Got To Bind Them All!

Computing Tetraquark Potentials on the Lattice

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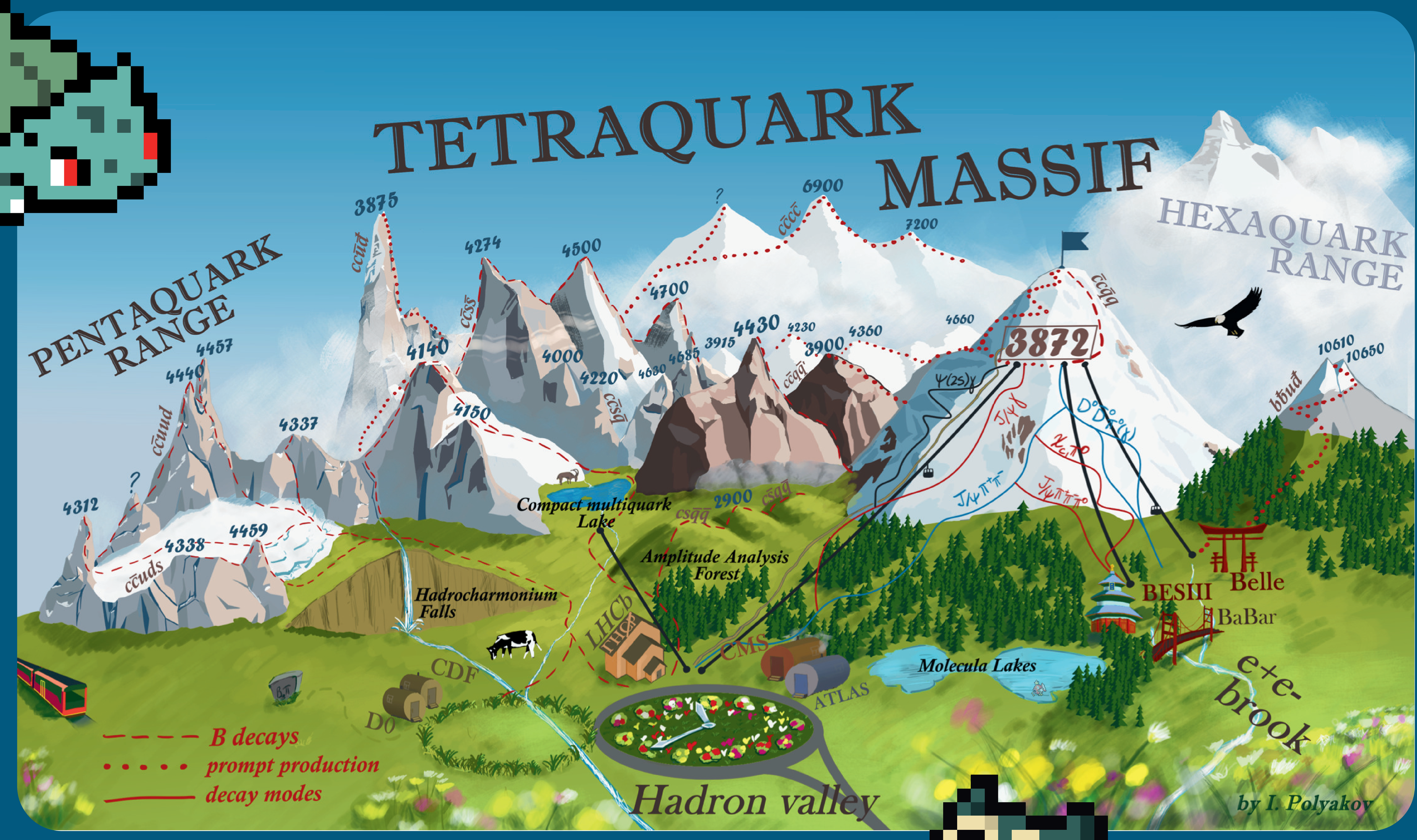
A Wild Tetraquark Appears!

I developed the quark model!

- They are exotic particles theorized by Gell-Mann in 1964, and first discovered by the Belle experiment in 2003. Since then, evidence of many tetraquark states has been observed.
- Their internal structure and properties are still mostly unknown, both theoretically and experimentally, for example the binding energy of the system.
- We can use Lattice QCD to simulate tetraquark systems with heavy quarks (mainly b quarks) in order to extract its static potential which can be used to predict the binding energies and guide further experimental detection.
- In this work, we expand on ongoing calculations in order to improve the precision of our previous measurement and reveal the true nature of these exotics!

Figurative representation of all detections of exotic hadrons up to now!



LQCD Is Super Effective!

The computation of observables on the Lattice is done using the path integral formalism in Euclidean space-time:

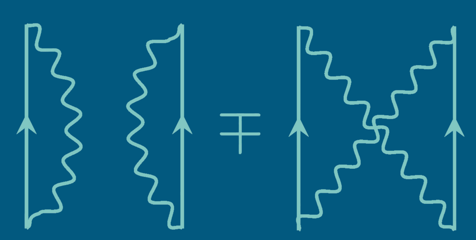
$$\langle\widehat{O}\rangle = \frac{1}{Z}\int \mathcal{D}[\psi,\overline{\psi}]\mathcal{D}U\; e^{-S_F[\psi,\overline{\psi},U]-S_G[U]}\; O[\psi,\overline{\psi},U]$$

with $S_F[\psi,\overline{\psi},U] = a^4 \sum_{n,m\in\Lambda} \overline{\psi}(n)D_W(n|m)\psi(m), \quad S_G[U] = \frac{\beta}{3}\sum_{n\in\Lambda}\sum_{\mu<\nu} \mathrm{Re}\,\mathrm{Tr}[1-U_{\mu\nu}(n)]$

We then perform the Grassmann integration, using Wick's theorem. What remains is a purely bosonic integral with measure proportional to the fermion determinant. The values of the operators are then sampled over many configurations, which are generated according to said distribution, and finally the measurement receives a rigorous statistical treatment.

For our spectroscopy calculation, we use the interpolators for the tetraquark system to compute the temporal correlator:

$$\mathcal{C}^{\mp,\Gamma}_{\bar{Q}\bar{Q}ud}(\mathbf{r}_1,\mathbf{r}_2,t_2-t_1) = \langle\Omega|\widehat{O}(t_2)\widehat{O}^\dagger(t_1)|\Omega\rangle \xrightarrow[(t_2-t_1)\to\infty]{} Ae^{-V^{\mp,\Gamma}_{\bar{Q}\bar{Q}ud}(\mathbf{r}_2-\mathbf{r}_1)\times(t_2-t_1)} + \dots$$

$\propto$ 

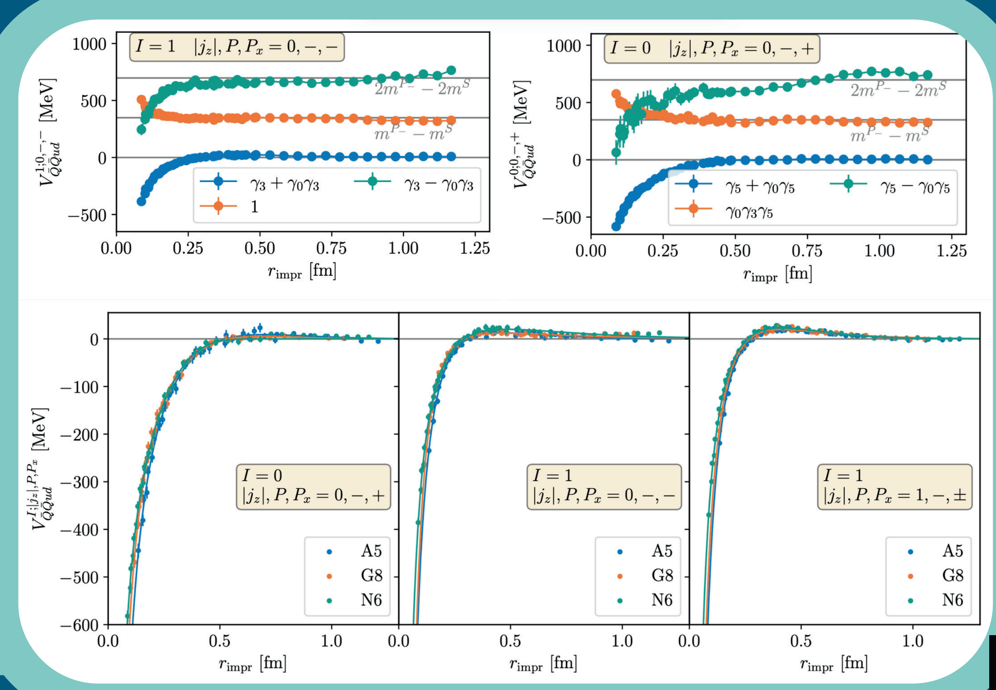
Finally, we extract the potential by calculating the effective mass, the discrete log of the expression above. Solving the radial Schrödinger equation with this potential gives us the binding energy of the system.

First Evolution

- For large separations, the system behaves as 2 non-interacting static-light mesons, which provide the normalisation.
- Potential is computed both on and off axis for all 32 independent creation operators, labeled by the 4 quantum numbers.
- OGE dominates at small distances, with Coulomb-like term, but insufficient data quality prohibits a meaningful quantitative estimate of the binding energy.
- Evidence of small OPE bump at large separations.

- The simulations are built upon the *openQ*D* codebase and were performed at CSC Frankfurt using configurations provided by the CLS effort with two dynamical flavors of *O(a)*-improved Wilson fermions, for 3 different ensembles with varying spacing and pion mass. Stochastic propagators and Gaussian smearing were used for the fermion fields and HYP smearing for the gauge links.

I Choose You!



Next Episode

- Compute the correlation matrix for the 3 lowest energy states of the system and for different smearings to decouple excited states.
- Use the recent tool *pyerrors* to perform a better statistical analysis of the results by taking autocorrelations into account
- Explore other smearing alternatives, like Wilson flow.

SCAN HERE! for YT video and refs.

Acknowlegments: