ALICE

Clocking the particle production and tracking of strangeness balance and radial flow effects at top LHC energy with ALICE

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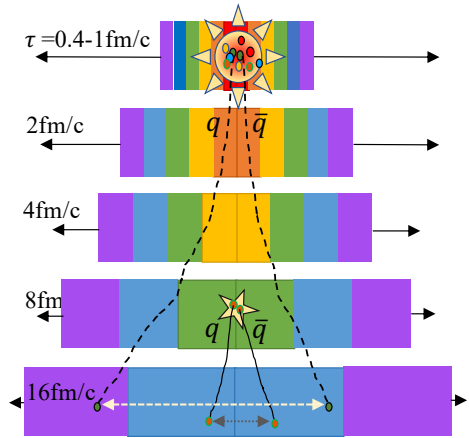
on behalf of the **ALICE Collaboration**
ICHEP 2024 Prague, Czech Republic

High-energy hadronic collisions

- **Quantum numbers are conserved**
- **Strong collective expansion**
  - After creation, pairs kept correlated
  - The larger the pair lifetime the longer the correlation reach
- **Full acceptance detector**
  - Quantum numbers fully balanced
- **Balance function**
  - A measure of quantum number balance



S.Basu, P.Christiansen, A.Ohlson, D.Silvermyr, EPJC **81** (2021) 11, 1024

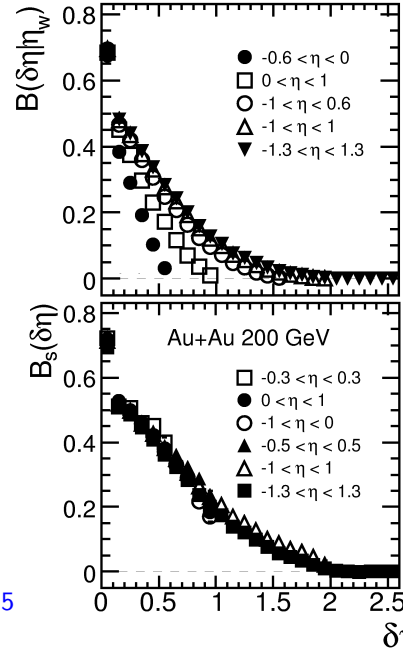
Charge balance function

S.A.Bass, P.Danielewicz and S.Prat,
PRL **85** (2000) 2689

$$B = \frac{1}{2}\left[\frac{N^{+-}}{N^{+}} - \frac{N^{--}}{N^{-}} + \frac{N^{-+}}{N^{-}} - \frac{N^{++}}{N^{+}}\right]$$

- **Probing radial flow**
- **Clocking hadronization**
- **Acceptance effects**
  - On the width (σ_B)
  - On the integral (I_B)

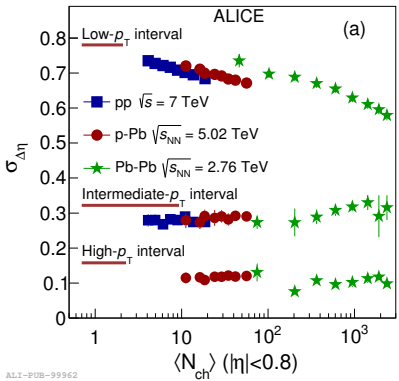
STAR, PRC **82** (2010) 024905

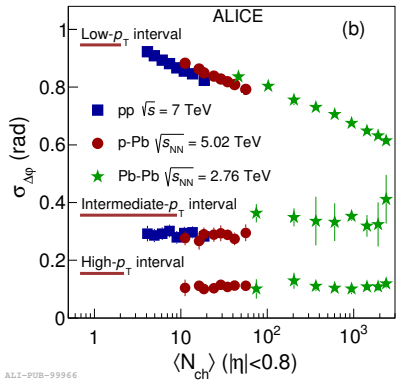


Charge balance function (unidentified particles)

ALICE, EPJ C **76** (2016) 86

σ: **width**



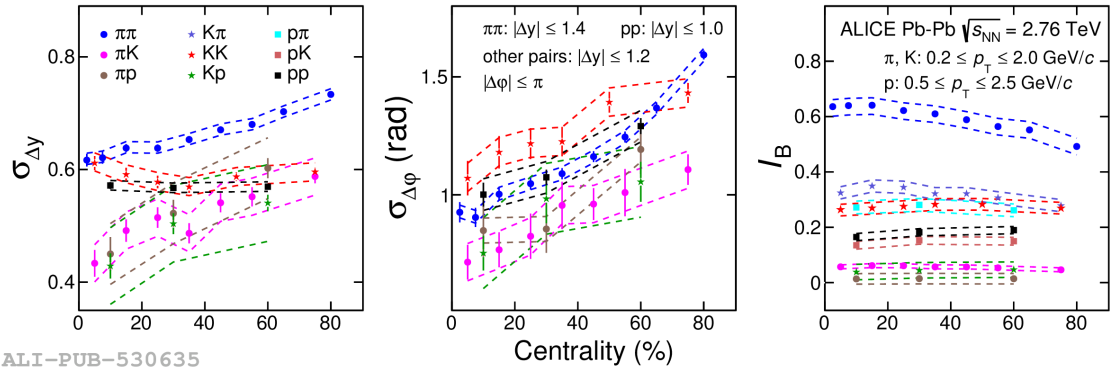


– **In the "bulk" regime different mechanism for Pb–Pb**
– **At high p_T same mechanism along the three systems**

Charge balance function (identified particles)

ALICE, PLB **833** (2022) 137338

σ: **width**, I_B: **integral**



– Similar $B^{\pi\pi}$ and B^{KK} $\sigma_{\Delta y}$ from Au–Au at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV/c (STAR, PRC **82** (2010) 024905)

– **Consistent with radial flow and two-stages quark hadronization**

– **The balancing share appears independent of multiplicity**

The Balance function observable

– **Generalized definition**

$$B^{\alpha\beta}(\Delta\eta,\Delta\varphi) = \frac{1}{2}\left\{\rho_1^{\bar{\beta}}\left[R_2^{\alpha\bar{\beta}} - R_2^{\bar{\alpha}\bar{\beta}}\right] + \rho_1^{\beta}\left[R_2^{\bar{\alpha}\beta} - R_2^{\alpha\beta}\right]\right\}$$

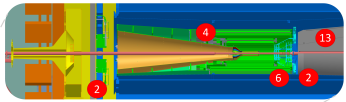
α, β: **realization of the quantum numbers of interest**

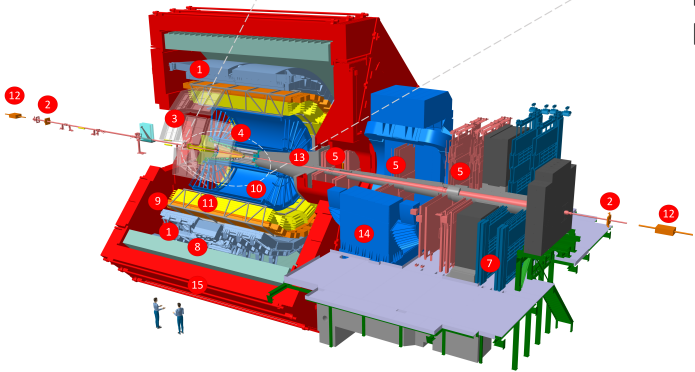
– **Based on the second order normalized cumulant**

$$R_2^{\alpha\beta}(\Delta\eta,\Delta\varphi) = \frac{\langle n_2^{\alpha\beta}\rangle}{\langle n_1^{\alpha}\rangle\langle n_1^{\beta}\rangle} - 1 \qquad \begin{cases} \rho_2^{\alpha\beta} = \dfrac{\mathrm{d}^2N^{\alpha\beta}}{\mathrm{d}\Delta\eta\,\mathrm{d}\Delta\varphi} \\ \rho_1^{\alpha} = \dfrac{\mathrm{d}^2N^{\alpha}}{\mathrm{d}\eta\,\mathrm{d}\varphi} \end{cases}$$

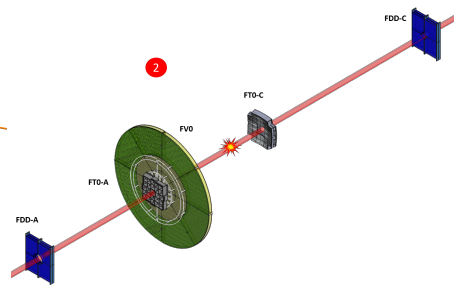
Automatically compensates for limited acceptance

The ALICE2 detector (LHC Run 3)



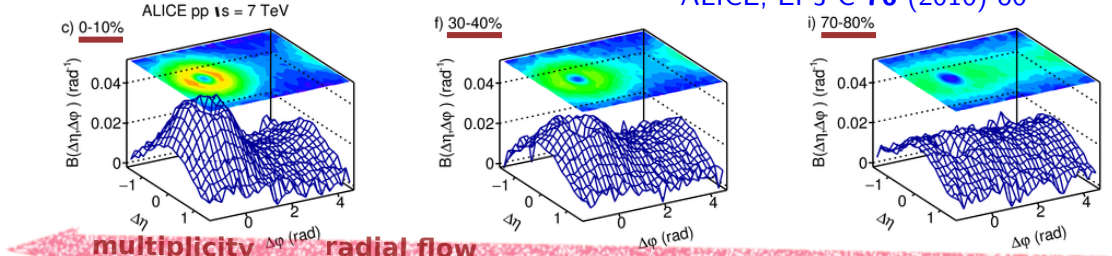


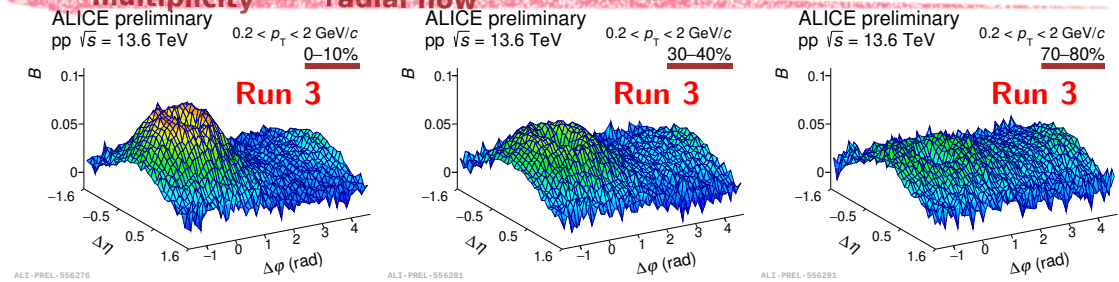
FIT Yury Melikyan, Friday 19
ITS Jian Liu, Thursday 18



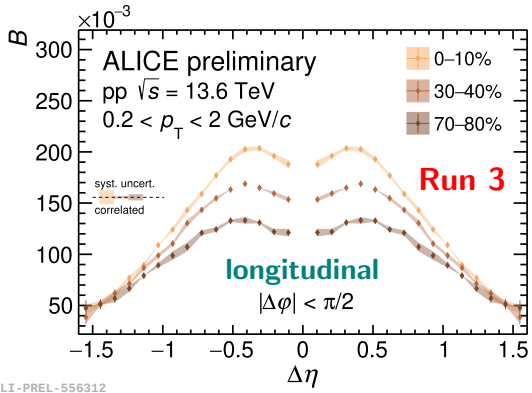
Charge balance function

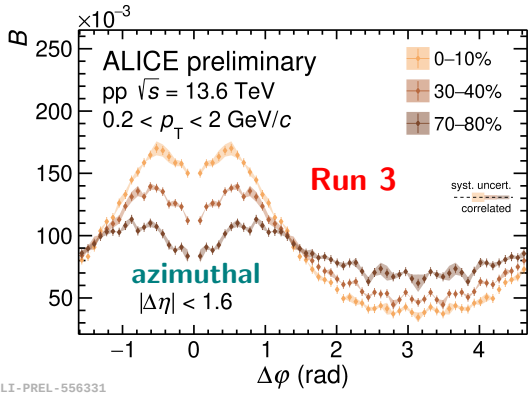
ALICE, EPJ C **76** (2016) 86





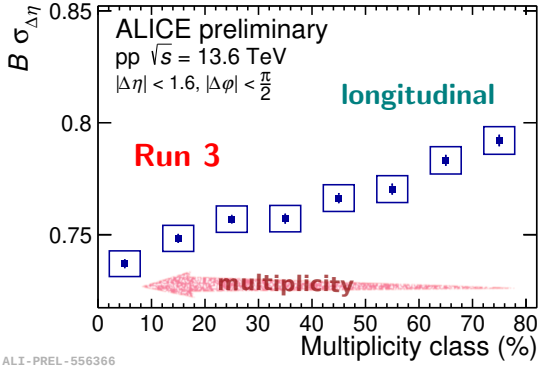
Charge balance function projections

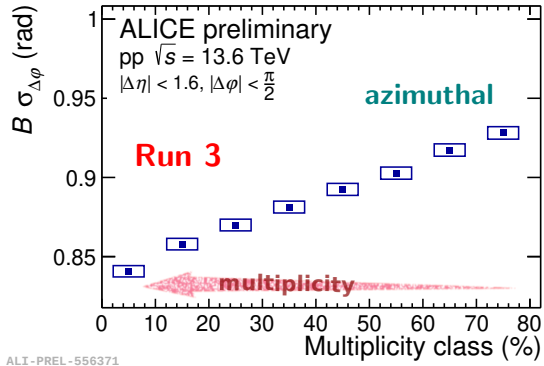




– **The charge balancing is redistributed with multiplicity**

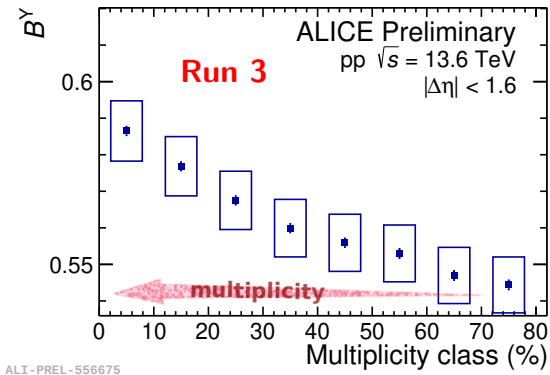
Charge balance function widths evolution





- Widths extracted as the RMS on the near side peak
- **Narrowing in both dimensions with increasing multiplicity**
- **Longitudinally $\sim 8\%$ and azimuthally $\sim 10\%$**

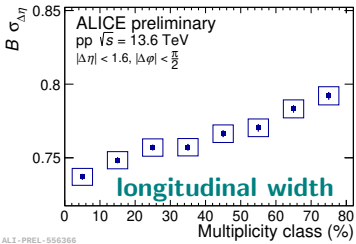
Charge balance function integral

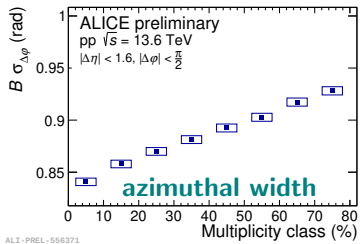


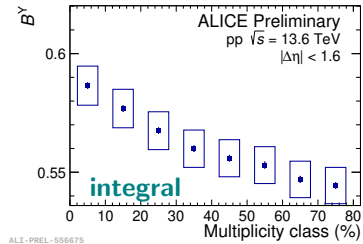
– **The redistribution of the charge balancing gets more and more portions out of the acceptance**

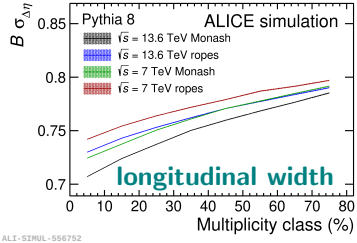
– **With complete acceptance, 4π, it should stay at one**
(C.Pruneau, VG, B.Hanley, A.Marin, S.Basu, PRC **107** (2023) 5, 054915)

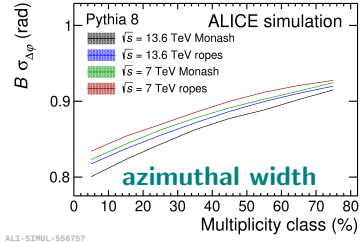
Comparison with models

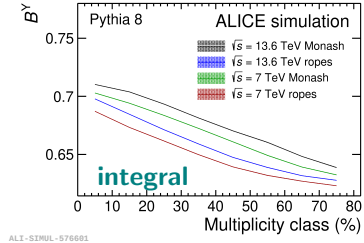












- **Qualitative and quantitative agreement on the widths**
- **Quantitative disagreement on the integral**

Next steps

- **Balance function of identified particles**
  - Hadronization of charged particles
  - Tracking baryon hadronization
  - Strangeness balancing
- **A better measure of EbyE fluctuations?**

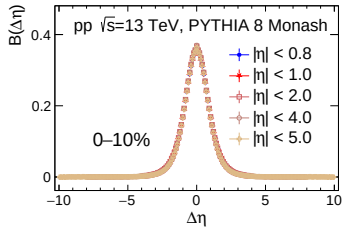
$$\nu_{\rm dyn}^{\alpha\beta} = -R_2^{\alpha\bar{\beta}} + R_2^{\bar{\alpha}\bar{\beta}} - R_2^{\bar{\alpha}\beta} + R_2^{\alpha\beta}$$

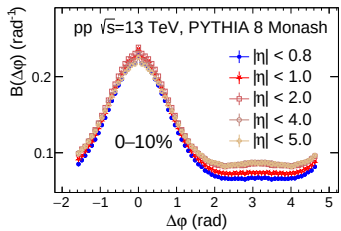
$$B^{\alpha\beta} = \frac{1}{2}\left\{\rho_1^{\bar{\beta}}\left[R_2^{\alpha\bar{\beta}} - R_2^{\bar{\alpha}\bar{\beta}}\right] + \rho_1^{\beta}\left[R_2^{\bar{\alpha}\beta} - R_2^{\alpha\beta}\right]\right\}$$

- It is usually suggested[*]

$$B^{\alpha\beta^{\rm Y}} = -\frac{\langle N\rangle}{4}\nu_{\rm dyn}^{\alpha\beta}$$

[*] **In general it is not true**

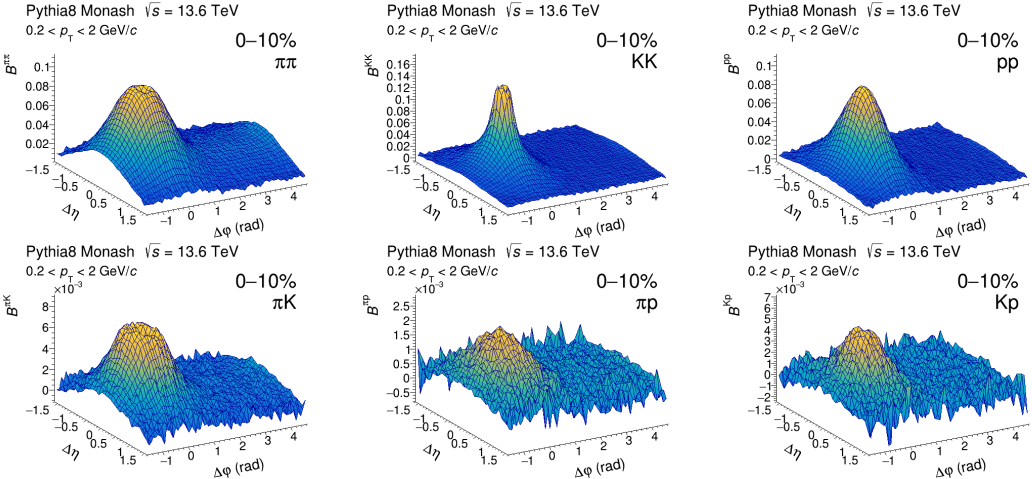




BF robust to volume fluctuations

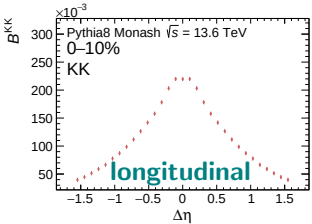
Charge $B^{\alpha\beta}$ of identified particles

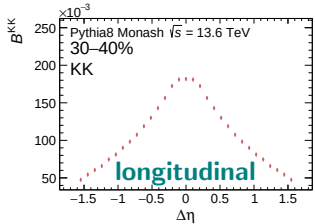
Pythia 8 Monash. 0-10% multiplicity class

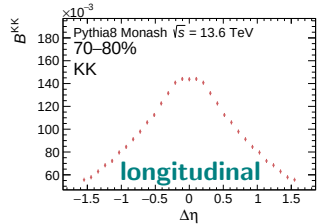


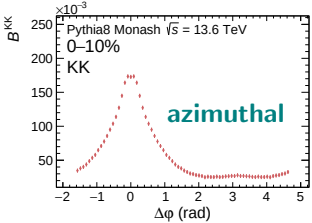
Charge B^{KK} projections evolution

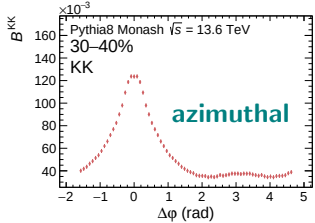
Pythia 8 Monash

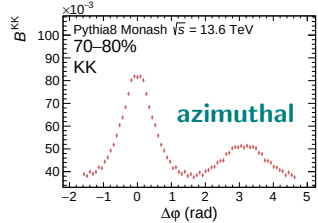








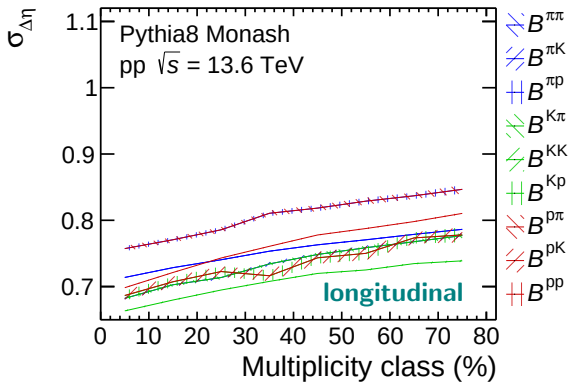


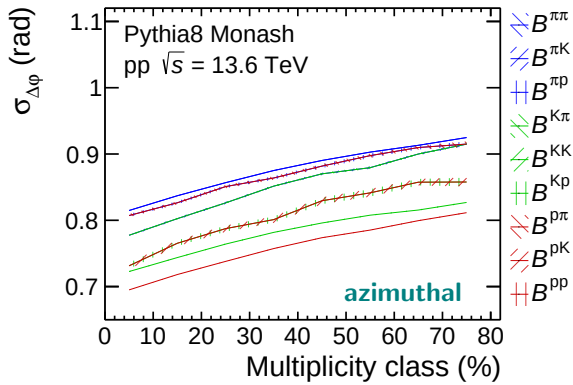


– **Charged K balancing redistribution**

Charge $B^{\alpha\beta}$ widths

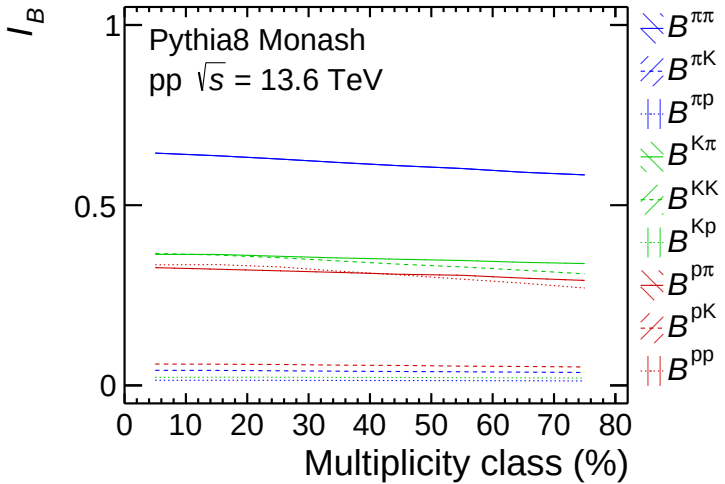
Pythia 8 Monash





– **Narrowing consistent with a radial expansion scenario**
– **No sign of two stages hadronization**

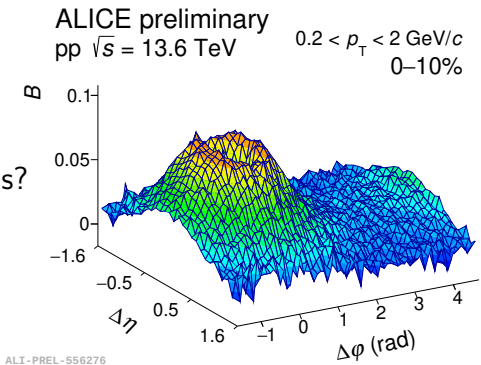
Charge $B^{\alpha\beta}$ integral evolution. Pythia 8 Monash



Balancing share (almost) independent of multiplicity

Conclusions and way forward

- **Balance function**
  - Robust to volume fluctuations observable
  - Clocking hadronization of different quantum numbers
  - Measure the balancing of quantum number production
- **Run 3 results**
  - Radial expansion scenario
  - Consistent with delayed hadronization
- **BF from identified particles**
  - Two stages hadronization in small systems?
  - DCC† and/or DIC‡ in small systems?
- **Stay tuned**



†**DCC**: disoriented chiral condensate
‡**DIC**: disoriented isospin condensate

Thank you!

Back up

Analysis configuration

- **Analysis period**: pp at $\sqrt{s} = 13.6$ TeV, 2022
- **Event selection**: MB
  - 70M selected events ($|z_{\mathrm{vtx}}| < 7$ cm)
- **Multiplicity estimator**: FT0M
  - Eight multiplicity classes: 0–10%, 10–20% . . . 70–80%
- **Track selection**: ITS+TPC tracks
  - $\mathrm{DCA}_z < 2$ cm
  - $\mathrm{DCA}_{xy} < 0.0105 + \frac{0.0350}{p_{\mathrm{T}}^{1.1}}$ cm ($2.16 - 0.27$ mm, p_{T} in GeV/c)
- **Kinematic range**
  - $|\eta| < 0.8$
  - $0.2 < p_{\mathrm{T}} < 2.0$ GeV/c