Higgs Cross section and Mass measurements at CEPC

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Introduction

- The discovery of a Higgs boson in 2012 by ATLAS and CMS opened a new era in particle physics
- Subsequent measurements of the properties indicate Standard Model (SM) Higgs boson
- However, the SM does not predict the parameters in the Higgs potential.
  - Vast difference between the Planck scale and weak scale remains a major mystery
- Precision measurements of Higgs boson properties will be a critical component of any road map for high energy physics in the coming decades.

New Physics beyond the SM

- Deviations in the Higgs couplings from the SM expectations.

$$\delta = c\frac{v^2}{M_{\mathrm{NP}}^2}$$

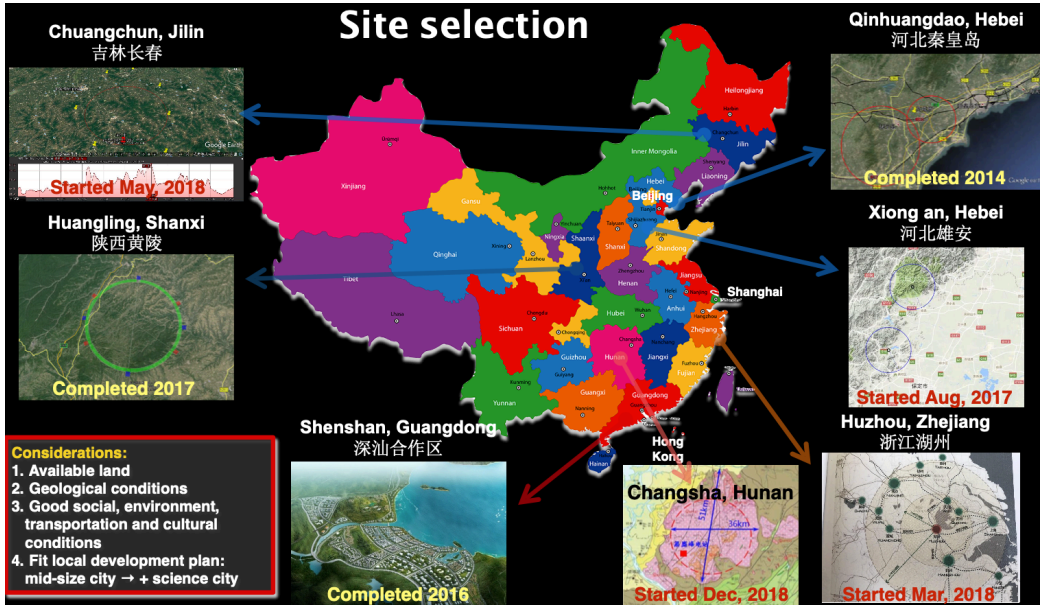
Vacuum expectation value of Higgs field

Typical mass scale of new physics

- The HL-LHC will measure the Higgs boson couplings ~5%.
- Probing new physics significantly beyond the LHC reach require ~% level of Higgs coupling measurement. → Need for Higgs factory.

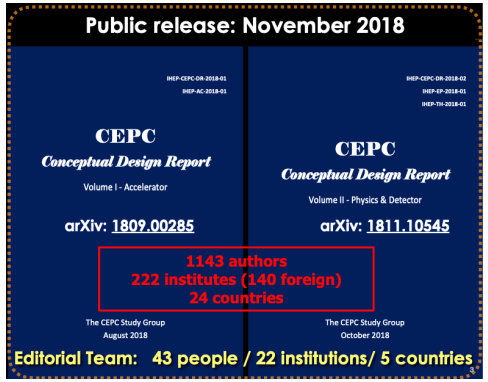
CEPC - Circular Electron Positron Collider

- E_{CM} = 240 GeV
- 100 km ring
- Higgs production : $e^+e^- \rightarrow ZH$, recoil mass method
- Expected int. lumi: 5.6 ab^{-1}, 1M Higgs (7 years with two detectors)
- Higgs coupling to Z accuracy ~ 0.25%
- Model independent measurement of Higgs width



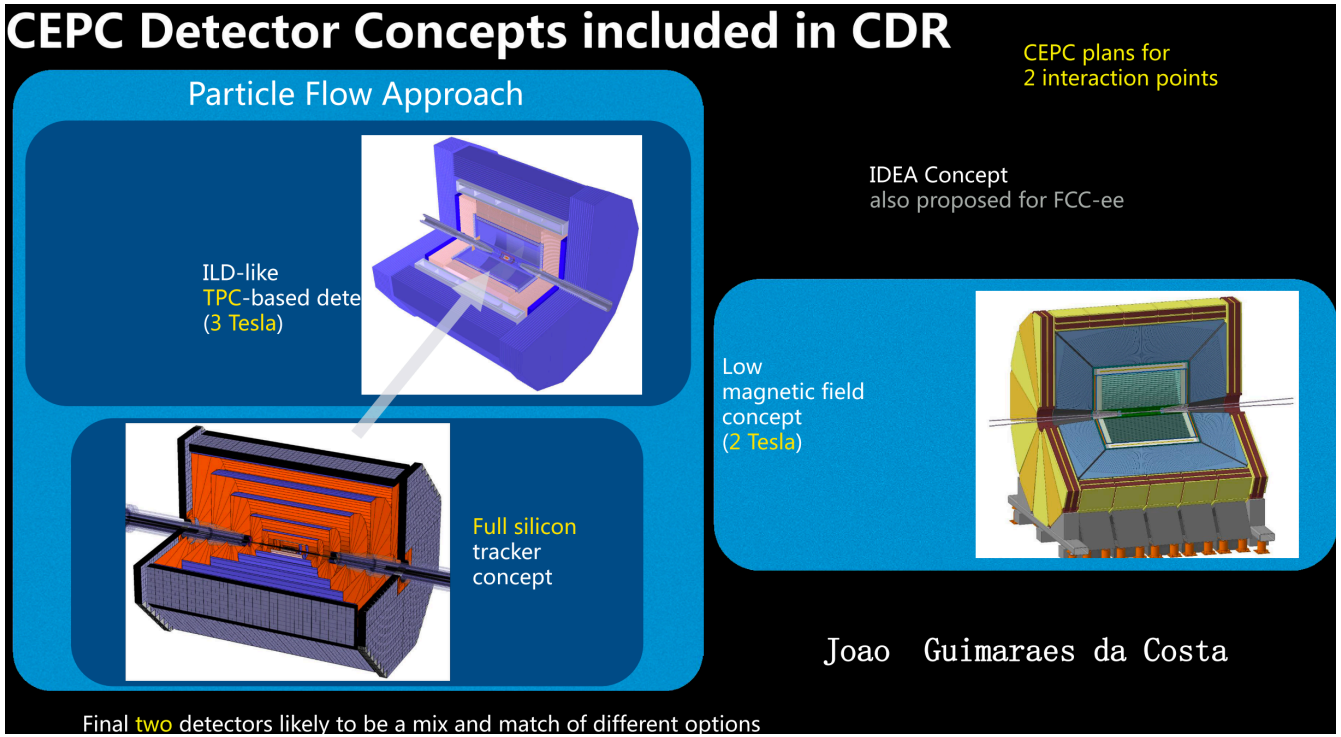
Joao da Costa

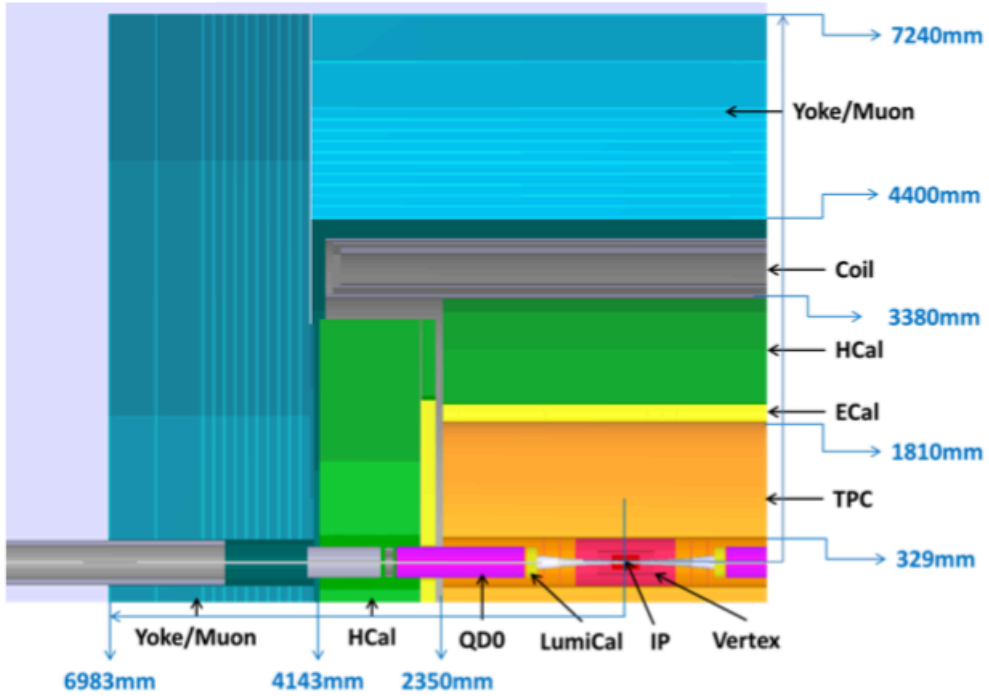
- CDR released on Nov 2018
  http://cepc.ihep.ac.cn/
- Input to European Strategy:
  arXiv: 1901.02170 , 1901.03169



CEPC Detector Concept

- Higgs factory $\sqrt{s}$ = 240 GeV 7 yrs → 1M Higgs, 1B Z, 100M W
- Z factory $\sqrt{s}$ = 91.2 GeV → 10^{11} – 10^{12} Z bosons
- WW threshold scans ~ $\sqrt{s}$ = 161 GeV → 10^{7} W



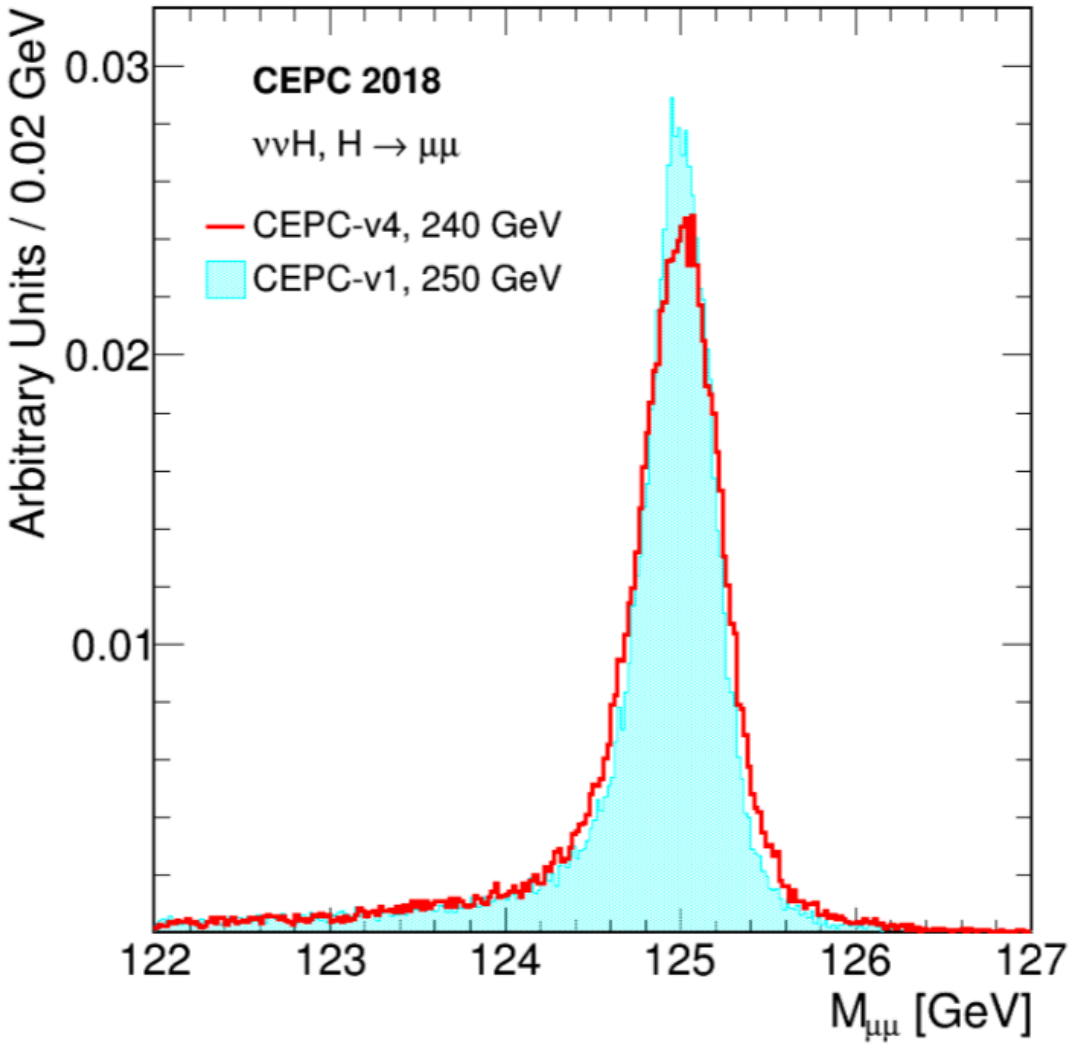


Object reconstruction and identification

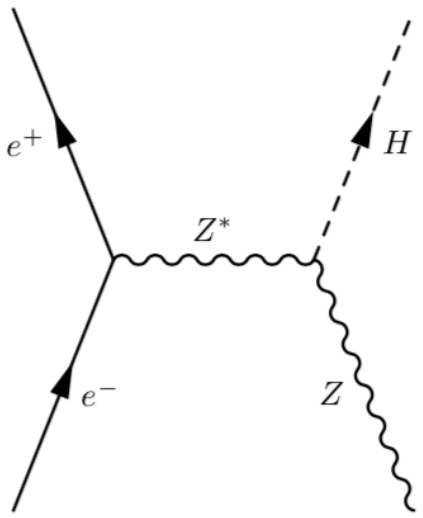
- ARBOR particle flow
- Leptons
  - 7% H production with leptons
  - Lepton ID algo: LICH eff 99.9%
  - Dimuon mass reso. 0.16%
- Photons
  - H2 gg and H2Zg
  - Tau leptons and jets
  - Mass reso. 2.5%
- Jets
  - 70% H decay into jets (bb, cc, gg)
  - 22% through WW,* ZZ* cascades
  - JES: 3-5%, W and Z: 4.4%.

CEPCv4 and optimization

- Smaller solenoidal field 3T
  (14% degrades of momentum reso.)
- Reduced calorimeter dimensions
- ECAL readout sensor size changed from 5x5 to 10x10 mm^2
- Add Time-of-Flight for flavor physics potential

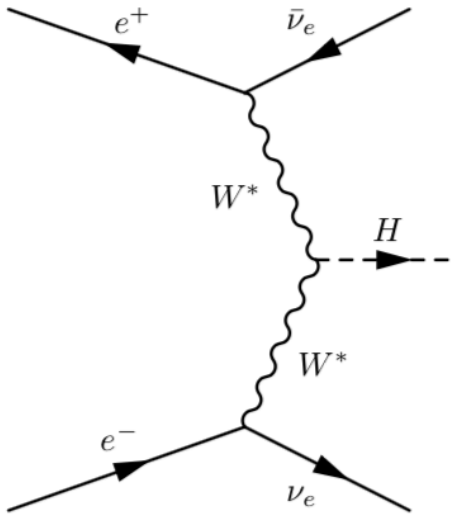


Higgs production and decay



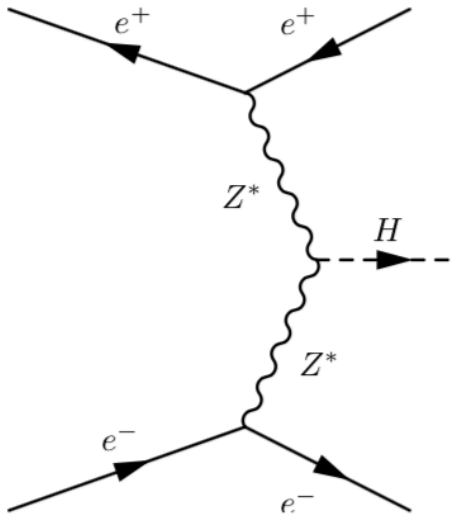
(a)

ZH associate production



(b)

W fusion

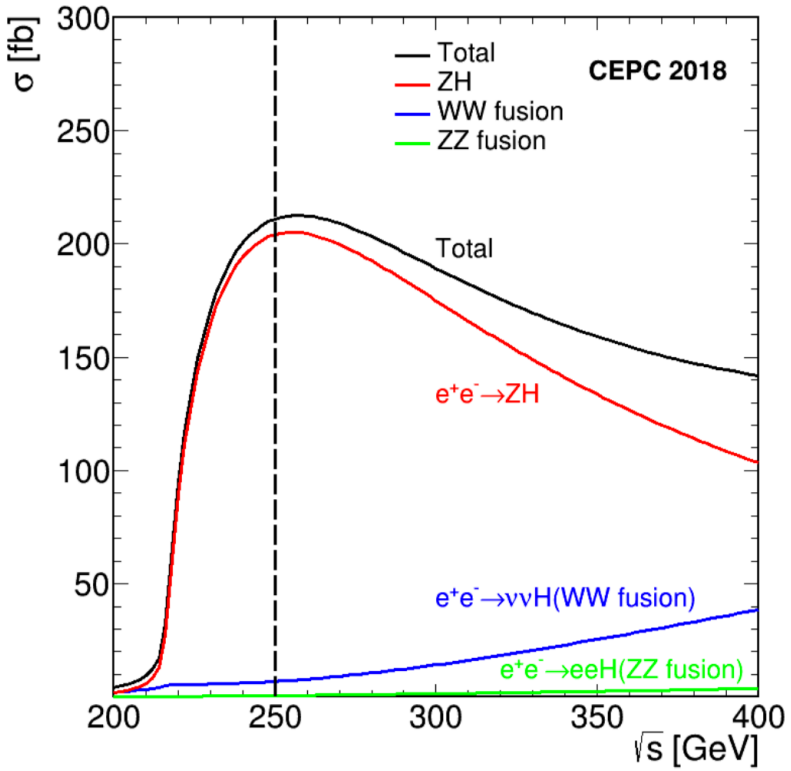


(c)

Z fusion

Vector Boson fusion (VBF)

Production cross sections



- ZH process reaches maximum at ~250 GeV, decreases asymptotically as 1/s
- VBF proceeds through t-channel, increases logarithmically as $\ln^2(s/M_V^2)$
- VBF dominated by W fusion due to small neutral-current Zee coupling

Higgs Decay in Standard Model predictions

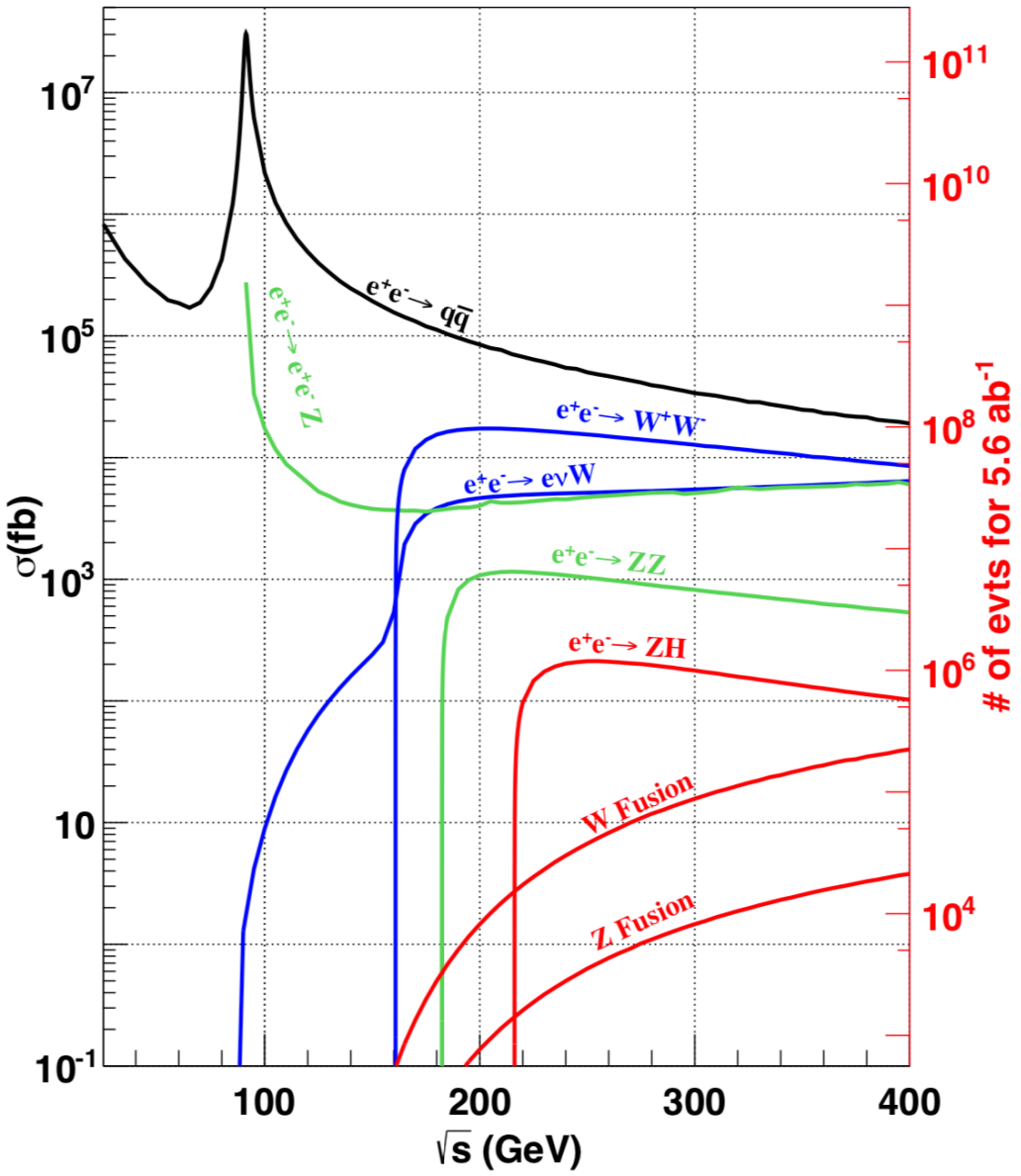
decay mode	branching ratio	relative uncertainty
$H \to b\bar{b}$	57.7%	+3.2%, −3.3%
$H \to c\bar{c}$	2.91%	+12%, −12%
$H \to \tau^+\tau^-$	6.32%	+5.7%, −5.7%
$H \to \mu^+\mu^-$	2.19×10^{-4}	+6.0%, −5.9%
$H \to WW^*$	21.5%	+4.3%, −4.2%
$H \to ZZ^*$	2.64%	+4.3%, −4.2%
$H \to \gamma\gamma$	2.28×10^{-3}	+5.0%, −4.9%
$H \to Z\gamma$	1.53×10^{-3}	+9.0%, −8.8%
$H \to gg$	8.57%	+10%, −10%
Γ_H	4.07 MeV	+4.0%, −4.0%

Uncertainties include contributions from theoretical and parametric sources.

Background processes

- Bhabha scattering (ee)
- ISR return (Z gamma)
- Diboson (WW/ZZ)
- Single boson production (eeZ, evW)

- Considered interference effects in the simulation
- Assume stable W and Z



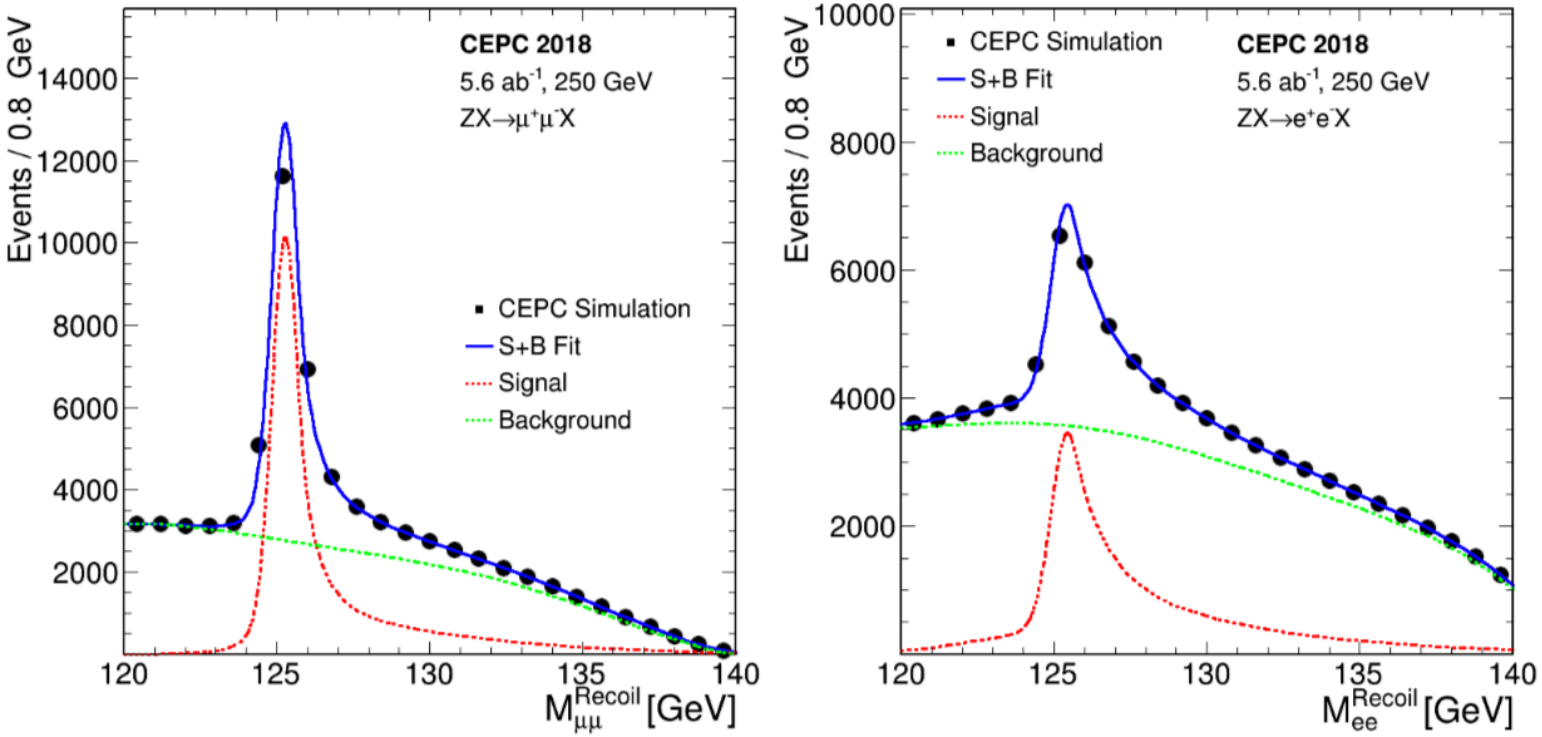
Cross sections of Higgs and other SM processes

process	cross section	events in 5.6 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	204.7	1.15×10^6
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.85	3.84×10^4
$e^+e^- \to e^+e^- H$	0.63	3.53×10^3
total	212.1	1.19×10^6
background processes, cross section in pb		
$e^+e^- \to e^+e^-(\gamma)$(Bhabha)	850	4.5×10^9
$e^+e^- \to q\bar{q}(\gamma)$	50.2	2.8×10^8
$e^+e^- \to \mu^+\mu^-(\gamma)[\text{or}\tau^+\tau^-(\gamma)]$	4.40	2.5×10^7
$e^+e^- \to WW$	15.4	8.6×10^7
$e^+e^- \to ZZ$	1.03	5.8×10^6
$e^+e^- \to e^+e^- Z$	4.73	2.7×10^7
$e^+e^- \to e^+\nu W^-/e^-\bar{\nu}W^+$	5.14	2.9×10^7

- Interference between ZH and $\nu_e\bar{\nu}_e H$ ZH and e^+e^-H
- The cross sections can not be separated
- √s = 250 GeV
- Assume stable W and Z
- ZZ, WW, and qqbar events used to characterize the detector performance
- Generated with WHIZARD, processed with MokkaC

Higgs tagging with recoil mass

- Higgsstrahlung (ee->ZH), Z decays to a pair of visible fermions(ff), the recoil mass against the Z: $M^2_{\text{recoil}} = (\sqrt{s} - E_{ff})^2 - p^2_{ff} = s - 2E_{ff}\sqrt{s} + m^2_{ff}$



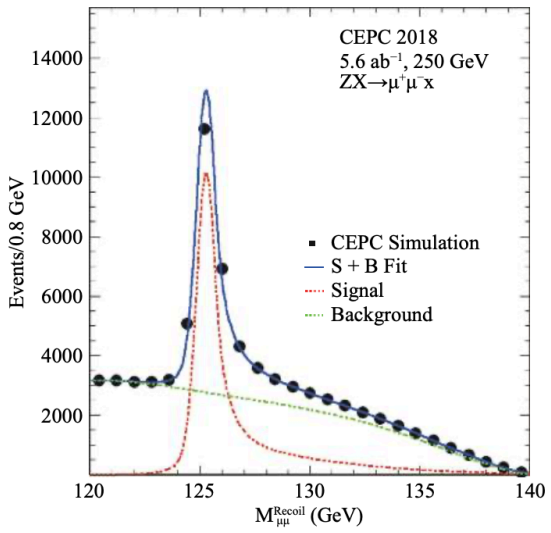
- Higgs boson mass can be measured from the peak of the recoil resonance
- Resonance width dominated by the beam energy spread (ISR included) and energy/momentum resolution (if Higgs width is 4.07MeV)
- σ (ZH) can be extracted by the fitting of M_{recoil}

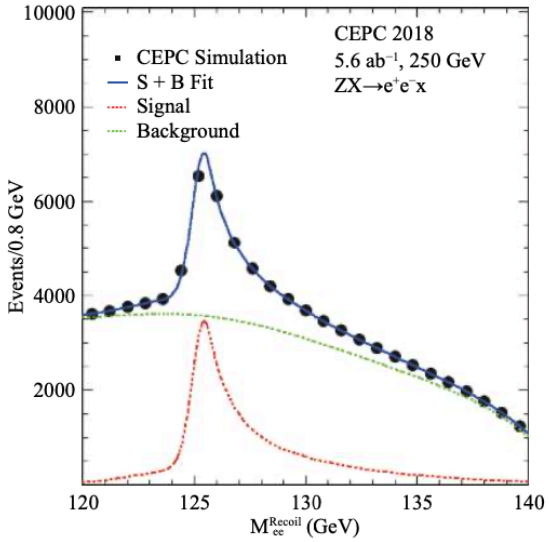
Z boson leptonic decays

- Easily identifiable and the lepton momenta can be precisely measured.
- Signal events with full detector simulation
- Background events with fast detector simulation
- SM process with at least 2 leptons in final states are considered as backgrounds

- Dimuon: (BDT)
  - Dimuon invariant mass 80 – 100 GeV
  - Recoil mass 120 – 140 GeV
  - Muon pair transverse momentum > 20 GeV , opening angle < 175°
  - Long high-mass tail due to ISR

- Electron-positron pair: (Cut based)
  - Larger backgrounds from Bhabha scattering and single boson production
  - Electron-positron pair invariant mass 86.2 – 96.2 GeV
  - Recoil mass 120 – 150 GeV
  - Dominant backgrounds: $e^+e^- \to e^+e^-(\gamma),\ e^+\nu W^-(e^-\bar{\nu}W^+), e^+e^-Z$





Z hadronic decays

- Benefits from larger $Z \to q\bar{q}$ decay branching ratio
- Suffers from worse jet energy resolution than tracks
- Ambiguity in selecting jets can degrade the analysis performance and introduce model-dependence
- Main backgrounds $Z\gamma$ and WW production
- Worse S/N and recoil mass resolution compared with leptonic decays

Measurements of σ(ZH) and m_H

- Fit to recoil mass distributions of $e^+e^- \to Z + X \to \ell^+\ell^- / q\bar{q} + X$ to extract inclusive σ(ZH) and Higgs boson mass m_H
- Modeled with Crystal ball + polynomial function
- Recoil mass distribution is insensitive to the intrinsic Higgs width
- Large statics $e^+e^- \to Z + X \to q\bar{q} + X$ dominates the cross section sensitivity

Z decay mode	Δm_H (MeV)	$\Delta\sigma(ZH)/\sigma(ZH)$
e^+e^-	14	1.43%
$\mu^+\mu^-$	6.5	0.86%
$q\bar{q}$	–	0.61%
Combined	5.9	0.5%

Summary

- The discovery of Higgs at LHC is a major breakthrough on both experiment and theory.

- The CEPC complements the LHC to study the Higgs in great detail with unprecedented precision.

- Higgs tagging using recoil mass of Z in the $e^+e^- \to ZH$ process could achieve an inclusive Higgs cross section uncertainty of 0.5% and Higgs mass uncertainty of 5.9MeV
  (combining all leptonic and hadronic channels with 5.6 ab^{-1} data).

Extra Slides

Basic parameters of CEPC-v1 detector

tracking system	
vertex detector	6 pixel layers
Silicon tracker	3 barrel layers, 6 forward disks on each side
time projection chamber	220 radial readouts
calorimetry	
ECAL	W/Si,24X_0,5×5 mm^{2}cell with 30 layers
HCAL	Fe/RPC,6λ,10×10 mm^2 cell with 40 layers
performance	
track momentum resolution	$\Delta(1/p_T) \sim 2\times10^{-5}(1/\mathrm{GeV})$
impact parameter resolution	$5\mu\mathrm{m}\oplus10\mu\mathrm{m}/[(p/\mathrm{GeV})(\sin\theta)^{3/2}]$
ECAL energy resolution	$\Delta E/E \sim 16\%/\sqrt{E/\mathrm{GeV}}\oplus1\%$
HCAL energy resolution	$\Delta E/E \sim 60\%/\sqrt{E/\mathrm{GeV}}\oplus1\%$

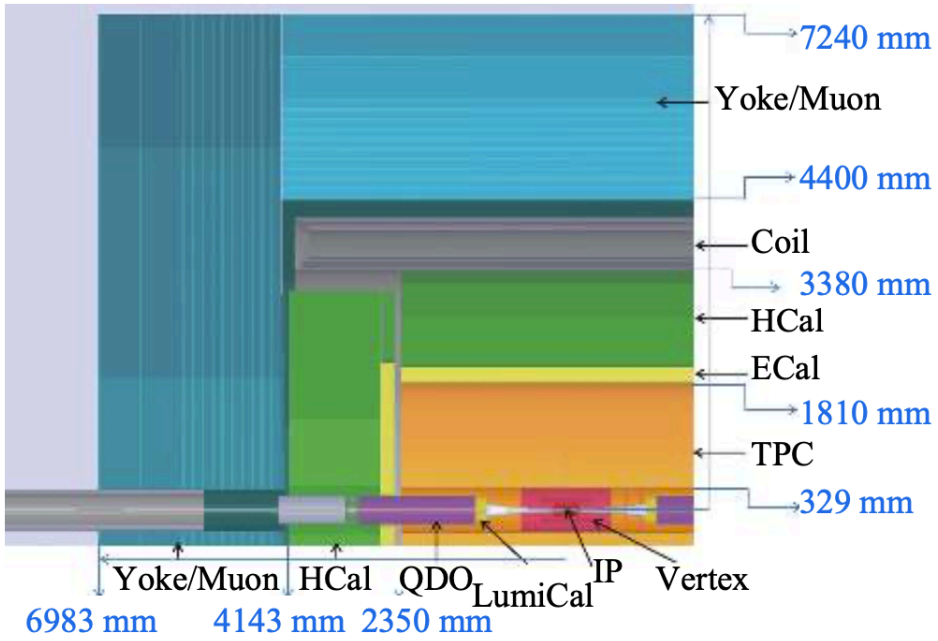


Fig. 2. (color online) The layout of one quarter of the CEPC-v1 detector concept.

Simulated invariant mass distributions