Studies of collective effects in pp collisions with the balance function of identified particles

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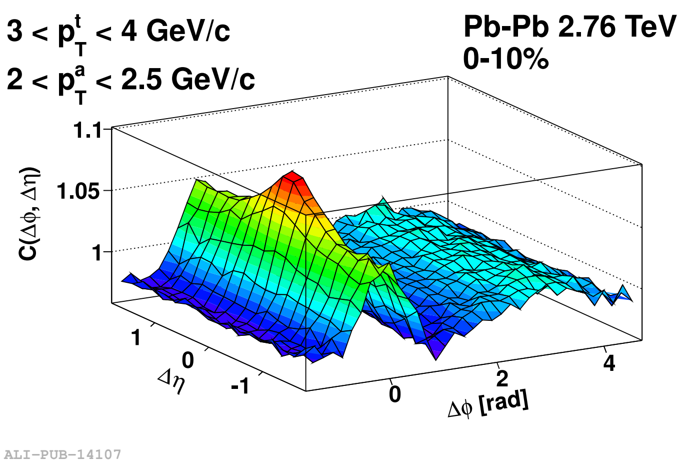
for the ALICE Collaboration

New development of hydrodynamics and its applications in heavy-ion collisions

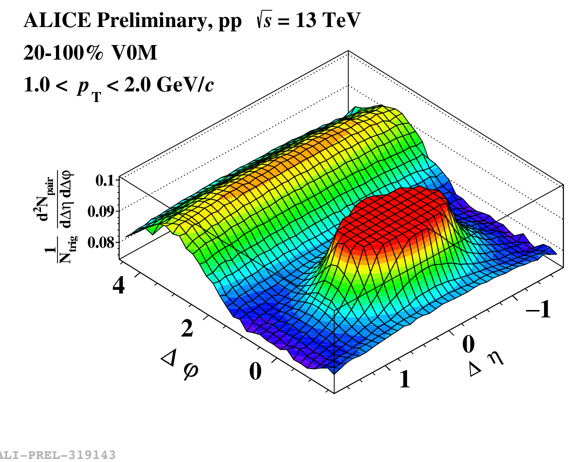
30.09 - 02.11.19
Shanghai, China

Collectivity in pp: what do we know?

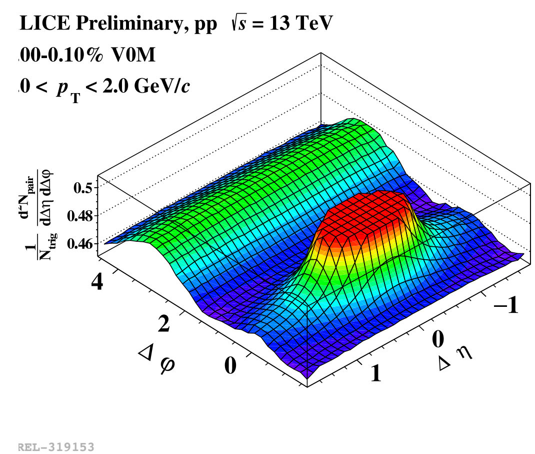
Pb-Pb



low-multiplicity pp

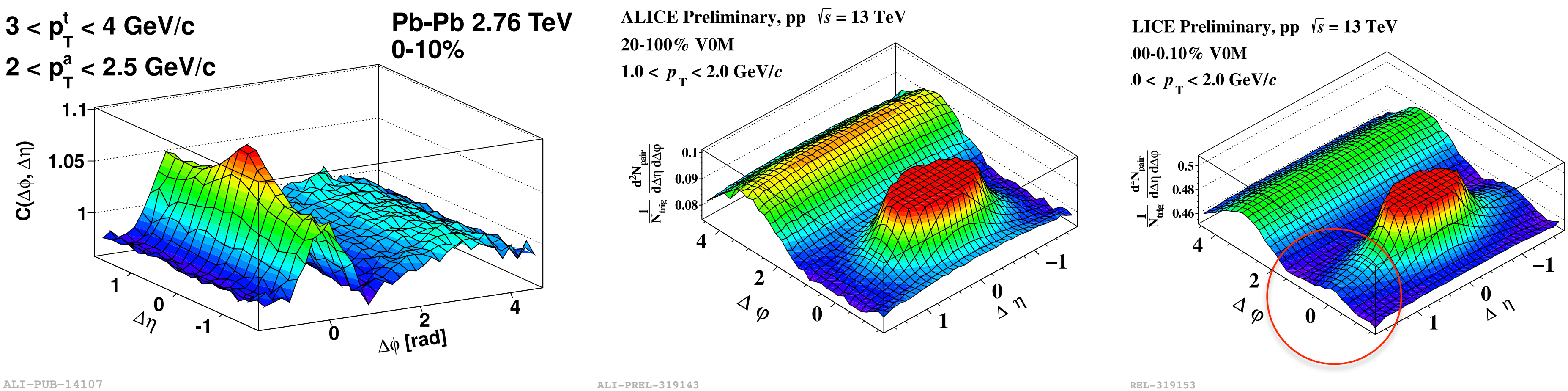


high-multiplicity pp



Collectivity in pp: what do we know?

Pb-Pb | **low-multiplicity pp** | **high-multiplicity pp**



- observation of the long-range correlations in high-multiplicity pp collisions
- what is the origin of these effects?
- how can we learn more? -> **balance function**

Balance function measurement in Pb-Pb

$$C_{(+,-)}(\Delta\varphi,\Delta\eta) = \frac{1}{N_{trig,+}}\frac{d^2N_{assoc,-}}{d\Delta\eta d\Delta\varphi} = \frac{S_{(+,-)}}{f_{(+,-)}}$$

$$S_{(+,-)} = \frac{1}{N_{trig,+}}\frac{d^2N_{same,(+,-)}}{d\Delta\eta d\Delta\varphi}$$

$$f_{(+,-)} = \alpha\frac{d^2N_{mixed,(+,-)}}{d\Delta\eta d\Delta\varphi}$$

Balance function measurement in Pb-Pb

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$$B(\Delta\varphi,\Delta\eta) = \frac{1}{2}\left[C_{(+,-)} + C_{(-,+)} - C_{(+,+)} - C_{(-,-)}\right]$$

- cancel charge-independent contribution: e.g. anisotropic flow
- keep charge-dependent correlations

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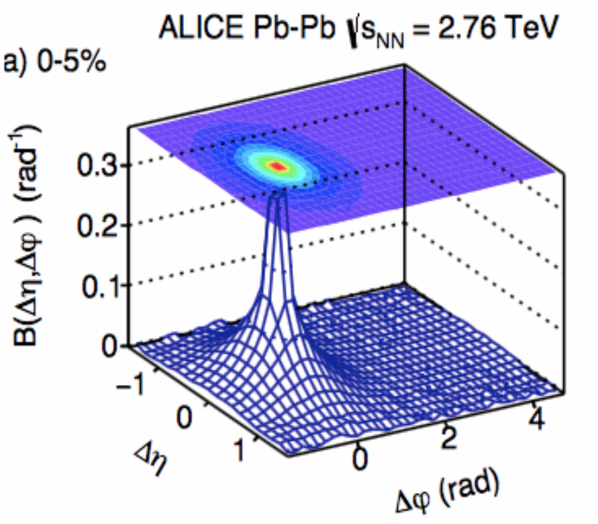

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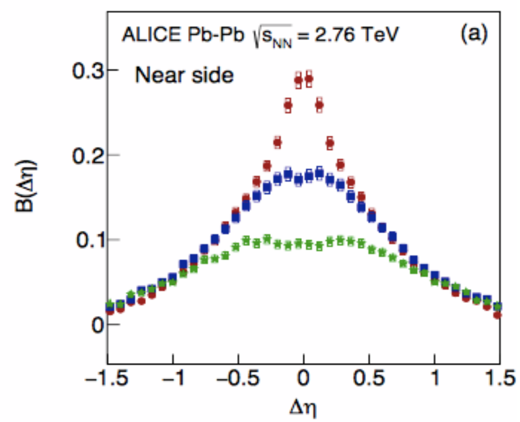
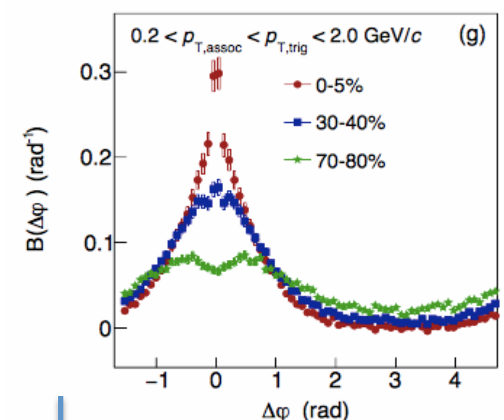
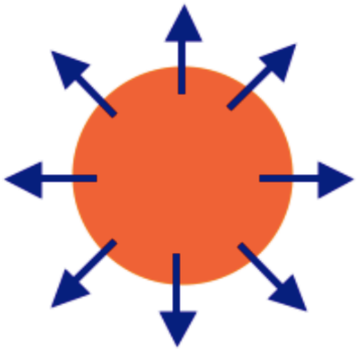




balance function width ($\sigma_{\Delta\eta}$, $\sigma_{\Delta\phi}$) and yield:
RMS and integral

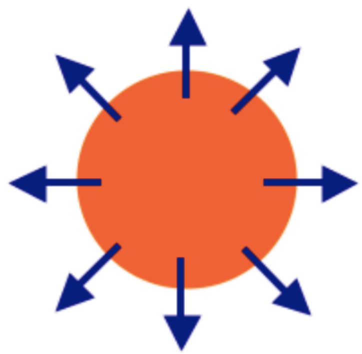
Sensitivity to collective motion and creation time of quarks



$$B(\Delta\varphi,\Delta\eta)=\frac{1}{2}\left[C_{(+,-)}+C_{(-,+)}-C_{(+,+)}-C_{(-,-)}\right]$$

- higher radial flow makes the unlike-sign correlations narrower

Sensitivity to collective motion and creation time of quarks



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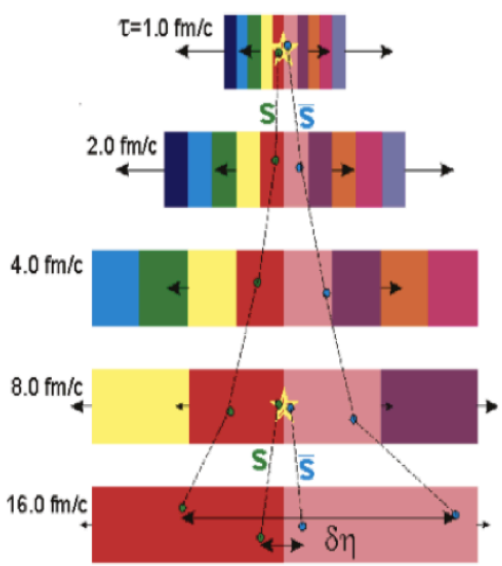
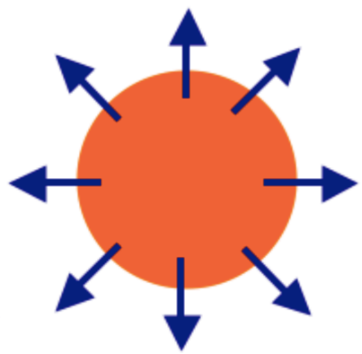
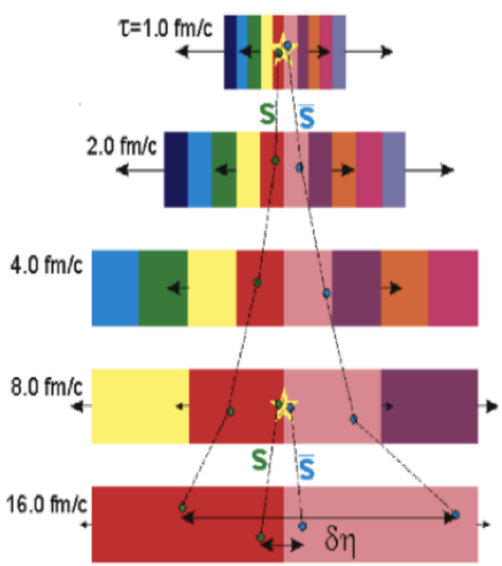


- "early stage"
  - ➢ dilution of correlations due to expansion and rescattering
- "late stage"
  - ➢ not enough time to break the correlation

Phys.Rev.Lett. 85 (2000) 2689-2692

Sensitivity to collective motion and creation time of quarks





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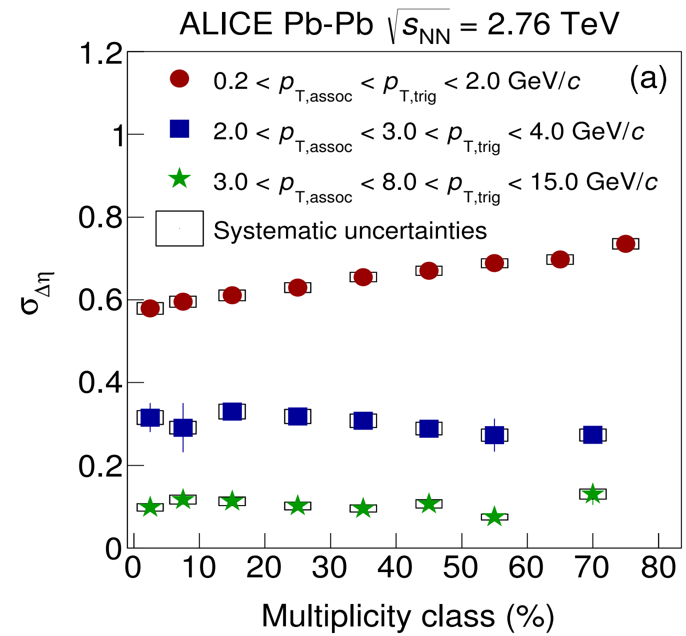

- narrower width is related to larger radial flow and later production of quarks in central with respect to peripheral collisions

- **how does balance function look like for pp?**

Balance function width for charged particles: data and model

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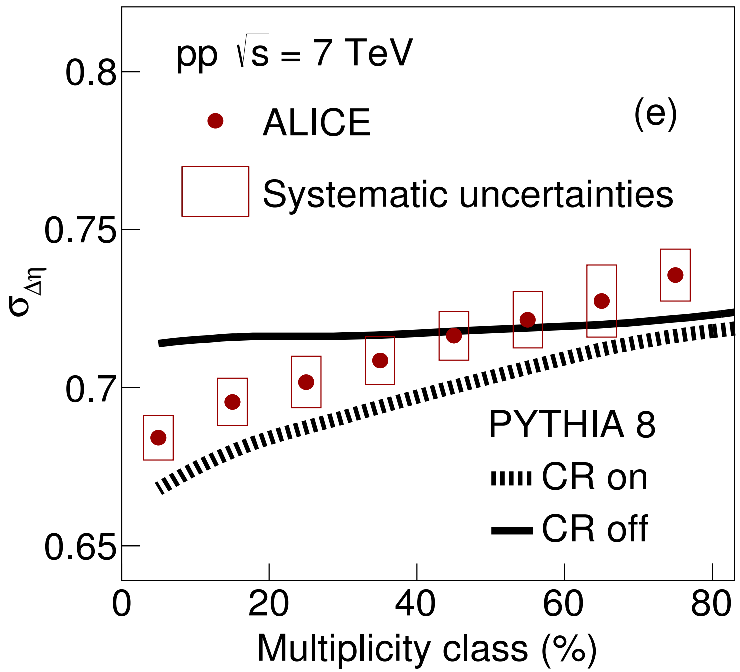
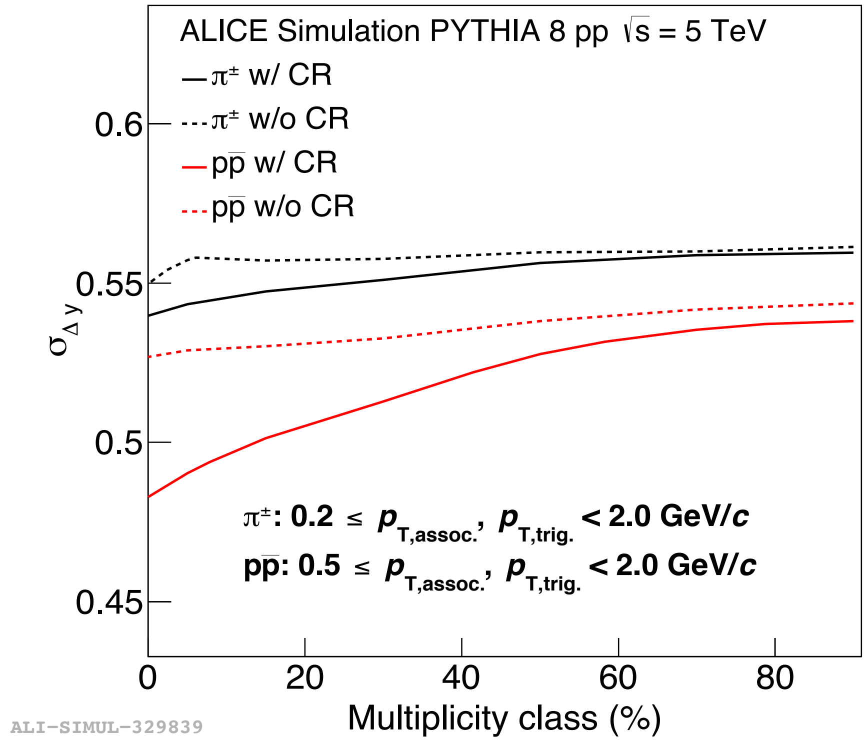


- narrowing of the balance function width with increasing multiplicity also in pp (similar to Pb-Pb)
- PYTHIA8 with color reconnection is able to describe the data qualitatively
- **<u>identified hadron studies</u>** allow a deeper investigation due to the **momentum dependence of the species on the mass**
- **<u>expectation for balance function width of identified species:</u>**

  if "radial flow-like" effects are responsible for narrowing, it should be more pronounced for heavier particles

Balance function width for identified particles: PYTHIA8 with CR and no CR



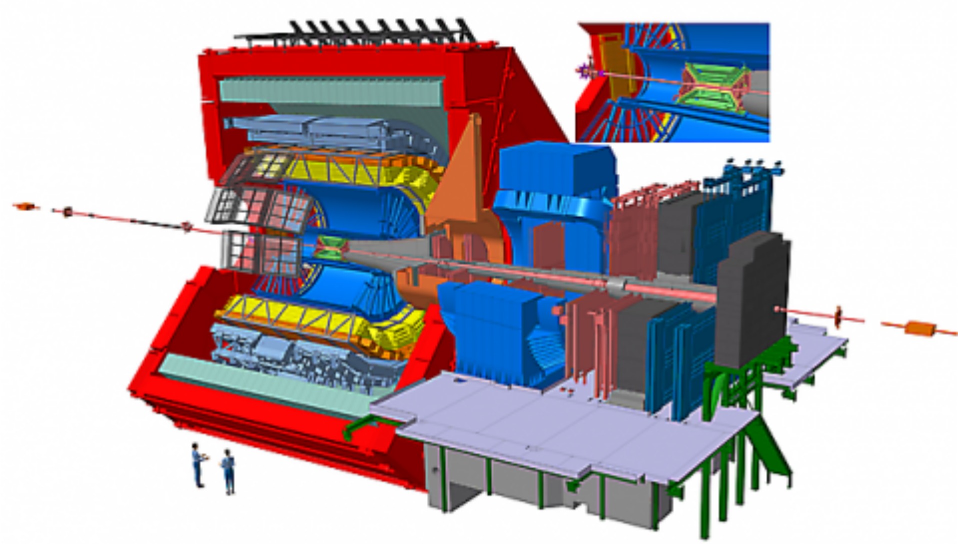
- PYTHIA8 w/o CR predicts no significant multiplicity dependence of the balance function width for pions and protons

- PYTHIA8 w/CR predicts a significant multiplicity dependence more pronounced for protons -> **in agreement with the expectation**

- **do we see the same in the data?**

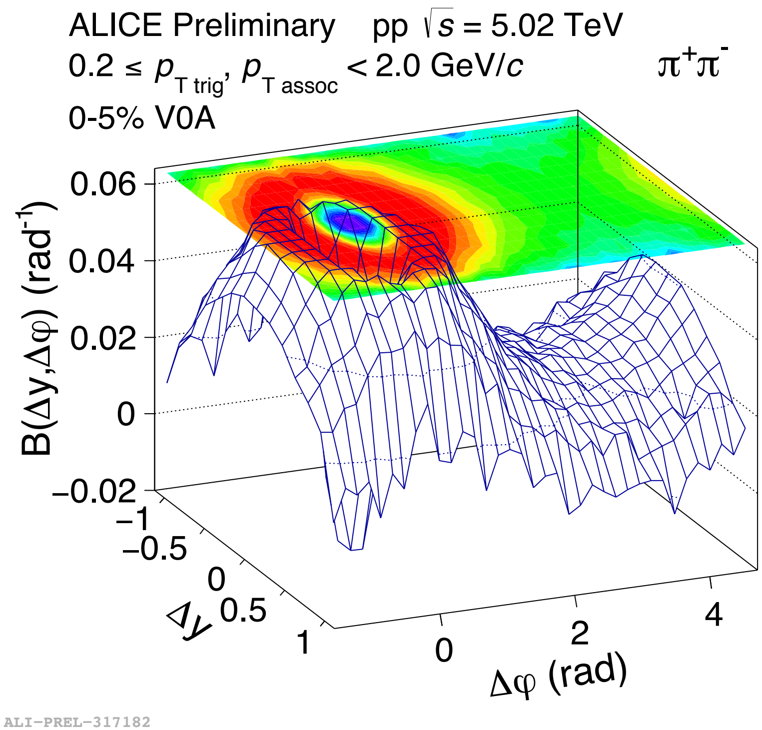
Details of analysis

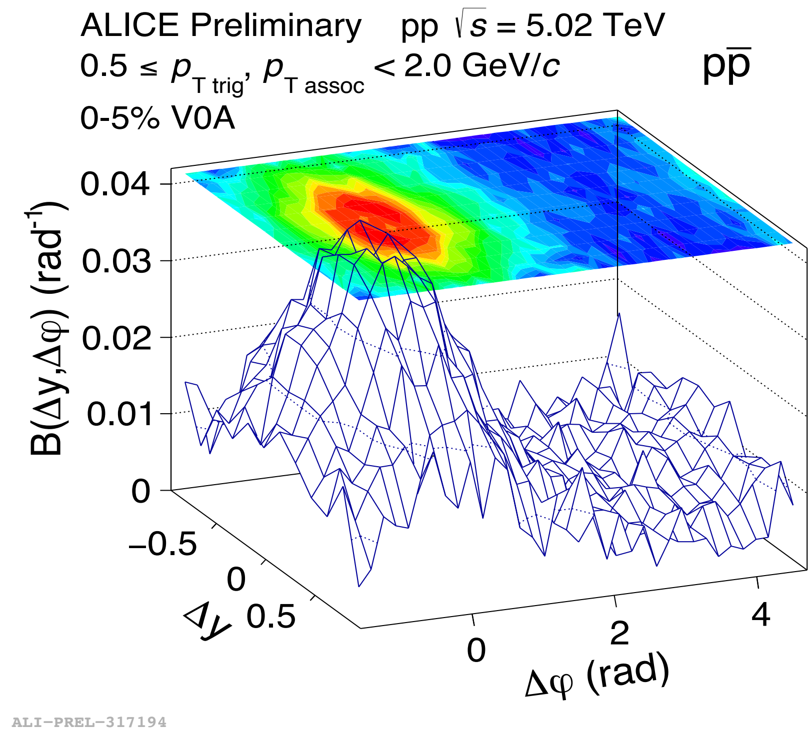
- **Data**
  - pp @ $\sqrt{s}$ = 5.02 TeV (LHC Run 2)
  - minimum bias trigger
  - 650 millions of events



- **Kinematic cuts**
  - $|y| < 0.5$
  - momentum intervals:
    - π: 0.2 – 2 GeV/c
    - p: 0.5 – 2 GeV/c due to the large secondary contamination at low p_T
- **Particle identification (PID)**
  - combined information of TPC and TOF detectors -> *purity ~ 98%*
- **Corrections (MC-based)**
  - tracking efficiency and secondary contamination
  - PID efficiency and contamination

Two-dimensional balance function results in pp

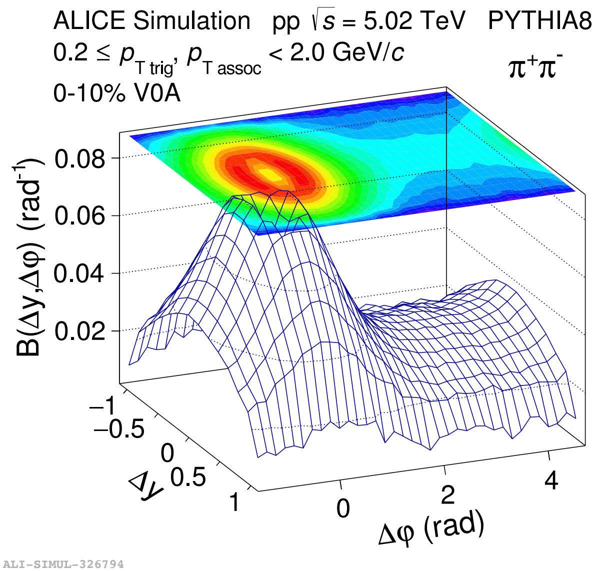




- near-side dip for pions -> originating from Hanbury Brown and Twiss (HBT) and resonances?
- the away-side is more pronounced for pions -> originating from resonances?
- <u>**what does PYTHIA8 show?**</u>

Balance function of pions in PYTHIA8 excluding resonances

0-10% multiplicity



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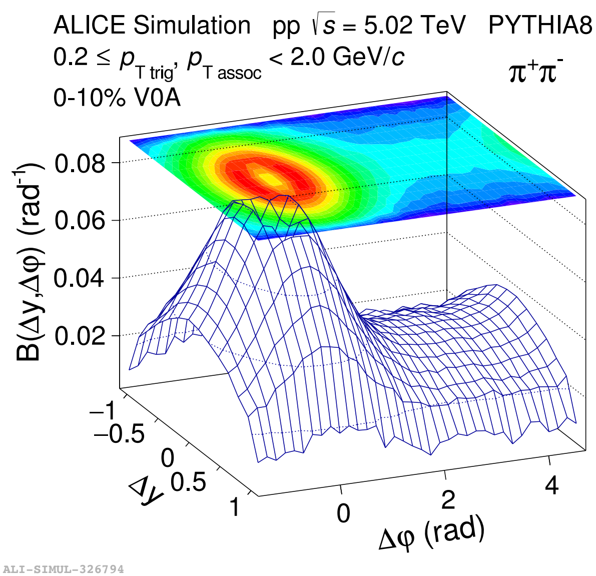

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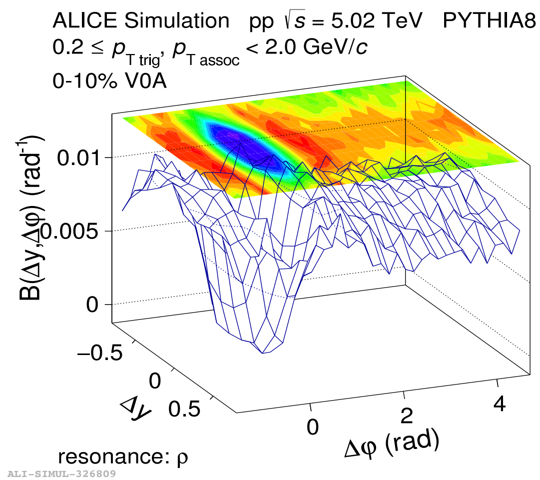

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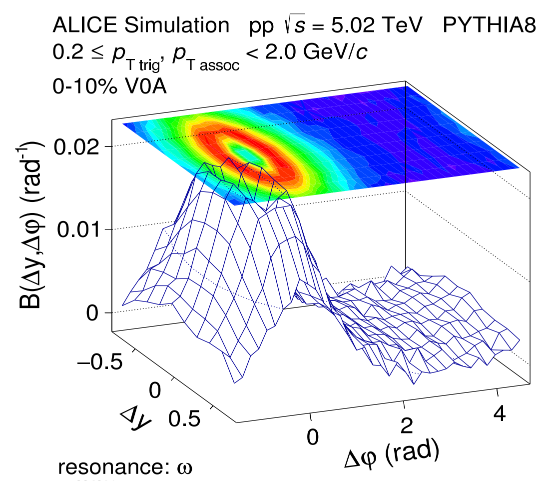

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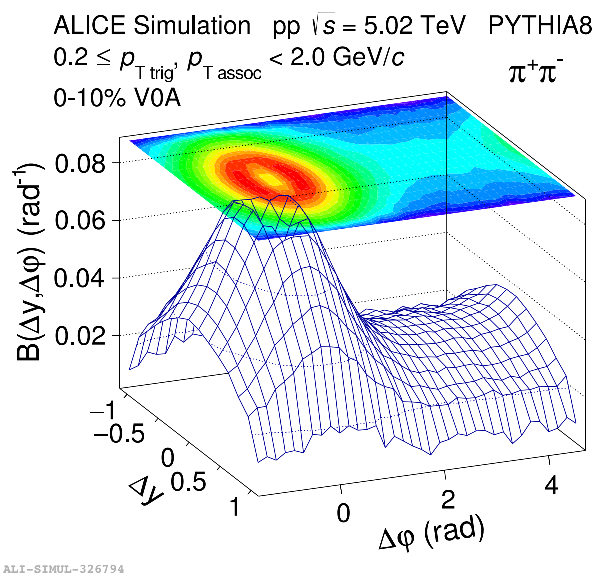

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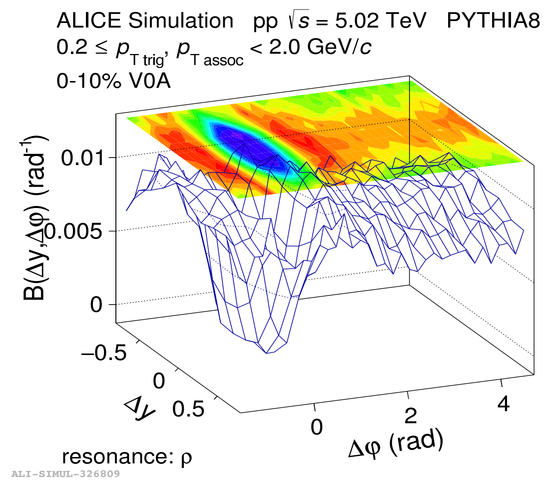

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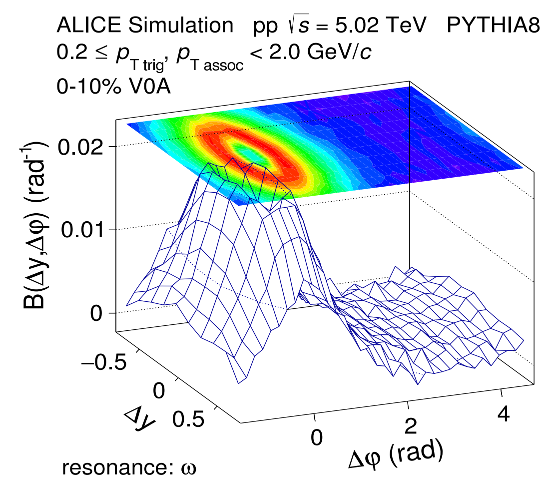

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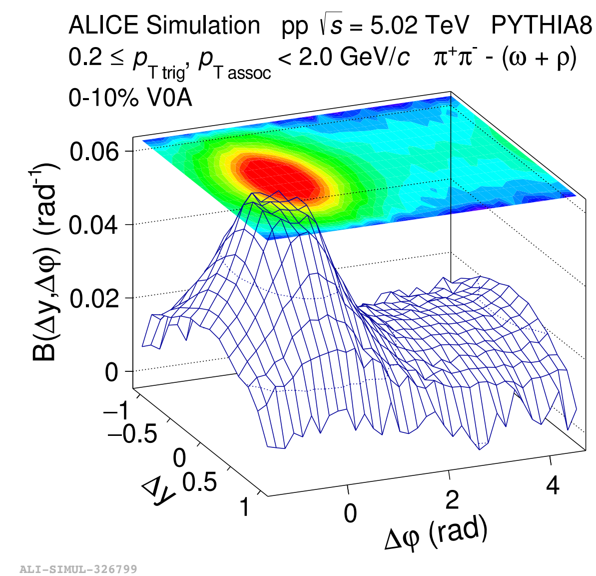
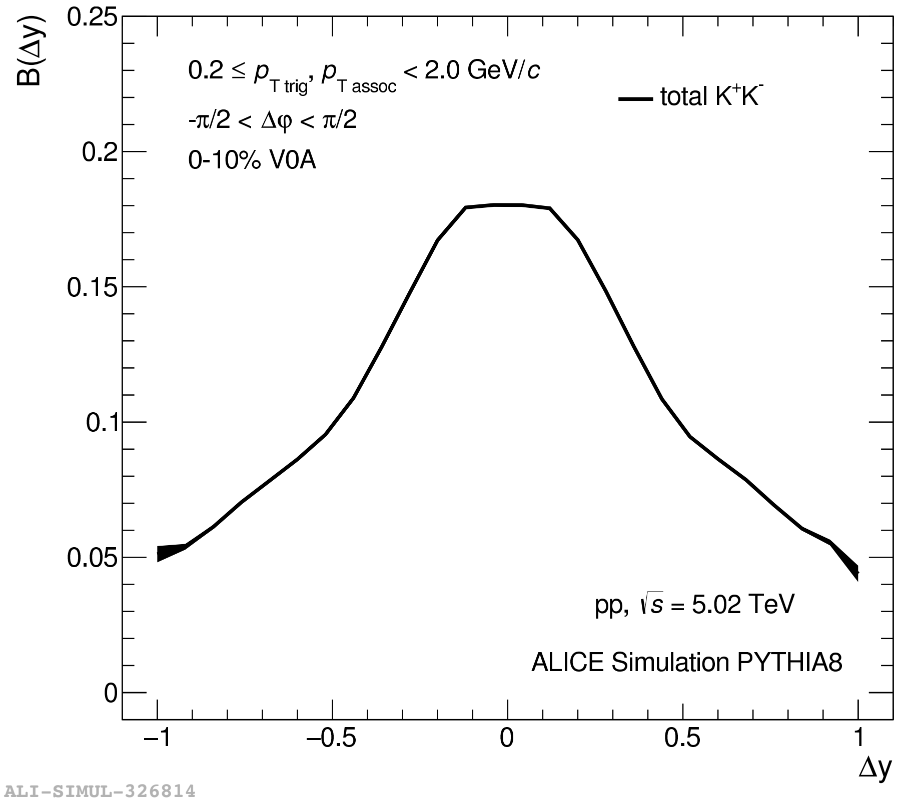
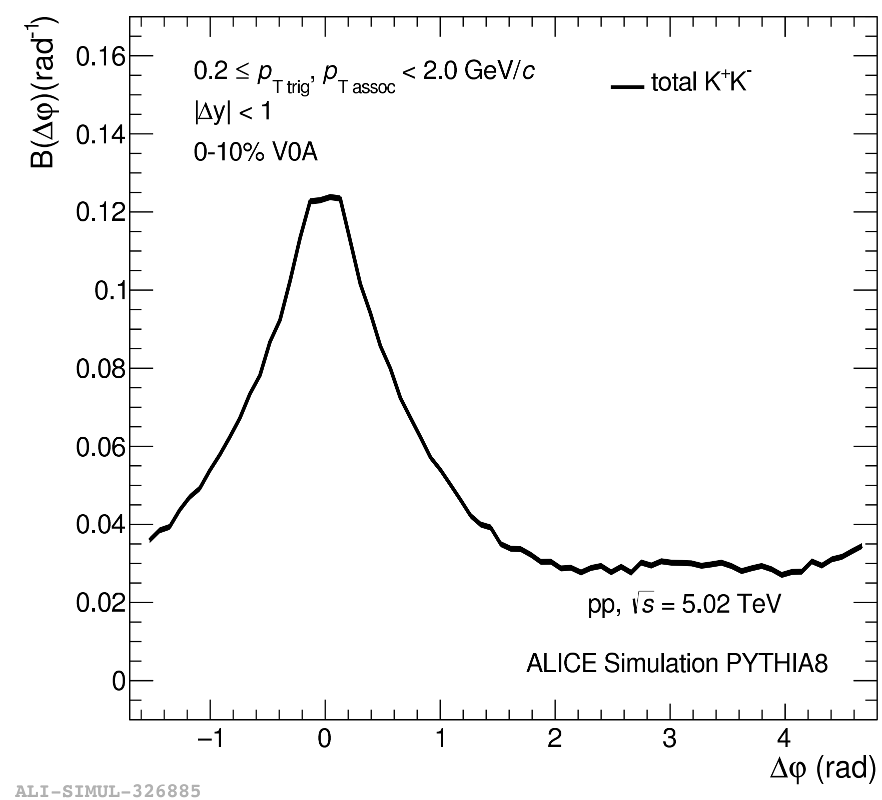


- after excluding ρ and ω the dip is not there anymore

Balance function of kaons in PYTHIA8

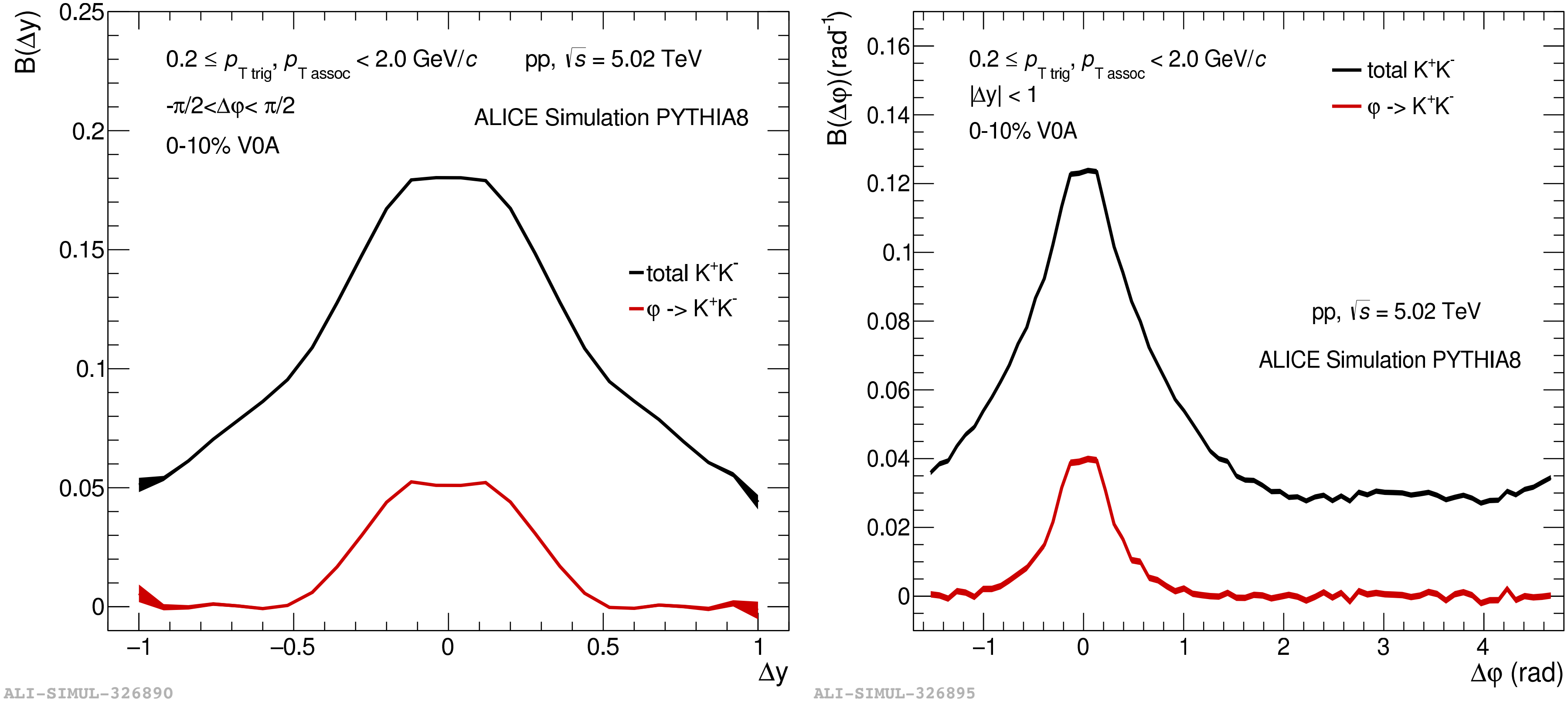
0-10% multiplicity





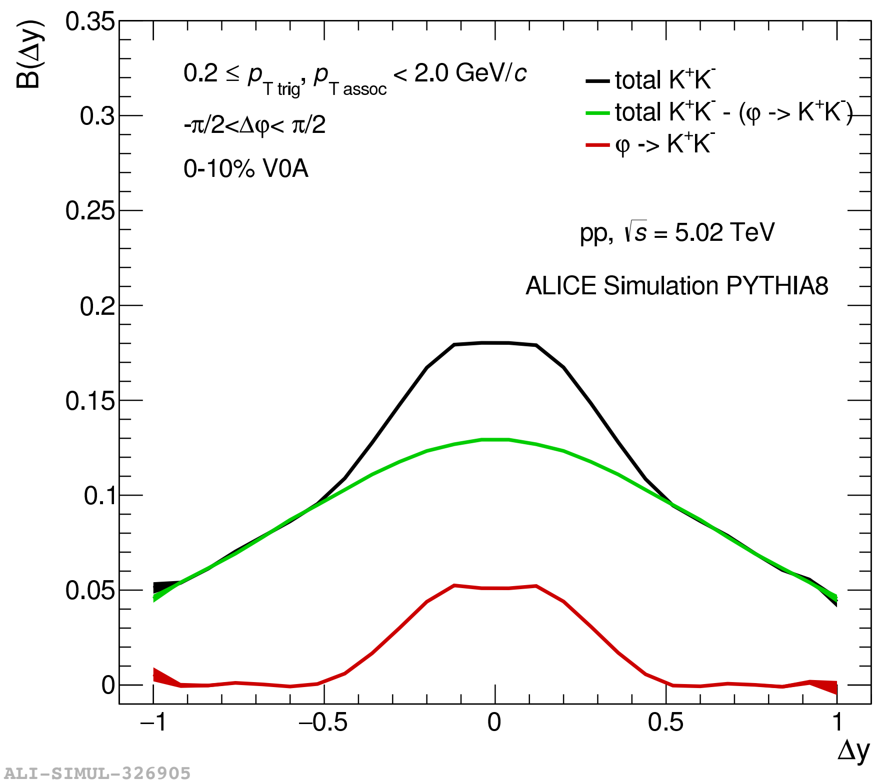
Balance function of kaons in PYTHIA8 excluding ϕ

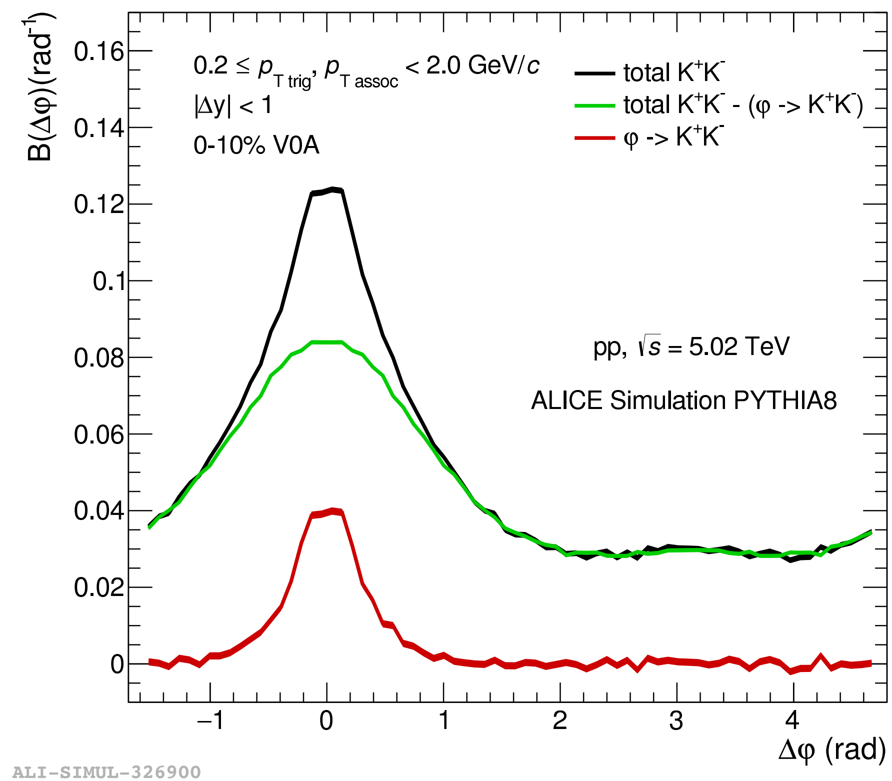
0-10% multiplicity



Balance function of kaons in PYTHIA8 excluding ϕ

0-10% multiplicity



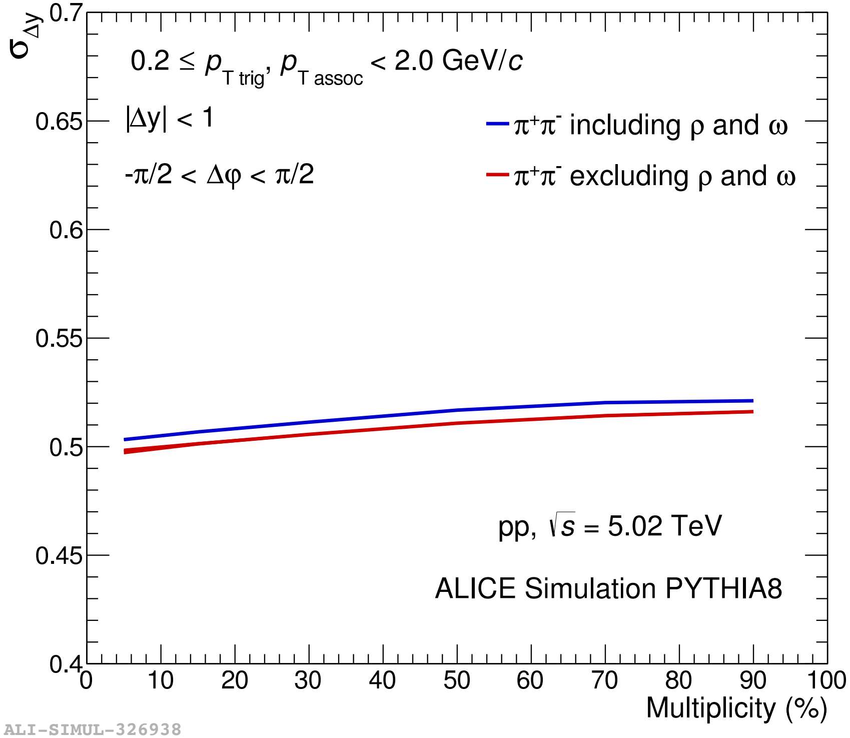


- two distinct structures are clearly seen coming from $\phi \to K^+K^-$ and the rest of the kaons
- **<u>outlook: removing $\phi \to K^+K^-$ in the data</u>**
- does resonance contribution affect narrowing of the width?

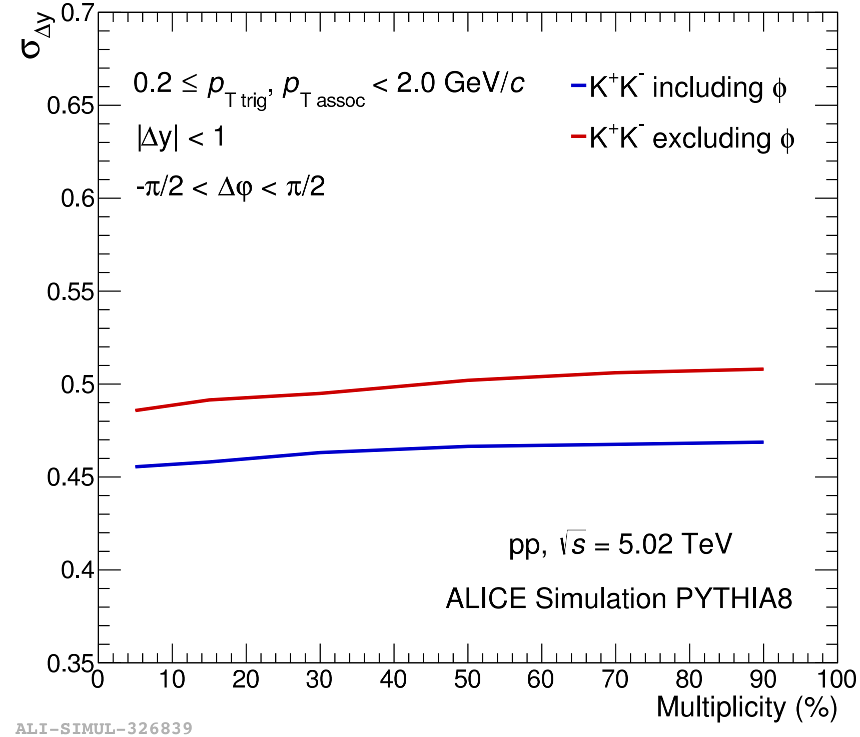
Balance function width of pions and kaons in PYTHIA8

0-10% multiplicity

π

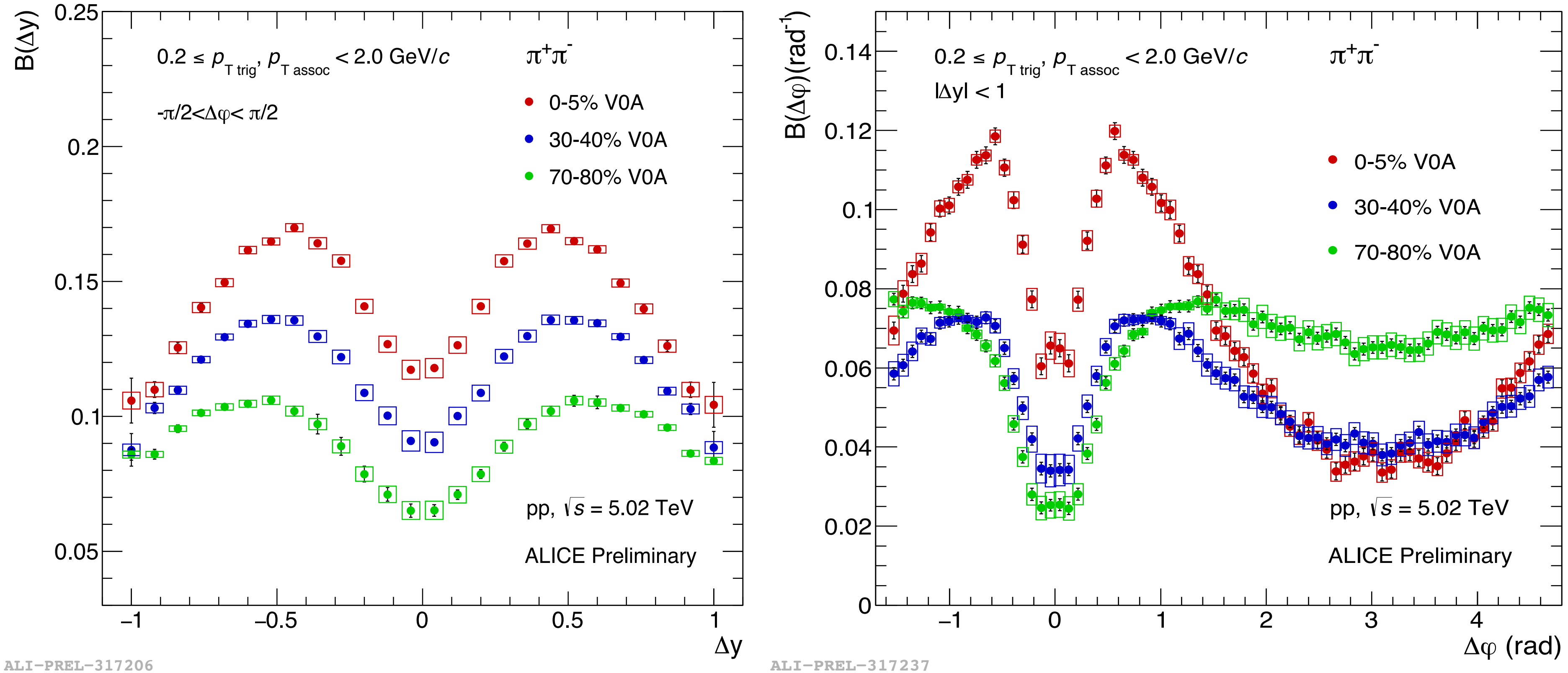


K



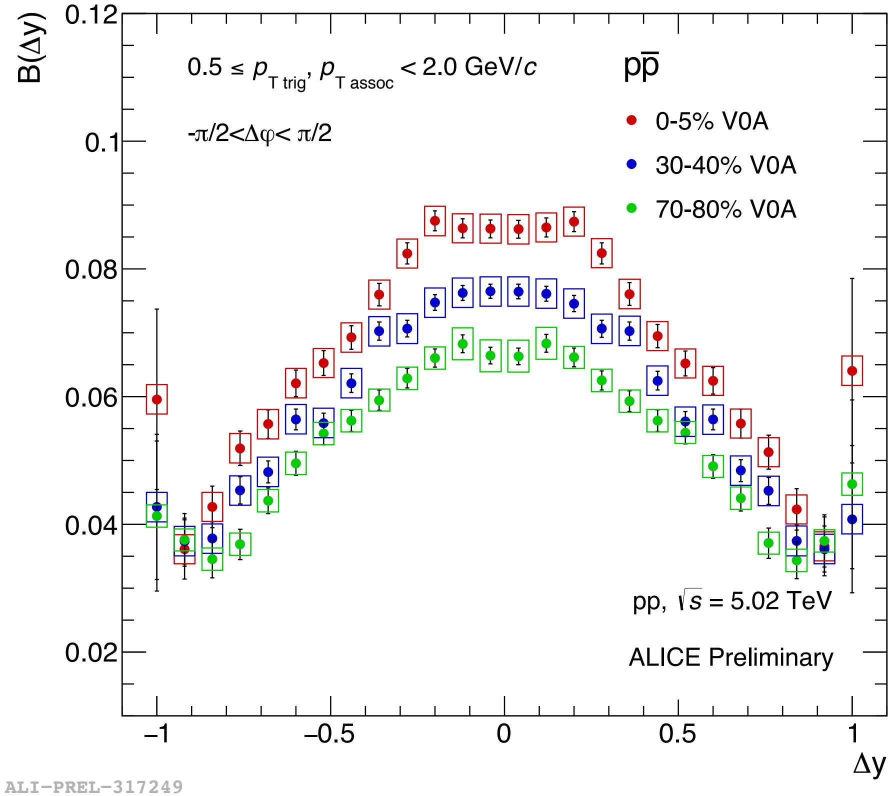
- contribution of resonances to the narrowing of the balance function width with increasing multiplicity in PYTHIA8 is irrelevant

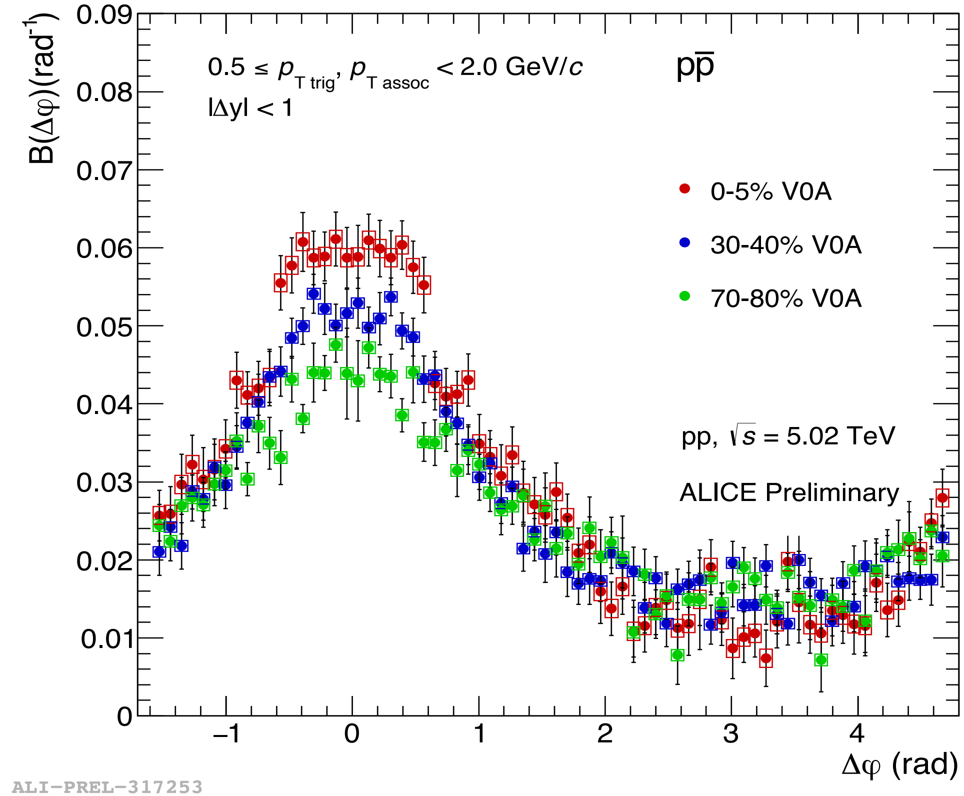
Balance function projections: pions



- reflect the structures seen in two-dimensional balance function distributions
- significant multiplicity dependence

Balance function projections: protons





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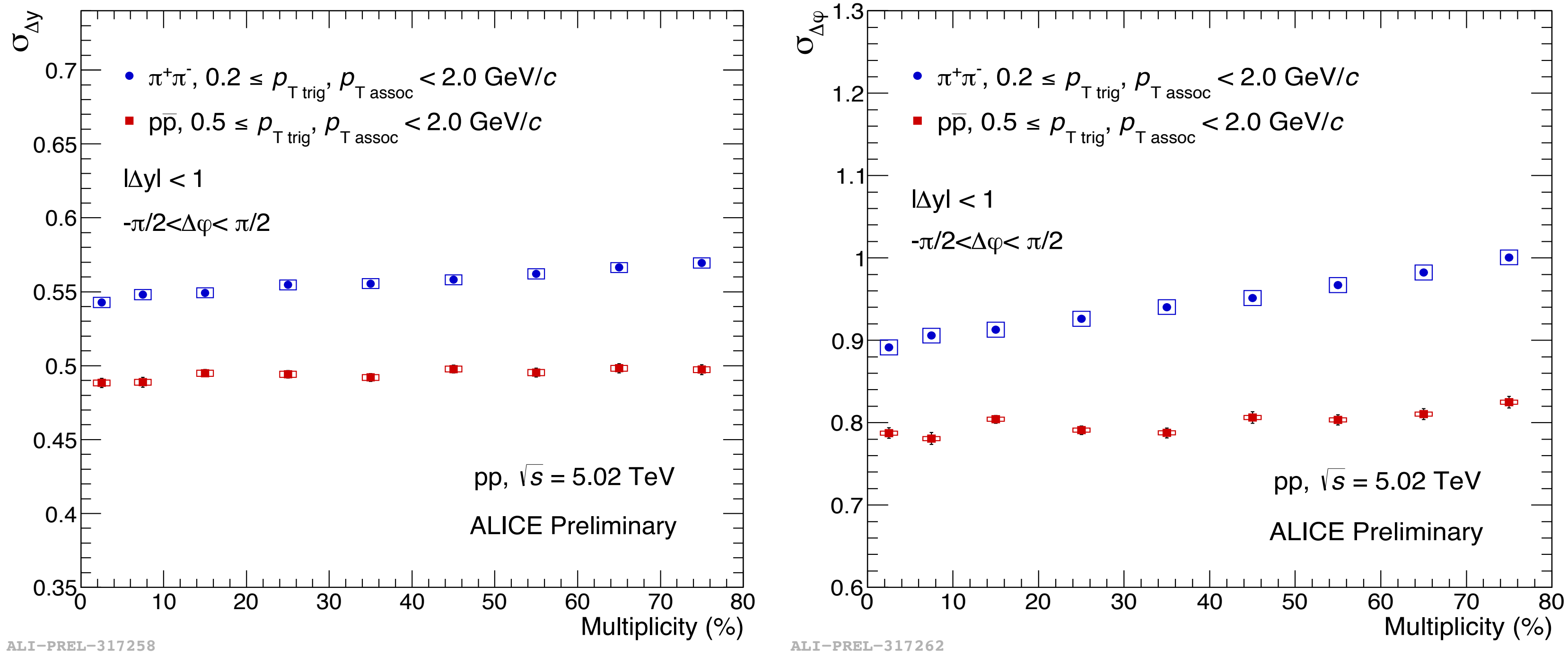
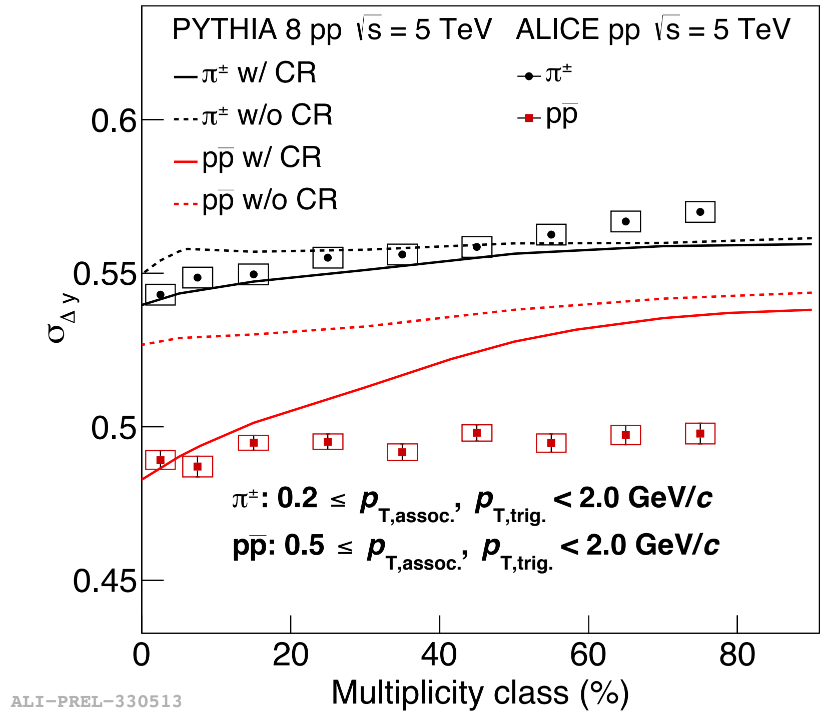
Balance function width



- clear narrowing of the balance function width with increasing multiplicity for pions is observed
- protons show flat dependence on multiplicity
- this observation is not in agreement with the assumption that radial flow-like effects should have a bigger impact on heavier particles
- **<u>physics interpretation and message</u>**: *radial flow-like effects are not the main driving force behind the narrowing of the balance function width*

Balance function width for identified particles vs PYTHIA8 with CR and no CR



- PYTHIA8 w/o CR predicts no significant multiplicity dependence of the balance function width for pions and protons
- PYTHIA8 w/CR predicts a significant multiplicity dependence more pronounced for protons
- data is not reproduced by predictions from PYTHIA8 w/o CR (pions) and with CR (protons)

<u>CR is also disfavored by data as the origin of narrowing</u>

Summary

- Balance function of identified particles allows **more detailed study of the collectivity in pp collisions**
- **Narrowing** of the balance function width with increasing multiplicity is observed **for pions** in both $\Delta\varphi$ and Δy, while **no significant narrowing is observed for protons**
- Data suggests that the narrowing of the balance function width in pp collisions is **not driven solely by the radial flow**
- **PYTHIA8 with color reconnection** predicts more pronounced decrease for heavier particles which is **not supported by data**
- Radial flow-like effects seem to be **not the main reason behind the narrowing** of the balance function width in pp collisions

Outlook

- Kaon balance function: removal of ϕ resonance contribution in the data

- Extensions that will help with understanding of hadron formation processes and provide an important input to the particle production models for pp collisions:

  - balance function yield studies
  - balance function at high p_T
  - balance function for cross correlations (πK, Kp, πp etc)

- Are particle production mechanisms the same across different collision systems? -> same studies and comparison of the results in pp, p-Pb and Pb-Pb collisions at the same energy

Thank you for attention!

Back up

Two-particle angular correlations

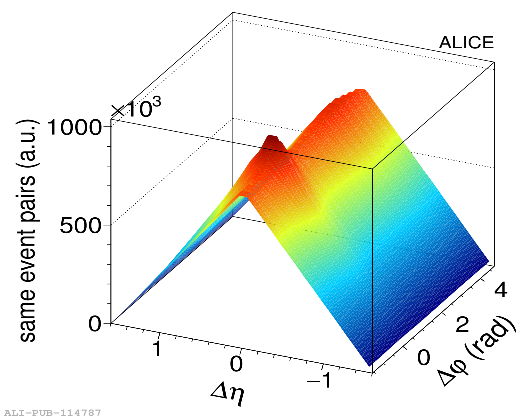
- trigger particle: $p_{T,trig}$
- assossiated particle: $p_{T,ass}$
- the associated per-trigger yield as a function of $\Delta\varphi$, $\Delta\eta$
- $\Delta\varphi = \varphi_{trig} - \varphi_{assoc}$, $\Delta\eta = \eta_{trig} - \eta_{assoc}$

$$C(\Delta\varphi,\Delta\eta) = \frac{1}{N_{trig}} \frac{d^2N_{assoc}}{d\Delta\eta d\Delta\phi} = \frac{S}{f}$$

$$S = \frac{1}{N_{trig}} \frac{d^2N_{assoc,same}}{d\Delta\eta d\Delta\phi}$$

$$f = \alpha \frac{d^2N_{assoc,mixed}}{d\Delta\eta d\Delta\phi}$$

signal



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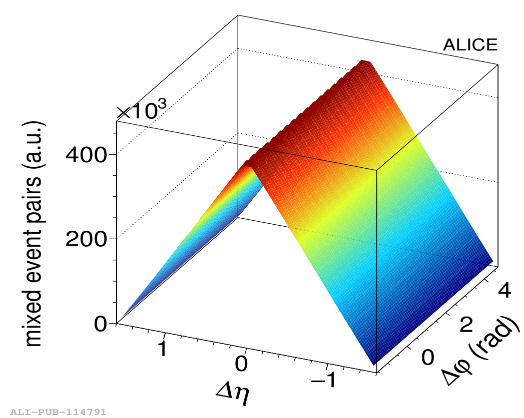
background



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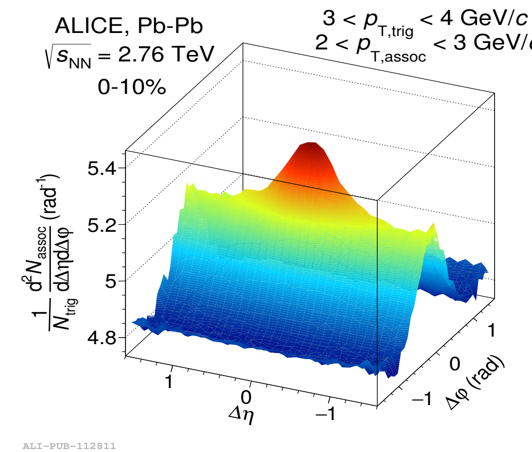


highest multiplicity
lowest multiplicity

Correction factors

$$C(p_T) = \left(\frac{1-c}{\varepsilon}\right)_{tracking} \left(\frac{1-c}{\varepsilon}\right)_{PID} \frac{1}{\varepsilon_{TOFmatch}}$$

$$S_{(+,-)} = \frac{1}{N_{trig,+}} \frac{d^2N_{same,(+,-)}}{d\Delta\eta d\Delta\varphi}$$

$$f_{(+,-)} = \alpha \frac{d^2N_{mixed,(+,-)}}{d\Delta\eta d\Delta\varphi}$$

Tracking efficiency:
Number of reconstructed π (K, p) / generated π (K, p)

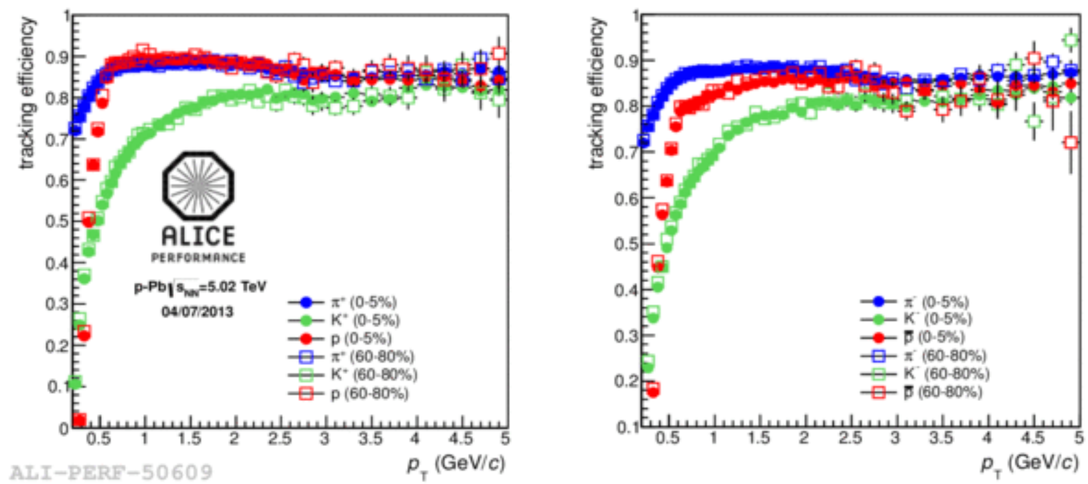
Secondary contaminations:
Number of secondary π (K, p) / primary + secondary π (K, p)

PID efficiency:
Number of true ID π (K, p) / number of true reconstructed π (K, p)

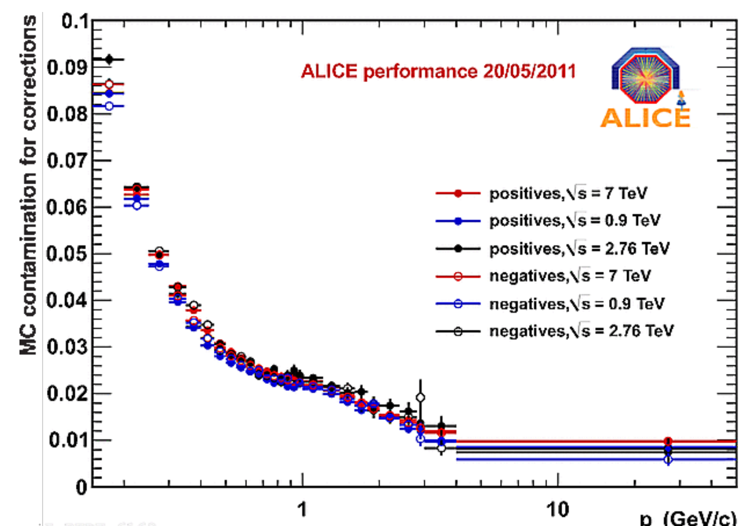
PID contamination:
Number of false ID π (K, p) / number of all ID π (K, p)

TOF matching efficiency:
Number of π (K, p) reconstructed in TOF / Number of π (K, p) reconstructed in TPC

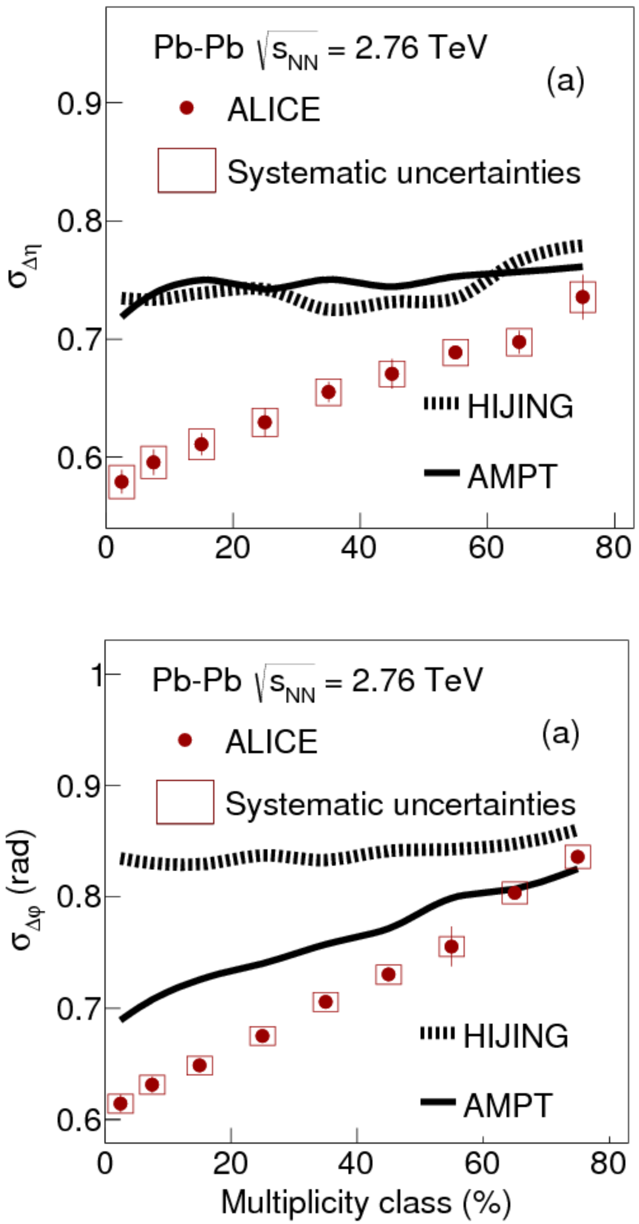
efficiency



contamination



Balance function Pb-Pb results (low p_T)



- A significant narrowing of balance function with increasing multiplicity in low p_T (0.2 – 2 GeV/c)
- The effect of radial flow which is larger for central collisions
- Results compared to model calculations which use the principles of hydrodynamics: HIJING and AMPT
- AMPT qualitatively reproduces the narrowing in $\sigma_{\Delta\phi}$
- Strong multiplicity-dependent radial flow in the AMPT

arXiv:1509.07255 [nucl-ex]

2D per-trigger yield (0-80%)

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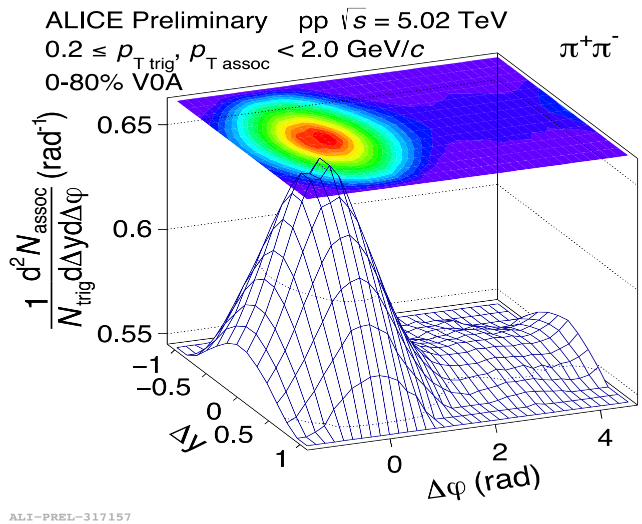

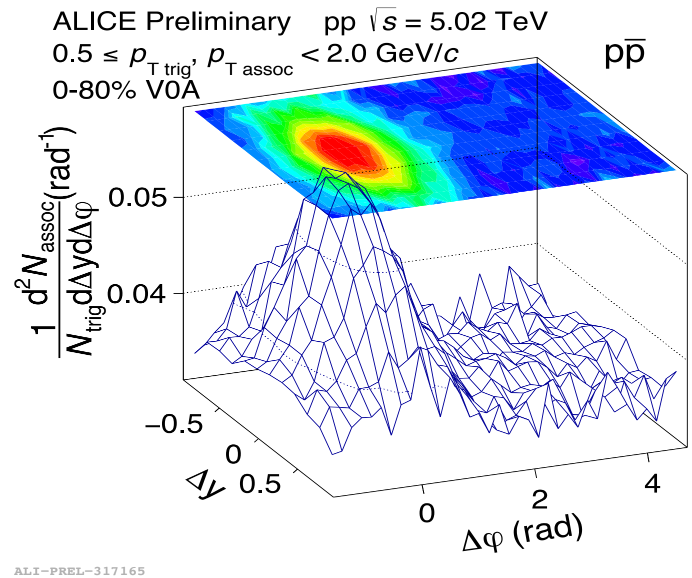

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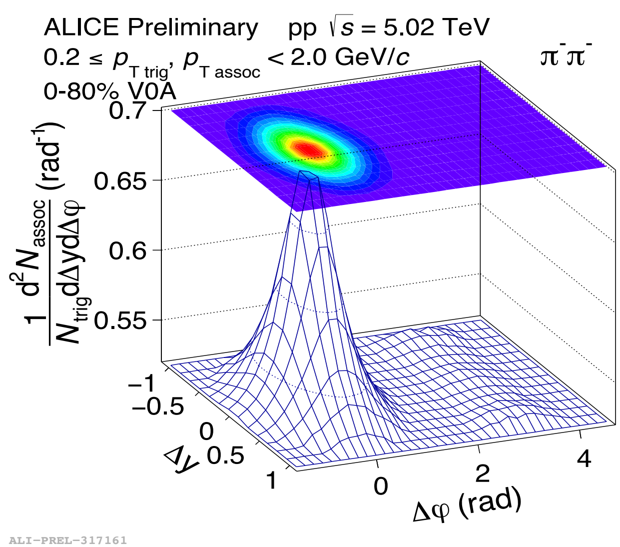
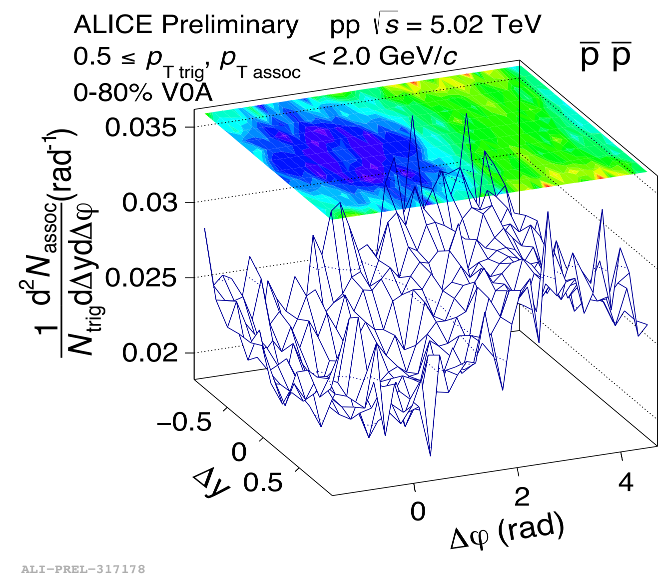
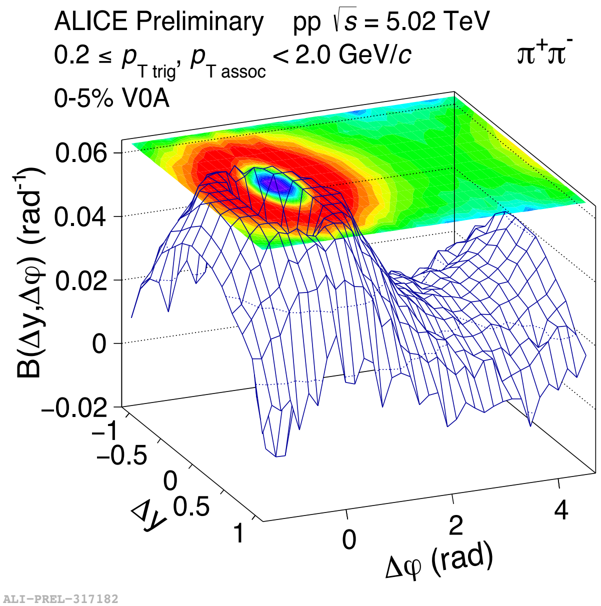
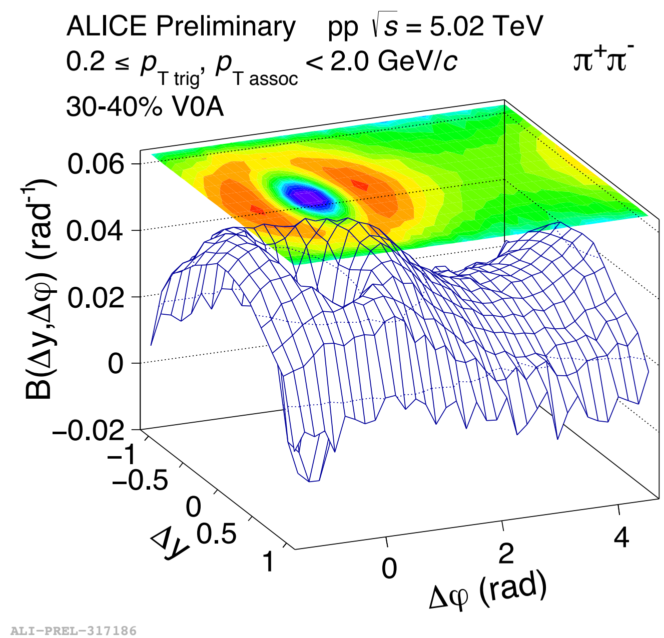


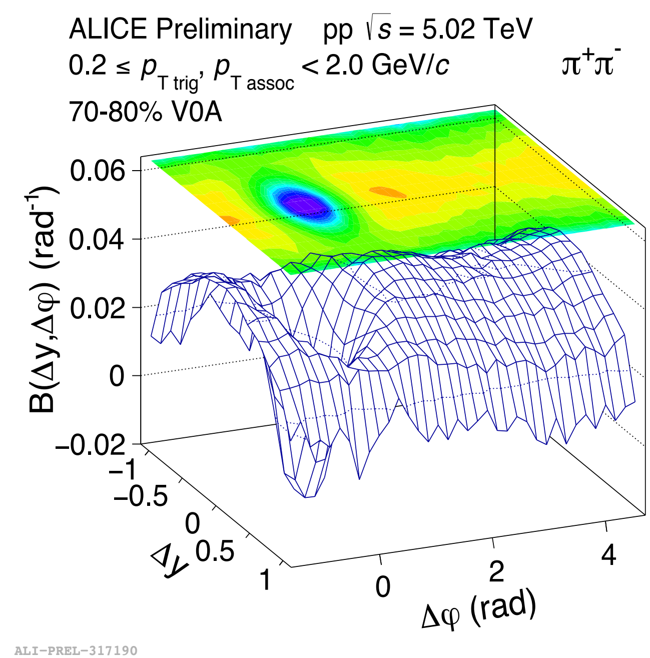


- similar characteristic structures: near-side jet peak and away-side jet ridge
  - near-side dip for antiprotons

2D Balance function: pions

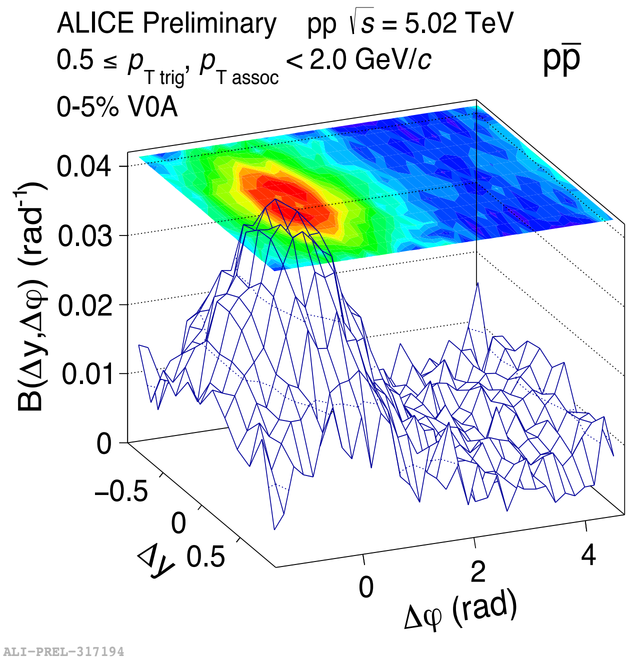


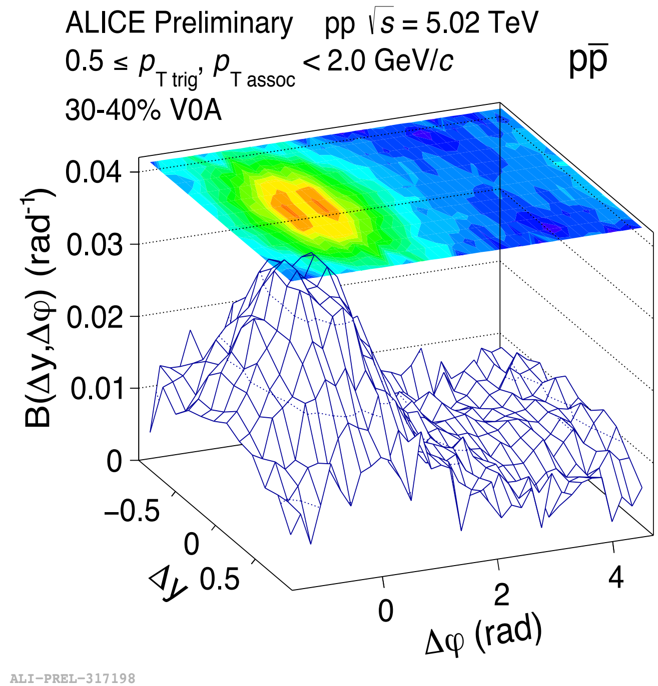


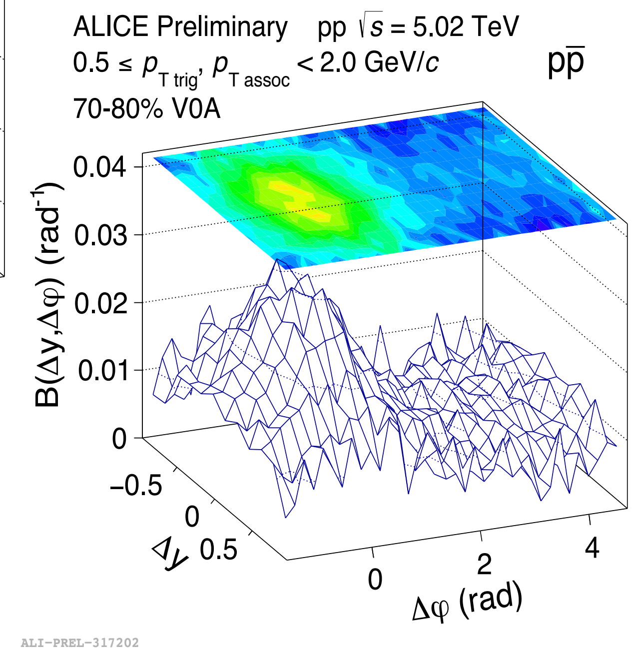


- near-side dip originating from HBT (?) -> more pronounced for low multiplicity
  - the magnitude of the away-side becomes larger for low multiplicity

2D Balance function: protons







- no near-side dip as for pions