Multiplicity-dependent production of heavy mesons with strangeness in small systems at LHCb

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on behalf of the LHCb collaboration

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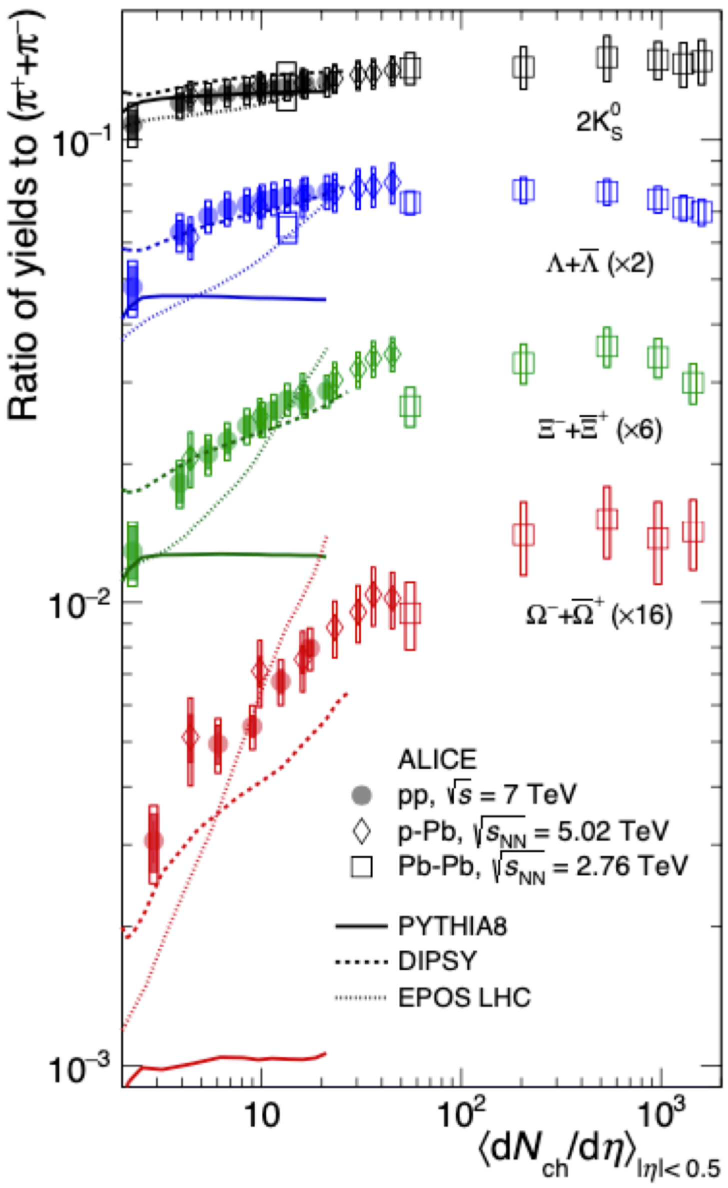
Motivation

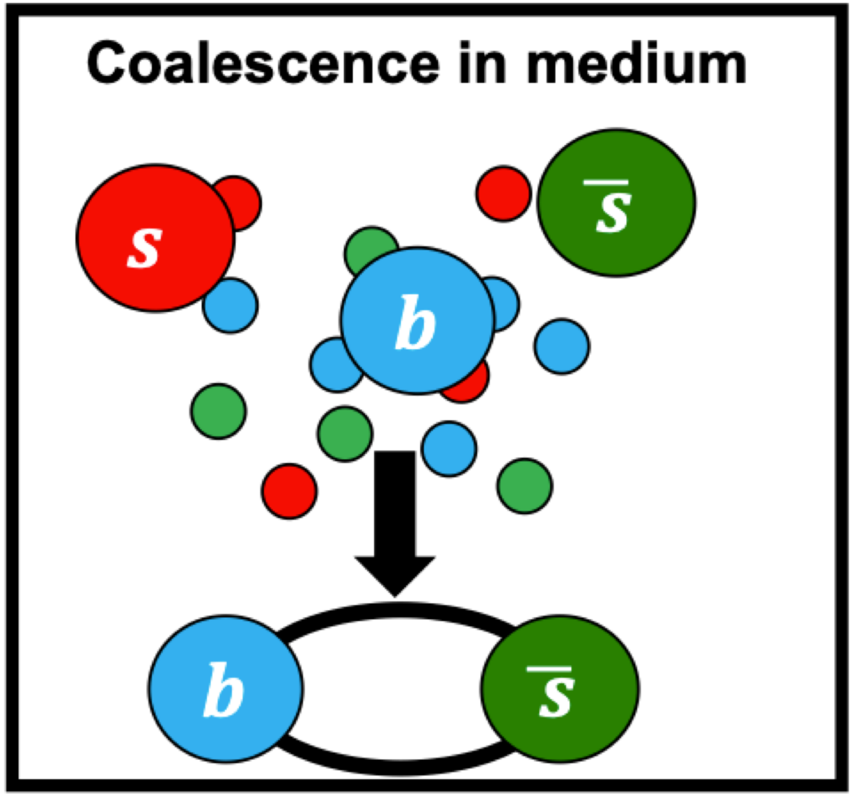
- Strangeness enhancement was one of the first proposed signatures of quark-gluon plasma (QGP) formation in heavy ion collisions
  - strangeness production proceeds mainly via gluons fusion in QGP.
  - s quark mass lower than QGP temperature, $s\bar{s}$ quark pairs can be produced thermally.
- Recently, enhanced strangeness production is also observed in high multiplicity *pp* and *p*Pb collisions.
- The QGP conditions could be approached in *pp* collisions where a large number of particles are produced.



Nature Phys **13,** 535–539 (2017)

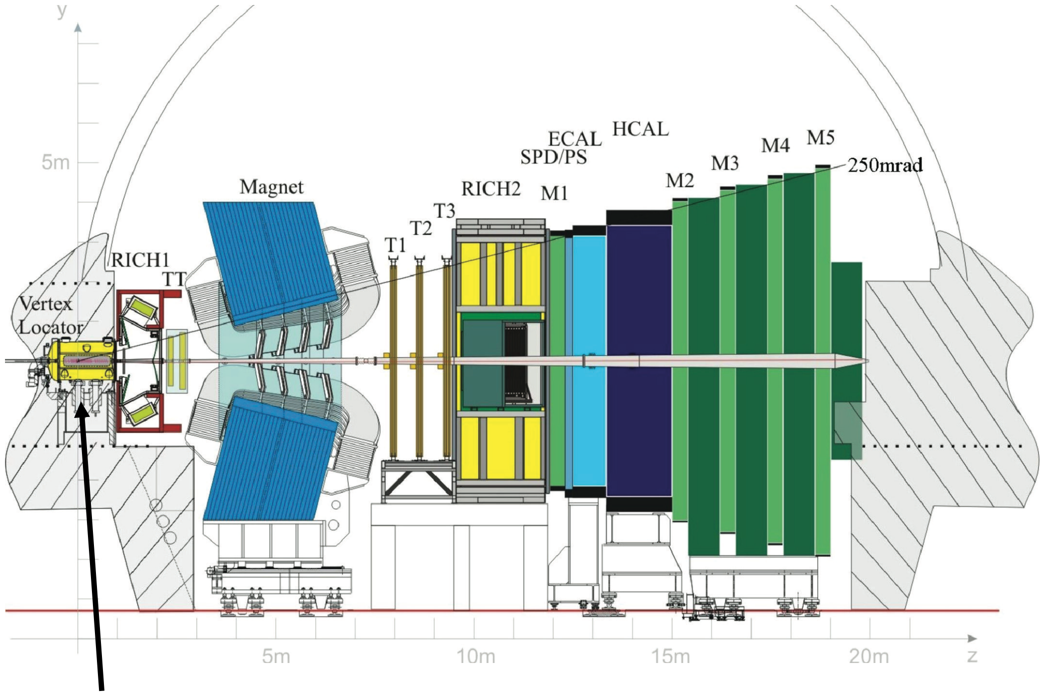
Hadronization Process

- Fragmentation mechanism
  - ➢ Lots of partons produced by outgoing quarks form into hadrons .
- Coalescence mechanism
  - ➢ Multiple quark wave functions overlap in position and velocity phase space.
  - ➢ Hadrons enhancement at low p_{T}.
- B mesons offer unique probes of the hadronization process
  - ➢ There is no b content in incoming beam particles.
  - ➢ Production well described by pQCD.
  - ➢ Fragmentation functions measured with B mesons.
  - ➢ Enhanced production of B_s^0 relative to B^0 as particle density increases could be caused by coalescence.



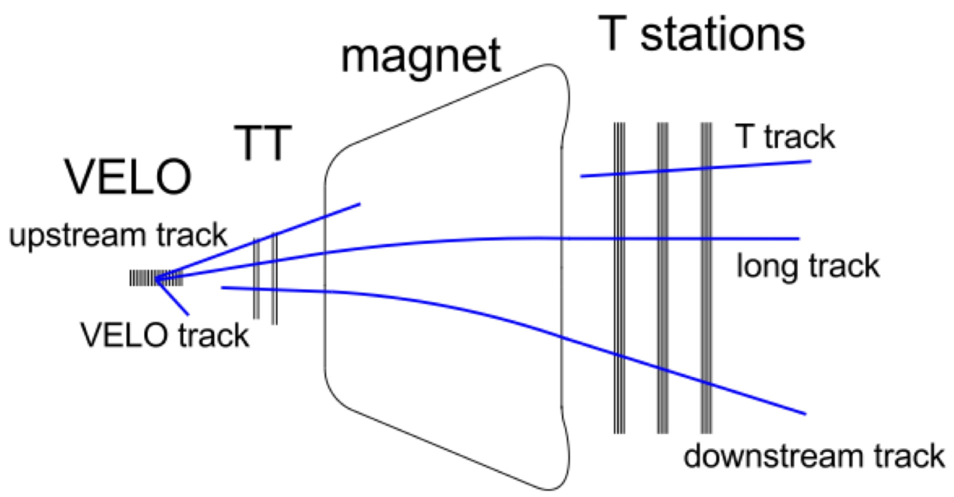
LHCb detector

- A single-arm spectrometer in the forward direction, charm & beauty factory
  - ➢ Vertex Locator (20 μm IP resolution)
  - ➢ Tracking system ($\Delta p/p = 0.5 - 1.0\%$)
  - ➢ RICH: p/K/π separation
  - ➢ Flexible software trigger



VErtex LOcator

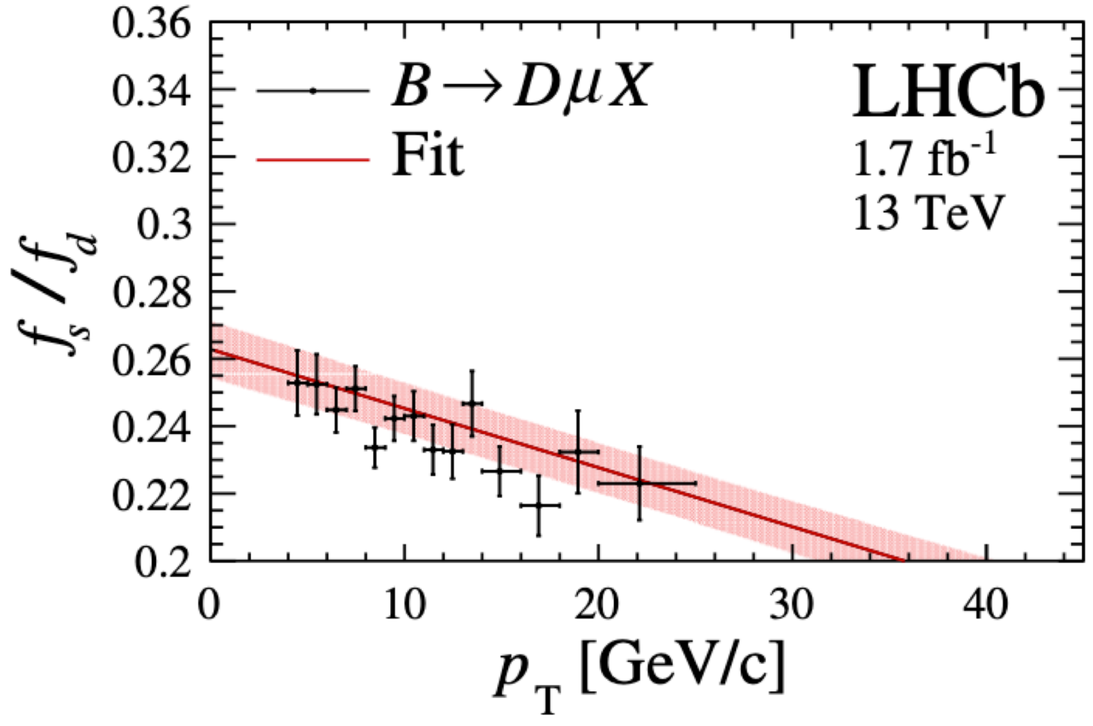
- VELO tracks : have hits in the VELO
- Back tracks : subset of VELO tracks, point in the backward direction

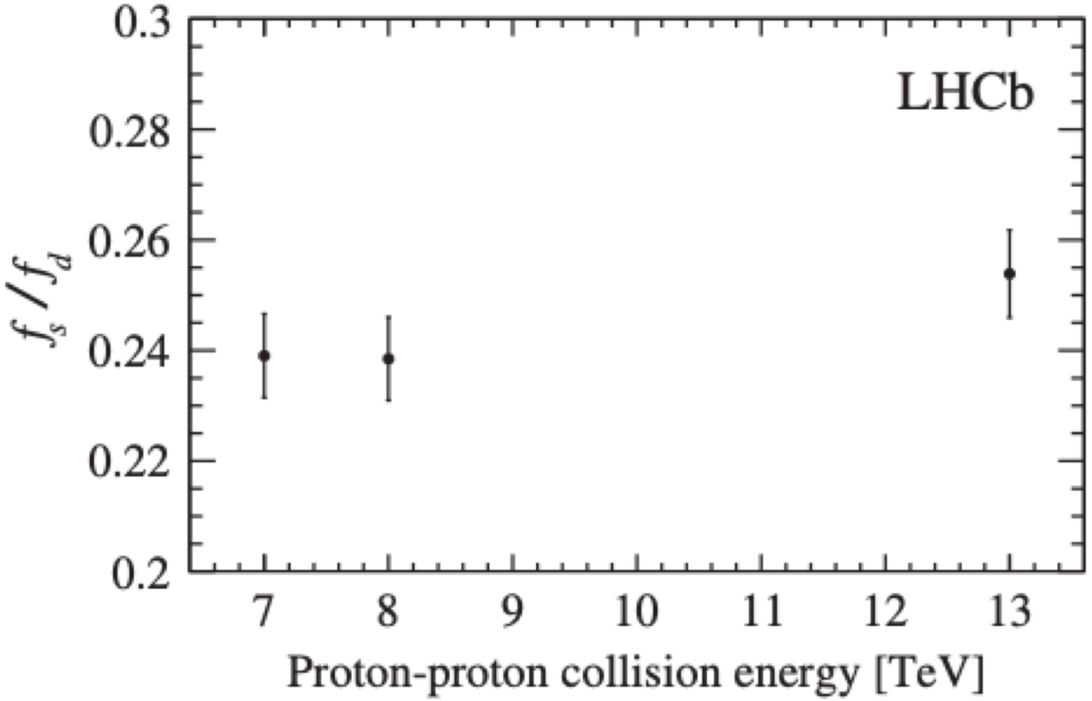


LHCb, JINST 3 (2008) S08005
LHCb, IJMPA 30 (2015) 1530022
JINST 10 (2015) 02 P02007

Fragmentation functions ratios in *pp* collisions

- Fragmentation functions measured with B mesons : $\frac{f_s}{f_d} \propto \frac{N_{corr}(B_s^0)}{N_{corr}(B^0)}$
  - $\frac{f_s}{f_d}$ is observed to depend on the B meson transverse momentum.
  - No dependence on the collision energy.





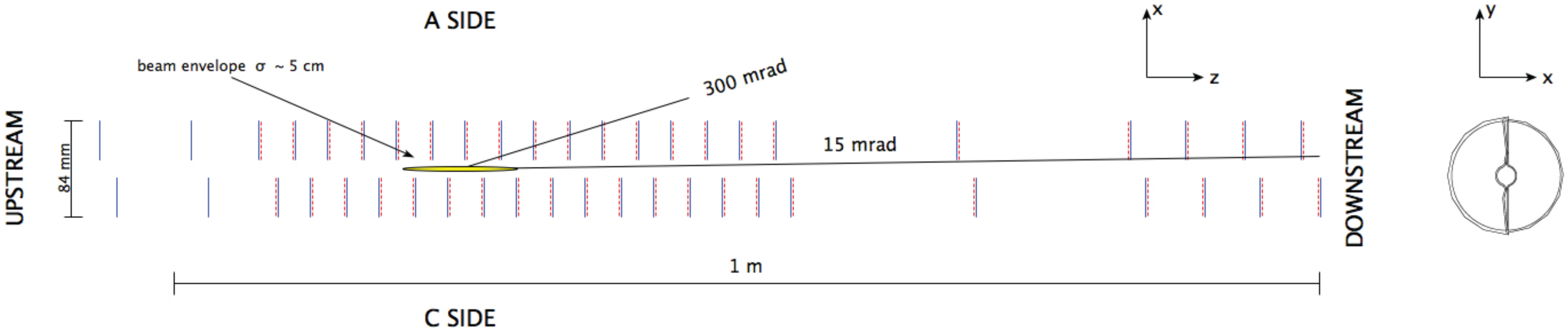
Phys. Rev. D 104(2021) 032005

Strangeness enhancement with B mesons in *pp* collisions at 13TeV

- The *pp* 13TeV data was taken in 2016+2017+2018 with 5.4 fb^{-1}.
- Ratio of B_s^0/B^0 cross sections versus multiplicity, in several $p_{\rm T}$ bins
  - Both states are simultaneously accessible in $J/\psi\pi^+\pi^-$, Relative corrections are generally close to 1 .

$$\frac{\sigma_{B_s^0}}{\sigma_{B^0}} = \frac{N_{B_s^0}}{N_{B^0}} \times \frac{\mathcal{B}_{B^0}}{\mathcal{B}_{B_s^0}} \times \frac{\varepsilon_{B^0}^{\rm acc}}{\varepsilon_{B_s^0}^{\rm acc}} \times \frac{\varepsilon_{B^0}^{\rm trig}}{\varepsilon_{B_s^0}^{\rm trig}} \times \frac{\varepsilon_{B^0}^{\rm PID}}{\varepsilon_{B_s^0}^{\rm PID}} \times \frac{\varepsilon_{B^0}^{\rm reco}}{\varepsilon_{B_s^0}^{\rm reco}},$$

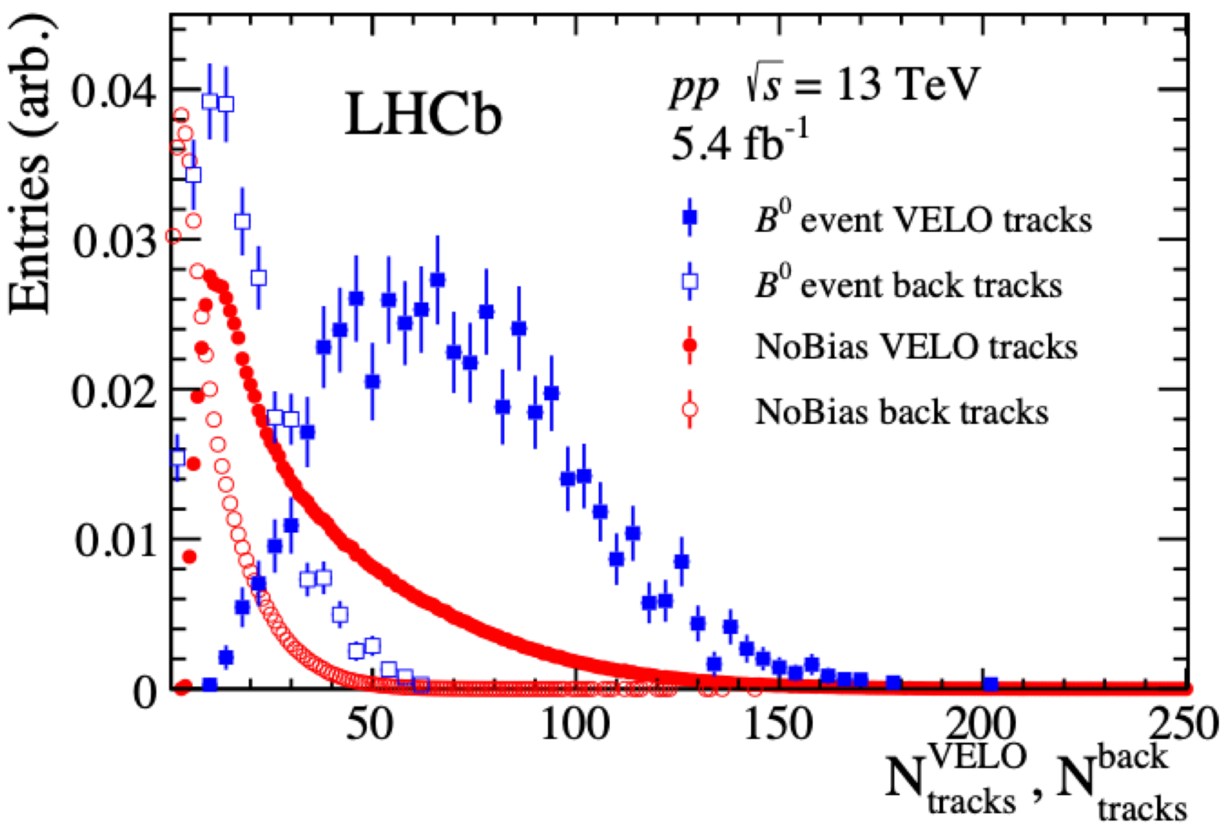
- Event characterization:
  - Multiplicity represented by VELO tracks or back tracks
  - Restrict to events a single reconstructed primary vertex
  - Require z position of primary vertex to fall in the central area for stable VELO acceptance



JINST 9 (2014) P09007

Event characterization

- NoBias events are selected based on the LHC beam clock, which indicates that a bunch crossing has occurred, without any other trigger requirements.
- B^0 signal events are extracted from the data, and background is removed using the *sPlot* method.
- Events with B mesons have significantly different charged particle densities than nobias events.

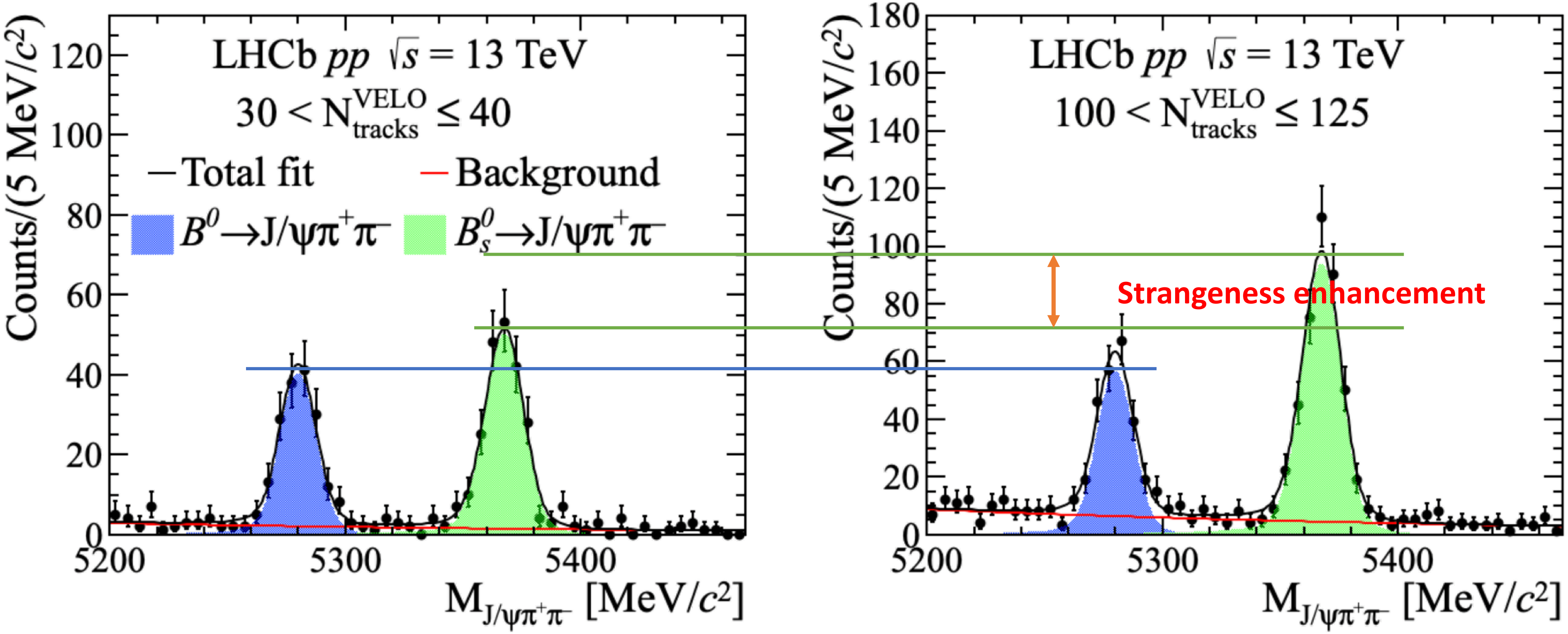


$$< N_{tracks}^{VELO} >_{NoBias} = 37.7$$
$$< N_{tracks}^{back} >_{NoBias} = 11.1$$
$$< N_{tracks}^{VELO} >_{B^0} = 71.1$$
$$< N_{tracks}^{back} >_{B^0} = 17.4$$

Yield

- Fit model: Crystal Ball functions + exponential function

$$\frac{\sigma_{B_s^0}}{\sigma_{B^0}} = \frac{N_{B_s^0}}{N_{B^0}} \times \frac{\mathcal{B}_{B^0}}{\mathcal{B}_{B_s^0}} \times \frac{\varepsilon^{\rm acc}_{B^0}}{\varepsilon^{\rm acc}_{B_s^0}} \times \frac{\varepsilon^{\rm trig}_{B^0}}{\varepsilon^{\rm trig}_{B_s^0}} \times \frac{\varepsilon^{\rm PID}_{B^0}}{\varepsilon^{\rm PID}_{B_s^0}} \times \frac{\varepsilon^{\rm reco}_{B^0}}{\varepsilon^{\rm reco}_{B_s^0}},$$

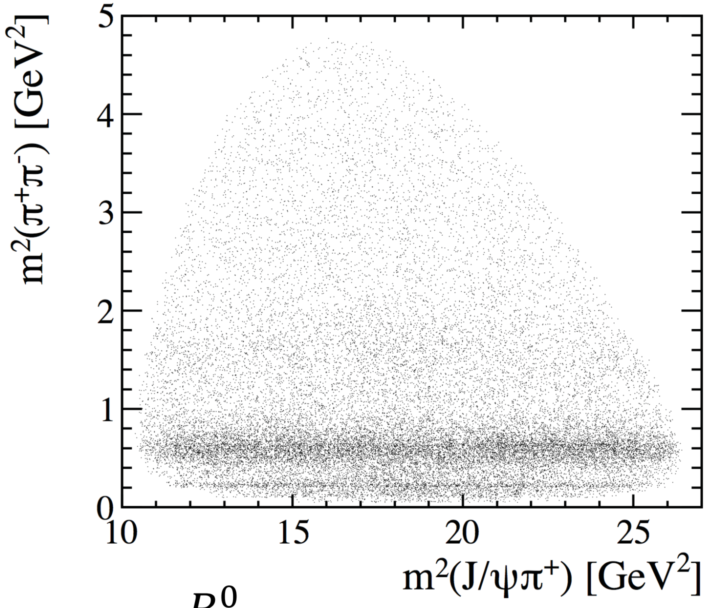


arXiv:2204.13042

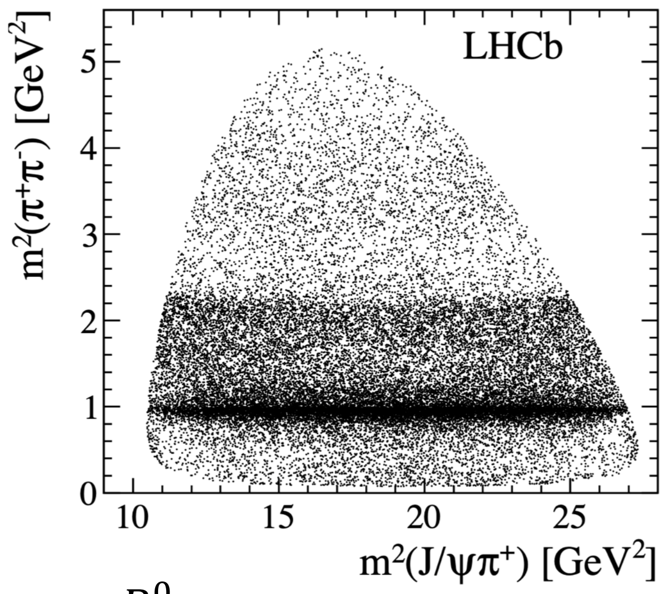
Efficiencies

$$\frac{\sigma_{B_s^0}}{\sigma_{B^0}} = \frac{N_{B_s^0}}{N_{B^0}} \times \frac{\mathcal{B}_{B^0}}{\mathcal{B}_{B_s^0}} \times \frac{\varepsilon_{B^0}^{\mathrm{acc}}}{\varepsilon_{B_s^0}^{\mathrm{acc}}} \times \frac{\varepsilon_{B^0}^{\mathrm{trig}}}{\varepsilon_{B_s^0}^{\mathrm{trig}}} \times \frac{\varepsilon_{B^0}^{\mathrm{PID}}}{\varepsilon_{B_s^0}^{\mathrm{PID}}} \times \frac{\varepsilon_{B^0}^{\mathrm{reco}}}{\varepsilon_{B_s^0}^{\mathrm{reco}}},$$

- $\frac{\varepsilon_{B^0}^{acc}}{\varepsilon_{B_s^0}^{acc}} = 1 \pm 0.01$， $\frac{\varepsilon_{B^0}^{trig}}{\varepsilon_{B_s^0}^{trig}} = 1 \pm 0.01$， $\frac{\varepsilon_{B^0}^{PID}}{\varepsilon_{B_s^0}^{PID}} = 1 \pm 0.01$
- $\frac{\varepsilon_{B^0}^{reco}}{\varepsilon_{B_s^0}^{reco}} = 0.86 \pm 0.04$: Due to the difference in the dipion mass distributions produced in the B_s^0 and B^0 decays.
- Due to the similarities of the B_s^0 and B^0 decays, many systematic uncertainties partially cancel in this ratio of cross sections.



B^0

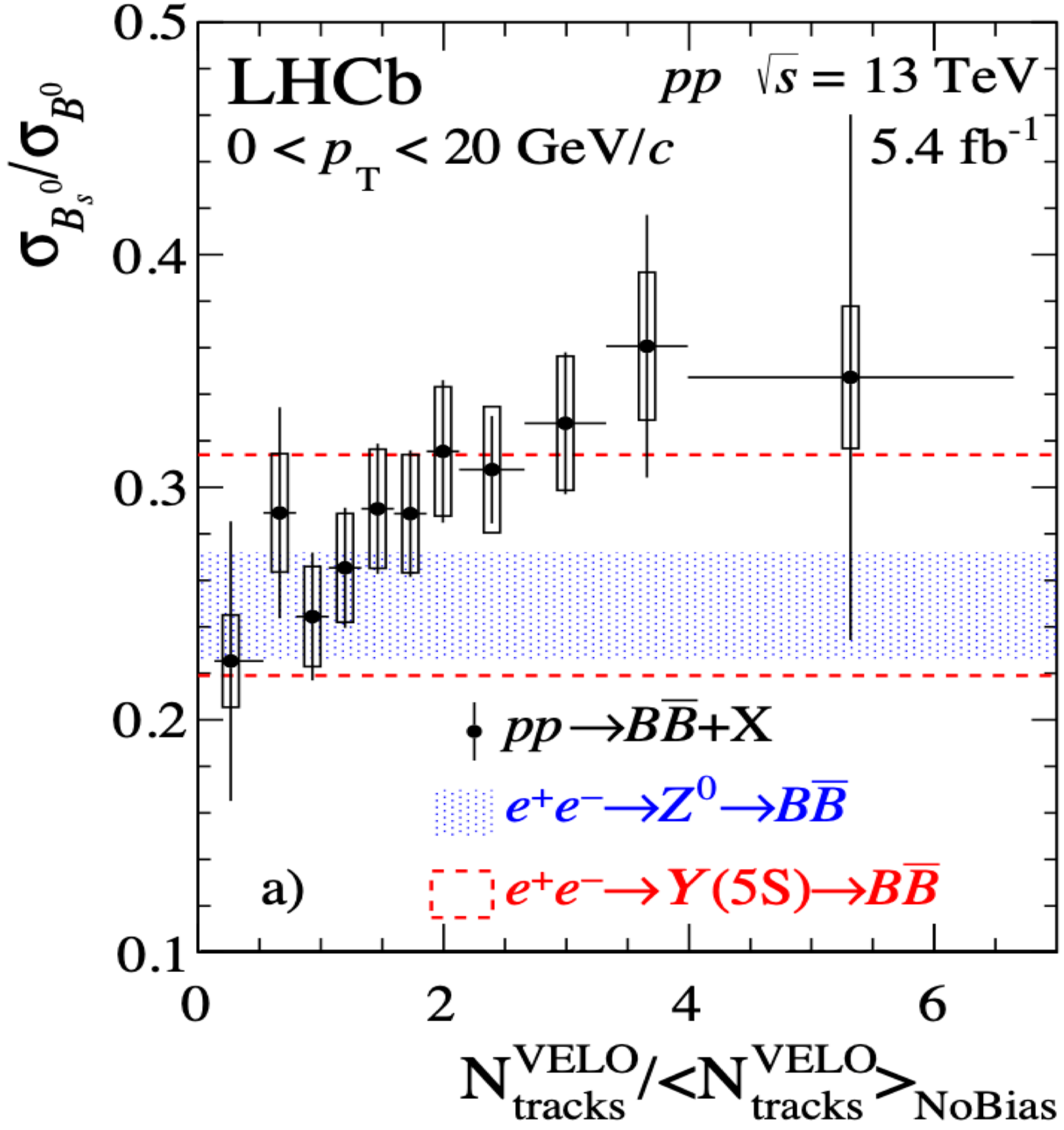


B_s^0

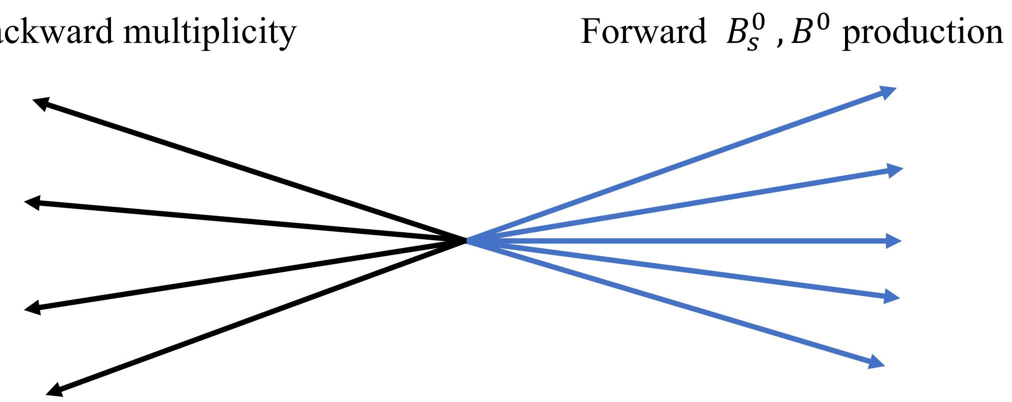
Phys. Rev. D89 (2014) 092006
Phys. Rev. D90 (2014) 012003

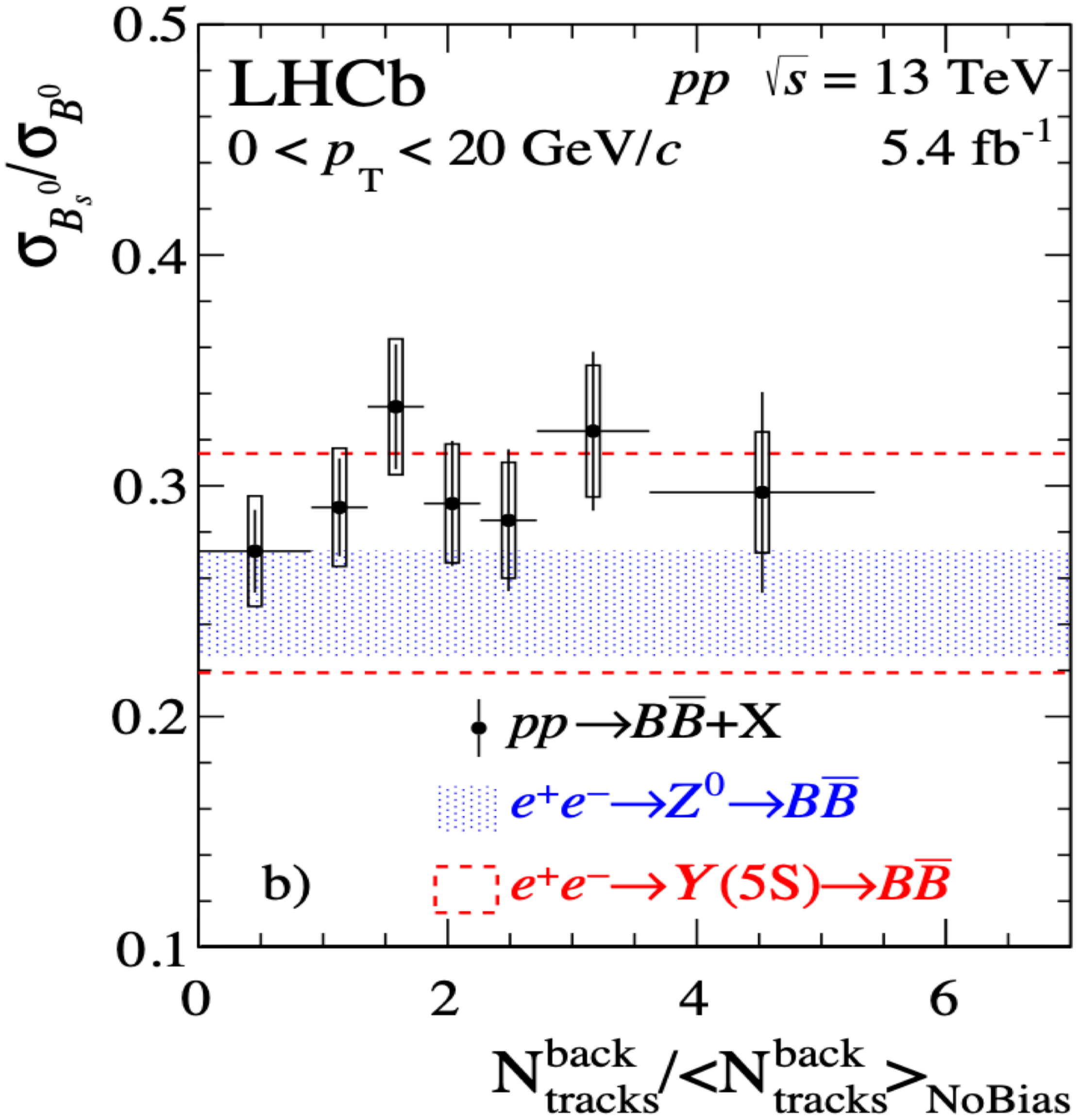
Results: B_s^0/B^0 vs VELO tracks

- The vertical error bars represent uncorrelated uncertainties.
- The vertical error boxes represent fully correlated uncertainties.
- The horizontal bands show the values measured in e^+e^- collisions.
- The ratio shows an increasing trend with the VELO tracks.
- At low multiplicity, consistent with fragmentation in vacuum.



Results: B_s^0/B^0 vs back tracks



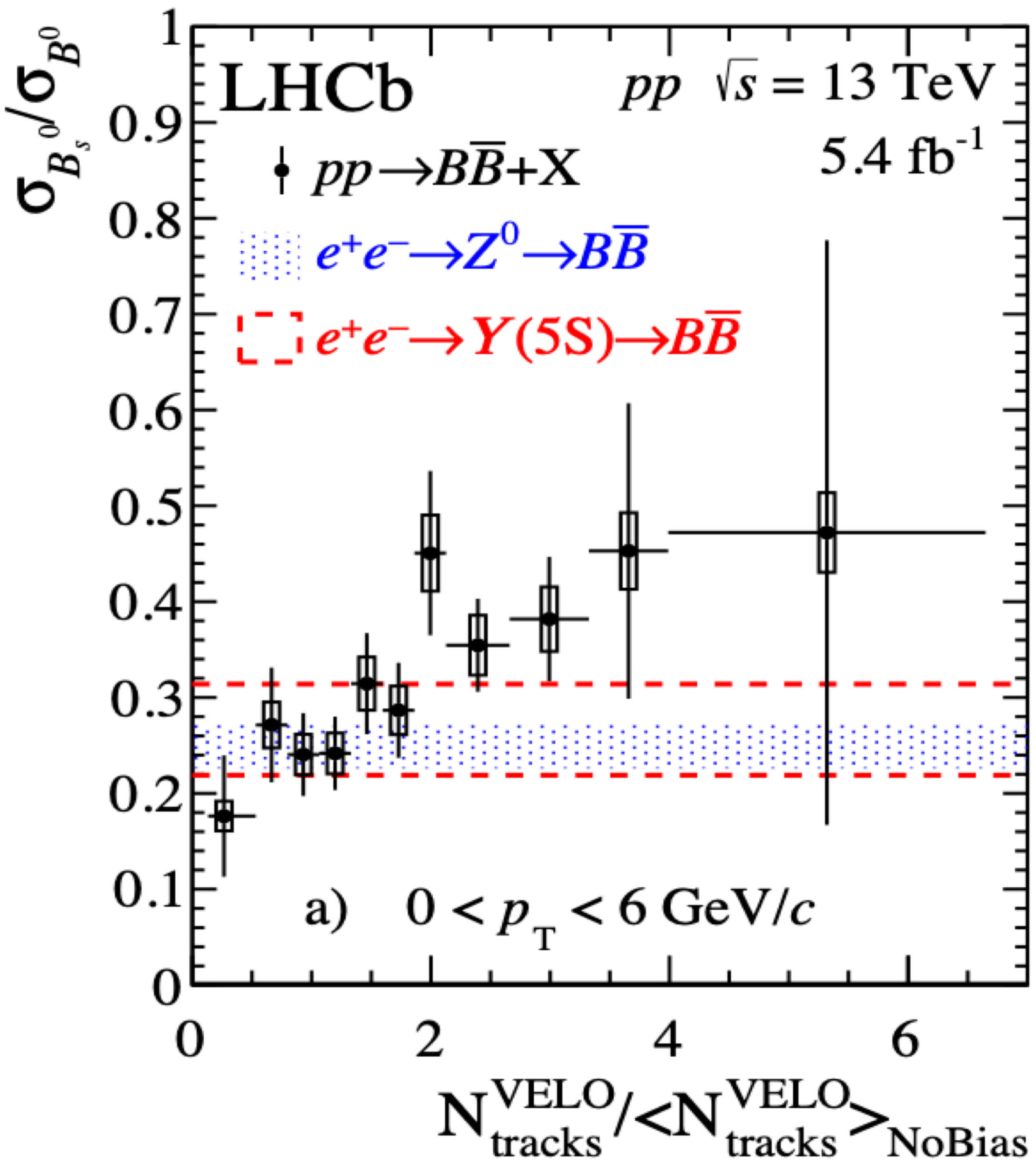


- No significant dependence of forward B_s^0/B^0 ratio on backward multiplicity.
- The results indicate that the mechanism responsible for the ratio increase is related to the local particle density.

arXiv:2204.13042

Results: B_s^0/B^0 in low p_T bins

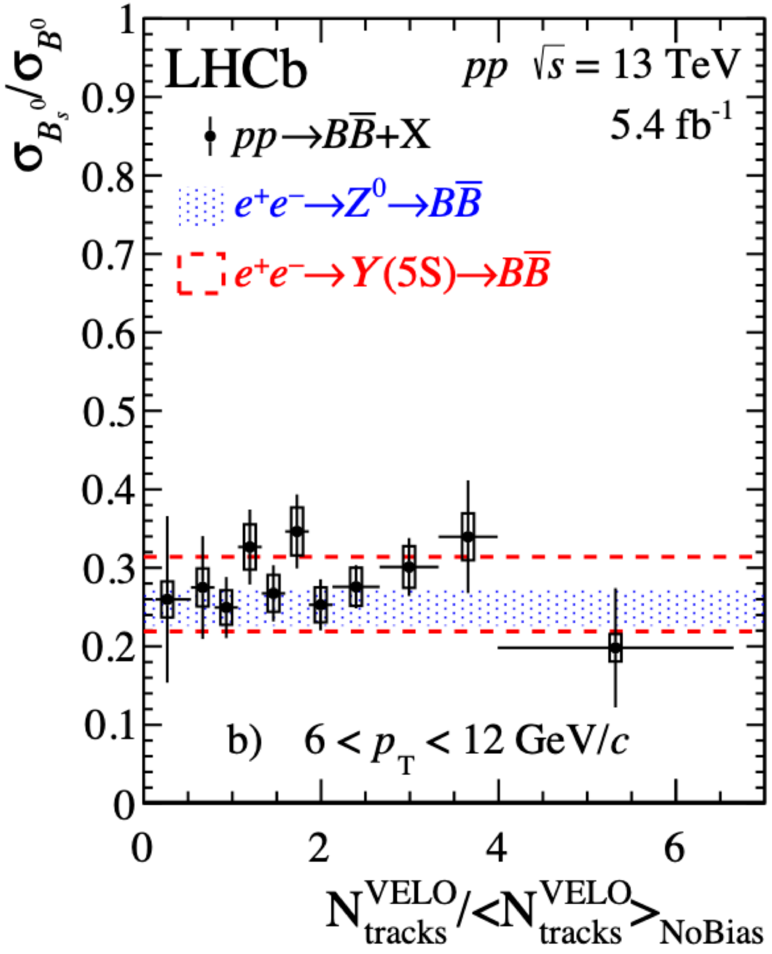
- The $\sigma_{B_s^0}/\sigma_{B^0}$ ratio increases with multiplicity (slope significance = 3.4σ). Consistent with coalescence mechanism qualitatively.
- At low multiplicity the ratio is consistent with values measured in e^+e^- collisions.

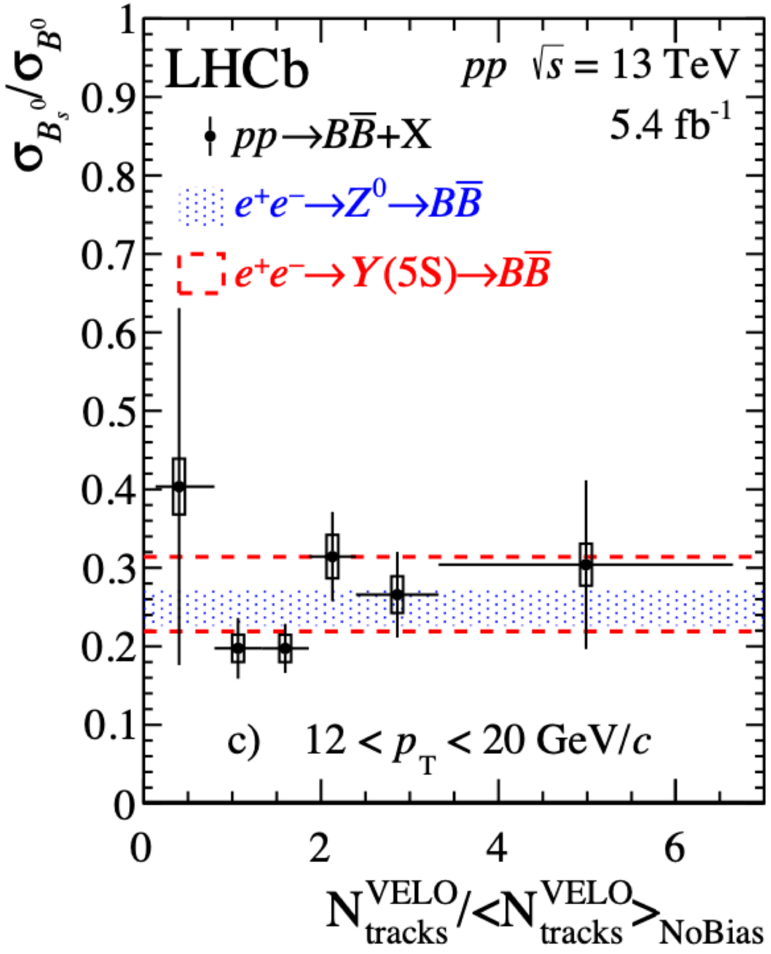


arXiv:2204.13042

Results: B_s^0/B^0 in high p_T bins

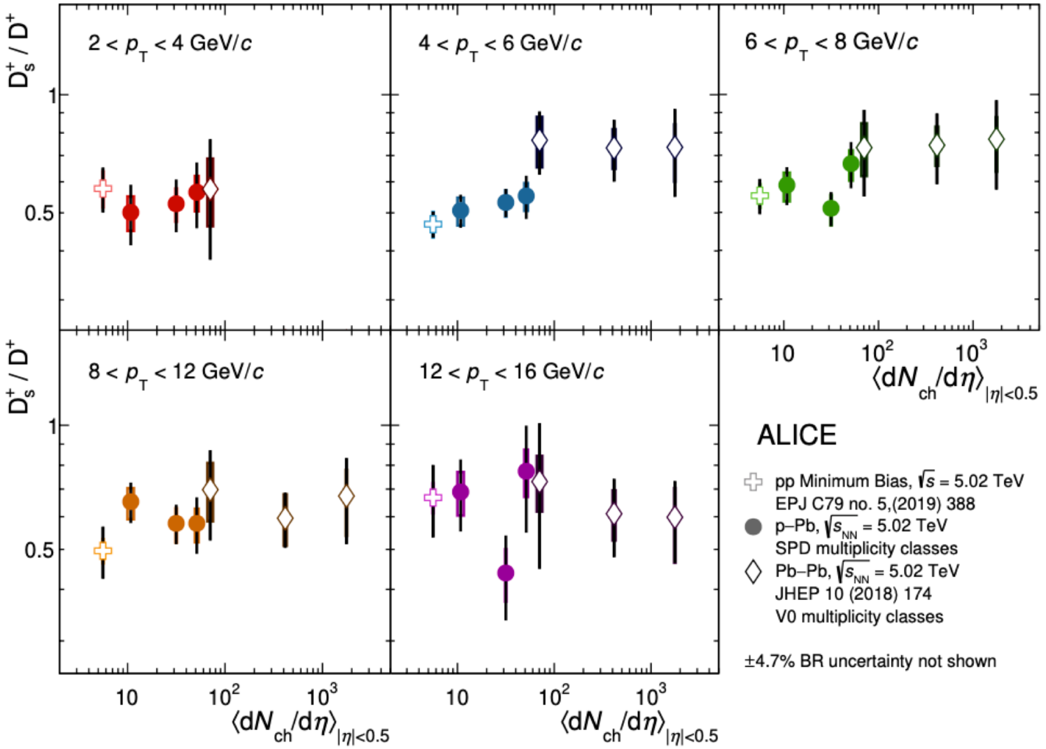
- No significant dependence on multiplicity and consistent with data from e^+e^- collisions.
- High p_T b quarks have less overlap with the low- p_T bulk of the quarks, thereby dominantly hadronize via fragmentation.





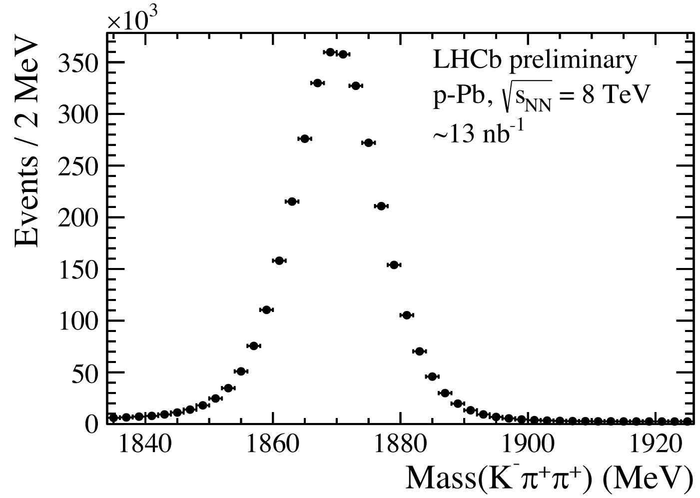
Work in progress: D_s^+/D^+ ratio in pPb collisions at 8.16TeV

- We are studying strangeness enhancement in pPb collision by D_s^+/D^+ ratio.
  - ➢ We use the same strategy as B analysis, the statistics of D mesons are larger.
- ALICE has studied in 5.02 TeV pPb collision.

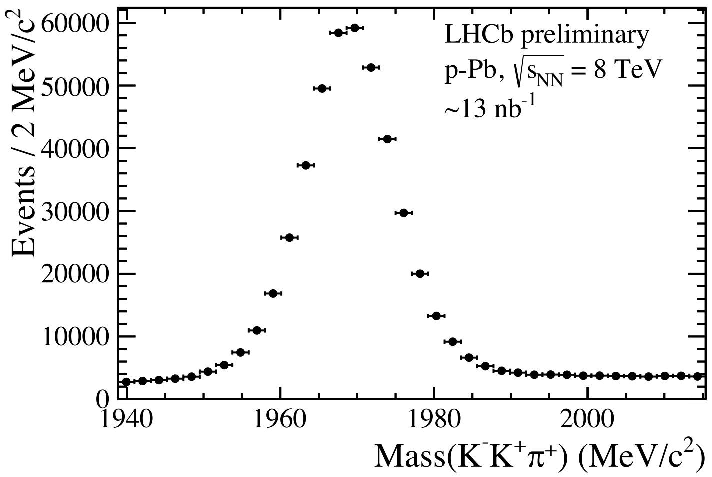


JHEP12(2019)092

$$D^+ \rightarrow K^-\pi^+\pi^+$$



$$D_s^+ \rightarrow K^+K^-\pi^+$$



$$R_{D_s^+/D^+}(p_T, y^*, \text{PV nTracks}) = \frac{N(D_s^{\pm} \to K^{\mp}K^{\pm}\pi^{\pm})}{N(D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm})} \times \frac{\mathcal{B}(D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm})}{\mathcal{B}(D_s^{\pm} \to K^{\mp}K^{\pm}\pi^{\pm})} \times \frac{\epsilon_{D^+}}{\epsilon_{D_s^+}}$$

Summary and outlook

- In pp system, the B_s^0/B^0 enhancement is observed at low p_{T} and consistent with coalescence mechanism qualitatively.
- No significant dependence on backwards multiplicity.
- In pPb system, the D_s^+/D^+ vs multiplicity is in progress.
- In Run3, we have more small systems, such as OO, pO to study multiplicity dependency.