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THEORY SUMMARY OF WORKING GROUP D: HEAVY FLAVOUR PHYSICS

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Ten theoretical talks presented in the working group D on "heavy flavour physics" are summarized. Reflecting the workshop's focus on "deep inelastic" physics, most of the contributions were centered around the phenomenology of heavy flavour production.

1 Introduction

Open heavy flavour as well as quarkonium production rates and differential distributions each pose their individual challenge to a theoretical description of the corresponding processes in perturbative QCD. Revisions and improvements on both ends of the comparison between experiment and theory have reaffirmed our confidence that the basic theoretical ideas derived from the heaviness of charm and bottom quarks are correct, and that remaining puzzles can be resolved through refining the detailed prescriptions along which these ideas are translated into concrete phenomenological analyses of experimental observables. Such refinements, as reported at DIS04, may still reveal the devil in the detail and turn out to be quite relevant phenomenologically, without necessarily altering the big ontological picture by much.

2 Open heavy flavour production

The theory of open heavy flavour production has reached a particularly mature stage. At the conference we heard about refinements of the collinearly factorized twist-2 formalism as well as about conceptually different developments along non-collinearly $k_\perp$-factorized approaches. The latter will be summarized under the aspect of *resummation* below.

Ingo Schienebein, along with early results from a reassessment of the hadroproduction process, presented a conceptual review of the various implementations of the collinear factorization approach to heavy flavour production. His discussion was guided by the factorization theorem with heavy quark masses and focused on power suppressed mass terms. A commonly accepted prescription to treat heavy quarks would be very valuable, not least for future LHC phenomenology, and it will be interesting to see how the final results will compare (phenomenologically and conceptually) with the results presented by S. Frixione which I am about to summarize next.

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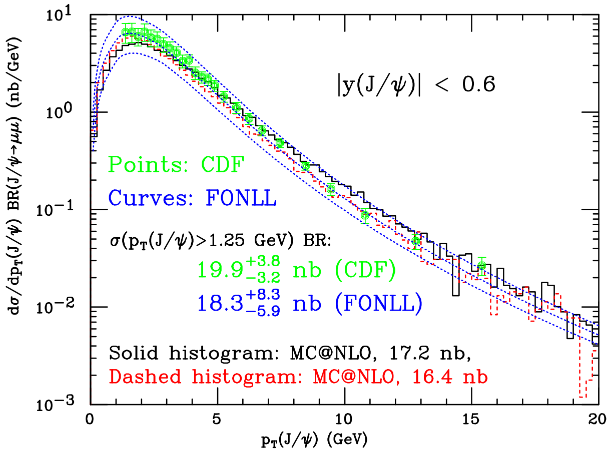

Figure 1. Not a common view in recent years: NLO QCD calculation describing bottom production at the Tevatron; presented by S. Frixione.

3 *The* puzzle in heavy quark production physics ?

One of the biggest worries in heavy quark production over the recent years has been the seeming excess in bottom production rates, measured e.g. as a $p_\perp$ spectrum at the Tevatron. Stefano Frixione presented the state-of-the-art of the pQCD calculations, where the NLO perturbative approximation is matched to the all order collinear resummation, thus defining a variant of a 5 flavour scheme with mass terms. (The calculation agrees well with final state parton showering as implemented into MC@NLO). The results indicate that an improved understanding of the $Q \to |Q\bar{q}\rangle X$ fragmentation function leaves us with a much more optimistic picture than was assumed over the previous years, during which it seems in retrospect that discrepancies may actually have been overstressed or theoretical uncertainties underestimated. In particular, the recent Run II Fermilab data appear to be in perfect agreement with NLO QCD (Fig. 1). Reassuringly, bottom production at HERA – though on average somewhat on top of the theory – compares better with the predictions now, too, within the phase space region that is visible to the H1 and ZEUS detectors. It should be remarked, though, that no corresponding resolution of the apparent bottom access in photon collisions has yet been proposed. Jiri Chyla suspected that missing higher order terms may be relevant, which could be clarified only through an explicit calculation. It seems in order to first have a similar update between NLO theory and experiment as S. Frixione presented for the Tevatron case.

4 Resummations

Collinear resummation populates the target remnant state and heavy quark jet with a higher multiplicity of unresolved partons, by means of (DGLAP) evolving the parton densities and fragmentation functions. These extra-partons are integrated over and approximated to be collinear, though, so they do not cure the perturbative artefact of a low number of resolved (noncollinear) particles in the final state. Adding a Monte Carlo parton shower phase can generate a configuration that resembles more the physical reality of the detected hadronic final states. Still, there are unphysical features of the pre-showering stage from soft gluons. They can be improved through analytic Sudakov resummations. Tom Mehen and Nick Kidonakis showed that for endpoint effects in Quarkonium production in e^+e^- annihilations and for threshold effects in bottom production rates at HERA-B, resummations are necessary to describe the data. In particular the kinematic endpoint region receives resummation "corrections" that change the theory predictions even qualitatively, explaining the absence of a large color octet contribution. (For other problems in quarkonium production that remain unresolved, I refer the reader directly to T. Mehen's talk.)

Resummations of a different kind, presented at this meeting by Sergey Baranov, Hannes Jung, Anatoly Kotikov and Antoni Szczurek, are at work in $k_\perp$-factorized approaches to heavy quark production. Introduced as a resummation of small-x logarithms in the high energy limit, $k_\perp$ factorization breaks the $k_\perp$ ordering of the ladder diagrams that constitute the DGLAP evolution (in a physical gauge). While it seems that at present energies this kind of resummation is not a phenomenological necessity, radiation patterns (such as BFKL or angular ordering) different from DGLAP are predictions of QCD and as such are of ontological interest. As discussed by Antoni Szczurek, correlations resolve the kinematics in greater detail and are likely to contain more information than inclusive production rates. The individual results presented here, depending on the assumed unintegrated gluon densities, certainly demonstrated a good description of e.g. the Tevatron data, even though A. Kotikov reminded us of the importance to know NLO corrections. It is the opinion of the author of this summary that also a global picture of $k_\perp$ factorization, matching all relevant data sets with one universal unintegrated gluon distribution, would add convincing evidence that the formalism is "real".

5 Heavy quarks and precision electroweak physics

Considering that the theory of heavy flavour production had to stand claims of undershooting the data by large factors, it seems almost ironic that it should be of any relevance to precision electroweak measurements. However, the link is through differences in neutrino- and anti-neutrino production of charm in the NuTeV anomaly (see contributions and summary of WG E). I have myself presented at this conference an analysis in terms of the strangeness asymmetry $s(x) - \bar{s}(x)$ that should be contrasted with experimental results presented by Panagiotis Spentzouris.

6 Final comments

To conclude my report I steal from one of the experimental talks and remark on what Matthias Grosse-Perdekamp told us about heavy flavour production in $AuAu$ collisions at RHIC. The theory of heavy quark production is based on the fact that the heavy quark mass cuts off the collinear singularity in inclusive production rates. As an angular distribution, this corresponds to the *dead cone* effect (Fig 2) which is expected to modify heavy flavour production differently from light partons in heavy ion collisions. I consider it a beautiful prospect to have such seemingly

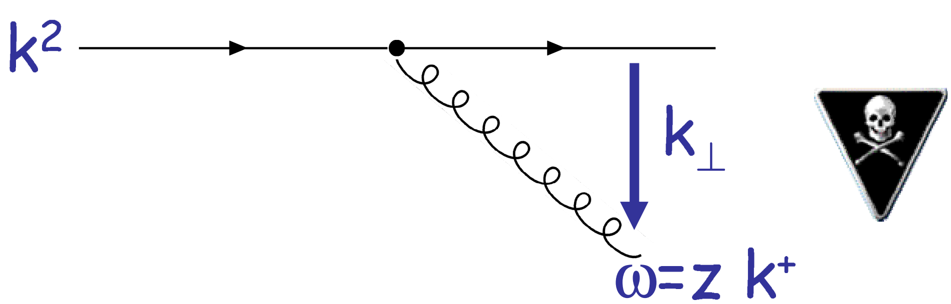

Figure 2. The dead cone cuts off radiation in the would-be nonperturbative region.

Acknowledgments

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