E_{ECL} in Semileptonic B decays at Belle II

Racha Cheaib

$B^0 \to D^*\ell\nu$

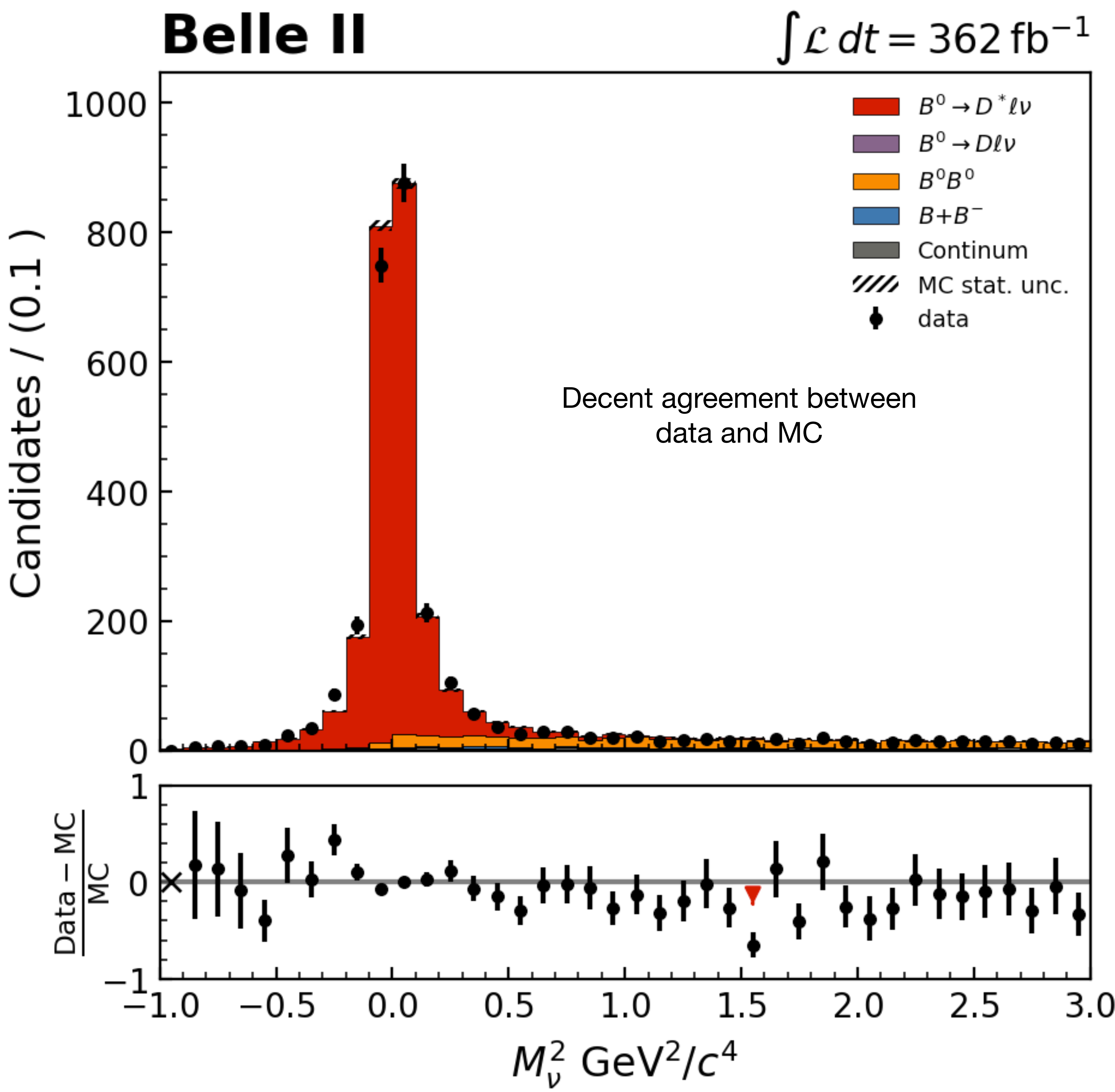
- **Apply MVA study on BB analysis: $B^0 \to D^{*+}\ell\nu_\ell$**
- Use samples are skimmed with the Full Event Interpretation, using the release-06 FEI training (without ECL cut) and release light-2210-devonrex.
  - 2.8 fb^{-1} of generic MC15 BB and 1.0 fb^{-1} qq run independent MC.
  - **Data: LS1 dataset.**

1. Apply hadronic FEI reconstruction:
Select events with one Btag with Mbc>5.27 Gev/c2 and -0.15<ΔE<0.1 GeV.
Apply fox Wolfram<0.2 offline.

2. Select $B^0 \to D^*\ell\nu_\ell, D^{*+} \to D^0\pi^+$
|d0| < 0.5 and -2 < z0 < 2.
muonID_noSVD>0.9

3. $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+, K_s^0\pi^+\pi^-, K^-K^+, \pi^-\pi^+$
Modes with π^0: 1.842<M_D<1.886 GeV/c2
Modes without π^0: 1.853 < M_D < 1.875 GeV/c2
D* mass difference cut: 0.142<ΔM_{D*}<0.150 GeV/c2

4. Apply a vertex fit to the Bsig candidate
5. Reconstruct $\Upsilon(4S) \to B\bar{B}$ and look in the ROE for additional energy deposits.
6. Choose best candidate based on the candidates with the highest Btag sig probability and the highest momentum of the slow pion daughter of the Bsig.
7. Apply ROE_charge ==0 and ROE_nTracks==0

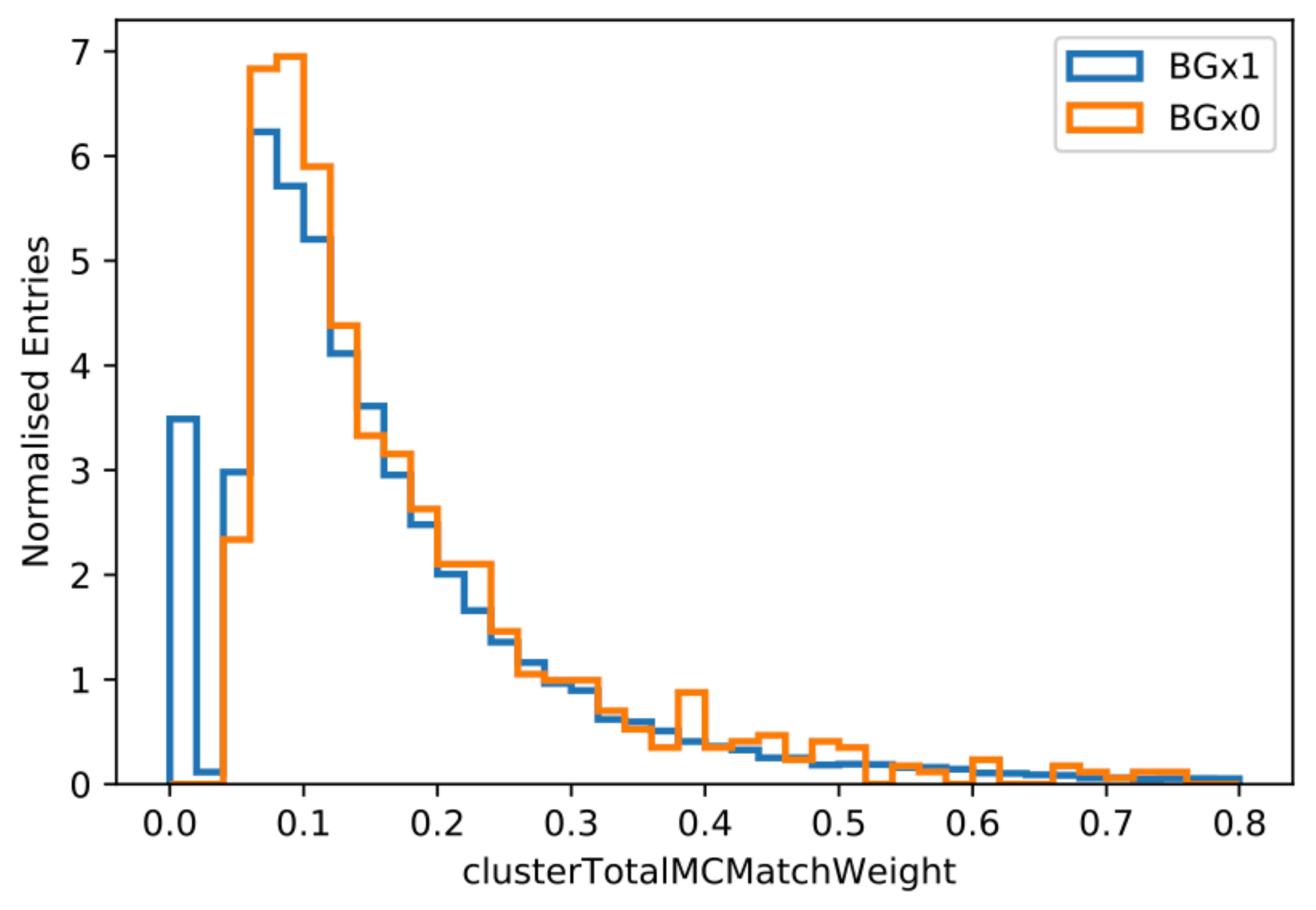


MC Cluster Classification

NaN clusters: **beam background clusters** and **hadronic split-offs or fake photons** are a considerate contributor in ROE gamma distribution.

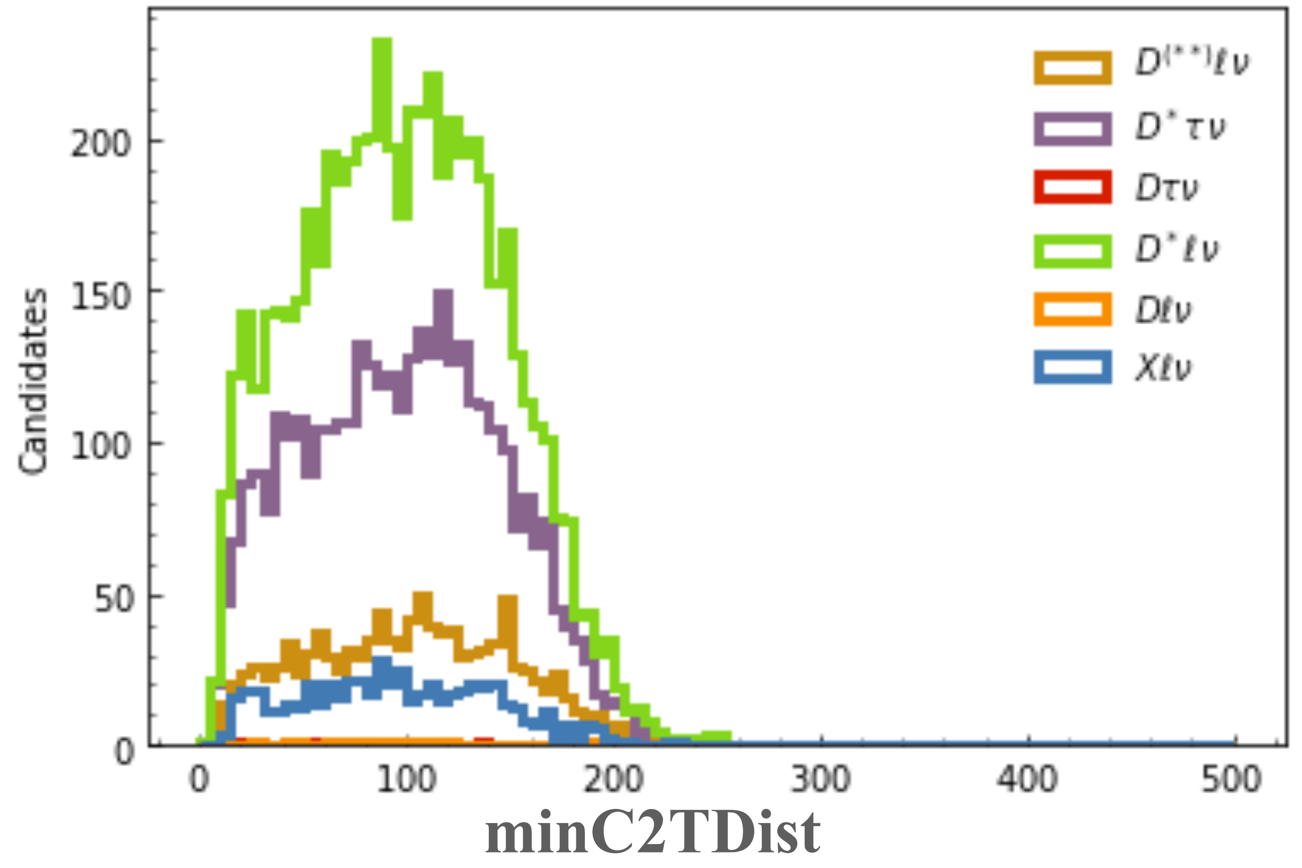
Sample	Xlv	D*lv	Dlv	D*tv	Dtv	D**tv
mcPDG ==22	45.8	20.5	38	22.9	45.8	39.3
mcPDG !=22	12.4	17.8	17	16.9	14.6	13.3
NaN	41.8	61.7	45	60.2	39.6	47.4

clusterTotalMCMatchWeight: compared BGx0 and BGx1 $D^*\ell\nu$

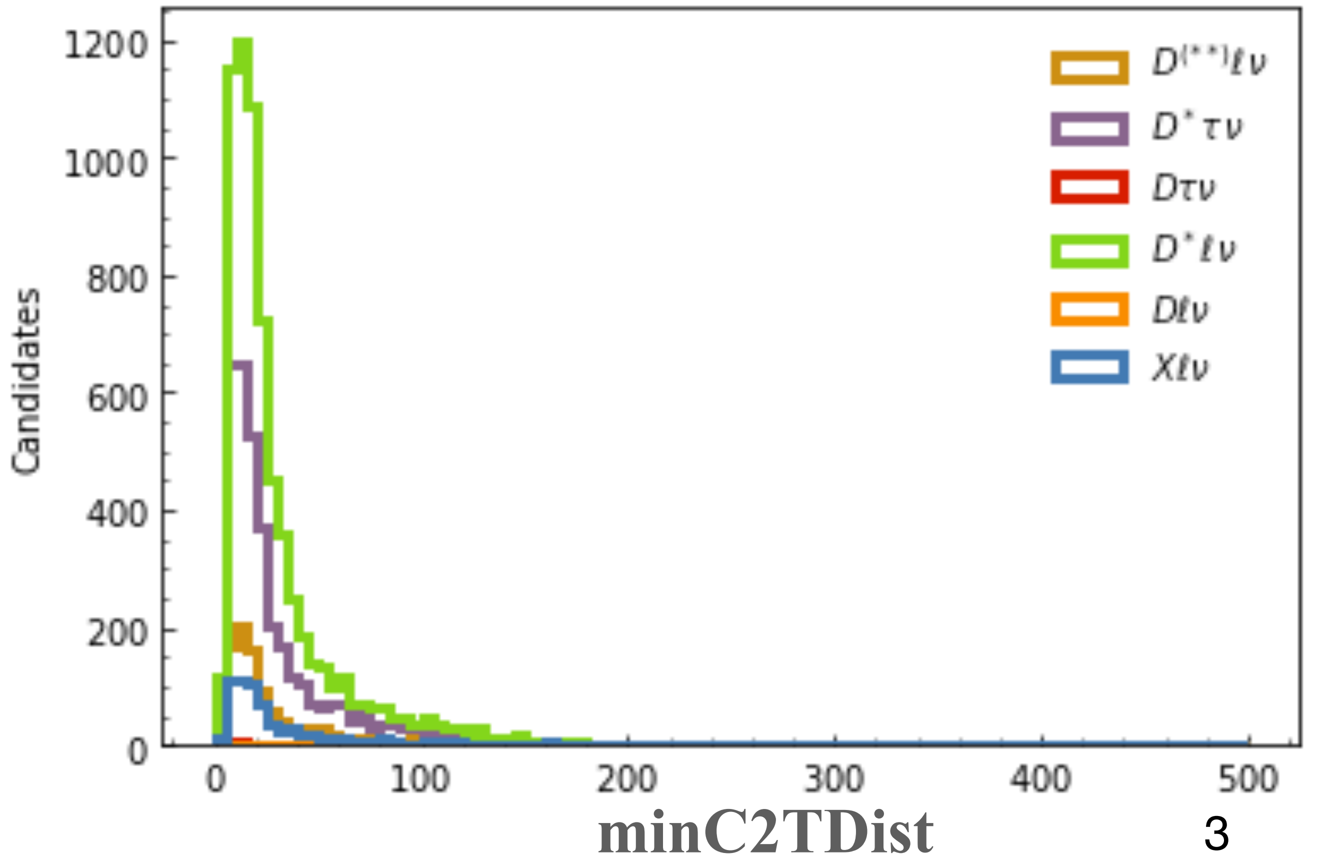


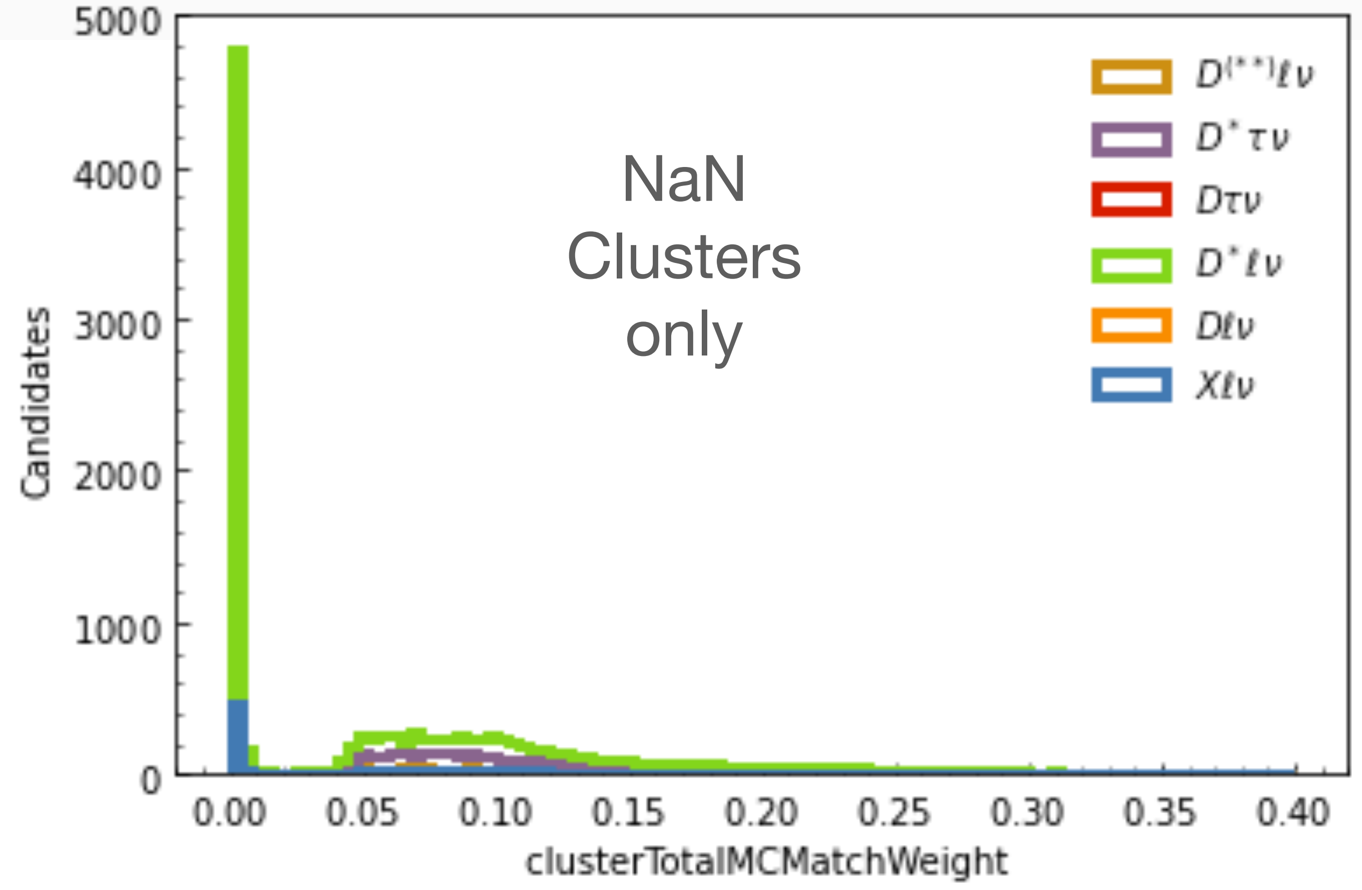
cutoff: precise value is 0.0529098535976118 → compare di-muon beam bkg to $D^*\ell\nu$ BGx1 beam bkg using this cutoff

clusterTotalMCMatchWeight <0.0529



clusterTotalMCMatchWeight >0.0529





MC Cluster Classification

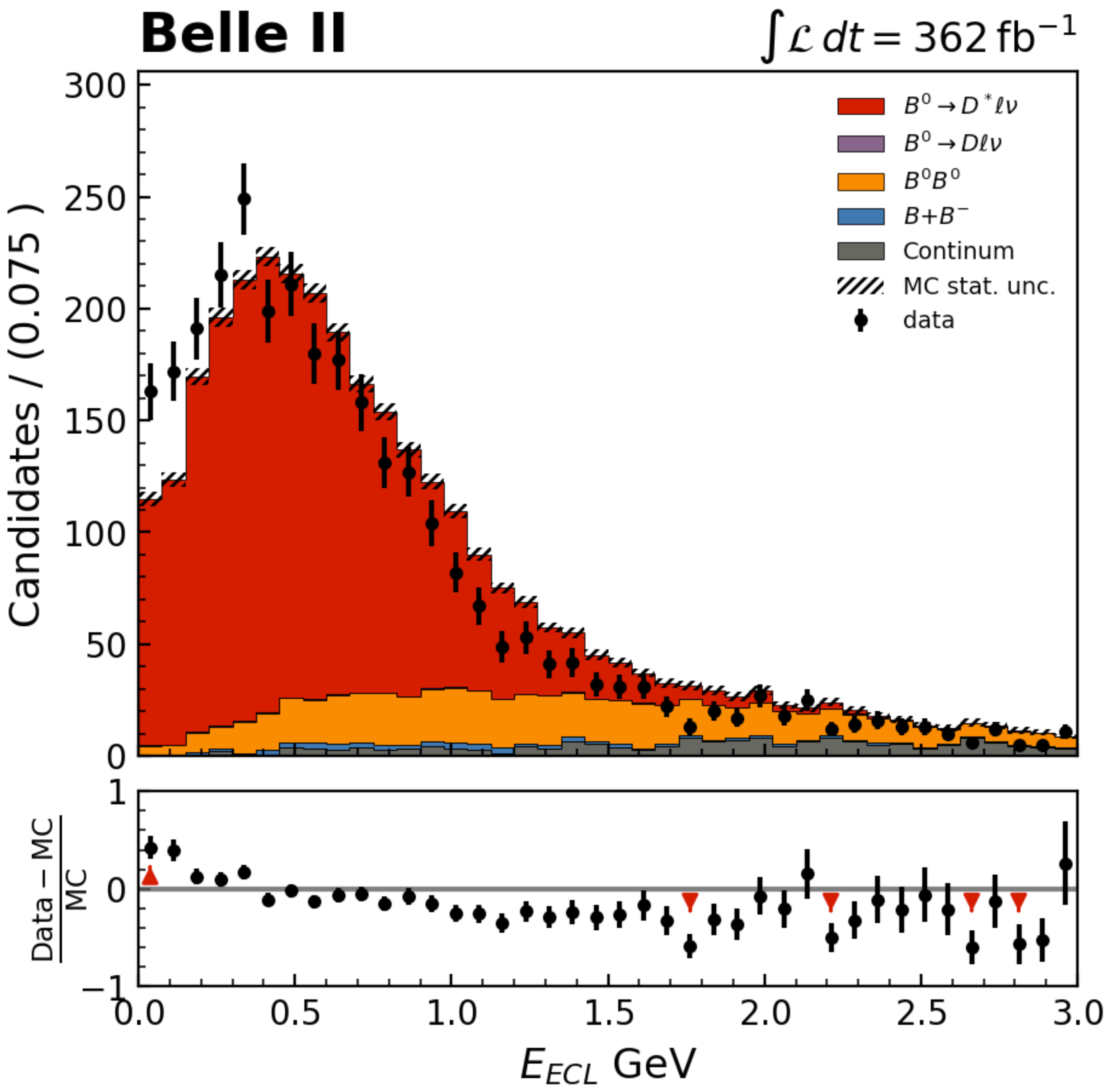
Cluster Attribute	Real Photon	Beam Bkg	Fake Photon
mcPDG	22	NaN	NaN or !=22
clusterTotalMCMatchWeight	—	<0.0529099	>0.0529099

ROE clusters are required to have:

- [[clusterNHits>1.5]
- [0.2967< clusterTheta<2.6180]]
- [[clusterReg==1 and E>0.080] or [clusterReg==2 and E>0.030] or [clusterReg==3 and E>0.060]]
- abs(clusterTiming)<200

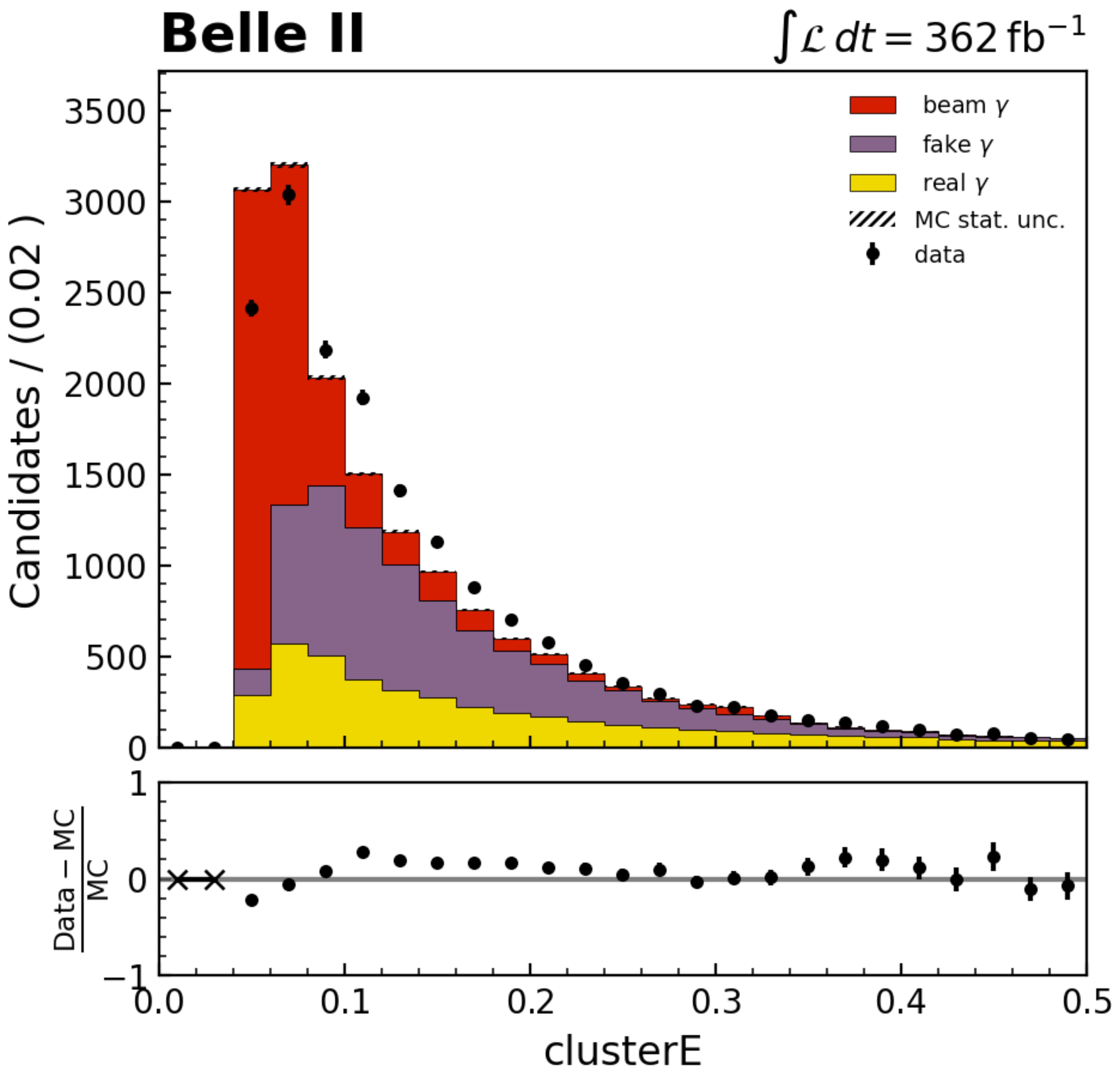
This is consistent with the ROE cuts of the FEI skim (if I recall correctly)

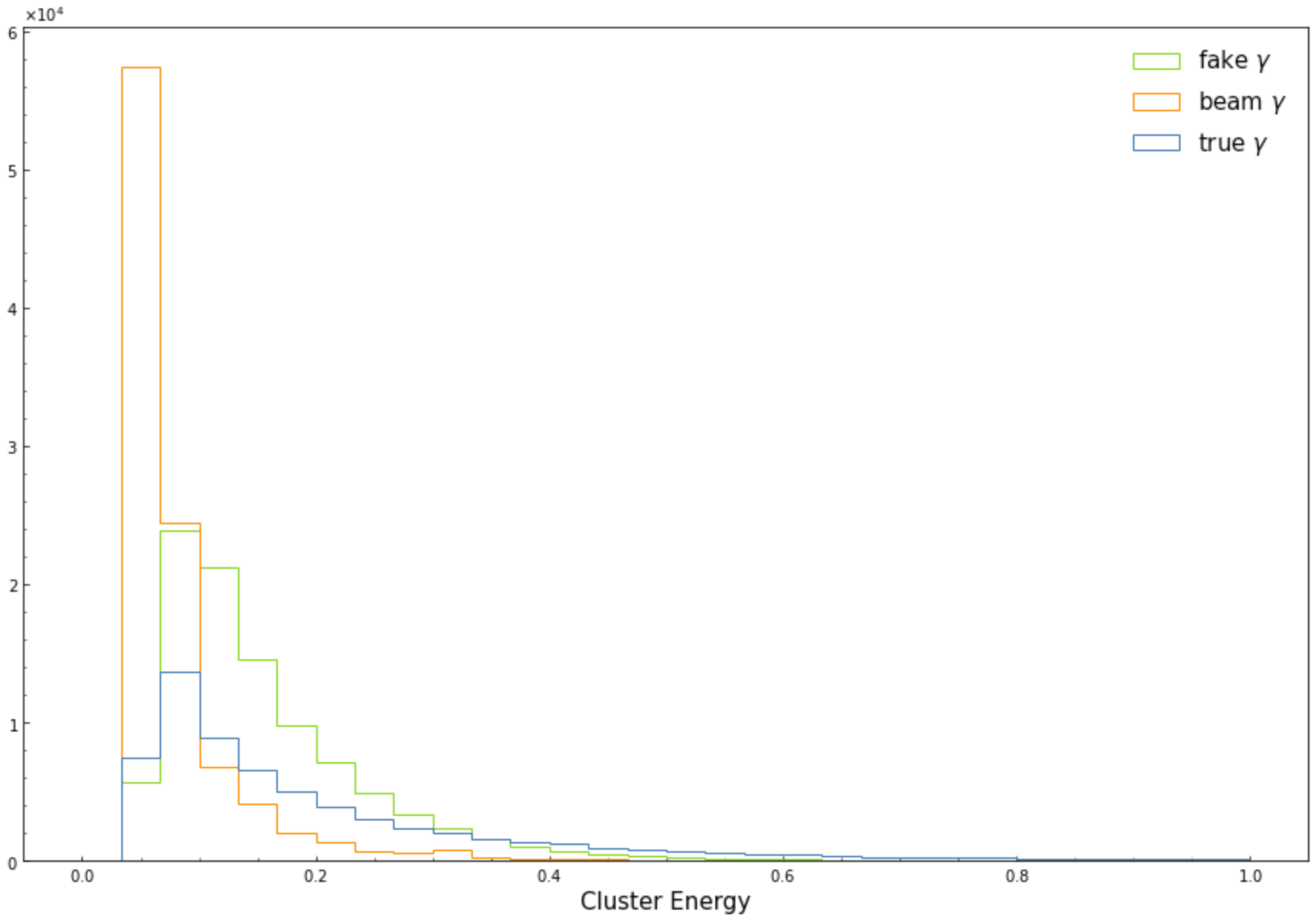
E_{ECL}



Belle II
$\int \mathcal{L}\, dt = 362\ \mathrm{fb}^{-1}$
$B^0 \to D^*\ell\nu$
$B^0 \to D\ell\nu$
B^0B^0
$B+B^-$
Continuum
MC stat. unc.
data
Candidates / (0.075)
300
250
200
150
100
50
0
1
0
−1
Data − MC / MC
0.0
0.5
1.0
1.5
2.0
2.5
3.0
E_{ECL} GeV

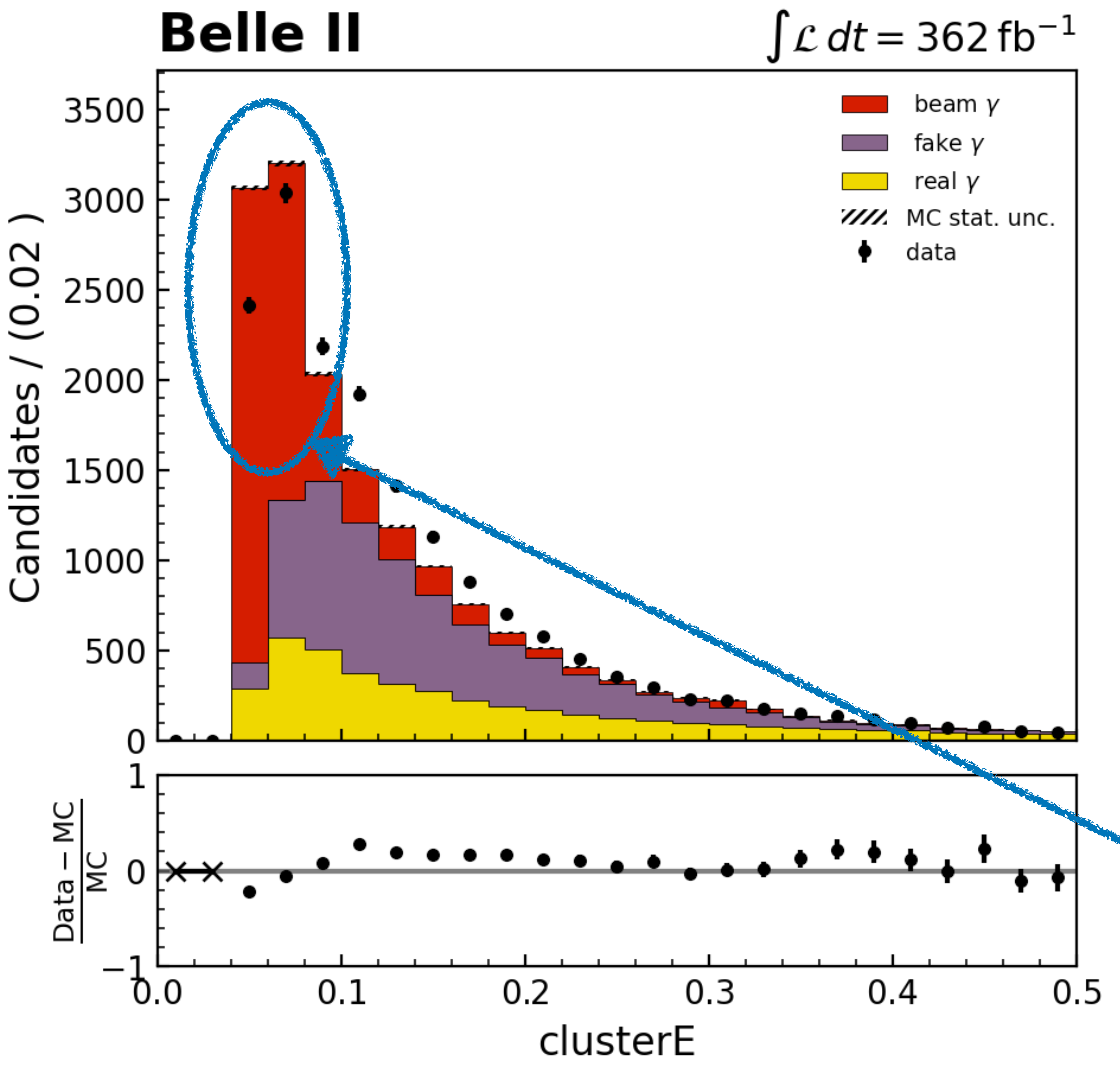
E_{ECL}

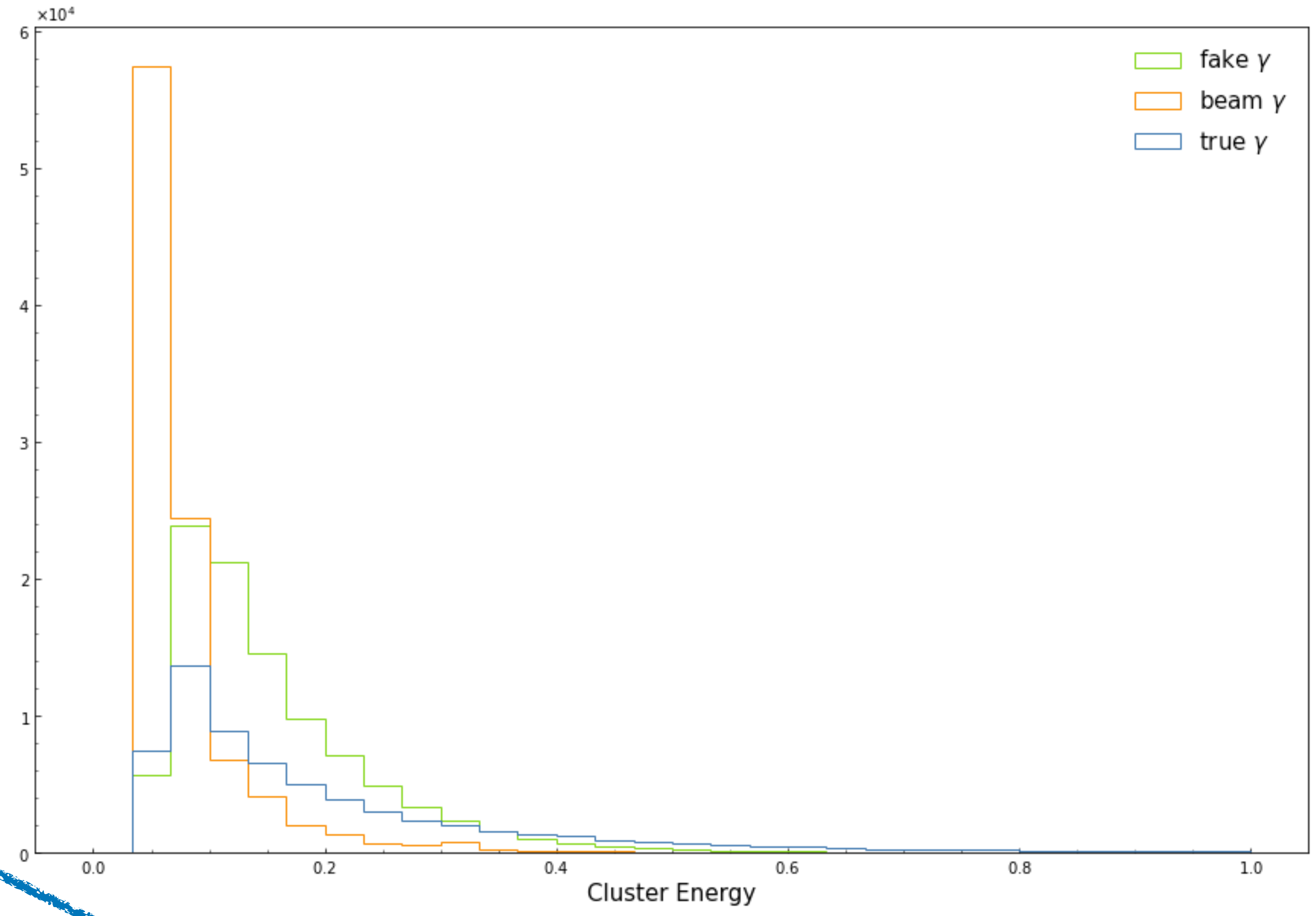




Higher abundance of lower E beam background clusters in MC.

E_{ECL}





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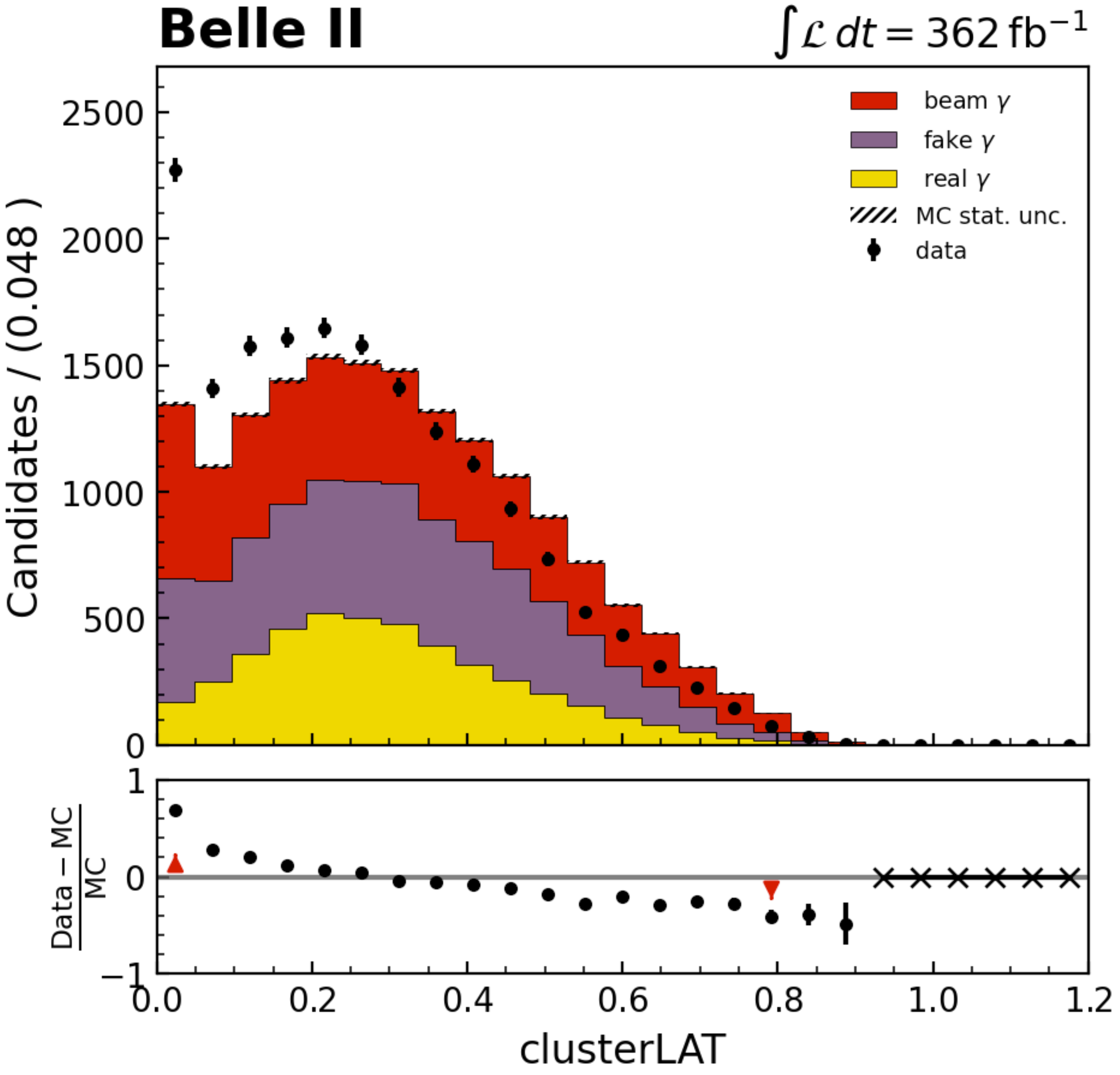

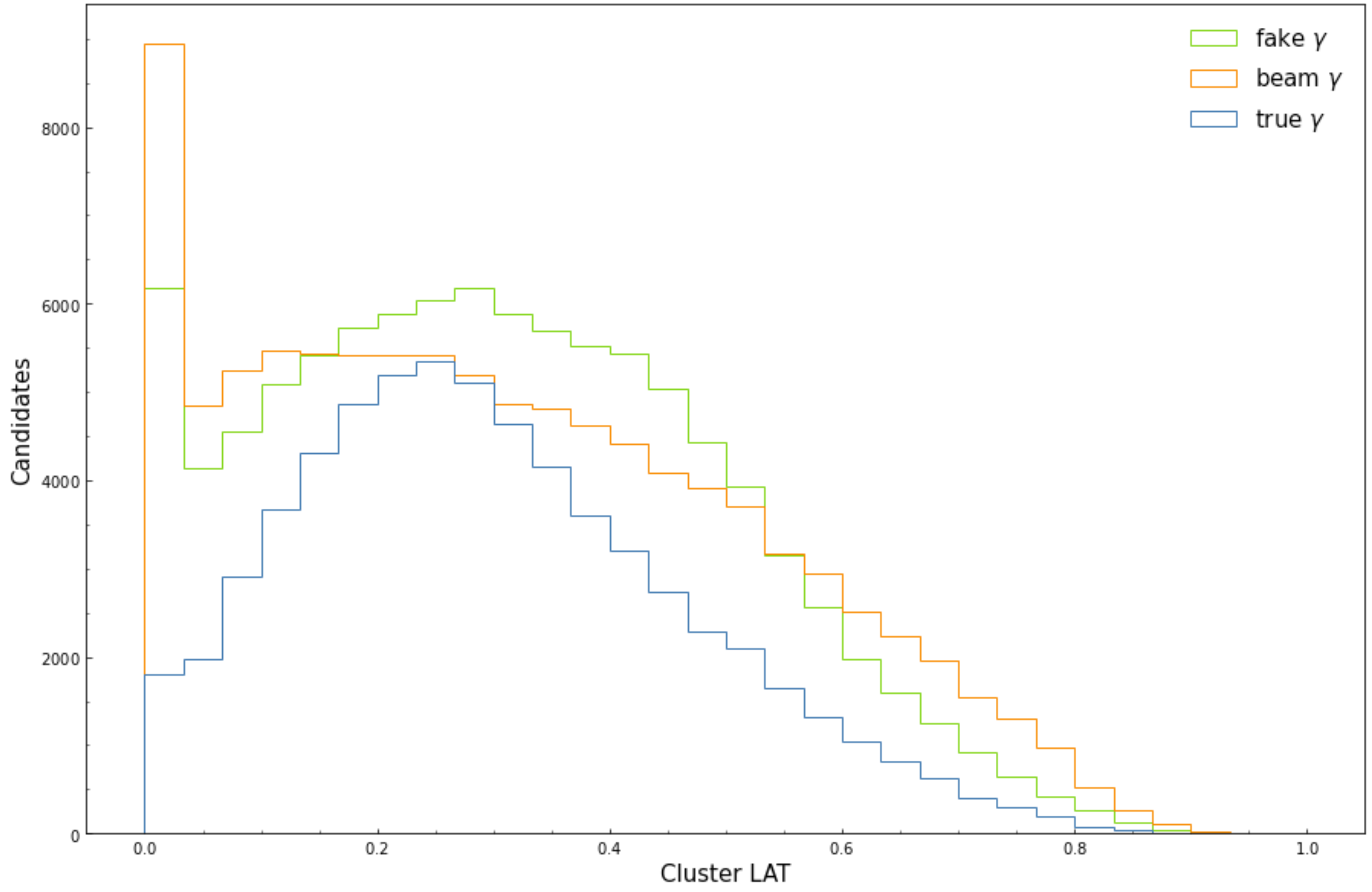

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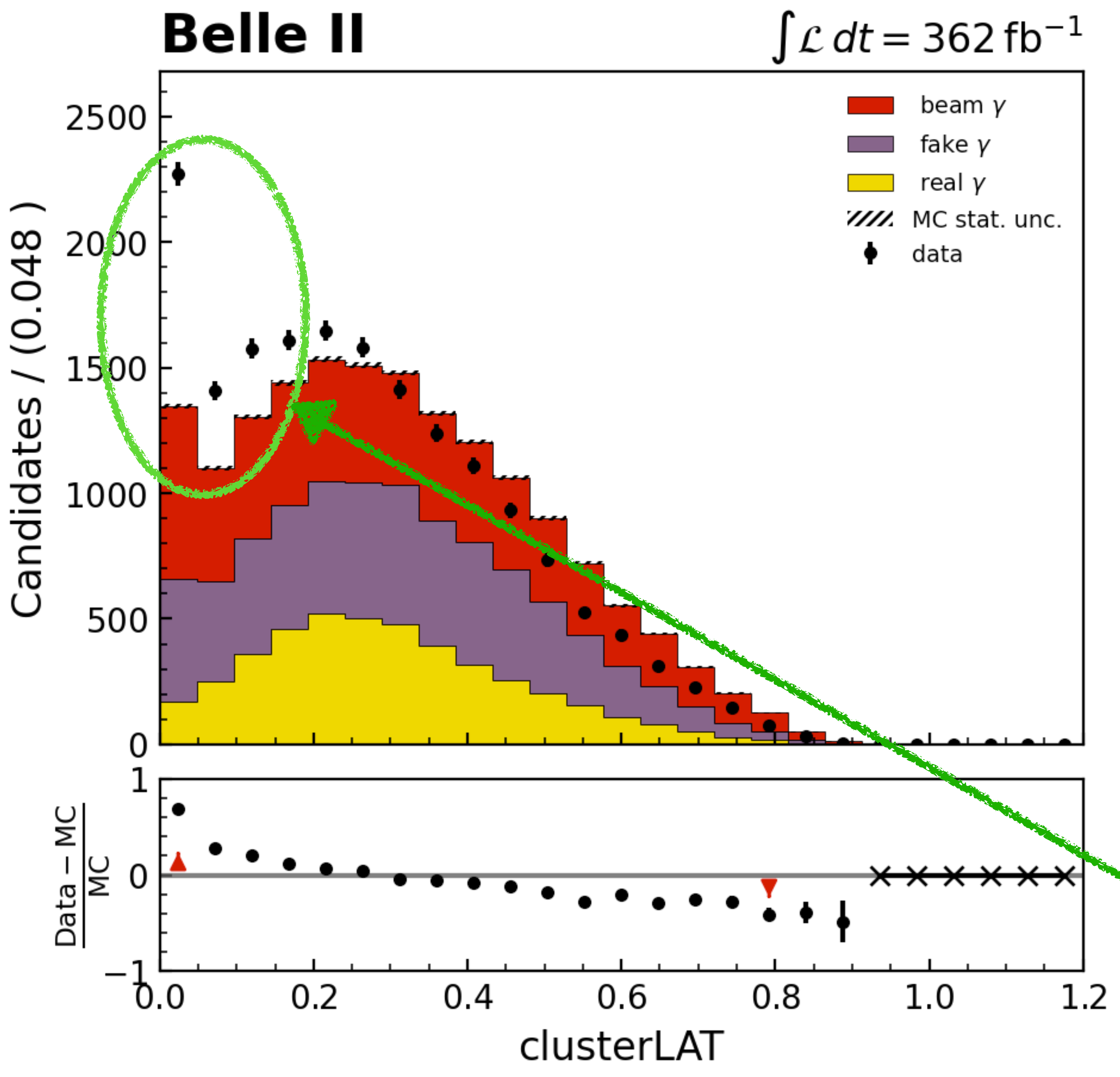
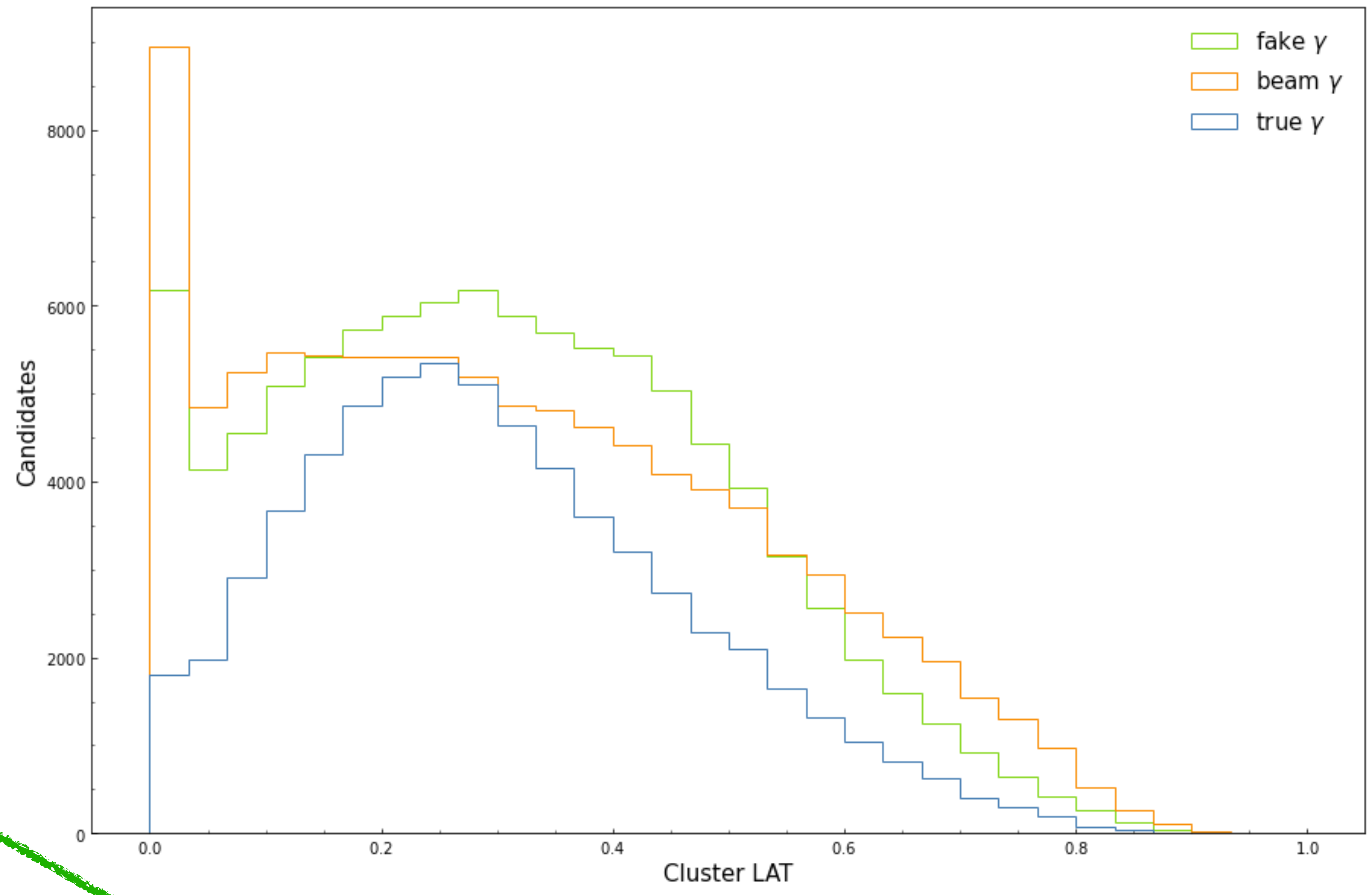
Returns lateral energy distribution (shower shape variable).

E_{ECL}



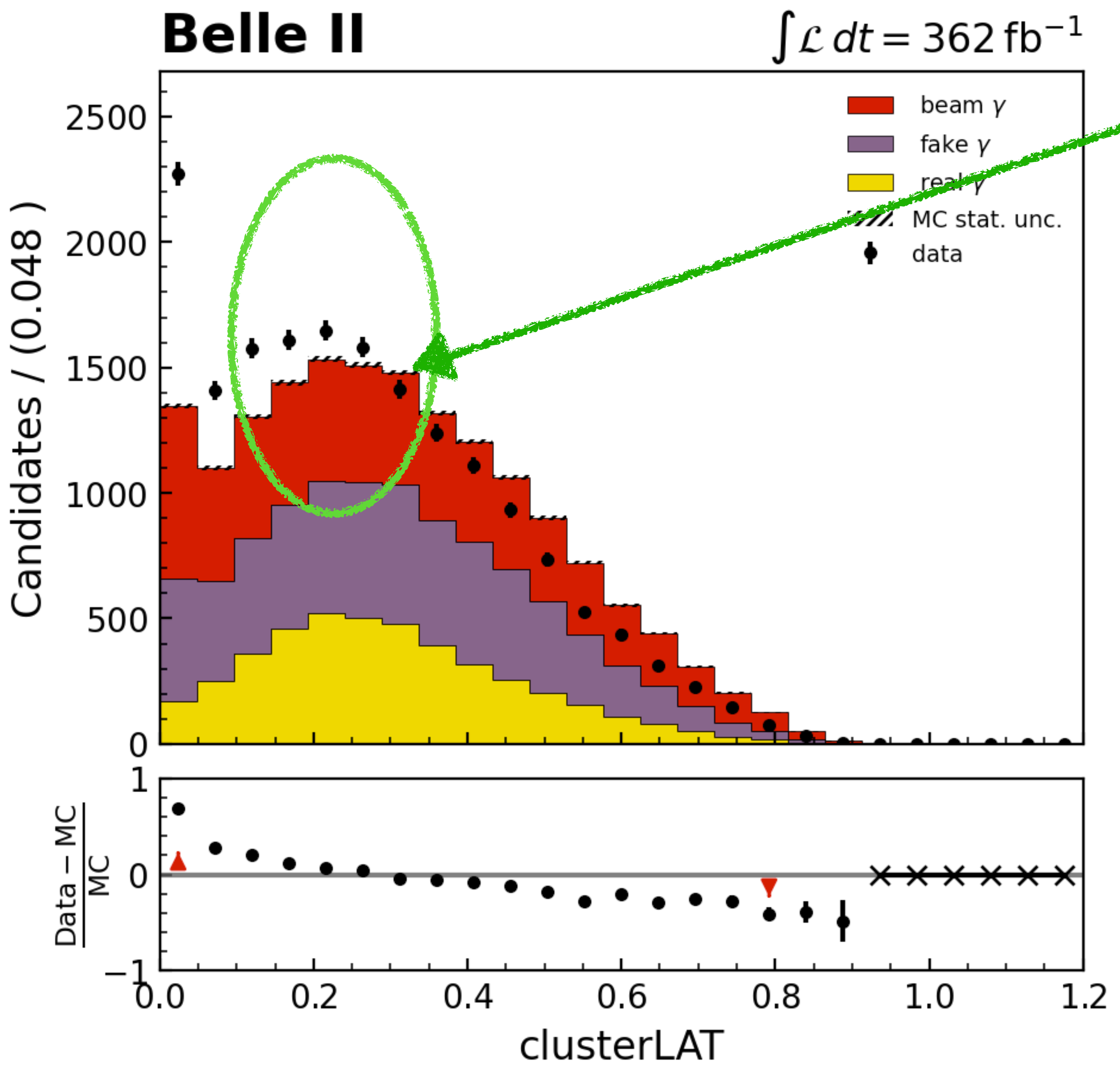


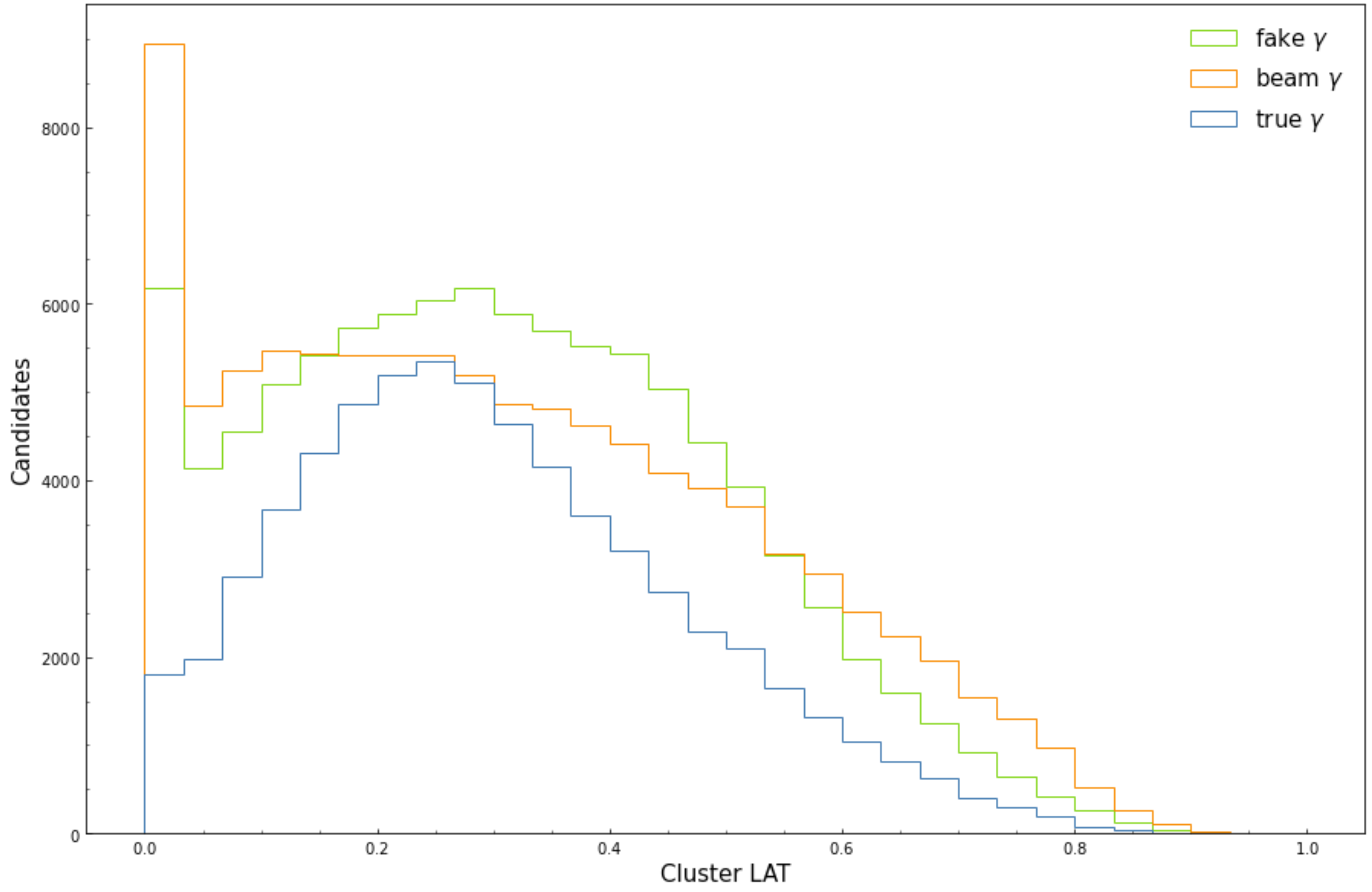
However it does look like there is an unaccounted for portion of beam of fake photon clusters in data at clusterLAT=0?

Returns lateral energy distribution (shower shape variable).

E_{ECL}

clusterLAT peaks around 0.3 for radially symmetrical electromagnetic showers and is larger for hadronic events, and electrons with a close-by radiative or Bremsstrahlung photon.

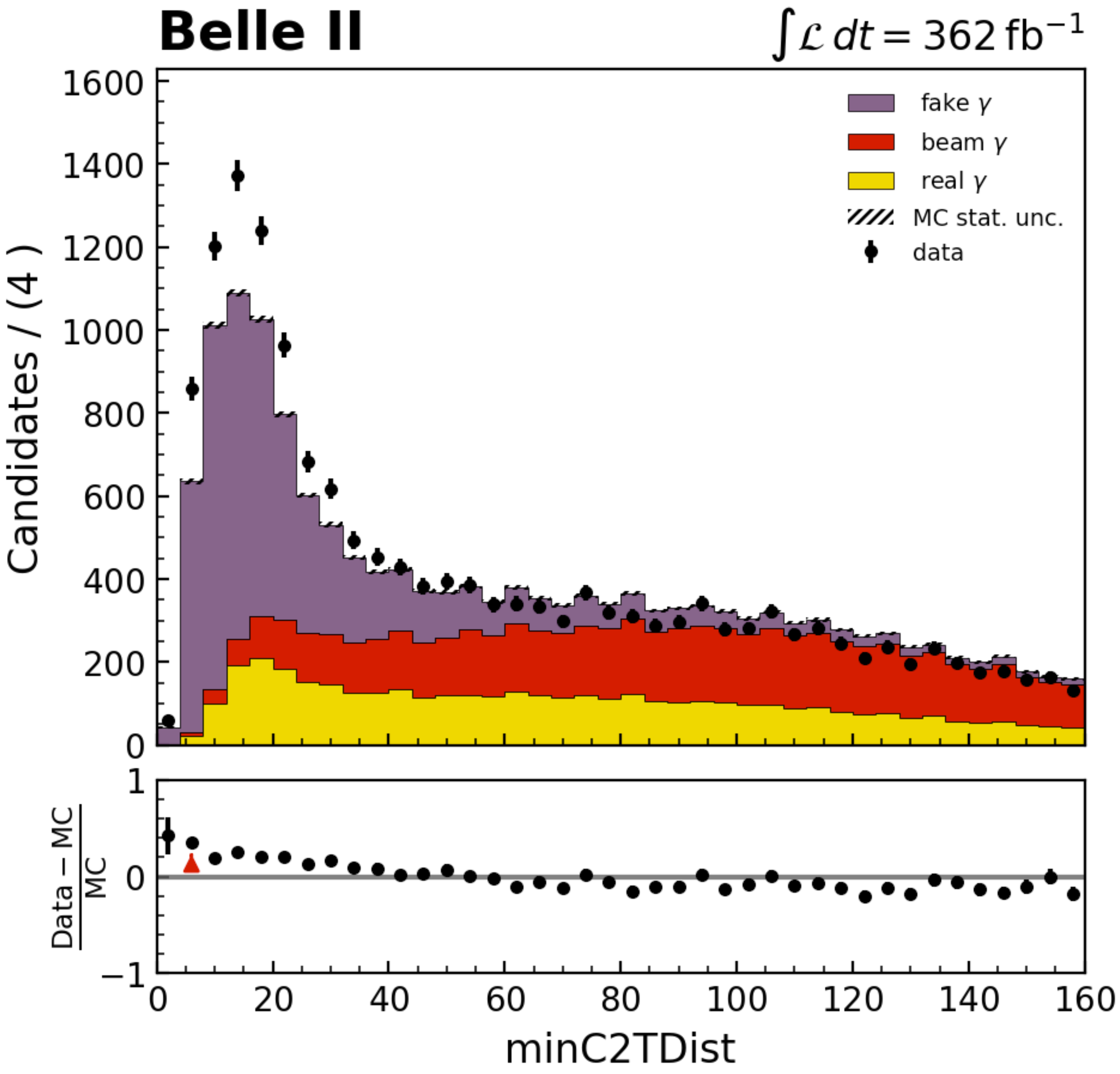


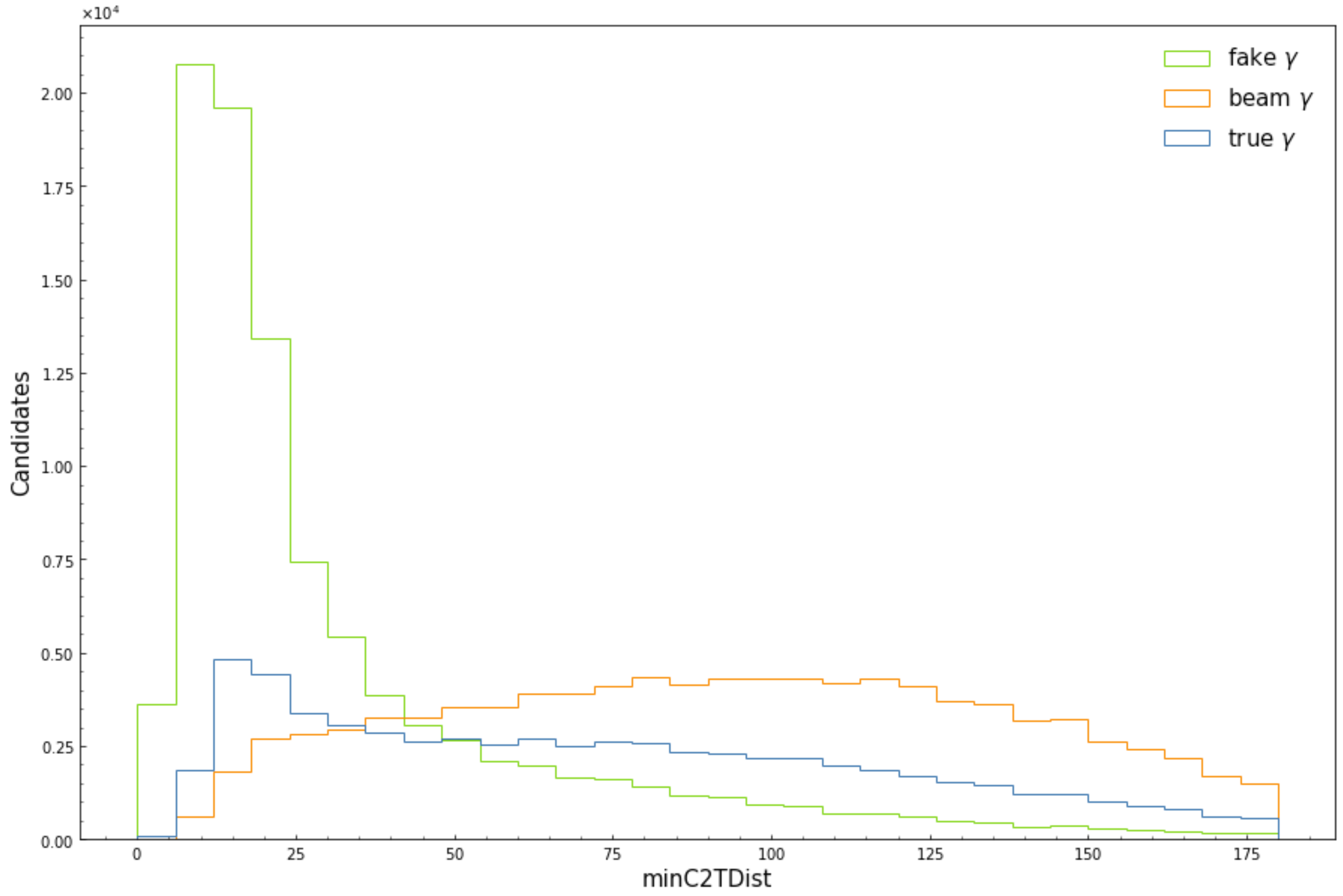


Returns lateral energy distribution (shower shape variable).

Real photon peak at 0.3 better defined in data.

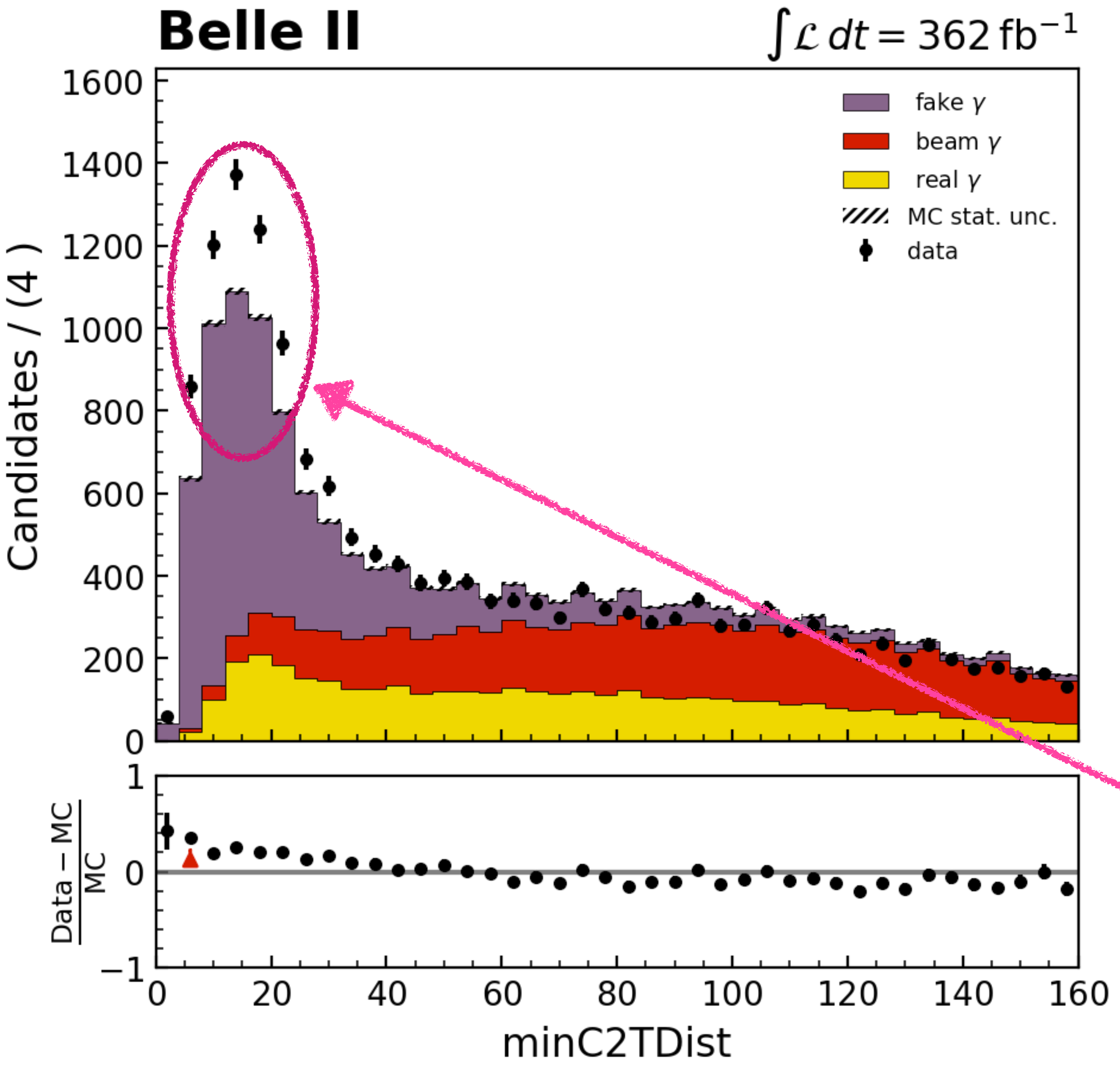
E_{ECL}

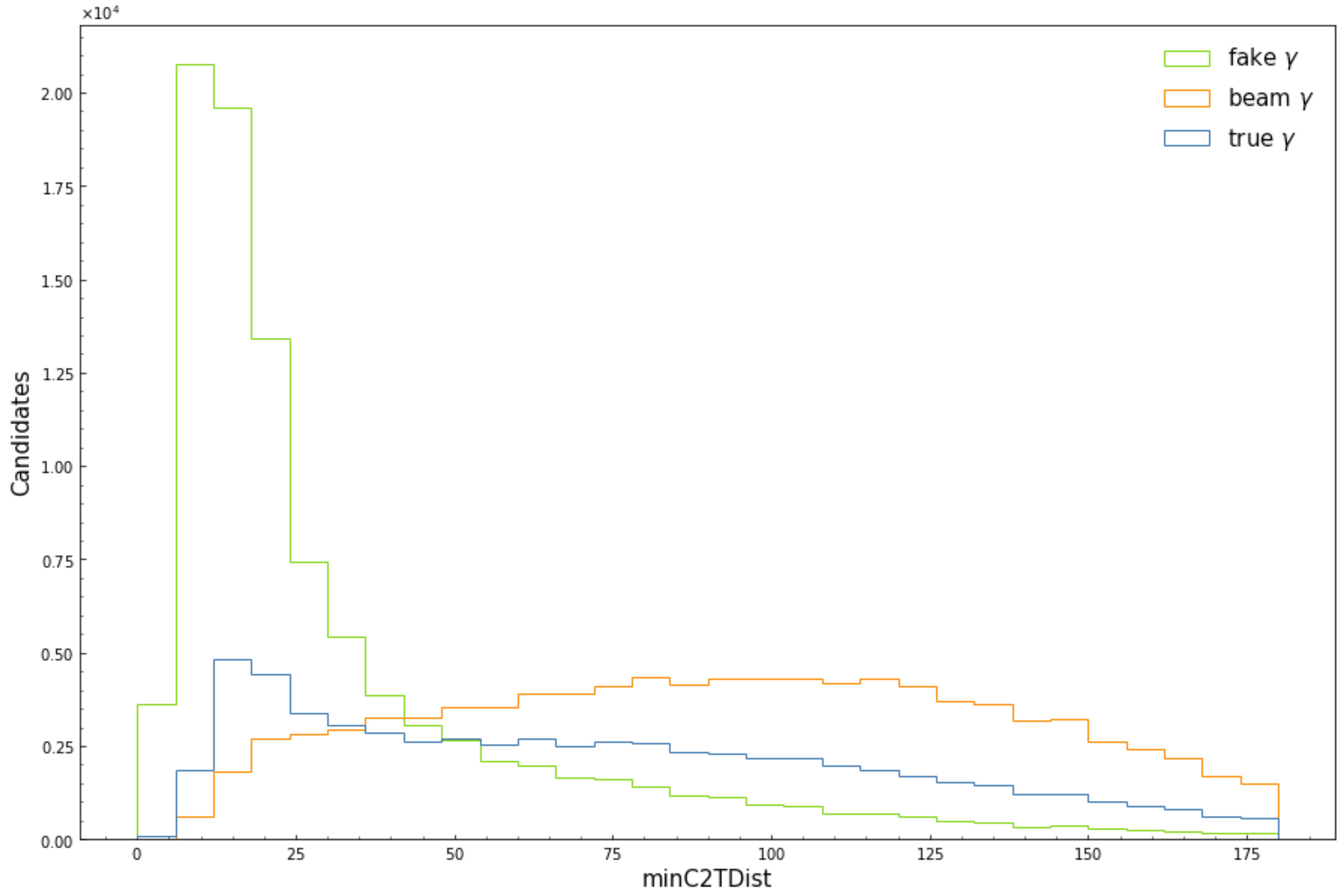




The unaccounted fraction seems to be mainly attributed to fake photons or hadronic split-offs.

E_{ECL}





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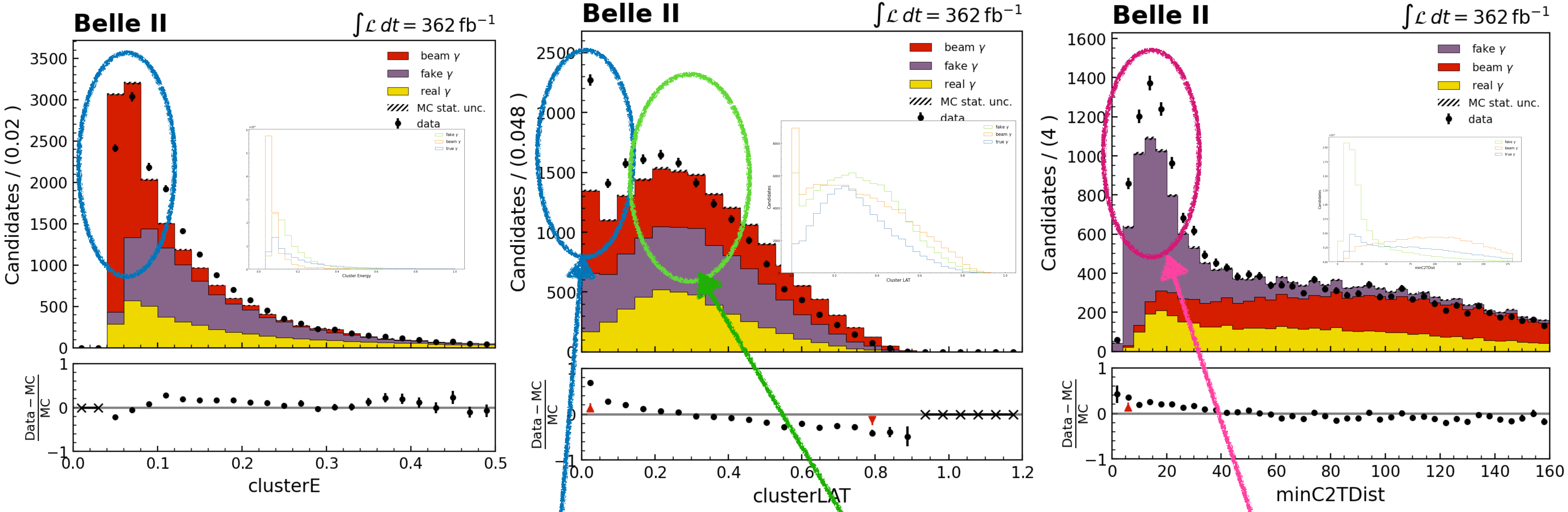


Higher abundance of lower E beam background clusters in MC.

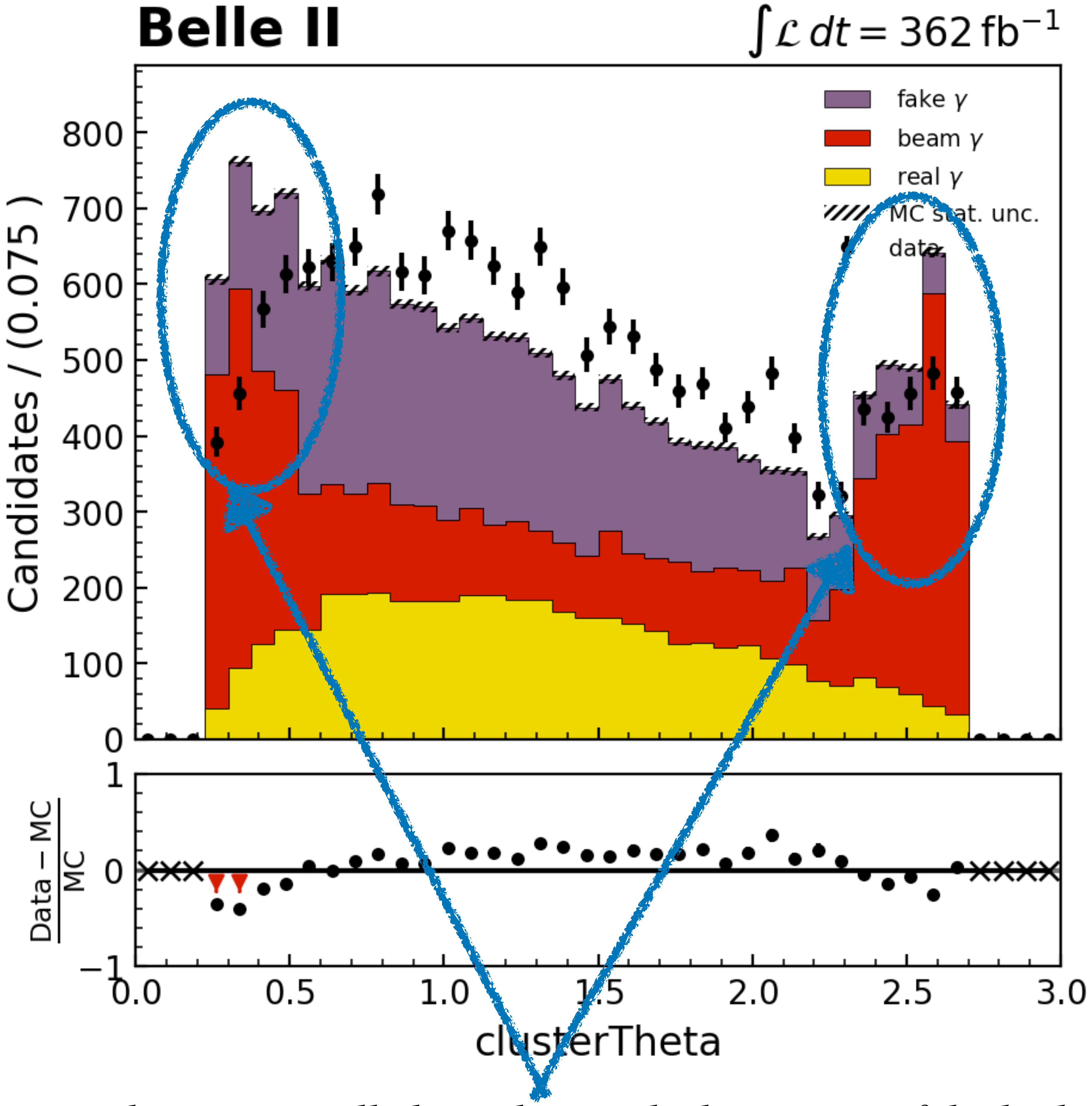
However it does look like there is an unaccounted for portion of beam of fake photon clusters in data at clusterLAT=0?

The unaccounted fraction seems to be mainly attributed to fake photons or hadronic split-offs.

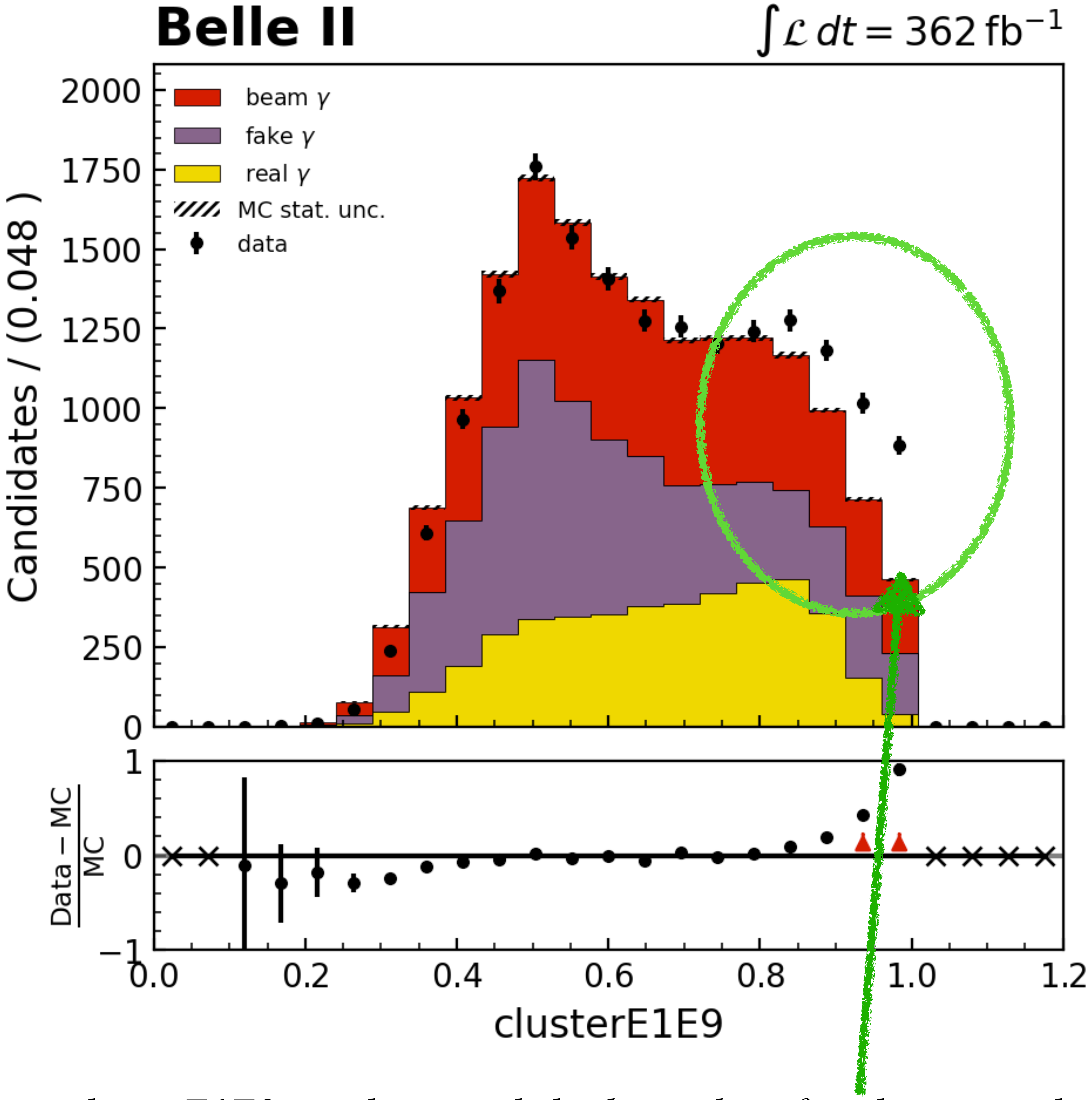
clusterLAT peaks around 0.3 for radially symmetrical electromagnetic showers and is larger for hadronic events, and electrons with a close-by radiative or Bremsstrahlung photon.

E_{ECL}

CosTheta: the direction of a cluster is given by the connecting line of origin and cluster centroid position in the ECL.

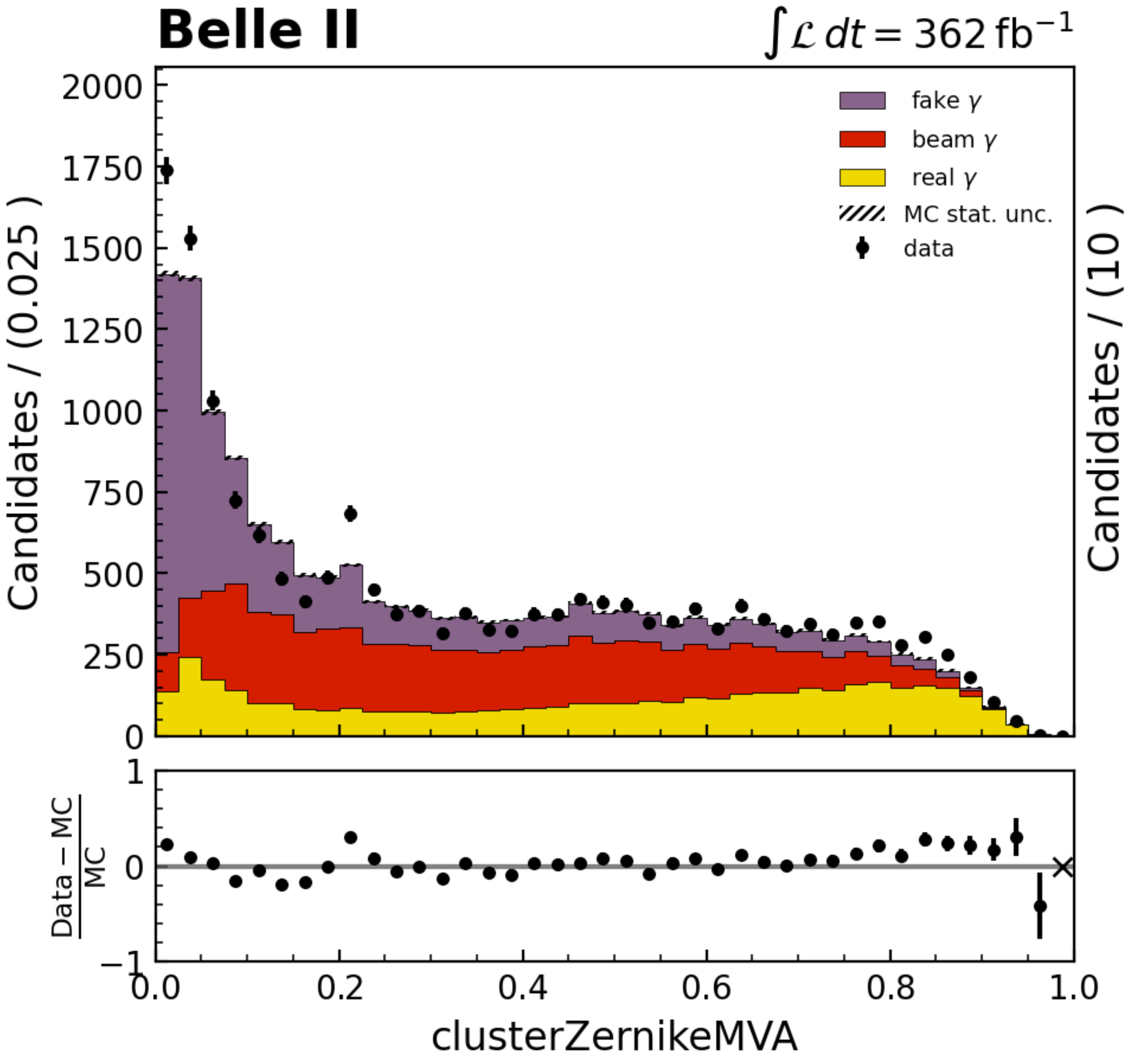


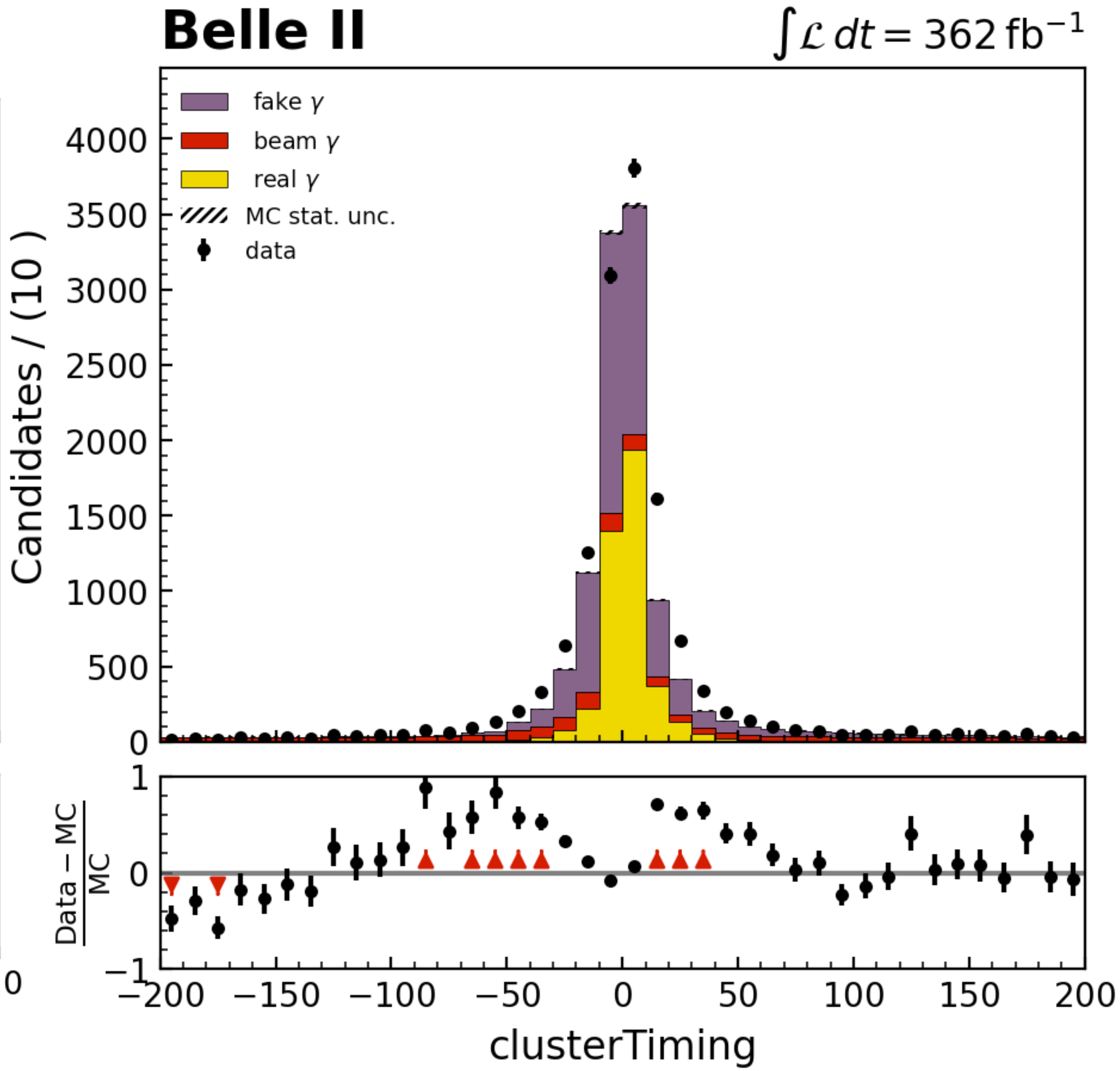
Cluster centroids are generally biased towards the centers of the highest energetic crystal. ***This effect is larger for low energetic photons.***



clusterE1E9: tends towards higher values for photons and lower values for hadrons.

E_{ECL}

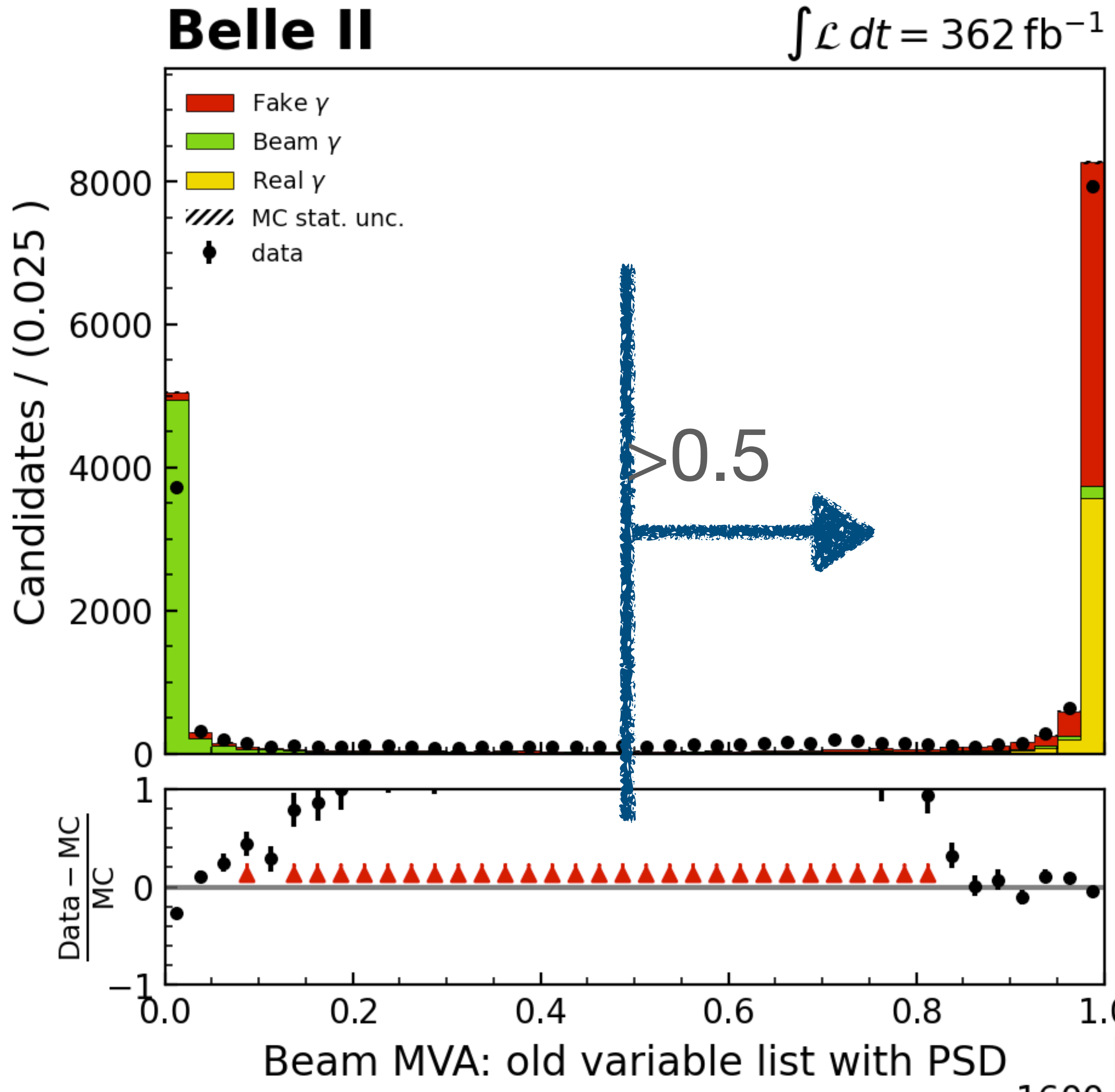

Belle II
$\int \mathcal{L}\, dt = 362\ \mathrm{fb}^{-1}$
fake γ
beam γ
real γ
MC stat. unc.
data
Candidates / (0.025)
Data − MC / MC
clusterZernikeMVA

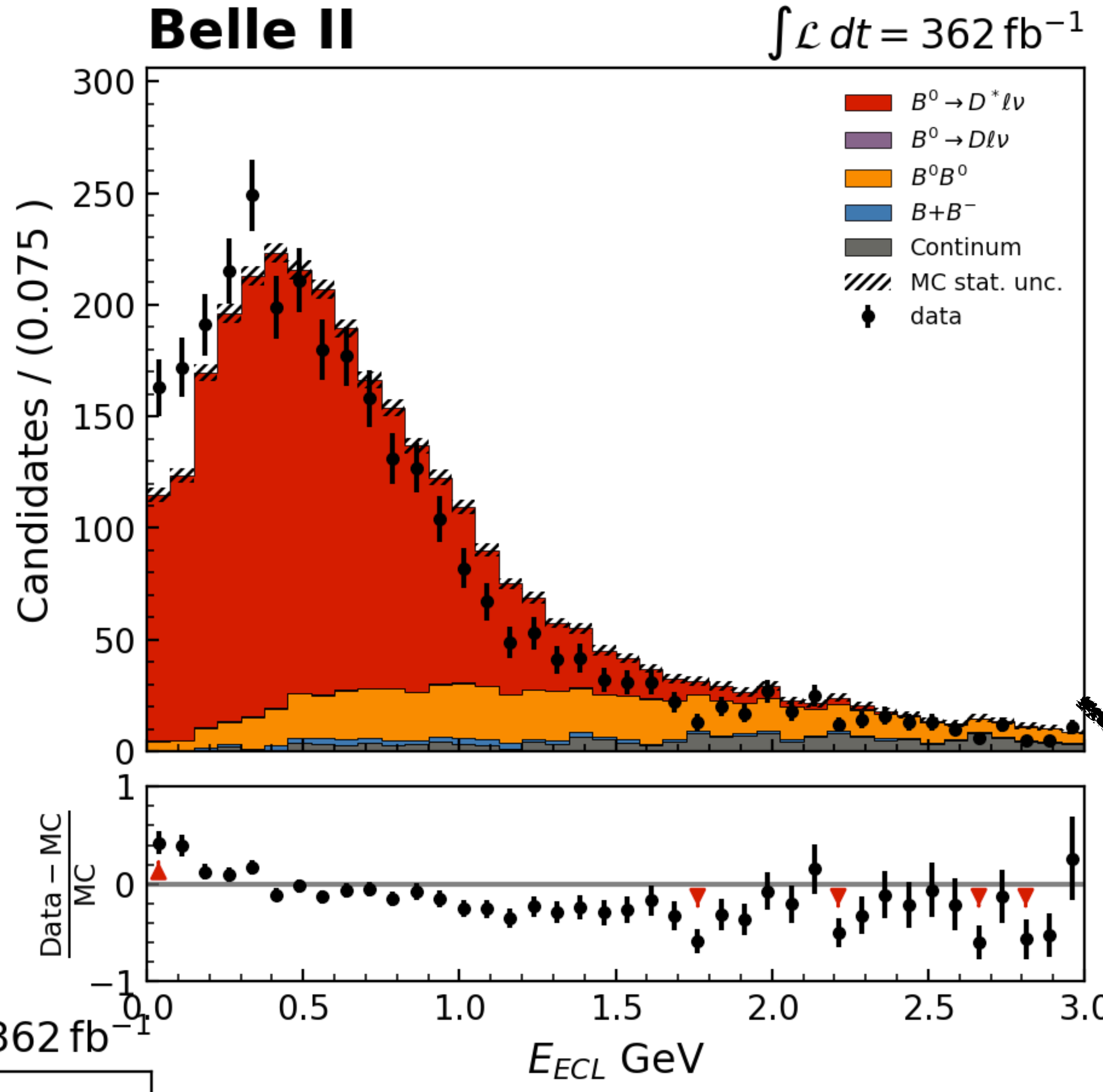

Belle II
$\int \mathcal{L}\, dt = 362\ \mathrm{fb}^{-1}$
fake γ
beam γ
real γ
MC stat. unc.
data
Candidates / (10)
Data − MC / MC
clusterTiming

E_{ECL}

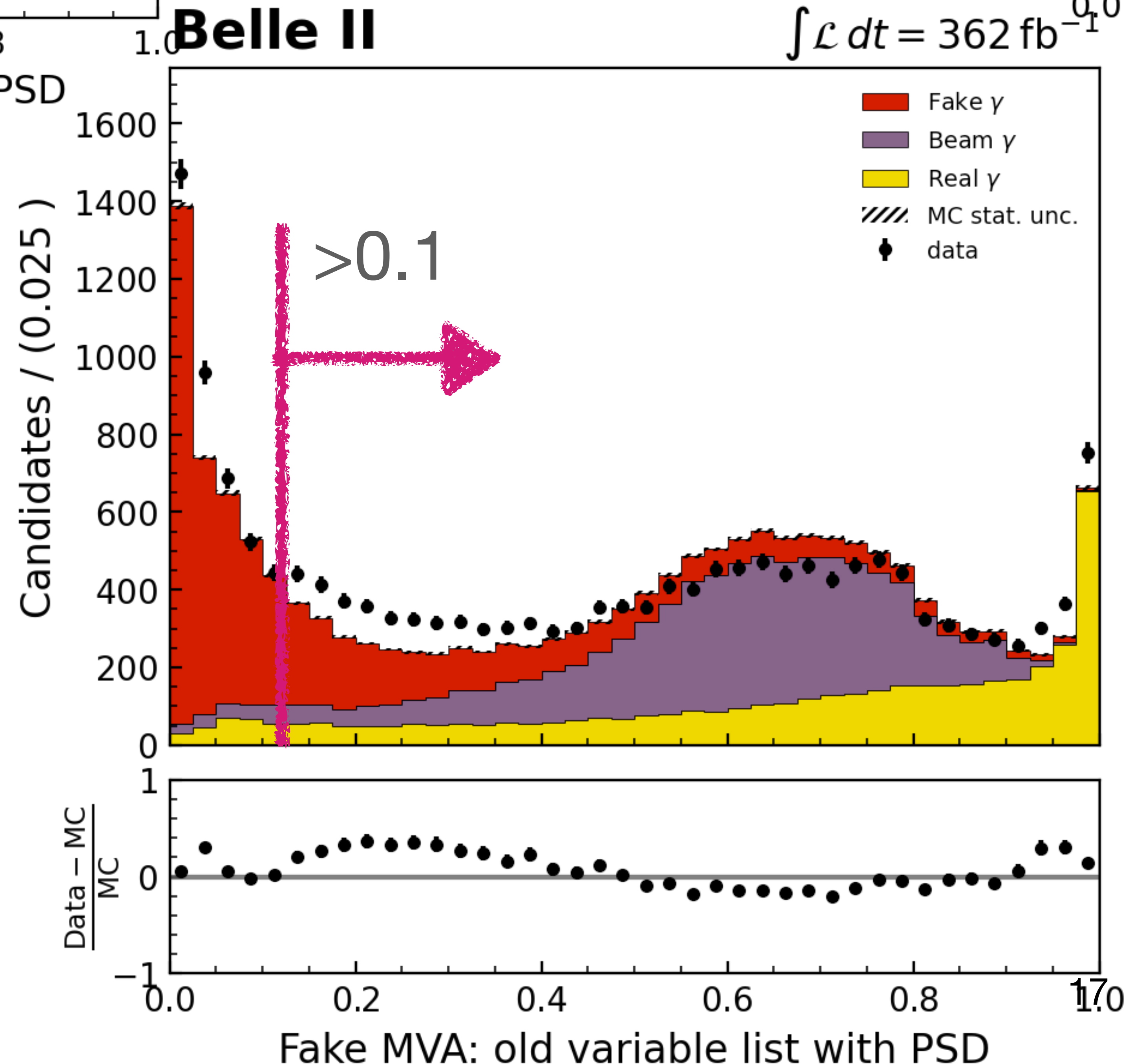
- Too much low energy beam backgrounds in MC.
- Deficit of clusters modelled as real photons in MC.
- Deficit of fake photons or hadronic split-offs in MC.
- Trained two MVA's to suppress beam backgrounds (get rid of excess) and fake photons (get rid of deficit).

Beam background and fake photon suppression

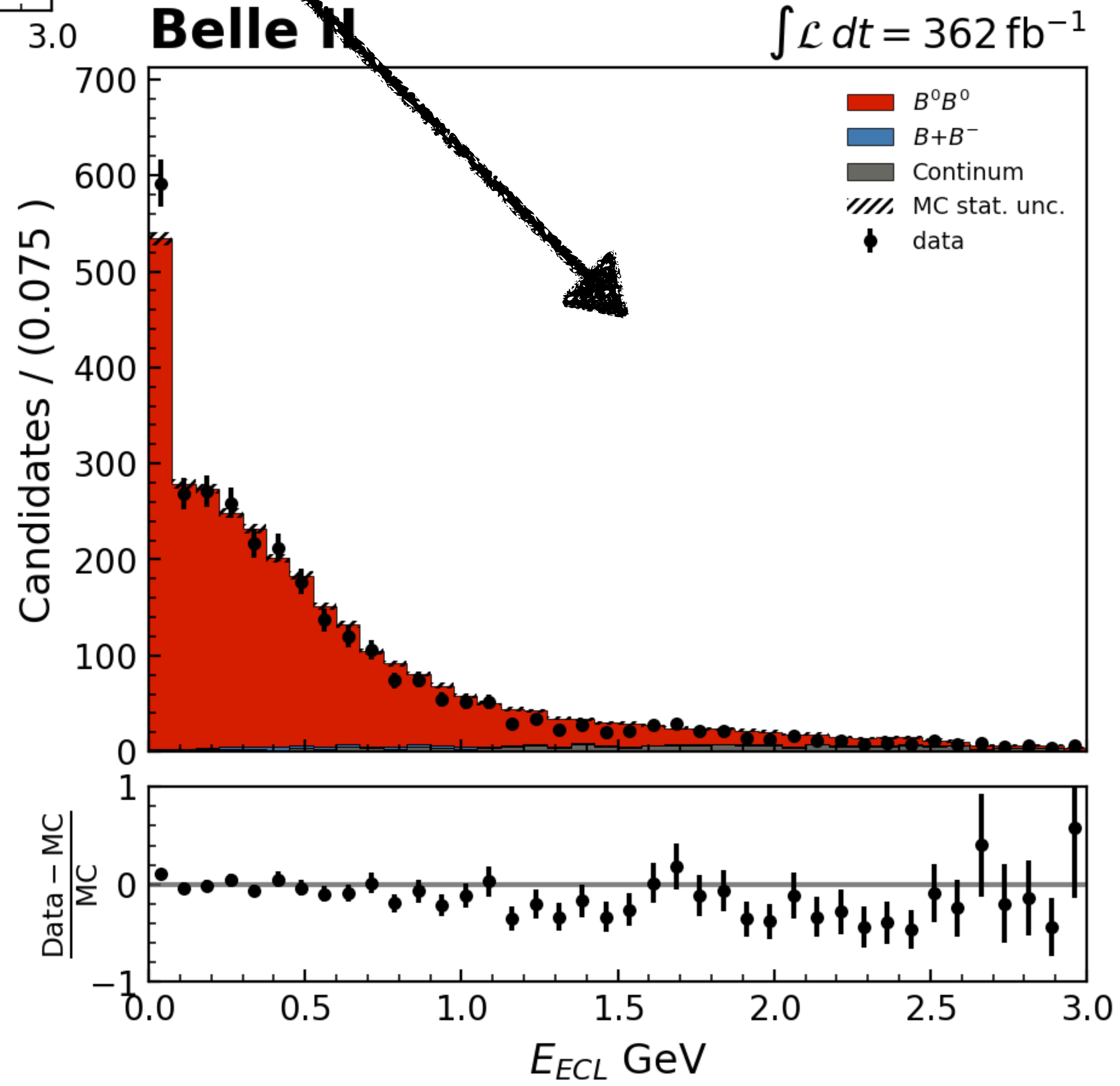




clusterE, clusterE1E9, clusterLAT, clusterTheta, clusterZernikeMVA, clusterTiming, clusterPulseShapeDiscriminationMVA



clusterE, clusterE1E9, clusterLAT, clusterZernikeMVA, clusterSecondMoment, minC2TDist, clusterPulseShapeDiscriminationMVA



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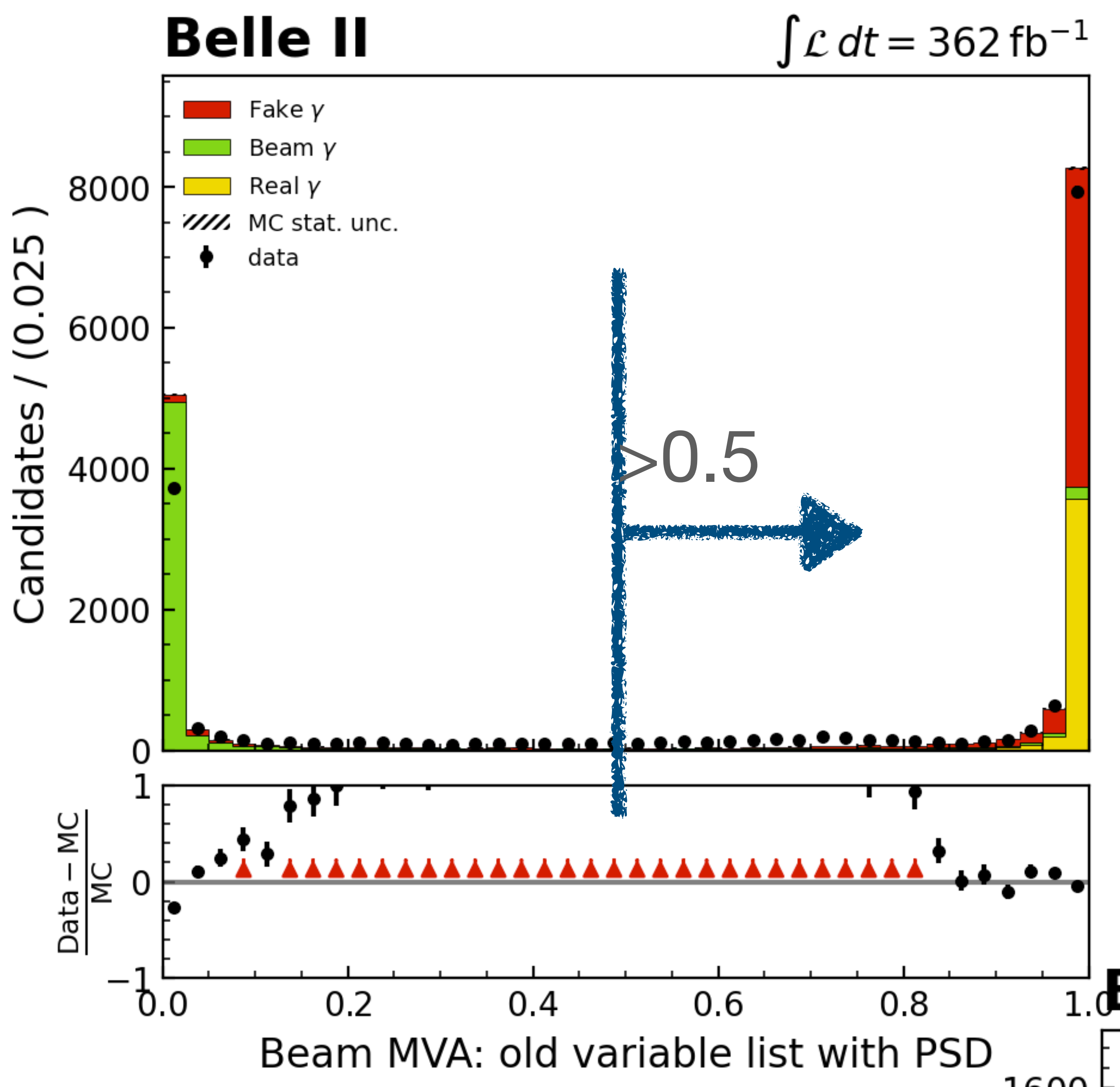

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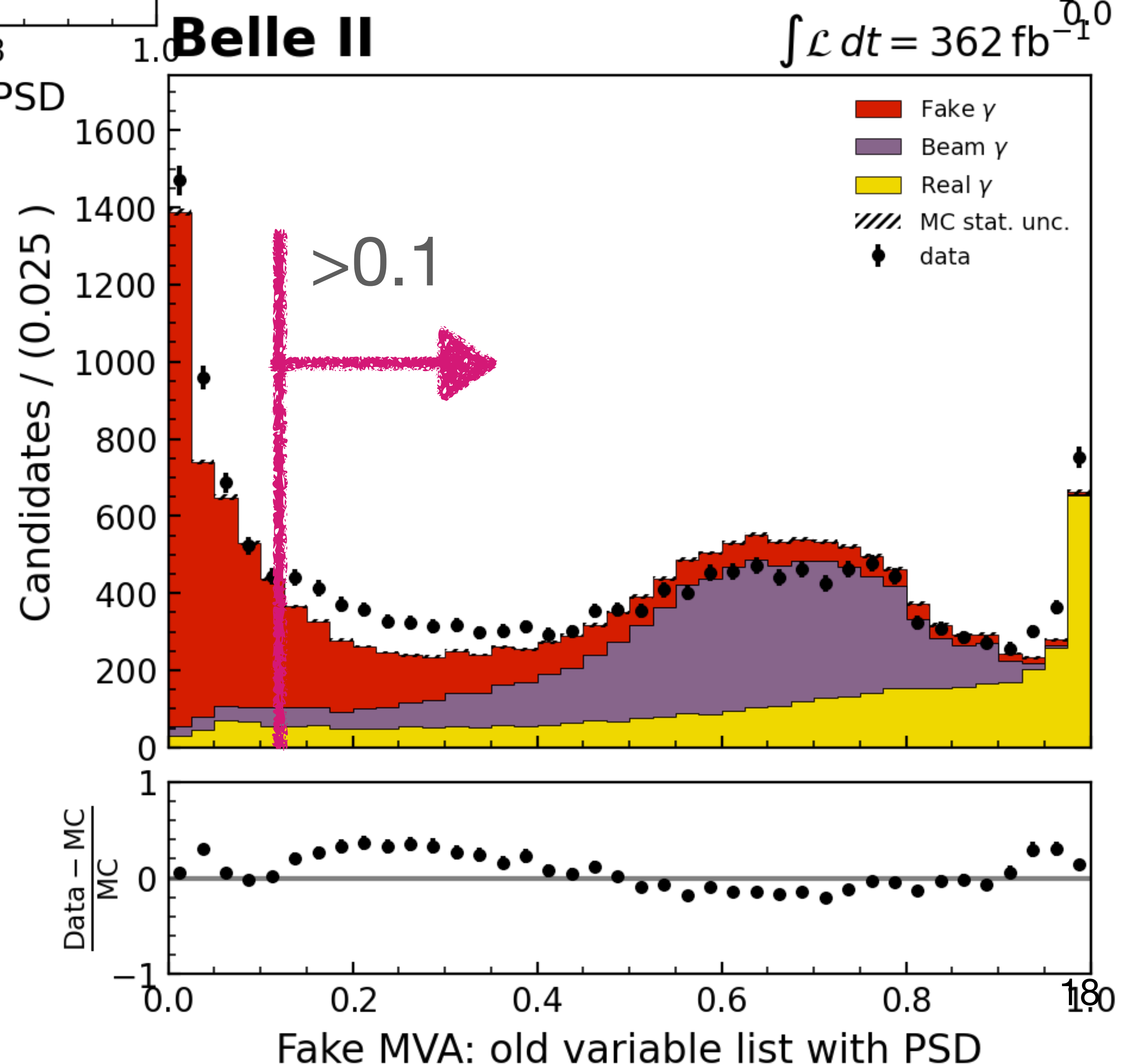
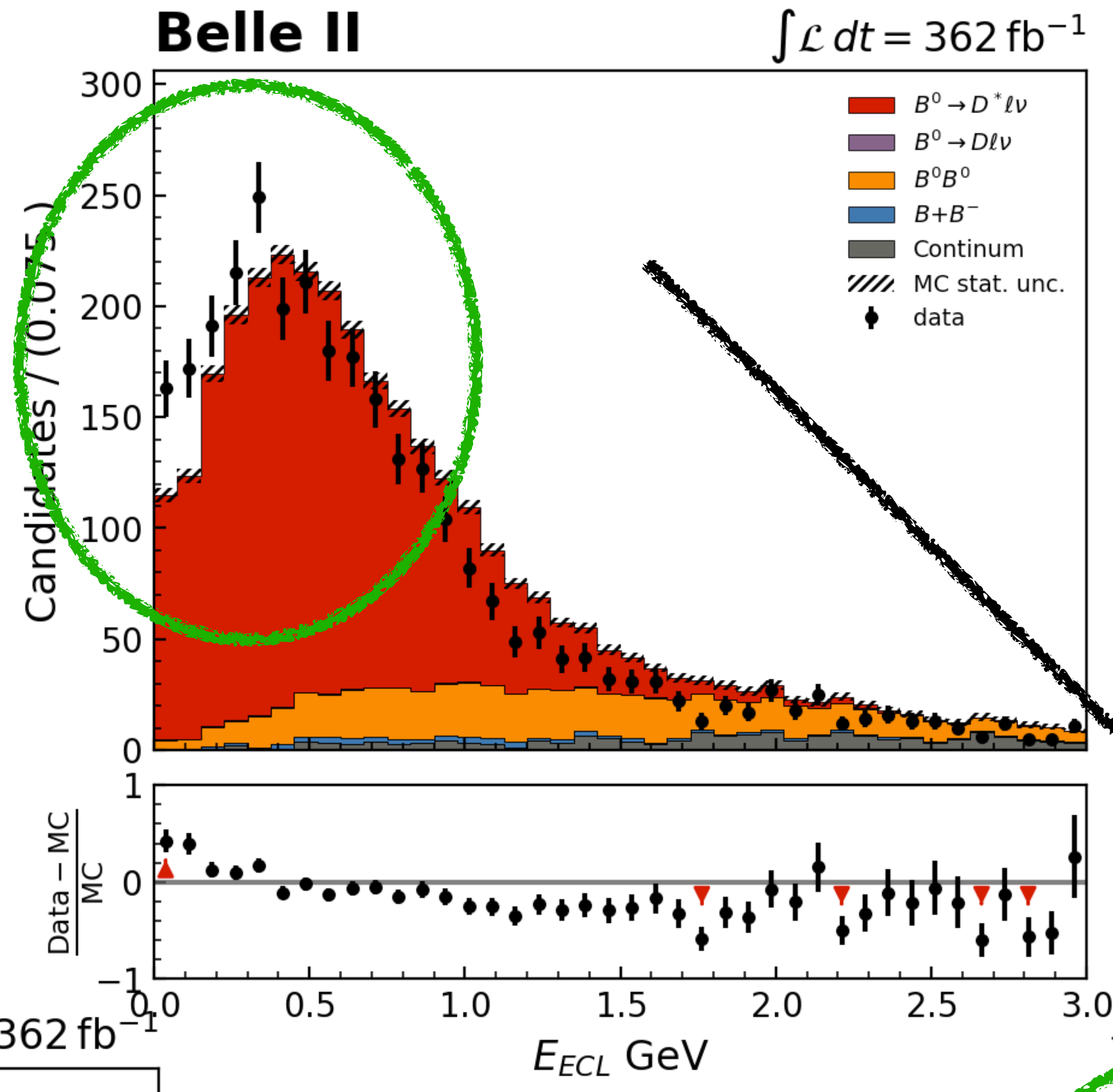
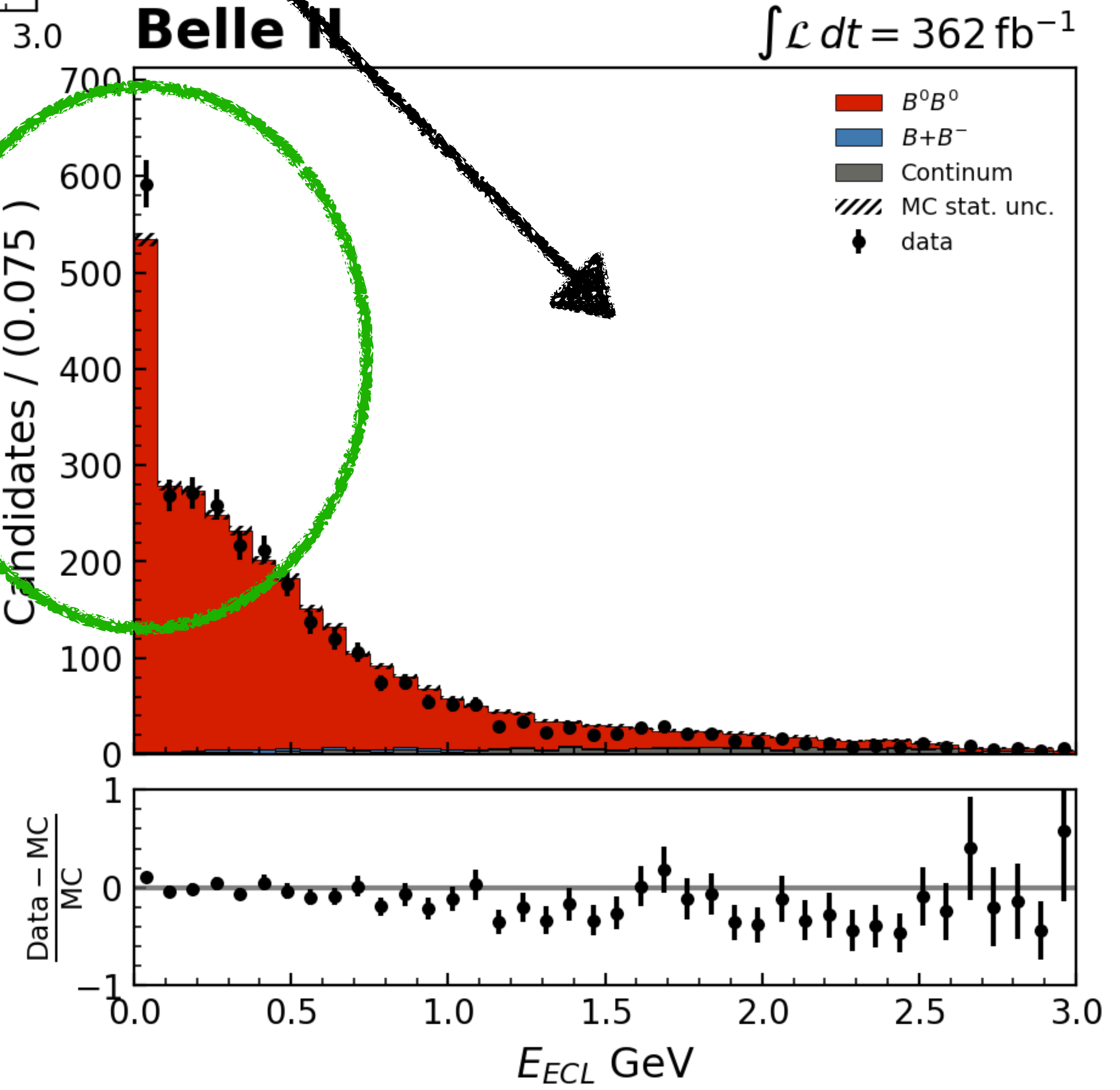


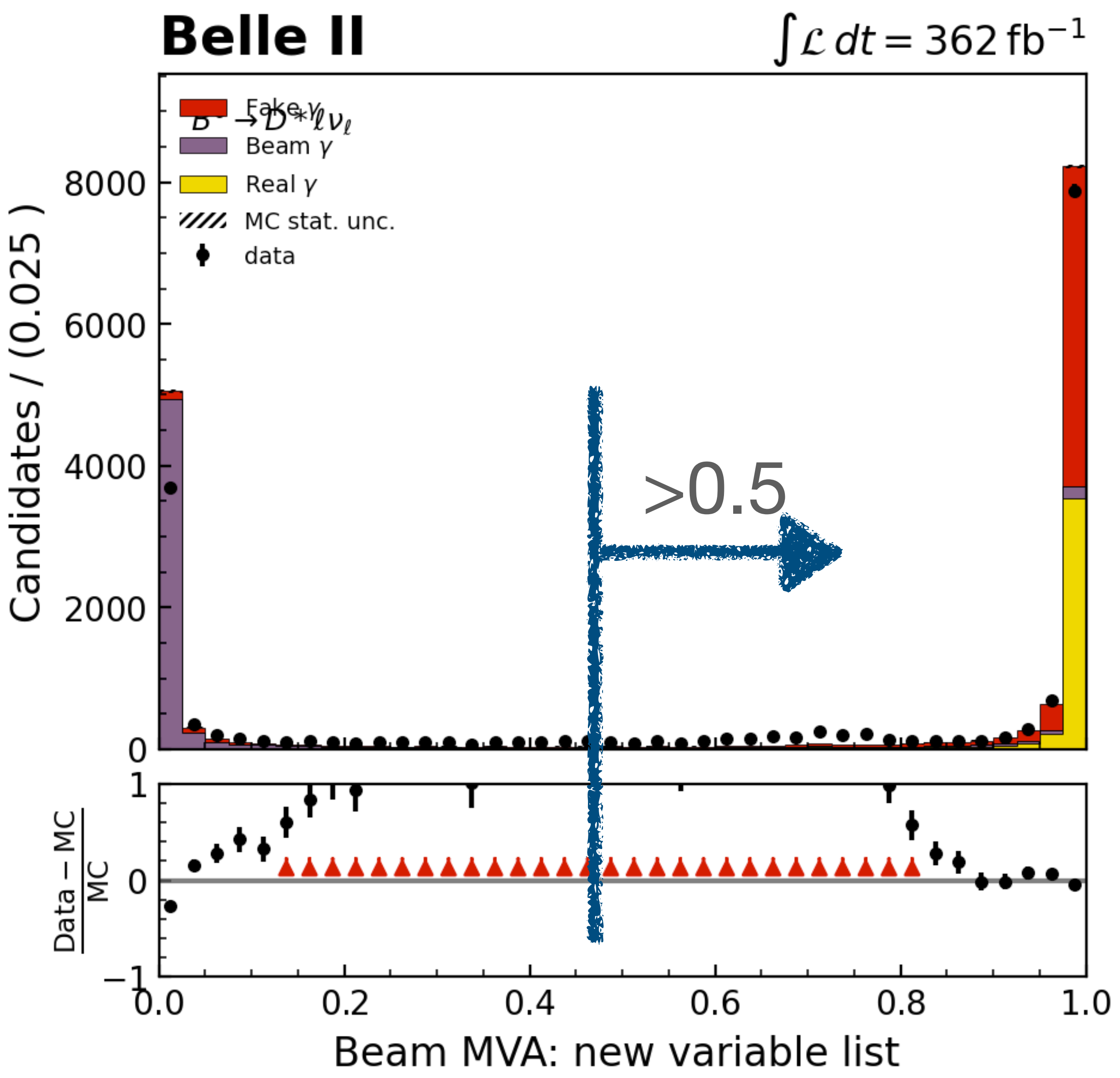
clusterE, clusterE1E9, clusterLAT, clusterZernikeMVA, clusterSecondMoment, minC2TDist, clusterPulseShapeDiscriminationMVA



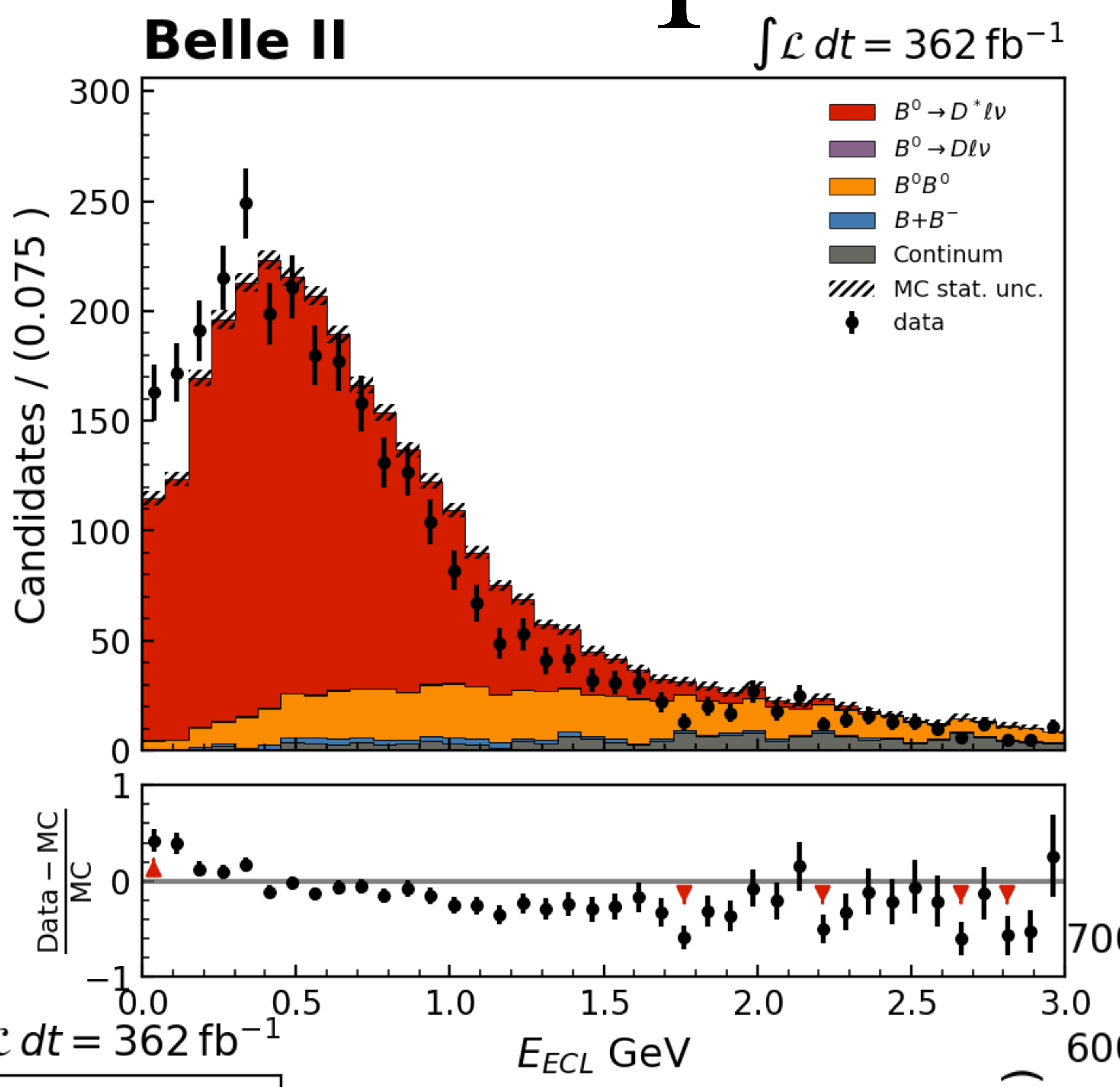
Residual discrepancy at zero bin



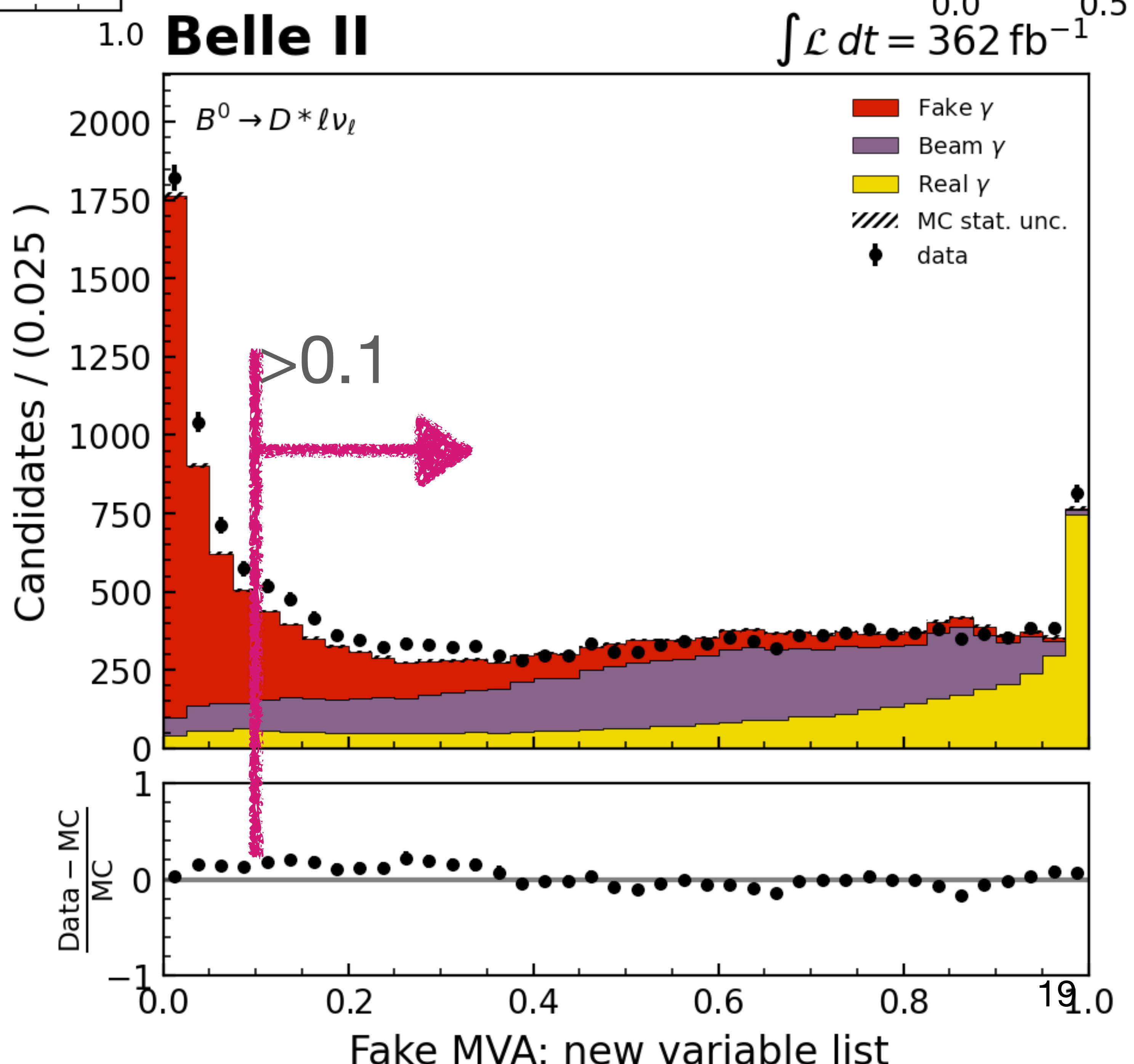
Beam background and fake photon suppression



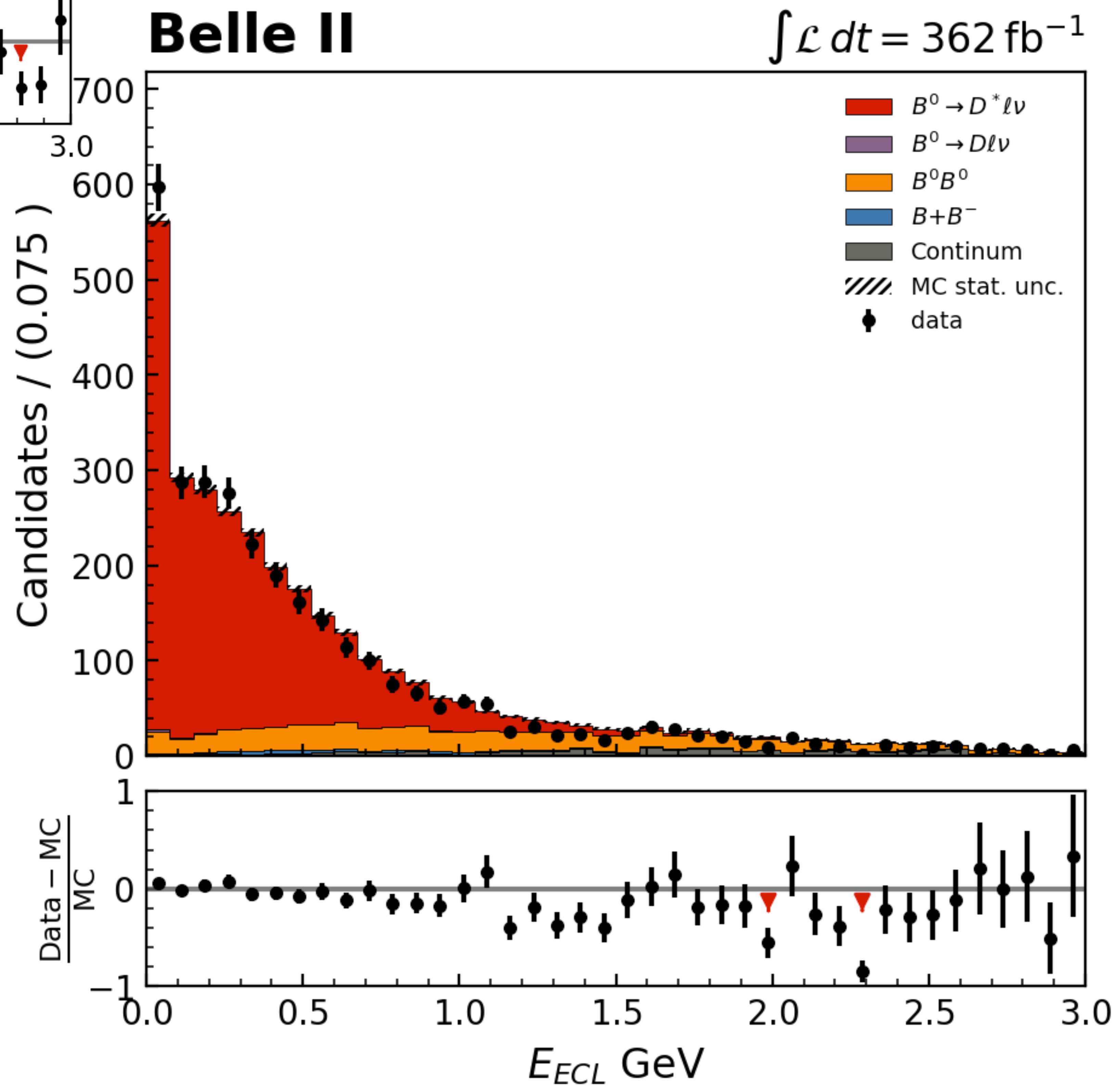
clusterE, ~~clusterE1E9~~, ~~clusterLAT,~~ clusterTheta, clusterZernikeMVA, clusterTiming, clusterPulseShapeDiscriminationMVA



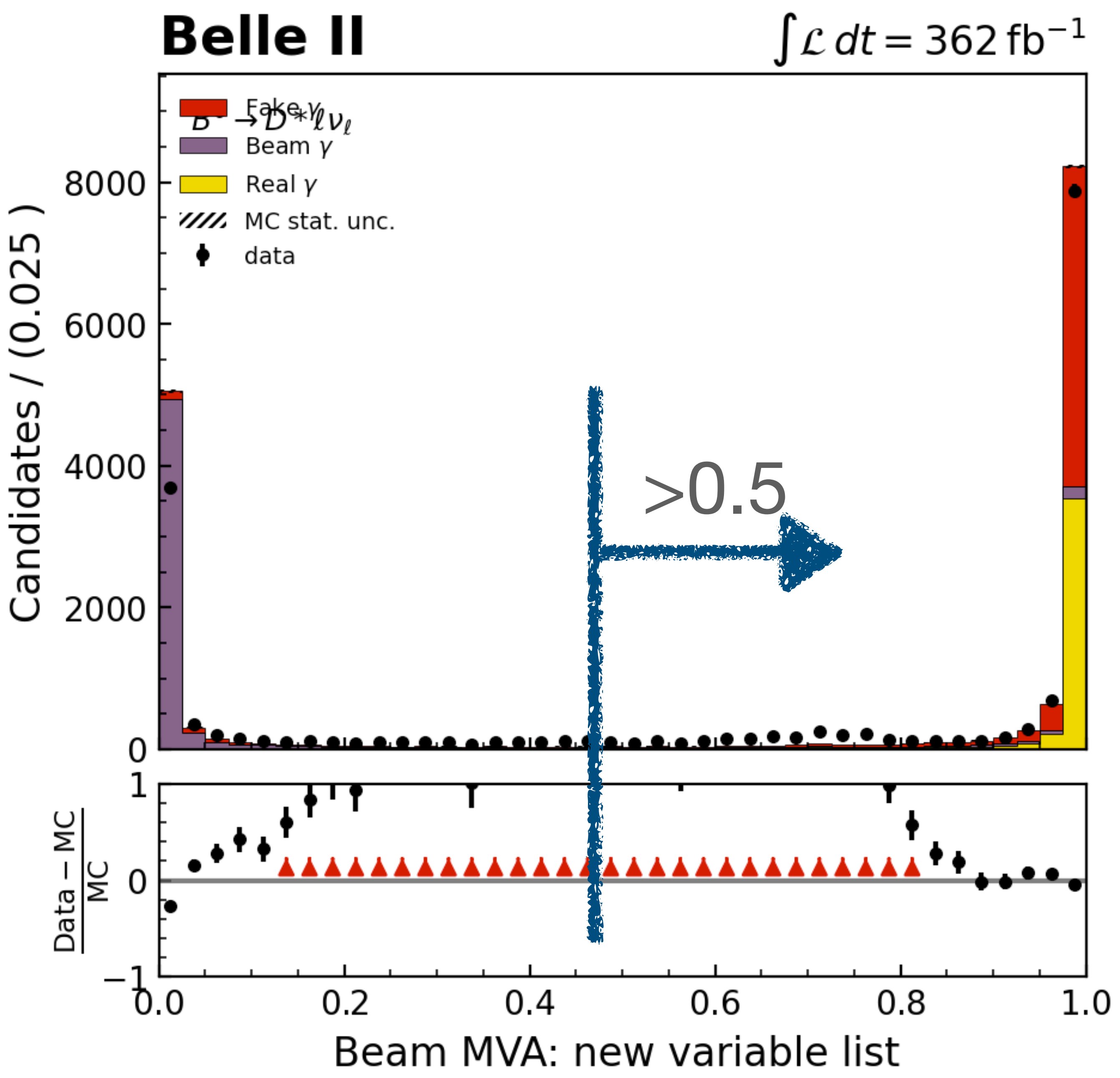
Updated variables, added clusterTheta to fake photon MVA



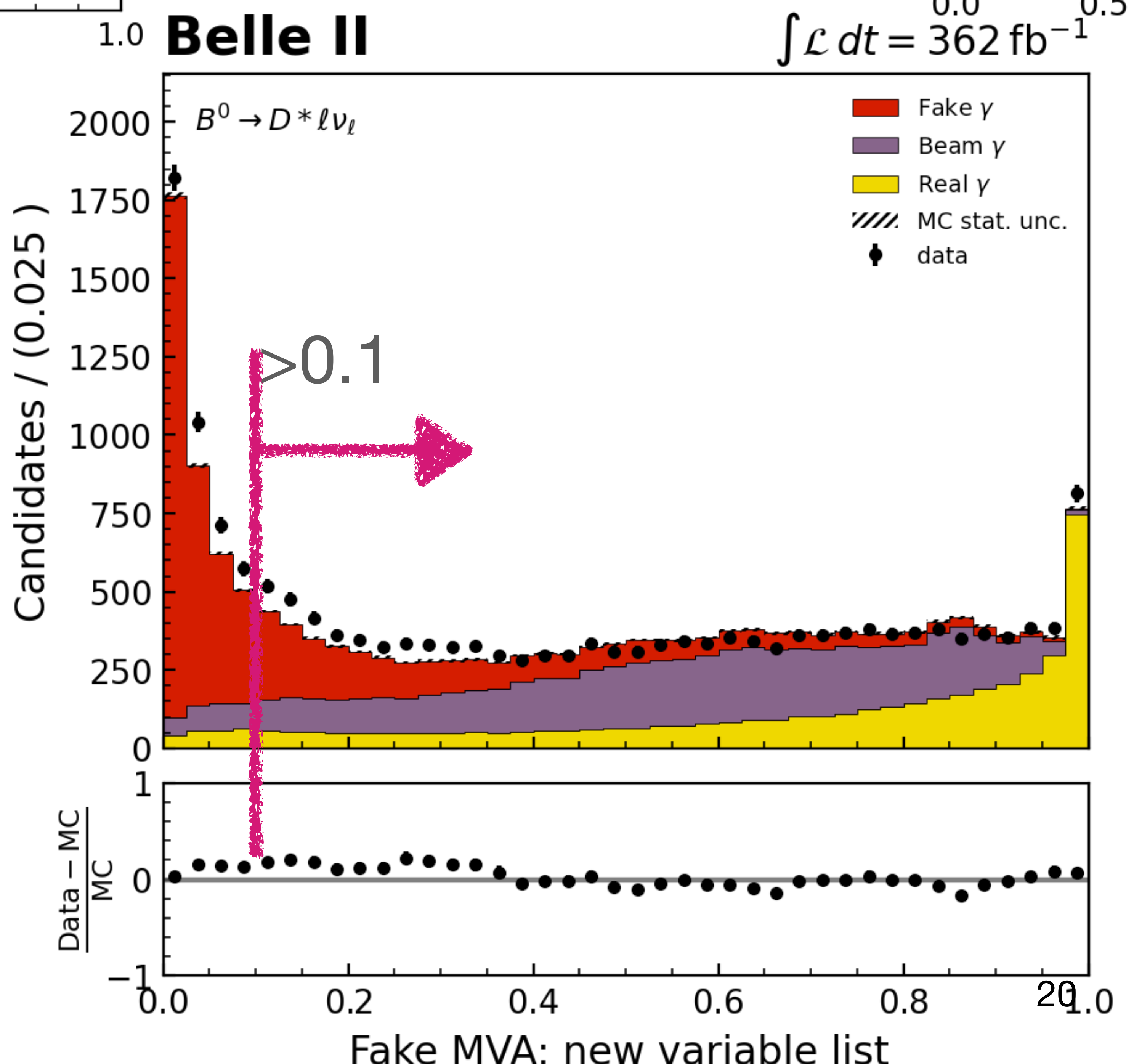
*clusterE, ~~clusterE1E9,~~ clusterLAT clusterZernikeMVA, ~~clusterSecondMoment,~~ minC2TDist, **clusterTheta** clusterPulseShapeDiscriminationMVA*



Beam background and fake photon suppression



clusterE, ~~clusterE1E9~~, ~~clusterLAT,~~ clusterTheta, clusterZernikeMVA, clusterTiming, clusterPulseShapeDiscriminationMVA



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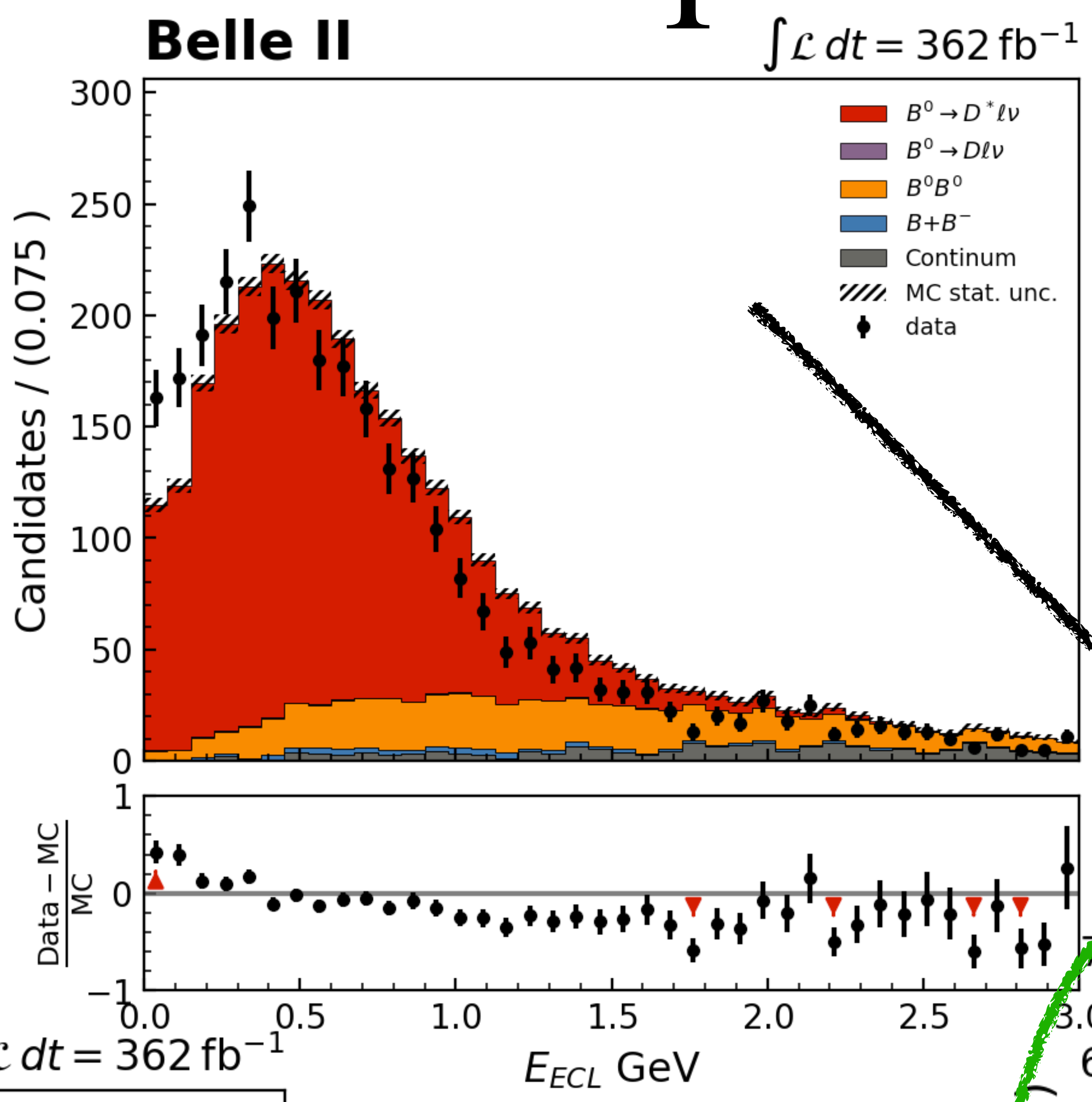
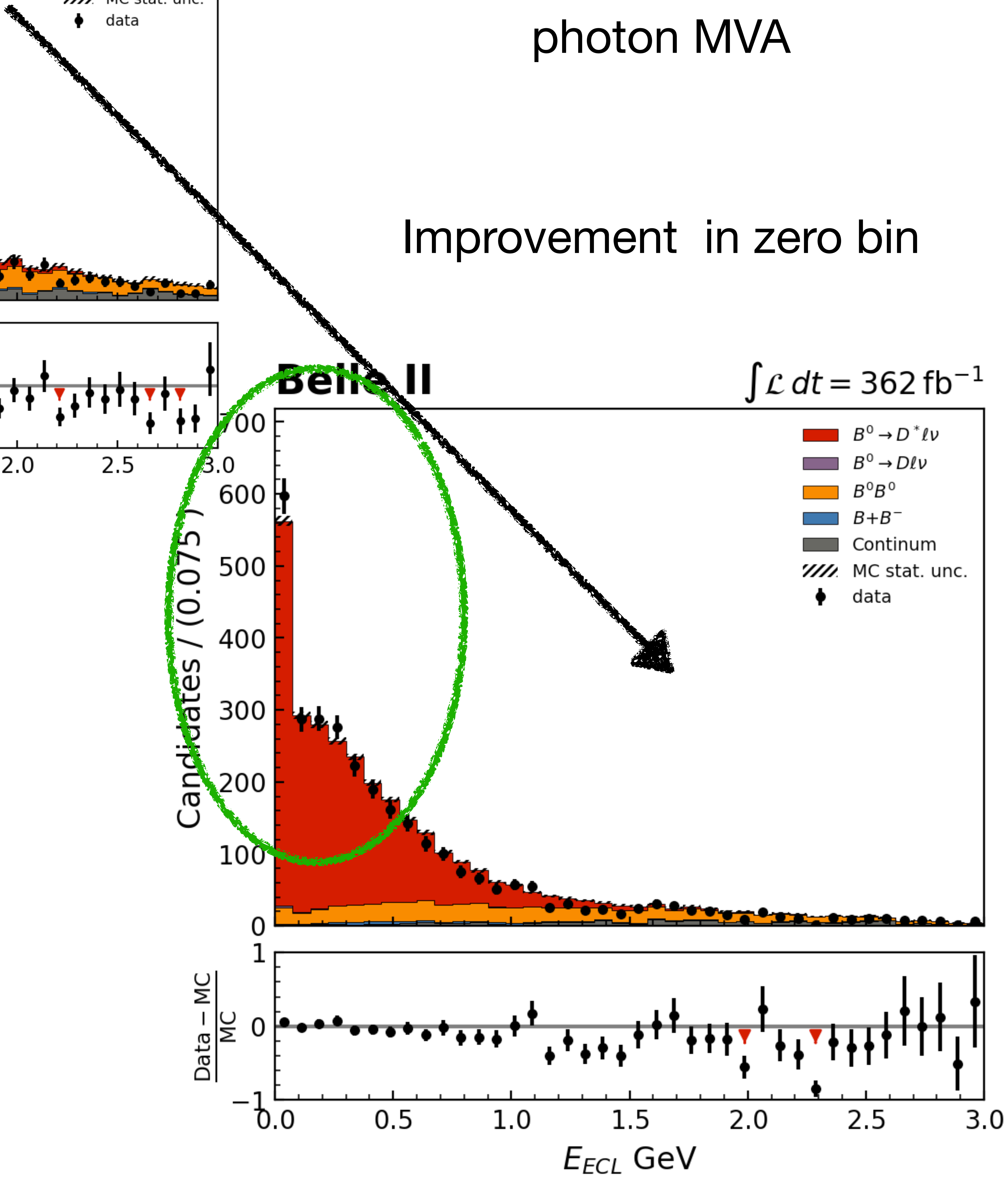


Updated variables, added clusterTheta to fake photon MVA

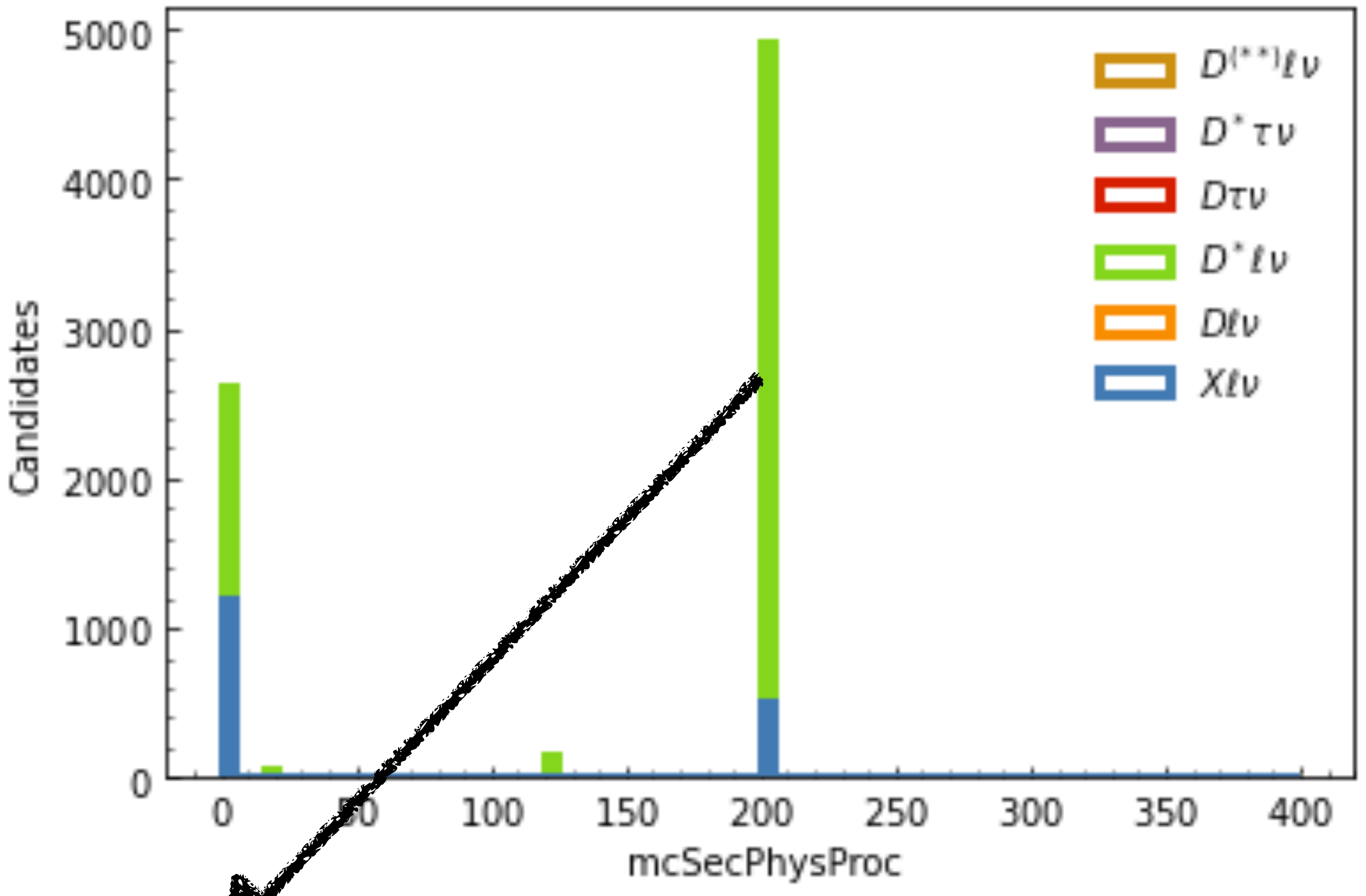
Improvement in zero bin



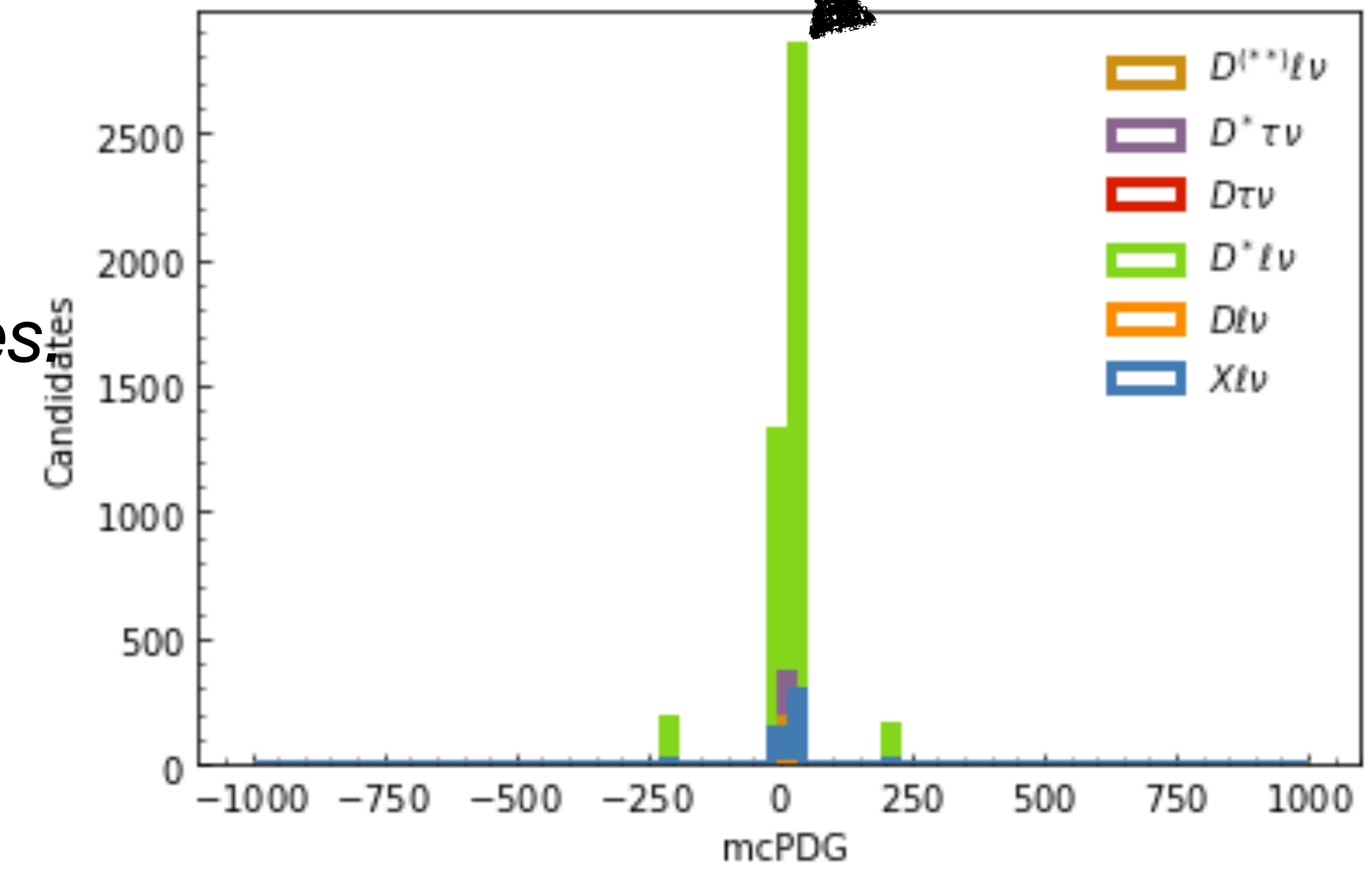
MC cluster classification

- Considerable fraction of IsSignal photons have mcSecPhysProc==201. These are secondary photons introduced by Geant4, which also pass IsSignal==1 or mcPDG==22.

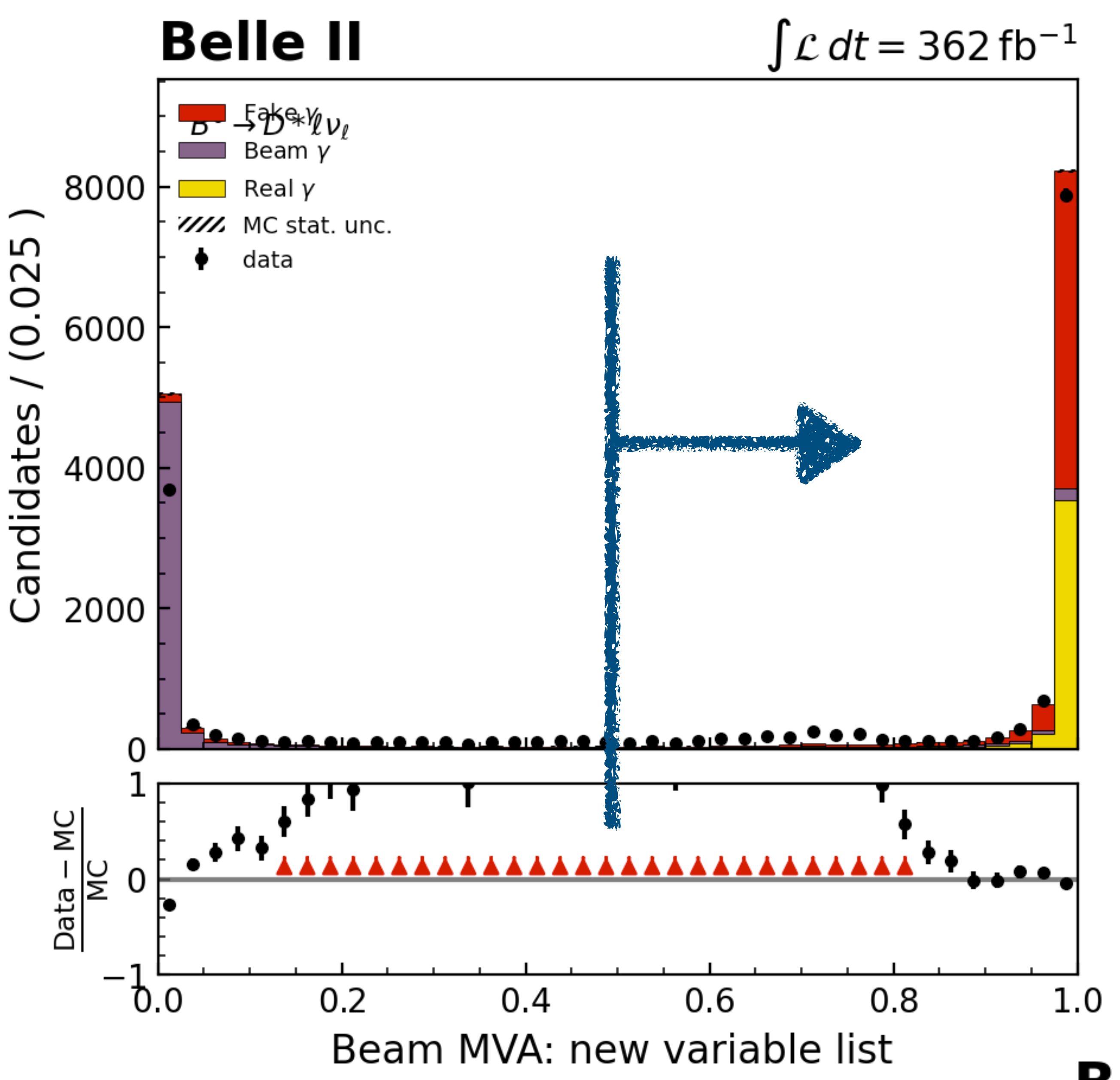
Sample	$X\ell\nu$	$D^*\ell\nu$	$D\ell\nu$	$D^*\tau\nu$	$D\tau\nu$	$D^{**}\tau\nu$
isSignal	45.8	20.5	38	22.9	45.8	39.3
mcSecPhysProc ==201	17.1	24.2	19	16.9	16.7	18.5
isSignal&201	9.8	14	8	16.2	12.5	10.6

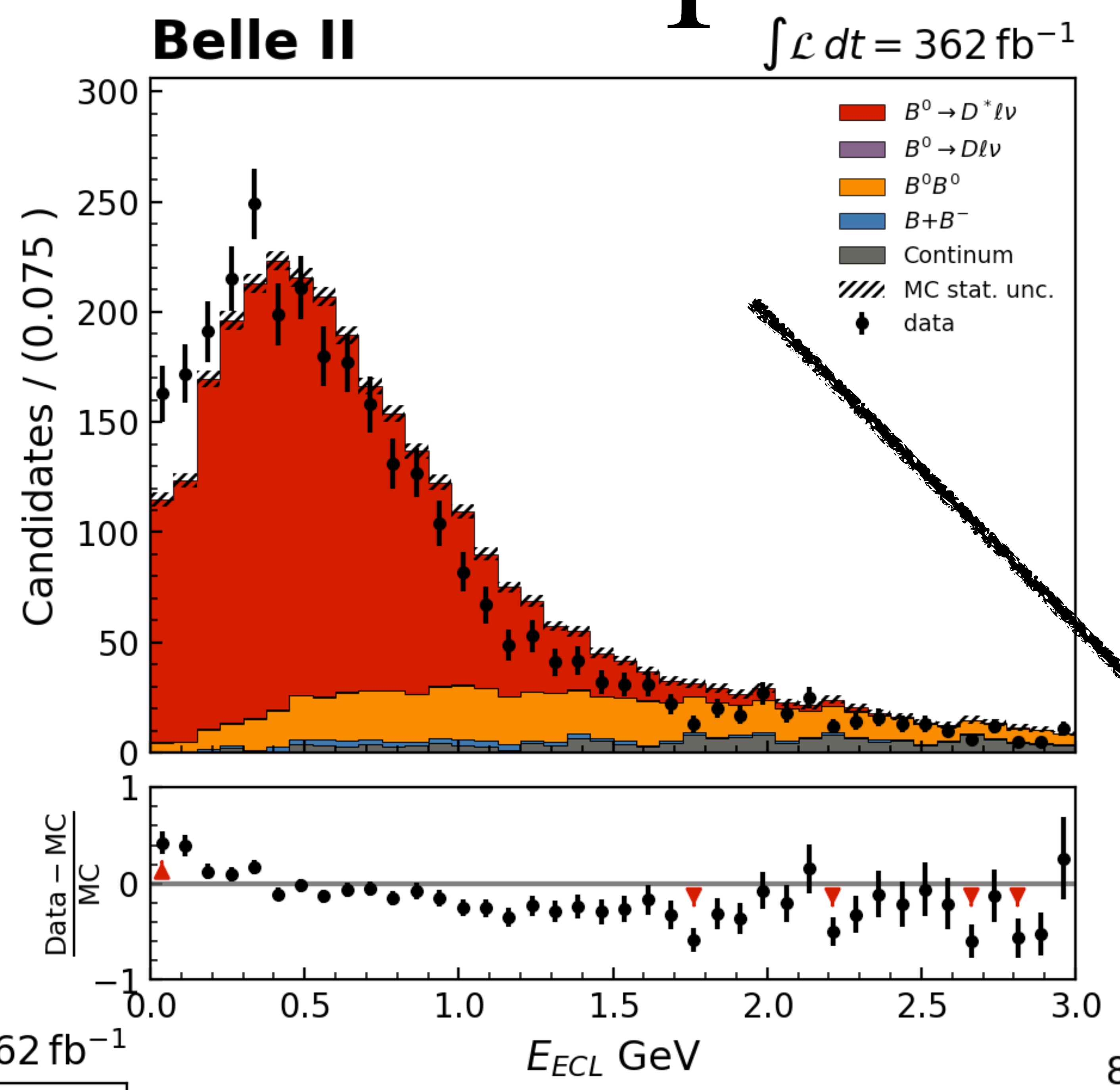


- New training files have been used with two options:
  - 201 photons moved to background sample
    - *Resulted in fake MVA identifying all photons as fakes*
  - **201 photons removed from training**

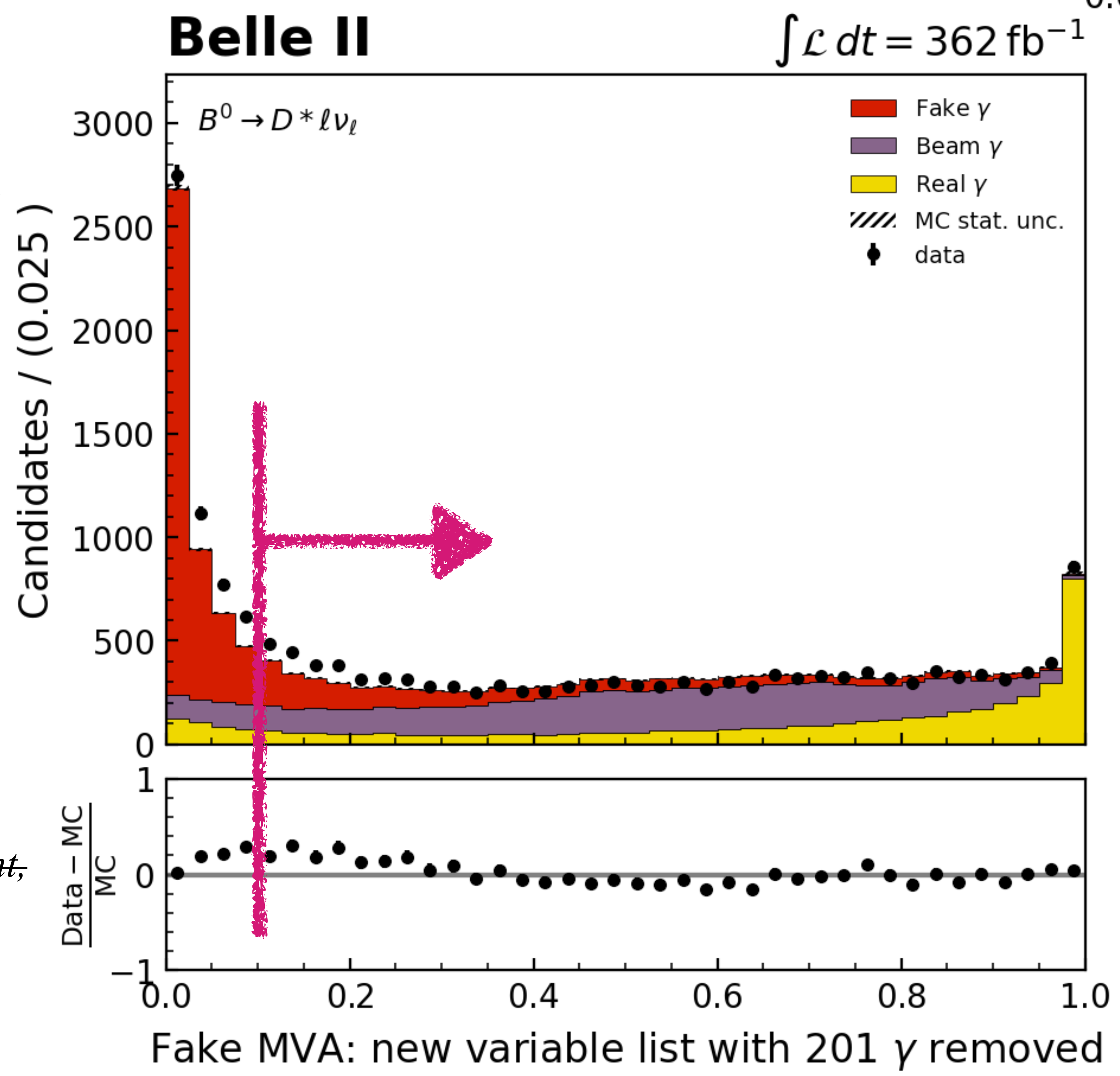


Beam background and fake photon suppression





clusterE, ~~clusterE1E9~~, ~~clusterLAT~~, clusterTheta, clusterZernikeMVA, clusterTiming, clusterPulseShapeDiscriminationMVA



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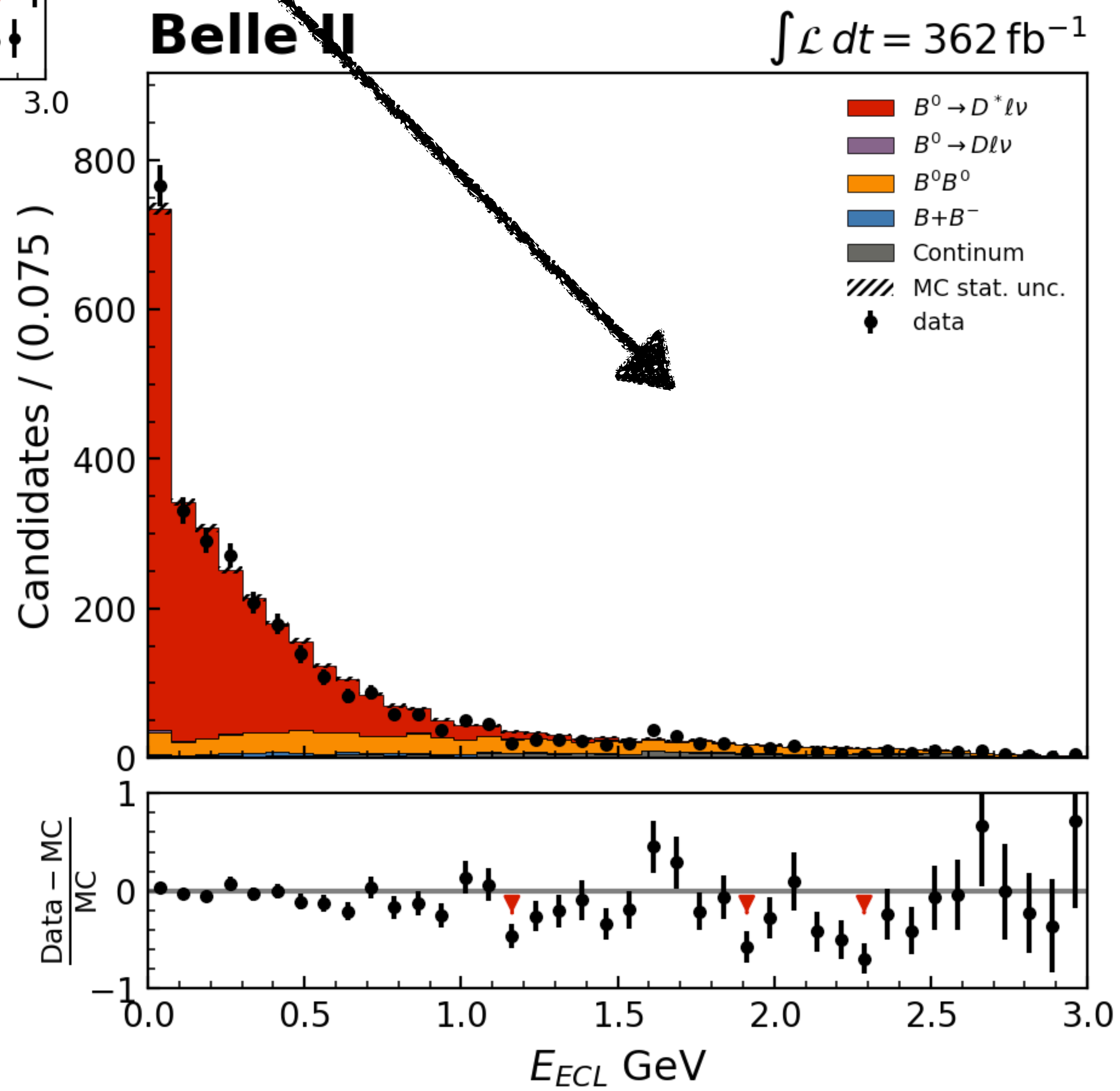

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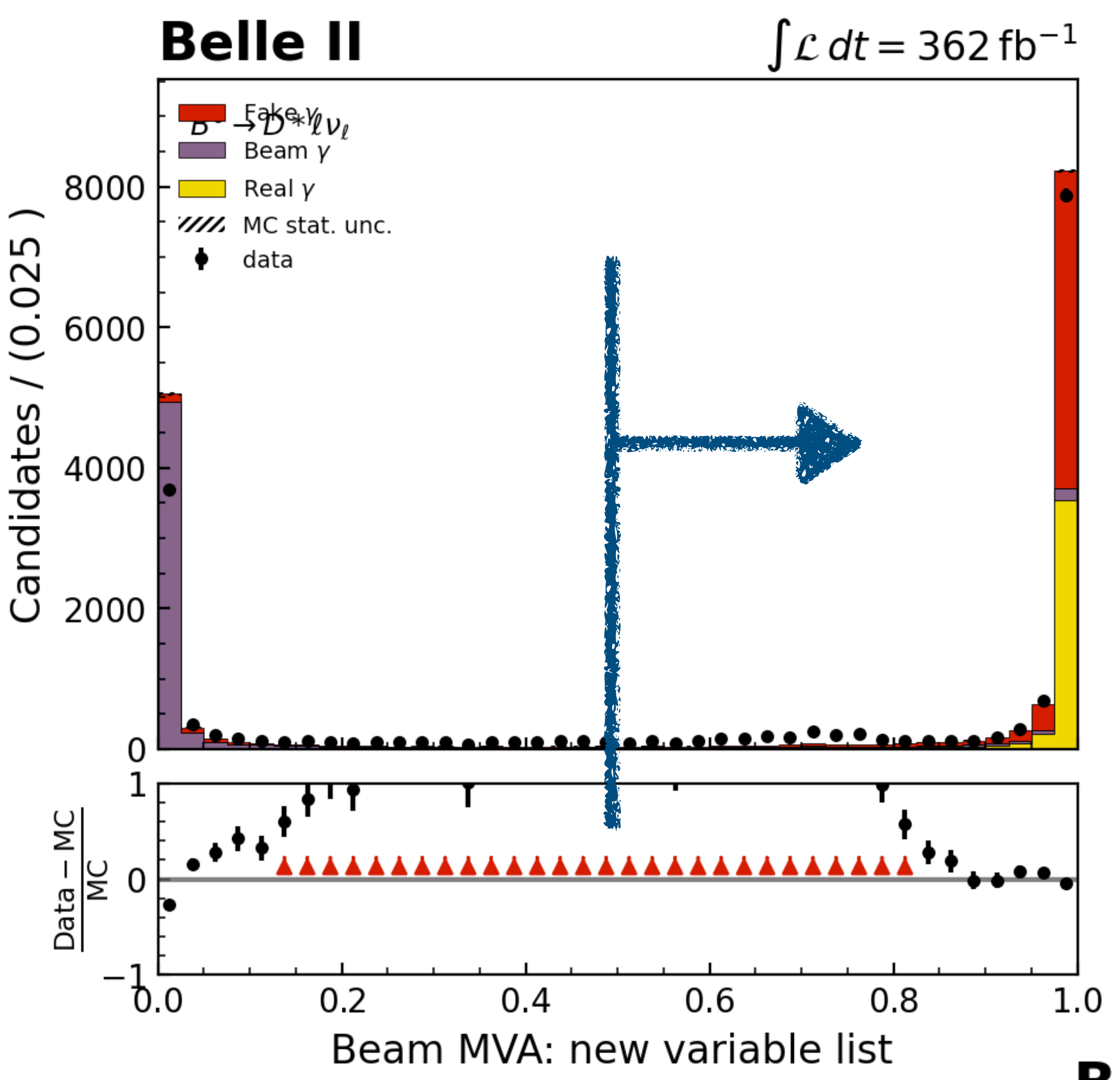
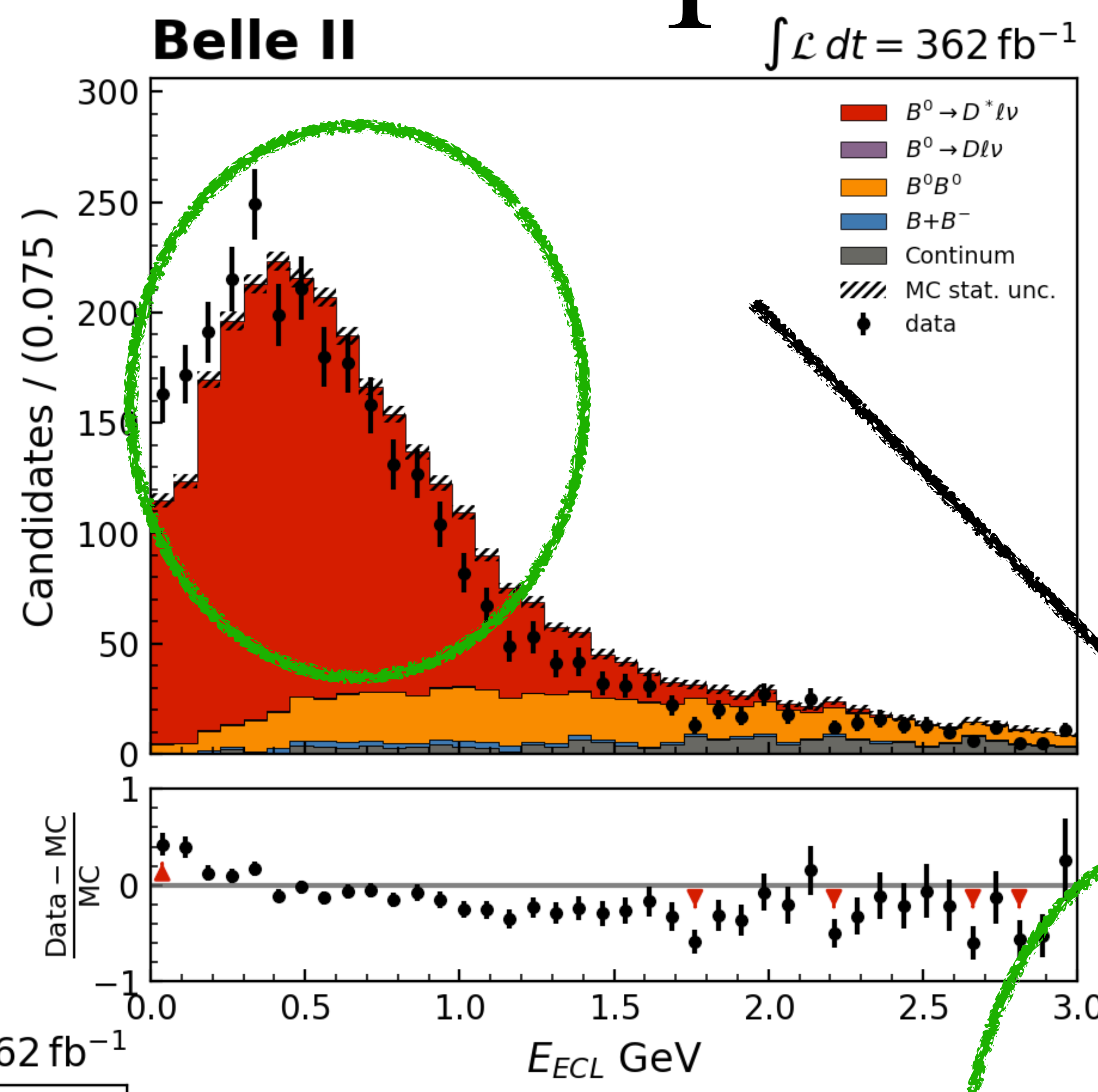
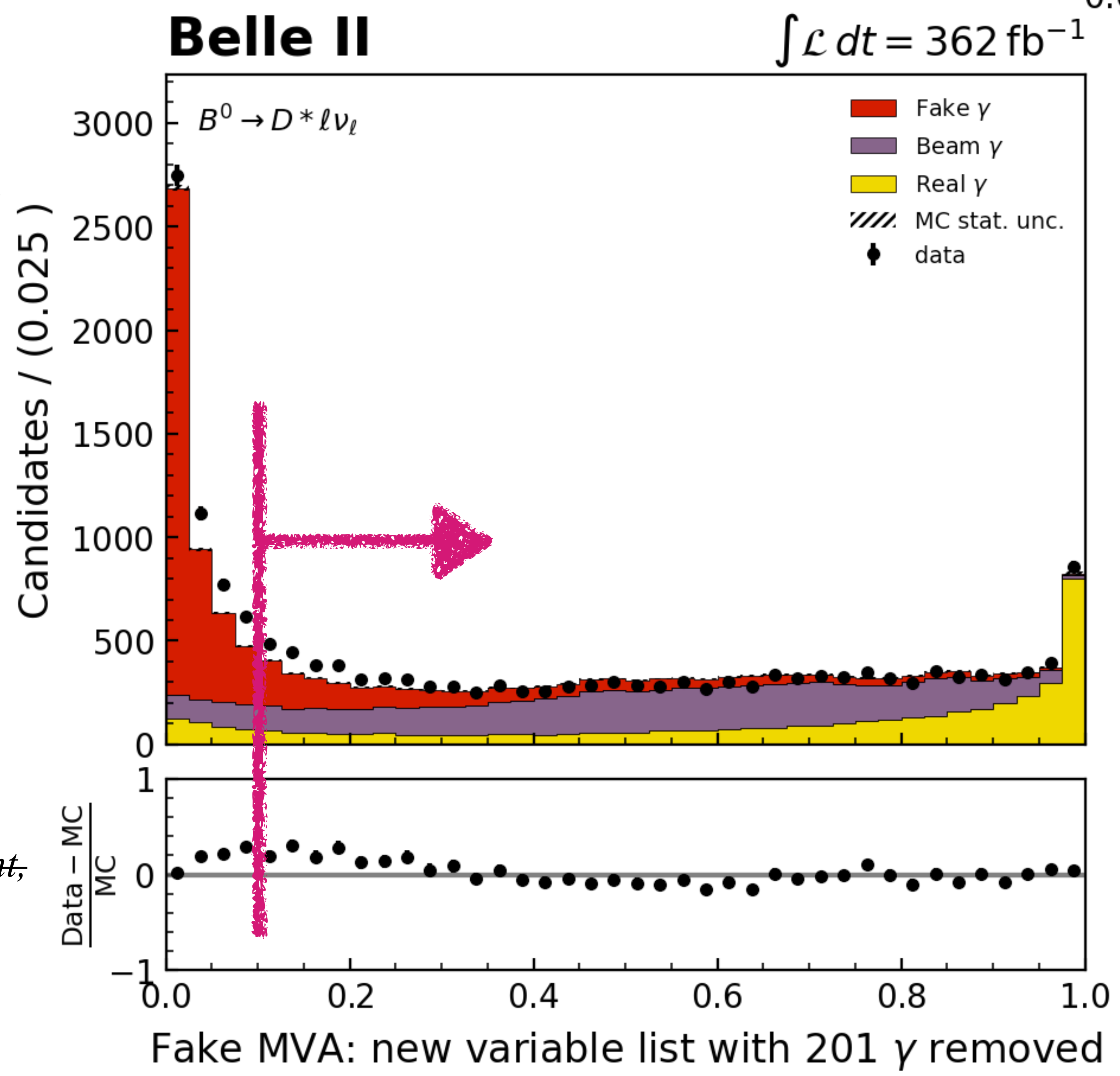




Agreement in zero bin!

clusterE, ~~clusterE1E9~~, ~~clusterLAT~~, clusterTheta, clusterZernikeMVA, clusterTiming, clusterPulseShapeDiscriminationMVA



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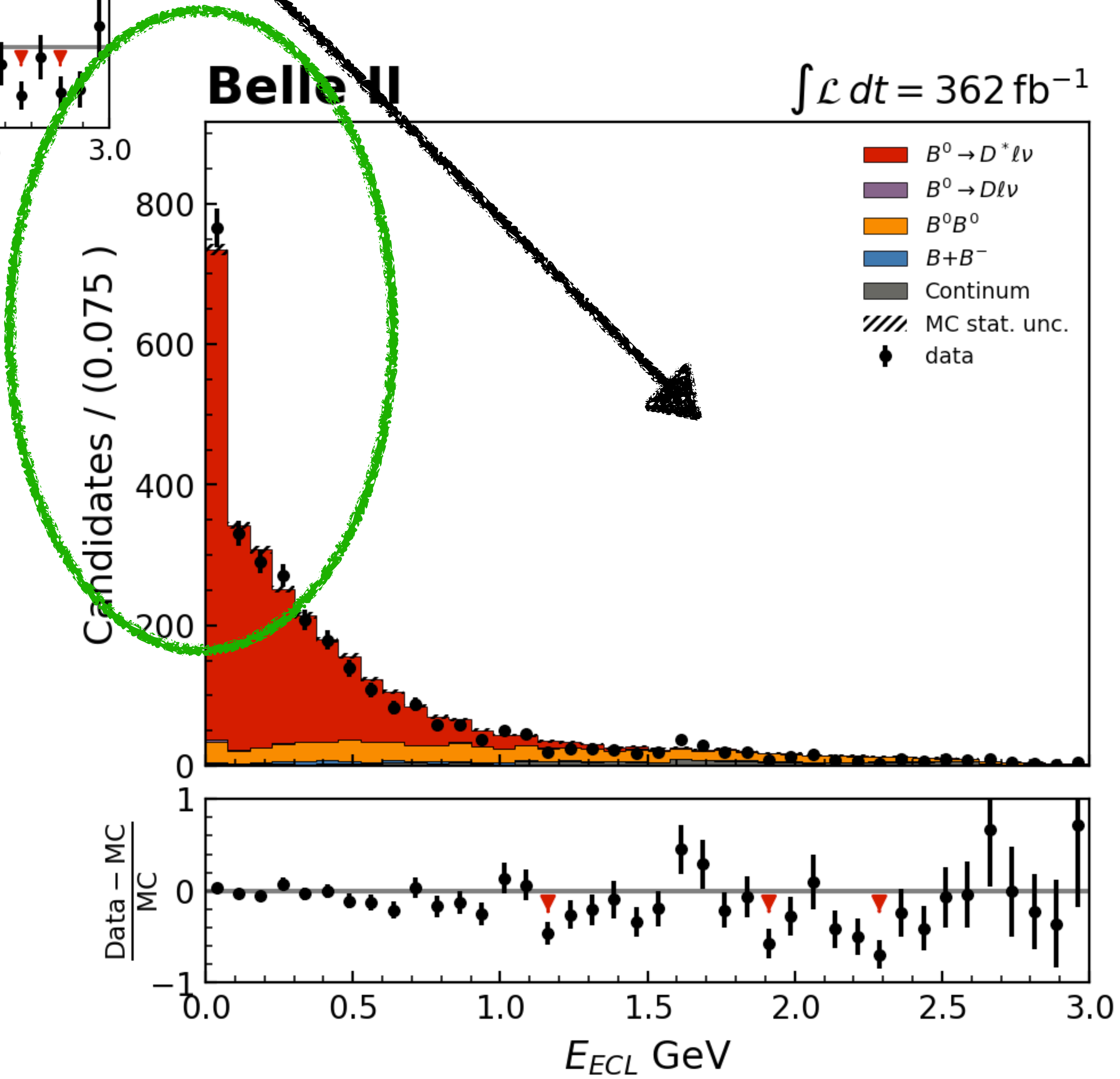
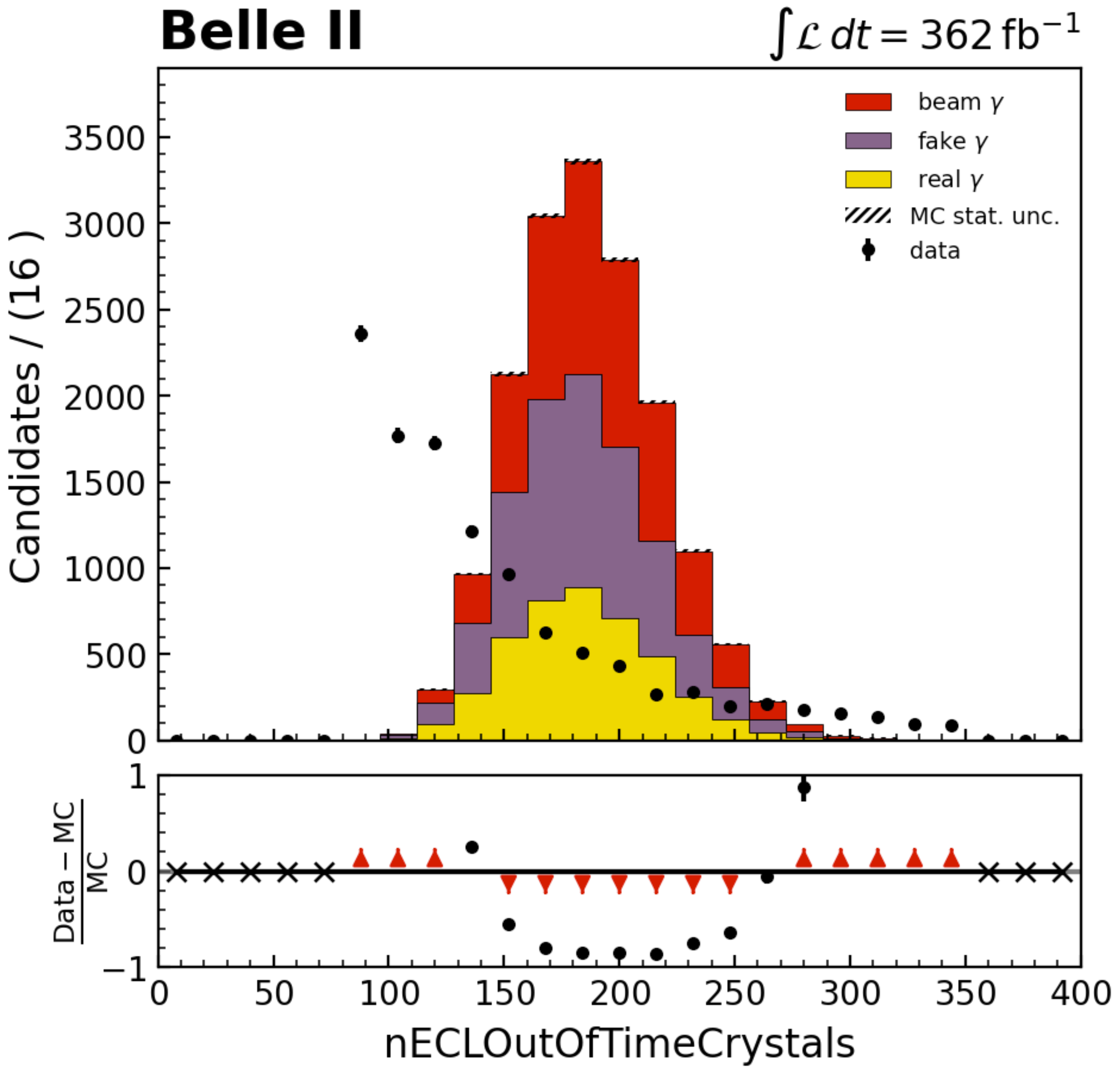
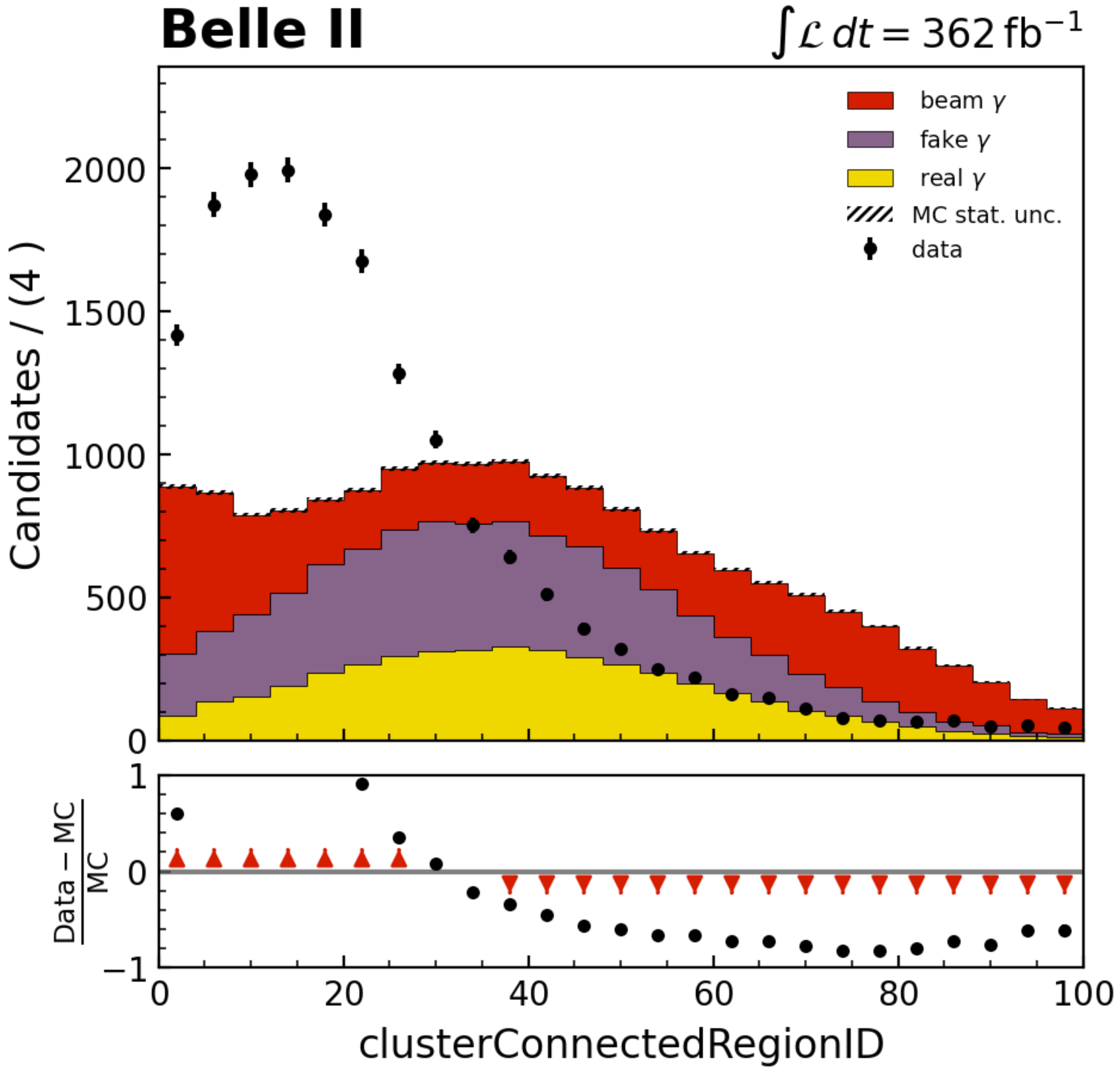


More to understand about ROE clusters



Out-of-time crystals identified to be a problem in MC15rd.



Follow up study (requiring re-run of tuples) in progress to examine overlapping clusters!

Conclusion

- E_{ECL} distribution requires more detailed study.
- Disagreement in some main variables hint to an excess of low energy beam background clusters and a deficit of fake photon clusters in run independent MC.
- Loose cuts on beam background suppression and fake photon suppression is useful.
- Further studies on run-dependent MC and overlapping clusters underway.
- Comments/suggestions.

clusterTheta

```
Returns ECL cluster's polar angle :math:`\theta`
(this is not generally equal to a photon polar angle).

| The direction of a cluster is given by the connecting
line of :math:`\,(0,0,0)\,` and
  cluster centroid position in the ECL.
| The cluster centroid position is calculated using up
to 21 crystals (5x5 excluding corners)
  after cluster energy splitting in the case of
overlapping clusters.
| The centroid position is the logarithmically weighted
average of all crystals evaluated at
  the crystal centers. Cluster centroids are generally
biased towards the centers of the
  highest energetic crystal. This effect is larger for
low energetic photons.
| Beam backgrounds slightly decrease the position
resolution, mainly for low energetic photons.

.. note::
    Radius of a cluster is almost constant in the barrel
and should not be used directly in any selection.

Unlike for charged tracks, the uncertainty (covariance)
of the photon directions is not determined
based on individual cluster properties but taken from on
MC-based parametrizations of the resolution
as function of true photon energy, true photon direction
and beam background level.

.. warning::
    Users must use the actual particle direction (done
automatically in the modularAnalysis using the average
    IP position (can be changed if needed)) and not the
ECL Cluster direction (position in the ECL measured
    from :math:`(0,0,0)`) for particle kinematics.

.. note::
    | Please read `this <importantNoteECL>` first.
    | Lower limit: :math:`0.0`
    | Upper limit: :math:`\pi`
    | Precision: :math:`16` bit
..
```

clusterTotalMCMatchWeight Returns the sum of all weights of the ECLCluster -> MCParticles relations.