

# QCD Spectroscopy, Structure, and Dynamics

*Parallel Session Summary for CIPANP 2003*

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**Abstract.** We summarize the parallel sessions on QCD Spectroscopy, Structure, and Dynamics, for the 2003 Conference on the Intersections of Particle and Nuclear Physics, held in New York City, 19-24 May 2003.

## OVERVIEW

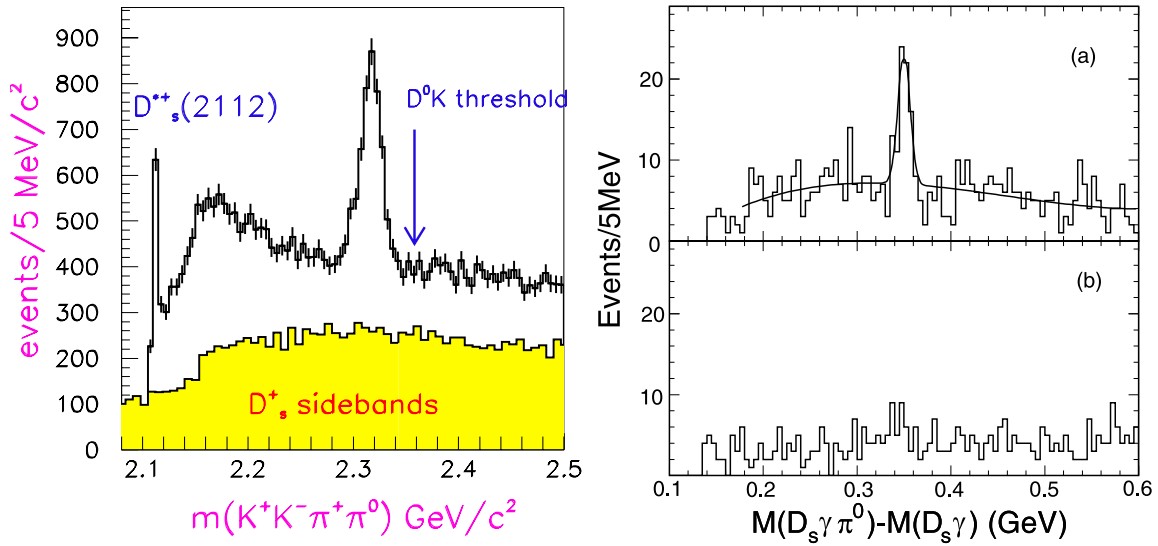
The parallel program on QCD Spectroscopy, Structure, and Dynamics for CIPANP03 covered six sessions, each about 100 minutes long. There were thirty presentations, most of which were contributed. Nineteen presentations were mostly concerned with experiment, while eleven were theoretical. We heard lots of exciting, new developments. It is unfortunate that we couldn't cover them all in the summary presentation or in this contribution to the proceedings, given time and page constraints.

This summary highlights only a few of the presentations. In all cases, refer to the other contributions to these proceedings for details, including references.

## NEW NARROW STATES

Several new, narrow states were presented in these sessions. Just prior to the conference, BaBAR announced the discovery of a new meson decaying to  $D_s\pi^0$ . This discovery was quickly confirmed by CLEO, who went further and identified a second narrow state decaying to  $D_s^*\pi^0$ . Both results were confirmed by BELLE. These results were covered in talks by Ray Cowan, Jon Urheim, and Tom Browder, representing BaBAR, CLEO, and BELLE respectively. Possibly related to these new meson states are new doubly charmed baryons, discovered by SELEX and presented by Peter Cooper. Ken Hicks and Stepan Stepanyan showed tantalizing evidence for a new pentaquark baryon  $\Theta^+(1540)$ .

The signals for the new mesons are shown in Fig. 1. These mesons decay via isospin violation to  $D_s\pi^0$  and  $D_s^*\pi^0$  respectively, and this leads to their narrow widths. The  $D_{sJ}^*(2317)$  lies just below the  $DK$  threshold. The  $D_{sJ}^*(2463)$  lies just below  $D^*K$  threshold, and does not decay to  $DK$  presumably because it has unnatural parity. This leads one



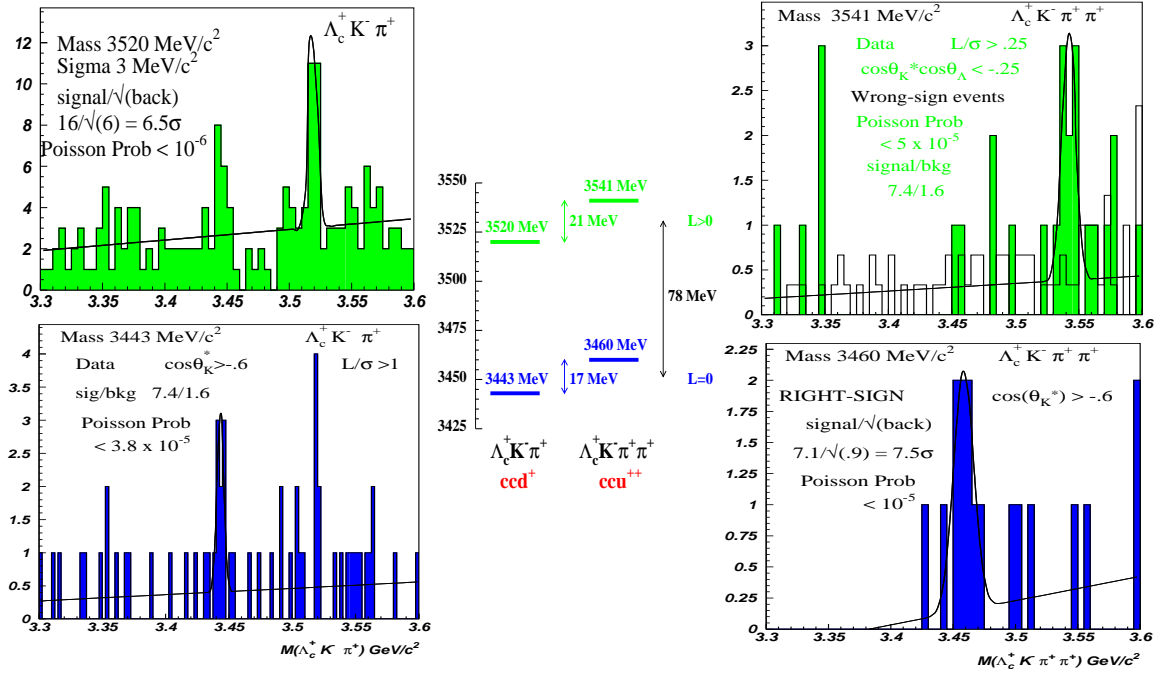
**FIGURE 1.** Observations of new narrow mesons with charm and strangeness, from BaBAR and CLEO. See talks by Ray Cowan and Jon Urheim respectively. On the left (from BaBAR) is the  $K^+K^-\pi^+\pi^0$  mass for  $D_s \rightarrow K^+K^-\pi^+$  and for the  $D_s$  sidebands. In addition to the well known  $D_s^*(2112)$ , a new state  $D_{sJ}^*(2317)$  is observed. The right plot (from CLEO) shows the  $D_s\gamma\pi^0$  mass for  $D_s^*(2112) \rightarrow D_s\gamma$  (a) and in the  $D_s^*(2112)$  sidebands (b). A second new state appears, the  $D_{sJ}^*(2463)$ .

to view the two new states as  $0^+$  and  $1^+$  “partners” of the  $D_s$  and  $D_s^*$ . Indeed, their mass difference (146 MeV) is very close to the  $D_s/D_s^*$  mass difference (142 MeV). (In fact, this leads to a potentially serious false  $D_{sJ}^*(2463)$  signal, but CLEO investigated this in detail and concludes that such contamination cannot account for their observations.)

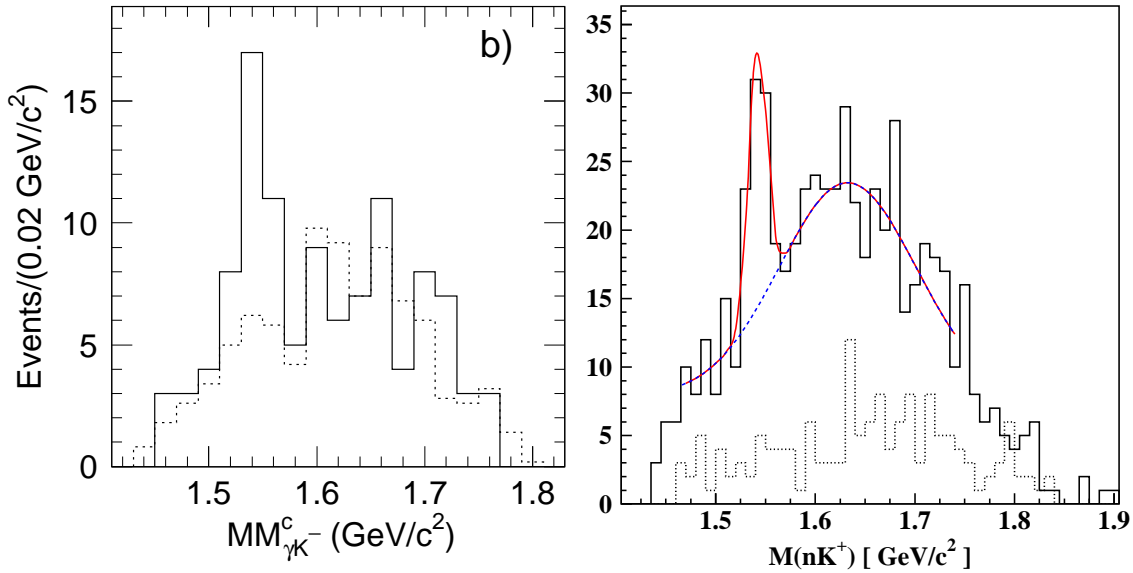
A variety of explanations for these states have been put forth. Harry Lipkin argued that they are  $DK$  and  $D^*K$  “molecular” states. A different explanation, from Bardeen, Eichten, and Hill (BEH), argues that the “partners” are required by an implementation of  $SU(3)_L \times SU(3)_R$  chiral symmetry in heavy-light quark systems.

The BEH picture may also apply to new results from SELEX who observe “partners” of their previously reported doubly charmed baryons. (These states are naturally narrow since they cannot decay via the strong interaction.) Their results are summarized in Fig. 2. In Heavy Quark Effective Theory, the  $cc$  combination is equivalent to a heavy antiquark, so far as the symmetry is concerned, so these baryons behave like heavy/light  $Q\bar{q}$  mesons, similar to the  $D_{sJ}$  system. The 78 MeV splitting in this case would not be the chromomagnetic fine structure splitting computed in potential models because the upper states also decay weakly, rather than by an  $M1$  photon. The experimenters have some evidence that the splitting may be due to orbital angular momentum in the  $cc$  system.

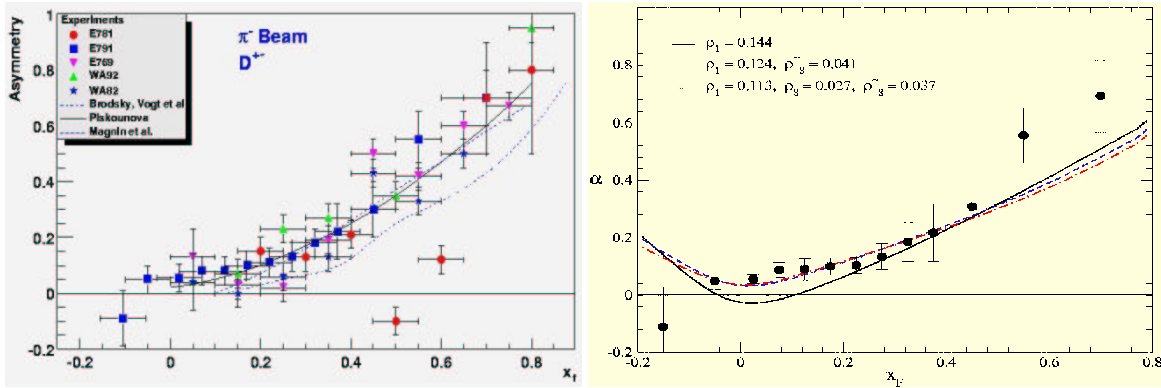
A different, but probably unrelated, observation of a new narrow state  $\Theta^+(1540)$  was reported by Ken Hicks for the SPRing-8 collaboration, with corroborating evidence given by Stepan Stepanyan for the CLAS collaboration, both using the reaction  $\gamma n \rightarrow \Theta^+K^-$ . This state, which decays  $\Theta^+ \rightarrow nK^+$ , is noteworthy because it implies  $uudd\bar{s}$ , i.e. “pentaquark”, degrees of freedom. The signals are shown in Fig. 3. Backgrounds are from competing reactions, in particular  $\gamma p \rightarrow \Lambda(1520)K^+$  on protons in the nuclear target. Work is ongoing in the collaborations, and new results should be available shortly.



**FIGURE 2.** New results from SELEX on doubly charmed baryons, as reported by Peter Cooper. A pair of isodoublets is suggested, where in both the  $ccd$  and  $ccu$  cases, the first orbital excitation is at  $\sim 78 \text{ MeV}$ . This may be consistent with the chiral symmetry mechanism put forth by Bardeen, Eichten, and Hill.



**FIGURE 3.** Evidence for the “pentaquark”  $\Theta^+(1540)$  from the SPRing-8 collaboration (left), presented by Ken Hicks, and from the CLAS collaboration (right), presented by Stepan Stepanyan. In both cases, the signal for  $\Theta^+ \rightarrow nK^+$  is derived from  $\gamma n$  interactions. Backgrounds are determined by interactions with a hydrogen target (SPRing-8) and from events associated with  $\Lambda(1520) \rightarrow pK^-$  production (CLAS).



**FIGURE 4.** Data, presented by Maurizio Iori, and calculations by Tom Mehen on a Heavy Quark Recombination description of charm production dynamics. Plotted here is the  $D^\pm$  asymmetry in the reaction  $\pi^- p \rightarrow D^\pm X$  as a function of Feynman  $x$  from a variety of experiments, with a subset compared to the HQR prediction.

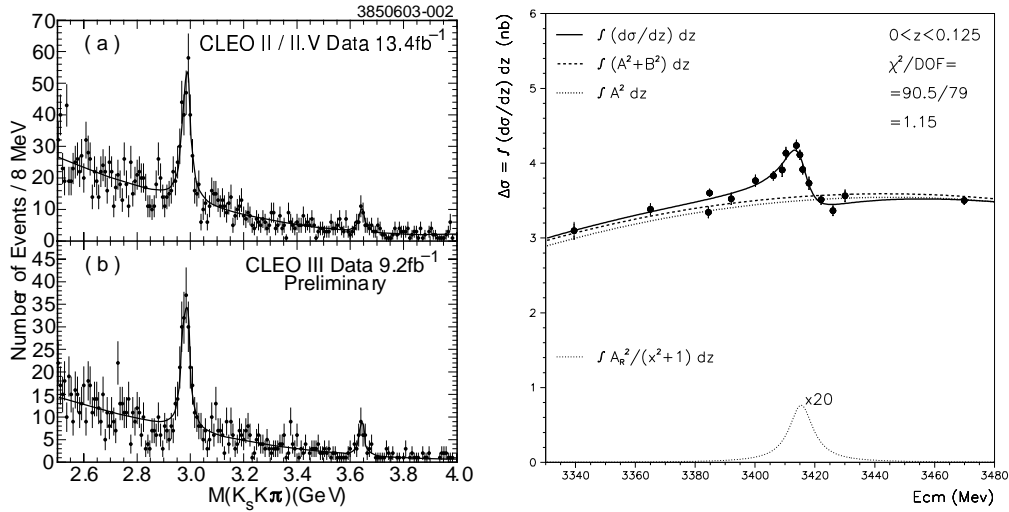
## HEAVY QUARK DYNAMICS

Maurizio Iori and Erik Gottschalk gave us detailed summaries of heavy quark production data from hadro- and photo-production reactions, respectively. Figure 4 shows the inclusive  $\pi^- p$  production asymmetry  $\alpha \equiv [D^- - D^+]/[D^- + D^+]$  from a variety of experiments, along with a prediction by Tom Mehen, based on Heavy Quark Recombination (HQR) theory. Not only is the agreement quite good, but unlike Monte Carlo simulations such as PYTHIA, HQR attempts a more fundamental calculation from QCD. This calculation is based on an expansion in  $\Lambda_{\text{QCD}}/m_c$ , and leads to a more economical description of this phenomenon.

## CHARMONIUM SPECTROSCOPY

New data on two  $c\bar{c}$  states were also presented, summarized in Fig. 5. As part of a detailed review talk on two photon physics, David Uner showed results from CLEO on the long sought after  $\eta'_c$ . Produced through  $\gamma\gamma \rightarrow \eta'_c \rightarrow K_S K^\pm \pi^\mp$ , a signal appears above background with a (preliminary) mass of  $3642.7 \pm 4.0$  MeV, in fair agreement with earlier measurements. This process is also observed by BaBAR.

Jerry Rosen, representing FNAL E835, showed data on the reaction  $\bar{p}p \rightarrow \pi^0\pi^0$  in the neighborhood of the  $\chi_{c0}(3415)$ . Although the resonant amplitude is much smaller than the nonresonant background, interference makes it possible to precisely extract parameters of the resonance using a partial wave expansion. (Also displayed in Fig. 5 is the fictional signal that would result if interference were not exploited, shown at 20 times its size.) E835 measurements significantly improve our knowledge of the basic  $\chi_{c0}$  parameters  $M$ ,  $\Gamma$ ,  $B(p\bar{p})$ ,  $B(J/\psi\gamma)$ ,  $B(\pi^0\pi^0)$ , and  $B(\eta\eta)$ . Seon-Hee Seo also presented E835 results, on a measurement of the relative helicity amplitude ratio in the reaction  $\bar{p}p \rightarrow \psi' \rightarrow e^+e^-$ .



**FIGURE 5.** Results on charmonium spectroscopy. On the left, from David Urner’s review of  $\gamma\gamma$  processes, is the observation of the  $\eta_c(2981)$  and the apparent discovery of the  $\eta'_c(3643)$ . On the right, data presented by Jerry Rosen, on an interferometric study of  $\bar{p}p \rightarrow \pi^0\pi^0$  yielding data on the  $\chi_{c0}(3415)$ .

## OTHER PRESENTATIONS

Curtis Meyer surveyed the status of mesons with exotic quantum numbers, including interpretations of  $\eta\pi$  and  $\eta'\pi$  signals. Gary Adams presented new results from BNL E852, and Mina Nozar showed work in progress on  $\gamma p \rightarrow 3\pi N$  at Jefferson Lab. Ryan Mitchell discussed a new state from FOCUS decaying to  $K^+K^-$  with mass 1750 MeV. Philip Page gave new results on selection rules for QCD exotic mesons.

Mats Selen summarized hadronic  $D$  decays, including  $D \rightarrow 3\pi$ . FNAL E791 requires an isoscalar, scalar  $\pi\pi$  component to fit this data, while CLEO sees no such term.

Rich Galik showed new results from CLEO on  $Y$  spectroscopy. This was complemented by Mikhail Voloshin who discussed the role of the axial anomaly in the  $Y(1D) \rightarrow \eta Y(1S)$  transition, and by Sean Fleming who presented calculations on  $Y$  continuum radiative decay.

Colin Morningstar reviewed lattice QCD, with emphasis on the baryon spectrum and emerging unquenched calculations. Matthew Bellis told us of new measurements on the (light quark) baryon spectrum using the reaction  $\gamma p \rightarrow p\pi^+\pi^-$  with CLAS.

Martin Olsson discussed reducing the QCD string to a time component vector potential. Dierdre Black gave us insight into the implementation of scalars in calculations of  $\eta \rightarrow 3\pi$ . Brett Van de Sande showed results on a transverse lattice treatment of QCD. Dan Pirjol and Boris Gelman discussed baryon spectroscopy calculated in large- $N_c$ .

## ACKNOWLEDGMENTS

Many thanks to all of our speakers and session convenors. We are also very grateful for all of the work of the conference organizers, especially Zohreh Parsa and Bill Marciano.