Identified Two-particle Correlations and Quantum Number Conservation in p-p, p-Pb and Pb-Pb Collisions at LHC Energies*

Gyula Bencédi[1],
Gergely Gábor Barnaföldi[1],
Levente Molnár[2]

[1] Wigner Research Centre for Physics, Budapest, Hungary
[2] Institut Pluridisciplinaire Hubert Curien, Strasbourg, France

*http://arxiv.org/abs/1309.5880arXiv:1309.5880 [nucl-ex]
http://arxiv.org/abs/1403.0117arXiv:1403.0117 [hep-ex]

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Outline

1. Motivation

- importance of particle correlations at high-p_T

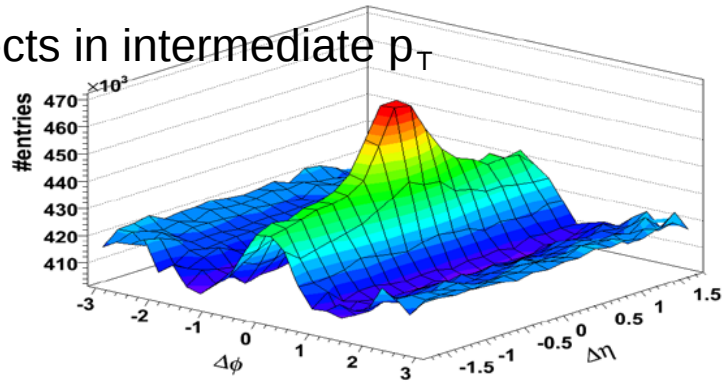
2. Monte Carlo studies of two-particle correlations in terms of quantum number conservations

- Focusing on identified associated particle spectra
- Identified particle yields from like-sign and unlike-sign correlations
- Comparison of triggered relative yields in p-p, Pb-Pb
  - Collision energy (p-p)
  - Event multiplicity (p-p)
  - Centrality (Pb-Pb)

3. Summary, Outlook

1. Importance of particle correlations at high p_T

- **Hadronization in QGP**
  - High-p_T hadrons, particle ratios, collective effects
  - High-p_T factorization holds: PDF x pQCD x FF + jet quenching HI (PID?)
  - Intermediate p_T: recombination rises
- Fragmentation effects, including PID: recombination effects in intermediate p_T (R_{CP},$R_{AA,}$Barion/Meson,v_2)
- Jet-like correlations: ridge (AuAu,dAu,pPb)
  - PID could shed light on formation mechanism...

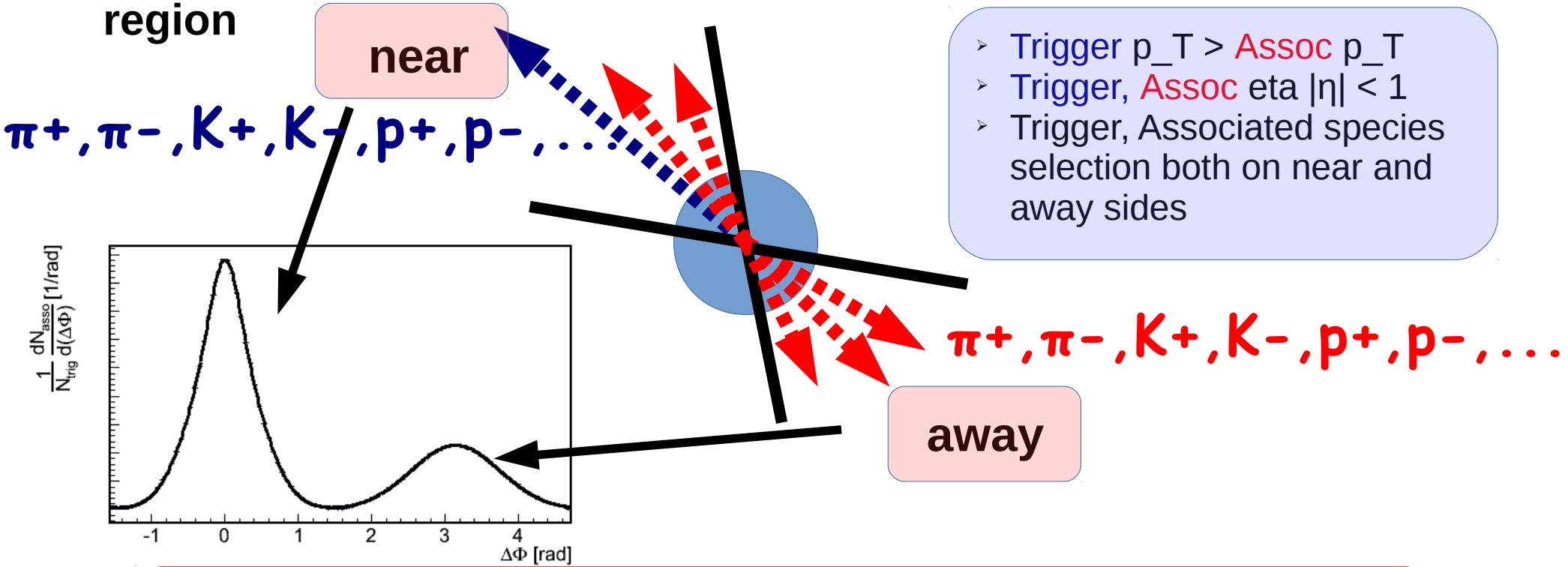


- **Quantum number conservations:**
  - The measured **hadron spectra** and extracted **fragmentation functions** are **integrated** distributions:
    - convolution of initial state, QCD and final state effects of high energy collisions
  - One **way to decouple** the specific **hadronization contributions** is
    - to test the **conservation of quantum numbers** by tracing the baryon number and flavor-specific emission patterns of hadrons from the partonic medium

2. Quantum number conservation in correlations

Identified two-particle azimuthal correlations

- Identified **triggers**, identified **associateds** integrated in **mid-rapidity region**



- Trigger p_T > Assoc p_T
- Trigger, Assoc eta |η| < 1
- Trigger, Associated species selection both on near and away sides

Expectation: conservation of quantum numbers

π,K,p – momentum p, charge Q (+K strangeness, +p baryon number)

Fragmentation / hadronization for different particle flavours

2. Quantum number conservation in correlations

Monte Carlo datasets and analysis cuts

Collision system	$\sqrt{s}$ ($\sqrt{s_{NN}}$)	Statistics
p-p	14 TeV	500 M
p-p	7 TeV	100 M
p-p	2.76 TeV	100 M
p-p	200 GeV	500 M
Pb-Pb (0-10%)	2.76 TeV	4 M
Pb-Pb (30-40%)	2.76 TeV	2 M
Pb-Pb (80-90%)	2.76 TeV	10 M
p-Pb (min.bias)	5.02 TeV	10 M

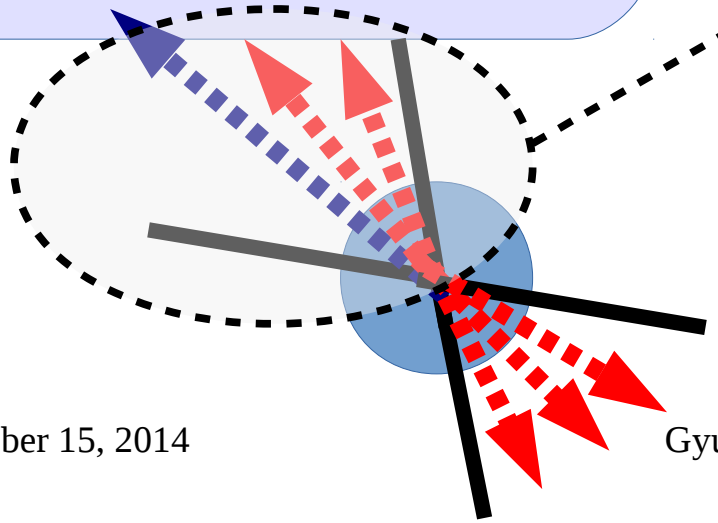
- p-p events generated by PYTHIA8 (tune 4C)
- Pb-Pb and p-Pb events generated by HIJING
- only charged, final-state particles ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, and the charged hadrons ($h^{\pm}$)
- $|\eta_{trig}| > 1$ and $|\eta_{assoc}| > 1$ were rejected
- transverse momenta of the trigger particles selected within 2 GeV/c $< p_{T,trig} <$ 25 GeV/c
- $p_{T,assoc} < p_{T,trig}$ to avoid double counting
- p_T spectra were projected within $|\Delta\eta| < 1$

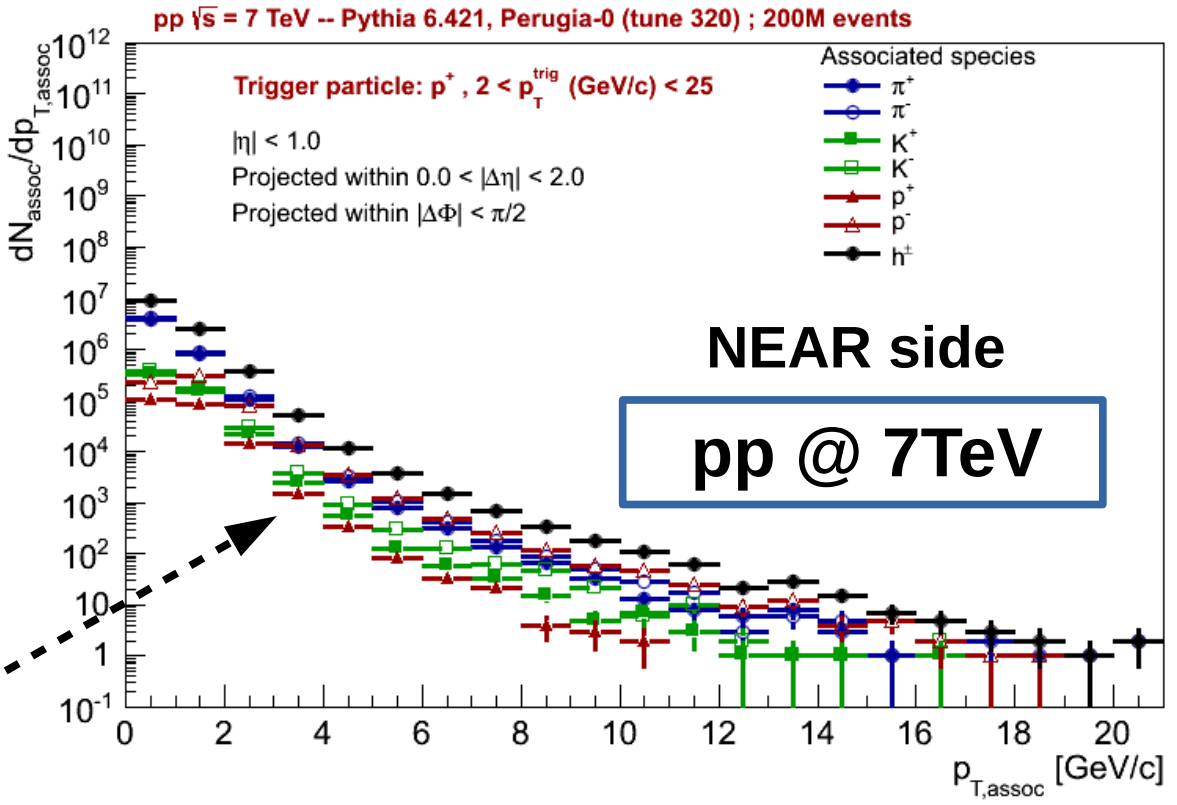
2. Quantum number conservation in correlations

Identified associated particle spectra, $dN_{assoc}/dp_{T,assoc}$

Example – NEAR side

- Trigger particle: proton in $2 < p_T$ [GeV/c] < 25 range
- PID-PID associated p_T spectra up to high-p_T
- p-p @ 7TeV, Pythia6 (tune320)
- Associated: π+,π-,K+,K-,p,pbar
- Acceptance: |η|<1.





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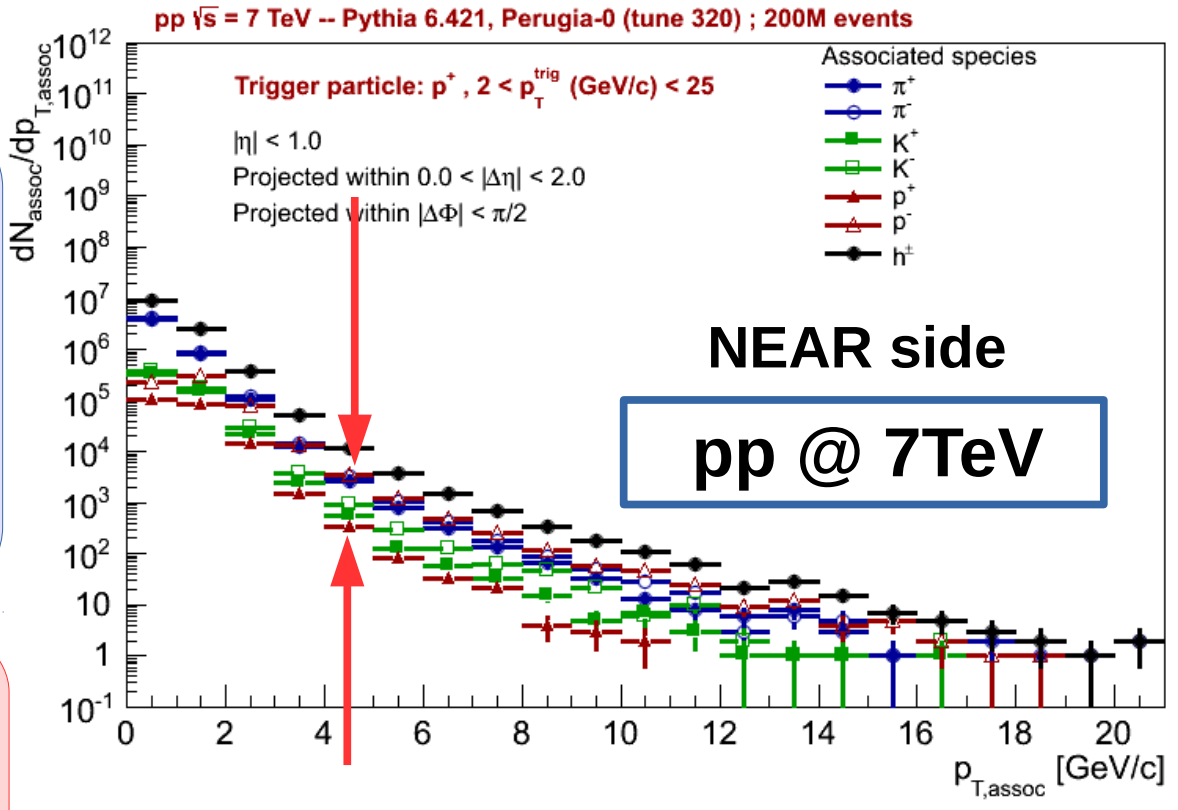
- Observation:
  differences between proton/anti-proton triggered associated yields

  Strong effect on the near side



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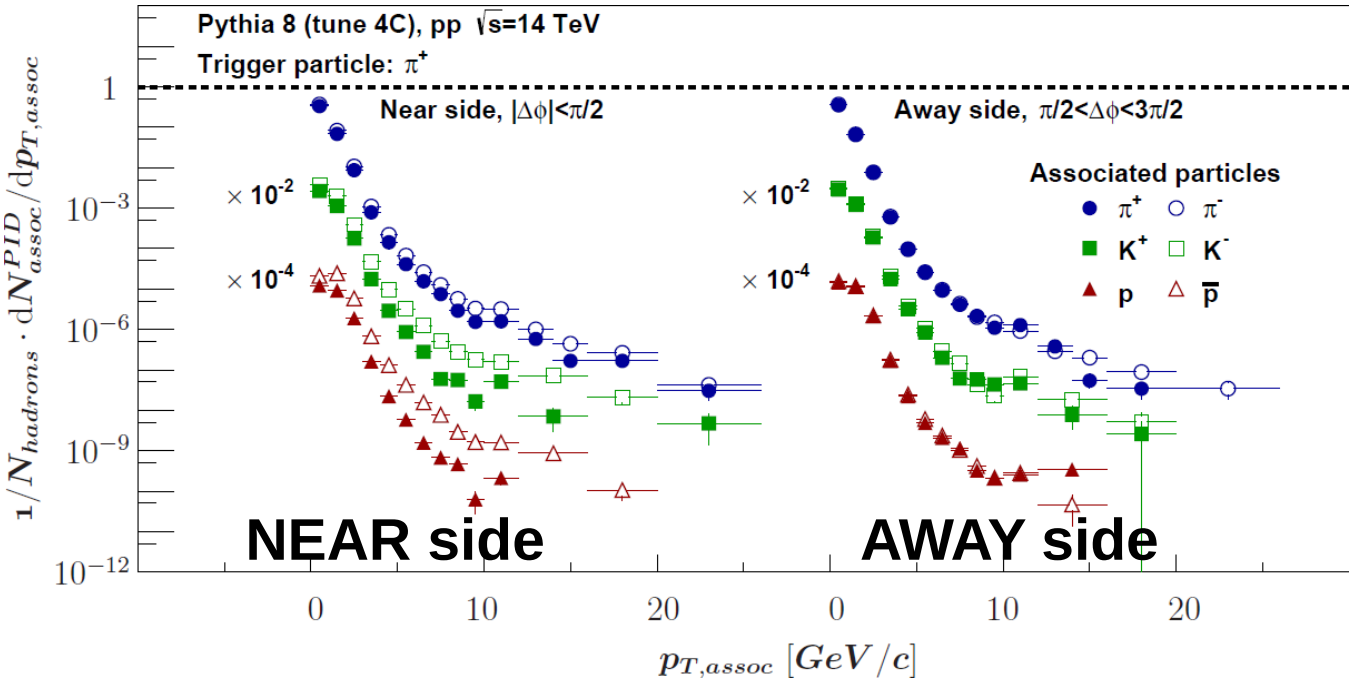
Identified associated particle spectra II.

- Quantum number conservation can be tested by plotting the identified associated spectra for identified trigger hadrons
- **Effect is on the NEAR side**
- The yields of the PID-associated spectra significantly decrease with the selection of charged pion, kaon and proton triggers, respectively
- The basic conservation laws of the quantum numbers – such as **charge (Q), baryon number (B), and strangeness (S)** – are fulfilled and could be reflected in the PID-associated spectra after the hadronization process



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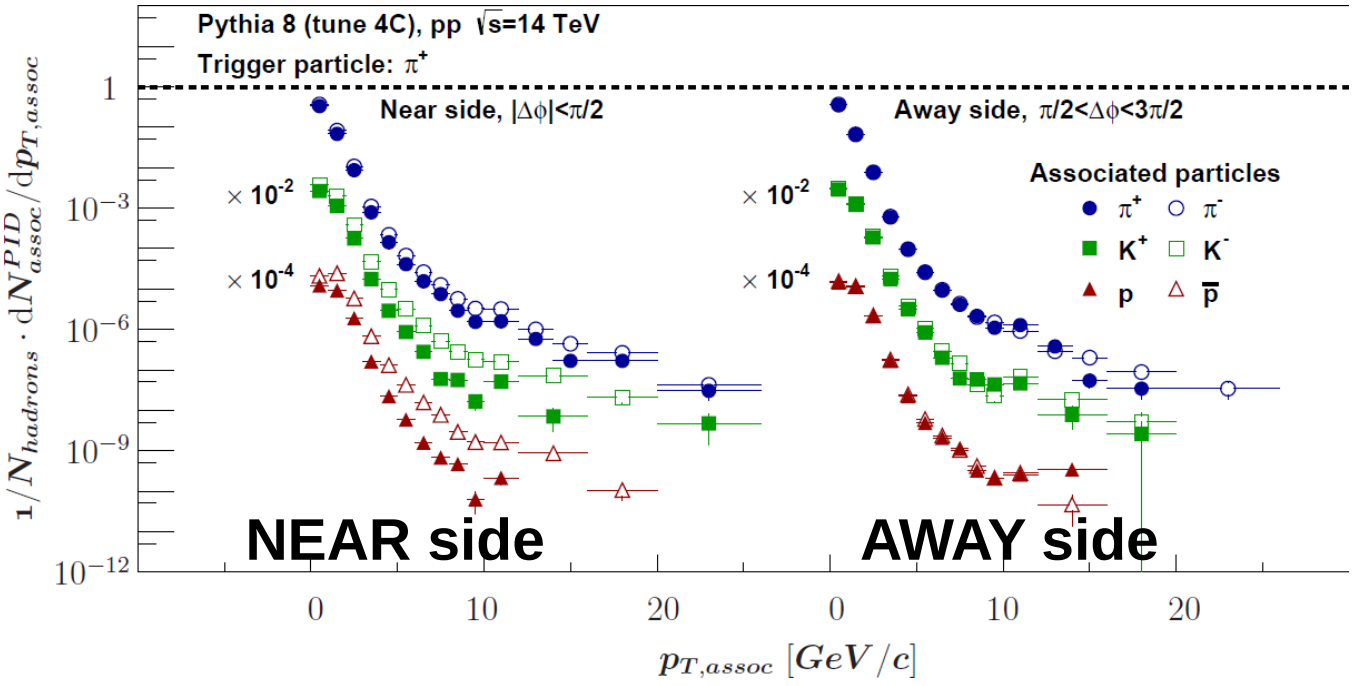


Trigger / Assoc	Strength of effect	
	Near side	Away side
π^+ / (π^+, π^-)	~ 2	~ 1
K^+ / (K^+, K^-)	~ 5	~ 1
p / $(p, \bar{p})$	~ 10	~ 1

2. Quantum number conservation in correlations

Identified associated particle ratios – a closer look

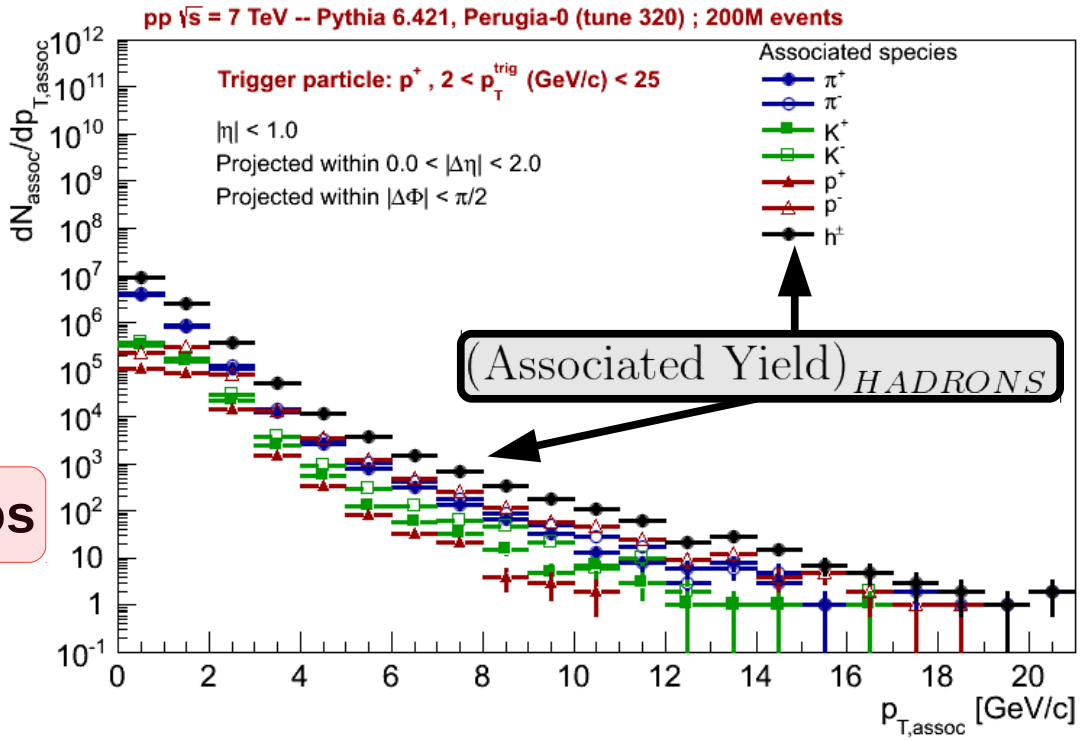
$$\frac{\frac{1}{N^{i}_{trig}} \times \frac{dN_{assoc}}{dp_{T,assoc}}}{\frac{1}{N^{j}_{trig}} \times \frac{dN_{assoc}}{dp_{T,assoc}}},$$

$$i \in \{\pi^{\pm}, K^{\pm}, p^{\pm}, h^{\pm}\}, \qquad j \in \{h^{\pm}\}$$

$$\frac{(\text{Associated Yield})_{PID}}{(\text{Associated Yield})_{HADRONS}}$$

=

Identified associated particle ratios



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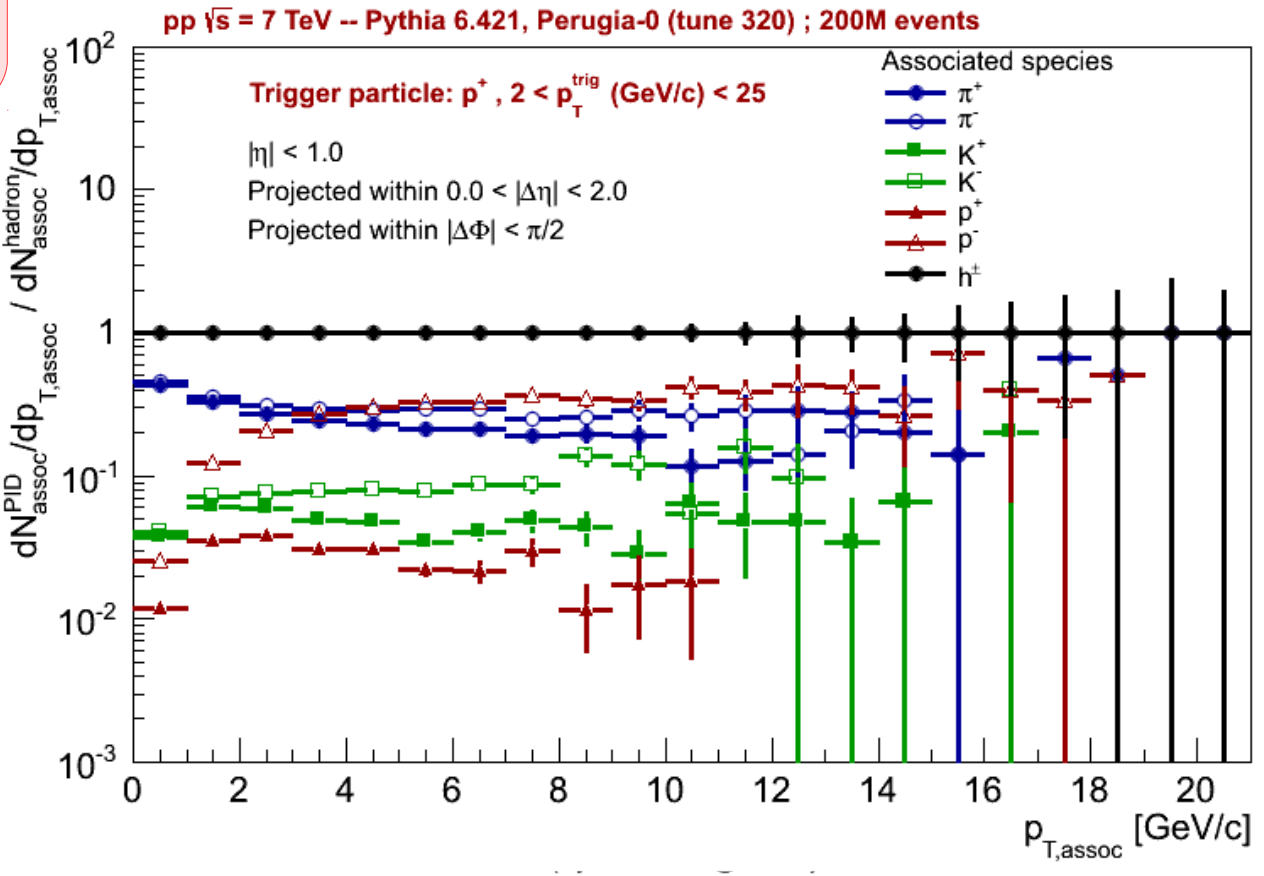
- **pp @ 7TeV, PYTHIA 6 (tune 320)**
- |Δφ| < pi/2, |Δη| < 2.
- Trigger particle: proton
  - in 2<p_T (GeV/c)<25
- Associateds:π+,π-,K+,K-,p,pbar
- Acceptance: |η|<1
- In an unmodified fragmentation process the baryon number and charge is conserved and leads to highly correlated distributions in the same phase space



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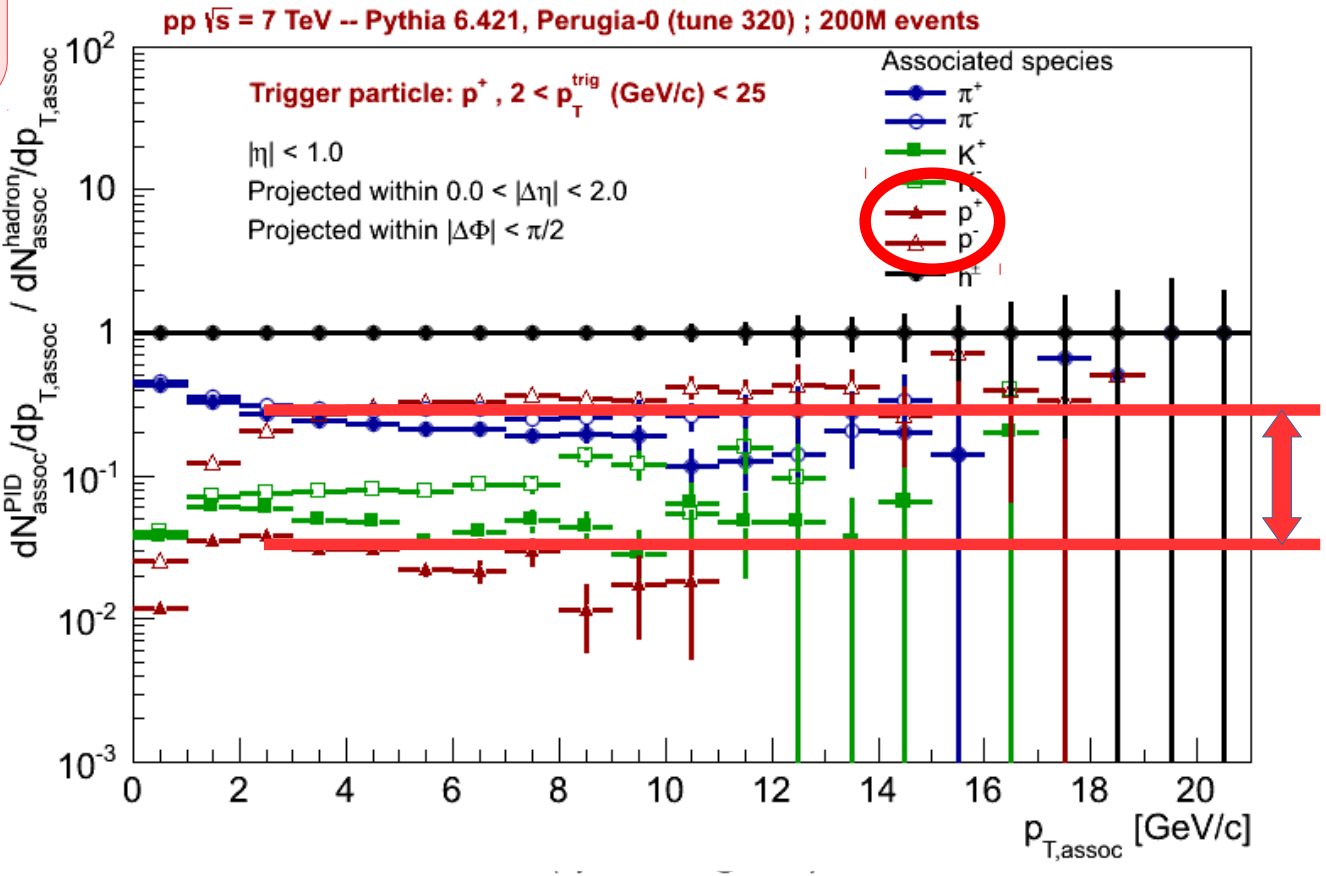


2. Quantum number conservation in correlations

Identified particle yields from like-sign and unlike-sign correlations in pp and PbPb collisions

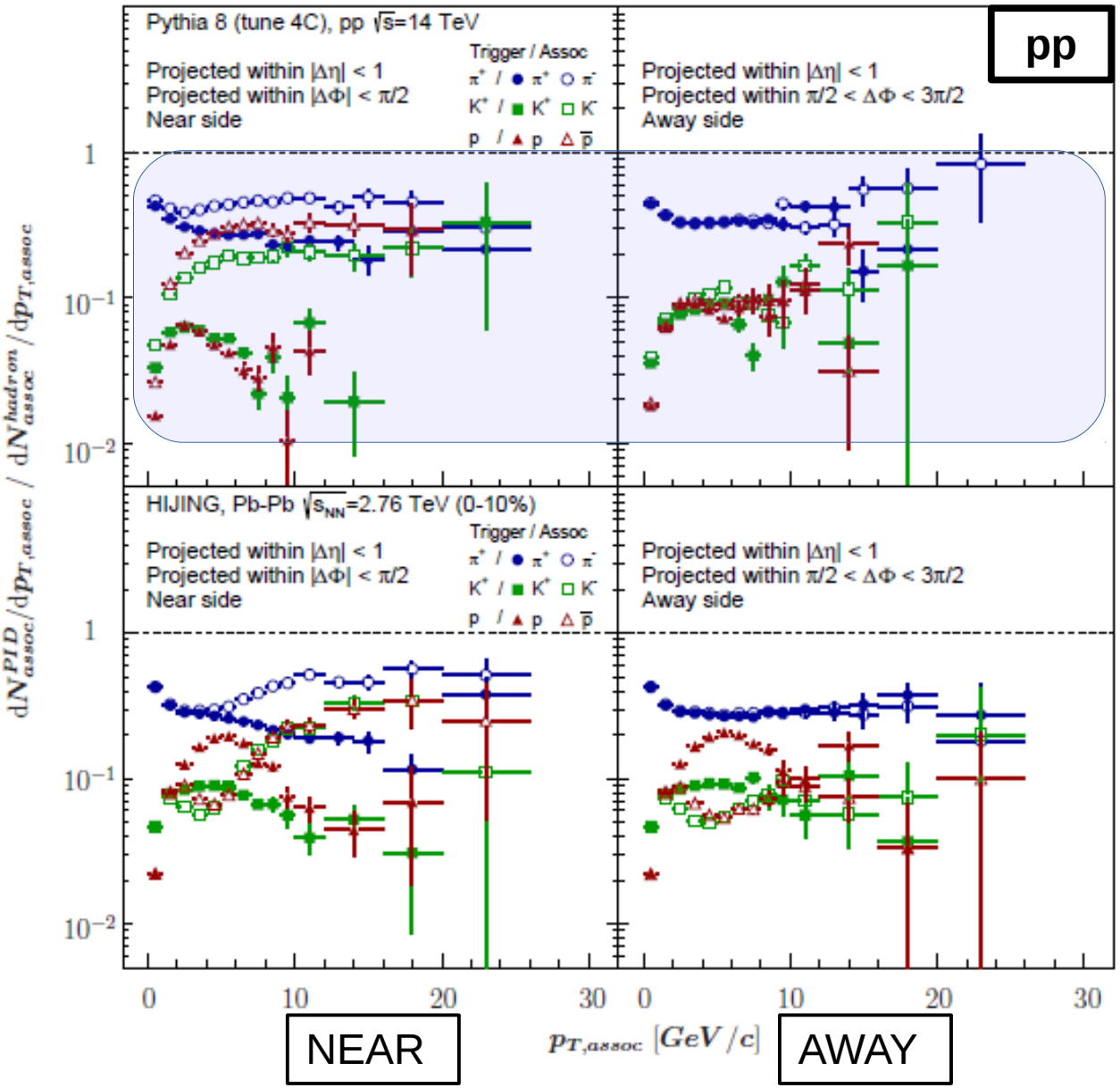
- To extract and enhance the expected quantum number conservation effects, the **ratio** of the PID-triggered-to-charged **hadron-triggered associated spectra** have been plotted

$$\frac{\mathrm{d}N^{PID}_{assoc}}{\mathrm{d}p_{T,assoc}} \Big/ \frac{\mathrm{d}N^{hadron}_{assoc}}{\mathrm{d}p_{T,assoc}}$$

- The splitting effect can be observed for any of the trigger species both in p-p and Pb-Pb collisions. The **splitting is larger on the near-side** than on the away-side.

- Qualitatively the strength of the quantum numbers:
charge (Q) < strangeness (S) < baryon number (B)

- The **largest splitting** effect can be seen for unlike-sign correlations of **protons and antiprotons**.



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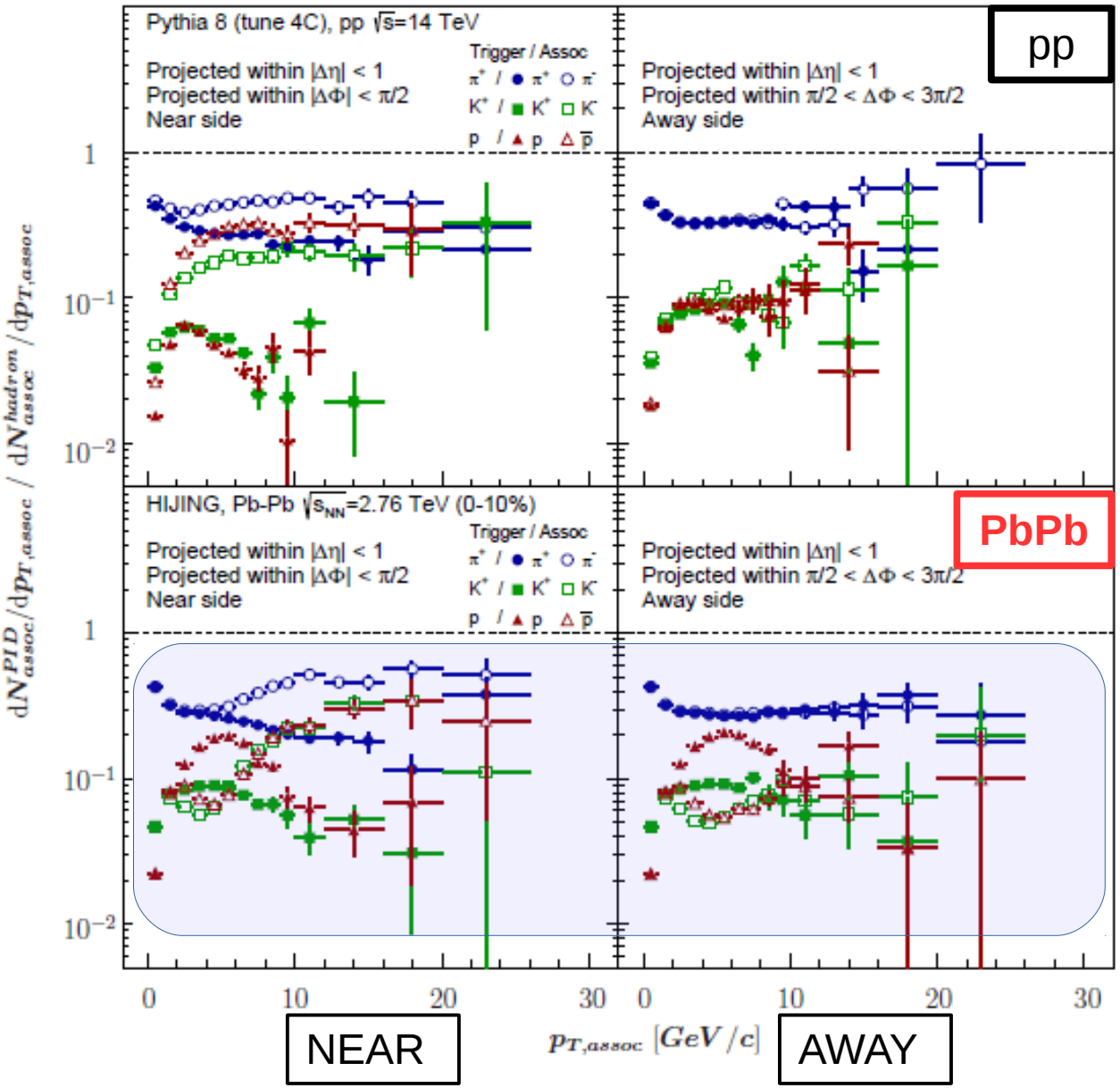
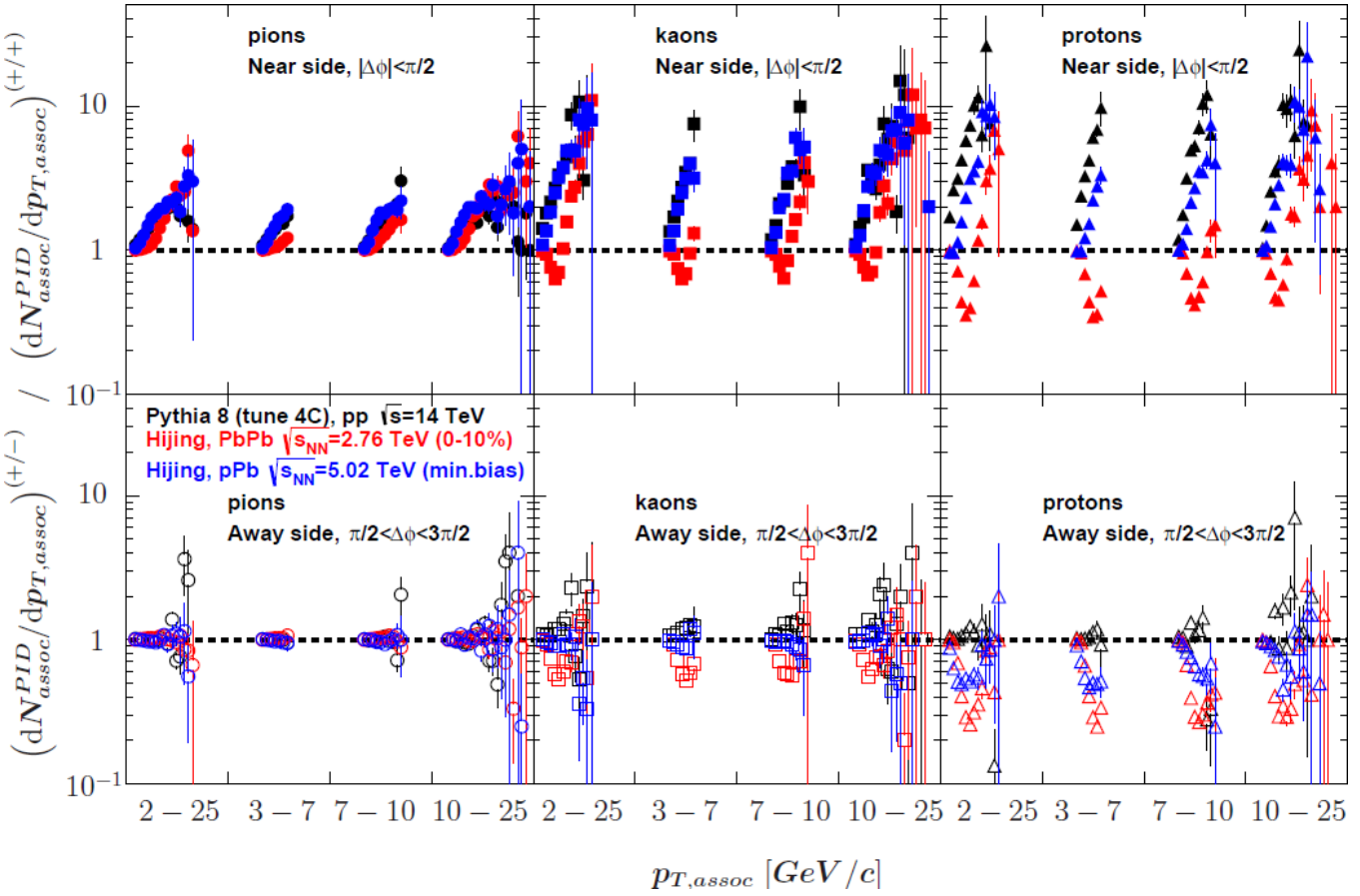


2. Quantum number conservation in correlations

Identified particle yields from like-sign and unlike-sign correlations in pp, pPb, and PbPb collisions

By plotting the differences between the **(+/-) unlike-sign and (+/+) like-sign** trigger/associated particles pairs for the PID-triggered-to/charged hadron triggered yields

$$\left(\frac{\mathrm{d}N^{PID}_{assoc}}{\mathrm{d}p_{T,assoc}} \Big/ \frac{\mathrm{d}N^{hadron}_{assoc}}{\mathrm{d}p_{T,assoc}}\right)^{(+/-)} \Big/ \left(\frac{\mathrm{d}N^{PID}_{assoc}}{\mathrm{d}p_{T,assoc}} \Big/ \frac{\mathrm{d}N^{hadron}_{assoc}}{\mathrm{d}p_{T,assoc}}\right)^{(+/+)} = \left(\frac{\mathrm{d}N^{PID}_{assoc}}{\mathrm{d}p_{T,assoc}}\right)^{(+/-)} \Big/ \left(\frac{\mathrm{d}N^{PID}_{assoc}}{\mathrm{d}p_{T,assoc}}\right)^{(+/+)}$$



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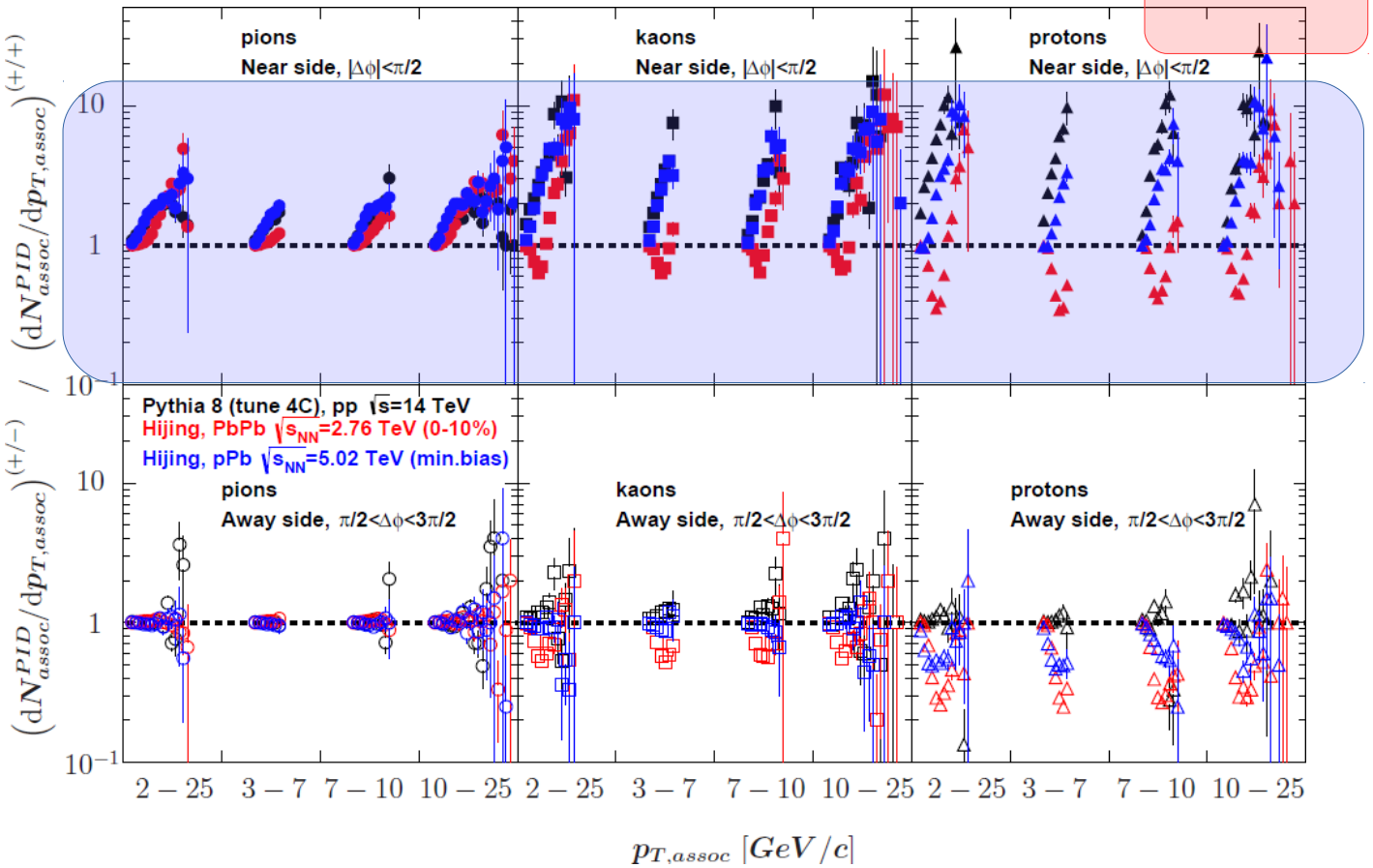
NEAR



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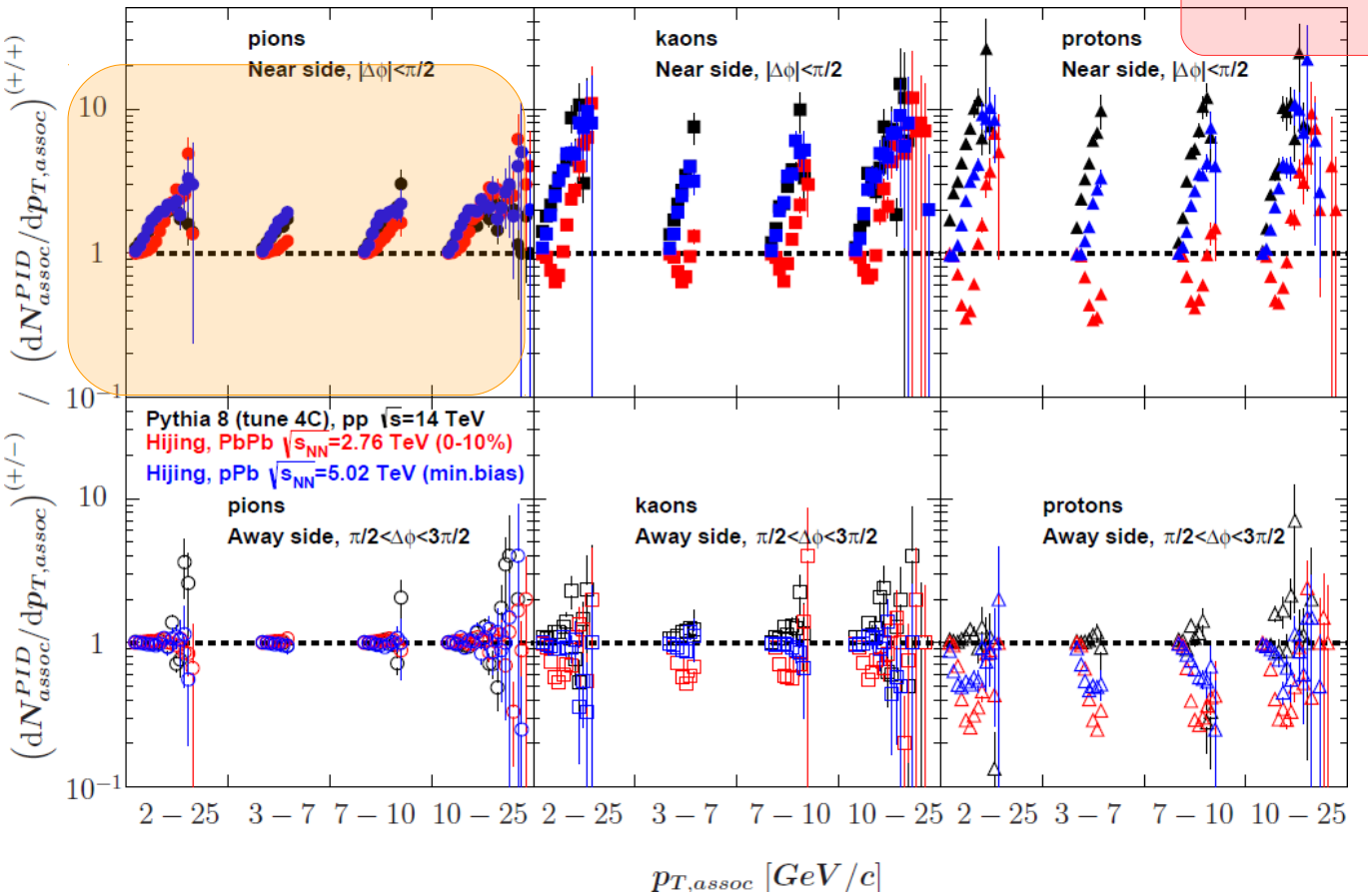
PION: The PID-triggered associated spectra for the like-sign and unlike-sign trigger/associated particle pairs is **similar for pions** in p-p, p-Pb and Pb-Pb collisions



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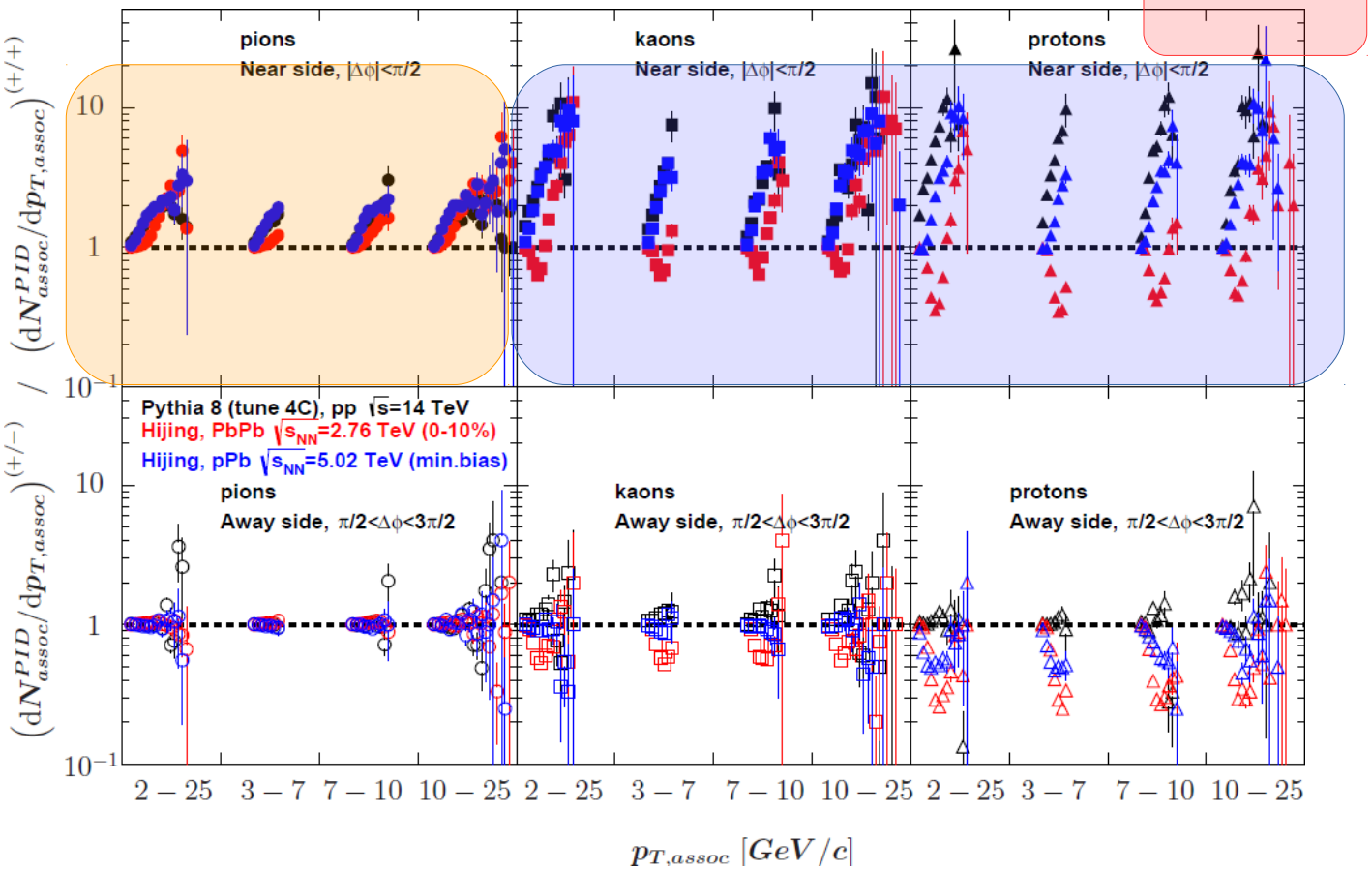
KAON / PROTON
In contrast, there is **clear difference between the p-p, p-Pb and Pb-Pb systems for kaons and protons** at the near side.



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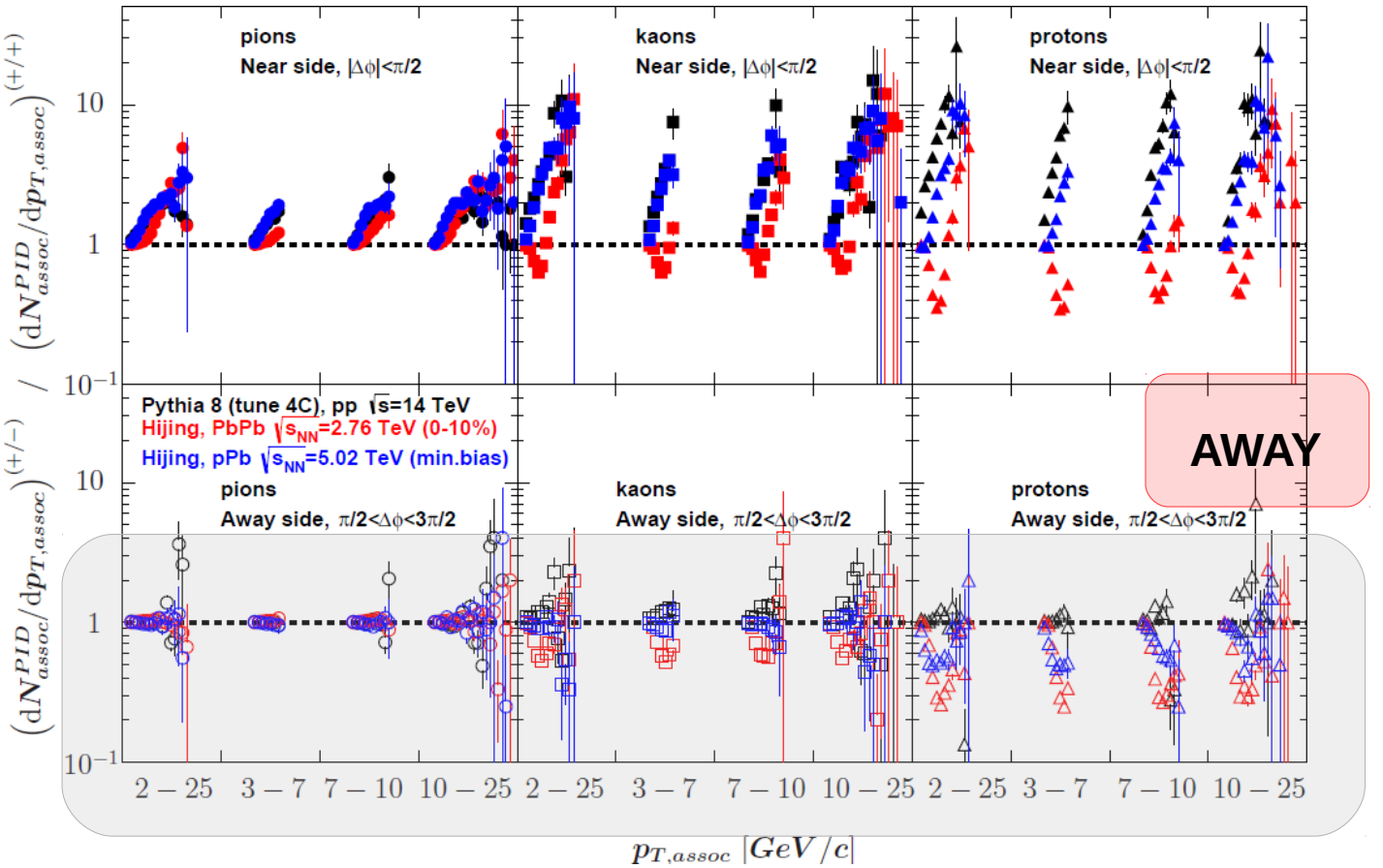
In contrast, there is clear **difference** between the p-p, p-Pb and Pb-Pb systems for **kaons and protons** at the near side.

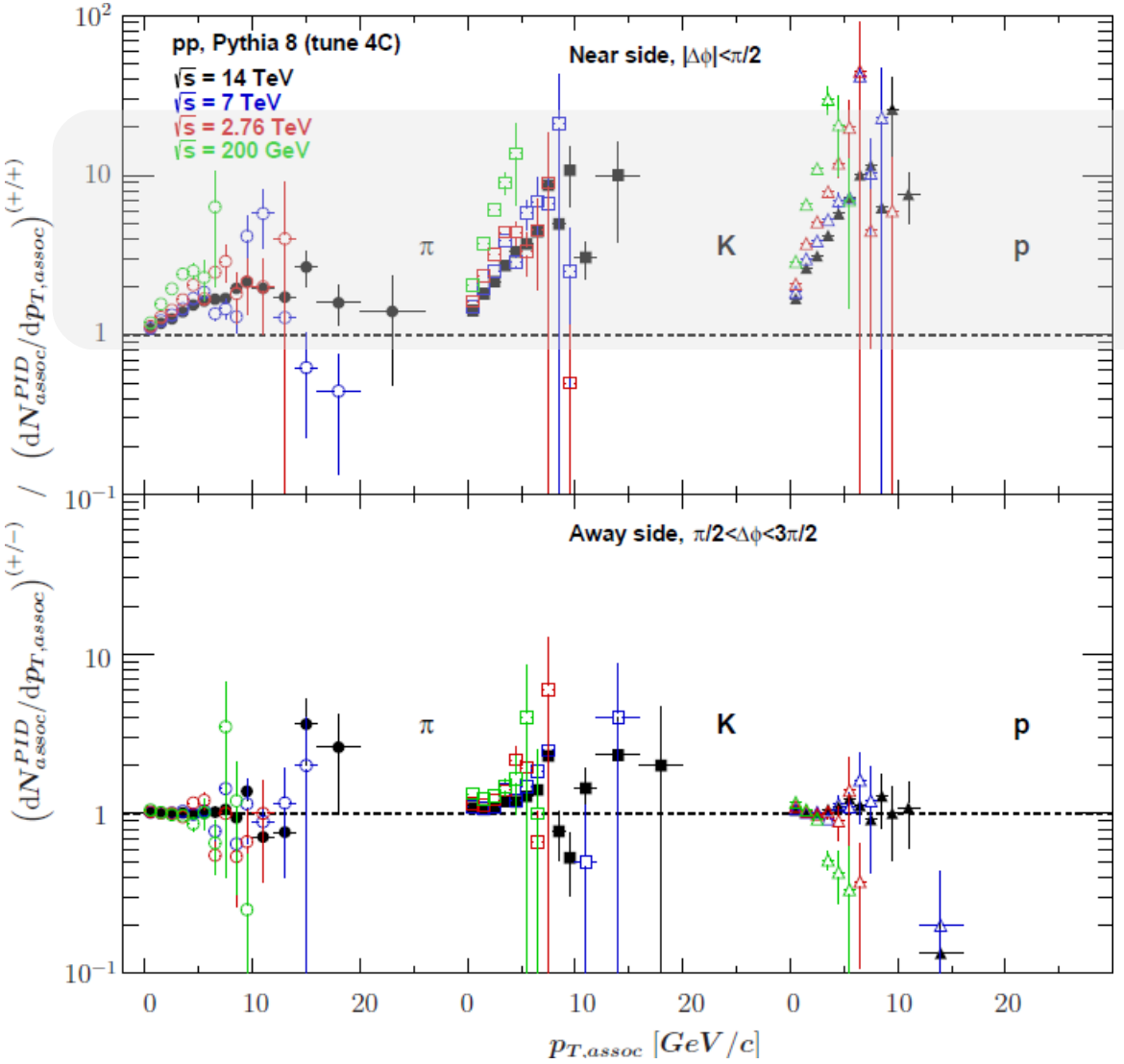
Less deviance on the away side.



2. Quantum number conservation in correlations

Yield dependence on collision energy in p-p

Near side:
the splitting decreases with increasing $\sqrt{s}$

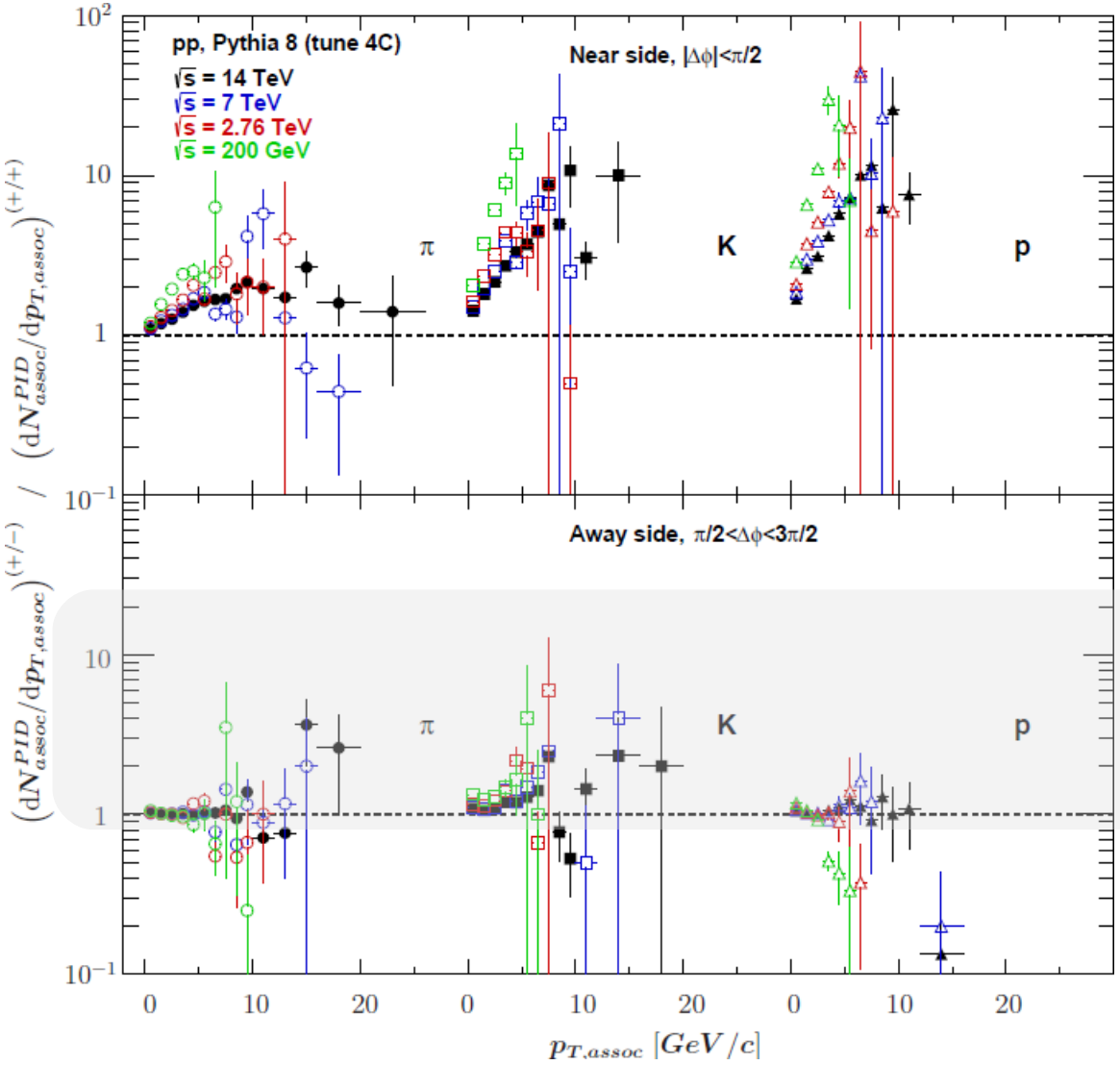


2. Quantum number conservation in correlations

Yield dependence on collision energy in p-p

Near side:
the splitting decreases with increasing $\sqrt{s}$

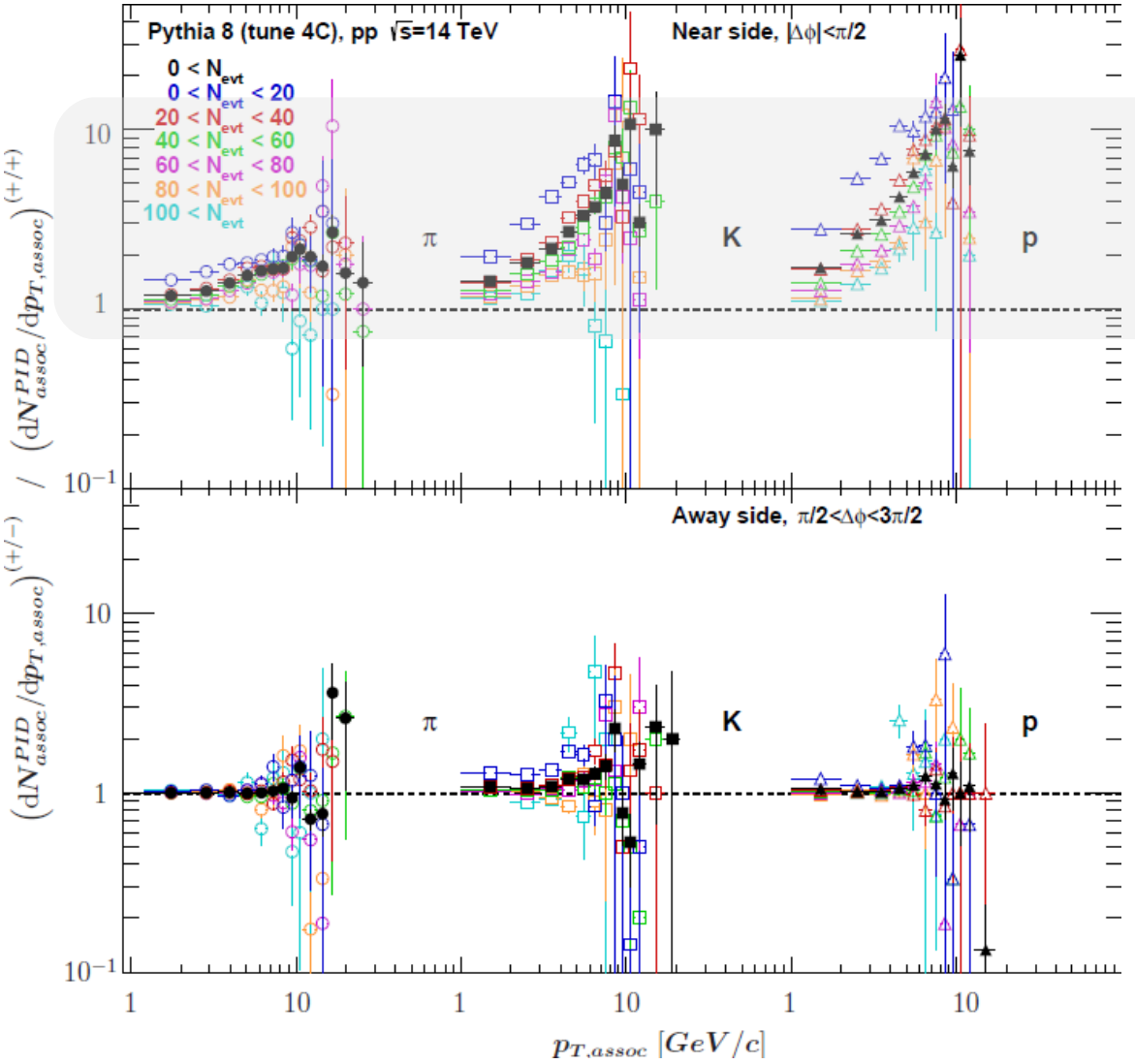
Away side:
no obvious energy dependence, kaons show small asymmetry for all $\sqrt{s}$



2. Quantum number conservation in correlations

Yield dependence on event multiplicity in p-p

Near side:
the higher the event multiplicity the smaller the size of the splitting due to increasing underlying event contribution at higher multiplicities



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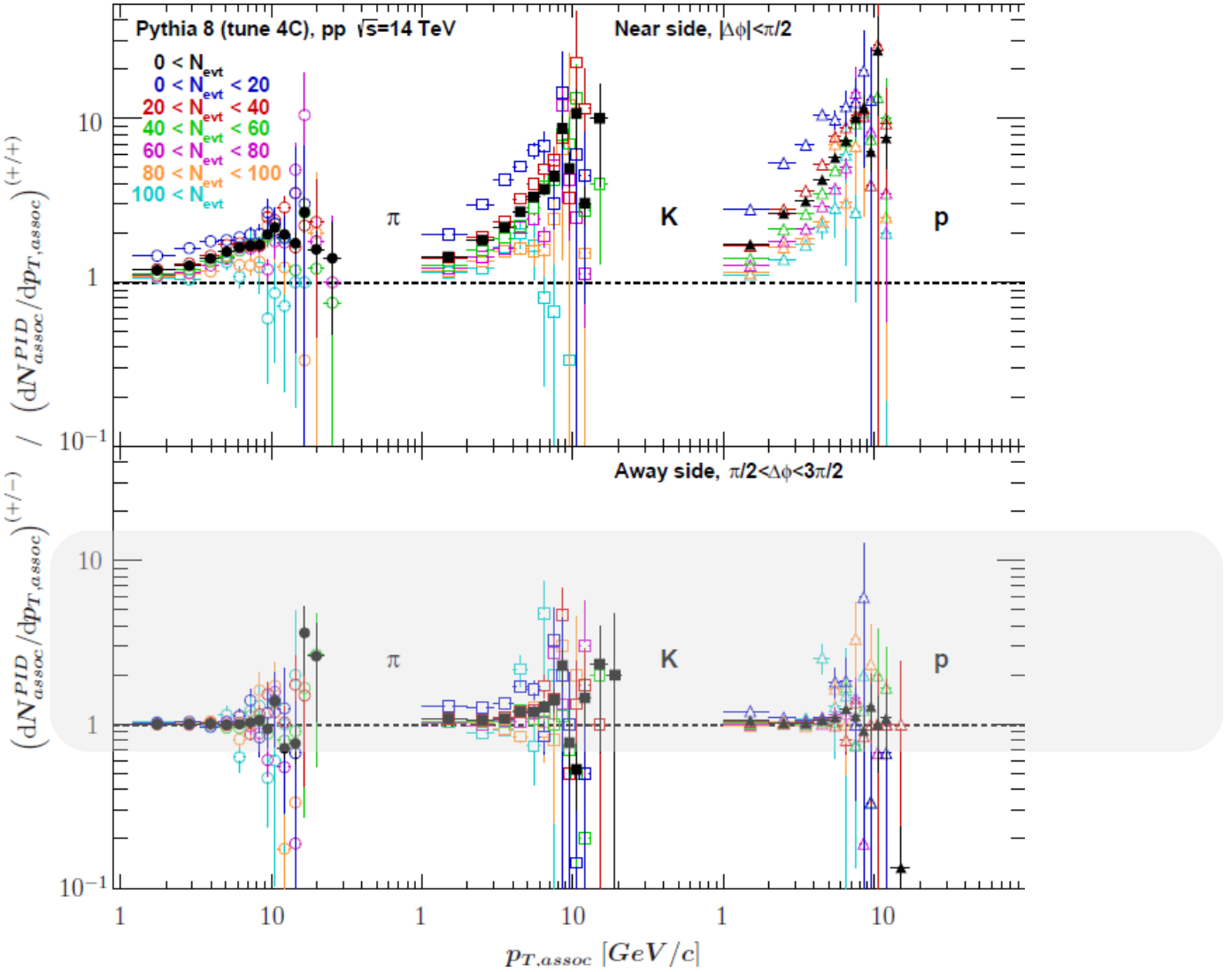

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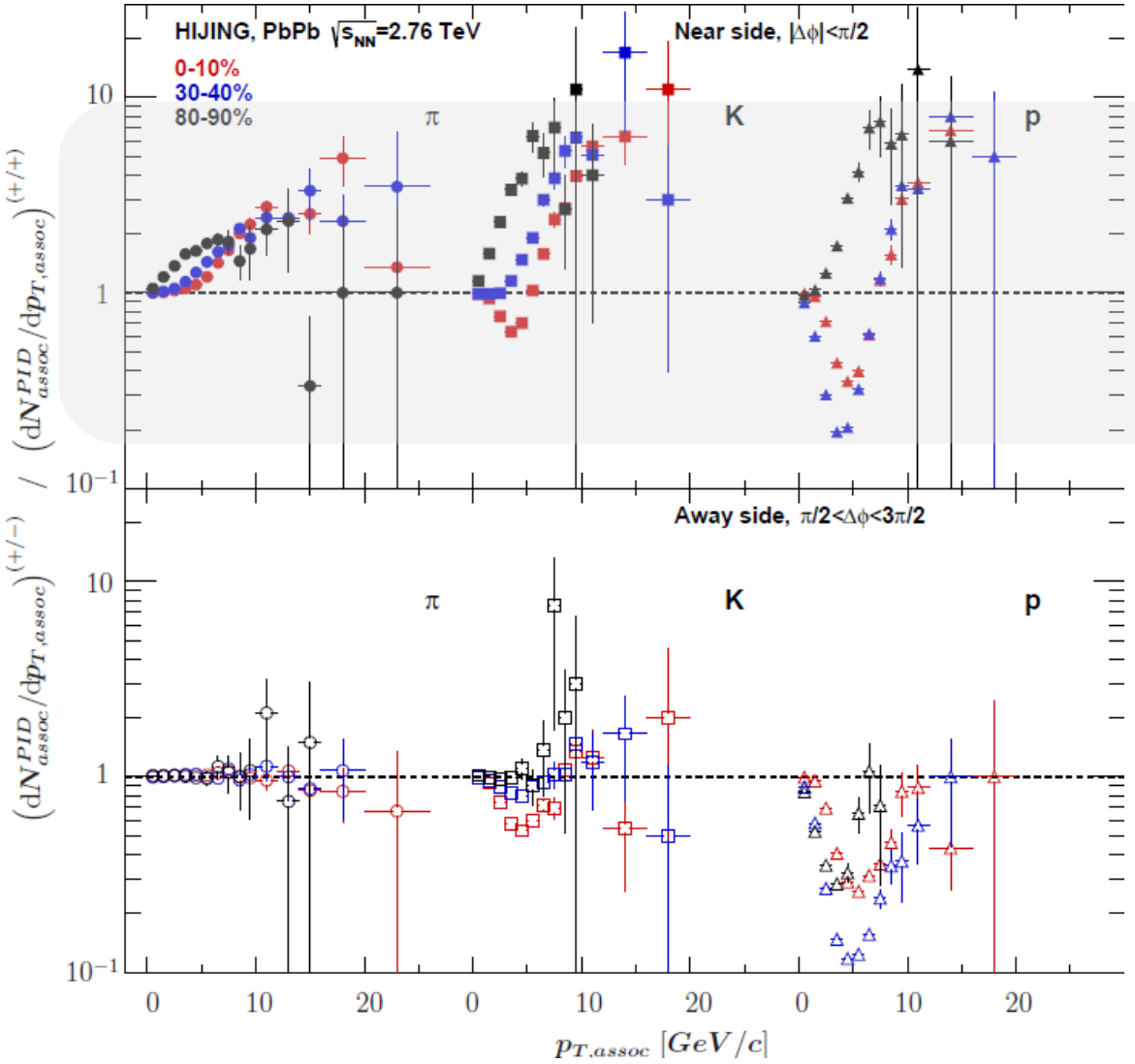
Yield dependence on centrality in Pb-Pb

Near side:
reverse evolution pattern is observed for kaons and protons as a function of centrality

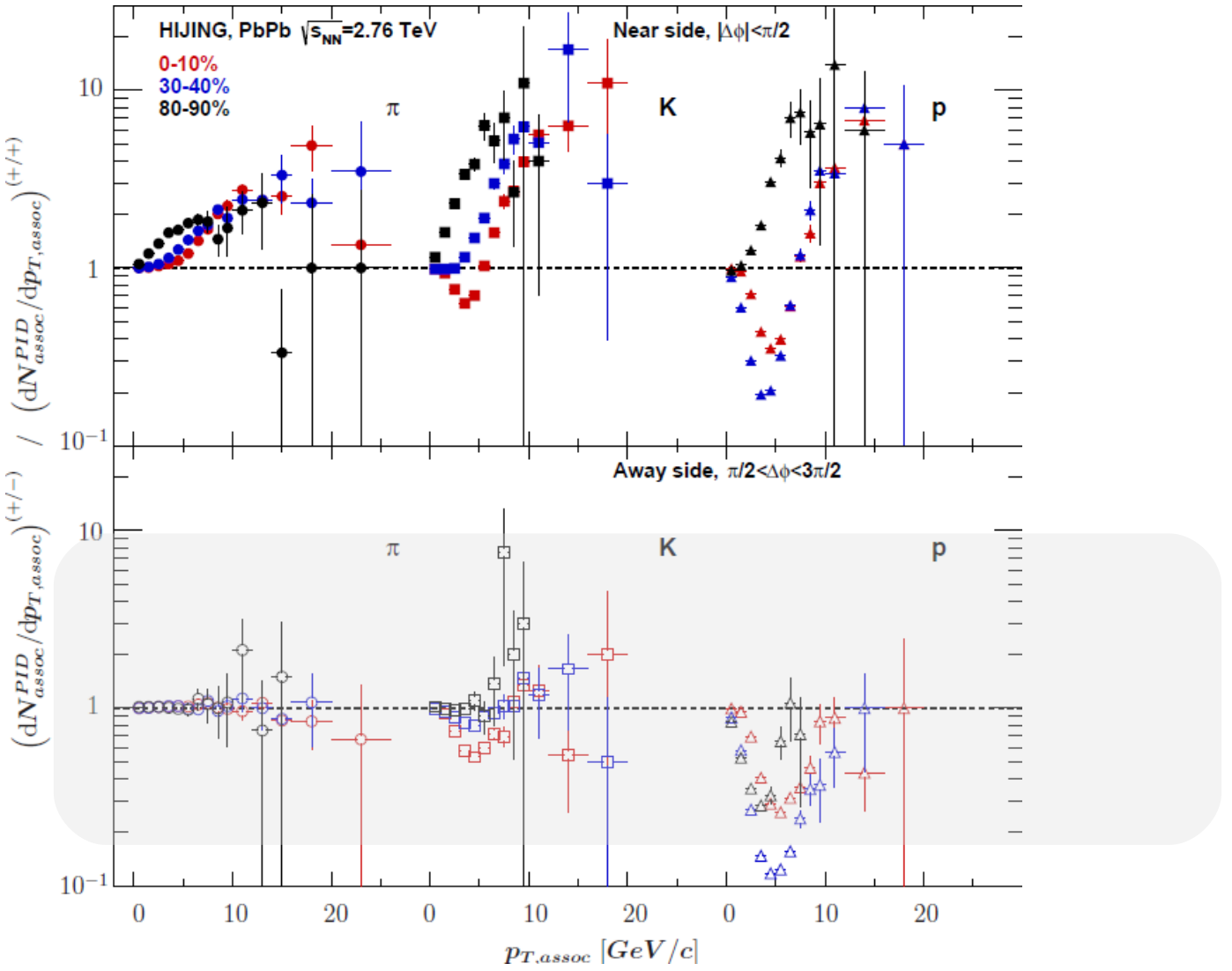


2. Quantum number conservation in correlations

Yield dependence on centrality in Pb-Pb

Near side:
reverse evolution pattern is observed for kaons and protons as a function of centrality

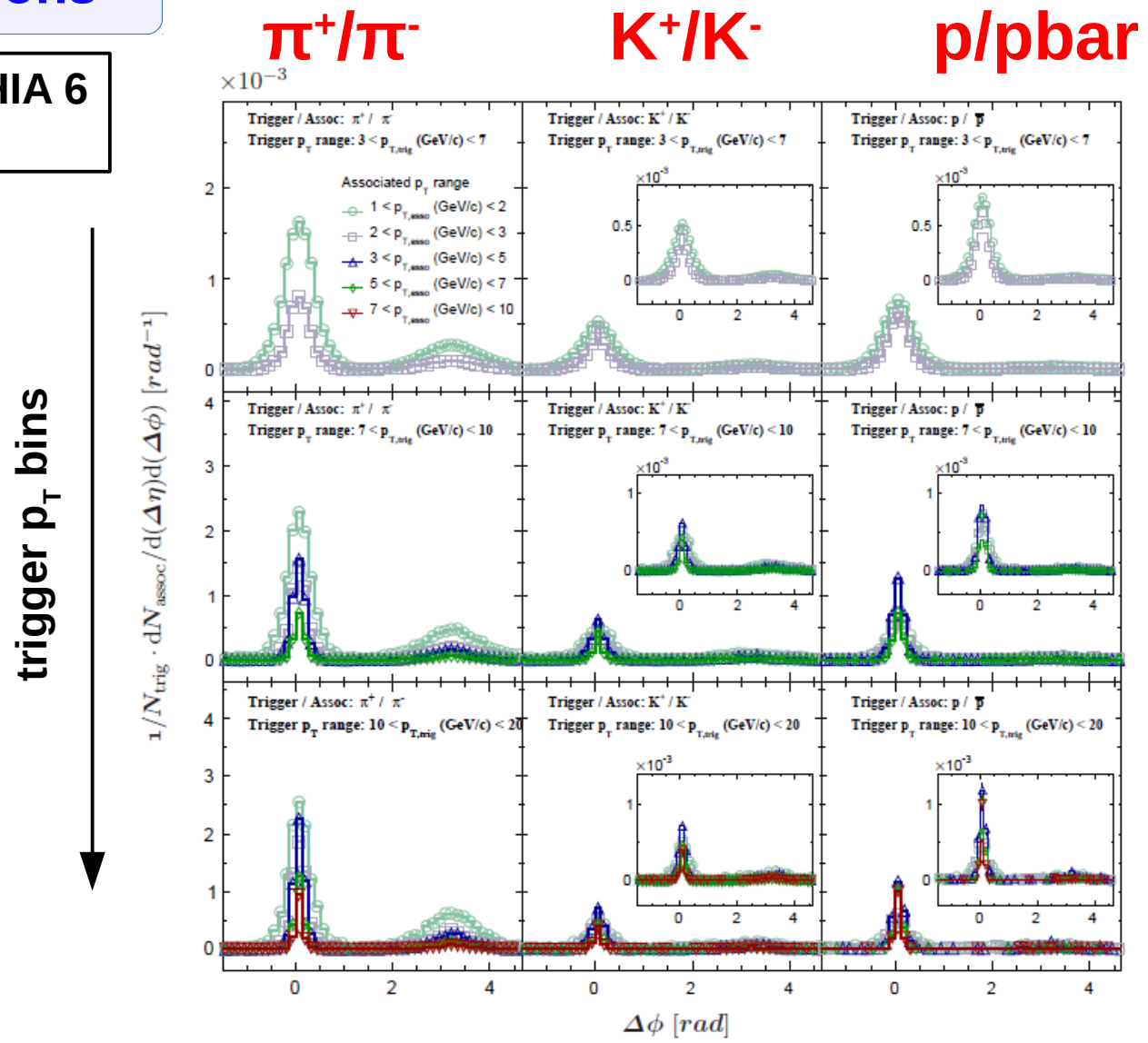
Away side:
kaons and protons show similar reversal trend as on the near side



2. Quantum number conservation in correlations

Δφ projections

p-p 7TeV, PYTHIA 6 (Perugia0)



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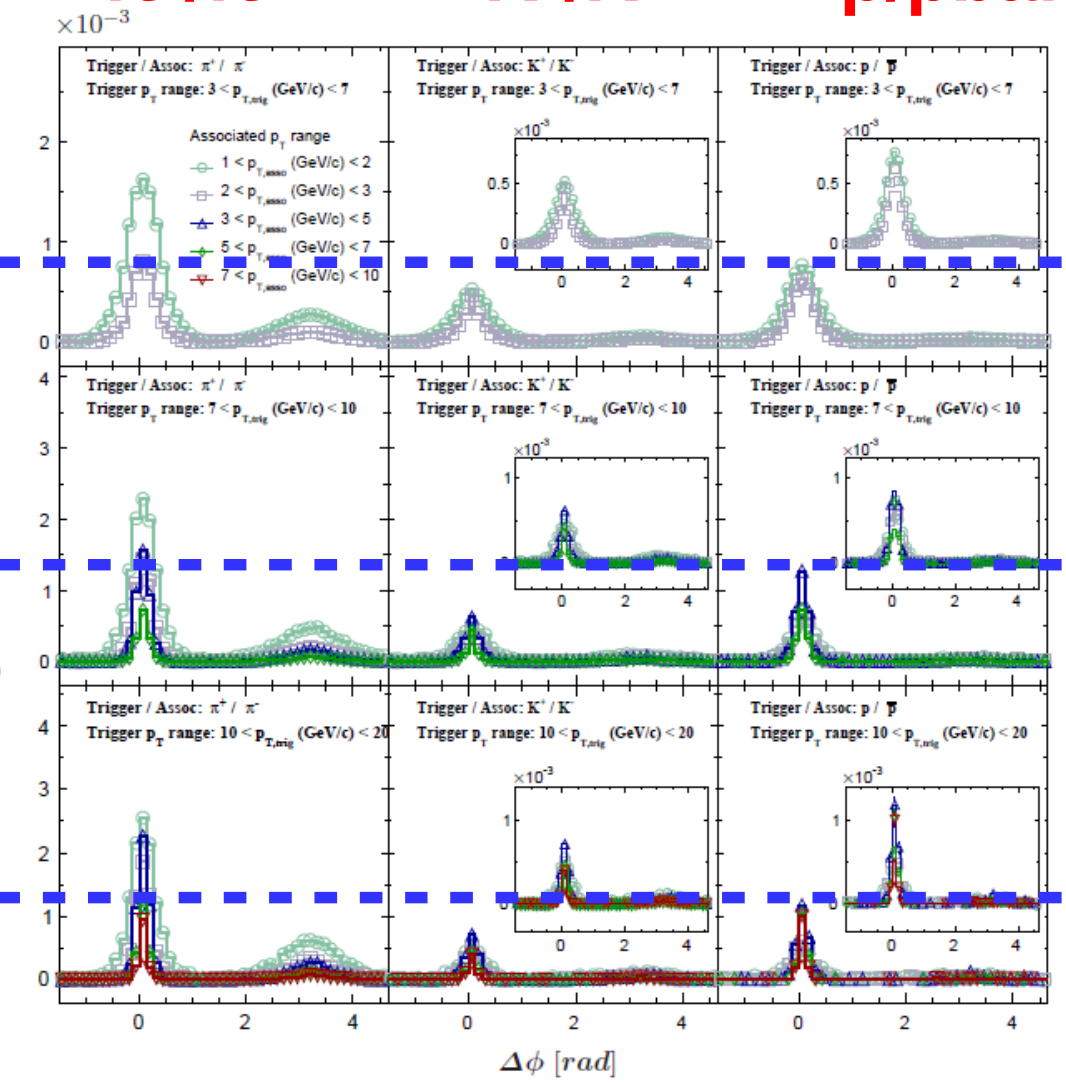
π^+/π^- K^+/K^- p/pbar

trigger p_T bins



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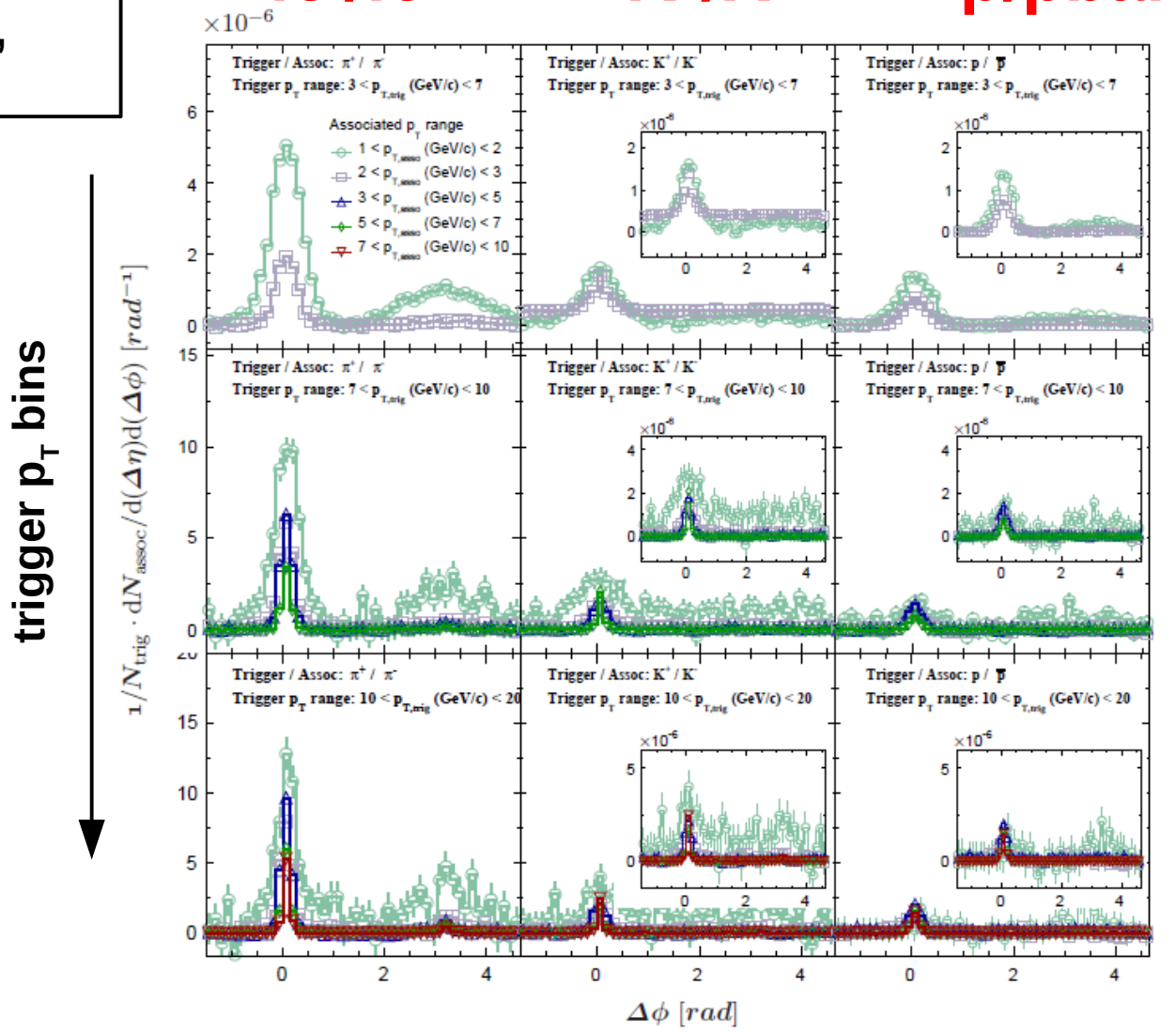

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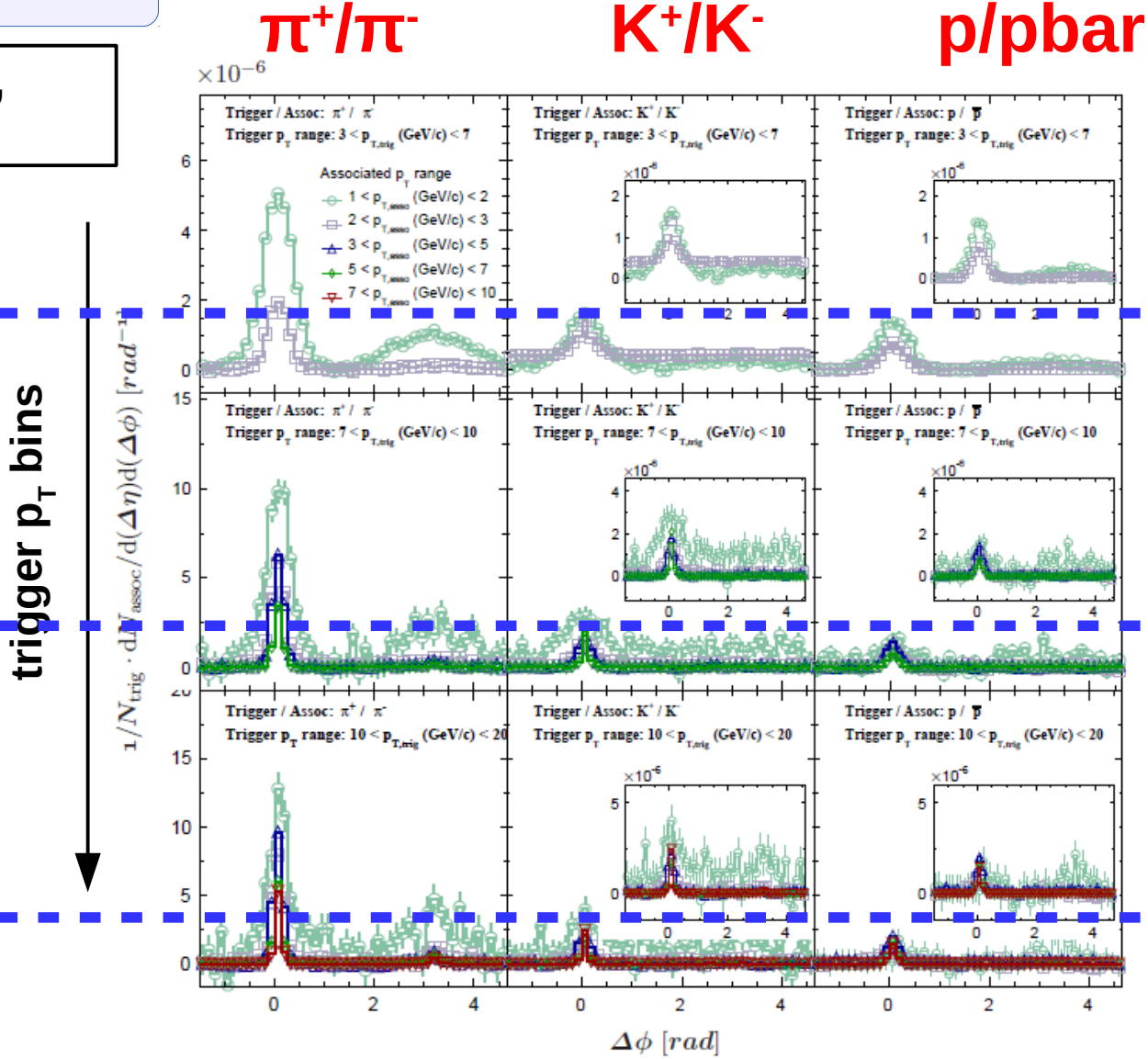

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Δφ projections

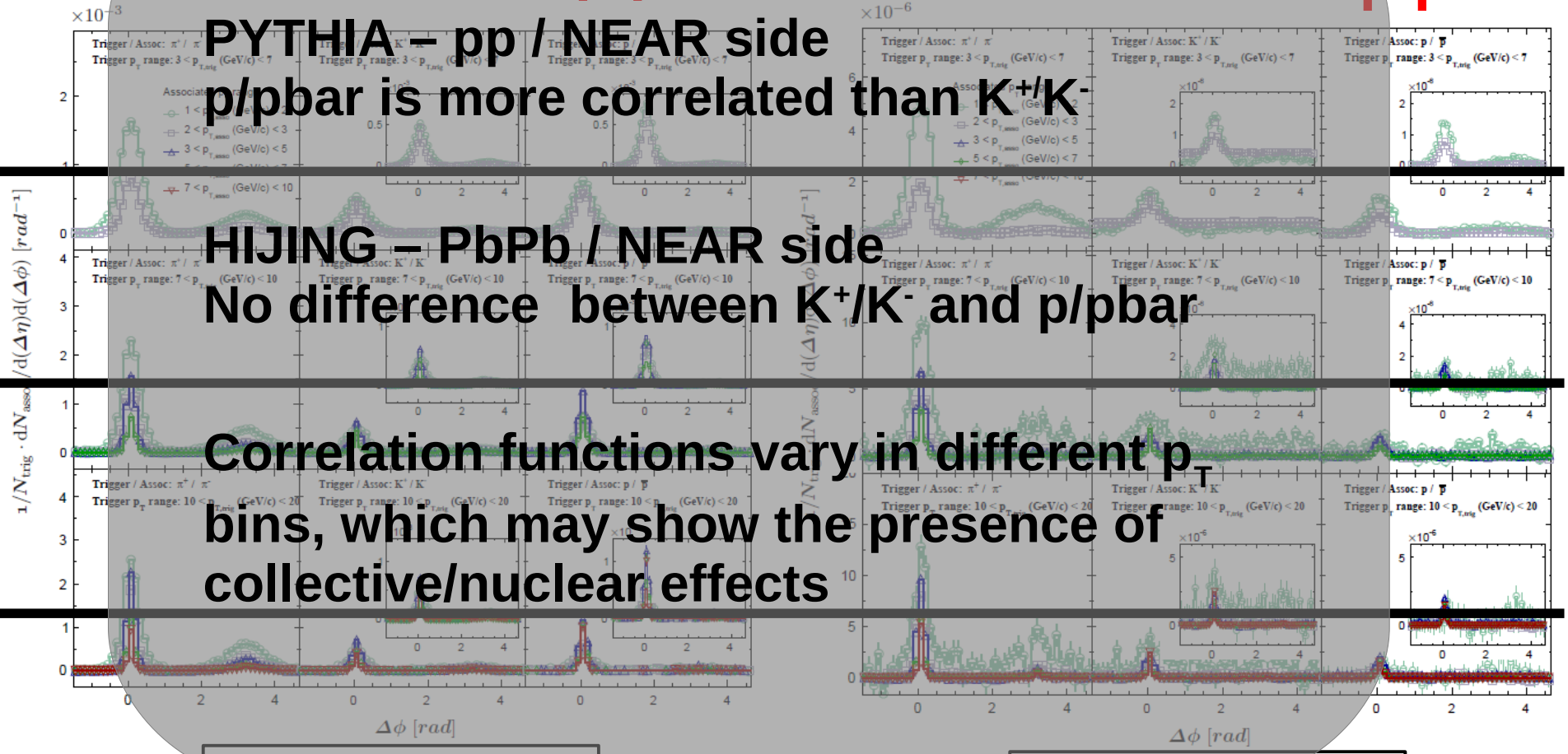
π^+/π^- K^+/K^- p/pbar π^+/π^- K^+/K^- p/pbar

PYTHIA – pp / NEAR side
p/pbar is more correlated than K^+/K^-

HIJING – PbPb / NEAR side
No difference between K^+/K^- and p/pbar

Correlation functions vary in different p_T bins, which may show the presence of collective/nuclear effects

trigger p_T bins



p-p 7TeV, PYTHIA 6 (Perugia0)

Pb-Pb 2.76TeV, HIJING

3. Summary

MC simulations and analysis have been performed to study PID-PID azimuthal correlations at mid-rapidity

The observed splitting effect of the PID-triggered-to-charged hadron-triggered associated spectra shows

- **a peculiar pattern which**
- is the most prominent for p-p unlike-sign associated particle pairs (compared to K+/K-, +- pairs) on the near- and away side;
- has a reverse behaviour in Pb-Pb and in p-Pb on the away-side and remains unchanged on the near-side

  in Pb-Pb;
- has similar behaviour in the p-p, peripheral Pb-Pb and minimum bias p-Pb on the near-side in terms of

  the conservation of baryon numbers;
- decreases towards higher event multiplicities in p-p;
- decreases with increasing collision energies from RHIC to LHC in p-p.

- **No experimental measurements to contrast with the observed MC analysis**
  - Further Monte Carlo checks needed to have a better understanding...

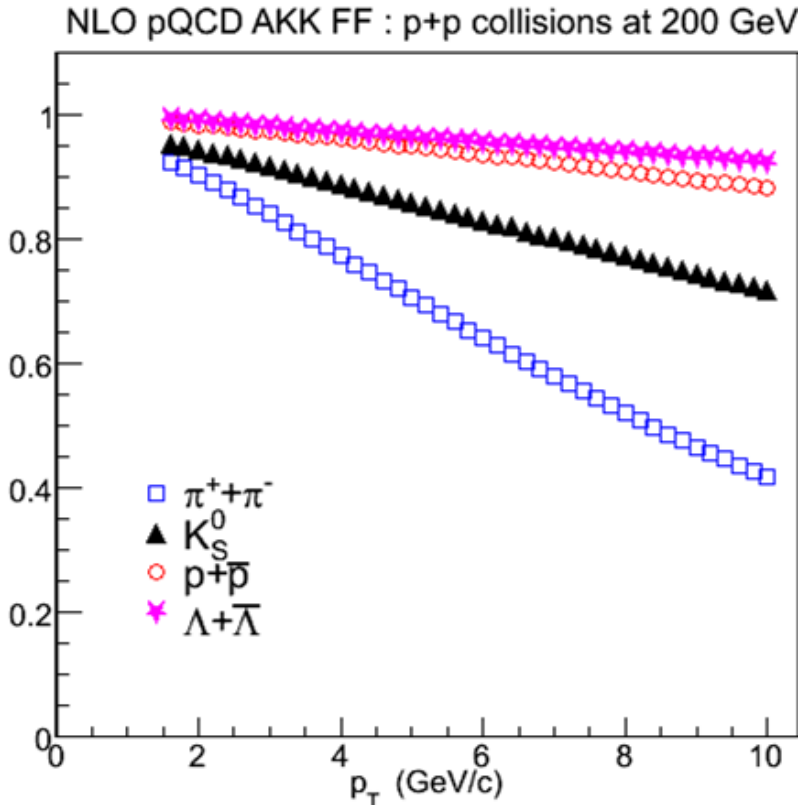
3. Outlook

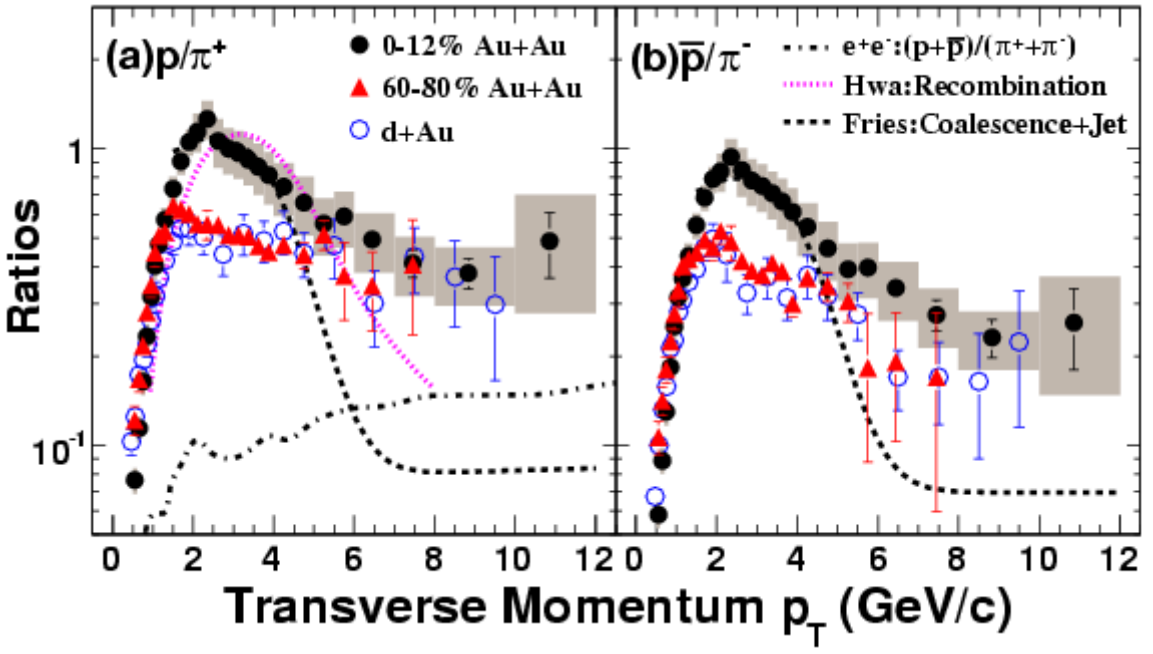
- Data analysis has been started to perform the same analysis exploiting the PID capabilities of ALICE at the LHC
- The observed interesting patterns can be measured at higher momentum in ALICE
- In principle this can be done by the TPC, statistical method: at relativistic rise, rdE/dx
  - Spectra analysis has been started under the supervision of Antonio Ortiz
    - on pp data @7TeV (investigating multiplicity dependence as well)
    - on p-Pb data with different centralities using different centrality estimators (V0A, SPD, V0M, ZDC)

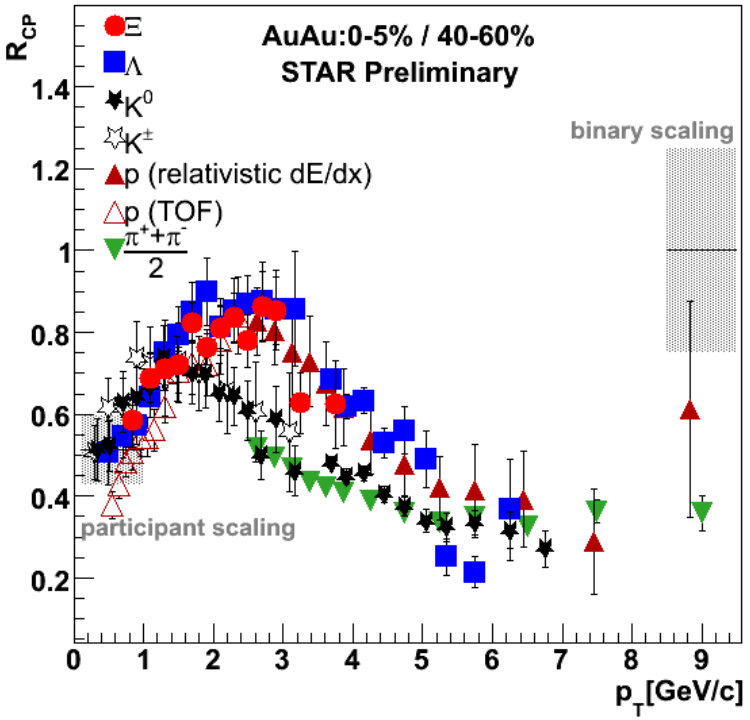
3. References

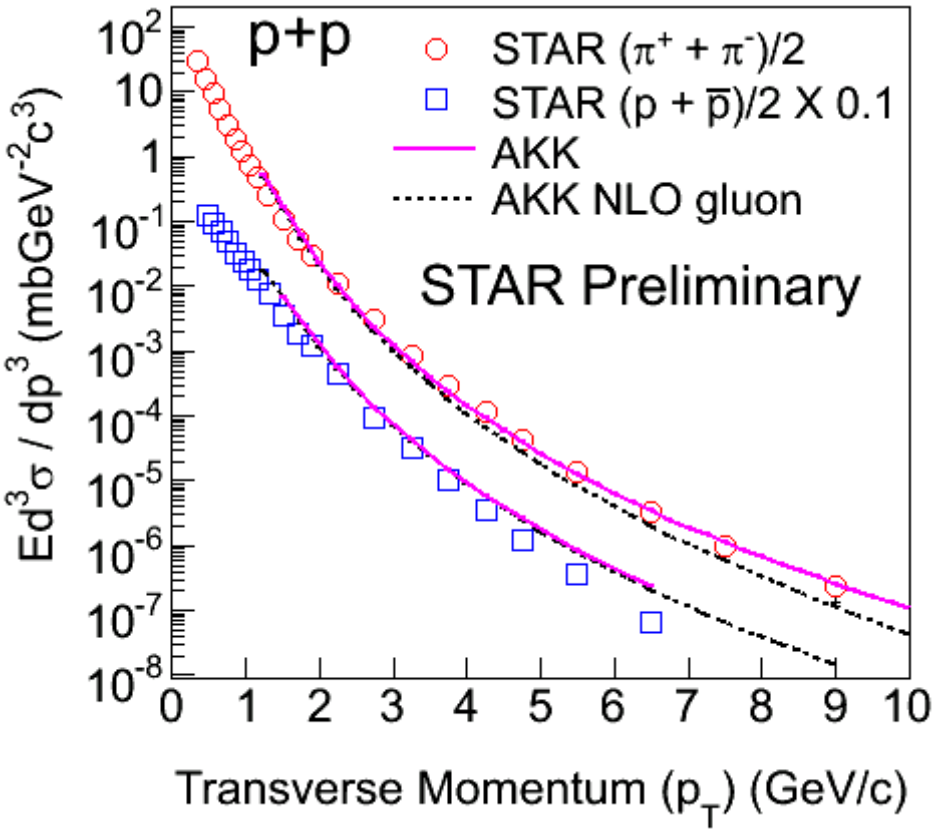
- [1] ALICE Collaboration, T. Acconcia et al., “A Very High Momentum Particle Identification Detector,” http://arxiv.org/abs/1309.5880arXiv:1309.5880 [nucl-ex]
- [2] G. Bencédi, G. G. Barnaföldi, and L. Molnár, “Monte Carlo Studies of Identified Two-particle Correlations in p-p and Pb-Pb Collisions,” http://arxiv.org/abs/1403.0117arXiv:1403.0117 [hep-ex]

Backups...

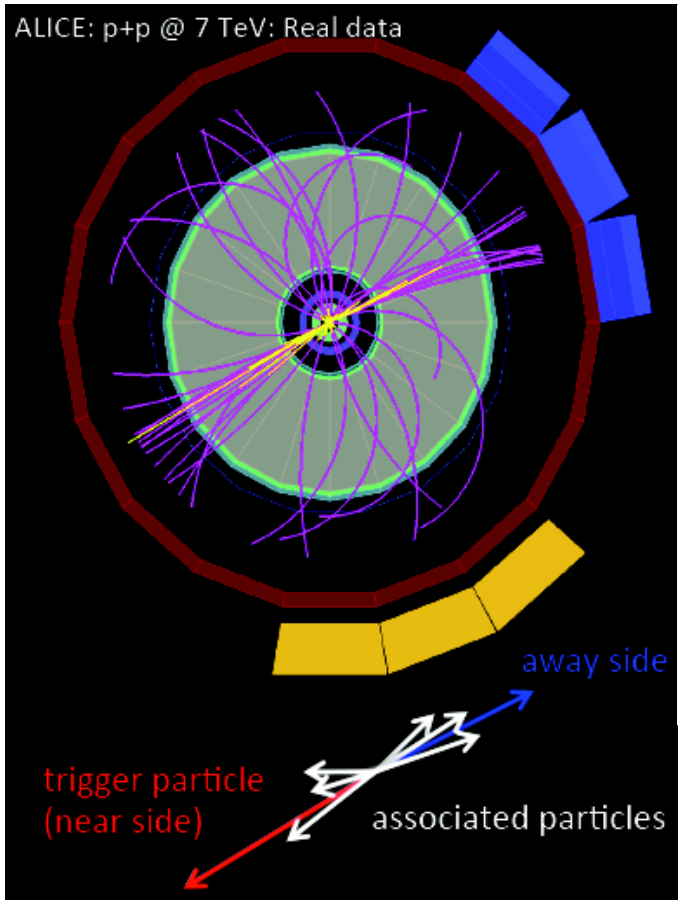

NLO pQCD AKK FF : p+p collisions at 200 GeV
$\pi^+ + \pi^-$
K^0_S
$p+\bar{p}$
$\Lambda+\bar{\Lambda}$
p_T (GeV/c)

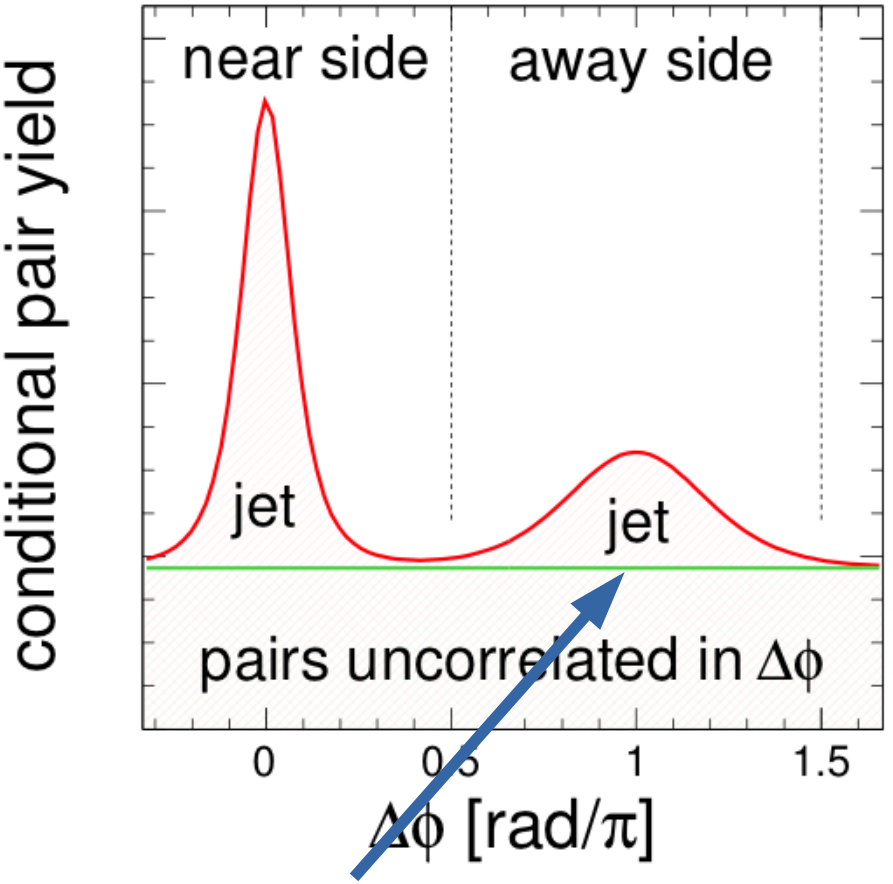

(a) p/π^+
0-12% Au+Au
60-80% Au+Au
d+Au
(b) $\bar{p}/\pi^-$
e^+e^-:$(p+\bar{p})/(\pi^+ + \pi^-)$
Hwa:Recombination
Fries:Coalescence+Jet
Ratios
Transverse Momentum p_T (GeV/c)


AuAu:0-5% / 40-60%
STAR Preliminary
R_{CP}
Ξ
Λ
K^0
$K^\pm$
p (relativistic dE/dx)
p (TOF)
$\frac{\pi^+ + \pi^-}{2}$
binary scaling
participant scaling
p_T[GeV/c]


p+p
STAR $(\pi^+ + \pi^-)/2$
STAR $(p + \bar{p})/2$ X 0.1
AKK
AKK NLO gluon
STAR Preliminary
$Ed^3\sigma / dp^3$ (mbGeV$^{-2}c^3$)
Transverse Momentum (p_T) (GeV/c)

Azimuthal correlations



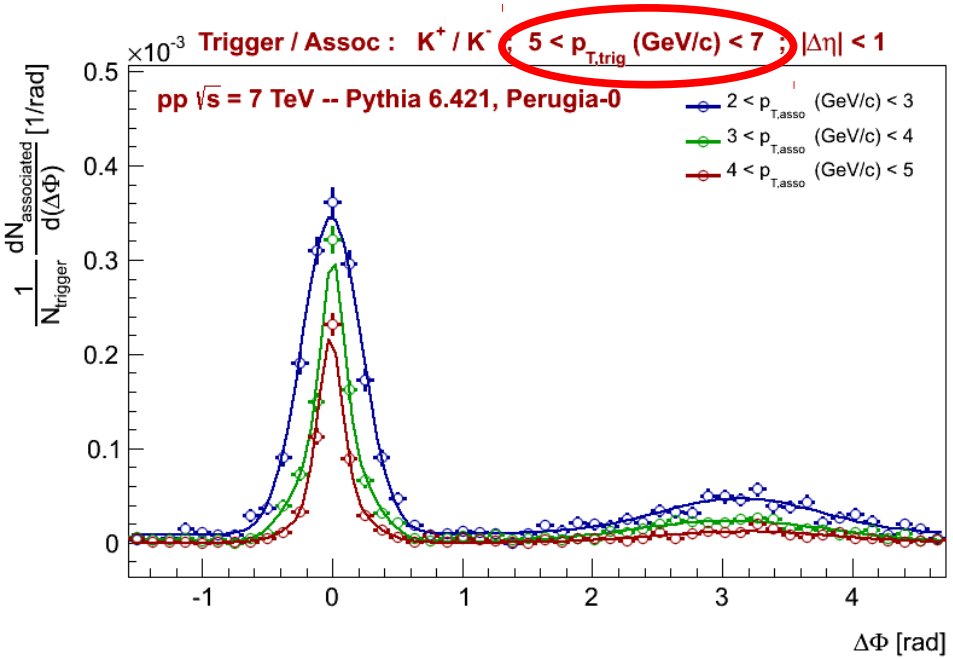


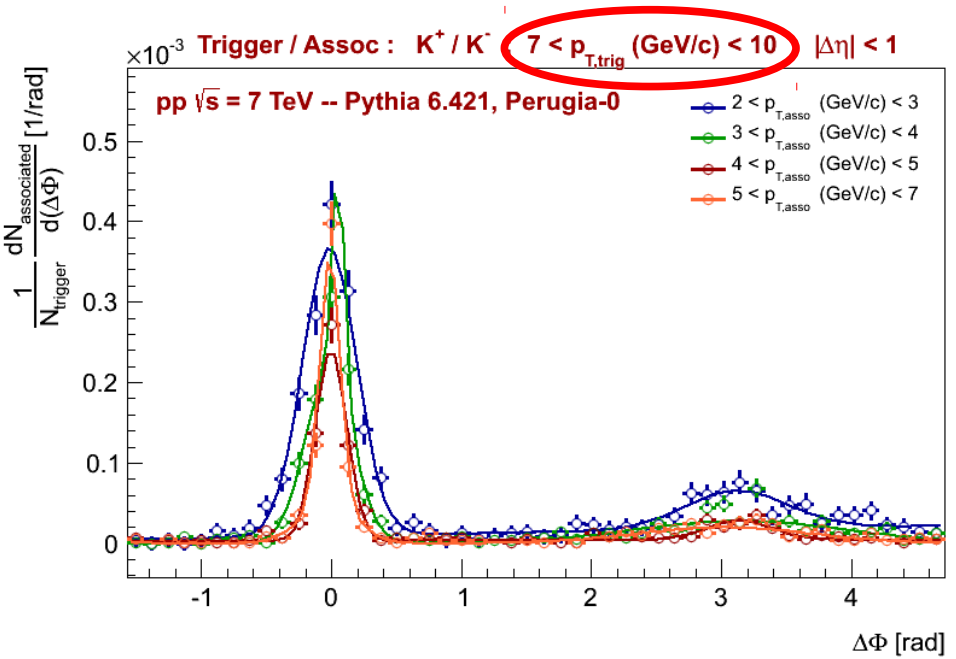
ZYAM: Zero Yield At Minimum

$\Delta\varphi = \varphi_{trigger} - \varphi_{assoc}$, $\Delta\eta = \eta_{trigger} - \eta_{assoc}$

2. Quantum number conservation in correlations

Δφ projections (flavor conservations, K)

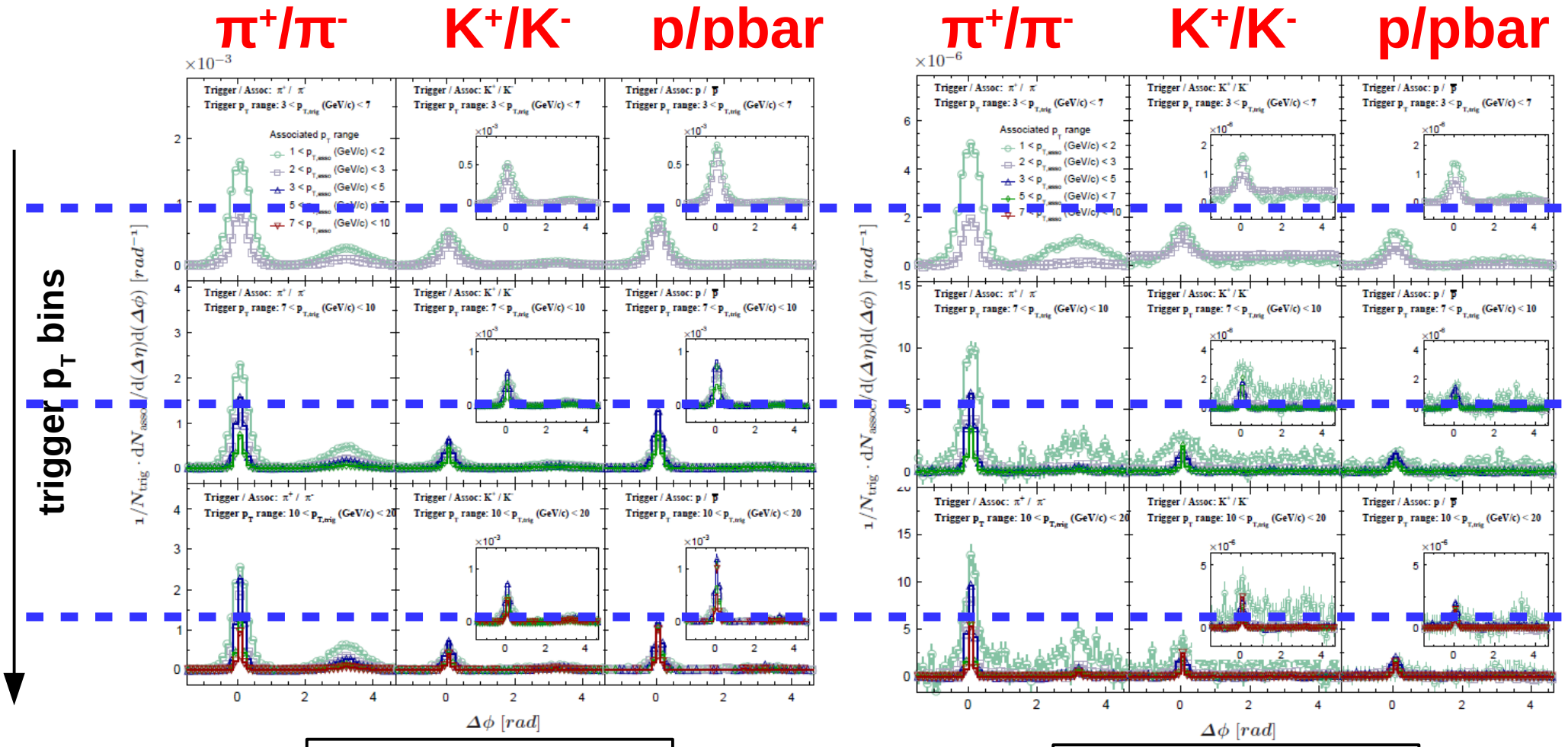




- **Near side** flavor and charge correlations decrease as a function of $p_{T,assoc}$ and $p_{T,trig}$ (the width narrows) compared to the away side correlations
- **Away side** stays roughly constant when the trigger particle momentum is increased

2. Quantum number conservation in correlations

Δφ projections



p-p 7TeV, PYTHIA 6 (Perugia0)

Pb-Pb 2.76TeV, HIJING