$E_{ECL}$ in Semileptonic $B$ decays at Belle II

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

- Apply MVA study on BB analysis: $B^0 \rightarrow D^{*+} \ell \nu_{\ell}$
- 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 $M_{bc} > 5.27$ GeV/c$^2$ and $-0.15 < \Delta E < 0.1$ GeV.
Apply for Wolfram<0.2 offline.

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

3. $D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^- \pi^+, K_0^0 \pi^+ \pi^-, K^- K^+, \pi^- \pi^+$
Modes with $\pi^0$: 1.842$<M_D<$1.886 GeV/c$^2$
Modes without $\pi^0$: 1.853 $< M_D <$ 1.875 GeV/c$^2$
$D^*$ mass difference cut: 0.142$<\Delta M_{D^*}<0.150$ GeV/c$^2$

4. Apply a vertex fit to the Bs candidate
5. Reconstruct $Y(4S) \rightarrow BB$ 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 Bs candidate.
7. Apply ROE_charge ==0 and ROE_nTracks==0

Decent agreement between data and MC
MN Cluster Classification

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

<table>
<thead>
<tr>
<th>Sample</th>
<th>Xlv</th>
<th>D*lv</th>
<th>Dlv</th>
<th>D*tv</th>
<th>Dtv</th>
<th>D**tv</th>
</tr>
</thead>
<tbody>
<tr>
<td>mcPDG ==22</td>
<td>45.8</td>
<td>20.5</td>
<td>38</td>
<td>22.9</td>
<td>45.8</td>
<td>39.3</td>
</tr>
<tr>
<td>mcPDG !=22</td>
<td>12.4</td>
<td>17.8</td>
<td>17</td>
<td>16.9</td>
<td>14.6</td>
<td>13.3</td>
</tr>
<tr>
<td>NaN</td>
<td>41.8</td>
<td>61.7</td>
<td>45</td>
<td>60.2</td>
<td>39.6</td>
<td>47.4</td>
</tr>
</tbody>
</table>

\[ \text{clusterTotalMCMatchWeight} \begin{cases} <0.0529 \\
>0.0529 \end{cases} \]

\[ \text{cutoff: precise value is 0.0529098535976118} \rightarrow \text{compare di-muon beam bkg to } D^* \ell \nu \text{ BGx1 beam bkg using this cutoff} \]
MC Cluster Classification

<table>
<thead>
<tr>
<th>Cluster Attribute</th>
<th>Real Photon</th>
<th>Beam Bkg</th>
<th>Fake Photon</th>
</tr>
</thead>
<tbody>
<tr>
<td>mcPDG</td>
<td>22</td>
<td>NaN</td>
<td>NaN or !=22</td>
</tr>
<tr>
<td>clusterTotalMCMMatchWeight</td>
<td>—</td>
<td>&lt;0.0529099</td>
<td>&gt;0.0529099</td>
</tr>
</tbody>
</table>

ROE clusters are required to have:

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

This is consistent with the ROE cuts of the FEI skim (if I recall correctly)
$E_{ECL}$

Belle II

\[ \int L \, dt = 362 \text{ fb}^{-1} \]

Candidates / \(0.075\) GeV

- $B^0 \rightarrow D^* \ell \nu$
- $B^0 \rightarrow D \ell \nu$
- $B^\ast\bar{B}^0$
- $B^+B^-$
- Continuum
- MC stat. unc.
- data

Data - MC

$E_{ECL}$ GeV
Higher abundance of lower E beam background clusters in MC.
Higher abundance of lower E beam background clusters in MC.
$E_{ECL}$

Returns lateral energy distribution (shower shape variable).
However it does look like there is an unaccounted for portion of beam of fake photon clusters in data at clusterLAT=0?

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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.

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

$\int \mathcal{L} \, dt = 362 \text{ fb}^{-1}$

**Belle II**

$\int \mathcal{L} \, dt = 362 \text{ fb}^{-1}$

- fake $\gamma$
- beam $\gamma$
- real $\gamma$
- MC stat. unc.
- data

### Candidates / 0.025

- 2000
- 1750
- 1500
- 1250
- 1000
- 750
- 500
- 250
- 0

### Candidates / 10

- 4000
- 3500
- 3000
- 2500
- 2000
- 1500
- 1000
- 500
- 0

### Data – MC

- 1
- 0
- -1

### clusterZernikeMVA

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0

### clusterTiming

- -200
- -150
- -100
- -50
- 0
- 50
- 100
- 150
- 200

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• 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
Beam background and fake photon suppression

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

Residual discrepancy at zero bin

clusterE, clusterE1E9, clusterLAT, clusterZernikeMVA, clusterSecondMoment, minC2TDist, clusterPulseShapeDiscriminationMVA
Updated variables, added clusterTheta to fake photon MVA

Updated variables, added clusterTheta to fake photon MVA
Beam background and fake photon suppression

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.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$X\ell\nu$</th>
<th>$D^*\ell\nu$</th>
<th>$D\ell\nu$</th>
<th>$D^*\tau\nu$</th>
<th>$D\tau\nu$</th>
<th>$D^{**}\tau\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>isSignal</td>
<td>45.8</td>
<td>20.5</td>
<td>38</td>
<td>22.9</td>
<td>45.8</td>
<td>39.3</td>
</tr>
<tr>
<td>mcSecPhysProc==201</td>
<td>17.1</td>
<td>24.2</td>
<td>19</td>
<td>16.9</td>
<td>16.7</td>
<td>18.5</td>
</tr>
<tr>
<td>isSignal&amp;201</td>
<td>9.8</td>
<td>14</td>
<td>8</td>
<td>16.2</td>
<td>12.5</td>
<td>10.6</td>
</tr>
</tbody>
</table>

- 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

![Graphs showing distributions of various decay modes](image)
Beam background and fake photon suppression

**Cluster Variables**: clusterE, clusterE1E9, clusterLAT, clusterZernikeMVA, clusterSecondMoment, minC2TDist, clusterTheta, clusterPulseShapeDiscriminationMVA

**Data Plots**:
- Belle II:积分 dt = 362 fb⁻¹
  - ECL vs. Candidates (0.075)
  - ECL vs. Data MC
  - Candidates (0.075)
  - ECL vs. Data MC

**Legend**:
- B⁺ → D⁰ ψ₂
- B⁺ → D²ψ
- B⁺ → Dψ²
- B⁺ → B⁺
- Continuum
- MC stat. unc.
- data

**Fake MVA**: new variable list with 201 y removed
Beam background and fake photon suppression

\[ \int \mathcal{L} \, dt = 362 \text{ fb}^{-1} \]

**Belle II**

- **Beam MVA:** new variable list
  - $\delta\theta \rightarrow \bar{D}^0 \bar{D}^0$
  - Beam y
  - Real y

**Cluster E, clusterE, cluster LAT, cluster Zernike MVA, cluster Timing, cluster Pulse Shape Discrimination MVA**

**Cluster E, cluster E1E9, cluster LAT, cluster Zernike MVA, cluster Timing, cluster Pulse Shape Discrimination MVA**

Agreement in zero bin!
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.
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

..