Particle yield fluctuation measurements: some ideas

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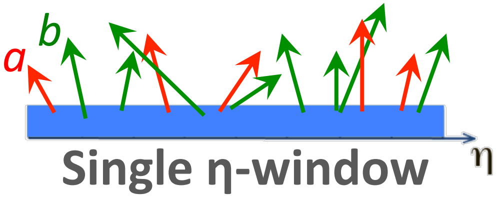
Part 1

Correlations between particle number ratios

1 Measures for particle number fluctuations

$r = n_a / n_b$



Variance of the ratio (norm.):

$$\nu \equiv \frac{\langle \Delta r^2 \rangle}{\langle r \rangle^2}$$

Observable (approximation):

Pruneau, Voloshin, Gavin
Phys.Rev. C66 (2002) 044904

$$\nu_{dyn} \equiv \nu - \nu_{stat} = \frac{\langle n_a(n_a-1)\rangle}{\langle n_a\rangle^2} + \frac{\langle n_b(n_b-1)\rangle}{\langle n_b\rangle^2} - 2\frac{\langle n_a n_b\rangle}{\langle n_a\rangle\langle n_b\rangle}$$

- measures deviations from Poissonian behaviour
- robust against volume fluctuations, efficiency losses
- sensitive to correlations between species *a, b*
- affected by resonance decays

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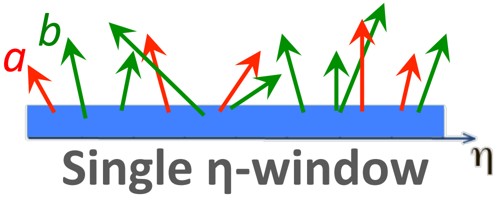

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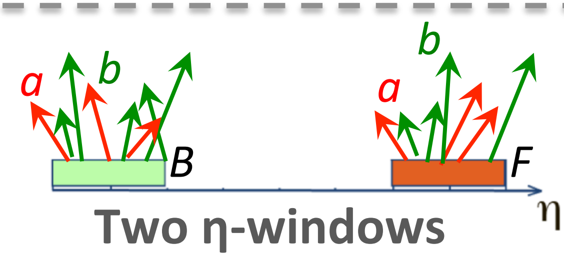


Correlation strength:

$$b_{\rm corr} = \frac{\langle r^F \cdot r^B \rangle}{\langle r^F \rangle \langle r^B \rangle} - 1$$

I.A., arXiv:1901.01635

Observable (approximation):

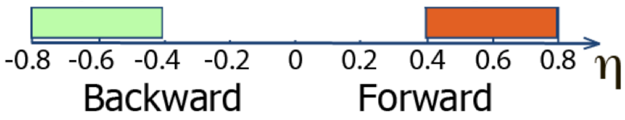
$$b_{\rm corr} \approx \frac{\langle n_a^F n_a^B\rangle}{\langle n_a^F\rangle\langle n_a^B\rangle} + \frac{\langle n_b^F n_b^B\rangle}{\langle n_b^F\rangle\langle n_b^B\rangle} - \frac{\langle n_a^F n_b^B\rangle}{\langle n_a^F\rangle\langle n_b^B\rangle} - \frac{\langle n_b^F n_a^B\rangle}{\langle n_b^F\rangle\langle n_a^B\rangle}$$

"same-species" terms — "cross-species" terms

- if independent particle production → b_{corr} = 0
- if only short-range effects (decays, jets) → at large η_{gap} b_{corr} = 0
  – not the case for the "classical" ν_{dyn}
- connection to the balance function: BF = $-\rho_1/4 \cdot b_{corr}$

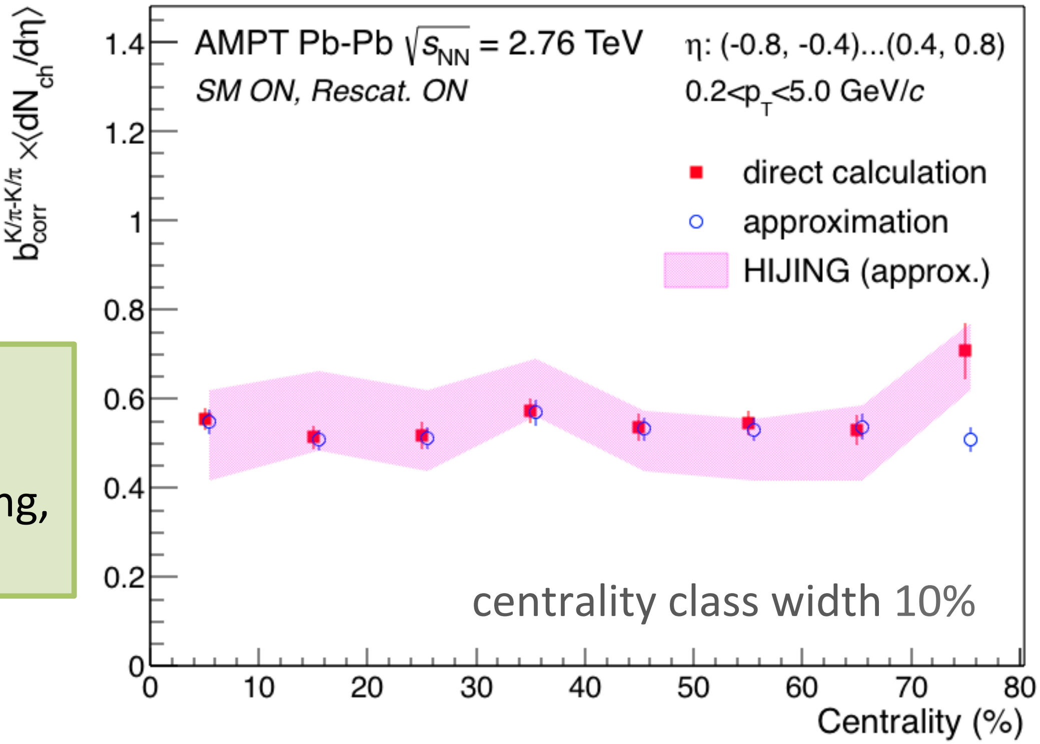
2 Correlations between particle number ratios

Example: take K/π ratios in windows, calculate in AMPT, HIJING



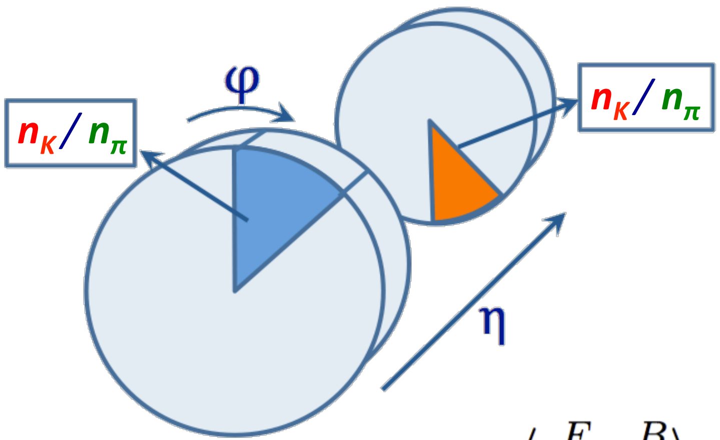
$$b_{\mathrm{corr}} = \frac{\langle r^F \cdot r^B \rangle}{\langle r^F \rangle \langle r^B \rangle} - 1$$

What it can probe:
correlations between strangeness production at large η gaps (string breaking, string interactions, thermal models, ...)



- direct calculations and the approximation in agreement
- **a flat trend in AMPT with centrality, same in HIJING**
- impact from strangeness conservation, resonance decays

2 What if sub-divide windows into φ sectors?



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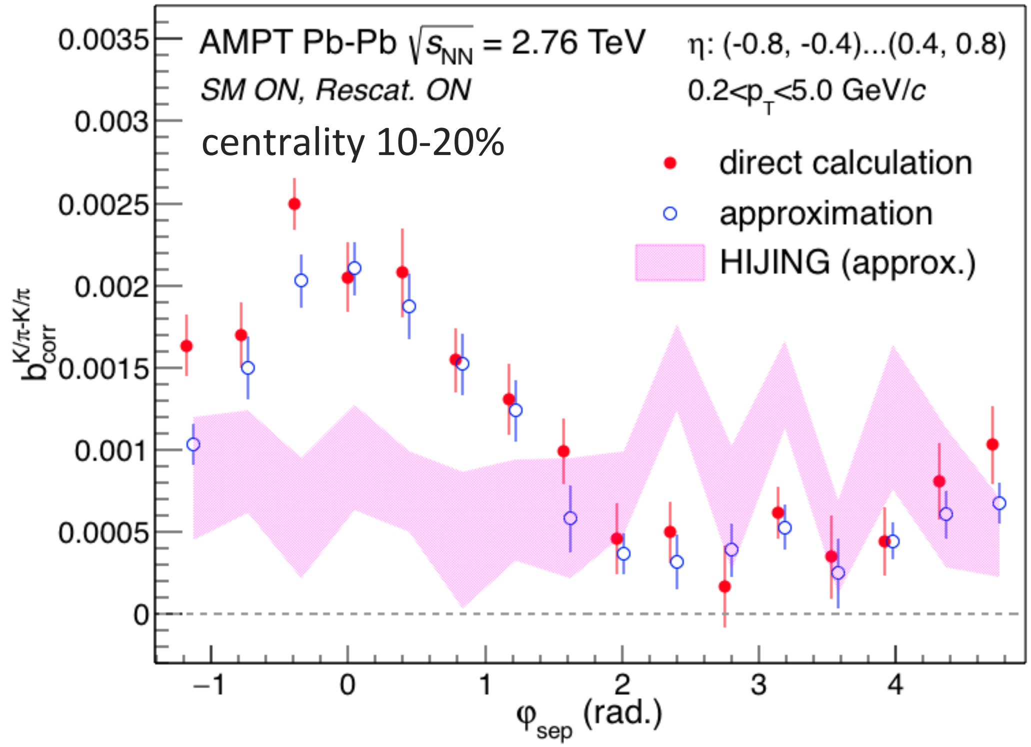
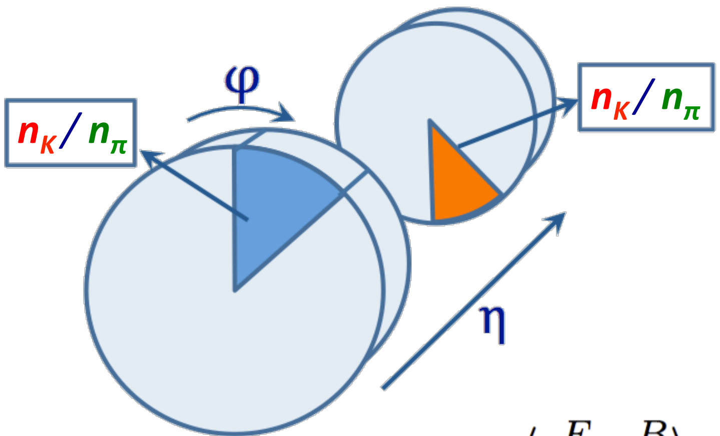
Correlations between K/π ratios:



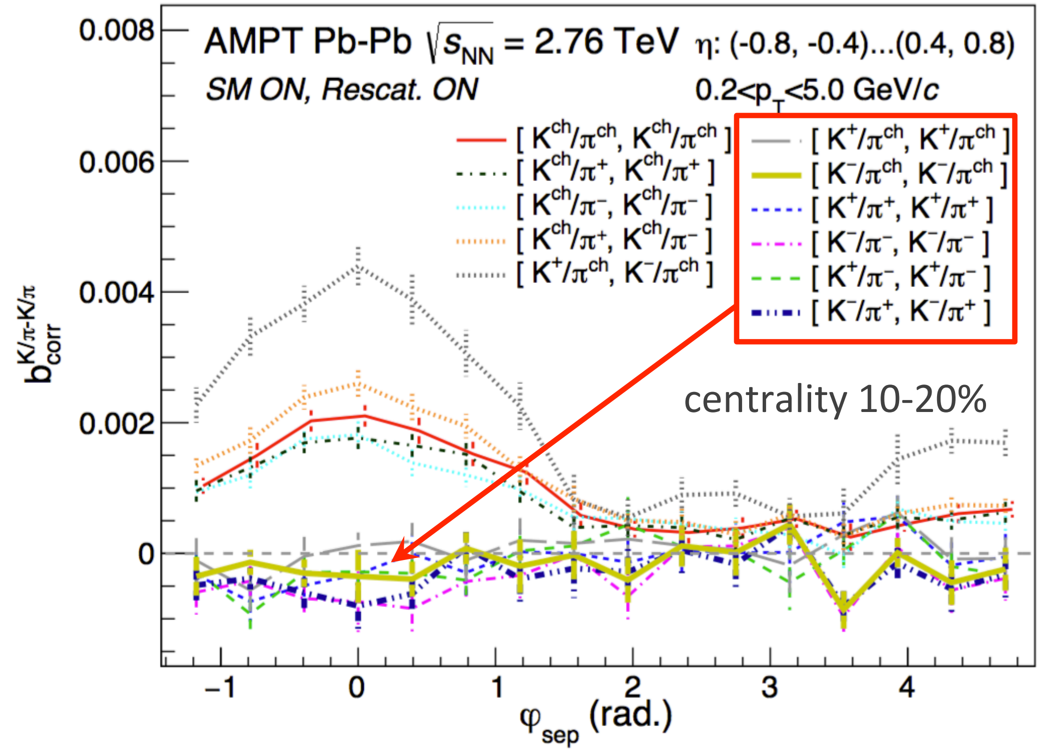
- The approximation works well (even when numbers of kaons in windows are small).
- **AMPT**: a visible azimuthal structure, while **HIJING** seems to give a constant.

2 What if sub-divide windows into φ sectors?



$$b_{\rm corr} = \frac{\langle r^F \cdot r^B \rangle}{\langle r^F \rangle \langle r^B \rangle} - 1$$

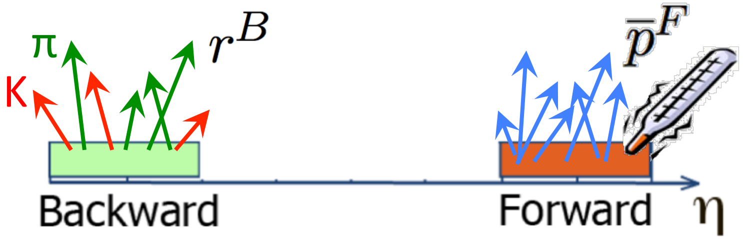
Correlations between K/π ratios (charge combinations):



- Absence of correlations in AMPT if one takes *same charge-sign kaons* in both windows (when impact from strangeness conservation and resonance decays is suppressed).

3 FB correlations between number ratio and mean-p_T

Another observable: in each event, take *mean p_T* in one window and number ratio in another.



Correlation strength:

$$b_{\mathrm{corr}}^{r,\overline{p}} = \frac{\langle \overline{p}^F \cdot r^B \rangle}{\langle \overline{p}^F \rangle \langle r^B \rangle} - 1$$

$$r^B = n_{\mathrm{K}}^B / n_{\pi}^B, \quad \overline{p}^F = \sum_{i=1}^{n_{tracks}} p_{\mathrm{T},i}^F$$

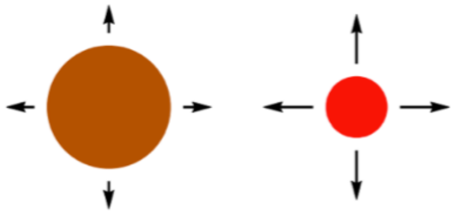
→

Approximation:

$$b_{\mathrm{corr}}^{r,\overline{p}} \approx \frac{\langle \overline{p}^F \cdot n_{\mathrm{K}}^B \rangle}{\langle \overline{p}^F \rangle \langle n_{\mathrm{K}}^B \rangle} - \frac{\langle \overline{p}^F \cdot n_{\pi}^B \rangle}{\langle \overline{p}^F \rangle \langle n_{\pi}^B \rangle}$$

- Properties are similar as of the b_{corr} between ratios

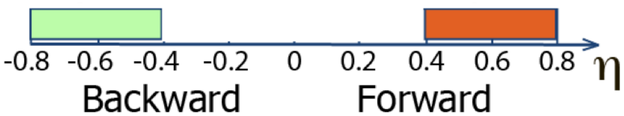
What it can probe:
correlations between strangeness production and density of the fireball (⟷ average p_T)



Phys. Rev. C 96, 014904 (2017)

FB correlations between number ratio and mean-p_T

Take K/π ratios in B-window, calculate in AMPT, HIJING



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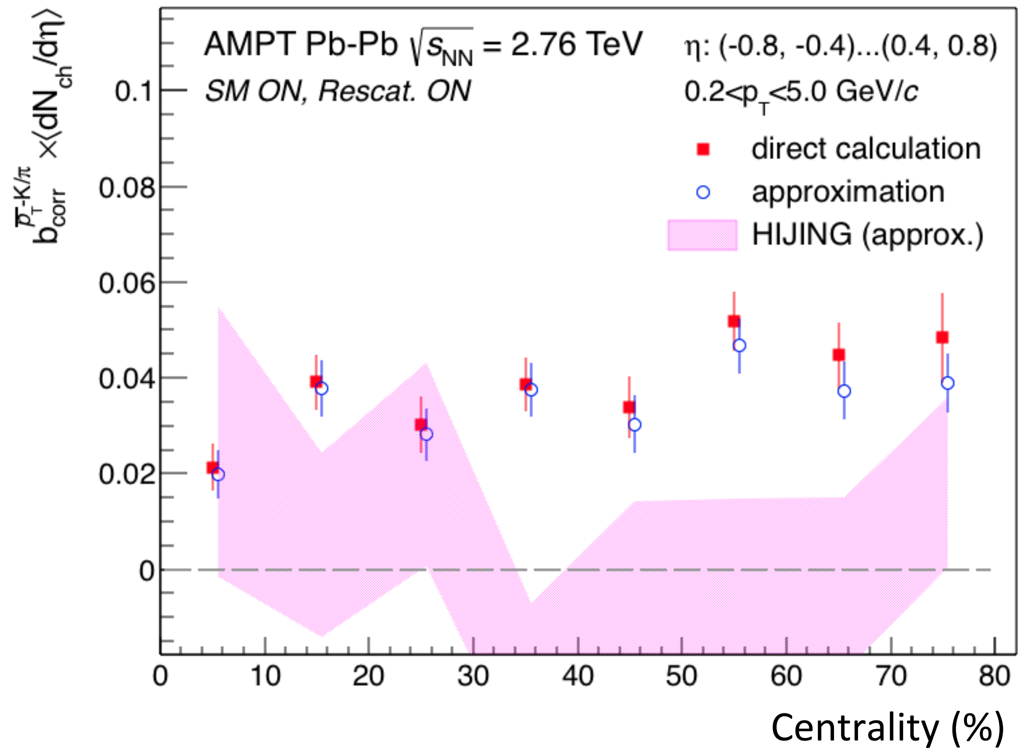
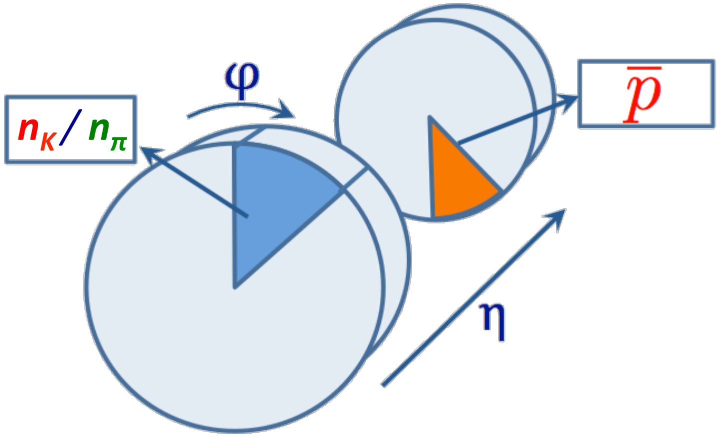


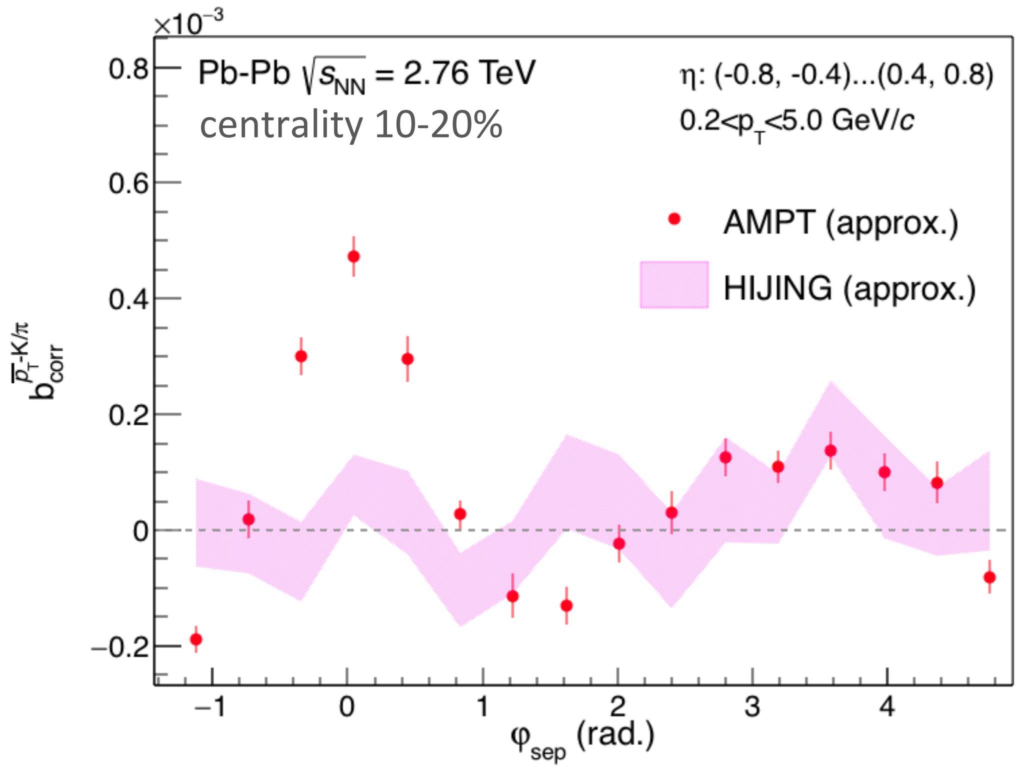
- good agreement between direct calculations and the approximation
- impact from strangeness conservation, resonance decays
- some evolution with centrality in AMPT

3 What if sub-divide also into φ sectors?



$$b_{\rm corr}^{r,\overline{p}} = \frac{\langle \overline{p}^F \cdot r^B \rangle}{\langle \overline{p}^F \rangle \langle r^B \rangle} - 1$$

Correlations between K/π and mean-p_T:



- **AMPT** shows clear azimuthal structure, while **HIJING** is consistent with zero
- End of Part 1.

Part 2

Charged pion balance functions
vs neutral resonance decays

4 Balance functions: reminder

BF is a measure of the correlations between the opposite charges.

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

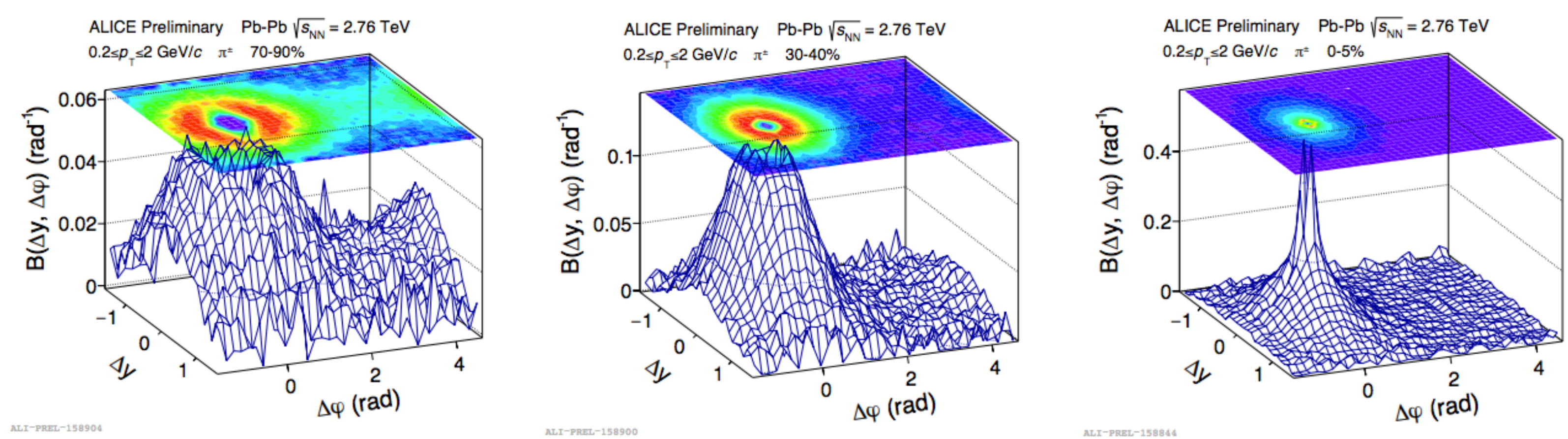
Bass et al., Phys. Rev. Lett. 85 (2000) 2689
Bozek et al., Acta Phys.Hung. A22 (2005) 149
Bozek PLB 609 (2005) 247
Kapusta, Plumberg PRC 97, 014906 (2018)
etc.

Characterized by: shape, width, magnitude, integral.
Physics picture: delayed hadronisation, diffusion
Affected by: radial flow, resonance decays, HBT, Coulomb effects

- Identified BF are measured by STAR and ALICE: narrowing shape with centrality.

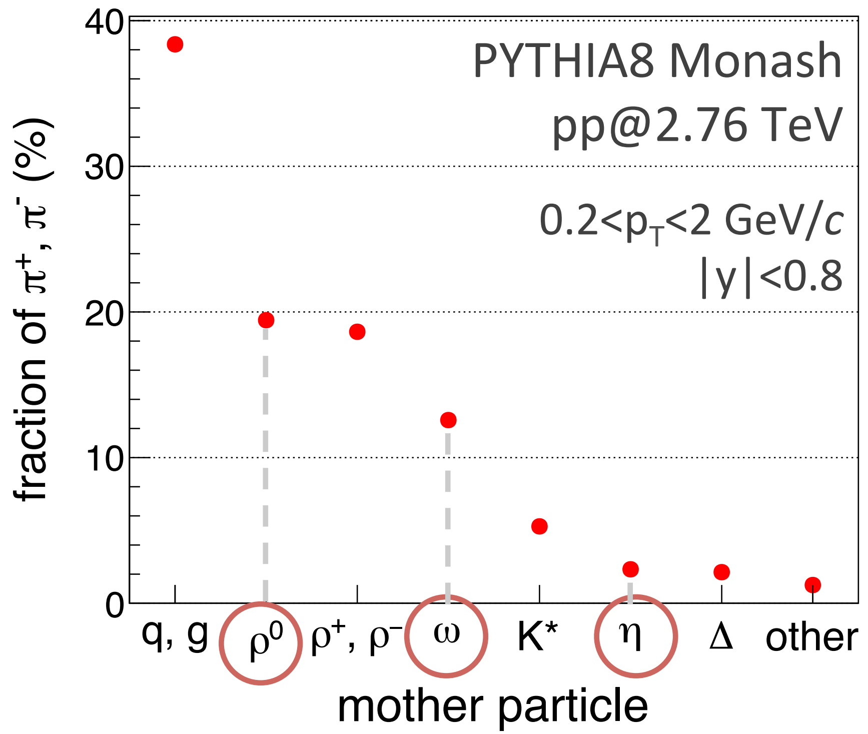
Preliminary ALICE Pb-Pb data for pion BF:

Jinjin Pan, QM2018, arxiv:1807.10377



more central events

5 Sources of charged pions and their balance functions



- ~35% of all charged pions are from **neutral resonance decays** (PYTHIA8, within given cuts)

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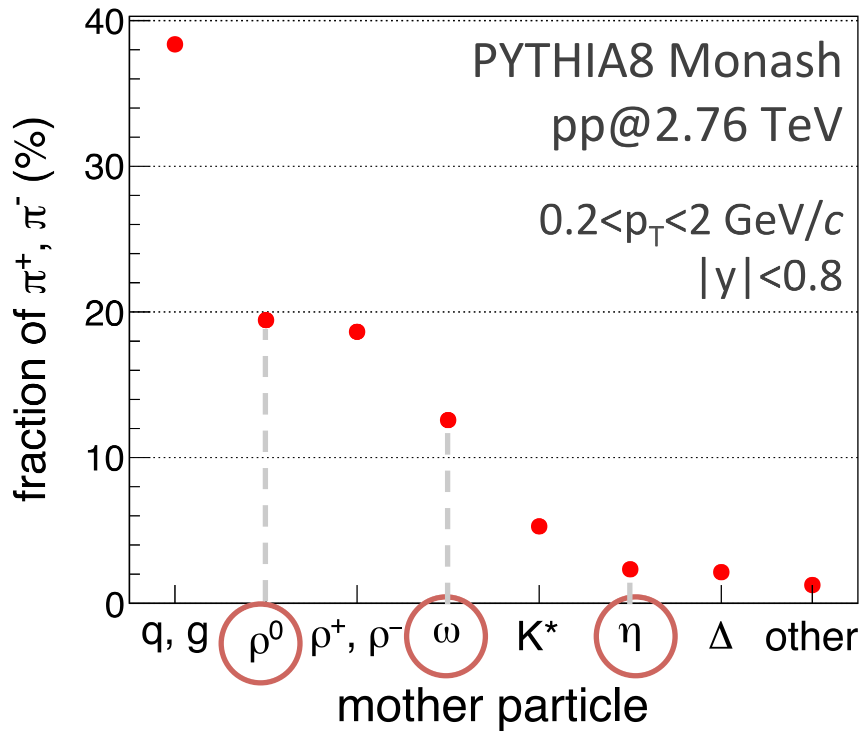
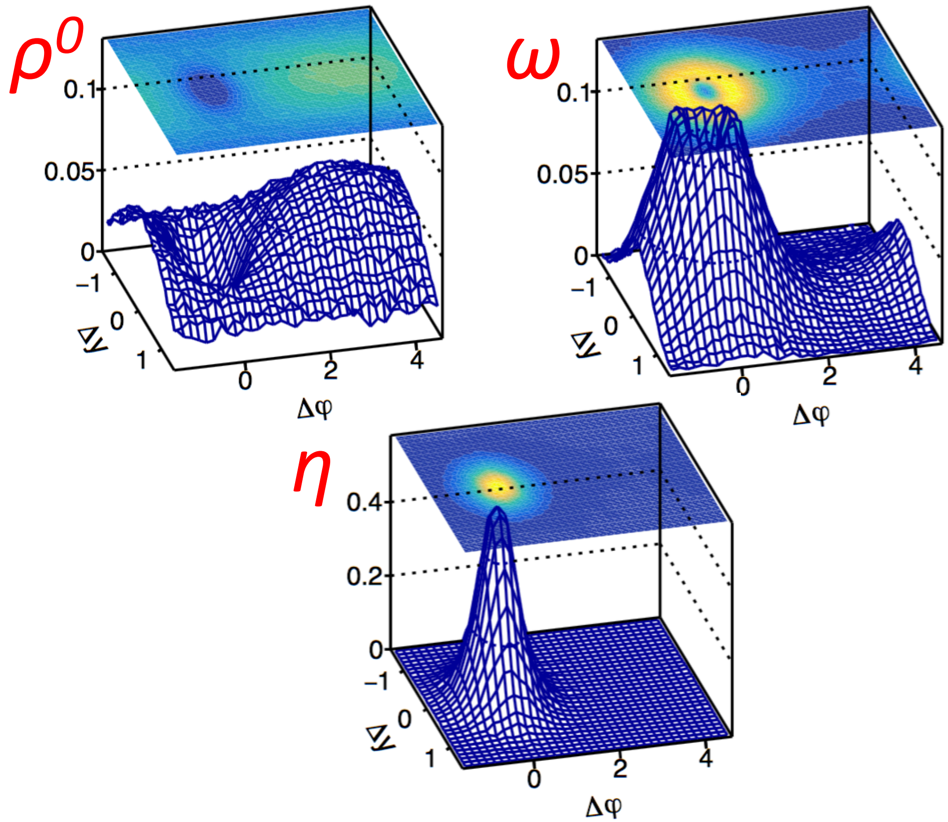


BF from neutral resonances:



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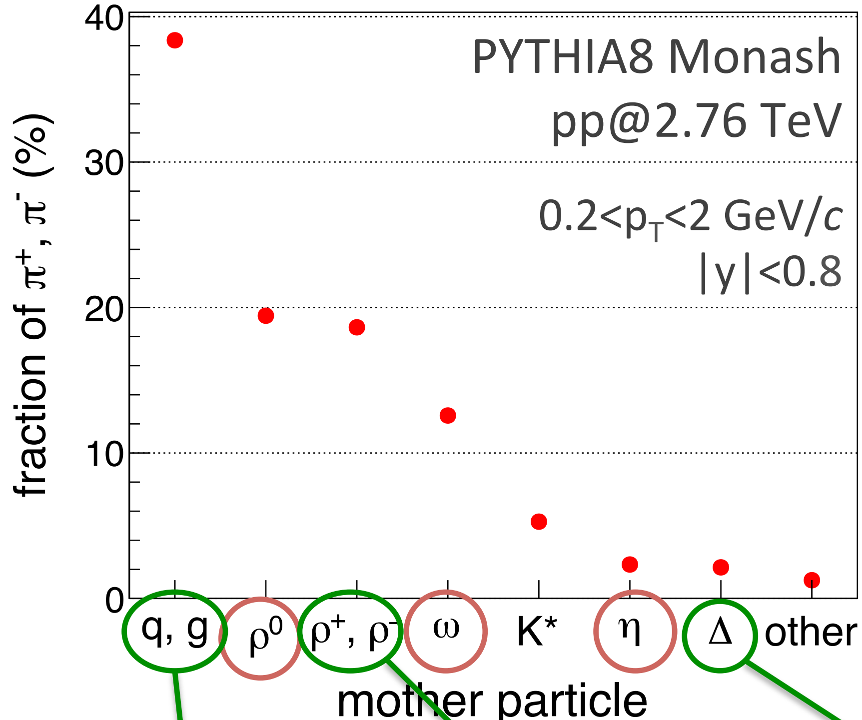
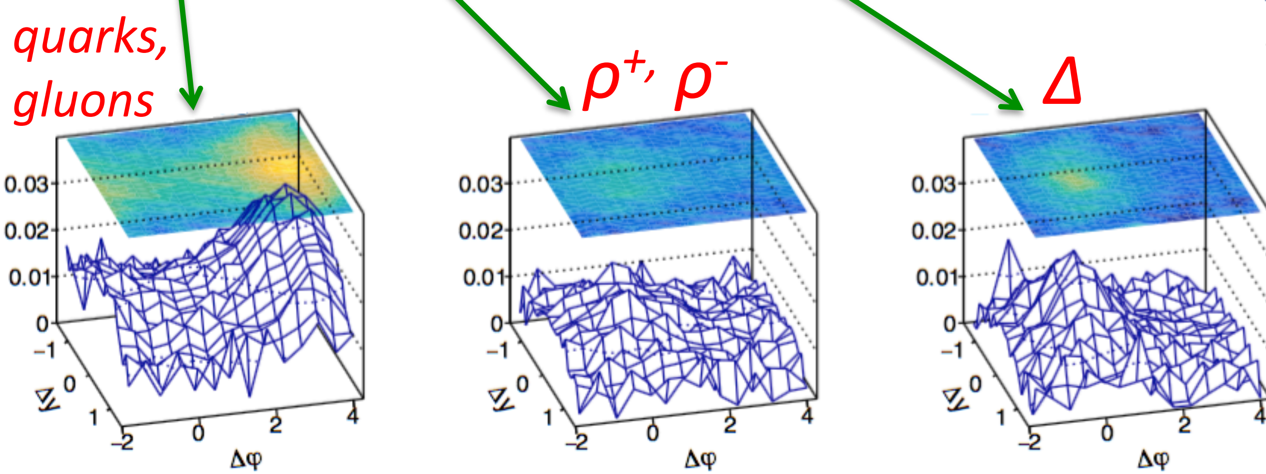
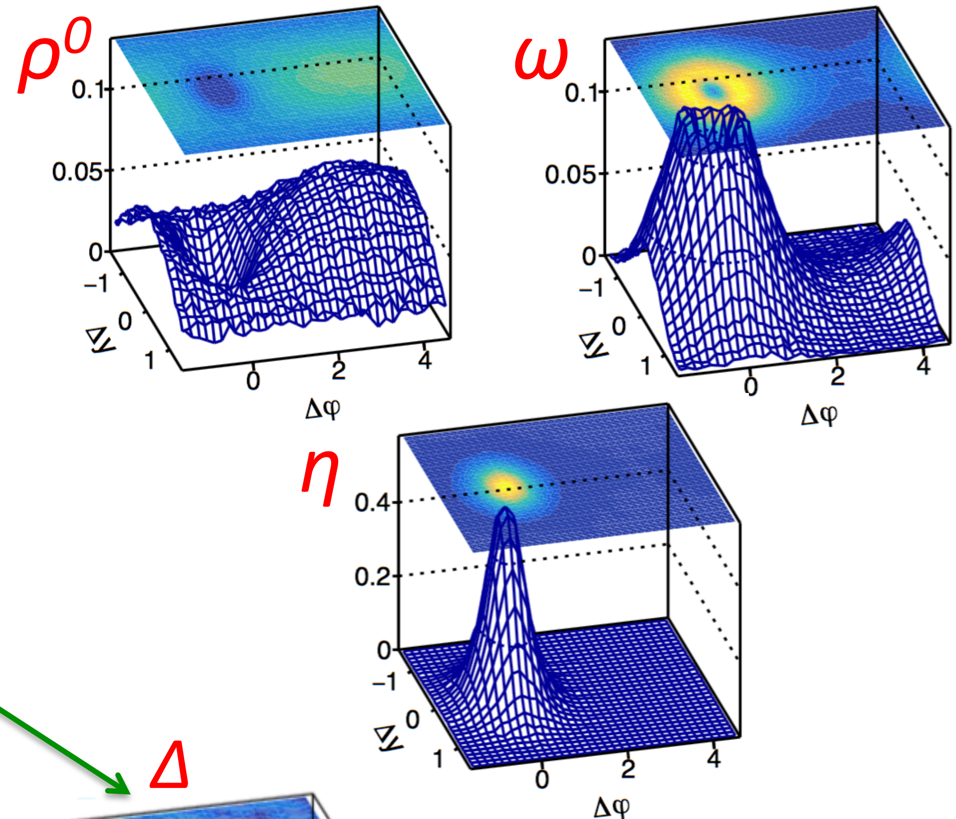




BF from neutral resonances:

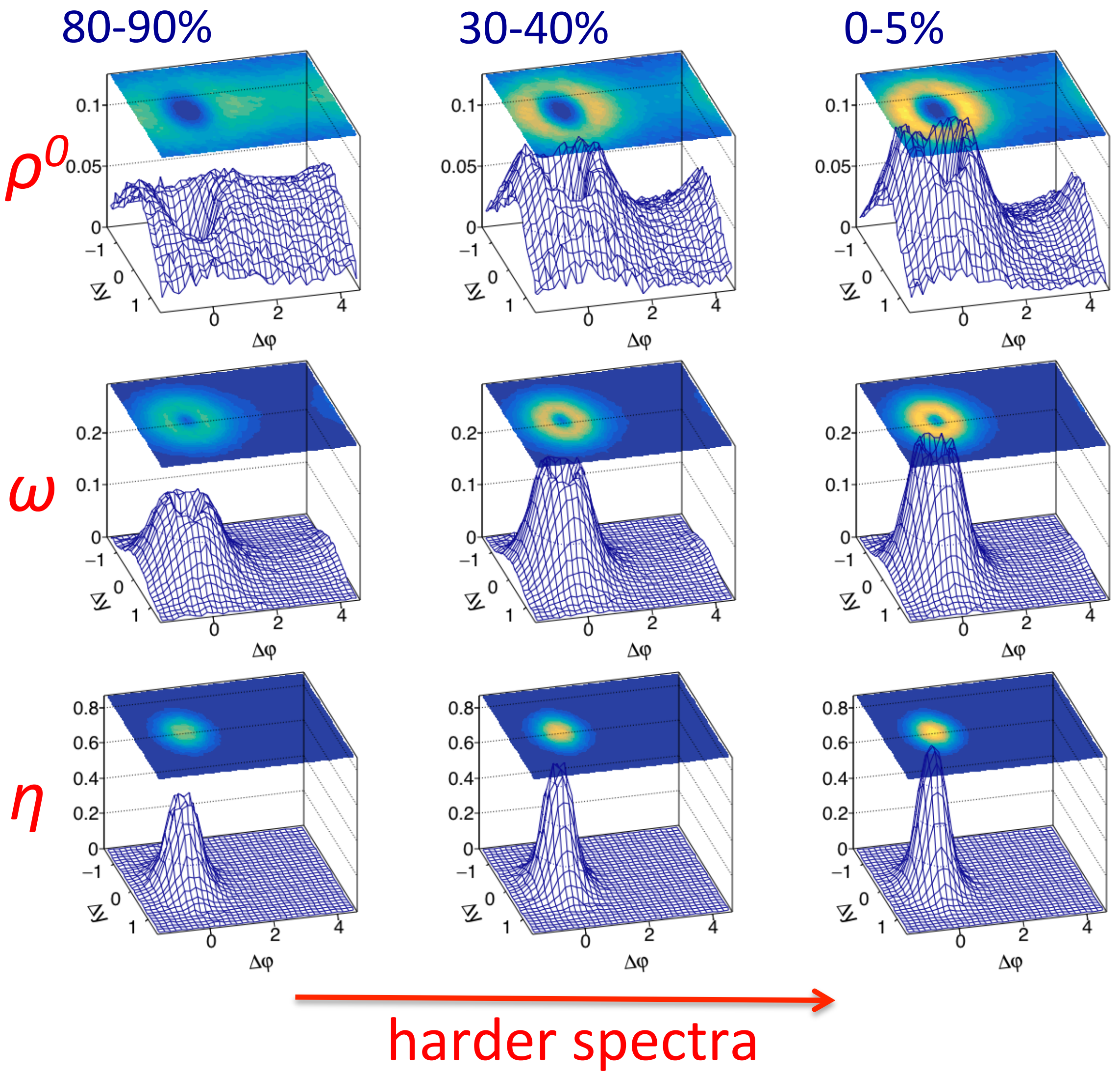


→ *Other pion sources:*
flatter behaviour of BF than for resonances

BF from resonances with realistic p_T spectra in Pb-Pb

- Take **blast wave fit parameters** for π, K, p from ALICE
  Phys. Rev. C 88, 044910 (2013)
  to generate resonance p_T spectra at different centralities
- Decay kinematics from PYTHIA8

→ *Calculate BF for charged pions*



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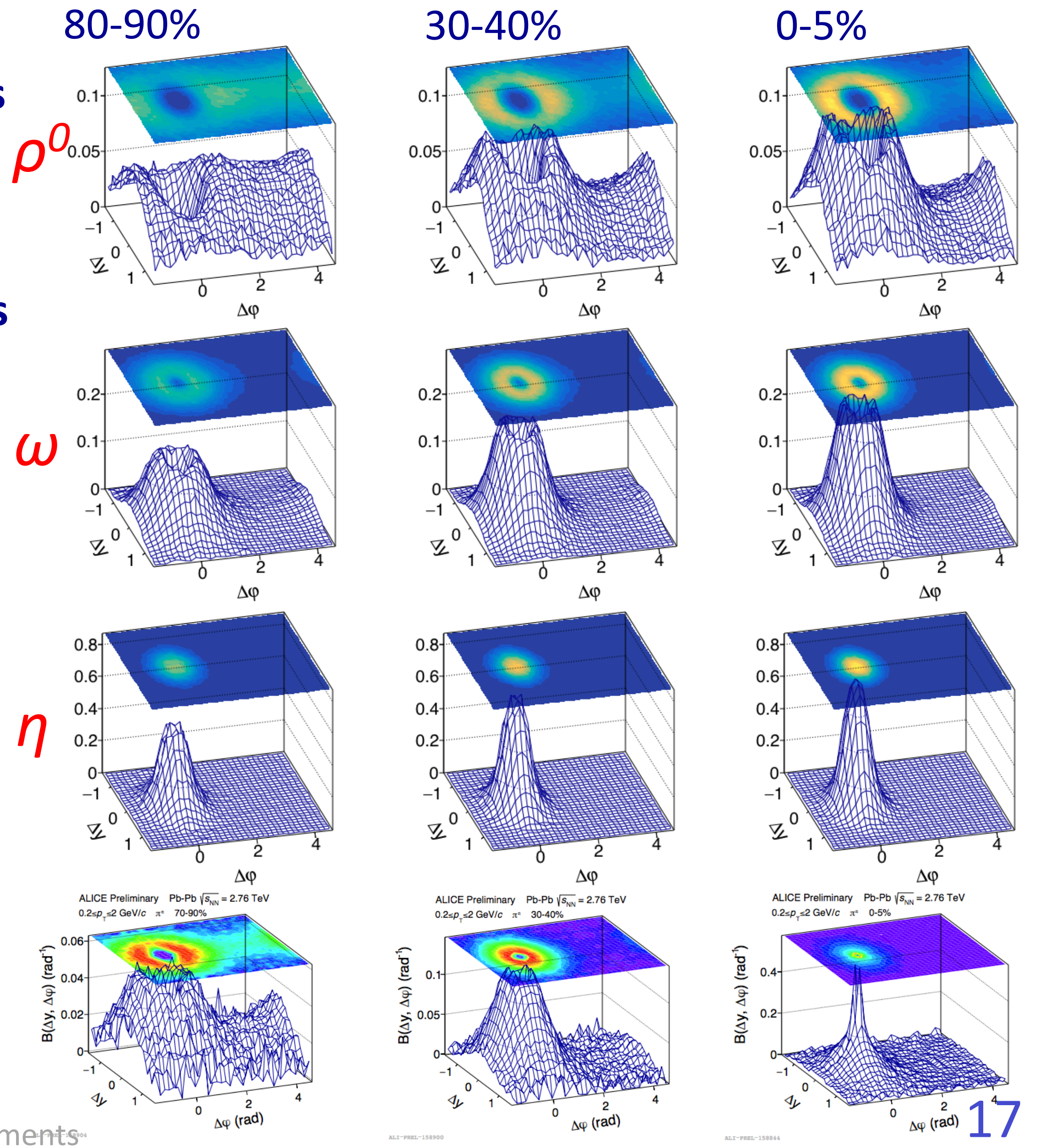


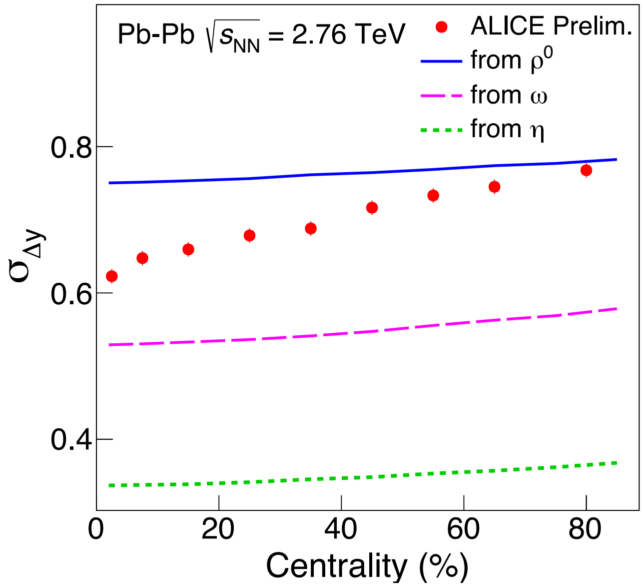
Compare (qualitatively) to ALICE Preliminary data:

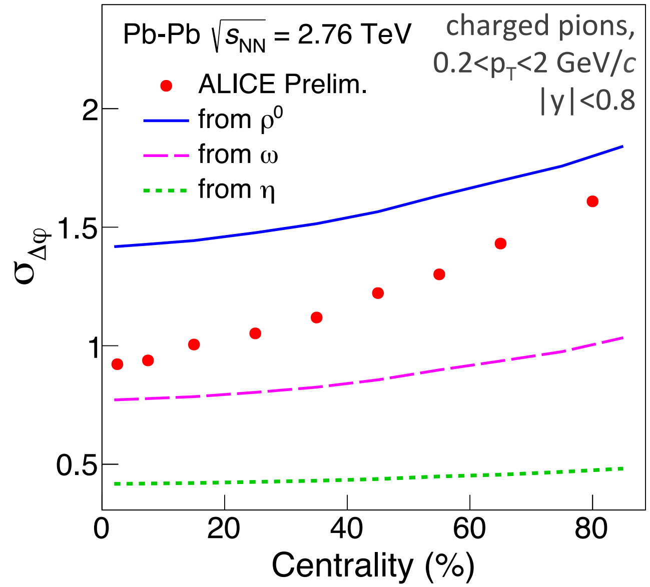
Jinjin Pan, QM2018
arxiv:1807.10377

6 BF from resonances with realistic p_T spectra in Pb-Pb

Width in Δ*y* and Δ*φ* dimensions:

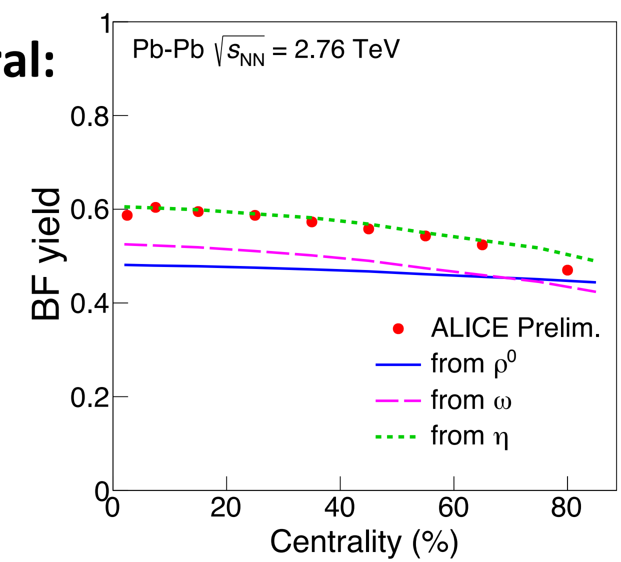
ALICE Preliminary data:
arxiv:1807.10377





(realistic resonance p_T spectra using ALICE blast wave fits)

BF integral:



Resonance BF *vs* data BF:

- orders of magnitude, centrality trends for width and integral are similar.
- Is it possible to *remove* resonance contribution from BF?..

7 Balance function for a system of neutral clusters

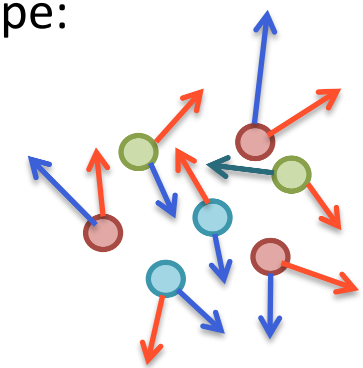
Driving idea:

A. Bialas, Physics Letters B 579 (2004), 31-38

In a model, where pions are produced from **neutral clusters** (can be correlated), **contribution from different clusters cancels in the balance function**, and thus **only (+,-) pairs from one cluster do contribute**.

→ If $\boldsymbol{M_s}$ types of (neutral) sources, $\boldsymbol{k^i}$ – number of sources of i-th type:

$$\mathrm{BF} = \frac{1}{2}\frac{\sum_{i=1}^{M_s}\langle k^i\rangle\left(\rho_2^{i\,(+,-)} + \rho_2^{i\,(-,+)} - \rho_2^{i\,(+,+)} - \rho_2^{i\,(-,-)}\right)}{\sum_{i=1}^{M_s}\langle k^i\rangle\rho_1^{i\,(+)}}$$



In particular, in case when all sources are *neutral resonances decaying into $\pi^+\pi^-$ pair:*

$$\mathrm{BF} = \frac{\sum_{i=1}^{M_s}\langle k^i\rangle\rho_2^{i\,(+,-)}}{\sum_{i=1}^{M_s}\langle k^i\rangle\rho_1^{i\,(+)}}$$

This fact was used to estimate neutral resonance contribution to BF in STAR data [Bozek, Broniowski, Florkowski, Acta Phys.Hung. A22 (2005) 149].

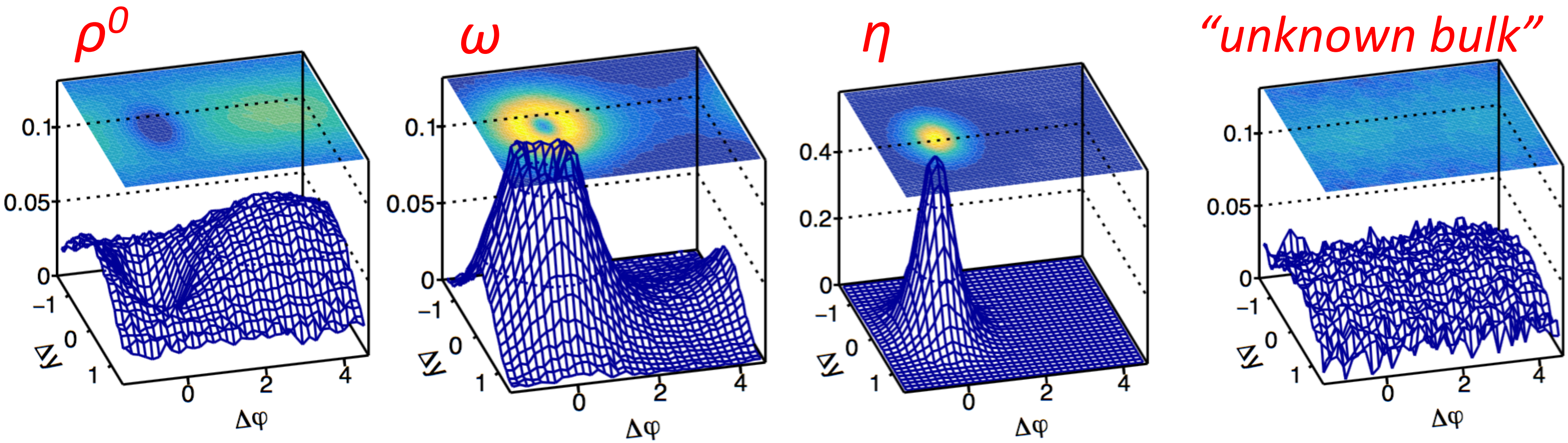
→ We can explicitly **remove resonance contributions** from measured BF

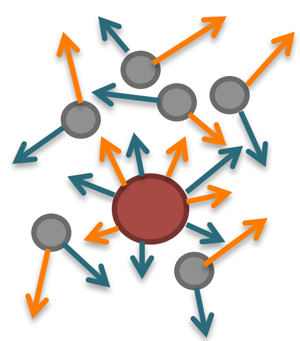
- for that, we need to know two- and single-particle densities from resonances, and single-particle distribution of resonances themselves → available

7 Test resonance removal from BF with PYTHIA events

Take 4 types of "neutral clusters": **ρ^0, ω, η** and **the rest of particles** (the "*bulk*").

Balance functions for each type of the source:





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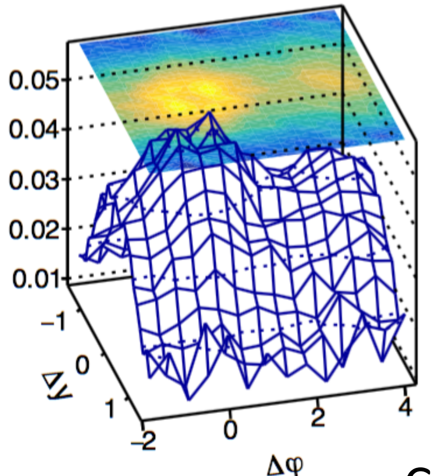
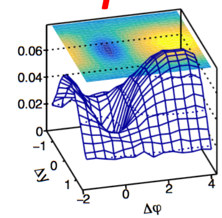
"Measured" BF (charged pions)

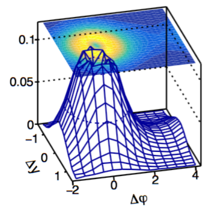


−

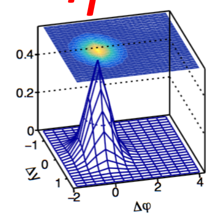
ρ^0



ω



η



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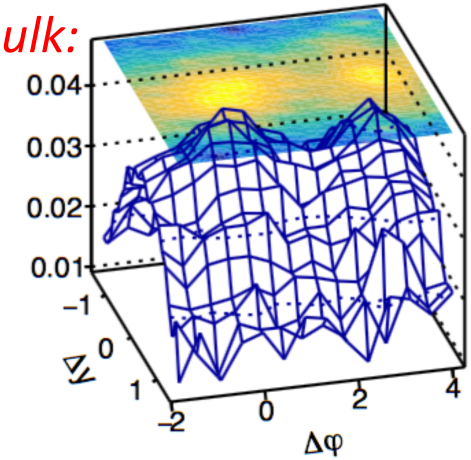
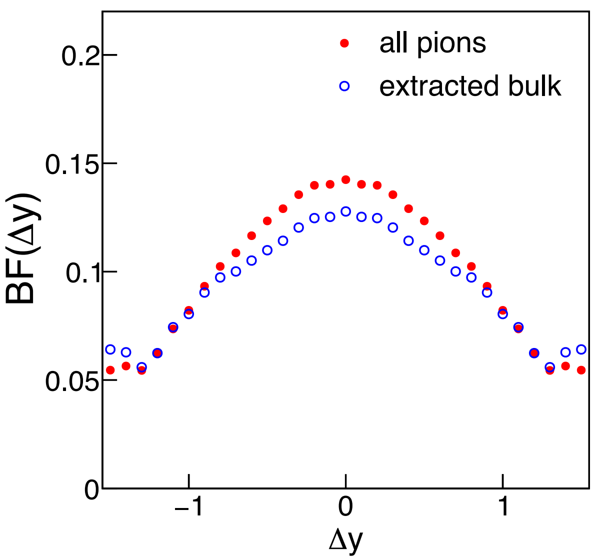
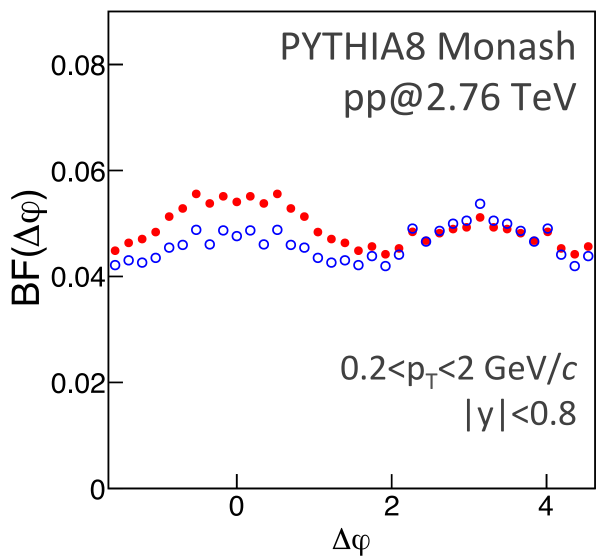
Extracted bulk:

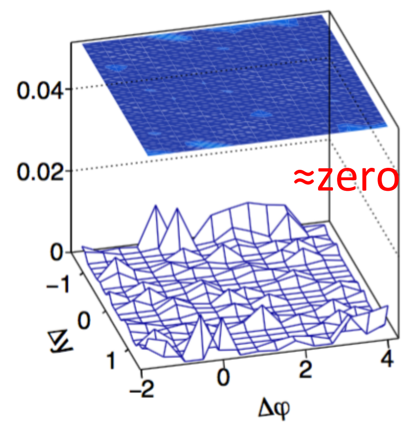


Checks projections:





Check:
subtract the "truth bulk" (we know it) from extracted:



Summary

- **Correlations between ratios of identified particle yields in two windows** are discussed
  - robust observable, allows to suppress contributions from decays
  - sensitive to correlation between strangeness production ↔ fireball density
  - approximate expression is provided, analogously to ν_{dyn}
  - possible to measure in experiments with strong PID capabilities, Identity Method can be utilized for corrections
  - variation: correlation between number ratio in one window and mean-p_T in another

- **Resonance contribution in charge balance function:**
  - it's possible to explicitly remove neutral resonance contributions from BF
  - can be done in 2D (Δy-$\Delta\varphi$) → it would be useful to have published data points for 2D BF, not only 1D projections.

Thank you for your attention!

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