DESY Summer Student programme 2010 report

Diffractive W production in ATLAS
– preparations for asymmetry measurement

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September 9, 2010

Abstract

Parton distribution ratio in the proton can be given by asymmetry in differential cross sections of $W^{\pm}$ boson production in function of rapidity. In this work, which is the continuation of last year's summer study done by P. Banka, the search for improvements in $W^{\pm}$ rapidity reconstruction has been performed. Also certain difference between theoretical and Monte Carlo's predictions for cross sections of mentioned process has been found.

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1 Introduction

Measurement of W boson charge asymmetry in ATLAS may lead to improvements in determining PDFs. There are two main W production channels with different features that have to be distinguished: inclusive and diffractive one. The W boson is not observed directly, but only its decay products: lepton and a corresponding neutrino (in leptonic decay channel). Thus, to reconstruct W rapidity, one needs to obtain information about invisible neutrino. In this case two different methods were studied, both with limited efficiency.

2 Charge asymmetry in W production

W production charge asymmetry is defined as follows[1]:

$$A(y) = \frac{d\sigma_{W^+}(y) - d\sigma_{W^-}(y)}{d\sigma_{W^+}(y) + d\sigma_{W^-}(y)}, \tag{1}$$

where $d\sigma_{W^\pm}(y)$ is a differential cross section for $W^\pm$ production in function of its rapidity. Asymmetry in pp collisions occurs due to the fact that usually the d quark carries larger fraction of proton's momentum than the u quark. Parton distribution ratio can be expressed in terms of asymmetry (defined above) as:

$$\frac{d_p(x)}{u_p(x)} \simeq \frac{1 - A(y)}{1 + A(y)}, \tag{2}$$

where x is the Bjorken variable and d_p, u_p – d, u quark distribution. In particular, for $x \to 1$ the quark distributions, written in terms of the valence (val) and sea (sea) distributions

$$\begin{aligned} u_p(x) &= u_{val}(x) + u_{sea}(x), & u_p(x) &= u_{sea}(x) \\ d_p(x) &= d_{val}(x) + d_{sea}(x), & d_p(x) &= d_{sea}(x) \end{aligned} \tag{3}$$

are dominated by the valence distribution, and relation (2) becomes

$$\frac{d_{val}(x)}{u_{val}(x)} \simeq \frac{1 - A(y)}{1 + A(y)}. \tag{4}$$

From the above it is clearly visible that the $W^\pm$ charge asymmetry measurement may help to determine proton PDFs more precisely.

3 W production channels

3.1 Inclusive case

In inclusive case one deals with simple quark annihilation (fig.1). In performed analysis this process was considered the main background. Its cross section as a function of W rapidity is expected to be symmetric – fig.4(a).

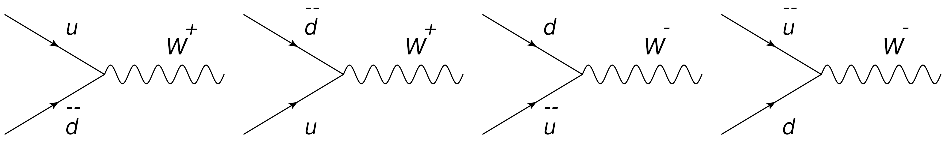


Figure 1: The leading order diagrams for inclusive $W^{\pm}$ boson production

3.2 Diffractive case

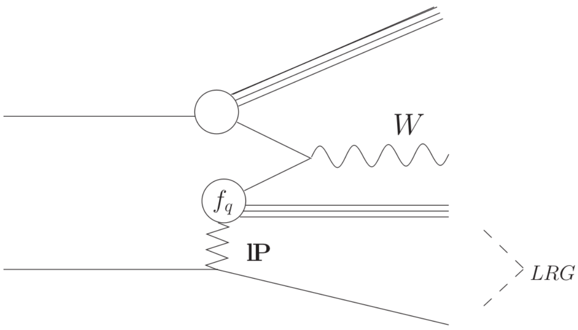


Figure 2: Diffractive $W^{\pm}$ production diagram

In the diffraction one has to deal with more sophisticated process shown in the fig.2. It is assumed that one of the colliding protons (diffractive one) emits a quantum object called pomeron ($\mathbb{P}$). The second proton interacts with this body producing W boson and particle showers. However, pomeron interaction leads to a large gap in rapidity (LRG) - no particles should be observed in the direction of diffractive proton remnant and the cross section for this process should be asymmetric – fig.5(a).

4 Theory and simulation comparison

In this section results from Monte Carlo generators - Pythia for inclusive and Pomwig for diffractive case - are compared with the theoretical predictions[1].

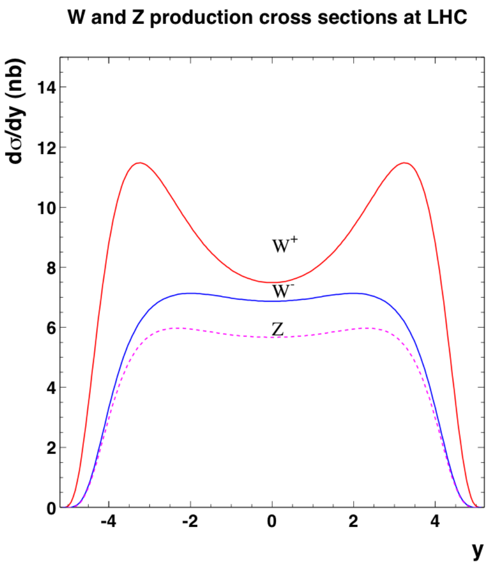
4.1 Inclusive case

Theoretical cross section in inclusive case is symmetrical and U-shaped in the middle (fig.4(a)). Positively charged W boson is produced more often because in pp colliders total charge in the collision is also positive. This result is qualitatively reproduced by Pythia (fig.4(b)).

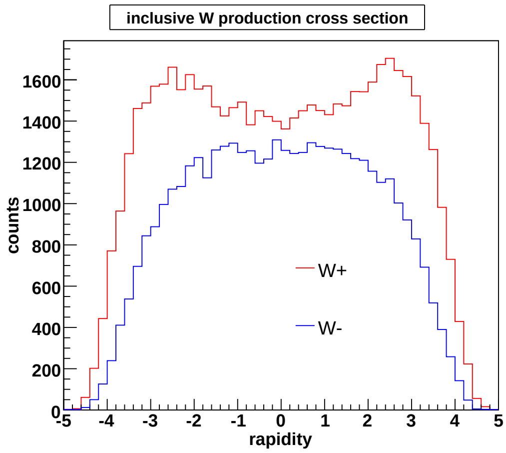
4.2 Diffractive case

Diffractive W production cross section is asymmetric (fig.5(a)). For negative rapidity there is a rapidity gap (negative z-axis direction is the diffractive proton direction). Two

Figure 3: Inclusive $W^{\pm}$ cross section theory and Pythia

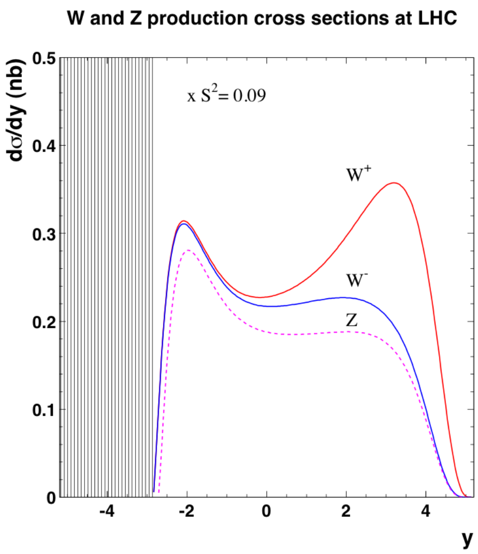


(a) Theory

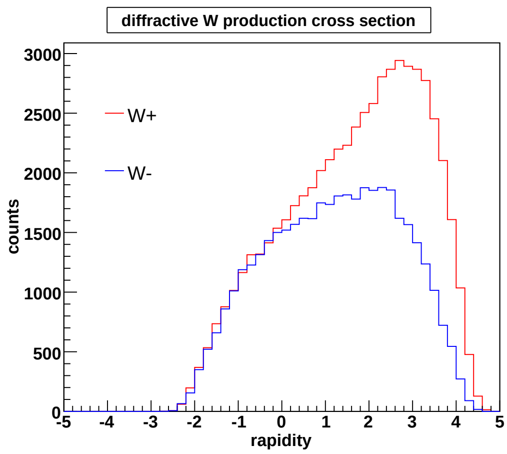


(b) Pythia

Figure 4: Diffractive $W^{\pm}$ cross section



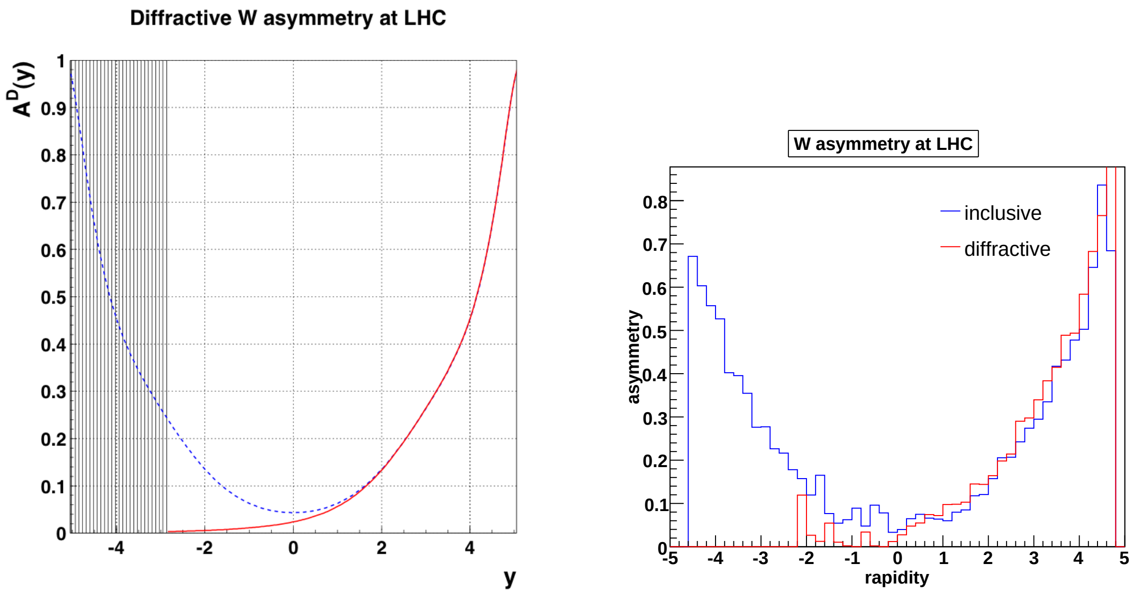
(a) Theory



(b) Pomwig

characteristic peaks are visible. This result is no longer so perfectly reproduced by Pomwig (fig.5(b)). The left peak is missing. The reason of the difference is not understood yet. Most probably it is due to different pomeron pdf setup. This inconsistency, however, does not harm the dependence for asymmetry (fig.5), as the ratio of W^+ to W^- production cross section remains the same.

Figure 5: Asymmetry at the LHC



(a) Theory

(b) Monte Carlo

5 Extracting signal

5.1 Simulated processes

Table 1 gives more detailed information about simulated processes. In both cases leptonic W decays were switched on. Another competitive process – photoproduction – is in this

MC Generator	Process	Cross section	Ratio
Pomwig	$p I\!P \to W^\pm \to l\nu_l$	1.97 nb	1
Pythia	$pp \to W^\pm \to l\nu_l$	35.6 nb	18

Table 1: Simulated processes

case negligible[2]. However, it is clear, that our signal (Pomwig) due to its relatively small X-section should be covered by the background (Pythia).

5.2 Standard cuts

Standard cuts applied to select the lepton from W decay were the following:

- lepton isolation condition: $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} \geq 0.4$ (there should be no other particles within the cone of radius 0.4)
- lepton's $p_\perp > 20\frac{\mathrm{GeV}}{\mathrm{c}}$
- $\not{E}_\perp > 20$ GeV
- an assumption of back to back decay in the W rest frame $(\pi - \angle(p_{\perp lep}, \not{p}_\perp)) < 1$ rad.

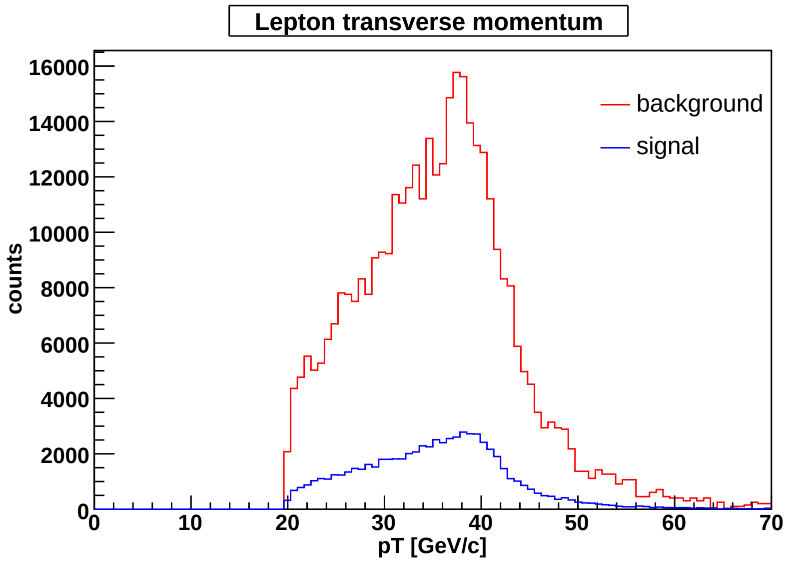
Also ATLAS geometrical acceptance had to be imposed:

- for leptons: $|\eta| < 2.5$ (ATLAS inner tracker cut)
- for hadrons: $|\eta| < 5.0$ (ATLAS calorimeter cut).

5.3 ATLAS forward detectors

The fact of covering signal by the background is shown in the fig.6. One can distinguish

Figure 6: Electron's transversal momentum as an exemplary observable



signal from background by means of ATLAS forward detectors[2]. Their acceptances are given by relative energy loss

$$\zeta = \frac{E_P - E_{P'}}{E_P}, \tag{5}$$

where E_P and $E_{P'}$ are proton's energy before and after collision. There are two forward detectors foreseen: at 240 and 420 m from the collision point (planned to be mounted during the ATLAS upgrade), with specific acceptances:

- RP240 (ALFA) – $0.02 < \zeta < 0.2$
- RP420 – $0.002 < \zeta < 0.02$

The fig.7 shows that the diffractive proton leaves a clear signal in a forward detector. Thus, a straightforward method of identifying the diffractive W production has been obtained.

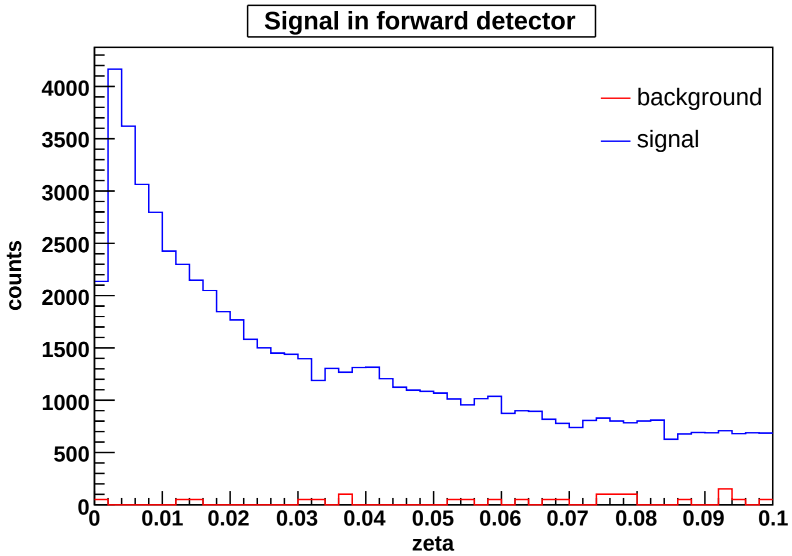


Figure 7: Signal in ATLAS forward detectors

6 W Rapidity reconstruction

To determine W boson rapidity

$$y = \frac{1}{2} \ln \frac{E + p_{\|}}{E - p_{\|}} \tag{6}$$

one needs its values of energy and longitudinal momentum. W is not observed directly, but only products of its decay, which in this case are a lepton and a corresponding neutrino (fig.8). After imposing standard cuts proper lepton is selected. Information about neutrino can be procured from missing momentum $\not{p}$ within the event. There are

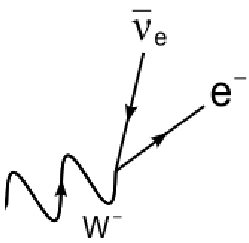


Figure 8: W leptonic decay

no difficulties in determining neutrino's transversal momentum $p_\perp^\nu$. However, significant fraction of longitudinal momentum is carried away by particles escaping into the beam pipe. Because of this, missing longitudinal momentum $\not{p}_{\parallel}$ does not agree any more with neutrino's $p_{\parallel}^{\nu}$. This way, the problem of finding W rapidity boils down to determining neutrino's longitudinal momentum $p_{\parallel}^{\nu}$. Two different methods were applied to solve this task.

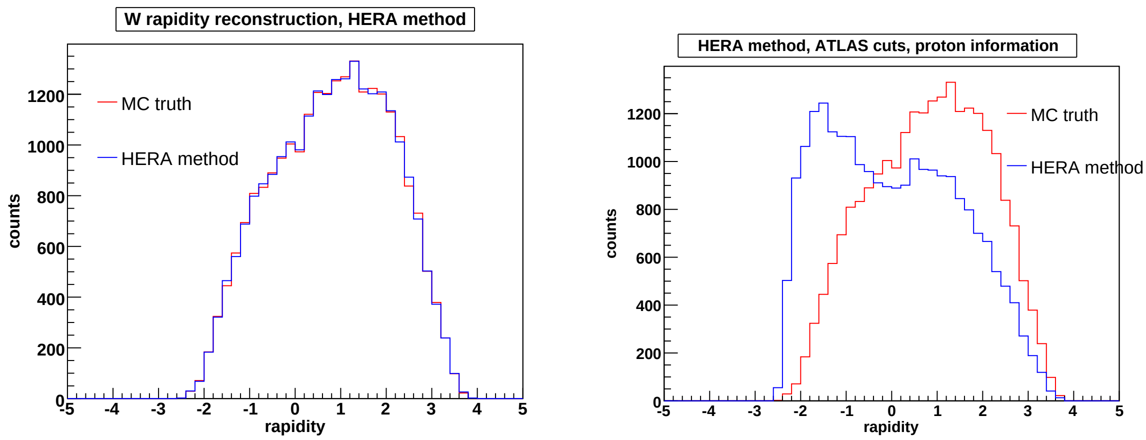
6.1 The HERA method

The HERA method, or so called "$E - p_z$ balance", allows to neglect particles going in positive z-axis direction with large rapidities by calculating the sum:

$$\sum(E - p_z), \tag{7}$$

over all visible particles. It should equal collision energy *i.e.* $2E_0$, where E_0 is the colliding proton's initial energy. The contribution to this sum from the particles running into the beam pipe with positive momenta is negligible. Thus, the fact that they escape should not harm our result. Note that also "$E + p_z$ balance" could be used to get rid of particles going in the other direction, but it is impossible to neglect both cases simultaneously. This is why this method works in asymmetric cases such as the one at HERA (most particles run in proton's direction) and is supposed to work in the diffractive case in ATLAS (most particles in non-diffractive proton's direction). If additionally we use information about diffractive proton's energy from forward detectors, we may hope to get some information about neutrino's longitudinal momentum. In fig.10(a) one may see that the method

Figure 9: The HERA method



(a) Without neutrinos only

(b) After ATLAS cuts

works without geometrical cuts. After imposing ATLAS geometrical acceptance cuts, one observes significant discrepancies between true and reconstructed longitudinal momentum of neutrino even after assumption that the energy of diffractive proton is known from the forward detectors (fig.10(b)).

6.2 The invariant mass method

Another method uses the fact that the sum of lepton's and neutrino's four momenta squared gives the W invariant mass squared:

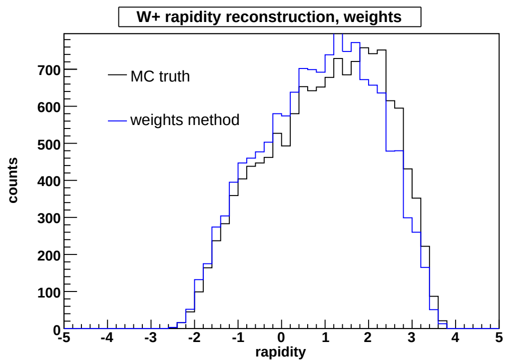
$$M_W^2 = (E^l + E^\nu)^2 - (\overrightarrow{p}^l + \overrightarrow{p}^\nu)^2. \tag{8}$$

The equation above, however, leads to two physical solutions for $p_\parallel^\nu$, which give rise to two solutions for W rapidity. This two-fold ambiguity was attempted to be solved on a statistical basis. Using theoretical cross sections of $W^\pm$ production in function of rapidity one weight

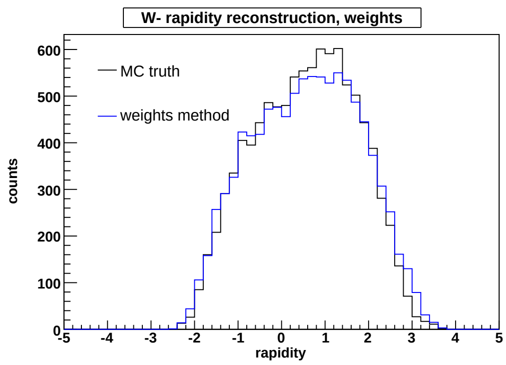
$$w_{1,2}^\pm = \frac{d\sigma_{1,2}^\pm}{d\sigma_1^\pm + d\sigma_2^\pm} \tag{9}$$

was ascribed to each solution $y_{1,2}$. Then the solution was randomly chosen with respect to these weights. Fig.10 shows the efficiency of this method. Although there is still some

Figure 10: The weights method



(a) W^+



(b) W^-

divergence with the MC truth, the W rapidity is relatively well reconstructed.
More sophisticated expressions for the weights have been applied at the Tevatron[3] in inclusive case, including cross sections from MC@NLO and calculations at NNLO. The misidentification rate in this case ranges from (0.18±0.05)% for $|\eta| < 1.1$ to (17.26±2.02)% for $|\eta| > 2.04$[4]. Unfortunately, analogous calculations for the ATLAS diffractive case have not been done yet.
In addition, it is worth mentioning that in the meantime another method in guessing the correct solution of the equation (8) is being developed. Namely with the use of neural network. Although this research is in the early stage of development, the accuracy reaches already 92%.

7 Conclusions

The measurement of diffractive W boson production in ATLAS may lead to improvements in proton PDFs. Inconsistency in theoretical predictions and Pomwig MC results for cross section of this process awaits the solution. The best way to derive signal of considered process from the background is to use ATLAS forward detectors. Even with the use of forward detectors the HERA method of W rapidity reconstruction does not work in ATLAS case. Better results are given by weights method. However, it still requires development similar to the work done at the Tevatron for inclusive case. In particular, additional calculations at NNLO are necessary. Using neural network can also help to reconstruct proper W rapidity and will be performed in parallel.

References

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8 Acknowledgments

I would like to thank Ewelina Lobodzinska for scientific supervision and valuable help in this work. I am also grateful to the DESY team for enabling me to gain experience during summer school and spend great time with people from various countries.