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Citation: AIP Conference Proceedings **1722**, 210003 (2016); doi: 10.1063/1.4944231
View online: http://dx.doi.org/10.1063/1.4944231
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1722?ver=pdfcov
Published by the AIP Publishing

Fast Simulation of Electromagnetic and Hadronic Showers in SpaCal Calorimeter at the H1 Experiment

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Abstract. The fast simulation of showers induced by electrons (positrons) in the H1 lead/scintillating-fiber calorimeter, SpaCal, based on shower library technique has been presented previously. In this paper we show the results on linearity and uniformity of the reconstructed electron/positron cluster energy in electromagnetic section of Spacal for the simulations based on shower library and GFLASH shower parametrisation. The shapes of the clusters originating from photon and hadron candidates in SpaCal are analysed and experimental distributions compared with the two simulations.

INTRODUCTION

H1 experiment [1, 2] was dedicated to the study of the deep inelastic scattering (DIS) process using colliding electron/positron and proton beams from the HERA accelerator in Hamburg. A method for the fast simulation of particle showers based on a shower library technique in the H1 calorimeters was presented in our previous papers [3, 4]. The shower library was implemented for two H1 lead/scintillating-fibre calorimeters, for so-called Spaghetti calorimeter SpaCal [3] and for the FNC (Forward Neutron Calorimeter) [4].

In this technique the detector response is simulated using a collection of stored showers for different particle types and topologies. The structure of the shower library depends on the construction of the calorimeter and particle kinematics. In the simulation using the shower library a generated particle is traced through the detector components up to the calorimeter surface. At this point, if the impact position of the particle is far enough from the calorimeter boundaries, such that the shower is expected to be fully contained in the calorimeter, the shower library is applied: instead of using the GEANT package to simulate the calorimeter response, a suitable pre-simulated shower is selected from the shower library. The selected shower is then corrected for a difference between the actual particle kinematics and the kinematics of the particle used for the shower creation. Corrected energy deposits are added to the calorimeter response.

In [3] we made a detailed analysis of shower shape of electron/positron candidates in the SpaCal and concluded that implementation of shower library accelerated the simulation of showers compared to the full GEANT simulation by about a factor of ten. In this paper we continue the study of simulation of the SpaCal response using shower library and compare it with experimental data and also with the simulation using the GFLASH based shower parametrization [5] which had been used for shower simulation in the H1 calorimeters before shower library implementation.

The SpaCal calorimeter is comprised of electromagnetic and hadronic sections. The electromagnetic part of the SpaCal consists of 1192 cells with an active volume of 4.05 x 4.05 x 25 cm^3 each. The hadronic part of the SpaCal is comprised of 136 cells of 12 x 12 x 25 cm^3 providing one nuclear interaction length.
Detailed description of shower library for SpaCal, its structure and packing is given in [3].

This paper is organised as follows: linearity and uniformity of the reconstructed electron/positron cluster energy in electromagnetic section of Spacal for the simulations based on shower library and GFLASH shower parametrisation are presented in the following section after which the shapes of photon and hadron clusters are analysed and the paper is summarised in the last section.

9th International Physics Conference of the Balkan Physical Union (BPU-9)
AIP Conf. Proc. 1722, 210003-1–210003-4; doi: 10.1063/1.4944231

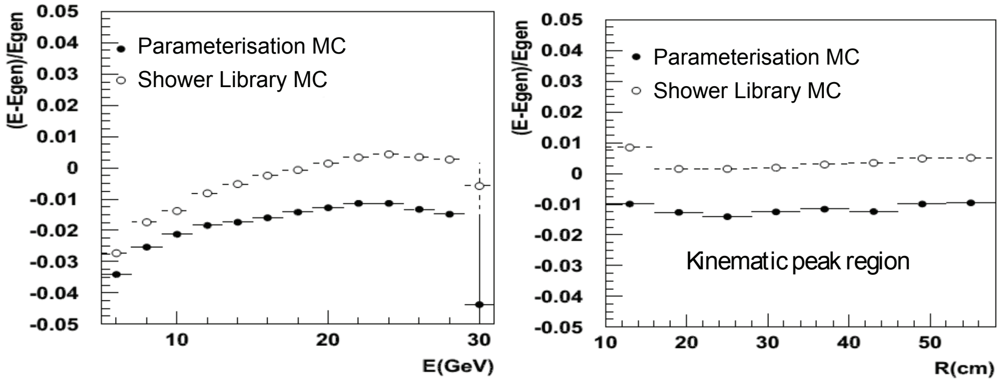

FIGURE 1. Linearity (left) and uniformity (right) of reconstructed cluster energy in SpaCal obtained from Monte Carlo simulations using the shower library and GFLASH used parameterisation (E_{gen} - generated e/e$^+$ energy, E and R - reconstructed e/e$^+$ candidate cluster energy and its radial position respectivelly).

e^+/e$^-$ CLUSTER ENERGY IN SPACAL

The main quantity used for particle identification in the SpaCal is the transverse size of the shower parametrised by a cluster radius. The determination of the cluster radius starts with the calculation of the cluster centre-of-gravity which is defined as a weighted average over the positions of the cluster cell centres:

$$X_{cluster} = \sum_i x_i w_i \qquad Y_{cluster} = \sum_i y_i w_i.$$

Here x_i, y_i are the x and y coordinates of the i-th cell centre and w_i defines the weight of cell i. Two definitions are used in H1 to calculate w_i, based on square root and logarithmic energy weighting:

$$w_{i,\mathrm{sqrt}} = \frac{\sqrt{E_i}}{\sum_j \sqrt{E_j}}, \quad w_{i,\log} = \frac{\max(0, w_{\mathrm{cut}} + \log(E_i/E_{\mathrm{cluster}}))}{\sum_j \max(0, w_{\mathrm{cut}} + \log(E_j/E_{\mathrm{cluster}}))}.$$

Here E_i corresponds to the energy reconstructed in the cell i, and w_{cut} defines the logarithmic cut-off parameter for the SpaCal taken to be 4.85.

The cluster radius is then calculated as a weighted sum over the distances, R_i, between the centre of each cell, i, and the cluster centre-of-gravity. Corresponding to the two definitions of weighting, two cluster radius calculations are employed at H1. These are, so called ECRA and the logarithmic cluster radius,

$$ECRA = \sum_i R_i w_{i,\mathrm{sqrt}}, \quad R_{log} = \sqrt{\sum_i (R_i w_{i,\log})^2}.$$

The main quantity measured by a calorimeter is a particle energy which is calculated as a sum of energies of all cells belonging to a cluster. In previous papers [3, 4] when analysing shape of e$^-$/e$^+$ cluster, a pure sample was obtained by applying the standard DIS cuts used in the H1 collaboration and requiring that the energy of the cluster exceeds 15 GeV; this avoids hadronic background contamination. The selected clusters were required to be in the region of the SpaCal far from the inner and outer acceptance edges. To analyse overall performance of the two simulations in calculating particle energy, here we consider a wide range in energy for clusters reconstructed in SpaCal and also we explore almost the whole active region of the calorimeter (except innermost and outermost cells to exclude edge effects). The left panel of Figure 1 shows result on linearity of the reconstructed e$^-$/e$^+$ candidate cluster energy in Spacal for Monte Carlo simulation using the shower library and Monte Carlo simulation using the GFLASH based shower parametrisation. As expected energy resolution deteriorates for lower energies when background contribution (mainly from hadrons) is larger.

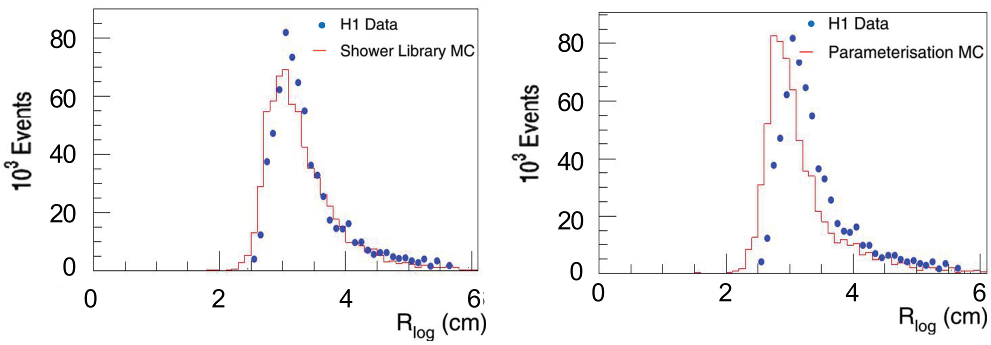

FIGURE 2. Comparison of H1 data (dots) with Monte Carlo simulation (histogram) using the shower library (left) and GFLASH based shower parameterisation (right) for logarithmic cluster radius for photon candidates.

To study the uniformity of the SpaCal response we again restrict to the almost pure e^-/e^+ sample selecting the clusters with energy around incoming lepton beam energy (27.6 GeV) which we term as "kinematic peak region". The right panel of Figure 1 shows result on uniformity of the reconstructed e^-/e^+ candidate cluster energy in Spacal for Monte Carlo simulation using the shower library and Monte Carlo simulation using the GFLASH based shower parametrisation.

The simulation of $e^{\pm}p$ collisions uses the DJANGO event generator [6].

As can be seen from Figure 1 cluster energy measurement is improved with implementation of shower library.

PHOTON AND HADRON CLUSTERS IN SPACAL

Properties of photon and hadron clusters in Spacal are studied using PHOJET 1.6 event generator [7] which is used to generate photoproduction background for $e^{\pm}p$ scattering.

To select photoproduction sample in data, specific requirements were applied and responses of two electromagnetic crystal calorimeters, a photon tagger (PT) and an electron tagger (ET) were used. The PT and ET were located downstream of the incoming lepton beam to monitor the luminosity via the measurement of the Bethe-Heitler process $ep \rightarrow \gamma ep$. To eliminate the DIS contribution, events with the scattered electron reconstructed in the e-tagger are used. The residual DIS and Bethe-Heitler overlaps are reduced by requiring: no energy deposition in the PT, energy in the ET is greater than 7 GeV and by applying energy/momentum conservation cuts.

We separate photon-like and hadron-like clusters based on absence/presence of the signal in a proportional chamber, Central Inner Proportional Chamber (CIP) along the calculated particle trajectory connecting the primary vertex and the selected cluster in the electromagnetic section of SpaCal. Photon candidate clusters have no match in CIP while hadron candidate clusters have a CIP signal match. This separation is not 100 % pure. Defined this way photon clusters may have small contamination from hadrons because of CIP inefficiency, whereas hadron clusters in fact also include electrons from photon conversions before the CIP.

Figure 2 shows the comparisons between H1 data and Monte Carlo simulation using the GFLASH based shower parametrisation and between data and Monte Carlo simulation using the shower library. The comparisons are made for the logarithmic cluster radius of photon candidate clusters. Figure 3 shows the same as Figure 2 but for hadron candidates.
As can be seen from these figures, using the shower library, a fair description of the cluster radius of photon and hadron candidates is achieved.

Distributions assigned to hadrons, as it has been already mentioned, contain contamination from the converted photons. Therefore, the differences between data versus MC for these distributions can not be attributed directly to the problems in description of the hadronic showers. In addition, the difference may arise because of: (i) not properly described conversions in the detector material before CIP, (ii) not properly described ratio of hadrons to photons in PHOJET, (iii) wrong simulation of the energies for the hadronic clusters.

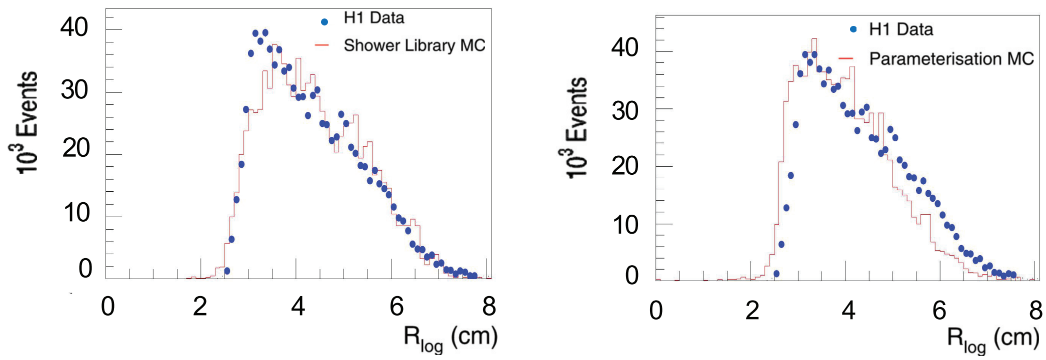

FIGURE 3. Comparison of H1 data (dots) with Monte Carlo simulation (histogram) using the shower library (left) and GFLASH based shower parameterisation (right) for logarithmic cluster radius for hadron candidates.

SUMMARY

In this paper we studied in more details the impact of shower library implementation to the overall response of the SpaCal calorimeter in the H1 experiment.

The results on linearity and uniformity of the reconstructed e^-/e^+ cluster energy in Spacal show that shower library provides accurate and uniform measurement of the selected cluster energy and in the kinematic peak region it is a few per-mille. Monte Carlo simulation using the shower library provides fair description of the photon and hadron cluster shapes observed in data. Shower library based simulation provides better description of the SpaCal data than Monte Carlo simulation using GFLASH based shower parametrization for all analysed variables.

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