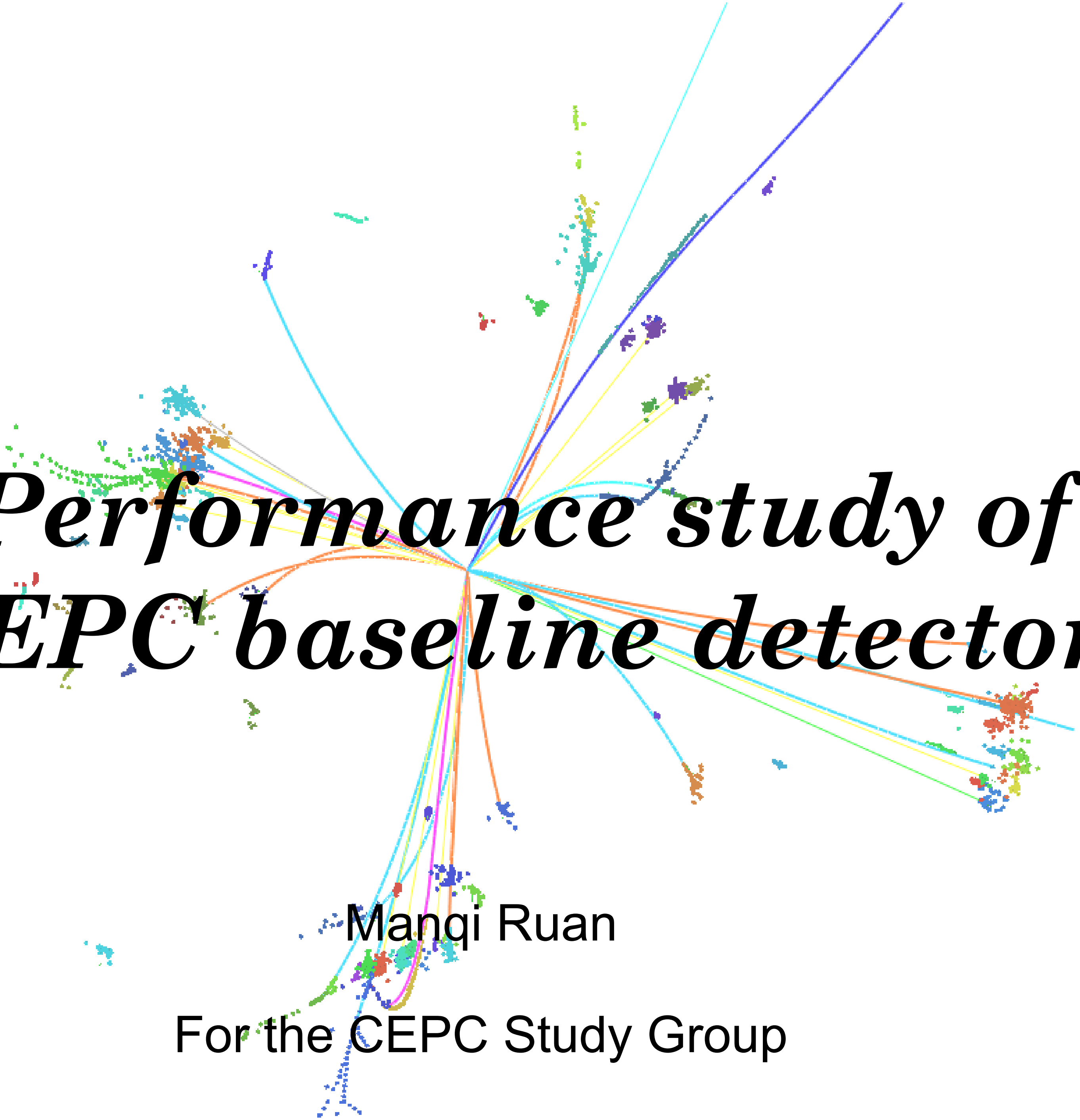


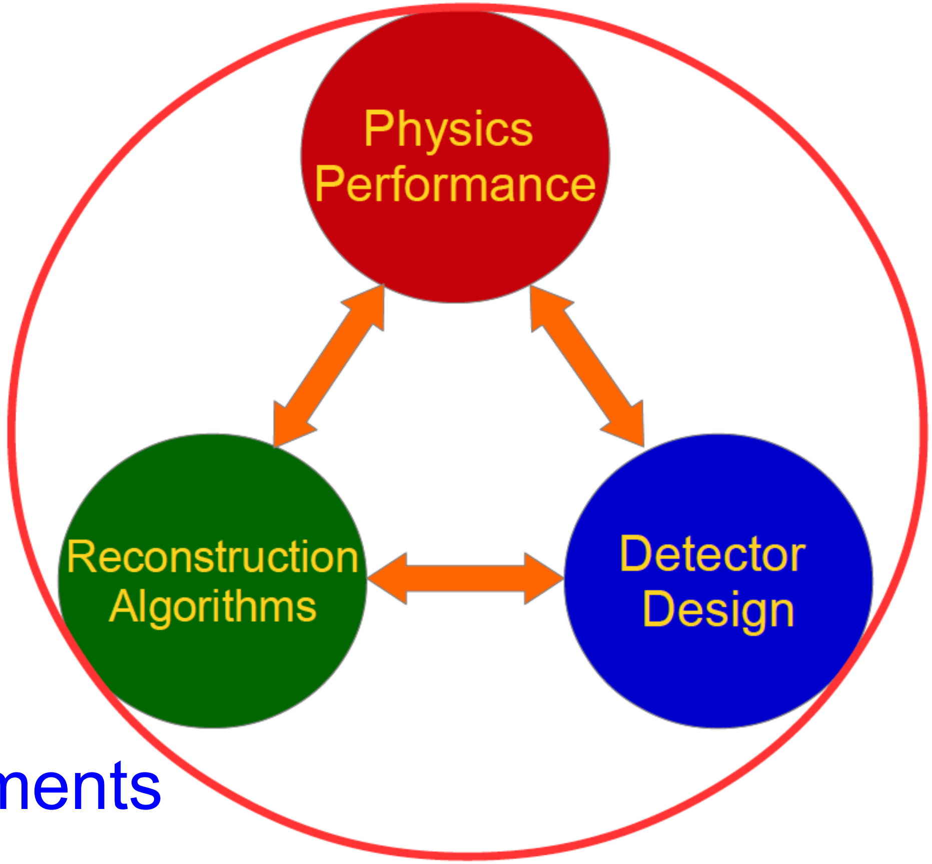
The Performance study of the CEPC baseline detector

Manqi Ruan

For the CEPC Study Group

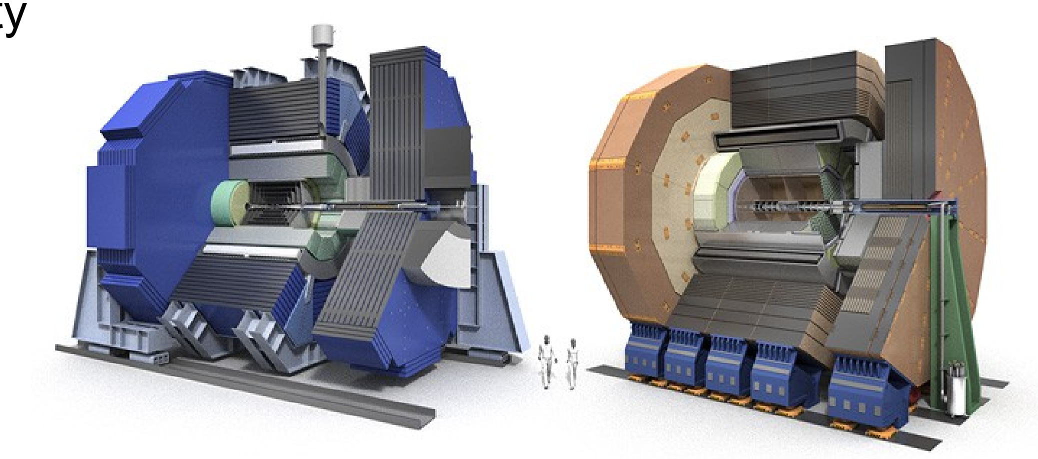
Performance

- Determined by
  - Detector concept
  - Reconstruction chain
- Characterized at
  - **Physics objects**
  - **Higgs signal**
  - Benchmark physics measurements (see Jianming's talk)

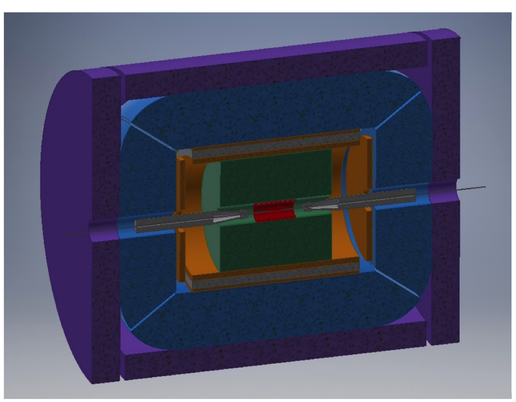


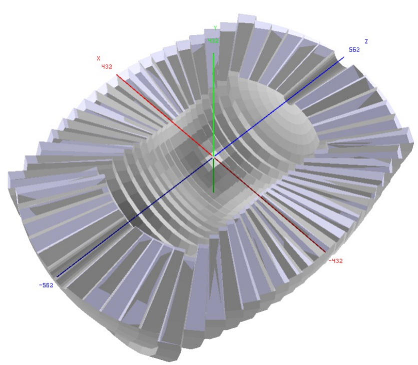
Two classes of Concepts

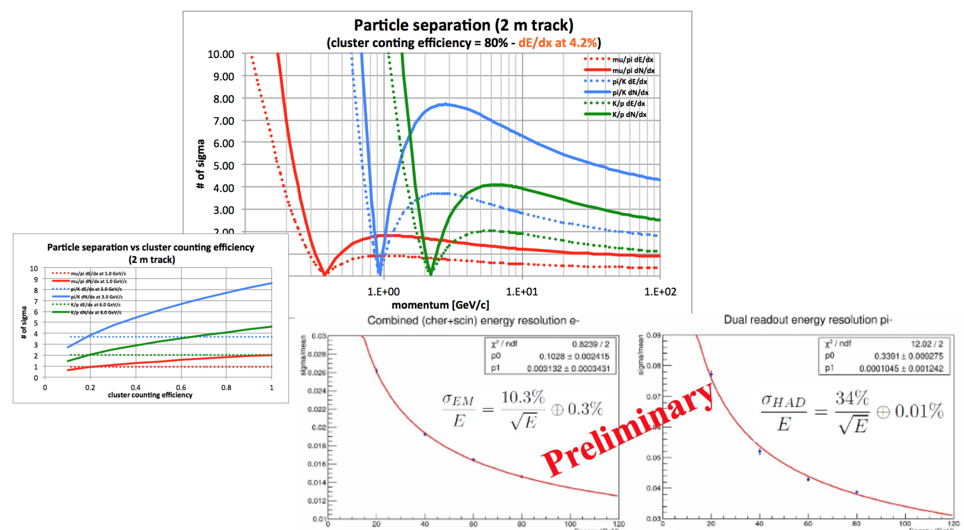
- PFA Oriented concept using High Granularity Calorimeter
  - **+ TPC (ILD-like, Baseline)**
  - + Silicon tracking (SiD-like)



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



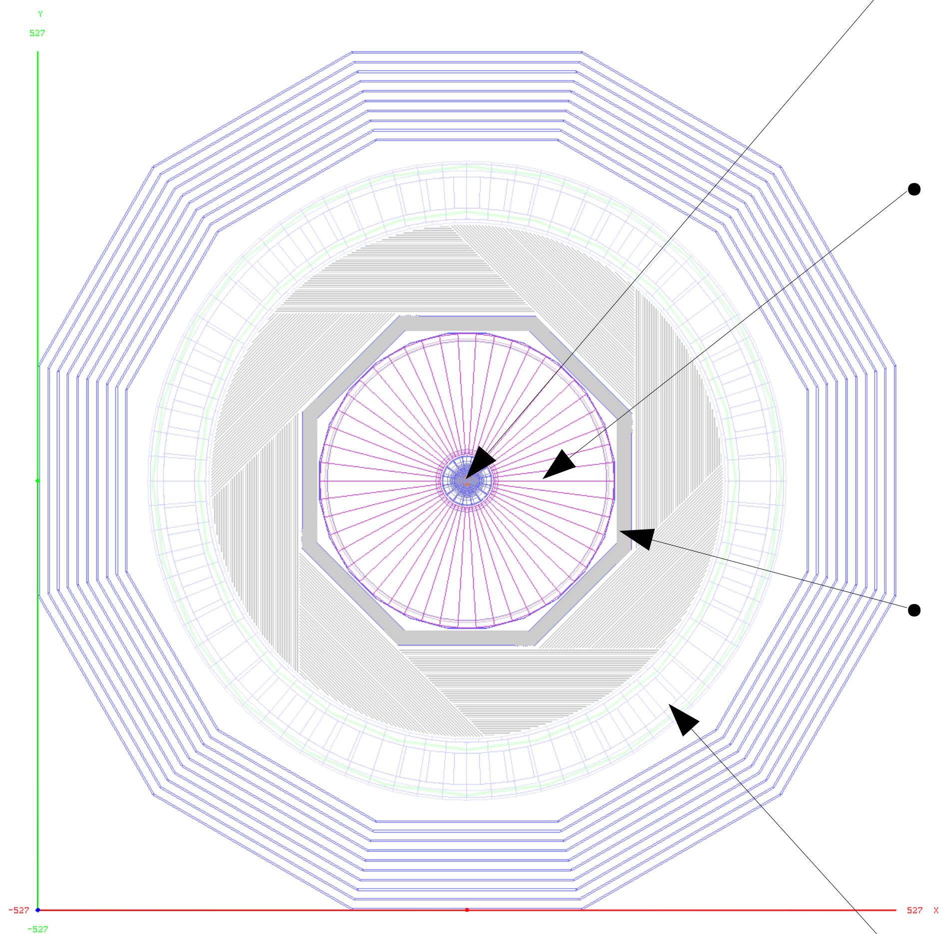




https://indico.ihep.ac.cn/event/6618/

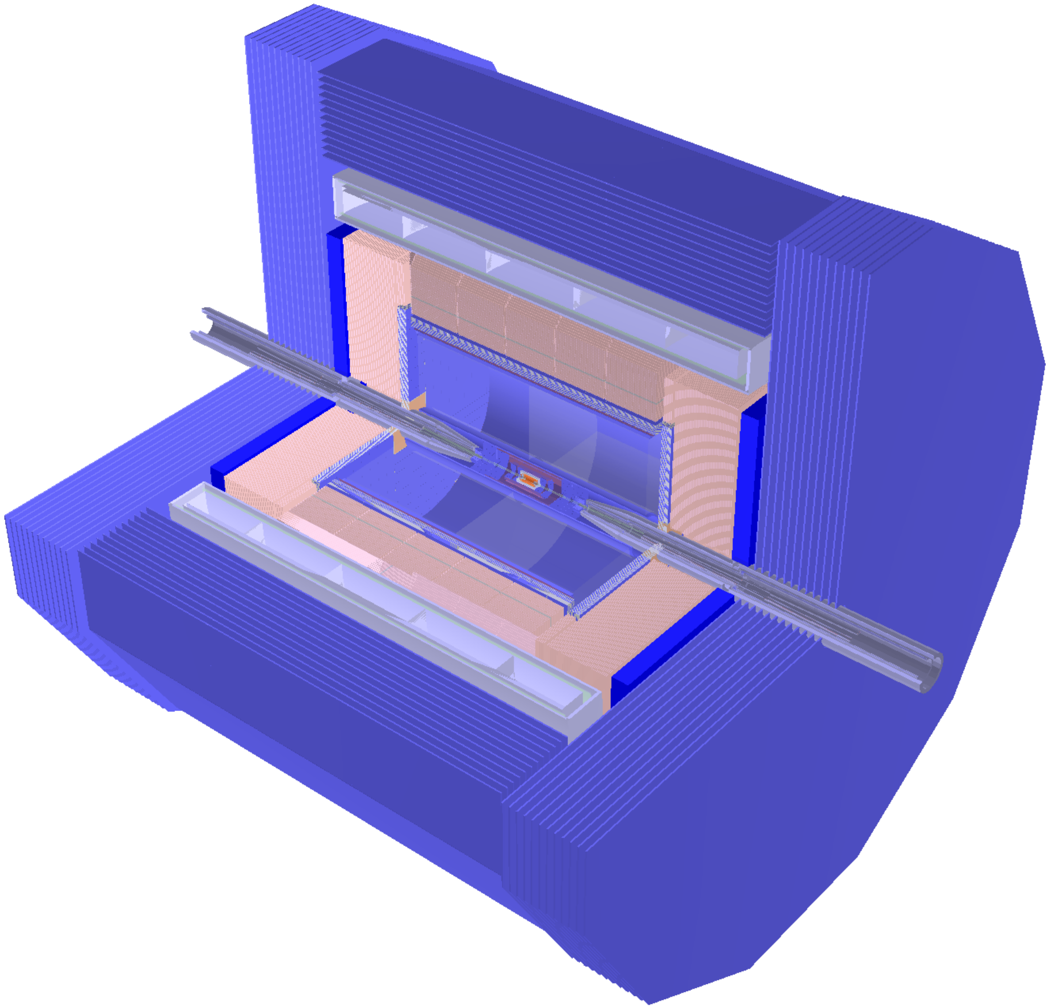
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

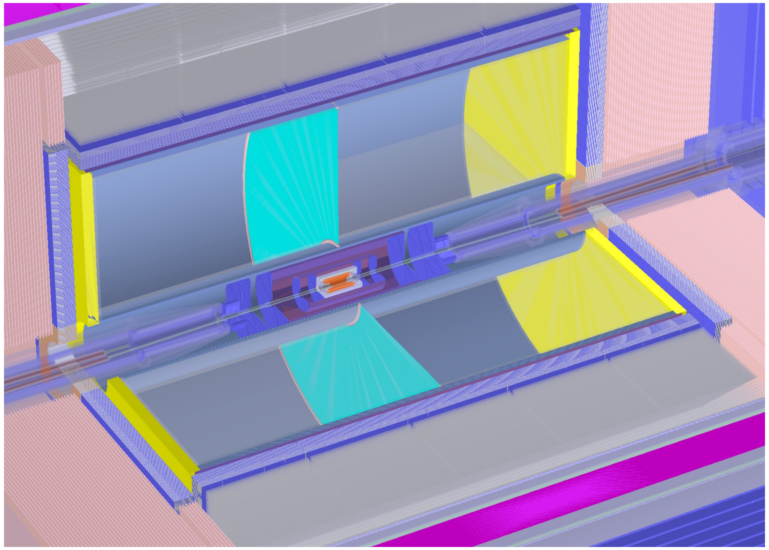
An ILD-like detector at the CEPC

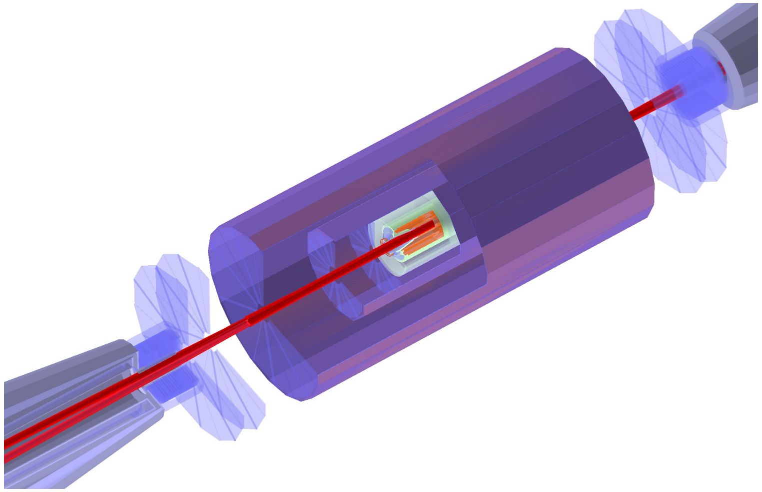


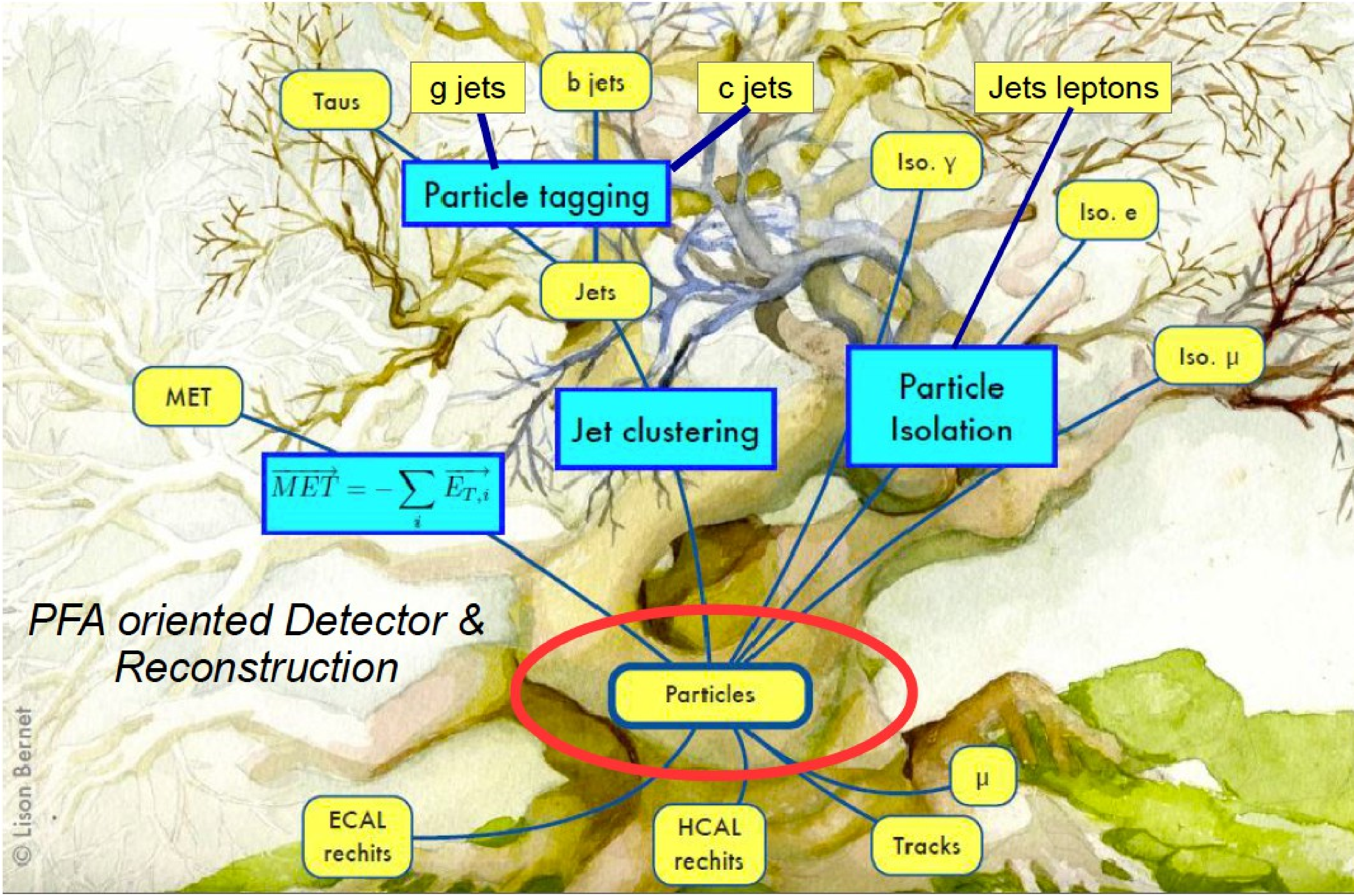
- Different collision environments/rates :
  - MDI design & Implementation: CEPC-SIMU-2017-001
- The CEPC Event rate is significantly higher than linear colliders, charged kaon id can strongly enhance the CEPC flavor physics program
  - TPC Feasibility: JINST-12-P07005 (2017)
  - Pid using TPC dEdx and 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

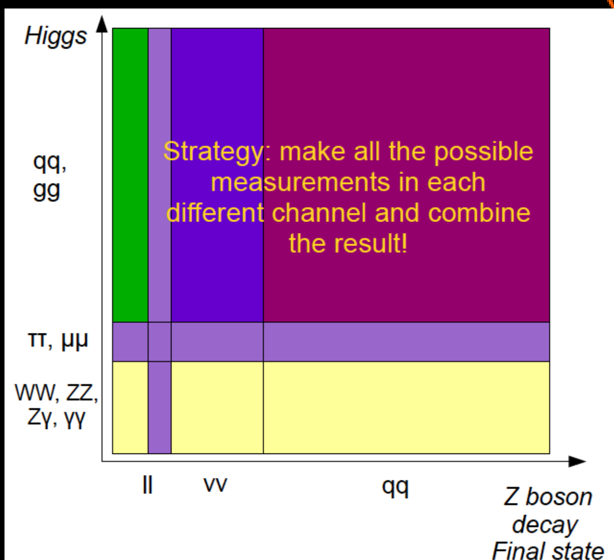


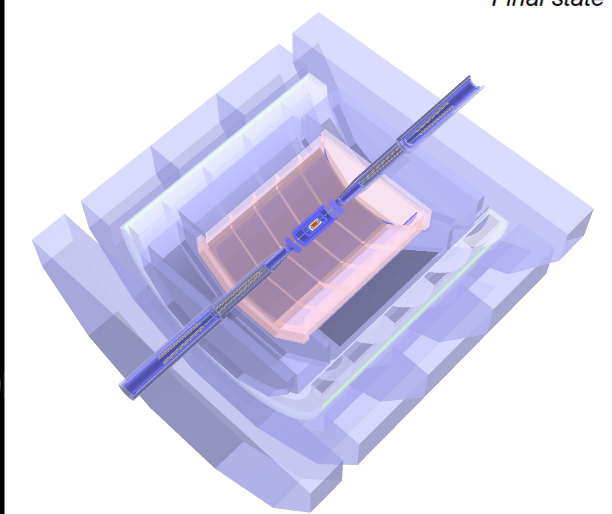


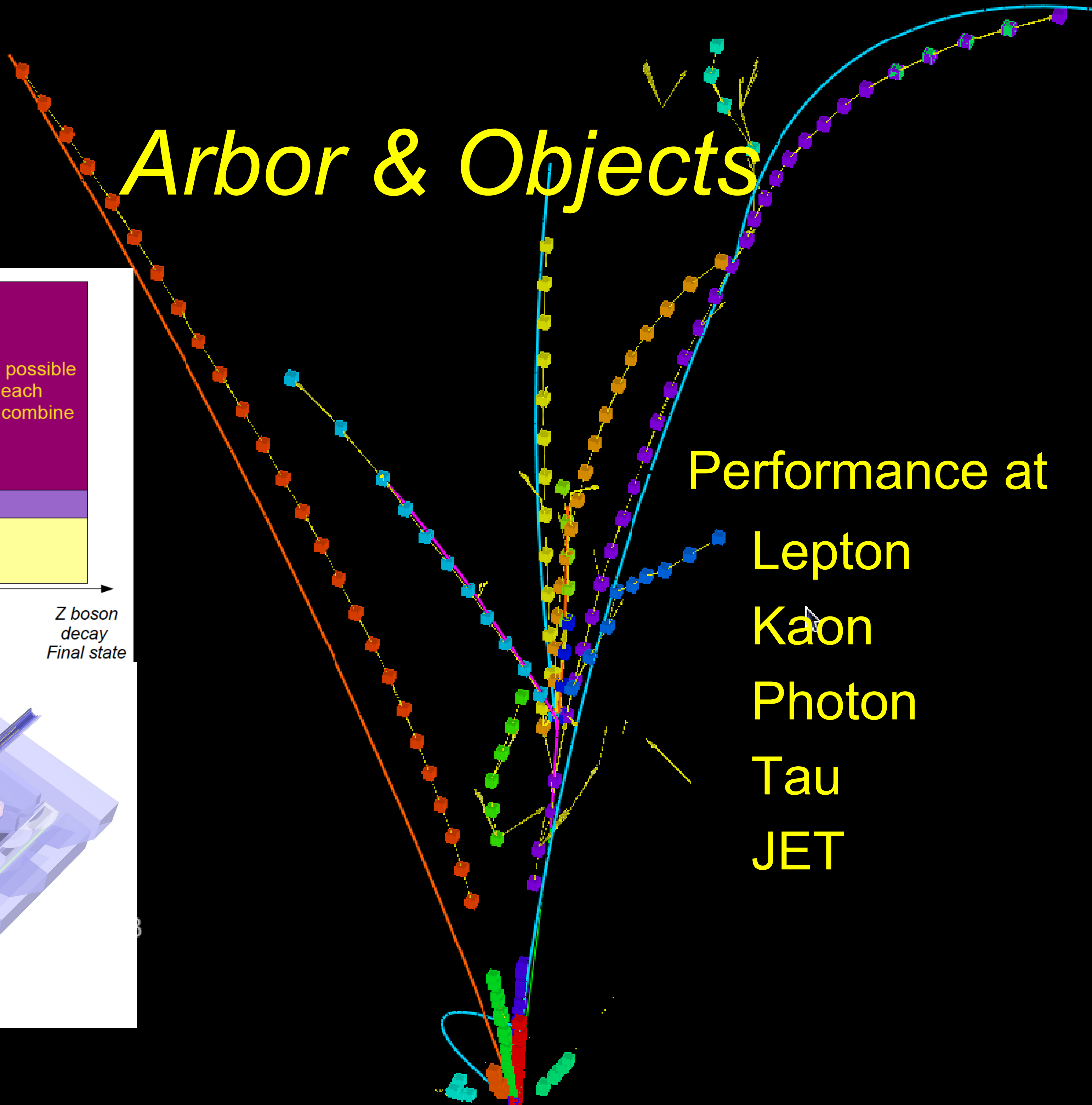



Taus
g jets
b jets
c jets
Jets leptons
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
PFA oriented Detector & Reconstruction
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

Arbor & Objects



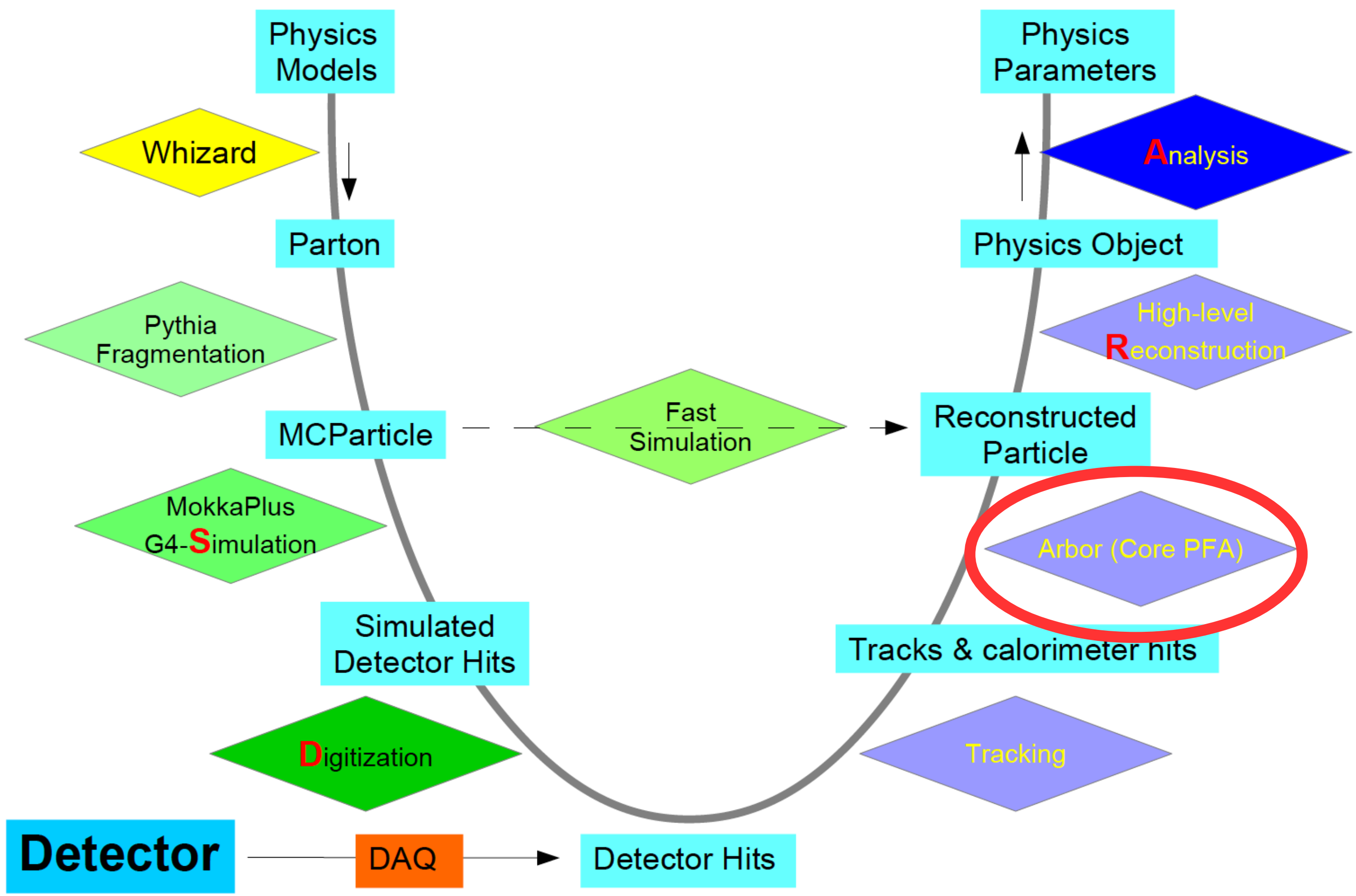




Performance at

- Lepton
- Kaon
- Photon
- Tau
- JET

The Simu-Reco Chain at CEPC

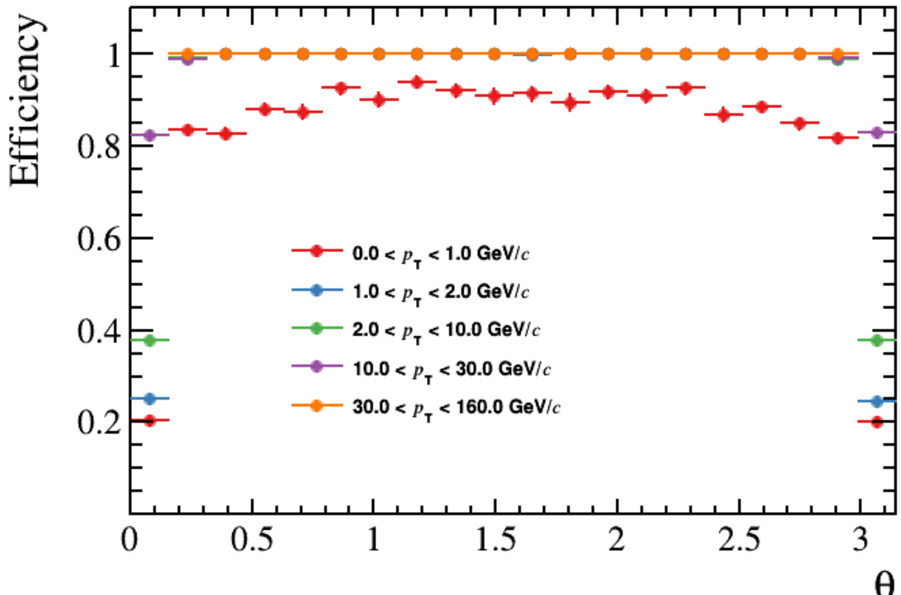


- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder (Coral)
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display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

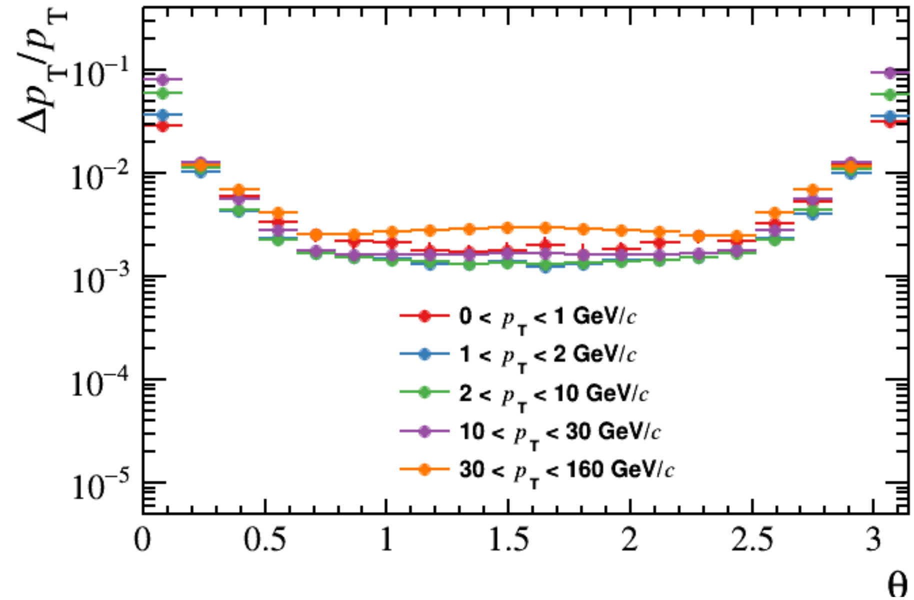
CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

General Software | ILCSoft | ILCSoft + Development | Developments

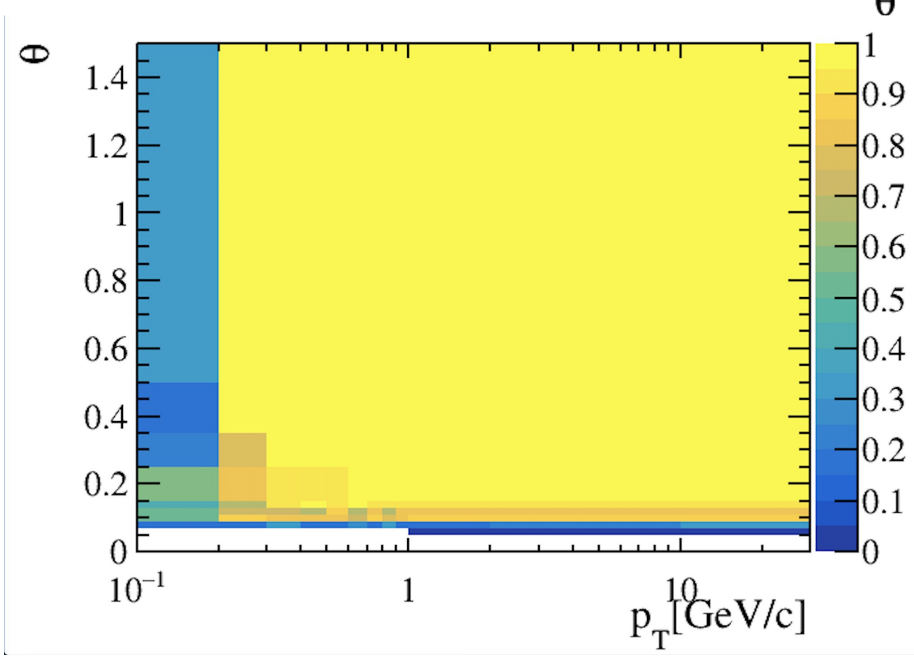
Tracking



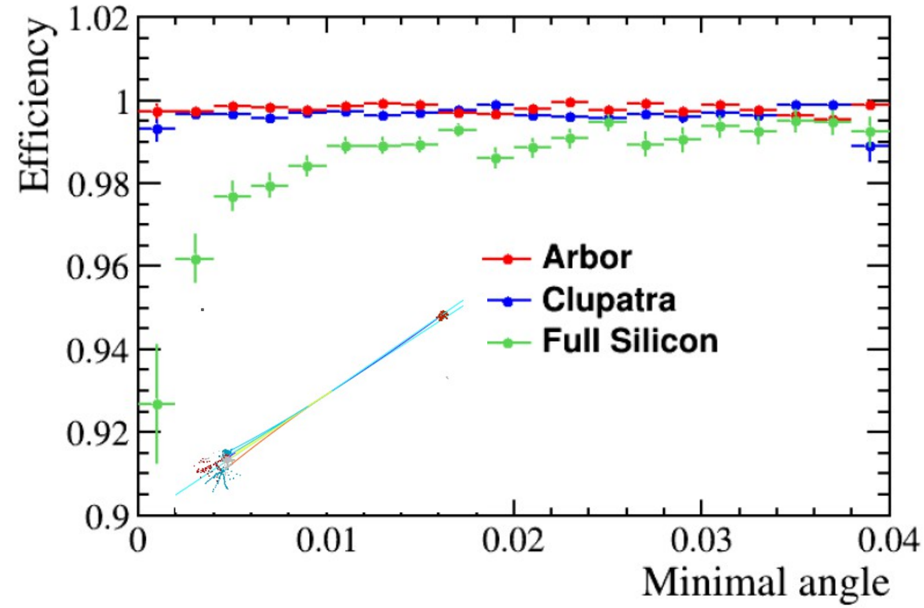
Efficiency
0.0 < p_T < 1.0 GeV/c
1.0 < p_T < 2.0 GeV/c
2.0 < p_T < 10.0 GeV/c
10.0 < p_T < 30.0 GeV/c
30.0 < p_T < 160.0 GeV/c
θ



$\Delta p_T / p_T$
0 < p_T < 1 GeV/c
1 < p_T < 2 GeV/c
2 < p_T < 10 GeV/c
10 < p_T < 30 GeV/c
30 < p_T < 160 GeV/c
θ

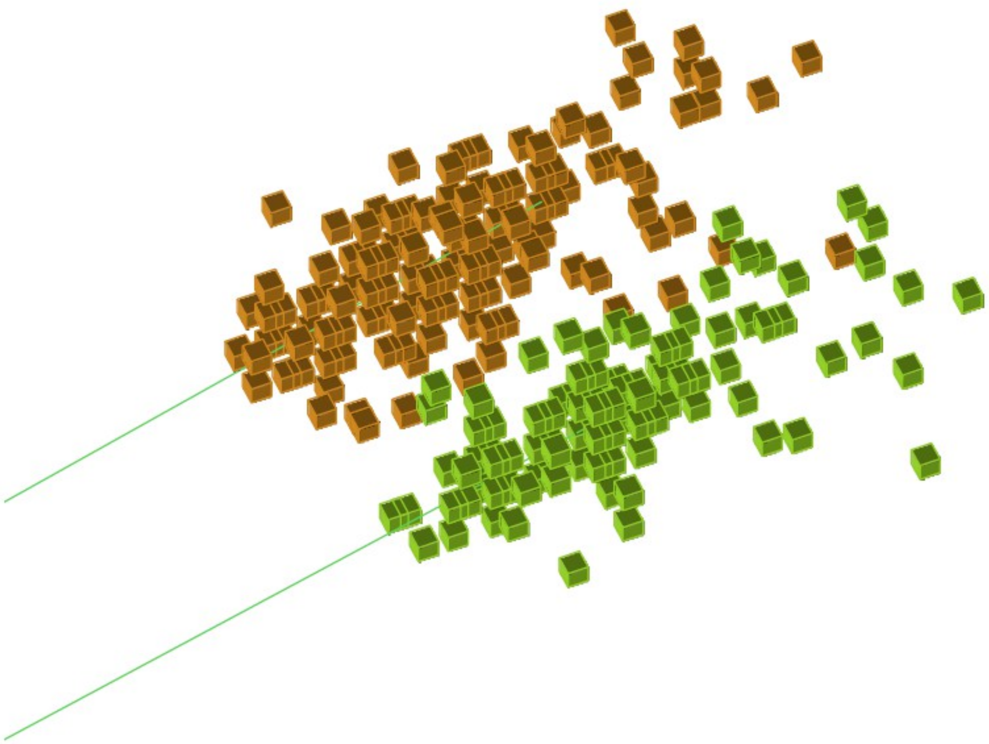


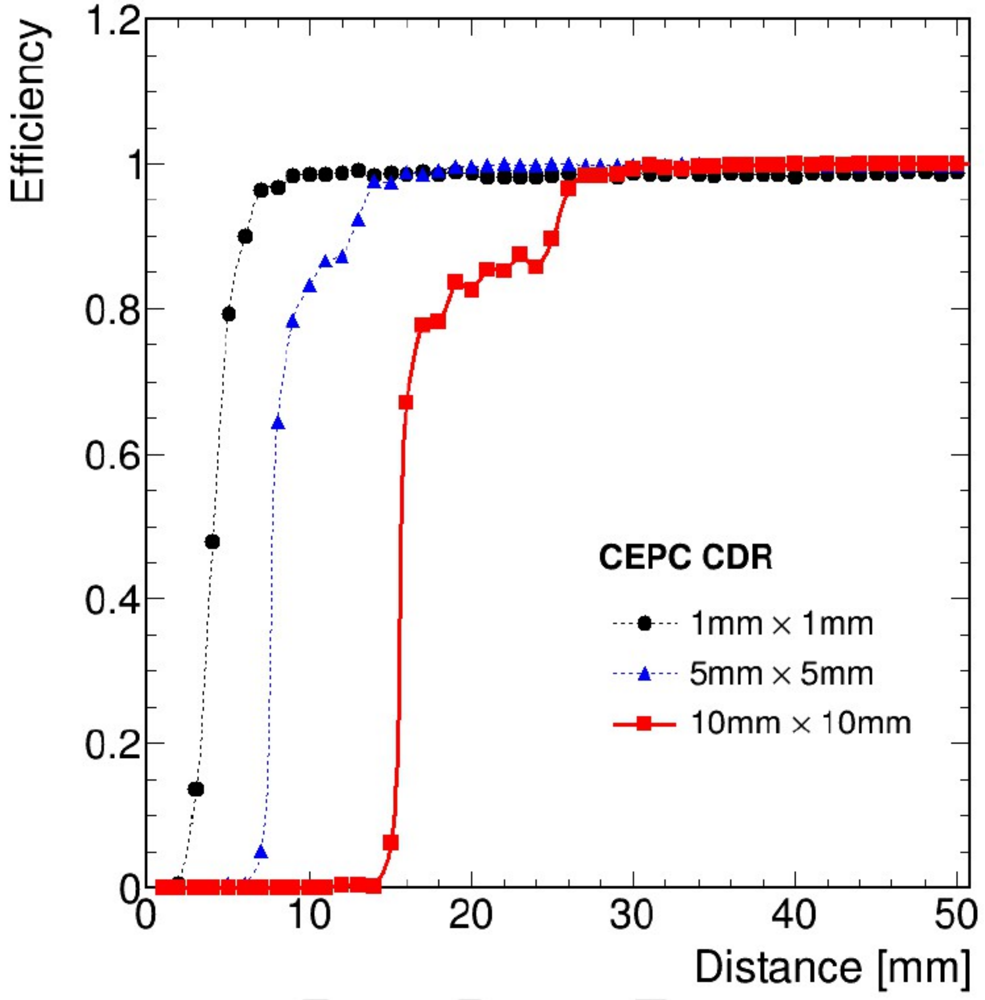
θ
p_T[GeV/c]



Efficiency
Arbor
Clupatra
Full Silicon
Minimal angle

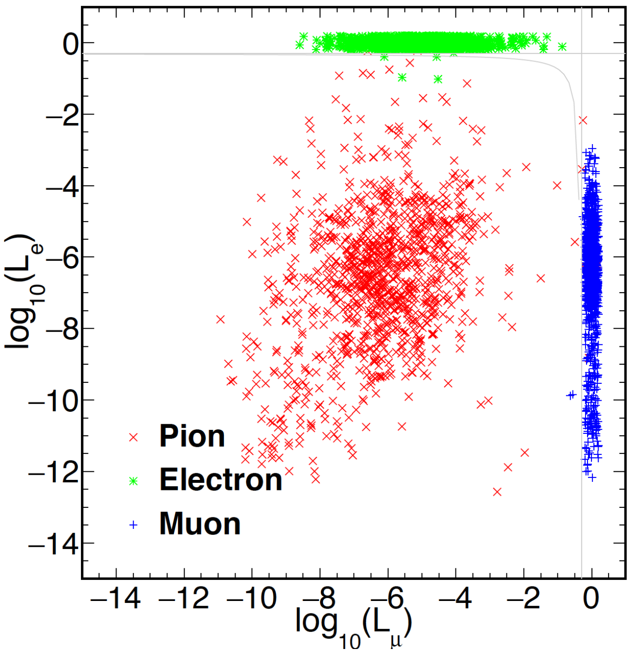
Clustering

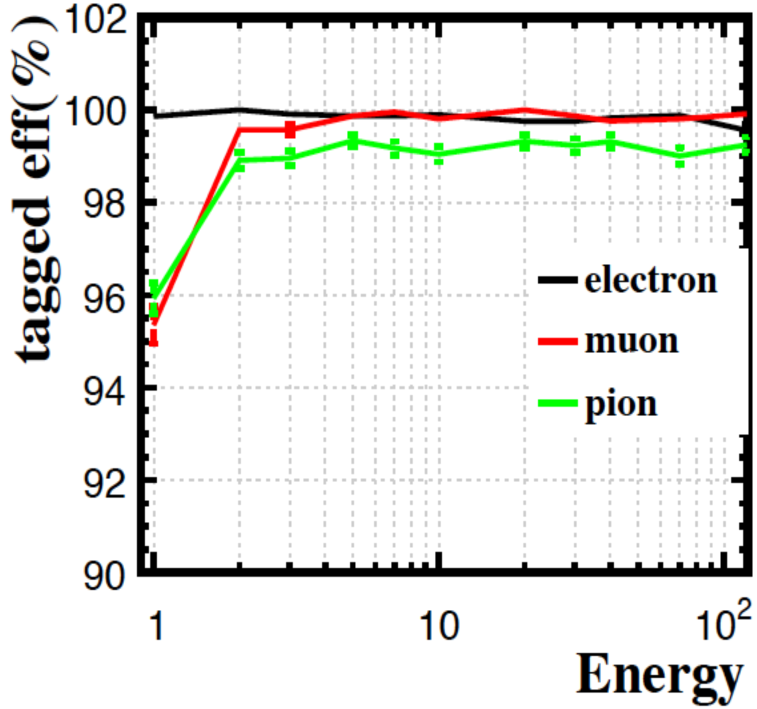


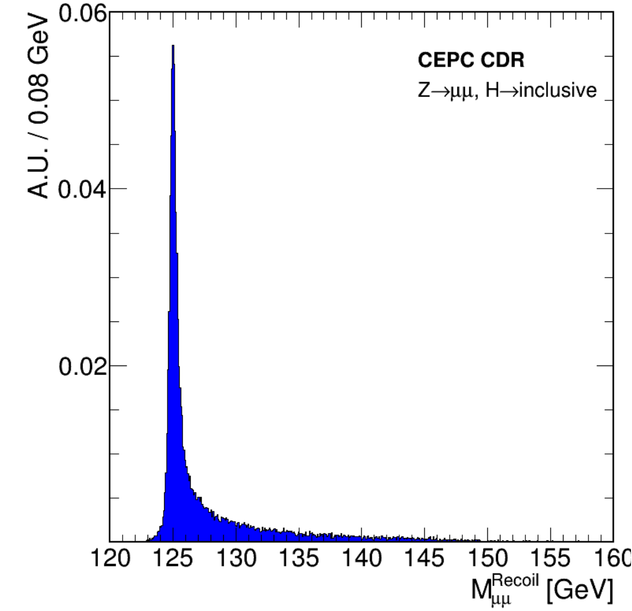


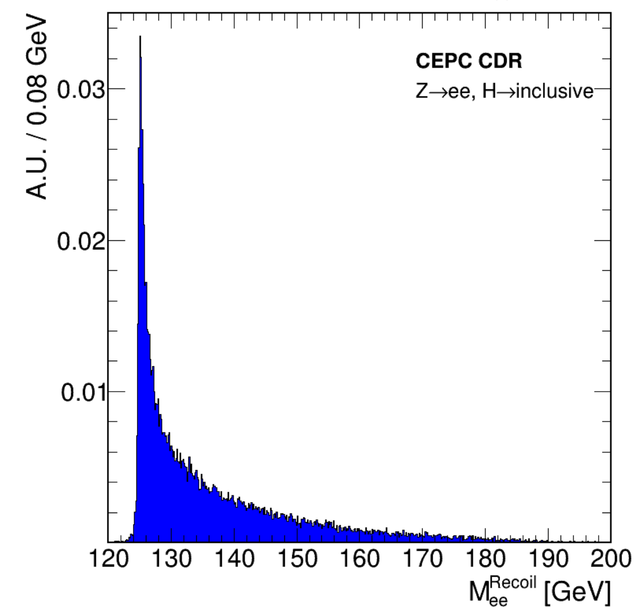
Critical energy to separate an evenly decay π_0: 30 GeV

Leptons







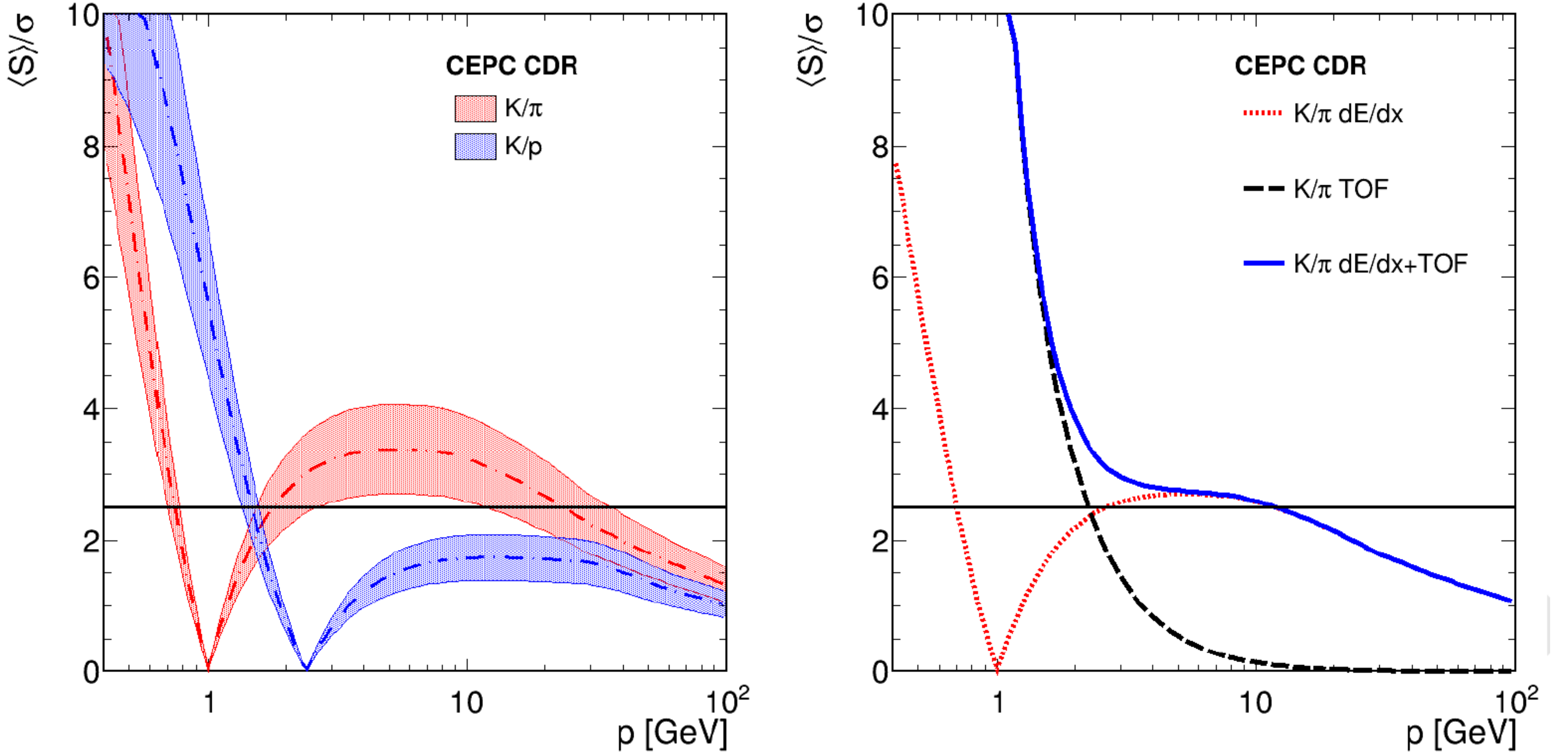


BDT method using 4 classes of 24 input discrimination variables.

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

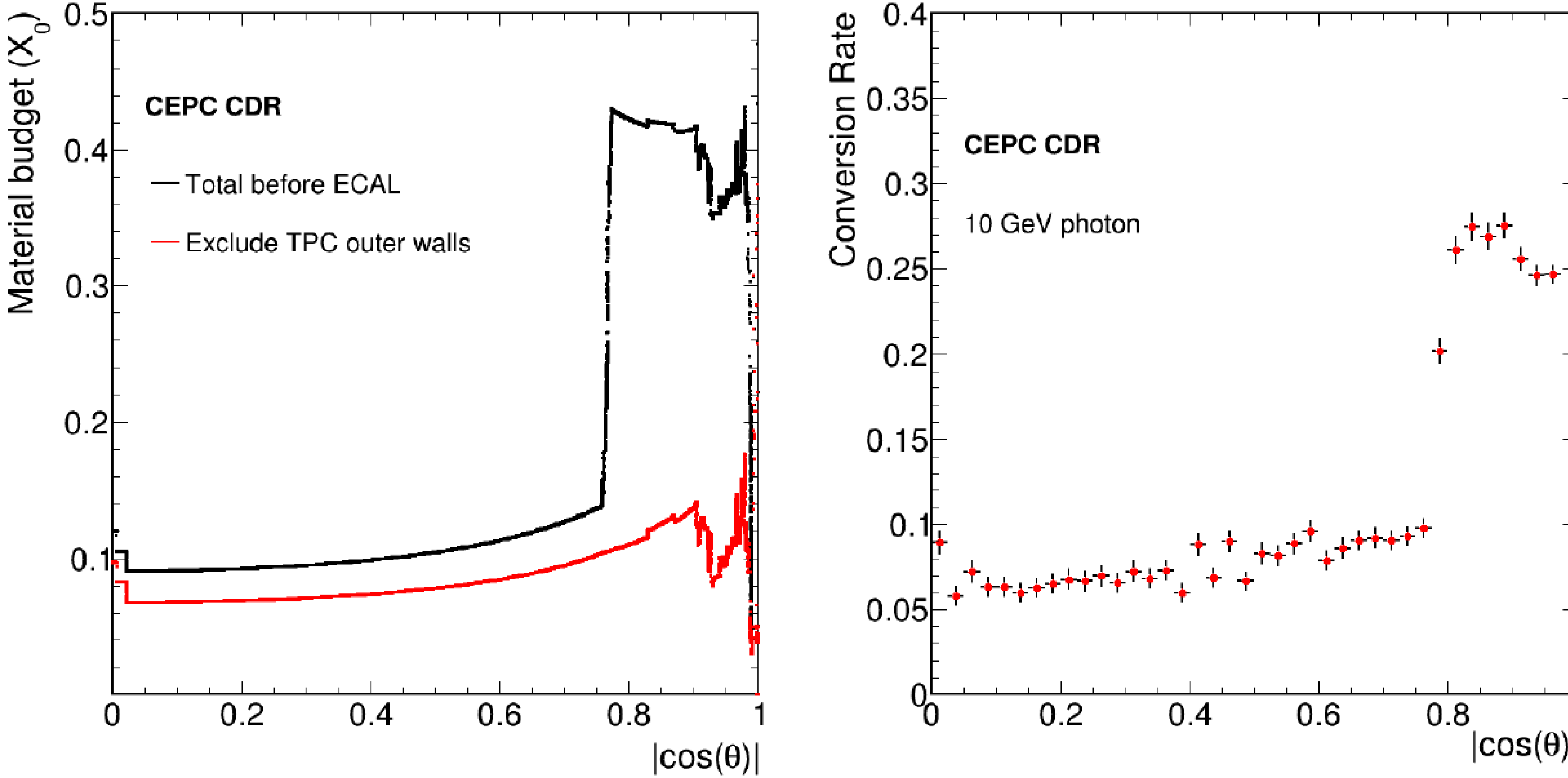
Eur. Phys. J. C (2018) 78:464

At inclusive Z pole sample:

Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)

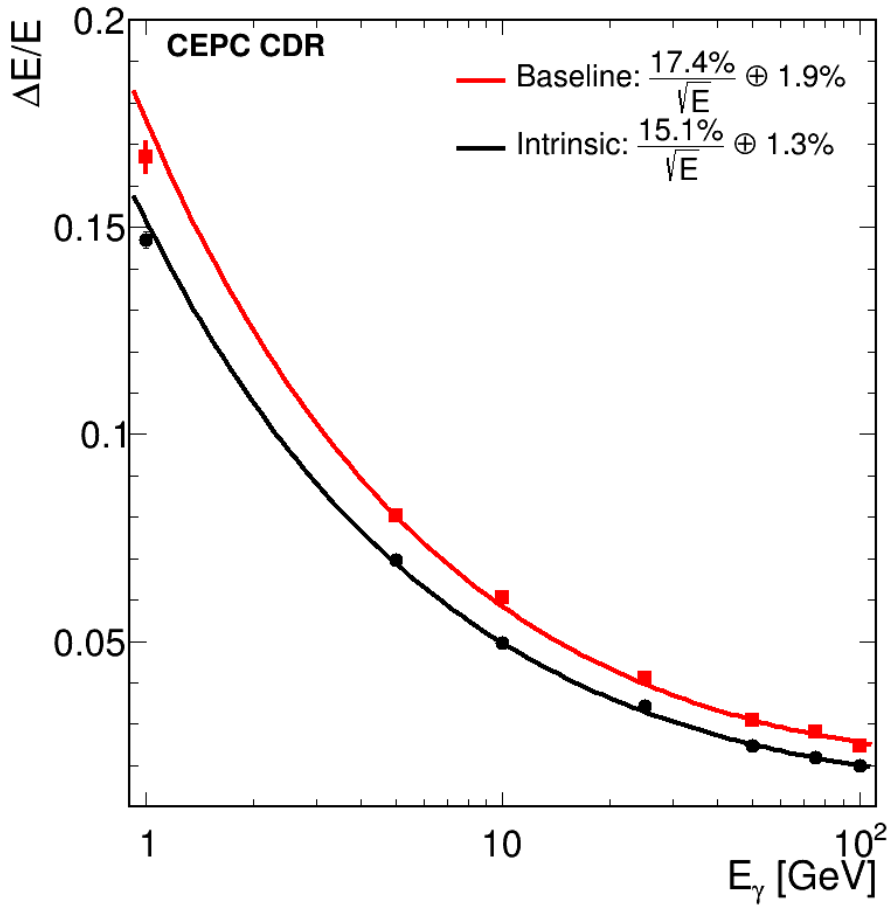
Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

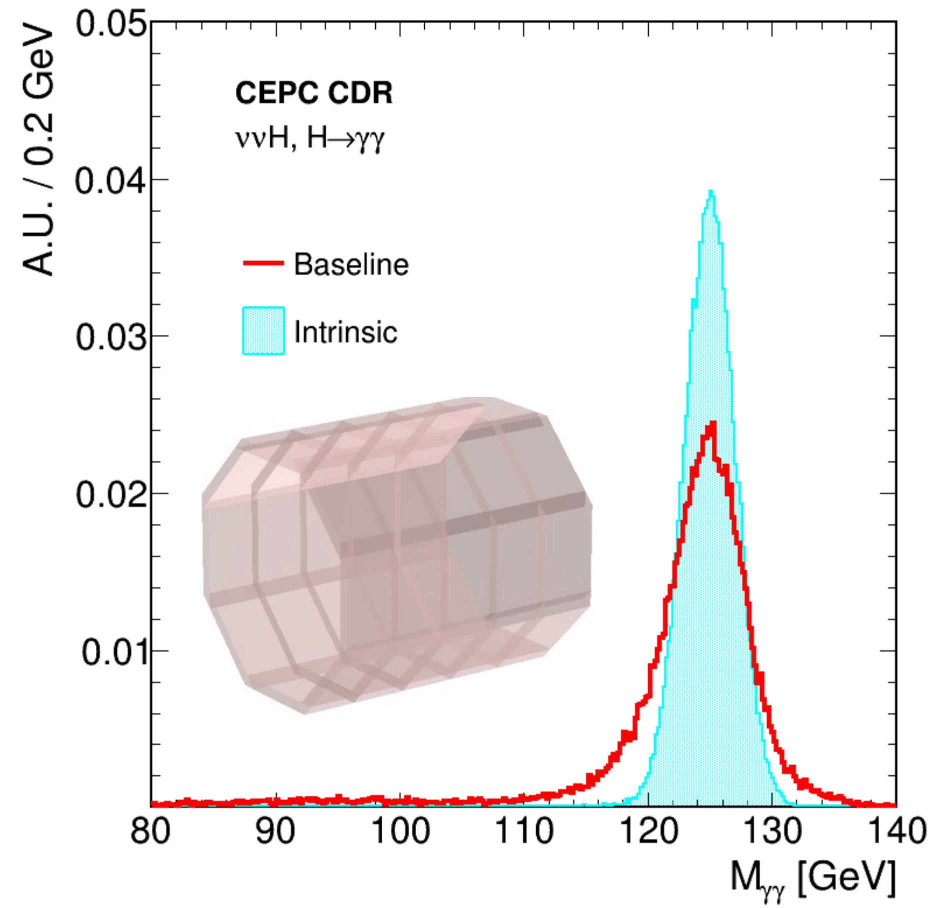
Photons - conversion



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

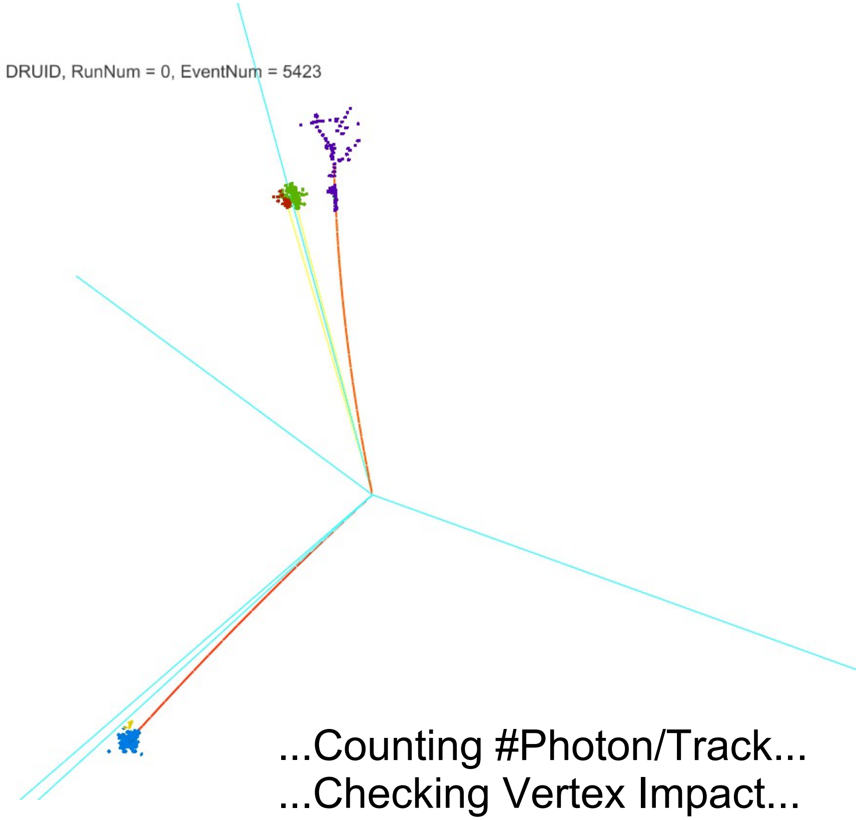
Photon resolution



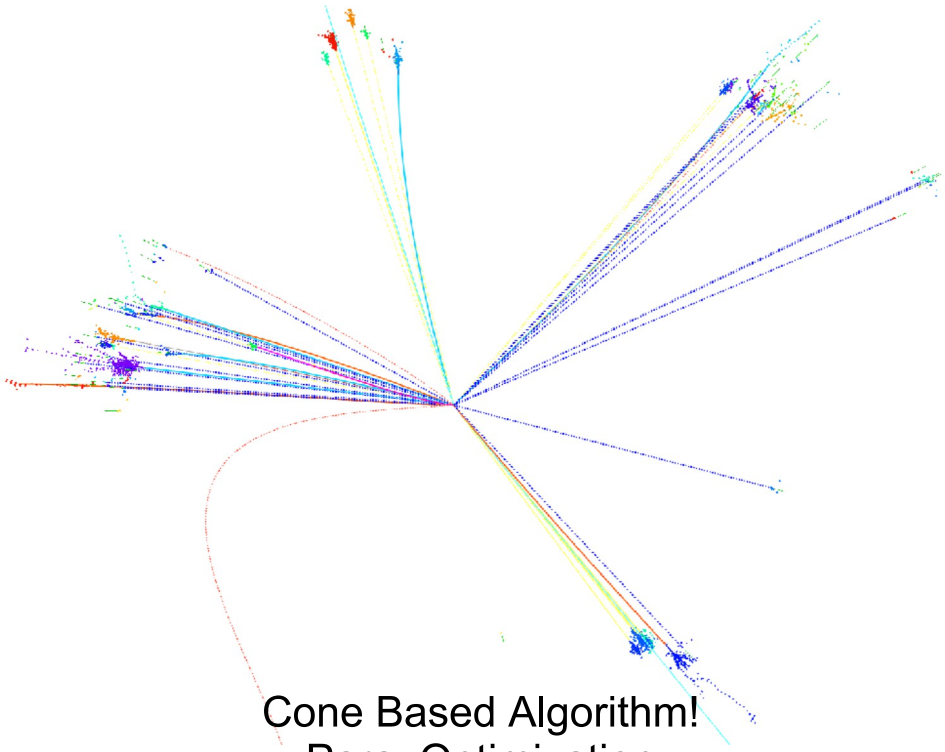


- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/APODIS geometry
- The geometry defects correction is mandatory (in progress)...

Tau



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

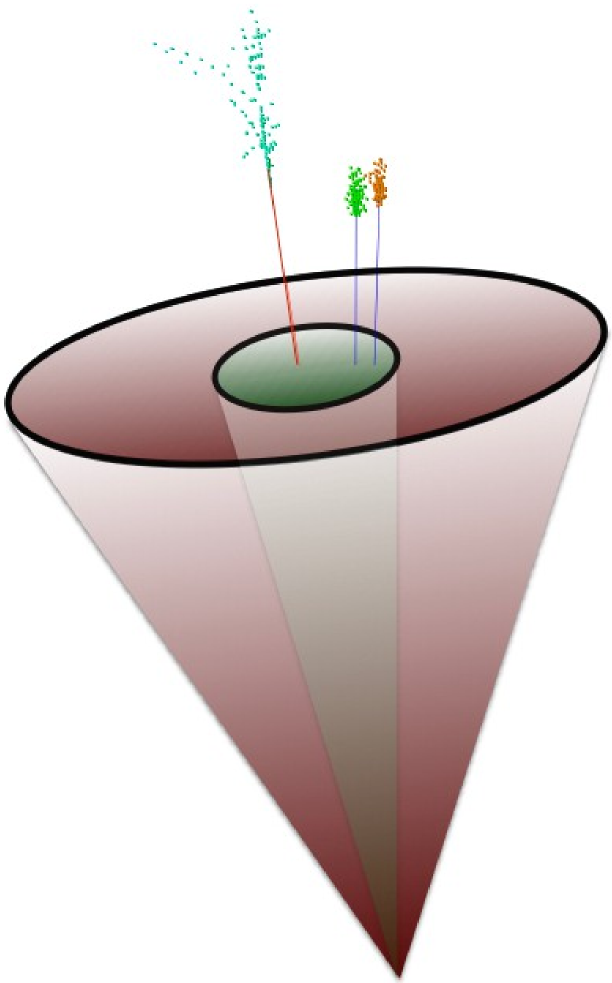


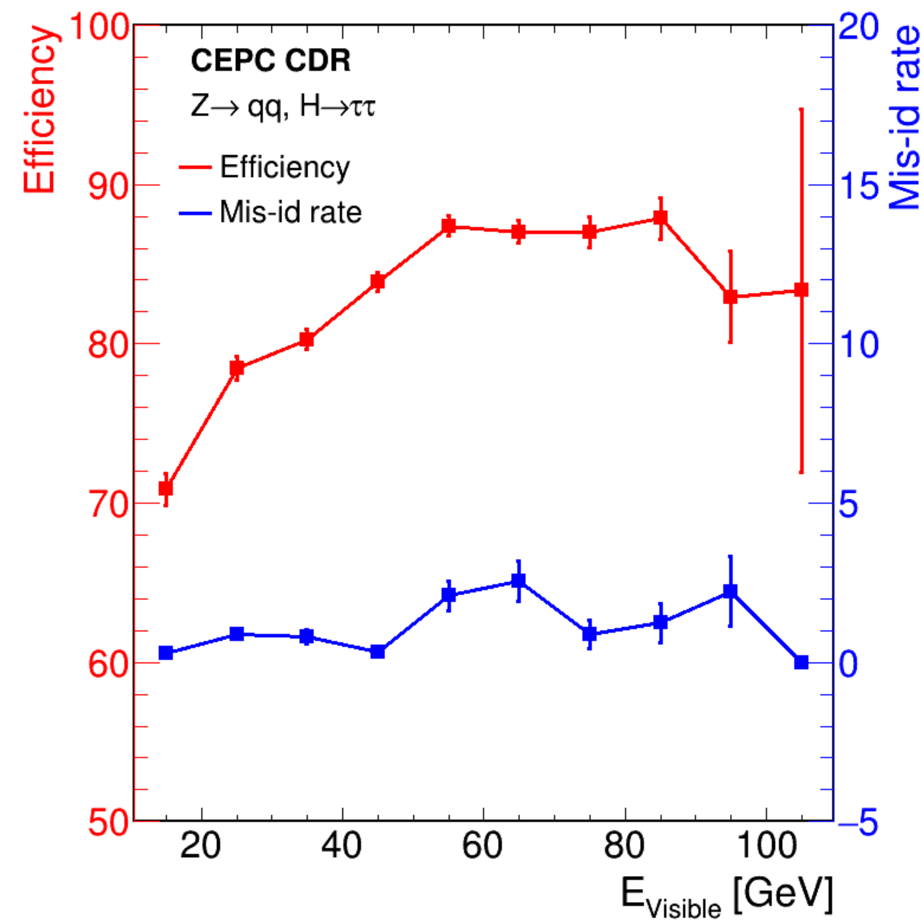
Cone Based Algorithm!
Para. Optimization

- 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

Tau finding



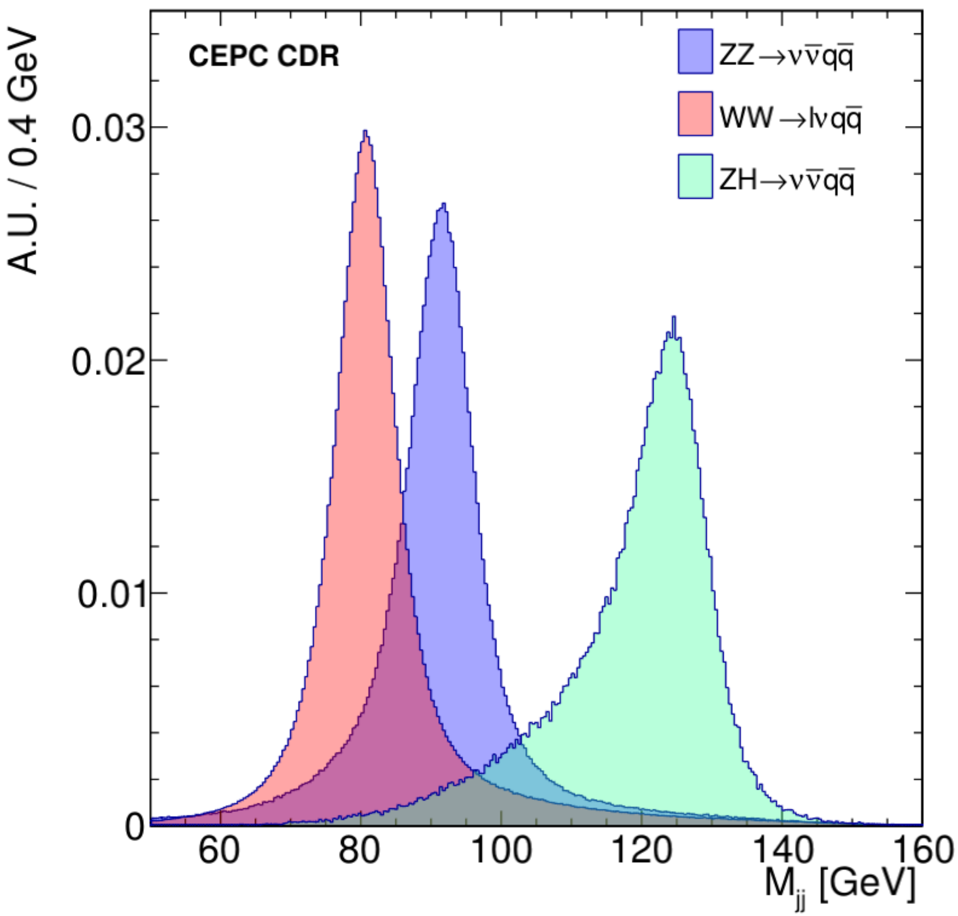


TAURUS (Tau ReconstrUction toolS) optimization in progress

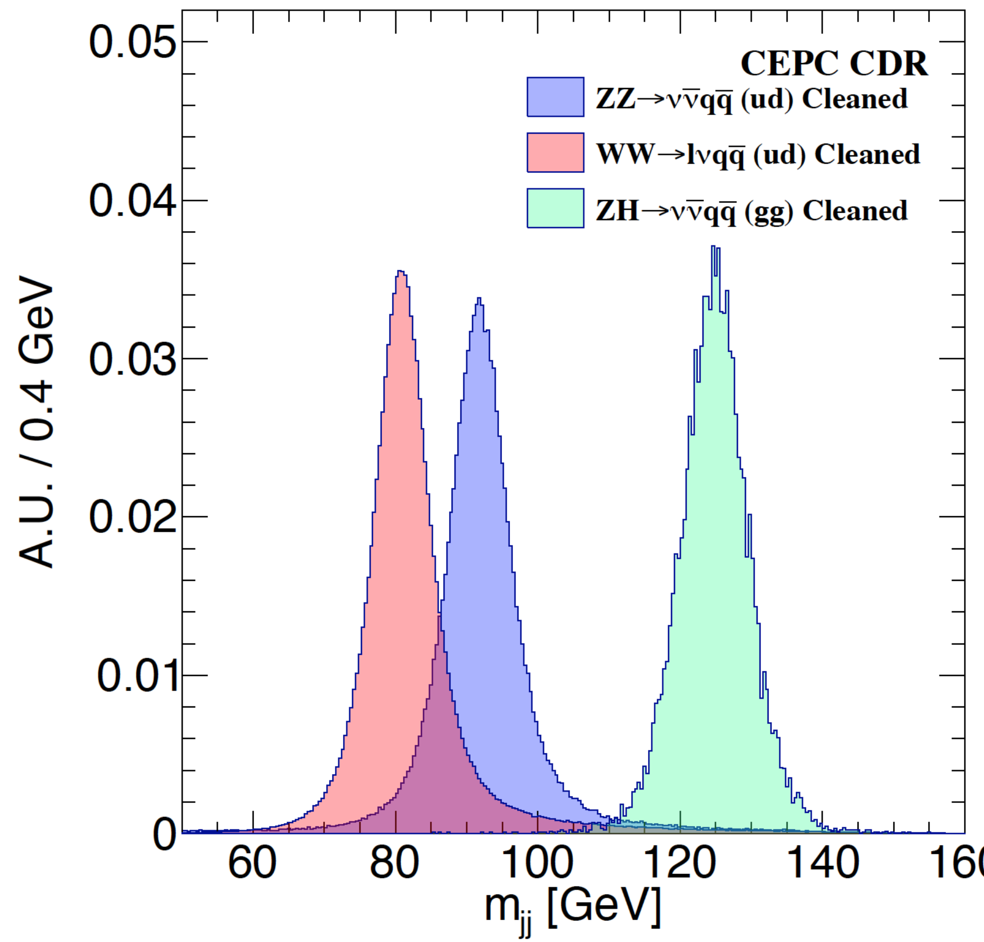
Jets

- Boson Mass Resolution: Separate W, Z and Higgs in hadronic decay mode
  - Essential for Higgs measurement
    - Separate Higgs from Z/W (relatively easy)
      - ZZ, ZH, WW event identification with semi-leptonic final state
    - qqH, H→non-jet final states (γγ, μμ, taus, invisible)
    - Br(H→ZZ/WW) events with jets final states
    - σ(ZH) measurement via qqH...
  - Appreciated in Triplet Gauge Boson Coupling measurements
    - Separate WW (Signal) from ZZ, ISR return Z, etc.
- Jet Clustering & Single jet response
  - To understand the Performance of Jet Clustering, Matching:
    - For Br(H→bb, cc, gg) measurements with 4 jet final states
  - Search for the most suited jet clustering algorithm for different event topology Understand the Corresponding Systematic
  - ...

Massive Boson Separation



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

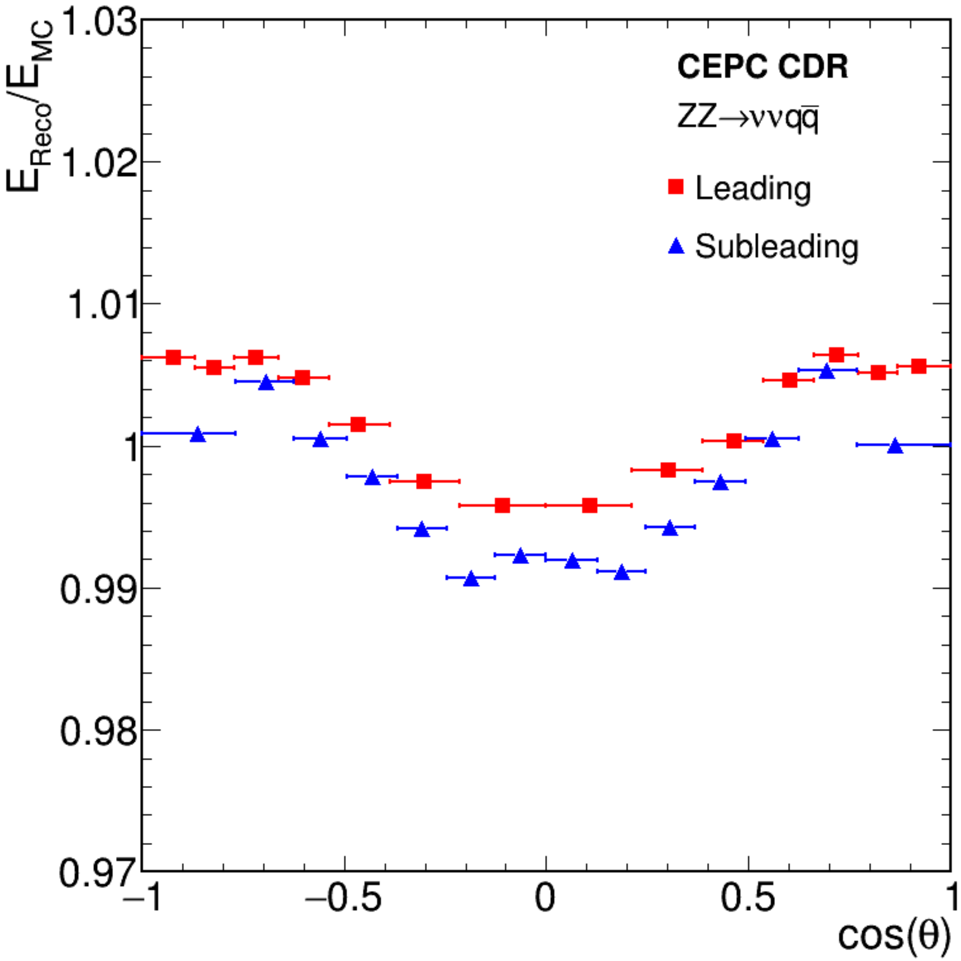


CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),

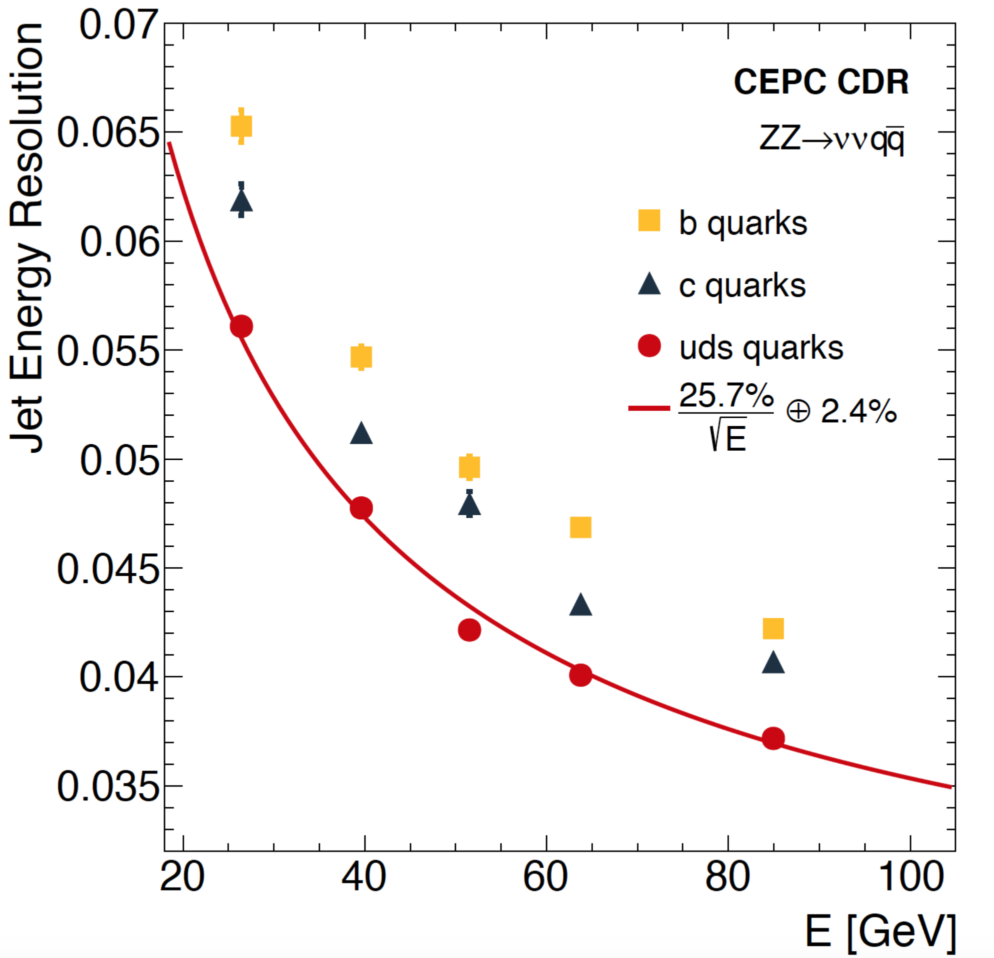
Eur. Phys. J. C78 (2018) no.5, 426

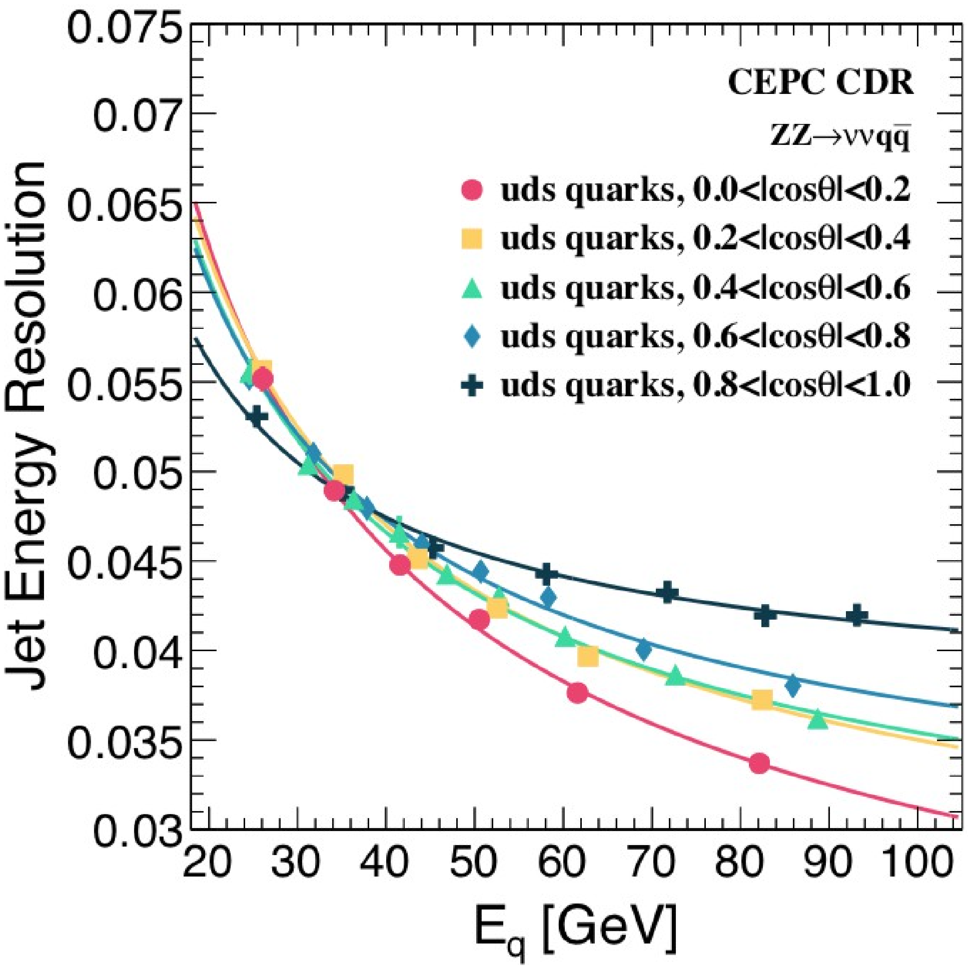
Jet Energy Scale

- JES ~ with 1% of the unity (without correction)
- Larger JES Observed at
  - Leading jets (correlated with energy)
  - Overlap/endcap region (Larger confusion term)
- *JES ~ with 0.1% of unity anticipated after correction (geometry/energy dependent)*



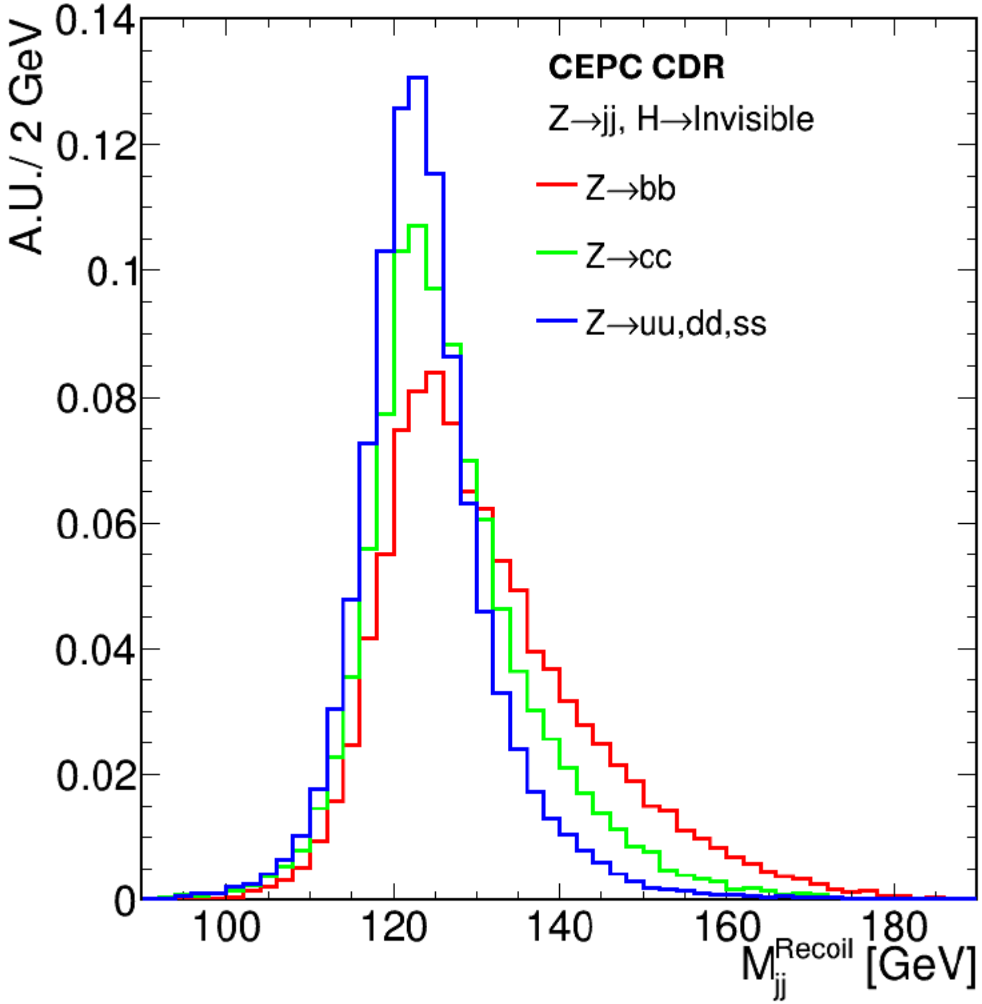
Jet Energy Resolution

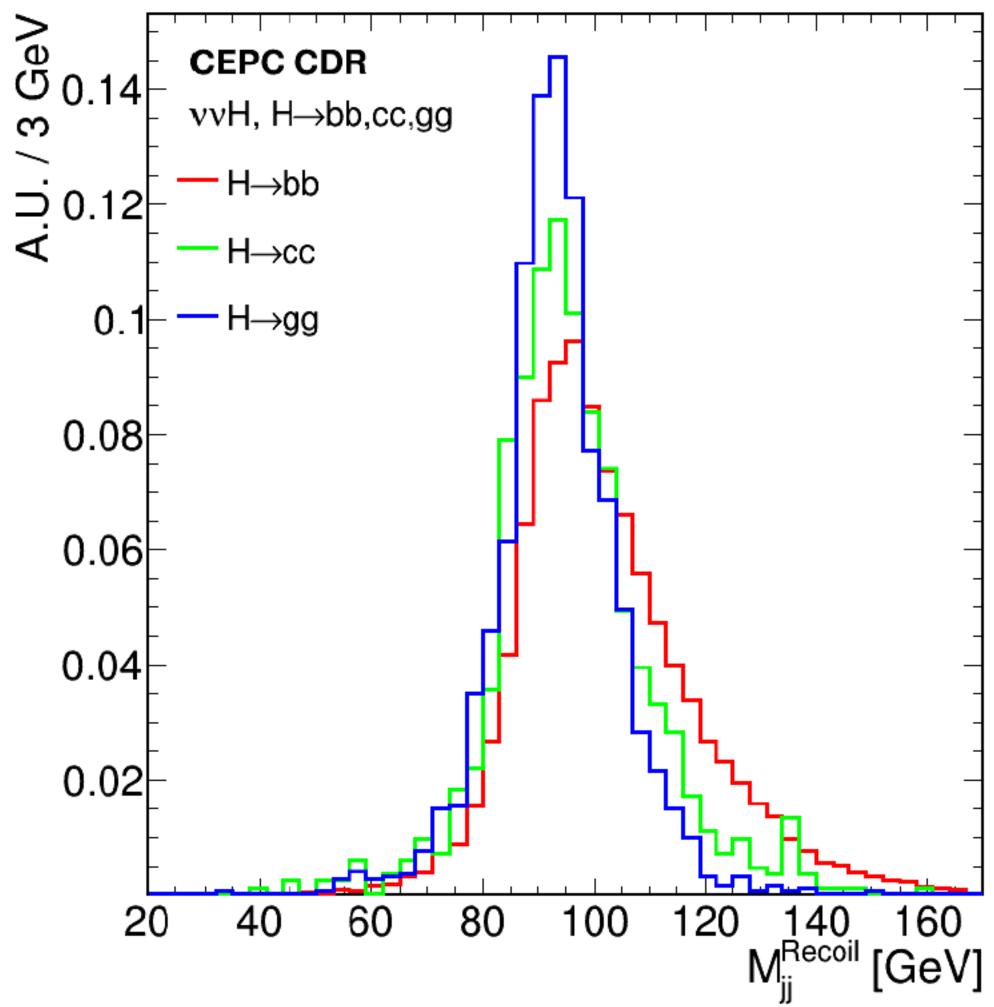




Amplitude ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
Depends on the Flavor, direction and jet energy
Superior to LHC experiments by 3-4 times

Missing Energy & Momentum

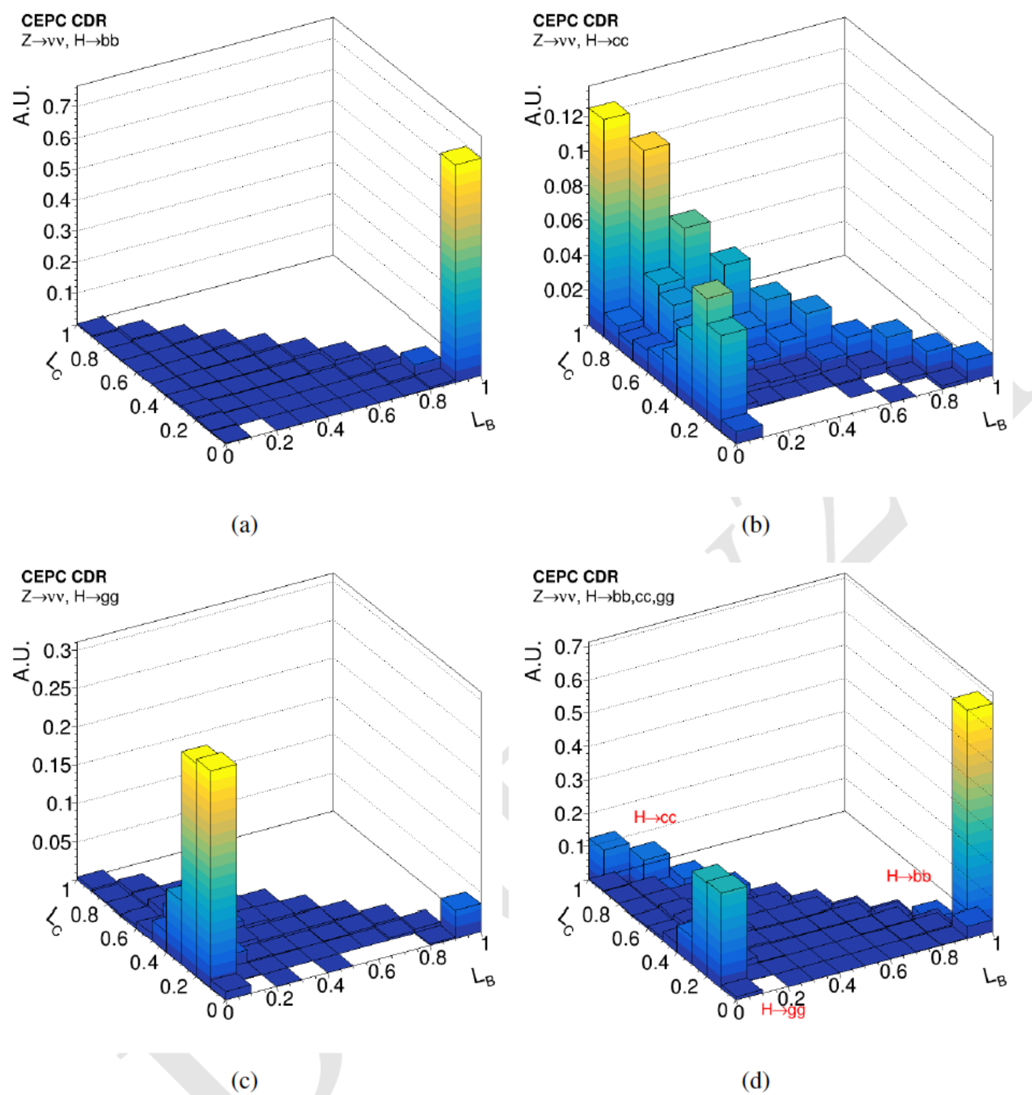




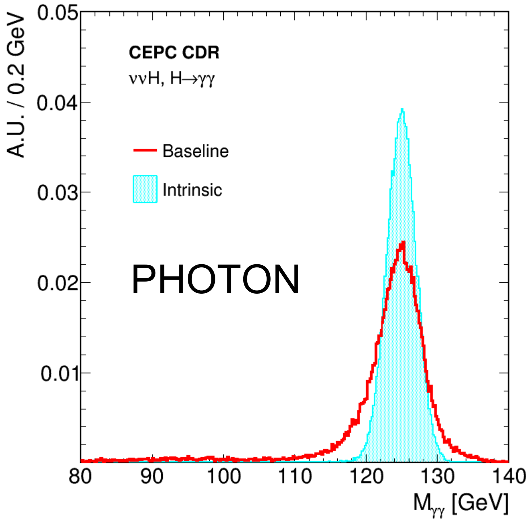
Width of the Light jets: 6GeV/8GeV (Left/Right Plots)

Flavor Tagging

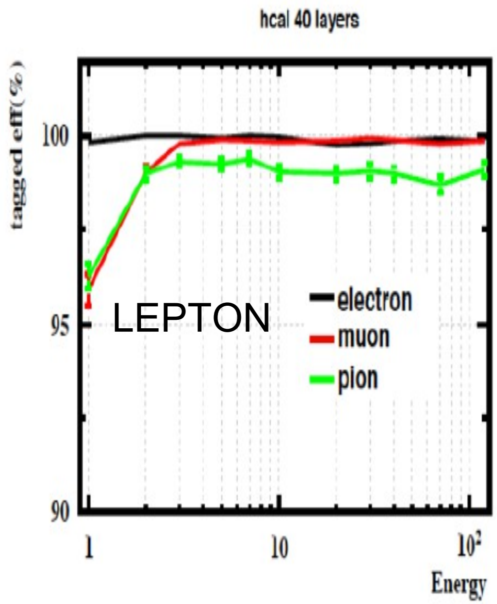
- Using LCFIPlus Package from ilcsoft
- At Higgs->2 jet samples:
  - *Clear separation between different decay modes*
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*

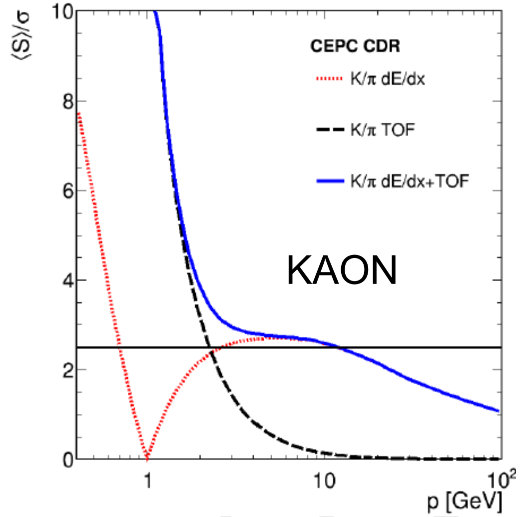


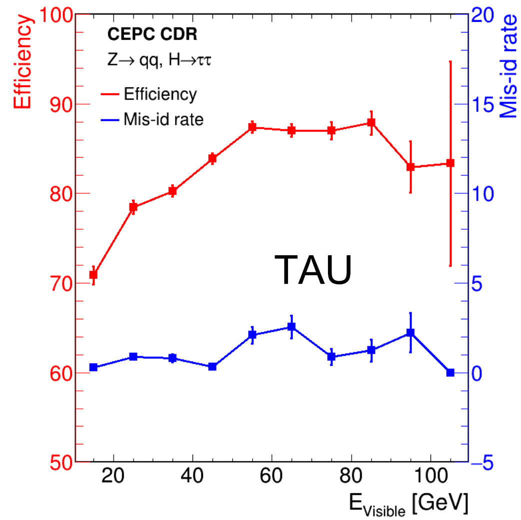
Physics Objects: Tamed

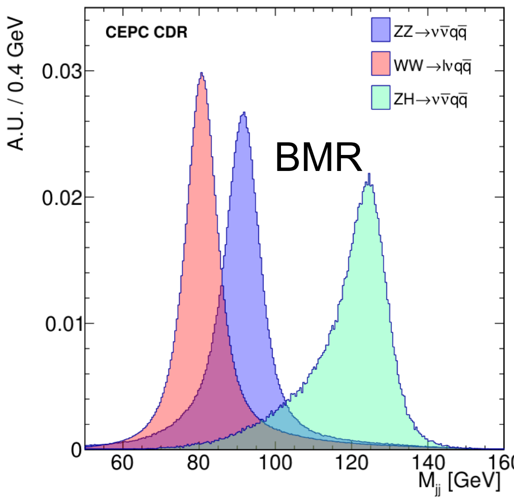


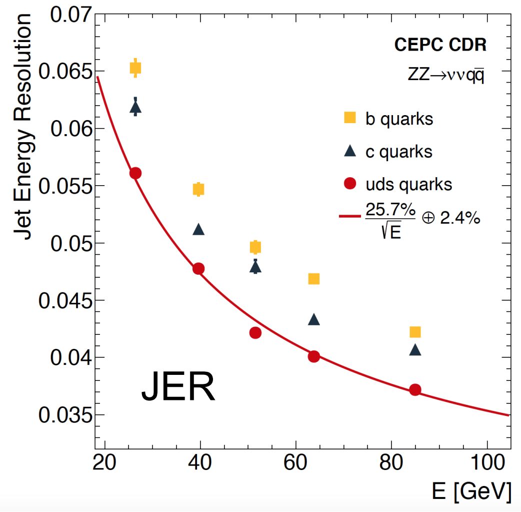
Higgs mass/GeV

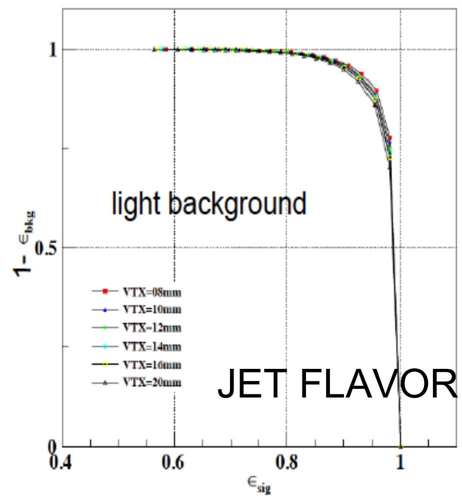


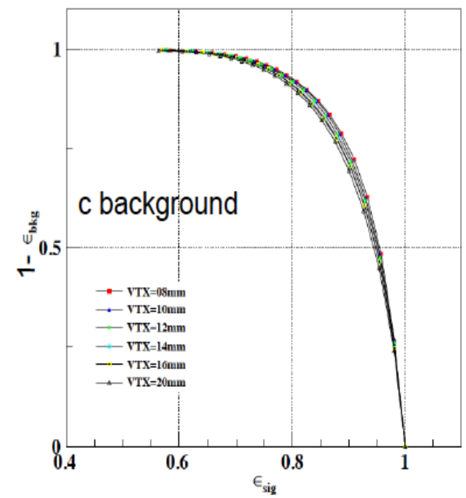




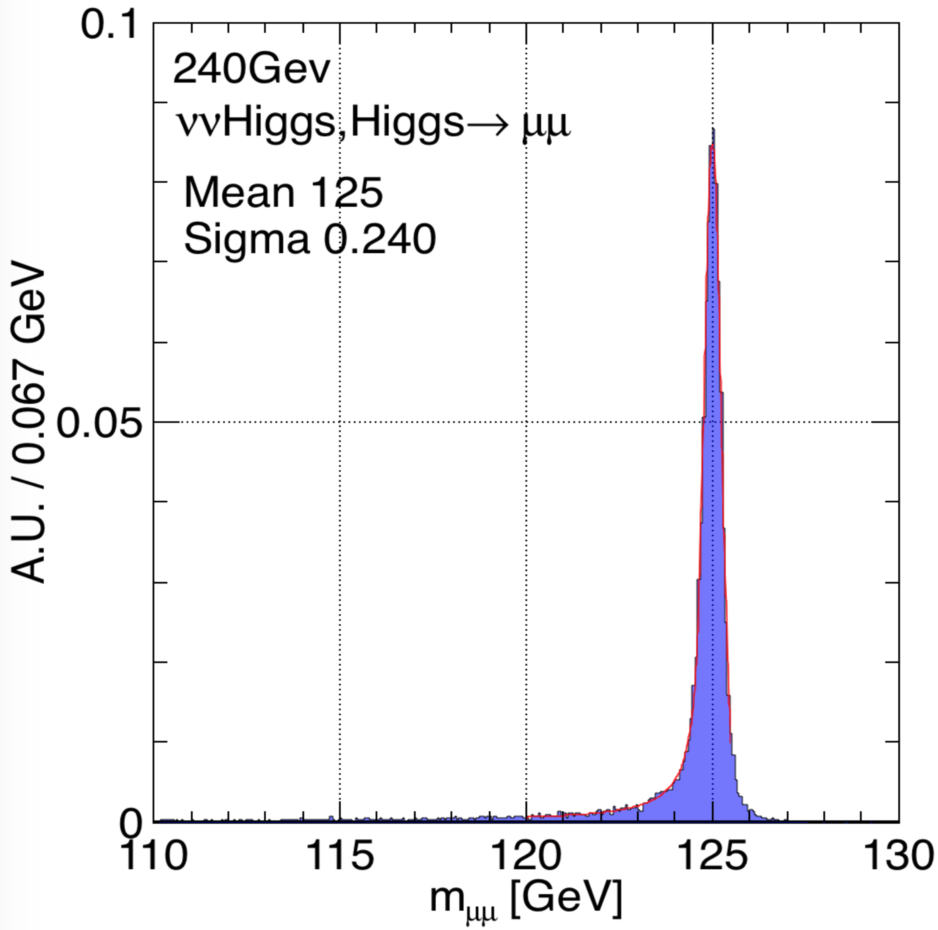


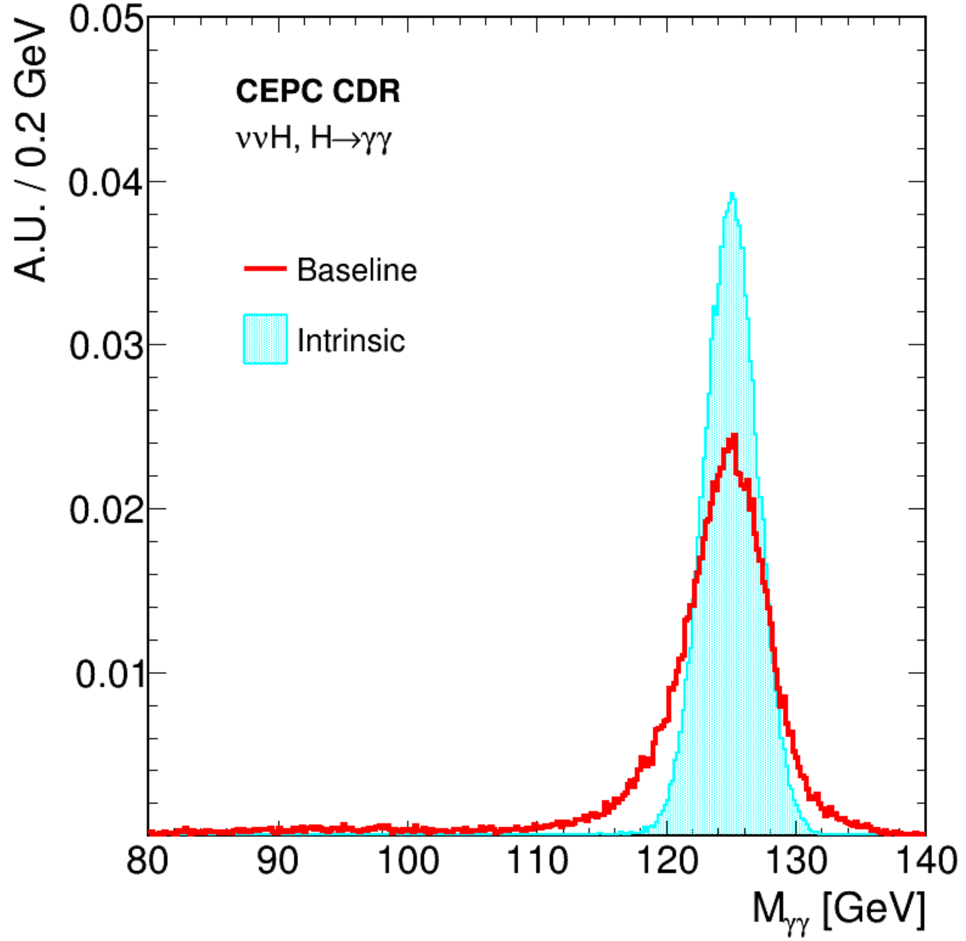






Higgs Signal at APODIS

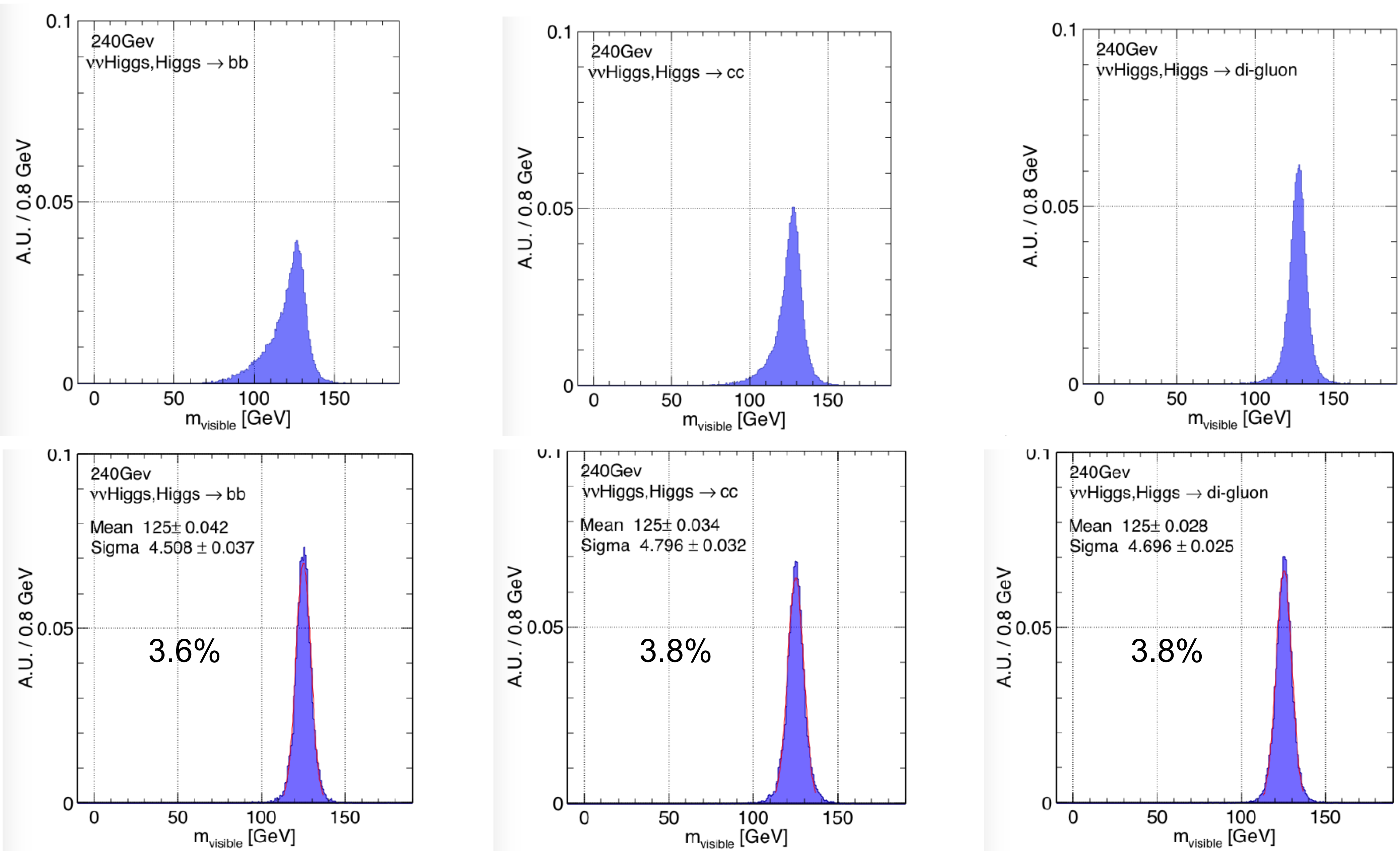




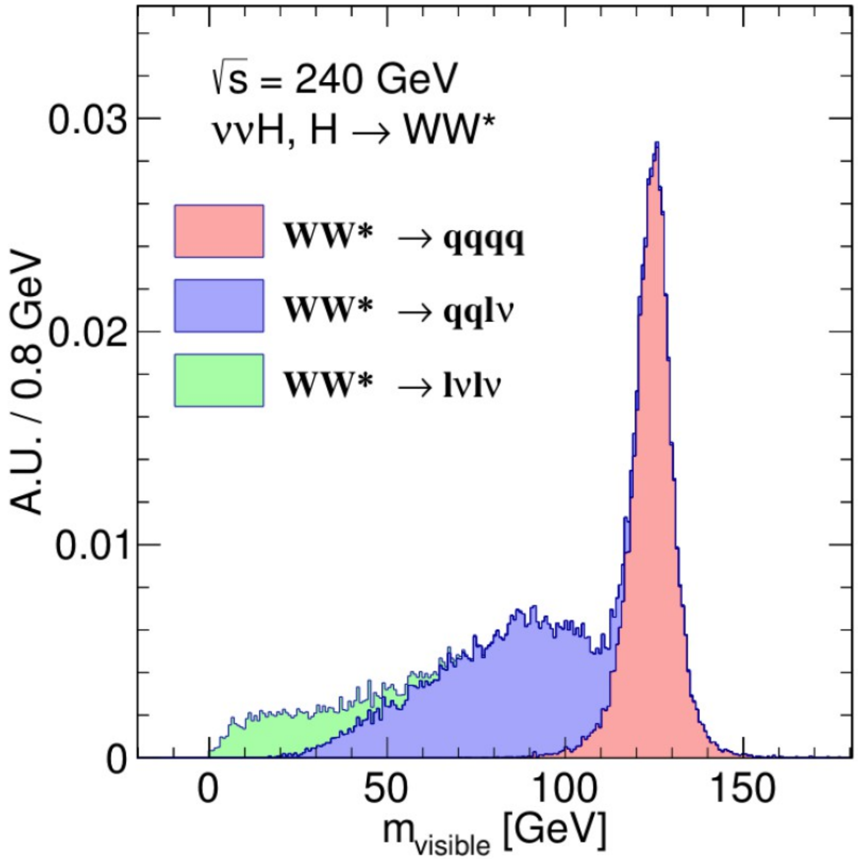
CEPC-RECO-2018-002
CEPC-Doc id 174, 175

Lepton tracks & Photon Clusters

Higgs to bb, cc, gg (Jets)



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



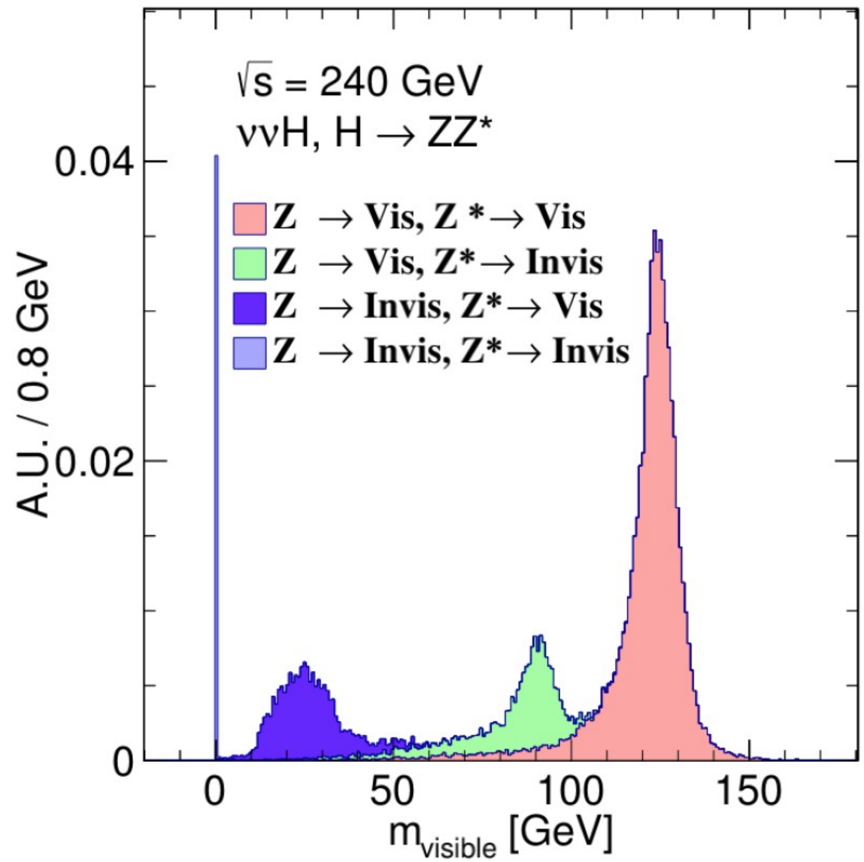


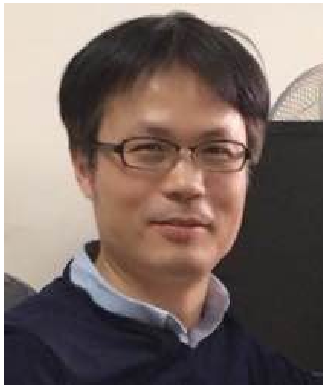
Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

	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]

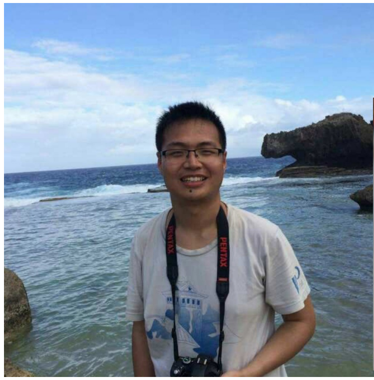
[1] primary result without geometry based correction and fine-tuned calibration.

https://arxiv.org/abs/1806.04992

Teams on Software/Performance



Chengdong FU:
Geant 4 &
Silicon tracking



Xianghu ZHAO:
Computing
Software

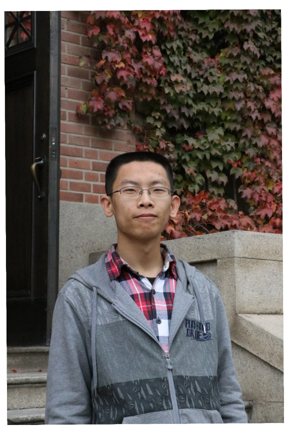
Dan YU:
Lepton ID, PFA
Tau

Peizhu LAI:
JET Response

Fenfen AN:
Kaon id

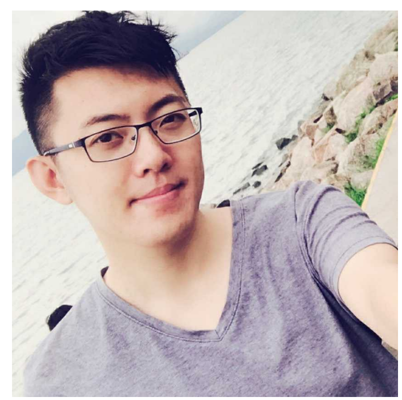
Zhigang WU:
VTX optimization

Xin XU:
Geant 4



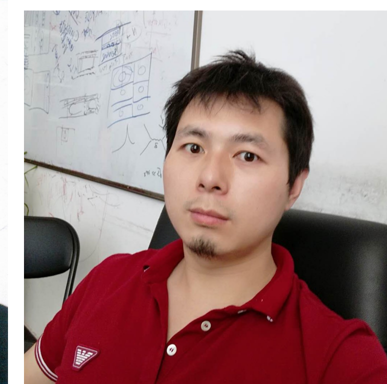
Mingrui ZHAO
Tracking & TPC

Gang LI
Generator
Jet flavor tagging



Hang ZHAO
Photon
Calo optimization

Liang LI
Muon detector



Manqi RUAN
Physics Objects
Reconstruction

…

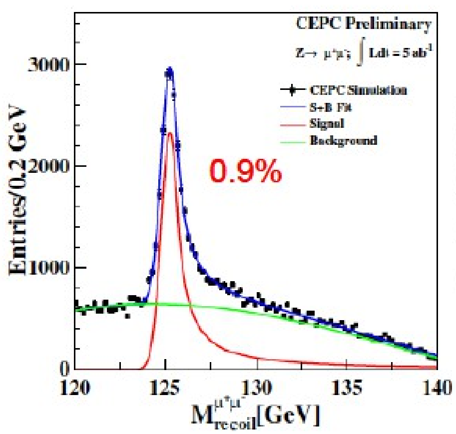
Summary

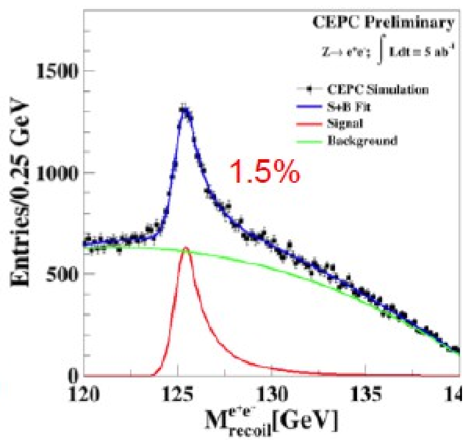
- CEPC, a super Higgs/W/Z factory, requests high efficiency/purity and high precision reconstruction of all key physics objects
- Performance at the baseline design (PFA: APODIS + Arbor)
  - All key physics objects tamed
  - Clear Higgs signature in all SM Higgs decay modes
  - Clear distinguish between the Signal and SM backgrounds → 0.1% – 1% relative error in Higgs coupling measurements (see Jianming's talk)
  - Fulfills the physics requirements of the CEPC Higgs operation
- To do
  - Reconstruction development/Optimization, iterate with detector design
  - Identification of Jet flavor, gluon jets, and color singlets
  - Data preservation, deep learning, parallel computing
  - Lots of challenges & excitements

backup

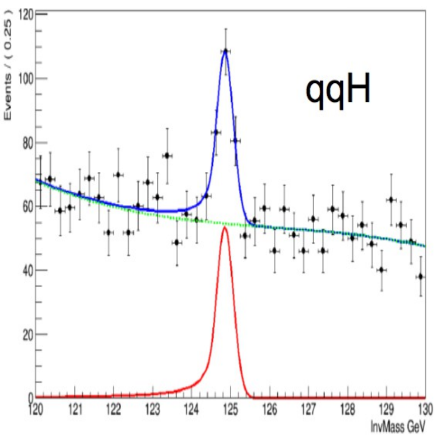
Higgs benchmark analyses

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

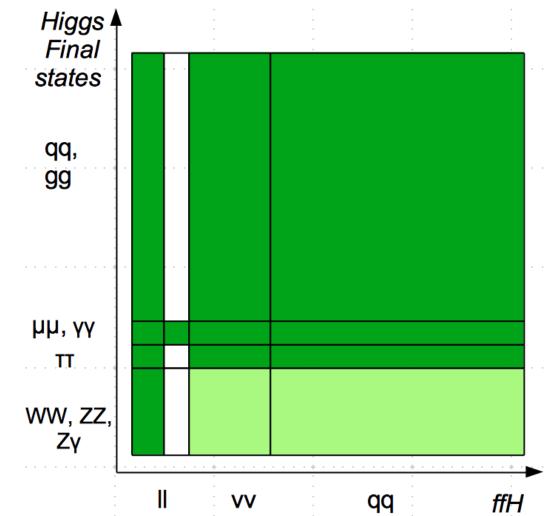




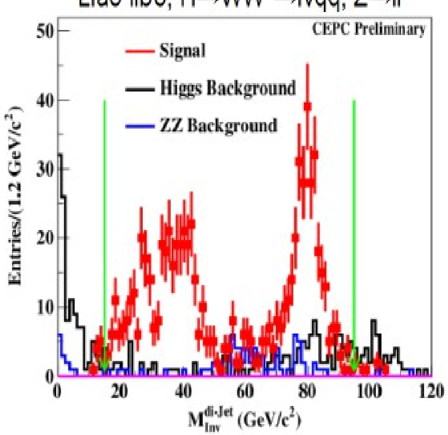
σ(ZH) measurements



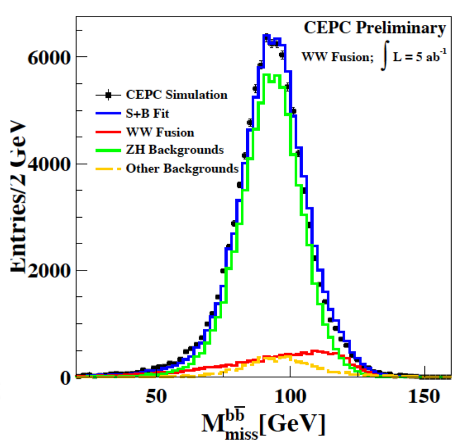
Br(H→μμ)



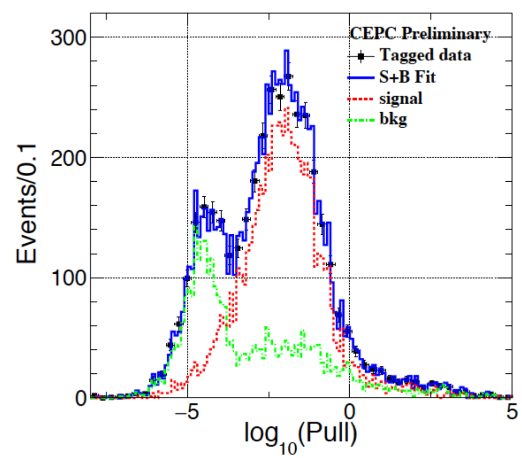
Liao libo, H→WW*→lνqq, Z→ll



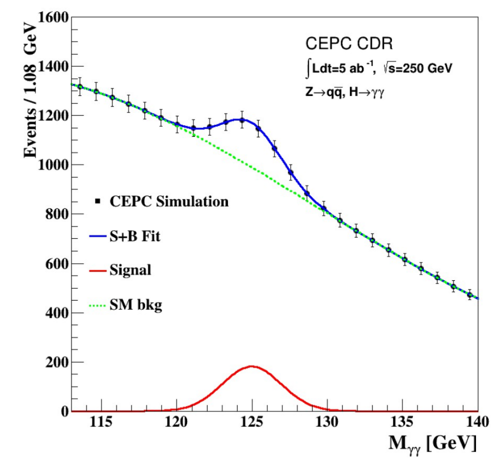
Br(H→WW)



σ(ννH)*Br(H→bb)



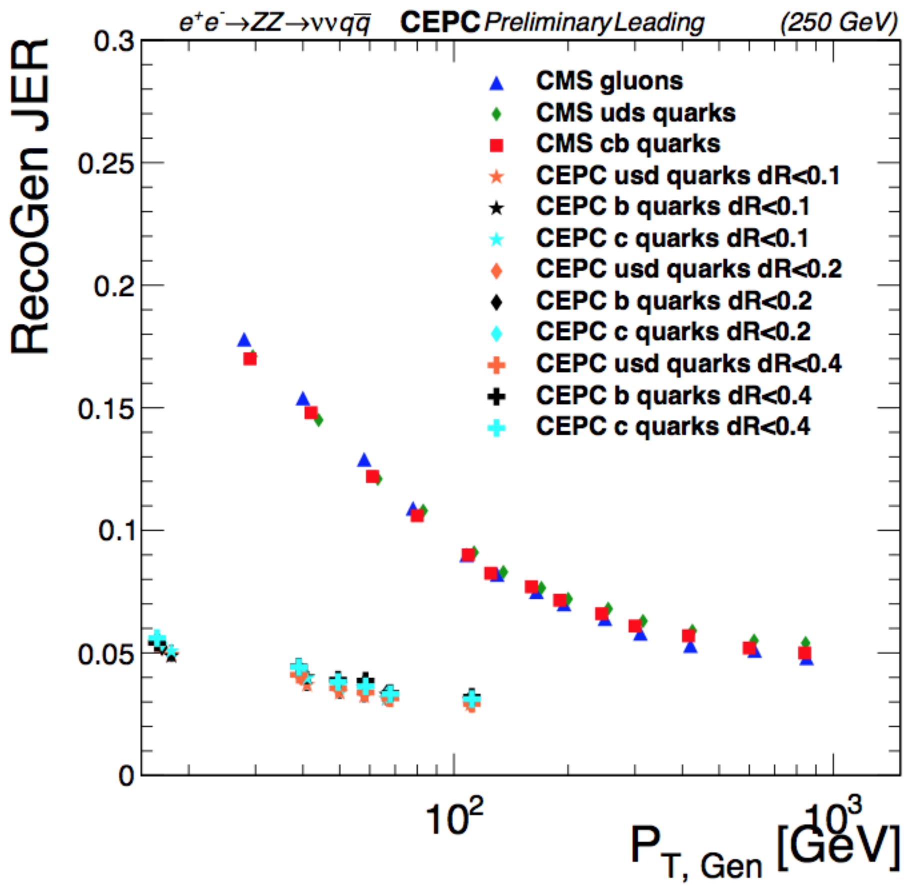
Br(H→ττ)

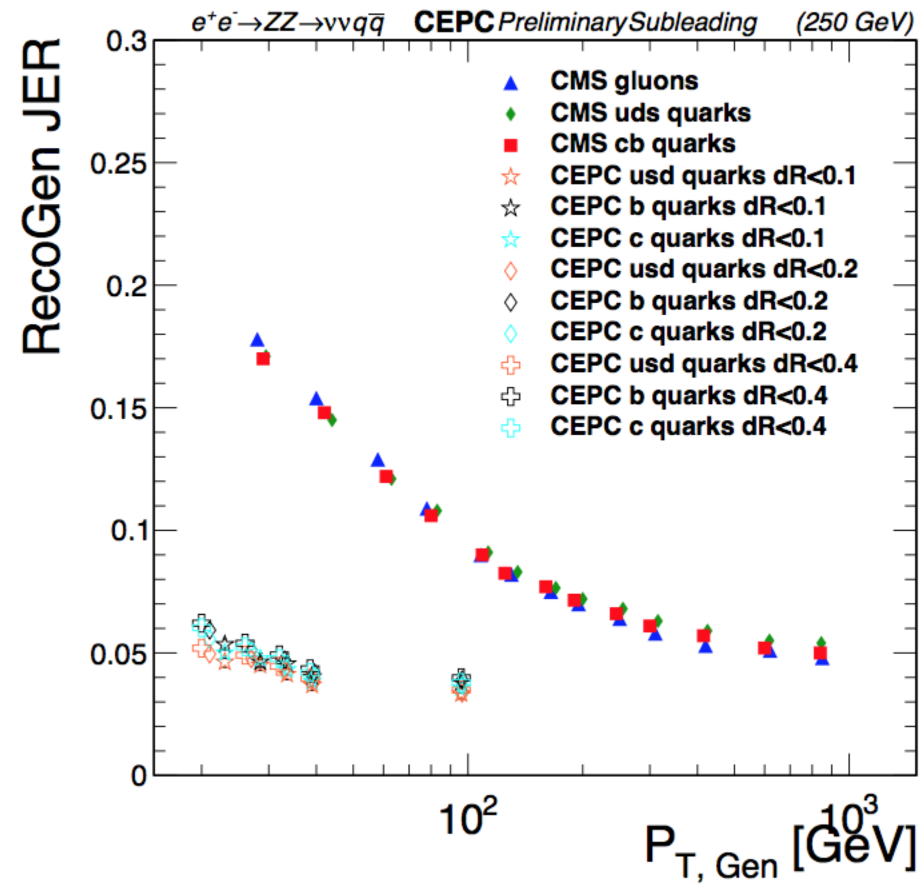


Br(H→γγ) (Asimov)

See Next Talk (On Higgs Performance)

Jet Energy Resolution

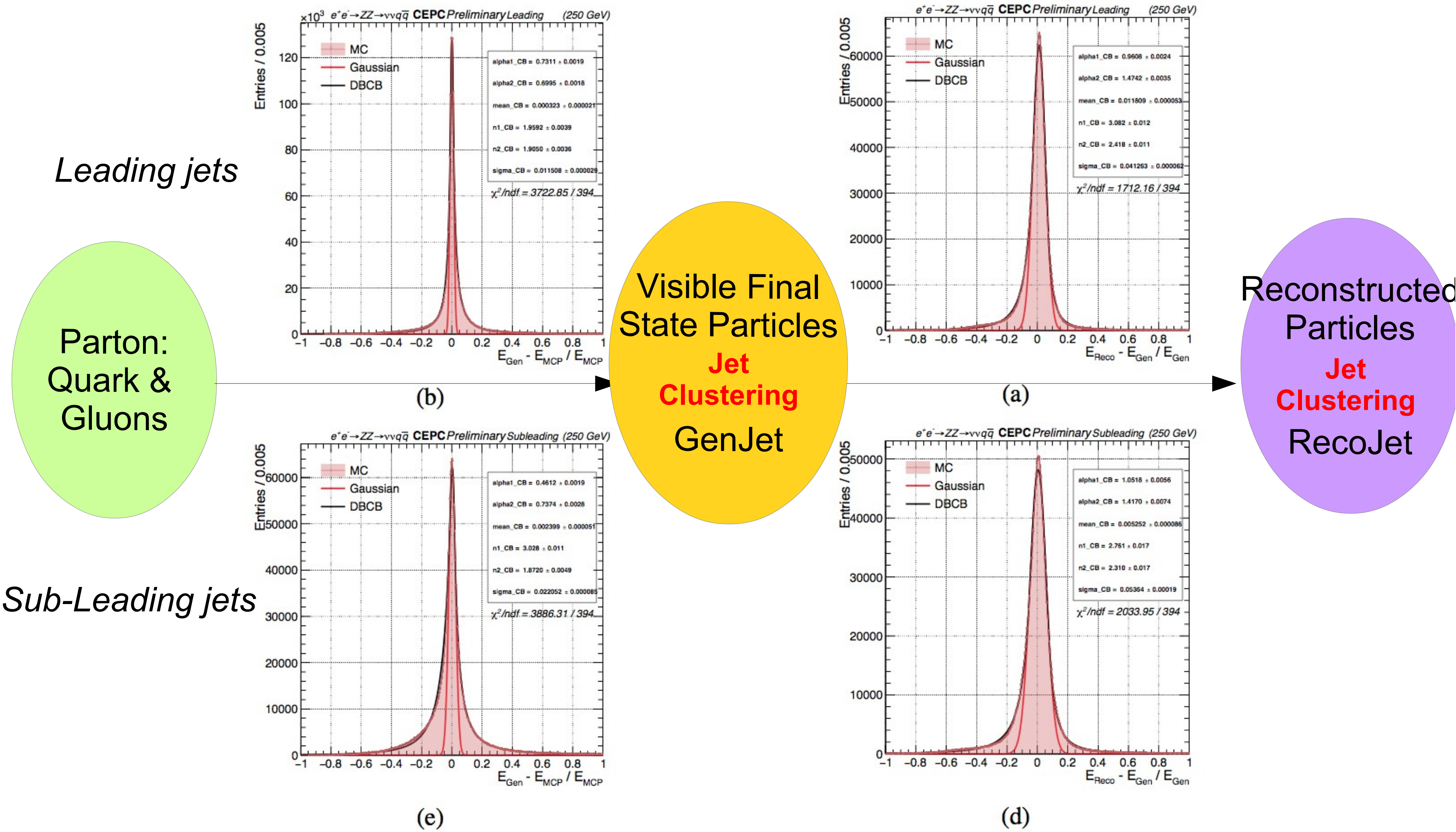




CMS Reference: CMS-JME-13-004,

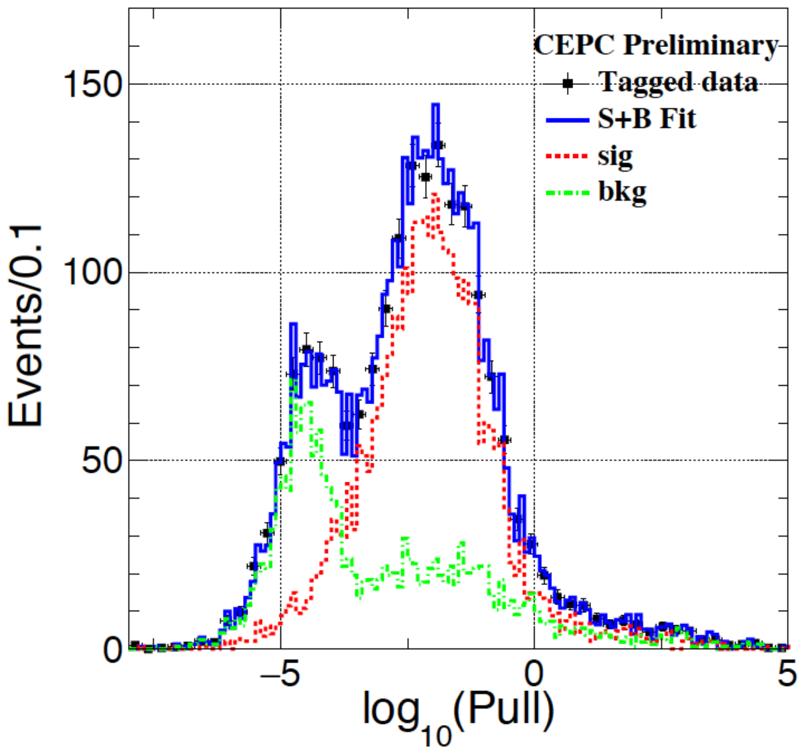
Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV

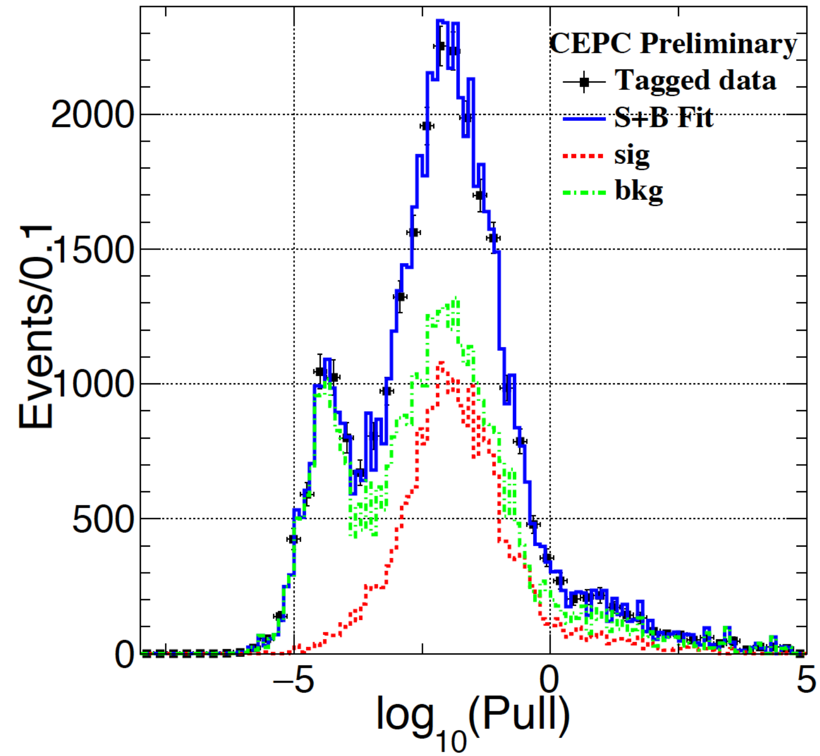
Impact of Jet Clustering: Significant



Jet Clustering is Mainly responsible for the tails

g(Hττ) measurement

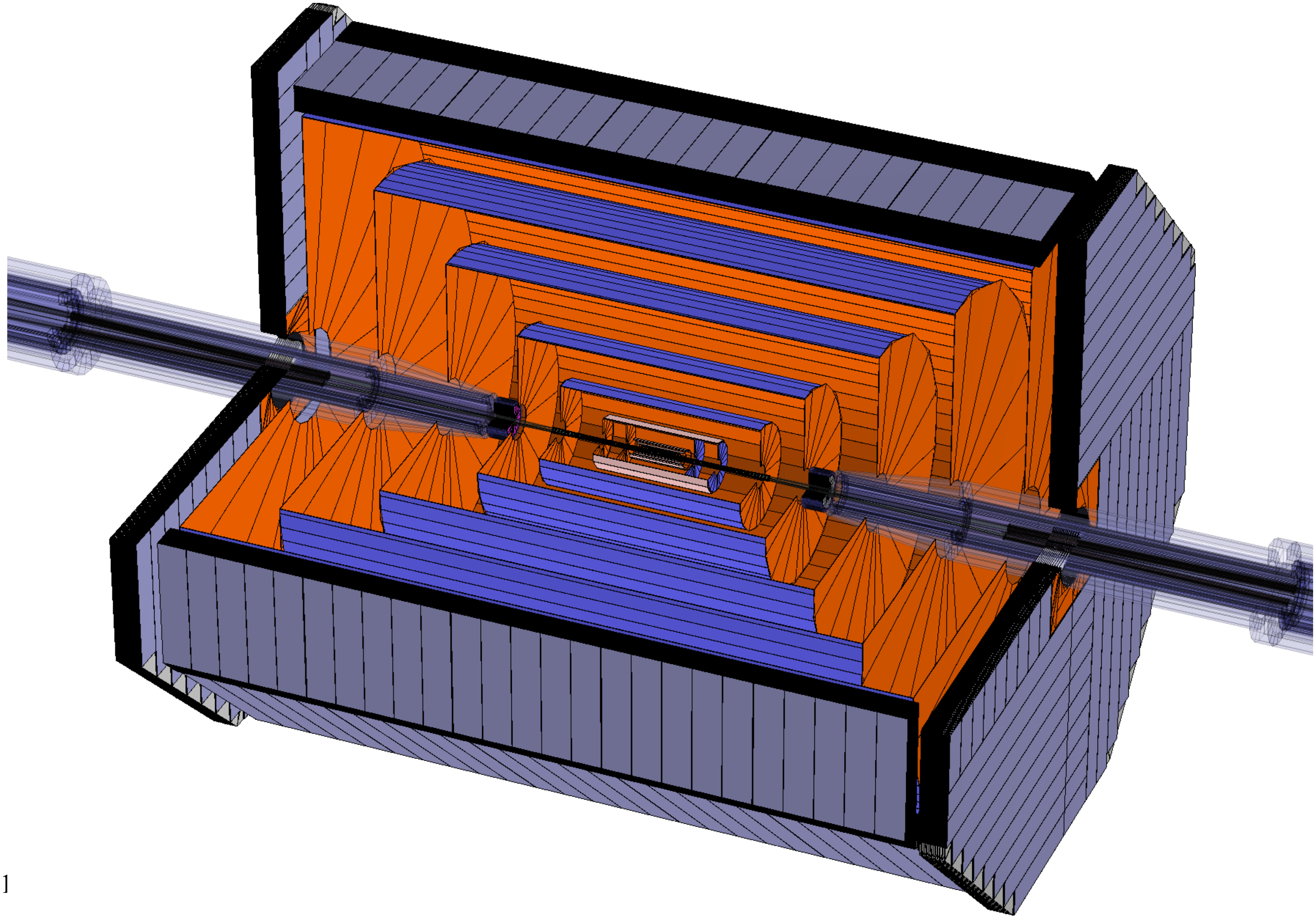




- ZH→μμττ
- Extremely Efficient Event Selection
- Signal efficiency of 93% - entire SM background reduced by 5 orders of magnitude

- ZH→qqττ
- Cone based tau finding algorithm, Compromise the efficiency & purity
- Signal efficiency of 51%

APODIS with Full Silicon Tracking...



Issues to be addressed

- Tracking
  - Dedx/material effect correction (induces o(100) MeV bias in Higgs mass at in H->mumu) (20, 30, 20)
  - Development, Performance analysis & Integration of CEPC tracking (Arbor & Conformal & ...) (50, 90, 90)
- PFA
  - Cluster energy estimator development
    - Photon (EM Shower) Geometry dependent energy correction (50, 90, 20)
    - HAD? (40, 50, 50)
  - Usage of Timing information... (60, 90, 80)
  - Optimization of HCAL geometry (50, 60, 70)
- Lepton ID & P ID:
  - Integration & Usage of Timing information (60, 80, 20)

Urgency, Importance, Difficulties

Issues to be addressed

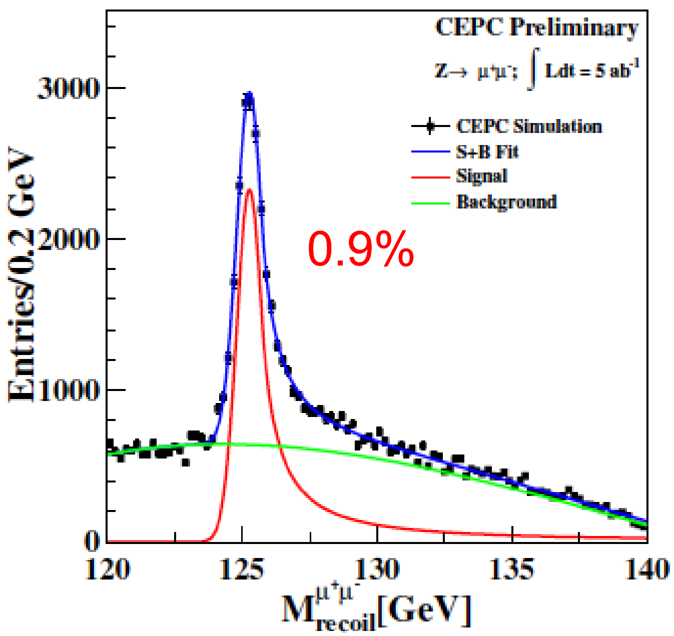
- Composited object finder: **CORAL** (finding Pi0, Kshort, Lambda, J/Psi, ...)
  - Framework is ready... and lots of performance study and optimization awaits (40, 90, 50)

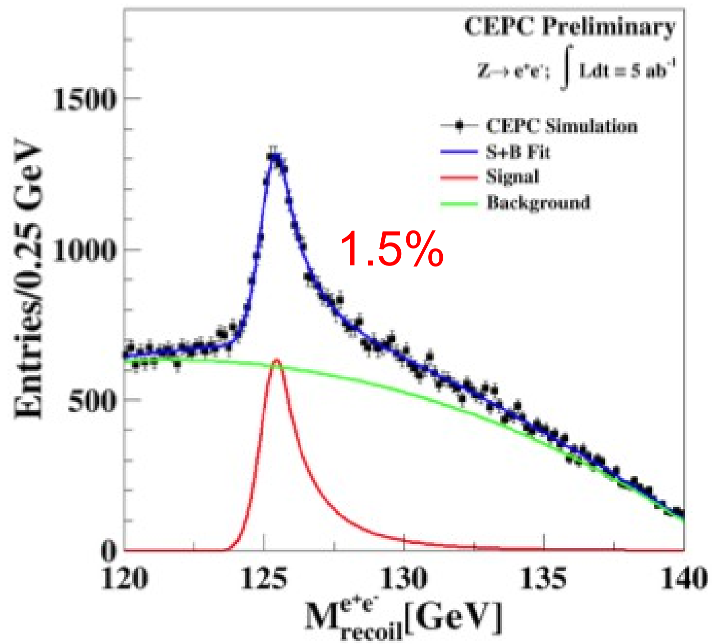
Urgency, Importance, Difficulties

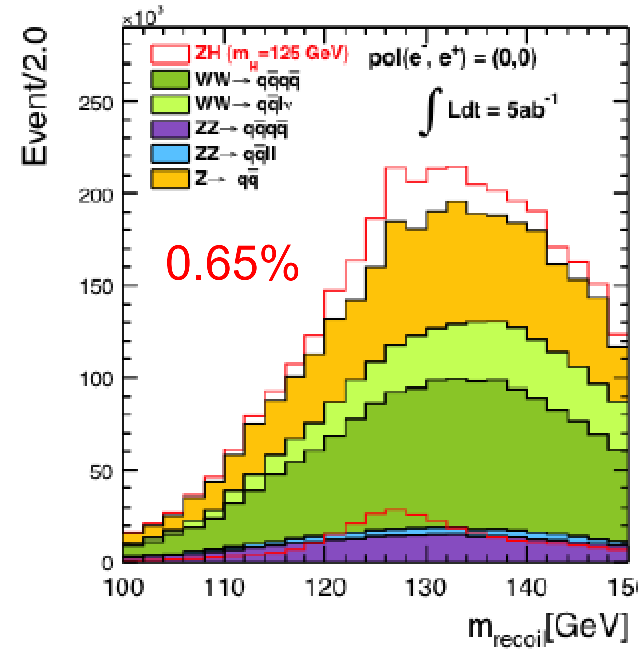
- Jets
  - Jet Clustering: finding the color singlet? (40, 90, 90)
  - Distinguish between 2 jet, 3 jet, 4jet, 5jet, 6jet events.... (80, 80, 60)
    - Mila's analysis (ZH->6 jets) gives a very good example
- **Jet Flavor Tagging** (**90**, **99**, **80**)
  - The efficiency of reconstruct 2^{nd} Vertex in Z->cc events is ONLY 20%!!!
- Separation of gluon to quark jets? (**50**, **50**, 50)
- Usage of Deep learning at reconstruction... (**30**, **90**, 50)
- ...Lots Lots of Detector Optimization & Integration....

Model-independent measurement of σ(ZH)

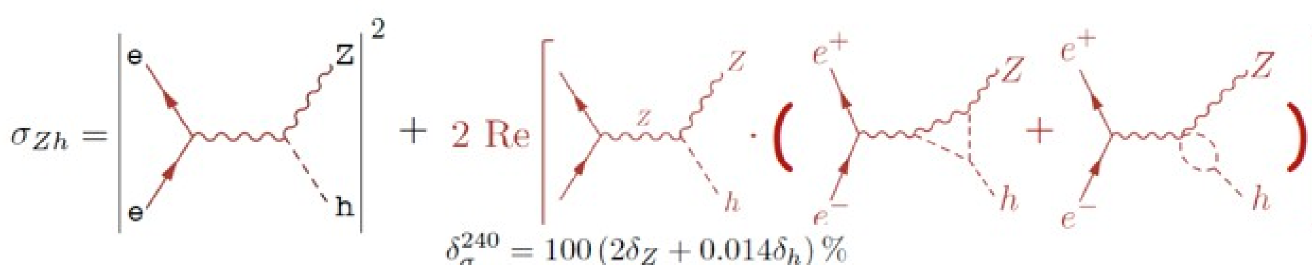
Zhenxing Chen & Yacine Haddad







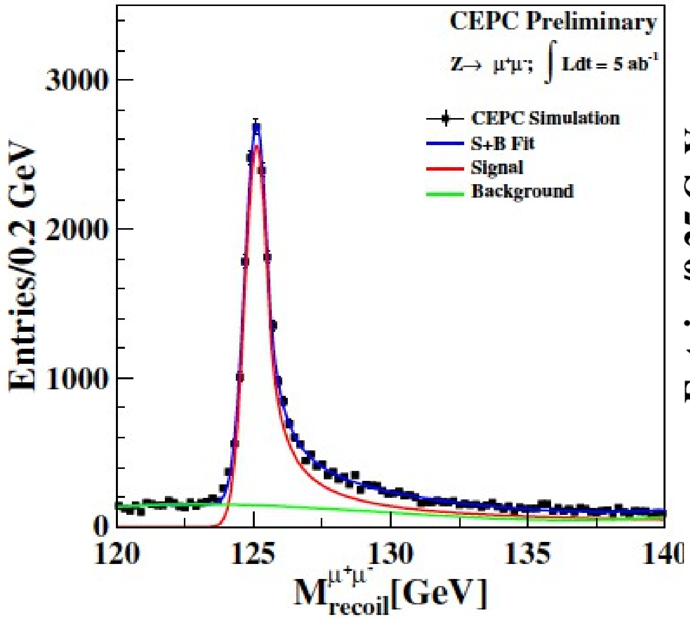
- Recoil mass method. Combined precision:
  $\delta\sigma(ZH)/\sigma(ZH) = 0.5\%$ -
  $\delta g(HZZ)/g(HZZ) = 0.25\%$
- Indirect Access to g(HHH)

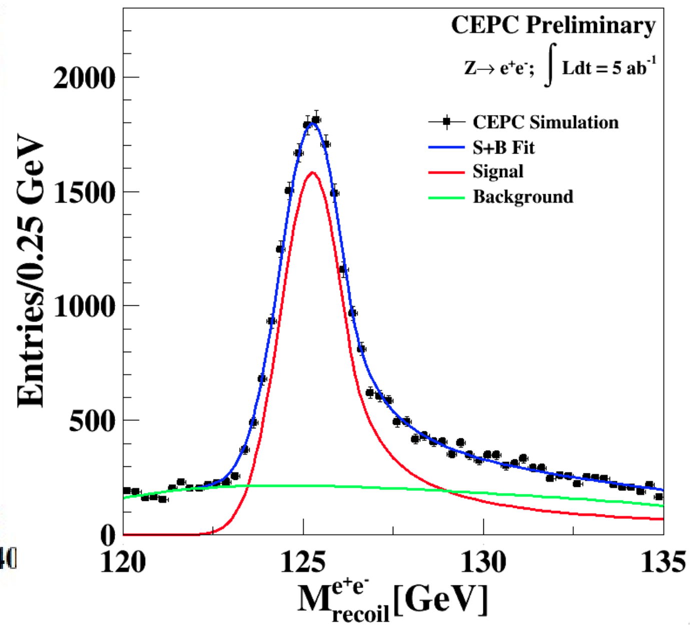


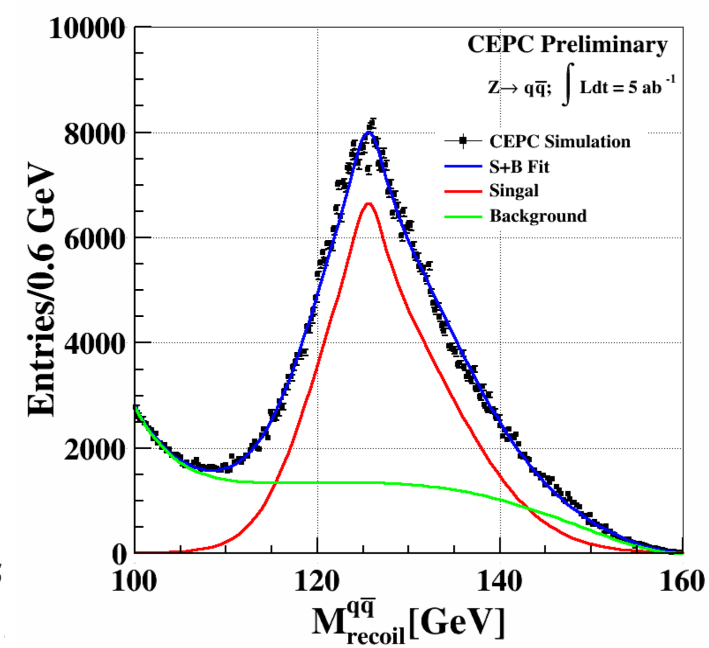
- *M. McCullough, 1312.3322*

Exotic: Higgs invisible decays

*Assuming sigma(ZH)*Br(H->inv) = 200 fb*

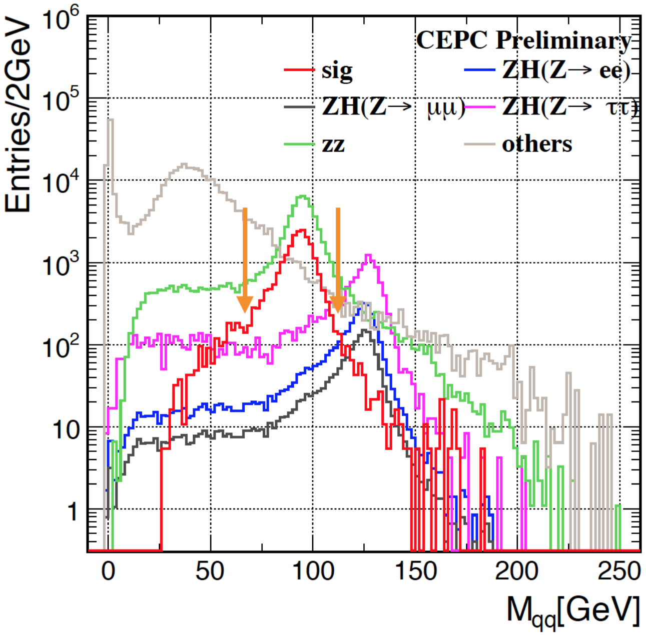


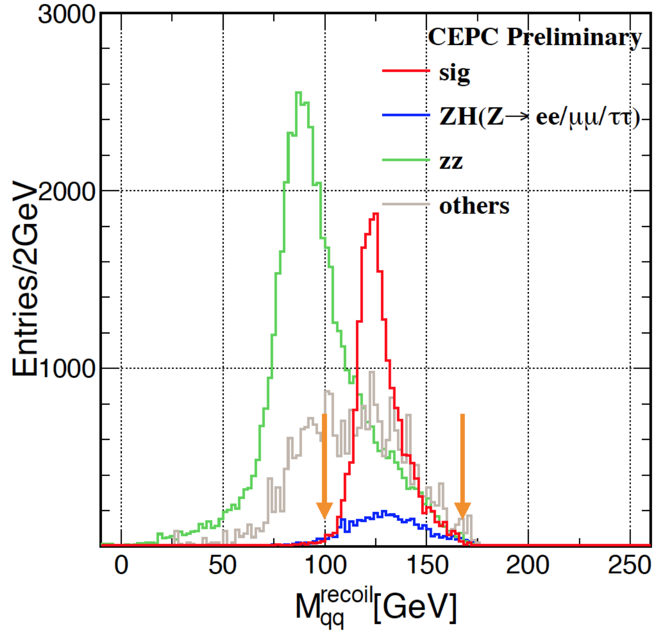


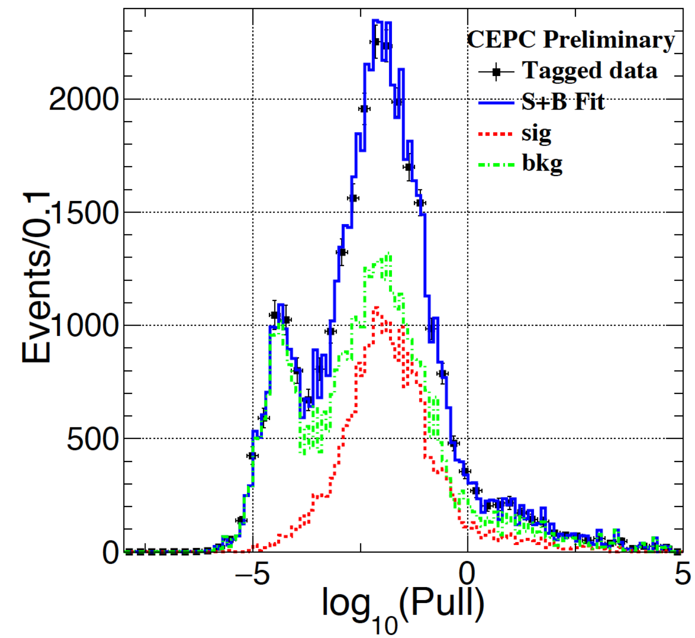


Invisible up limit at CEPC: ~0.3% at 95% C.L

An Analysis Example (Dan): *g(Hττ)* at qqH







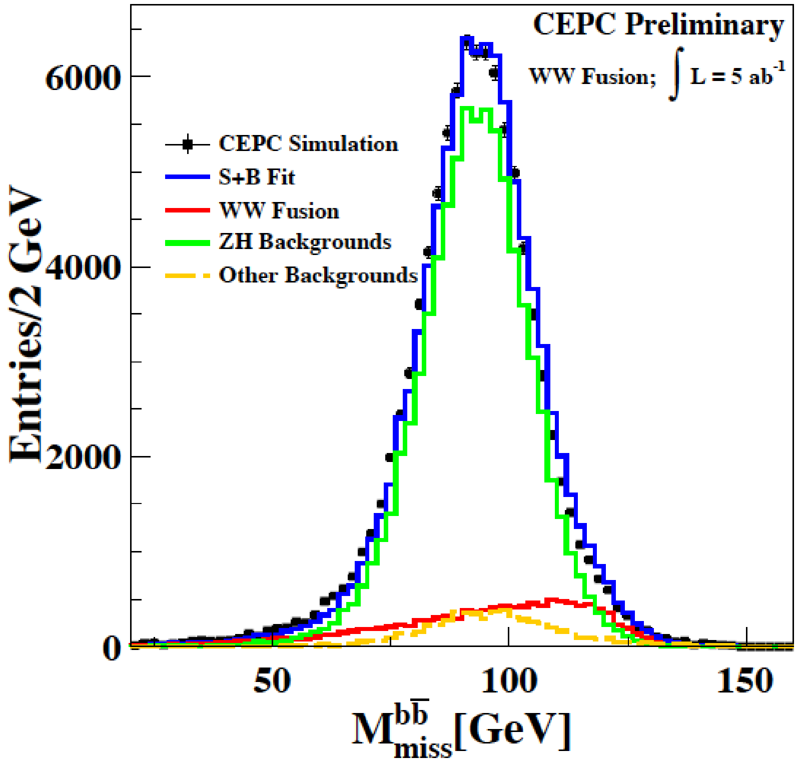
- Cone based tau finding: di-tau system
- The other particles are define as the di-jet system: to distinguish the qqττ background
- Isolated tracks are intensionally defined as tau candidate: be distinguished by the VTX

	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

Ph.D thesis of D. Yu

Higgs width measurement

- $g^2(HXX) \sim \Gamma_{H\to XX} = \Gamma_{total}*Br(H\to XX)$
- Branching ratios: determined simply by
  - σ(ZH) and σ(ZH)*Br(H→XX)
- Γ_{total} : determined from:
  - σ(ZH) (~g^2(HZZ))
    σ(ZH)*Br(H→ZZ) (~$g^4(HZZ)/\Gamma_{total}$)
  - σ(ZH)*Br(H→bb),
    σ(vvH)*Br(H→bb),
    σ(ZH)*Br(H→WW),
    σ(ZH)

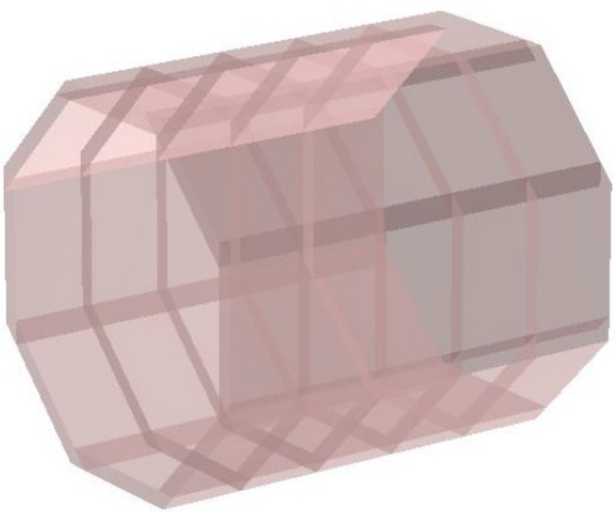


Br(H->ZZ): relative error of 6.9% achieved with ZH->ZZZ*->vv(Z)llqq(H) final states. Extrapolation of TLEP result leads to 4.3% relative error

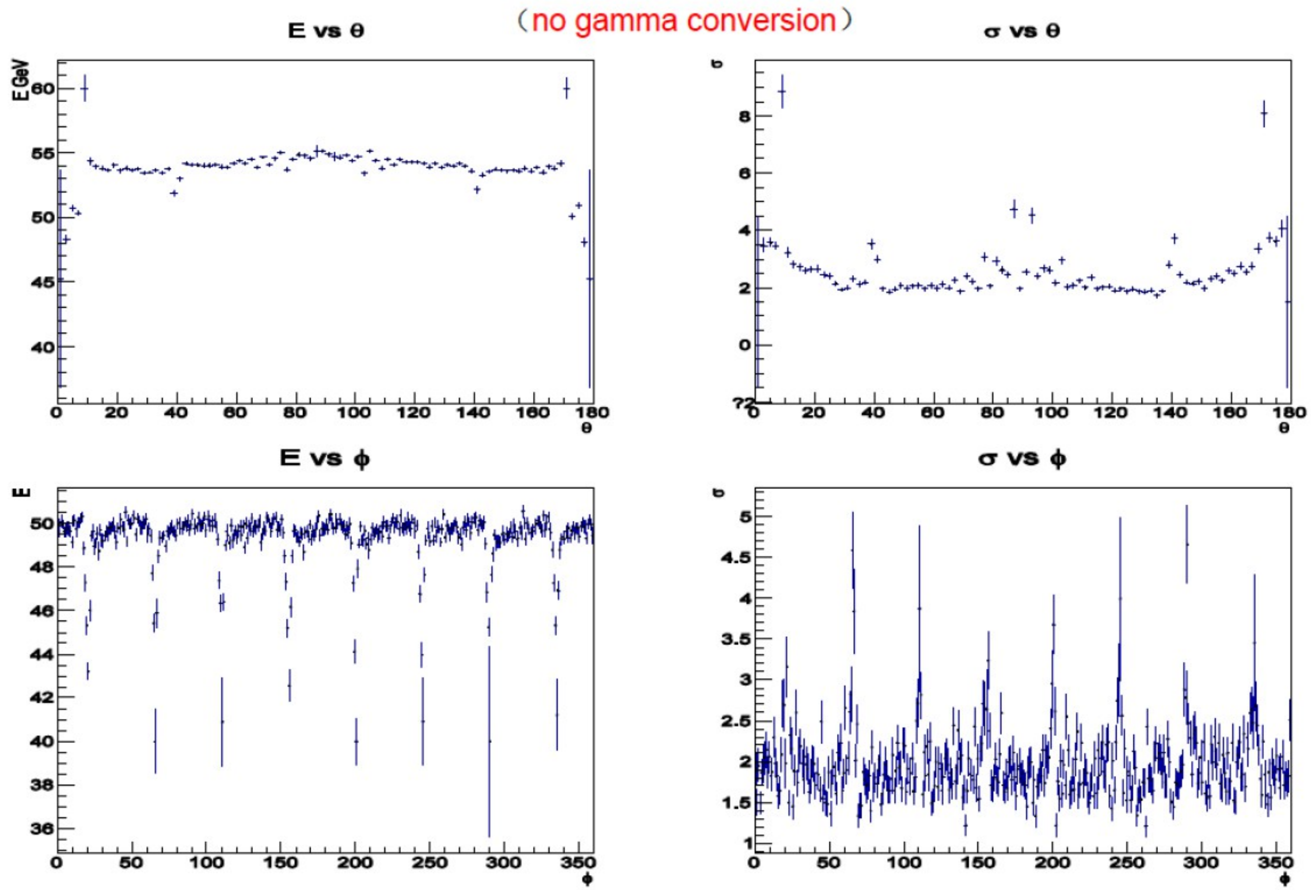
σ(vvH)*Br(H->bb): relative error of 2.8%

A combined accuracy of 2.8% for the Higgs total width measurements

Arbor: photon reconstruction



ECAL Barrel of ILD/CEPC_v1



Angular Correlation of EM Shower energy response