Low-Lying penta-quarks and their small widths

S. Nussinov

Introduction

- Recently, there has been a surge of activity in hadronic spectroscopy and the D(s) 2316 0(+) state discovered at babar may complete the list of four cs[bar] states expected in the quark model.

- It is, however, possible that this state is Crypto-exotic" containing as Jaffe first suggested for the f,a (980) 0(+) an extra uu[bar]+dd[bar] pair.

- This is certainly the case for the narrow resonance decaying into J/psi+Pi(+)Pi(-) claimed by Belle.

Penta-Quark Mass

- The focus of the present workshop is the explicit exotic penta quark s[bar]uudd Theta(+) 1540, discovered in photo induced processes and other reactions.

- The lightness of the penta-quark while somewhat surprising can conceivably be accounted for by favorable hyperfine interactions in correlated subsystems: the color 3[bar] ud I=0 S=0 diquarks suggested by Jaffe and Wilczeck [JW] and by me [N] and the uds[bar] 3 of color emphasized by Karliner and Lipkin [KL]. Also the Chiral Soliton model motivated the light Penta-quark {and the anti-decuplet} in the first place.

Penta-Quark Width

- The issue of the width of the Theta(+) 1540 is rather different.

- The value of the width is still unknown. Indirect bounds on this width of O(1-4 MeV) [N] [ASW] [Tri] follow from the lack of an enhancement - albeit broadened by the Fermi motion - in old K(+)-d total cross section data.

- Such a SMALL width may be problematic on several counts
  .

Problem of Penta-Quark Width

- First it may be difficult to explain theoretically. {It inspired [CPR] the extreme, unlikely, suggestion that the penta-quark is an isotensor so that the decay into KN channels is forbidden by iso-spin}.

- Second if the cross sections for penta-quark photo-production can be approximated via K exchange, much larger widths are suggested.

- Only SAPHIR has published cross sections . Yet we argue [CN] that KN invariant mass plots where a penta-quark signal is evident strongly suggest widths of order 5-15 MeV.

- The argument which is just the converse of that used in establishing the upper bounds above is straightforward: Once a K exchange model is adopted the number of events in the "penta-quark enhancement" above a smooth "background" is proportional to the known Breit-Wigner resonant KN cross section (34 mb) times the Theta width.

Problem of Penta-Quark Width Cont'd

- Likewise the number of the "background" events is proportional to the known non-resonant Kn cross section ~12 mb times the rather broad window ~(20-40) MeV where the enhancement is seen. The large ratio ~1/1 or 1/2 of resonance-to-background events yields the above high width estimates.
- Footnote:

  No such lower bounds on the width follow from the complete, uncut m(K-N) distribution where the theta signal is hardly evident. Cuts enhancing the resonance relative to the background could, in principle, avoid these bounds (V. Kubarovsky recent private communication). This need not be the case . Thus, consider the Theta K* final state where where cuts on the Φ(1020) KK(bar] and Δ(1238) have been applied. Since the K exchange is not contributing much to the latter processes the cuts may equally enhance the K exchange part and the ratio of resonance/background events is not modified.

Future Steps

- Thus, it is of the greatest importance to ESTABLISH the Theta(1540) signal in the K-deuteron channel . Planned high precision photo-induced experiments may measure a few MeV width. Yet due to the much larger hadronic cross-sections, low-energy K beam (at BNL?) -deuteron reactions could reveal even sub-MeV widths.
- Let us assume that future experiments will corroborate a VERY < O(MeV) narrow Theta. This seems most unlikely for a generic multi-quark cluster and suggests [GN,CN} that the Penta-quark (and the Cascade(--)!) may belong to a novel family of "Topologically" excited hadrons with extra "Junction" points. These arise in a "flux tube" or string picture of hadrons where the chromo-electric fields are confined to relatively narrow flux tubes.

Topologically Excited Hadrons

- In this model the baryon has a "Y" structure- with the three relatively narrow chromo-electric flux tubes emanating from the three quarks join at a single junction, a picture supported by lattice calculations with static quarks.

- The next in junction # hierarchy are the "Tetra-quarks". These are mesons made of two quarks, say sd, which join into the 3[bar] diquark and two anti-quarks, say u[bar]s[bar], coupled into a 3 of color "anti-diquark" and altogether make a color singlet hadron, say the a(980).
-

  The corresponding flux tube picture with one junction and one anti-junction is: >--< . The two quarks/anti-quarks are (say) at the left most/right most two "Tips".

Topological Penta-Quark Model

- The penta-quark has three junctions one for each of the ud diquarks and one connecting the two diquarks and the s[bar] to the complete color singlet "anti-baryon like" hadron.

- The longevity of the Theta is related to the need of annihilating one of the junctions with the anti-junction - a process that is impeded by the l=1 centrifugal barrier existing in this system.

Penta-Quark Production

- The production of the penta-quark may well be "associated“, namely in gamma-proton collisions it may tend to emerge with an su--u[bar]d[bar] Tetra-quark.

- We note that the Schwinger mechanism for "Lund Model" type multi-particle production in a single jet leads naturally to the production of mesons : baryons : Tetraquarks : penta-quarks ~1 ; a: a^2 : a^3 with each higher order exotic being suppressed by powers of a small quantity a.