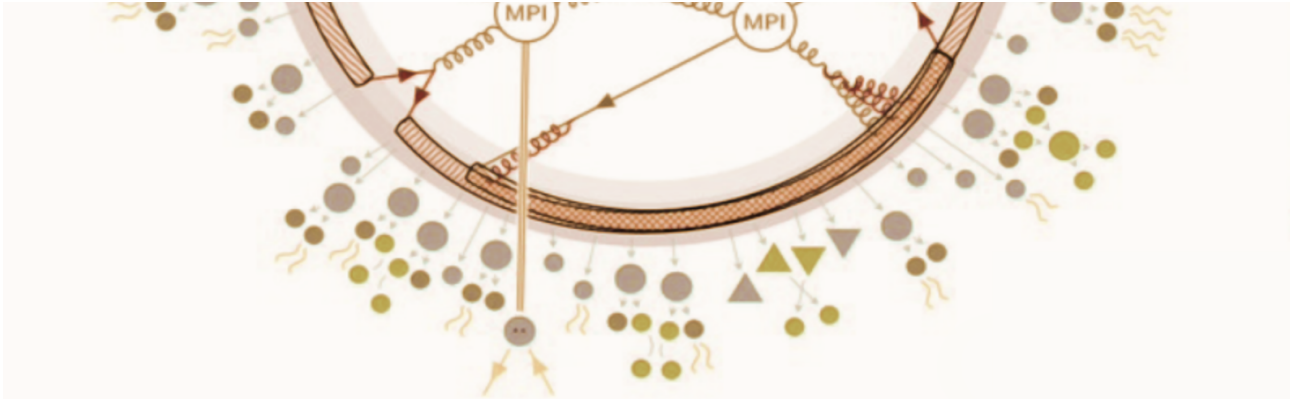
The Angantyr Model
(Pythia for Heavy-ion Collisions)



The Angantyr model
Pythia for Heavy-Ion Collisions

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Non-perturbative and Topological Aspects of QCD
May 29, 2024

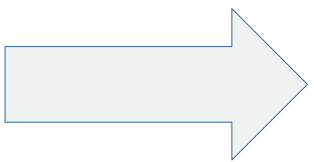
Outline

What is the **Angantyr model** in Pythia?

What is **its status** in reproducing the heavy-ion collisions specific observables?

What will be its **future prospectives** and desire from experiments?

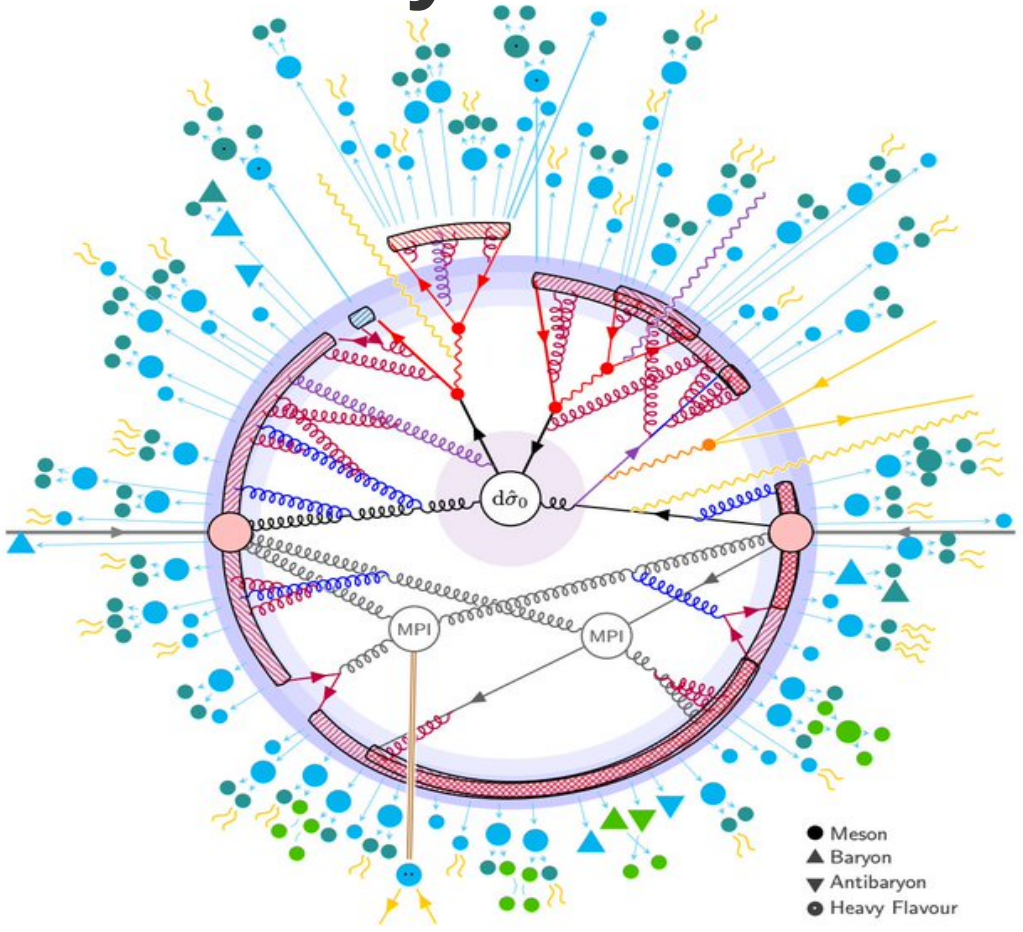
I will not talk about:



- Details of the recents updates in Pythia,
- Angnatyr with photon-nuclear collisions and cosmic rays physics ideas,
- Jet-Queanching,
- Quarkonia suppression.

Pythia event-simulation

arXiv: 2203.11601



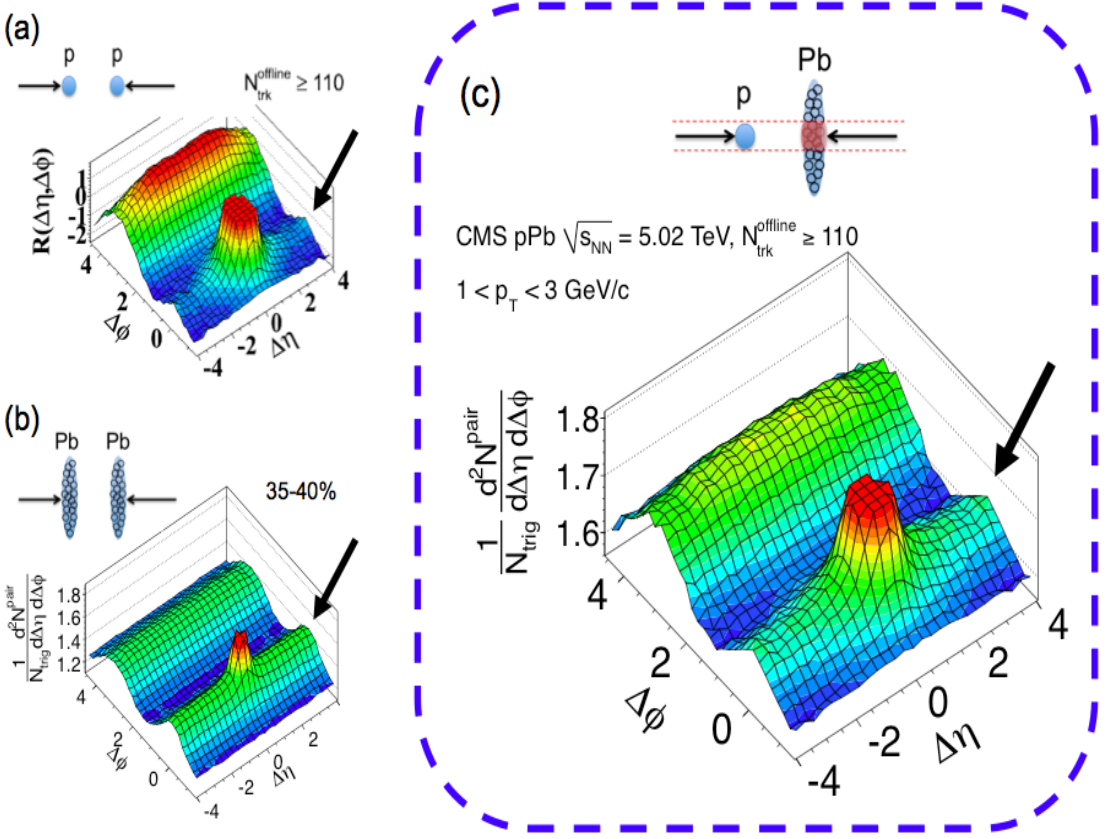
- Hard Interaction
- Resonance Decays
- MECs, Matching & Merging
- FSR
- ISR*
- QED
- Weak Showers
- Hard Onium

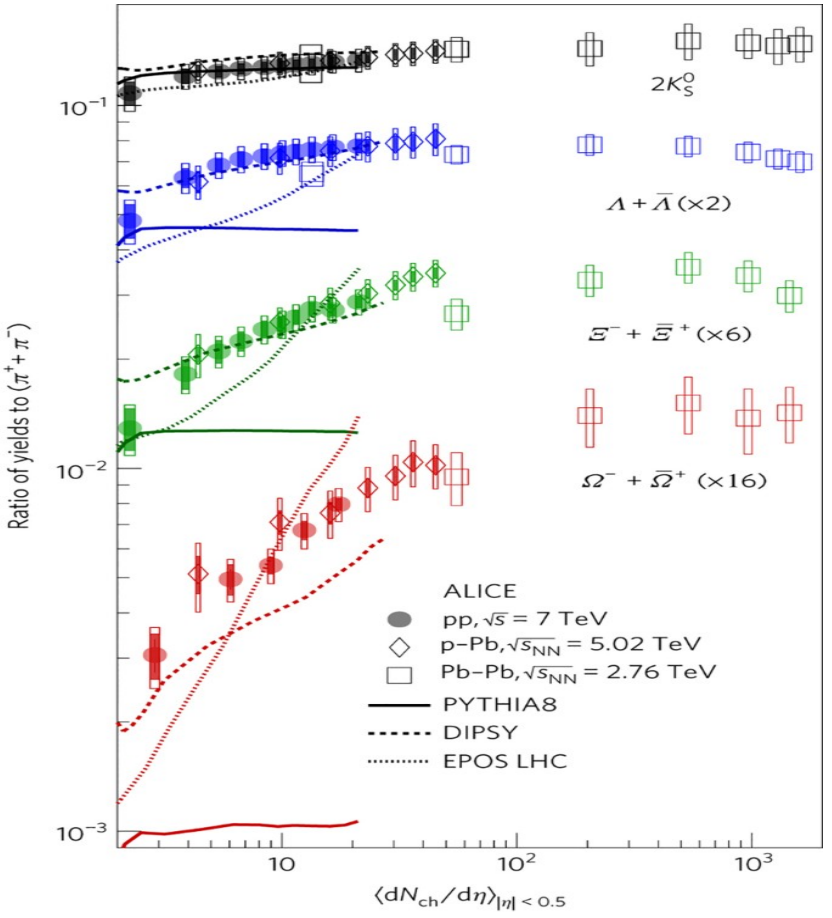
- Multiparton Interactions

- Beam Remnants*
- Strings
- Ministrings / Clusters
- Colour Reconnections
- String Interactions
- Bose-Einstein & Fermi-Dirac
- Primary Hadrons
- Secondary Hadrons
- Hadronic Reinteractions

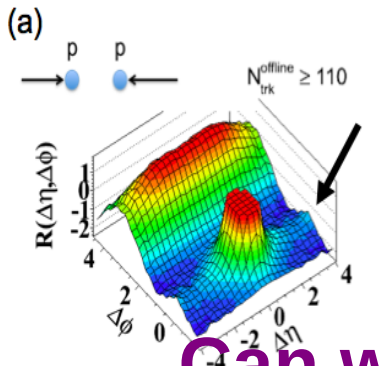
(: incoming lines are crossed)*

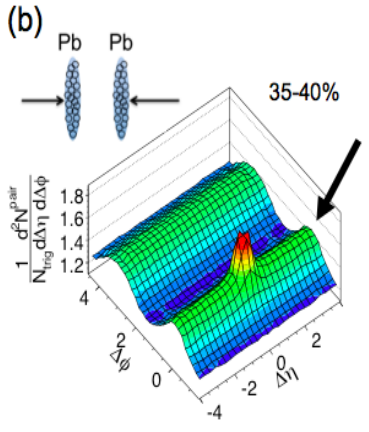
What has been changed in last decade?

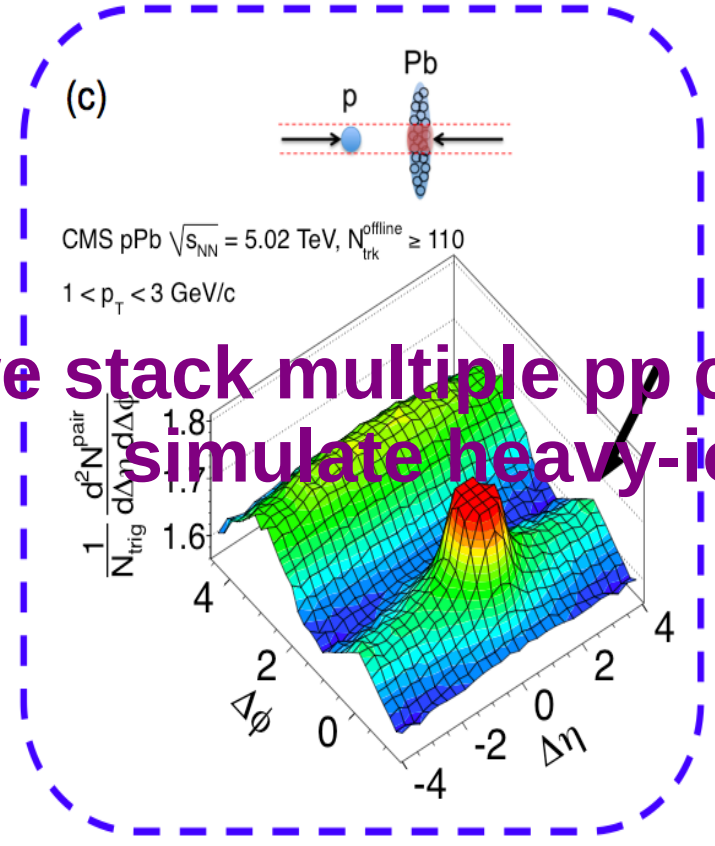




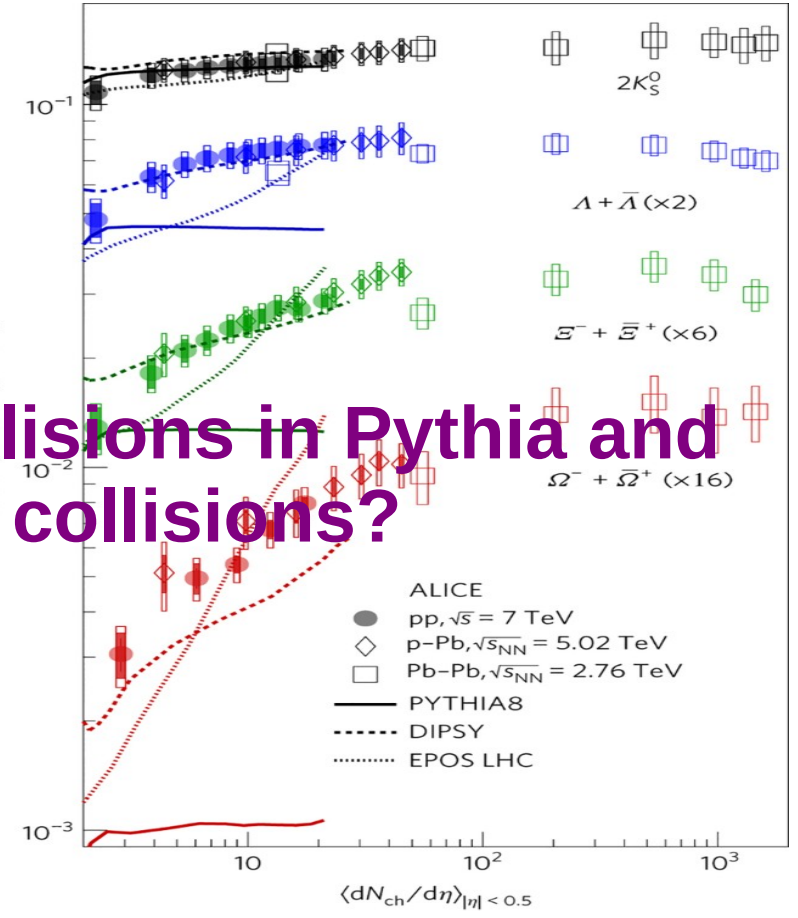
What has been changed in last few years?







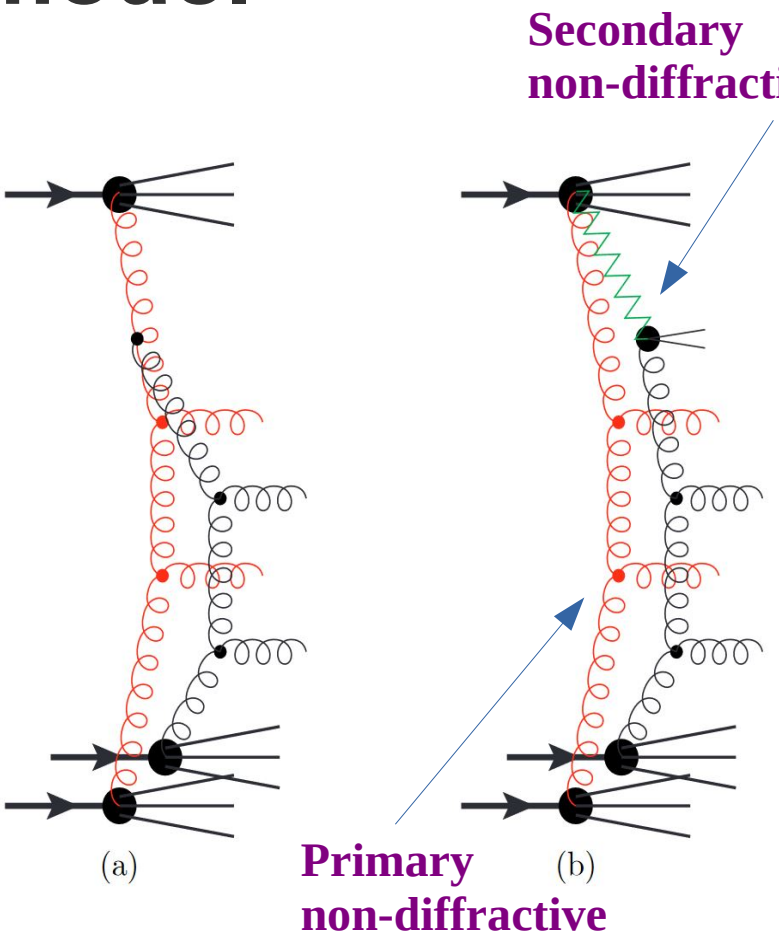
Can we stack multiple pp collisions in Pythia and simulate heavy-ion collisions?



The Angantyr model

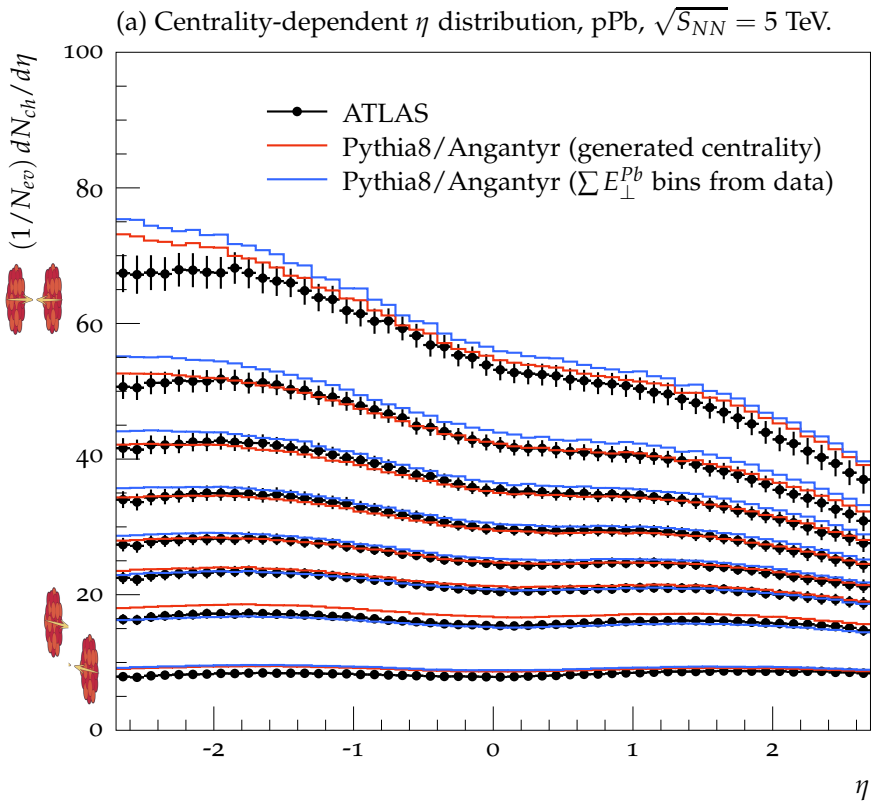
arXiv:1806.10820, 1607.04434

- Glauber Gribove formalism with fluctuations in projectile and target nuclei;
- Wounded nucleons are tagged with the type of collisions;
- Pythia machinery is used to generate multiple nucleon-nucleon sub-collisions;
- A scenario like Figure (a) is not possible to simulate directly with Pythia;
- Pythia's single diffraction machinery is modified and the scenario like Figure (a) is generated as two pp events stacked together like Figure (b);
- The model is tuned at pp collisions;
- The secondary non-diffractive is tuned at pPb collisions;
- **No** tuning at PbPb (or AA) collisions.

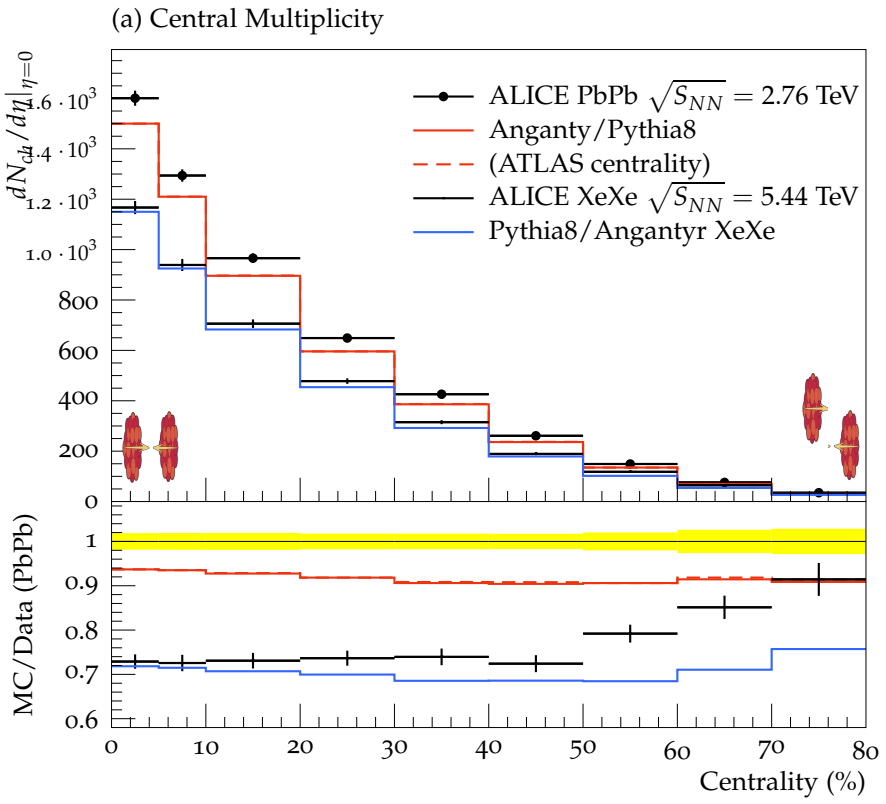


Results: Event multiplicity as a function of centrality in heavy-ion collisions

pPb collisions



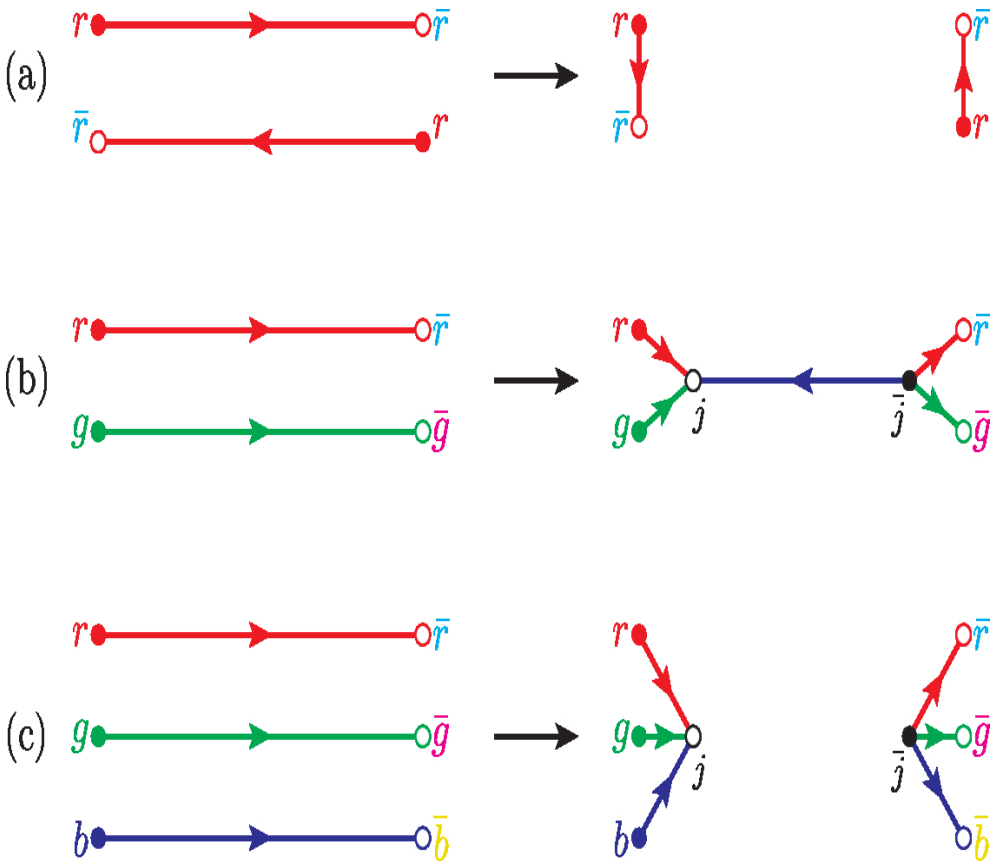
PbPb and XeXe collisions



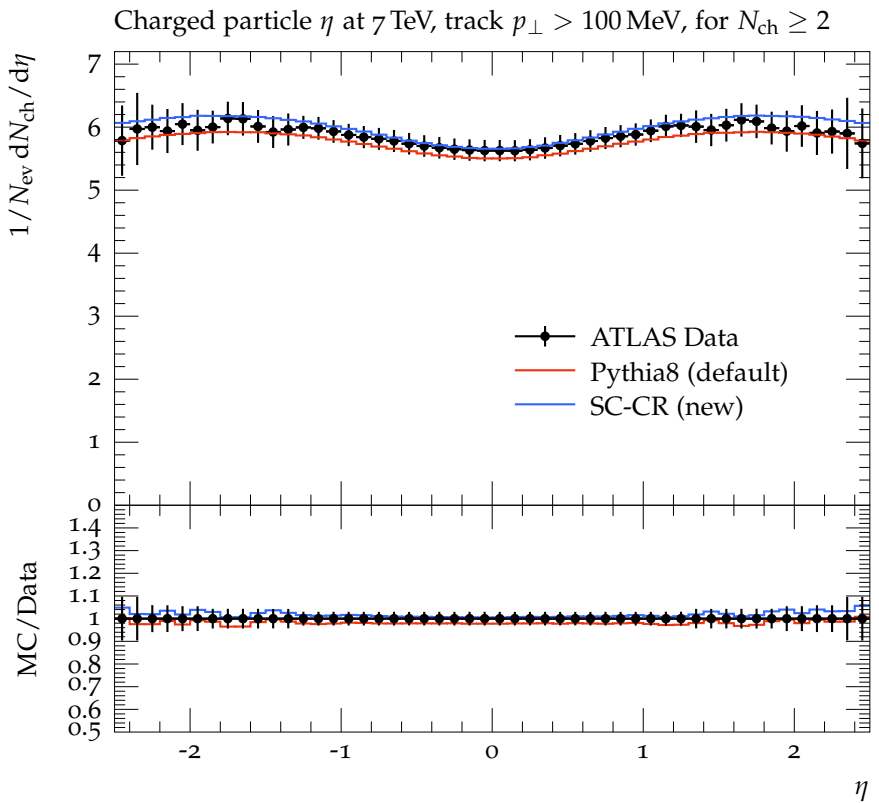
Global Colour Reconnection

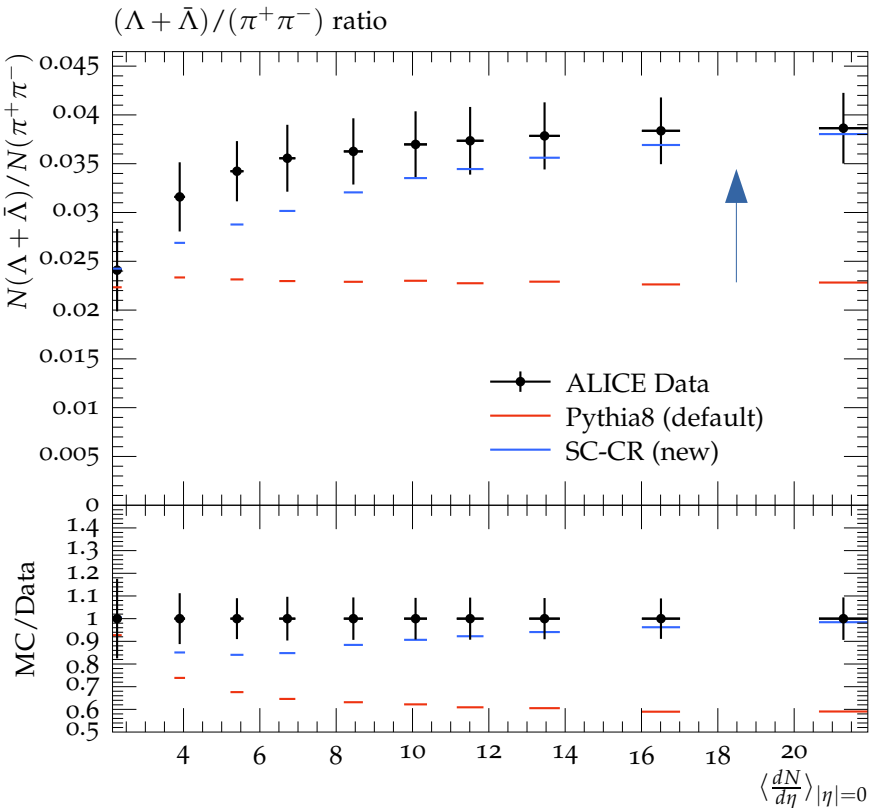
arXiv:2303.11747, 1505.01681

- Angantyr model has HI event generated by multiple pp-like **sub-collisions are super positioned**, but the **partons** produced in different sub-collisions **do not** interact with each other;
- In Pythia, **partons** produced in perturbative scatterings **interact** with each other **at colour reconnection** stage;
- We use QCD inspired CR model, which rearranges colour connections between the colour dipoles according to **SU(3)** colour algebra;
- Configurations like (b) and (c) give **additional contributions to baryons production;**
- The spatial constraint is introduced between colour dipoles to be colour reconnected, the junction fragmentation is extended, and the model is re-tuned.



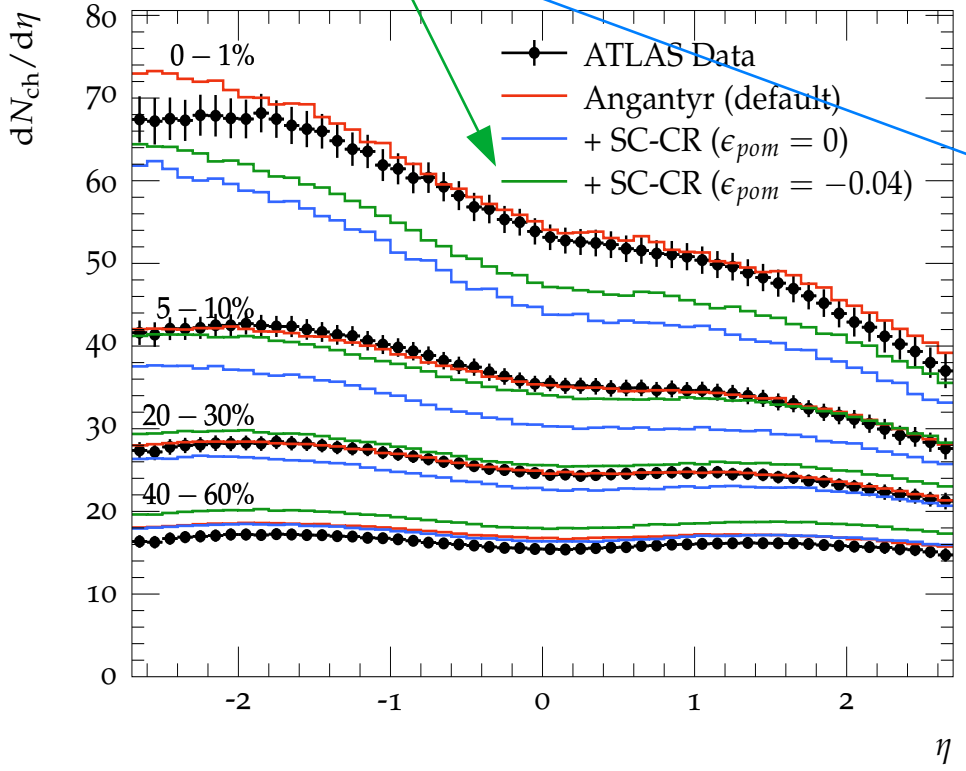
Results: spatially constrained CR in pp collisions

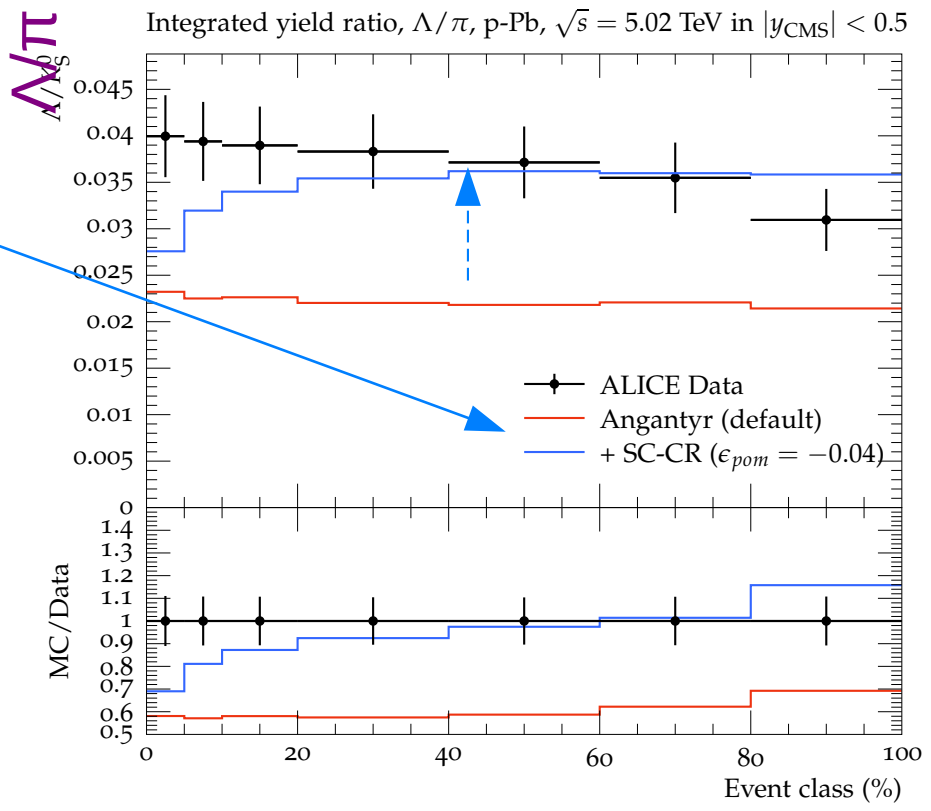




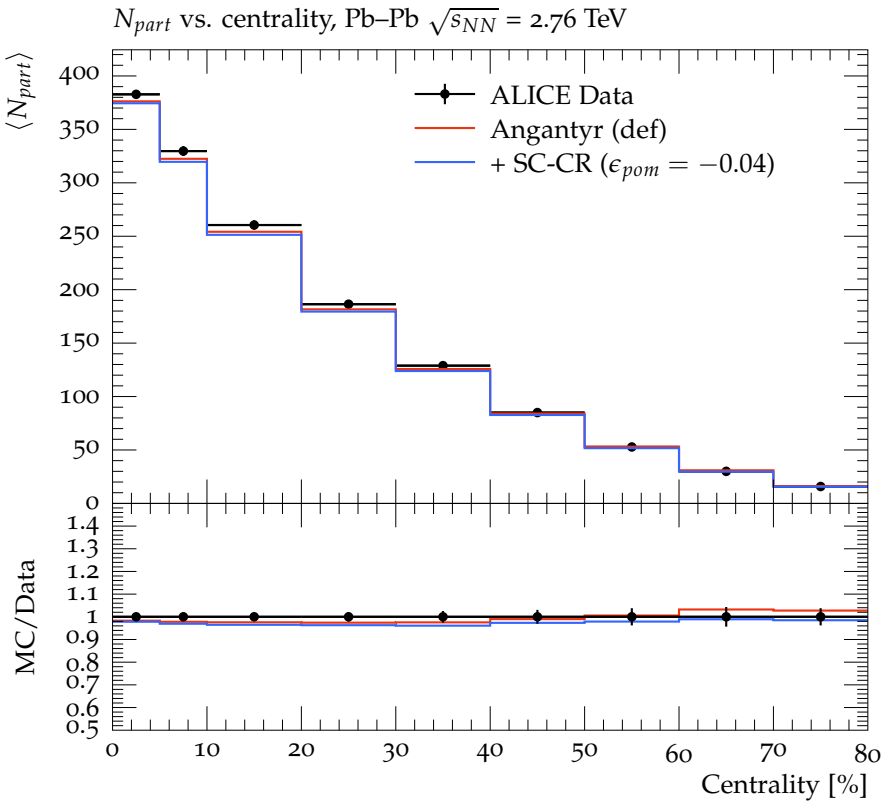
Results: Global CR effects in pPb collisions

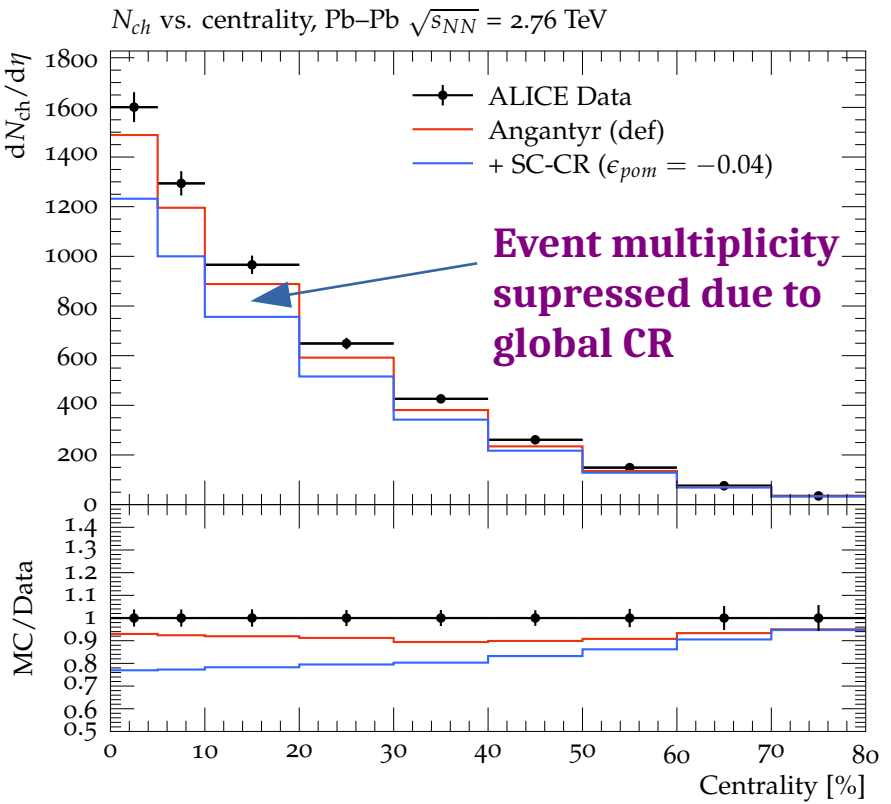
Modified Pomeron flux in SND





Results: Global CR effects in PbPb collisions





String Shoving and Rope Hadronization

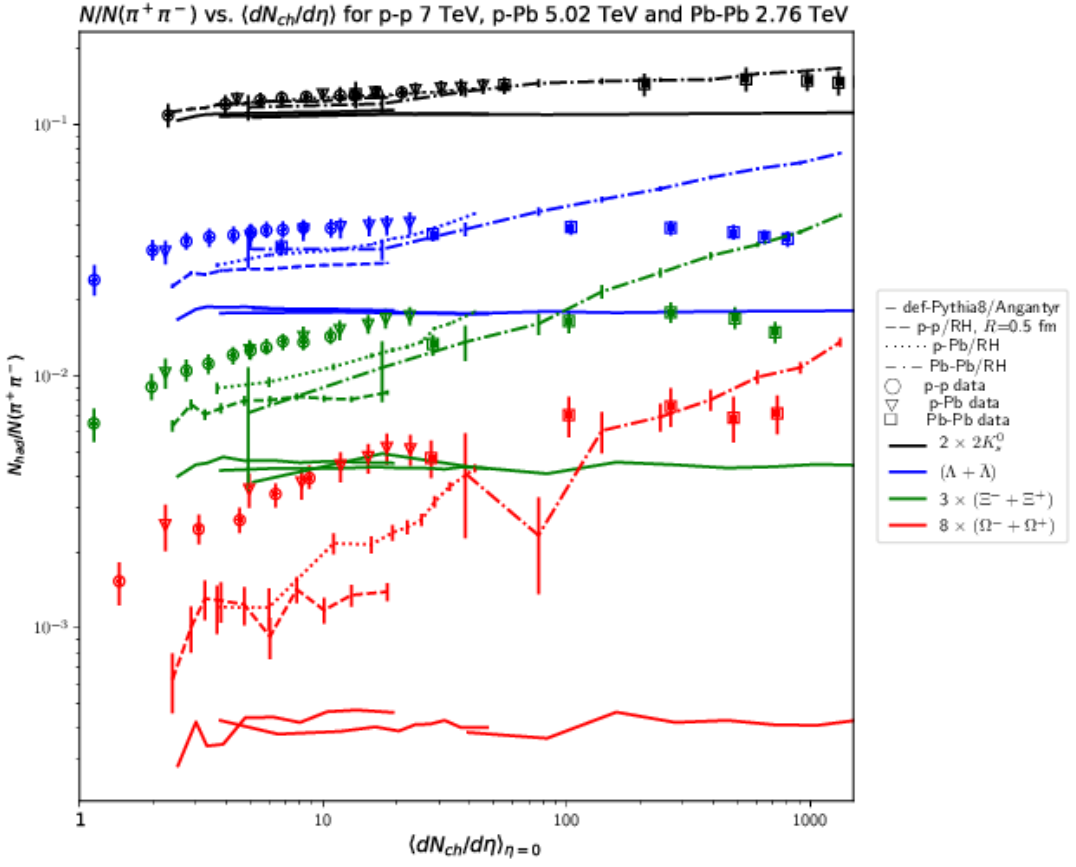
arXiv:2010.07595, 1710.09725

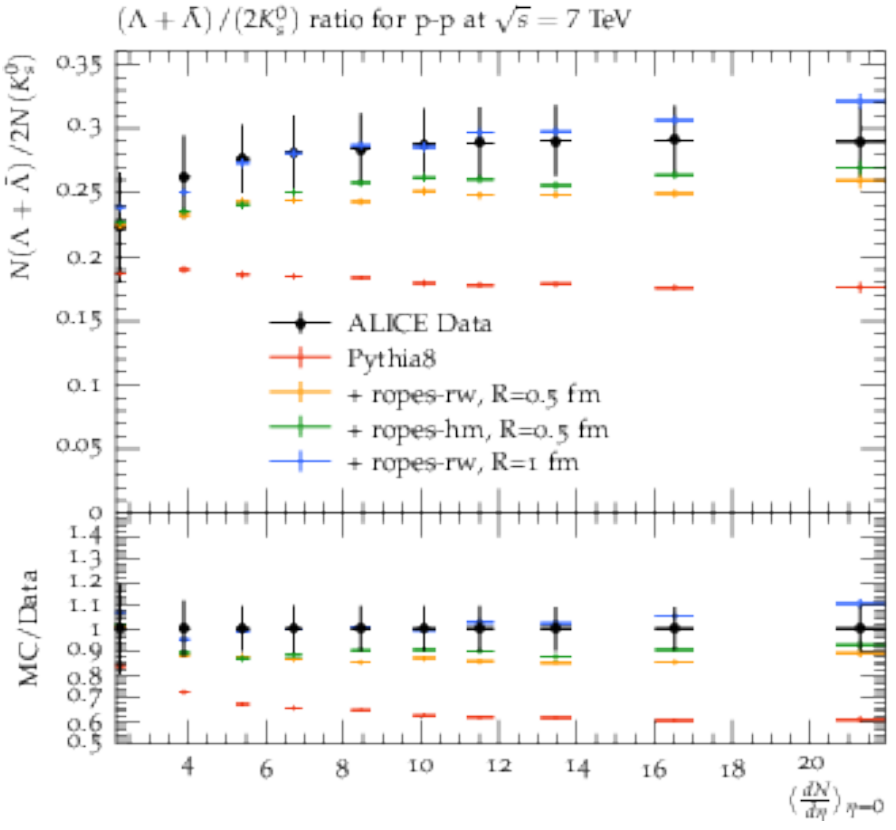
arXiv:2205.11170

- The colour strings can push each other in the transverse direction;
- They can contribute to collective flow;
- The overlapping colour strings can also form a colour rope and increase the string tension;
- The increased string tension results into higher probability for heavier quarks production during the string fragmentation, namely strangeness enhancement.

- The string shoving is tested in pp collisions, and its full integration with the Angantyr model is a work in progress. See **backup slides** for some results from string shoving and collectivity in pp collisions.

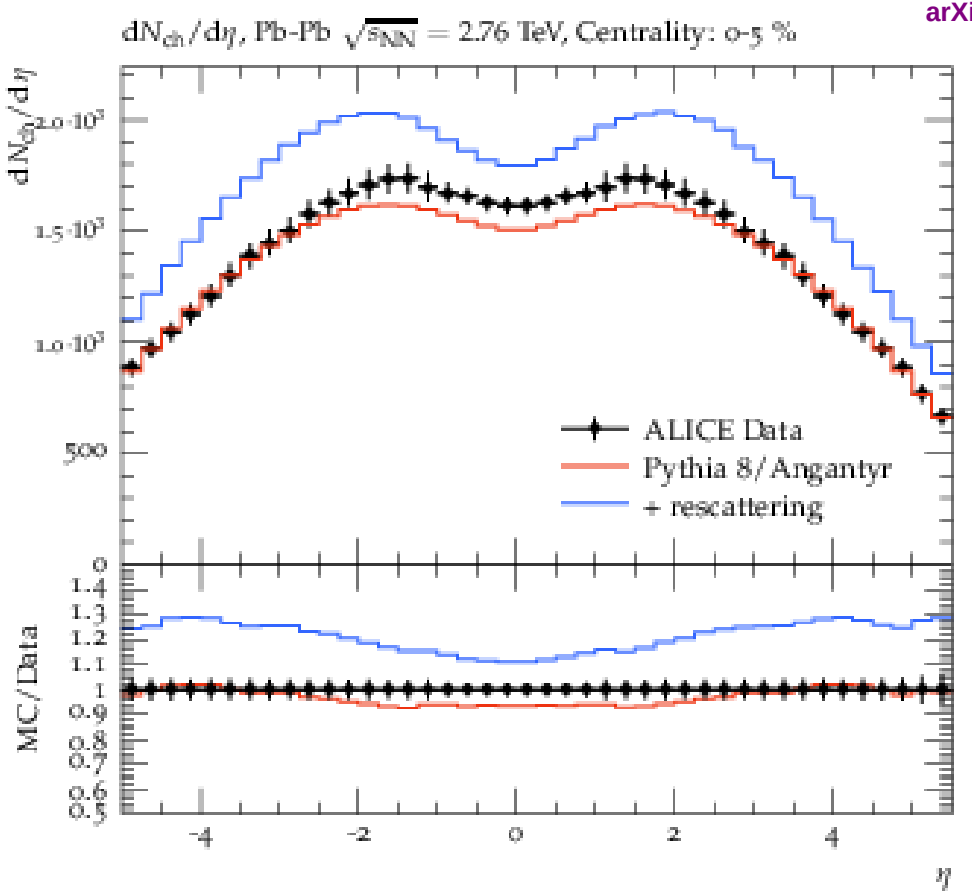
Results: Strangeness enhancement due to Rope Hadronization arXiv:2205.11170

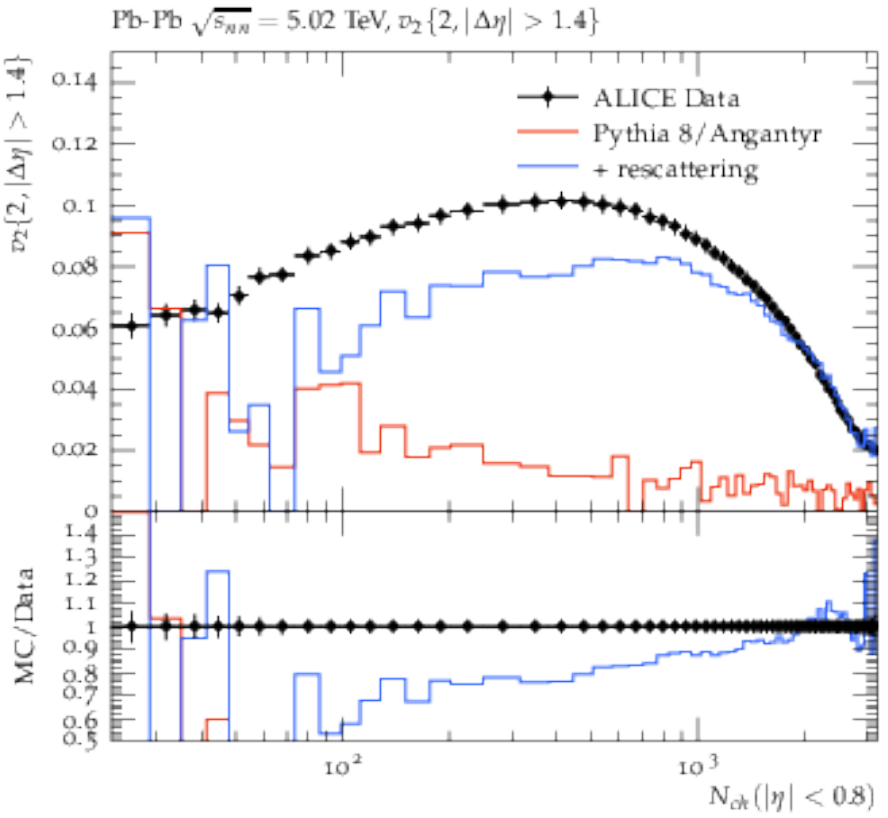




Results: Hadronic Rescattering

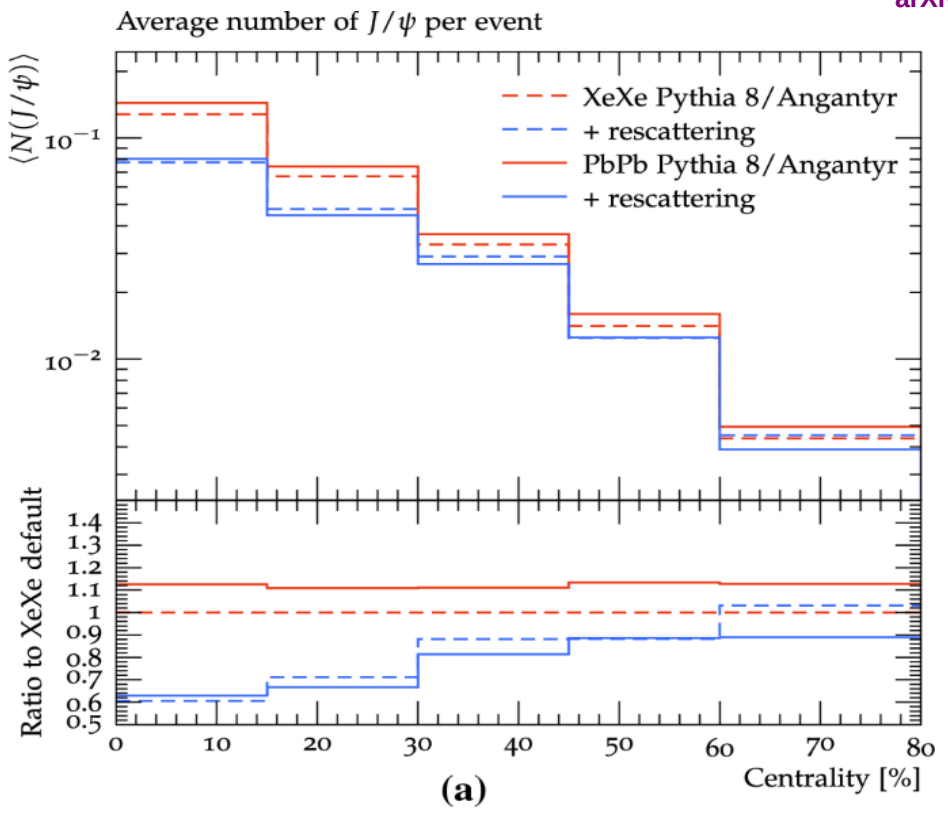
arXiv:2103.09665 [hep-ph]

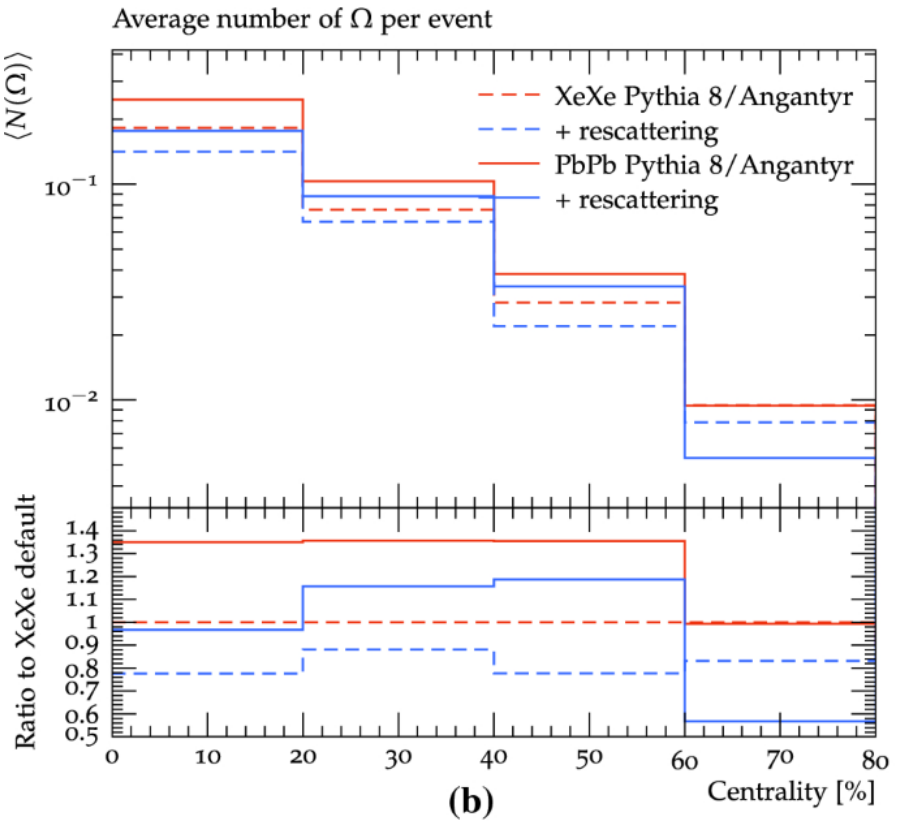




Results: Hadronic rescattering

arXiv:2103.09665 [hep-ph]

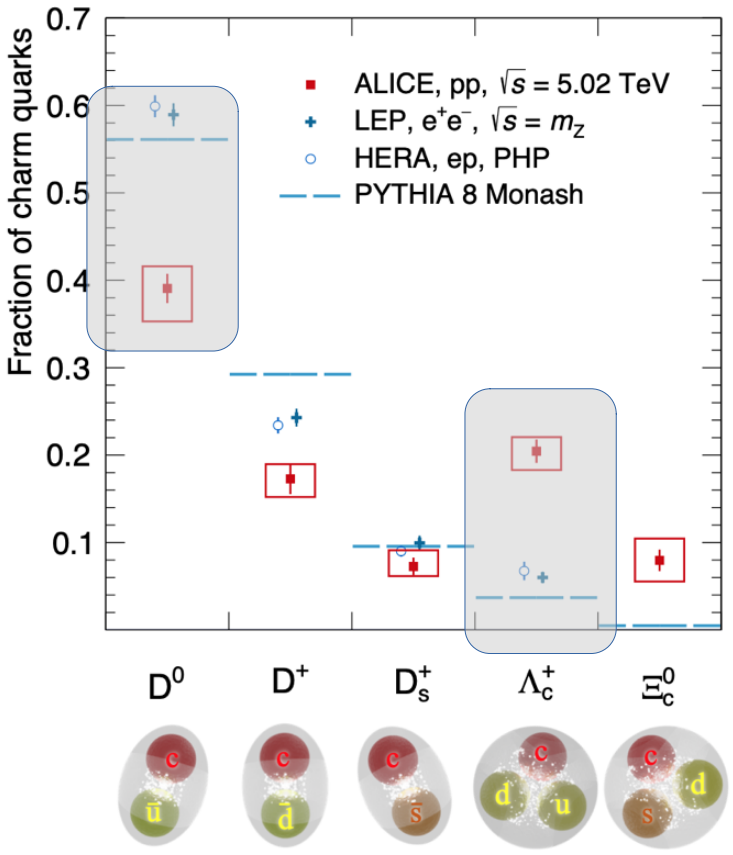




The fraction of charm quarks in different colliding systems

- Charm quarks are produced **only** in perturbative interactions in Pythia;
- The fraction of charm quarks in **baryons increases** in pp collisions;
- QCD inspired CR model can reconnect colour dipoles to junction systems;
- We **modified** junction formation and fragmentation to enhance the probability of a heavy quark forming a baryon;
- We enhanced the probability of strange quarks production, which shall be replaced by appropriate tuning of **rope hadronization**.

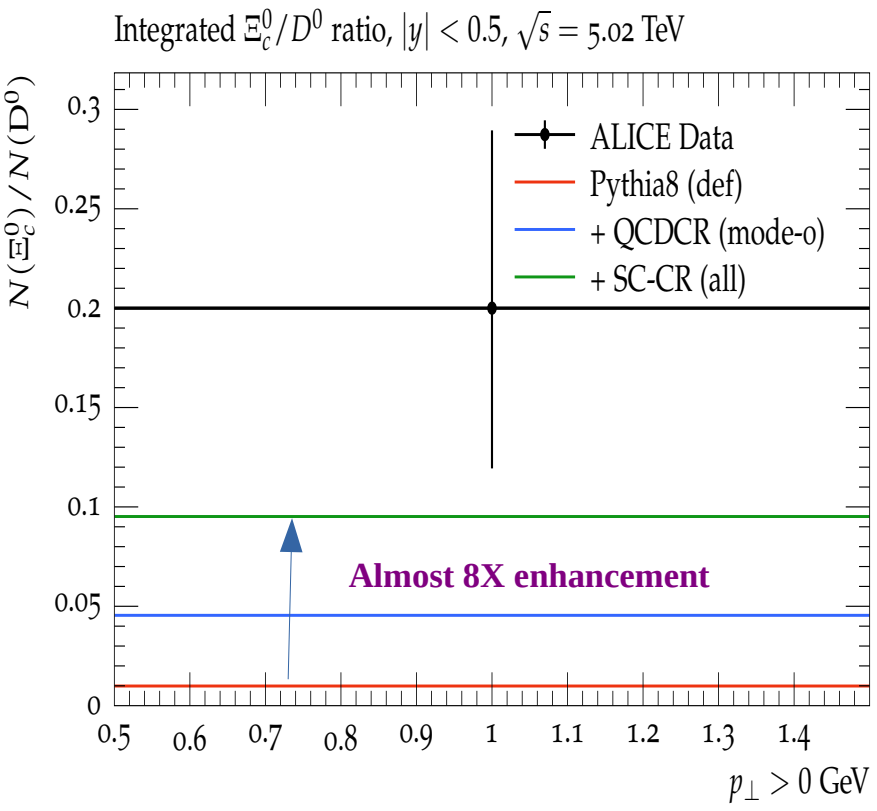
https://home.cern/news/news/physics/alice-finds-charm-hadronisation-differs-lhc

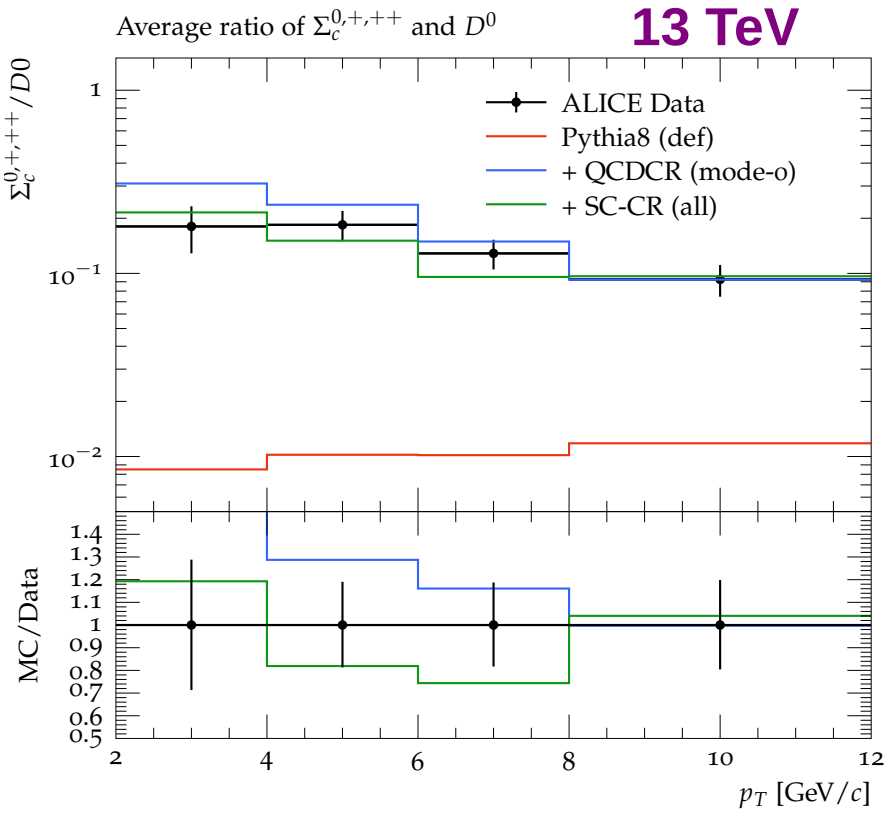


see also Phys.Rev.D 105 (2022) 1, L011103

Results: Baryon-to-meson ratio in pp collisions

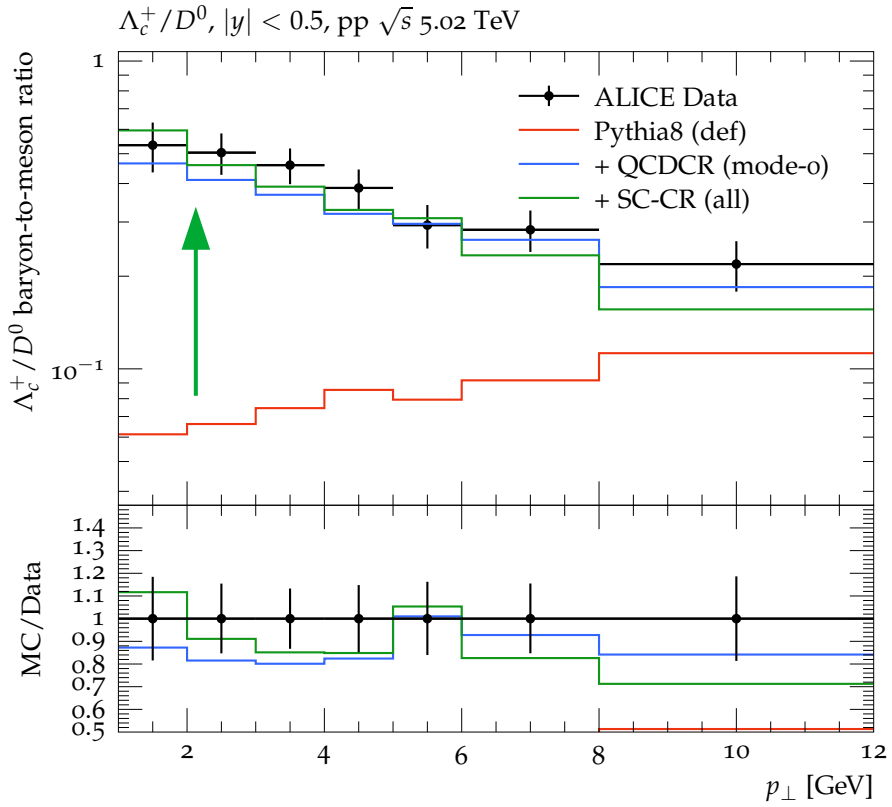
arXiv:2309.12452

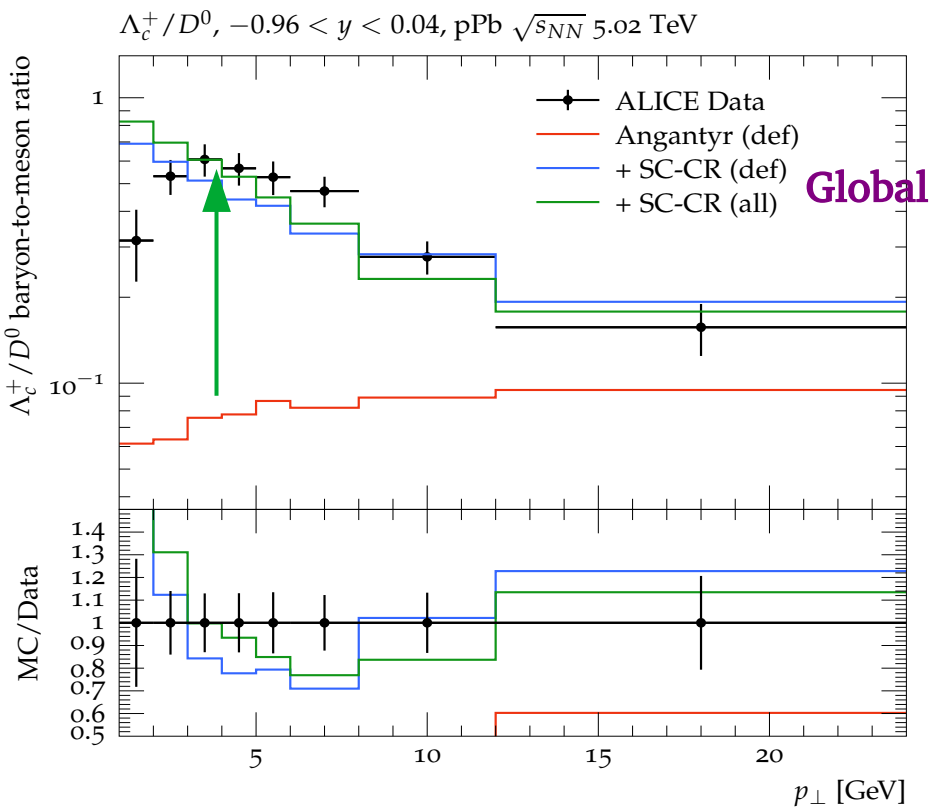




Results: pp and pPb collisions at 5.02 TeV

arXiv:2309.12452





Concluding remarks

- We **developed the Angantyr model** for heavy-ion collisions as an extension of Pythia and without any assuption of a thermalised medium creation.
- We introduced **a Global CR** using spatial constraint, which allows partons produced in different sub-collisions to interact.

- The **rope hadronization** is the primary model for **strangeness enhancement** in Pythia.
- We also **show strangeness enhancement-like effects in baryon sector** without any special treatment.
- The **string shoving** and **hadronic rescattering** contributes to flow especially v_2.

- The **Global CR** and **Hadronic rescattering** modify hadrons yield.
- The **Quarkonia suppression** and **jet queanching** are yet to be explored.
- The new Pythia/Angantyr tune is required.

Publications for detailed information

The Angantyr Model:
Christian Bierlich, Gösta Gustafson, Leif Lönnblad, and Harsh Shah
arXiv:2303.11747, 1806.10820, 1607.04434

String Shoving and Rope Hadronization:
Christian Bierlich, Smita Chakraborty, Gösta Gustafson, and Leif Lönnblad, also ALICE publications
ArXiv: 2205.11170, 2101.03110, 2010.07595, 1710.09725, 1412.6259

Hadronic Rescattering:
Christian Bierlich, Torbjörn Sjöstrand, and Marius Utheim
ArXiv:2103.09665, 2005.05658, 2002.10236, 1808.04619

QCD Colour reconnection and Heavy Flavour in Pythia
Javir Altmann, Jesper Christiansen, Leif Lönnblad, Peter Skands, and Harsh Shah
arXiv:2404.12040, 2309.12452, 1505.01681

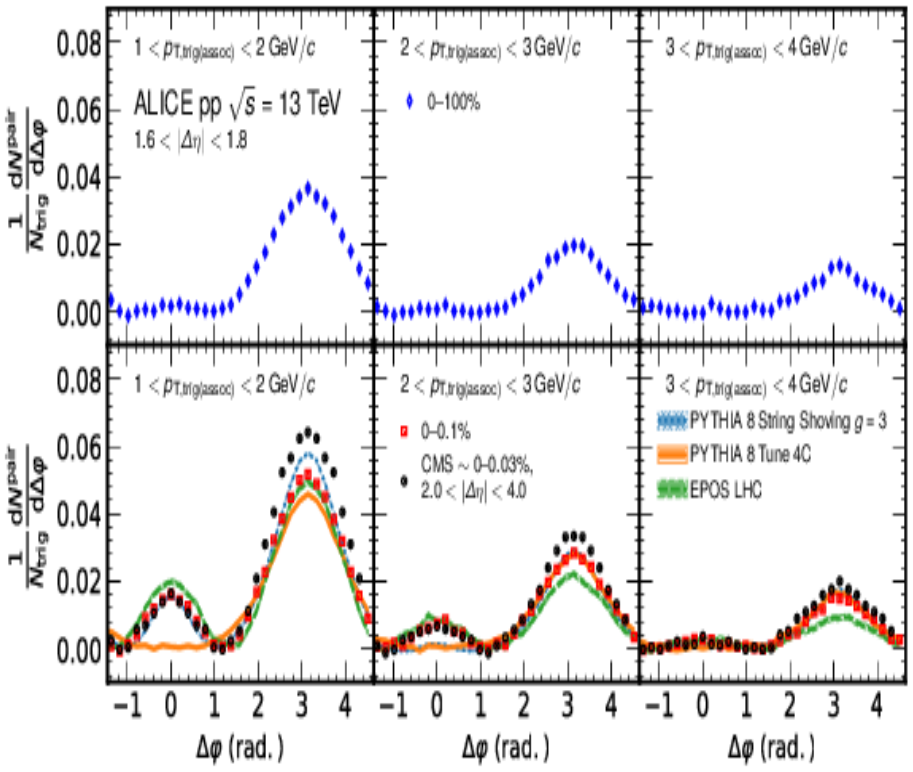
Pythia8 Manual:
arXiv: 2203.11601

Referenses within these papers

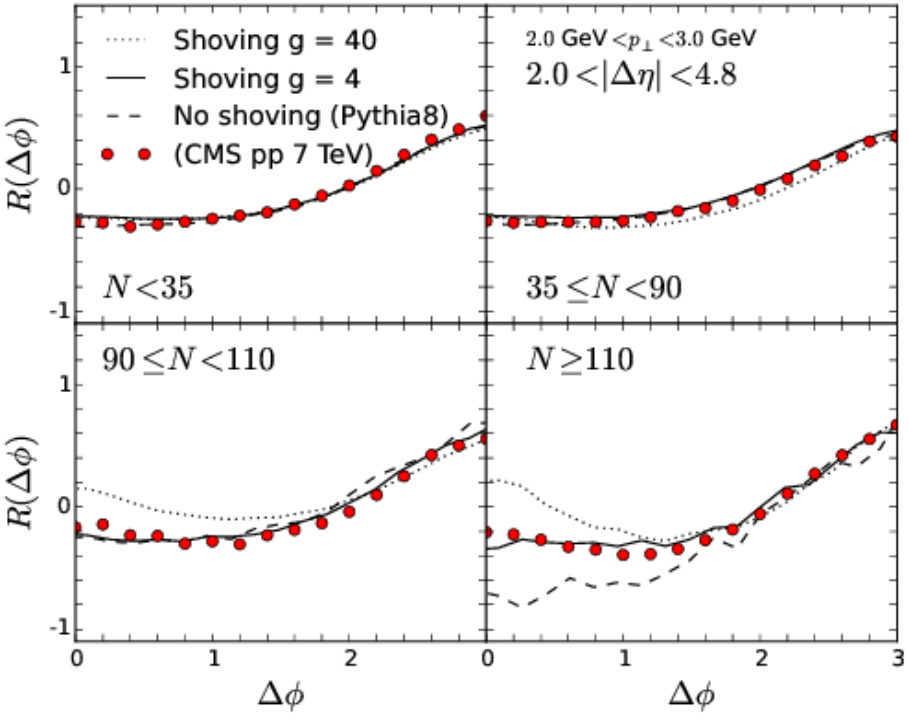
Additional slides

Results: string shoving and inclusive flow

ArXiv:2101.03110 [nucl-ex]

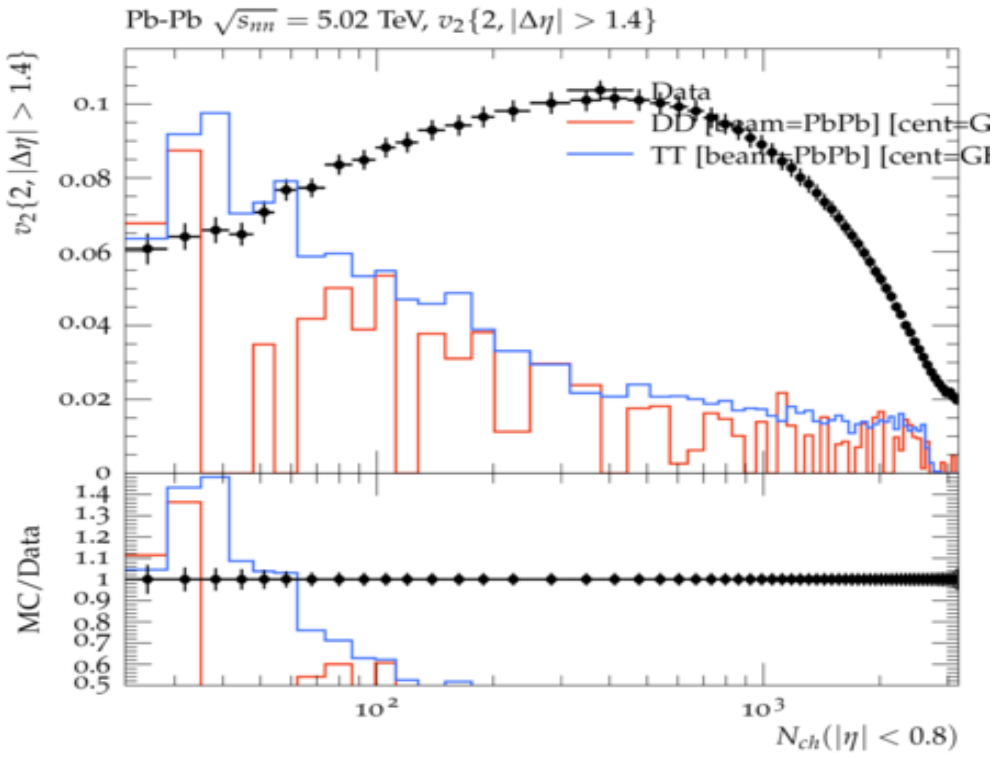


ArXiv: 1710.09725 [hep-ph]

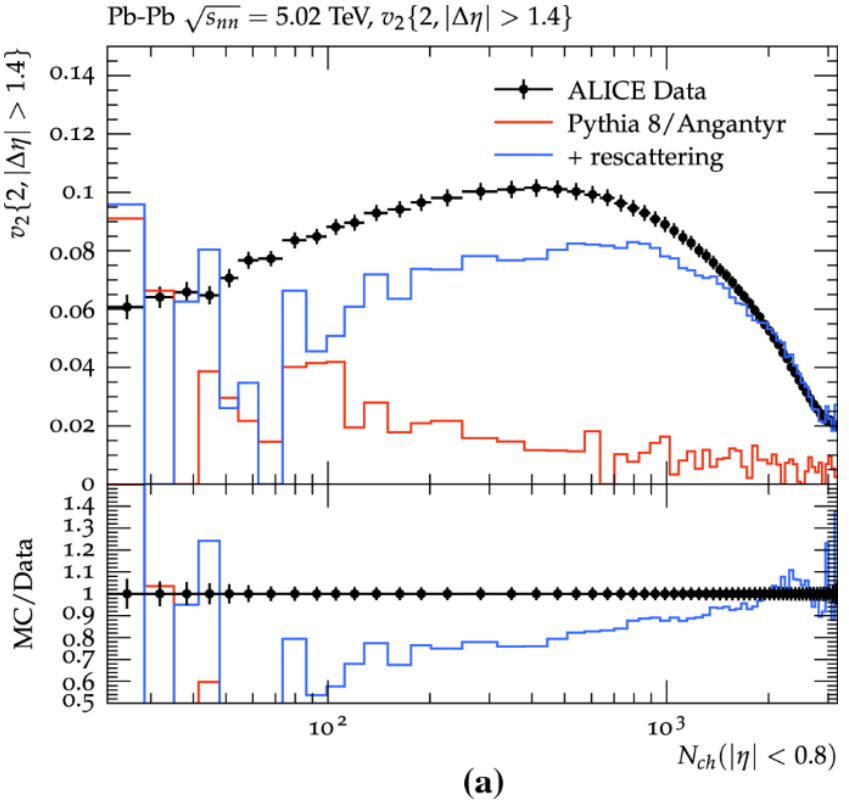


Results: flow Global CR and hadronic rescattering

Unpublished priliminary results:
DD: Angantyr default
TT: Global CR

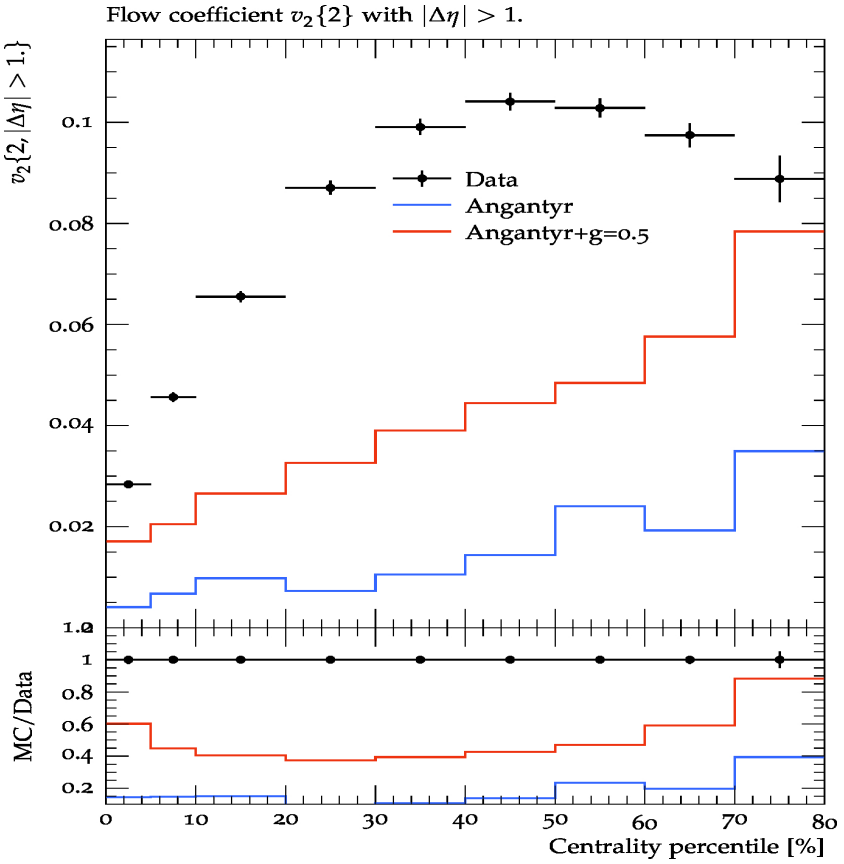


Hadronic rescattering

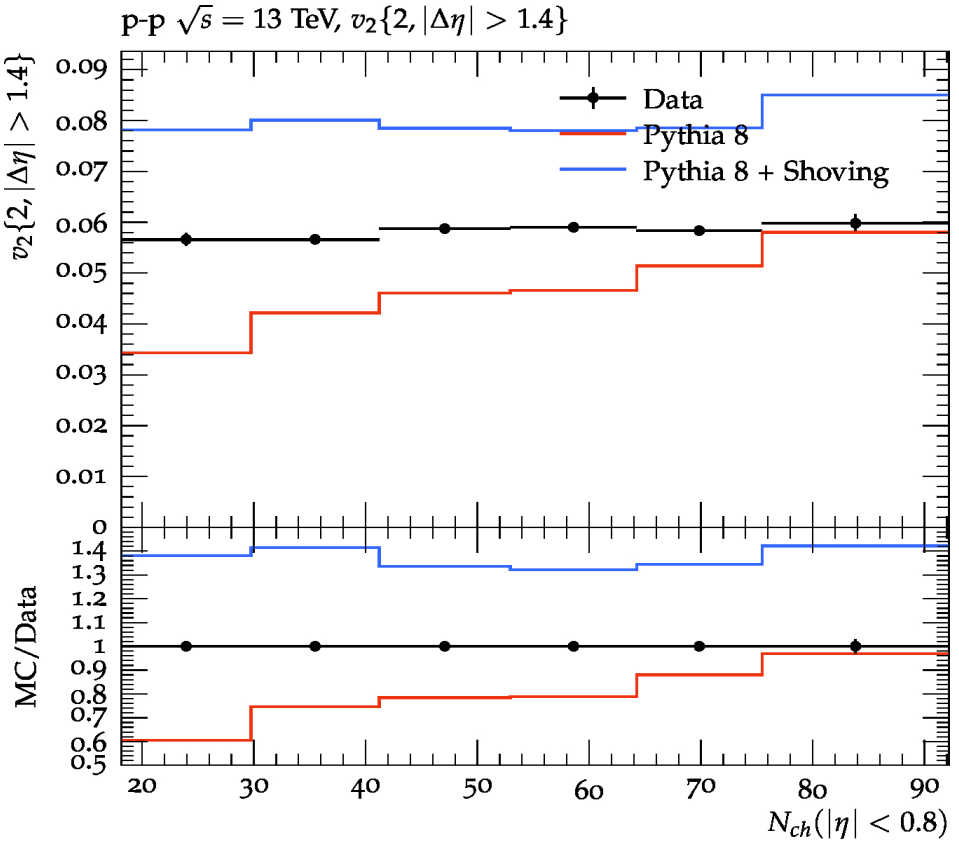


Results: effects of string shoving on collectivity

PbPb collisions

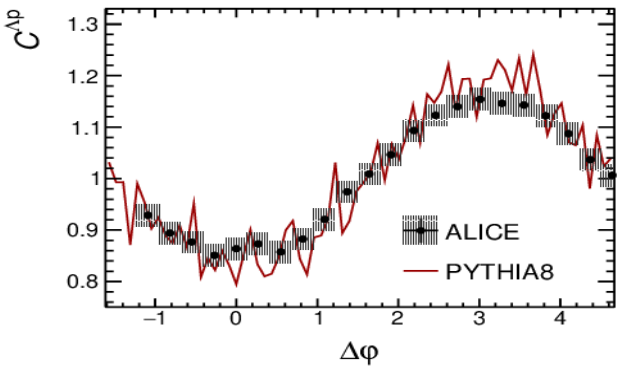


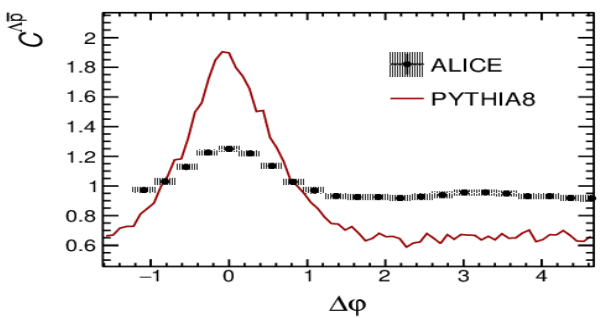
pp collisions

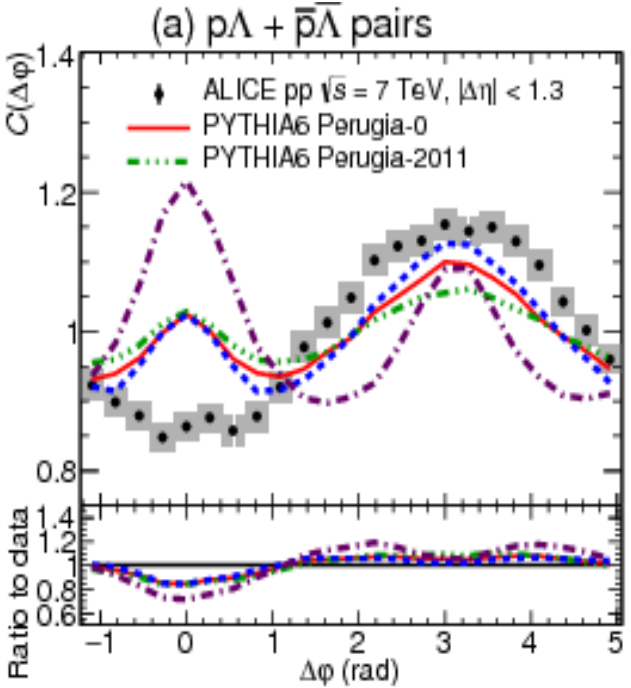


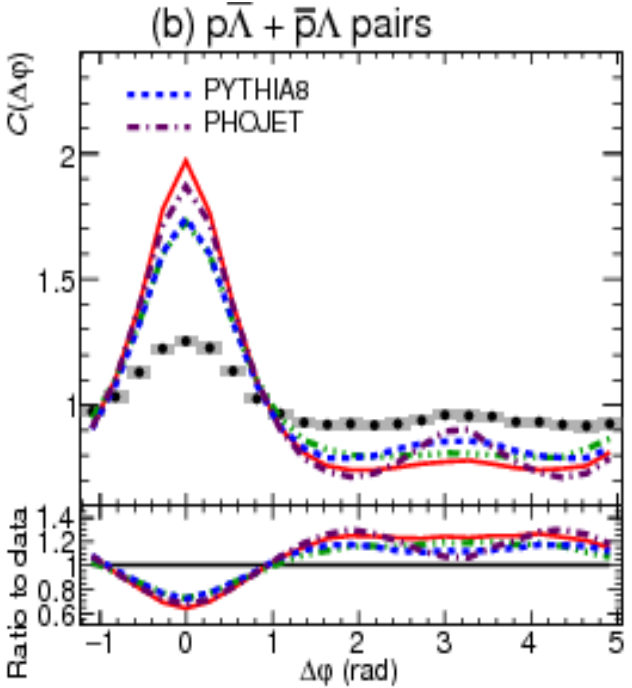
Baryon Correlations in Pythia

Brute Force: N. Demazure et al., Few Body Syst. 64 (2023) 3, 57





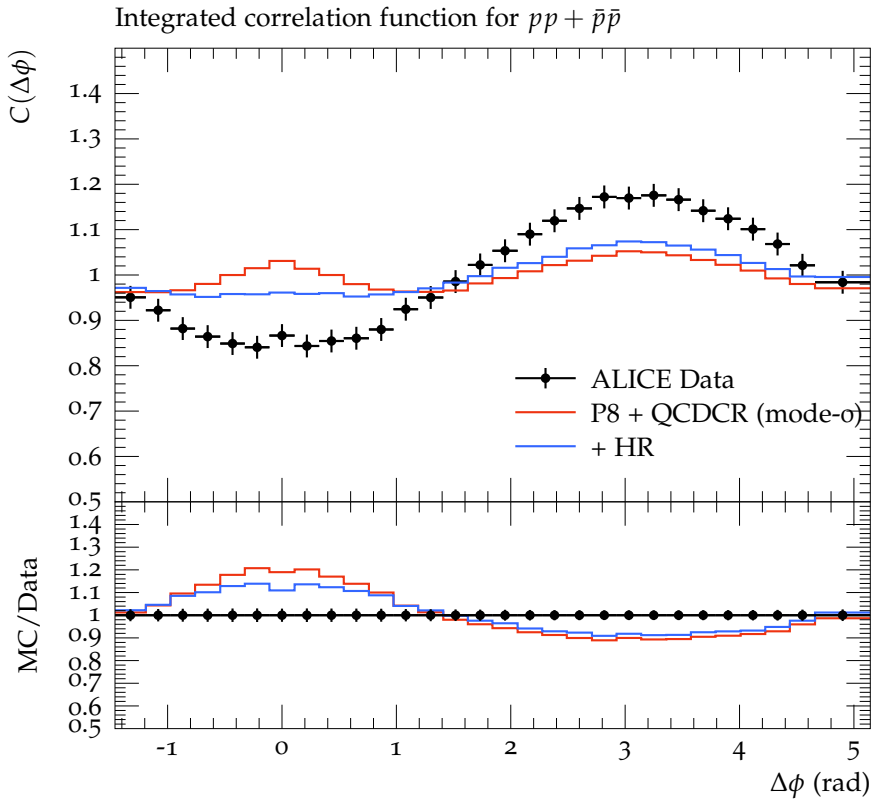


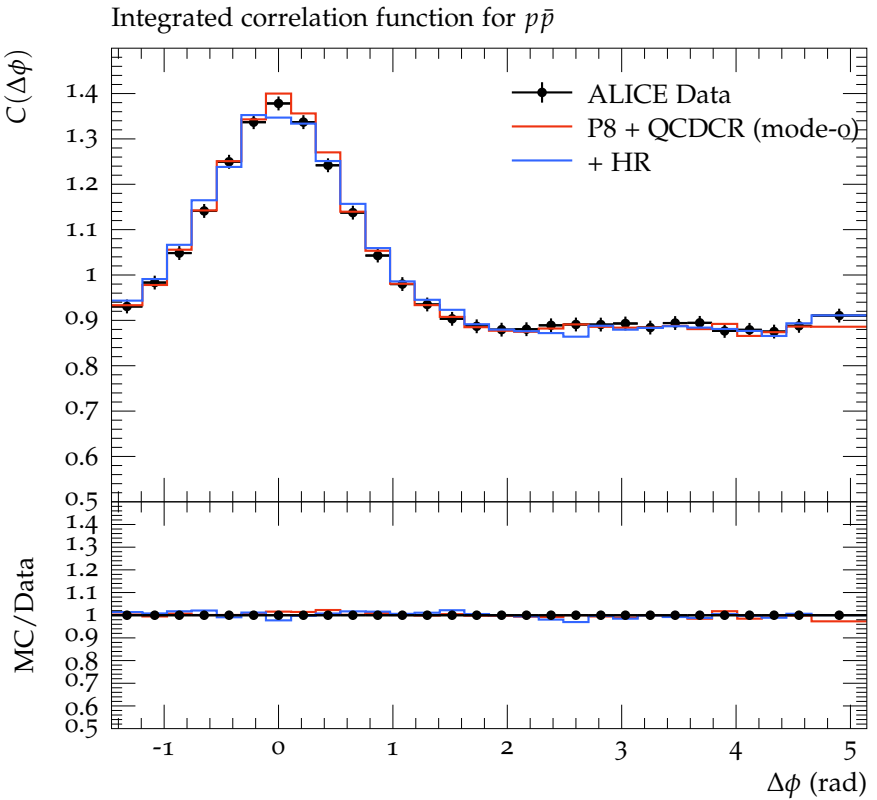


ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569

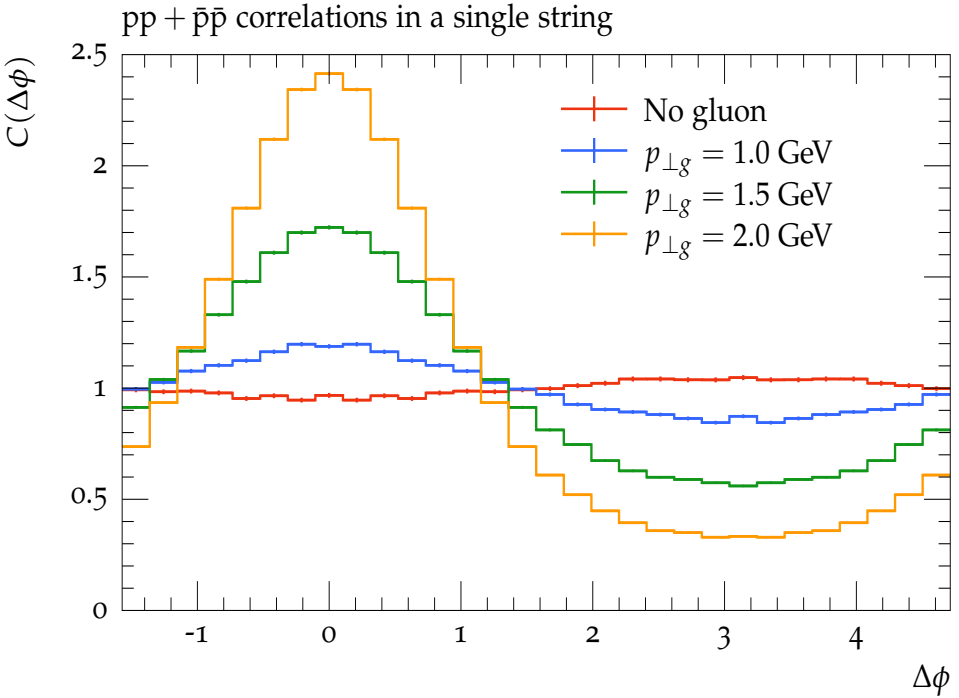
Pythia fails to reproduce baryon correlations.

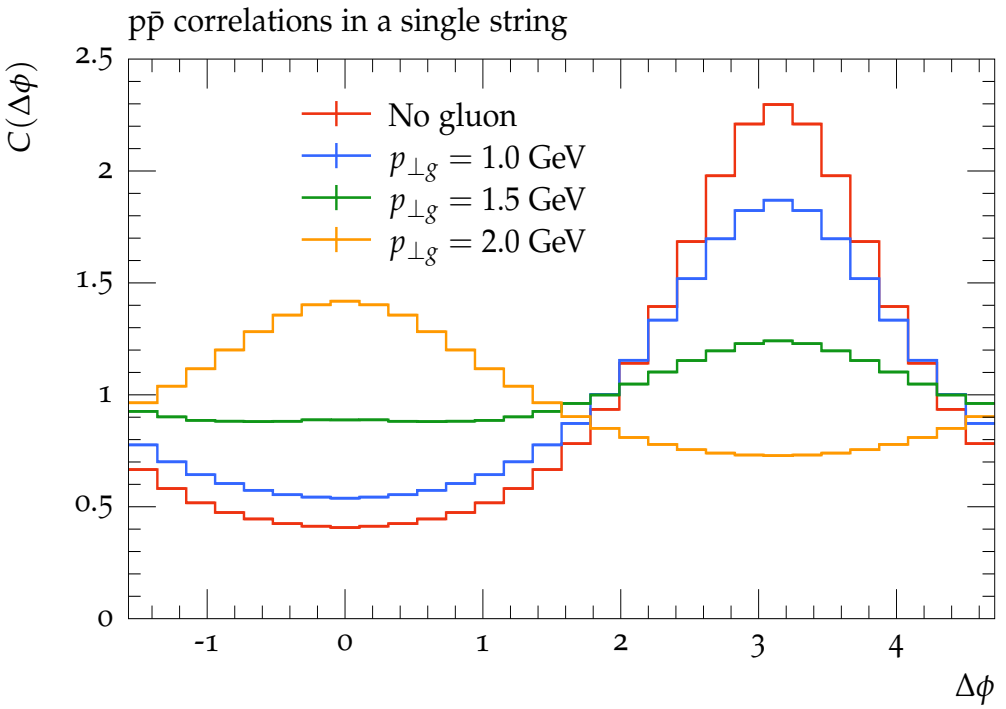
Results: **Pythia with QCD colour reconnection and hadronic rescattering**



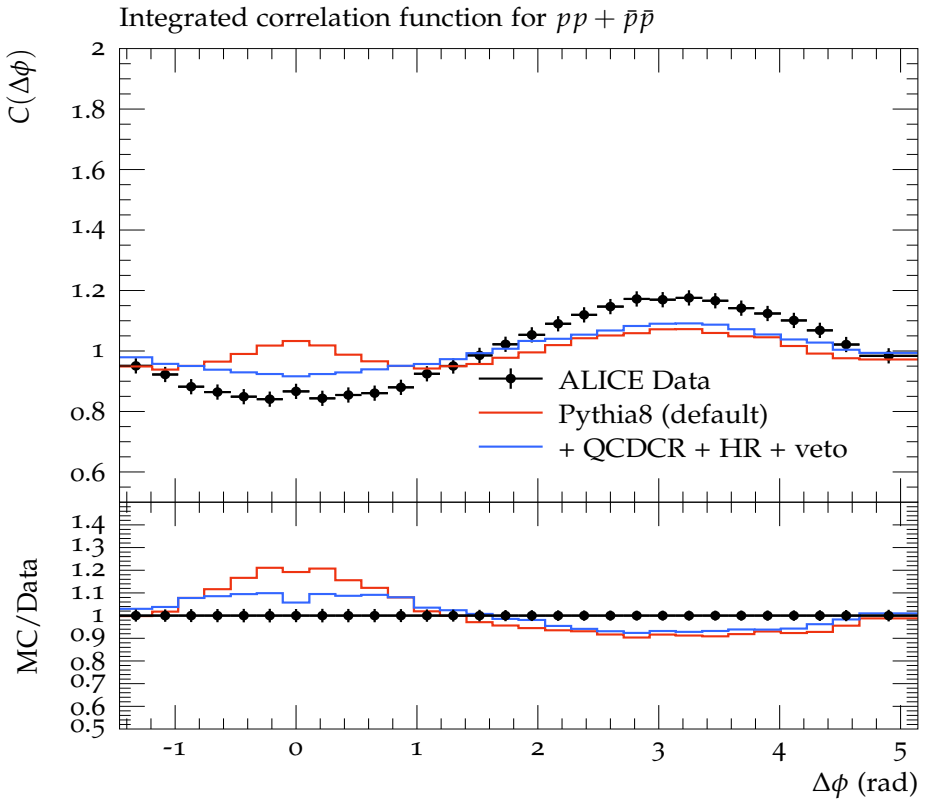


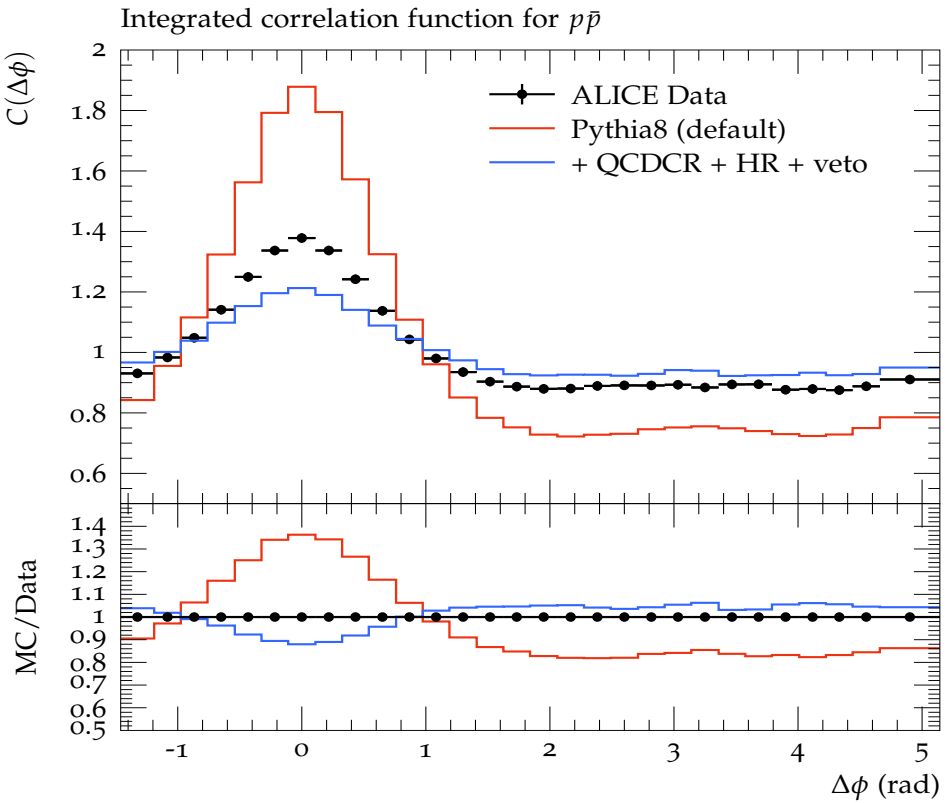
Role of gluons in baryon correlations



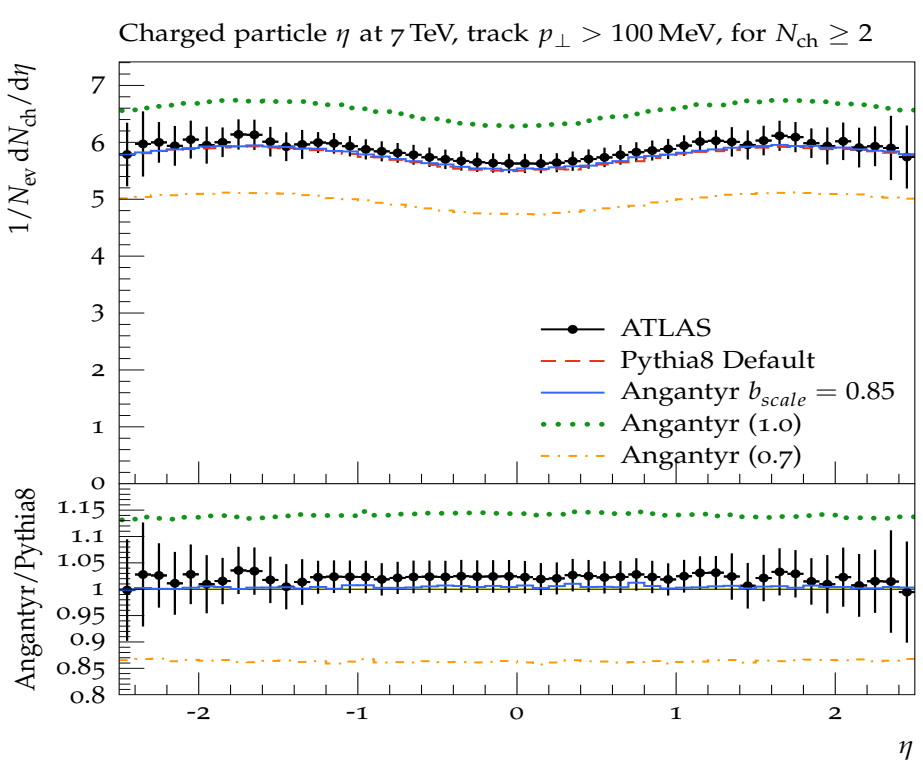


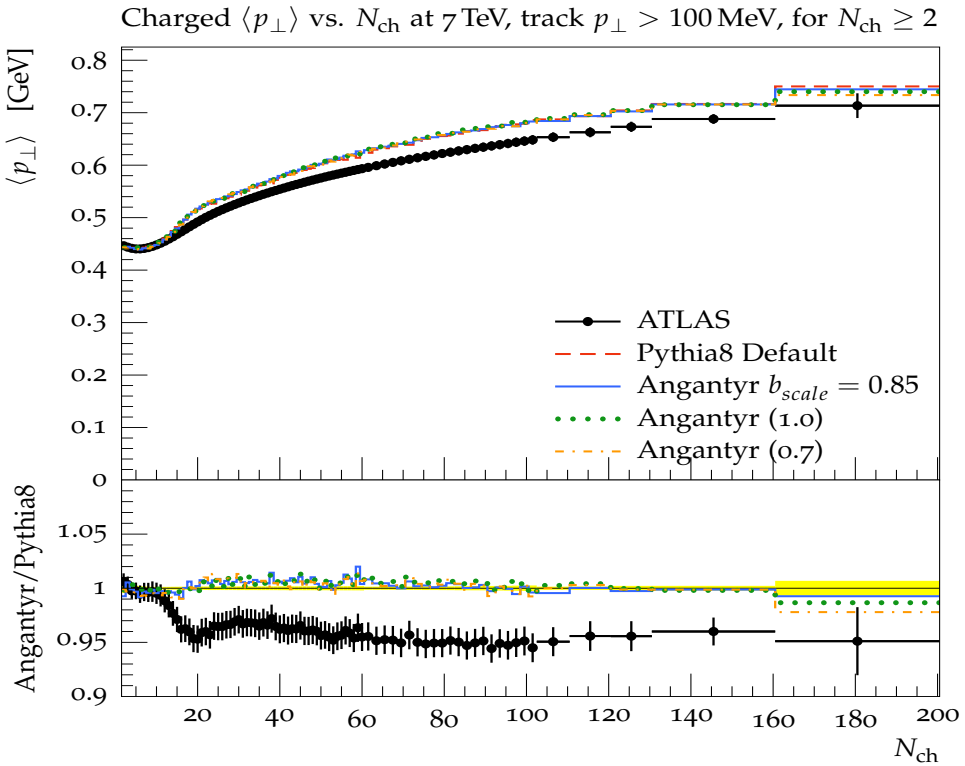
Results: **Pythia with suppressed baryon production near gluon kinks**





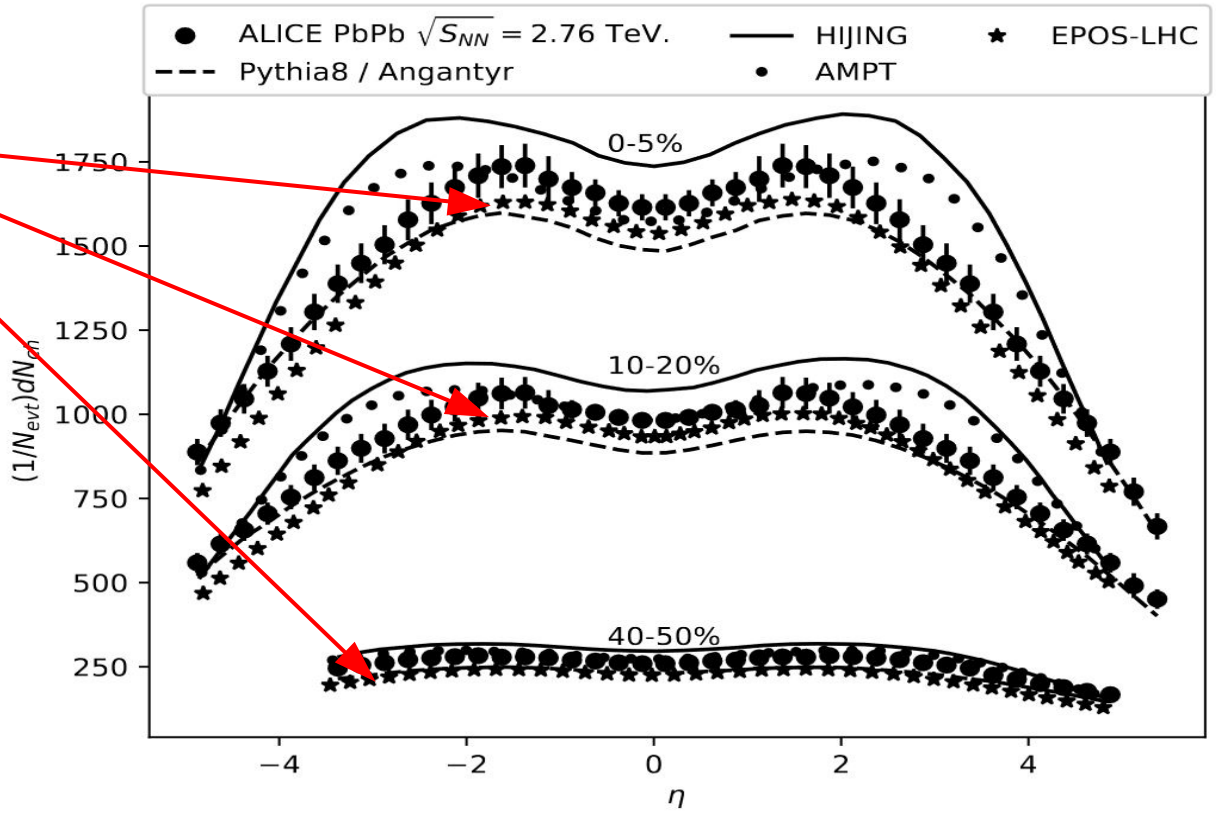
Angantyr Results: pp collision





Event multiplicity compared to other event generators

Angantyr is producing competing results.



Results: Avg. Pt and baryon-to-meson ratio in pp collisions with spatially constrained CR