



Forward Energy Flow and Central Charged-particle Multiplicities in W boson events

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Abstract

This is my summer school report. It contains details about the central multiplicities and forward energy flow in W boson events. My task was to generate events with PYTHIA D6T and PYTHIA Z2 and to apply a correction factor and cutoff energy to obtain results close to a full MC prediction in reference paper and data. It shows that the results from my project are comparable to the reference paper.

Acknowledgements

First of all, I am extremely grateful to Hannes Jung, my supervisor, for teaching and inspiring me to love and take interest in quantum chromodynamics, and giving me advices on my project until it is finished. Moreover, I would like to thank Albert Knutsson and Panos Katsas, my advisor, for giving me useful advices about programming, discussing forward energy flow and presentation.

Next I would like to thank Olaf Behnke, Andrea Schrader, and Doris Eckstein for organizing this very nice DESY summer school. This city is very nice and suitable for studying particle physics. I will be missing this place where all of summer student spend their time together. Thank you again for everything. It will be in my memory forever.

Furthermore I would like to thank Samantha Dooling, Paolo Gunnellin, Nastja Grebenyuk, Khilesh Mistry, and Andrew McMahon for their help and very nice friendship since the first day that I have joined this school. I don't know when we will meet again, but please remind that you are in my memory forever and I will contact you if we have a chance to meet again.

Finally I would like to thank NSTDA under the patronage of HRH Princess Maha Chaki Sirinhorn for a chance to go to this prefect summer school in my life.

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1 Introduction

This report is the summary of my work during DESY summer school 2012. I work in CMS group under supervision of Hannes Jung, Panos Katsas and Albert Knutsson. My main studies in this school are forward energy flow and central charge multiplicities in W boson events, which are used for studying the underlying events in hard process in order to improve the underlying models that we have today. In my project, I use PYTHIA with D6T and Z2 for Monte Carlo generator and Rivet for analysis in hadron level without detector simulation. Because of the limited resolution in detector and the MC studies are done on hadron level. Then, there is some disagreement between two levels. So energy correction factors are needed for correcting energy in hadron level to be close to detector level. The main goal of this study is to correct the forward energy flow in MC generator in order to get close to data and full MC prediction in the reference paper [1].

2 Theory

At Large Hadron Collider (LHC), many high energy events occur during proton-proton collisions. The outgoing particles from the collisions are detected by two main detectors; ATLAS (A Toroidal LHC Apparatus), and CMS (Compact Muon Solenoid). The process in the collision can be written as $pp \rightarrow XY$, where X are particles coming from perturbative parton-parton interaction, and Y composes of the beam remnants which contributes the large fraction of the total energy. The system of Y represents the underlying event which consists of low transverse momentum hadrons coming from parton showers and multiparton interaction.

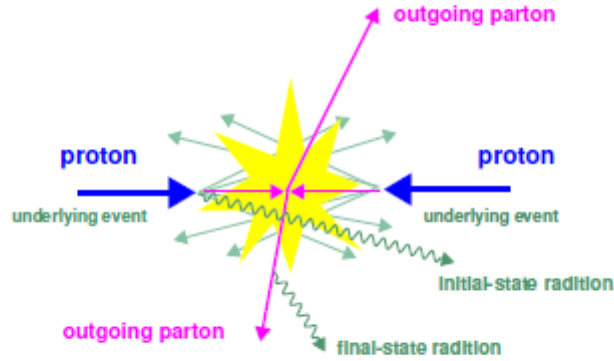


Figure 1: The outgoing products during proton-proton collision
(CMS PAS QCD-08-005)

As you see in figure 1, there are many processes during proton-proton collision; initial state radiation, final state radiation, outgoing parton, and underlying event. In this project, we investigate the underlying event by measuring central charged-particle multiplicities and forward energy flow.

The analysis of underlying events in colorless final state, such as $pp \rightarrow W(Z)X \rightarrow l\nu(l)X$ is used to compare data and simulation for improving the model because it allows us to separate hard events and underlying events. The measurement of underlying event in W or Z events are central charge multiplicity and forward energy which give us the information about multi-parton interaction.

Moreover, some event in proton-proton interaction can arise from single-diffractive processes, where one of the colliding protons emerges intact from the interaction and has lost only a few percent of its energy. This process can be described by exchanging vacuum quantum numbers called pomeron. In figure 2, this is the diffractive process. There is a large region where no hadron produced called large rapidity gap. So, in parton-parton interaction with single-diffractive process, the large rapidity gap appears adjacent to the outgoing proton direction. However, the large rapidity gaps can be filled by particle originating from soft multi-parton interactions. This reduces the observable yields of the hard-diffractive events.

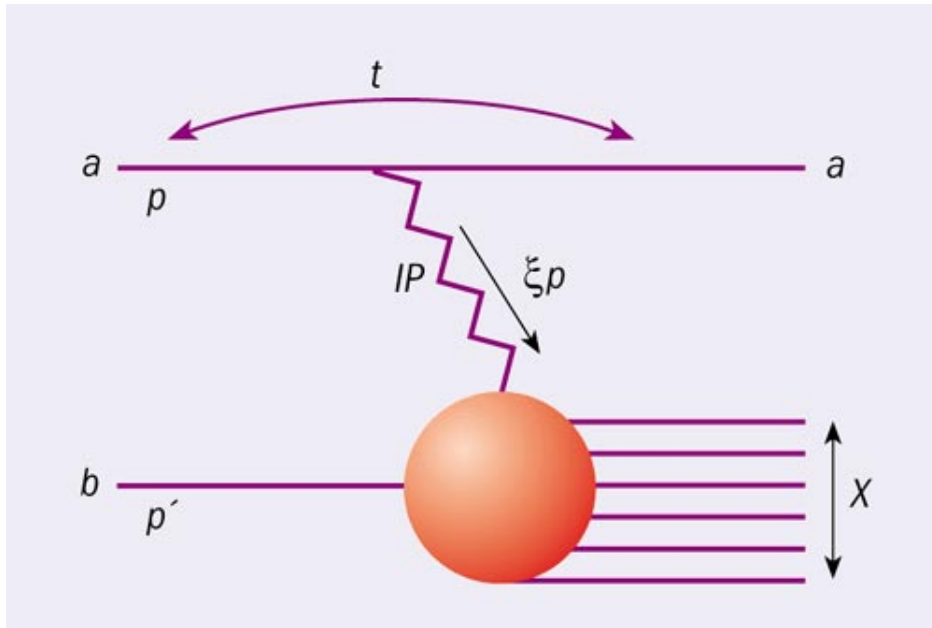


Figure 2: The diffractive process with large rapidity gap
(<http://cerncourier.com/cws/article/cern/28899>)

During proton-proton collision, W and Z bosons are produced from hard parton-parton interaction. In figure 3 (a.), this is the standard picture of W or Z boson productions in parton level. In figure 3 (b.), these are W or Z boson productions from

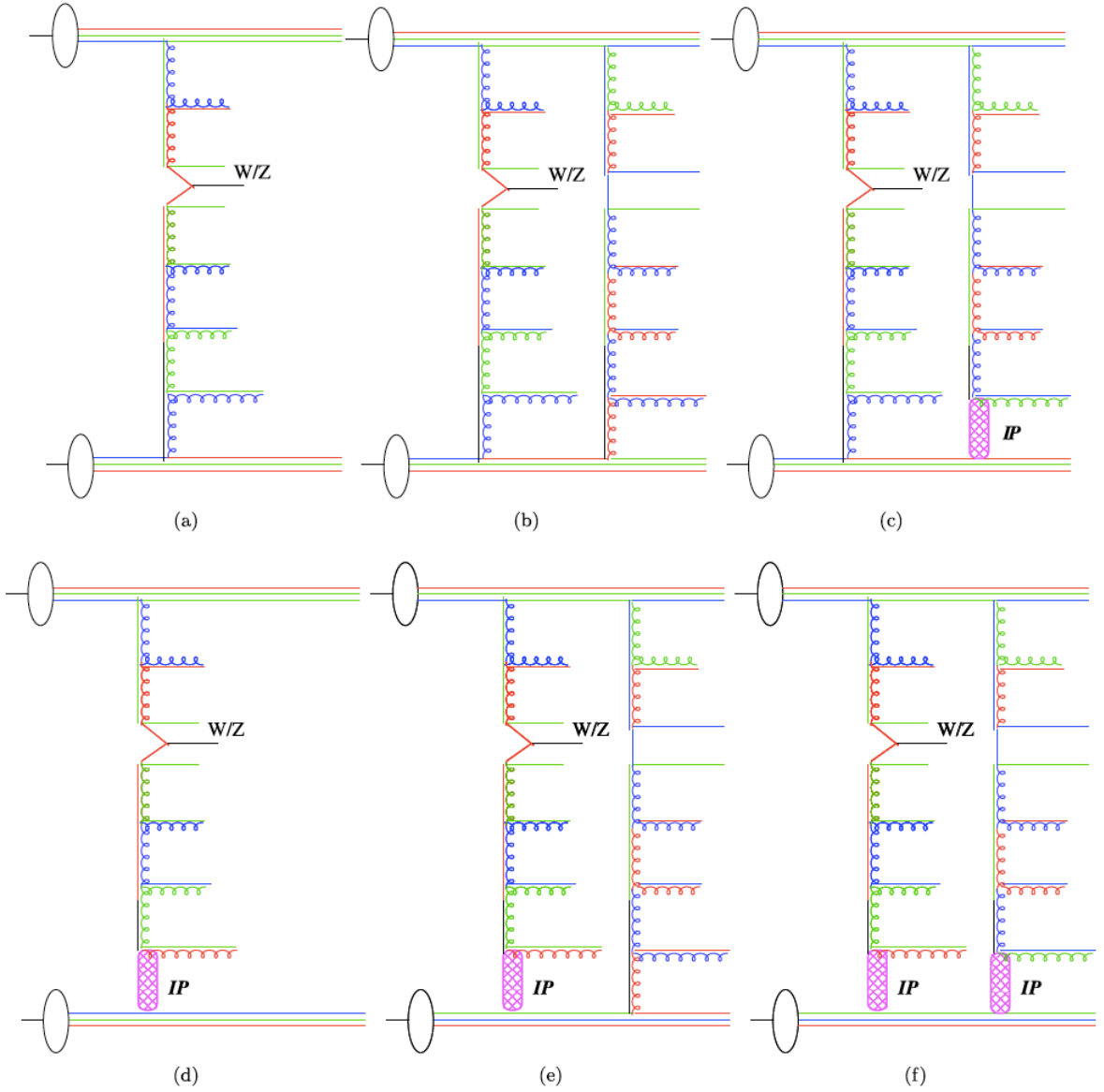


Figure 3: W or Z boson production in colliding protons from various processes, where curly and straight line are gluons and quarks, respectively. The symbol \mathbb{P} refers to the pomeron exchange. (a.) The standard picture of W or Z boson productions. (b.) Standard picture with multi-parton interaction. (c.) Standard picture with multi-parton interaction with diffractive component. (d.) Hard diffractive process. (e.) Hard diffractive with multiparton interaction. (f.) Diffractive processes in both hard parton-parton interaction and multi-parton interaction. (Eur. Phys. J. C (2012) 72:1839)

hard process with soft multi-parton interaction. With this process, the multiplicities of particle increase from soft multi-parton interaction. In 3 (c.) and (d.), are processes with diffractive contributed in soft multi-parton and hard process, respectively. The hard process with diffractive component is called hard diffractive process. Large rapidity gap where no hadron produced appears in these processes. But these processes do not contribute to charged particle multiplicities in central region. However, there is a larger fraction of events with a relatively small energy deposition in the forward region. The hard diffractive production with multi-parton interaction are shown in figure 3 (e.). In this process, large rapidity gap is filled by particle produced from multi-parton interaction and only survive if multi-parton interaction is small. Lastly, figure 3 (f.) shows diffractive processes in both hard interaction and multi-parton interaction.

3 The CMS Detector

In this section, we give information about the camera which takes pictures of particles that are produced in the collision, the detector. The main detectors at CERN are Compact Muon Solenoid (CMS) and A Toroidal LHC Apparatus (ATLAS). There are many general purposes of these detectors, such as, Higgs finding, QCD studying, SUSY searching, etc. In this summer school, as mentioned before, I work in CMS group. Then, data in this project are measured by CMS detector. A description of CMS experiment can be found in [2]. There are many components in CMS detector as you see in figure 4.

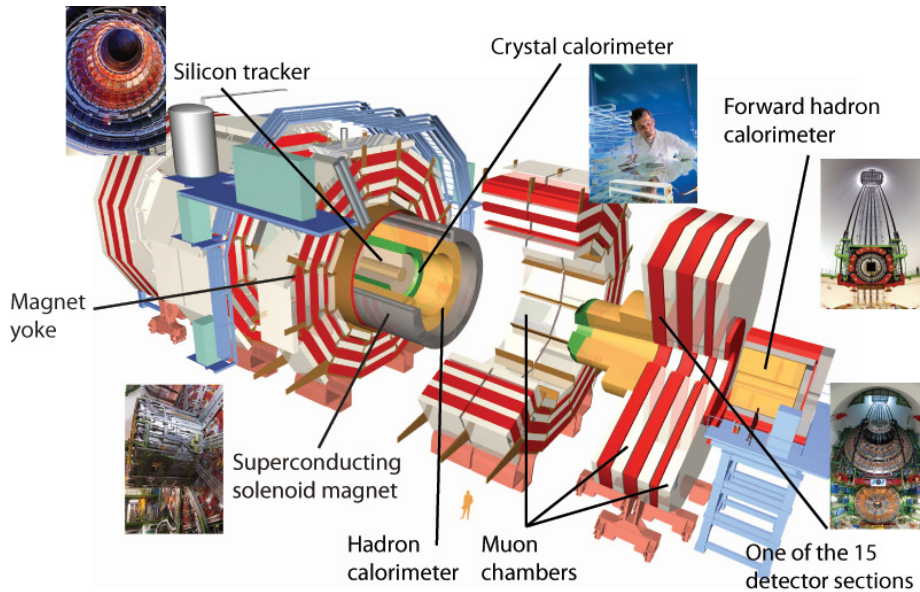


Figure 4: The CMS detector

(<http://bigscience.web.cern.ch/bigscience/en/cms/cms2.html>)

The silicon trackers are used for measuring charged-particle tracks. The charged-particles are bend in this region because of the magnetic field produced by superconducting solenoid magnet. Next to the silicon tracker, there are electromagnetic calorimeter where electrons and photons have lost all of their energy. The hadrons pass through these regions by losing little energy into hadronic calorimeter where they lose most of their energy. The outer layers are muon chambers which are used for detecting muon. This is the reason why we call this detector as "Compact Muon Solenoid".

The coordinate system has the origin at the interaction point, The Z-axis is parallel to the anti-clockwise beam direction. It uses for defining the polar angle, θ , and pseudorapidity, $\eta = -\ln(\tan(\theta/2))$. The azimuthal angle, ϕ , is defined in the plane transverse to the beam where X-axis points into the center of the LHC ring and Y-axis is in upward direction.

Moreover, we can classify regions in the detector by using pseudorapidity: central region, $|\eta| < 2.5$, and forward region, $3.0 < |\eta| < 4.9$. In forward region, CMS has the forward hadronic calorimeter (HF) which consists of steel absorber and embedded radiation-hard quartz fibers providing fast collection of Cherenkov light. With this calorimeter, we can measure forward energy flow in this region.

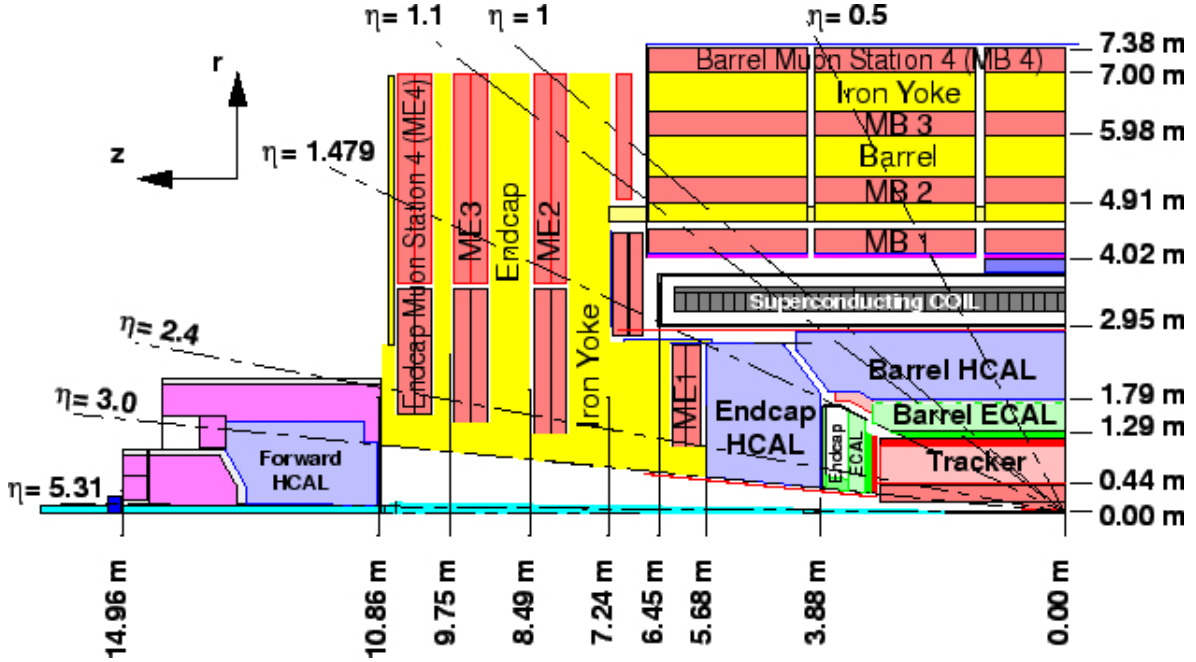


Figure 5: The longitudinal section of CMS detector

(<http://www.hephy.at/user/friedl/diss/html/node8.html>)

4 Event Selection

W and Z bosons are short-lived particles. They can decay in to stable particles in various ways. In quark channel, it is hard to identify where the jets come from. However, in lepton channel, the identification of W and Z bosons is based on the presence of isolated electrons or muons with high transverse momentum. The lepton channel is cleaner than hadron channel because it is easy to identify electrons and easier to identify muons in muon chamber.

For W boson events, the requirements are

1. One isolated lepton with a transverse momentum greater than 25 GeV and $|\eta| < 1.4$. Events with second isolated lepton with transverse momentum greater than 10 GeV are rejected.
2. The missing transverse momentum from escaping neutrino must be greater than 30 GeV.

Note that : we can get the missing transverse momentum from minus of summation of transverse momentum of all particle except neutrino because it does not interact with detector.

3. The transverse mass, $m_T = \sqrt{2p_T(l)p_T(\nu)(1 - \cos \Delta\phi)}$, of charged-lepton and neutrino must be greater than 60 GeV, where $\Delta\phi$ is different between azimuthal angle of lepton and neutrino.

Moreover, for Z boson events, the requirements are

1. Two isolated leptons with opposite charge and each with a minimum transverse momentum of 25 GeV.
2. At least one lepton with $|\eta| < 1.4$
3. The invariant mass of dilepton system must be between 60 and 120 GeV

5 Analysis

To simulate events with W and Z boson production, we use PYTHIA6 for Monte Carlo generator. Two tunes of PYTHIA 6 such as D6T, and Z2 are used in this project. The difference between these two tunes are multi-parton interaction parameters, such as energy dependence, and p_T cut off, etc. Moreover, for analysis events from MC generator, we use Rivet analysis. Our Rivet analysis code is divided into 3 parts. The first part is function `init()`, this is initial part which we use for booking histograms such as number of charged-particle in central region , initializing value such as number of W found in events, and declaring final-states that we are interested such as electrons, muons, charged-particle in central region and hadron in forward region.

The second one is function `analyze()`, this is analysis part which read events generated from MC generator. In this part, electrons and muons from final state that we declare

in function `init()` are investigated. If there are neither electrons nor muons in this event, it is rejected. Electrons and muons from final-state are used to reconstruct W and Z boson, if their properties agree with the selection criteria in section 4. After we identify the events with W or Z boson, we will find central charged-particles from charged final-state particle in central region and forward energy flow from summation of energy of all final-state particle except muons and neutrinos in forward region that we declare before and fill them in histogram corresponding to parameter that we are interested .

Finally, the last part is function `finalize()` which we use for scaling histogram . The analysis code that I wrote is found in section 8, appendix A.

After we write this code in C++ format, we compile it with Rivet command for building Rivet analysis. This command are shown below,

```
rivet-buildplugin RivetWZelectron WZelectron.cc .
```

To generate 200,000 events with center of mass energy 7 TeV with PYTHIA 6, we use the command below,

```
agile-runmc Pythia6:426 --beams=LHC:7000 -0 /tmp/chaemn/hepmc.fifo
-n 200000 --paramfile=fpythiaWenumunu.params & ,
```

where `fpythiaWenumunu.params` is parameter file where we can set parameters and can be found in section 9, appendix B. In this file, `MSEL = 11` and `12` are included for Z and W production, respectively. Moreover, we can tune PYTHIA 6 to be PYTHIA 6 D6T or Z2 by including `MSTP(5) = 109` or `343` in this file, and `hepmc.fifo` is the file that records events from MC generator.

After we run MC generator, then we compile Rivet for analysis events by using this command,

```
rivet --analysis=WZelectron /tmp/chaemn/hepmc.fifo
--histo-file=WZelectron_1.aida ,
```

where `WZelectron_1.aida` is the histogram file in AIDA format. Moreover, to plot this histogram file with data from CMS, we use

```
rivet-mkhtml WZelectron.aida:'Title=Data' WZelectron_1.aida:'Title=
PYTHIA 6' .
```

6 Results

To investigate underlying events from W and Z boson events, we study central charged-particle multiplicities and forward energy flow. For central region, as mentioned in section 3, there are silicon trackers for charged-particle tracking. Then multiplicities of charged-particle are gathered from this region. On the other hand, in forward region, it is hard to measure particle track. However, there are forward hadronic calorimeters in this region. Then we can measure particle energy in this region. Moreover, to compare with CMS data where we have only W events from electron, so, in this projects, we

investigate only W events from electron. In [1], they told that no difference between the results from W or Z from electrons or muons. Moreover, the main focusing of this project is described in forward energy flow section where we develop the cut-off energy technique to compare data gathered from detector level and the results generated from MC generator in hadron level.

6.1 Central charged-particle multiplicity

To investigate the multiplicities of charged-particle in central region, in this project, we use only events having W boson reconstructed from electron. When we get these events, multiplicities of charged-particle final state in central region with cut-off transverse momentum 1.0 GeV are found from size of charged final state projection that we declare before in function `init()` and `analyze()`.

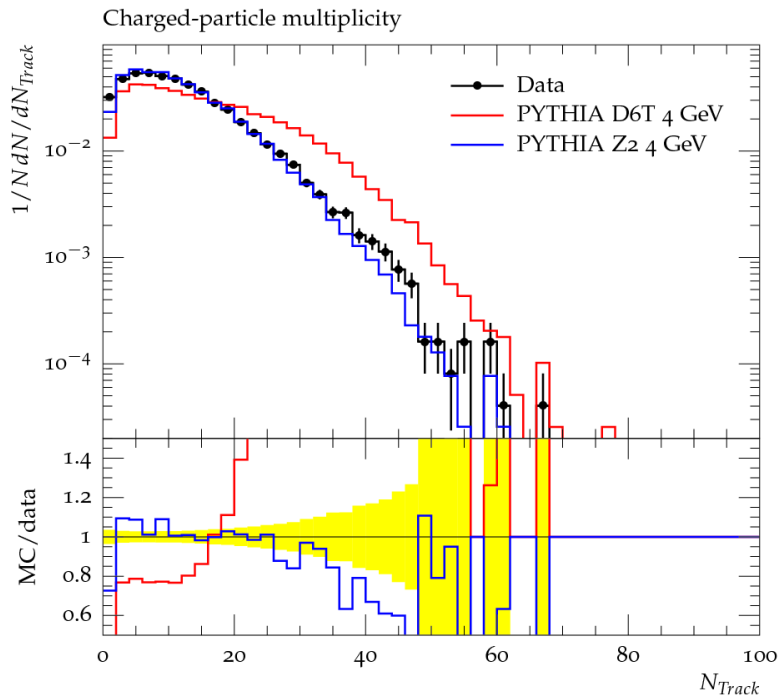


Figure 6: The central charge multiplicities from PYTHIA 6 with D6T and Z2 comparing to data from CMS

The histogram of central charge multiplicities from PYTHIA 6 with D6T, and Z2 and data from CMS is shown in figure 6. It shows that for PYTHIA D6T, it predicts too much events at large multiplicities. However, for PYTHIA Z2, the generator prediction is in reasonable agreement with data. The predictions from both of PYTHIA tunes are close to the prediction from full MC generator with the same PYTHIA tunes as you see in [1]

6.2 Forward Energy Flow

To investigate forward energy flow from generator level, in function `analyze()`, we have loops for summation of particle energies in forward region. Neutrinos and muons are excluded because neutrinos don't interact with detector and muons lose only a few percent of its energy in detector.

6.2.1 Correction Factor

In this project, as we mention before, we use PYTHIA 6 for MC generator at hadron level (no detector simulation), and data that we use for comparing are gathered from detector level. There is some disagreement between these two level. The solution of this problem is a correction factor for applying to hadron level before comparing to data from detector. There are two ways to apply the correction factors,

1. bin to bin correction where correction factors depend only pseudorapidity.
2. matrix correction where correction factors depend both of particle energy and pseudorapidity.

In this project, we apply only bin to bin correction. We get the correction factor from a thesis [3] and classify η into 5 regions as given in table 1

$ \eta $	Correction factor
3.1 - 3.5	0.80
3.5 - 3.8	0.98
3.8 - 4.2	1.03
4.2 - 4.5	1.01
4.5 - 4.9	0.79

Table 1: The correction factors for different pseudorapidity ranges

From the table 1, we see that for the outer ring, the correction factors are less than one, on the other hand, for inner ring, the correction factors are close to one. These effects come from various sources, such as, scattering from dead material, and deviation of the particle track into adjacent bin from magnetic field.

6.2.2 Cutoff Energy

The way that we use to improve the prediction from MC generator for getting close to data is to apply particle energy cutoff. The results with different energy cutoff are investigated in this section for both PYTHIA D6T and Z2.

The histogram of forward energy flow with data from PYTHIA D6T is shown in figure 7. As you see in this figure, the 12 GeV cutoff energy can describe well the data [1].

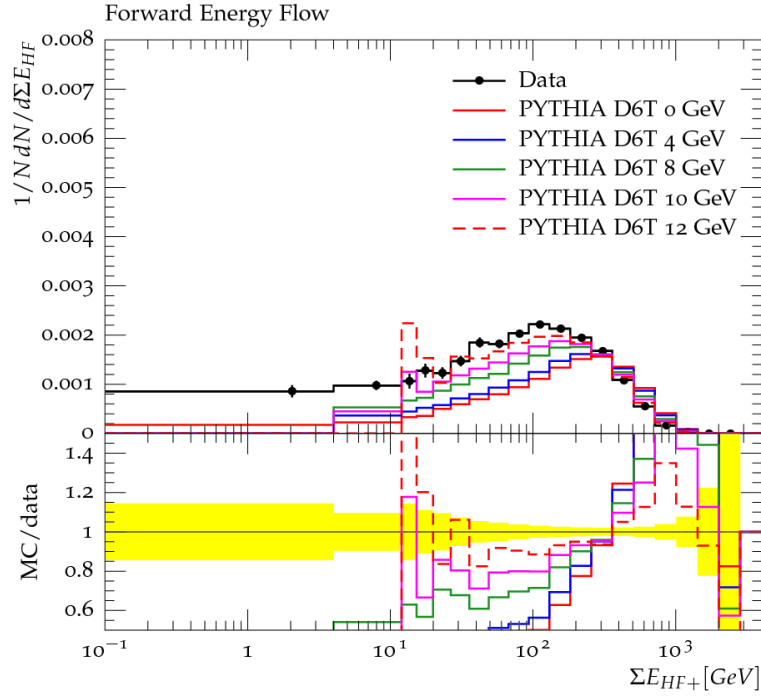


Figure 7: The histogram of forward energy flow generated from PYTHIA D6T with different particle energy cutoff

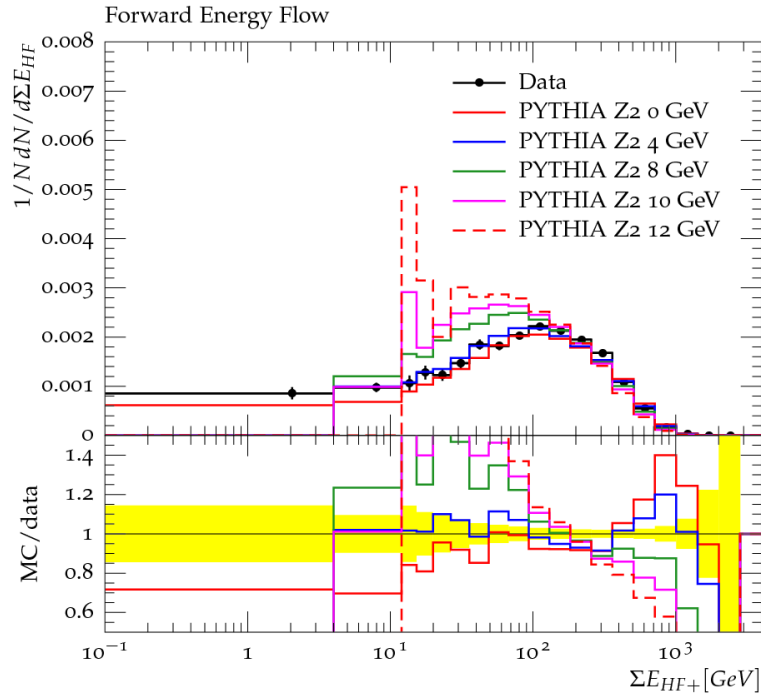


Figure 8: The histogram of forward energy flow generated from PYTHIA Z2 with different particle energy cutoff

On the other hand, for PYTHIA Z2 in figure 8, the low cutoff energy such as 0 and 4 GeV can give better agreement with the data rather than higher cutoff energy.

6.3 Correlation between central charge multiplicities and forward energy flow

To study the correlation between central charge multiplicities and forward energy flow, in this project, we divide the investigated quantities into 3 groups classified by energy deposition in negative eta ranges (HF-), where the negative sign comes from the sign of eta.

1. 20 - 100 GeV (low energy deposition)
2. 200 - 400 GeV (medium energy deposition)
3. more than 500 GeV (high energy deposition)

The central charge multiplicity histograms of three deposition groups are shown in figure 9, 10, and 11 for low, medium, and high energy deposition in HF-, respectively. From these three figures, we see that in low and medium energy deposition PYTHIA D6T and Z2 can give good description of the data. For high energy deposition, PYTHIA Z2 provides a good description, however, PYTHIA D6T predicts more events at large multiplicities.

For energy deposition in HF+, we use correction factors and cutoff particle energies for getting close to data and full MC prediction in [1]. The results from PYTHIA D6T are shown in figure 12, 13, and 14. For low energy deposition in HF-, all of cutoff energies except 12 GeV give a good description in energy deposition in HF+, on the other hand, for medium and high energy depositions in HF-, the description of data is poor. Although PYTHIA D6T tune can't give prediction for all energy depositions, it can predict close to full MC generator in reference paper [1].

For PYTHIA Z2, the results are shown in figure 15, 16, and 17. The histograms that all of energy deposition except 12 GeV provide good descriptions of data and are close to full MC generator, and PYTHIA Z2 can predict all of energy deposition.

To sum up, as you see in the previous section, the charge multiplicities in central region and energy flow in forward region are strongly correlated. More energy is deposited in HF+ as we increase the energy deposition in HF- and more charge multiplicities when the energy deposition in HF- increases.

7 Conclusion

Central charged-particle multiplicities, forward energy flow, and correlation between them in this project are studied in W boson events from electron by using the 2010 data sample of pp collision at 7 TeV. From the results in our study, we can conclude that for central charged-particle multiplicities, PYTHIA D6T predicts too much event at large

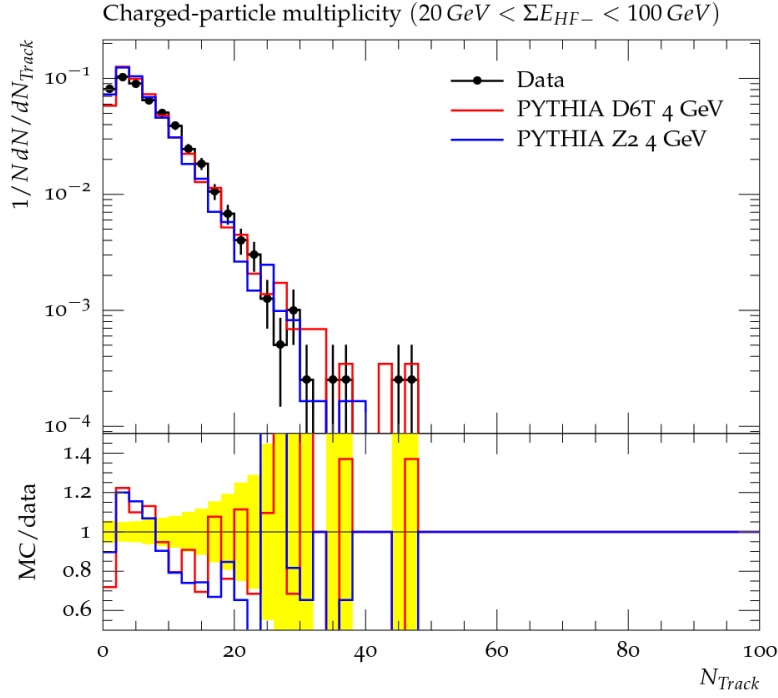


Figure 9: The central charged-particle multiplicity in low energy deposition

multiplicities, however, PYTHIA Z2 can give a good description of the data. Moreover, central charge multiplicities and energy deposition are strongly correlated; more charge multiplicities in higher energy deposition regions.

For forward energy flow, PYTHIA D6T with 12 GeV cutoff energy can describe reasonably well data. However, PYTHIA Z2 with 0 and 4 GeV cutoff energy can give reasonable description of data. On the other hand, for correlation between energy deposition in positive eta range and negative eta range, PYTHIA D6T can explain only low energy deposition. On the contrary, PYTHIA Z2 with all of cutoff energy except 12 GeV can describe data. Moreover, even if PYTHIA D6T cannot describe data in medium and high energy deposition, its as well as PYTHIA Z2 close to full MC generator in reference paper [1].

From this study, we have the way to get close to CMS data, by applying correction factor and appropriated cutoff particle energy.

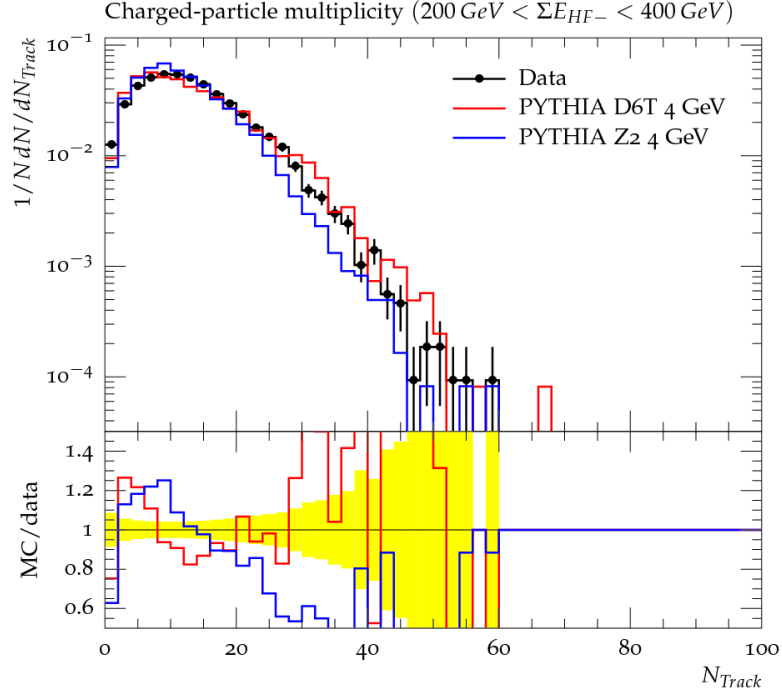


Figure 10: The central charged-particle multiplicity in medium energy deposition

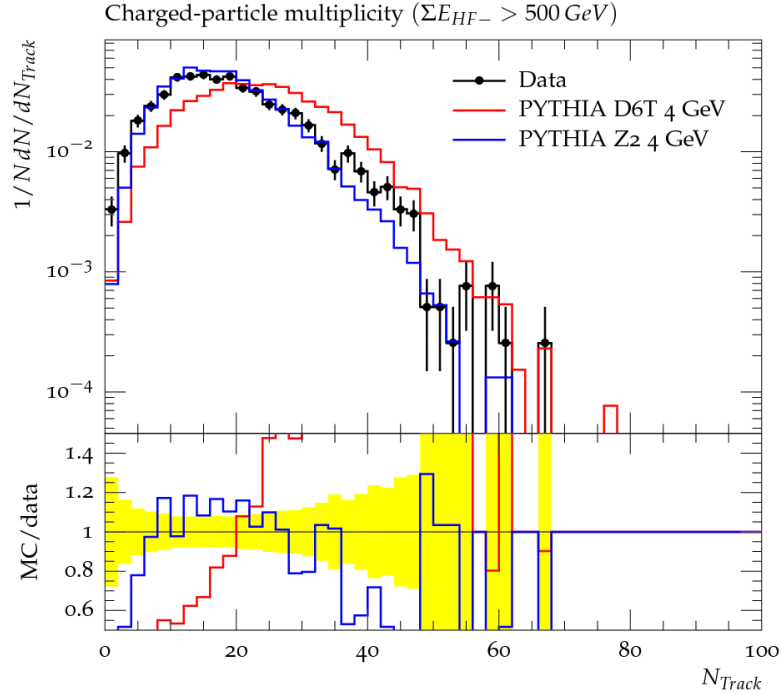


Figure 11: The central charged-particle multiplicity in high energy deposition

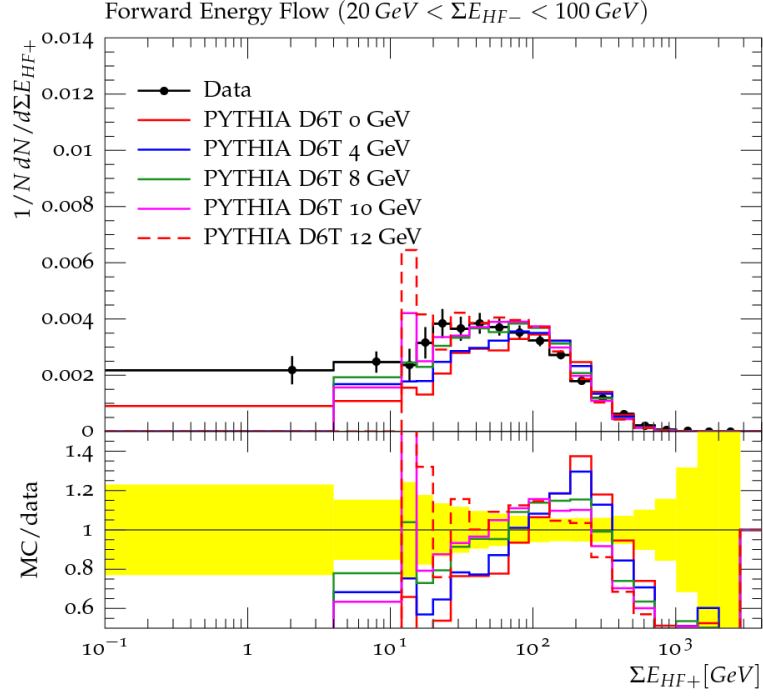


Figure 12: The forward energy deposition in HF+ in low energy deposition in HF-

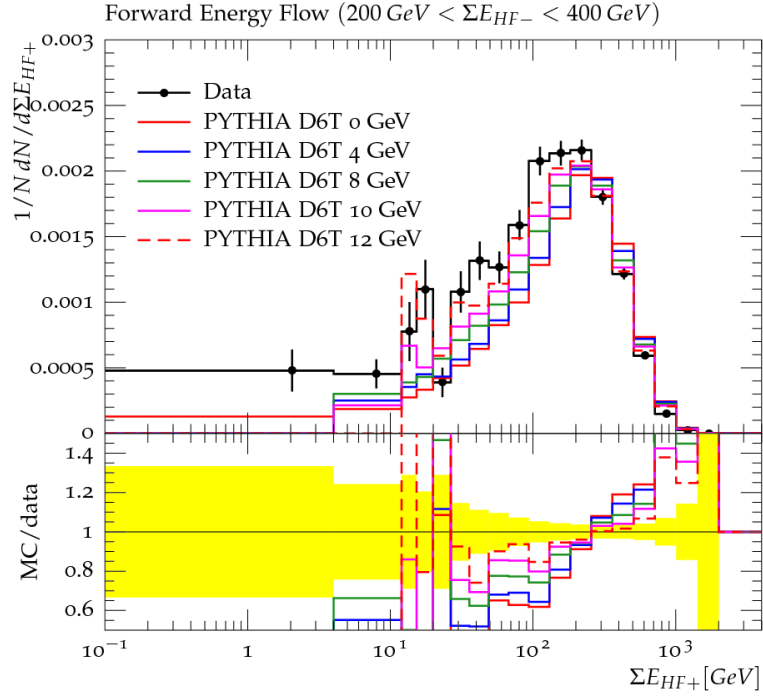


Figure 13: The forward energy deposition in HF+ in medium energy deposition in HF-

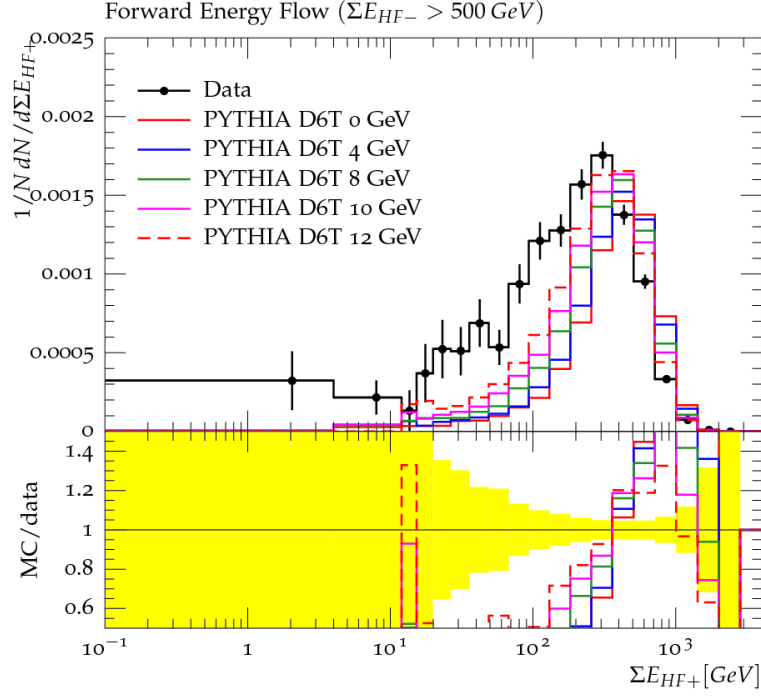


Figure 14: The forward energy deposition in HF+ in high energy deposition in HF-

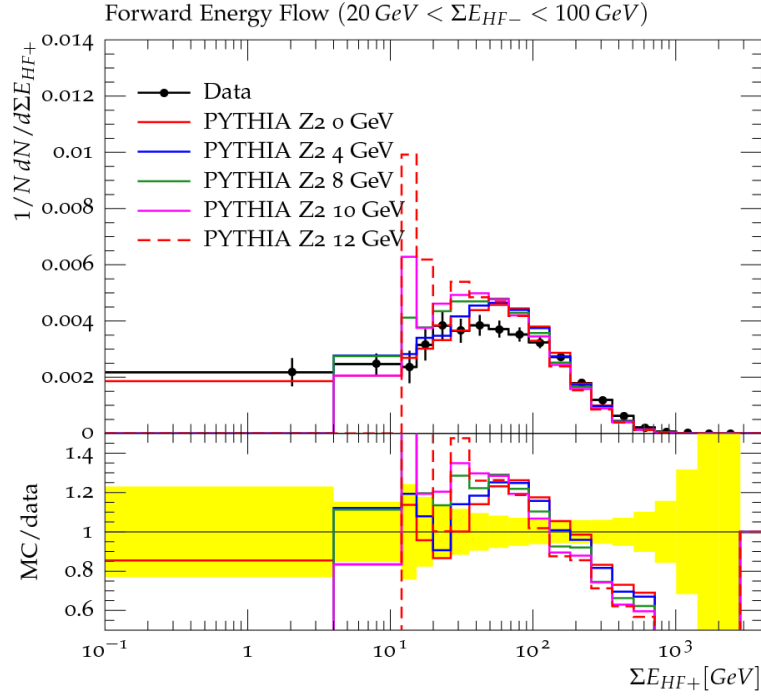


Figure 15: The forward energy deposition in HF+ in low energy deposition in HF-

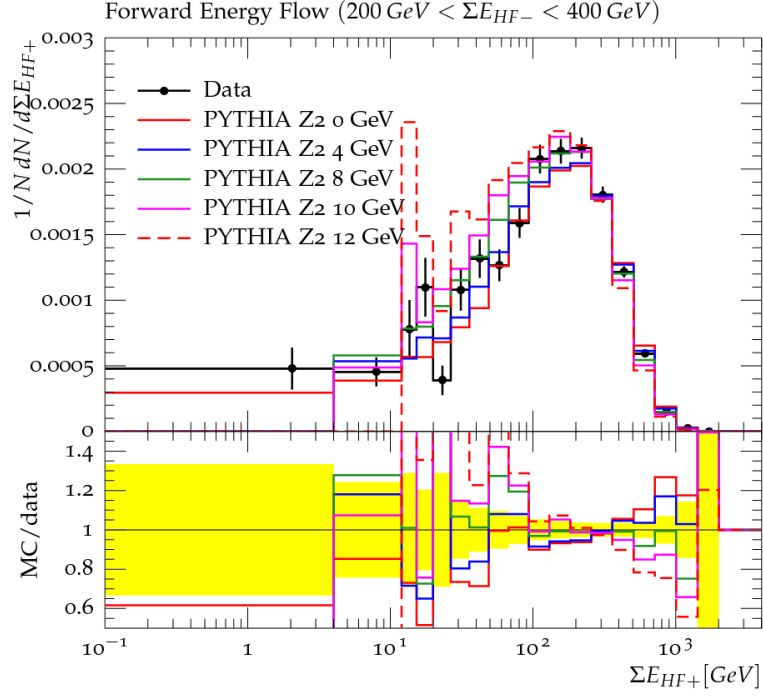


Figure 16: The forward energy deposition in HF+ in medium energy deposition in HF-

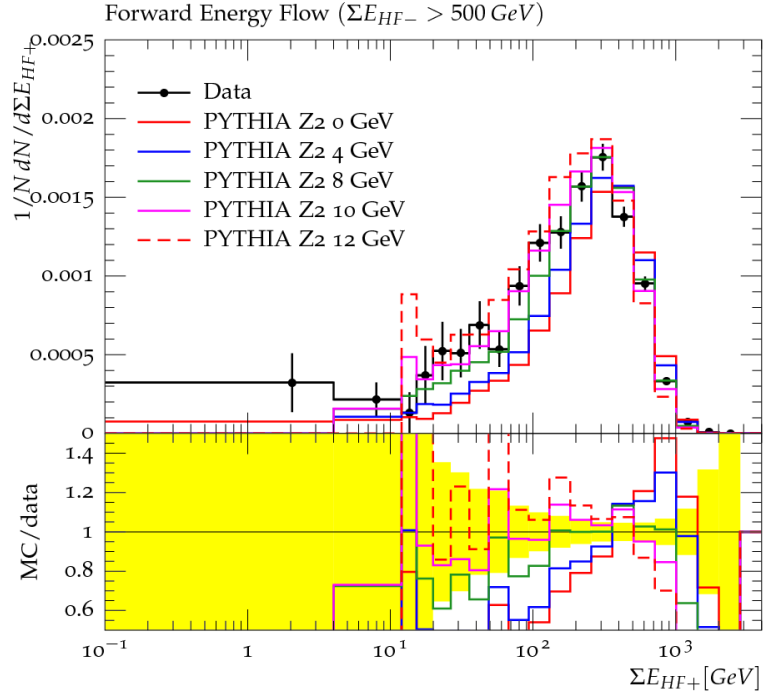


Figure 17: The forward energy deposition in HF+ in high energy deposition in HF-

8 Appendix A

```
// -*-WZelectron.cc-*-
// -*- Nipol Chaemjumrus (Ben), DESY summer student 2012, CMS group -*-
#include "Rivet/Analysis.hh"
#include "Rivet/Tools/Logging.hh"
#include "Rivet/RivetAIDA.hh"
#include "Rivet/Projections/ChargedFinalState.hh"
#include "Rivet/Tools/ParticleIdUtils.hh"
#include "Rivet/Projections/IdentifiedFinalState.hh"
#include "Rivet/Projections/VetoedFinalState.hh"
#include "HepMC/IO_AsciiParticles.h"

//This is the fuction to applt the correction factors at each eta bin
double correctEnergy(double Esim, double eta){
    double Ecorr;
    if(fabs(eta)>3.1&&fabs(eta)<3.5) Ecorr = 0.80*Esim;
    else if(fabs(eta)>3.5&&fabs(eta)<3.8) Ecorr = 0.98*Esim;
    else if(fabs(eta)>3.8&&fabs(eta)<4.2) Ecorr = 1.03*Esim;
    else if(fabs(eta)>4.2&&fabs(eta)<4.5) Ecorr = 1.01*Esim;
    else if(fabs(eta)>4.5&&fabs(eta)<4.9) Ecorr = 0.79*Esim;
    return Ecorr;
}

namespace Rivet {

class WZelectron : public Analysis{
public:
    WZelectron() : Analysis("WZelectron"){

        int    WbosonNum;    // for counting numbers of W bosons from generator
        double Weventweight; // for summation of total weight of w events
        double lowweight;    // for summation of weight in low energy depostion
        double midweight;    // for summation of weight in medium energy deposition
        double higweight;    // for summation of weight in high energy depostion

        void init(){ // This is initializing part

            WbosonNum = 0;
            Weventweight = 0.0;
            lowweight = 0.0;
            midweight = 0.0;
            higweight = 0.0;
        }
    }
};

}
```

```

//Central charged-particle multiplicity with pT greater than 1.0 GeV
ChargedFinalState ecfs(-2.5,2.5,1.0*GeV);
VetoedFinalState eecfs(ecfs);
eecfs.addVetoPairId(ELECTRON); // excluding electron from
addProjection(eecfs,"eCFS");    // charged-particle multiplicity

FinalState fs(-100.0,100.0,0.0*GeV);
addProjection(fs,"FS"); // projection of all final-state particle
VetoedFinalState vfs(fs); // for reconstructing neutrino
vfs.vetoNeutrinos(); // excluding neutrinos from final-state particle
addProjection(vfs, "VFS");

FinalState ffs(-4.9,4.9,0.0*GeV);
addProjection(ffs,"FFS"); // projection of particle that we use to
VetoedFinalState vffs(ffs); // find forward energy flow where we exclude
vffs.vetoNeutrinos(); // neutrino and muon in this final state
vffs.addVetoPairId(MUON);
addProjection(vffs, "VFFS");

FinalState cfs(-2.5,2.5,25.0*GeV);
addProjection(cfs,"CFS"); // projection of electron that we use to
IdentifiedFinalState efs(cfs); // reconstruct W boson
efs.acceptIdPair(ELECTRON);
addProjection(efs, "Electrons");

FinalState ee(-2.5,2.5,10.0*GeV);
addProjection(ee,"Elec"); // projection of second electron
IdentifiedFinalState eefs(ee); // if this size is not zero,
eefs.acceptIdPair(ELECTRON); // the event is rejected
addProjection(eefs, "Elecs");

// Charged-particle multiplicity histogram
_h_dE_dCH = bookHistogram1D(1,1,1);

// Forward energy flow histogram
_h_dE_dHFP = bookHistogram1D(1,1,2);

// Charged particle multiplicity
_h_dE_dCC_Low = bookHistogram1D(2,1,1); // for low energy deposition
_h_dE_dCC_Med = bookHistogram1D(2,1,2); // for medium energy deposition
_h_dE_dCC_Hig = bookHistogram1D(2,1,3); // for high energy deposition

// Forward energy flow
_h_dE_dHF_Low = bookHistogram1D(3,1,1); // for low energy deposition

```

```

_h_dE_dHF_Med = bookHistogram1D(3,1,2); // for medium energy deposition
_h_dE_dHF_Hig = bookHistogram1D(3,1,3); // for high energy deposition

// Particle enrgy spectrum
_h_dE_dE = bookHistogram1D("Particle_Energy",300,0.0,3000.0); // All range
_h_dE_dEP = bookHistogram1D("Particle_Energy_P",300,0.0,3000.0); //+eta range
_h_dE_dEM = bookHistogram1D("Particle_Energy_M",300,0.0,3000.0); //-eta range
}

void analyze(const Event& event){ // This is analysis part which reads event

    const double weight = event.weight(); // weight from this event

    // This is projection of electron that we use to check second electron
    //with pT > 10 GeV
    const FinalState& elec = applyProjection<FinalState>(event,"Elecs");

    // This is projection of central charged-particle state
    const FinalState& ecfs = applyProjection<FinalState>(event,"eCFS");

    //If there is second electron with pT> 10.0 GeV, event rejected
    if (elec.size()>1) vetoEvent;

    // This is projection of electron that we use to reconstruct W boson
    const FinalState& e = applyProjection<FinalState>(event,"Electrons");

    // looping
    foreach(const Particle& p, e.particles()){

        if(e.particles().size()>1); // rejected event with more than one electron
        else{
            const double pT = p.momentum().pT(); // pT of electron
            const double eta = p.momentum().eta(); // eta of electron
            const double PhiE = p.momentum().phi(); // azimuthal angle of electron

            if(fabs(eta)<1.4){ // choosing electron in this region

                //final-state particle for reconstructing neutrino from missing pT
                const FinalState& N = applyProjection<FinalState>(event,"VFS");

                FourMomentum spT(0,0,0,0); // constructing initial missing pT

                foreach(const Particle& pa, N.particles()){
                    spT += pa.momentum(); // summation of all particle momentum
                }
            }
        }
    }
}

```

```

} // except neutrino which we already exclude before
const FourMomentum MPT(0,-spT.px(),-spT.py(),0); // missing pT
double PhiN = MPT.phi(); // azimuthal angle of neutrino

//transverse mass of electron and neutrino
double TranMass = sqrt(2*(p.momentum().pT()*(MPT.pT())*
(1-cos(PhiE-PhiN))));

//events with missing pT > 30 GeV and mT > 60 GeV are selected
if(MPT.pT()>30.0*GeV && TranMass > 60.0*GeV){

    //final-state for measuring forward energy flow
    const FinalState& H = applyProjection<FinalState>(event,"VFFS");
    double eHFP,eHFM;
    eHFP =0.0; // energy deposition in positive eta range
    eHFM =0.0; // energy deposition in negative eta range

    //looping particle for forward energy deposition
    foreach(Particle ph, H.particles()){
        int charge = PID::threeCharge(ph.pdgId());
        double eph = ph.momentum().E(); // energy of particle
        double ptph = ph.momentum().pT(); // pT of particle
        double etaph = ph.momentum().eta(); // eta of particle
        if(ph.pdgId()!=-13||ph.pdgId()=-13); // excluding muon
        else{
            if((fabs(etaph)>3.1 && fabs(etaph)<4.9)){// central region
                if(correctEnergy(eph,etaph) >4.00*GeV){// cut off energy
                    _h_dE_dE->fill(correctEnergy(eph,etaph),weight);
                    if(etaph>0.0){ //choosing positive eta range
                        eHFP+=correctEnergy(eph,etaph); // sum particle energy
                        _h_dE_dEP->fill(correctEnergy(eph,etaph),weight);
                    }else{ // negative eta particle
                        eHFM+=correctEnergy(eph,etaph); // sum particle energy
                        _h_dE_dEM->fill(correctEnergy(eph,etaph),weight);
                    }
                }
            }
        }
    }
}

Weventweight+=weight; // sum of all weight
_h_dE_dCH->fill(ecfs.particles().size(),weight); //fill multiplicitty
_h_dE_dHFP->fill(eHFP,weight); // forward energy flow
if(eHFM > 20.0*GeV && eHFM < 100.0*GeV){// for low deposition

```

```

        lowweight+=weight;// sum of low energy deposition weight
        _h_dE_dCC_Low->fill(ecfs.particles().size(),weight);
        _h_dE_dHF_Low->fill(eHFP,weight);
    }else if(eHFM > 200.0*GeV && eHFM < 400.0*GeV){// for med-deposition
        midweight+=weight;// sum of medium energy deposition weight
        _h_dE_dCC_Med->fill(ecfs.particles().size(),weight);
        _h_dE_dHF_Med->fill(eHFP,weight);
    }else if(eHFM > 500.0*GeV){// for high energy depostion
        higweight+=weight;// sum of high energy deposition weight
        _h_dE_dCC_Hig->fill(ecfs.particles().size(),weight);
        _h_dE_dHF_Hig->fill(eHFP,weight);
    }
    WbasonNum++;// count numbers of W boson found in generator
}
}
}
}
}
}
}
}
}
}

```

```

void finalize(){ // finalize function
    std::cout << "Number of W-boson are " << WbasonNum << endl;//show # W boson
    const double normfac = 1.0/Weventweight;
    scale(_h_dE_dE,normfac);//scaling histogram
    scale(_h_dE_dEP,normfac);
    scale(_h_dE_dEM,normfac);
    scale(_h_dE_dCH,normfac);
    scale(_h_dE_dHFP,normfac);
    scale(_h_dE_dCC_Low,1.0/lowweight);
    scale(_h_dE_dCC_Med,1.0/midweight);
    scale(_h_dE_dCC_Hig,1.0/higweight);
    scale(_h_dE_dHF_Low,1.0/lowweight);
    scale(_h_dE_dHF_Med,1.0/midweight);
    scale(_h_dE_dHF_Hig,1.0/higweight);
}

```

private:

```

AIDA::IHistogram1D* _h_dE_dCH;
AIDA::IHistogram1D* _h_dE_dHFP;
AIDA::IHistogram1D* _h_dE_dE;
AIDA::IHistogram1D* _h_dE_dEP;
AIDA::IHistogram1D* _h_dE_dEM;
AIDA::IHistogram1D* _h_dE_dCC_Low;

```



```

        AIDA::IHistogram1D* _h_dE_dCC_Med;
        AIDA::IHistogram1D* _h_dE_dCC_Hig;
        AIDA::IHistogram1D* _h_dE_dHF_Low;
        AIDA::IHistogram1D* _h_dE_dHF_Med;
        AIDA::IHistogram1D* _h_dE_dHF_Hig;

};
// The hook for the plugin system
AnalysisBuilder<WZelectron> plugin_WZelectron;

}

```

9 Appendix B

```
//-*- fpythia-Wenumunu.params-*-  
## W+- decays to e nu_e and mu nu_mu (+ conjs) only  
MSEL = 12  
# dbar u  
MDME(190,1) 0  
# dbar c  
MDME(191,1) 0  
# dbar t  
MDME(192,1) 0  
# dbar t'  
MDME(193,1) -1  
# sbar u  
MDME(194,1) 0  
# sbar c  
MDME(195,1) 0  
# sbar t  
MDME(196,1) 0  
# sbar t'  
MDME(197,1) -1  
# bbar u  
MDME(198,1) 0  
# bbar c  
MDME(199,1) 0  
# bbar t  
MDME(200,1) 0  
# bbar t'  
MDME(201,1) -1  
# b'bar u  
MDME(202,1) -1  
# b'bar c  
MDME(203,1) -1  
# b'bar t  
MDME(204,1) -1  
# b'bar t'  
MDME(205,1) -1  
# e+ nu_e  
MDME(206,1) 1  
# mu+ nu_mu  
MDME(207,1) 1  
# tau+ nu_tau  
MDME(208,1) 0  
# tau'+ nu'_tau
```

```
MDME(209,1) -1
MSTP(5) = 109 # This line for D6T tune
MSTP(5) = 343 # This line for Z2 tune
```

References

- [1] Forward energy flow, central charged-particle multiplicities, and pseudorapidity gaps in W and Z boson events from pp collisions at $\sqrt{s} = 7$ TeV *The CMS Collaboration* Eur. Phys. J. C (2012) 72:1839
- [2] The CMS experiment at the CERN LHC. *The CMS Collaboration* J. Instrum. 0803, S08004 (2008).
- [3] Studies of W and Z Bosons with the CMS Experiment at the LHC. *Ann-Karin Nathalie Sanchez*