# Υ and Drell-Yan production in p-A collisions at 450 GeV incident energy

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In the past few years the NA50 experiment carried out a comprehensive study of heavy quarkonia production, both in proton-nucleus and nucleus-nucleus collisions. Along with the studies on J/$\psi$ and $\psi'$, NA50 measured for the first time Υ production at 450 GeV incident energy ($\sqrt{s} = 29.1$ GeV) on five nuclear targets (Be, Al, Cu, Ag and W) in the dimuon decay channel. We report here results on the cross section at mid-rapidity and the nuclear dependence of Υ and Drell-Yan cross sections. The results are compared with previous measurements and with the predictions of theoretical models.

The study of quarkonia production in p-A collisions is a key issue in high energy nuclear physics. First of all, being a test-bench of the theory of strong interactions, it allows to probe the aspects of quarkonia production that are calculable in pQCD. Secondly it allows to disentangle non-perturbative aspects of the production process such as the color neutralization of the $q\overline{q}$ pair and its interactions with cold nuclear matter [1–3]. These are key pieces of information for the study of heavy-ion interactions where quarkonia production can be affected also by the presence of hot and dense hadronic matter and by quark deconfinement [4, 5]. In this respect the Υ nuclear absorption has been measured only by one experiment at $\sqrt{s} = 38.8$ GeV [6] and therefore new data are useful in view of future collider esperiments.

A detailed description of the NA50 dimuon spectrometer can be found elsewhere [7]. Here we recall the basic features that are relevant for the discussion. The apparatus is made of 8 MWPC stations for tracking, 4 scintillator hodoscopes for triggering and an air-core toroidal magnet that are placed behind a hadron absorber. The target is placed before the hadron absorber and is surrounded by three centrality detectors, beam monitors and interaction detectors. Most of them are used during heavy-ion data taking only. We took data at two different beam intensities to check for possible systematical effects. The rapidity coverage of the spectrometer is $3 < y < 4$ in the laboratory, which translates into $-0.5 < y_{cm} < 0.5$ in the center of mass. The spectrometer selects dimuons according to their polar decay angle: $|\cos\theta_{CS}| < 0.5$ in the Collins-Soper reference frame. The acceptance is nearly flat as a function of the dimuon $p_{\mathrm{T}}$ and there is a smooth dependence on the invariant mass. Within the coverage of the spectrometer typical values are 14% for the J/$\psi$, 21% for DY events with masses above 6 GeV/c$^2$ and 22% for the Υ.

The extraction of the signal yields is based firstly on a series of quality cuts. The resulting invariant mass spectra are then fit to a sum of Drell-Yan and Υ events in the region above 6 GeV/c$^2$, where combinatorial background and contributions from other

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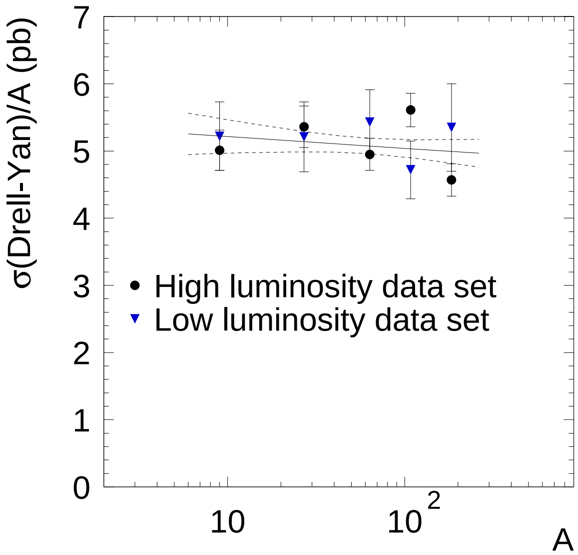


Figure 1. The Drell-Yan cross section for $m_{\mu\mu} > 6$ GeV/c$^2$, divided by the target mass number A. The errors are the combination of statistical and systematical uncertainties. The solid line is the result of a fit with $\sigma_{DY}^{pA} = \sigma_0 \cdot A^{\alpha}$, the dashed lines represent the uncertainty on the fit results. There is good agreement between data taken at two different beam luminosites showing that the dependence on beam intensity of the detection efficiency has been properly taken into account.

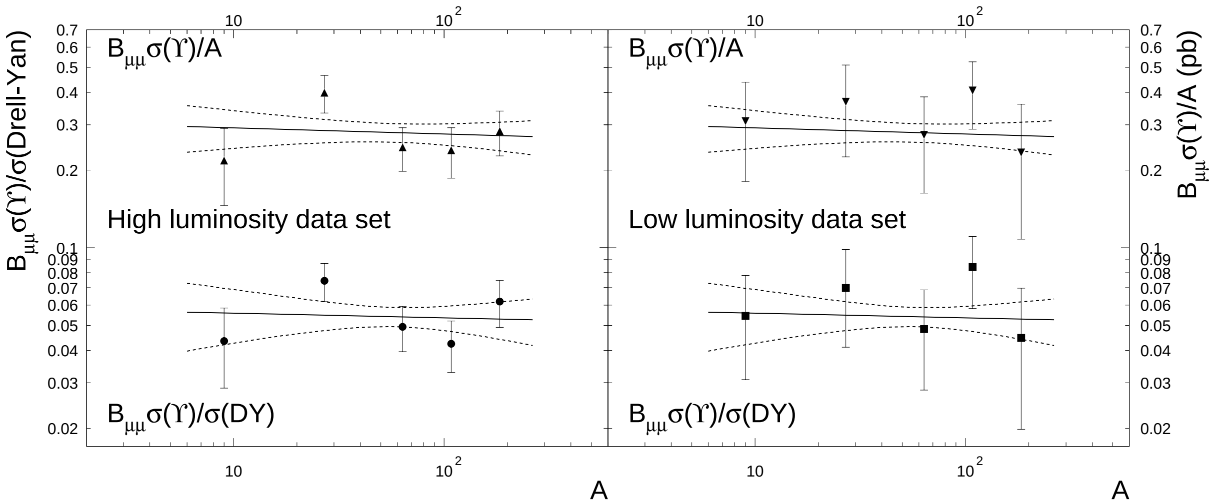


Figure 2. The ratio $B_{\mu\mu}\sigma_\Upsilon/\sigma_{DY}$ and the $\Upsilon$ cross section per nucleon-nucleon collision $B_{\mu\mu}\sigma_\Upsilon/A$, as a function of $A$. The solid lines are the results of the fits, the dashed lines represent their uncertainties.

physics processes are completely negligible. The mass resolution is $\sim 4\%$ at 10 GeV/c$^2$ preventing to resolve the three $\Upsilon$ states. Therefore we report results for the total $\Upsilon$ yield.

In Figure 1 we show, as a function of the target mass number A, the Drell-Yan cross sections divided by A. By means of a fit to a power law we quantify the size of nuclear effects. We obtain $\alpha_{DY} = 0.98 \pm 0.02$ with $\chi^2/d.o.f. = 1.4$, a value compatible with unity, showing that, in our kinematic domain, Drell-Yan scales with the number of nucleon-nucleon collisions.

In Figure 2 we plot the $\Upsilon$ cross section per nucleon-nucleon collision $B_{\mu\mu}\sigma_\Upsilon/A$ and the ratio of $\Upsilon$ and DY cross sections $B_{\mu\mu}\sigma_\Upsilon/\sigma_{DY}$, a quantity less sensitive to the systematical uncertainties connected with the luminosity estimation. With a simultaneous fit of the two data sets to a power law we obtain: $\alpha_\Upsilon = 0.98 \pm 0.08$ with $\chi^2/d.o.f. = 0.8$ and $\alpha_{\Upsilon/DY} = 0.98 \pm 0.09$ with $\chi^2/d.o.f. = 0.9$, values consistent with unity. This result seems to indicate small nuclear absorption at mid rapidity when compared with Ref. [6].

Because of the relatively small statistics of our data samples, in order to study the $p_{\rm T}$ or rapidity dependence of $\Upsilon$ and Drell-Yan production, it is not practical to divide the data into bins. We perform instead a global analysis of the full $p_{\rm T}$ and $y_{cm}$ spectra. We start from a sample of Monte-Carlo events that are then filtered by the NA50 simulation program and reconstructed using the same procedure as for real data. The experimental and MC spectra are then compared. To quantify the agreement between them we use a $\chi^2_L$ function, according to the prescription of [8], taking into account that both data and MC have finite statistics. By varying the parameters of the input distributions it is possible to minimize the $\chi^2_L$ and obtain therefore the most probable parameters together with the corresponding errors.

When analyzing the dependence of the cross sections on other kinematic variables, the Drell-Yan rapidity and $\theta_{CS}$ distributions are taken as known at leading order. For the study of the $p_{\rm T}$ distribution we adopt the parametrization $d\sigma/dp_{\rm T} \propto p_{\rm T}/\left(1+(p_{\rm T}/p_0)^2\right)^6$ and, using the procedure described above, we fit the experimental Drell-Yan distributions for dimuons with $m_{\mu\mu}/\sqrt{s} \sim 0.22$. We obtain $p_0 = 2.95 \pm 0.05$ GeV/c which corresponds to $\langle p_{\rm T}\rangle = 1.27 \pm 0.02$ GeV/c.

For the $\Upsilon$ transverse momentum distribution we apply the same procedure, taking into account that the Drell-Yan events act as a background with respect to the $\Upsilon$ events. We obtain $p_0 = 3.0 \pm 0.2$ GeV/c which corresponds to $\langle p_{\rm T}\rangle = 1.30 \pm 0.08$ GeV/c. For the $\Upsilon$ rapidity distribution we assume that it is Gaussian and centered at $y_{cm} = 0$. Using the procedure described above, we try to fix the width of the rapidity distribution. Unfortunately, due to the narrow rapidity coverage, it is only possible to set a lower limit: $\sigma_{450} > 0.30$ at 95% confidence level. This result is consistent with the measurements at 400 GeV [9,10] and 800 GeV [6,11] incident energy where similar fits yield $\sigma_{400} = 0.35 \pm 0.01$ and $\sigma_{800} = 0.46 \pm 0.01$.

Finally we derive the $\Upsilon$ cross section at mid-rapidity, assuming for the width of the rapidity distribution the value $\sigma_{400}$ logarithmically rescaled to 450 GeV incident energy.

| $\sqrt{s}$ (GeV) | $\frac{d\sigma}{dy_{cm}}\big\|_{y_{cm}=0}$ (pb) | System | $f_{corr}$ | Ref. |
|---|---|---|---|---|
| 19.4 | 0.038±0.032 | pPt | 0.781 | [12] |
| 19.4 | 0.003±0.003[a] | pPt | (0.781)[d] | [13] |
| 23.7 | 0.14±0.03[b] | pPt | (0.843)[d] | [13] |
| 27.4 | 0.42±0.08[c] | pPt | (0.882)[d] | [13] |
| 27.4 | 0.34±0.03 | pCu pPt | 0.882 | [14] |
| 27.4 | 0.44±0.06 | pPt | (0.882)[d] | [9] |
| 29.1 | 0.73±0.06 | pBe÷pW | 0.897 | |
| 38.8 | 2.31±0.39 | pBe | 0.961 | [15] |
| 38.8 | 2.06±0.17 | pCu | 0.961 | [11] |
| 41.6 | 3.4±0.8 | pA | 0.974 | [16] |
| 44 | 6±3 | pp | | [17][e] |
| 53 | 13.5±7.4 | pp | | [18] |
| 62 | 9±3 | pp | | [17] |
| 62 | 14.5±3.5 | pp | | [19] |
| 63 | 15.2±5.5 | pp | | [18] |

Table 1
The cross sections at mid-rapidity for $\Upsilon + \Upsilon' + \Upsilon''$. Results obtained in pA collisions reported in second column have to be multiplied by the factor $f_{corr}$ to cancel the effect of Fermi motion in the target nuclei, obtaining therefore the $\Upsilon$ cross section per nucleon-nucleon collision. To perform this correction the approximate formula reported in [13] has been used.

a,b,c) results refer to $y_{cm}$ = 0.40, 0.20 and 0.03, respectively.
d) the quoted results have already been corrected for Fermi motion. We report the correction factor according to [13].
e) result is quoted from Ref. [20].

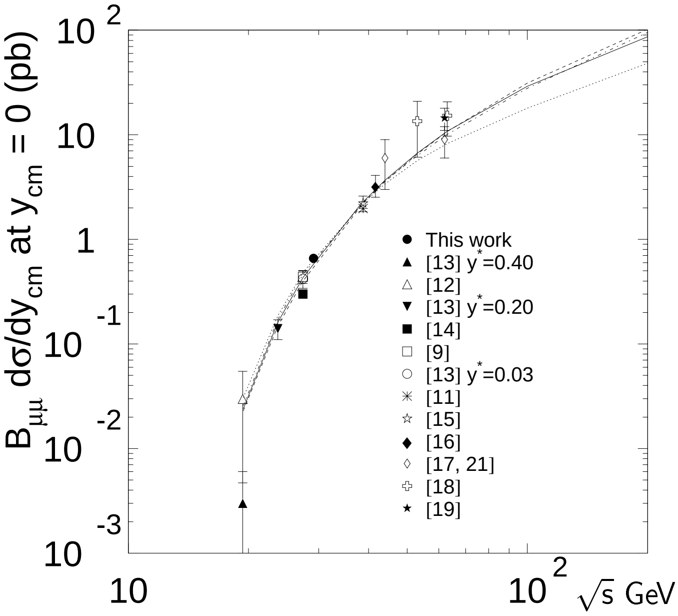


Figure 3. The $\Upsilon$ cross section at midrapidity as a function of $\sqrt{s}$. $\alpha_\Upsilon = 1$ is assumed. The lines represent the results of a NLO CEM calculation [21]. In particular the solid line uses the MRST HO distributions with $m_b = \mu = 4.75$ GeV, the dashed $m_b = \mu/2 = 4.5$ GeV, the dot-dashed $m_b = 2\mu = 5$ GeV, and the dotted GRV HO with $m_b = \mu = 4.75$ GeV. It is assumed that $\mu = \mu_R = \mu_F$, where $\mu_R$ is the renormalization scale and $\mu_F$ is the factorization scale.

We obtain $\frac{d\sigma}{dy}\Big|_{y=0} = 0.73 \pm 0.06$, a value compatible with the available systematics and with theoretical calculations [21], as shown in Table 1 and Figure 3.

If we do not rely on data at 400 GeV and use the uncertainty on $\sigma_y$ resulting from our own measurement we get $\frac{d\sigma}{dy}\Big|_{y=0} = 0.73^{+0.08}_{-0.12}$ at 95% confidence level.

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