J/Ψ suppression

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For the NA50 Collaboration

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The cross section for J/Ψ production in Pb–Pb interactions at 158 GeV per nucleon is measured at the CERN SPS by the NA50 experiment. The final results from the 1995 run are presented here together with preliminary ones from the high–statistics 1996 run.

An anomalous J/Ψ suppression is observed in Pb–Pb collisions as compared to extrapolations of the previous results obtained by the NA38 experiment with proton and lighter ion beams. The results of the two runs are in good agreement. The results from the 1996 run allow the study of the onset of the anomalous suppression within the same set of data, showing evidence of a sharp change of behaviour around a value of neutral transverse energy, as measured by our electromagnetic calorimeter, of about 50 GeV.

1. Introduction

The aim of the NA50 experiment is the study of nuclear matter under extreme conditions of energy density, with the ultimate goal of detecting signals of a phase transition from ordinary nuclear matter to a plasma of deconfined quarks and gluons (QGP), as predicted by QCD. In particular, the experiment is designed to look for specific signals of a phase transition in the production of muon pairs. In fact, the dissociation of the J/Ψ and Ψ' resonances, which might result from De-

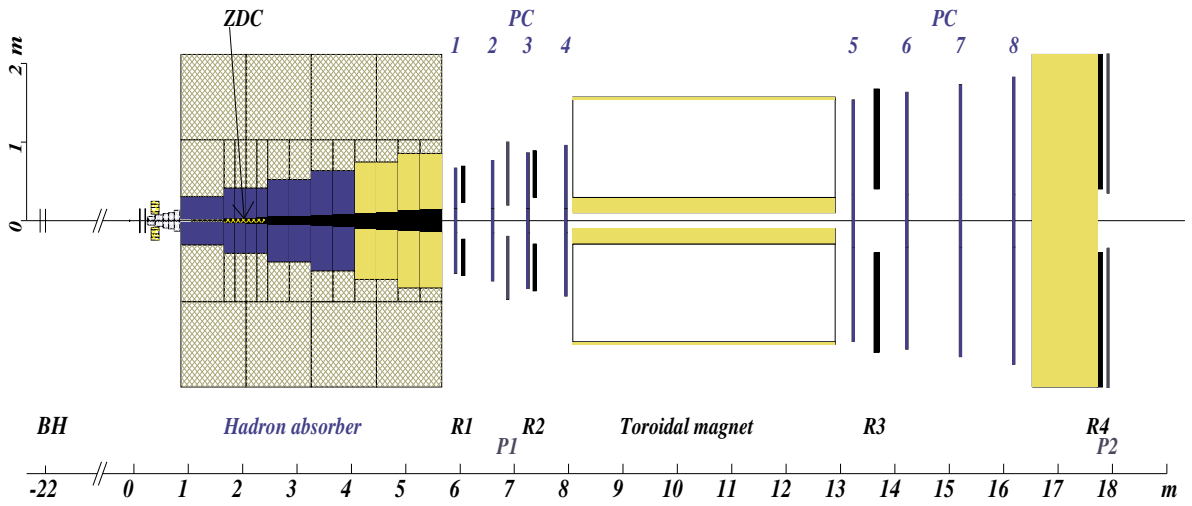

Figure 1. Layout of the NA50 experiment

bye screening in a medium of deconfined quarks and gluons[8], is one of the most promising signatures of the onset of this new state of matter.

The NA50 experiment follows the pioneering program started in 1986 by the NA38 collaboration, which studied J/Ψ, Ψ' and Drell–Yan production in collisions between protons, oxygen and sulphur on various heavy targets. The very extensive set of measurements[1] performed by the NA38 experiment has triggered a considerable amount of theoretical work, leading to our present understanding of the evolution of the cross-section for J/Ψ production from Proton-Nucleus to Sulfur-Nucleus collisions in terms of absorption in the nuclear medium. In the following, we will refer to this trend as "J/Ψ suppression", while the novel features encountered in measuring J/Ψ production in Pb-Pb collisions will be indicated as "anomalous J/Ψ suppression". This paper reports the results obtained from the data collected in 1995 on J/Ψ production in Pb–Pb interactions at 158 GeV per nucleon, and preliminary results from the high-statistics run of 1996.

2. The NA50 experimental apparatus and data taking conditions

The NA50 detector, which is an upgraded version of the NA38 apparatus, consists of a dimuon spectrometer complemented by a set of detectors which measure the global characteristics of the events, i.e. the very forward (zero-degree) energy, the neutral transverse energy and the charged multiplicity. The layout of the experiment is shown in fig. 1, while fig. 2 shows an enlarged view of the target region.

The $\mu^+\mu^-$ pair from the decay of the J/Ψ and Ψ' is detected by the magnetic spectrometer, which consists of a hadron absorber, an air core toroidal magnet, 8 MWPCs and 6 hodoscopes for trigger purposes. To optimize at the same time the reduction of the background from the decay of π and K mesons and the resolution on the invariant mass of the dimuon, the absorber has been located very close (15 cm) to the last target, and is constituted by a 60 cm section of BeO, followed by 4 meters of carbon and finally 80 cm of iron. The muons are detected in the rapidity interval $2.8 \leq y_{lab} \leq 4.0$; the mass resolution obtained for the J/Ψ is 3.2%.

The event centrality is estimated on an event by event basis by means of three independent detectors, covering different pseudo–rapidity intervals: the Pb–scintillating fibers electromagnetic calorimeter ($1.1 \leq \eta \leq 2.3$), which measures the neutral transverse energy produced in the interaction; the Tantalum–quartz fibers zero degree calorimeter ($\eta \geq 6.3$), measuring the energy of beam spectator fragments; the 2–plane, high–granularity silicon strip detector ($1.6 \leq \eta \leq 4$), measuring the charged particle multiplicity.

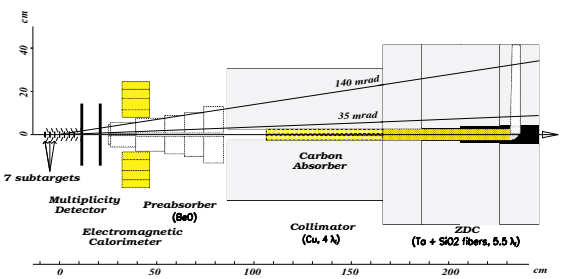

Figure 2. The NA50 target region

Due to the small production cross sections (3 nb/nucleon^2 for J/Ψ) and the small branching ratios in the $\mu^+\mu^-$ channel (6% for J/Ψ, 7.7 10^{-3} for Ψ') high beam intensity and thick target are needed to achieve good statistical accuracy in severals bins of centrality. In 1995, an incident beam of 3.2×10^7 Pb ions per burst has been used; in 1996 the intensity has been increased to 5.4×10^7 Pb ions per burst. The incident Pb–ions are counted by a quartz beam hodoscope, which is also used to reject beam pile–up. The active target is made of 7 Pb subtargets with vertex identification, in order to reject reinteractions of spectator fragments which could lead to an incorrect measurement of centrality. In 1995, the subtargets were each 1 mm thick, for a total of 17.5% of an interaction length; in 1996 5 of them were replaced by 2 mm ones, bringing the total thickness to 30% of an interaction length. In 1996, in addition, an improved beam quality led to a lower amount of background and therefore a better ratio of useful events to total number of triggers. In 1995, $58*10^6$ dimuon triggers were collected, giving ≈50,000 J/Ψ events at the end of the analyisis; in 1996, about $170*10^6$ were collected, leading to 250,000 J/Ψ events, i.e. a five–fold increase in the statistical sample.

3. Analysis method

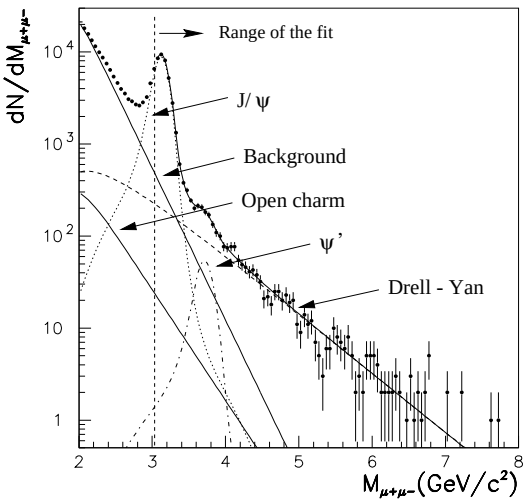

Figure 3. Muon pair invariant mass spectrum (from the 1995 data)

Events are selected for analysis if only one incident ion is detected, no signal is given by the halo counters and the event is identified as having taken place in the target. In addition, it is required that two and only two muon tracks are in the acceptance of the spectrometer, and that they would both be accepted if they had been of the opposite sign, in order to make the acceptance of the spectrometer independent from the sign of the charge of the detected muons.In this way the systematic effects in the background subtraction are minimized. The dimuon kinematical domain used in the analysis is restricted to

$0 \leq y_{cm} \leq 1$ (y_{cm} = center of mass dimuon rapidity) and to $-0.5 \leq cos(\theta_{CS}) \leq 0.5$ (θ_{CS} = muon polar angle in the Collins–Soper frame), where the acceptance of the spectrometer is sizeable (above 10% of its maximum). The final acceptance of the spectrometer is 13.4% for J/Ψ, 15.8% for Ψ' and 18% for Drell–Yan events (with $M_{\mu\mu} \geq 4.5\ GeV/c^2$). The invariant mass spectrum for opposite sign muon pairs is shown in fig. 3 for masses above 2 GeV/c^2. The contribution due to the combinatorial background originating from uncorrelated π and K decays is determined with a standard procedure using the sample of like–sign muon pairs, and is subtracted from the distribution. The signal-to-background ratio is larger than 10 at the J/Ψ peak. After background subtraction, the mass spectrum above $M \geq 3.05\ GeV/c^2$ is fitted using the maximum likelihood method as the superposition of four contributions: J/Ψ, Ψ', Drell–Yan and background:

$$\frac{dN^{+-}}{dM} = A_{J/\psi} \cdot \frac{dN^{J/\psi}}{dM} + A_{\psi'} \cdot \frac{dN^{\psi'}}{dM} + \\ + A_{DY} \cdot \frac{dN^{DY}}{dM} + \frac{dN^{bg}}{dM} \qquad (1)$$

The contribution due to the semi–leptonic decay of couples of charmed mesons ($D\bar{D}$), negligible for the J/Ψ, has been estimated of the order of 8% under the Ψ' peak, and is not taken explicitly into account in the fit. The fit is performed with five free parameters: $A_{J/\psi}$, $A_{\psi'}$, A_{DY}, and the mass and width of the gaussian distribution of the J/ψ. Mass and with of the Ψ' are linked to those of the J/ψ. The results are not very sensitive to the choice of the shape used in the fit, and the main features are unchanged if the raw numbers of events in the J/Ψ peak and the Drell–Yan events above 4.2 GeV/c^2 (essentially background-free) are used instead of the fitted values.

Each contribution has been studied as a function of the centrality of the collision, represented by the measured neutral transverse energy, which is strongly correlated to the impact parameter b. The data have been divided into approximately equipopulated bins, 5 for the 1995 data and 15 for the 1996 ones.

4. Final results from the 1995 run

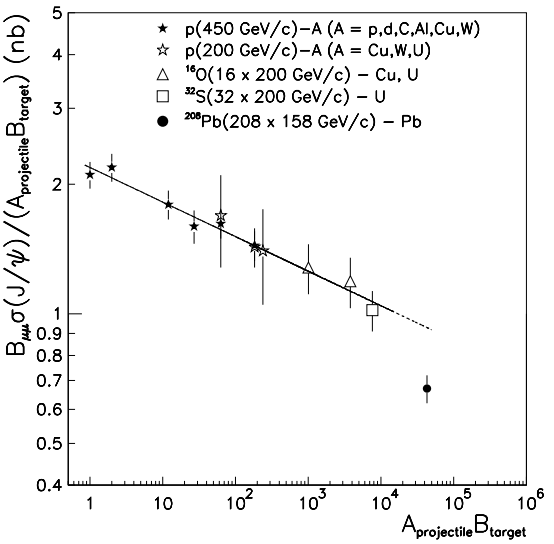

Figure 4. J/ψ cross–section vs. $A \cdot B$ (1995 data).

The final results obtained from the 1995 data for the cross section for J/Ψ production have recently been published[2], and will only be briefly summarized here.

The nuclear dependence of the production of hard processes in $A_{projectile}$ on B_{target} collisions can be parametrized as

$$\sigma^{AB} = \sigma^{NN} \cdot (AB)^{\alpha} \qquad (2)$$

For Drell–Yan production, the cross section for $A_{projectile}B_{target}$ collisions is essentially a superposition of nucleon–nucleon collisions, and the value of α is consistent with 1 for all NA38 measurements. In Pb–Pb, the measured value is $\sigma_{Pb+Pb} = 1.40\mu b \pm 0.02 \pm 0.11$ at 158xA GeV/c. To compare this result with the NA38 ones, it has to be rescaled to 200 GeV/c and corrected for the isospin effect[3]. The value obtained in this way is compatible with the results obtained with lower mass nuclei. In fact, when including the Pb point

in the fit, a value of 1.002 ± 0.0011 is obtained for α, which also suggests that the procedure used for the correction of the Pb result is well understood.

An expression like (2) describes very well all J/ψ production data, from proton–nucleus and nucleus–nucleus collisions up to Sulfur on Uranium, with a value $\alpha = 0.93 \pm 0.03$. This value is in very good agreement with the values obtained by Fermilab experiment E772 at higher energy [4]. This result has led to a description of this nuclear effect, called "J/ψ suppression", in terms of the absorption of the pre-resonant $c\overline{c}$ state in nuclear matter[6]. In fig. 4 the J/ψ cross section divided by $A_{projectile}B_{target}$ is plotted versus $A \cdot B$ for several systems (including data from the NA38, NA51 and NA50 experiments). The value obtained for Pb–Pb collisions is significantly smaller than the value one would extrapolate from the other results. Quantitatively, the Pb point is lower by a factor 0.74 ± 0.06. This result suggests an additional suppression, which is referred to as "anomalous J/ψ suppression".

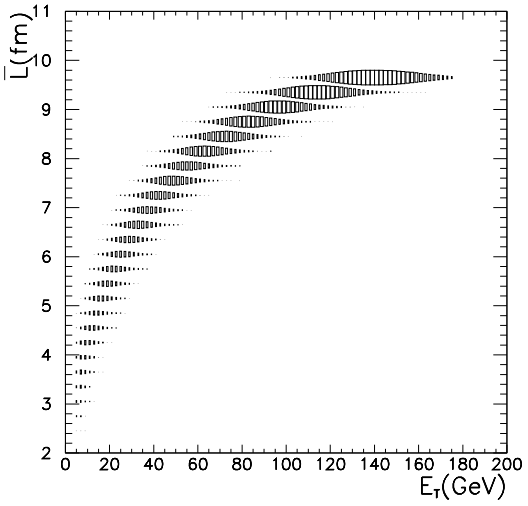

Figure 5. Correlation between L and E_T

Since, as mentioned above, the cross-section for Drell–Yan scales exactly as $A \cdot B$ from p+p collisions to Pb+Pb, one can use the ratio $\sigma^{J/\psi}/\sigma^{DY}$ instead of the ratio $\sigma^{J/\psi}/A_{projectile}B_{target}$. In this way, the result is free from luminosity normalization errors, and the results can be studied as a function of the centrality of the collision. This is done by introducing the now–well–known L variable[7], which expresses the average length traveled by the produced $c\overline{c}$ state in nuclear matter. From Monte–Carlo calculations, which take into account the nuclear geometry, the correlation between the measured transverse energy and the average value of L can be extracted, as plotted in fig.5, so that a mean value of L can be associated to each transverse energy class. In the framework of the absorption model, the J/Ψ production cross section can be written as:

$$\sigma(AB \to J/\Psi) \propto (AB) e^{-\rho_o \bar{L} \sigma_{abs}}$$

where the exponential accounts for the $c\bar{c}$ survival probability. σ_{abs} stands for the $c\bar{c}$ absorption cross section.

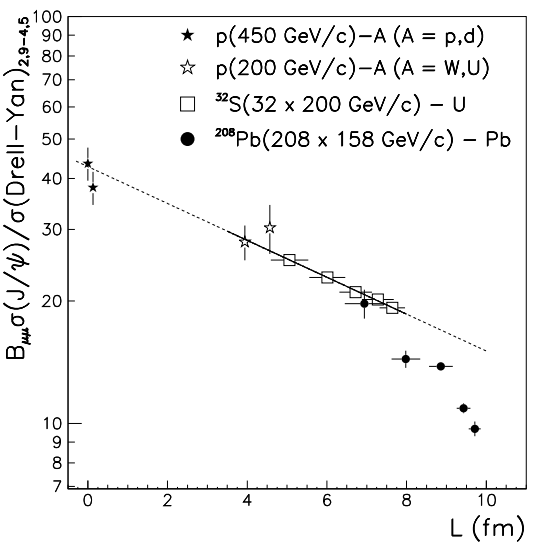

Figure 6. Ratio of J/Ψ to Drell–Yan cross sections as a function of $\overline{L}$ (1995 data)

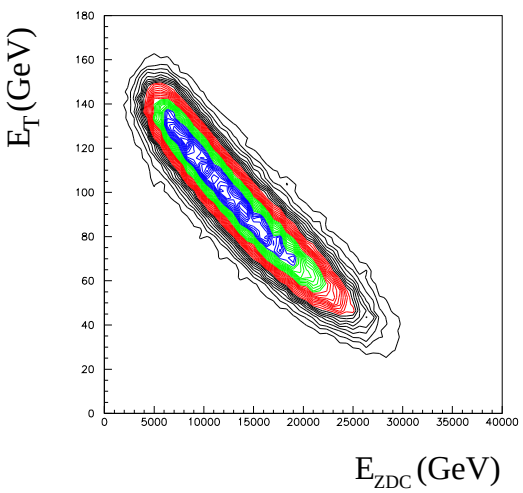

Figure 7. Correlation between neutral transverse energy and forward energy for events selected using the target identification algorithm

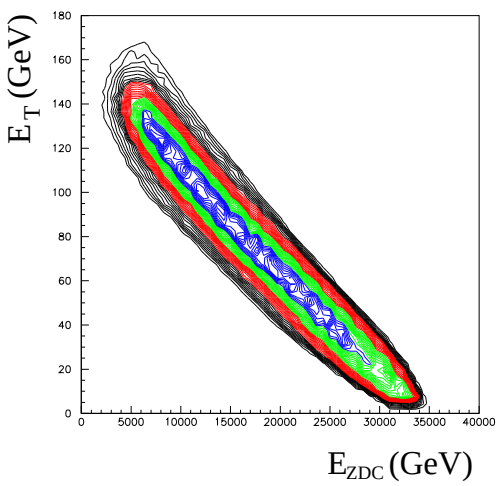

Figure 8. Correlation between neutral transverse energy and forward energy for events selected using the new vertex selection

In fig.6 the ratio of J/Ψ to Drell–Yan cross sections is shown as a function of $\overline{L}$ for several systems: p+p, p+d (data from NA51), S+U (data from NA38) and Pb+Pb. It is well known that the data up to S+U are well described by the expression quoted above, with a value $\sigma_{abs} = 6.2 \pm 0.7 mb$. Two features of this plot are very striking:
the data points for central Pb+Pb collisions lie dramatically below the fit line, the most central one by a factor $.62 \pm 0.04$,
the most peripheral Pb+Pb collisions agree rather well at similar $\overline{L}$ with the S+U results.

5. Preliminary results from the 1996 run

The improved statistical sample in the 1996 data allows a finer binning of the data, and therefore a more detailed study of the evolution of the J/Ψ cross–section with E_T. Yet, the number of peripheral collisions in the final sample remained very limited because of the low efficiency of the target identification algorithm at low multiplicity, as it can be seen in fig.7, where the correlation between neutral transverse energy and energy at zero degrees is shown for events with an identified vertex. In 1996, the two planes of silicon multiplicity detectors were fully operational, and the study of the pattern correlation between the two planes should allow the identification of the target also per peripheral events. Yet, at the moment, this algorithm is still being optimized, and a different approach is used[5]. Thanks to the limited size of the electromagnetic calorimeter, the 2σ region of the E_T vs E_{ZDC} correlation includes only events originated in the target region with high efficiency and low background. Several cross–checks have been applied to the data, such as the comparison between target-in and target-out runs and the analysis of the longitudinal distribution of the dimuon vertex, which all confirm the good quality of the selection algorithm. The fact that for these events the exact vertex is not available, and the coordinate of the central subtarget is used instead, introduces only a marginal degradation of the mass resolution for dimuons. Overall, the width of the J/Ψ peak goes from 97

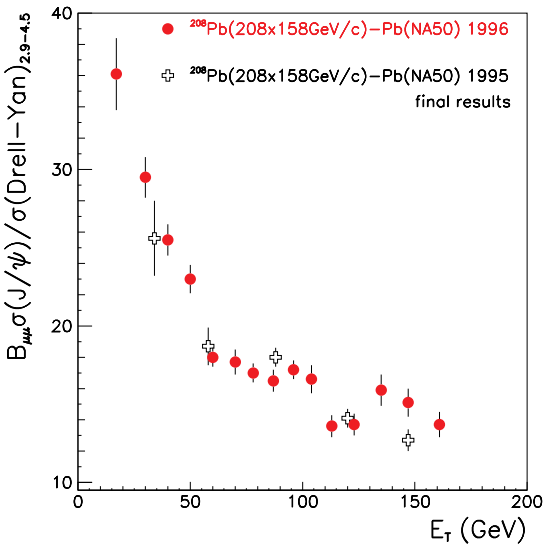

Figure 9. Ratio J/ψ/DY vs E_T at 158 GeV/c (1996 and 1995 data).

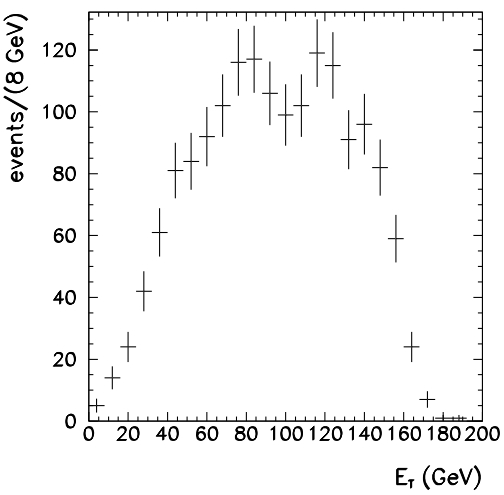

Figure 10. Counted Drell–Yan ($M > 4.2 GeV/c^2$) vs. E_T.

to 100 MeV (σ). The new E_T vs E_{ZDC} correlation plot is shown in fig.8.

In fig.9 the dependence of the J/ψ/DY cross–section ratio on E_T is shown for both the 1995 and 1996 data. The two data set are fully in agreement. A sharp change in the value of this ratio is apparent around 50 GeV of E_T. It must be noted that this effect can now be observed within the same data sample, without the need of the correction and rescaling procedures necessary for the comparison of different data sets, thus removing systematic effects potentially introduced by them. In fig.10 is shown the E_T dependence of the Drell-Yan production, from which it is clear that the rapid decrease in the J/ψ/DY ratio around 50 GeV cannot be accounted for by an increase in the Drell-Yan. In this plot the raw number of Drell-Yan events for $M > 4.2$ GeV/c^2 is shown; the distribution of the fitted values exhibits the same features.

Finally, in fig.11, the 1996 Pb+Pb results for the J/ψ/DY ratio are plotted versus L, together with p+nucleus and S+U data (rescaled to 158 GeV/c). The peripheral Pb+Pb collisions can essentially be described by the same exponential function as the S+U ones, with an absorption cross–section of 6.2 ± 0.7mb. Around $L \approx 7.5$fm, which corresponds to E_T about 50 GeV, a discontinuity can be observed. The most central bins lay almost 10σ below the absorption line.

6. Conclusion

The new measurement performed in 1996 by the NA50 collaboration of the J/ψ production cross-section in Pb+Pb collisions is consistent with the results previously obtained with lower statistics by the same collaboration. The 1996 data sample, thanks to the higher statistics and the use of a new algorithm for the selection of the events, allows the detailed study of the change of the cross-section with the event centrality. A sharp change in the E_T dependence can be observed around 50 Gev, i.e. around an impact parameter of approximately 8.5 fm. More peripheral interactions are compatible with the absorption curve which well describes the data obtained with lighter projectile nuclei, while the central

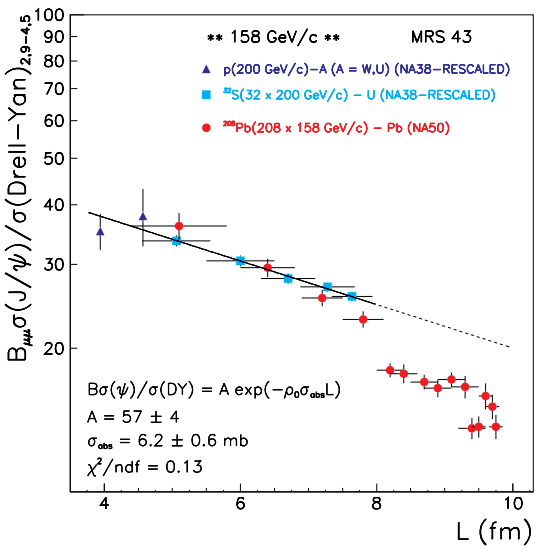

Figure 11. Ratio J/ψ/DY vs L at 158 GeV/c (1996 data).

ones exhibit an additional strong anomalous suppression.

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