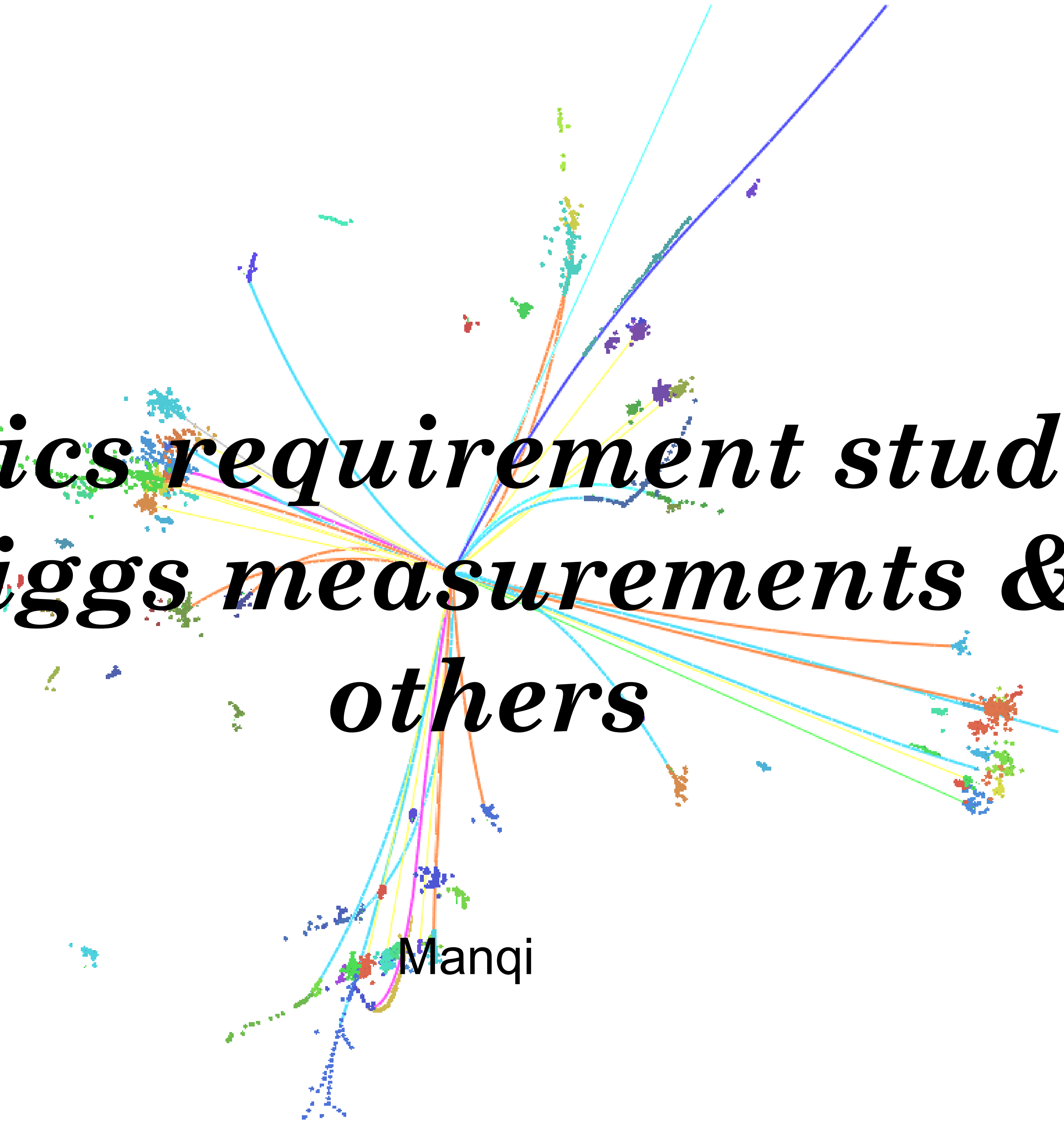
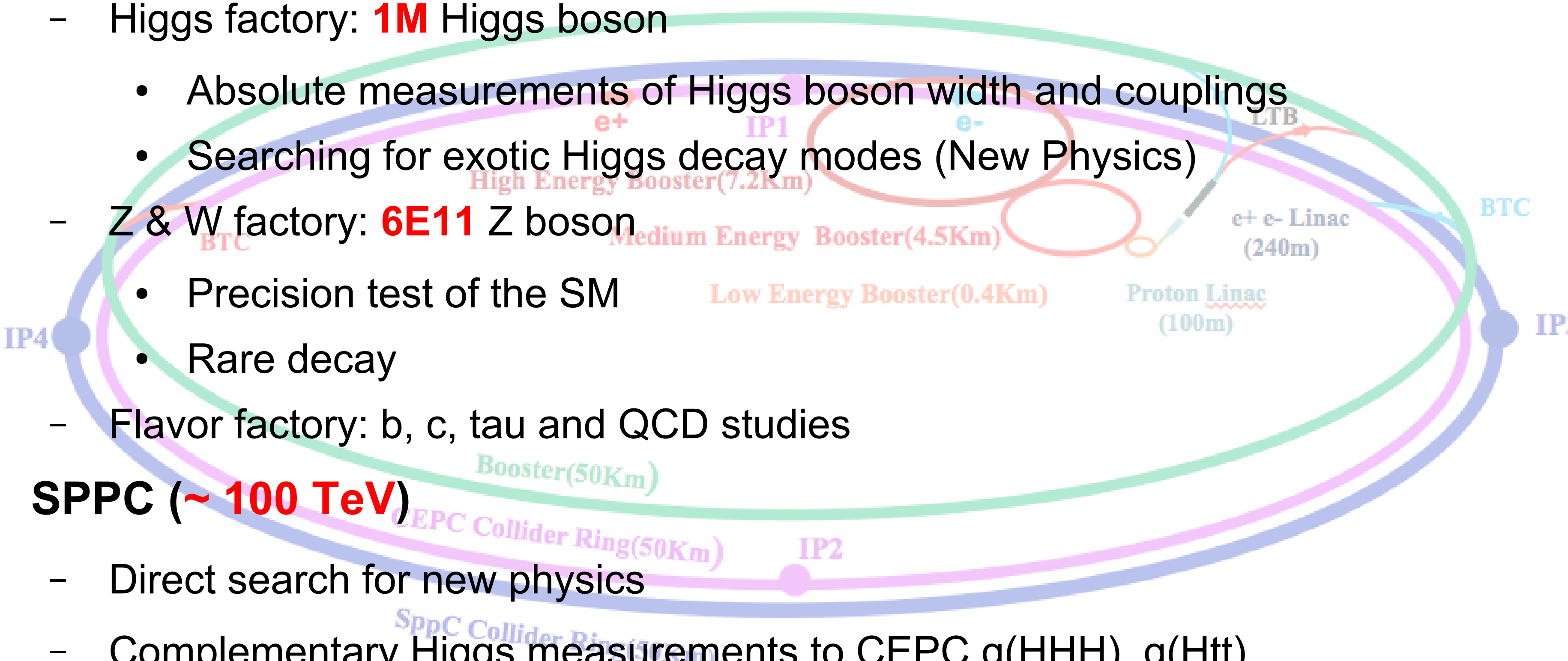
Physics requirement studies: Higgs measurements & others



Manqi

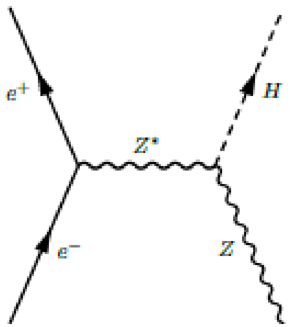
Science at CEPC-SPPC

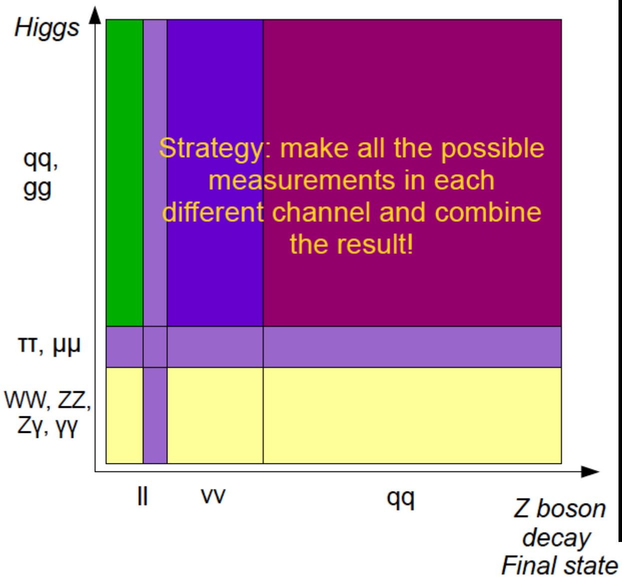


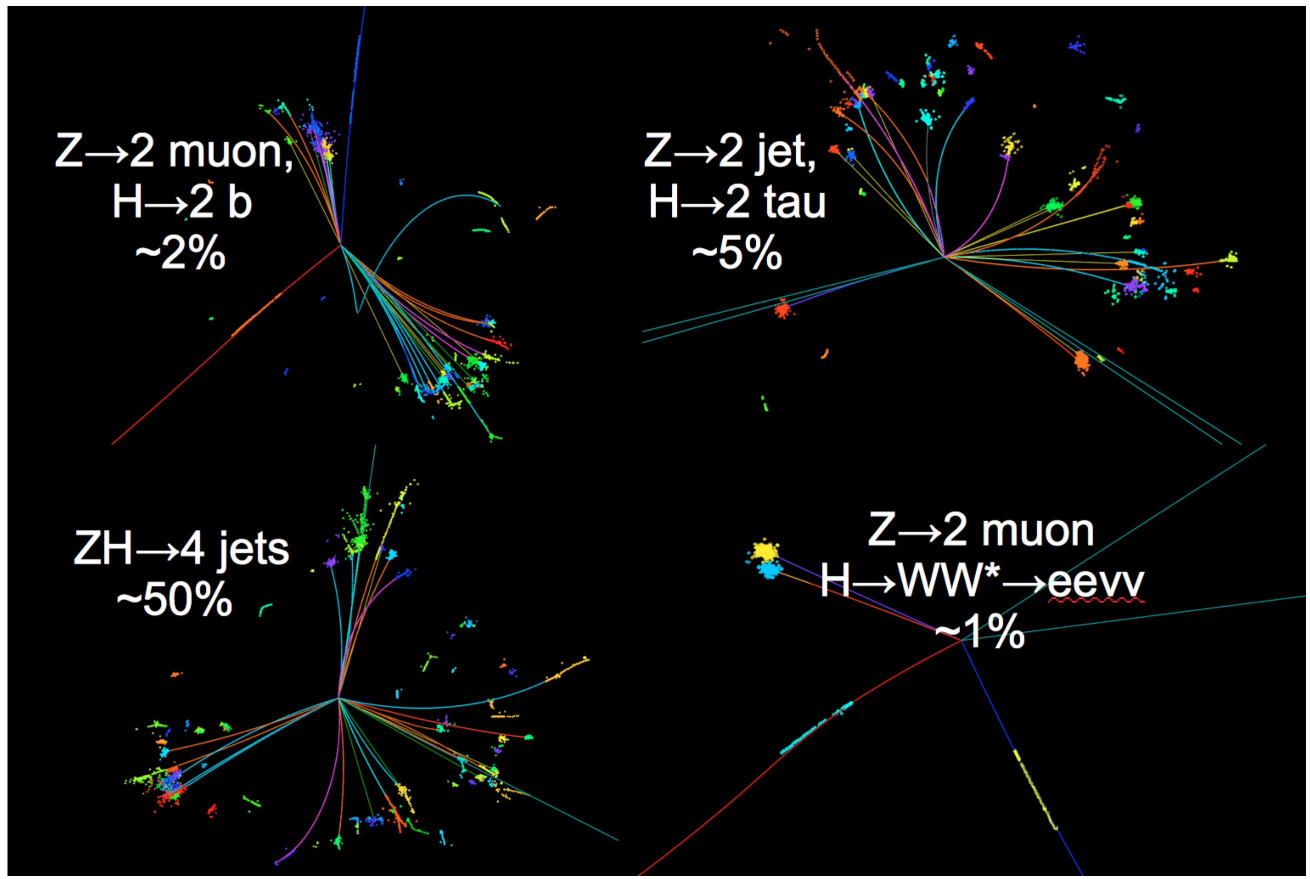
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **6E11** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor 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

Physics Requirements







Detector:

To reconstruct all the physics objects with high efficiency, purity & resolution

Homogenous & Stable enough to control the systematic

This talk quantifies the requirement/key questions of Jet reconstruction at CEPC/ILC

Qualitative requirement at the CDR

Physics process	**Measurands**	**Detector subsystem**	**Performance requirement**
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Table 3.3: Physics processes and key observables used as benchmarks for setting the requirements and the optimization of the CEPC detector.

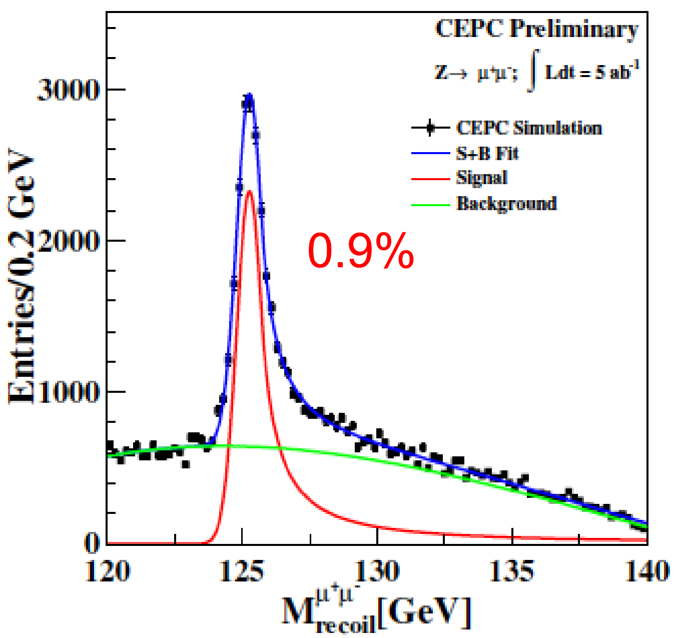
Requirement benchmark analyses

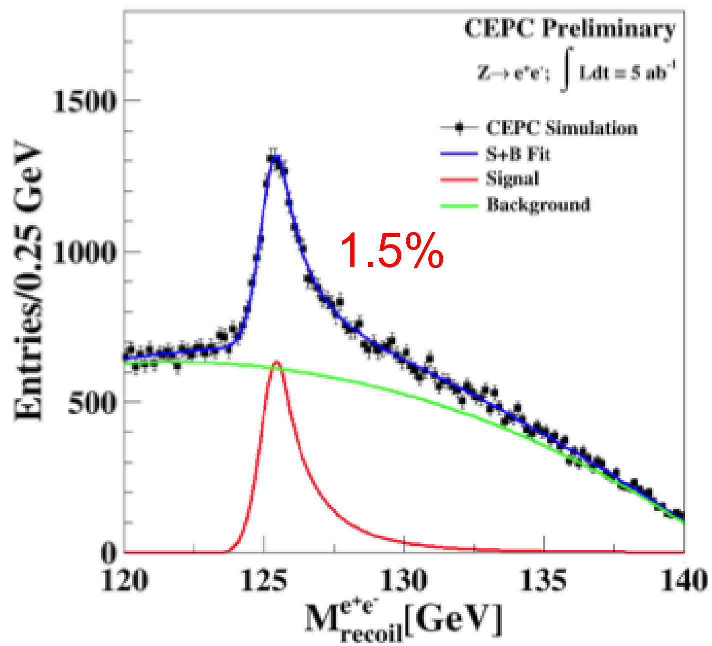
- From Higgs measurements
  - Track Momentum: Higgs recoil mass from μμH; μ(H→μμ).
  - Photon: μ(H→γγ)
  - Hadronic event
    - Total visible mass (Characterized by Boson Mass Resolution):
      - μ(vvH, H→bb);
      - μ(qqH, H→inv);
      - μ(qqH, H→tautau);
    - Jet clustering-matching: ZZ/WW separation
- From other measurements
  - Tau factory...
  - Flavor & QCD...

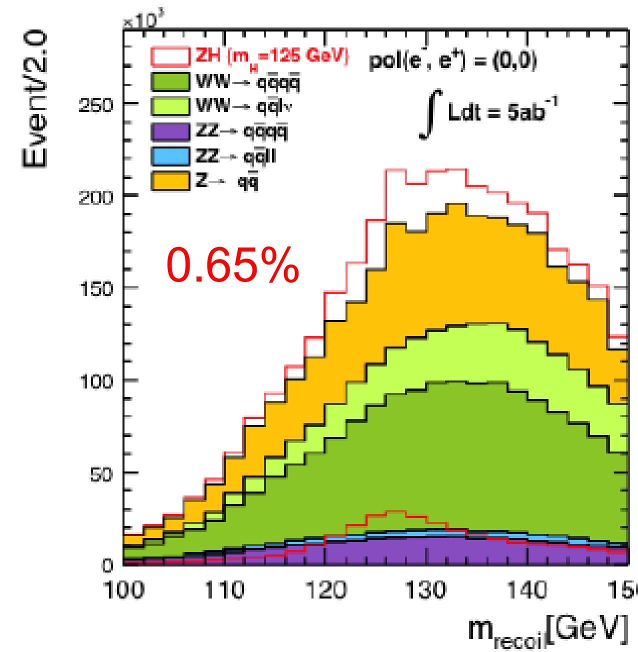
Higgs recoil analysis with μμH event

Zhenxing Chen & Yacine Haddad

Chinese Physics C Vol. 41, No. 2 (2017) 023003



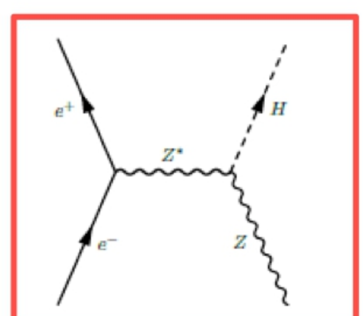


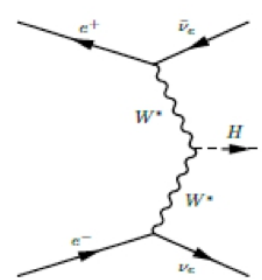


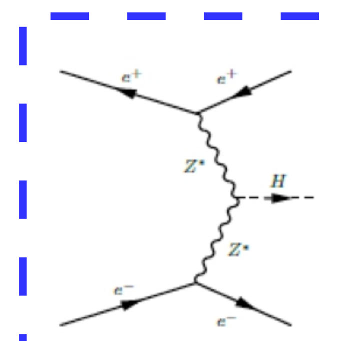
- Combined precision:

  δσ(ZH)/σ(ZH) = 0.5%

  δg(HZZ)/g(HZZ) = 0.25%







Optimization study w.r.t the TPC/Tracker radius & resolution

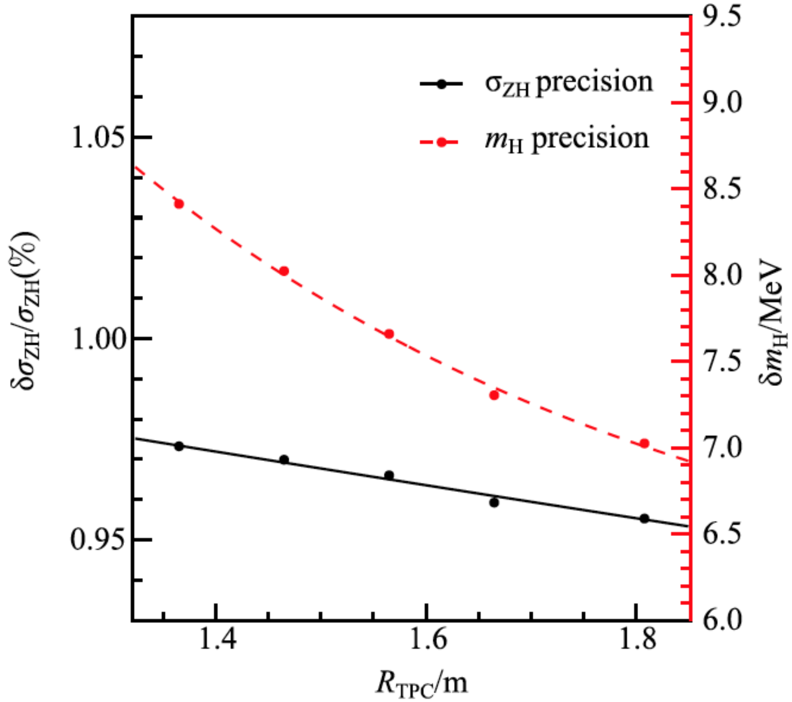
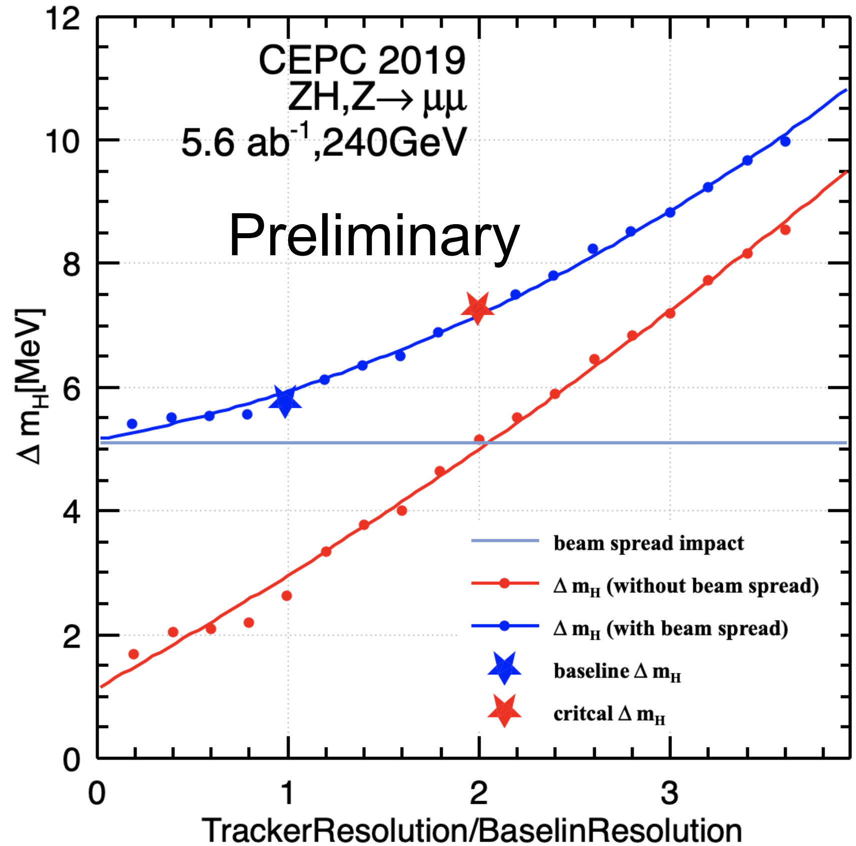


Fig. 6. The precisions of σ_{ZH} and m_{H} measurements versus different TPC radii. The solid line represents the precision of σ_{ZH}, and the dashed line is for m_{H}.

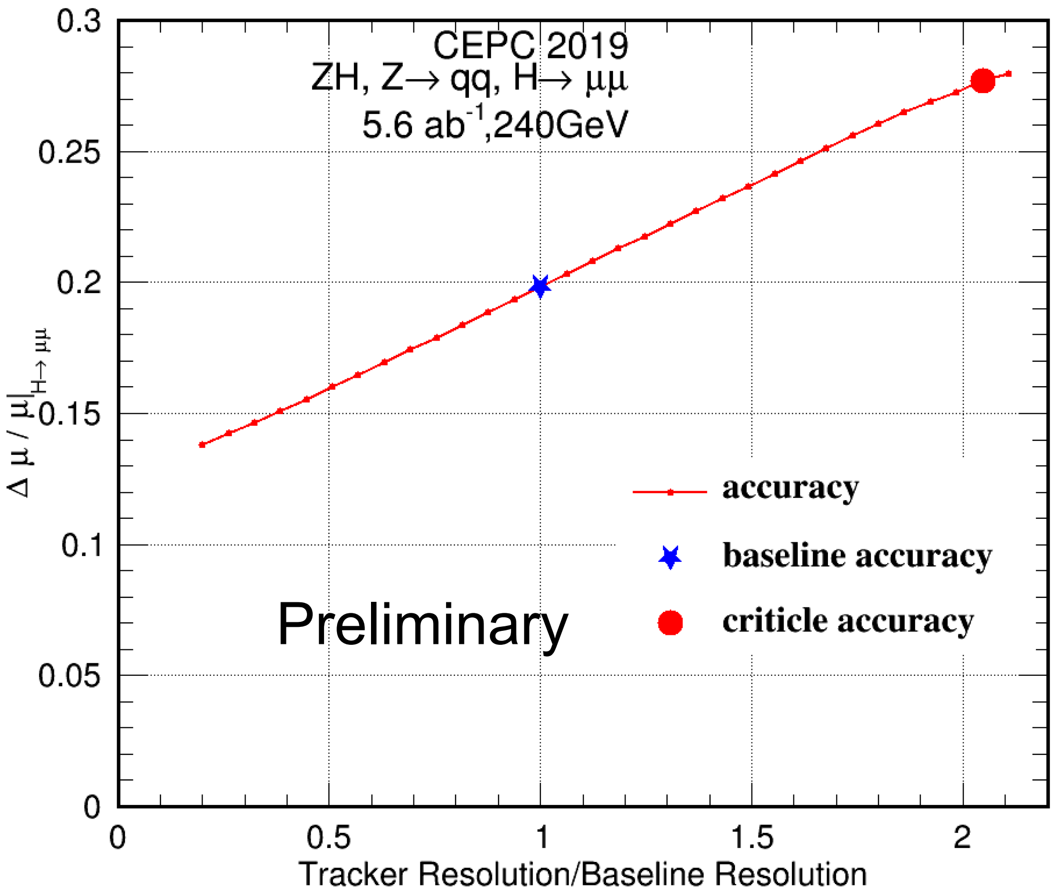
$$\frac{\delta\sigma_{\mathrm{ZH}}}{\sigma_{\mathrm{ZH}}} = 0.52 \times \left(1 + \mathrm{e}^{-0.09 \cdot R_{\mathrm{TPC}}}\right), \quad (4)$$

$$\delta m_{\mathrm{H}} = 5.85 \times \left(1 + 5.19 \times \mathrm{e}^{-1.81 \cdot R_{\mathrm{TPC}}}\right) \mathrm{MeV}. \quad (5)$$



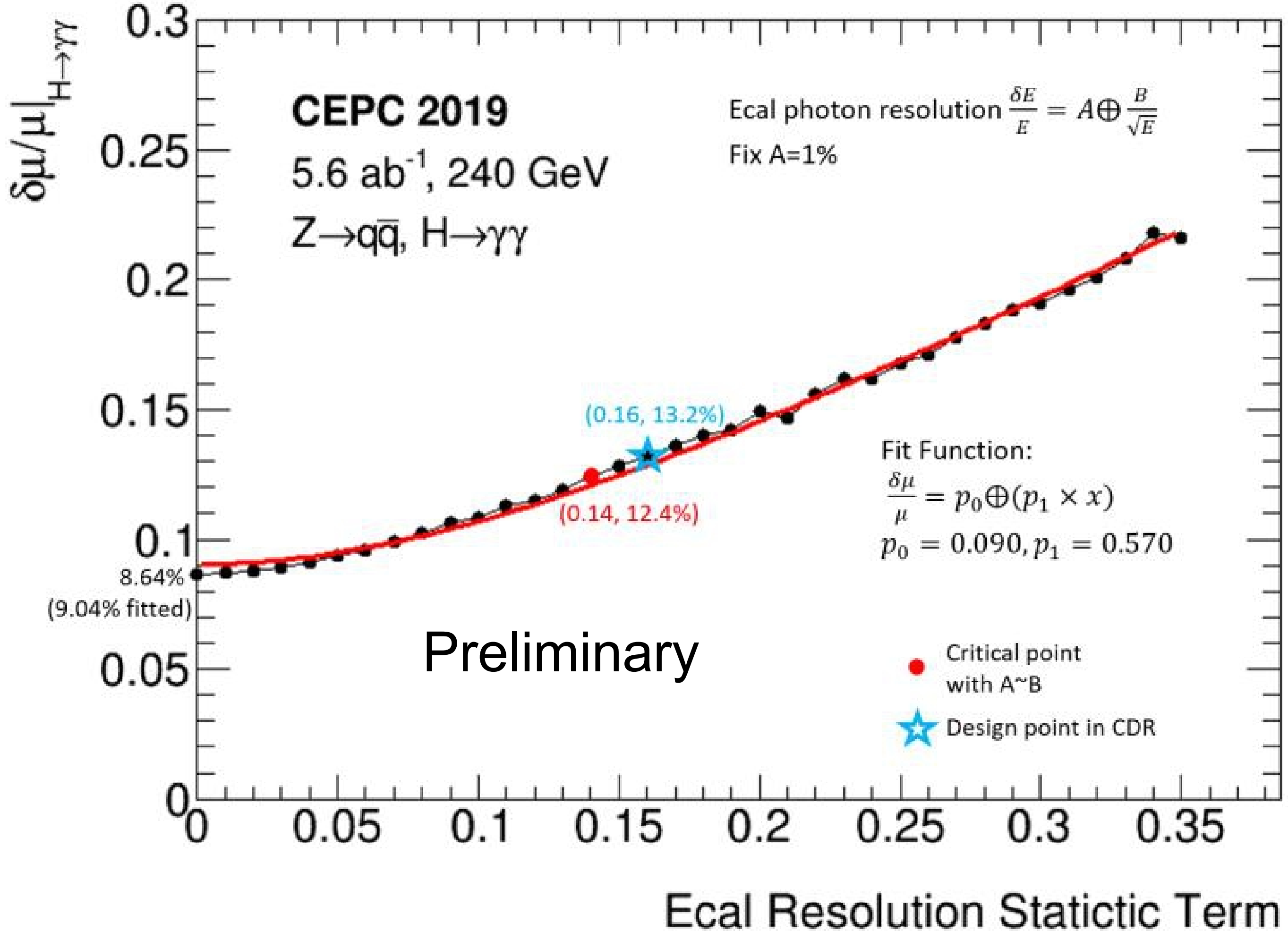
Note: Higgs mass is more accurately measured From Model-dependent analysis, which is used In the analysis show in the right side

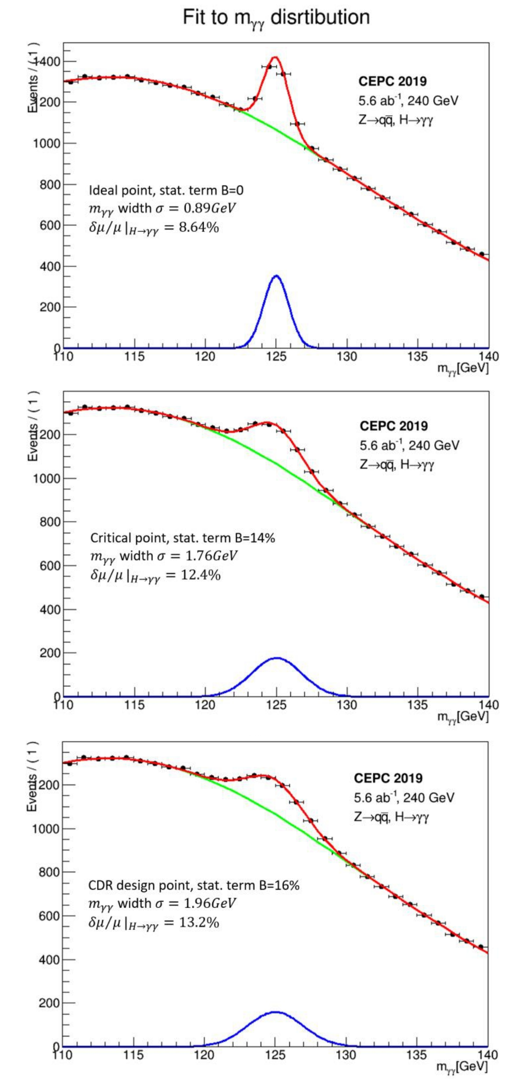
μ(H→μμ) measurement at qqH event



- Degrading the tracking resolution by 2 times leads to a degrading of 40% in the signal strength measurement

ECAL resolution benchmark on μ(H→γγ)

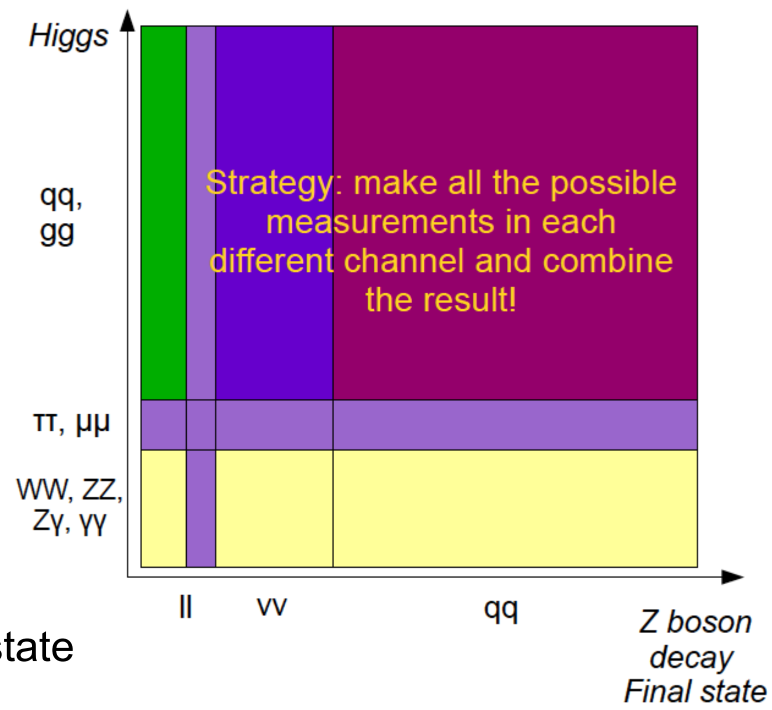




14% of statistic term is adequate to 1% constant term

Hadronic event: @ Higgs

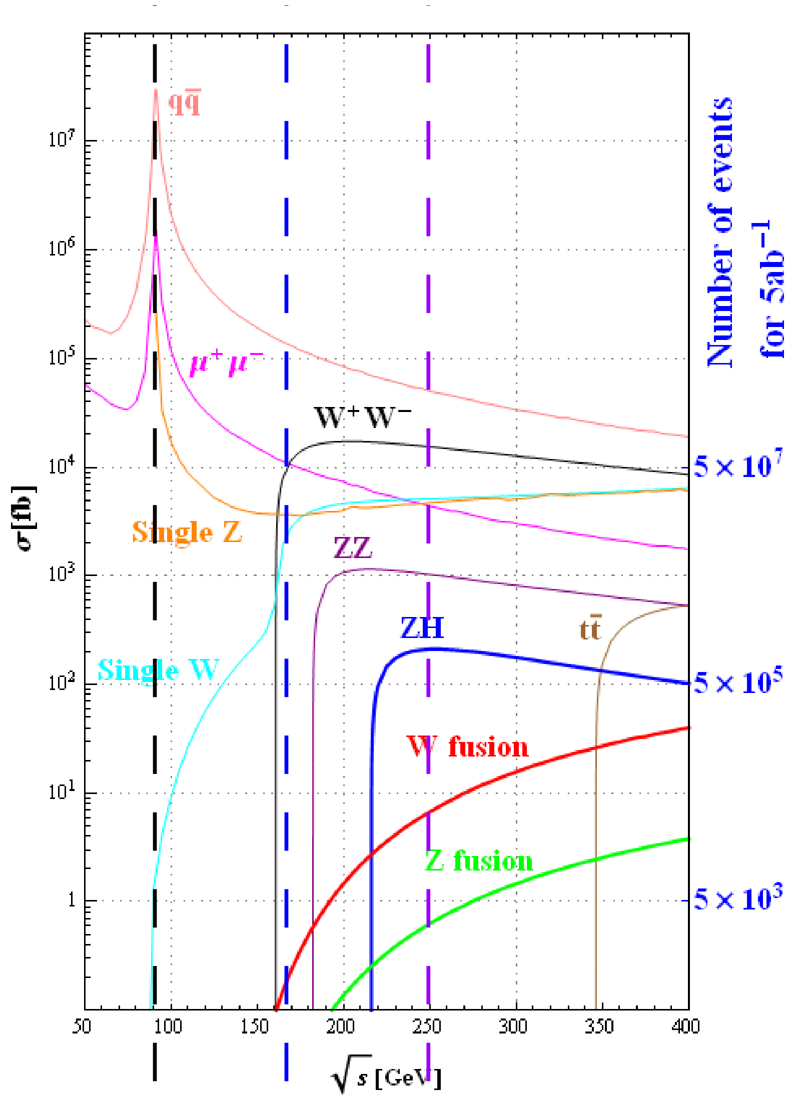
- SM Higgs
  - ***0 jets: 3%:*** *Z→ll, νν (30%); H→0 jets (~10%, ττ, μμ, γγ, γZ/WW/ZZ→leptonic)*
  - ***2 jets: 32%***
    - *Z→qq, H→0 jets. 70%*10% = 7%*
    - *Z→ll, νν; H→2 jets. 30%*70% = 21%*
    - *Z→ll, νν; H→WW/ZZ→semi-leptonic. 3.6%*
  - ***4 jets: 55%***
    - *Z→qq, H→2 jets. 70%*70% = 49%*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

Hadronic event

- Multi-jet events, especially the dominant 2-jet events, are critical
  - Measurement: TGC, Afb, etc
  - Background control
  - Calibration & in-situ monitoring
- 0 jets:
  - Di-photon events;
  - bhabha, ττ, μμ;
- 2 jets:
  - *ee→qq(γ) (ISR return & full energy)*
  - *WW/ZZ→semi-leptonic*
  - *Single W/Z events*
- 4 jets:
  - WW/ZZ→Full hadronic
  - ZH→qq+(bb, cc, gg)
- 6 jets: ZH→qqWW*, qqZZ*→Full hadronic

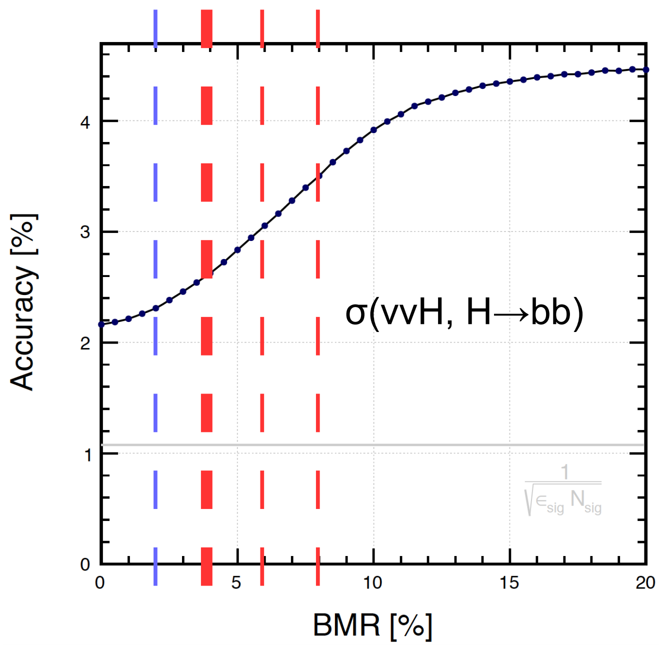


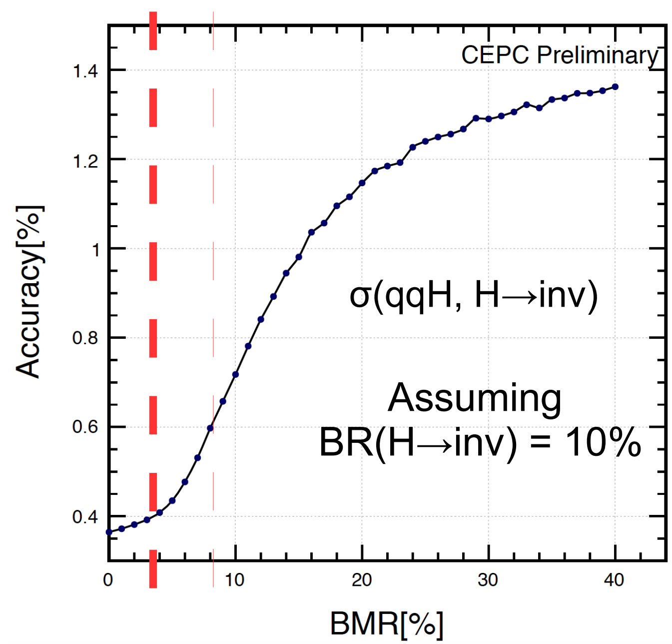
Performance quantification on the hadronic event reconstruction

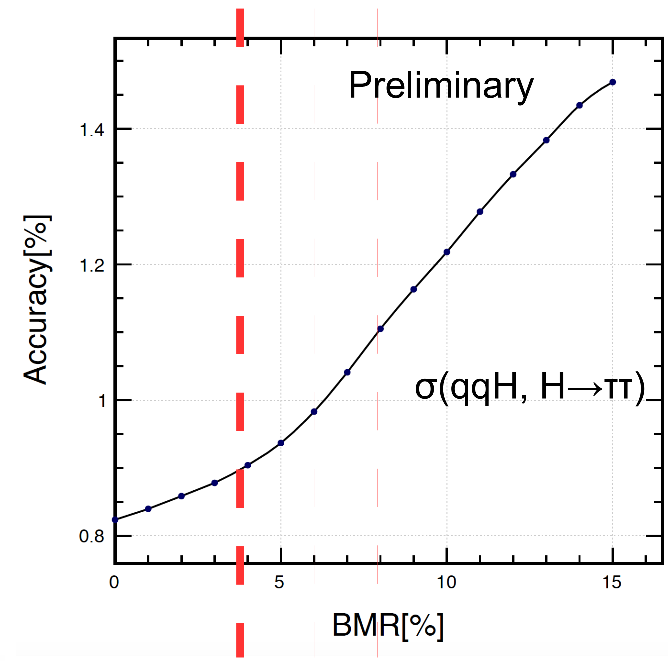
- Visible mass of hadronic system
  - Identify the hadronic system & calculate its visible mass
  - At 2-jets event: the visible mass is the mass of the intermediate boson
  - At fixed c.m.s. energy, the recoil mass of hadronic system is mostly determined by the visible mass.

- Jet: via jet clustering, and match to/interpret as parton
  - Essential for differential measurements
  - Essential for identifying the right combination of jets – the color singlet – for physics event with jet number > 2
  - The jet clustering can induce significant uncertainties

Requirement from benchmark analysis: BMR < 4%





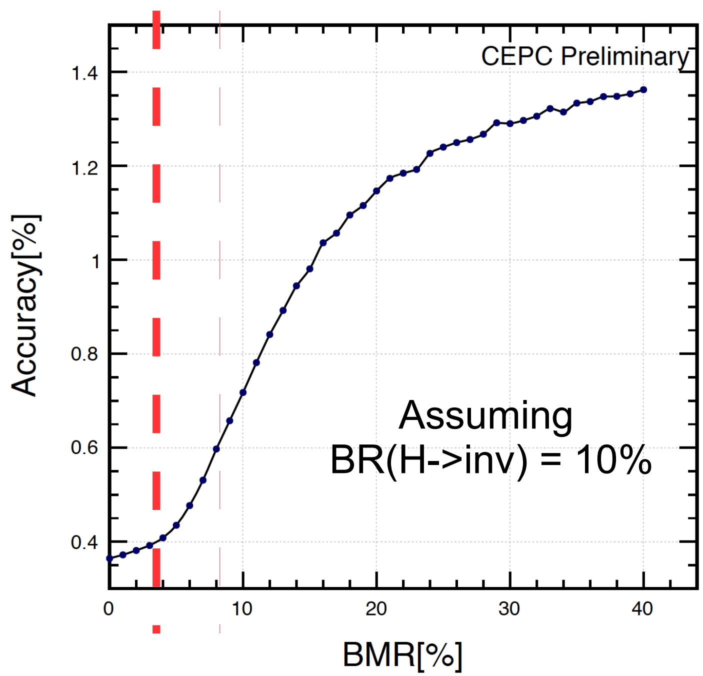


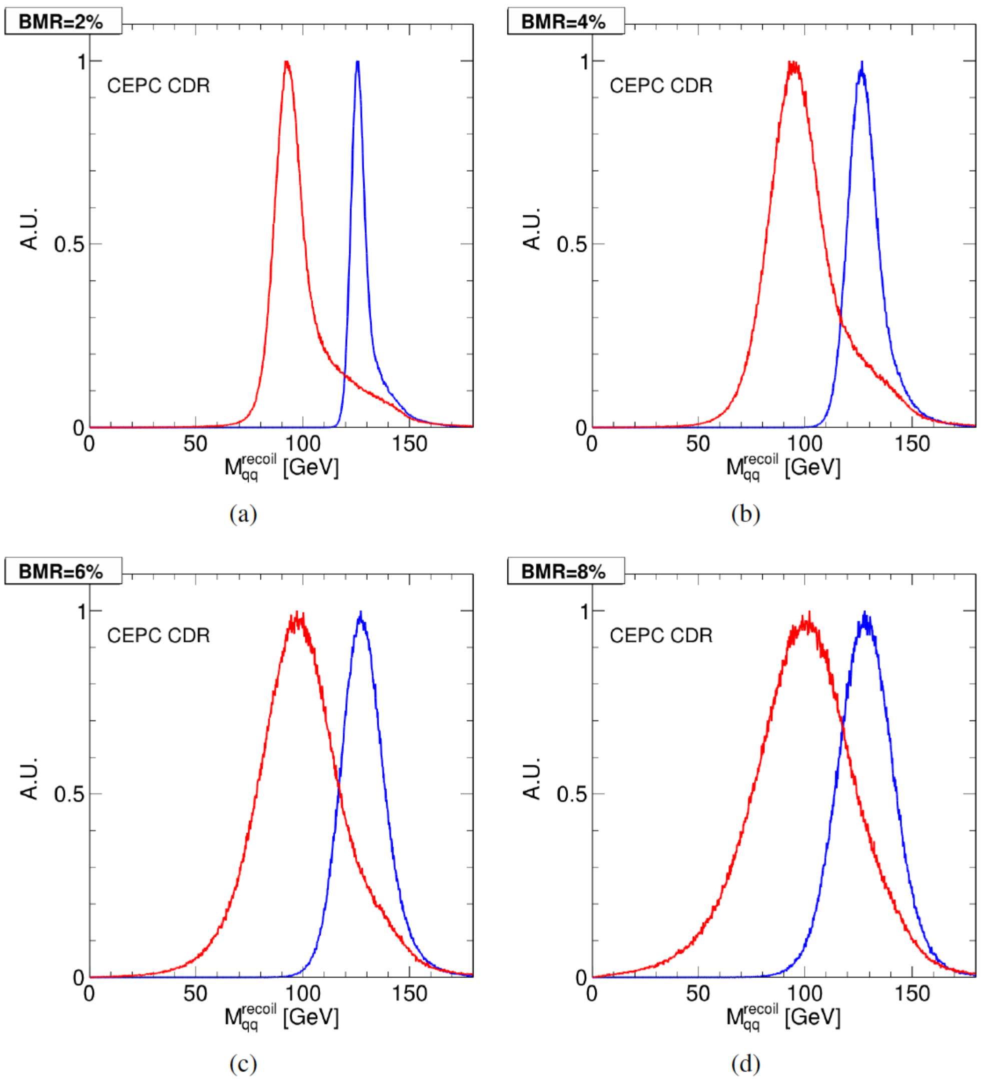
- Boson Mass Resolution: relative mass resolution of ννH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

	BMR = 2%	4%	6%	8%
σ(ννH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(ννH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

2nd Benchmark: qqH, H→invisible

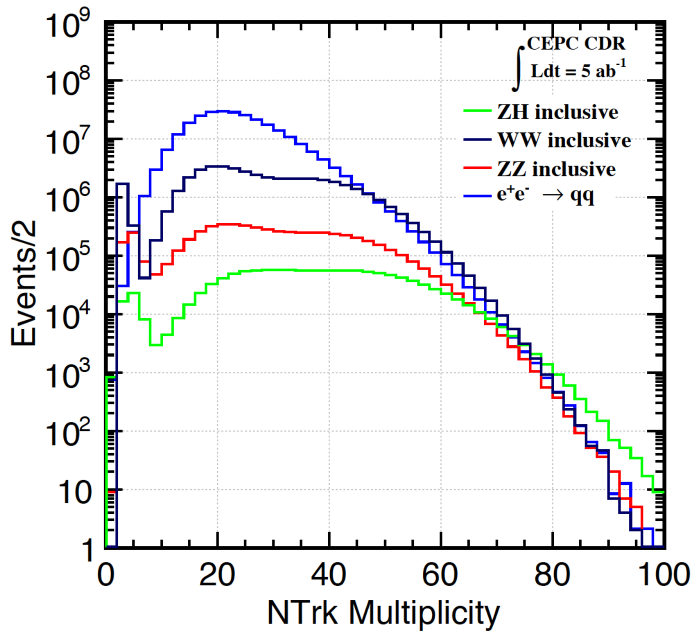
- Portal to DM...
- qqH dominants the precision & rely on the recoil mass to separate the ZZ bkg
- Essential for qqH analysis, especially H→non jet final state

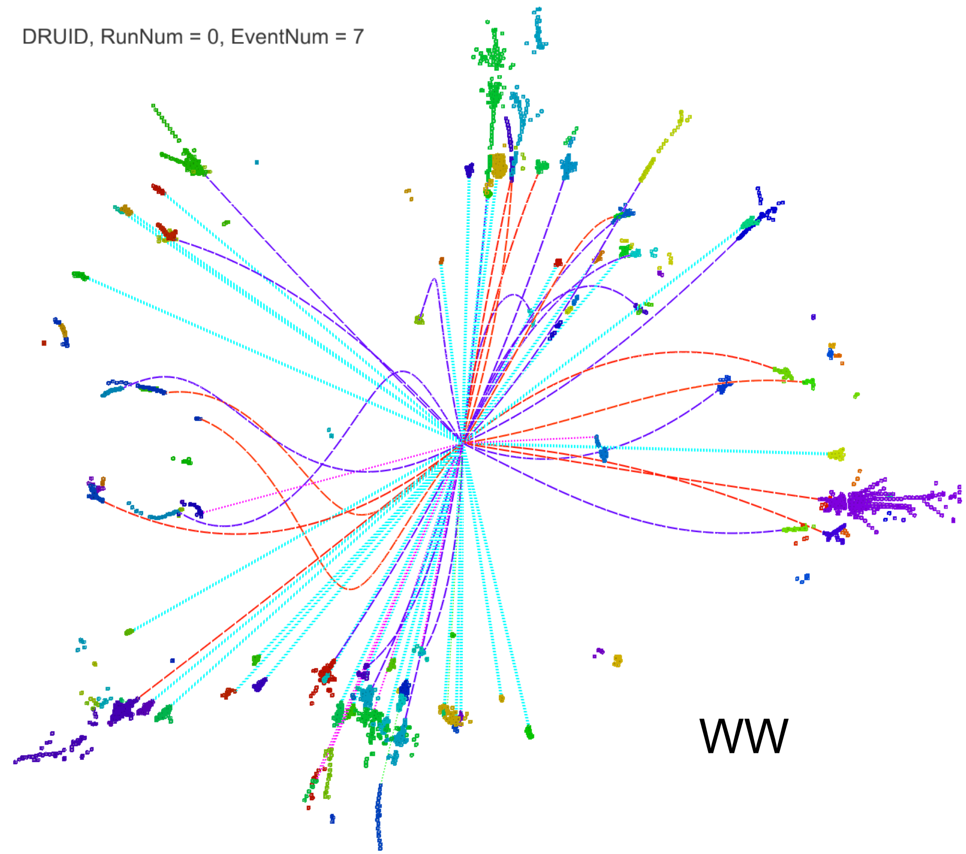




If the BMR degrades from 4% to 6/8%: the Higgs invisible measurement degrades by 20/50%

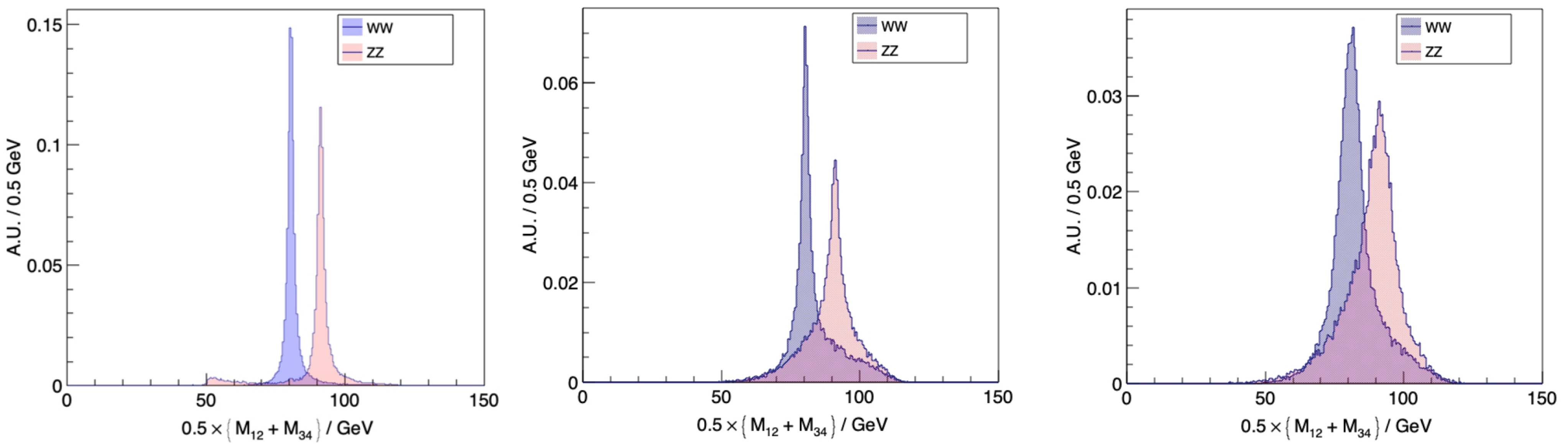
Full hadronic WW-ZZ separation





- 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



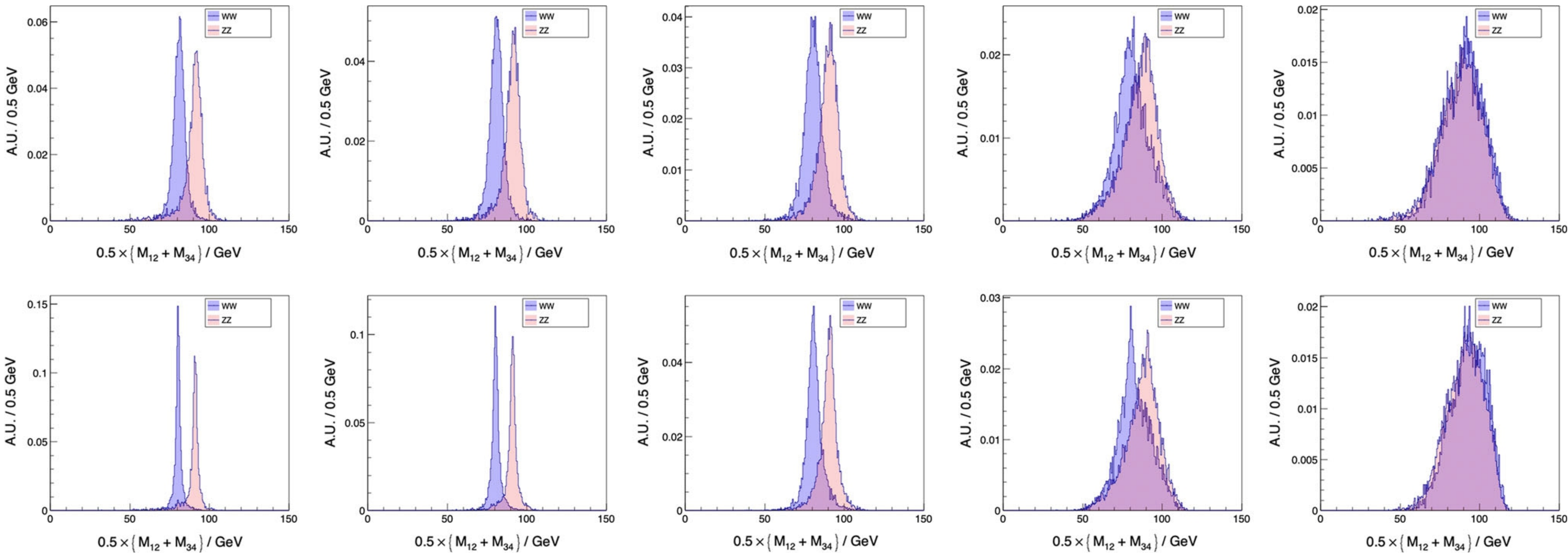
- Separation be characterized by
- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2

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

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

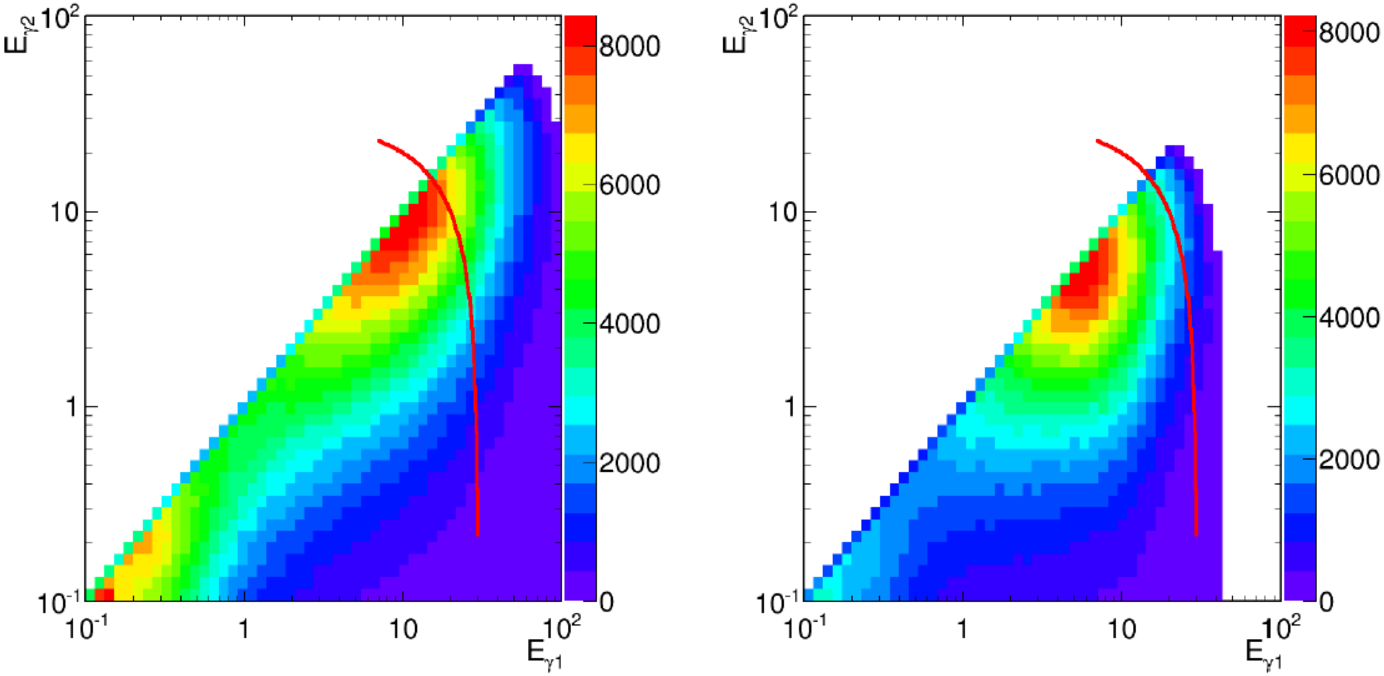
- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - \+ Jet confusion – Genjet: Overlapping ratio of **53%**
  - \+ Detector response – Recojet: Overlapping ratio of 58%

Separation V.S. clustering



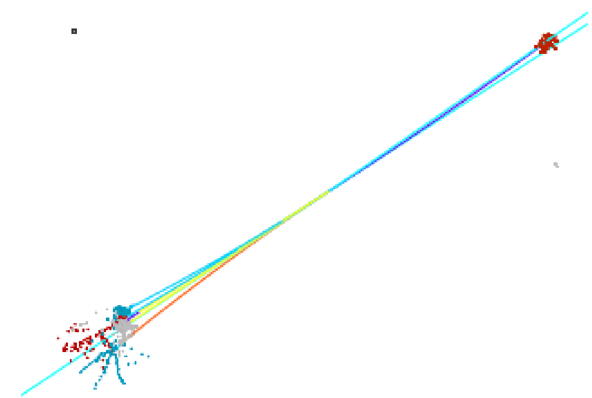
Eur. Phys. J. C (2019) 79:274

Separation requirement on Z→tautau event at Z pole



(a) (b)

Fig. 14 The generated π^0 distribution as a function of the energies of diphotons from $\pi^0 \to \gamma\gamma$ in inclusive Higgs (a) and $Z \to \tau\tau$ samples (b). $E_{\gamma1}$ is the energy of leading photon. $E_{\gamma2}$ is the energy of sub-leading photon. The red line is the function of $E_{\gamma1} + E_{\gamma2} = 30$ GeV.



- Separation of tracks from 3 prong decay taus, and photons decayed from high energy pi-0 (up-to 30 GeV)

Updates on the requirements w.r.t the CDR

128 EXPERIMENTAL CONDITIONS, PHYSICS REQUIREMENTS AND DETECTOR CONCEPTS

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Table 3.3: Physics processes and key observables used as benchmarks for setting the requirements and the optimization of the CEPC detector.

Higgs recoil at μμH: 2*baseline resolution is adequate with current beam energy spread
H→μμ: 2*baseline leads to 40% degrading

Closer > Lighter > Resolution

More accurately: BMR<4%
Color-Singlet identification for events with Number of Jets > 4

A critical value of 14% statistical term is Identified with 1% constant term

Separation: able to separate photons decayed from 30 GeV pi-0.

Leptons:

Isolated, high-energy ones with acceptance: eff*purity > 99%

Inside jet: need further quantification – benchmark analysis

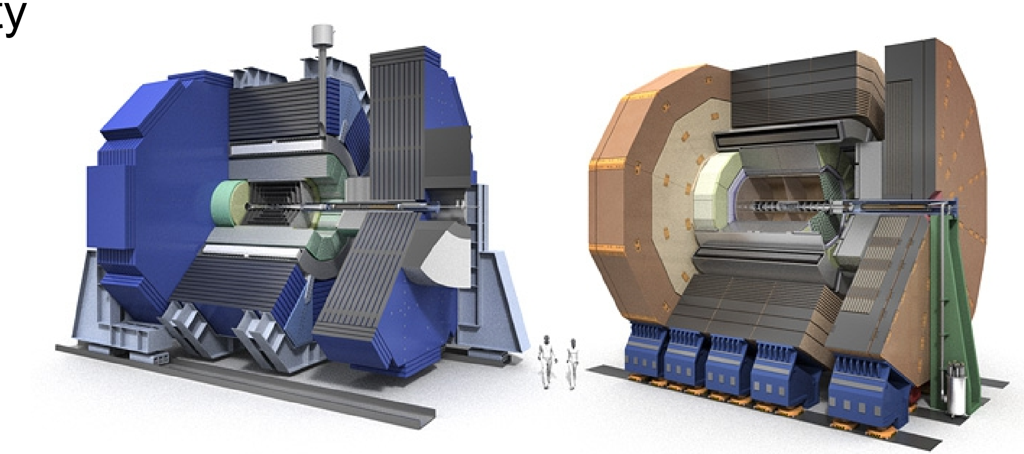
Kaon: need further quantification

Summary

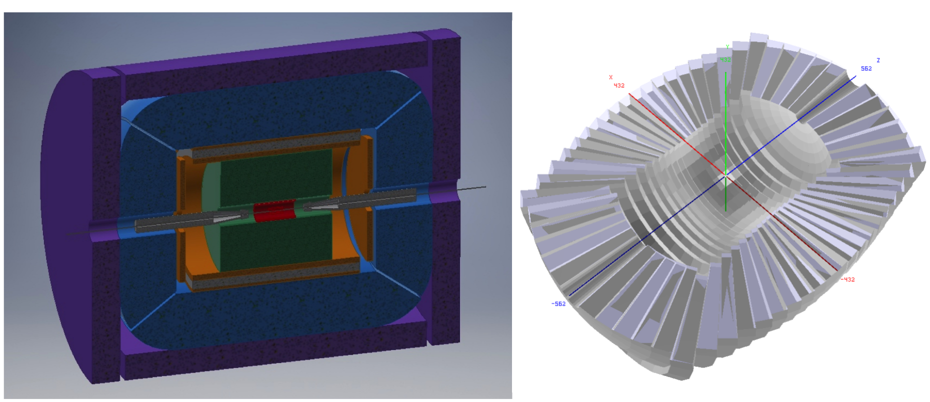
- The CEPC detector should precisely identify and measure the key objects. The qualitative requirements are re-evaluated on the Higgs benchmarks, a minor update is concluded with respect to the CDR (in blue)
  - Tracker: How about degrading the requirement by 100%?
    - Adequate at Higgs mass measurement using μμH event (recoil)
    - Leads to 40% degrading on the μ(H→μμ) measurement
    - A slight degrading, say 30-40% w.r.t the CDR requirement should be OK
  - ECAL: Stochastic term of 14% is adequate to 1% constant term
  - Jet: BMR < 4% is required & Color-Singlet identification calls for innovative algorithm development
- The requirement should be evaluated at more benchmarks
  - Differential measurement (angular resolution of jet, MET)
  - Physics with Z→tautau (at Z pole) requires an efficient separation of photons decayed from 30 GeV pi-0, and 3-prong decay tau
  - Object identification in jets: Kaon, lepton, and hadron decay products identification

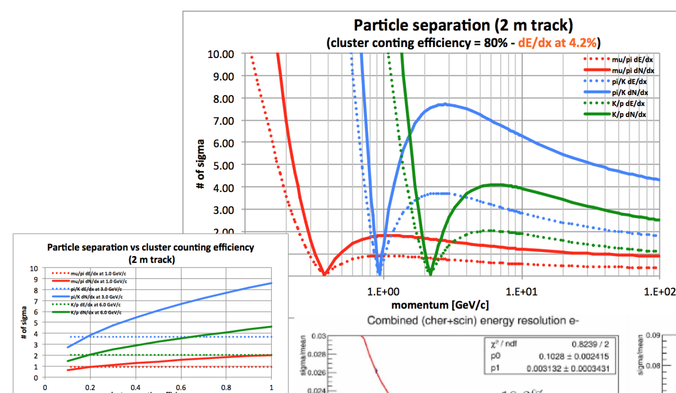
Two classes of Concepts

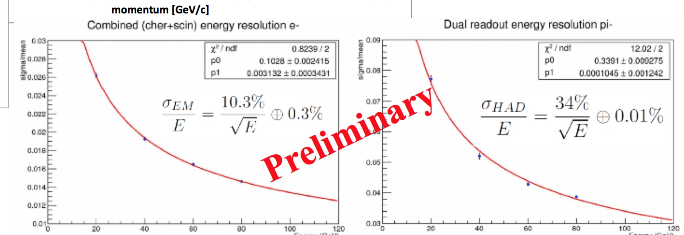
- PFA Oriented concept using High Granularity Calorimeter
  - + TPC (ILD-like, **Baseline**)
  - + Silicon tracking (SiD-like)



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



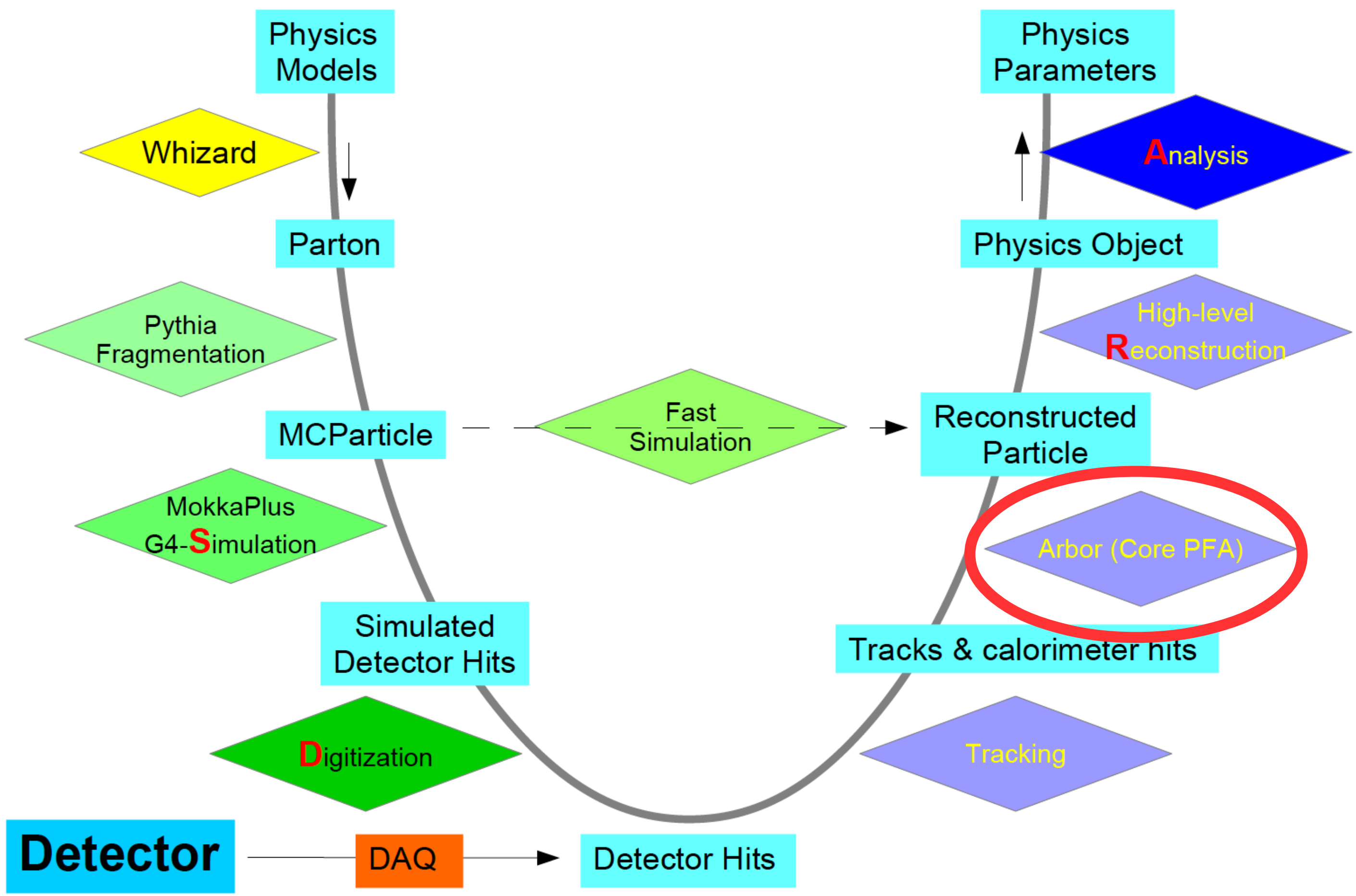




https://indico.ihep.ac.cn/event/6618/

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

The Simu-Reco Chain at CEPC

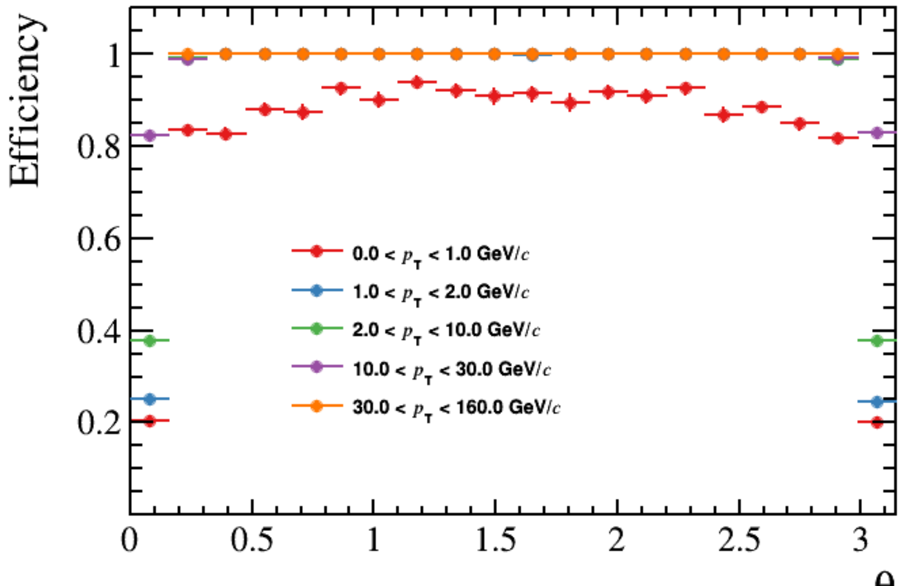


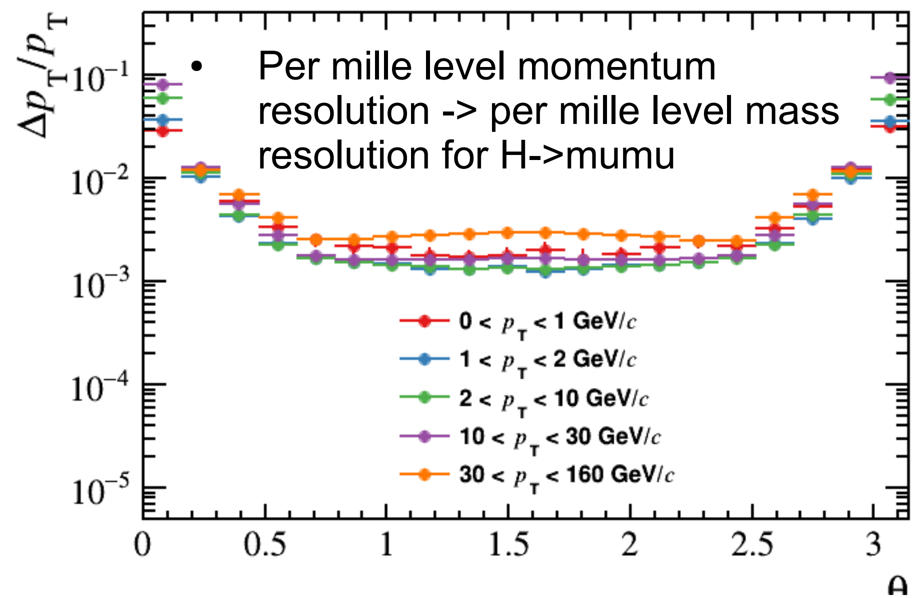
Generators (Whizard & Pythia)
Data format & management (LCIO & Marlin)
Simulation (MokkaC)
Digitizations
Tracking
PFA (Arbor)
Single Particle Physics Objects Finder (LICH)
Composed object finder (Coral)
Tau finder
Jet Clustering (FastJet)
Jet Flavor Tagging (LCFIPLus)
Event Display (Druid)
General Analysis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

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

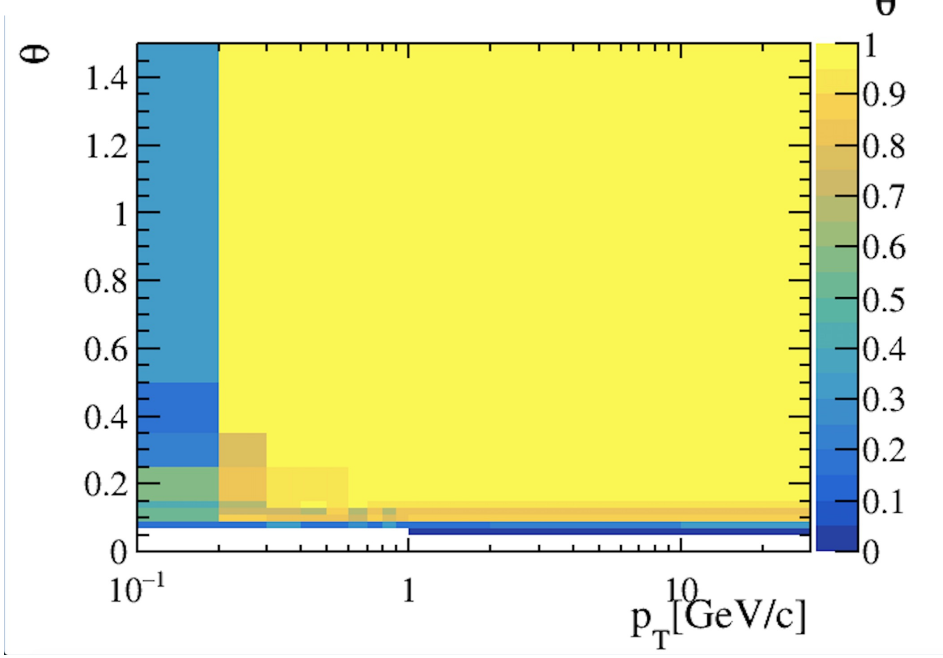
General Software | ILCSoft | ILCSoft + Development | Developments

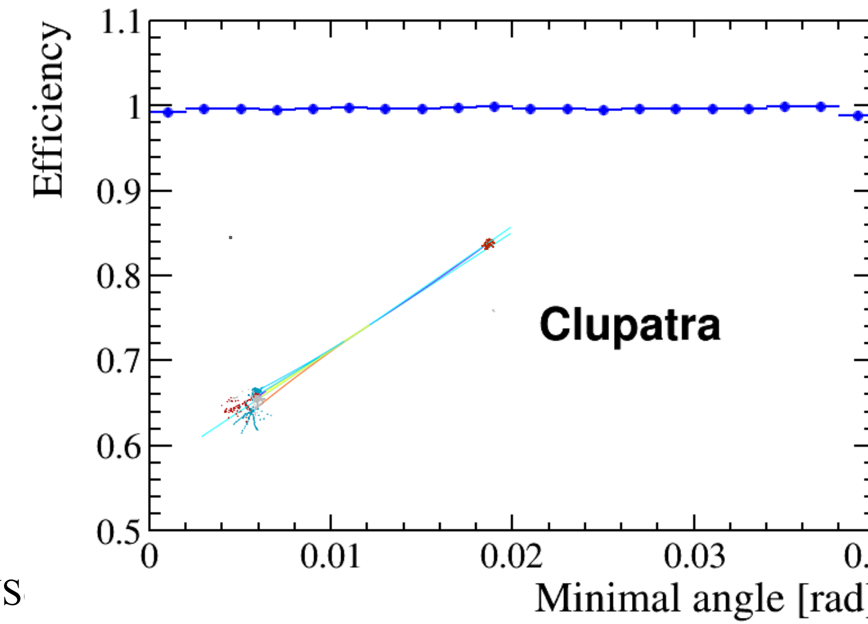
Tracking



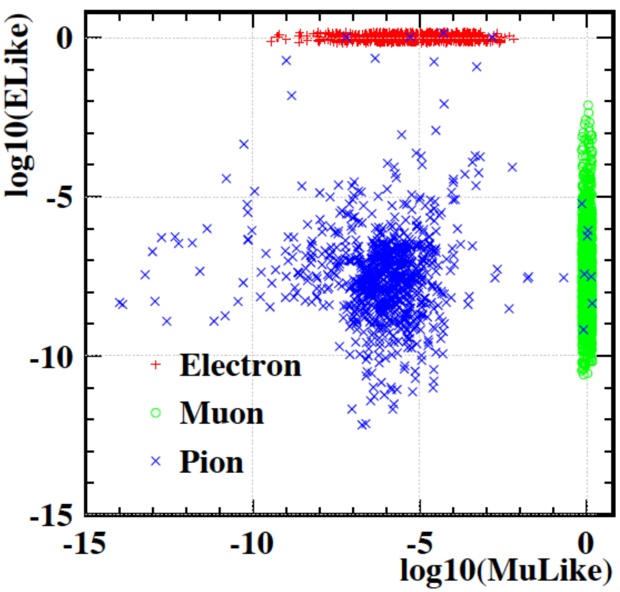


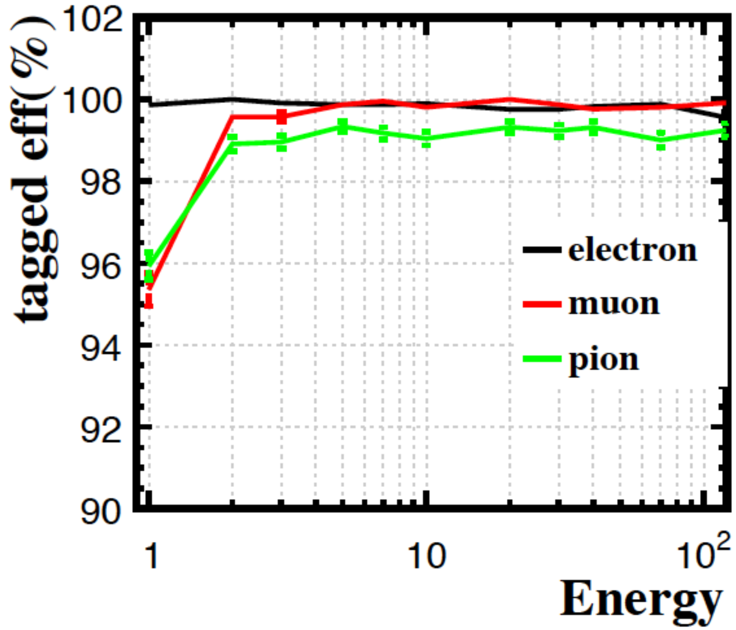
- Per mille level momentum resolution -> per mille level mass resolution for H->mumu

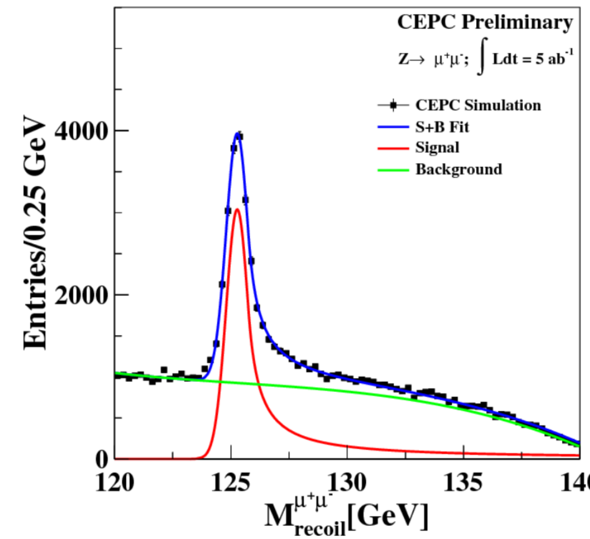


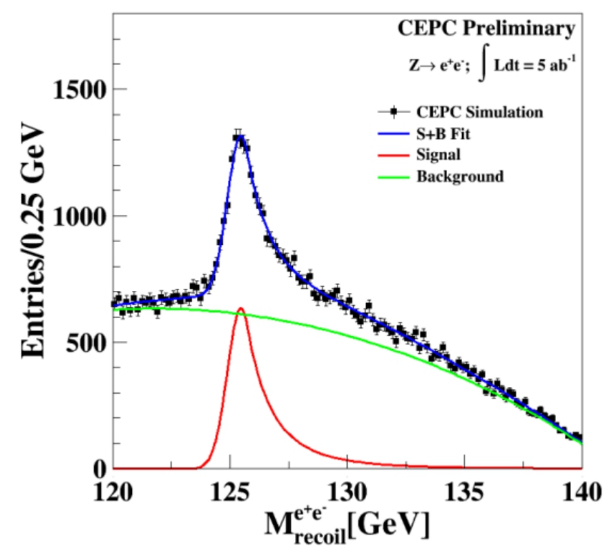


Lepton







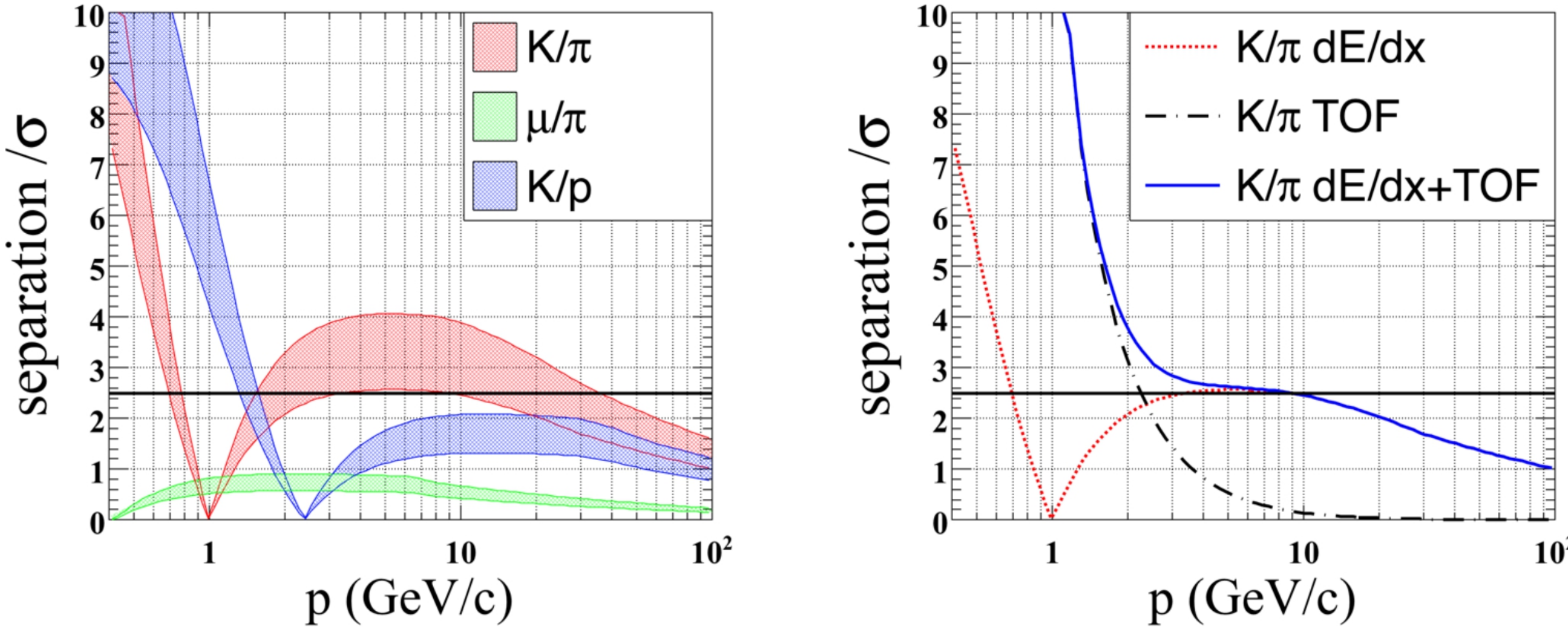


BDT method using 4 classes of 24 input discrimination variables.

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

Kaon

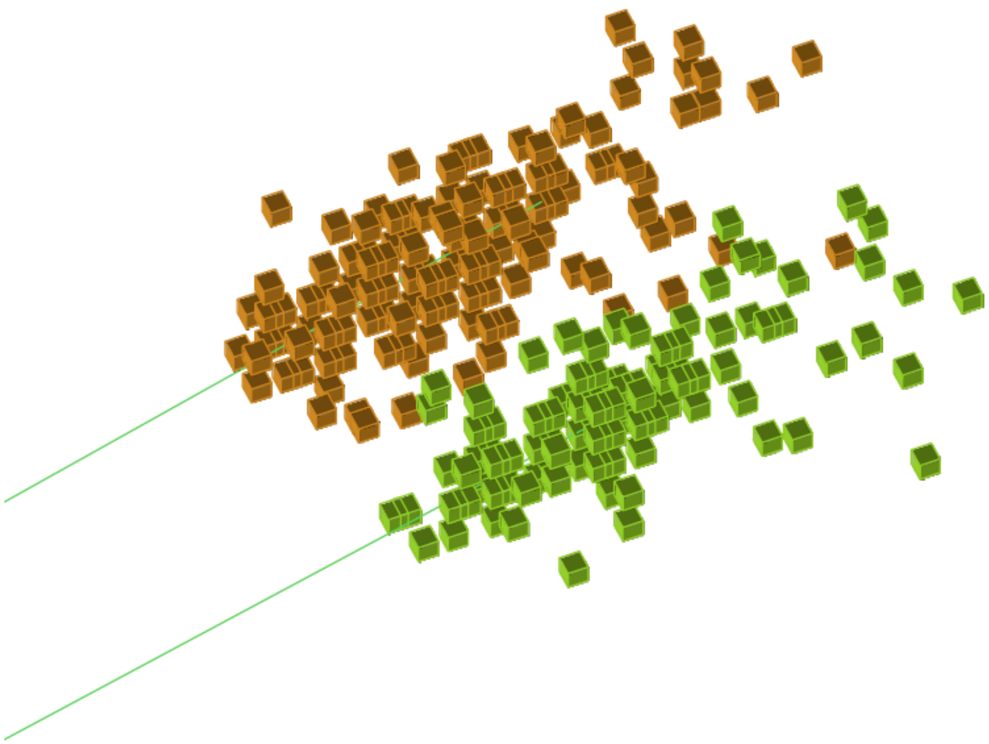


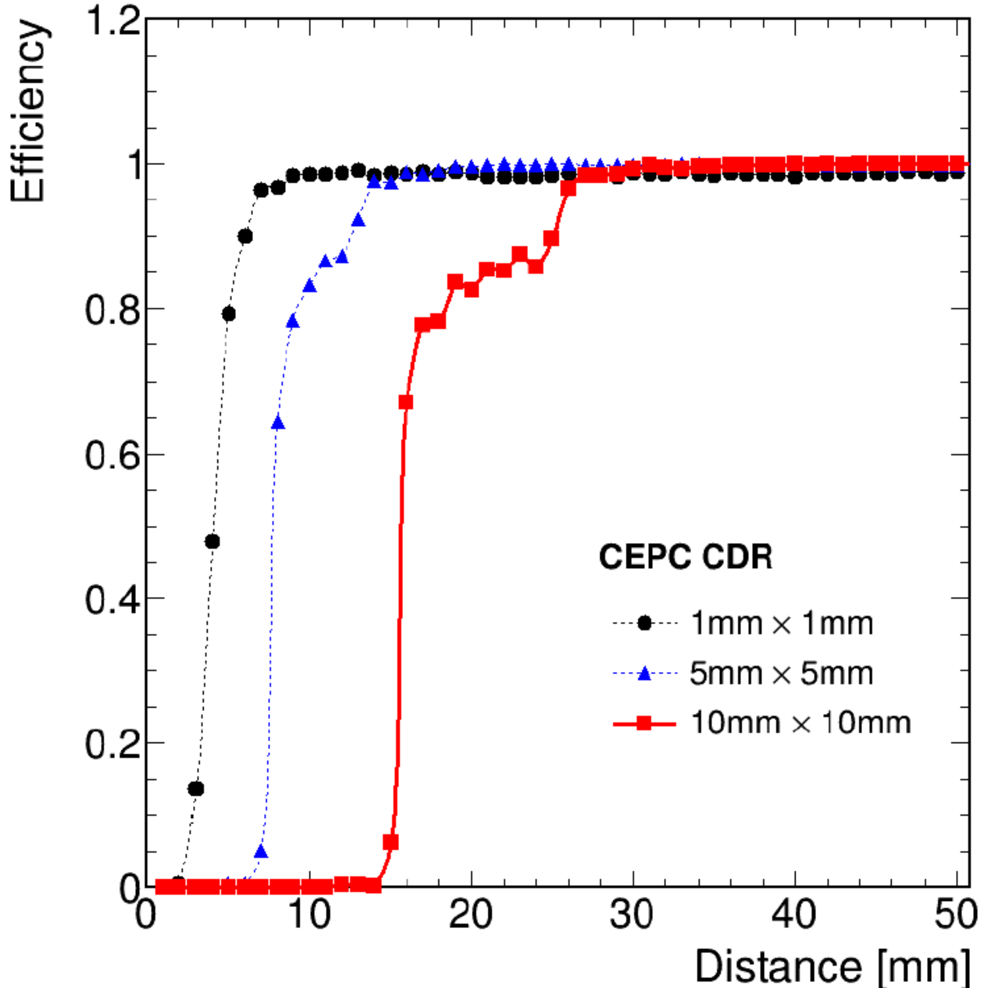
Highly appreciated in flavor physics @ CEPC Z pole
- TPC dEdx + ToF of 50 ps

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

Clustering

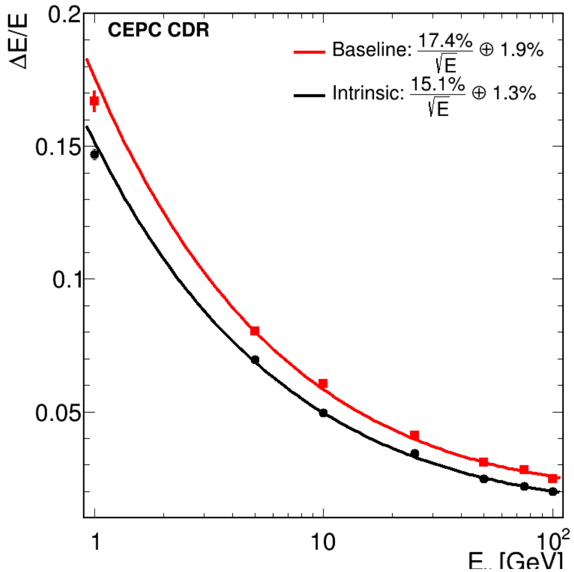


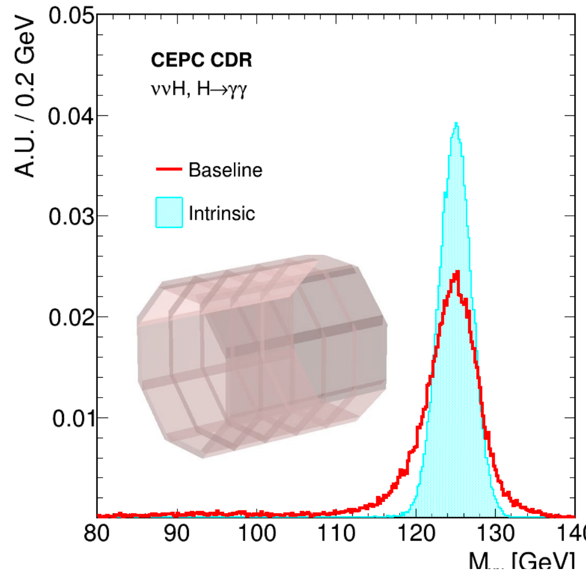


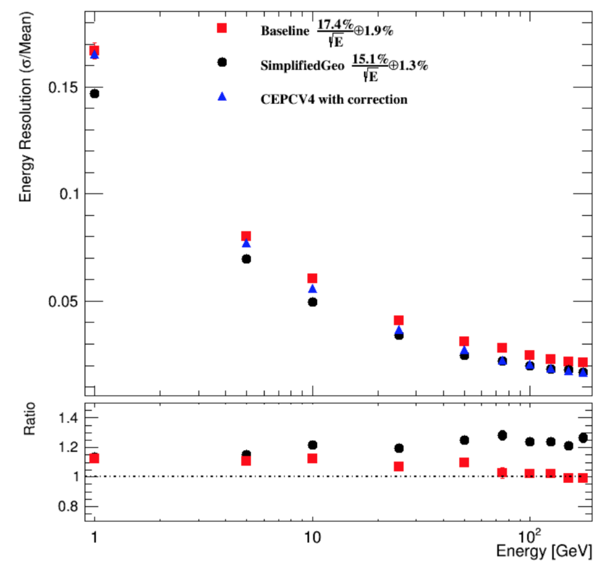
Critical energy to separate an evenly decay π_0: 30 GeV

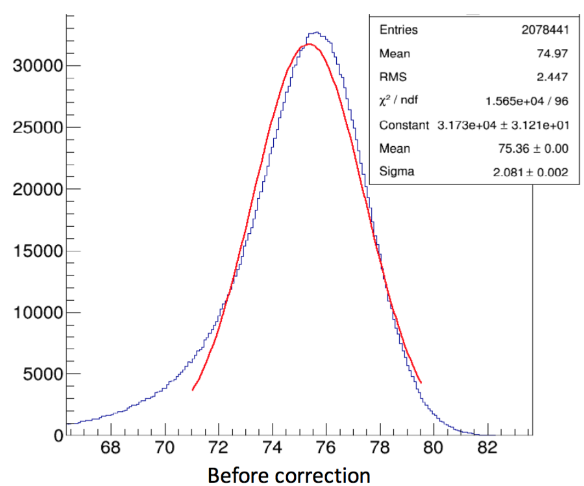
See Hang Zhao's talk

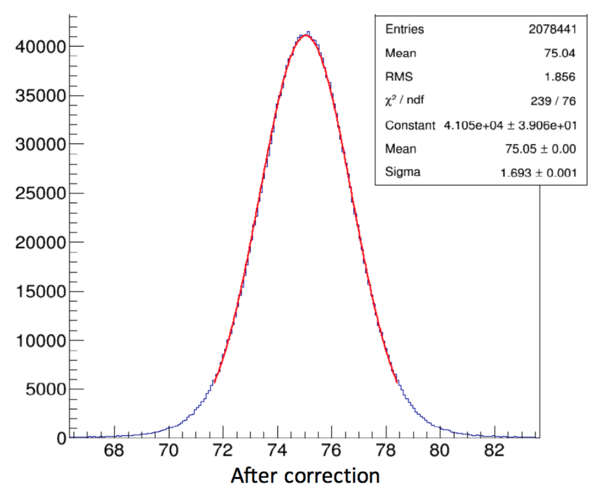
Photon: resolution







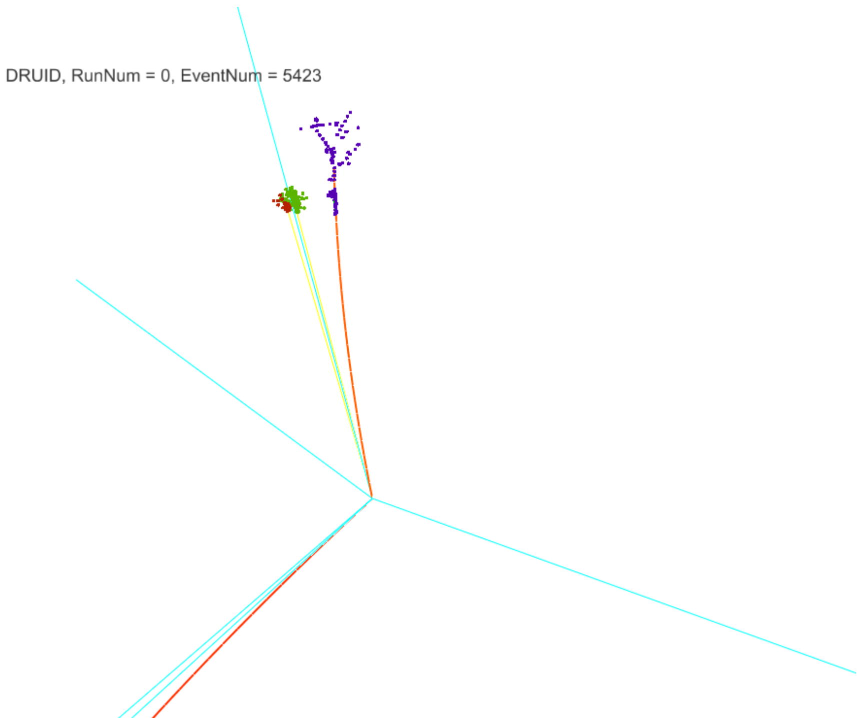




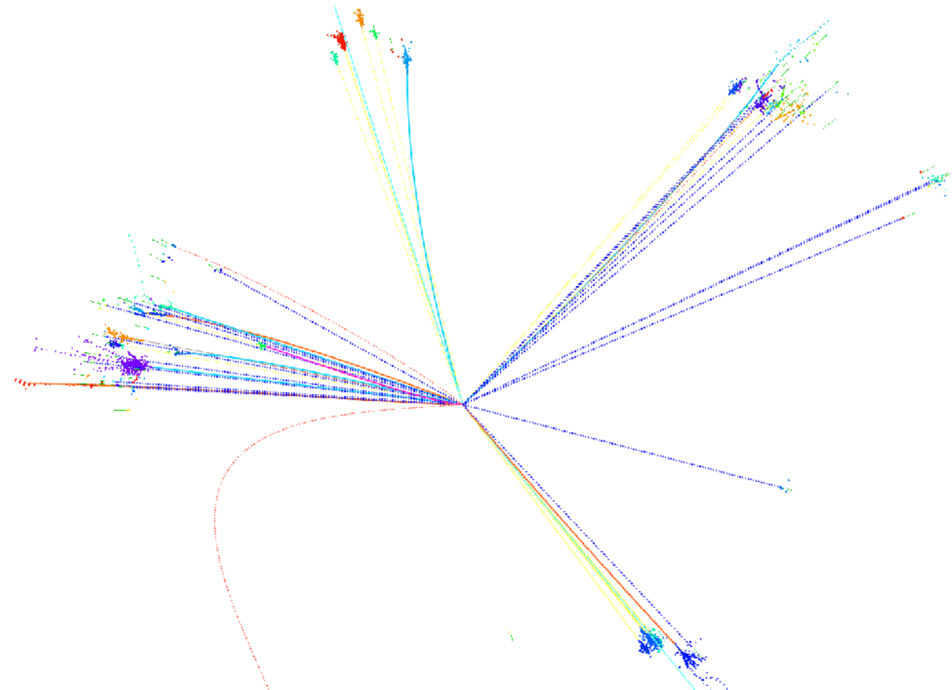
- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/baseline geometry
- The geometry defects correction could be efficiently corrected (Preliminary)

See Yuqiao Shen's talk

Tau



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

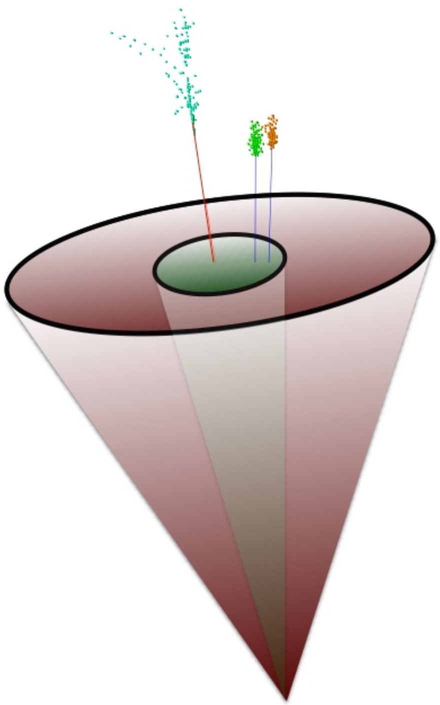


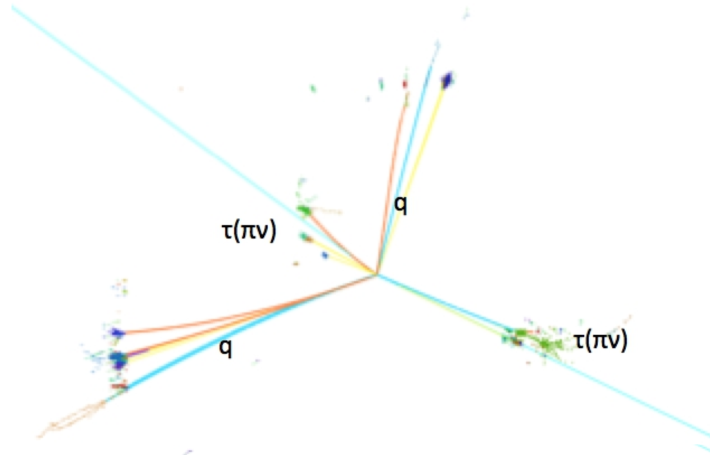
Cone Based Algorithm!
Para. Optimization

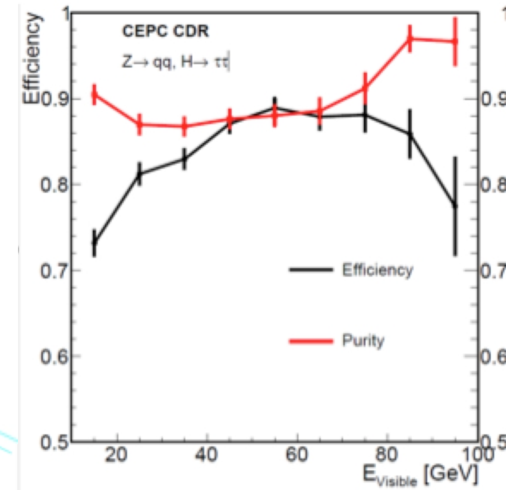
- Two catalogues:
  - Leptonic environments: i.e, llττ(ZZ/ZH), ννττ(ZZ/ZH/WW), Z→ττ;
  - Jet environments: i.e, ZZ/ZH→qqττ, WW→qqντ;

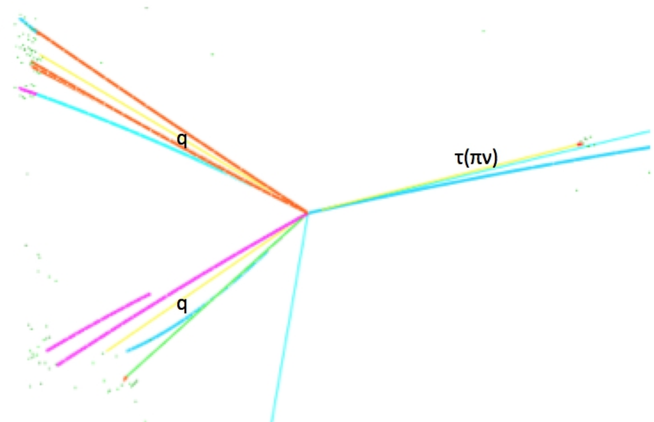
Ph.D thesis: D. Yu, reconstruction of leptonic objects at e+e- Higgs factory

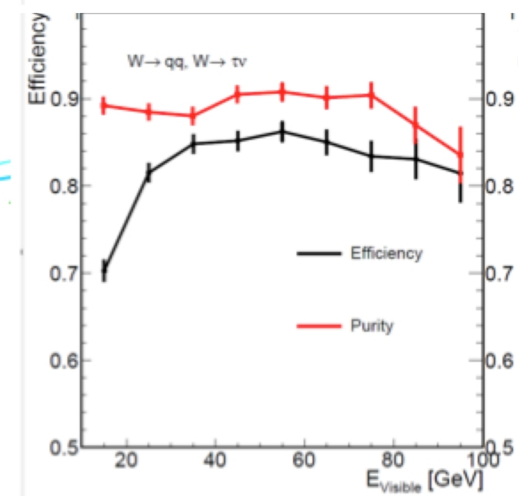
Tau finding at hadronic events









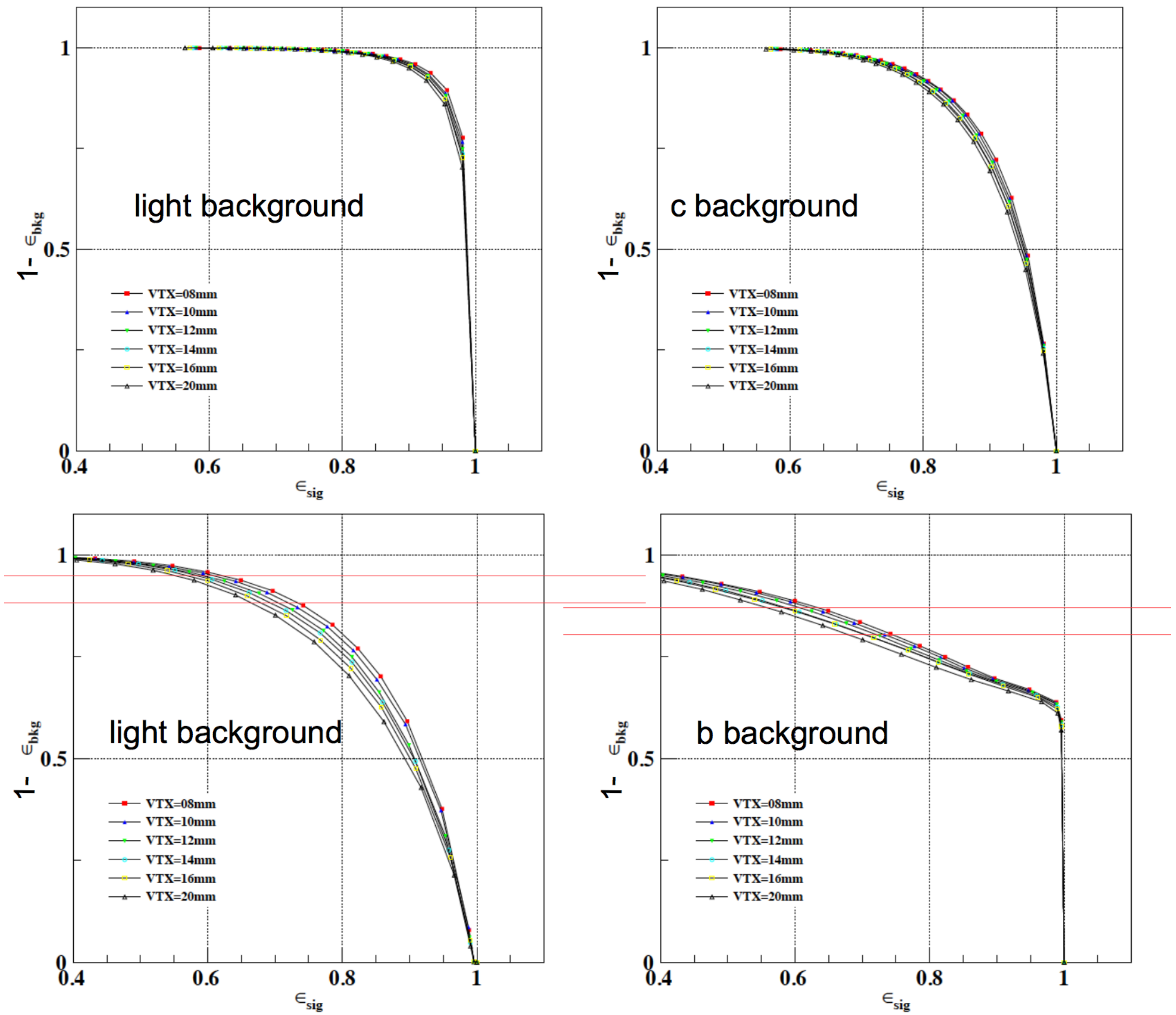


TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for qqττ, and qqτν events

See Zhigang Wu's talk

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/

Performance quantification on the hadronic event reconstruction

- Visible mass of hadronic system
  - Identify the hadronic system & calculate its visible mass
  - At 2-jets event: the visible mass is the mass of the intermediate boson
  - At fixed c.m.s. energy, the recoil mass of hadronic system is mostly determined by the visible mass.

- Jet: via jet clustering, and match to/interpret as parton
  - Essential for differential measurements
  - Essential for identifying the right combination of jets – the color singlet – for physics event with jet number > 2
  - The jet clustering can induce significant uncertainties

The performance - requirement benchmark analyses

- 2 jet final state
  - σ(vvH, H→bb)
  - σ(qqH, H→inv)
  - σ(qqH, H→tautau)

- 4 jet final state: ZZ/WW separation at full hadronic final states

- Jet response: Jet Energy/Angluar Resolution/Scale and impact from jet clustering algorithms, see Peizhu Lai's presentation yesterday

  https://agenda.linearcollider.org/event/8217/contributions/44662/

Visible mass of hadronic system

- Quantified by BMR (Boson Mass Resolution): the relative mass resolution on fully hadronic decay Higgs
- At CEPC, the BMR is determined on vvH event, with a standard cleaning procedure to control the effect of ISR photon, neutrinos generated in Higgs decay, and detector acceptance

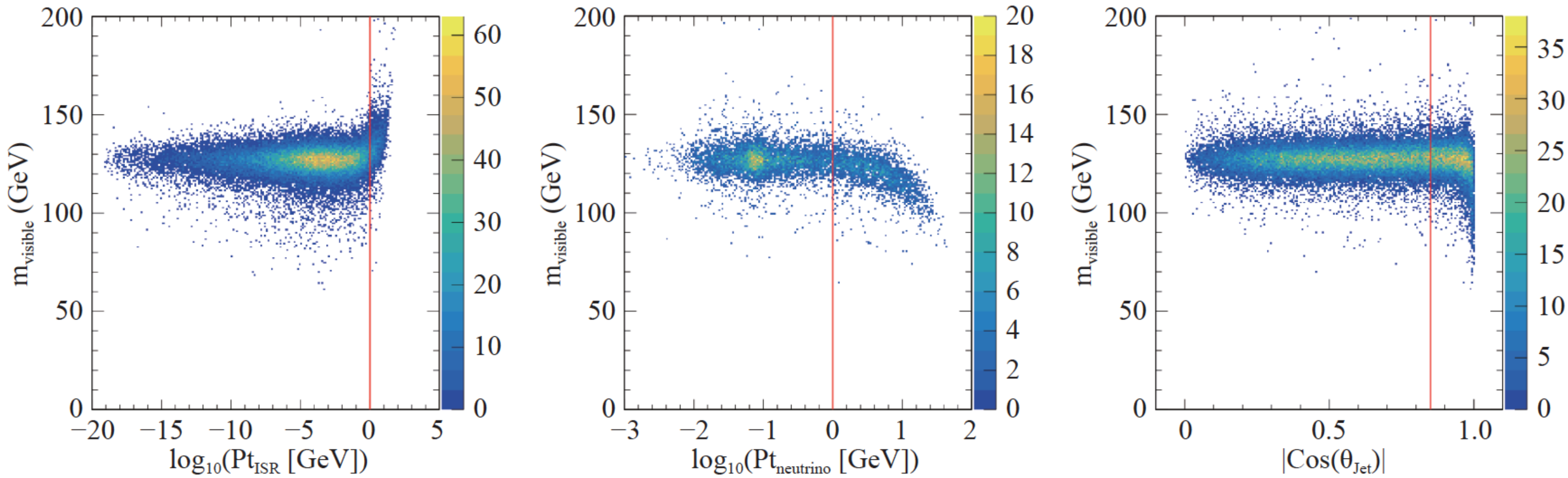


Fig. 4. (color online) Correlation between the reconstructed Higgs boson mass and the sum of the transverse momentum of the ISR photons (Pt_{ISR}) (left); the sum of the transverse momentum of the neutrinos generated by the Higgs bosons decay products ($Pt_{neutrino}$) (center); and the minimum angle between jets and the beam pipe ($|\cos\theta_{Jet}|$) (right). These plots are based on the $H \to gg$ events, and similar conclusions are obtained with $H \to bb$ and cc events. The red lines in the plots are the cut values used for event cleaning.

BMR at the CEPC baseline ~ 3.75%

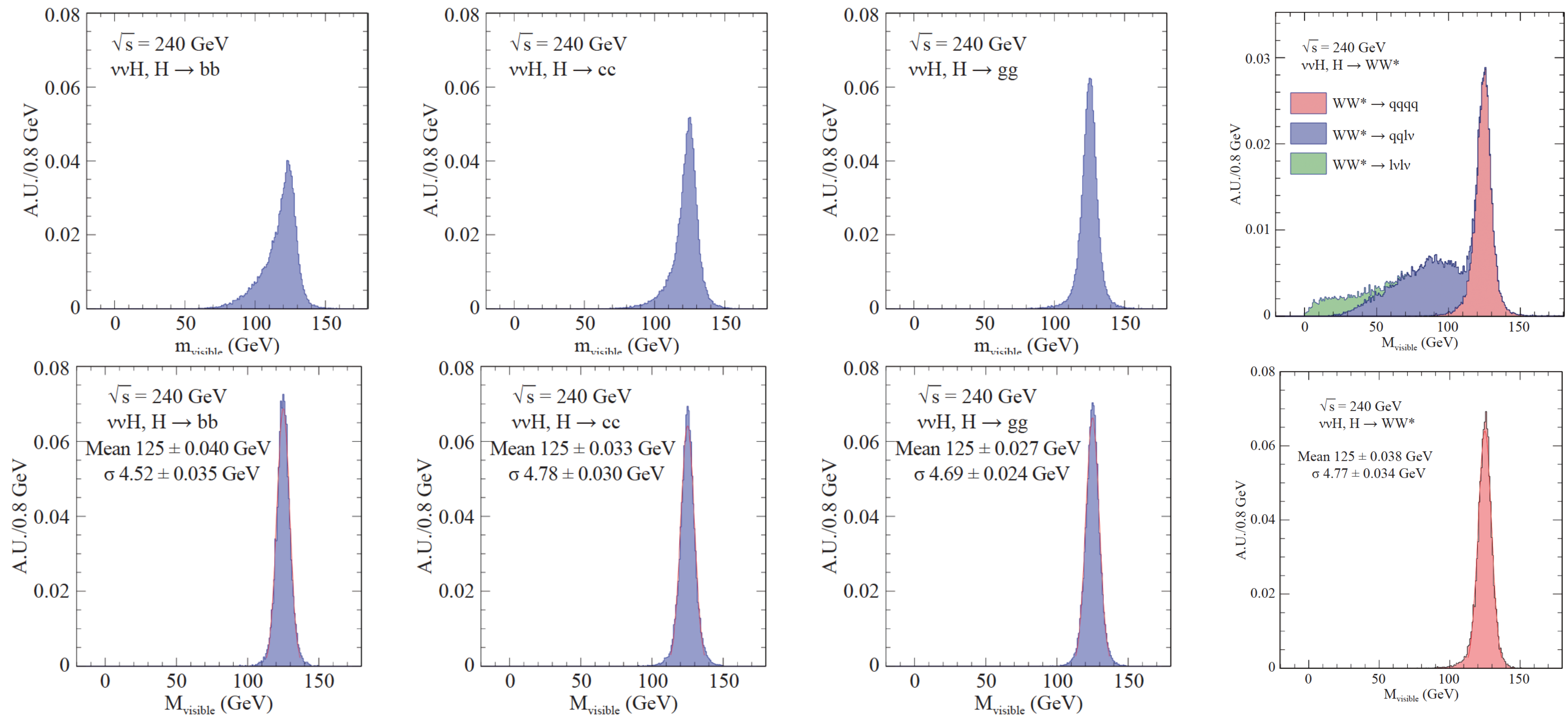


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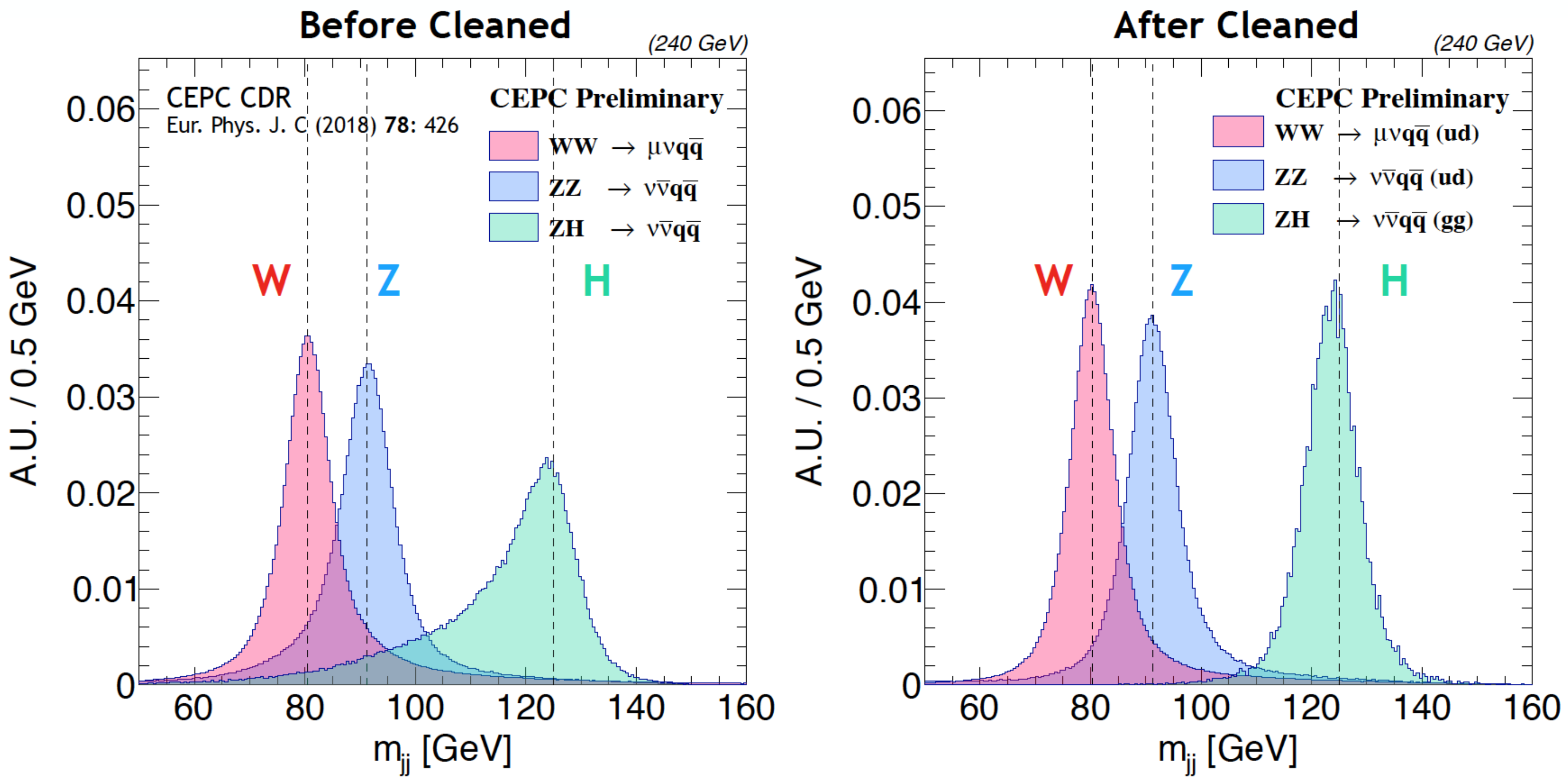
Table 1. Event cumulative efficiency for Higgs boson exclusive decay at the CEPC with $\sqrt{s} = 240$ GeV.

	gg(%)	bb(%)	cc(%)	WW*(%)	ZZ* (%)
Pt_ISR < 1 GeV	95.15	95.37	95.30	95.16	95.24
Pt_neutrino < 1 GeV	89.33	39.04	66.36	37.46	41.39
|Cos(Theta_Jet)| < 0.85	67.30	28.65	49.31	–	–

Table 3. Higgs boson mass resolution (sigma/Mean) for different decay modes with jets as final state particles, after event cleaning.

$H \to bb$	$H \to cc$	$H \to gg$	$H \to WW^*$	$H \to ZZ^*$
3.63%	3.82%	3.75%	3.81%	3.74%

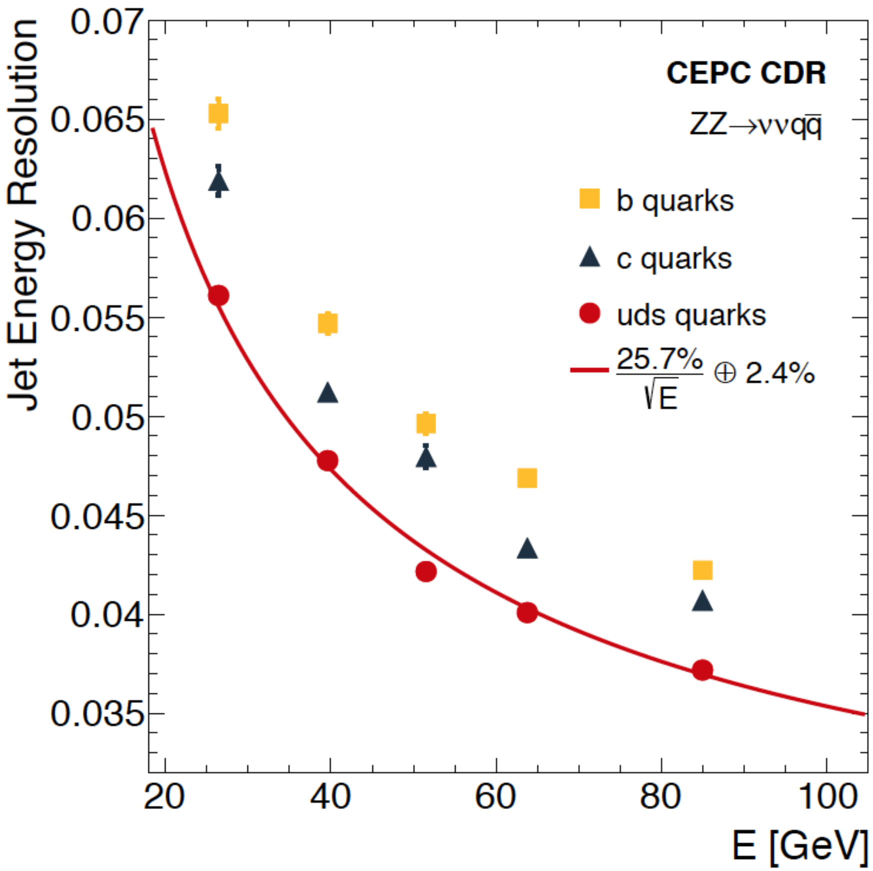
BM1: Massive Boson Mass Resolution

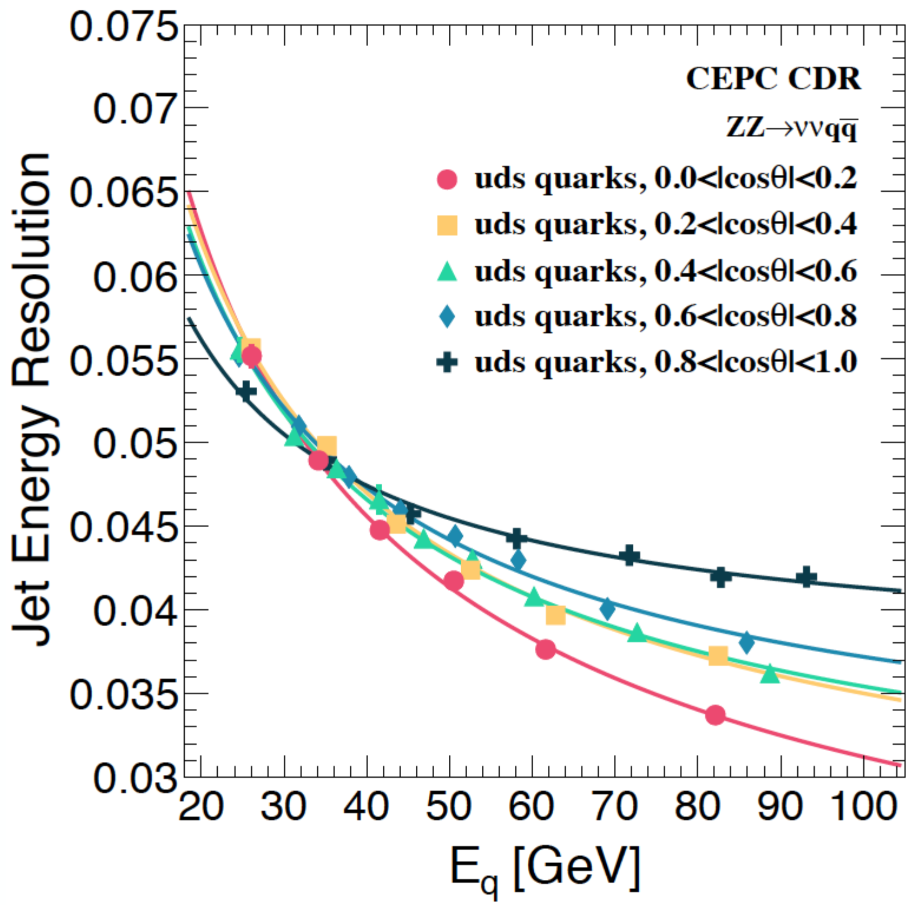


- W-, Z-, and Higgs-boson masses in dijet final state can be well separated at CEPC.
- After cleaned, Z- and W-boson could be separated ≈ 2σ, and the Higgs Boson Mass Resolution = 3.8% achieving the CEPC baseline.

Cleaned: Select the light flavor jet event with low energy ISR, low energy neutrino inside jet, and within $|\cos\theta| < 0.85$.

BM3: JER (Reco-Gen)



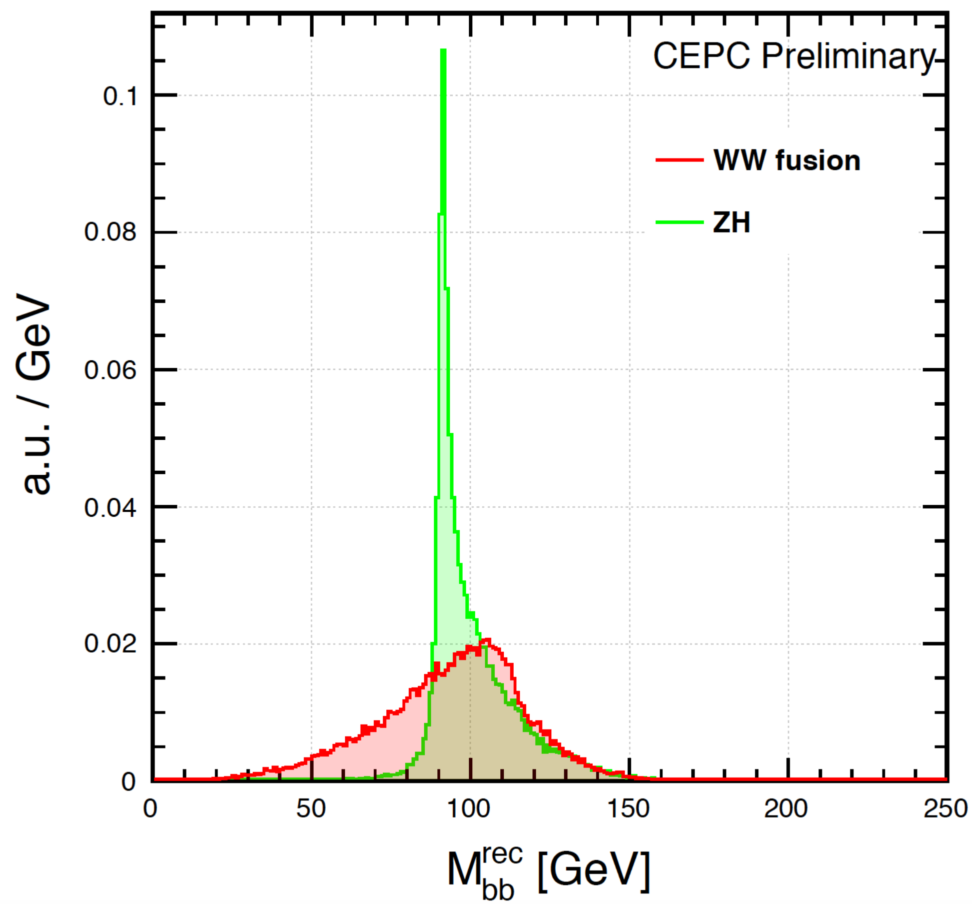


- **JER also depends on jet flavors.**
- **For light-flavor jets with high energy and within central region of barrel, JER could reach 3%.**

https://agenda.linearcollider.org/event/8217/contributions/44662/

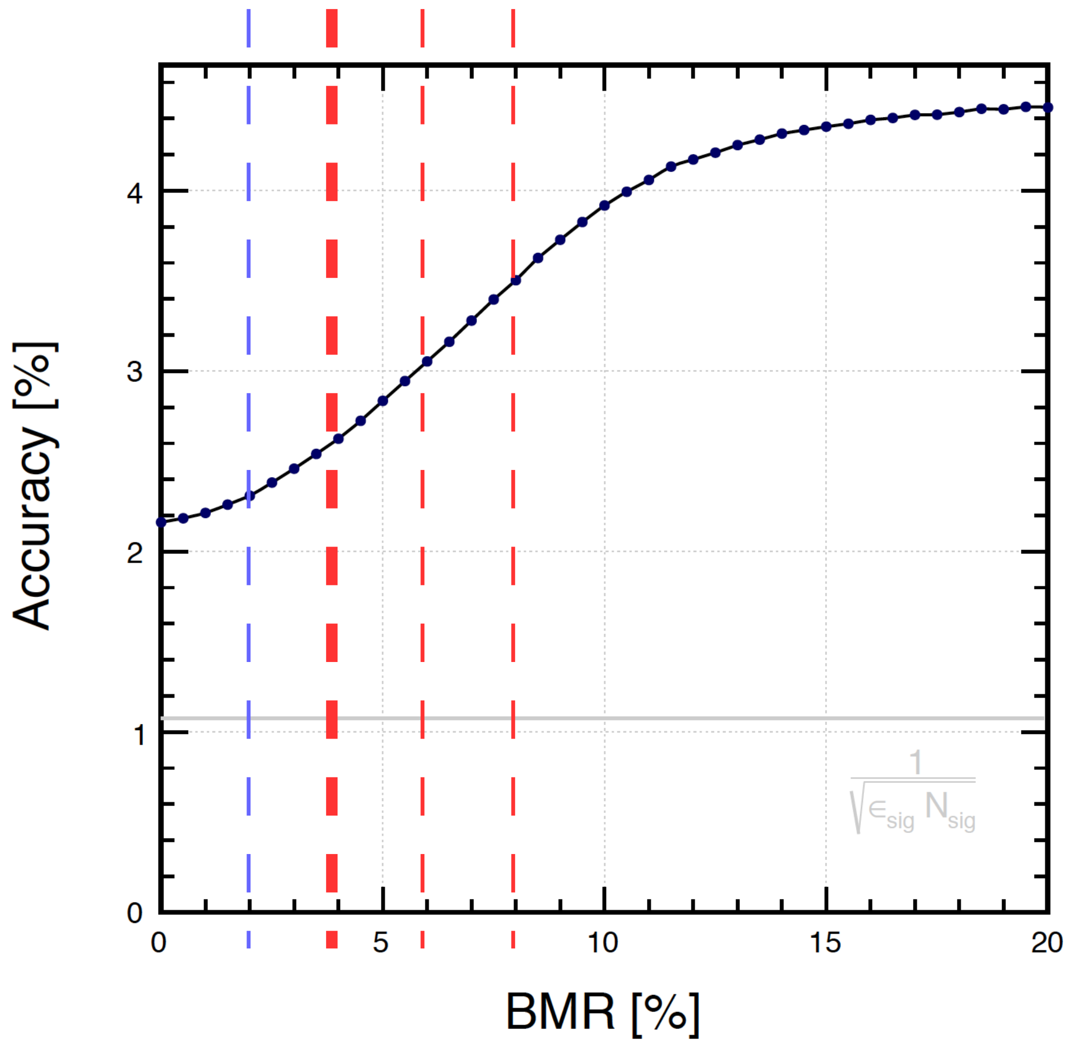
1^{st} Benchmark: σ(vvH, H→bb) ~ Higgs width

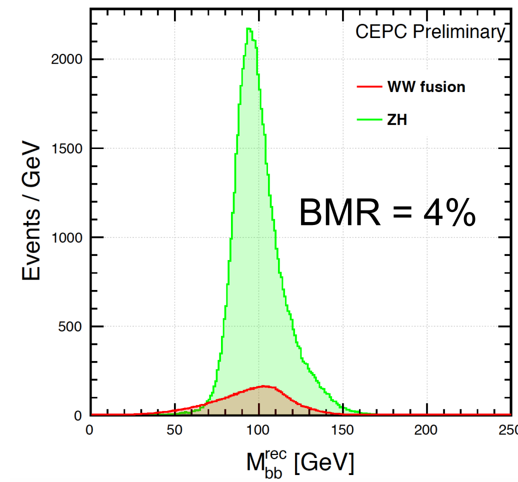
- $g^2(HXX) \sim \Gamma_{H\to XX} = \Gamma_{total}*Br(H\to XX)$
- Γ_{total} : determined by combining:
  - 1^{st}, σ(ZH) (~g^2(HZZ)), σ(ZH, H→ZZ) (~$g^4(HZZ)/\Gamma_{total}$)
  - 2^{nd}, σ(ZH, H→bb), σ(ZH, H→WW), σ(ZH), $\sigma(vvH|_{w\ fusion}$, H→bb), (bb can be replaced by X)
  - The 2nd method dominant the accuracy
- Critical to identify the W fusion events from the Higgsstrahlung ones with vvH final state: rely on the recoil mass agains the Higgs (and the Higgs direction).

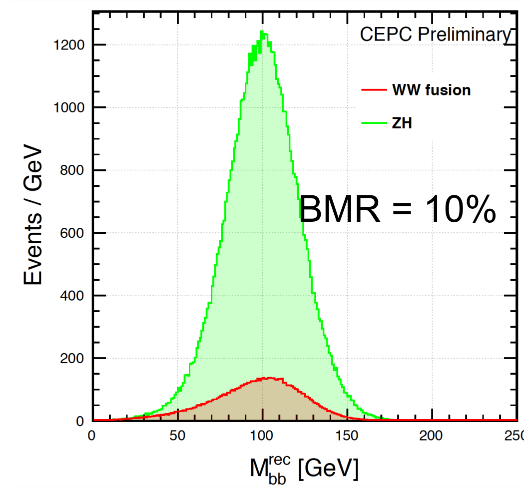


Hao Liang

σ(vvH, H→bb): Accuracy V.S. BMR



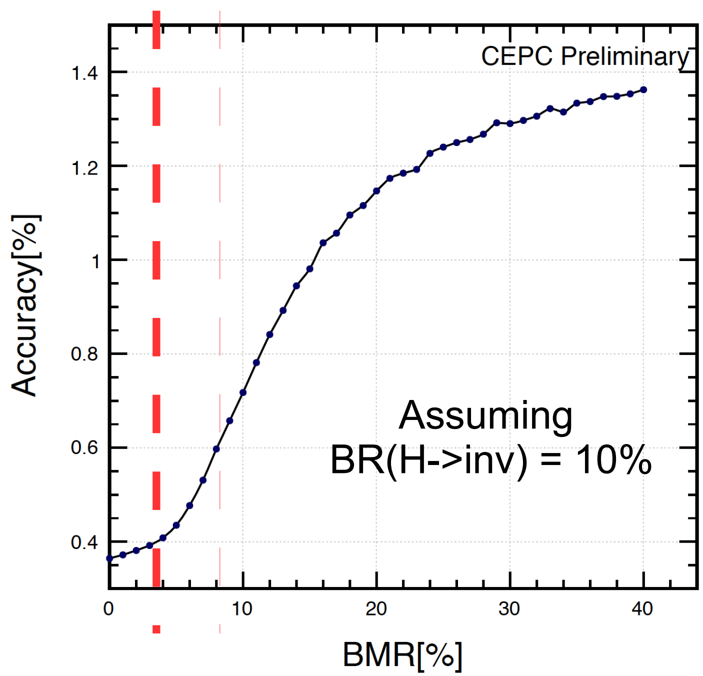


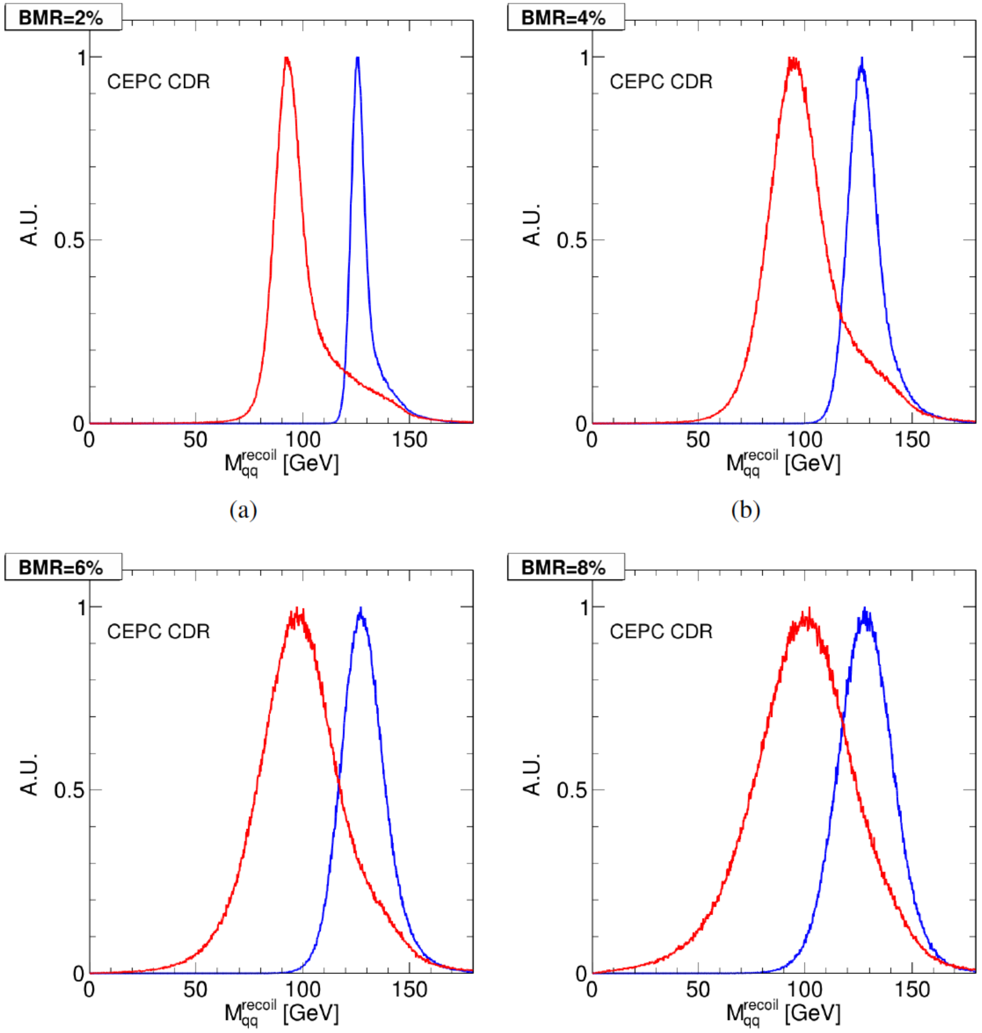


If the BMR degrades from 4% to 6/8%: the Higgs width measurement degrades by 20/40%
improves to 2%: the width measurement will improve by 15%

2nd Benchmark: 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

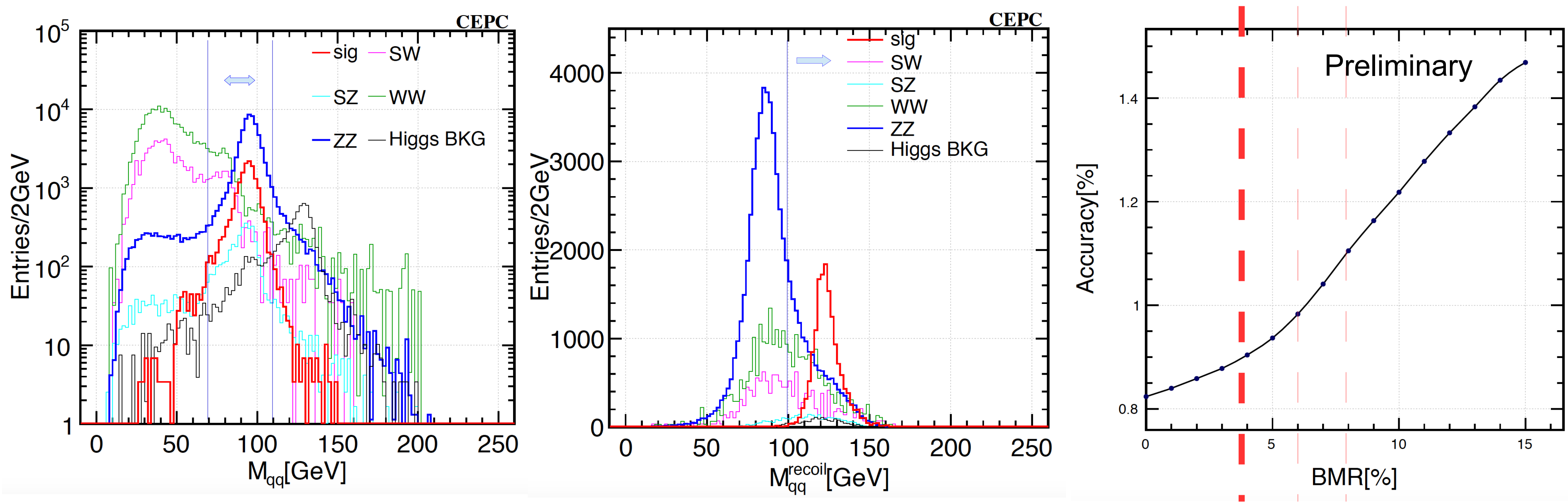




(a) (b) (c) (d)

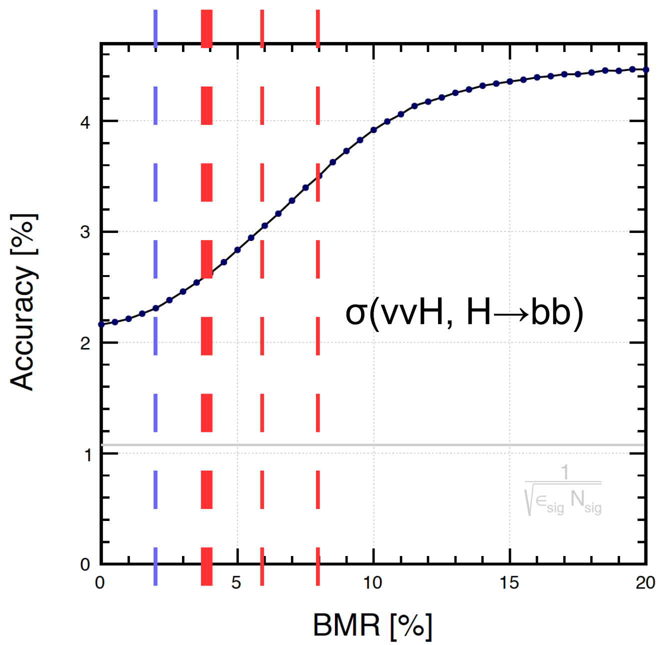
If the BMR degrades from 4% to 6/8%: the Higgs invisible measurement degrades by 20/50%

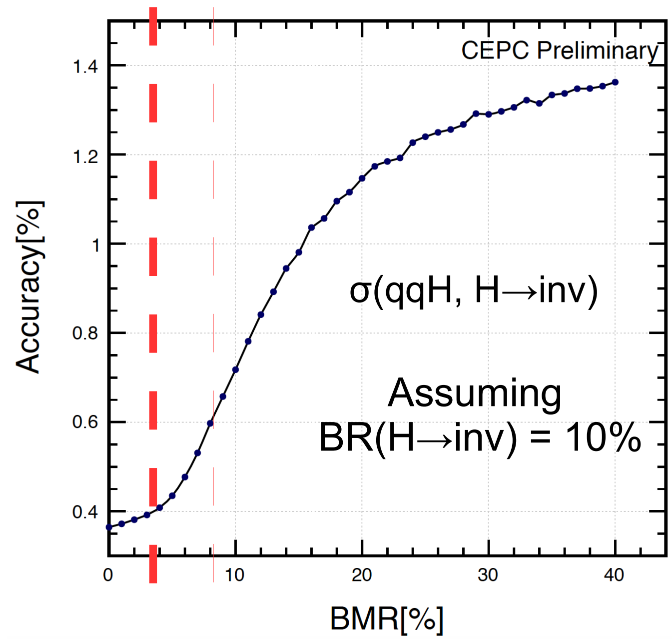
3rd Benchmark: g(Hττ) at qqH

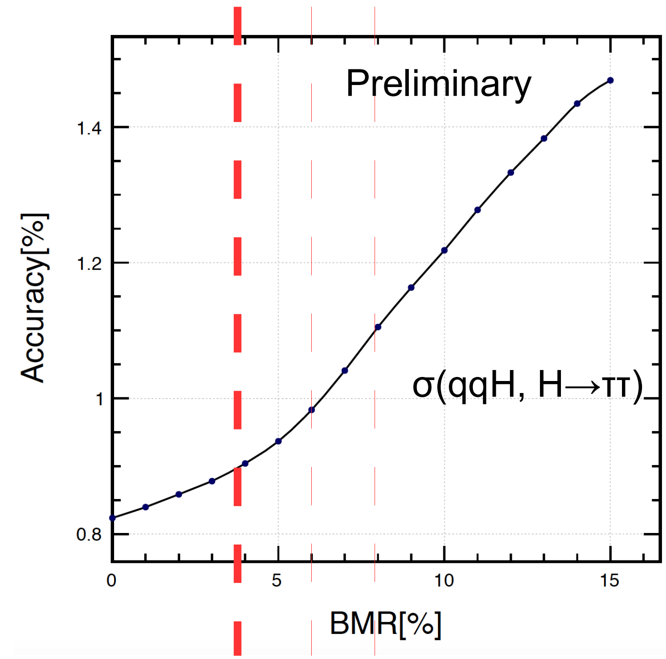


- TAURUS: di-tau system identification
- The rest particles are identified as the di-jet: to distinguish the ZZ/ZH background & Improves the accuracy by more than a factor of 2: **BMR < 4% is crucial**
- Isolated tracks are intensionally defined as tau candidate: be distinguished by the VTX
- Relative accuracy of 0.9% at 5.6 ab^{-1} integrated luminosity, dominate the combined accuracy (0.8%)
- Changing BMR from 4% to 6/10%, the Accuracy degrades by 10/20%

Requirement from benchmark analysis: BMR < 4%







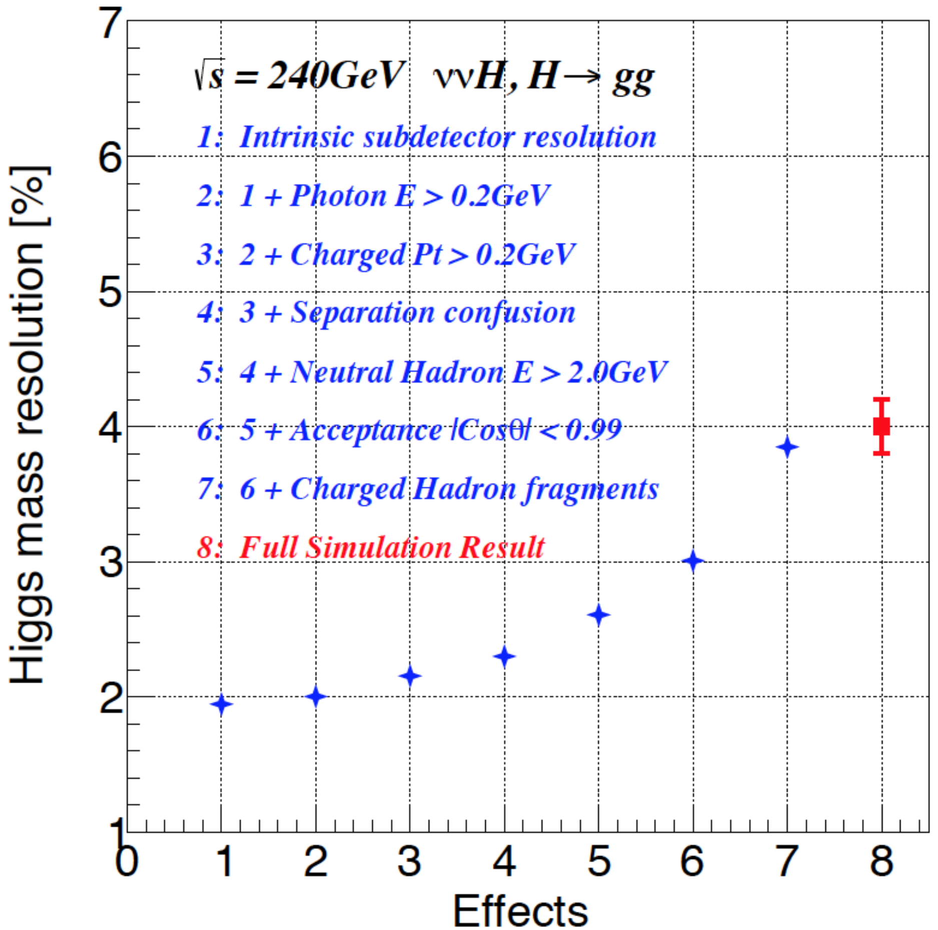
- Boson Mass Resolution: relative mass resolution of vvH, H→gg events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

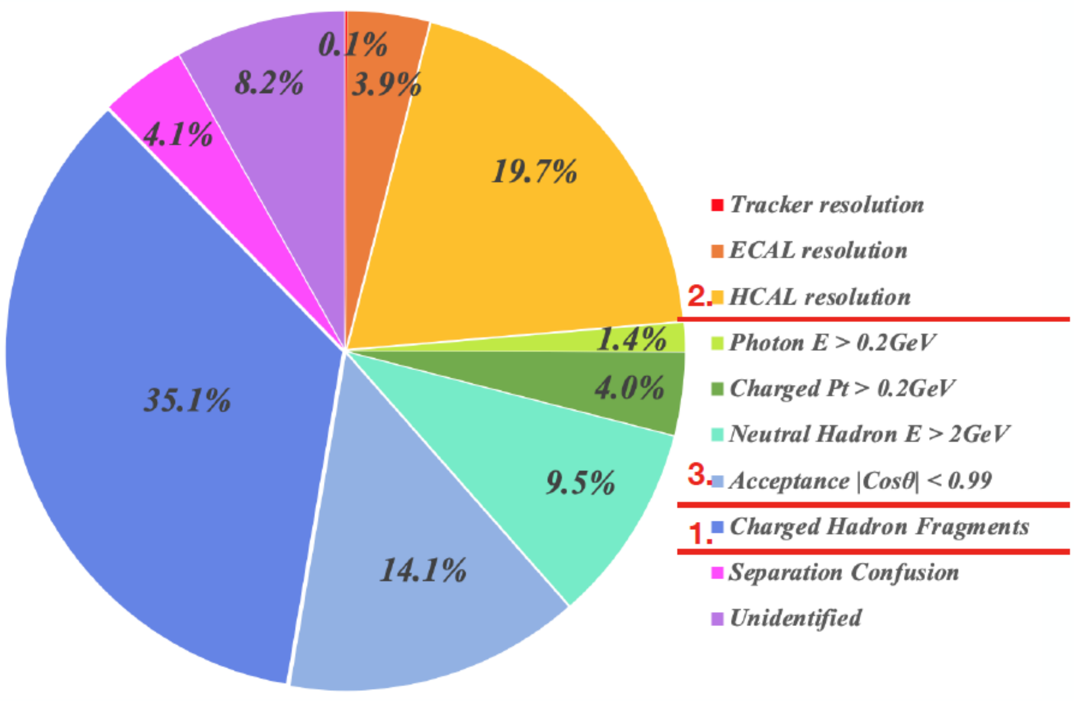
	BMR = 2%	4%	6%	8%
σ(vvH, H→bb)	2.3%	2.6%	3.0%	3.4%
σ(vvH, H→inv)	0.38%	0.4%	0.5%	0.6%
σ(qqH, H→ττ)	0.85%	0.9%	1.0%	1.1%

BMR factorization

- BMR is composed of
  - Sub detector responses
    - Intrinsic resolutions
    - Thresholds
    - Acceptance
  - Confusions
    - Overlapping between nearby clusters
    - Cluster splitting: double counting
    - Back scattering, interactions inside tracker
    - ...
- A fast simulation tool is developed to quantify individual impact

PFA Fast simulation (Preliminary)

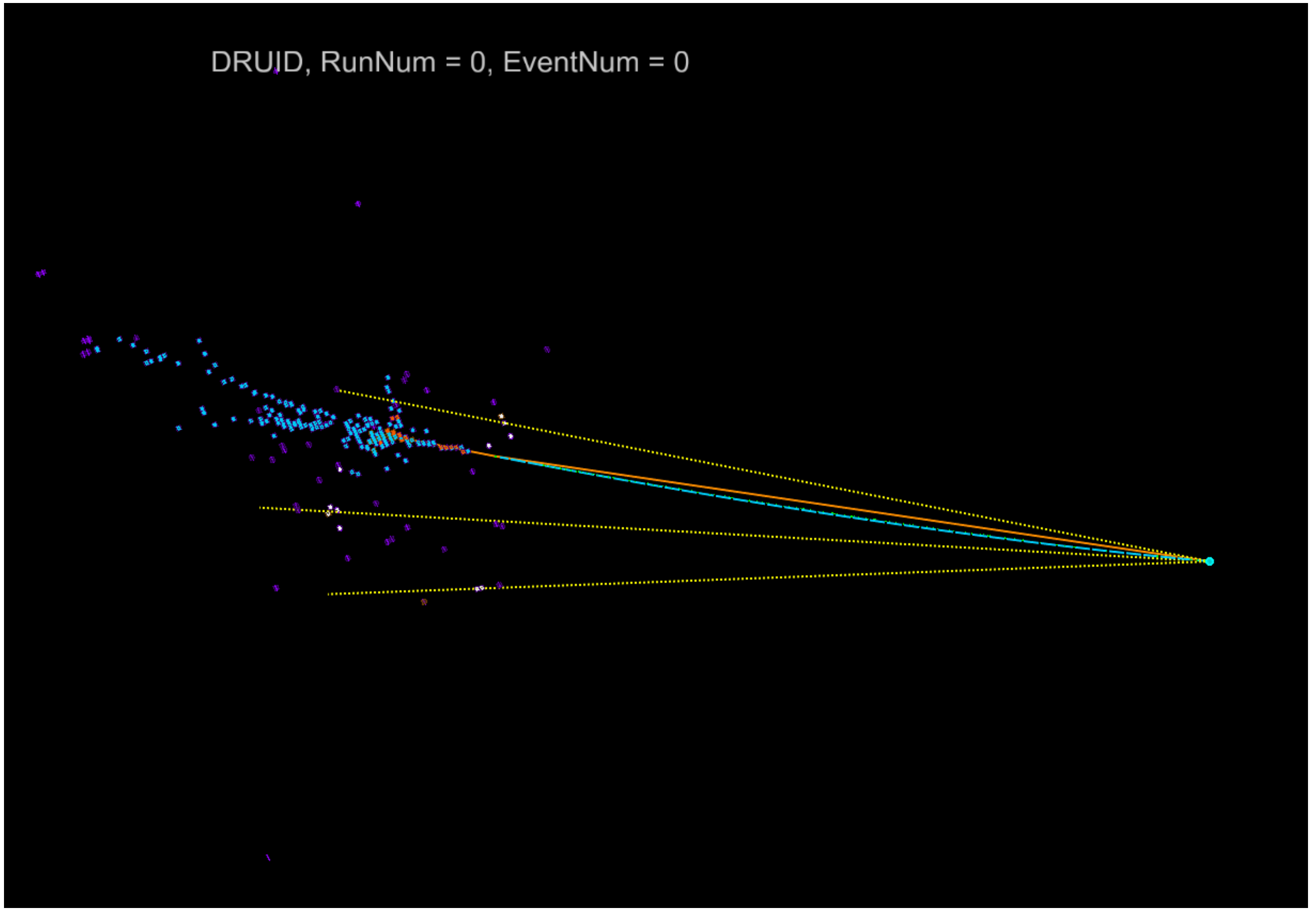


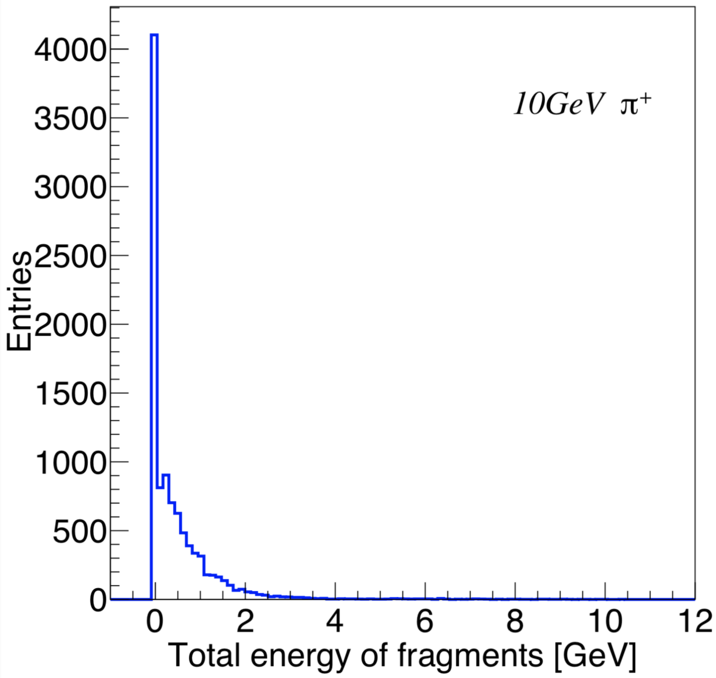


YX. Wang

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

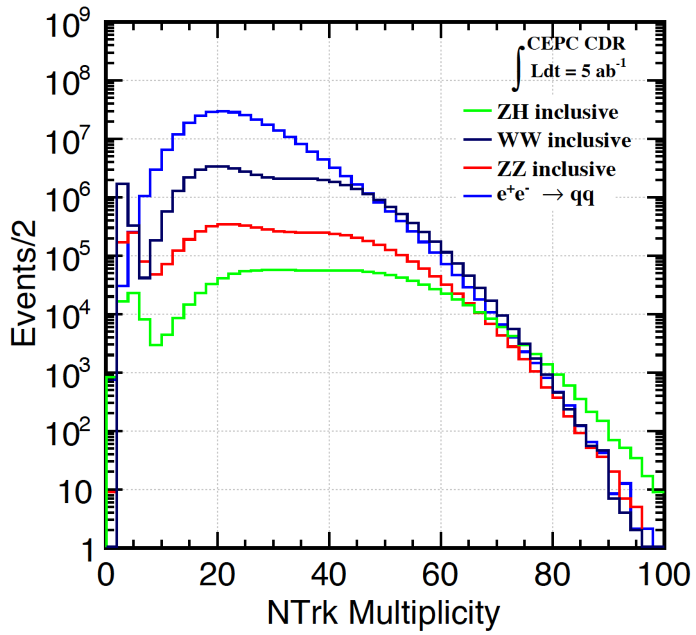
Cluster splitting: the most severe confusions

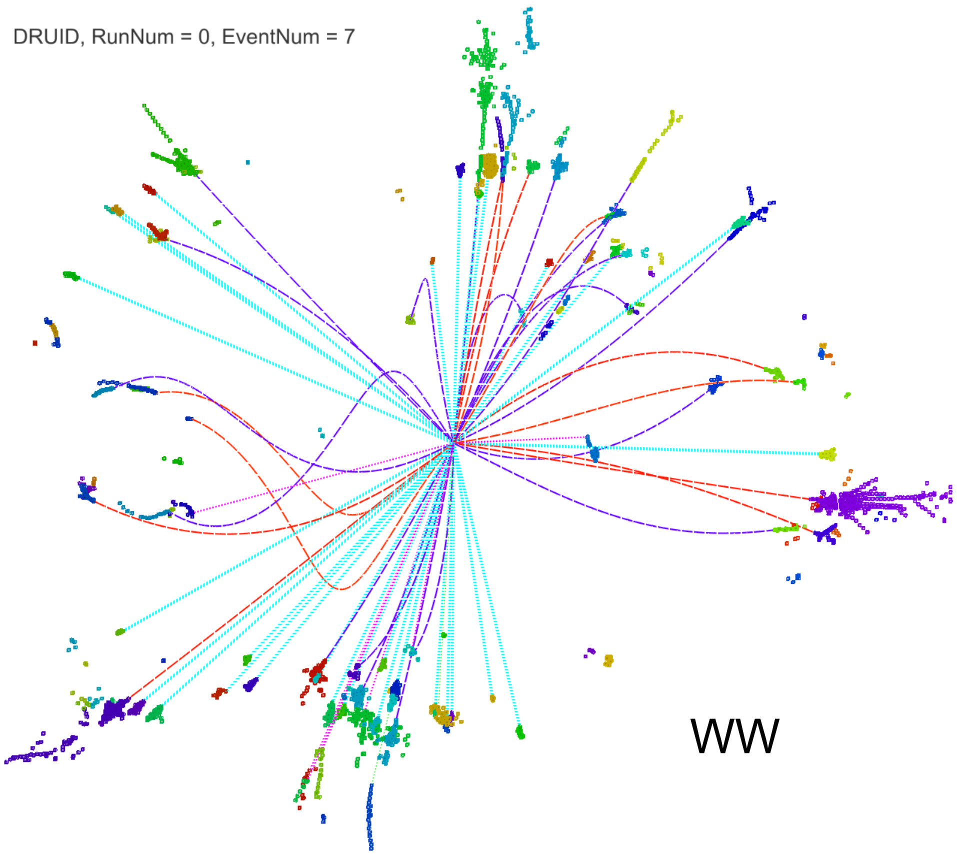




Time/pattern recognition may help a lot, in identify the charged cluster fragmentations without arise the threshold for the neutral hadron significantly...

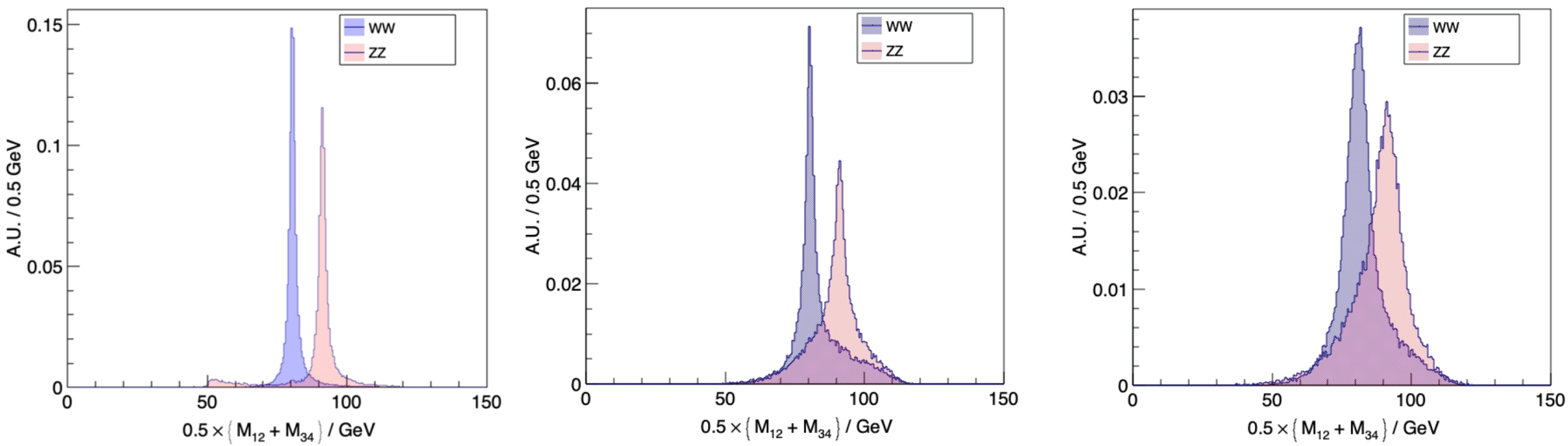
Full hadronic WW-ZZ separation





- 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

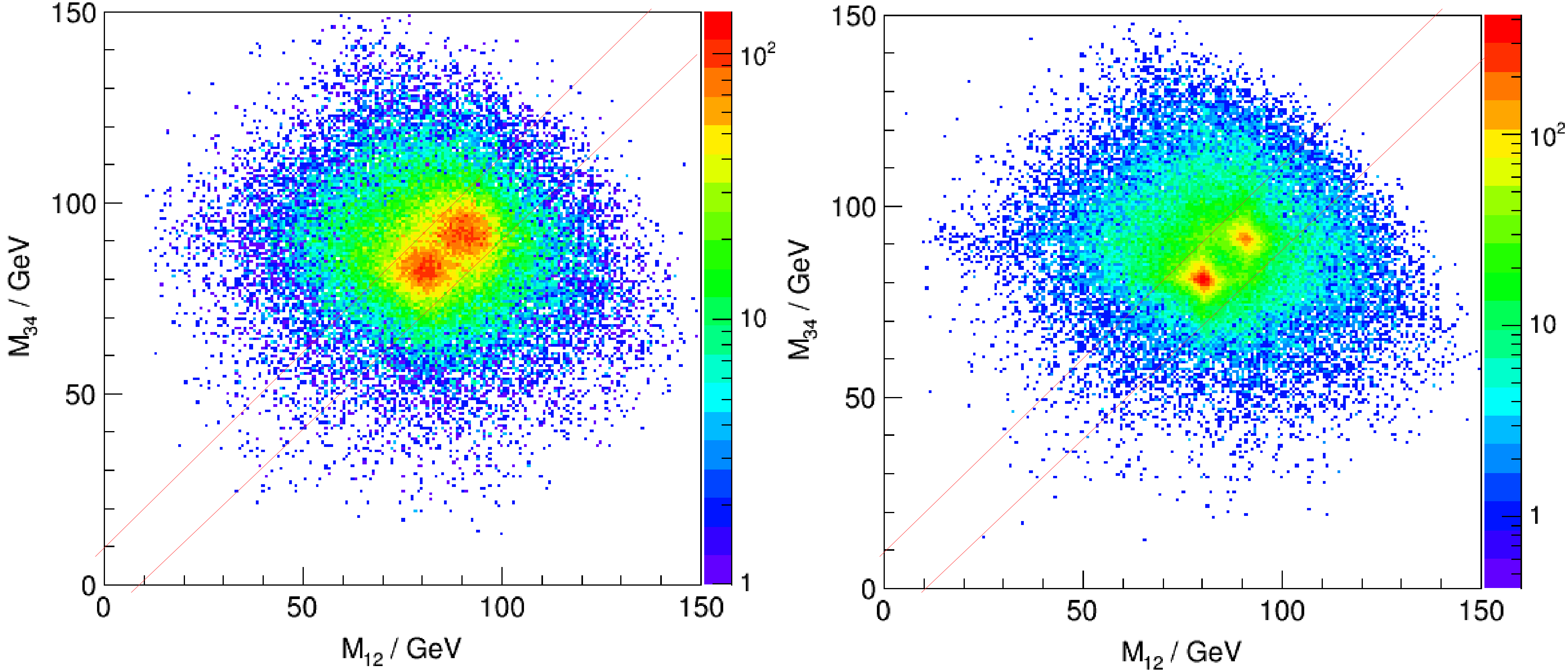


- Separation be characterized by
- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2
- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - \+ Jet confusion – Genjet: Overlapping ratio of **53%**
  - \+ Detector response – Recojet: Overlapping ratio of 58%

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

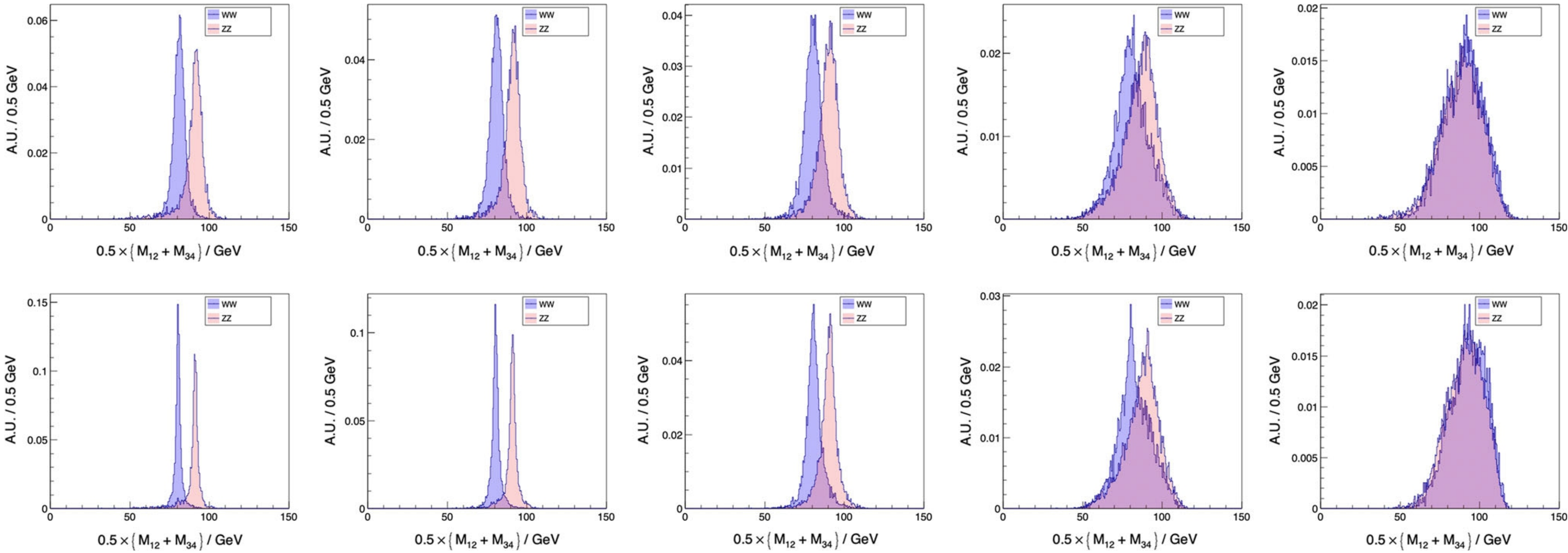
$$\chi^2 = \frac{(M_{12} - M_B)^2 + (M_{34} - M_B)^2}{\sigma_B^2}$$

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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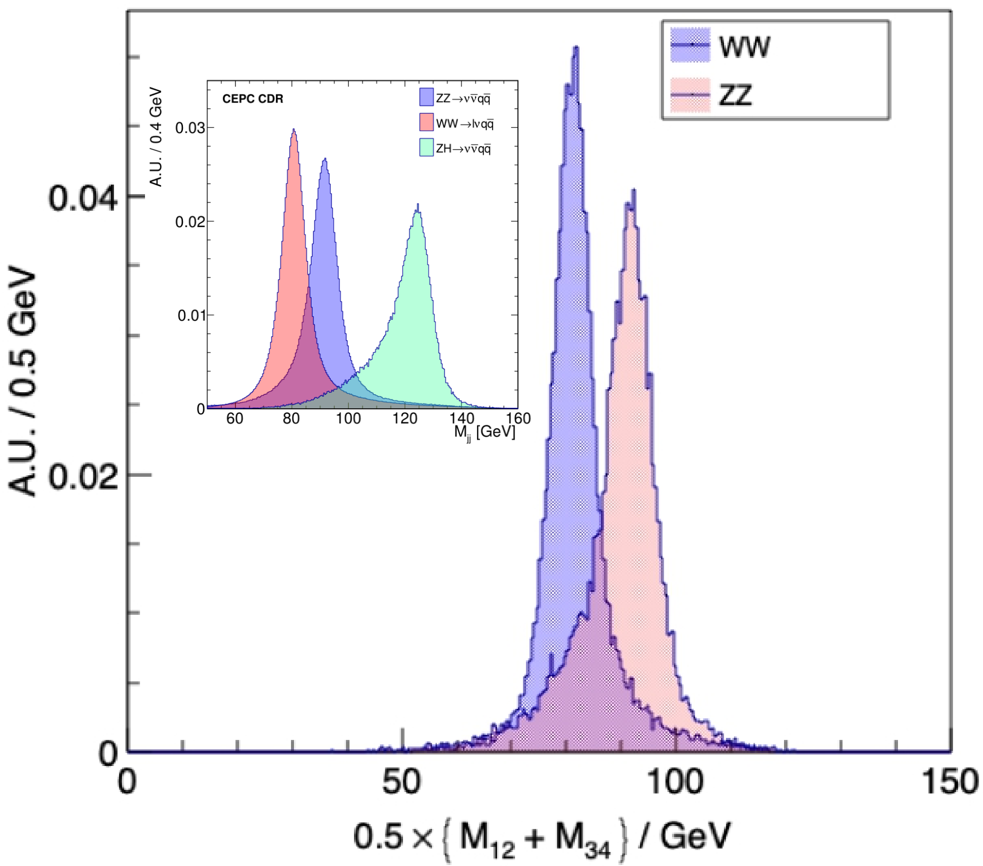
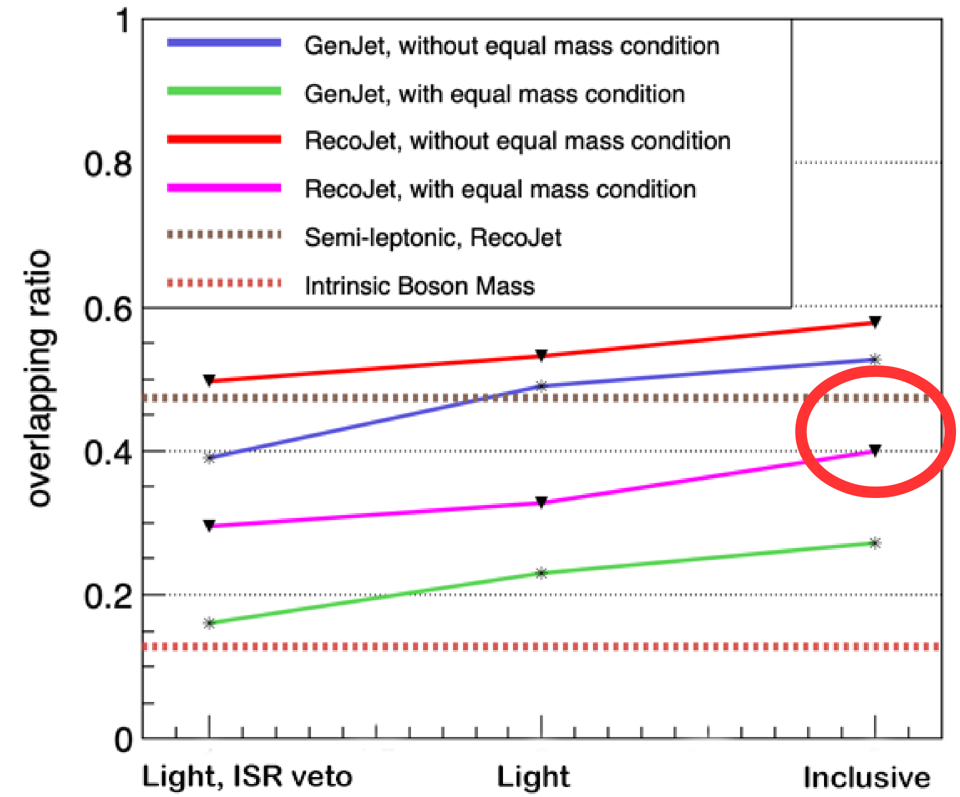
Separation of full hadronic WW-ZZ event





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

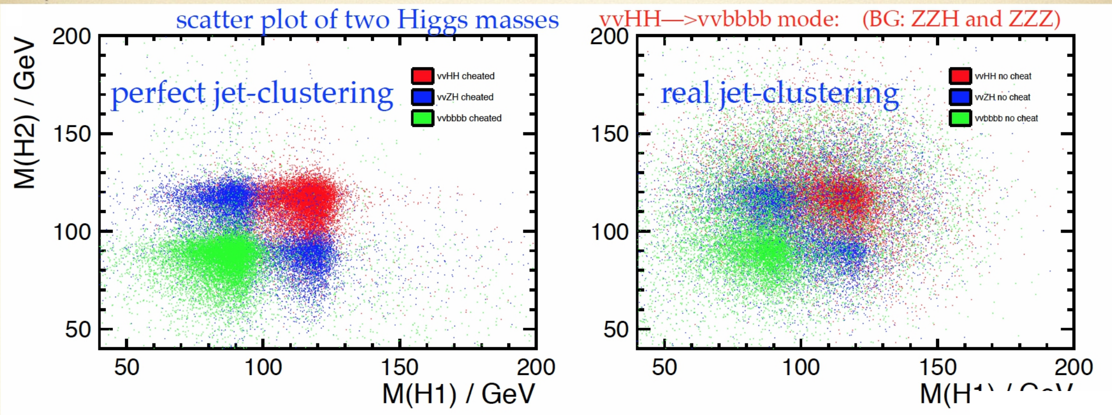
Critical to develop color singlet reconstruction: improve from the naive Jet clustering & pairing.

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) woul already be possible at 500 GeV ILC with the H20 scenario

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

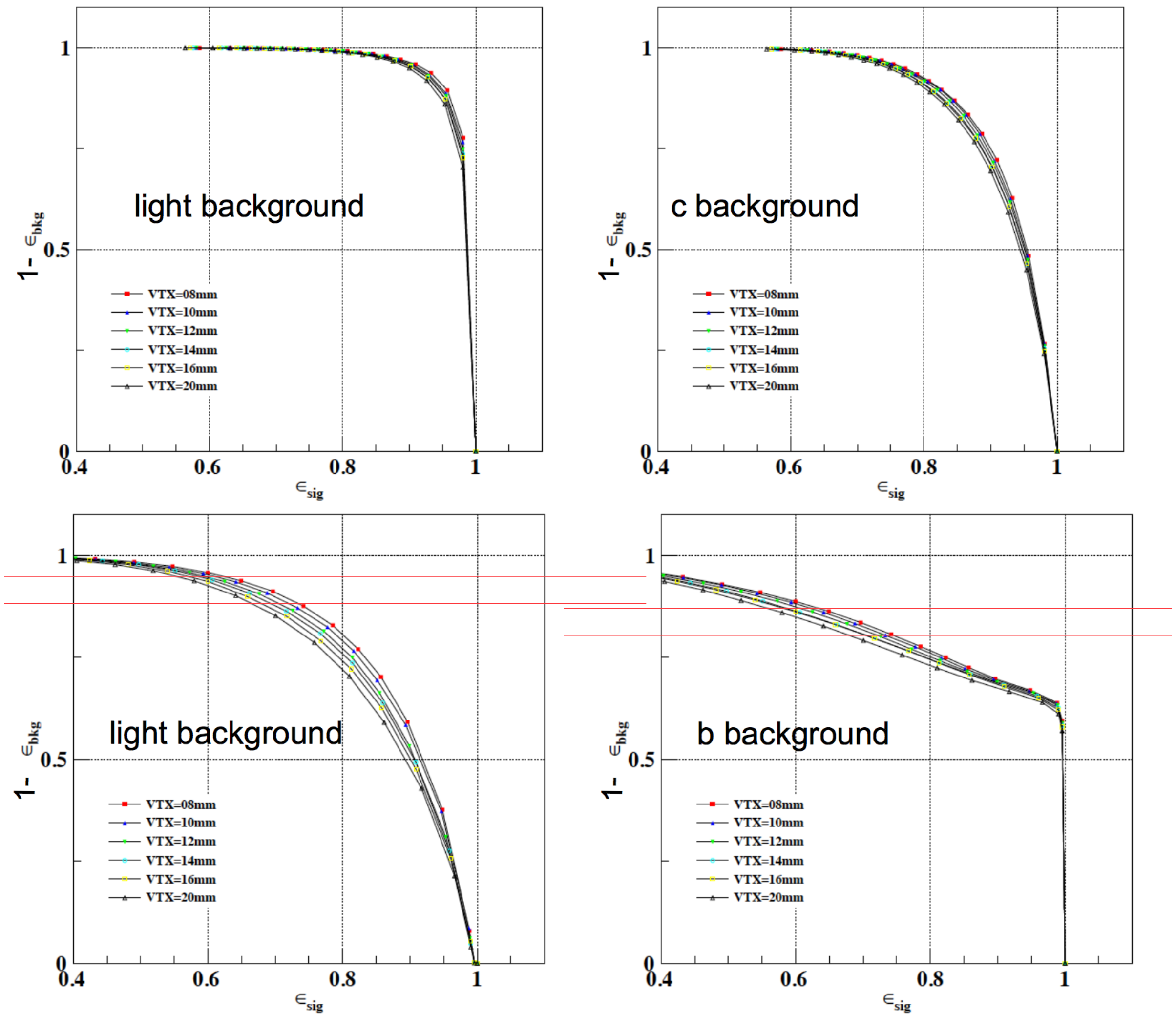
Refurbished e^+e^- algorithms can be better still:

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

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



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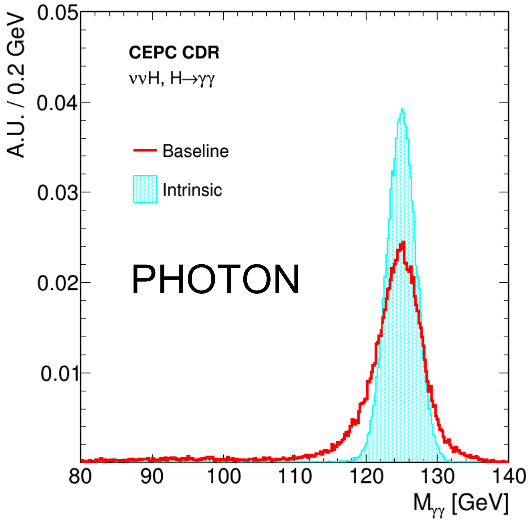
Physics Objects



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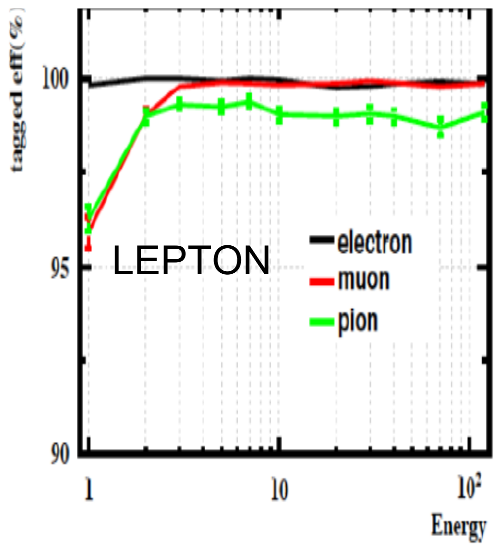

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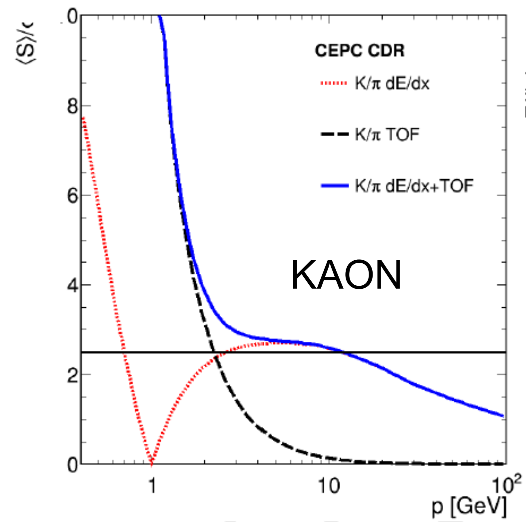

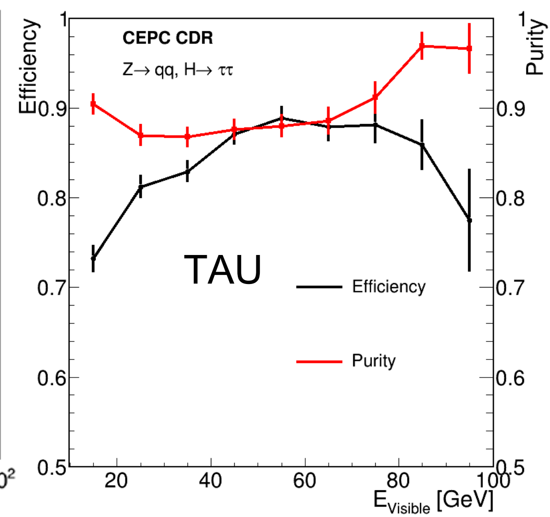

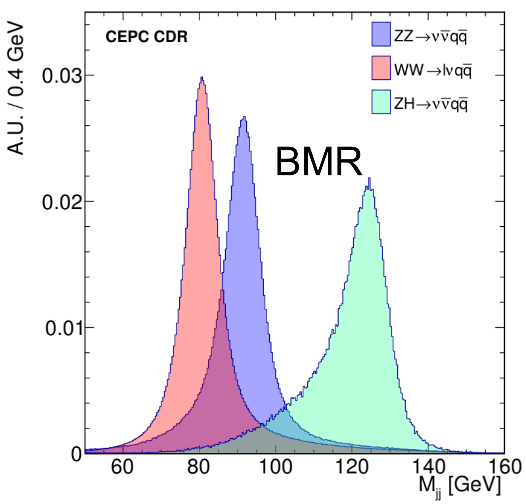

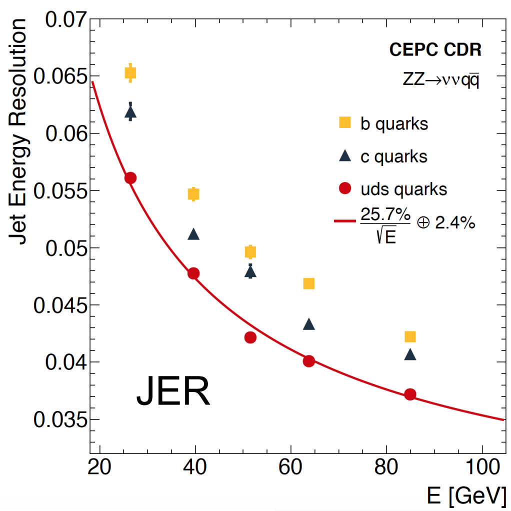

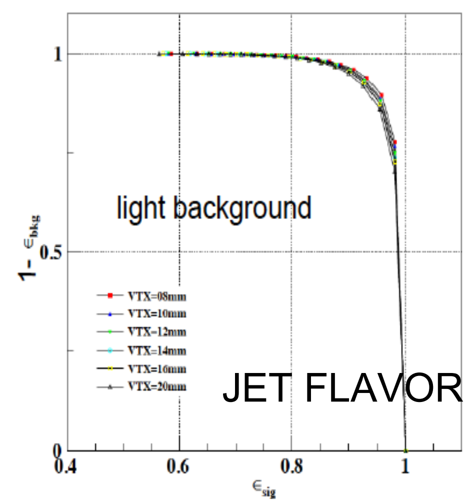

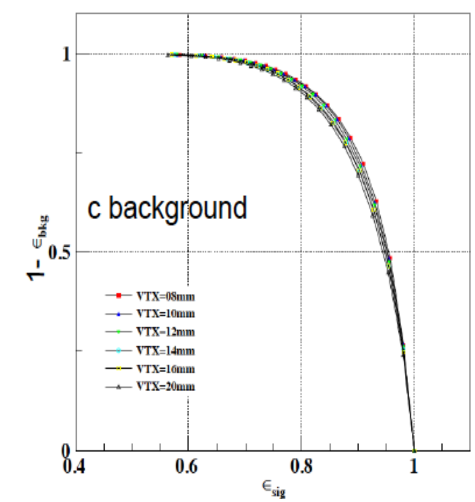

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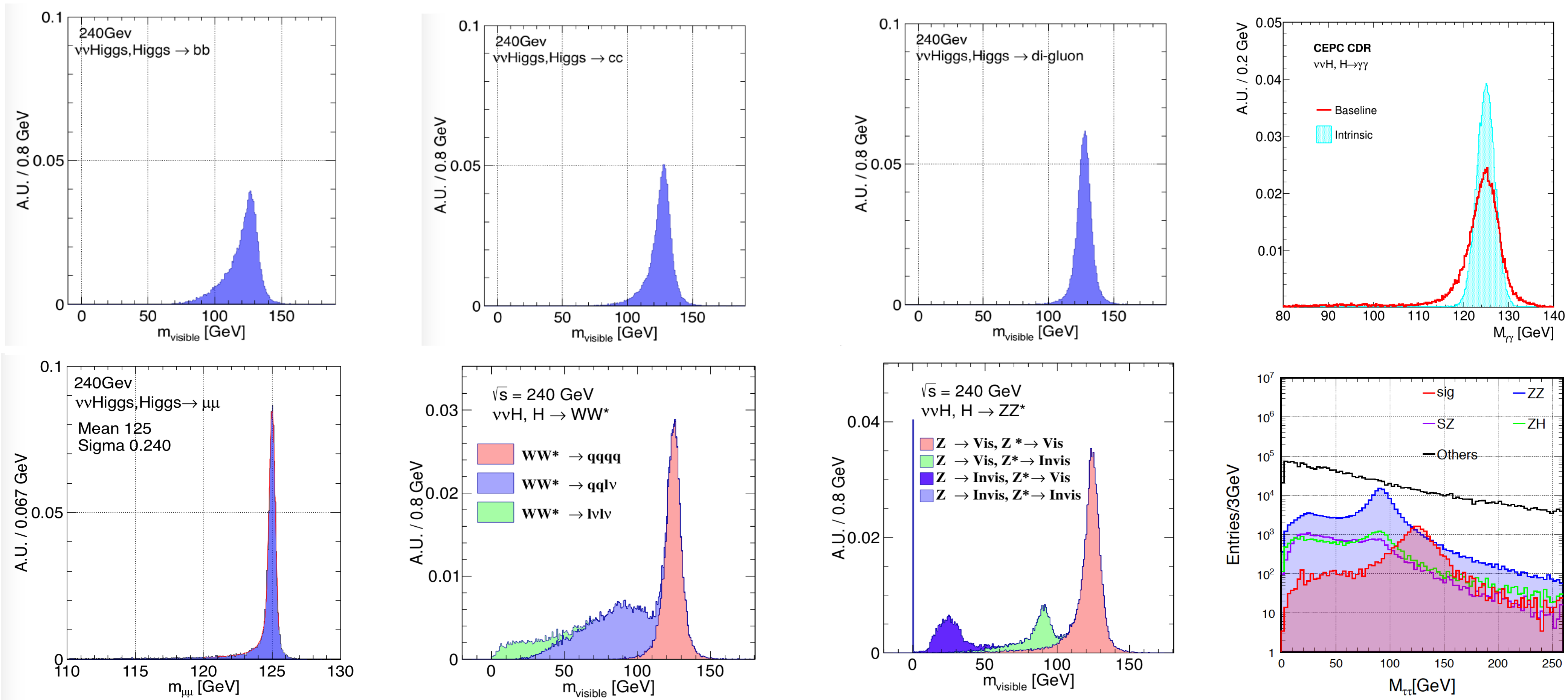
Higgs Signals

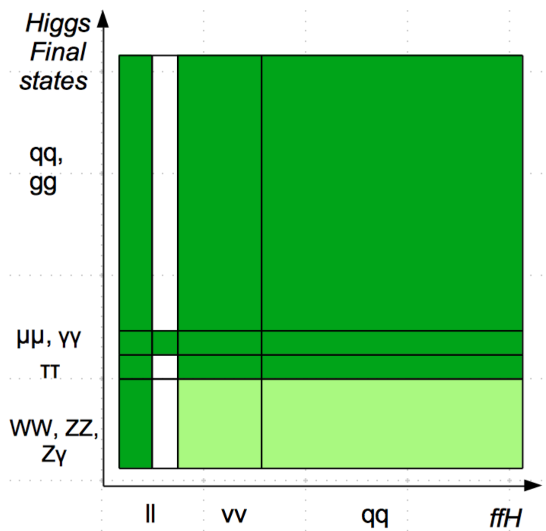


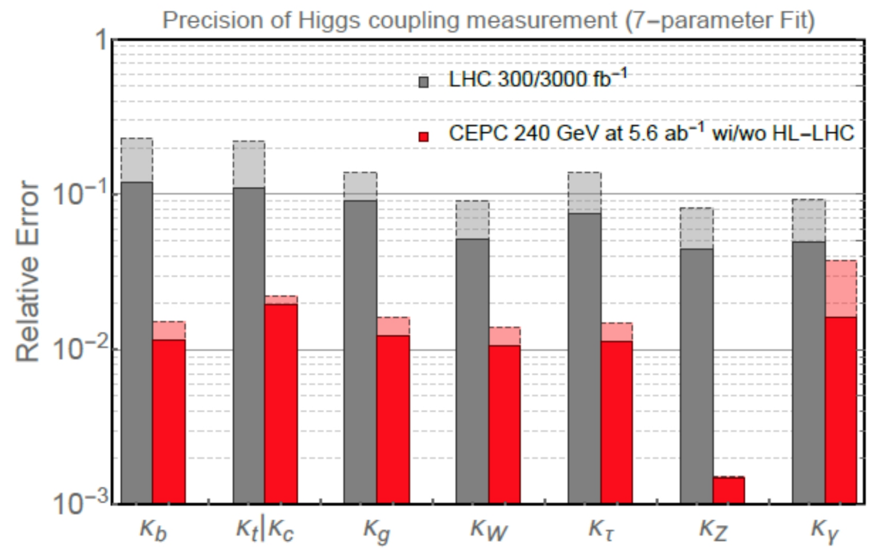
Clear Higgs Signature in all SM decay modes

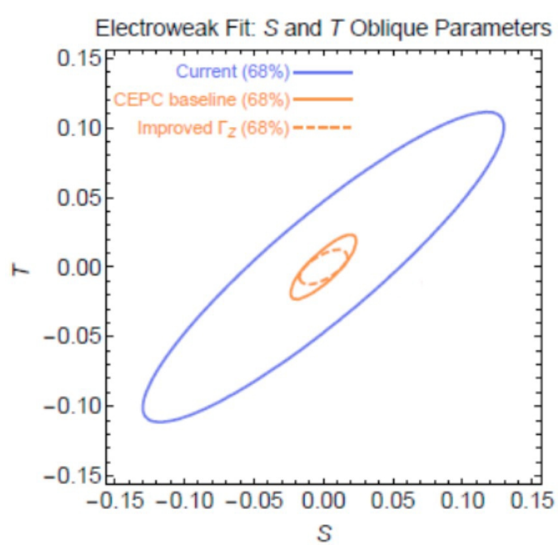
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

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

Applied on Higgs physics, et.al







Precision Higgs Physics at CEPC

Initial assessments of Higgs physics potential at the CEPC based on the white paper (to be submitted)

Chinese Physics C Vol. XX, No. X (201X) 010201

Precision Higgs Physics at the CEPC*

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Zhenwei Cui[3] Yaquan Fang[4,6] Chengdong Fu[4] Jun Gao[10] Yanyan Gao[20] Yuanning Gao[5]
Shao-Feng Ge[15,27] Jiayin Gu[13] Fangyi Guo[1,4] Jun Guo[10,11] Tao Han[5,29] Shuang Han[4]
Hong-Jian He[10,11] Xianke He[10] Xiao-Gang He[10,11] Jifeng Hu[10] Shih-Chieh Hsu[30] Shan Jin[8]
Maoqiang Jing[4,7] Ryuta Kiuchi[4] Chia-Ming Kuo[19] Pei-Zhu Lai[19] Boyang Li[5] Congqiao Li[3] Gang Li[4]
Haifeng Li[12] Liang Li[10] Shu Li[10,11] Tong Li[12] Qiang Li[3] Hao Liang[4,6] Zhijun Liang[4]
Libo Liao[4] Bo Liu[4,21] Jianbei Liu[1] Tao Liu[14] Zhen Liu[24,28] Xinchou Lou[4,6,31] Lianliang Ma[12]
Bruce Mellado[17] Xin Mo[4] Mila Pandurovic[16] Jianming Qian[22] Zhuoni Qian[18]
Nikolaos Rompotis[20] Manqi Ruan[4] Alex Schuy[30] Lian-You Shan[4] Jingyuan Shi[9] Xin Shi[4]
Shufang Su[23] Dayong Wang[3] Jing Wang[4] Lian-Tao Wang[25] Yifang Wang[4,6] Yuqian Wei[4]
Yue Xu[5] Haijun Yang[10,11] Weiming Yao[26] Dan Yu[4] Kaili Zhang[4,6] Zhaoru Zhang[4]
Mingrui Zhao[2] Xianghu Zhao[4] Ning Zhou[10]

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

Summary

- CEPC, a super Higgs/W/Z factory
- Physics Potential
  - Higgs:
    - Absolute determination of Higgs couplings, width...
    - 1 order of magnitude improvement w.r.t HL-LHC (Signal Strength)
    - Exotic decay: 2-3 orders of magnitude better than HL-LHC
  - EW: boost by at least 1 order of magnitude
  - Rich program on Flavor physics
- Performance at the baseline design
  - High efficiency/accuracy reconstruction of all key physics objects
  - Clear Higgs signature in all SM Higgs decay modes
  - Clear distinguish between the Signal and SM backgrounds
  - Fulfills the physics requirements of the CEPC Higgs operation

Summary

- CDR in finalization: long to do list towards the TDR
  - Physics Potential study:
    - Pheno Study & Systematic control
    - Higgs Differential measurements
    - QCD, Flavor, EW...
    - *Dedicated discussion on July 1-5th, at Peking University of Beijing*
  - Detector design & optimization:
    - Lots of efforts needed, to bridging the CDR design to TDR & construction: especially the integration & systematic controls
    - Multiple IP: new ideas are always welcome
  - Software, Reconstruction, Algorithms, Analysis tools...

- **You ideas, supports & participations are essential!**

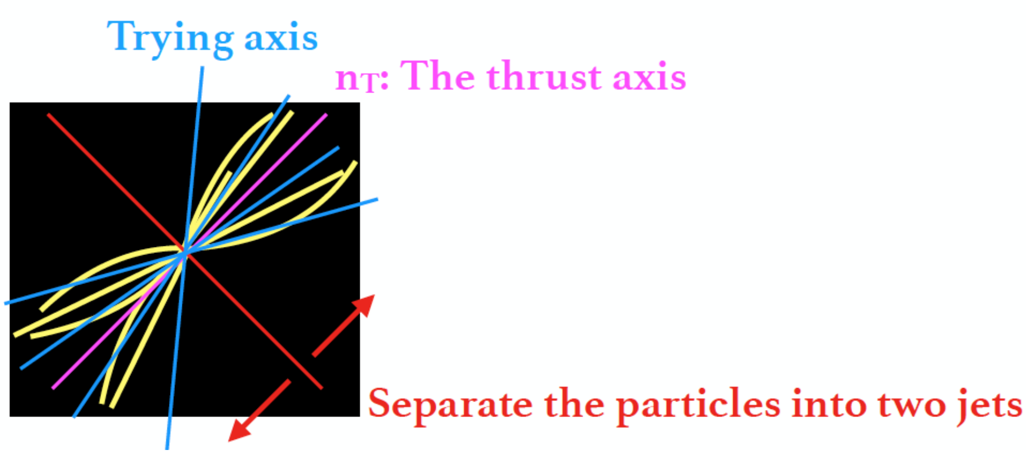
Summary

- Hadronic events are critical
- To disentangle the impact of detector/PFA and jet algorithms (clustering-matching), we uses BMR and full hadronic WW-ZZ overlapping ratio
- Benchmark analyses shows BMR < 4% is required for the detector/PFA
  - The recoil mass of di-jet system is an important observable to separate the signal from major backgrounds (ZZ, ZH)
  - BMR decomposition: At the CEPC baseline reconstruction: mainly limited by hadronic shower fragmentation, may potentially be improved using time information - better algorithms – need further quantification...
- Jet algorithms can dominate the uncertainty for the measurement on multi-jet event: need better algorithms.
  - Clear consensus, and need further collaboration with QCD/pheno-theory!...

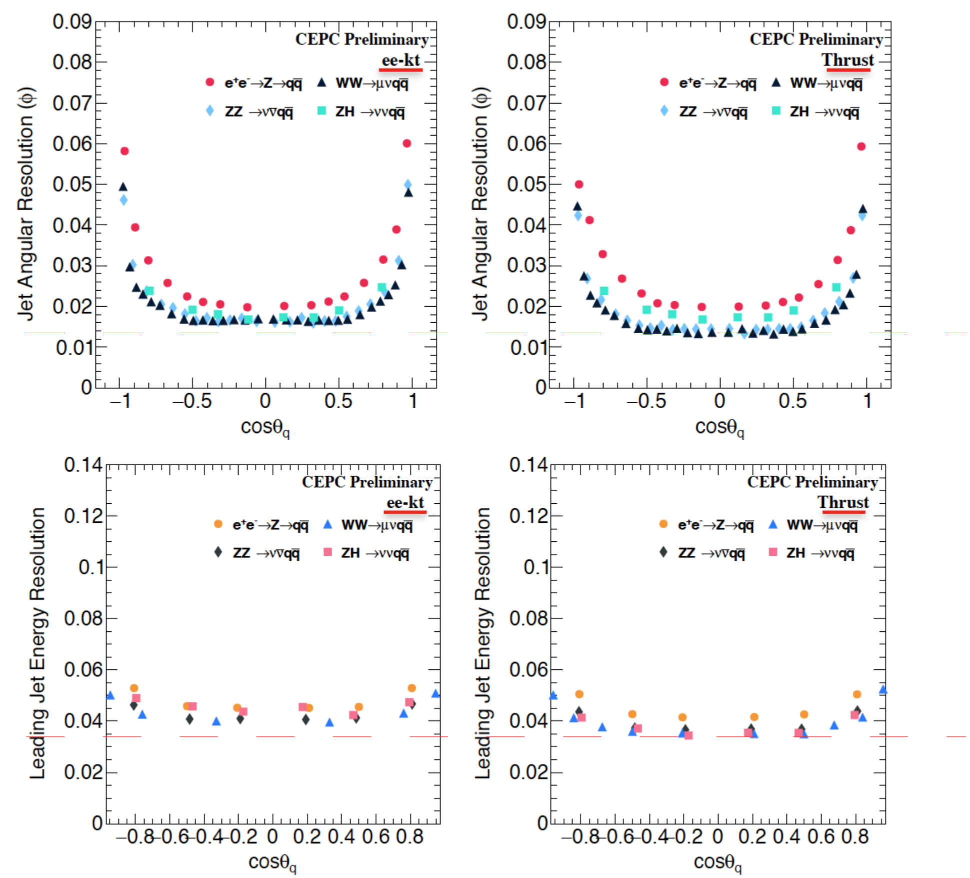
Back up: related physics performance studies

A test: thrust algorithm (Preliminary)

- Thrust based
  - Boost the hadronic system back to its rest frame
  - Divide into 2 hemisphere with a plane perpendicular to the thrust, each identified as a jet (applicable only to 2 jet state)

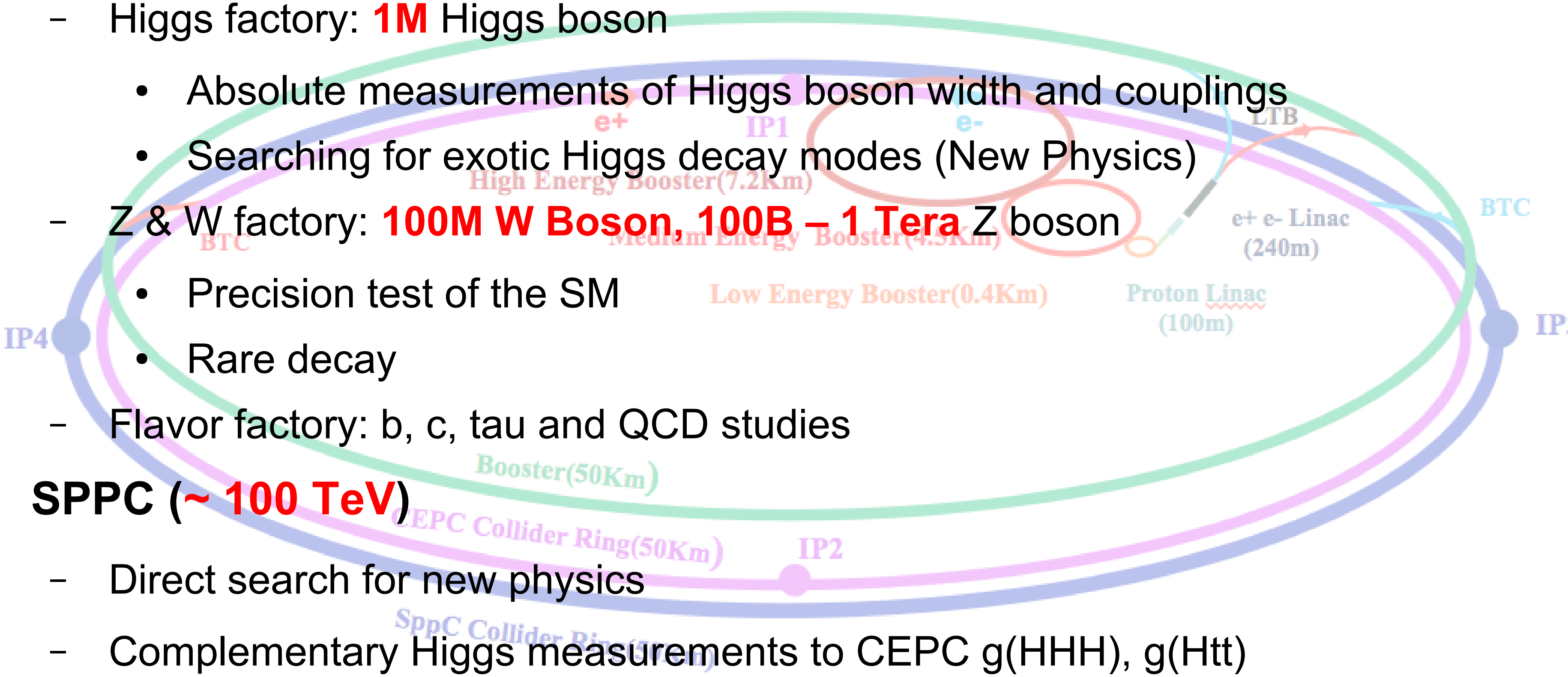


- VS eekt (the baseline, recommended by the full hadronic WW/ZZ study): up to 20% improvement in Jet Angular/Energy Resolution



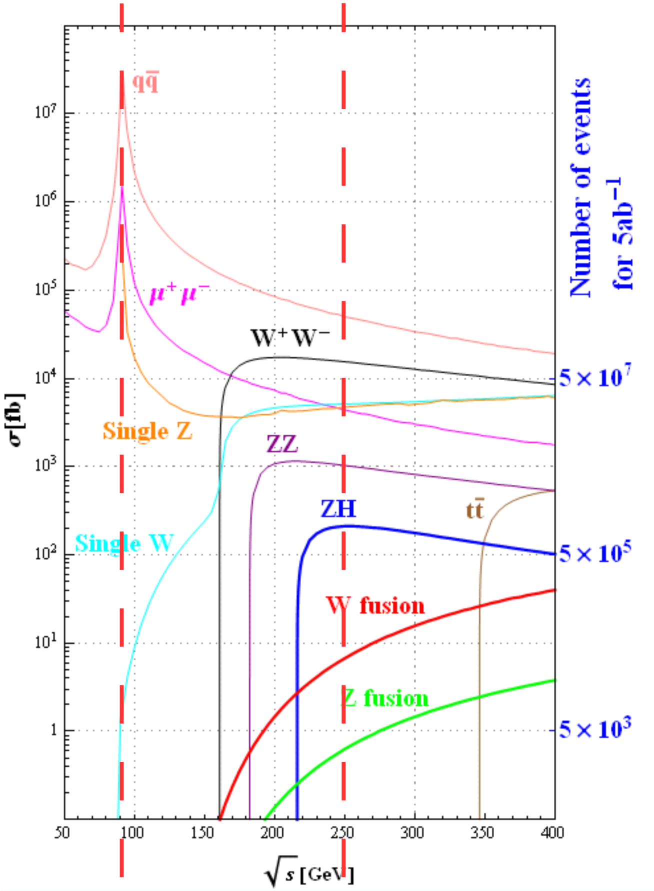
Science at CEPC-SPPC

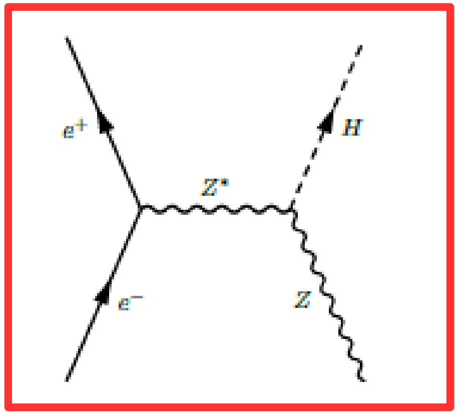
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **100M W Boson, 100B – 1 Tera** Z boson
    - Precision test of the SM
  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

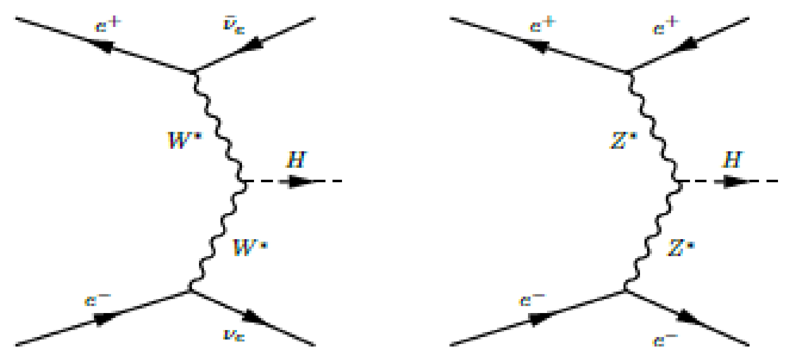


Complementary

Higgs @ CEPC







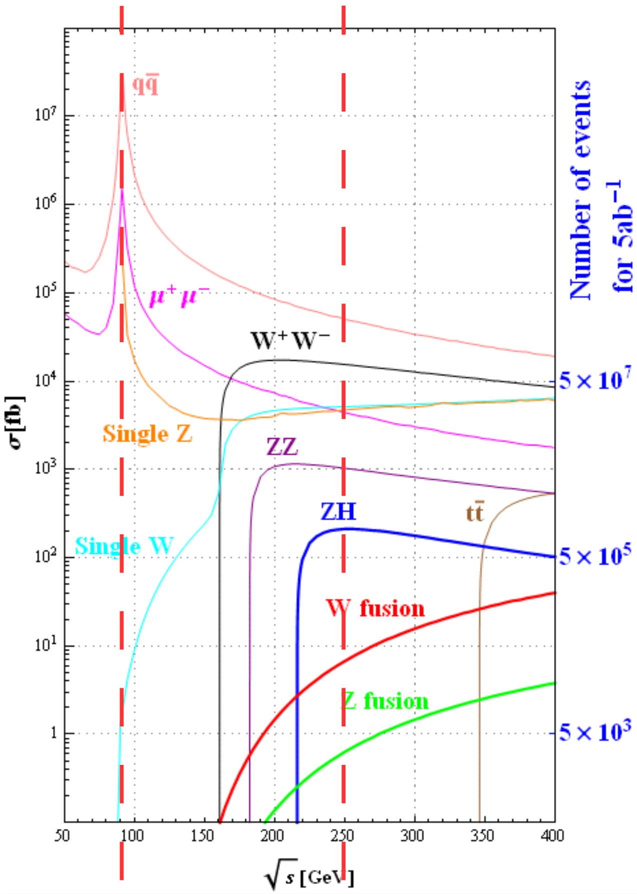
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

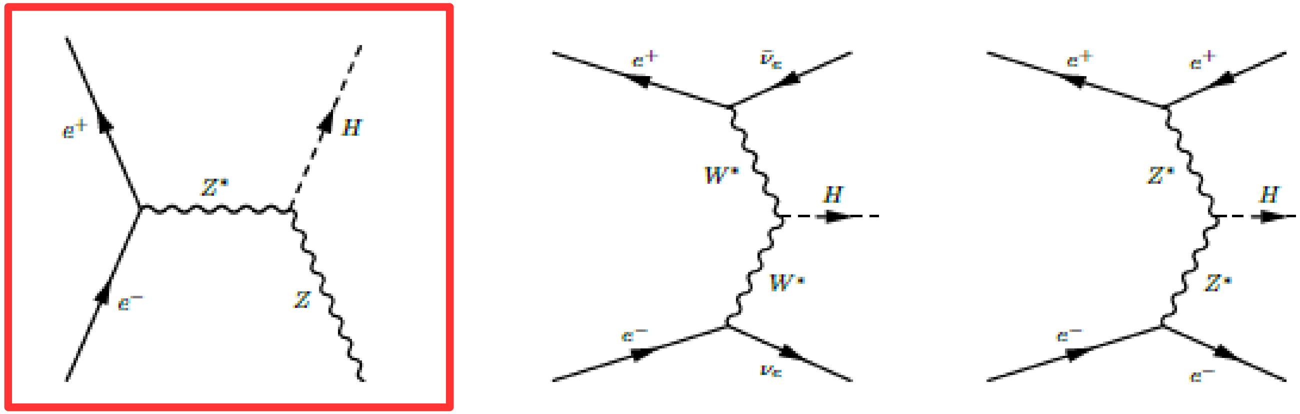
S/B ~ 1:100 - 1000

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

Derive: Absolute Higgs width, branching ratios, couplings

Jets @ CEPC





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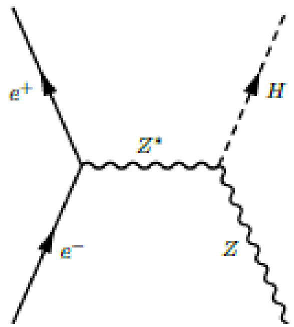
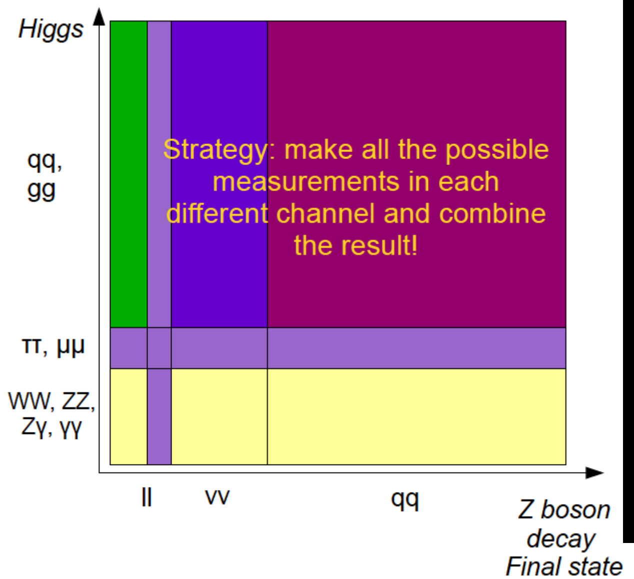
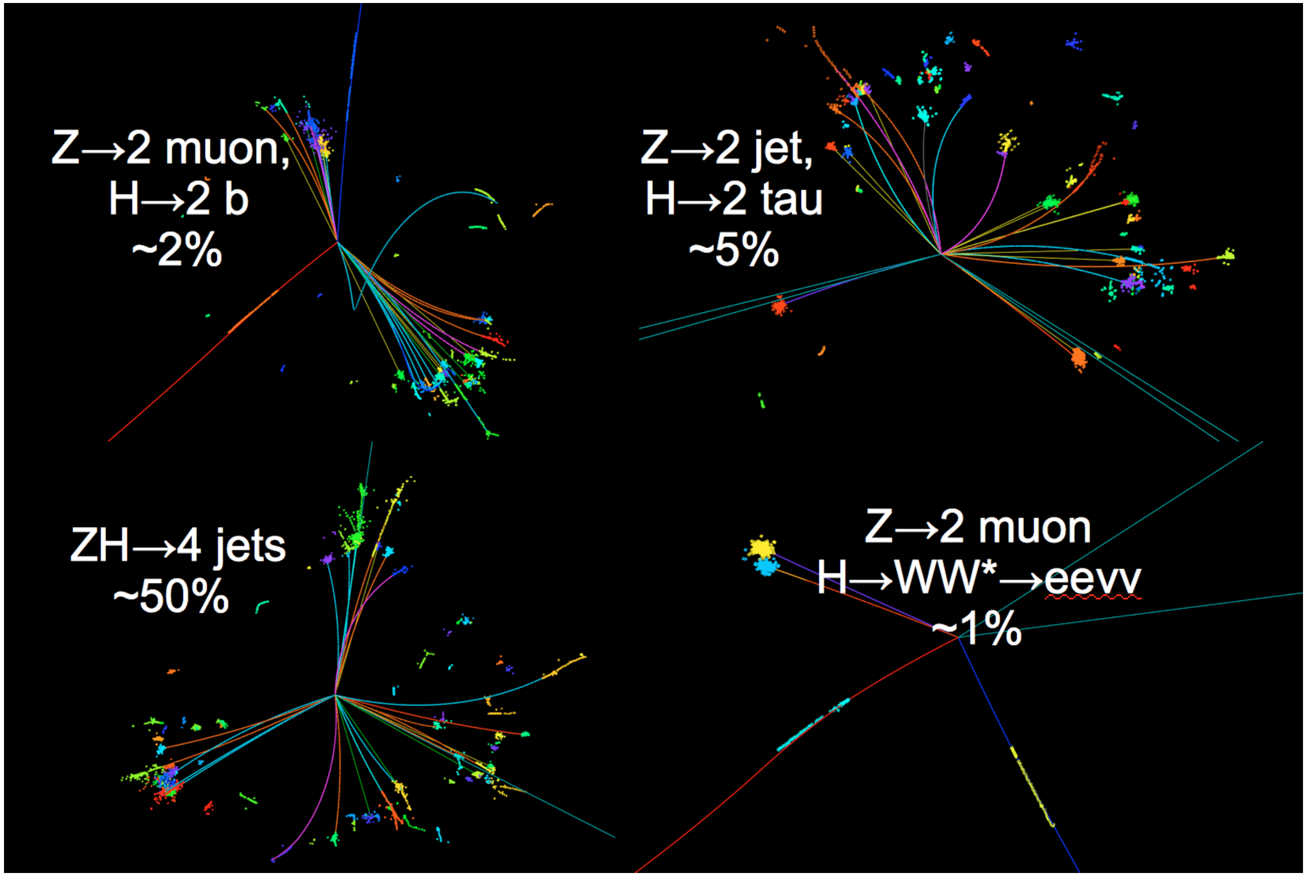
Physics Requirements







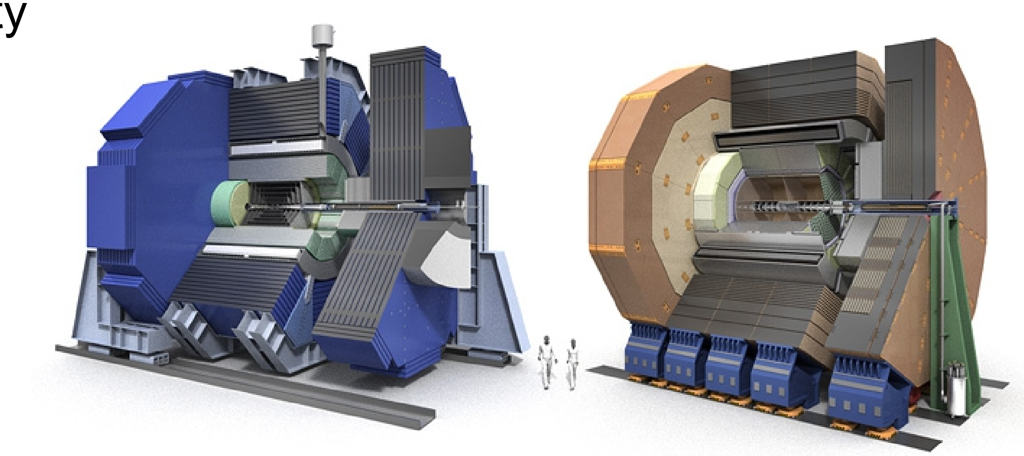
Detector:

- To reconstruct all the physics objects with high efficiency, purity & resolution
- Homogenous & Stable enough to control the systematic

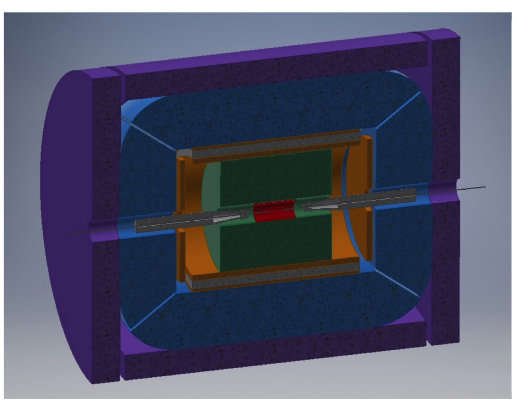
This talk quantifies the requirement/key questions of Jet reconstruction at CEPC/ILC

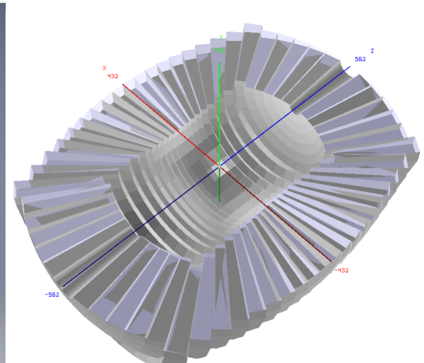
Two classes of Concepts

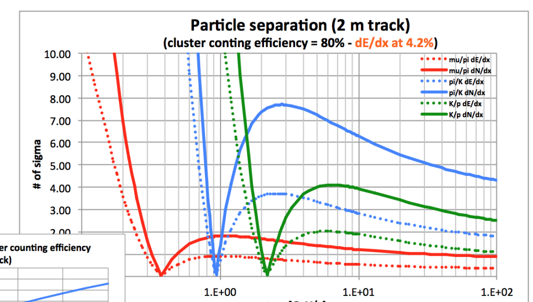
- PFA Oriented concept using High Granularity Calorimeter
  - **+ TPC (ILD-like, Baseline)**
  - + Silicon tracking (SiD-like)

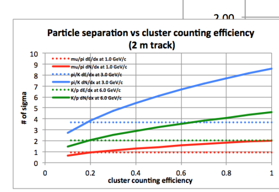


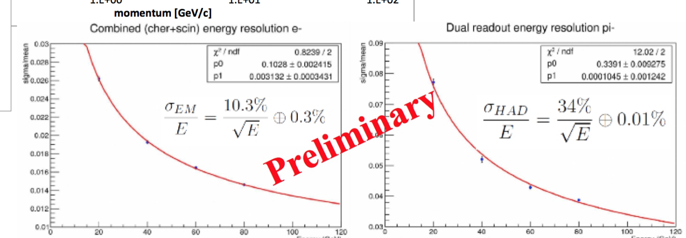
- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter











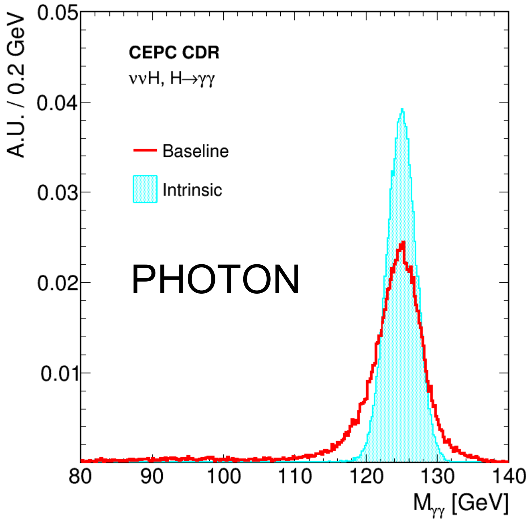
https://indico.ihep.ac.cn/event/6618/

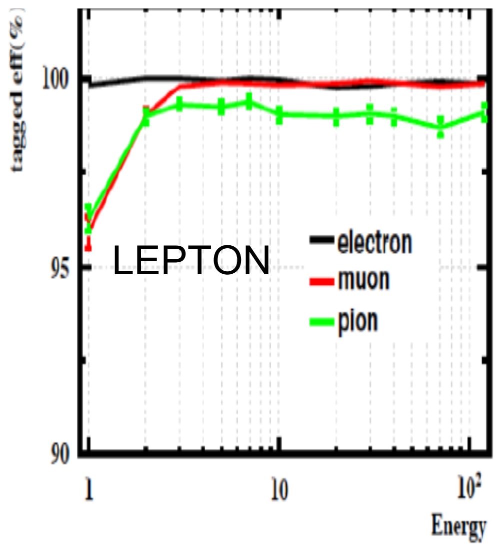
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

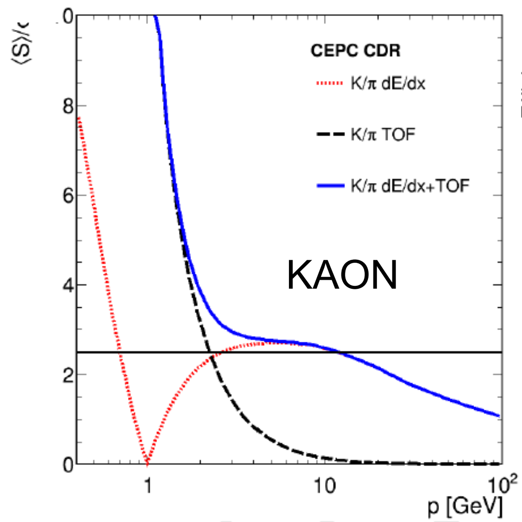
Physics Objects

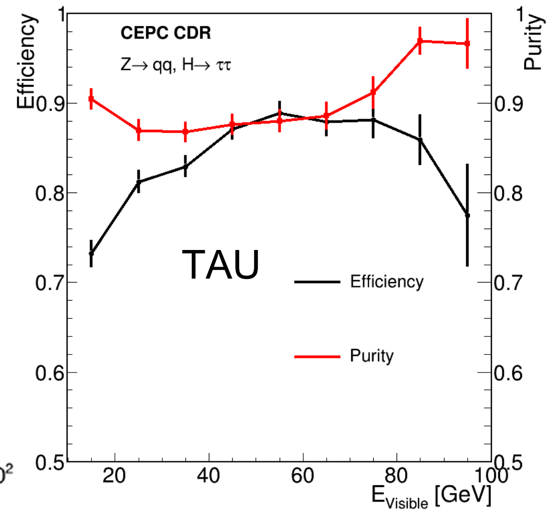
Eur. Phys. J. C (2017) 77: 591

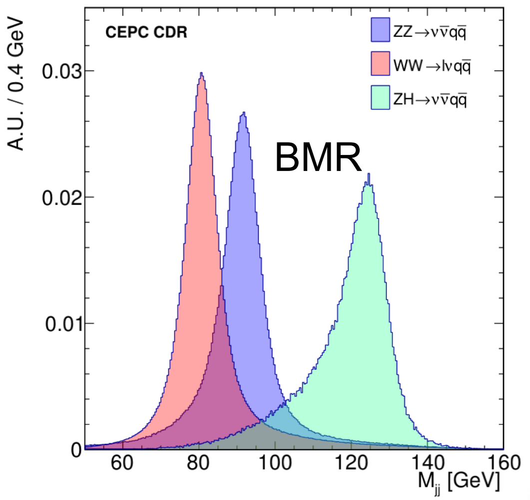
Eur. Phys. J. C (2018) 78:464

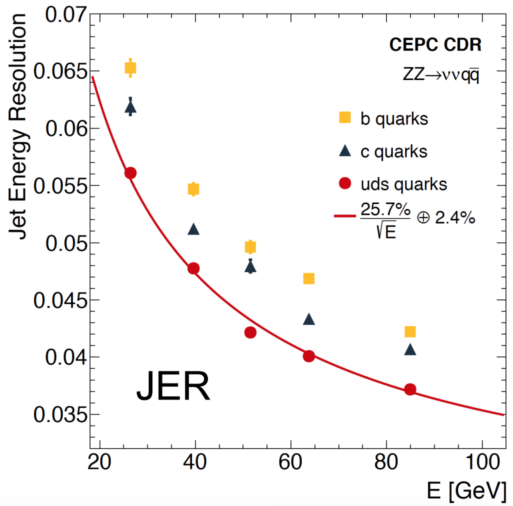


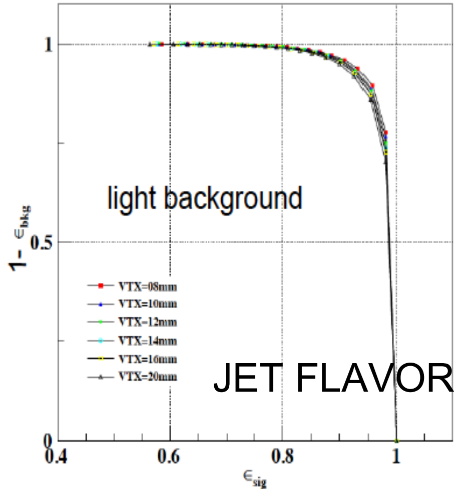


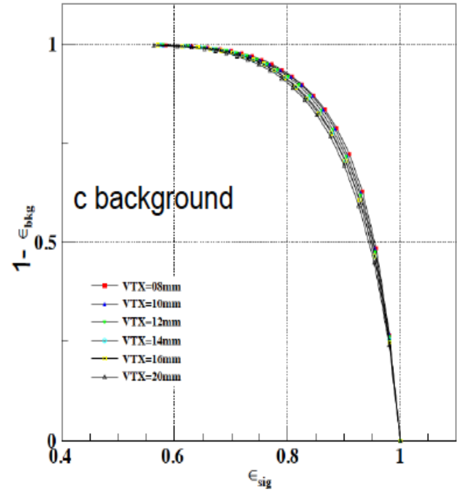






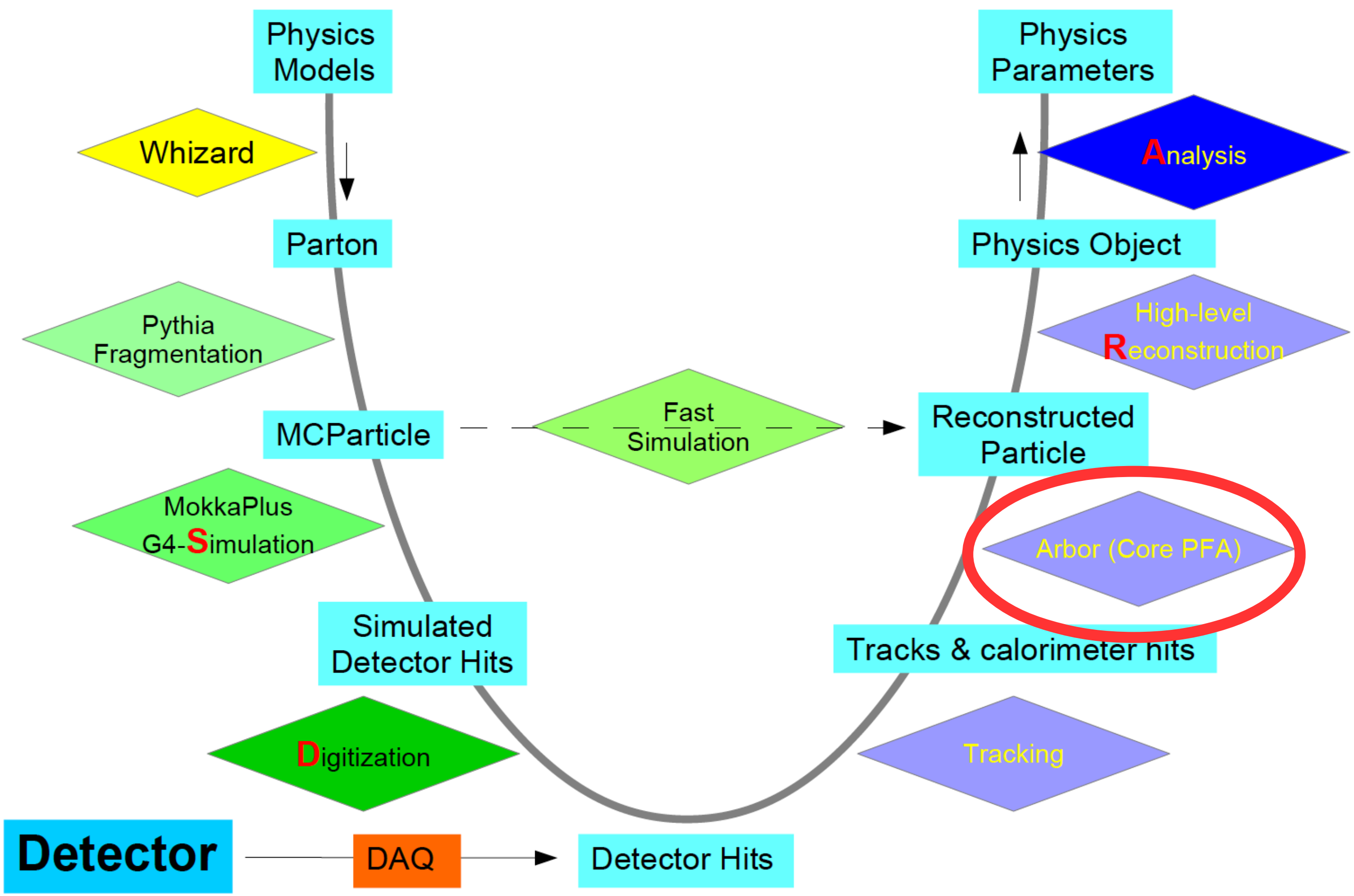






Eur. Phys. J. C (2018) 78: 426

The Simu-Reco Chain at CEPC

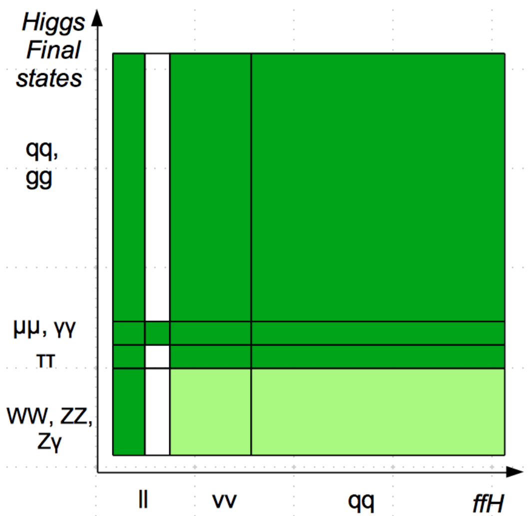


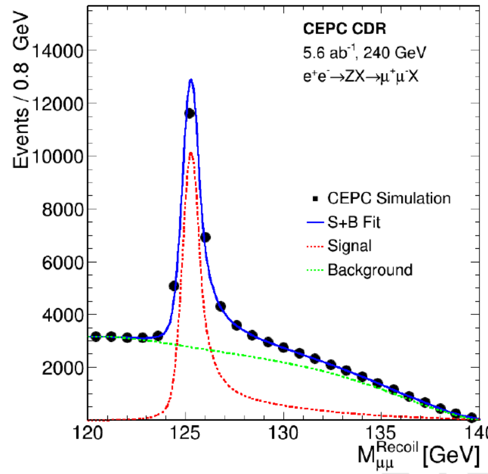
- Generators (Whizard & Pythia)
- Data format & management (LCIO & Marlin)
- Simulation (MokkaC)
- Digitizations
- Tracking
- PFA (Arbor)
- Single Particle Physics Objects Finder (LICH)
- Composed object finder (Coral)
- Tau finder
- Jet Clustering (FastJet)
- Jet Flavor Tagging (LCFIPLus)
- Event Display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

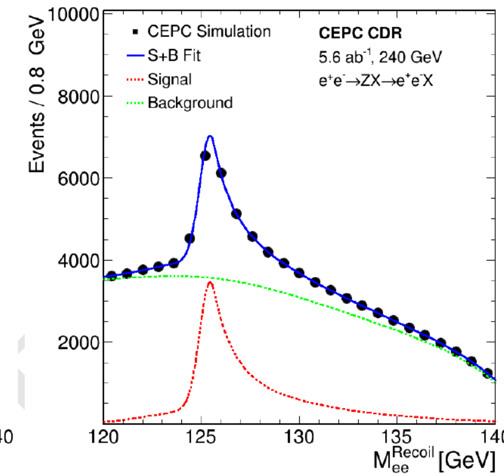
CEPC-SIMU-2017-001, CEPC-SIMU-2017-002, (DocDB id-167, 168, 173)

General Software | ILCSoft | ILCSoft + Development | Developments

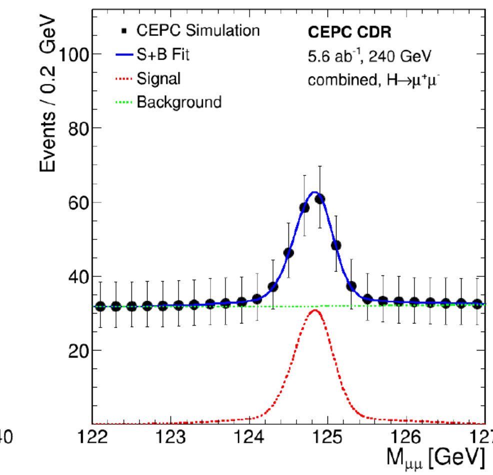
Higgs benchmark analyses



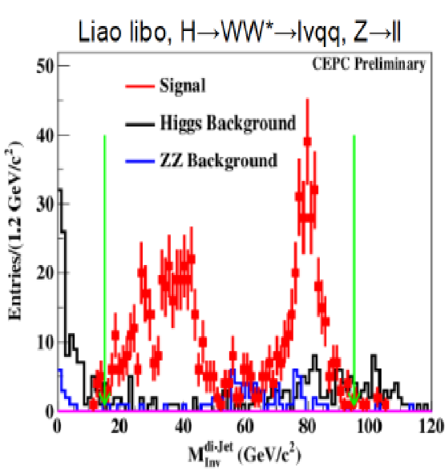




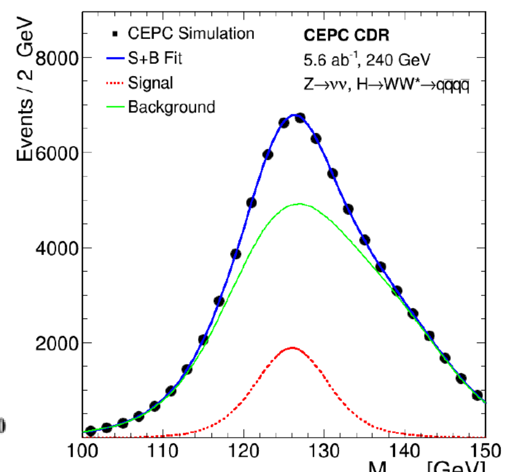
σ(ZH) measurements



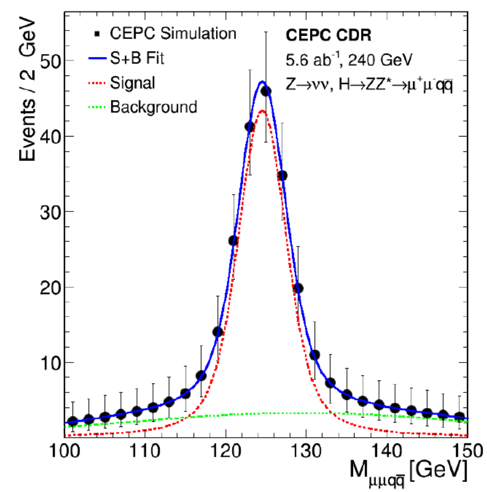
Br(H→μμ)



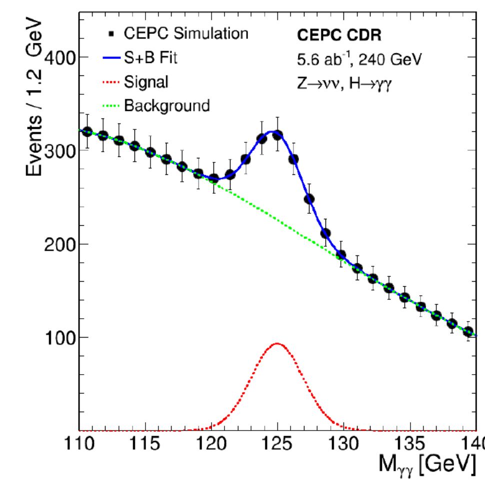
Br(H→WW)



σ(ννH)*Br(H→bb)



Br(H→ττ)



Br(H→γγ) (Asimov)