Study of extra ECL energy in $B^+ \to \bar{D}^0 l^+ \bar{\nu}_l$ decays

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(S)L/ EWP mini-workshop

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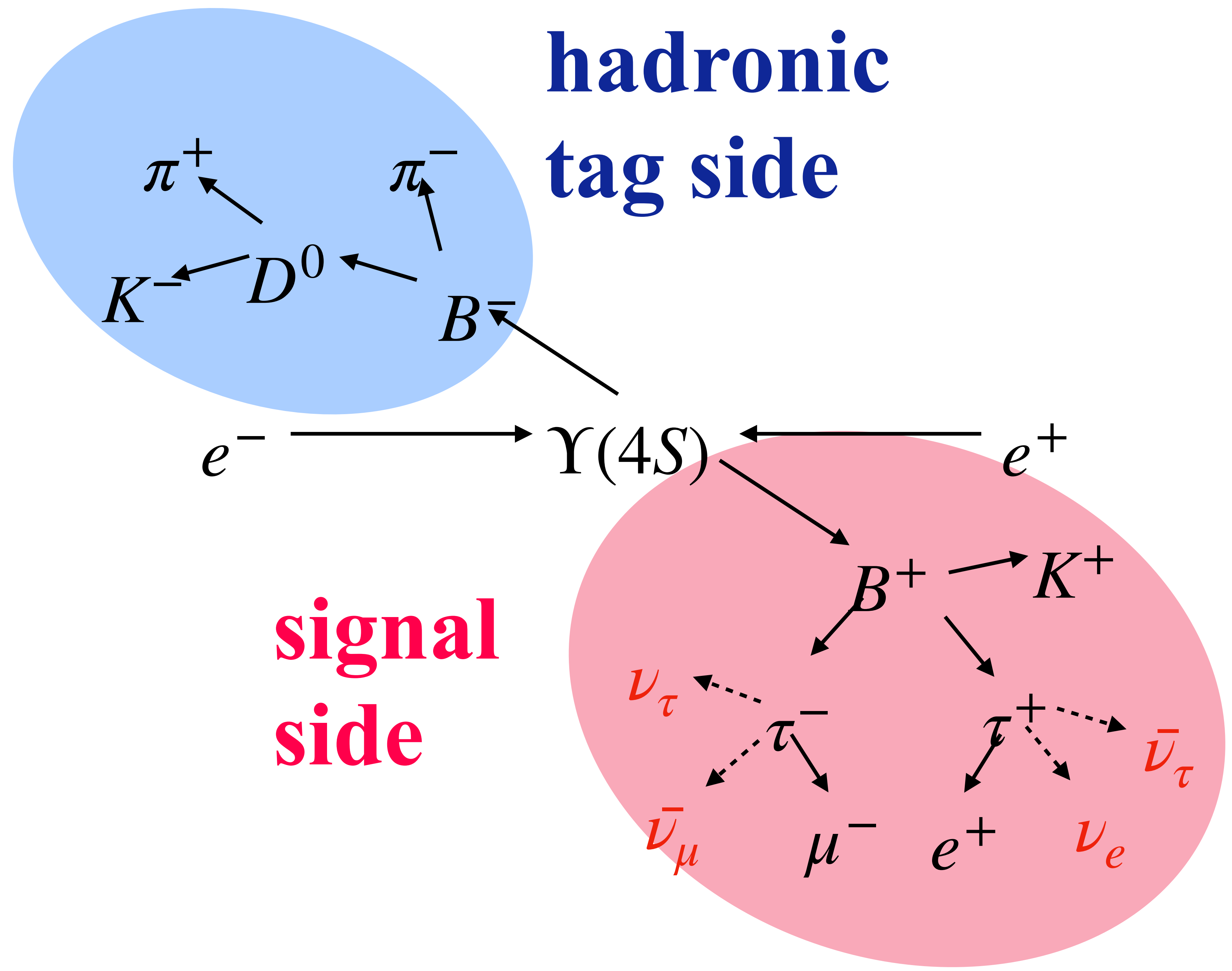
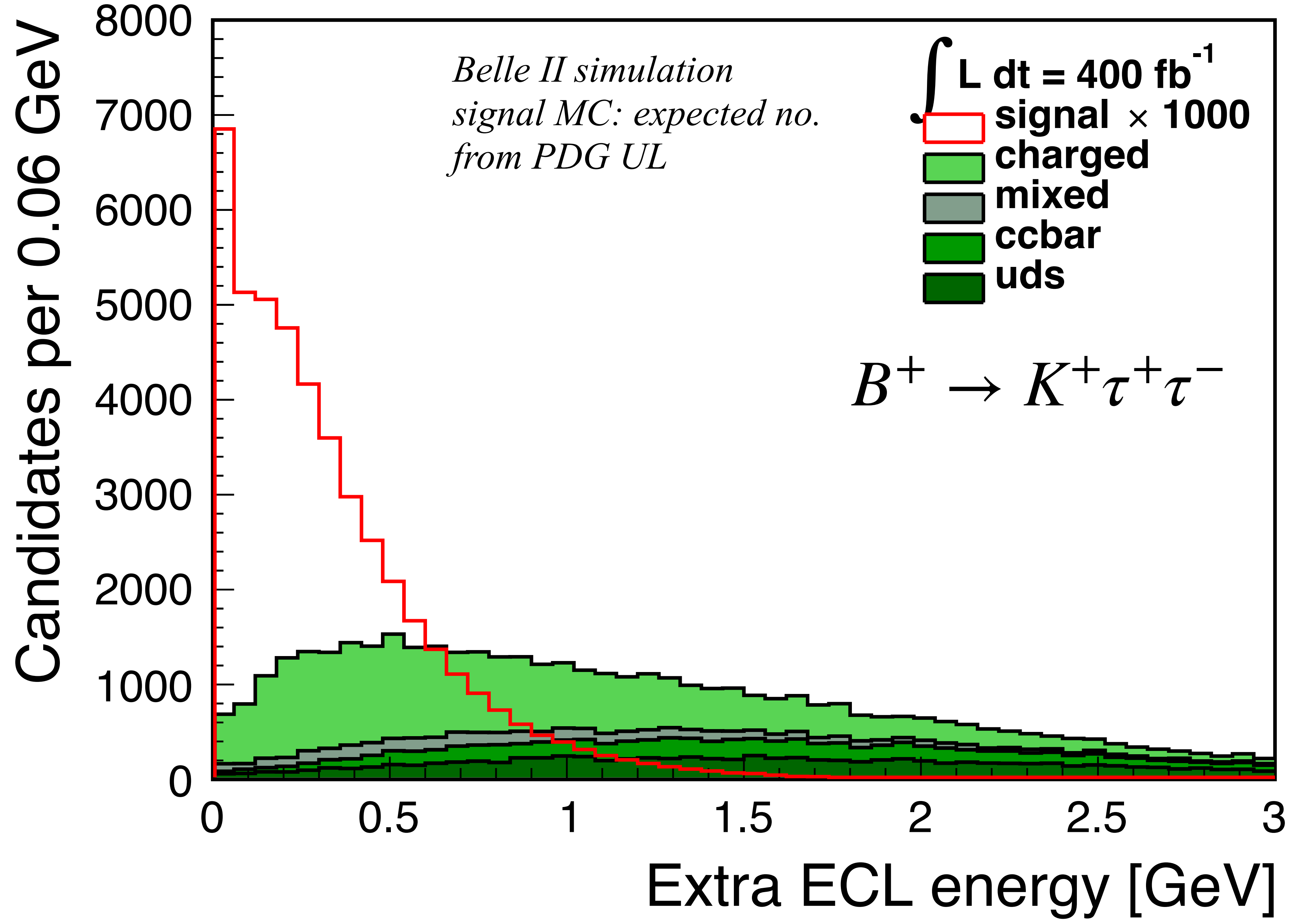
E_{ECL} importance in $B^+ \to K^+\tau^+\tau^-$



- Extra ECL energy (E_{ECL}) is the residual energy left in calorimeter after reconstructing hadronic tagged B meson (B_{tag}) and signal B meson (B_{sig})

- E_{ECL} is the signal extraction variable: spot the signal as a peak at zero in E_{ECL}

- Control sample, $B^+ \to \bar{D}^0 l^+ \bar{\nu}_l (\bar{D}^0 \to K^+\pi^-)$, is used to check data/MC comparison as it has three tracks in the final states (similar to signal)



Samples and selections

photon energy bias correction is applied on data

- Data: Proc 13 + Moriond 23 prompt ($\mathscr{L} = 362 fb^{-1}$)
- Simulation: MC15 run dependent ($4 \times \mathscr{L}$)
- Release: light-2212-foldex

Reconstruct hadronic B_{tag} using FEI:

- Weight files- 'FEIv4_2022_MC15_light-2205-abys'
- $M_{bc} > 5.27\,GeV/c^2$; $|\Delta E| < 0.1\,GeV$
- FEI signal probability > 0.001
- Best probable B_{tag} candidates is accepted

Continuum suppression

- event sphericity > 0.2
- $cos(\text{Trust}(B_{tag}), \text{Trust(ROE)}) < 0.9$

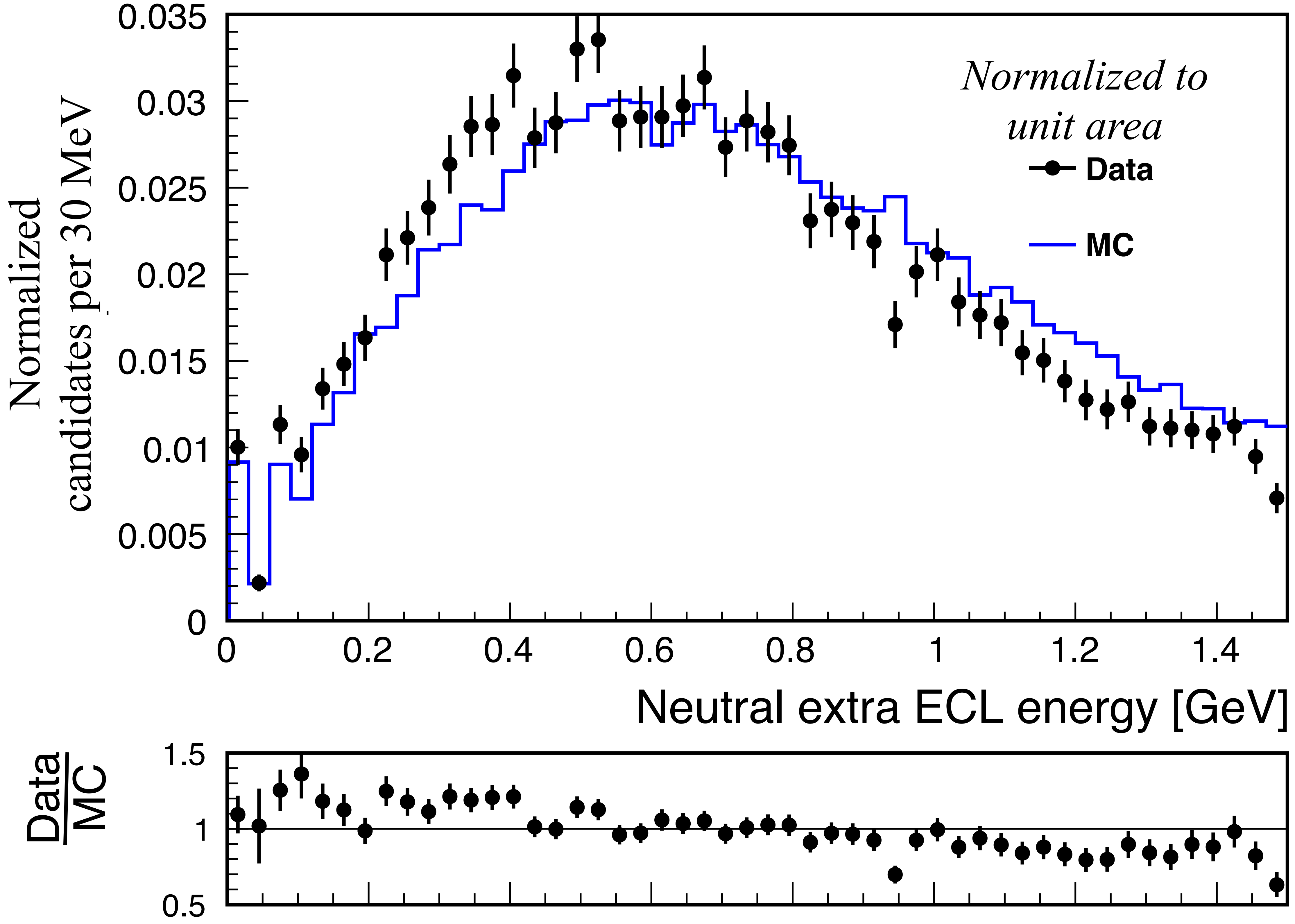
Rest of B_{tag} selection:

- only 3 tracks should remain to reconstruct B_{sig}.
- $dr < 0.5$ cm; $|dz| < 2$ cm; thetaInCDCAcceptance
- Cluster energy > 55 MeV (to avoid the interplay of the variable $|\frac{\text{cluster timing}}{\text{cluster error timing}}|$ selection: see backup)

Reconstruct $B_{sig} \to \bar{D}^0 l^+ \bar{\nu}_l$; $\bar{D}^0 \to K^+\pi^-$:

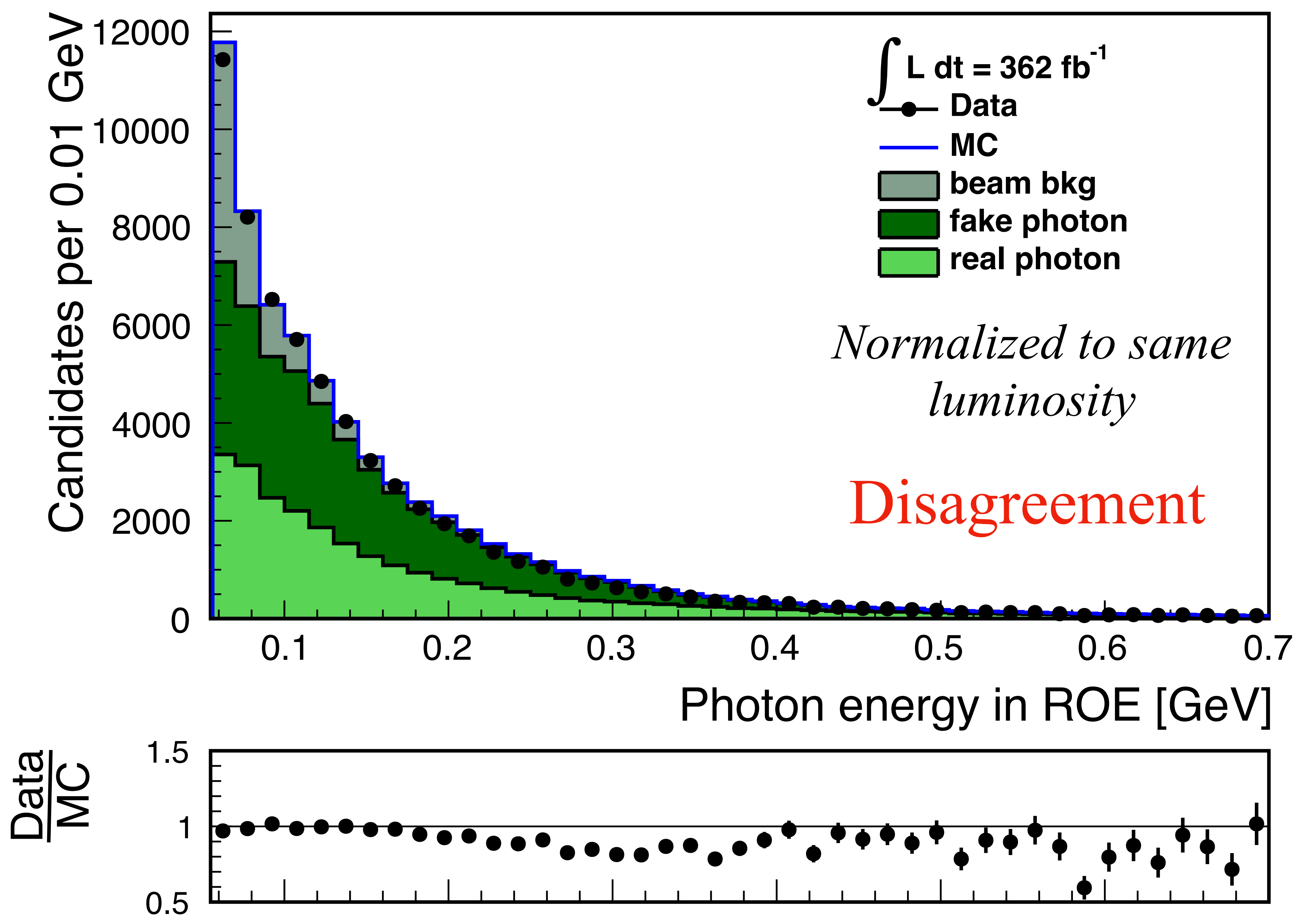
- Kaon binary PID, $\mathscr{L}(K/\pi) > 0.6$
- Electron PID, $\mathscr{L}(e) > 0.9$
- Muon PID, $\mathscr{L}(\mu) > 0.9$
- Pion binary PID, $\mathscr{L}(\pi/K) > 0.6$
- $1.84 < m(K^+\pi^-) < 1.89\,Gev/c^2$

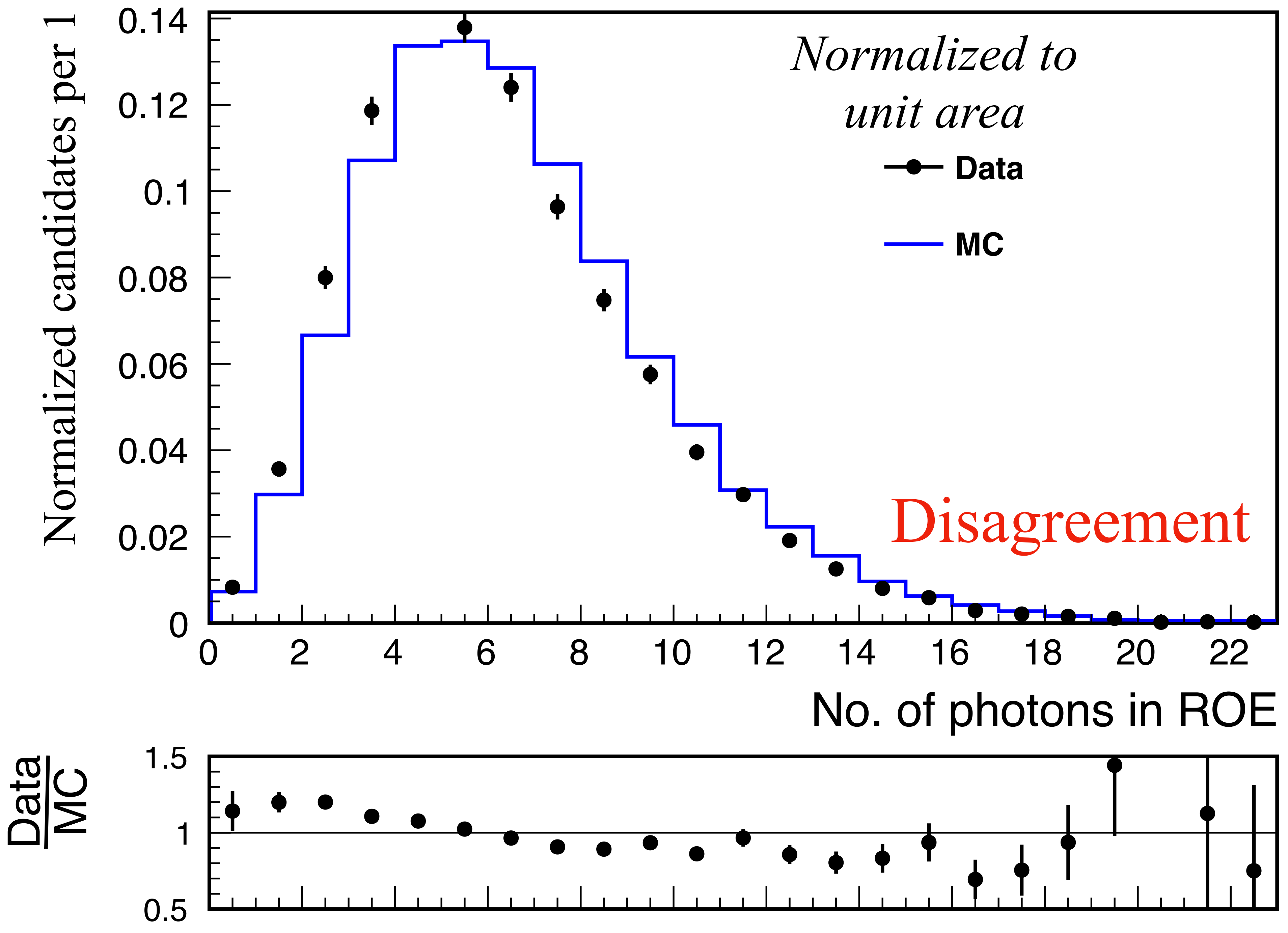
E_{ECL}



- Shows large data/MC discrepancy
- Needs to investigate gamma level properties which contribute to this distribution.
- E_{ECL} is the sum of all photons energy per event: depends on photon energy, $E(\gamma)$, and photon multiplicity, $N(\gamma)$

Photon energy $E(\gamma)$ and multiplicity $N(\gamma)$



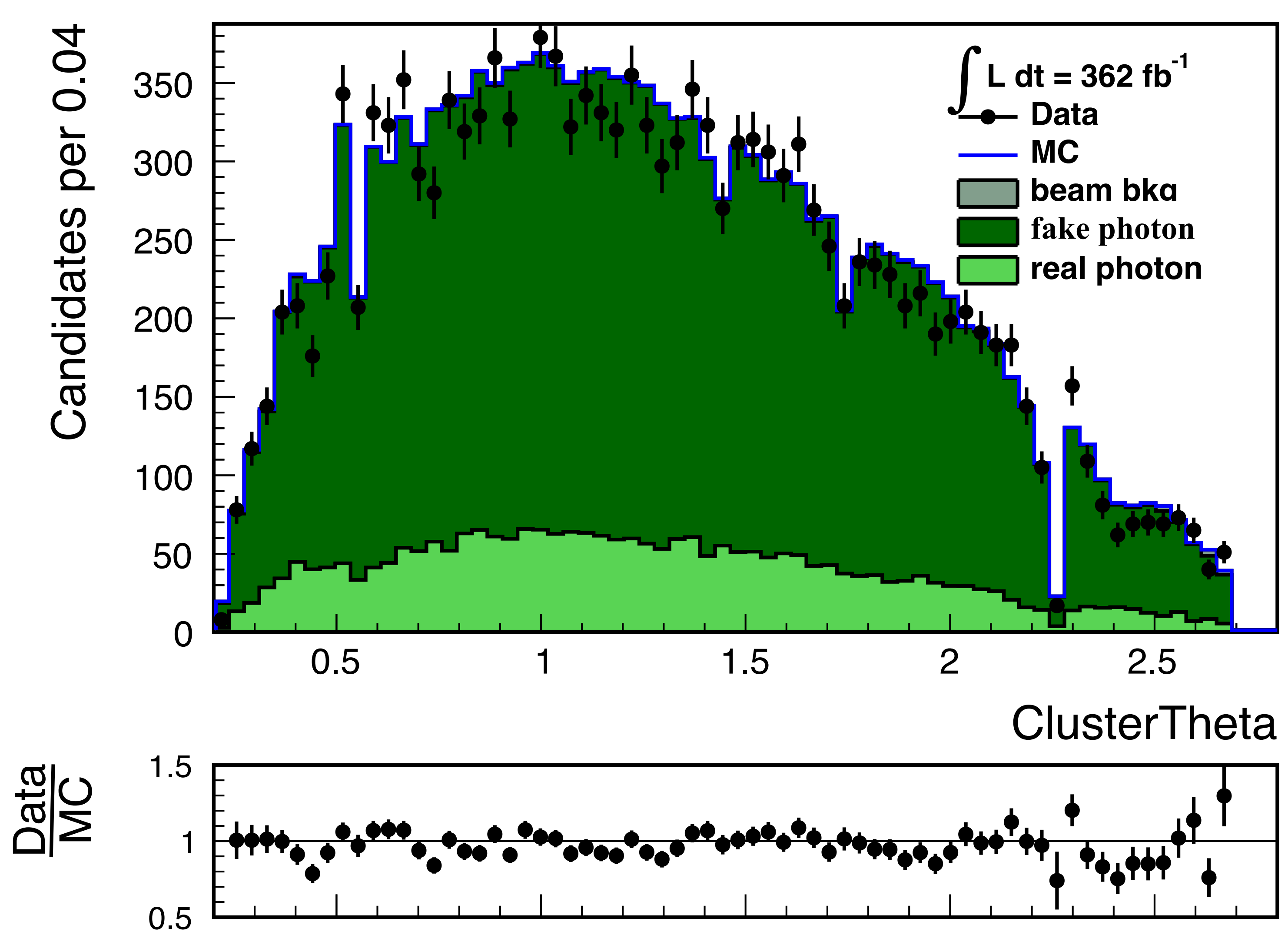


- E_{ECL} discrepancy comes from both $E(\gamma)$ and $N(\gamma)$ data/MC discrepancies
- These may originate from certain types of photon:
  real photons, fake photons or beam-backgrounds photons
- Study each photon type separately to get better understanding of these discrepancies

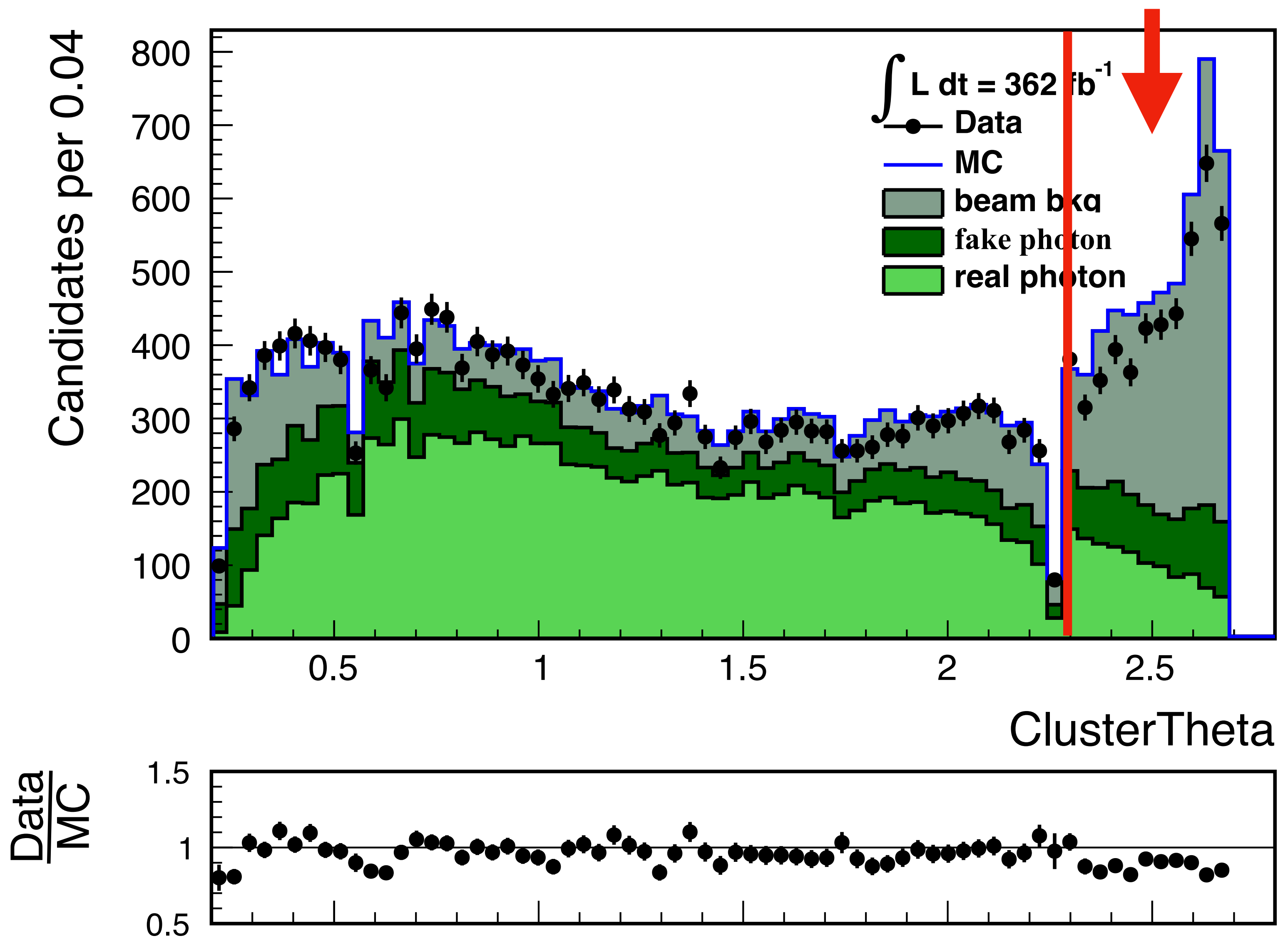
Isolating pure samples

MC and data are normalised to same luminosity in these plots

Fake photon dominated



Beam-background dominated



Selections:

Fake photon dominated:

- $E > 55\,\mathrm{MeV}$
- minimum cluster to track distance <20 cm

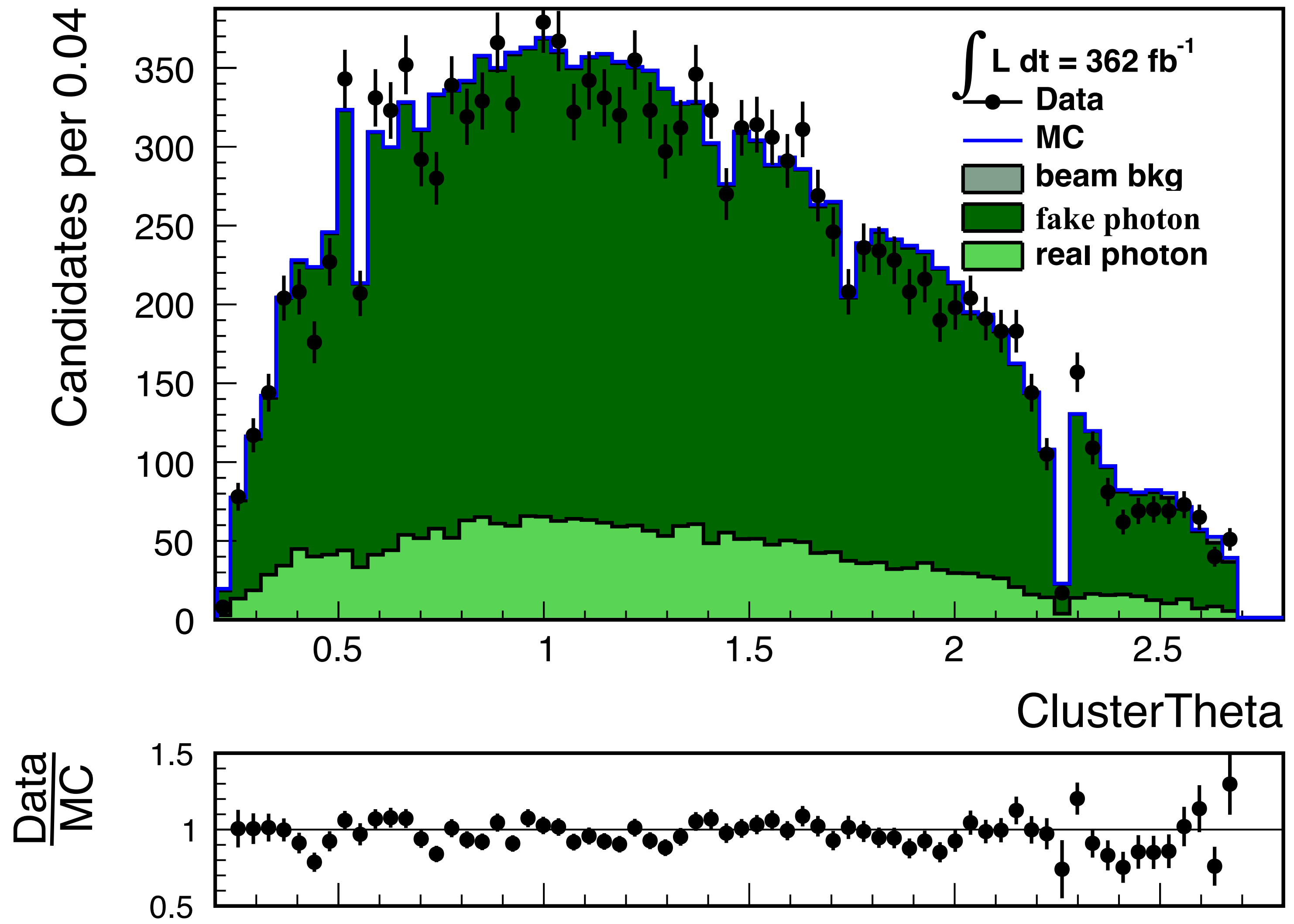
Beam-background dominated:

- $E > 55\,\mathrm{MeV}$
- minimum cluster to track distance >80 cm
- Backward region of ECL

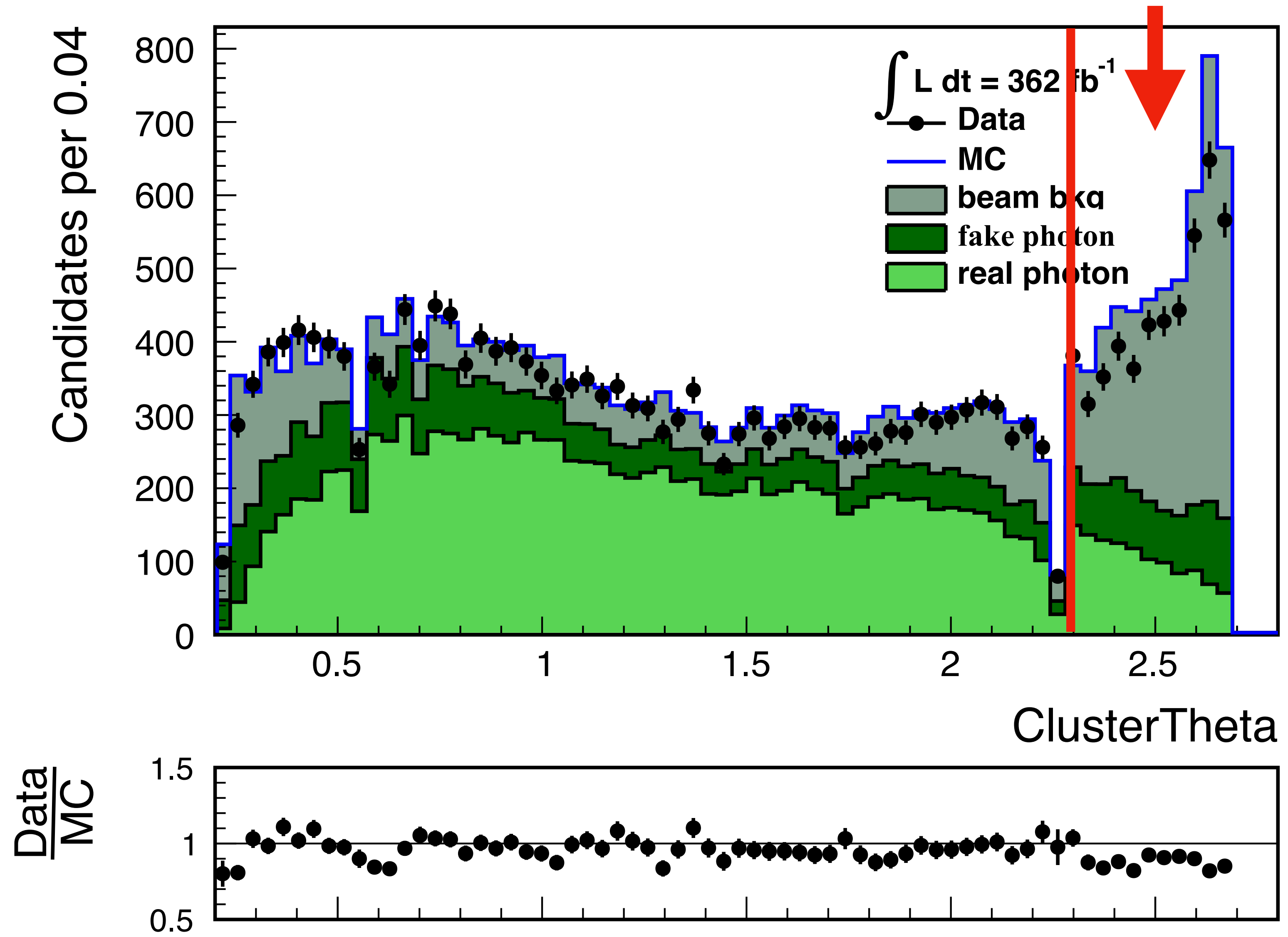
Unable to find a real photon enriched sample. Need to study in other channel containing π^0:
$B^+ \to \bar{D}^{*0}(\bar{D}^0\pi^0)\pi^-$, $B^+ \to J/\psi K^{*+}(K^+\pi^0)$

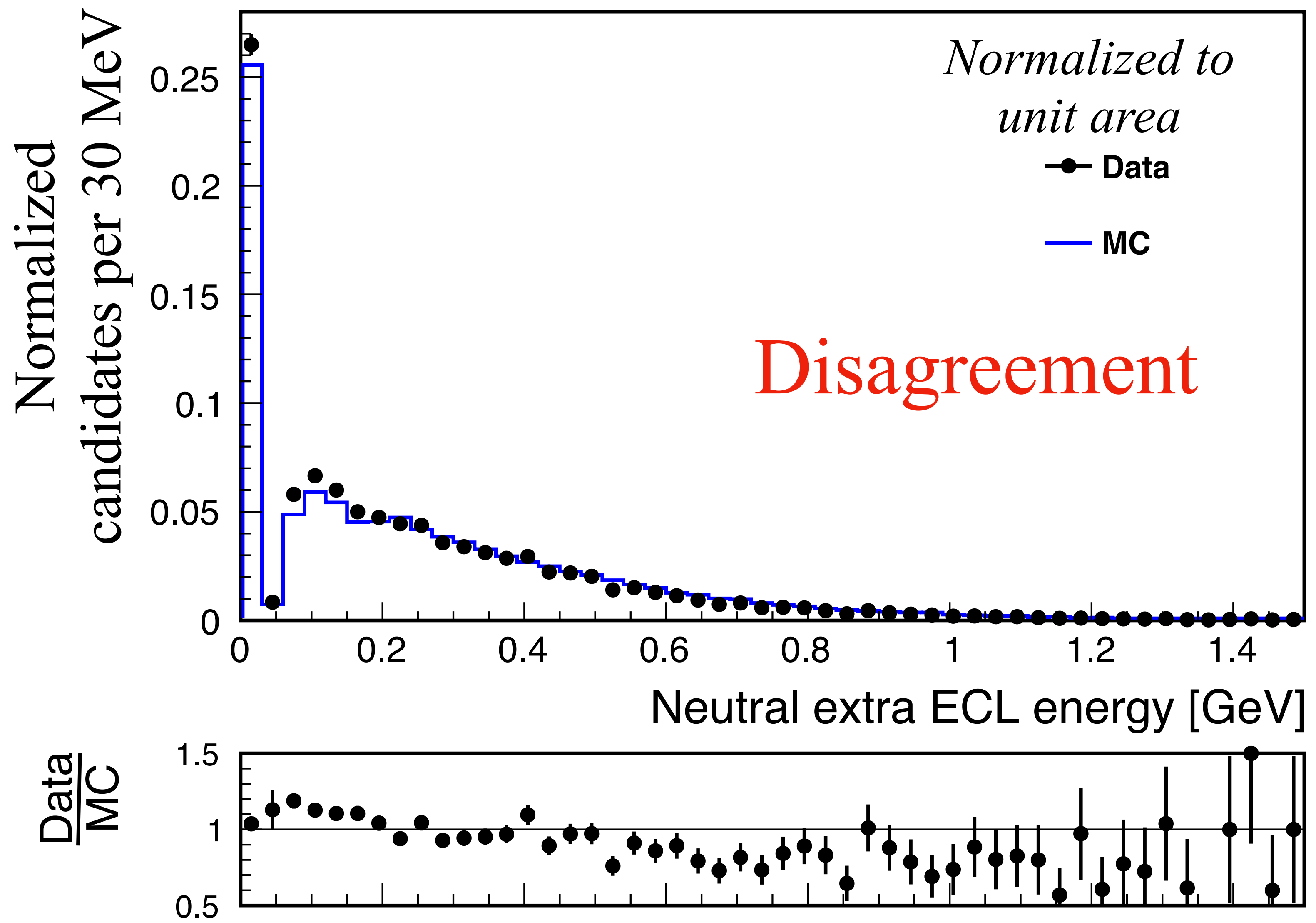
E_{ECL}

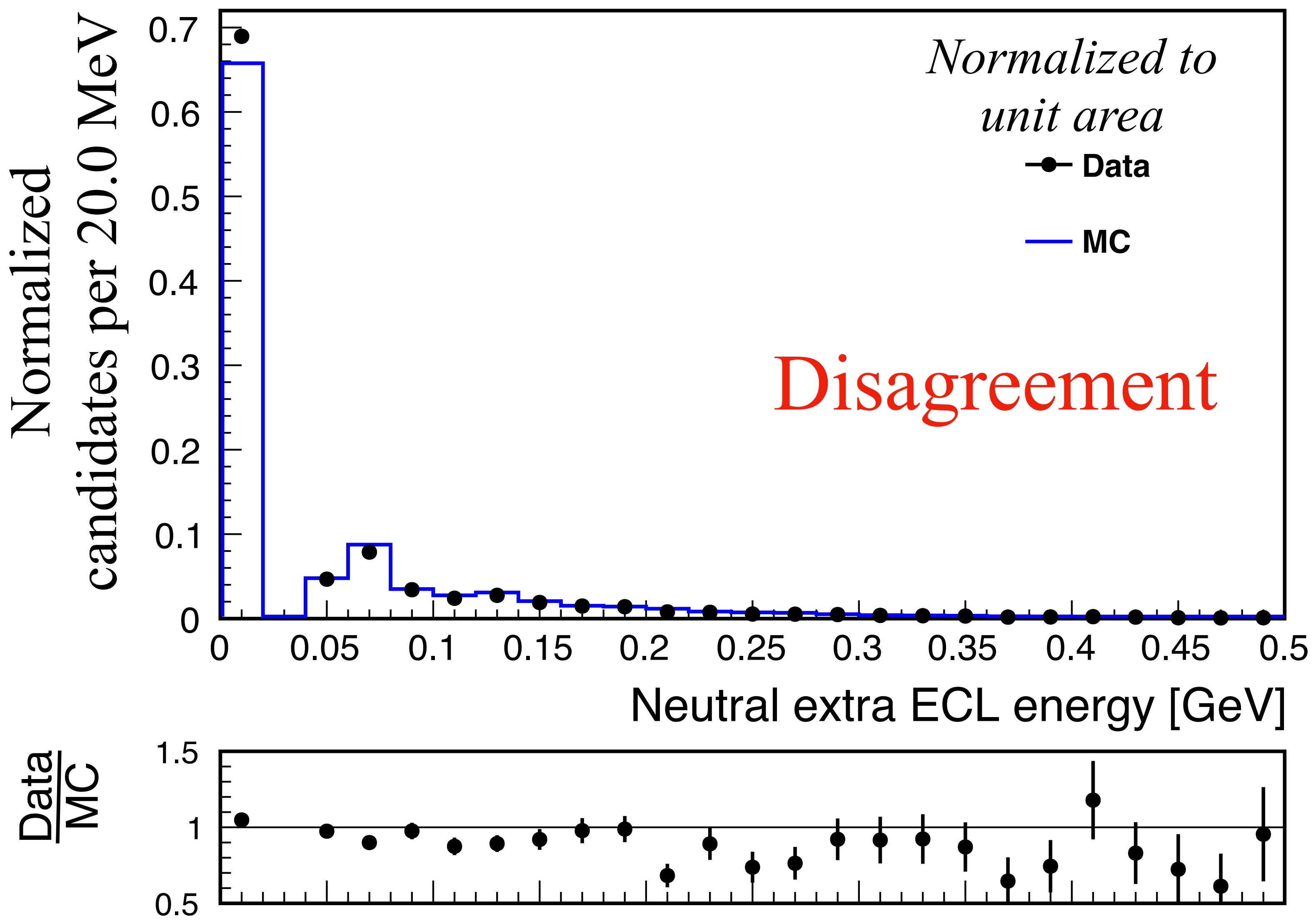
Fake photon



Beam-background



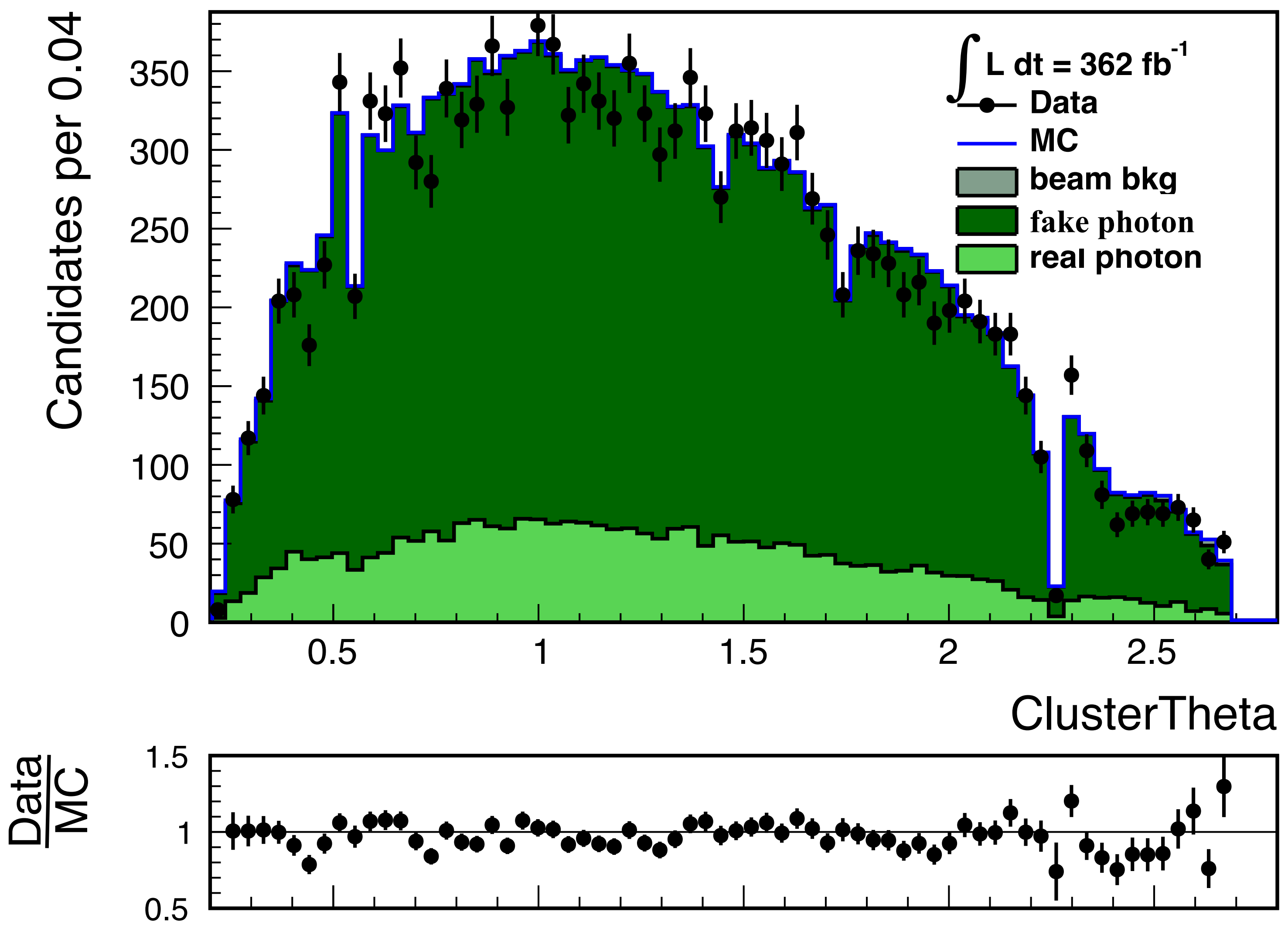




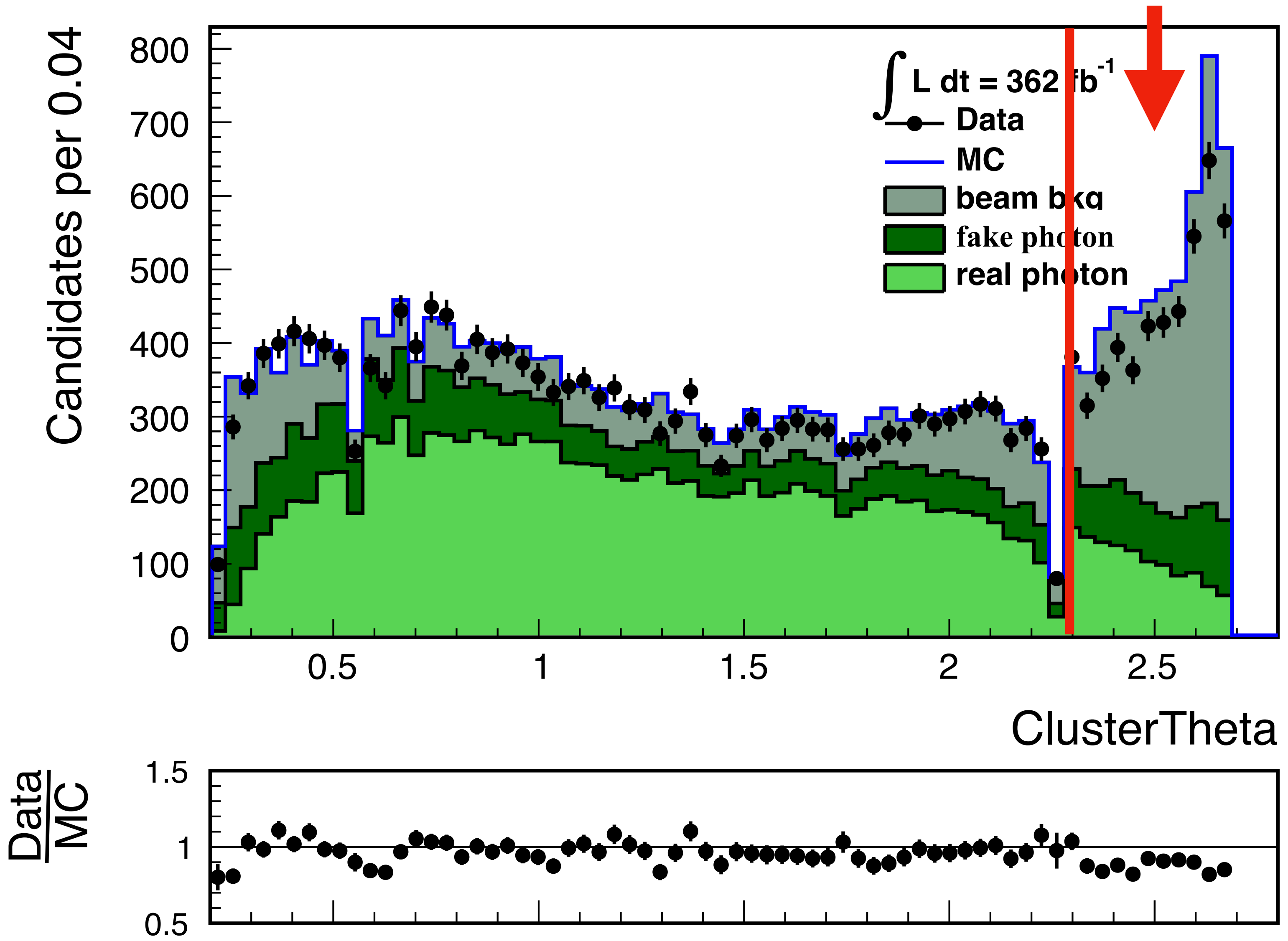
- Both fake and beam-background photons have E_{ECL} data/MC disagreement
- Check how $E(\gamma)$ and $N(\gamma)$ contribute to E_{ECL} mismodeling

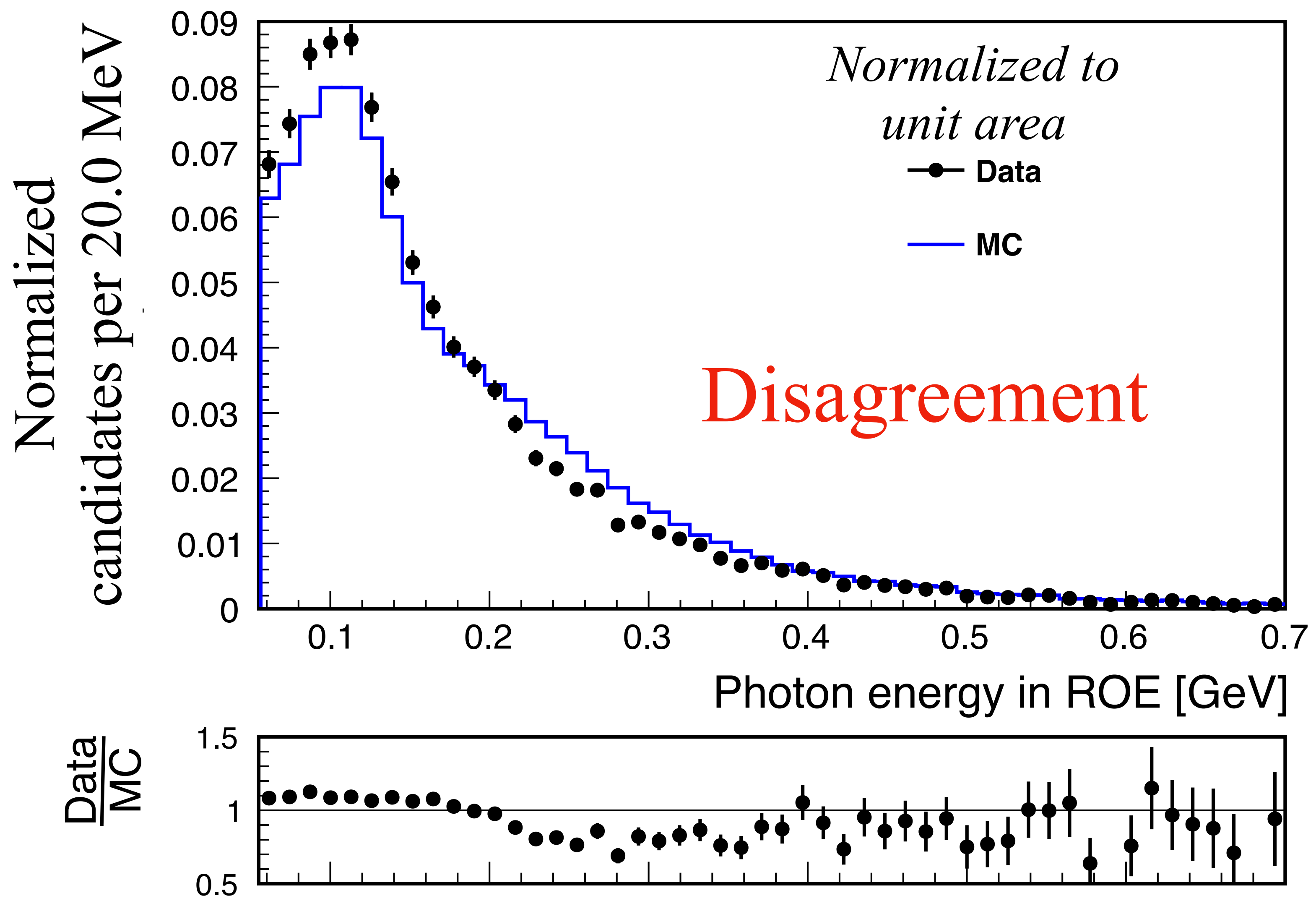
Photon energy E(γ)

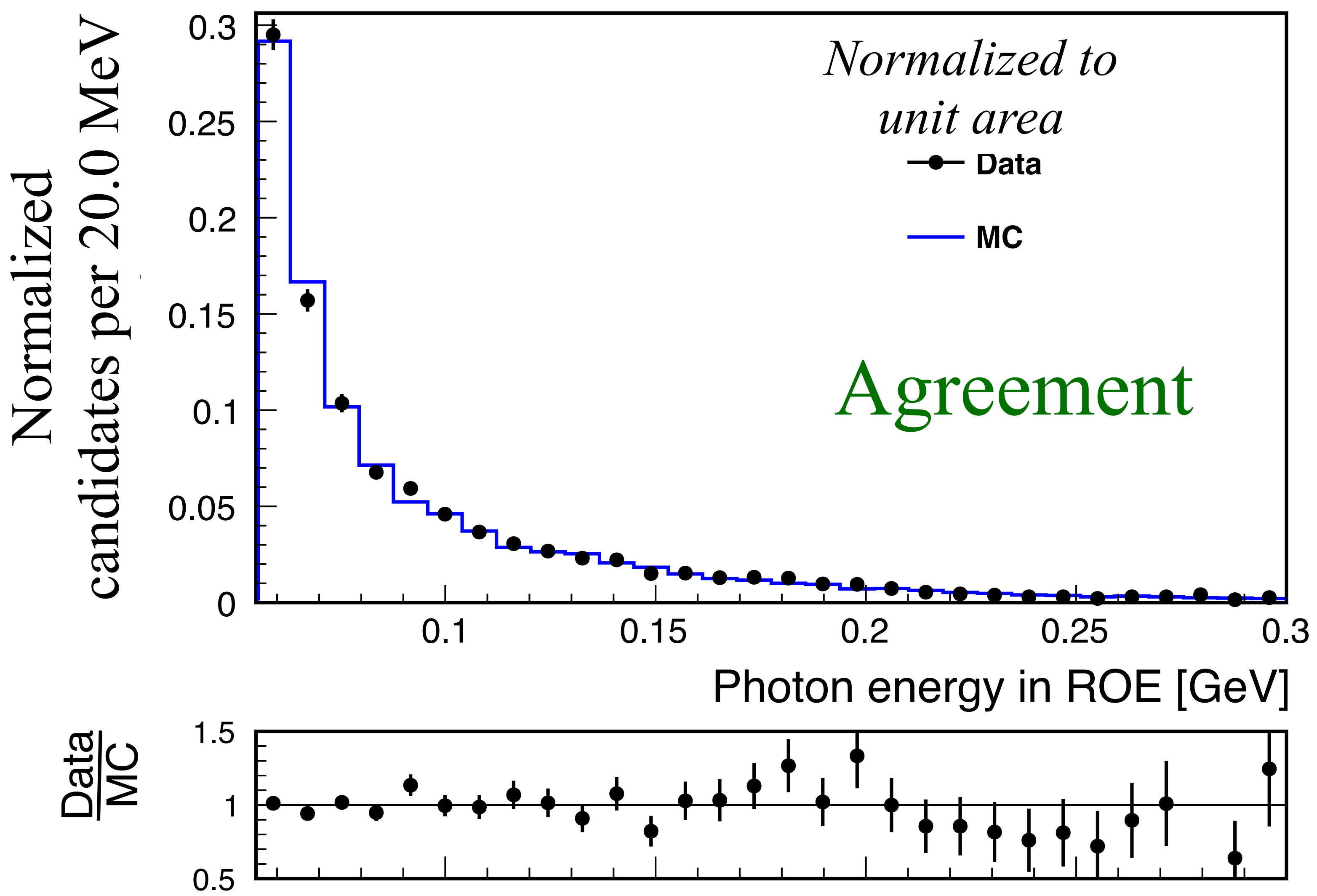
Fake photon



Beam-background



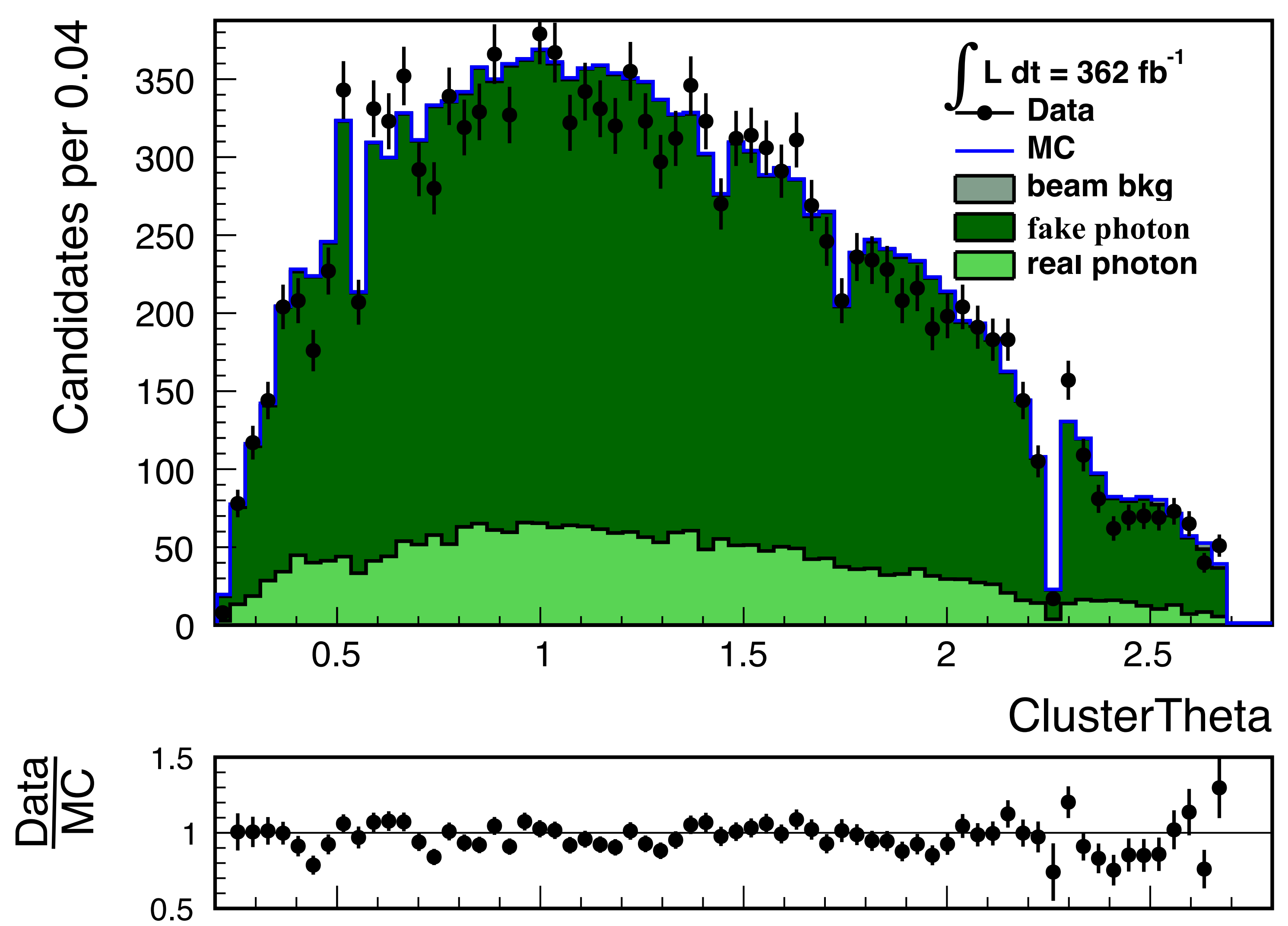


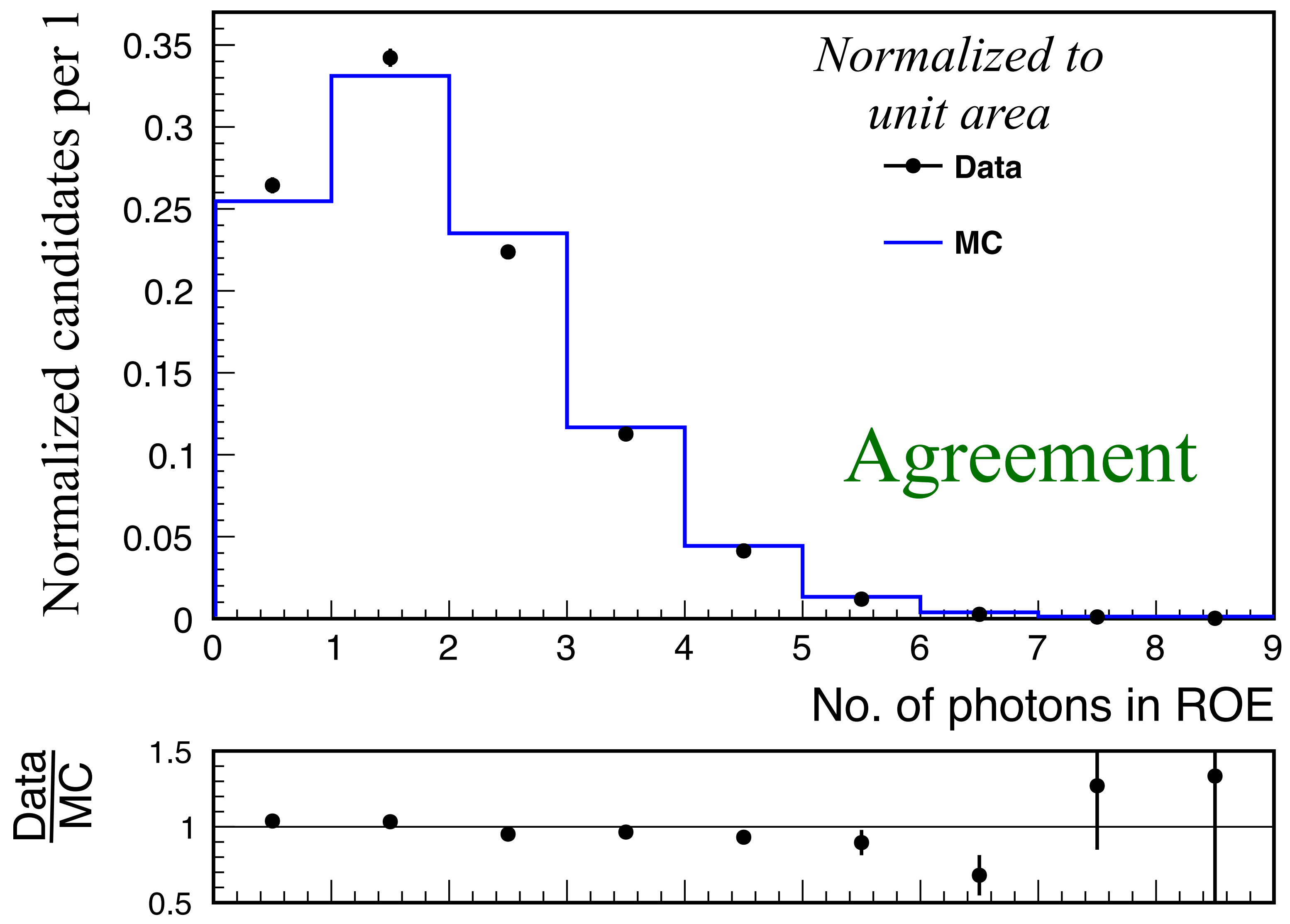


Only fake photons has E(γ) data/MC disagreement

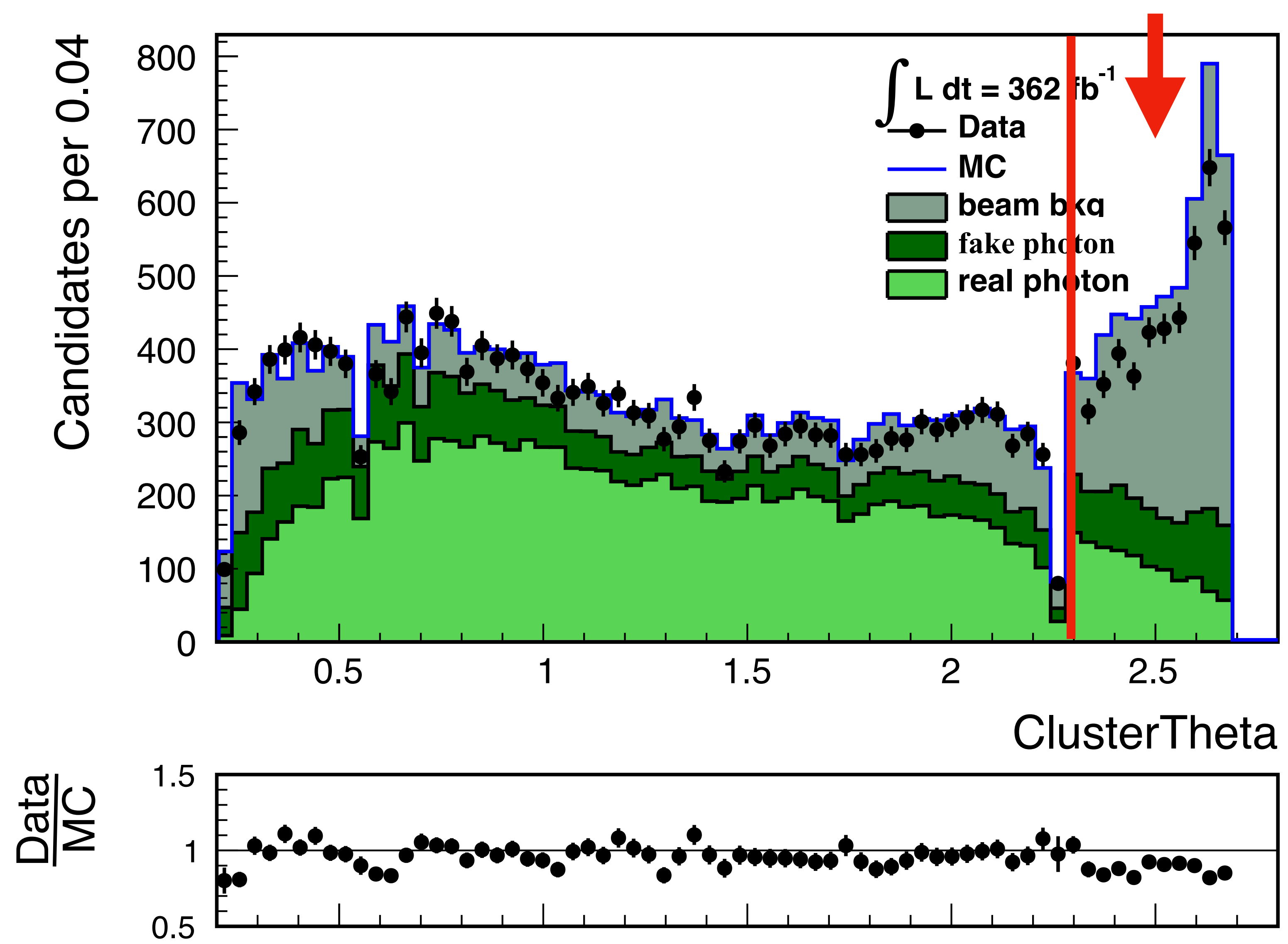
Photon multiplicity N(γ)

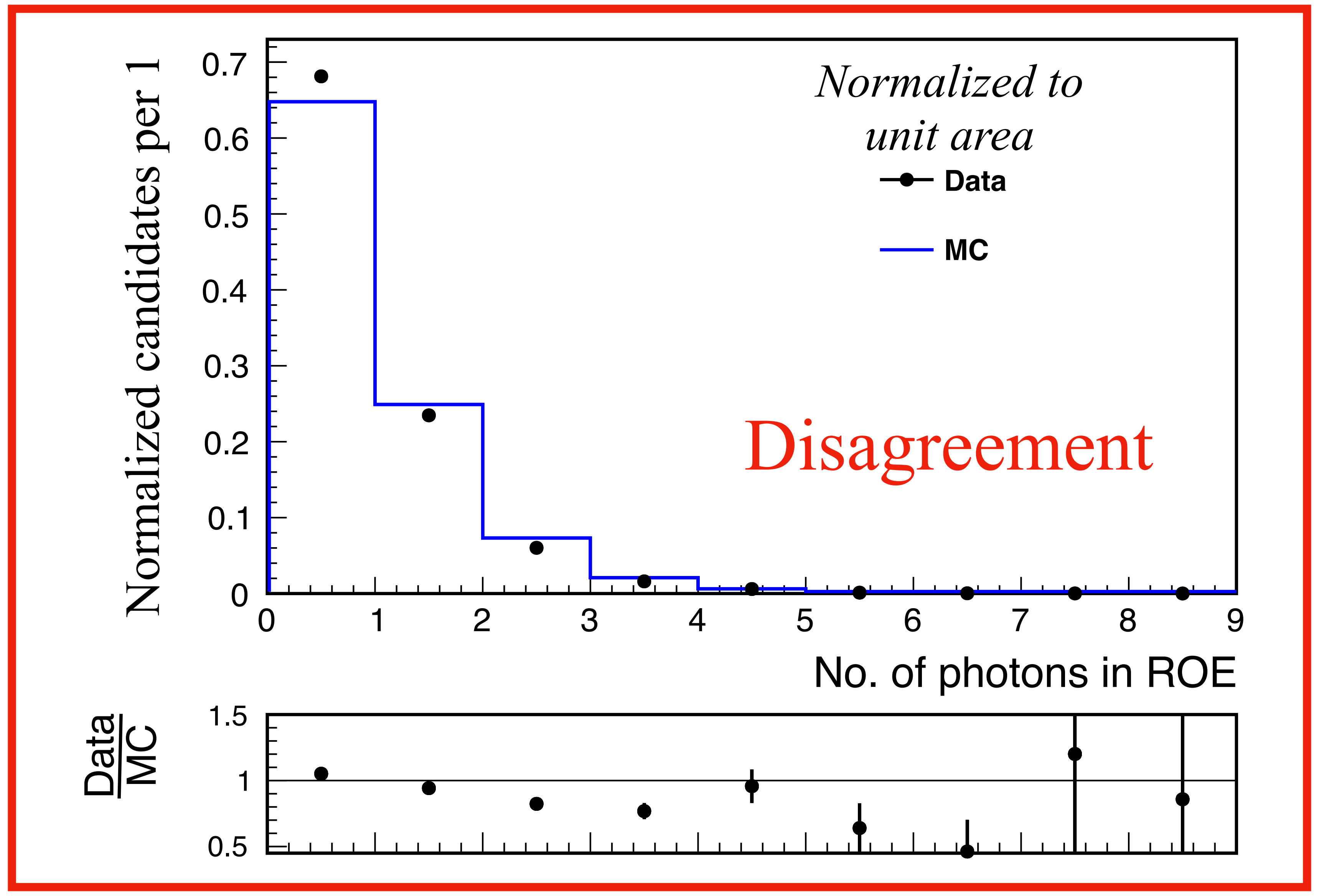
Fake photon





Beam-background





Only beam-background photons has N(γ) data/MC disagreement

Fix E(γ) mismodeling: strategy

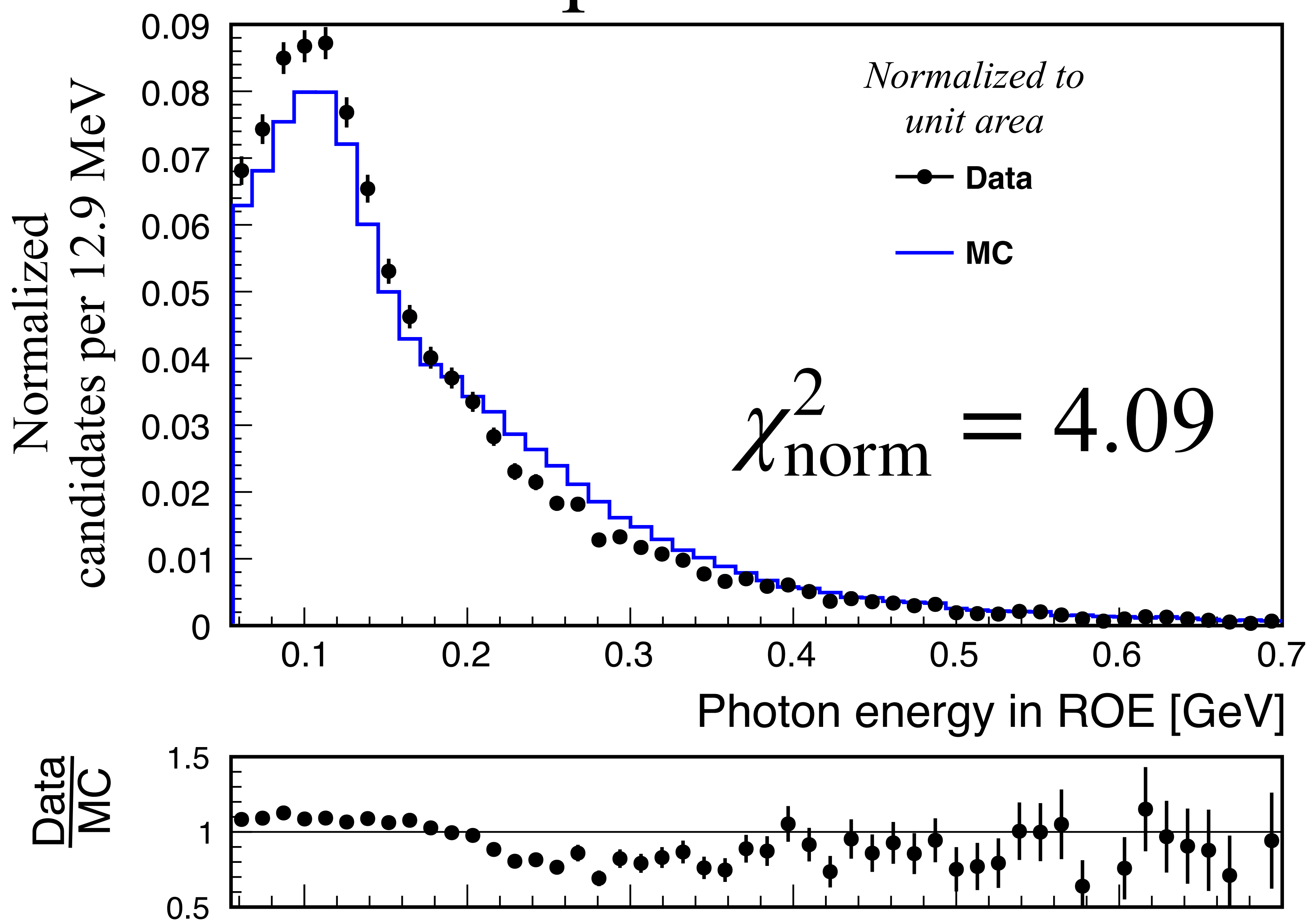
- E(γ) discrepancy comes from fake photon: fixing fake photon energy should fix overall E(γ) data/MC disagreement
- Method to find E(γ) correction factor: perform χ^2 minization by optimizing the correction factors which modify fake photon energy in MC to get the best E(γ) data/MC agreement
- Correction factor may vary with different photon energies: divide E(γ) in bins and find corrections for each bin simultaneously
- Easy to calculate E_{ECL} from the corrected photon energy

Fake photon $E(\gamma)$ correction

work in progress

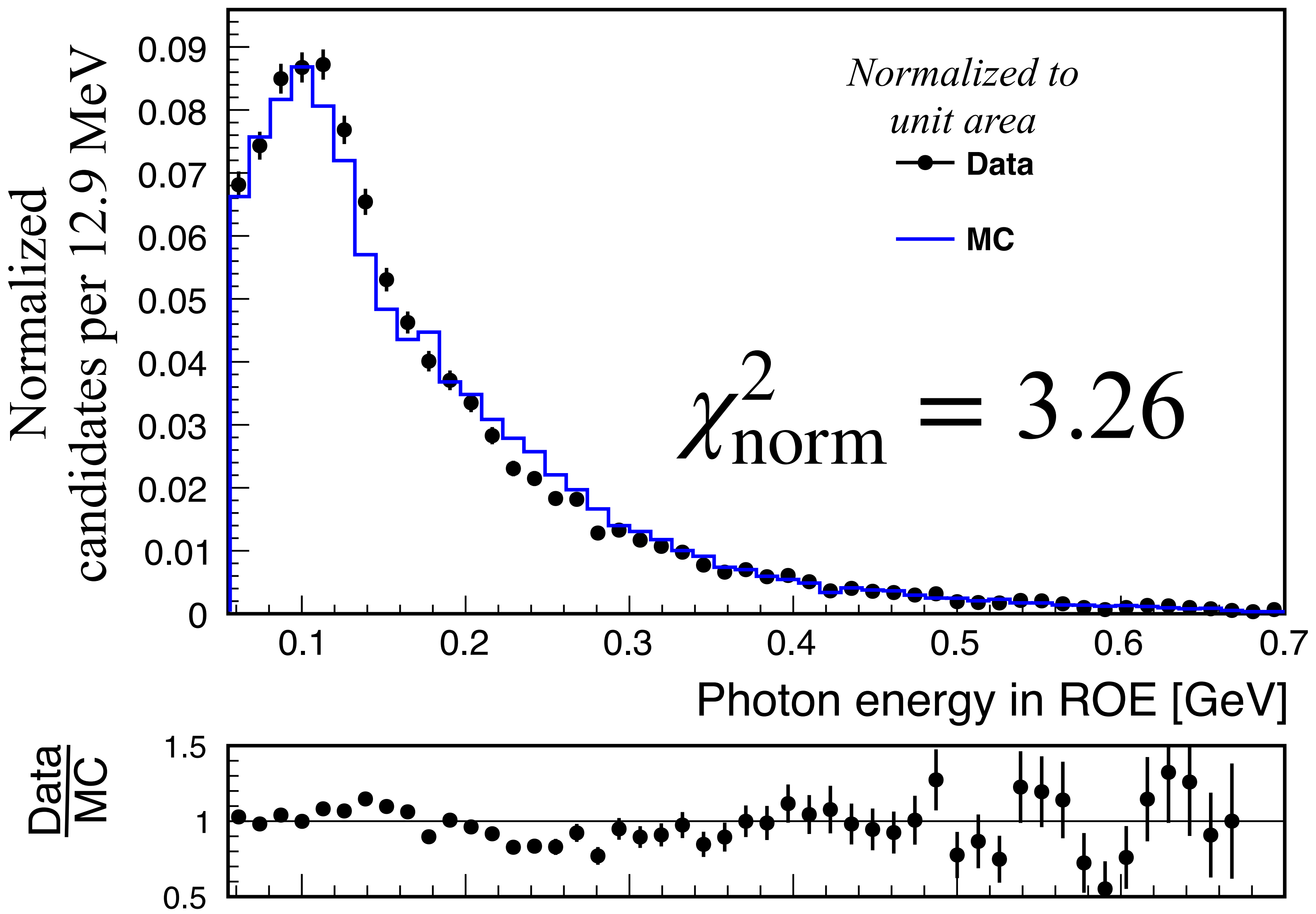
- Tried to find 10 correction factors for 10 different bins of $E(\gamma)$
- Fit doesn't converge yet. However, parameters optimize towards the right direction: shows better data/MC agreement of $E(\gamma)$ in fake photon

pre-fit



fake photon sample

post-fit



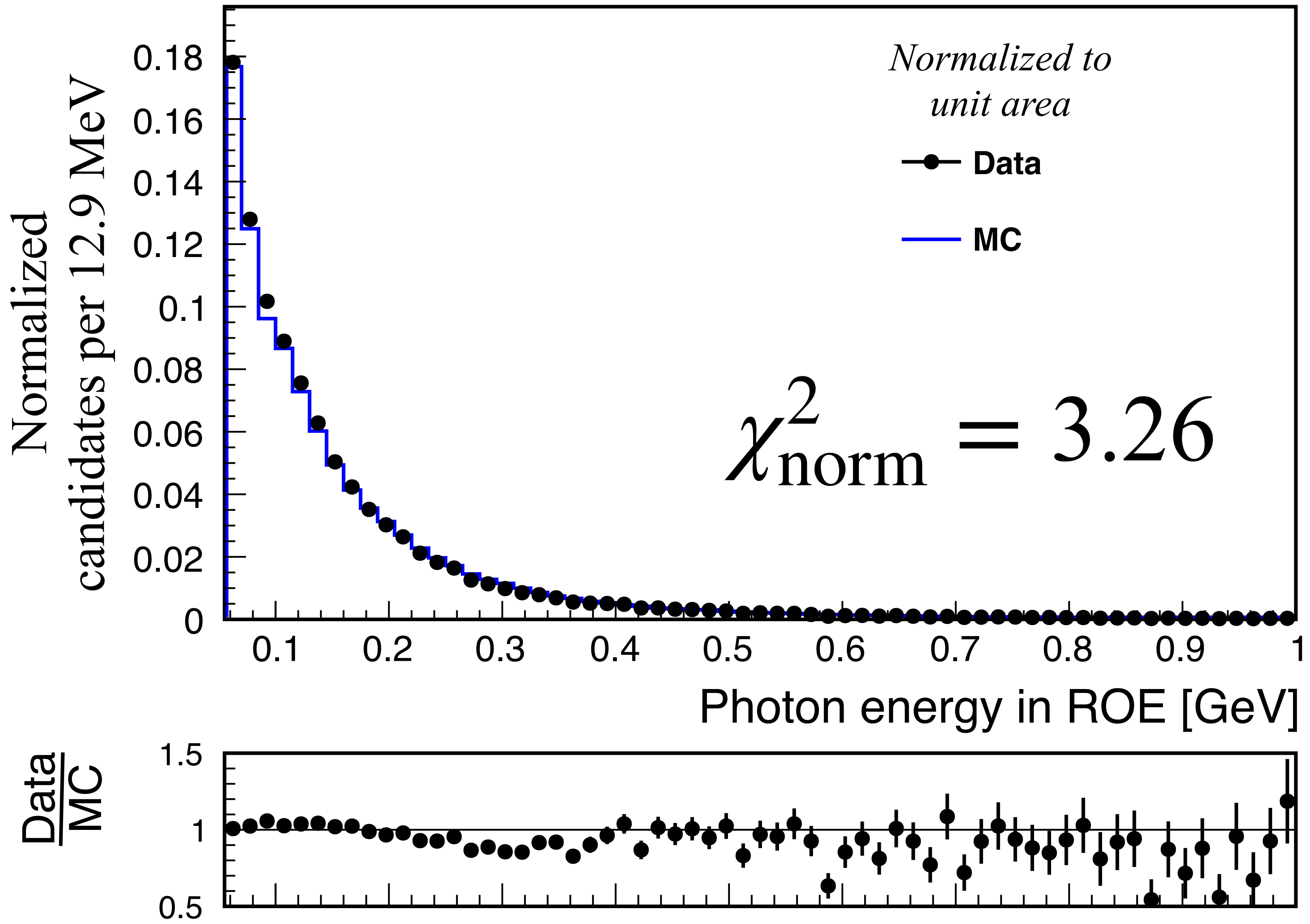
fake photon sample

Corrected E(γ)

work in progress

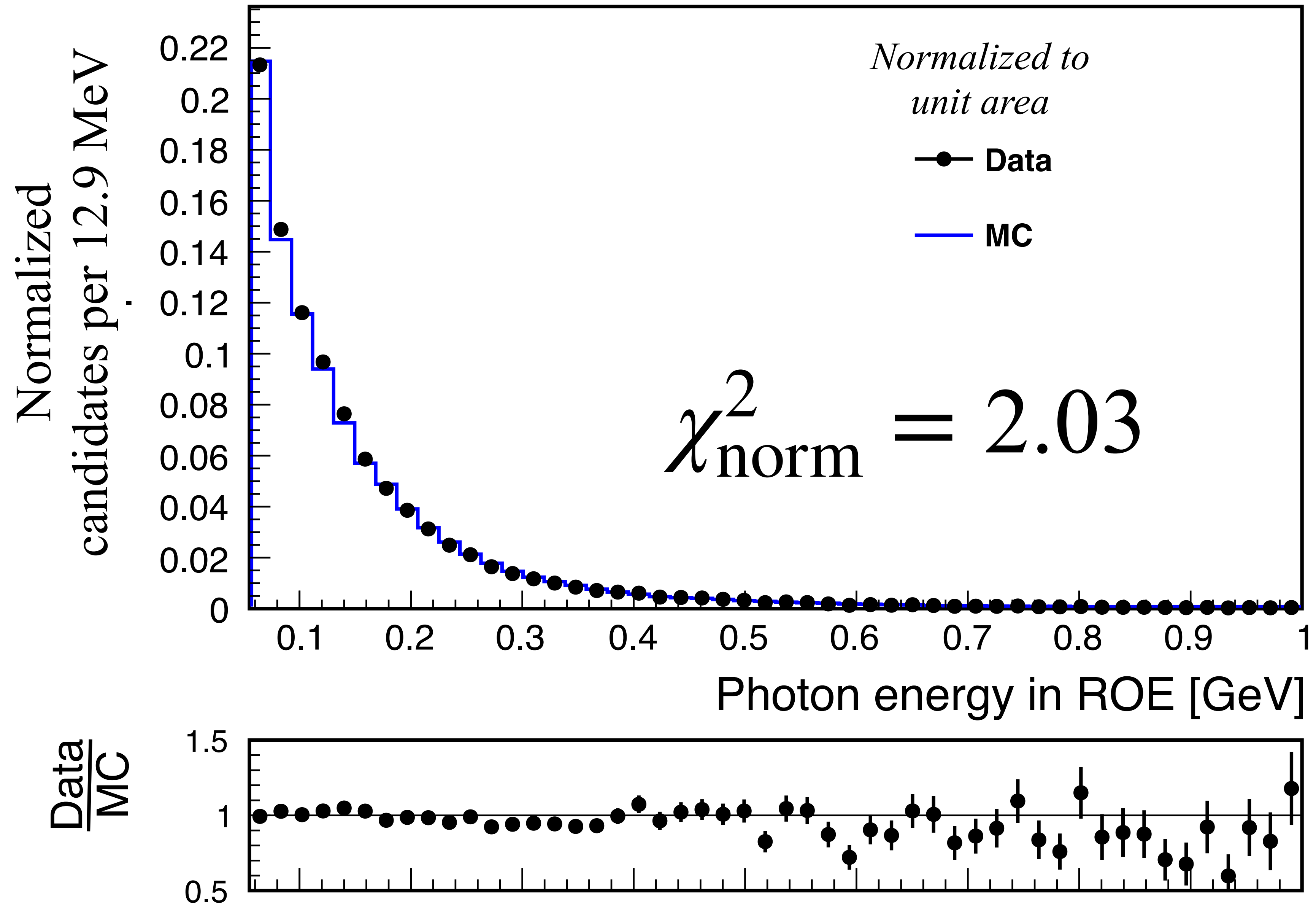
- Data/MC agreement of E(γ) of all photons improve after applying fake photon energy correction

without correction



integrated sample

with correction



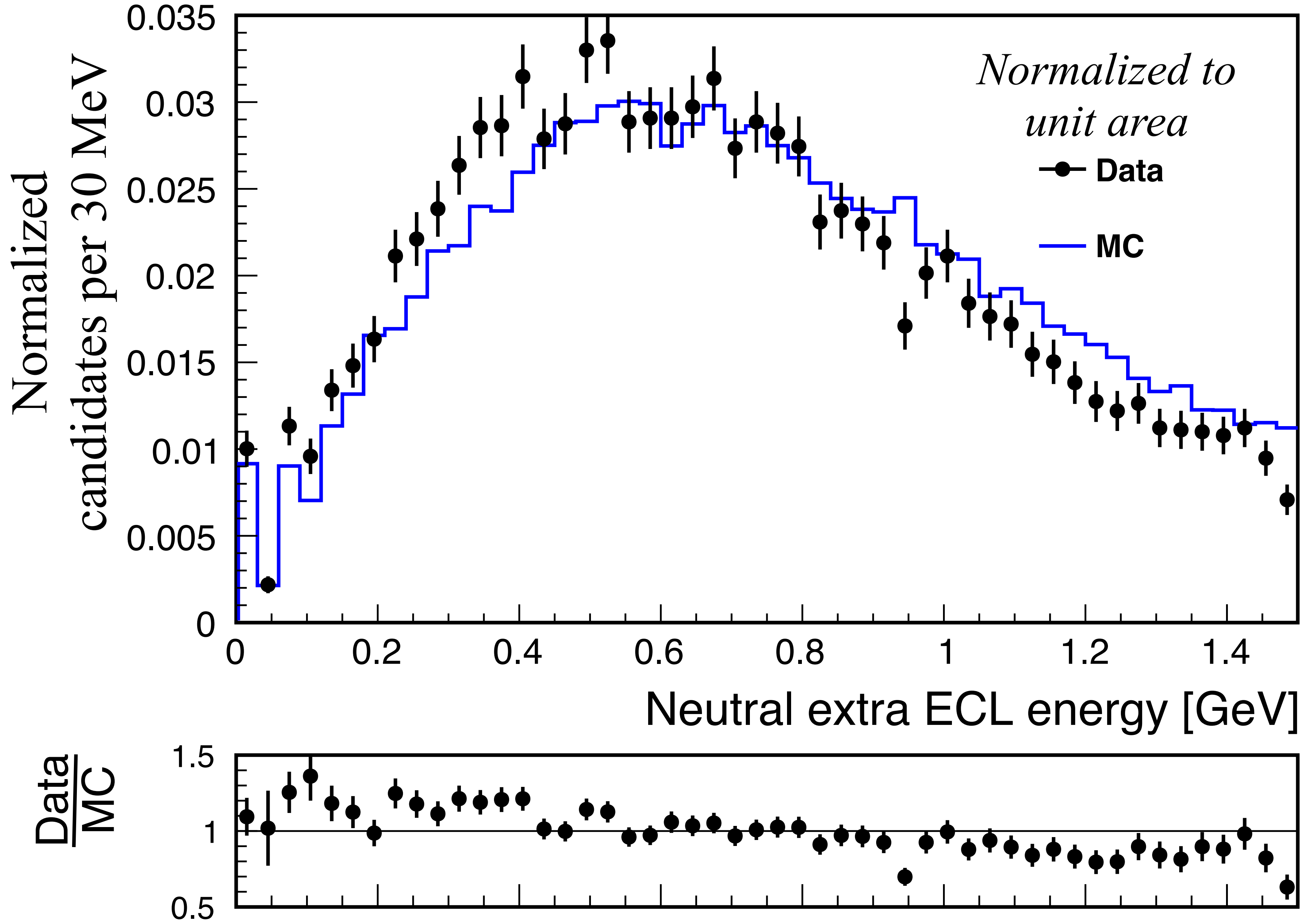
integrated sample

E_{ECL} with corrected $E(\gamma)$

work in progress

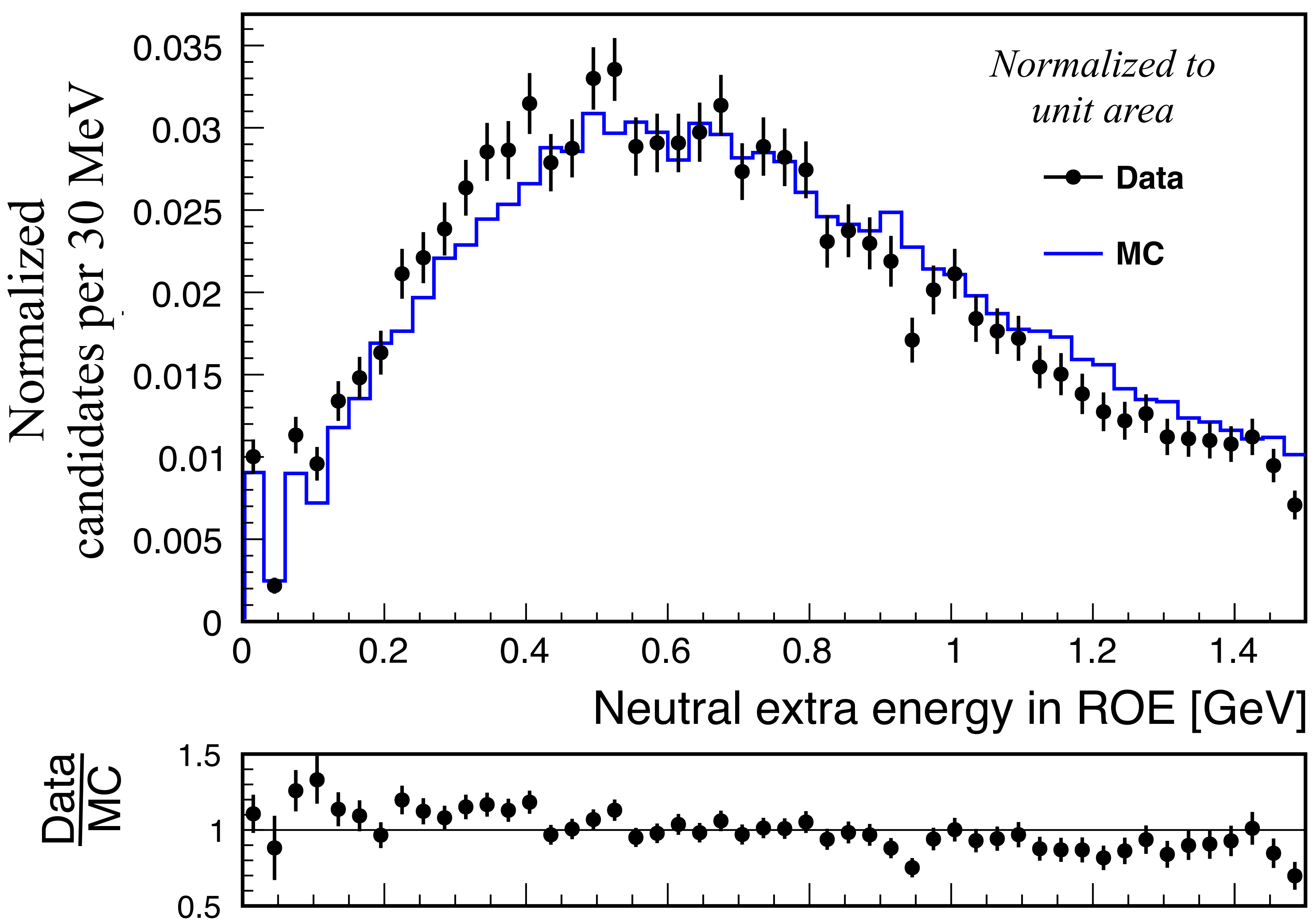
- Data/MC agreement of E_{ECL} slightly improves after applying $E(\gamma)$ correction in the integrated MC sample

without correction



$\chi^2_{\text{norm}} = 3.03$

with correction



$\chi^2_{\text{norm}} = 1.95$

- Need to correct beam-background photon multiplicity to fix E_{ECL} mismodeling completely

Next steps

- Fix the χ^2 minimization fitter and validate the correction factors in other control channels: $B^+ \to \bar{D}^0\pi^+$, $B^+ \to J/\psi K^+$.

- Perform a similar study to get correction factor of N(γ) from beam-background sample.

- Find a real photon sample in $B^+ \to \bar{D}^{*0}(\bar{D}^0\pi^0)\pi^-$ or $B^+ \to J/\psi K^{*+}(K^+\pi^0)$ channel and study E(γ) and N(γ) data/MC comparison

- Check other γ properties such as cluster timing, clusterNhits etc

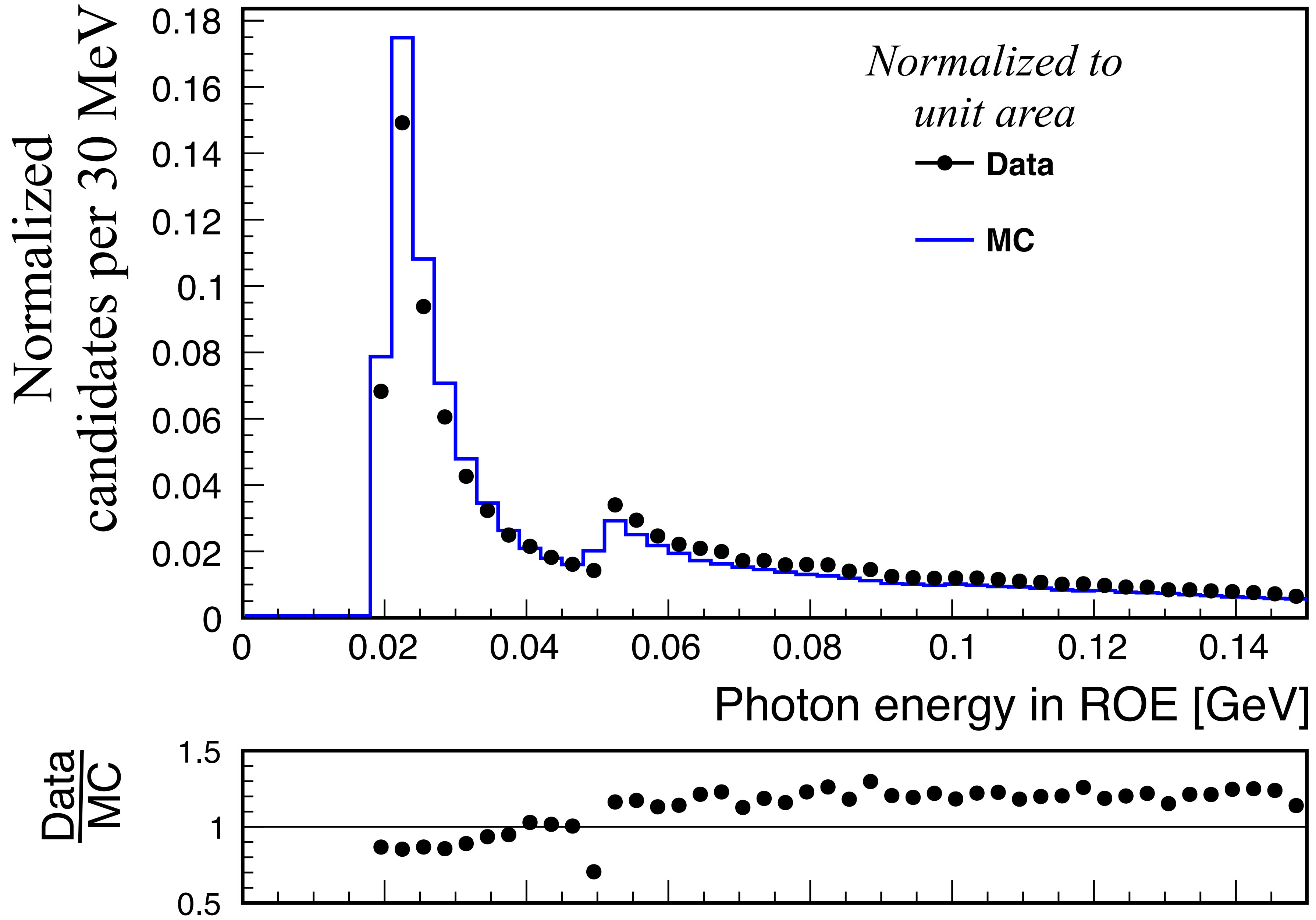
Summary

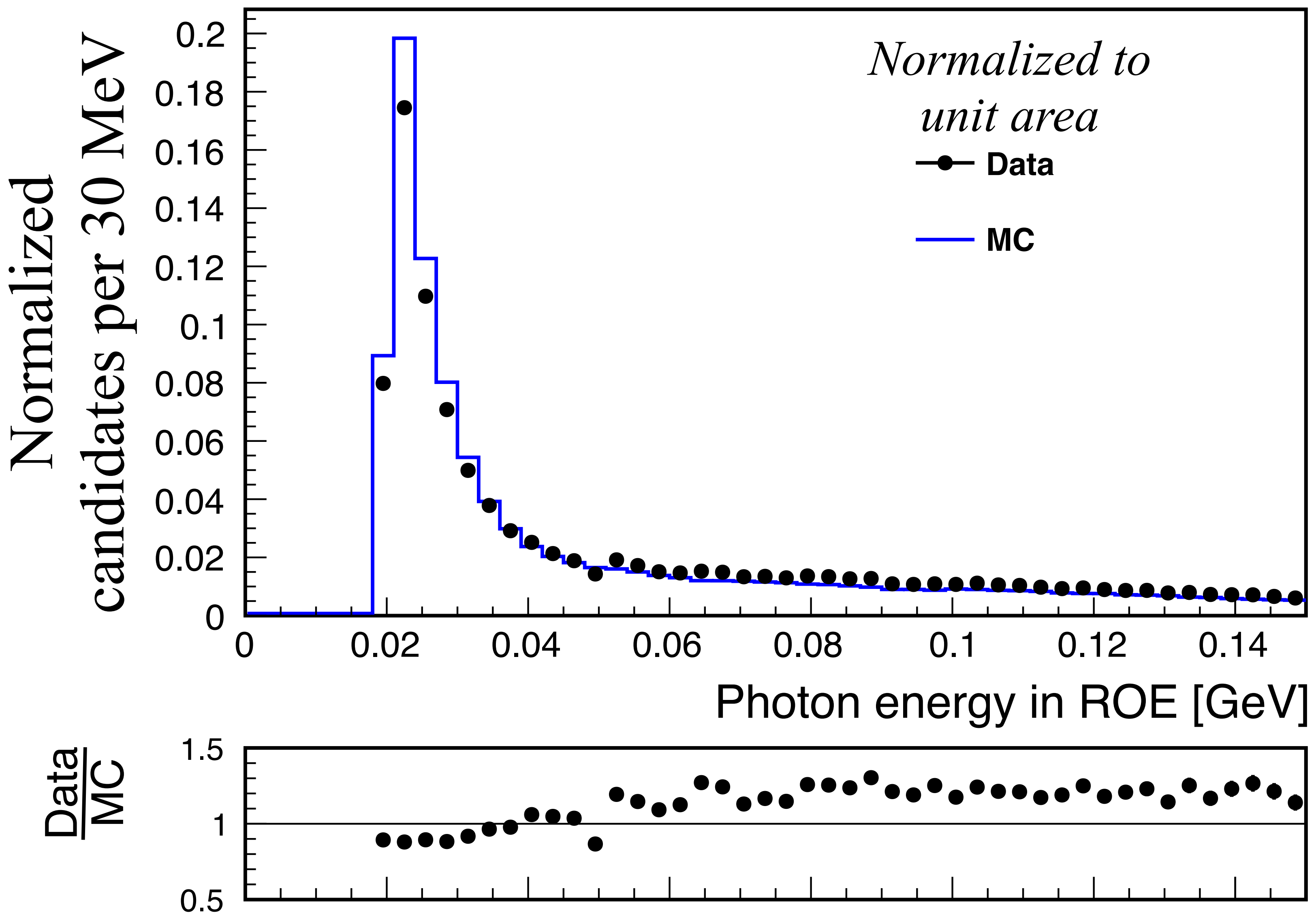
- E_{ECL} is important for most of the missing energy analyses.
- Studied data/MC comparison of photon energy and multiplicity to understand better E_{ECL} discrepancy using $B^+ \to \bar{D}^0 l^+ \bar{\nu}_l$ channel.
- The fake-photon shows data/MC discrepancy in photon energy and beam-background photons shows discrepancy in photon multiplicity.
- Correction of fake photon energy slightly improves E_{ECL} data/MC agreement.
- Correction of beam-background photon multiplicity is required to fix E_{ECL} mismodeling completely.

Backup

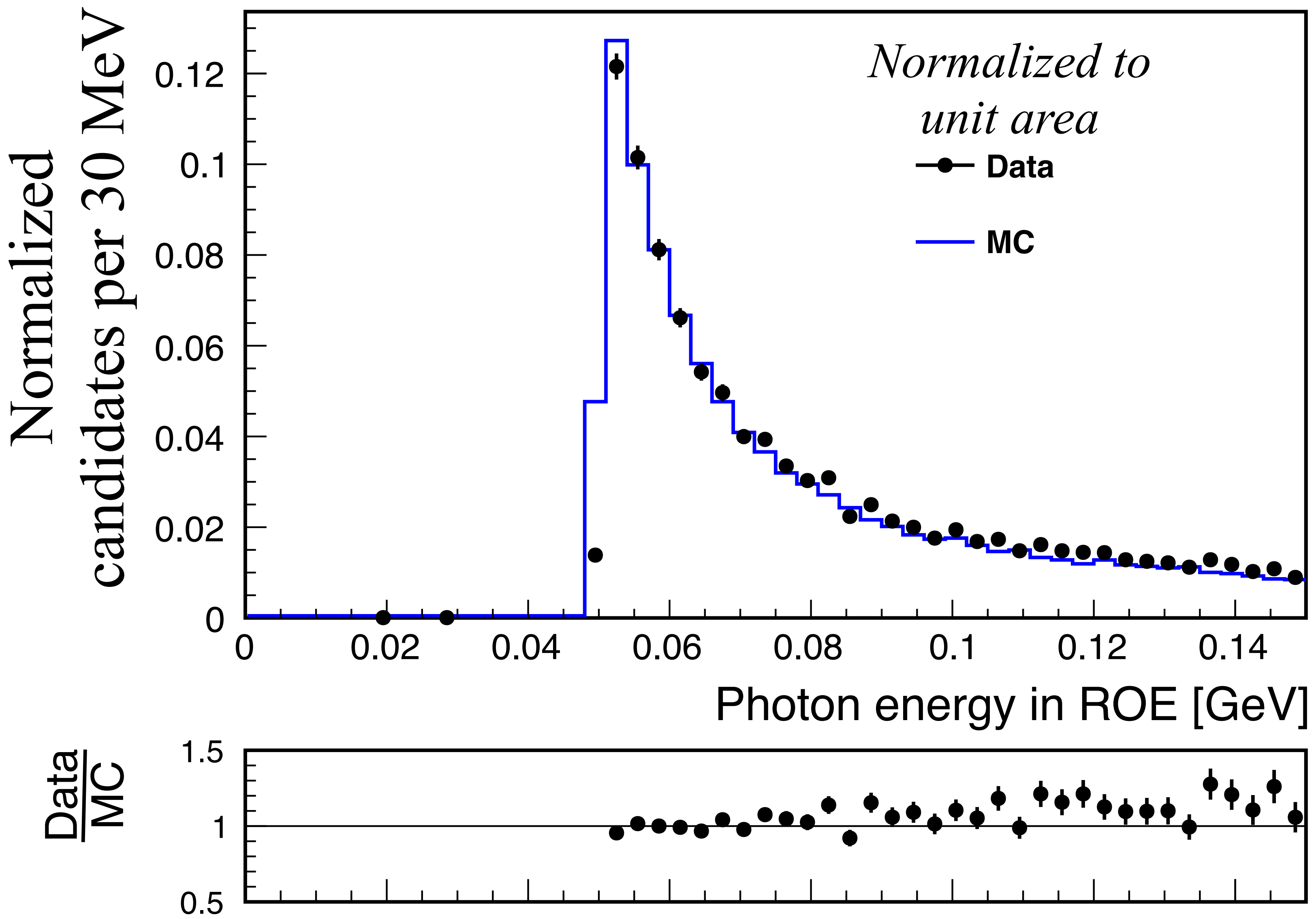
Reason of E(γ) > 55 MeV selection

without any selection





$$|\frac{\text{cluster timing}}{\text{cluster error timing}}| < 1$$



$$|\frac{\text{cluster timing}}{\text{cluster error timing}}| \geq 1$$

Low energy photon (E(γ) < 50 MeV) has cluster time ratio selections:

$$|\frac{\text{cluster timing}}{\text{cluster error timing}}| < 1$$

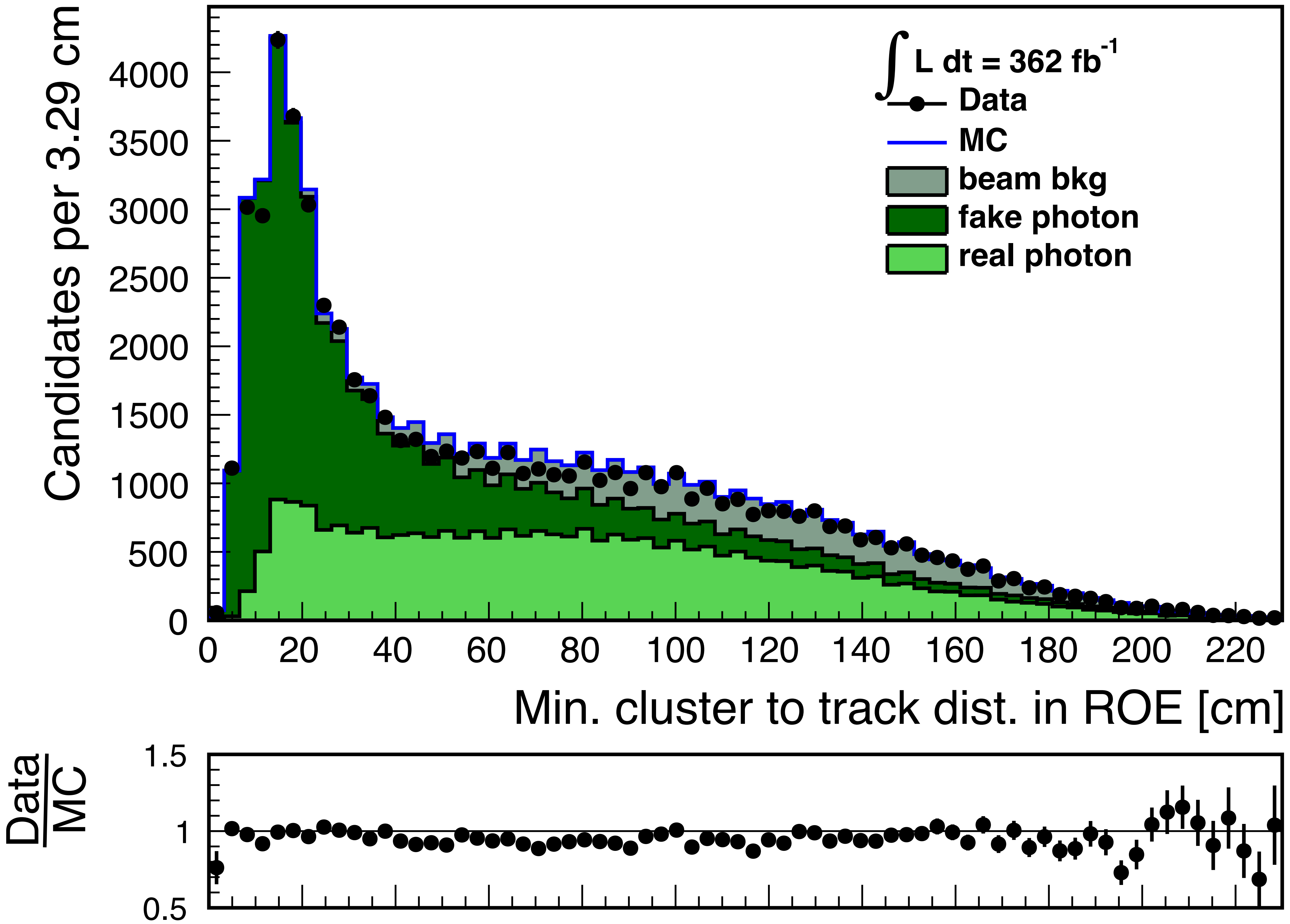
Definition of photon types

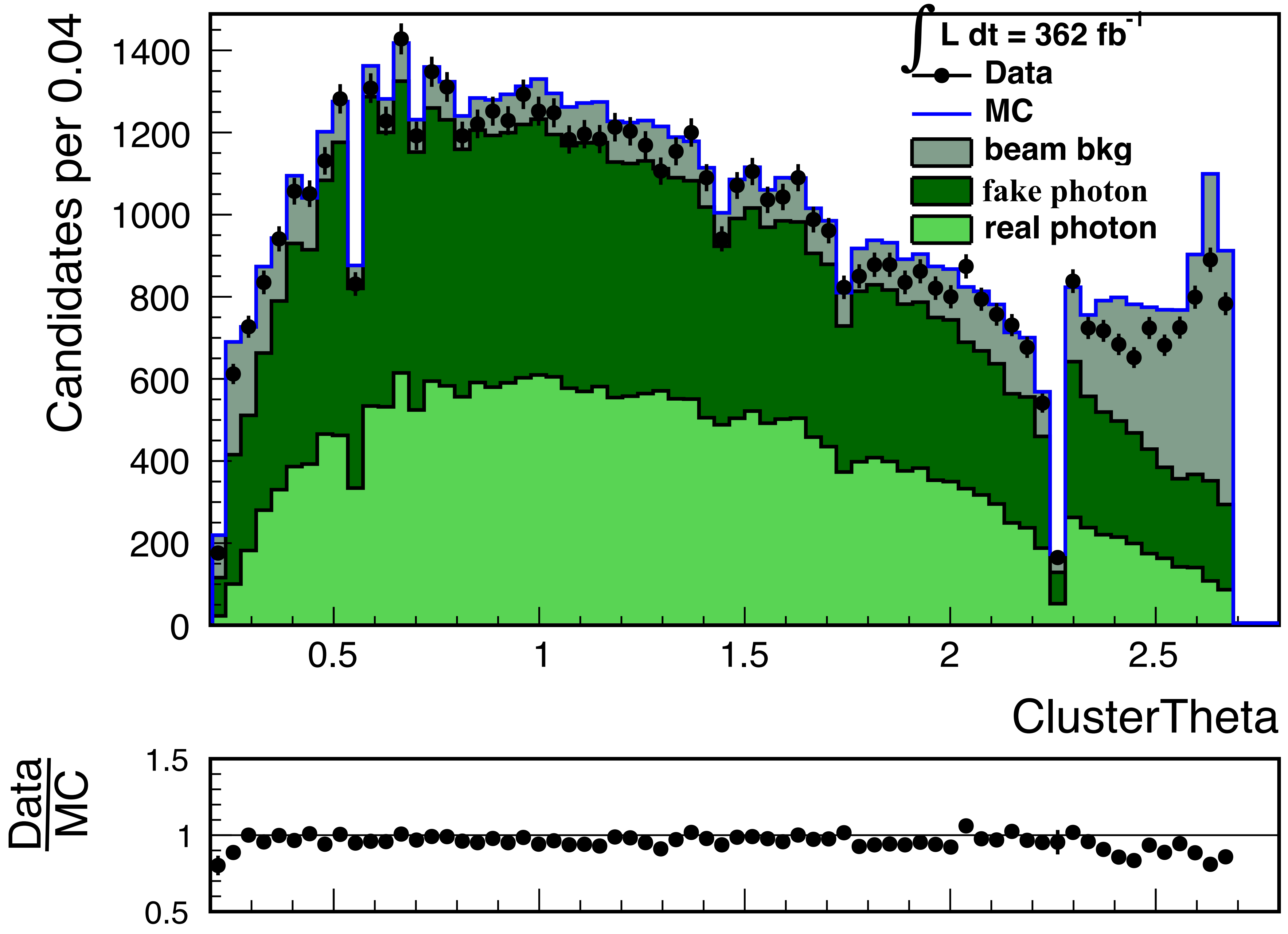
- Following definitions are taken from this post: *https://questions.belle2.org/question/11685/how-can-i-identify-merged-pi0s-and-beam-background-clusters-in-mc/*

  - Real photon: mcPDG=22 and $\frac{\text{clusterTotalMCMatchWeight}}{\text{clusterE}} > 0$
  - Fake photon: mcPDG≠22 and $\frac{\text{clusterTotalMCMatchWeight}}{\text{clusterE}} > 0$
  - Beam background: $\frac{\text{clusterTotalMCMatchWeight}}{\text{clusterE}} = 0$

Polar angle and minC2TDist

Normalized to same luminosity

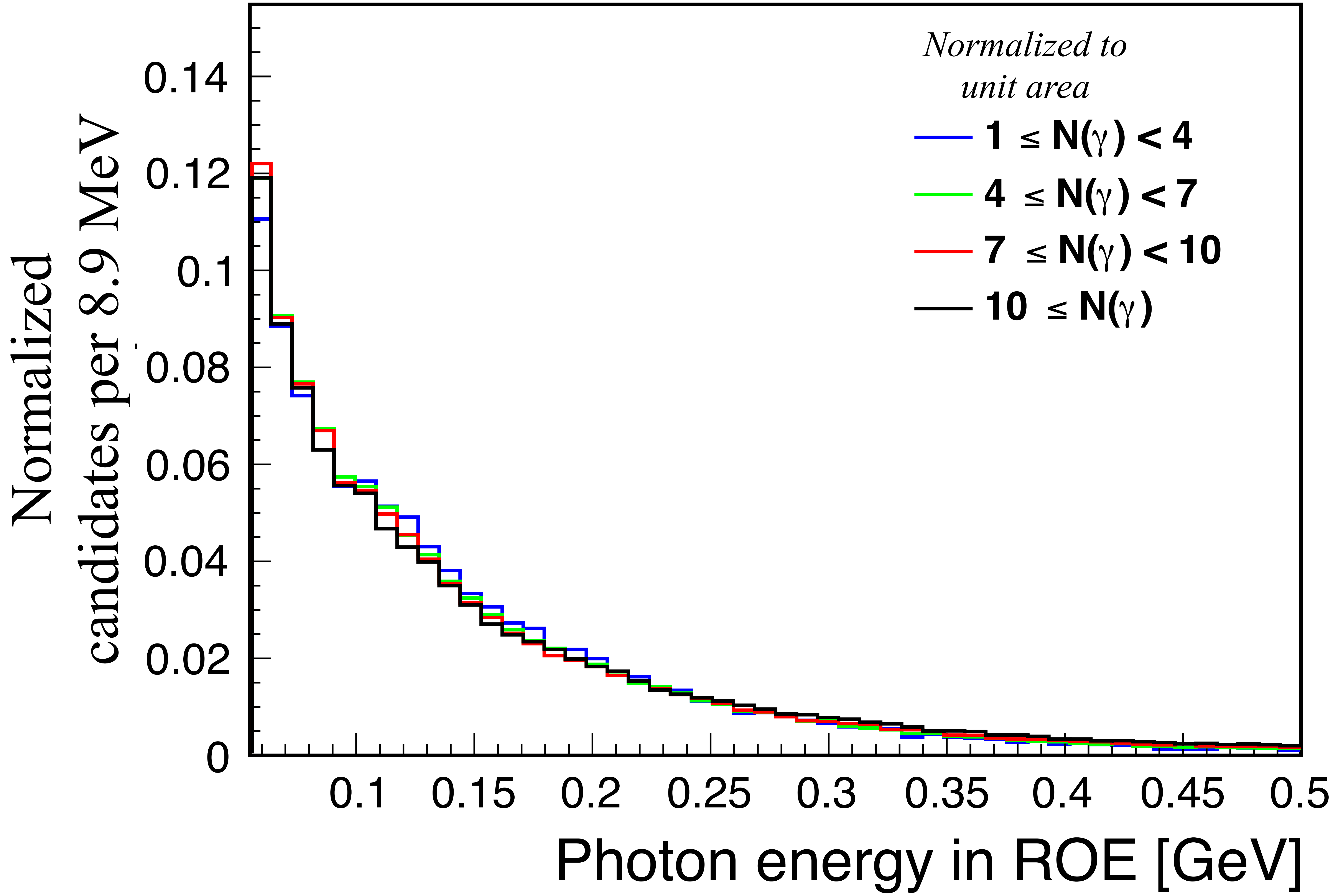




MC is scaled by FEI correction factor

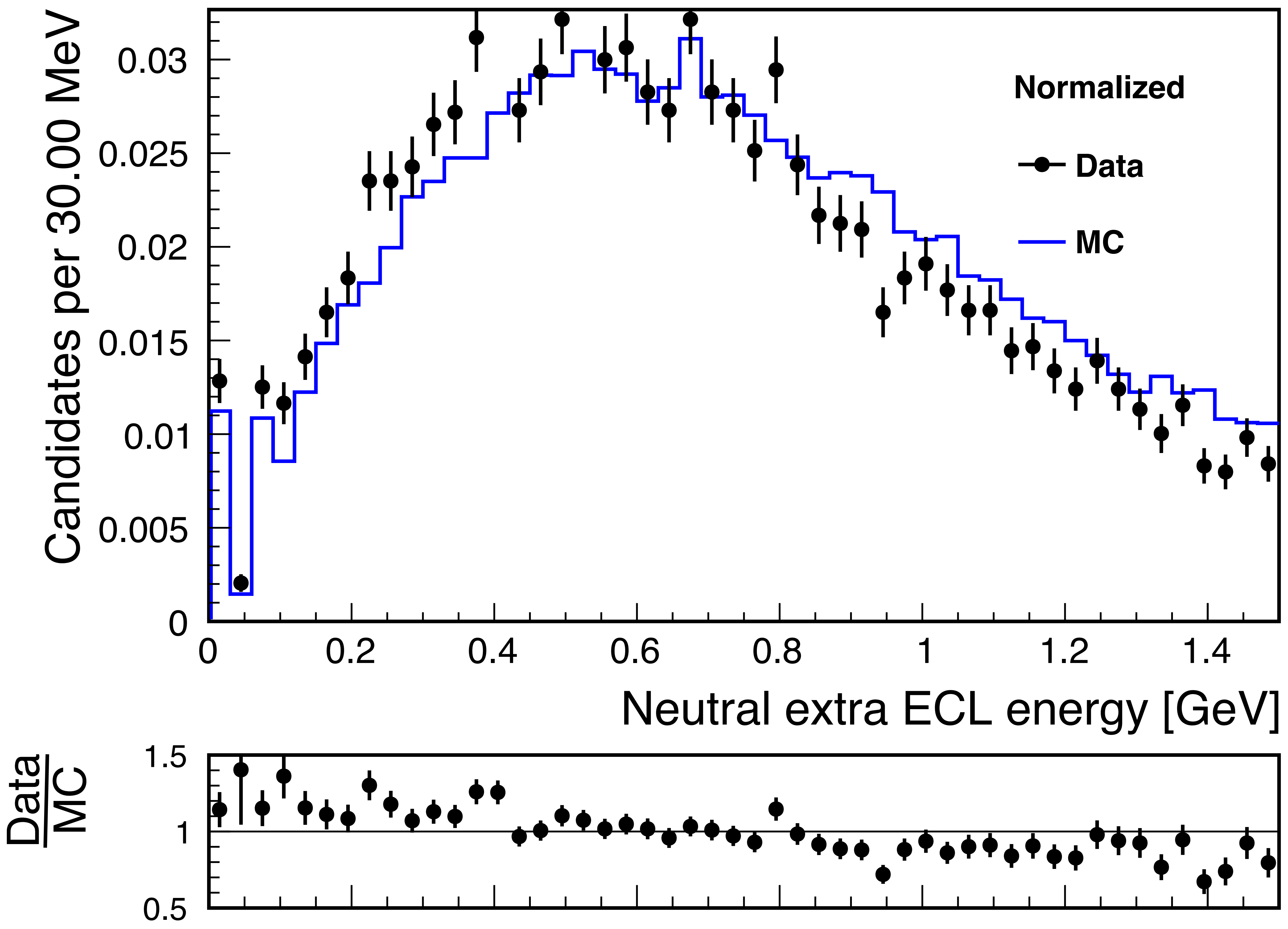
- charged: 0.65
- mixed: 0.65
- $q\bar{q}$: 0.86

$E(\gamma)$ vs $N(\gamma)$

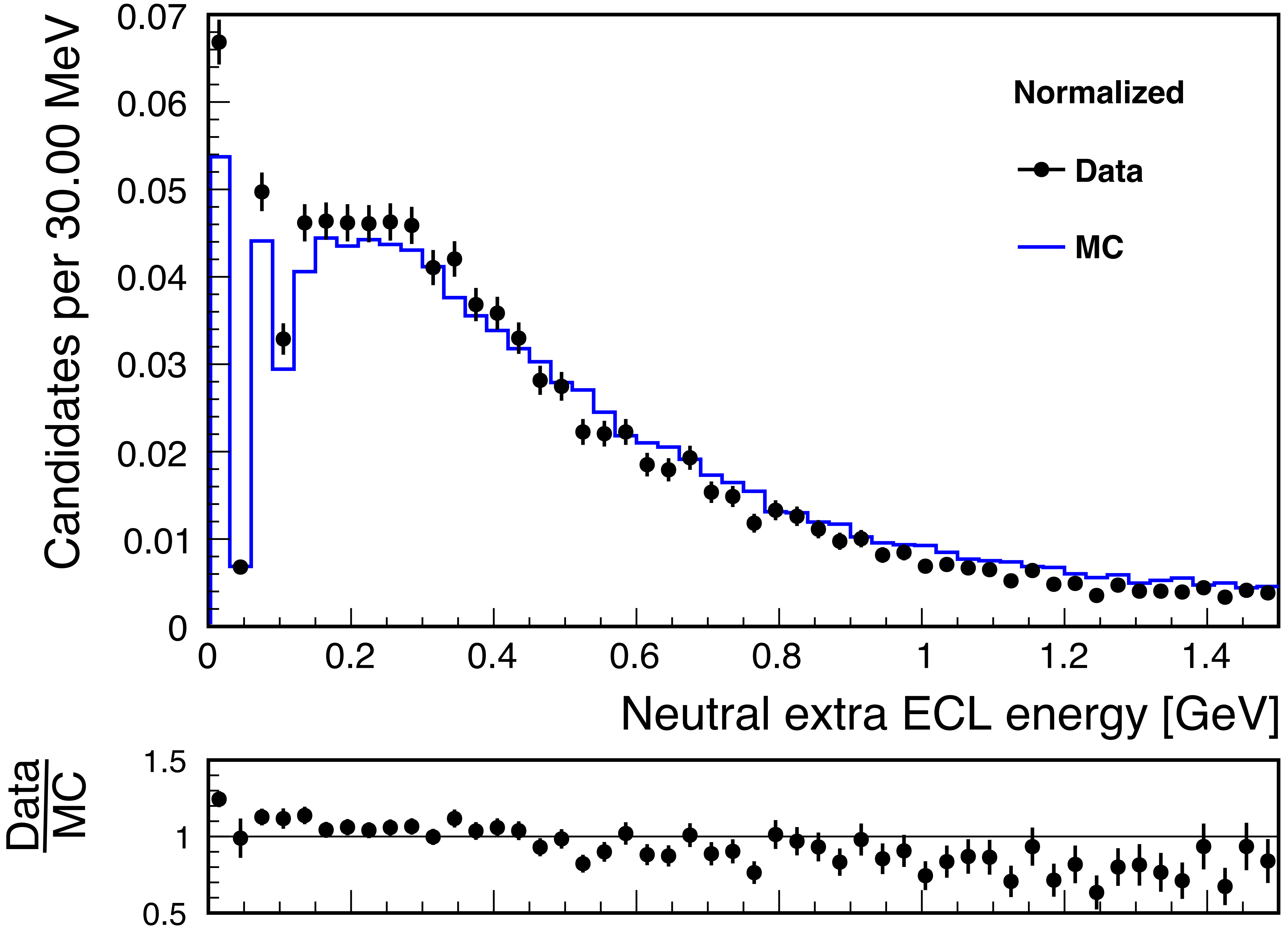


E_{ECL}: γ selections

selection: $E(\mathrm{fwd, brl, bkwd}) > (80{,}55{,}60)\mathrm{MeV}$



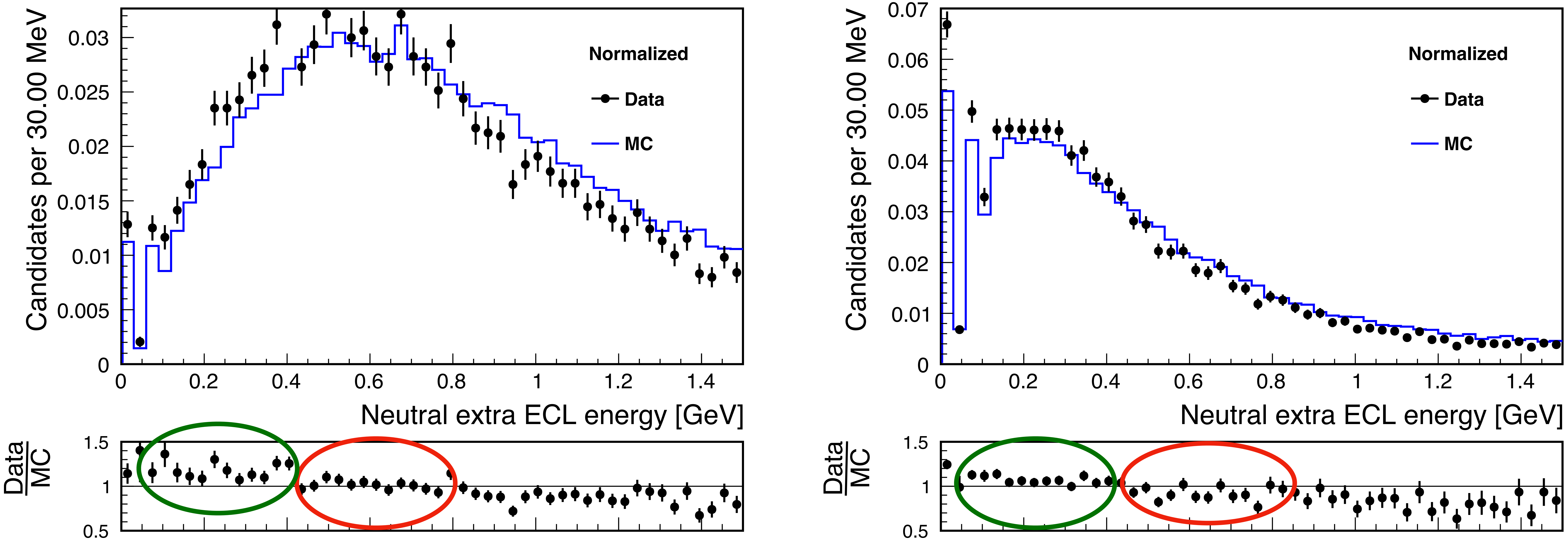
no minC2TDist selection



minC2TDist>30

E_{ECL}: γ selections

selection: $E(\text{fwd, brl, bkwd}) > (80{,}55{,}60)\text{MeV}$



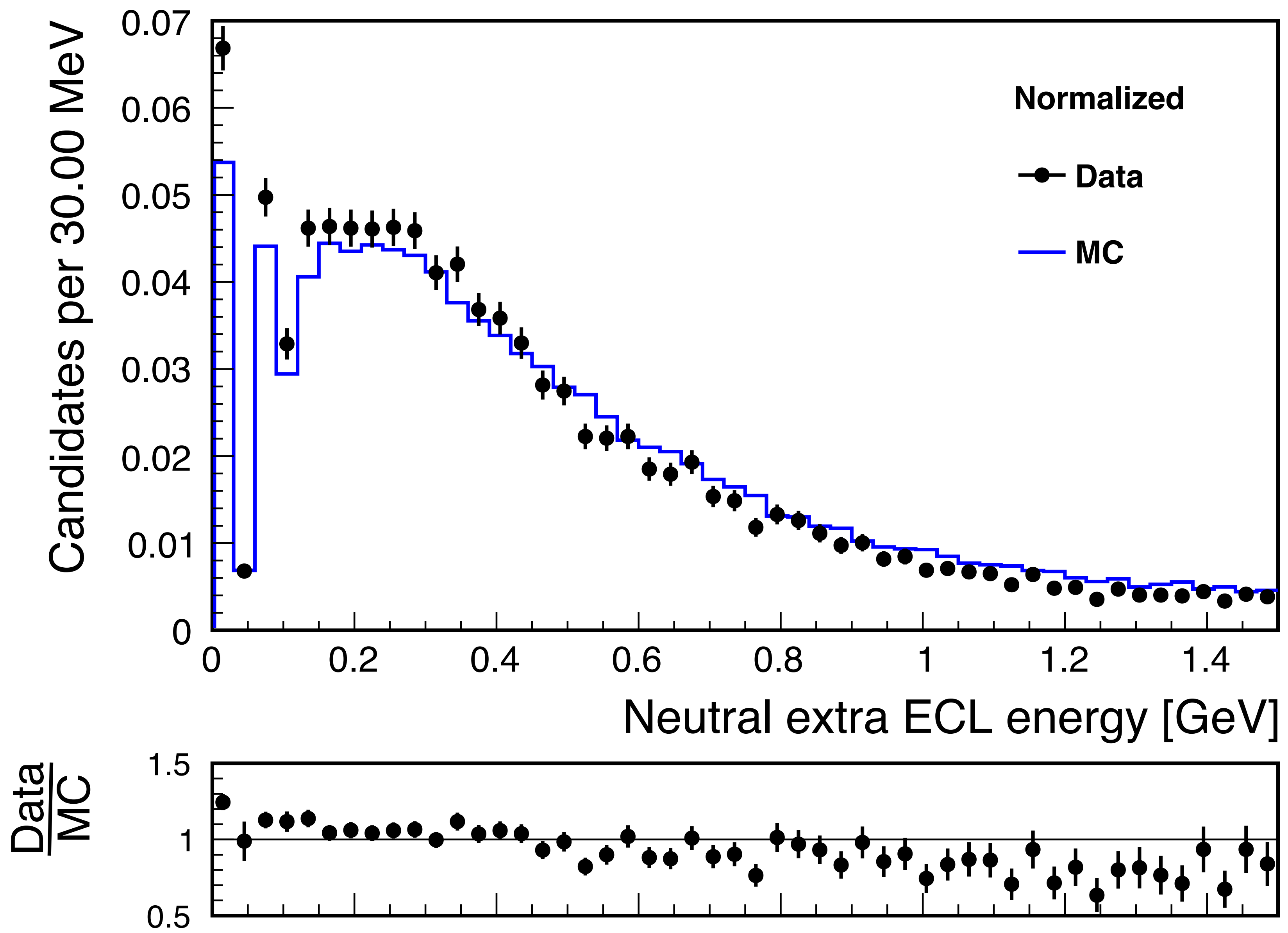
no minC2TDist selection

minC2TDist>30

E_{ECL}: γ selections

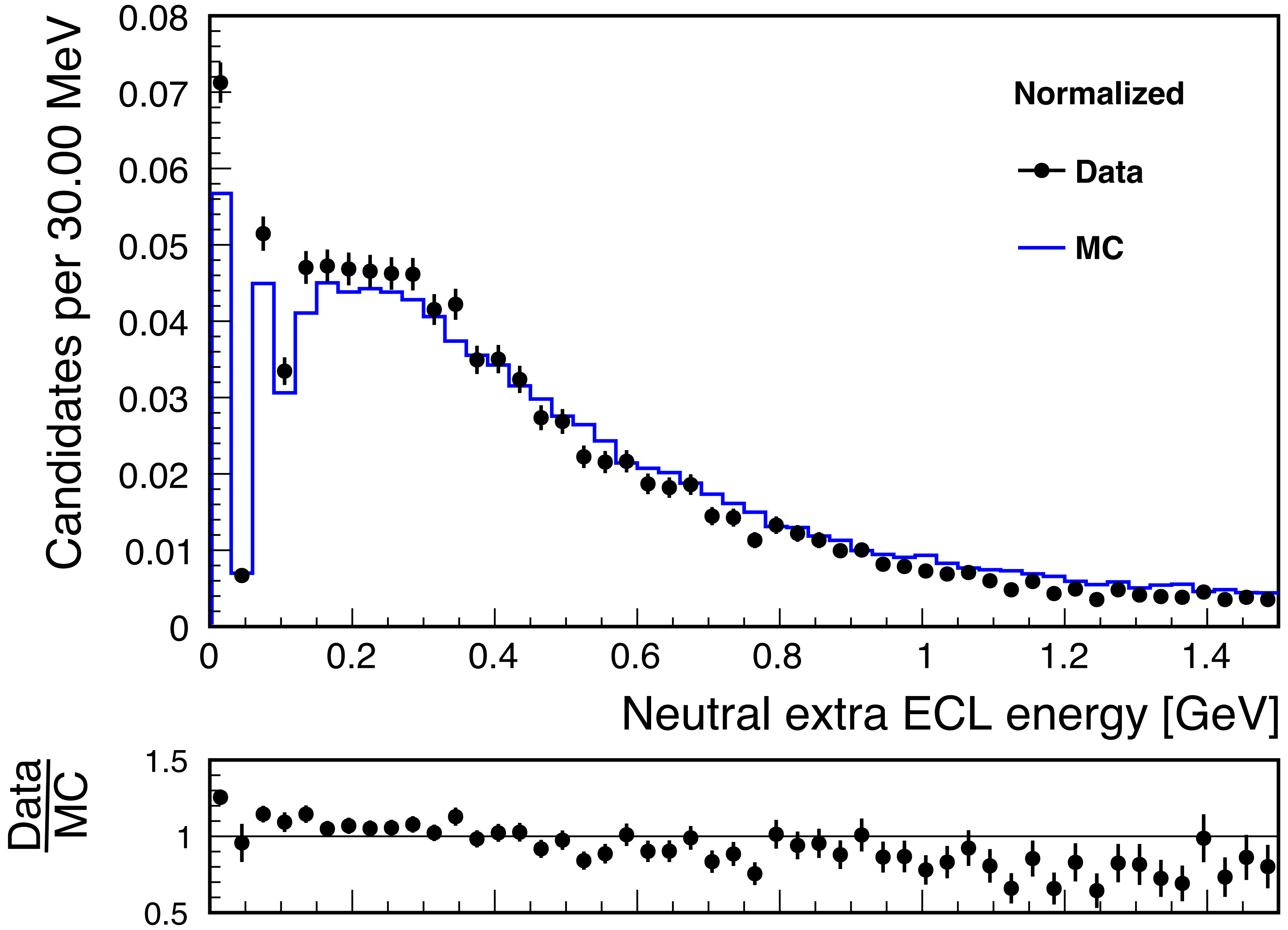
common selection: E(fwd, brl, bkwd) > (80,55,60)MeV

minC2TDist>30



minC2TDist>30

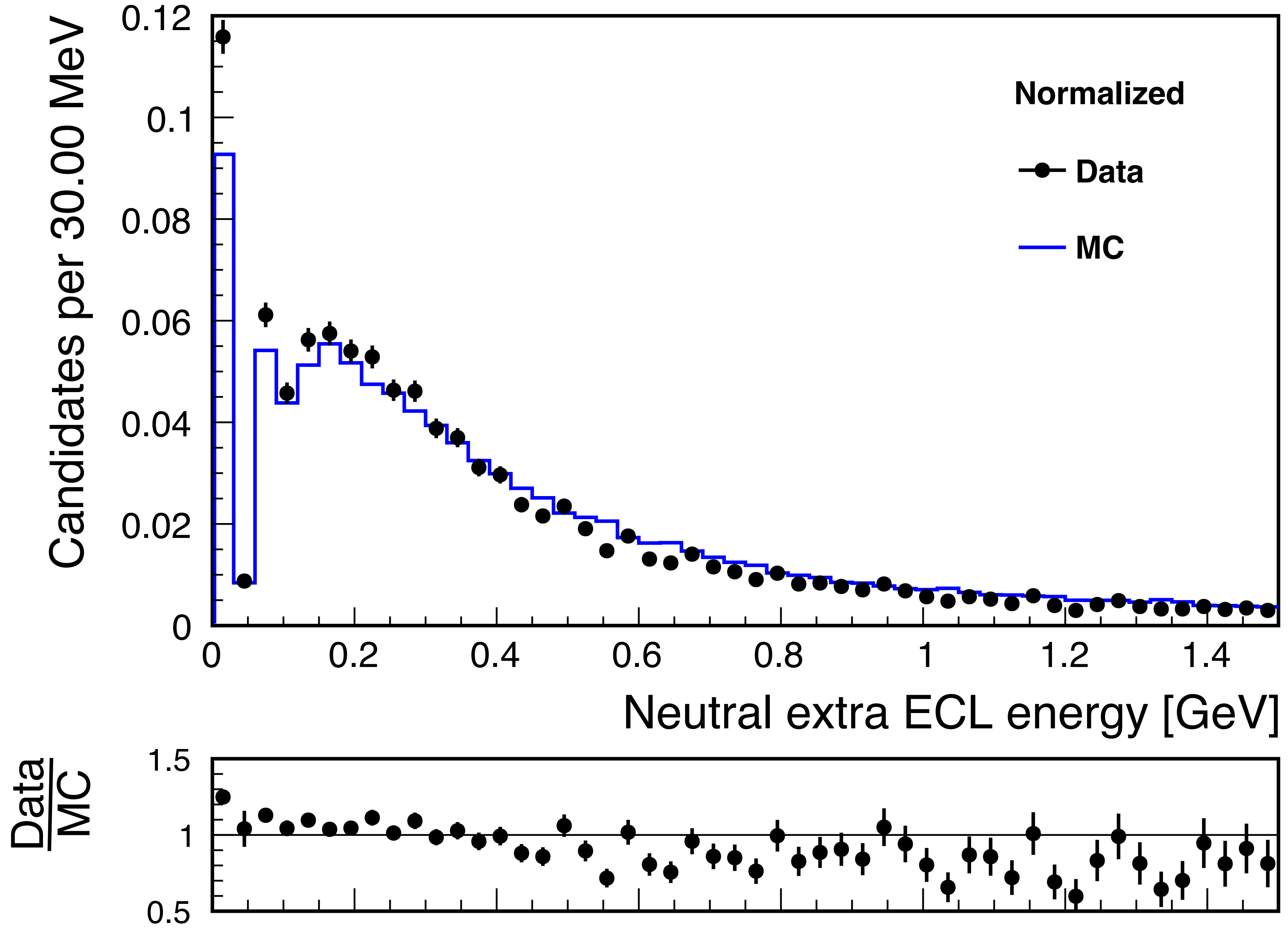
clusterNHits>1.5

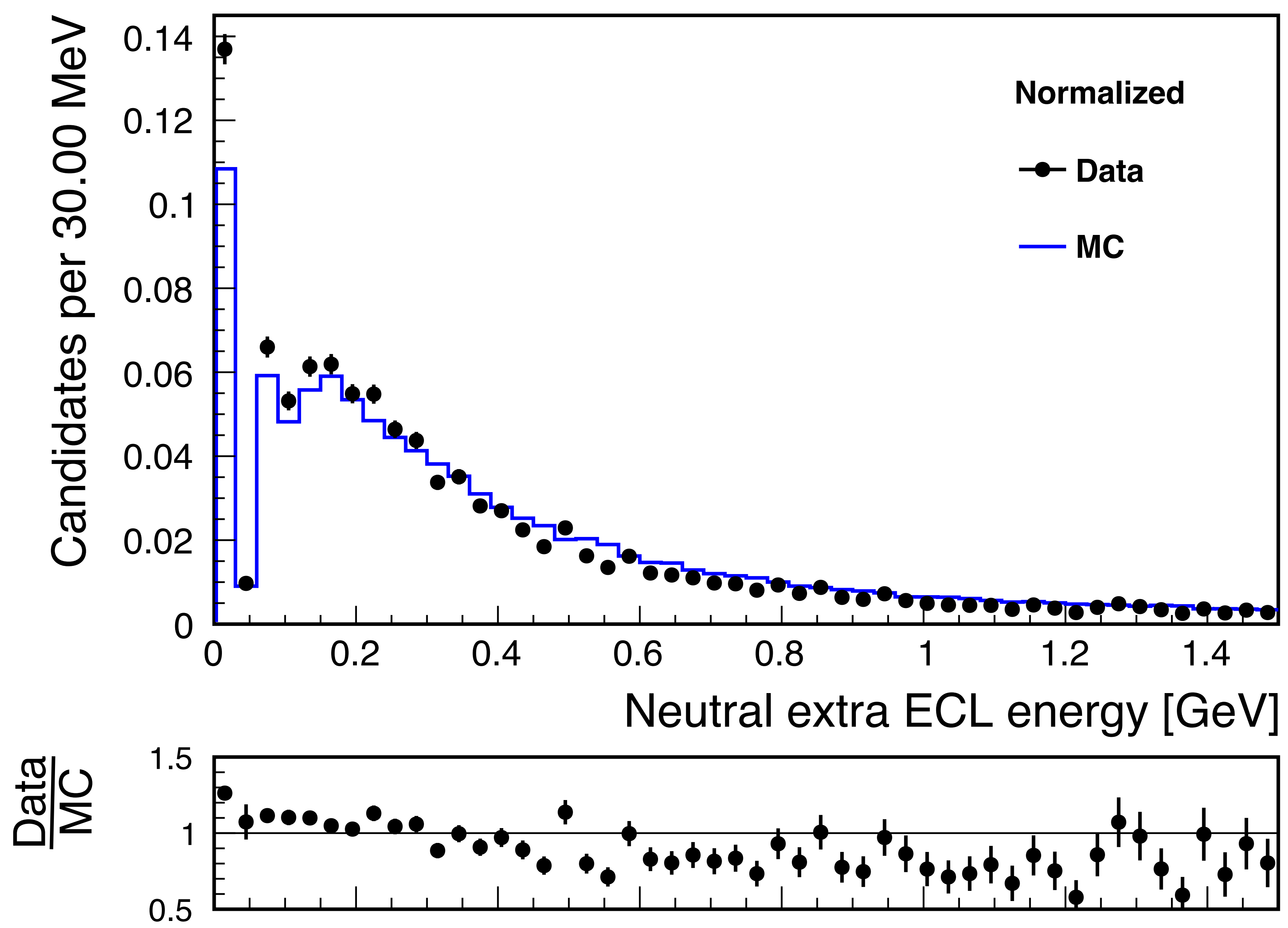


minC2TDist>30

clusterNHits>1.5

|clusterTime|<200





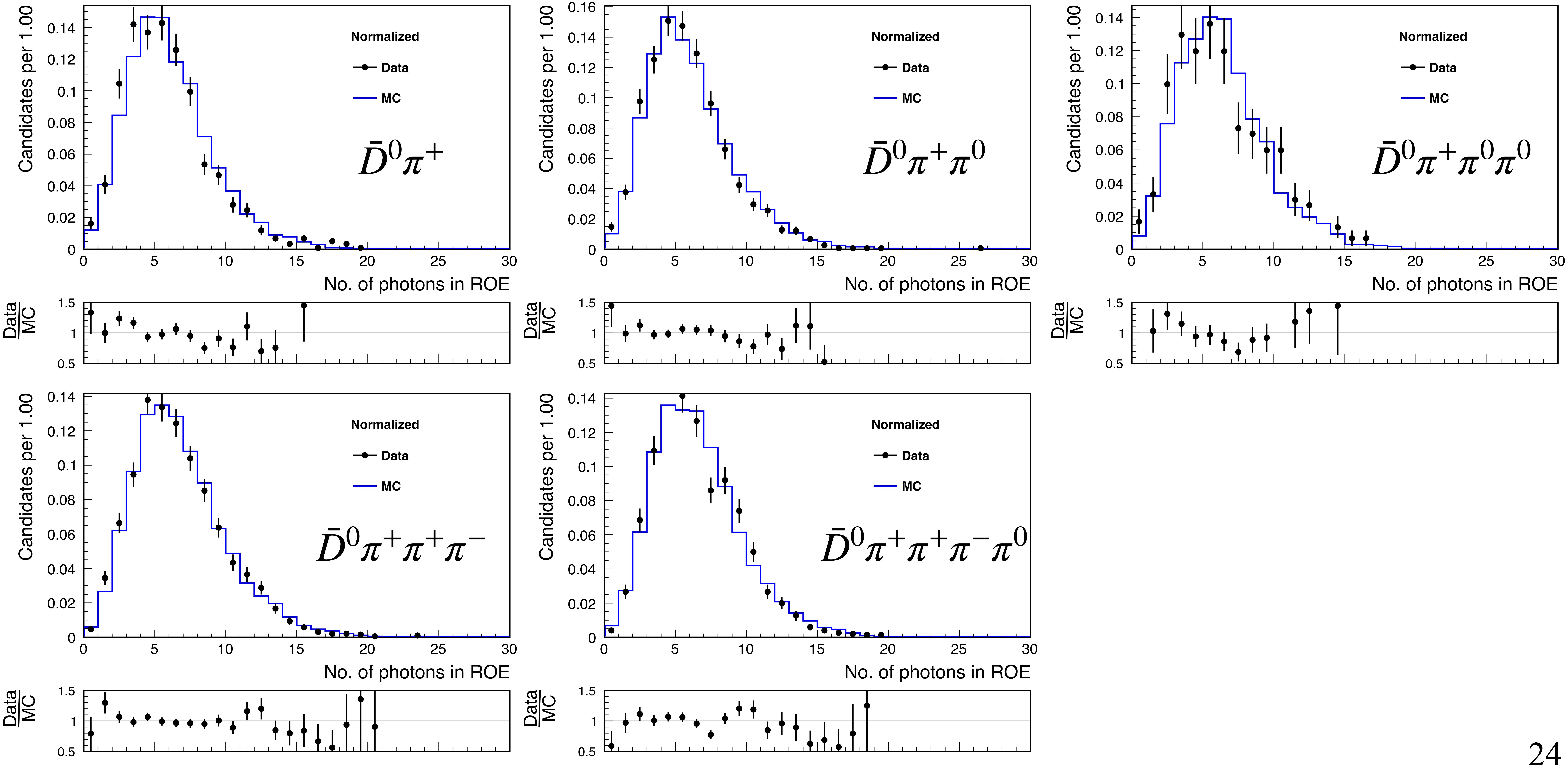
minC2TDist>30

clusterNHits>1.5

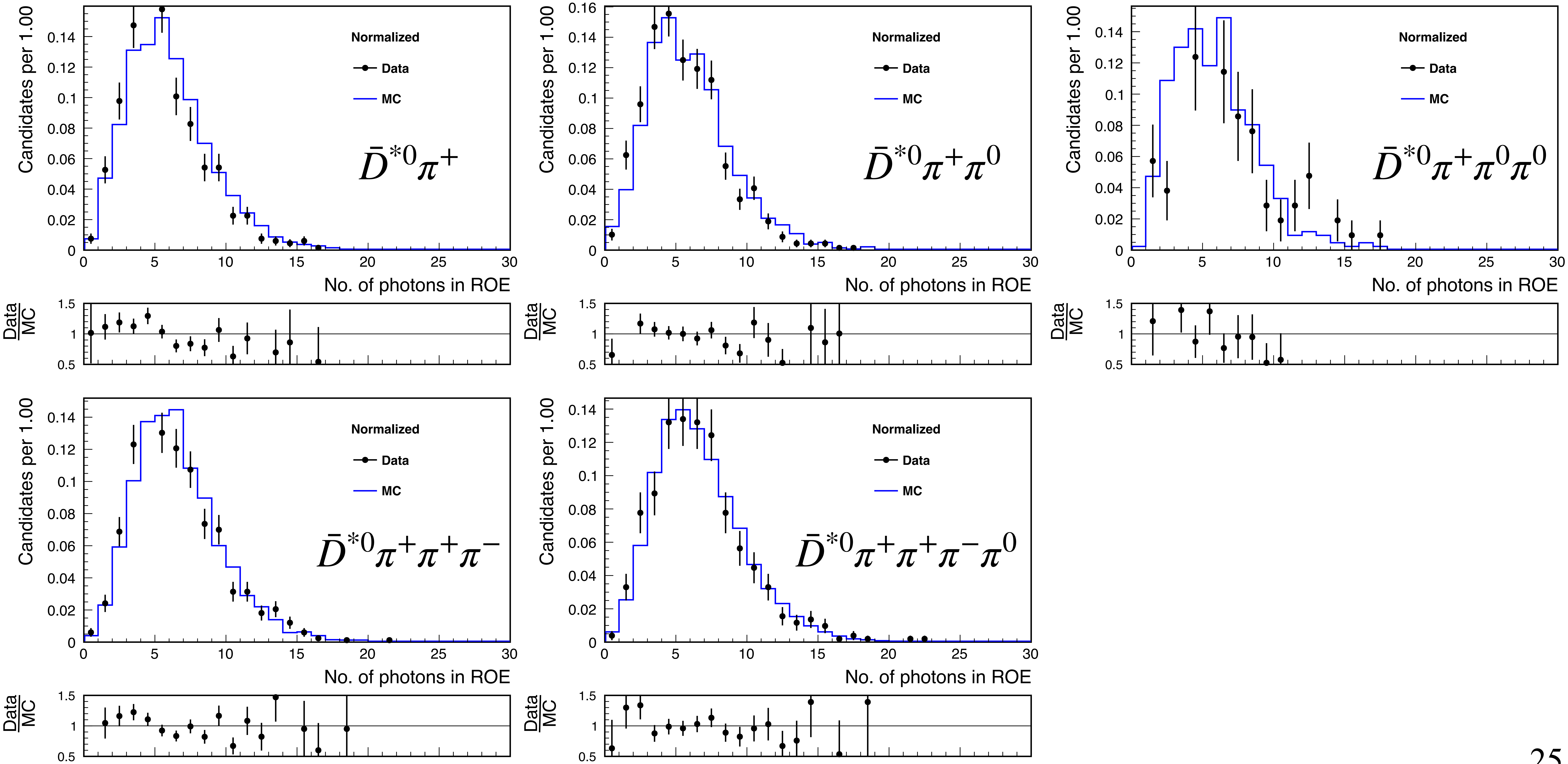
|clusterTime|<200

$\left|\frac{\text{clusterTime}}{\text{errorTime}}\right|<200$

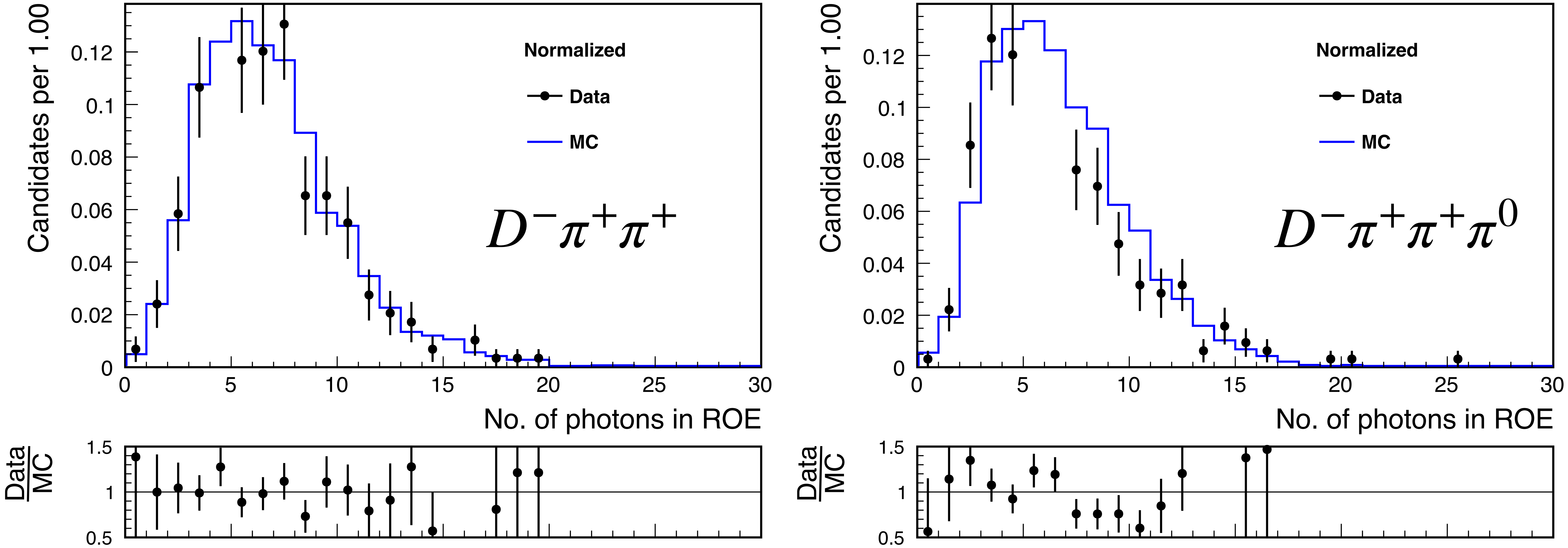
$N(\gamma)$ vs D^0 FEI mode



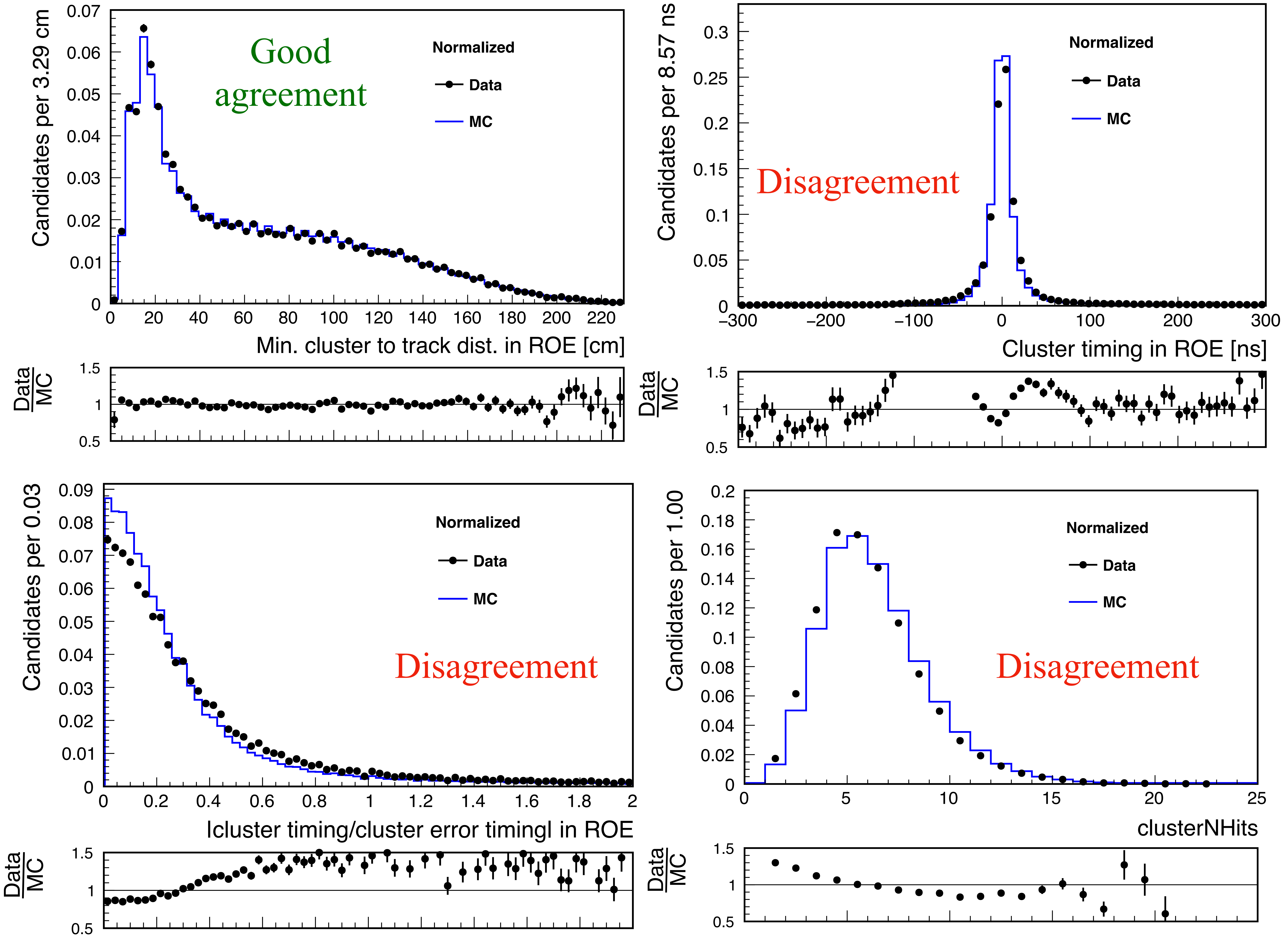
$N(\gamma)$ vs D^* FEI mode



$N(\gamma)$ vs D^- FEI mode

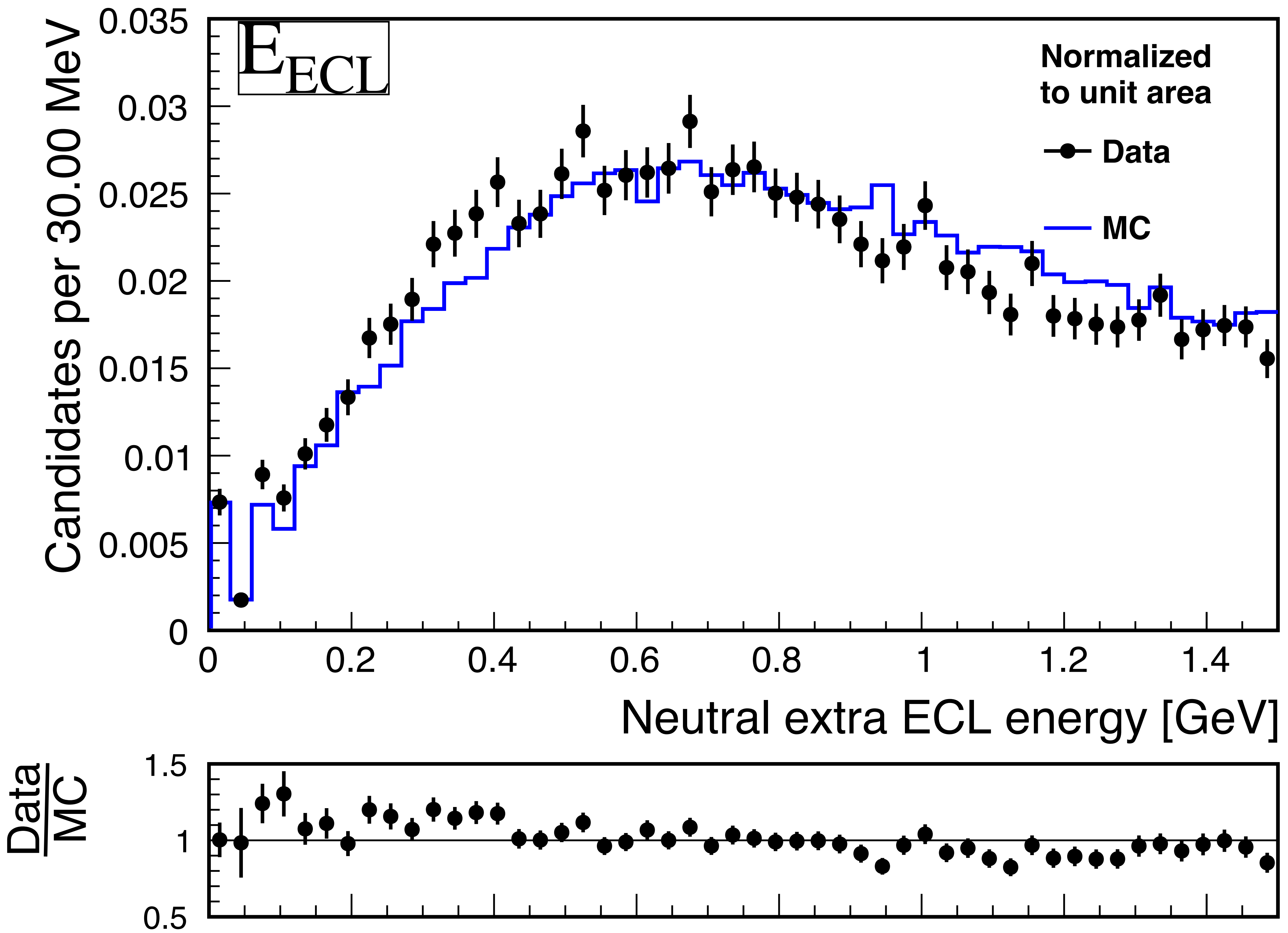


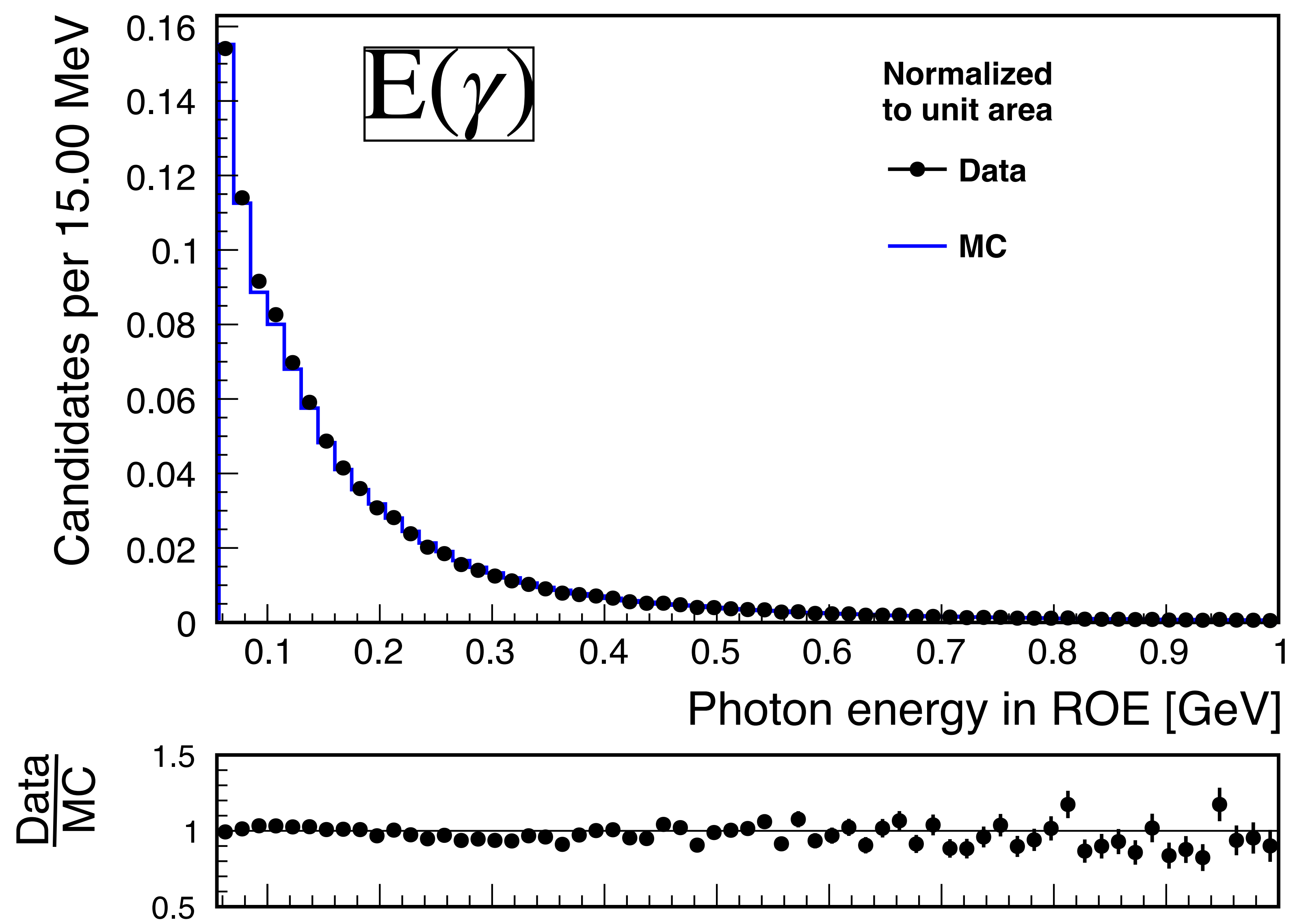
Data/MC comparison of other γ variables

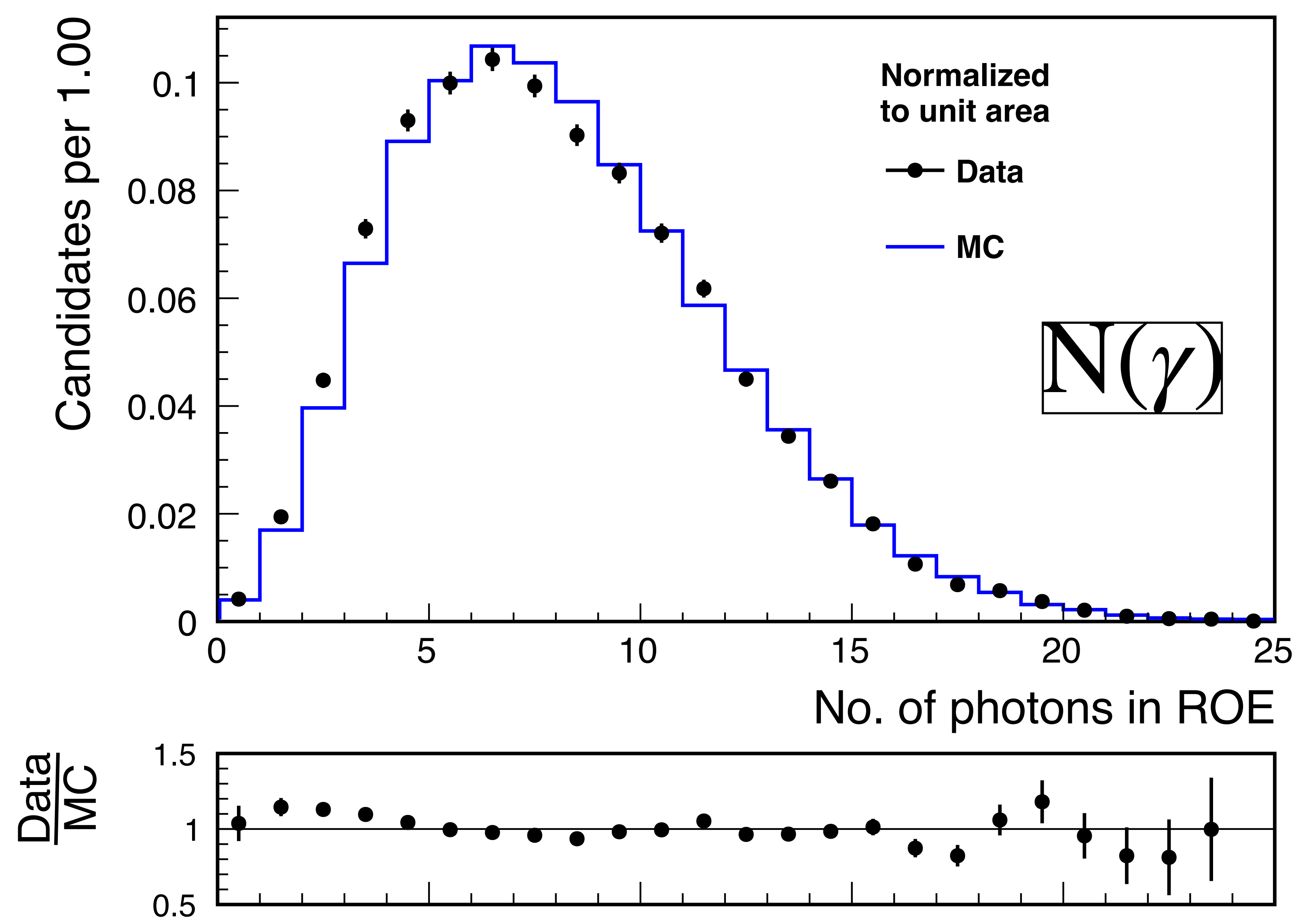


- γ variables like minC2TDist and cluster time are important to suppress beam background and fake photons
- Only minC2TDist has good data/MC agreement

$B^+ \to \bar{D}^0 \pi^+$







E(γ) has good agreement;

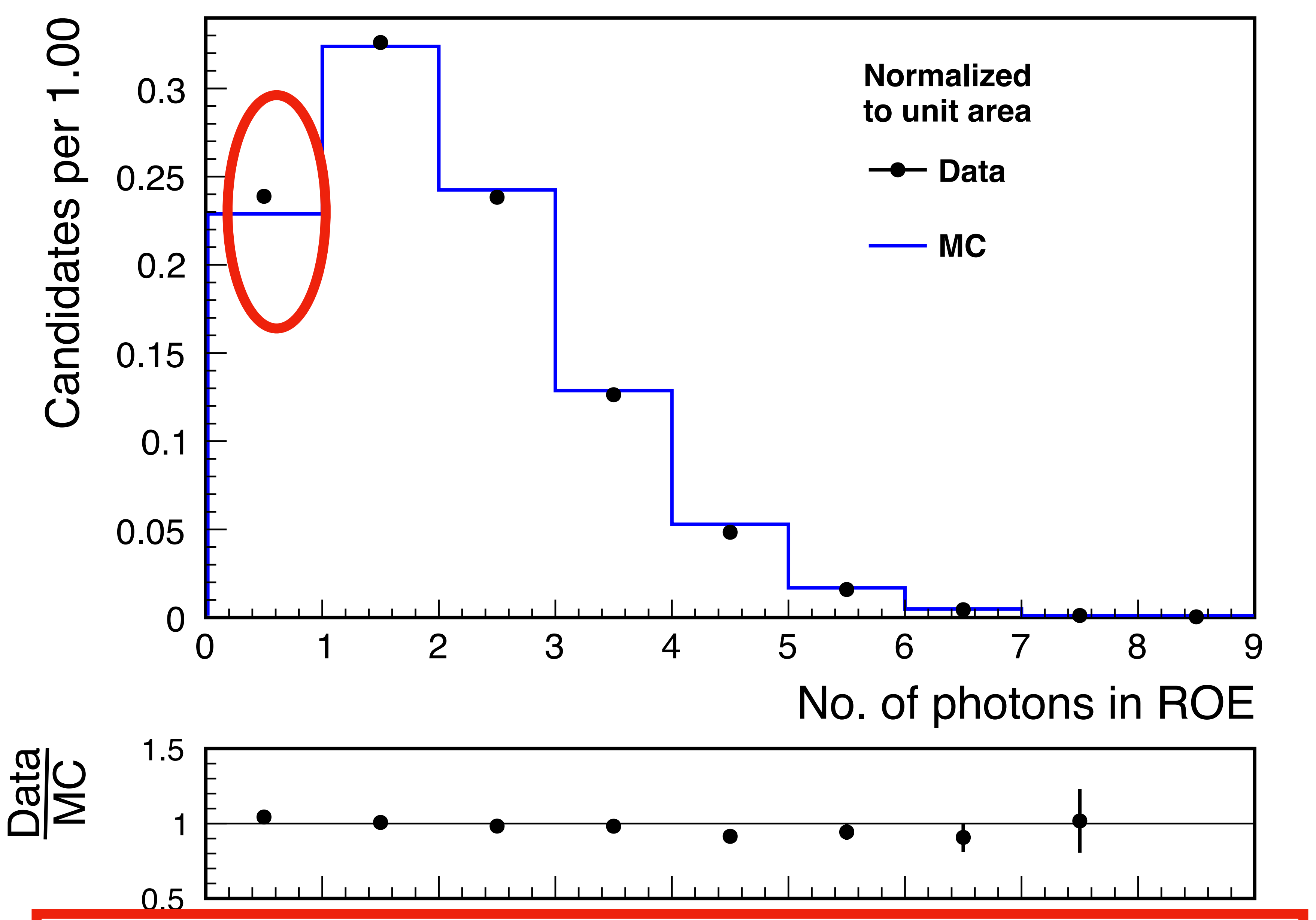
N(γ) has disagreement in lower bins

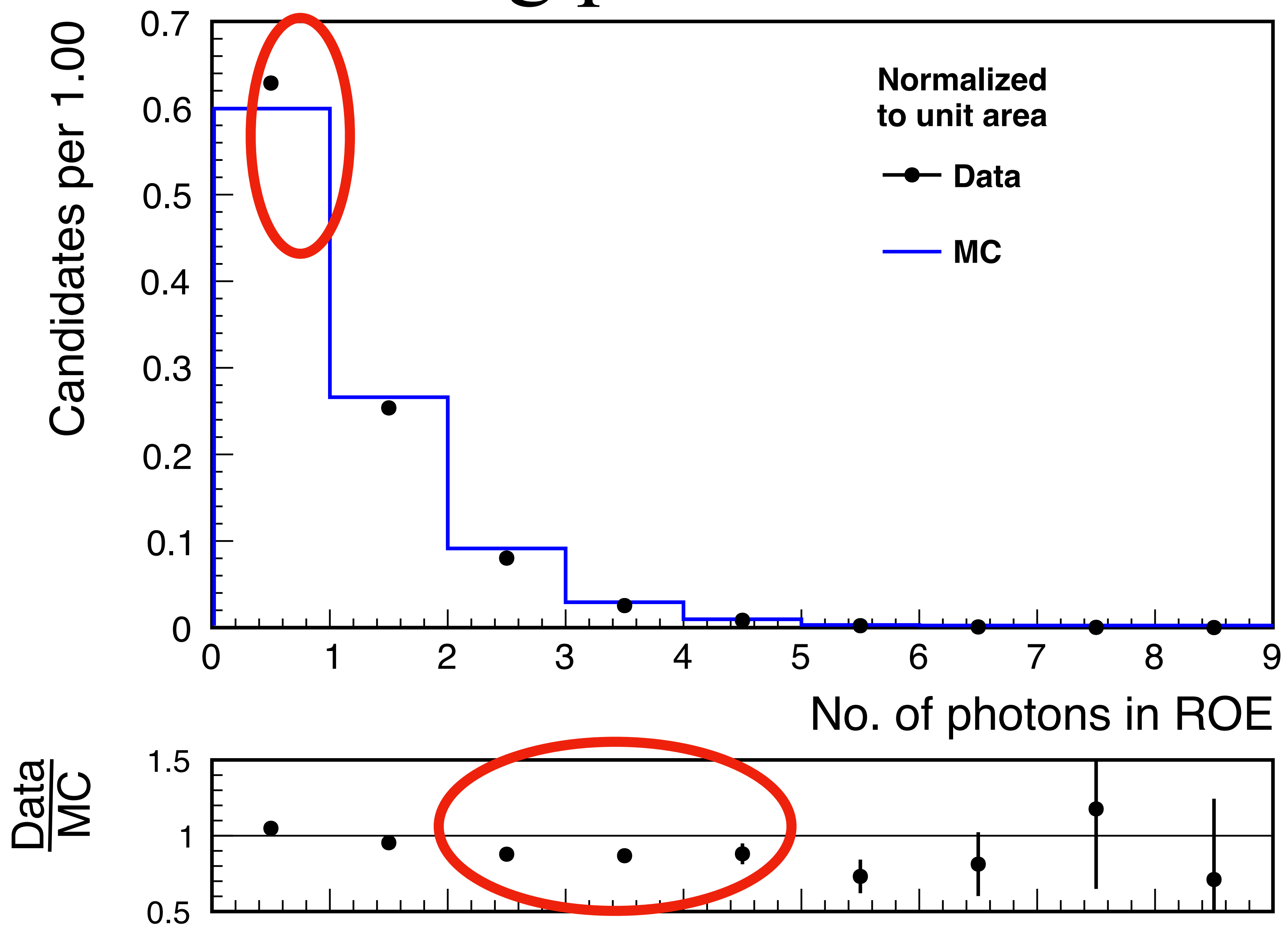
$B^+ \to \bar{D}^0\pi^+$

Fake photon dominated

Beam-bkg photon dominated

$N(\gamma)$





$E(\gamma)$