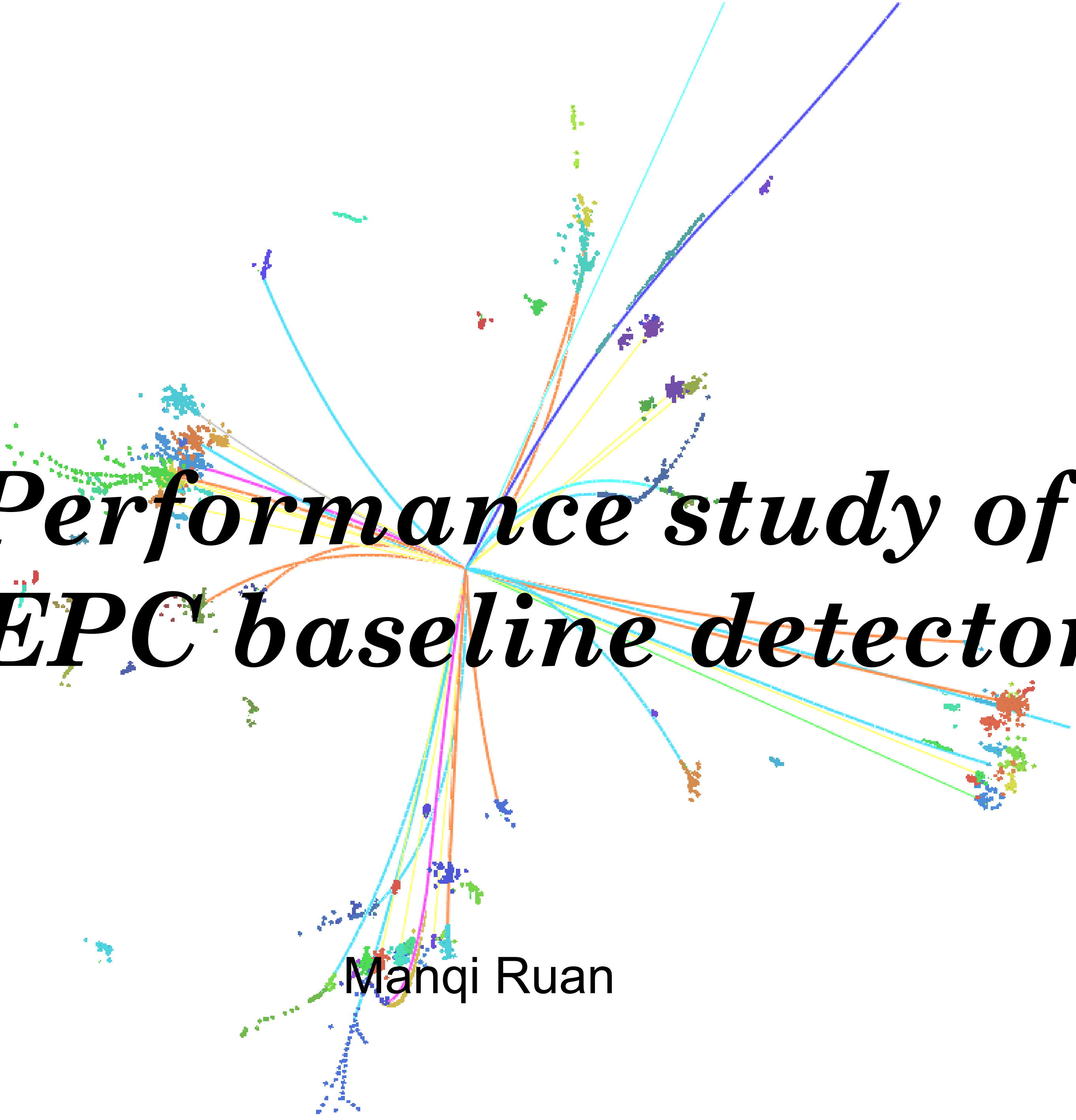
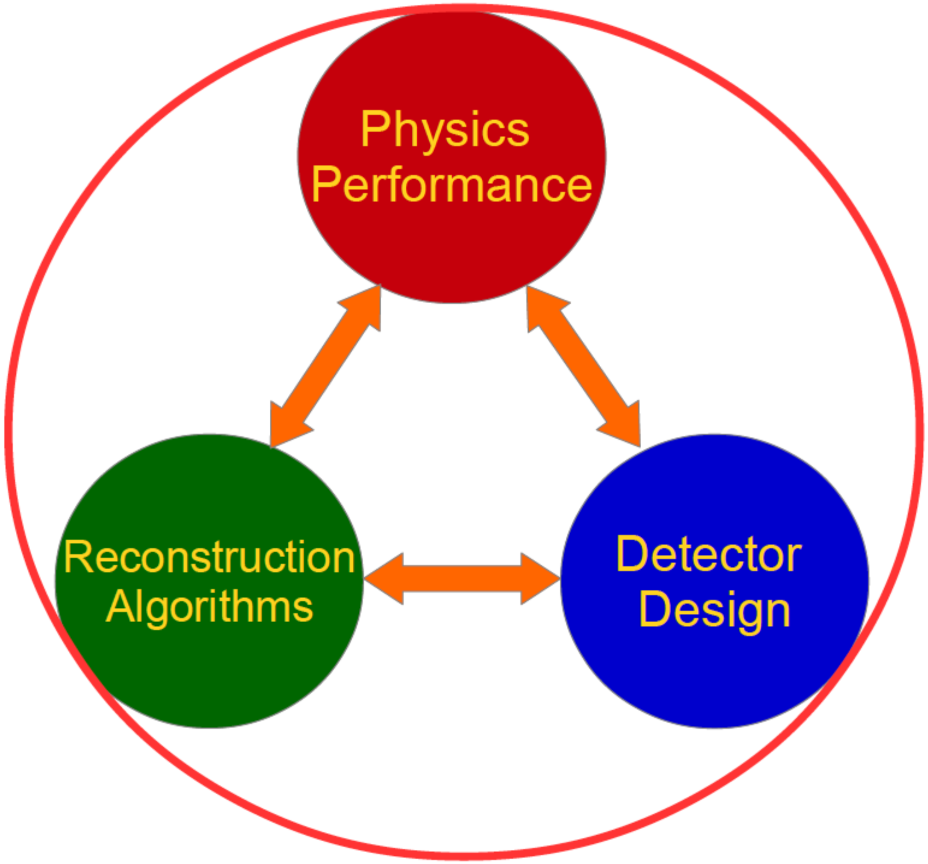


The Performance study of the CEPC baseline detector

Manqi Ruan

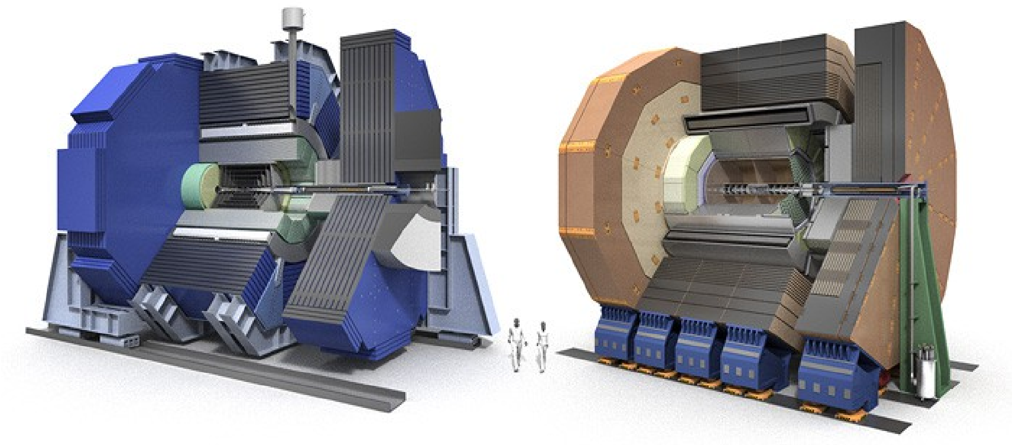
Performance

- Determined by
  - Detector concept
  - Reconstruction algorithm
- Characterized at
  - **Physics Objects**
  - **Higgs Signal**
  - Benchmark Physics Analyses (see Jianming's talk)

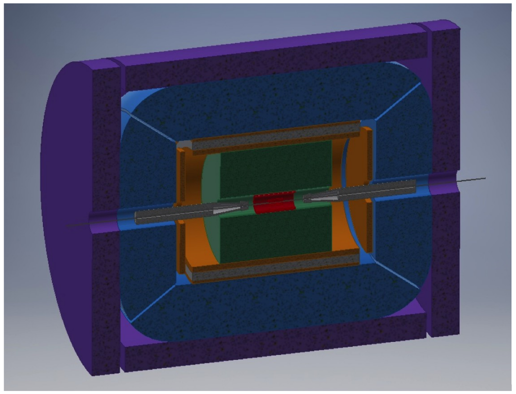


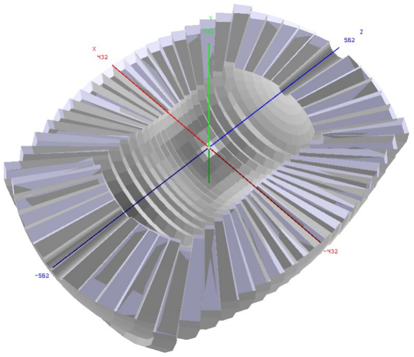
Two classes of Concepts

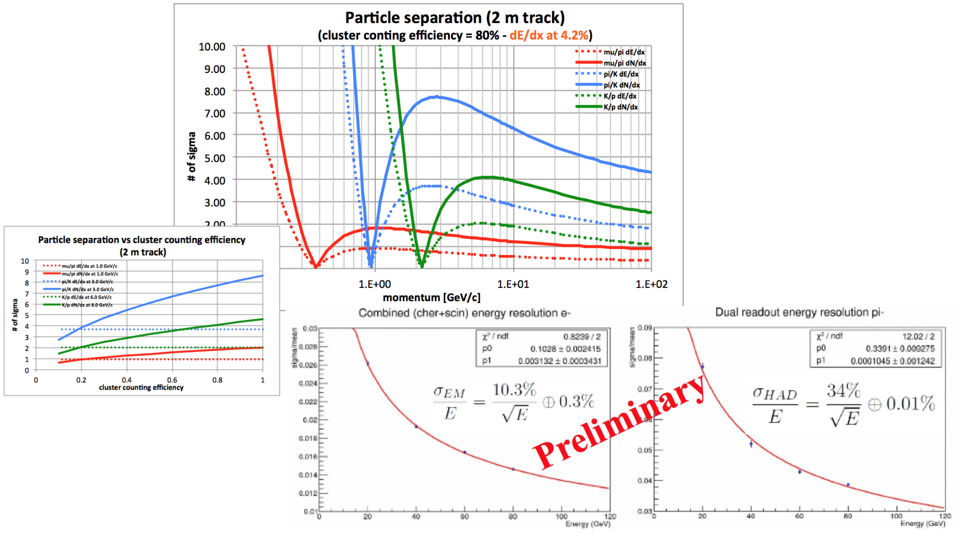
- PFA Oriented concept using High Granularity Calorimeter
  - **+ TPC (ILD-like, Baseline)**
  - + Silicon tracking (SiD-like)



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



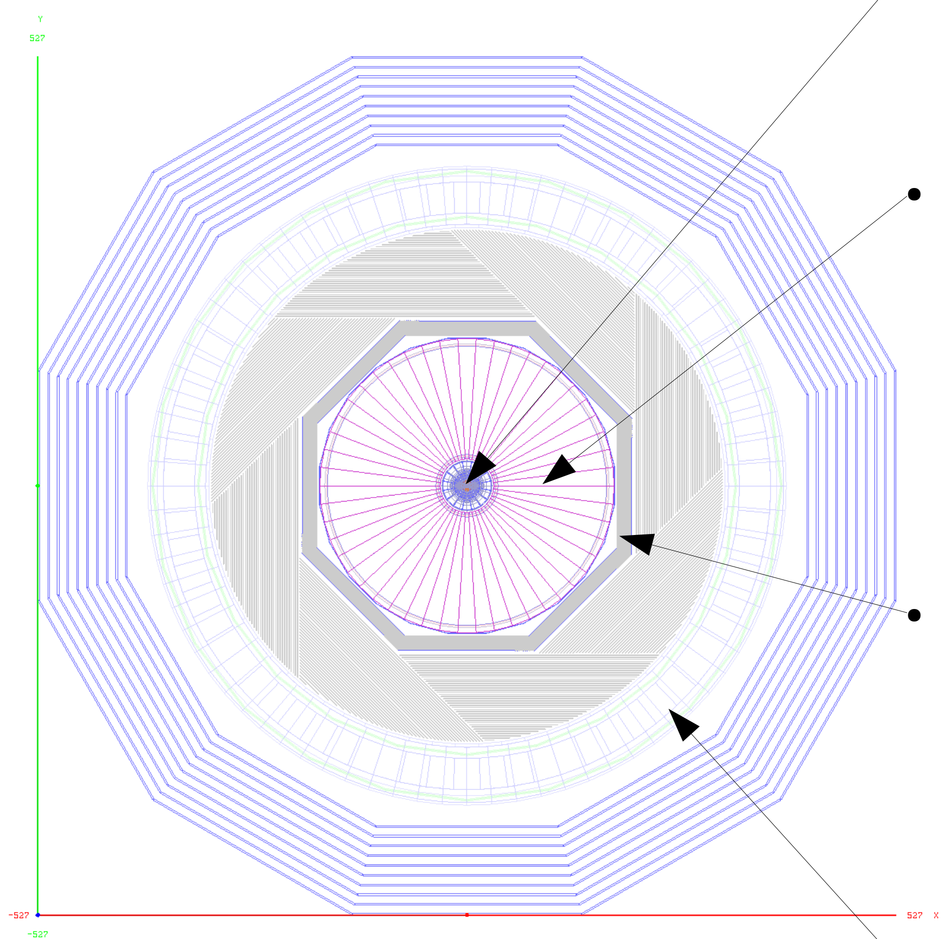




https://indico.ihep.ac.cn/event/6618/

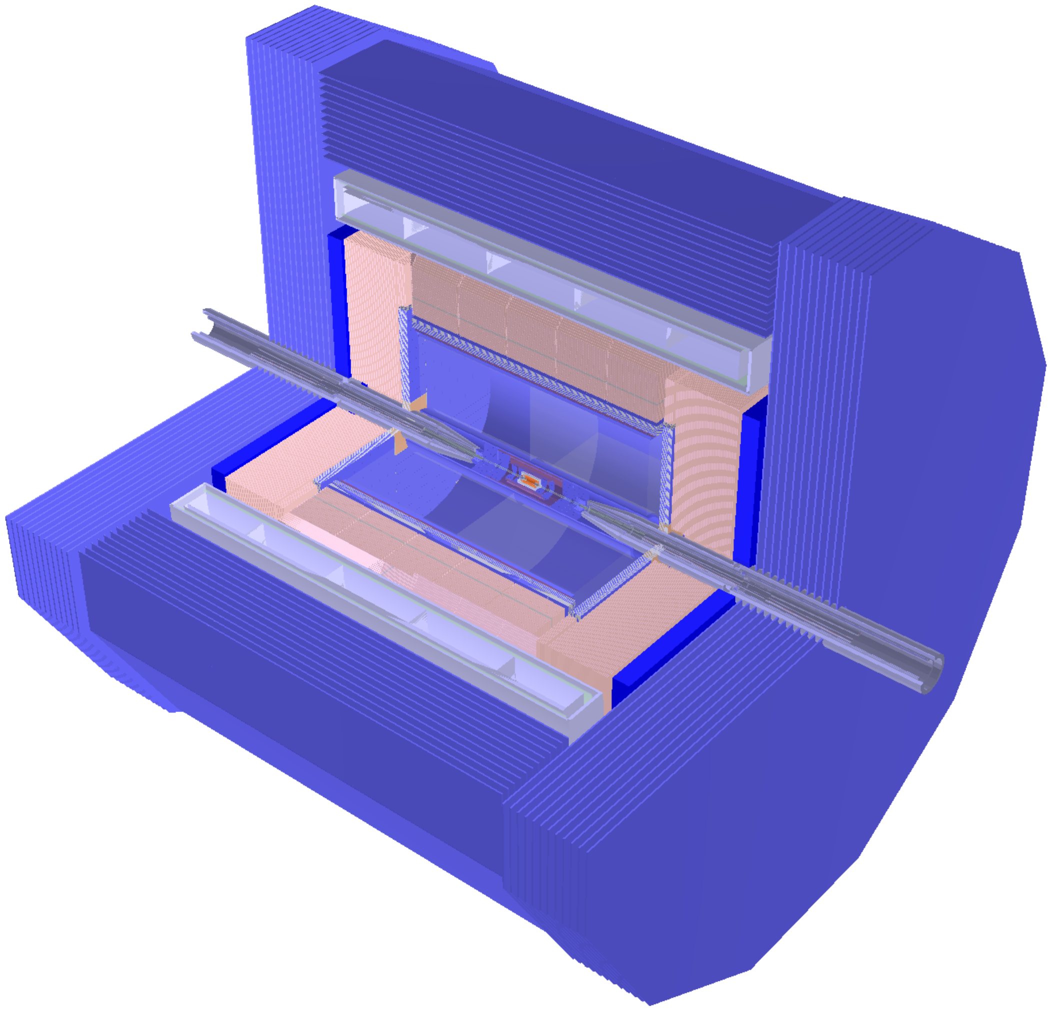
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

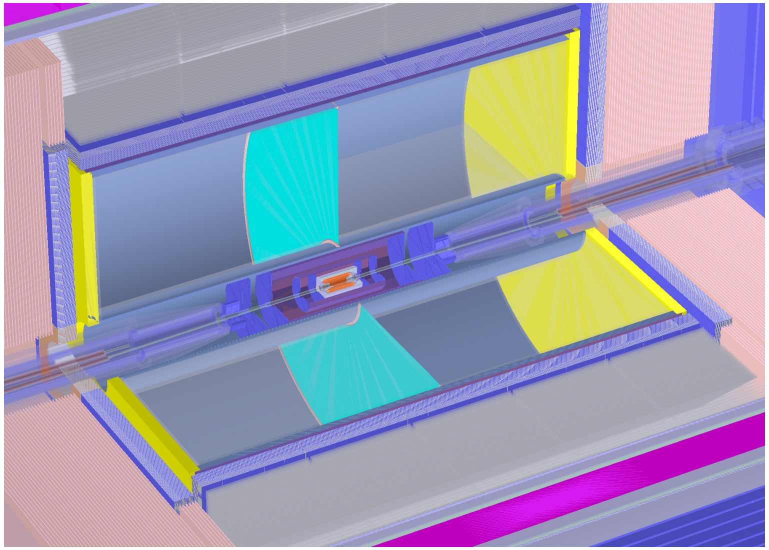
An ILD-like detector at the CEPC

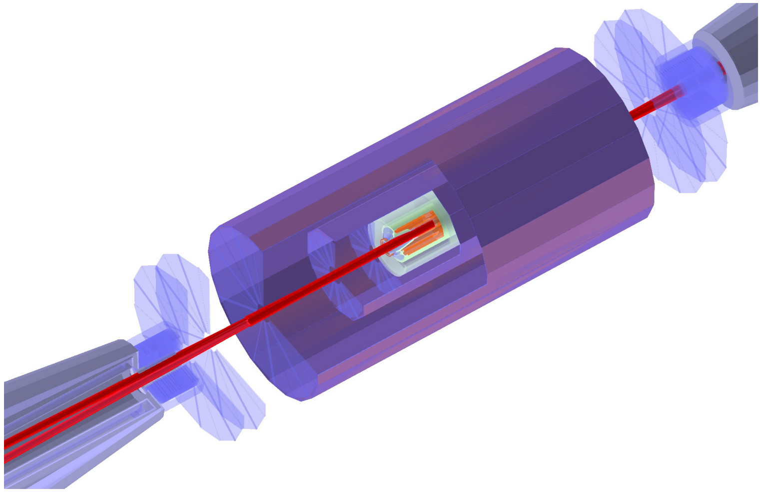


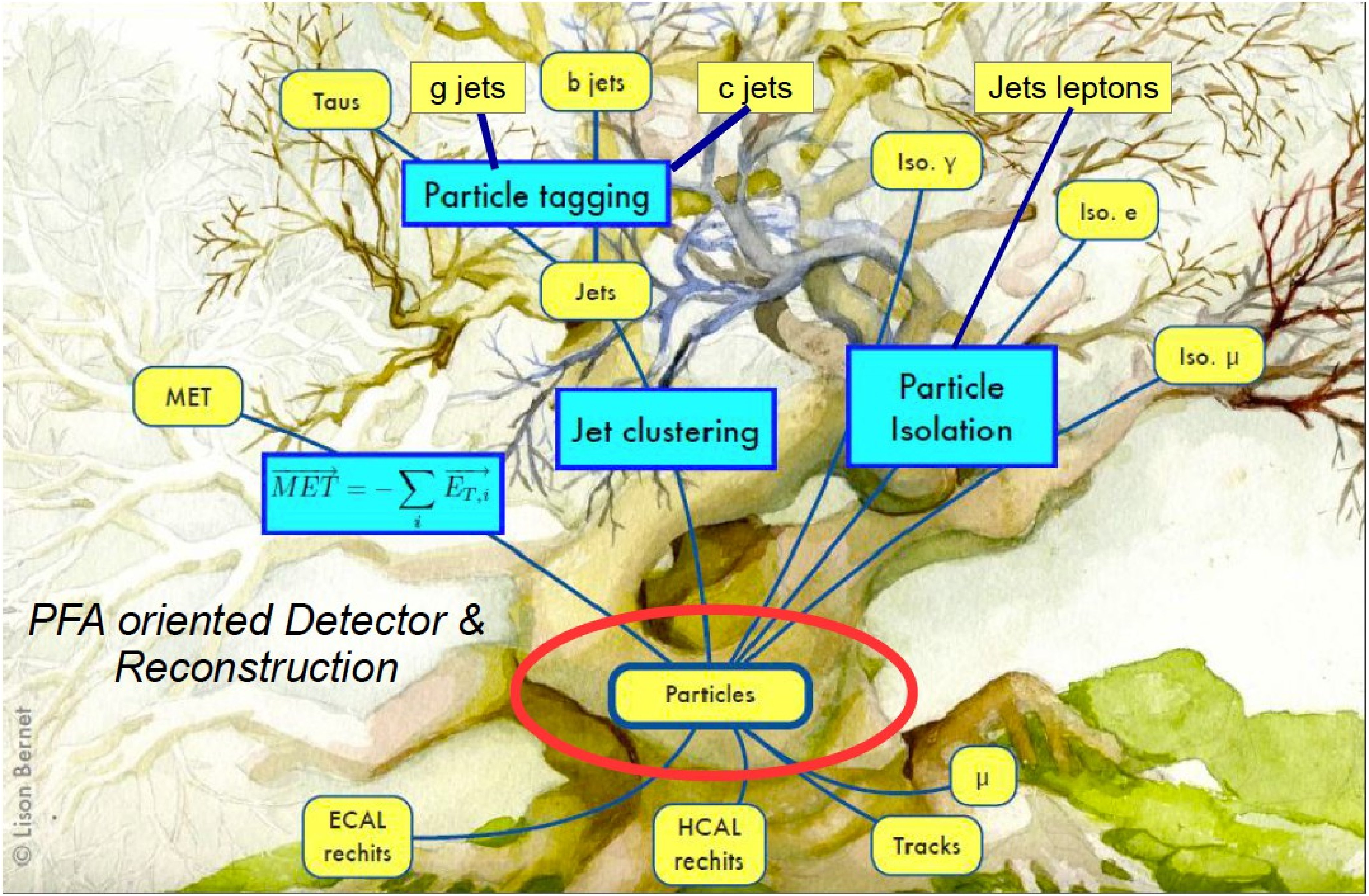
- Different collision environments/rates :
  - MDI design & Implementation: CEPC-SIMU-2017-001
- The CEPC Event rate is significantly higher than linear colliders, charged kaon id can strongly enhance the CEPC flavor physics program
  - TPC Feasibility: JINST-12-P07005 (2017)
  - Pid using TPC dEdx and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

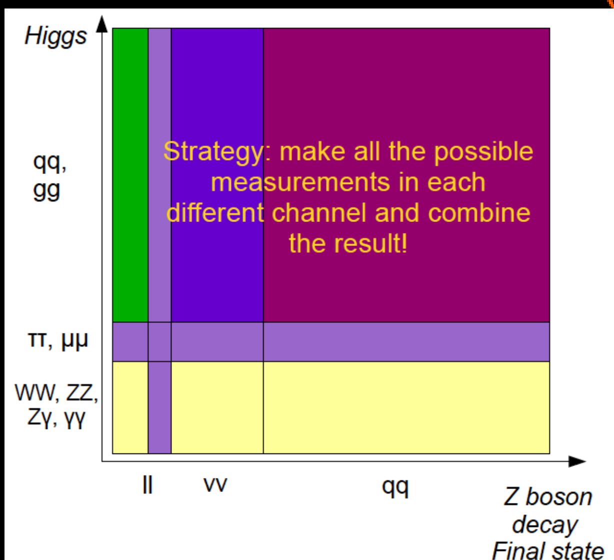


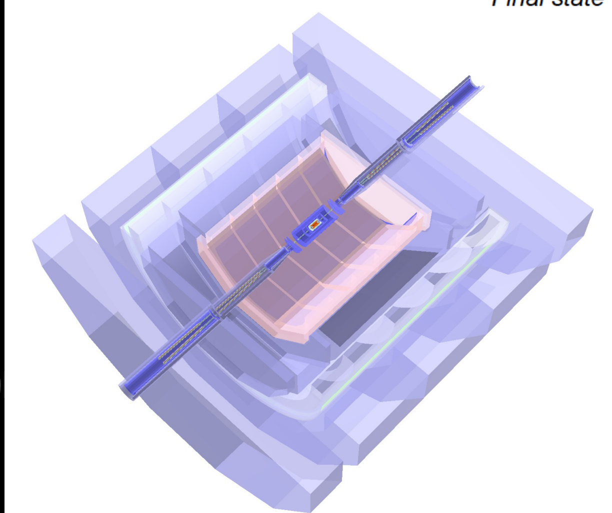


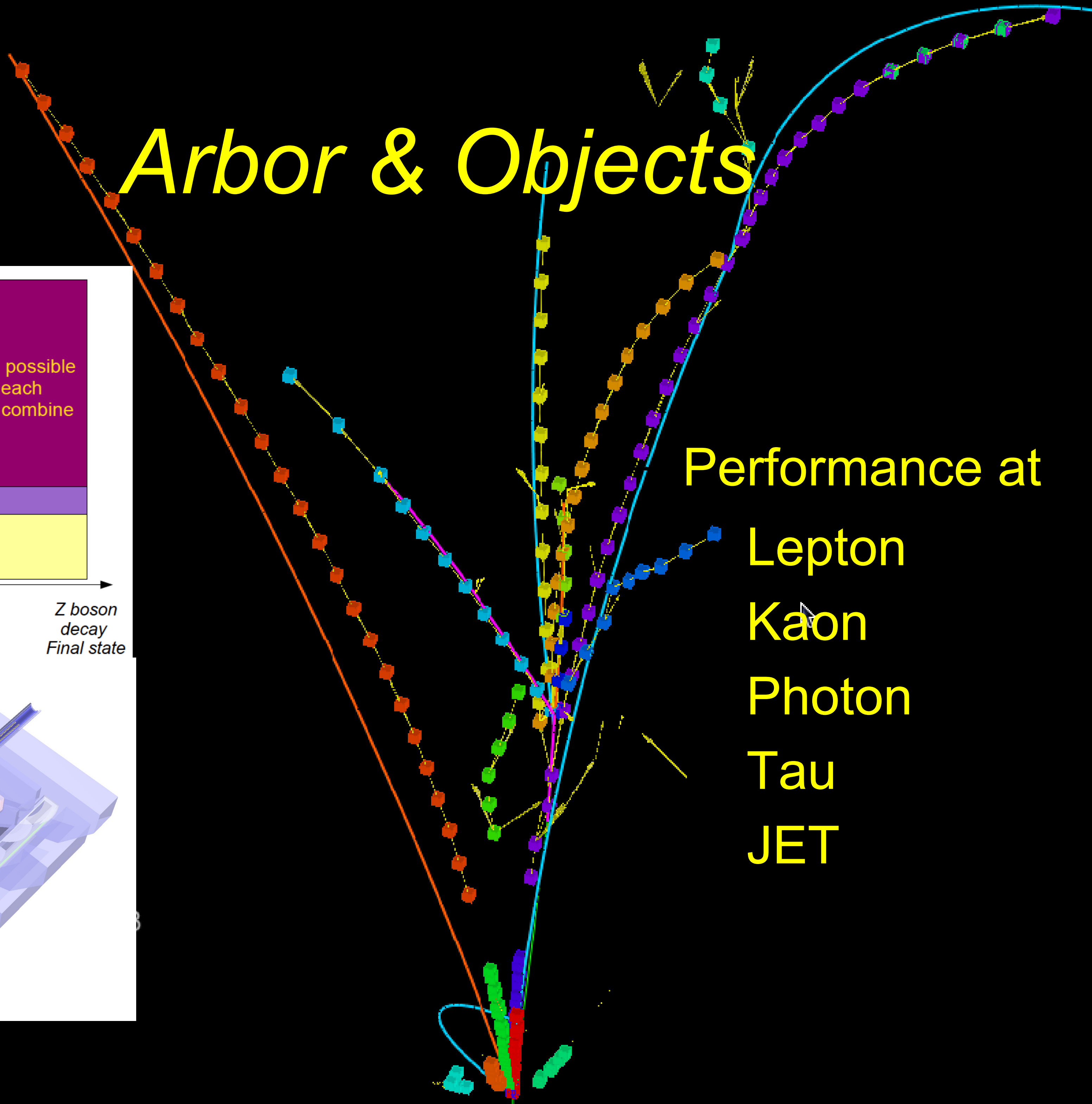



Taus
g jets
b jets
c jets
Jets leptons
Particle tagging
Iso. γ
Iso. e
Jets
Iso. μ
MET
Jet clustering
Particle Isolation
$\overrightarrow{MET} = -\sum_i \overrightarrow{E_{T,i}}$
PFA oriented Detector & Reconstruction
Particles
μ
ECAL rechits
HCAL rechits
Tracks
© Lison Bernet

Arbor & Objects



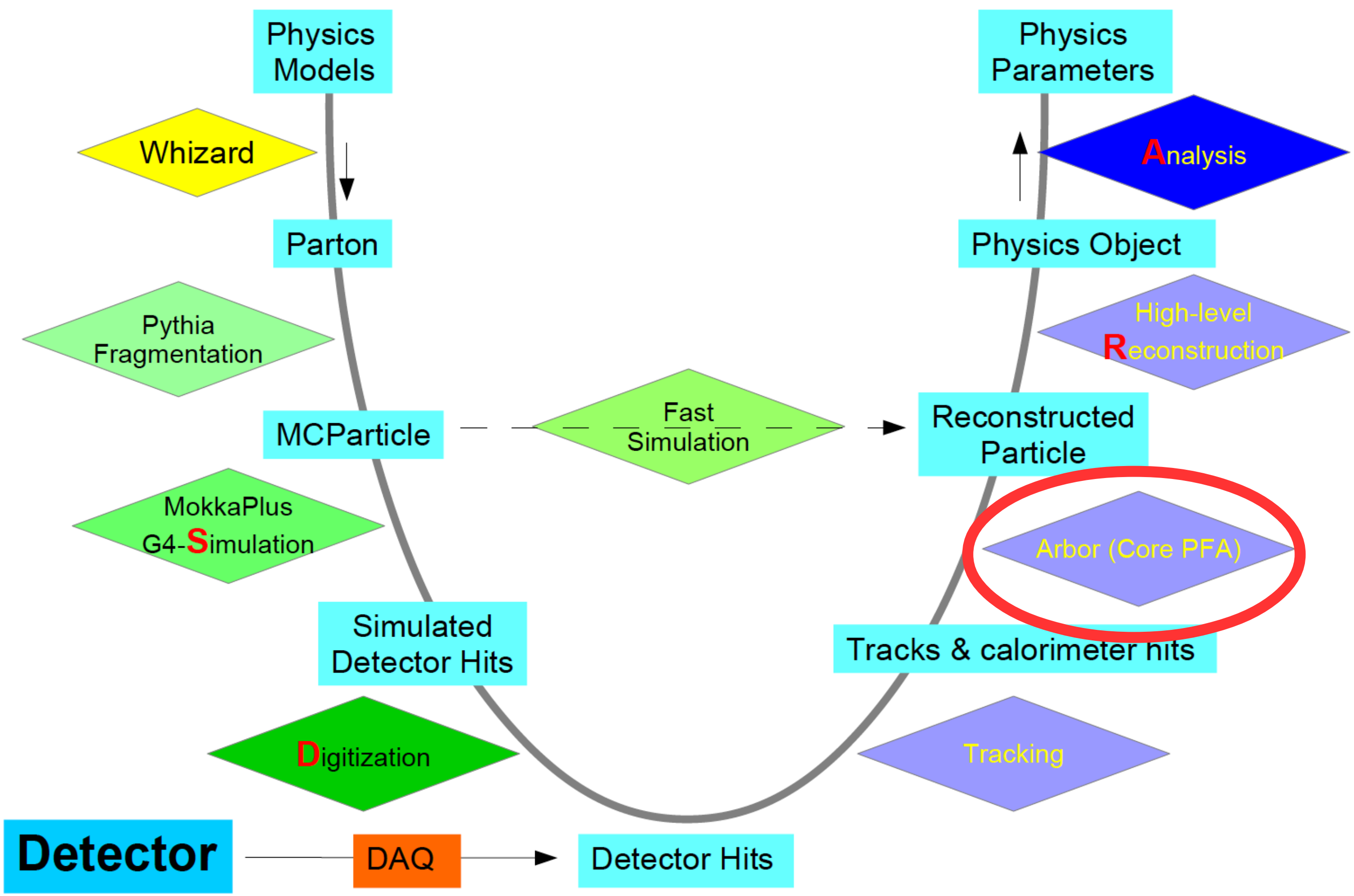




Performance at

- Lepton
- Kaon
- Photon
- Tau
- JET

The Simu-Reco Chain at CEPC

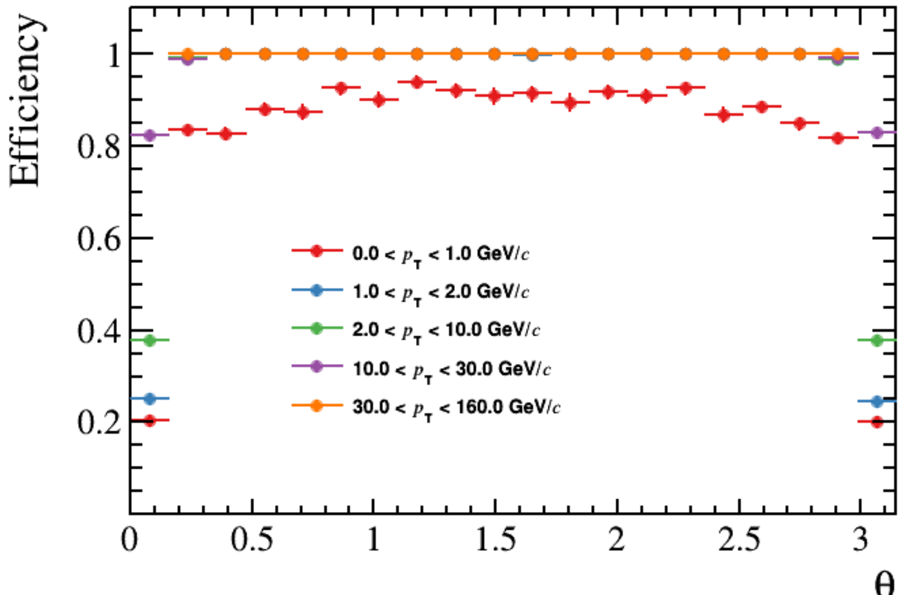


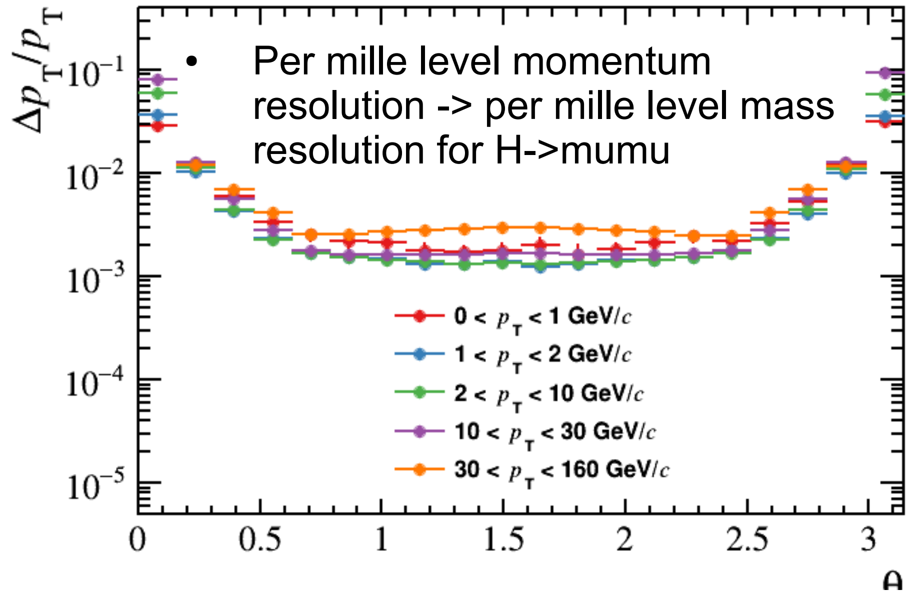
Generators (Whizard & Pythia)
Data format & management (LCIO & Marlin)
Simulation (MokkaC)
Digitizations
Tracking
PFA (Arbor)
Single Particle Physics Objects Finder (LICH)
Composed object finder (Coral)
Tau finder
Jet Clustering (FastJet)
Jet Flavor Tagging (LCFIPLus)
Event Display (Druid)
General Analysis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

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

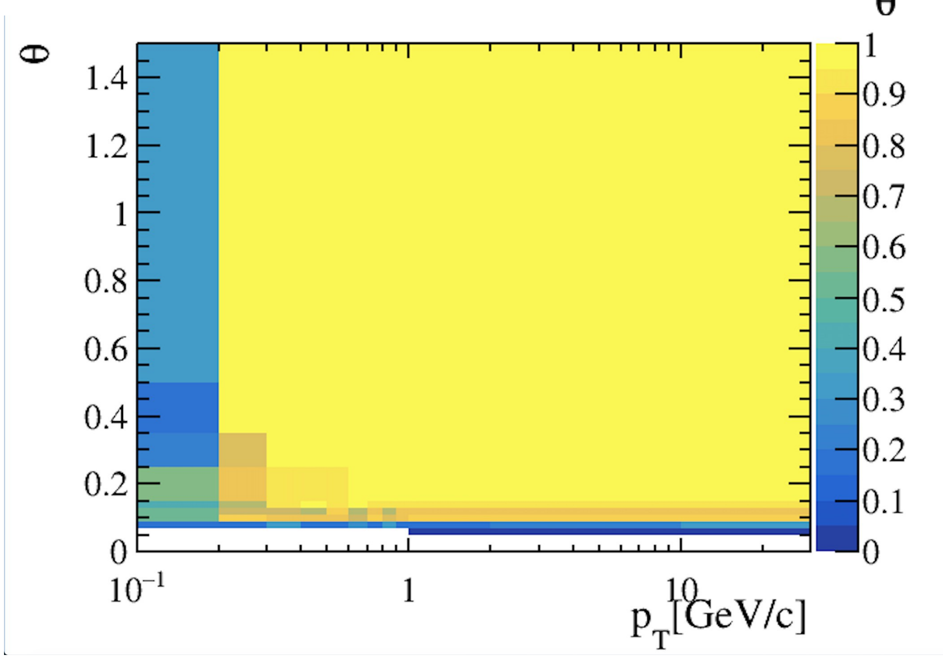
General Software | ILCSoft | ILCSoft + Development | Developments

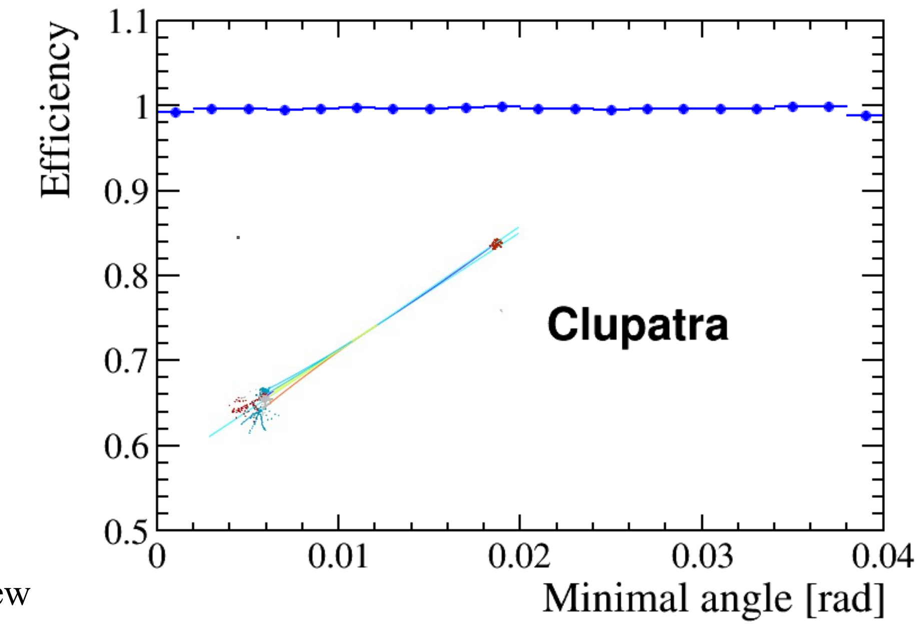
Tracking



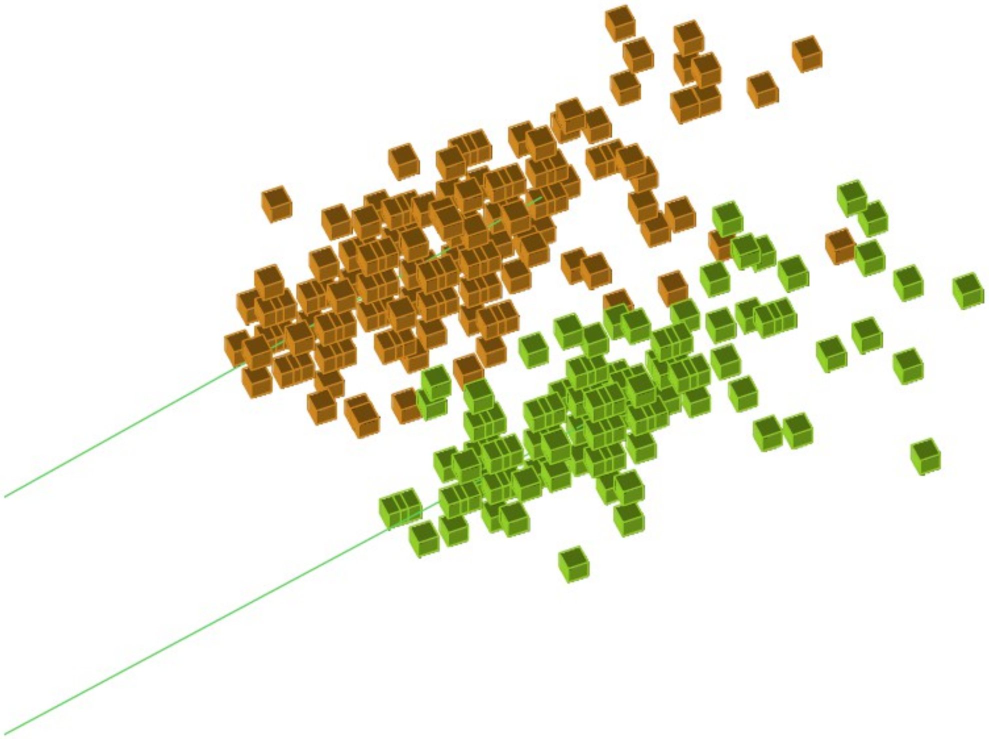


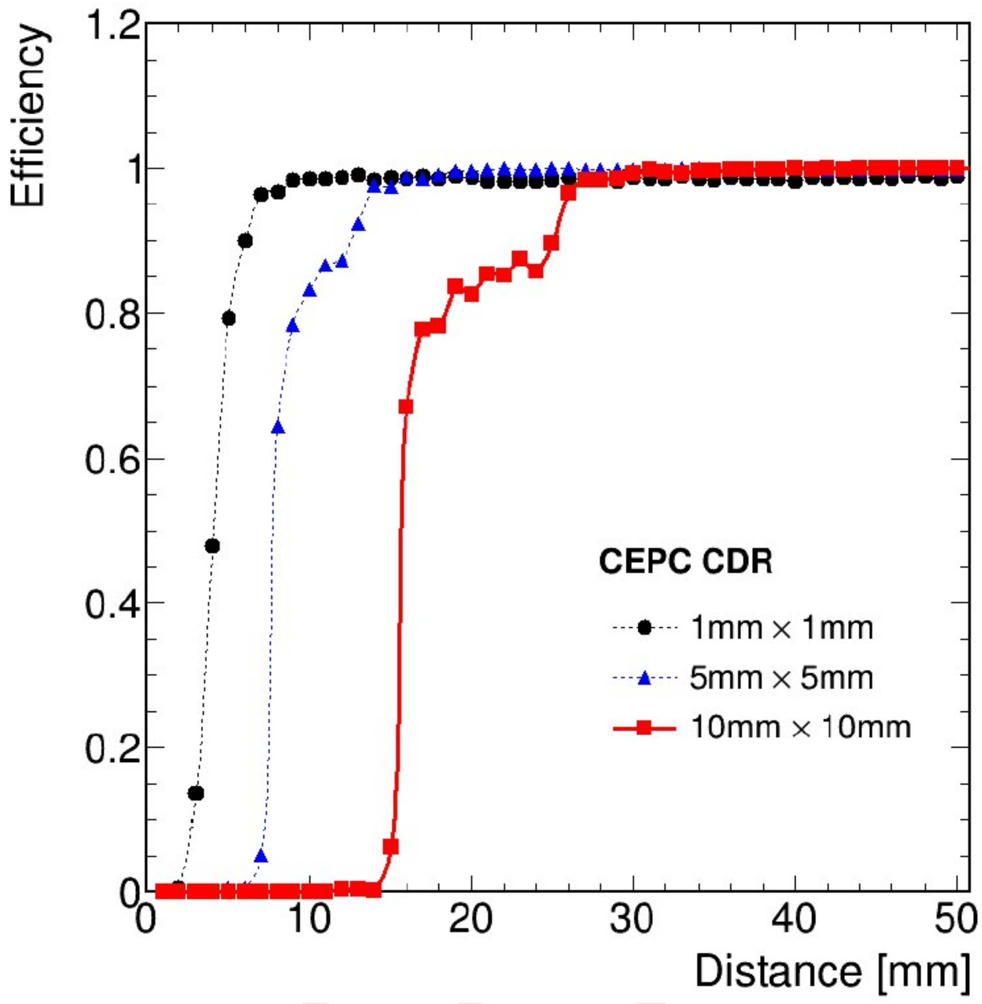
- Per mille level momentum resolution -> per mille level mass resolution for H->mumu





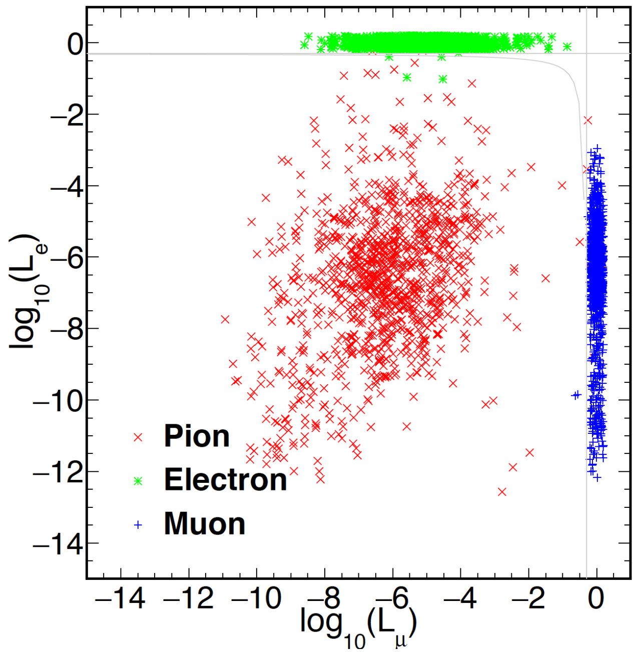
Clustering

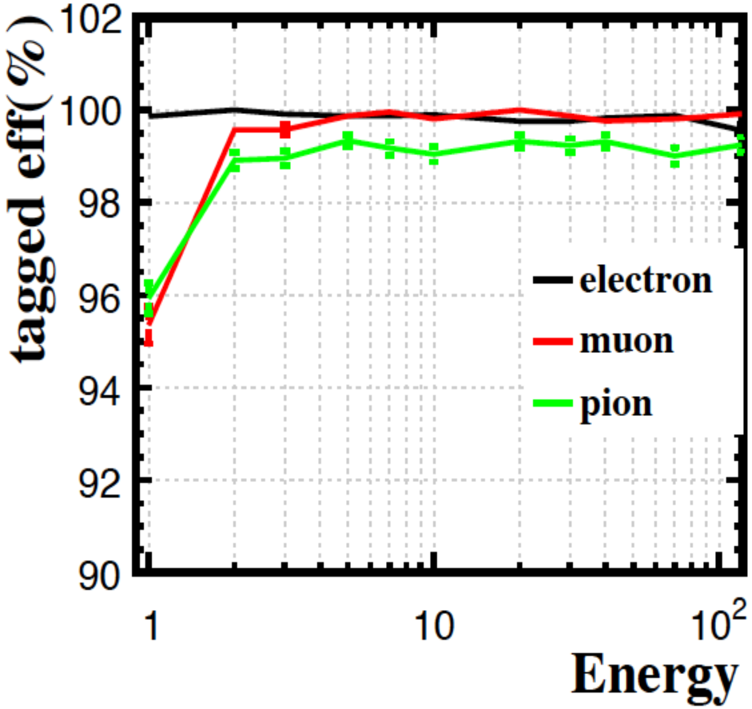


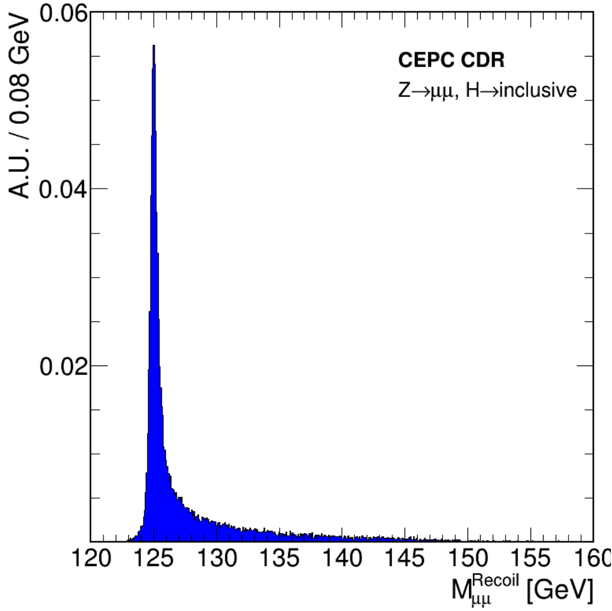


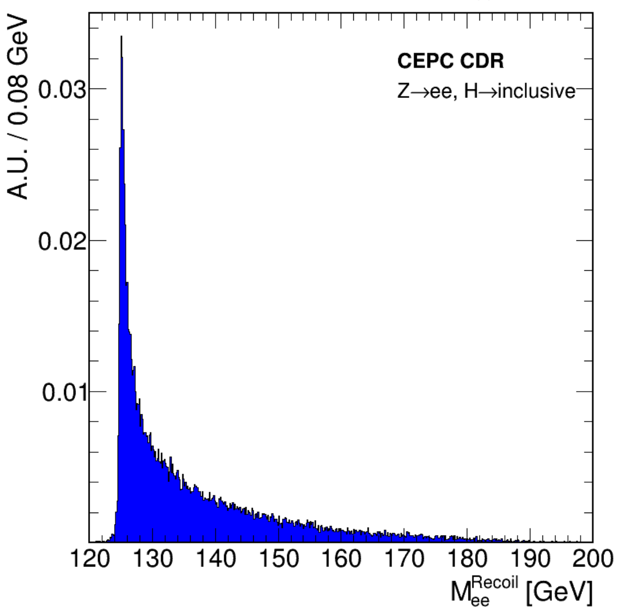
Critical energy to separate an evenly decay π_0: 30 GeV

Leptons







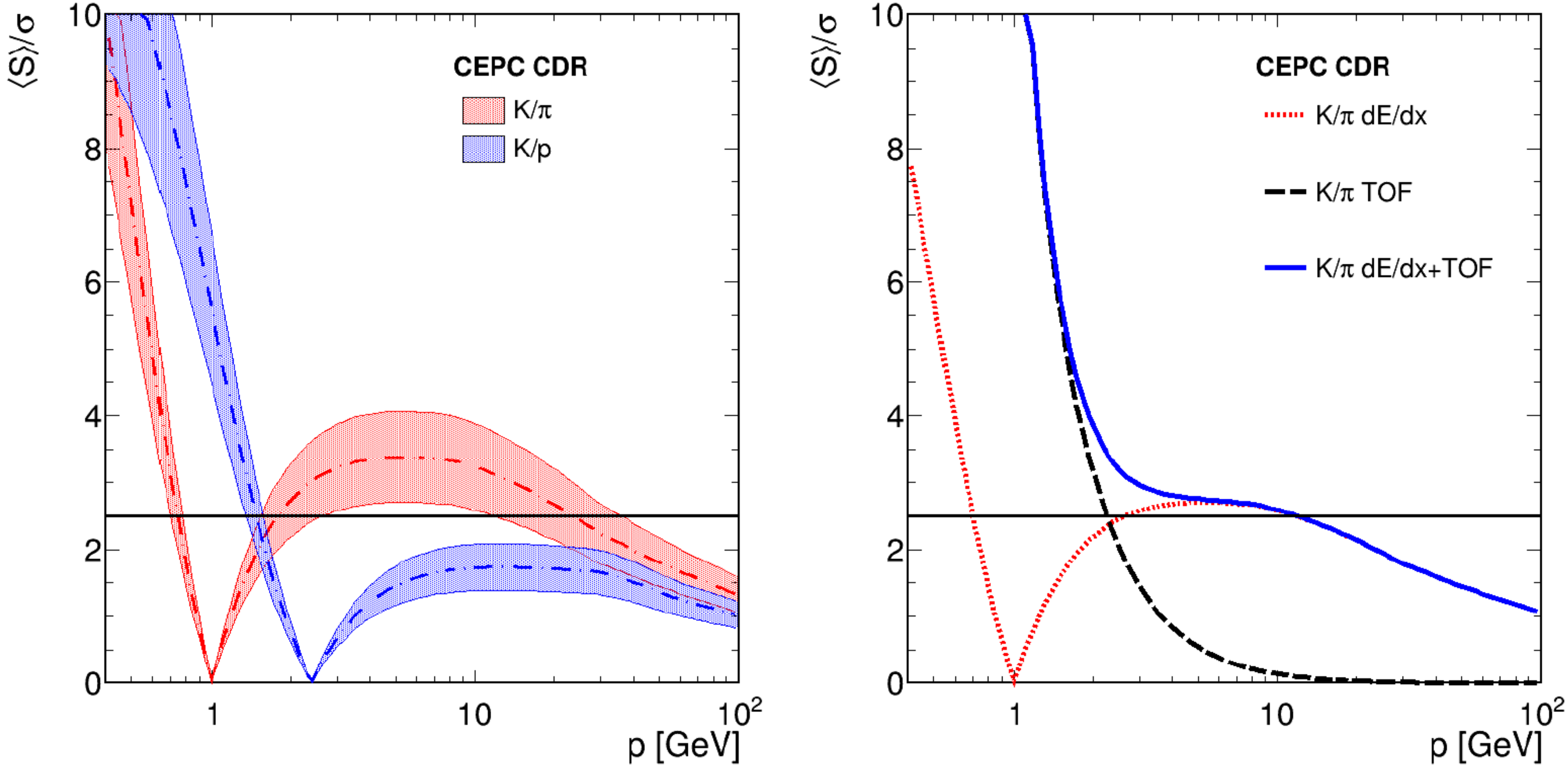


BDT method using 4 classes of 24 input discrimination variables.

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

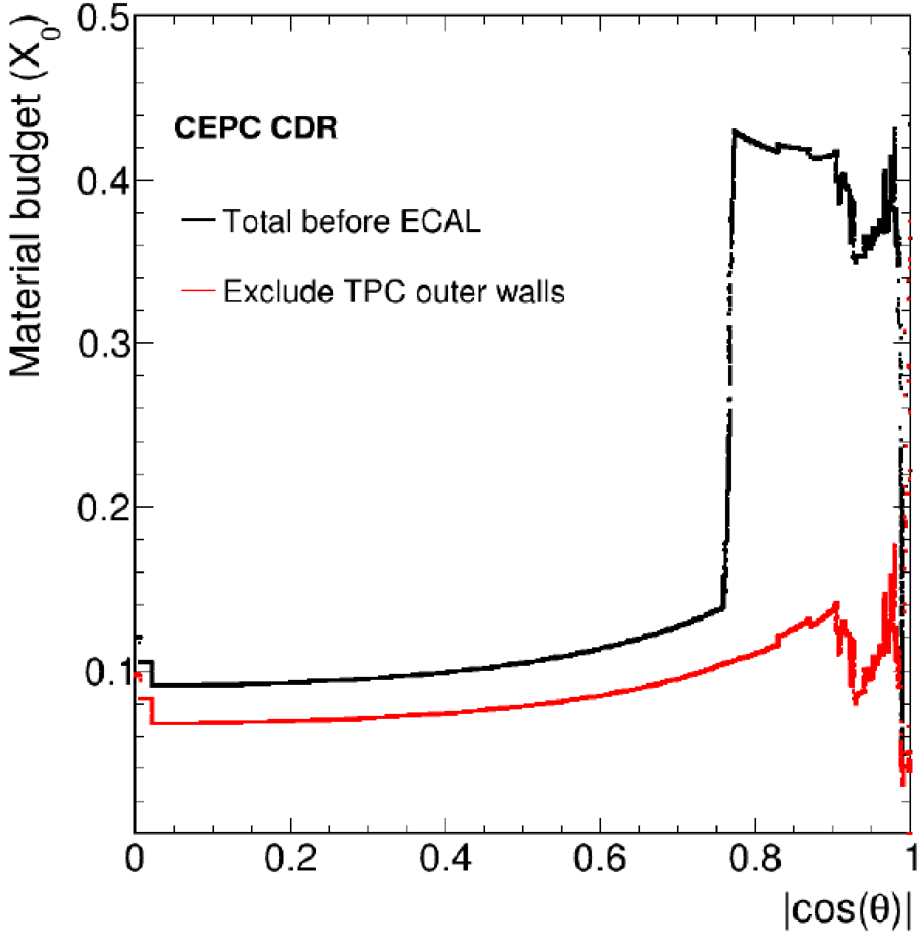
Eur. Phys. J. C (2018) 78:464

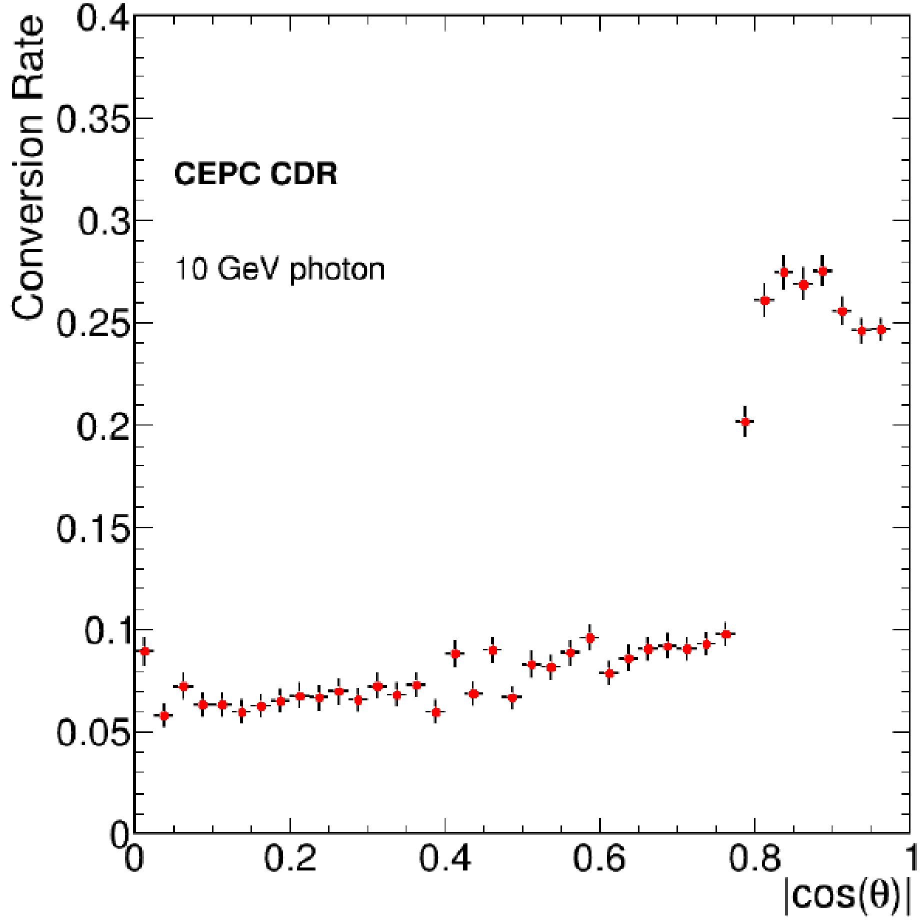
At inclusive Z pole sample:

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)

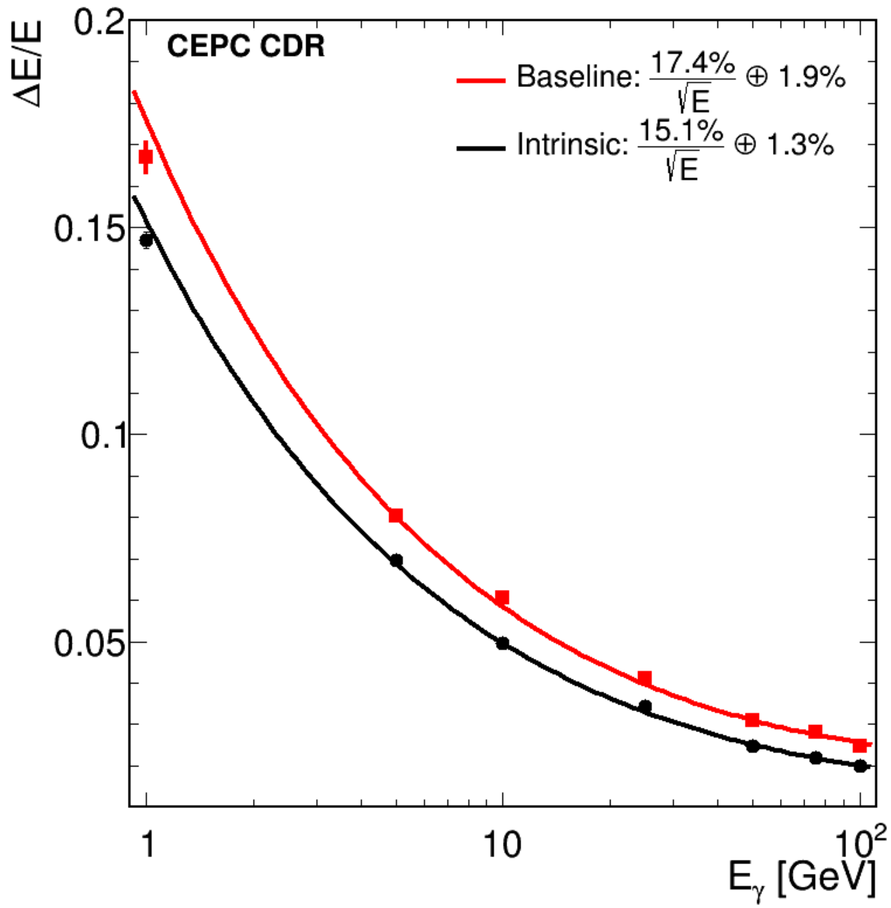
Photons - conversion

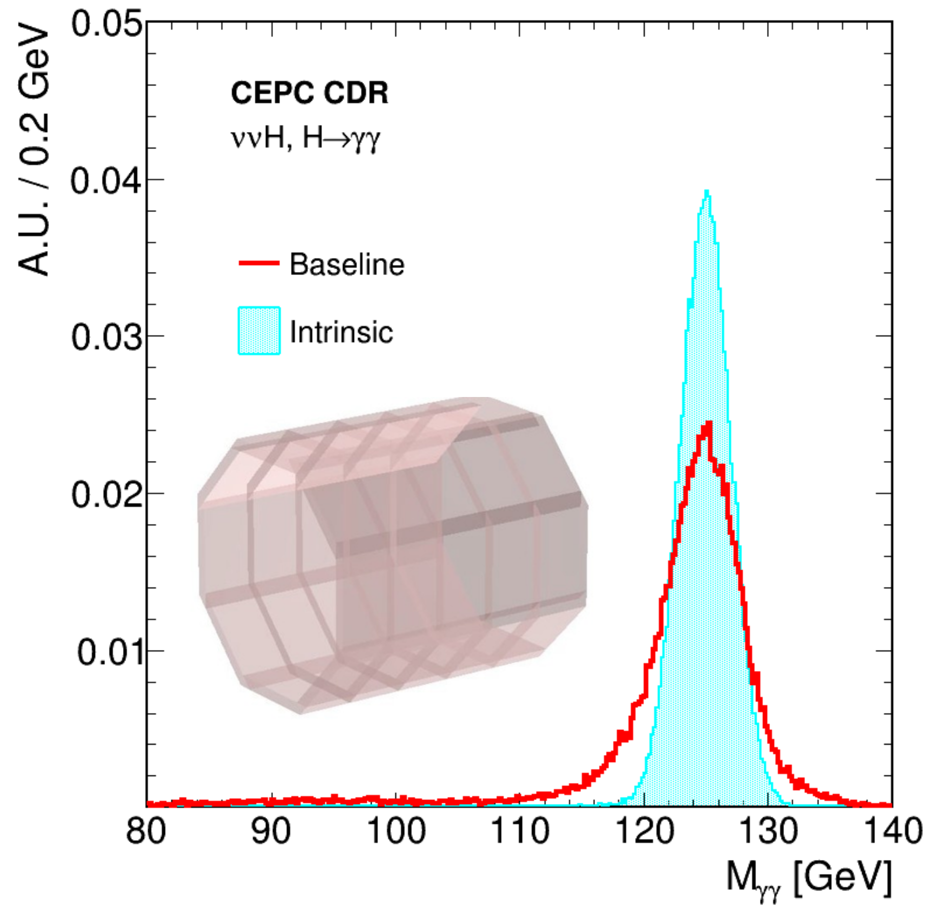




In the barrel region: Roughly 6-10% of the photons converts before reaching the Calorimeter.

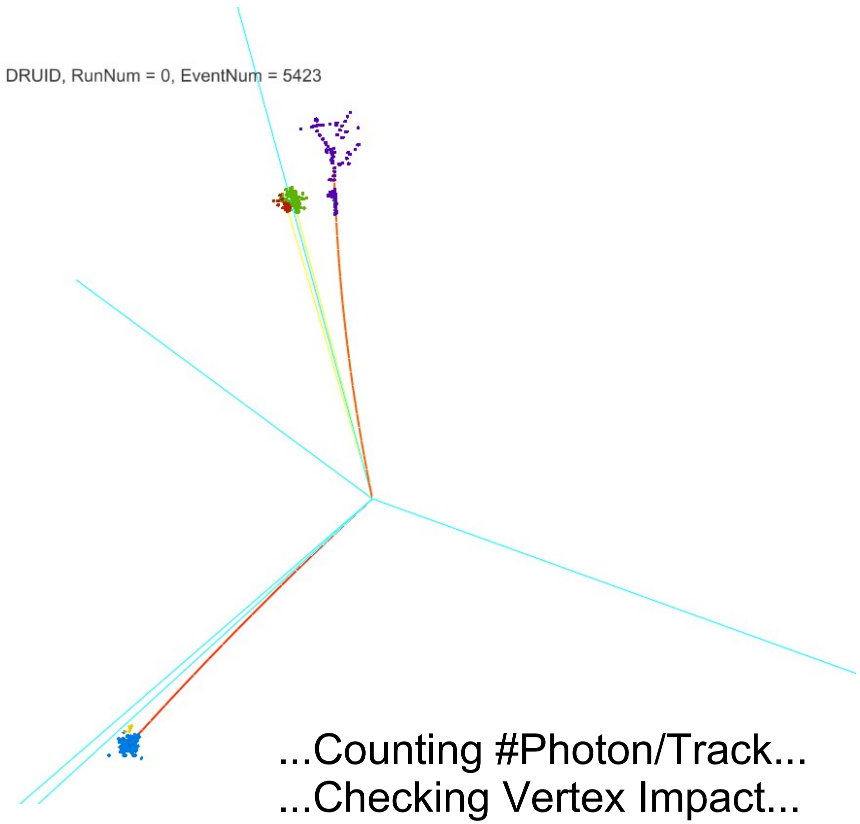
Photon resolution



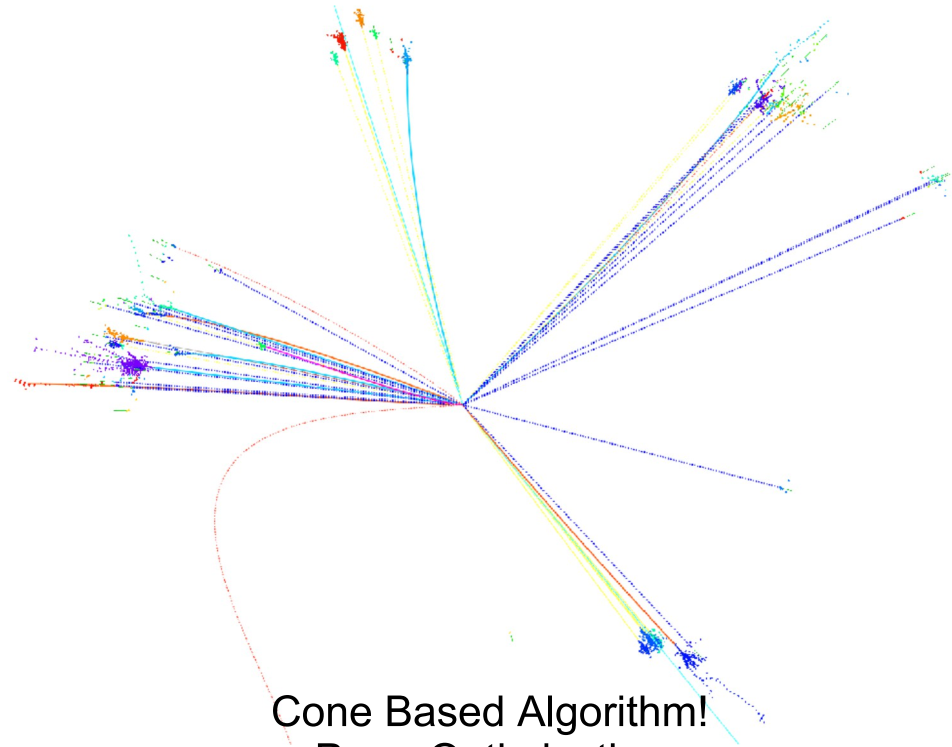


- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/APODIS geometry
- The geometry defects correction is mandatory (in progress)...

Tau



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

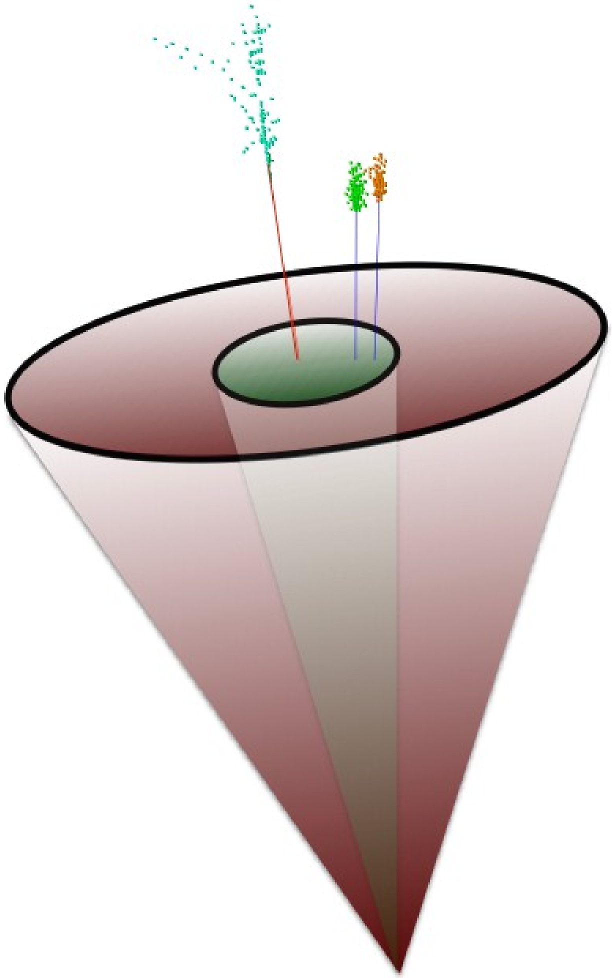


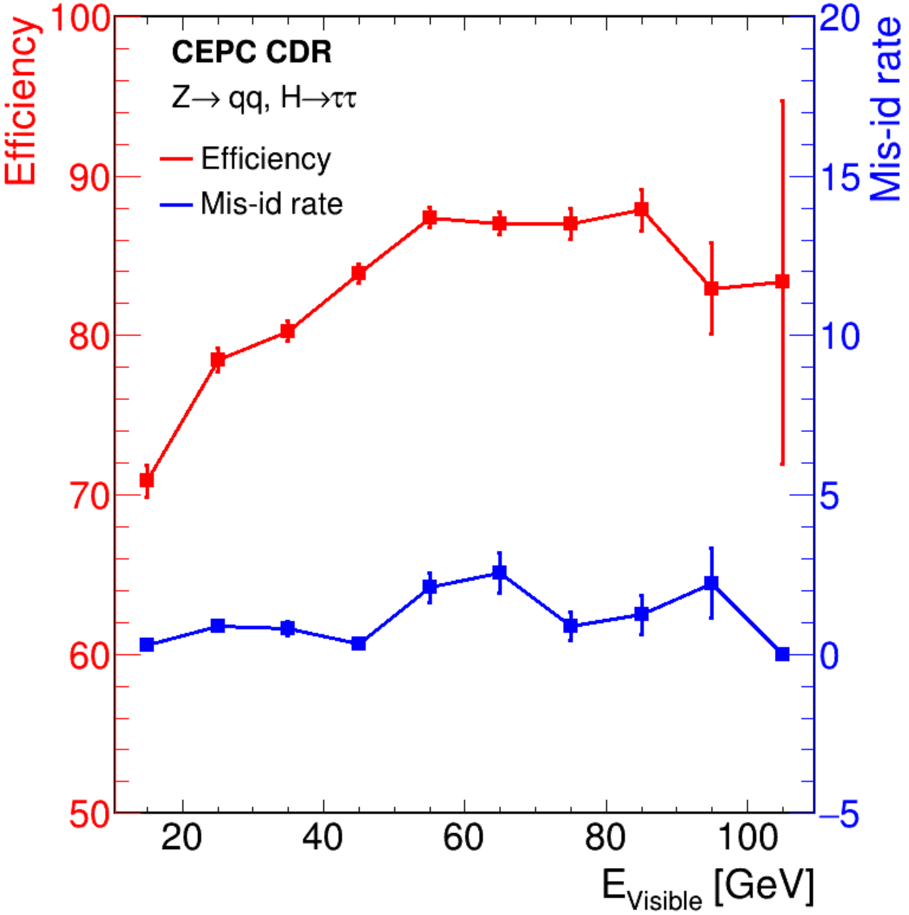
Cone Based Algorithm!
Para. Optimization

- Two catalogues:
  - Leptonic environments: i.e, $ll\tau\tau$(ZZ/ZH), $\nu\nu\tau\tau$(ZZ/ZH/WW), $Z\rightarrow\tau\tau$;
  - Jet environments: i.e, $ZZ/ZH\rightarrow qq\tau\tau$, $WW\rightarrow qq\nu\tau$;

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

Tau finding



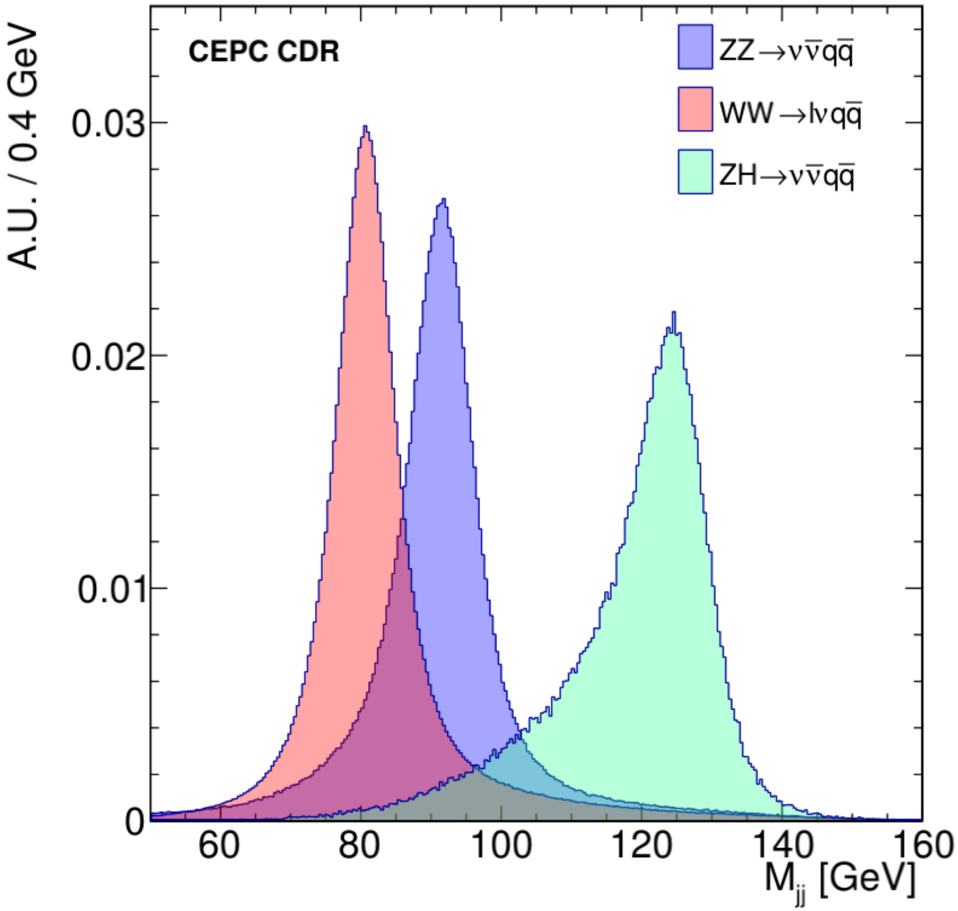


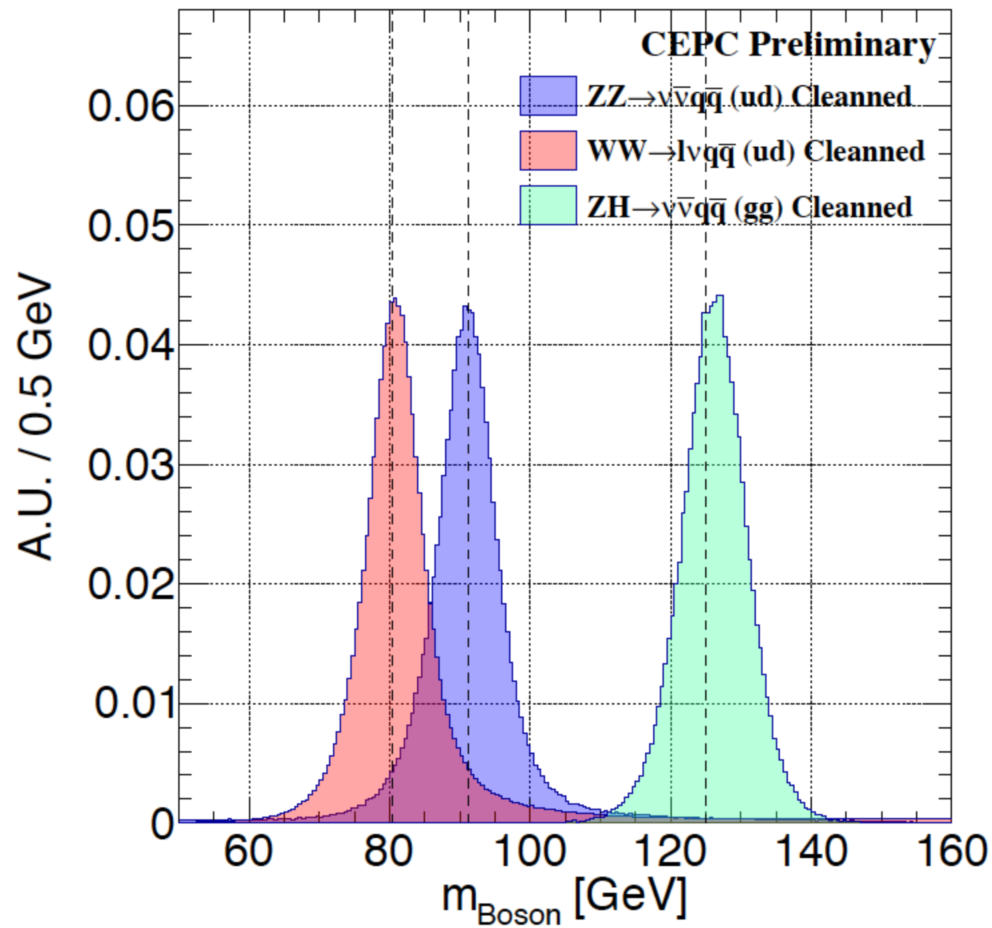
TAURUS (Tau ReconstrUction toolS) optimization in progress

Jets

- Boson Mass Resolution: Separate W, Z and Higgs in hadronic decay mode
  - Essential for Higgs measurement
    - Separate Higgs from Z/W (relatively easy)
    - Separate H→ZZ/WW events (challenging)
  - Appreciated in Triplet Gauge Boson Coupling measurements
    - Separate WW (Signal) from ZZ, ISR return Z, etc.
  - ...
- Jet Clustering & Single jet response
  - To understand the Degrading induced by Jet Clustering, Matching, etc
  - Search for the most suited jet clustering algorithm (Presumably channel dependent) – Understand the Corresponding Systematic
  - ...

Massive Boson Separation





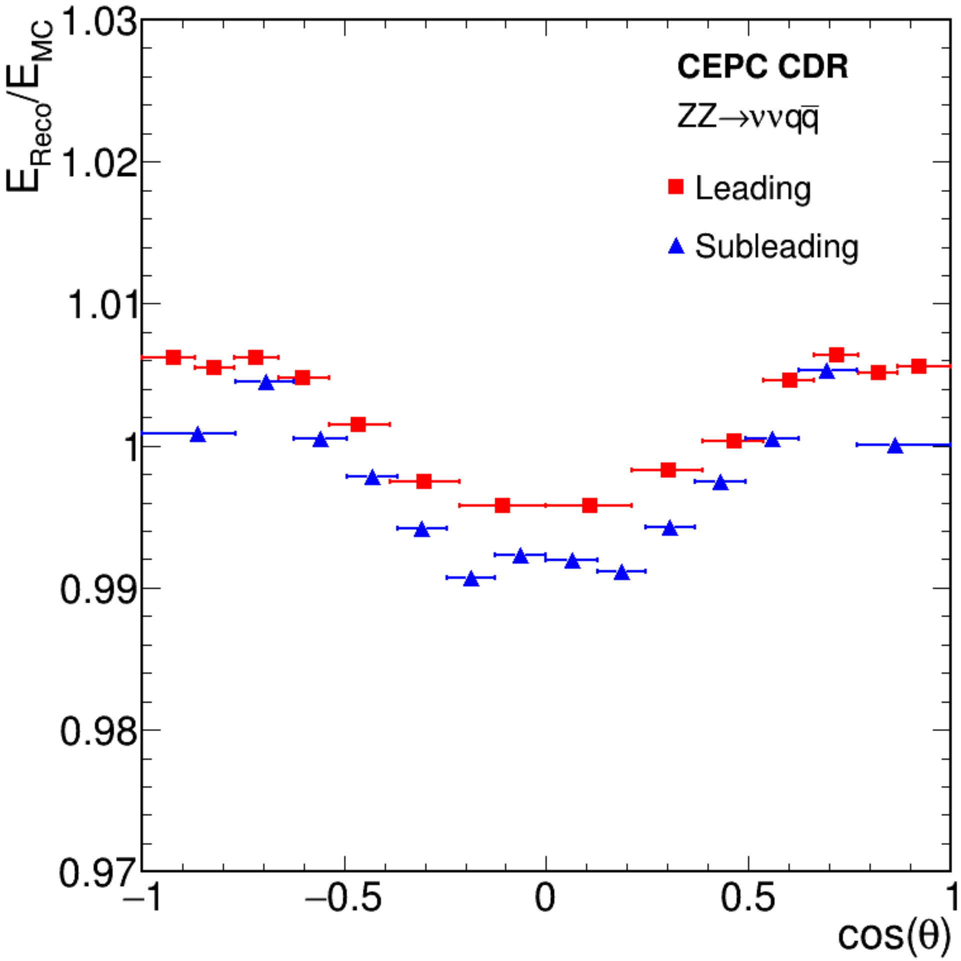
WW sample: using μvqq sample,
Plot: the visible mass without the muon

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

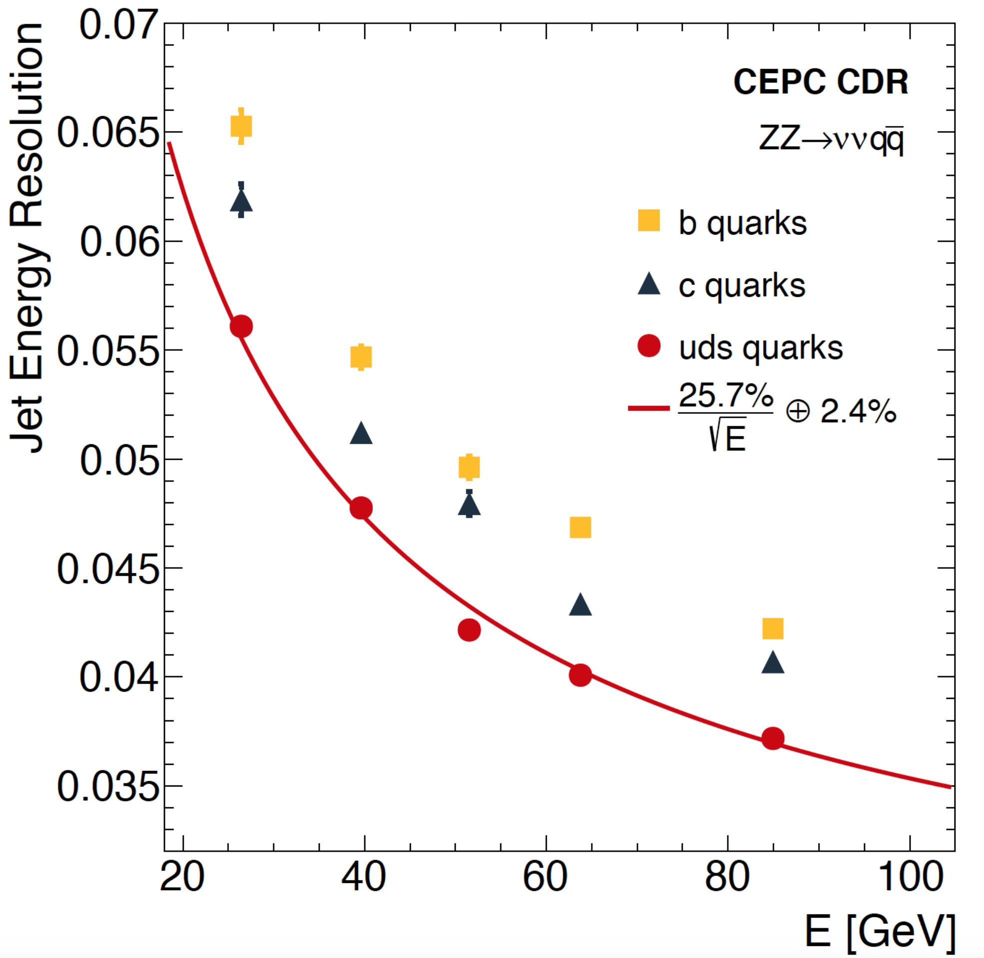
Eur. Phys. J. C78 (2018) no.5, 426

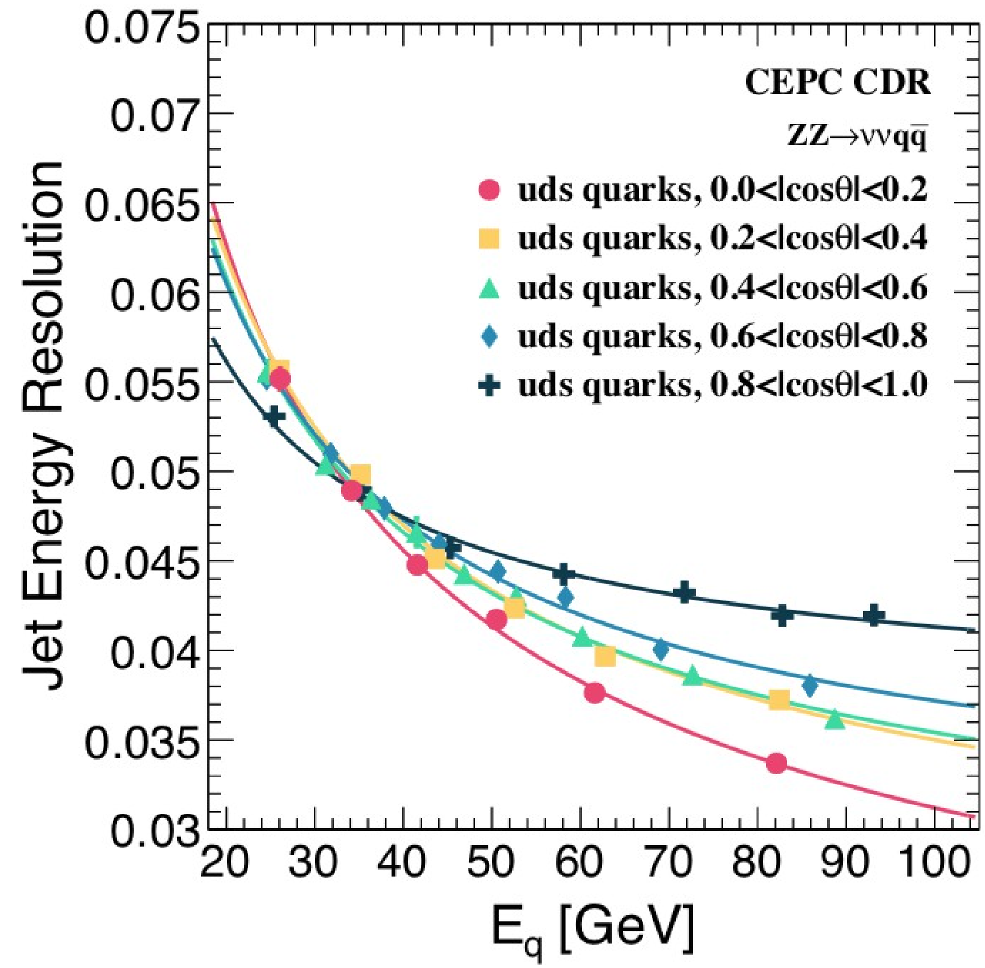
Jet Energy Scale

- 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)*



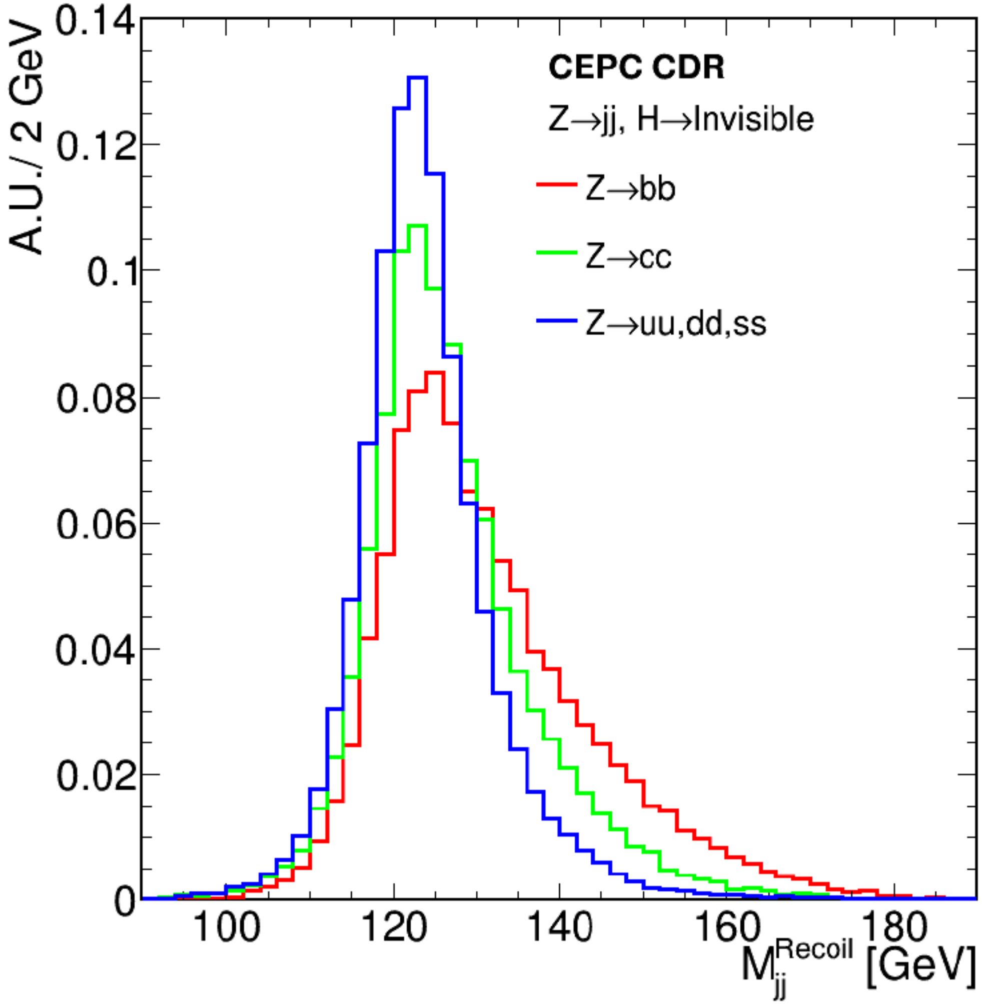
Jet Energy Resolution

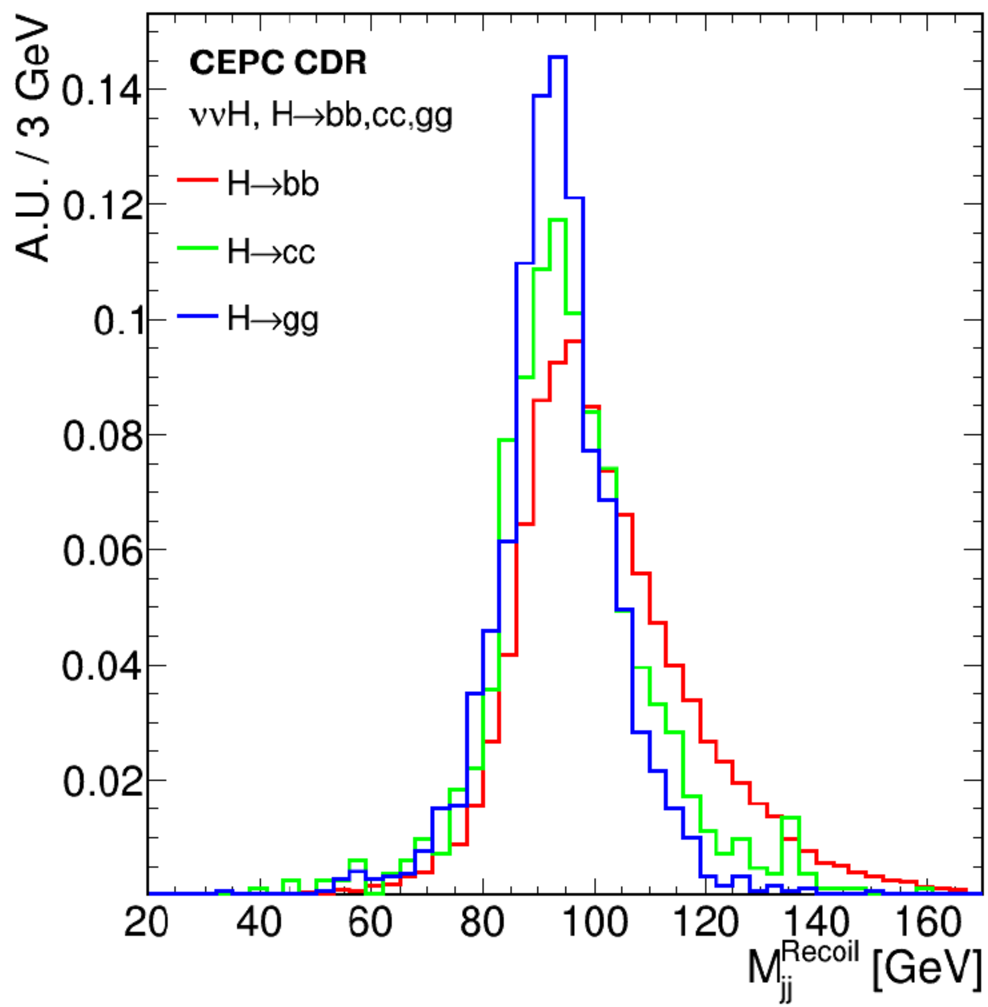




Amplitude ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
Depends on the Flavor, direction and jet energy
Superior to LHC experiments by 3-4 times

Missing Energy & Momentum

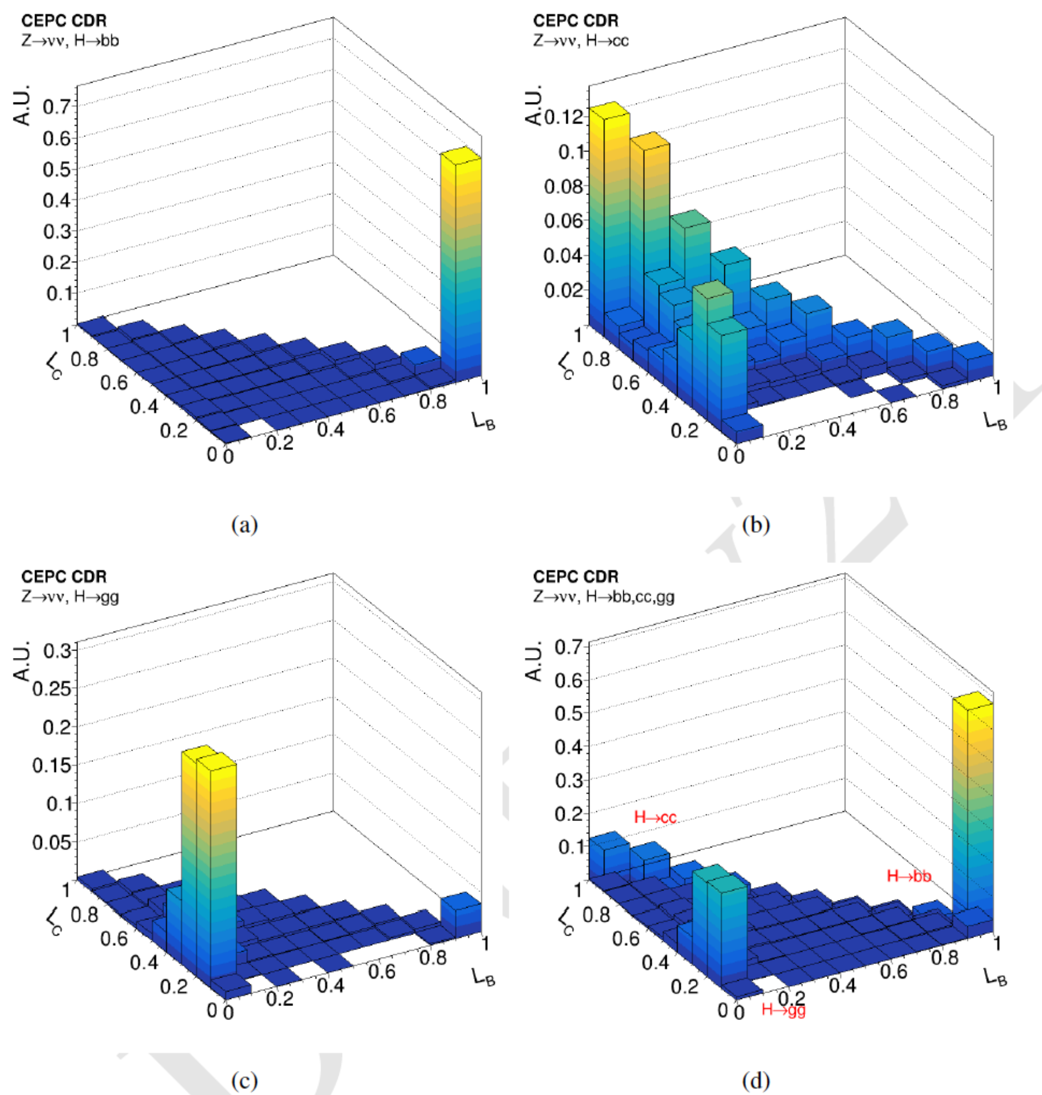




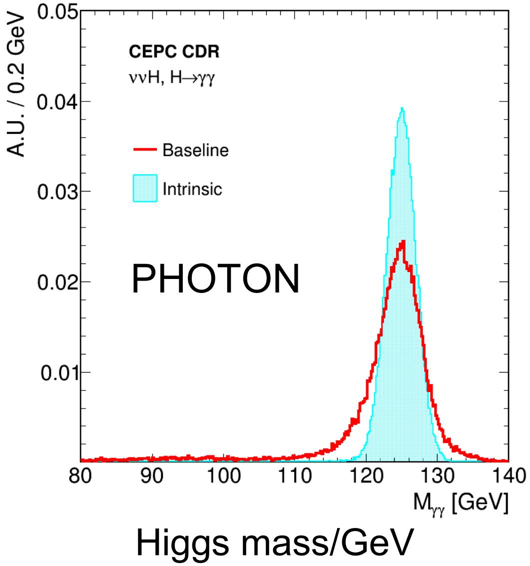
Width of the Light jets: 6GeV/8GeV (Left/Right Plots)

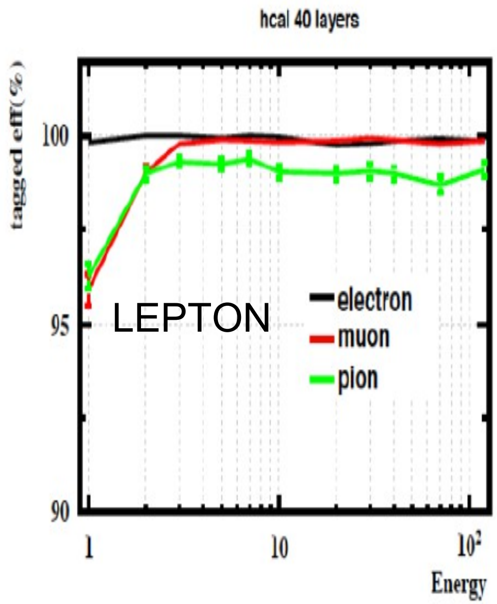
Flavor Tagging

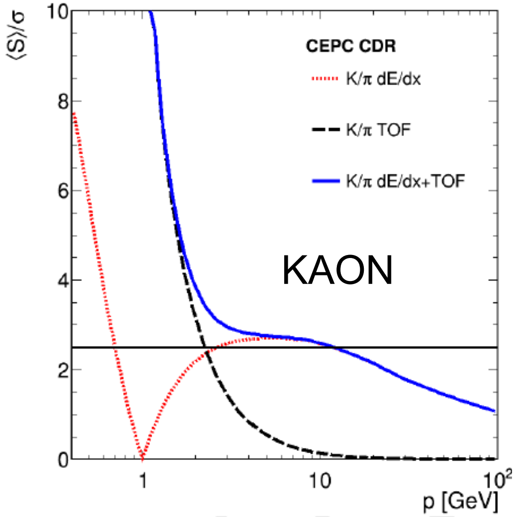
- Using LCFIPlus Package from ilcsoft
- At Higgs->2 jet samples:
  - *Clear separation between different decay modes*
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*

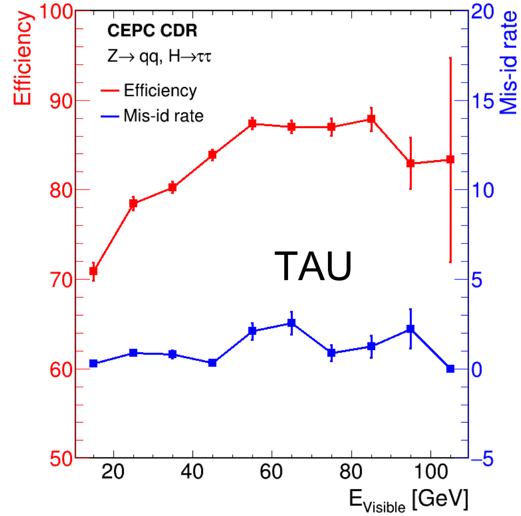


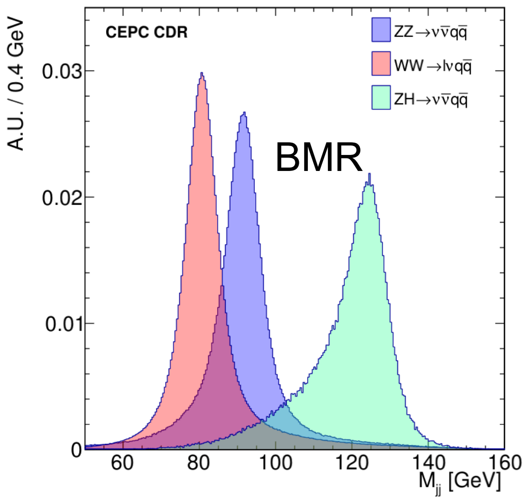
Physics Objects: Tamed

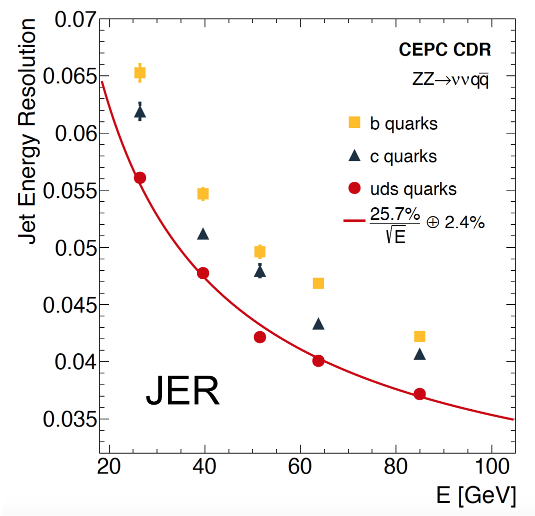


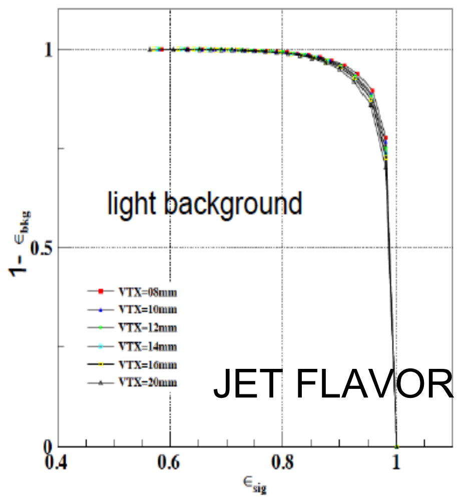


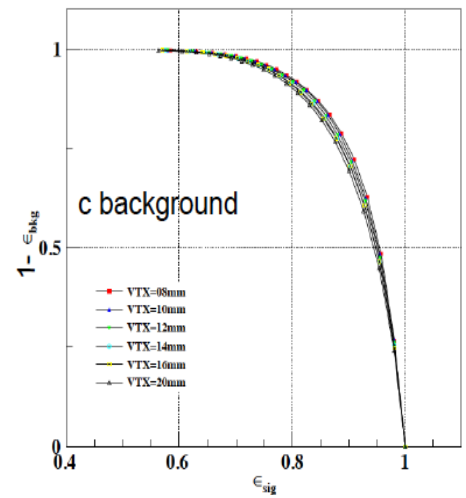




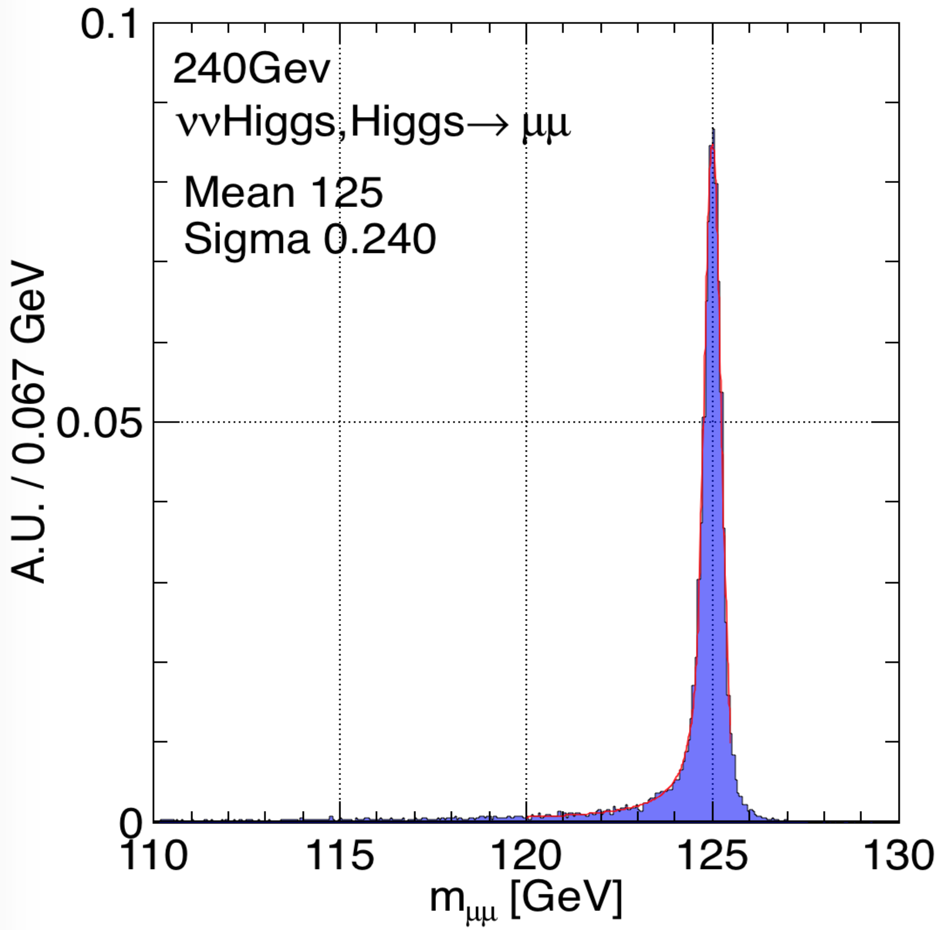


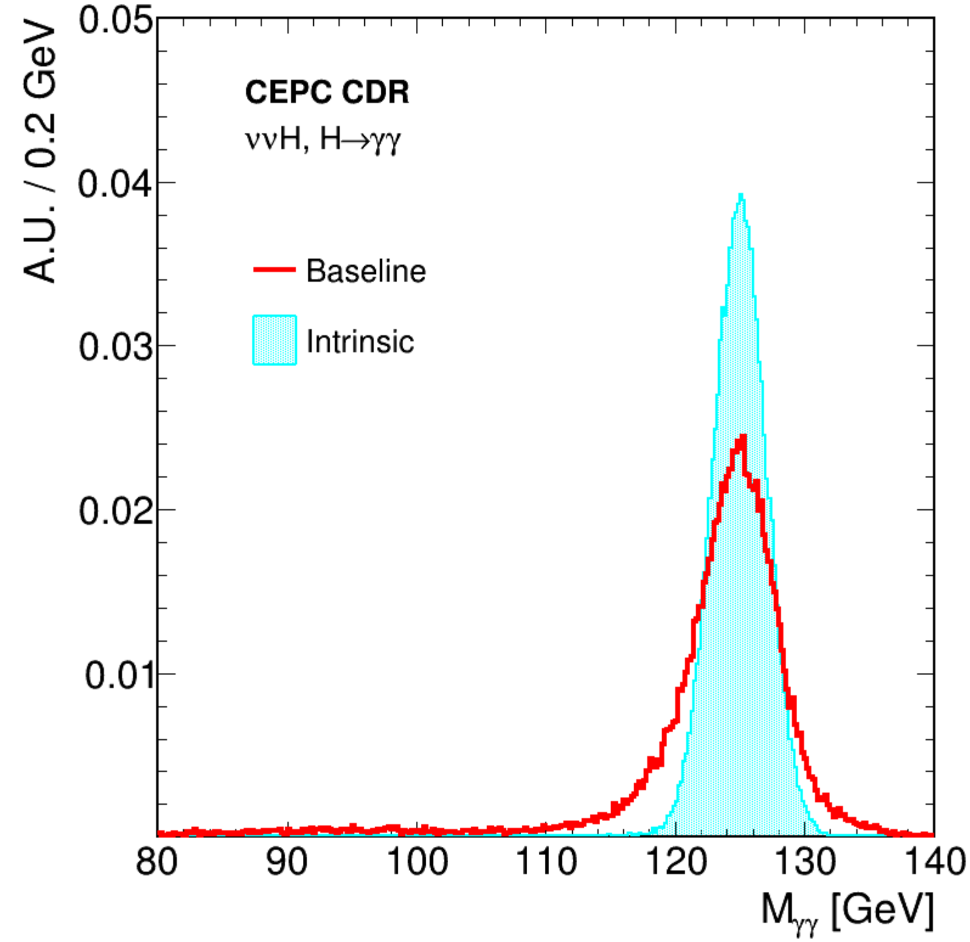






Higgs Signal at APODIS

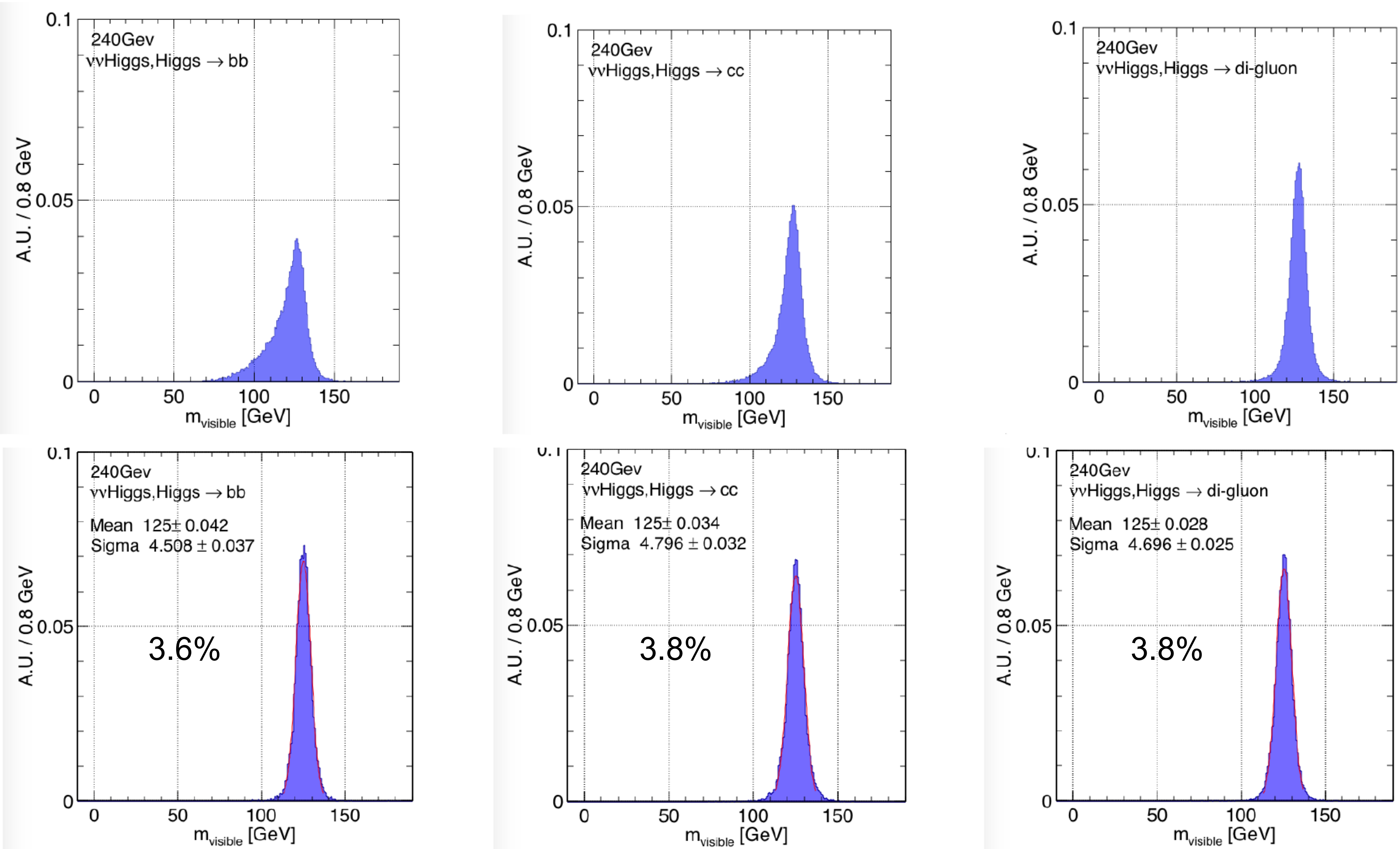




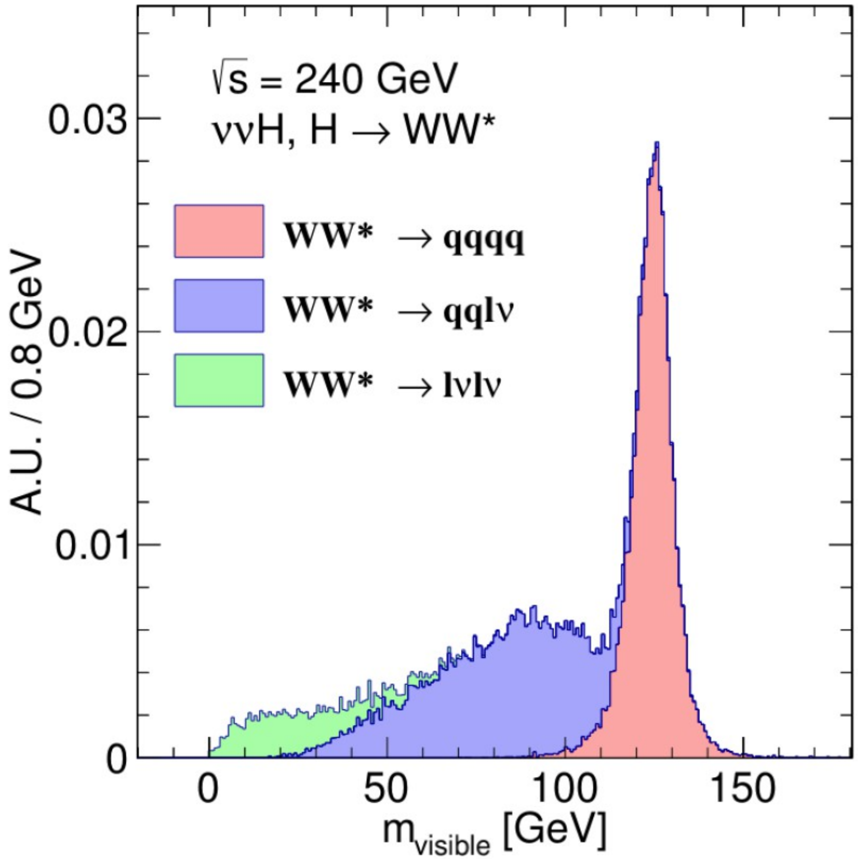
CEPC-RECO-2018-002
CEPC-Doc id 174, 175

Lepton tracks & Photon Clusters

Higgs to bb, cc, gg (Jets)



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



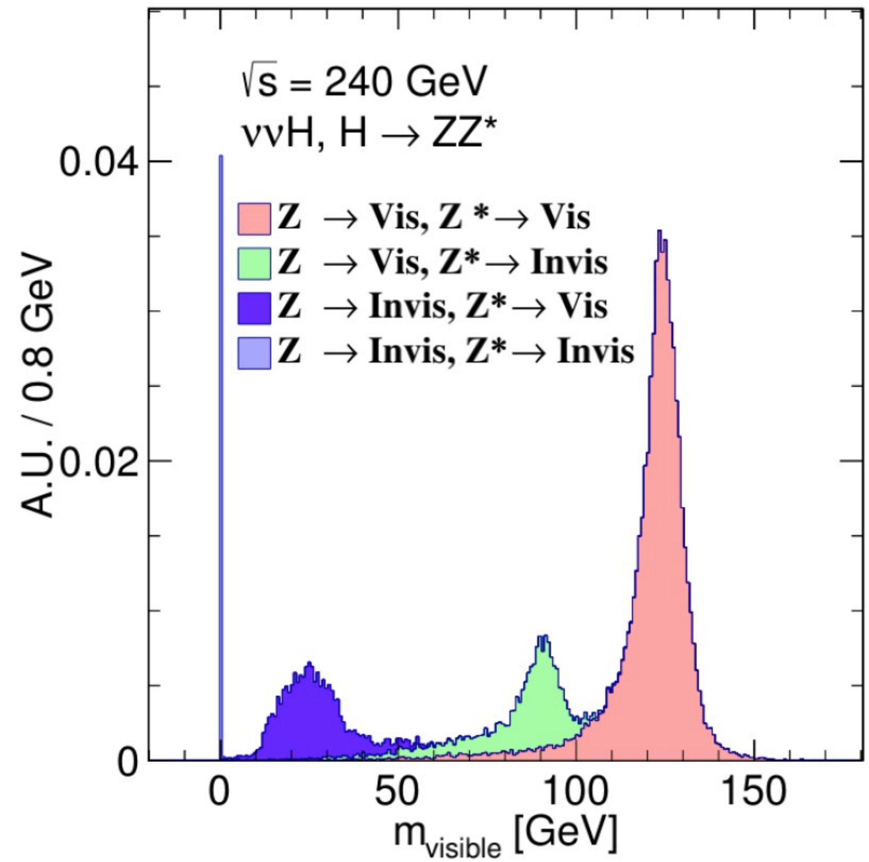


Table 2. Benchmark resolutions ($\sigma/Mean$) of reconstructed Higgs boson mass, comparing to LHC results.

	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

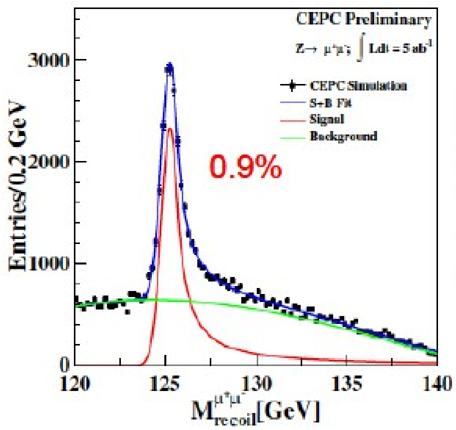
Summary

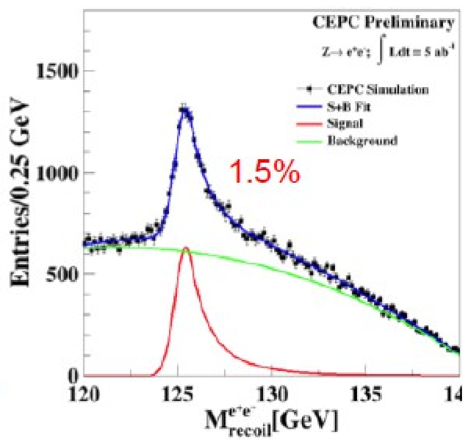
- CEPC, a super Higgs/W/Z factory, requests high efficiency/purity and high precision reconstruction of all key physics objects
- Performance at the baseline design (PFA: APODIS + Arbor)
  - All key physics objects tamed
  - Clear Higgs signature in all SM Higgs decay modes
  - Clear distinguish between 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

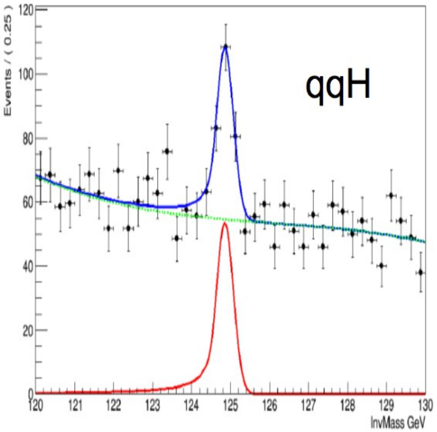
Higgs benchmark analyses

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

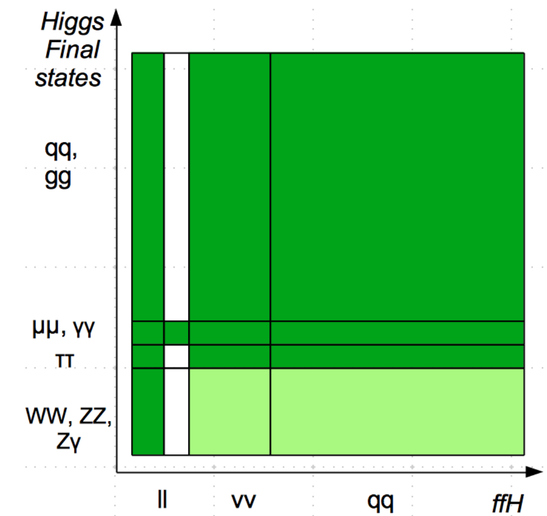


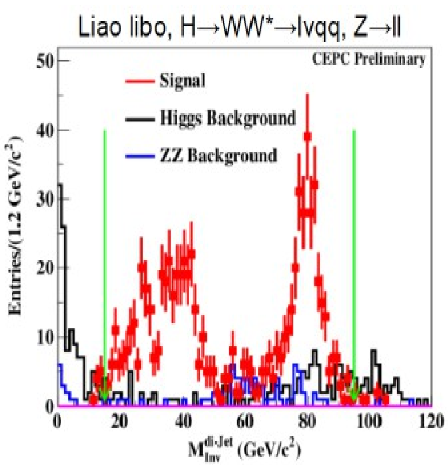


σ(ZH) measurements

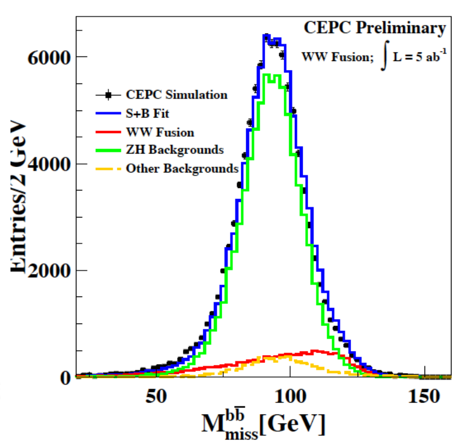


Br(H→μμ)

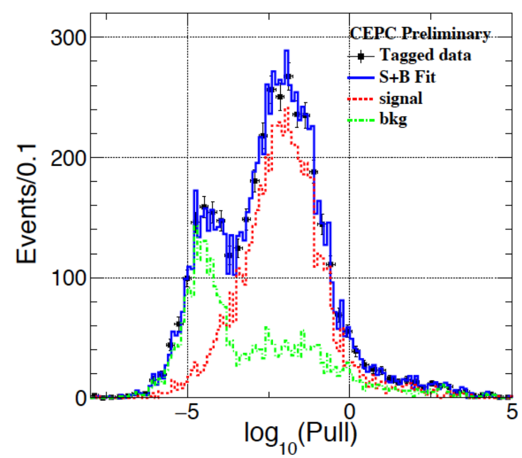




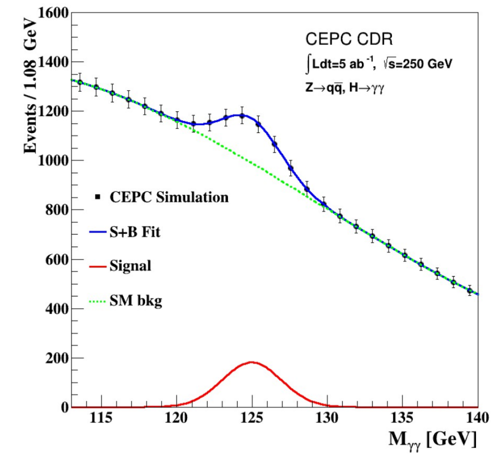
Br(H→WW)



σ(ννH)*Br(H→bb)



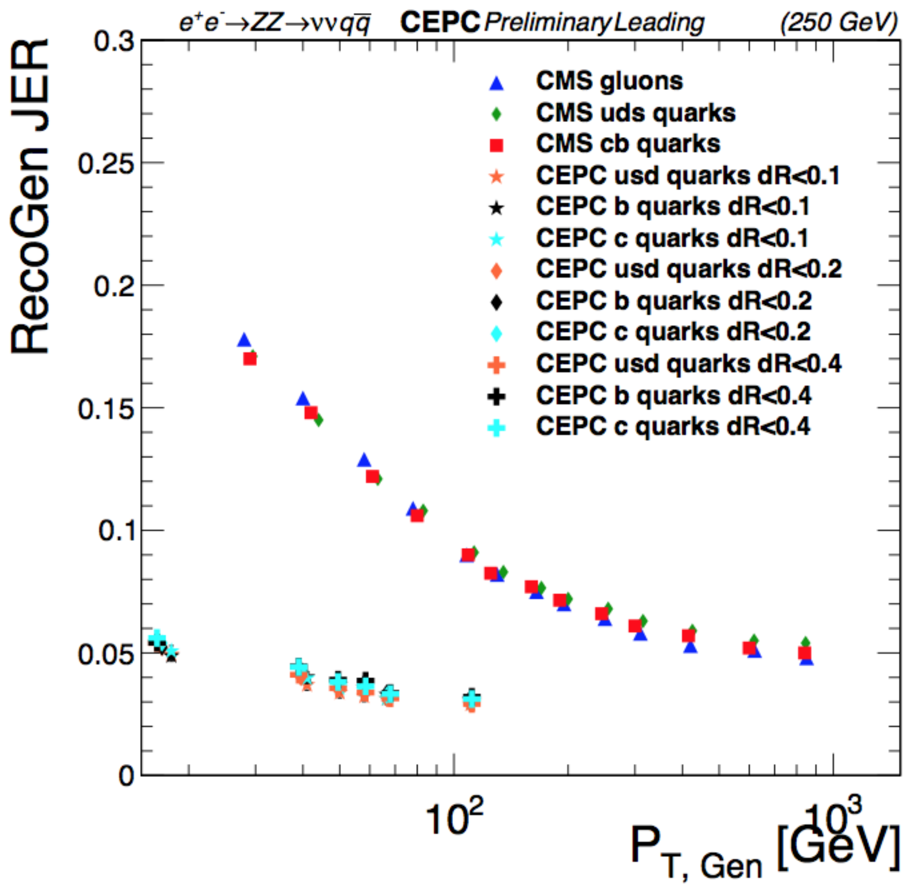
Br(H→ττ)

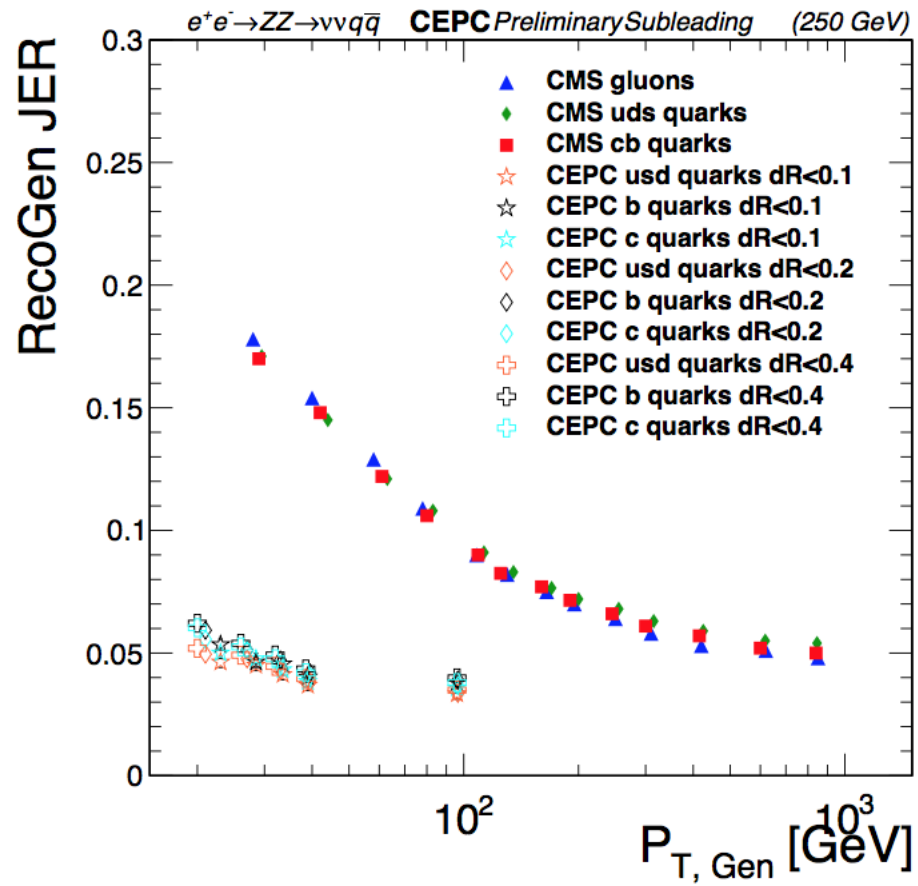


Br(H→γγ) (Asimov)

See Next Talk (On Higgs Performance)

Jet Energy Resolution

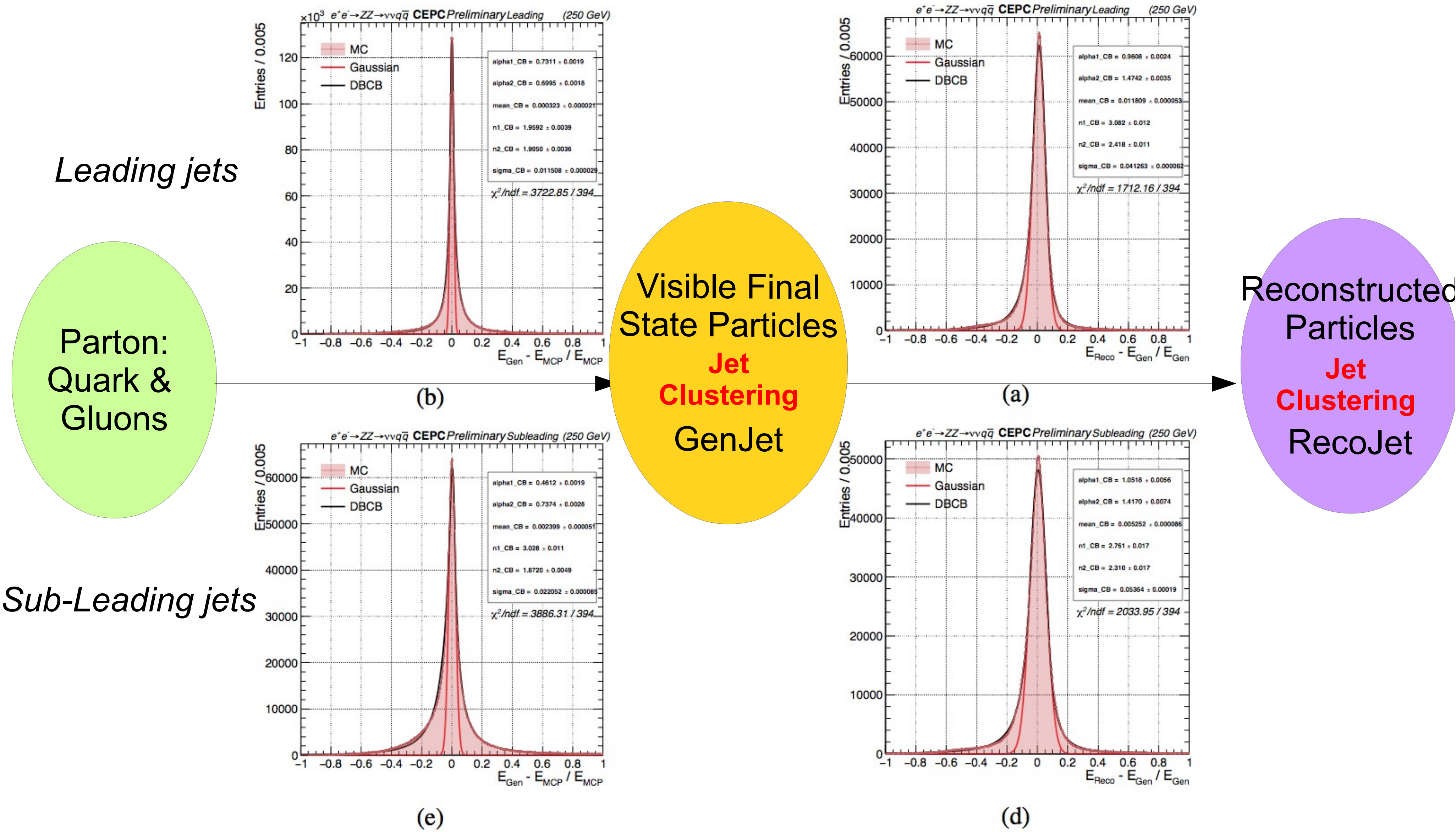




CMS Reference: CMS-JME-13-004,

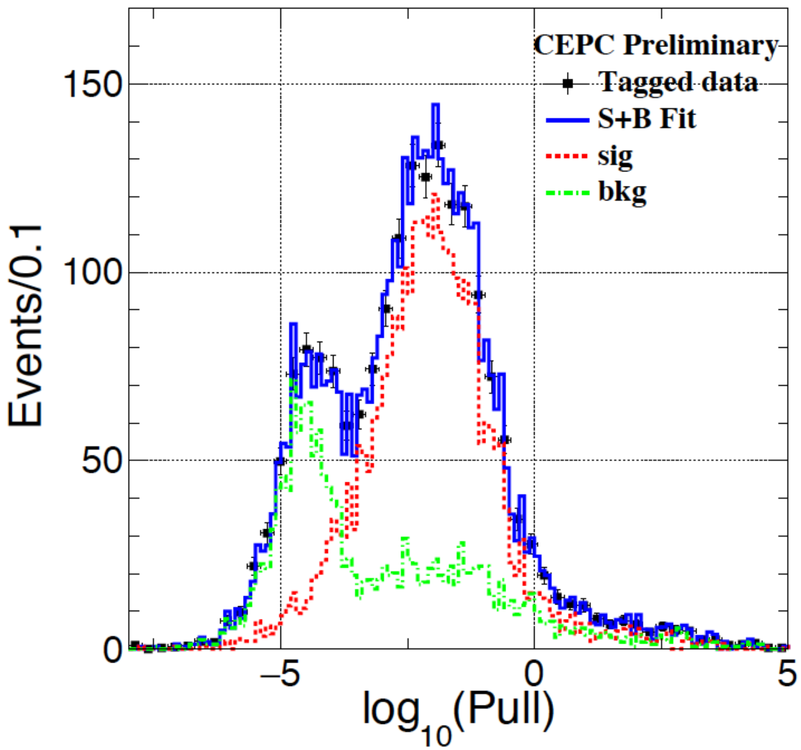
Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV

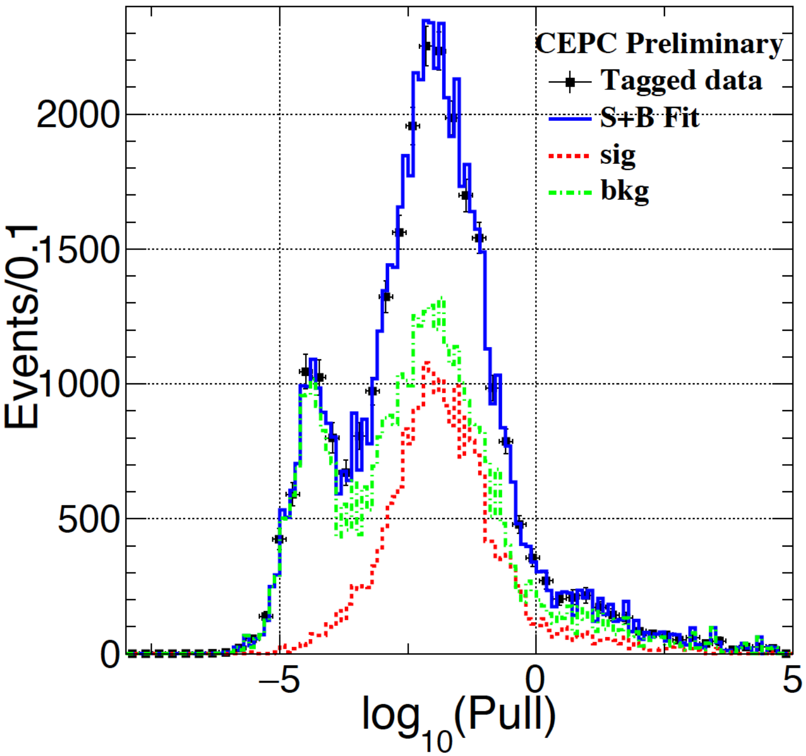
Impact of Jet Clustering: Significant



Jet Clustering is Mainly responsible for the tails

g(Hττ) measurement

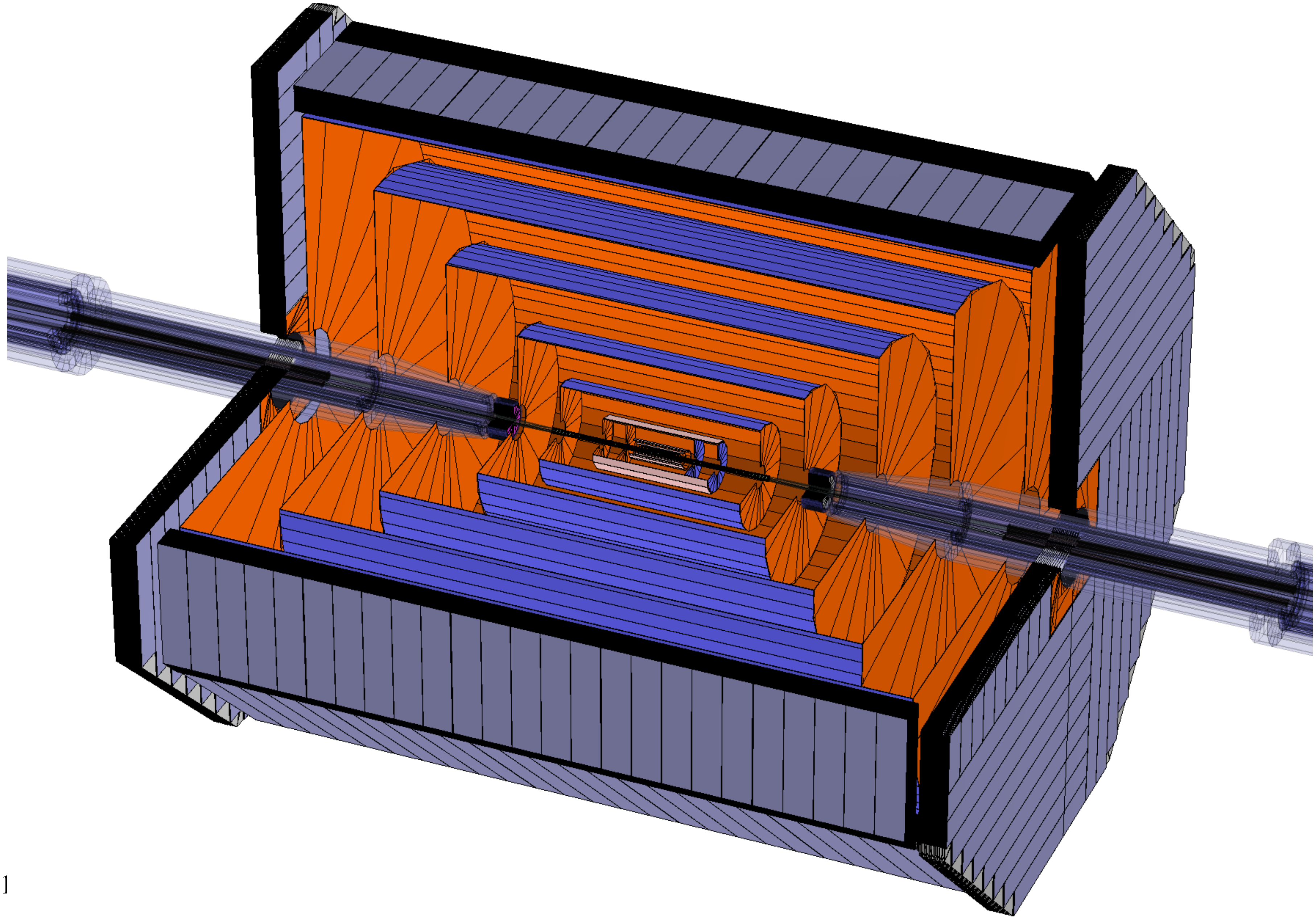




- ZH→μμττ
- Extremely Efficient Event Selection
- Signal efficiency of 93% - entire SM background reduced by 5 orders of magnitude

- 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

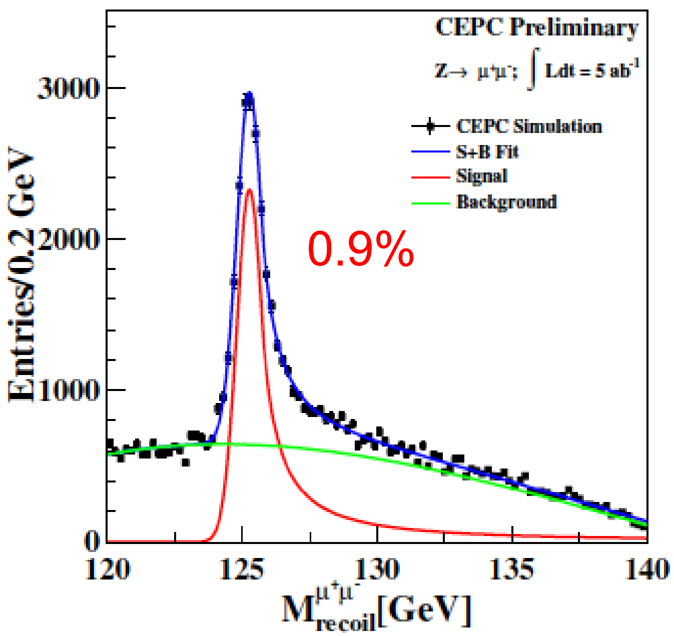
- Composited object finder: **CORAL** (finding Pi0, Kshort, Lambda, J/Psi, ...)
  - Framework is ready... and lots of performance study and optimization awaits (40, 90, 50)

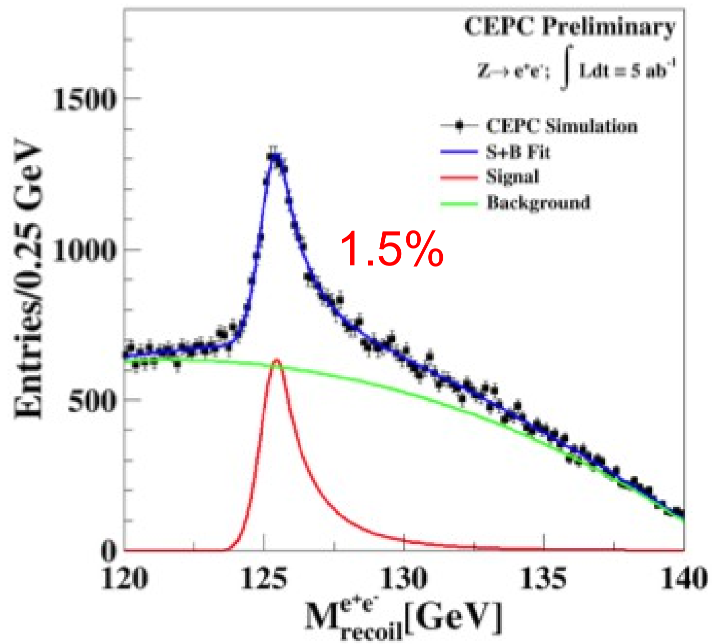
Urgency, Importance, Difficulties

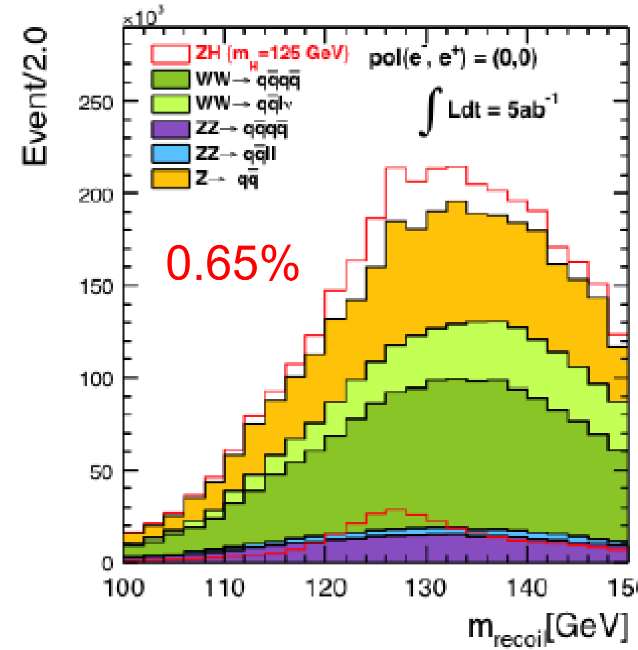
- Jets
  - Jet Clustering: finding the color singlet? (40, 90, 90)
  - Distinguish between 2 jet, 3 jet, 4jet, 5jet, 6jet events.... (80, 80, 60)
    - Mila's analysis (ZH->6 jets) gives a very good example
- **Jet Flavor Tagging** (**90**, **99**, **80**)
  - The efficiency of reconstruct 2nd Vertex 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)

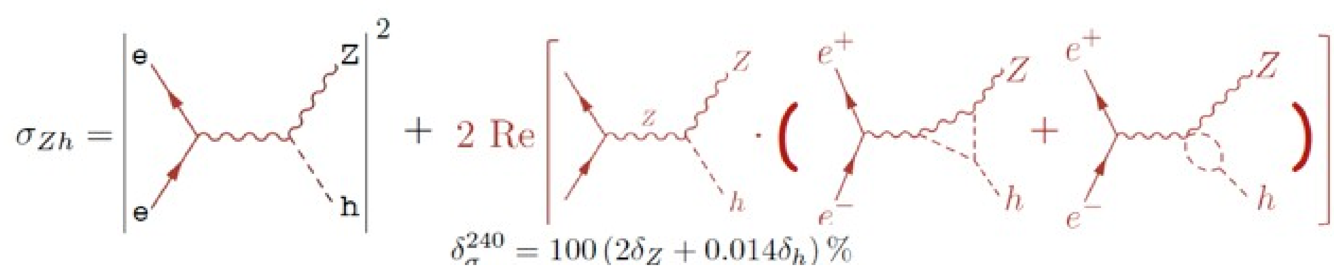
Zhenxing Chen & Yacine Haddad







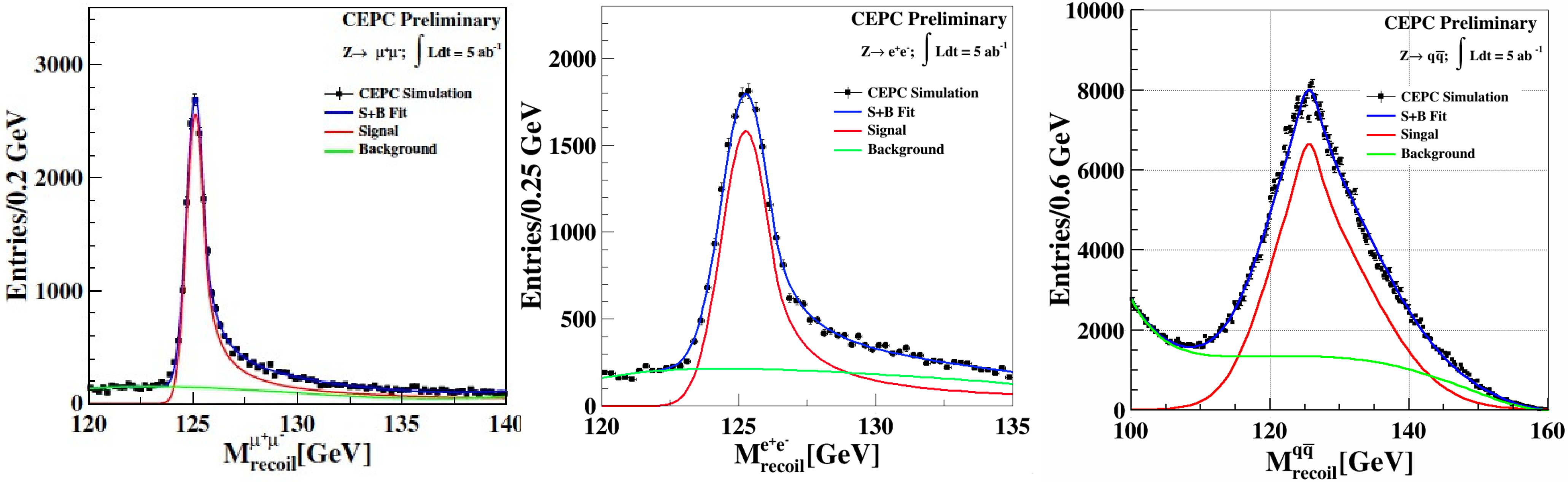
- Recoil mass method. Combined precision:
  $\delta\sigma(ZH)/\sigma(ZH) = 0.5\%$ -
  $\delta g(HZZ)/g(HZZ) = 0.25\%$
- Indirect Access to g(HHH)



- *M. McCullough, 1312.3322*

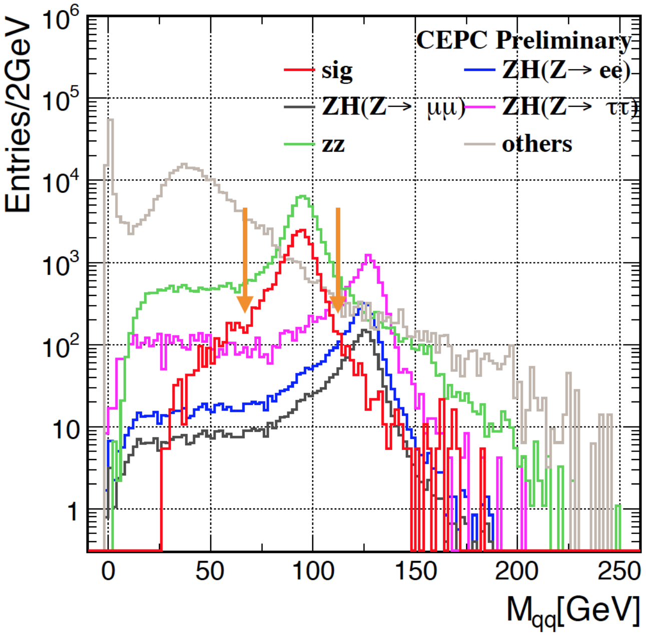
Exotic: Higgs invisible decays

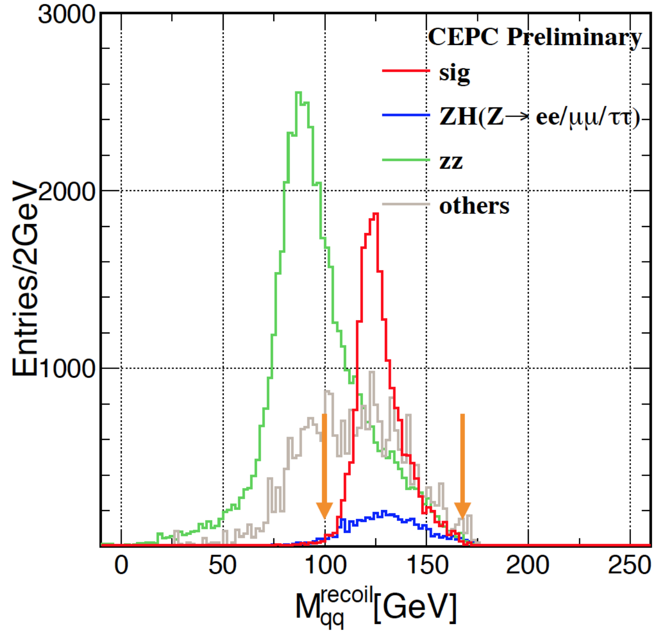
*Assuming sigma(ZH)*Br(H->inv) = 200 fb*

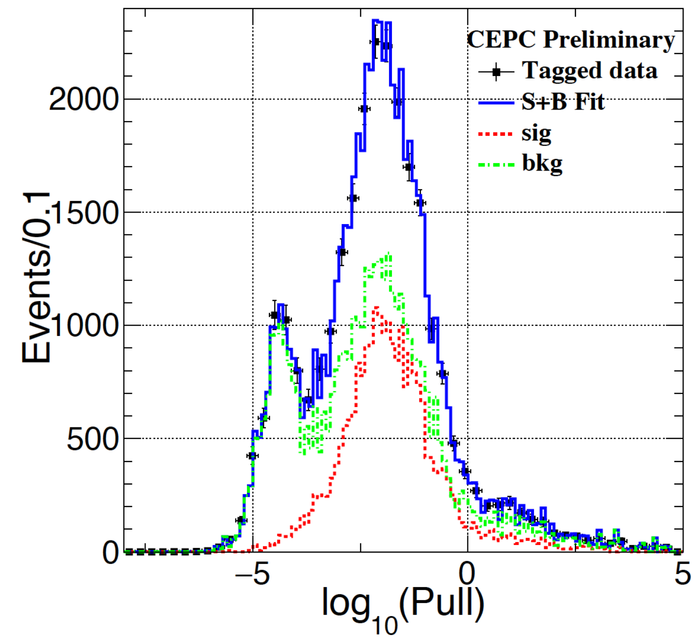


Invisible up limit at CEPC: ~0.3% at 95% C.L

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







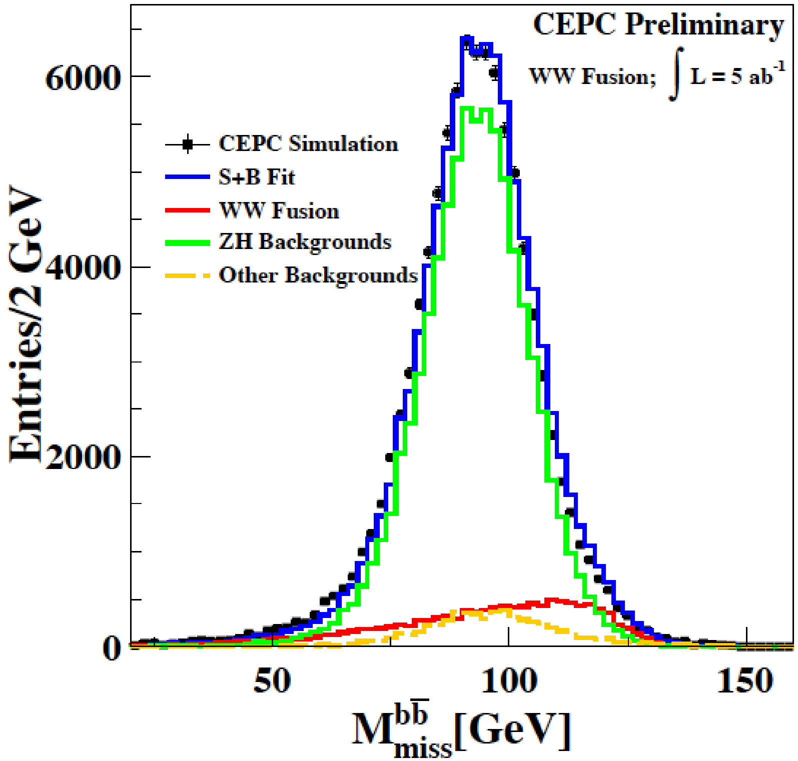
- Cone based tau finding: di-tau system
- The other particles are define as the di-jet system: to distinguish the qqττ background
- Isolated tracks are intensionally defined as tau candidate: be distinguished by the VTX

	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) ($\sim g^2(HZZ)$)
    σ(ZH)*Br(H→ZZ) ($\sim g^4(HZZ)/\Gamma_{total}$)
  - σ(ZH)*Br(H→bb),
    σ(vvH)*Br(H→bb),
    σ(ZH)*Br(H→WW),
    σ(ZH)

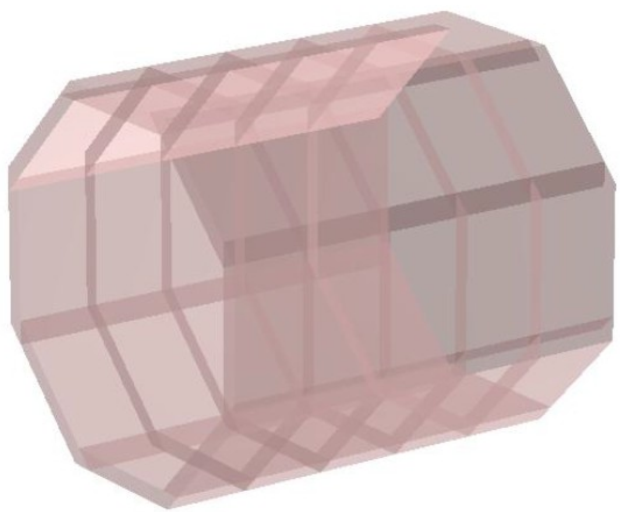


Br(H->ZZ): relative error of 6.9% achieved with ZH->ZZZ*->vv(Z)llqq(H) final states. Extrapolation of TLEP result leads to 4.3% relative error

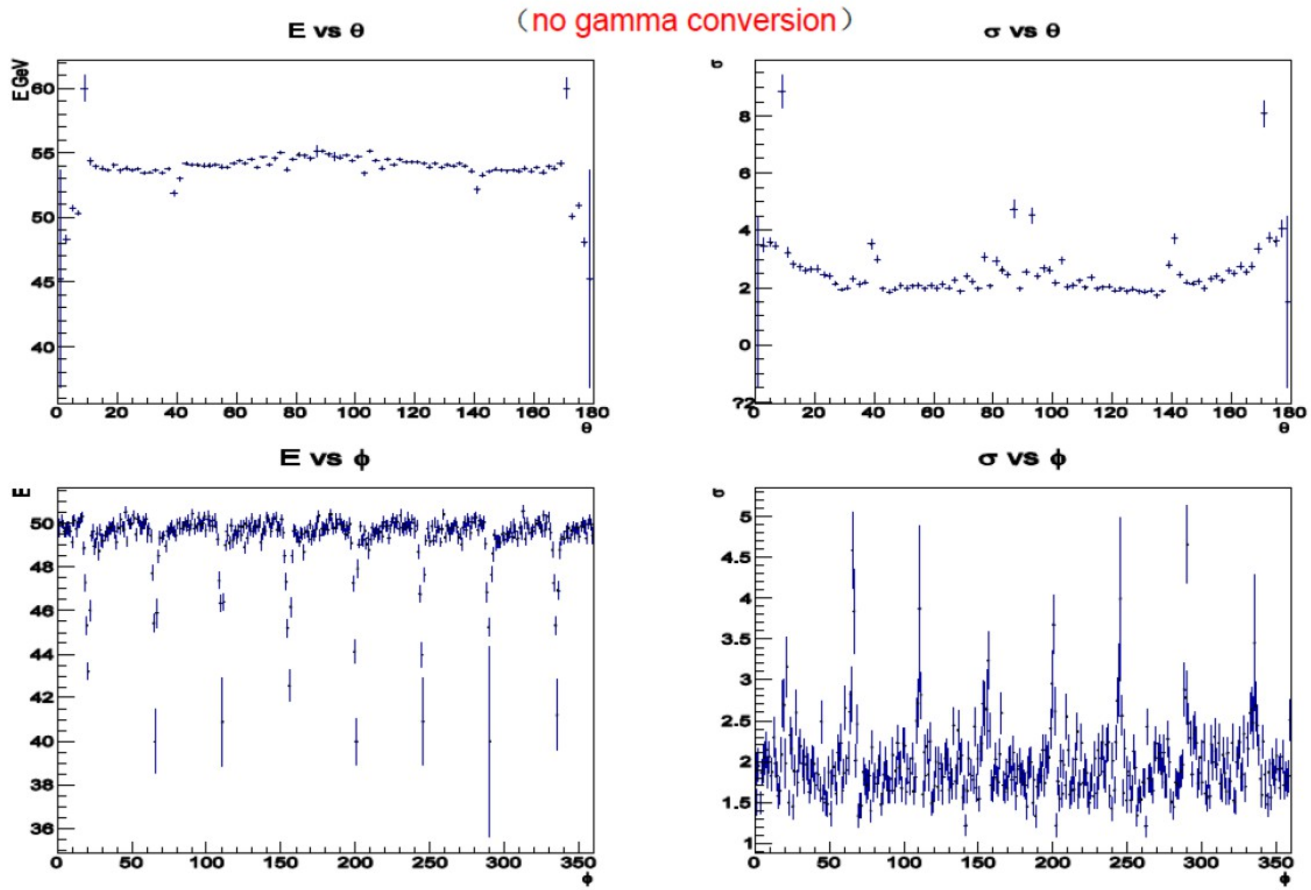
σ(vvH)*Br(H->bb): relative error of 2.8%

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