Measurements of $H \to \mu\mu$ for $e^+e^- \to Z(qq)H$ production at the CEPC

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Outline

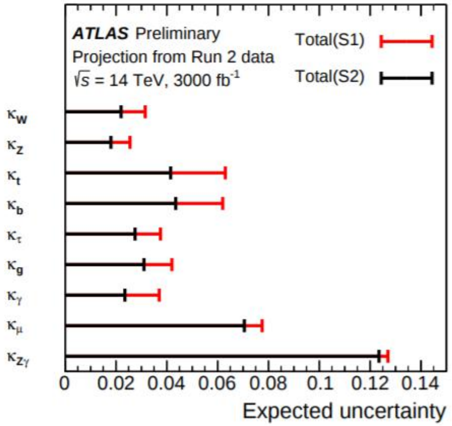
- Motivation
- Detector and samples
- Event selection
- Inclusive analysis
- MVA(BDTG) optimization
- Summary

Motivation

- H → $\mu\mu$ is important for probing the Higgs Yukawa couplings.
  - The interactions of Higgs to the third generation charged fermions have already been observed by both ATLAS and CMS experiment. JHEP08(2016)045
  - Only upper limits exist on the Higgs interactions with other generations fermions.
  - Also, it offers the best opportunity to measure the couplings to the second generation fermions.

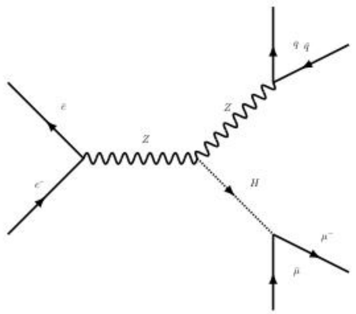
- In the ATLAS experiment, An upper limit of 2.2 at 95% CL is set on the signal strength(u). arxiv2007.07830

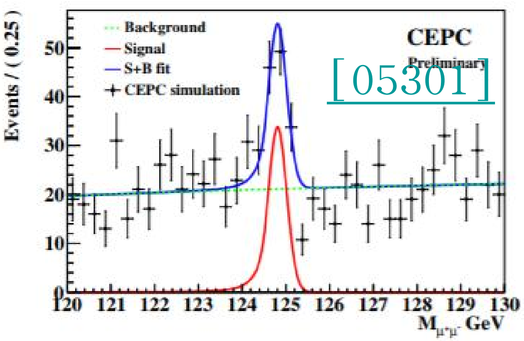
- In the projections with the ATLAS detector at HL-LHC(3000 fb^{-1}), the expected uncertainty of κ_{μ} is ~7%. ATL-PHYS-PUB-2018-054



Introduction of $e^+e^- \to Z(qq)H(\mu\mu)$

- With electron-positron colliders, we can gain much higher significance due to extremely cleaner background.
- Previous Measuerment(Zhen-Wei Cui et al.)[05301]gave counting significance at [124, 125] GeV: 10.8σ.





We'd like to update and improve the analysis.

- Develop new selection criterial by keeping most signals and suppressing background.
- Further make event categories by applying MVA method.
- Use new detector geometry and new samples to show the latest sensitivity of the CEPC detector for measuring mumu events.

Detector and samples

- CEPC Detector: v4 , $\sqrt{s}$=240GeV, luminosity:5 ab^{-1},3.5 Tesla magnetic field.

- Sample:
  — signal :qqh_e2e2, ~100M
  — background :
    - 2 fermions, ~28 M
    - 4 fermions
      —Single W, ~18M
      —Single Z, ~8 M
      —WW, ~46 M
      —ZZ, ~6 M
      —Z or W: ~20 M

Event selction

- To suppress background and keep most signals, event selections are developed.
- After several studies, considering both signal/background efficiencies, event selections are finalized.
- Table show you that the aims of each cut component.
- Performances of each cut can be found in the backup.

cut	reason
$N_\mu^+ > 0, N_\mu^- > 0$	H to mumu requires 2 opposite charged muons
$105 < M_{\mu\mu} < 130GeV$	$M_{\mu\mu}$ should be close to M_H (125 GeV)
$25 < N_{particle} < 115$	di-jet system requires more objects than all leptons final stats
$55 < M_{qq} < 125GeV$	M_{qq} should be close to M_Z (91.2 GeV)
$P_{qq\mu\mu} < 32GeV$, $195 < E_{qq\mu\mu} < 265GeV$	$qq\mu\mu$ system should has 4 momentum close to (0, 0, 0, En), En=240 GeV
$35 < E_\mu^- < 100GeV$, $35 < E_\mu^+ < 100GeV$	To suppress WW background
$16 < p_{\mu\mu} < 72GeV$	To suppress hadronic background components with muons in jet clusters
$-20 < Px_{miss}$,$Py_{miss} < 20$ and $\Delta_{\mu^- qq,\mu^+}, \Delta_{\mu^+ qq,\mu^-} > 2.5$	To suppress WW background

- Signal efficiency: 79.4%
- The background : zz (95.4%) , ww (4%) , 2f (0.6%)

The mass spectrum

- After selection criterial, the signal significance in the $\mu\mu$ mass spectrum can be obtained by counting expression $\sqrt{2\left[(s+b)\cdot\ln\left(1+\frac{s}{b}\right)-s\right]}$.

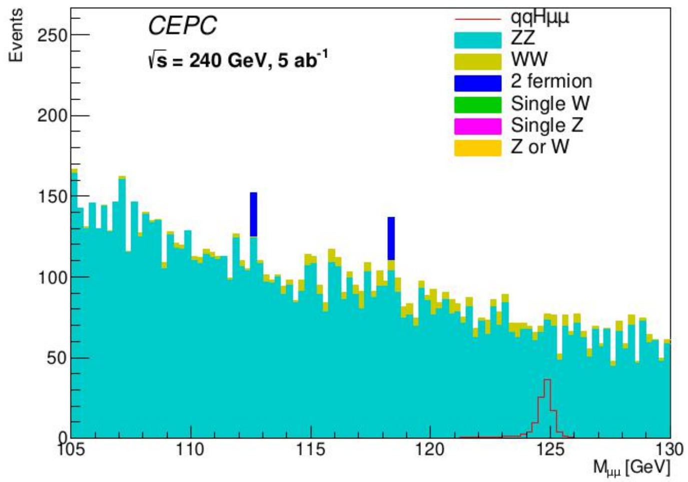
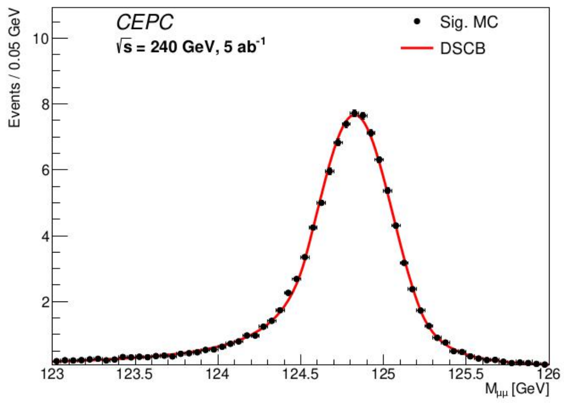


Fig. :The distribution $M_{\mu\mu}$

- It is estimated that signal significance in [124,125] GeV:4.288 σ
- The significance is smaller than previous measuerment due to the width of Z boson being considered in our study.

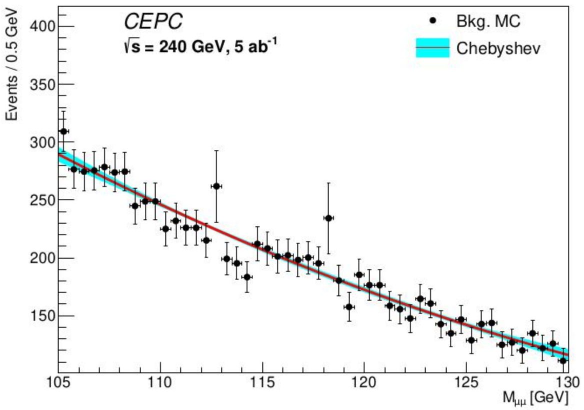
Signal and background modelling

- signal probability function: Double side crystal ball(DSCB).



$M_{\mu\mu}$

- background probability function: Second order Chebyshev.



$M_{\mu\mu}$

- DSCB is commonly used for fitting resonant H mass spectrum and shows great agreement with the signal MC.
- For background, I tested many other functions such as Exponential, Bernstein, finally we choose the best Chebyshev function.

Fitting strategy

- Signal model : double side crystal ball.
- Background model : Chebyshev.

- POI: μ . (the signal strength $\mu = \frac{\sigma_{Z(qq)H}}{\sigma^{SM}_{Z(qq)H}} \times \frac{Br_{\mu\mu}}{Br^{SM}_{\mu\mu}}$)

- Parameters:

Parameters in signal and background model are fixed by fitting simulated events.,

The number of background and μ are float.

- Then a unbinned maximum likelihood fit are performed.

Fitting results in the inclusive analysis

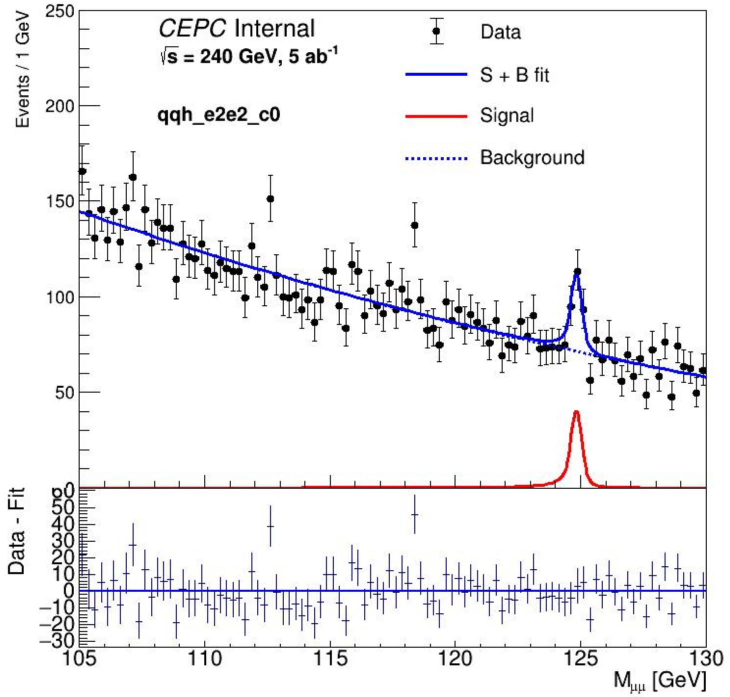


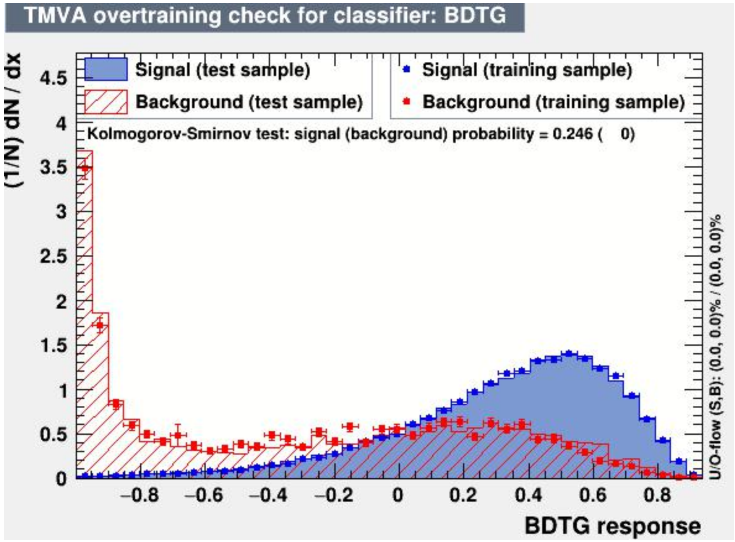
Fig. :The fit resluts of $M_{\mu\mu}$

- μ = 0.996578 +/- (-0.19,0.20).
- significance: 5.67σ .

MVA optimization

- In order to improve signal significance, MVA analysis is performed. We exploit BDTG to further classify two categories.
- These 8 variables are trained(see backup): $\cos\theta_{qq}$, M_{qq} ,$\cos\theta_{jet2}$, $\Delta_{jet2,\mu+}$, $\Delta_{jet1,\mu-}$,Px_{jet2} ,Py_{jet2} ,$\Delta_{\mu-,\mu+}$.

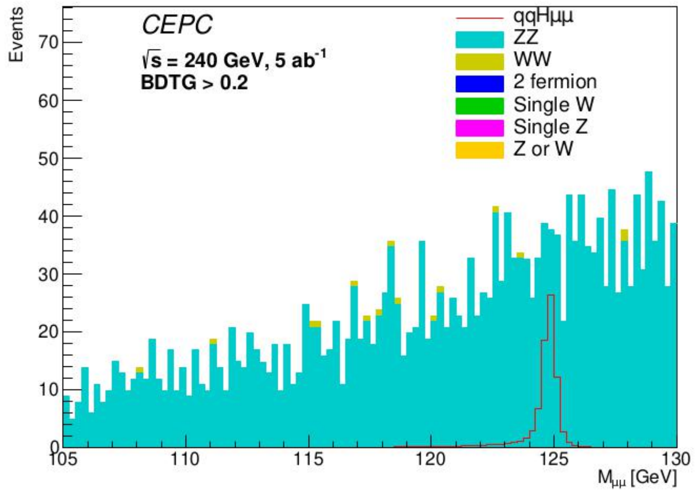
- The BDT response distribution are shown in Fig.

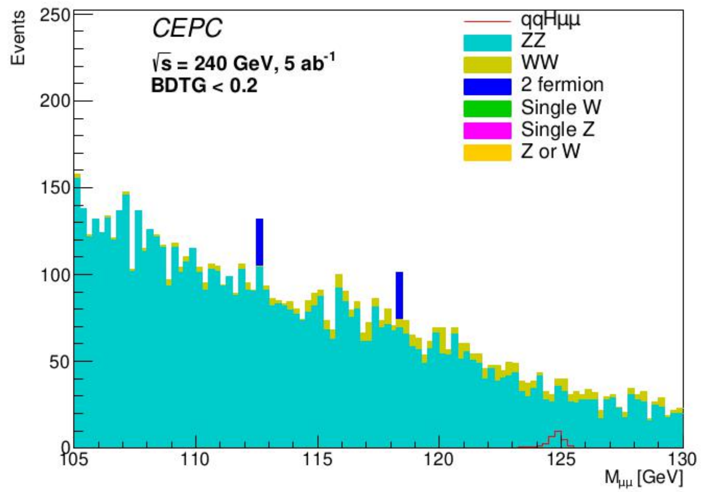


- We can take two categories, BDTG response > 0.2, denoted by tight category, otherwise loose category.

Mass distribution under tight and loose category

- We get two categories : tight(BDTG>0.2) and loose(BDTG<0.2).

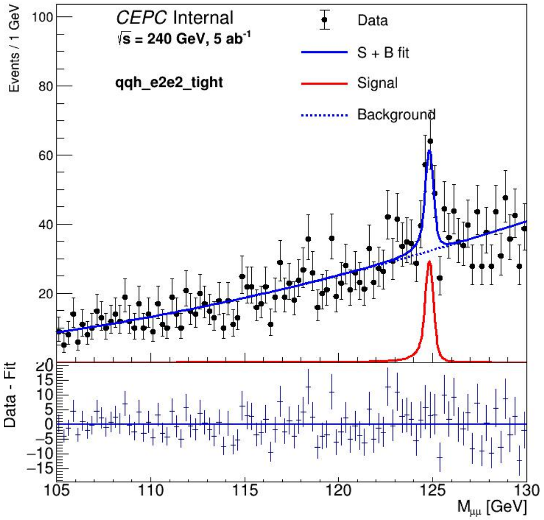




- The signal and background probability functions are parametrized in the same model as the previous inclusive analysis.

Simultaneous fit

- We performed a simultaneous fit on 2 categories to get the signal significance and strength.



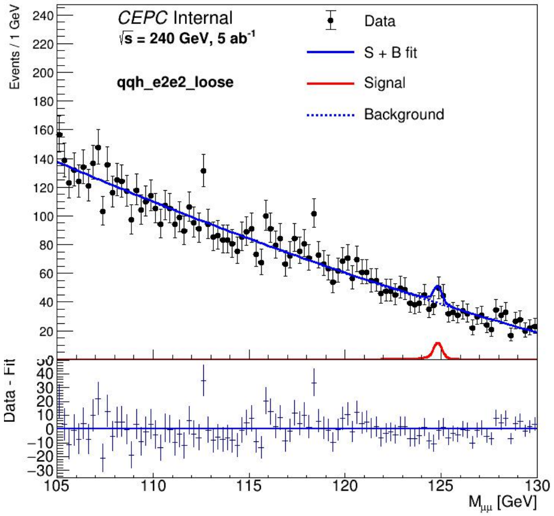


Fig. The simutaneous fit results in two categories, tight(left) and loose(right).

- u = 1.12472+/- 0.19
- significance: 6.9σ
- 17.8% improvement comparing to inclusive analysis.

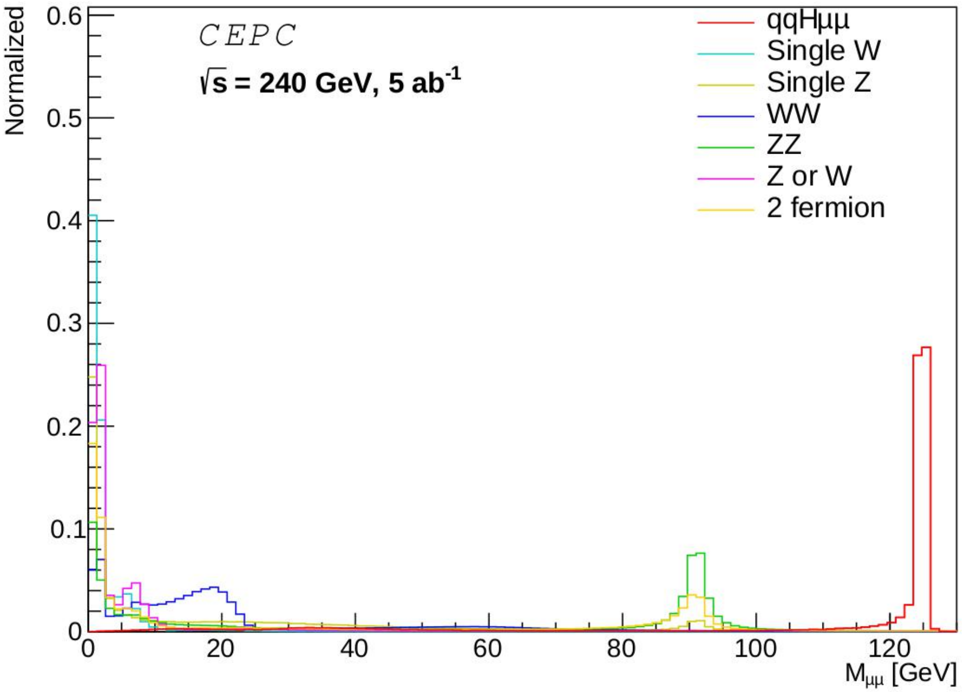
Summary

- After event selections, the signal efficiency is 79%; The dominant background is ZZ to muons/jets.
- It is estimated the signal significance is 5.67σ in $e^+e^- \to Z(qq)H(\mu\mu)$ inclusive analysis.
- Applying the optimal BDTG cut and making a simultaneous fit on 2 categories, the significance of 6.9σ can acheived with 17.8% improvement comparing to inclusive analysis.
- The signal strength value can be determined as 1.12 with an uncertainty of 19.%.

THANK YOU

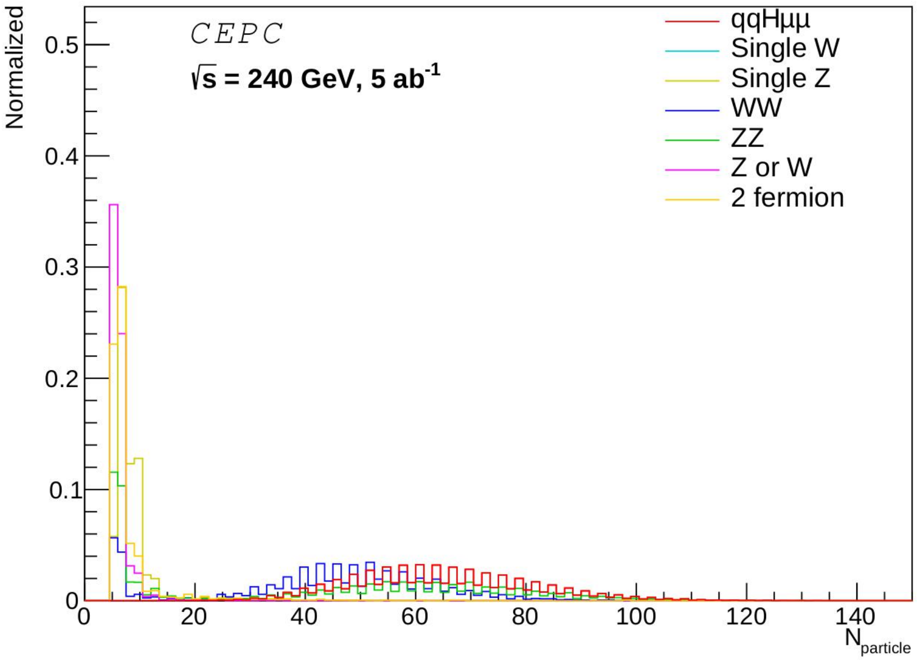
backup

Event selction



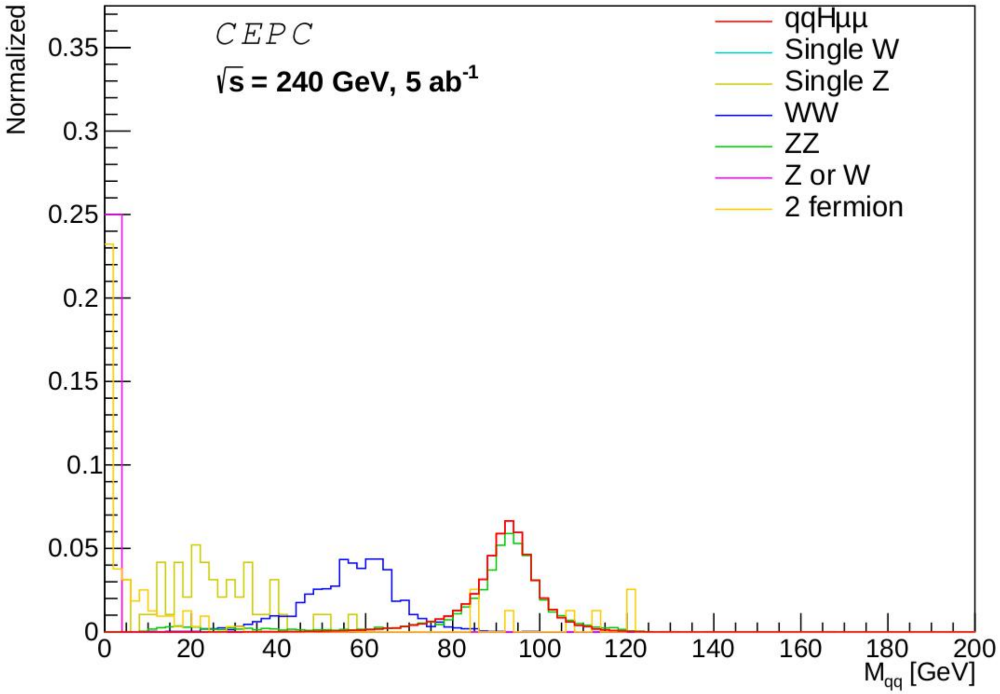
- M_mumu cut: (105,130)
- M_mumu should close to M_H < (125 GeV)

Event selction



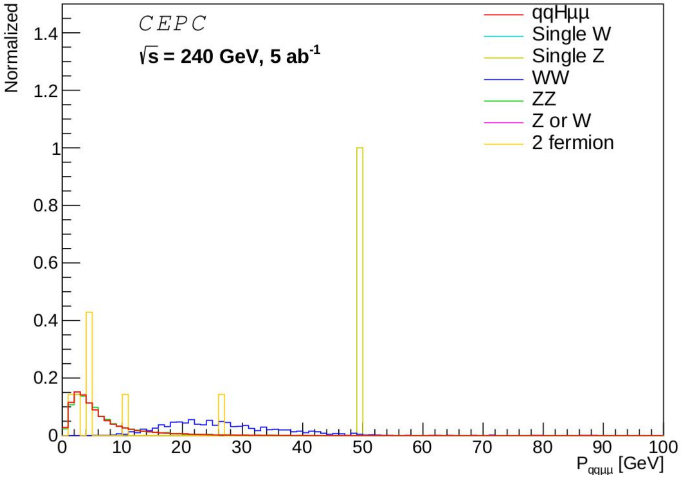
- N_particle cut: (25,115)
- di-jet system requires more objects.

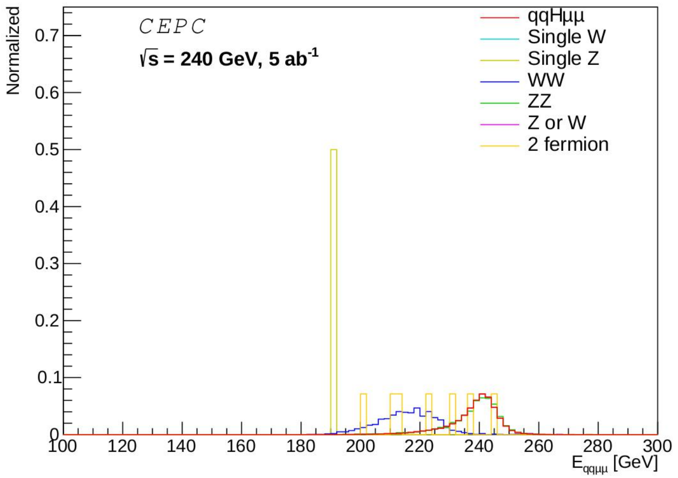
Event selction



- M_dijet cut: (55,125)
- M_dijet should be close to M = (91.2GeV).

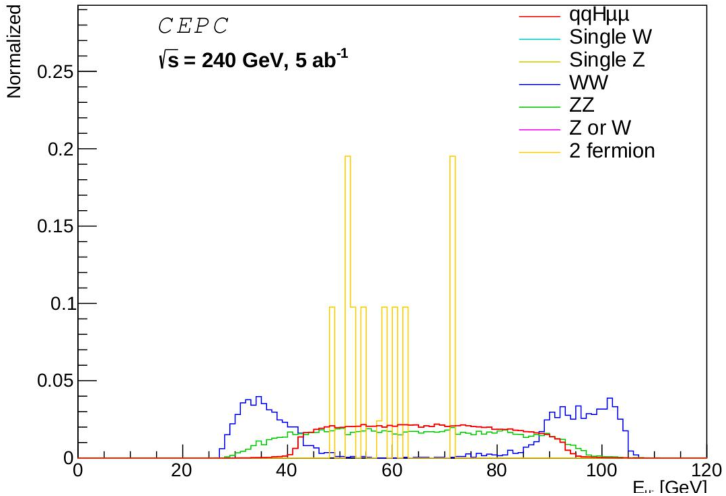
Event selction

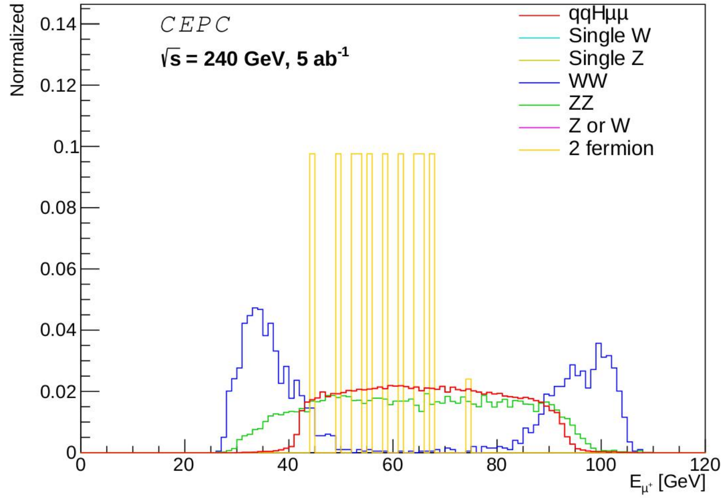




- P_qqmumu cut: (0,32)
- E_qqmumu cut: (195,265)

Event selction

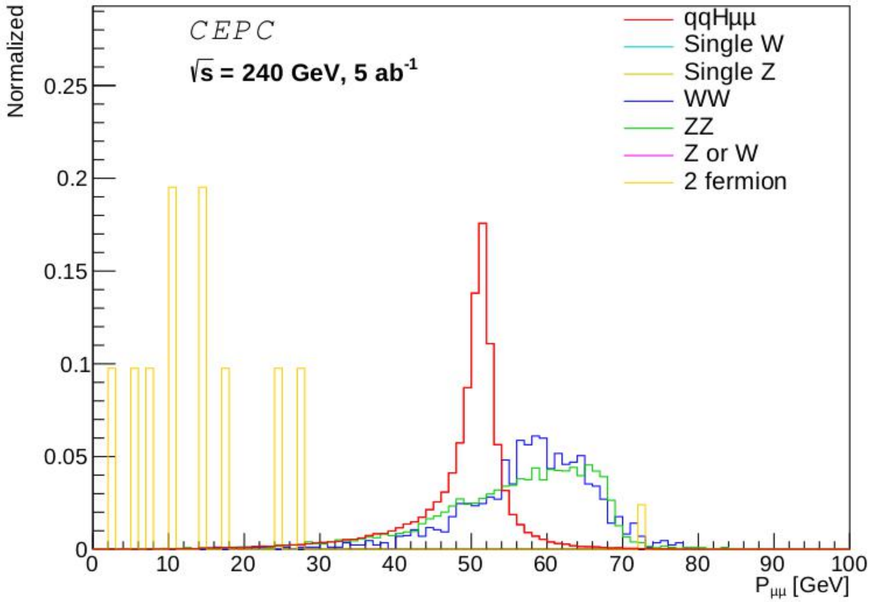




- E_muM cut: (35,100)
- E_muP cut: (35,100)

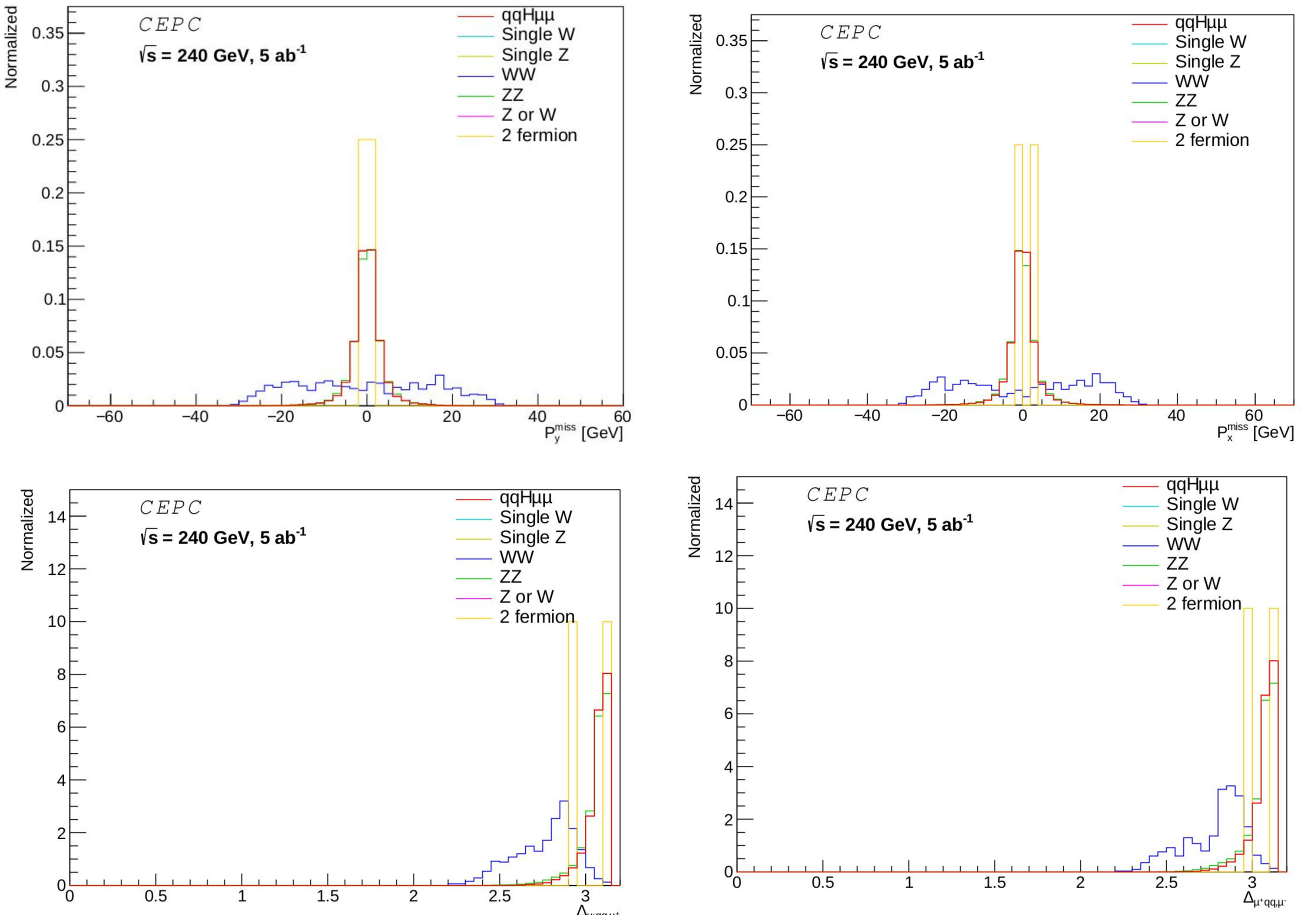
To suppress WW background

Event selction



- P_mumu cut: (18,72)

Event selction

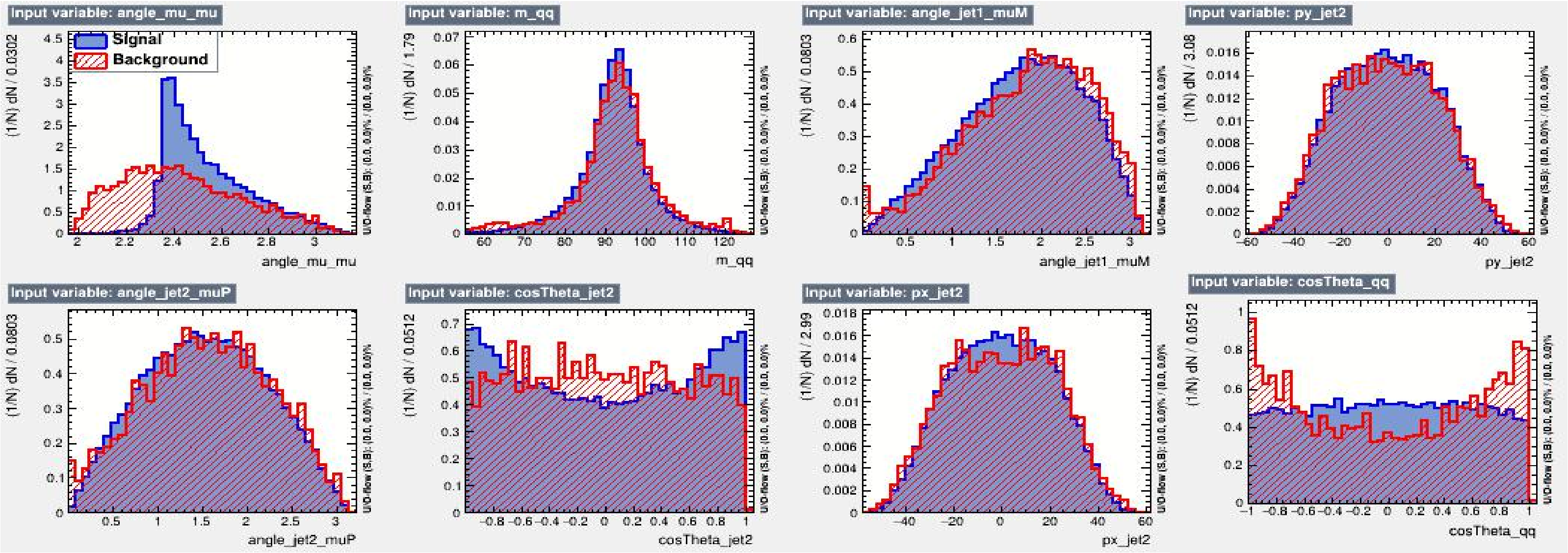


- Px_miss cut: (-20,20)
- Py_miss cut: (-20,20)
- angle_muMqq_muP (2.5,3.2)
- angle_muPqq_muM (2.5,3.2)

To suppress WW background

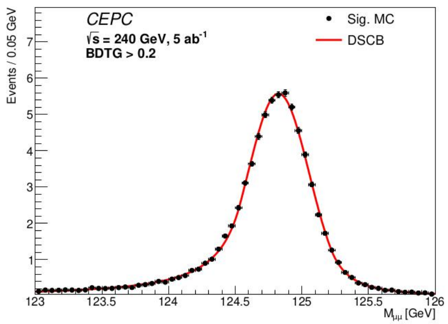
MVA optimization

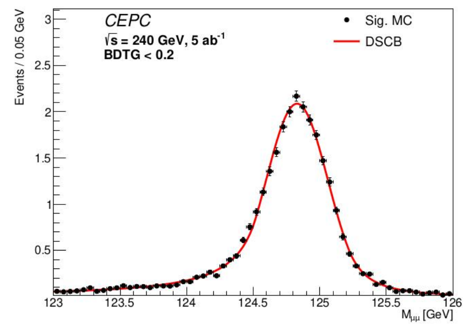
- In order to improve signal significance, MVA analysis is performed. We exploit BDTG to further classify two categories.
- Training variables selection criterial
  - — Not highly correlated with $M_{\mu\mu}$.
  - — Not strongly anti-correlated with each other.
- Variable $\cos\theta_{qq}$, M_{qq}, $\cos\theta_{jet2}$, $\Delta_{jet2,\mu+}$, $\Delta_{jet1,\mu}$, Px_{jet2}, Py_{jet2}, $\Delta_{\mu-,\mu+}$ are taken eventually.



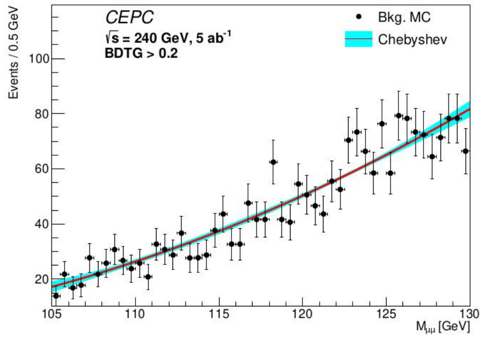
Signal/background modellings in categories

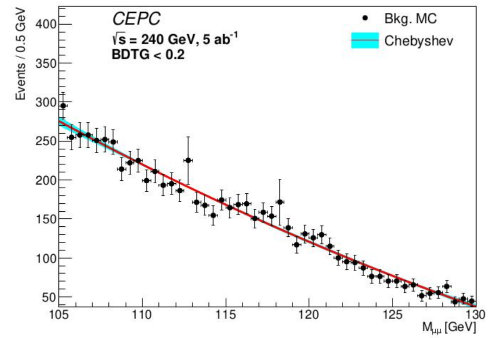
- tight(left) and loose(right)
  - signal function: DSCB



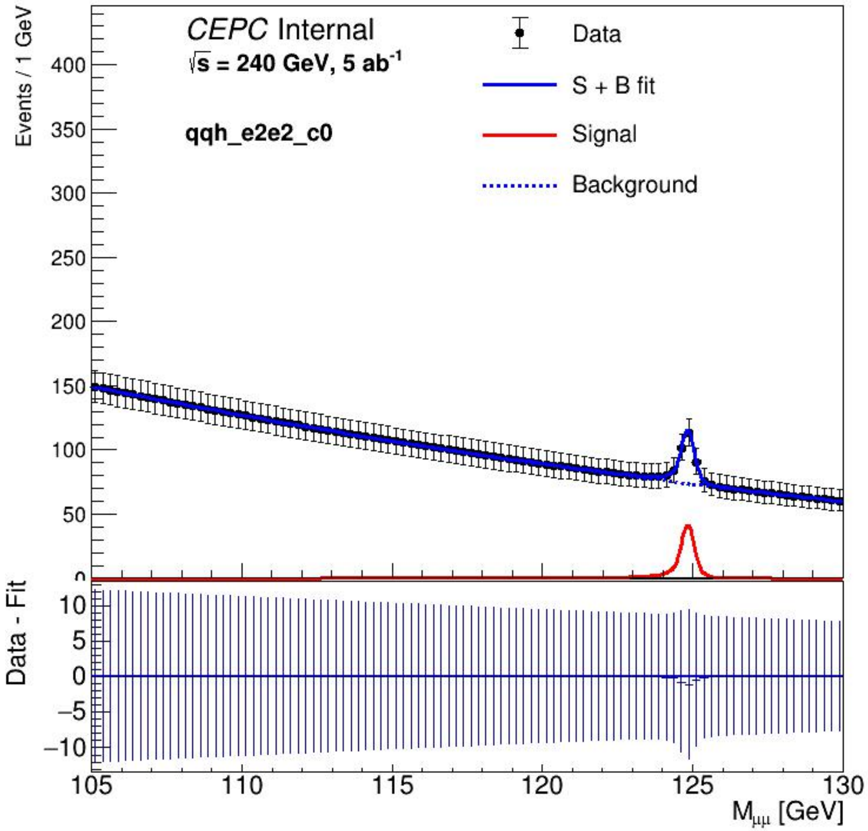


  - background function: second order Chebyshev





Asimov fit results



Asimov fit results

- two categories