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Top quark theory

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Abstract. The theoretical aspects of a number of top quark properties such as its mass and its couplings are reviewed. Essential aspects in the theoretical description of top quark production, singly, in pairs and in association, as well as its decay related to spin and angular correlations are discussed.

Keyword. Top quark.

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1. Introduction

Being in Mumbai, the financial centre of India, we are at this point, as it were, awaiting the IPO of the Higgs boson (suggested symbol: HX). However, for the shrewd investor in new physics possibilities it would be wise to keep the blue-chip top quark (TQ) in his portfolio. Top has, in my view, definite up-side potential. By this talk, and by the accompanying experimental talks [1,2], we strive to motivate this.

The history of heavy flavours and what they taught us promises much. From the charm quark we learned that the Standard Model is consistent, through the GIM mechanism. Moreover, its discovery cemented the belief in QCD as the quantum theory of the strong interactions [3]. From the bottom quark, we learned that a complete third family was there to find, in turn allowing for CP violation to be part of the Standard Model. Though already discovered 15 years ago, the top quark has not yet led to such fundamental new insights. However, this promise may still be fulfilled in the coming decade, a hope strengthened once one contemplates top's attributes.

The top quark is an interesting study object because it has many quantum numbers and thus couples to almost all other particles through various (chiral, vector, scalar) structures, all of which should be examined for deviations. Such precise scrutiny is feasible because the large top mass implies, first, that it couples strongly to whatever breaks the electroweak symmetry, and second, that the resulting large width minimizes obscuring hadronization effects and allows preservation of spin information. Top acts as a stepping-stone at the EW scale. In particular, by its effect in loops it is a gateway to Higgs production.

Top is of course also a troublemaker for the Standard Model, contributing significantly to the quadratic divergences of the Higgs self-energy, while yet, at the same time, extending a lifebuoy to the MSSM by raising the upper limit on the light Higgs in that theory. The Tevatron has made the first precious thousand top quarks, leading to its discovery and test some of its properties. The LHC is a genuine top quark factory and will allow us to study the top quark and its behaviour in scattering processes in great detail. Here, in this paper, some of the interesting aspects of top quark physics are reviewed. I shall visit a number of important observables, provide some background to these, discuss their state-of-the-art description and what we learn from them.

2. Top pair production cross-section

The measured Tevatron pair production cross-sections

$$\begin{aligned} \text{CDF:}\ & 7.5 \pm 0.31(\text{stat}) \pm 0.34(\text{sys}) \pm 0.15(\text{th})\ \text{pb}, \\ \text{D0:}\ & 7.56^{+0.63}_{-0.56}(\text{stat} + \text{sys} + \text{lumi})\ \text{pb}, \end{aligned}$$

are in excellent agreement with theory [4–6]. The measured pair production cross-sections by ATLAS and CMS after 35 and 36 pb^{-1}, respectively, are

$$\begin{aligned} \text{ATLAS:}\ & 176 \pm 5(\text{stat}) \pm 13(\text{sys}) \pm 7(\text{lum})\ \text{pb}\,, \\ \text{CMS:}\ & 150 \pm 9(\text{stat}) \pm 17(\text{sys}) \pm 6(\text{lum})\ \text{pb}\,. \end{aligned}$$

These are in agreement both with each other and with NLO and NLO plus threshold-resummation calculations. While this may not lead to immediate excitement, it is worth appreciating this agreement in the light of having a very different collision type and energy from the Tevatron, and of having a different mixture of partonic subprocesses. This gives us solid confidence in the value of the top quark QCD coupling. It prepares the stage where we might use this process in determining PDF's, in particular the gluon density, at large scales.

Let us review the status of, and main ideas behind the main theoretical calculations for top quark pair production. The NLO corrections were computed already in the late 80s [7–10], and for many years these were among the most difficult one-loop calculations done. These first calculations were integrated over phase space partly analytically, a fully differential calculation (still available) was completed shortly after [11]. The state-of-the-art at the time of this conference is the combination of such a fully differential calculation with parton showers, such as `MC@NLO` [12,13] and `POWHEG` [14,15]. These codes combine the virtues of the exclusiveness of a parton shower event generator with the accuracy of a NLO calculation. For such an inclusive quantity as the pair production cross-section we can however do better, using the method of threshold resummation. As this method also underlies recent theoretical estimates of the top quark forward–backward asymmetry, let me review it briefly here.

When the top quark pair is produced near the threshold, logarithms whose argument represents the distance to threshold in the perturbative series become numerically large. It is important to note here that the definition of the threshold depends on the observable.

Thus, for the inclusive cross-section threshold is given by the condition T_1: $s - 4m^2 = 0$. For the transverse momentum distribution we have T_2: $s - 4(m^2 + p_T^2) = 0$, and for the doubly differential distribution in p_T and rapidity we can choose

$$T_3: \; s - 4(m^2 + p_T^2)\cosh y = 0 \quad \text{or} \quad T_3: \; s + t + u - 2m^2 = 0\,. \tag{1}$$

The perturbative series for any of these (differential) cross-sections can be expressed as

$$d_\alpha \sigma(T_\alpha) = \sum_n \sum_k^{2n} \alpha_s^n c_{n,k}^\alpha \ln^k(T_\alpha)\,, \tag{2}$$

plus non-logarithmic terms. Here T_α represents any of the threshold conditions, suitably normalized, for the observables enumerated by α. Note that it is allowed to use, e.g. T_2 for the inclusive cross-section, by first analysing $\mathrm{d}\sigma/\mathrm{d}p_T$ and then integrating over p_T. For any complete fixed order calculation this will give the same answer, but if one only selects the logarithmic terms because the exact answer is unknown, numerical differences will occur. This can then be classified as a theoretical uncertainty [16].

The logarithms result from phase-space regions where the extra gluons emitted are soft and/or collinear to their on-shell emitter. Resummation concerns itself with carrying out the sum in eq. (2). The resummed result takes the generic form

$$\mathrm{d}\sigma = \exp(Lg_0(\alpha_s L) + g_1(\alpha_s L) + \alpha_s g_2(\alpha_s L) + \cdots) \times C(\alpha_s) \tag{3}$$

including up to the function g_i in the exponent amounts to N^{i}LL resummation. Of course, for increasing i these functions are progressively more difficult to determine. Key benefits of resummation are: (i) gaining all-order control of the large, positive terms that plague fixed-order perturbation theory, thereby restoring predictive power and (ii) reduction of scale uncertainty. Regarding the first point, the reason these resummable terms are positive is that, though the hadronic cross-section is Sudakov-suppressed near the threshold, of its components, the PDFs provide too much suppression, which the partonic cross-section partially compensates. Regarding the second point, when examining the sources of μ_F dependence, they occur both in the PDF and in the partonic cross-section now both in the exponent, which improves the cancellation.

The state-of-the-art accuracy for the inclusive pair production cross-section at present is NNLL [17,18]. A consistent combination of NNLL accuracy in both threshold and Coulomb corrections has now also been achieved [19].

Besides the all-order results, approximate NNLO also are available, where the NNLO correction is constructed using resummation methods, in particular for both thresholds 1 and 3. The latter, being dependent on t and u, is also useful for estimating corrections to the forward–backward asymmetry, a point we return to below. An important recent software tool incorporating NNLL corrections, exact NNLO scale dependence, and a possibility to use the running top mass instead of the pole mass is `HATHOR` [20]. Other approximate NNLO calculations use threshold 3, and assign the ambiguities due to pair-invariant mass (PIM) or one-particle inclusive (1PI) kinematics in the precise definition of the threshold to a theoretical error [16,21,22].

Results such as those above serve to whet the appetite for an exact NNLO calculation for the inclusive cross-section, and also on this front much progress is being made. The double-real emission calculations are well underway [23–25]. The one-loop, one real emission contributions are done, since the NLO calculation for $t\bar{t}$+ jet is available [26,27]. Much work has also been done on the 2-loop virtual corrections [28–31].

3. Top mass

The top quark property that is most readily employed in top physics is its mass. The Tevatron experiments have set the standard to a level that the LHC experiments are moving towards, but will not find easy to surpass

$$\begin{aligned}\text{CDF/D0}\,[5.6\,\text{fb}^{-1}]:&\quad 173.3 \pm 1.1\,\text{GeV/c}^2,\\ \text{ATLAS}\,[36\,\text{pb}^{-1}]:&\quad 175.5.3 \pm 4.6(\text{stat}) \pm 4.6(\text{sys})\,\text{GeV/c}^2,\\ \text{CMS}\,[35\,\text{pb}^{-1}]:&\quad 169.3 \pm 4.0(\text{stat}) \pm 4.9(\text{sys})\,\text{GeV/c}^2.\end{aligned} \tag{4}$$

Together with an accurately measured W boson mass, a precisely known top mass severely constrains the mass range of a possible Higgs boson both in the Standard Model and in the MSSM. Therefore, its precise measurement is of considerable importance, and so also its careful definition. However, given the present uncertainty on the W mass, for testing the Standard Model, an accuracy of about 1 GeV should suffice. For constraining the MSSM, however, better accuracy would be very valuable.

A natural definition of an elementary particle mass is based on the location of the pole of the full top quark propagator, i.e. the pole mass. After summing self-energy corrections, the full propagator reads as

$$\frac{1}{\not{p} - m_0 - \Sigma(p, m_0)}\,, \tag{5}$$

where Σ contains $1/\epsilon$ UV divergences from loop integrals. Renormalization now amounts to replacing the bare mass m_0 by an expression involving the renormalized mass m

$$m_0 = m\left(1 + \frac{\alpha_s}{\pi}\left[\frac{1}{\epsilon} + z_{\text{finite}}\right]\right), \tag{6}$$

after which the UV divergences cancel in (5). The choice of z_{finite} determines the scheme. Choosing it such that

$$\frac{1}{\not{p} - m_0 - \Sigma(p, m_0)} = \frac{c}{\not{p} - m} \tag{7}$$

defines the pole-mass scheme, which amounts to pretending that the particle can be free and have long life. However, because the top quark, being coloured, can never propagate out to infinite times – a requirement for the definition of a particle mass in scattering – such a pole only exists in perturbation theory, and its location is intrinsically ambiguous by $\mathcal{O}(\Lambda_{\text{QCD}})$ [32–34]. Experimentally, the top quark mass is reconstructed by collecting jets and leptons. Soft particles originating from both within and outside these jets may affect the reconstructed mass. Moreover, various experimental methods used (e.g. track quality cuts) and corrections do not have a clean perturbation theory description. Though it is considered generally a measurement of the pole mass, the full procedure has led to some discussion about the precise ‘scheme’ of the mass measured [35].

A theoretically more precise definition is the $\overline{\text{MS}}$ mass $\bar{m}(\mu)$ whose relation to the pole mass is known to sufficiently high order. For μ one often takes the implicit value found when intersecting the $\bar{m}(\mu)$ curve with the $\bar{m}(\mu) = \mu$ axis, yielding $\bar{m}(\bar{m})$. For the top quark, this value is about 10 GeV/c^2 smaller than the pole mass. The $\overline{\text{MS}}$ mass may be extracted somewhat more indirectly, by comparing, for instance, the measured inclusive cross-section with the theoretical one expressed in the $\overline{\text{MS}}$ mass [36]. A recent measurement by D0 [37] along these lines yield about 157 GeV/c^2 with an uncertainty of about 5 GeV/c^2. At this conference a poster was shown extending this to the 3-jet rate [38].

4. Single top

Single tops are produced by the weak interaction, in processes that are customarily categorized (figure 1) using Born kinematics. A particularly important aspect of single-top production is the prospect of directly measuring V_{tb} and testing the chiral structure of the associated vertex: top produced singly in this way is highly polarized, and offers a chance to study the chirality of the coupling. Furthermore, the dominant t channel at the LHC will, when confronting measurements with a 5-flavour NLO calculation, allow extraction of the b-quark density. (In a 4-flavour scheme, one would demand an extra (b) jet, which may be used for (anti)-tagging [39].) This will be useful in predicting other production processes at the LHC. The single top production characteristics are sensitive to new physics, depending on the channel. Thus, the s-channel will be sensitive to e.g. W' resonances, the t-channel to FCNCs.

Experimentally, this process turns out to be rather difficult to separate from backgrounds. The Tevatron combination of a number of CDF and D0 measurements of the inclusive single top production cross-section is

$$2.76^{+0.58}_{-0.47}\,\text{pb}\,. \tag{8}$$

A recent D0 measurement [40] of only the t-channel cross-section finds 2.9 ± 0.6 pb. The measured cross-sections agree within errors with the NLO calculations [41–46].

The inclusive cross-sections at the Tevatron are rather small, 0.9 (s) and 2 (t) pb, with the Wt channel negligible. Both `MC@NLO` [47] and `POWHEG` [48] describe these processes, in good (mutual) agreement. At a 14 TeV LHC the numbers are, approximately, 10, 246 and 60 pb, respectively. So clearly, at the LHC the t-channel will be dominant. Besides interesting in its own right, this process is a background to many new physics processes involving both neutral and charged Higgs production.

4.1 *Wt*

An interesting issue arises in the Wt mode of single top production. Some diagrams that are part of the NLO corrections contain an intermediate antitop that can become resonant.

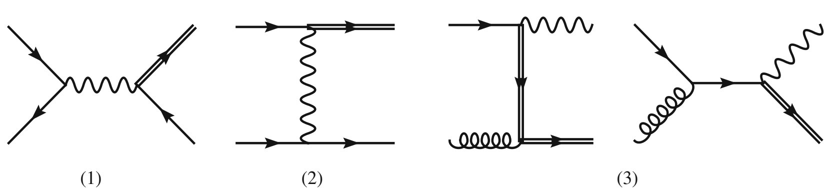

Figure 1. From left to right the s-channel (1), t-channel (2) processes, and the Wt associated (3) production channel.

These diagrams can therefore be interpreted as LO $t\bar{t}$ 'doubly resonant' production, with subsequent $\bar{t}$ decay (see figure 2). It thus becomes an issue to what extent Wt and $t\bar{t}$ can be properly defined as individual processes. Several definitions of the Wt channel have been given in the literature, each with the aim of recovering a well-behaved expansion in α_s. The problem of interference in fact affects any computation that considers contributions beyond the leading order, i.e. at least $\mathcal{O}(g_w^2\alpha_s^2)$. The cross-section at this order has been previously presented in refs [49–51], where only tree-level graphs were considered, and in refs [45,52,53], where one-loop contributions were included as well.

In ref. [54] the issue of interference was addressed extensively in the context of event generation, in particular the MC@NLO framework (POWHEG has implemented the same method [55]). Two different procedures for subtracting the doubly resonant contributions and recovering a perturbatively well-behaved Wt cross-section were defined. In 'diagram removal (DR)' the graphs in figure 2 were eliminated from the calculation, while in 'diagram subtraction (DS)' the doubly resonant contribution was removed via a subtraction term. The DS procedure leads to the following expression for the cross-section:

$$\mathrm{d}\sigma^{(2)} + \sum_{\alpha\beta} \int \frac{\mathrm{d}x_1 \mathrm{d}x_2}{x_1 x_2 S} \mathcal{L}_{\alpha\beta} (\hat{S}_{\alpha\beta} + I_{\alpha\beta} + D_{\alpha\beta} - \tilde{D}_{\alpha\beta}) \mathrm{d}\phi_3, \tag{9}$$

where $\alpha\beta$ labels the initial-state channel in which the doubly resonant contribution occurs: gg or $q\bar{q}$. $\hat{S}$ is the square of the non-resonant diagrams, I their interference with D, the square of graphs of figure 2. The subtraction term $\tilde{D}$ requires careful construction [54]. It was shown that, with suitable cuts, the interference terms are small. From eq. (9) one sees that the difference of DR and DS is essentially the interference term. A particularly suitable cut is putting a maximum on the p_T of the second hardest b-flavoured hadron, a generalization of a proposal made in ref. [45]. Thus defined, the Wt and $t\bar{t}$ cross-sections can be separately considered to NLO. However, their separation at LHC does remain difficult.

5. Charge asymmetry

Another test of the QCD production mechanism of top quarks is the charge asymmetry: the difference in production rate for top and antitop at fixed angle or rapidity

$$A_t(y) = \frac{N_t(y) - N_{\bar{t}}(y)}{N_t(y) + N_{\bar{t}}(y)}\,. \tag{10}$$

While electroweak production via a Z-boson could produce a (very small) asymmetry at LO, QCD itself does produce it at $\mathcal{O}(\alpha_s^3)$ through a term proportional to the $SU(3)$ d_{abc}

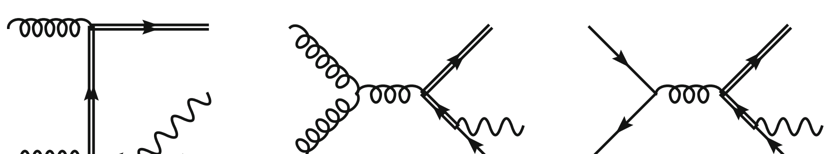

Figure 2. Doubly resonant diagrams in NLO corrections to Wt production.

symbol [8,10,26,56]. A more precise look [56] shows that the asymmetry is due to an interference between C-odd and C-even terms. In top quark pair production in the $q\bar{q}$ channel, this amounts to the Born diagram and the one-loop box diagram, respectively. In practice, when computing such interference contributions, the asymmetry reveals itself in terms of the Mandelstam variables t and u in terms that are odd under $t \leftrightarrow u$ interchange, e.g. $t^2 - u^2$. In $t\bar{t} + 1$ jet production this can already occur at tree-level (essentially, this amounts to a different cut of the same amplitude). With recent measurements [57–60] by the Tevatron experiments showing substantial deviations from the Standard Model prediction for pair production, there is considerable interest in this observable.

The effect of this interference can be understood more intuitively by the statement that the incoming quarks, via the interference, tend to repel the produced top quarks towards larger rapidity, and/or attract the produced antitop quarks toward slightly smaller rapidities. The net effect, therefore, at the Tevatron, where the top–antitop pairs are produced in $q\bar{q}$ annihilation, is a shift of the top quark rapidity distribution towards larger rapidity, and of the antitop distribution towards smaller values. This clearly creates a y-dependent asymmetry of the type (10), and even a forward–backward asymmetry.

This intuition may be inferred in threshold resummation from the so-called soft anomalous dimension in the $q\bar{q}$ channel, which governs subleading threshold logarithms; leading logarithms are symmetric under $t \leftrightarrow u$ interchange, and therefore cancel in the asymmetry, but the subleading contribution reads as

$$\Delta\sigma = \exp\left\{\alpha_{\rm s} L\left[\frac{32}{6} - \frac{27}{6}\right]\ln\frac{u}{t}\right\}\sigma_{\rm Born}, \tag{11}$$

where L is the threshold logarithm. This expression, through $\ln(u/t)$, is clearly antisymmetric under $t \leftrightarrow u$ interchange, and expresses the intuition mentioned above. The experimental status of this observable was reviewed in the talk by De Roeck [1]. In fact, CDF and D0 have measured a considerable number of related observables, distinguished for instance by using the rapidity of the lepton from top decay. Particularly noteworty is the asymmetry restricted to bins of large $t\bar{t}$ invariant mass, where an effect with a signifcance of 3.4σ was reported by CDF [58].

Since the leading contribution to this effect for pair production uses a loop diagram, the asymmetry itself is of leading order accuracy. Clearly, the impact of even higher orders becomes interesting which at this stage can only be assessed from approximate, resummation-based calculations to NLL [16,61] or NNLL [62]. These use a threshold T_3 (1). As discussed, only subleading logarithmic contributions are sensitive to the difference of top and antitop production. The asymmetry was found to be stable with respect to the inclusion of such higher order corrections, and to be much less sensitive to scale variations.

As noted above, the charge asymmetry is present at leading order in $t\bar{t}+$ jet production. However, NLO corrections [26,27] appear to wash out asymmetry for this reaction. An interesting explanation for this effect was given in [27] based on the structure

$$A_{\rm FB}(t\bar{t}j) = \alpha_{\rm s}^3\frac{C}{\ln(m/p_{{\rm T},j})} + \alpha_{\rm s}^4 D_{\rm hard}, \tag{12}$$

where the second term, only appearing at NLO, cancels the first as they have opposite signs. The inverse logarithm is due to the fact that the denominator in the asymmetry has a higher power of leading soft logarithms. Also for $t\bar{t}jj$ the NLO term seems to reduce the LO contribution to the asymmetry [63].

At LHC, the net effect is an overall broadening of the top quark rapidity distributions and a slight narrowing of the antitop rapidity distribution. This produces no forward–backward asymmetry, but an imbalance of tops and antitops is present at larger rapidities. One proposal [64] is e.g. to assess the asymmetry using only events with (anti)tops above a certain minimum rapidity, of about 1.5. Early measurements show no disagreement with NLO theory. Other ideas to test asymmetries involve same-sign tops [65], produced in qq collisions via Z' exchange. For masses of Z' at the 2 TeV level, such unusual cross-sections can be of order pb in size.

6. Associated production at higher order

Electroweak corrections to top pair production have been computed [66–68], which can be large in certain phase-space regions, depending on transverse momentum. They can also impact the charge asymmetry [69].

The NLO revolution has left its mark on processes involving top as well, yielding calculations that would be hard to imagine in the late eighties. Production of a top pair in association with a jet is known to NLO [26,27]. Production in association with a Higgs boson is also known to NLO accuracy [70,71], and in addition interfaced to parton showers [72]. Production of a top quark pair with two extra partons is known for $t\bar{t} + b\bar{b}$ [73], and even for the case + two jets [63], a calculation with no less than about 10K 6-point one-loop diagrams. Calculations including off-shell effects are beginning to appear as well [74,75].

7. Spin and angular correlations

Part of the attractiveness of the top quark as a study object is its power to self-analyse its spin, through its purely left-handed SM weak decay. This is both a useful aid in signal-background separations, and itself a property worthy of detailed scrutiny, as certain new physics models could introduce right-handed couplings. The correlation between top spin and directional emission probability for its decay products is expressed by the equation

$$\frac{\mathrm{d}\ln\Gamma_f}{\mathrm{d}\cos\chi_f} = \frac{1}{2}\left(1 + \alpha_f \cos\chi_f\right), \tag{13}$$

where $|\alpha_f| \leq 1$, with 1 indicating 100% correlation. For the dominant decay mode

$$t \to b + W^+(\to l^+ + \nu) \tag{14}$$

at lowest order, we have $c_b = -0.4, c_\nu = -0.3, c_W = 0.4, c_l = 1$. QCD corrections to these values are small. The charged lepton direction (or the down-type quark in a hadronic decay of the intermediate W) is indeed 100% correlated with the top quark spin. This is amusingly more than for its parent W boson, a consequence of interference of two amplitudes with different intermediate W polarizations.

In single-top quark production, which occurs via the charged weak interaction, the top produced is left-handed. So a correlation should be a clear feature of the production process and a discriminant from the background. In figure 3 this correlation as computed with MC@NLO [76] is shown. In top quark pair production, a correlation of an individual quark with a fixed direction is almost absent. However, there is a clear correlation between the top and antitop spins. The size of the correlation depends on the choice of reference axes $\hat{\mathbf{a}}$, $\hat{\mathbf{b}}$ [77–80]. At the Tevatron the beam direction $\hat{\mathbf{a}} = \hat{\mathbf{b}} = \hat{\mathbf{p}}$ is a good choice, and at the LHC the helicity axes $\hat{\mathbf{a}} = \hat{\mathbf{b}} = \hat{\mathbf{k}}_{\rm top}$ should give near-maximal correlation

$$\frac{d\sigma}{d\cos\theta_a d\cos\theta_b} = \frac{\sigma}{4}\left(1 + B_1\cos\theta_a + B_2\cos\theta_b - C\cos\theta_a\cos\theta_b\right). \tag{15}$$

Indeed, the correlation coefficient C depends on the correlation axis. Thus, at LO in QCD, the values for $\{C_{\rm hel}, C_{\rm beam}\}$ at the Tevatron (LHC) is $\{0.47, 0.93\}$ ($\{0.32, -0.01\}$). NLO corrections modify these numbers somewhat [80]. BSM models that influence the pair production mechanism (e.g. new resonances) can noticeably influence these correlations.

Interesting recent research addresses the possibility of azimuthal angular distributions as discriminants of new physics. Thus, in the dilepton decay channel, after an invariant mass cut, $t\bar{t}$ spin correlations may be revealed through the $\Delta\phi$ distribution of leptons in the laboratory frame [81]. This observable is quite robust, as the correlation remains visible even after summing over spurious neutrino momentum resolutions, and persists at NLO [82].

Other angular distributions can function as quite selective probes of new physics [83,84]. For instance, if a Z' would polarize tops at production, the azimuthal asymmetry

$$A_\phi = \frac{\sigma(\cos\phi_l > 0) - \sigma(\cos\phi_l > 0)}{\sigma(\cos\phi_l > 0) + \sigma(\cos\phi_l > 0)}, \tag{16}$$

where ϕ_l is the azimuthal angle of the lepton with respect to the beam-top plane, would be sensitive to the amount of left-handed and right-handed coupling, even more so when

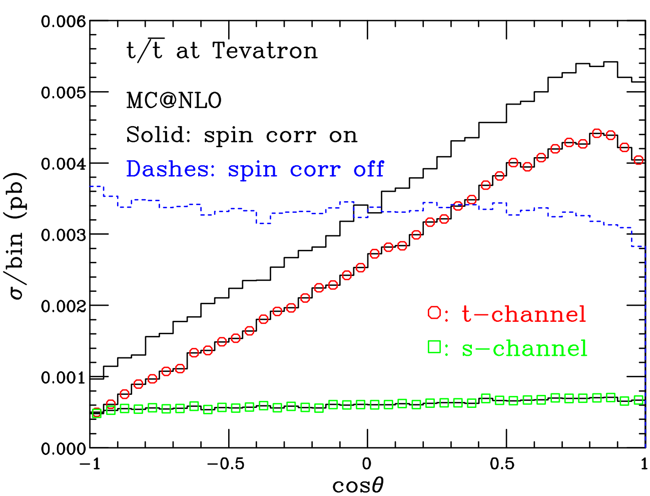

Figure 3. In t-channel single-top production at the Tevatron, a clear correlation of the lepton flight direction with the recoiling light quark jet is present. The correlation disappears when spin correlations are turned off in MC@NLO [76].

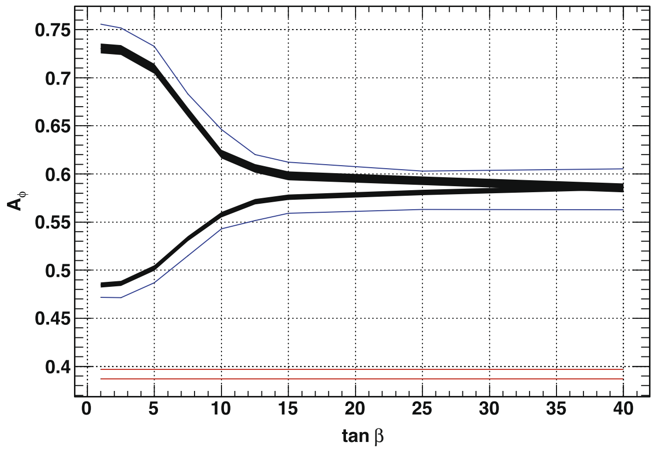

Figure 4. Azimuthal asymmetry parameter for Ht production. LO (MC@NLO) results are shown in blue (black), for $m_{\mathrm{H}} = 200$ GeV (lower curves) and $m_{\mathrm{H}} = 1500$ GeV (upper curves). The error band is statistical. Results for Wt production, using both the DR and DS approaches, are shown in red.

judicious cuts on p_{T} of the top are chosen. When a charged Higgs is present, such an asymmetry would also discriminate [85] among Wt and H^-t productions, as shown both at LO and for MC@NLO in figure 4.

8. Conclusions

At this conference we have witnessed the LHC moving towards a leading position in the top quark physics market (but not for all the observables: the Tevatron analyses of the charge asymmetry/asymmetries will stay in the centre of attention). Analyses requiring large top samples are starting, enabled by the LHC, a veritable T-factory. Besides the classic observables such as as cross-section and mass, correlations, angular distributions, and considerably more complex final states are becoming possible, and constitute a very interesting platform on which to confront precise measurements with precision predictions. As in other areas, the available tools for the latter have improved impressively in the last few years. With projected demand for top physics high, we advise to keep top prominently in the portfolio of promising physics options.

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