Searching for Exotic Mesons - E852

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The universe as we know it consists of three types of particles: leptons, hadrons, and mediators. Leptons are considered elementary point particles and do not participate in the strong interaction. The mediators are also considered to be elementary particles of which only the gluon interacts strongly. The hadrons, however, are composite particles formed by combinations of particles called quarks. One subclass of hadrons is baryons which are composed of 3 quarks (qqq) held together by the strong interaction. All other allowed particles which are composed of quarks are called mesons. They are classified by a baryon number zero.

The typical meson, of which dozens have been seen and identified experimentally, is formed by a quark/anti-quark ($q\overline{q}$) combination. For the $q\overline{q}$ state the main quantum numbers can have only certain values, such as charge ($Q = 0, \pm 1$), strangeness ($S = 0, \pm 1$), or isospin ($I = 0, 1/2, 1$). The quark spins can only combine to give a meson spin of 0 or 1. Since the total angular momentum (J) is the vector sum of the spin (S) and orbital angular momentum (L) any value of $\vec{J} = \vec{L} + \vec{S}$ is allowed. However, since $P = (-1)^{L+1}$ and $C = (-1)^{L+S}$ there are only certain J^{PC} which are allowed.

Any meson which is not formed by a $q\overline{q}$ state is termed an exotic. The theory of the strong interaction, Quantum Chromodynamics (QCD), predicts the existence of several types of exotics. The first type is a meson molecule or diquonium which consists of a $q\overline{q}q\overline{q}$ state. The second type is a hybrid formed by a quark/anti-quark with a valence gluon, $q\overline{q}g$. The third type is two or three gluons forming a bound state. These are termed glueballs. Many theorists make predictions about the properties of these exotics.(1) However, it is left to the experimentalists to find these particles and their properties.

Experimentally, exotics can be broken down into three important types.(2) Using the classifaction of Close and Landsburg, they are: 1) Exotics of the first kind have exotic main quantum numbers $|Q|, |S|, or I > 1$; 2) Exotics of the second kind which have J^{PC} combinations not allowed for $q\overline{q}$ states, for example $1^{-+}, 0^{--}$; 3) Exotics of the third kind which have no exotic quantum numbers but which belong to meson nonets which are already filled.

While the theories which predict exotic properties do not agree exactly, they do indicate that the meson spectrum for 1-3 GeV/c^2 should contain exotics. Several searches in this region have been carried out and are under way at this time. No candidates of the first kind have been identified. There is one strong candidate of the second kind, the M(1405), a 1^{-+} meson. There are many candidates of the third kind which may or may not be $q\overline{q}$ states.

The M(1405) and many others of these states have been seen by the GAMS collaboration. GAMS looked at all neutral final states in the reaction $\pi^- p \rightarrow XN$ with 38 GeV/c and 100 GeV/c pions incident on a proton producing a meson resonance (X) and a nucleon (N). One channel which they have studied is X$\rightarrow \omega\omega \rightarrow \pi^o\gamma\pi^o\gamma \rightarrow 6\gamma$. In this spectrum they identified the $f_4(2050)$ (already discovered), the X(1640) and the X(1920).(3)(4) The latter two are previously unseen states. Their analysis leads to claims of $J^{PC} = 2^{++}$ for both states. This means they might possibly be classified as exotics of the third kind even though GAMS makes no such claims.

The E852 collaboration, which will investigate the $\pi^- p \rightarrow XN$ reaction for 18 GeV/c pions at Brookhaven National Laboratory with the Multi-Particle Spectrometer (MPS), plans an improved experiment(5) (see figure 1). By combining the existing MPS charged particle tracking capabilities with some upgrades including a large electromagnetic calorimeter, E852 will be able to investigate not only all neutral final states, but also charged and neutral final states. The E852 tracking system will consist of a cylindrical drift chamber surrounding the target for recoil protons, 3 sets of proportional chambers and 7 sets of drift chambers. It also includes several detectors for triggering and vetoing which include a CsI(Tl) barrel for soft photon detection, CPV for charged particle identification and DEA for solid angle coverage. The electromagnetic calorimeter is a 3053 element lead glass hodoscope for neutral particles.

The E852 experiment should be able to explore the $X \to \omega\omega$ channel much better than GAMS. Since the cross-section is proportional to $1/\mathrm{p}_{lab}^2$ the production rate will be much higher. The $\omega \to \pi\gamma \to 3\gamma$ branching ratio is only 8.5%. E852 will also be able to see the $\omega \to \pi^+\pi^-\pi^o \to \pi^+\pi^-\gamma\gamma$ (BR=88.8%) channel which should increase the statistics by at least an order of magnitude. By analyzing the 6γ, 2 charge track/5γ and possibly the 4 charged track/4γ data sets it will be possible to further identify and/or verify the particles and their properties seen previously by GAMS and other experiments. The spectrum can also be scanned for any additional resonances.

Because most of the current exotic theories predict the 2^{++} glueball state to be one of the lower mass states it is very important to classify as many of the 2^{++} mesons as possible. So while one explanation of the X(1640) and X(1920) mesons is as radial excitations of the $\mathrm{f}_2(1270)$ this must be determined. A casual scan of the 2^{++} mesons seems to yield an overabundance. It is quite possible that the 2^{++} glueball has already been discovered, but has yet to be identified as such. Therefore the X(1640) and X(1920) states should be further studied along with any other states which may be found in the $X \to \omega\omega$ channel.

References

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