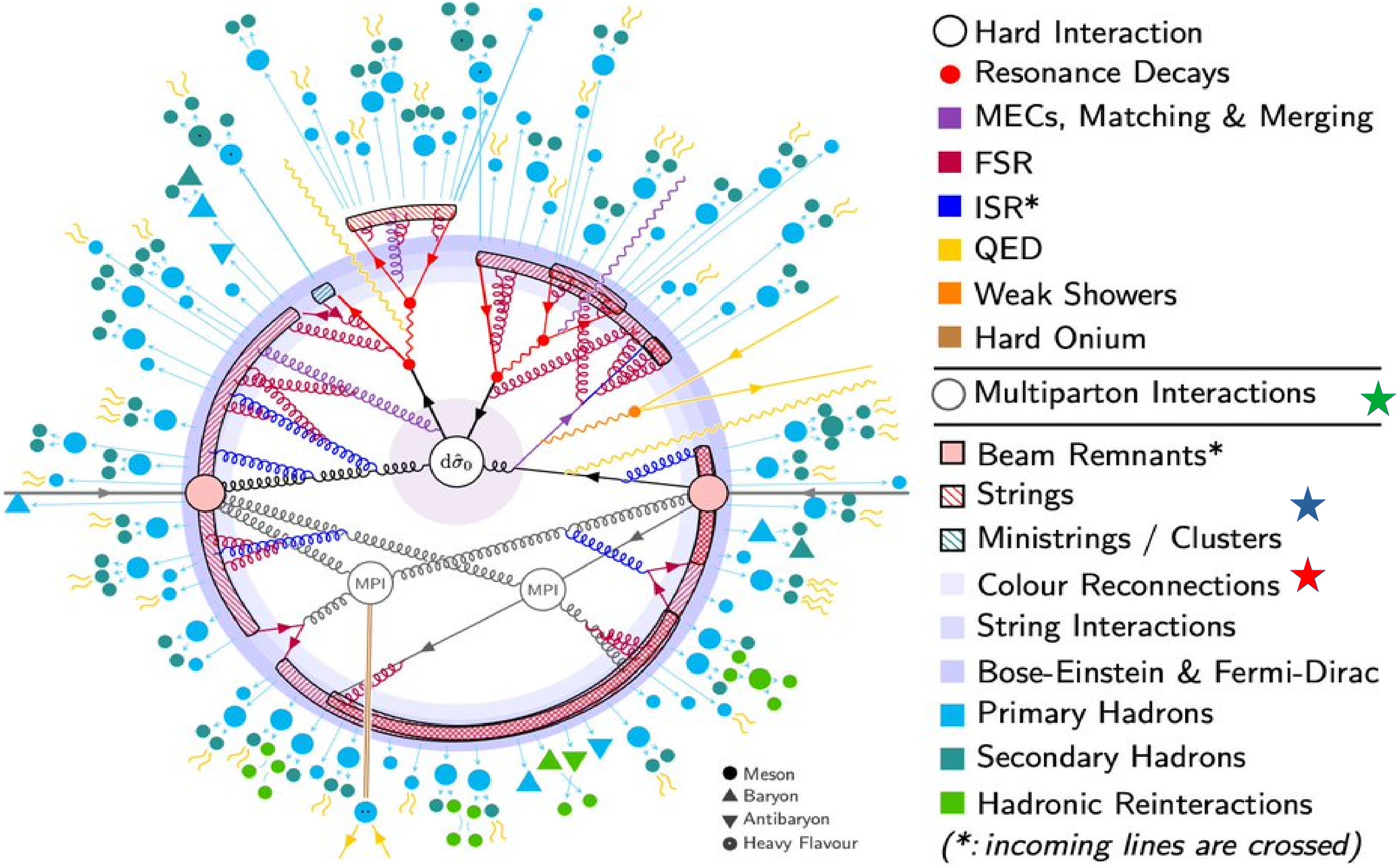
Pythia/Angantyr: A Journey of a Microscopic Event Generator from e+e- to heavy-ion Collisions

Harsh Shah
IFJ-PAN
Krakow, Poland
Contact: harsh.shah@ifj.edu.pl

Particle and Astro-particle Physics Division seminar
February 25, 2024

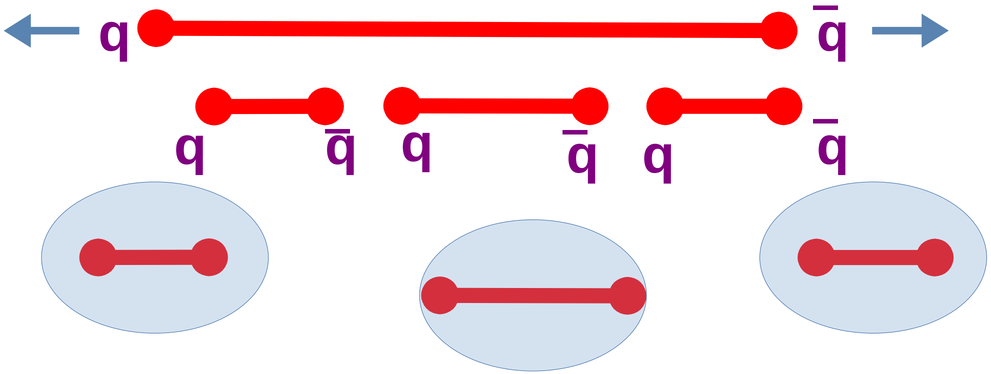
Pythia event-simulation

arXiv: 2203.11601



The Lund Colour String

The colour confinment field is modelled as a 1D string



The hadronisation ($m_{string} \geq 1$ GeV):

- Pick a random string end,
- Select the string break flavour,
- Apply suppression according to spin,
- Break the string,
- Pick the transverse momentum,
- Pick a "z" and construct the over all hadron momentum,
- **If** (no energy/momentum with remaining string piece) break; **else** repreat.

For the other cases try to produce one or two hadrons

No c or b quarks

$$\mathcal{P} \propto \exp\left(-\frac{\pi m_{\perp}^2}{\kappa}\right)$$

κ: string tension; ~ 1 GeV/fm
$m_{\perp}$: transverse mass of the quark
$m_{\perp h}$: hadron's transverse mass

$$f(z) = \frac{(1-z)^a}{z} \exp\left(-\frac{b m_{\perp h}^2}{z}\right)$$

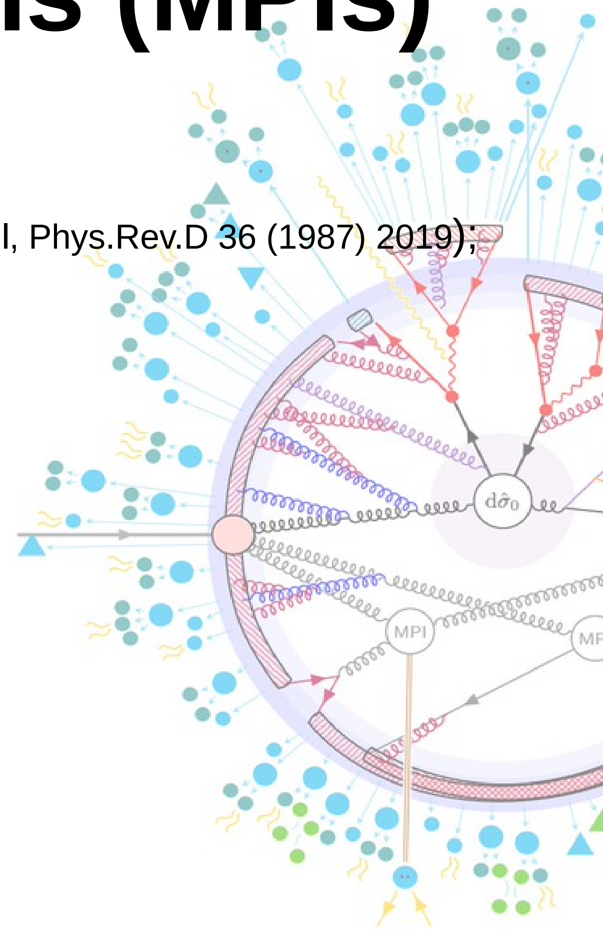
a & b parameters are fixed by fit to the data

z is a fraction of the quark momentum taken by the hadron

The Multiparton Interactions (MPIs)

A proton beam = A beam of partons.

- Already 1987 it was realised and introduced in Pythia (Sjöstrand & van Zijl, Phys.Rev.D 36 (1987) 2019);
  - MPIs implemented with Sudokov style constraints on p_t,
  - Along with impact parameter dependence.

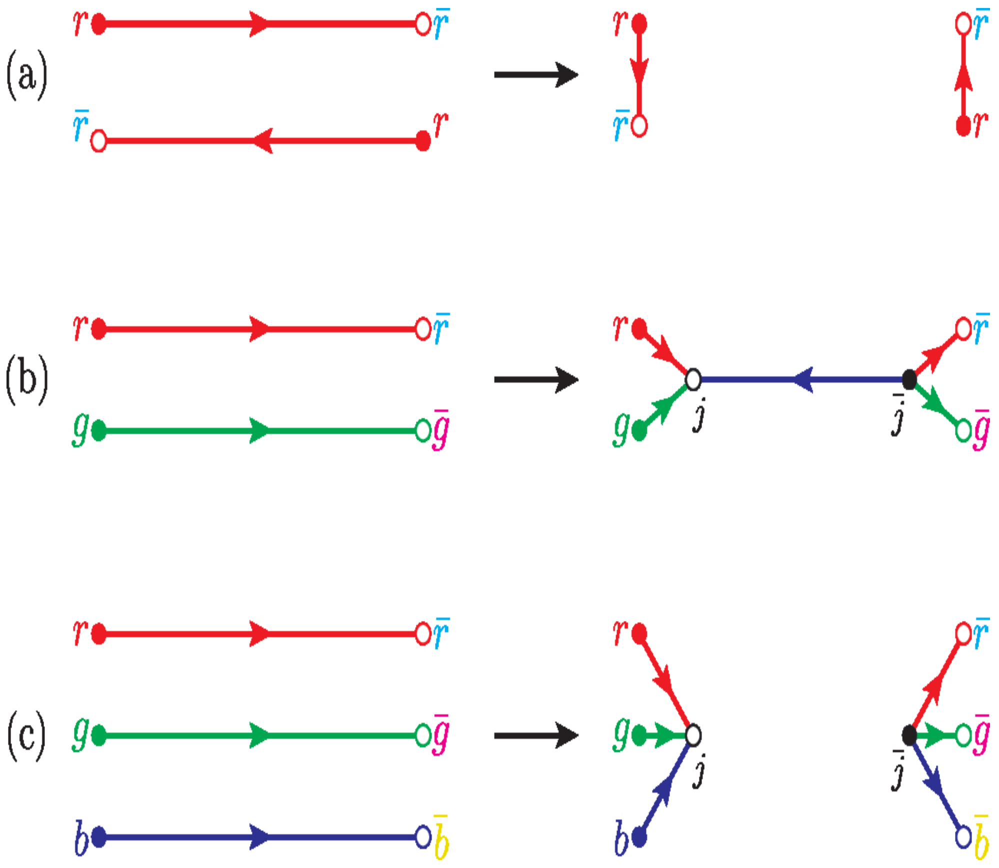


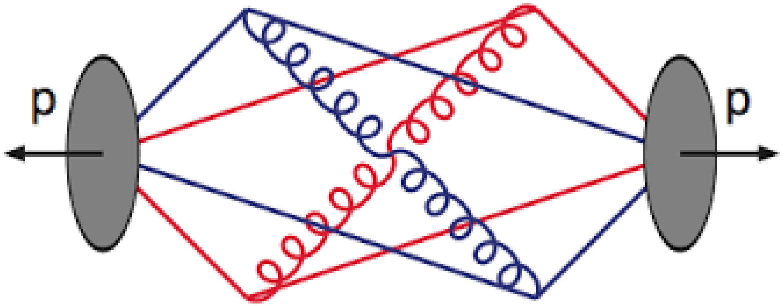
- MPIs are crucial to explain “underlying events”,
- MPIs → **lots** of colour partons are produced in the final state
- The low-p_t divergence is constrained by a minimum $p_{\perp 0}$.

Colour Reconnection (CR)

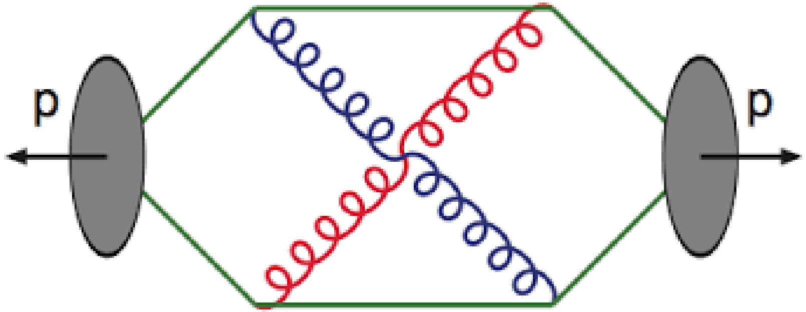
ArXiv: 2404.12040, 2309.12452, 1505.01681

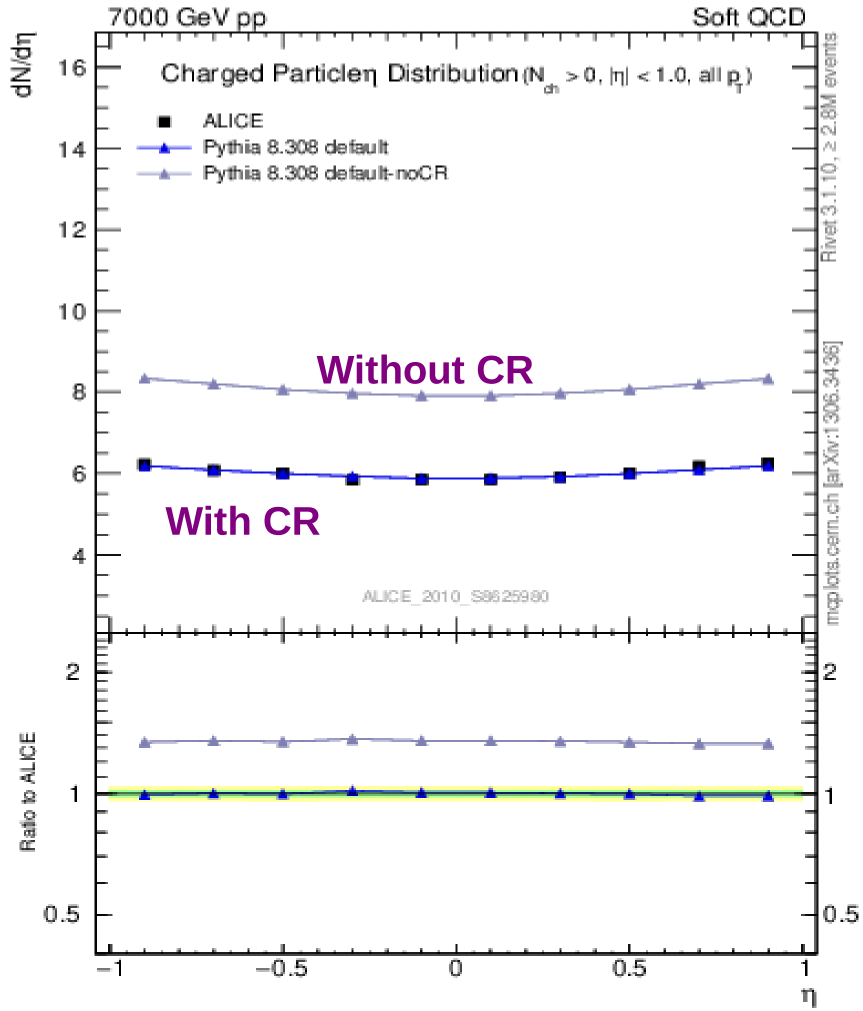
- In Pythia, **partons** produced in perturbative scatterings are colour connected;
- Assuming that the nature preferes minimization of the net string length, the colour dipoles **interact** with each other **at colour reconnection** stage;
- At this stage configuration like (a) occurs in the default set-up of the Pythia model, where colour dipoles rearranges to shorter dipoles with a probability of 1/9;
- Configurations like (b) and (c) are allowed in a QCD colour algebra based CR and they have **additional contributions to baryon production and excusive contributions to low-p⊥ heavy baryon production.**

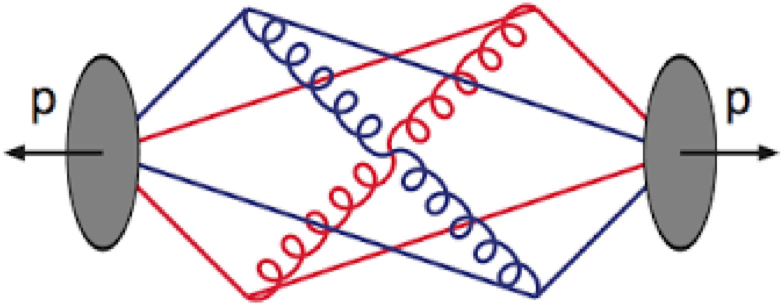


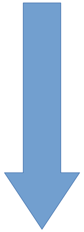


CR rearranges the dipole connections & reduces net-string length









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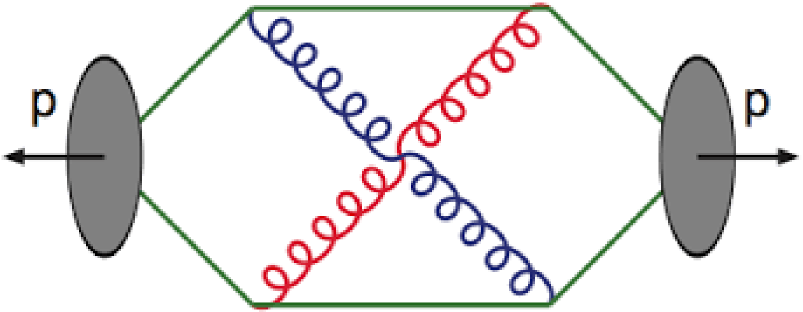
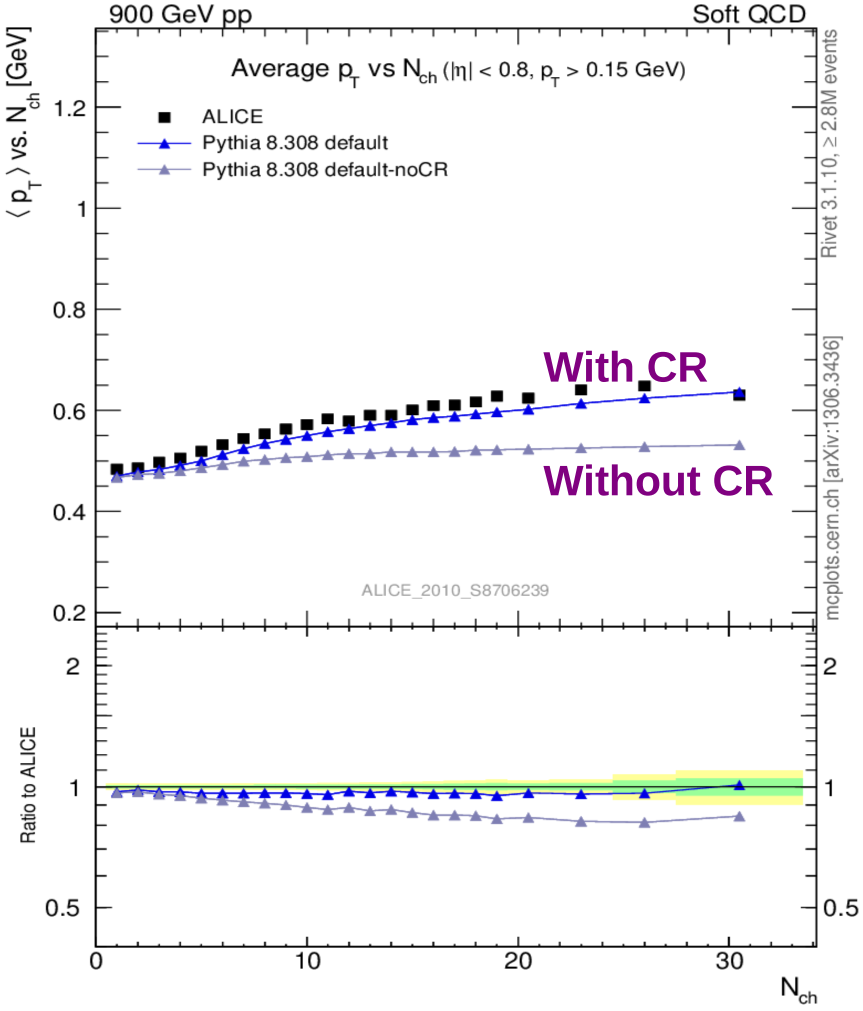
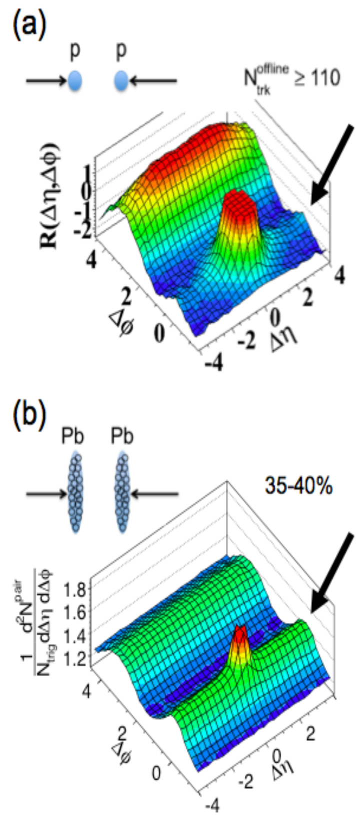
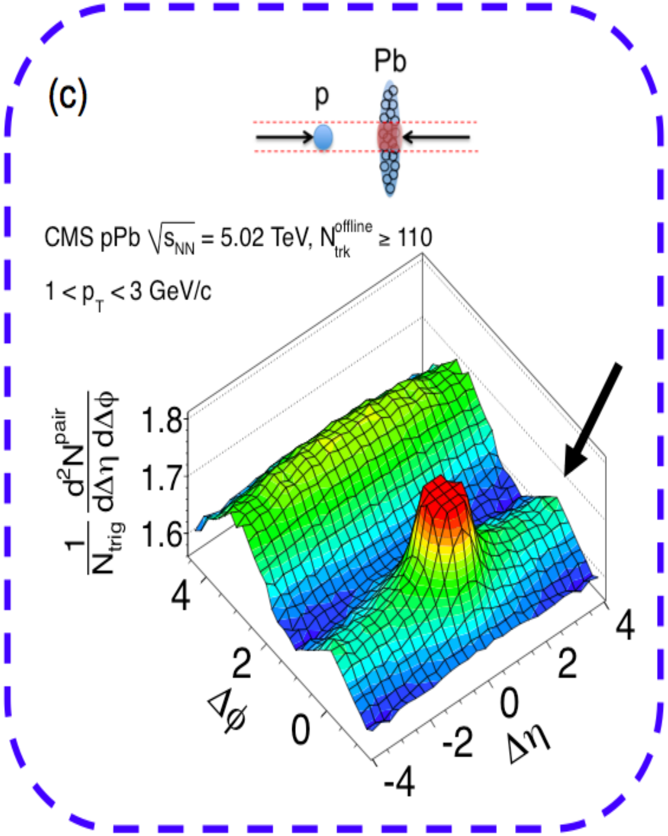
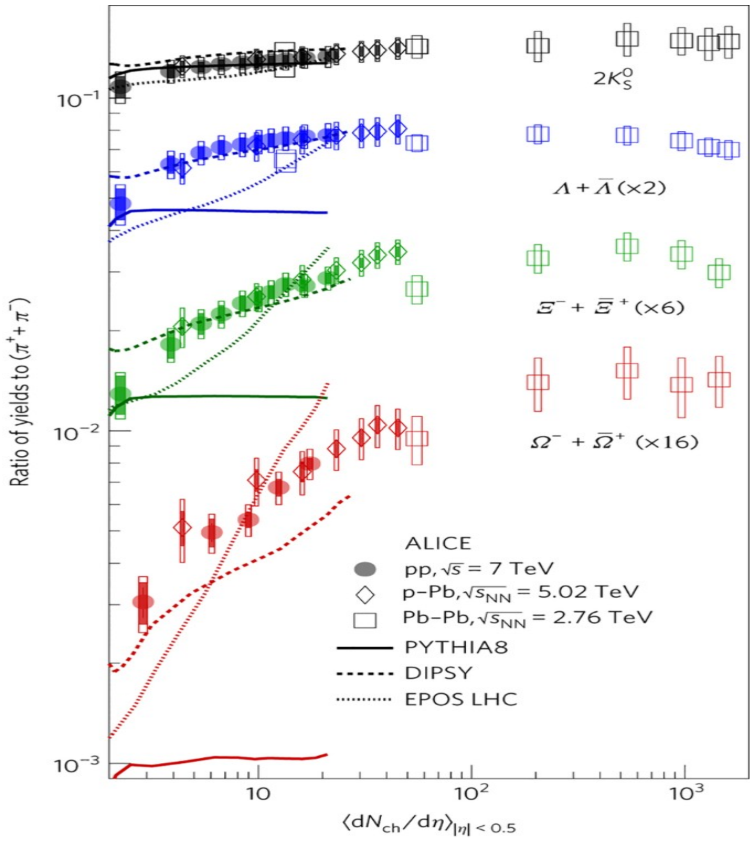




Surprising results in pp collision experiments at LHC







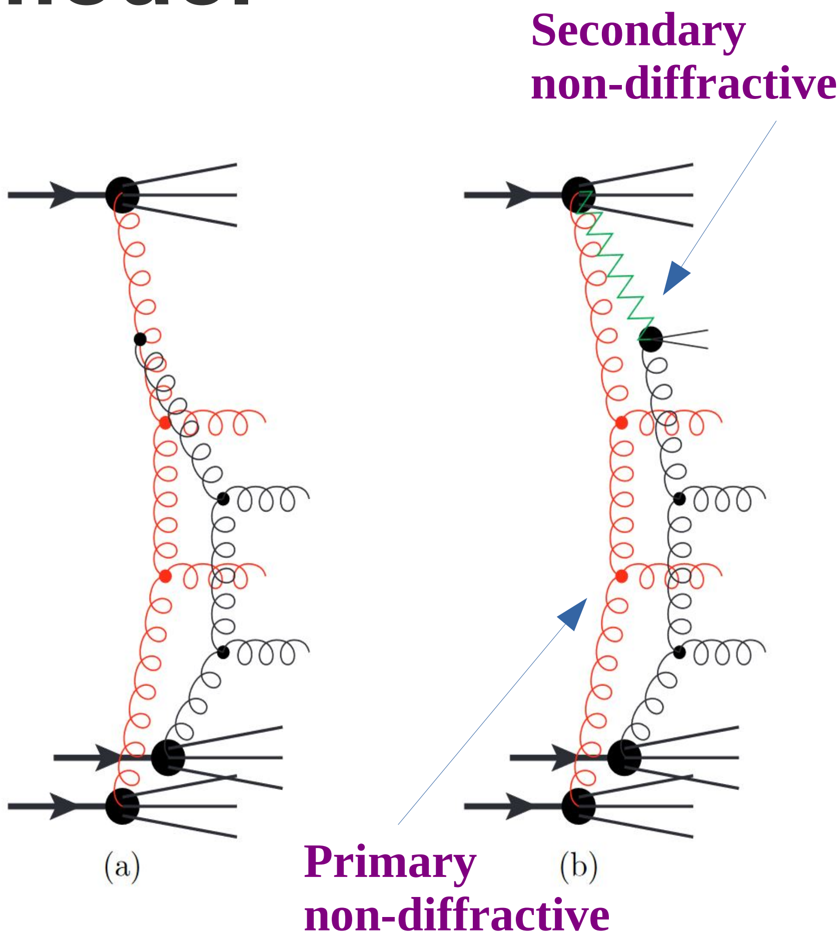
CMS: arXiv:1009.4122

ALICE: arXiv:1606.07424

The Angantyr model

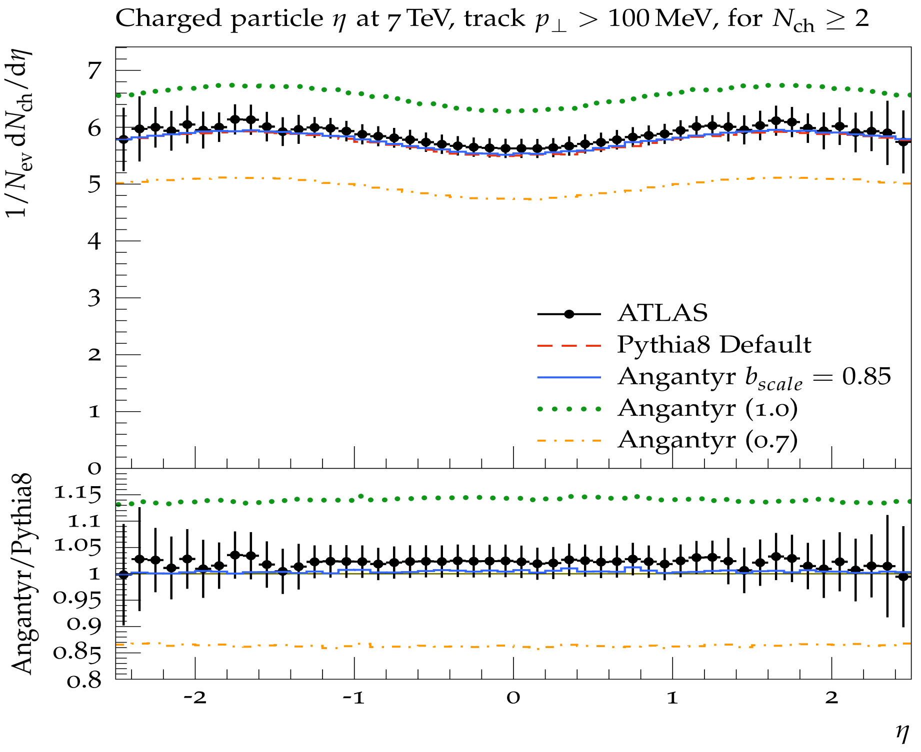
arXiv: 2303.11747, 1806.10820, 1607.04434

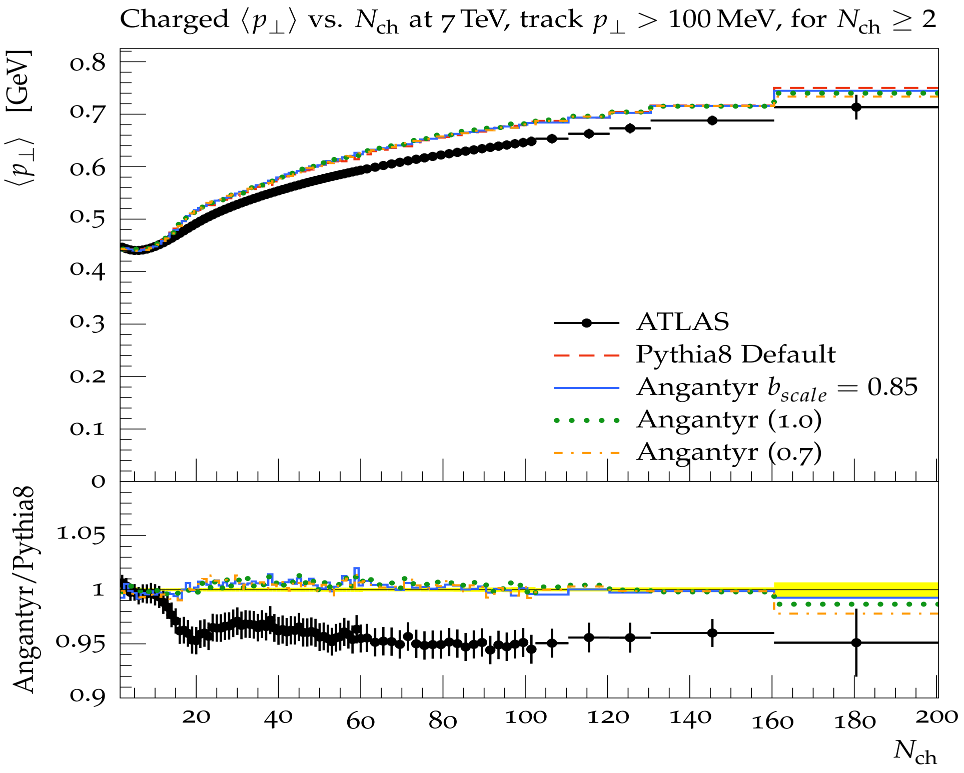
- ‘Wounded’ nucleons are tagged with the types of nucleon-nucleon collisions;
- Pythia machinery is used to generate multiple nucleon-nucleon sub-collisions;
- A scenario like Figure (a) is not possible to simulate with Pythia;
- Pythia’s single diffraction machinery is modified and the scenario like Figure (a) is generated as two pp events stacked together like Figure (b);
- The model is tuned with pp collisions;
- The secondary non-diffractive is tuned with pPb collisions;
- **No** tuning with PbPb (or AA) collisions.



Angantyr Results: pp collision

arXiv:1806.10820

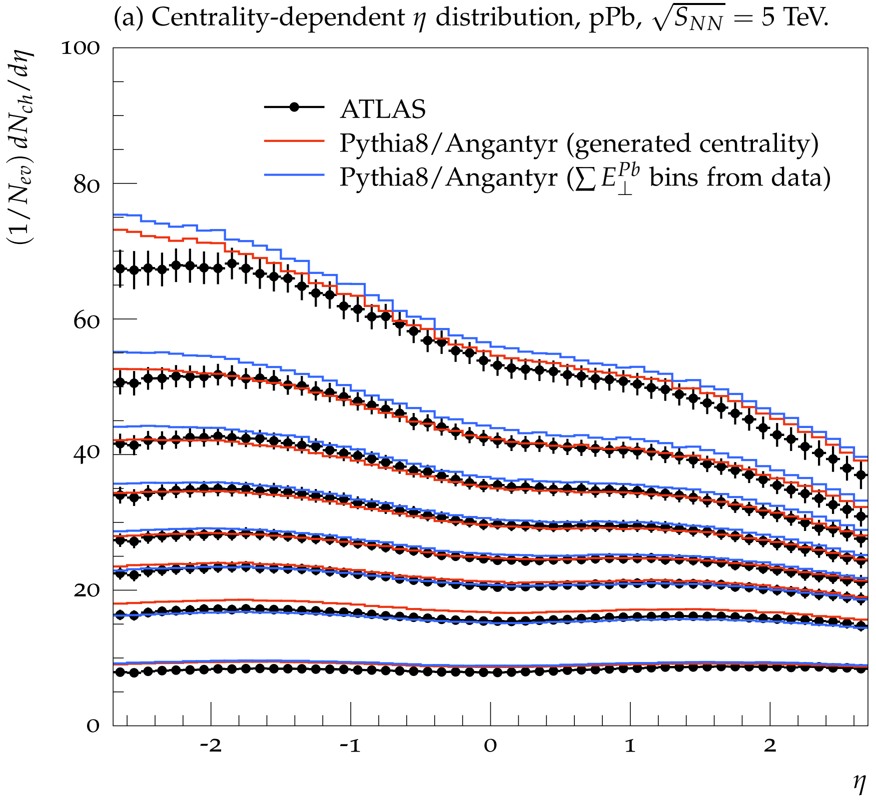




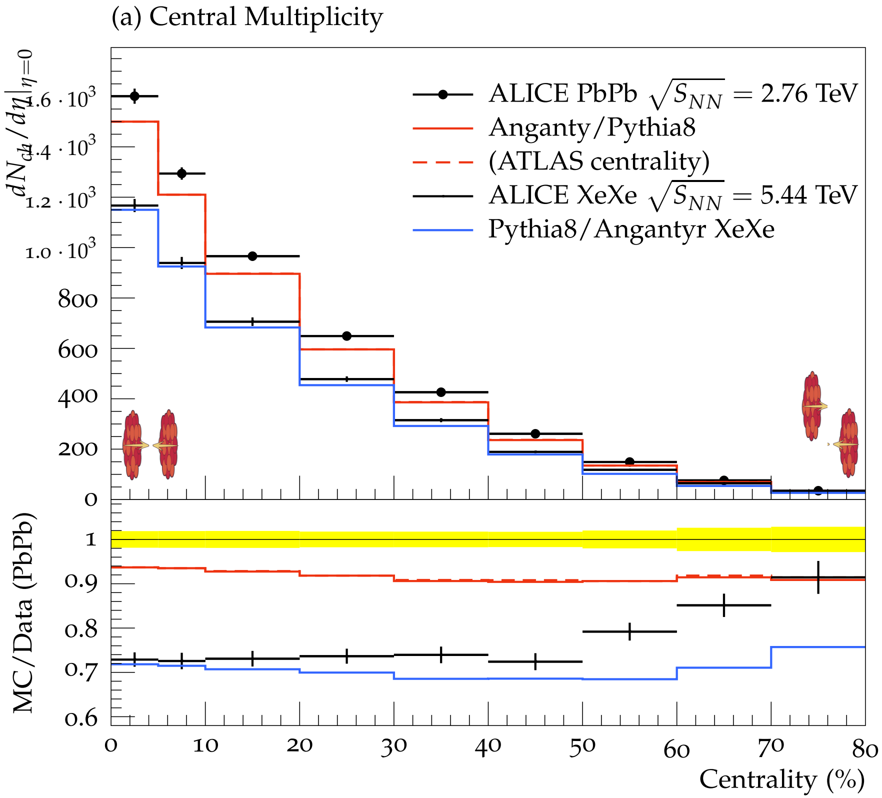
Results: Event multiplicity as a function of centrality in heavy-ion collisions

arXiv:1806.10820

pPb collisions



PbPb and XeXe collisions



Ar + Sc collisions

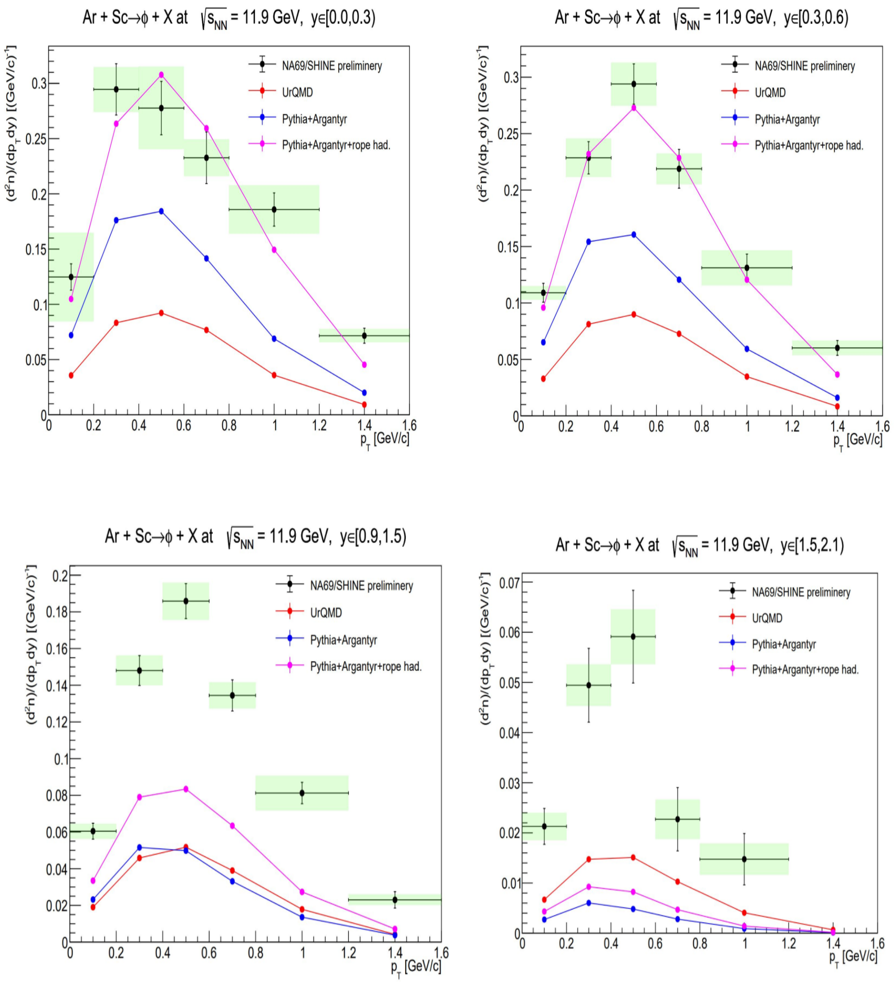
- Φ- meson production is studied,
- Results are generated for different rapidity ranges,
- The Angantyr model and its preliminary modifications fails to reproduce the Φ-meson yield in the forward rapidity.

Preliminary results with NA61 data

Purple lines: Angatyr + strings modification

Blue lines: Angantyr model

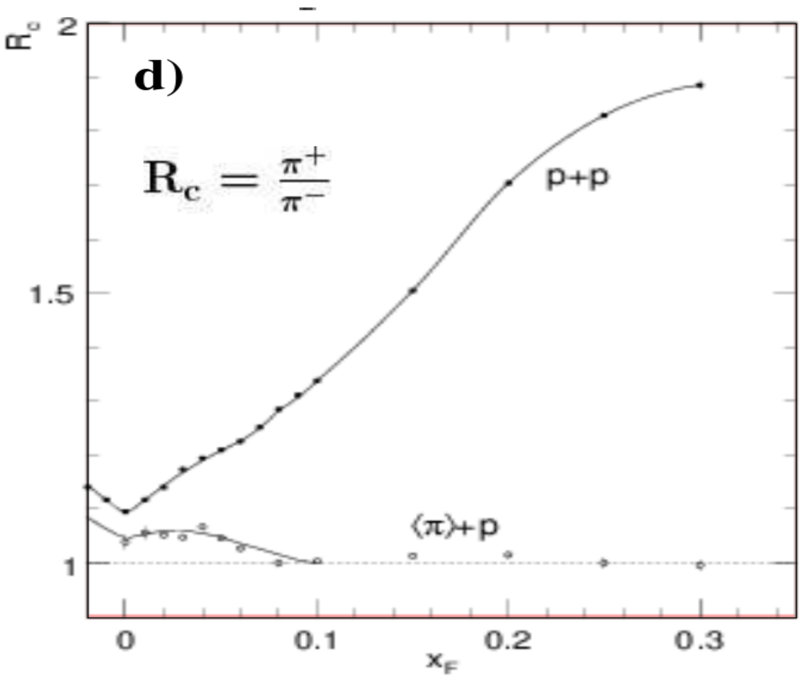
Red lines: URQMD model

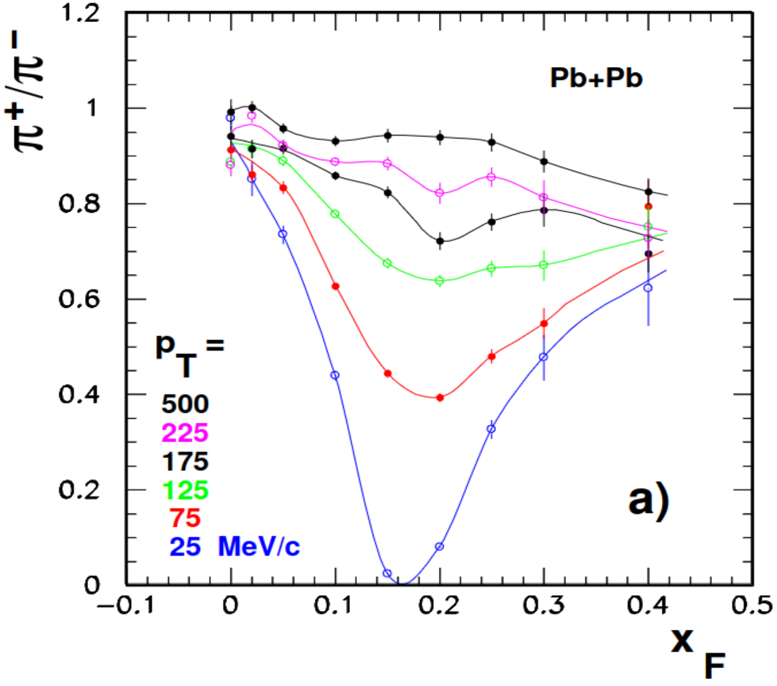


2024: Sena Veli, Tomasz Janiec, Łukasz Rozpłochowski, HS, Vitalii Ozvenchuk

Electromagnetic effects on the pion ratio in PbPb collisions

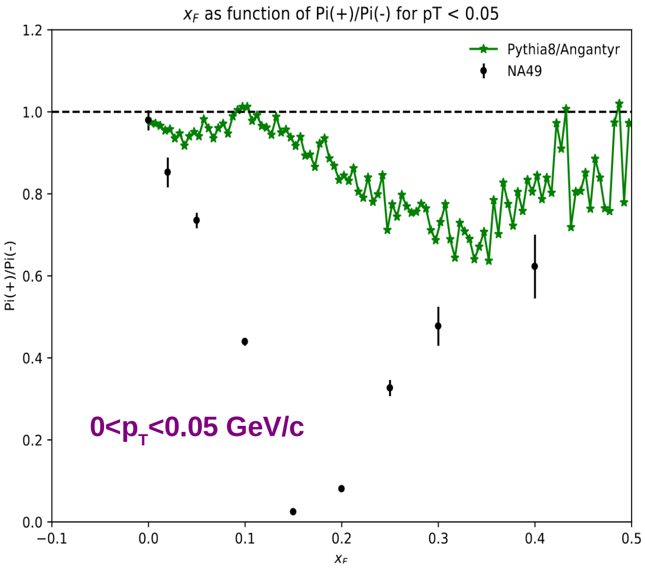
Feynman variable $x_F = 2p_L/\sqrt{s_{NN}}$,

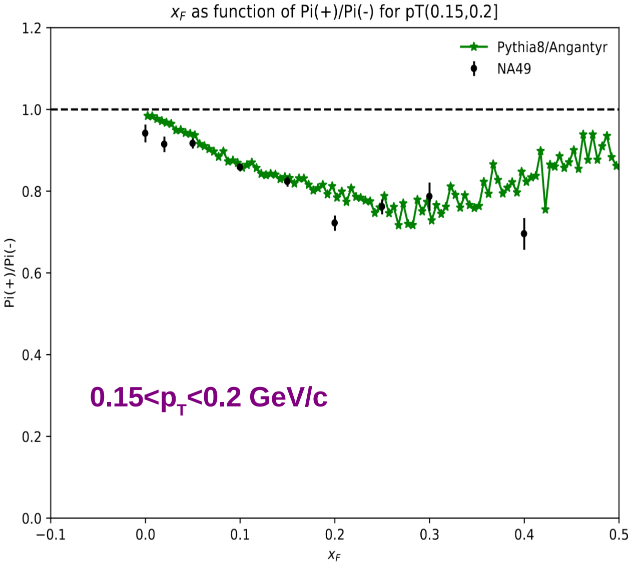


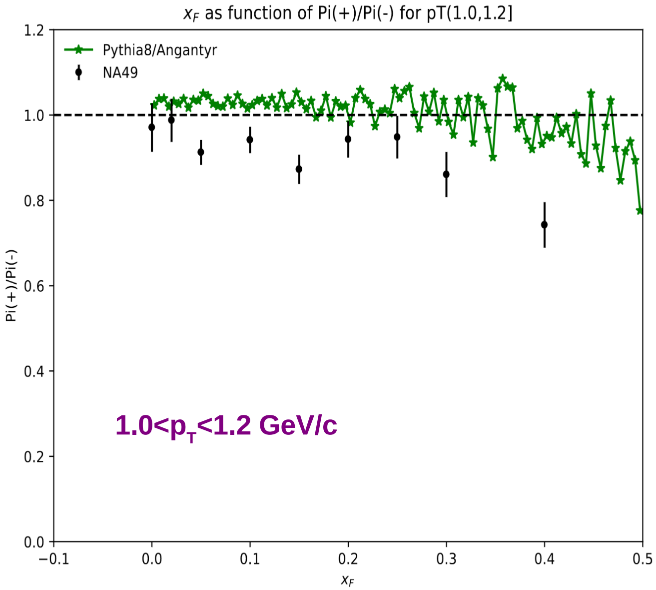


G. Barr (A. Rybicki) et al., Eur. Phys. J. C49 (2007) 919-945
A. Rybicki [NA49 Collab.], PoS EPS-HEP2009 (2009), 031

Results: Charged pion ratio in PbPb collisions NA49 data vs Angantyr model

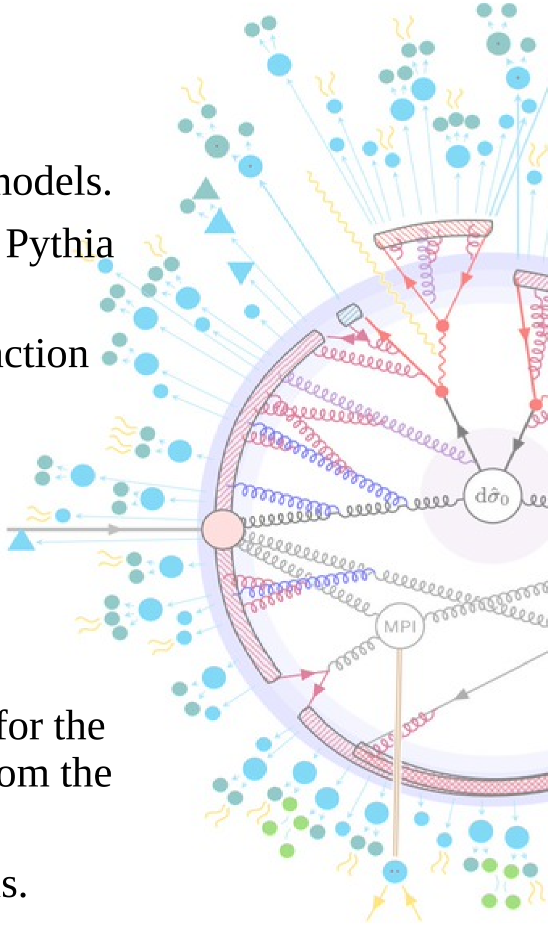






- This is the first-ever comparison of Angantyr with experimental data in such a large range of x_F,
- The model evidently **does not** contain spectator-induced electromagnetic effects.
- Qualitatively, the model reproduces the decrease of π^+/π^- with x_F (valence quarks!), but fails on the quantitative level,
- This shows the **importance** of SPS (NA61/SHINE) experimental data **for any future modeling of nucleus-nucleus collisions**.

Concluding remarks

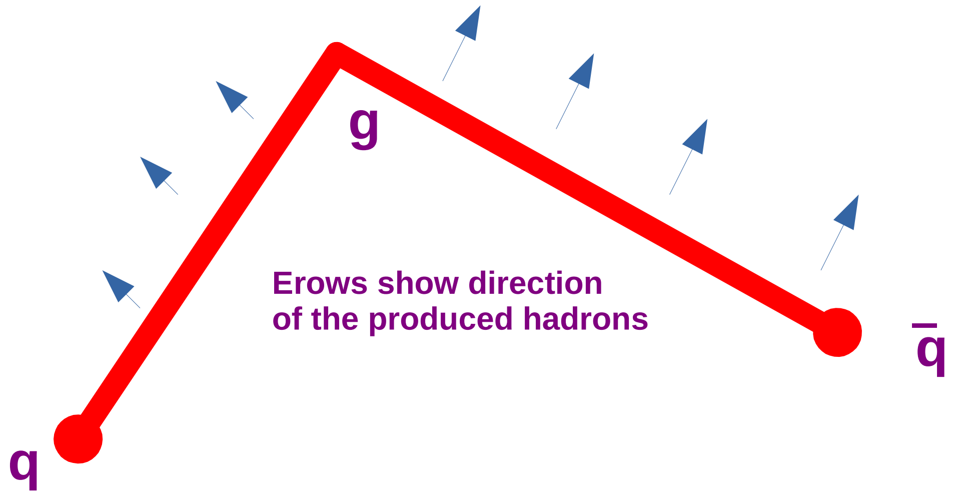


- Pythia is a widely used event-generator with continuous development in its physics models.
- We have **developed the Angantyr model** for heavy-ion collisions as an extension of Pythia and without any assuption of a thermalised medium creation.
- There are many **improvements** required and work in progress especially with the junction type string fragmentation, forward physics at LHC, and collisions at SPS energy.
- I ommitted discussions about many recent developments.

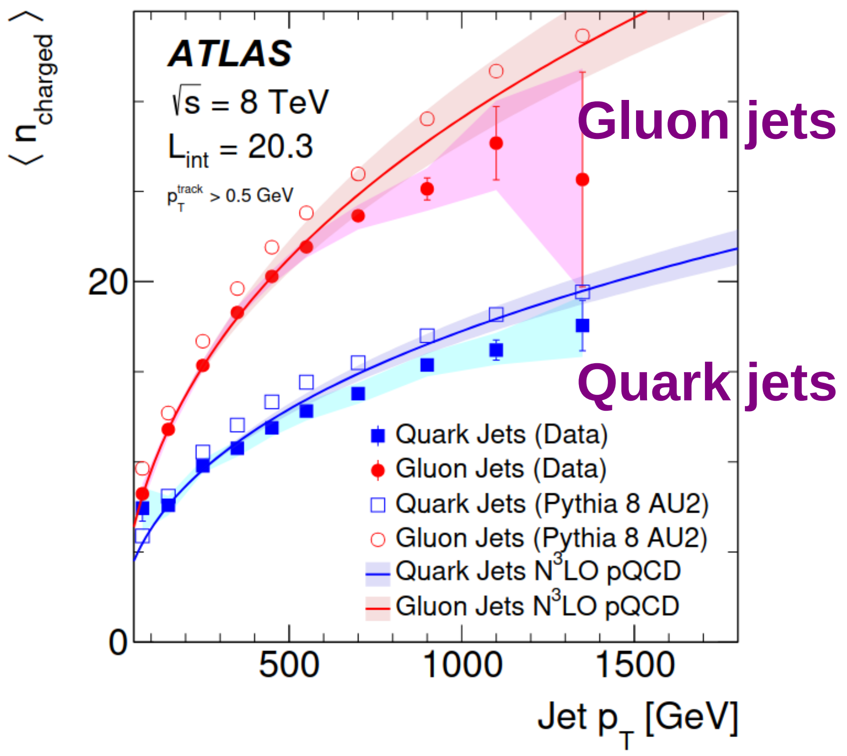
Outlook

- Next step is to analyse ArSc collision data from NA61/SHINE experiment primarily for the electromagnetic effects study for pion ratio (especially to understand contributions from the beam remnants using the Angantyr model).
- Continue the Φ- meson production study in the forward rapidity in the ArSc collisions.
- Upon successful conclusions, one of the possible profits will be **improvements in the Angantyr model** to reproduce these important experimental data.

Additional slides



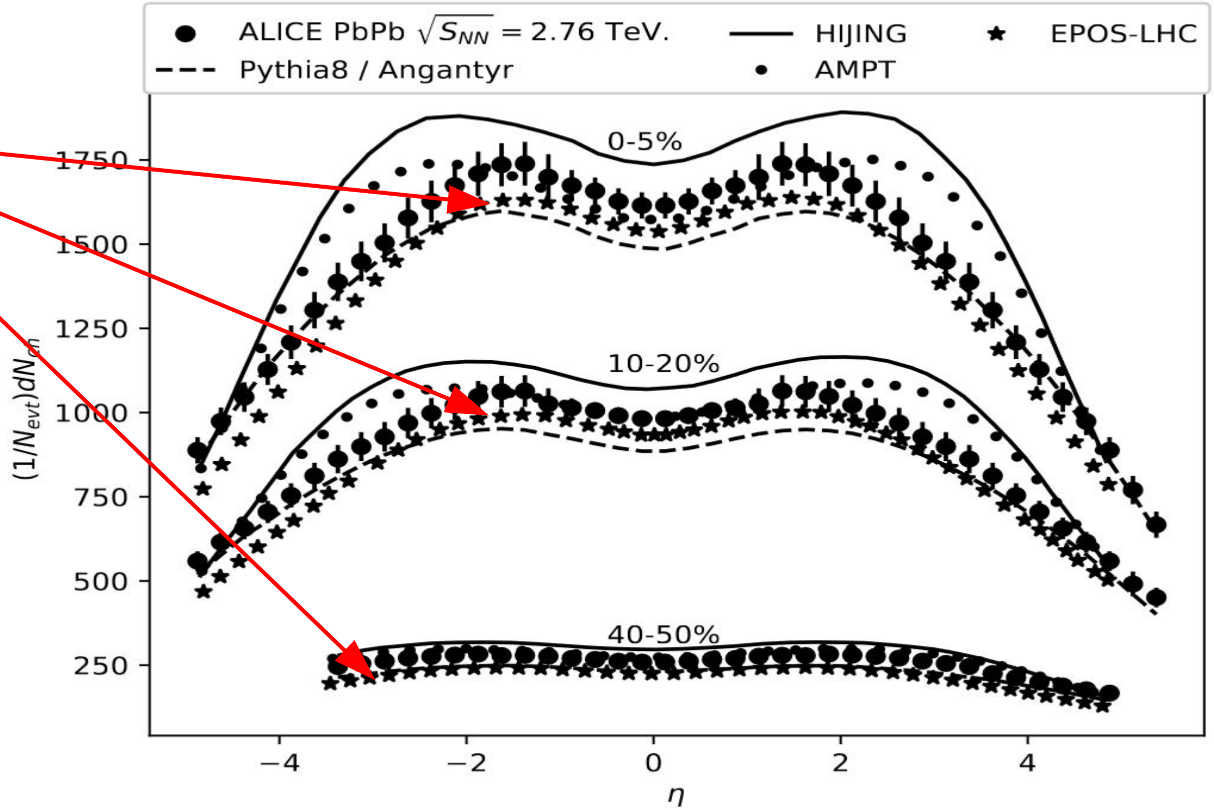
ATLAS, Eur.Phys.J. C76 (2016) no.6, 322



- Gluons are transverse kink on the Lund strings,
- Hadrons produced along the colour connections,
- Average twice more hadrons produced around gluons compared to quarks due to their colour charge.

Event multiplicity distribution compared to other heavy-ion collision event generators

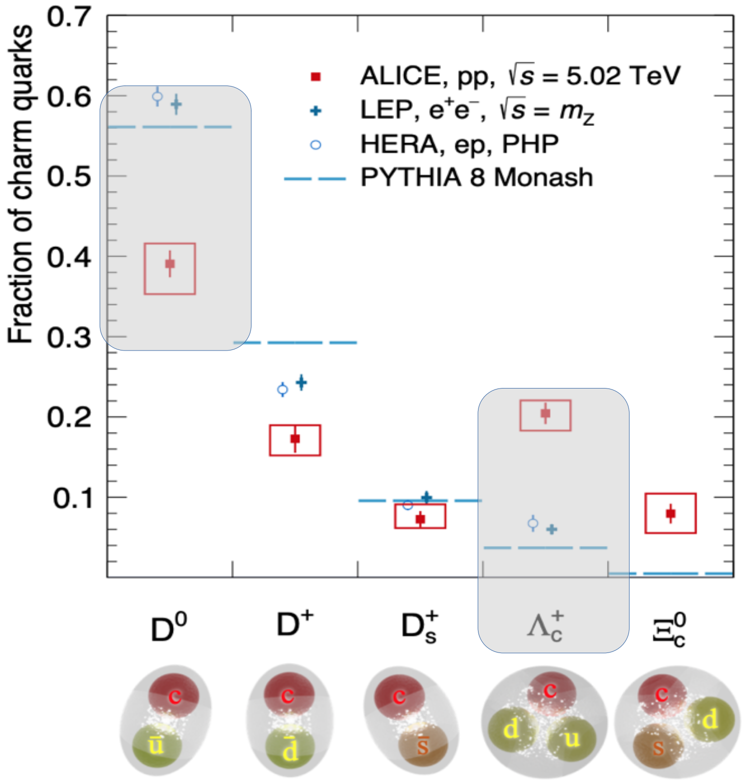
Angantyr is producing competing results.



The fraction of charm quarks in different colliding systems

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

- The charm quarks are produced **only** in perturbative interactions in Pythia;
- There are more charm **baryons** in pp collisions than in ep and e^+e^- collisions;
- We **modified** junction formation and fragmentation to enhance the probability of a heavy quark forming a baryon.

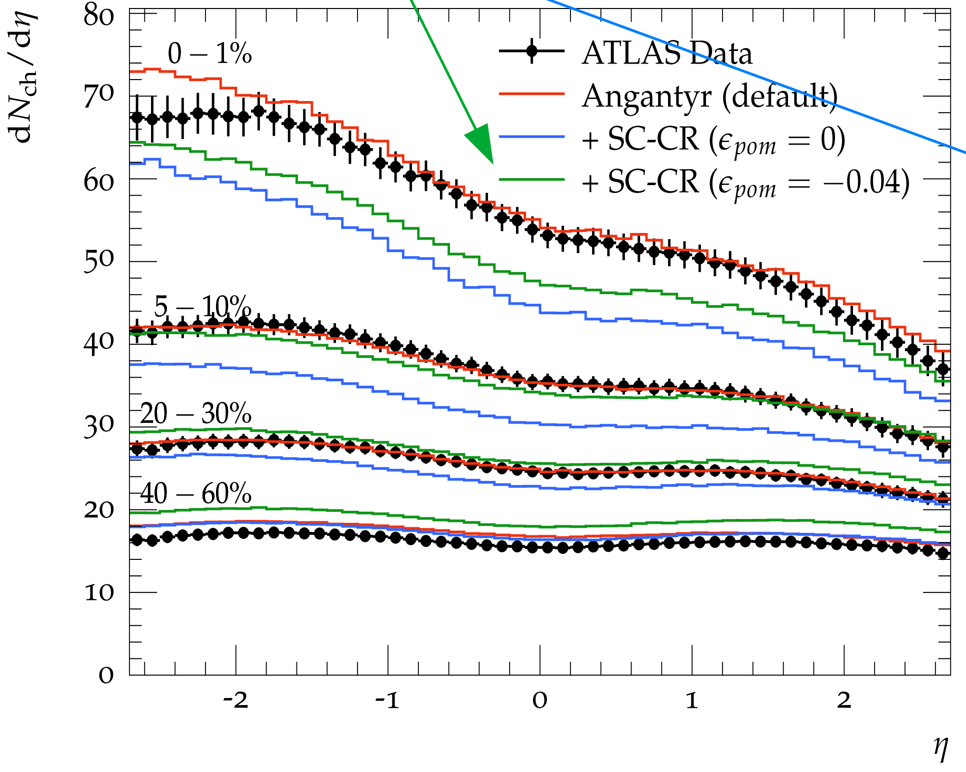


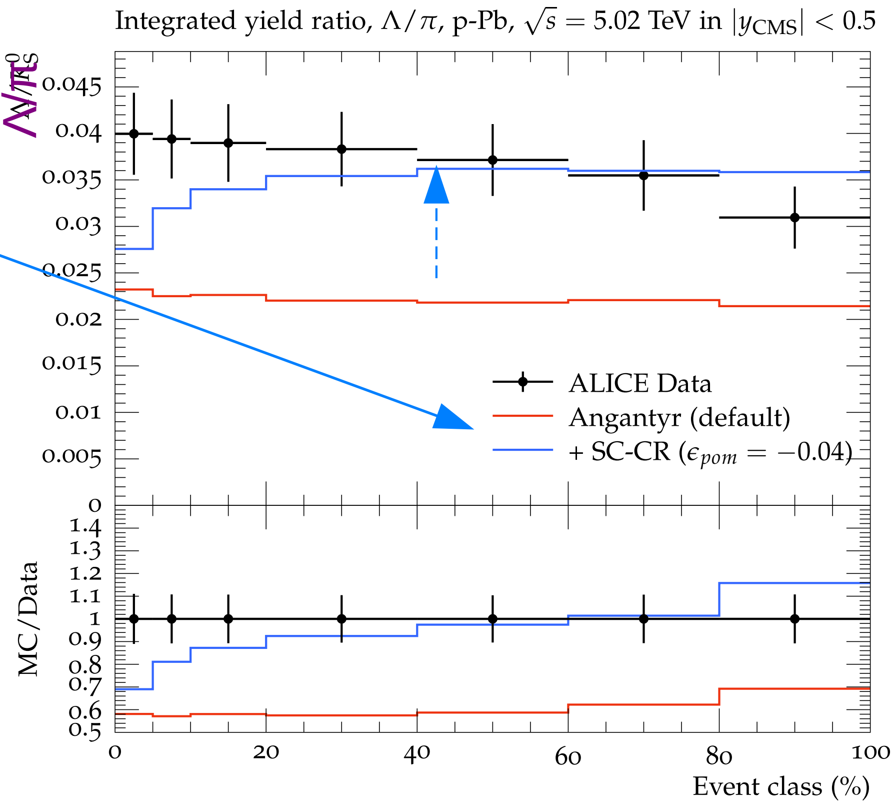
see also Phys.Rev.D 105 (2022) 1, L011103

Results: pPb collisions

arXiv:2303.11747

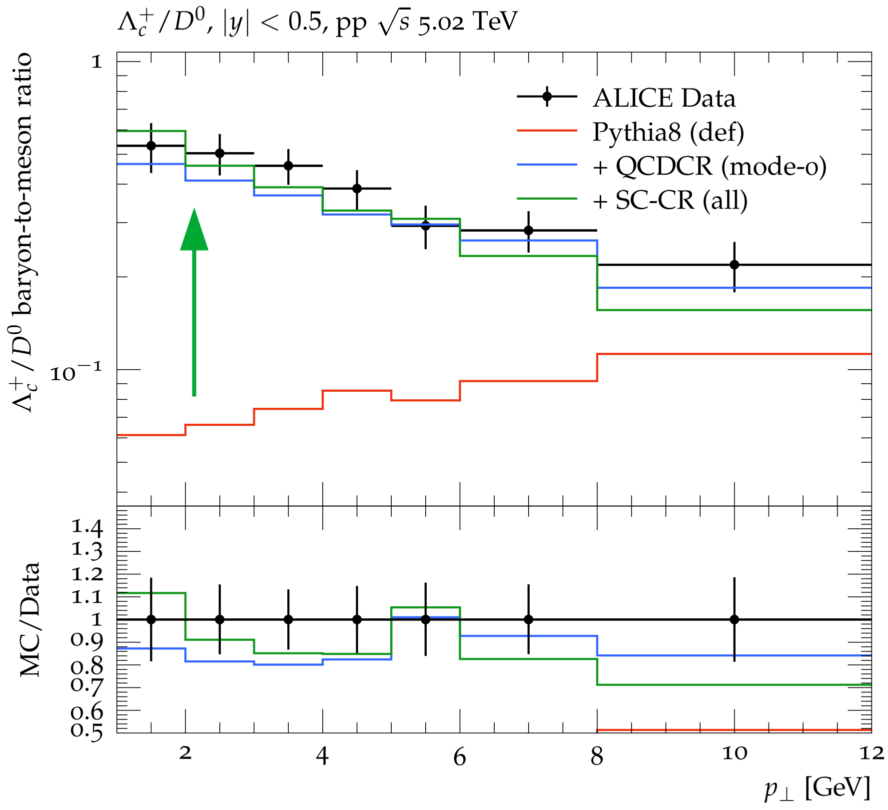
Modified Pomeron flux in SND

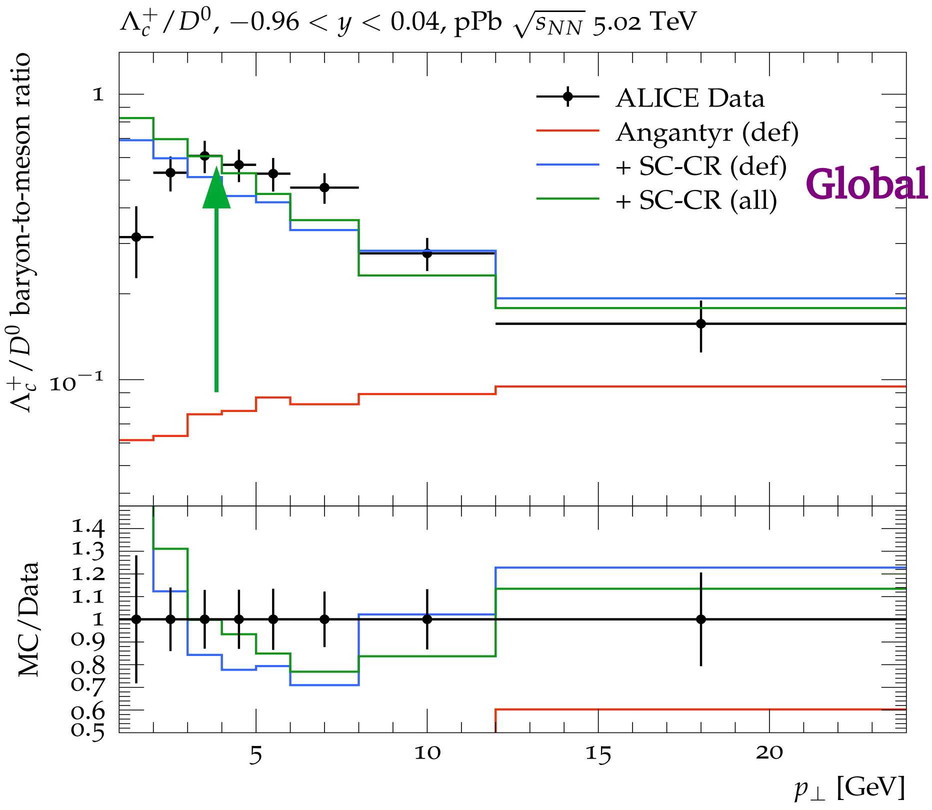




Results: pp and pPb collisions at 5.02 TeV

arXiv:2309.12452

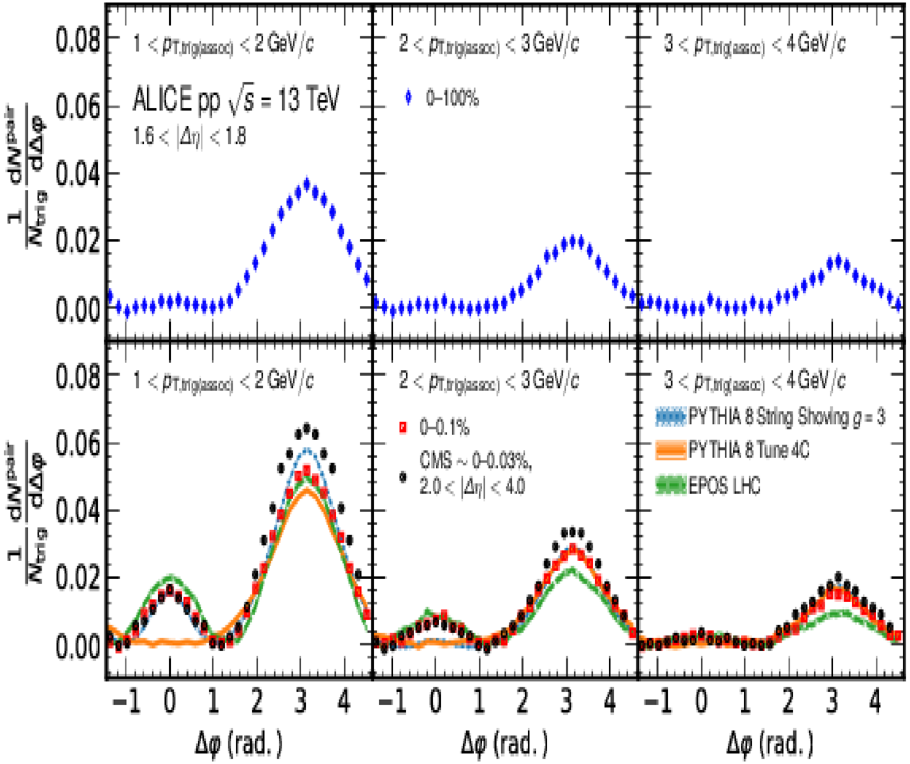




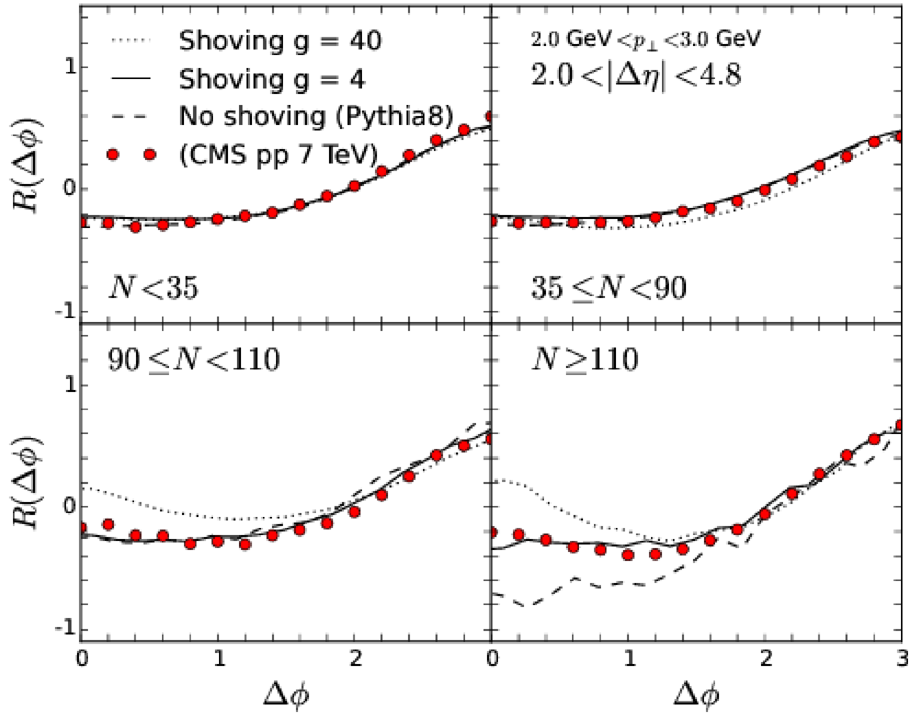
Global CR

Results: string shoving and inclusive flow

ArXiv:2101.03110 [nucl-ex]

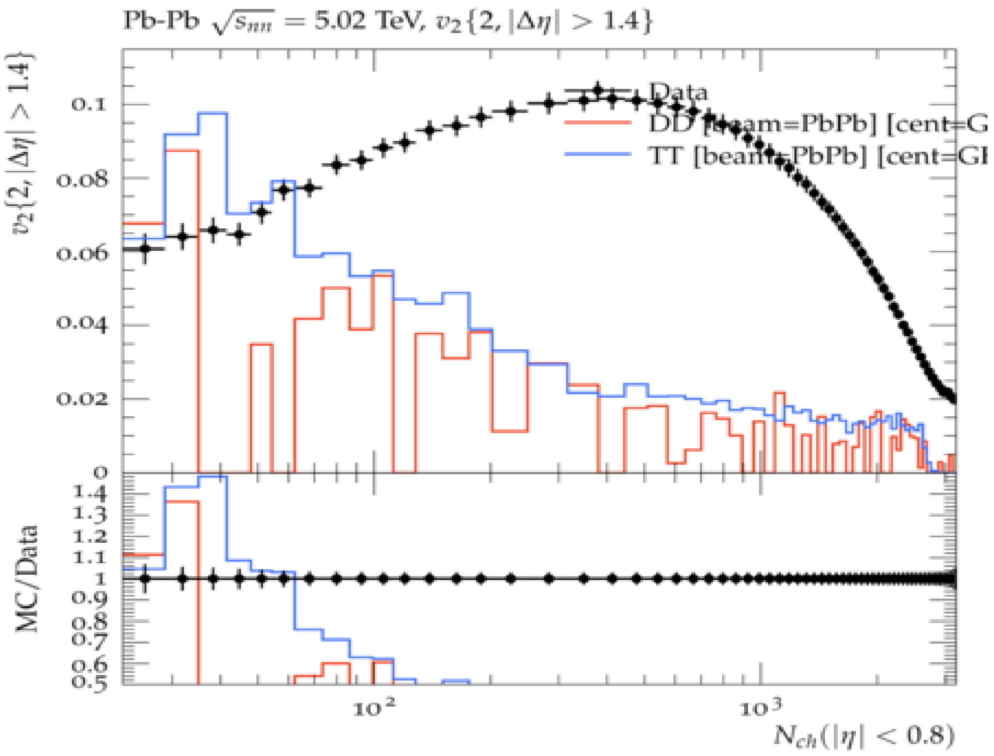


ArXiv: 1710.09725 [hep-ph]

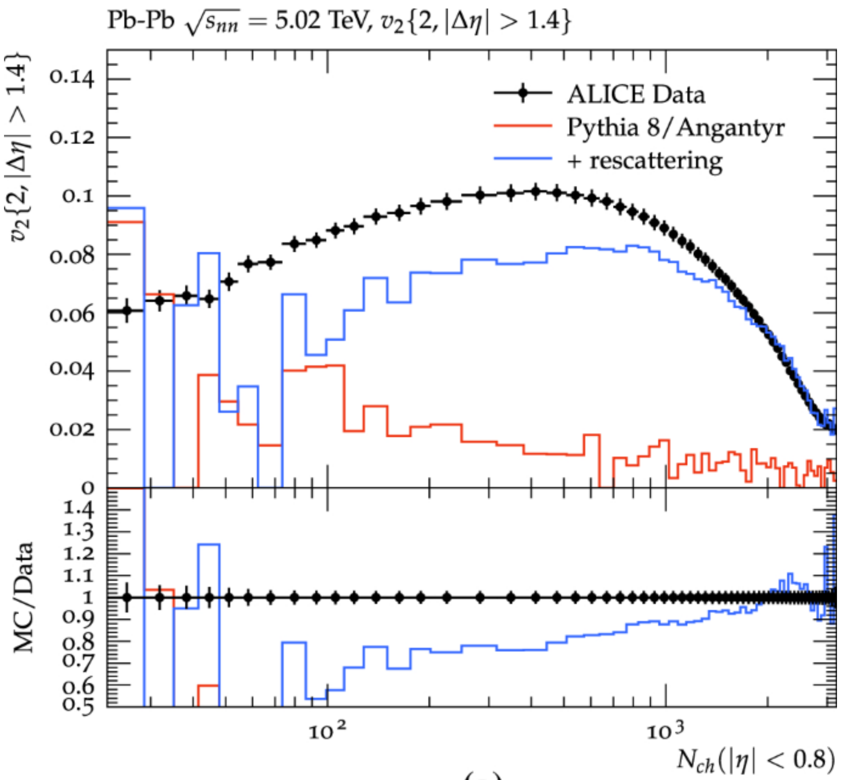


Results: flow Global CR and hadronic rescattering

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



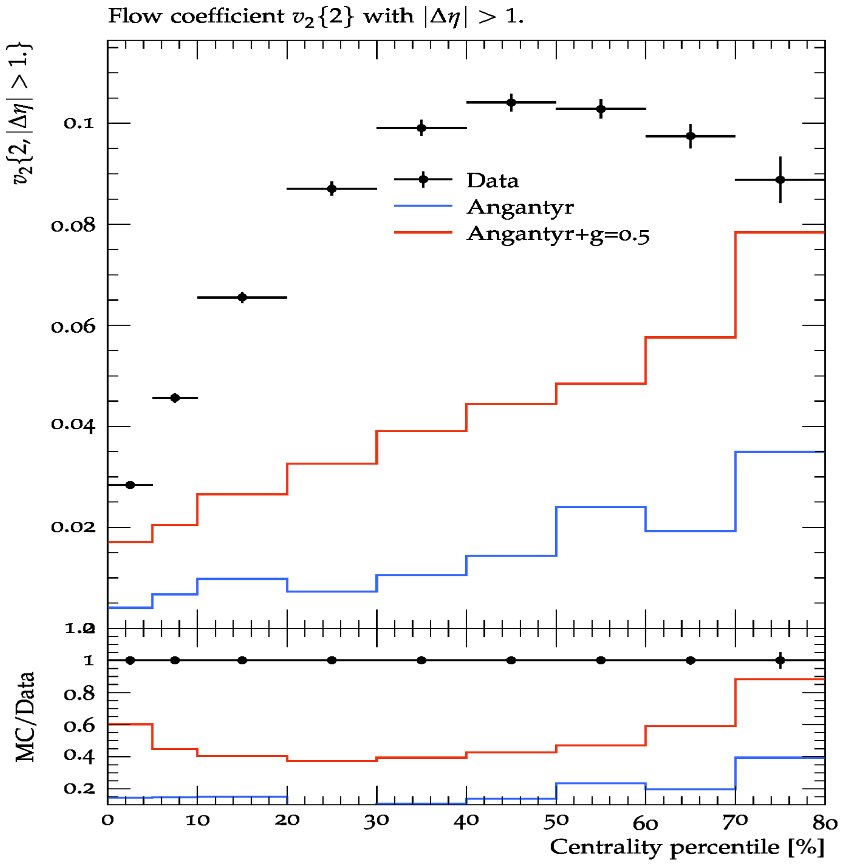
Hadronic rescattering



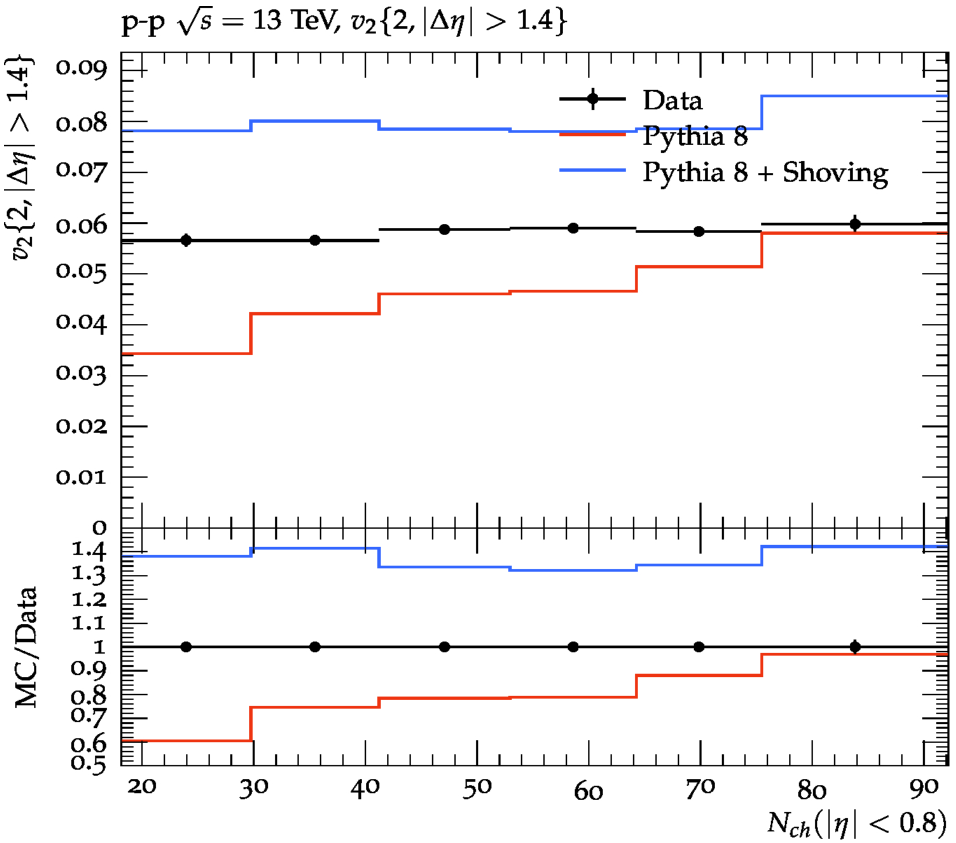
(a)

Results: effects of string shoving on collectivity

PbPb collisions

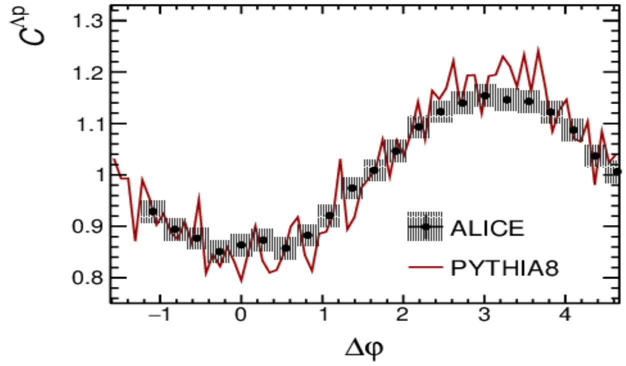


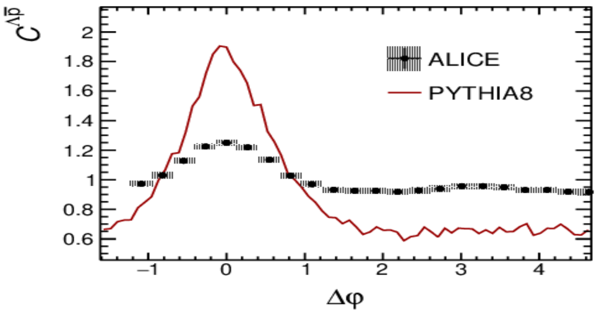
pp collisions

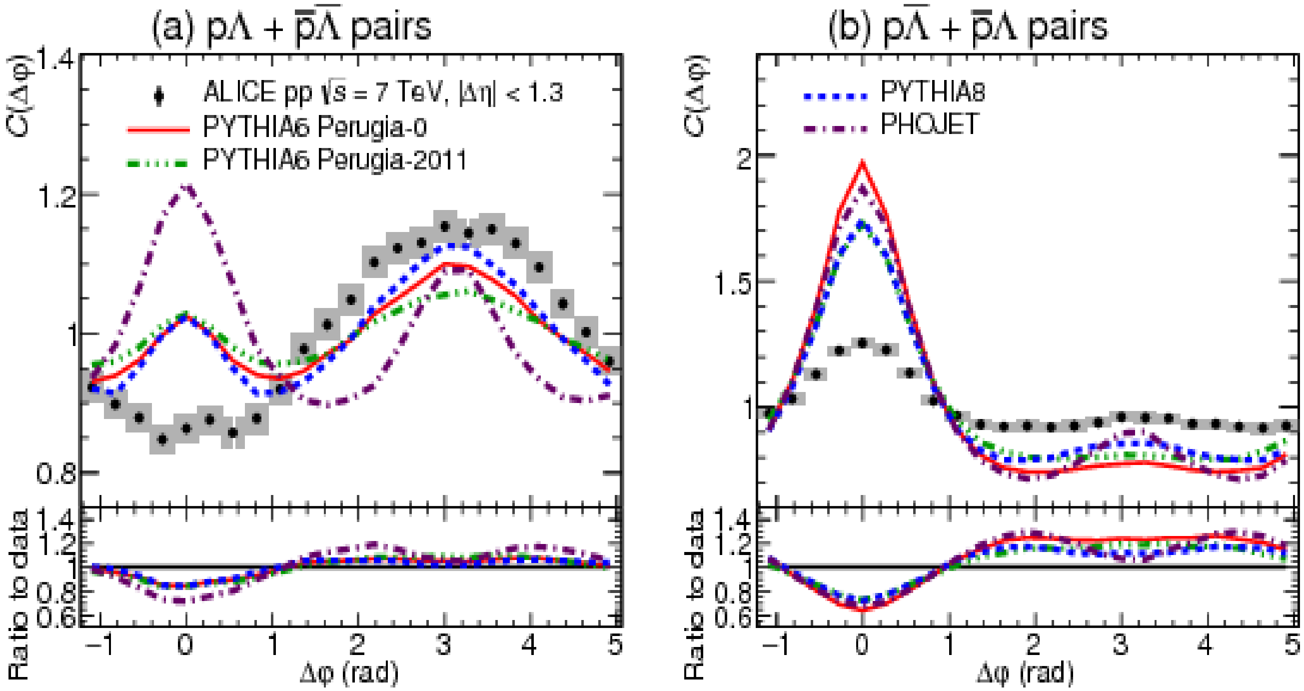


Baryon Correlations in Pythia

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



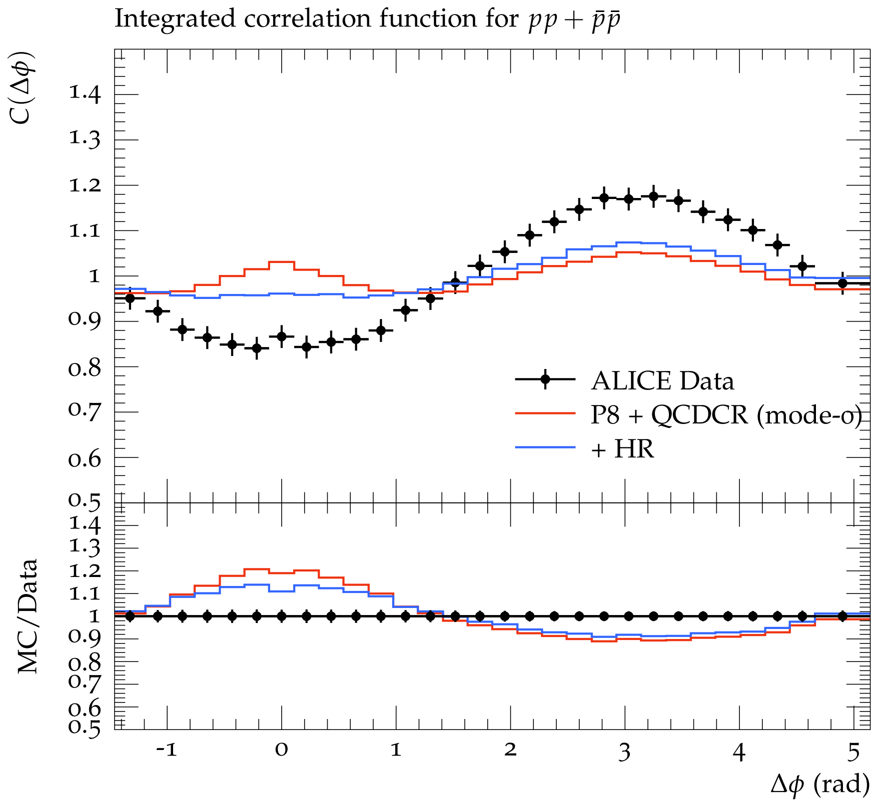


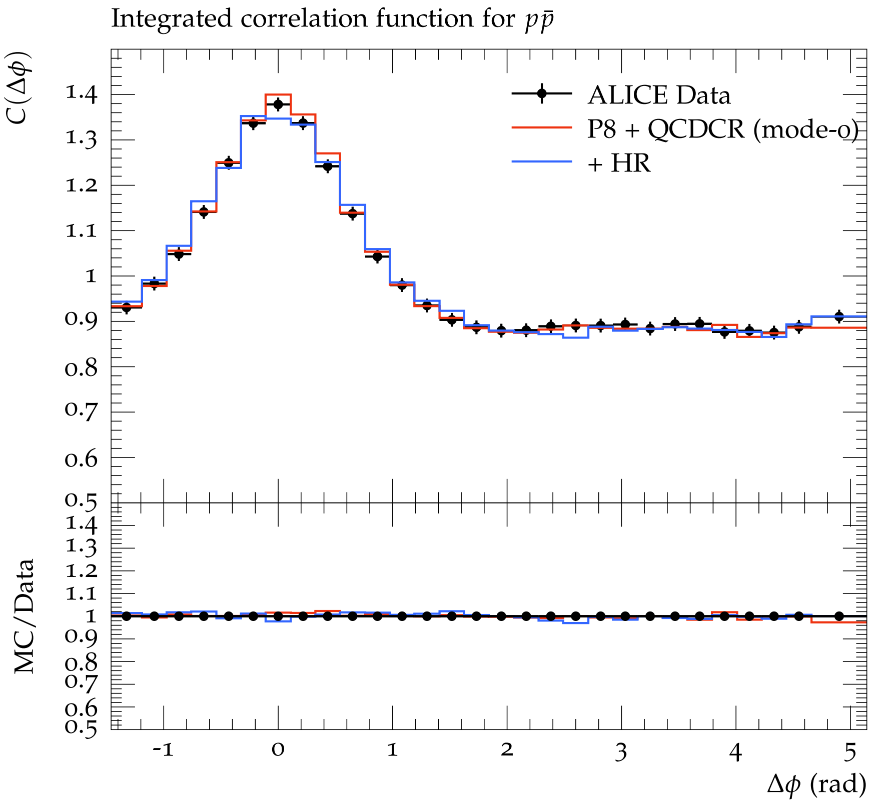


ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569

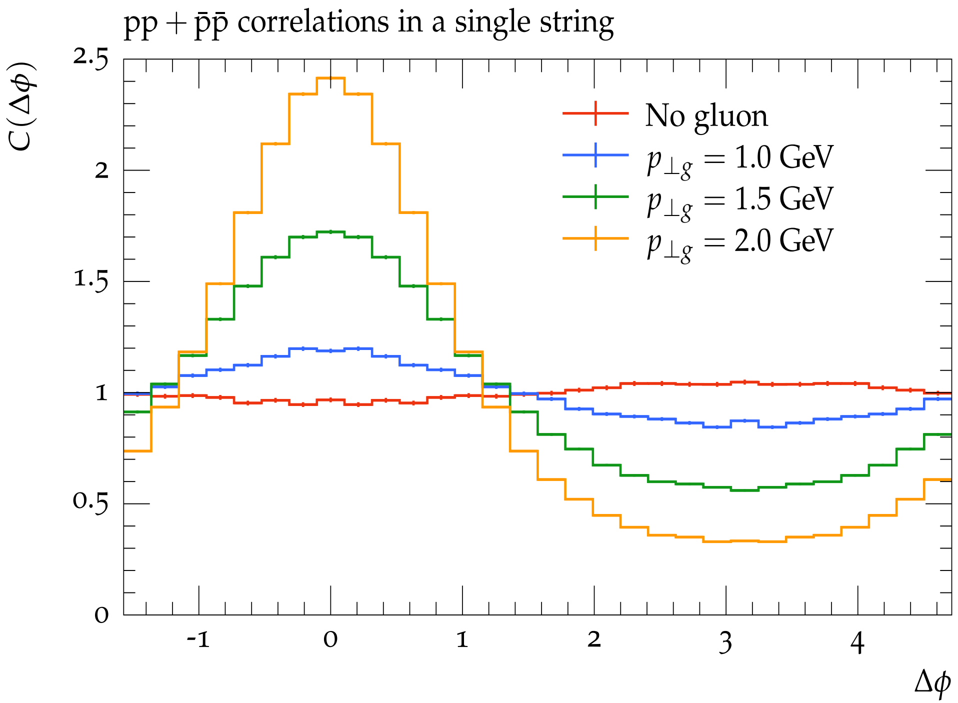
Pythia fails to reproduce baryon correlations.

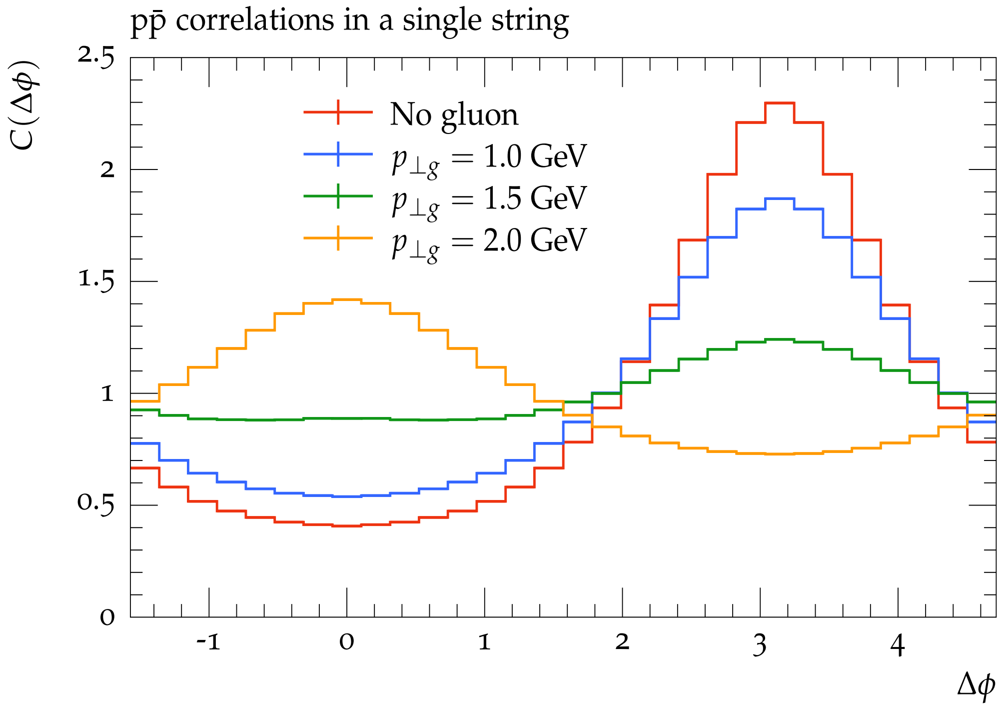
Results: **Pythia with QCD colour reconnection and hadronic rescattering**



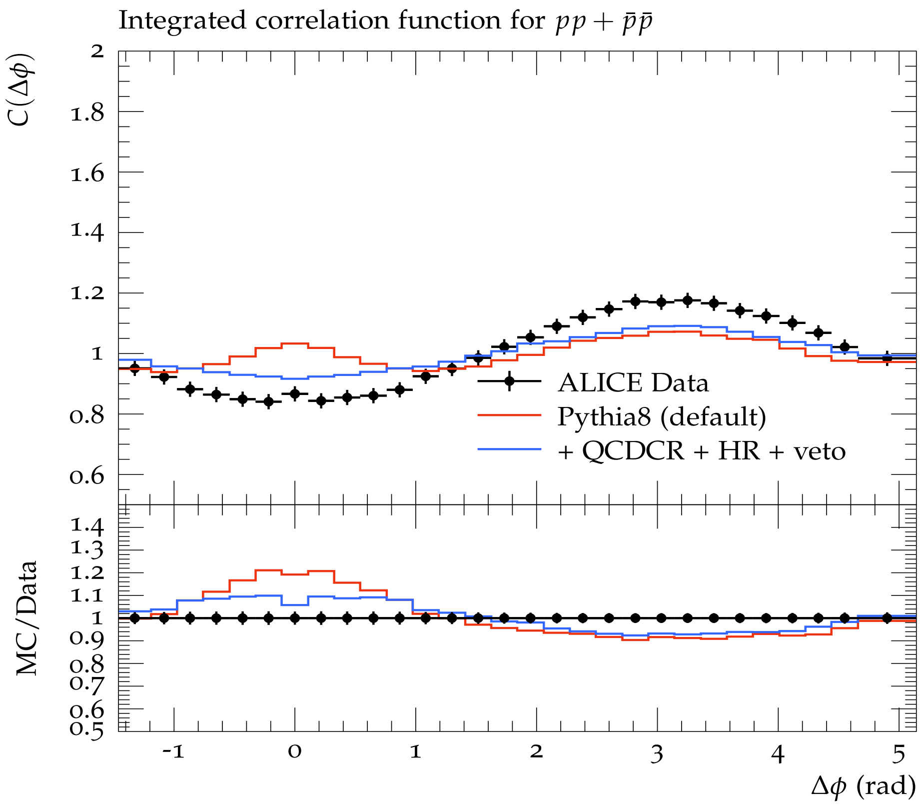


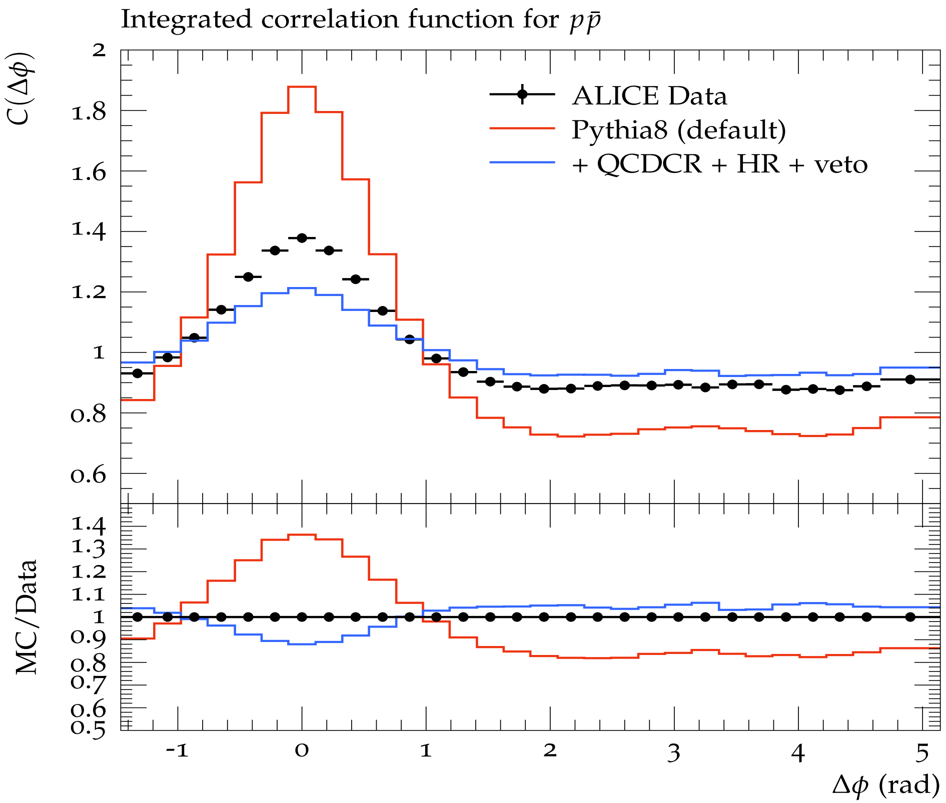
Role of gluons in baryon correlations



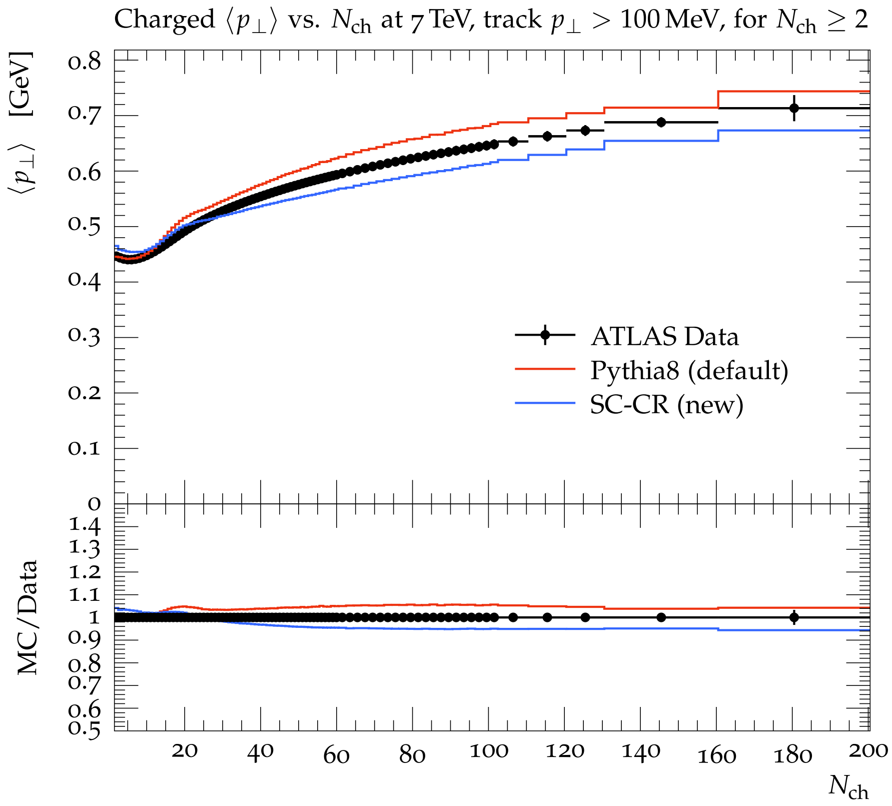


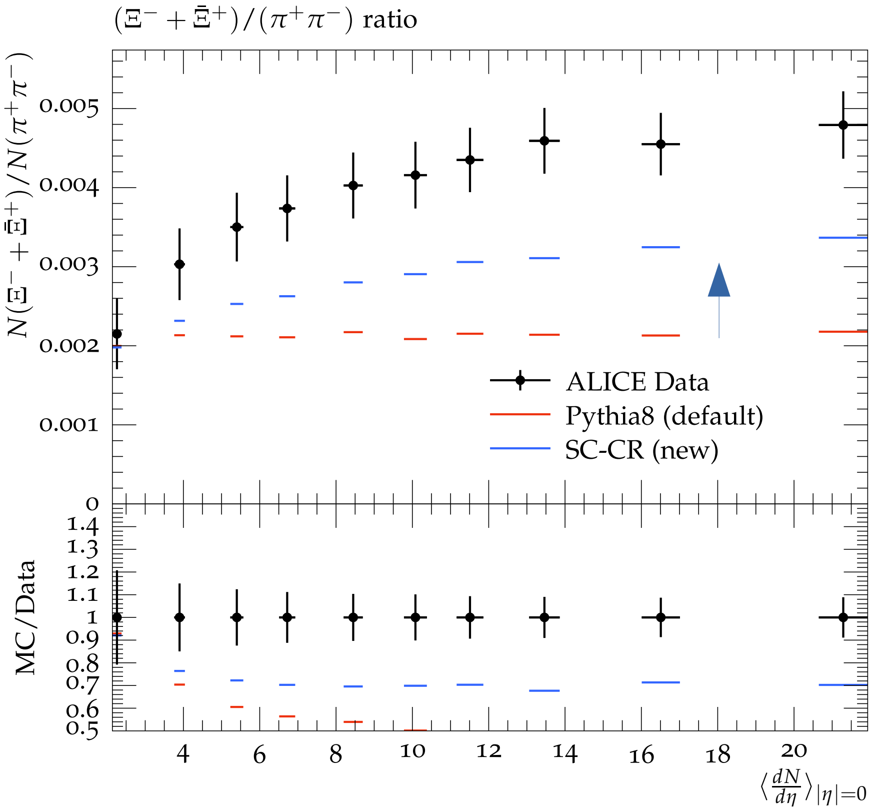
Results: **Pythia with suppressed baryon production near gluon kinks**





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





String Shoving and Rope Hadronization

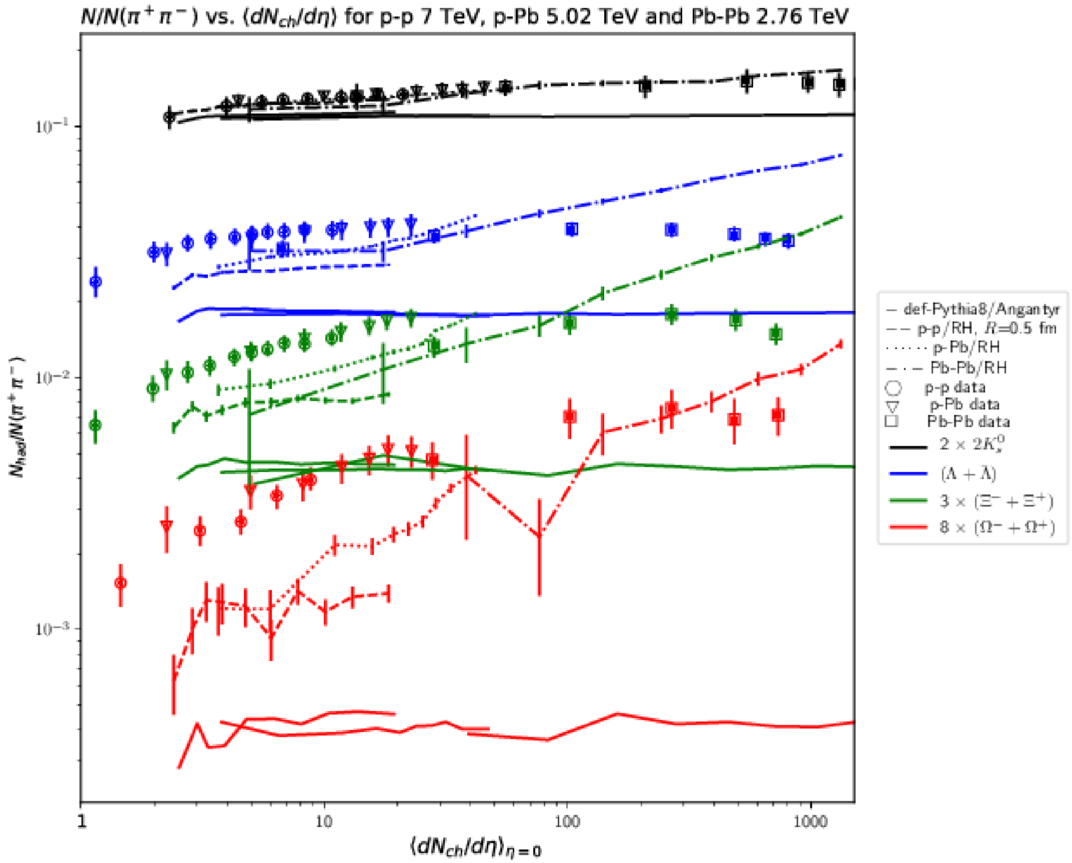
arXiv:2010.07595, 1710.09725 arXiv:2205.11170

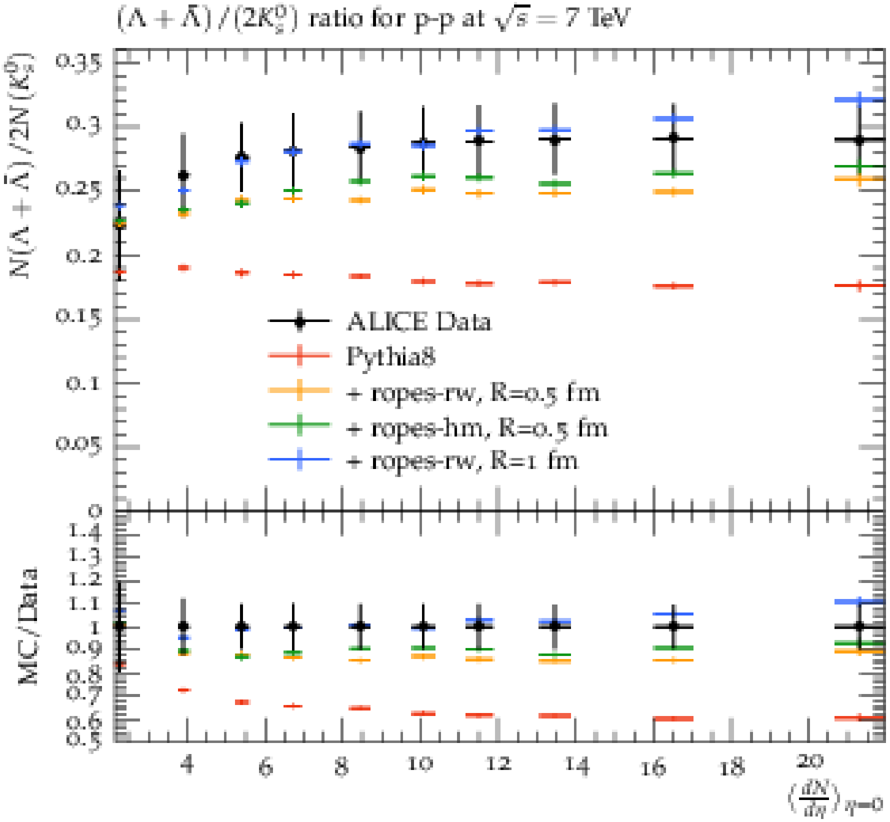
- The colour strings can push each other in the transverse direction;
- They can contribute to collective flow;
- The overlapping colour strings can also form a colour rope and increase the string tension;
- The increased string tension results into higher probability for heavier quarks production during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

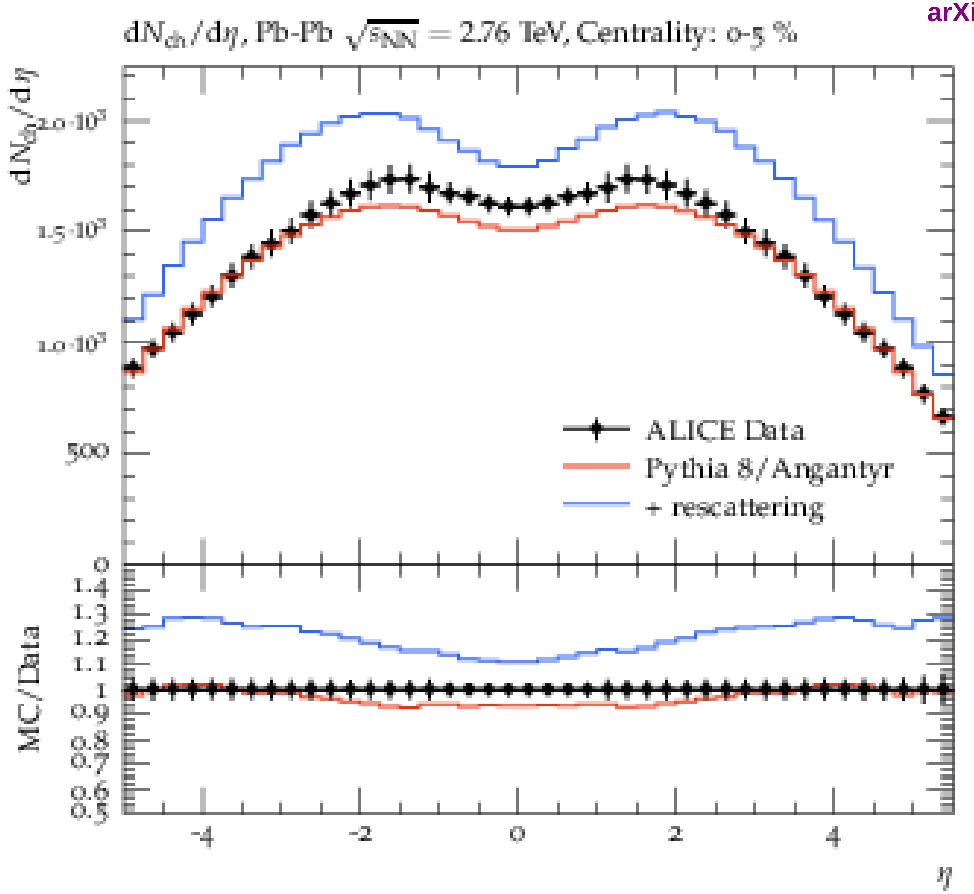
arXiv:2205.11170

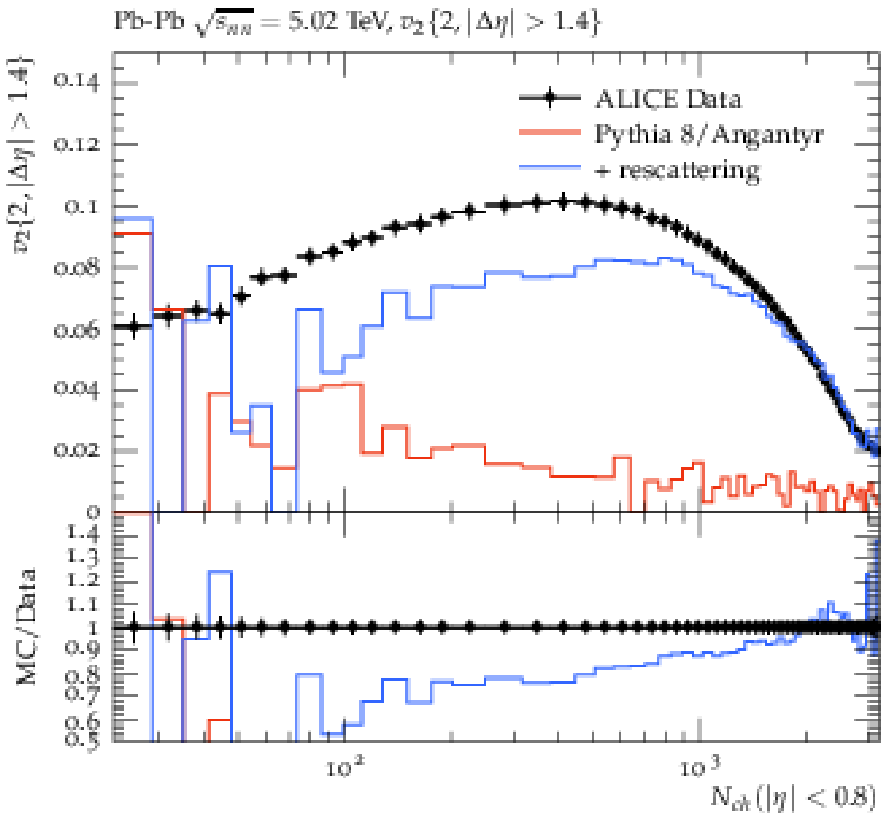




Results: Hadronic Rescattering

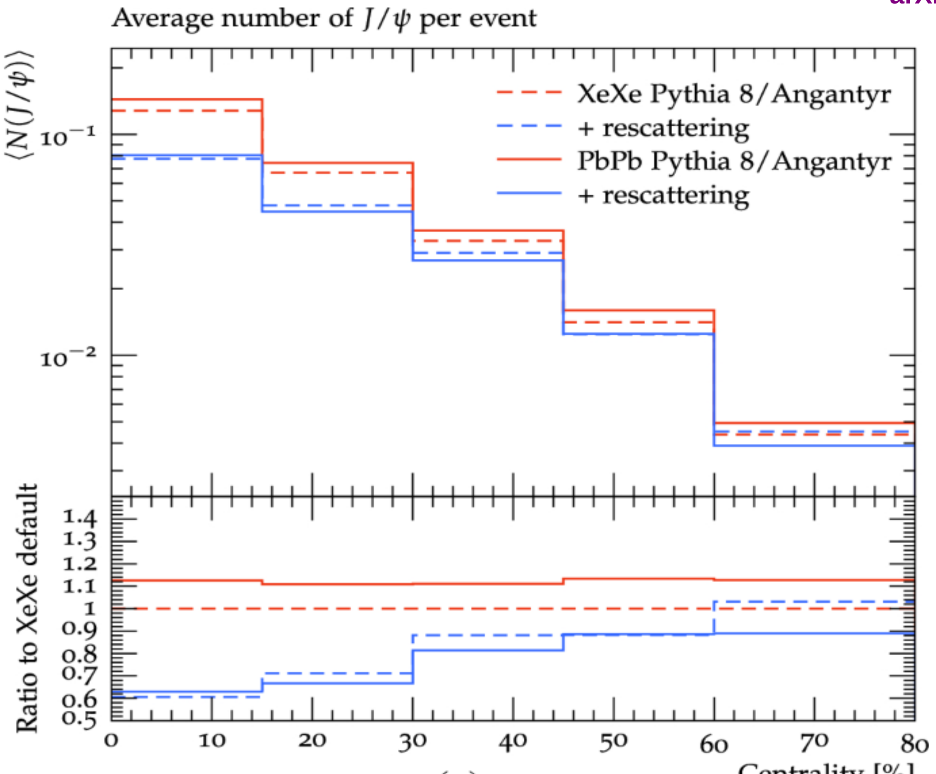
arXiv:2103.09665 [hep-ph]



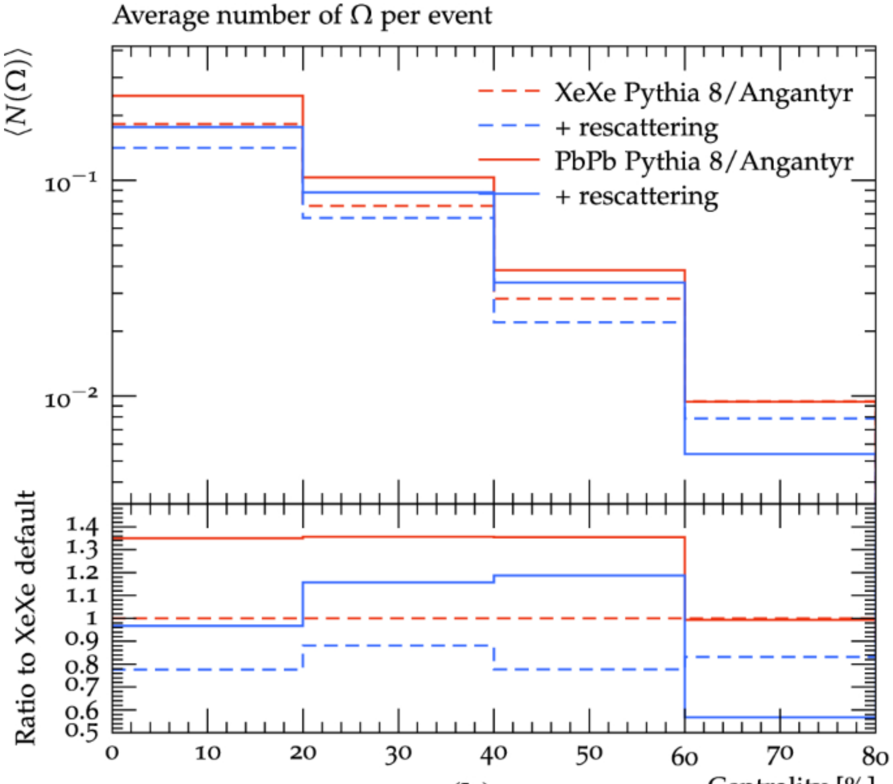


Results: Hadronic rescattering

arXiv:2103.09665 [hep-ph]

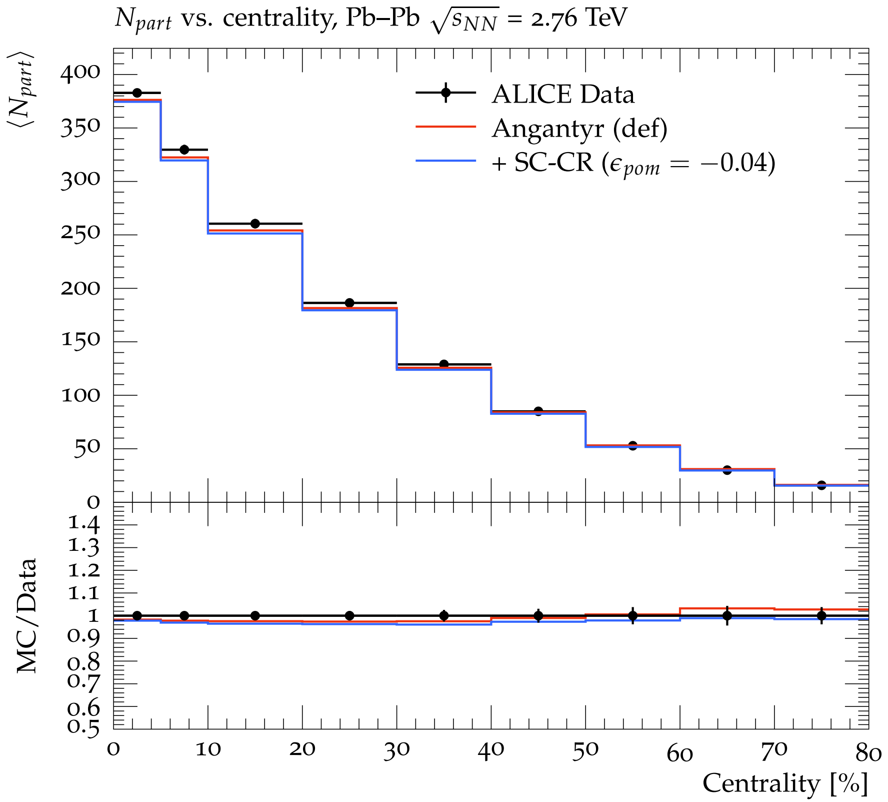


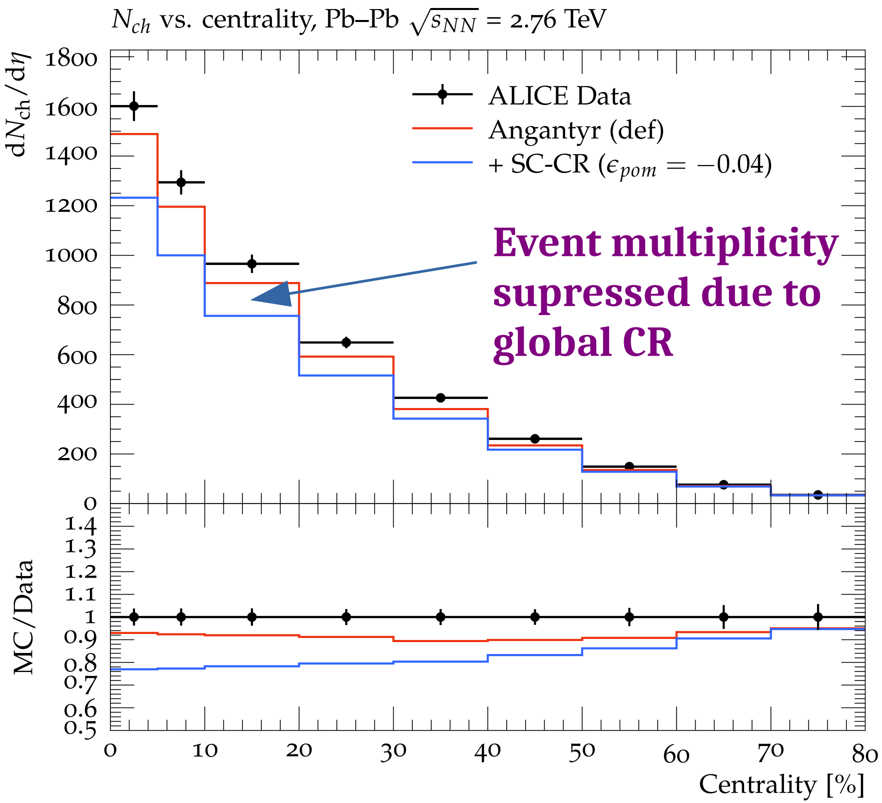
(a)



(b)

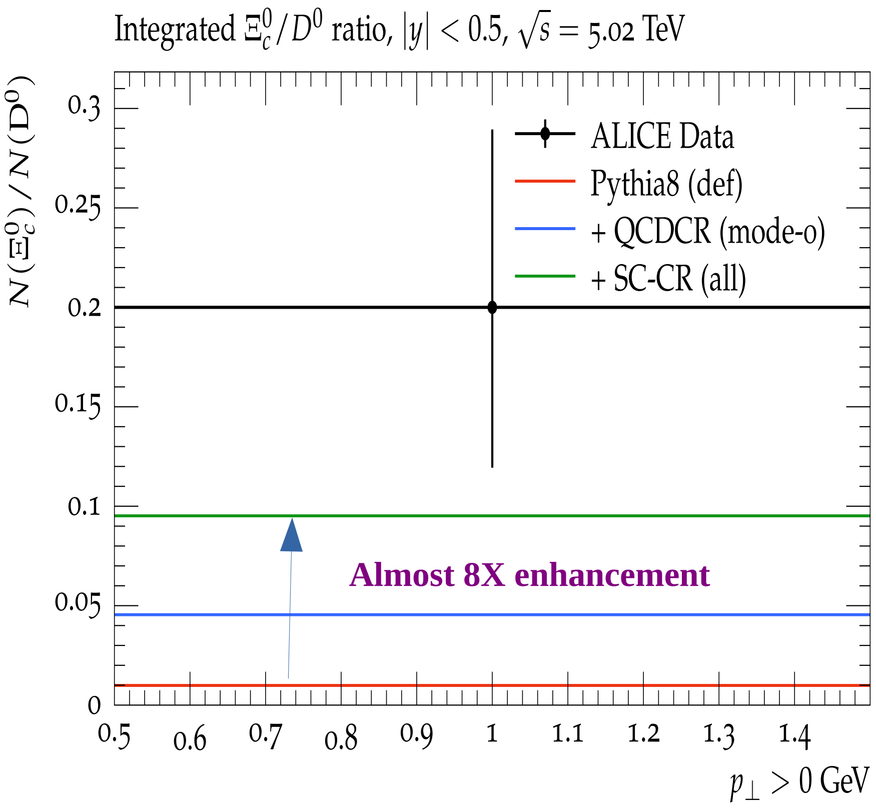
Results: Global CR effects in PbPb collisions



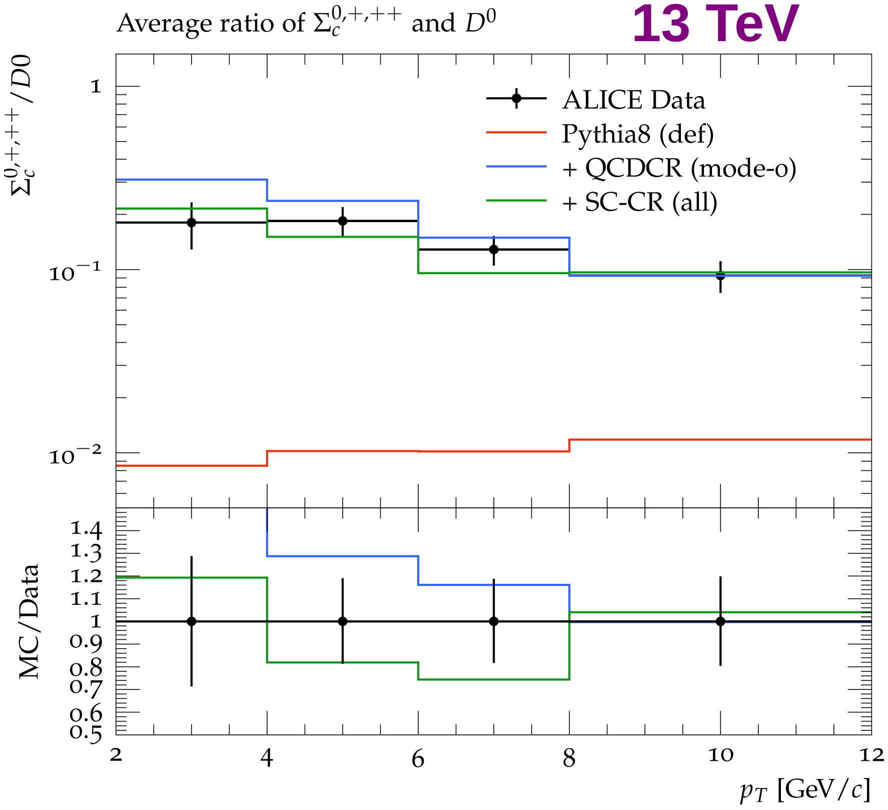


Results: Baryon-to-meson ratio in pp collisions

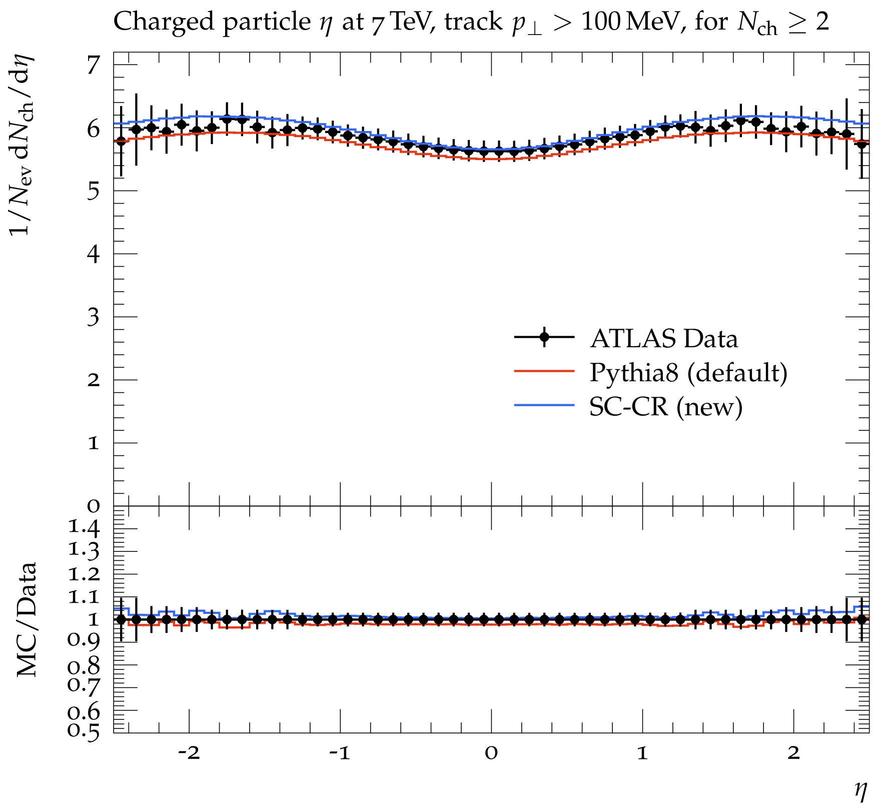
arXiv:2309.12452

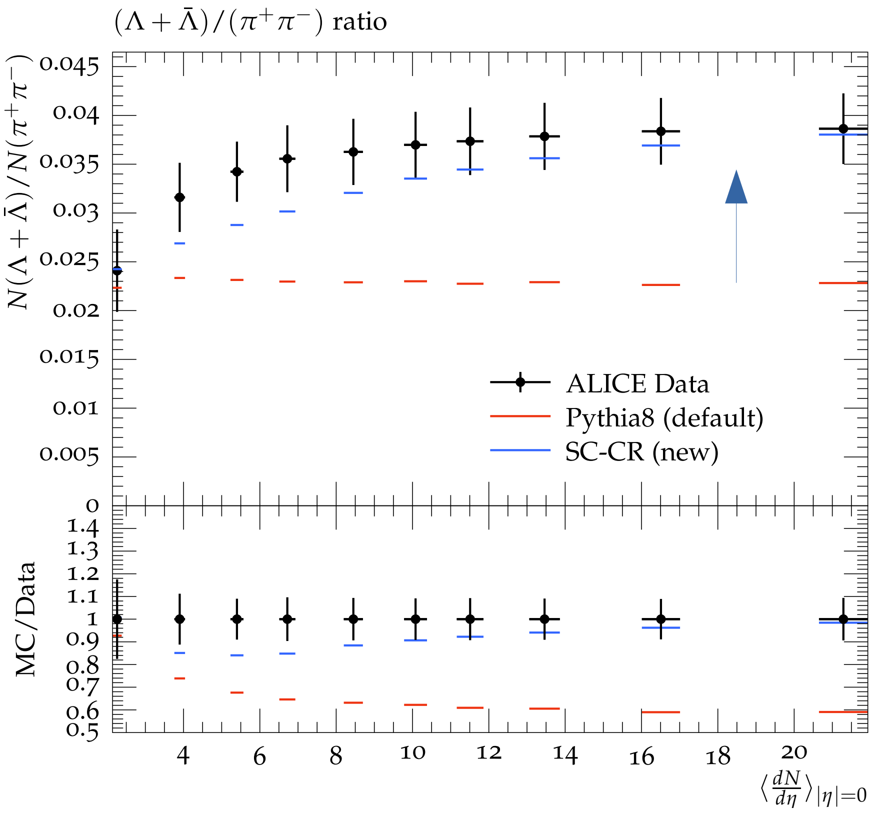


13 TeV



Results: pp collisions





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