Highlights of Cern Workshop on Charm Production in A+A Collisions

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Abstract. Models and experimental effort concerning open and hidden charm production in nuclear collisions discussed at Cern Workshop in December 99 are reviewed. The most recent development is also mentioned.

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1. Introduction

Basic aim of the Workshop [1] organised at Cern by U. Heinz and C. Lourenco in December 1999 was the discussion of two questions concerning open charm production in nucleus–nucleus (A+A) collisions at Cern SPS energies:

- do we want to measure it?
- can we measure it?

The workshop should be seen as an important element of an ongoing debate on future of heavy ion physics at Cern SPS. Two proposals were formulated for the experimental studies of A+A collisions in year 2000 and beyond:

- a measurement of open charm production at the top SPS energies (158–200 A·GeV) by NA60 [2] and NA49 [3] and
- a study of onset of deconfiment at low SPS energies (20, 30 and 80 A·GeV) by NA49 [4].

The Workshop allowed for a review and critical discussion of theoretical and experimental aspects of open charm proposals.

During the last 25 years a pQCD–based framework for a treatment of open (charm mesons and hyperons) and hidden (charmonia) charm production was formulated and it dominated the interpretation of the experimental data. It is based on the assumption that the perturbative QCD apparatus is applicable for open charm production in hadronic and nuclear collisions and that charmonium creation is due to binding interaction between perturbatively produced c–$\overline{c}$ quarks. Since recent analysis of J/ψ and dimuon production in Pb+Pb collisions put the standard framework to question, a new and vivid discussion has started on the subject. Several non–standard models for open and hidden charm production were proposed, the most controversial among them are statistical models. During the Workshop data and models were discussed mainly within the standard framework. There are, however, many excellent reviews [5] written by experts in this subject. Thus in my brief report I will focus on the new developments instead of repeating details of a well known standard approach. For completeness I will mention recent results which were not presented during the Workshop.

In section 2 of this report J/ψ production and its relation to open charm are discussed. A summary of various approaches to open charm production is given in section 3. Finally a first attempts to measure an open charm yield in A+A collisions at SPS and future plans for continuation of this effort are presented.

2. J/ψ Production

The Workshop was opened by Satz [6] who discussed J/ψ production and its relation to open charm in nuclear collisions. The J/ψ has been measured in A+A collisions over the last 15 years by NA38 and NA50 Collaborations. This experimental program was mainly motivated by a hypothesis of Matsui and Satz [7] formulated within standard framework. They suggested that J/ψ may serve as a probe of the state of matter created in the early stage of the collision. Recent results and their new interpretations indicate that Matsui–Satz approach may be incorrect.

Two years ago Gorenstein and myself [8, 9] observed that the J/ψ yield in nuclear collisions is proportional to the pion multiplicity. We further showed [10] that the data may be explained assuming statistical production of J/ψ at hadronization. Recently several models in which J/ψ creation is due to coalescence of c–$\overline{c}$ quarks or D–$\overline{D}$ mesons at different stages of collision were formulated. A brief summary of these approaches is given below.

2.1. Standard Approach

In the standard approach reviewd by Satz [6] charmonium production is considered as a three stage process: the creation of a c–$\overline{c}$ pair, formation of a bound c–$\overline{c}$ state, and its subsequent interaction with the surrounding matter. The first process is calculated within pQCD, whereas non–perturbative QCD is needed to describe the last two stages. The interaction of the c–$\overline{c}$ bound state with matter results in suppression of the final J/ψ yield in comparison with its initial number. In order to comapre the model to the data, the assumption is made that the initial J/ψ yield is proportional to multiplicity of Drell–Yan pairs. Within this framework the significant suppression of J/ψ production relative to Drell–Yan which is observed when going from peripheral to central Pb+Pb interactions at 158 A·GeV [11] is attributed to the formation of a QGP in the latter collisions [12].

The data on J/ψ production in proton–nucleus (p+A) interactions serve as a first test of the model. Aichelin [13] pointed out that recent precise results on x_F dependence of the charmonium yield in p+A collisions [14] are difficult to understand within the standard framework.

2.2. Statistical Approach

The statistical approach, presented by Gorenstein and myself [15], assumes that J/ψ mesons are created at hadronization according to the available hadronic phase–space. Thus, within this model, the J/ψ yield is independent of the open charm yield. Moreover, the J/ψ production is, in good approximation, insensitive to the state of matter created at the early stage. This is because charmonium is created only at the hadronization stage. The model offers natural explanation of the proportionality of the J/ψ and pion yields and the magnitude of the multiplicity of J/ψ mesons in hadronic and nuclear collisions [10].

It should be noted that a consistent picture of hadron production within this model is still missing. As an example one can consider ψ' production. The statistical approach used for J/ψ description works for ψ' production in central A+A collisions [16, 17]. It does not give, however, a natural explanation of a substantial increase of the $\psi'/J/\psi$ ratio measured in p+p and p+A interactions.

2.3. Microscopical Coalescence Model

Microscopical coalescence model [18], presented by Lévai [19], assumes that J/ψ mesons are formed at hadronization as a result of coalescence of c–$\overline{c}$ quarks created in the earlier stages of the collision. By introduction of microscopic coalescence factors and accounting for quark number conservation one can relate J/ψ and open charm production. Starting from the measured multiplicity of J/ψ mesons in central Pb+Pb collisions at SPS, one predicts mean multiplicity of c–$\overline{c}$ pairs, $n_{c\overline{c}} \approx 3$.

2.4. Statistical Coalescence Model

Also in the statistical coalescence model, recently introduced by Braun–Munzinger and Stachel [17], charmonium states are produced at hadronization as a coalescence of earlier created c–$\overline{c}$ quarks. It is further assumed that the number of c–$\overline{c}$ quarks is given by pQCD and that the redistribution of these quarks among hidden and open charm hadrons follows the maximum entropy principle. The model reproduces the measured J/ψ yield in central Pb+Pb collisions at 158 A·GeV using parameters fitted to the light hadron sector.

This model, however, does not give a natural explanation for the observed proportionality of J/ψ and pion yields in nuclear collisions.

2.5. Coalescence in QGP

A possible contribution from the coalescence of c–$\overline{c}$ quarks originating from different elementary interactions was calculated by Thews, Schroedter and Rafelski [20]. The coalescence process is assumed to take place in the QGP phase in parallel with the expected disintegration of charmonium states. Starting from the pQCD charm yield they calculated that the coalescence contribution can lead to enhanced production of J/ψ mesons in A+A collisions at RHIC and LHC energies. This prediction should be confronted with the expectation of J/ψ suppression derived within the standard approach [12].

2.6. Secondary Hadronic Production

Charmonium production resulting from the interaction of D and $\overline{D}$ mesons in hadronic matter was considered by Braun–Munzinger and Redlich [21]. The contribution from this process to the total J/ψ yield was found to be small even at LHC energies. This is not the case for ψ' production, where the secondary production may substantially exceed the primary yield.

Presented models predict very different relations between hidden and open charm production. In the statistical model the J/ψ and open charm yields are independent. Initial charmonium production is proportional to $n_{c\overline{c}}$ in the standard approach. This relation is however modified by the suppression processes. In the coalescence models J/ψ multiplicity increases approximately as $n^2_{c\overline{c}}$.

It is therefore clear that data on open charm in A+A collisions are necessary in order to understand mechanism of J/ψ production.

3. Open Charm Production

Open charm production is not measured in A+A collisions. The presentation of Capelli [22] was, however, devoted to the question whether open charm yield can be indirectly estimated from the current data. NA50 observes enhancement of dimuon pairs in the mass region between ϕ and J/ψ peaks (intermediate mass region, IMR) in central A+A collisions at SPS [23]. A possible interpretation of this effect, favoured by NA50, is that it is due to enhanced open charm production. The enhancement factor is relative to the pQCD prediction. Note that the possible enhamcement already questions the validity of the standard approach [5].

The basic ideas concerning open charm production presented during the Workshop are summarised below.

3.1. Standard Approach

In standard model, revied by Vogt [24], one assumes validity of pQCD calculations for open charm production in hadronic and nuclear interactions. A comparison with the open charm measurements in hadronic interactions serves as a first test of the model. In fact the data can be described assuming reasonable values of input parameters (charm quark mass, Λ_{QCD}, renormalization and factorisation scales). One should note, however, that uncertainties in this parameters lead to the variation of the calculated open charm multiplicity by a factor of about 100 (Frixione et al. [5]).

The model with the parameters fitted to the hadronic data can be used to predict open charm multiplicity in p+A and A+A collisions. Unfortunately present p+A data are too sparse for a precise test of the model [9].

In good approximation the following A–dependence is expected for central A+A collisions:

$$\langle n_{c\overline{c}} \rangle_{AA} = \langle n_{c\overline{c}} \rangle_{NN} \cdot A^{4/3}. \quad (1)$$

This results in an estimate of the mean multiplicity of $D^0 + \overline{D}^0$ mesons in central Pb+Pb collisions at 158 A·GeV: $\langle D^0 + \overline{D}^0 \rangle \approx 2 \cdot 10^{-1}$ [25].

3.2. Secondary Production

The pQCD based calculations on open charm production from secondary collisions occurring in the expanding QGP were reported by Braun–Munzinger [26]. This additional contribution to the initial open charm yield was found to be negligible at Cern SPS energies.

3.3. Statistical Approach

The statistical model, introduced by Gorenstein and myself [8], assumes that charm quarks and antiquarks are created according to the early stage partonic phase space. This non–standard assumption was motivated by a success the statistical model of the early stage of A+A collisions in description of strangeness and entropy production. Within the model the expected number of c–$\overline{c}$ pairs is about 8 in central Pb+Pb collisions at 158 A·GeV and the corresponding number of $D^0 + \overline{D}^0$ mesons is about 6.

For central collisions of large enough nuclei ($A > 30$) the grand canonical approximation can be used and consequently one expects that open charm multiplicity increases as A^1.

The pQCD based and statistical estimates of open charm yield in central Pb+Pb collisions at 158 A·GeV differ by a factor of about 30. The predicted A–dependence in these two approaches is also different. Only direct measurements of open charm production in A+A collisions can uniquely distinguish between these spectacularly different models. In particular open charm measurements should give a unique opportunity to set limits to the applicability of pQCD and statistical models of strong interactions.

4. Open Charm Measurements

4.1. Present

NA50 (Capelli [22]) reported increased production of dimuon pairs in the intermediate mass region over the standard sources in A+A collisions. The enhancement factor is about 3 for central Pb+Pb collisions at 158 A·GeV. The observed effect can be attributed to enhanced production of open charm.

However other interpretations are also possible. Wang argued [27] that the data can be reproduced assuming that only the momentum spectrum of charm hadrons is modified in A+A collisions with respect to p+p and p+A interactions. Thermal radiation of dimuons was also shown to reproduce the experimental results on dimuon enhancement [23].

Finally one can argue [29] that the background subtraction procedure used by NA50 may lead to biased results in the case of central Pb+Pb collisions.

NA49 [15] made first attempt to estimate an upper limit of mean multiplicity of D and $\overline{D}$ mesons in central Pb+Pb collisions at 158 A·GeV by a direct measurement. In this case invariant mass distribution of identified kaons and pions is studied [25]. Using the currently analysed number of events ($4 \cdot 10^5$) the estimated upper limit is on the level of the statistical model prediction.

4.2. Future

NA49 [3] is planning to significantly increase (up to $5 \cdot 10^6$ events) the statistics of central Pb+Pb collisions at 158 A·GeV during this year's Pb–run. Statistical resolution of this new data should allow to exclude models predicting $\langle D^0 + \overline{D}^0 \rangle > 1$.

Shahoian [30] reported that one of the main goals of the recently proposed and approved experiment NA60 [2] is to study the origin of the dimuon enhancement in the IMR observed by NA50. Main components of NA60 experiment are:

- the present NA50 detector with the muon arm as a basic instrument,
- a new pixel vertex spectrometer and
- a new beam scope.

This set–up will allow for a precise measurements of the track impact parameter at the interaction point. It will also result in significant improvement of the momentum resolution in comparison to that achieved by NA50. Consequently NA60 will be able to distinguish between prompt dimuons (Drell–Yan and thermal contributions) and dimuons from decays of charm hadrons. This should lead to clarification of the origin of dimuon enhancement. NA60 was approved for p–beam in 2001. The decision concerning requested ion beams in 2002 and 2003 will be made in September this year.

Systematic charm measurements in nuclear collisions are key elements in the upcoming RHIC and LHC programs. Indirect and direct measurements of open charm should be possible in PHENIX at RHIC (Averbeck [31]) and in ALICE at LHC (Safarik).

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