Hadronization summary
Heavy Quark Edition

We would like to charge each speaker to share their thoughts on the hadronization problem, both for small and large collisions systems, based on their personal expertise and preferences.

Christian Bierlich, Münster, September 2024
QCD challenges from pp to AA
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https://www.pythia.org/

Speakers (Wed):
A. Dubla, J. Wang, D. Bala, R. Rapp, J. Stachel
(plus ad hoc contributions)

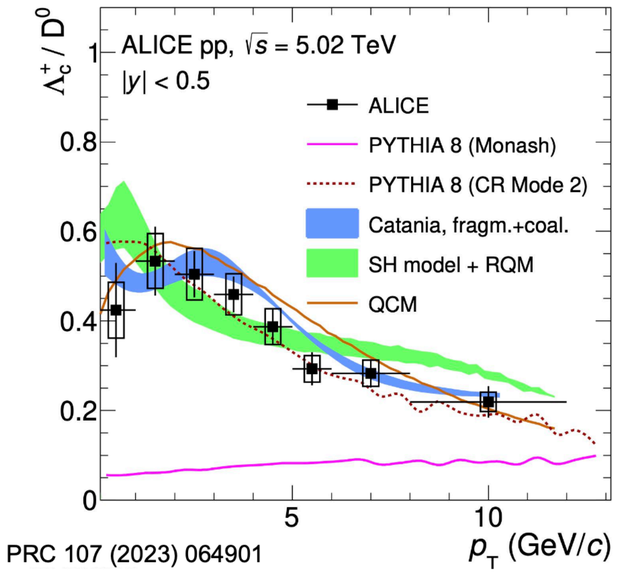
Identification of **four main challenges** across talks and models

1. The Ξ_c problem - why does the coalescence model work so well?
2. The heavy quark potential - is it screened or not?
3. Model validity - can we find common limiting cases? What are the “describe or bust” datasets?
4. Rapidity/multiplicity dependence of baryon production

Bonus: **Wealth of data. See beautiful overview resources by Jing:**
https://boundino.github.io/hinHFplot/ (plot data) https://boundino.github.io/hinHFplot/datasets/publication.html (pub. Overview)

The Ξ_c problem

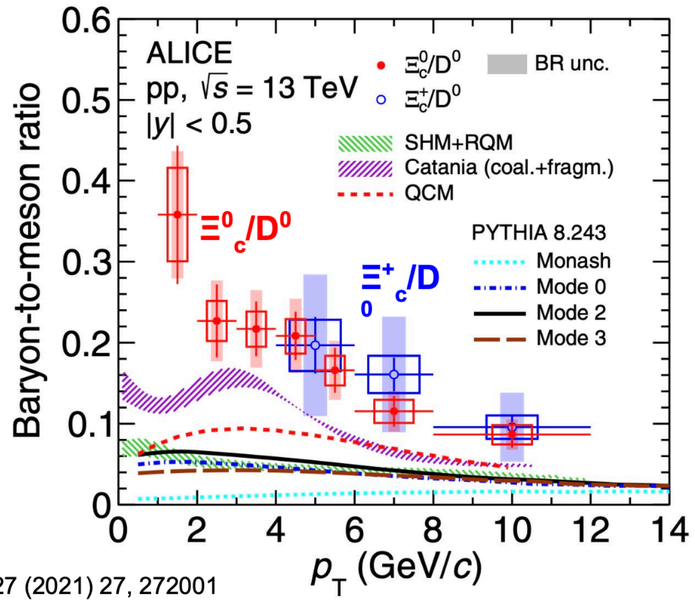
Why is coalescence so successful?



PRC 107 (2023) 064901

Old news:
PYTHIA8+junctions, Catania coalescence and SH+extra states from RQM all describe this.

Problem:
2/3 of above models have a hard time with this



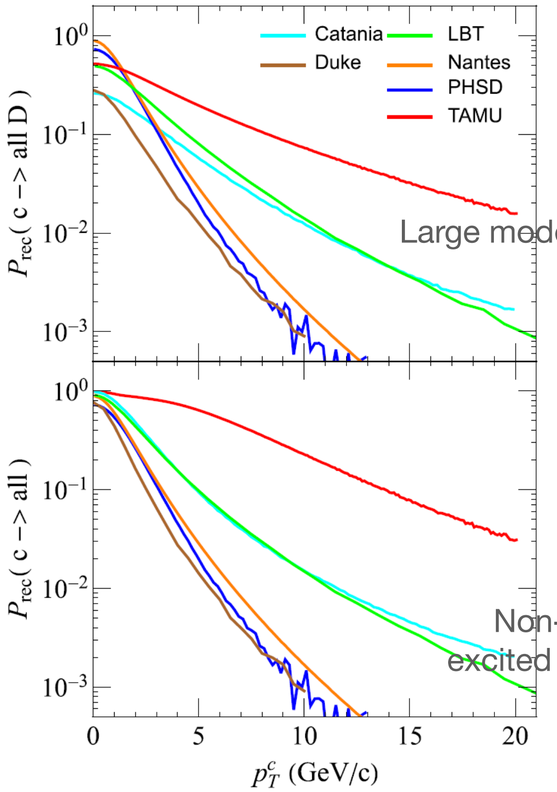
PRL 127 (2021) 27, 272001

As models, coalescence is a “middle ground” between the other two
Is there a physics mechanism responsible?

Homework: Can we make a model comparison with identical feed-down?

Coalescence tension, or?

Heavy quark recombination probabilities

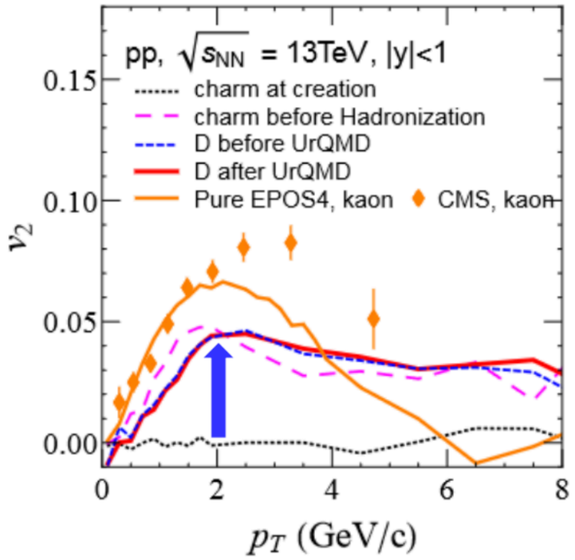


Large model spread

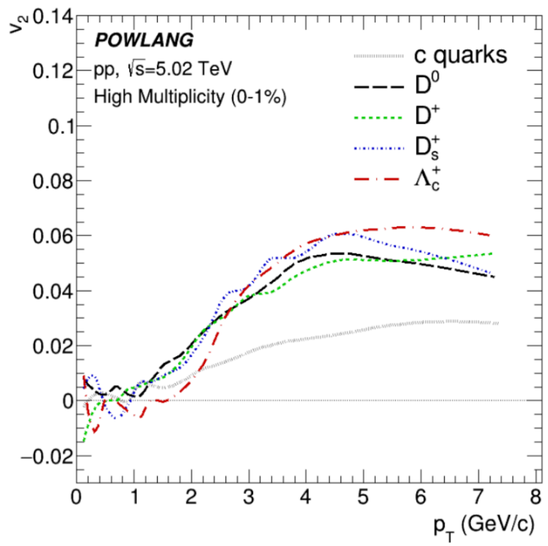
Non-linear recombination + excited resonances reach high pT

Different coalescence models provide different results for charm and charm hadrons v2 in pp collisions

EPOS4@HQ



POWLANG



Advantages of implementing coal. in **EPOS4**:

- Full dynamical realistic dynamics from ep, pp to AA

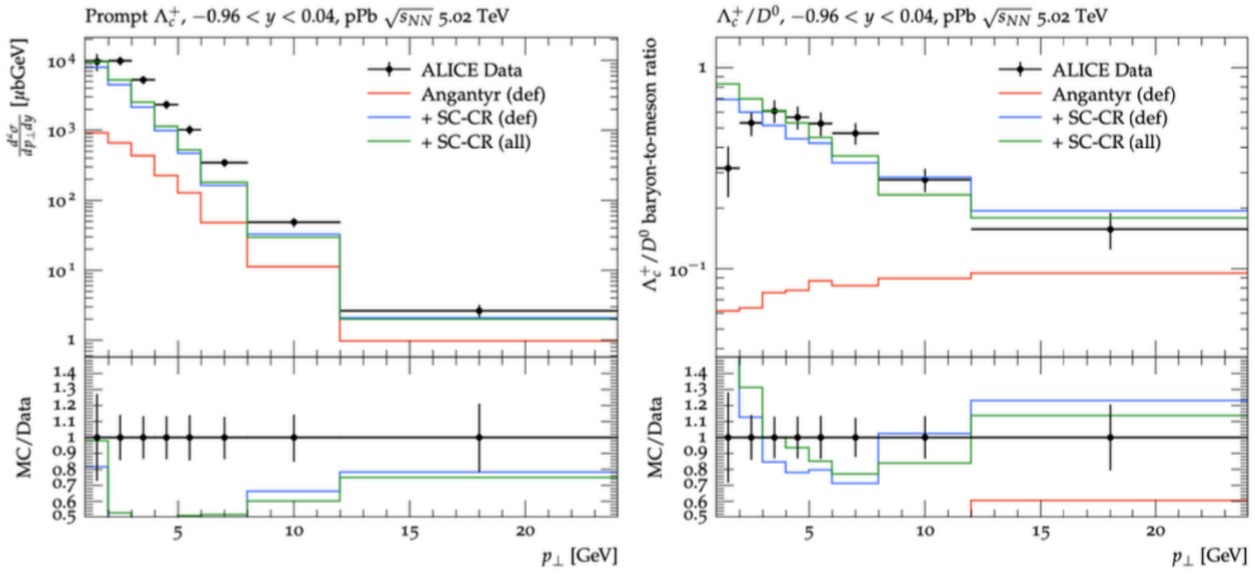
J. Zhao et al., PRD 109, no.5, 054011 (2024)

J. Zhao et al., PRC 110, no.2, 024909 (2024)

difference in coal. wrt Catania: Assume RQM states like in RRM and SHM

Homework: Can we talk about "coalescence" as a single thing? How implementation/model dependent are predictions?

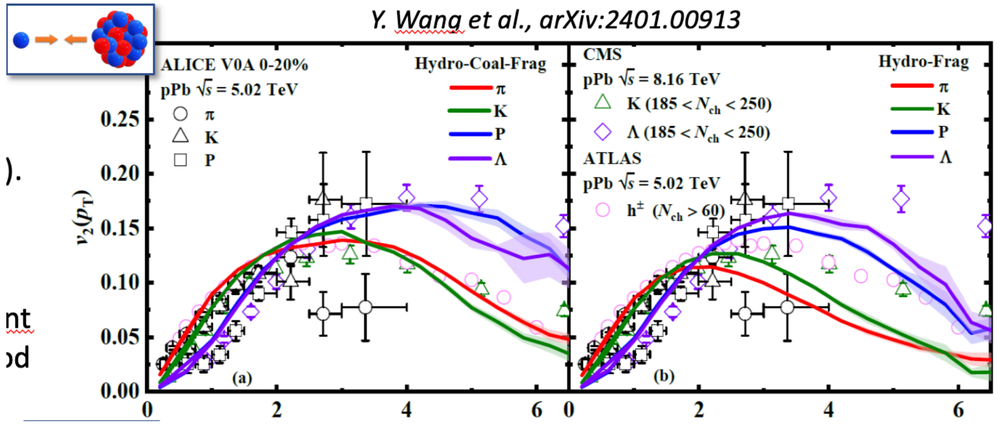
New: Descriptions of pPb data



PYTHIA junctions in pPb for the first time. But a long way to describe elliptic flow

TRENTo + (2+1) viscous hydro VISH2+1
Initial hard partons from PYTHIA8
interaction between hard partons and bulk modeled by linear Boltzmann transport model
hadronic evolution with UrQMD

Y. Wang et al., arXiv:2401.00913

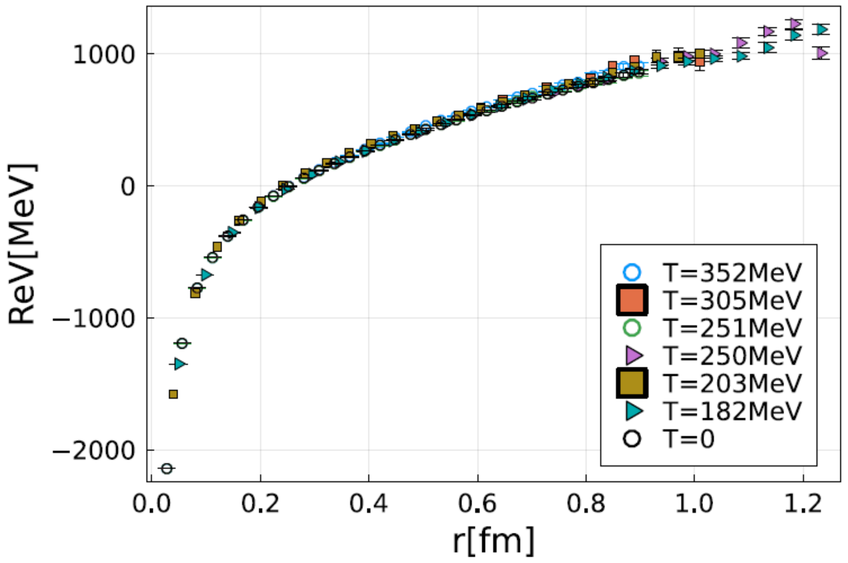


Very competitive description - highly hybrid calculation.

What can pPb tell us that pp/AA cannot? Fertile ground for coalescence and CR viz. unique geometry

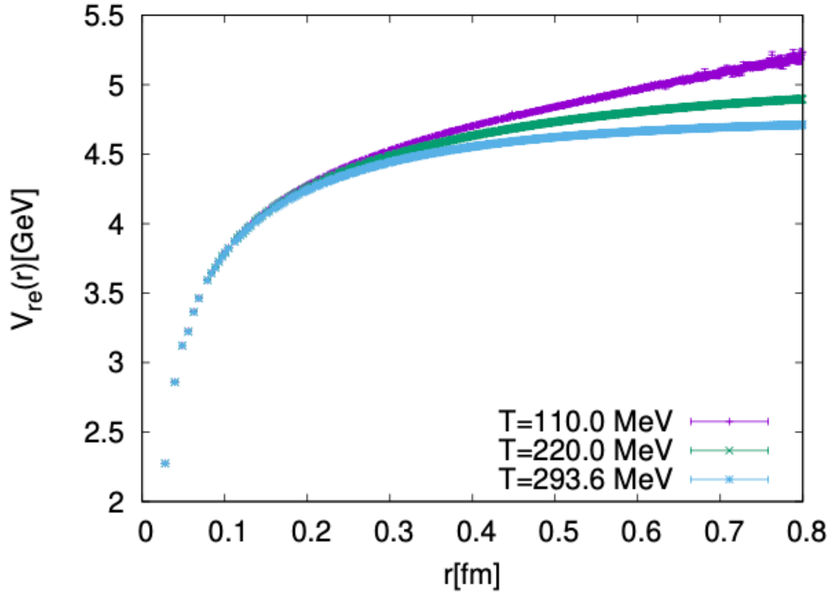
Heavy quark potential

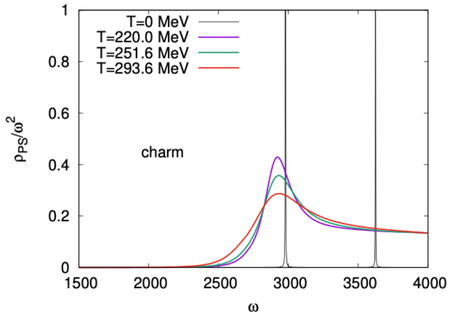
Conflicting lattice interpretation of same simulation



Bazavov et al (2308.16587):
Real part of potential is not screened at short time scales ~1/T

Bala et al:
Wrong! This is due to unphysical choice of spectral functions!



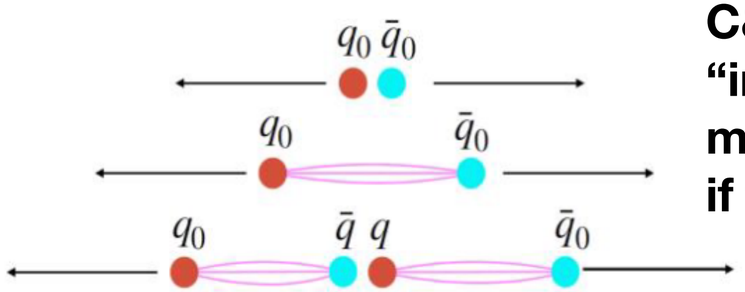


Clearly of large importance for HQ physics (as well as for strings)
Can these results be understood dynamically?

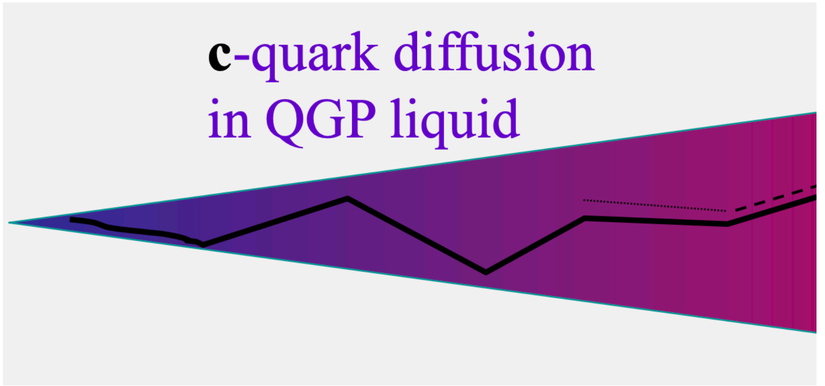
Homework: Can these results be reconciled or will one have to give in?

Model validity

Models are built from fundamentally different starting points



C&C models are the only "interpolators". Correlation measurements to determine if they are successful or not!



Strings: start from vacuum and extrapolate up

SHM: Start from equilibrium and extrapolate down

Agreement: We need to challenge the models away from their comfort zones!

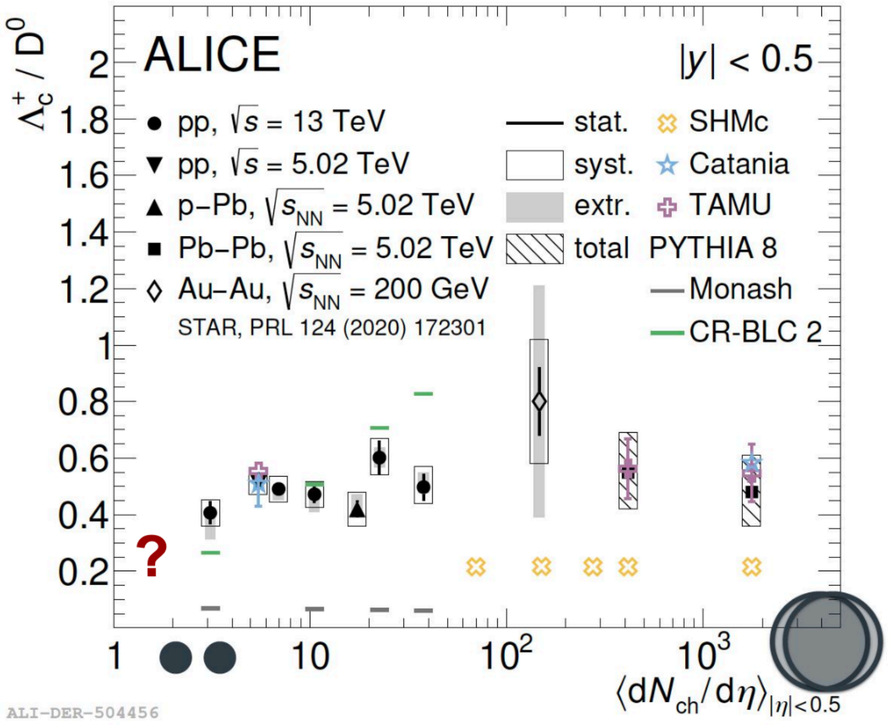
For strings: clearly going to central AA or to theoretically find an equilibrium

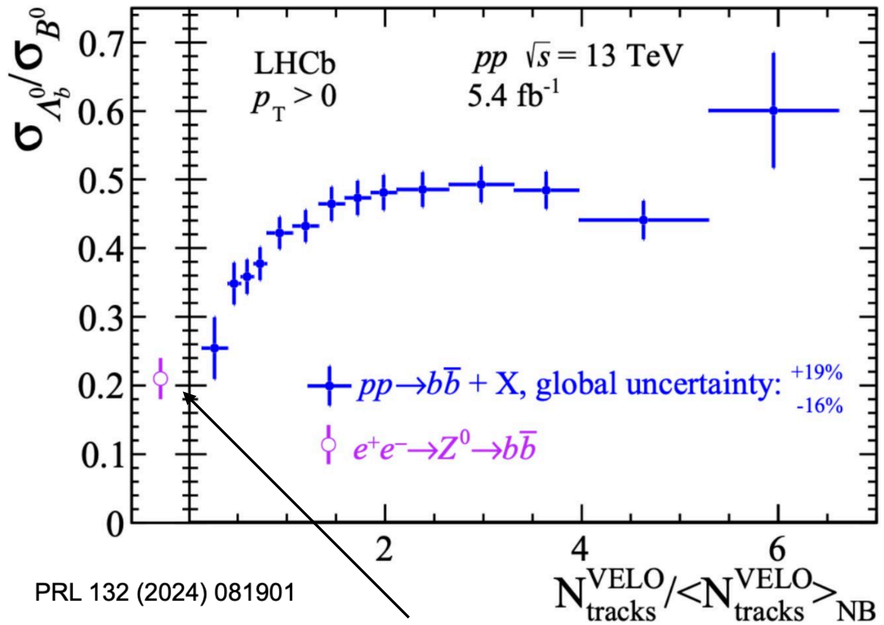
For SHM more unclear. Corona components will necessarily capture vacuum yields.

Correlations/Balance functions more promising (see Peter C)

Model validity/multiplicity dependence

Multiplicity dependence of yield ratios promising testing ground





Importance of connecting to LEP limit!

To be repeated for charm? What about SHM?

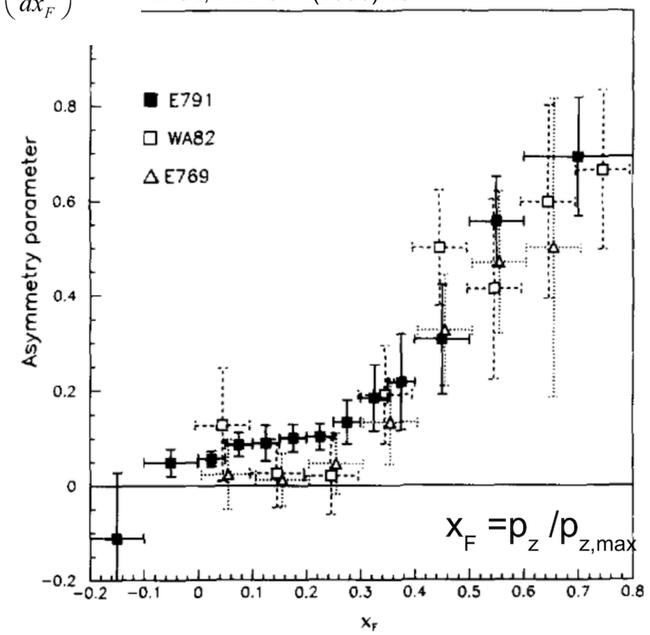
Homework: Can all models be made to saturate? Will strings always have B/M rising?

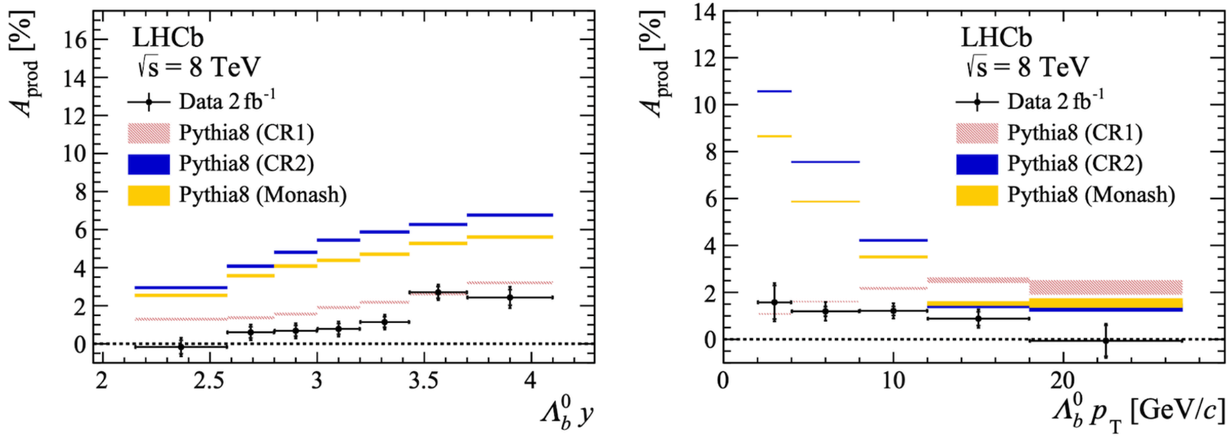
Rapidity dependence

A good proxy for multiplicity or too polluted by remnants?

$$A(x_F) = \frac{\left(\frac{d\sigma}{dx_F}\right)^{D^-} - \left(\frac{d\sigma}{dx_F}\right)^{D^+}}{\left(\frac{d\sigma}{dx_F}\right)^{D^-} + \left(\frac{d\sigma}{dx_F}\right)^{D^+}}$$

WA82, PLB 305 (1993) 402
E791, PLB 371 (1996) 157





History repeat at LHCb

Well explained by Pythia junctions.
Fragmentation = dynamics!

At large x_F: favoured the production of hadrons sharing valence quarks with beam hadrons

Rapidity dependence is a dangerous game - also necessary (?)