Predicting the properties of subatomic particles using large scale computer simulations

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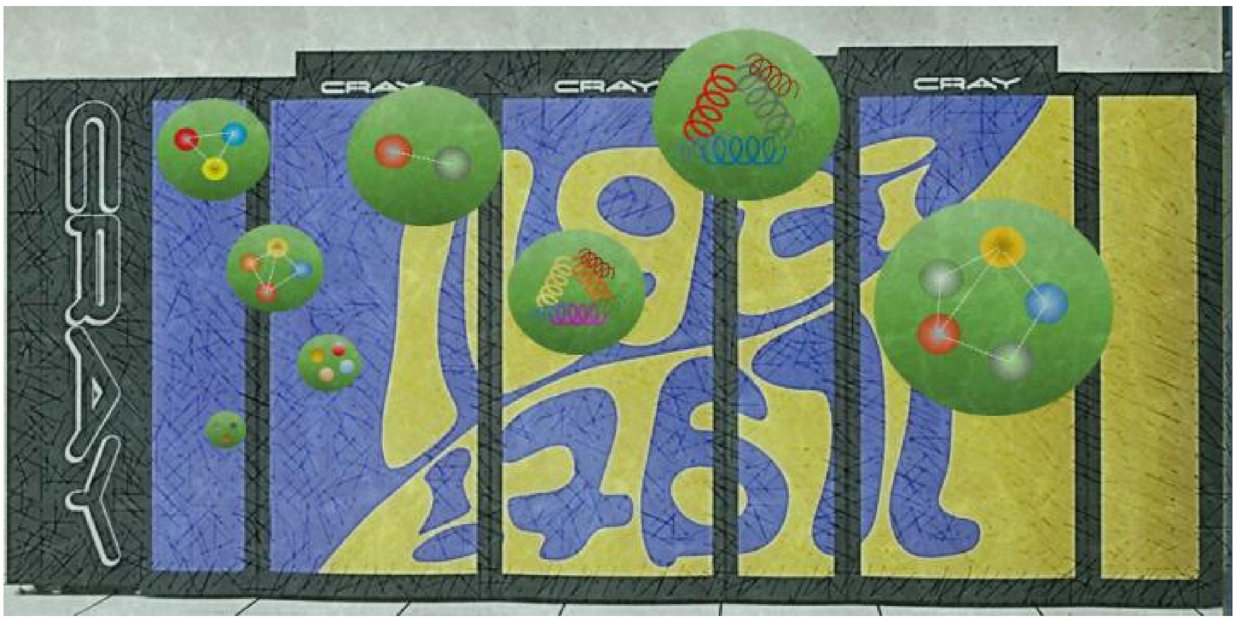

The properties of subatomic particles are being studied using supercomputers of the Indian Lattice Gauge Theory Initiative (ILGTI) at TIFR. Credit: TIFR

Predicting the properties of subatomic particles before their experimental discovery has been a big challenge for physicists. In a recent paper published on 28 July in *Physical Review Letters* Nilmani Mathur from the Tata Institute of Fundamental Research, Mumbai, and M. Padmanath, a former student from TIFR, have predicted the quantum numbers of five Ω^0_c baryons which have recently been discovered by an experiment at the Large Hadron Collider (the LHCb collaboration) at CERN. These results will help in understanding the nature of strong interactions in the Universe.

A baryon is a composite subatomic particle made of three valence quarks and is bound by gluons through strong interactions. The most well known baryon is the proton which along with an electron constitutes a hydrogen atom. A simplistic picture of a proton is a combination of two up quarks and one down quark. In the theory of strong interactions there are six quarks each with three colours charges. This theory allows any combination of a quark and an anti-quark as well as any combination of three quarks in a colour neutral state resulting in varieties of subatomic particles called mesons and baryons, respectively. The discovery of many mesons and baryons since the middle of the 20th century, has played a crucial role in understanding the nature of strong interactions. It is expected that many other mesons and baryons will be discovered in ongoing experiments at CERN and future high energy experiments.

These recently discovered baryons are called Ω^0_c made of two strange quarks and one charm quark. These are the excited states of Ω^0_c baryon, much like the excited states of the hydrogen atom.

Quantum Chromodynamics (QCD) which is believed to be the theory of strong interactions, is a highly non-linear theory and can be solved analytically only at very high energies where the strength of interactions is quite small. Till date there is no analytical solution of QCD to obtain the properties of subatomic particles, like the proton and Ω_c. This demands the numerical implementation of QCD on space-time lattices which is known as lattice QCD (LQCD). LQCD methods can describe the spectrum of subatomic particles and also their properties, like decay constants. LQCD also plays a crucial role in understanding matter under high temperature and density similar to the condition in the early stages of the universe.

In this work Padmanath and Nilmani predicted the quantum numbers of these newly discovered Ω^0_c baryons which were otherwise unknown experimentally. Infact, Padmanath's thesis work predicted the masses of these particles four year before their discovery. Using state-of-the-art methods of LQCD and computational resources of the Department of Theoretical Physics and the Indian Lattice Gauge Theory Initiative (ILGTI), they performed a precise and systematic determination of energies and quantum numbers for the tower of excited states of Ω^0_c baryons. Their predicted results are compared with experimental findings (see table). Predicted quantum numbers of these particles will help to understand the properties of these particles which in turn will help to understand the nature of strong interactions.

Since 2001 Nilmani and his collaborators have predicted the masses of various other subatomic particles with different quark contents some of which have already been discovered (after they were predicted) and many others will presumably be discovered in future experiments. For example, their prediction of the mass of Ξ_{cc} baryon (a baryon made of two charm quarks and a light quark) in as early as 2001 and as late as 2014 was confirmed by the discovery of this particle on July 6, 2017, by the LHCb collaboration.

Nilmani and Padmanath along with other theoretical physicists at TIFR are currently studying the properties of various subatomic particles, particularly those made of heavy quarks, using large scale computer simulations. They use the computational facilities of ILGTI's high performance computer center at the Balloon Facility, Hyderabad, which hosts a Cray supercomputer. The results of their work will help to understand the nature of strong interactions in the Universe.

More information: M. Padmanath et al, Quantum Numbers of

Recently Discovered Ωc0 Baryons from Lattice QCD, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.042001

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