Two-particle angular correlations of identified particles in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE

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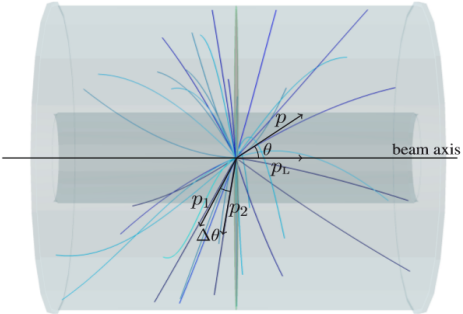
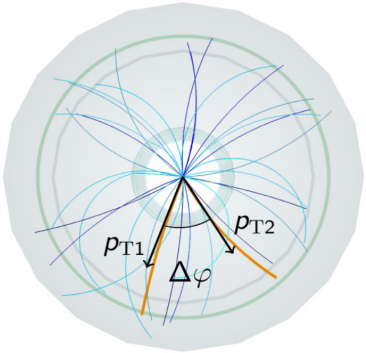
on behalf of the ALICE Collaboration

Warsaw University of Technology

MESON 2023

$\Delta\eta\Delta\varphi$ angular space





pseudorapidity : $\eta = -\ln|tg\frac{\theta}{2}|$
polar angle : θ

transverse momentum : p_{T}
azimuthal angle : φ

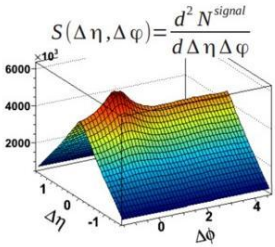
Fig. A.Zaborowska

$\Delta\eta\Delta\varphi$ correlation functions

$$C_P(\Delta\eta, \Delta\varphi) = \frac{N_{pairs}^{mixed}}{N_{pairs}^{signal}} \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)}$$

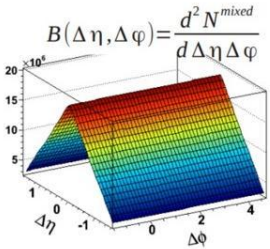
C_P is the Probability-ratio correlation function

SIGNAL distribution



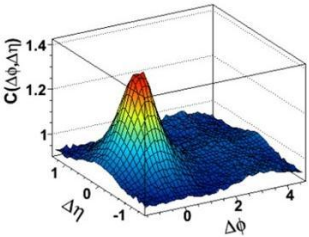
$\div$

BACKGROUND distribution



$=$

RATIO signal/background



Anatomy of angular correlations

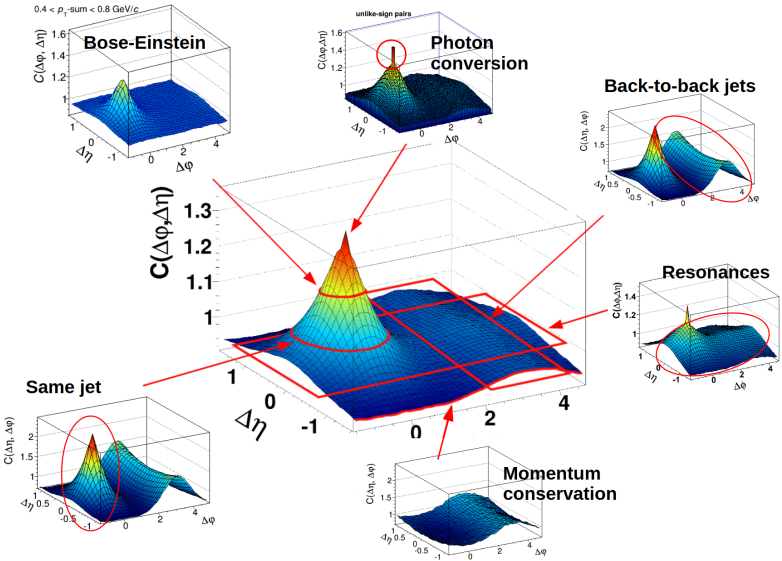
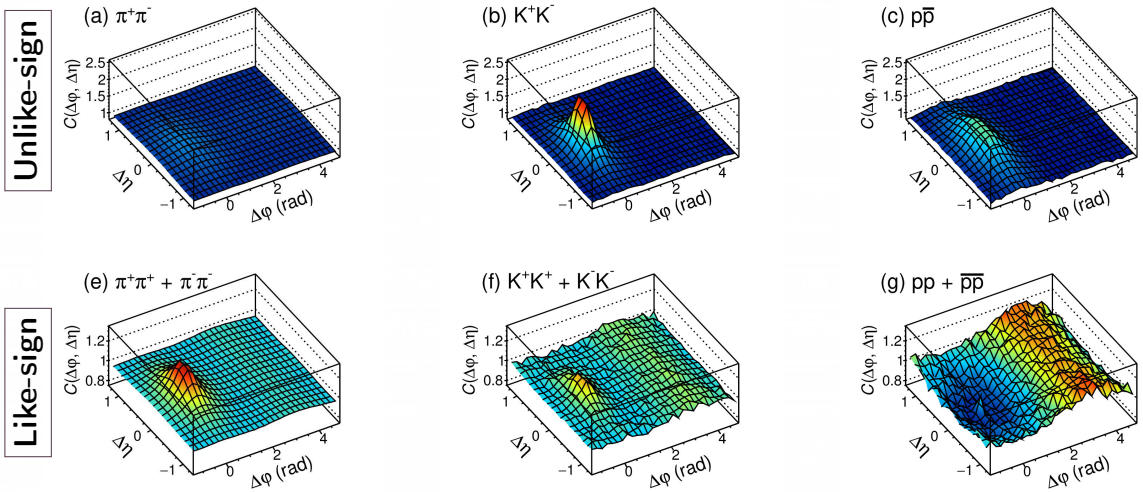


Fig. M.A.Janik

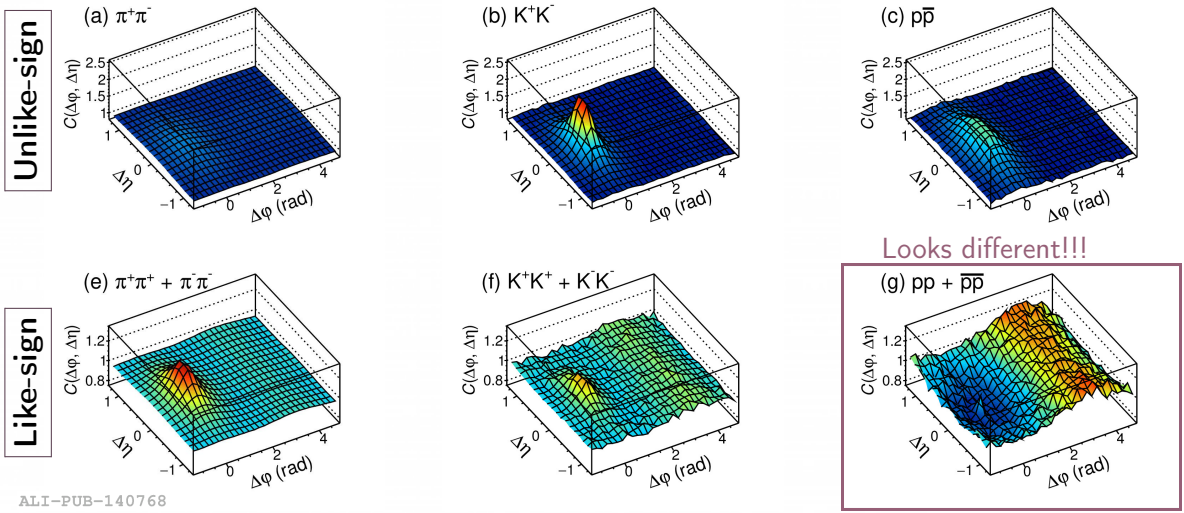
Identified mesons and baryons



ALI-PUB-140768

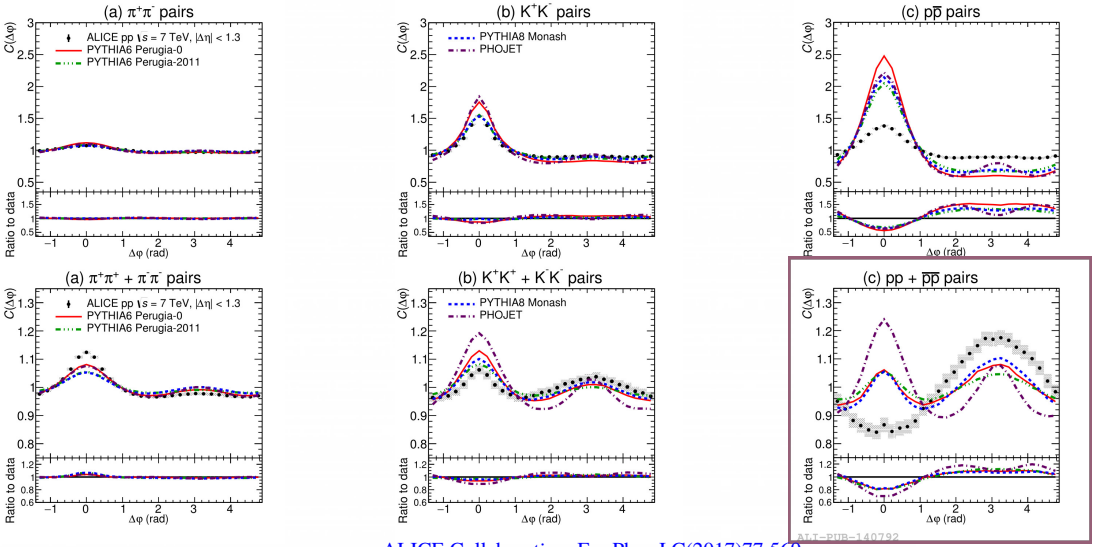
ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Identified mesons and baryons



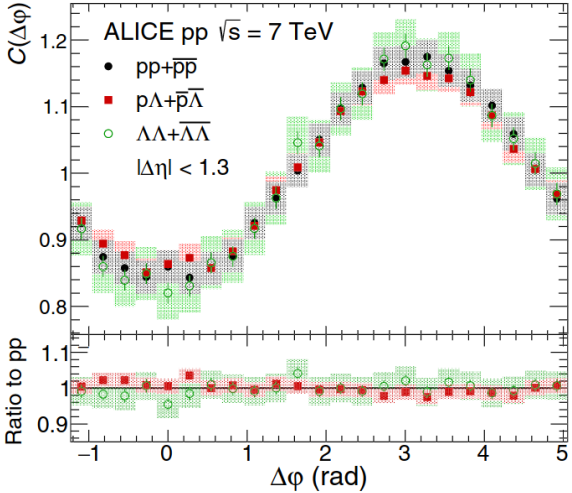
ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Mesons and baryons compared to MC models



ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Can we understand the anti-correlation of baryons?

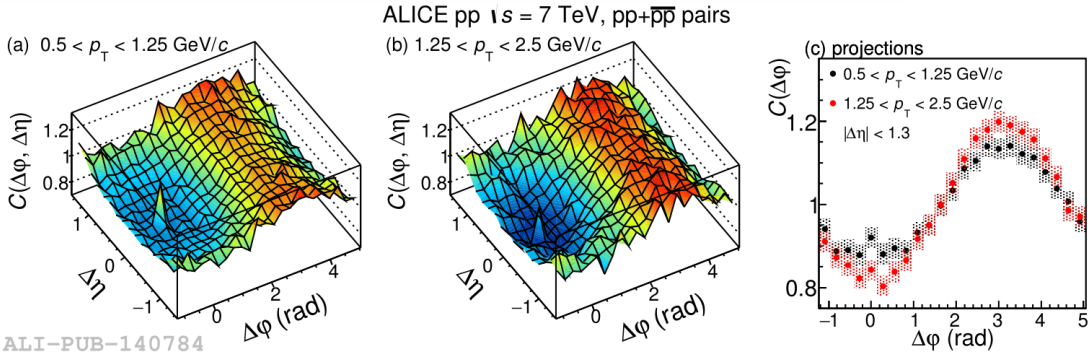


ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Possible explanation:

- ☐ Small p_T range
- ☐ Coulomb repulsion
- ☐ Effect of other baryons
- ☐ Fermi-Dirac quantum statistics
- ☐ Other experimental measurements

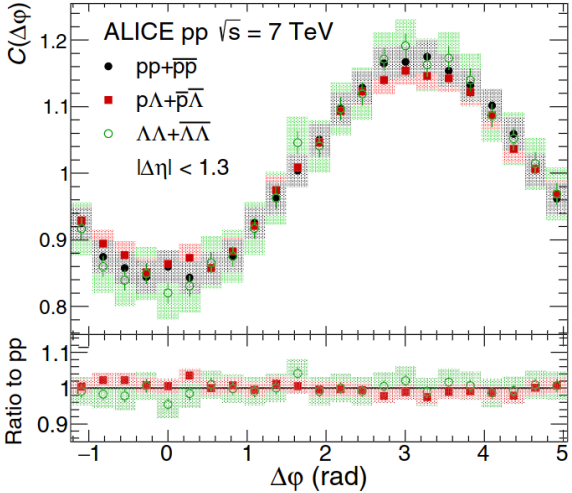
p_T dependence



p_T growth

ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Can we understand the anti-correlation of baryons?



ALICE Collaboration, Eur.Phys.J.C(2017)77:569

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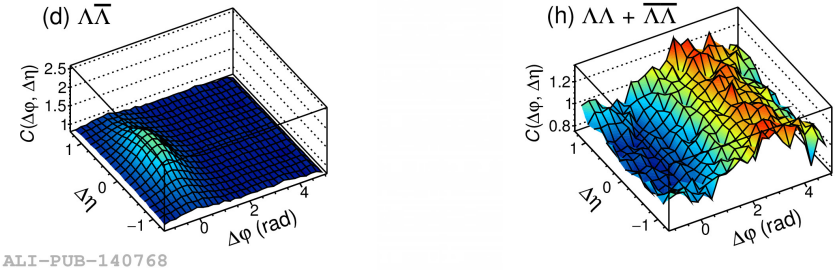
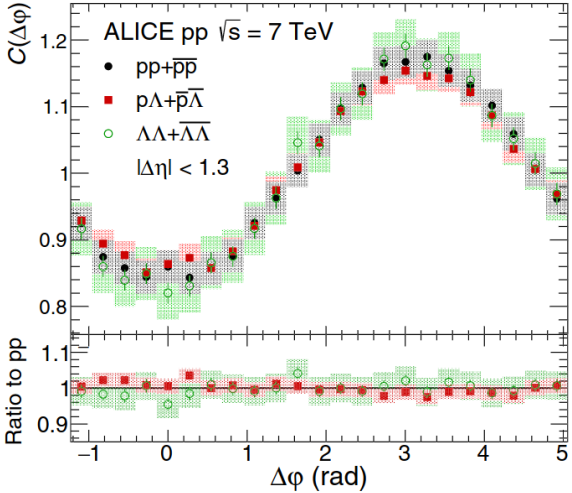
Coulomb repulsion and other baryons



- Λ is a neutral particle useful for testing how much the influence of Coulomb repulsion affects the anti-correlation → Coulomb repulsion plays marginal role.
- It is possible to check whether the effect also applies to baryons other than protons → for all baryons, anti-correlation is a common feature.

ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Can we understand the anti-correlation of baryons?



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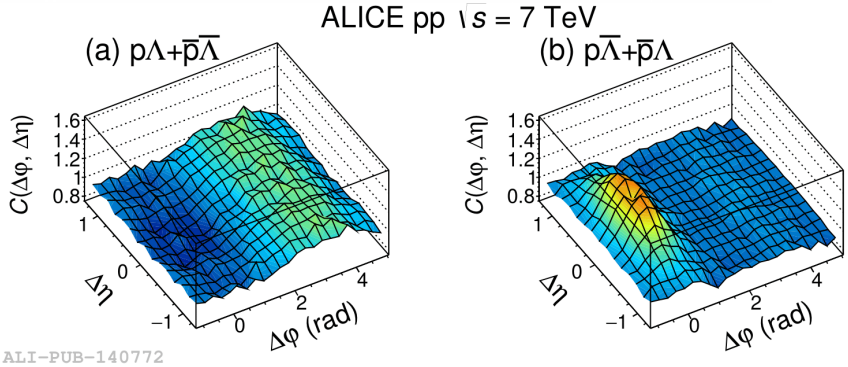
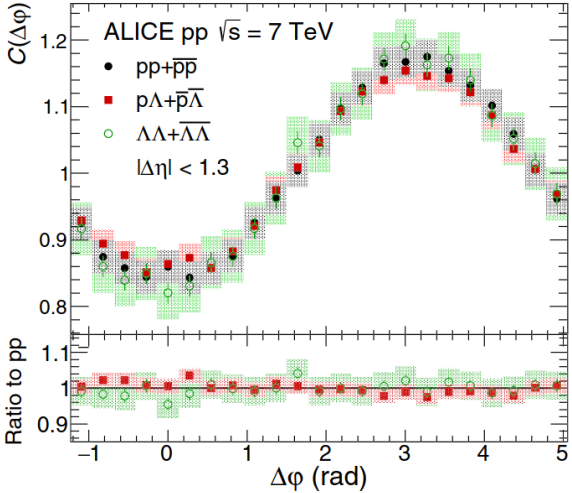
Fermi-Dirac quantum statistics



- Fermi-Dirac quantum statistics plays a marginal role, since p and Λ are not identical.

ALICE Collaboration, Eur.Phys.J.C(2017)77:569

Can we understand the anti-correlation of baryons?



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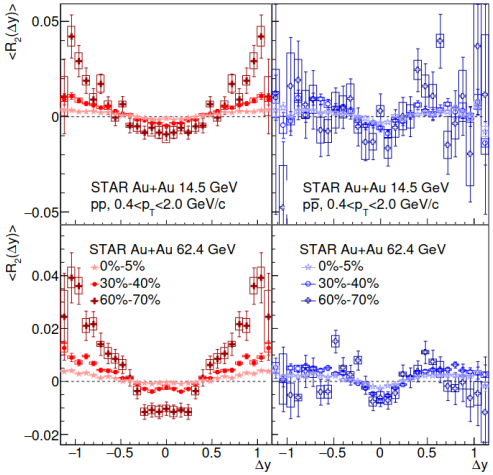
STAR Au–Au data



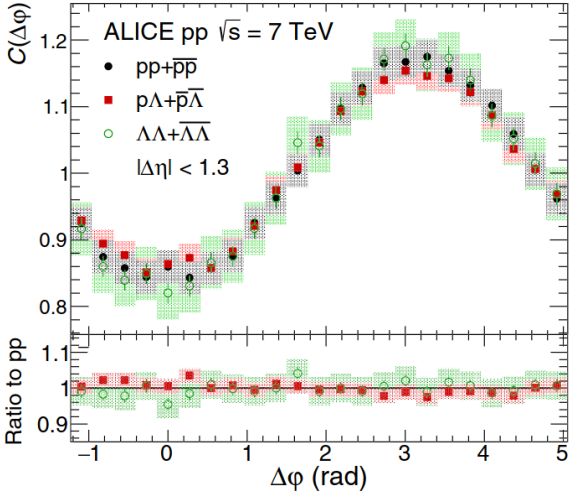
(b) protons

- The anti-correlation effect is present for Au–Au results
- Beam energy, p_{T} range and centrality dependencies were studied
- $R_2(\Delta y, \Delta\varphi) = \frac{\rho_2(\Delta y, \Delta\varphi)}{\rho_1(y_1, \varphi_1)\rho_2(y_2, \varphi_2)} - 1$

  Correlation amplitudes decrease as collisions become more central

STAR, Phys.Rev.C101,014916(2020)

Can we understand the anti-correlation of baryons?



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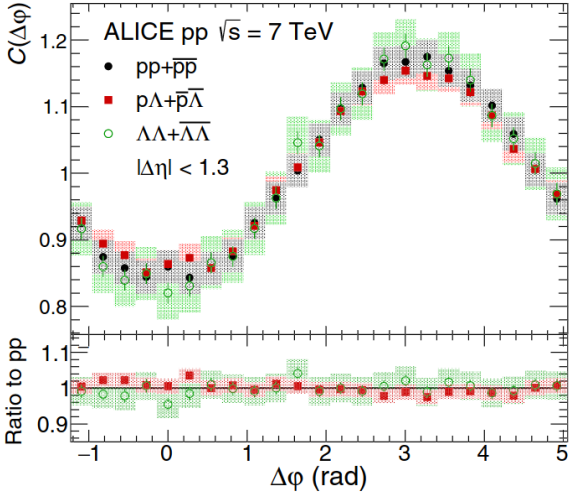

ALICE Collaboration, Eur.Phys.J.C(2017)77:569

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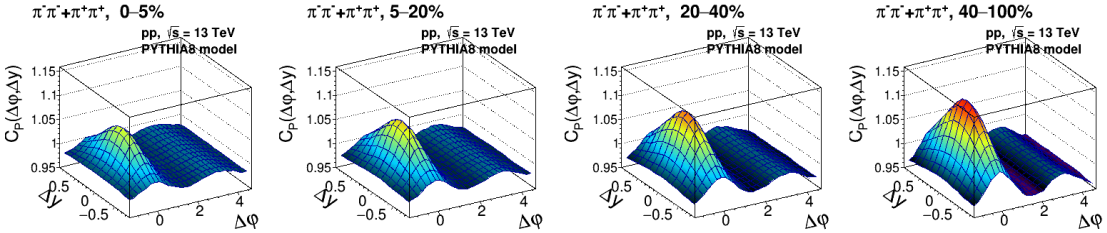
How does anti-correlation behave in different multiplicity classes and collision systems in ALICE???

Limitation of the probability-ratio definition

pp, p–Pb and Pb–Pb results cannot be compared easily:

Using the probability-ratio definition we have:

- ☐ Difference in multiplicities
- ☐ Trivial multiplicity scaling, $1/N$



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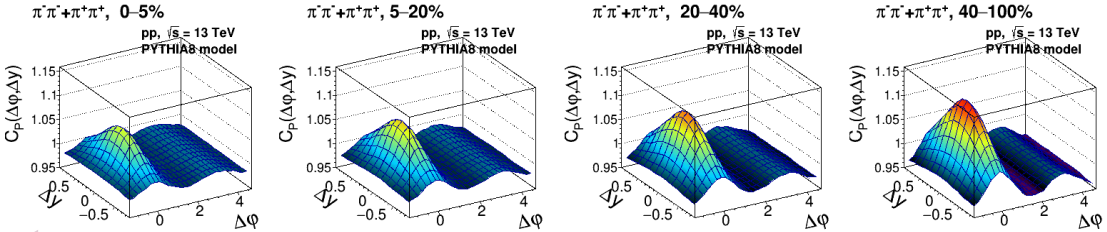


INCREASING MULTIPLICITY

Rescaled two-particle cumulant definition

- How to overcome trivial multiplicity scale $1/N$?
  - Use a **rescaled two-particle cumulant definition** (C_C) for correlation functions:

$$C_C(\Delta y \Delta\varphi) = \frac{N_{av}}{\Delta y \Delta\varphi}(\mathrm{R}_2)$$

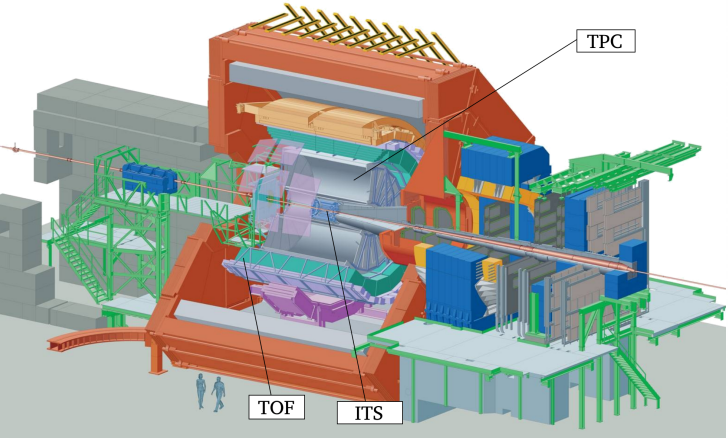
– R_2 = probability ratio correlation function - 1.
– $\mathrm{N_{av}}$ = average number of particles produced in the analyzed multiplicity classes;

  - Change $\eta \rightarrow$ y (pseudorapidity to rapidity) because the latter is more natural for identified particles: $y = \frac{1}{2}\ln(\frac{E+p_z c}{E-p_z c})$

STAR Collaboration, Phys.Rev.C86(2012),064902.

Data samples & settings

- pp collisions at 13 TeV registered by ALICE in 2016, 2017 and 2018.



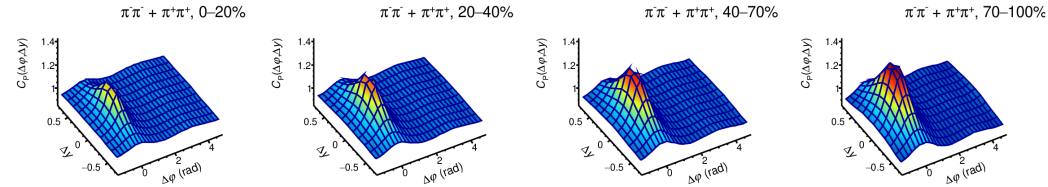
- Tracking:
  - Inner Tracking System (ITS);
  - Time Projection Chamber (TPC);
- Particle Identification:
  - Time Projection Chamber (TPC);
  - Time of Flight (TOF);
- Kinematic cuts:
  - $|y| < 0.5$;
  - pions : $0.2 < p_{\mathrm{T}} < 2.5$ GeV/c;
  - kaons : $0.5 < p_{\mathrm{T}} < 2.5$ GeV/c;
  - protons : $0.5 < p_{\mathrm{T}} < 2.5$ GeV/c.
- Multiplicity classes:
  - 0–20%,20–40%,40–70%,70–100%

$\Delta y \Delta \varphi$ correlation functions

π like-sign

Probability-ratio

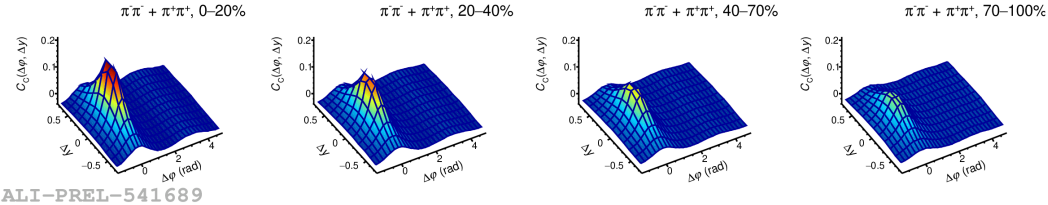
ALICE preliminary, pp $\sqrt{s}$ = 13 TeV



Increasing multiplicity

Rescaled two-particle cumulant

ALICE preliminary, pp $\sqrt{s}$ = 13 TeV

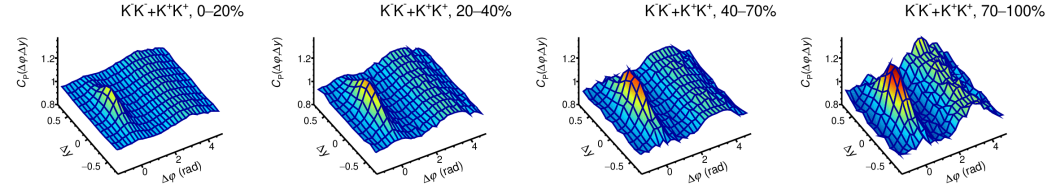


$\Delta y \Delta \varphi$ correlation functions

K like-sign

Probability-ratio

ALICE preliminary, pp $\sqrt{s}$ = 13 TeV



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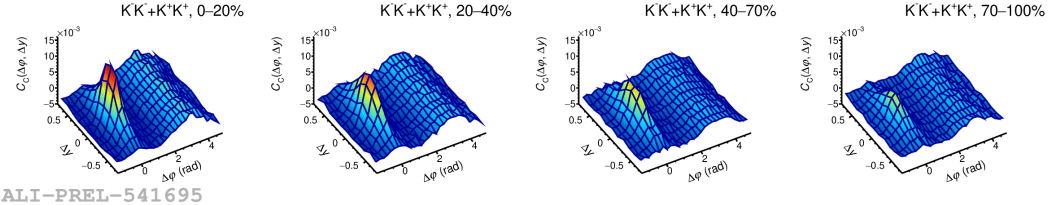
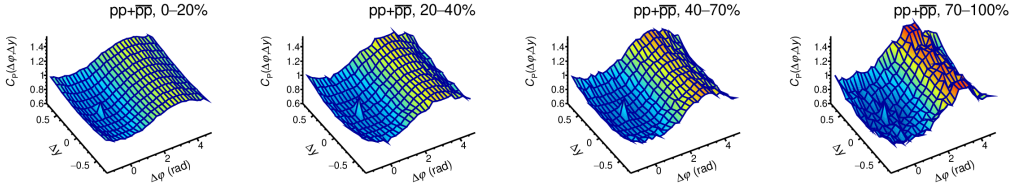


$\Delta y \Delta \varphi$ correlation functions

p like-sign

Probability-ratio

ALICE preliminary, pp $\sqrt{s}$ = 13 TeV

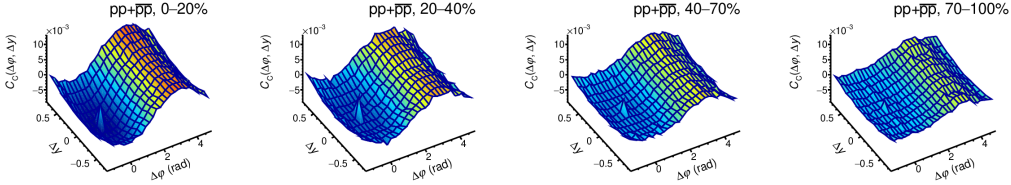


ALI-PREL-541683

Increasing multiplicity

Rescaled two-particle cumulant

ALICE preliminary, pp $\sqrt{s}$ = 13 TeV

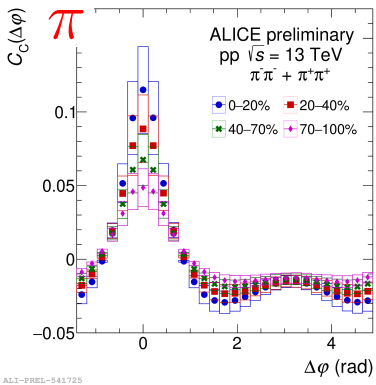


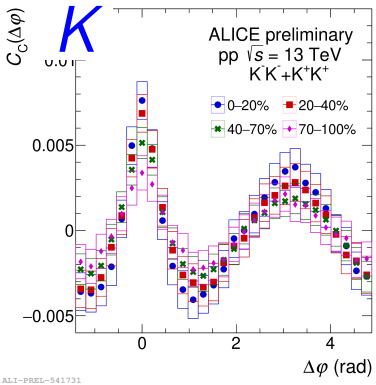
ALI-PREL-541701

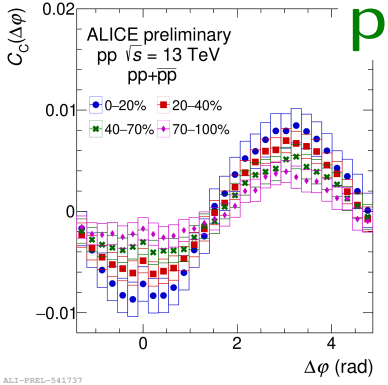
Projection of the correlation functions

like-sign

Rescaled two-particle cumulant



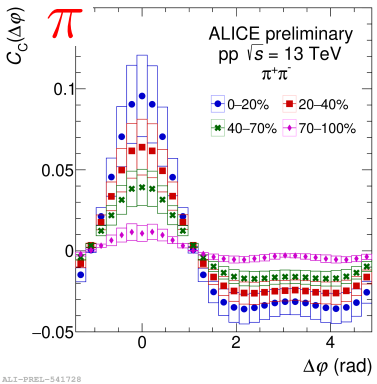


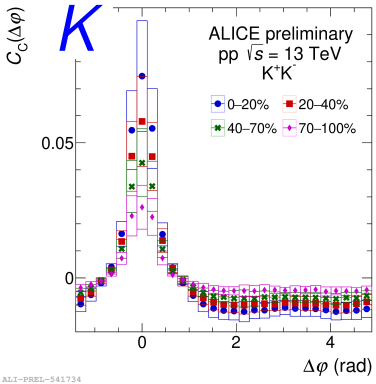


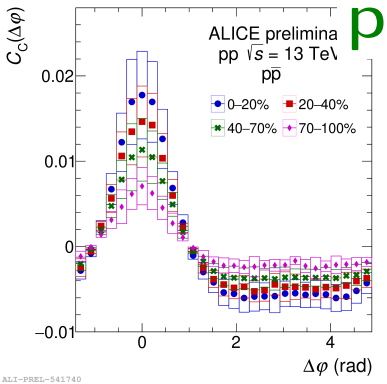
- Correlation functions **rise** with increasing multiplicity

Projection of the correlation functions unlike-sign

Rescaled two-particle cumulant







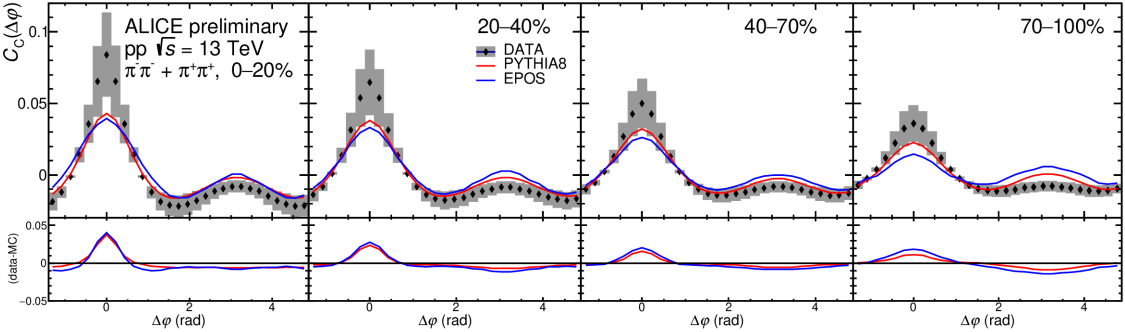
- Correlation functions **rise** with increasing multiplicity

Comparison to MC models

π like-sign

PYTHIA8
EPOS

Rescaled two-particle cumulant



ALI-PREL-541761

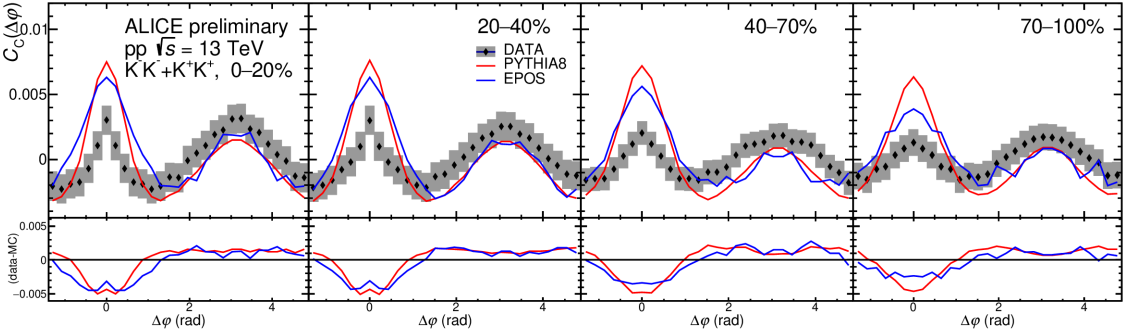
- The MC models are able to reproduce the correlation function well for mesons.

Comparison to MC models

K like-sign

PYTHIA8
EPOS

Rescaled two-particle cumulant



ALI-PREL-541767

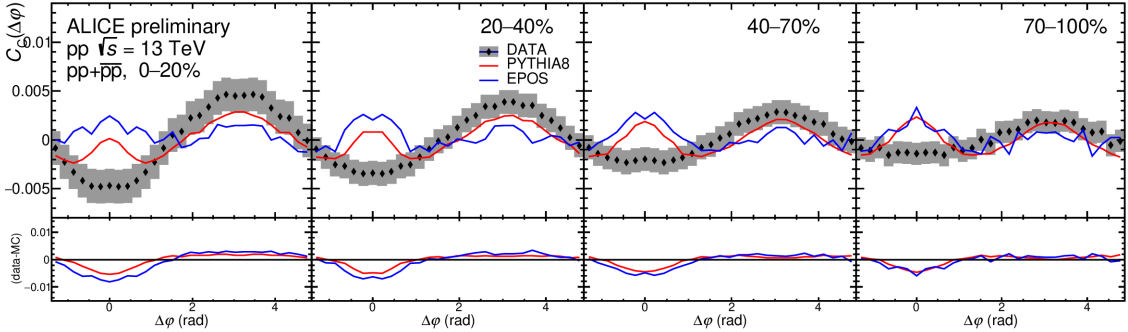
- The MC models are able to reproduce the correlation function well for mesons.

Comparison to MC models

p like-sign

PYTHIA8
EPOS

Rescaled two-particle cumulant



ALI-PREL-541773

- Baryonic correlations cannot be reproduced by MC models: no anti-correlation is visible.

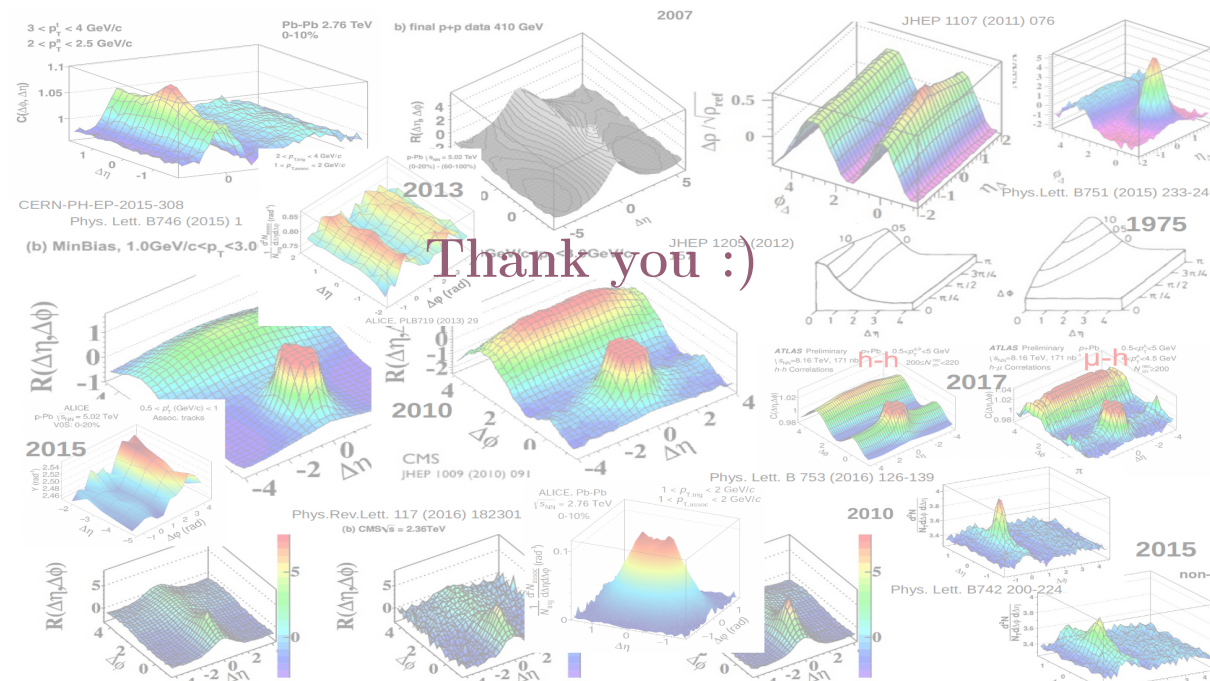
Summary

- $\Delta y \Delta \varphi$ correlation functions:
  - probability ratio definition
  - rescaled two-particle cumulant definition
- Comparison with Monte Carlo generators (PYTHIA8 and EPOS)

TAKE-HOME MESSAGE:

Rescaled two-particle cumulant definition is the most appropriate for multiplicity dependence studies because it allows to untangle and delve into the various phenomena that contribute to the structure of the $\Delta y \Delta \varphi$ correlation function. The baryon anti-correlation remains to be understood.

Thank you :)

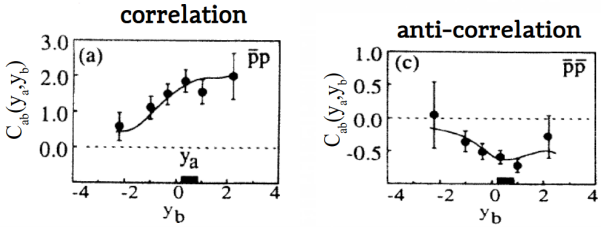

3 < p_T^t < 4 GeV/c
2 < p_T^a < 2.5 GeV/c
Pb-Pb 2.76 TeV
0-10%
b) final p+p data 410 GeV
2007
JHEP 1107 (2011) 076
CERN-PH-EP-2015-308
Phys. Lett. B746 (2015) 1
2013
Phys.Lett. B751 (2015) 233-24
(b) MinBias, 1.0GeV/c<p_T<3.0
JHEP 1205 (2012)
1975
ALICE, PLB719 (2013) 29
2015
2010
CMS
JHEP 1009 (2010) 091
h-h
2017
μ-h
Phys. Lett. B 753 (2016) 126-139
Phys.Rev.Lett. 117 (2016) 182301
(b) CMS √s = 2.36TeV
ALICE, Pb-Pb
√s_NN = 2.76 TeV
0-10%
2010
2015
non-
Phys. Lett. B742 200-224

Backup slides

baryon-baryon anti-correlation

Rapidity correlations in e^+e^-

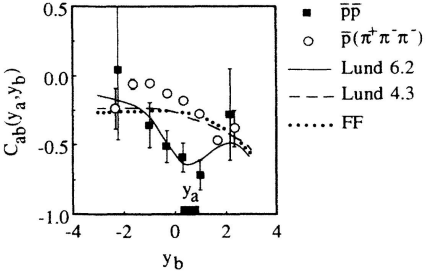
From the mechanism of jet production: Two primary hadrons with the same baryon number are separated by at least two steps in "rank" → we are not likely to find two baryons or two antibaryons very close to each other. Nucl.Phys.B136(1978)131



Local baryon number conservation is partially responsible for anti-correlation at 29 GeV

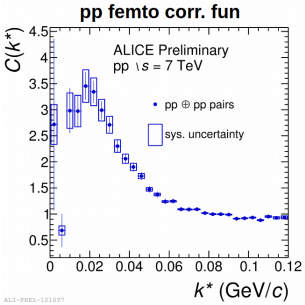
TPC/Two Gamma Collaboration, Phys.Rev.Lett. 57 (1986) 3140

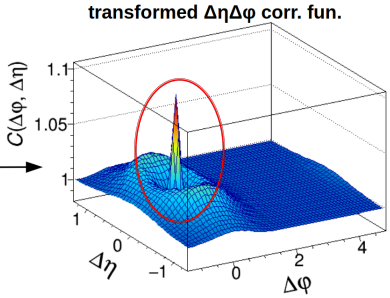
Models at lower energies agree with observations seen in data: **LUND 6.2**

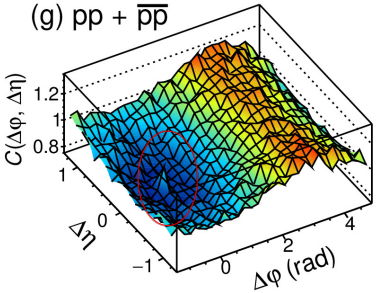


Strong Final-State Interaction

- Femtoscopic measurements are more suitable for the study of the strong interaction;
- Femto correlation generates peak at $\Delta\eta\Delta\varphi = (0,0)$ comparable with the peak observed in the anti-correlation;



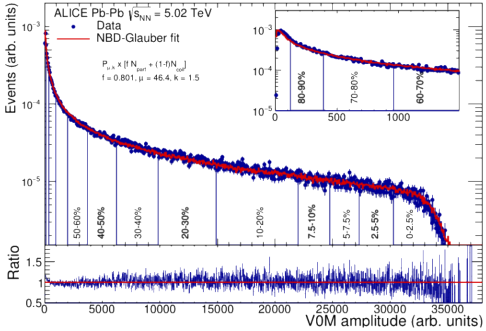


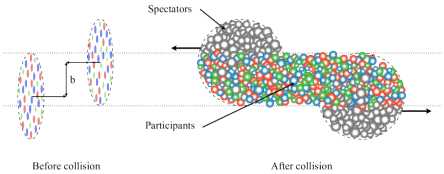


Ł.K.Graczykowski and M.A.Janik, Phys. Rev. C 104, 054909

Multiplicity classes

Multiplicity classes





Parameter b is defined as the distance perpendicular to the direction of the radius between two nuclei.

- For central collisions b∼0;
- For peripheral collisions b > 2R;
- Not measured directly → estimated from centrality

0-5% : most central collision

80-100% : most peripheral collision

N_{av} estimation

N_{av} estimation

$$C(\Delta y \Delta \varphi) = \frac{N_{av}}{\Delta y \Delta \varphi}(R_2)$$

N_{av} is the average number of particles produced in the multiplicity classes analyzed after applying the efficiency corrections;

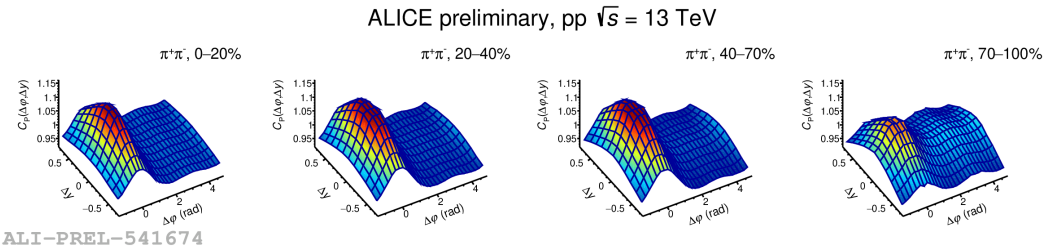
Nav estimation	0-20%	20-40%	40-70%	70-100%
Pions	5.5	3.25	2.1	1.3
Kaons	0.65	0.35	0.2	0.1
Protons	0.3	0.2	0.1	0.06

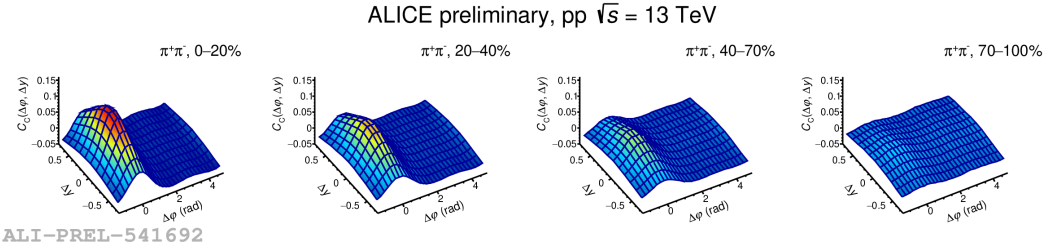
Table: N_{av} values estimated for all particles involved in the analysis, i.e., pions, kaons and protons, and for the multiplicity classes involved. The values are applied as a normalization factor to the correlation function $\Delta y \Delta \varphi$ defined as the rescaled two-particle cumulant.

STAR collaboration, Phys. Rev. C 86 (2012), 064902.

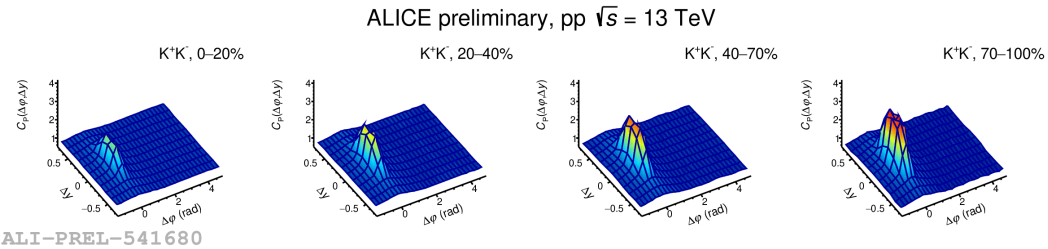
$\Delta y \Delta \varphi$ correlation functions

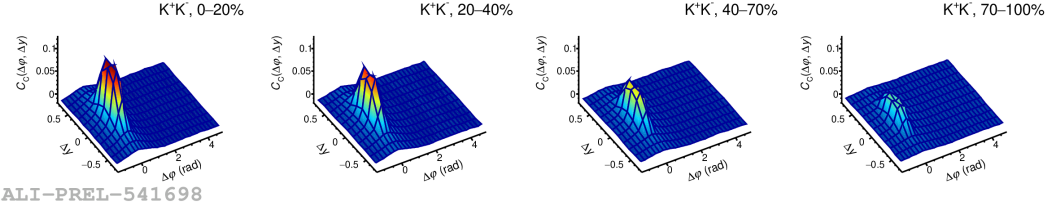
$\Delta y \Delta \varphi$ correlation functions



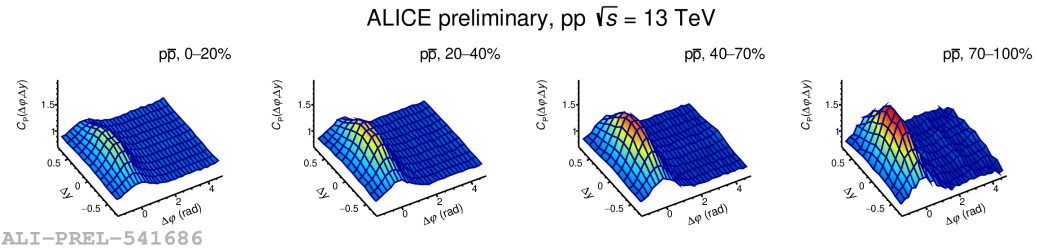


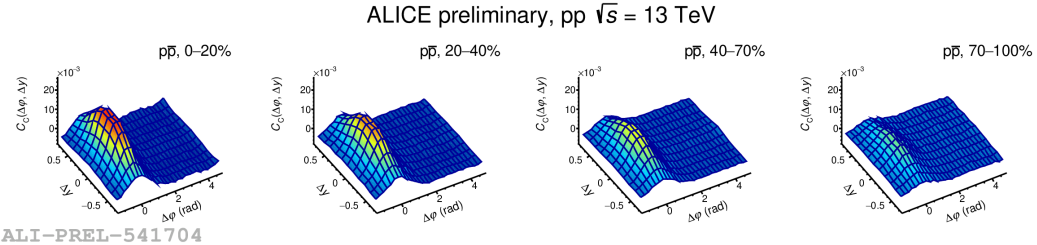
$\Delta y \Delta \varphi$ correlation functions





$\Delta y \Delta \varphi$ correlation functions



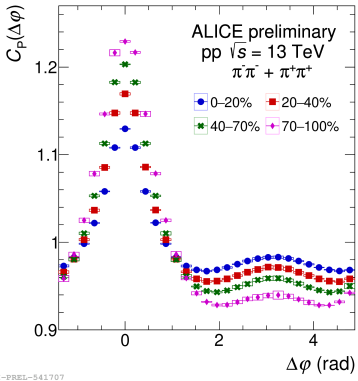


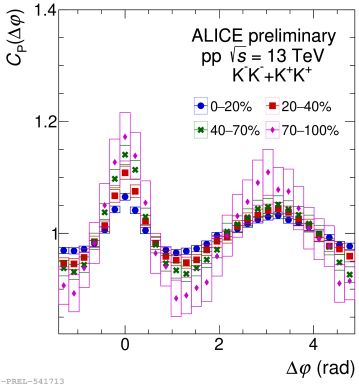
Projection of $\Delta y \Delta \varphi$ correlation functions

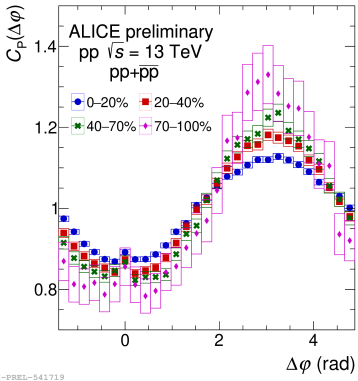
probability ratio definition

Projection of $\Delta y \Delta \varphi$ correlation functions

Probability ratio

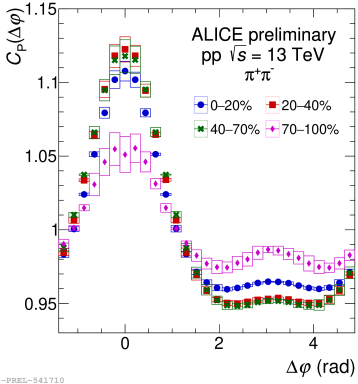


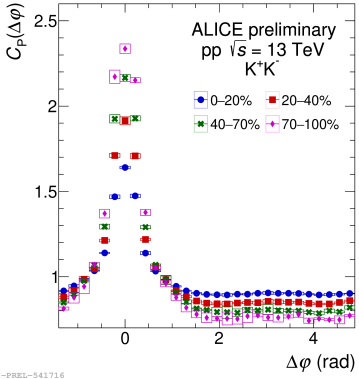


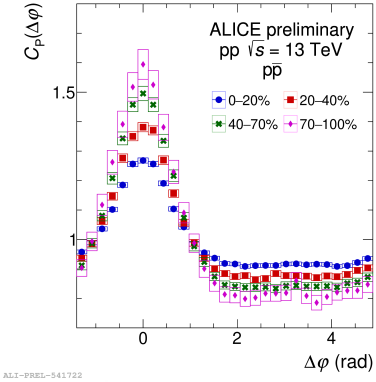


Projection of $\Delta y \Delta \varphi$ correlation functions

Probability ratio





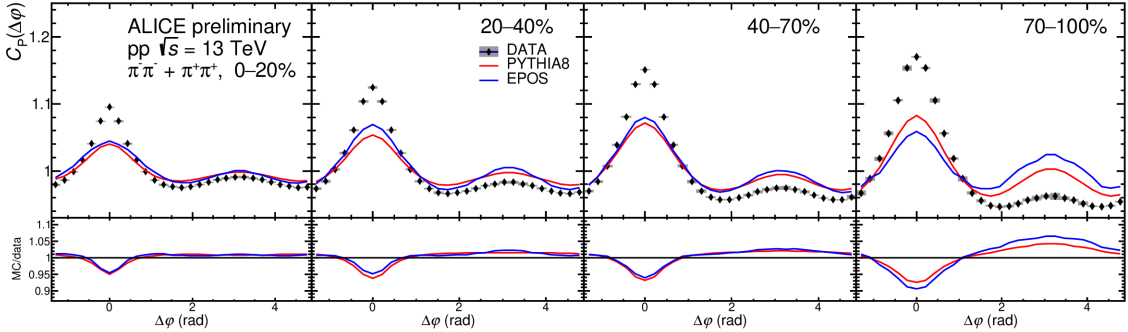


Comparison to MC models

probability ratio definition

Comparison to MC models

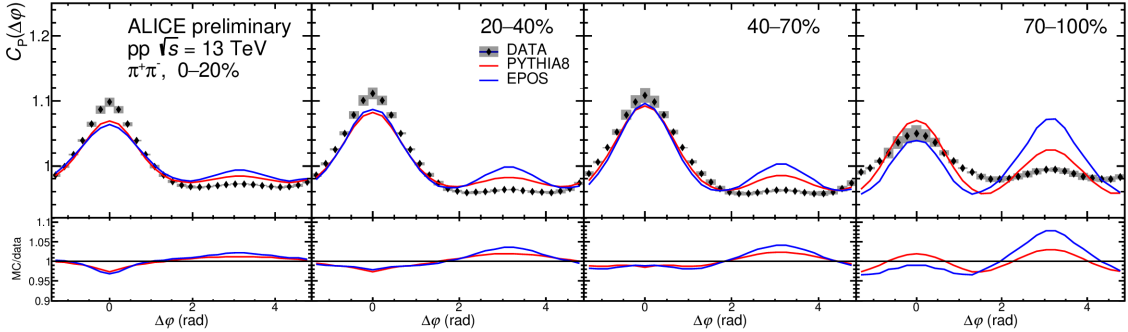
Probability ratio



ALI-PREL-541743

Comparison to MC models

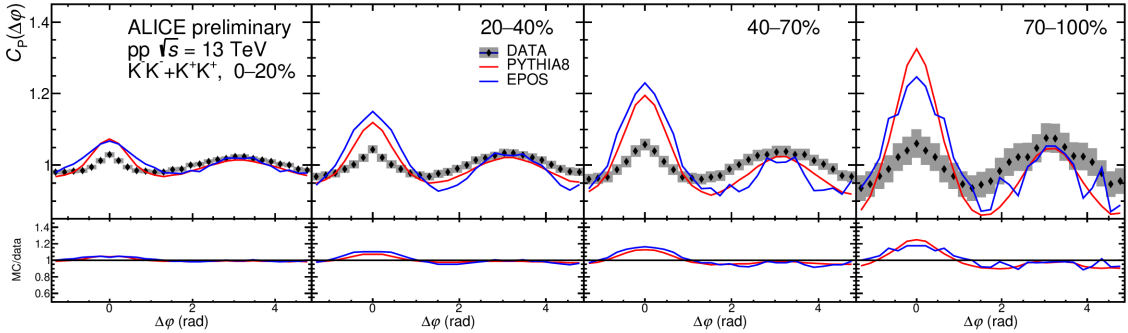
Probability ratio



ALI-PREL-541746

Comparison to MC models

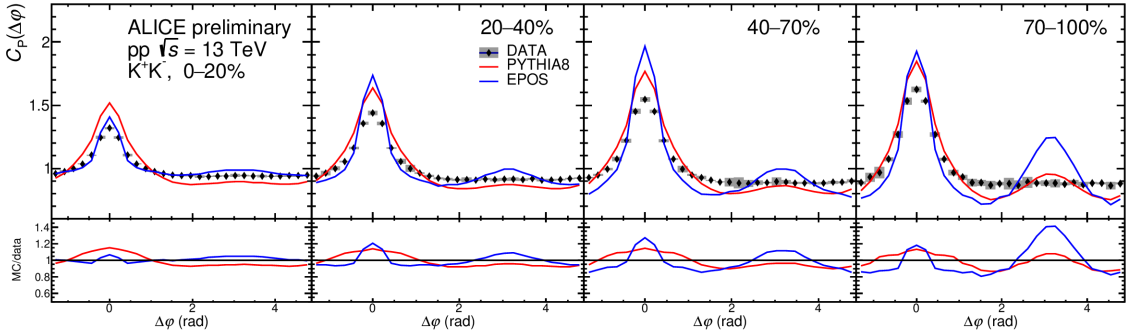
Probability ratio



ALI-PREL-541749

Comparison to MC models

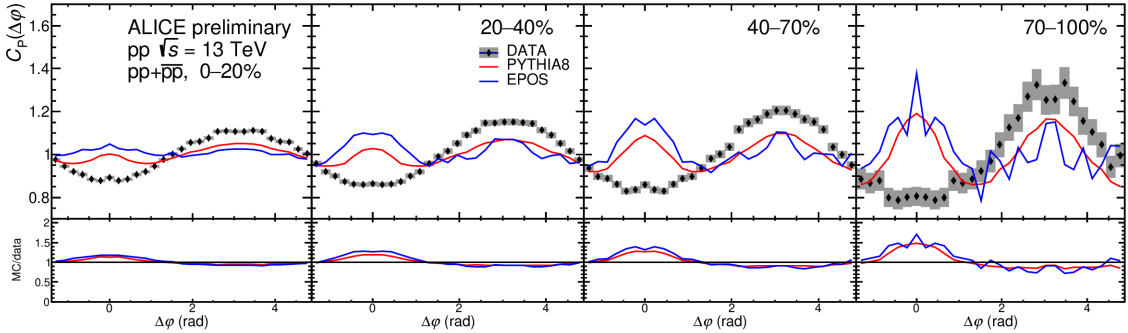
Probability ratio



ALI-PREL-541752

Comparison to MC models

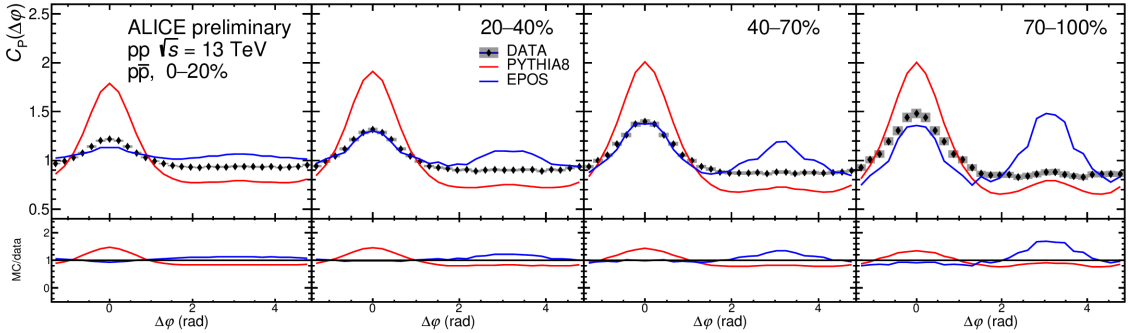
Probability ratio



ALI-PREL-541755

Comparison to MC models

Probability ratio



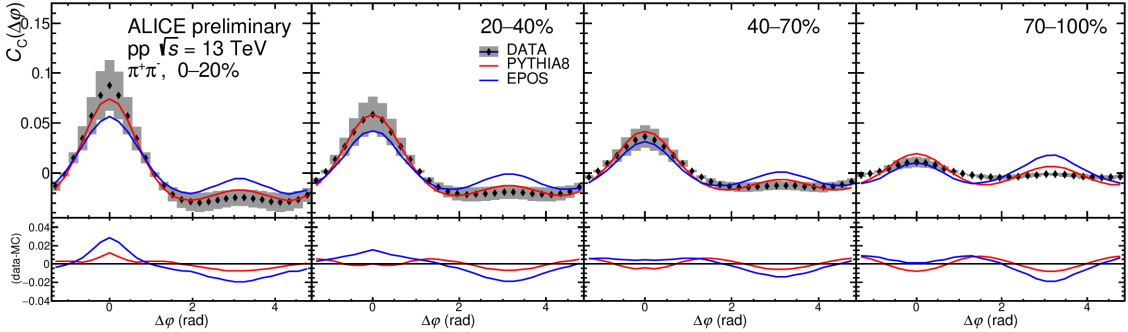
ALI-PREL-541758

Comparison to MC models

rescaled two-particle cumulant definition

Comparison to MC models

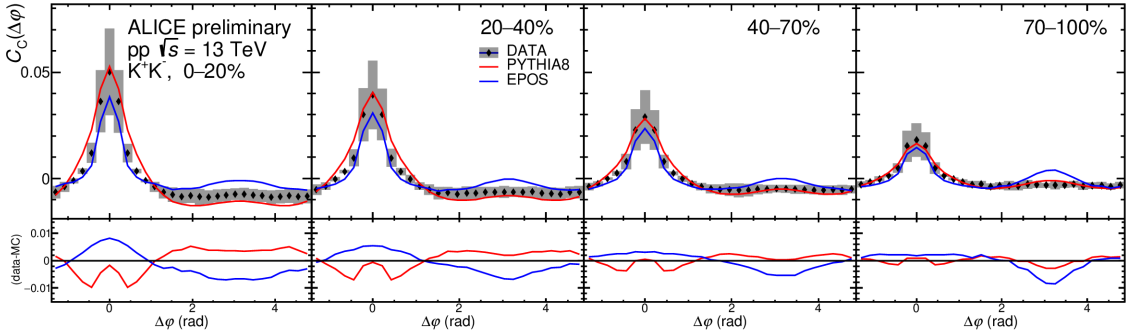
Rescaled two-particle cumulant



ALI-PREL-541764

Comparison to MC models

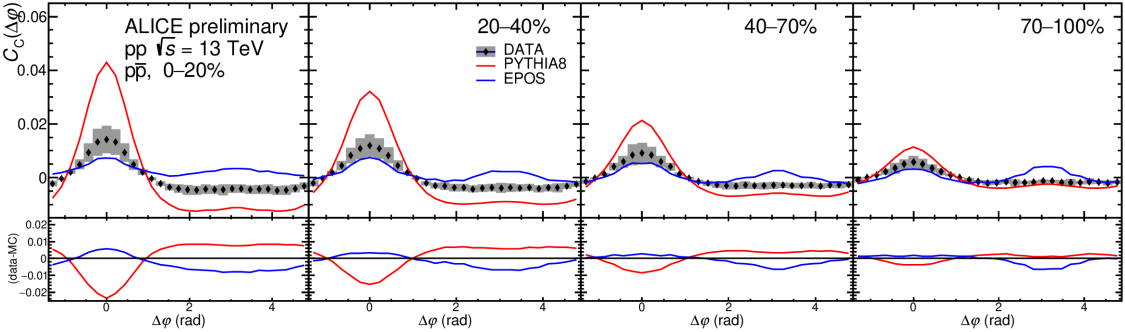
Rescaled two-particle cumulant



ALI-PREL-541770

Comparison to MC models

Rescaled two-particle cumulant



ALI-PREL-541776