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MASTER

MASS RESOLUTION FOR LEPTON PAIRS AT ISABELLE *

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Experiments measuring e^+e^- and $\mu^+\mu^-$ pairs will be the principal way of searching at ISABELLE for the Z^o and for vector mesons made from new heavy quark-antiquark ($Q\bar{Q}$) pairs. Although the best possible mass resolution is clearly of benefit in such experiments, excessive resolution would lead to an unnecessarily large detector. We believe that a mass resolution of a few percent is appropriate in searching both for the Z^o and for new $Q\bar{Q}$ states. However, there are some interesting experiments which would require much better mass resolution, of order ½% FWHM.

Z^o PRODUCTION

The Z^o cross section is estimated to be about three orders of magnitude larger than the Drell-Yan continuum.[1] Since the Z^o has a width which is about 1% of its mass, any reasonable mass resolution is adequate in looking for it.

A direct measurement of the Z^o width would be of great interest. In the parton model this width is given by

$$\Gamma_Z = [3 \sum_q (a_q^2 + b_q^2) + \sum_\ell (a_\ell^2 + b_\ell^2)] \frac{GM_Z^3}{24\pi\sqrt{2}}$$

where $a_{q,\ell}$ and $b_{q,\ell}$ are the vector and axial couplings, and the sum is over all quarks and leptons lighter than $\frac{1}{2}M_Z$. That is, Γ_Z measures the sum of the squares of the weak charges, just as

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

measures the sum of the squares of the electromagnetic charges. In the Weinberg model for 6 quarks and 6 leptons with $\sin^2\theta_W = 0.25$,

$$\Gamma_Z = 1.09 \text{ GeV} \quad \text{and} \quad M_Z = 87.8 \text{ GeV} .$$

Adding one additional neutral lepton would change Γ_Z by

$$\Delta\Gamma = 0.07 \text{ GeV}.$$

A quantitive measurement of Γ_Z would require a mass resolution several times smaller than Γ_Z/M_Z , or

$$\Delta M/M \sim ½\% \text{ (FWHM)} .$$

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$Q\bar{Q}$ PRODUCTION

Production of a vector meson V made from a heavy $Q\bar{Q}$ pair is less well understood than Z^0 production. As a guide we adopt the scaling hypothesis of Gaisser, Halzen, and Paschos,[2]

$$\frac{d\sigma_V}{dx} = \frac{\Gamma_V}{M_V^3} F\left(\frac{s}{M_V^2}, x\right)$$

where F is a universal function. This is plausible if one imagines that the vector meson couples through gluons to some constituents of the proton; the factor Γ_V measures the strength of the coupling. From this hypothesis the lepton pair cross section is

$$B_V \left.\frac{d\sigma_V}{dy}\right|_{y=0} = \frac{\Gamma_{V,ee}}{\Gamma_{\psi,ee}} B_\psi \left.\frac{d\sigma_\psi}{dy}\right|_{y=0} .$$

(Note, however, that the BCSY experiment indicates that the Υ cross section increases faster than this.[3])

Besides an obvious dependence on the quark charge, $\Gamma_{V,ee}$ depends on the quark mass in the model dependent way. Gaisser et al. assume

$$\Gamma_{V,ee} = \text{constant} .$$

Quigg and Rosner[4] suggest a nonrelativistic potential model with a logarithmic potential, in which

$$\Gamma_{V,ee} \propto 1/\sqrt{M_V} .$$

Taking these as typical possibilities and using data on J/ψ production from the CP,[5] CFS,[6] and BCSY[7] groups, we obtain the cross section estimates shown in Fig. 1. For charge 1/3 quarks these should be reduced by a factor of $\frac{1}{4}$. However, for the higher masses the 1/r potential from one gluon exchange should become dominant, leading to

$$\Gamma_{V,ee} \propto M_V$$

and thus larger cross sections.

It seems reasonable to contemplate an experiment running for 1000 h at a luminosity of 10^{33} cm^{-2} sec^{-1}. Then, if the backgrounds are small enough, resonances with masses of order 100 GeV would be observable.

Given a Gaussian resolution with a FWHM of ΔM, the peak of the resonance cross section is

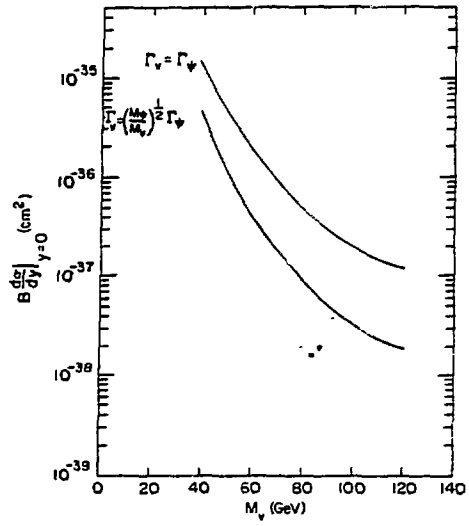

Fig. 1. Estimated cross sections for $Q\bar{Q}$ vector mesons vs meson mass.

$$B \frac{d\sigma}{dMdy}\Big|_{y=0} = 2\sqrt{\frac{\log 2}{\pi}} \frac{1}{\Delta M} B \frac{d\sigma}{dy}\Big|_{y=0} .$$

Taking $Bd\sigma/dy$ from Fig. 1, we plot the envelope of the resonance peaks in Fig. 2 for $\Delta M/M = 2\%$ together with the Drell-Yan continuum. Again the resonance cross sections should be reduced by a factor of ½ for charge 1/3 quarks. Since we do not expect $\Gamma_{V,ee}$ to fall as $1/\sqrt{M_V}$ up to $M_V \sim 100$ GeV, it appears likely that any resonance peaks will be substantially above the Drell-Yan background. The search for high-mass states would then be limited by counting rate and not by mass resolution. Since the model is rather uncertain, however, one would not want to make the mass resolution much worse than 2%.

The Υ is observed to be split into at least two peaks, presumably the ground state and its first radial excitation, with the same splitting as the ψ and ψ'. A constant splitting is predicted by the logarithmic potential model and indeed is the main motivation for it. Poggio and Schnitzer[8] have suggested a model with more dynamical content in which the splittings for $Q\bar{Q}$ systems heavier than the Υ would first decrease with mass but eventually would increase as one gluon exchange became dominant. Furthermore, Gottfried[9] has argued on the basis of a multipole expansion of the gluon field that the cascade decay rate between an excited $^3S_1$ state and the ground state should decrease as M_Q^{-2} so that, while it is large for $\psi' \to \psi\pi\pi$, it is small for $\Upsilon' \to \Upsilon\pi\pi$ and all heavier

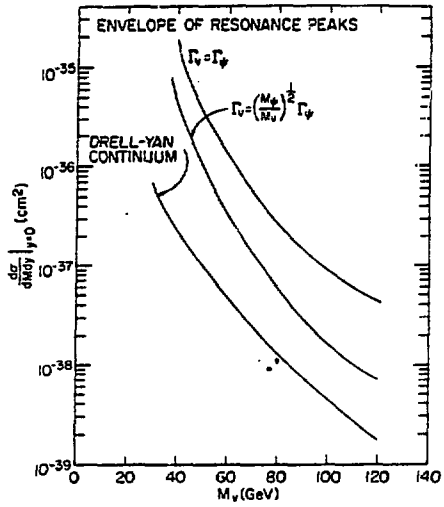

Fig. 2. Envelope of resonance peaks for $Q\bar{Q}$ vector mesons with $\Delta M/M = 2\%$.

systems. Thus one may need to resolve a splitting of order 600 MeV in a 50-GeV $Q\bar{Q}$ system. Like a measurement of the Z^o width, this would require a mass resolution of order ¼%.

EXPERIMENTAL IMPLICATIONS

To get ¼% mass resolution for a 100-GeV particle decaying into two leptons back-to-back in the lab, one has to measure a 50-GeV muon or electron with $\Delta p/p$ of $\sim 1/3\%$. In a large-solid-angle detector using a solenoid magnet, for example, for 100-μm spatial resolution one needs a 9-m-diameter solenoid with a 20-kG field. This seems like quite a large device. Another solution might be a two-arm spectrometer, in which one would need 4-m lever arms with a bending magnet having a 1-GeV transverse momentum kick. This is not unreasonable except that the solid angle would be very small.

One possible strategy might be to start with a spectrometer having a 1 to 2% mass resolution. Such a device should be designed, if possible, in such a way that the mass resolution can be improved by an order of magnitude if heavy vector mesons or a Z^o are discovered and their production cross sections are measured.

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