Recent Results in Meson Spectroscopy

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- Spectroscopy Intro and Background
- <u>Recent</u> Results:
 - Checkout what has happened in the charm system!
 - A few notes light quark states
- Prospects for Future Discovery

Note: Results presented here are only a small sampling of ongoing work. There are many other unmentioned recent results in meson spectroscopy.





- There has been long-standing interest in the search for hybrids and glueballs in our quest to understand the bound states of QCD.
- These states arise from the gluon-gluon interaction and are therefore seen as fundamental predictions of QCD.

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- In light quark (u,d,s) sector, states are broad and are difficult to resolve and "bump hunting" is not so successful -- need amplitude analysis
- Separation from conventional states is challenging, especially when states mix -- look for overpopulation of states or exotic quantum numbers
- Much info comes from older lower statistics experiments
- This has lead to a very murky picture of states below charm threshold, especially in the 1-3 GeV region despite 20+ years of pioneering experimental work
- Is there potential for a breakthrough? (Yes!)



A (2nd) Charm Revolution

- With high-statistics data samples at B factories (BaBar, Belle, and CLEO) we have seen discovery of many new states above open charm threshold (and a few conventional ones)
- Modern detectors exploring a somewhat lower energy region with high statistics
- Fascinating results: potential models do a decent job with heavy cc spectrum, but some new states are difficult to accommodate

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Production Mechanisms

- B Factories: e^+e^- at the $\Upsilon(4S)$
 - CM energy of about 10.5 GeV
 - Υ(4S)→BB (~100%)
- Several production mechanisms:
 - B decay
 - Direct $e^+e^- \rightarrow c\overline{c}$ Production
 - Initial State Radiation (ISR)
 - Two Photon Fusion





- Originally discovered by Belle in $B^+ \rightarrow X(3872)K^+$
 - X(3872)→J/ψпп
- Confirmed in the same channel by BaBar
- Observed in pp production at FNAL by CDF and D0
- <u>Extensive</u> subsequent studies to understand nature of this state!
- DD* molecule?





- While searching for X(3872) a state was observed in ISR production at BaBar and subsequently confirmed at CLEO also seen at Belle
- e⁺e⁻→Y(4260)→J/ψπ⁺π⁻
- All I⁻⁻ charm states in this mass region seem to be accounted for!





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X, Y, Z at Belle

- X(3940)
 - e⁺e⁻→J/ψX
 - $X \rightarrow D\overline{D}^*$ seems favored over $X \rightarrow D\overline{D}$
- Y(3940)
 - $B \rightarrow KY; Y \rightarrow \omega J/\psi$
 - no DD^(*) decays (yet)
- Z(3929)
 - $\gamma\gamma \rightarrow Z; Z \rightarrow D\overline{D}$
 - ang. dist. favors J=2
- Can be accommodated as radial excitations??
 - $X=\eta_{c}$ ", $Y=\chi_{c1}$ ', $Z=\chi_{c2}$ '?





Needs Further Study -- Confirmation by BaBar DD^(*) Branching Fractions/EM Transitions?





- Charmonium in 2002 (10 states):
 η_c, J/Ψ, χ_{c0}, χ_{c1}, χ_{c2}, Ψ', Ψ(3770), Ψ(4040), Ψ(4160), Ψ(4415)
- Recent Discoveries:
 - Expected: η_c , h_c
 - Curious: X(3940), Y(3940), Z(3929)
 - Surprising: X(3872),Y(4260),Y(4320)?
- Additional interesting discoveries in D_s meson spectrum!
- The dust is still settling -- more experimental results are on the way in addition to a dedicated future experiment:

Are there connections to Light Quark Spectroscopy?



Hybrid Status

- $\pi_1(1400)$
 - $\eta\pi$: lighter than expected, observed by multiple experiments, final state rescattering?
- $\pi_1(1600)$
 - $\eta'\pi$: nice signal, what fraction is rescattering background?
 - $\rho \pi$: high statistics 3π channel, new analysis shows leakage from $\pi_2(1670)$
 - $b_1\Pi$ and $f_1\Pi$: very interesting, but \cdot statistics limited
- π₁(2000)
 - $b_1 \pi$ and $f_1 \pi$: exciting -- need more statistics!



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We look to GlueX at JLab to provide definitive answers on the existence of these states. NDIANA UNIVERSITY Jefferson Lab Users' Group Meeting DEPARTMENT OF PHYSICS



- B-factories active in light quark spectroscopy also
- ISR production of vector states (1⁻⁻)
- Observe $e^+e^- \rightarrow Y(2175);$ $Y \rightarrow \Phi f_0(980)$
- Note:
 - $M_{Y(4260)}$ - $M_{J/\psi}$ ~ 1160 MeV
 - $M_{Y(2175)}$ - $M_{\Phi} \sim 1160 \text{ MeV}$

...hmm...coincidence?





Glueball Status

- Three f₀ (0⁺⁺) states where two are expected: f₀(1370), f₀(1500), and f₀(1710)
- Much experimental progress: CBAR, WA102, BES, and others
- Are all experimental data consistent with this picture?
 - need extensive cross checks in a variety of production and decay modes
 - need to better understand properties of states themselves
 - how to accommodate $f_0(1790)$ seen by BES in $J/\psi \rightarrow \phi \pi^+\pi^-$?
- What about the tensor glueball?



Light Quark Outlook

- What seemed to work for charm:
 - large increase in statistics
 - new energy regime
 - large acceptance multipurpose detectors to study many decay modes
 - different production mechanisms
 - complementary/competing experiments: cross-checks
- Many of these same ingredients are on the horizon in the light quark sector
- Perhaps one key difference: Sophisticated analysis techniques are needed to tackle complex production mechanisms and broad overlapping resonances.

Near Future

- Expect continued results from B factories although statistical potential has probably already been realized
- CLEO has worlds largest (28M) ψ ' sample
 - excellent glue-rich decay channels: $\psi', \chi_{cJ}, J/\psi$
 - very versatile high-resolution detector ideal for coupled channel analysis
 - Ψ ' running finished -- analysis underway
- BES III has extraordinary potential
 - IOB J/ψ per year
 - 3B ψ' per year

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 greatly improved detector capability over BES II





BES III BEPCII/Beijing

Closer to Home: GlueX

- Itself has all the ingredients of being a thrilling discovery experiment:
 - high statistics in key mass range: up to 3 GeV
 - largely unexplored production mechanism: photoproduction
 - multipurpose: try to optimize resolution, acceptance, and charged particle identification
- GlueX is in a position to make a unique and significant contribution to the global meson spectroscopy program
 - light hybrid focus
 - BESIII better for glueballs





- Meson spectroscopy, a key part of our understanding of QCD, is still active on many fronts and producing very interesting results
- There has been a recent renaissance in charm spectroscopy due largely to new, high-statistics studies carried out at B factories
 - Results are exciting and still emerging
 - New facilities on the horizon
- The future of light quark spectroscopy also looks quite promising as modern, high-statistics experiments begin acquiring data
- GlueX is well poised to play a key role in what we hope will be the next "spectroscopy renaissance." (Want to join us?)

