national accelerator laboratory

NAL-THY-72
July 1972

HEAVY VECTOR MESON PRODUCTION IN A FIREBALL MODEL*

B. MARGOLIS †‡
National Accelerator Laboratory
P. O. Box 500, Batavia, Illinois 60510

and

W. J. MEGGS ‡
Physics Department, McGill University,
Montreal 101, Quebec, Canada

ABSTRACT

The production of heavy vector mesons is calculated in a diffractive fireball model. The heavy vector meson spectrum resembles the spectrum of muon pairs measured in a recent Brookhaven experiment.

---

† Visiting Scientist from McGill University

‡ Supported in part by the National Research Council of Canada and the Quebec Department of Education.

* Submitted to XVI International Conference on High Energy Physics, Chicago, September 6 - 13, 1972.

We address ourselves to calculating the rate of production of heavy vector mesons in p - p interaction here. The model used assumes diffractive production of a single fireball is dominant for this process. The statistical bootstrap model of Frautschi[1] is then invoked to get the branching ratio for the fireball to emit the heavy vector mesons. The resulting spectrum of heavy vector mesons resembles closely the spectrum of μ pairs seen in a recent experiment at Brookhaven.[2] This suggests that the muon pairs couple to the heavy vector meson in a fashion not very dependent on the mass of the mesons.

We write the cross section for production of a fireball of mass M in the reaction

$$p + p \to M + p \tag{1}$$

as $d\sigma/dM$, independent of energy, as diffraction implies. Consider the decay of the fireball of mass M into a fireball of mass m plus anything (x).

$$M \to m + x \tag{2}$$

The branching ratio for such a decay according to the statistical bootstrap model is given by the relative weight of states of mass m in the density of states $\rho(M)$ given by[1]

$$\rho(M) \simeq \frac{A}{M^3}\, e^{M/m_\pi} \simeq \sum_{n=2}^{\infty} \frac{V^{n-1}}{n!} \int \prod_{i=1}^{n} \rho(m_i)\, dm_i \times \int d^3p_i\, \delta^3\!\left(\Sigma \vec{p}_i\right) \delta\!\left(M - \sum_i^n E_i\right) \tag{3}$$

Here V is the volume of the hadronic matter, $E_i = \sqrt{\vec{p}_i^{\,2} + m_i^2}$ and the m_i, the mass of the hadronic constituents, range from the pion mass to maximum values given by $\Sigma m_i = M$.

We have extracted from the right side of (3) the component of some mass m_1 in various approximations. We find that the spectral shape for m_1 production remains essentially unchanged from the term corresponding to $n = 2$.

This term in ratio to the total hadronic density of states is given by[3]

$$F(M,m_1) = V\frac{\rho(m_1)}{\rho(M)}\int dm_2\,\rho(m_2)\int d^3p_1\,d^3p_2\;\delta^3(\vec{p}_1+\vec{p}_2)\,\delta(E_1+E_2-M) \tag{4}$$

We now note that if m_1 is a vector particle of mass m_v the corresponding level density is given by[3]

$$\rho_v(m_v) \simeq \frac{A_v}{m_v^{9/2}}\,e^{m_v/m_\pi} \tag{5}$$

It follows using (4) and (5) that the quantity analogous to (4) for vector mesons is

$$F_v(M,m_v) = \frac{\pi V}{2}\,\frac{\rho_v(m_v)}{\rho(M)}\int_{m_p}^{\sqrt{s}-m_p-m_v} dm_2\,\rho(m_2)\,\lambda^{1/2}(M^2,m_v^2,m_2^2)\left[\frac{M^4-(m_v^2-m_2^2)^2}{M^4}\right] \tag{6}$$

where $\lambda(x^2,y^2,z^2) = x^4+y^4+z^4-2x^2y^2-2y^2z^2-2z^2x^2$.

We can now write down the cross section for producing vector mesons of mass m_v as

$$\frac{d\sigma}{dm_v} \simeq \text{Const.} \times \int_{m_p+m_v}^{\sqrt{s}-m_p} \frac{d\sigma(M)}{dM} F_v(M,m_v)\, dM \qquad (7)$$

The calculated results using formula (7) are shown in Fig. 1. We have taken $\frac{d\sigma(M)}{dM} \propto \frac{1}{M^2}$.[4,5] The cross section is normalized to the measured cross section for μ- pair production[2] which is also shown in Fig. 1. One readily estimates that (7) is larger than the μ

pair cross section by the order of the inverse fine structure constant squared, $(e^2/\hbar c)^{-2}$. The measured μ-pair cross section $d\sigma/dm_{\mu^+\mu^-}$ is seen to be very similar in shape to (7). This suggests that the vector mesons couple to the μ-pairs in a fashion which is not very mass dependent.

If one neglects momentum conservation in the statistical bootstrap Eq.(6)one readily shows that to all orders

$$F_v(M,m_v) \simeq \frac{\rho_v(m_v)\,\rho(M-m_v)}{\rho(M)} \qquad (8)$$

which is to be compared with Eq. (6). The form for $d\sigma/dm_v$ resulting from this approximation is also shown in Fig. 1 and agrees closely with that obtained using Eq. (6).

We comment now on the spectral shape of $d\sigma/dm_v$ as a function of m_v. The rapid fall at the low mass end of the spectrum is the result of the $1/m_V^{9/2}$ factor in the density of hadronic states of a given spin.[3] The shoulder near the high mass limit follows from additional weaker m_V dependence in (6) and (8). The rapid drop at the high mass end is the result of the limit on m_V imposed by kinematics.

We see from the above that using the statistical bootstrap model we can calculate yields of heavy hadron production with no parameters other than overall normalization, which in principle can also be determined provided one knows the relative frequency of one fireball production. Distributions in rapidity, momentum transfer or other variables can be calculated by the usual methods.[6]

REFERENCES

[1] S. Frautschi, Phys. Rev. D3, 2821 (1971).

[2] J.H. Christenson, G.S. Hicks, L.M. Lederman, P.J. Limon, B.G. Pope and E. Zavattini , Phys. Rev. Lett. 25, 1523 (1970).

[3] C.B. Chiu and R.L. Heimann, Phys. Rev. D4, 3184 (1971).

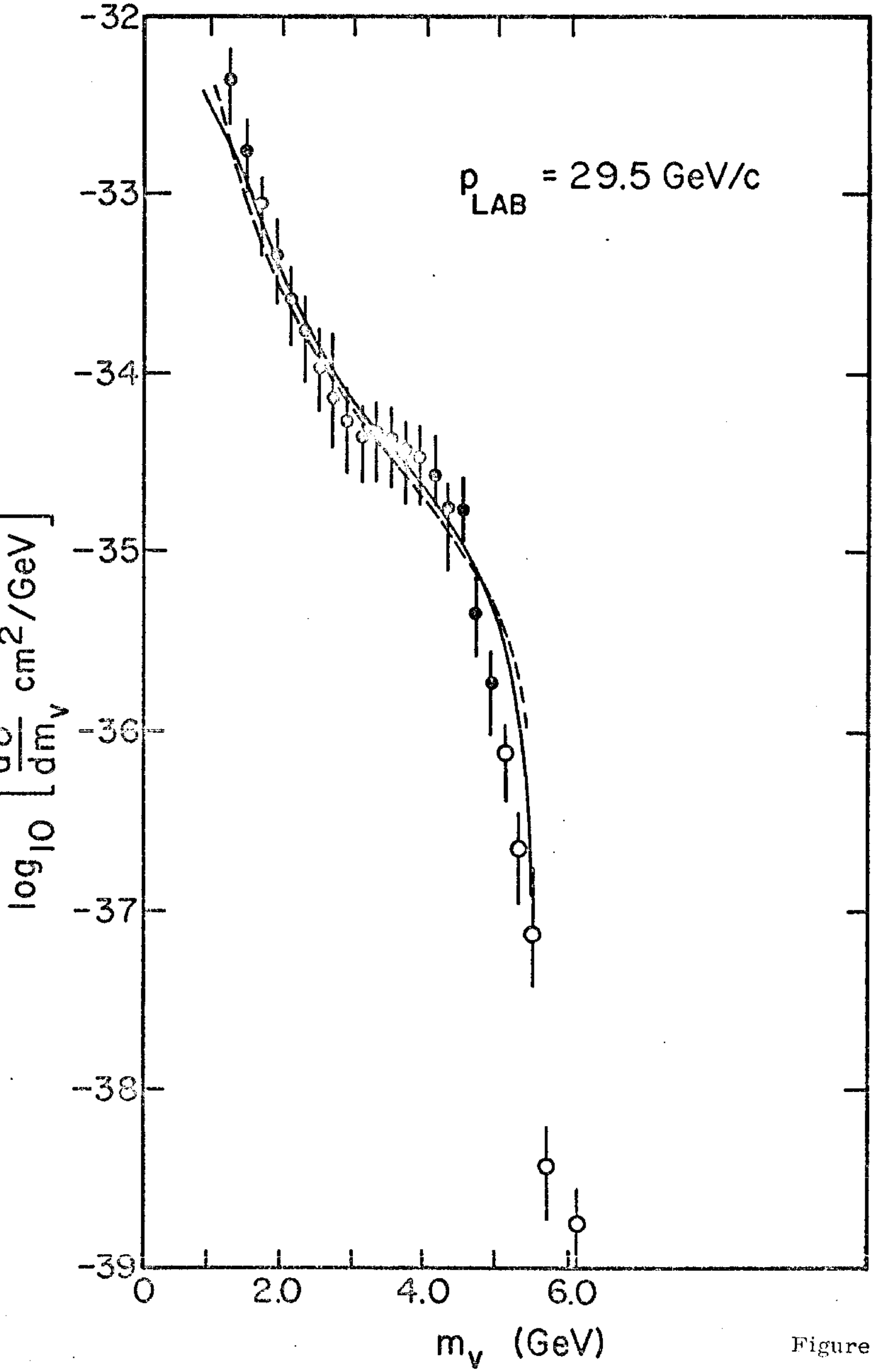
[4] A. Mueller, Phys. Rev. D2, 2963 (1970).

[5] R.C. Hwa, Phys. Rev. Lett. 26, 1143 (1971).

[6] M. Jacob and R. Slansky, Phys. Lett. 37B, 408 (1971).

FIGURE CAPTION

Figure 1: Theoretical spectra for heavy vector meson production $\frac{d\sigma}{dm_V}$ using (6) ———, and (8) ----. Also plotted are experimental results for $d\sigma/dm_{\mu^+\mu^-}$ from Ref. 2. The theoretical calculations are normalized to the experimental results for producing muon pairs. The open circles correspond to wide angle μ-pair data.



p_{LAB} = 29.5 GeV/c
$\log_{10}\left[\frac{d\sigma}{dm_V}\ cm^2/GeV\right]$
-32
-33
-34
-35
-36
-37
-38
-39
0
2.0
4.0
6.0
m_V (GeV)

Figure 1