MUOPRODUCTION OF J/ψ- MESONS AND THE GLUON DISTRIBUTION IN THE NUCLEON

Ewa Rondio
New Muon Collaboration (NMC)
Warsaw University, Poland

Abstract

Results are presented on inelastic J/ψ-production from muon interactions with hydrogen, deuterium, carbon and tin. The data were collected by the experiment NA37 at the CERN SPS. The measured cross section ratio per nucleon for muon-induced J/ψ-production in deuterium and hydrogen was found to be $R(D_2/H_2) = 1.01 \pm 0.15$. The Colour Singlet model is shown to provide a good description of the observed differential cross section apart from a normalisation factor. The comparison between the observed cross section and the Colour Singlet model prediction allows the extraction of the gluon structure function G(x) of the nucleon. The momentum fraction x of the nucleon carried by the gluon is measured in the range of x=[0.02,0.3]. The normalised gluon distribution of free nucleons thus found can be parametrised as: $xG(x) = \frac{\eta+1}{2}(1-x)^\eta$, with $\eta = 5.1 \pm 0.9(stat.)$.

The cross section ratio per nucleon for carbon and tin was studied as a function of the energy fraction, z, taken by the J/ψ-meson and its squared transverse momentum, p_T^2.

Introduction

The production of J/ψ mesons in deep inelastic scattering (DIS) can be related to the gluon distribution in the nucleon. Data from muon interactions with hydrogen and deuterium were used extract the gluon distribution using the colour singlet model based on photon-gluon fusion, after it had been verified that this model describes the data.

The question how the gluon distribution is modified in nuclear matter was approached by comparing of J/ψ production in tin and carbon targets.

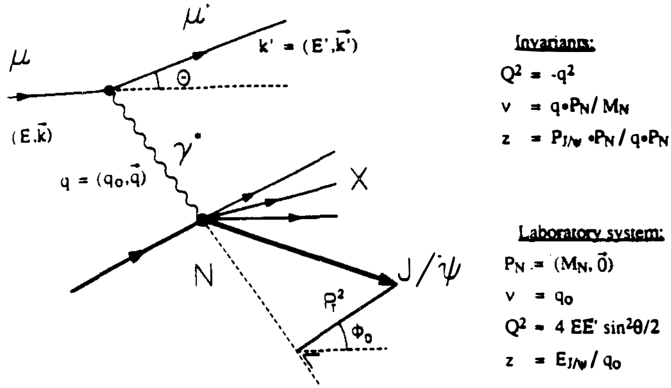

Figure 1: The kinematics of muon induced J/ψ production in one photon exchange approximation.

Experimental data

The experiment was performed in the M2 beam at the CERN-SPS with muons of 280 GeV incident energy using an upgraded version of the EMC forward spectrometer [1]. The kinematics of the μ-nucleon interaction producing a J/ψ meson (in the one-photon exchange approximation) is shown in fig.1. For hydrogen and deuterium the trigger accepting DIS events with scattering angles larger than 10 mrad was used whereas for carbon and tin a special multimuon trigger was applied. Special care was taken to observe muons at small scattering angles (in the beam region). Only J/ψ mesons decaying into a muon pair were detected. All events with at least three reconstructed tracks were considered. For such cases the invariant mass of oppositely charged muons was calculated and the scattered muon was selected from the remaining reconstructed tracks with the same charge as that of the incident muon.

J/ψ production on hydrogen and deuterium

The invariant mass distributions for inelastic interactions on hydrogen and deuterium are presented in fig.2 a) and b). Inelastic events were selected by requiring $z \leq 0.9$ and transverse momentum squared $p_T^2 \geq 0.1\ GeV^2/c^2$. The sum of a gaussian distribution and an exponentially falling background were fitted to the mass spectra. The fitted value of the J/ψ mass is $3.093 \pm 0.005\ GeV^2/c^2$, which is in good agreement with [2]. The width corresponds to the spectrometer momentum resolution of 1%. The background corrected number of J/ψ mesons was found to be 85 ± 10 and 194 ± 15 on hydrogen and deuterium respectively. This yields the ratio of the cross sections per nucleon for muoproduction of the J/ψ in deuterium and hydrogen to be R(D/H)=1.01 ± 0.15 where the error is statistical only. The systematic error was estimated to be small due to the cancelation of acceptances and beam fluxes [1].

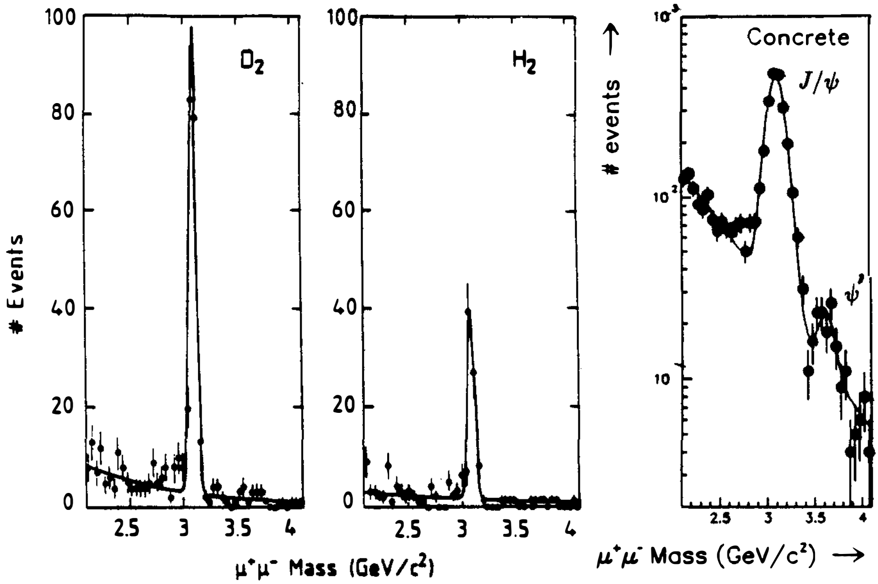

Figure 2: The invariant mass distribution of selected $\mu^+\mu^-$ pairs produced in deuterium(a), hydrogen(b) as well as pairs produced in the concrete absorber placed behind the carbon and tin target(c) where the high statistics allows the observation of the ψ' peak.

This result is consistent with equal J/ψ production rates for neutron and proton. In the subsequent analysis the hydrogen and deuterium data were therefore combined giving 279 inelastic J/ψ events in the invariant mass interval 2.9-3.3 GeV/c^2 and 41 background events.

To obtaine absolute cross sections from the experimental counting rates, the acceptance was calculated using a Monte Carlo simulation. The branching ratio of J/ψ into a muon pair was taken to be (6.9±0.9)% [2]. Radiative effects on the measured cross section were estimated to be 5% or less [3,4]. The background contribution to the inelastic J/ψ rate coming through ψ' production and subsequent decay into J/ψ was estimated using data from interactions in the concrete absorber placed behind the carbon and tin targets. The invariant mass distribution for this sample is shown in fig.2 c). The signal of ψ' is clearly visible and after the corrections for branching ratios one obtains $\sigma(\psi')/\sigma(J/\psi) = 0.24 \pm 0.05 \pm 0.08$. Using this ratio in a Monte Carlo simulation, the ψ' contribution to the inelastic J/ψ production is found not to exceed a few percent and was therefore neglected.

As possible mechanisms of J/ψ production the vector meson dominance with the Drell-Yan mechanism and photon-gluon fusion [5] were considered. The corresponding graphs are presented in fig.3. The model predictions were compared to experimental distributions. The two mechanisms give largely different predictions for the J/ψ rapidity distribution. In fig.4 the observed differential cross section is shown together with the model expectations. The data which is peaking at high values of the rapidity, favour the CS model description. The normalisation factor applied in the CS model necessary to give a good description of the data was estimated to be 2.4. The comparison of the differential cross section as a function of z and p_T^2 extracted from the data with the predictions of the CS model (applying again the same normalisation factor) is shown in fig.5. For z values corresponding to inelastic J/ψ production ($z \leq 0.9$) the agreement is good. The model also gives a good description of the differential cross sections as a function of Q^2 and ν.

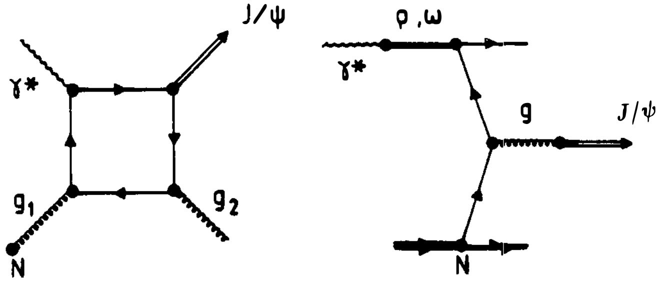

Figure 3: The diagrams for muon induced J/ψ production in the Colour Singlet model (CS) and Vector Meson Dominance description with the Drell-Yan mechanism (VMD-DY).

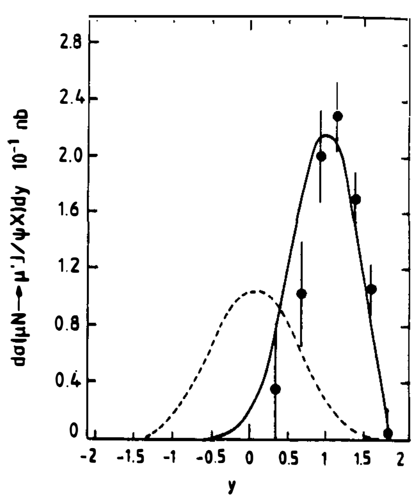

Figure 4: Cross section for J/ψ muoproduction as a function of rapidity and comparison with model predictions. The CS prediction (times 2.4) is represented by the solid curve; the dashed curve represents the VMD-DY expectation.

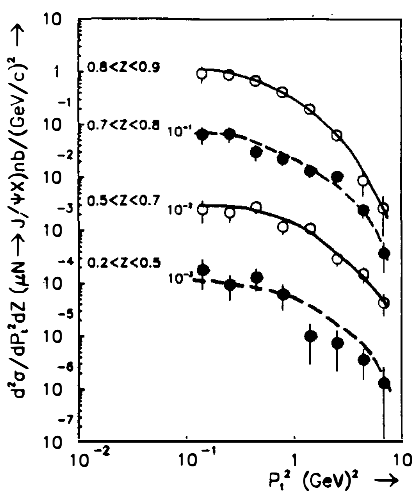

Figure 5: Cross section for J/ψ muoproduction as a function of z and p_T^2 and a comparison with the CS model prediction with a normalisation factor of 2.4 (the same as for the rapidity distribution).

Colour Singlet Model

In the CS model, the J/ψ is represented by a definite wave function of the $c\bar{c}$ system, describing a colour singlet state of spin and parity $J^P = 1^-$ and the mass of the J/ψ.

The calculation was performed according to ref [6] with a QCD radiative correction factor to the leptonic width $\Gamma_{J/\psi}$ of $1 - 16\alpha_s M^2_{J/\psi}/3\pi$ (ref[7]). The values of α_s and the charm quark mass were taken from [2]. The normalisation is not described correctly but the shape of rapidity distribution as well as the other differential cross-sections are in good agreement with the data in the region where the model is applicable (i.e. the inelastic domain).

Gluon distribution

Since the CS model provides a good description of the data it has been used to extract the gluon distribution of the nucleon. The function :$c \cdot \frac{\eta+1}{2} \cdot (1-x)^\eta$ was used in fitting the data, which yielded c=2.4±0.4 (i.e.the above introduced normalisation factor) and $\eta = 5.1 \pm 0.9$ The variable $x = \frac{\hat{s}_{\gamma^* g}}{s_{\gamma^* N}}$ in CS model can be express as $x = \frac{1}{s}[\frac{M^2_{J/\psi}}{z} + \frac{p_T^2}{z(1-z)}]$. The normalised (c=1) gluon distribution is presented in fig.6.

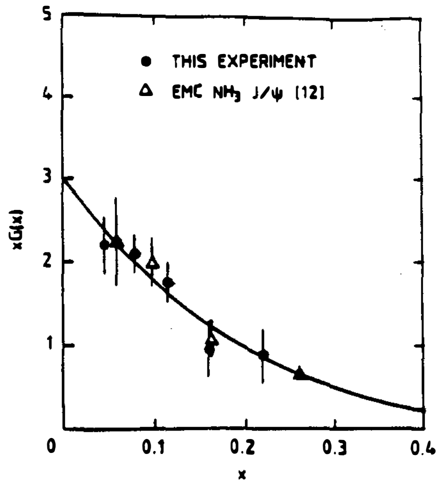

Figure 6: The normalised nucleon gluon distribution $x \cdot G(x)$ from hydrogen and deuterium data extracted with the CS model. Also shown are earlier results from an EMC measurement on amonia [3] .

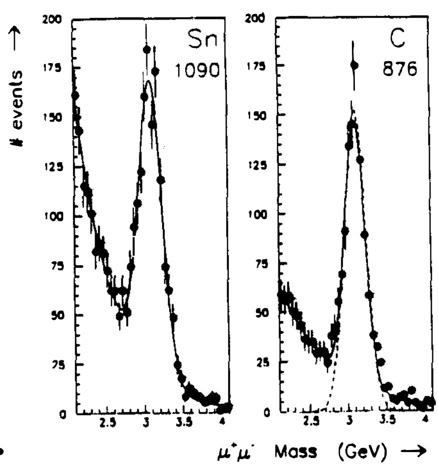

Figure 7: The invariant mass distribution of $\mu^+\mu^-$ pairs produced in tin and carbon.

J/ψ production on nuclear targets

A complementary setup of carbon and tin targets [8] was exposed to muons with an average energy 280 GeV. The J/ψ events were selected by a dedicated multimuon trigger. The results presented here are preliminary.

The invariant mass spectra of $\mu^+\mu^-$ pairs are shown in fig.7 for both materials. The widths of the peaks are larger than those fot the hydrogen and deuterium data due to higher multiple scattering in the targets and the absorber placed behind it. The number of J/ψś (in the mass interval 2.7-3.5 GeV/c^2 after background subtraction) is 1090±34 for tin and 876±30 for carbon.

Production of the J/ψ in nuclear target can take place through:

* a coherent process (elastic on the nucleus),

* a diffractive process (elastic on the nucleon),
* an inelastic process (inelastic on nucleon).

Coherent production on the nucleus is expected at z near unity and at low p_T^2. The corresponding cross section should be dependent on the size of the nucleus.

To study the first two processes, a sample of interactions with z≥0.9 was selected. Distributions of p_T^2 for this sample are shown in fig.8 a). One can clearly distinguish two slopes corresponding to coherent scattering at low p_T^2 and elastic scattering on the nucleon. The coherent signal for tin is larger than that for carbon. Smearing effects dominate the slope of this part of the distribution. At higher p_T^2, the distributions for both materials are described by the same exponential slope.

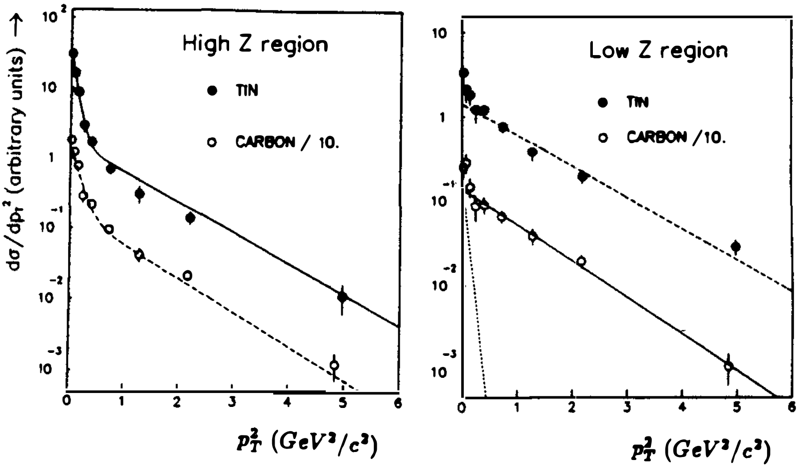

Figure 8: The p_T^2 distribution for J/ψ mesons for carbon and tin in two z intervals high z ($z \geq 0.9$)-the coherent and diffractive region and low z ($0.2 \leq z \leq 0.9$)-the inelastic region. The solid and dashed lines show the fitted exponential curves for tin and carbon respectively. Dotted line, for the low z region, represents estimated coherent contribution for carbon.

In fig.8 b) the p_T^2 distribution for the inelastic region (z≤0.9) is shown. The dotted line corresponds to the expected coherent contribution of ψ', and its subsequent decay, for carbon. A p_T^2 cut of $p_T^2 \geq 0.4\ GeV/c^2$ is applied to reduce this contribution.

The ratio of cross sections for J/ψ production in the inelastic sample was found to be $\frac{\sigma(J/\psi)_{Sn}}{\sigma(J/\psi)_C} = 1.20 \pm 0.13$

In the Colour Singlet model the cross section is proportional to the gluon momentum distribution, so that within this model the ratio of gluon distributions in tin and carbon is equal to this cross-section ratio.

Summary

The gluon distribution has been extracted from the J/ψ muo-production on hydrogen and deuterium with the Colour Singlet model. The accuracy of this result is comparable with that reached in the QCD analysis of scaling violations in F^2 structure functions [9]. The J/ψ production on the neutron and the proton was found to be the same. For carbon and tin the J/ψ production ratio is strongly dependent on z and p_T^2.

This fact might explain the discrepancy between previous results obtained by EMC [10] and at FNAL [11]. In the inelastic domain the ratio was found to be 1.20 ± 0.13.

References

[1] NMC,D.Allasia et al,Phys.Lett.B249(1990),366.

[2] Review of Particle Properties,Phys.Lett. B223(1990).

[3] N.Dyce, Ph.D.thesis, Lancaster University(1980).

[4] L.W.Mo and Y.S.Tsai,Rev.Mod.Phys.41(1969),205; Y.S.Tsai, SLAC-848(1971).

[5] NMC,D.Allasia et al,Phys.Lett.258B(1991),493.

[6] K.J.Abraham,Phys.Lett.240B(1990),224.

[7] R.Barbieri,R.Gatto and E.Remiddi, Phys.Lett.106B(1981),497.

[8] M.de Jong,Ph.D.thesis, Free University Amsterdam(1991)

[9] EMC,J.J.Aubert et al,Nucl.Phys. B272(1986),158 and BCDMS,A.C.Benvenuti et al, Phys.Lett. B223(1989),490.

[10] EMC,J.J.Aubert et al,Phys.Lett. 152B(1985),433.

[11] M.D.Sokoloff et al,Phys.Rev.Lett. 57(1986),3003.