$e^+e^- \to \gamma\gamma$ as luminosity process at CEPC

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Outline

1. Motivation
2. MC samples and selections
3. Distributions over main parameters
4. Possible systematical uncertainty sources
5. Summary

Motivation

According to the article [1] ee $\rightarrow$ ee theoretical uncertainty is limited by hadronic vacuum polarization at the level 10^{-4}, while for ee $\rightarrow \gamma\gamma$ process hadronic loops contribution is less then 10^{-5}.

Current MC generators uncertainty for ee $\rightarrow \gamma\gamma$ is 10^{-3} at M_Z tested with BABAYagaNLO [2], if some NNLO corrections from [1] are applied the accuracy ~ 10^{-4} could be reached. To get accuracy 10^{-4}-10^{-5} a full calculation of NNLO QED corrections and, eventually, of two-loop weak contributions will be ultimately needed.

[1] Carlo M. Carloni Calame et all, Physics Letters B, Volume 798, 2019, 134976 (corrections for the $\theta>20°$ are present in this paper)
[2] G. Balossini et all, Phys.Lett.B663:209-213,2008

MC samples

We using CEPCSW tdr25.3.3, all MC is for E = 91.2 GeV

$ee \to \gamma\gamma$ 1M events produced with BABAYagaNLO (θ>10°) and converted to stdhep:
/cefs/higgs/alexey/Converter/gg_cepc_E91_stdhep/

Reco level output: /cefs/higgs/alexey/SamplesProd/E91_gg/Reco/

MiniTree /cefs/higgs/alexey/TestNt/Init.C

$ee \to ee$ 200k events is taken from:
/cefs/higgs/zhagkl/stdhep/E91.2/2fermions/E91.2.Pe1e1.e0.p0.whizard195/

$ee \to \mu\mu$ 1M events from /cefs/higgs/wanjiawei/work/E91_e2e2/Reco/

$ee \to \tau\tau$ 200k events /cefs/higgs/wanjiawei/work/E91_e3e3/Reco/

$ee \to bb$ 100k events /cefs/higgs/wanjiawei/work/E91_bb.e0.p0/Reco/

$ee \to cc$ 100k events /cefs/higgs/wanjiawei/work/E91_cc.e0.p0/Reco/

Selections

Selections:

$1 < nn < 10$ – number of neutral particles

$E_{\gamma 2} > 5$ GeV – energy of the second energetic neutral particle

$nc=0$ – number of charged particles

$40 <$ Etot < 100 GeV – sum of all particle energies (PFO_E)

$M_{2\gamma} > 40$ GeV – invariant mass of the 2 most energetic neutral particles

$20° < \theta_{1,2} < 160°$ – polar angle of the 2 most energetic neutral particles

Not used Ecal, $\Delta\varphi$, $\Delta\theta$ (could be used if some background will be present)

ee $\rightarrow \gamma\gamma$ 497531 selected from 1M (if no $\theta_{1,2}$ cut 753790, correspond to 75% efficiency)

ee $\rightarrow$ ee 0 selected from 200k events

ee $\rightarrow \mu\mu$ 0 selected from 1M events

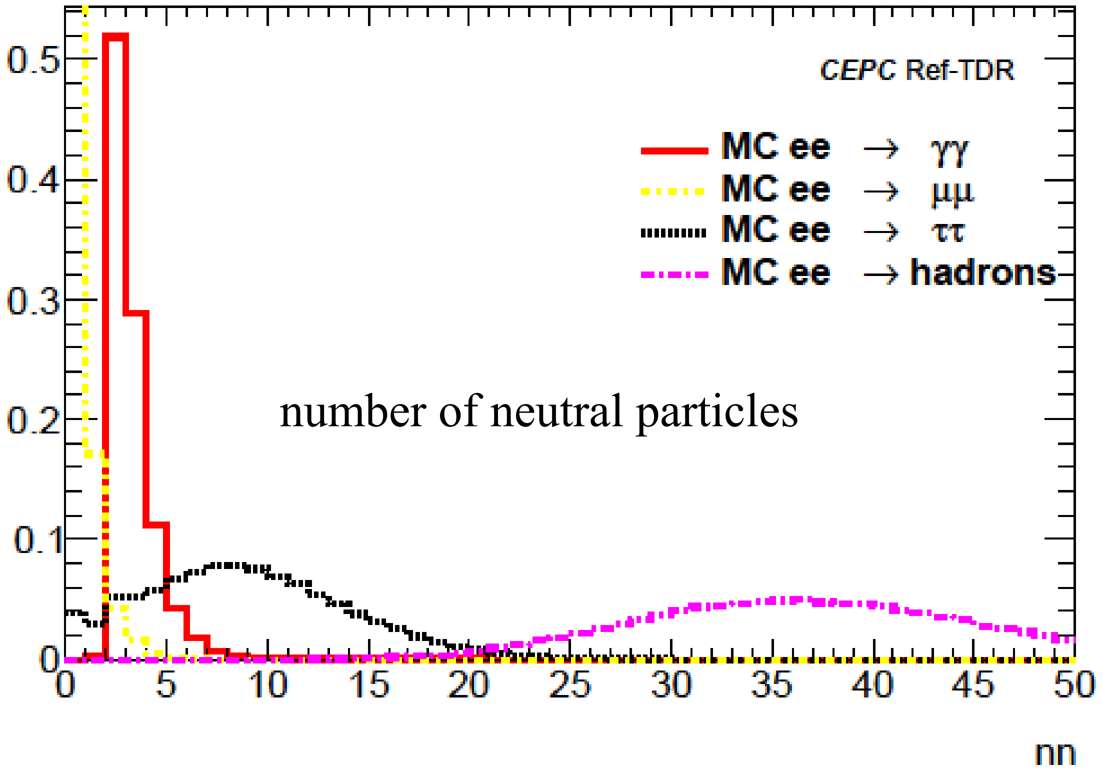
ee $\rightarrow \tau\tau$ 0 selected from 200k events

ee $\rightarrow$ bb 0 selected from 100k events

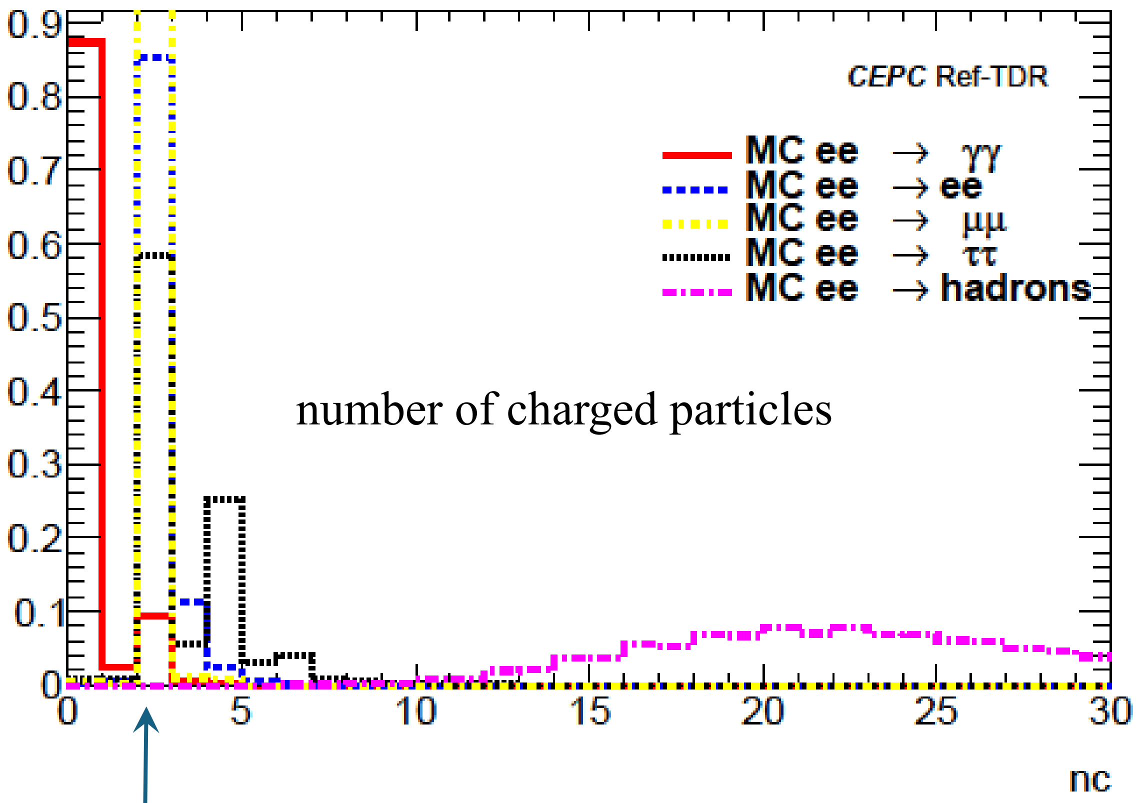
ee $\rightarrow$ cc 0 selected from 100k events

Distributions of the selection variables are at the next slides.

Selections: number of particles



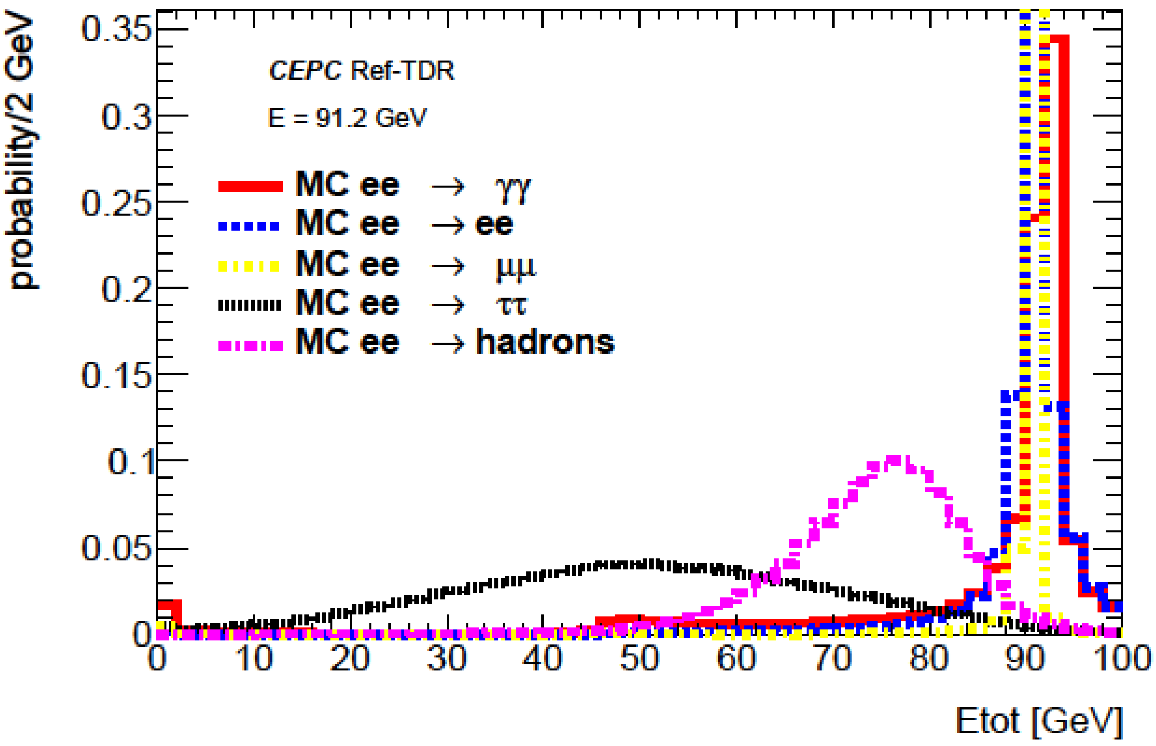
Strong suppression of the hadronic background

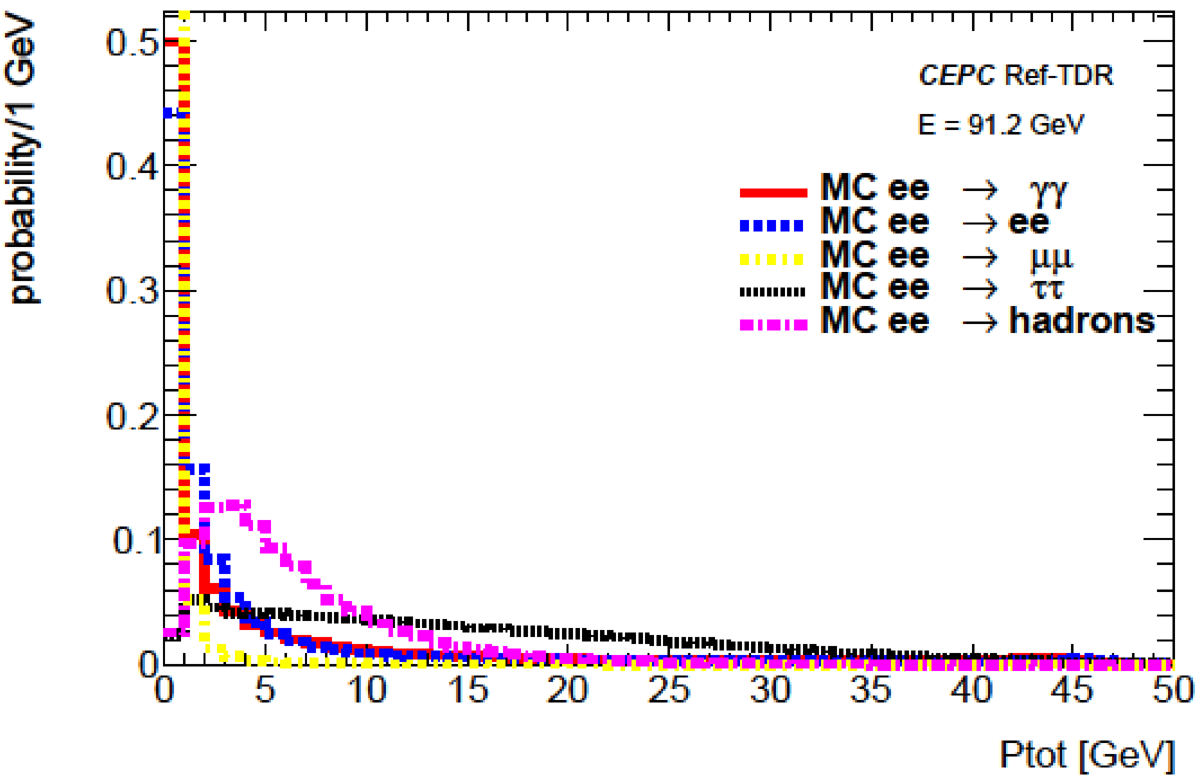


ee → γγ with conversion

Photon conversion should be studied in detail with data to control systematics of the nc==0 selection

Selections: total energy and momentum



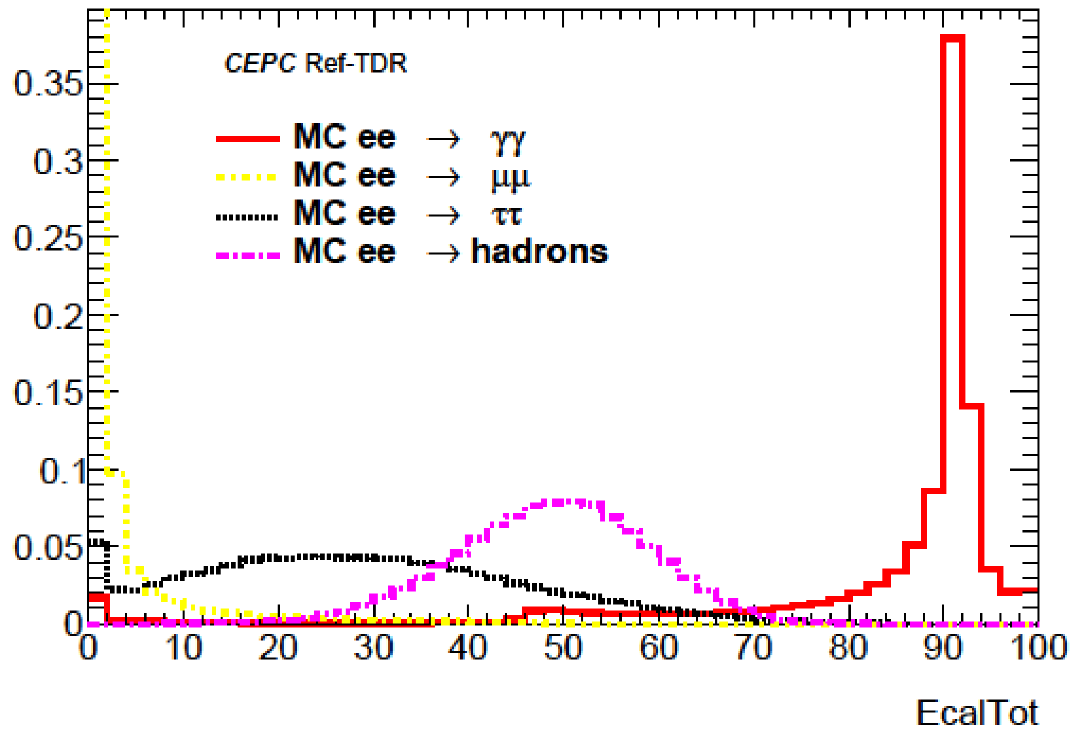


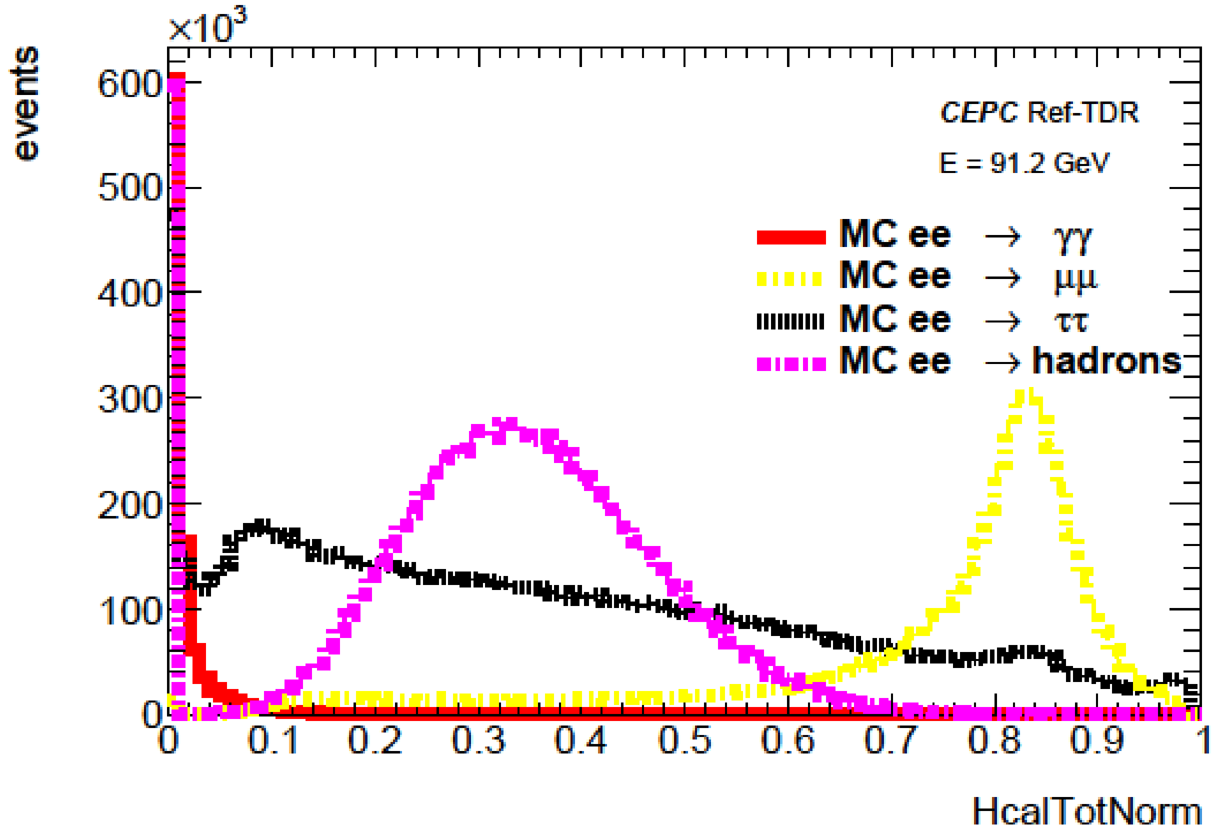
Etot = Sum PFO_E

Ptot = $|\text{Sum } \vec{p}|$

Processes with neutrino contamination in the final state could be rejected by energy and momentum conservation

Selections: Ecal and Hcal energy deposition

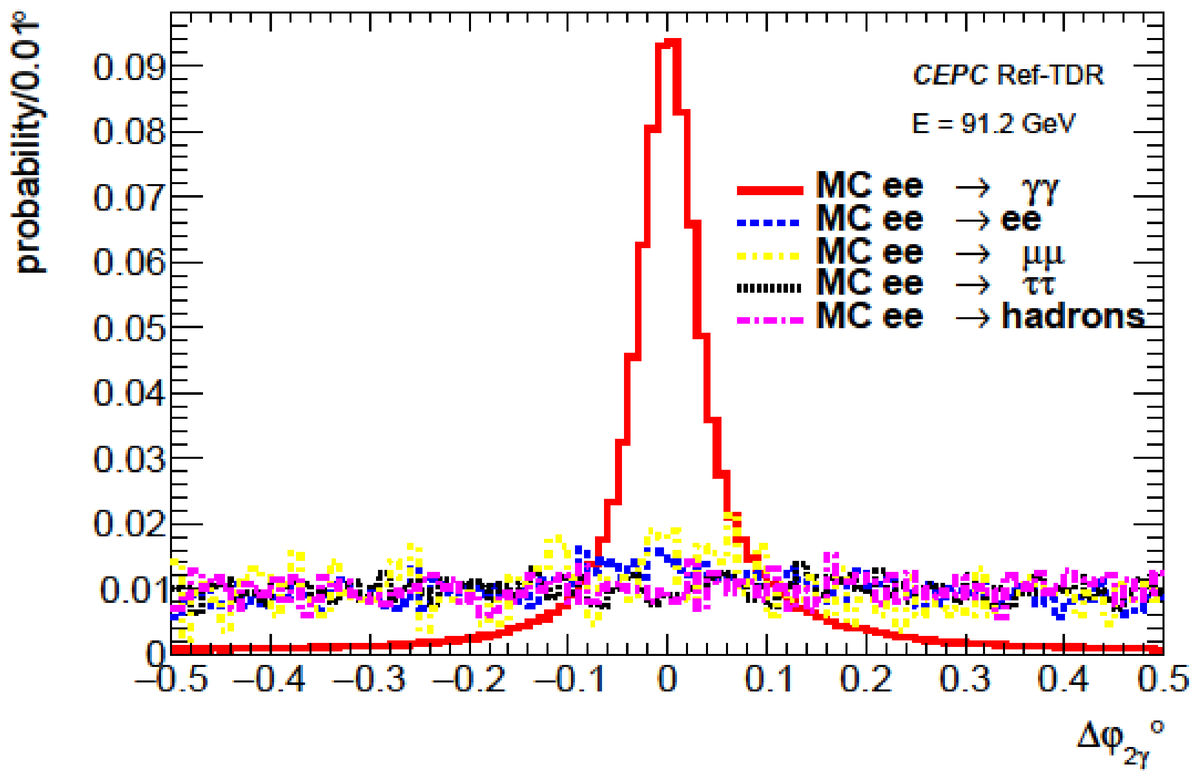


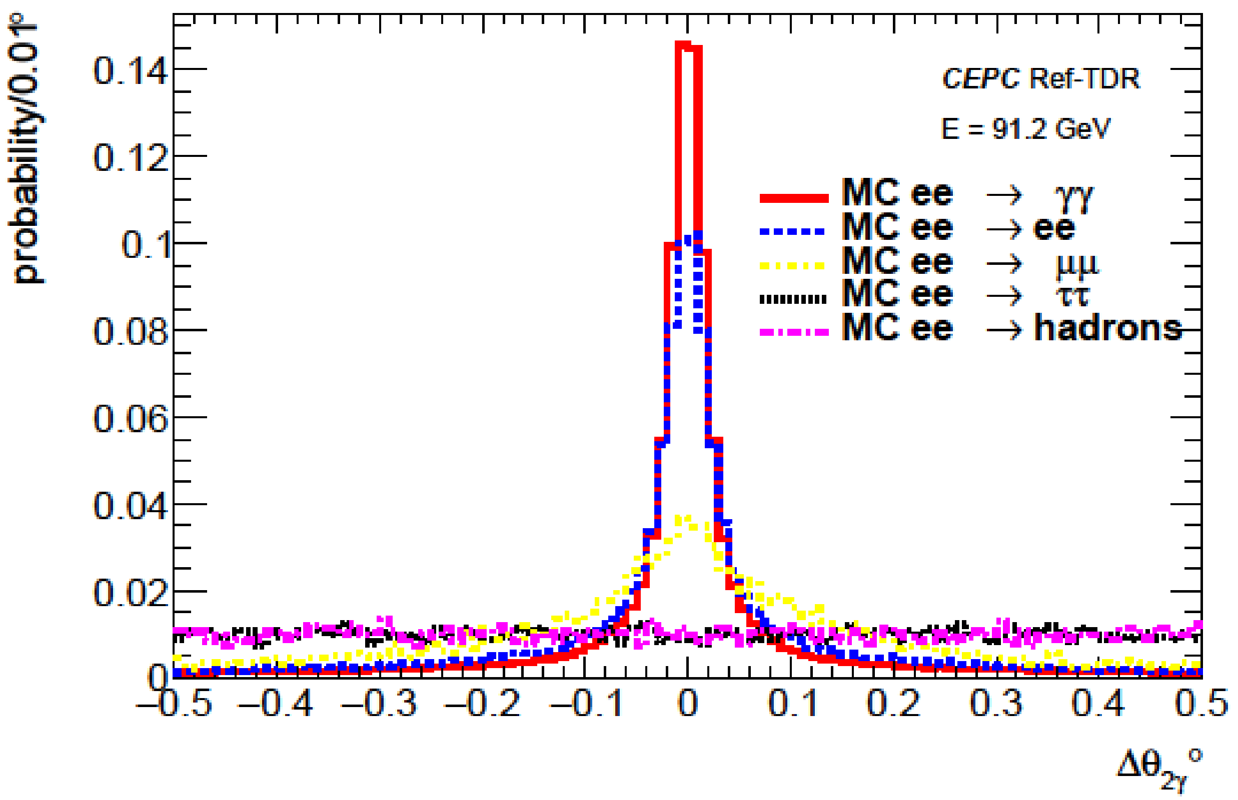


γγ final state could be separated with total energy deposition at electromagnetic calorimeter. e+e- final state should have close to 2γ energy deposition in Ecal , but there is some issue (see backup slides).

HcalTotNorm = Sum(Hcal_E)/(Sum(Hcal_E)+Sum(Ecal_E))
Normalized hadronic leakage could be used to suppress muons, hadrons, taus.

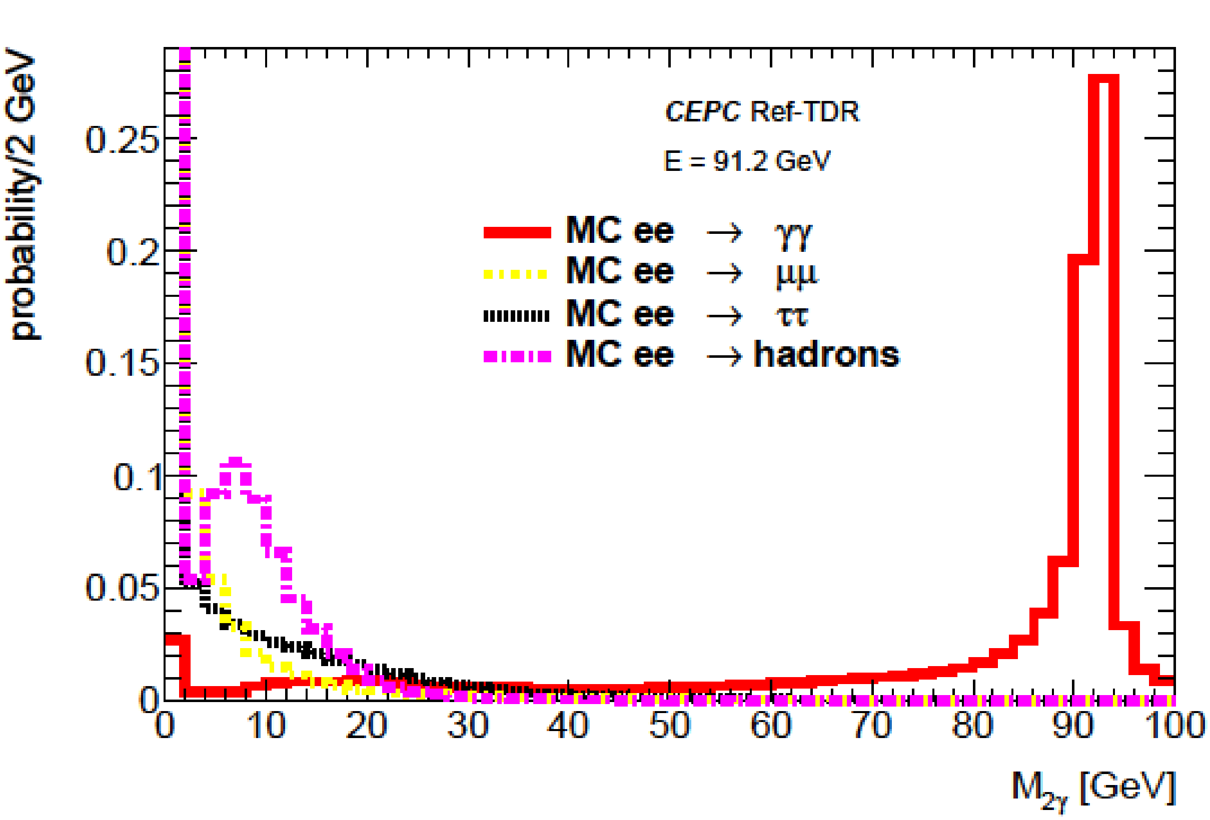
Selections: collinearity



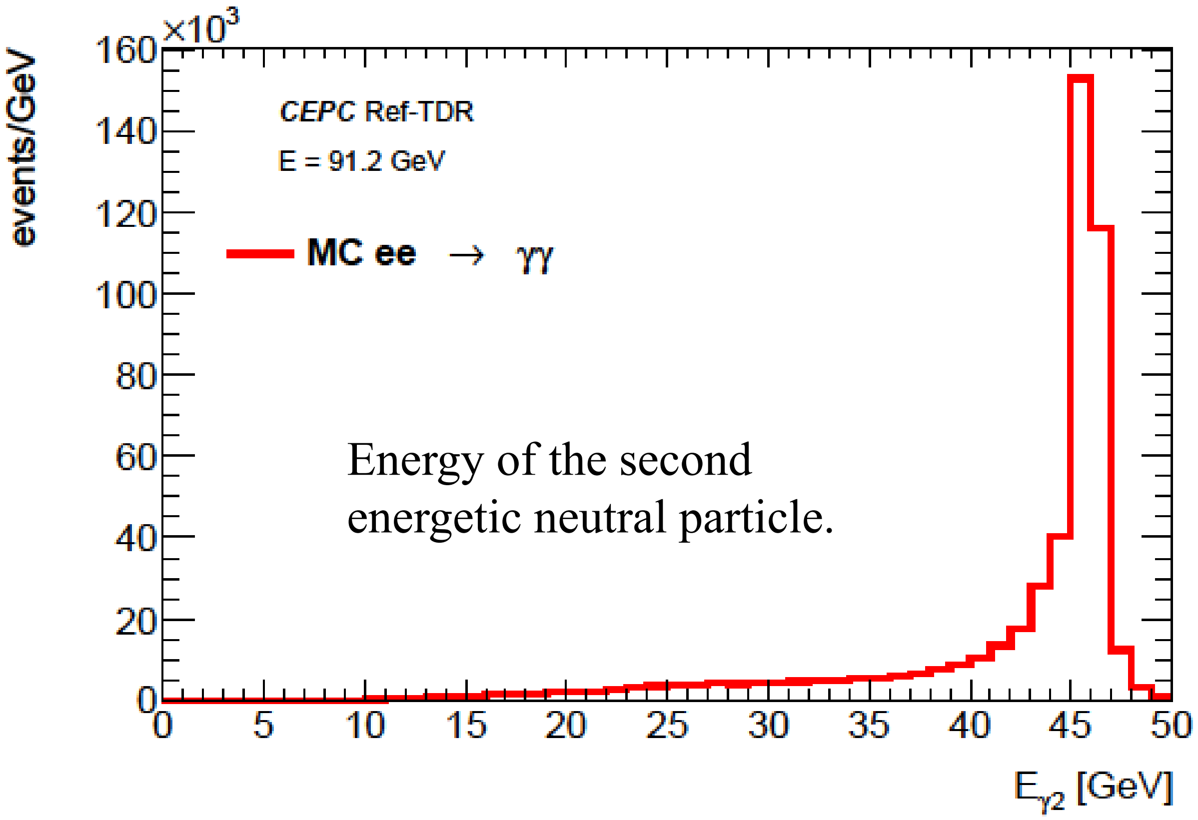


Collinearity between 2 most energetic neutral particles is shown.

Selections: 2γ invariant mass, and energy of the second energetic photon

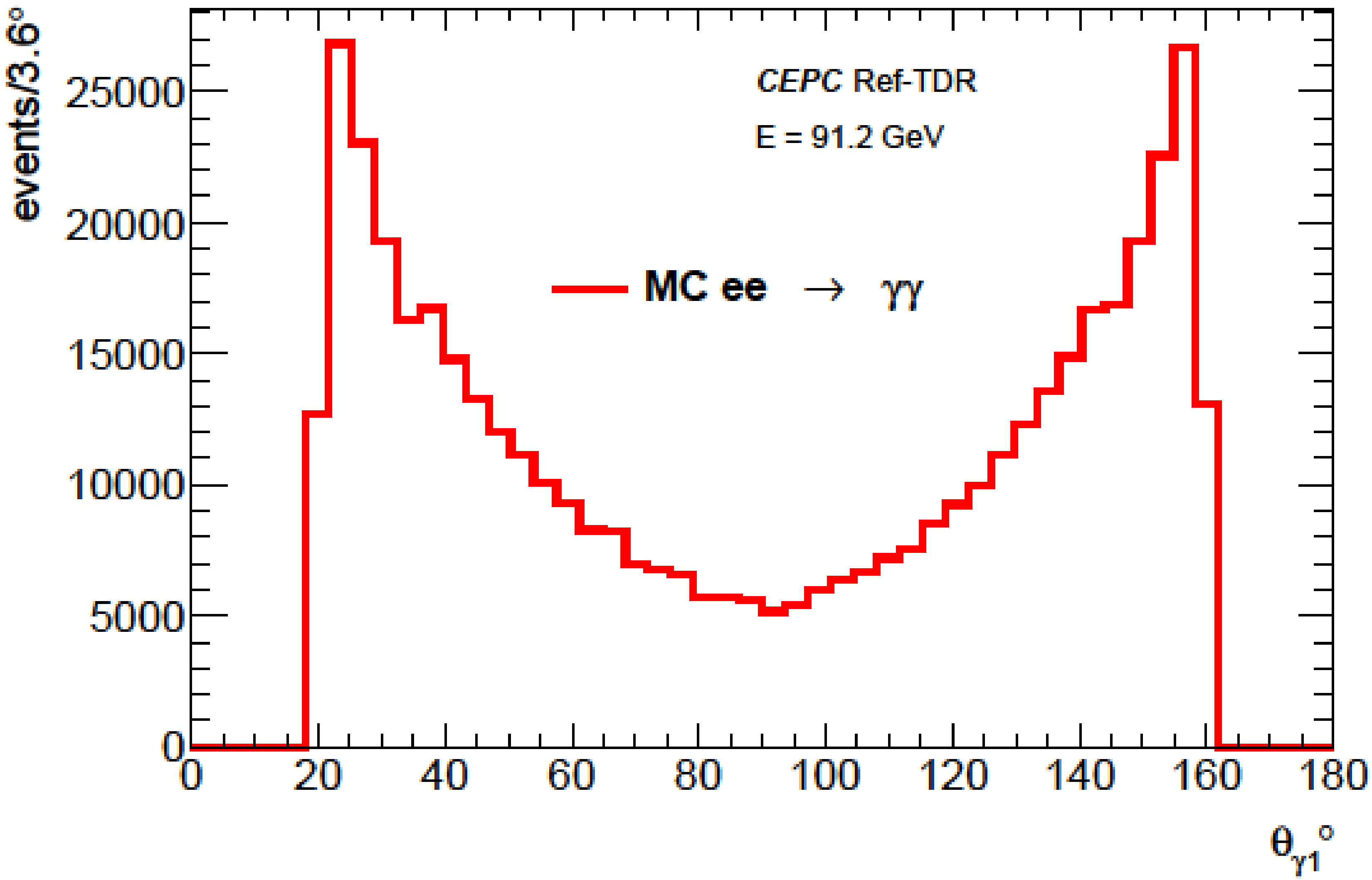


At E = M_Z invariant mass of 2 photons allow to select **ee → γγ.**

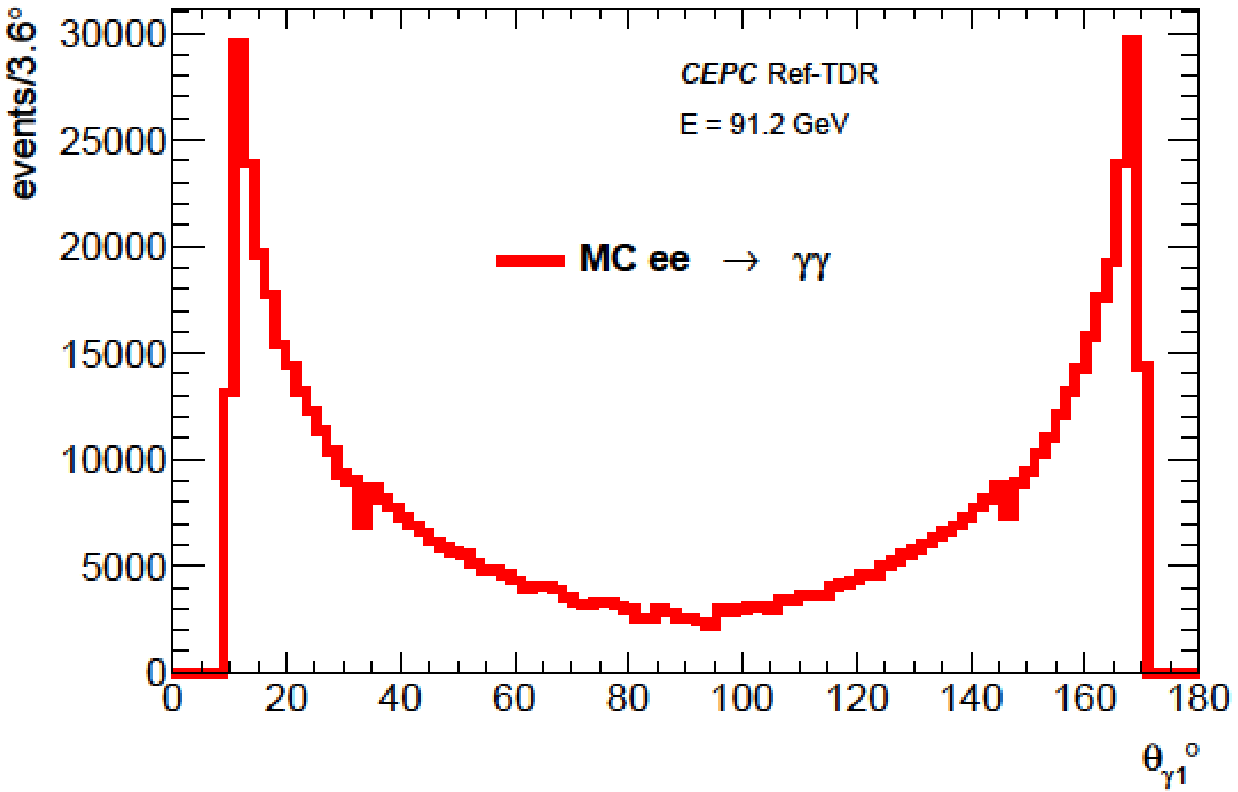


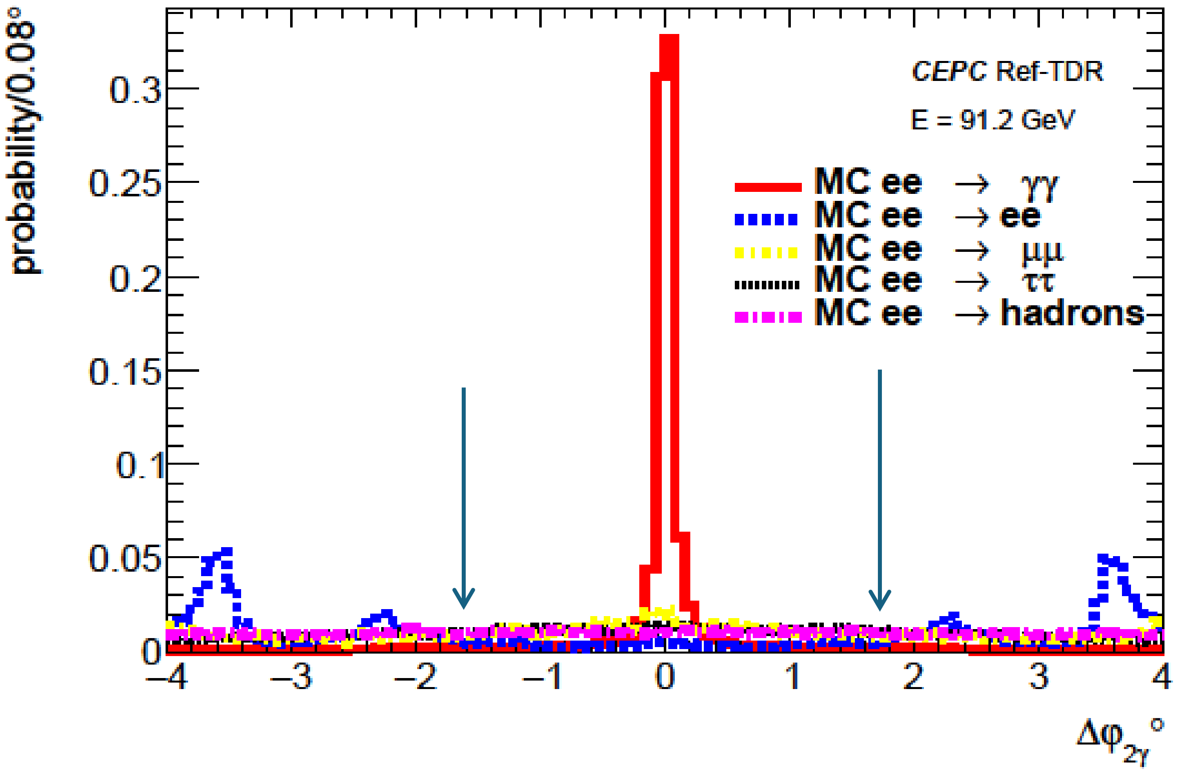
Minimal photon energy is used to calculate number of neutral particles.

Angular distribution for $ee \to \gamma\gamma$ process.



Relaxed selection 10<θ<170°





If we want to increase statistics by using 10<θ<170° selection then 10^{-4} contamination from the ee → ee process appears.

To suppress this ee → ee background the condition **abs($\Delta\varphi_{2\gamma}$) <1.75** could be used. In this case:

ee → γγ 688081 events selected from 1M (~69% efficiency)

ee → ee 0 events selected from 200k (without abs($\Delta\varphi_{2\gamma}$) <1.75 2 events selected)

Possible systematical uncertainty sources

1. Theoretical total cross section should be known with accuracy 10^{-4}
2. γ – conversion should be studied with data
3. Detector acceptance at small angles (10-20°), beam spot position and width
4. Scale and resolution of the electromagnetic calorimeter, trigger efficiency
5. Backgrounds (are expected to be small: 0 events passed the selection criteria, and several cuts as Ecal, $\Delta\varphi$, $\Delta\theta$ are not used yet)

Comparison with $ee \to ee$ could be used to check the systematical uncertainty.

$ee \to \gamma\gamma$ cross section dependence on energy (line shape) could be used to control background.

Summary

1. ee → γγ luminosity measurement with main detector is possible at CEPC. This will be offline luminosity measurement, not the online monitoring.
2. Theoretical uncertainty could be decreased to the level 10^{-5} if NNLO calculations will be available
3. The backgrounds are expected to be small
4. Resolutions of the detector systems are well enough for precision ee → γγ study

Cross section $ee \to \gamma\gamma$

Cross section is calculated with BABAYagaNLO [2]. Expected systematical uncertainty is 10^{-3}. To get the uncertainty 10^{-4}, corrections from [2] should be used (calculated for $20<\theta<160°$).

$\sigma(5<\theta<175°)$ = 100.181 +/- 0.019 pb
$\sigma(8<\theta<172°)$ = 80.299 +/- 0.035 pb
$\sigma(10<\theta<170°)$ = 71.602 +/- 0.034 pb

$\sigma(ee \to ee\ 5<\theta<175°)$ = 17375.6 +/- 2.4 pb

$\sigma(20<\theta<160°)$ = 40.870(4) pb (calculated at [1] w h.o.)
Only this calculation have 10^{-4} accuracy

$\sigma(ee \to ee\ 20<\theta<160°)$ = 2625.9 pb

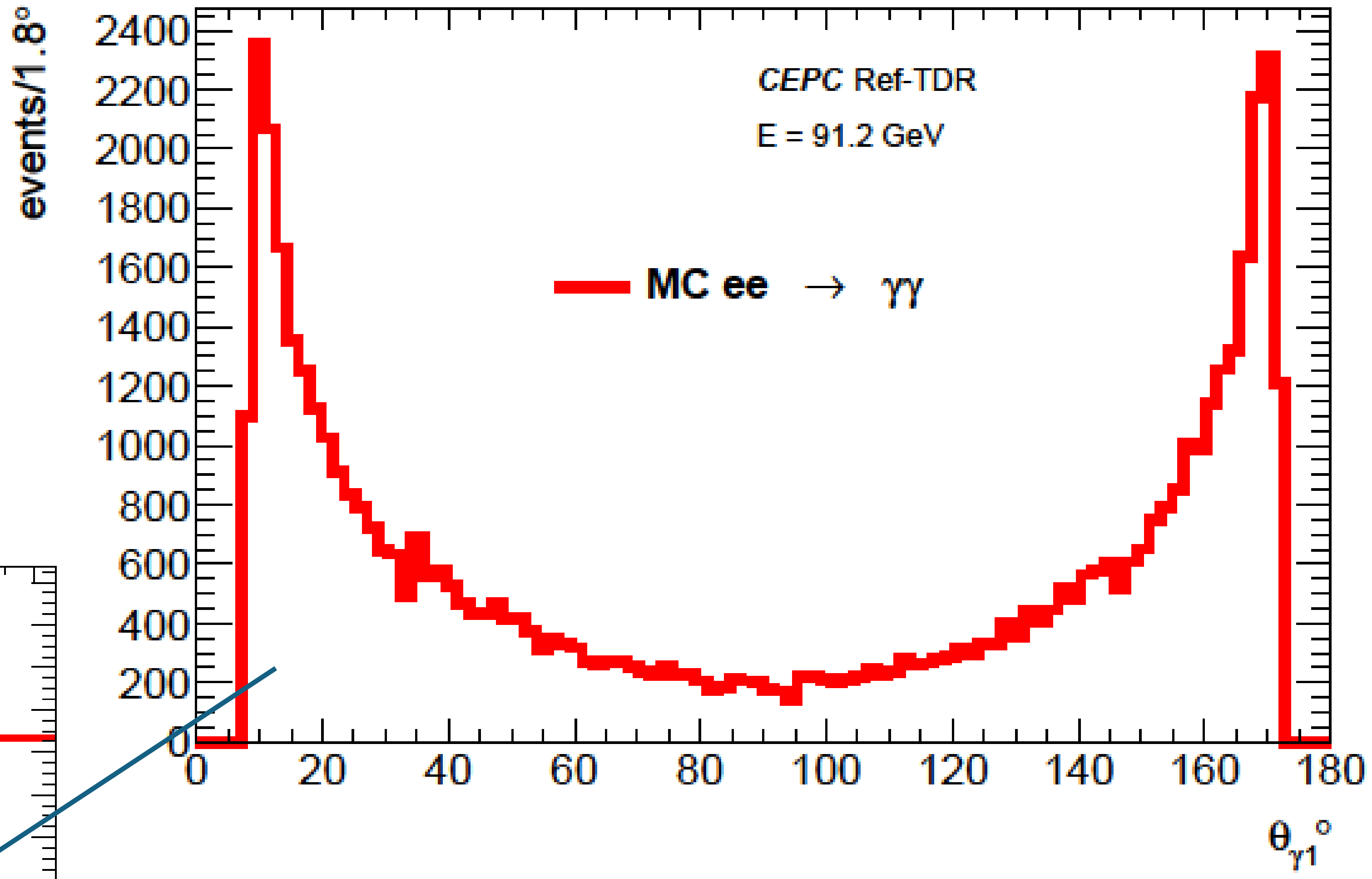
$\sigma(5<\theta<175°\ \&\&\ |\Delta\theta|<10°)$ = 81.740 +/- 0.003 pb
$\sigma(8<\theta<172°\ \&\&\ |\Delta\theta|<10°)$ = 65.978 +/- 0.006 pb
$\sigma(10<\theta<170°\ \&\&\ |\Delta\theta|<10°)$ = 58.720 +/- 0.005 pb

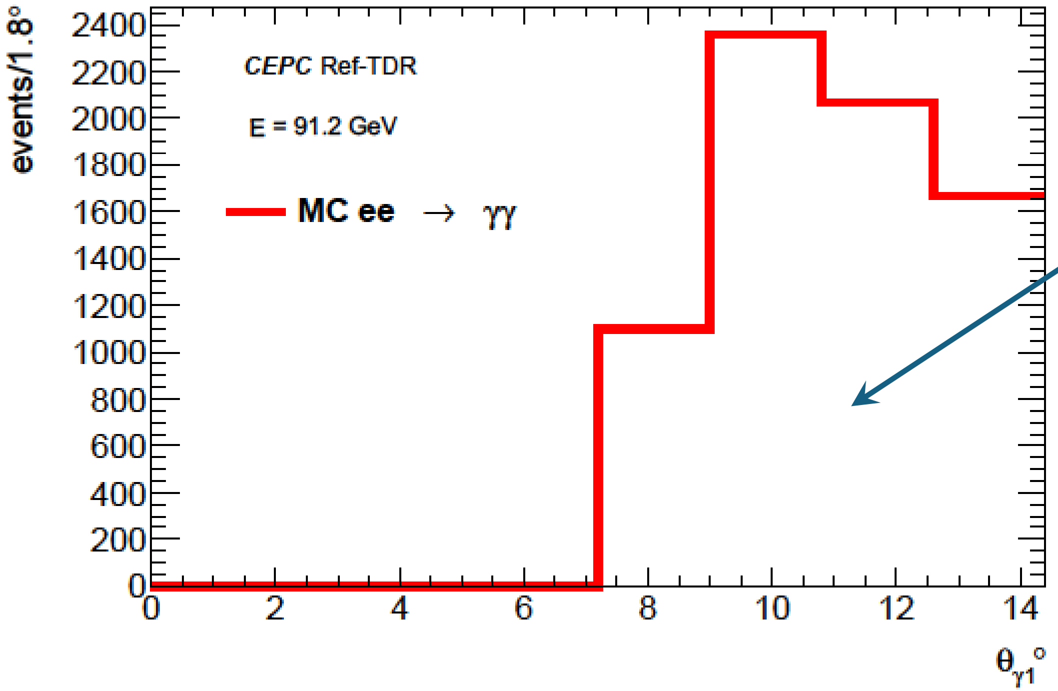
[1] Carlo M. Carloni Calame et all, Physics Letters B, Volume 798, 2019, 134976 (corrections for the θ>20° are present in this paper)
[2] G. Balossini et all, Phys.Lett.B663:209-213,2008

At L= 1.15 pb-1 s-1 and σ(10°) = 71 pb we have 81 event/s. To get 10^8 events 14 days required.
For 10^{-3} accuracy ~2 hour required.

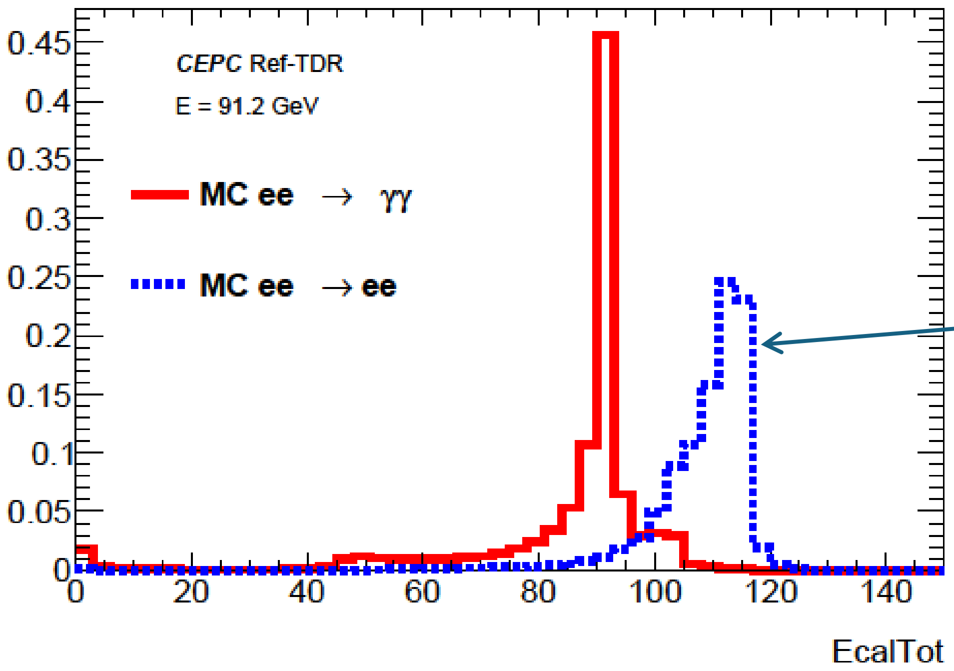
Relaxed selection 5<θ<175°

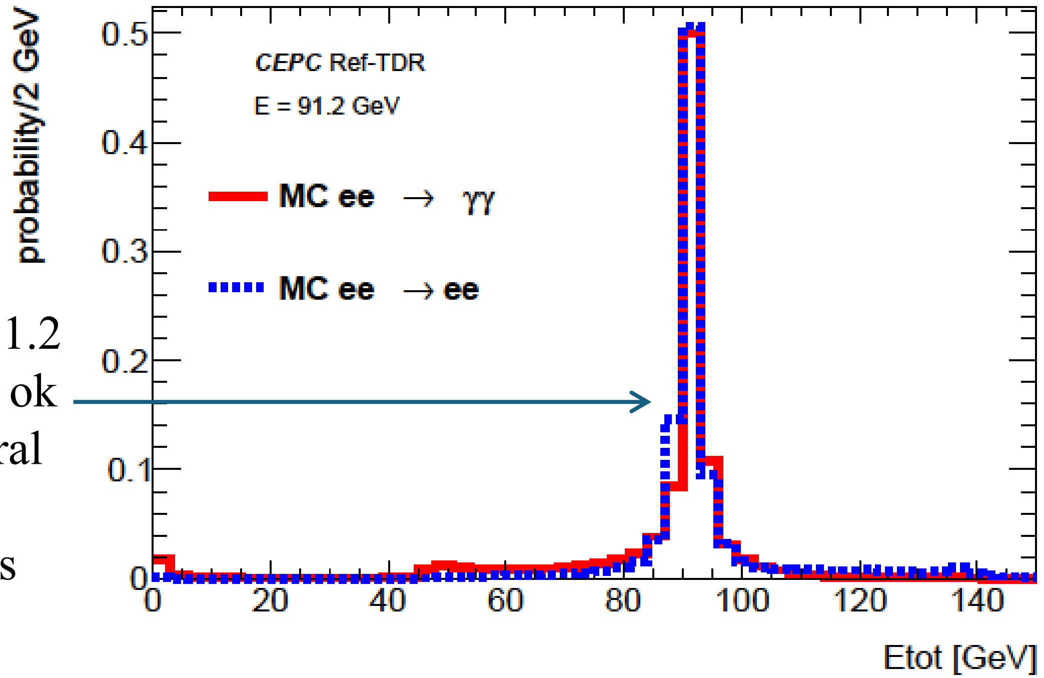
Special sample ee → γγ 500 K events produced with BABAYagaNLO (θ>5°) and converted to stdhep: /cefs/higgs/alexey/Converter/gg_cepc Th5_E91_stdhep/



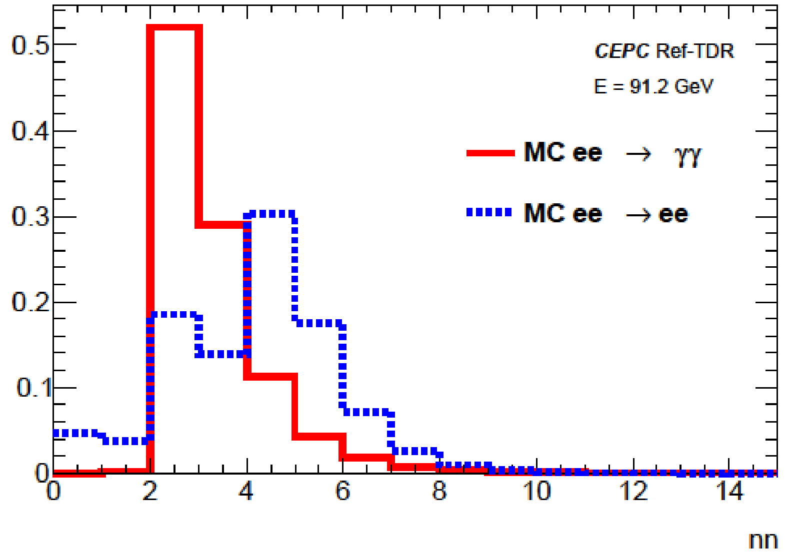


Some issue with electrons

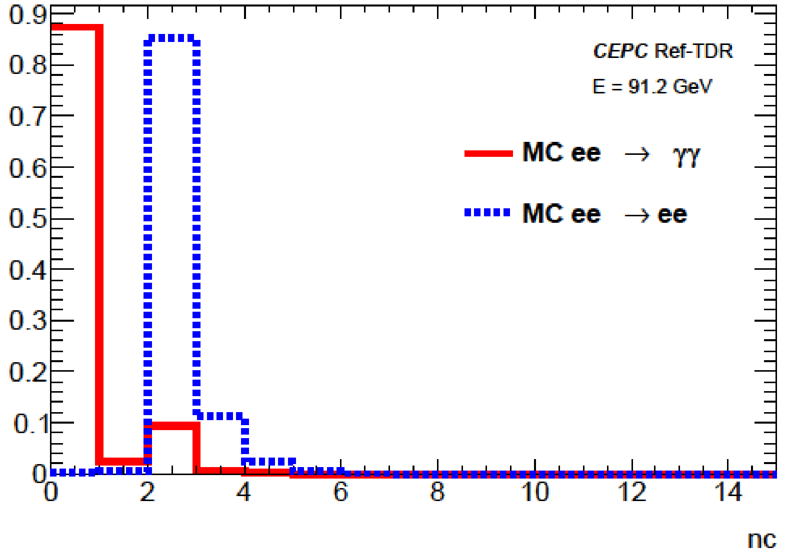




Sum(Ecal_E) >91.2
Sum (PFO_E) is ok
Some extra neutral particles nn>4
Charged particles look also ok.



Have I correctly processed **ee → ee sample** with tdr25.3.3 ?



Is /cefs/higgs/zhagkl/stdhep/E91.2/2fermions/E91.2.Pe1e1.e0.p0.whizard195/ ee → ee sample?