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HEAVY FLAVOURS: EXPERIMENTAL SUMMARY

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The experimental talks presented in the working group D "Heavy Flavours" of the DIS04 workshop are summarised. New and recently updated results from Tevatron, HERA, LEP, B-factories and neutrino experiments are discussed.

1 Introduction

Production and hadronisation of heavy quarks is one of the most attractive laboratories for QCD prediction tests. There is an active interplay between experimental analyses and theoretical developments in this area. The aim of the working group was to discuss the relevant experimental and theoretical results which become available or updated after the previous DIS workshop. The theoretical talks are summarised in [1] New and recently updated results from Tevatron, HERA, LEP, B-factories and neutrino experiments are discussed in this note.

2 New resonances

An observation of a narrow resonance decaying to $D^{*\pm}p^{\mp}$ has been reported by the H1 collaboration [2]. Fig. 1 shows the $D^{*\pm}p^{\mp}$ invariant-mass distributions in DIS with $Q > 1\,\mathrm{GeV}^2$ and in photoproduction. A fit of the signal in DIS yielded 50.6 ± 11.2 signal events, the mass of $3099 \pm 3(\mathrm{stat.}) \pm 5(\mathrm{syst.})\,\mathrm{MeV}$ and the Gaussian width of $12 \pm 3(\mathrm{stat.})\,\mathrm{MeV}$, compatible with the experimental resolution. A signal with compatible mass and width was also observed in photoproduction. The observed resonance was reported to contribute roughly 1% to the total $D^{*\pm}$ production rate in the kinematic region studied. This resonance can be considered as a candidate for the charmed pentaquark state, $\Theta_c^0 = uudd\bar{c}$.

The observation of the H1 collaboration has been challenged by the ZEUS collaboration [3]. Using a larger sample of $D^{*\pm}$ mesons, ZEUS observed no signature of the narrow resonance in the $M(D^{*\pm}p^{\mp})$ spectra shown in Fig. 2. The fake Gaussian signals shown in Fig. 2 have the mass and the width of the H1 resonance and contain numbers of events roughly estimated assuming the resonance contributes 1% to the visible $D^{*\pm}$ production rate. The ZEUS data constrain the uncorrected fraction of $D^{*\pm}$ mesons originating from Θ_c^0 decays to be well below 1%.

The incompatibility between the H1 and ZEUS results on the charmed pentaquark should be clarified in further studies. The negative result on the Θ_c^0 search in Z^0 decays has been reported by the ALEPH Collaboration in this conference [4]. Reports from other collaborations are expected soon.

Recent results on the excited charmed-strange meson studies have been reported

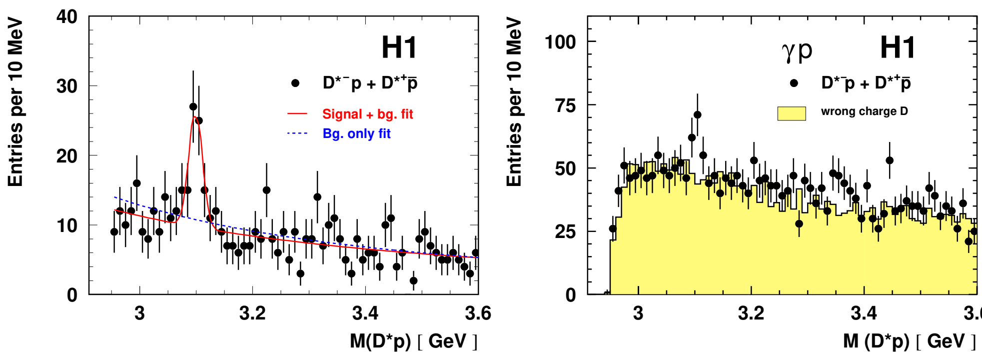

Figure 1. The distribution of $M(D^{*\pm}p^{\mp})$ obtained by the H1 collaboration in DIS (left) and photoproduction (right).

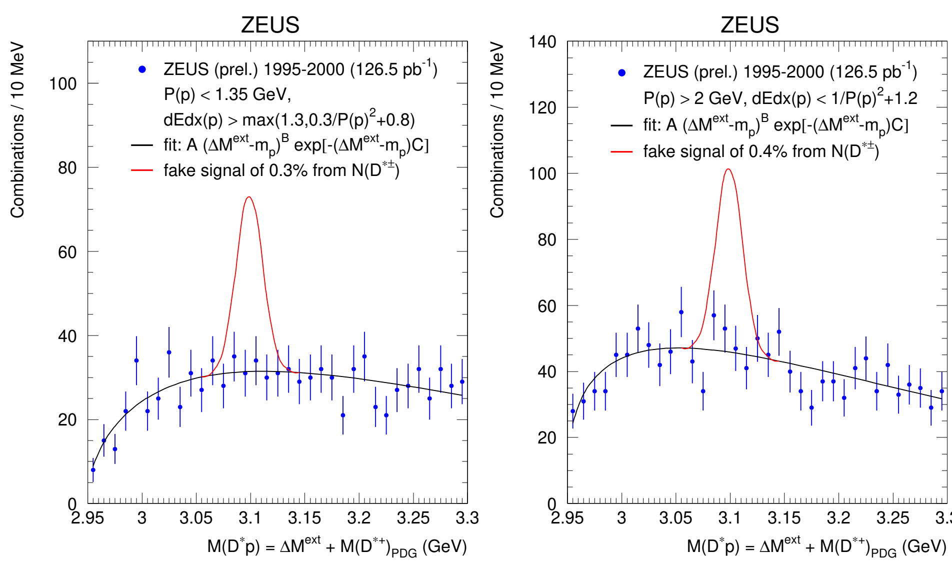

Figure 2. The distribution of $M(D^{*\pm}p^{\mp})$ obtained by the ZEUS collaboration with low-momentum (left) and high-momentum (right) proton selections.

by the Belle collaboration [5]. The BABAR collaboration discovery of the narrow $D_s(2317)$ meson decaying to $D_s\pi^0$ [6] was confirmed by the CLEO collaboration [7]. The CLEO collaboration was also established the state $D_s(2457)$ decaying to $D_s^*\pi^0$ [7]. The Belle collaboration confirmed both new excited charmed-strange mesons and measured the following $D_s(2457)$ relative branching ratios:

$$B(D_s(2457) \to D_s\gamma)/B(D_s(2457) \to D_s^*\pi^0) = 0.55 \pm 0.13 \pm 0.08,$$

$$B(D_s(2457) \to D_s\pi^+\pi^-)/B(D_s(2457) \to D_s^*\pi^0) = 0.14 \pm 0.04 \pm 0.02.$$

Upper limits on the branching ratios $B(D_s(2317) \to D_s\gamma)$, $B(D_s(2317) \to D_s^*\gamma)$, $B(D_s(2317) \to D_s\pi^+\pi^-)$, $B(D_s(2457) \to D_s^*\gamma)$ and $B(D_s(2457) \to D_s\pi^0)$ were also set. These results and an analysis of the helicity distributions of the $D_s(2317)$ and $D_s(2457)$ mesons in fully reconstructed B decays permitted to constrain the spin-parity of these mesons to 0^+ for $D_s(2317)$ and 1^+ for $D_s(2457)$.

The Belle collaboration has reported [5] measurements of the excited neutral charmed mesons with the following masses and widths:

$$M(D_0^{*0}) = 2308 \pm 17 \pm 15 \pm 28\,\mathrm{MeV},\ \Gamma(D_0^{*0}) = 276 \pm 21 \pm 18 \pm 60\,\mathrm{MeV};$$

$$M(D_1^{\prime 0}) = 2427 \pm 26 \pm 20 \pm 15\,\mathrm{MeV},\ \Gamma(D_1^{\prime 0}) = 384^{+107}_{-75} \pm 24 \pm 70\,\mathrm{MeV}.$$

The Belle Collaboration discovery of the narrow state $X(3872)$ decaying to $J/\psi\pi^+\pi^-$ [8] has been confirmed by the BABAR [9], D0 [10] and CDF [11] collaborations.

3 D/B decays

The flavour-changing neutral current decays $D^0 \to \mu^+\mu^-$ and $B^0_{d,s} \to \mu^+\mu^-$ are strongly suppressed in the Standard Model (SM). Anomalously large branching ratios of the decays would indicate new physics beyond the SM, e.g. R-parity violating SUSY.

In the D-meson sector, the most stringent published upper limit, $\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.5 \times 10^{-6}$ (90% C.L.), was set by the CDF Collaboration [12,13]. The HERA-B Collaboration has reported [14] results of a search for the $D^0 \to \mu^+\mu^-$ decay with the data collected during the 2002-2003 HERA running period. The measurement was based on normalising the number of events in the D^0 signal region to the number of reconstructed $J/\psi \to \mu^+\mu^-$ events. Using the D^0 and J/ψ production cross sections measured elsewhere, the upper limit was obtained to be $\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.0 \times 10^{-6}$ (90% C.L.).

The CDF Collaboration has reported results of a search for $B^0_{d,s} \to \mu^+\mu^-$ decays with $171\,\mathrm{pb}^{-1}$ of Run II data [13]. The upper limits were obtained to be $\mathcal{B}(B^0_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}$ (90% C.L.) and $\mathcal{B}(B^0_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}$ (90% C.L.). The D0 Collaboration has reported results of a search for the $B^0_s \to \mu^+\mu^-$ decay with $240\,\mathrm{pb}^{-1}$ of Run II data [15]. Using reconstructed $B^\pm \to J/\psi K^\pm$ events for normalisation, the upper limit was set to be $\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.6 \times 10^{-7}$ (95% C.L.). The obtained upper limits constrain several SUSY models.

4 Top production

Progress on the t-quark mass and production cross section measurements has been reported by the CDF Collaboration [16]. Top production cross section is expected to be $30 - 40\%$ larger at Run II due to the increase of the Tevatron centre-of-mass energy from 1.8 TeV to 1.96 TeV. The top pair production cross section was measured using dilepton, lepton+jets and all-hadronic modes. The measured cross sections are in agreement with each other and with the Run I results. The NLO QCD predictions for the top production cross section describe the experimental results well. No evidence for single top production was found.

5 Beauty production

The high performance of the upgraded CDF detector has been demonstrated by the new beauty production cross section measurements [11]. Using a new dimuon trigger, CDF recorded central $J/\psi \to \mu^+\mu^-$ production down to $p_T = 0$. The fraction of J/ψ arising from B-meson decays was unfolded using the displaced vertex identification with the help of the new silicon vertex tracker. The resulting differen-

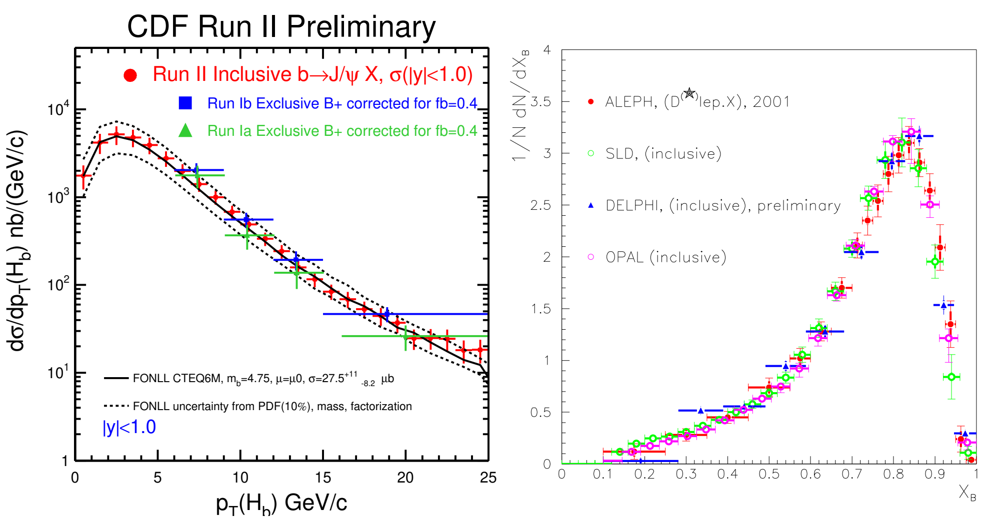

Figure 3. (Left) Differential cross section for inclusive B hadron production as a function of p_T measured by CDF. (Right) the measured distribution for x_B from ALEPH, DELPHI, OPAL nd SLD.

tial cross section for inclusive B hadron production as a function of p_T is shown in Fig. 3(left). The measured cross sections agree with the Run I measurements. The data are well described by predictions of the matched FONLL calculations [17] and the MC@NLO Monte Carlo [18]. The improved agreement between the measured and predicted beauty hadroproduction cross sections is connected in part with the description of the b quark hadronisation.

To constrain the b quark hadronisation parameters, the LEP and SLD measurements were used [19]. Fig. 3(right) shows the LEP and SLD measurements of the

$1/NdN/x_B$ distribution, where $x_B = 2E_B/\sqrt{s}$ and E_B is the b-hadron energy. The measurements favour the LUND and Bowler fragmentation models and disfavour the Peterson model. To obtain the b-hadron production fractions, the LEP and TEVATRON measurements were combined producing: $f_{B_u} = f_{B_d} = (39.8 \pm 1.0)\%$, $f_{B_s} = (10.5 \pm 1.5)\%$ $f_{b-baryon} = (9.9 \pm 1.7)\%$.

A new b-quark mass measurement has been reported by the DELPHI Collaboration [20]. Using the 3-jet rate, the running mass was measured to be

$$m_b(M_Z) = 2.85^{+0.18}_{-0.19}(\mathrm{stat}) \pm 0.13(\mathrm{exp})^{+0.19}_{-0.20}(\mathrm{had}) \pm 0.12(\mathrm{theor})\,\mathrm{GeV}.$$

A compatible result was obtained using 4-jet events.

The 4-jet rate in e^+e^- collisions is sensitive to the b quark production by gluon splitting ($g \to b\bar{b}$). The fraction of hadronic Z^0 decays with $g \to b\bar{b}$ was obtained [21] by combining LEP and SLD measurements to be $(2.54 \pm 0.51) \times 10^{-3}$. The result is well described by the theoretical predictions at next-to-leading logarithmic approximation [22].

A new measurement of the beauty production in proton-nucleus collisions at $\sqrt{s} \approx 41.6\,\mathrm{GeV}$ has been reported by the HERA-B Collaboration [23]. Using 35% of the J/ψ sample collected in 2002-2003, the preliminary result is

$$\sigma(b\bar{b}) = 12.3^{+3.5}_{-3.2}(\mathrm{stat})\,\mathrm{nb/nucleon}$$

with the systematic uncertainty of around 25%. The new result is $1.5\,\sigma$ lower the previous HERA-B measurement [24] taking into account uncertainties of the both measurements.

New results on beauty production with a muon in the final state in ep scattering have been reported by the H1 [25] and ZEUS [26,27] Collaborations. The beauty signals were extracted using the transverse momentum distribution of the muon relative to the axis of the associated jet and, in the H1 analyses, the impact parameter distribution of muons. The measured cross sections were compared to the fixed-order ("massive") NLO QCD predictions and various Monte Carlo models. Fig. 4 shows the ratio of the recent HERA measurements of b-production cross sections to the fixed-order NLO QCD expectations as function of Q^2. The NLO predictions are generally smaller than but agree with the data within large experimental and theoretical uncertainties. Shapes of various differential beauty production cross sections are generally well reproduced by the NLO predictions. The HERA analyses reported somewhat stronger disagreements with the NLO predictions at low values of muon transverse momentum and low values of Q^2 and Bjorken x in DIS.

6 Open charm production

The CDF Collaboration has reported the inclusive charm production cross section measurement [11,28]. The differential cross sections of D^0, $D^{*\pm}$, $D^\pm$ and $D_s^\pm$ production were measured as a function of transverse momentum in the central rapidity range $|y| < 1$. Both FONLL calculations [17] and "massless" calculations from Kniehl et al. describe shapes of the measured distributions. The absolute normalisation of the measured cross sections is slightly underestimated by the predictions.

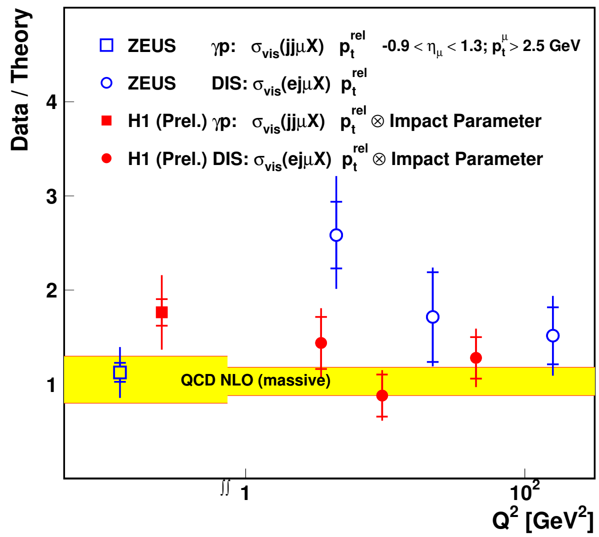

Figure 4. Ratio of measured b-production cross sections at HERA to NLO QCD expectations as function of Q^2.

New measurement of inclusive jet cross sections in $D^{*\pm}$ photoproduction has been reported by the ZEUS Collaboration [29]. Differential cross sections as a function of $E_T^{\rm jet}$ and $\eta^{\rm jet}$ were compared to the fixed-order NLO QCD predictions. The correction from parton-level to hadron-level jets was done by multiplying the NLO QCD prediction by hadronisation correction factors, evaluated using PYTHIA and HERWIG Monte Carlo simulations. The predictions underestimate the data normalisation but agree with that within large theoretical uncertainties. The shapes of the $d\sigma/dE_T^{\rm jet}$ distributions are well described by the NLO predictions. There is an indication of a stronger data underestimation by the predictions at the very highest $E_T^{\rm jet}$. The shapes of the $d\sigma/d\eta^{\rm jet}$ distributions are described by the NLO predictions after applying the hadronisation correction.

The high-statistics measurement of charm production in DIS has been reported by the ZEUS Collaboration [30]. The differential $D^{*\pm}$ cross sections as a function of Q^2, x, $p_T(D^{*\pm})$ and $\eta(D^{*\pm})$ are reasonably well described by the fixed-order NLO predictions. The predictions using the ZEUS NLO fit gives a better description than that using CTEQ5F3 or GRV98-HO for the cross section $d\sigma/d\eta(D^{*\pm})$. The double-differential cross section in y and Q^2 was used to extract the open-charm contribution, $F_2^{c\bar{c}}$, to the proton structure function F_2.

Both charm and beauty contribution to the proton structure function have been measured by the H1 Collaboration for $Q^2 > 110\,{\rm GeV}^2$ [31]. In this analysis, all events with at least 1 reconstructed track with hits from the central silicon vertex tracker were used. The transverse distance of closest approach of the track to the primary vertex was used to separate the different quark flavours. Fig. 5 shows the relative charm (H1, ZEUS) and beauty (H1) contributions to the total ep cross section as a function of x for two Q^2 values. The data are well described by the predictions from the H1 NLO QCD fit in which the c and b quarks are teated in the "massless" scheme.

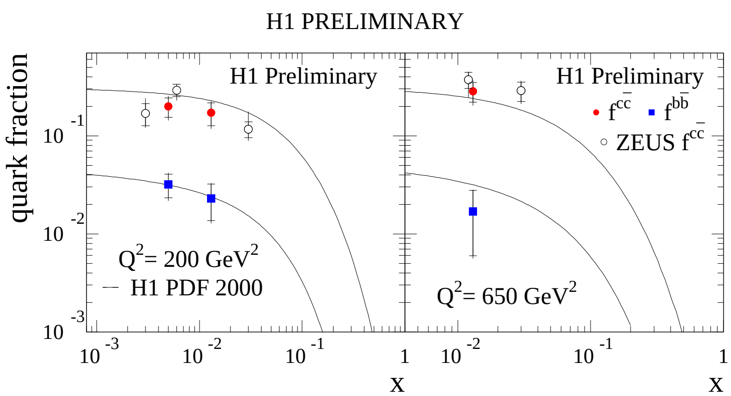

Figure 5. The relative charm (H1, ZEUS) and beauty (H1) contributions to the total ep cross section as a function of x for two Q^2 values. The predictions of the H1 NLO QCD fit are also shown.

The ZEUS Collaboration has measured the open-charm contribution, $F_2^{D(3),c\bar{c}}$, to the diffractive proton structure function [32]. The diffractive charm production was identified by reconstructing of $D^{*\pm}$ mesons in DIS events with a large rapidity gap between a proton at high rapidities and the centrally-produced hadronic system. The measurement was performed in the diffractive kinematic range $x_{I\!P} < 0.35$ and $\beta < 0.8$. Fig. 6 shows the quantity $x_{I\!P} F_2^{D(3),c\bar{c}}$ as a function of $\log(\beta)$ for different Q^2 and $x_{I\!P}$ values. The curves show the NLO ACTW calculations with proton diffractive structure function fits B, D and SG [33]. Only the fit B predictions agree with the data.

7 Charmonium production

The J/ψ hadroproduction cross section, measured by the CDF Collaboration [11] down to $p_T(J/\psi) = 0$, is more than one order larger than the charmonium cross sections measured at Run I for $p_T(J/\psi)$ values above $4 - 5\,GeV$. New resummed colour octet matrix elements are awaited to perform a comparison of the new measurement with the NRQCD predictions.

The HERA-B Collaboration has reported new measurement of charmonium

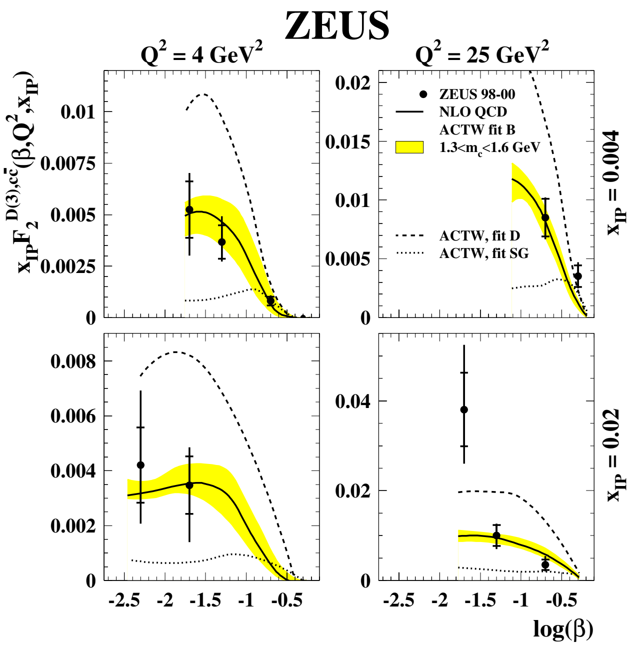

Figure 6. The quantity $x_{I\!P} F_2^{D(3),c\bar{c}}$ as a function of $\log(\beta)$ for different Q^2 and $x_{I\!P}$ values. The curves show the NLO ACTW calculations with proton diffractive structure function fits B, D and SG.

production cross sections in proton-nucleus collisions, differential distributions and nuclear effects [34]. Using the power law for J/ψ cross section in pA collisions, $\sigma_{pA} = \sigma_{pN} A^{\alpha(x_F)}$, the suppression parameter α was measured down to $x_F = -0.3$. Using the full accumulated statistics, the measurement will be able to validate various theoretical predictions.

The ZEUS Collaboration has performed new measurement of the J/ψ helicity distributions using the full data sample from HERA I [35]. The results are described by the NRQCD predictions using both colour singlet and colour octet contributions. Using only the colour singlet contribution, the predictions are somewhat above the data.

The Belle Collaboration has reported an update of their measurement of double charmonium production in e^+e^- annihilations[36]. The spectrum of recoil masses against the J/ψ was fitted using known charmonium states. The measured cross sections are well above of the HQET predictions. One can conclude that the double charmonium production in e^+e^- annihilations is not yet understood. The production cross sections and helicity characteristics of processes $e^+e^- \to D^{(*)}\bar{D}^{(*)}$, observed by the Belle Collaboration for the first time, are generally described by the theoretical predictions.

8 Neutrino charm production

A wide spectrum of results on charm physics in neutrino-induced processes has been reported by the CHORUS collaboration [37]. The inclusive and quasi-elastic Λ_c production was measured in ν_μ charged-current interactions at an average neutrino energy of 27 GeV. The quasi-elastic component of the Λ_c production cross section was found to be $\approx 15\%$. The charm contribution to the cross section of charged-current interactions induced by $\bar{\nu}_\mu$ was also measured.

New results on the strange sea asymmetry have been reported by the NuTeV Collaboration [38]. The dimuon data were fitted in LO and NLO QCD using different methods of parameterising the strange sea. The fits tended toward a small negative asymmetry at low x, always consistent with zero. Using the same data, the CTEQ group has extracted a positive asymmetry. NuTeV and CTEQ will continue collaborate to resolve possible discrepancies in the theoretical assumptions used. Both NuTeV and CTEQ agree that the NuTeV $\sin^2\theta_W$ discrepancy [39] is unlikely covered completely by an asymmetry in the strange and anti-strange PDFs.

9 Conclusions

The charm hadron spectroscopy is an actual topic again. The discovery $D_s(2317)$ by the BABAR Collaboration and $X(3872)$ by the Belle Collaboration were confirmed by other experiments. The situation with pentaquarks in general and, in particular, with the charmed pentaquark is not clear. More experimental efforts are needed to clarify the picture.

New results on top, beauty and charm production provides additional opportunities for testing the perturbative QCD predictions. In general, the pQCD calculations can describe the experimental results. In many cases, the predictions are below the data that is often hidden by large experimental and theoretical uncertainties. Increasing experimental precision of the Tevatron and HERA data on charm and beauty production requires more precise theoretical calculations. One should add that there is still no adequate theoretical description of the double charmonium production in e^+e^- annihilations.

The neutrino experiments provide invaluable information on charm production and on the strange component of the proton structure. Recent NuTeV analysis reports no significant asymmetry between strange and anti-strange PDFs.

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