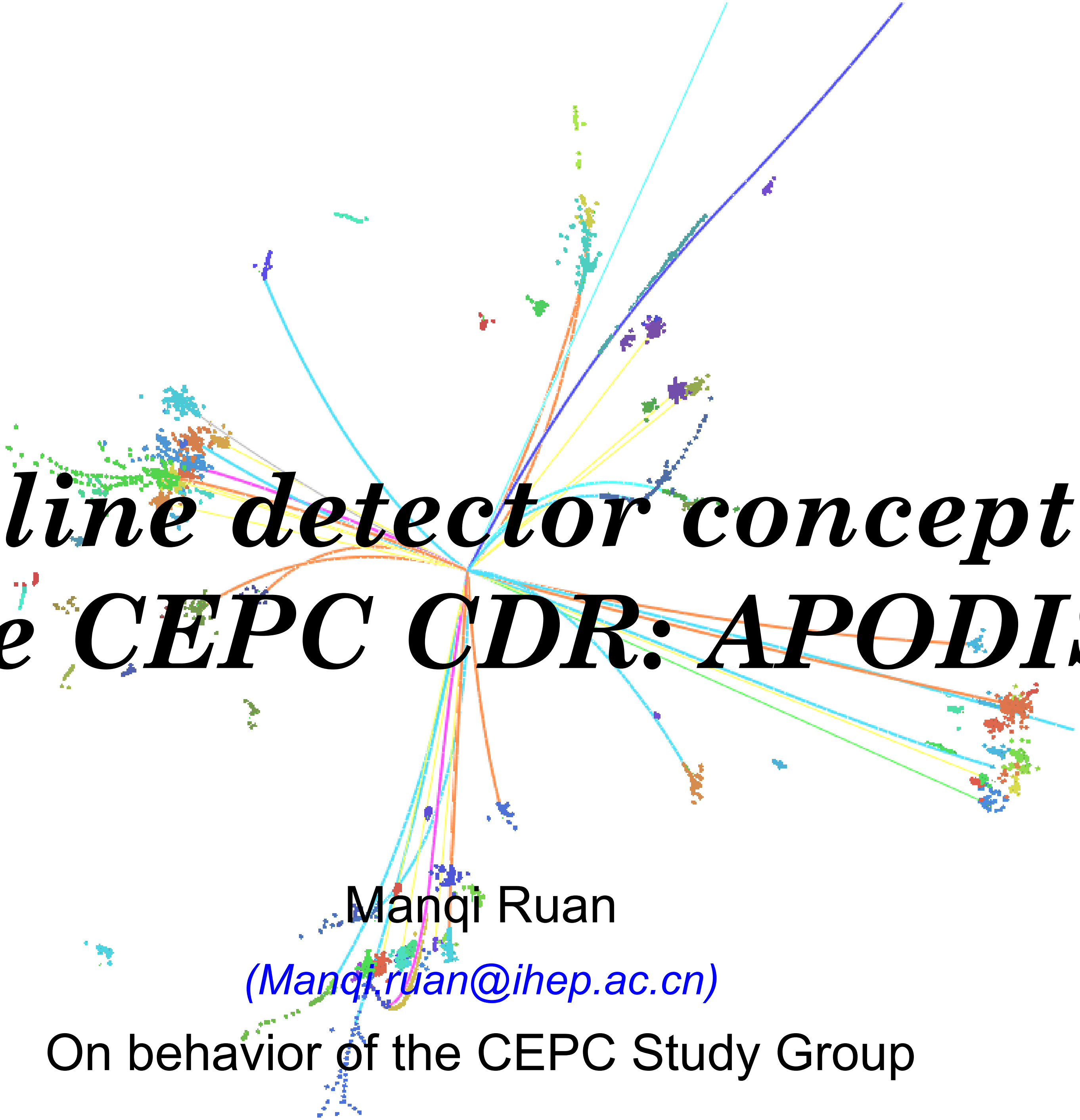


Baseline detector concept for the CEPC CDR: APODIS

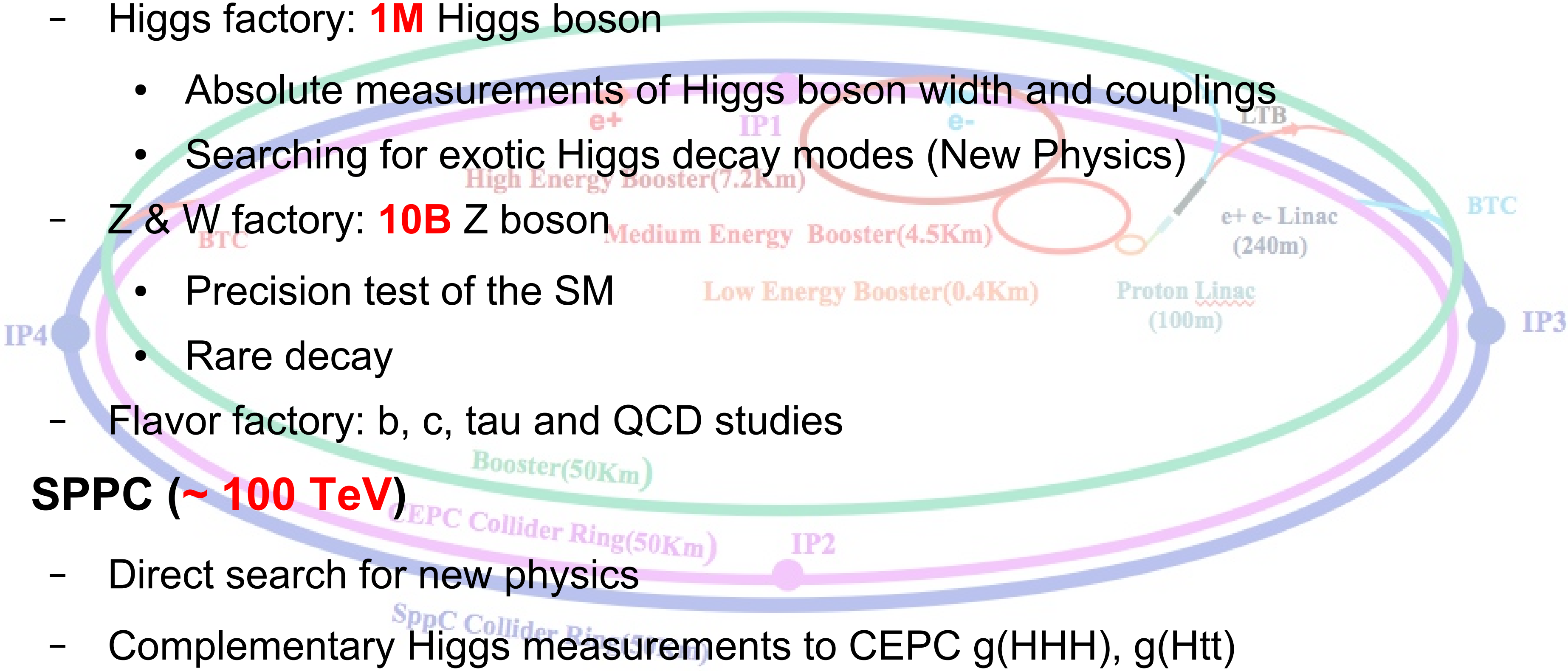
Manqi Ruan

(Manqi.ruan@ihep.ac.cn)

On behavior of the CEPC Study Group

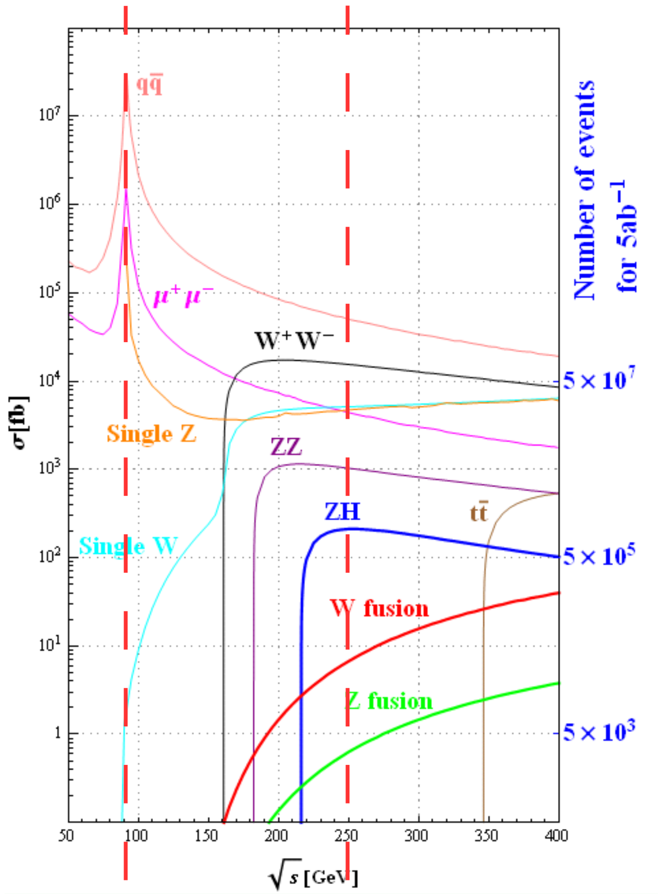
Science at CEPC-SPPC

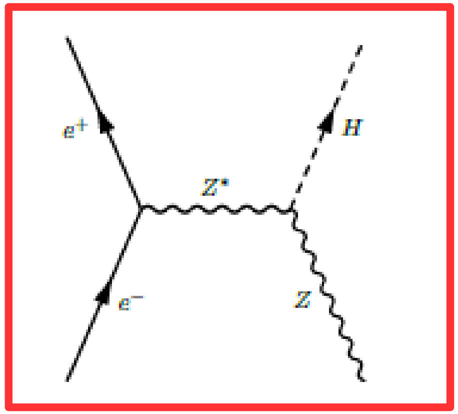
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**

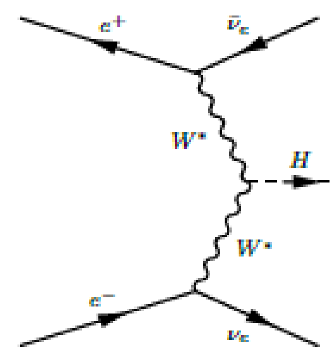


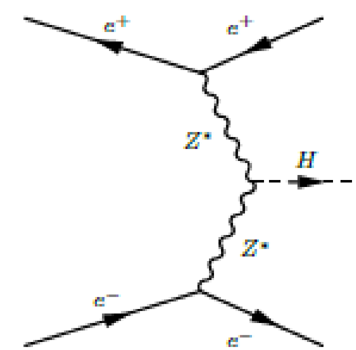
Complementary

Higgs @ CEPC









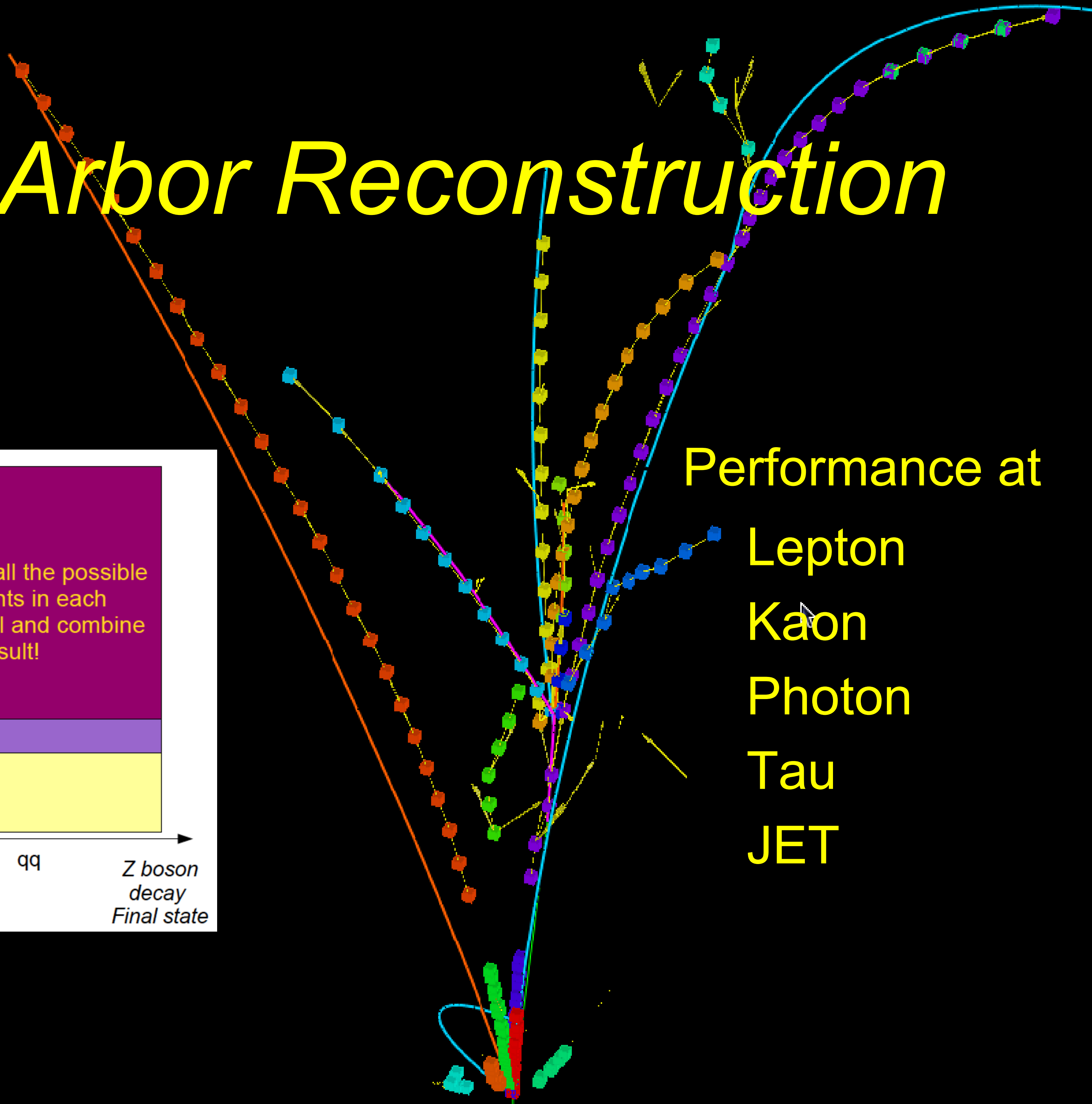
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

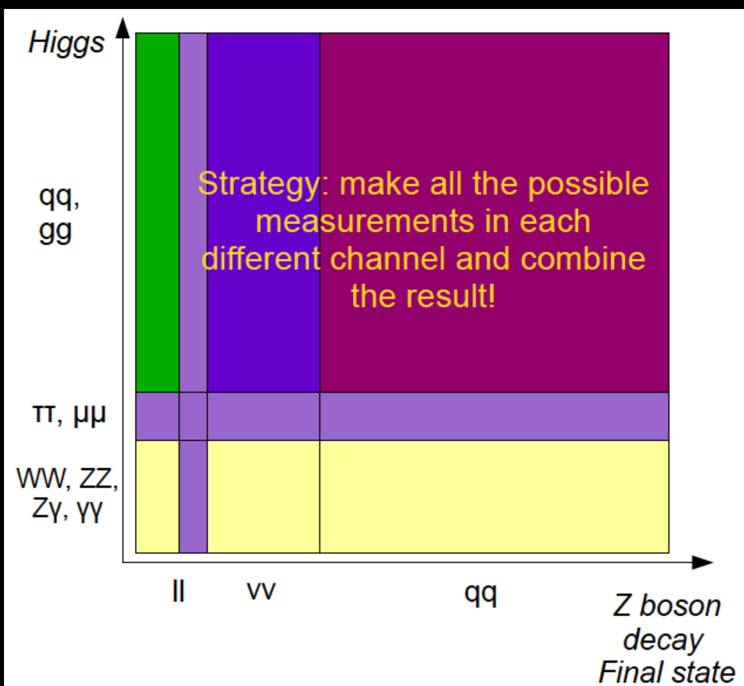
S/B ~ 1:100 - 1000

Observables: Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H→X)), Diff. distributions

Derive: Absolute Higgs width, branching ratios, couplings

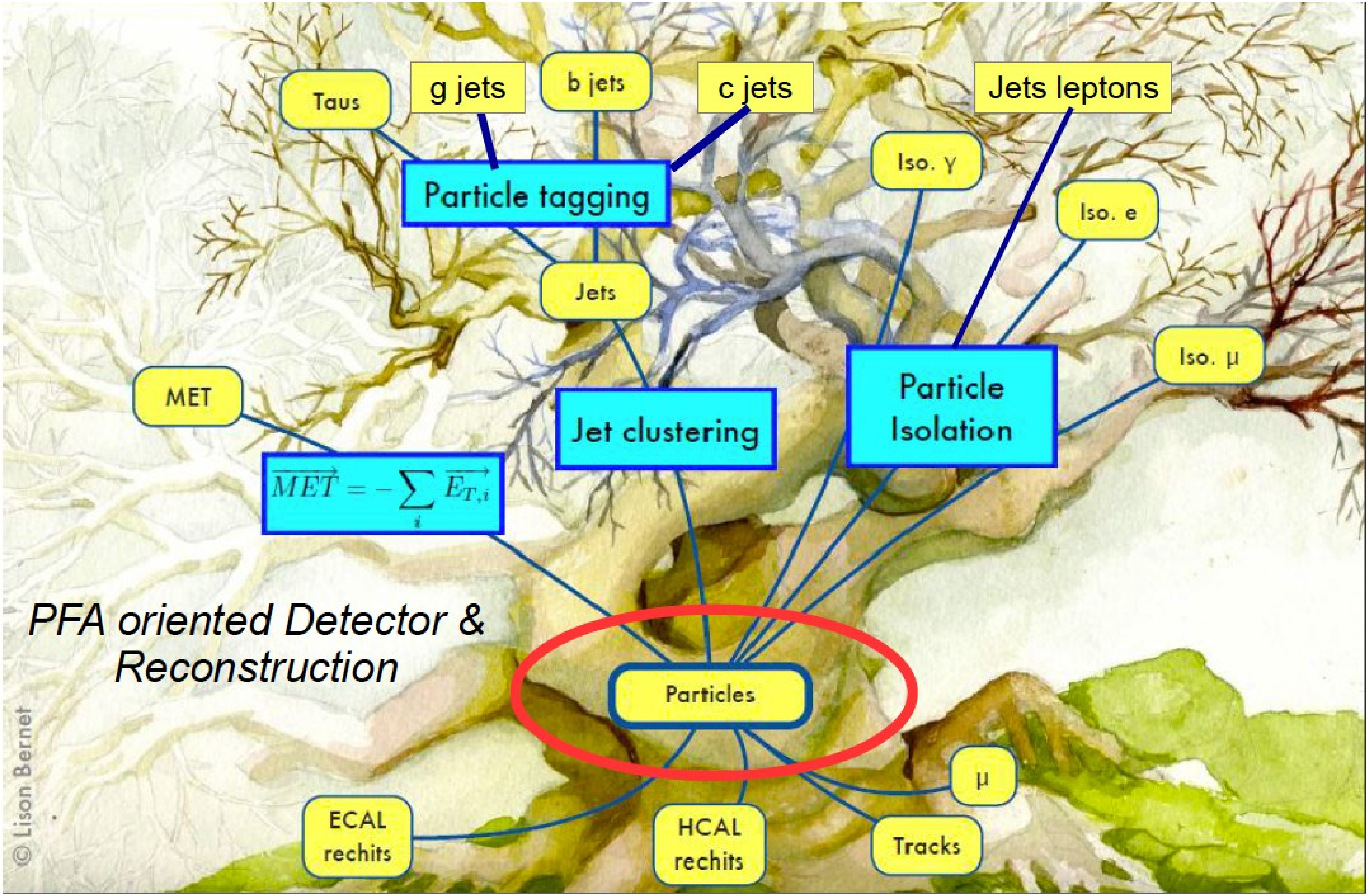
Arbor Reconstruction



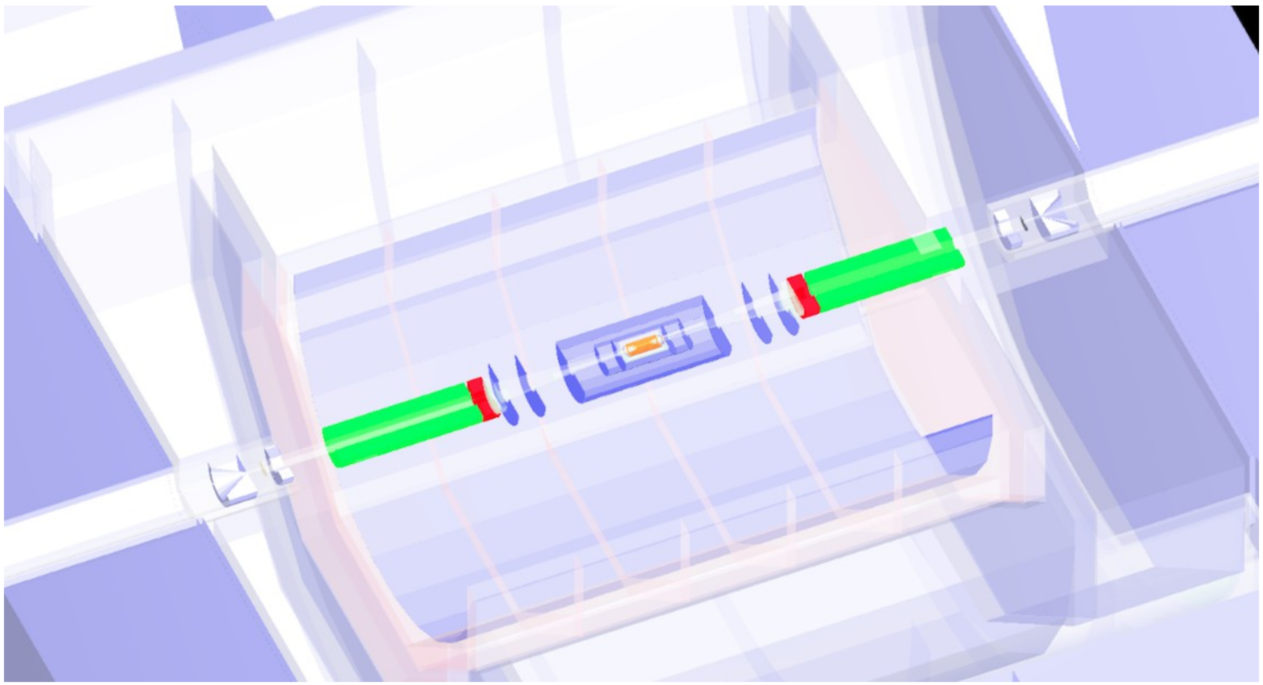


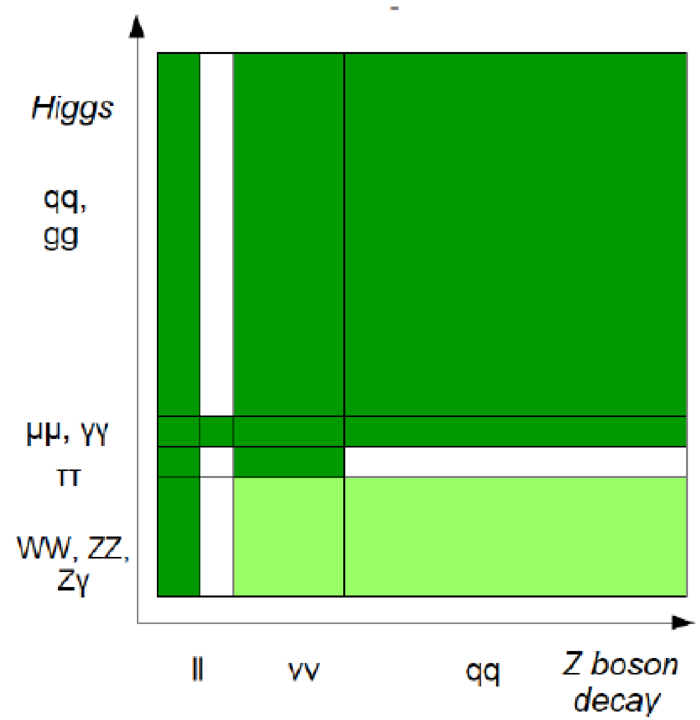
Performance at

- Lepton
- Kaon
- Photon
- Tau
- JET


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

CEPC-v1, reference detector for the CEPC PreCDR studies



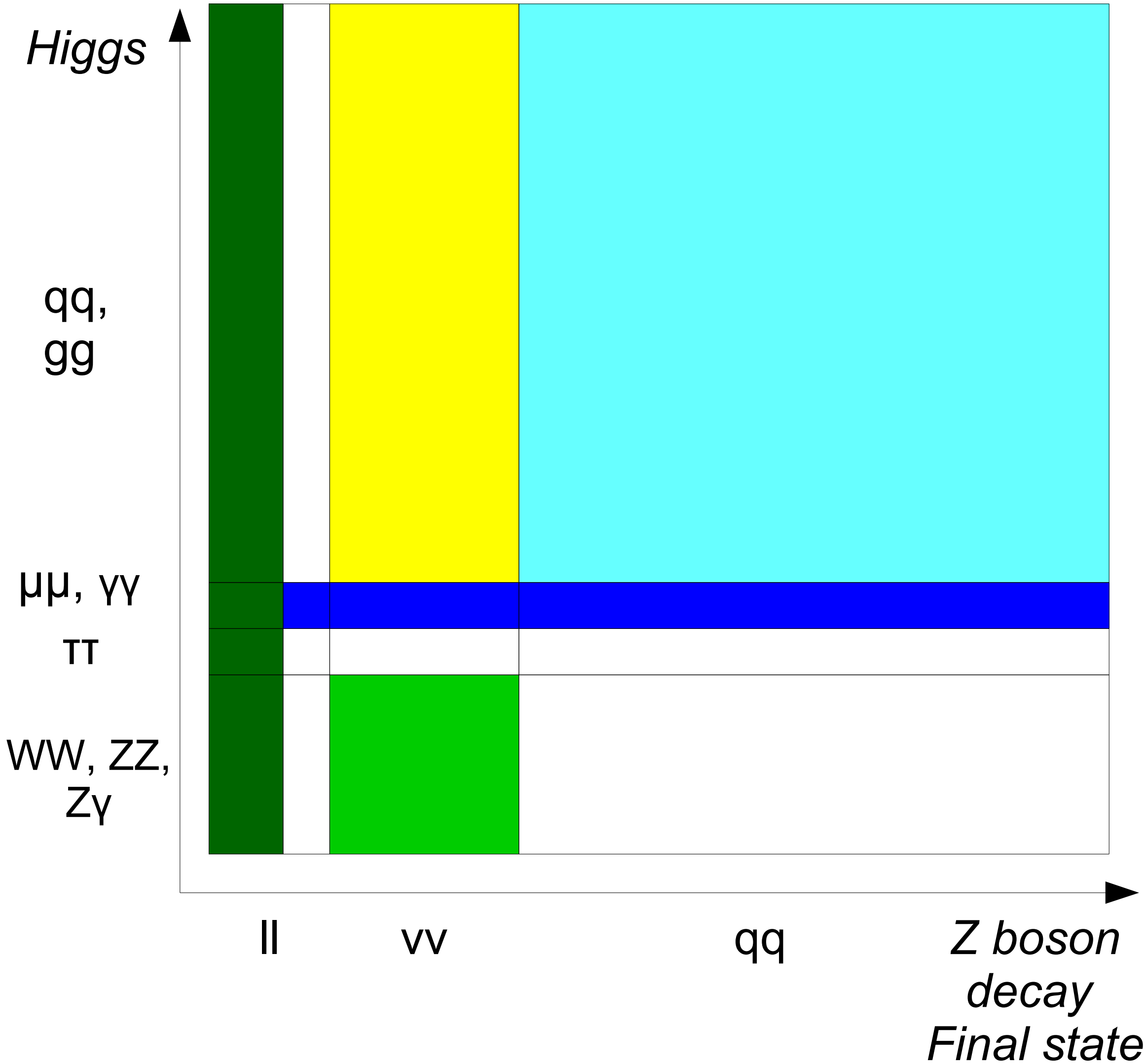


Supports most of the CEPC physics analysis till now;

Summarized into the CEPC PreCDR.

To be summarized in Higgs white paper, in final polishing stage

Benchmark measurements



Lepton & Momentum resolution: Br = 6.7%

Flavor Tagging & JER: Br = 14%

Composition of Jet/MET, lepton: Br = 4%

Jet Clustering: Br = 50%

Photon/ECAL: Br = 0.2%

qqH, H->inv. MET & NP: SM Br = 0.1%

EW, Br(tau->X) @ Z pole: Separation

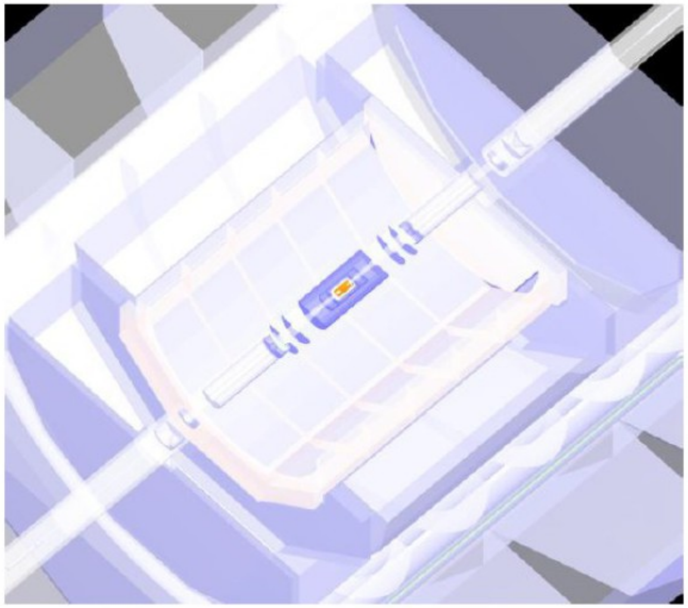
Feasibility & Optimized Parameters

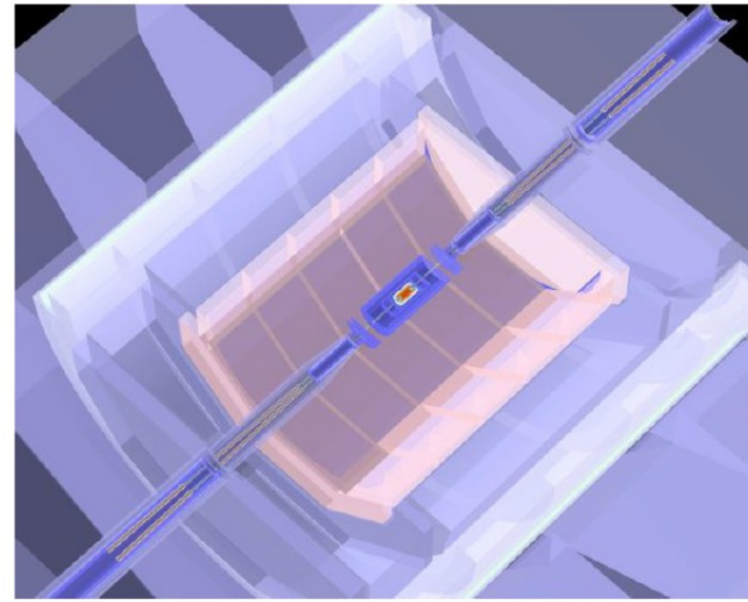
Feasibility analysis: TPC and Passive Cooling Calorimeter is valid for CEPC

	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	84 mm is optimized on Br(H->di photon) at 250 GeV; 90mm for bhabha event at 350 GeV
ECAL Cell Size	5 mm	10 mm	Passive cooling request ~ 20 mm. 10 mm should be highly appreciated for EW measurements – need further evaluation
ECAL NLayer	30	30	Depends on the Silicon Sensor thickness
HCAL Thickness	**1.3 m**	**1 m**	-
HCAL NLayer	**48**	**40**	Optimized on Higgs event at 250 GeV; Margin might be reserved for 350 GeV.

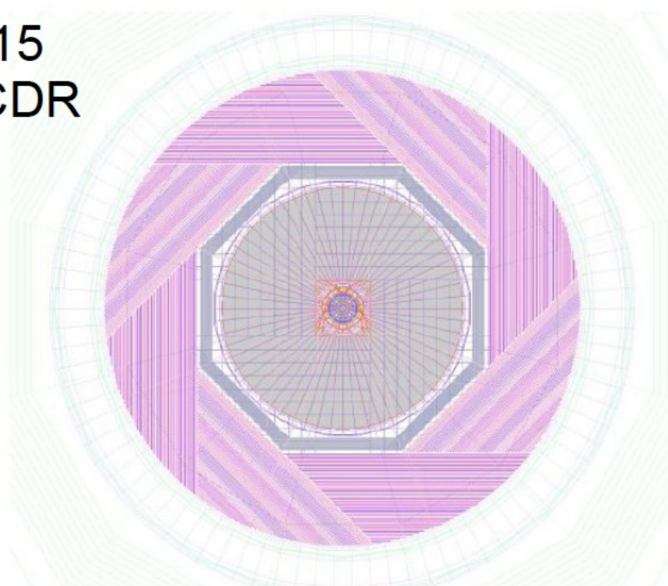
Benchmark detector for CDR: **APODIS**

(A PFA Oriented Detector for HIggS factory. a.k.a CEPC_v4)

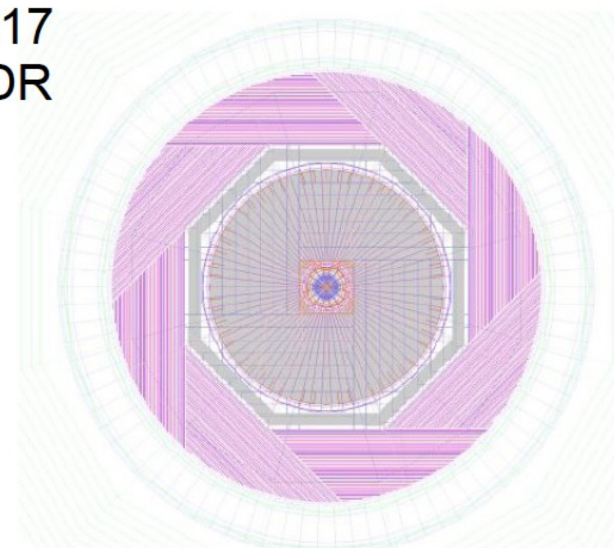




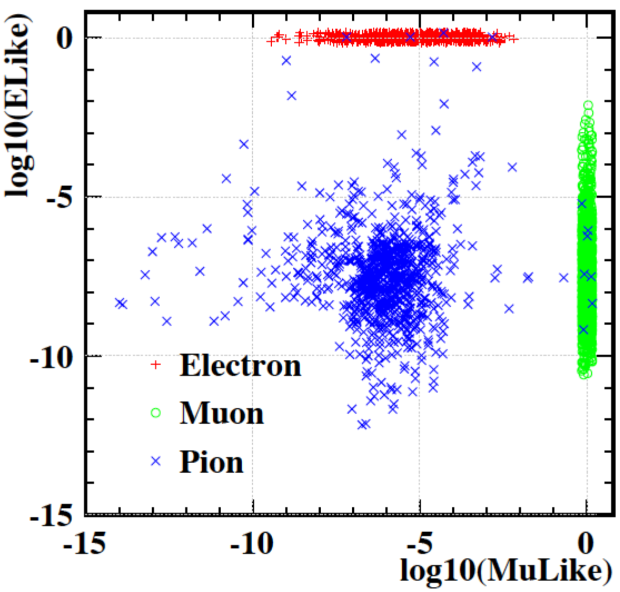
2015
PreCDR

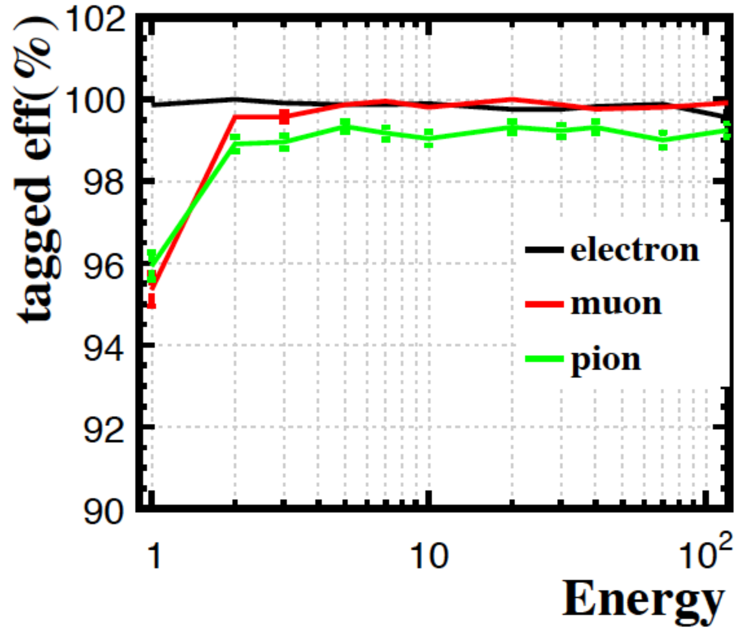


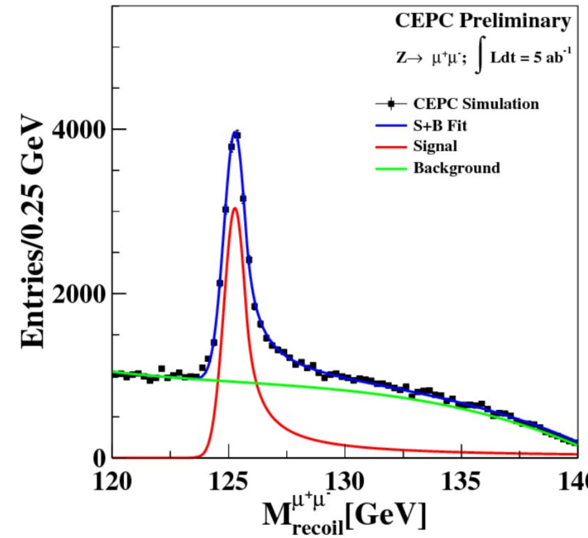
2017
CDR

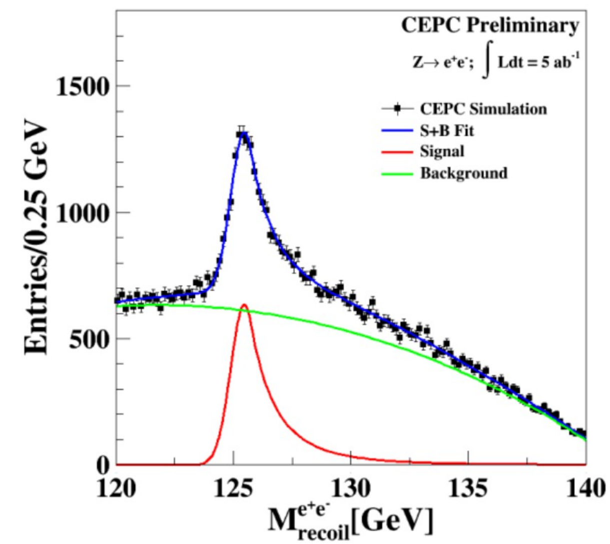


Lepton







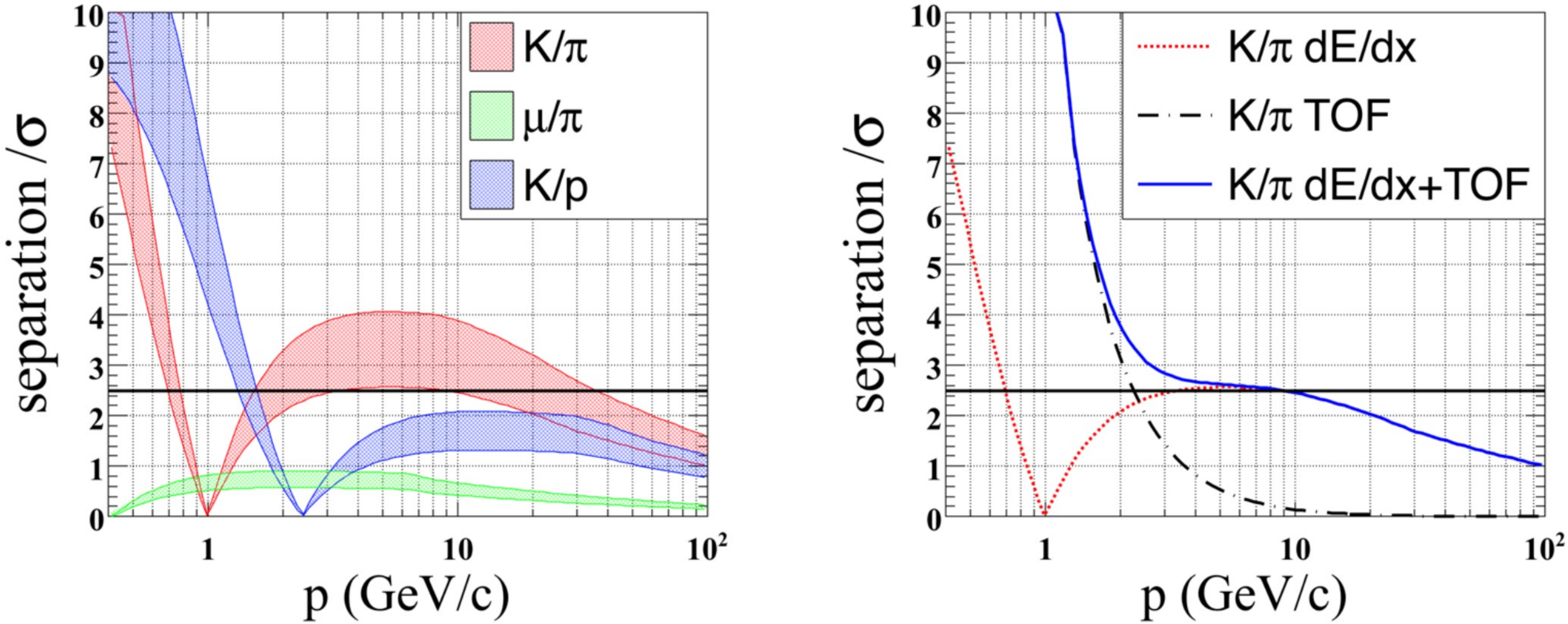


BDT method using 4 classes of 24 input discrimination variables.

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%

https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5
CEPC-DocDB-id:148

Kaon



Highly appreciated in flavor physics @ CEPC Z pole

TPC dEdx + ToF of 50 ps

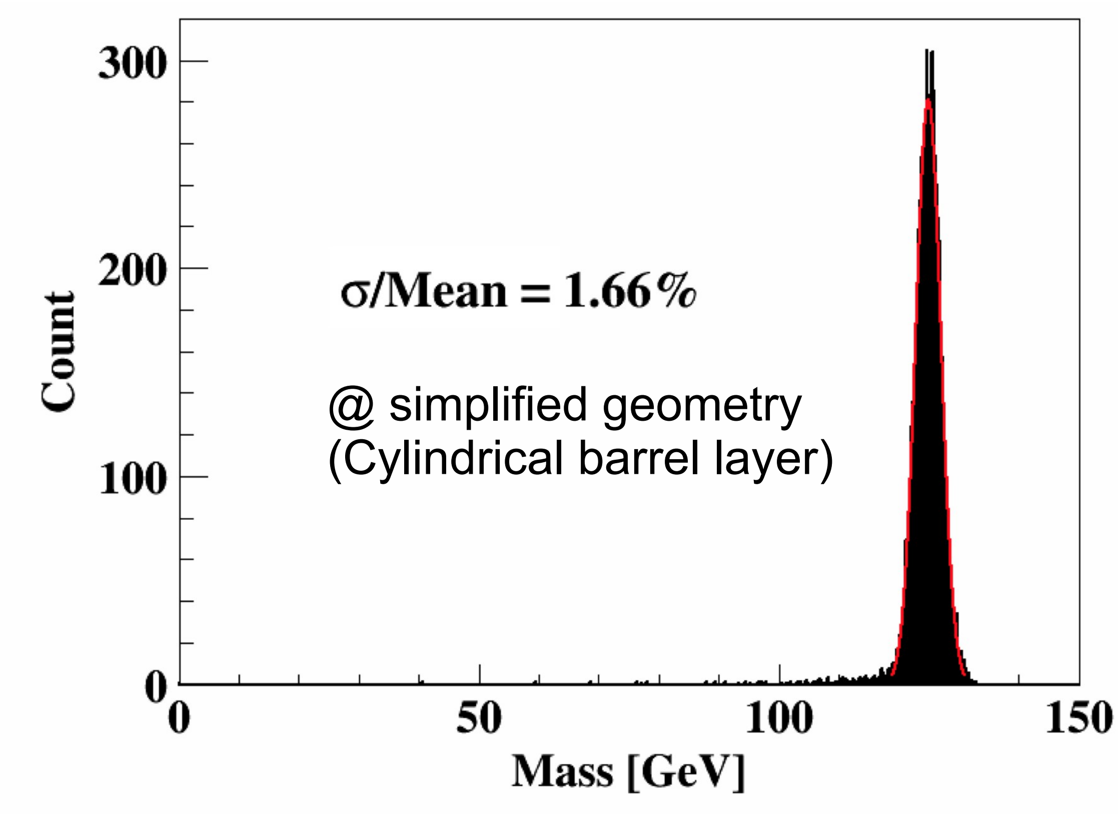
At inclusive Z pole sample:

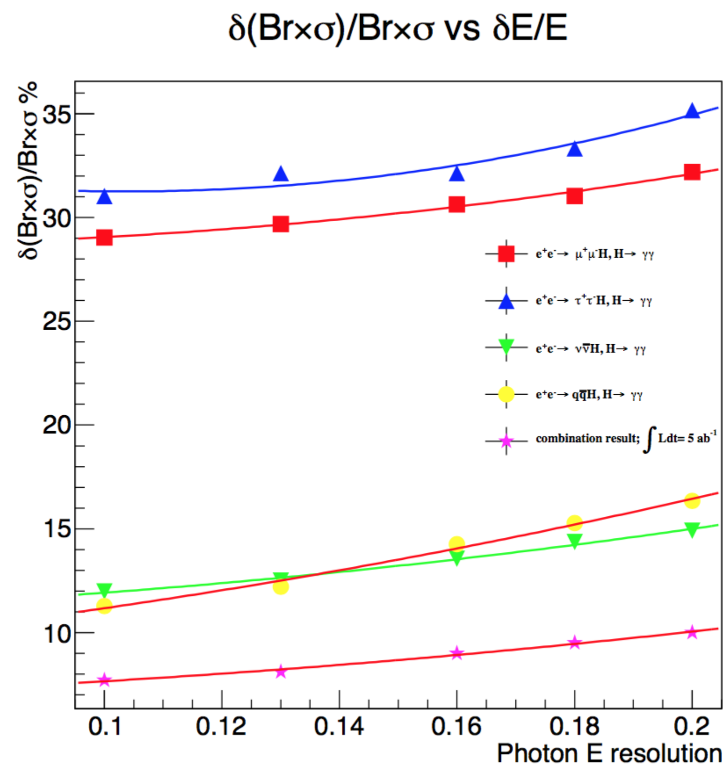
Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)

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
EPJC Accepted

Photon



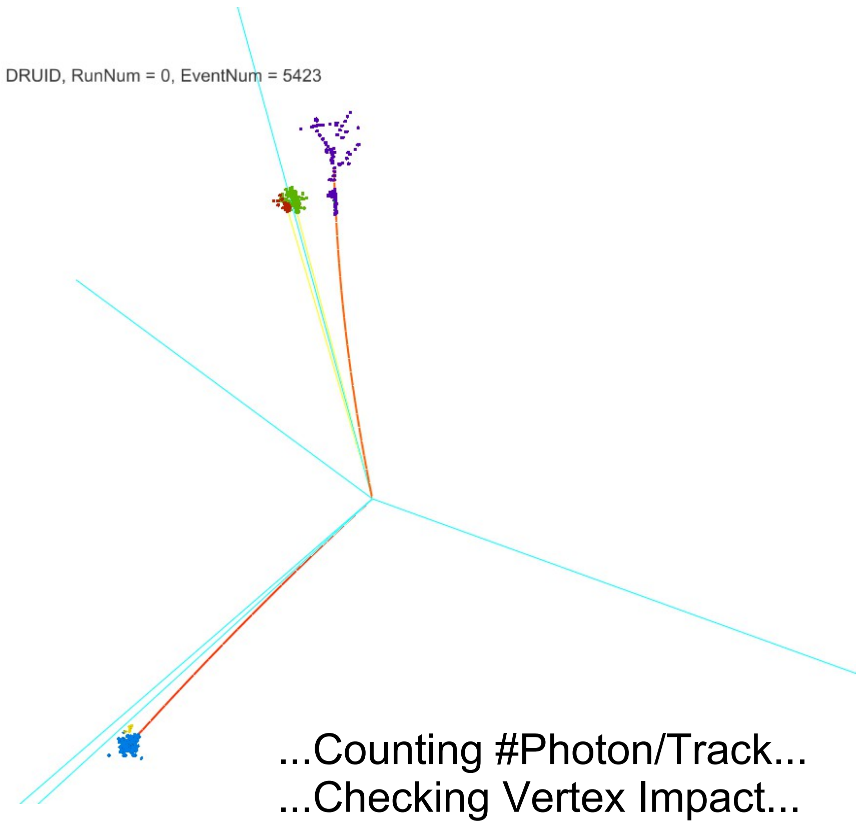


Relative Accuracy: ~ 8.5%

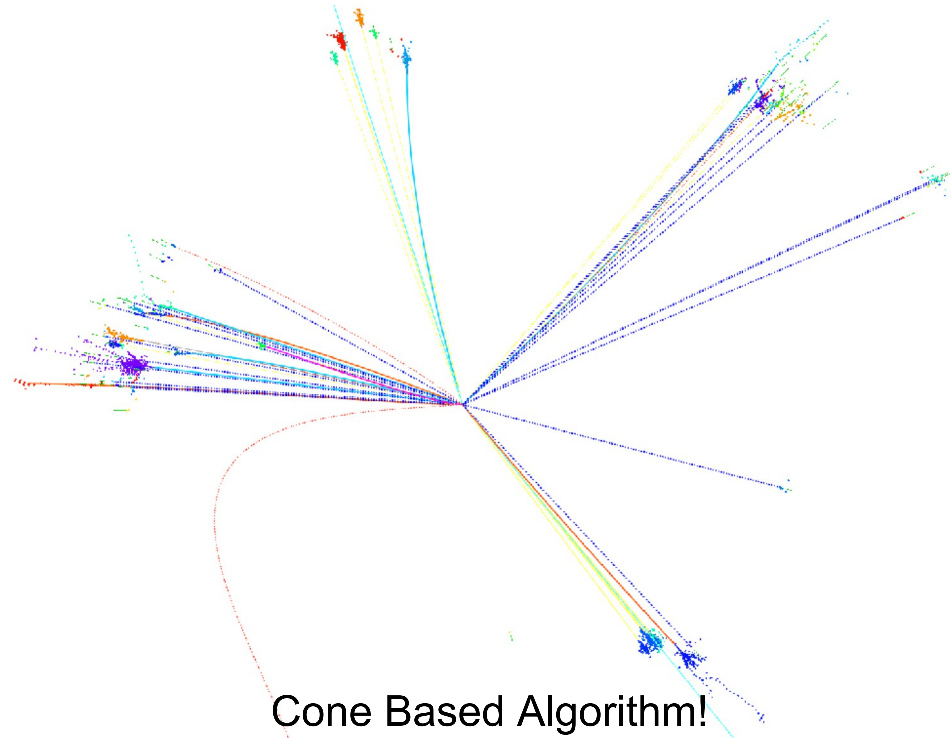
Inhomogeneity degrades the resolution significantly.
Physics requirement: constant term < 1%
Detector geometry defects degrades the mass resolution to **2.2%** (after correction);

http://iopscience.iop.org/article/10.1088/1748-0221/13/03/P03010
CEPC-DocDB-id (149, 169)
https://arxiv.org/pdf/1712.09625.pdf

Tau



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

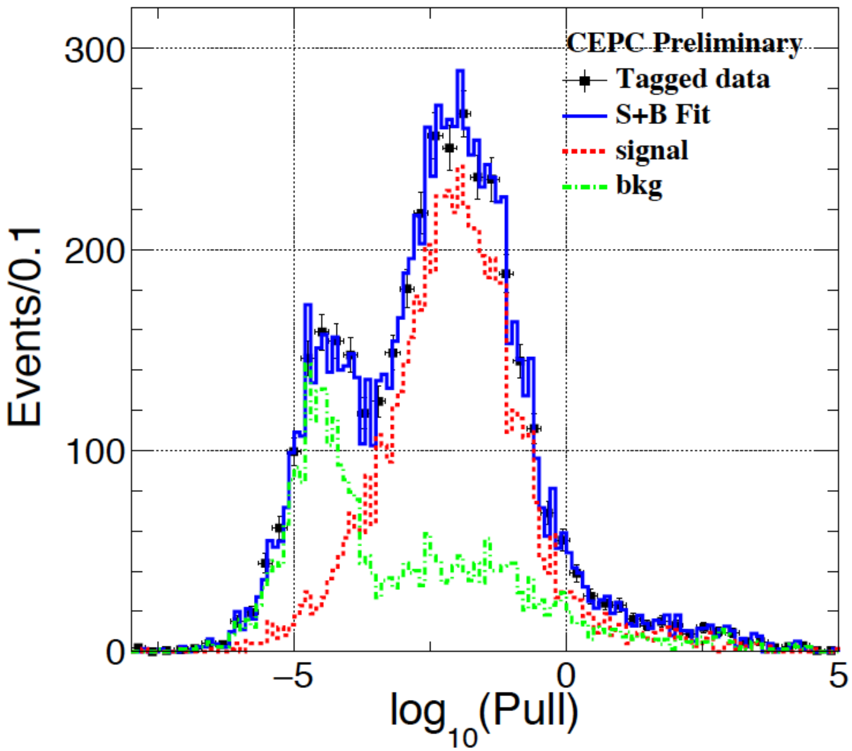


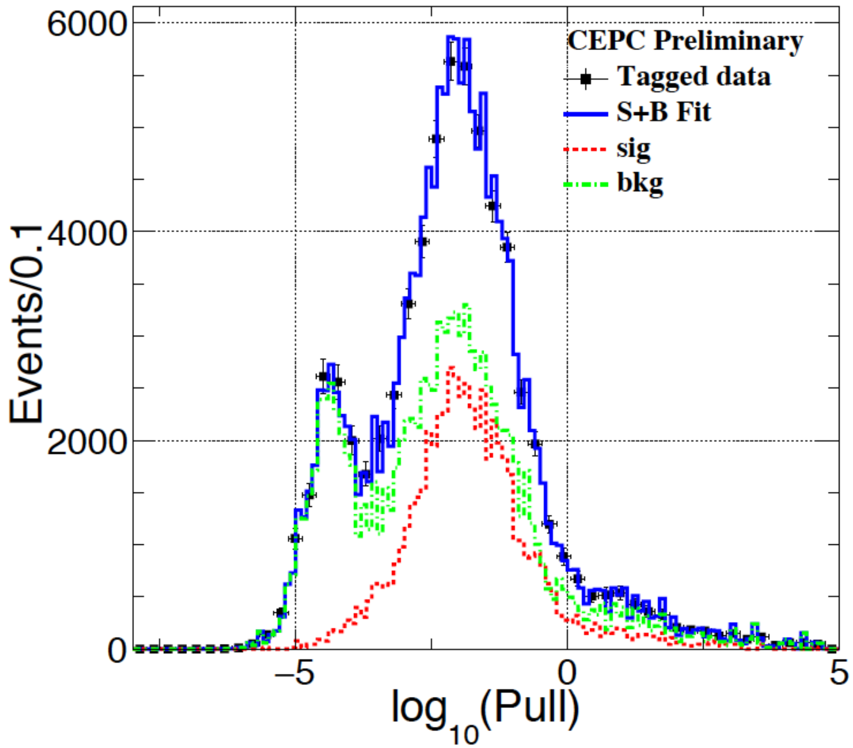
Cone Based Algorithm!
Para. Optimization

- 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

g(Hττ) measurement: preliminary





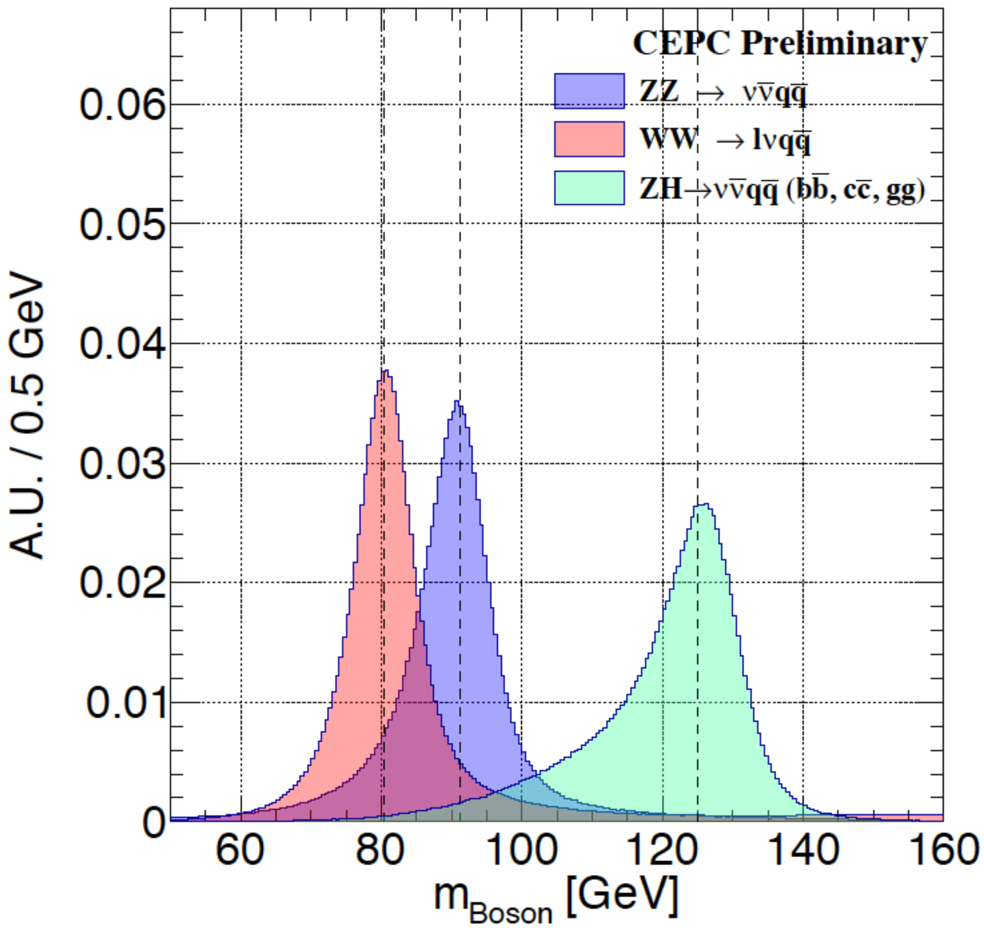
- ZH→μμττ
- Extremely Efficient Event Selection
- Signal efficiency of 93% - entire SM background reduced by 5 orders of magnitude

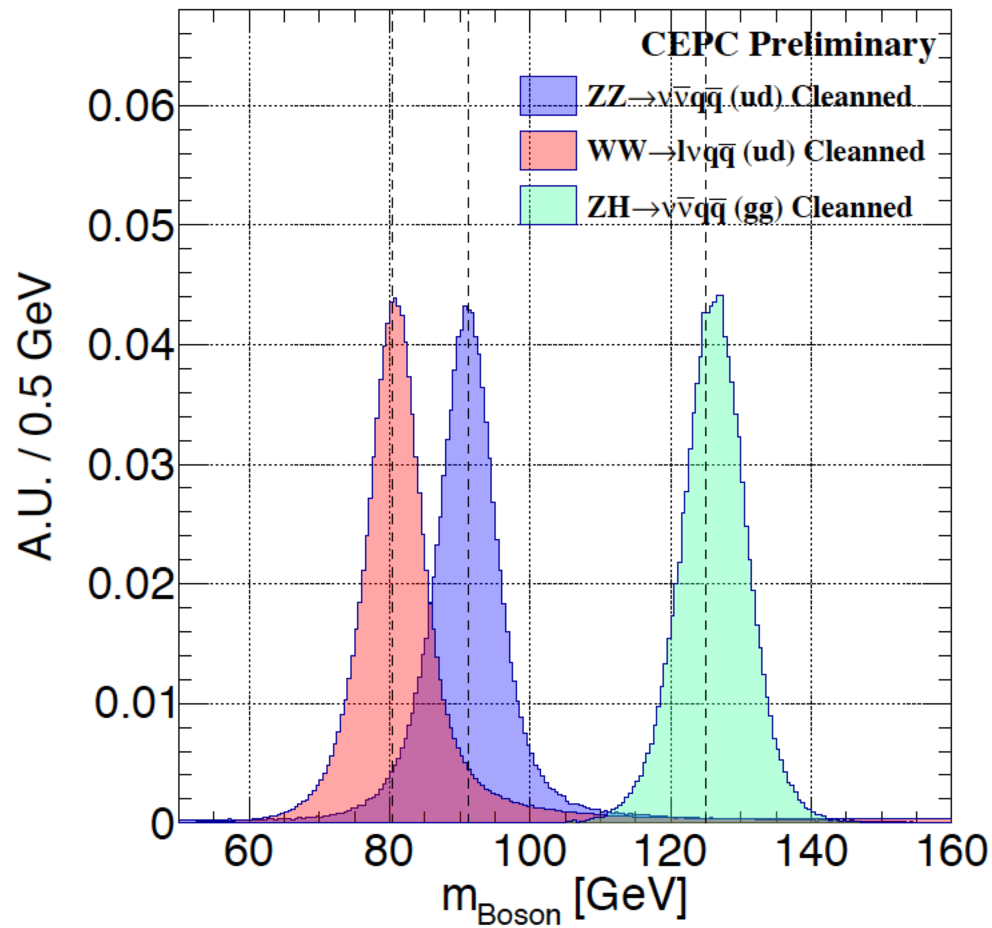
- ZH→qqττ
- Cone based tau finding algorithm, Compromise the efficiency & purity
- Signal efficiency of 51%

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
  - ...

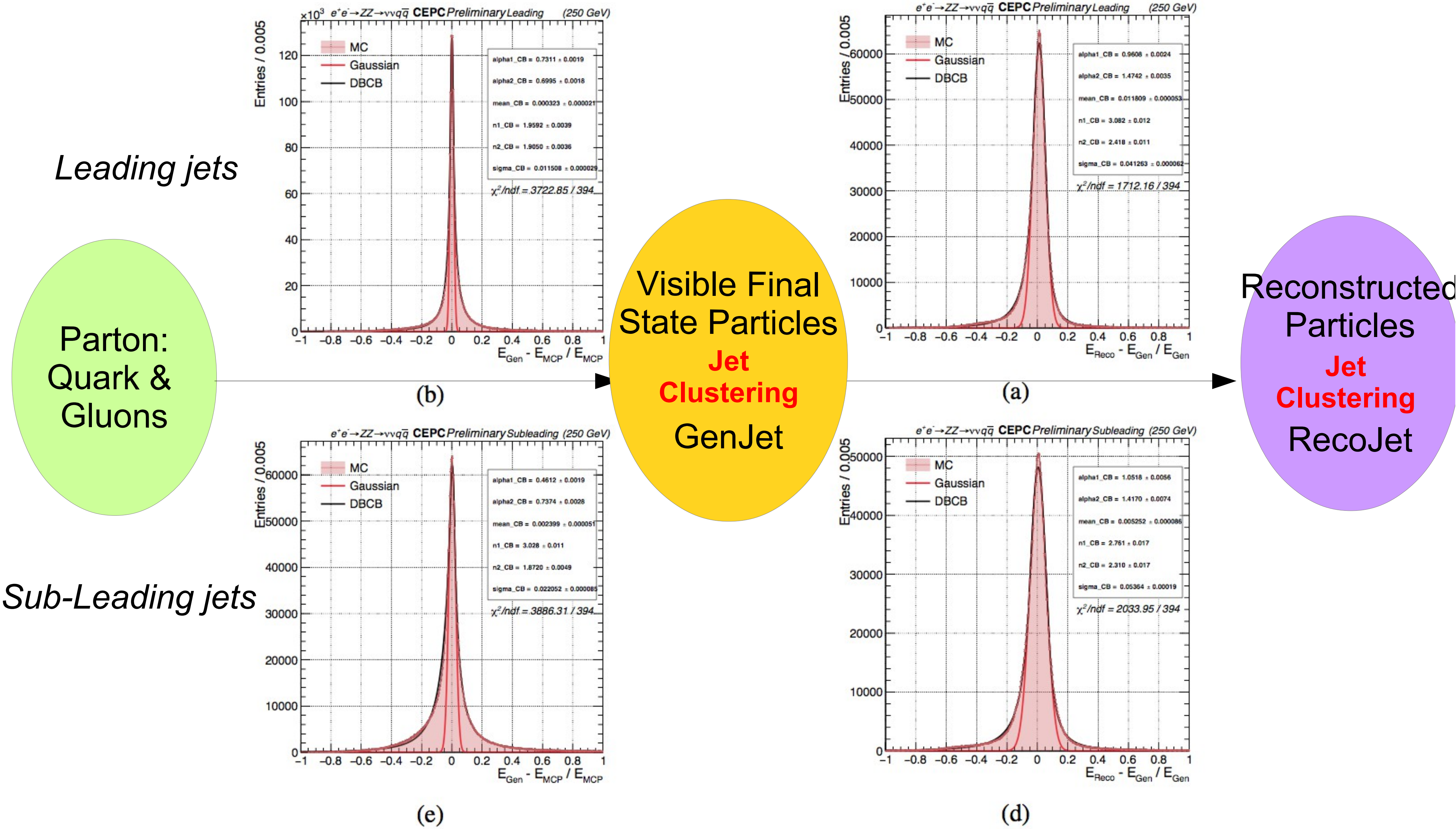
Massive Boson Separation





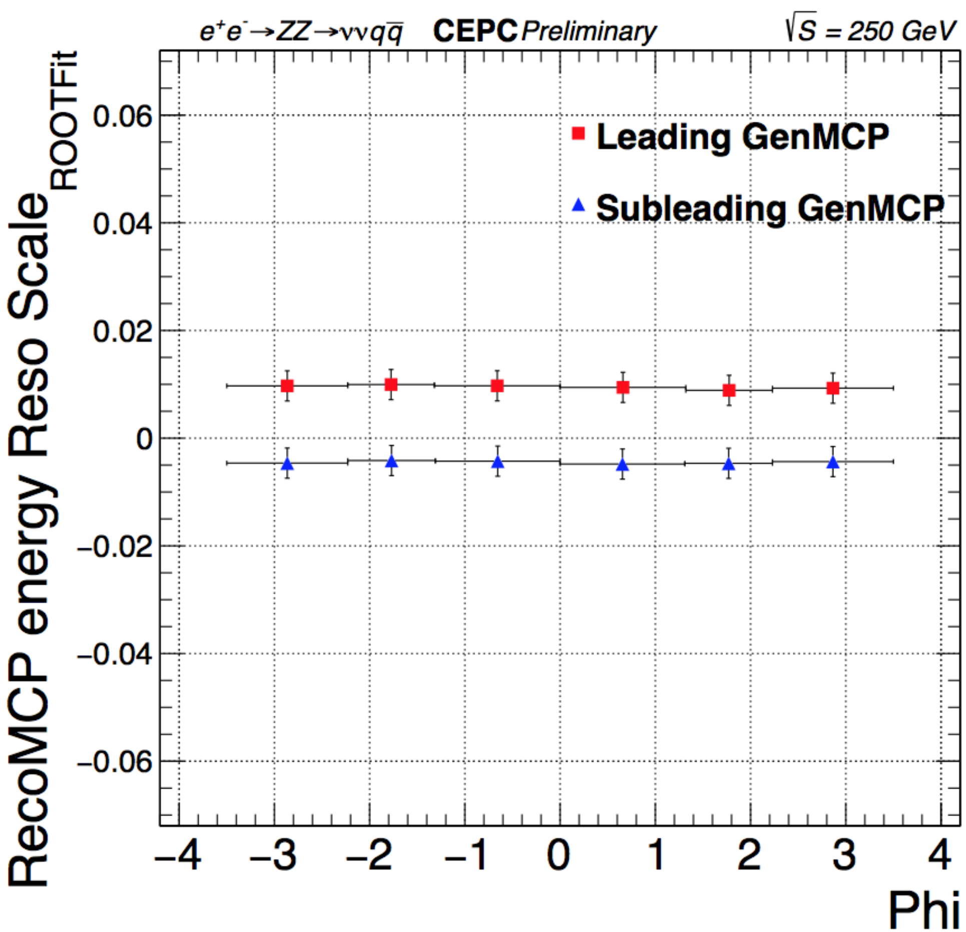
CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),
EPJC accepted

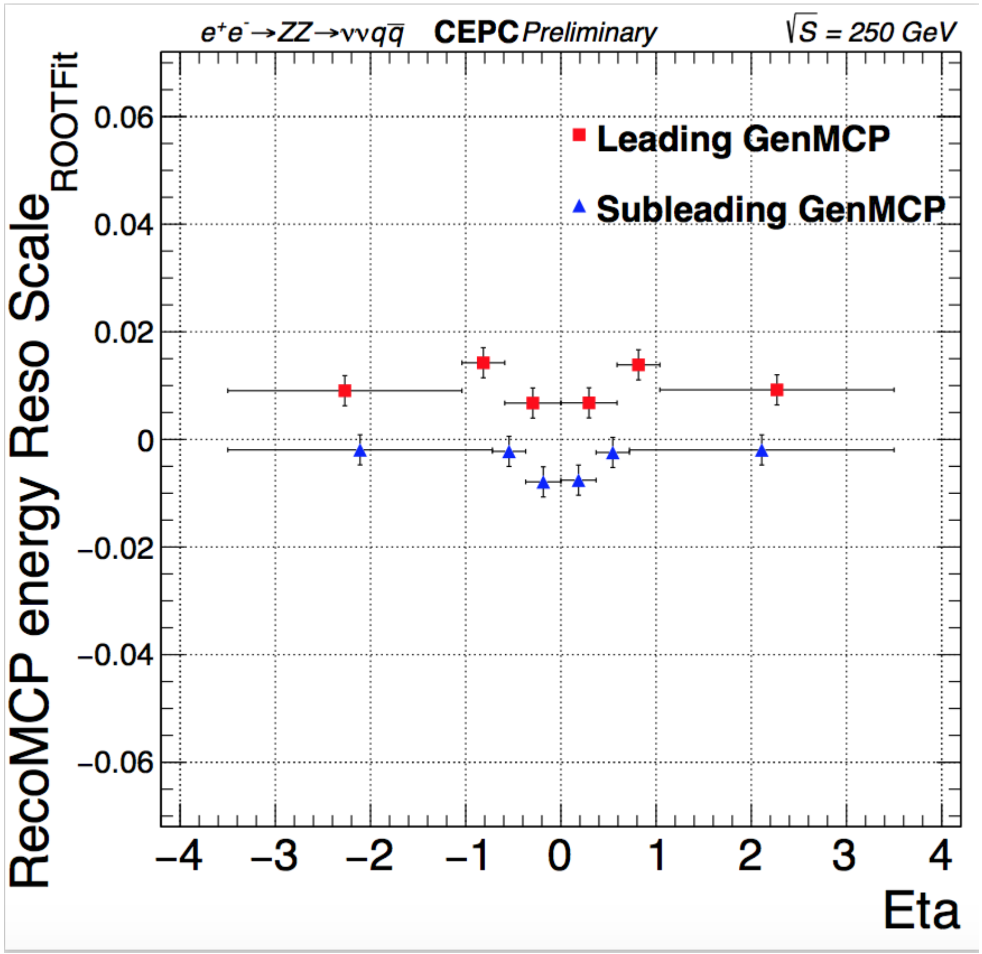
Impact of Jet Clustering: Significant



Jet Clustering is Mainly responsible for the tails

Jet energy Scale

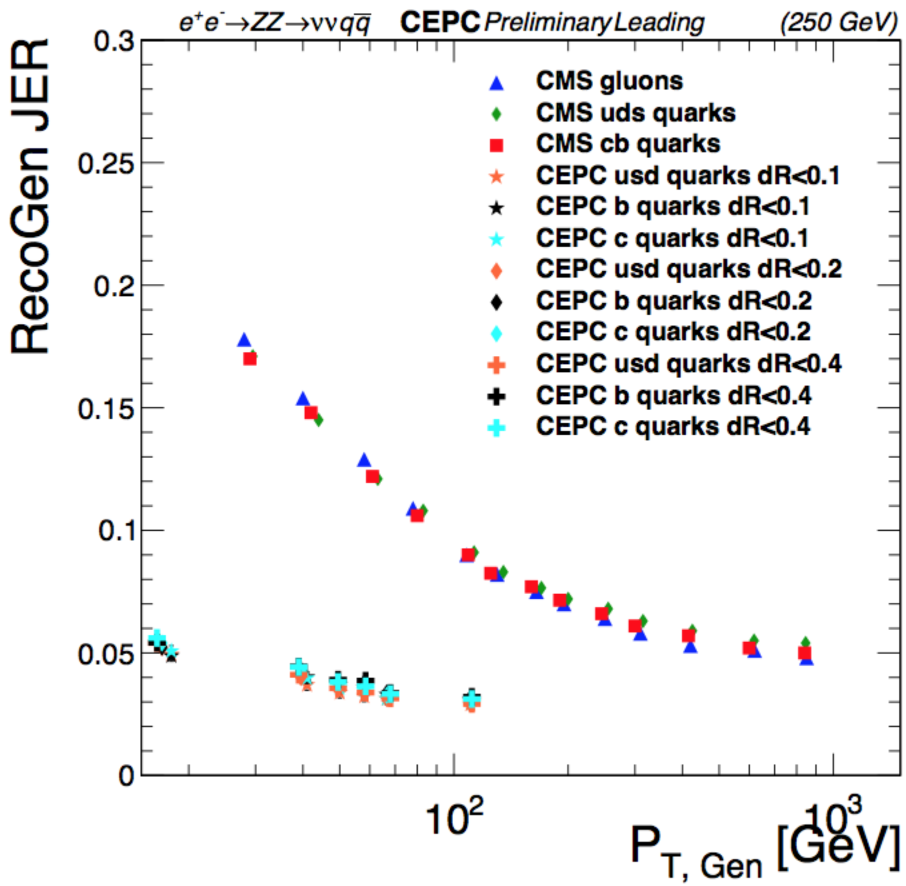


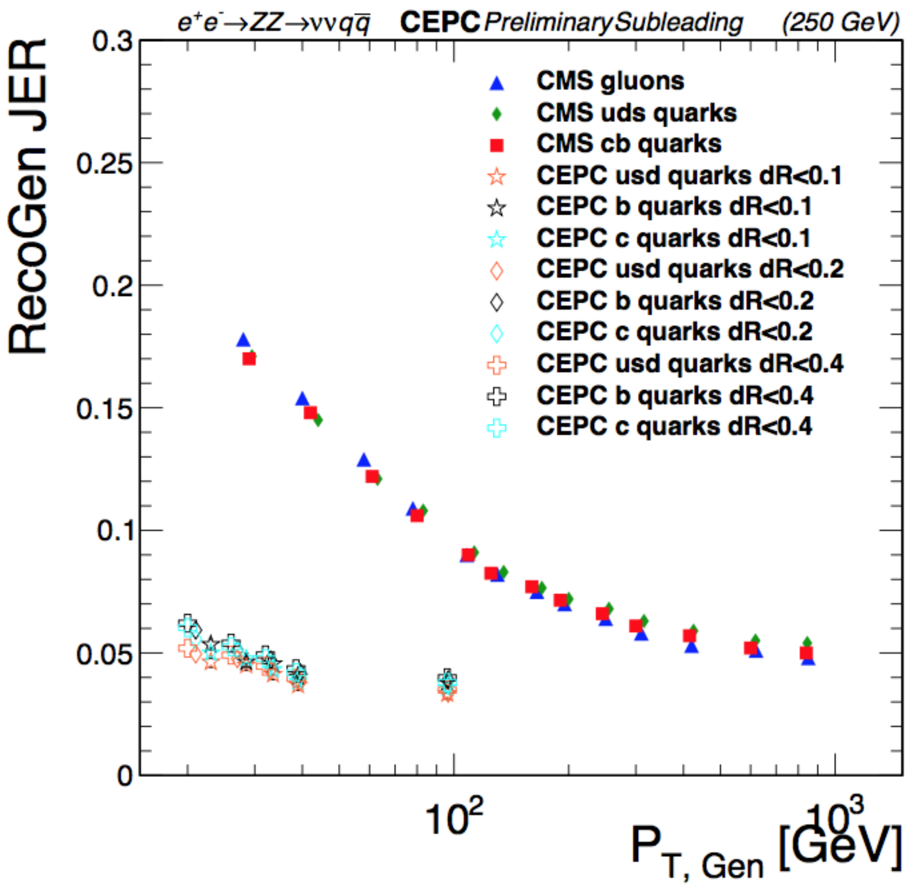


Amplitude ~ 1%

Large JES observed at Leading Jet (Correlated), and at overlap region (Increasing of Splitting)

Jet Energy Resolution



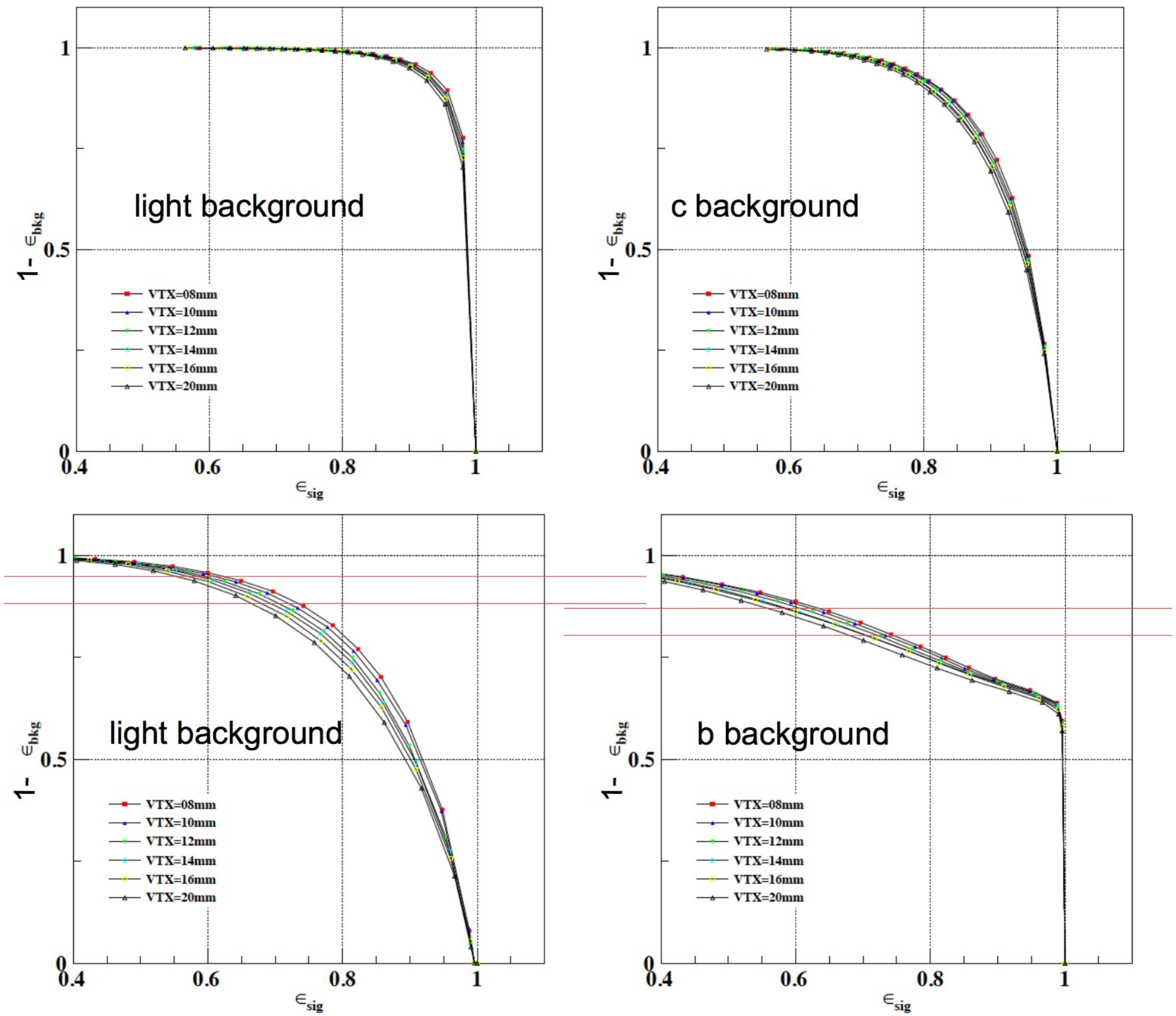


CMS Reference: CMS-JME-13-004,

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

Flavor Tagging

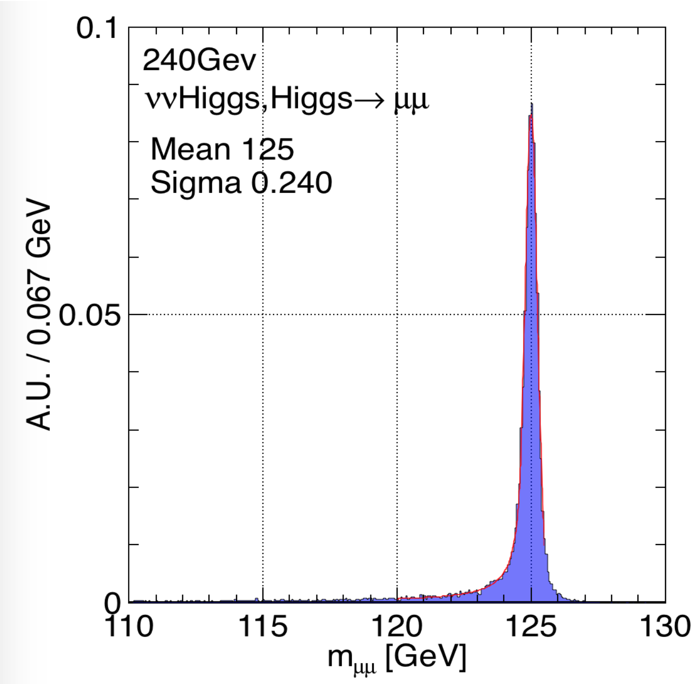
- LCFIPlus Package
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*
- Geometry Dependence of the Performance evaluated

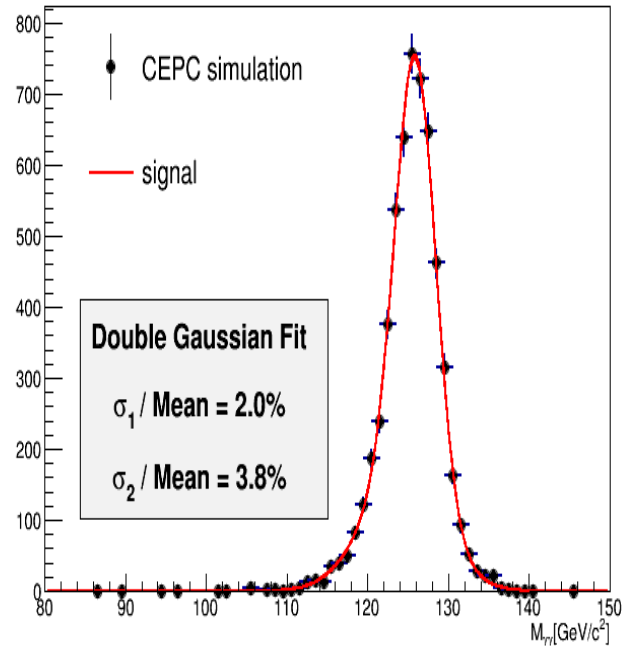


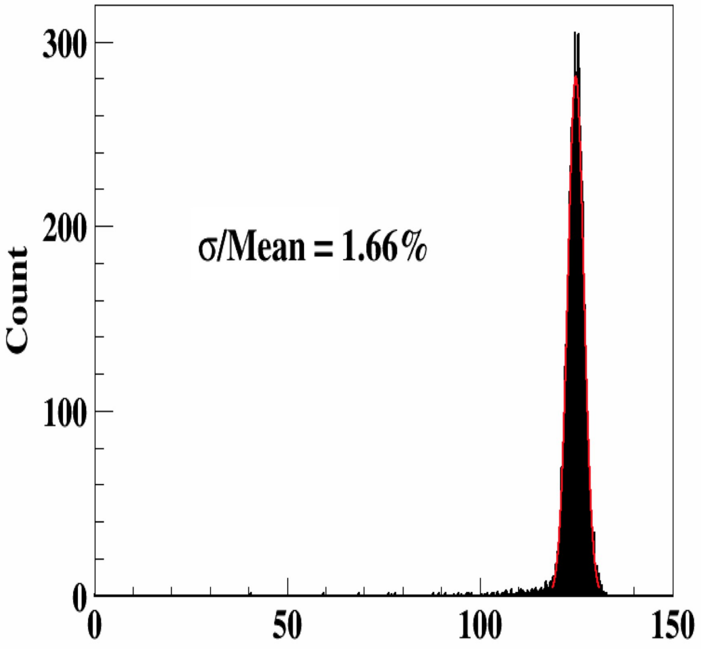
https://agenda.linearcollider.org/event/7645/contributions/40124/

Higgs Signal at APODIS

- Tracks & Photons





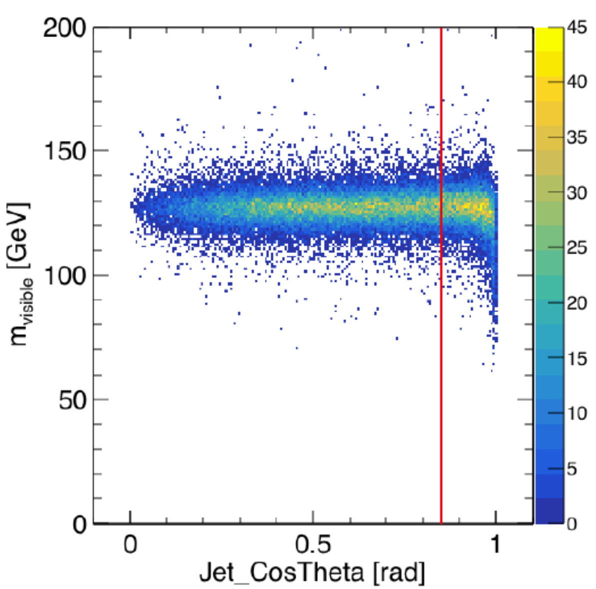


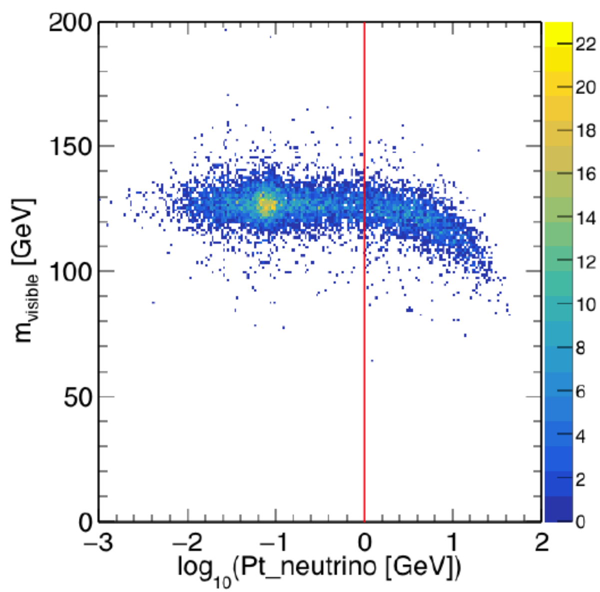
H->gammagamma at CEPC-v4/Simplifed geometry

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

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

H to gluons: total visible mass





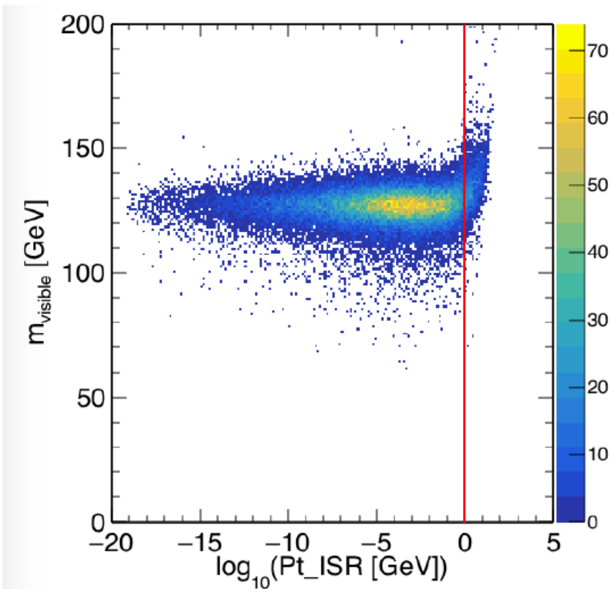
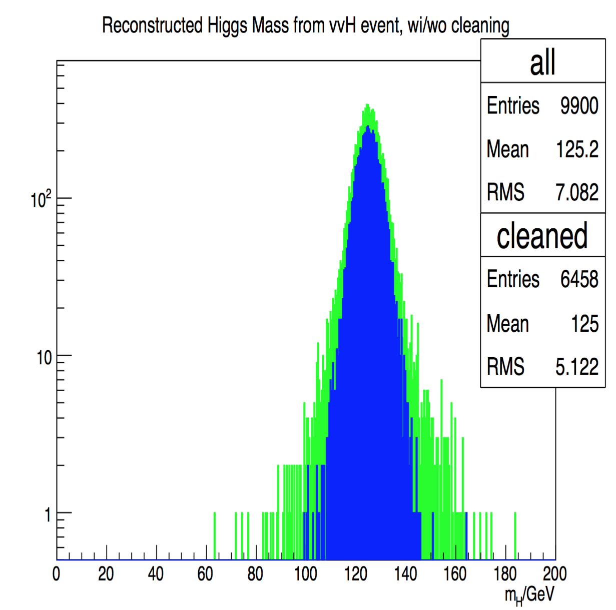
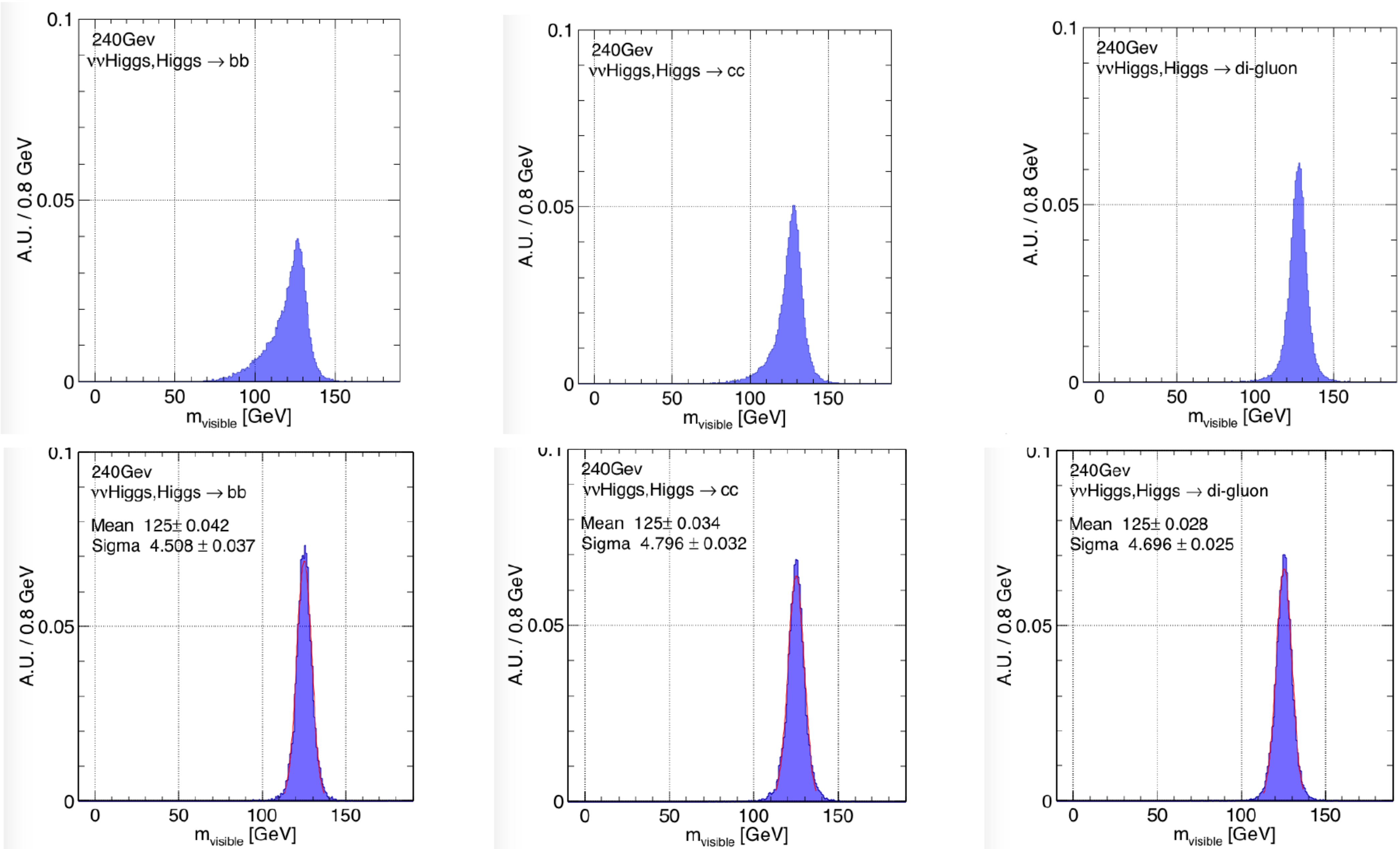


Table 1. Event selection efficiency for Higgs boson exclusive decay at CEPC with $\sqrt{s} = 240$ GeV.

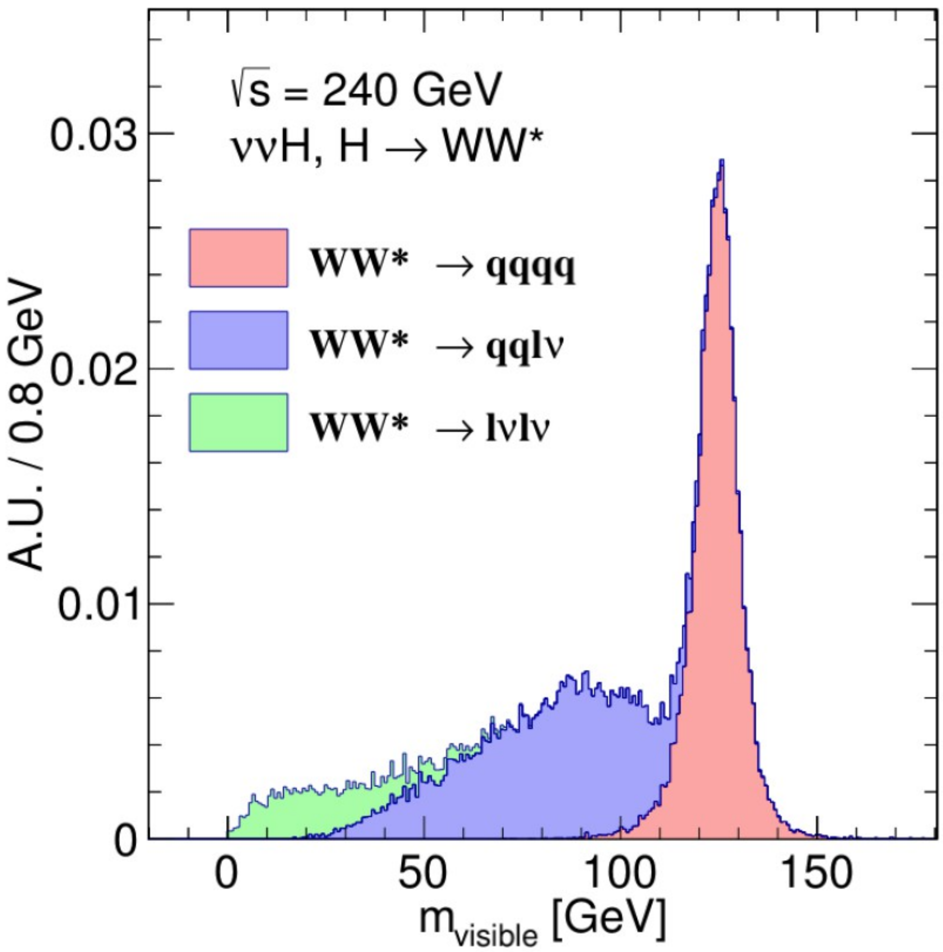
	$\mu\mu$	$\gamma\gamma$	di_gluon	bb	cc	WW^*	ZZ^*
Total	45000	48000	48000	45000	46000	47000.	45000
$Pt\_ISR < 1GeV$	-	95.52%	95.14%	95.37%	95.27%	95.19%	95.22%
$Pt\_neutrino < 1GeV$	-	-	89.35%	39.00%	66.30%	37.41%	41.42%
$\lvert costheta\rvert < 0.85$	-	-	67.27%	28.58%	49.23%	37.03%	40.91%

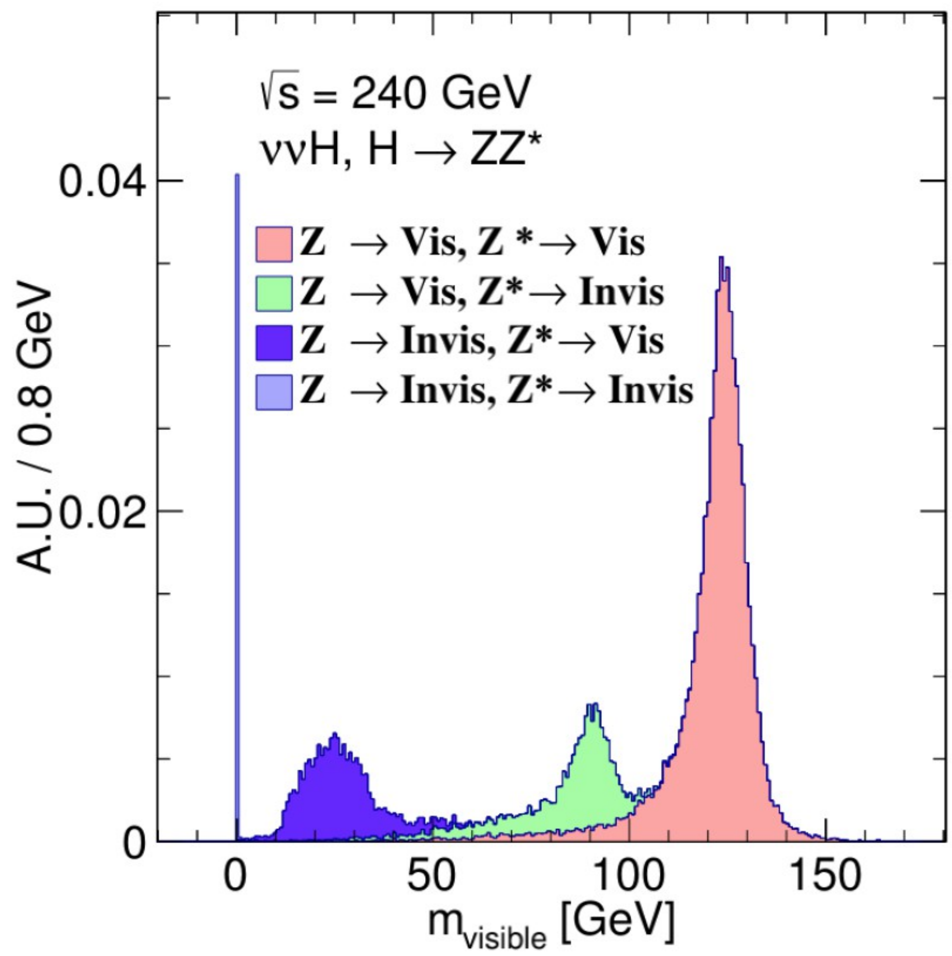


Higgs to bb, cc, gg

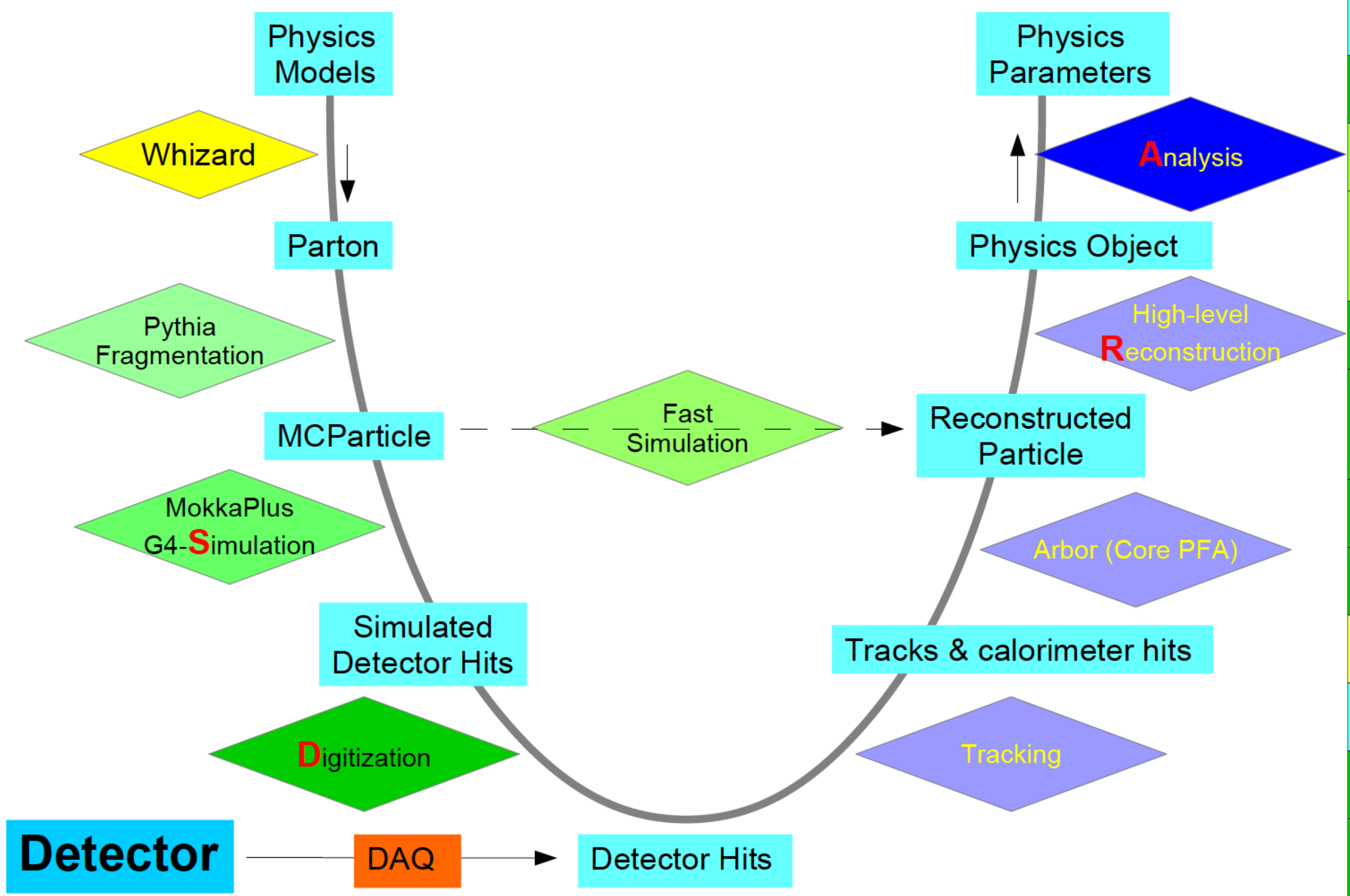


Higgs to WW, ZZ





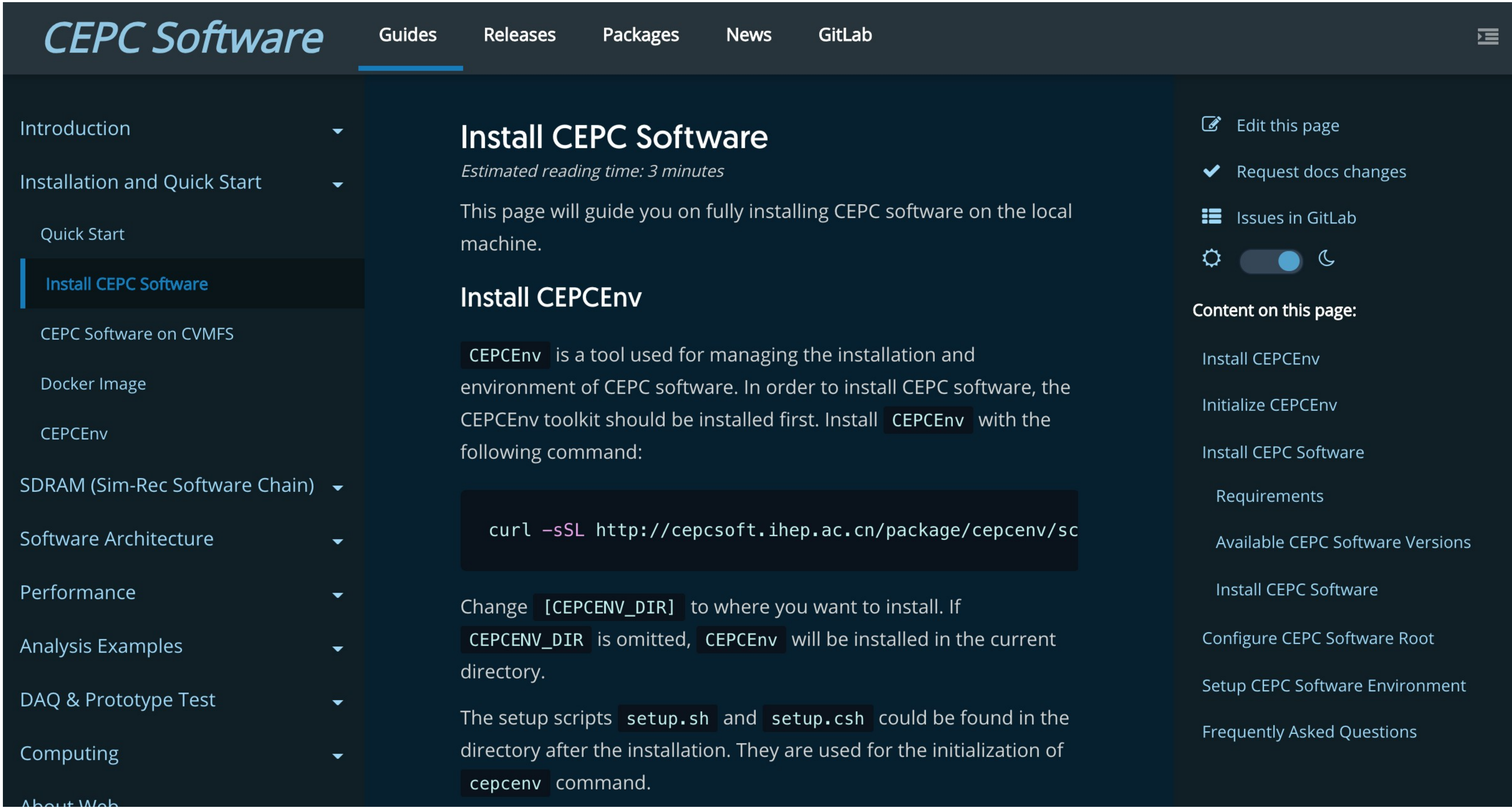
Software & Services



- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking (Arbor tracking, conformal tracking)
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder
- 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/



5 commands & you got the cepcsoft installed on an SL6 machine

http://cepcdoc.ihep.ac.cn

Search Results

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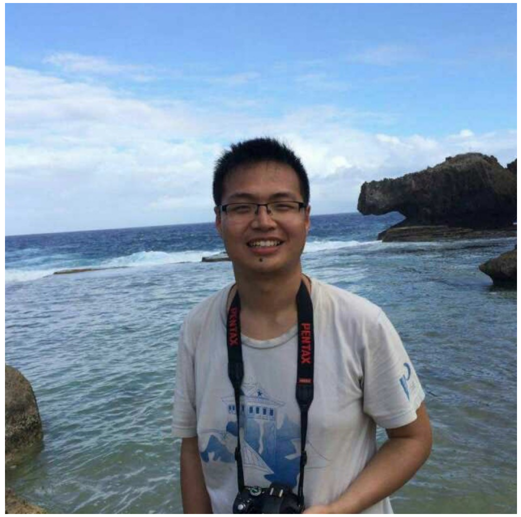
CEPC DocDB-doc-#	Title	Author(s)	Topic(s)	Last Updated
176-v1	Fast simulation of the CEPC detector with Delphes	Gang LI	Simulation: Full/Fast Simulation Software Journal Publications	17 May 2018
175-v2	Higgs Signal Reconstruction at CEPC-v4 Baseline Detector when CEPC Operate at 240GeV	YongFeng Zhu	Software Higgs Physics	13 May 2018
174-v1	Higgs Signal Reconstruction at CEPC-v4 Baseline Detector for the CEPC CDR	Hang Zhao	Simulation: Full/Fast Simulation Higgs Physics	10 Apr 2018
173-v1	Detector Geometry in Model CEPC IDEA	Yin Xu	Implementation into Full Simulation Software Framework General of CEPC	27 Mar 2018
172-v1	Performance study of particle identification at the CEPC using TPC dE/dx information	fenfen An	TPC Physics at CEPC	15 Mar 2018
171-v1	Reconstruction of physics objects at the Circular Electron Positron Collider with Arbor	Manqi RUAN	Physics at CEPC General	06 Mar 2018
170-v1	Optimization for CEPC vertex	Zhigang Wu	VTX	10 Jan 2018
169-v1	PFA Oriented ECAL Optimization for the CEPC	Hang Zhao	Simulation: Full/Fast Simulation Calo	27 Dec 2017
166-v3	Jet Energy Deposition Studies with CEPC Electromagnetic Calorimeter, Hadronic Calorimeter and Muon Detector	Jifeng Hu *et al.*	Calo Muon Reconstruction Higgs Physics General of CEPC	14 Nov 2017
168-v1	Mannual of the CEPC software	Gang LI	Software	02 Nov 2017
167-v1	Full Simulation Software at CEPC	Chengdong Fu	Software	23 Oct 2017
165-v1	Physics Impact of the Solid Angle Coverage at CEPC	Peizhu Lai	Detector Design Physic Analysis	17 Oct 2017
164-v1	Jet Reconstruction at CEPC	Peizhu Lai	Detector Design Physic Analysis	17 Oct 2017

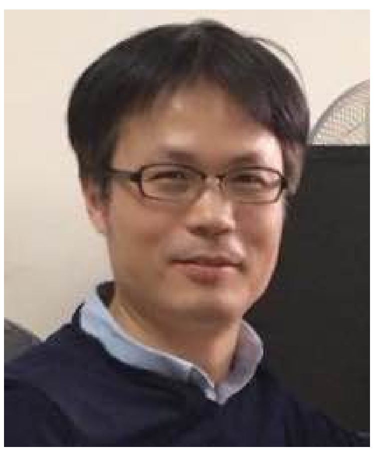
Yin Xu: Geometry



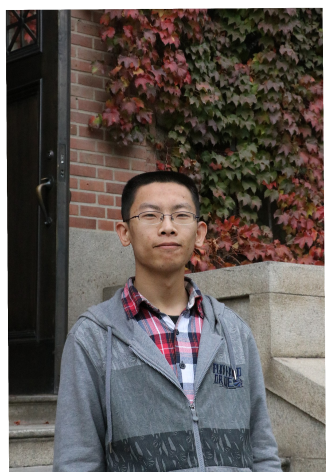
Xianghu Zhao:
Software & Computing

Dan Yu:
PFA, Lepton & Tau

Peizhu Lai:
Jet performance



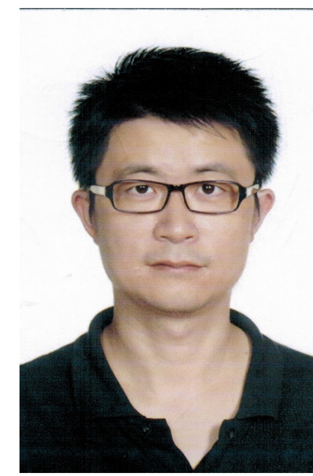
Chengdong Fu:
Tracking &
Geometry



Mingrui Zhao:
Tracking & Software

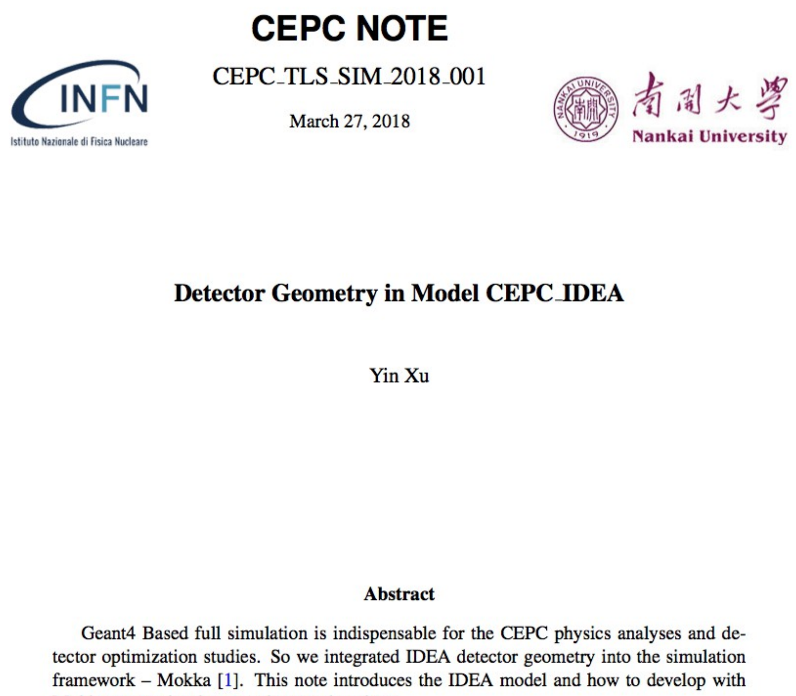
Gang:
Flavor Tagging
Generator
Logistic

Hang Zhao:
Calo-optimization
Performance analysis



Liang Li:
Lepton

IDEA Simulation & Validation


CEPC NOTE

CEPC_TLS_SIM_2018_001

March 27, 2018

Detector Geometry in Model CEPC_IDEA

Yin Xu

Abstract

Geant4 Based full simulation is indispensable for the CEPC physics analyses and detector optimization studies. So we integrated IDEA detector geometry into the simulation framework – Mokka [1]. This note introduces the IDEA model and how to develop with Mokka, some simple examples are also given.

Figure 4: SVX

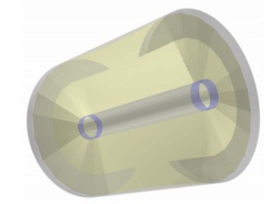
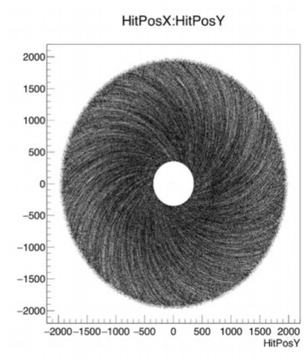
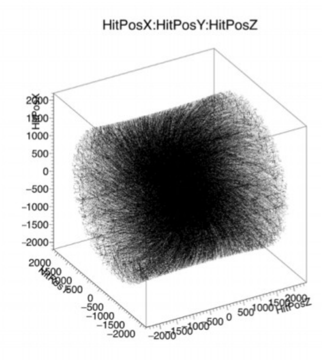
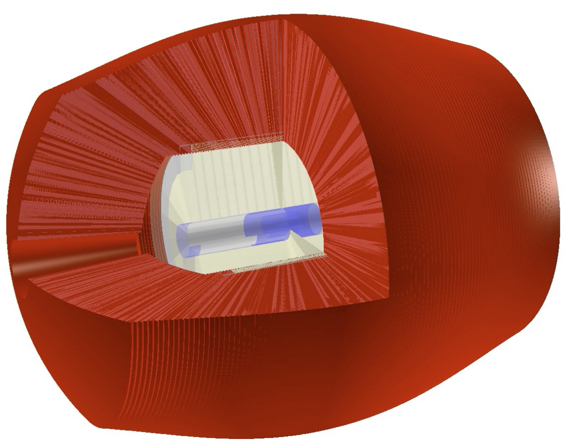
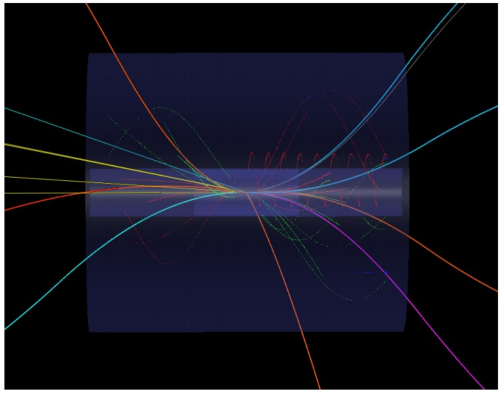


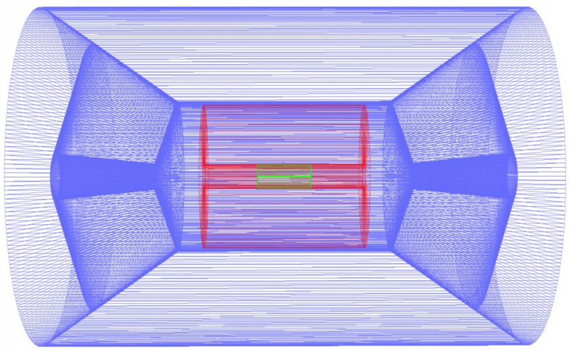
Figure 5: CDCH









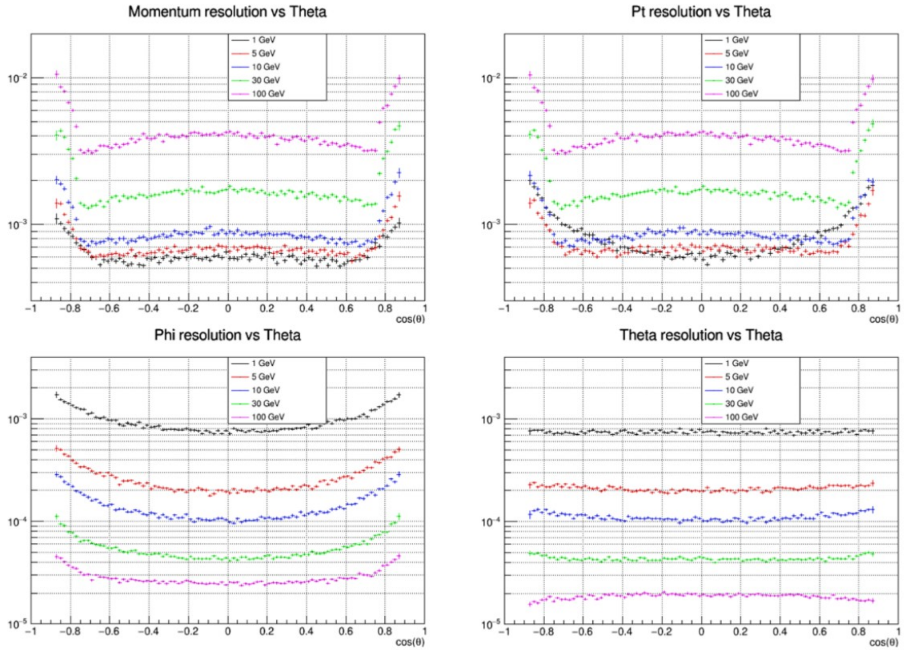


Summary

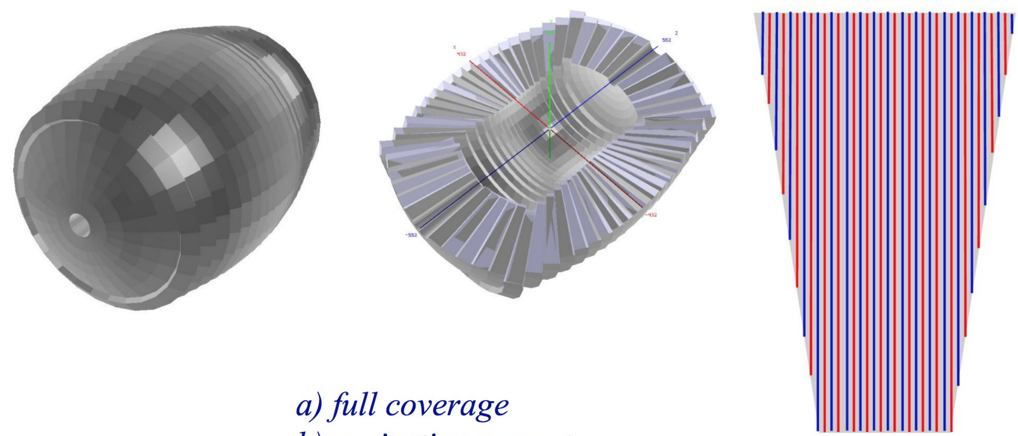
- The Particle Flow oriented detector is well established and serves as the baseline detector for the CEPC CDR studies
  - High efficiency/accuracy reconstruction of all key physics objects;
  - Clear Higgs signature in all SM Higgs decay mode
  - Mature software/reconstruction tool/team
- APODIS, Optimized for the CEPC collision environments
  - Significantly reduced B-Field (15%), #readout channels (75% in ECAL) & HCAL layer-thickness (20%) & cost (15%/30% w.r.t CEPC-v1/ILD)
  - Same Higgs performance & enhanced Pid Performance
- Todo:
  - Physics analysis, especially towards EW measurements
  - Towards the TDR:
    - Integration, Sub detector modeling
    - Systematic control studies

backup

Implemented into Simulation



Dual-readout calorimeter description for CepC/FCCee simulation sw:



a) full coverage
b) projective geometry

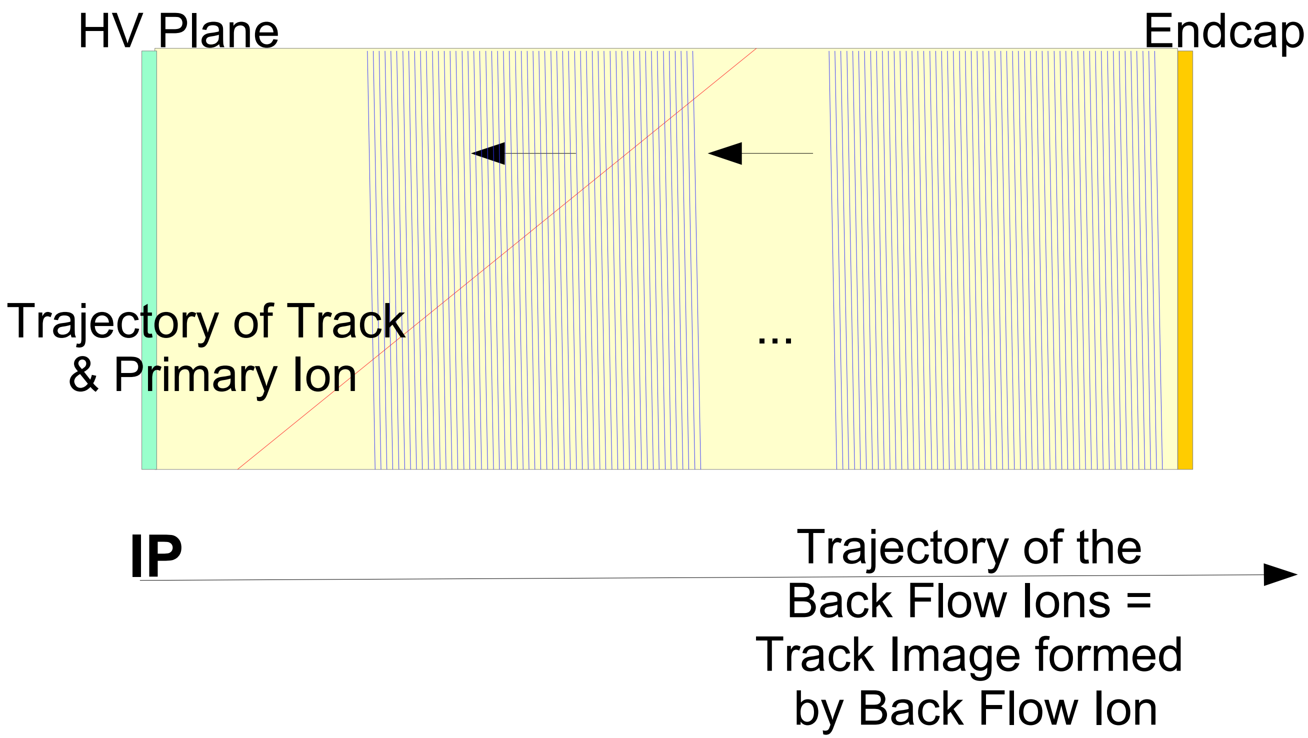
Both Wire Chamber & Dual readout Calorimeter have been implemented;

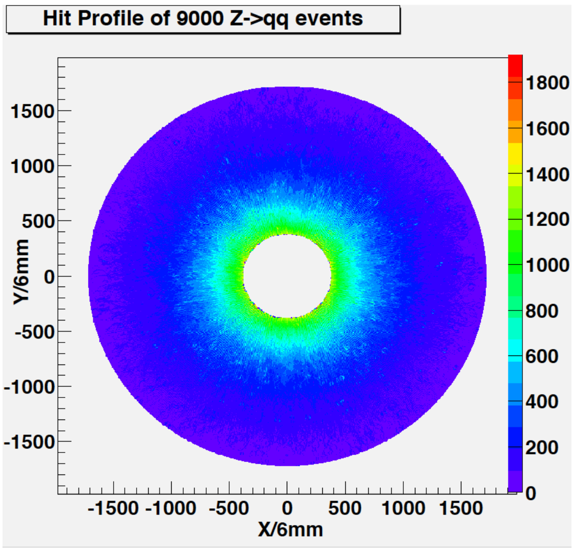
Need Validation, Digitization & Dedicated Analysis to Study the performance at jet and Physics event level

TPC Usage

- Feasibility not limited by
  - Voxel occupancy (1E-4 - 1E-6)
  - IBF & Ion Charge Distortion
- Dedx: TPC +50 ps ToF: a full range pi-kaon separation at Z pole operation
- Tech. Difficulties to be further studied
  - Complex, unstable field maps
  - Stability & Homogeneity of Amplification/DAQ system, temperature/pressure monitoring & corrections
  - Radiation background: Working Gas selection is essential
    - Neutron Flux + Working gas with hydrogens
    - Delta Ray Noise
    - Gamma Ray Noise
- Be iterated with Hardware/Electronic Design & Test beam studies

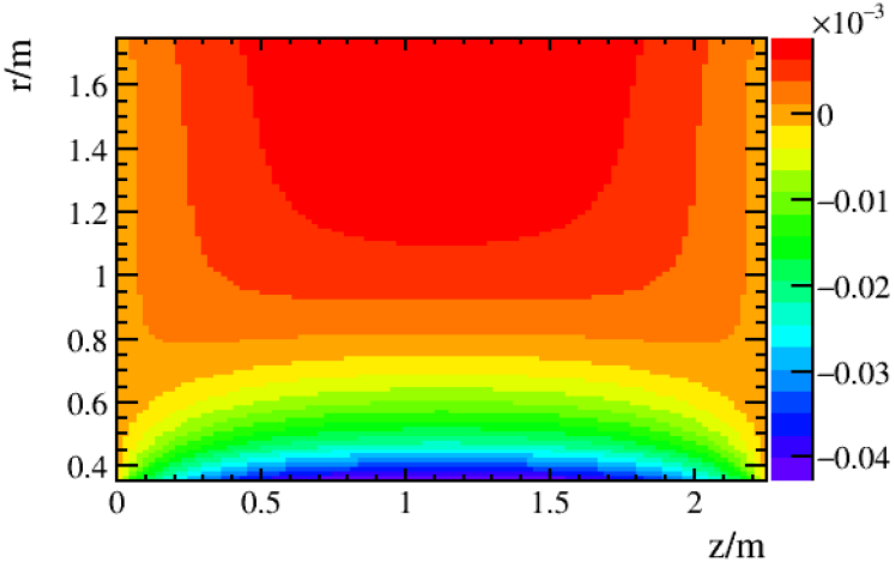
Feasibility of TPC at Z pole

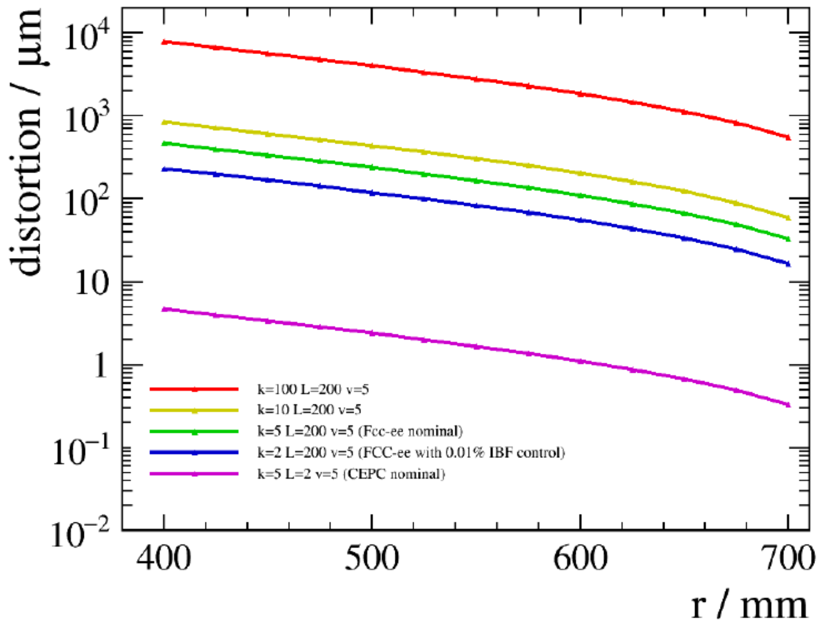




- 600 Ion Disks induced from Z->qq events at 2E34cm^{-2}s^{-1}
- Voxel occupancy & Charge distortion from **Ion Back Flow** (IBF)
- Cooperation with CEA & LCTPC

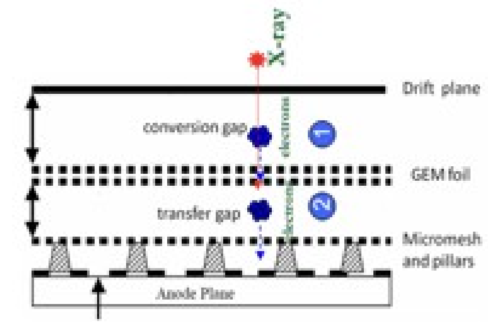
TPC Feasibility

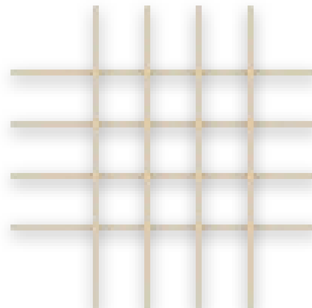


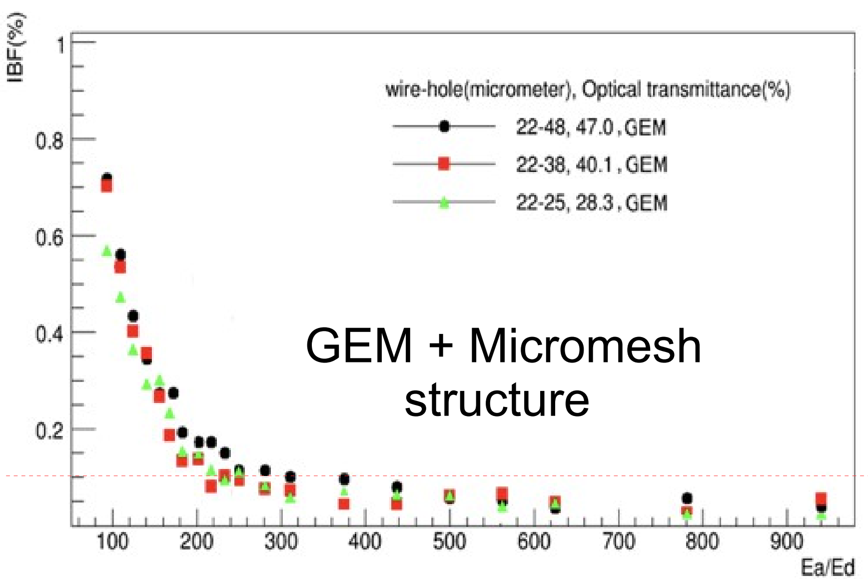


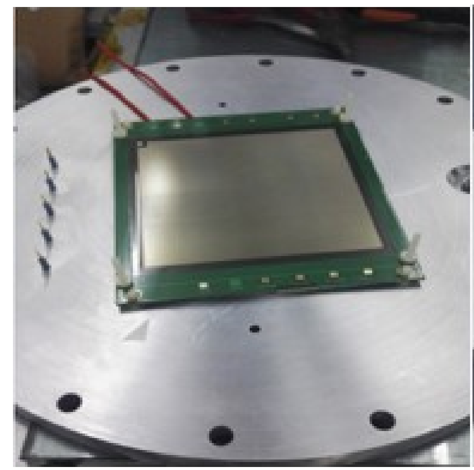
- Conclusion (JINST_12_P07005, CEPC-DocDB-id-147):
  - Voxel occupancy ~ (10^-4 – 10^-6) level, safe
  - **Safe for CEPC If the ion back flow be controlled to per mille level** (k = 5) -
    - The charge distortion at ILD TPC would be one order of magnitude then the intrinsic resolution (L = 2E34 $cm^{-2}s^{-1}$)
    - TPC usage is not limited by the Physics Hits;
    - Beam background needs further investigation (a priori not the dominant source at Z pole)

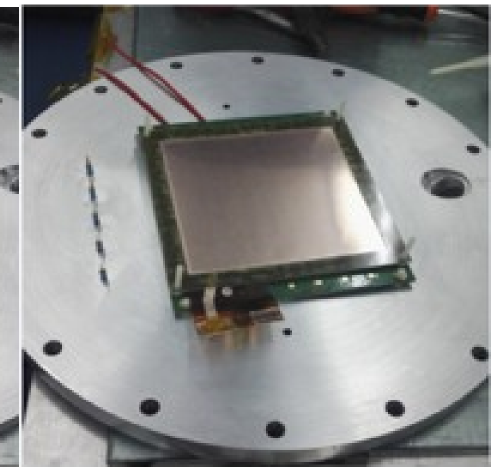
R&D on the IBF control





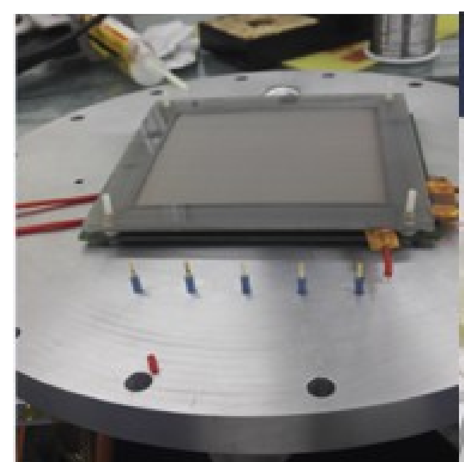


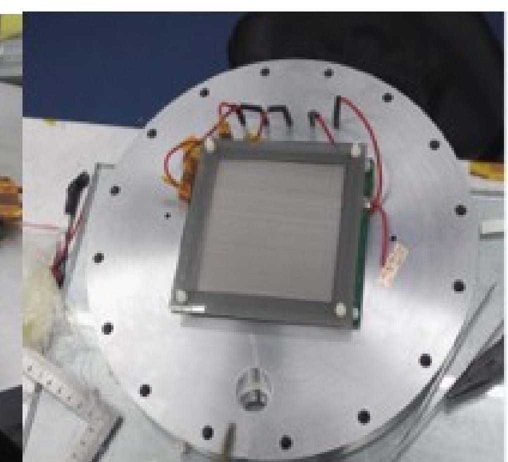




Micromegas(Saclay)

GEM(CERN)



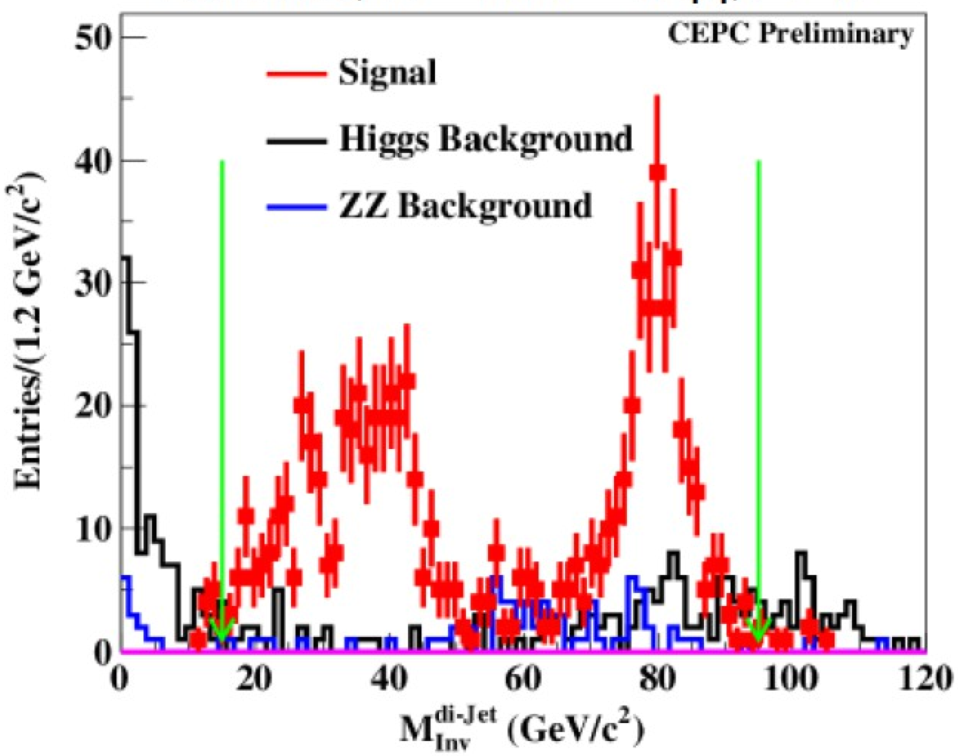


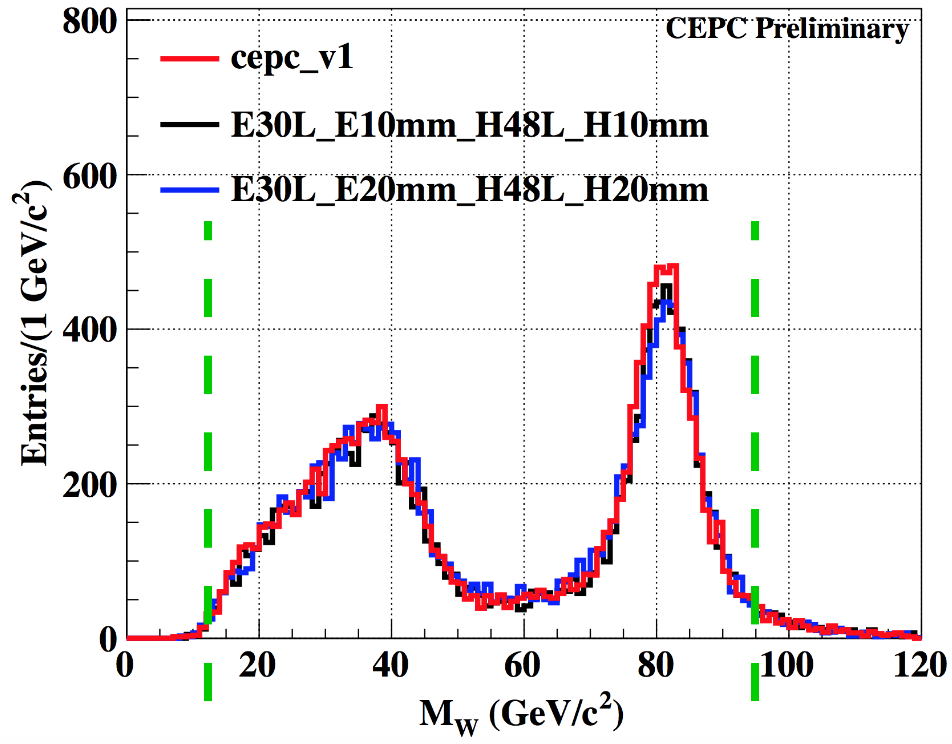
Cathode with mesh

GEM-MM Detector

Br(H→WW) @ 10mm/20mm Cell size

Liao libo, H→WW*→lνqq, Z→ll



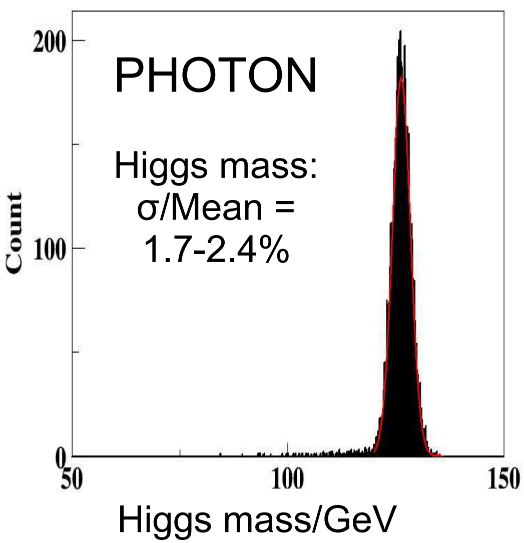


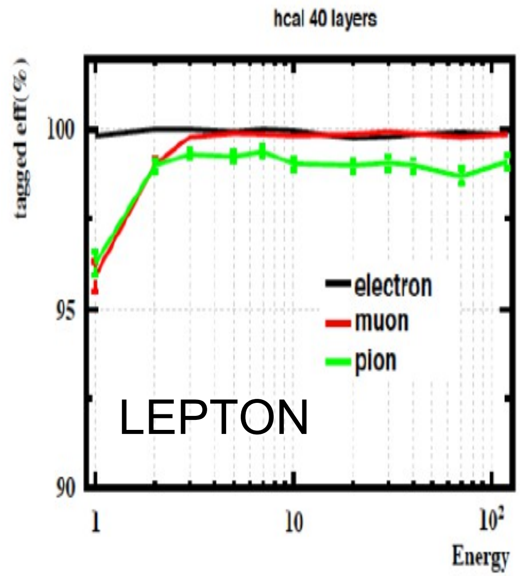
Br(H→WW) via ννH, H→WW*→lνqq

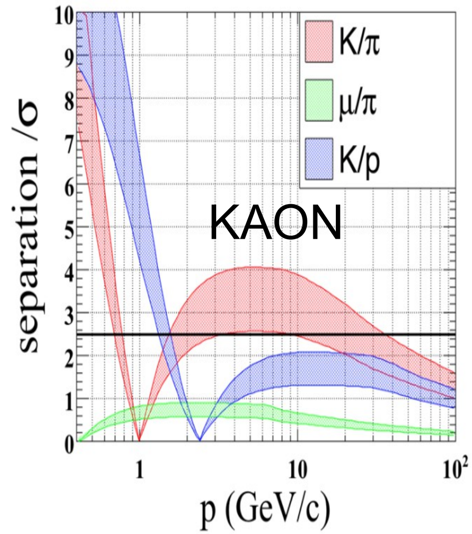
No lose in the object level efficiency: JER degraded, ~ 5/10% at 10/20 mm

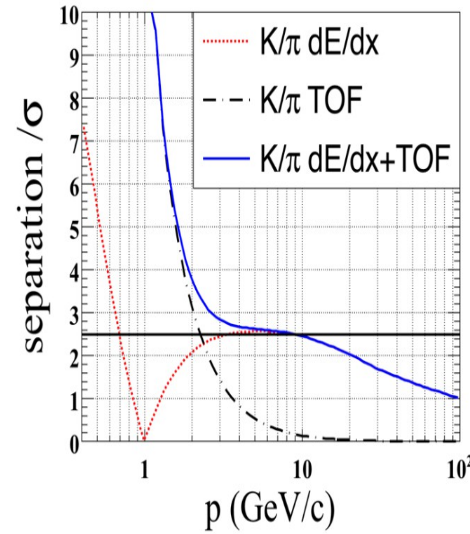
Over all: event reco. efficiency varies ~1%

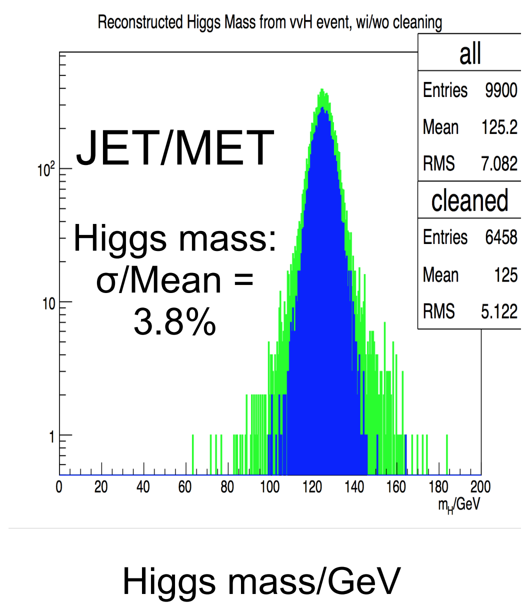
PFA Oriented Reconstruction

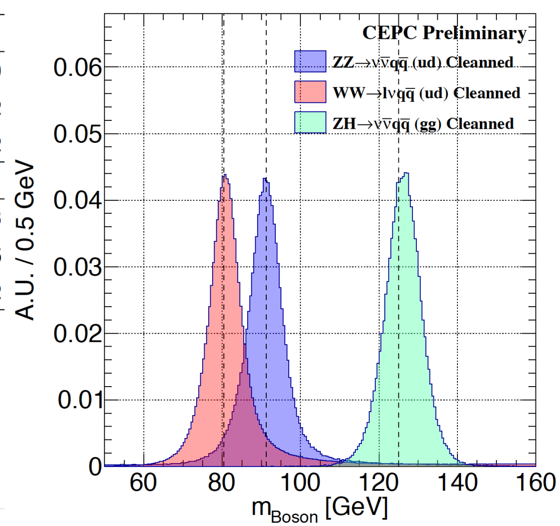


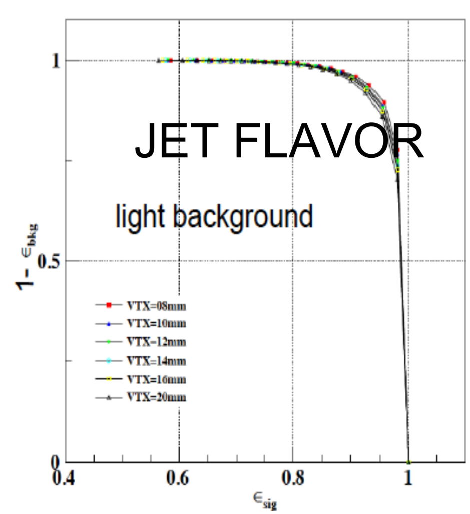


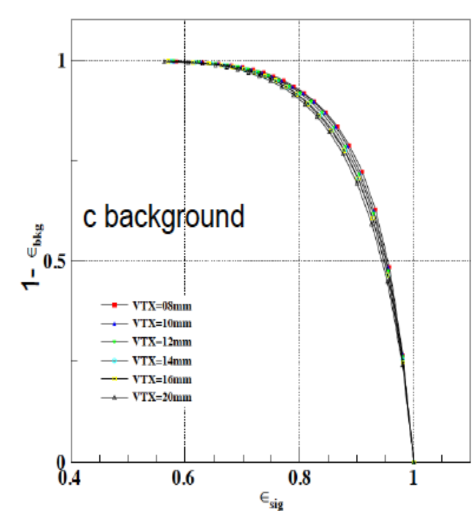










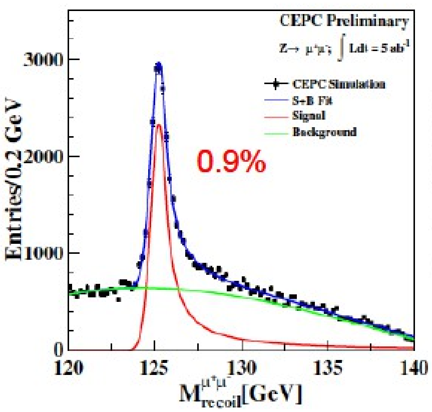


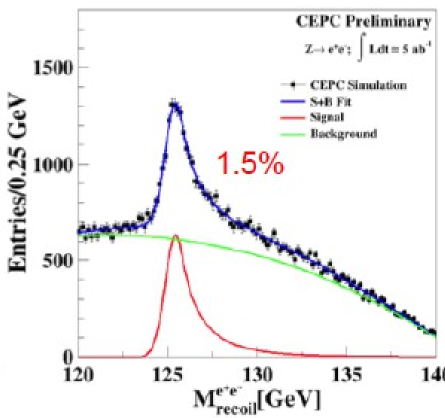
Example Working Points & Performance for Object identification (Preliminary)

	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%

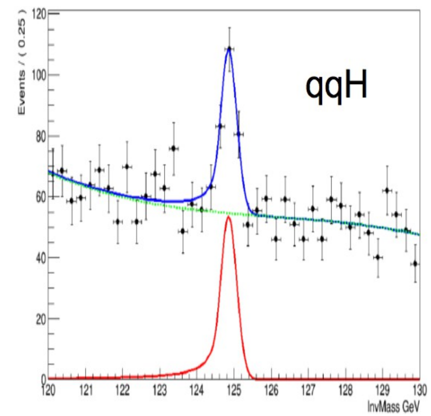
CEPC: absolute Higgs measurements

Zhenxing Chen & Yacine Haddad

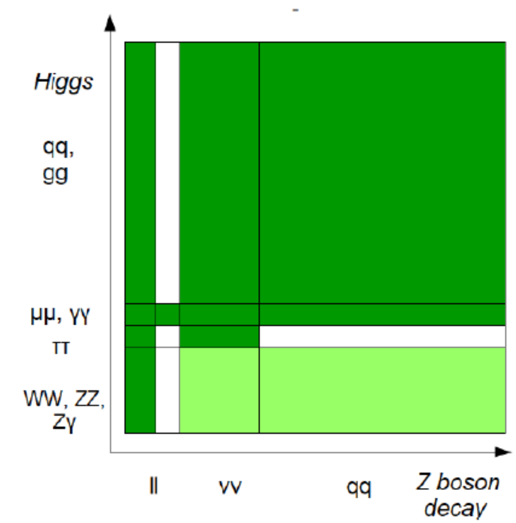




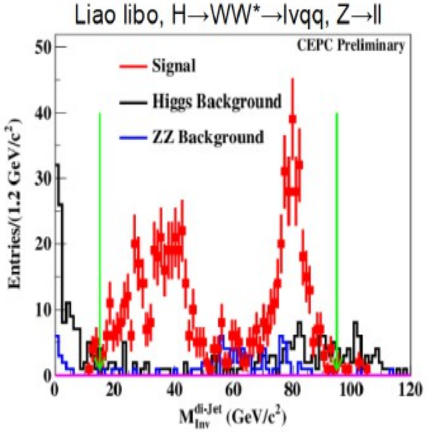
σ(ZH) measurements



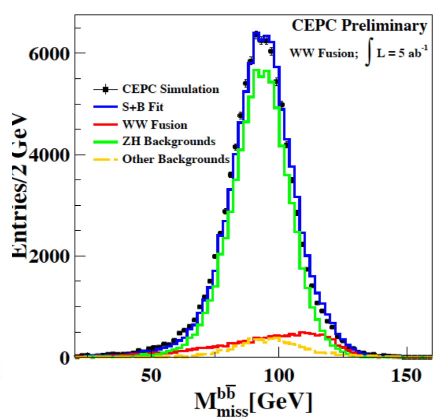
Br(H→μμ)



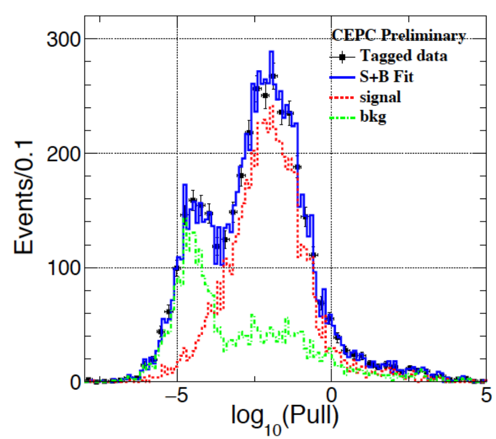
Liao libo, H→WW*→lνqq, Z→ll



Br(H→WW)



σ(ννH)*Br(H→bb)

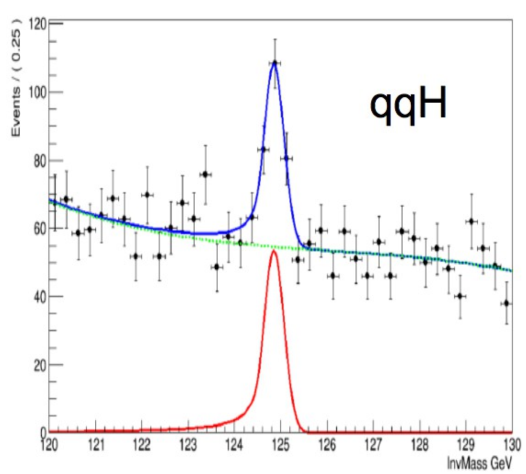


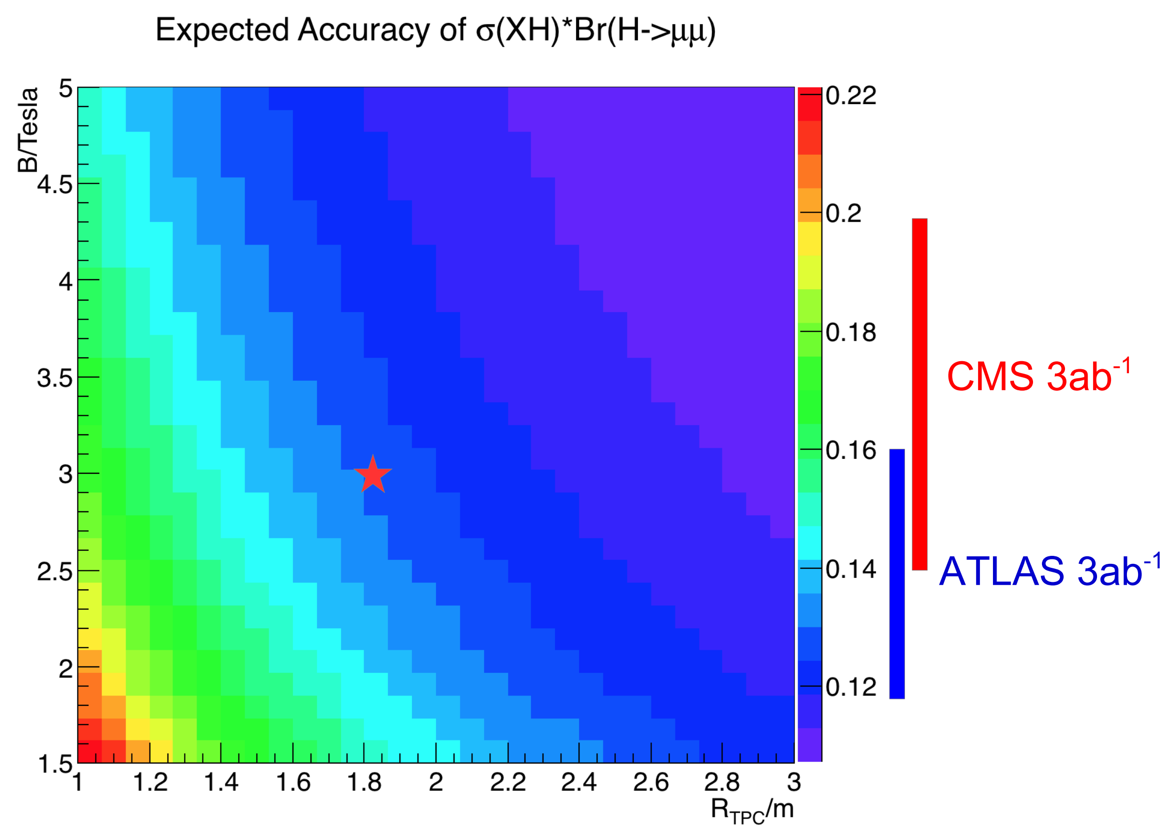
Br(H→ττ)

	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.2%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	12%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

Tracker Radius: the optimized value

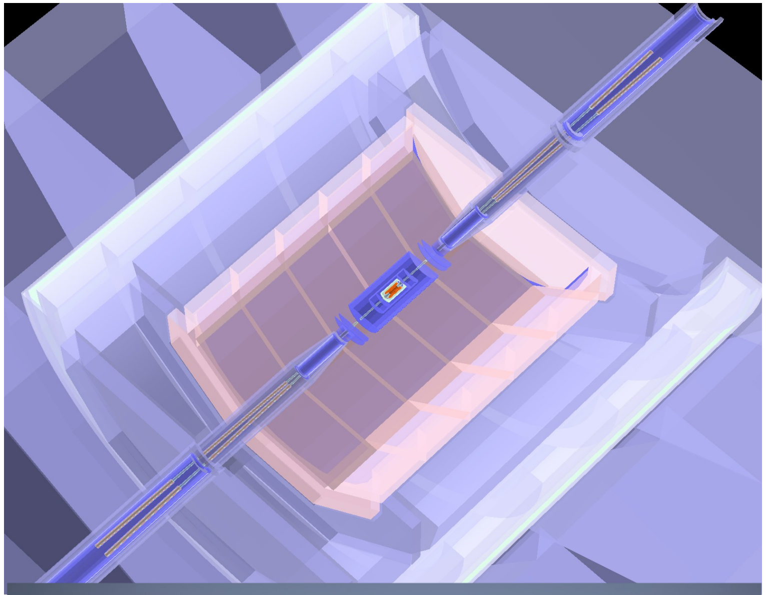
- Detector cost is sensitive to tracker radius, however, I recommend TPC radius >= 1.8m:
  - Better separation & JER
  - Better dEdx
  - **Better (H->di muon) measurement**

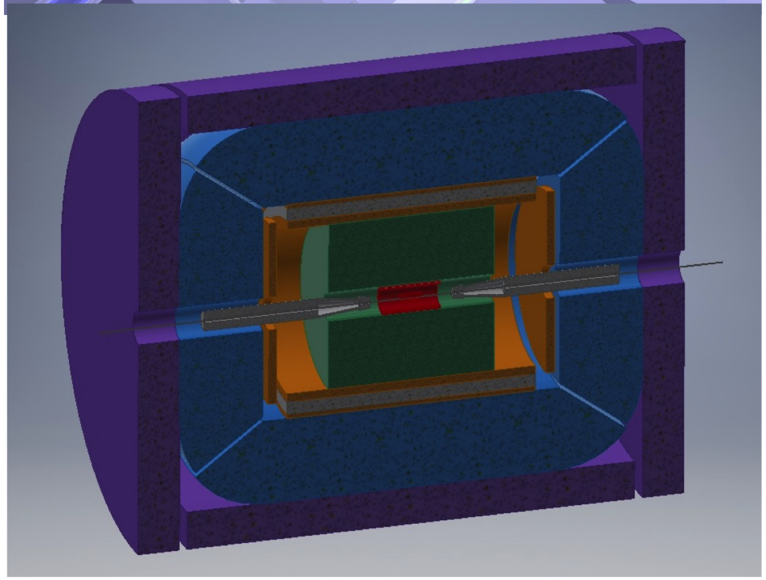


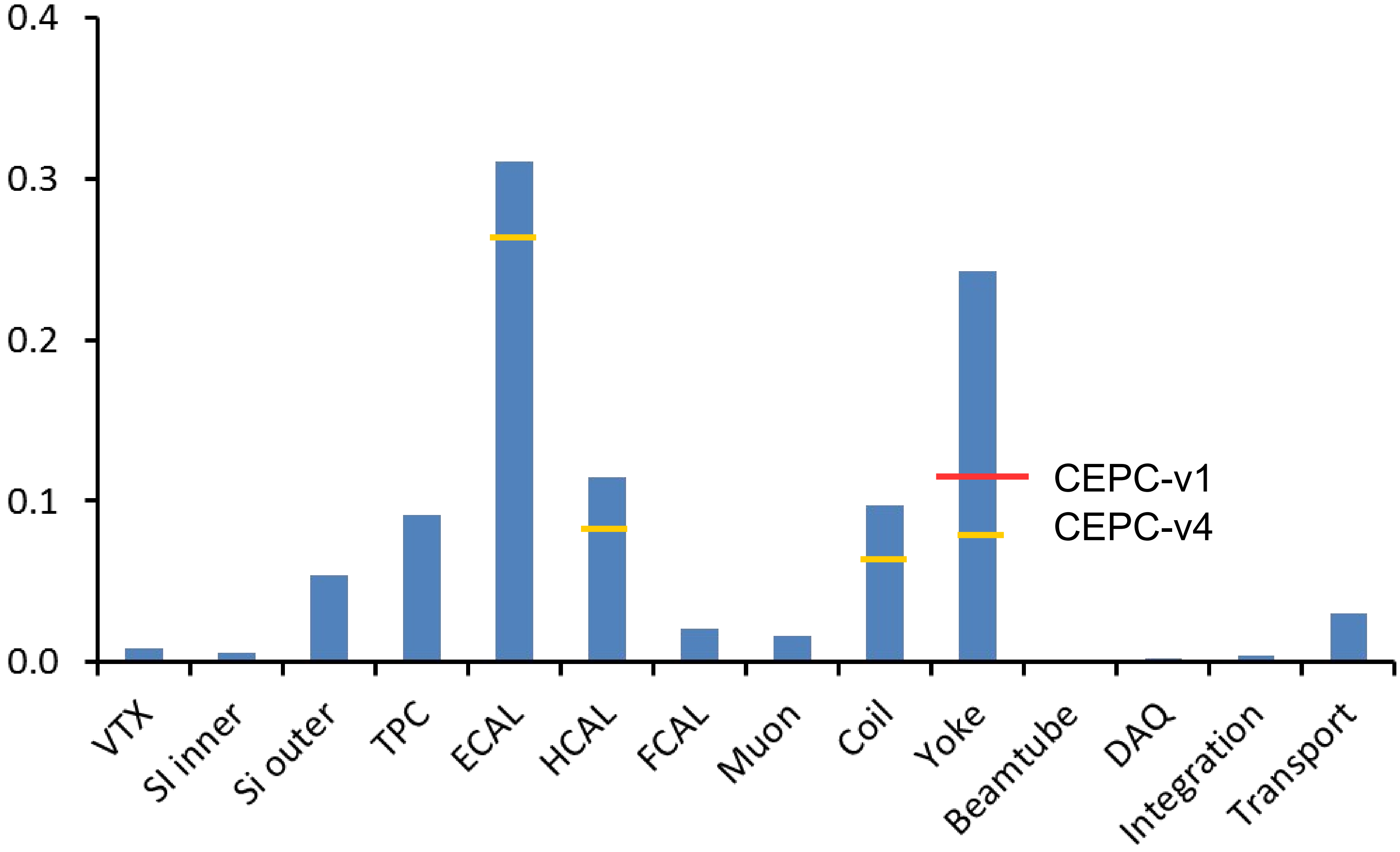


Detectors for the CDR

- APODIS (Baseline)
  - A PFA Oriented Detector for HIggS factory (Reference: ALEPH, SiD and **ILD**)
  - Low material tracker + ultrahigh granularity calorimeter (serve also as ToF) + large Solenoid
  - Dedicated MDI (Ongoing)
  - Fully implemented into Geant 4 simulation and full reconstruction
  - Optimized versus Physics Benchmarks
- IDEA (Alternative)
  - Wire Chamber + Dual Readout based: implementing into full simulation
- Multiple detectors & New ideas are welcome!







0.4
0.3
0.2
0.1
0.0
CEPC-v1
CEPC-v4
VTX
SI inner
Si outer
TPC
ECAL
HCAL
FCAL
Muon
Coil
Yoke
Beamtube
DAQ
Integration
Transport