Measurement of cross section of the process $W \to e\nu$ based on the data from CMS detector.

Mateusz Stepniak

March 1, 2023

Abstract

The following report is an analysis of the measurement of a cross section of the process $W \to e\nu$ based on the CMS detector in LHC performed in 2011. Data are available here: [1].

1 Introduction

The Large Hadron Collider (LHC) is the world's largest and highest-energy particle collider. The building built by the European Organization for Nuclear Research (CERN) lies beneath the France–Switzerland border near Geneva. For the first time, it was started in 2008. It consists of a 27 km long tunnel covered by superconducting magnets and an installation that accelerates particles. In this report, data from the experiment measuring the W production cross section in pp collision at $\sqrt{s} = 7$TeV are analyzed [2], collected by the compact muon solenoid detector (CMS). The integrated luminosity in the experiment was $36pb^{-1}$. The main part of the CMS apparatus is a 6 m internal diameter superconducting solenoid, which provides a magnetic field of 3.8T [2]. An important parameter is the polar angle θ that is measured from the axis along the beam direction. A derivative quantity is the pseudorapidity given $\eta = -\ln\tan\frac{\theta}{2}$ Inside there is a silicon pixel and strip tracker , an electromagnetic calorimeter (ECAL), and a hadron calorimeter (HCAL). The electromagnetic calorimeter is divided into two regions: the cylindrical barrel region (EB) corresponding to pseudorapidity $|\eta| < 1.479$ and two endcap regions (EE) corresponding to pseudorapidity $1.479 < |\eta| < 3.0$. The inner tracker measures the trajectories of charged events in the pseudorapidity range $|\eta| < 2.5$. More detailed information can be found here[3]. CMS is equipped with a trigger system composed of custom hardware processors, designed to select the most interesting events in less than 1 μs. Candidate events are selected from data sets collected with lepton trigger requirements. Events are selected online if they pass an L1 trigger filter that requires energy deposit in ECAL with a E_T threshold of 5 or 8 GeV depending on the data collection period. Subsequently, they must pass the HLT filter. Furthermore, there is an offline filter with a E_T threshold of 25 GeV.

2 Data

Data used are available on CERN's Open Data website [1]. Data that describe the canal $W \to e\nu$ are used. Unfortunately, files with Monte Carlo simulation are not available. The data analyzed were used by the CMS experiment to provide measurement with integrated luminosity of 36 pb^{-1}.

On Cern Data website is available only 100000 selected events coresponding to small fraction (10%) of the full dataset.

The variables used for analysis are as follows:

- `Run` - The run number of the event.
- `Event` - The event number.
- p_T - The transverse momentum of the lepton (in units of GeV), either a muon or an electron
- `Q` - The charge of the lepton, either a muon or an electron.
- η -The pseudorapidity of the lepton, either a muon or an electron.
- ϕ - The phi angle (in radians) of the lepton, either a muon or an electron.
- $\not{E}_T$ - The missing transverse momentum of the event (in units of GeV).
- $\phi_{\not{E}_T}$ -The phi angle (in radians) of the missing transverse momentum.
- $\eta\eta$ -The weighted cluster rms along eta for an electron.
- H/E - The energy of the electron in the HCAL divided by the energy of the electron in the ECAL
- I_{trk} - The isolation variable for the electron in the tracker.
- I_{ECAL} - The isolation variable for the electron in the ECAL.
- I_{HCAL} - The isolation variable for the electron in the HCAL.

The number of events split by calorimeter region, where an electron was detected and its charge is presented in Table 1. The fact that the number of events with positive charge is greater than that with negative charge draws attention. It occurs due to the higher probability of W^+ production in pp collisions.

Table 1: Number of events in the channel $W \to e\nu$ depending on the direction and charge of the electron. The total number of events is 100,000.

Charge	-1	1
EB	25475	28606
EE	21694	24225

The evens counts for different runs is presented in Table 2. We see that for different runs there is a different number of events.

Charge	-1		1		Total events
Run number	EE	EB	EE	EB	
161312	959	1217	1076	1414	4666
163376	542	540	657	611	2350
163402	342	373	373	368	1456
163659	505	571	549	616	2241
163758	299	370	390	361	1420
163759	3501	3854	3832	4321	15508
163817	879	960	916	1037	3792
165121	531	468	552	493	2044
165415	137	114	162	174	587
165467	1138	1037	1210	1163	4548
165514	532	534	610	575	2251
165537	475	400	449	452	1776
165567	3064	2776	3229	3248	12317
165633	529	520	586	584	2219
166034	471	512	558	526	2067
166049	1289	1337	1392	1490	5508
166408	547	623	600	650	2420
166512	212	241	203	247	903
166514	545	598	660	595	2398
166565	542	652	653	699	2546
166782	518	557	562	616	2253
167676	480	664	500	760	2404
170876	763	1158	894	1337	4152
171446	1183	2111	1497	2482	7273
171484	395	714	466	841	2416
172822	244	488	307	561	1600
172868	730	1384	922	1609	4645
172949	342	702	420	776	2240

Table 2: The number of events in channel $W \to ev$ in dependence of charge and region for different run number and total number of events.

In Figures 1,2,3, I present the distribution of events as a function of transverse momentum, pseudorapidity, angle in plane transverse to beam direction, charge, the missing transverse momentum, and ϕ angle of missing transverse momentum ($\phi_{\not{E}_T}$). As mentioned before, we see that there are more events with positive charge. One may notice modulation in the $\phi_{\not{E}_T}$ distribution that is not physical and should be considered as a detector or trigger effect.

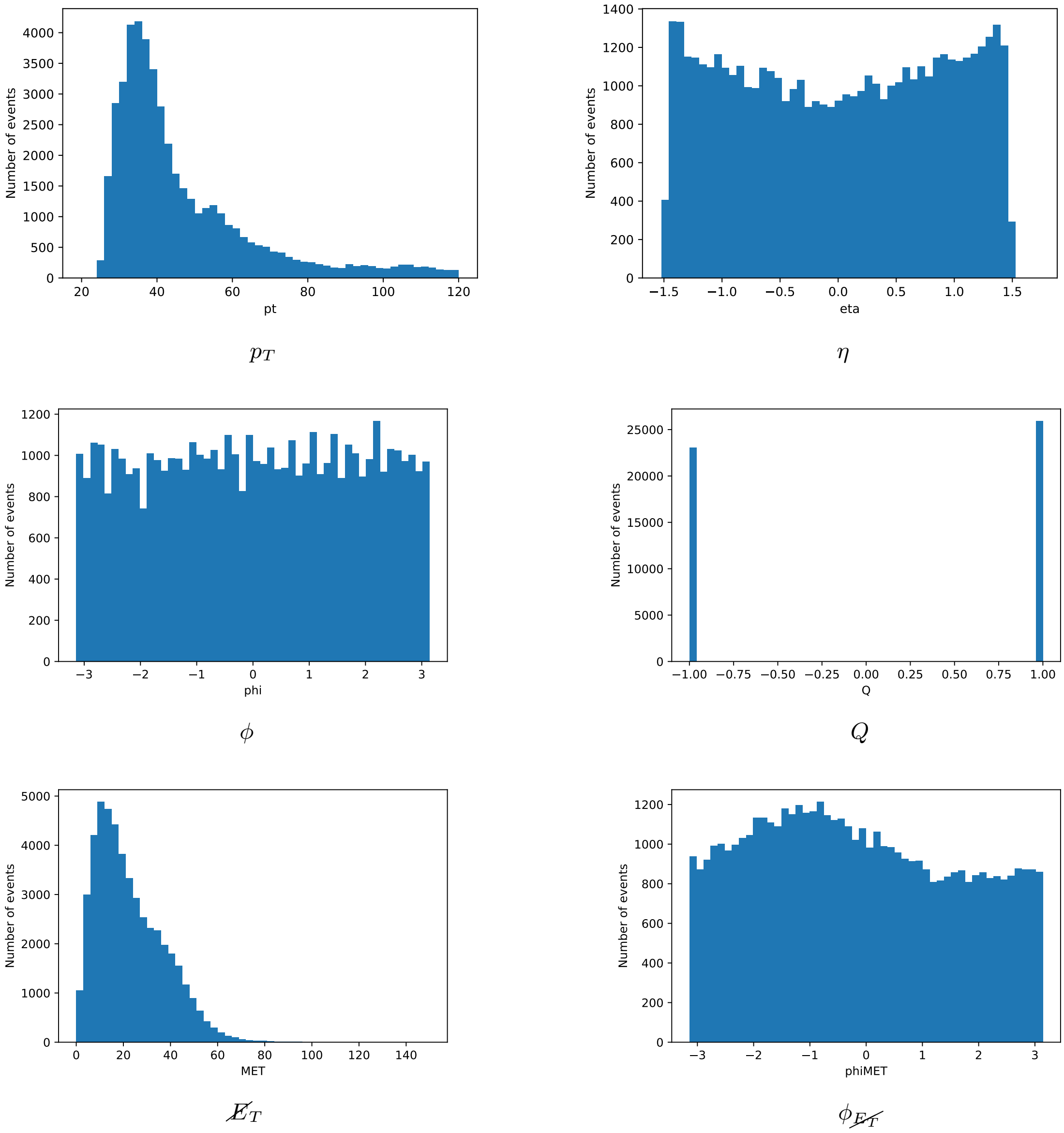


Figure 1: The distribution of the transverse momentum, pseudorapidity, angle distribution, charge, missing transverse momentum, and phi angle of missing transverse momentum for $W \to e\nu$ for events with electron in EB region.

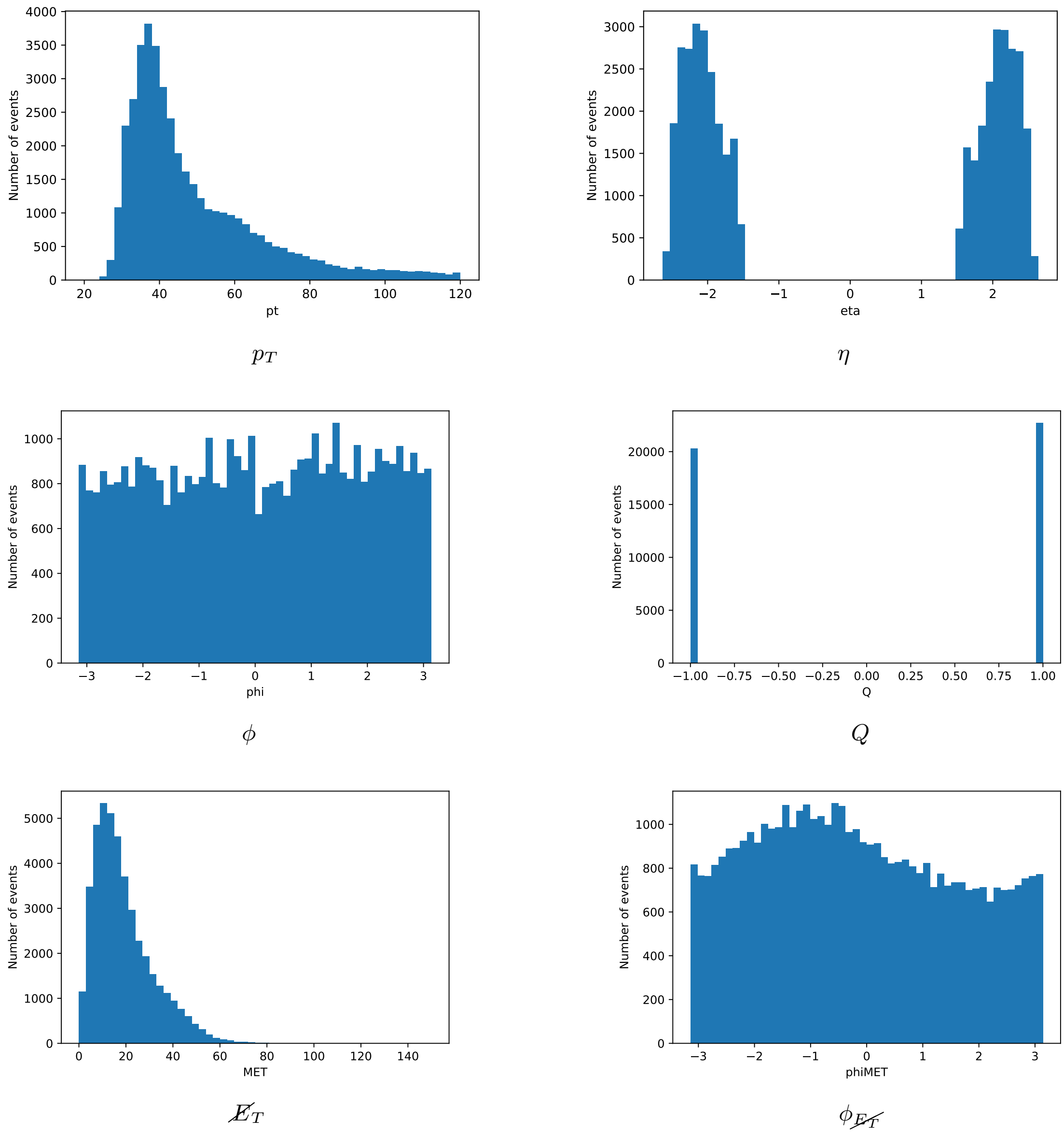


Figure 2: The distribution of the transverse momentum, pseudorapidity, angle distribution, charge, missing transverse momentum, and phi angle of missing transverse momentum for $W \to e\nu$ for electrons in EE region.

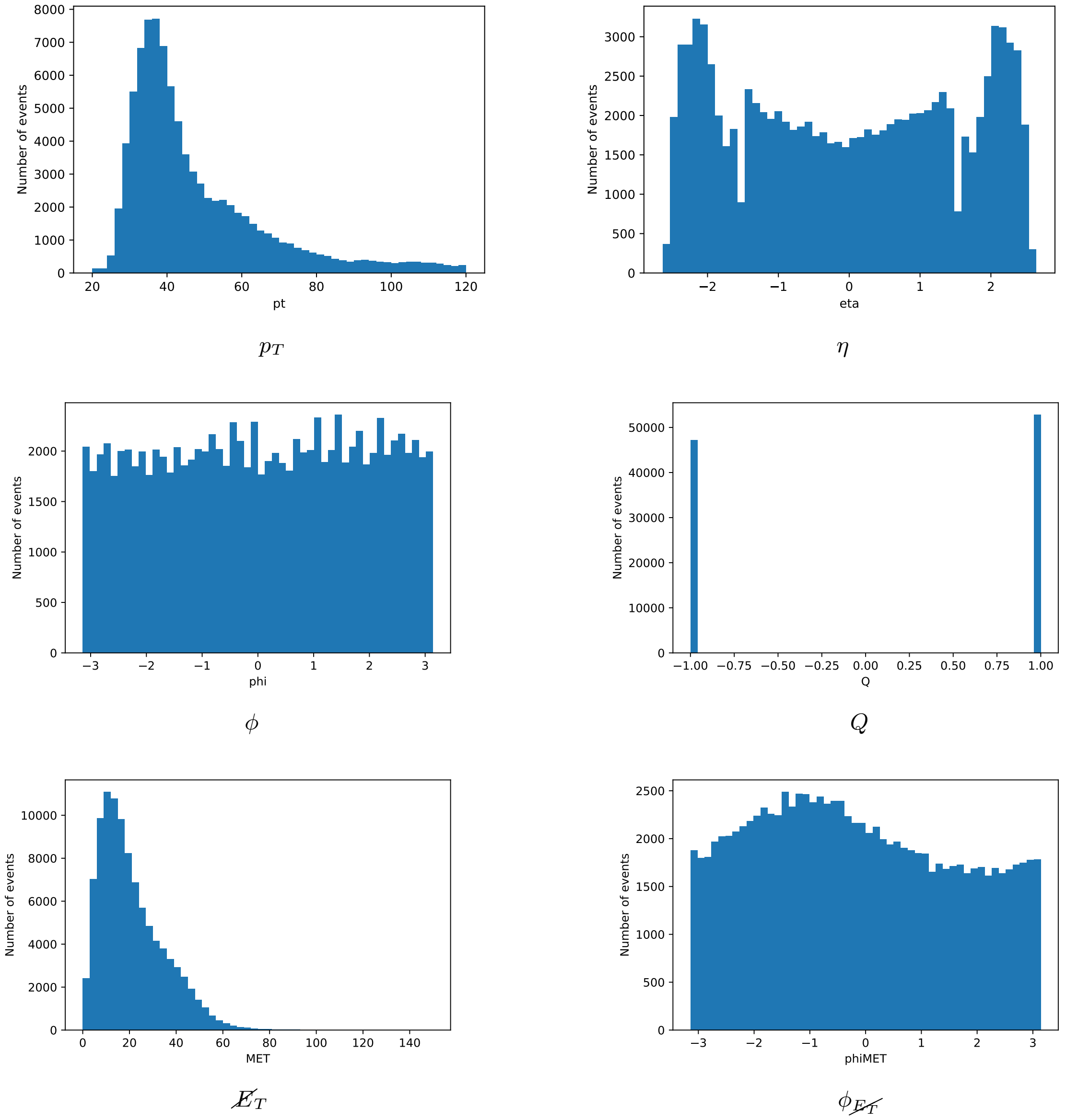


Figure 3: The distribution of the transverse momentum, pseudorapidity, angle distribution, charge, the missing transverse momentum and phi angle of missing transverse momentum for $W \to e\nu$ for events with electrons in regions EB or EE

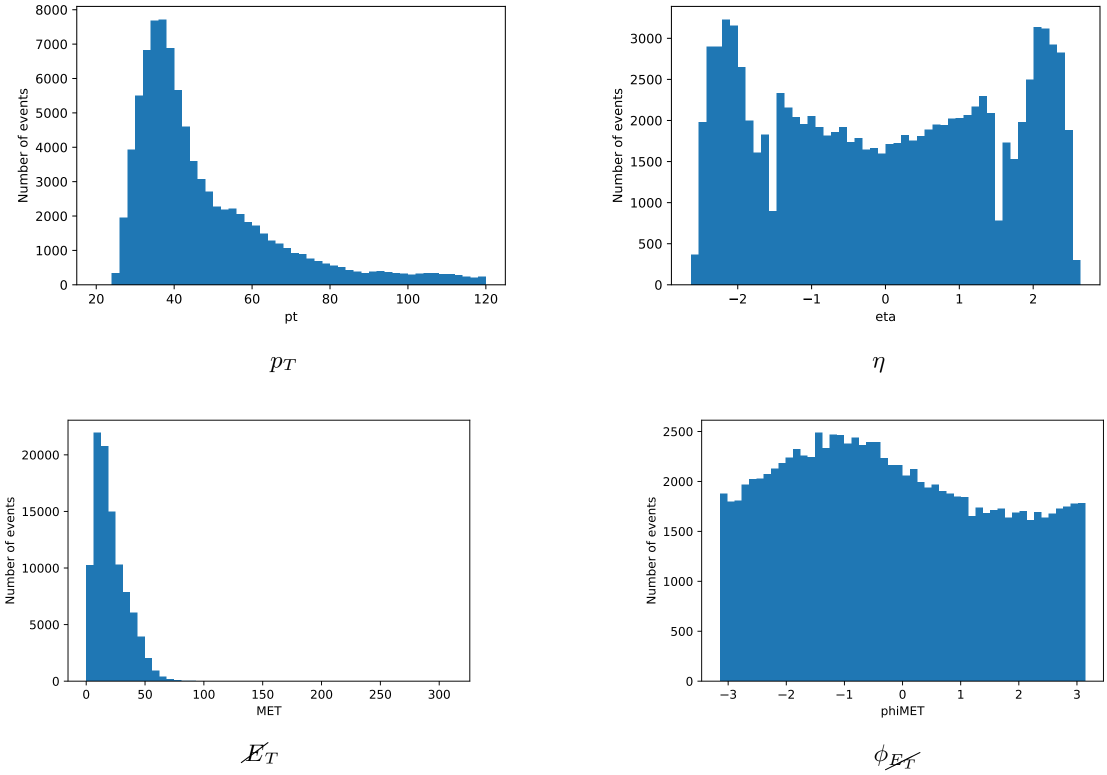


Figure 4: The distribution of the transverse momentum, pseudorapidity, angle distribution, charge, the missing transverse momentum and phi angle of missing transverse momentum for $W \to e\nu$ in regions EB and EE

3 Reconstruction and identification of electron in CMS experiment.

3.1 Requirments on identification variables.

To reject events that do not correspond to the true electron, requirements on the identification variables are imposed. The requirements values are presented in Table 3. Acceptance values after applying the requirements are presented in Tables 4, 5. The distribution of electron identification variables is presented in Figs. 5,6. The shape of the distribution is similar to the correspoding distribution presented in [2], but the number of events is different due availability of only fraction of data. After requiring electron to pass ”tight” identification, the number of candidate events selected in the data used in [2] is 235687 with 132696 positrons and 102991 electrons. In available data sample, the corresponding number of events is 19250 with 10624 positrons and 8575 electrons. We see that the ratio of the number of positrons to the number of electrons is similar for both samples. Therefore, we estimate that the original number of events in the data was 1224348. Therefore, since this number corresponds to luminosity $36pb{-}1$, therefore the rescaled luminosity corresponding given the available data sample is $5.08pb^{-1}$

Table 3: The value of tight requirements on the selection variables

Selection variable	$\sigma_{\eta\eta}$	H/E	I_{trk}/p_T	I_{ECAL}/p_T	I_{HCAL}/p_T
EB	0.011	0.045	0.1	0.08	0.1
EE	0.033	0.025	0.04	0.06	0.03

Table 4: The acceptance values after applying tight requirements to the single selection variable.

Selection variable	$\sigma_{\eta\eta}$	H/E	I_{trk}/p_T	I_{ECAL}/p_T	I_{HCAL}/p_T
EB	0.912	0.892	0.588	0.427	0.821
EE	0.964	0.750	0.571	0.668	0.451

Table 5: The acceptance values after applying tight requirements to all except one selection variable.

Selection variable	$\sigma_{\eta\eta}$	H/E	I_{trk}/p_T	I_{ECAL}/p_T	I_{HCAL}/p_T	Total
EB	0.344	0.342	0.372	0.507	0.342	0.334
EE	0.270	0.284	0.326	0.304	0.388	0.266

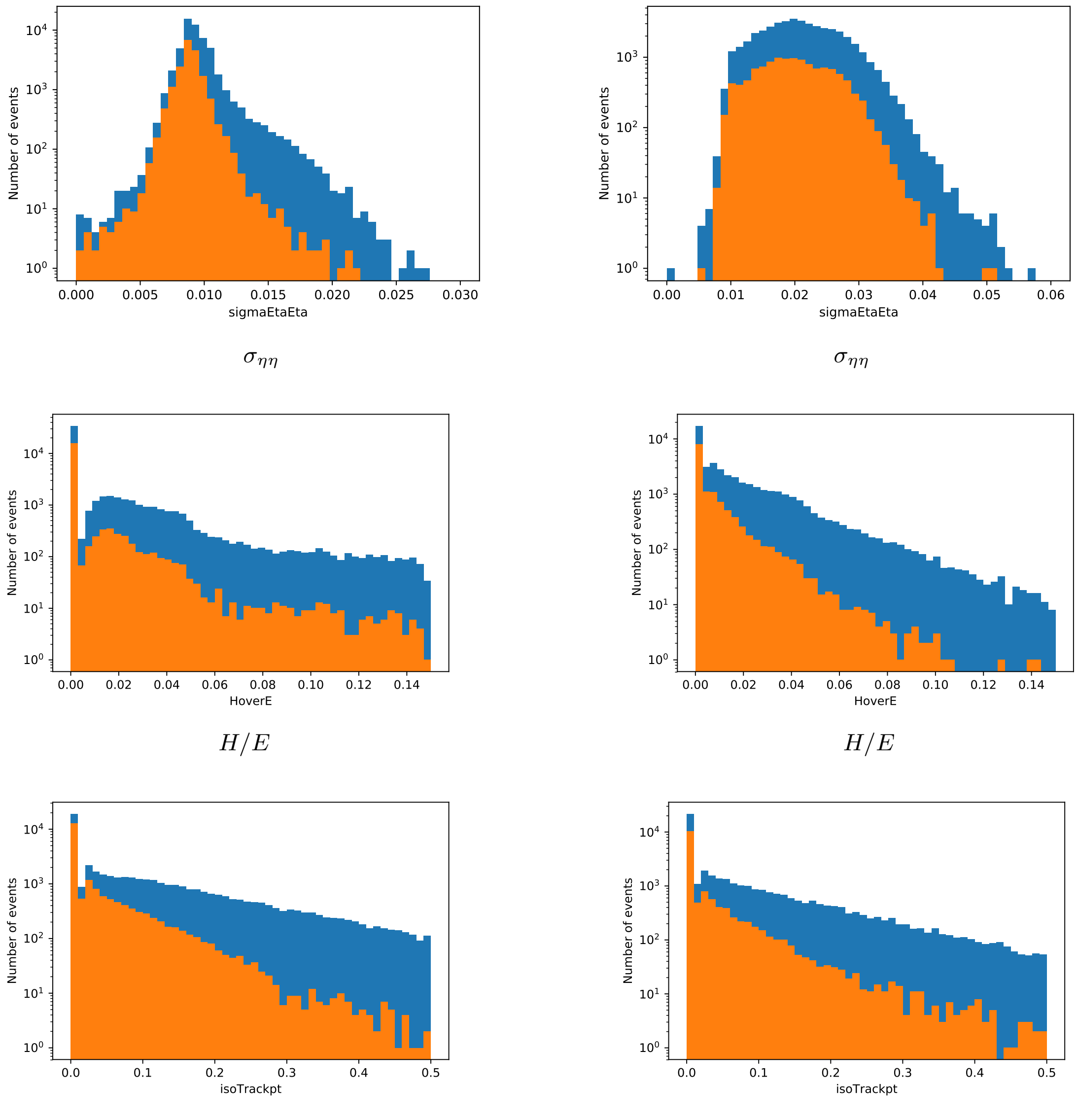
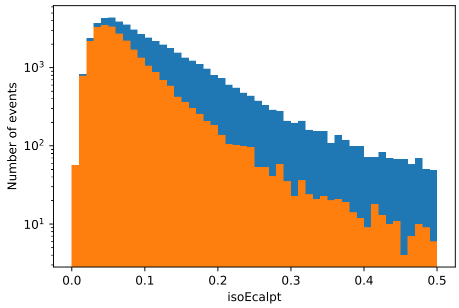
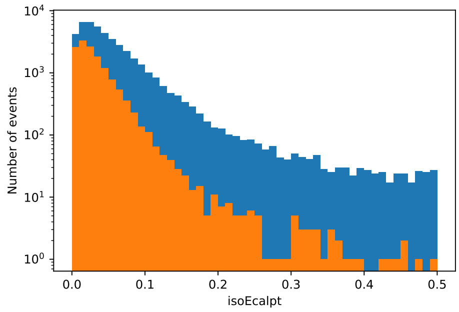


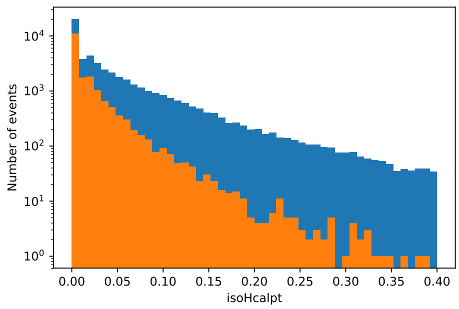
Figure 5: Distribution of $\sigma_{\eta\eta}$ and H/E before and after imposing tight identification requirements on other variables.



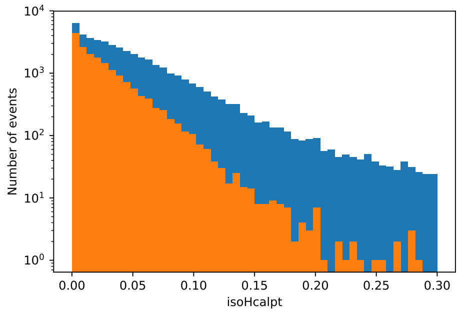
I_{ECAL}/p_T



I_{ECAL}/p_T



I_{HCAL}/p_T



I_{HCAL}/p_T

Figure 6: Distribution of $_{trk}/p_T$,$_{ECAL}/p_T$ and $_{HCAL}/p_T$ before and after imposing tight identification requirements on other variables.

4 Measuring cross-section for $W \rightarrow e\nu$

4.1 Acceptance

The kinematical selection for this analysis requires electron with $\not{E}_T > 25GeV$; therefore, we must define acceptance, which is a fraction of all events that pass the requirements and could potentially be detected. In [2] acceptance was estimated using numerical calculations. The fraction of simulated W events that have $E_T > 25GeV$ was calculated numerically in [2] by Monte Carlo simulation. The results are presented in Table 6.

Table 6: Fraction of generated W events with electron $E_T > 25GeV$

Process	$\ell = e$
$W^+ \rightarrow \ell^+\nu$	0.5017 ± 0.0004
$W^- \rightarrow \ell^-\bar{\nu}$	0.4808 ± 0.0004
$W \rightarrow \ell\nu$	0.4933 ± 0.0003

4.2 Eficiencies

Key component of analysis is estimation of lepton efficiencies, it is determined for different selection steps:

- Offline reconstruction of the lepton
- lepton selection with identification and isolation criteria
- trigger

Multiplying all these factors, we can estimate the total lepton efficiency.

$$\epsilon_{tot} = \epsilon_{trg}\epsilon_{tight}\epsilon_{rec} \tag{1}$$

where, rec state for reconstruction, tight state for identification and isolation criteria, and trg state for trigger efficiency. The analysis data presented in [2] estimate that $\epsilon_a ll$ by simulation, results are presented in Table 8.

Table 7: Simulation efficiencies and final corrected selection efficiencies for the W^+, W^-, and their average.

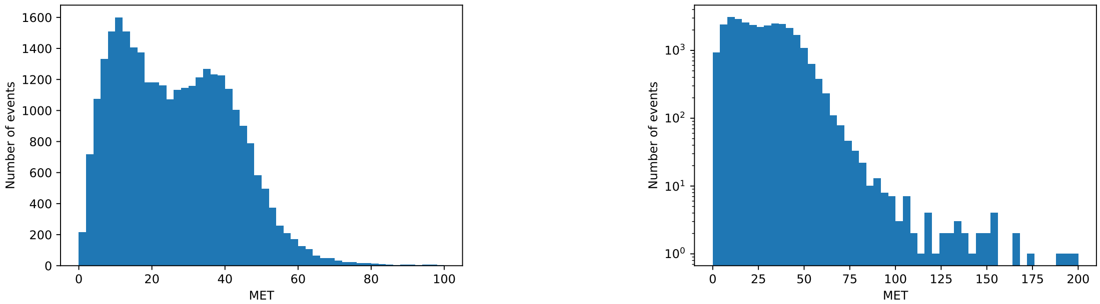
Process	ϵ_{sim}
$W^+ \to e^+\nu$	$(76.04 \pm 0.03)\%$
$W^- \to e^-\bar{\nu}$	$(76.94 \pm 0.03)\%$
$W \to e\nu$	$(76.40 \pm 0.02)\%$

4.3 QCD background

In figures 7, 8, 9, I present the distributions of missing transverse energy and transverse mass determined by the equation:

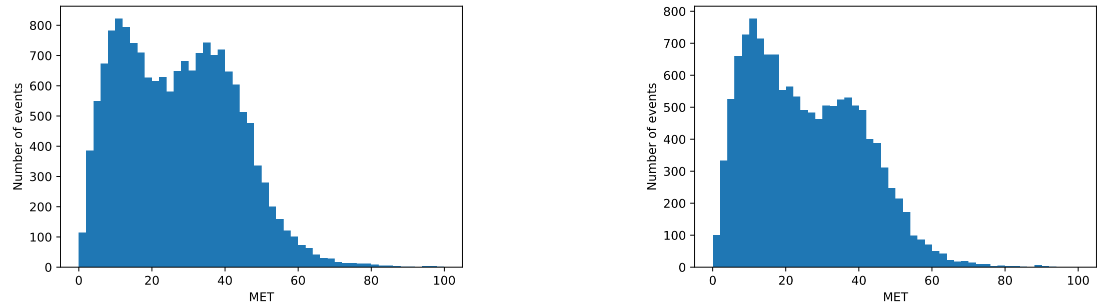
$$M_T = \sqrt{2p_T \not{E}_T(1 - \cos(\phi_{l,\not{E}_T}))} \tag{2}$$

where $\phi_{l,\not{E}_T}$ is the azimuthal angle between the lepton and the $\not{E}_T$ direction. For the original data, in each plot, we shall see two peaks, the first one corresponding to the QCD background. It appears also in our results. We can see that additional requirements can be found to reject the QCD background; it is $\not{E}_T$ ¿ 20 GeV, and $M_T > 50GeV$, where M_T is the transverse mass described in Sec 3.4, and these requirements were defined based on [2] plots.



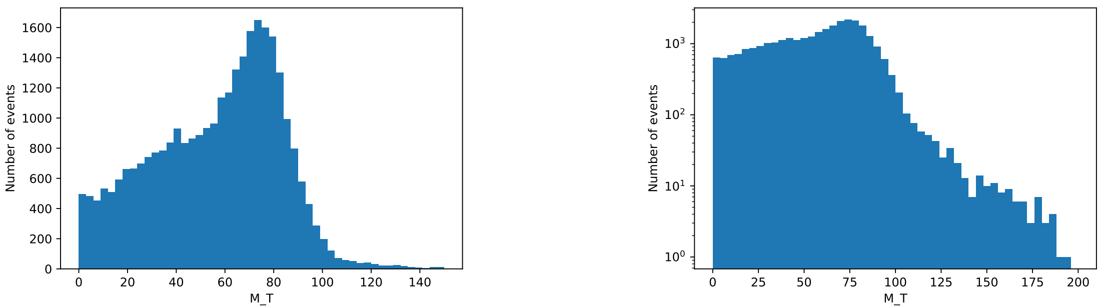
$\not{E}_T$ $\not{E}_T$

Figure 7: The $\not{E}_T$ distribution for selected Wev candidates on a linear scale (left) and logartithimic scale (right)



$\not{E}_T$ $\not{E}_T$

Figure 8: The $\not{E}_T$ distribution for selected W^+ (left) and W^- (right) candidates



M_T M_T

Figure 9: The M_T distribution for selected $W \to e\nu$ candiates on a linear scale (left) and on a logarithmic scale (right).

5 Calculating cross section

We can calculate the cross section with the following equation:

$$\sigma = \frac{\text{Number of events}}{\alpha \epsilon L} \tag{3}$$

, where α is total aceptance (fraction of events passing selection requirements, ϵ - efficiency (reconstruction efficiency of relevan objects), L luminosity). The number of events is calculated after imposing requirements on the selection variables described in 3.1. Acceptance is described in 4.1. The efficiency is described in 4.2. Additionally, we reject events that do not meet the electron identification requirements and have a high probability of origin from a QCD background. That was described in Section 3.4. Finally, we can estimate that the cross section, results are presented in Table 8. The calculated value agrees with the result obtained in [2] ($\sigma = 10.48 \pm 0.70 nb^{-1}$) The systemic error was estimated using errors for acceptance and efficiency.

Table 8: Information required for calculating cross-section.

N events	19250
ϵ	0.76 ± 0.03
Akceptance	0.4933 ± 0.0003
Luminosity	$5.08 pb^{-1}$
Calculated cross-section	$10.17 \pm 0.34 nb^{-1}$

References

[1] Data used `http://opendata.cern.ch/record/545`

[2] Chatrchyan, Serguei, et al. "Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment." Journal of High Energy Physics 2011.10 (2011): 1-76.

[3] Collaboration, C. M. S., et al. "The CMS experiment at the CERN LHC." (2008).