MVA method in $ZH \to qq\gamma\gamma$ analysis in CEPC

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Content

Review of CEPC CDR

CEPC CDR release: Nov 2018, IHEP

Higgs$\rightarrow \gamma\gamma$ physics analysis:

- Design point at CEPC_v4, $\sqrt{s} = 240GeV$, $\mathcal{L} = 5.6ab^{-1}$
- Whizard 1.95 + MoccaC generator, dedicated fast simulation based on parametrized detector response.
- Considered $H \rightarrow \gamma\gamma$ signal and 2 fermion dominant background
- Result: $\delta(Br(H \rightarrow \gamma\gamma) \times \sigma(ZH))$=6.84% in 3 combined channel, and 9.84% in $q\bar{q}\gamma\gamma$ channel.
- Could be improved by applying MVA method

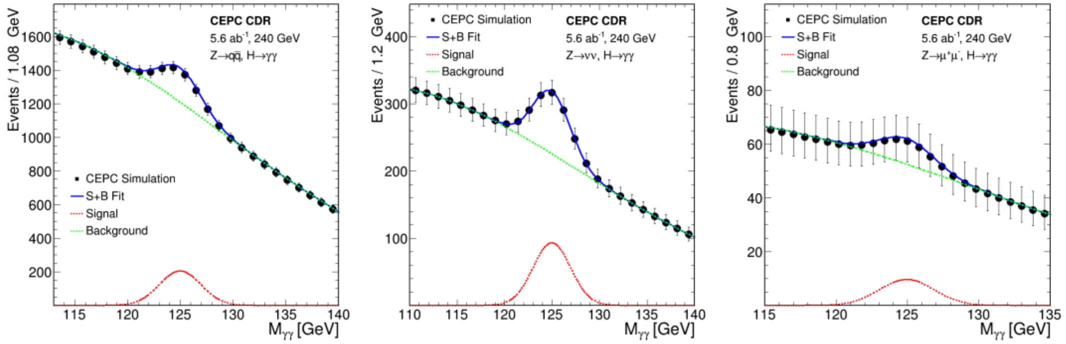


Figure1. di-photon invariant mass distributions in 3 sub-channel

Results

The combination of three sub-channel provides a final result of $\sigma(ZH) \times BR(H \rightarrow \gamma\gamma)$ measurement precision

Sub-channel	$q\bar{q}\gamma\gamma$	$l\bar{l}\gamma\gamma$	$\nu\bar{\nu}\gamma\gamma$	combined
precision	9.84%	23.7%	10.5%	6.84%

Arxiv: 1810.09037
Report in 2018 CEPC WS

MC sample and simulation

In order to keep consistent with CDR:

MC sample:

- Signal: $ee \to ZH \to q\bar{q}\gamma\gamma,$ 100k events.
- Background: $ee \to qq$+radiation photons, 20M events.

Simulation and event reconstruction

- Fast simulation: smear the objects with the resolution and efficiency with parametrized detector response, $\frac{\Delta E}{E} \sim \frac{16\%}{\sqrt{E}} \oplus 1\%$
- Event reconstruction: FSClasser FastJetClustering processer.

  reconstructed 2 on-shell photon with $m_{\gamma\gamma}$~125GeV and 2 jets

  define: γ_1/j_1 as photon/jet with lower energy, and γ_2/j_2 as higher energy one.

Event selection adjustment

Release the event selection criteria for the further MVA method

Selection in CDR:

$E_{\gamma 1} > 35GeV$

$35GeV < E_{\gamma 2} < 96GeV$

$cos\theta_{\gamma\gamma} >$ -0.95, $cos\theta_{jj}$>-0.95

$pT_{\gamma 1} > 20GeV, pT_{\gamma 1} > 30GeV$

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

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

$min|cos\theta_{\gamma j}|$<0.9

Present:

$E_{\gamma 1} > 25GeV$

$35GeV < E_{\gamma 2} < 96GeV$

$cos\theta_{\gamma\gamma} >$ -0.95, $cos\theta_{jj}$>-0.95

$pT_{\gamma 1} > 20GeV, pT_{\gamma 1} > 30GeV$

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

$E_{\gamma\gamma} > 120GeV$

$\min|cos\theta_{\gamma j}|$<0.9

Old	signal	background
Total efficiency	53.08%	0.010%
Scaled to 5.6 ab^{-1}	923.13	29875.6

New	signal	background
Total efficiency	53.34%	0.010%
Scaled to 5.6 ab^{-1}	927.65	31587.6

MVA method

Considered variables:

- P, E, pT, $cos\theta$ of two photon and 2 jets
- P, E, pT, $cos\theta$, recoil mass, pTt, Pt* of di-photon system
- P, E, mass, recoil mass, $cos\theta$ of jj system
- ΔP, ΔE, $\Delta\phi$ between two photon, $\gamma\gamma$-qq
- Cosine angle between 2 photon, 2 jets, 1 photon and 1 jet, $\gamma\gamma$ and jj system.
- Minimum ΔR between any photon and jet

Totally 42 variables

Pt*: Di-photon P projected perpendicular to the di-photon thrust axis.(similar as pTt but replace pT with P)

pTt = $|(\overrightarrow{P_1} + \overrightarrow{P_2}) \times \frac{\overrightarrow{P_1}-\overrightarrow{P_2}}{|\overrightarrow{P_1}-\overrightarrow{P_2}|}|$

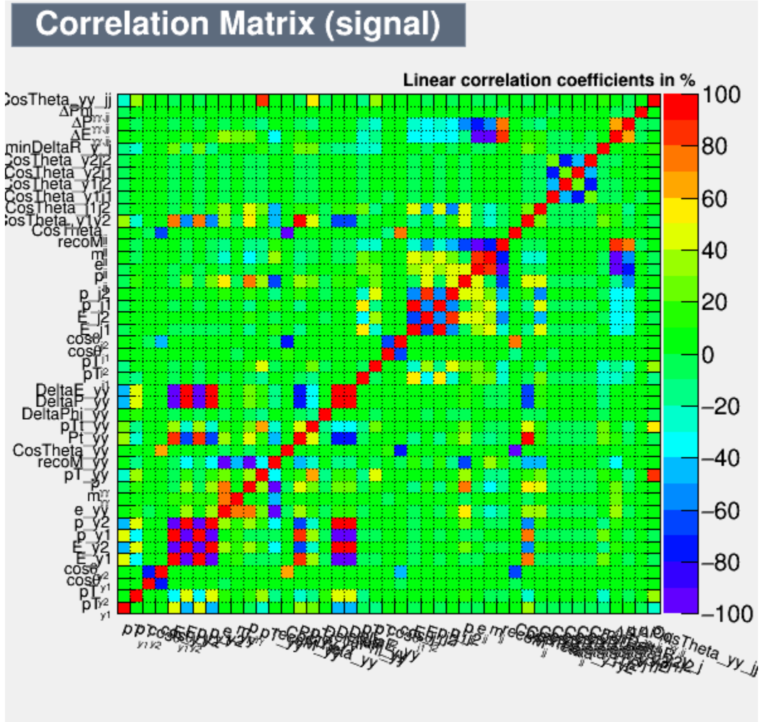
Separation power:

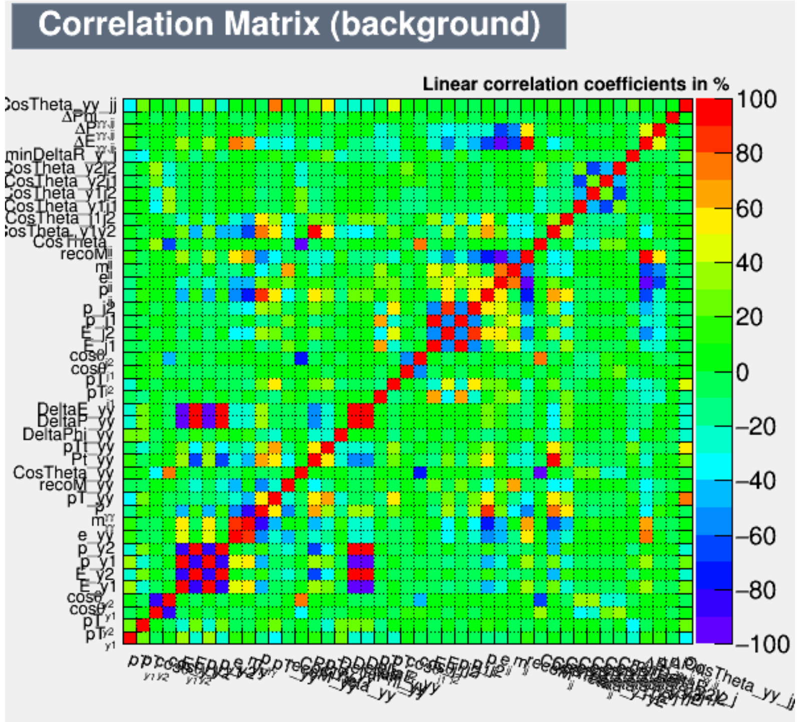
$$< S^2 >= \frac{1}{2}\int \frac{(\hat{y}_s(y) - \hat{y}_b(y))^2}{\hat{y}_s(y) + \hat{y}_b(y)} dy.$$

y: discriminating variable
$\hat{y}_s(y)$and$\hat{y}_B(y)$: the distributions of the variable for signal and background samples

MVA method

Variable correlation matrix





First step: remove high $m_{\gamma\gamma}$-related variable $|Corr_{v-m_{\gamma\gamma}}|$<30%

Second step: remove high co-related variables $|Corr_{v_1-v_2}|$<40%

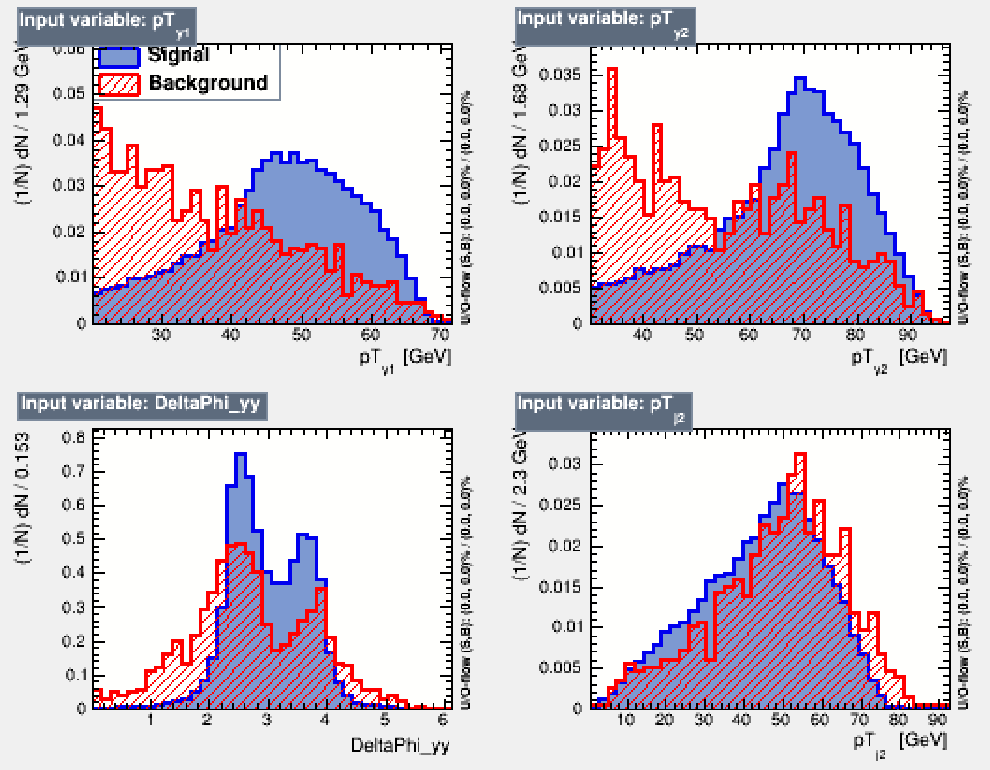
MVA method

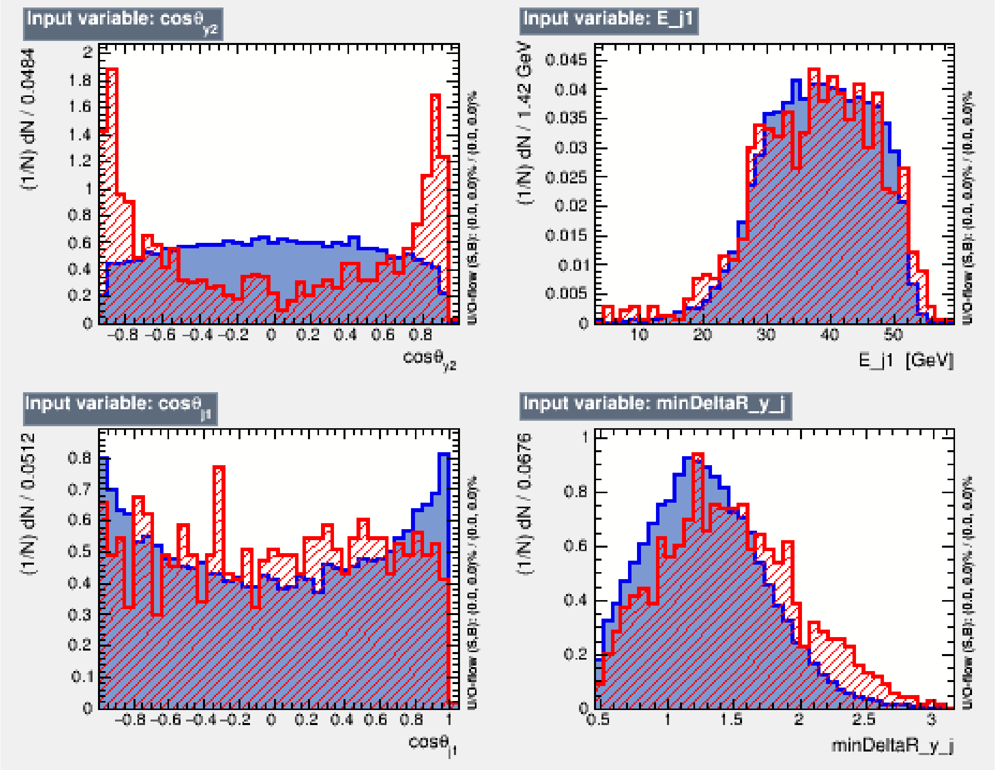
Remaining variables:

Variable	Definition	$\langle S^2 \rangle$
$pT_{\gamma 1}$ / $pT_{\gamma 2}$	pT of $\gamma 1$ or $\gamma 2$	0.39 / 0.30
$cos\theta_{\gamma 2}$	Cosine polar angle of $\gamma 2$	0.39
$\lvert\Delta\Phi_{\gamma\gamma}\rvert$	$\lvert\Delta\Phi\rvert$ between 2 photon	0.30
$min\Delta R_{\gamma,j}$	Minimum ΔR between photon and jet	0.09
$cos\theta_{j1}$	Cosine polar angle of $j1$	0.08
pT_{j2}	pT of $j2$	0.08
E_{j1}	Energy of $j1$	0.03
$cos\theta_{\gamma 2-j2}$	Cosine value of the angle between $\gamma 2$ and $j2$	0.03
$cos\theta_{\gamma 1-j1}$	Cosine value of the angle between $\gamma 1$ and $j1$	0.02
$\lvert\Delta\Phi_{\gamma\gamma-jj}\rvert$	$\lvert\Delta\Phi\rvert$ between $\gamma\gamma$ and jj system	0.01
$cos\theta_{\gamma\gamma-jj}$	Cosine value of the angle between $\gamma\gamma$ and jj system	0.01

BDT training parameter:
“BDTG”,“NTrees=900:nEventsMin=50:BoostType=Grad:Shrinkage=0.06:UseBaggedGrad:GradBaggingFraction=0.6:nCuts=20:MaxDepth=3”

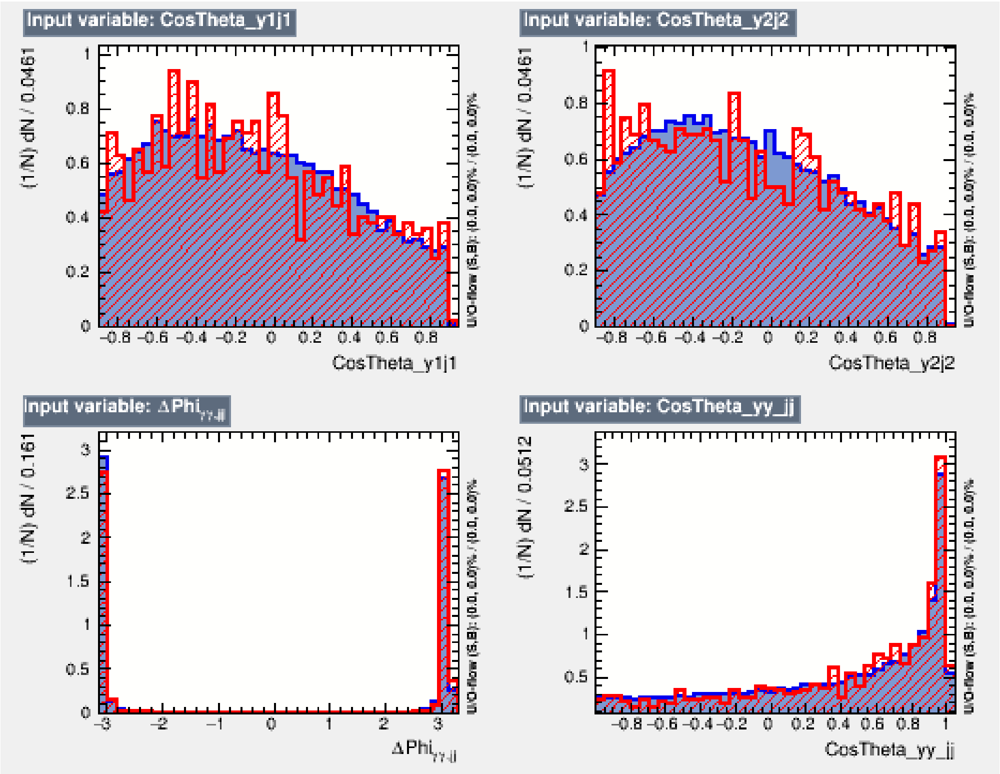
MVA method

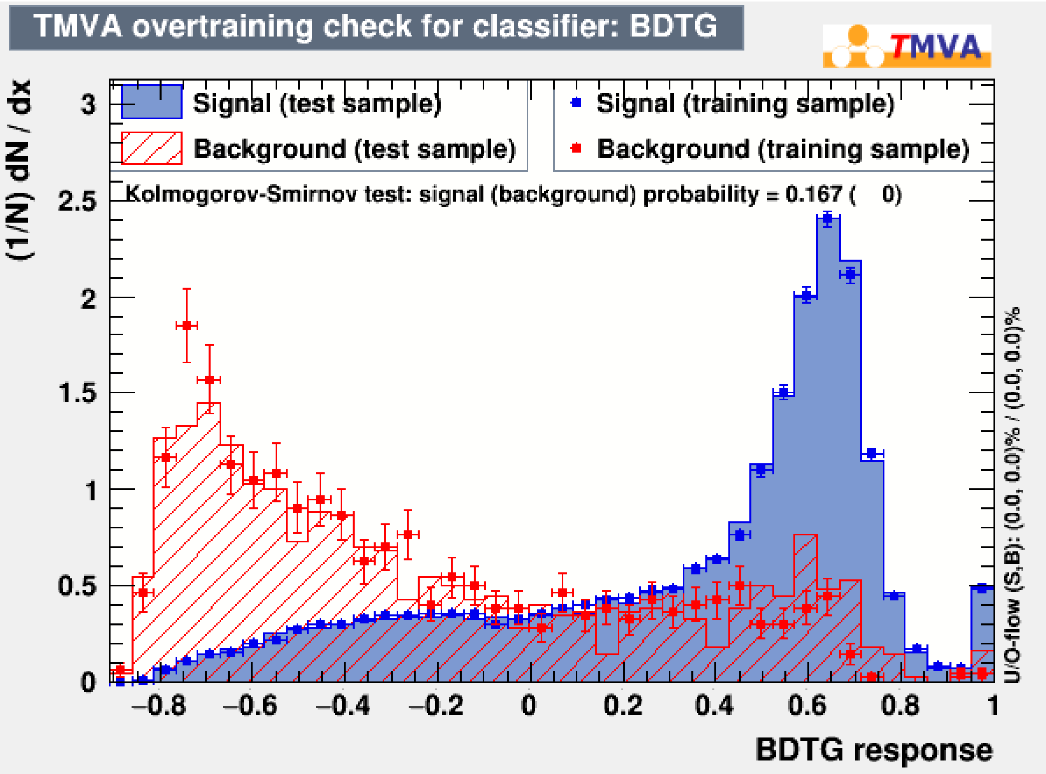




MVA variables distribution for signal(blue) and background(red)

MVA method





MVA variables distribution(left) and BDT response(right) for signal(blue) and background(red)

$|Corr_{m_{\gamma\gamma}-BDTout}|$ is 5.4% in signal and 17% in background

2-D signal and background fit

Fit the sample in 2 dimension

- Di-photon invariant mass $m_{\gamma\gamma}$

  Signal: Gaussian PDF

  Background: 2nd polynomial exponential PDF

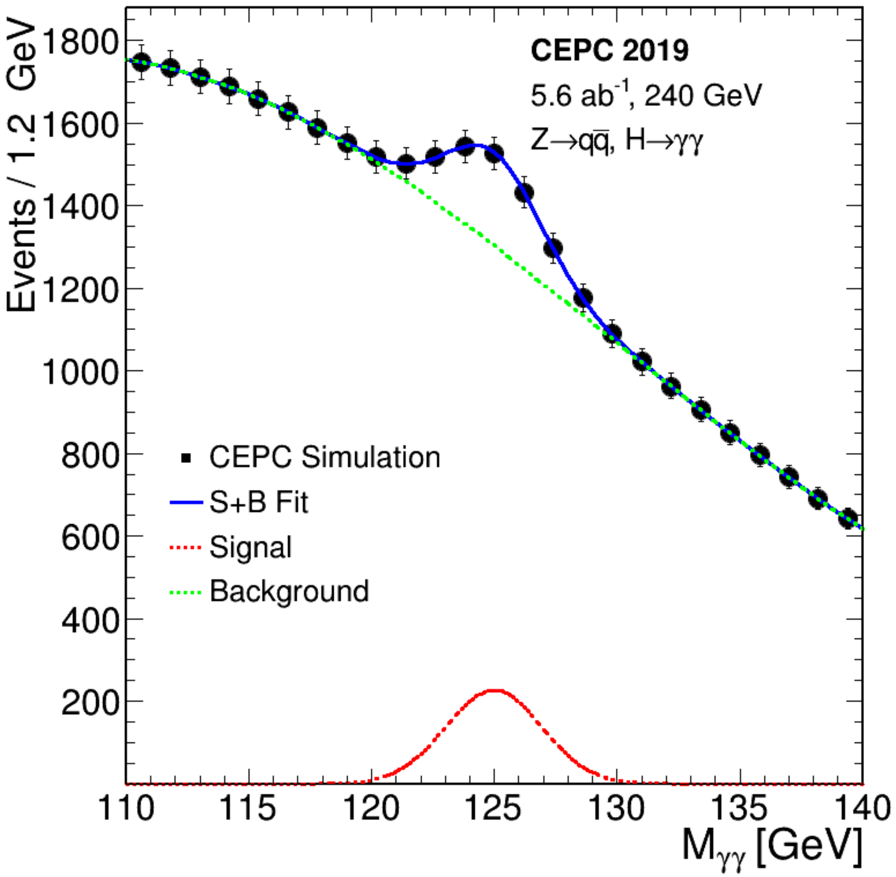
  $$PDF_{m_{\gamma\gamma}} = \mu \times N_{sig}^{SM} \times PDF_{sig} + N_{bkg} \times PDF_{bkg}$$

- BDT response ($\left|Corr_{m_{\gamma\gamma}-BDT}\right|$ <20%)

  Binned PDF for signal and background

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

- $PDF_{2D} = PDF_{m_{\gamma\gamma}} \times PDF_{BDT}$



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Results

Fit result in $ee \to ZH \to qq\gamma\gamma$ channel

$$\mu = 1.000 \pm 0.066$$

	$qq\gamma\gamma$ channel	3 Combined channel
Pre MVA (CDR result)	9.84%	6.80%
After MVA	6.56%	5.39%
Improvement	33%	21%

*combined results are based on MVA $qq\gamma\gamma$ + no MVA $(ll\gamma\gamma + \nu\nu\gamma\gamma)$

FCC-ee case:

- 3% @240GeV, 10ab^{-1}, based on CMS ECal resolution, TLEP physics, 2013
- 9% @240GeV, 5ab^{-1}, FCC-ee CDR, 2018

Future work

MVA method in $ZH \to ll\gamma\gamma, ZH \to \nu\nu\gamma\gamma$ channel

- Estimation: if the same improvement(30%) could be reached in these two channel

  $ll\gamma\gamma$ channel: 23.7% ➡ 16.6%

  $\nu\nu\gamma\gamma$ channel: 10.5% ➡ 7.4%

  combined results after MVA: ~4.7%

Simulation sample

- Update the fast simulation sample to full simulation

  Signal: broaden the $m_{\gamma\gamma}$ distribution, lose ~7.5% events

  Background: include more high energy photon, might be excluded by reconstruction algorithm.

Conclusion

MVA method improvement in CEPC $H \to \gamma\gamma$ analysis

- $qq\gamma\gamma$ channel has been tested: 33% improvement in one sub-channel, reaching the result $\delta(Br \times \sigma) = 6.56\%$
- Prospect: 4.7% combined precision could be reached after MVA in 3 channels

Next step towards TDR

- Full simulation samples are ready, but a accurate reconstruction algorithm is necessary
- Based on previous study, a ~20% decrease would appear after converting to full simulation

Back up

Correlation matrix (after removing $m_{\gamma\gamma}$-related variables)