First indication for a sharp onset of anomalous J/ψ suppression in Pb+Pb collisions at 158 GeV/c.

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Abstract

New results on cross section ratios ψ/(Drell-Yan) are presented. The new data set from the 1996 run is in very good agreement with the final results from the 1995 run. They confirm the anomalous J/ψ suppression observed in Pb+Pb central collisions for b$\leq$ 8 fm where b represents the average impact parameter of the collisions calculated from the measurement of both the neutral transverse energy and the very forward hadronic energy. No anomalous suppression is seen in Pb+Pb collisions for b$\geq$ 9 fm.

1 Introduction

The production of charmonia (J/ψ,ψ') and Drell-Yan pairs in heavy ion collisions has been studied extensively by the experiment NA38 and its successor, NA50, for the lead beam. The first Pb+Pb data were taken late 1994 at CERN and used essentially to identify and reduce all sources of dimuon background located outside the lead target. The first production run took place during fall 1995 and preliminary results were presented at the Quark-Matter conference at Heidelberg [1]. We reported an anomalous J/ψ suppression in Pb+Pb collisions in comparing this result and the suppression observed in lighter systems. The overall set of data collected by NA38 [2] in p+A, O+A and S+U collisions seemed to support the absorption mechanism of charmonia by nuclear matter. The Pb+Pb data could not be described by this mechanism. These preliminary results have been confirmed by the final analysis of the 1995 data [3][4]. Based on these results, the main purpose of the 1996 run was to enhance the NA50 luminosity in order to increase significantly the number of high mass muon pairs recorded on tape and produced in particular for peripheral Pb+Pb collisions. The program aimed at confirming the anomalous suppression in one single system. One other important question which the 1995 run had insufficient statistics to answer was the precise comparison of the Pb+Pb peripheral data to the S+U data.

The first new results from the 1996 run are reported in this paper and compared with the 1995 and NA38 results. No experimental detail for the NA50 spectrometer and centrality detectors will be given here due to the fact that the 1996 and 1995 experimental setups were similar [4]. Regarding analysis, a new procedure for vertex identification has been used in addition to the standard target algorithm, and will be described in the text. The high statistics 1996 run produced roughly $170{*}10^6$ triggers ($56{*}10^6$ for 1995) written on tapes which correspond to $\simeq$ 250000 final J/ψ (50000 for 1995) events. These numbers represent the full statistics of the 1996 run. Pile-up events corresponding to 29 % of the total number of events (20 % for 1995) were not included in this analysis. Cross sections for ψ' will not be presented in this paper but preliminary results from the 1995 run can be found elsewhere [5].

2 Final results from the 1995 lead run

The nuclear dependence for hard process production in $A_{projectile} + B_{target}$ collisions can be parametrized as

$$\sigma_{AB} = (A_{projectile} \cdot B_{target})^{\alpha} \cdot \sigma_{NN} \tag{1}$$

The measured Drell-Yan cross section is $\sigma_{Pb+Pb} = 1.49\ \mu\text{b} \pm 0.02 \pm 0.11$ for Pb+Pb collisions at 158$\times$A GeV/c with $M_{\mu+\mu-} \geq 2.9$ GeV/c^2. In order to compare this value with p+p, p+B_{target} and S+U values, the Pb+Pb cross section was scaled up to 200 GeV, calculated in the mass range of [2.9-4.5] GeV and corrected for isospin effect [1]. Finally, the values for p+p, p+d, p+W, S+U and Pb+Pb were found to be fully compatible with the power law (1). The value $\alpha = 1.002 \pm 0.011$ was obtained from a fit to the data.

The measured J/ψ cross section times branching ratio to muon pairs is $B\sigma_{Pb+Pb} = 21.9\ \mu\text{b} \pm 0.20 \pm 1.6$ for Pb+Pb collisions at 158$\times$A GeV/c. This result, rescaled to 200 GeV, is compared in Fig.1 with a systematic of the NA38 and NA51 results. Early experiments have observed "nuclear effect" for the J/ψ production; the α value was found to be significantly different from one. Near 200 GeV/c and for kinematical domains similar to NA50, the values deduced are $\alpha = 0.96 \pm 0.01$ using pion beams and $\alpha = 0.93 \pm 0.03$ using proton beams [6]. At Fermilab for the same kinematical domain than NA50 but at 800 GeV/c, the E772 experiment found $\alpha = 0.920 \pm 0.008$ with proton beams [7]. In addition, they have shown x_F dependence for this value which drops to $\simeq 0.80$ at large x_F. The following value $\alpha = 0.92 \pm 0.02$ was obtained from a fit to the NA38 and NA51 data presented in Fig.1 where the error quoted is a statistical error. This "nuclear effects" was called "J/ψ suppression" by the NA38 collaboration. It should be pointed out that in contrast with previous experiments, this value is deduced for a wide range of projectile and target masses. Nonetheless this value is in very good agreement, better than systematic errors, with the value obtained at higher energy by E772 or by the NA3 experiment using proton beams.

As can be seen from Fig.1, the J/ψ cross section for Pb+Pb is smaller than the expected value obtained with the relation $(A_{projectile} \cdot B_{target})^{0.92}$ shown by the solid line. This result suggests an anomalous J/ψ suppression in Pb+Pb collisions in comparison with p+B_{target}, O+B_{target} and S+U collisions. All the data presented in Fig.1 are obtained for the same kinematical domain for the J/ψ, namely $0 < y^* < 1$ for the rapidity in the center of mass and $-0.5 < \cos(\theta) < 0.5$ for the polar decay angle in the Collins-Soper reference frame.

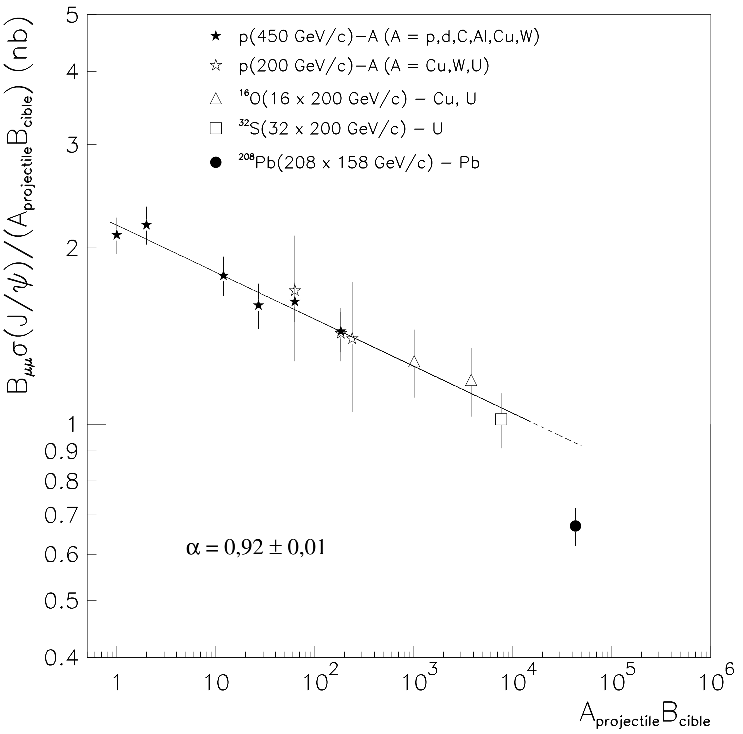

Figure 1: J/ψ cross sections measured in NA51, NA38 and NA50 experiments

As already mentioned, the Drell-Yan cross section scales exactly from p+p up to Pb+Pb collisions as ($A_{projectile} \cdot B_{target}$) implying that the measurement of the ratio $\sigma^{J/\psi}/(A_{projectile}B_{target})$ can be replaced by the measurement of $\sigma^{J/\psi}/\sigma^{Drell-Yan}$. An important difference for the $\sigma^{J/\psi}/\sigma^{Drell-Yan}$ ratios is that they are free from luminosity normalization errors. Fig.2 shows the cross section ratios versus the average length L seen by the produced ($c\bar{c}$) pair in nuclear matter [8]. In the framework of the absorption model, the cross section for dissociation of the ($c\bar{c}$) pair by nucleons is $\sigma_{absorption} = 6.2 \pm 0.7$ mb. This value is obtained from the fit of the NA38 data. The data on Fig.2 are divided by the value of the absorption model. Errors presented on this figure are statistical errors only. The lack of data points in Fig.2 with respect to Fig.1 is due to poor statistics for the Drell-Yan mechanism for the missing data. The data sample for S+U and Pb+Pb are divided on this figure in five centrality intervals using neutral transverse energy measurement. It should be noted that Fig.2 confirms the anomalous suppression shown in Fig. 1 obtained with absolute cross section. As can be seen from this figure and in contrast with NA38 data, the suppression of J/ψ in Pb+Pb collisions cannot be explained by nuclear absorption only. When plotted versus L the anomalous suppression appears as a discontinuity from the nuclear absorption mechanism in Pb+Pb collisions. For the lower Pb+Pb centrality bin corresponding to moderately large impact parameter the data point seem to be compatible with the one obtained in S+U central collisions. Nevertheless it is clear that more statistics was required before drawing any conclusion.

In order to estimate quantitatively the anomalous J/ψ suppression, the ratio r_k was defined as

$$r_k = \frac{(\sigma^{J/\psi}/\sigma^{Drell-Yan})_{measured}}{(\sigma^{J/\psi}/\sigma^{Drell-Yan})_{absorption}} \qquad (2)$$

where $(\sigma^{J/\psi}/\sigma^{Drell-Yan})_{absorption}$ stands for the expected Pb+Pb value from the nuclear absorption mechanism. The data give the following value

$$r_k = 0.71 \pm 0.03 \quad \cdot \qquad (3)$$

The measured value lies 10 standard deviations below the expected nuclear absorption value. The value r_k

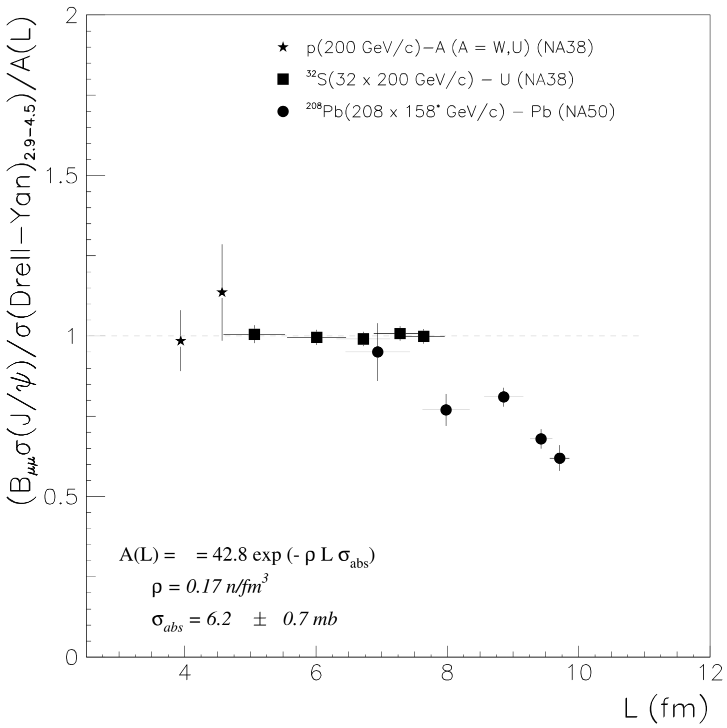

Figure 2: (J/ψ)/(Drell-Yan) cross section ratios versus L for five centrality intervals in S+U and Pb+Pb collisions.

drops to (0.62 ± 0.04) for the most central collisions which correspond still to non zero impact parameter ($b \simeq$ 2 fm).

3 Preliminary results from the 1996 lead run

A technical summary on data taking and data analysis is given in table 1 for the 1995 and 1996 runs. As already pointed out, the number of J/ψ collected in 1996 was multiplied by roughly a factor of 5 with respect to the 1995 data. This was due to higher beam intensity, thicker targets and better efficiencies for data taking. Fine tuning of the beam optics along with higher beam intensity delivered by the CERN-SPS improved our data taking conditions by increasing significantly the signal/background ratio. Extensive online analysis have fixed the optimum conditions for data recording and target-out runs were also recorded for quality controls.

Regarding the offline analysis of the 1996 data, a major effort has been undertaken to significantly increase our efficiency for peripheral Pb+Pb collisions. For the 1995 data the precise identification of the vertex, i.e. one of the seven subtargets, was achieved with a set of quartz detectors surrounding the subtargets [9]. Such a precision was obtained to the detriment of reasonable efficiency for peripheral collisions.

For the analysis of the 1996 data a new additional procedure was used for vertex identification: 2σ cuts were applied in the correlation plots (E_T,E_{ZDC}) where E_T stands for the neutral transverse energy and E_{ZDC} for the zero degree hadronic energy. These cuts were applied in order to assure that the events were produced in one of the seven subtargets. The excellent beam conditions achieved in 1996 allowed us to introduce this new procedure for vertex identification. For example, two anti-halo quartz counters located in front of the seven subtargets were used to measure the fraction of the beam intercepted by the subtargets; more than 99% of the incoming lead beam was on the small subtargets (2.5 mm in diameter). The efficiency of the new procedure is close to unity and independent of centrality.

1995 Pb + Pb DATA		**1996 Pb + Pb DATA**
Intensity $\simeq$ $3.2 * 10^7$ (*per burst*)		$I \simeq 5.4 * 10^7$ (*per burst*)
Interaction length $\simeq$ 17% (*segmented targets*)		$l \simeq$ 30% (*segmented targets*)
Target algorithm *for* *vertex ID*		• *Better beam quality* $\rightarrow$ *Lower amount of background* $\rightarrow$ *New Vertex ID*
		• *Multiplicity detector* $\eta \simeq 3.0$ ($\simeq$ 1.9 *for EM Cal*)
$58 * 10^6$ *dimuon triggers*		$\simeq 170 * 10^6$
$\simeq$ 50000 ψ		$\simeq$ 250000 ψ
GRV LO (*Drell* − *Yan*)		*MRS* 43 (*Drell* − *Yan*)
Rescaling to 200*GeV*		*No rescaling*
$\sigma(\psi) = 97$ *MeV*		$\sigma(\psi) = 100$ *MeV*
$r_K = 0.71 \pm 0.03$		$r_K = 0.73 \pm 0.02$
Final results		*Preliminary results*

Table 1:

Nevertheless this procedure cannot identify which one of the seven subtargets has produced the Pb+Pb interaction leading to some loss for the mass resolution (Δz $\simeq$ 7 cm for the vertex) as seen in table 1. Note also that events where the projectile spectator reinteracts in a subsequent target are not rejected by using the 2σ cuts analysis but the 1995 analysis has shown that for high mass dimuon events, this contamination reached only few percent (2% for 17% interaction length). Moreover the comparison between the 1995 data which includes rejection of reinteraction events, and the new 1996 data show that this effect can be neglected at least in central collisions where such an effect is the most significant.

Correlations (E_T,E_{ZDC}) for J/ψ events are presented on Fig.3. On the left side (a) the events were selected with the target algorithm leading to few events for peripheral collisions. On the right side (b) the events were selected either by the target algorithm or by the new procedure and no bias for peripheral events can be seen. From target-out runs, the contamination from Pb+Air events in peripheral Pb+Pb events was calculated to be less than 1 % of the total number of J/ψ events.

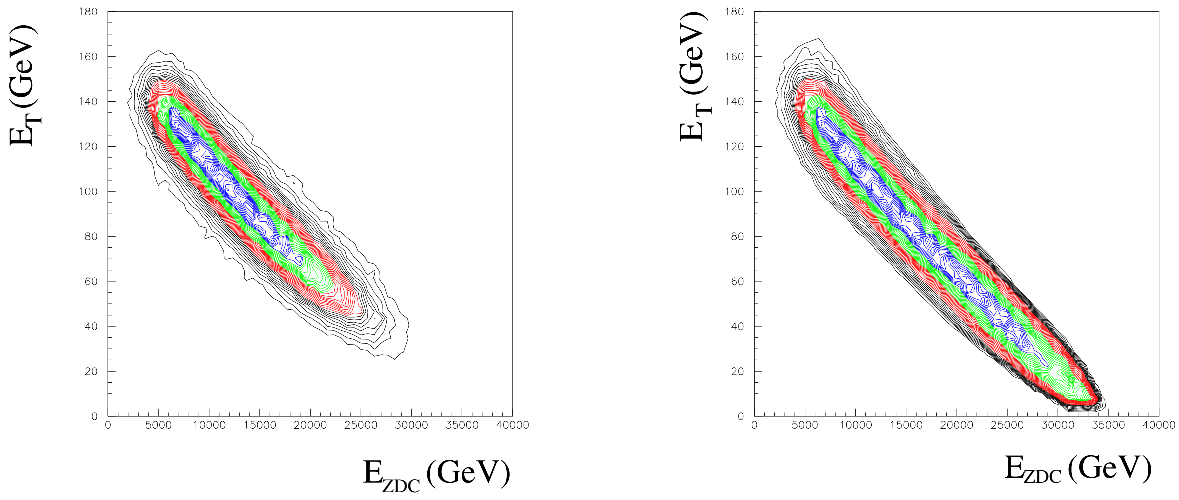

Figure 3: (a) Correlation between neutral transverse energy and hadronic energy measured by the “zero degree” calorimeter for J/ψ events and using target algorithm selection. (b) Same as before with the addition of the new vertex selection.

Fig.4 shows the neutral transverse energy distribution for pure Drell-Yan events. These events were selected by applying a mass cut of M$\geq$ 4.2 GeV on the dimuon spectra. The contribution of J/ψ, ψ' and combinatorial background to the dimuon mass spectra can be neglected at very high mass. The spectra shown on this figure is typical for hard process events produced in minimum bias heavy ion collisions. Note that these events do not represent the total number of Drell-Yan events used to calculate the cross sections (M$\geq$ 3.05 GeV) but are the only pure (without fitting procedure) Drell-Yan obtained from the 1996 run. As can be seen from the figure more statistics and better understanding of systematic errors for E_T spectra is required to be able to use only this kind of events to calculate absolute cross section ratios per E_T bins.

In order to determine the number of J/ψ and Drell-Yan events, the mass spectra for each E_T bin were fitted above M$\geq$ 3.05 GeV to an expression taking into account the J/ψ, ψ', Drell-Yan and expected open charm contributions. The procedure used in this paper is the same as described in Ref.1 and Ref.3 . Absolute cross sections will not be presented. Cross section ratios are free from systematics errors and therefore only statistical errors are plotted.

The preliminary new cross section ratios ψ/(Drell-Yan) are presented versus the neutral transverse energy on Fig.5a. The final results from 1995 measurements in 5 centrality intervals are also shown and as can be seen the two data set are in excellent agreement. For the 1996 data set the number of centrality intervals was increased to 15 due to the higher statistics. It should be pointed out that the data presented on this figure are not and should not be corrected for isospin effects, nor for energy rescaling. The new data seem to show a sharp discontinuity around $E_T \simeq 55$ GeV. It is clear from the figure that different patterns in the data are observed below 55 GeV and above 55 GeV. Note that the resolution of the calorimeter is about 5 GeV for $E_T = 55$ GeV. Although much less pronounced, a second discontinuity seems to be seen in the data around 110 GeV. The most peripheral interval for the new data correspond to an average impact parameter of b $\simeq$ 11.3 fm ($b_{max} \simeq 14.$ fm) and the discontinuity is observed for b $\simeq$ 8.6 fm. This discontinuity could be seen as a threshold effect for the anomalous J/ψ suppression in Pb+Pb collisions.

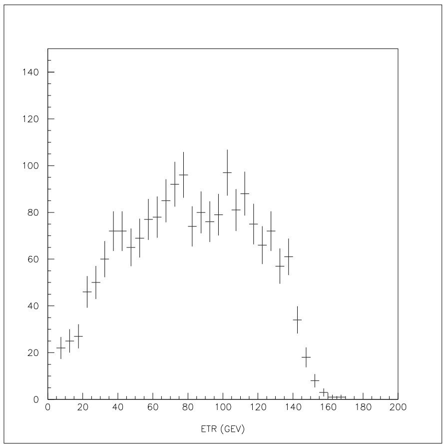

Figure 4: Neutral transverse energy spectrum of pure Drell-Yan events with mass larger than M$\geq$ 4.2 GeV. Note that the total number of Drell-Yan per E_T intervals is obtained for M$\geq$ 3.05 GeV. Only statistical errors are plotted.

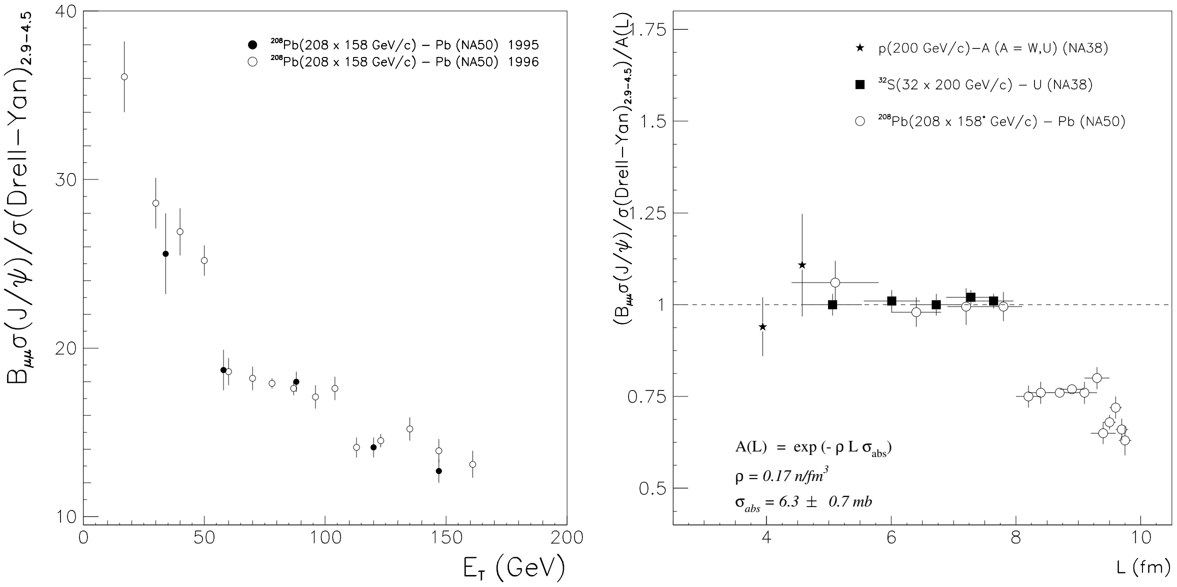

Figure 5: (a) J/ψ /Drell-Yan cross-sections ratio at 158 GeV as a function of neutral transverse energy. (b)J/ψ /Drell-Yan cross-sections ratios at 158 GeV divided by an exponential fit (nuclear absorption) as a function of $\bar{L}$ for NA38 and NA50 data.

These preliminary results are compared with the NA38 data on Fig.5b where all 200 GeV data were rescaled to 158 GeV. The data presented on this figure were corrected for isospin effects for Drell-Yan cross sections following the procedure described in Ref.1 but using MRS 43 [10] instead of GRV LO [11] as set of parton distributions. This change is due to the fact that the latest version of MRS 43 includes the ratio $\bar{u}/\bar{d}$ for nucleons as measured by NA51 [12]. The Pb+Pb Drell-Yan cross sections were multiplied by 1.02 for isospin correction while the S+U results were multiplied by 0.99. For the system S+U, the $\sqrt{s}$ correction was (1/1.31) for the J/ψ cross sections and (1/1.38) for the Drell-Yan cross sections.The data were also divided by an exponential fit to part of the data which includes the p+A and S+U data points. As can be seen, the Pb+Pb peripheral data are fully compatible with the S+U results where no anomalous J/ψ suppression was observed.

4 Summary

A preliminary analysis of the new 1996 data performed for the full statistics was presented in this paper. The high statistics new data are in excellent agreement with the final results of the 1995 run. A discontinuity is observed in the cross section ratios ψ/(Drell-Yan) at an average impact parameter b $\simeq$ 8.5 fm when going from peripheral to central Pb+Pb collisions. Based on the nuclear absorption model which reproduce all NA38 p+A, O+A and S+U data, the amount of anomalous suppression reaches 20-25 % at that discontinuity which represents a large fraction of the global effect $\simeq$ 30 % (r_k = 0.71) seen in Pb+Pb collisions. The new set of data for peripheral Pb+Pb are fully compatible with the S+U data. Based on the new results, it is clear now that the system S+U was not heavy enough, even for very central collisions, to see an anomalous suppression for the J/ψ. For models which include a quark-gluon plasma phase Gupta and Satz [13] have predicted few years ago a two-step pattern for J/ψ suppression versus centrality due to the fact that only 60% of J/ψ are directly produced. More recently several theorists [14][15] have studied the possible effects of sharp onset for suppression on measured J/ψ/(Drell-Yan) ratios.

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