Probing hadronization in high-multiplicity collisions at LHCb

Julie Berkey (*jlnelson@lanl.gov*) for the LHCb collaboration

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Hadronization

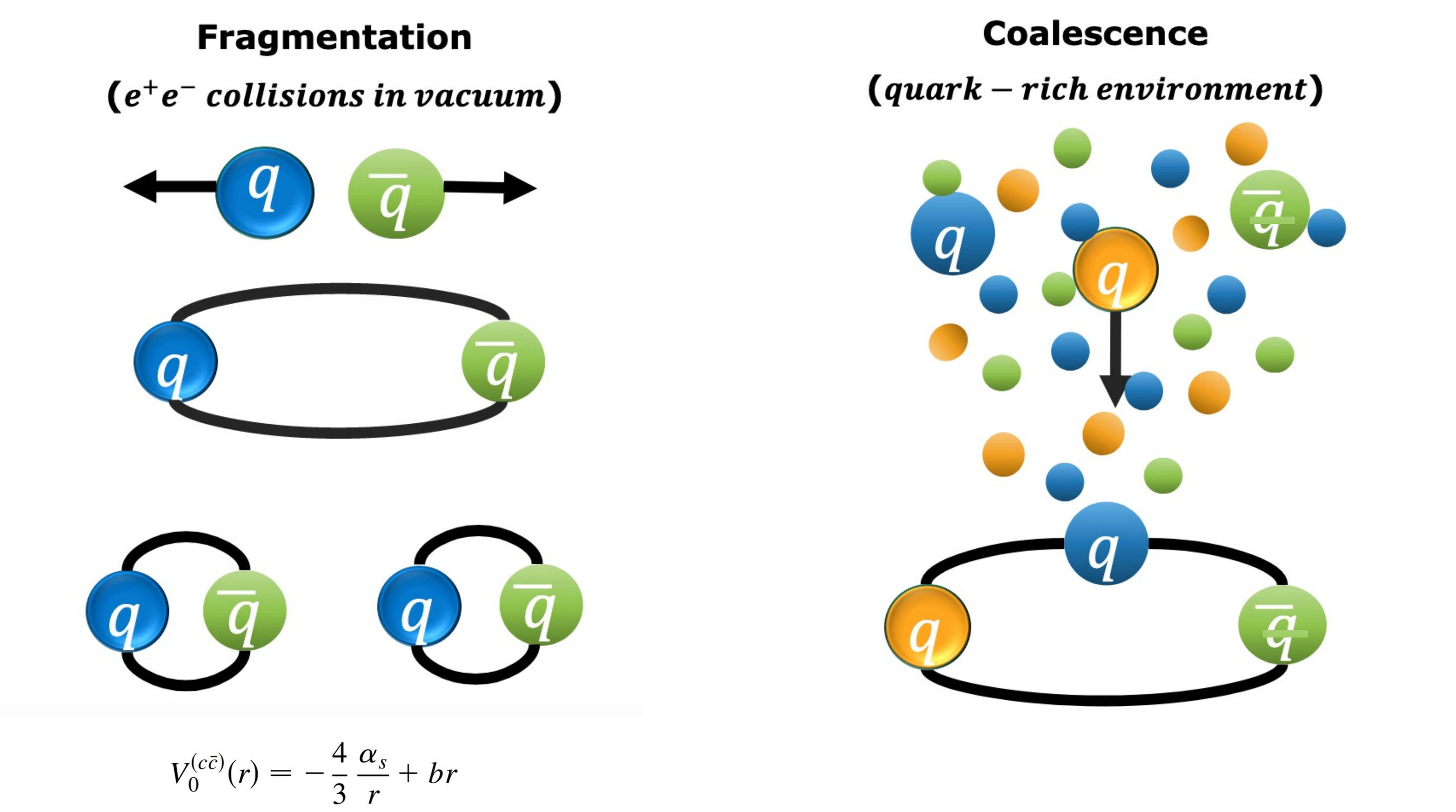
Measurements of b hadrons at colliders offer unique insights into the hadronization process by which single quarks evolve into color-neutral hadrons. Production of $b\bar{b}$ pairs at large hadron colliders is dominated by hard parton-parton interactions in the initial stages of a collision, and there is no b content in the valence quarks of the incoming beam particles. The large mass of b quarks suppresses their production via non-perturbative processes, making them ideal candidates for the study of hadronization mechanisms and the effects of the quantum chromodynamic medium.

Fragmentation

During hadron collisions, showers of energetic quarks are created and dispersed. As the quarks separate, a large potential is created between individual quarks, resulting in the creation additional quark-antiquark pairs that evolve into color neutral hadrons.

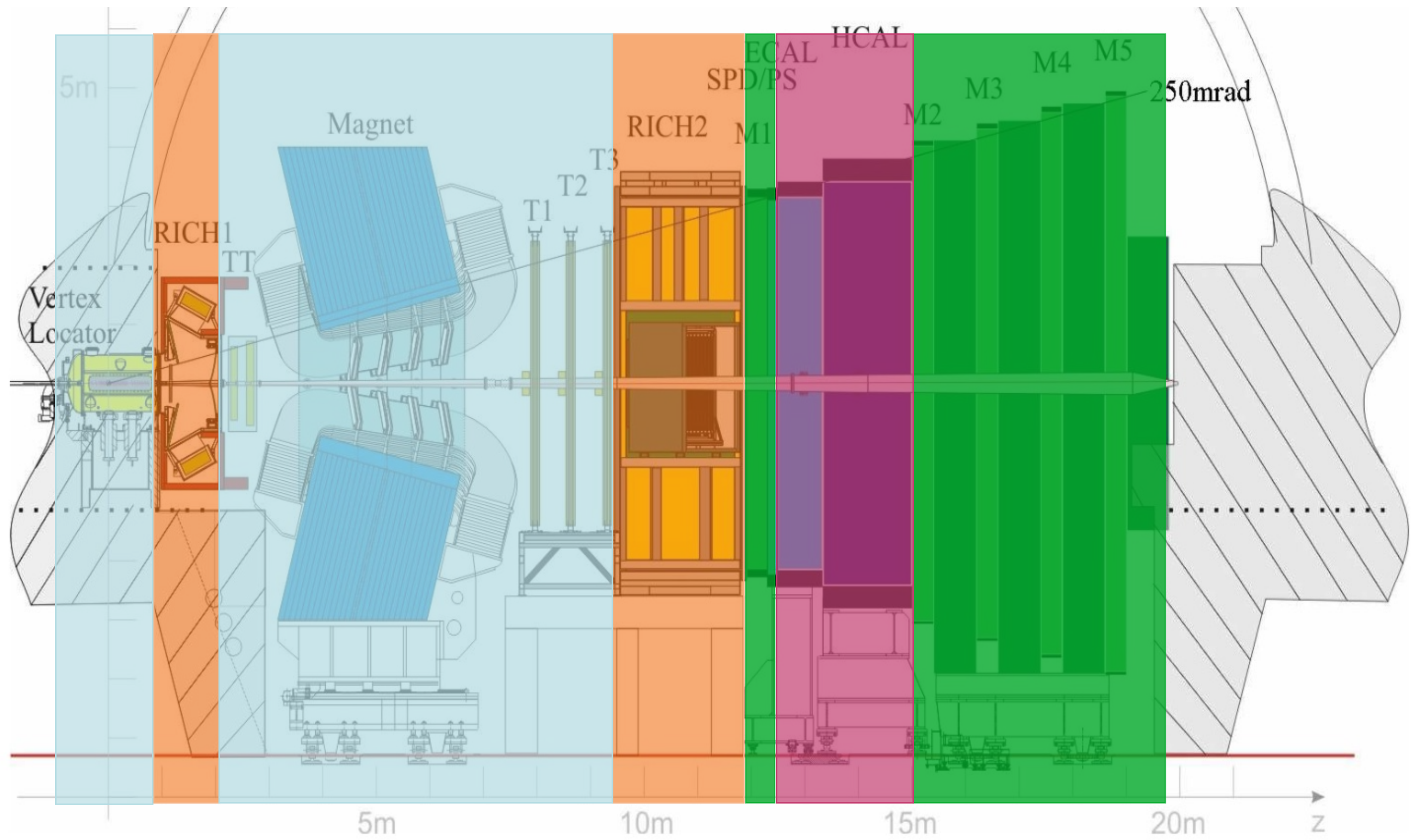
Coalescence

When there is a high enough quark density, free quarks can combine with surrounding quarks to form color singlet hadrons. The effects are expected to be much more pronounced at high multiplicity and low transverse momentum, p_T, potentially leading to baryon enhancement.



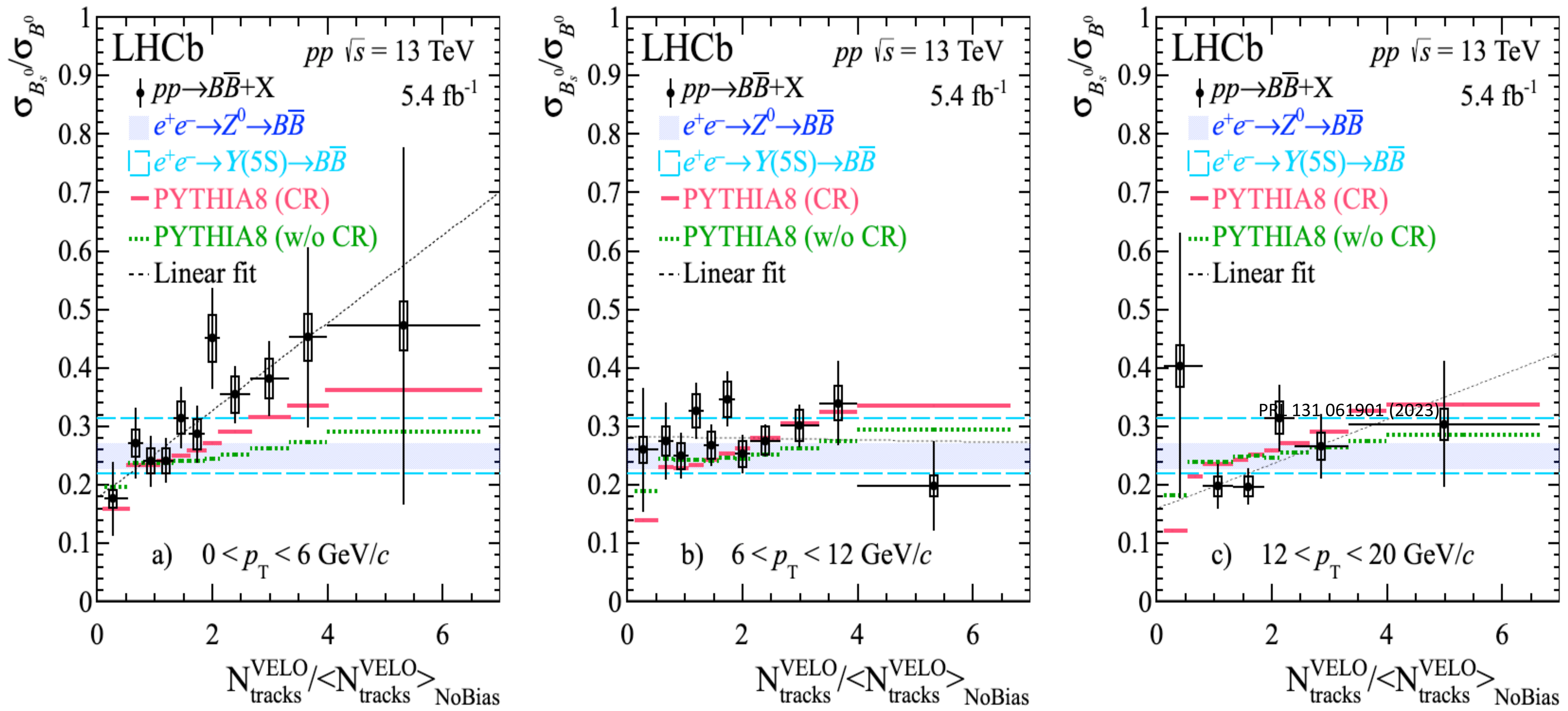
The LHCb Experiment

The LHCb Detector: Full tracking, particle ID, hadronic and electromagnetic calorimetry and muon ID in $2 < \eta < 5$



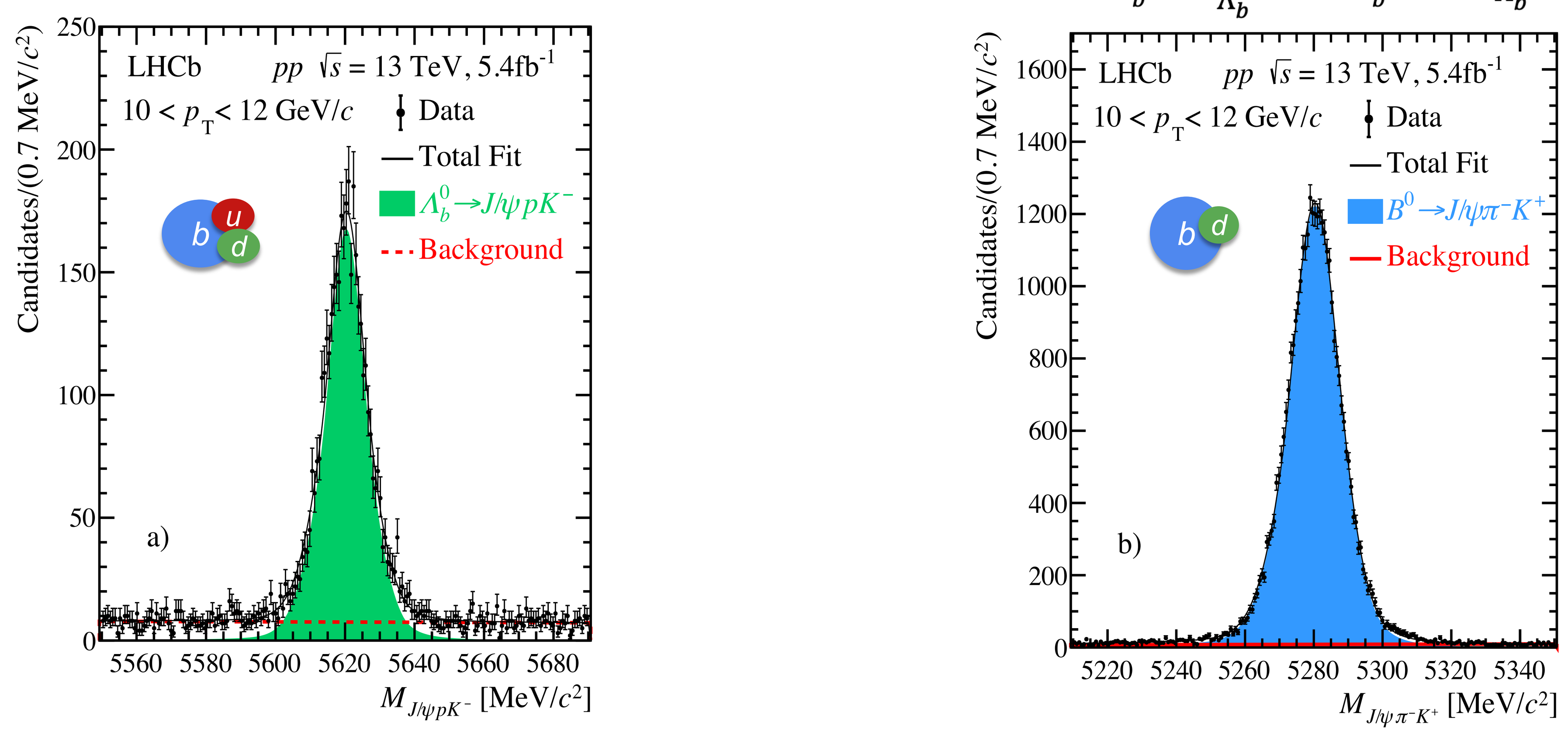
Strangeness and Baryon Enhancement

Heavy quarks are produced during the initial stages of a collision and move relatively slowly, making them especially sensitive to QCD medium properties and evolution. The production of mesons with strange quarks is expected to be enhanced due to the overlap of quark wave functions. If hadronization via coalescence emerges as a mechanism for forming final state B hadrons, the production rate of B_s^0 is expected to increase relative to the production of B^0 as particle multiplicity increases at low p_T.

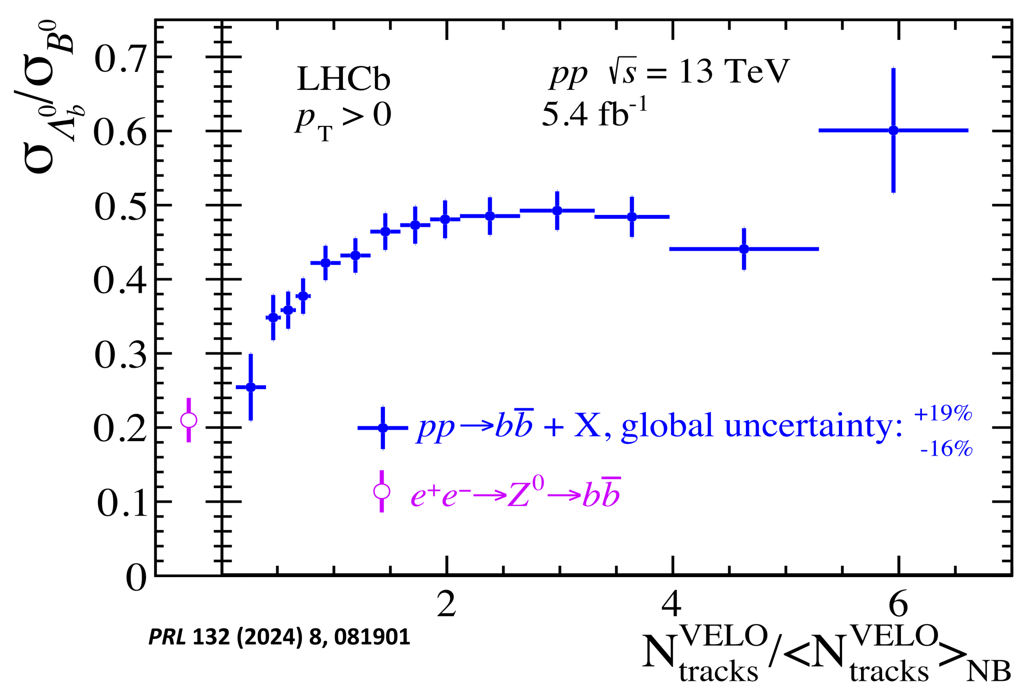


The formation of b baryons relative to b mesons can also indicate quark coalescence emerging as an additional hadronization mechanism:

$$\frac{\sigma_{\Lambda_b^0}}{\sigma_{B^0}} = \frac{N_{\Lambda_b^0}}{N_{B^0}} \times \frac{BR(B^0\to J/\psi K\pi)}{BR(\Lambda_b^0\to J/\psi p\pi)} \times \frac{\varepsilon^{acc}_{B^0}}{\varepsilon^{acc}_{\Lambda_b^0}} \times \frac{\varepsilon^{trig}_{B^0}}{\varepsilon^{trig}_{\Lambda_b^0}} \times \frac{\varepsilon^{reco}_{B^0}}{\varepsilon^{reco}_{\Lambda_b^0}} \times \frac{\varepsilon^{PID}_{B^0}}{\varepsilon^{PID}_{\Lambda_b^0}}$$



Enhanced Λ_b^0 to B^0 cross-section yields deviate from fragmentation value obtained in e^+e^- collision as charged particle multiplicity increases in small collision systems. The cross-section production rate increases by a factor of ~2, before plateauing at 2X the average multiplicity and greater.



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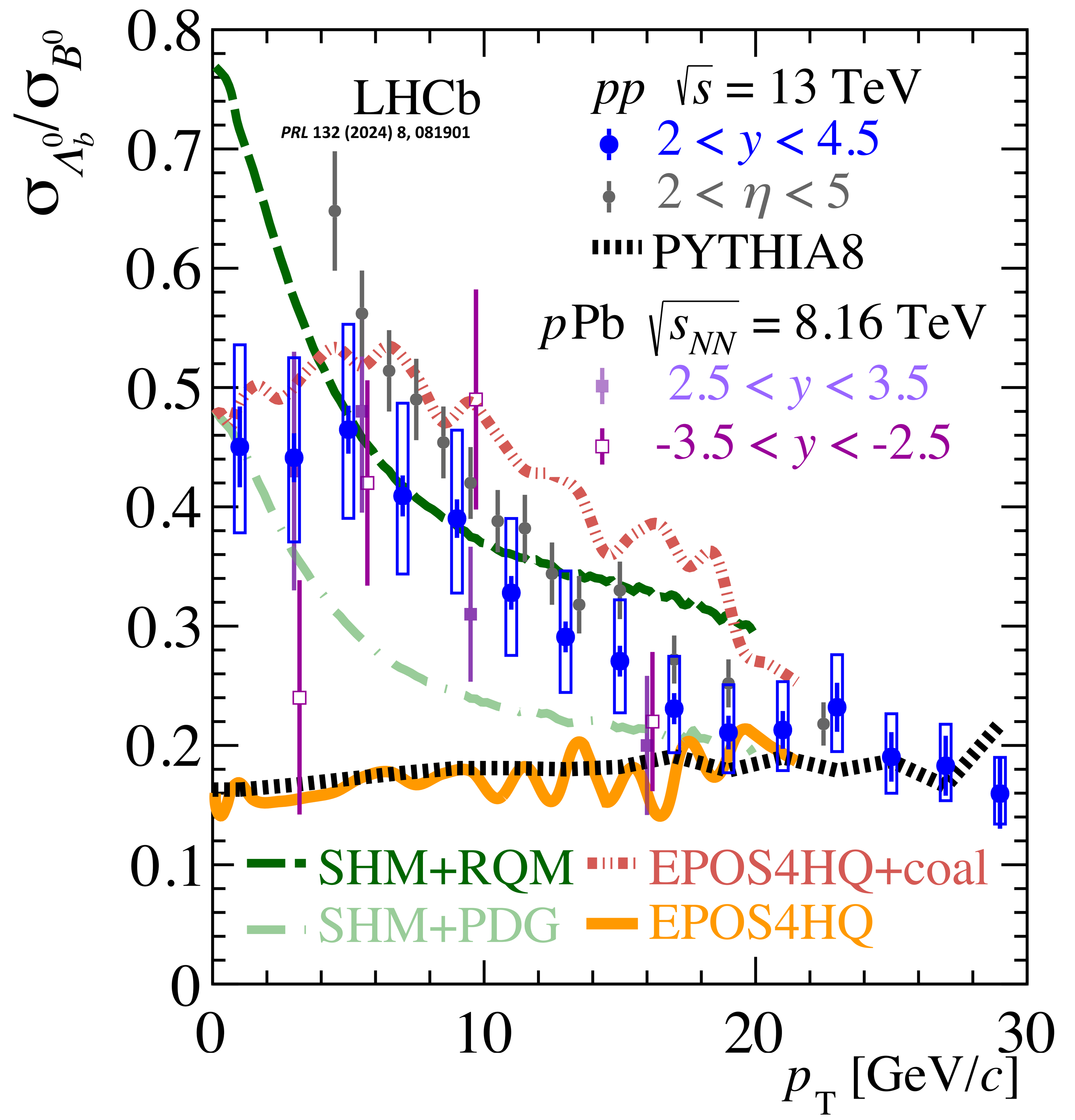
Comparing data to Models



Recent Λ_b^0 / B^0 data from LHCb shows a significant dependence on collision energy and p_T, which is not expected in a pure fragmentation scenario. Data are compared to calculations from event generators, PYTHIA8 and EPOS4HQ (with and without coalescence included), and calculations that use a Statistical Hadronization Model (SHM) of b quarks plus independent b fragmentation at high p_T. The PYTHIA8 and EPOS4HQ without coalescence models can only reproduce the data at high p_T. The results favor the SHM with an expanded set of b baryons from the Relativistic Quark Model (RQM) as opposed to the known baryons collected in the Particle Data Group (PDG) listings.

Conclusion

- LHCb is uniquely well suited to study heavy quarks and hadronization.
- Fragmentation alone fails to reproduce the production of heavy- and strange- quark hadrons in high multiplicity events at low p_T.
  - Breaks the universality of hadronization across collision systems.
  - An additional hadronization mechanism is required.
- Clear indication that the underlying event has an effect on the hadronization process.

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