Studies on positron counting using LUXE ECAL-P calorimeter.

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Motivation

- Number of positrons reaches 10⁶ we expect shower overlapping.
- Under those circumstances energies of single positrons cannot be measured.
- We would like to reconstruct their energy spectrum or at least count how many of them were produced – that is the main point of the following analysis.



Figure 5.1: Number of positrons per bunch crossing produced in the *e-laser* and γ -*laser* setups for phase-0 and phase-1, as a function of ξ . The electron beam energy is set to 16.5 GeV, and the laser waist parameter varies between 100 μ m and 3 μ m in the range of ξ .

 ξ -intensity parameter of the laser field.

Sample information

- Monte Carlo generated events positron source aimed at the center of the calorimeter, perpendicular to it.
- 25k events in every file.
- Energy range analysed: from 3 to 17 GeV.
- Example file name: luxe_ecalp_30gev_cv11qgsphp_tv33_hv1.root (30 is in 0.1 GeV unit).
- Example Kamil's file name: mc21.singlePositron_*_ECALP.G4gun.SIM.se0003.root
- In the simulation the ECAL is made of 21 layers. The last one is not included in the project, but can be used for linearity or leakage studies.

Comparison with Kamil's work – linearity.



- μ_E : Kamil got it from fit and I got it from average energy deposit for number of layers.
- Good agreement with higher statistics. Kamil: 1k events, Me: 25k events.
- Errors much lower on the right plot (not even visible).
- Leakage from the ECAL can be observed with decreasing number of layers and increasing e+ energy.

Comparison with Kamil's work – resolution.



- Good agreement with higher statistics. Kamil: 1k events, Me: 25k events.
- Errors much lower on the right plot (not even visible) and fluctuations decreased.

• Fitted function:
$$\frac{\sigma_{\rm E}}{E} = \sqrt{\frac{A^2}{E} + B^2}$$
.



Kamil's fits.

My fits.

$$20X_0: \frac{\sigma_E}{E} = \sqrt{\frac{(18.8 \pm 0.2)^2}{E/GeV}} + (1.9 \pm 0.2)^2$$

$$18X_0: \frac{\sigma_{\rm E}}{E} = \sqrt{\frac{(18.6 \pm 0.2)^2}{E/GeV} + (2.9 \pm 0.2)^2}$$

$$15X_0: \frac{\sigma_E}{E} = \sqrt{\frac{(17.9 \pm 0.2)^2}{E/GeV}} + (5.3 \pm 0.2)^2$$

 $20X_0$ Data Fit $20X_0$: A=19.3490 ± 0.0055; B=1.9633 ± 0.0110 $18X_0$ Data Fit $18X_0$: A=19.1632 ± 0.0062; B=3.0526 ± 0.0083 $15X_0$ Data Fit $15X_0$: A=18.5688 ± 0.0087; B=5.5937 ± 0.0067

Energy distribution – 1 vs 2 positrons.



- Left plot: energy distributions of 2 positrons from 3 GeV file and 1 positron from 6 GeV file.
- Right plot: energy distributions of 2 positrons from 4 GeV file and 1 positron from 8 GeV file.
- No difference between observing 1 positron with higher energy and 2 with lower (adding two random values from Gaussian Distribution).

Energy distribution – 1 ... 5 positrons (20 layers).



Energy of positrons - 20 layers, 3 GeV sample.

Energy of positrons - 20 layers, 17 GeV sample.

- Sums of energies of a specific number of positrons. The calculated sums are statistically independent.
- Higher energies provide better peak separation.
- Easier to distinguish whether 4 or 5 positrons were observed from higher energy plot.

Energy distribution – 1...5 positrons (15 layers).

Energy of positrons - 15 layers, 3 GeV sample.

Energy of positrons - 15 layers, 17 GeV sample.



- Sums of energies of a specific number of positrons. The calculated sums are statistically independent.
- With less layers the mean value of the distribution gets lower and the RMS gets higher due to the leakage.
- Changes due to the number of layers are more significant on the higher energy plot.
- It is still easier to distinguish whether 4 or 5 positrons were observed from higher energy sample.

Energy distribution – 20...24 positrons (20 layers).

Energy of positrons - 20 layers, 3 GeV sample.

Energy of positrons - 20 layers, 17 GeV sample.



- Sums of energies of a specific number of positrons. The calculated sums are statistically independent.
- Visible difference in comparison to previous plots distributions are wider and their mean values are closer to each other.
- Still for higher energies it is easier to tell wether 20 or 21 positrons were observed.
- Distinction between the number of positrons not so clear as before.

Energy distribution – 20...24 positrons (15 layers).

Energy of positrons - 15 layers, 3 GeV sample.

Energy of positrons - 15 layers, 17 GeV sample.



- Sums of energies of a specific number of positrons. The calculated sums are statistically independent.
- With less layers the mean value of the distribution gets lower and the RMS gets higher.
- Bigger overlapping for higher energy positrons-> more significant leakage.

Number of positrons – not compensated for leakage: 20 layers.

True N of pos. vs Reconstructed. - 20 layers, 3 GeV sample.

True N of pos. vs Reconstructed. - 20 layers, 17 GeV sample.



- Idea: further check whether distinction between 4 and 5 up to 100 and 101 positrons is possible.
- X axis true number of positrons, for which the energy sum was found.
- Y axis number of positrons calculated by summing energies of n positrons and dividing by calibrated average energy obtained from linearity plot for 21 layers (in my case $\frac{\sigma_E}{E} \approx 0.0116$). It is a good aproximation of infinitely thick calorimeter.

Number of positrons – not compensated for leakage: 15 layers.



True N of pos. vs Reconstructed. - 15 layers, 3 GeV sample.

True N of pos. vs Reconstructed. - 15 layers, 17 GeV sample.

- X axis true number of positrons, for which the energy sum was found.
- Y axis number of positrons calculated by summing energies of n positrons and dividing by calibrated average energy obtained from linearity plot for 21 layers (in my case $\frac{\sigma_E}{F} \approx 0.0116$).
- Leakage clearly visible, especially for higher energy.
- Weighting method possible to correct for leakage the number of reconstructed positrons!



 We apply a uniform correction to all cells within a layer based on the true positron energy from Monte Carlo and the number of layers in the ECAL-P.

Number of positrons – compensated: 20 layers.

True N of pos. vs Reconstructed. - 20 layers, 3 GeV sample.

True N of pos. vs Reconstructed. - 20 layers, 17 GeV sample.



- Idea: further check whether distinction between 4 and 5 up to 100 and 101 positrons is possible.
- X axis true number of positrons, for which the energy sum was found.
- Y axis number of positrons reconstructed by summing energies of n positrons and dividing by average energy.
- Lower energy means higher dispersion.

Number of positrons – compensated: 15 layers.

True N of pos. vs Reconstructed. - 15 layers, 3 GeV sample. True N of pos. vs Reconstructed. - 15 layers, 17 GeV sample. Z axis is in Reconstructed N positrons [-] Reconstructed N positrons [-] 100 log scale. 80 80 60 60 20 20 20 40 60 80 100 20 40 60 80 100 True N positrons [-] True N positrons [-]

- X axis true number of positrons, for which the energy sum was found.
- Y axis number of positrons reconstructed by summing energies of n positrons and dividing by average energy.
- Less layers also makes the dispersion a little higher but leakage of energy can not be seen on the provided plots.

Differences – not compensated for leakage: 20 layers.

True N of pos. vs difference - 20 layers, 3 GeV sample.

True N of pos. vs difference - 20 layers, 17 GeV sample.



- X axis true number of positrons, for which the energy sum was found.
- Y axis –the difference between true and calculated (average energy) number of positrons.
- Assymetry visible on the right plot-> leakage.

Differences – not compensated for leakage: 15 layers.

True N of pos. vs difference - 15 layers, 3 GeV sample.

True N of pos. vs difference - 15 layers, 17 GeV sample.



- X axis true number of positrons, for which the energy sum was found.
- Y axis –the difference between true and calculated (average energy) number of positrons.
- The leakages are clearly visible. Connecting energies with a certain number of positrons gets harder.
- For highest energies and biggest numbers of particles, without necessary corrections, we are off by 8 positrons.

Differences – compensated: 20 layers.

True N of pos. vs difference - 20 layers, 3 GeV sample.

True N of pos. vs difference - 20 layers, 17 GeV sample.



- X axis true number of positrons, for which the energy sum was found.
- Y axis –the difference between true and calculated (average energy) number of positrons.
- Higher energies provide lower differences.
- It is easier to distnguish 1 from 2 positrons than 100 from 101 positrons.
- The histograms are symmetrical.

Differences – compensated: 15 layers.

True N of pos. vs difference - 15 layers, 3 GeV sample.

True N of pos. vs difference - 15 layers, 17 GeV sample.



- X axis true number of positrons, for which the energy sum was found.
- Y axis –the difference between true and calculated (average energy) number of positrons.
- Less layers makes the differences a little bigger.
- Results, as expected, very similar to the ones obtained 2 slides ago.



Future plans: weights also adjusted for individual cells of the calorimeter because of the correlation between
position on x axis and energy after calibrating the ECAL-P for cascades and energy-momentum correlation
(from the tracker).

Summary

- 1. The first part of the work (i.e. linearity and resolution study) is consistent with previously known results, which were obtained by analysing a smaller sample.
- 2. Number of positrons is easier (in case of overlapping showers) to identify for higher energies than for lower.
- **3**. For highest energies and biggest numbers of positrons, without necessary leakage corrections, we can be off by up to 10% of positrons.
- 4. A weighting method to correct for leakage (for real data where calibration is applied) could be developed to obtain better resolution. This method can be applied for very high multiplicity when the individual cascades cannot be resolved.

Bibliography

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Thank you!

Backup

Energy distribution – 1 ... 5 positrons (20 layers).

Energy of positrons - 20 layers, 6 GeV sample.



Energy of positrons - 20 layers, 13 GeV sample.



Energy distribution – 1 ... 5 positrons (15 layers).

Energy of positrons - 15 layers, 6 GeV sample.



Energy of positrons - 15 layers, 13 GeV sample.



Energy distribution – 20...24 positrons (20 layers).

Energy of positrons - 20 layers, 6 GeV sample.



Energy of positrons - 20 layers, 13 GeV sample.



Energy distribution – 20...24 positrons (15 layers).

Energy of positrons - 15 layers, 6 GeV sample.



20 pos. Mean=1.317, RMS=0.0287 21 pos. Mean=1.383, RMS=0.0290 22 pos. Mean=1.448, RMS=0.0301 23 pos. Mean=1.514, RMS=0.0310 24 pos. Mean=1.580, RMS=0.0323 Energy of positrons - 15 layers, 13 GeV sample.



Number of positrons – not compensated for leakage: 20 layers.



True N of pos. vs Reconstructed. - 20 layers, 6 GeV sample.

True N of pos. vs Reconstructed. - 20 layers, 13 GeV sample.

Number of positrons – not compensated for leakage: 15 layers.



True N of pos. vs Reconstructed. - 15 layers, 6 GeV sample.

True N of pos. vs Reconstructed. - 15 layers, 13 GeV sample.

Number of positrons – compensated: 20 layers.

True N of pos. vs Reconstructed. - 20 layers, 6 GeV sample.

True N of pos. vs Reconstructed. - 20 layers, 13 GeV sample.



Number of positrons – compensated: 15 layers.



True N of pos. vs Reconstructed. - 15 layers, 13 GeV sample.



Differences – not compensated for leakage: 20 layers.

True N of pos. vs difference - 20 layers, 6 GeV sample.

True N of pos. vs difference - 20 layers, 13 GeV sample.



Differences – not compensated for leakage: 15 layers.

True N of pos. vs difference - 15 layers, 6 GeV sample.

True N of pos. vs difference - 15 layers, 13 GeV sample.



Differences – compensated: 20 layers.

True N of pos. vs difference - 20 layers, 6 GeV sample.

True N of pos. vs difference - 20 layers, 13 GeV sample.



Differences – compensated: 15 layers.

True N of pos. vs difference - 15 layers, 6 GeV sample.

True N of pos. vs difference - 15 layers, 13 GeV sample.

