Baryon correlations in Pythia

Based on arXiv:2309.01557

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Seminarium HEP Białasówka
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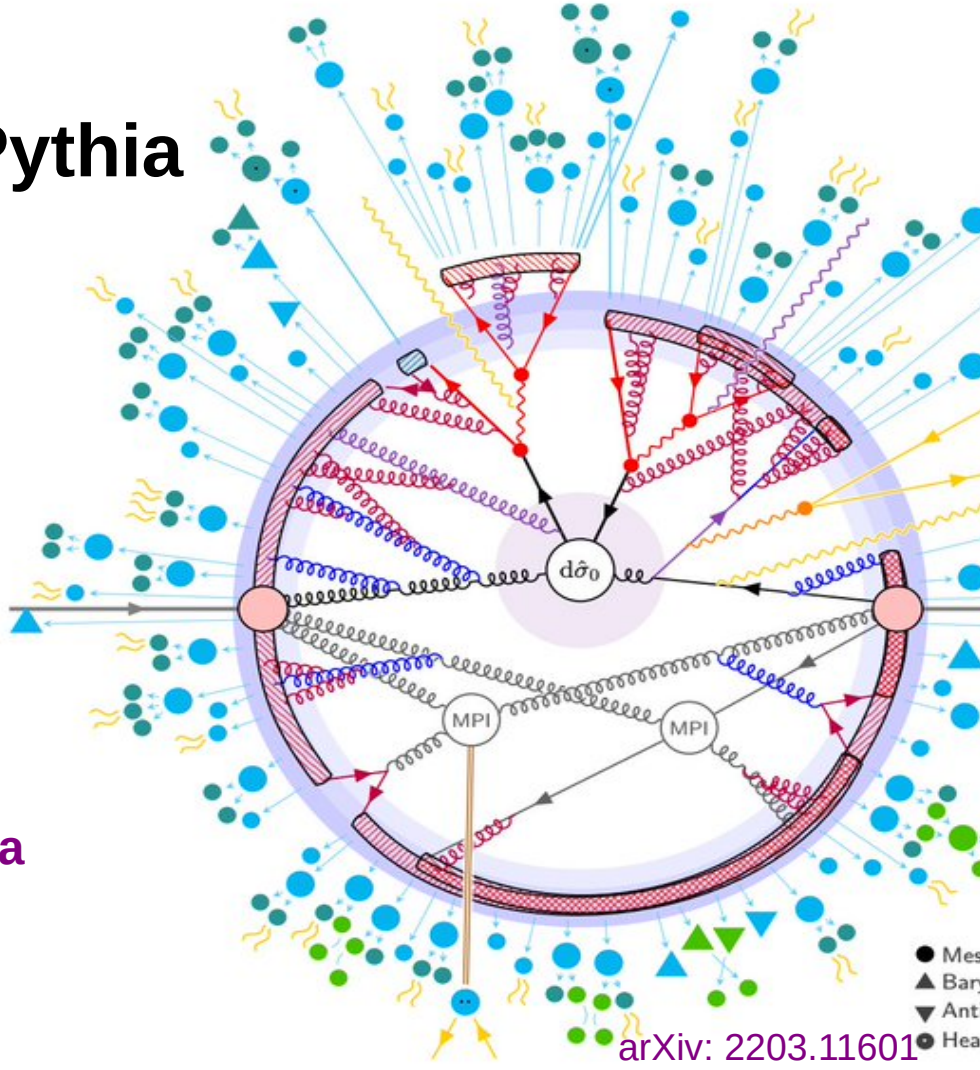
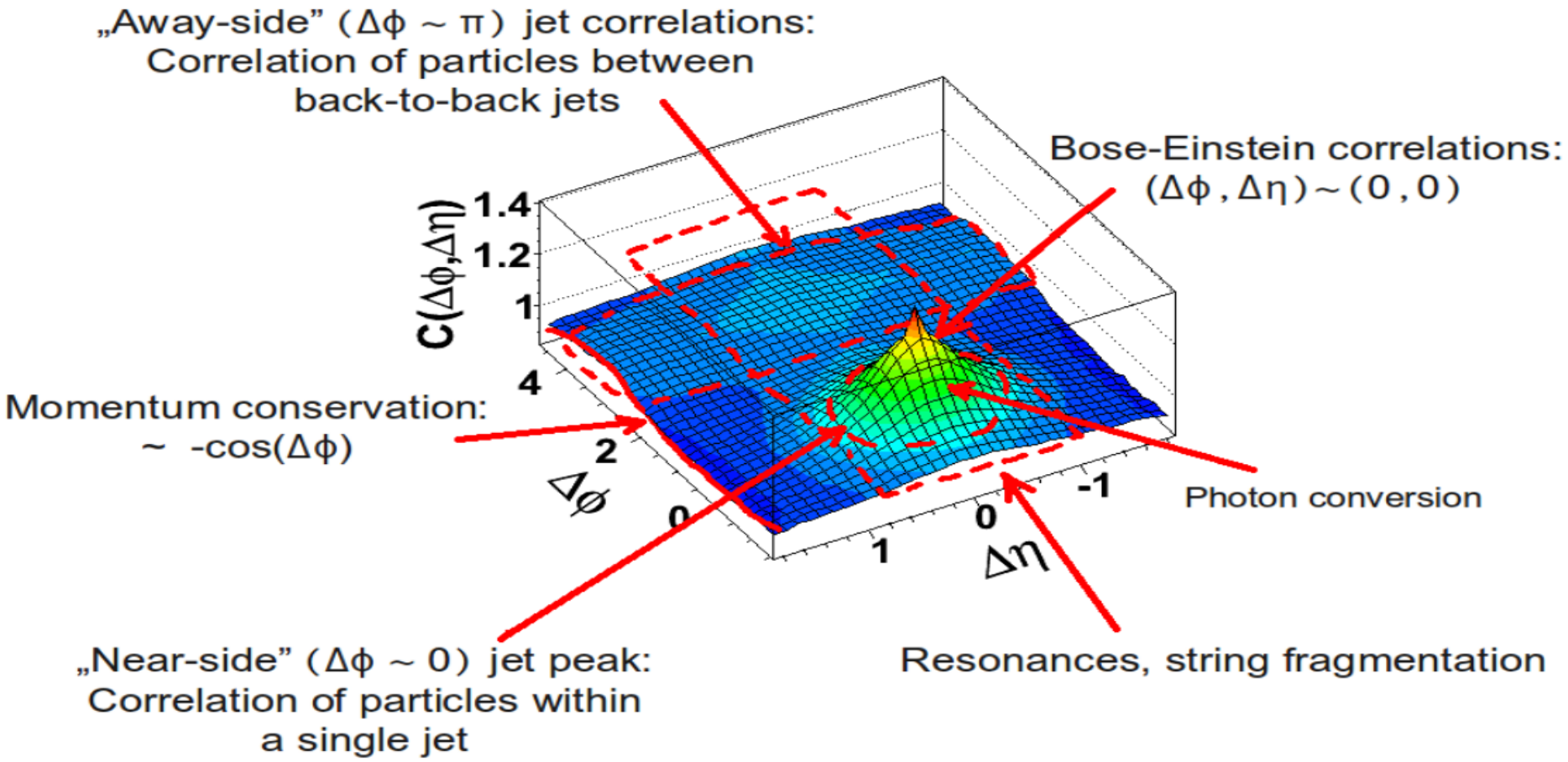


arXiv: 2203.11601

Two-particle correlations in pp @ 7 TeV collisions, ALICE



Study of baryon correlations in e+e− annihilation @ 29-GeV

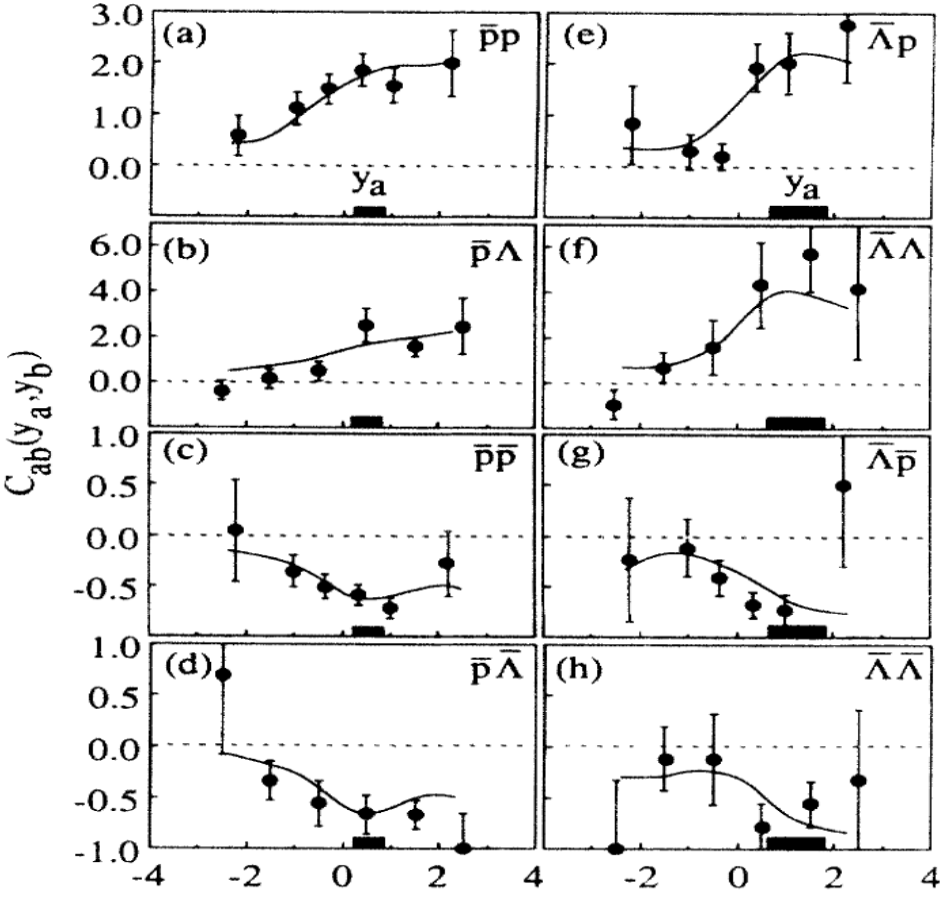
Phys. Rev. Lett. 57, 3140 (1986)

As a measurement for the correlation between two baryons a and b, we define the correlation function C_{ab}:

$$C_{ab}(y_a,y_b) = \rho_{ab}(y_a,y_b)/\rho_a(y_a)\rho_b(y_b) - 1 \qquad (1)$$

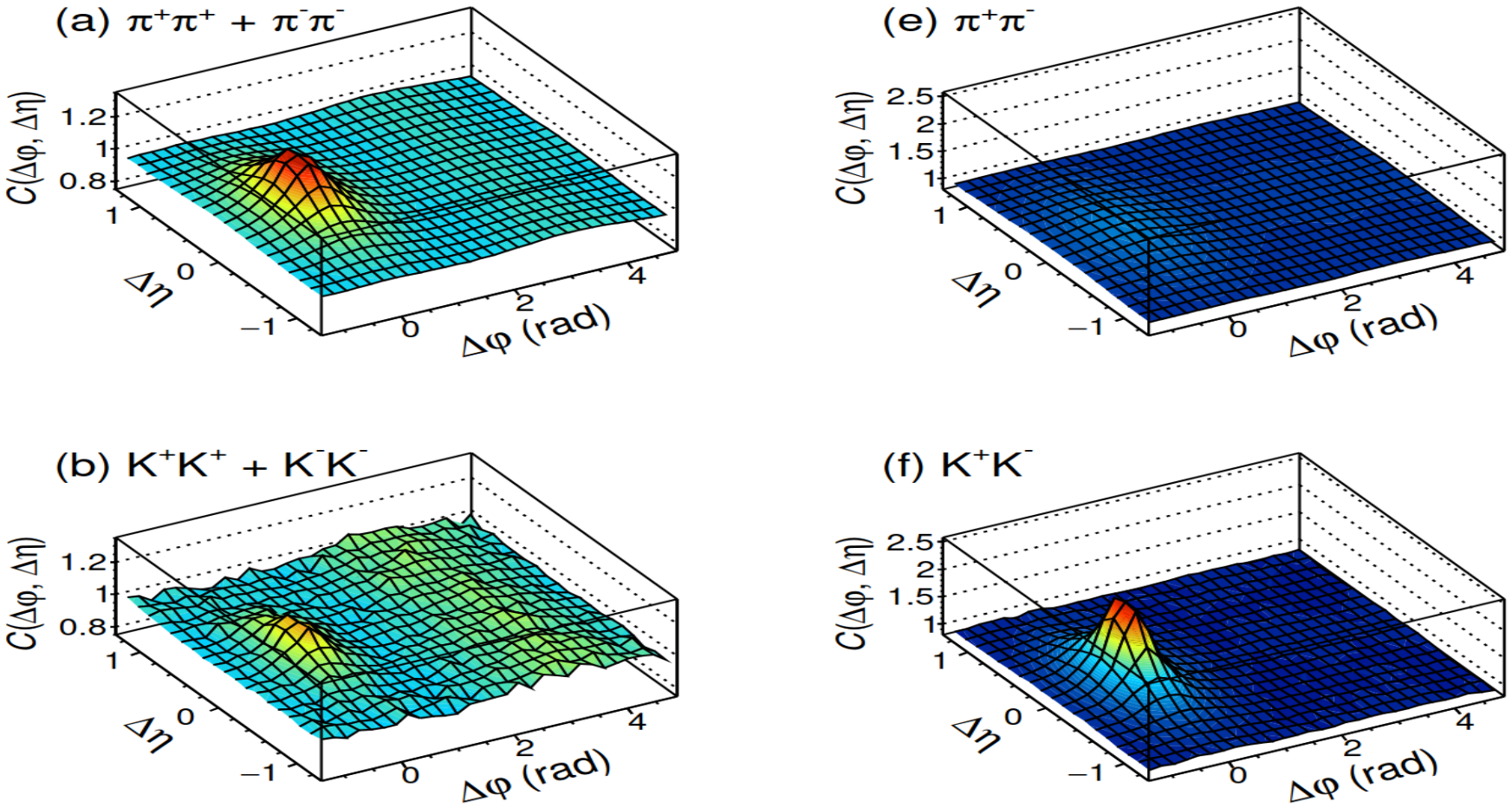
Solid curves → Lund hadronisation model

FIG. 1. (a)–(d) Correlation function $C_{ab}(y_a,y_b)$ for a $\bar{p}$ in the rapidity interval $0 < y_a < 1.25$ and an additional baryon b at rapidity y_b, for (a) p, (b) Λ, (c) $\bar{p}$, (d) $\bar{\Lambda}$. The rms width of the rapidity distribution of the $\bar{p}$ a is indicated by the black bar. (e)–(h) The corresponding correlation functions for a $\bar{\Lambda}$ in the rapidity range $y_a > 0$ as particle a. Curves indicate predictions by the Lund hadronization model (Ref. 7).



ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569; arXiv:1612.08975v3, 1401.4306v3

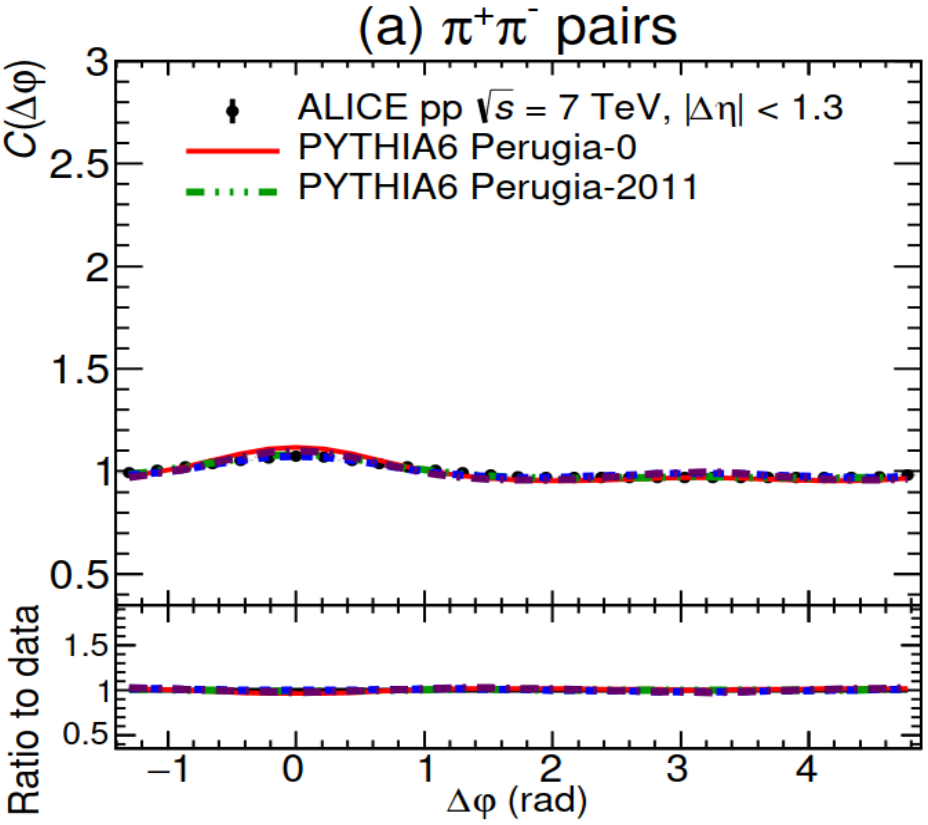
Meson correlations in pp @ 7 TeV, ALICE

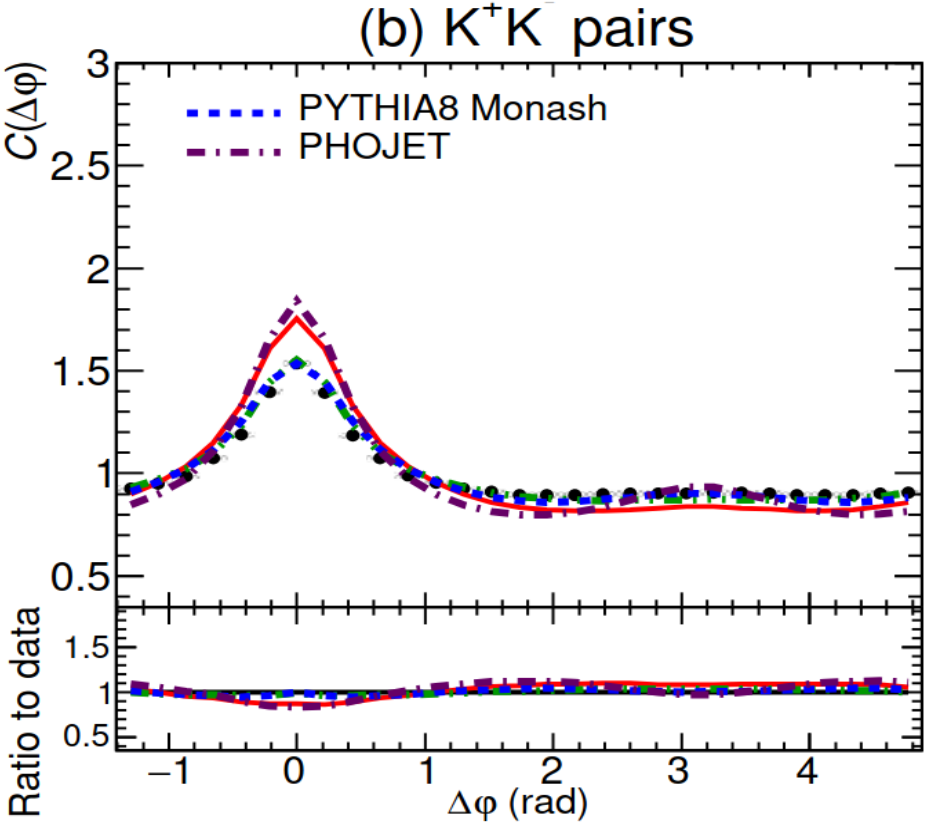


ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569; arXiv:1612.08975v3, 1401.4306v3

Opposite-sign meson pairs correlations in Pythia

reproduces meson correlations





ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569; arXiv:1612.08975v3, 1401.4306v3

Same-sign meson pairs correlations in Pythia

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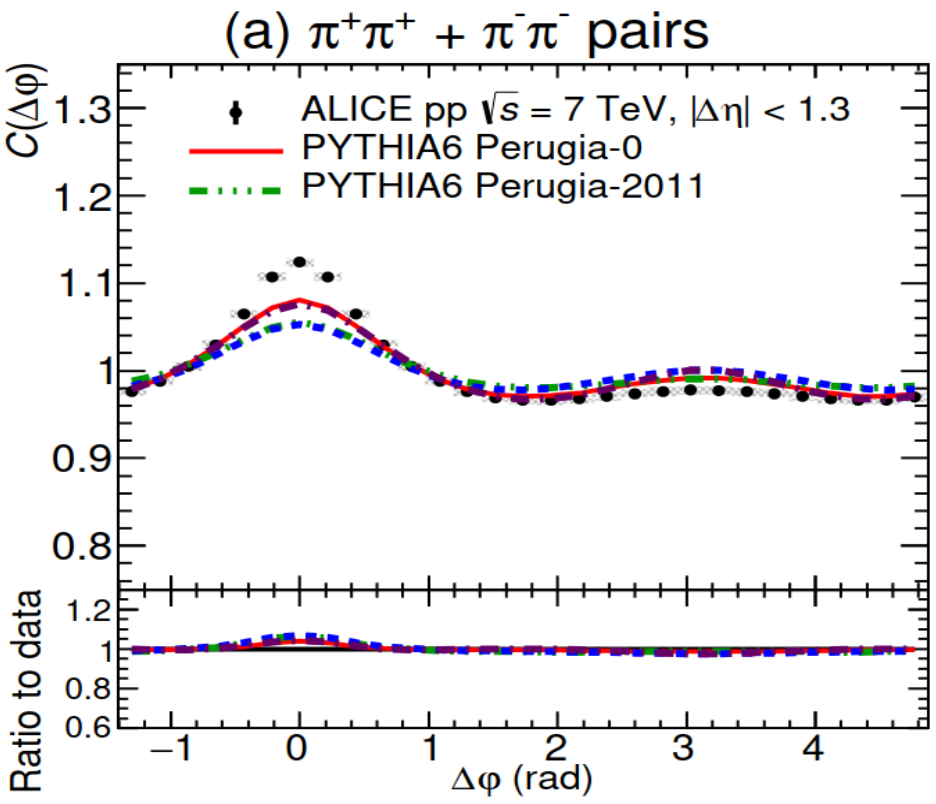
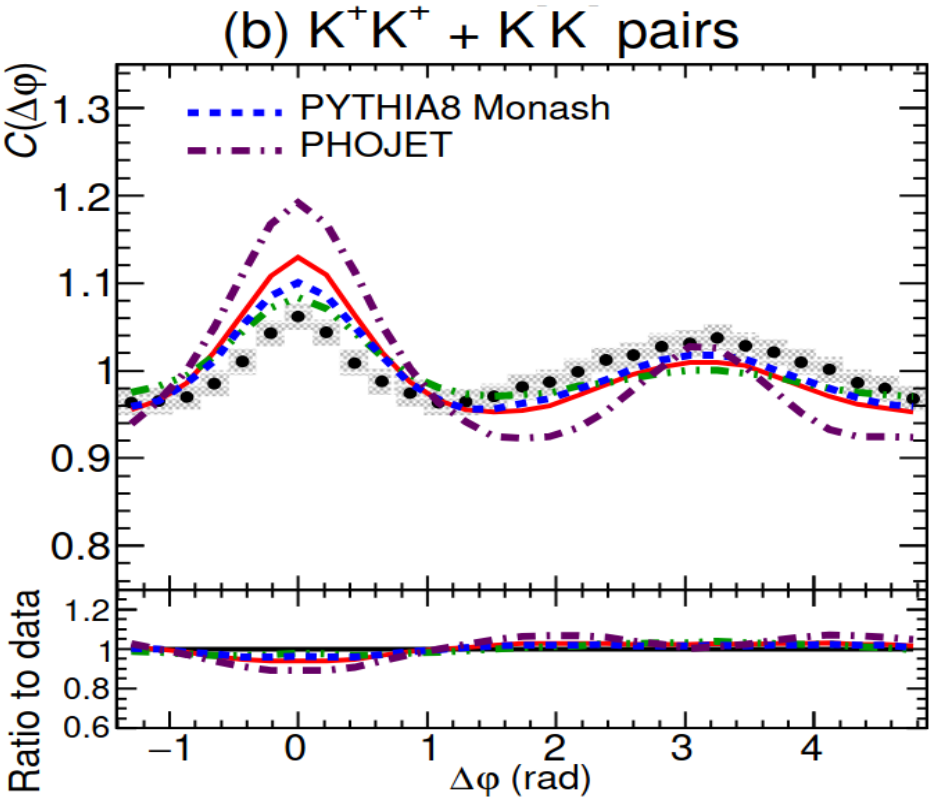
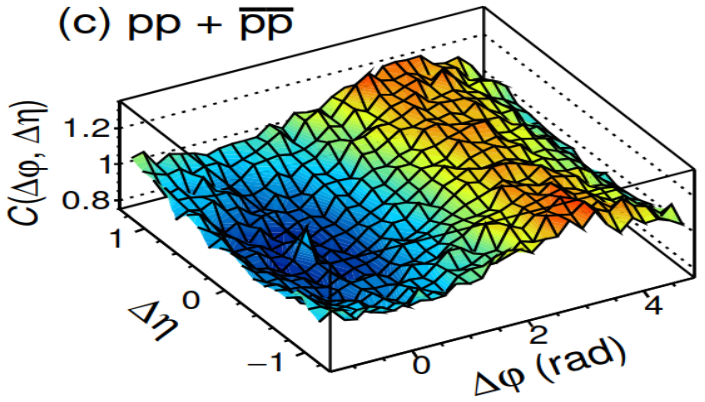
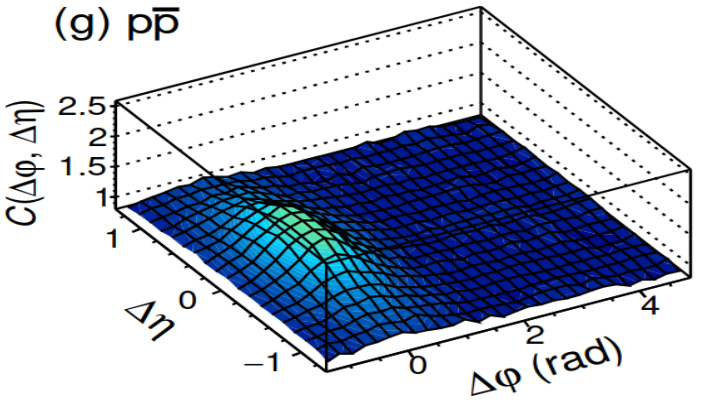


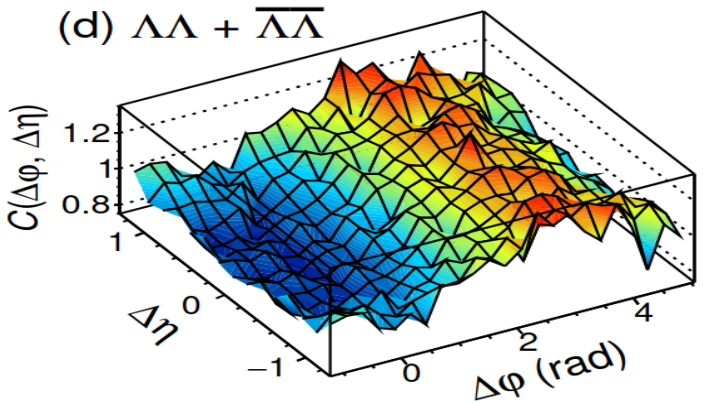


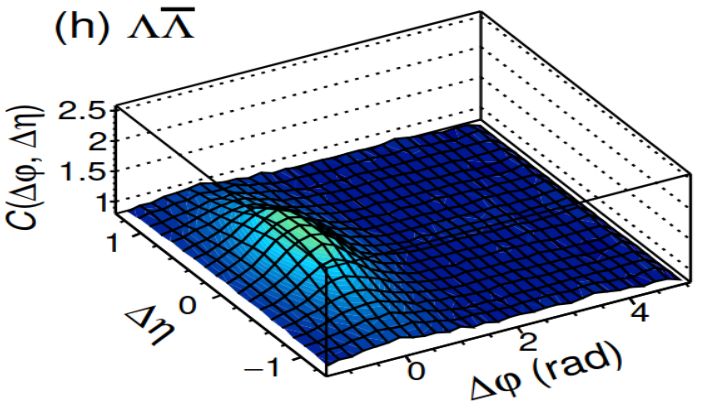
ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569; arXiv:1612.08975v3, 1401.4306v3

Baryon correlations in pp @ 7 TeV, ALICE





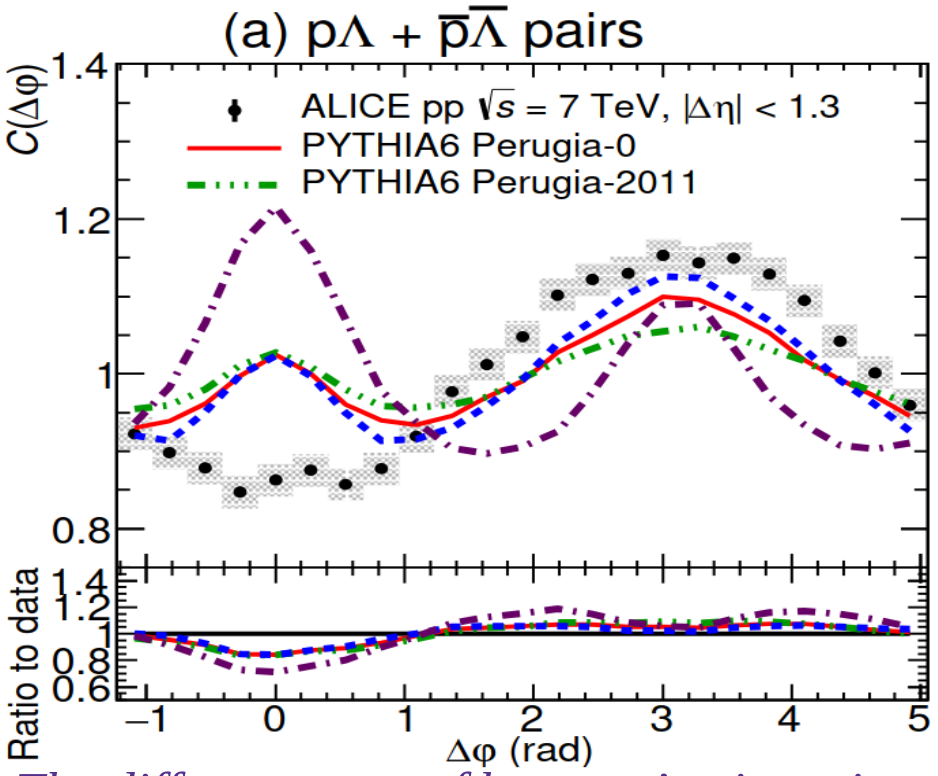


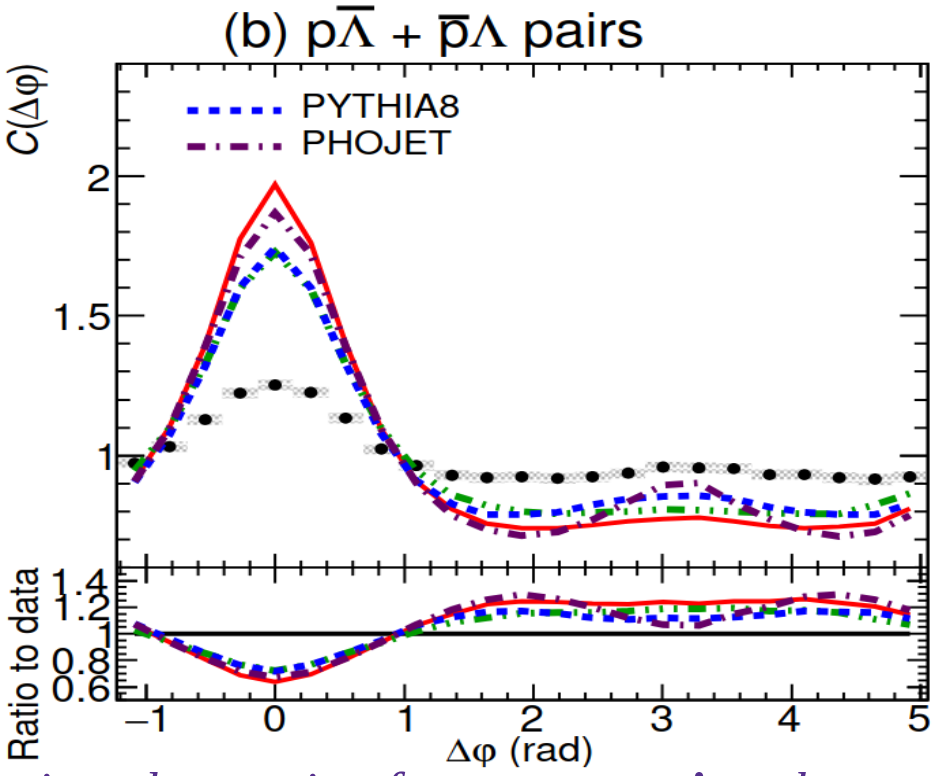


ALICE results: ALICE Collab., Eur. Phys. J. C77 (2017) 569; arXiv:1612.08975v3, 1401.4306v3

Baryon correlations in Pythia

fails to reproduce baryon correlations





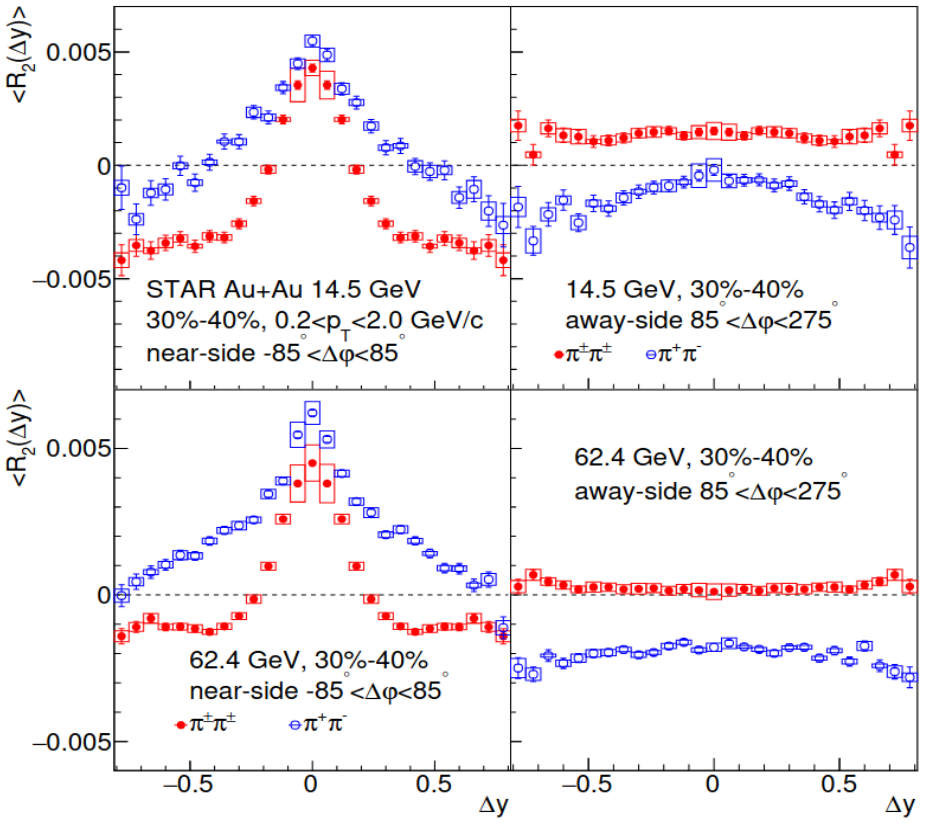
*The different types of baryons' pair anti-correlation observation forces us to **reject** the Fermi-Dirac statistics and repulsion of the same-sign baryons hypothesis.*

Surprising results in AuAu collision experiments at STAR

pions

STAR: arXiv:1906.09204v2

protons

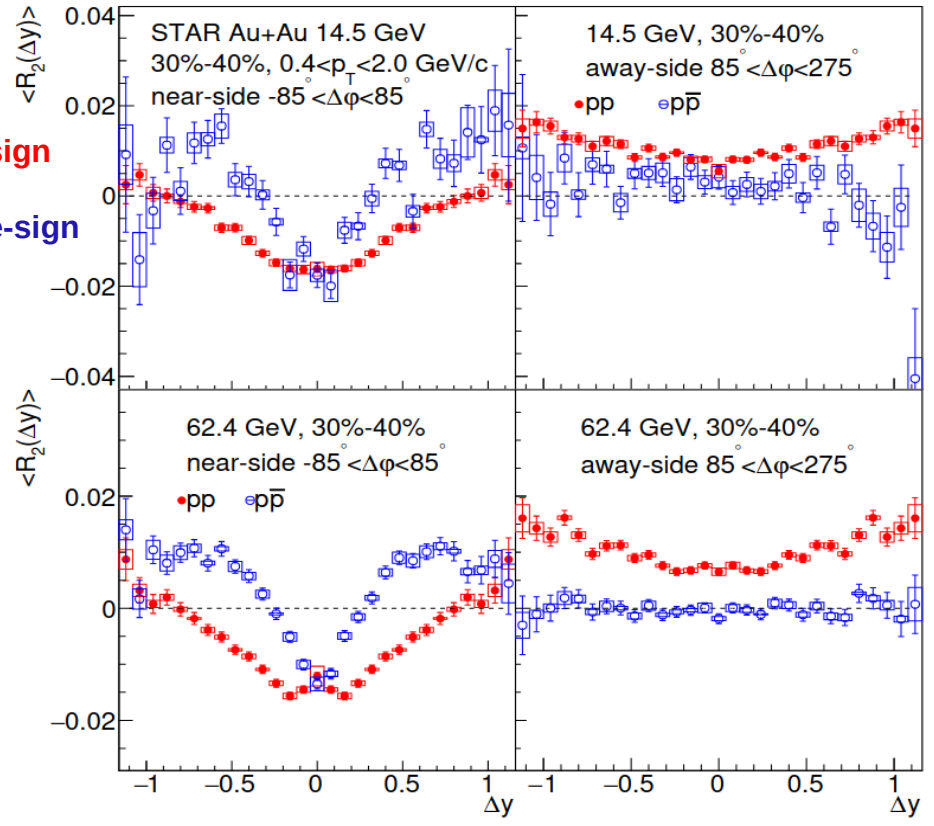


(a) pions

Φ → 0 Φ → π

same-sign

opposite-sign

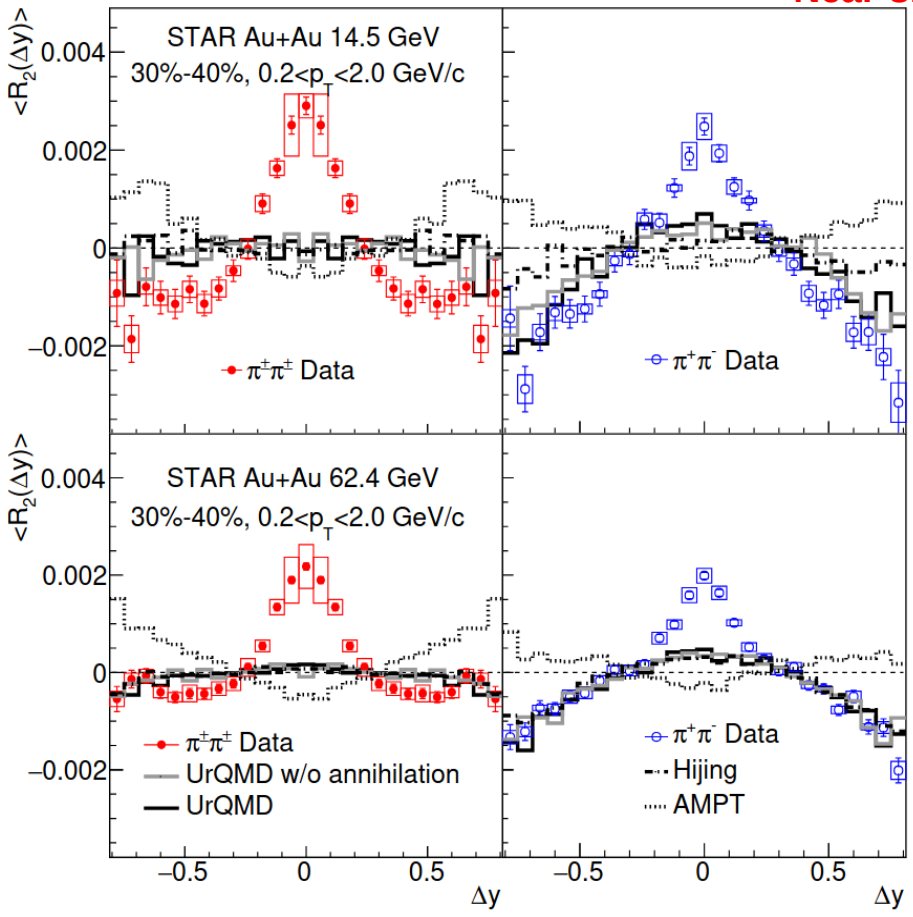


(b) protons

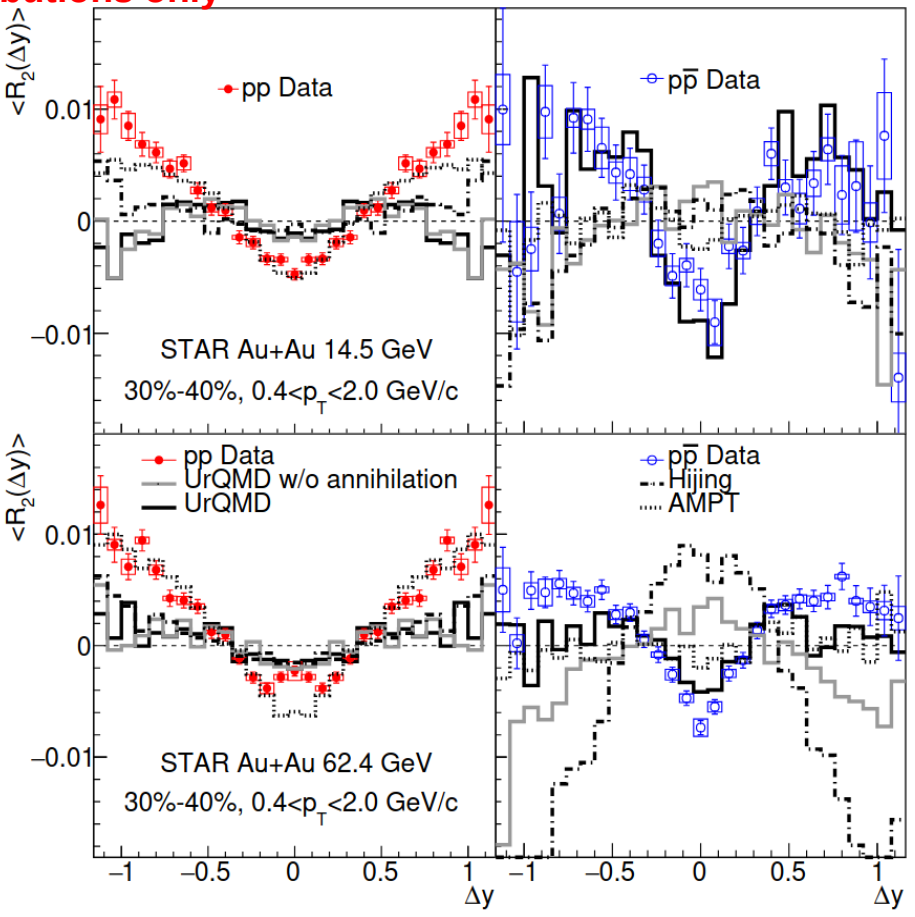
Φ → 0 Φ → π

Surprising results in AuAu collision experiments at STAR

Near-side distributions only



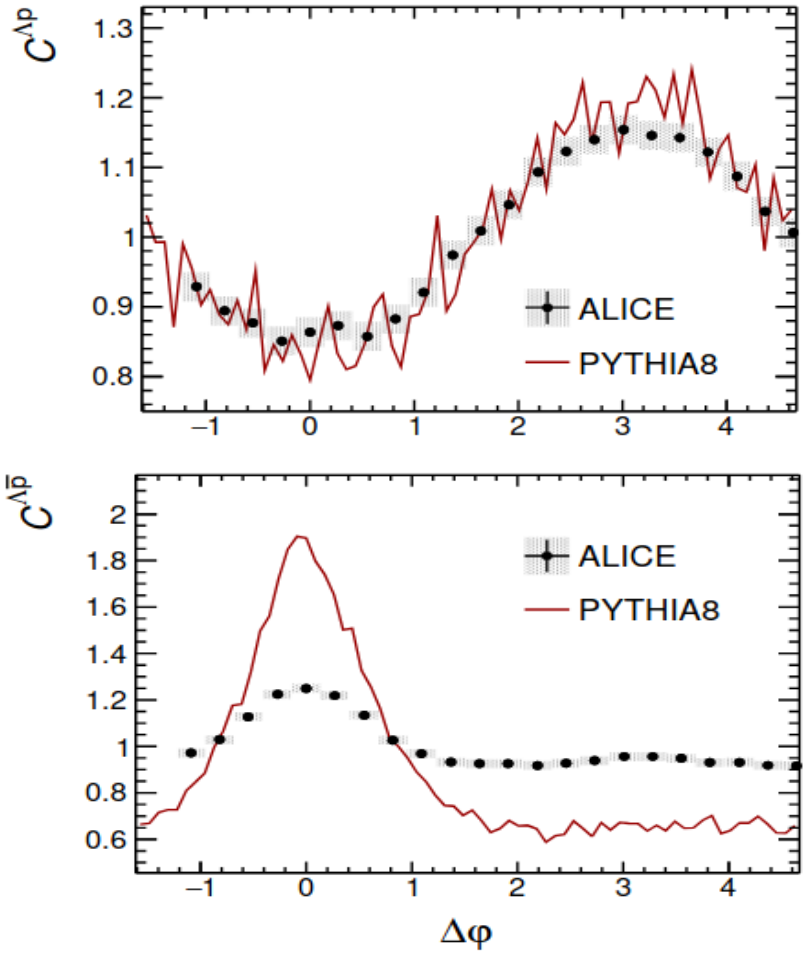
(a) pions



(b) protons

Brute Forced: Baryon Correlations in Pythia

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



We propose two ad-hoc alterations of the fragmentation code, a "**one-baryon**" and an "**always-baryon**" policies that qualitatively reproduce the data behaviour, i.e anticorrelation,

One baryon or zero baryon

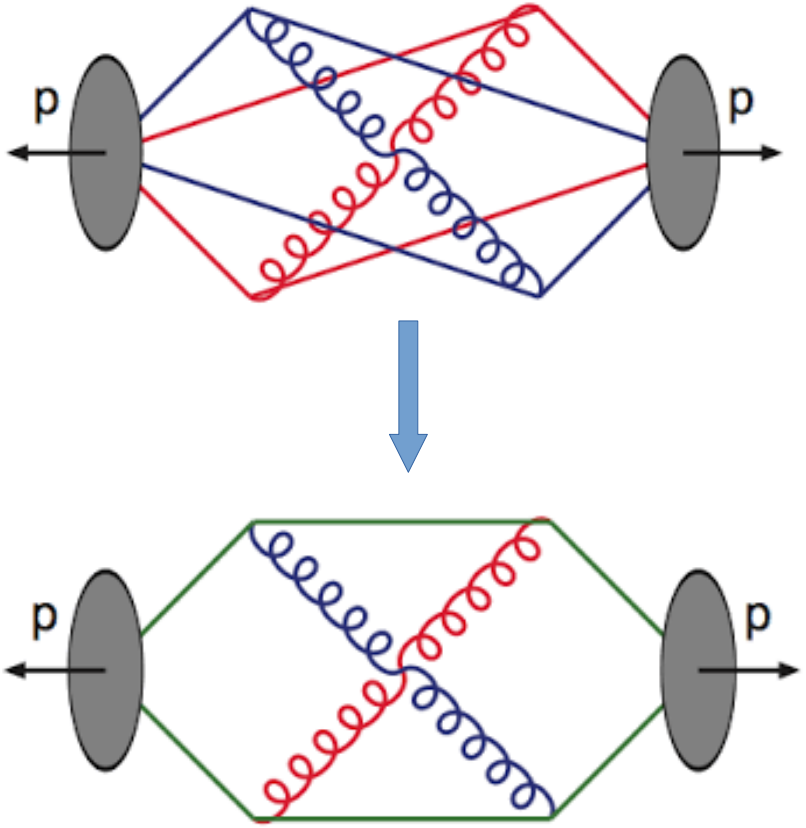
Always one baryon

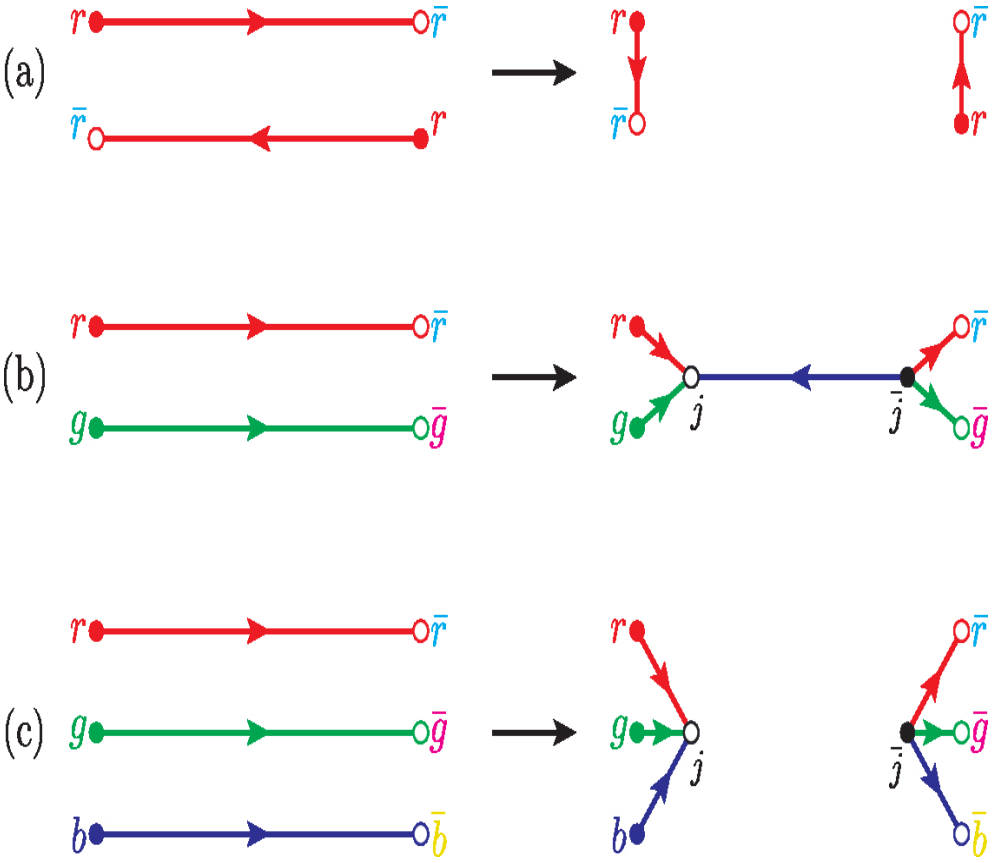
Baryons produced (10^6)	p	pp	p$\bar{\text{p}}$
Uncorrected PYTHIA	5.44	1.52	2.61
One-baryon policy	1.55	0.14	0.44
Always-baryon policy	5.20	1.32	2.28

3rd and 4th columns : number of same-event pairs.
Less pairs entail a noisier figure.

Colour Reconnection (CR)

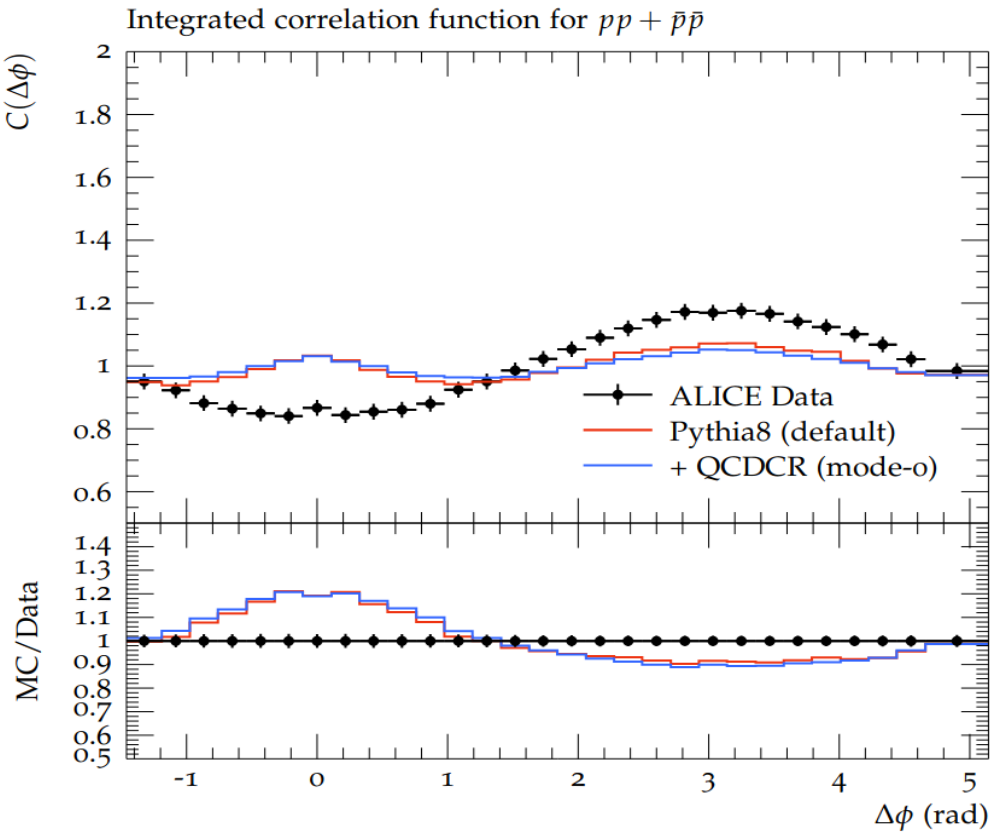
CR rearranges the dipole connections & reduces net-string length

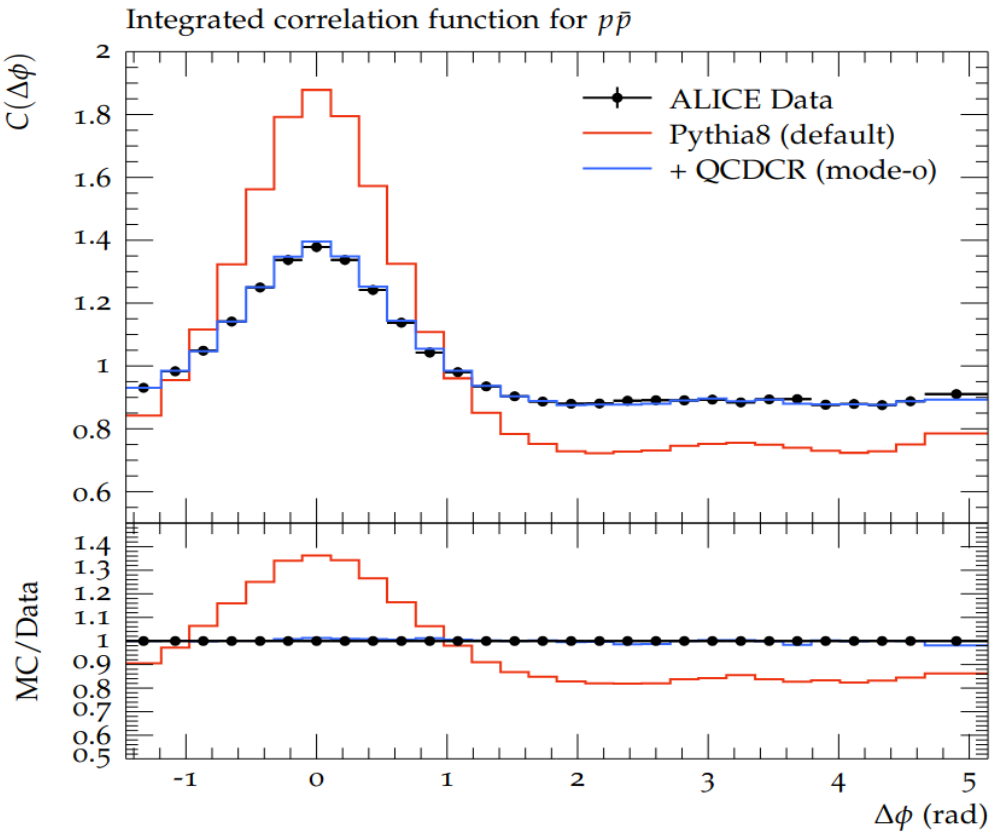




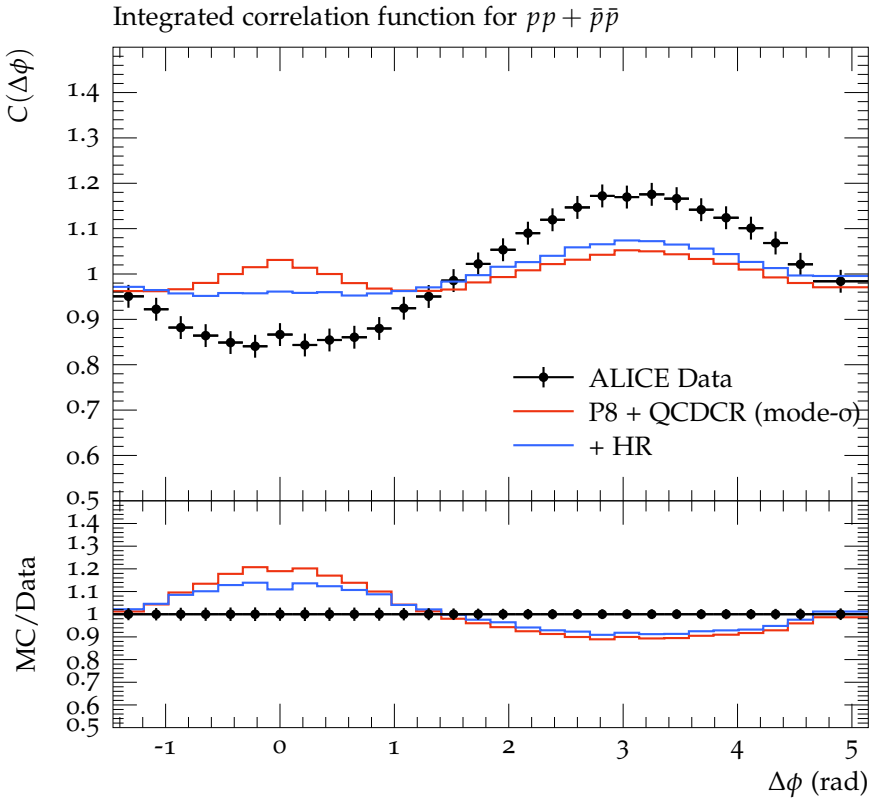
ArXiv: 2404.12040, 2309.12452, 1505.01681

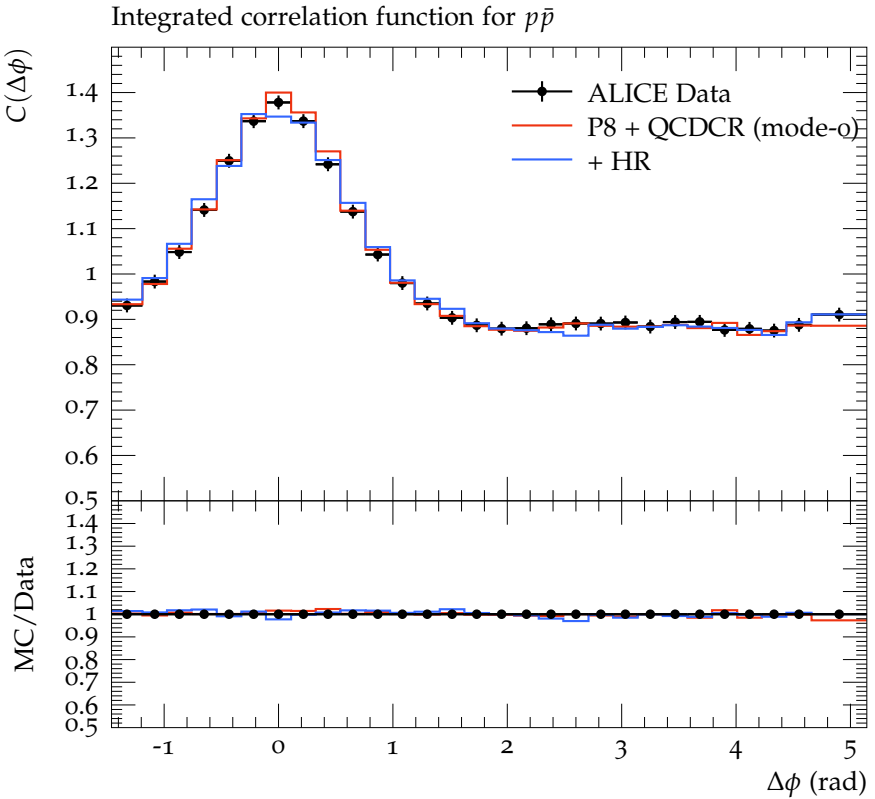
Results: **Pythia default vs QCD-inspired colour reconnection**

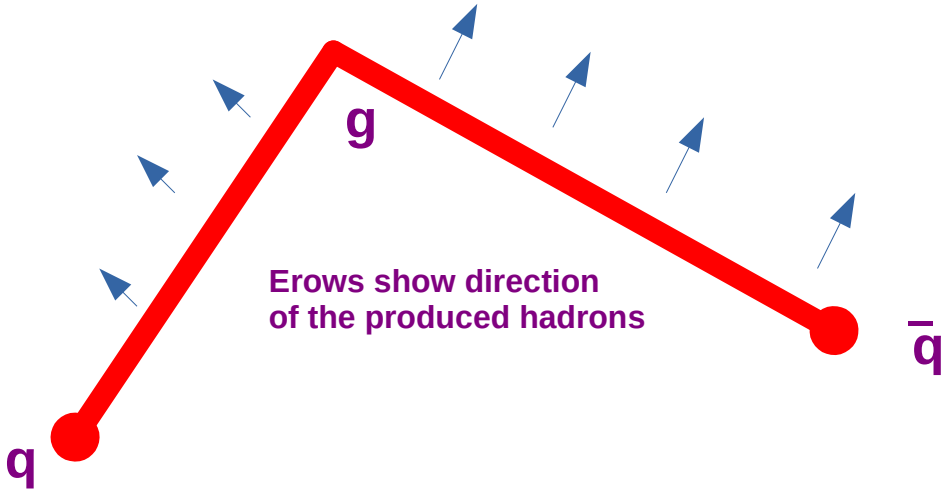




Results: **Pythia with QCD colour reconnection and hadronic rescattering**

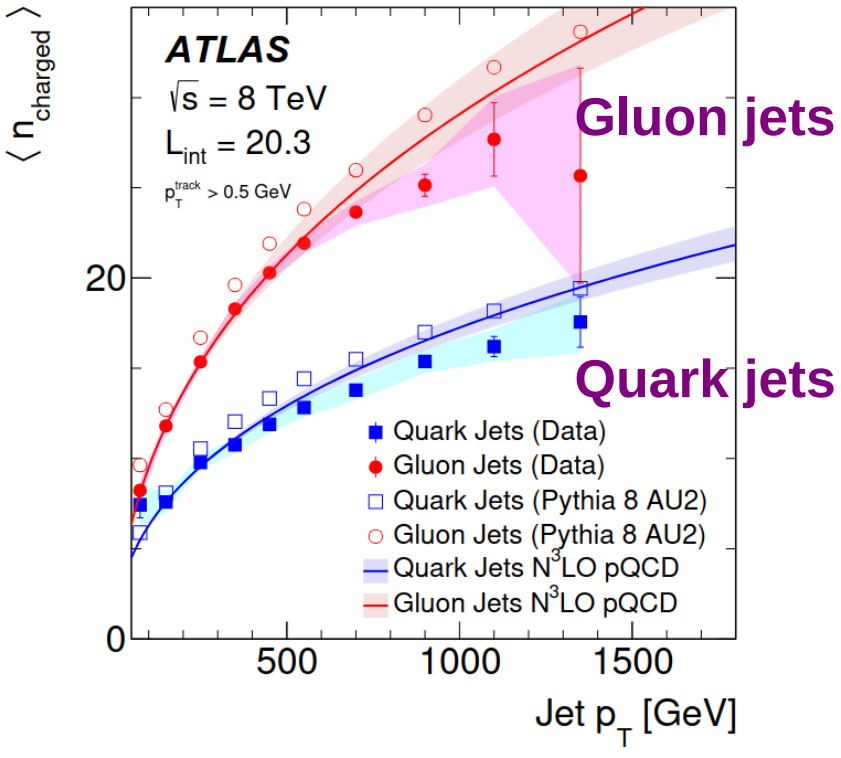




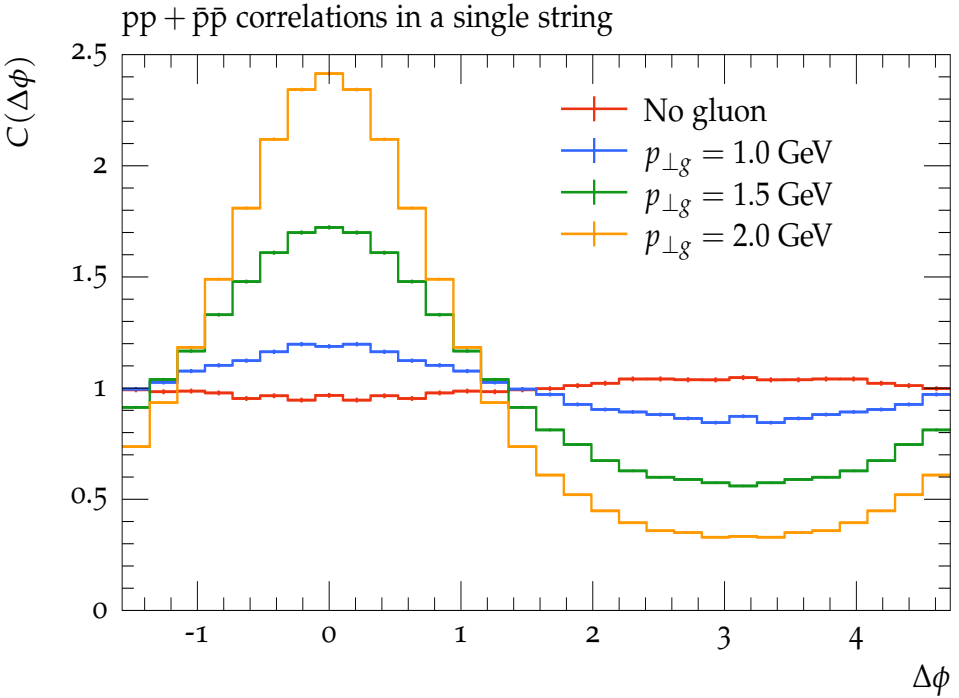


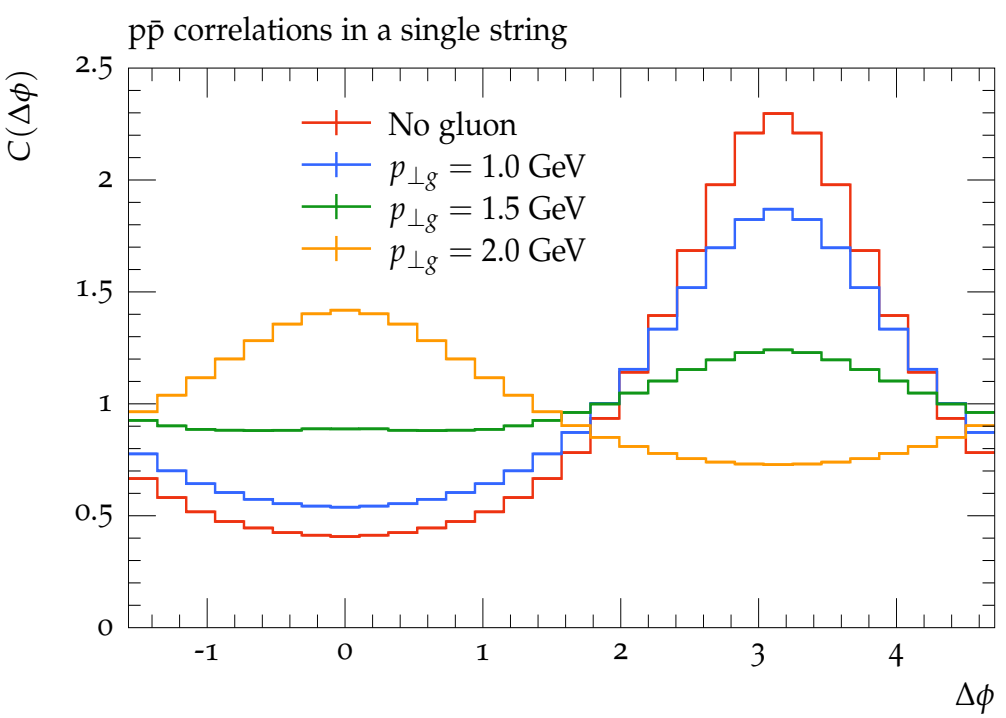
- Gluons are transverse kink on the Lund strings,
- Hadrons produced along the colour connections,
- On average twice more hadrons produced around gluons compared to quarks due to their colour charge.

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

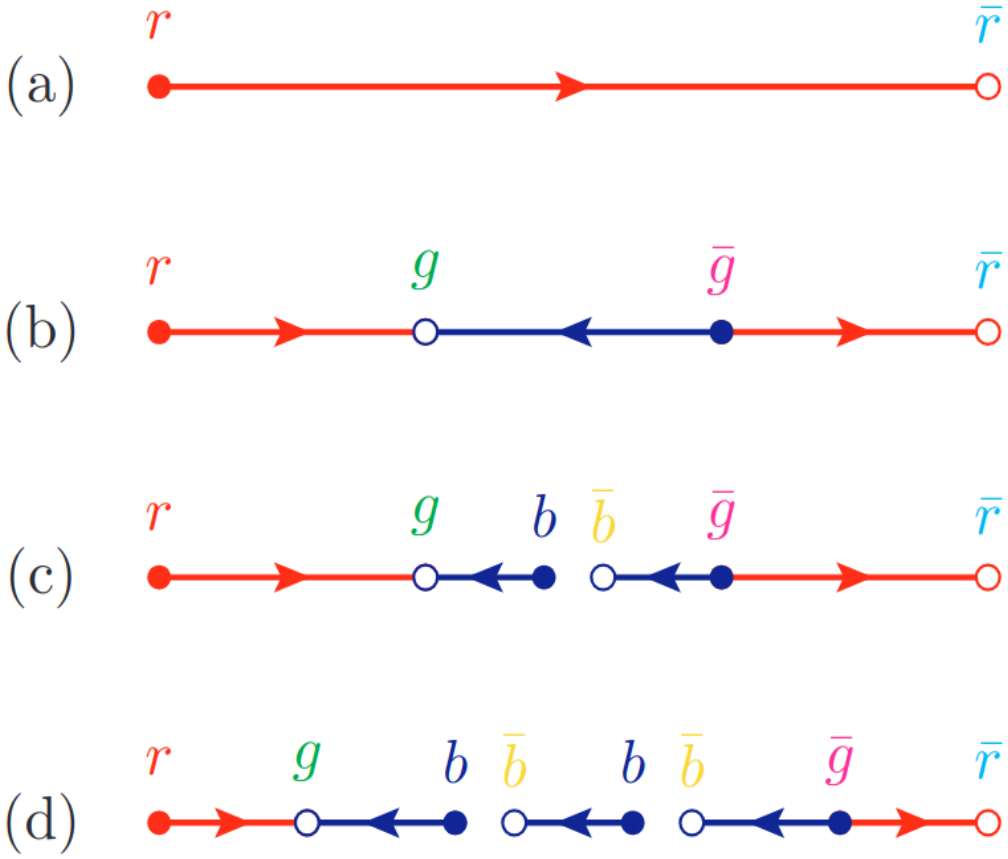


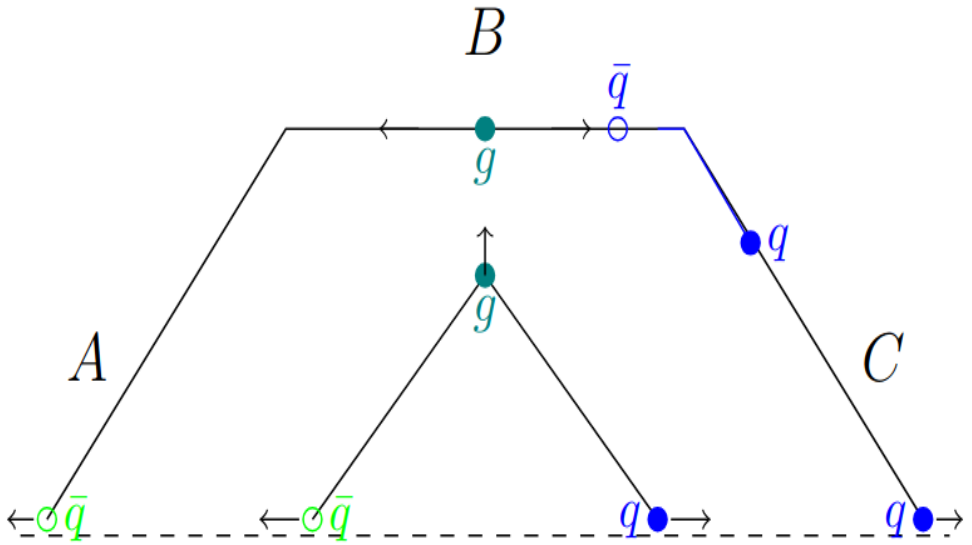
Role of gluons in baryon correlations



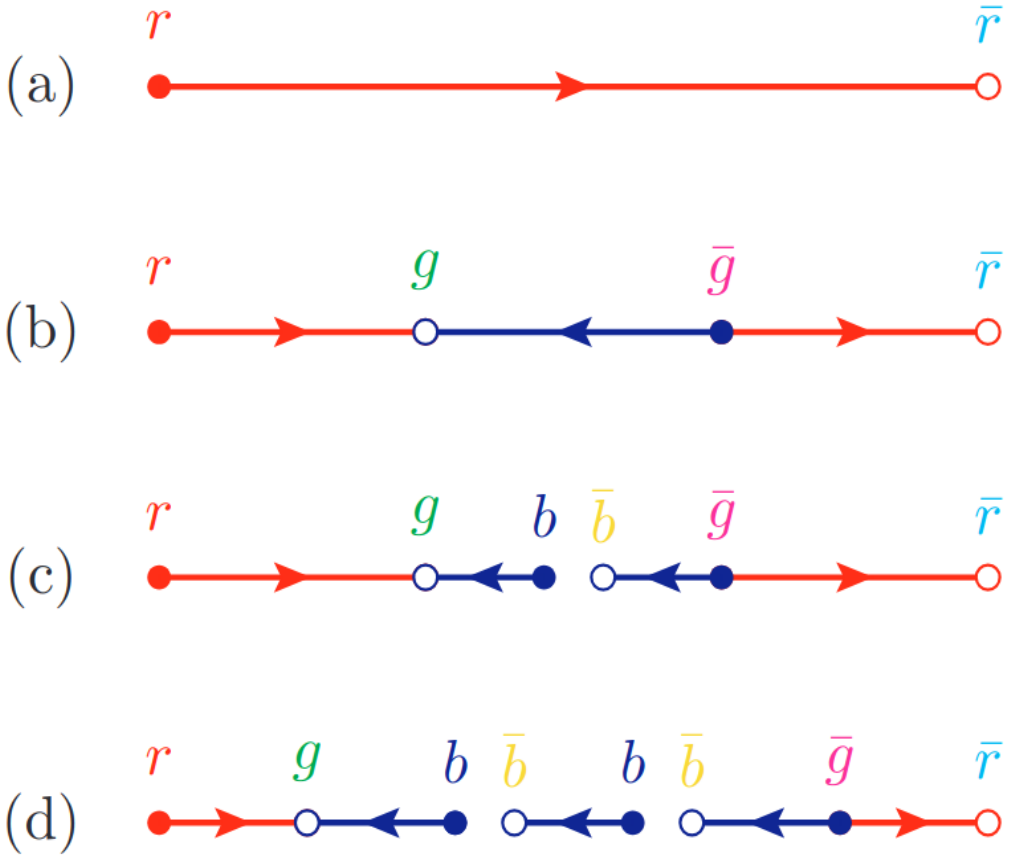


Popcorn mechanism for baryon production

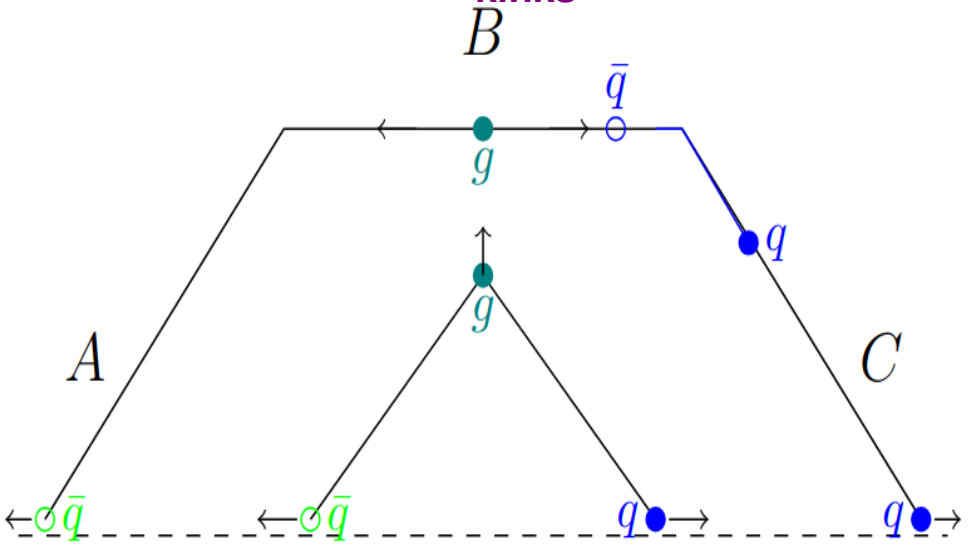




Popcorn mechanism for baryon production

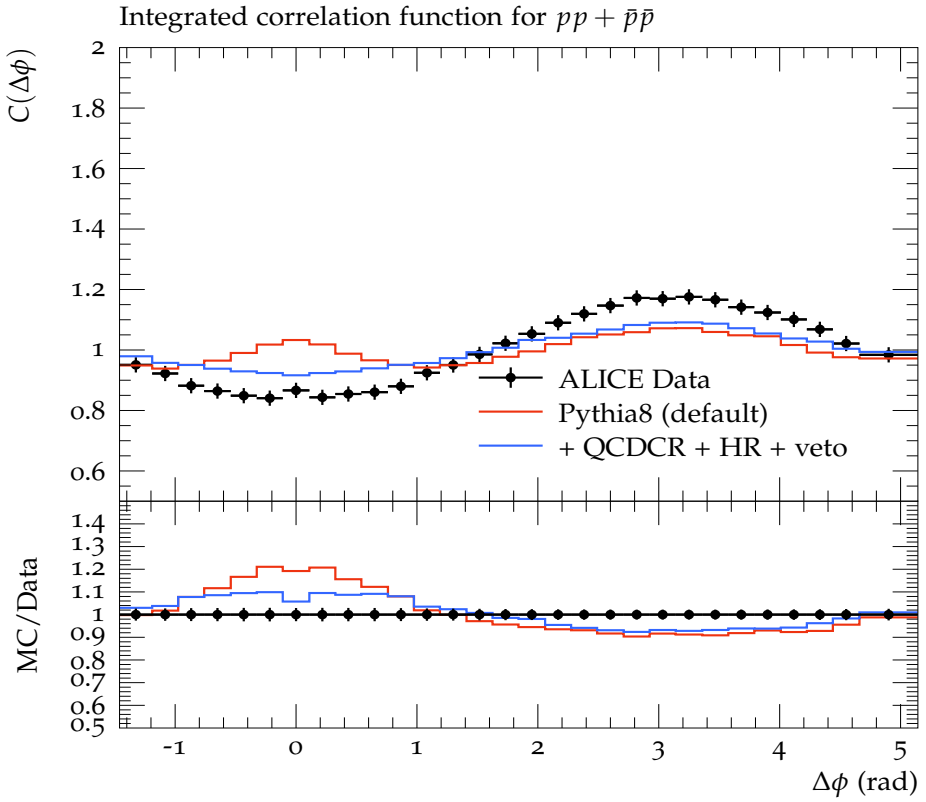


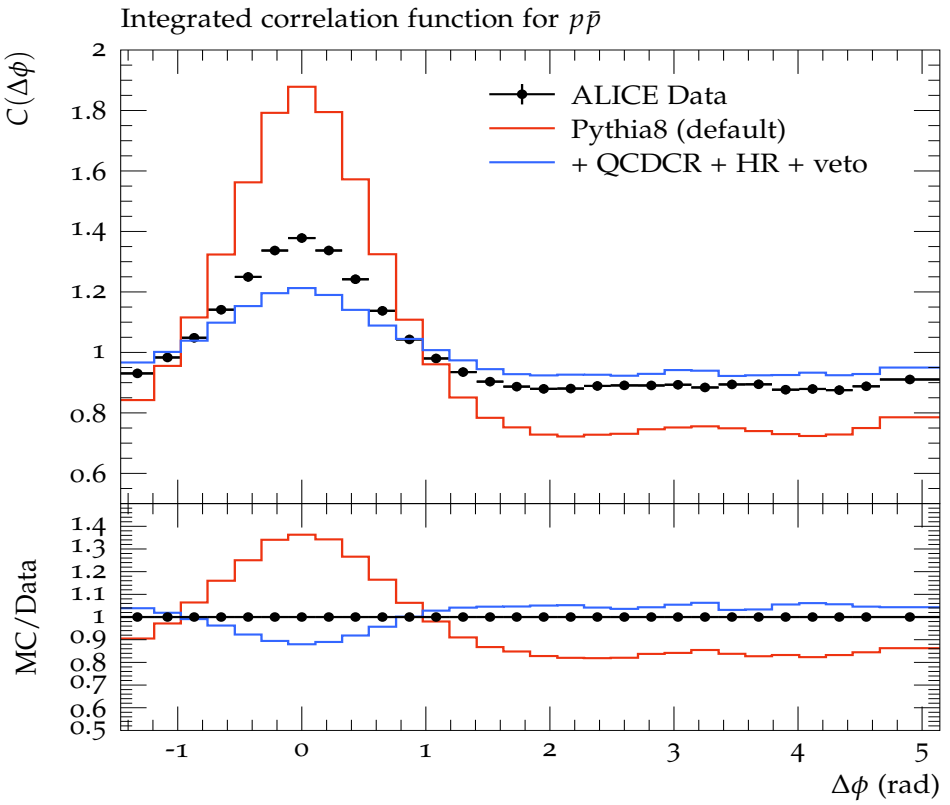
Veto: Suppress baryon production across gluon kinks



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

Euro.Phys.J.C Volume 83, 1105, (2023); arXiv:2309.01557v2

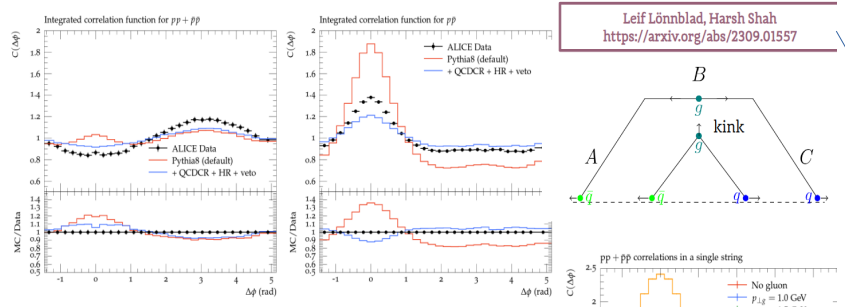




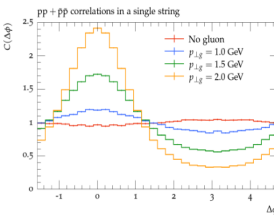
Real life anti-correlations in ALICE !!

Talk in 2023 @ Kielce from ALICE WUT group

Modified PYTHIA (2)



Leif Lönnblad, Harsh Shah
https://arxiv.org/abs/2309.01557

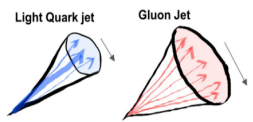


Correlation along single string

Effect of **gluons** on the baryon production mechanism in the Lund string fragmentation model.

Hypothesis for **suppressing baryons produced in gluon jets**.

Independent measurements that could verify the hypothesis of suppressed baryon production close to gluons. One obvious example is to compare the **baryon-to-meson ratio inside a gluon jet to that of a quark jet**, which could be done by comparing inclusive jets to jets produced together with hard photons.



Talk in 2025 @ Initial stages from ALICE WUT group

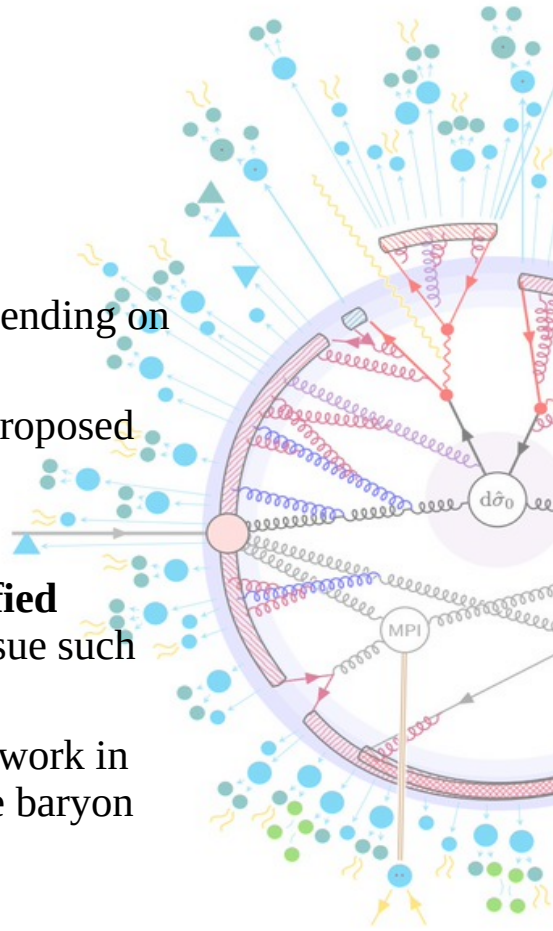
Conclusion

- Anti-correlation persists in heavier baryon-baryon and anti-baryon-anti-baryon pairs
- New precision results indicate that
  - jet fragmentation may not be the dominant mechanism in baryon production
  - the mechanism(s) which would produce a peak dominated by effects associated with mini-jets are either not present or produce a very different correlation shape
  - Combination of energy and baryon-number conservation is not enough to explain this anti-correlation structure
- While some aspects of the experimental data are described quantitively, no model can reproduce all features of the data
  - string melting version of a multi-phase transport (AMPT) model with improved quark coalescence [*Phys. Rev. C 98, no.3, 034912 (2018), Phys. Lett. B 829, 137063 (2022)*]

?????

Concluding remarks

- Two particle correlations in baryons are non-trivial observables whose shape varies depending on the colliding systems.
- We **attempted to improve** the Pythia model to reproduce the baryon correlations and proposed experimental input for baryon-to-meson ratio in **gluon jets vs quark jets**.
- Our hypothesis is that **baryons should be suppressed** in the gluon jets.
- We are **not aware of** any study where the **jet substructure** has been studied **for identified hadrons**, but we would certainly like to **encourage** our experimental colleagues to pursue such measurements at the LHC.
- There are yet many **improvements** required and **collaborations are welcomed** for the work in progress especially with the junction type string fragmentation and detailed study of the baryon production across gluon kinks as well as their pt dependence study, and then to test **Pythia/Angantyr** for the baryon correlations in **heavy-ion 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

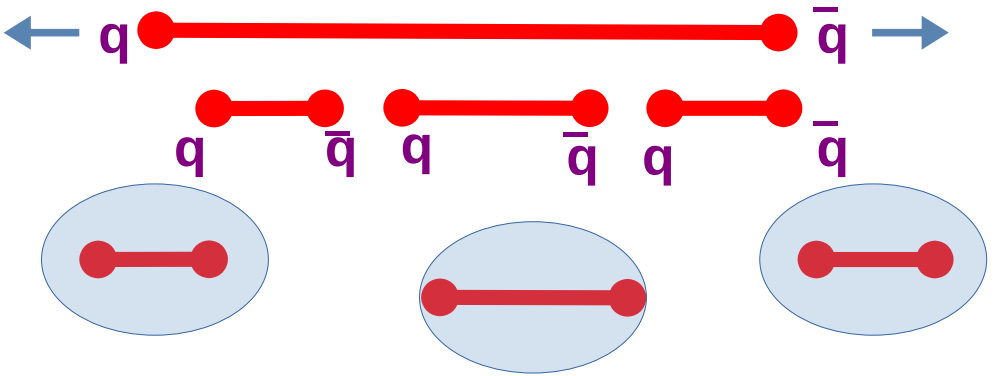
QCD Colour reconnection and Heavy Flavour in Pythia
Javira Altmann, Jesper Christiansen, Leif Lönnblad, Harsh Shah, and Peter Skands
arXiv:2404.12040, 2309.12452, 1505.01681

Pythia8 Manual:
arXiv: 2203.11601

Referenses within these papers

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** repeat.

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

For the other cases try to produce one or two hadrons

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

a & b parameters are fixed by fit to the data

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

AMPT: L.Y. Zhang et al., Phys. Lett. B 829 (2022) 137063