Study of back-scattering and e^-/γ identification in LumiCal detector test beam 2016

Bohdan Dudar

Taras Shevchenko National University of Kyiv
bohdan96@gmail.com

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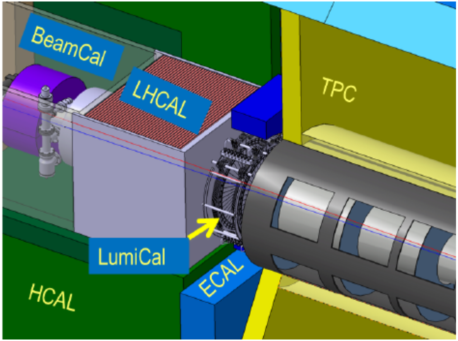
Overview

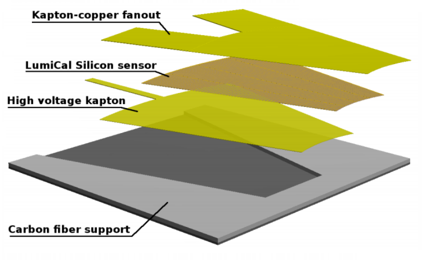
LumiCal – forward region calorimeter for ILC

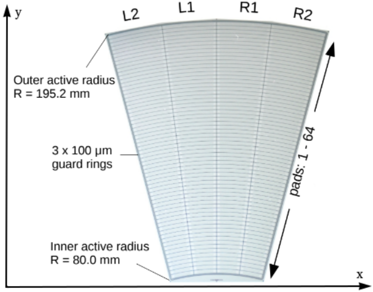


Goals:

- Precise ($\sim 10^{-4}$) luminosity measurement counting Bhabha events.
- Extend calorimeter coverage for mrad polar angles.
- Provide e^-/γ identification for mrad polar angles.

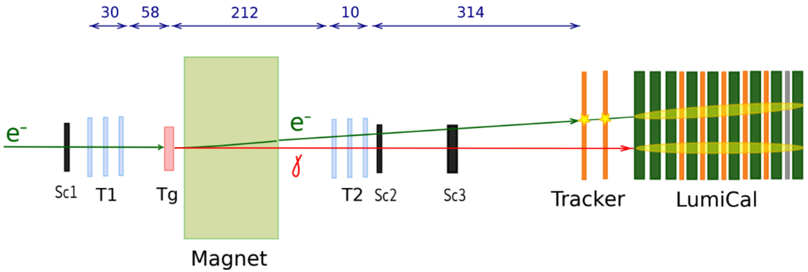
Sensor design





- Si/W sandwich, 320 μm/3.5 mm thickness
- 64 radial pads, pitch 1.8 mm
- 4 azimuthal sectors in one tile, each 7.5°
- 12 tiles make full azimuthal coverage
- DC coupled with read-out electronics

DESY test beam in 2016



Facilities:

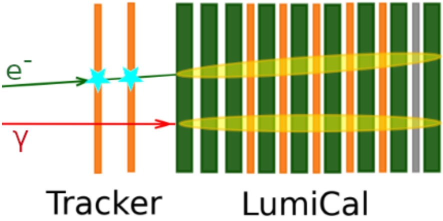
- 1-5 GeV e^- beam
- 1.5 mm Cu target for γ production
- Dipole magnet for e^-/γ separation
- 8 sensor planes (6 – LumiCal, 2 – tracker)

Goals:

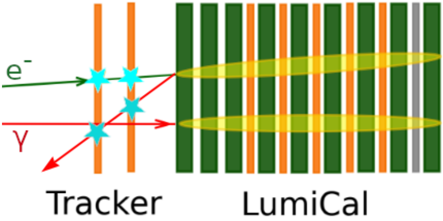
- Test the performance of the LumiCal (sensors, electronics, etc.)
- Test the tracker as a tool for the e^-/γ identification

Back-scattering events

"Good" event



Back-scattered event



! Secondary pre-showered particles also appear in the tracker. They are considered background and also studied further.

My contribution

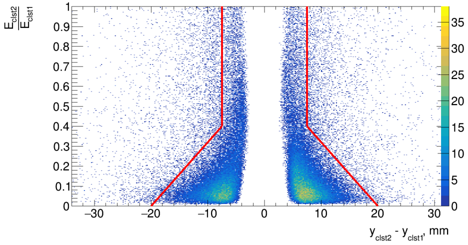
1. Shower clustering algorithm in the calorimeter

Shower clustering algorithm in the calorimeter

- **Clustering in towers**
- **E-clustering algorithm:**
  1. Mark towers with a local maximum of deposited energy and >1 active pads as cluster seeds.
  2. Assign each cluster seed to a separate cluster cluster.
  3. Add unassigned tower to the cluster of most energetic neighbor tower already assigned to some cluster.
  4. Repeat (3) until all towers become assigned.

- **Merge pair of clusters if:**
  - $d < 7.5$ mm OR
  - $\frac{E_2}{E_1} < 0.032 \cdot (20 - d)$
- d - distance between clusters

  E_i - energy of cluster i



Position reconstruction of the shower

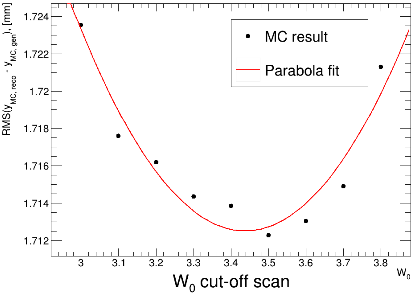
Position reconstruction method: Logarithmic weightings

$$y_{cluster} = \frac{\sum_i y_i \cdot w_i}{\sum_i w_i} \quad (1)$$

$$w_i = max(0, W_0 + ln\frac{E_i}{\sum_i E_i})) \quad (2)$$

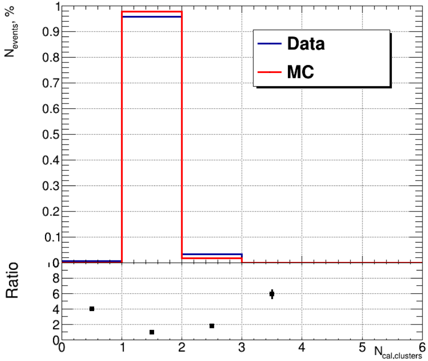
$\sum_i$ - sum over all pads in the cluster

W_0 - cut-off. Best resolution is achieved with a value 3.4

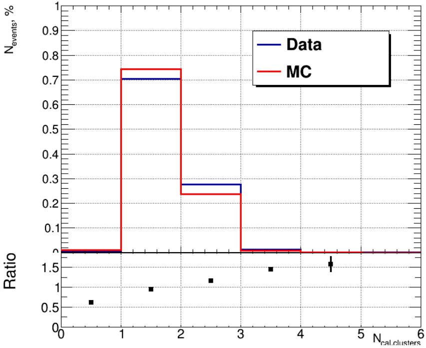


Test of the clustering algorithm

ONLY e^- RUNS:



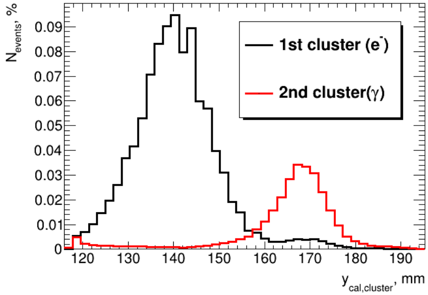
$e^- + \gamma$ **RUNS:**



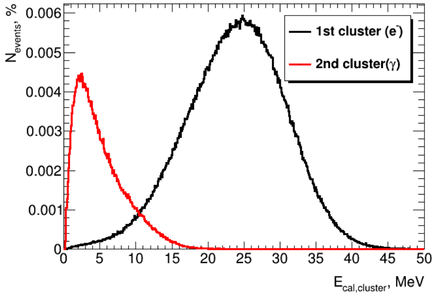
- Only e^- runs show mostly 1 cluster per event
- $e^- + \gamma$ runs show $\sim 30\%$ fraction of events with 2 clusters
- 3 absorber plates before 1st calorimeter sensor suppress low energetic photons to create a cluster

Test of the clustering algorithm

Positions of 2 clusters:



Energies of 2 clusters:



Everything is in agreement with common sense. Good.

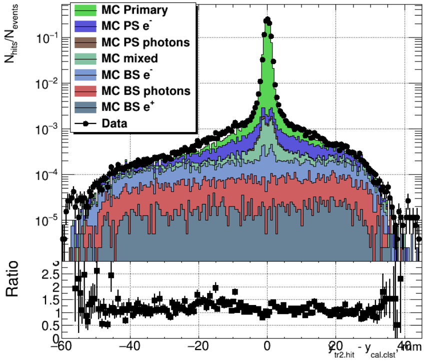
My contribution

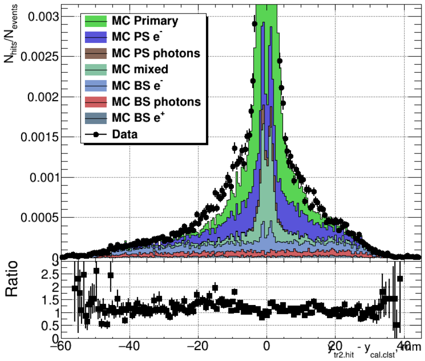
1. Shower clustering algorithm in the calorimeter
2. Geant4 back-scattering analysis

Analysis of back-scattered particles

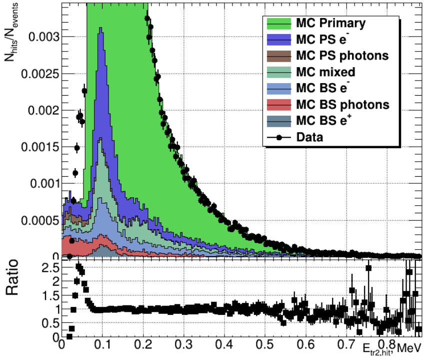
- Geant4 allows to track direction and type of particles which enter tracker logical volume. Further figures is an example of information that can be extracted from Monte Carlo.
- These figures for ONLY e^- run.

Hits' position relative to the shower in the tracker2

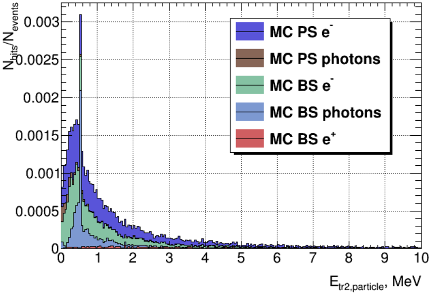




Deposited energy in the tracker2



Particles energy on the boundary of the tracker2



- Deposited energy of electrons shows Landau convoluted with Gauss distribution
- Back-Scattered and Pre-Showered particles are mostly below 5 MeV energies
- Particles spectrum shows clear anihilation peak from BS photons

Analysis of back-scattered particles

Fraction of hits for each particle source for ONLY e^- (left) and $e^- + \gamma$ (right) runs

Origin	Tracker1	Tracker2
Primary e^-	95.16 %	92.29 %
PS e^-	1.28 %	2.77 %
Mixed	1 %	1.6 %
BS e^-	0.92 %	1.35 %
PS e^+	0.74 %	0.77 %
BS γ	0.5 %	0.74 %
PS γ	0.3 %	0.23 %
BS e^+	0.12 %	0.22 %
BS hadrons	0.015 %	0.019 %

Origin	Tracker1	Tracker2
Primary e^-	92.11 %	89.16 %
PS e^-	2.39 %	3.76 %
Mixed	1.72 %	2.67 %
BS e^-	0.98 %	1.38 %
PS e^+	1.63 %	1.55 %
BS γ	0.52 %	0.79 %
PS γ	0.48 %	0.42 %
BS e^+	0.15 %	0.24 %
BS hadrons	0.014 %	0.023 %

- Total fraction of back-scattered hits in the tr1/tr2 $\approx$ 1.6/2.4 %

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2. Geant4 back-scattering analysis
3. e^{-}/γ identification algorithm of separate clusters

e^-/γ identification algorithm

Particle is identified by the presence of the signals in the tracker within cut-off distance to the shower position:

- Both trackers have a signal within cut-off distance to the shower: e^-
- Neither tracker has a signal within cut-off distance to the shower: γ

Efficiency – ratio of particles that should be reconstructed and were reconstructed to number of particles that should be reconstructed.

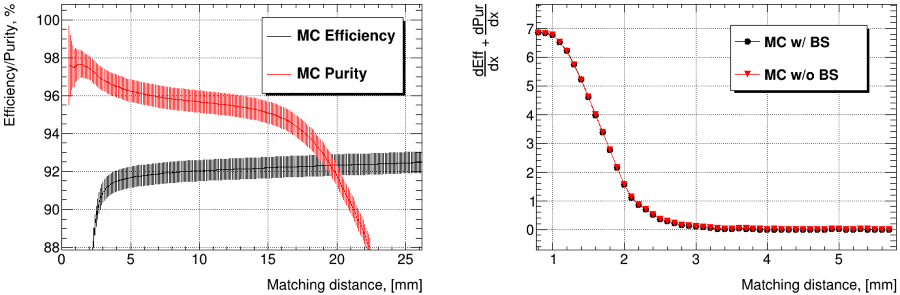
$$Eff = \frac{N_{true\&\&reco}}{N_{true}}$$

Purity – ratio of particles that should be reconstructed and were reconstructed to the number of reconstructed particles.

$$P = \frac{N_{true\&\&reco}}{N_{reco}}$$

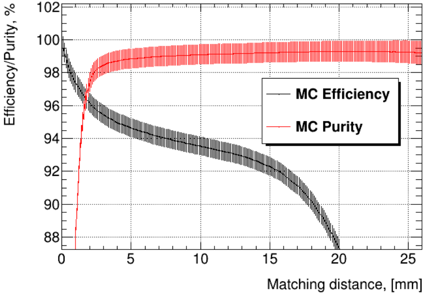
To estimate efficiency and purity we use events where we certainly know we have one e^- and one γ

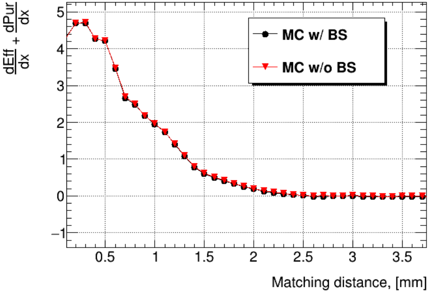
e^- identification algorithm



- On the left are Efficiency and Purity vs matching distance for electron identification.
- Appropriate matching distance around 3 mm
- Efficiency saturates at 92% assuming due to the trackers inefficiency

γ identification algorithm





- On the left are Efficiency and Purity vs matching distance for photon identification.
- Appropriate matching distance around 2.5 mm

Final results on $e^- \gamma$ identification algorithm

Electron identification	Efficiency, %	Purity, %	Matching distance
MC total	90.89 ± 0.56	96.82 ± 0.6	3 mm
w/o BS	90.87 ± 0.57	96.89 ± 0.61	3 mm
Difference	-0.02 ± 0.8	0.07 ± 0.86	

Table 2: Final results on electron identification algorithm performance.

Photon identification	Efficiency, %	Purity, %	Matching distance
MC total	95.77 ± 0.58	98.17 ± 0.6	2.5 mm
w/o BS	96.11 ± 0.59	98.18 ± 0.61	2.5 mm
Difference	0.34 ± 0.83	0.01 ± 0.86	

Table 3: Final results on photon identification algorithm performance.

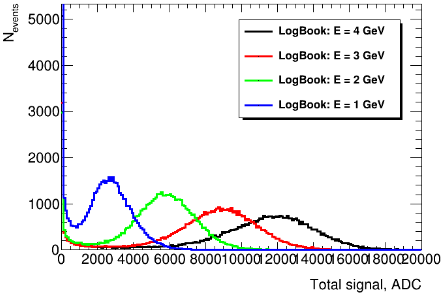
- Maximum impact back-scattering has is on photon identification efficiency and is around 0.3%
- Statistics should be improved to get smaller uncertainties

My contribution

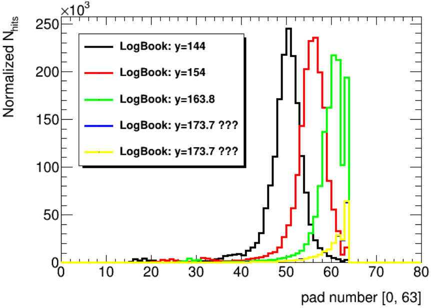
1. Shower clustering algorithm in the calorimeter
2. Geant4 back-scattering analysis
3. e^{-}/γ identification algorithm of separate clusters
4. Helping with TB19 analysis

TB19 analysis

Energy scan:



Position scan:



changes in TB19:

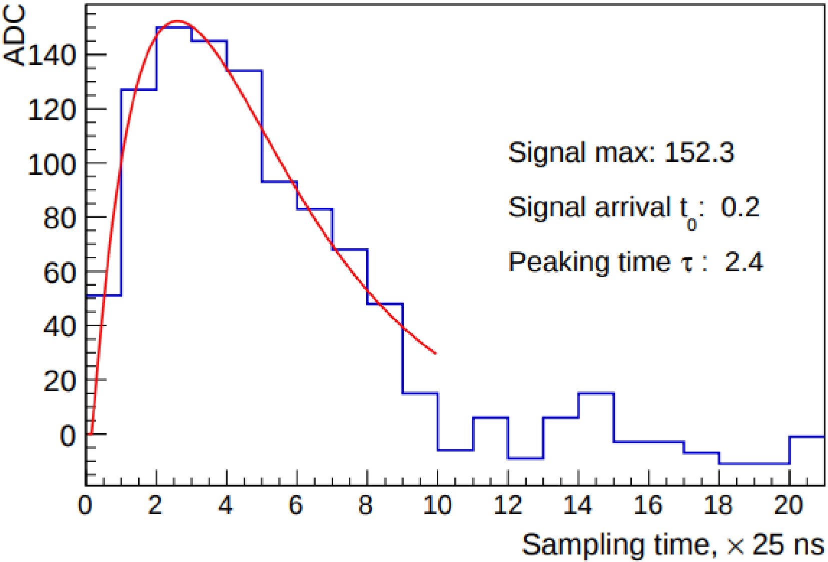
- Low and High gain mode test for APV readout
- 20 sensor+absorber planes are ready
- new ALPIDE telescope
- preparation for the new FLAME readout test in TB20

Summary

- Analysis is almost finished and on the stage of writing thesis/paper text and getting fancy plots with final conclusions
- Helped to analyse TB19 data
- Participated in TB2020 at DESY during this March
- Educating younger students to involve them into the analysis

BACK UP

Signal shape after RC-CR APV readout



Signal and geometrical selection

APV's CR-RC filter response function: $S(t) = A\frac{t-t_0}{\tau}e^{-\frac{t-t_0}{\tau}}\Theta(t-t_0)$

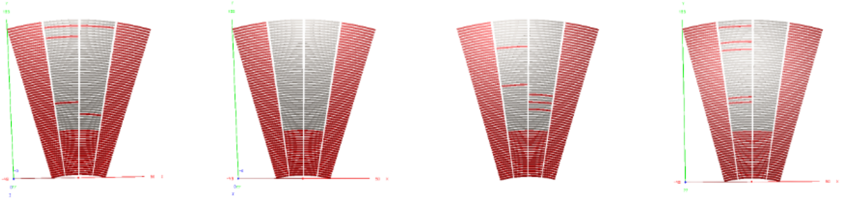
Signals selection: (taken from Sasha's analysis)

- $1 < \tau_{fit} < 3$
- $S_{max} < 2000$ ADC
- $t_{1,bin} - 2.7 < t_{0,fit} < t_{1,bin} - 0.5$
- $NN_{output} > 0.5$ (Neural Network output)

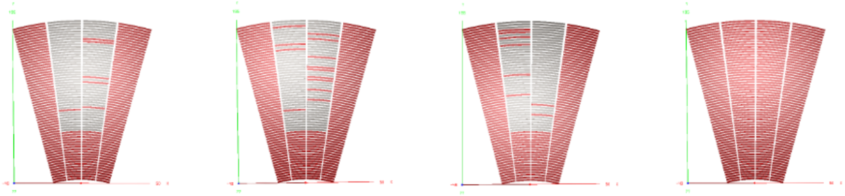
Hits selection:

- sector: L1 or R1 only
- pad > 20 - cross talk noisy area
- Exclude bad channels
- Energy in calorimeter pad > 1.4 MIP - suppress noise

Pads included in the analysis



(a) Tracker 1 (b) Tracker 2 (c) Calorimeter plane 1 (d) Calorimeter plane 2



(e) Calorimeter plane 3 (f) Calorimeter plane 4 (g) Calorimeter plane 5 (h) Calorimeter plane 6

Figure 6: Active pads which were included in the analysis.

Example of clustering algorithm

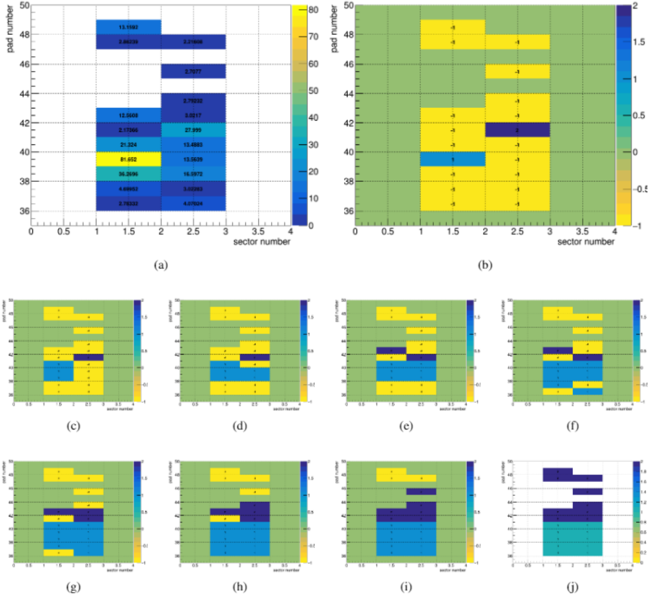
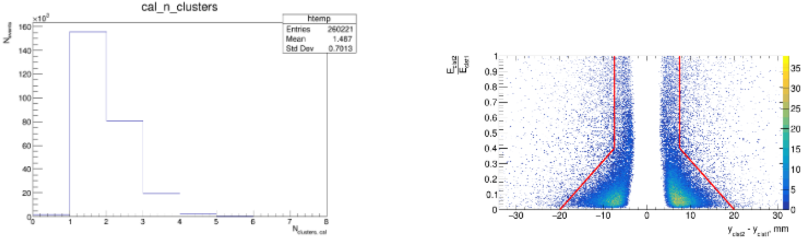


Figure 8: (a) shows energy deposits in the towers of the calorimeter. (b-i) show how towers being attached to the

Number of cluster without merging



(a) (b)

Figure 9: (a) Number of clusters in calorimeter reconstructed without merging. (b) Distance and energy ratio of first 2 clusters in each event filled in 2d histogram. Pairs of clusters being too close in the event are merged into 1 cluster.