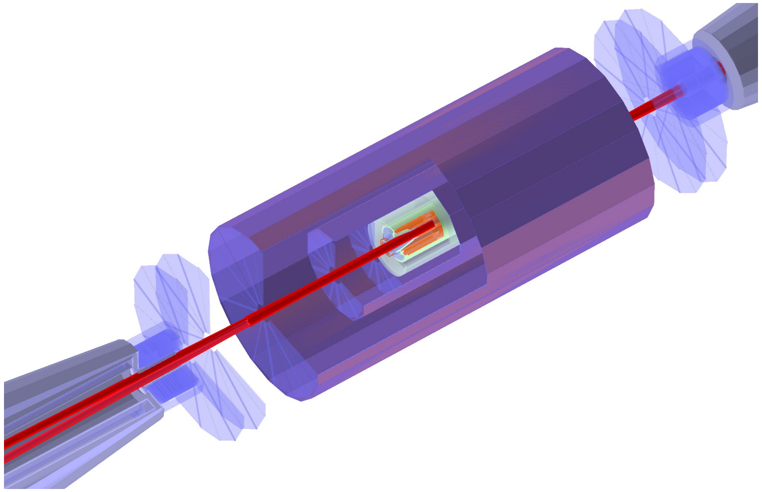


- Different collision environments/rates :
  - MDI design & Implementation: CEPC-SIMU-2017-001
- The CEPC Event rate is significantly higher than linear colliders, charged kaon id can strongly enhance the CEPC flavor physics program
  - TPC Feasibility: JINST-12-P07005 (2017)
  - Pid using TPC dEdx and ToF: Eur. Phys. J. C (2018) 78:464
- No power pulsing at CEPC detector
  - A significant reduction of the readout channel, especially the Calorimeter Granularity: JINST-13-P03010 (2018)
  - HCAL Optimization
- 3 Tesla Solenoid: requested by the Accelerator/MDI

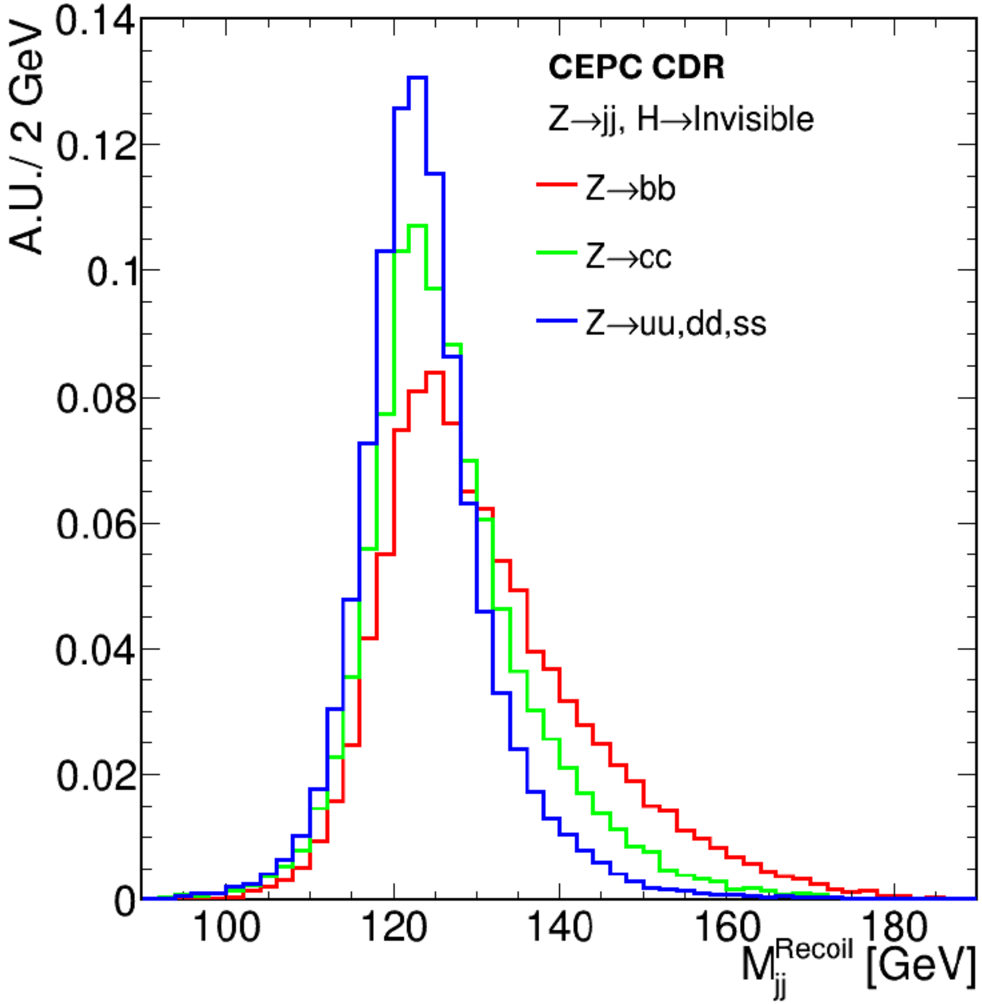
APODIS Geometry

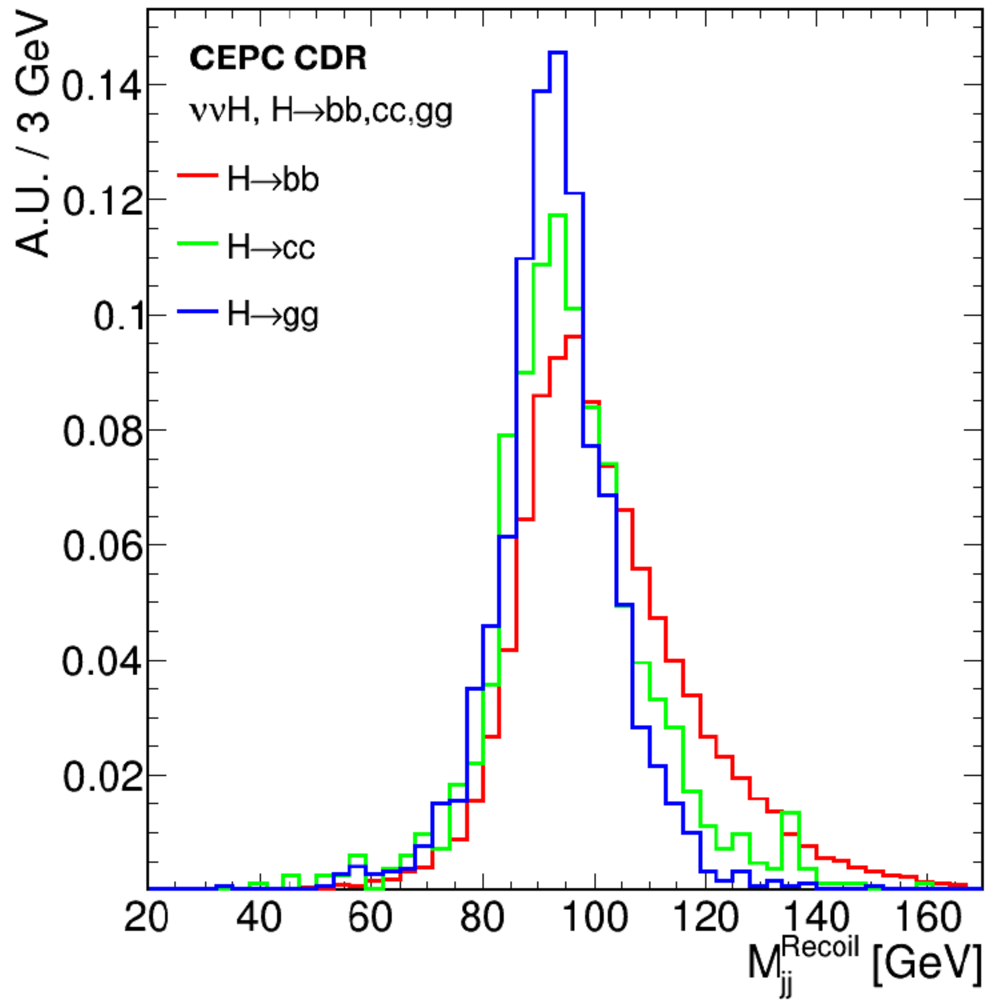






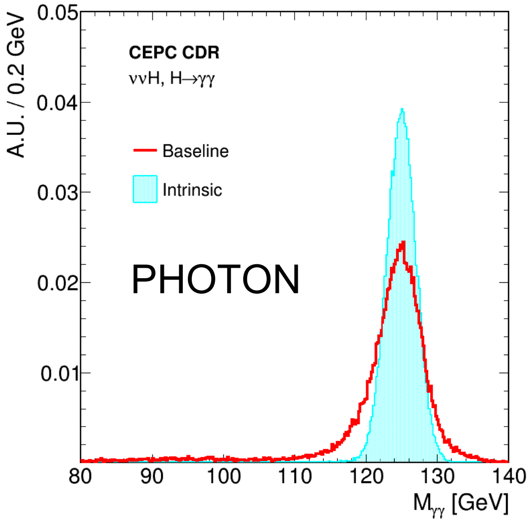
Missing Energy & Momentum



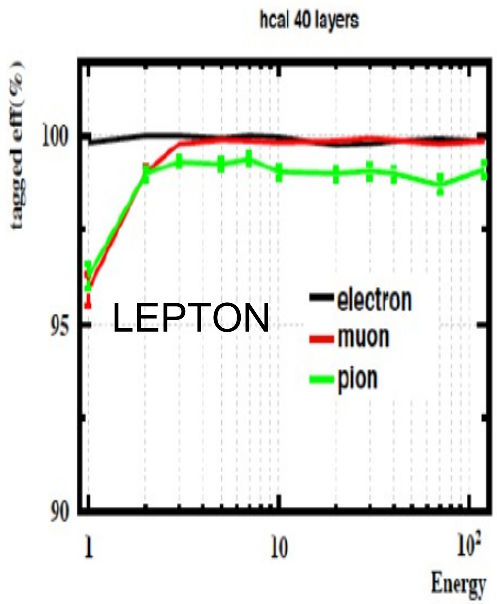


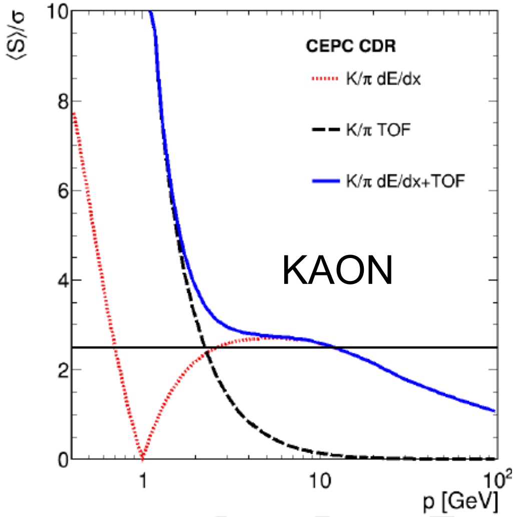
Width of the Light jets: 6GeV/8GeV (Left/Right Plots)

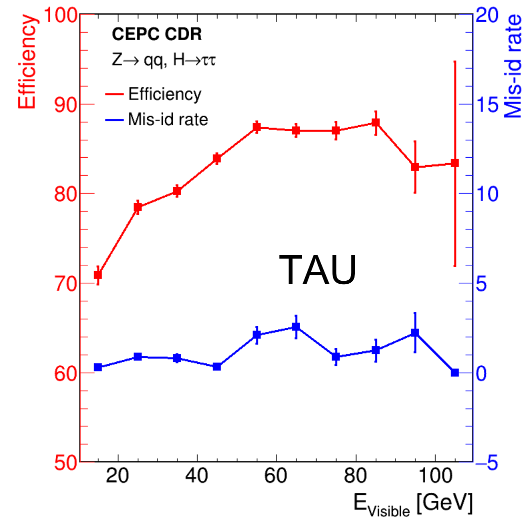
Physics Objects: Tamed

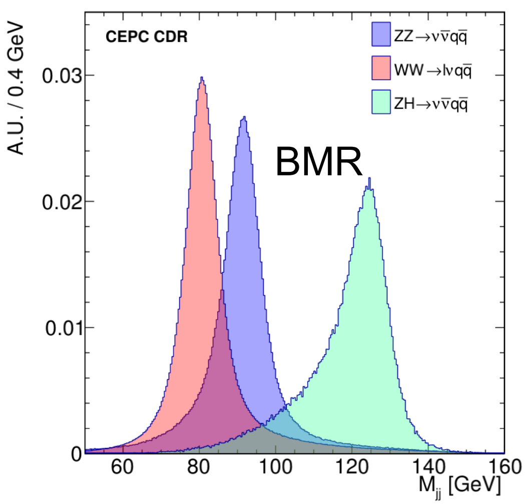


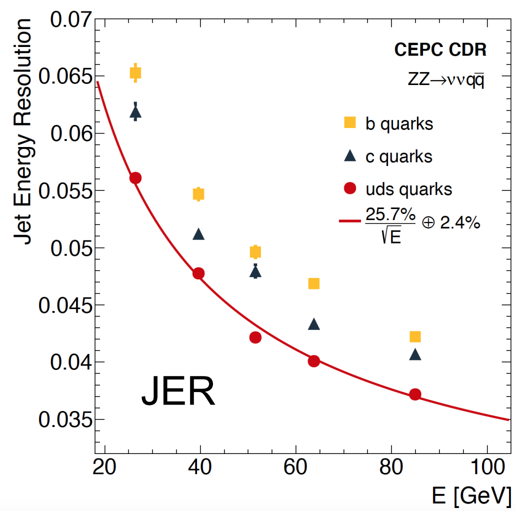
Higgs mass/GeV

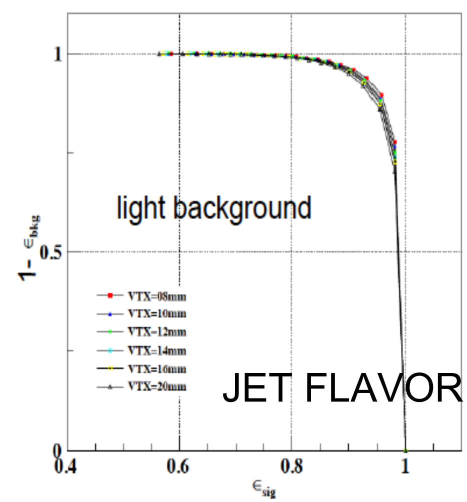


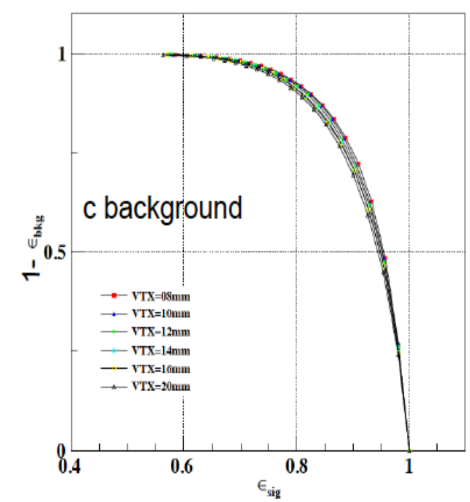




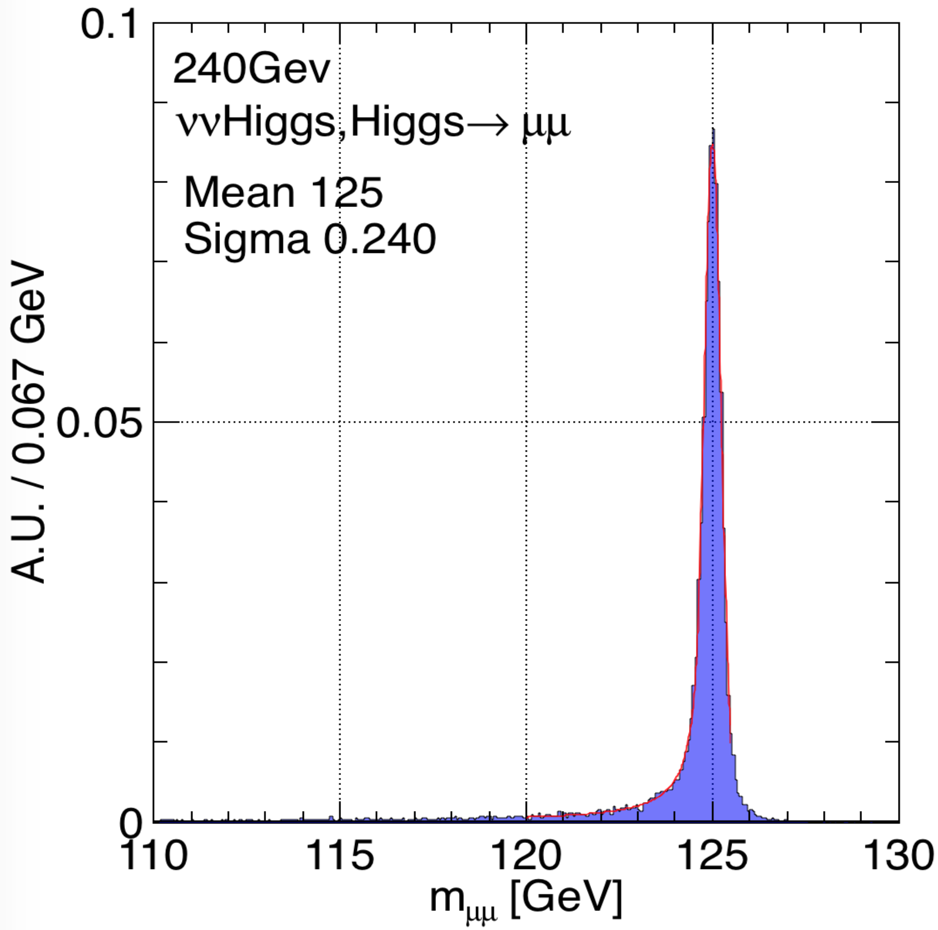


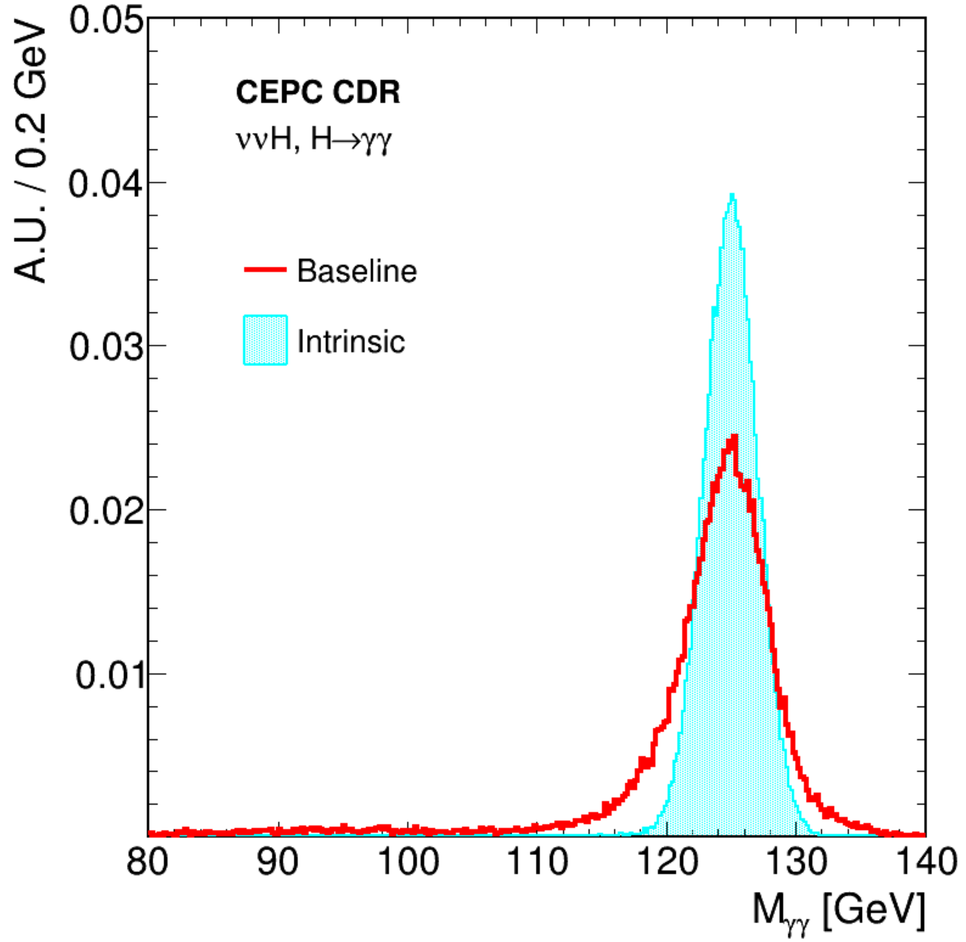






Higgs Signal at APODIS

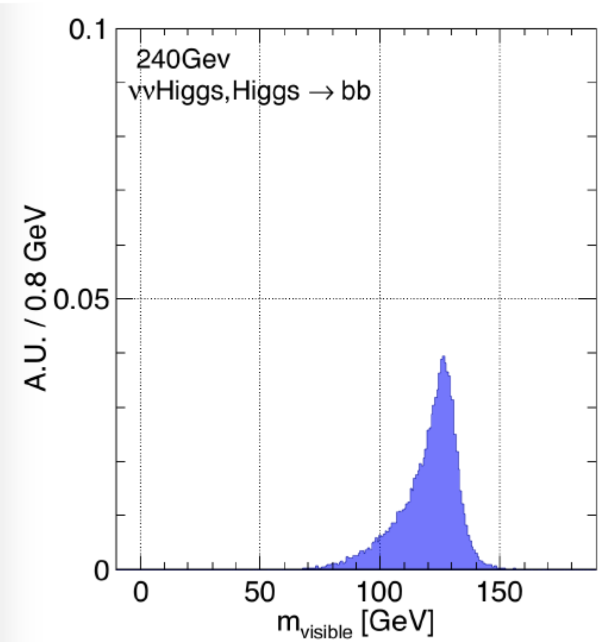


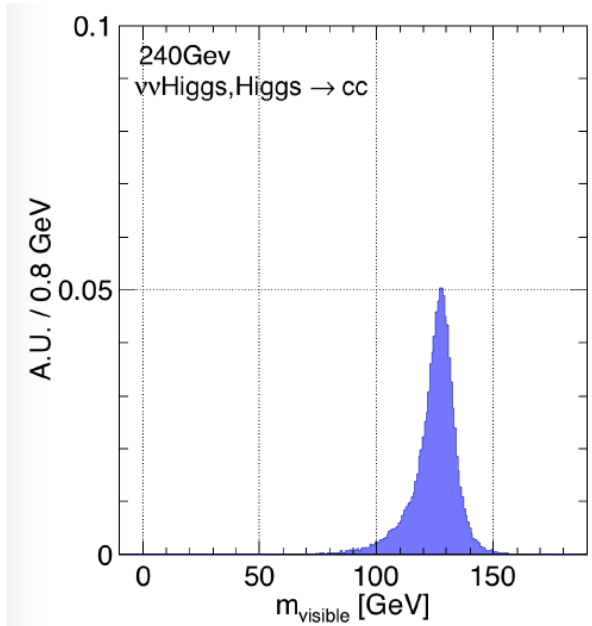


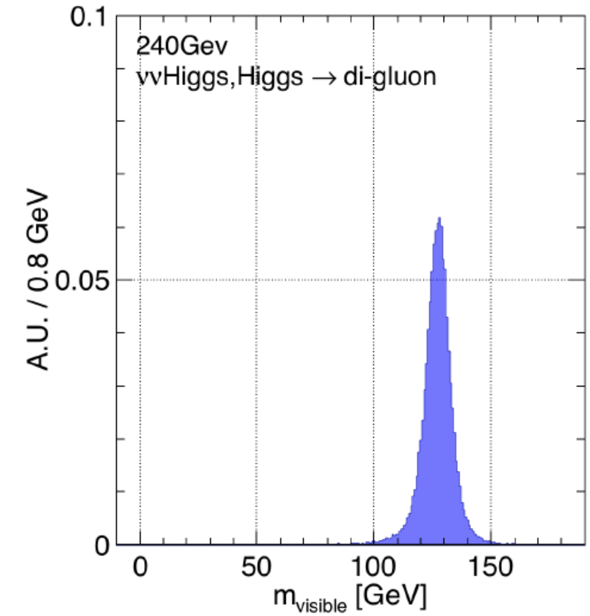
CEPC-RECO-2018-002
CEPC-Doc id 174, 175

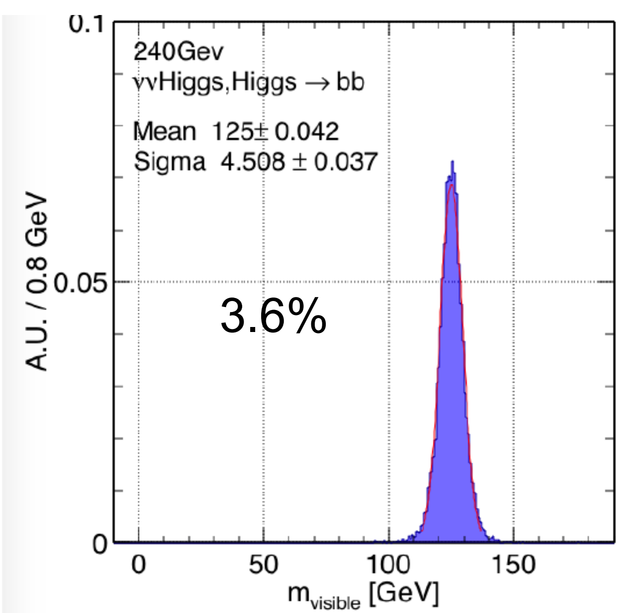
Lepton tracks & Photon Clusters

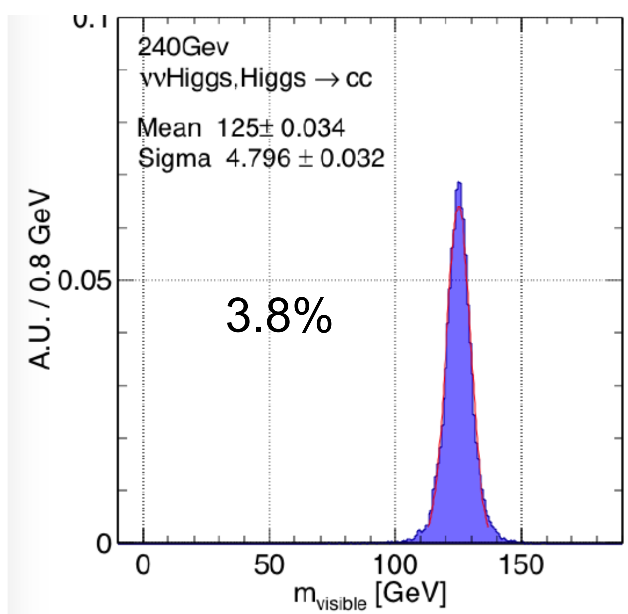
Higgs to bb, cc, gg (Jets)

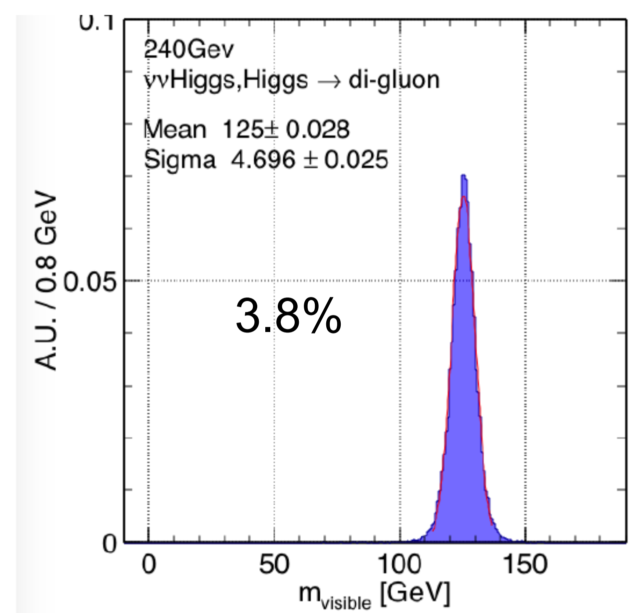




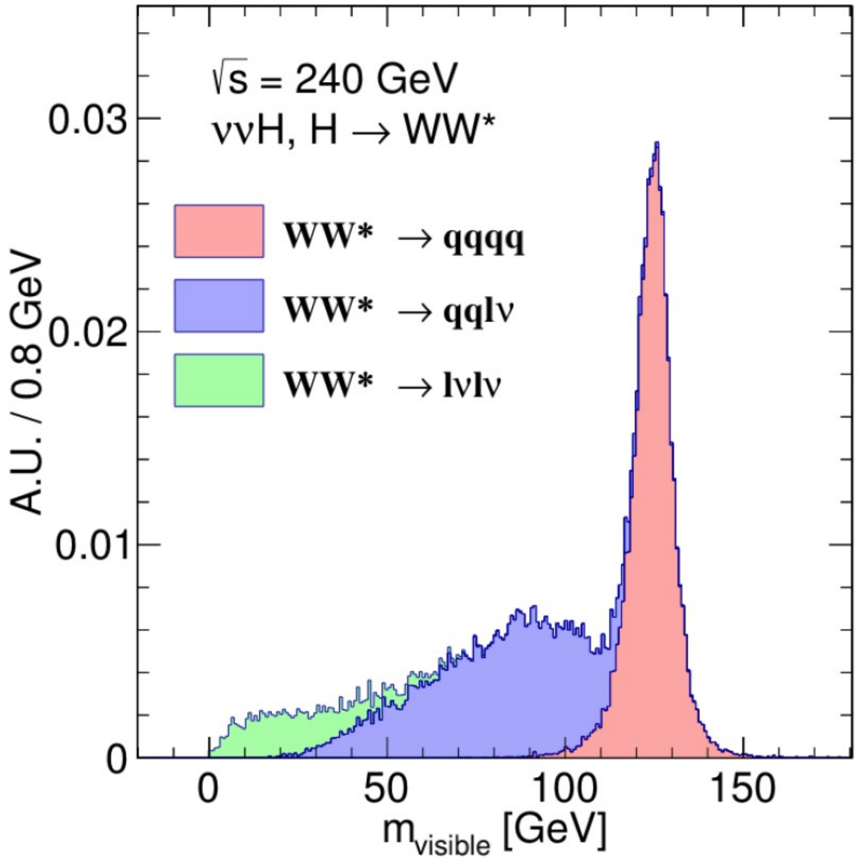








Higgs to WW, ZZ (Jets + leptons + neutrinos)



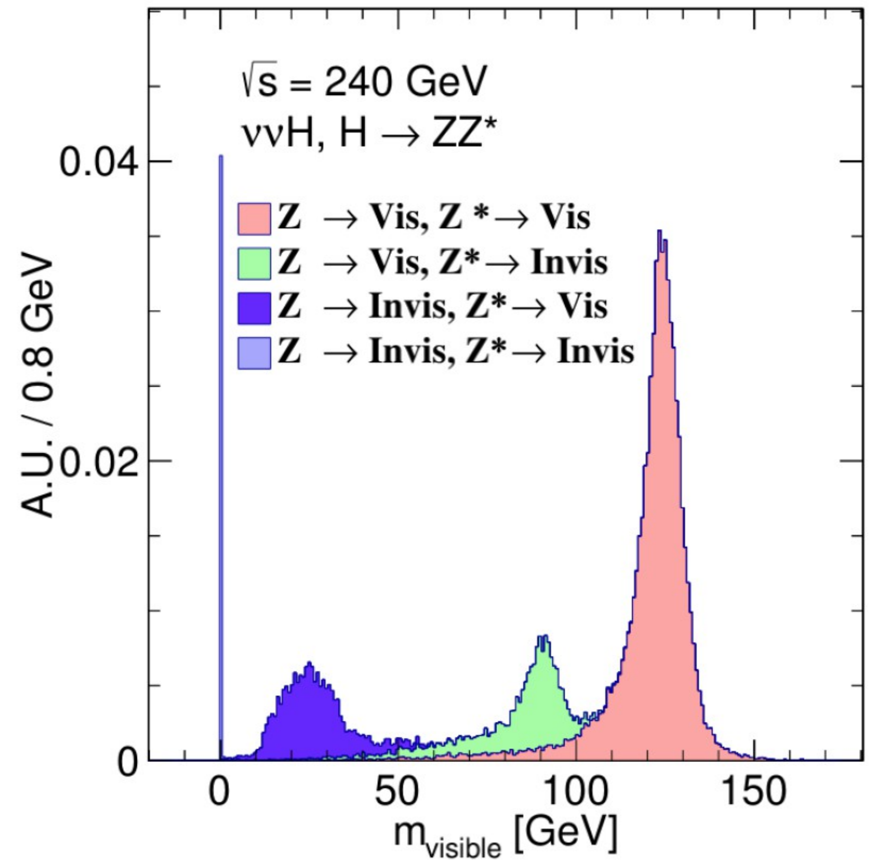
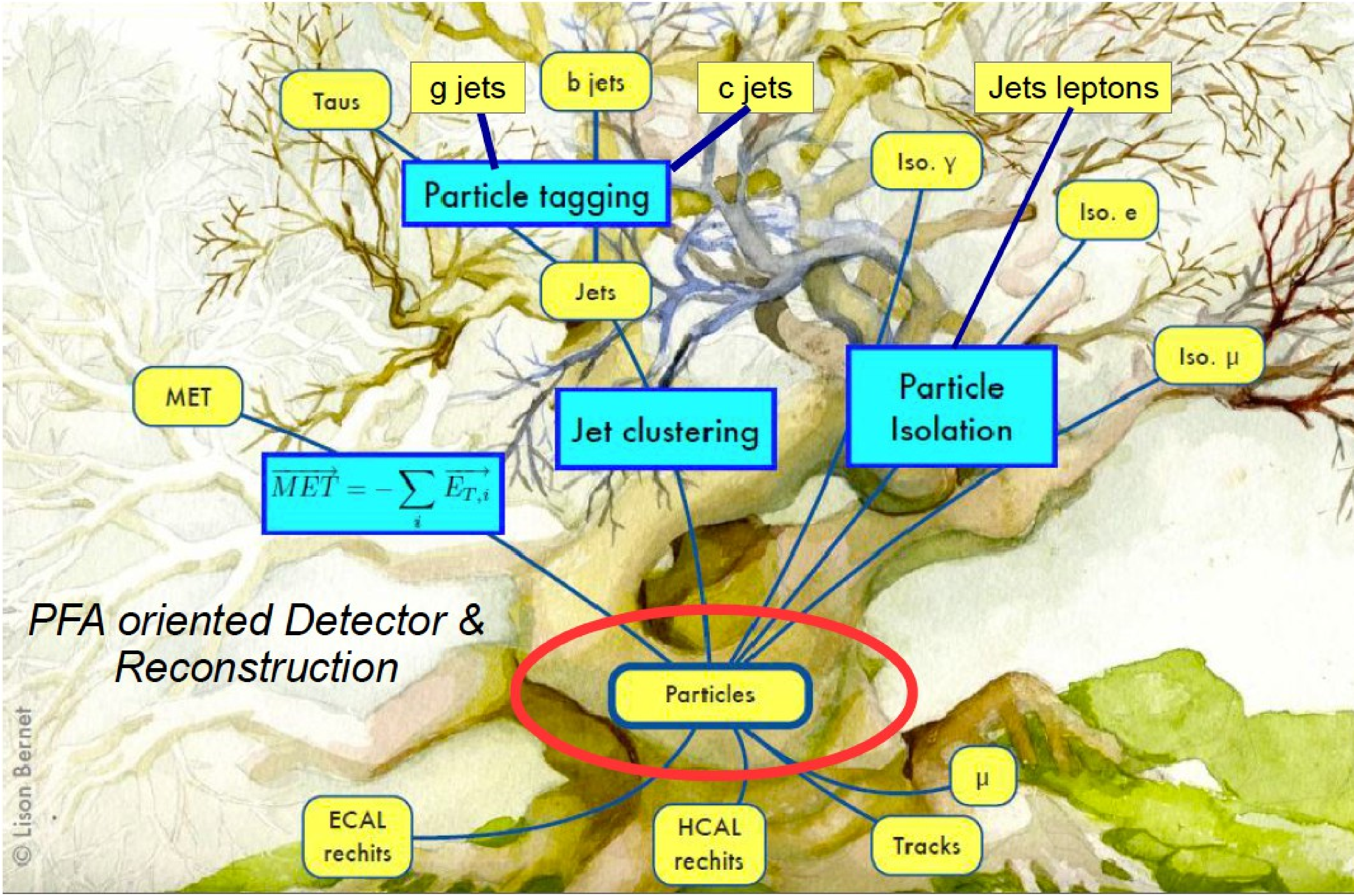


Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

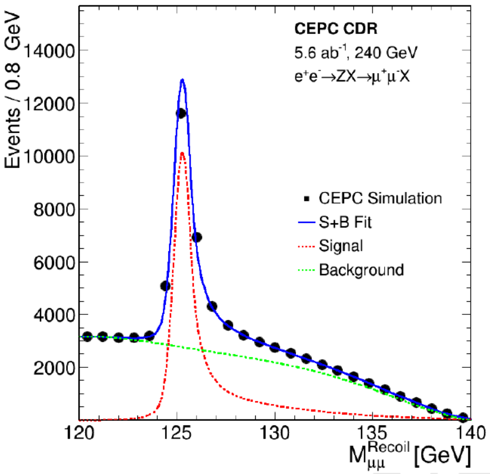
	Higgs→ $\mu\mu$	Higgs→ $\gamma\gamma$.	Higgs→bb
CEPC (APODIS)	0.20%	2.59%[1]	3.63%
LHC (CMS, ATLAS)	∼2% [19, 20]	∼1.5% [21, 22]	∼10% [23, 24]

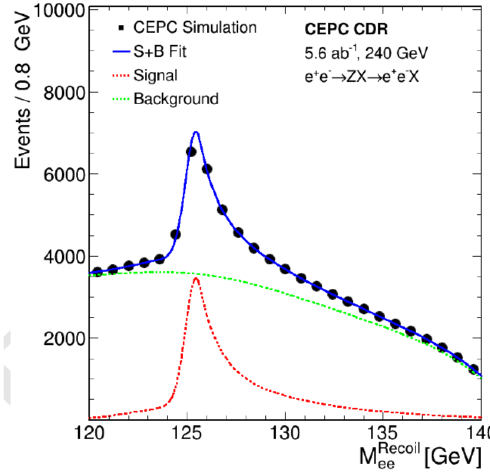
[1] primary result without geometry based correction and fine-tuned calibration.

https://arxiv.org/abs/1806.04992

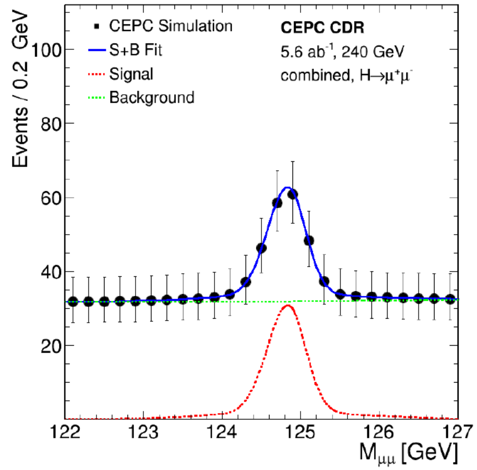

Taus
g jets
b jets
c jets
Jets leptons
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
PFA oriented Detector & Reconstruction
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

Higgs benchmark analyses

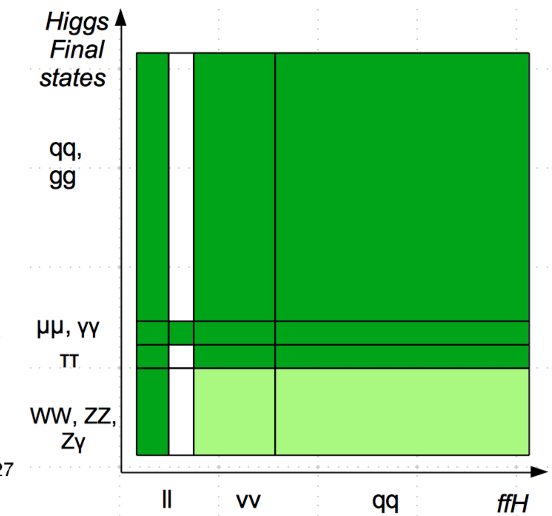


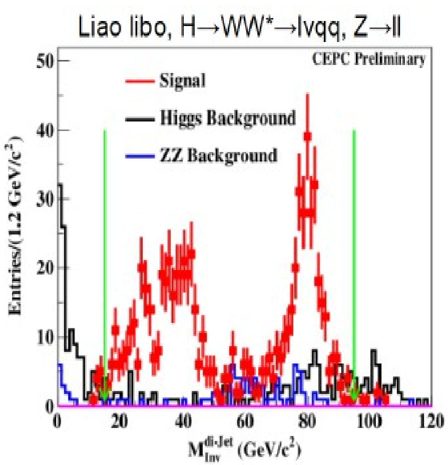


σ(ZH) measurements

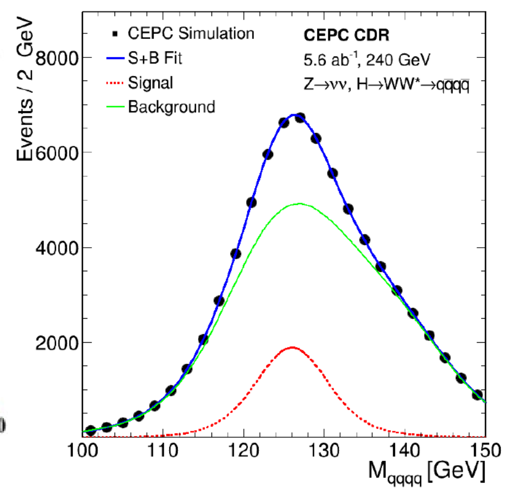


Br(H→μμ)

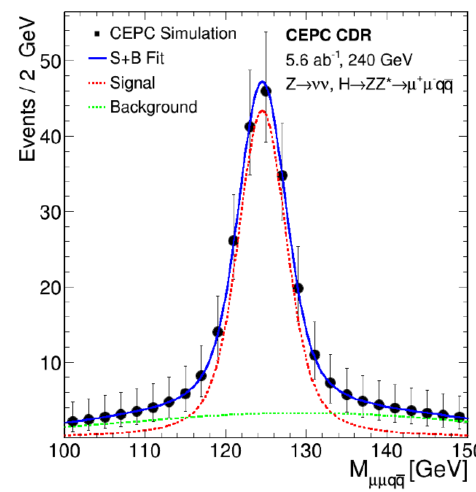




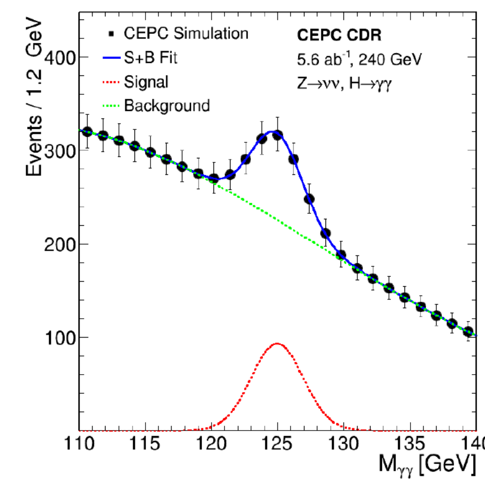
Br(H→WW)



σ(ννH)*Br(H→bb)



Br(H→ττ)



Br(H→γγ) (Asimov)

See Next Talk (On Higgs Performance)