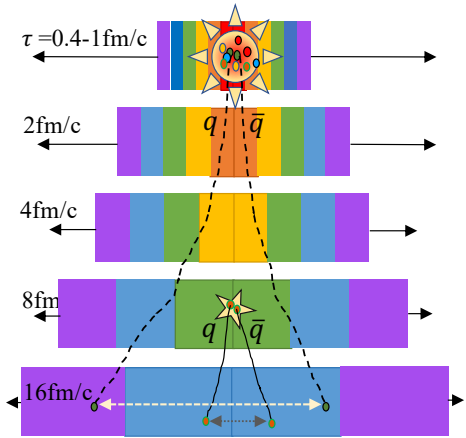
Clocking the particle production and tracking quantum numbers balance and radial flow effects at top LHC energy with ALICE

Victor Gonzalez, Wayne State University
on behalf of the **ALICE Collaboration**

High-energy hadronic collisions

- **Quantum numbers**
  - 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



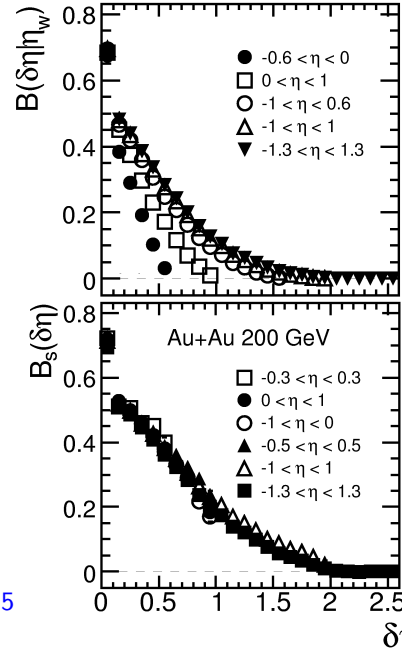
S.Basu, P.Christiansen, A.Ohlson, D.Silvermyr, EPJC **81** (2021) 11, 1024

Charge balance function

S.A.Bass, P.Danielewicz and S.Pratt,
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)

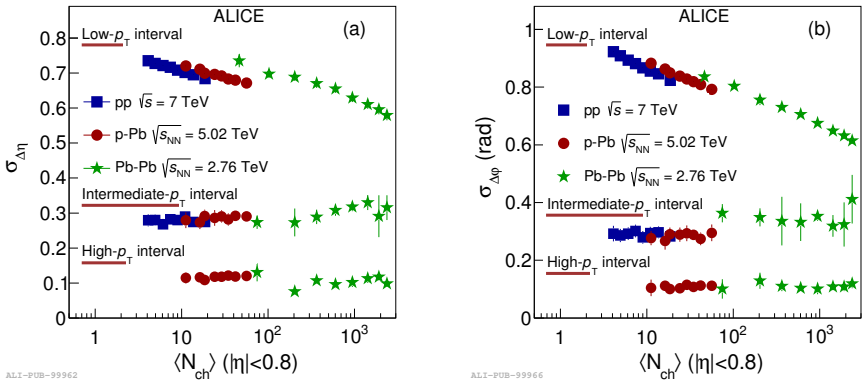


STAR, PRC **82** (2010) 024905

Charge balance function (unidentified particles)

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

σ: **width**



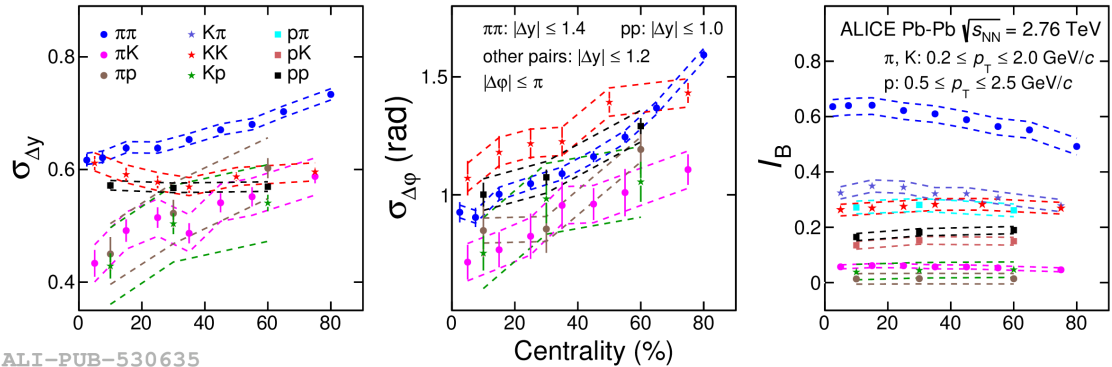
– **In the "bulk" regime different mechanism for Pb–Pb**

– **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**



ALI-PUB-530635

– 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**

Analysis goal

– **Balance function of identified particles**

- Hadronization of charged particles
- Tracking baryon hadronization
- Strangeness balancing

– **A better measure of EbyE fluctuations?**

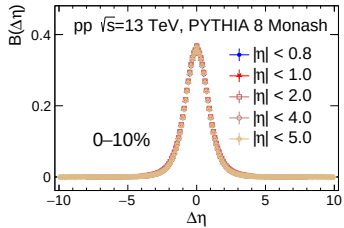
$$\nu_{\rm dyn}^{\alpha\beta} = -R_2^{\alpha\bar{\beta}} + R_2^{\bar{\alpha}\bar{\beta}} - R_2^{\bar{\alpha}\beta} + R_2^{\alpha\beta}$$

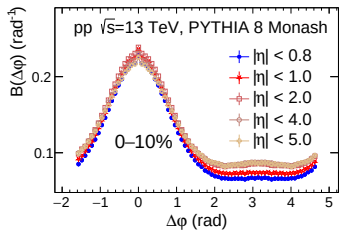
$$B^{\alpha\beta} = \frac{1}{2}\left\{\rho_1^{\bar{\beta}}\left[R_2^{\alpha\bar{\beta}} - R_2^{\bar{\alpha}\bar{\beta}}\right] + \rho_1^{\beta}\left[R_2^{\bar{\alpha}\beta} - R_2^{\alpha\beta}\right]\right\}$$

- 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 acceptance limitations

The balance function observable

– **Generalized definition**

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

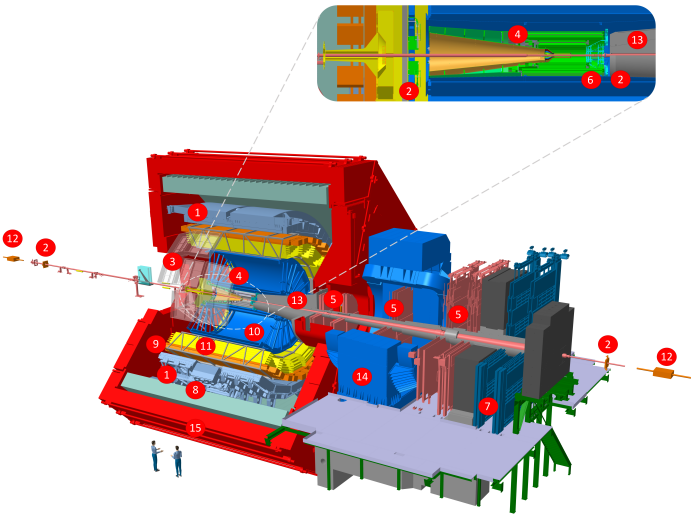
α, β: **realization of the quantum numbers of interest**

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

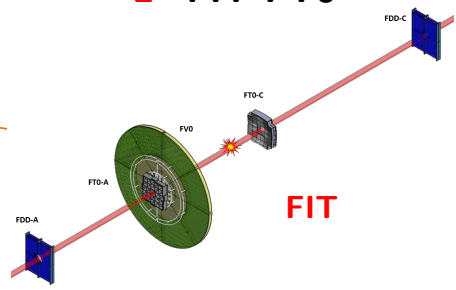
$$R_2^{\alpha\beta}(\Delta\eta,\Delta\varphi)=\frac{\langle n_2^{\alpha\beta}\rangle}{\langle n_1^{\alpha}\rangle\langle n_1^{\beta}\rangle}-1 \qquad \begin{cases}\rho_2^{\alpha\beta}=\dfrac{\mathrm{d}^2N^{\alpha\beta}}{\mathrm{d}\Delta\eta\,\mathrm{d}\Delta\varphi}\\ \rho_1^{\alpha}=\dfrac{\mathrm{d}^2N^{\alpha}}{\mathrm{d}\eta\,\mathrm{d}\varphi}\end{cases}$$

Automatically compensates for limited acceptance

The ALICE2 detector (LHC Run 3)

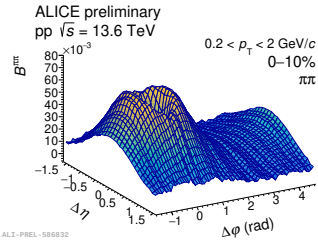


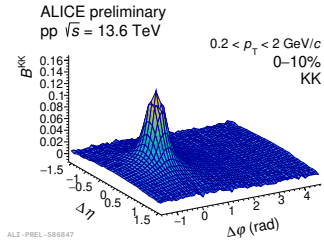
10 TPC
4 ITS
6 FIT-FV0
2 FIT-FT0

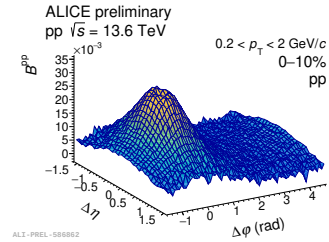


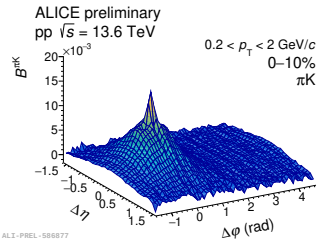
FIT

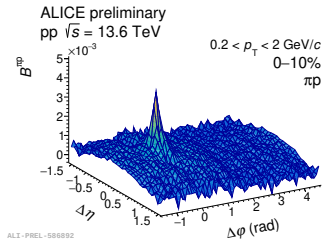
Charge $B^{\alpha\beta}$ of identified particles, 0–10%

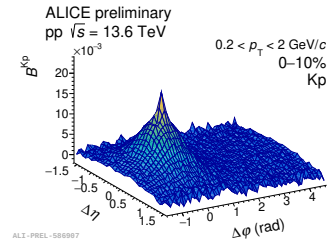




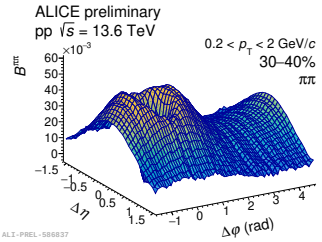


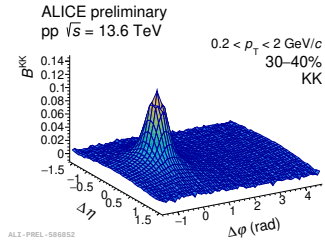


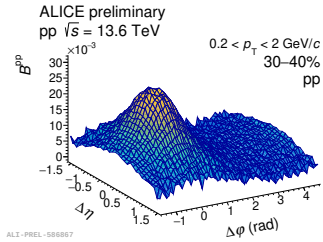


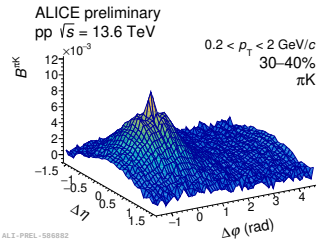


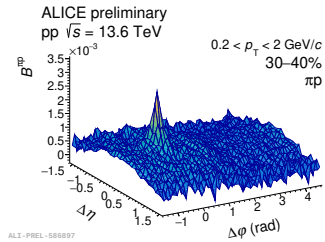
Charge $B^{\alpha\beta}$ of identified particles, 30–40%

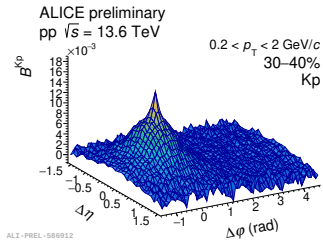




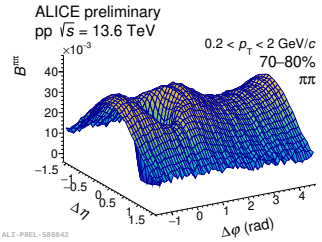


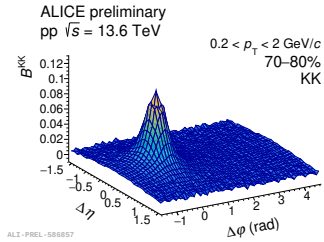


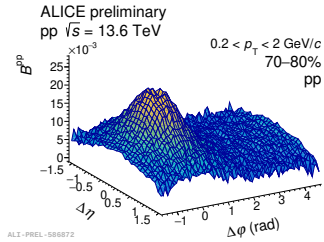


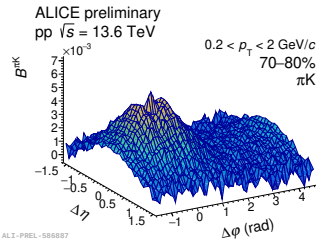


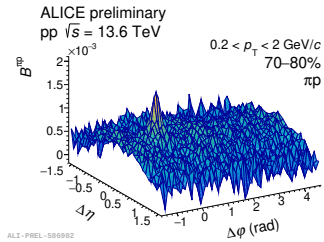
Charge $B^{\alpha\beta}$ of identified particles, 70–80%

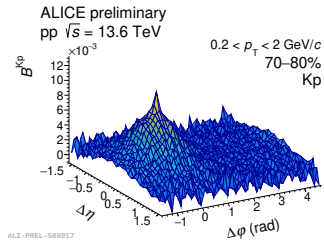






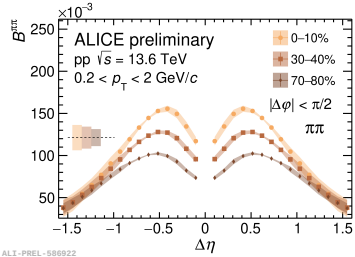


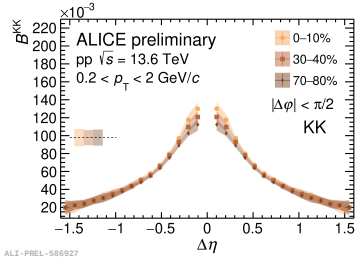


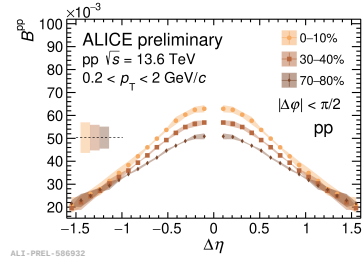


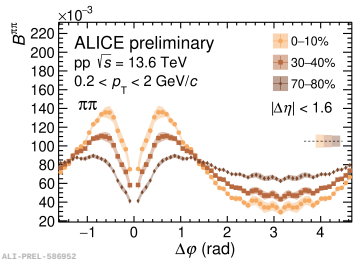
Charge $B^{\alpha\beta}$ of identified particles

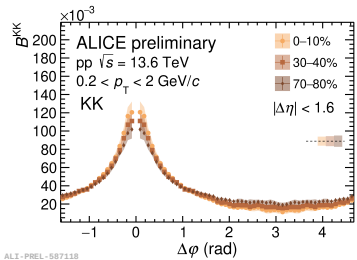
Projections. Same species

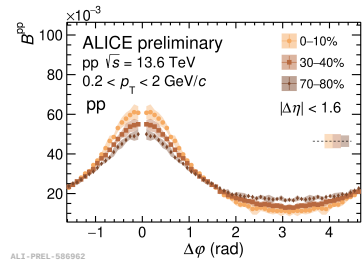






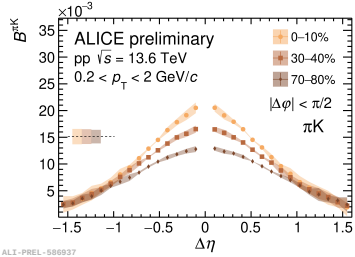


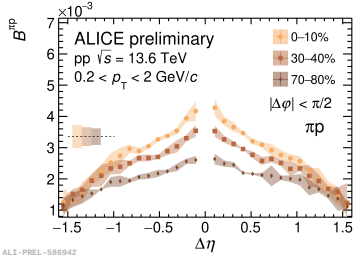


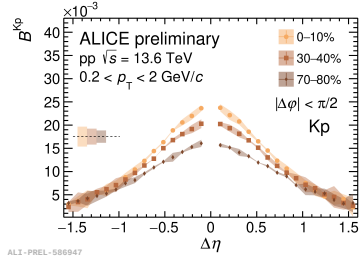


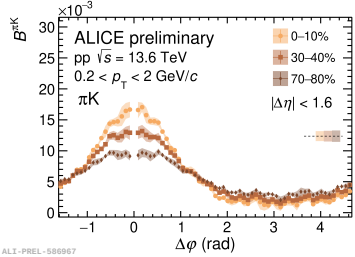
Charge $B^{\alpha\beta}$ of identified particles

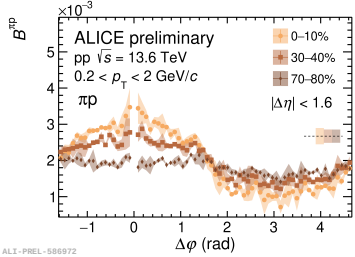
Projections. Cross species

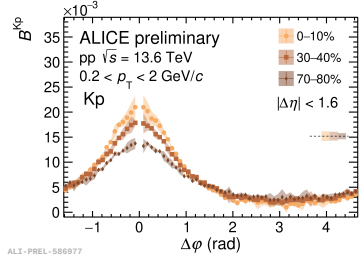






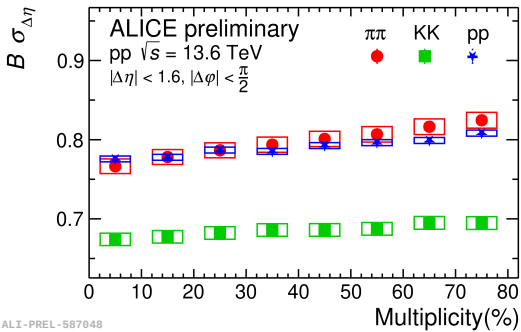


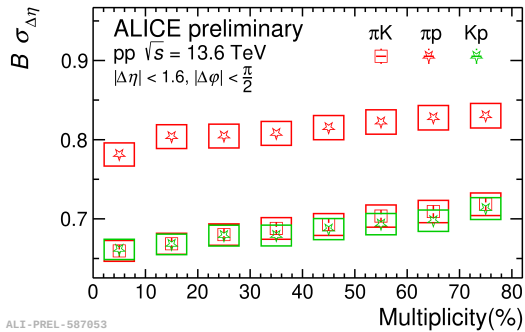




Charge $B^{\alpha\beta}$ of identified particles

Longitudinal width evolution with multiplicity

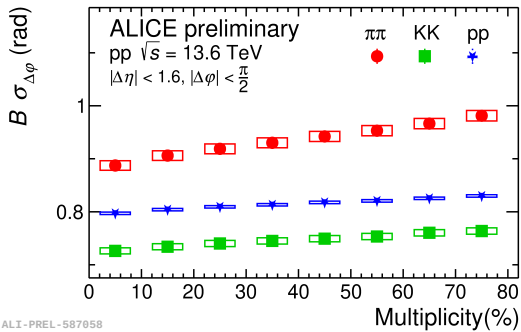


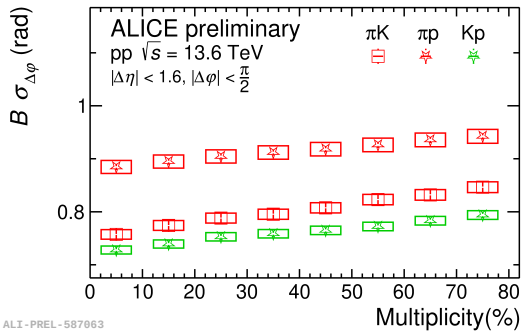


- Widths extracted as the RMS on the near-side peak
- **Strangeness enforces its width**
- **Same species (left), cross species (right)**

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

Azimuthal widths evolution with multiplicity

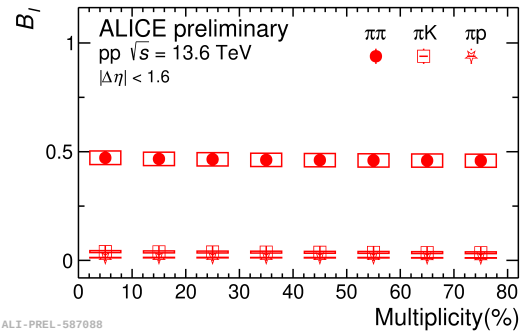


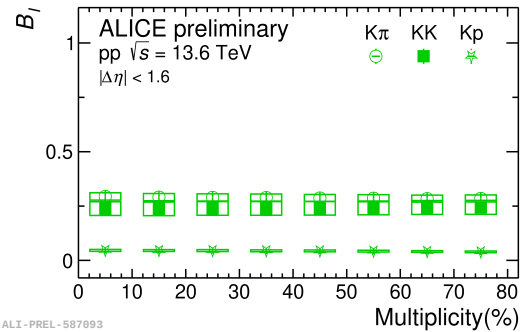


- Widths extracted as the RMS on the near-side peak
- **Ordering but not mass based**
- **Same species (left), cross species (right)**

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

π (left) K (right) charge balancing

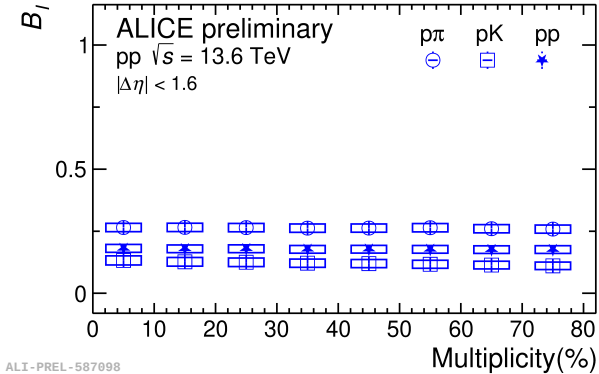




- **Balancing share not multiplicity dependent**
- **With complete acceptance, 4π, it should add up to one**
  (C.Pruneau, VG, B.Hanley, A.Marin, S.Basu, PRC **107** (2023) 5, 054915)

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

p charge balancing



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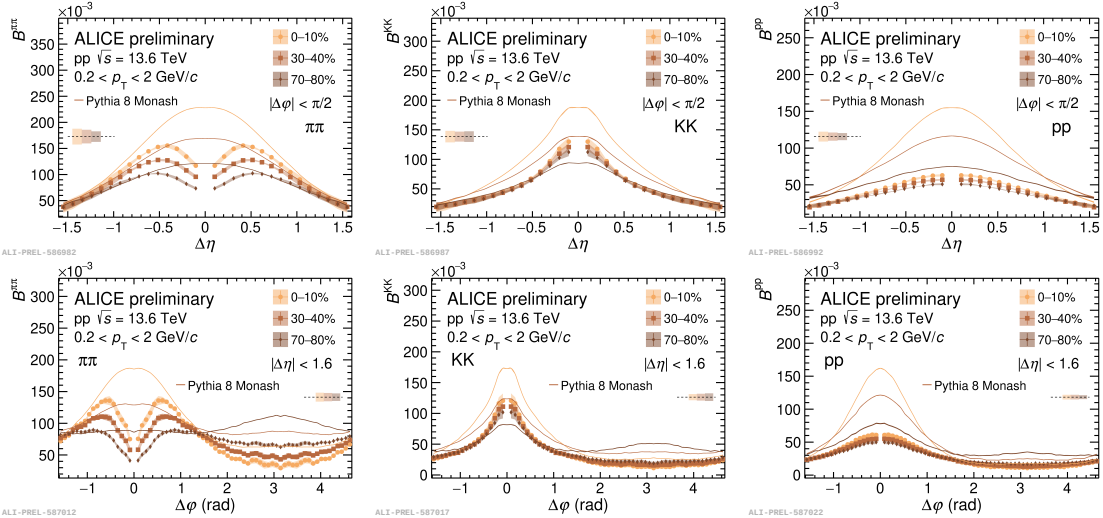
Model comparison

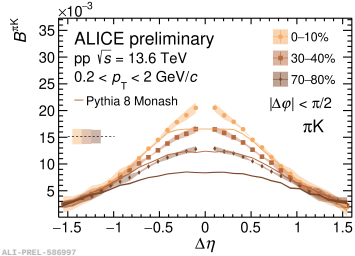
Charge $B^{\alpha\beta}$ of identified particles

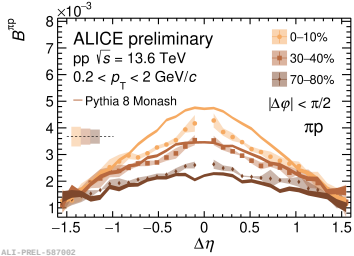
Projections. Same species

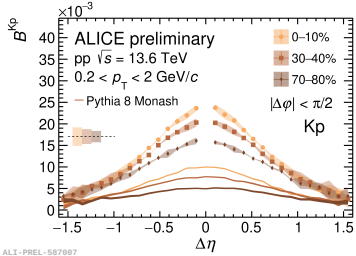


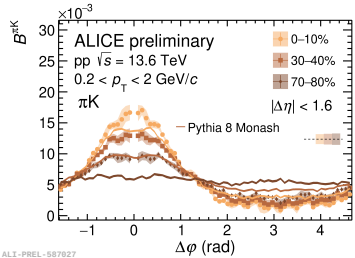
Charge $B^{\alpha\beta}$ of identified particles

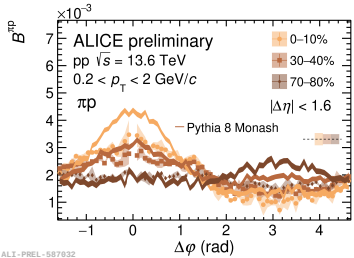
Projections. Cross species

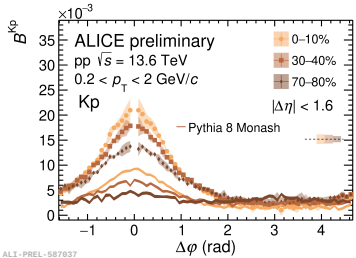






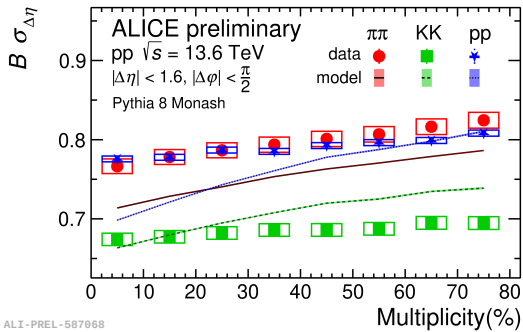


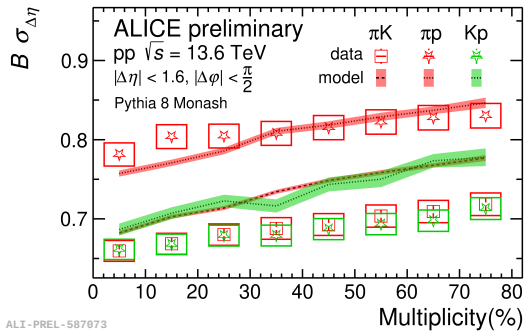




Charge $B^{\alpha\beta}$ of identified particles

Longitudinal width evolution with multiplicity

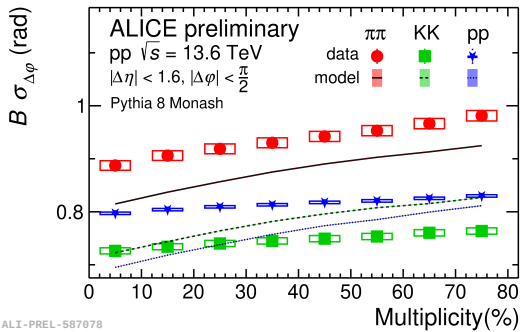


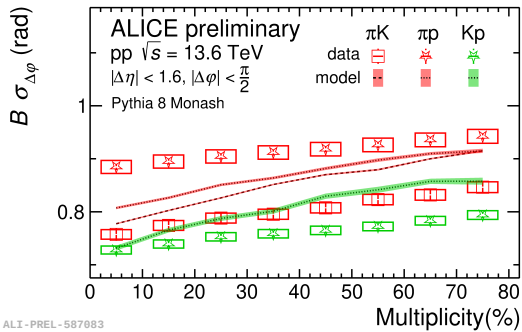


- **Model predicts the strangeness drive but only qualitatively**
- **Model predicts stronger narrowing**
- **Same species (left), cross species (right)**

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

Azimuthal widths evolution with multiplicity

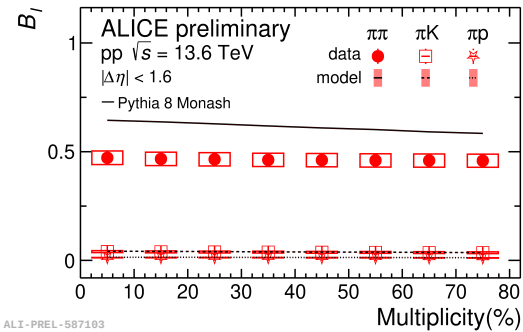


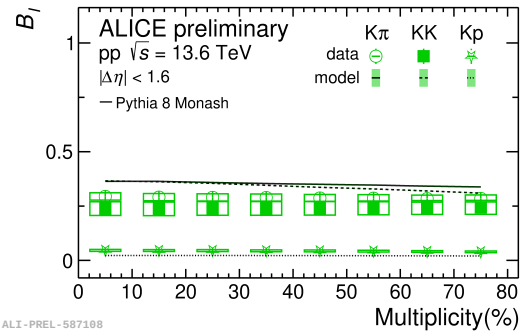


- **Model does not preserve the same species ordering**
- **Model predicts stronger narrowing**
- **Same species (left), cross species (right)**

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

π (left) K (right) charge balancing



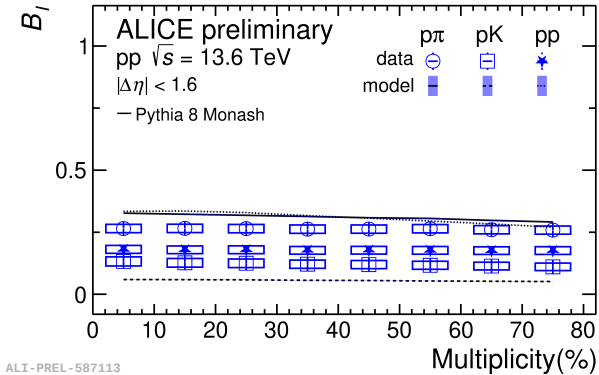


– **Rebalancing towards the away side probably drives the multiplicity dependence shown by model**

– **Unequal balancing reproduction although right fraction order**

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

p charge balancing



– **Rebalancing towards the away side probably drives the multiplicity dependence shown by model**

– **Balance fraction not reproduced**

Concluding

- **General and charge $B^{\alpha\beta}$**
  - Is there any sign of two stages hadronization?
    - Longitudinally, strangeness imposes its width
    - Azimuthally, ordering
  - Is the balancing share multiplicity dependent?
    - No, it is not!
- **Baryon B^{pp}**
  - The balancing share for protons is the same for charge as for baryon number
- **Strangeness B^{KK}**
  - The balancing share for kaons is the same for charge as for strangeness

Concluding

- **General and charge $B^{\alpha\beta}$**
  - Is there any sign of two stages hadronization?
    - Longitudinally, strangeness imposes its width
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  - The balancing share for kaons is the same for charge as for strangeness

Thank you!