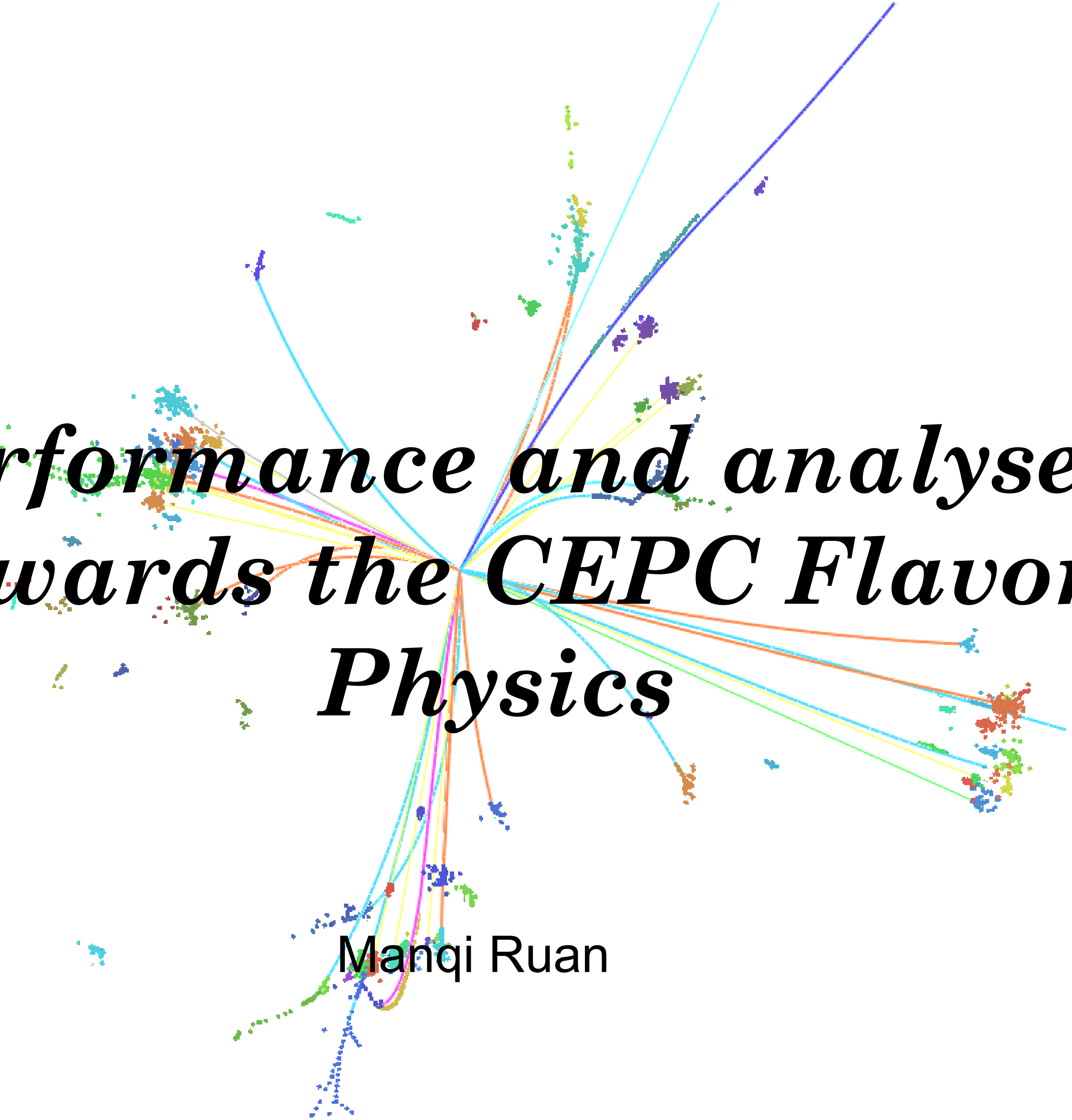
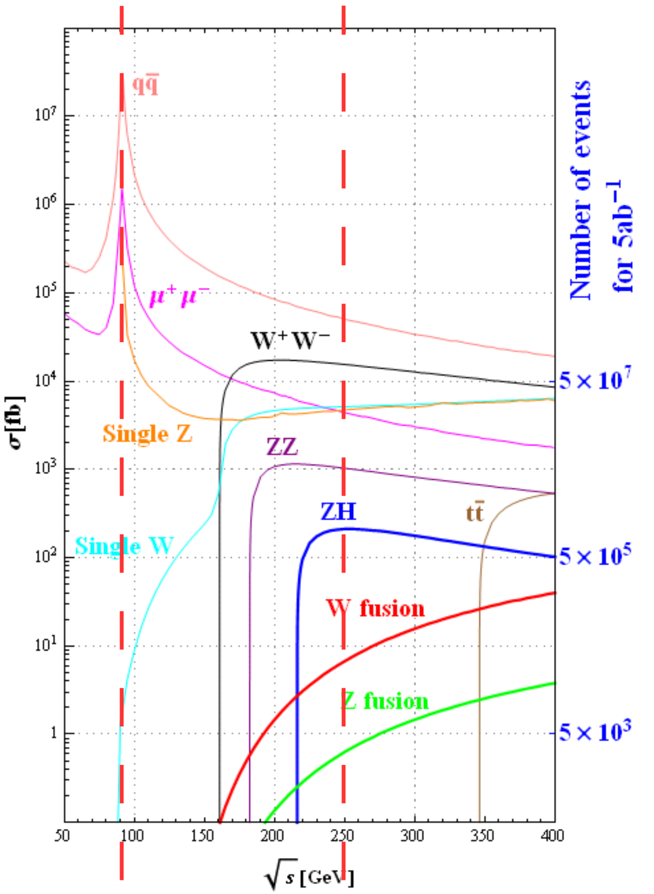
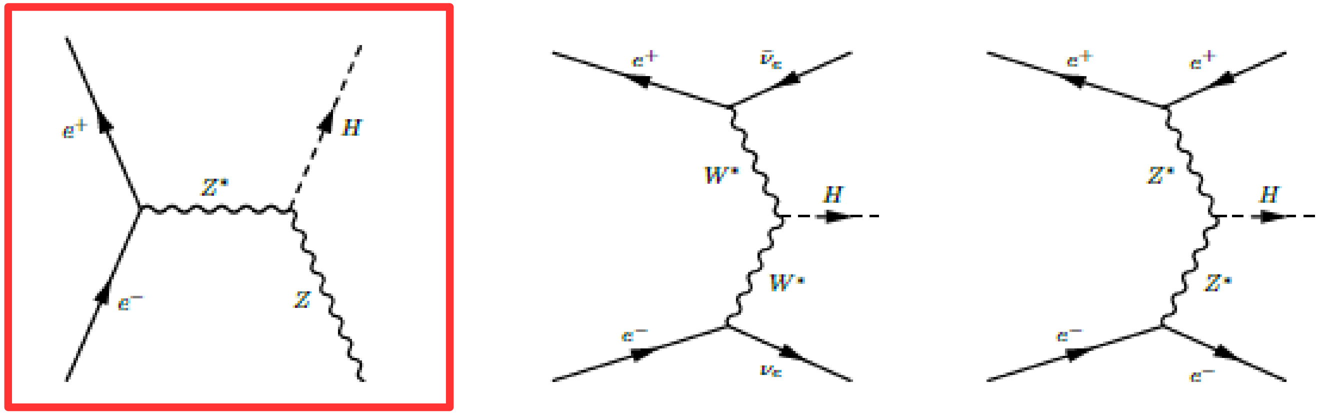
Performance and analyses towards the CEPC Flavor Physics



Manqi Ruan

Higgs @ CEPC





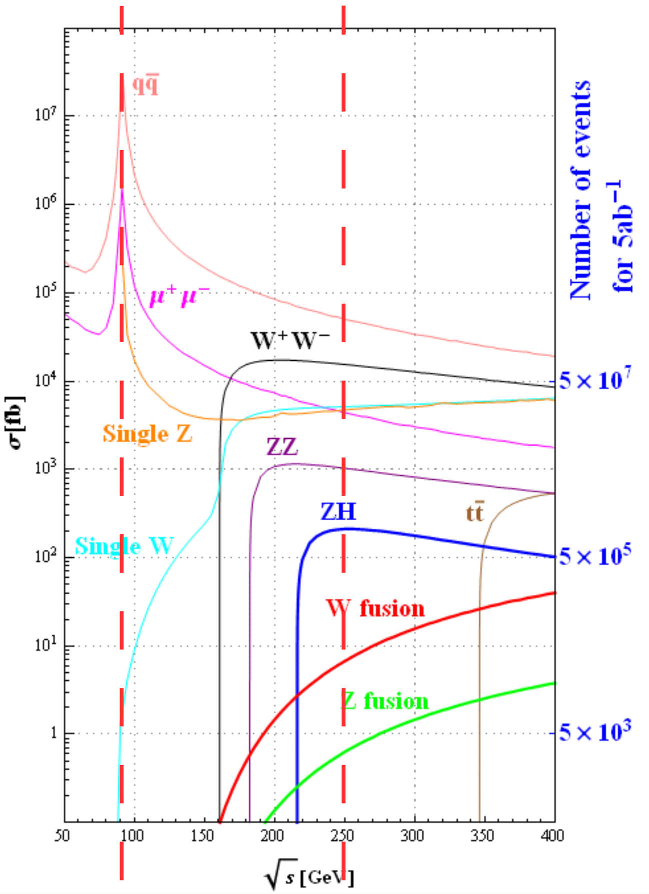
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

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

CEPC: a Higgs & Z factory

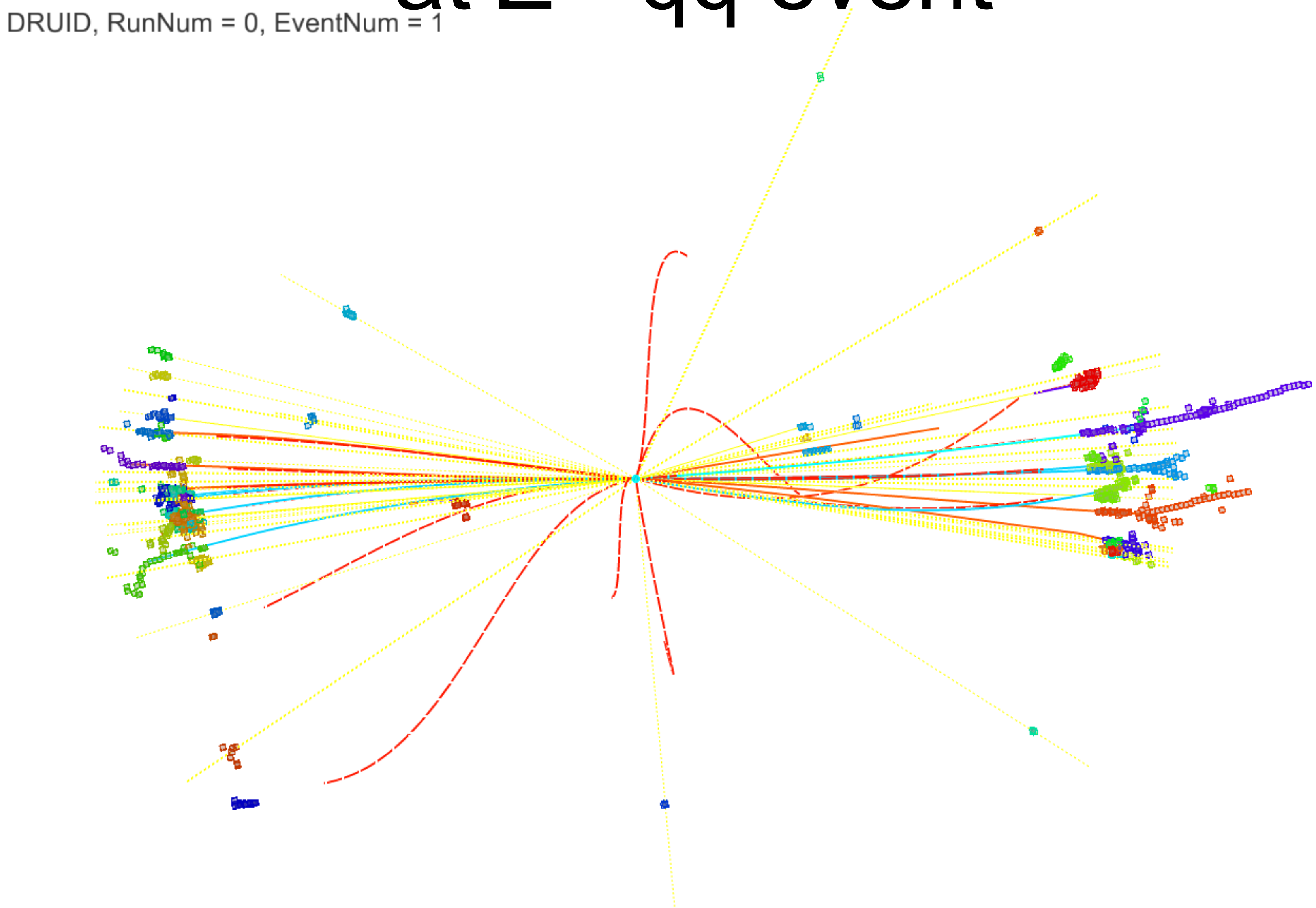


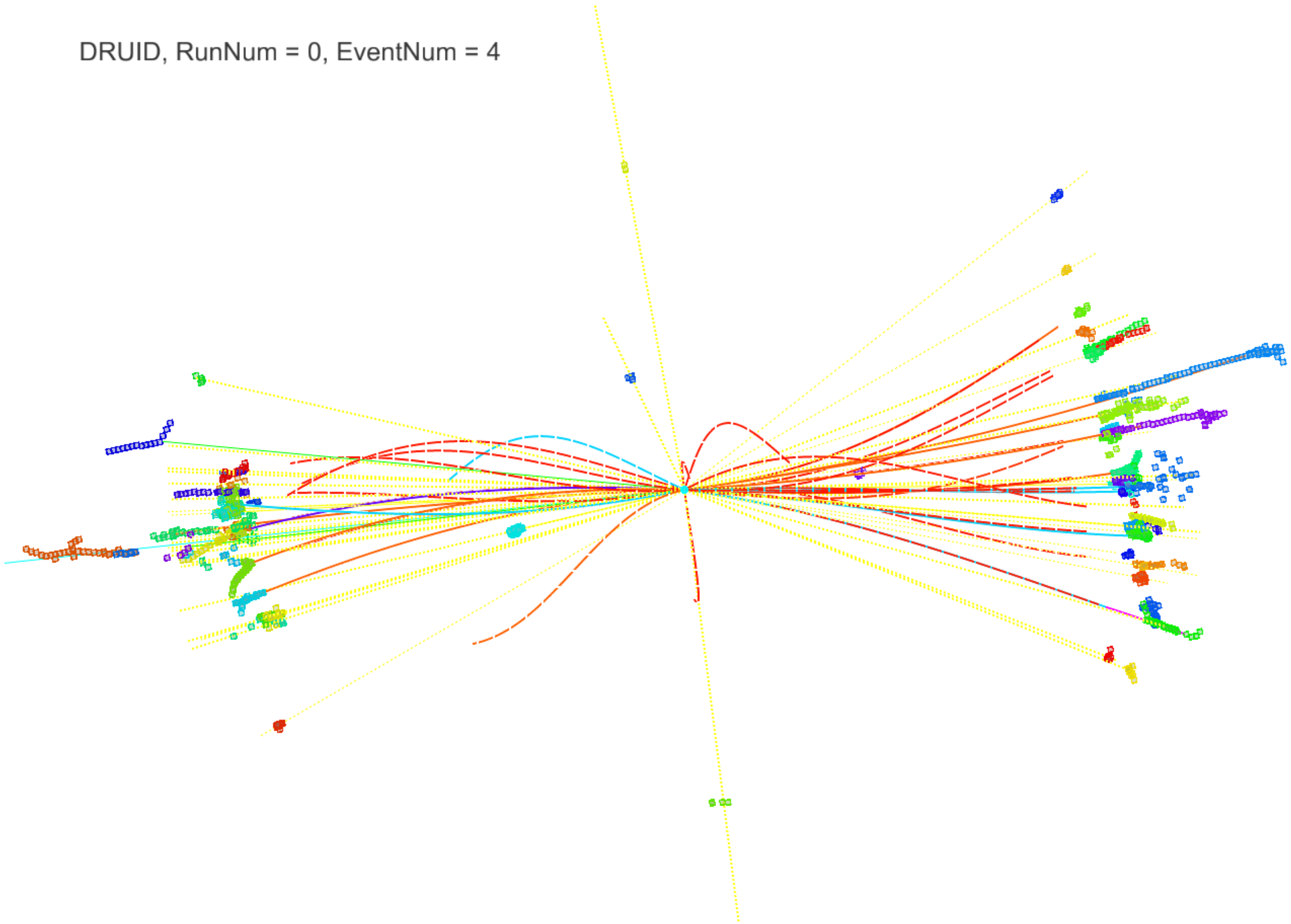
70 OVERVIEW OF THE PHYSICS CASE FOR CEPC

Particle	Tera-Z	Belle II	LHCb
b hadrons			
B^+	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B^0	6×10^{10}	3×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	3×10^{13}
B_s	2×10^{10}	3×10^{8} ($5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S)$)	8×10^{12}
b baryons	1×10^{10}		1×10^{13}
Λ_b	1×10^{10}		1×10^{13}
c hadrons			
D^0	2×10^{11}		
D^+	6×10^{10}		
D_s^+	3×10^{10}		
Λ_c^+	2×10^{10}		
τ^+	3×10^{10}	5×10^{10} ($50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$)	

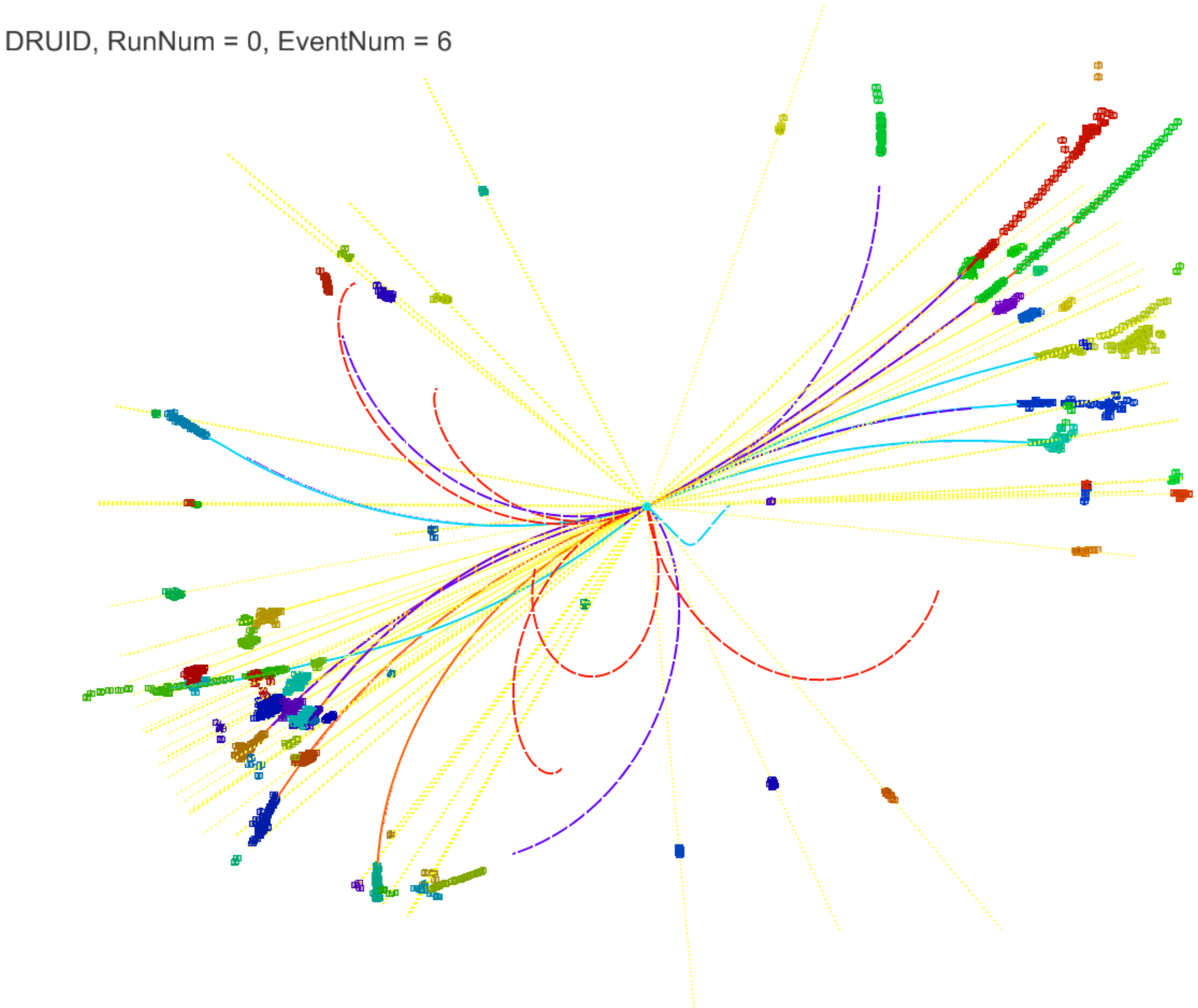
Table 2.4: Collection of expected number of particles produced at a tera-Z factory from 10^{12} Z-boson decays. We have used the hadronization fractions (neglecting p_T dependencies) from Refs. [431, 432] (see also Ref. [433]). For the decays relevant to this study we also show the corresponding number of particles produced by the full $50\,\mathrm{ab}^{-1}$ on $\Upsilon(4S)$ and $5\,\mathrm{ab}^{-1}$ on $\Upsilon(5S)$ runs at Belle II [430], as well as the numbers of b hadrons at LHCb with $50\,\mathrm{fb}^{-1}$ (using the number of $b\bar{b}$ pairs within the LHCb detector acceptance from [435] and the hadronization fractions from [431]).

CEPC Flavor measurement: mostly at Z->qq event

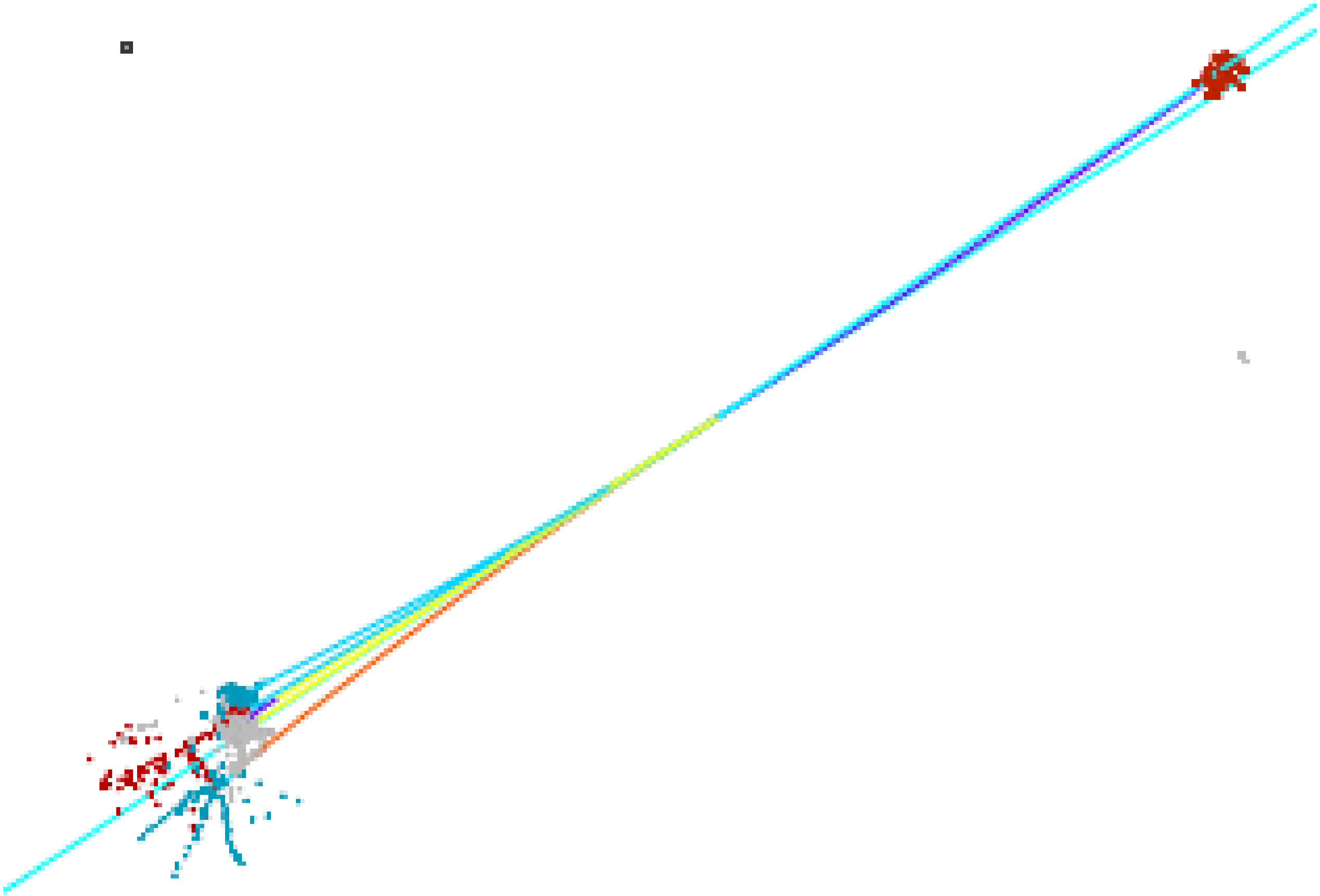




DRUID, RunNum = 0, EventNum = 4


DRUID, RunNum = 0, EventNum = 6

And Z->tautau events...



Objective

- Via Benchmark Physics Analyses (see Haibo's talk)
  - To quantify the potential and comparative advantage of the CEPC Flavor Physics Program
  - To quantify the Detector performance requirement.
- Limit: Huge statistics, cannot be all processed with Full Simulation.
- Methodology:
  - Full simulation based Performance study
  - Fast simulation based analyses
  - Key point: development and validation of Fast simulation tool, working point optimization, etc...

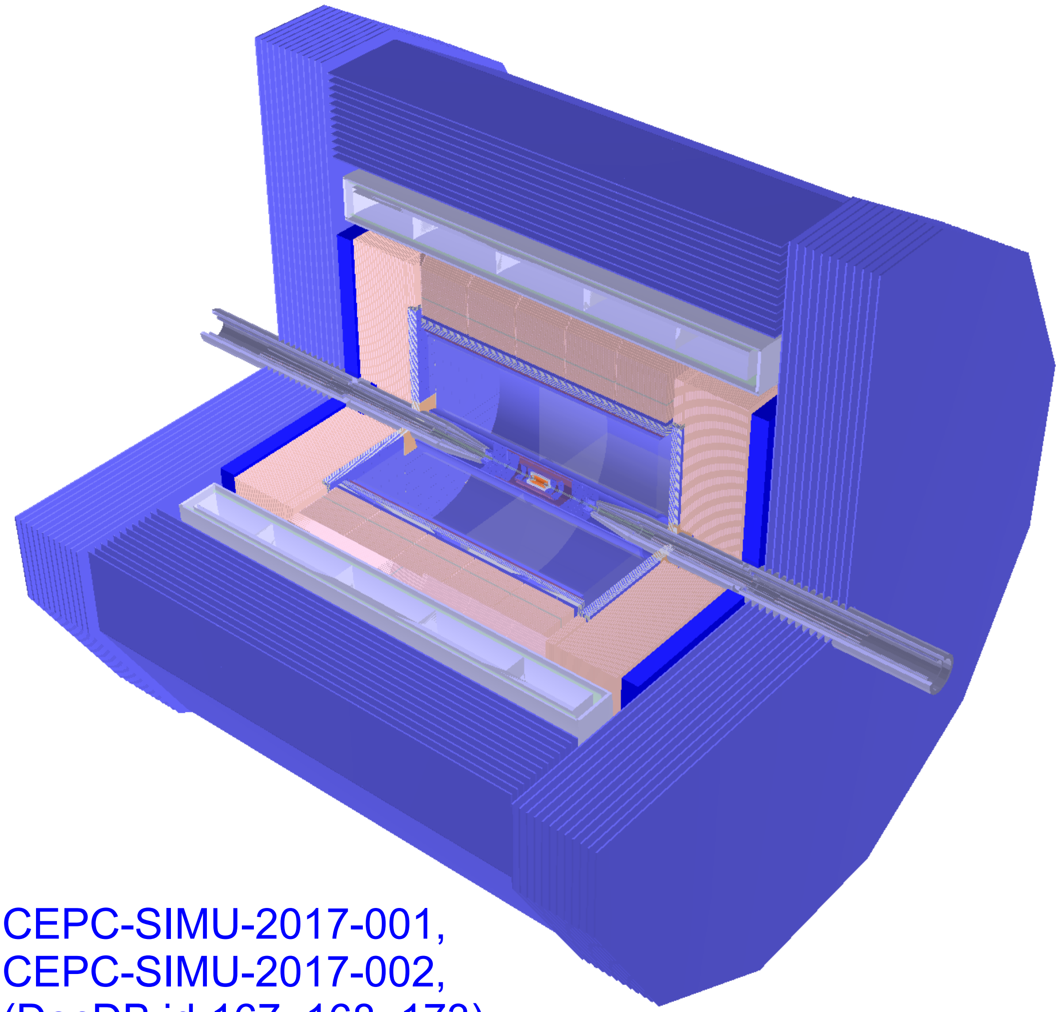
Key performance to flavor Physics

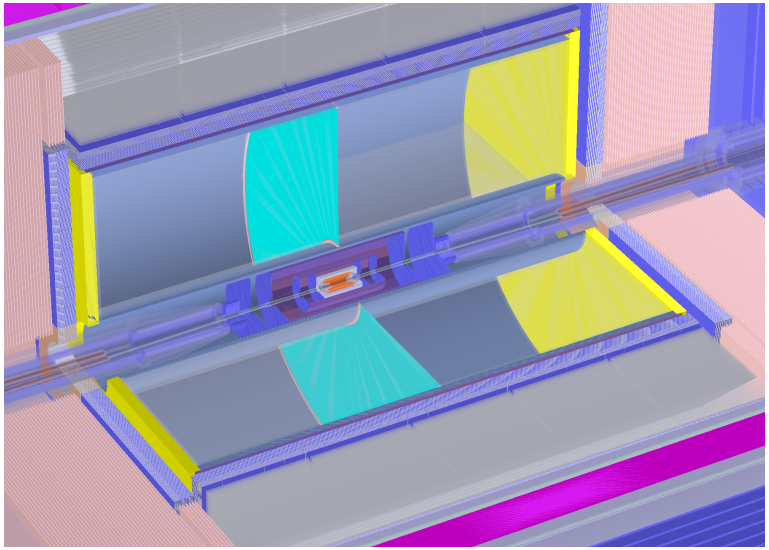
	CEPC Relative Advantage	Physics Significant	Simple	Strong Dependent on Performance	Status and Foundation	
B0/B+->K*ee Lamdda_c → pee						
B0->K*mumu (P8) Lambda_b → Lambda mumu Lamdda_c → p mumu	Can LHCb rec. Track with sufficient low Energy? Delta(m)/m (q^2)			Lepton id + Pid Low Energy Track Angular + Momentum		
b->stautau (P10) Bs->Phi + tautau B->K* + inv Lambda_b → Lambda tau tau	CEPC Golden Channel, as the tau finding in CEPC jet is good CEPC Performance should be very good enough to reconstruct 3-prong decay tau VTX, and low-E track decay from K* (if K* exist)			Reducible Background as Misidentify the D in to tau, by losing one pi0/photon VTX reconstruction. 3-prong tau shall be the golden sub-channel	Tau finding partly understood HKUST has interests	
Bc->tauv (P21) B+->tauv ()					Covered, hopefully a presentation can be held in 1-2 week	
				Tau finding +	Tau finding in B-jet	

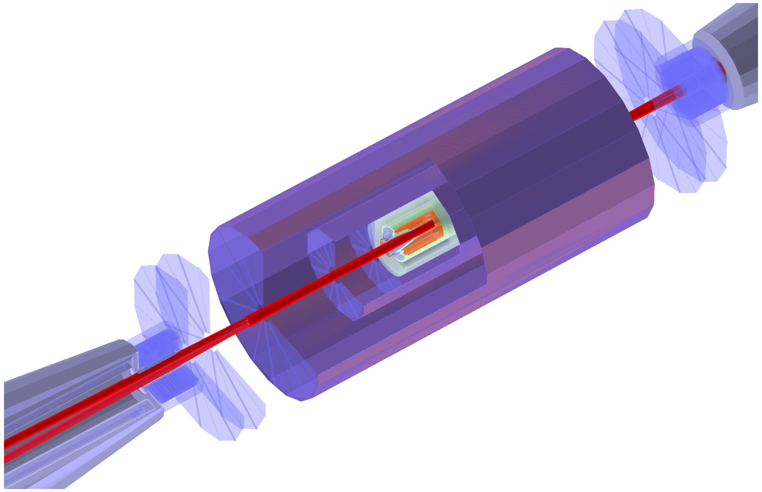
Key performances to flavor physics

- Identification of decay final state particles from Jet (against combination background)
- Lepton: identification of isolated, and Jet lepton
- Kaon: identification of Kaon inside jet
- Tau:
  - Finding performance of isolated, and jet tau.
  - Identification of Tau decay final state
- Pi-0 reconstruction performance
- Kshort, Lambda, Phi, J/psi reconstruction
- Missing Energy...
- Jet Flavor Tagging;
- Jet Charge measurement;
- Track threshold, track momentum, photon energy, etc.
- VTX: reconstruction efficiency & accuracy

Baseline Geometry

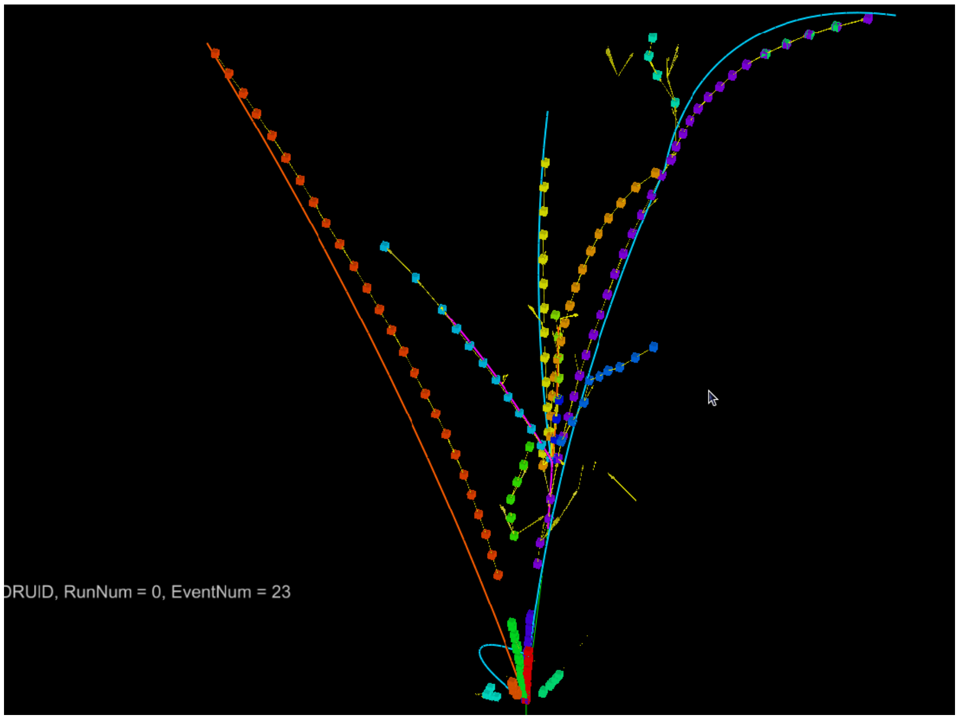


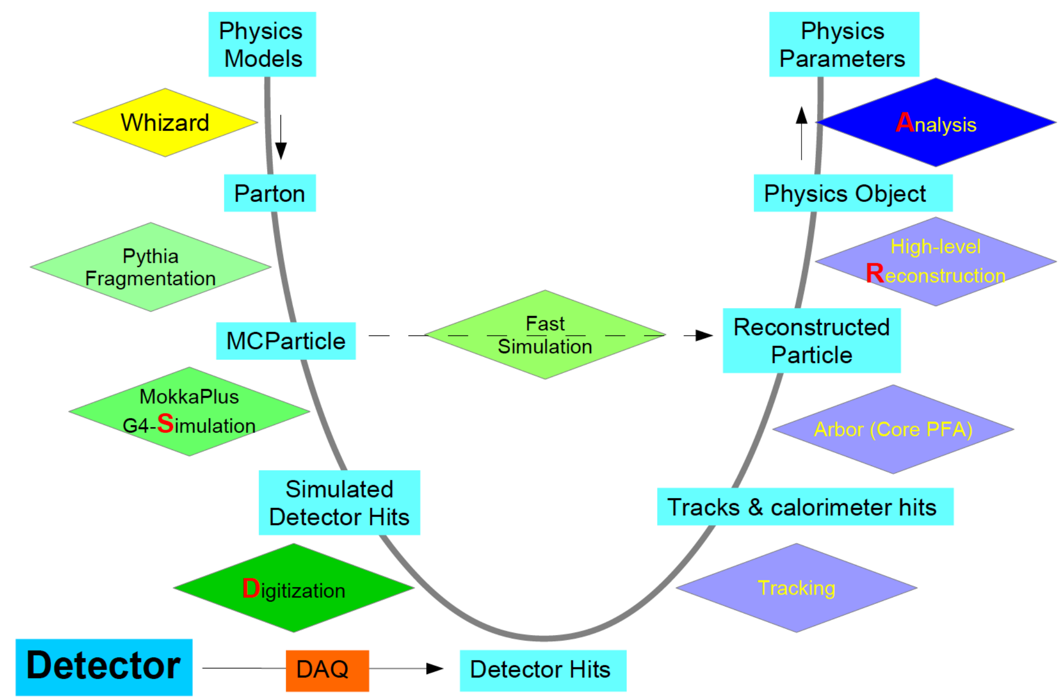




CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

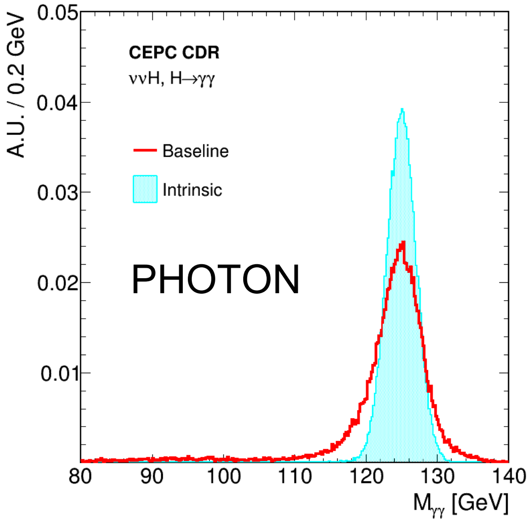
Software & Reconstruction



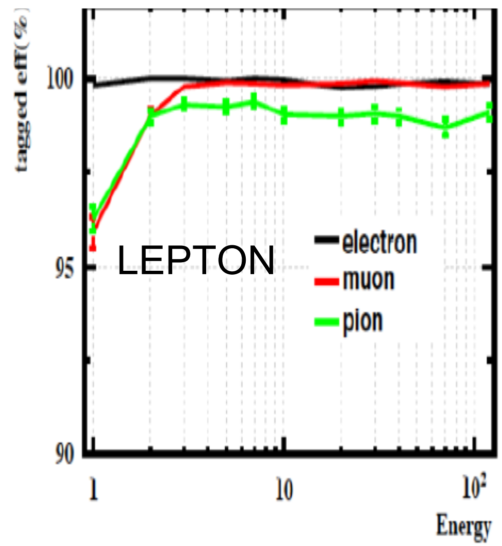


Starting from the ilcsoft & replace all the PFA/high-level reconstruction algorithms.

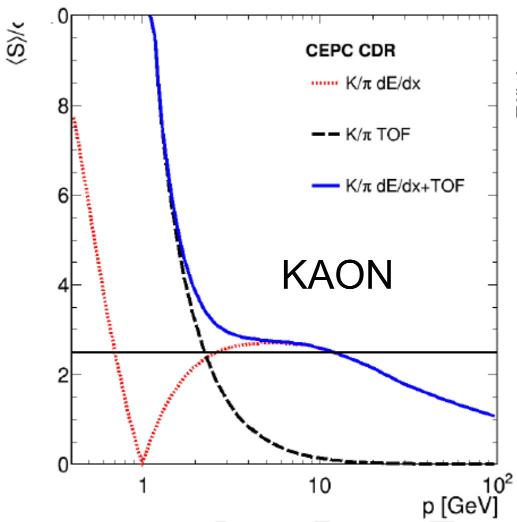
Physics Objects

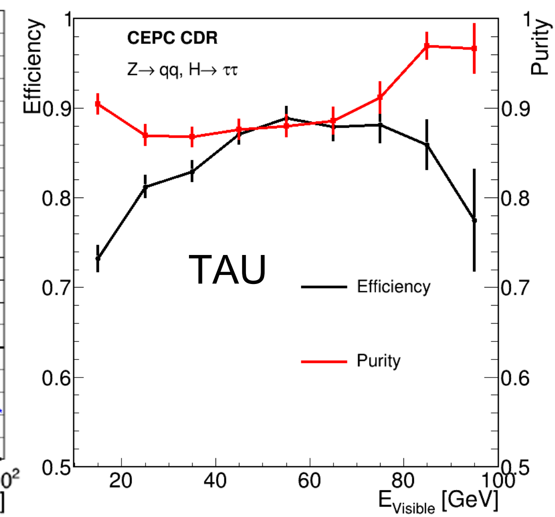


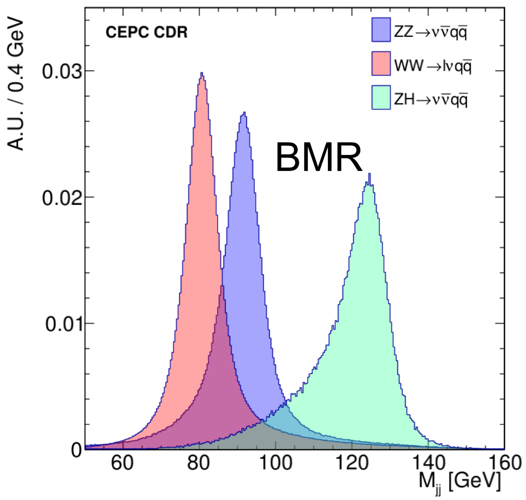
Eur. Phys. J. C (2017) 77: 591

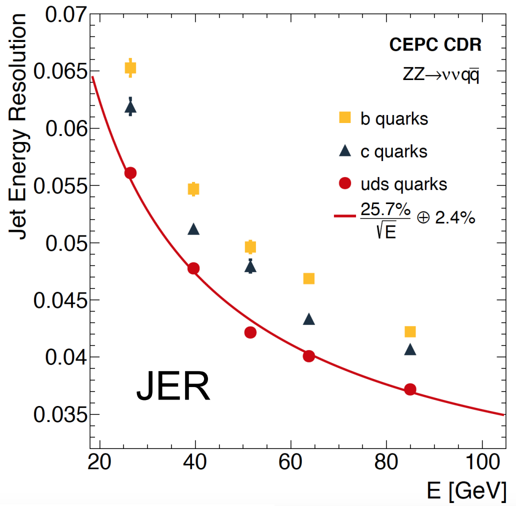


Eur. Phys. J. C (2018) 78:464









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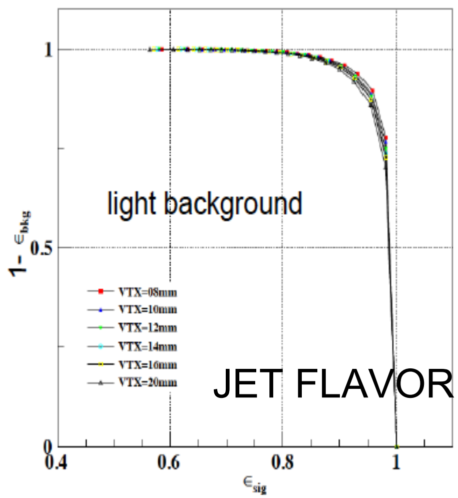
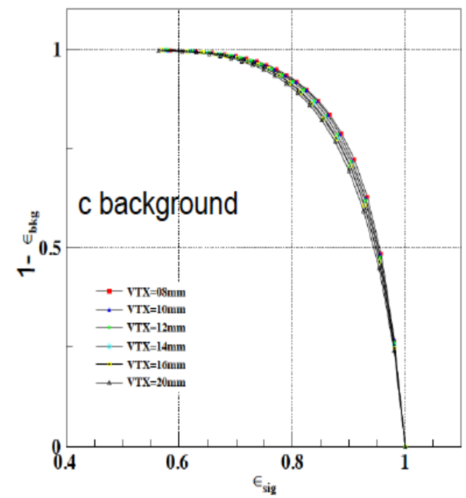
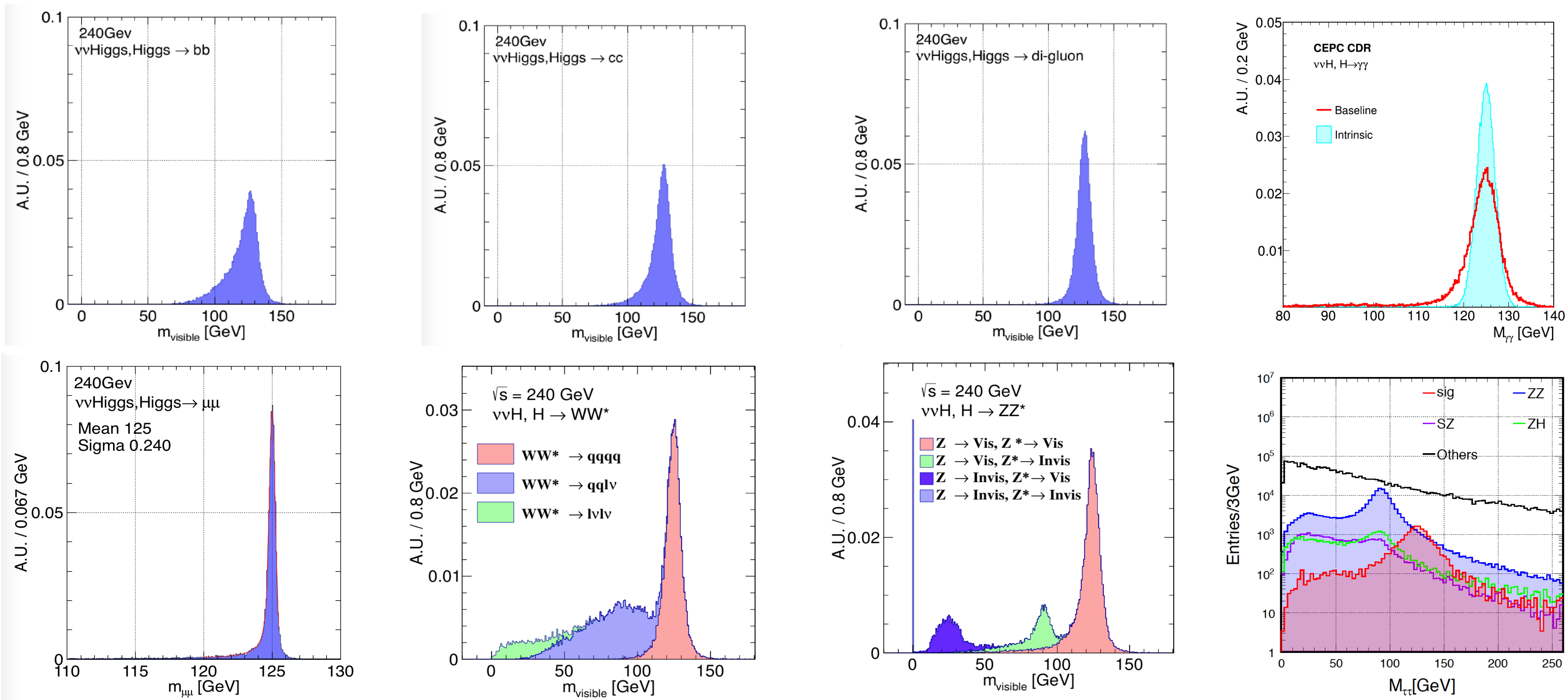




Higgs Signals

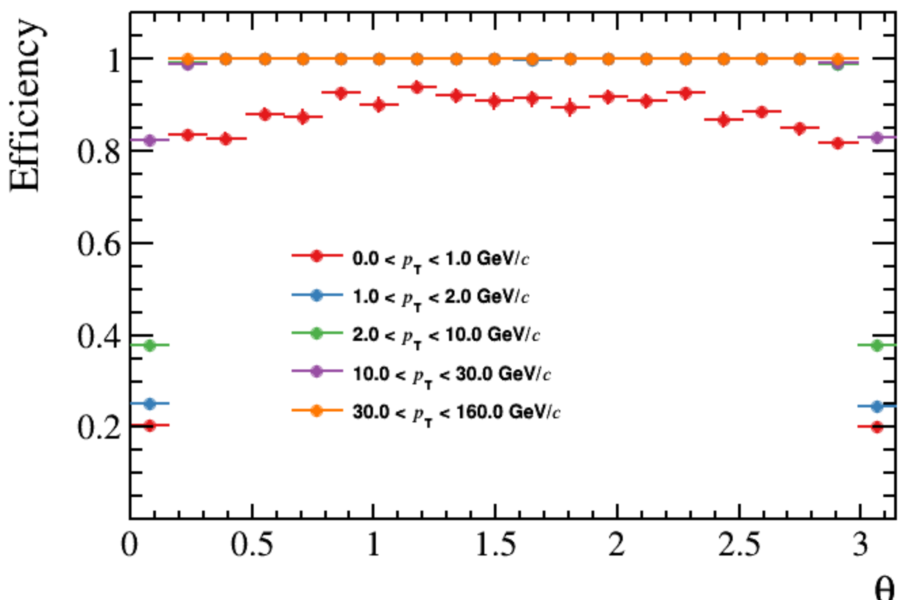


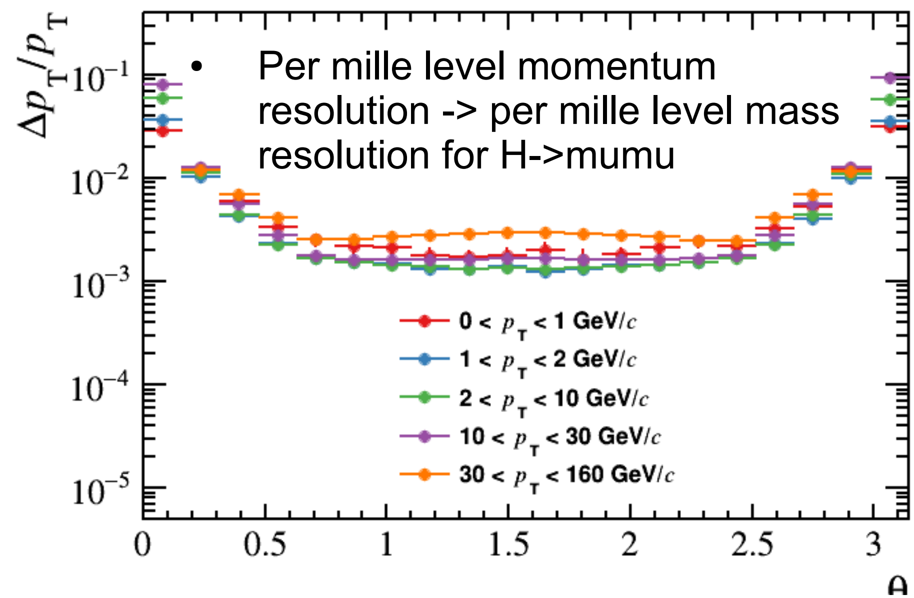
Clear Higgs Signature in all SM decay modes

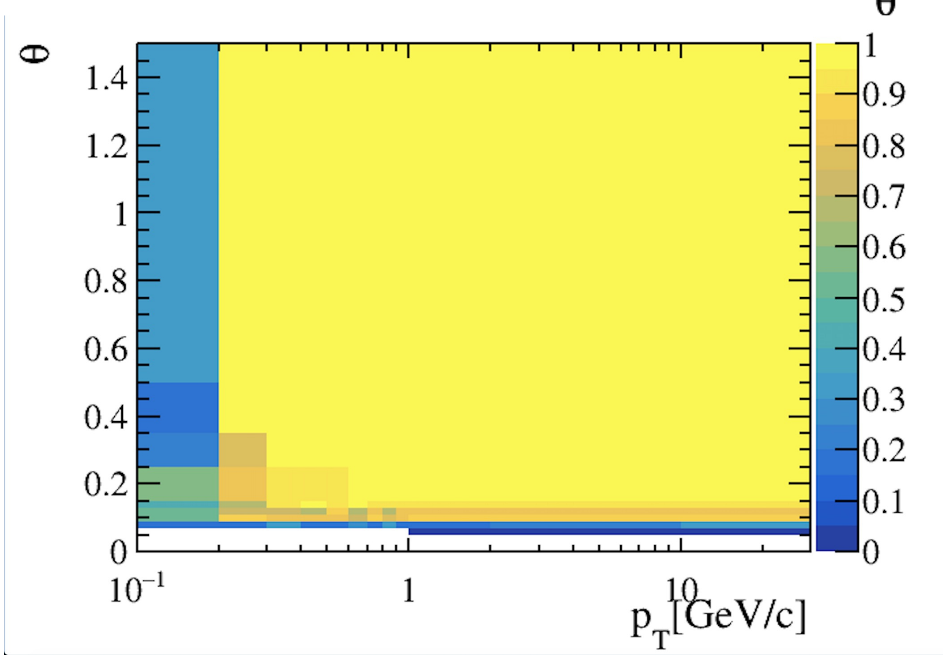
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

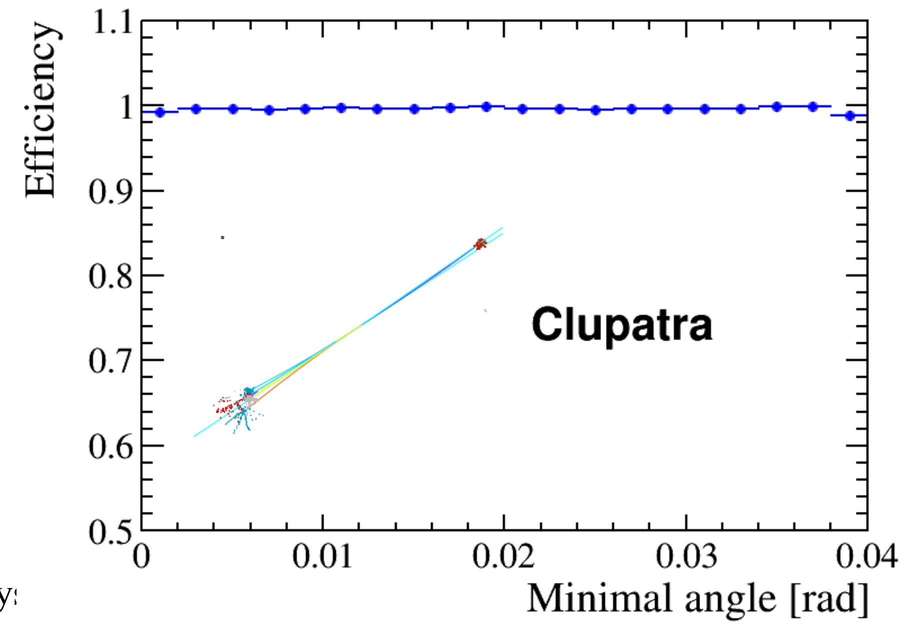
Right corner: di-tau mass distribution at qqH events using collinear approximation

Tracking

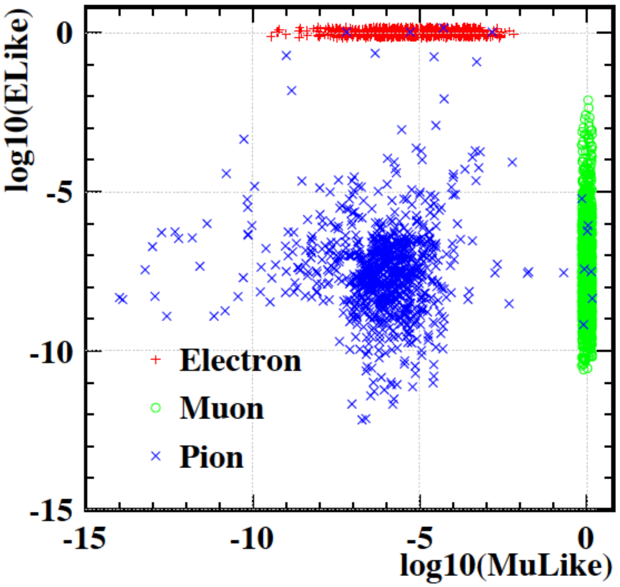

Efficiency
0.0 < p_T < 1.0 GeV/c
1.0 < p_T < 2.0 GeV/c
2.0 < p_T < 10.0 GeV/c
10.0 < p_T < 30.0 GeV/c
30.0 < p_T < 160.0 GeV/c
θ

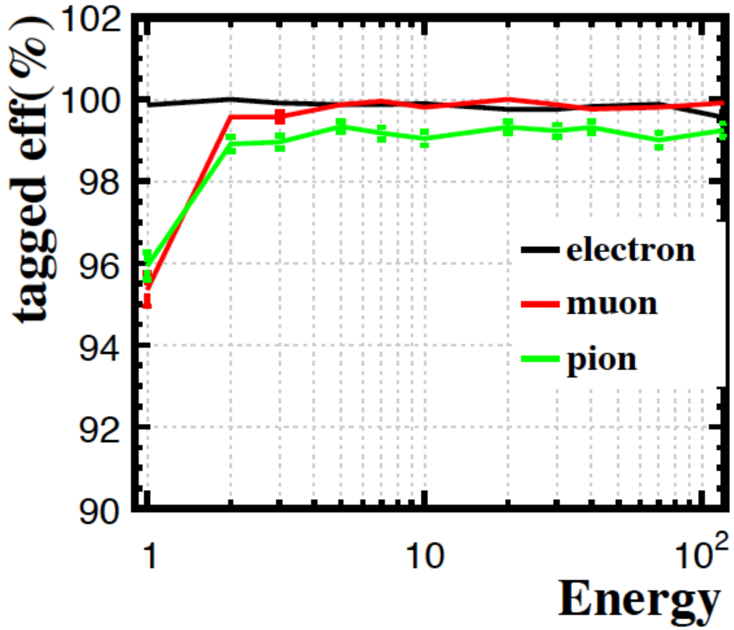

Δp_T/p_T
• Per mille level momentum resolution -> per mille level mass resolution for H->mumu
0 < p_T < 1 GeV/c
1 < p_T < 2 GeV/c
2 < p_T < 10 GeV/c
10 < p_T < 30 GeV/c
30 < p_T < 160 GeV/c
θ

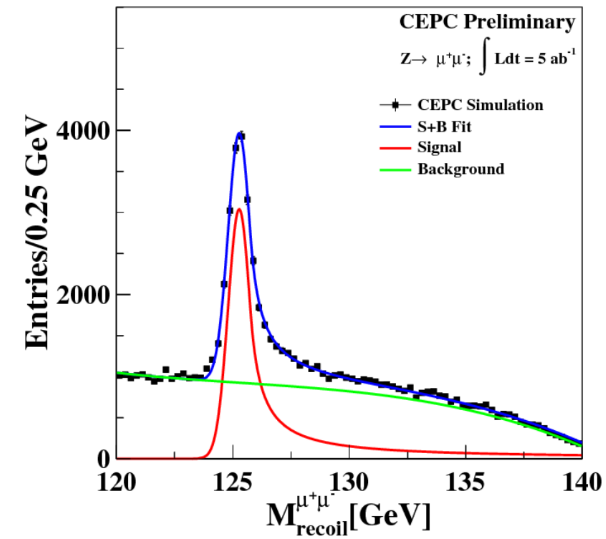

θ
p_T[GeV/c]

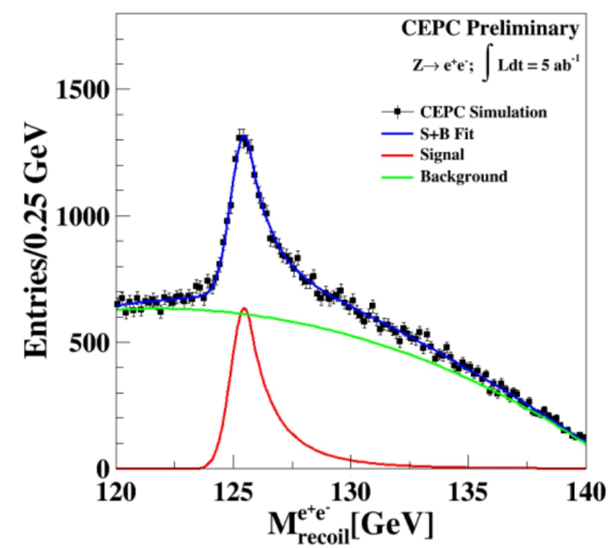

Efficiency
Clupatra
Minimal angle [rad]

Lepton







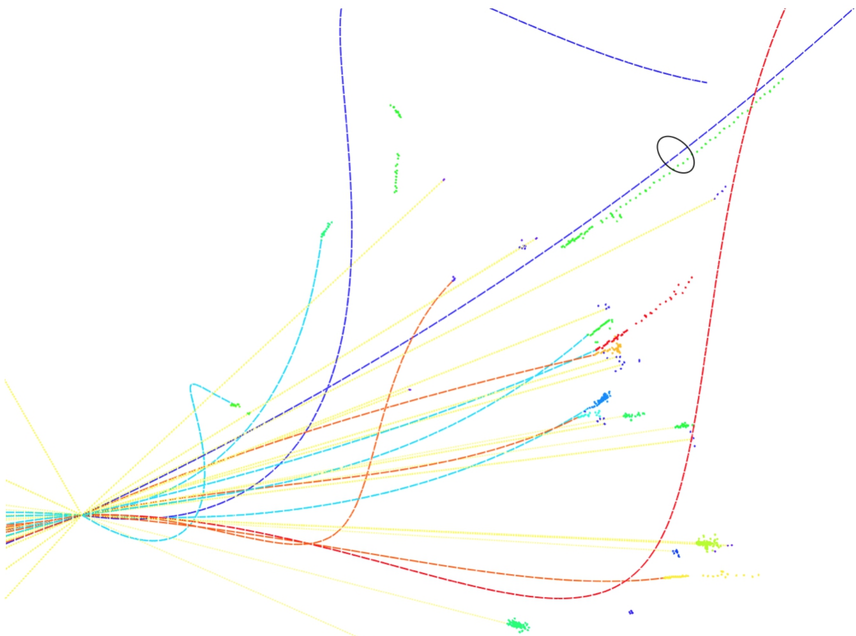


BDT method using 4 classes of 24 input discrimination variables.

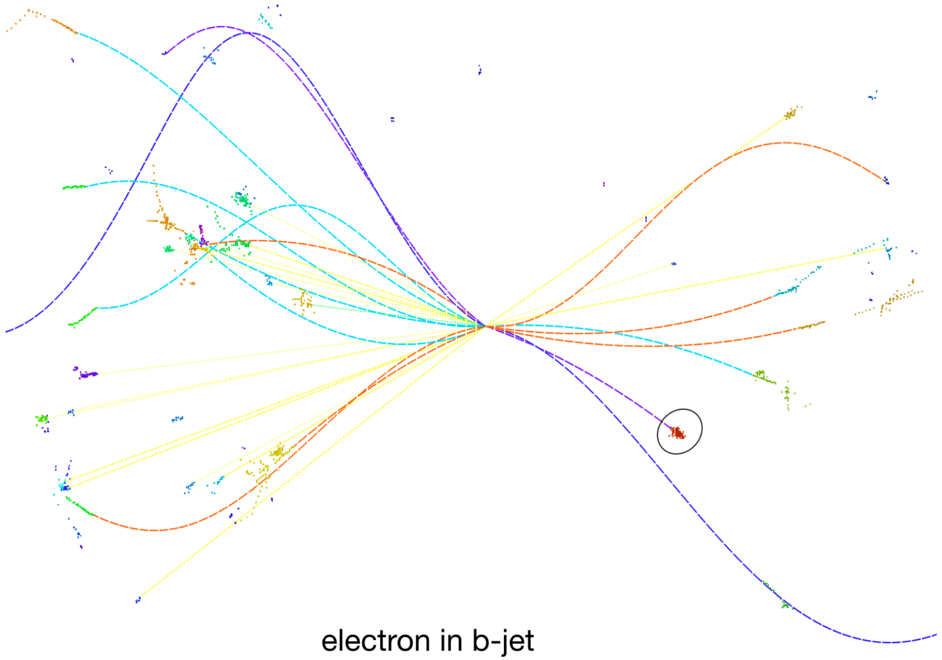
Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

https://link.springer.com/article/10.1140/epjc/s10052-017-5146-5
CEPC-DocDB-id:148, Eur. Phys. J. C (2017) 77: 591

Lepton inside Jet



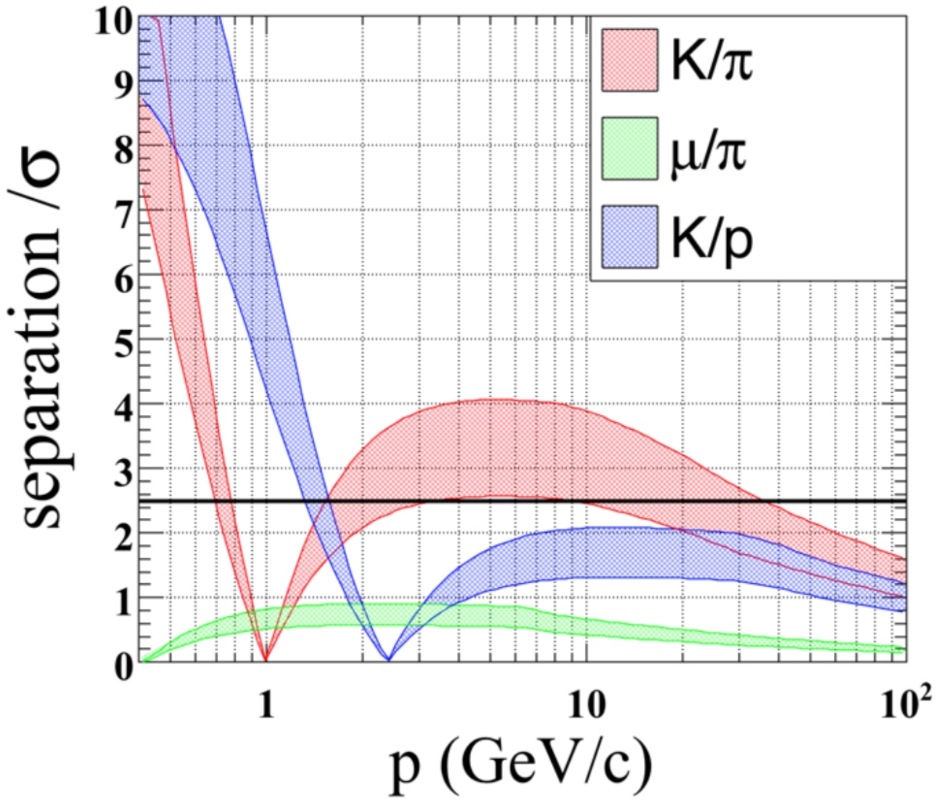
muon in b-jet

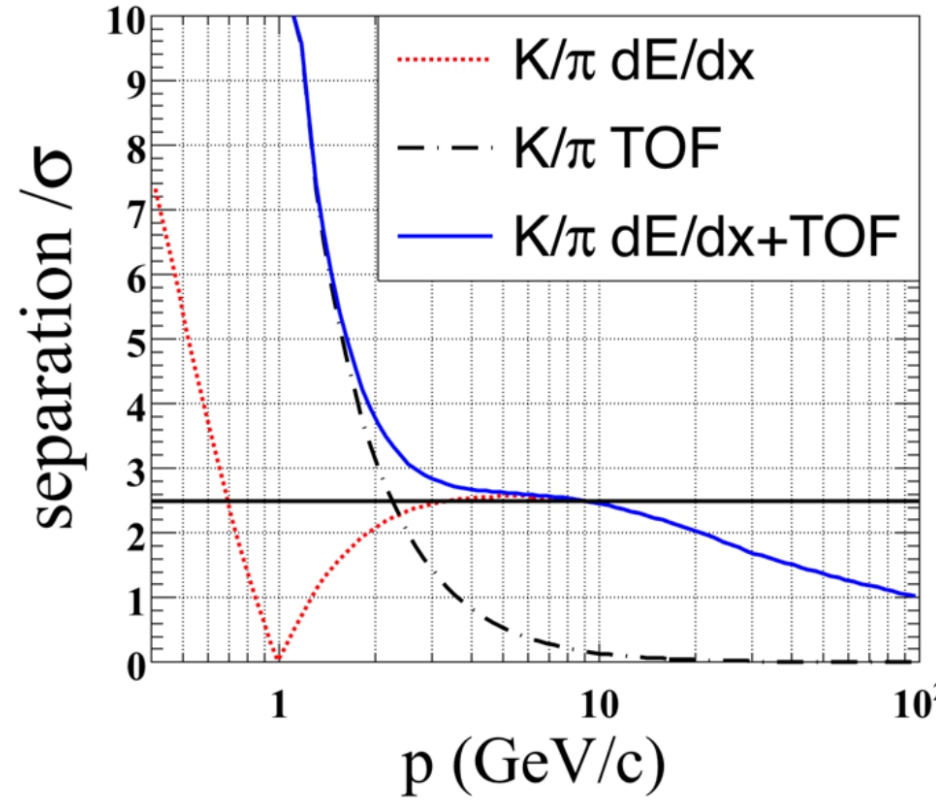


electron in b-jet

- Identification efficiency/purity slightly degrades w.r.t isolated ones

Kaon





Highly appreciated in flavor physics @ CEPC Z pole

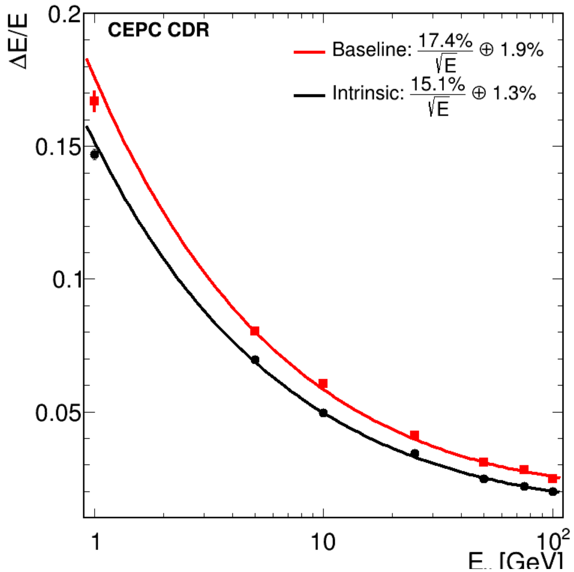
- TPC dEdx + ToF of 50 ps

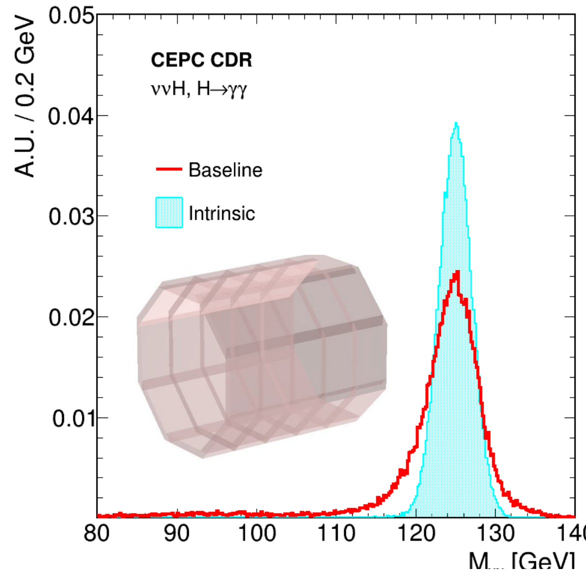
At inclusive Z pole sample:

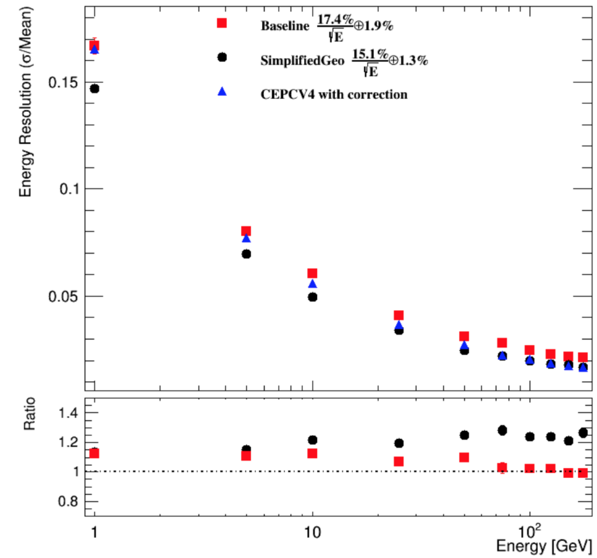
- Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
- Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

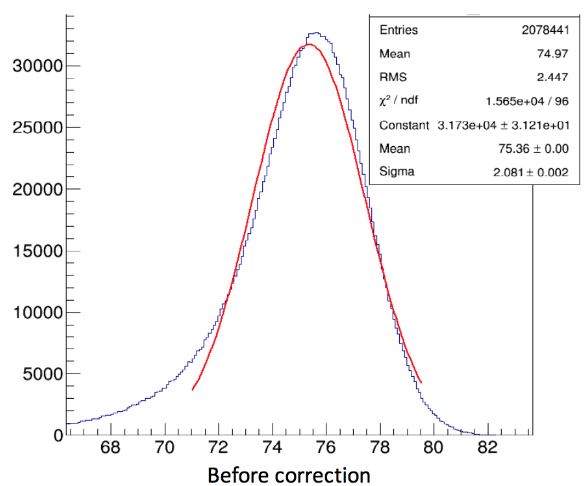
CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464

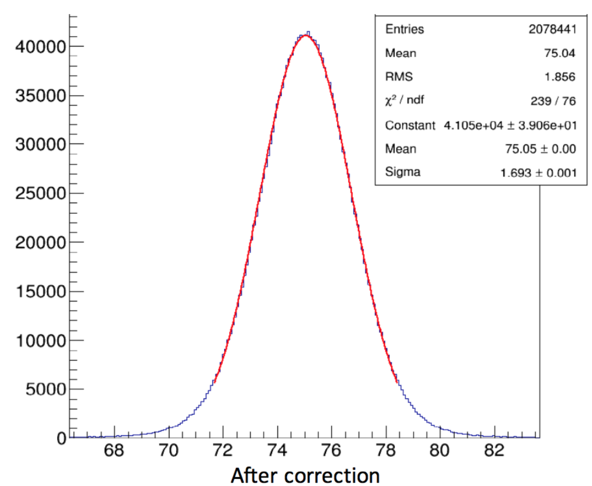
Photon: resolution







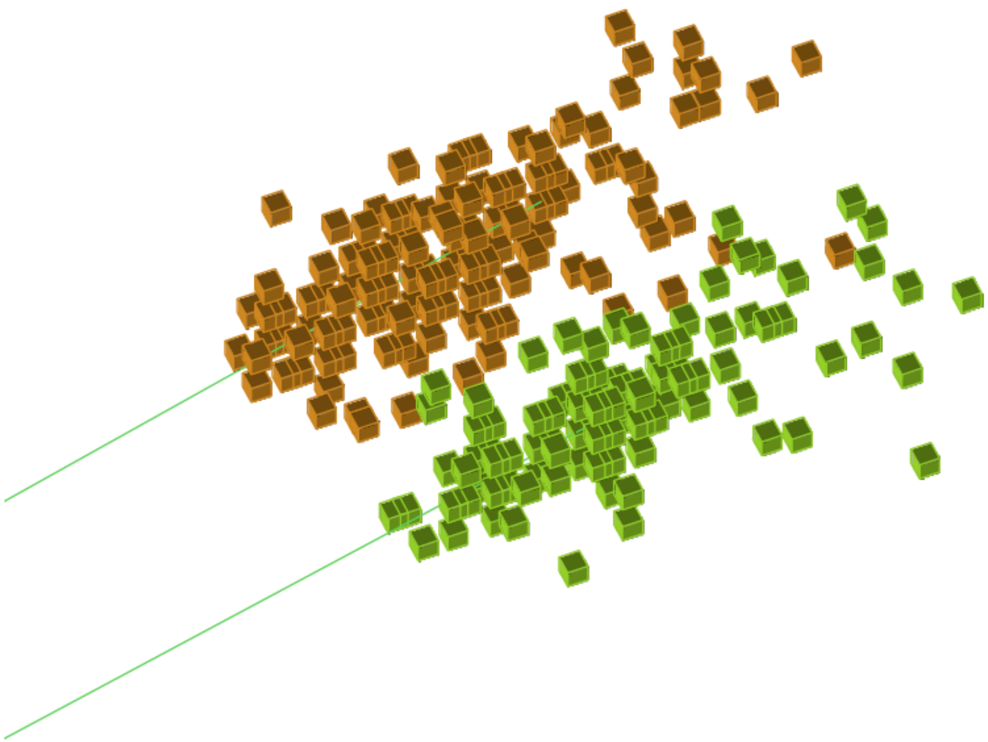


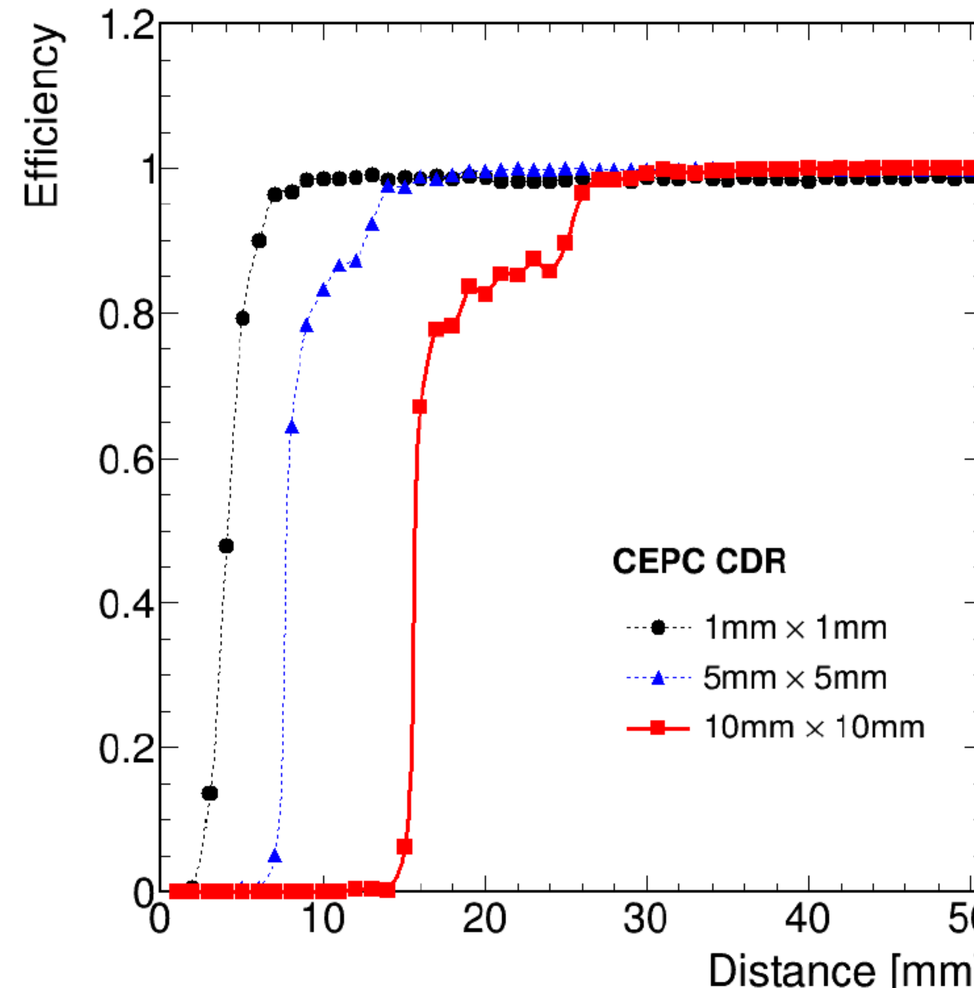


- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/baseline geometry
- The geometry defects correction could be efficiently corrected (Preliminary)

See Yuqiao Shen's talk

Photon: Clustering and separation

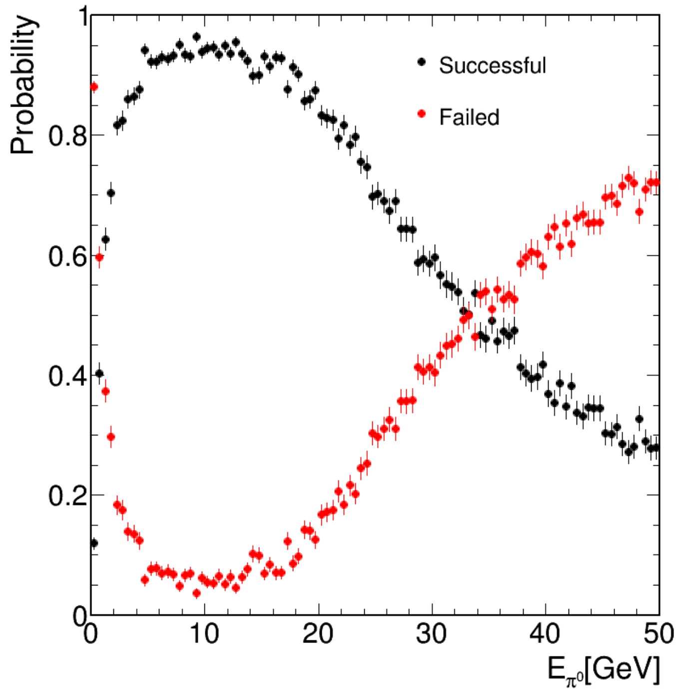


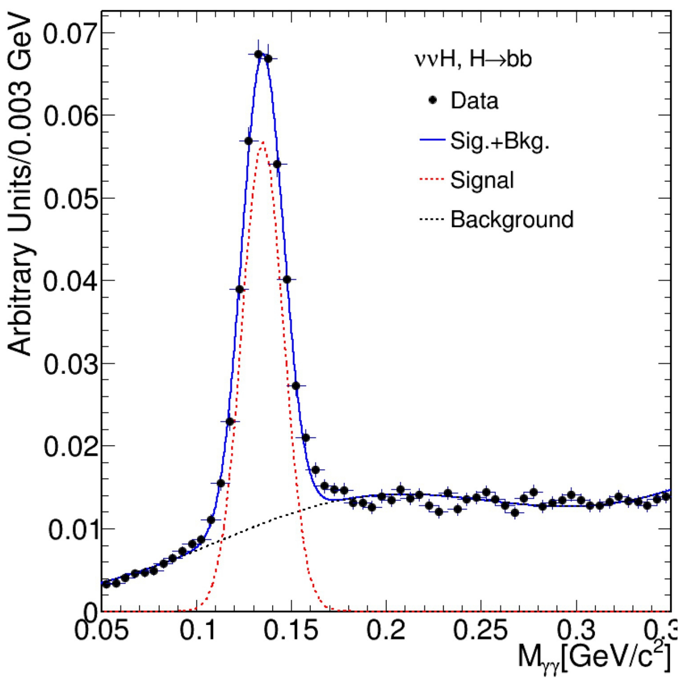


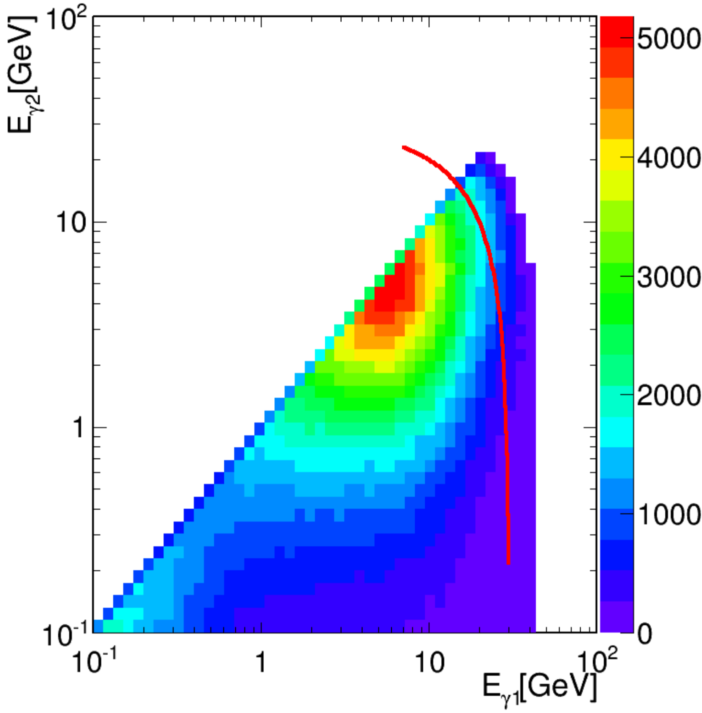
Critical energy to separate an evenly decay π_0: 30 GeV

See Hang Zhao's talk

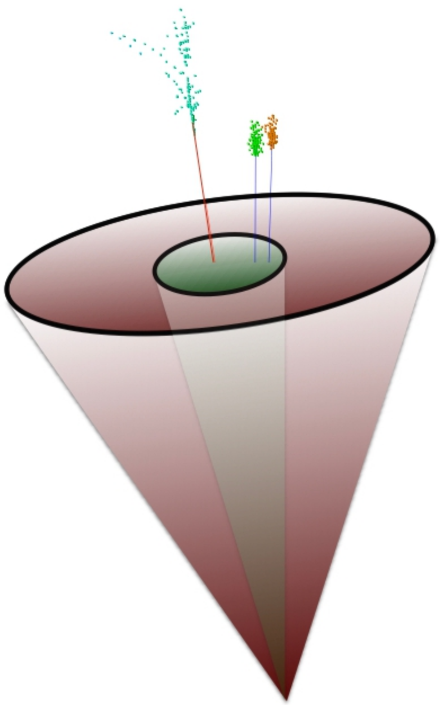
pi-0

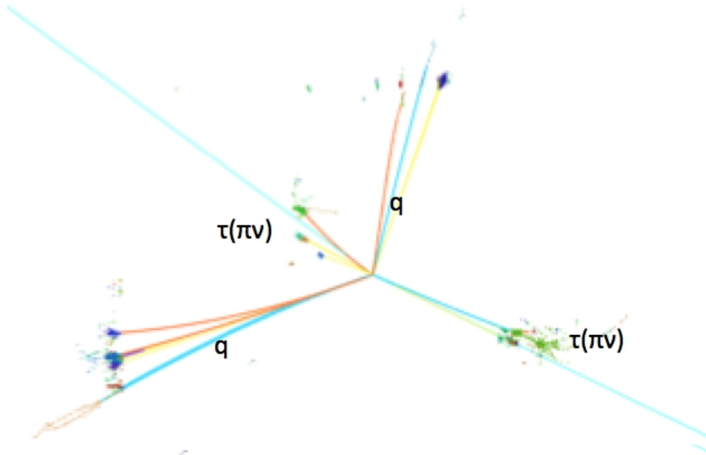

Probability
Successful
Failed
E_{π^0}[GeV]

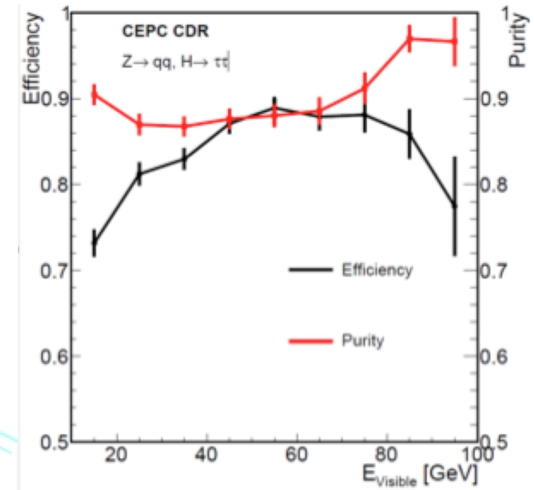

Arbitrary Units/0.003 GeV
ννH, H→bb
Data
Sig.+Bkg.
Signal
Background
$M_{\gamma\gamma}$[GeV/c^2]

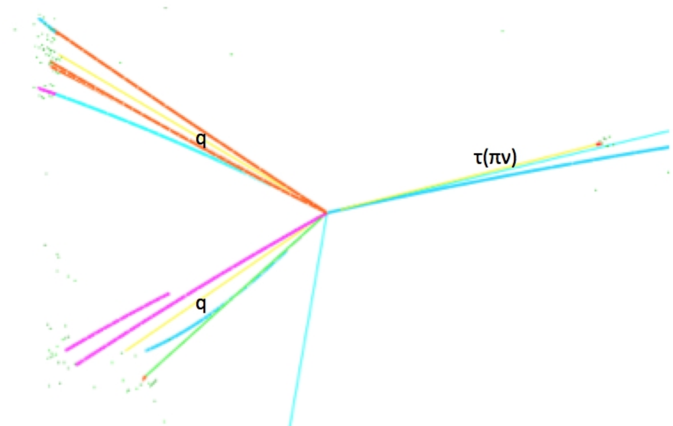

$E_{\gamma 2}$[GeV]
$E_{\gamma 1}$[GeV]

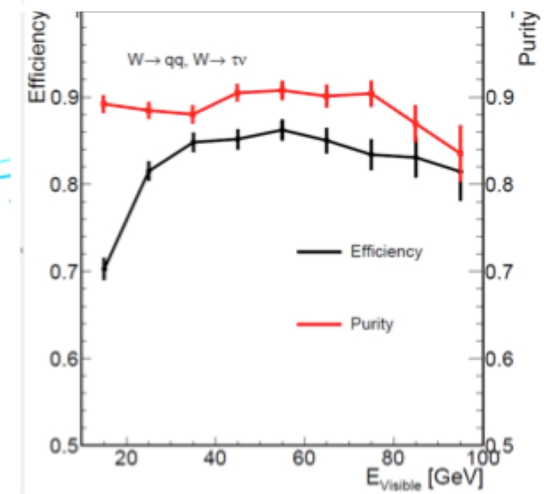
Tau finding at hadronic events







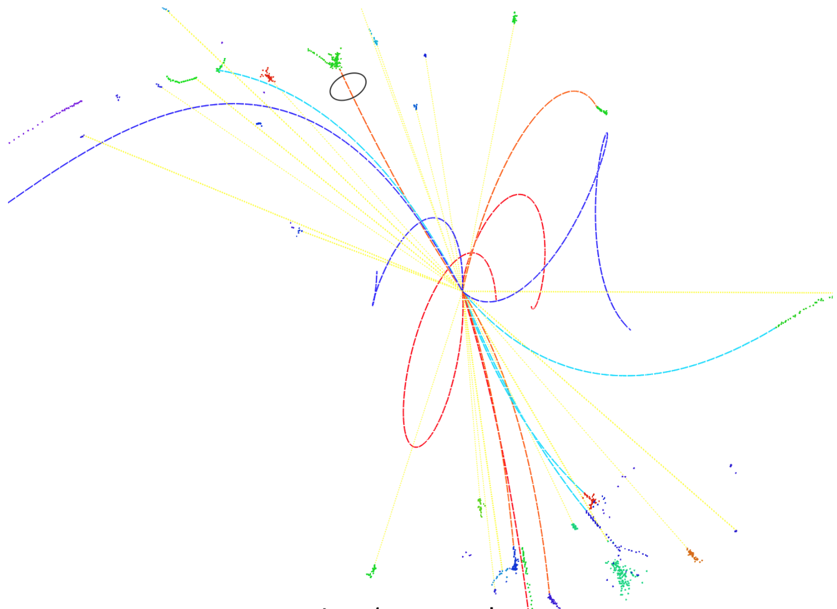




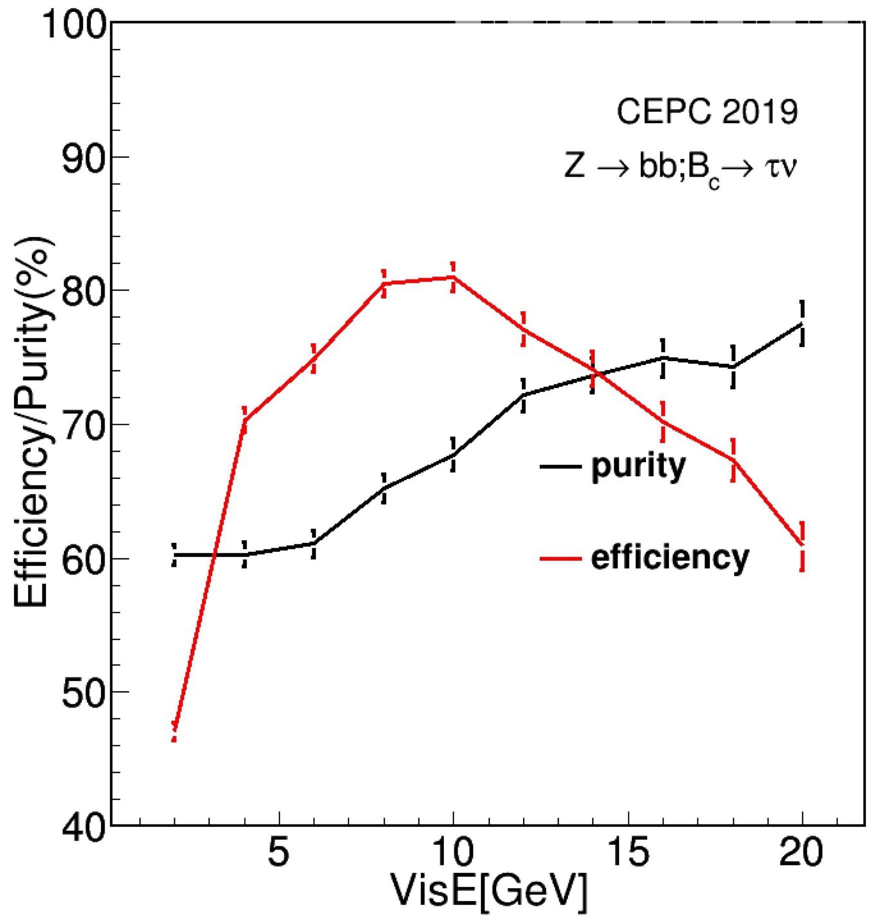
TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for qqττ, and qqτν events

See Zhigang Wu's talk

Tau finding inside Jet


tau 1-prong decay

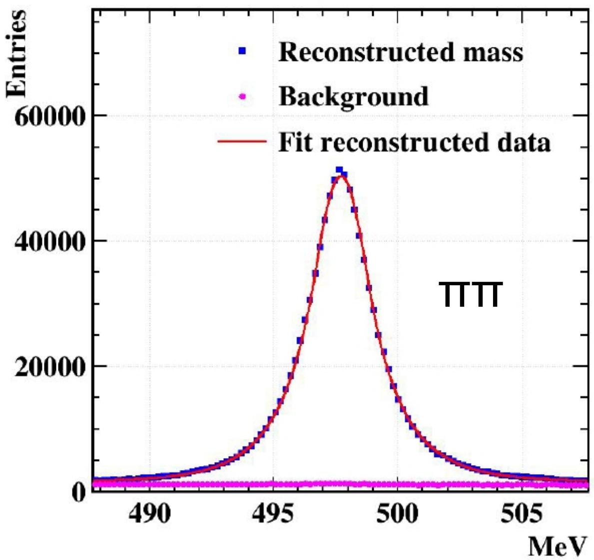

tau 1-prong +2photon



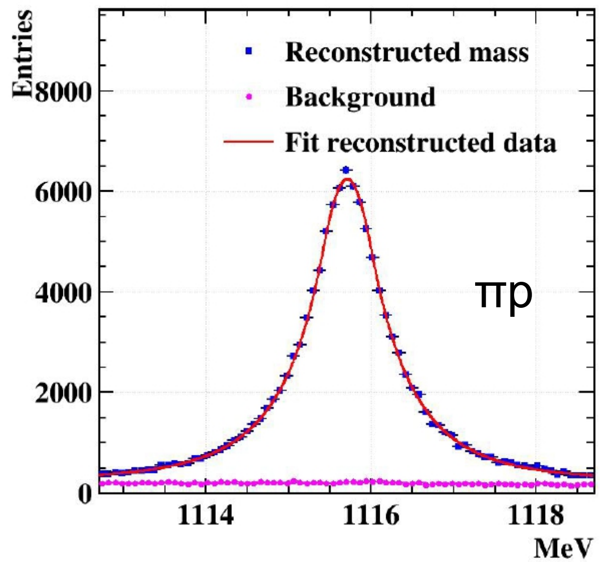
Tau finding

- At 91.2 GeV
  - Z->tautau events: eff*purity > 90%
  - Z->qq->tau + X: eff*purity ~ 50%
- At 240 GeV,
  - qqH, H->tautau; WW->qqtauv: eff*purity ~ 70%

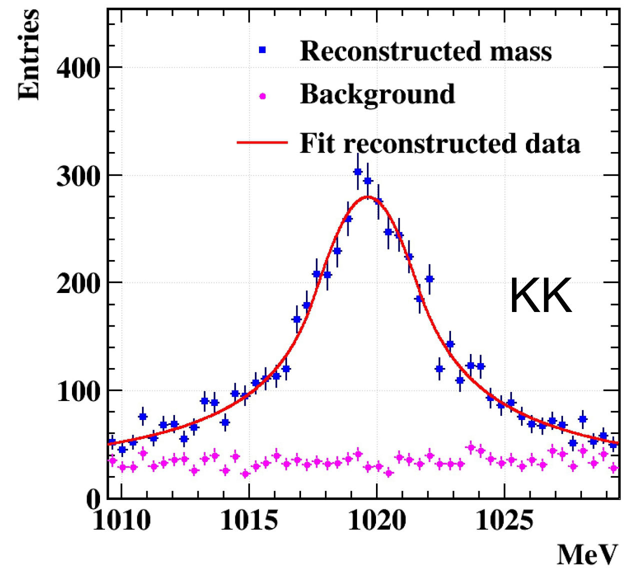
K_short, Lambda, Phi

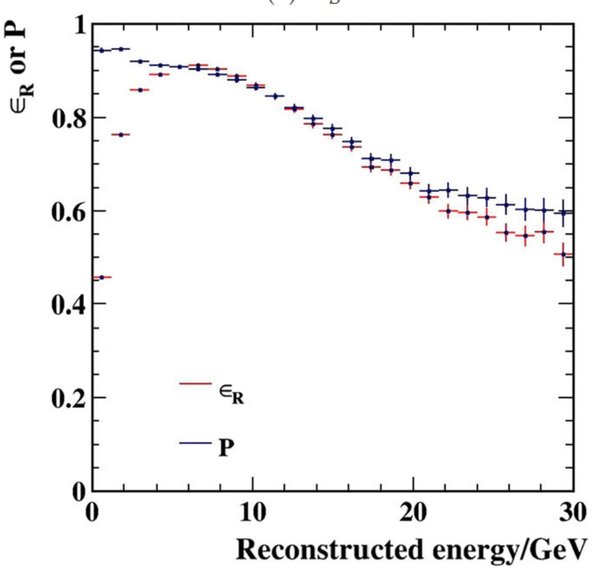


(a) K_S^0

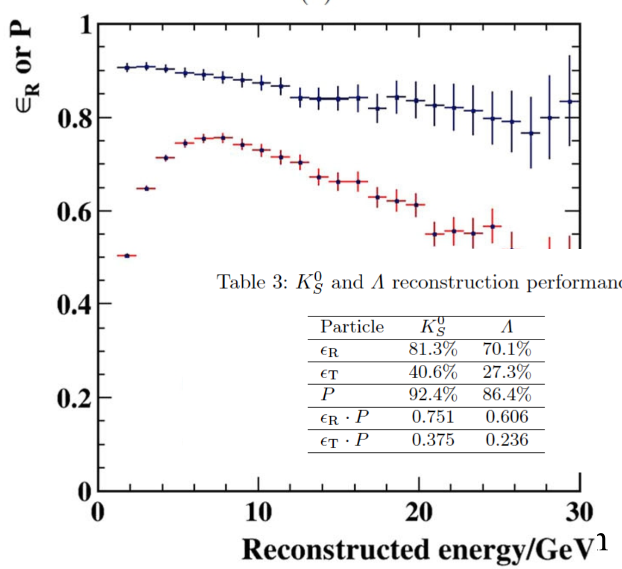


(b) Λ





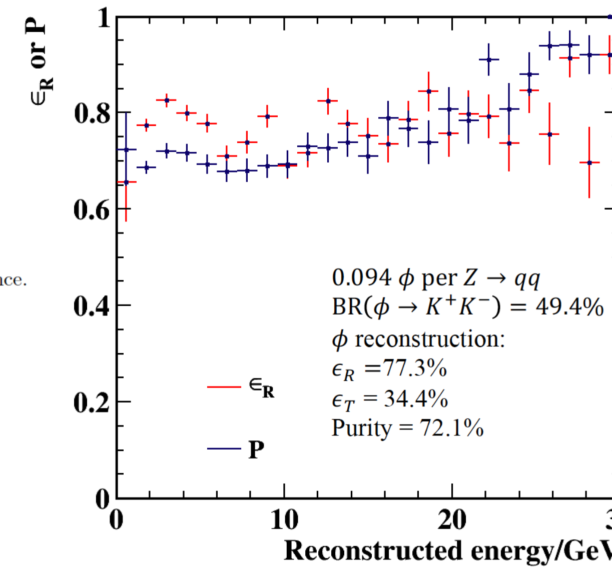
(a) K_S^0



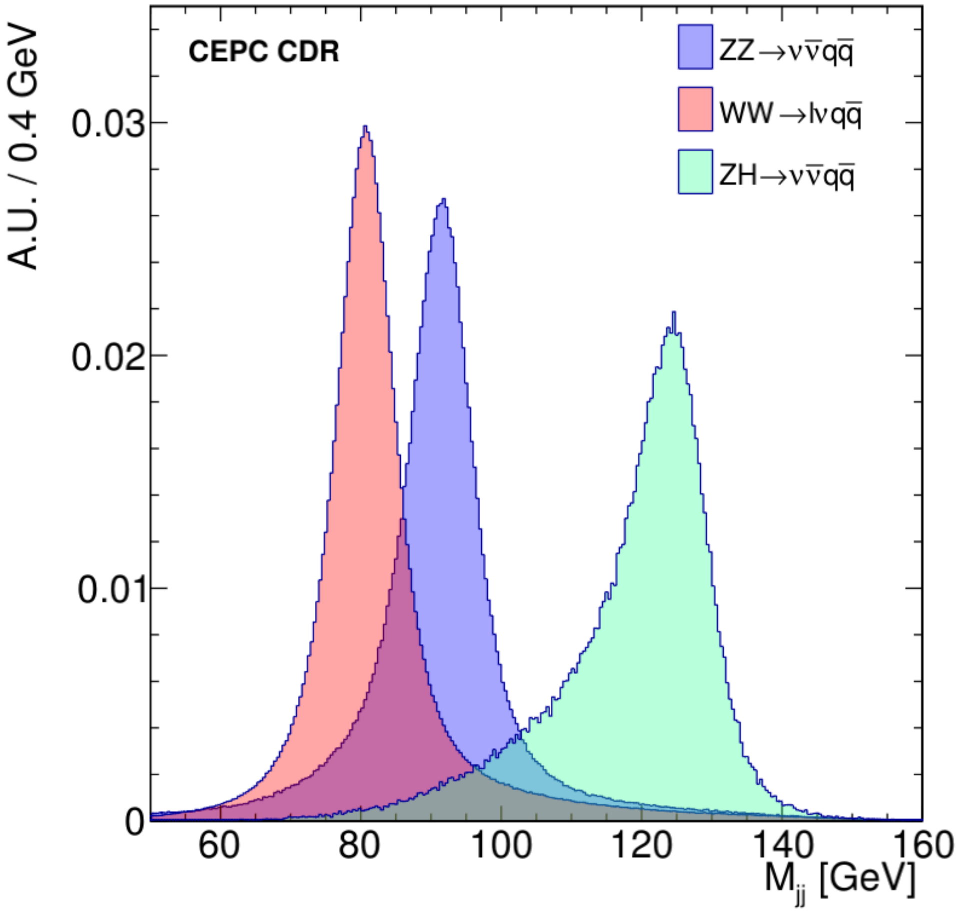
(b) Λ

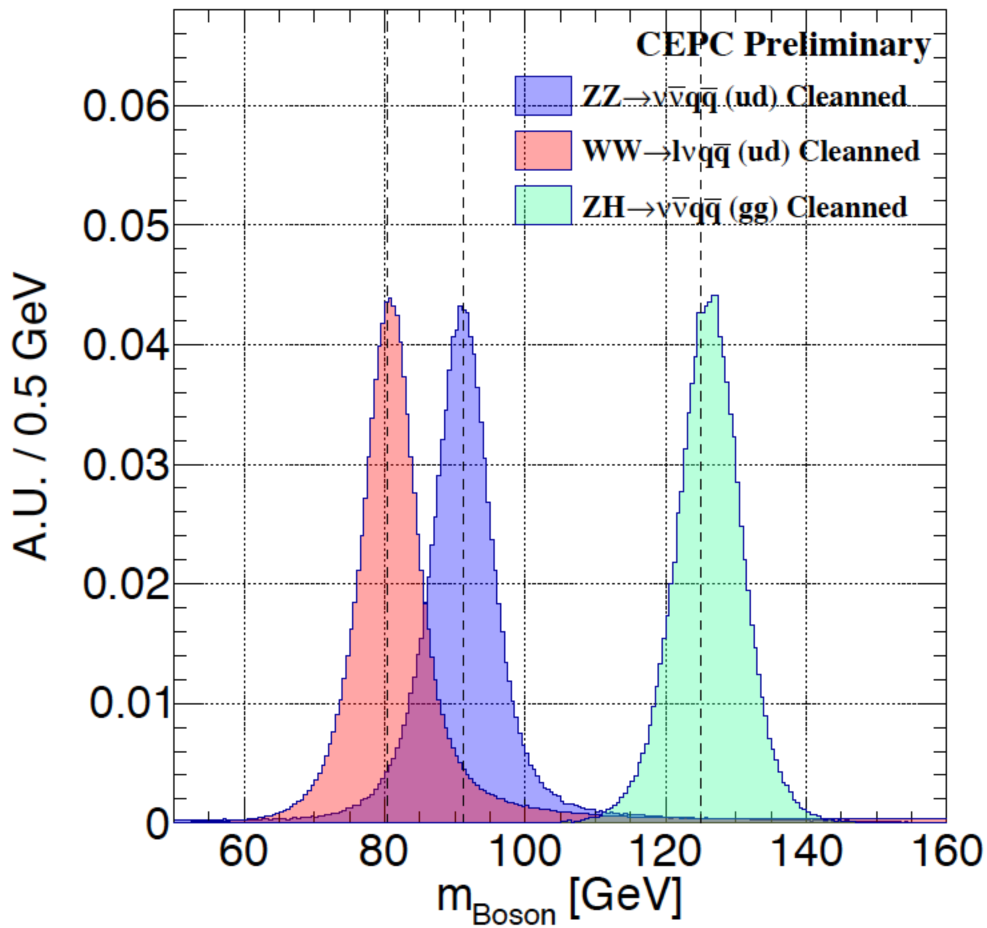
Table 3: K_S^0 and Λ reconstruction performance.

Particle	K_S^0	Λ
ϵ_R	81.3%	70.1%
ϵ_T	40.6%	27.3%
P	92.4%	86.4%
$\epsilon_R \cdot P$	0.751	0.606
$\epsilon_T \cdot P$	0.375	0.236



Massive Boson Separation





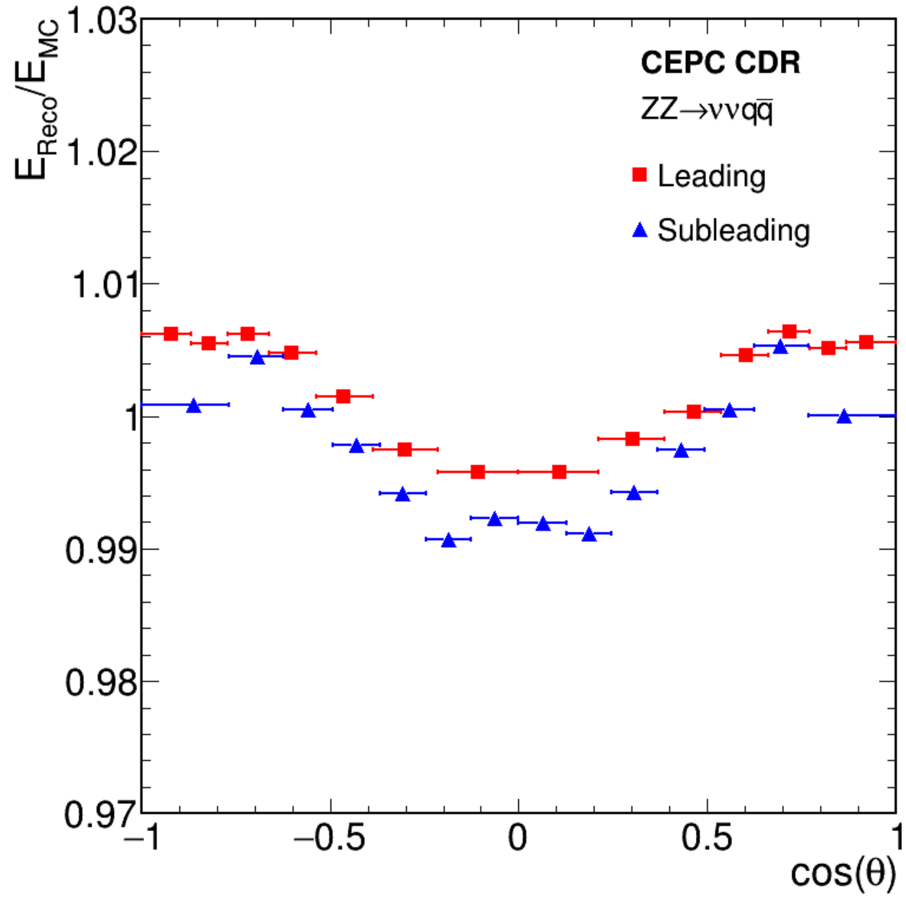
See Peizhu Lai's talk

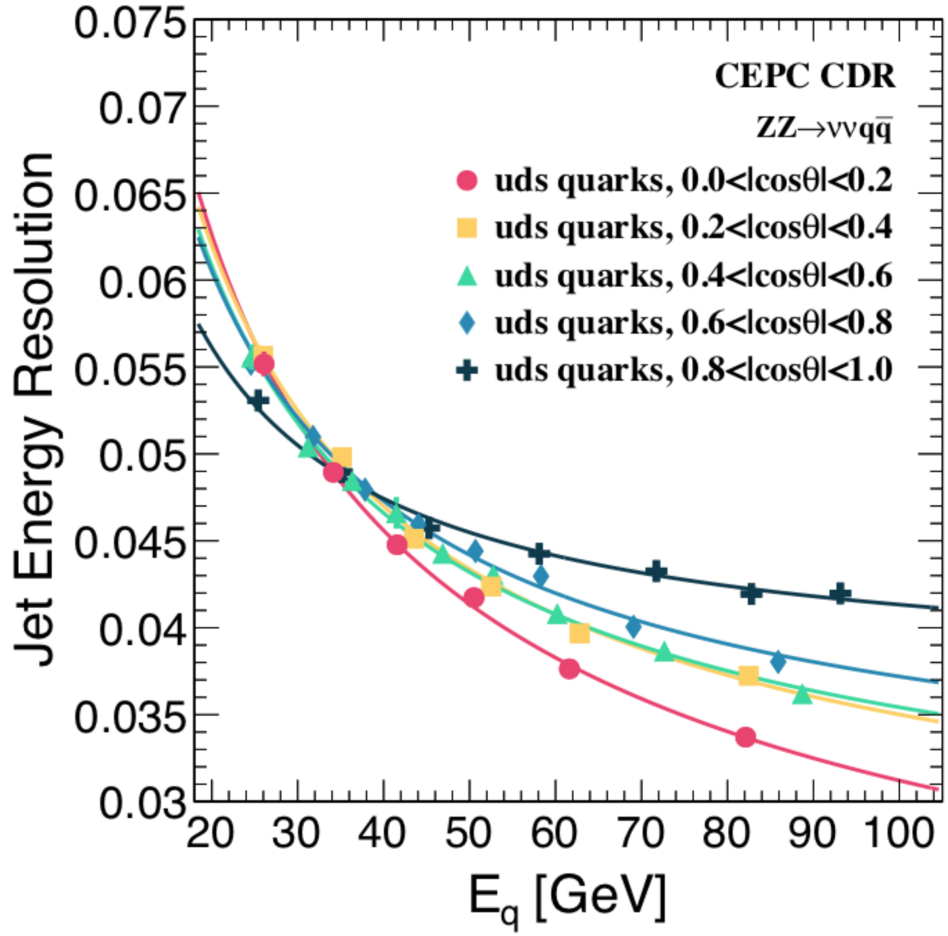
WW sample: using μvqq sample,
Plot: the visible mass without the muon

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 & Resolution





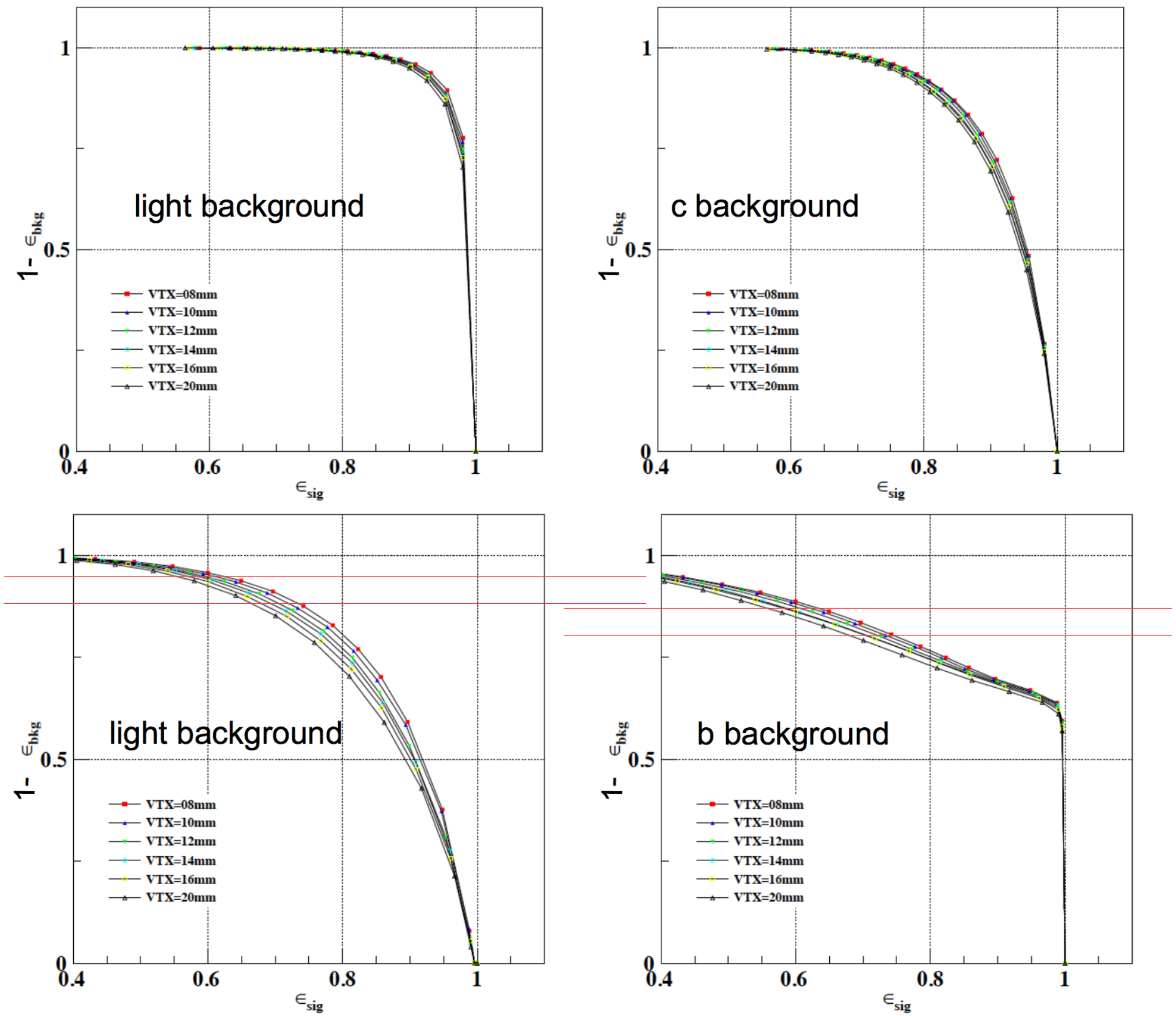
- JES ~ with 1% of the unity (without correction)
- JER ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
- **Both Superior to LHC experiments by 3-4 times**

See Peizhu Lai's talk

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/

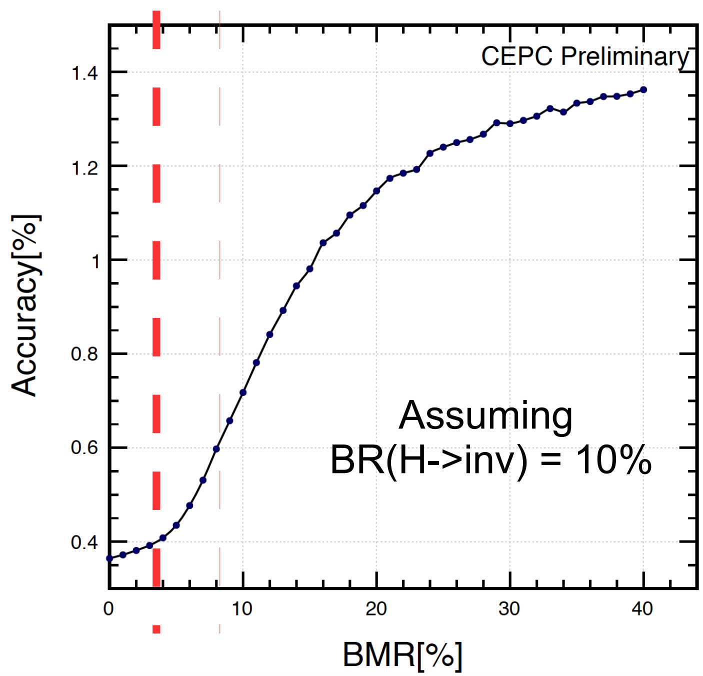
Key performances to flavor physics

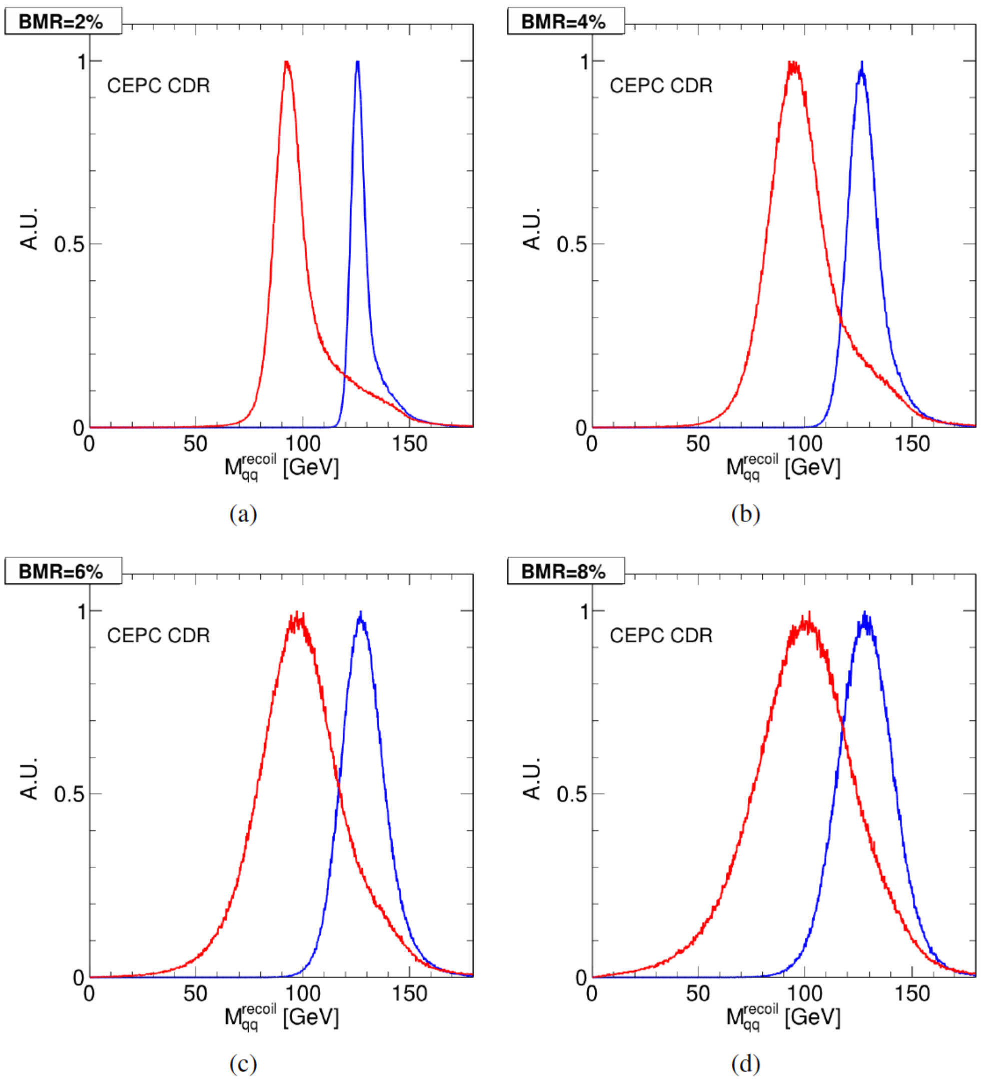
- Identification of decay final state particles from Jet (against combinatory background)
- Lepton: identification of isolated, and Jet lepton
- Kaon: identification of Kaon inside jet
- Tau:
  - Finding performance of isolated, and jet tau.
  - Identification of Tau decay final state
- Pi-0 reconstruction performance
- Kshort, Lambda, Phi, J/psi reconstruction
- Missing Energy...
- Jet Flavor Tagging;
- Jet Charge measurement;
- Track threshold, track momentum, photon energy, etc.
- VTX: reconstruction efficiency & accuracy

We know how the performance is alike in CEPC baseline detector; but we don't know if it's good enough/overkill -> need quantification

Objective - an example: qqH, H→invisible

- Portal to DM...
- qqH dominants the precision & rely on the recoil mass to separate the ZZ bkg
- Essential for qqH analysis, especially H→non jet final state





If the BMR degrades from 4% to 6/8%: the Higgs invisible measurement degrades by 20/50%

Analyses tactic: recommendation

- What we have:
  - Signal & Background Generator file
  - 10M fully simulated Background Z->qq events
  - Potentially: ~ 1 Million full simulated signal
- Key question: to identify the signal from the background
  - Contaminations via mis-id of physics objects (inpurity)
  - Resolution
- Tactic:
  - Understand the event topology and key signature
  - Workout the finding criteria at Z->qq sample (Event Selection Variables) through MC-truth level analysis
  - For the corresponding physics object – workout the optimal working point by maximize the eff*purity at the signal and the SM background - To mimic the contamination/combinatory background
  - Develop the Fast simulation code and validate it on Full simulation distributions – on key variable distributions
  - Parameterize the key performance in the Fast simulation code, and extract the final accuracy at different working point.

Summary

- Key physics object identified for the CEPC flavor program: most of their reconstruction performance is analyzed via Full simulation at the CEPC baseline detector
  - Reference point for benchmark physics analysis fast simulation tool
  - Several performance need further quantification (VTX, Jet Charge, Combination background control)
- The existing Full simulated Z->qq sample could be used to study the SM & Combination background analyses.
- Dedicated generator sample/toolkit will be needed for benchmark analyses, however, some fast estimation could be started even before that.

Backup

Generator: a potential barrel

Quantification of the physics requirement: 1st example...

Quantification of the physics requirement: 2nd example...