



New Observable for the $t\bar{t}$ Asymmetry Measurement in ATLAS

Natascha Rupp, University of Heidelberg, Germany

September 4, 2013

Abstract

The analysis of the forward-backward asymmetry in the dileptonic channel in $t\bar{t}$ events is presented using events on truth and reconstructed level for pp collisions at $\sqrt{s} = 7$ TeV collected by the ATLAS detector. The CDF and DØ Collaboration at the Tevatron measured recently an asymmetry larger than the Standard Model prediction in $p\bar{p}$ collision. In order to investigate a comparable forward-backward asymmetry A_{FB} in pp collisions at the LHC we introduced the variable FBrp. The value of A_{FB} for events in MC truth agrees well with the expectation whereas the analysis of events after reconstruction requires further investigation.

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1. Introduction

This is the report of the work that I've done during the Summer Student Program at DESY in Hamburg in the Summer of 2013. I did some research about the so called forward-backward asymmetry A_{FB} (fb-asymmetry) which appears in the production of top-antitop quark pairs. It describes the phenomenon by which the top and antitop are produced anisotropically with respect to the direction of the initial quark. The asymmetry is defined to be positive when the top quark is emitted preferentially in the direction of the incoming quark. The Standard Model predicts an asymmetry of $A_{\text{FBSM}} = (8.8 \pm 0.6)\%$ [1] but recent measurements at the Tevatron (a proton-antiproton collider) were not in complete agreement with the prediction [3]. The CDF Collaboration measured $A_{\text{FBCDF}} = (15.8 \pm 7.2 \text{ (stat.)} \pm 1.7 \text{ (syst.)})\%$ with a sample corresponding to an integrated luminosity of 5.3 fb^{-1} [2]. The DØ Collaboration determined a $A_{\text{FBDO}} = (19.6 \pm 6.0^{+1.8}_{-2.6})\%$ using 5.4 fb^{-1} data [2]. This strongly demands for confirmation in other measurements since it could be a hint that there is physics which is not described by the Standard Model so far.

At first I will give an introduction about the top quark and its decay properties. Then I will explain the asymmetry in general and fb-asymmetry measurement at the Tevatron. With this in mind it will be clearer to understand the measurement at the LHC. After the corresponding explanation of the asymmetry measured at the LHC I will describe the new observable FBrp that we introduced for the $t\bar{t}$ fb-asymmetry measurement in ATLAS. In the next part, I will show the A_{FB} in Monte Carlo (MC) events at the truth level and after reconstruction. In the end I will briefly summarize my work.

2. The Top Quark

2.1. Production of the Top Quark

The top quark was discovered in 1995 by the CDF and DØ Collaborations at the Tevatron. With the current state of knowledge it is the heaviest elementary particle with a mass of $m_t = (173.2 \pm 0.51(\text{stat.}) \pm 0.71(\text{syst.})) \text{ GeV}/c^2$ [11]. Due to this very high mass it decays really rapidly with a lifetime of $\tau_t = 5 \cdot 10^{-25} \text{ s}$ and hence the strong force has no time to affect it and form bound states [4].

The top quarks are mostly created in pairs by strong interaction or as single top quarks through weak interaction. We just consider the strong production mechanism. At leading order in QCD the top-antitop pair is created via the annihilation of a quark and an antiquark or the fusion of two gluons. At the Tevatron with $\sqrt{s} = 1.96 \text{ TeV}$, the cross section of top quark pair production is $\sigma = 7.46^{+0.48}_{-0.67} \text{ pb}$ at a top mass of $m_t = 172.5 \text{ GeV}$ [5]. At the LHC at $\sqrt{s} = 8 \text{ TeV}$ it is roughly twenty times larger with $\sigma = 164.6^{+11.4}_{-15.7} \text{ pb}$ [5].

2.2. Decay of the Top Quark

In the Standard Model the top quark decays almost 100 % of the time into a b quark and a W boson. The top-antitop pair will thus most likely decay into a W^+ and W^- boson and a b and \bar{b} quark. The subsequent decay possibilities of these particles are shown in Fig. 1. One option is that both of the W bosons decays into charged leptons and the corresponding neutrinos (dilepton channel). Another possibility is that just one of the W bosons decay into a charged lepton and a neutrino and the other one into quarks (lepton + jets channel). The third alternative is that both W bosons decay into quarks (all hadronic channel). The quarks will fragment and be detected as jets in the detector.

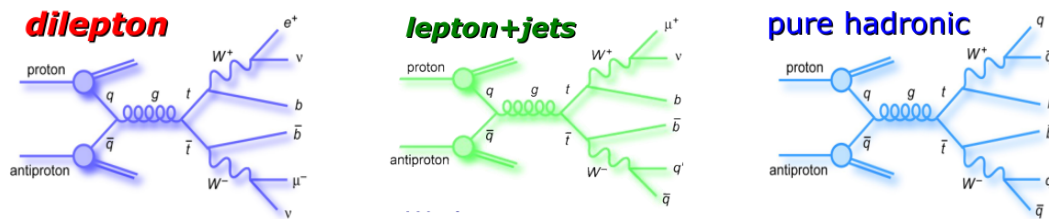


Figure 1: The decay of $t\bar{t}$ into either dilepton, leptons + jets or all hadrons in the final state [5].

Figure 2 shows the branching ratios of the different decay channels. The event selection is done according to the kinematics and topology of the events. The selection criteria for the all hadronic decay mode is the detection of at least six jets [5]. The background for

this decay channel is high making an reconstruction of top quark pairs complicated [10]. The selection conditions for the channel lepton + jet are the detection of one isolated lepton and at minimum four jets. The missing transverse energy E_T^{miss} of the neutrino is determined by energy conservation which holds in the transverse plane of the detector. The charged lepton in the final state is easier to reconstructed than the hadronically decaying top quarks. One limits oneself to the detection of electrons and muons for the analysis. The decay channel dilepton has the smallest contribution to the total decay cross section and is constituted by two leptons, two jets and a high missing transverse energy E_T^{miss} from the non detected neutrinos. The background contribution are rather low in this channel which makes it interesting to study. We will use this channel for the analysis presented in this report.

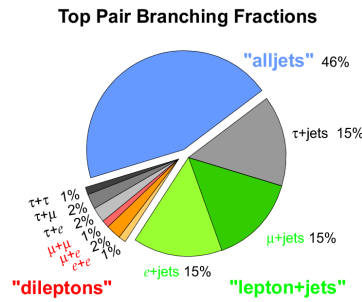


Figure 2: Branching fractions of top quark pair decay [9].

3. Asymmetry of the $t\bar{t}$ Pair



Figure 3: Tree and box diagram [10].

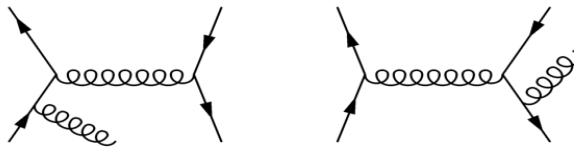


Figure 4: Diagram of initial and final state radiation [10].

At leading order (LO) in QCD no asymmetry is present. The process of $q\bar{q} \rightarrow t\bar{t}$ is similar to $e^+e^- \rightarrow \mu^+\mu^-$ at LO in QED. No asymmetric term in the differential cross section appears and no forward-backward asymmetry. In the next-to-leading order in QCD a positive asymmetry appears [4]. The asymmetry is driven by the interference of tree and box diagrams, shown in Fig. 3, or the interference between diagrams with the radiation of a gluon in the initial and final state, which is shown in Fig. 4. The asymmetry appears in an anisotropical decay of top and antitop. The top quarks is preferentially emitted into the direction of the initial quark and the antitop is more likely emitted into the direction of the incoming antiquark [6].

3.1. Asymmetry Measurement at the Tevatron

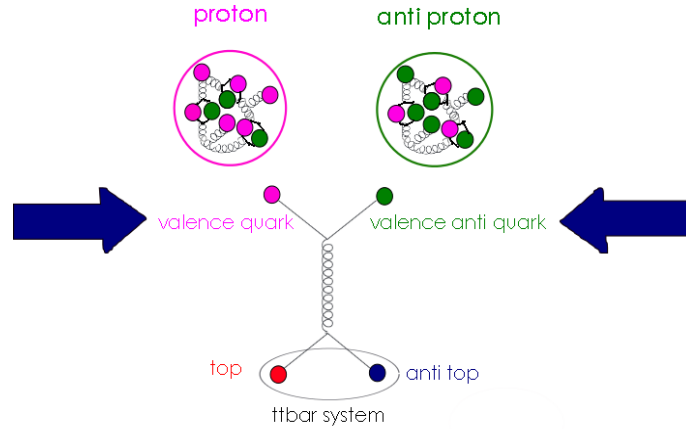


Figure 5: Collision of proton and antiproton at Tevatron and the $t\bar{t}$ production.

The Tevatron was a particle accelerator at the Fermi National Accelerator Laboratory close to Chicago in the United States. It collided protons, made up of quarks with antiprotons, made up of antiquarks at a center-of-mass energy of $\sqrt{s} = 1.96 \text{ TeV}$ [3]. In the top quark pair production at lowest order in QCD, the process $q\bar{q} \rightarrow t\bar{t}$ contributes to 85 % to the total production whereas $gg \rightarrow t\bar{t}$ arises just in 15 % of the cases [4]. We will just consider the quark annihilation process in the following because the fusion of the gluons does not contribute to the asymmetry. The probability for top quark pair production is much higher for valence quarks than for sea quarks. That is why most likely a valence quark from the proton and a valence antiquark originating from the antiproton annihilate as shown in Fig. 5 [6]. The cross section is $\sigma = 7.46^{+0.48}_{-0.67} \text{ pb}$ at a top mass of $m_t = 172.5 \text{ GeV}$ [5]. The Parton Distribution Function (PDF) is the same for the quarks in the proton and the antiquarks in the antiproton. That means that they are carrying on average the same momentum fraction. Due to momentum conservation the $t\bar{t}$ system

will thus on average not have a preferred direction in space as shown in Fig. 6. The asymmetry is translated in a forward-backward asymmetry which was measured so far by the CDF and DØ Collaboration at the Tevatron.

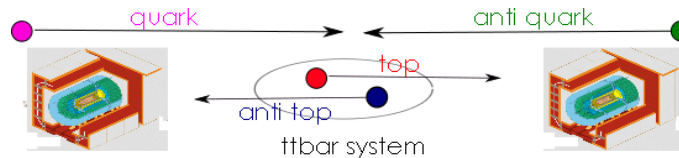


Figure 6: At the Tevatron the $t\bar{t}$ system is on average at rest after the collision of the protons and antiprotons at the Tevatron. The top and antitop are more likely emitted into the direction of the initial quark and antiquark, respectively.

We define the rapidity

$$y = \frac{1}{2} \cdot \ln \left(\frac{E + p_z}{E - p_z} \right) \quad (3.1)$$

where E is the energy and p_z the three-momentum of the particle in z -direction, in this case the top and the antitop. Without a forward-backward asymmetry one would expect a distribution centered around zero similar to the one in the illustration of Fig. 7. One could define the direction of flight of the valence quark towards positive rapidity values in the detector and the direction of flight of the anti-valence quark into the opposite direction. In the case of a positive fb-asymmetry one measures a rapidity distribution similar to the example in Fig. 8. Due to the asymmetry, the distribution of top and antitop is split up and the one of the top is shifted towards positive values of rapidity whereas the distribution of the antitop becomes more negative.

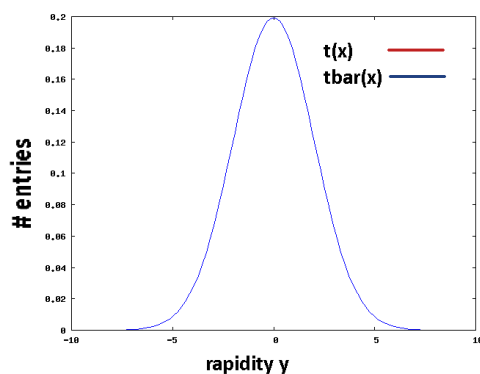


Figure 7: Illustration for rapidity distribution of top and antitop without the asymmetry.

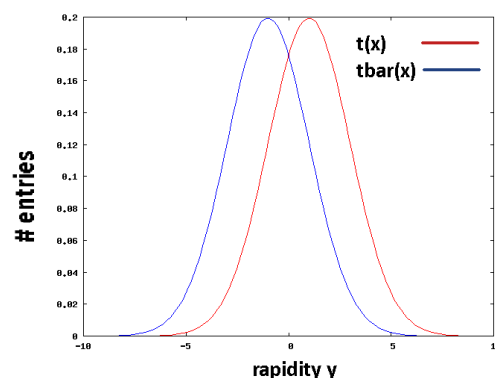


Figure 8: Illustration for rapidity distribution of top and antitop with the asymmetry.

3.2. Asymmetry Measurement at the LHC

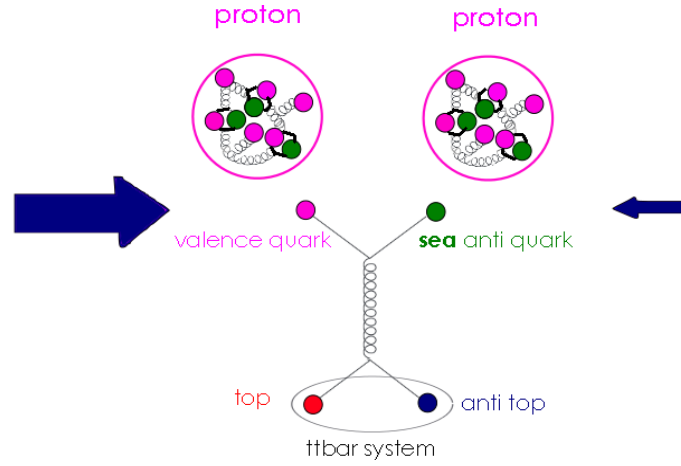


Figure 9: Collision of proton and proton at LHC and the $t\bar{t}$ production.

At the Large Hadron Collider (LHC) located at CERN near Geneva in Switzerland two beams of protons are collided with $\sqrt{s} = 7 \text{ TeV}$ (in 2011). This initial symmetric state causes differences in how to investigate the asymmetry compared to the method at the Tevatron. One of the differences is that the amount of $t\bar{t}$ pairs originating either from $q\bar{q}$ annihilation or from gg fusion is now reversed with just 15 % for the $q\bar{q}$ annihilation and 85 % for the gluon fusion. This causes an alleged decrease in the number of asymmetric distributed top and antitops which is lessened by the high cross section for top pair production at the LHC. The second difference in comparison with Tevatron is that since just protons are collided no valence antiquarks are available any more. That is the reason why antiquarks from the sea are involved in the top pair production. Sea quarks are carrying a lower momentum fraction than valence quarks and thus the $t\bar{t}$ system will not be at rest anymore as seen in Fig. 9. We made the assumption that the most probable direction of flight is the same as the one from the initial valence quark due to its higher momentum and we will review this assumption later on again.

In Fig. 11 the distribution of top and antitop is again shown for the case of no asymmetry. The $t\bar{t}$ system is boosted strongly into the direction of the initial valence quark which becomes apparent in highly positive or negative values of the rapidity measured by the detector. This boost can be either to the left or to the right in the detector system, depending from which proton the valence quarks originates. Without an asymmetry the $t\bar{t}$ system decays isotropically. Adding up these two effects would lead again to a distribution symmetric around zero and shown in the illustration in Fig. 11. Given a positive asymmetry the momentum direction of the top quark is more likely into the same direction as the one of the incoming quark. Since the entire $t\bar{t}$ system is already flying into

this direction, these two effects are adding up and the top will be emitted towards even higher rapidity values. This results in a broadened top rapidity distribution as seen in the example of Fig. 12.

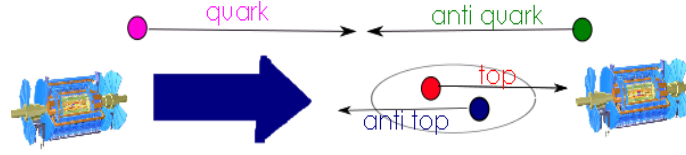


Figure 10: At the LHC, the $t\bar{t}$ system is more likely flying into the same direction as the incoming valence quark. The top and antitop are more likely emitted into the direction of the initial quark and antiquark, respectively.

The discrepancy between the one of the top and antitop is called the *charge asymmetry* which is also a possible way of investigating this phenomenon. The measurement of this charge asymmetry is also a recent topic of research at the LHC, but not comparable directly to the fb-asymmetry measured at the Tevatron, even though it is based on the same origin [7]. My work was to investigate if we could measure in ATLAS an asymmetry similar to the fb asymmetry, as is suggested by some theorists [12]. In order to measure a fb-asymmetry we had to find a new method to make it again visible. This will be explained in more detail in the next section.

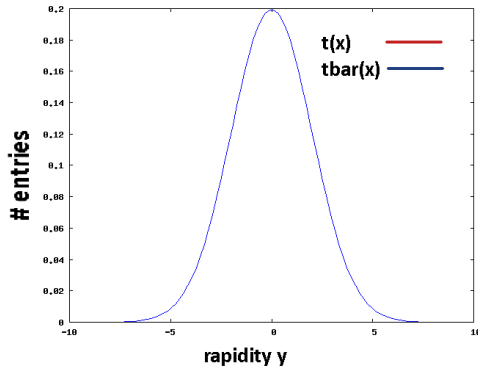


Figure 11: Illustration for rapidity distribution of top and antitop without the symmetry.

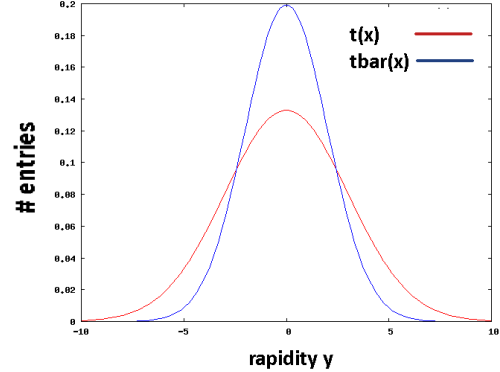


Figure 12: Illustration for rapidity distribution of top and antitop with the asymmetry.

3.3. The new Observable FBrp and the Determination of the FB-Asymmetry A_{FB}

The observable FBrp is defined as

$$FBrp = y_t \cdot \text{sign}(\beta_{\bar{t}\bar{t}Z}) \quad (3.2)$$

where y_t is the rapidity of either the top or antitop measured in the $\bar{t}\bar{t}$ rest frame system and $\beta_{\bar{t}\bar{t}Z} = v_z/c$ is the boost of the $\bar{t}\bar{t}$ system (v_z is its velocity in beam-direction and c the speed of light).

In order to measure the asymmetric distributions of the top and the antitop, one needs to know their rapidity relative to the initial quark direction. Since two beams of protons are collided, the high momentum valence quark could in principle originate from either of them. Hence its direction is not known and we have also no possibility to extract this information directly. The only thing we can measure is the direction of the boost $\beta_{\bar{t}\bar{t}Z}$ of the $\bar{t}\bar{t}$ system, by taking its sign. We made the assumption that the $\bar{t}\bar{t}$ system has the same direction as the incoming quark.

Besides this we determine the rapidity y_t of the top and antitop in the rest frame of the $\bar{t}\bar{t}$ system. In the laboratory frame both, the top and the antitop will be boosted in direction of the incoming quark and the fb-asymmetry becomes adulterated. By combining these two factors, the rapidity y_t and the direction $\text{sign}(\beta_{\bar{t}\bar{t}Z})$ of the $\bar{t}\bar{t}$ system we can unveil the fb-asymmetry again.

We define our fb-asymmetry as

$$A_{FB} = \frac{N(\Delta_{AS} > 0) - N(\Delta_{AS} < 0)}{N(\Delta_{AS} > 0) + N(\Delta_{AS} < 0)} \quad (3.3)$$

with

$$\Delta_{AS} = y_t \cdot \text{sign}(\beta_{\bar{t}\bar{t}Z}) - y_{\bar{t}} \cdot \text{sign}(\beta_{\bar{t}\bar{t}Z}) \quad (3.4)$$

and $N(\Delta_{AS} > 0)$ the number of events with Δ_{AS} greater than zero and $N(\Delta_{AS} < 0)$ is the number of events with Δ_{AS} smaller than zero. If there is a positive asymmetry as predicted by the Standard Model, the distribution of Δ_{AS} should be slightly shifted to greater positive values.

4. FB-Asymmetry in MC on truth Level

The first study we did was to determine the asymmetry A_{FB} for MC truth. MC truth represents the simulated events in the state without influence of any measuring apparatus. At this level all the properties of the involved particles are known even though it is not possible to measure all of them. An example is the four-vector of the top quarks and the neutrinos. The generator that was used is called MC@NLO and the events are

simulated for pp collisions at $\sqrt{s} = 7$ TeV. We analyzed about $1.7 \cdot 10^6$ events at the truth level. The events were divided into four categories for the following studies:

- **all events:** no selection cut was applied on the initial state
- **gg events:** top and antitop quark pairs that originate from gluon-gluon fusion process
- **q \bar{q} events:** top and antitop quark pairs that originate from q \bar{q} annihilation
- **correct sign events:** $\beta_{t\bar{t}Z}$ of $t\bar{t}$ system has same direction as the initial quark and originates from q \bar{q} annihilation

4.1. FBrap Distribution of Top and Antitop Quarks and Asymmetry A_{FB}

In Fig. 13 and Fig. 14 the FBrap distribution is shown for all events and correct sign events, respectively. In the latter one the fb-asymmetry is the most visible, as all the influence of disturbing effects, like events from gluon-gluon fusion which don't contribute to the asymmetry, are removed.

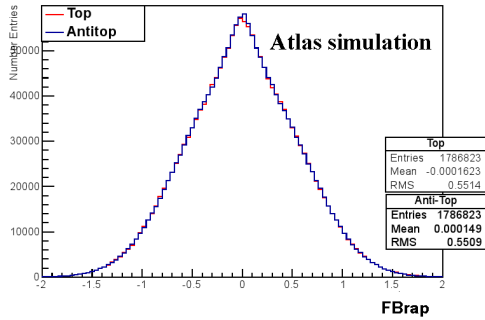


Figure 13: FBrap distribution for top (red) and antitop (blue) for the category: all events.

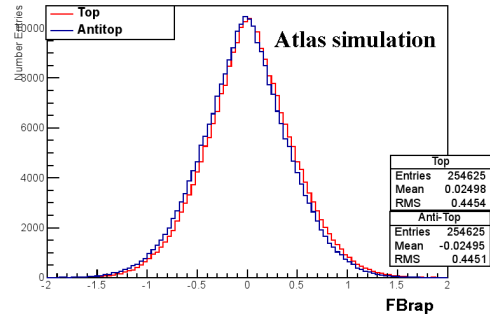


Figure 14: FBrap distribution for top (red) and antitop (blue) for the category: correct sign.

In Table 1 the values of the asymmetry A_{FB} are shown. The one for the events from gluon-gluon fusion is compatible with zero within the uncertainty because it does not contribute to the asymmetry. The value of the asymmetry for all events is the one we can later on compare with the measured one after unfolding.

event category	value of A_{FB}
gg fusion	0.00041 ± 0.00085
all events	0.00617 ± 0.00075
$q\bar{q}$ events	0.02223 ± 0.00172
correct sign	0.04194 ± 0.00198

Table 1: Values of A_{FB} for MC truth

4.2. Testing the Assumption about the same Direction of the initial Quark and $t\bar{t}$ System in MC truth

In the next step, the assumption whether the $t\bar{t}$ system and the initial quark direction are correlated was checked. The ratio R of the number of correct sign events to the number of events from $q\bar{q}$ annihilation was calculated for different cuts on the value of the $t\bar{t}$ boost in beam direction (defined as z -direction). The result is shown in Fig. 15. Each bin corresponds to a higher threshold of the boost. In the first bin the ratio R of all events is shown whereas, in the last bin only events with a higher $\beta_{t\bar{t}Z}$ than 0.9 are presented. This plot shows that the higher the $\beta_{t\bar{t}}$ in z -direction, the higher is the amount of $t\bar{t}$ systems flying in the same direction as the incoming quark and the better our assumption holds. In Fig. 16, the corresponding values A_{FB} for each boost level are shown. The asymmetry clearly increases as expected with the increasing number of correct sign events.

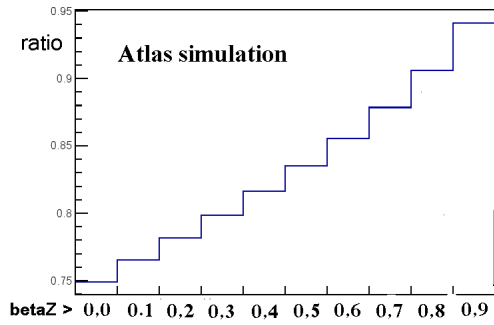


Figure 15: Ratio R of correct sign events to all events from $q\bar{q}$ annihilation with cut on the $\beta_{t\bar{t}}$ boost in beam direction for MC truth.

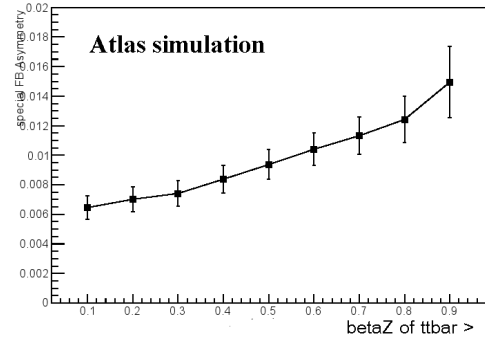


Figure 16: Asymmetry A_{FB} with cut on the $\beta_{t\bar{t}Z}$ boost in beam direction for MC truth.

5. FB-Asymmetry in MC on reconstructed Level

In order to verify a theory, one has to compare it with a measurement. Hence one needs to know what measured value is theoretically predicted and how well we can measure this value with our instruments. The first part is done with MC truth. For the second one we now do the next step by looking at MC reconstructed. It takes the influence of our detector into account such as limited energy resolution, undetected neutrinos etc. and it simulates the events the same way as what we could expect to measure in the detector. In this analysis we used events where the $t\bar{t}$ pairs decay in the dileptonic channel, as seen in Fig. 1. With the information about the kinematics of the charged leptons and the jets which evolve from the b quarks, one is able to reconstruct the kinematics of the initial top and antitop quarks. We used Geant4 for the reconstruction of the events. The neutrinos cannot be detected and thus their energy and momentum stays unknown. The only property that can be constructed from the energy conservation is their missing transverse energy. The momenta of the neutrinos are represented by free parameters in the reconstruction of each event and need to be extracted using a dedicated method.

5.1. Asymmetry A_{FB} for Events in MC reconstructed

In Table 2 the asymmetry values are shown after reconstruction. It is not possible to determine the asymmetry values for the category of gluon-gluon fusion, $q\bar{q}$ annihilation and correct sign events just with the information of MC reconstructed. Since we don't have access to all the necessary information anymore, like the production mechanism of the top-antitop pair we have to take also information of MC truth into account.

The A_{FB} for all events and events from $q\bar{q}$ annihilation are negative while the values in MC truth are positive in MC@NLO. The value for correct sign events is positive but as all the other values it has a very high statistical uncertainty and thus it could be compatible with zero. The statistical uncertainty of the reconstructed events is higher than the one on the truth event level. In MC reconstructed we just have approximately $0.2 \cdot 10^6$ events whereas on the truth level we had a higher statistic with about $1.7 \cdot 10^6$ events.

event category	value of A_{FB}
gg fusion	-0.00928 ± 0.00277
all events	-0.00699 ± 0.00247
$q\bar{q}$ events	-0.00021 ± 0.00590
correct sign	$+0.00955 \pm 0.00700$

Table 2: Values of A_{FB} for reconstructed MC events

5.2. Testing the Assumption about same Direction of initial Quark and $t\bar{t}$ System in MC reconstructed

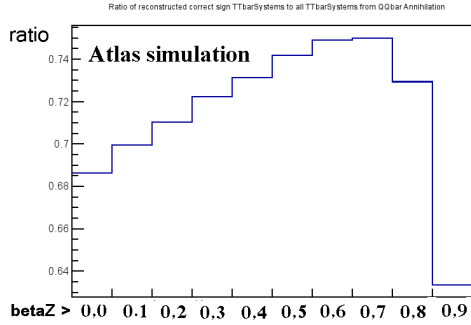


Figure 17: Ratio R of correct sign events to all events from $q\bar{q}$ annihilation with cut on the $\beta_{t\bar{t}}$ boost in beam direction for MC reconstructed.

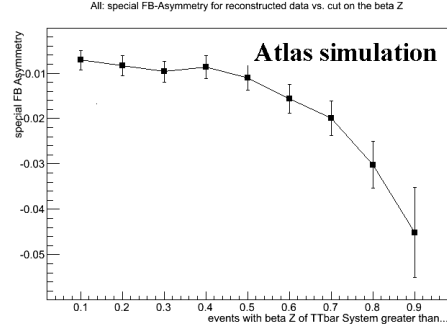


Figure 18: Asymmetry A_{FB} with cuts on the $\beta_{t\bar{t}}$ boost in beam direction for MC reconstructed.

In Fig. 17 and Fig. 18 the corresponding plots to Fig. 15 and Fig. 16 in MC truth are shown, respectively. The fraction of correct sign events in Fig. 17 is increasing up to a boost threshold of 0.7 but the relative increase is not as large as in MC truth. Moreover the relative amount of correct sign events is not as high as in Fig. 15 for the different boost levels. The most significant difference is that for a boost higher than 0.8 the relative amount of correct sign events strongly decreases which is not expected. This different characteristic of MC truth and MC reconstructed appears also in the comparison of Fig. 18 and Fig. 16. The asymmetry values A_{FB} are decreasing with stronger constraints on the $\beta_{t\bar{t}}$ in beam-direction. This development is true for all four categories of events (shown in Appendix A) and leads to the assumption that there are probably some effects in the reconstruction of the events which need further studies in the future.

5.3. Investigating the Asymmetry Values after Reconstruction

In order to investigate the difference between the results of MC truth and MC reconstructed Δ_{AS} , for both event categories were compared. One expects that they are correlated and thus one would expect a linear slope in Fig. 19. However there are also events with opposite sign for all four event categories (see Appendix B). This flipped sign could mean that there are effects in the reconstruction method which could also induce the negative asymmetry. In Fig. 20 a cut on the $\beta_{t\bar{t}}$ is applied. It requires a maximal relative deviation of 10% between the truth and the reconstructed boost. Thus many

of the flipped sign events were reduced but the asymmetry $A_{FB} = -0.0101 \pm 0.0046$ became even more negative for all the reconstructed events.

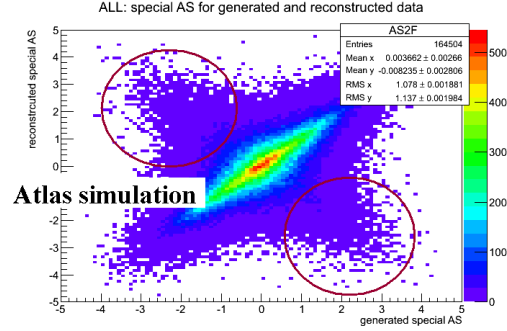


Figure 19: Comparison between A_{FB} of reconstructed and truth events.

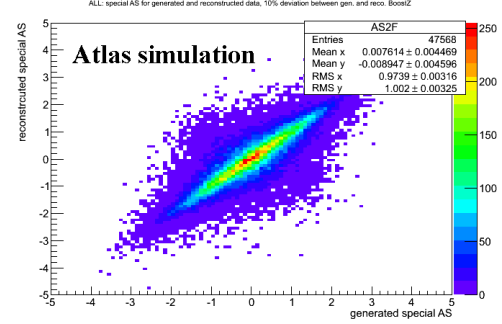


Figure 20: Comparison between A_{FB} of reconstructed and truth events with maximal 10% deviation between their $\beta_{i\bar{i}Z}$.

Furthermore the boost $\beta_{i\bar{i}Z}$ in z-direction of the truth and reconstructed events were compared. The result is shown in Fig. 21 for all events and Fig. 22 for correct sign events. Truth and reconstructed events tend to agree most of the time. However it can be seen clearly that there are also many events smeared around the expected linear slope. This fact confirms again the assumption that the reconstruction method is not completely efficient and more detailed studies will be required.

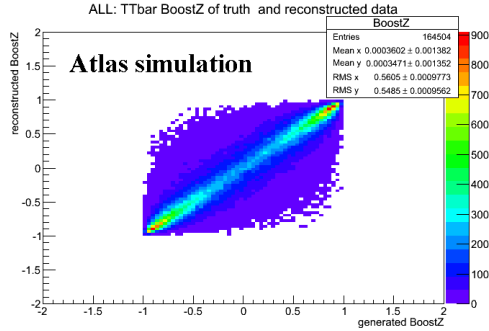


Figure 21: Comparison of boost $\beta_{i\bar{i}Z}$ of MC truth vs. MC reconstructed for all events.

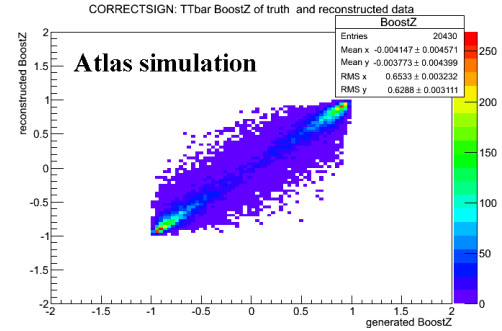


Figure 22: Comparison of boost $\beta_{i\bar{i}Z}$ of MC truth vs. MC reconstructed for correct sign events.

6. Summary and Discussion

The Standard Model predicts an asymmetry of $A_{\text{FBSM}} = (8.8 \pm 0.6)\%$ [1] in the production mechanism of top and antitop pairs. At the Tevatron this asymmetry is visible as a dissociation of the rapidity distribution of the top and antitop quarks in the detector system. In case of a positive asymmetry the top quarks are rather measured at positive values of the rapidity and the antitop quarks at rather negative rapidity values. Therefore this asymmetry is called forward-backward asymmetry at the Tevatron. The CDF Collaboration measured an asymmetry of $A_{\text{FBCDF}} = (15.8 \pm 7.2 \text{ (stat.)} \pm 1.7 \text{ (syst.)})\%$ using 5.3 fb^{-1} data [2]. The DØ Collaboration determined a $A_{\text{FBDO}} = (19.6 \pm 6.0^{+1.8}_{-2.6})\%$ using 5.4 fb^{-1} data [2]. This deviation between measurement and theory could be a hint for physics beyond the Standard Model which requires further analysis.

The corresponding measurement of the asymmetry at the LHC has to be done differently. The initial state of proton-proton collision is symmetric in comparison with the collision of protons and antiprotons at the Tevatron. This is the reason why a measurement of the spatial top-antitop quark rapidity distribution is not possible anymore in order to measure a similar forward-backward asymmetry. This is why we introduced the new observable FBrp. It is defined as

$$\text{FBrp} = y_t \cdot \text{sign}(\beta_{t\bar{t}Z}) \quad (6.1)$$

where y_t is the rapidity of either the top or antitop measured in the $t\bar{t}$ rest frame system and $\beta_{t\bar{t}Z} = v_Z/c$ the boost of the $t\bar{t}$ system (v is its velocity in beam-direction and c the speed of light). After identifying the FBrp it was possible to determine the fb-asymmetry A_{FB} in the ATLAS detector.

At first it was studied in MC truth. The events were divided into four categories and for all of them the asymmetry was positive and agreed well with the expectation. The asymmetry of the category "all events" is

$$A_{\text{FBTruth}} = 0.00617 \pm 0.00075 \quad . \quad (6.2)$$

The assumption was proven that the $t\bar{t}$ system is most probable flying into the same direction as the incoming quark. It turned out that it holds especially for very high boost values of the $t\bar{t}$ system in direction of the incoming quark. This information could be used later on in the analysis with data by applying cuts on the $\beta_{t\bar{t}Z}$ in terms of considering just top and antitop quark events originating from $t\bar{t}$ system with a high boost value. Thereby one could increase the relative fraction of them and the value of the fb-asymmetry.

In the second part the same analysis was repeated with MC reconstructed. One found out that the asymmetry

$$A_{\text{FBReco}} = -0.00699 \pm 0.00247 \quad (6.3)$$

is negative within the errors for all the events. By combining MC truth information with MC reconstructed we were also able to determine A_{FB} for the events originating from $q\bar{q}$ annihilation and with the correct sign. The asymmetry for the event category $q\bar{q}$ is negative with a very large statistical uncertainty. This means that it could also be compatible with zero. The asymmetry for correct sign events is positive within the error. In general more events will be required in order to better understand this variable.

After that the ratio R was calculated of the correct sign events to all events from $q\bar{q}$ annihilation for different cuts on $\beta_{t\bar{t}}$. It does not agree with MC truth for very high boost values. This means that events boosted very strongly into the forward direction of the detector are not correctly reconstructed. This requires further analysis about the reconstruction methods of the events. The events in the considered sample are based on the dilepton channel, allowing three jets from which the two with the best fit are used for reconstruction. One idea to improve the understanding of the reconstructing method could be the increase of the probability that these jets really originates from top pair production. In order to do this one could constrain the maximum number of jets to two. Another idea could be to check whether the boost of the $t\bar{t}$ system has a negative bias. In summary we saw that the new introduced observable FBrp works well on truth level which is promising to use it in the determination of the fb-asymmetry at the LHC. However the results of the events after reconstruction have to be investigated again in order to better understand the reconstruction method in particular in the case of boosted topologies.

A. Asymmetry A_{FB} for different Boost Levels in MC reconstructed

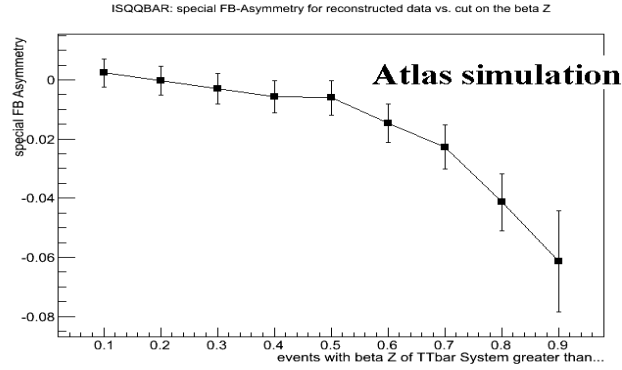


Figure 23: Asymmetry A_{FB} for $q\bar{q}$ events with cuts on the $\beta_{t\bar{t}}$ boost in beam direction for MC reconstructed.

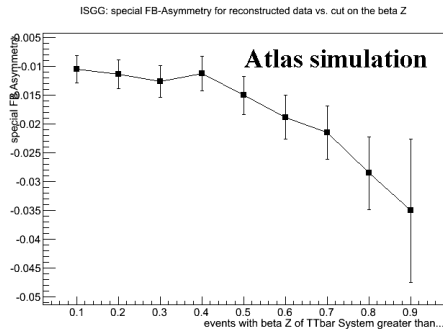


Figure 24: Asymmetry A_{FB} for gluon-gluon fusion with cuts on the $\beta_{t\bar{t}}$ boost in beam direction for MC reconstructed.

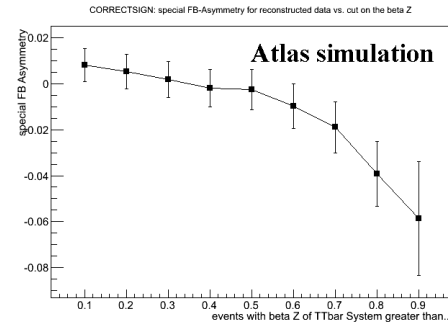


Figure 25: Asymmetry A_{FB} for correct sign events with cuts on the $\beta_{t\bar{t}}$ boost in beam direction for MC reconstructed.

B. Comparison of A_{FB} in MC truth and MC reconstructed for different Event Categories

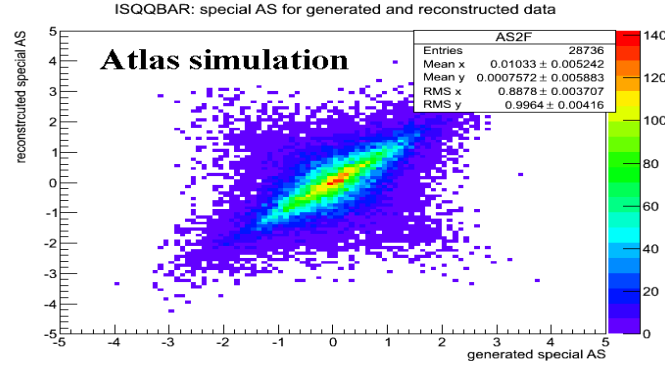


Figure 26: Asymmetry A_{FB} for $q\bar{q}$ events with cuts on the $\beta_{i\bar{i}Z}$ boost in beam direction for MC reconstructed.

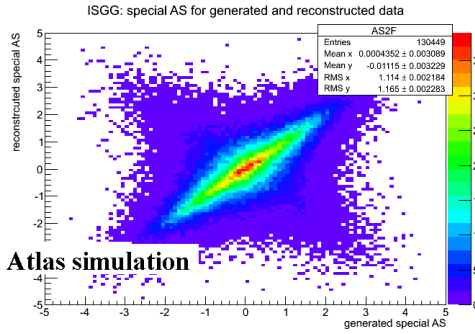


Figure 27: Asymmetry A_{FB} for gluon-gluon fusion with cuts on the $\beta_{i\bar{i}Z}$ boost in beam direction for MC reconstructed.

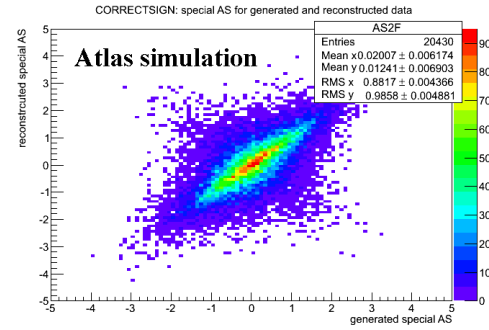


Figure 28: Asymmetry A_{FB} for correct sign events with cuts on the $\beta_{i\bar{i}Z}$ boost in beam direction for MC reconstructed.

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Acknowledgment

I want to thank *Yvonne Peters* for giving me the opportunity to work in the fascinating field of Top Physics. I gained a lot of new and interesting experiences.

I also want to express my gratitude to *Cécile Deterre* for her support and for all the new knowledge I gained.

Thanks also to the entire ATLAS group, especially my office mates *Roger Naranjo* and *Ralph Schäfer* for their help and the friendly atmosphere.

I want to thank all the Summer Students, I really had a great time here in Hamburg. Vielen Dank and tack så mycket especially to *Thomas Köhler*, *Tina Weigel*, *Anne Schütz*, *Paul Schütze*, *Tobias Bisanz*, *Riccard Andersson* and *Hauke Sandmeyer*. I'm glad that we met each other and I wish you all the best for the future.