Discover new hadrons at LHCb

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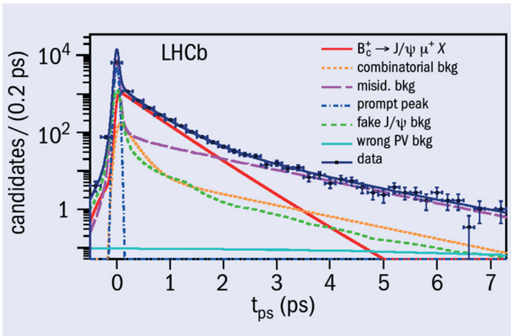
The LHCb experiment is a heavy hadron discovery factory, with more than 50 new states observed for the first time in LHCb since its startup in 2010. Heavy hadrons are extremely useful to test and tune the models describing phenomenological QCD models, lattice QCD computations and strong interactions at large. Indeed, the large mass of heavy quarks makes their motion within the hadron bound state much slower with respect to the motion of light quarks, passing from being ultra-relativistic to a quasi-classical regime for which the theory is more consolidated and robust. Most notably, LHCb provided conclusive evidence for the existence of hadron states with four (tetraquark) or five (pentaquark) valence quarks. The observation of these states, whose theoretical interpretation is still challenging, provided a new portal to the understanding of strong interactions and is currently a lively field of research.

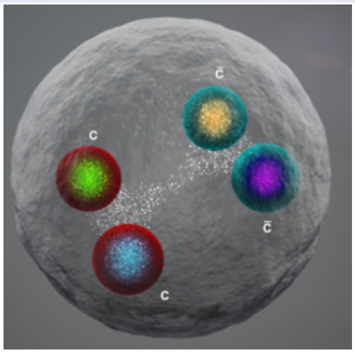
The Firenze group has a wide experience in these studies, both with ordinary meson and baryon states and with "exotic" states. An early relevant contribution was the precision measurement of the lifetime of the B_c meson, the first observed hadron composed of heavy quarks with different flavours. This result, a key ingredient to the development of B_c physics at the LHC, was obtained from the $B_c^+ \to J/\psi\mu^+ \to \mu^+\mu^-\mu^+$ semileptonic decay, using a novel approach conceived and developed within the group.

Another noticeable example is the discovery of the T_{cccc} tetraquark state, announced in 2020 and obtained from an analysis of double J/ψ production mostly carried out within our group. This tetraquark state is particularly interesting as, being composed only by heavy quarks, can be interpreted in QCD only as a compact tetraquark state, rather than a molecular-like binding of two ordinary $q\bar{q}$ mesons.

The Ph.D candidate can contribute to this program through novel ways to exploit the data collected during LHC Runs 1 and 2, and through the development of data analysis with the upgraded LHCb detector in Run 3. Possible thesis subjects are:

- search for the Ξ_{bc} baryon, a still unobserved hadron state. Our group pioneered the search effort in 2013, and the discovery is expected to be likely in the next future;
- search for new states of fully-charm tetraquarks: as accurate predictions based on non-relativistic QCD are available for these unambiguous compact tetraquark states, the T_{cccc} spectroscopy is a powerful new probe for the theory of strong interactions;
- study of the form factors of the B_c meson and other ordinary heavy hadrons where theoretical models can be probed with precision measurements.





Top: determination of the B_c lifetime from semileptonic decays; Bottom: Artist's view of the fully-charmed tetraquark.

Further reading

- LHCb Collaboration, *Measurement of the B_c^+ meson lifetime using $B_c^+ \to J/\psi\mu^+\nu_\mu X$ decays*, Eur.Phys.J.C 74 (2014) 5, 283
- LHCb Collaboration, *Observation of structure in the J/ψ -pair mass spectrum*, Sci.Bull. 65 (2020) 23
- N. Brambilla *et al*, *Substructure of Multiquark Hadrons (Snowmass 2021 White Paper)* , arXiv:2203.16583
- LHCb Collaboration, *Search for the doubly heavy baryon Ξ_{bc}^+ decaying to $J/\psi\Xi_c^+$* , arXiv:2204.09541

About the group

Giacomo Graziani is Senior Researcher at INFN-Firenze and an early member of the LHCb Florence group, where he initiated the research activity on heavy hadronic states. Dr. Graziani is currently coordinating the group of experimental physics with particle accelerators of INFN-Firenze.
Lucio Anderlini is Researcher at INFN-Firenze. He provided significant contributions to the hadron physics programme of LHCb, that he coordinated from 2016 to 2018. His Ph.D. Thesis on the measurement of the B_c^+ meson lifetime was awarded with INFN's Conversi Prize and the LHCb Thesis Award in 2015.