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Recent Results from the Tevatron Experiments

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The Tevatron proton-antiproton synchrotron has provided the collider experiments CDF and D0 with 7 fb^{-1} of data in Run II. This large dataset has spawned many recent physics results, out of which a small selection is presented.

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1. Introduction

Since the beginning of Run II in 2001, the Tevatron proton-antiproton synchrotron operating at the Fermi National Accelerator Laboratory in Batavia, IL, USA, has delivered 7 fb^{-1} to the two collider experiments CDF and D0. This large dataset has facilitated a plethora of physics results. This presentation selects a rather subjective list of the most recent highlights, with emphasis on results most closely related to the theme of this symposium.

2. QCD and Parton Distribution Functions

Jet production at a hadron collider provides a powerful tool to test perturbative quantum chromodynamics (pQCD) and allows extraction of information on the parton distribution functions (PDF) of the proton. At the Tevatron, dijet production probes mass scales up to 1.2 TeV, testing possible resonance production such as extra gauge bosons Z' and W', Randall-Sundrum gravitons etc. No deviation from the pQCD prediction have been observed. Measurements of the differential inclusive jet cross sections of CDF [1] and D0 [2], shown in Fig. 1, agree very well with next-to-leading-order (NLO) predictions and with each other. The experimental precision of the differential measurement in bins of jet p_T and rapidity y is now smaller than the PDF uncertainties, allowing to constrain the gluon PDF. Experimentally, this requires control of the jet energy scale to about 1% due to the steeply falling p_T spectrum. Recent global fits [3, 4] suggest that the Tevatron inclusive jet data requests a softer gluon in the high x region. Additional constraints on the ratio of the down to the up quark PDF is provided by the most recent measurements of the W lepton/charge asymmetry [5, 6]. D0 has also recently extracted the strong coupling constant α_s from inclusive jet production with a mean value of $\alpha_s(m_Z) = 0.1161^{+0.0041}_{-0.0048}$ [7].

3. Vector Boson Production

The mass of the W-boson, m_W, is one of the most important parameters to indirectly constrain the Standard Model Higgs boson mass. Recently, The D0 collaboration published a precision mea-

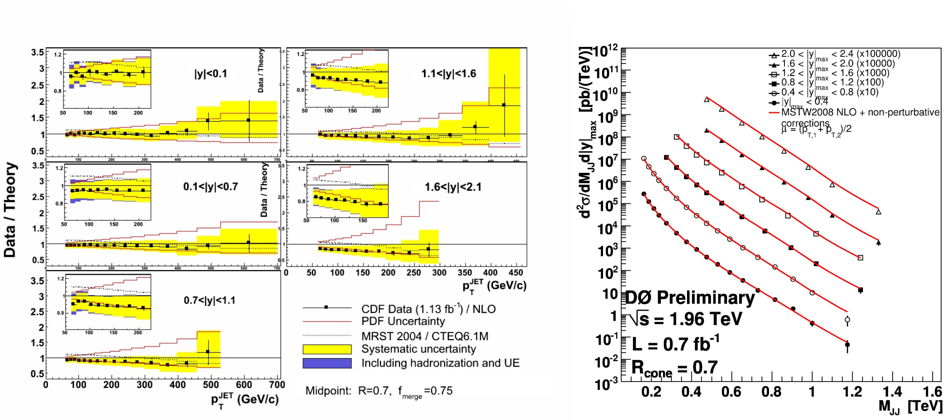

Figure 1: Left: Ratio of the measurement of inclusive jet production by CDF to NLO pQCD expectation in multiple rapidity regions. Right: Dijet mass distribution in multiple rapidity regions as measured by D0.

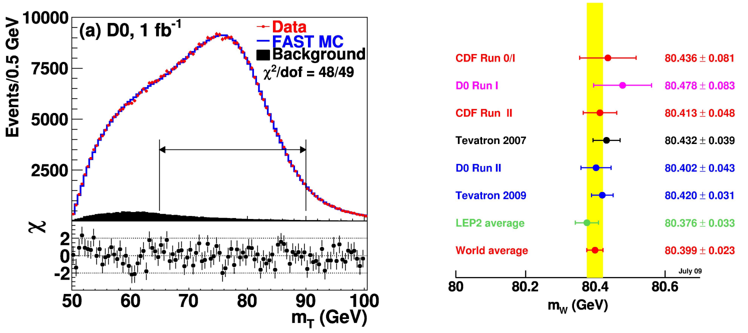

Figure 2: Left: ,$_T$ distribution from $W \rightarrow e\nu$ data and simulation. Right: Summary of m_W measurements at the Tevatron.

surement of m_W based on 1 fb^{-1} of data [8], determining $m_W = 80.401 \pm 0.023(stat)$ GeV. The precision of this result surpasses the previously most precise determination of the CDF collaboration [9] based on 320 pb^{-1} of data. Sensitive variables for this measurement are the transverse mass of the W-boson $m_T = \sqrt{2p_T^e p_T^\nu(1-\cos\Delta\phi)}$ shown in Fig. 2, as well as the transverse momentum $p_T$of the leptons from the leptonic decay of the W boson. The combination of the results of both Tevatron experiments now yields $m_W = 80420 \pm 31$ MeV (0.038%), see Fig. 2. The dominating experimental uncertainties are the lepton energy scales and resolution, while the dominating theoretical uncertainties are due to the PDF and radiative (QED) uncertainties. While the former will improve with statistics, the latter will ultimately limit the precision. Determining m_W to better than 25 MeV will be the ultimate goal in Run II.

Vector boson production in association with multiple jets is a critical background for top quark physics, searches for the Higgs boson and Supersymmetry as well as other beyond the Standard Model physics both at the Tevatron and at the LHC. Current Monte-Carlo tools rely on matched tree-level matrix element calculations with parton shower Monte Carlo simulation (ALPGEN [10], Sherpa [11]) to approximate NLO effects. Recent measurements of W+jets (CDF) and Z+jets (D0) production show that the experimental shapes are generally well described by these models [12, 13]. Recently, full NLO pQCD calculations for W+ >=2 jets became available [14, 15]. Heavy flavor production in conjunction with vector bosons (Z+b-jets, W+b-jets) shows some deviation from the ALPGEN Monte Carlo simulation. $W+b$-jet production is an important background to electroweak single top production and searches for the Standard Model Higgs boson in the $WH \rightarrow l\nu b\bar{b}$ channel, described below. A recent measurement by the CDF collaboration using fits to secondary vertex mass templates determines the cross section times branching ratio $\sigma \cdot B = 2.74 \pm 0.27(stat) \pm 0.42(syst)$ pb , twice as large as the prediction by ALPGEN [16]. A NLO QCD calculation yields $\sigma \cdot B = 1.22 \pm 0.14$ pb, also showing a discrepancy between theory and experiment [17]. $Z+b$-jet production is another important background to searches for the Standard Model Higgs boson in the $ZH \rightarrow \nu\nu b\bar{b}$ channel and probes the not-well known b-quark content of the proton. A measurement of the CDF collaboration determines the $Z+b$ production cross section normalized to the Z+jets cross section to $\frac{\sigma_{Z+b}}{\sigma_{Z+jets}} = 2.08 \pm 0.33 \pm 0.34\%$ [18]. A discrepancy between the data and the ALPGEN Monte Carlo simulation appears in the low transverse jet energy region, see

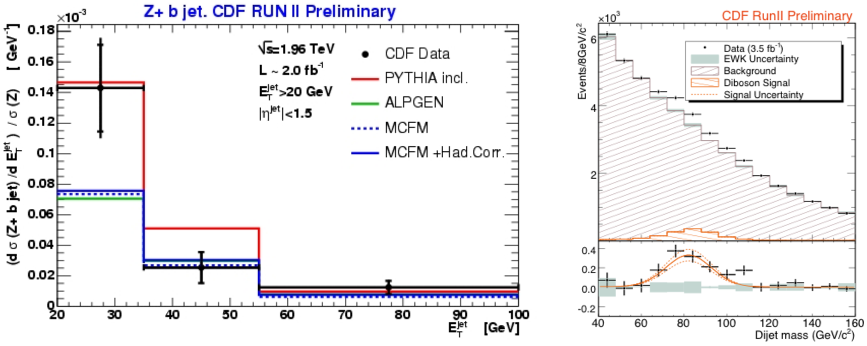

Figure 3: Left: Ratio of the $Z+b$-jet to the inclusive Z production cross section as a function of jet transverse Energy E_T. Right: Dijet mass distribution in diboson production in the missing E_T + jets topology.

Fig. 3. A pQCD prediction using the MCFM calculation [19] determines this ratio between 1.8% and 2.2% depending on the choice of factorization and renormalization scale, in agreement with the experimental result. The rather large dependence on the scale uncertainty is due to the fact that $Z+b\bar{b}$ process is not fully implemented to NLO in the MCFM calculation. Diboson production is another important set of background processes for Standard Model Higgs boson searches at the Tevatron. All relevant processes (WW,ZZ,WZ) have now been observed in the most pure (highest S/B) channels involving high $p_T$leptons. A recent diboson cross section measurement employing the complementary jets plus missing transverse energy ($\not{E}_T$) topology has been performed by the CDF collaboration using 3.5 fb^{-1} of data [20]. The extracted cross section $\sigma = 18.0 \pm 2.8(stat) \pm 2.4(syst) \pm 1.1(lumi)$ pb is in agreement with the NLO prediction of 16.8 ± 0.5 pb. The observation of diboson production in the $\not{E}_T$plus jets channel is an important milestone for searches for the Standard Model Higgs boson in the $ZH \to \nu\nu b\bar{b}$ channel.

4. Top Physics

The top quark is the most massive particle in the Standard Model and as such may play a special role in the mechanism of electroweak symmetry breaking. In the Standard Model, the top quark decays almost 100% of the time into a W boson and a b-quark jet, $t \to Wb$. The mass of the top quark, m_{top}, together with the mass of the W-boson, provides through radiative corrections and indirect determination of the Standard Model Higgs boson mass, see Fig. 4. The top quark mass is the single most precisely measured property of the top quark. The best accuracy is achieved in the lepton + jets decay channel where one W boson from one top quark decay decays leptonically and the other one hadronically. The hadronically decaying W in the final state serves as an in-situ calibration candle to constrain the jet energy scale, the dominating systematic uncertainty in the top quark mass measurement. The Tevatron wide combination of all experimentally accessible channels determine $m_{top} = 173.1 \pm 0.6(stat) \pm 1.1(syst)$ GeV, a determination to better than 0.8% precision [21]. The best single measurement approaches an uncertainty of about 1 GeV. Recent work on phenomenological uncertainties such as color reconnection effects [22] have been included in these results.

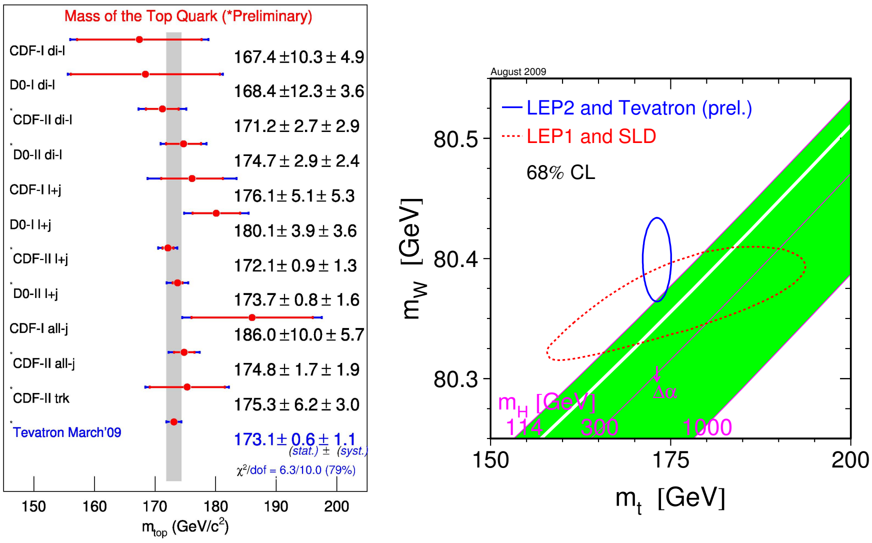

Figure 4: Left: Compilation of Tevatron measurements of the top quark mass. Right: Indirect constraint on the Higgs boson mass using the most recent Tevatron measurements of the top quark and W-boson mass.

The top pair production cross section via the strong interaction was measured by the CDF collaboration to be $\sigma_{t\bar{t}} = 7.50 \pm 0.31(stat) \pm 0.34(syst) \pm 0.15(lumi)$ pb and by the D0 collaboration to be $\sigma_{t\bar{t}} = 7.84^{+0.46}_{-0.45}(stat)^{+0.66}_{-0.54}(syst)^{+0.54}_{-0.46}(lumi)$ pb, in good agreement with the theoretical predictions [23]. The experimental precision of 6.5 % approaches the theory uncertainty. A Tevatron wide combination is currently underway. Recently, electroweak single top production has been observed by both experiments [24, 25] in 2.3 fb^{-1} (D0) and 3.2 fb^{-1} (CDF) of data, using the combination of several multivariate techniques to extract the small signal out of the overwhelming background (signal-to-background ratio ≈ 1:20). The combined production cross section is experimentally determined to be $\sigma_{st} = 2.76^{+0.58}_{-0.47}$ GeV in good agreement with the theoretical prediction [26]. From the cross section, a determination of the hitherto only indirectly measured CKM matrix element $|V_{tb}|$ can be performed. The extract value is $|V_{tb}| = 0.91 \pm 0.08(stat + syst)$, constraining physics beyond the Standard Model and extra fermion families.

5. Search for the Standard Model Higgs Boson

Electroweak fits using the most recent top quark and W-boson mass measurements constrain the mass of the Standard Model Higgs boson to $m_H < 157\,\mathrm{GeV}$ at 95% C.L. and predict a central value of $m_H = 87^{+35}_{-26}\,\mathrm{GeV}$ [27]. Searches for the Higgs boson at the Tevatron in the mass range $m_H < 135\,\mathrm{GeV}$ proceed via the vector boson (V) associated production modes VH with the Higgs boson decaying to a $b\bar{b}$ pair and the vector boson V decaying into leptons ($l\nu, ll, l\nu$). In the mass range $m_H > 135\,\mathrm{GeV}$, the search proceeds via the gluon fusion process with ensuing decay of the Higgs into a WW pair. The high mass range $m_H > 135\,\mathrm{GeV}$ provides the highest sensitivity as the spin structure of the WW final state from the Higgs decay is distinct from the dominant background, WW diboson production. The opening angle of dileptons resulting from the decay of the two W-bosons can be employed to discriminate against the background. Still, multivariate

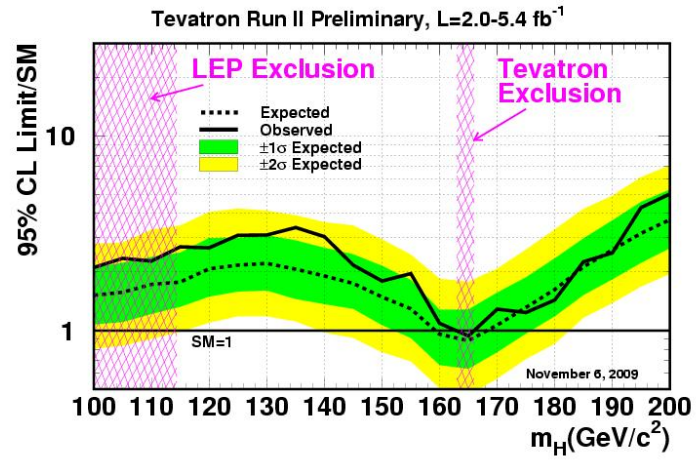

Figure 5: Combined Tevatron limit on the Standard Model Higgs boson mass.

techniques such as Neural Network or matrix element likelihood techniques need to be employed to boost the signal-to-background ratio which is still typically 1:100.

The experimental result of the Standard Model Higgs boson search is reported as a the ratio of the experimentally determined 95% C.L. limit on the cross section with respect to the theoretically expected cross section. As such, this ratio is dependent on the theoretical cross section calculation known to NNLO [28, 29, 30, 31]. Progress in the theoretical calculation as regards inclusion of two-loop electroweak diagrams [32, 33] as well as mixed QCD-electroweak corrections [34] have shifted the theoretical cross sections up, but changes in the most recent gluon PDFs [4] have largely compensated for this increase. The experimental limit is shown in Fig. 5 [35]. The Higgs boson mass is excluded at 95 C.L. in the mass range $m_H = 163 - 166$ GeV. At the mass $m_H = 115$ GeV, the experimental 95% C.L. limit is still a factor 2.7 above the Standard Model expectation.

6. Summary

The large data sets available at the Tevatron proton-anti-proton collider have facilitated stringent tests of the Standard Model and allowed precision determination of Standard Model parameters such as the mass of the top quark and the W-boson. The Standard Model Higgs boson mass range of 163-166 GeV has been excluded at 95% C.L., the first such exclusion since the limit of $m_H > 114.4\,\text{GeV}$ by LEP. The Tevatron may run until the end of 2011, in which case a total delivered luminosity of 12 fb^{-1} can be expected, roughly doubling the data set currently available to the Tevatron experiments CDF and D0.

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