

# Status of the requirement study

- The CEPC detector should precisely identify and measure the key physics objects.
- The qualitative requirements are re-evaluated [on the Higgs benchmarks](#), a tentative update is concluded with respect to the CDR baseline ([in blue](#))
  - Tracker: if degrading the requirement by 100%...
    - Adequate at Higgs mass measurement using  $\mu\mu H$  event (recoil)
    - Leads to 40% degrading on the  $\mu(H \rightarrow \mu\mu)$  measurement
    - [A degrading of 30-40% w.r.t the CDR requirement seems 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](#)
  - Eff\*purity > 10% of  $H \rightarrow cc$  tagging in  $H \rightarrow jj$  sample: Closer > Light > Preciser + MDI input...

# Future activities

- Quantify the requirement more precisely, especially on the Flavor measurements:
  - Pid
  - Object finding in jets
  - Differential measurement (angular resolution of jet, MET)
  - Physics as a Z factory using  $Z \rightarrow \text{tautau}$  (at Z pole)
- Study on Color Singlet Identification
- Establish more precisely the constrains from MDI, integration, etc
- Precisely model the detector responses of key technologies
- Optimization Establish the correlation between key requirement (eff\*purity, resolution) V.S. the detector geometry parameters

# Back up

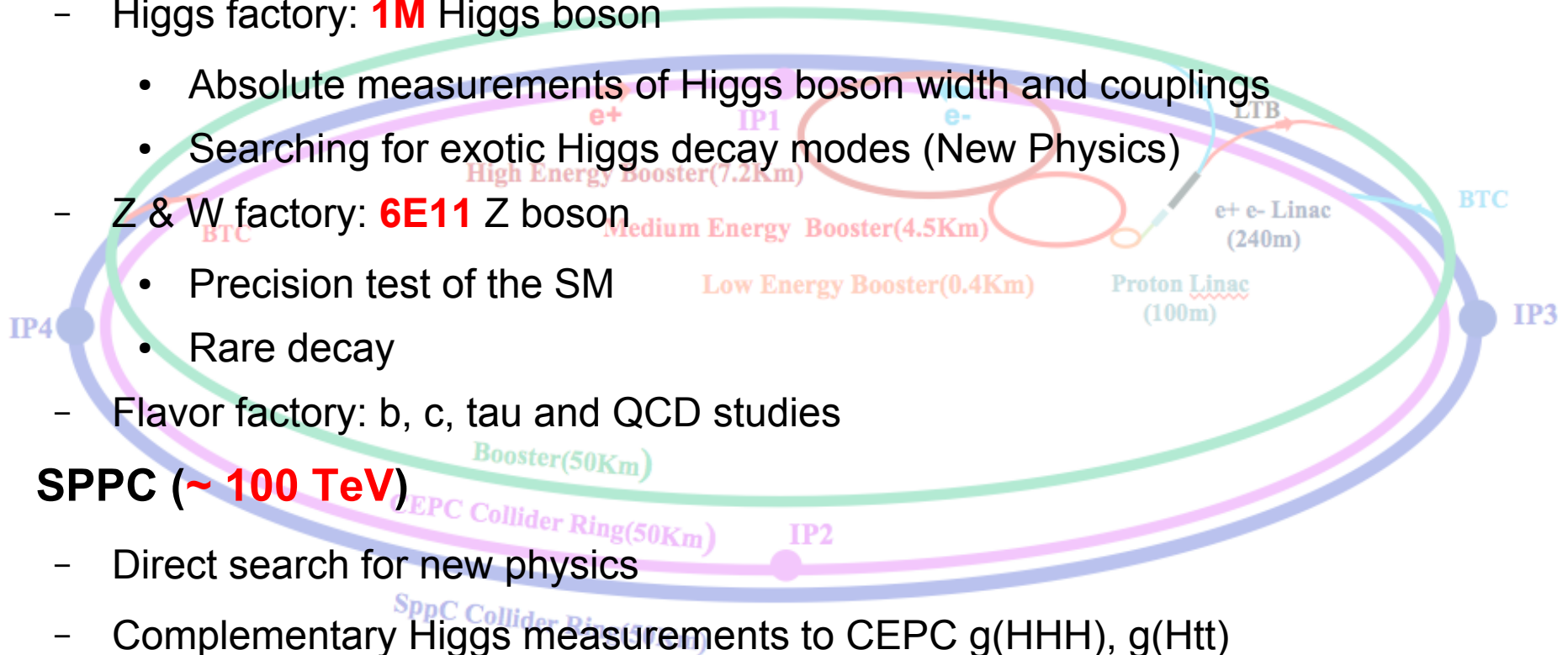


*Physics requirement at the  
CEPC: Higgs measurements  
& others*

Manqi

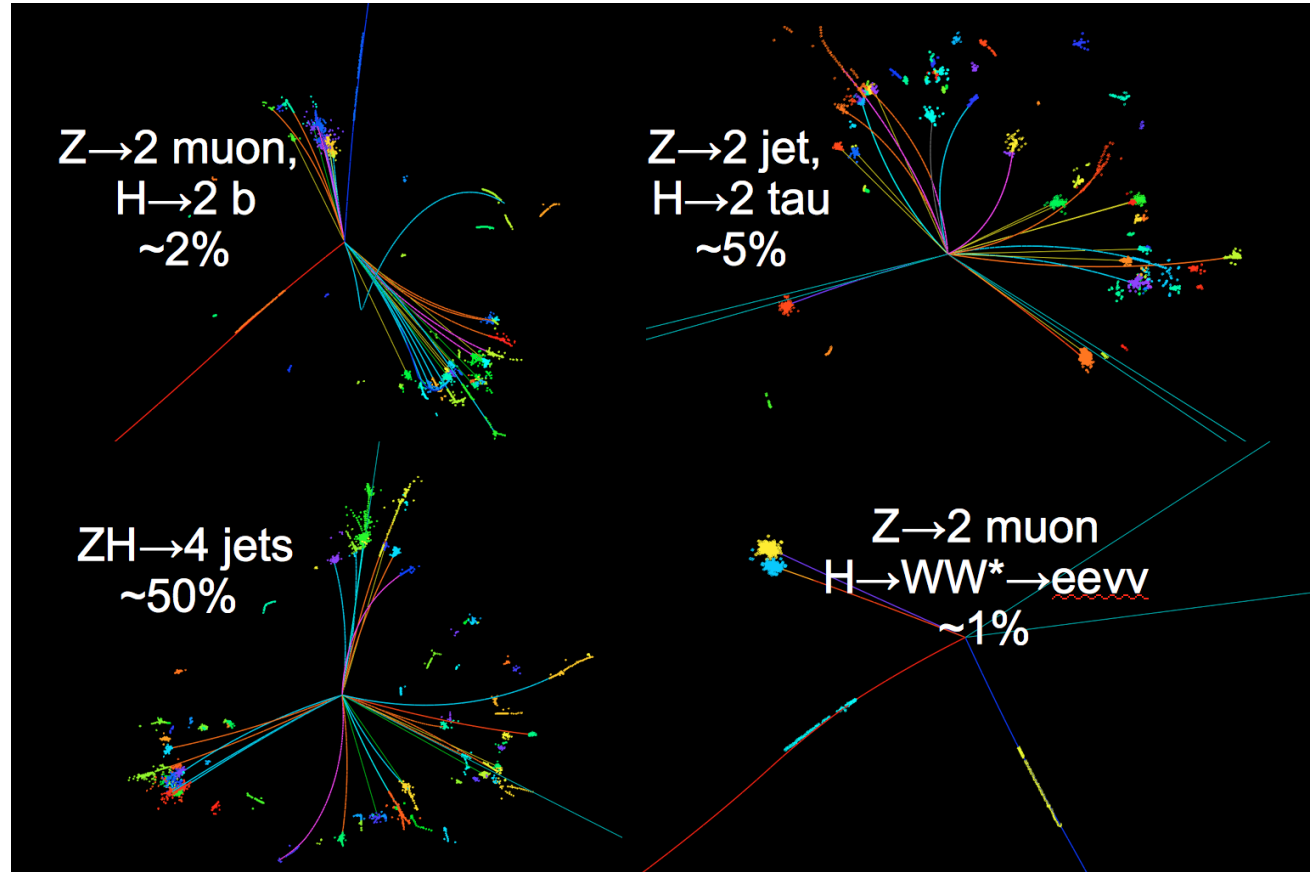
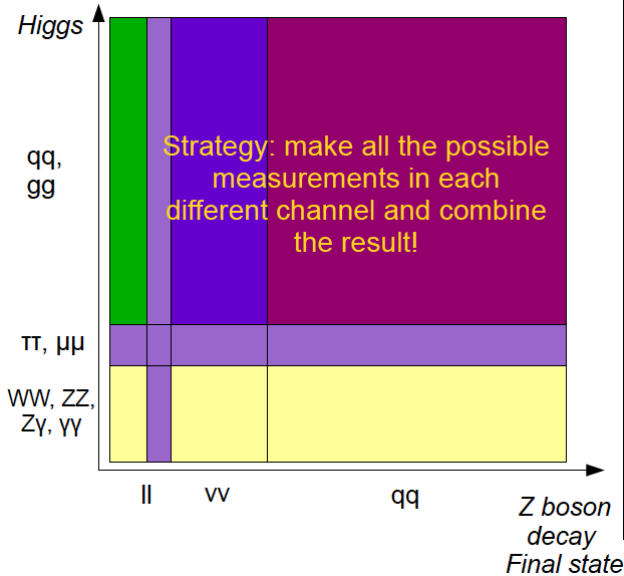
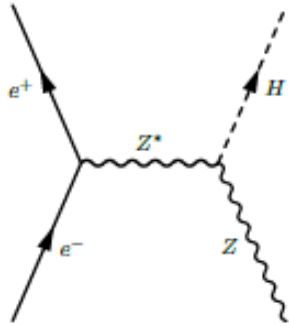
# Science at CEPC-SPPC

- 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  $g(\text{HHH})$ ,  $g(\text{Htt})$
  - ...
- **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

128 EXPERIMENTAL CONDITIONS, PHYSICS REQUIREMENTS AND DETECTOR CONCEPTS

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

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

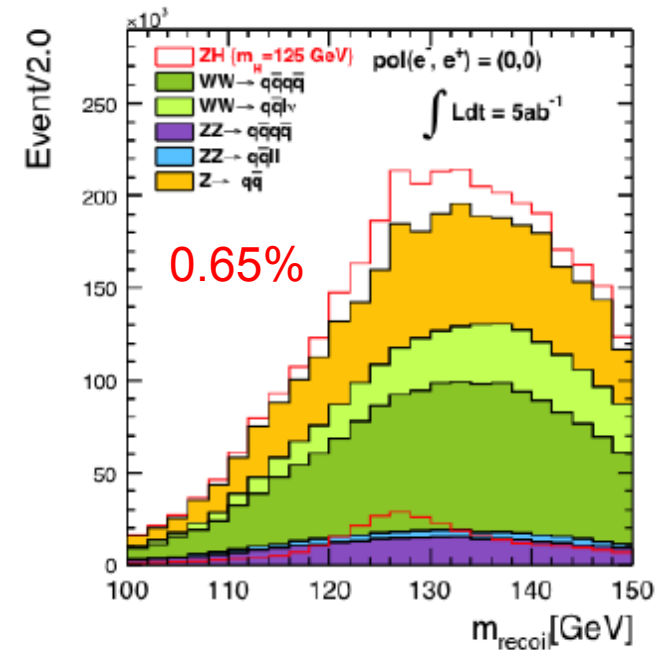
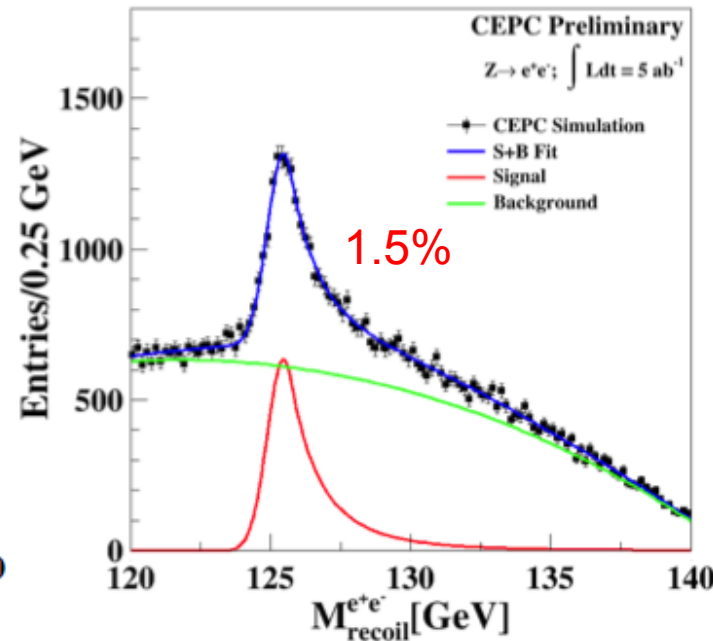
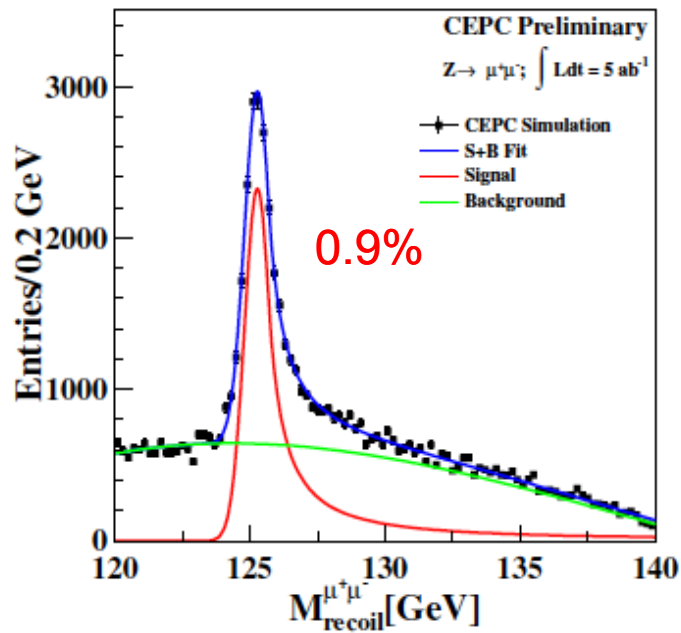
# Requirement benchmark analyses

- Higgs measurements
  - Track Momentum: Higgs recoil mass from  $\mu\mu H$ ;  $\mu(H \rightarrow \mu\mu)$ .
  - Photon:  $\mu(H \rightarrow \gamma\gamma)$
  - Hadronic event
    - Total visible mass (Characterized by Boson Mass Resolution):
      - $\mu(\nu\nu H, H \rightarrow bb)$ ;
      - $\mu(qqH, H \rightarrow inv)$ ;
      - $\mu(qqH, H \rightarrow \text{tautau})$ ;
    - Jet clustering-matching: ZZ/WW separation
  - Flavor tagging:  $g(Hcc)$ ,  $g(Hbb)$ ,  $g(Hgg)$
- Other measurements: EW, Flavor & QCD
  - $\pi^0$  reconstruction

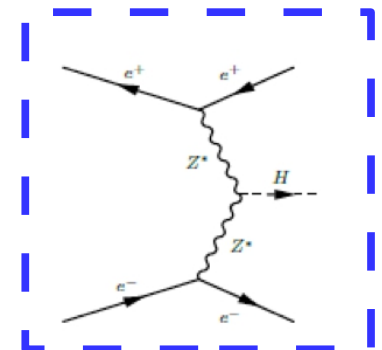
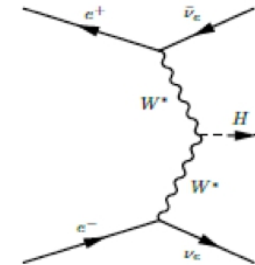
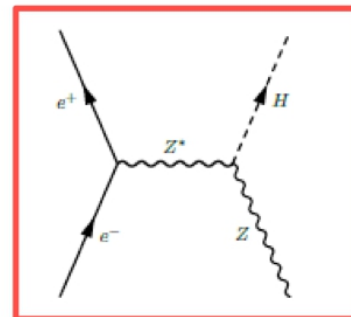
# Higgs recoil analysis with $\mu\mu H$ event

Zhenxing Chen & Yacine Haddad

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



- Combined precision:  
 $\delta\sigma(ZH)/\sigma(ZH) = 0.5\%$   
 $\delta g(HZZ)/g(HZZ) = 0.25\%$



HKIAS 2019

18/11/19

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

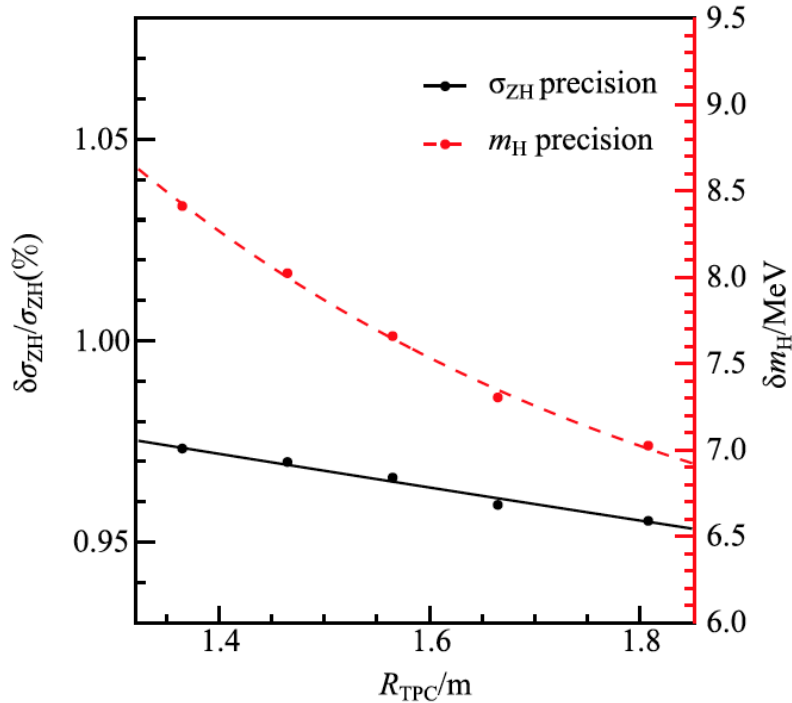
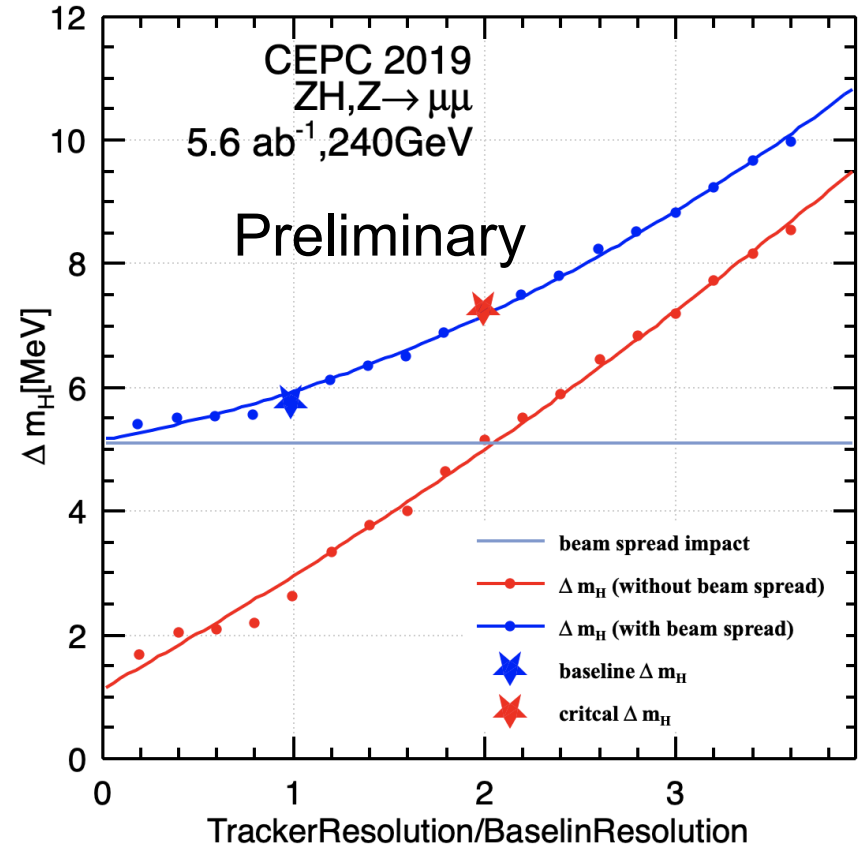


Fig. 6. The precisions of  $\sigma_{ZH}$  and  $m_H$  measurements versus different TPC radii. The solid line represents the precision of  $\sigma_{ZH}$ , and the dashed line is for  $m_H$ .

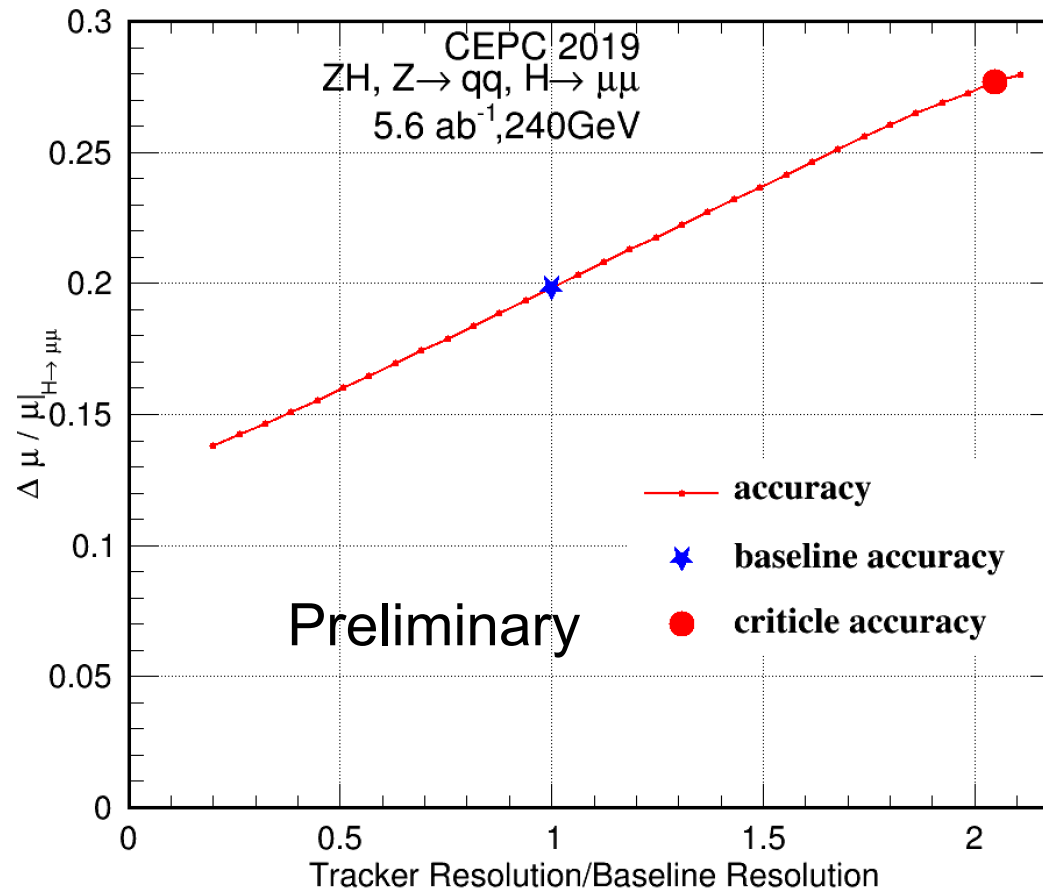
$$\frac{\delta\sigma_{ZH}}{\sigma_{ZH}} = 0.52 \times (1 + e^{-0.09 \cdot R_{TPC}}), \quad (4)$$

$$\delta m_H = 5.85 \times (1 + 5.19 \times e^{-1.81 \cdot R_{TPC}}) \text{ MeV}. \quad (5)$$



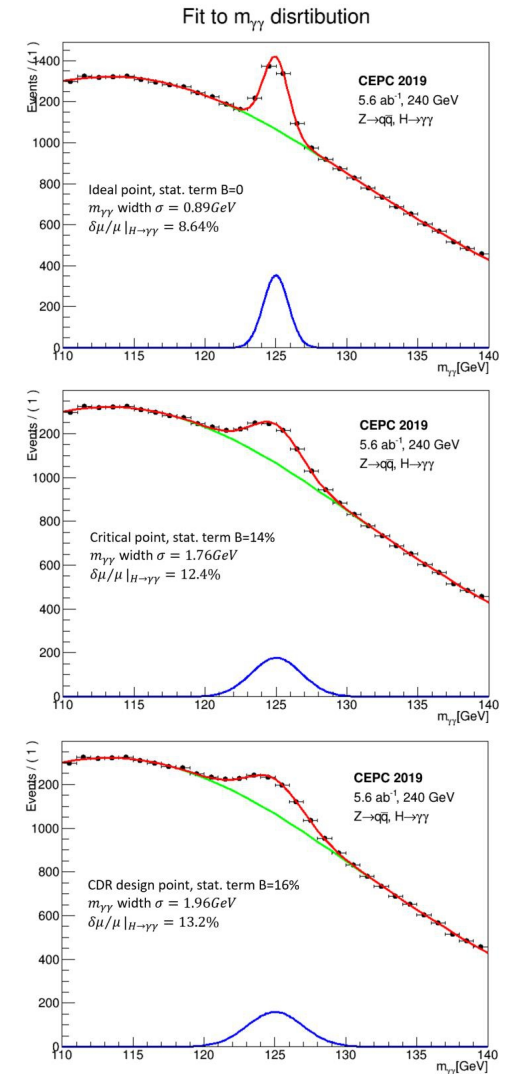
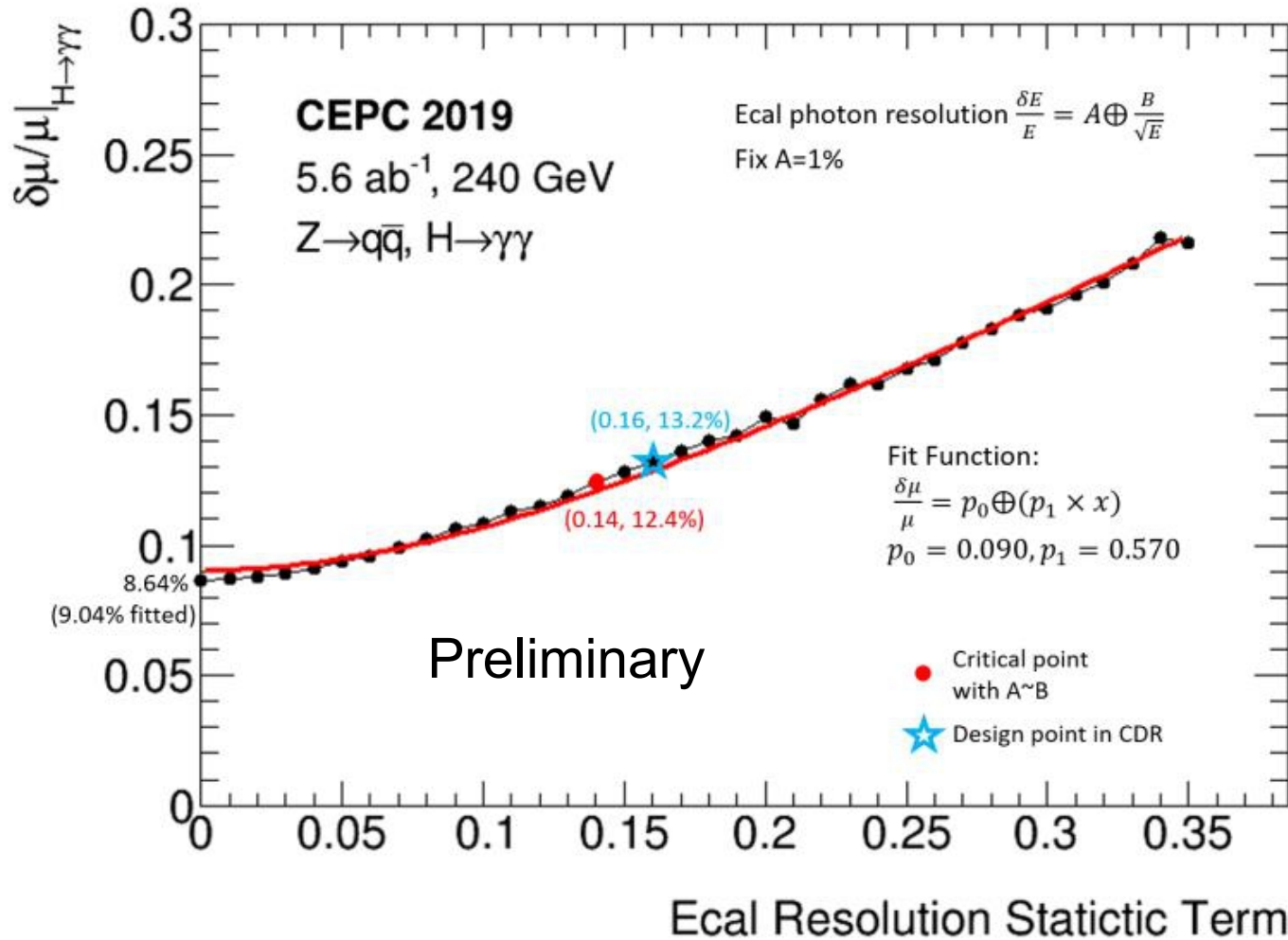
*Note: Higgs mass is more accurately measured From Model-dependent analysis, which is used In the analysis show in the right side*

# $\mu(H \rightarrow \mu\mu)$ measurement at qqH event



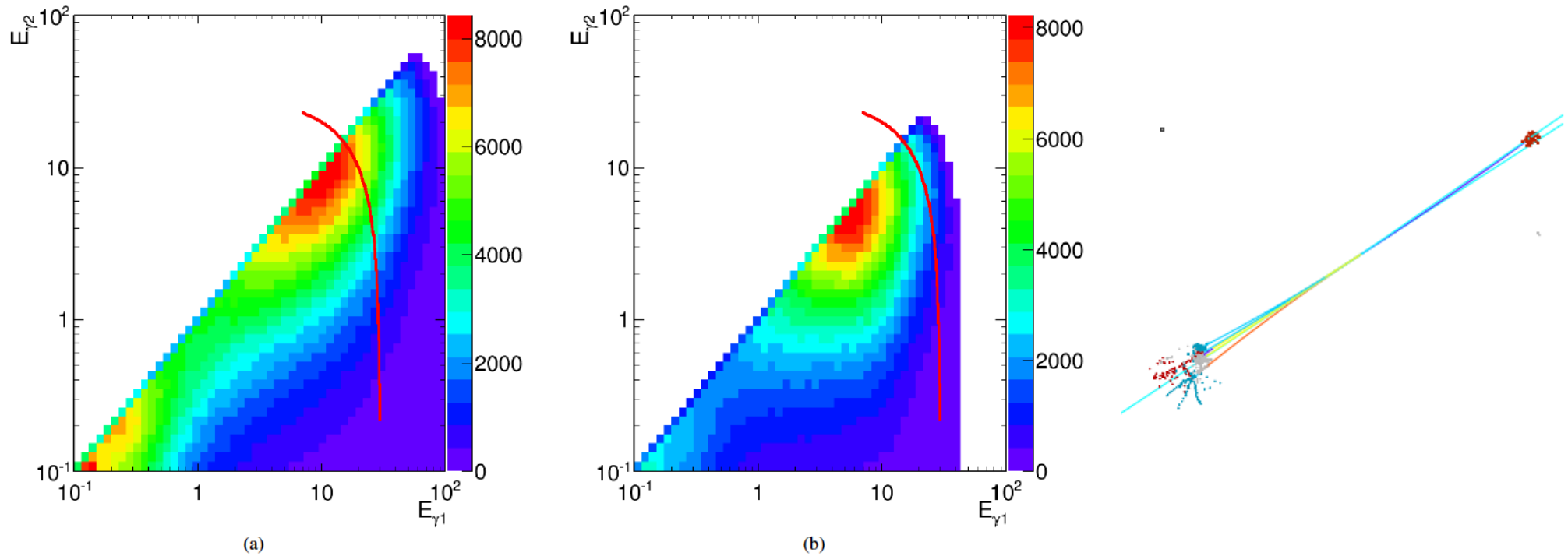
- Degrading the tracking resolution by 2 times leads to a degrading of 40% in the signal strength measurement

# ECAL resolution benchmark on $\mu(H \rightarrow \gamma\gamma)$



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

# Separation requirement on $Z \rightarrow \tau\tau$ event at Z pole



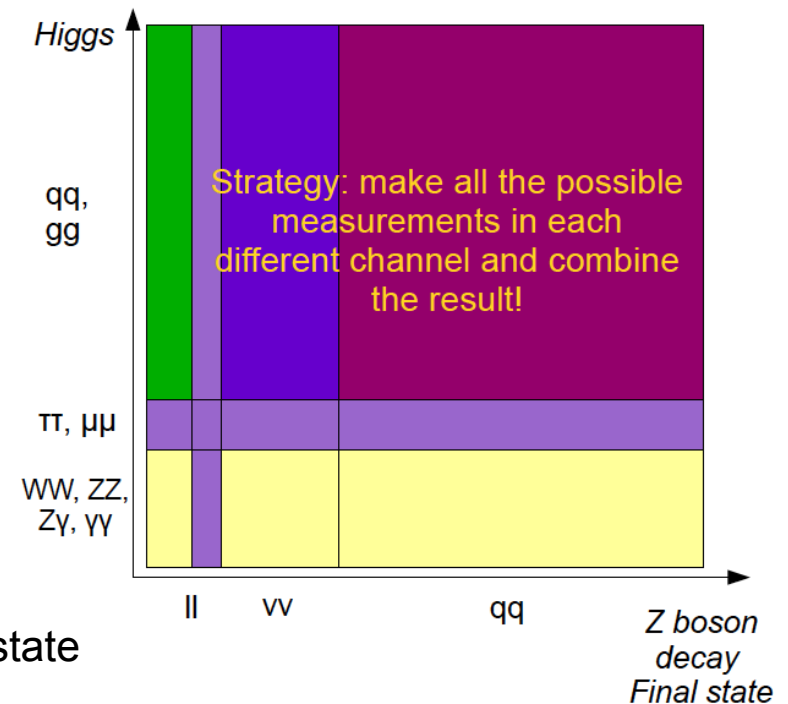
**Fig. 14** The generated  $\pi^0$  distribution as a function of the energies of diphotons from  $\pi^0 \rightarrow \gamma\gamma$  in inclusive Higgs (a) and  $Z \rightarrow \tau\tau$  samples (b).  $E_{\gamma 1}$  is the energy of leading photon.  $E_{\gamma 2}$  is the energy of sub-leading photon.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

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

# Hadronic event: @ Higgs

- SM Higgs

- **0 jets: 3%:**  $Z \rightarrow ll, \nu\nu$  (30%);  $H \rightarrow 0$  jets ( $\sim 10\%$ ,  $\pi\pi, \mu\mu, \gamma\gamma, \gamma Z/WW/ZZ \rightarrow$  leptonic)
- **2 jets: 32%**
  - $Z \rightarrow qq, H \rightarrow 0$  jets.  $70\% * 10\% = 7\%$
  - $Z \rightarrow ll, \nu\nu; H \rightarrow 2$  jets.  $30\% * 70\% = 21\%$
  - $Z \rightarrow ll, \nu\nu; H \rightarrow WW/ZZ \rightarrow$  semi-leptonic. 3.6%
- **4 jets: 55%**
  - $Z \rightarrow qq, H \rightarrow 2$  jets.  $70\% * 70\% = 49\%$
  - $Z \rightarrow ll, \nu\nu; H \rightarrow WW/ZZ \rightarrow 4$  jets.  $30\% * 15\% = 4.5\%$
- **6 jets: 11%**
  - $Z \rightarrow qq, H \rightarrow WW/ZZ \rightarrow 4$  jets.  $70\% * 15\% = 11\%$

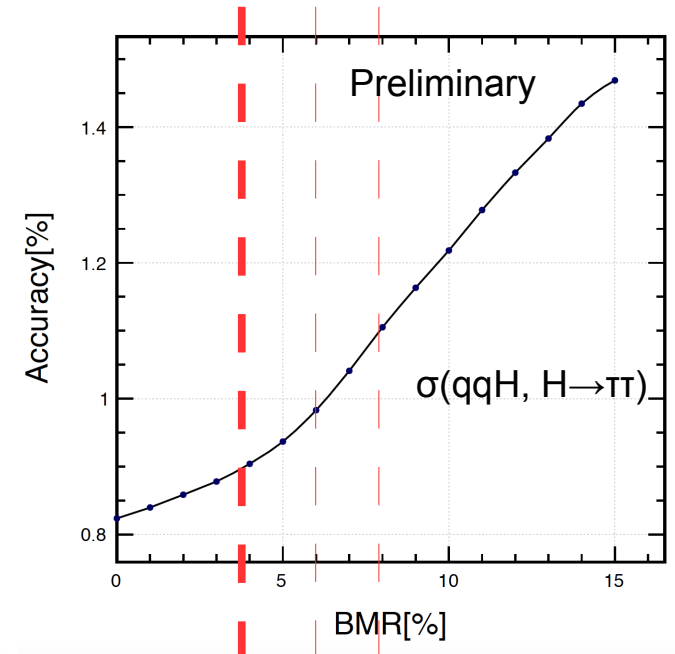
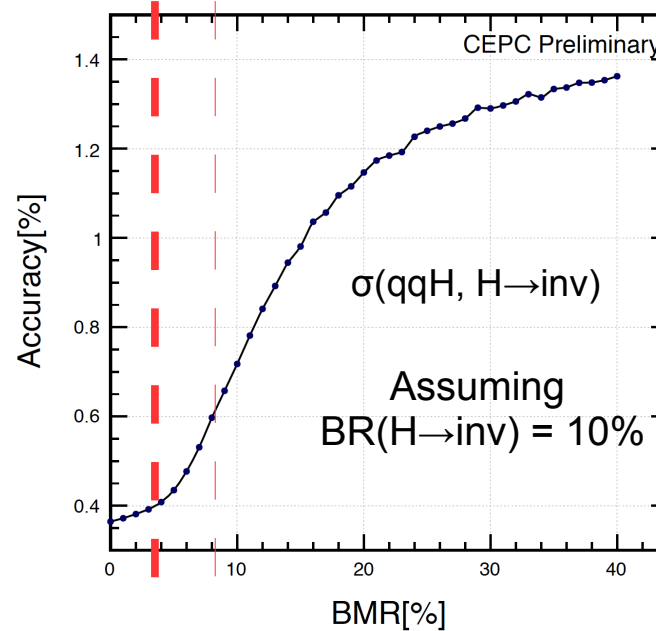
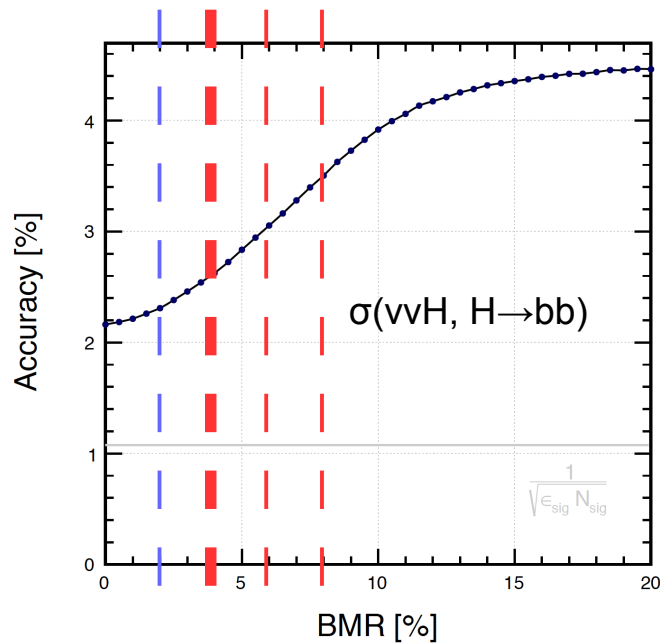


- **97%** of the SM Higgsstrahlung Signal has Jets in the final state
- **1/3** has only 2 jets: include all the SM Higgs decay modes
- **2/3** need **color-singlet identification**: grouping the hadronic final state particles into color-singlets
- Jet is important for EW measurements & jet clustering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

# 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%

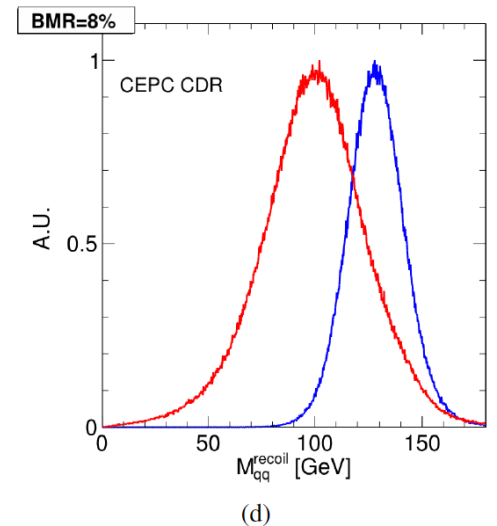
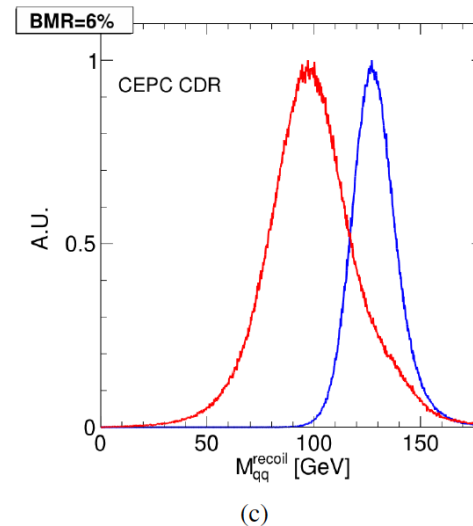
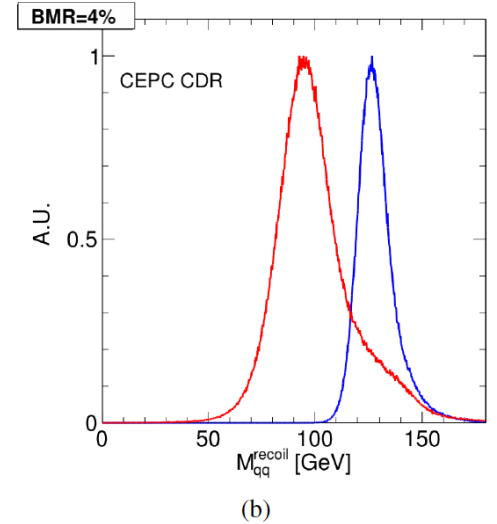
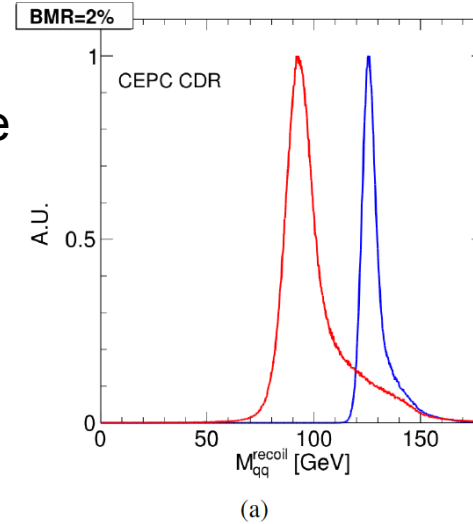
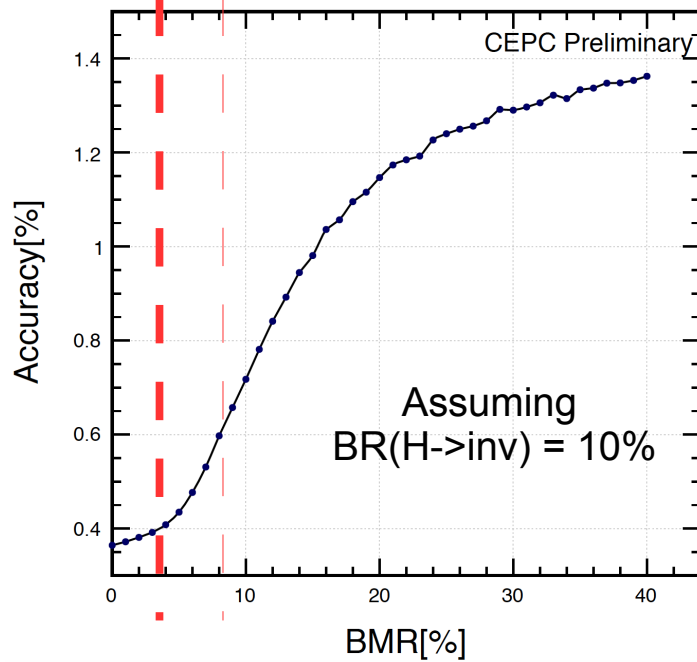


- Boson Mass Resolution: relative mass resolution of  $vvH, H \rightarrow gg$  events
  - Free of Jet Clustering
  - Be applied directly to the Higgs analyses
- The CEPC baseline reaches 3.8%

	BMR = 2%	4%	6%	8%
$\sigma(vvH, H \rightarrow bb)$	2.3%	2.6%	3.0%	3.4%
$\sigma(vvH, H \rightarrow \text{inv})$	0.38%	0.4%	0.5%	0.6%
$\sigma(qqH, H \rightarrow \tau\tau)$	0.85%	0.9%	1.0%	1.1%

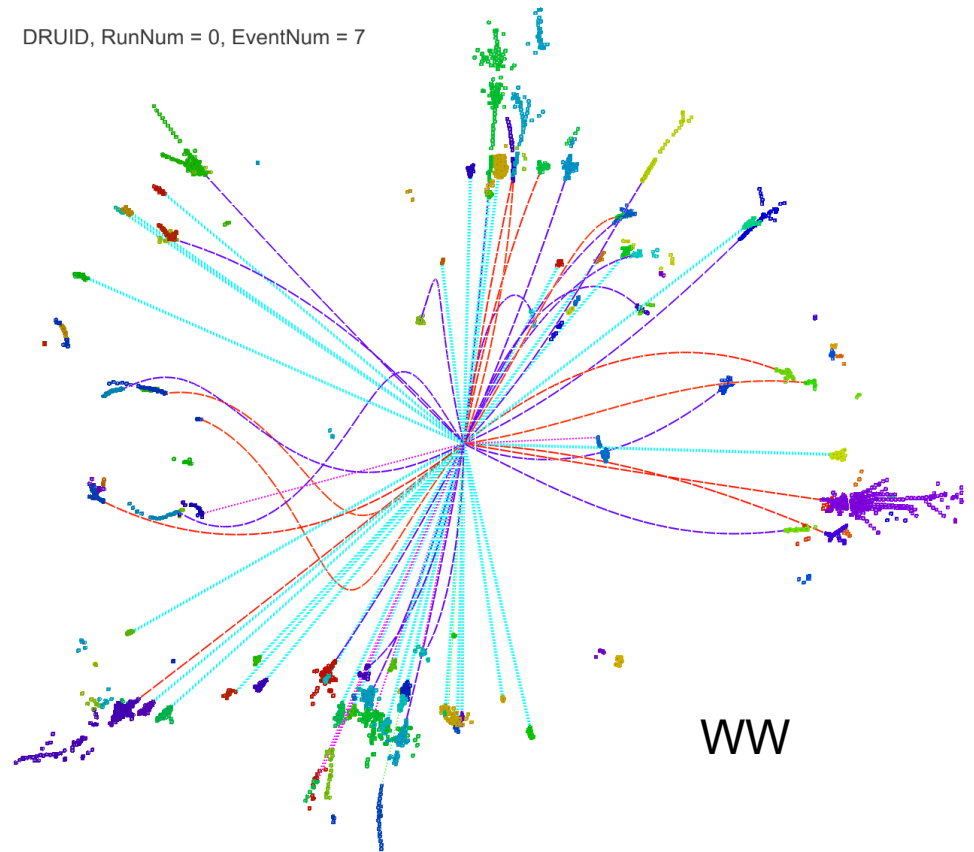
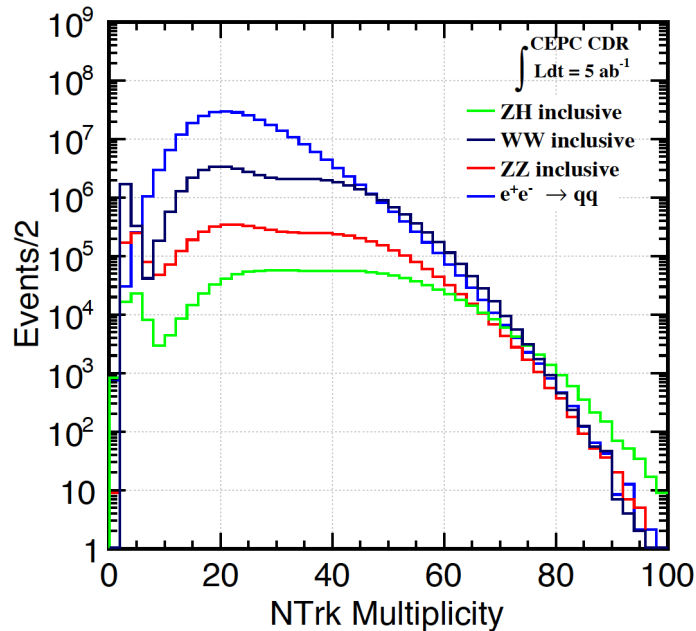
# 2<sup>nd</sup> Benchmark: qqH, H→invisible

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



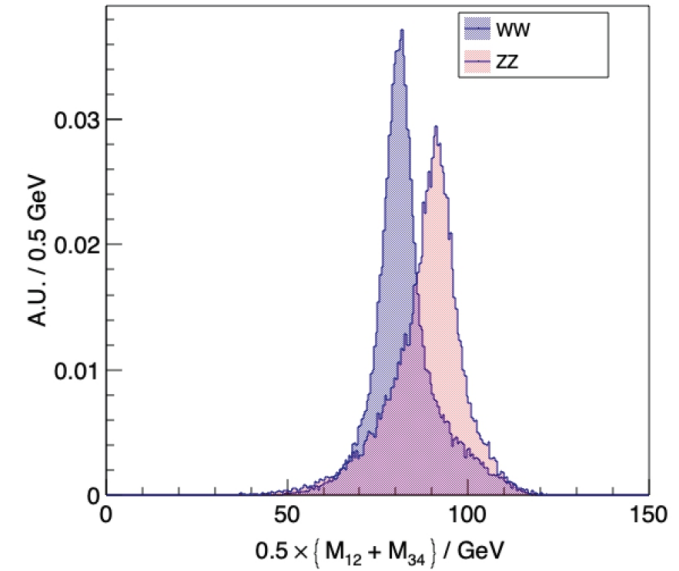
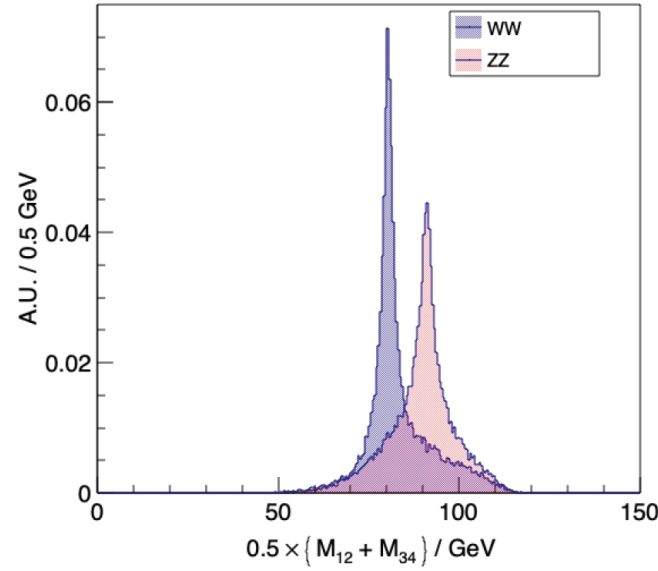
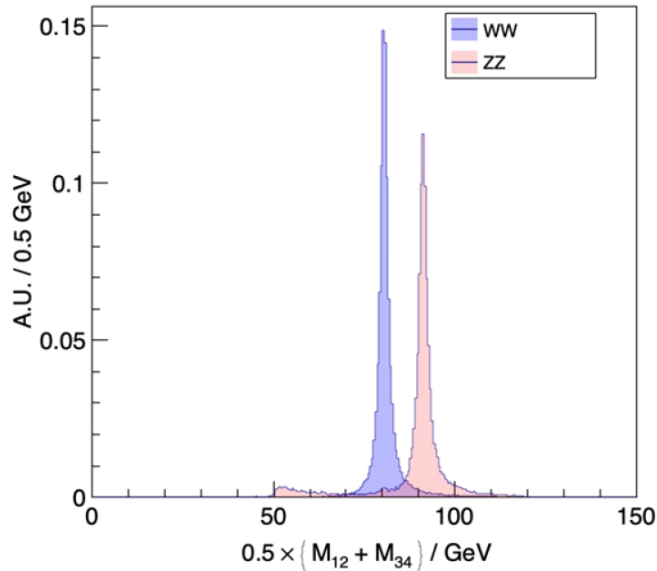
If the BMR degrades from 4% to 6/8%: the Higgs invisible measurement degrades by 20/50%

# 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

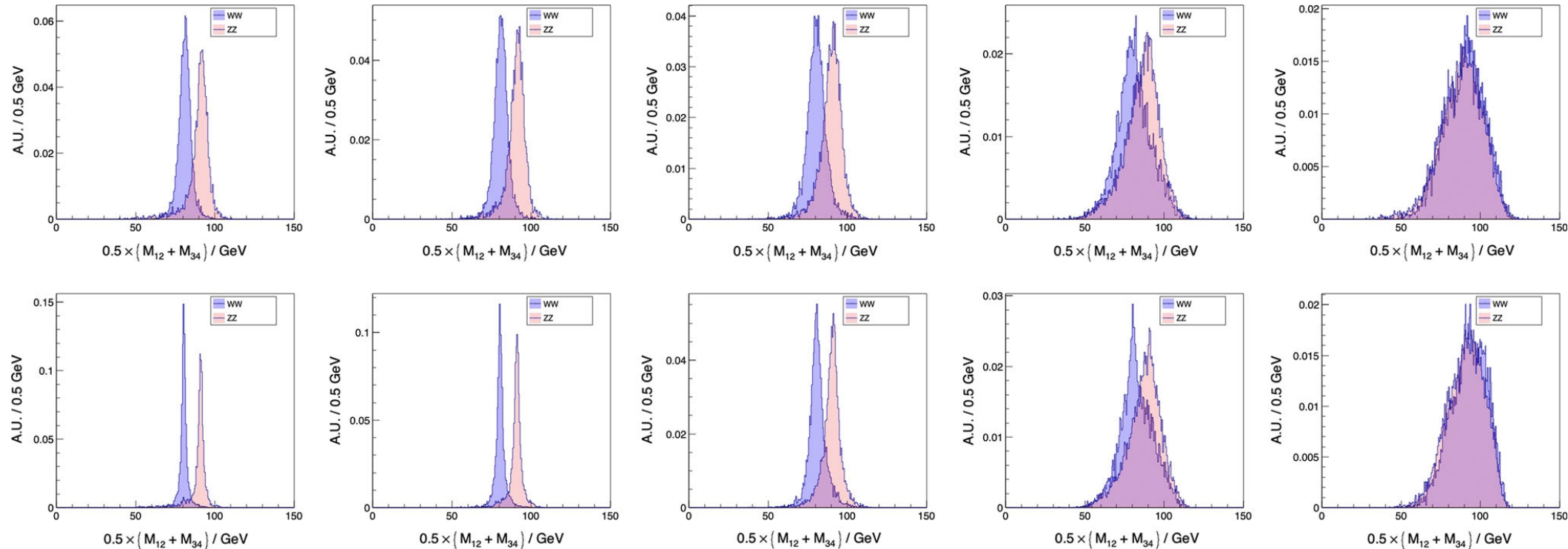


- Separation be characterized by
- Final state/MC particles are clustered into Reco/Genjet with ee-kt, and paired according to chi2
- WW-ZZ Separation at the inclusive sample:
  - Intrinsic boson mass/width - lower limit: Overlapping ratio of 13%
  - + Jet confusion – Genjet: Overlapping ratio of **53%**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

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

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

# Separation V.S. clustering



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

Jet confusion can be the dominant term, for any Higgs measurements with full hadronic final States ( $N_{\text{jet}} \geq 4$ )...

# Jet: Flavor tagging and charge

- Essential for
  - The Higgs coupling measurements  $g(Hcc)$ ,  $g(Hgg)$ ,  $g(Hbb)$
  - The EW measurements  $A_{fb}(b) \sim$  weak mixing angle
  - FCNC/Rare-decay of Higgs/W/Z with jets
  - The Flavor measurements: CP violation phases measurements
- Need benchmark & algorithm development/analyses, to understand
  - The typical **eff & purity** of objective object finding performance;
  - Dependence on the detector geometry

# Finding $H \rightarrow cc$ from $H \rightarrow jj$ events

Wu: 2018 JINST 13 T09002

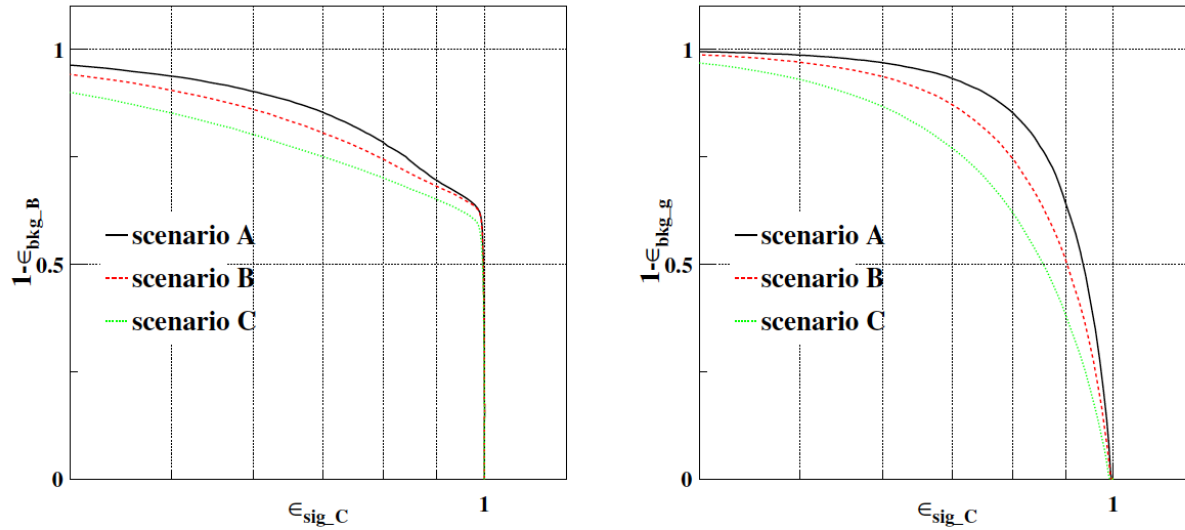
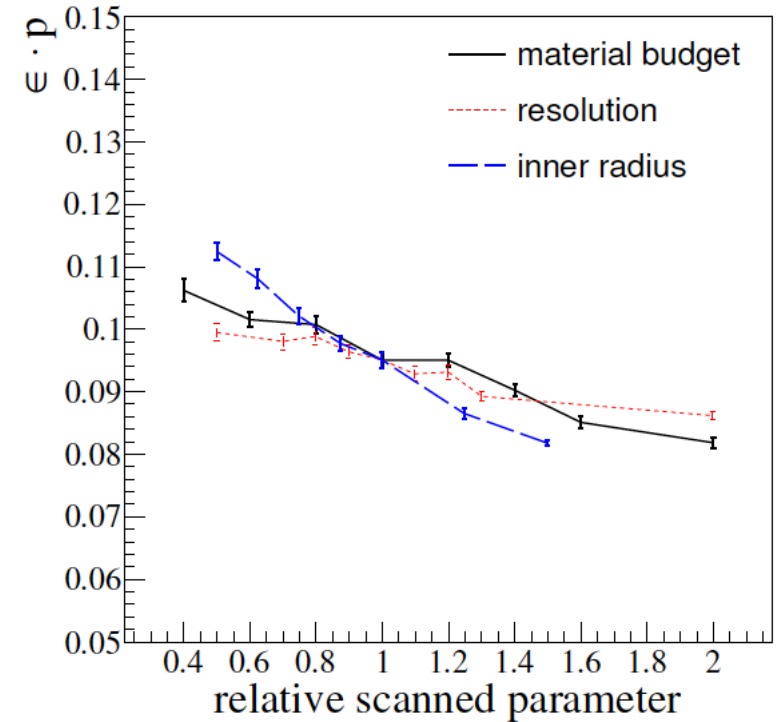


Table 2. Reference geometries.

	Scenario A (Aggressive)	Scenario B (Baseline)	Scenario C (Conservative)
Material per layer/ $X_0$	0.075	0.15	0.3
Spatial resolution/ $\mu\text{m}$	1.4 - 3	2.8 - 6	5 - 10.7
$R_{\text{in}}$ /mm	8	16	23



$$\epsilon \cdot p = 0.095 \left(1 - 0.14 \frac{\Delta x_{\text{material}}}{x_{\text{material}}}\right) \left(1 - 0.09 \frac{\Delta x_{\text{resolution}}}{x_{\text{resolution}}}\right) \left(1 - 0.23 \frac{\Delta x_{\text{radius}}}{x_{\text{radius}}}\right) \quad (4.1)$$

# Updates on the requirements

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

Higgs recoil at  $\mu\mu H$ : 2\*baseline resolution is adequate with current beam energy spread  
 $H \rightarrow \mu\mu$ : 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

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

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