CHARGE ASYMMETRY OF TOP PRODUCTION AT HADRON COLLIDERS

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A sizeable difference in the differential production cross section of top and antitop quarks, respectively, is predicted for hadronically produced heavy quarks. It is of order α_s and arises from the interference between charge odd and even amplitudes respectively. For the TEVATRON it amounts up to 15% for the differential distribution in suitable chosen kinematical regions. The resulting integrated forward-backward asymmetry of 4–5% could be measured in the next round of experiments. At the LHC the asymmetry can be studied by selecting appropriately chosen kinematical regions.

Top quark production at hadron colliders has become one of the central issues of theoretical [1] and experimental [2] research. The investigation and understanding of the production mechanism is crucial for the determination of the top quark couplings, its mass and the search for new physics involving the top system. A lot of effort has been invested in the prediction of the total cross section and, more recently, of inclusive transverse momentum distributions [1].

In this work we point to a different aspect of the hadronic production process, which can be studied with a fairly modest sample of quarks. Top quarks produced through light quark-antiquark annihilation exhibit a sizeable charge asymmetry – an excess of top versus antitop quarks in specific kinematic regions – induced through the interference of the final-state with initial-state radiation and the interference of the box with the lowest-order-diagram. The asymmetry is thus of order α_s relative to the dominant production process.

Top production at the TEVATRON is dominated by quark-antiquark annihilation, hence the charge asymmetry will be reflected not only in the partonic rest frame but also in the center of mass system of proton and antiproton. The situation is more intricate for proton-proton collisions at the LHC, where no preferred direction is at hand in the laboratory frame. Nevertheless it is also in this case possible to pick kinematical configurations which allow the study of the charge asymmetry [3].

The charge asymmetry has also been investigated in [4] for a top mass of 45 GeV. There, however, only the contribution from real gluon emission was considered requiring the introduction of a physical cutoff on the gluon energy and rapidity to avoid infrared and collinear singularities. Experimentally, however, only inclusive top-antitop production has been studied to date, and the separation of an additional soft gluon will in general be difficult. In this work, we include virtual corrections and consider inclusive distributions only. The sign of the asymmetry we found is opposite to the one given for the $t\bar{t}g$ process in [4]. The charge asymmetry of heavy flavour production in quark-antiquark annihilation to bottom quarks was also discussed in [5,6,7] where its contribution to the forward-backward asymmetry in proton-antiproton collisions was shown to be very small. In addition there is also a slight difference between the distribution of top and antitop quarks in the reaction $gq \to t\bar{t}q$. At the TEVATRON its contributions is bellow 10^{-4}.

At the partonic level the QCD asymmetry is related to the corresponding QED asymmetry [8] through the replacement of $\alpha_{QED}QQ'$ by the factor $\frac{1}{2}\alpha_s(d_{abc}/4)^2 = \alpha_s{\cdot}5/12$. The asymmetry can in principle be studied experimentally in the partonic restframe, as a function of $\hat{s}$, by measuring the invariant mass of the $t\bar{t}$ system plus an eventually radiated gluon. It is, however, also instructive to study the asymmetry in the laboratory frame by folding the angular distribution with the structure functions [9]. For the total charge asymmetry in the laboratory frame we predict [10]

$$\bar{A} = \frac{N_t(\cos\theta \geq 0) - N_{\bar{t}}(\cos\theta \geq 0)}{N_t(\cos\theta \geq 0) + N_{\bar{t}}(\cos\theta \geq 0)} = 4.3 - 4.6\% \ , \tag{1}$$

where different choices of the structure function and different choices of the factorization scale, $\mu = \sqrt{\hat{s}}$ and $\mu = \sqrt{\hat{s}}/2$, have been considered. We defined $\cos\theta$ as the top quark production angle in the $p\bar{p}$ restframe and $N(\cos\theta) = d\sigma/d\Omega(\cos\theta)$.

In principle one might expect that cuts on the top quark or its decay products at large rapidities could affect the asymmetry. Nevertheless, the rapidity distribution shows that the asymmetry approaches its maximal value already for $y_{cut} = 1$, indicating that also cuts on the top decay products W and b jets with rapidities, say, larger than 2 will not lead to a significant reduction of the asymmetry. We would also like to mention that event generators which do not include the full NLO matrix elements [11,12] cannot predict the asymmetry.

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