Recent results on J/Ψ suppression from the NA50 experiment

Federica Sigaudo[11] for the NA50 Collaboration

B. Alessandro[11], C. Alexa[4], R. Arnaldi[11], M. Atayan[13], C. Baglin[2], A. Baldit[3], M. Bedjidian[12], S. Beolè[11], V. Boldea[4], P. Bordalo[7,a], S.R. Borenstein[10,b], G. Borges[7], A. Bussière[2], L. Capelli[12], C. Castanier[3], J. Castor[3], B. Chaurand[10], B. Cheynis[12], E. Chiavassa[11], C. Cicalò[5], T. Claudino[7], M.P. Comets[9], S. Constantinescu[4], P. Cortese[1], J. Cruz[7], A. DeFalco[5], N. DeMarco[11], G. Dellacasa[1], A. Devaux[3], S. Dita[4], O. Drapier[10], B. Espagnon[3], J. Fargeix[3], P. Force[3], M. Gallio[11], Y.K. Gavrilov[8], C. Gerschel[9], P. Giubellino[11,c], M.B. Golubeva[8], M. Gonin[10], A.A. Grigorian[13], S. Grigoryan[13], J.Y. Grossiord[12], F.F. Guber[8], A. Guichard[12], H. Gulkanyan[13], R. Hakobyan[13], R. Haroutunian[12], M. Idzik[11,d], D. Jouan[9], T.L. Karavitcheva[8], L. Kluberg[10], A.B. Kurepin[8], Y. LeBornec[9], C. Lourenço[6], P. Macciotta[5], M. Mac Cormick[9], A. Marzari-Chiesa[11], M. Masera[11], A. Masoni[5], M. Monteno[11], A. Musso[11], P. Petiau[10], A. Piccotti[11], J.R. Pizzi[12], W. PradodaSilva[11,e], F. Prino[1], G. Puddu[5], C. Quintans[7], L. Ramello[1], S. Ramos[7,a], P. RatoMendes[7], L. Riccati[11], A. Romana[10], H. Santos[7], P. Saturnini[3], E. Scalas[1], E. Scomparin[11], S. Serci[5], R. Shahoyan[7,f], F. Sigaudo[11], M. Sitta[1], P. Sonderegger[6,a], X. Tarrago[9], N.S. Topilskaya[8], G.L. Usai[5], E. Vercellin[11], L. Villatte[9], N. Willis[9], T. Wu[9] [1]

Universitá del Piemonte Orientale, Alessandria and INFN-Torino, Italy
[2] LAPP, CNRS-IN2P3, Annecy-le-Vieux, France
[3] LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France
[4] IFA, Bucharest, Romania
[5] Università di Cagliari/INFN, Cagliari, Italy
[6] CERN, Geneva, Switzerland
[7] LIP, Lisbon, Portugal
[8] INR, Moscow, Russia
[9] IPN, Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France
[10] Laboratoire Leprince-Ringuet, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France
[11] Università di Torino/INFN, Torino, Italy
[12] IPN, Univ. Claude Bernard Lyon-I and CNRS-IN2P3, Villeurbanne, France
[13] YerPhI, Yerevan, Armenia
a) also at IST, Universidade Técnica de Lisboa, Lisbon, Portugal
b) on leave of absence from York College CUNY
c) also at CERN, Geneva, Switzerland
d) also at Faculty of Physics and Nuclear Techniques, Academy of Mining and Metallurgy, Cracow, Poland
e) now at UERJ, Rio de Janeiro, Brazil
f) on leave of absence of YerPhI, Yerevan, Armenia

Abstract

At the end of the year 2000 the NA50 Collaboration has performed a new measurement of J/Ψ production in Pb–Pb collisions at 158 GeV/c per nucleon under improved experimental conditions, with particular interest for the most peripheral Pb–Pb interactions. The preliminary results confirm the departure from the normal nuclear absorption and a steady decrease for the most central collisions.

1 Introduction

According to Quantum-Chromo Dynamics, for temperatures higher than $140 - 180\,MeV$ and energy densities greater than $1 - 3\,GeV/fm^3$, nuclear matter should undergo a phase transition towards a new state of matter, where quarks and gluons are no more confined into hadrons but behave as free particles [1]. This state of matter is called Quark-Gluon Plasma (QGP).

Experimentally, ultra–relativistic heavy–ion collisions are a powerful tool to investigate the transition from ordinary nuclear matter to QGP. Over the past 15 years, an extensive program of high energy nuclear collisions was carried out at the CERN SPS and at the BNL AGS in order to study the quark–gluon plasma formation in heavy ion collisions. CERN started the program with the acceleration of light ions (^{16}O and ^{32}S) at 200 GeV/c per nucleon on heavy targets, while from 1994 a ^{208}Pb beam of 158 GeV/c per nucleon has become available. At the AGS ^{28}Si beams of 15 AGeV/c were followed by ^{200}Au beams of 12 AGeV/c. Nowadays at the BNL RHIC collider Au–Au collisions are studied at center of mass energies 10 times higher than the SPS ones.

The experiments involved in this heavy ion program were intended to detect the signals proposed as possible signatures of QGP formation. In particular, the NA50 experiment is aimed to study, by means of Pb-Pb collisions at 158 GeV/c per nucleon, the suppression of the charmonium state production, expected in a QGP environment, where the Debye color screening prevents the $c\bar{c}$ pairs from binding in J/ψ mesons [2].

The data collected by the NA38, NA51 and NA50 experiments, in collisions from p–p up to S–U, has shown a continuous and monotonic J/ψ suppression pattern from the lighter to the heavier interacting nuclei. This result can be understood in terms of ordinary nuclear absorption of the $c\bar{c}$ pair before it forms a J/ψ state. The measurements with proton and light ions are useful to establish a reference baseline (the "normal" charmonium absorption by nuclear matter) with respect to which the heavy ion specific features can be identified.

The previous results obtained by NA50 in Pb–Pb collisions at 158 AGeV/c, have indicated a decreasing pattern of the J/ψ production yield from peripheral to central Pb–Pb collisions, with a clear departure from the "normal" nuclear absorption curve.

The results presented here concern the measurement of the J/ψ suppression as a function of the collision centrality, from data collected in the year 2000 with, in particular, the aim of extending the previous knowledge to very peripheral Pb–Pb interactions.

2 Experimental setup and data taking conditions

In the NA50 experiment the J/ψ mesons are detected via their $\mu^+\mu^-$ decays by a muon spectrometer (illustrated in Fig. 1), which consists of an air–gap toroidal magnet equipped with two sets of multiwire proportional chambers (to track the particles) and four scintillator hodoscopes (for triggering purposes)[3]. The covered rapidity window is $2.8 < y_{lab} < 4.0$ in the laboratory reference frame. The target region is followed by an hadron absorber where the beam, as well as the hadrons produced in the collision, are stopped. The absorber is passed through by muons, which are then detected by the muon spectrometer.

Since the transition from ordinary hadronic matter to QGP requires high temperatures and baryon densities, it is very important to be able to distinguish central collisions, where the high energy density reached is more favorable to the phase transition. For this purpose the NA50 experiment makes use of three independent centrality detectors (Fig. 2): an electromagnetic calorimeter, which measures the transverse energy (E_T) of the neutral particles emitted in the collision (essentially γ particles coming from π° decays), a zero–degree calorimeter (ZDC), which measures the forward energy (E_{ZDC}) released by the projectile nucleons that have not taken part to the collision, and a multiplicity detector, which counts the charged secondary particles produced in the interaction.

All the quantities measured by these detectors are related to the centrality of the collision. In Fig. 3 the correlation between E_T and E_{ZDC} is reported in logarithmic scale: high E_{ZDC} values (peripheral collisions, where most of the projectile nucleons are not involved in the interaction, leave the target region with nearly the same energy as the incident beam and reach the ZDC) correspond to low E_T values and vice–versa. The events out of the correlation band are attributed to off-target interactions or to pile–up problems and are discarded from the analysis.

The latest NA50 data taking period was devoted mainly to investigate the J/Ψ suppression in extremely peripheral Pb–Pb interactions. For this reason the experimental apparatus was modified with respect to the previous runs. A vacuum system has been designed for the target region to avoid interactions of the Pb projectiles

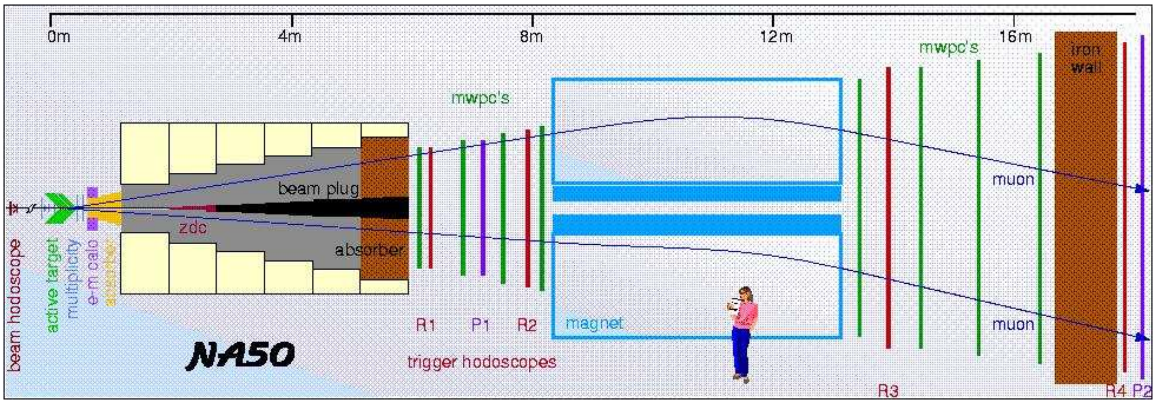

Figure. 1. *The NA50 experimental apparatus.*

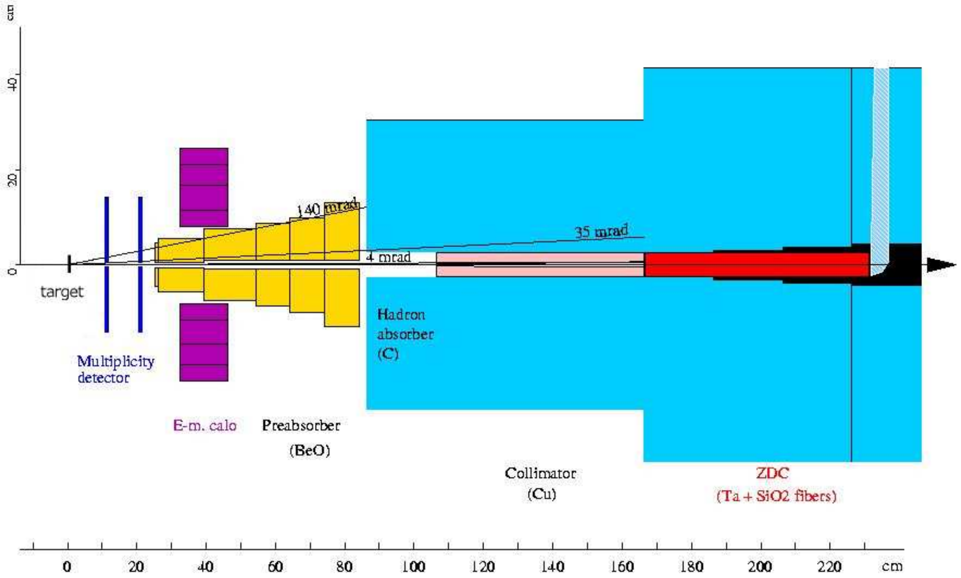

Figure. 2. *Details of the NA50 setup in the target area.*

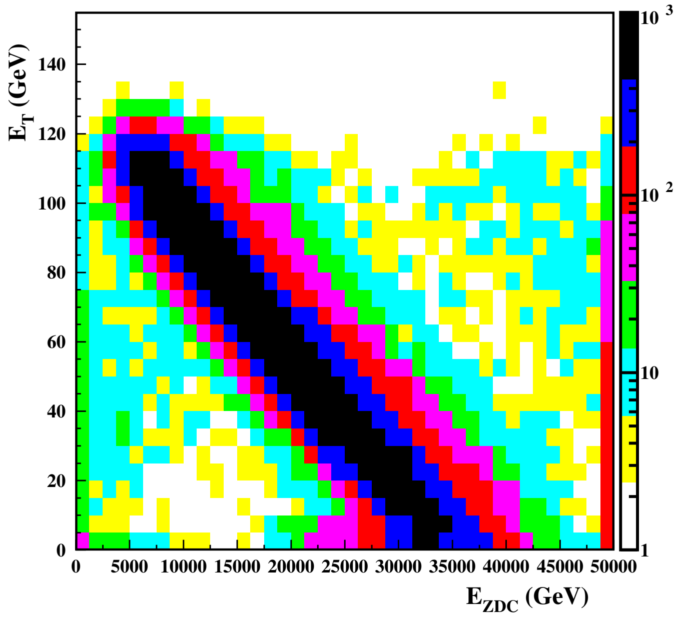

Figure. 3. *Correlation between the neutral transverse energy E_T and the forward hadronic energy E_{ZDC}.*

with the air around the target, which can produce a bias on the most peripheral points. Moreover a thin target (4 mm) was adopted, in order to reduce the probability to of reinteractions in the target from the secondary particles produced in the collision, which can bias the most central events. Data were collected with a 158 AGeV/c Pb beam at an intensity of $1 - 1.4 \cdot 10^7$ ions/s.

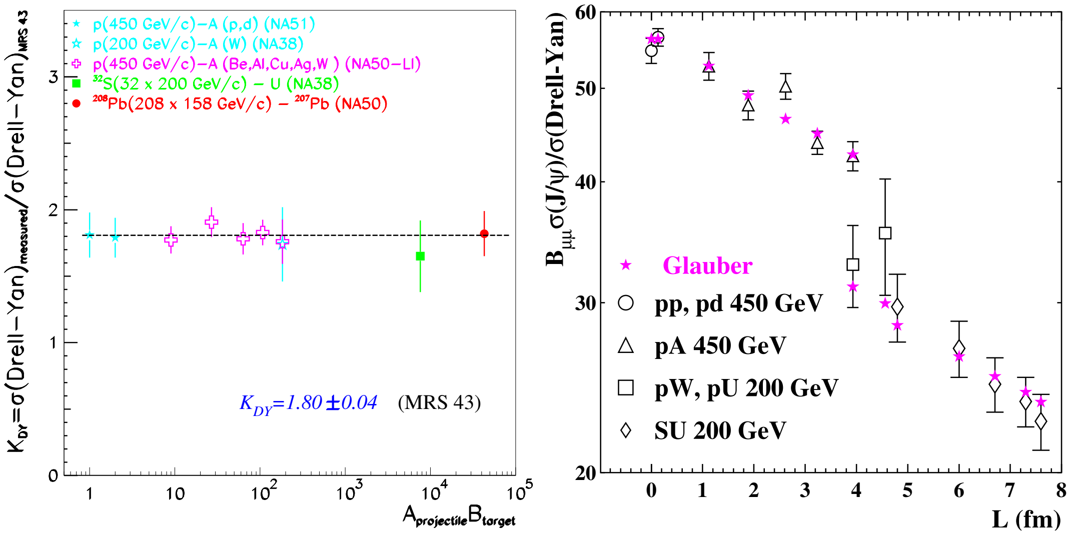

Figure. 4. *Left: ratio between measured and computed Drell–Yan cross–sections. The experimental data have been obtained by the NA51, NA38 and NA50 experiments and the MRS A PDF's set [7] has been used for the calculation of theoretical Drell–Yan. Right: $J/\psi/DY$ ratio vs. L for p–A and S–U data sets.*

3 The Drell–Yan reference

As already said, the J/ψ mesons are identified in NA50 through their decays into two opposite–sign muons. The process used as a reference in the J/ψ suppression study is the Drell–Yan, which produces opposite–sign muon pairs in the invariant mass range of the J/ψ. A systematic study of the Drell–Yan behaviour, ranging from p–p and some p–A systems to S–U and Pb–Pb collisions [4–6], is shown in Fig. 4 (left), which displays the ratio between the measured Drell–Yan cross–sections and the lowest order Drell–Yan cross–sections computed using the MRS A set of parton distribution functions [7]. This ratio (called K–factor) is plotted as a function of the product AB of the target and the projectile atomic mass numbers. Its constant value proves that the Drell–Yan cross–section is proportional to the number of nucleon–nucleon collisions for systems from p–p up to Pb–Pb. In particular, the Pb–Pb cross–section exhibits a behaviour fully compatible with lighter systems and does not suffer from any further suppression mechanism. Hence the Drell–Yan mechanism provides a good reference for studying the J/ψ production and the ratio $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ can be used to study the centrality dependence of the J/ψ suppression.

4 The normal nuclear absorption of charmonium

In absence of QGP formation, a "normal" J/ψ suppression is expected, due to the nuclear absorption of the $c\bar{c}$ states by the projectile or the target nucleons or by the hadrons produced in the collision. This normal suppression is already present in p–p, p–A and S–U interactions, while in Pb–Pb collisions it superimposes to a possible anomalous suppression, due to the screening of the attractive color force between the c and the $\bar{c}$ in a QGP environment. In Fig. 4 (right) the $J/\psi/DY$ ratios obtained from p–p, p–A and S–U data at two different energies (450 and 200 AGeV/c) by the NA51, NA38 and NA50 Collaborations [4–6] are plotted as a function of L, defined as the average thickness of nuclear matter crossed by the $c\bar{c}$ pair in its way through the projectile and the target nuclei, as calculated in the frame of the Glauber model. The interaction cross–section of the $c\bar{c}$ pair in its way through the nuclei corresponds to the absorption cross–section of the charmonium states in nuclear matter if no QGP is present. Fig. 4 (right) displays also the results of a Glauber calculation in which the free parameters were the separate normalizations of data at different kinematic conditions and a common value for the J/ψ absorption cross–section, which turned out to be $\sigma_{abs} = 4.4 \pm 0.5\ mb$ [6]. Therefore all the $J/\psi/DY$ points from p–p to S–U can be satisfactorily described by a common value of the nuclear absorption cross–section. In particular, the S–U data can be explained without invoking J/ψ suppression mechanisms different from the one that accounts for lighter systems. The value found for the J/ψ absorption cross–section is therefore a useful reference for the study of the J/ψ suppression in Pb–Pb collisions.

5 The standard analysis method

In the so–called standard analysis, the number of J/ψ and Drell–Yan events is obtained by fitting the invariant mass spectrum of opposite–sign muons as the sum of five contributions from different physical sources: the J/ψ and ψ' resonance decays, the Drell–Yan, the open charm, i.e. muons coming from semi–leptonic decays of D and $\bar{D}$ mesons and the combinatorial background, due to uncorrelated decays of π and K pairs [3]. The shapes of the mass spectra for the first four contributions are extracted from Monte–Carlo simulations including the resolution of the muon spectrometer, while the combinatorial background is evaluated from the sample of like–sign muons [3]. Once the combinatorial background is estimated, the absolute normalizations of the other physical contributions are adjusted on the experimental mass spectrum through a multi–step fit procedure. Finally the $J/\psi/DY$ ratios are obtained from the ratio between the total number of J/ψs and the number of Drell–Yan events in the mass range 2.9–4.5 GeV/c^2, estimated from the fit and corrected for the spectrometer acceptances. The use of ratios of experimentally measured quantities has the advantage of being insensitive both to systematic errors related to detector inefficiencies and to flux uncertainties which simply cancel out.

6 Experimental results

The $\sigma(J/\psi)/\sigma(DY)$ preliminary results of the NA50 standard analysis method are presented in Fig. 5 as a function of two different centrality estimators, E_T and E_{ZDC}, measured respectively by the NA50 electromagnetic and zero degree calorimeters [8,9]. Three independent analyses using E_T and one using E_{ZDC} have been performed in different laboratories collaborating to the NA50 experiment, using slightly different criteria of data selection and analysis methods. All the E_T analyses give consistent results within few %.

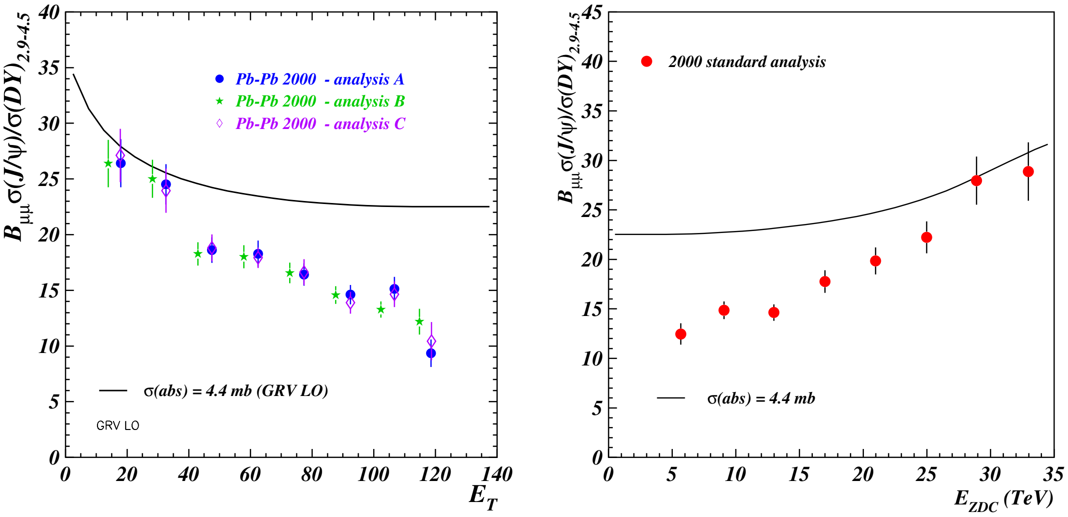

Figure. 5. $\sigma_{J/\psi}/\sigma_{DY}$ ratio as a function of E_T (left) and E_{ZDC} (right).

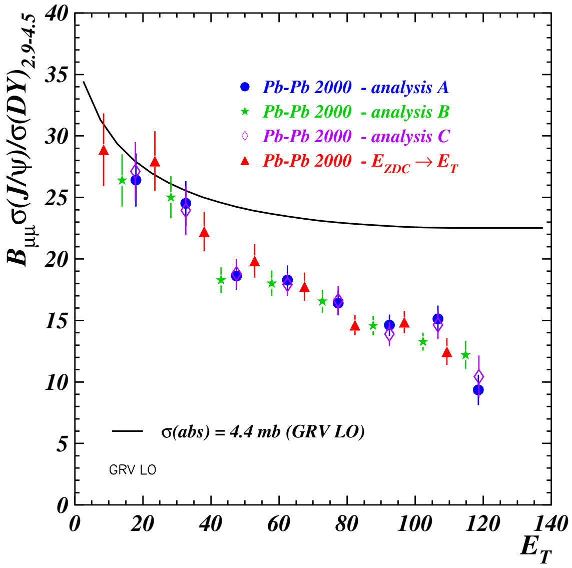

Figure. 6. *Comparison between the $\sigma_{J/\psi}/\sigma_{DY}$ results obtained as a function of E_T and E_{ZDC} (converted to E_T)*

The continuous line represents the normal nuclear absorption reference, corresponding to a J/ψ absorption cross section of $4.4 \pm 0.5\ mb$. The J/ψ production yield in peripheral collisions for all the analyses is compatible with the normal absorption curve. A departure from this curve is observed at around $E_T \sim 40\,GeV$ (or $E_{ZDC} \sim 27\,TeV$) and no saturation is observed for the most central collisions (at high E_T or low E_{ZDC} values).

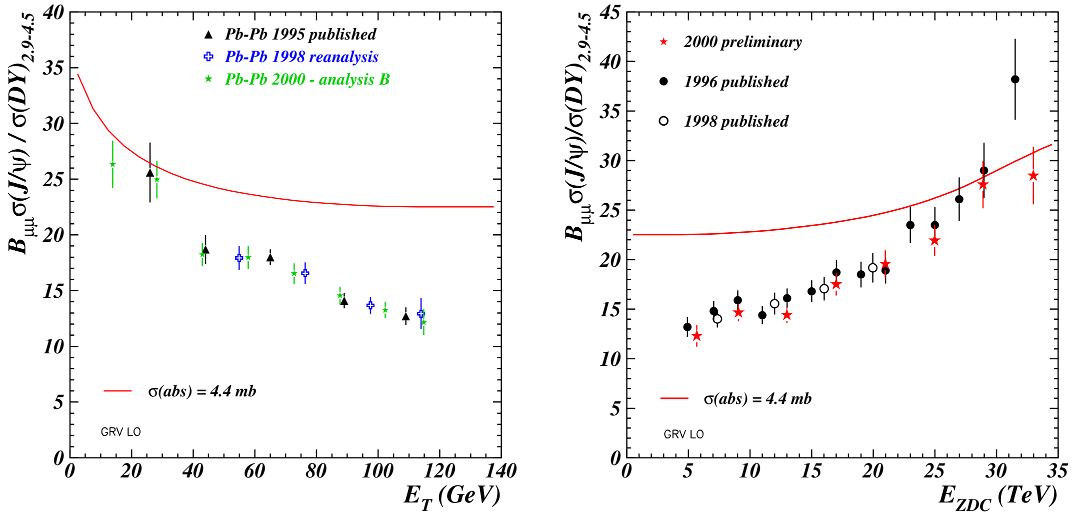

Figure. 7. Comparison between the 2000 standard analysis results and previous NA50 results, as a function of E_T (left) and E_{ZDC} (right).

The consistency of the analyses as a function of E_T and E_{ZDC} is clearly visible in Fig. 6, where the $J/\psi/DY$ results as a function of E_{ZDC} have been converted into E_T by means of the E_T–E_{ZDC} correlation reported in Fig. 3 (right). The so–converted E_{ZDC} analysis shows a fair agreement with the E_T analyses, within the different resolutions of the two calorimeters as a function of centrality.

Finally, the results obtained with the standard analysis method as a function of two different centrality estimators for the 2000 data are compared in Fig. 7 to the previous NA50 results. A good agreement can be observed both as a function of E_T and E_{ZDC}, except for the most peripheral collisions, which could have suffered in the past from the contamination of Pb–air interactions. This problem has been solved in the 2000 data taking by using a vacuum system for the target region.

7 Conclusions

The latest NA50 data taking was performed at the end of the year 2000 under improved experimental conditions with the aim of extending the previous knowledge about the J/ψ suppression mechanism to very peripheral Pb–Pb interactions. Two different centrality estimators, namely the neutral transverse energy and the forward energy, have been used to study the charmonium suppression as a function of the collision centrality. The preliminary results have allowed to confirm that the most peripheral $J/\psi/DY$ points are compatible with the normal nuclear absorption curve, determined with greater precision by new more accurate and high statistics p–A data, together with previous p–p, p–d, p–A and S–U results from the NA38, NA51 and NA50 experiments. A departure from this curve is visible for impact parameters larger than about 8.5 fm, followed by a steady decrease for the most central Pb–Pb collisions.

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