$H \rightarrow \gamma\gamma$ Channel Branching Ratio Measurement at New Concept ECAL

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Content

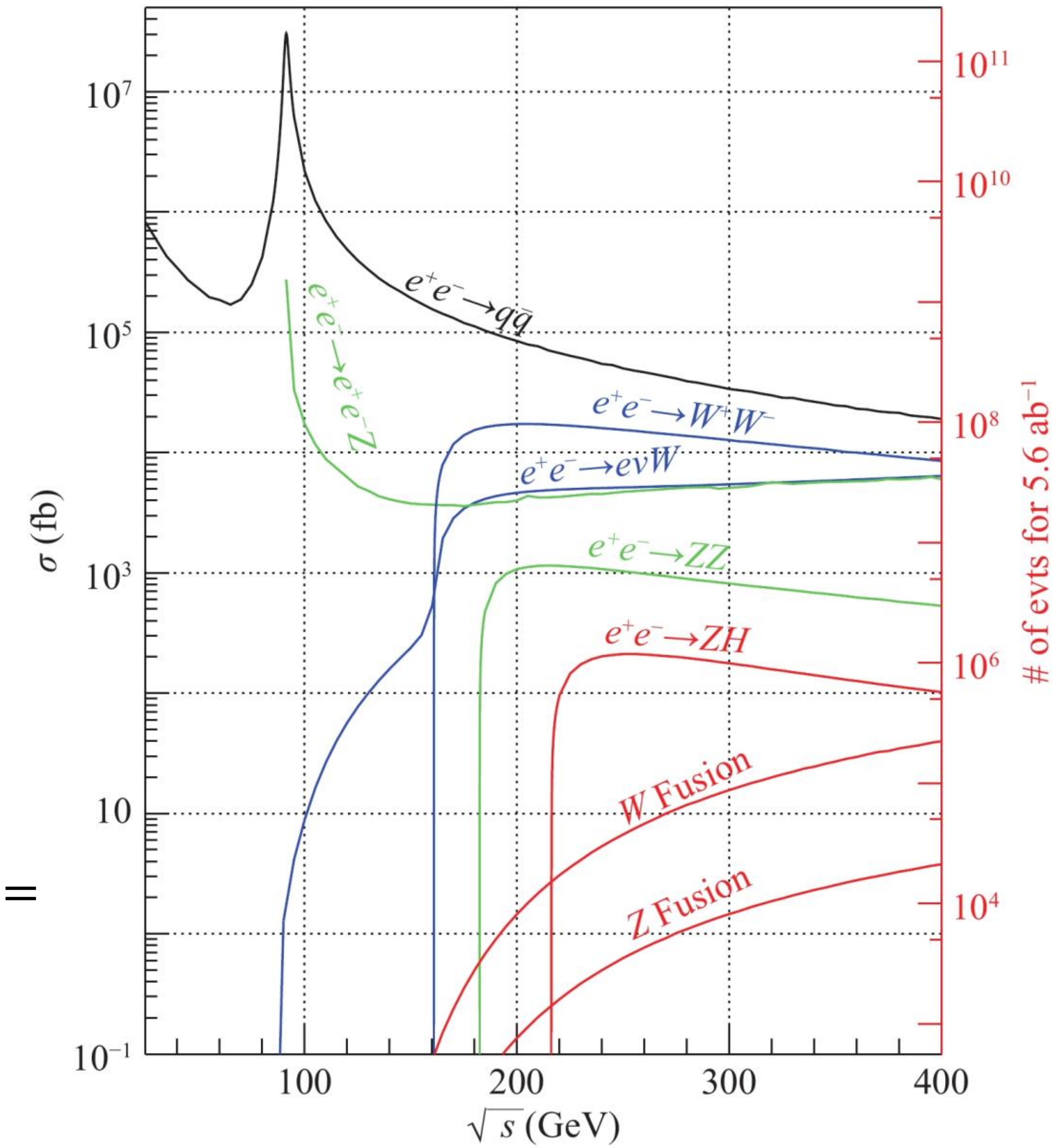
Introduction

CEPC project

- Electron-Positron collider, one of the goals is to operate as Higgs Factory
- More precise measurement in Higgs
- CEPC_v4: center of mass energy $\sqrt{S} = 240\ GeV$
- Higgsstrahlung (ZH) process is the main production mode

$H \rightarrow \gamma\gamma$ channel

- Low branching ratio ($Br \approx 0.227\%$), but clean final state topology → relatively high precision of measurement
- Present result from LHC ATLAS group:
  - $\sigma \times Br = 127 \pm 10\ fb\ (with\ SM\ prediction\ 116 \pm 5\ fb, \mu_{global} = 1.09^{+0.098}_{-0.098}$, $\mathcal{L} = 139\ fb^{-1})$ ATLAS-CONF-2020-026
- Difficulty: complex background components & large background XS



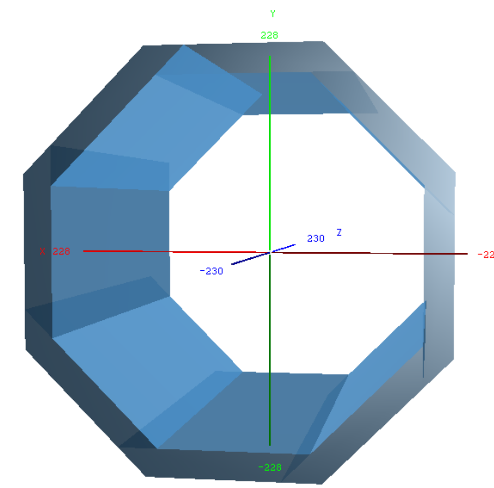
Introduction

New ECAL design for CEPC

- Material: BGO crystal
  - Expected energy resolution: $\sim 1\% \oplus \sim \frac{3\%}{\sqrt{E}}$
  - SiW design in CEPC-v4: $\sim 1\% \oplus \sim \frac{16\%}{\sqrt{E}}$

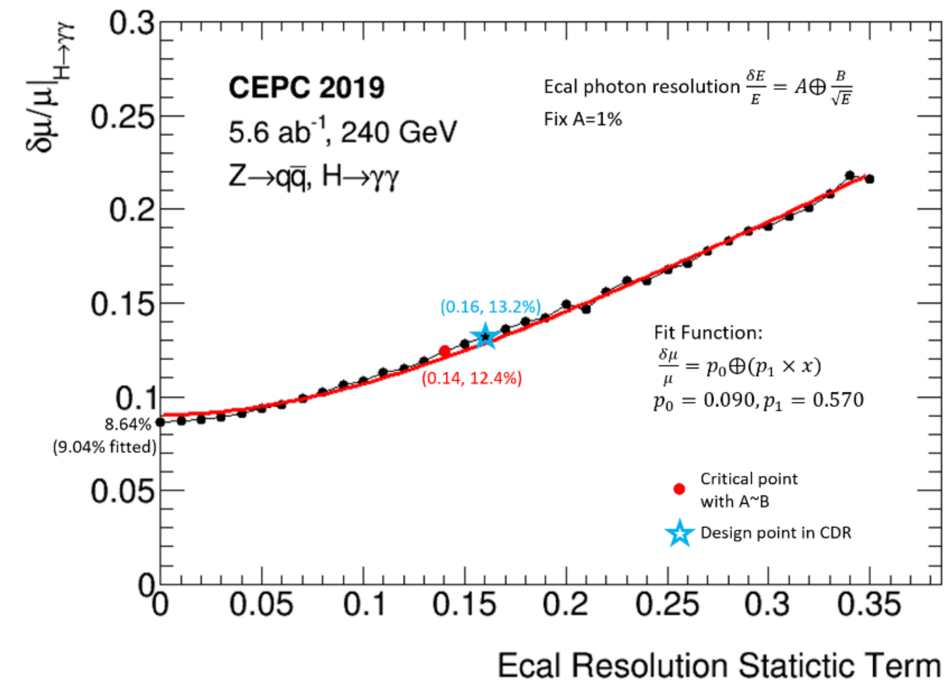
Parametrized detector response:

$$\frac{\Delta \mathrm{E}}{\mathrm{E}} \sim \mathrm{A} \oplus \frac{B}{\sqrt{E}} = \sqrt{A^2 + \frac{B^2}{E}}$$



Motivation

- $H \rightarrow \gamma\gamma$ analysis could gain benefits from this new Ecal
- Also the precision of $\sigma(ZH) \times Br(H \rightarrow \gamma\gamma)$ can be a benchmark for detector design.



Investigate the $H \rightarrow \gamma\gamma$ performance

- In $\nu\nu H \rightarrow \gamma\gamma$ and $\mu\mu H \rightarrow \gamma\gamma$ channel
- Fast simulation: based on smearing in truth MC.

Simulation

MC simulation:

- $\sqrt{s} = 240 GeV, \mathcal{L} = 5.6\ ab^{-1}$, Wizard 1.95 + MoccaC,

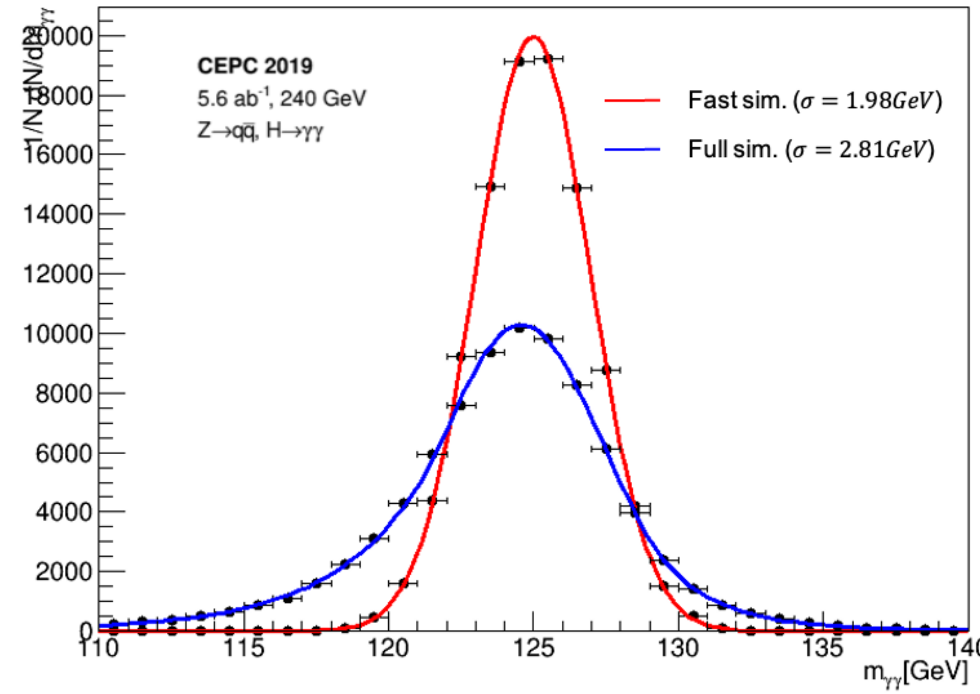
Detector simulation:

- Smear the MC truth photon energy with stochastic term B:

  3%: expected crystal Ecal resolution.

  16%: SiW Ecal in CEPC-v4.

  Constant term A is fixed to 1% for both cases.



Full sim = SiW Ecal results.
Fast sim = smearing based

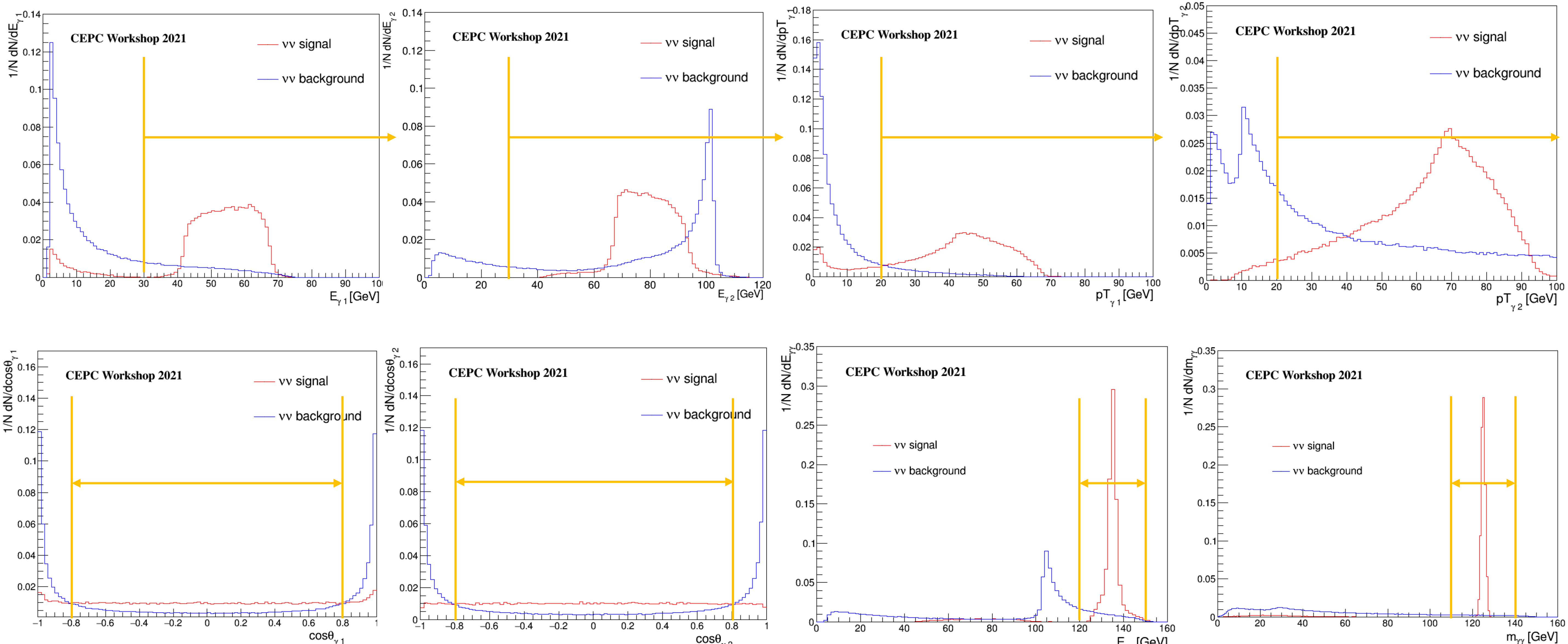
There is a discrepancy.

Event Selection —— $\nu\nu\gamma\gamma$ channel

- Signal: $e^+e^- \to ZH \to \nu\nu\gamma\gamma$
- Background: 2 fermion background only $e^+e^- \to \nu\bar{\nu}$
- Advantage: only have photons in final state, no influence from other objects

- Photon: 2 on-shell photons with highest energy
- Define:
  - γ_1: photon with lower energy
  - γ_2: photon with higher energy

Event Selection —— $\nu\nu\gamma\gamma$ channel distribution & selection criteria



B = 3%

Event Selection —— $\nu\nu\gamma\gamma$ channel cut flow

	$\nu\nu$ signal				$\nu\nu$ background	
generated	100000	B = 16%	100000	B = 3%	200000000	
$\nu\nu\gamma\gamma$	109362	109.362%	109362	109.362%	673991	0.337%
E_γ > 30 GeV	99175	90.685%	99171	90.681%	135659	20.128%
$\lvert cos\theta_\gamma \rvert$ < 0.8	69114	69.689%	69114	69.692%	15646	11.533%
p_{T_γ} > 20 GeV	69113	99.999%	69112	99.997%	15521	99.201%
120GeV<$E_{\gamma\gamma}$<150GeV	68716	99.426%	68789	99.533%	6966	44.881%
110GeV<$m_{\gamma\gamma}$<140GeV	68713	99.996%	68787	99.997%	3556	51.048%
Total eff.		68.713%		68.787%		0.018%
Scaled to 5.6 ab-1	404.33			404.76	5386.58	

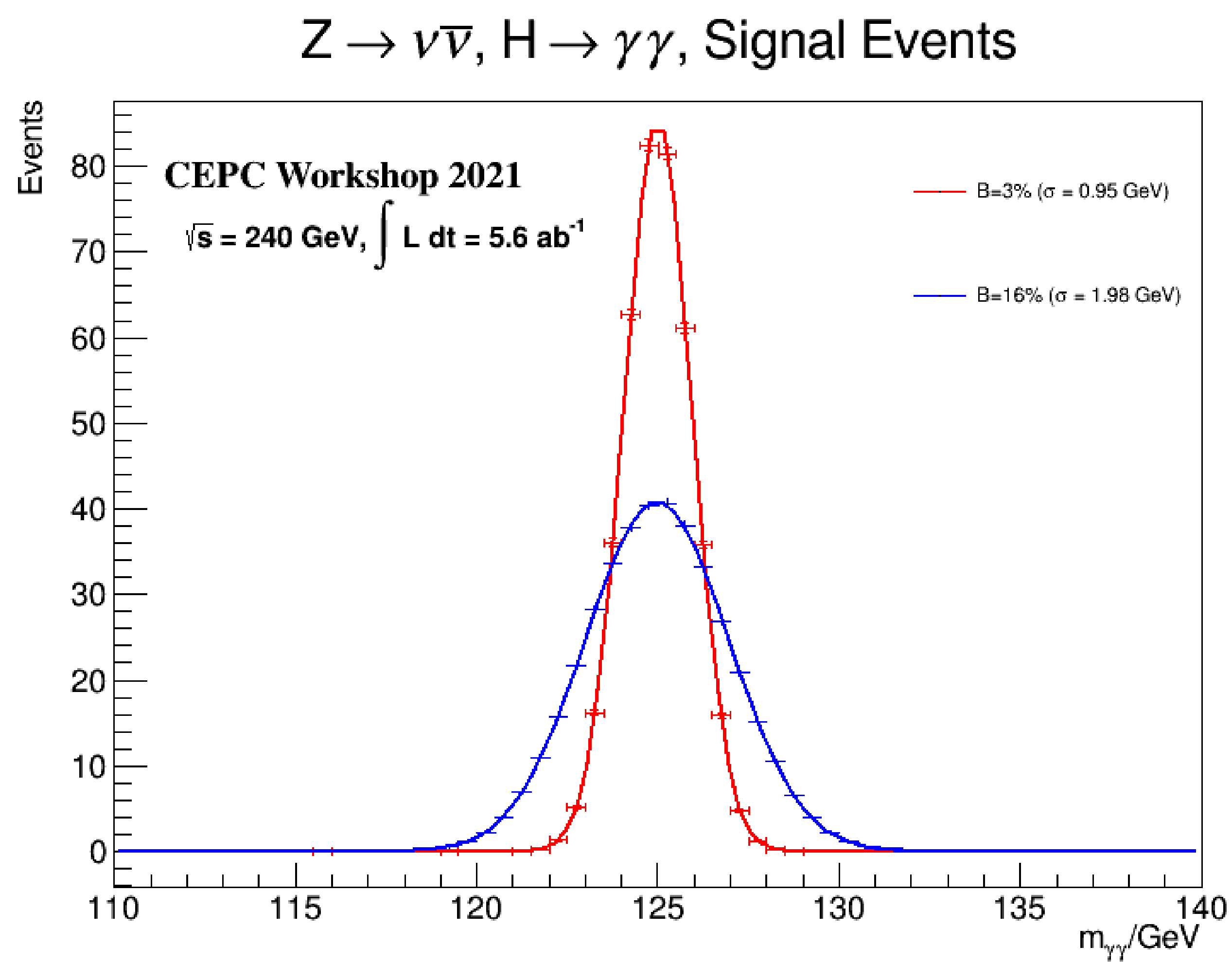
Fit Model—— $\nu\nu\gamma\gamma$ channel signal model

Fit variable: di-photon invariant mass $m_{\gamma\gamma}$

Signal model:

- Gaussian distribution

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-x^2/2\sigma^2}$$

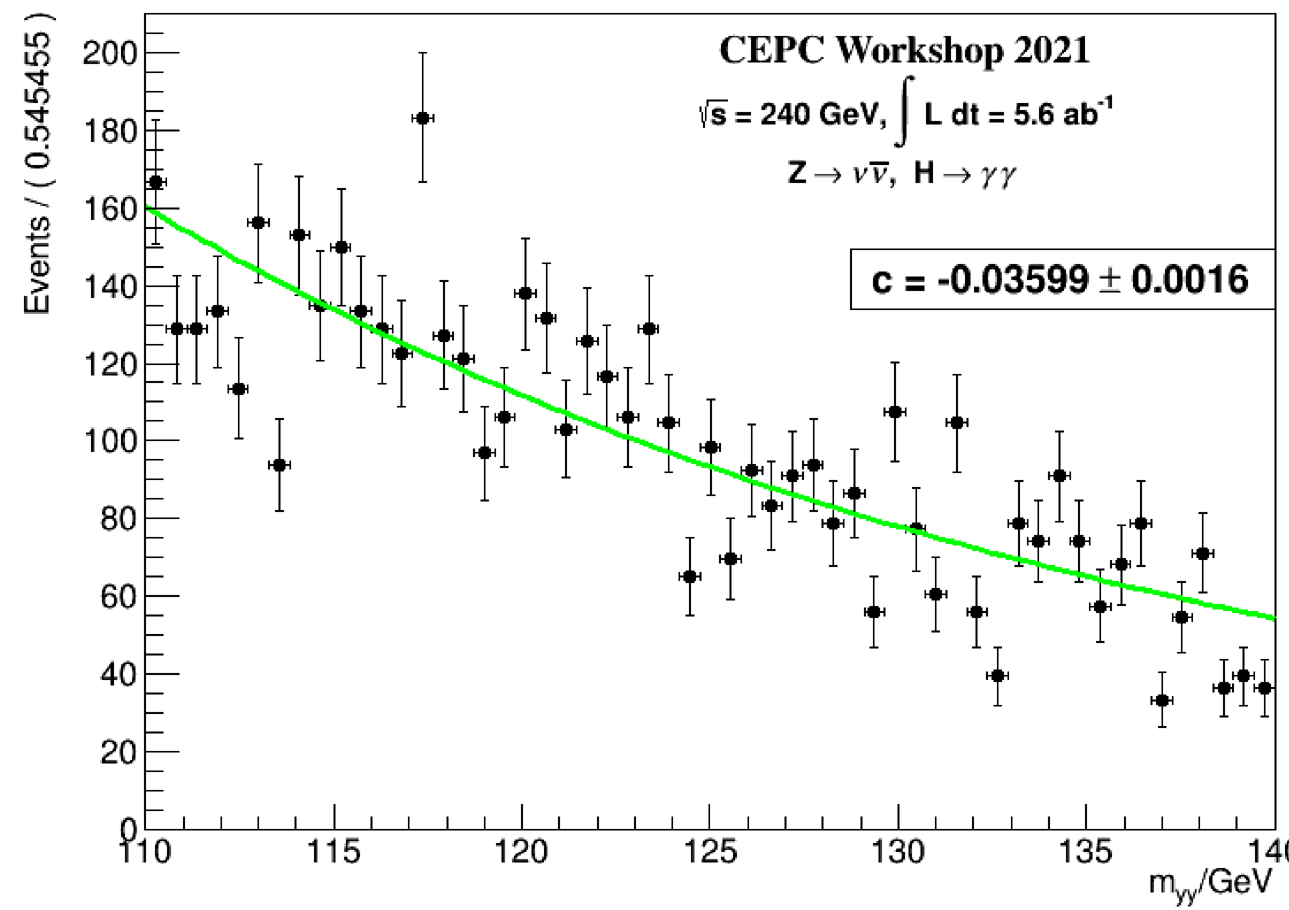


Fit Model—— $\nu\nu\gamma\gamma$ channel background model

Background model:

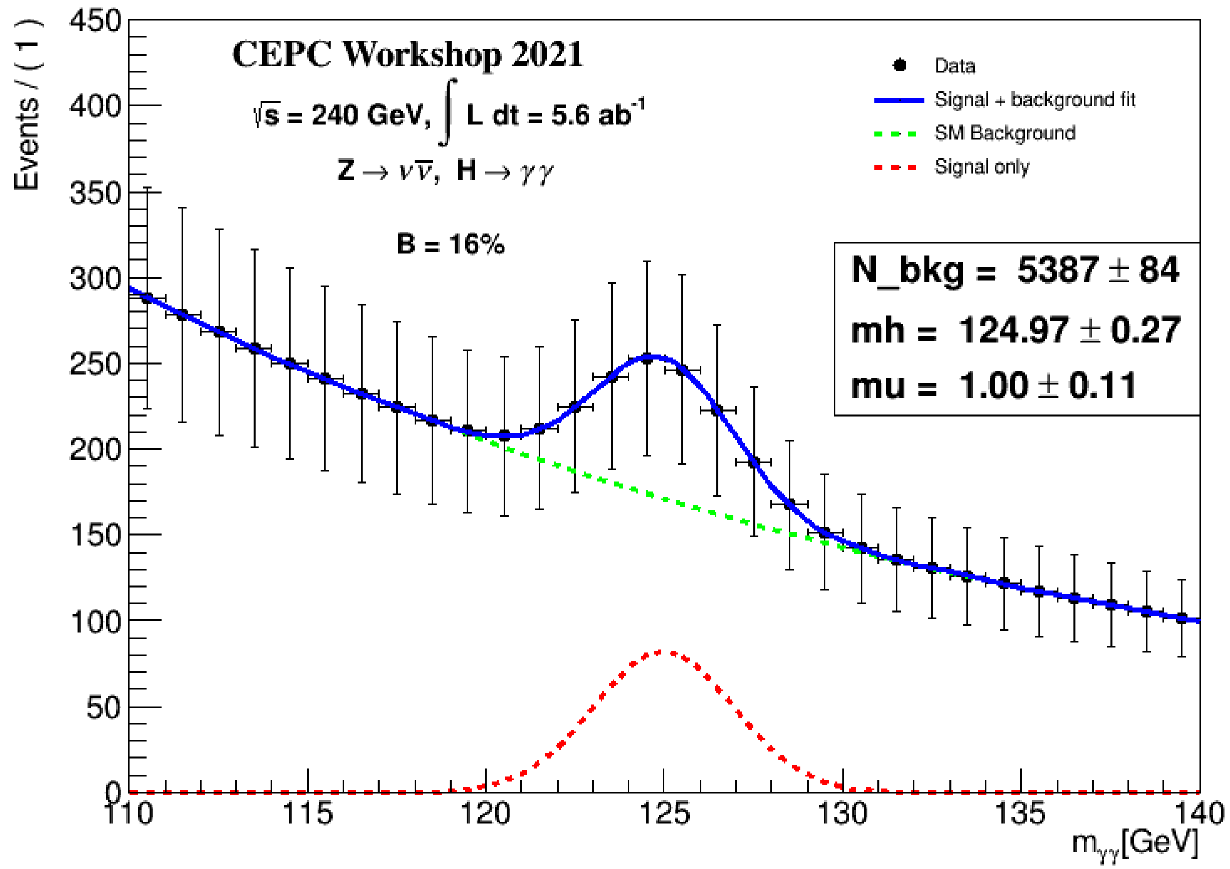
- Exponential function

$$\mathrm{RooExponential}(x,c) = \mathcal{N} \cdot \exp(c \cdot x),$$



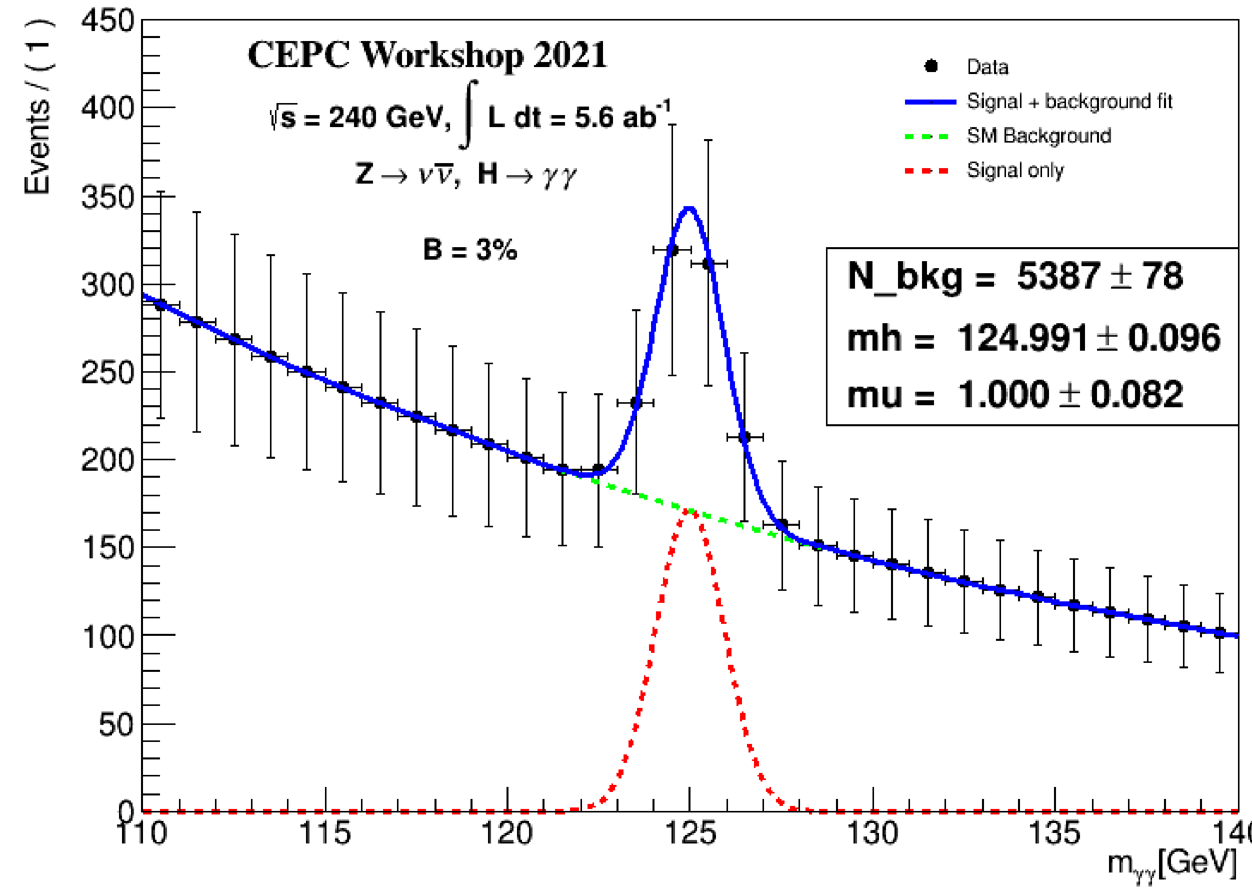
Results —— $\nu\nu\gamma\gamma$ channel, $\sigma(ZH) \times Br(H \to \gamma\gamma)$ precision

- Fit $m_{\gamma\gamma}$ in Asimov data to get signal strength and precision.
- $PDF_{sum} = \mu \times N_{sig}^{SM} \times PDF_{sig} + N_{bkg} \times PDF_{bkg}$



Stochastic term: 16% (SiW in CEPC-v4)

$\delta Br(H \to \gamma\gamma) = 11\%$

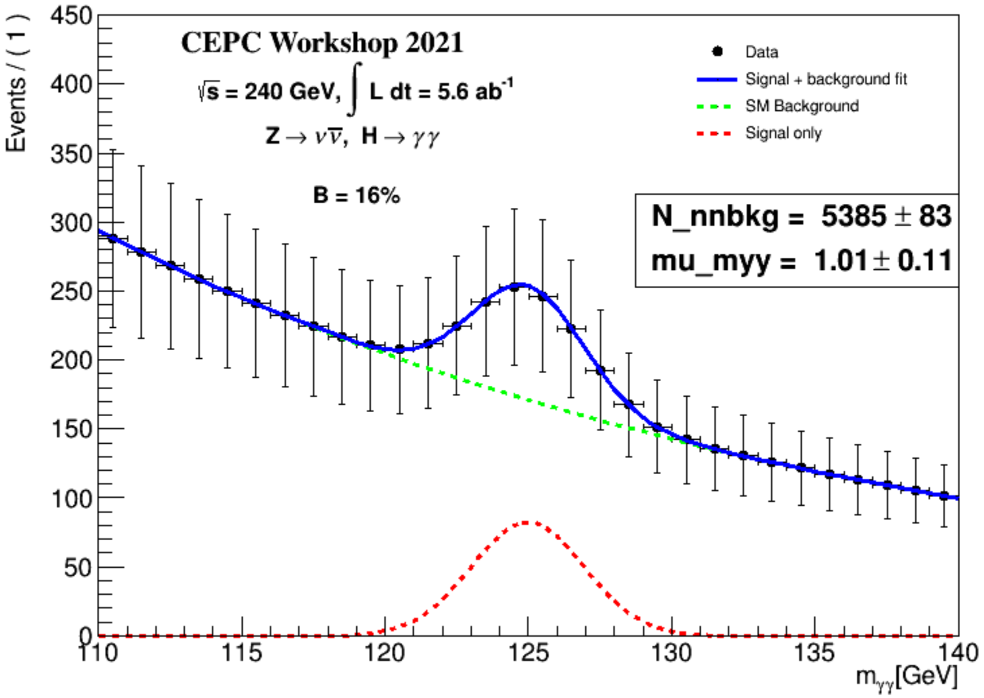


Stochastic term: 3% (Exp. crystal)

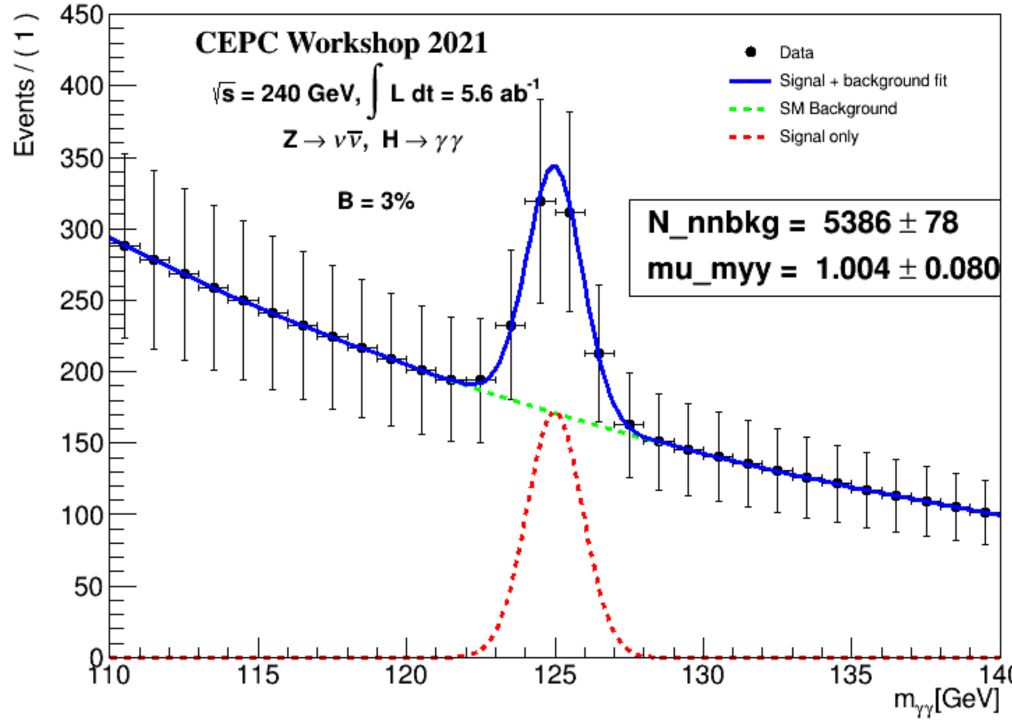
$\delta Br(H \to \gamma\gamma) = 8.2\%$

Results —— combined channel, $\sigma(ZH) \times Br(H \to \gamma\gamma)$ precision

- Repeat the former process in $\mu\mu\gamma\gamma$ channel
- m_H fixed to the fitted value in each corresponding channel



Stochastic term: 16% (SiW in CEPC-v4)
$\delta Br(H \to \gamma\gamma) = 11\%$



Stochastic term: 3% (Exp. crystal)
$\delta Br(H \to \gamma\gamma) = 8.0\%$
27% improvement from new EM calorimeter

Channel	$\mu \pm \delta\mu\ (stats)$	
	B = 16%	B = 3%
$\nu\nu\gamma\gamma$	$1.000^{+0.11}_{-0.11}$	$1.00^{+0.08}_{-0.08}$
$\mu\mu\gamma\gamma$	$1.00^{+0.48}_{-0.48}$	$1.02^{+0.34}_{-0.34}$
combined	$1.01^{+0.11}_{-0.11}$	$1.00^{+0.08}_{-0.08}$

Conclusion

Fast simulation, combined 2 sub-channels

- $\sigma(ZH) \times Br(H \to \gamma\gamma)$ precision reaches 8.0%
- 27% improvement from new EM calorimeter

Next steps

- Consider $qq\gamma\gamma$ channel as well
- Optimize the selection method using BDT
- Update the results with full simulation after finishing the 4th Conceptual Detector design

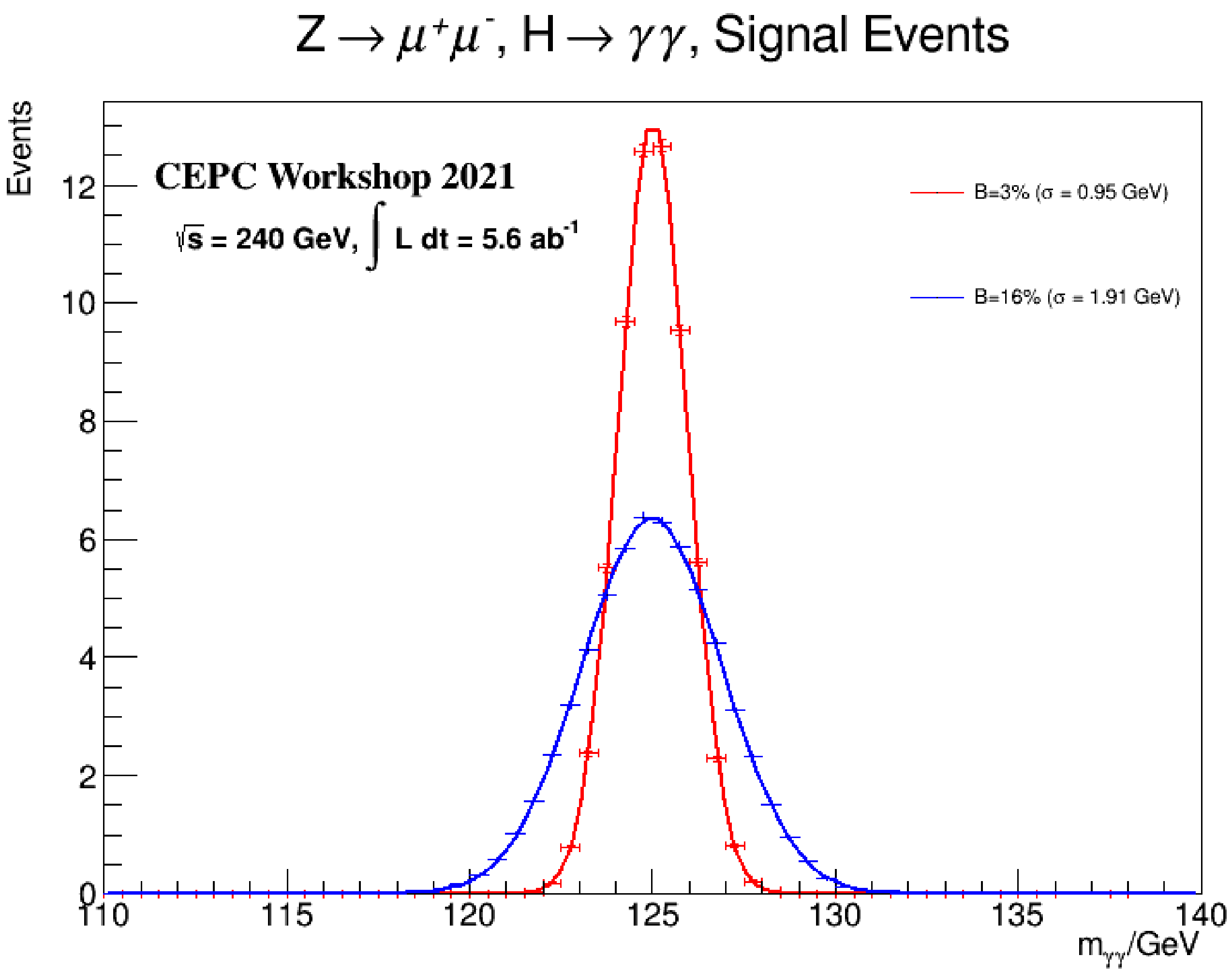
Thank you

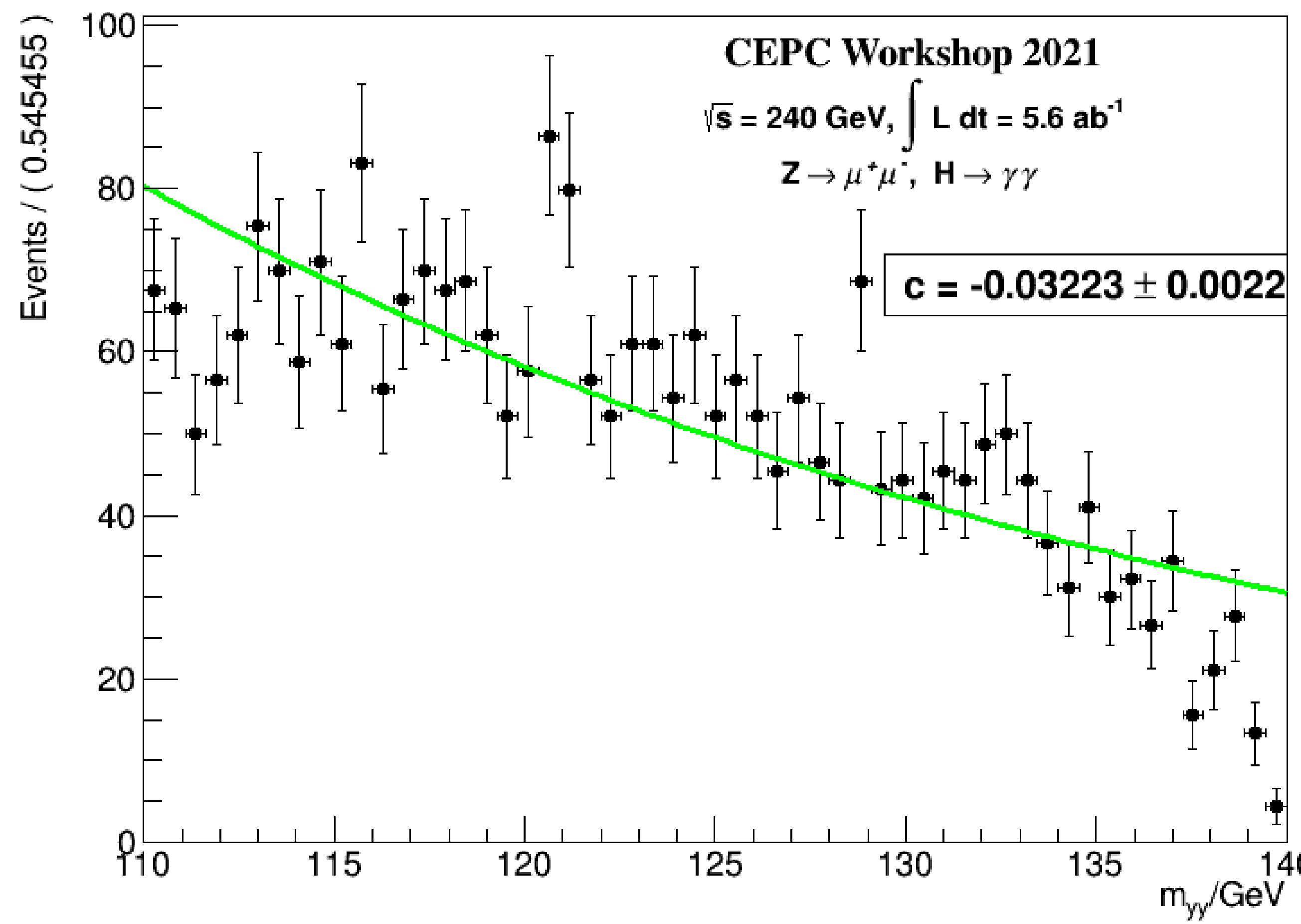
Back up

$\mu\mu\gamma\gamma$ channel cut flow

	$\mu\mu$ signal				$\mu\mu$ background	
generated	100000	B = 16%	100000	B = 3%	26930165	
$\mu\mu\gamma\gamma$	138039	138.04%	138039	138.04%	1393678	5.18%
E_γ > 35 GeV	99722	72.24%	99721	72.24%	116828	8.38%
$\lvert cos\theta_\gamma \rvert$ < 0.9	83043	83.27%	83036	83.27%	44506	38.10%
10 GeV< $p_{T_{\gamma 1}}$ <70 GeV	83024	99.98%	83000	99.96%	41983	94.33%
110 GeV<$p_{T_{\gamma 2}}$<140 GeV	82944	99.90%	82906	99.89%	40917	97.46%
110GeV<$m_{\gamma\gamma}$<140GeV	81708	98.51%	81685	98.53%	15815	38.65%
84 GeV<$M_{\gamma\gamma}^{recoil}$<103 GeV	72732	89.01%	71348	87.35%	2944	18.62%
125 GeV<$E_{\gamma\gamma}$<143 GeV	72721	99.98%	71339	99.99%	2848	96.74%
$min\lvert cos\theta_{\gamma l} \rvert$	72552	99.77%	71176	99.77%	2553	89.64%
Total eff.		72.552%		71.176%		0.009%
Scaled to 5.6 ab-1	62.44			61.25	2831.05	

$\mu\mu\gamma\gamma$ channel fit model





$\mu\mu\gamma\gamma$ channel Asimov data fit result