



WAYNE STATE
UNIVERSITY

APRIL 12-14
Minneapolis, MN



GHP 2023
WORKSHOP

Baryon anticorrelations and the Pauli principle in Pythia

Noe Demazure (ENS Lyon), Felipe J. Llanes-Estrada (UC Madrid),
[Victor Gonzalez](#) (WSU)

Minneapolis, April 14, 2023

10th WORKSHOP OF THE APS TOPICAL GROUP ON HADRONIC PHYSICS

Two-particle correlations

Single ...

$$\rho_1^\alpha(\eta_1, \varphi_1) \equiv \frac{d^2 N_1^\alpha}{d\eta_1 d\varphi_1}$$

... and pair densities

$$\rho_2^{\alpha\beta}(\eta_1, \varphi_1, \eta_2, \varphi_2) \equiv \frac{d^4 N_2^{\alpha\beta}}{d\eta_1 d\varphi_1 d\eta_2 d\varphi_2}$$

Measuring correlations

zero if no correlations

$$\rho_2^{\alpha\beta} - \rho_1^\alpha \rho_1^\beta$$

Normalized two-particle cumulant

$$R_2^{\alpha\beta} = \frac{\rho_2^{\alpha\beta}}{\rho_1^\alpha \rho_1^\beta} - 1$$

Traded for $C^{\alpha\beta} = R_2^{\alpha\beta} + 1 = \frac{\rho_2^{\alpha\beta}}{\rho_1^\alpha \rho_1^\beta}$

\Rightarrow

$$C^{\alpha\beta} = \frac{\rho_2^{\alpha\beta} |_{\text{same}}}{\rho_2^{\alpha\beta} |_{\text{mixed}}}$$

**Powerful tool to investigate particle production
and system dynamics**

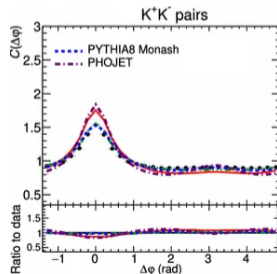
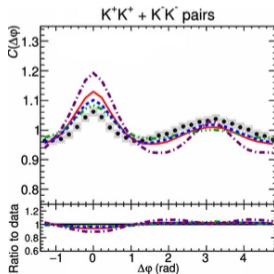
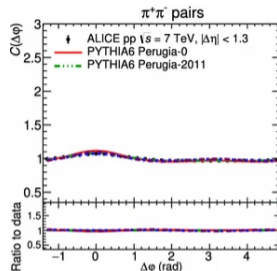
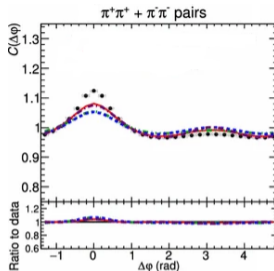
Correlations, meson–meson

pp at $\sqrt{s} = 7$ TeV

- Same and opposite sign short range correlations
- Standard Monte Carlo event generators qualitatively reproduce correlations

ALICE, EPJC 77 (2017) 569

(STAR, PRC 101, 014916 (2020) for Au–Au)



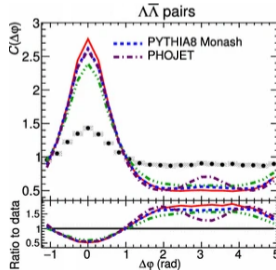
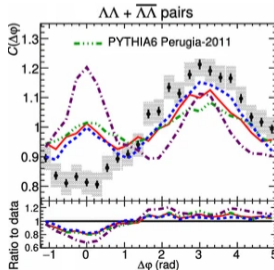
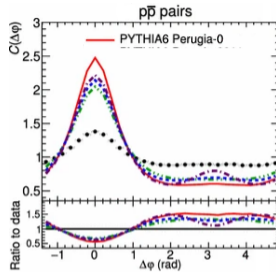
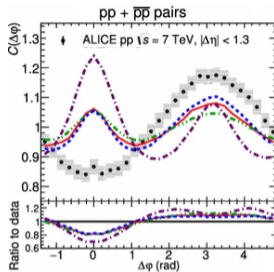
Correlations, baryon–baryon

pp at $\sqrt{s} = 7$ TeV

- baryon–antibaryon correlation
- baryon–baryon anticorrelation
- Standard Monte Carlo event generators **fail** to reproduce anticorrelations

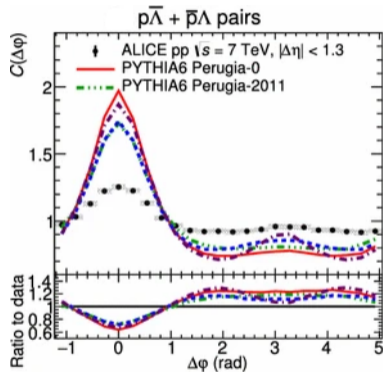
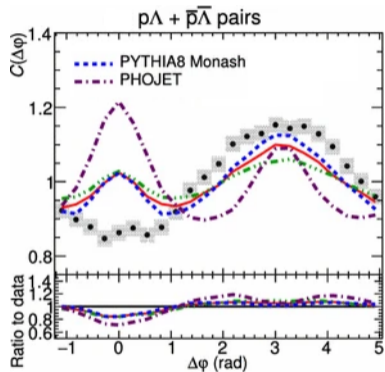
ALICE, EPJC 77 (2017) 569

(STAR, PRC 101, 014916 (2020) for Au–Au)



Correlations, baryon–baryon

pp at $\sqrt{s} = 7$ TeV



Even for distinguishable species

ALICE, EPJC 77 (2017) 569 (STAR, PRC 101, 014916 (2020) for Au–Au)

At the core of Pythia generator

String fragmentation

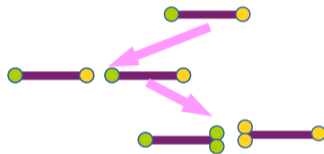
As the mechanism for hadronization



At the core of Pythia generator

String fragmentation

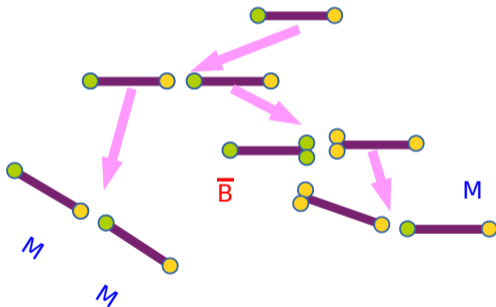
As the mechanism for hadronization



At the core of Pythia generator

String fragmentation

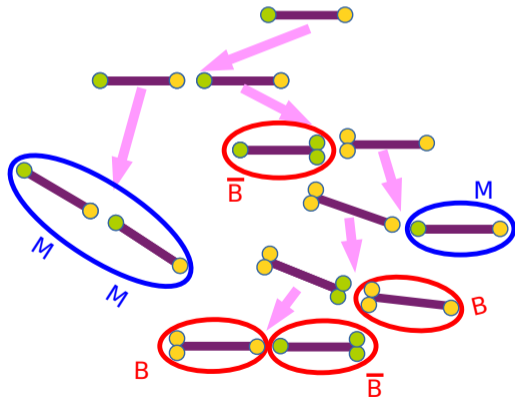
As the mechanism for hadronization



At the core of Pythia generator

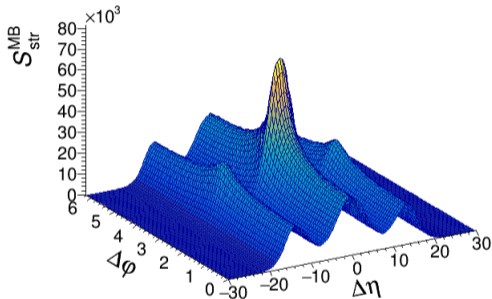
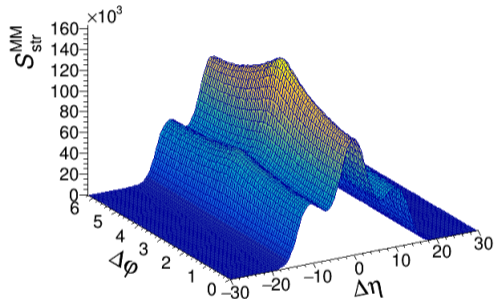
String fragmentation

As the mechanism for hadronization



String-string correlations

Strings which produce mostly mesons (M) / at least one baryon (B)



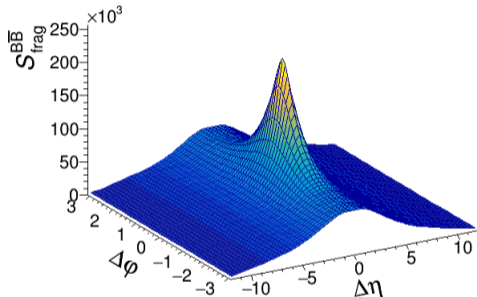
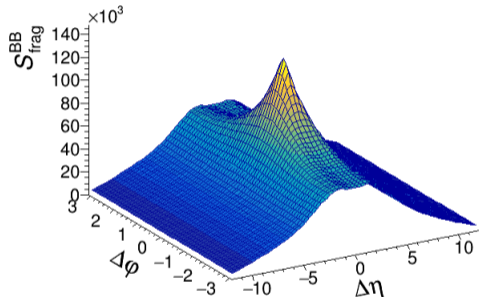
Azimuthally: mostly isotropic or back to back

NOTE: not mixed events normalized; azimuthal shape interest

$$S^{\alpha\beta} \propto \rho_2^{\alpha\beta} |_{\text{same}}$$

Two baryons from the same string

Baryon–(anti)baryon correlations



Azimuthally: Clear forward peak

NOTE: not mixed events normalized; azimuthal shape interest

$$S^{\alpha\beta} \propto \rho_2^{\alpha\beta} \Big|_{\text{same}}$$

Two quick fixes to the Pythia code

At the string fragmentation level

- **One baryon policy**

Each string can at most produce one baryon

- Eliminates the positive correlations
- Depresses the total B number too much

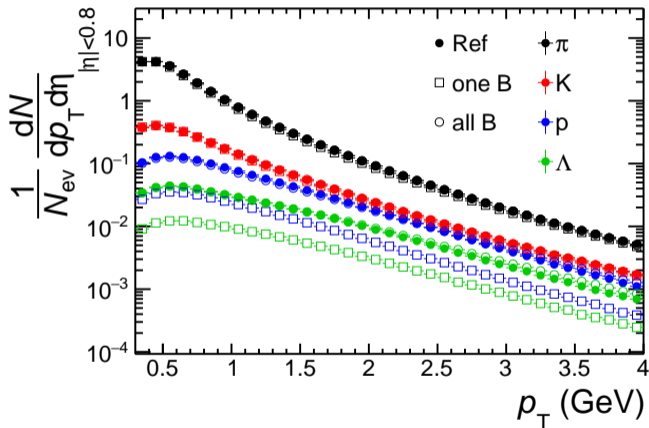
- **Always baryon policy**

Every string must produce one baryon

- Baryons remain anti-correlated
- Their abundance is now correct

π , K, p, and Λ spectrum

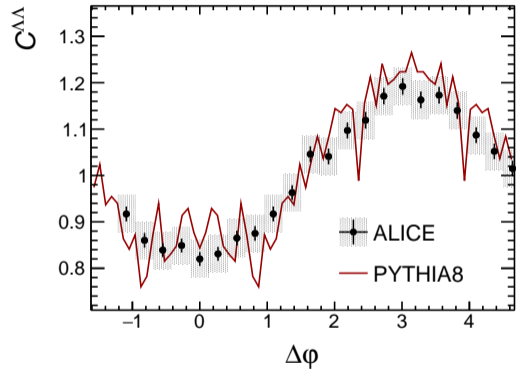
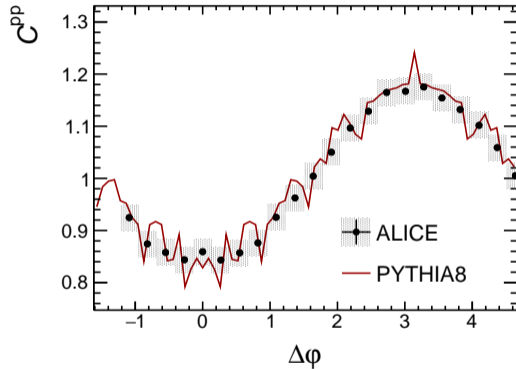
pp at $\sqrt{s} = 7$ TeV



Always baryon policy: baryon spectra slightly hardened

Always baryon policy

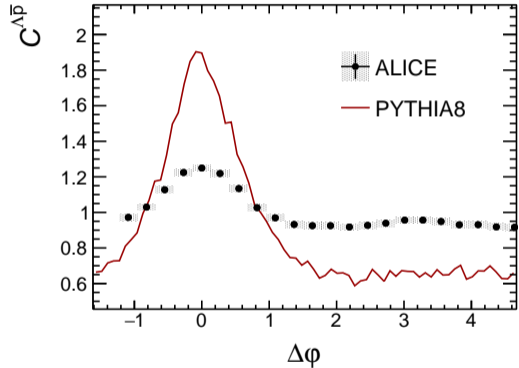
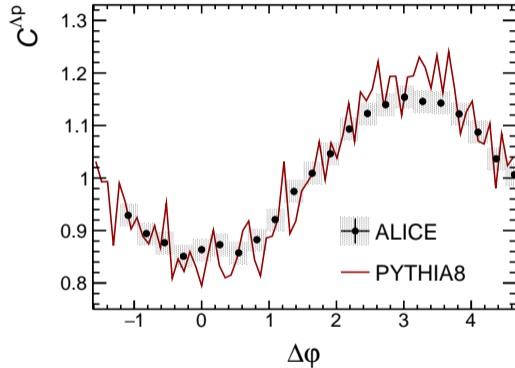
Indistinguishable species



Reproduced the anticorrelation

Always baryon policy

Distinguishable species



Reproduced the anticorrelation and preserved the correlation

Conclusions

- **Two-particle correlations**
 - Powerful tools
 - Constrain models behind event generators
- **Baryon–baryon anticorrelation**
 - Not reproduced by Standard Monte Carlo event generators
- **Essential exclusion (Pauli?) needed**
 - At the string fragmentation level (in Pythia at least)
- **Read about it in e-Print: [2210.02358 \[hep-ph\]](https://arxiv.org/abs/2210.02358)**