Measurements of Higgs boson Mass in the μμH final state at 240 GeV in CEPC Reference detector

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Motivations

- The recoil mass method in $\mu\mu H$ final state exploits the exellent trkcing resolution in CEPC to determine the Higgs mass by measuring the four-momentum of the accompanying Z boson.

$$M_{\mathrm{rec}}^2 = (\sqrt{s} - E_{\mu^+} - E_{\mu^-})^2 - |p_{\mu^-} + p_{\mu^+}|^2$$

- The method reduces dependence on direct Higgs decay mode and provides a clean channel that is unaffected by Higgs decay branching fraction uncertainties, allowing model-independent measurements of Higgs properties.

- The mass uncertainty is expected to be a value ~4MeV, which is much smaller comparing the uncertainty from LHC, enhancing the sensitivity to New Physics Beyond the SM

- The results will give a good performance test on CEPC tracking system, and PID software for muon objects.

Datasets

Process	$\sqrt{s} = 240$ GeV
Higgs boson production, cross section in fb	
$e^+e^- \to ZH$	196.9
$e^+e^- \to \nu_e\bar{\nu}_e H$	6.2
$e^+e^- \to e^+e^- H$	0.5
Total Higgs	**203.6**
background processes, cross section in pb	
$e^+e^- \to e^+e^-(\gamma)$ (Bhabha)	930
$e^+e^- \to q\bar{q}(\gamma)$	54.1
$e^+e^- \to \mu^+\mu^-(\gamma)$	5.30
$e^+e^- \to \tau^+\tau^-(\gamma)$	4.75
$e^+e^- \to WW$	16.7
$e^+e^- \to ZZ$	1.1
$e^+e^- \to e^+e^- Z$	4.54
$e^+e^- \to e^+\nu W^- + \text{c.c.}$	5.09

- All the relevant processes are included
- Integrated luminosity: 21.6/ab
- Only high momentum muon pairs are selected

Event Selection

- Muon Selection:
- PID 90%WP （XGBoost based BDT)
- 20 < p < 80 GeV
- Best Muon Pair Selection:
- The nearest inv. mass to Z PDG mass value

$$\chi^2(M_{l^-l^+}, M_{\text{rec}}) = \frac{(M_{l^-l^+} - M_{\text{rec}})^2}{\sigma^2_{M_{l^-l^+}}}$$

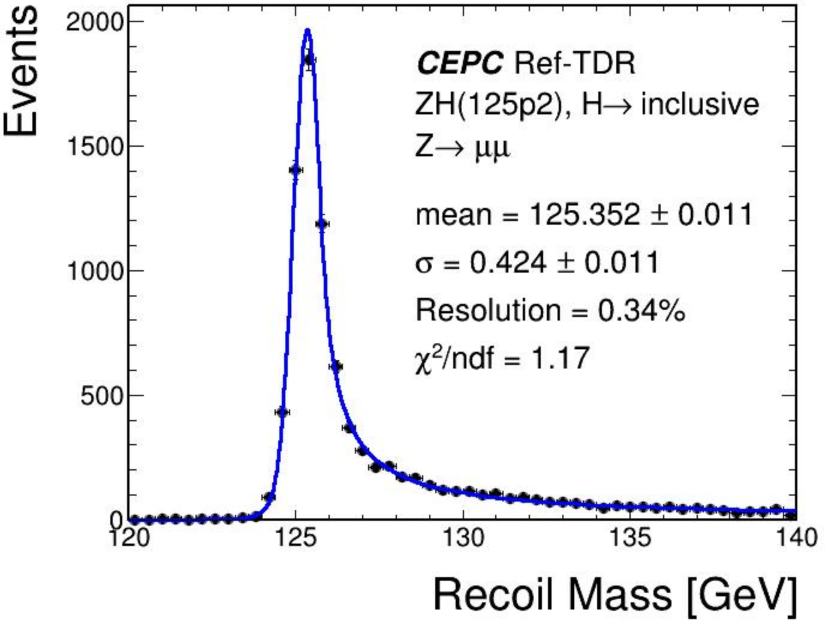
- 120 < recoil mass < 140 GeV
- Missing EZ < 50 GeV
- E(μμ)< 110 GeV, 20 < p(μμ) < 60 GeV, 50 < m(μμ)< 120 GeV

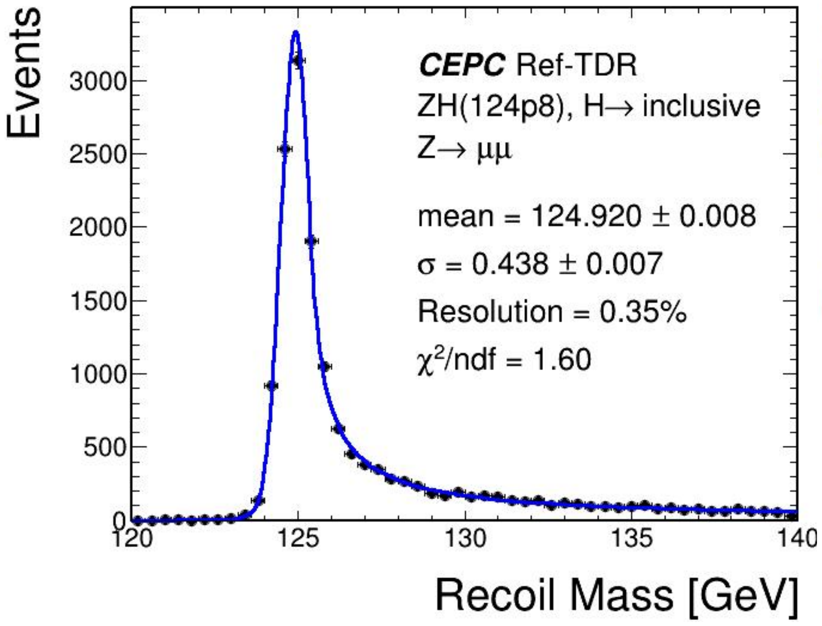
Cutflow

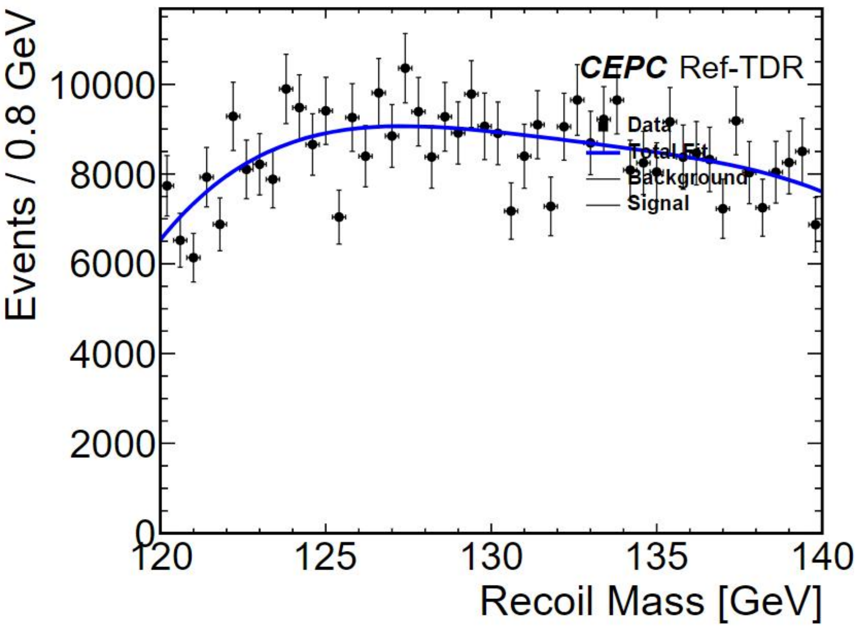
Final States	$2\nu2\mu$	4μ	$2\mu2e$	$2\mu2\tau$	$2\mu2q$	2μ	$\mu\mu H$
Events number	120000	40000	40000	40000	80000	100000	40000
Muon pair	31.4%	41.7%	6.7%	25.8%	29.5%	88.2%	95.6%
MEZ $\in [0, 50]$ GeV	26.5%	29.9%	4.7%	17.1%	25.7%	54.2%	94.4%
$E_{\mu\mu} \in [0, 110]$ GeV	12.7%	16.5%	4.1%	10.0%	15.0%	53.0%	93.8%
$p_{\mu\mu} \in [20, 60]$ GeV	7.5%	9.9%	2.1%	5.6%	8.0%	9.8%	83.7%
$m_{\mu\mu} \in [50, 120]$ GeV	5.8%	6.7%	0.4%	3.1%	3.1%	9.8%	83.6%
$M_{\text{rec}} \in [120, 140]$ GeV	2.6%	3.2%	0.1%	1.6%	1.7%	6.5%	78.7%

- **Nearly 80% signal events are retained after the selections, while the backgrounds are suppressed under 5%.**
- **2mu events has been pre-selected with GEN-filter in sample production.**

Modeling







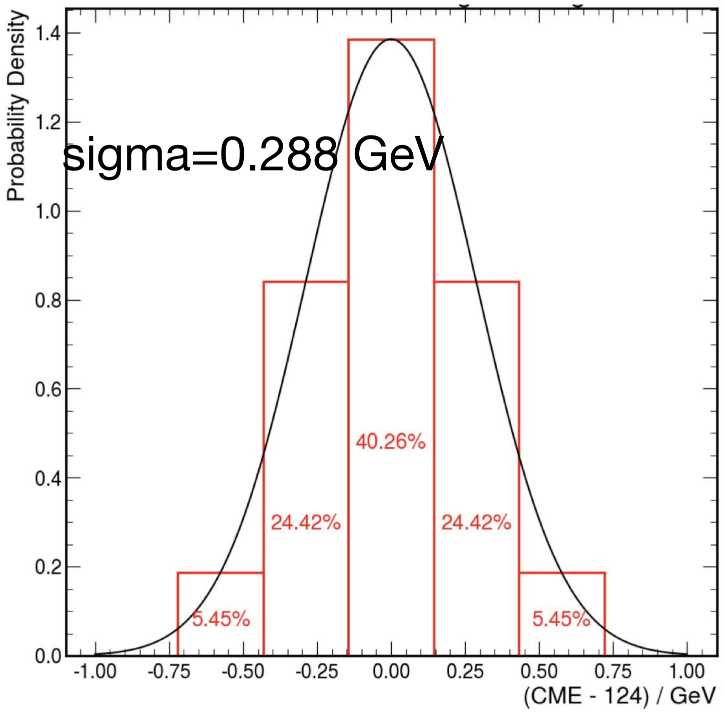
- **The mean and sigma in the DCB function in signal model are parameterized as a linear function of mH**
- **The analysis includes 5 mass points: 124.8, 124.95 125, 125.05 and 125.2 GeV**
- **The combined background can be properly modeled using Chebychev Polynomial**

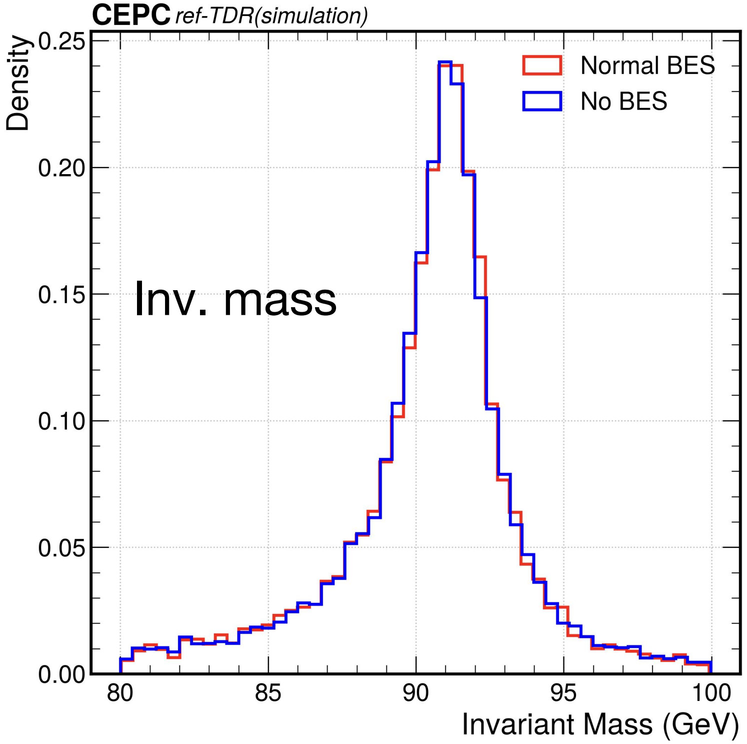
Systematic Uncertainty: Beam Energy Spread(1MeV)

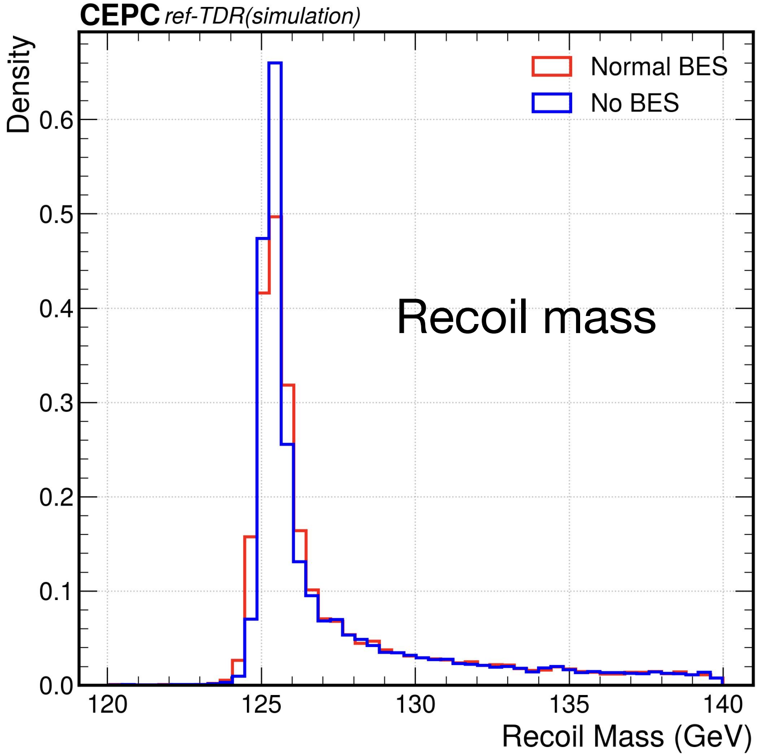
- BES ~ 0.17% at Higgs run
- BES configurations:

$$\sqrt{s} = 240 \pm 0,1,2 \times [\frac{\sqrt{2} \times 0.17 \times BE}{2 \times BE}]\text{GeV}$$

- Higgs samples are generatated at thoese 5 CME points
- The fractions for each are below

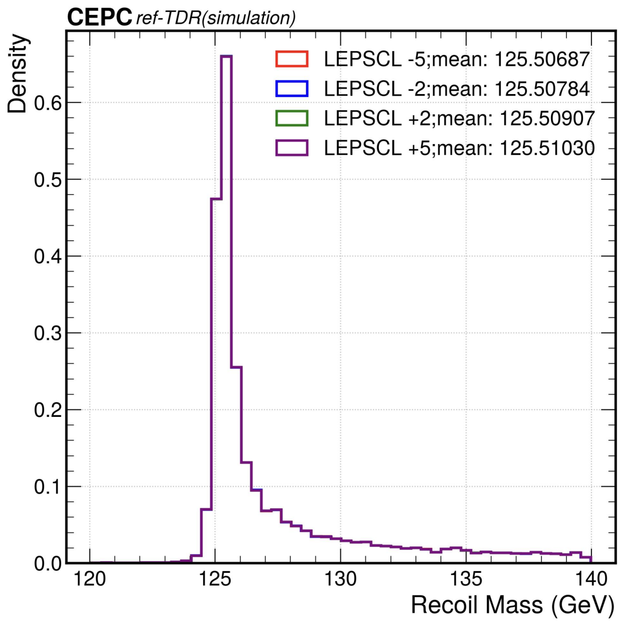


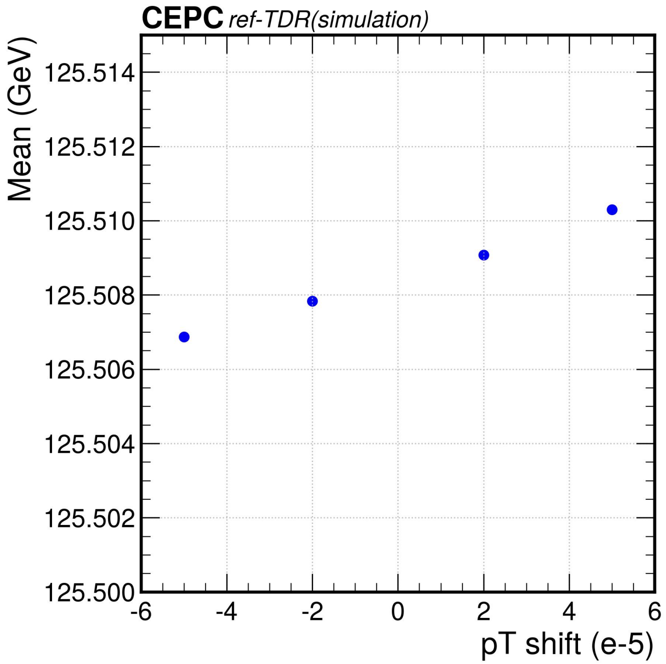




Systematic Uncertainty: Lepton Scale(2MeV)

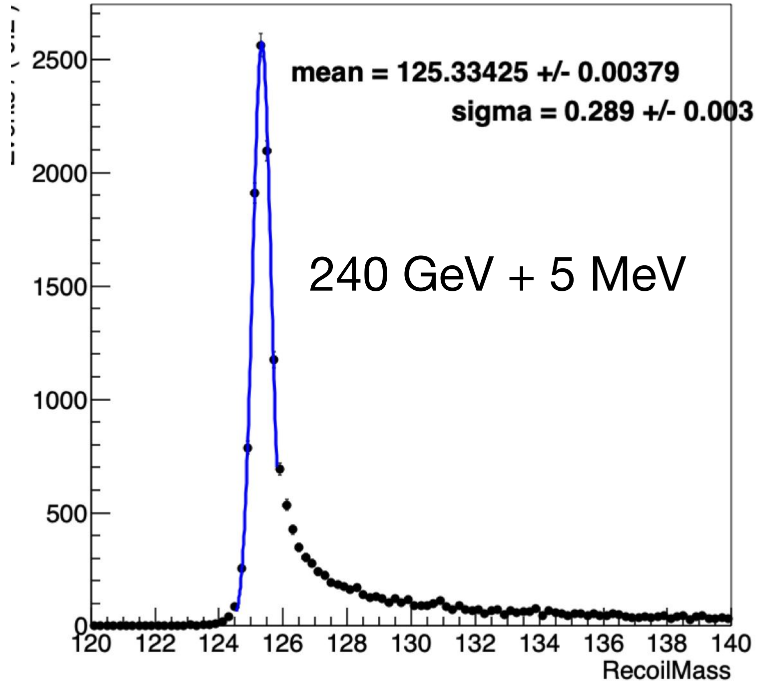
- A large number of radiative return events can be used to monitor the momenta precision
  - $\delta Z_{\text{peak}} = \frac{\sigma_{p_T}}{\sqrt{N}}, \sigma_{pT} = 2 \times 10^{-3}, N = 30\text{M}$ (21.6/ab, radiative return only)
  - Together with low–lumi–Z events, a precision of $\delta\, p_T \sim 10^{-6}$ can be visible from the Z boson mass peak
- To account for conservative assumption and potential unforseeable bottlenecks, this scale is set to be 10^{-5}
- Injet relative shifts of –5 ,–2, 2, 5 x 10^{-5} to the muon pT, then check the resulting variations in the recoil mass peak

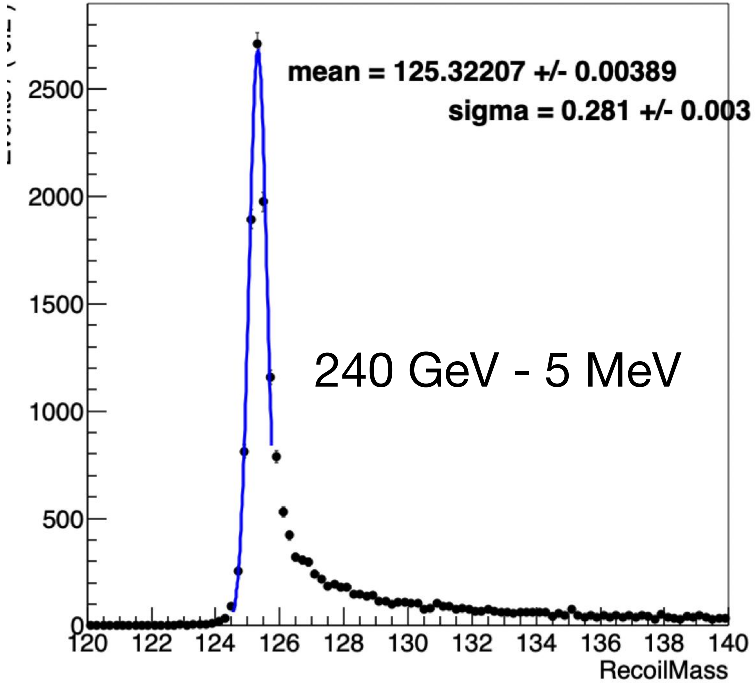


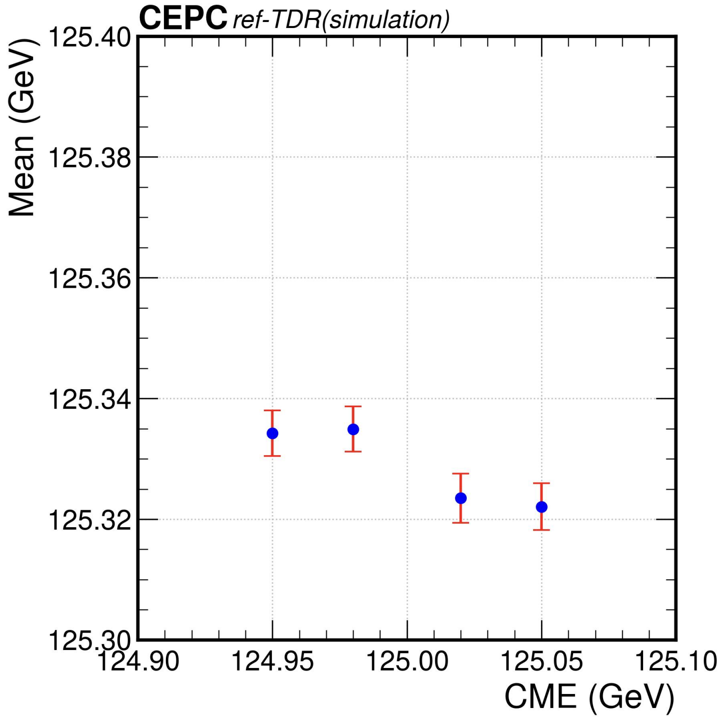


Systematic Uncertainty: Centre-of-mass Energy(2MeV)

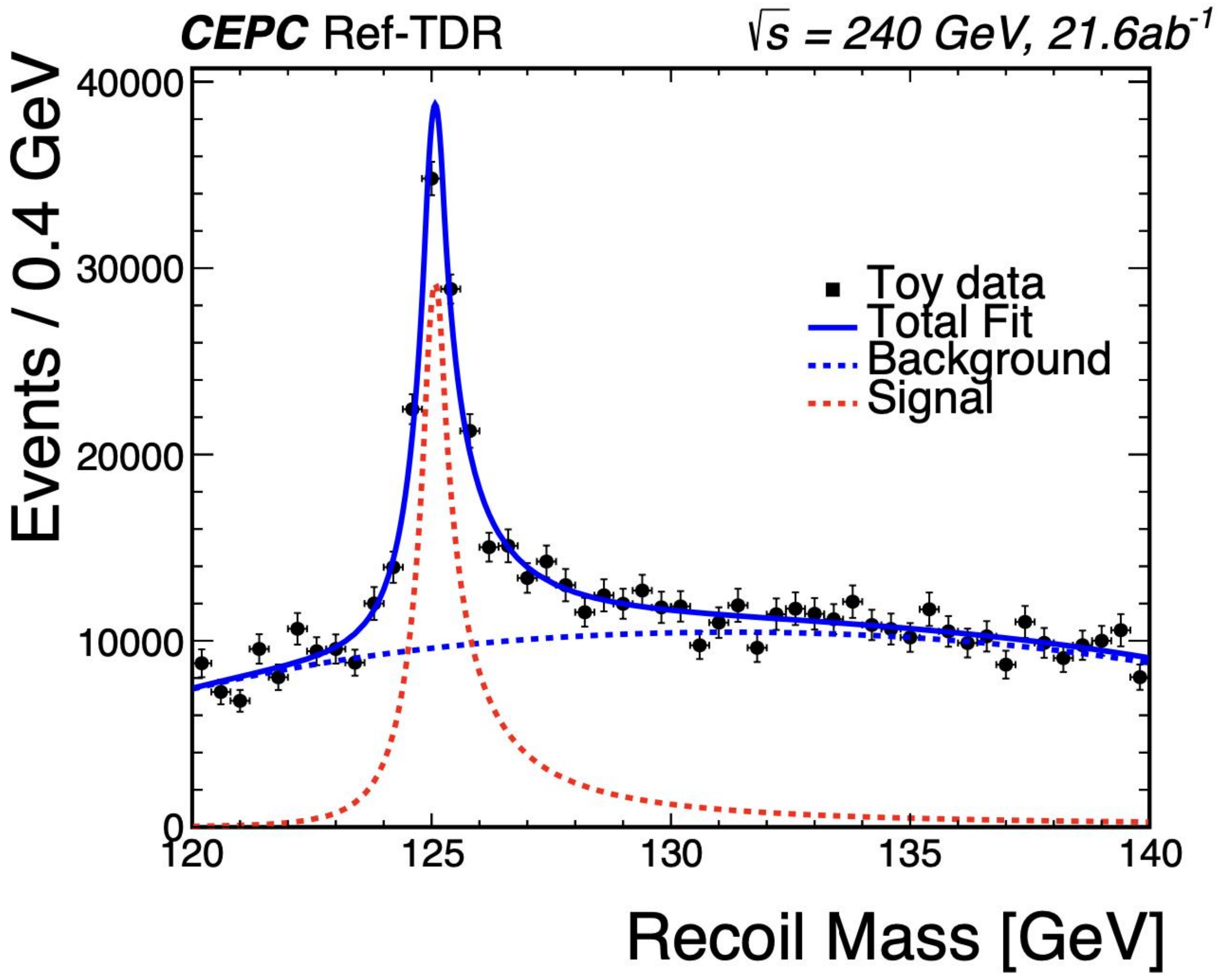
- $\delta\sqrt{s}$ should be at MeV level and is provided by accelerator team; a value of 2 MeV is used for the current study
- It is visible in the recoil spectra of radiative return events
- The Higgs samples are generated with CME=240 GeV +/– 0, 2, 5 MeV
- Analytically, it should equal to the $\delta\, m_H$, as demostrated in the full simulations







Final results



- **The distribution of recoil mass is rescaled to 21.6/ab, corresponding to the full planned CEPC luminosity.**
- **The statistical uncertainty is extracted from toyMC samples generated based on post–fit S+B model.**
- **The statistic uncertainty can be extracted from toyMC generated by post–fitted S+B model.**
- **mH = 125 GeV ± 3.1 MeV(stat.) ± 2.5MeV(sys.)**

Summary

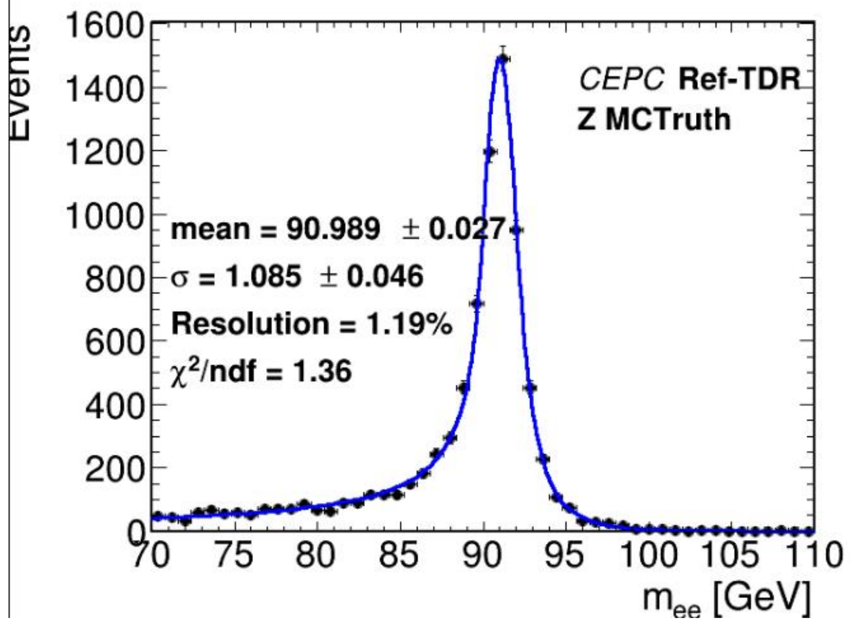
- The final result are presented with a total uncertainty of 4.0MeV.
  - Much better than HL-LHC projection: 21 MeV
  - Comparable with FCC-ee: 4.4 MeV with Z(ee/mumu)H at 10/ab [ref]

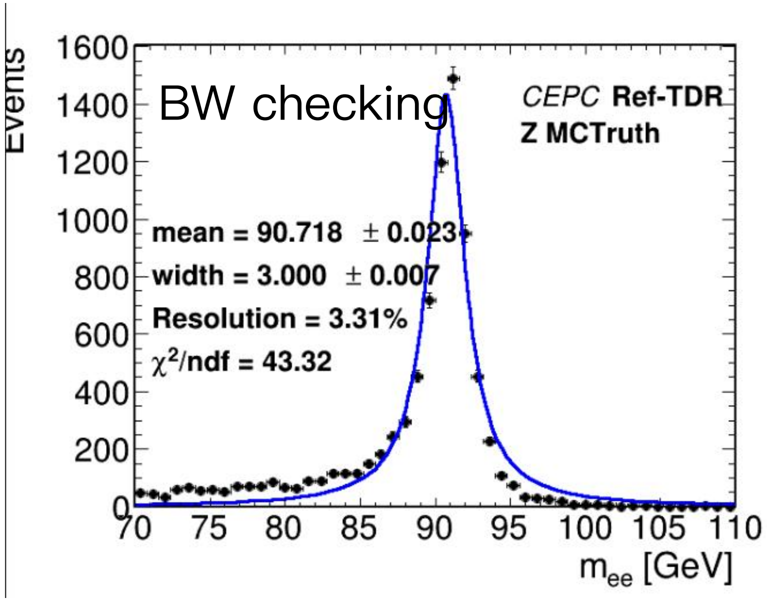
- This results can be considered as a probe of the current detector performance

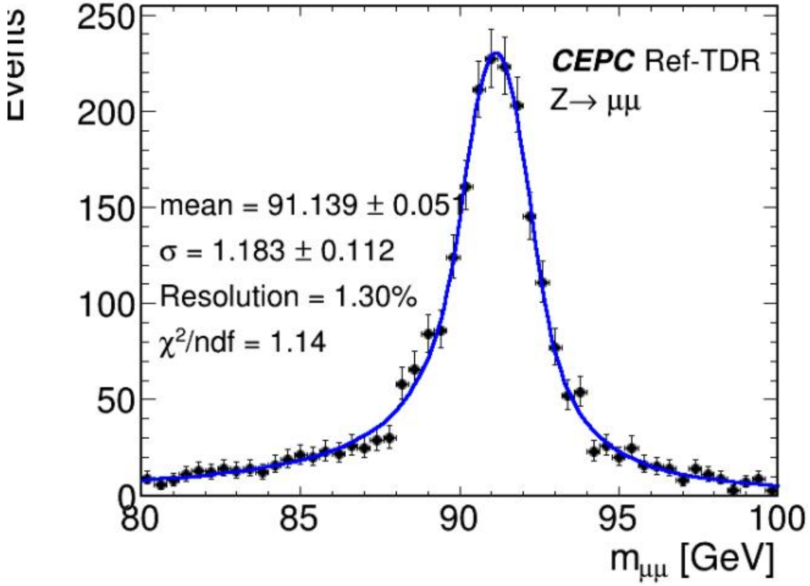
- The result can be combined with eeH final state in the future anayses, which would reduce the statistical uncertainty
- Some systimatic uncertainties are treated conservitively, and they can be studied more comprehensively in the furture

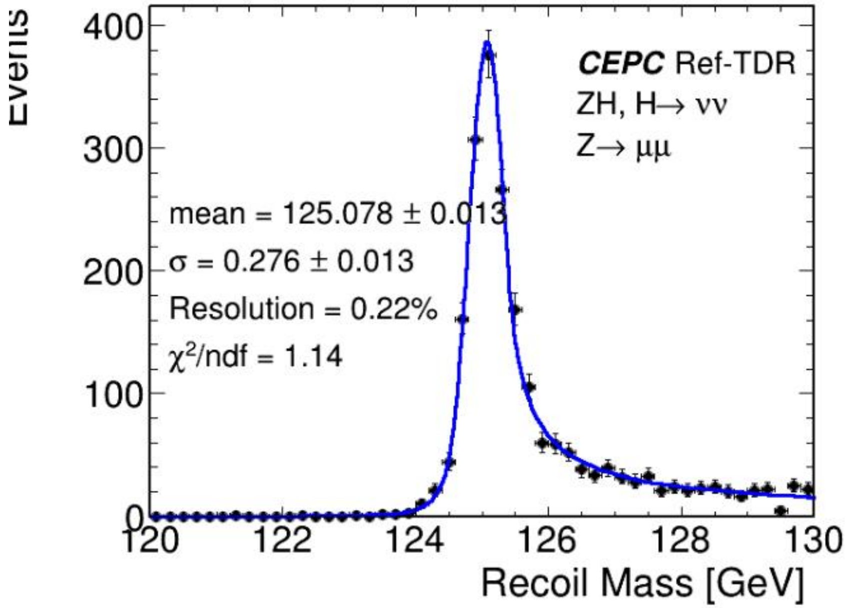
Thanks!

Backup

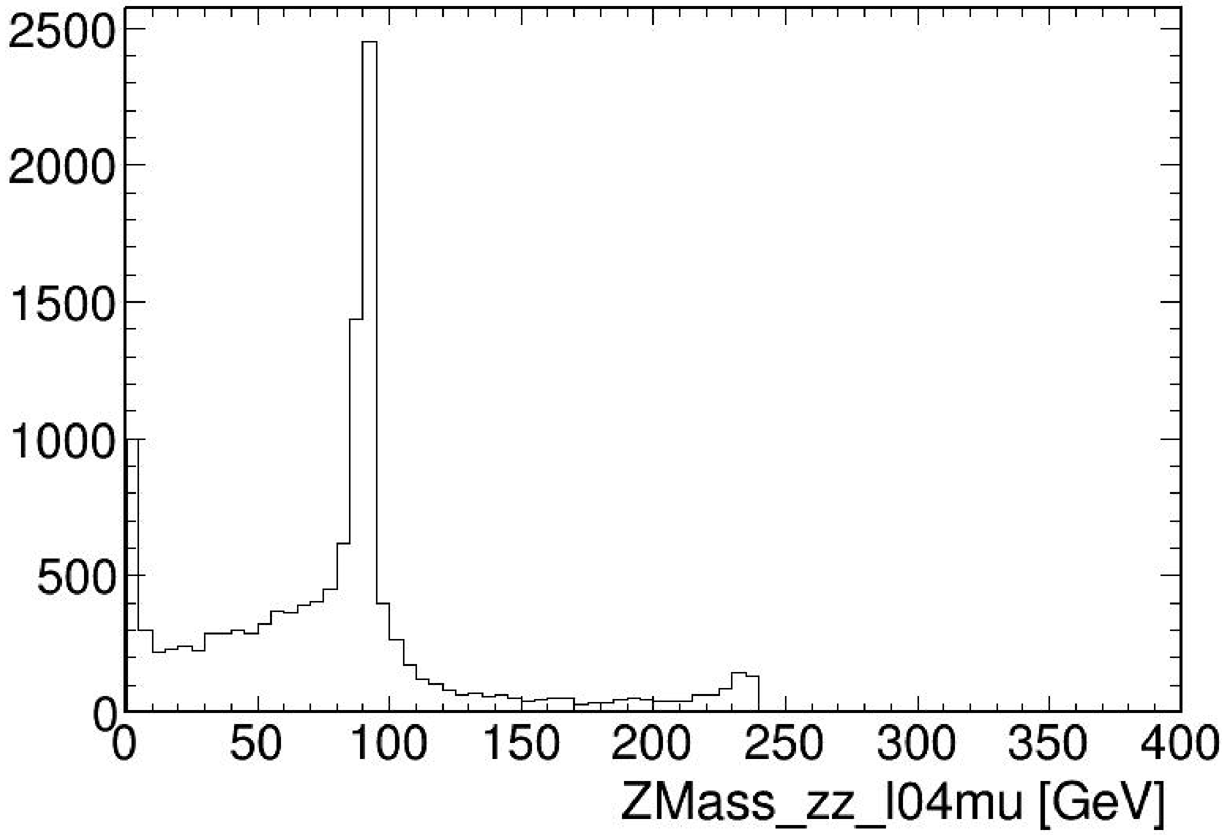

Events
CEPC Ref-TDR
Z MCTruth
mean = 90.989 ± 0.027
σ = 1.085 ± 0.046
Resolution = 1.19%
χ2/ndf = 1.36
m_ee [GeV]

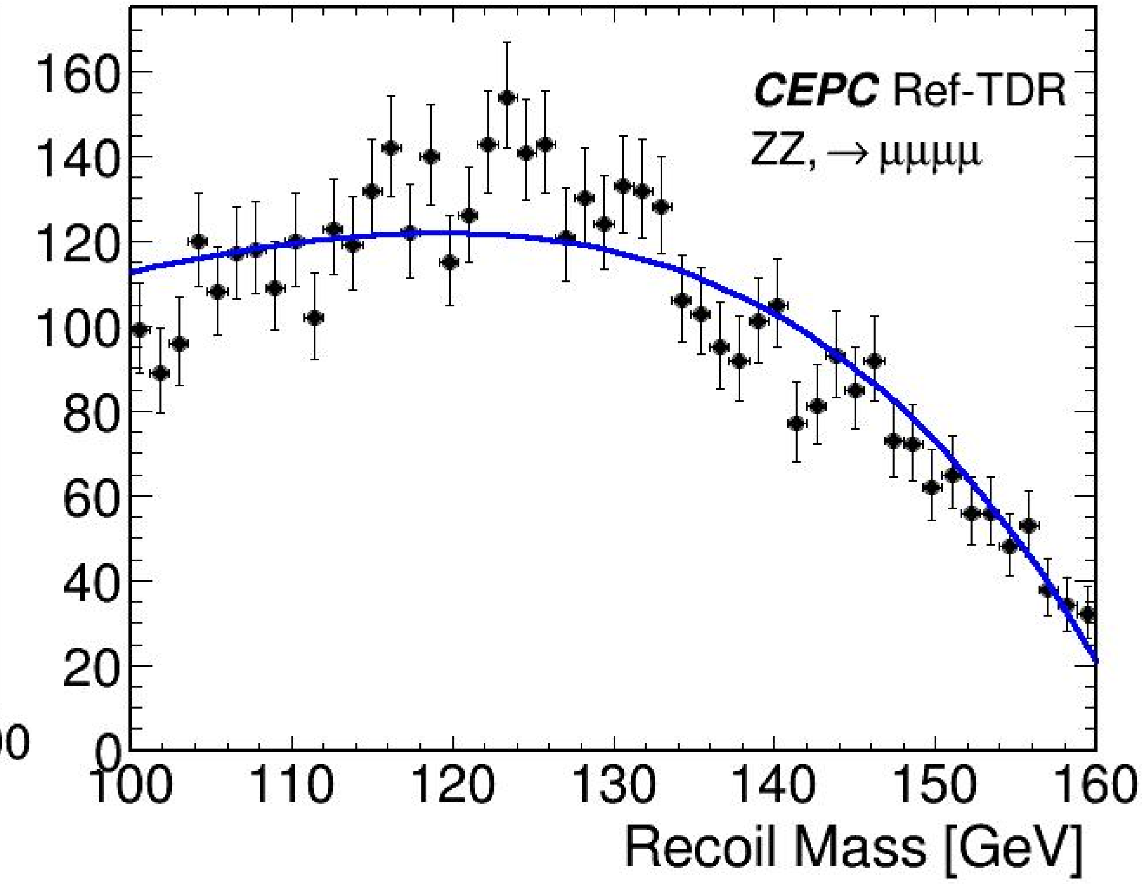

Events
BW checking
CEPC Ref-TDR
Z MCTruth
mean = 90.718 ± 0.023
width = 3.000 ± 0.007
Resolution = 3.31%
χ2/ndf = 43.32
m_ee [GeV]


Events
CEPC Ref-TDR
Z→ μμ
mean = 91.139 ± 0.051
σ = 1.183 ± 0.112
Resolution = 1.30%
χ2/ndf = 1.14
m_μμ [GeV]


Events
CEPC Ref-TDR
ZH, H→ νν
Z→ μμ
mean = 125.078 ± 0.013
σ = 0.276 ± 0.013
Resolution = 0.22%
χ2/ndf = 1.14
Recoil Mass [GeV]

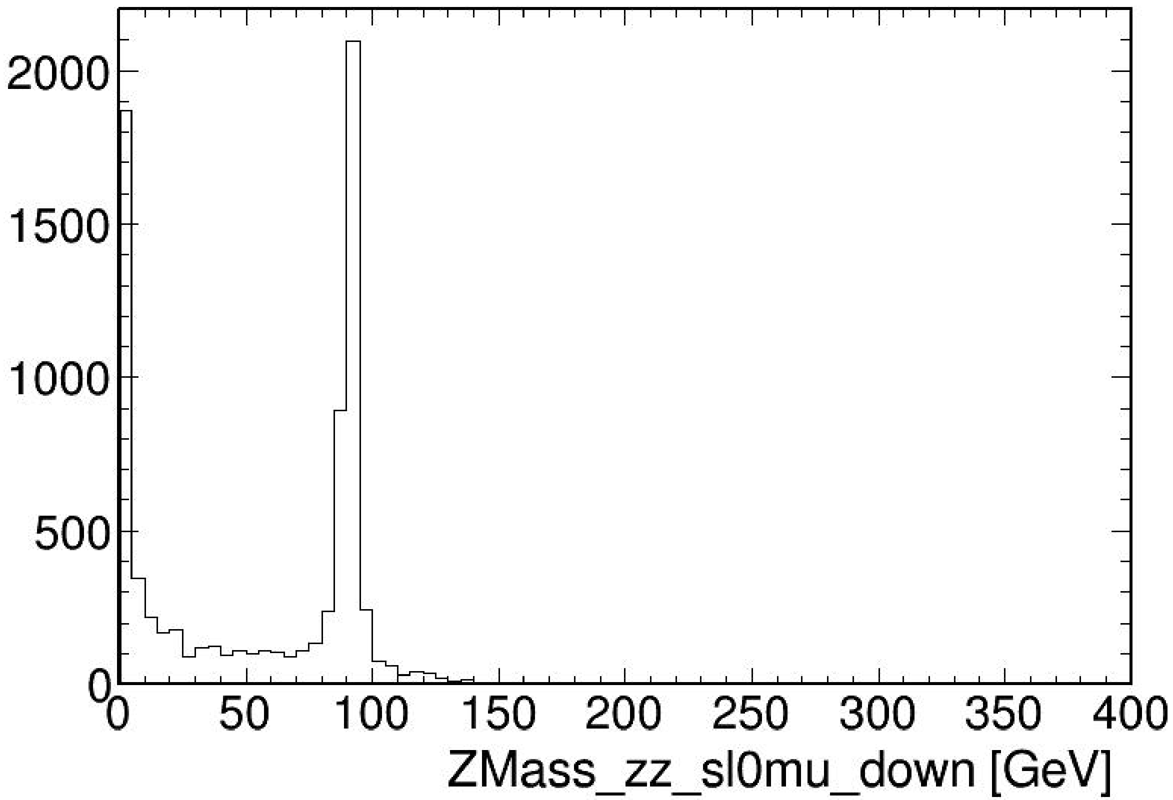
BKG Samples: eeToZZ4L

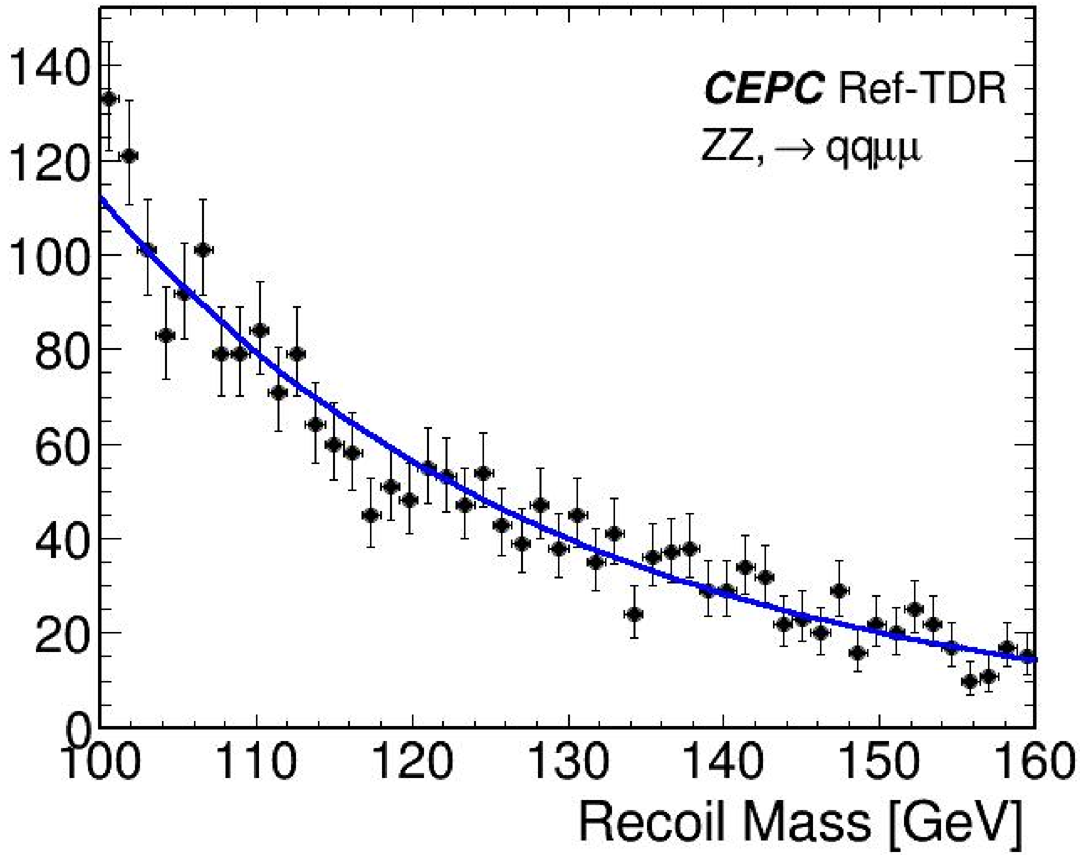




Fitted by polynomial

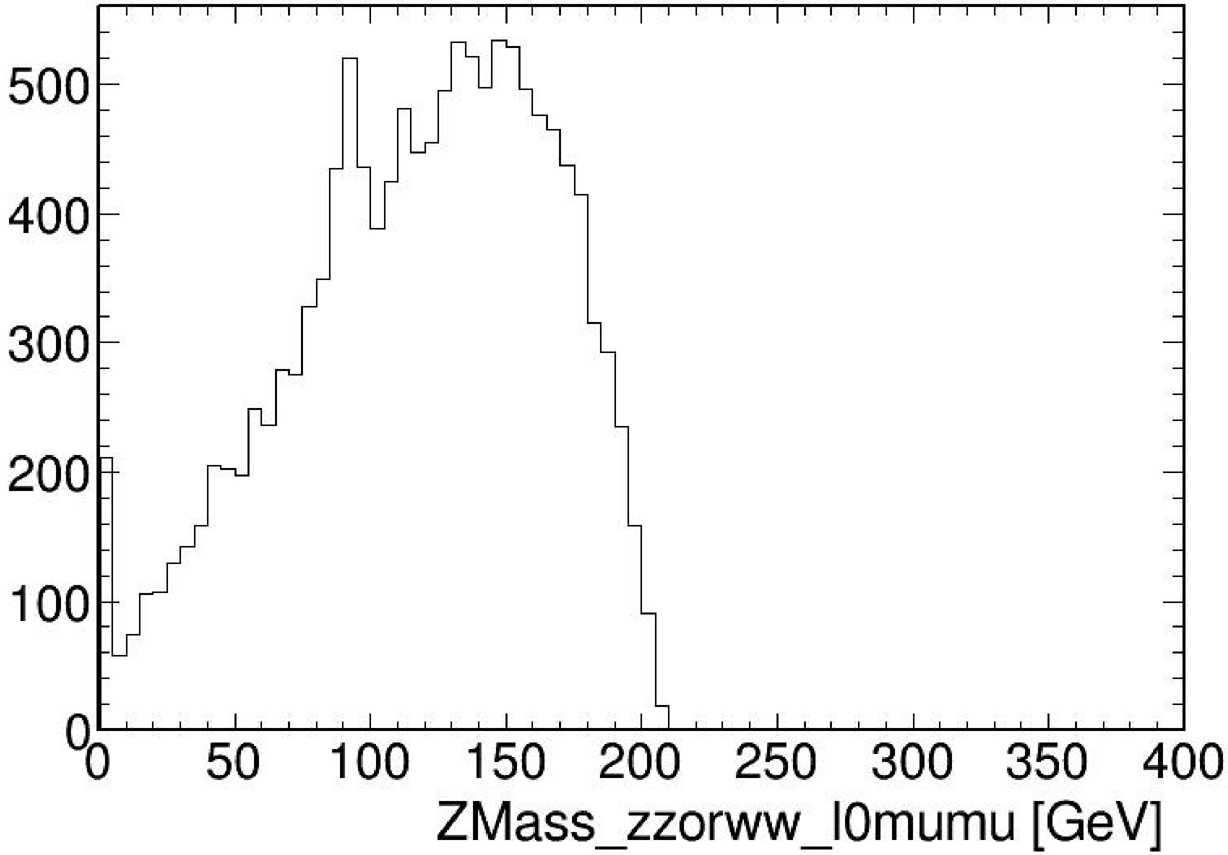
BKG Samples: eeToZZTo2l2q

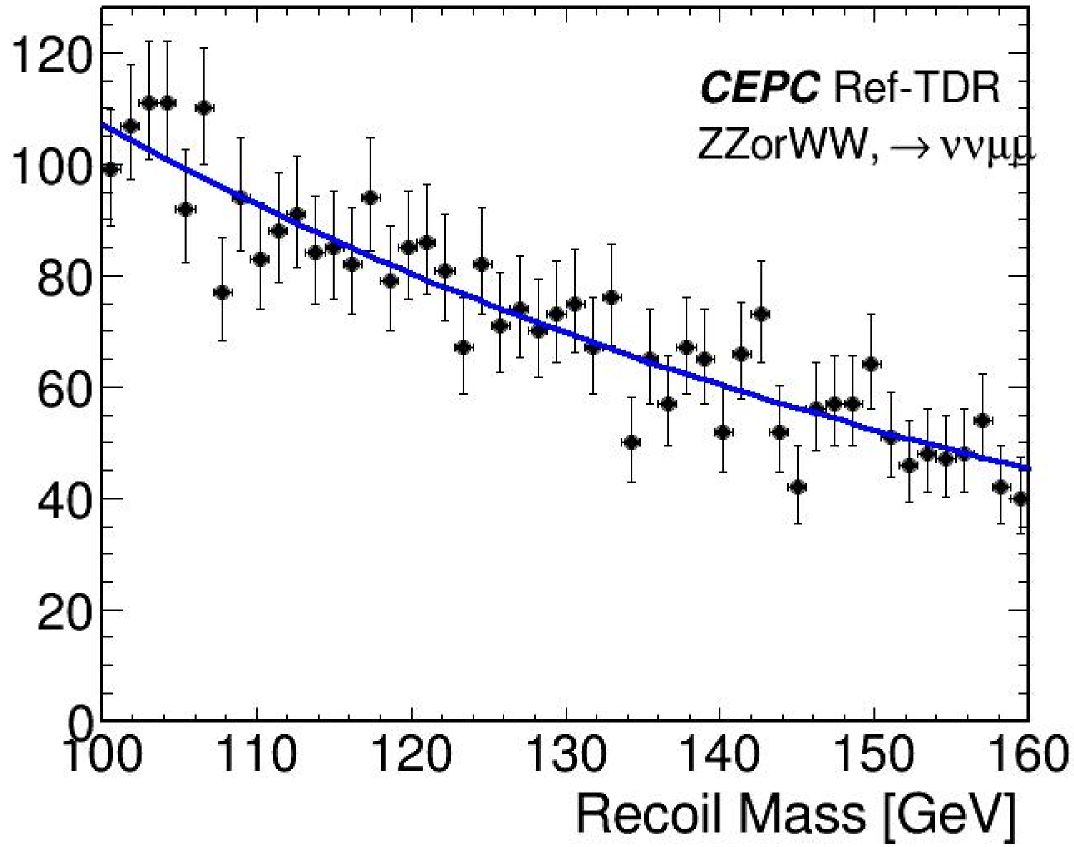




Fitted by exponential

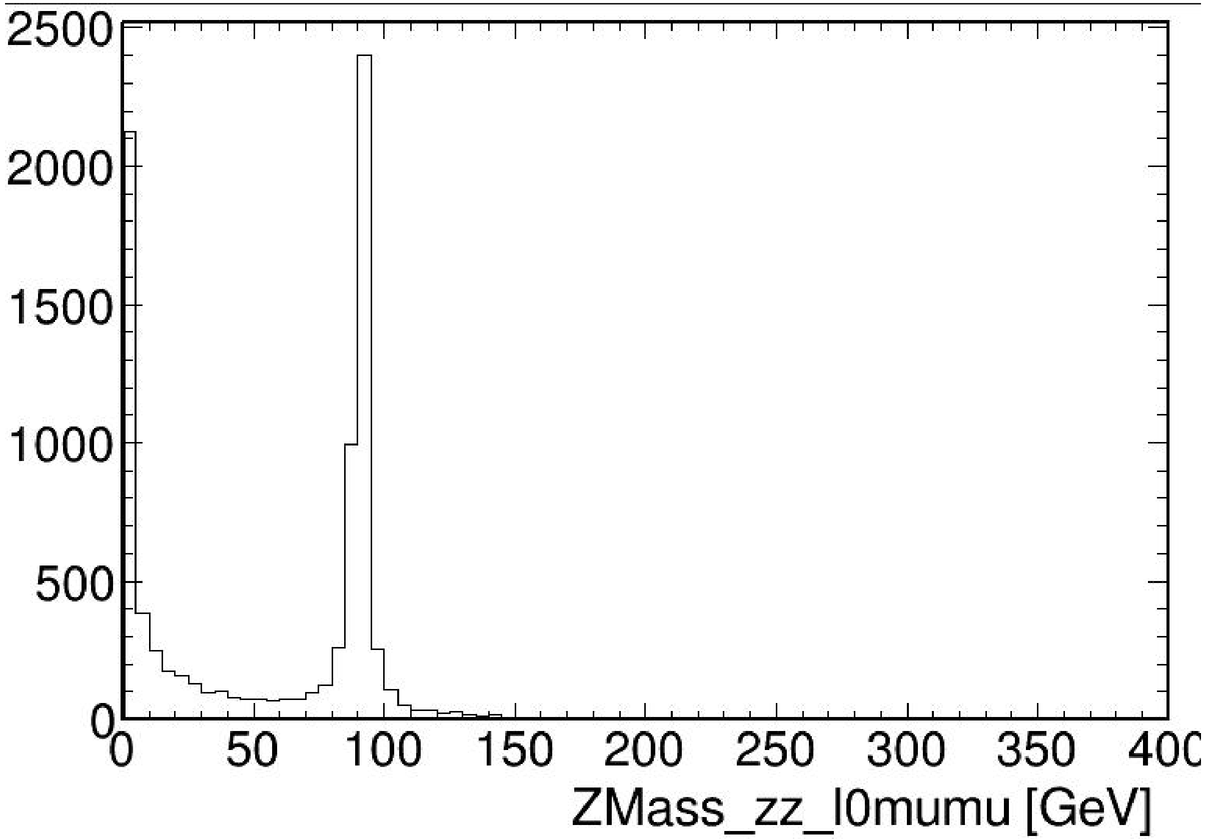
BKG Samples: eeToZZ(WW)To2l2nu

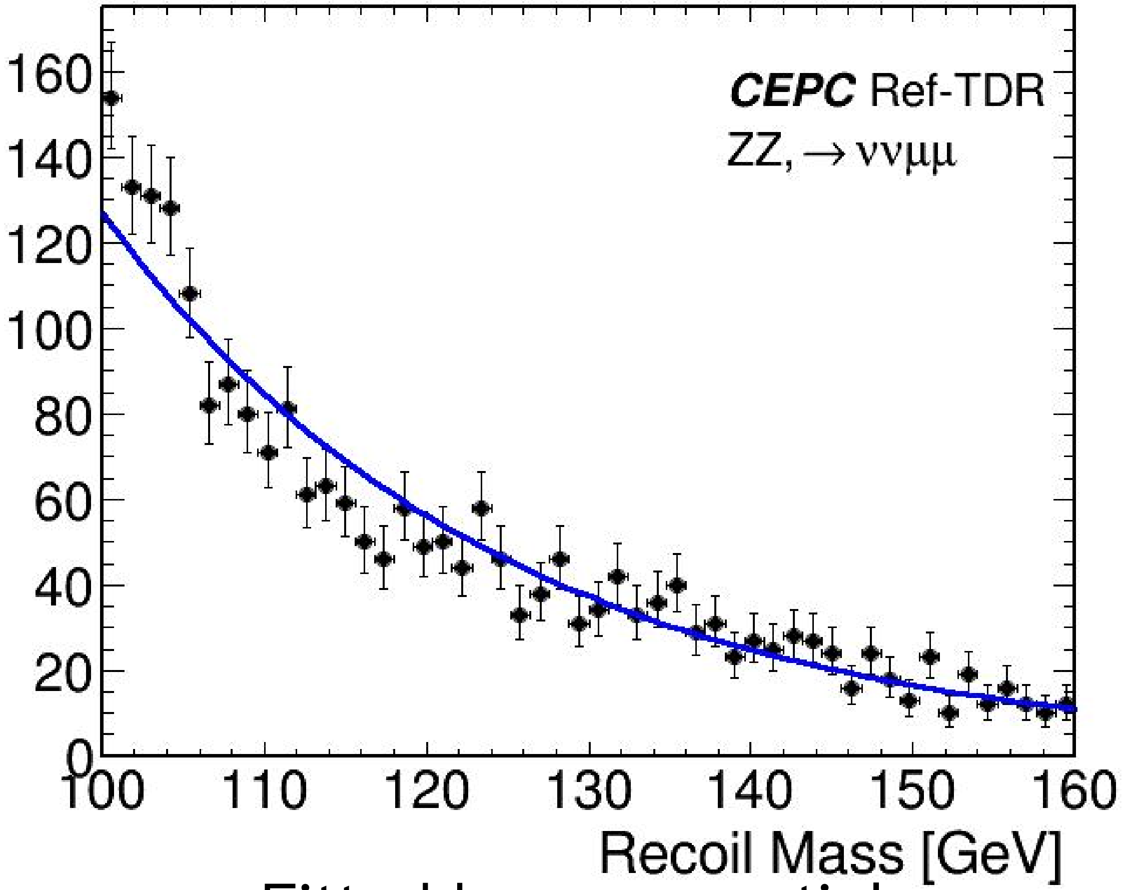




Fitted by exponential

BKG Samples: eeToZZTo2l2nu





Fitted by exponential