AcerDET-2.0\textsuperscript{1}: a particle level fast simulation and reconstruction package for phenomenological studies on high $p_T$ physics at LHC.

Patryk Mikos  
*Theoretical Computer Science, Jagellonian University; 30-348 Krakow, ul. Lojasiewicza 6, Poland.*  
Elżbieta Richter-Wąs  
*Institute of Physics, Jagellonian University; 30-348 Krakow, ul. Lojasiewicza 11, Poland.*

**Abstract**

The fortran version of the AcerDET package has been published in [1], and used in the multiple publications on the predictions for physics at LHC. The package provides, starting from list of particles in the event, the list of reconstructed jets, isolated electrons, muons, photons and reconstructed missing transverse energy. The AcerDET represents a simplified version of the package called ATLFAST, used since several years within ATLAS Collaboration. In the fast simulation implemented in AcerDET, some functionalities of ATLFAST are absent, but the most crucial detector effects are implemented and the parametrisations are largely simplified. Therefore it is not representing details neither of ATLAS nor CMS detectors.

This short paper documents a new C++ implementation of the same algorithms as used in [1]. We believe that the package can be well adequate for some feasibility studies of the high $p_T$ physics at LHC and at planned ppFCC. The further evolution of this code is planned.

[1] E. Richter-Wąs, *AcerDET: A Particle level fast simulation and reconstruction package for phenomenological studies on high p(T) physics at LHC*, hep-ph/0207355.

\textsuperscript{1}Package is available for the web page http://erichter.home.cern.ch/erichter/AcerDET.html
Title of the program: AcerDET version 2.0
Operating system: Linux
Programming language: C++
External libraries: HepMC, ROOT.
Size of the compressed distribution directory: about 25 kB.
Key words: Fast simulation, Physics at LHC.

Nature of physical problem: A particle level fast simulation and reconstruction package. The package provides, starting from the list of particles in the event, list of reconstructed jets, isolated electrons, muons and photons and reconstructed missing transverse energy. The algorithmic part is just rewritten from fortran version of the package AcerDET-1.0 [1]. The default input is generated event in format of HepMC structure [2], output is in form of ROOT file [4], containing tree with reconstructed objects and set of control histograms. Distribution version includes also example of the main program for execution with PYTHIA 8.2 generator [3]. Implemented set of parametrisations is not representing in details ATLAS or CMS detectors, some of them are simple and can be considered rather as place-holders for future adaptation of any detector. Nevertheless, we believe that the package will be well adequate for some feasibility studies on the high \(p_T\) physics at LHC.

[1]. E. Richter-Was, AcerDET: A Particle level fast simulation and reconstruction package for phenomenological studies on high \(p(T)\) physics at LHC, hep-ph/0207355; http://erichter.web.cern.ch/erichter/AcerDET.html
[2]. M. Dobbs and J.B. Hansen, HepMC a C++ Event Record for Monte Carlo Generators, Comput. Phys. Commun. 134 (2001) 41; http://lcgapp.cern.ch/project/simu/HepMC/
[3]. T. Sjstrand, S. Mrenna and P. Skands, A Brief Introduction to PYTHIA 8.1 Comput. Phys. Comm. 178 (2008) 852; T. Sjstrand, S. Mrenna and P. Skands, PYTHIA 6.4 Physics and Manual, JHEP05 (2006) 026; http://home.thep.lu.se/ torbjorn/pythia81html/Welcome.html
[4]. ROOT: Data analysis framework https://root.cern.ch/drupal/
1 Introduction

The potential of the LHC detectors for physics at high \( p_T \) is very rich, as first three years of data taking during so called Run I have shown.

The discovery of the Higgs boson, searches results for Supersymmetry particles, Exotic particles, New Vector Bosons are very impressive. All these is thanks to the high sensitivity of the detectors in terms of acceptance and identifying efficiencies to variety of signatures: photons, electrons, muons, multi-b-jets, \( \tau \)-jets, missing transverse energy.

Those high sensitivities allow to study very exclusive signatures; the discovery potential is limited in some cases by the rare background processes. It is evident, that the multi-jet and multi-b-jet production in association with known vector bosons, W and/or Z, or with top-quark pair is the the serious background to the several observables as well. The importance of effect beyond the leading order: effects coming from the finite width or angular spin correlations (eg. from the intermediate resonances decays) is becoming more evident. Limitations and complementarity of the matrix element and parton shower predictions for the diversity of signatures need to be investigated.

The package for particle-level simulation and reconstruction is one of the intermediate steps between simple parton-level analysis and very sophisticated and CPU consuming full detector simulation. The package provides, starting from list of particles in the event, list of reconstructed jets, isolated electrons, muons and photons and reconstructed missing transverse energy. It can serve for phenomenological feasibility studies on the prospects for observability of a given signature. Such package can be useful for the dedicated comparisons between matrix element and parton shower predictions. In that case, one can compare experimental signatures (reconstructed jets, leptons, photons) to quantify size of the discrepancies between different predictions in a straightforward way.

The Fortran version of presented here package \cite{1} has played such role since several years, more than 80 papers published in the last 10 years was using it or this purpose \cite{2}. Here, we present the new \texttt{C++} implementation, where all the algorithmic components have been preserved, changed is format of the input event. Now comonly accepted \texttt{HepMC} and the output format of \texttt{ROOT} tree with reconstructed objects and control histograms is introduced.

The package simulates some key features of the LHC detectors like ATLAS and CMS. It is based on the calorimetric energy deposition for jets reconstruction and tracks reconstruction for electrons and muons. It takes into account very high granularity of the electromagnetic calorimetry for the photon reconstruction. The missing transverse energy is calculated for the total energy balance of the reconstructed objects. The capability for the identification of b-jets and \( \tau \)-jets is also explored. Implemented set of parametrisations is not representing in details performance of neither ATLAS nor CMS detectors. Nevertheless, we believe that the package is still adequate for feasibility studies on the high \( p_T \) physics at LHC and offer starting option also for future FCC program.

The paper is organised as follows. In Section 2 we discuss (recall) algorithms used for objects reconstruction and show benchmarking distributions. Given the Higgs boson discovery at mass 125 GeV, benchmark which were published in \cite{1} are now updated to this value of teh Higgs mass. Also \texttt{Pythia 8.1} showering model used here are different than what was used for \cite{1}, hence some benchmark figures are different despite same algorithms used for fast simulation and reconstruction. Section 3 gives an outlook. We
don’t recall comparison with ATLAS performance numbers (Appendix A of [1]) as those are not updated as well with the better understanding of the detector using Run I data and are much more now detailed and analysis dependent. One should just to look for the publications related to the signature of interest. It was however checked that numbers from Appendix A of [1], are reproduced by AcerDET-2.0 code.

In the Appendixes A-F, we give more technical details concerning input parameters and output structure. In Appendix G we show control output logfile.

2 Simulation and reconstruction

Fully or partially generated event i.e. event generated including or not QED/QCD initial and final state radiation, fragmentation, hadronisation and decays of unstable particles can by analysed by this package. The list of the partons/particles of the generated event should be stored in the HepMC format. It is then copied into internally used vector of particles, with added few flags i.e. additional information regarding particles status and its type. This information is used by the AcerDET algorithms for event-be-event simulation and reconstruction.

Events simulation is limited to the following steps:

• Deposition of the particles energies in the calorimetric cells.
• Smearing of the energy of electrons, photons, muons with the parametrised resolutions.
• Smearing of the energy of hadronic clusters and not-clustered cells with the parametrised resolution.

Events reconstruction is limited to the following steps:

• Reconstruction of the calorimetric clusters.
• Verification of the isolation criteria for electrons/photons/muons.
• Rejection of clusters associated with electrons and photons.
• Acceptation of remaining clusters as hadronic jets and identification (labeling) of those associated with b-quarks, c-quarks, tau-leptons.
• Jets energy calibration.

There is no clear separation between the simulation and reconstruction parts in the structure of algorithms. A larger blocks (algorithms) may realise both tasks.

As a final result provided are four-momenta of reconstructed objects: electrons, photons, muons, labeled and calibrated jets and calculated is total missing transverse energy in analysed event.
2.1 Calorimetric clusters

The transverse energy of all undecayed particles stored in the event record, (InputRecord:Particles, except of muons, neutrinos and other invisible particles\(^2\) eg. the lightest SUSY particle, are summed up in the map of calorimetric cells with a given granularity in \((\eta \times \phi)\) coordinates (default: \(0.1 \times 0.1\) for \(|\eta| < 3.2\) and \(0.2 \times 0.2\) for \(|\eta| > 3.2\), with the calorimetric coverage up to \(|\eta| = 5.0\)). As an effect of the solenoidal magnetic field in the inner part of the detector we assume that the \(\phi\) position of charged particles with transverse momenta above the threshold (default: \(p_T > 0.5\) GeV) will be shifted as parametrised in function \texttt{Particle::foldPhi}. The contribution from all charged particles with transverse momenta below that threshold is neglected.

All calorimetric cells with the transverse energy greater than a given threshold (default: \(E_T > 1.5\) GeV) are taken as possible initiators of clusters. They are scanned in order of decreasing \(E_T\) to verify whether the total \(E_T\) summed over all cells in a cone \(\Delta R = \sqrt{\Delta^2 \eta + \Delta^2 \phi}\) exceeds the minimum required threshold for the reconstructed cluster (default \(E_T > 5\) GeV). Cells with deposited transverse energy below the threshold (default: \(E_T = 0\)) are not accounted for. As a coordinates \((\eta_{clu} \times \phi_{clu})\) of the reconstructed cluster taken are the coordinates of the bary-center of the cone weighted by the cells \(E_T\) for all cells inside the cone around the initiator cell. Information about energy deposition in cells is stored in OutputRecord:Cells.

All reconstructed clusters are stored in the container of ClusterData objects, OutputRecord:Clusters. Fig. 1 shows the \(\Delta \eta\) (left) and \(\Delta \phi\) (right) distribution between the reconstructed bary-center of particles falling within the geometrical cluster cone and the reconstructed cluster position.

![Histograms](hist10111.png)

![Histograms](hist10112.png)

Figure 1: The \(\Delta \eta\) (left) and \(\Delta \phi\) (right) distribution between the reconstructed bary-center of particles falling within the cluster cone and the reconstructed cluster position. Shown are results for generated \(gg \rightarrow H, H \rightarrow u\bar{u}\) process with \(m_H = 125\) GeV.

\(^2\)User may want to make any particle invisible to the detector. For this one should overwrite its \texttt{pdgId} code in the vector<Particle> to that specified for the invisible particles in acerdet.dat file.
2.2 Isolated muons

Algorithm reconstructing isolated muons uses information of the generated muons, reconstructed calorimetric clusters and the cells map.

Isolated muon candidates are searched for in the container InputRecord.particles. The inverse muon four-momentum is smeared according to the Gaussian resolution parametrised with function Smearing::forMuon (default: $\sigma = 0.05\% \cdot p_T$). The muon direction remains unsmeared.

For all muons which pass selection criteria in $p_T$ and $\eta$ (default: $p_T > 6$ GeV and $|\eta| < 2.5$ GeV), isolation criteria, in terms of the distance from calorimetric clusters and of maximum transverse energy deposition in cells in a cone around the muon, are then applied (defaults: separation by $\Delta R > 0.4$ from other clusters and $\sum E_T < 10$ GeV in a cone $\Delta R = 0.2$ around the muon). All muons passing the isolation criteria are stored in the container OutputRecord.Muons and those not passing are stored in OutputRecord.NonisolatedMuons.

As a control physics process the $gg \rightarrow H \rightarrow ZZ^* \rightarrow 4\mu$ production with the Higgs boson mass of 125 GeV is used. The default isolation selection has 97.8% efficiency for muons passing kinematical selection with $p_T^{\mu_1,\mu_2} > 20$ GeV and $p_T^{\mu_3,\mu_4} > 7$ GeV. As the predicted intrinsic width of the Higgs boson of this mass is very small, the resolution is completely dominated by the resolution assumed for the single muon reconstruction. Fig. 2 (left) shows the reconstructed distribution of the 4-muon system. The assumed single muon transverse momenta resolution of $\sigma = 0.05\% \cdot p_T$ leads to the $\sigma_m = 1.57$ GeV resolution for the invariant mass of the four-muon system originating from the $H \rightarrow ZZ^* \rightarrow 4\mu$ decay.

![Figure 2: Left: The multiplicity of hard-process isolated muons (left) and reconstructed isolated muons (right) for $gg \rightarrow H, H \rightarrow ZZ^* \rightarrow 4\mu$ events with $m_H = 125$ GeV.](image)

2.3 Isolated electrons

Algorithm reconstructing isolated electrons uses information of the generated electrons, reconstructed calorimetric clusters and the cells map.

Isolated electron candidates are searched for in the InputRecord.particles. The electron four-momentum is smeared according to the Gaussian resolution parametrised
with function `Smearing::forElectron` (default: \( \sigma = 12\%/\sqrt{E} \)). The electron direction remains unsmeared.

For all electrons which pass selection criteria in \( p_T \) and \( \eta \) (default: \( p_T > 5 \) GeV and \( |\eta| < 2.5 \) GeV), the associated reconstructed calorimeter cluster is identified (default: \( \Delta R_{e,\text{cluster}} < 0.1 \)). Electron isolation criteria, in terms of the distance from other clusters and of maximum transverse energy deposition in cells in a cone around the electron, are then applied (defaults: separation by \( \Delta R > 0.4 \) from other clusters and \( \sum E_T < 10 \) GeV in a cone \( \Delta R = 0.2 \) around the electron). All electrons passing the isolation criteria are stored in `OutputRecord.Electrons` and the clusters associated with them are removed from the `OutputRecord.Clusters`.

As a control physics process the \( gg \rightarrow H \rightarrow ZZ^* \rightarrow 4e \) production with the Higgs boson mass of 125 GeV is used. The default isolation selection has 95.2% efficiency for electrons passing kinematical selection with \( p_{e1, e2}^T > 20 \) GeV and \( p_{e3, e4}^T > 7 \) GeV. As the predicted intrinsic width of the Higgs boson of this mass is very small, the resolution is completely dominated by the resolution assumed for the single electron reconstruction. Fig. 3 (left) shows the reconstructed distribution of the 4-electron system. The assumed single electron energy resolution of \( \sigma = 12\%/\sqrt{E} \) leads to the \( \sigma_m = 1.26 \) GeV resolution for the reconstructed invariant mass of the four-electron system originating from the \( H \rightarrow ZZ^* \rightarrow 4e \) decay.

![Figure 3](hist10331)

**Figure 3:** *Left: The multiplicity of hard-process isolated electrons (left) and reconstructed isolated electrons (right) for \( gg \rightarrow H, H \rightarrow ZZ^* \rightarrow 4e \) events with \( m_H = 125 \) GeV.*

### 2.4 Isolated Photons

Algorithm reconstructing isolated photons uses information of the generated photons, reconstructed calorimetric clusters and the cells map.

Isolated photon candidates are searched for in the `InputRecord.particles`. The photon four-momentum is smeared according to the Gaussian resolution parametrised with function `Smearing::forPhoton` (default: \( \sigma = 10\%/\sqrt{E} \)). The photon direction remains unsmeared.

For all photons which pass selection criteria in \( p_T \) and \( \eta \) (default: \( p_T > 5 \) GeV and \( |\eta| < 2.5 \) GeV), the associated reconstructed calorimeter cluster is identified (default:
Photon isolation criteria, in terms of the distance from other clusters and of maximum transverse energy deposition in cells in a cone around the photon, are then applied (defaults: separation by $\Delta R > 0.4$ from other clusters and $\sum E_T < 10$ GeV in a cone $\Delta R = 0.2$ around the photon). All photons passing the isolation criteria are stored in `OutputRecord.Photons` and the clusters associated with them are removed from the `OutputRecord.Clusters`.

As a control physics process the Standard Model $gg \rightarrow H \rightarrow \gamma\gamma$ production with the Higgs boson mass of 125 GeV is used. The isolation selection has 98.0% efficiency for photons passing the kinematical selection of $p_{T1} > 40$ GeV and $p_{T2} > 25$ GeV. As the predicted intrinsic width of the Higgs boson of this mass is much below 1 GeV, the resolution of the reconstructed invariant mass of the di-photon system is completely dominated by the resolution assumed for the single photon reconstruction. Fig. 4 (left) shows the reconstructed distribution of the di-photon system of photons passing selection criteria. The assumed energy resolution of $\sigma = 10\%/\sqrt{E}$ leads to the $\sigma_m = 0.85$ GeV resolution for the reconstructed invariant mass of the di-photon system originating from the $H \rightarrow \gamma\gamma$ decay.

![Figure 4](image_url)

Figure 4: *Left:* The multiplicity of hard-process isolated photons (left) and reconstructed isolated photons (right) for $gg \rightarrow H, H \rightarrow \gamma\gamma$ events with $m_H = 125$ GeV.

### 2.5 Jets

Clusters which have not been selected as associated with electrons or photons are smeared with Gaussian resolution parametrised in function `Smearing::forHadron` (default: $\sigma = 50\%/\sqrt{E}$ and $100\%/\sqrt{E}$).
Figure 5: Multiplicity of jets (top), ΔR cone distance between reconstructed jet and barycenter of particles (middle-left) and hard-process parton (middle right). The ratio of $p_T^{jet}/p_T^{particles}$ (bottom-left) and $p_T^{jet}/p_T^{H\text{parton}}$ (bottom-right) for $gg \rightarrow H, H \rightarrow u\bar{u}$ and $m_H = 125$ GeV.
If the non-isolated muon falls into the cone of a cluster its 4-momenta is added to the cluster 4-momenta and the cluster direction is recalculated. The resulting clusters are classified as jets if their transverse momentum is greater than a given threshold (default: $p_T > 15$ GeV). They are removed from the \texttt{OutputRecord.Clusters} and stored in the common \texttt{OutputRecord.Jets}.

The jets reconstruction efficiencies and di-jet mass resolution have been studied using control physics process of the $gg \rightarrow H$ production with $m_H = 125$ GeV and forcing the Higgs boson decay into specific partons, namely $H \rightarrow u\bar{u}$, $H \rightarrow c\bar{c}$ and $H \rightarrow b\bar{b}$. We used also process $gg \rightarrow H \rightarrow \tau\tau$ for estimating tau-jet reconstruction efficiency (we forced tau-leptons decay into hadrons). For estimating reconstruction efficiency we consider only jets which have been reconstructed within the cone $\Delta R = 0.4$ from the primary parton (particle) and we require that the primary parton (particle) has passed the same kinematical selection as required for reconstructed jets.

2.5.1 Labeling

Very important for the physics at LHC are jets originating from b-quarks (so called b-jets) which can be identified in the detector using b-tagging technique (vertex or soft-lepton tags). The package labels a jet as a b-jet if it is reconstructed within a limited rapidity range (default: $|\Delta \eta| < 2.5$) and if a b-quark of a transverse momenta (after FSR) above the threshold (default: $p_T > 5$ GeV) is found within the cone (default: $\Delta R = 0.2$) around the axis of reconstructed jet. The similar criteria are used for labeling the c-jets.

Equivalently important are also jets originating from the hadronic $\tau$-decay (so called $\tau$-jets) which can be identified using dedicated algorithms. The package labels jet as a tau-jet if the hadronic decay product is relatively hard (default: $p_T^{\tau-had} > 10$ GeV), inside limited rapidity range (default: $|\eta| < 2.5$), dominates reconstructed jet transverse momenta (default: $p_T^{\tau-had}/p_T^{jet} > 0.9$), and is within the cone (default: $\Delta R_{jet,\tau-had} < 0.3$) around the axis of a jet.

Table 1 summarises the jets reconstruction+labeling efficiencies as obtained for the $WH, H \rightarrow b\bar{b}, c\bar{c}, u\bar{u}$ and $gg \rightarrow H \rightarrow \tau\tau$ events. Jets labeling is optional, can be switched off for b- and c-jets and/or separately for tau-jets (default: ON).

Table 1: Efficiency for jet reconstruction+labeling for different types of initial partons with $p_T^{parton} > 15$ GeV (required $p_T^{jet} > 15$ GeV). The rapidity coverage is limited to $|\eta| < 2.5$. The $\Delta R_{cone} = 0.4$ is used for cluster reconstruction and $\Delta R_{cone} = 0.2$ is used for matching criteria. The $gg \rightarrow H, H \rightarrow b\bar{b}, c\bar{c}, u\bar{u}$ and $gg \rightarrow H \rightarrow \tau\tau$ processes were generated with $m_H = 125$ GeV. In case of tau-jets only hadronic tau decays were generated.

| Parton type | Reconstruction + Labeling |
|-------------|---------------------------|
| u-quark     | 95%                       |
| b-quark     | 81%                       |
| c-quark     | 87%                       |
| tau-jet     | 80%                       |
Figure 6: Multiplicity of b-jets (top left) and hard-process b-quarks (top-right), $\Delta R$ cone distance between b-labeled jet and hard-process b-quark (bottom-left); the ratio of $p_T^{\text{jet}}/p_T^{H\text{b-quarks}}$ (bottom-right). Distributions are shown for $gg \to H, H \to b\bar{b}$ and $m_H = 125$ GeV.
Figure 7: Multiplicity of tau-jets (top left) and hadronic tau (top-right), $\Delta R$ cone distance between tau-labeled jet and hard-process tau-had (bottom-left); the ratio of $p_T^{\text{tau-jet}} / p_T^{\text{tau-had}}$ (bottom-right). Distributions are shown for $gg \rightarrow H$, $H \rightarrow \tau\tau$ and $m_H = 125$ GeV.

2.5.2 Calibration

The reconstructed jets four-momenta need to be corrected for the out-cone energy loss (cascade outside the jet-cone) and for the loss of the particles escaping detection (those below threshold at $p_T = 0.5$ GeV, neutrinos, invisible particles, muons outside acceptance range or below the observability threshold). Such correction, called calibration, can be performed on the statistical basis only. The single default calibration function (the same for any type of jets), as a function of transverse momenta of reconstructed jet, $p_T^{\text{jet}}$, is provided in the package. The calibration algorithm corrects jets four-momenta without altering their direction. Calibration can be switched off (default: ON).

The quality of the calibration algorithm can be verified by monitoring the ratio of $p_T^{b-\text{quark}} / p_T^{b-\text{jet}}$, taking into account a hard-process quark which originates a given jet. One can note, (see Fig. 7, bottom plots) that the implemented calibration function has a tendency to undercalibrate b-jets while calibrates reasonably well u-jets. We can observe also rather large tail in the $p_T^{\text{jet}} / p_T^{b-\text{quark}}$ distribution, caused by the semileptonic b-quarks decays and larger spread of the cascading particles than in the case of light jets.

As an effect of the hadronisation and cascading decays, the expected resolution for the resonance reconstruction in the hadronic channels will be much worse than in the leptonic
ones. The precision for reconstructing the peak position of the invariant mass of the di-jet system will relay on the precision of the calibration procedure.

2.6 Missing transverse energy

The missing transverse energy is calculated by summing up transverse momenta of identified isolated photons, electrons and muons, of jets and clusters not accepted as jets and of non-isolated muons not added to any jet. Finally, the transverse energies deposited in cells not used for clusters reconstruction are also included in the total sum. Transverse energies deposited in unused cells are smeared with the same energy resolution function as for jets, and cells with deposited transverse energy below a given threshold (default: 0 GeV) are excluded from the sum. From the calculation of the total sum $E_T^{\text{obs}}$, the missing transverse energy is obtained, $E_T^{\text{miss}} = -E_T^{\text{obs}}$ as well as the missing transverse momentum components $p_x^{\text{miss}} = -p_x^{\text{obs}}$, $p_y^{\text{miss}} = -p_y^{\text{obs}}$. The total calorimeter transverse energy, $\sum E_{T\text{calo}}$, is calculated as the sum of all the above transverse energies except that of muons. Please note, that missing transverse energy is calculated from the energy balance before jets calibration is performed, as the possible out-cone energy loss is already taken into account by summing up energy deposition of unused cells/clusters.

Fig. 8 shows the resolution of the transverse missing energy obtained for the di-jet events generated with the transverse momenta of the hard process above 17 GeV.

Figure 8: The reconstructed missing transverse energy (left) and transverse momenta on neutrino in $W \rightarrow e\nu$ events.

2.7 Additional efficiencies

The algorithms of the AcerDET package are not correcting for inefficiencies of photon, electron and muon reconstruction and identification. To be more realistic, one should apply a weighting factor of 70%-90% for each isolated lepton used in the analysis and of 80% for each isolated photon.

The package is also not correcting for tagging-efficiencies, namely the labeling procedure is not equivalent to the b- and tau-jet identification in the experiment. One can assume b-tagging efficiency of 60% per b-labeled jet with mistagging probability of 10%
for c-labeled jet and 1% for the light jet. For the tau-jets using efficiency of 50% (per tau-labelled jet) and 5 - 10 % mistagging probability for other jets could be a reasonable assumptions. One should be well aware that what proposed above represents quite crude estimates.

The package is also not correcting for trigger efficiencies which has to be applied in addition if a given reconstructed object is foreseen to trigger an event.

2.8 OUTPUT format

By the end of the simulation and reconstruction algorithm, reconstructed entities: photons, electrons, muons, jets, transverse missing energy are available as collections of objects in the OutputRecord. Provided is algorithm to store this information in the ROOT [11] tree. However, the user might decide to use his preferred data-base technology for storing output from the simulation and reconstruction algorithms.

3 Outlook

We presented an update from Fortran to C++ of a package which can be useful for several phenomenological studies on the high $p_T$ physics at LHC. As examples of applications some recent publications which have been using its fortran version AcerDET-1.0 [1] are papers eg. [14, 15, 16, 17] ( for the more complete list see link [2] ).

It is not the aim of the package to represent in details performance neither of ATLAS nor of CMS detectors, nevertheless some global features of these would be reproduced well. We have presented some benchmark results in Section 2. In particular we believe that the analyses performed with the package for physics at LHC will be more realistic than parton-level studies alone.

The package allows also for flexible adjusting of key parameters which characterise features of any detector be it for LHC or for future ILC or FFC experiments.

Acknowledgments

This work on AcerDET-1.0 was inspired by the several years of ERW involvement in the activity of the Physics Working Groups of the ATLAS Collaboration. ERW grateful to all colleagues for a very creative atmosphere. In particular, for several suggestions and inspiring discussions to, Daniel Froidevaux, who some years ago initiated and guided her work on the first version of the fast simulation package. The AcerDET-2.0 represents continuation of this project in new software environment.

The work of P. Mikos and E. Richter-Was is supported in part by the Polish National Centre of Science, Grant No. DEC-2011/03/B/ST2/00220. Work of E. Richter-Was is also supported in part by the Executive Research Agency (REA) of the European Commission under the Grant Agreement PITN-GA-2012-316704 (HiggsTools).
References

[1] E. Richter-Was, *AcerDET: A Particle level fast simulation and reconstruction package for phenomenological studies on high p(T) physics at LHC*, hep-ph/0207355.

[2] SPIRES database, citations list to [1] see https://inspirehep.net/search?ln=en&p=refersto%3Arecid%3A591605&sf=earliestdate

[3] ATLAS Collaboration, ATLAS Detector and Physics Performance TDR, ATLAS TDR 15, CERN/LHCC/99-15, 25 May 1999.

[4] E. Richter-Was, D. Froidevaux and L. Poggioli, ATLAS Internal Note ATL-PHYS-98-131 (1998).

[5] B. Kersevan and E. Richter-Was, *The Monte Carlo event generator AcerMC version 1.0 with interfaces to PYTHIA 6.2 and HERWIG 6.3*, hep-ph/0201302, Comp. Phys. Commun. in print.

[6] B. Kersevan, M. Malawski and E. Richter-Was, *Prospects for observing an invisibly decaying Higgs boson in the t ¯tH production at the LHC*, hep-ph/0207014.

[7] B. Kersevan and E. Richter-Was, *What is the Wb ¯b, Zb ¯b and t ¯tb ¯b background at LHC*, hep-ph/0203148, JHEP in print.

[8] CERN program Library Long Writeups Y250. HBOOK Statistical Analysis and Histogramming, Reference Manual.

[9] T. Sjostrand et al., *High energy physics generation with PYTHIA 6.2*, eprint hep-ph/0108264, LU-TP 01-21, August 2001.

[10] G. Marchesini et al., Comp. Phys. Commun. 67 (1992) 465, G. Corcella et al., JHEP 0101 (2001) 010.

[11] ROOT: Data analysis framework
https://root.cern.ch/drupal/

[12] T. Sjstrand, S. Mrenna and P. Skands, *A Brief Introduction to PYTHIA 8.1* Comput. Phys. Comm. 178 (2008) 852; T. Sjstrand, S. Mrenna and P. Skands, *PYTHIA 6.4 Physics and Manual*, JHEP05 (2006) 026;
http://home.thep.lu.se/~torbjorn/pythia81html/Welcome.html

[13] M. Dobbs and J.B. Hansen, *HepMC a C++ Event Record for Monte Carlo Generators*, Comput. Phys. Commun. 134 (2001) 41;
http://lcgapp.cern.ch/project/simu/HepMC/

[14] N. Nagata, H. Otono and S. Shirai, *Probing Bino-Gluino Coannihilation at LHC*, arXiv:1504.00504

[15] S. Schaetzel, *Boosted Top Quarks and Jet Structure*, arXiv:1403.5176.
[16] S. Y. Choi, M. M. Muhlleitner and P. M. Zerwas, *Theoretical Basis of Higgs-Spin Analysis in $H \rightarrow \gamma\gamma$ and $Z\gamma$ Decays*, Phys.Lett. B718 (2013) 1031-1035, arXiv:1209.5268.

[17] J. A. Aguilar-Saavedra, F. R. Joaquim, *Measuring heavy neutrino couplings at the LHC*, Phys.Rev. D86 (2012) 073005.
A General informations

The simulation and reconstruction algorithm is executed by a call to the routine AcerDET.analyseRecord. The events which is going to be processed should be stored in the InputRecord.

The convention for the particles status, mother-daughter relations, particles codes, etc. should be the same as in the HepMC standard.

The input/output logical identifiers should be defined in configFileName.

The package reads single input file acerdet.dat which contains parameters for events simulation and reconstruction and write out single control output file acerdet.out. If initialised by the user in the main program, control histograms and ntuple with reconstructed events will be stored in the XXX.root file, where XXX stands for file which configures generator used for generating events. In the distributed example the Pythia 8.1 is used.

A.1 Class AcerDET

This is the main class, called to execute simulation and reconstruction algorithms. The following methods are implemented:

- AcerDET constructor – initialisation, which should be called before the first event is processed.
- AcerDET::analyseRecord – simulation and reconstruction, should be called event by event.
- AcerDET destructor – finalisation, should be called after last event is processed.

The AcerDET::analyseRecord invokes other methods: analyse_Cell, analyse_Cluster, analyse_Muon, analyse_Electron, analyse_Photon, analyse_Jet, analyse_Mis, analyse_BJet, analyse_CJet, analyse_Tau, analyse_Calibration. The order in which methods are invoked should not be changed.

The AcerDET::printInfo() invokes printing information on the configurations used for individual methods and AcerDET::printResults() summary information on the reconstructed objects.

A.2 Interfaces to Event Generators

The event, which is going to be processed, should be stored in the HepMC format. In the source code of the program provided are methods to translate this format into internal event structure, vector of Particles stored in InputRecord and to interpret status and pdgId codes of the particles.

The following internal types are introduced, based on the information available in the HepMC conversion of Pythia 8.1 event record.

- ParticleType
  - PT_CJET - particle with pdgId code = -4, 4
  - PT_BJET - particle with pdgId code = -5, 5
  - PT_ELECTRON - particle with pdgId code = -11, 11
- PT_NEUTRINO_ELE - particle with pdgId code = -12, 12
- PT_MUON - particle with pdgId code = -13, 13
- PT_NEUTRINO_MUON - particle with pdgId code = -14, 14
- PT_TAU - particle with pdgId code = -15, 15
- PT_NEUTRINO_TAU - particle with pdgId code = -16, 16
- PT_PHOTON - particle with pdgId code = 22
- PT_BOSON_Z - particle with pdgId code = 23
- PT_BOSON_W - particle with pdgId code = -24, 24
- PT_BOSON_H - particle with pdgId code = 25
- PT_UNKNOWN - other

- ParticleStatus
  - PS_BEAM - corresponding HepMC: part− >is_beam() = true;
  - PS_FINAL - corresponding HepMC: part− >is_undecayed() = true;
  - PS_DECAYED - corresponding HepMC: part− >has_undecayed() = true;
  - PS_HISTORY - corresponding HepMC: part− >is_undecayed() = true;
  - PS_CASCADE_QUARK - corresponding HepMC: abs(part− >status()) ≥=30;
  - PS_HP_QUARK - corresponding HepMC: abs(part− >status()) = 20 - 29;
  - PS_NULL - other;

While ParticleStatus and ParticleType become an attribute of the object Particle, the method AcerDet::core::isHardProcess is also provided to decide if a given particle is from hard process. This method (so far) relies on information of the particle origin, i.e. type of the mother particle, but more refined procedure can be implemented there as well.

A.3 External calling sequence

The following calling sequence should be provided in the main program (see demo.cpp):

- initialise generator
- initialise and configure AcerDET
- initialise root tree and histogram manager
- start even loop
  - generate new event
  - convert to HepMC format (if needed)
  - process with AcerDET
  - fill root tree with reconstructed objects
- write tree and histograms into file, write information into log file.
Invoking method which fill root tree is optional. User however may decide to skip this part, or implement different output format.

In general, if user do not wish, the dependencies on ROOT could be easily removed. It requires linking into executable the respective alternative library and providing very simple conversion package where the existing calls to ROOT functions for histograming are used to fill information into the user’s preferred ones.

A.4 Execution sequence

After the initialisation phase, the event by event execution sequence is a following one:

- Map of the cells energy deposition is created: \texttt{analyse\_Cell}.
- Calorimetric clusters are reconstructed: \texttt{analyse\_Cluster}.
- Isolated and non-isolated muons are reconstructed: \texttt{analyse\_Muon}.
- Isolated electrons are reconstructed: \texttt{analyse\_Electron}.
- Isolated photons are reconstructed: \texttt{analyse\_Photon}.
- The remaining calorimetric clusters are identified as jets: \texttt{analyse\_Jet}.
- Missing transverse is calculated for the reconstructed event: \texttt{analyse\_Mis}.
- Optionally, if specified in the acerdet.dat file, algorithms for jets labeling and calibration of jets are executed (default=ON): \texttt{analyse\_BJet}, \texttt{analyse\_CJet}, \texttt{analyse\_Tau}, \texttt{analyse\_Calibration}
- Reconstructed event is stored in the final record: \texttt{OutputRecord}.

The respective sequence of calls is executed in the \texttt{AcerDET::analyseRecord}.

A.5 Structure of the distribution version

The distribution version consists of the source code of the \texttt{AcerDET} and example of the main program for execution with \texttt{PYTHIA 8.1} generator.
Figure 9: Structure of AcerDET package.

AcerDET is designed to be an universal tool. It does not depend on any external library (except C++ STL). In order to provide functionalities not built-in directly in AcerDET, it provides a set of interfaces.

Instantiation of AcerDET requires providing instances of such interfaces. Because of separation between analyse logic and data structures AcerDET might work with a various number of external libraries.

The AcerDET package provides a set of default implementations for its interfaces, grouped in AcerDET::external subpackage containing:

- **Root HistogramManager** – a default implementation of IHistogramManager interface. Provides methods for storing weighted data in named histograms. For more details see AcerDET::core::IHistogramManager.

- **Pythia8_ParticleDataProviderFactory** – a default implementation of IParticleDataProviderFactory interface. Represents a particle types database, providing particle charge, name, etc. For more details see AcerDET::core::ParticleDataProvider.

- **HepMC_InputConverter** – static class converting HepMC event record to AcerDET internal representation of input record. For more details see AcerDET::io::InputRecord.

- **Root_NTupleManager** – wrapper for ROOT’s NTuple. Provides methods for storing and saving weighted events. The demo uses it like an external database.

The acerdet.dat file (configuration file for AcerDET package) resides in main directory acerdet.dat. Source code resides in src which has one level deeper internal structure (see
Interfases to external libraries are in directory external. The library will be created in src directory, provided is also example of the main program demo.cpp to execute AcerDET algorithms with PYTHIA 8.1 generator:

- Structure of directory acerdet

```
-rw-rw-r-- 1 erichter erichter 3703 Jun 10 16:07 acerdet.dat
-rw-rw-r-- 1 erichter erichter 65 Jun 10 16:07 common.inc
drwxrwxr-x 2 erichter erichter 4096 Jun 12 10:31 conf
-rw-rw-r-- 1 erichter erichter 2719 Jun 10 17:25 demo.cpp
-rw-rw-r-- 1 erichter erichter 590 Jun 10 16:07 demoCreateConfig.cpp
drwxrwxr-x 3 erichter erichter 4096 Jun 12 10:31 external
-rw-rw-r-- 1 erichter erichter 861 Jun 10 16:08 external.inc
drwxrwxr-x 8 erichter erichter 4096 Jun 12 17:55 .git
-rw-rw-r-- 1 erichter erichter 74 Jun 10 16:09 .gitignore
-rw-rw-r-- 1 erichter erichter 848 Jun 10 16:07 Makefile
-rw-rw-r-- 1 erichter erichter 204 Jun 10 16:08 path.inc
-rw-rw-r-- 1 erichter erichter 274 Jun 10 16:07 README
-rw-rw-r-- 1 erichter erichter 69 Jun 10 16:07 setup.sh
drwxrwxr-x 6 erichter erichter 4096 Jun 12 10:31 src
```

- Structure of directory acerdet/src (after compilation using 'make')

```
-rw-rw-r-- 1 erichter erichter 4078 Jun 10 17:25 AcerDET.cpp
-rw-rw-r-- 1 erichter erichter 3994 Jun 10 17:25 AcerDET.h
-rw-rw-r-- 1 erichter erichter 264412 Jun 10 17:25 AcerDET.o
drwxrwxr-x 2 erichter erichter 4096 Jun 12 10:31 analyse
drwxrwxr-x 2 erichter erichter 4096 Jun 10 17:25 conf
drwxrwxr-x 2 erichter erichter 4096 Jun 11 19:14 core
-rw-rw-r-- 1 erichter erichter 99229 Jun 10 16:08 doxygen.config
drwxrwxr-x 2 erichter erichter 4096 Jun 10 17:25 io
-rw-rw-r-- 1 erichter erichter 5538158 Jun 12 10:31 libAcerDET.a
drwxrwxr-x 1 erichter erichter 3803523 Jun 12 10:31 libAcerDET.so
-rw-rw-r-- 1 erichter erichter 1689 Jun 10 16:07 Makefile
-rw-rw-r-- 1 erichter erichter 132 Jun 10 16:08 path.inc
-rw-rw-r-- 1 erichter erichter 252 Jun 10 16:07 README
```

To execute the package following actions should be taken:

- In subdirectory acerdet edit files external.inc and path.inc. Then type: `make`. It will compile the code and create the src/libAcerDET.a and src/libAcerDET.so. It will create also demo executable demo.exe

- To execute, type
  ```
  ./demo.exe conf/XXX.conf nEvent
  ```
  where conf/XXX.conf stands for file configuring generated process and nEvent is a integer number of required events to be generated.

- Output will be stored in file conf/XXX.conf.root

### A.6 Development

Regarding modifications in AcerDET algorithms, package users are able to develop own extensions to our main algorithm. As it was shown in previous section AcerDET provides a set of interfaces to implement in order to use the package. AcerDET::external sub-package contains default implementations of those interfaces, but user may develop his
own implementations. For instance if someone wants to use other histogram manager, it is enough to create new class inheriting from `AcerDET::core::IHistogramManager` and pass it’s instance when create new `AcerDET` instance (as it is shown in `demo.cpp`).

```cpp
const std::string configFileName = "acerdet.dat";
Configuration configuration = Configuration::fromFile( configFileName );
IParticleDataProviderFactory *pdpFactory =
new external::Pythia8_ParticleDataProviderFactory();
IHistogramManager *histoManager =
new external::Root_HistogramManager(); // HERE USE OWN INSTANCE
external::Root_NTupleManager nTuple;

AcerDET acerDet(
    configuration,
    pdpFactory,
    histoManager
);
```

Analoguously user may use own instance of `IParticleDataProviderFactory`. ROOT NTuple is used in demo like na external database, so using other databases is possible in similair way. Distributed demo version uses `HepMC` as input data standard, while `AcerDET` uses its own input format. Default conversion algorithm is placed in `AcerDET::external::HepMCInputConverter`. In order to use other input format, similair converter to `AcerDET` input format is required.
## B List of input parameters: acerdet.dat file

| Parameter                        | Value   | Description                                                                 |
|----------------------------------|---------|-----------------------------------------------------------------------------|
| Flag.HistogramID                | 10000   | .id for histograms                                                          |
| Flag.Smearing                   | 1       | .smearing on=1, off=0                                                       |
| Flag.B-Field                    | 1       | .B-field on=1, off=0                                                        |
| Flag.SUSY_LSP_Particle          | 66      | .code for SUSY LSP particle                                                 |
| Flag.BC-JetsLabeling            | 1       | .b- and c-jets labeling on=1, off=0                                         |
| Flag.Tau-JetsLabeling           | 1       | .tau-jets labeling on=1, off=0                                              |
| Flag.JetCalibration             | 1       | .jet calibration on=1, off=0                                                |
| Cell.RapidityCoverage           | 5.000   | .rapidity coverage                                                          |
| Cell.MinpT                      | 0.500   | .min p_T for B-field                                                        |
| Cell.MinEt                      | 0.000   | .min E_T for cell                                                           |
| Cell.EtaTransition              | 3.200   | .eta transition in cells granularity                                        |
| Cell.GranularityEta             | 0.100   | .granularity in eta (within Cell.EtaTransition), 2x outside                 |
| Cell.GranularityPhi             | 0.100   | .granularity in phi (within Cell.EtaTransition), 2x outside                 |
| Cluster.MinEt                   | 5.000   | .minimum E_T for cluster                                                    |
| Cluster.ConeR                   | 0.400   | .cone R for clustering                                                      |
| Cluster.RapidityCoverage        | 5.000   | .rapidity coverage                                                          |
| Cluster.MinEtInit               | 1.500   | .min E_T for cluster initiator                                              |
| Muon.MinMomenta                 | 6.000   | .minimum muon-momenta to be detected                                        |
| Muon.MaxEta                     | 2.500   | .maximum muon eta to be detected                                            |
| Muon.MinIsolRlj                 | 0.400   | .min R_lj for muon-isolation                                               |
| Muon.ConE                       | 0.200   | .R_cone for energy deposition                                              |
| Muon.MaxEnergy                  | 10.000  | .max energy deposition for isol                                              |
| Photon.MinMomenta               | 5.000   | .minimum photon-momenta to be isol                                          |
| Photon.MaxEta                   | 2.500   | .maximum photon eta to be isol                                              |
| Photon.MinJetsRlj               | 0.150   | .min R_lj for photon-jet                                                    |
| Photon.MinIsolRlj               | 0.400   | .min R_lj for photon-isolation                                              |
| Photon.ConE                     | 0.200   | .R_cone for energy deposition                                              |
| Photon.MaxEnergy                | 10.000  | .max energy deposition for isol                                              |
| Electron.MinMomenta             | 5.000   | .minimum electron-momenta to be isol                                        |
| Electron.MaxEta                 | 2.500   | .maximum electron eta to be isol                                             |
| Electron.MinJetsRlj             | 0.150   | .min R_lj for electron-jet                                                  |
| Electron.MinIsolRlj             | 0.400   | .min R_lj for electron-isolation                                            |
| Electron.ConE                   | 0.200   | .R_cone for energy deposition                                              |
| Electron.MaxEnergy              | 10.000  | .max energy deposition for isol                                              |
| Jets.MinEnergy                  | 10.000  | .jets energy_min threshold                                                  |
| Jets.RapidityCoverage           | 5.000   | .rapidity coverage for jets                                                |
| BJets.MinMomenta                | 5.000   | .minimum b-quark pT (after FSR) momenta for b-jet label                     |
| BJets.MaxEta                    | 2.500   | .maximum b-quark eta for b-jet label                                        |
| BJets.MaxRbj                    | 0.200   | .max R_bj for b-jet label                                                   |
| CJets.MinMomenta                | 5.000   | .minimum c-quark pT (after FSR) momenta for c-jet label                     |
| CJets.MaxEta                    | 2.500   | .maximum c-quark eta for c-jet label                                        |
| CJets.MaxRcj                    | 0.200   | .max R_cj for c-jet label                                                   |
| Tau.MinpT                       | 10.000  | .minimum tau-had pT for tau-jet label                                       |
| Tau.MaxEta                      | 2.500   | .maximum tau-eta for tau-jet label                                          |
| Tau.MinR                        | 0.300   | .max R_taj for tau-jet                                                      |
| Tau.MaxR                        | 0.900   | .max R_taj for tau-jet                                                      |
| Misc.MinEt                      | 0.000   | .min E_T for energy in cell to count unused cell                            |
C  Reconstructed entities

Reconstructed entities are stored as vectors of ObjectData (for isolated photon, muons, electrons), as CellData (for cells), as JetData (for jets) and MisData for missing energy. Objects in each category of ObjectData and JetData are ordered with the decreasing transverse momenta.

C.1  ObjectData

For ObjectData stored is information of the pdg_id, so the information of the charge is preserved, eta, phi and pT which allows to recalculate full kinematics assuming that mass is equal to zero, and the internal flag alreadyUsed needed for calculating missing tranverse energy for the event.

C.2  JetData

For JetData stored is information on the type which flags if a given jet is b-quark tagged, c-quark tagged or matched with hadronic-tau decays. The angular kinematic variables eta, phi and eta_rec, phi_rec and pT.

C.3  MisData

For MisData stored is information on reconstructed momenta both transverse components of electrons, muons, photons, clusters and jets, PXSUM, PYSUM, on reconstructed total transverse components i.e. after adding non-clustered cells PXREC, PYREC, sum of transverse momenta components, the reconstructed transverse momenta SUMET, the transverse components of momenta of neutrinos and invisible particles (as defined by the user) in the event PXNUES, PYNUES and finally sum of the total transverse energy components deposited in the calorimeter PXXCALO, PYYCALO.

D  Content of the ACDTree

Reconstructed objects and, for convenience of the analysis, also partial information on generated event are stored in the format of ROOT tree, the ACDTree.

- Generator info: Event weight and identifier for generated process.
- Generated particles: stored are those participating in the hard-scattering, which is defined using isHardProcess method and flags: PS_Beam, PS_HISTORY. Stored are 4-momenta, and pdg_id code.
- Isolated photons, electrons, muons: stored are 4-momenta, and pdg_id code.
- Jets: stored are 4-momenta, the pdg_id code indicate if jet was labeled as -batteg, c-tagged or hadronic-decay of tau lepton.
- Missing energy: stored are transverse momenta components of missing energy, invisible energy and energy reconstructed in the calorimeter.
E  Parametrisation for energy/momenta resolution

E.1 Smearing::forPhoton

The parametrisation for photon energy resolution assumes only energy dependence and the Gaussian smearing with $10\% / \sqrt{E_\gamma}$ resolution.

$$E_\gamma^{\text{smeared}} = E_\gamma^{\text{true}} \cdot (1 + r_n \cdot \frac{0.10}{\sqrt{E_\gamma^{\text{true}}}}),$$  \hspace{1cm} (1)

Where $r_n$ is the random number generated according to the Gaussian distribution (normal distribution from Standard C++ library). All 4-momenta components of the photon are smeared with the same resolution so the direction of the photon is not altered.

E.2 Smearing::forElectron

The parametrisation for electron energy resolution assumes only energy dependence and the Gaussian smearing with $12\% / \sqrt{E_e}$ resolution.

$$E_e^{\text{smeared}} = E_e^{\text{true}} \cdot (1 + r_n \cdot \frac{0.12}{\sqrt{E_e^{\text{true}}}}),$$  \hspace{1cm} (2)

Where $r_n$ is the random number generated according to the Gaussian distribution (normal distribution from Standard C++ library). All 4-momenta components of the electron are smeared with the same resolution so the direction of the electron is not altered.

E.3 Smearing::forHadron

The parametrisation for clusters momenta resolution assumes only energy dependence and Gaussian smearing with $50\% / \sqrt{E_{\text{clus}}}$ or $100\% / \sqrt{E_{\text{clus}}}$ resolution. The transition region, $|\eta^{\text{clus}}| = \text{CALOTH}$ is the same as the transition of the cells granularity.

For $|\eta^{\text{clus}}| < \text{CALOTH}$:

$$E_{\text{clus}}^{\text{smeared}} = E_{\text{clus}}^{\text{true}} \cdot (1 + r_n \cdot \frac{0.50}{\sqrt{E_{\text{clus}}^{\text{true}}}}),$$  \hspace{1cm} (3)

For $|\eta^{\text{clus}}| > \text{CALOTH}$:

$$E_{\text{clus}}^{\text{smeared}} = E_{\text{clus}}^{\text{true}} \cdot (1 + r_n \cdot \frac{1.00}{\sqrt{E_{\text{clus}}^{\text{true}}}}),$$  \hspace{1cm} (4)

Where $r_n$ is the random number generated according to the Gaussian distribution (normal distribution from Standard C++ library). All 4-momenta components of the muon are smeared with the same resolution so the direction of the muon is not altered.
E.4 Smearing::forMuon

The parametrisation for muon momenta resolution assumes only transverse momenta dependence and Gaussian smearing with $0.0005 \cdot p_T^\mu$ resolution.

$$p_T^{\mu \text{smear}} = \frac{p_T^\mu}{1 + r_n \cdot 0.0005 \cdot p_T^{\mu \text{true}}}.$$  (5)

Where $r_n$ is the random number generated according to the Gaussian distribution (normal distribution from Standard C++ library). All 4-momenta components of the muon are smeared with the same resolution so the direction of the muon is not altered.

E.5 Particle::foldPhi

The effect of the magnetic field is included by simple shifting the $\phi$ position of the charged particles respectively to its transverse momenta, parametrised as following:

$$\delta \phi = 0.5/p_T^{\text{part}}.$$  (6)

The $\delta \phi$ is calculated in radians and $p_T^{\text{part}}$ is given in $GeV$. The sign of the $\delta \phi$ is the same as the sign of the particle charge. Charged particles with $p_T^{\text{part}} < 0.5$ GeV are assumed to be looping in the detector and not depositing energy in the calorimeter.

F Some formulas

We work with the assumptions of massless reconstructed objects. The following relations were used to translate between $(p_T, \eta, \phi)$ coordinates and four-momenta $(p_x, p_y, p_z, E)$.

$$p_x = p_T \cdot \cos(\phi)$$  (7)

$$p_y = p_T \cdot \sin(\phi)$$  (8)

$$p_z = p_T \cdot \cosh(\eta)$$  (9)

$$E = p_T \cdot \sinh(\eta)$$  (10)

$$p_T = \sqrt{p_x^2 + p_y^2}$$  (11)

$$\eta = \text{sign}(\ln(\sqrt{p_T^2 + p_z^2 + |p_z|}/p_T), p_z)$$  (12)

$$\phi = \text{asinh}(p_y/\sqrt{p_x^2 + p_y^2})$$  (13)
### G Output content

#### G.1 Output ACDTree content: acerdet.ntup file

The content of the ntuple is exactly as described in the previous section. As an auxiliary info, within the stored information, could be provided code on the generated process, IDPROC.

| *Tree :ACDTree : ACDTree* | *Entries : 100000 : Total = 176704219 bytes File Size = 83438909* |
|----------------------------|--------------------------------------------------------------------------------------------------|
| *Tree compression factor = 2.12* |                                                                                                  |

| *Br 0 :ProcessID : ProcessID/I* | *Entries : 100000 : Total Size= 785597 bytes File Size = 401027* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96* | |

| *Br 1 :part_n : part_n/I* | *Entries : 100000 : Total Size= 785546 bytes File Size = 400988* |
|----------------------------|------------------------------------------------------------------|
| *Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96* | |

| *Br 2 :part_pdgId : vector<int>* | *Entries : 100000 : Total Size= 14579602 bytes File Size = 708584* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 3 :part_mother_pdgId : vector<int>* | *Entries : 100000 : Total Size= 14581275 bytes File Size = 7088229* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 4 :part_px : vector<float>* | *Entries : 100000 : Total Size= 14578885 bytes File Size = 7085879* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 5 :part_py : vector<float>* | *Entries : 100000 : Total Size= 14578885 bytes File Size = 7085879* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 6 :part_pz : vector<float>* | *Entries : 100000 : Total Size= 14578885 bytes File Size = 7085879* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 7 :part_E : vector<float>* | *Entries : 100000 : Total Size= 14578646 bytes File Size = 7085644* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 235 : Basket Size= 32000 bytes Compression= 2.06* | |

| *Br 8 :ele_n : ele_n/I* | *Entries : 100000 : Total Size= 785529 bytes File Size = 400975* |
|-------------------------|------------------------------------------------------------------|
| *Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96* | |

| *Br 9 :ele_pdgId : vector<int>* | *Entries : 100000 : Total Size= 3204969 bytes File Size = 1411515* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27* | |

| *Br 10 :ele_px : vector<float>* | *Entries : 100000 : Total Size= 3204786 bytes File Size = 1411344* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27* | |

| *Br 11 :ele_py : vector<float>* | *Entries : 100000 : Total Size= 3204786 bytes File Size = 1411344* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27* | |

| *Br 12 :ele_pz : vector<float>* | *Entries : 100000 : Total Size= 3204786 bytes File Size = 1411344* |
|--------------------------------|------------------------------------------------------------------|
| *Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27* | |
• Br 13 : ele_E : vector<float>
  Entries : 100000 : Total Size= 3204725 bytes File Size = 1411287
  Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27

• Br 14 : muo_n : muo_n/I
  Entries : 100000 : Total Size= 785529 bytes File Size = 400975
  Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96

• Br 15 : muo_pdgId : vector<int>
  Entries : 100000 : Total Size= 3204997 bytes File Size = 1411543
  Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27

• Br 16 : muo_px : vector<float>
  Entries : 100000 : Total Size= 3204814 bytes File Size = 1411372
  Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27

• Br 17 : muo_py : vector<float>
  Entries : 100000 : Total Size= 3204814 bytes File Size = 1411372
  Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27

• Br 18 : muo_pz : vector<float>
  Entries : 100000 : Total Size= 3204753 bytes File Size = 1411315
  Baskets : 57 : Basket Size= 32000 bytes Compression= 2.27

• Br 19 : pho_n : pho_n/I
  Entries : 100000 : Total Size= 785529 bytes File Size = 400975
  Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96

• Br 20 : pho_pdgId : vector<int>
  Entries : 100000 : Total Size= 4558940 bytes File Size = 2093066
  Baskets : 78 : Basket Size= 32000 bytes Compression= 2.18

• Br 21 : pho_px : vector<float>
  Entries : 100000 : Total Size= 4558694 bytes File Size = 2092832
  Baskets : 78 : Basket Size= 32000 bytes Compression= 2.18

• Br 22 : pho_py : vector<float>
  Entries : 100000 : Total Size= 4558694 bytes File Size = 2092832
  Baskets : 78 : Basket Size= 32000 bytes Compression= 2.18

• Br 23 : pho_pz : vector<float>
  Entries : 100000 : Total Size= 4558694 bytes File Size = 2092832
  Baskets : 78 : Basket Size= 32000 bytes Compression= 2.18

• Br 24 : jet_n : jet_n/I
  Entries : 100000 : Total Size= 785529 bytes File Size = 400975
  Baskets : 13 : Basket Size= 32000 bytes Compression= 1.96

• Br 25 : jet_pdgId : vector<int>
  Entries : 100000 : Total Size= 4991805 bytes File Size = 2301791
  Baskets : 85 : Basket Size= 32000 bytes Compression= 2.17

• Br 26 : jet_px : vector<float>
  Entries : 100000 : Total Size= 4991538 bytes File Size = 2301536
  Baskets : 85 : Basket Size= 32000 bytes Compression= 2.17

27
Br 29 : jet_py : vector<float>
• Entries : 100000 : Total Size = 4991538 bytes File Size = 2301536
• Baskets : 85 : Basket Size = 32000 bytes Compression = 2.17

Br 30 : jet_pz : vector<float>
• Entries : 100000 : Total Size = 4991538 bytes File Size = 2301536
• Baskets : 85 : Basket Size = 32000 bytes Compression = 2.17

Br 31 : jet_E : vector<float>
• Entries : 100000 : Total Size = 4991449 bytes File Size = 2301451
• Baskets : 85 : Basket Size = 32000 bytes Compression = 2.17

Br 32 : pxmiss : pxmiss/F
• Entries : 100000 : Total Size = 785546 bytes File Size = 400988
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

Br 33 : pymiss : pymiss/F
• Entries : 100000 : Total Size = 785546 bytes File Size = 400988
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

Br 34 : pxnue : pxnue/F
• Entries : 100000 : Total Size = 785529 bytes File Size = 400975
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

Br 35 : pynue : pynue/F
• Entries : 100000 : Total Size = 785529 bytes File Size = 400975
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

Br 36 : pxcalo : pxcalo/F
• Entries : 100000 : Total Size = 785546 bytes File Size = 400988
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

Br 37 : pycalo : pycalo/F
• Entries : 100000 : Total Size = 785546 bytes File Size = 400988
• Baskets : 13 : Basket Size = 32000 bytes Compression = 1.96

r
G.2 Control printout

**********************************************************
* AcerDET, version: 2.0 *
* Released at: 30.06.2015 *
* *
* Simplied event simulation and reconstruction package *
* *
* by E. Richter-Was (Institute of Physics) *
* and P. Mikos (Theoretical Computer Science) *
* Jagiellonian University, Cracow, Poland *
**********************************************************

Initial configuration:

```
clusters definition ...
eta coverage 5.000000
E_T_min cell thresh 0.000000
eta gran. transition 3.200000
gran in eta(central) 0.100000
gran in phi(central) 0.100000
```

B field apply ....
B-field on
p_T min non looping 0.500000

```
clusters definition ...
E_T_min cluster 5.000000
E_T_min cell initia 1.500000
R cone 0.400000
eta coverage 5.000000
eta gran. transition 3.200000
```

... muon isolation ...
min. muon p_T 6.000000
max. muon eta 2.500000
min R_lj for isolation 0.400000
R for energy deposit 0.200000
max E_dep for isolation 10.000000
smearing on
... electron isolation ...
  min. lepton p_T 5.000000
  max. lepton eta 2.500000
  max R_ej for ele-clu 0.150000
  min R_lj for isolation 0.400000
  R for energy deposit 0.200000
  max E_dep for isolation 10.000000
  smearing on

... photon isolation ...
  min. photon p_T 5.000000
  max. photon eta 2.500000
  max R_gam-clust 0.150000
  min R_isol 0.400000
  R for energy deposit 0.200000
  max E_dep for isolation 10.000000
  smearing on

clusters definition ....
  R cone 0.400000
  jets definition ....
  E_T_jets [GeV] 10.000000
  eta coverage jets 5.000000
  smearing on
  B-field on
muon coverage
min. muon p_T 6.000000
max. muon eta 2.500000
unused cells ...
smearing on
cells threshold 10.000000
invisible particles ...
KF code for invis 66

... jets labeling ...
labeling on/off on
bjets ...
min b-quark p_T 5.000000
max b-quark eta 2.500000
max R_bj for b-jets 0.200000

... jets labeling ...
labeling on/off on
cjets ...
min c-quark p_T 5.000000
max c-quark eta 2.500000
max R_cj for c-jets 0.200000

... tau-jets labeling ...
labeling on/off on
tau-jets ...
min tau-had p_T 10.000000
max tau-had eta 2.500000
max R_tauj for tau-jets 0.300000
tau-had frac. of jet 0.900000
jets calibration ....
calibration on

G.3 Control histograms: XXX.conf.root file

Below is the list of control histograms which monitors performance of the simulation/reconstruction. The are store together with ACDTree tuple in file XXX.conf.root.

```plaintext
OBJ: TTree ACDTree ACDTree : 0 at: 0x8190c80
KEY: TH1F hist10000;1 Cell: multiplicity
KEY: TH1F hist10101;1 Cluster: multiplicity
KEY: TH1F hist10111;1 Cluster: delta eta cluster barycentre
KEY: TH1F hist10112;1 Cluster: delta phi cluster barycentre
KEY: TH1F hist10113;1 Cluster: delta r cluster barycentre
KEY: TH1F hist10123;1 Cluster: delta r cluster HP parton
KEY: TH1F hist10114;1 Cluster: ptclus/SumpT particle
KEY: TH1F hist10210;1 Muon: muon multiplicity NOISOLATED
KEY: TH1F hist10211;1 Muon: muon multiplicity ISOLATED
KEY: TH1F hist10221;1 Muon: muon multiplicity HP
KEY: TH1F hist10231;1 Muon: muon multiplicity HP+ISOL
KEY: TH1F hist10311;1 Electron: multiplicity ISOLATED
KEY: TH1F hist10321;1 Electron: multiplicity HP
KEY: TH1F hist10331;1 Electron: multiplicity HP+ISOL
KEY: TH1F hist10411;1 Photon: photon multiplicity ISOLATED
KEY: TH1F hist10421;1 Photon: photon multiplicity HP
KEY: TH1F hist10431;1 Photon: photon multiplicity HP+ISOL
KEY: TH1F hist10501;1 Jet: multiplicity
KEY: TH1F hist10511;1 Jet: delta phi jet-barycentre
KEY: TH1F hist10512;1 Jet: delta eta jet-barycentre
KEY: TH1F hist10513;1 Jet: delta r jet-barycentre
KEY: TH1F hist10514;1 Jet: delta r jet HP parton
KEY: TH1F hist10523;1 Jet: pTjet/pT particles in Rcone
KEY: TH1F hist10524;1 Jet: pTjet/pT HP parton
KEY: TH1F hist10611;1 Mis: reconstructed p_T
KEY: TH1F hist10612;1 Mis: reconstructed p_T + cells
KEY: TH1F hist10613;1 Mis: reconstructed pTmiss
KEY: TH1F hist10621;1 Mis: true p_T invisible
KEY: TH1F hist10622;1 Mis: pT miss (true - reco)/reco
KEY: TH1F hist10711;1 BJet: b-jets multiplicity
KEY: TH1F hist10721;1 BJet: b-quarks HP multiplicity
KEY: TH1F hist10723;1 BJet: delta r bjet-bquark HP
KEY: TH1F hist10724;1 BJet: ptbjet/pTbquark HP
KEY: TH1F hist10811;1 CJet: c-jets multiplicity
KEY: TH1F hist10821;1 CJet: c-quarks HP multiplicity
KEY: TH1F hist10823;1 CJet: delta r cjet-cquark HP
KEY: TH1F hist10824;1 CJet: ptcjet/pTcquark HP
KEY: TH1F hist10911;1 Tau: tau-jets multiplicity
KEY: TH1F hist10921;1 Tau: tau-had multiplicity
KEY: TH1F hist10923;1 Tau: delta r tau-jet, tau-had
KEY: TH1F hist10924;1 Tau: pttaujet/pttau-had
KEY: TH1F hist11001;1 Calibration: calibration correction
KEY: TH1F hist11011;1 Calibration: pT jets before calibration
KEY: TH1F hist11012;1 Calibration: pT jets after calibration
KEY: TTree ACDTree;1 ACDTree
```
This figure "acerdet_structure.png" is available in "png" format from:

http://arxiv.org/ps/1507.00995v1