$H \rightarrow \gamma\gamma$ channel branching ratio measurement in CEPC

Fangyi Guo, USTC
Feng Wang, IHEP
Yitian Sun, UChicago

Workshop on the Circular Electron-Positron Collider
25th May, 2018, Rome

Content

- Motivation
- Monte-Carlo Samples
- Simulation
- Event selection
- Fit model
- Results
- Comparison due to different magnetic fields
- Further work
- Conclusion

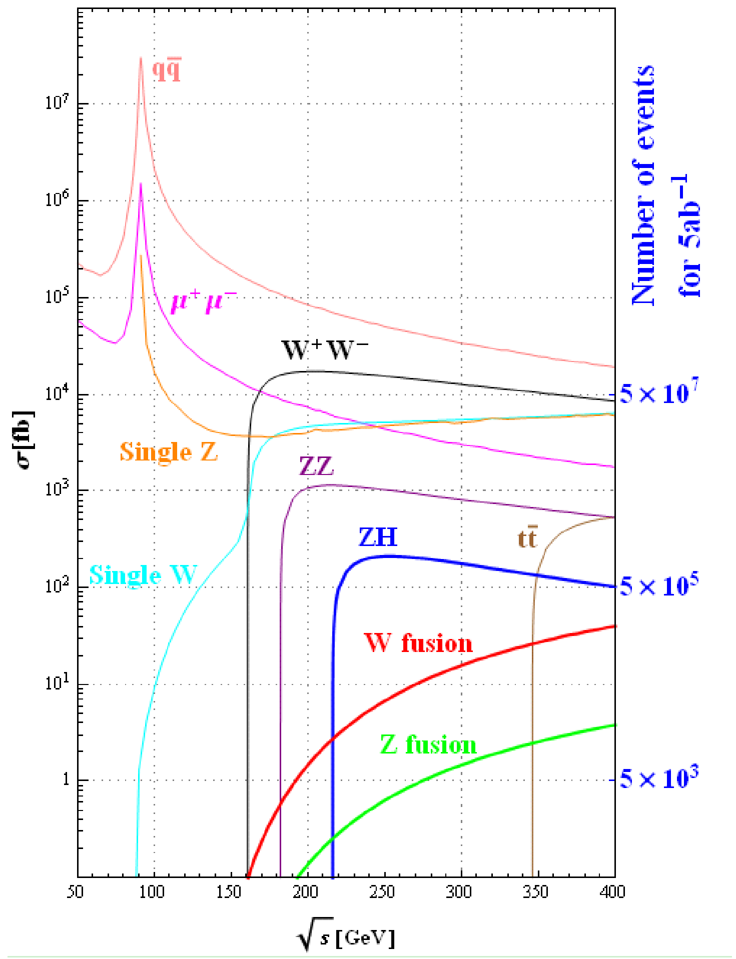
Motivation

- Standard Model Higgs physics is one of the major topic in the CEPC

- CEPC project
  Electron-Positron collider, operate as Higgs Factory
  Hope to have more precise measurement in Higgs-relative parameters.

- In center of mass energy $\sqrt{s}\sim 250GeV$ in lepton collider, the Higgsstrahlung(ZH) process is the main production mode

- Design point:
  preCDR(CEPC_v1): $\sqrt{s} = 250GeV$, magnetic field B=3.5T, etc.
  Present(CEPC_v4): $\sqrt{s} = 240GeV$, magnetic field B=3.0T, etc.



Motivation

- $\mathrm{Br}(H \to \gamma\gamma) \approx 0.227\%$, low branching ratio but clean final state topology.

  The measurement should achieve a relative high precision.

- Present results from LHC ATLAS group:

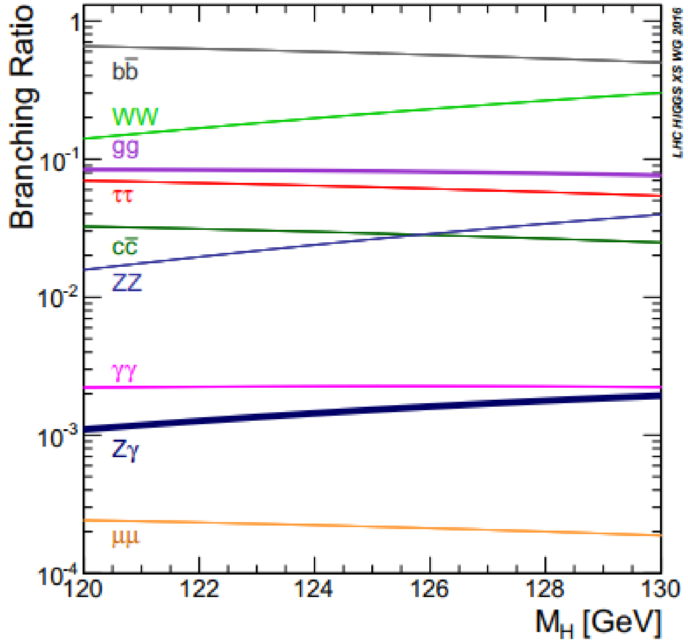
$$\mu_{global} = 0.99^{+0.14}_{-0.13}\ (\mathcal{L} = 36.1 fb^{-1})$$

Arxiv:1802.04146

- Difficulty:

  Complex background components

  Low $Br(H \to \gamma\gamma)$ VS. Large background process XS



Monte Carlo Samples

(Generated with Whizard1.95, include ISR)

- Signal

$ee \to ZH \to ll\gamma\gamma$

$ee \to ZH \to qq\gamma\gamma$

$ee \to ZH \to \nu\nu\gamma\gamma$

100k events per channel

$ee \to ZH,\ H \to \gamma\gamma, Z \to inclusive$ 400k totally

Monte Carlo Samples

- Background Components

    Similar final states with ISR photon

Signal	Background	Dominant one(chosen one)	Generated event number
$ZH \to ll + \gamma\gamma$	$ee \to Z \to ee/\mu\mu/\tau\tau$+ISR photon $ee \to WW \to l\nu l\nu$+ISR photon $ee \to ZZ \to ll\nu\nu$+ISR photon	$ee \to Z \to ee/\mu\mu/\tau\tau$+ISR photon	~26M($\mu\mu$)+10M($\tau\tau$)
$ZH \to qq + \gamma\gamma$	$ee \to Z \to qq$+ISR photon $ee \to WW \to qq\gamma\gamma$ $ee \to ZZ \to qq\nu\nu$+photon	$ee \to Z \to qq$+ISR photon	20M
$ZH \to \nu\nu + \gamma\gamma$	$ee \to Z \to \nu\nu$+photon Other $ee \to invisible$ process+photon	$ee \to Z \to \nu\nu$+photon	200M

Simulation

- Full simulation

  Use Geant4-based tools to simulate the detector response

  $ee \rightarrow ZH,\ H \rightarrow \gamma\gamma, Z \rightarrow inclusive$ signal sample

- Fast simulation

  Smear the objects with the resolutions and efficiencies from full simulation

  $ee \rightarrow ZH \rightarrow ll/\mathrm{qq}/\nu\nu + \gamma\gamma$ signal samples

  All background samples

Event selection $——qq\gamma\gamma$ channel

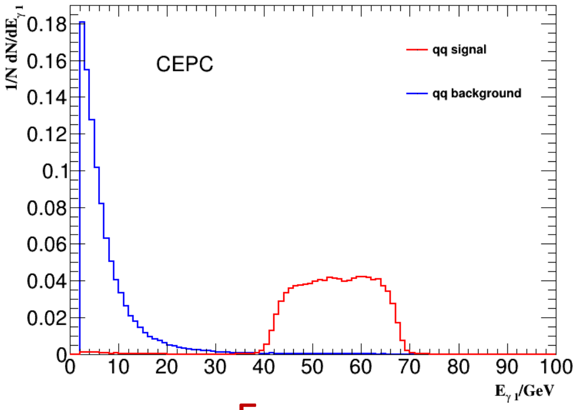
- Signal: $ee \rightarrow ZH \rightarrow qq\gamma\gamma$
- Background: $ee \rightarrow qq\gamma\gamma$

Whizard1.95+Fast simulation,
B=3.0T, $\sqrt{s} = 240GeV$

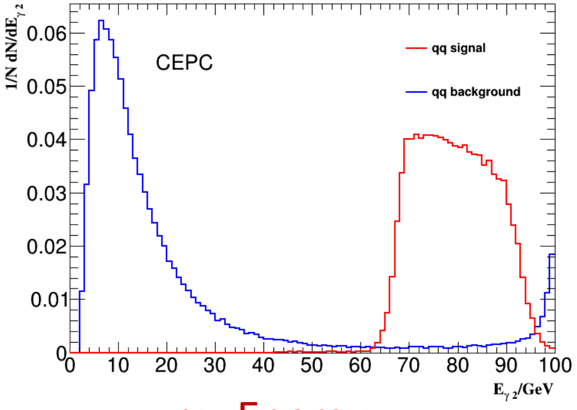
- Photon: 2 on-shell photon whose invariant mass is closest to $m_H = 125GeV$
- Jets: Force the other particles into 2 jets

- Define:
  - γ_1/j_1: $photon/jet\ with\ lower\ energy$
  - γ_2/j_2: $photon/jet\ with\ higher\ energy$

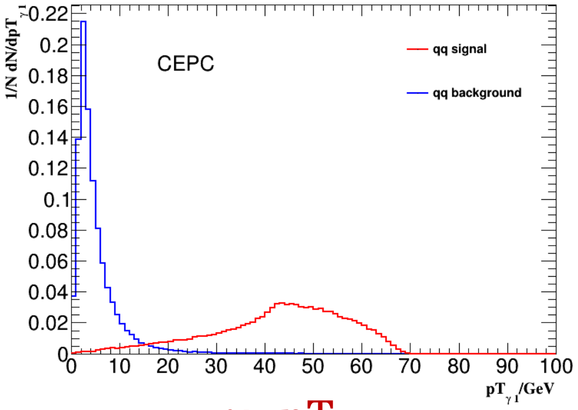
Event selection ——$qq\gamma\gamma$ channel distribution



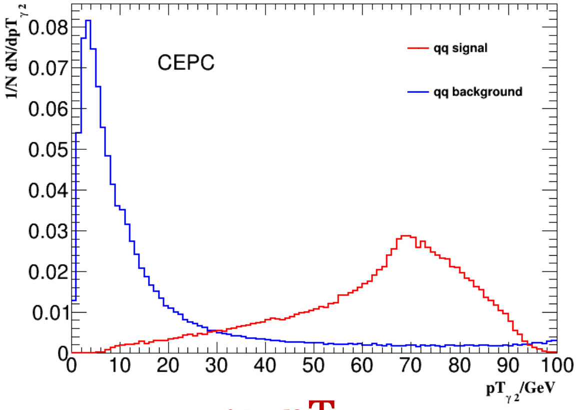
γ_1 Energy



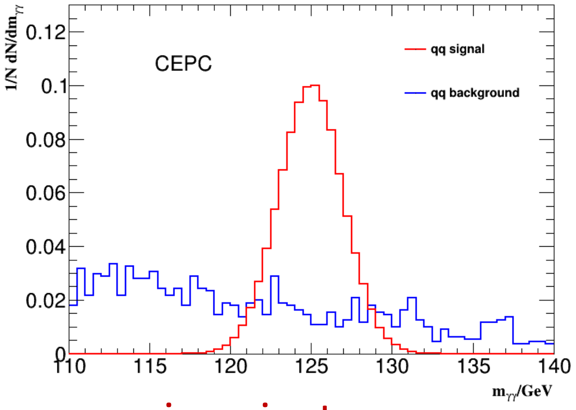
γ_2 Energy



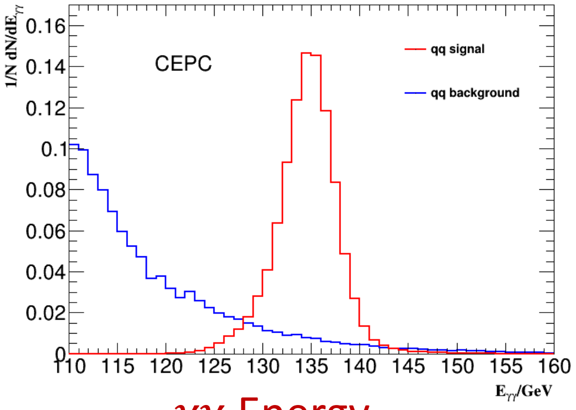
γ_1 pT



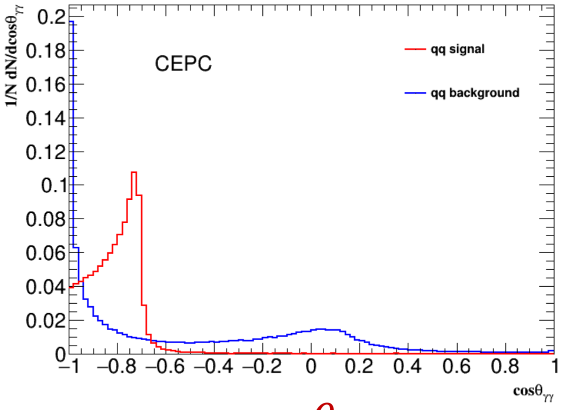
γ_2 pT



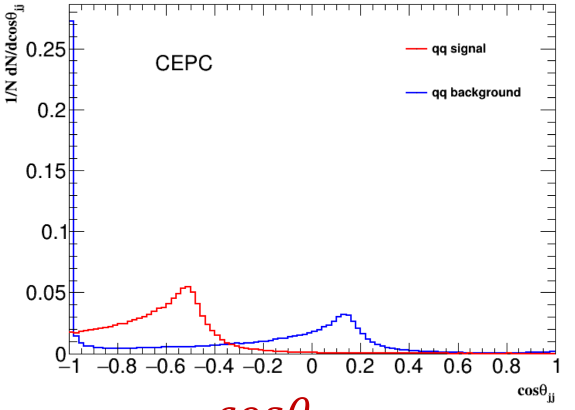
$\gamma\gamma$ invariant mass



$\gamma\gamma$ Energy



$cos\theta_{\gamma\gamma}$



$cos\theta_{jj}$

Event selection $——qq\gamma\gamma$ channel selection criteria

$E_{\gamma1} > 35GeV$

$35GeV < E_{\gamma2} < 96GeV$

$cos\theta_{\gamma\gamma} >$ -0.95, $cos\theta_{jj}$>-0.95 ← Cosine polar angle between two photons/ two jets

$pT_{\gamma1} > 20GeV, pT_{\gamma1} > 30GeV$

$110GeV < m_{\gamma\gamma} < 140GeV$

$125GeV < E_{\gamma\gamma} < 145GeV$

$\min|cos\theta_{\gamma j}|$<0.9 ← Minimum cosine polar angle between the photon and jet

! The selections are not optimized

Event selection ——$qq\gamma\gamma$ channel cut flow

	qq signal		qq background	
generated	100000		20000000	
$qq\gamma\gamma$	99893	99.893%	13914611	69.573%
$E_{\gamma 1}$>35GeV	99025	99.131%	120726	0.868%
35GeV<$E_{\gamma 2}$<96GeV	97922	98.886%	55583	46.041%
$cos\theta_{jj}$>-0.95	93631	95.618%	44012	79.182%
$cos\theta_{\gamma\gamma}$>-0.95	84930	90.707%	36794	83.600%
$pT_{\gamma 1}$>20GeV	79339	93.417%	22481	61.100%
$pT_{\gamma 2}$>30GeV	73929	93.181%	11733	52.191%
110GeV<$m_{\gamma\gamma}$<140GeV	73927	99.997%	4316	36.785%
125GeV<$E_{\gamma\gamma}$<145GeV	73571	99.518%	3912	90.639%
min|$cos\theta_{\gamma j}$|<0.9	53088	72.159%	1972	50.409%
		53.088%		0.010%
scaled to 5 ab-1	824.38		26674.65	

Fit model——$qq\gamma\gamma$ channel

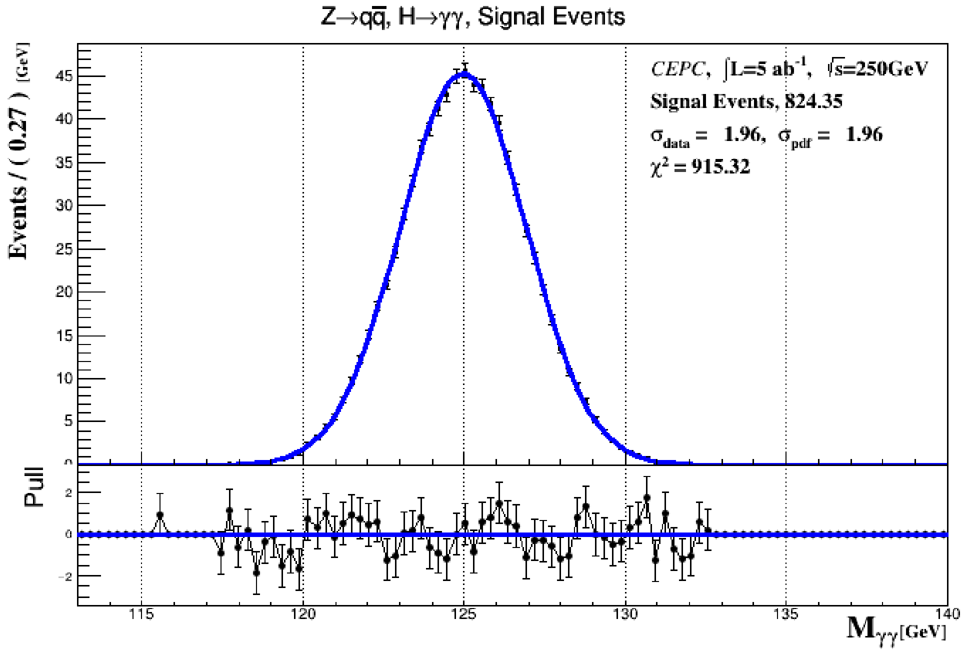
Fit variable: di-photon invariant mass

- Signal model

  Double-side Crystal Ball PDF

$$CB(m_{\gamma\gamma}) = N \times \begin{cases} e^{-t^2/2} & \text{if } -\alpha_{low} \leqslant t \leqslant \alpha_{high} \\ \dfrac{e^{-\frac{1}{2}\alpha_{low}^2}}{\left[\frac{1}{R_{low}}(R_{low}-\alpha_{low}-t)\right]^{n_{low}}} & \text{if } t < -\alpha_{low} \\ \dfrac{e^{-\frac{1}{2}\alpha_{high}^2}}{\left[\frac{1}{R_{high}}(R_{high}-\alpha_{high}-t)\right]^{n_{high}}} & \text{if } t > \alpha_{high} \end{cases}$$

$$t = (m_{\gamma\gamma} - \mu_{CB})/\sigma_{CB}$$



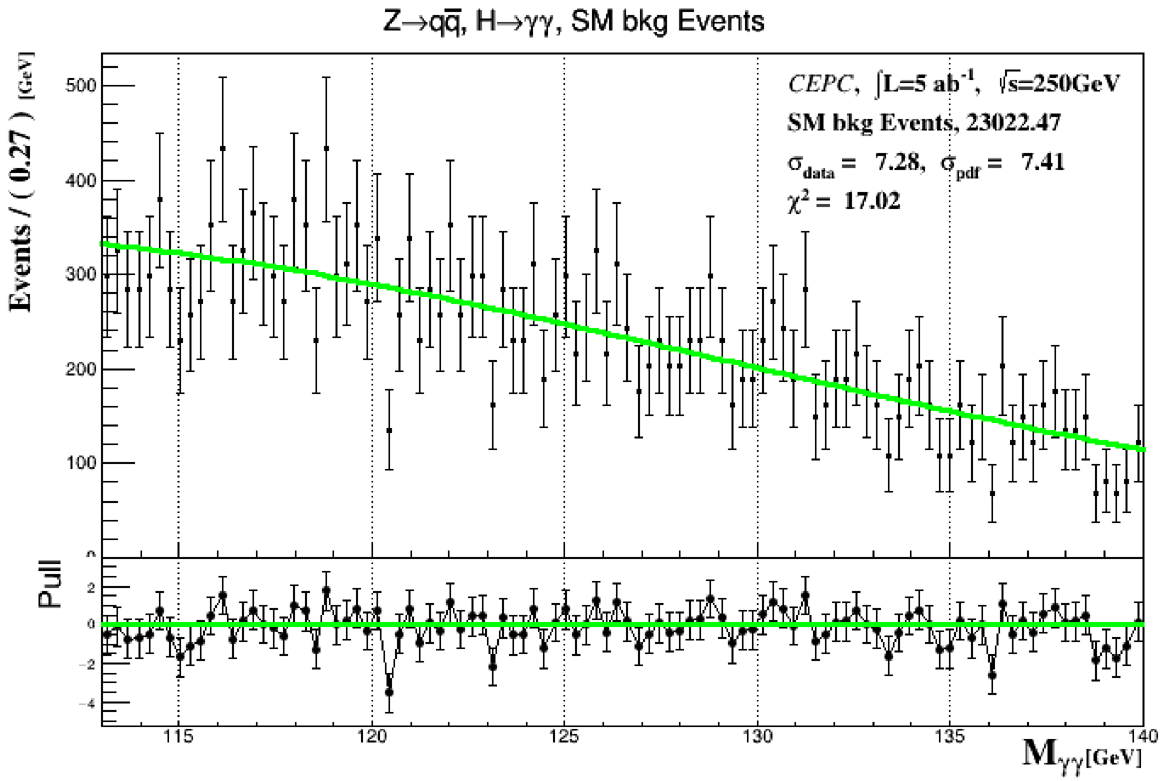
Fit model——$qq\gamma\gamma$ channel

- Background Model

  2nd polynomial exponential PDF

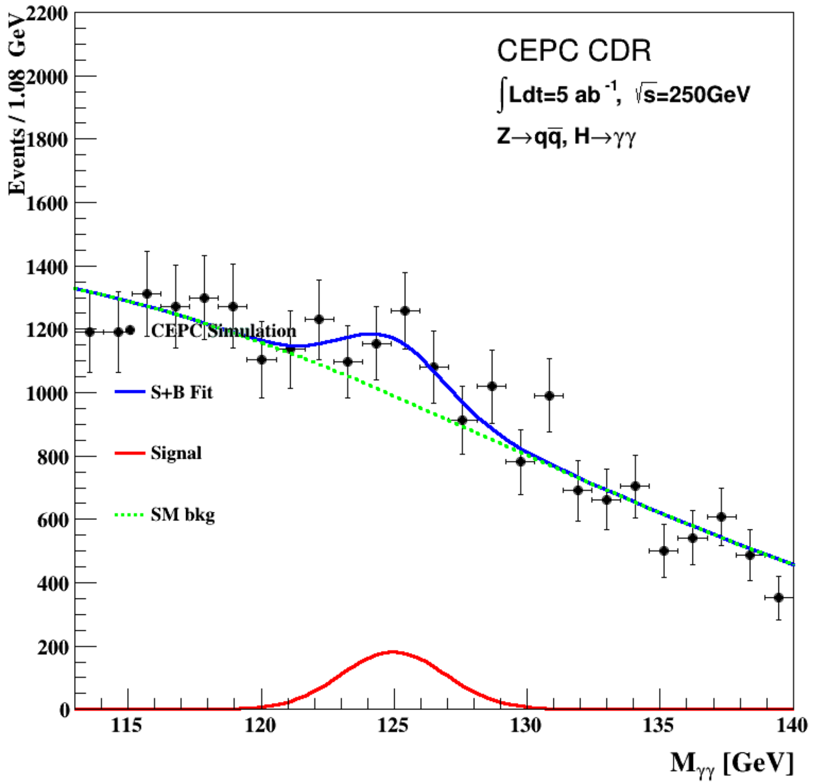
$$\mathrm{PDF}(m_{\gamma\gamma}) =$$

$$\exp[a \times \frac{(m_{\gamma\gamma} - 100)}{100} + b \times (\frac{m_{\gamma\gamma} - 100}{100})^2]$$



Results——$qq\gamma\gamma$ channel

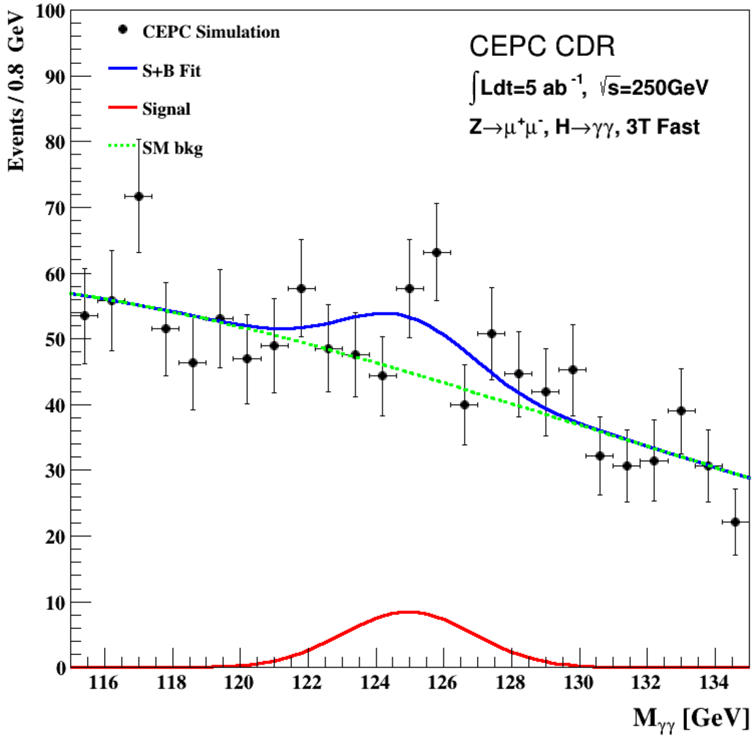
$$PDF_{sum} = \mu \times N_{sig}^{SM} \times PDF_{sig} + N_{bkg} \times PDF_{bkg}$$

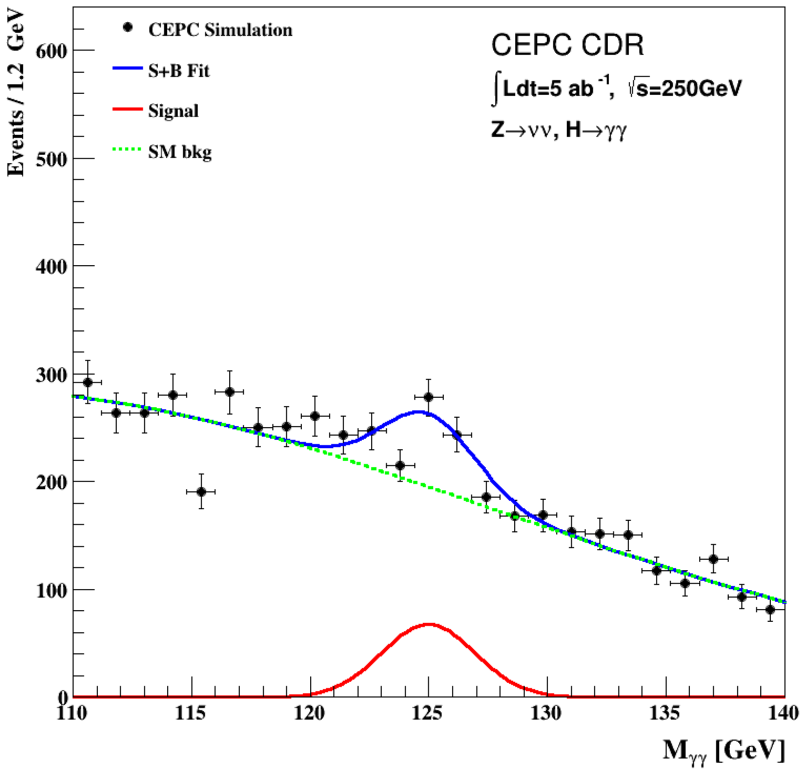


$$\mu = 0.996^{+0.104}_{-0.103}$$

Results——all channels

Repeat the former process in the other 2 sub-channels





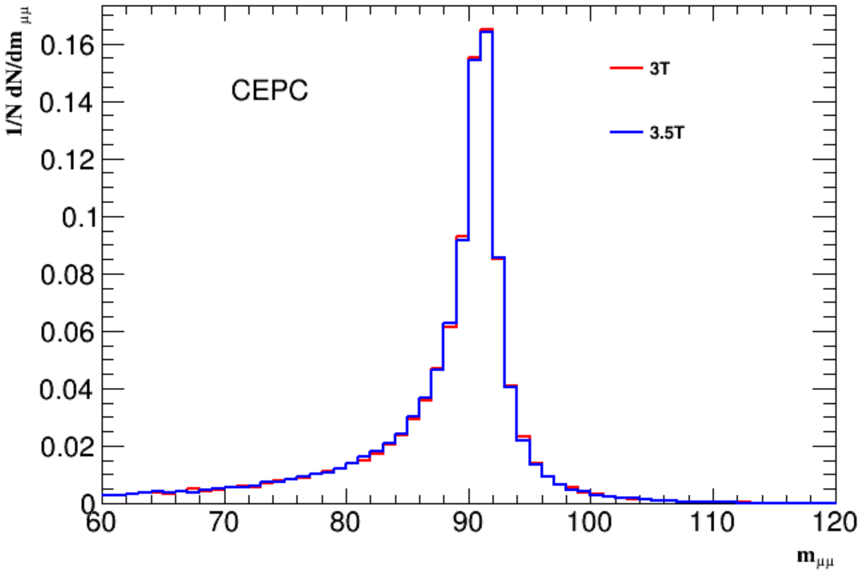
Channel	$\mu \pm \delta(\mu)(stats)$
$ll\gamma\gamma$	$0.997^{+0.419}_{-0.404}$
$qq\gamma\gamma$	$0.996^{+0.104}_{-0.103}$
$\nu\nu\gamma\gamma$	$0.997^{+0.138}_{-0.135}$
combined	$0.996^{+0081}_{-0.081}$

Comparison due to different magnetic fields

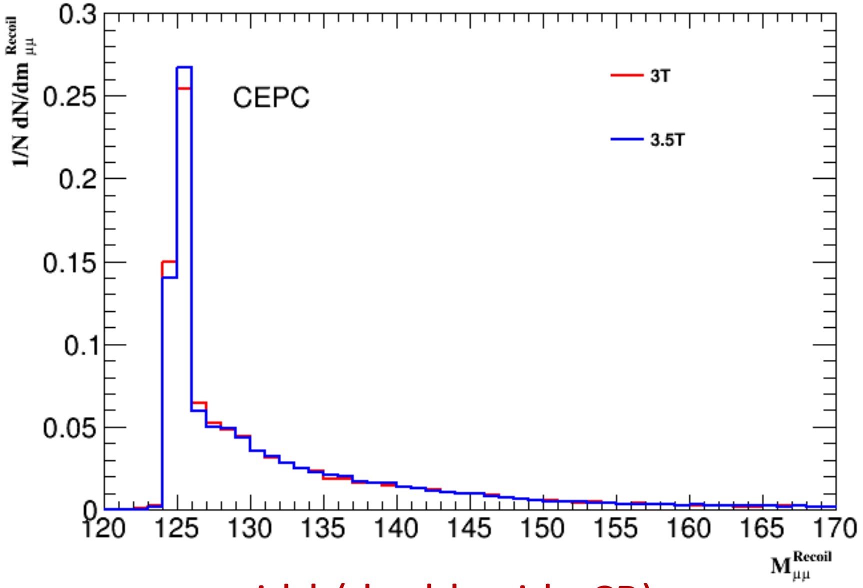
——$\mu\mu\gamma\gamma$ channel

Magnetic field design: 3.5T(preCDR) → 3.0T(present)

Effect: charged particle reconstruction and resolution



width(double-side CB)
3.5T: 1.01±0.73GeV
3.0T: 1.05±0.69GeV



width(double-side CB)
3.5T: 0.21±0.07GeV
3.0T: 0.33±0.08GeV

Comparison due to different magnetic fields

Measurement precision in 3.5T
fast simulation by Feng Wang

Channel	$\boldsymbol{\delta(Br \times \sigma)/(Br \times \sigma)}$
$ZH \rightarrow \mu\mu\gamma\gamma$	30.04%
$ZH \rightarrow \tau\tau\gamma\gamma$	32.14%
$ZH \rightarrow qq\gamma\gamma$	13.56%
$ZH \rightarrow \nu\nu\gamma\gamma$	14.26%
Total	9.0%

Measurement precision in 3.0T
fast simulation present

Channel	$\boldsymbol{\delta(Br \times \sigma)/(Br \times \sigma)}$
$ZH \rightarrow \mu\mu\gamma\gamma$	41.11%
$ZH \rightarrow \tau\tau\gamma\gamma$	
$ZH \rightarrow qq\gamma\gamma$	10.35%
$ZH \rightarrow \nu\nu\gamma\gamma$	13.65%
Total	8.09%

! Not completely repeat

Further work

- Simulation method:

    fast simulation

    ↓ Include photon conversion, track reconstruction, etc.

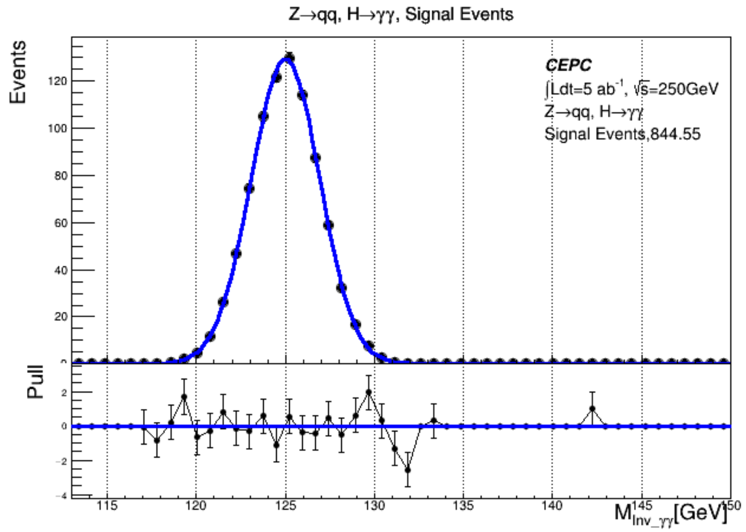
    full simulation

Photon conversion:

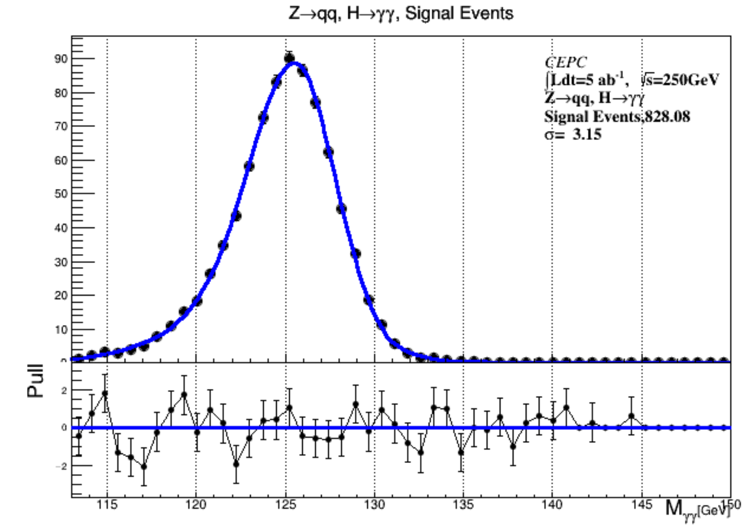
High- energy photon converted to di-electron, which is not considered in fast simulation

- ➢ Lose 7.5% events
- ➢ Broaden the $m_{\gamma\gamma}$ peak

Precision: 10.6%(fast sim.) vs. 12.8%(full sim.)



Fast sim. Width=1.93GeV

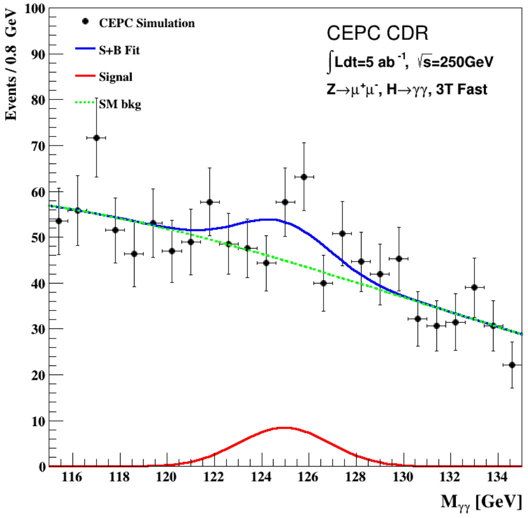


Full sim. Width=3.15GeV

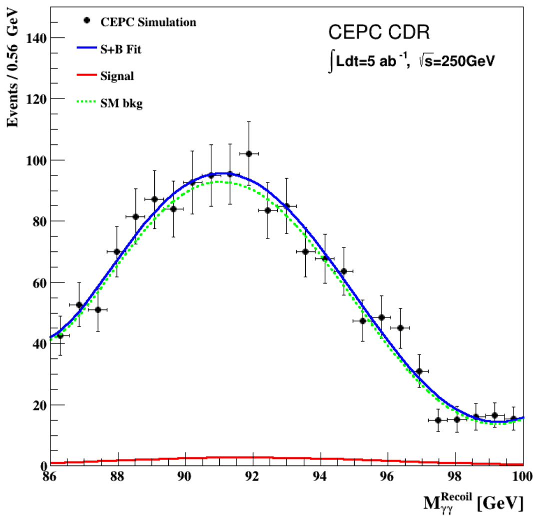
Further work

- Measurement variable (fast sim. $\mu\mu\gamma\gamma$ channel for example)

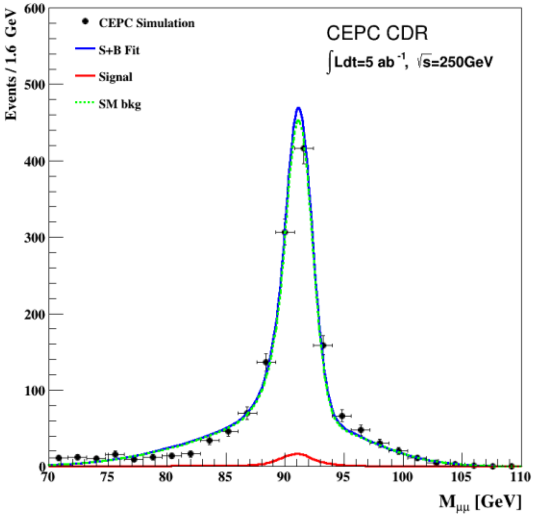
  $m_{\gamma\gamma}, m_{\gamma\gamma}^{recoil}, m_{\mu\mu}, m_{\mu\mu}^{recoil}$



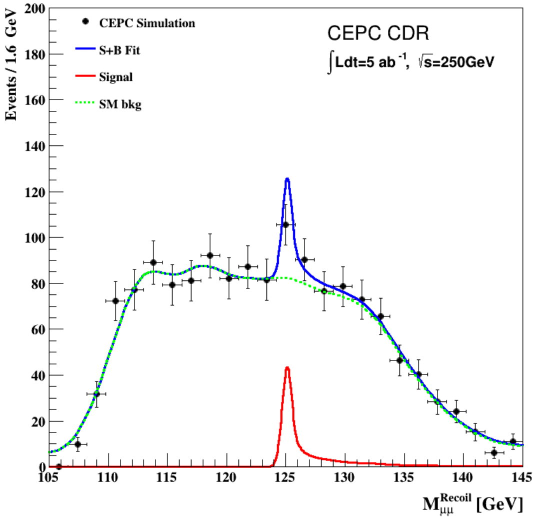
$m_{\gamma\gamma}$
Precision: 47.2%



$m_{\gamma\gamma}^{recoil}$
Precision: 93.8%



$m_{\mu\mu}$
Precision: 81.6%



$m_{\mu\mu}^{recoil}$
Precision: 36.7%

gfy@mail.ustc.edu.cn

Conclusion

- The present $\delta(Br \times \sigma)/(Br \times \sigma)$ for $H \to \gamma\gamma$ reaches to 8.09% with the results combined with 3 sub-channels, and can be approved by optimizing the selection methods.

- The change of magnetic field has limited influences in the measurement precision.

- Next step: apply the full simulation into all sub-channels for a more credible simulation.

Thank you

gfy@mail.ustc.edu.cn

Back up

$ll\gamma\gamma$ channel cut flow

Select $\mu\mu\gamma\gamma$ final state from ll samples

	$\mu\mu$ signal		$\tau\tau$ signal		$\mu\mu$ background		$\tau\tau$ background	
generated	100000		100000		26930165		10000000	
$\mu\mu\gamma\gamma$	138039	138.039%	3274	3.274%	1393678	5.175%	6204	0.062%
E_γ>35GeV	100602	72.879%	2980	91.020%	149107	10.699%	1045	16.844%
$\lvert cos\theta_\gamma \rvert < 0.9$	83759	83.258%	2470	82.886%	58507	39.238%	369	35.311%
10GeV<$pT_{\gamma 1}$<70GeV	83740	99.977%	2470	100.000%	55978	95.677%	358	97.019%
30GeV<$pT_{\gamma 2}$<100GeV	83509	99.724%	2466	99.838%	48173	86.057%	327	91.341%
110GeV<$m_{\gamma\gamma}$<140GeV	81610	97.726%	2449	99.311%	16799	34.872%	126	38.532%
84GeV<$M_{\gamma\gamma}^{recoil}$<103GeV	71416	87.509%	2180	89.016%	3174	18.894%	37	29.365%
125GeV<$E_{\gamma\gamma}$<143GeV	71409	99.990%	2180	100.000%	3048	96.030%	35	94.595%
min|$cos\theta_{\gamma l}$|<0.9	71248	99.775%	2172	99.633%	2704	88.714%	35	100.000%
		71.248%		2.172%		0.010%		0.0004%
scaled to 5 ab-1	55.43		1.66		2677.23		83.18	

$\nu\nu\gamma\gamma$ channel cut flow

	$\nu\nu$ signal		$\nu\nu$ background	
generated	100000		10000000	
$\nu\nu\gamma\gamma$	109362	109.362%	339131	3.391%
E_γ>30GeV	107475	98.275%	241700	71.270%
$\lvert cos\theta_\gamma \rvert < 0.8$	71613	66.632%	31037	12.841%
pT_γ>20GeV	69172	96.591%	10351	33.351%
120GeV<$E_{\gamma\gamma}$<150GeV	68731	99.362%	3783	36.547%
110GeV<$m_{\gamma\gamma}$<140GeV	68727	99.994%	1752	46.312%
		68.727%		0.018%
scaled to 5 ab-1	360.82		4436.2	

Results from Feng Wang ——$\nu\nu\gamma\gamma$ channel

- Cut1: E_γ>35GeV
- Cut2: $\left|cos\theta_\gamma\right| < 0.84$
- Cut3: $M_{\gamma\gamma}^{recoil}$<110GeV
- Cut4: $pT_{\gamma 1}$>37GeV & $pT_{\gamma 2}$>48GeV

Channel	Generate	cut1	cut2	cut3	cut4
nnH_aa	Efficiency	100%	82.94%	61.22%	57.45%
nnH_aa	557	557	462	341	320
nnaa	1276400	401626	105008	16182	13231

Results from Feng Wang —— $qq\gamma\gamma$ channel

- Cut1: E_γ>35GeV
- Cut2: $|cos\theta_\gamma| < 0.9$
- Cut3: 20GeV<$pT_{\gamma 1}$<97GeV & 26GeV<$pT_{\gamma 2}$<100GeV
- Cut4: 85GeV<$M_{\gamma\gamma}^{recoil}$<100GeV
- Cut5: $pT_{\gamma\gamma}$>118GeV
- Cut6: 130GeV<$E_{\gamma\gamma}$<150GeV

Channel	Generate	cut1	cut2	cut3	cut4	cut5	cut6
qqH_aa	Efficiency	100%	89.41%	75.81%	54.38%	34.78%	34.78%
qqH_aa	1633	1633	1460	1238	888	568	568
qqaa	11011914	2027271	803856	228018	93878	24390	19184
ww	42455430	46318	20339	6616	17	0	0
zz	5805561	15716	2913	990	51	17	11
wworzz	19700221	18953	8723	3630	14	14	14

Results from Feng Wang ——$ll\gamma\gamma$ channel

- Cut1: E_{γ}>35GeV
- Cut2: $|cos\theta_{\gamma}| < 0.9$
- Cut3: 20GeV<$pT_{\gamma1}$<93GeV & 30GeV<$pT_{\gamma2}$<100GeV ($\mu\mu$ channel)
  30GeV<$pT_{\gamma1}$<93GeV & 36GeV<$pT_{\gamma2}$<100GeV ($\tau\tau$ channel)
- Cut4: 86GeV<$M_{\gamma\gamma}^{recoil}$<100GeV
- Cut5: 136GeV<$E_{\gamma\gamma}$<148GeV ($\mu\mu$ channel)
  130GeV<$E_{\gamma\gamma}$<148GeV ($\mu\mu$ channel)
- Cut6: min|$cos\theta_{\gamma j}$|<0.9

Channel	Generate	cut1	cut2	cut3	cut4	cut5	cut6
$\mu^+\mu^-H\_aa$	Efficiency	100%	91.56%	72.28%	55.42%	54.21%	42.17%
$\mu^+\mu^-H\_aa$	83	83	76	60	46	45	35
$\mu^+\mu^-aa$	1135659	214725	66703	23786	6427	1887	1026
$\tau^+\tau^-H\_aa$	Efficiency	98.67%	89.33%	61.33%	48.00 %	46.67%	41.89%
$\tau^+\tau^-H\_aa$	75	74	67	46	36	35	31
$\tau^+\tau^-aa$	429975	146922	49424	14533	3562	1778	1410

Results from Yitian——$qq\gamma\gamma$ channel fast sim. VS. full sim.

Fast

	After:	UnCut	Cut1	Cut2	Cut3	Cut4
Signal 914	Run:	39997	39183	29304	25274	22378
	Weighted:	1632	1599	1196	1031	914
	Efficiency:	100%	97.96%	73.27%	63.19%	55.95%
Bkg 32744	Run:	11300000	99092	91418	51406	33601
	Weighted:	11011914	96565	89087	50095	32744
	Efficiency:	100%	0.88%	0.81%	0.45%	0.30%

Full

	After:	UnCut	Cut1	Cut2	Cut3	Cut4
Sig 828	Event:	37154	36540	27597	23821	20296
	Weighted:	1516	1491	1126	972	828
	Efficiency:	100%	98.35%	74.28%	64.11%	54.63%
Bkg 29137	Event:	11300000	92362	85041	51049	29900
	Weighted:	11011914	90007	82872	49747	29137
	Efficiency:	100%	0.82%	0.75%	0.45%	0.26%

Sig:	Fast:914 * 92.5% = 845,	Full: 828
Bkg:	Fast:32744 * 92.5% = 30288(could be different)	Full: 29137

Cut1: E_γ>35GeV, $|cos\theta_\gamma| < 0.99$

Cut2: $(cos\theta_{\gamma1} + 1)\left(cos\theta_{\gamma2} - 1\right) < -0.07$

$(cos\theta_{\gamma1} - 1)\left(cos\theta_{\gamma2} + 1\right) < -0.07$

$|cos\theta_{\gamma1} + cos\theta_{\gamma2}| < 0.9$

Cut3: $\cos\left(p_{\gamma1}, p_{recoil}\right)$> -0.95

$\cos\left(p_{\gamma2}, p_{recoil}\right)$< 0.70

Cut4: $E_{\gamma\gamma} < 0.48M_{\gamma\gamma} + 41GeV$

$E_{\gamma\gamma} > 0.74M_{\gamma\gamma} + 41GeV$