



Hadron-hadron spectroscopy

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LOI:

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a combination of many theoretical groups with
experimentalists from different experiments

structures near two heavy hadron thresholds

- many narrow states near heavy quark meson-meson thresholds: – $X(3872)$, $Z_c^{\pm,0}$, $Z_b^{\pm,0}$
 - anomalously light and narrow $D_{s0}^*(2317)^{\pm}$, $D_{s1}(2460)$
 - likely B_s analogues
 - and near heavy quark baryon-meson thresholds: P_c^{\pm} -s
- ⇒ hadron-hadron interactions & structures beyond nuclei:
- deuteron-like “molecular states”
 - or virtual states
 - or resonances slightly above threshold
- proximity of hadron-hadron thresholds can affect conventional $q\bar{q}$ meson and qqq baryon spectra and properties
 - coupled-channel cusps and/or triangle diagrams can lead to mass structures w/o poles in amplitudes

- nucleon-nucleon forces \rightarrow nuclei \equiv multiquark states

$$\approx \underbrace{(qqq)} (qqq) \dots (qqq)$$

nearly confined into baryons

- simplest: deuteron $\equiv p^\uparrow n^\uparrow$, $J^P = 1^+$, $l = 0$,
stable bound state, $E_b = 2.2$ MeV
 $\exists p^\uparrow n^\downarrow$, $J^P = 0^+$, $l = 1 \rightarrow$ virtual state, $E_b = 0.06$ MeV
- hypernuclei: $q \rightarrow s$
- long-standing question:
baryon-meson: pentaquark $(qqqq\bar{q})$ and
meson-meson: tetraquark $(qq\bar{q}\bar{q})$ analogues?
- old suspects: $f_0(980)$ near $K\bar{K}$ and $\Lambda(1405)$ near $N\bar{K}$
- new suspects:
 $X(3872)$ a.k.a. $\chi_{c1}(3872)$ right at $\bar{D}D^*$ threshold, $\Gamma < 1$ MeV
still controversial: huge $\bar{D}D^*$, or small $\chi_{c1}(2P)$,
or mixture, or $(cu)(\bar{c}\bar{u})$ Dq-Dq, or ...

- $Z_{b-s} \rightarrow \Upsilon \pi$ near $\bar{B}^{(*)} B^*$
 $Z_{c-s} \rightarrow J/\psi \pi$ near $\bar{D}^{(*)} D^*$
 $l = 1$, so definitely not ordinary quarkonia,
 \Rightarrow credence to meson-meson
but exact structure not yet clear,
compact Tq-s still offered
- LHCb 2015 & 2019:
3 narrow ($\Gamma \lesssim 20$ MeV) ($c\bar{c}uud$) states $\rightarrow J/\psi p$
just below $\Sigma_c \bar{D}^{(*)}$ thresholds
 \Rightarrow looks like a tie-breaker
- predictions for $\Lambda_c \bar{D}^{(*)}$ with big BR
- recent LHCb results on $J/\psi J/\psi$ and $D^+ K^-$ resonances
strongly suggestive of compact Dq - Dq $cc\bar{c}\bar{c}$ and $cs\bar{u}\bar{d}$ tetraquarks
- $cc\bar{u}\bar{d}$, $bc\bar{u}\bar{d}$, $bb\bar{u}\bar{d}$?
- more analogues in bottom sector, doubly-heavy dibaryons? ...

status, aims & means

- rich literature, but no consensus about interpretation & about optimal strategy to resolve the issues
- better and new measurements & discoveries crucial
 - Belle II & LHCb upgrades: sensitivity \gg
 - ATLAS & CMS: world-record pp \mathcal{L}
 - BES III & new tau-charm factories
 - photoproduction at JLab & EIC
 - production studies in high mult. pp , pA , AA
 - PANDA: $p\bar{p}$ annihilation near charm threshold
- collaboration of theorists and experimentalists to
 - study key existing measurements
 - identify experimental wishlist for next decade
 - synergy of experiment, advanced data analysis, analytic TH methods & lattice QCD

- Whitepaper will be prepared
- expectations from Snowmass process:
 - US support for related TH work
 - identify specific tasks
 - set up corresponding working subgroups