Probing QGP formation in pp collisions with Balance Functions

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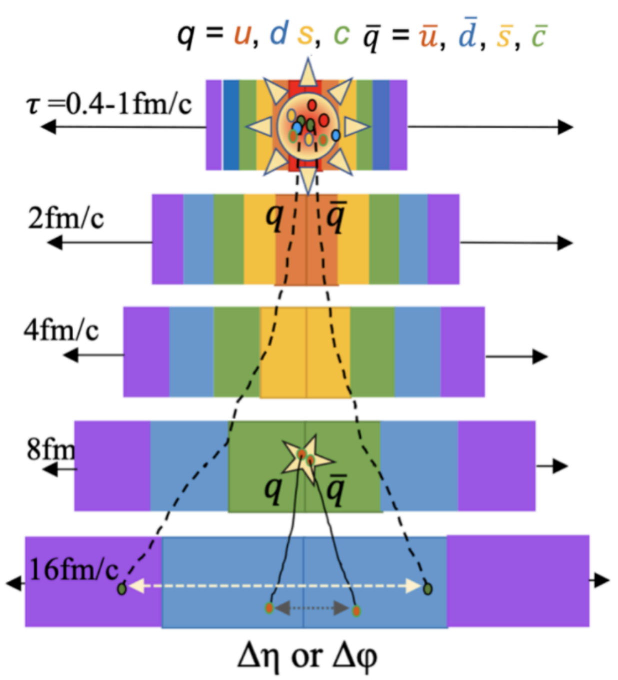
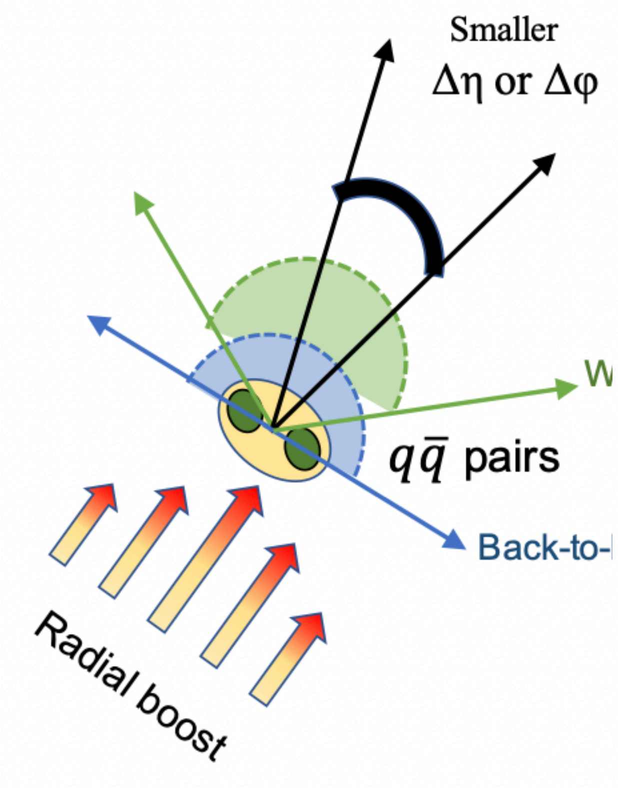
XVII Workshop on Particle Correlations and Femtoscopy

Clocking hadronization

Difference in conditional densities

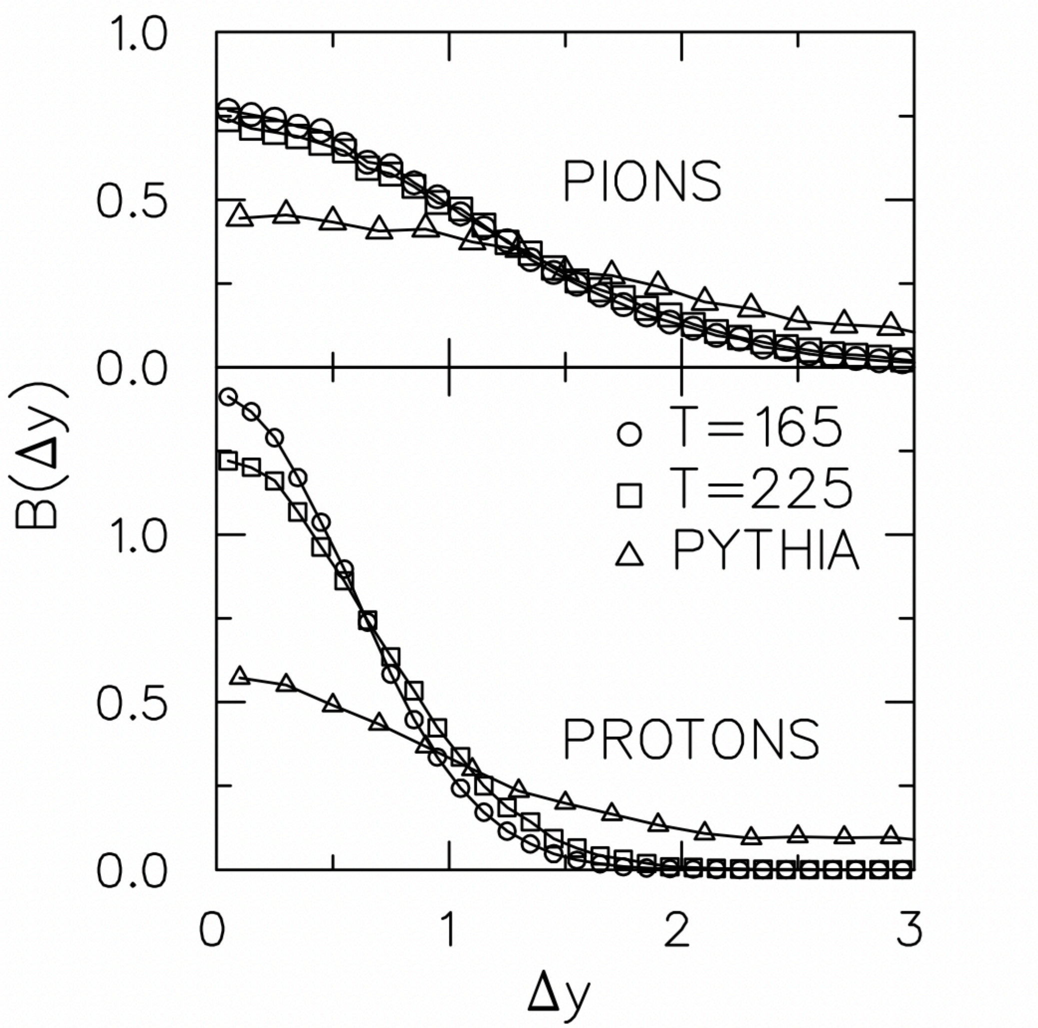
$$B(\Delta\eta, \Delta\varphi) \equiv \frac{1}{2}\left(\frac{\rho_2^{+-} - \rho_2^{--}}{\rho_1^{-}} + \frac{\rho_2^{-+} - \rho_2^{++}}{\rho_1^{+}}\right)$$





arXiv:2110.05134 **[hep-ph]**

Bass, Danielewicz, Pratt, PRL 85, 2689 (2000)



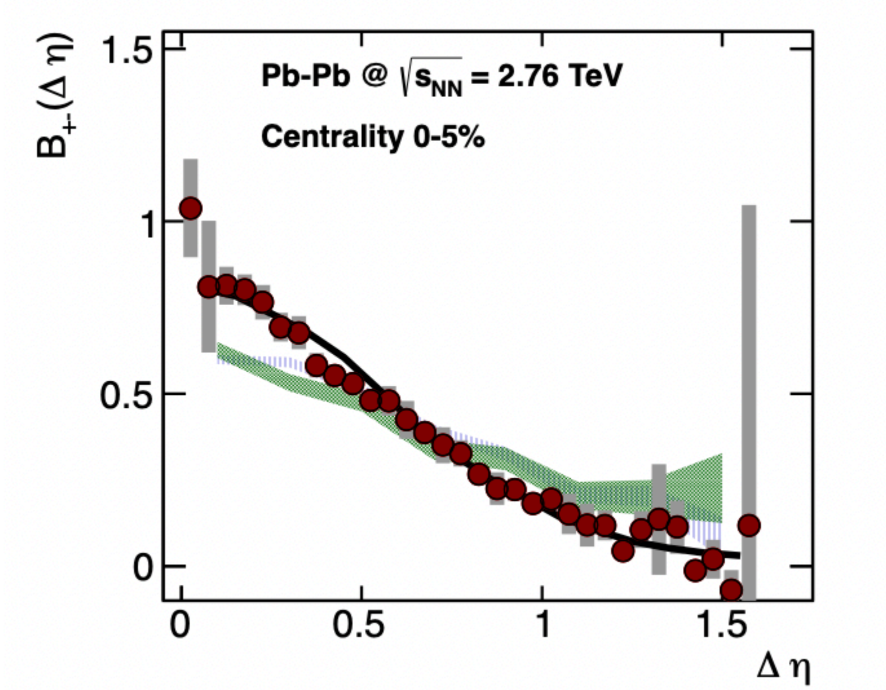
Measurement of correlations of charges with their respective anti-charge

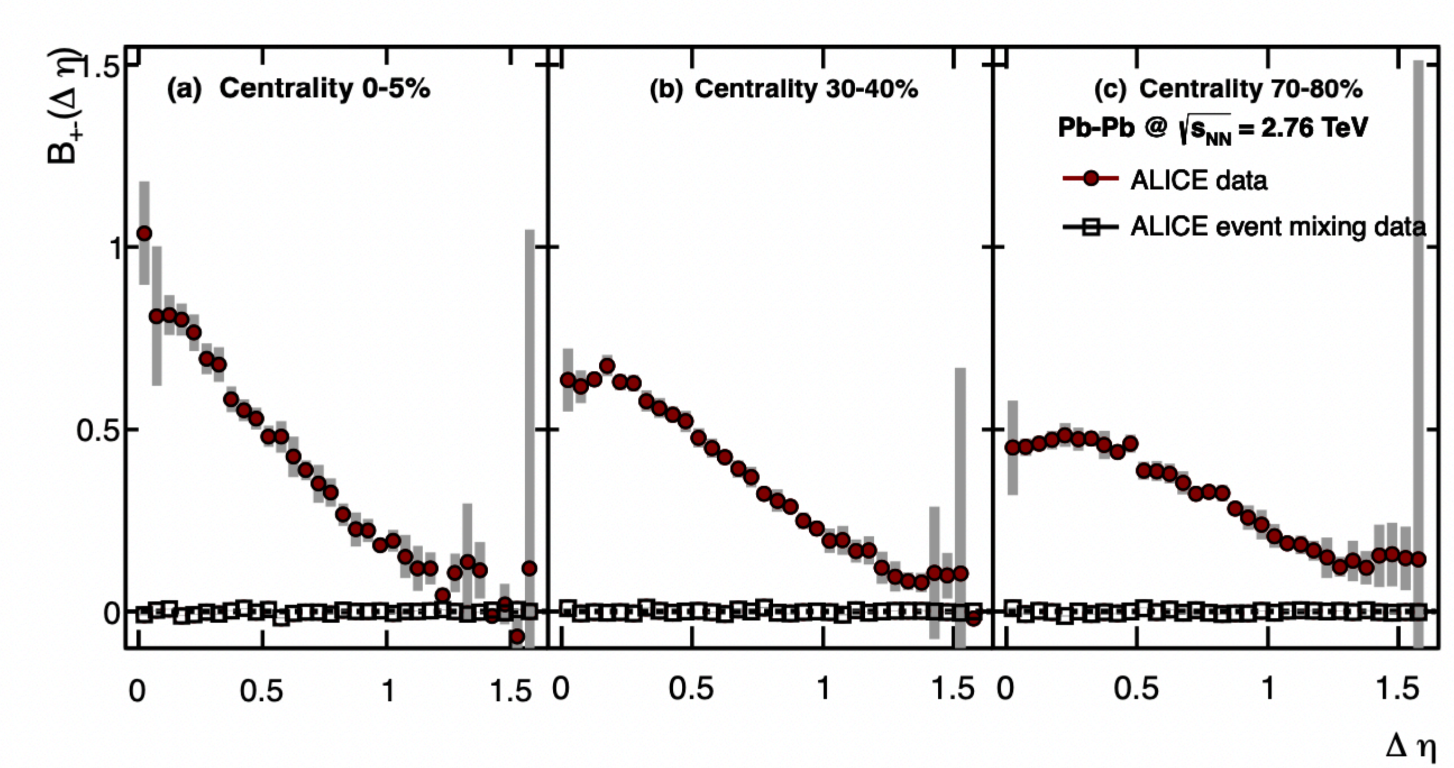
Investigate late-stage hadronization and formation of quark-gluon plasma

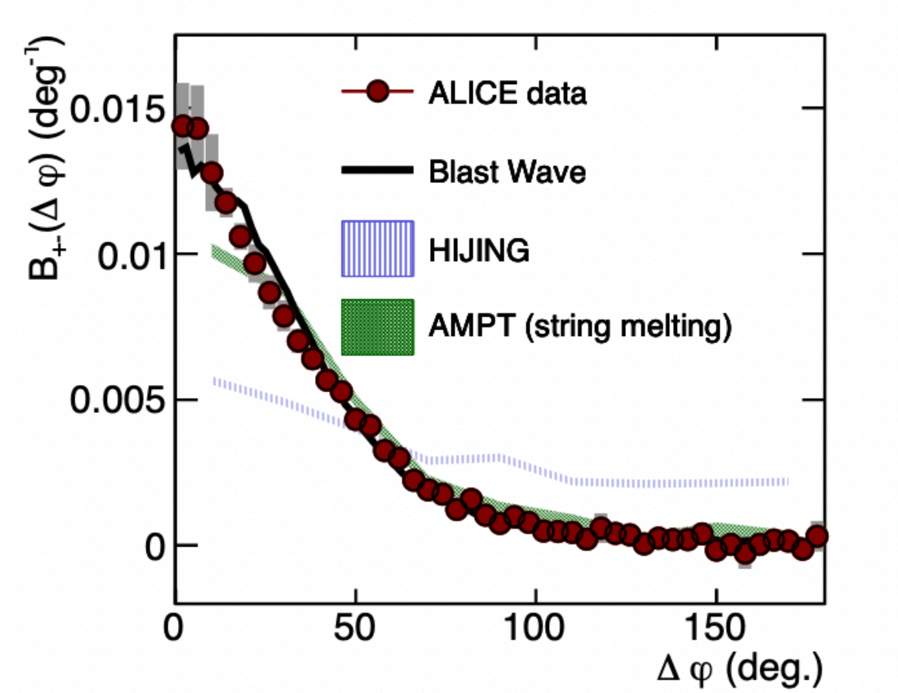
Balance function at ALICE and STAR

arXiv:1509.07255 **[nucl-ex]**
arXiv:1301.3756 **[nucl-ex]**

- Balance function reproduced by models with hydro evolution of medium
- Do correlations survive in thermal models as in QCD string ones?







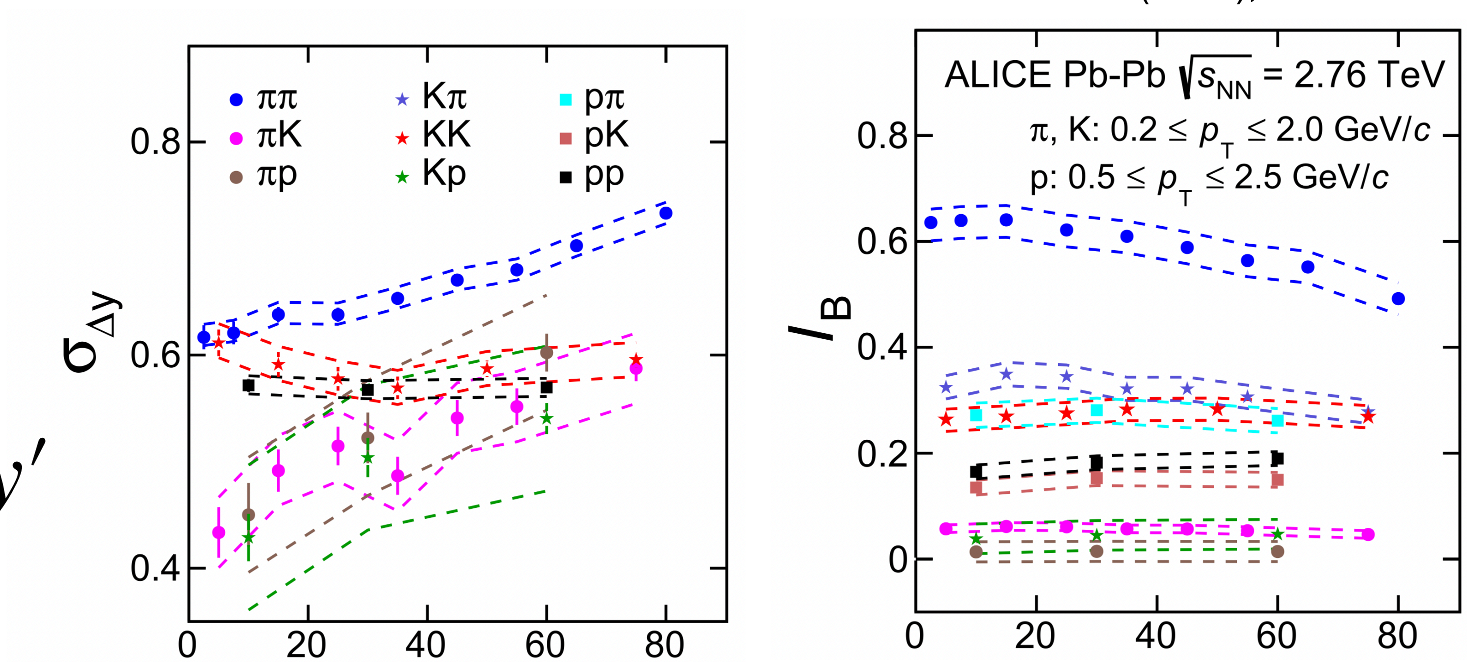
Integrals of Balance Function

- Balancing of charges almost independent of collision centrality in data mesurements of Pb-Pb collisions

- Cumulative integral of balance function

$$I^{\alpha\bar{\beta}} = \int_{\Delta y} B^{\alpha\bar{\beta}}(\Delta y')d\Delta y'$$

ALICE PLB 833 (2022), 137338



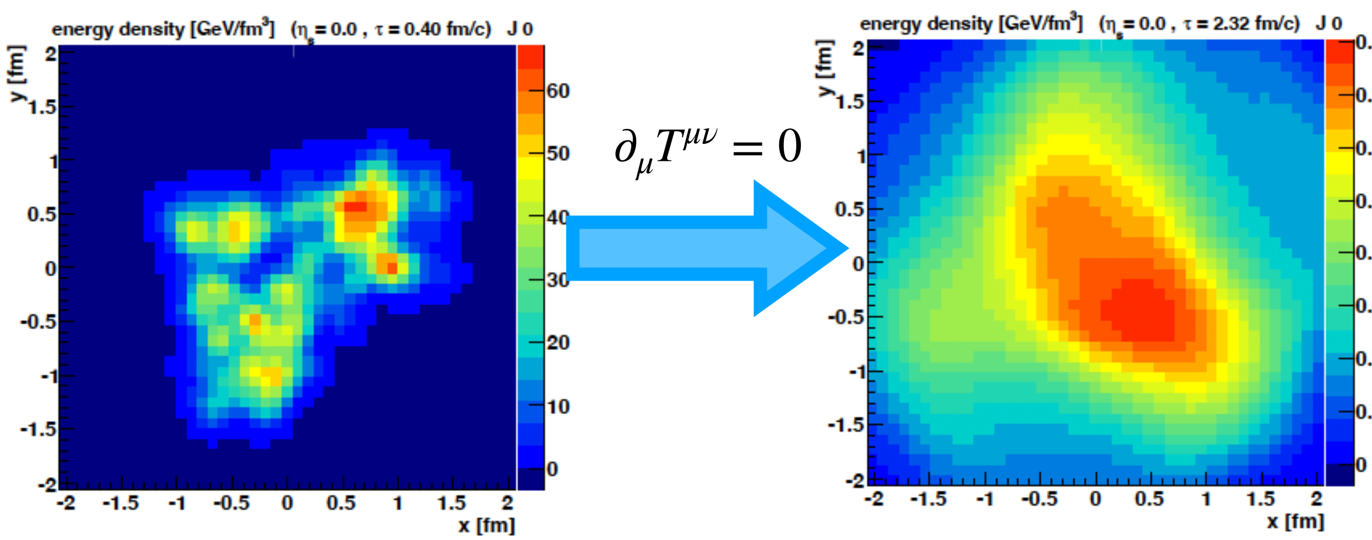
In full acceptance $I^{\alpha\beta}(4\pi) \rightarrow 1$

In finite acceptance it shows the degree to which charges are balanced -> affected by production and transport

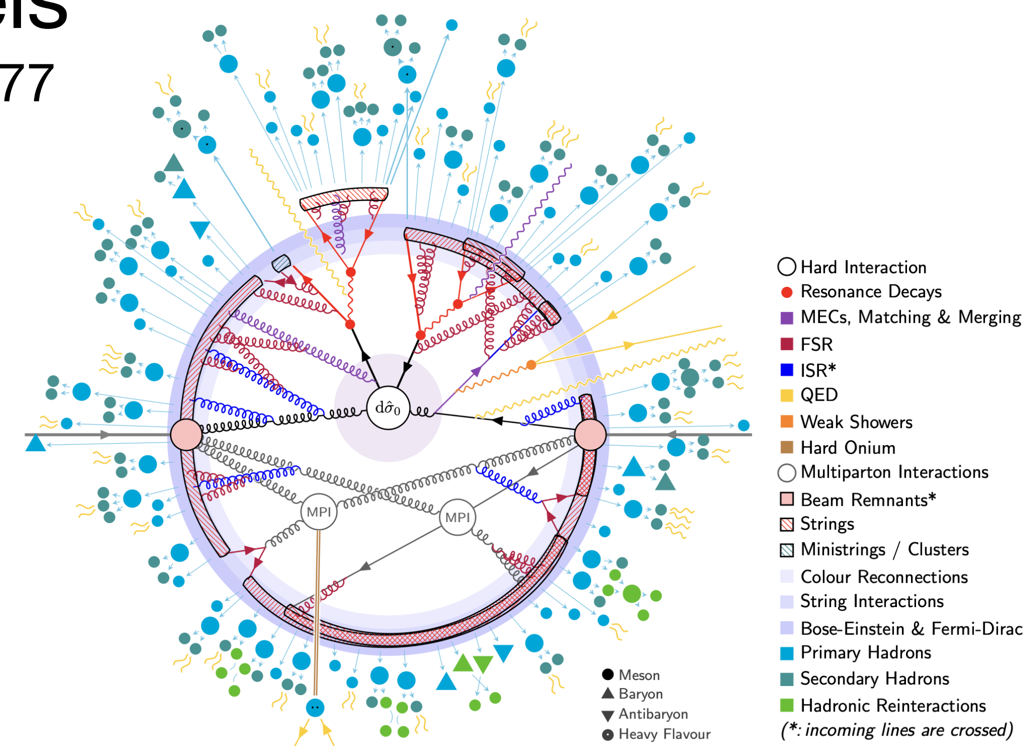
Monte Carlo Models

We look at two state of the art models

K. Werner, arXiv: 2306.10277



C. Bierlich et al., arXiv: 2203.11601



- Macroscopic model:EPOS4
  - Core-corona model with statistical hadronization
  - Core is micro-canonical and conserves charges

- Microscopic model:PYTHIA8
  - QCD strings with LUND fragmentation
  - Implicit quantum number conservation

Difference in particle production mechanisms and system evolution results in different correlations

Generalized Balance Functions

General Balance Function definition arXiv:2209.10420 **[hep-ph]**

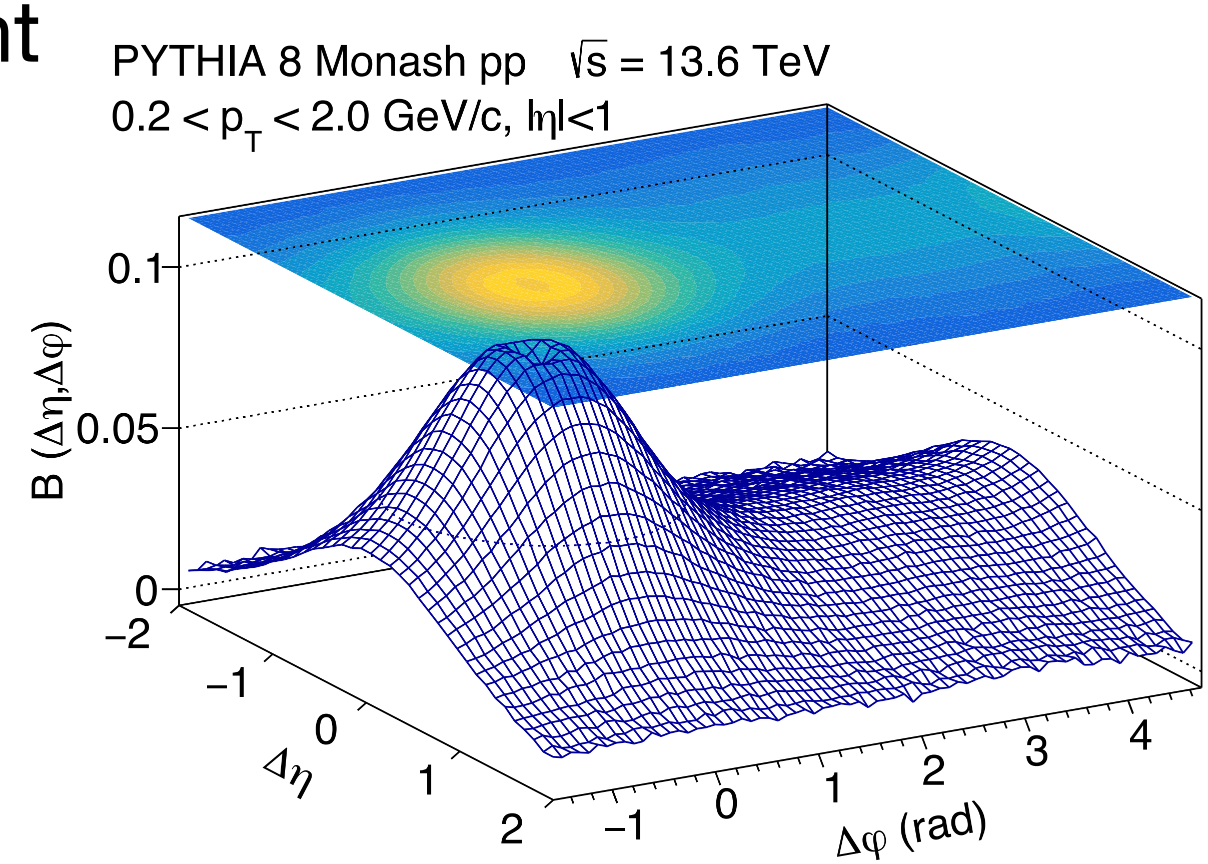
$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}\{\rho_1^{\bar{\beta}}(R_2^{\alpha\bar{\beta}} - R_2^{\bar{\alpha}\bar{\beta}}) + \rho_1^{\beta}(R_2^{\bar{\alpha}\beta} - R_2^{\alpha\beta})\}$$

Normalized second order cumulant

$$R_2^{\alpha\beta}(\Delta\eta, \Delta\varphi) = \frac{\rho_2^{\alpha\beta}(\Delta\eta, \Delta\varphi)}{\rho_1^{\alpha}\rho_1^{\beta}} - 1$$

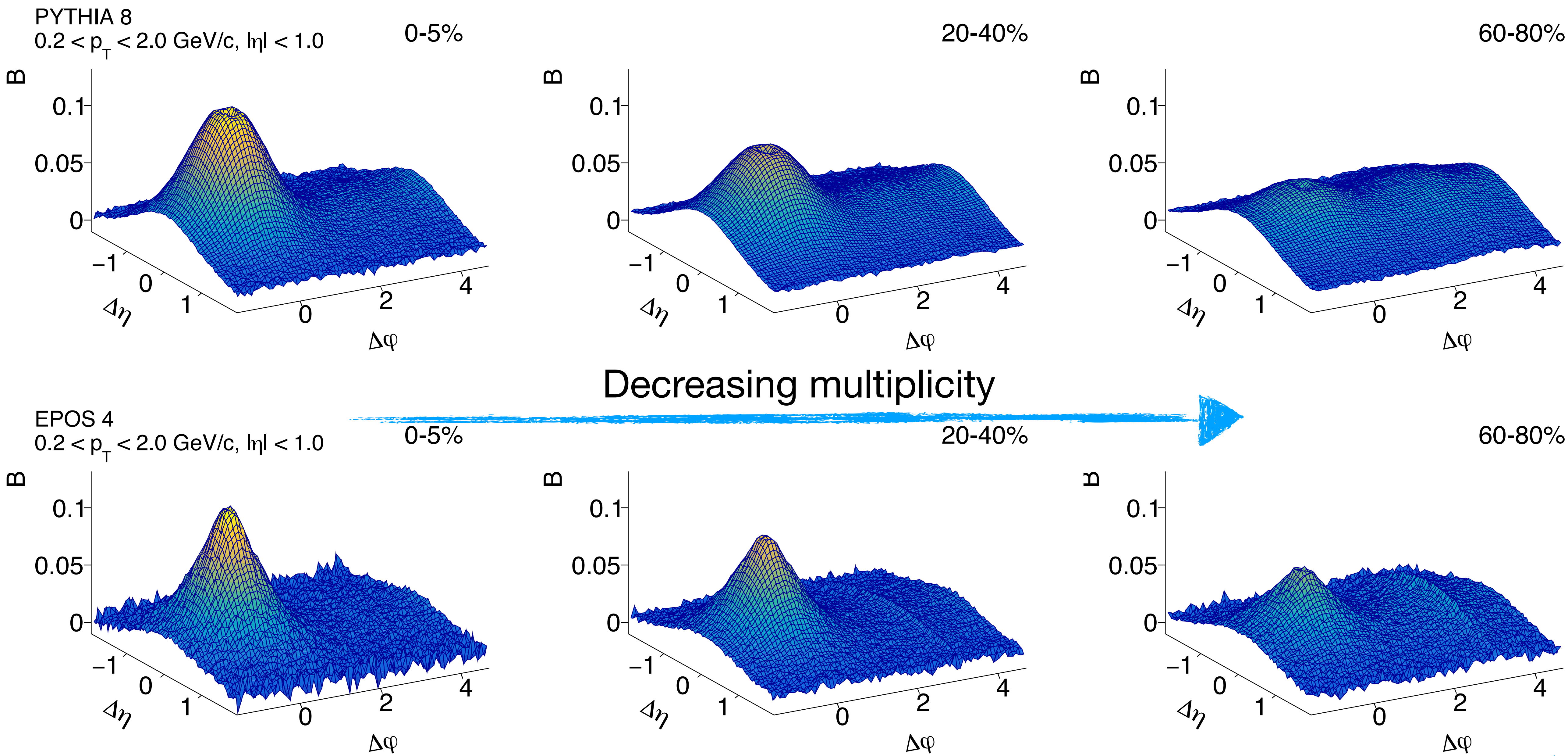
$$\rho_2^{\alpha\beta} = \frac{d^2N^{\alpha\beta}}{d\Delta\eta d\Delta\varphi}$$

$$\rho_1^{\alpha} = \frac{d^2N^{\alpha}}{d\eta d\varphi}$$



This method is not affected by acceptance factors and robust against efficiency corrections

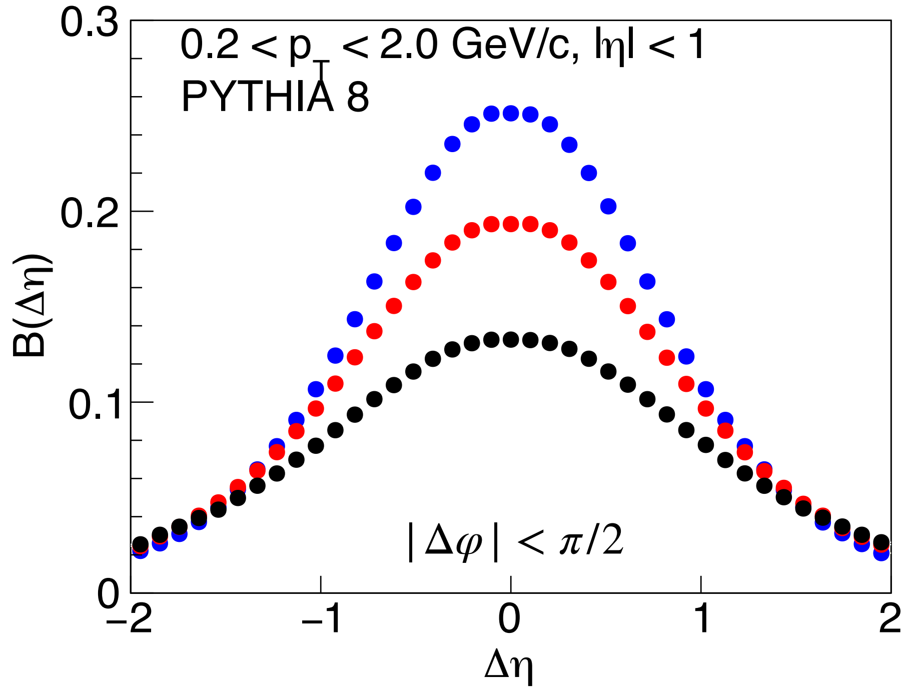
Charge Balance Function

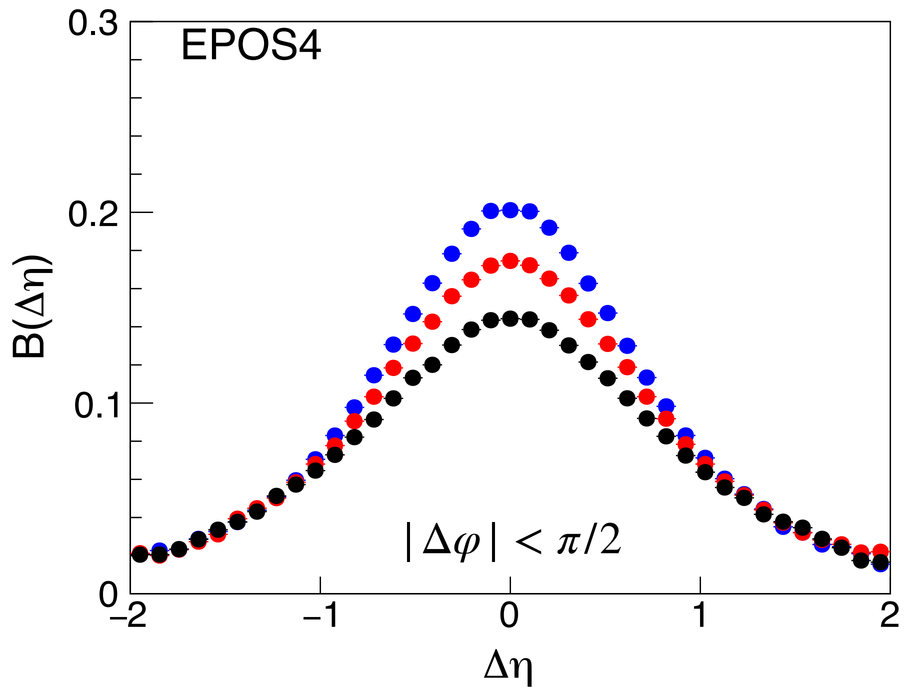


- Near side peak of PYTHIA shows decay contribution
- Very peculiar correlation in away side for EPOS

Strong dependence of multiplicity for both models

Projections of Charge BF

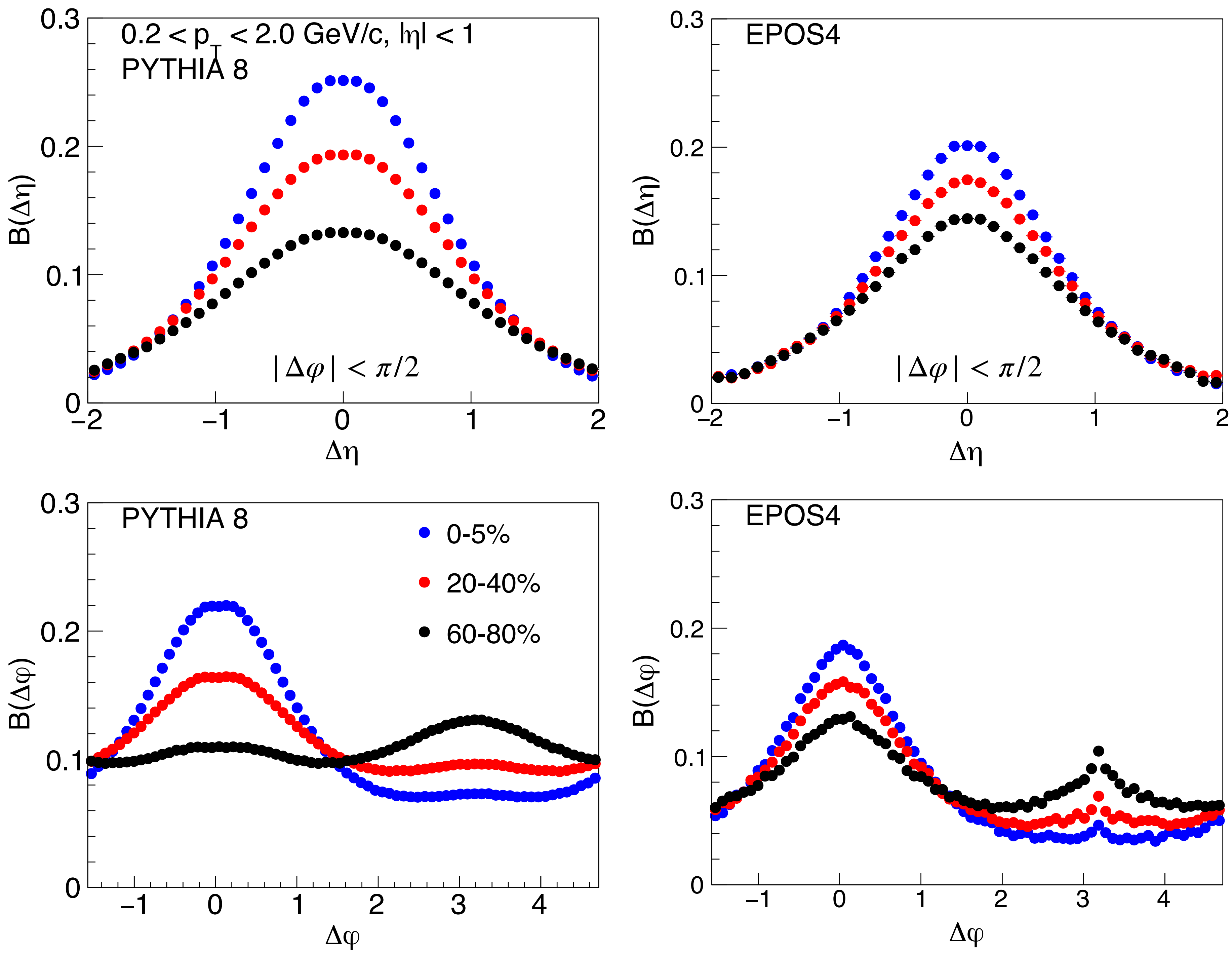




Scaling of near side peak is different

Widths of projections are similar but evolve differently with multiplicity

Projections of Charge BF



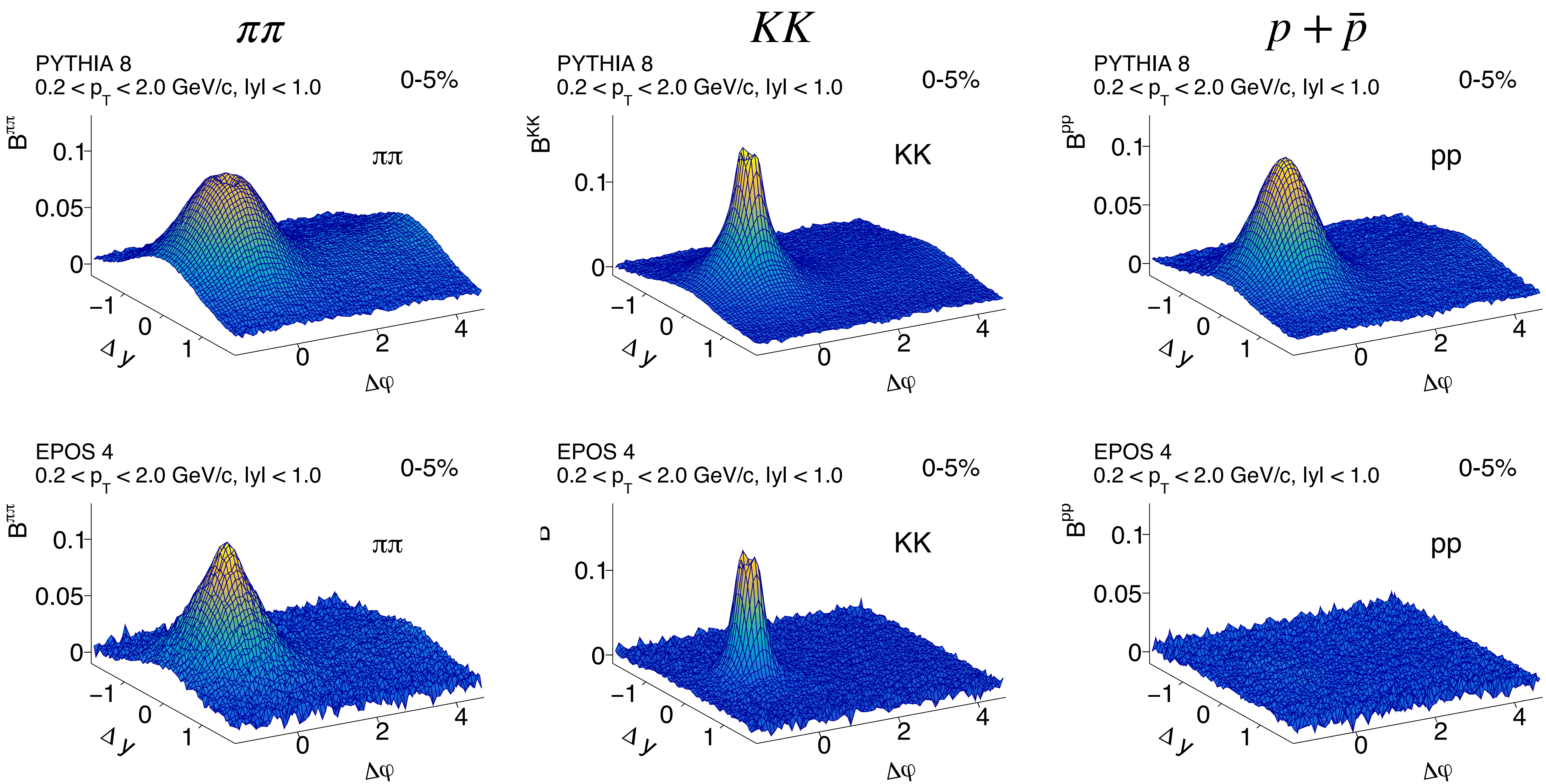
Scaling of near side peak is different

Widths of projections are similar but evolve differently with multiplicity

Unexpected structure in away side seen in EPOS -> depends on multiplicity

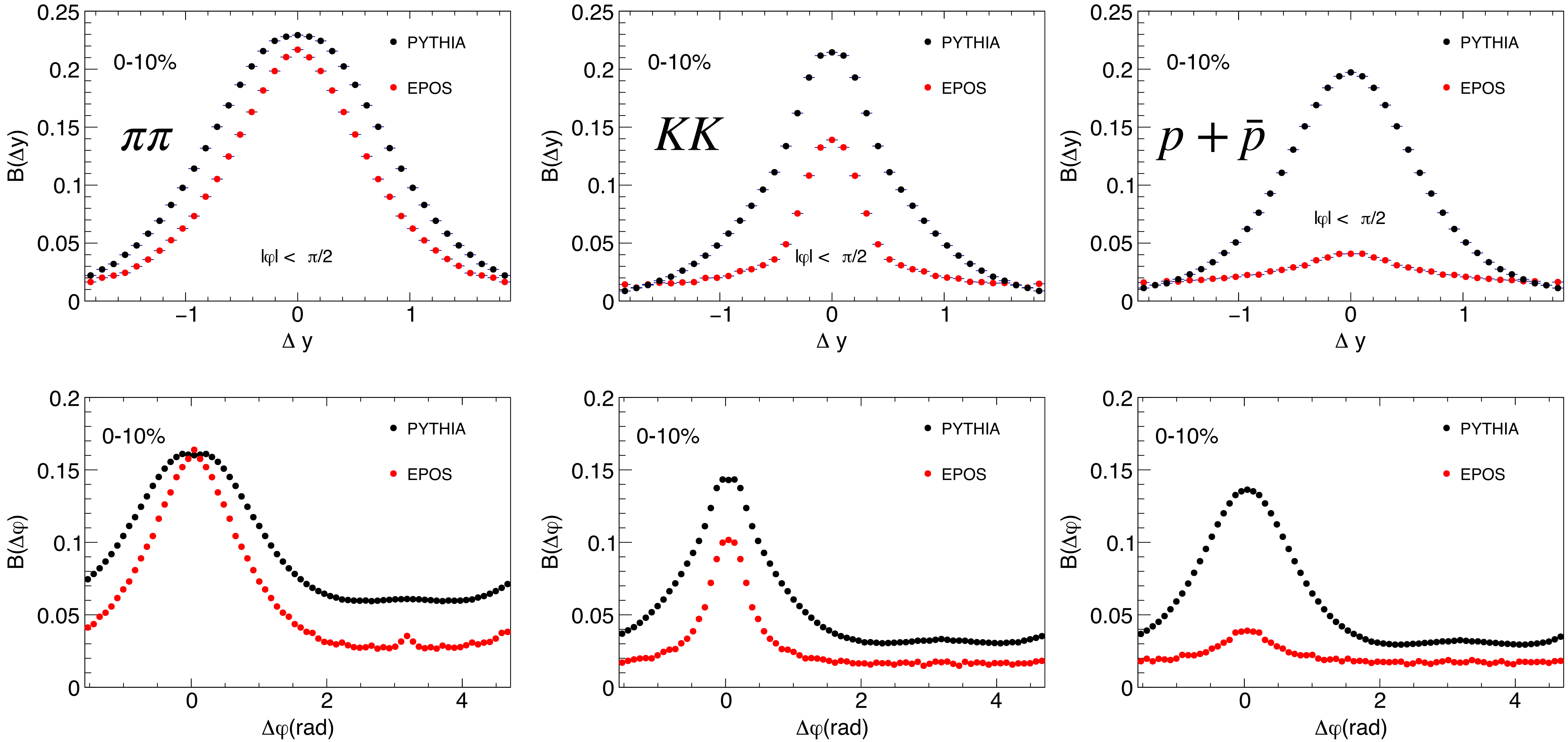
Impact of micro-canonical decay in EPOS?

Identified Particle BF



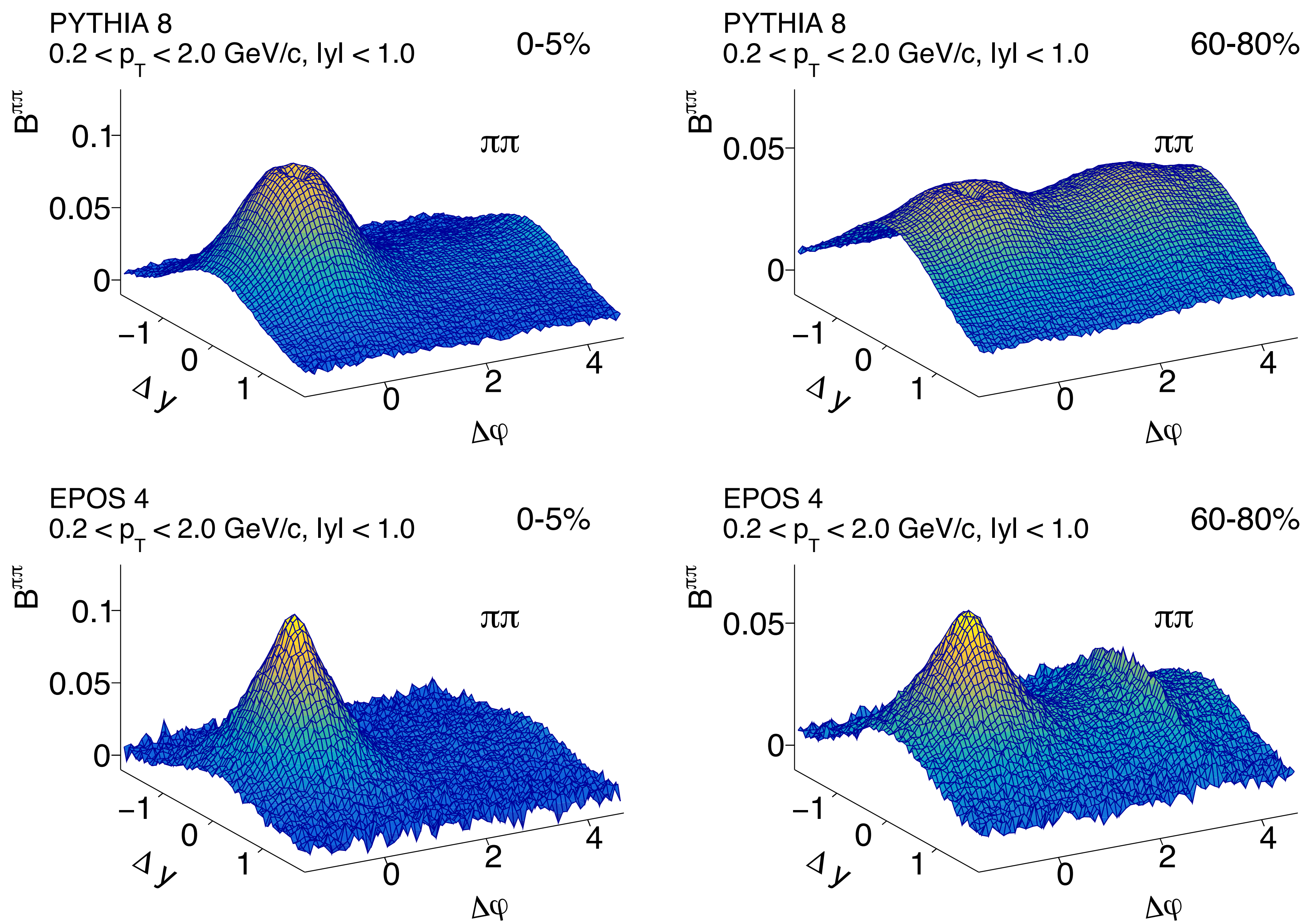
Particle balancing shows underlying production mechanisms

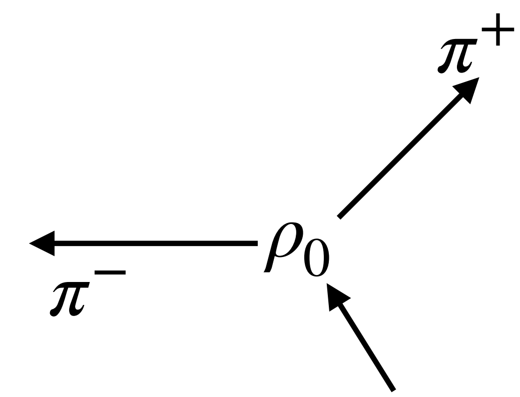
Identified Particle BF



- Essentially flat away side for kaons and protons in EPOS
- Proton balancing shows divergence of models for baryon balancing

$\pi\pi$ balance with multiplicity



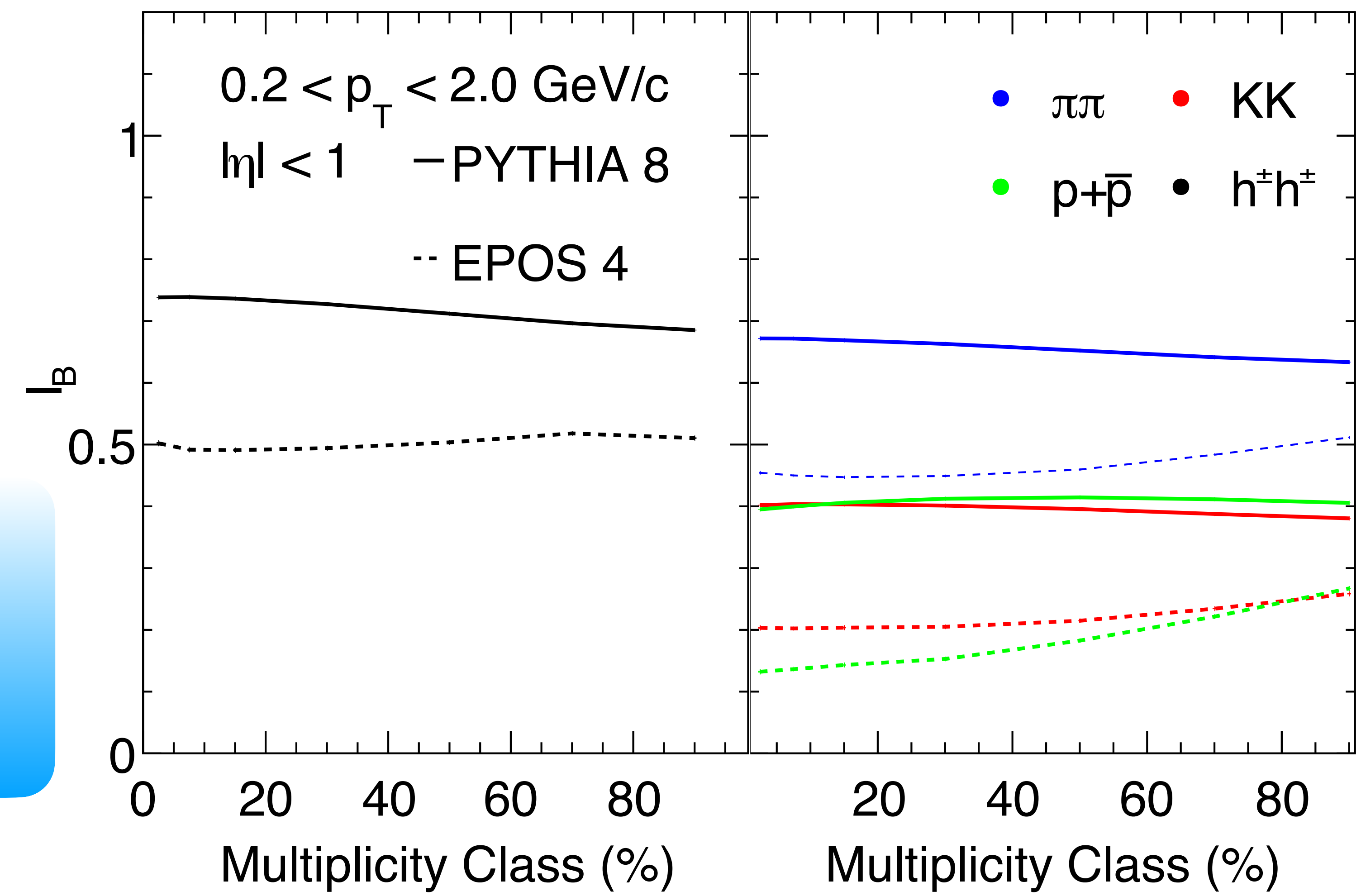


- Anti-correlation for pions in low multiplicity collisions
- EPOS increases correlation strength in the away side

Integrals of Balance Function

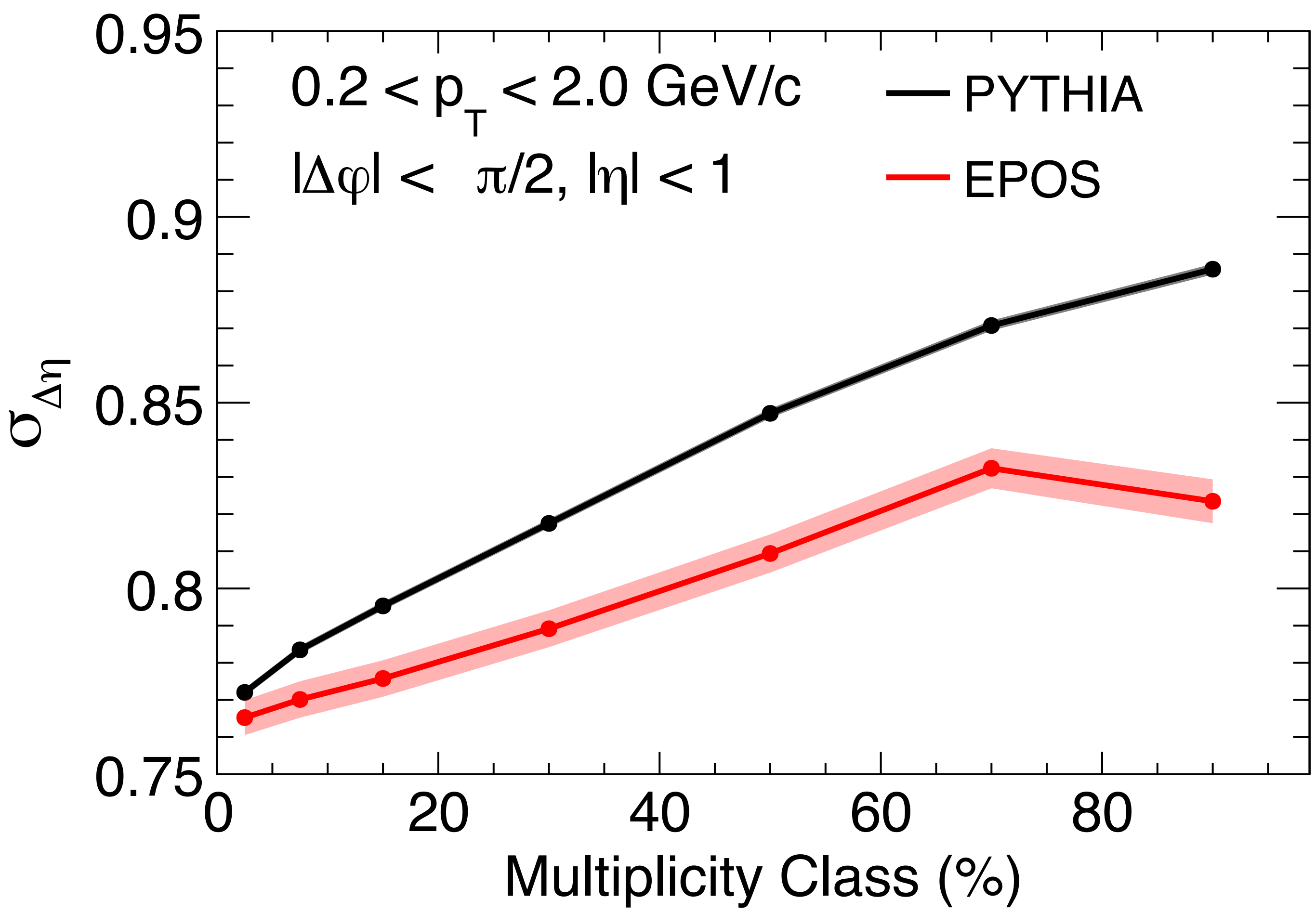
- Cumulative integral of balance function

$$I^{\alpha\bar{\beta}} = \int_{\Delta y} B^{\alpha\bar{\beta}}(\Delta y')d\Delta y'$$



- Charged particles almost independent of collision multiplicity
- Different balancing trends for PYTHIA and EPOS with growing multiplicity

Longitudinal width of charge BF



$$\sigma^2_{\Delta\eta} = \frac{\sum_{i,j} [O(\Delta\eta_i, \Delta\varphi_j) - O_{offset}]\Delta\eta_i^2}{\sum O(\Delta\eta_i, \Delta\varphi_j)}$$

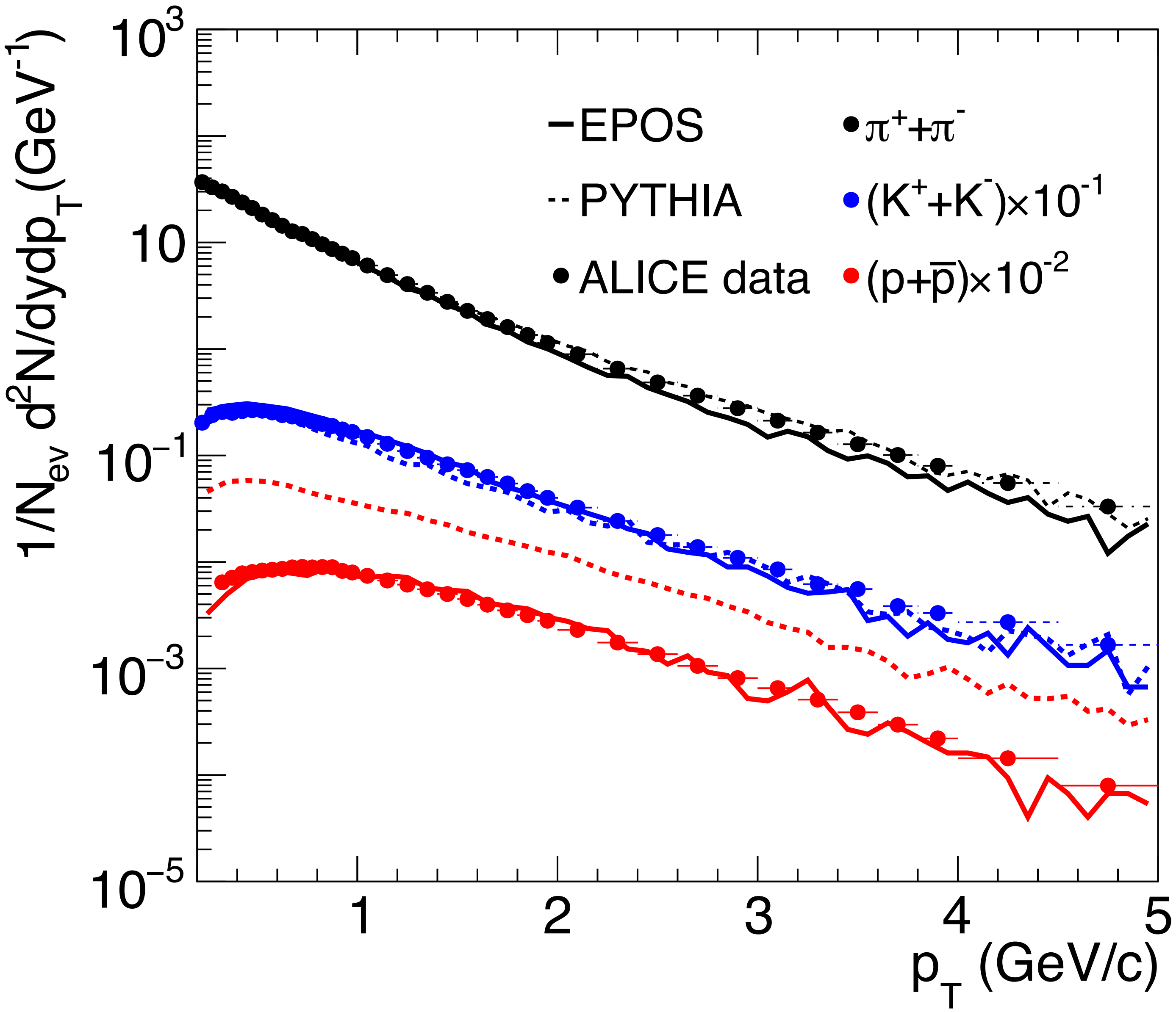
- Width evolution with multiplicity is showing unexpected trend in PYTHIA

- Widths estimate the near side peak

Summary

- Different models can be distinguished from balance function measurements
- Evidence for different decay mechanisms
- Opposite trends for integrals
- Extensive measurements of balance functions can improve models

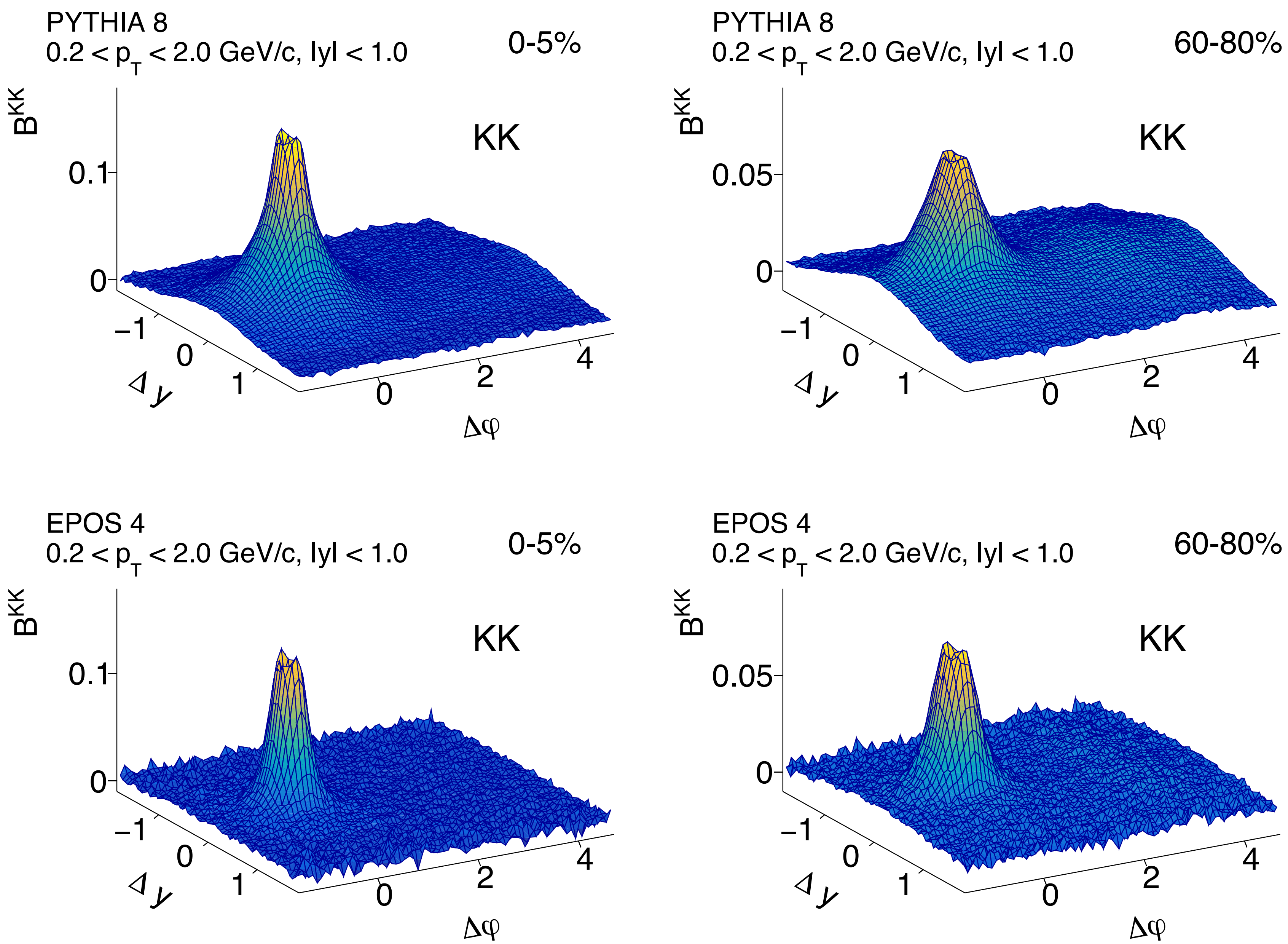
Back-up



Multiplicity Class	$\langle p_T \rangle$		$\sigma_{\Delta\eta}$ (GeV/c)	
Model	PYTHIA	EPOS	PYTHIA	EPOS
0-5%	0.680	0.688	0.772	0.765
5-10%	0.669	0.671	0.783	0.770
10-20%	0.655	0.659	0.795	0.775
20-40%	0.627	0.638	0.817	0.789
40-60%	0.592	0.597	0.847	0.809
60-80%	0.564	0.556	0.870	0.832
80-100%	0.547	0.533	0.885	0.823

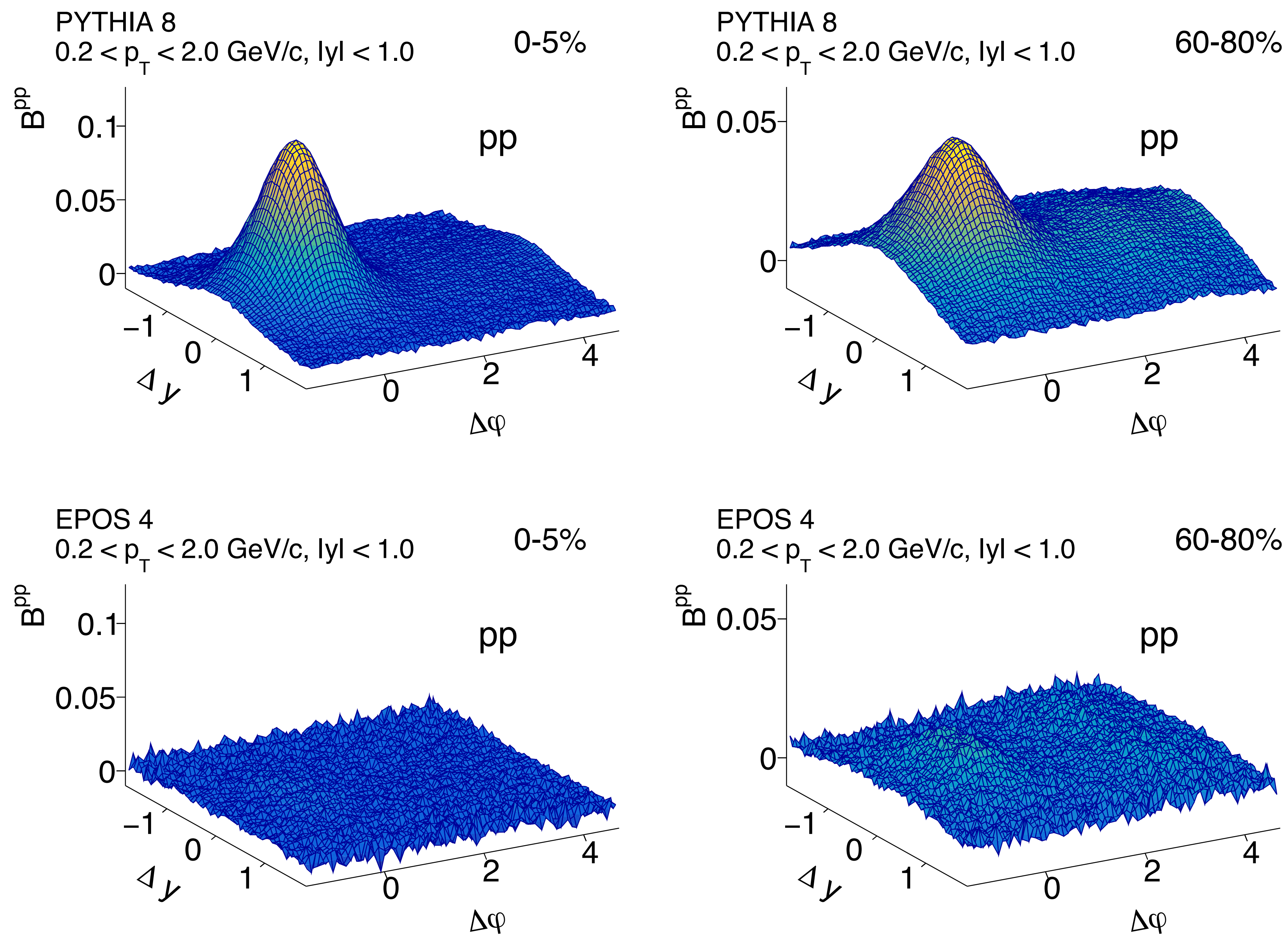
$\langle p_T \rangle$ evolution with multiplicity -> decrease with multiplicity

KK balance with multiplicity



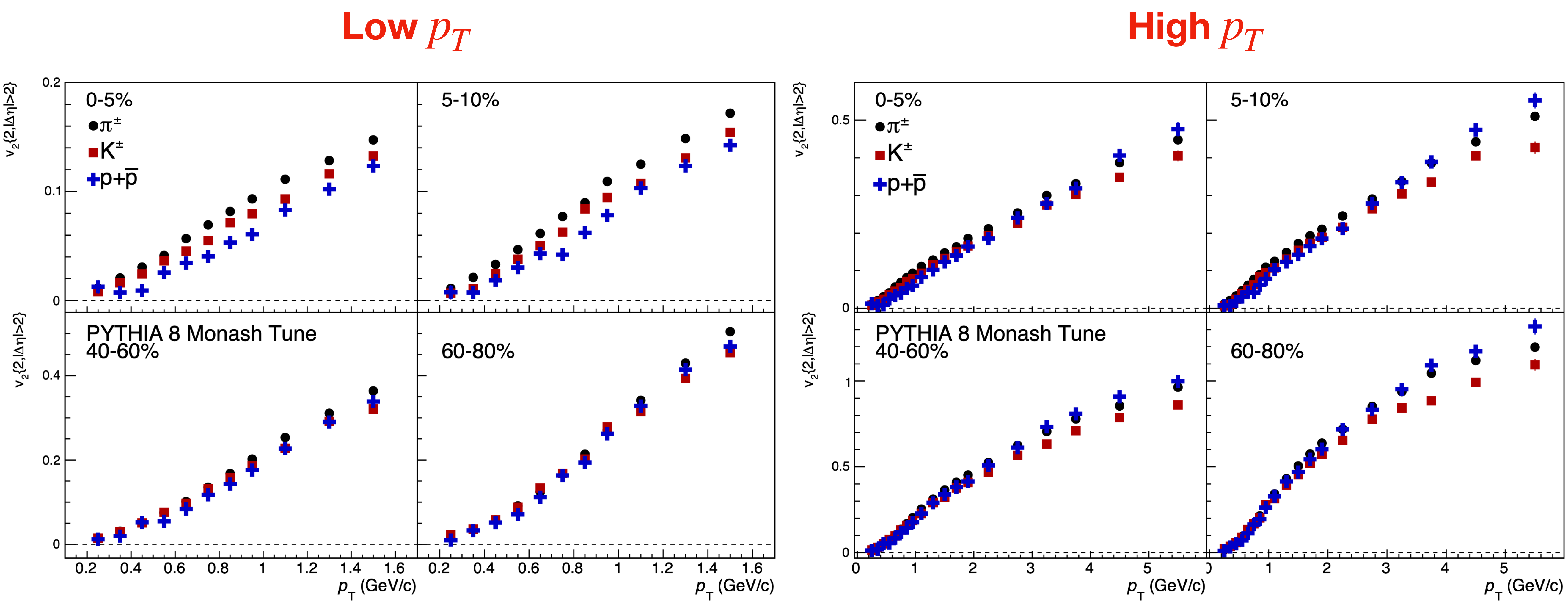
- EPOS increases correlation strength in the away side

$p + \bar{p}$ balance with multiplicity



- PYTHIA is very different from EPOS

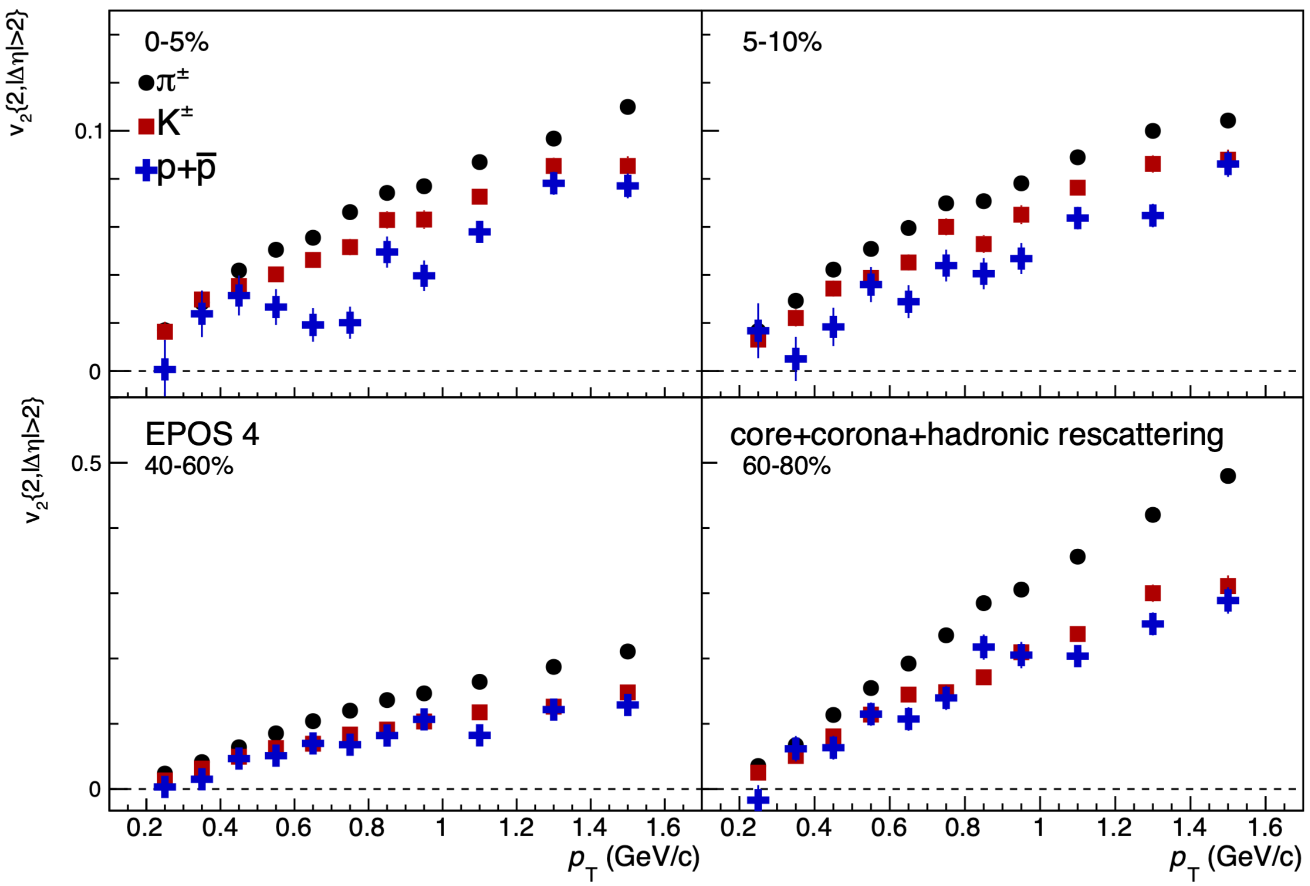
$v_2\{2, |\Delta\eta| > 2\}$ Monash tune



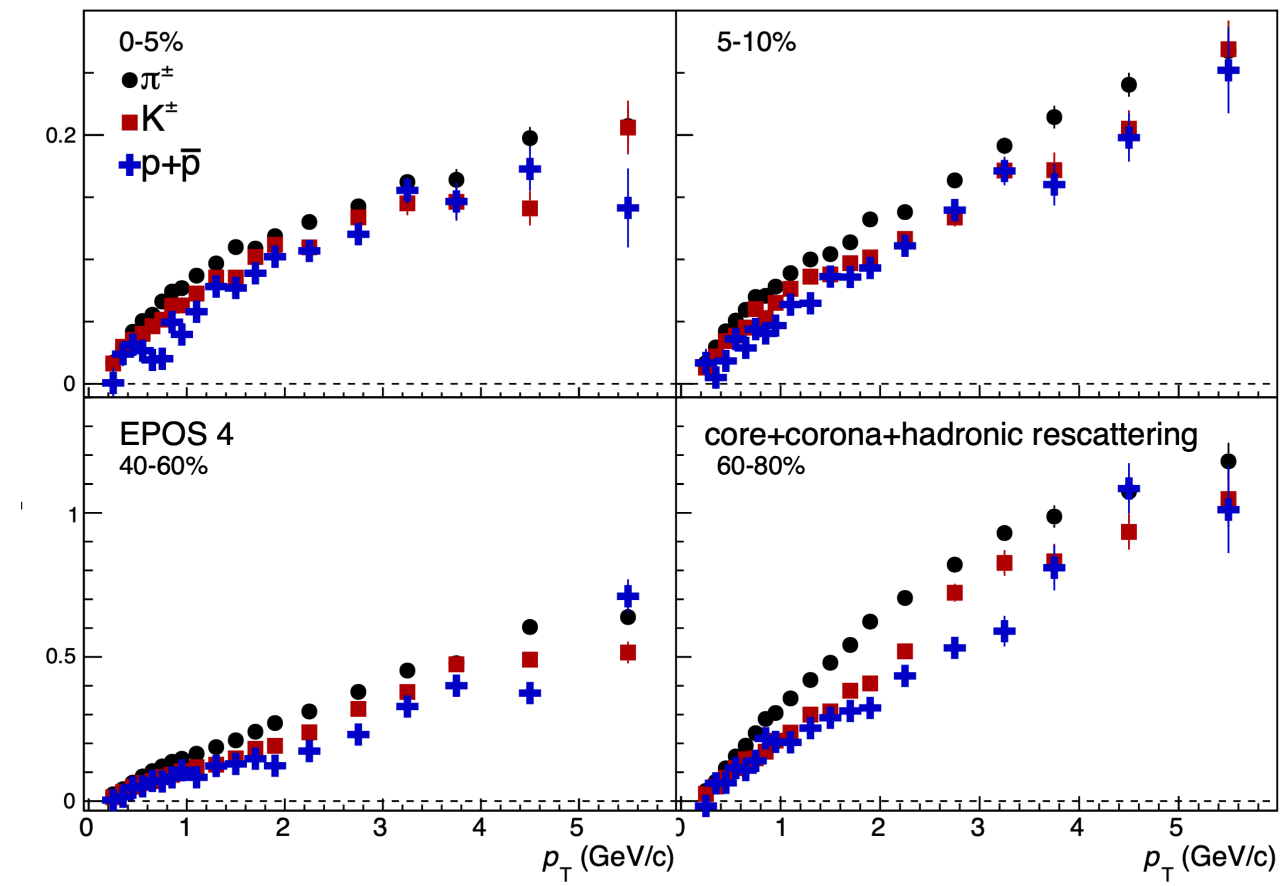
- Mass ordering at low p_T at high multiplicity
- Crossing between baryon and meson v_2
- Evolution with multiplicity class
- No particle type grouping

$v_2\{2, |\Delta\eta| > 2\}$ EPOS 4

Low p_T



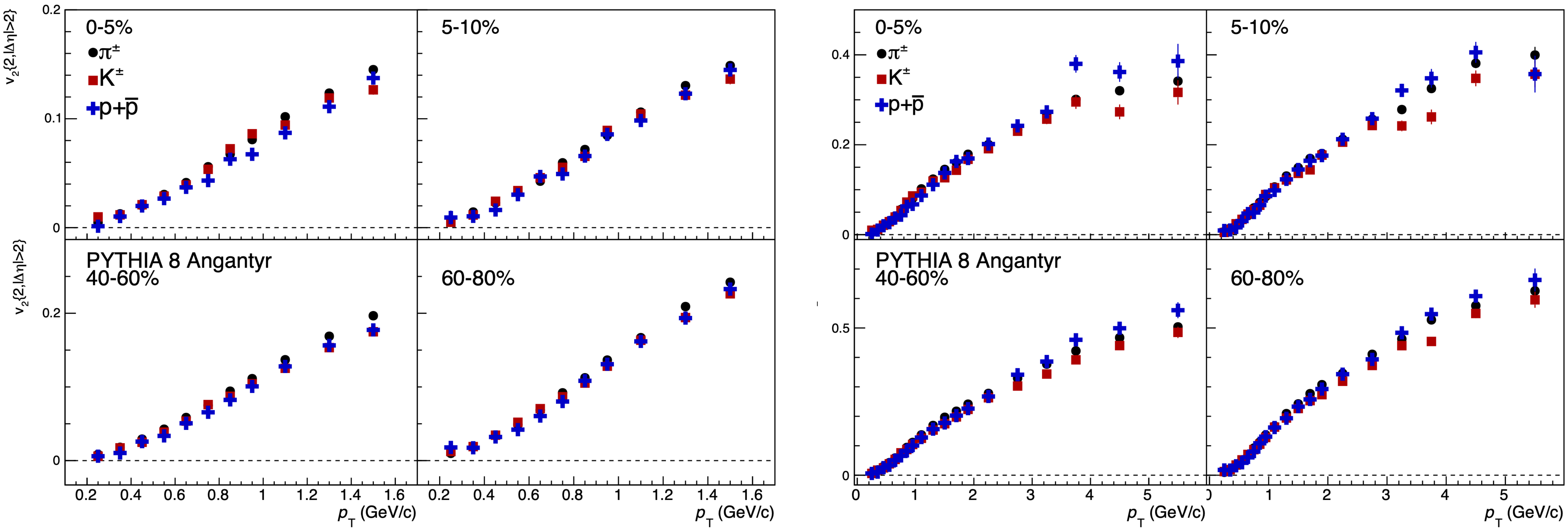
High p_T



- Mass ordering at low p_T at high multiplicity
- No crossing between pion and proton v_2
- Evolution with multiplicity class
- No particle type grouping

$v_2\{2, |\Delta\eta| > 2\}$ Angantyr

Low p_T | **High p_T**



- Heavier particles have smaller v_2 than lighter ones
- Similarities between multiplicity classes
- Crossing between pion and proton v_2
- No particle type grouping