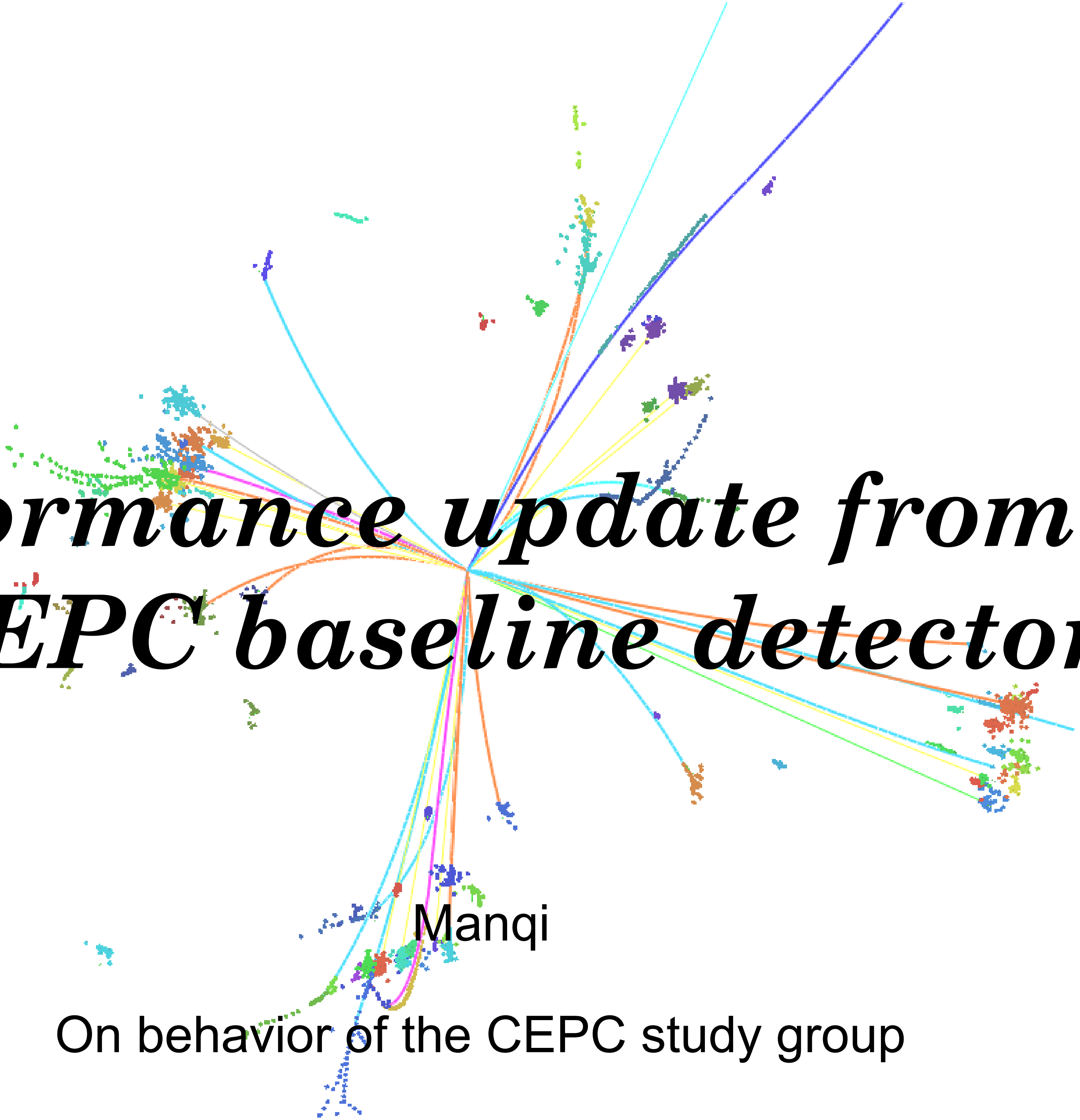


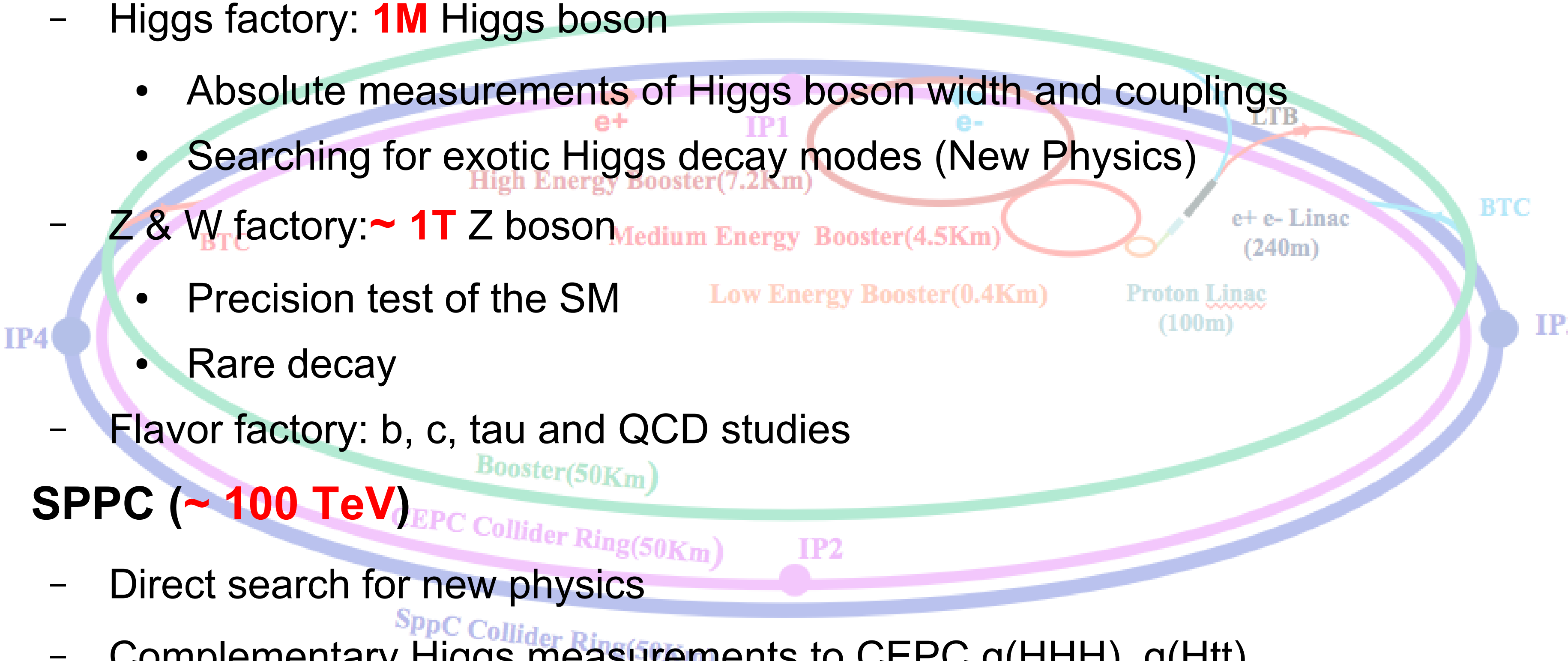
Performance update from the CEPC baseline detector

Manqi

On behalf of the CEPC study group

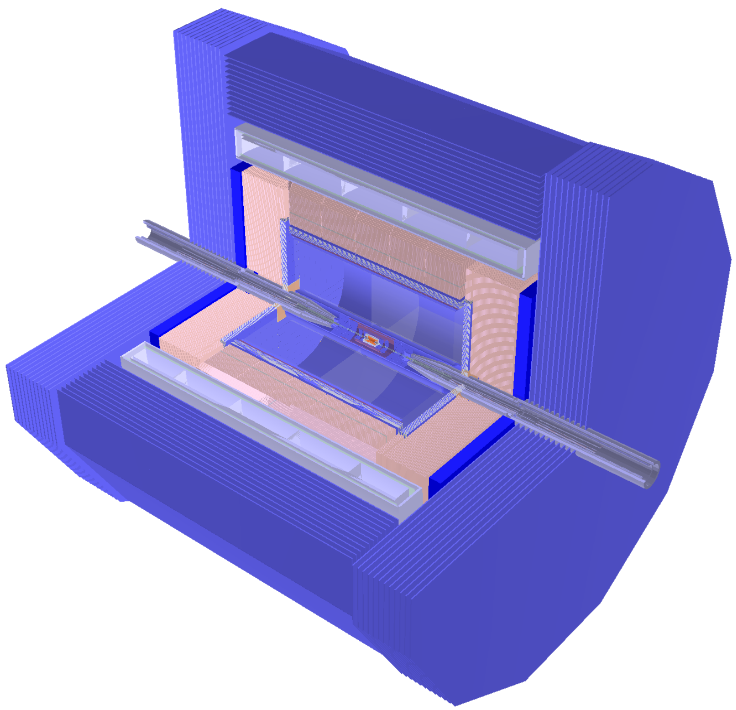
Science at CEPC-SPPC

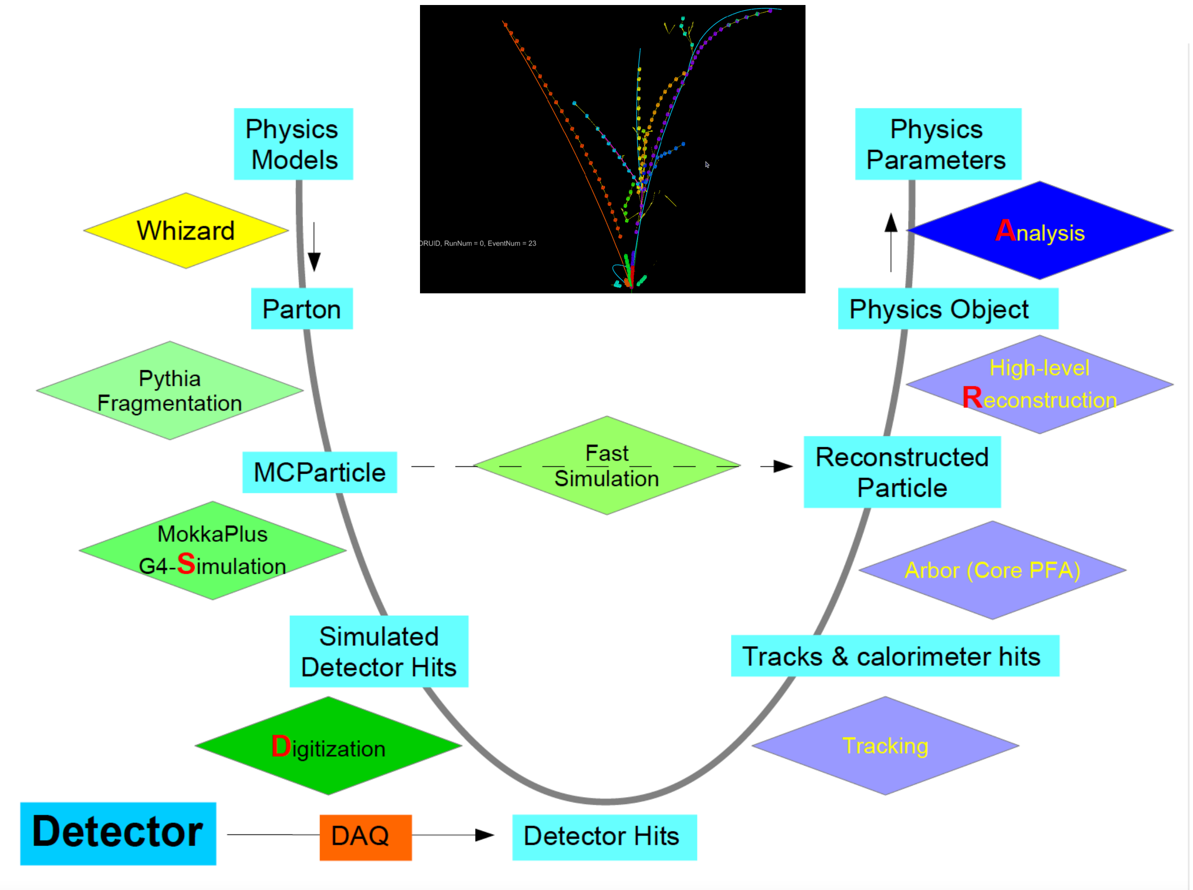
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **~ 1T** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor 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...**



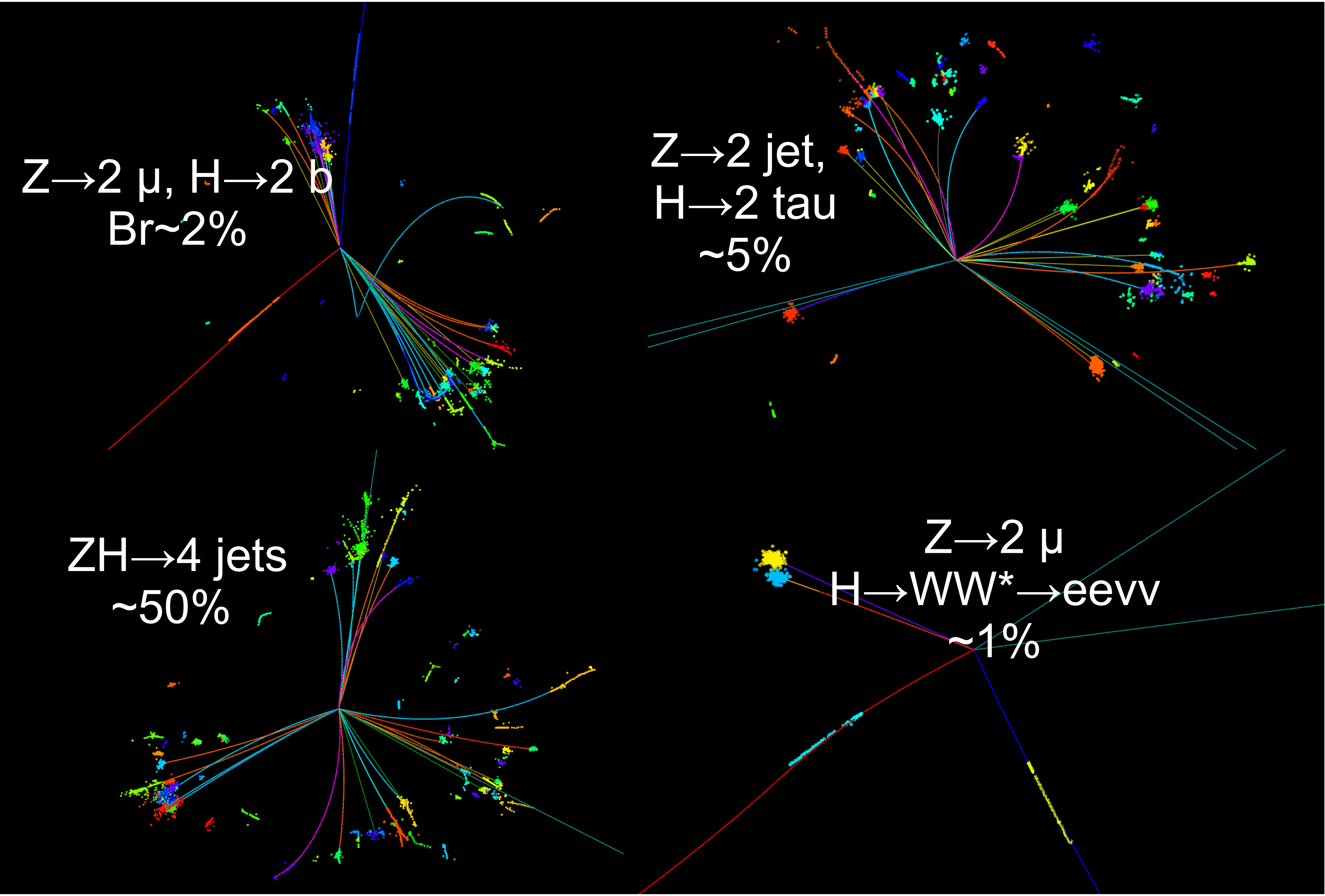
Complementary

Baseline detector: Simu & Reco

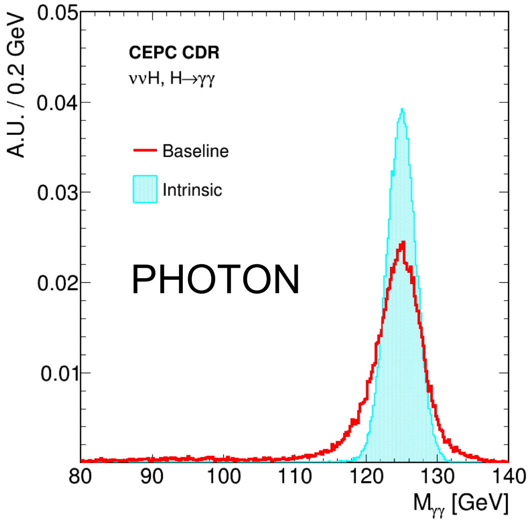




Starting from the ILD/ilcsoft, adjust-optimize the geometry, developing PFA (Arbor) & other high-level reconstruction algorithms.


Z→2 μ, H→2 b
Br~2%
Z→2 jet,
H→2 tau
~5%
ZH→4 jets
~50%
Z→2 μ
H→WW*→eevv
~1%

Reconstruction of Physics objects



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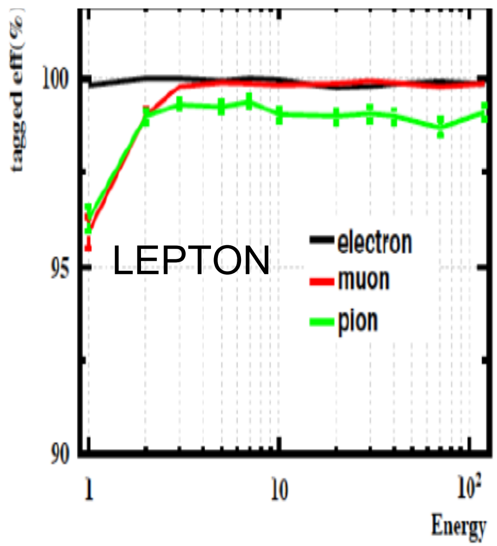

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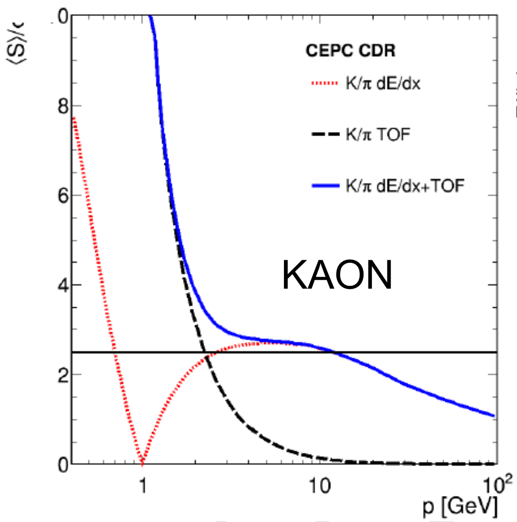

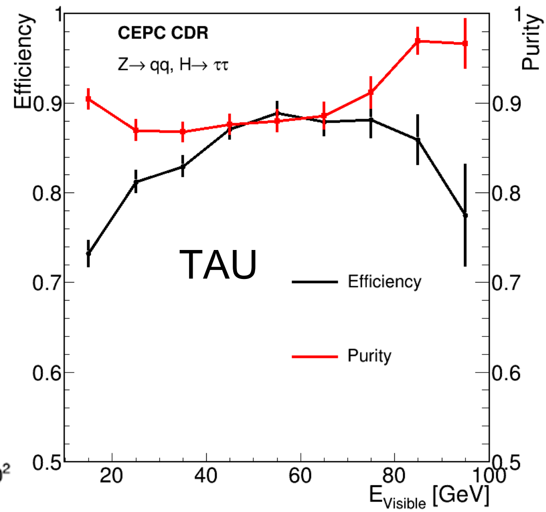

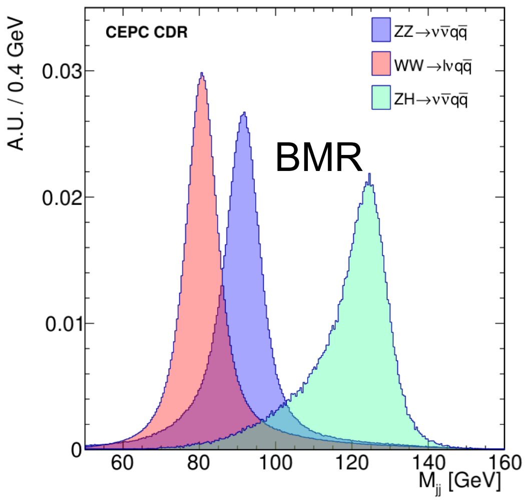

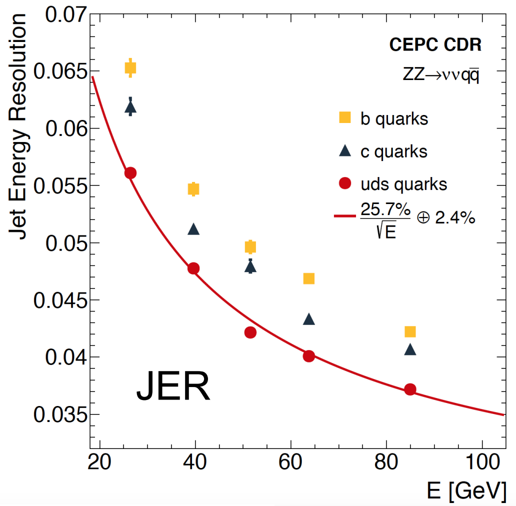

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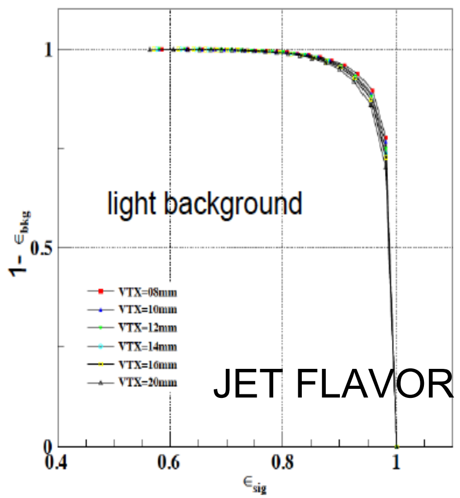
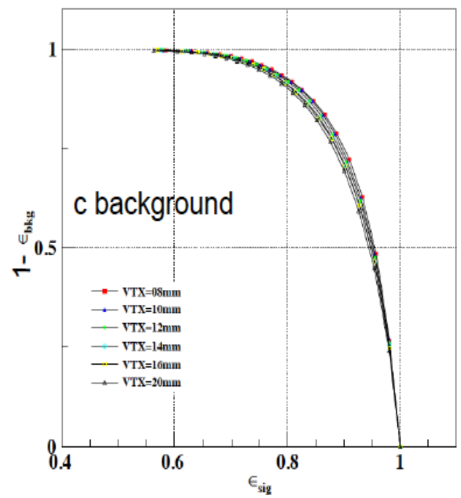
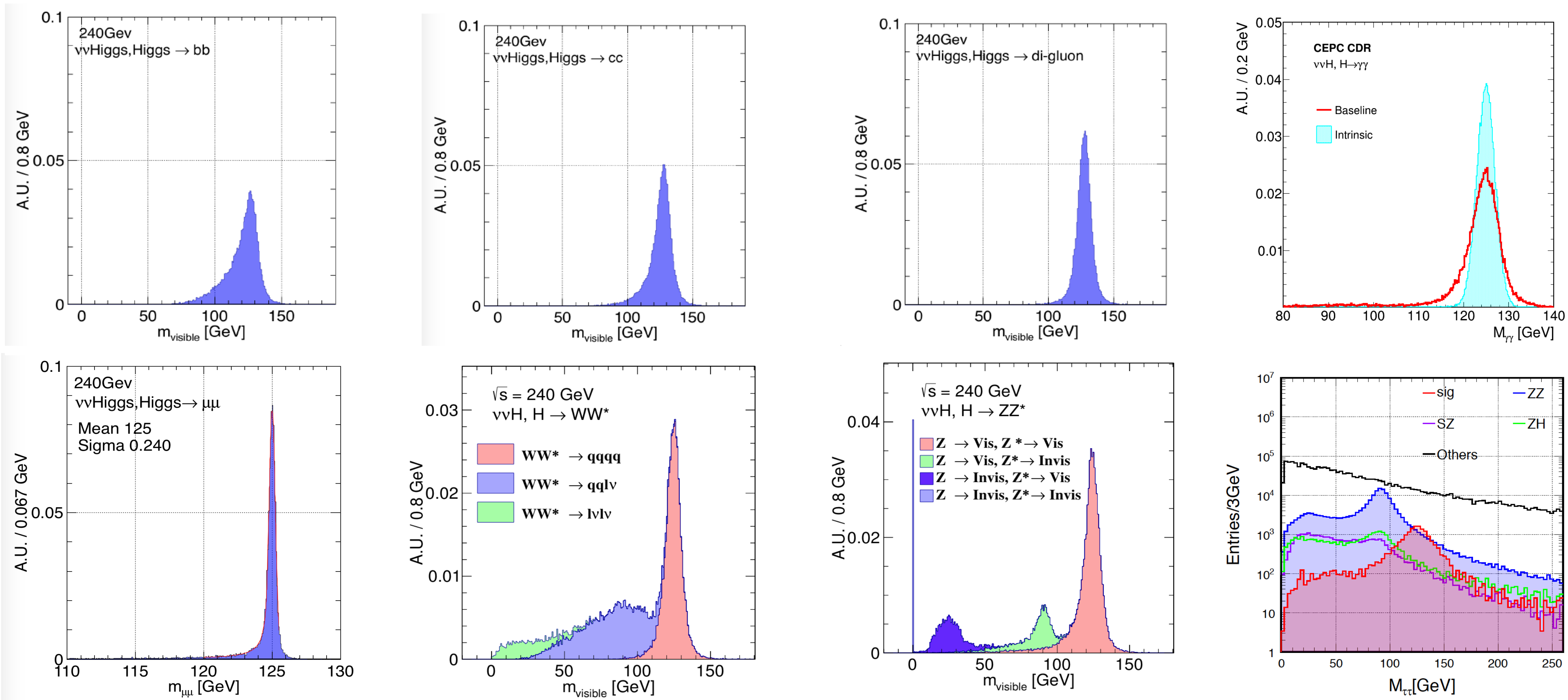




Higgs Signals

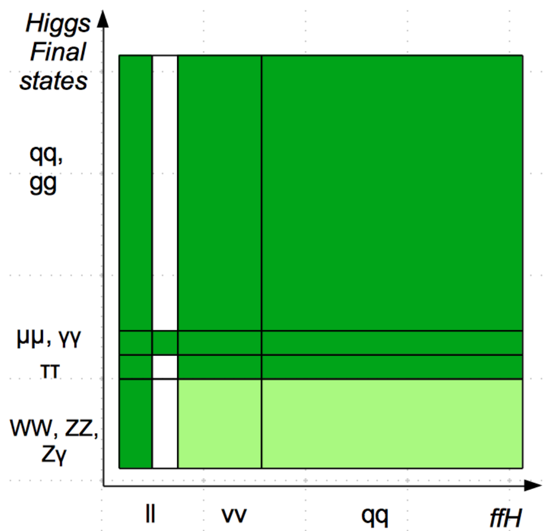


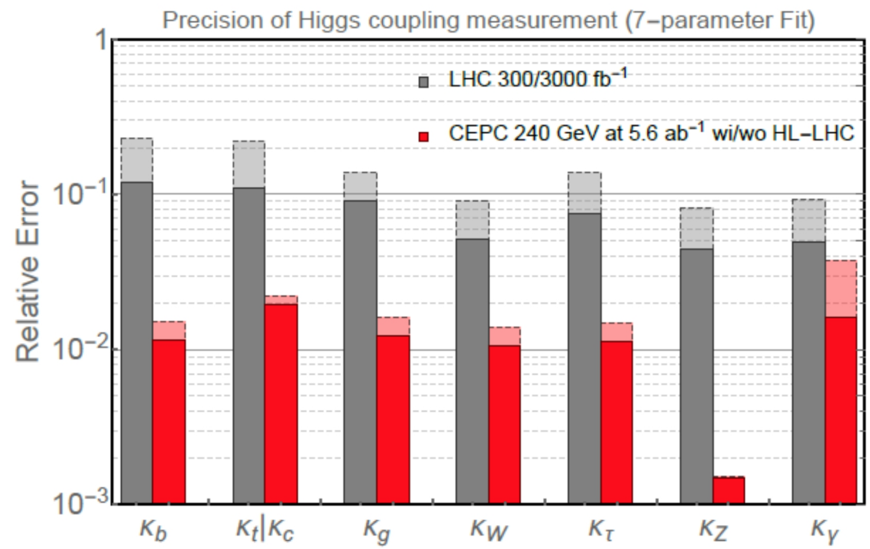
Clear Higgs Signature in all SM decay modes

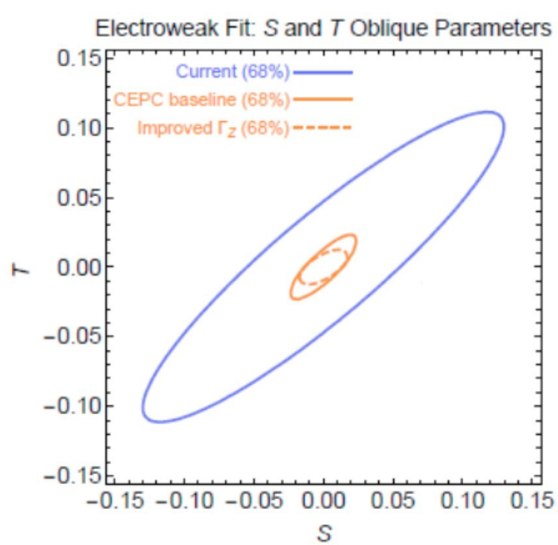
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

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

Applied on Higgs physics, et.al







Chinese Physics C

PAPER • **OPEN ACCESS**

Precision Higgs physics at the CEPC

To cite this article: Fenfen An *et al* 2019 *Chinese Phys. C* **43** 043002

View the article online for updates and enhancements.

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

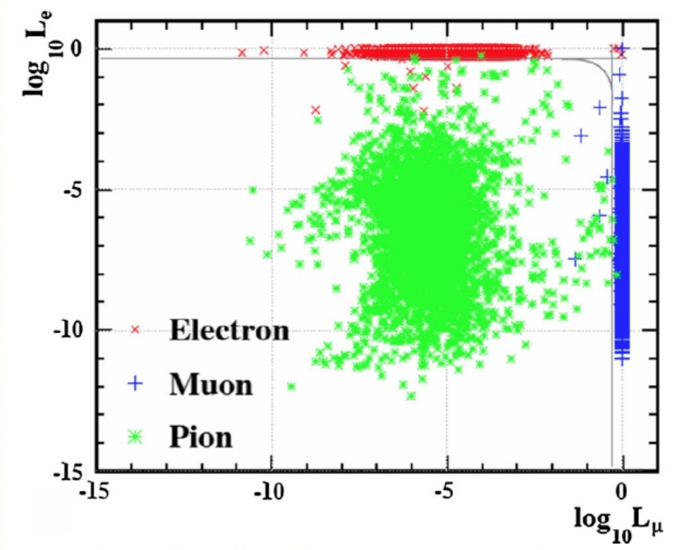
Recent Progresses

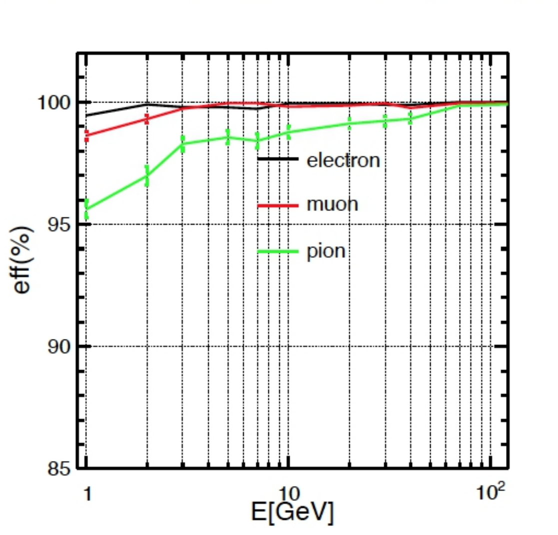
- Leptons: Inside jets
- Taus: isolated, or inside jet
- Hadronic systems:
  - Jets: differential performances
  - Dependence of the BMR on Detector geometry
- ...

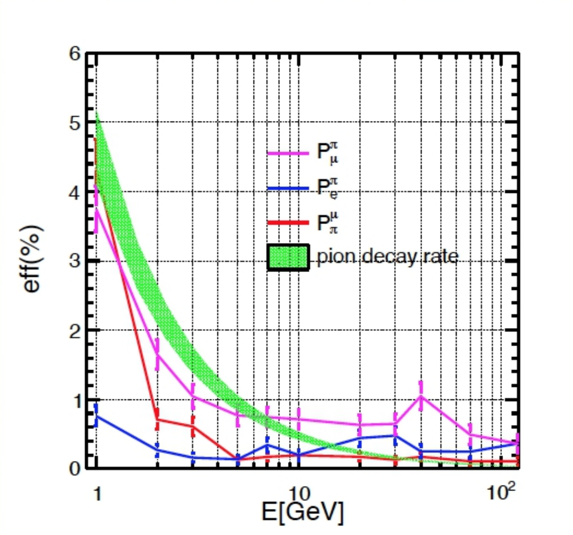
Light Lepton Identification

Dan Yu

- LICH uses TMVA methods to summarize 24 input variables into two likelihoods, corresponding to electrons and muons.
- The efficiency for electron and muon is higher than 99.5% (E>2 GeV). Pion efficiency ~ 98%.







Migration Matrix at 40GeV (LICH)

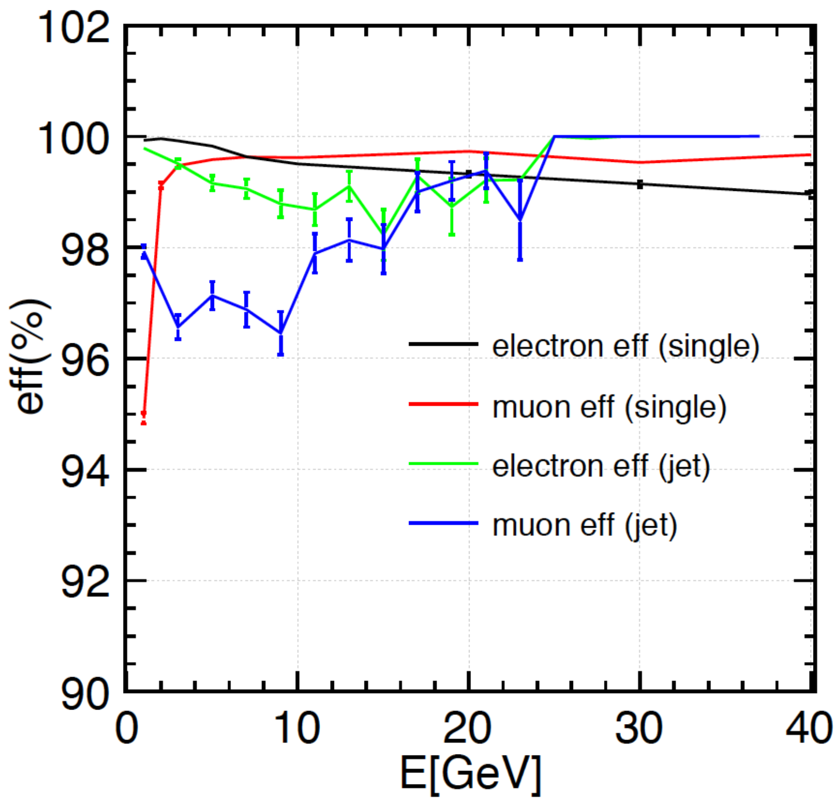
Type	e^- *like*	μ^- *like*	π^+ *like*
e^-	99.71 ± 0.08	< 0.07	0.21 ± 0.07
μ^-	< 0.07	99.87 ± 0.08	0.05 ± 0.05
π^+	0.14 ± 0.05	0.35 ± 0.08	99.26 ± 0.12

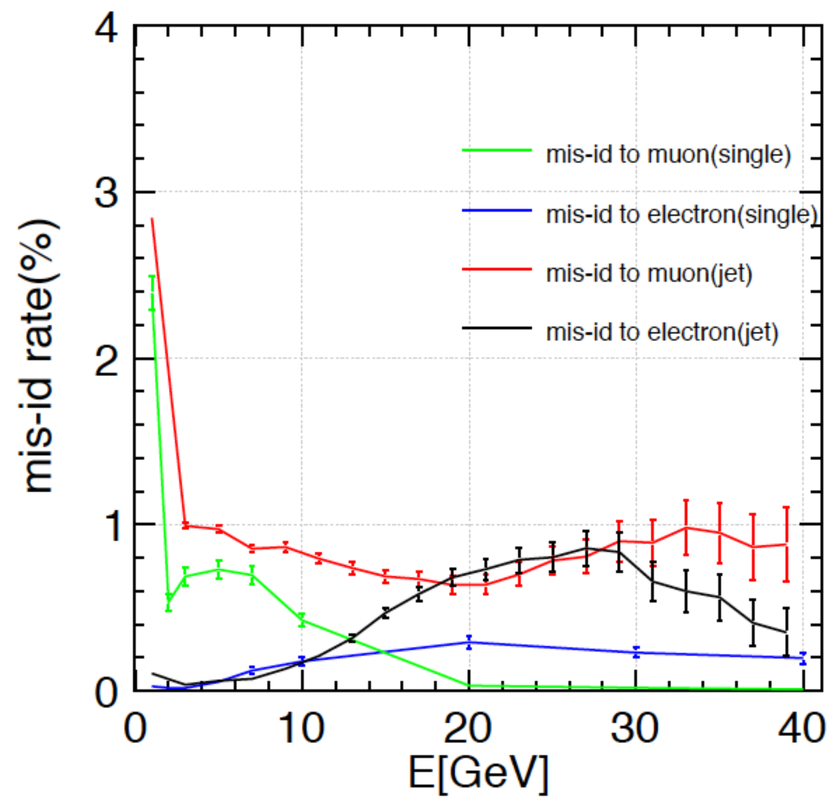
Migration Matrix for ALEPH PID ($> 2GeV$)(*Eur.Phys.J.C20:401-430,2001*)

Type	e^- *like*	μ^- *like*	π^+ *like*	undefined
e^-	99.57 ± 0.07	< 0.01	0.32 ± 0.0	0.09 ± 0.04
μ^-	< 0.01	99.11 ± 0.08	0.88 ± 0.08	0.01 ± 0.01
π^+	0.71 ± 0.04	0.72 ± 0.04	98.45 ± 0.06	0.12 ± 0.03

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

Jet lepton

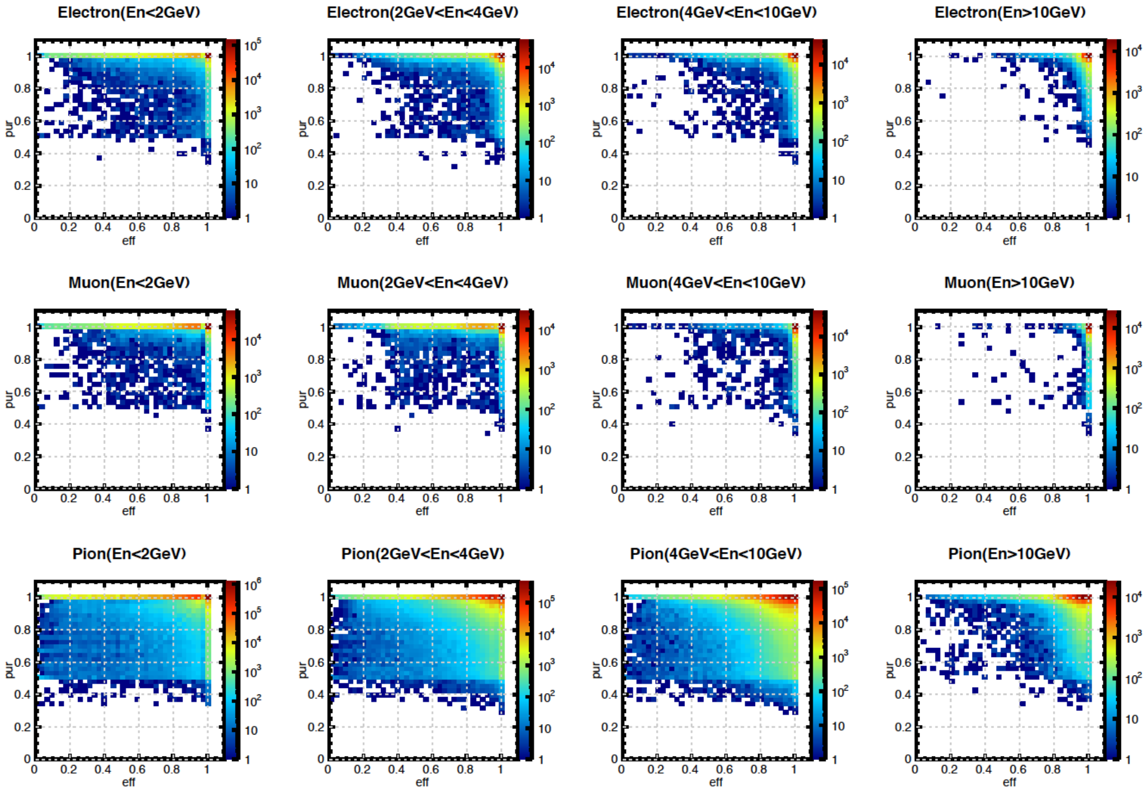


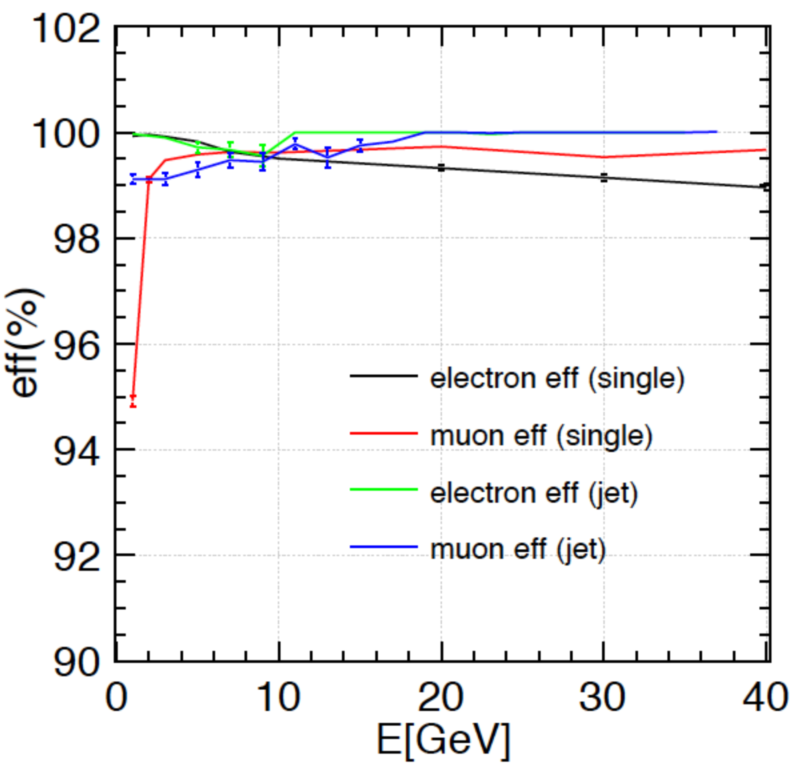


Compared the single particle sample, the jet lepton (at Z->bb sample at sqrt = 91.2 GeV) Performance will be slightly degraded. At the same working point,

The efficiency can be reduced by up to 3%; while mis-id rate increases up to 1%. Marginal Impact on Flavor Physics measurements as Bc->tauv.

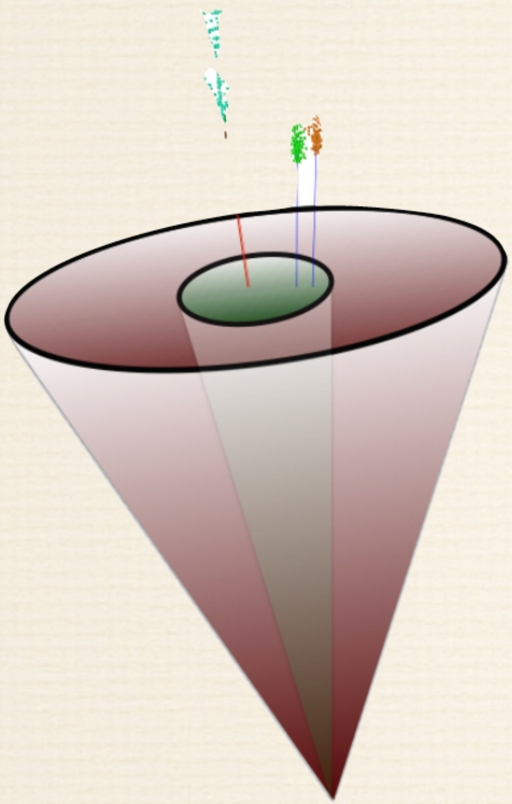
Jet lepton: performance depends on calorimeter clustering





Relative difference reduced once require a good Calorimeter Clustering Performance

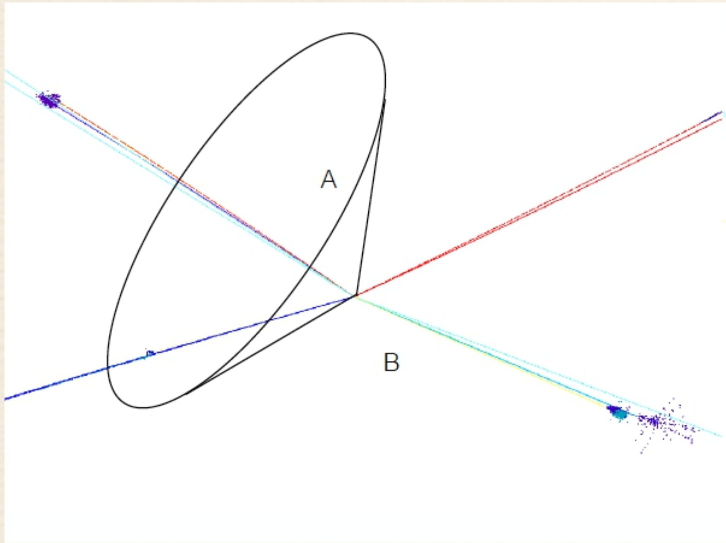
Taurus

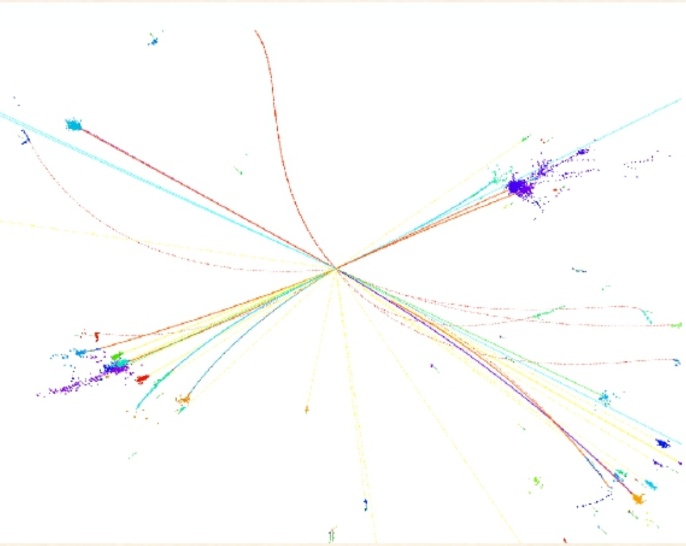


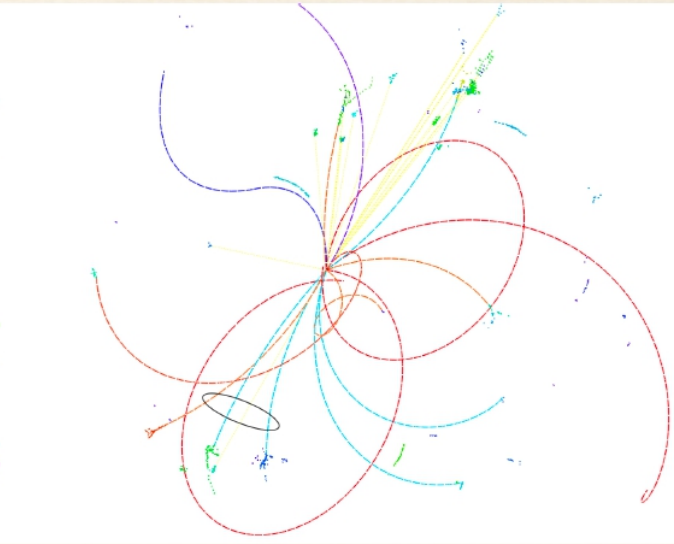
- Double cone based algorithm
  - Find seeds(Tracks with enough energy)
  - Collect particle in two cones
  - Use the multiplicity, energy ratio between two cones, invariant mass for τ tagging

Event topology

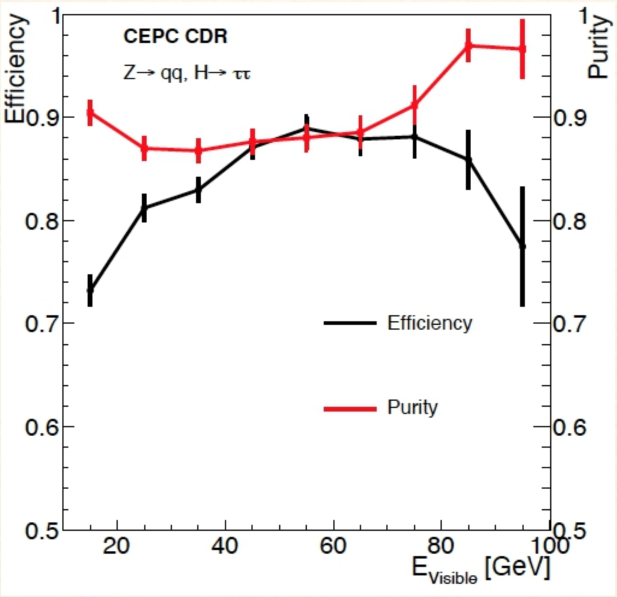
- llH channel / Z→ττ
- qqH (isolate τ with jets)
- τ inside jets

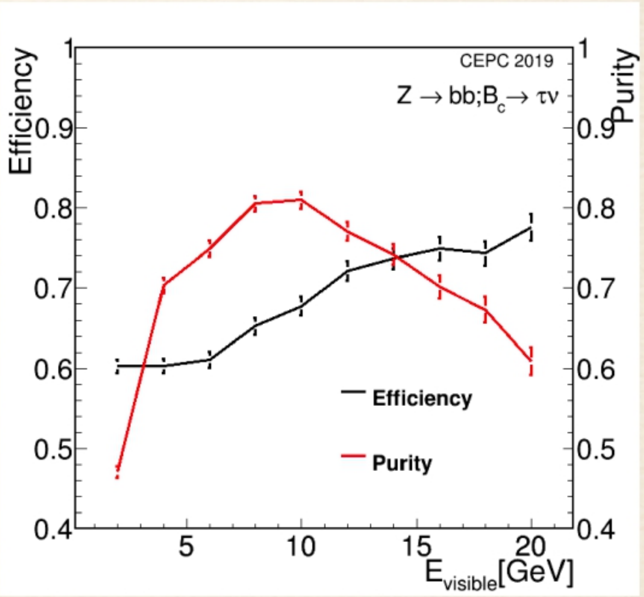




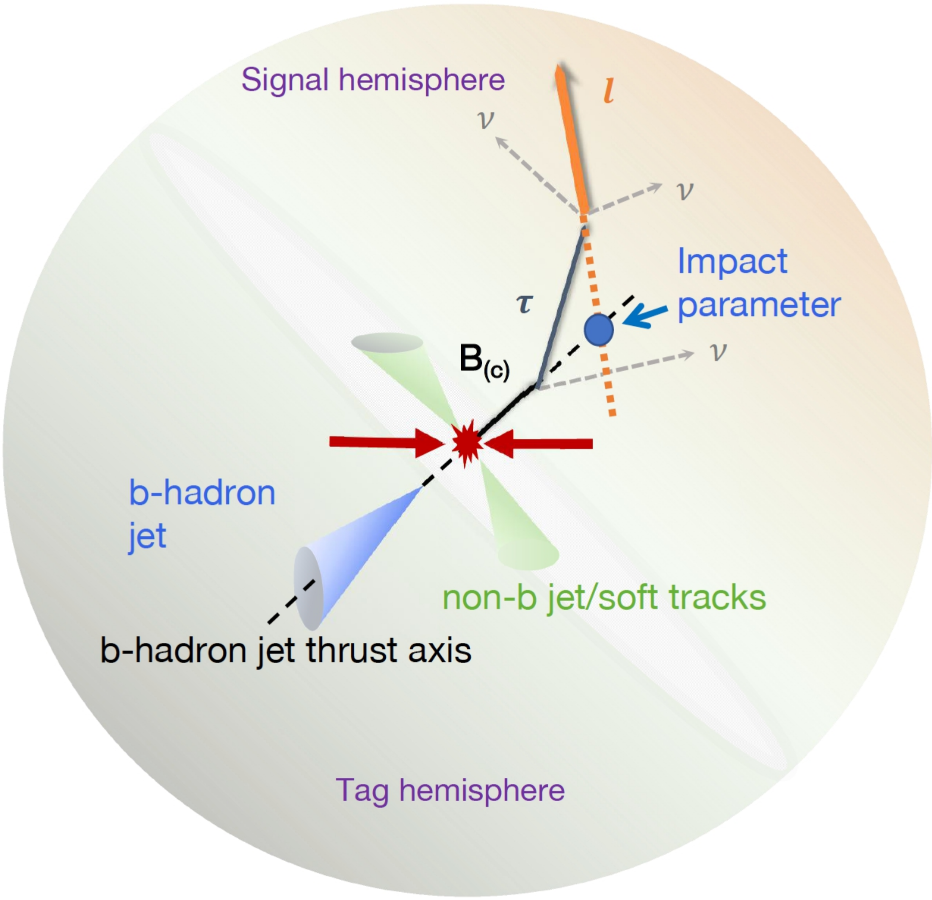


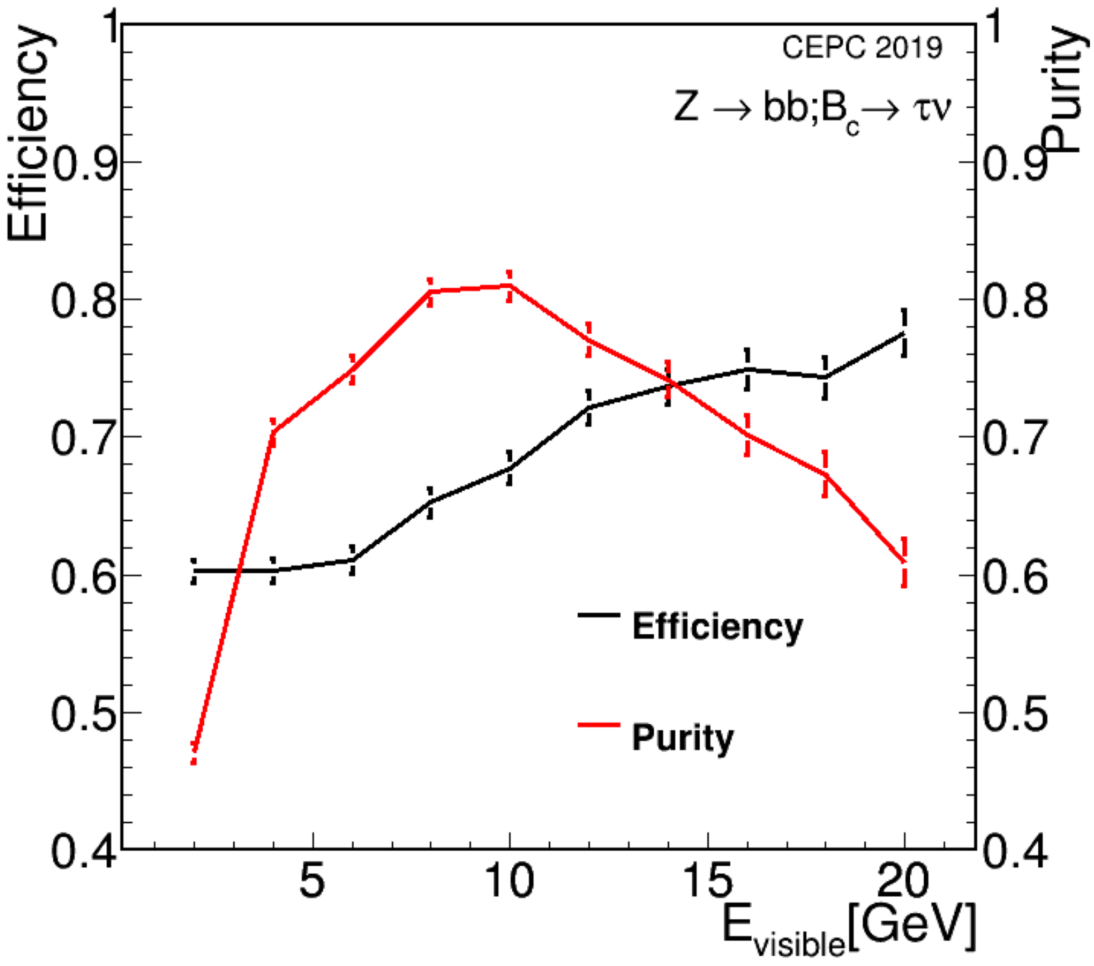
- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter
- Efficiency > 90%





Tau finding inside jet

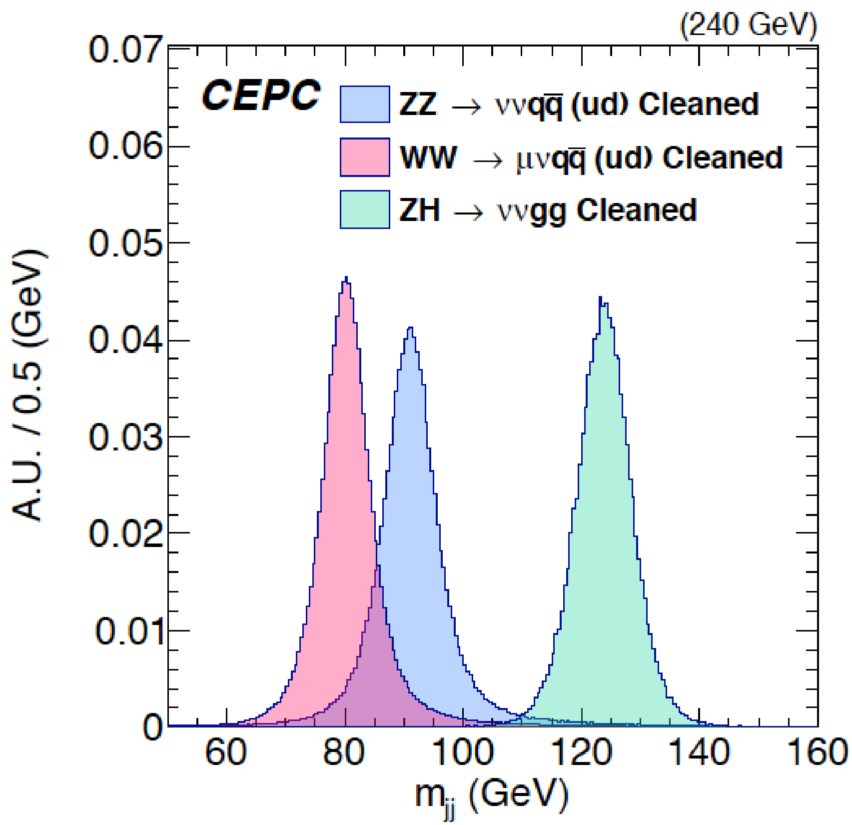




Lepton & Tau at the baseline

- Leptons: identified with LICH
  - Isolated ones: (eff ~ 99.5-99.9%, mis-id < 1%) the best for e+e- Higgs factories full simulation, approaching the physics limit
  - Jet leptons: ~o(1%) degrading w.r.t. Isolated ones
    - not signifiant impact on current physics benchmarks
    - caused by calorimeter clustering performance, in-turn become an estimator on clustering performance
- Taus: identified with Taurus
  - Isolated ones: eff*purity ~ 0.7;
  - Inside jets (as Z->bb): eff*purity ~ 0.5;
  - Further optimization on going.
  - Next step: Identification of tau decay modes at different benchmark.

CEPC Baseline: BMR = 3.8%



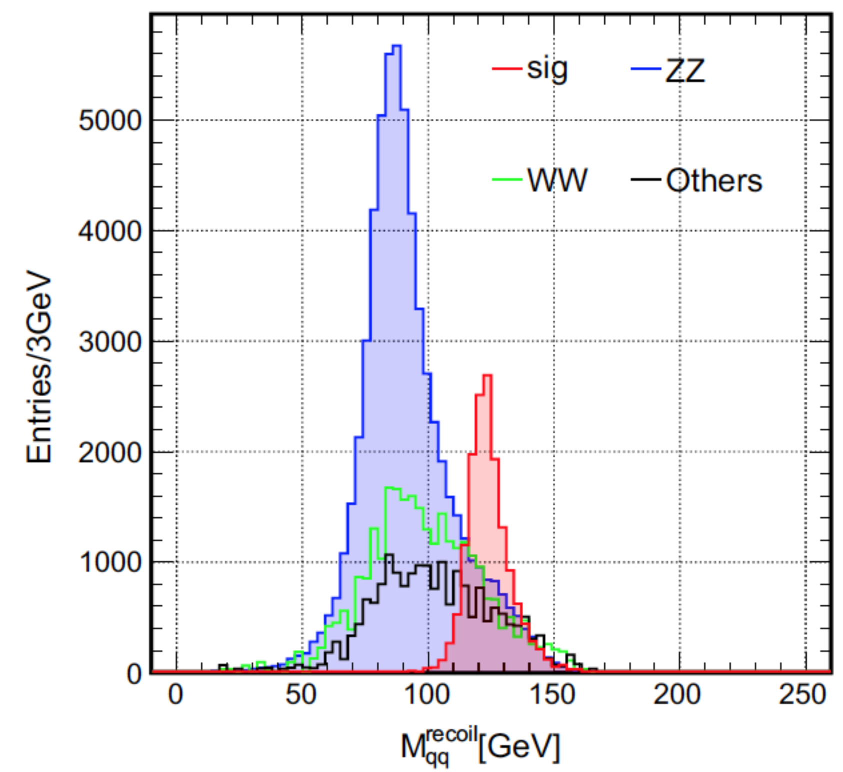
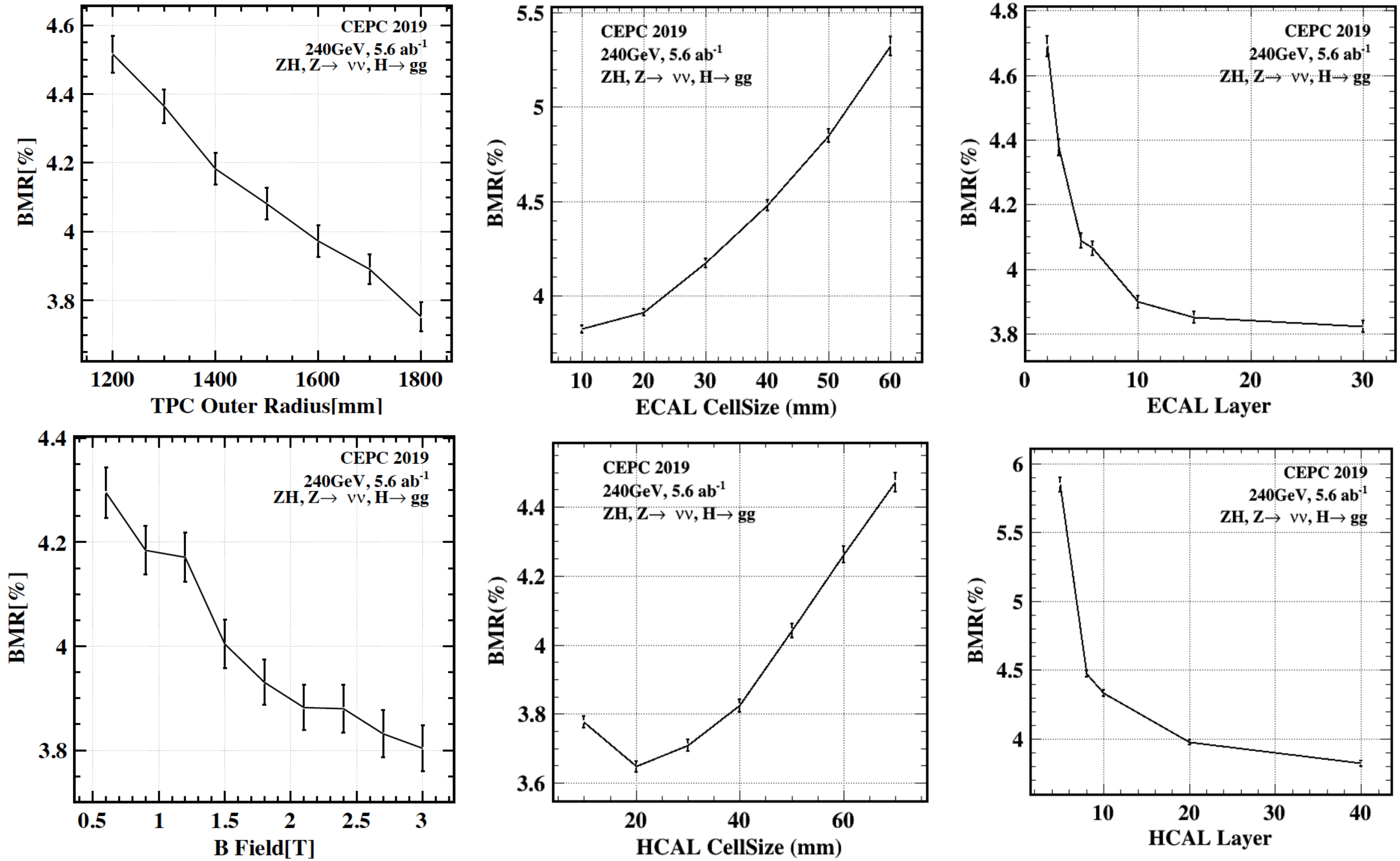


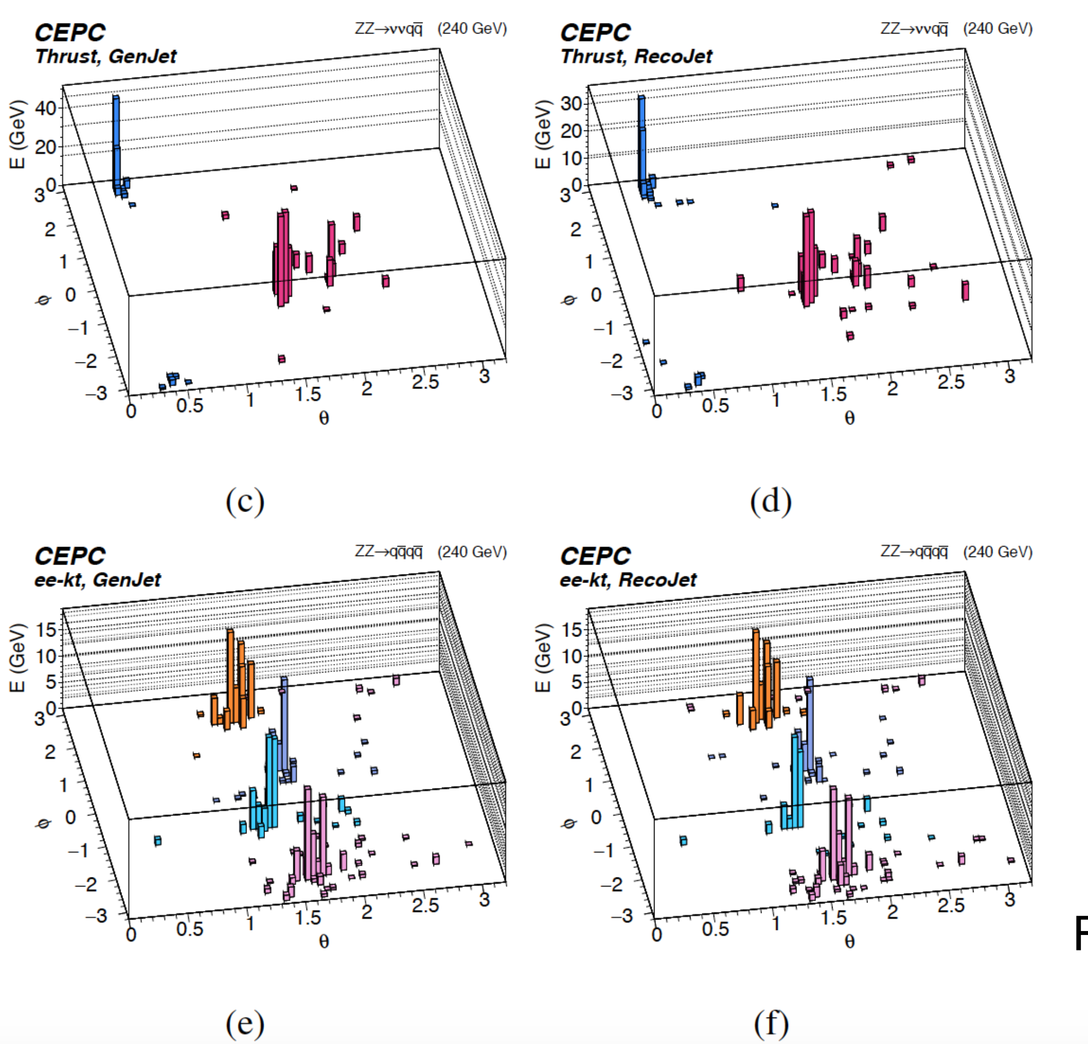
Fig. 7 Distribution of the recoil mass of the qq, M_{qq}^{recoil} for $Z \to qq$, $H \to \tau\tau$ and each background at $\sqrt{s} = 240$ GeV after the previous cuts

FulFill the requirement of BMR < 4%, to separate the W/Z/Higgs with hadronic system invaraint mass, and the qqH signal from qqX background with recoil mass spectrum.

BMR V.S. Geometry



Individual jet: jet clustering - matching



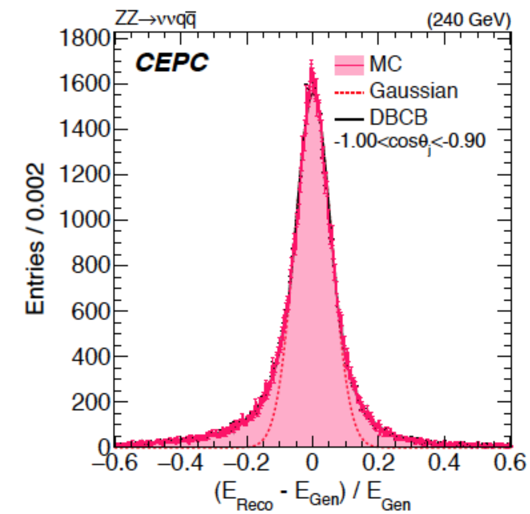


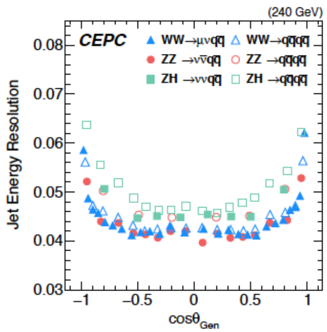
Fig. 7: σ and $\bar{x}$ from the core of the DBCB fit to R are defined as JER/S, respectively. The $cos\theta_j$ indicates the specific polar angle of the jets.

Jet Clustering & Matching is critical:
ee-kt is used as CEPC baseline

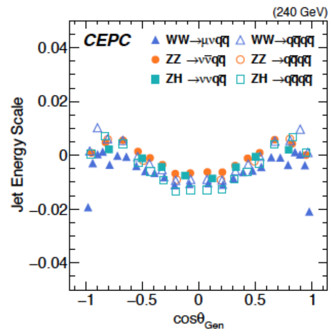
Relative difference between Gen/Recojet is define to be the detector jet response

New Progress: Differential jet response on Jet energy & Polar angle

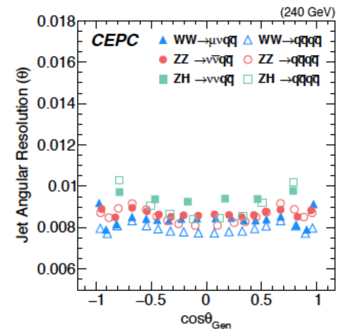
Peizhu



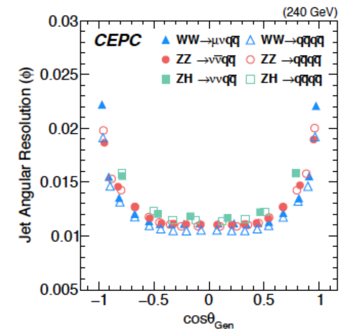
(a)



(b)



(a)



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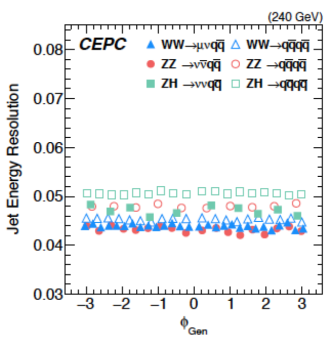

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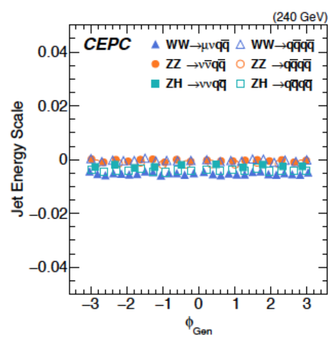
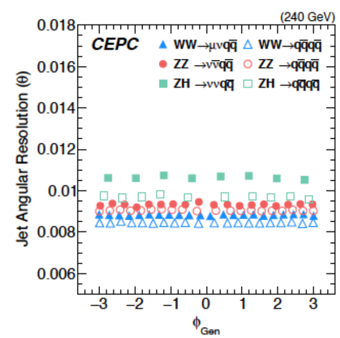
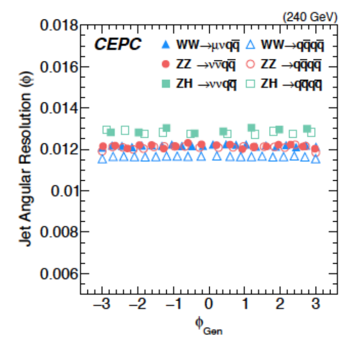


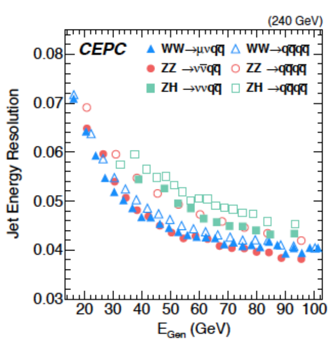
(d)



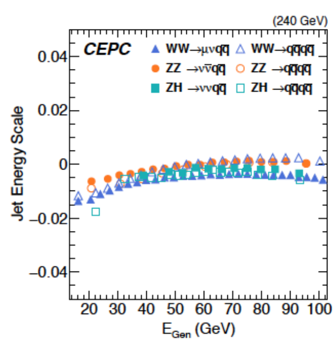
(c)



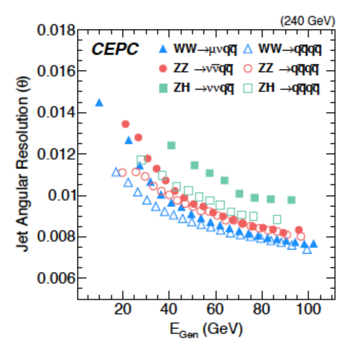
(d)



(e)



(f)



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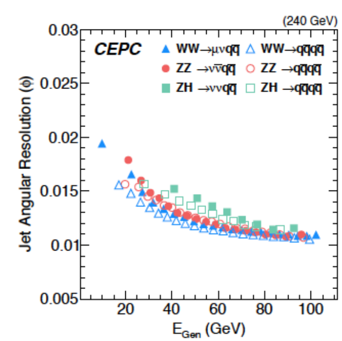
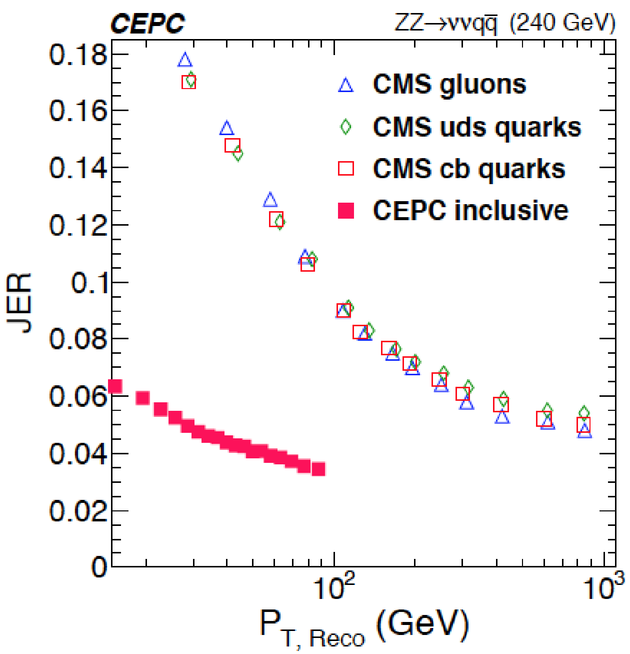
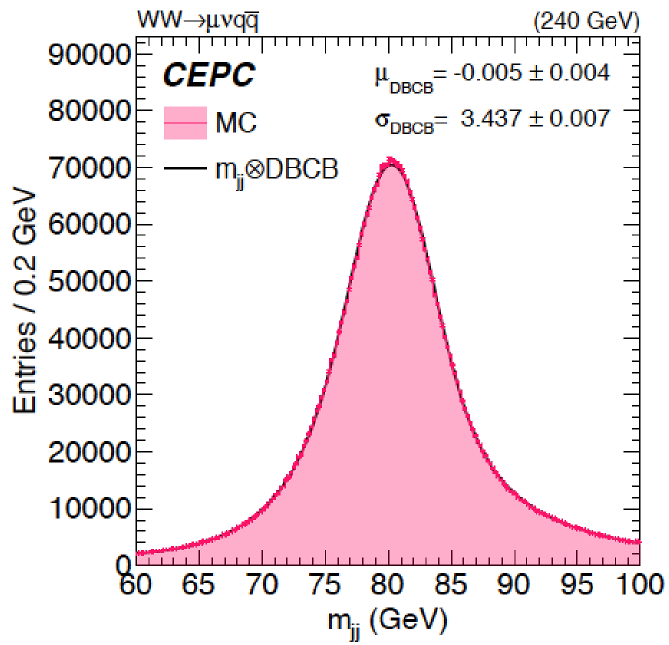
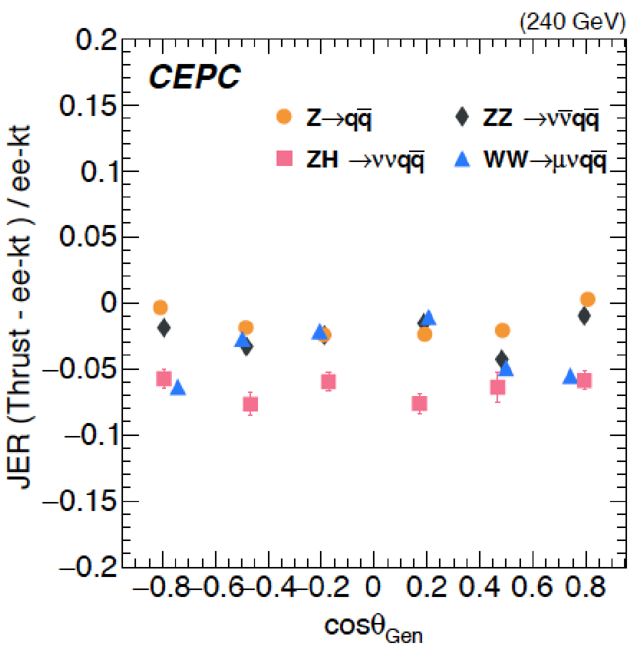


(f)

Jet Response







- Significantly better than LHC experiments (at 0 PU);
- Jet Calibration: control the W mass measurements at Higgs run ~ 10 MeV
- Thrust based JC could improve JER ~ 5-10% w.r.t baseline (ee-kt);

Pid: Identify charged hadrons with energy up to 20 GeV...

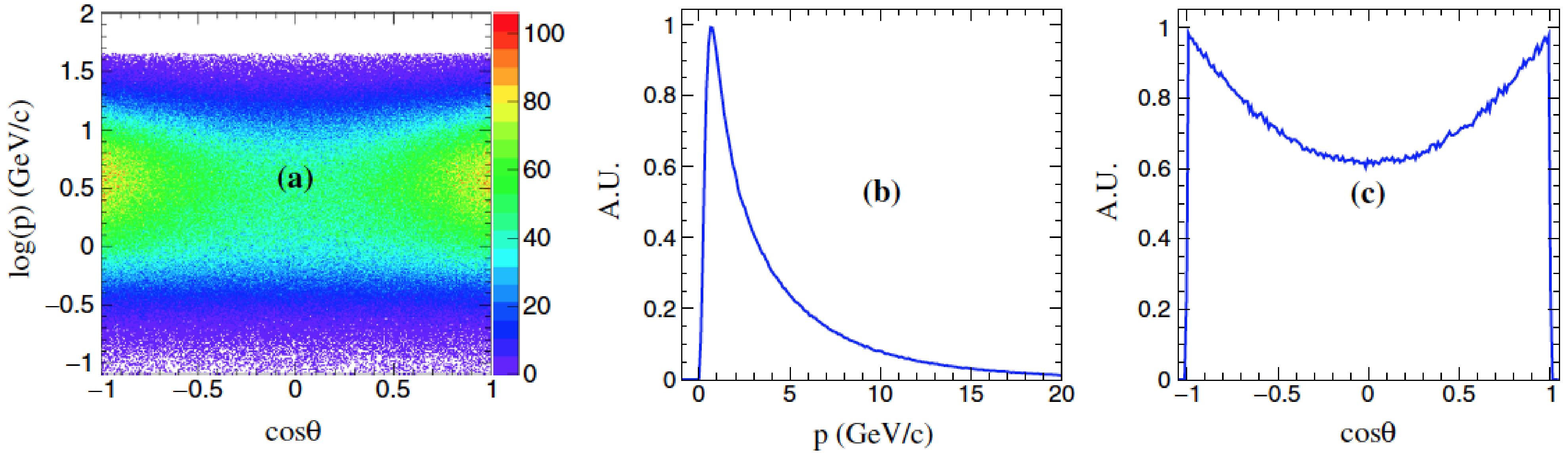
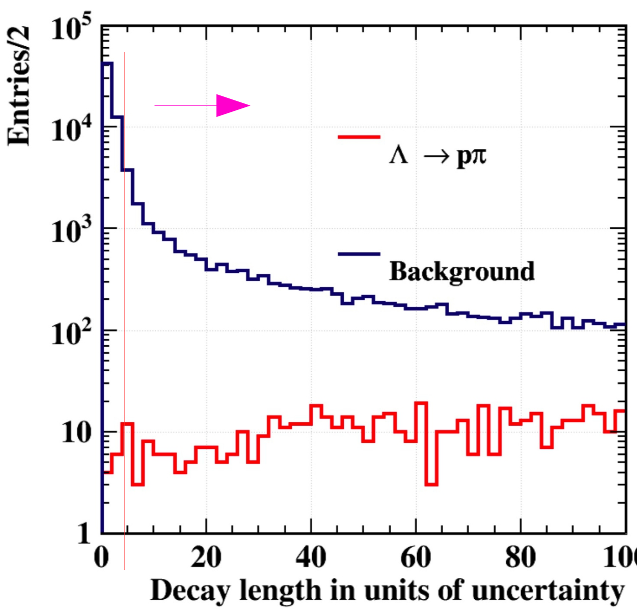
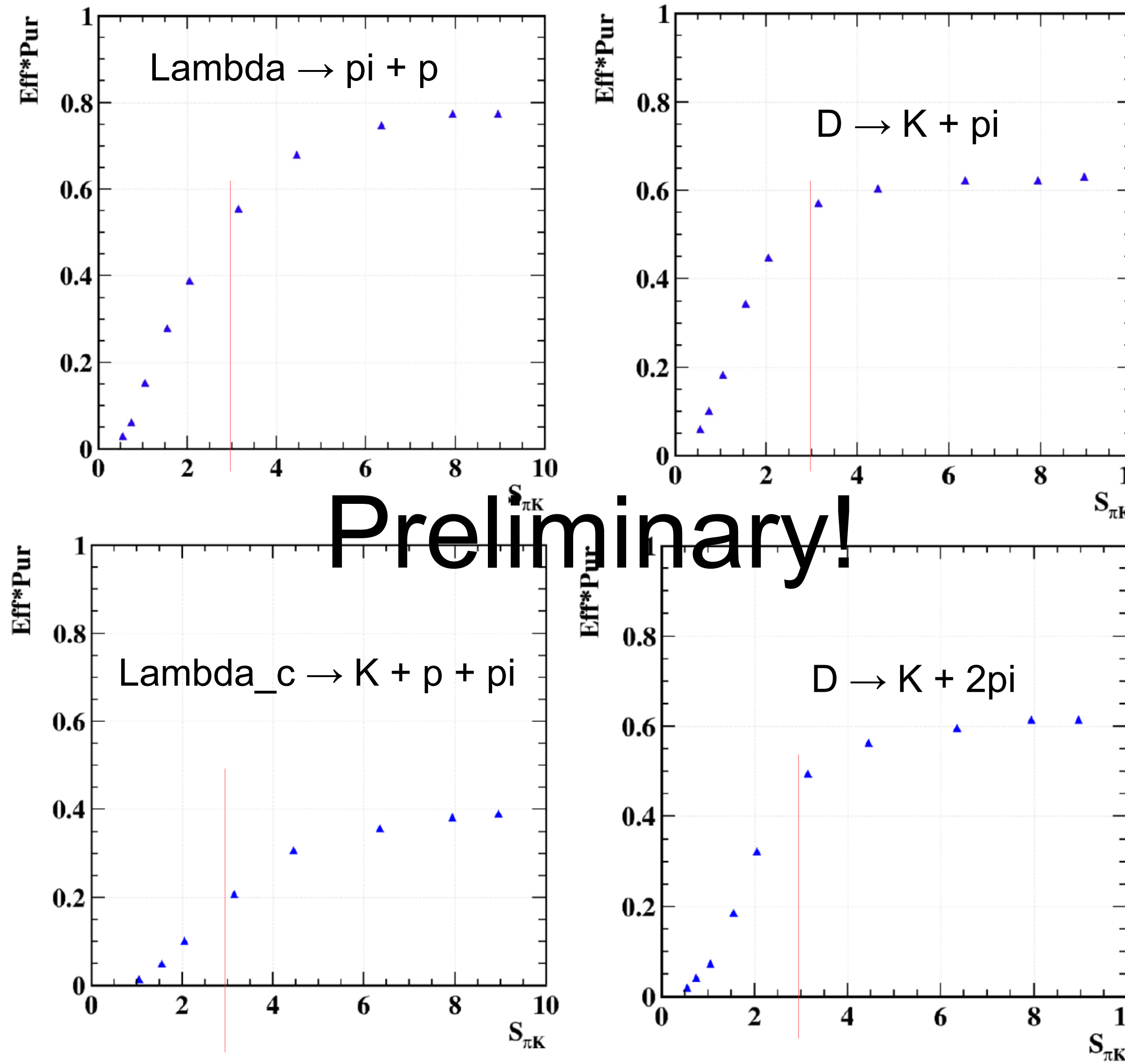


Fig. 3 Kinematic distribution of kaons in $e^+e^- \rightarrow Z \rightarrow q\bar{q}$ MC events as a function of $\log(p)$ and $\cos\theta$ (**a**), p (**b**), and $\cos\theta$ (**c**)

Pid & Objective Hadron finding

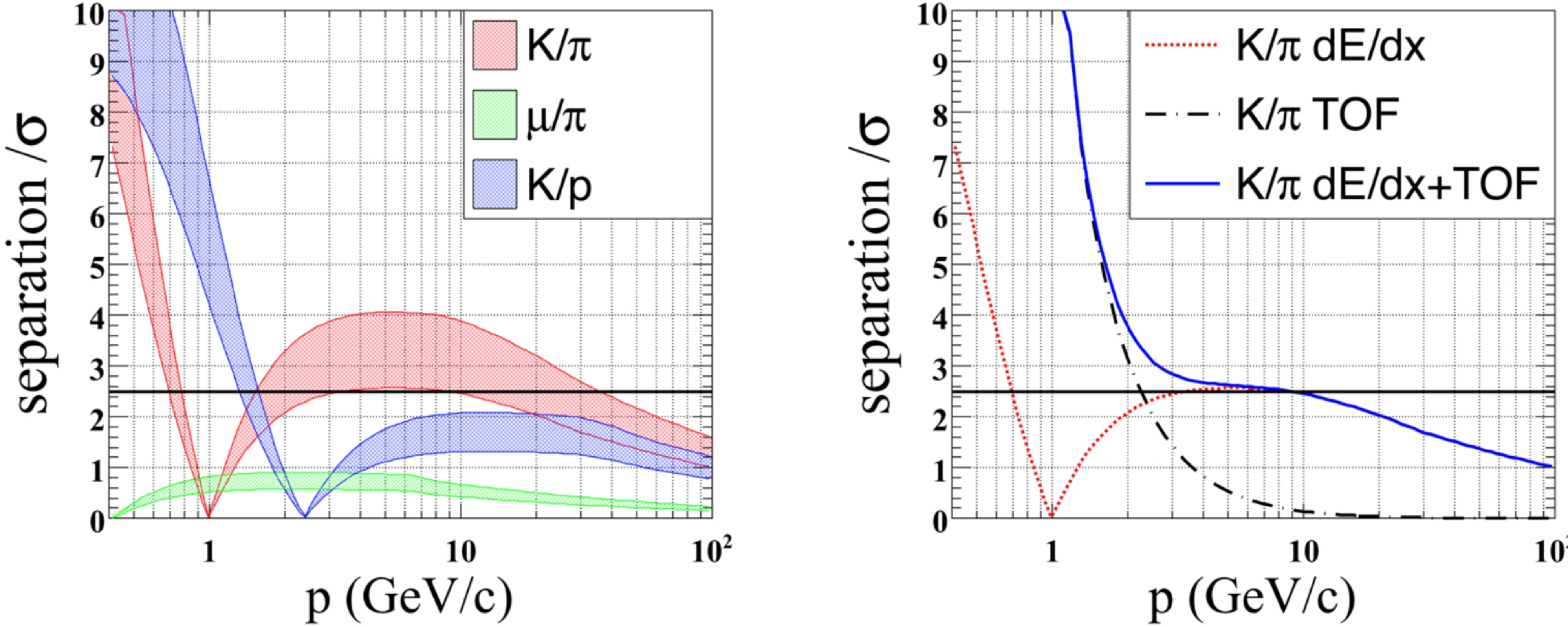
$$S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma_{I_A}^2 + \sigma_{I_B}^2}},$$





Preliminary!

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

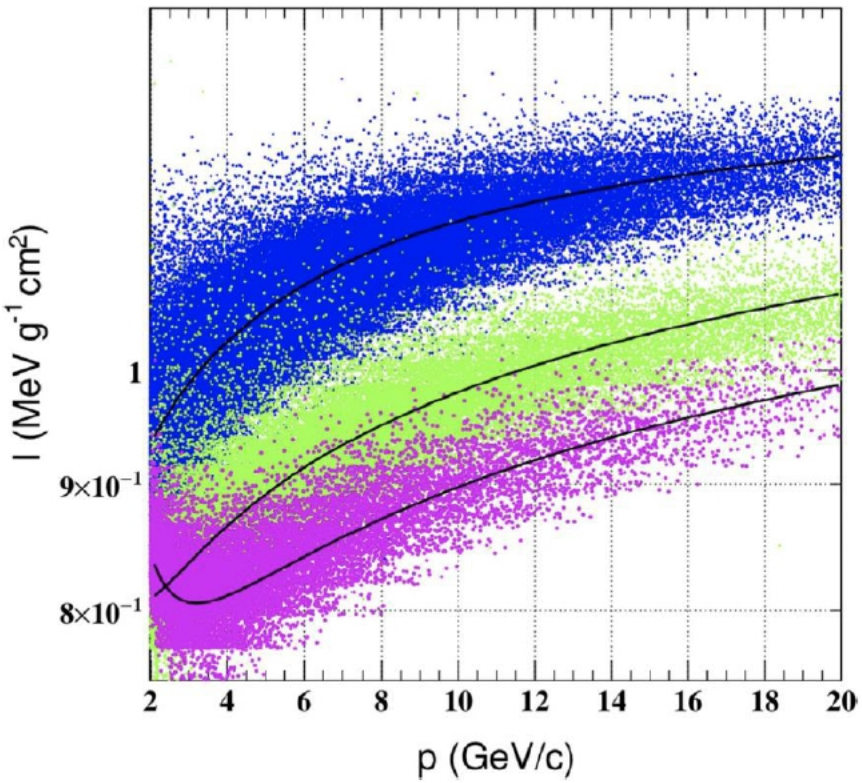
Summary

- The baseline detector with precision tracker and high granularity calorimeter, fulfills the core physics requirement on Higgs/EW measurements.
  - Reconstruct all physics objects from Higgs decay with elegant ε, purity & precision
  - Clearly identify and separate different Higgs signals from the SM bkg
- It provides a reasonable starting point for the flavor physics (Tera Z)
  - Jet lepton (performance close to isolated)
  - Kaons (eff & purity of 95% at Z pole)
  - high energy neutral pion (up-to 30 GeV)
- Lots of interesting questions ahead:
  - Dependence between VTX geometry & 2^{nd} vertex, jet flavor/charge reconstruction
  - Jet clustering & color singlet identification: optimization & systematic control
  - Quantification of the physics requirement, especially on flavor physics
  - Detector optimization-integration study

Back up

Pid & dEdx

Fenfen, Taifan, Zhiyang, etc



MC result of single-particle events with the theoretical prediction by the Bethe equation [16] overlaid. In the right plot the dots are from simulation of $e^+e^- \to Z \to q\bar{q}$ events

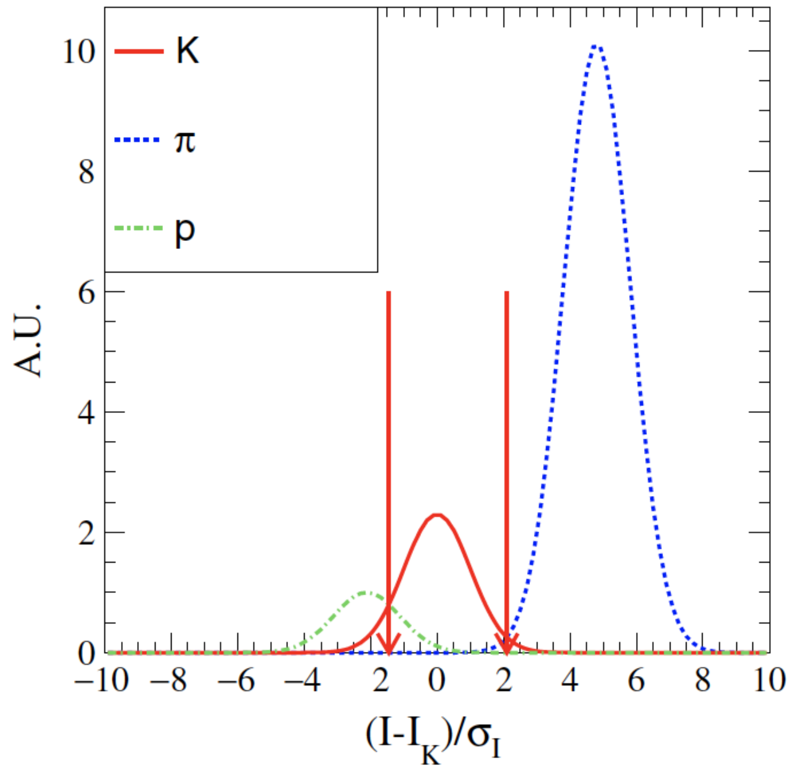


Fig. 6 The scaled spectra of $(I - I_K)/\sigma_I$ using dE/dx measurements alone for particles with a momentum of 5 GeV/c, assuming a 20% degradation. The relative populations are $N_\pi = 4.4N_K$ and $N_K = 2.3N_p$ according to MC simulation. The intersections marked by the arrows are chosen as the cut points

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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

The measurement of the $H \to \tau\tau$ signal strength in the future e^+e^- Higgs factories

Dan Yu[1], Manqi Ruan[1,a], Vincent Boudry[2], Henri Videau[2], Jean-Claude Brient[2], Zhigang Wu[1], Qun Ouyang[1], Yue Xu[3], Xin Chen[3]

[1] IHEP, Beijing, China
[2] LLR, Ecole Polytechnique, Palaiseau, France
[3] Tsinghua University, Beijing, China

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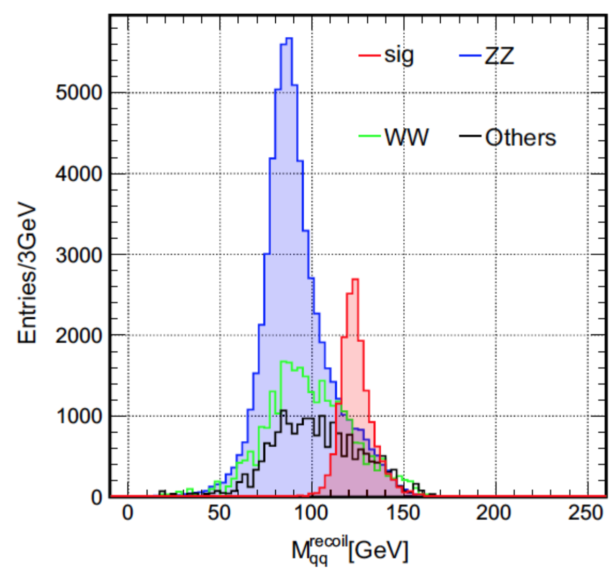
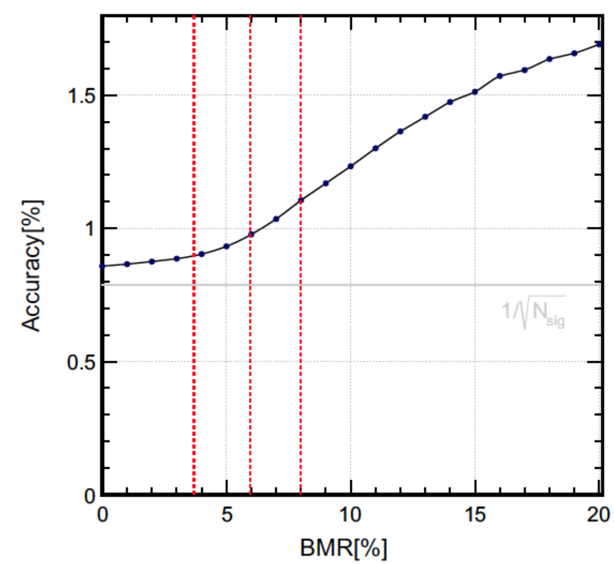
Table 9 Extrapolated accuracy $\delta(\sigma \times BR)/(\sigma \times BR)$ in the ILC 250 GeV (2000 fb^{-1})

	CEPC	ILC(L)	ILC(R)
Luminosity (ab^{-1})	5.6	2	2
Polarization (e^-, e^+)	–	(0.8, −0.3)	(−0.8, 0.3)
Total Higgs	1.18 M	0.60 M	0.40 M
Accuracy (%)	0.8	1.09	1.21



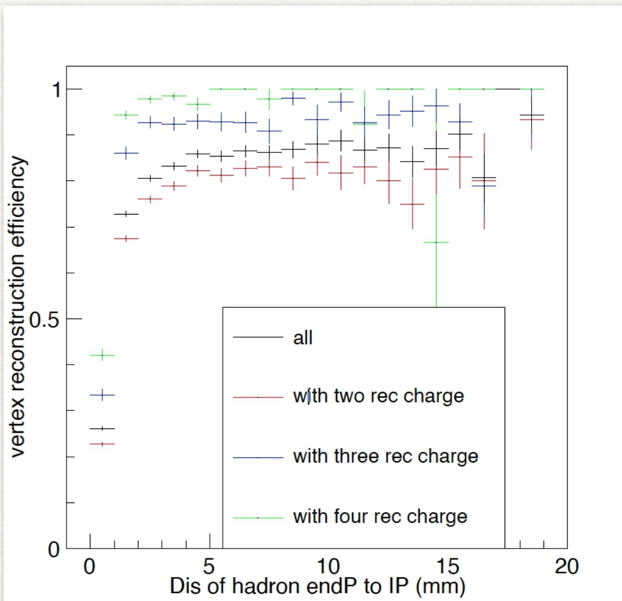


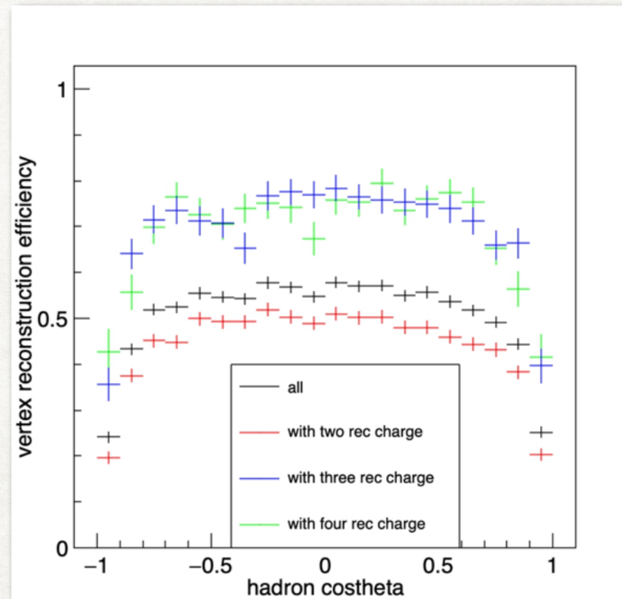
VTX reconstruction: Diagnosis

$$\frac{\textit{should been reconstructed vertex \&\& have been reconstructed vertex}}{\textit{should been reconstructed vertex}}$$

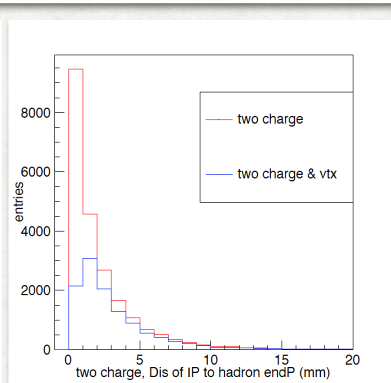
C-hadron with given charge multiplicity && corresponding tracks reconstructed

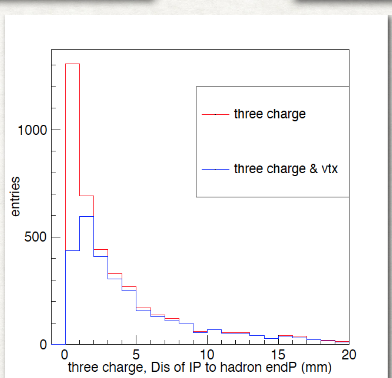
- At vvH, H→cc events.

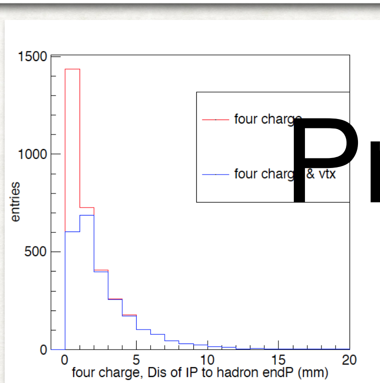




Yongfeng



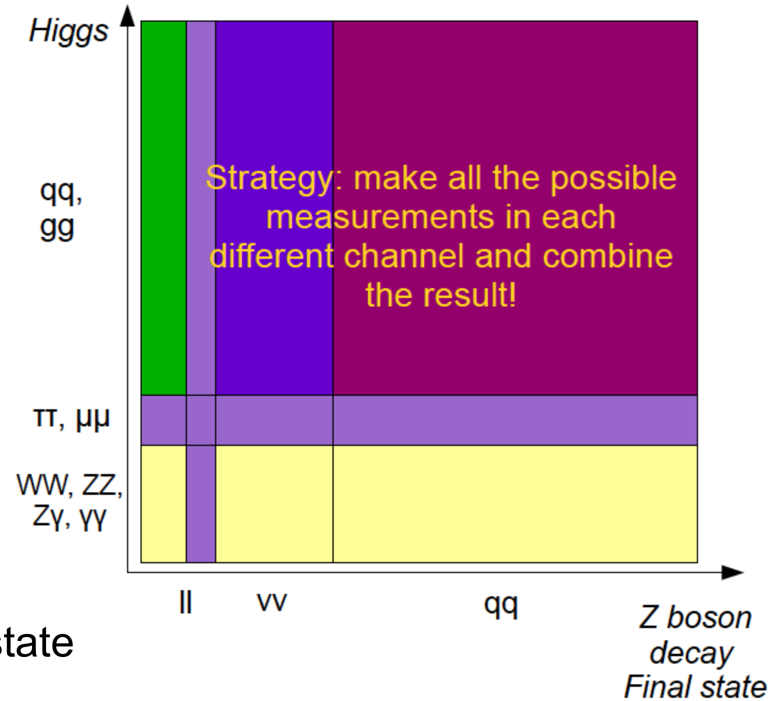




Preliminary

Jets at 240 GeV Higgs factory

- SM Higgs
  - ***0 jets: 3%:*** *Z→ll, νν (30%); H→0 jets (~10%, ττ, μμ, γγ, γZ/WW/ZZ→leptonic)*
  - ***2 jets: 32%***
    - *Z→qq, H→0 jets. 70%*10% = 7%*
    - *Z→ll, νν; H→2 jets. 30%*70% = 21%*
    - *Z→ll, νν; H→WW/ZZ→semi-leptonic. 3.6%*
  - ***4 jets: 55%***
    - *Z→qq, H→2 jets. 70%*70% = 49%*
    - *Z→ll, νν; H→WW/ZZ→4 jets. 30%*15% = 4.5%*
  - ***6 jets: 11%***
    - *Z→qq, H→WW/ZZ→4 jets. 70%*15% = 11%*

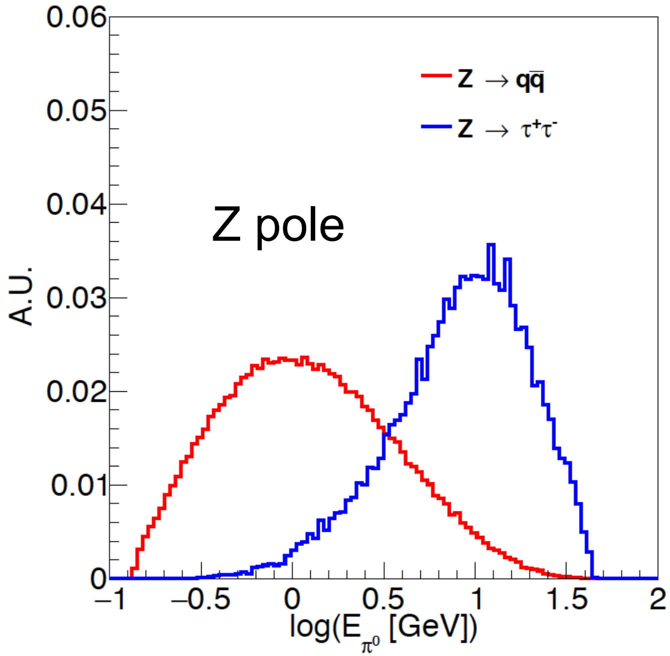


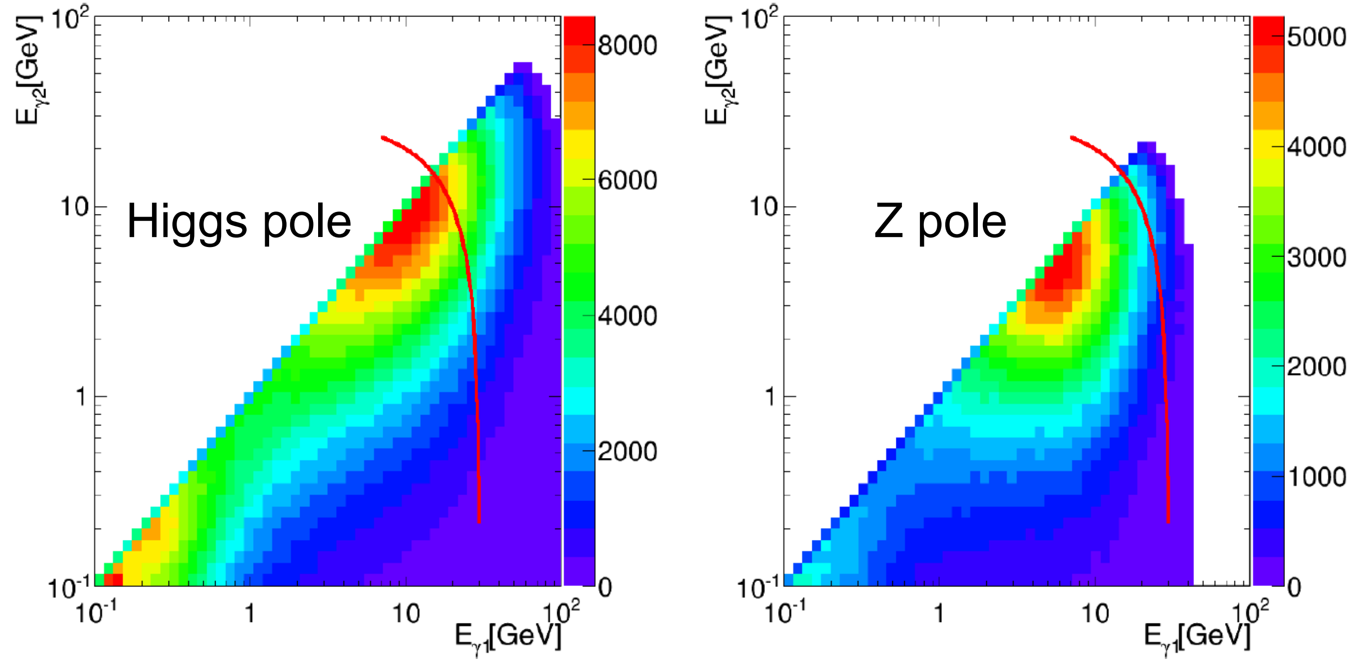
- **97%** of the SM Higgsstrahlung Signal has Jets in the final state
- **1/3** has only 2 jets: include all the SM Higgs decay modes
- **2/3** need color-singlet identification: grouping the hadronic final sate particles into color-singlets
- Jet is important for EW measurements & jet clustering is essential for **differential** measurements

Photon & π^0

- Larger acceptance: for ISR photon tagging (Need further quantification) as well as luminosity measurement
- Threshold: ~o(100) MeV;
- Low energy photons < 20 GeV, mostly from π^0 decay
  - Flavor physics: narrow resonances
  - Exotic
- High energy photons: 20 – 100 GeV
  - $H \to \gamma\gamma$
  - Measurements with Zγ events (ISR),
    - Neutrino generation measurements
    - Jet calibration, etc
- Good linearity for 3 orders of magnitude (100 MeV – 100 GeV)

π^0: energy range





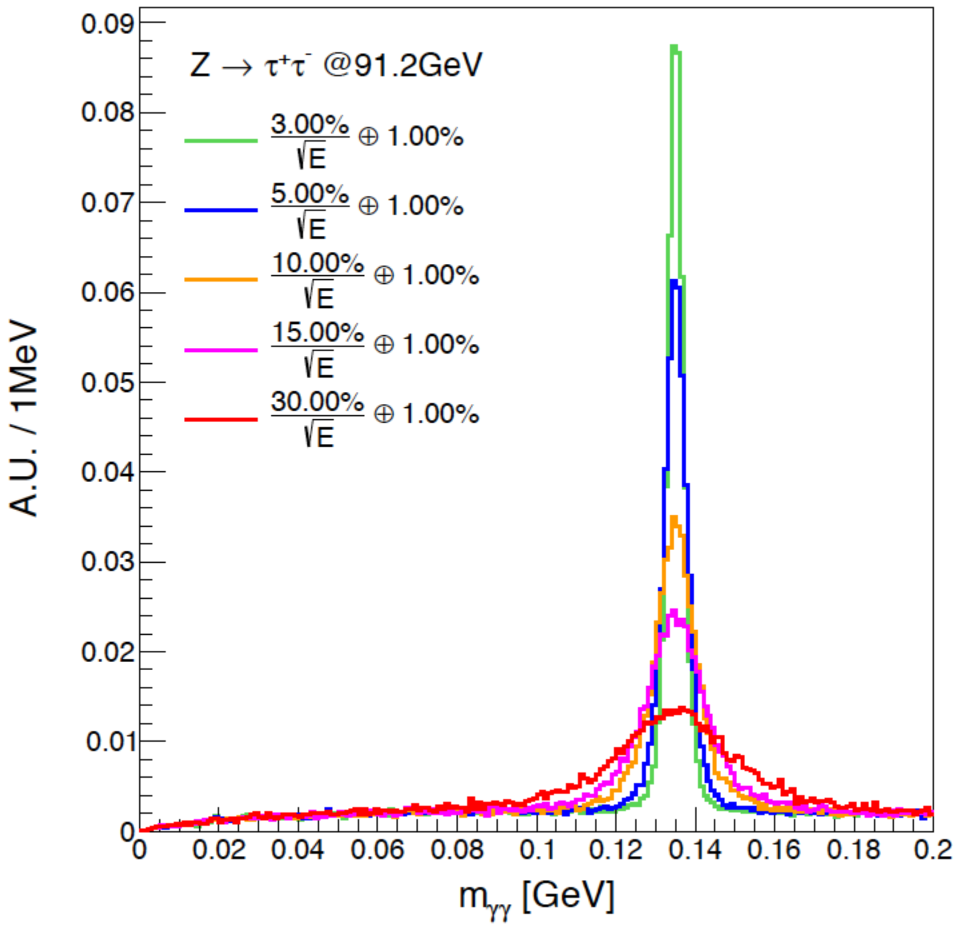
(a) (b)

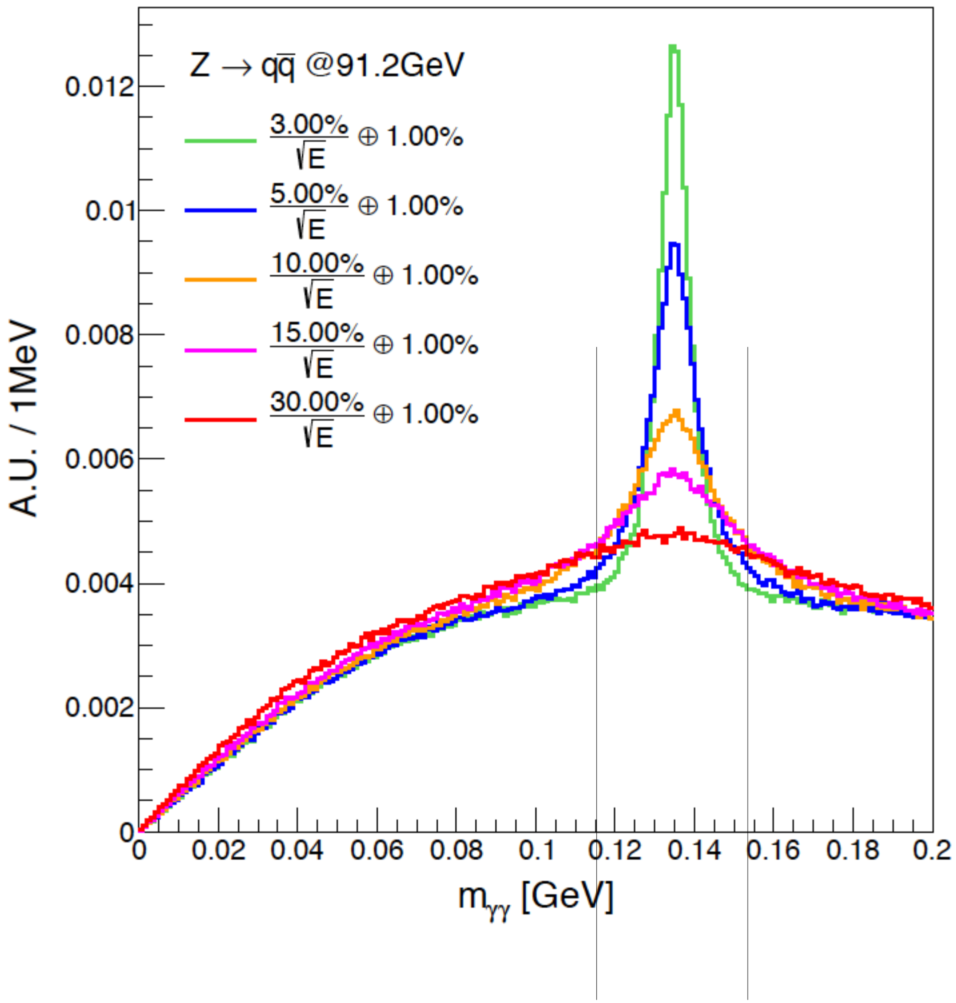
Fig. 14: The generated π^0 distribution as a function of the energies of di-photons from $\pi^0 \to \gamma\gamma$ in inclusive Higgs (a) and $Z \to \tau\tau$ samples (b). $E_{\gamma 1}$ is the energy of the leading photon. $E_{\gamma 2}$ is the energy of the sub-leading photon. The red line is the function of $E_{\gamma 1} + E_{\gamma 2} = 30$ GeV.

- π^0 energy (rest-mass, 30 GeV – 60 GeV): photon threshold ~ o(100) MeV
- At Z pole: be able to separate photons from Pi-0 decay, up to 30 GeV

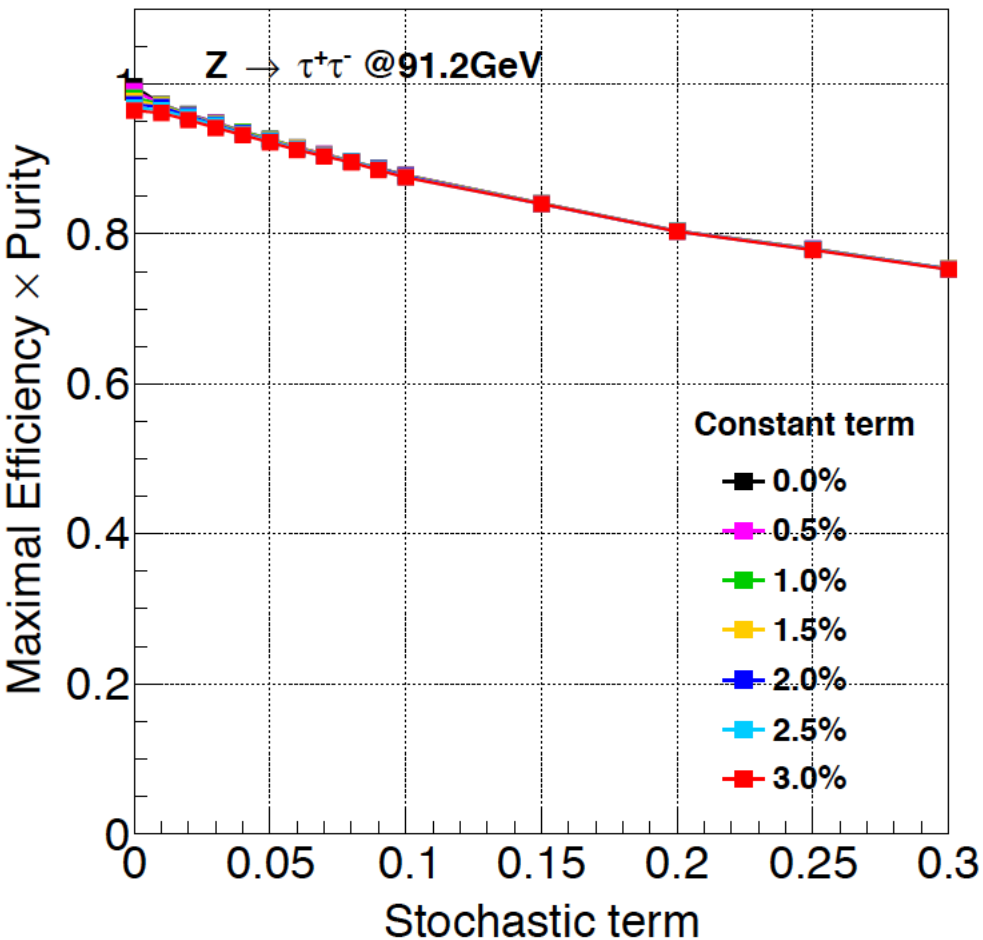
π^0: truth level analysis

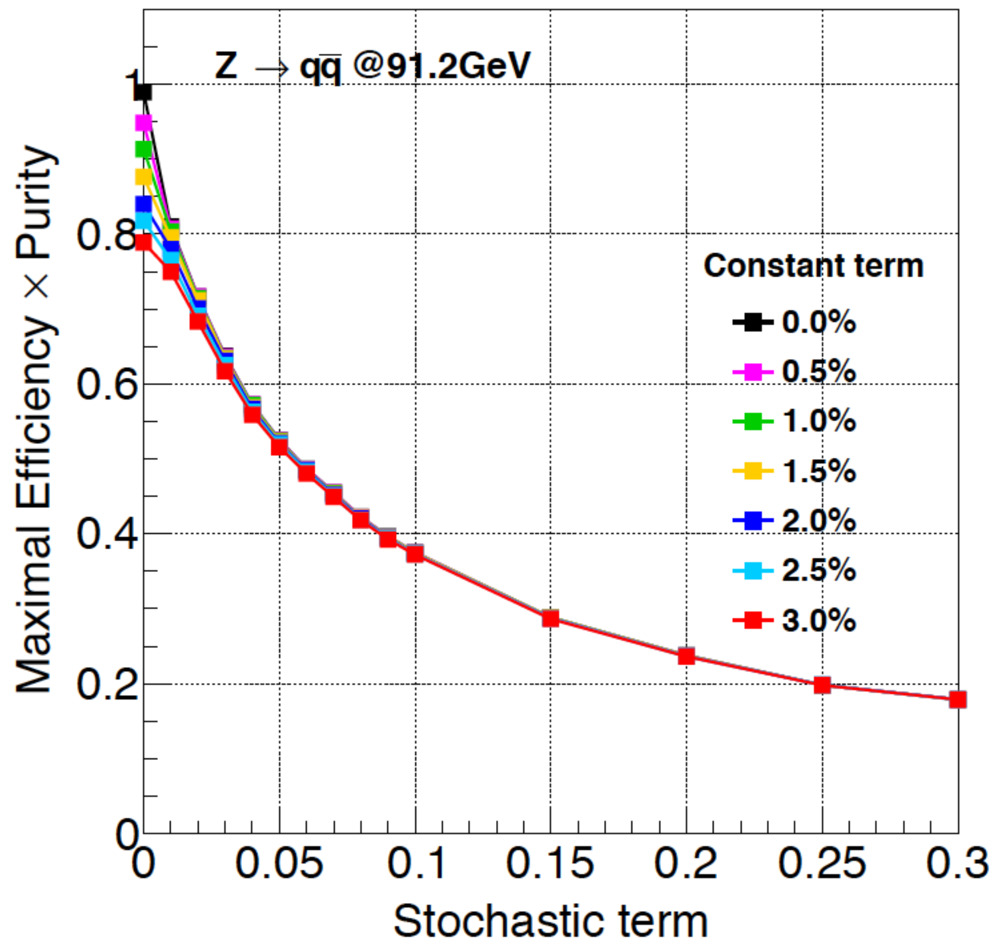
Yuexin





Impact of EM resolution on π^0 finding





Dependency on π^0 energy

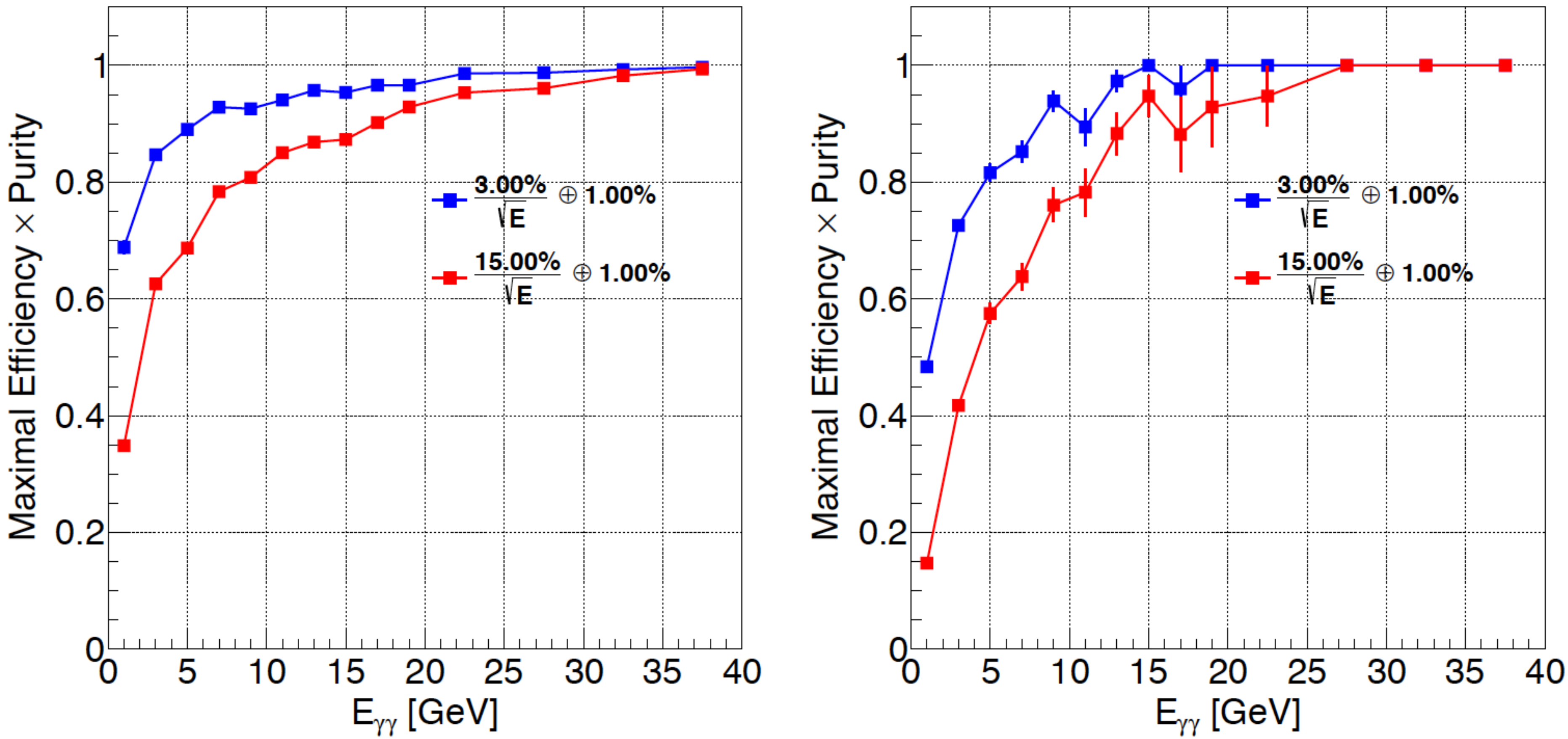


Figure 13: Energy differential maximal $\epsilon \times p$ for $Z \to \tau^+\tau^-$ (left) and $Z \to q\bar{q}$ (right).

...Surely the low energy pi-0 reconstruction benefit more from a better EM resolution...

π^0: energy spectrum decomposition

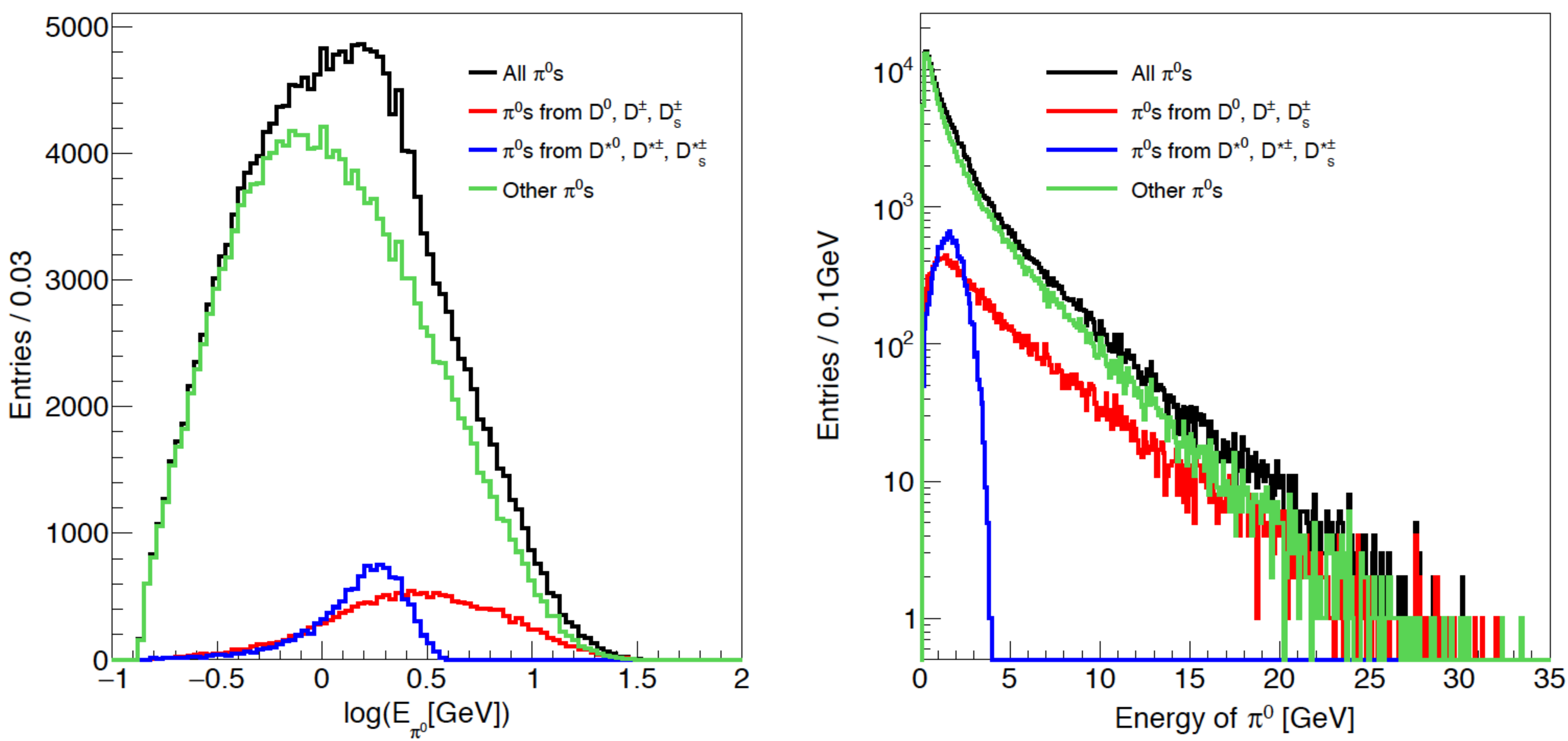


Figure 13: Energy spectrum of π^0 from different origins in $Z \to c\bar{c}$.

π^0 reco

- ECAL resolution is critical: improving the ECAL resolution from 15%/sqrt(E) to 5%/sqrt(E) (with 1% constant term) significantly improve the inclusive π^0 reconstruction efficiency
  - From 85% to 92% at Z→tautau
  - From 30% to 50% at Z→qq

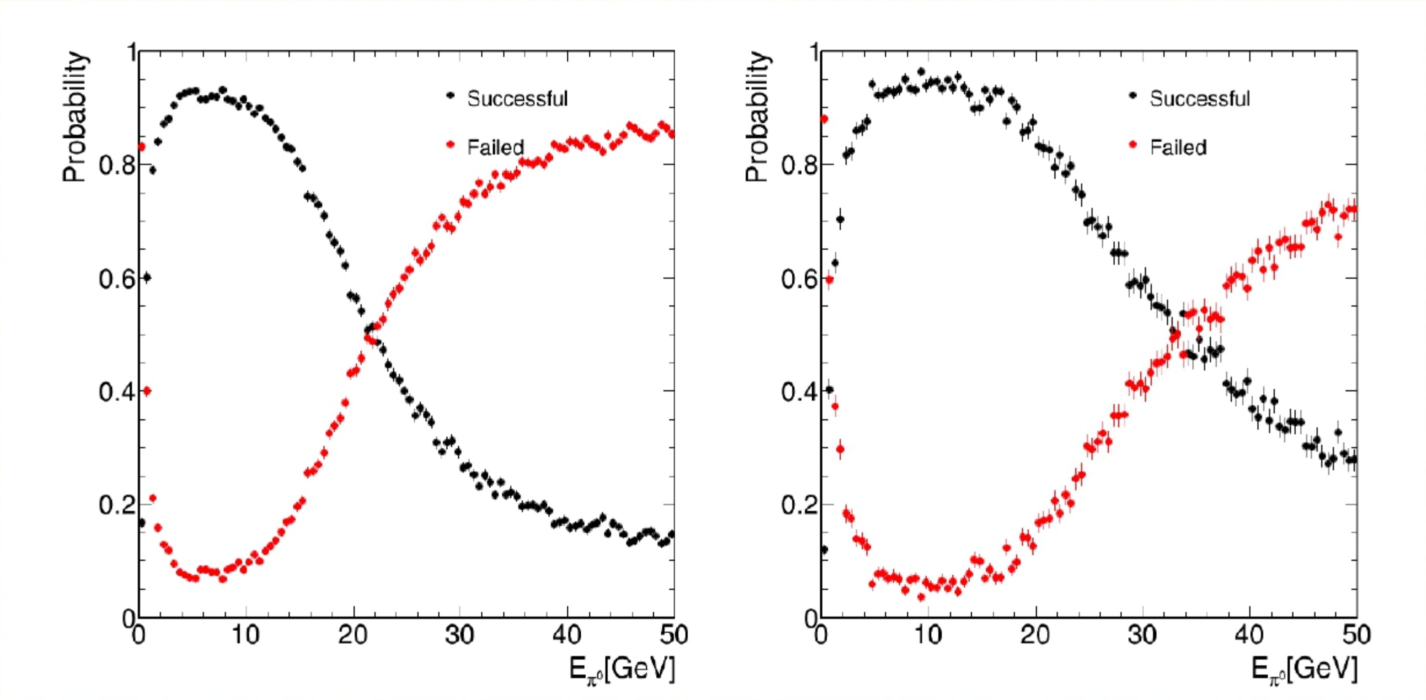
- Low energy π^0 is more sensitive to ECAL energy resolution.

- Further quantification needs physics benchmarks
  - Narrow States → n*π^0 + X, X are a set of charged Particle. For example Bs → 2π^0

π0 Reconstruction Rate

by Yuqiao Shen

- The probability of successfully reconstructing π0 in the barrel region and in the endcap region
- In the barrel region, 50% can be reconstructed when π0 energy lower than 22 GeV.
- In the endcap region, 50% can be reconstructed when π0 energy lower than 34 GeV.
- The lower energy degrading caused by photon identification and reconstruction.
- Most within the region with above 50% reconstruction rate



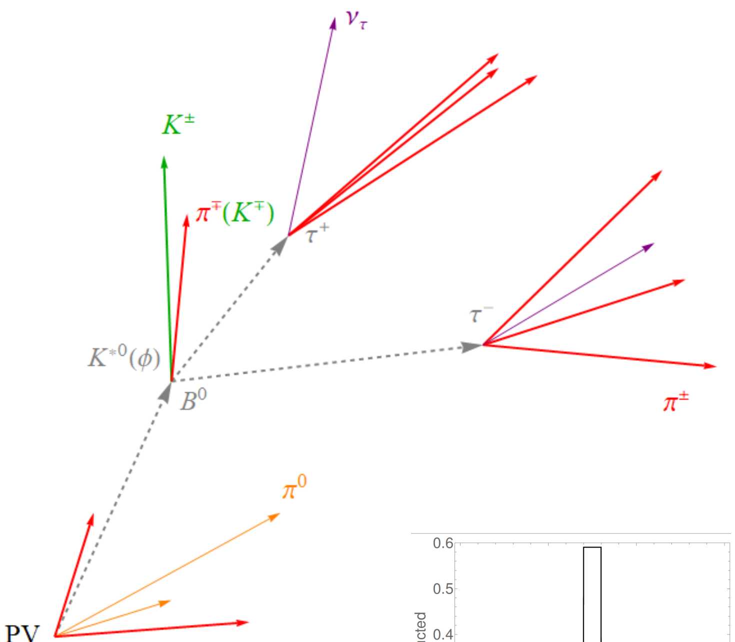
Lepton identification

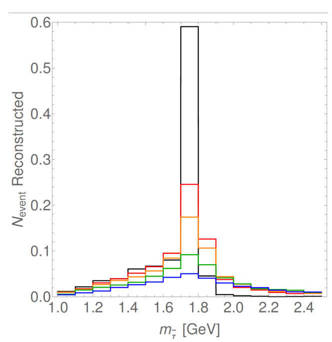
- Typically Lepton id performance:
  - Isolated, high energy one: Eff > 99.5%, Mis-id rate of hadron to lepton ~ 1%.
  - Performance limited by the leptonic decay of low energy hadron, etc.
- Aim at similar performance for all leptons
  - Full energy range (1-100 GeV), full detector acceptance (|cos(θ)|<0.99).
  - For all leptons: isolated, and generated in jet (jet lepton), and even secondaries (generated from photon conversion & hadron decay)
  - The jet lepton identification is essential for the flavor physics measurements such as LFU in hadrons, etc.

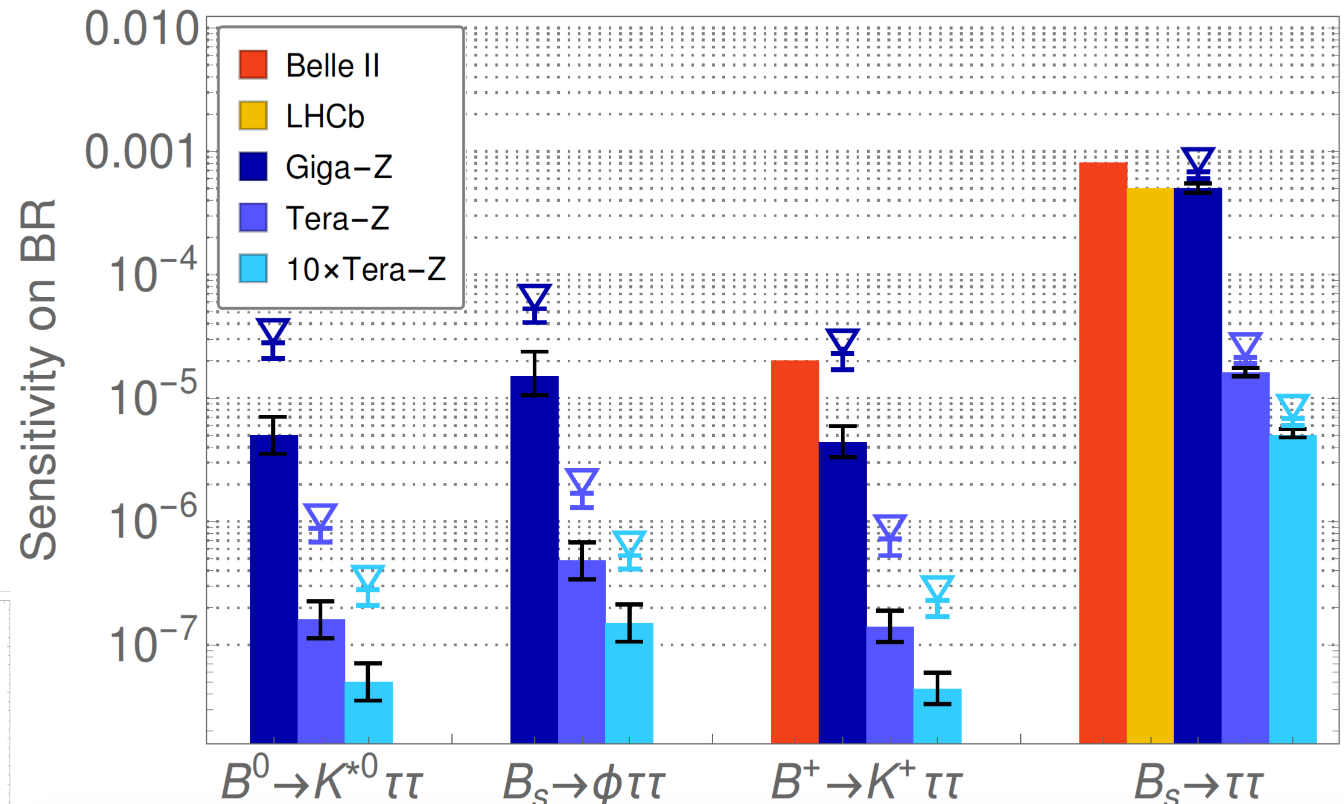
$$R_{D^{(*)}} \equiv \frac{\mathrm{BR}(B \to D^{(*)}\tau\nu)}{\mathrm{BR}(B \to D^{(*)}\ell\nu)}, \; \ell = e, \, \mu$$

$$R_{K^{(*)}} \equiv \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)}$$

Tau & VTX







...

Contamination of D decay that mimics tau 3-prong decay;

reconstruction accuracy V.S final accuracy: ideal, 1, 2, 5, 10μm resolution

...

LINGFENG @ HKIAS

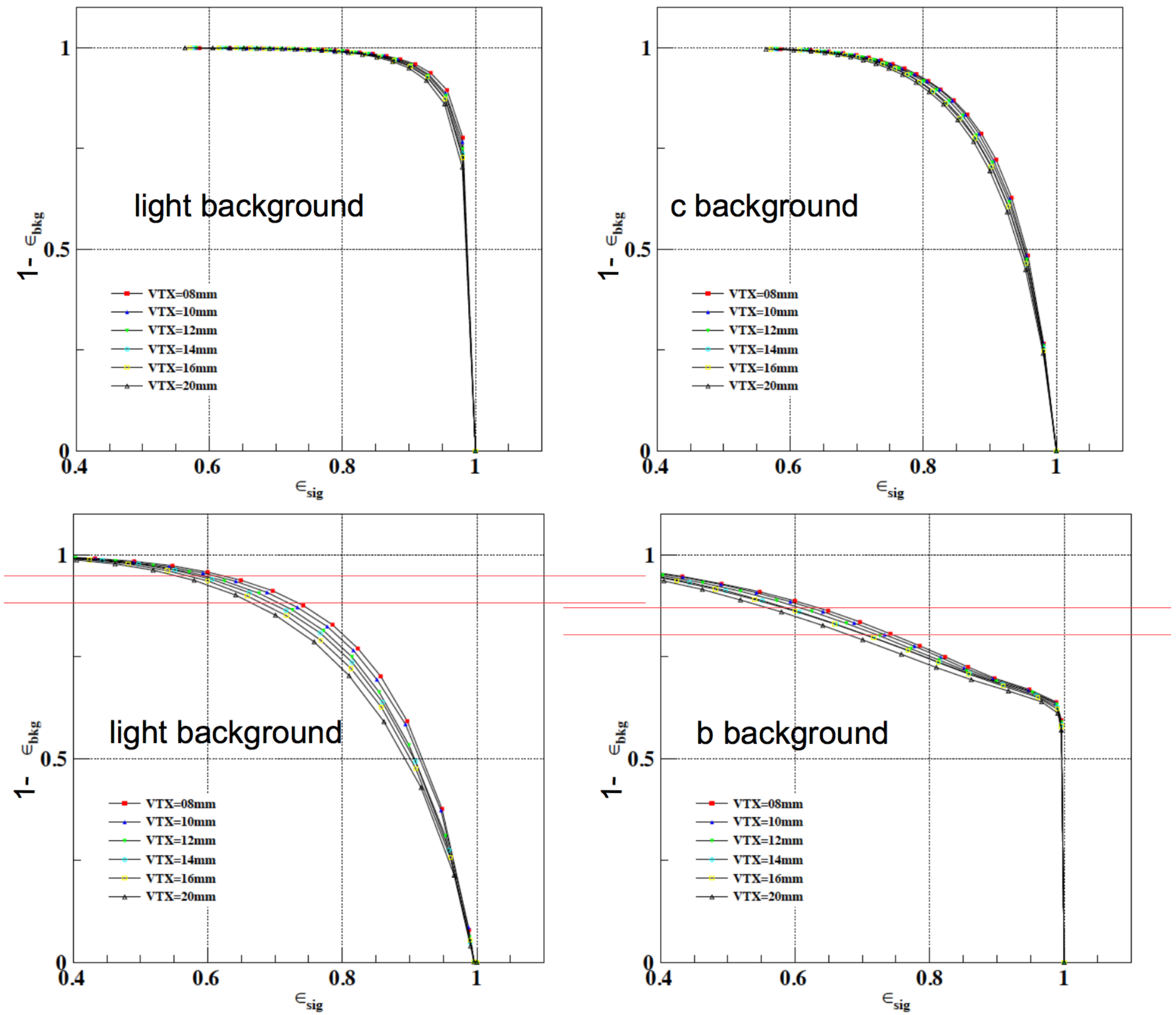
Pid & dEdx

- Preliminary:
  - Energy Spectrum: identify charged hadrons up to 20 GeV...
  - 3σ separation of pi-Kaon, corresponding to 2% of dEdx resolution, is appreciated for the mass hadron reconstruction with kaon/proton in its decay final state
  - Need to have further physics benchmark analysis.

- For objects with kaon and/or proton in its decay product: performance depends on
  - Momentum (fully charged final state)
  - Hadron separation, especially pi-K separation
  - VTX reco. (for heavy flavor hadrons)

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/

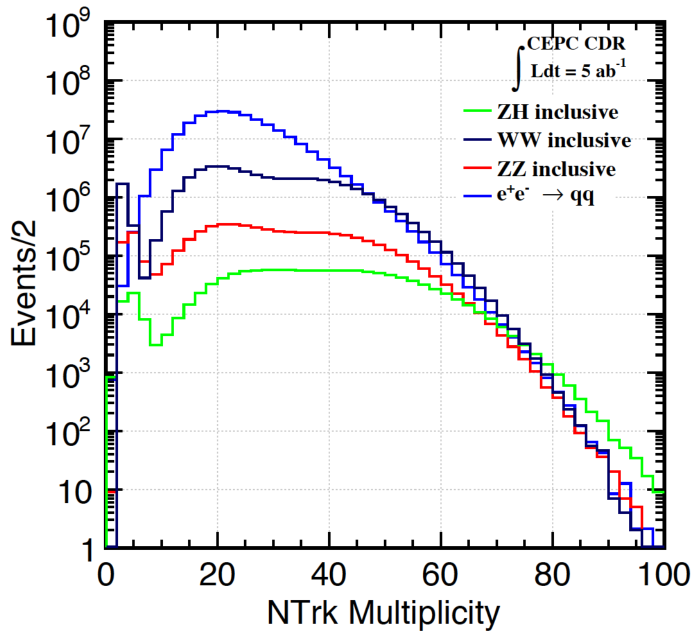
Hadronic system: more than 2 jets?

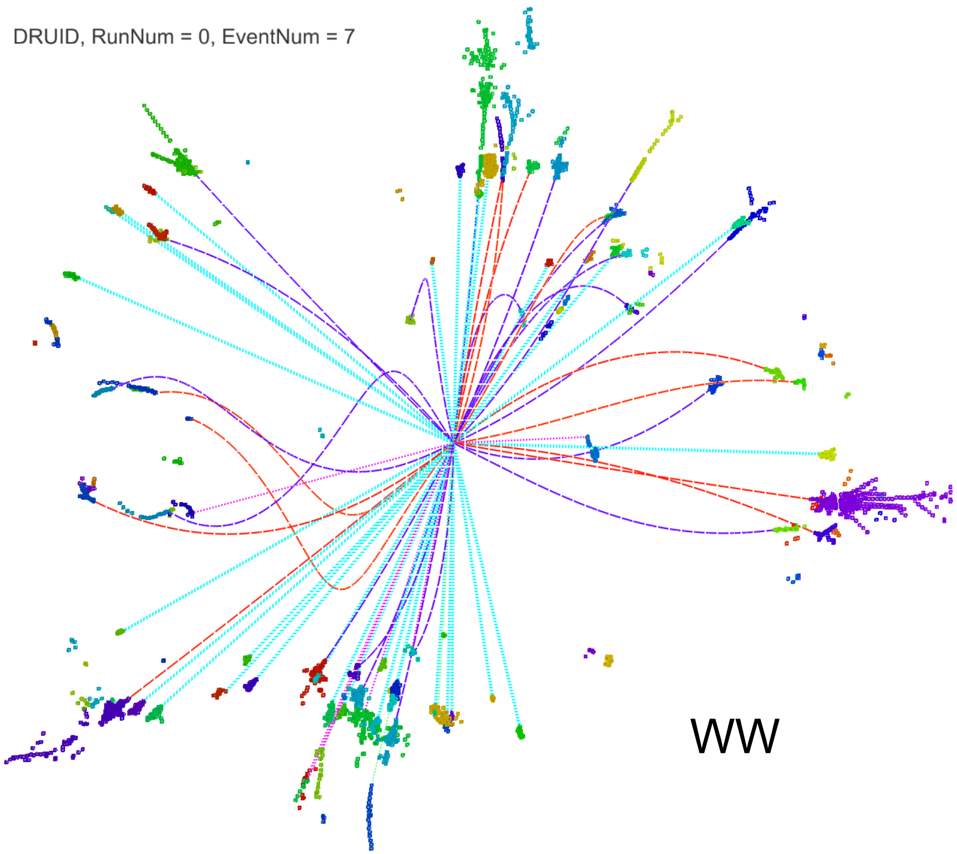
- Matching the final state particles to the colored partons (quarks, gluon, etc) can induce significant uncertainties

- For physics event with multiple color singlets that decay hadronically, how to identify all the final state particles corresponding to one color singlet?
  - i.e., Essential for full hadronic ZH, ZZ, WW events separation

- Conventionally: Jet Clustering & Matching
  - Dominant the performance in physics benchmark of full hadronic WW/ZZ separation at the CEPC baseline detector
  - Can we goes beyond?

Full hadronic WW-ZZ separation

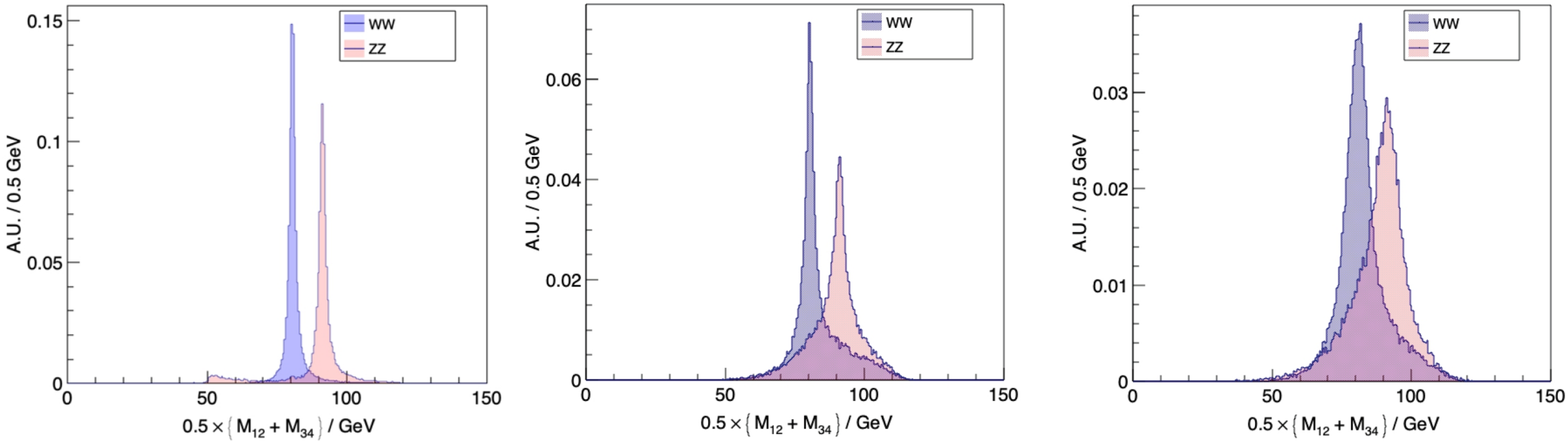




WW

- Low energy jets! (20 – 120 GeV)
- Typical multiplicity ~ o(100)
- WW-ZZ Separation: determined by
  - Intrinsic boson mass/width
  - Jet confusion from color single reconstruction – jet clustering & pairing
  - Detector response

Jet confusion: the leading term



- Separation be characterized by

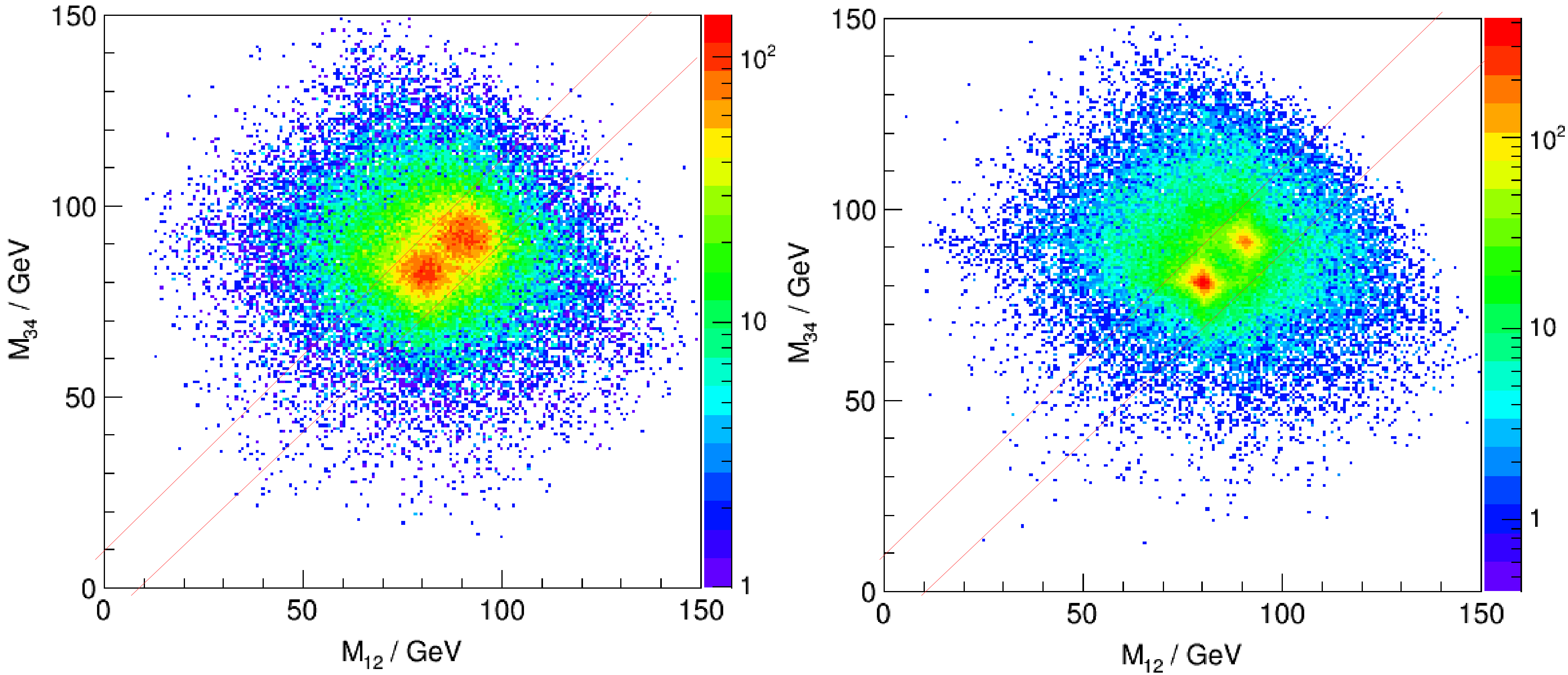
$$overlapping\ ratio = \sum_{bins} min(a_i, b_i)$$

- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2

$$\chi^2 = \frac{(M_{12} - M_B)^2 + (M_{34} - M_B)^2}{\sigma_B^2}$$

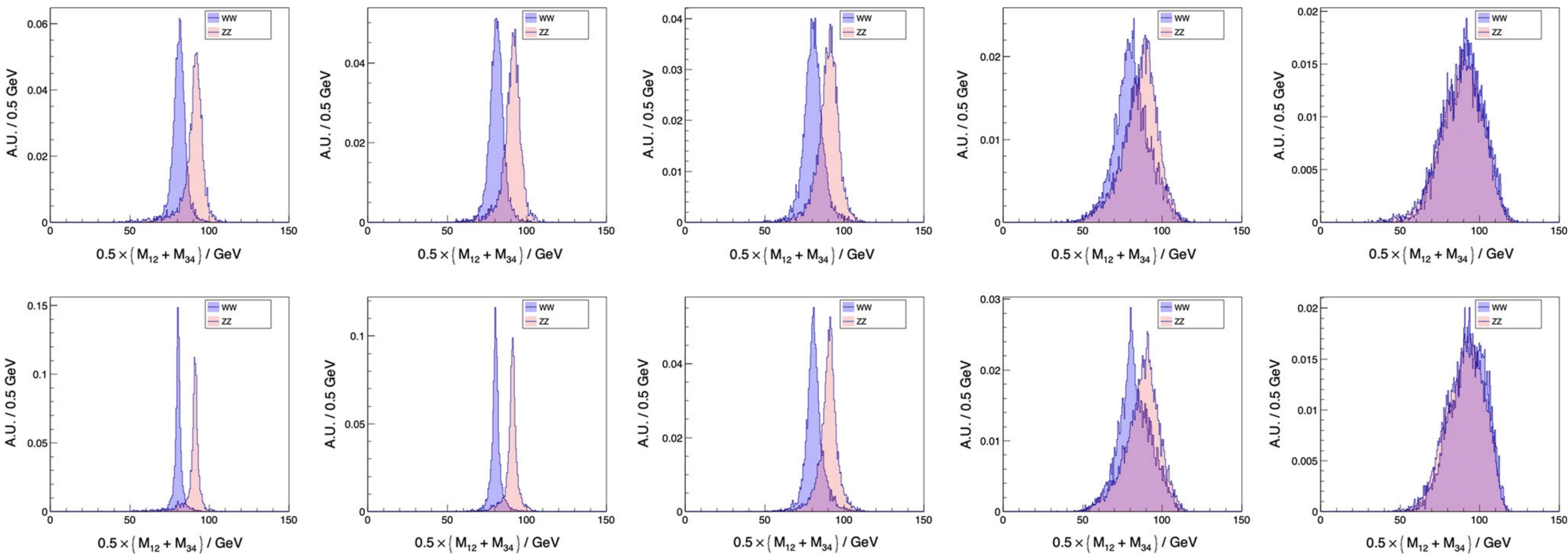
- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - \+ Jet confusion – Genjet: Overlapping ratio of **53%**
  - \+ Detector response – Recojet: Overlapping ratio of 58%

Reconstructed mass of the two di-jet system



Equal mass condition |M12 – M34| < 10 GeV: At the cost of half the statistic, the overlapping ratio can be reduced from 58%/53% to 40%/27% for the Reco/Genjet

Separation V.S. clustering



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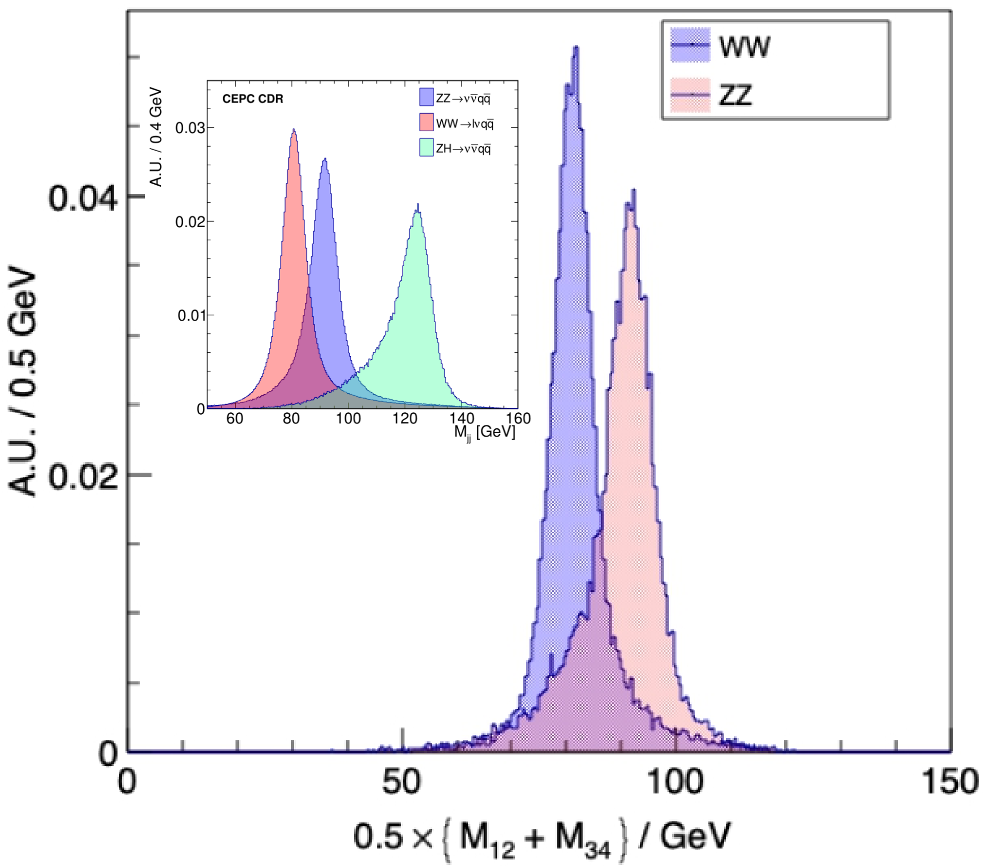
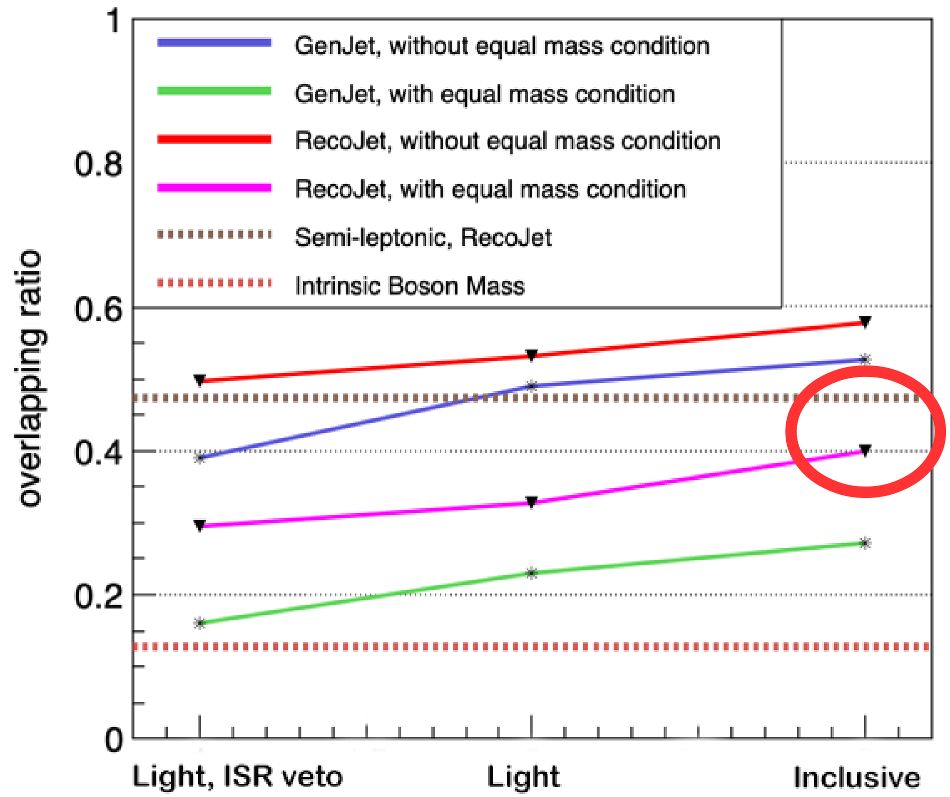
Separation of full hadronic WW-ZZ event





The CEPC Baseline could separate efficiently the WW-ZZ with full hadronic final state.

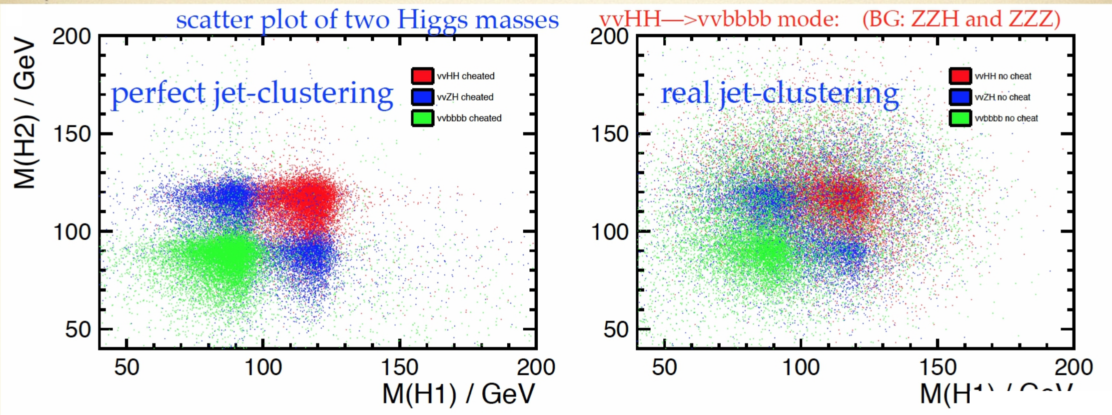
Critical to develop color singlet reconstruction: improve from the naive Jet clustering & pairing.

Quantified by differential overlapping ratio.

Control of ISR photon/neutrinos from heavy flavor jet is important.

impact of jet-clustering in Higgs self-coupling measurement

(without beam overlay now)



it has been studied if a color singlet jet clustering can be implemented for both signal and BG, λ_{HHH} measurement improved by 40%, which means 20% $\delta\lambda_{HHH}/\lambda$ (5σ) would already be possible at 500 GeV ILC with the H20 scenario

Also critical for the measurement with qqH,
Especially the Higgs goes into hadronic
Final state...

Summary

Future lepton colliders:

- an opportunity to understand the process from parton to jet.
- a challenge to jet reconstruction (better detectors, complex final states, enhanced phase space, background, tighter control over systematics)

Traditional lepton collider algorithms fail to cope with the background level expected at future linear (circular?) colliders

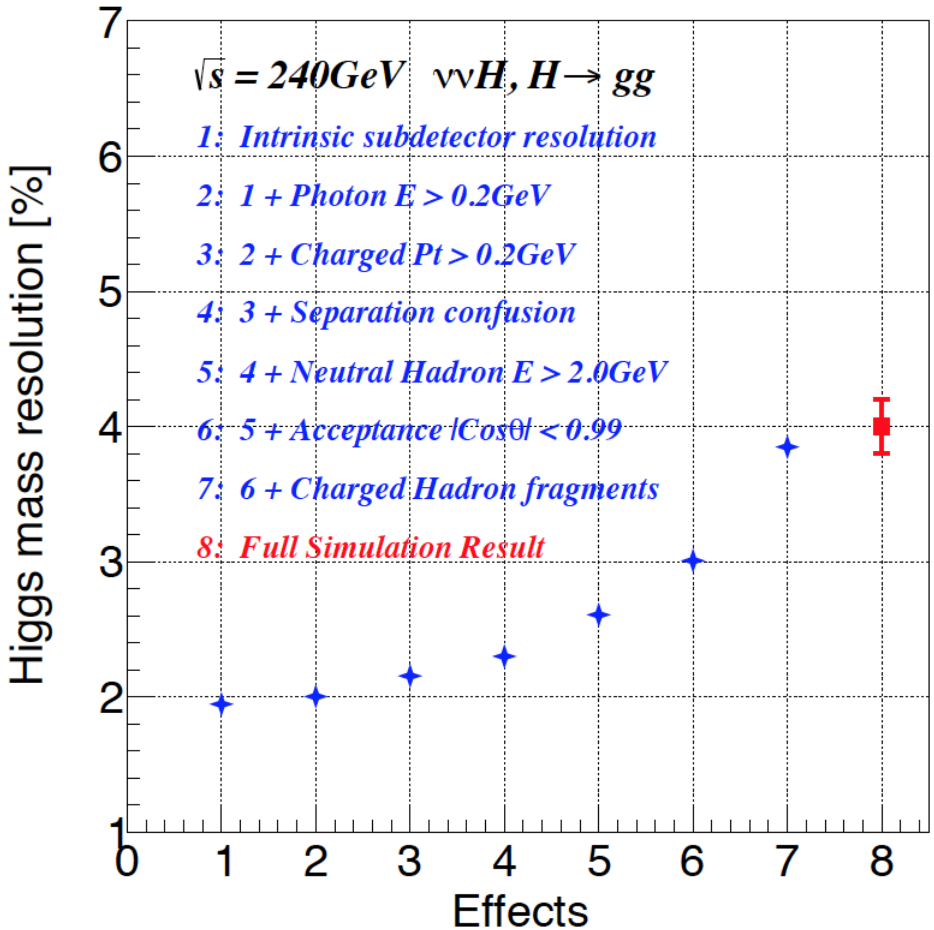
Longitudinally invariant algorithms work well... and we understand why

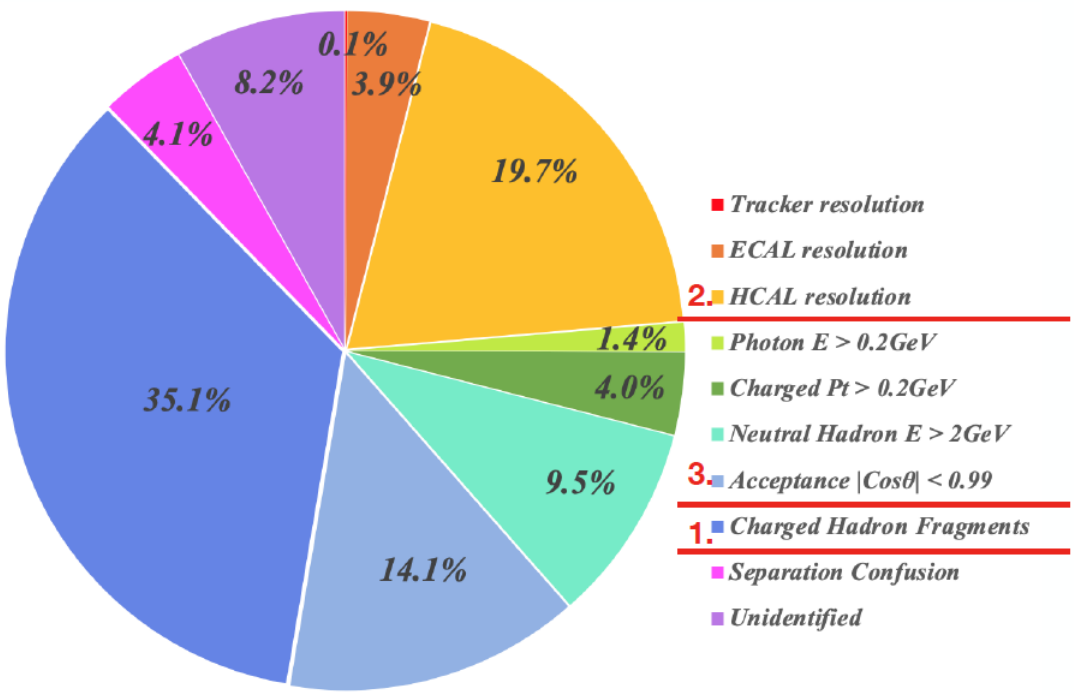
Refurbished e^+e^- algorithms can be better still:
VLC is currently the most robust algorithm on the market

Non-perturbative corrections are less important than at LEP, but non-trivial differences between algorithms merit further study

CEPC workshop, Oxford, April 2019 Marcel Vos (marcel.vos@ific.uv.es) 17

PFA Fast simulation (Preliminary)





YX. Wang

Fast simulation reproduces the full simulation results, factorize/quantifies different impacts
Same cleaning condition as in the Full simulation applied
Early phase of modeling/tuning