Resolved component of the photon in heavy quark photoproduction

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Heavy quarks in $\gamma - N$ interactions are produced mainly by photon-gluon fusion. Nevertheless a small contribution to the total cross section comes from processes like those appearing in heavy quarks hadroproduction through the resolved component of the photon. Here we concentrate on the resolved contributions of the photon to heavy meson photoproduction. We discuss the calculation of the cross section to $D's$ and $B's$, as well as its dependence on the fragmentation function and the center of mass energy available in the collisions.

Keywords: Heavy meson; production.

La producción de sabores pesados en interacciones $\gamma - N$ son principalmente por fusión fotón-gluón. No obstante, una pequeña contribución a la sección eficaz total viene de procesos similares a los que aparecen en hadroproducción a través de la componente resuelta del fotón. Aquí nos concentramos en la contribución resuelta del fotón y la fotoproducción de mesones pesados. Se discute el cálculo de la sección eficaz de $D's$ y $B's$, así como su dependencia con las funciones de fragmentación y la energía del centro de masa usado en las colisiones.

Descriptores: Producción de sabores pesados; funciones de fragmentación.

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1. Introduction

Heavy hadrons in photon-nucleon interactions at typical fixed target energies, are expected to be produced predominantly by photon-gluon fusion with the subsequent fragmentation of the quarks into the final state. Furthermore, associated production, together with leading particle effects have been observed to play an important role in the hadroproduction asymmetries for charm and anti-charm particles [1, 2]. As Q and $\bar{Q}$ (Q, $\bar{Q}$ indicate a heavy quark and anti-quark, respectively) quarks in the $\gamma g \rightarrow Q\bar{Q}$ process are produced at the same rate, the total cross section for heavy hadron and anti-hadron production are approximately the same. A small $\bar{Q}$ excess from Next to Leading Order (NLO) contributions [3] produces a non- significant enhancement in anti-hadron production. This contribution was estimated to give a ratio (R) of $\bar{c}$, c cross section in the forward direction of about $R = 1.006$ [4].

Photoproduction results from the SLAC Hybrid Photon Facility Collaboration [5] have reported a noticeable production asymmetry in charm mesons. This result has been confirmed more recently by E691 [6] and E687 [7]. A qualitative model to account for the observed results has been presented [5]. Another interesting model is the Lund or string [8], where the color field between the target diquark and the charm quark produced in the photon-gluon interaction builds a string. Similarly the bachelor quark builds a string with the anti-charm quark, producing mesons without any asymmetry. Similar processes could give the production of B mesons; however, there are no experimental results on photoproduction asymmetries for these mesons. An alternative scheme for studying the charm anti-charm asymmetries is through the recombination mechanism of the heavy quark with a light anti-quark from the sea in photoproduction [9] and hadroproduction [10].

The goal of the present work is to investigate the production asymmetry of D and B mesons coming from the resolved component of the photon, as well as the effects on this asymmetry of the fragmentation function used to produce the mesons. The remainder of this work is organized as follows: in Sec. 2 we describe the heavy quark cross section and fragmentation function, Sec. 3 the resolved component of the photon is discussed, as well as the cross section of meson production. Section 4 shows the calculation for the production asymmetry of mesons from the resolved component of the photon and the effects when the fragmentation function is changed. Finally, conclusions are drawn in Sec. 5.

2. Heavy quark cross section and fragmentation function

The invariant cross section for the photoproduction of a heavy quark is given by [3]

$$\frac{Ed^3\sigma}{dp^3} = \sum_i \int dx \frac{Ed^3\hat{\sigma}_{\gamma i}}{dp^3} f_i^H(x) + \sum_{i,j} \int dx_1 dx_2 \frac{Ed^3\hat{\sigma}_{i,j}}{dp^3} f_i^{\gamma}(x_1) f_j^H(x_2) \,, \quad (1)$$

where the sum runs over light quarks and gluons. In Eq.(1) the dependence on the factorization scale μ_F is implicit in the elementary cross sections $\hat{\sigma}$ and in the parton distribution functions (PDFs) in the hadron $[f_i^H(x)]$ and the photon $[f_i^\gamma(x)]$. The short distance cross sections $\hat{\sigma}$ are calculable as a perturbative series in $\alpha(\mu_R^2)$.

The first term in the right hand side of Eq.(1) is known as the point-like contribution, while the second term is the hadronic component of the photon. The separation of the two terms is controlled by the scale μ_F (see Ref. 3).

The convolution of the differential cross section $d\sigma/dx_F$ for heavy quark (Q=c,b) production with a fragmentation function gives the production of hadrons.

The hadronization of the perturbatively produced $Q\,(\bar{Q})$ quark through the recombination with the debris of the photon is discussed in Ref. 11.

There are different fragmentation functions (FF) reported in the literature [12]. The Peterson fragmentation function [13] is the following:

$$D_Q^H(z) = \frac{N}{z\left[1 - \frac{1}{z} - \frac{\epsilon}{1-z}\right]^2}\ , \tag{2}$$

where z is the fraction quark's energy carried by the produced hadron, N is a normalization constant and ϵ is the ratio between light and heavy quark masses. This FF with $\epsilon = 0.11$ gives a good description of the main features of $D^\pm$ photoproduction.

For the string fragmentation models, the well known Lund fragmentation model [8] has the function

$$D_Q^H(z) = \frac{1}{z}(1-z)^a e^{-\frac{bm_T^2}{z}}, \tag{3}$$

where $z = (E+P_L)_{hadron}/(E+P_L)_{quark}$, m_T is the transverse mass of the hadron, b is a universal constant related to the inverse of the string tension, a is a constant which could be flavor dependent. This seems to give also a good description of D meson photoproduction, when $a = 1.0$ and $b = 0.7$ [14].

Another fragementation function of this kind is that of Nason and Colangelo [15],

$$D_Q^H(z) = A(1-z)^\alpha z^\beta, \tag{4}$$

where A is the normalization constant, and α and β are parameters extracted from experimental data. Nevertheless they are not completely free, since they are related to Λ QCD scale, corresponding to the experimental energy range of the process. This function has been used to describe the production of D mesons with $\alpha = 0.8$ and $\beta = 0.32$. An exhaustive data analysis and set of parameters were investigated [15], predicting B meson production with $\alpha = 0.025$ and $\beta = 25.69$. These functions with their set of parameters could describe the data available within the errors; however, as will be shown in the following section, we need to take care which function and set of parameters are used since those functions could change results such as the production of heavy mesons.

3. Heavy meson production from resolved component of the photon

The hadronic structure of the photon contributes to the total cross section of Eq.(1) and produces additional contributions to the heavy meson production. Resolved contribution to the heavy quark production can come from three different processes:

i) when the anti-quark of the photon is annihilated with a quark of the nucleon ($\bar{q}_\gamma q_N \to Q + \bar{Q}$),

ii) when a quark of the photon is annihilated with an anti-quark of the nucleon ($q_\gamma \bar{q}_N \to Q + \bar{Q}$) and

iii) gluon-gluon fusion ($gg \to Q + \bar{Q}$) with gluons from photon and nucleon, respectively.

The first process is favored due to the partonic structure of nucleons which do not contain anti-quarks as valence quarks.

Consequently in the fluctuation of the photon to $q_\gamma \bar{q}_\gamma$, more q_γ are liberated in the collision respect to $\bar{q}_\gamma$, and then, there should be an excess in the production of mesons (M) containing a $q_\gamma \bar{Q}$ compared to $\bar{q}_\gamma Q$. If the quark from the photon released in the collision is $q_\gamma = d$, then we should observe more mesons, $M^-(\bar{Q}d)$ than $M^+(Q\bar{d})$, (see Fig. 1.) When $q_\gamma = u$, an excess of $\bar{M}^\circ(\bar{Q}u)$ over $M^\circ(Q\bar{u})$ mesons should be measured. In this production scheme we use the assumption that q_γ recombine easily with a $\bar{Q}$ to form a meson in the final state. This mechanism tends to produce more heavy anti-mesons than mesons.

The case of heavy flavor, $Q = c$, where a D meson is produced, has been widely investigated; for instance, there are results obtained by the E691 and E687 Collaborations where the interaction γ-Beryllium is studied. Since the Beryllium nucleus has more neutrons than protons, an excess of D^- over $\bar{D}^\circ$ appears. In the case of $Q = b$, we have a B meson with similar behavior in the sense that those mesons have a similar constitution: a light and a heavy quark. Nevertheless, we do not know of experimental results on production asymmetries of $B's$.

The outlined production scheme described in the previous paragraph is employed to estimate the cross section shown in Fig. 2. This shows two different contributions to the cross section for the charm (left) and bottom (right), illustrating that contribution from interaction of the valence quark (d) of the proton when the photon is larger than those coming from the interaction of sea quark ($\bar{d}$) with the photon. One can see that those differences increase with the mass of the produced quark: from D to B mesons. From Fig. 2, adding the contributions of the u and d sea quarks and comparing them with the valence contribution, clearly a production asymmetry is expected.

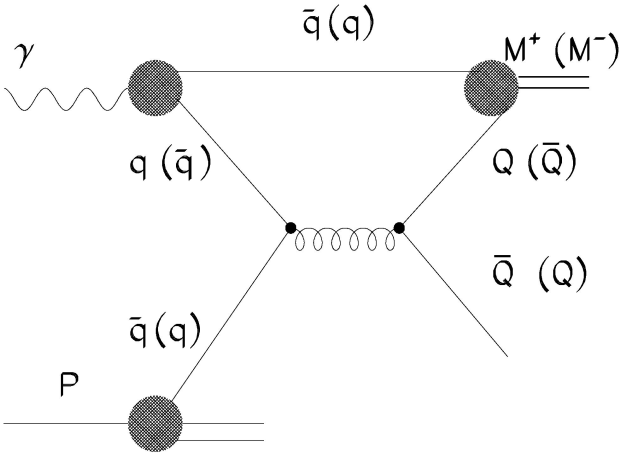

FIGURE 1. Production of charm (bottom) mesons and anti-mesons in the model. The amplitude for M^+ production is smaller than for M^- just because the anti-quarks density in protons is smaller than the quarks densities.

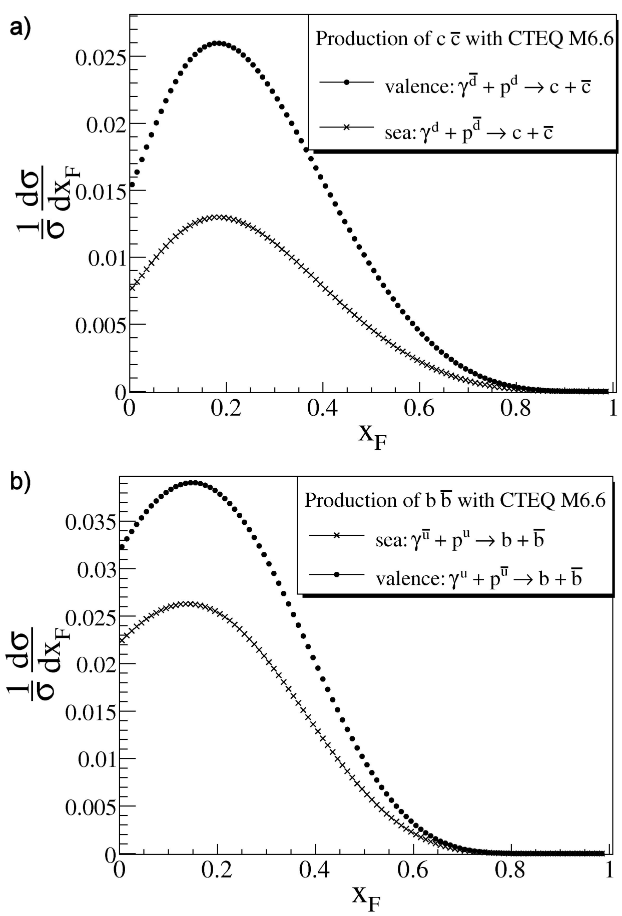

FIGURE 2. Different resolved contributions to the cross section for charm (left) and bottom (right) quarks.

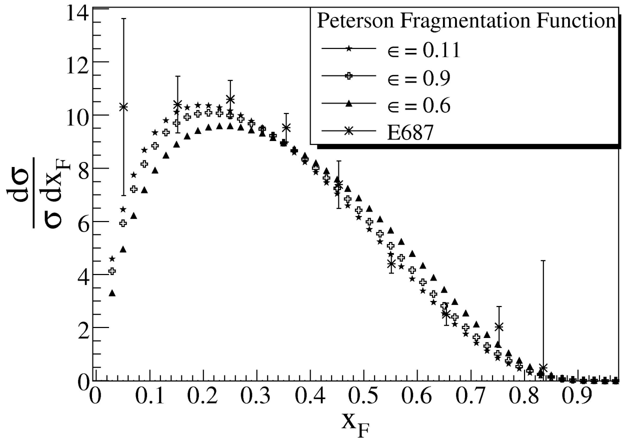

FIGURE 3. Total cross section using the best fragmentation function with a set of values for ϵ parameter, compared to experimental data [6].

4. Production asymmetries from the resolved component of the photon

In order to make a quantitative estimate of the production of mesons accordingly to the diagrams in Fig.1, we consider that the Q flavor cross section from point-like contribution is the same as for $\bar{Q}$ at leading order QCD processes. The resolved component has three contributions as described in the previous section. Nevertheless, the two quark annihilation processes can produce a difference in meson production according to the production mechanism outlined in the previous section. Then, an asymmetry can be defined as

$$A(x_F) = \frac{N(\sigma_{q_\gamma \bar{q}_p} - \sigma_{\bar{q}_\gamma q_p})}{2[\sigma_{\gamma\, p} + N\sigma_{g\, g}] + N[\sigma_{q_\gamma \bar{q}_p} + \sigma_{\bar{q}_\gamma q_p}]}, \quad (5)$$

where

$$\sigma_{\bar{q}_\gamma q_p} = \sum_{i,j} \int dx_1 dx_2\; \bar{q}_i^\gamma(x_1)\; q_j^p(x_2)\; E\; \frac{d^3\hat{\sigma}_{i,j}}{dp^3} \quad (6)$$

$$\sigma_{q_\gamma \bar{q}_p} = \sum_{i,j} \int dx_1 dx_2\; q_i^\gamma(x_1)\; \bar{q}_j^p(x_2)\; E\; \frac{d^3\hat{\sigma}_{i,j}}{dp^3} \quad (7)$$

where N should be obtained from normalization to the experimental total cross section for $D's$ (see Fig. 3). The figure is done with Peterson FF, three values of the ϵ parameter and using a mix of 96% of the point-like and 4% of the resolved component. This contribution of the resolved and point-like are in agreement with QCD calculation [3, 16] where the resolved component of the photon is less than 10% of the point-like contribution.

Quantitative estimation of the asymmetry defined by Eq.(5) can be done using a factorization scale μ_F=1 GeV, in the parton distribution functions of the photon and of the proton. We would like to remark that this free parameter could introduce effects into the QCD calculations at next leading and higher order correction which are less than 5% in phoproduction with photon energy between 50 and 400 GeV [3, 16].

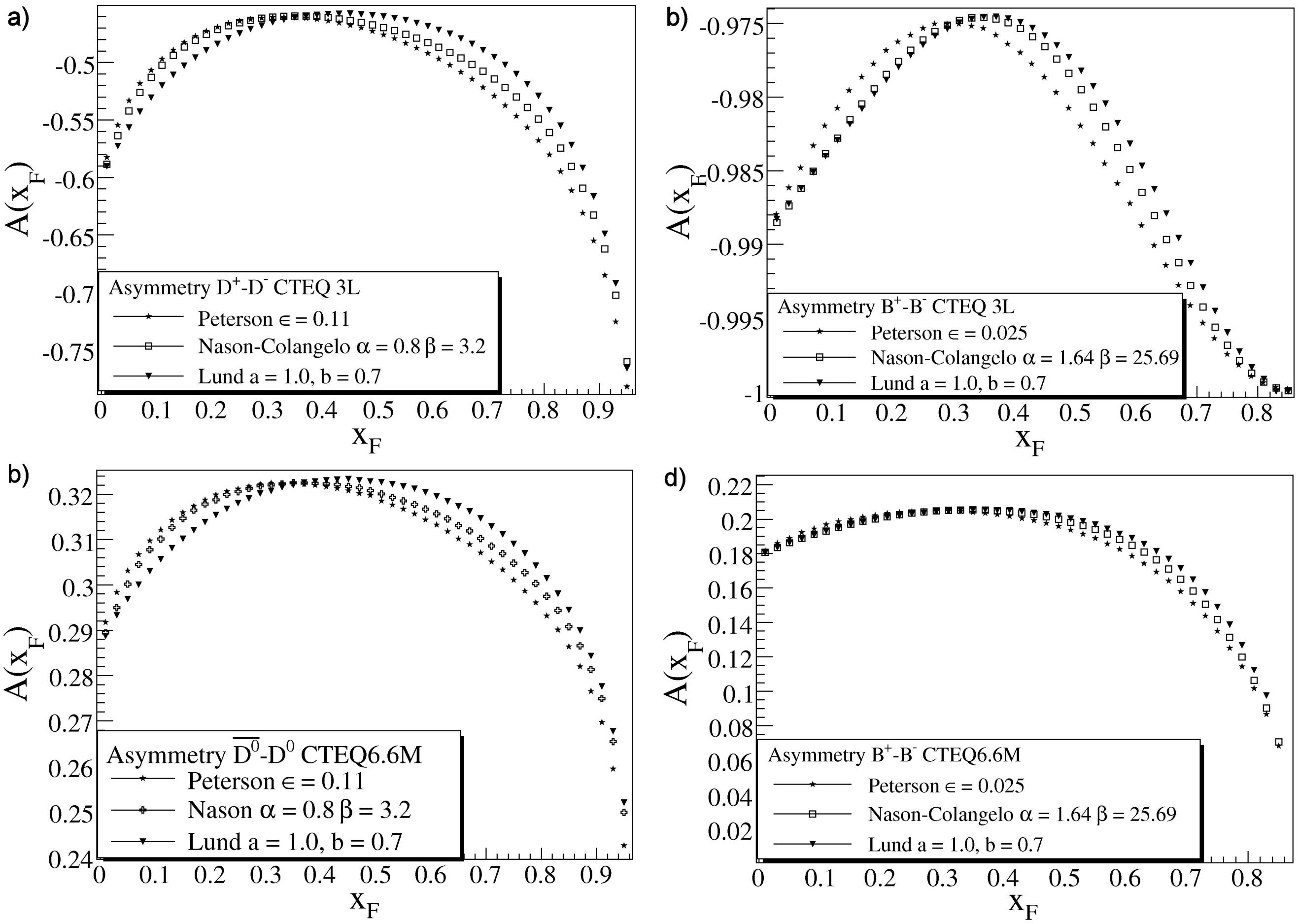

FIGURE 4. Production asymmetries of charm(left) and bottom (right) which arises from photon fluctuation to pairs $q\bar{q}$. The asymmetry depends on the fragmentation function.

TABLE I. Integrated asymmetries for D and B mesons, using three different fragmentation function.

PDF	Meson	Peterson FF	Nason FF	Lund FF
CTEQ 3L	$D^{\pm}$	0.496	0.489	0.469
	$B^{\pm}$	0.830	0.829	0.809
CTEQ 6.6M	$D^0(\bar{D}^0)$	0.262	0.263	0.258
	$B^{\pm}$	0.148	0.150	0.145

However, our calculations are at leading order. Consequently, effects of the factorization scale do not need to be taken into account. The results of S. Frixione [16] indicate that the factorization scale in the parton distribution functions of the photon does not noticeably affect the results. Effects from other parameters such as quark mass, renormalization scale, have also been discussed [3, 16]. The renormalization scale has been taken as $\mu_R{=}m_Q$ with $m_c{=}1.5$ GeV and $m_b{=}4.5$ GeV.

The results presented were obtained with the CTEQ6.6M [17] parton distribution functions for the protons, and for the photons we use the WHIT-G3 [18].

The results of Eq.(5) without $\sigma_{\gamma p}$, σ_{gg} and under the consideration described previously, are shown in Fig. 4 for D (left) and B (right) mesons at photon energy of 200 GeV. Taking only the resolved component we can see a significant production asymmetry in the D and B mesons for all x_F.

Table I presents the absolute values of the integrated results of Fig. 4. From the table we can see a differences of the order of 2-5% among the fragmentation functions. This observation is for the D and B mesons. Those results indicate that one has to take care in choosing the fragmentation function used to calculate quantities where the resolved component of the photon is taken into account. Large differences are observed on $B^{\pm}$ asymmetry calculated with the same fragmentation function and two PDFs. Considering that CTEQ3L is older than CTEQ6.6M, the main difference comes from the data analyzed and the method of analysis, obtaining more precision on the PDFs in the CTEQ6.6M. Large differences are observed for $B^{\pm}$, compared to $D^{\pm}$. The same trend is observed for B^0 and D^0, as indicated by the asymmetry for the $D^0(\bar{D}^0)$ for three fragmentation functions.

Quantification of the asymmetries also greatly depends on the precision of the PDFs. The extraction of PDFs by the CTEQ group allows for uncertainties of about 10-20% [17], which are obviously reflected in the quantification of the asymmetries, as indicated in the second and last line of Ta-

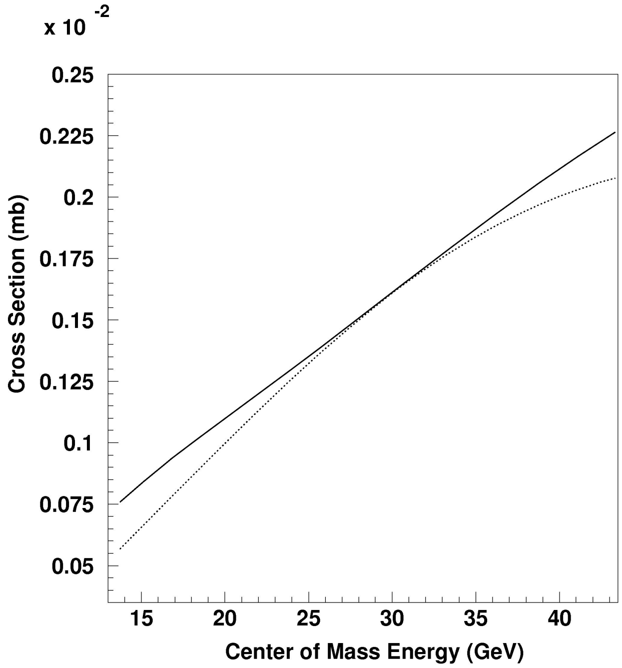

FIGURE 5. Integrated cross section for charm photoproduction as a function of the center of mass energy, for point like (solid line) and resolved (dotted line) contributions. The resolved contribution has been re-scaled by a factor 9.6 in order to compare the shape with the point-like contribution.

ble I where a difference of $\sim$ 82% is observed for the Peterson fragmentation function.

As an attempt to understand the behavior of those asymmetries, we calculate the total charm cross section, the resolved plus the point-like contributions. Figure 5 shows the cross section as a function of the center of mass energy where the resolved component to charm production has been rescaled to compare the shape with the point like contribution to charm production. We can see a different behavior with the energy. The point-like contribution increases almost linearly when the energy increases, whereas the resolved cross section does not. These results explain the behavior of the asymmetry when the photon energy in the interaction increases. The resolved part shows an inflexion point about 30 GeV, which could be due to the different dependences on the energy of the point-like and the resolved photon component of the cross section [3, 16].

Since the experiment E831 at FNAL [19] used a beam energy of the same order as experiment E687, we do not expect a significant change in the predicted asymmetry shown here.

5. Conclusions

Heavy meson in photoproduction arising from the resolved component of the photon has been calculated. The results of the resolved component show important contributions to the cross section giving a large production asymmetry of meson anti-mesons. These asymmetries have a strong dependence on the fragmentation function. Quantification of the asymmetries for a set of PDFs and three different fragmentation functions for D and B mesons, were presented. The numerical values are larger for B than D mesons. Another effect on the asymmetry comes from the uncertainties of the PDFs which are manifested in a large difference on the asymmetries. Nevertheless, when the cross section is calculated taking into account that the resolved component contributes 4% and the point-like 96%, to the total cross section, the first one seems to vanish and consequently the production asymmetries from the total cross section are small. The point-like and the resolved component present slight differences with the collision energy, indicating a weak asymmetry dependence on the energy. We show a clear difference of the behavior of the point-like and resolved cross section components as a function of the energy.

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