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Physics

STUDY OF ELECTRONS ENERGY RESOLUTION, IN CMS (LHC) EXPERIMENT USING SIMULATED DATA

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This work is dedicated to the study of the energy resolution of electrons using simulated data of “Drell-Yan” process with $e^- e^+$ yield in pp-interactions at $\sqrt{s} = 13\ TeV$. The work contains a brief description of event modeling and electron reconstruction from the simulated data. The energy resolution was estimated from the distribution of the ratio of the transverse energies of reconstructed and generated electrons. Two approaches used in calculations. In the first approach – the standard definition of energy resolution was used (Full width at half maximum – FWHM), and in the second – the root mean square of distribution was taken as a describing value for energy resolution.

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Keywords**:** Large Hadron Collider, CMS, electron, energy resolution, process simulation.

Introduction. Since 2010, at European Center for Nuclear Research (CERN), in experiments on Large Hadron Collider (LHC) [1] the fundamental properties of matter have been studied. The physics program of CMS (LHC) experiment includes the search for new phenomena, as well as investigation and clarification of the known components of Standard model. pp-collisions at LHC energies provide an opportunity for investigation of large spectra of physics processes. One of the main difficulties for accurate measurements in CMS experiment is related to the very high intensity of data recording. In 2018 bunch crossing rate was at the level of 25 ns^{-1} with 32 pp-interaction at single bunch-bunch collision in average. Typical yield of pp-interaction with a high transfer momentum (inclusive QCD process – hard interaction of partons in colliding protons) is a large multiplicity of charged and neutral hadrons. For this scenario of interaction, difficulties (sometimes very complex) arises in object reconstruction and event interpretation. Another scenario is electroweak interaction of quarks in pp-collisions. In contrast to QCD inclusive process such interactions (especially with leptons in the final state) has very small number of

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particles. In general, the processes with stable (leptons that are directly detected, and not by their decay yield) charged leptons in the final state are most desired for accurate measurements. Although cross section of such interactions is much smaller than that for hard interaction. This scenario is very attractive for physics analysis for following reasons:

1) the charged leptons identification has high efficiency and purity;

2) the energy resolution of the registered charged leptons is much better than that for hadrons (hadron jets);

3) small number of particles in such a process yield makes it relatively easy to reconstruct the topology of the event.

This is why pp-interactions with charged leptons in the final state are so interesting. In this terms investigation of charged leptons registration characteristics are very important. In this work we study the energy resolution of electron registration in CMS experiment using simulated data of “Drell-Yan” process with $e^- e^+$ yield.

Event Modeling Using the CMSSW Package. Modeling and reconstruction of events takes place in three stages.

1. Data generation, which has been performed by Monte Carlo (MC) generators. The MC method is based on random (pseudo-random) numbers generation. This process is generated at the elementary level using a Powheg [2] generator whose output information is input information for the PYTHIA 8 generator. The PYTHIA generator performs the modeling of hadronization, particle decay etc., giving the final particle set and kinematics of the process.

2. Interaction of generated final state particles with different subsystems of CMS detector, i.e. simulation of particles passage through the layers of the CMS detector, which was done using Geant4 package.

3. Event reconstruction, in which the signals (simulated) from various subsystems of CMS detector are processed with appropriate algorithms, and as a result, objects (particles), used for physical analysis are obtained: electrons, photons, muons, charged and neutral hadrons etc.

Electron Reconstruction in CMS Detector. Electron identification and four-dimensional momentum reconstruction in CMS is performed using PF (Particle Flow) reconstruction algorithm based on information obtained from the electromagnetic calorimeter (ECAL) [3] and the tracking system [1]. The energy of the electrons is measured in the ECAL. The ECAL is one of the most important parts of CMS detector. It is designed primarily to measure the energy of electrons and photons. However, some of the detected hadron energy is also spread at ECAL, so it is also used to detect hadrons. It consists of 80.000 crystals which are made of lead tungsten ($PbWO_4$) with about 22×22 mm^2 front surface and 23 cm length, and covers the range of pseudorapidity $|\eta| < 3.0$. During operation of ECAL, high accuracy must be ensured, which may deteriorate due to radiation, particle intense flux, temperature etc. The tracker system is used for interaction vertex reconstruction and charged particle momentum measurement with high accuracy. The system consists of pixel and strip detectors, made of silicon and covering the pseudorapidity region $|\eta| < 2.4$ [1].

Electron energy measurement in ECAL is performed with the clustering algorithm, which searches for $5 \times 1(\phi, \eta)$ or $5 \times 5(\phi, \eta)$ [4] clusters of energy above a certain threshold. Such a distribution of crystals ensures a high efficiency of particle energy registration, for example, for experimental electrons with 120 *GeV* energy, in case of falling into the center of a crystal, the particle distributes about 97% of its energy lost in the surrounding 5×5 crystal array. In addition, electron 3-momentum can be accurately measured based on tracker information. Reconstitution is carried with the matching of the energetic cluster in electromagnetic calorimeter and the track in the tracker system. The combination of the information from these two subsystems ensures both high efficiency and purity of electron identification and high accuracy of four-dimensional momentum recovery. However, there are some effects that lead to some inaccuracies in the reconstruction of the electron kinematics: the energy resolution of the electromagnetic calorimeter, the spatial resolution of the tracker system. Also the accuracy of reconstruction of electron 4-momentum can be significantly affected by the electron bremsstrahlung before entering ECAL [3].

Electron Energy Resolution Calculation. The energy resolution calculation, using simulated data is presented. Simulated data of "Drell-Yan" process from CMS official database was used. The events were selected with requirement of presence of two oppositely charged electrons with $E_T > 10$ and $|\eta| < 2.4$. The energy resolution dependence on the electron transverse energy is considered in the two pseudorapidity intervals: $|\eta| < 1.479$ (barrel ECAL and tracker) and $1.479 < |\eta| < 2.4$ (ECAL endcap to $|\eta| < 2.4$ interval and tracker). Energy resolution was estimated from the distribution of transverse energy ratio of reconstructed and generated electrons, and has been calculated for the following values of transverse energy of the generated electron: 15, 17.5, 20, 25, 30, 35, 45, 60, 80 and 110 *GeV*, in narrow intervals around the selected values: ±0.5 *GeV* for low energies and from ±1 up to 5 *GeV* for large energies. For each case, the reconstructed and generated electrons are matched by a $\Delta R < 0.1$ criteria, where

$$\Delta R = \sqrt{(\phi_2 - \phi_1)^2 + (\eta_2 - \eta_1)^2},$$

where η_1, ϕ_1 and η_2, ϕ_2 are the pseudorapidity and azimuthal angles of the generated and reconstructed electrons. For each interval, the ratio distributions of transverse energies of the reconstructed and generated electrons are created: E_T^{rec}/E_T^{gen}. The energy resolution was estimated based on these distributions using two approaches:

1) full width at half maximum (FWHM) of E_T^{rec}/E_T^{gen} distributions in selected intervals of E_T and η;

2) root mean square error (RMS) in $1 \pm 15\%$ range of E_T^{rec}/E_T^{gen} distributions in selected intervals of E_T and η:

$$\sigma = \sqrt{\sum_i (\frac{(1 - (E_{T,i}^{rec}/E_T^{gen})^2)}{(N-1)})}.$$

Results. Fig. 1 and Fig. 2 present the E_T^{rec}/E_T^{gen} ratio for the 25 and 60 *GeV* values of E_T^{gen}, for $|\eta| < 1.479$ and $1.479 < |\eta| < 2.4$ pseudorapidity intervals.

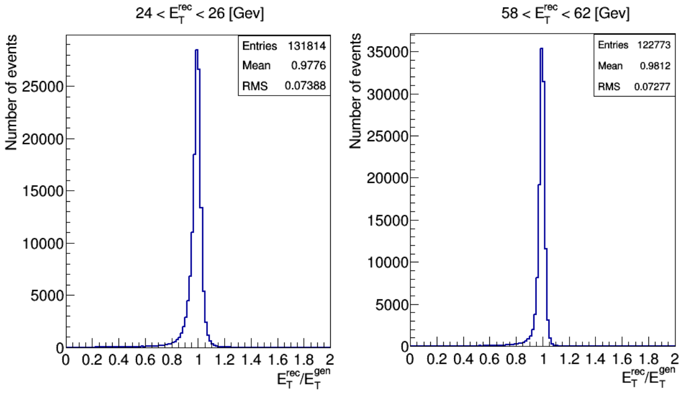


Fig. 1. E_T^{rec}/E_T^{gen} - distribution, $|\eta| < 1.479$.

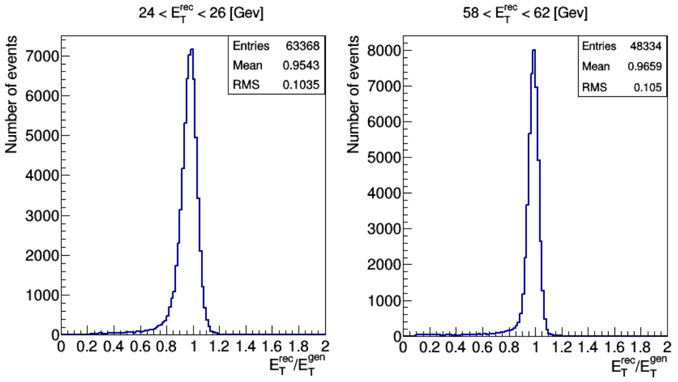
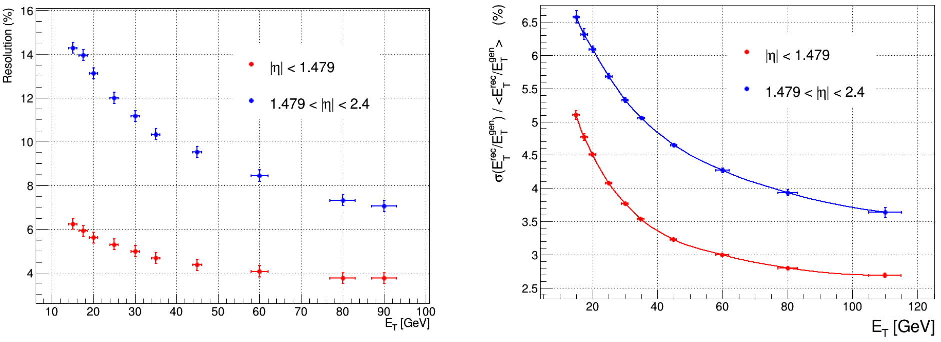


Fig. 2. E_T^{rec}/E_T^{gen} - distribution, $1.479 < |\eta| < 2.4$.



(a) (b)

Fig. 3. Electron energy resolutionn in two pseudorapidity intervals: a) FWHM; b) RMS.

The resolution decrease can be explained by the decrease of energy loss in the crystals of the ECAL. The calculations of the energy resolution of electrons by the methods described above in the two pseudo-rapidity regions are shown in Fig. 3.

Conclusion. A study was made of the energy resolution of electrons in CMS (LHC) experiment. In calculations, simulated data of "Drell-Yan" process with $e^- e^+$ yield in pp-interactions at $\sqrt{s} = 13 TeV$ were used. Estimations of electron energy resolution were extracted from distributions of E_T-ratio of reconstructed and generated electrons in narrow E_T-intervals of generated electrons. Two approaches to describe energy resolution were considered: FWHM and RMS. As a result, the energy resolution is presented as a function of the transveerse energy of the generated electron in two regions of pseudorapidity. The results of this work will be very useful for data analysis and can be used by CMS collaboration. This method can also be used by other specialists in this field.

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ԷԼԵԿՏՐՈՆՆԵՐԻ ԷՆԵՐԳԵՏԻԿ ԼՈՒԾՈՂԱԿԱՆՈՒԹՅԱՆ ՈՒՍՈՒՄՆԱՍԻՐՈՒԹՅՈՒՆՆԵՐԸ CMS (LHC) ԳԻՏԱՓՈՐՁԻ ՊԱՅՄԱՆՆԵՐՈՒՄ ՕԳՏԱԳՈՐԾԵԼՈՎ ՄՈԴԵԼԱՎՈՐՎԱԾ ՏՎՅԱԼՆԵՐ

Այս աշխատանքը նվիրված է էլեկտրոնների էներգետիկ լուծողականության ուսումնասիրությանը օգտագործելով $\sqrt{s} = 13\ TeV$ էներգիայով pp-փոխազդեցության արդյունքում "Դրելլ-Յան" $e^- e^+$ ելքով պրոցեսի մոդելավորված տվյալները: Աշխատանքը պարունակում է իրադարձությունների մոդելավորման և էլեկտրոնների վերականգման կարճ նկարագրություն: Էներգետիկ լուծողականությունը հաշվվել է ոգտագործելով վերականգնված և գեներացված էլեկտրոնների ուղղահայաց բաղադրիչների հարաբերության բաշխվածությունը: Հաշվարկներում օգտագործվել է երկու մոտեցում: Առաջին մոտեցման մեջ օգտագործվել է էներգետիկ լուծողականությնա, ստանդարտ սահմանումը (կիսաբարձրության լայնությունը), իսկ երկրոդ մոտեցման մեջ որպես էներգետիկ լուծողականության բնութագրվող մեծութուն օգտագործվում է վերականգնված և գեներացված էլեկտրոնների ուղղահայաց բաղադրիչների բաշխվածության միջին քառակուսային սխալը:

А. А. АЙРАПЕТЯН

ИЗУЧЕНИЕ ЭНЕРГЕТИЧЕСКОГО РАЗРЕШЕНИЯ ЭЛЕКТРОНОВ В ЭКСПЕРИМЕНТЕ CMS (LHC) С ИСПОЛЬЗОВАНИЕМ СМОДЕЛИРОВАННЫХ ДАННЫХ

Данная работа посвящена изучению энергетического разрешения электронов в эксперименте CMS (LHC) с использованием смоделированных данных процесса “Дрелл-Ян” с выходом e^-e^+ в pp-взаимодействиях при $\sqrt{s} = 13\ TeV$. Работа содержит краткое описание моделирования событий и восстановления электронов на основе смоделированных данных. Энергетическое разрешение оценивалось по распределению поперечных энергий восстановленных и генерируемых электронов. В расчетах использовались два подхода. В первом подходе – стандартное определение энергетического разрешения (полуширина распределения), а во втором – в качестве величины для описания энергетического разрешения было взято среднее квадратическое значение.