Constraining the B quark hadronization mechanism

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Abstract

This project focuses on the study of B meson production in 13 TeV proton-proton collisions at the Large Hadron Collider measured with the LHCb experiment. The measured production rate of differently flavored B mesons was compared to monte carlo simulations. Simulation software contains only well-studied hadronization methods (fragmentation), so discrepancies between simulations and experimental data could imply the observation of novel hadronization methods (quark coalescence).

Introduction

QUARKS

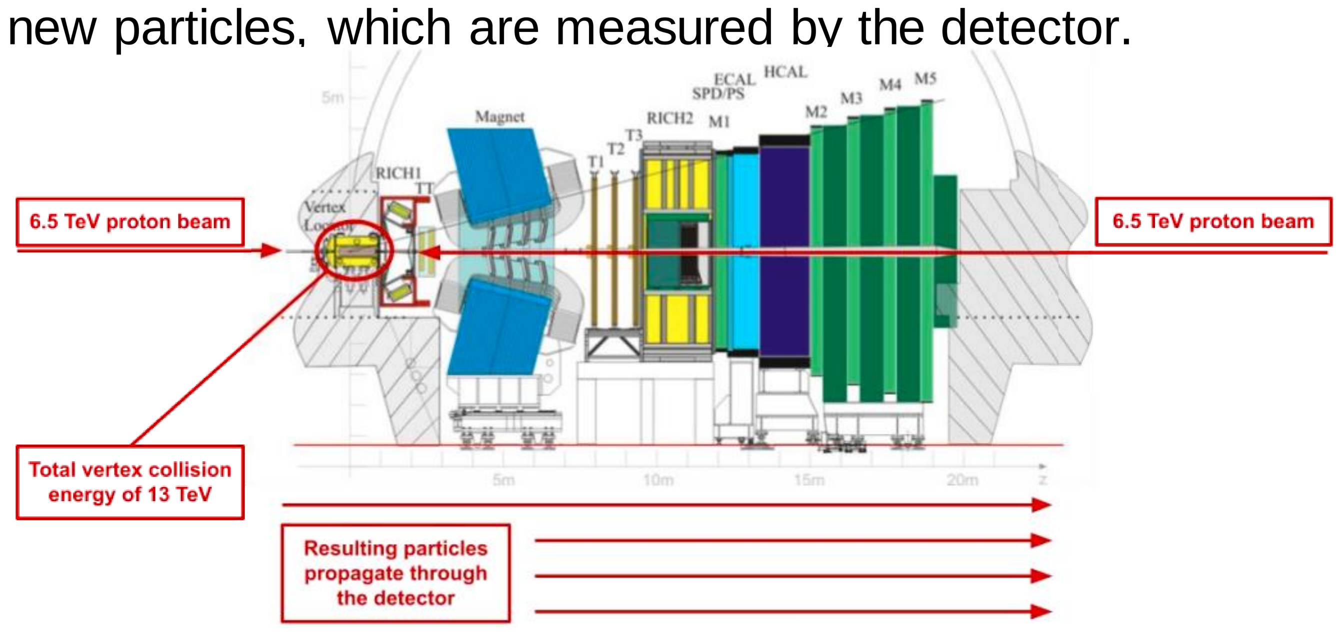
The bulk of the matter that we interact with every day is made up of subatomic particles called quarks. Quarks have fractional charges, but combine to form particles of whole number charge called hadrons. **The process by which individual quarks combine to form hadrons is one of the central areas of study in quantum chromodynamics.**

$+2/3$	u	c	t
$-1/3$	d	s	b

mass ⟶ **mass**

THE LHCB EXPERIMENT

LHCb is one of several experiments housed at the Large Hadron Collider in Geneva, Switzerland. The collider accelerates two proton beams in opposite directions, and protons are collided within the LHCb detector. Mass-energy equivalence allows for the energy of the protons to be transformed into mass in the form of new particles, which are measured by the detector.

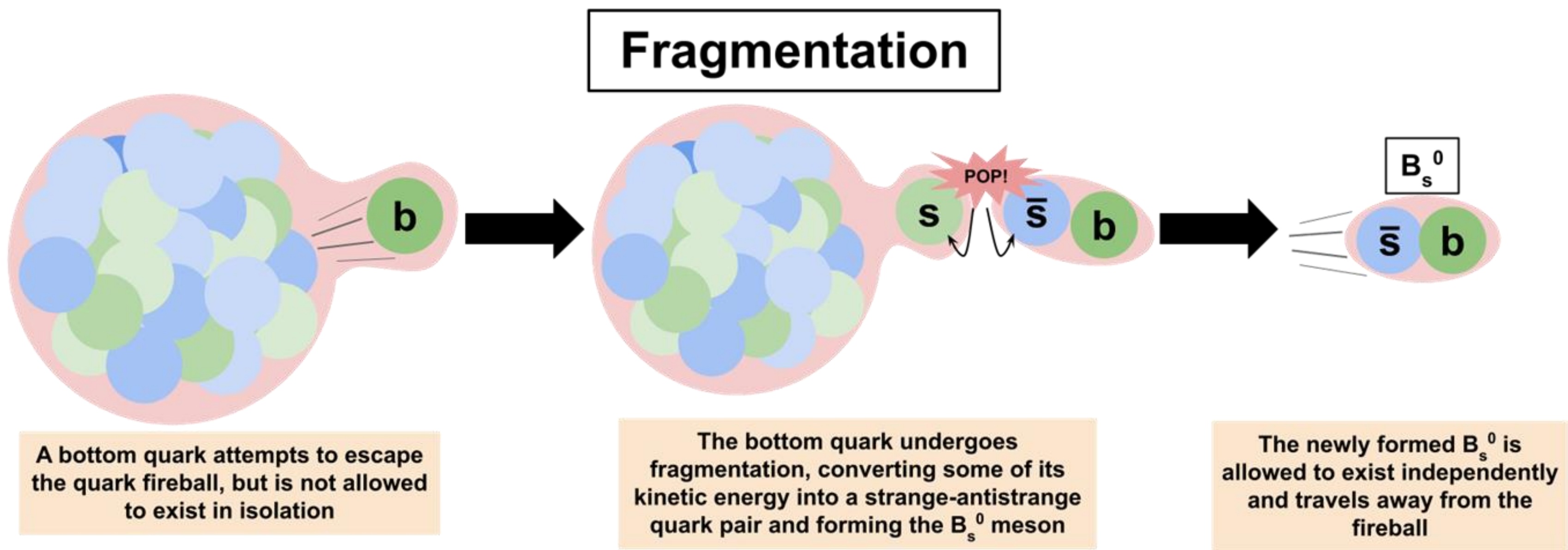


Hadronization

In a proton-proton collision at the LHC, many quarks are produced very rapidly, forming a quark fireball. The individual quarks are not allowed to exist in isolation, so they combine with other quarks to form hadrons, which are able to travel away from the fireball. This process is called hadronization and is thought to occur via two main processes: fragmentation and coalescence.

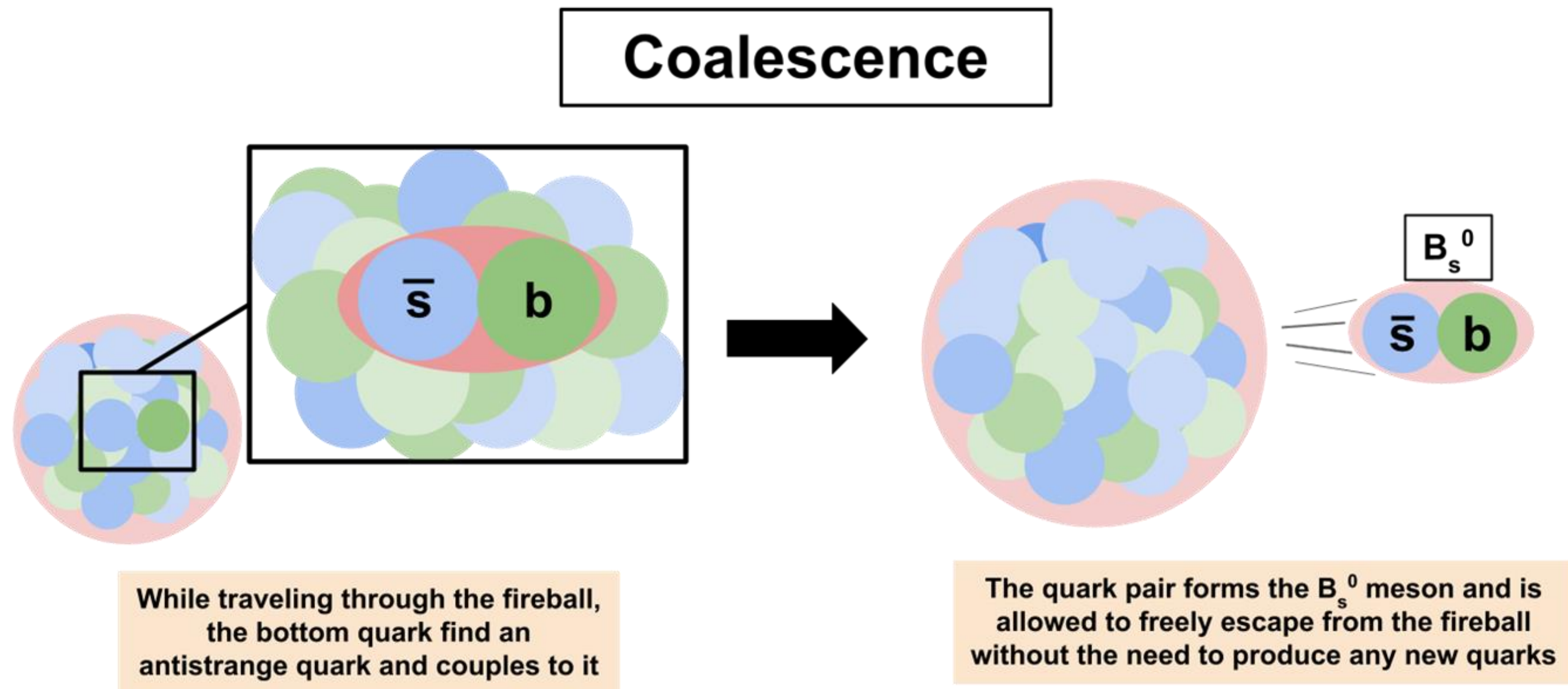
Fragmentation

As a quark begins to leave the fireball, the strong force causes the quark's potential energy to rise rapidly. If the quark has insufficient energy, it will remain contained within the fireball. However, a highly energetic quark is able to convert some of its energy to a quark-antiquark pair, combining with one of the newly formed quarks to form a hadron. This process is called fragmentation and is how most hadrons are produced in proton-proton collisions.



Coalescence

If quark density is high enough, it is possible for free quarks to find one another within the fireball and form a hadron without fragmentation. This process is called quark coalescence, and the rate at which it occurs increases as quark density increases. Coalescence is not well understood, so mechanisms of studying coalescence can enrich our understanding of quantum chromodynamics.



Data and Analysis

PYTHIA

PYTHIA is a program designed to simulate particle production in high-energy physics collisions. This project utilizes PYTHIA simulations to estimate the effect of coalescence on particle counts. PYTHIA8 contains a feature called "color reconnection" which simulates interactions between free quarks and is able to approximate some effects seen by coalescence.

DATA

Fig. 1 shows the experimental data collected with the LHCb detector, as well as the estimated particle yields as simulated by PYTHIA. nVeloTracks, also called multiplicity, is the number of particle tracks seen by the LHCb vertex locator detector and acts as an indicator for quark density in the fireball. The y-axis displays the ratio of B_s^0 to B^0 mesons seen by the detector.

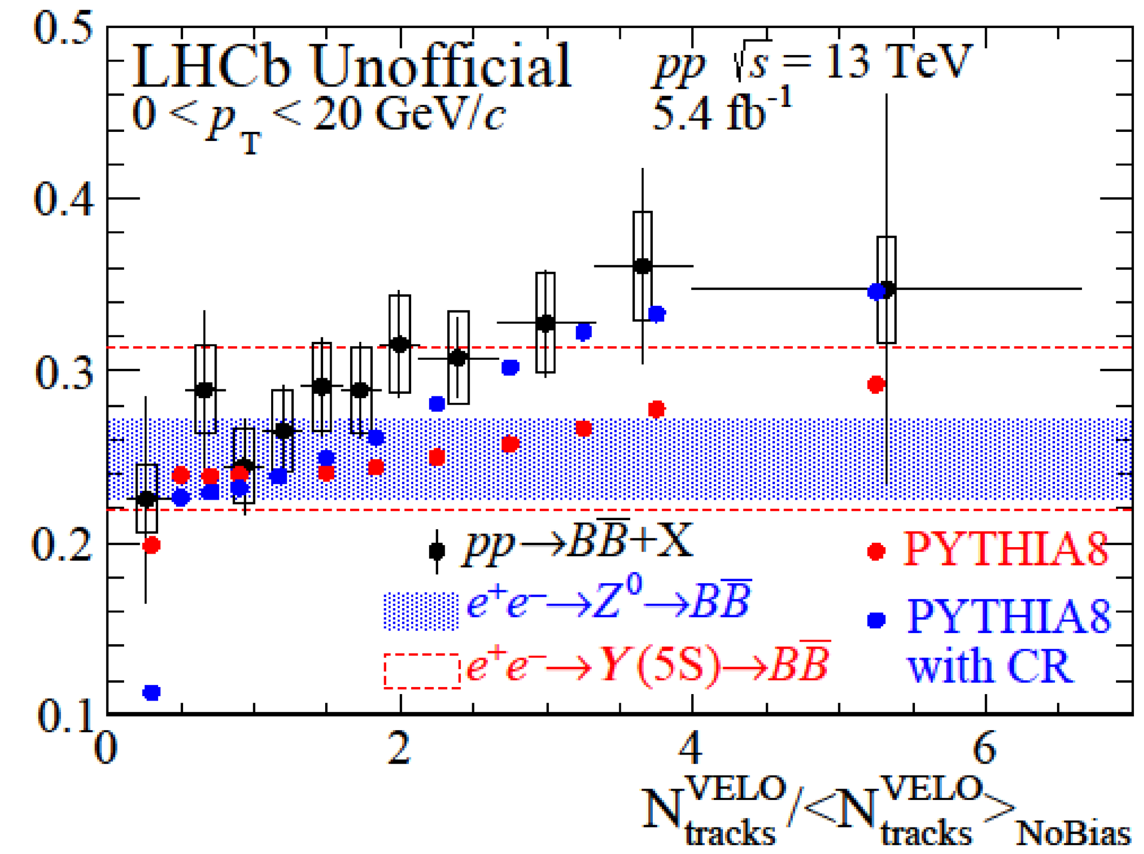


Fig. 1. Experimental data compared to simulated data with and without color reconnection. Color reconnection undershoots the data, indicating there may be room for an additional hadronization mechanism.

ANALYSIS AND CONCLUSIONS

In fragmentation, the ratio of strange quark to down quark production is not dependent on quark density, so if fragmentation were the only hadronization mechanism, one would expect the ratio of B_s^0 to B^0 mesons to stay approximately flat with increasing multiplicity as seen in the simulation without color reconnection. However, due to the abundance of strange quarks within the fireball and the fact that coalescence becomes more prevalent at higher quark densities, one should see the ratio increase as multiplicity in cases with quark coalescence. This effect is seen in the simulation with color reconnection, and even more dramatically in the experimental data. These data provide strong evidence of quark coalescence being a contributing mechanism to b quark hadronization at high multiplicity.

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