Testing hadronization with strange particles in mini-jets with ALICE

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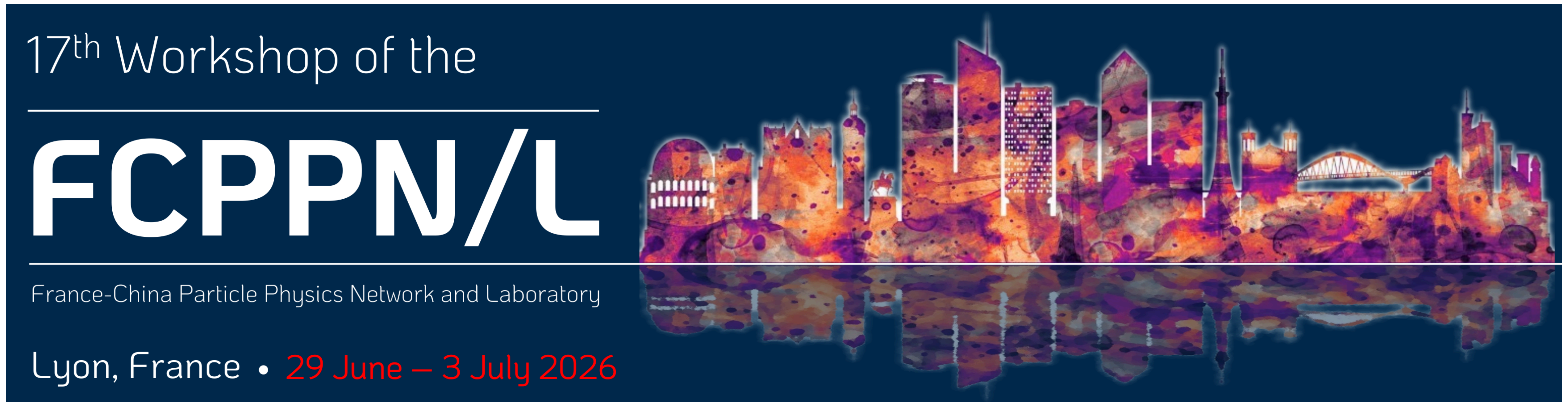
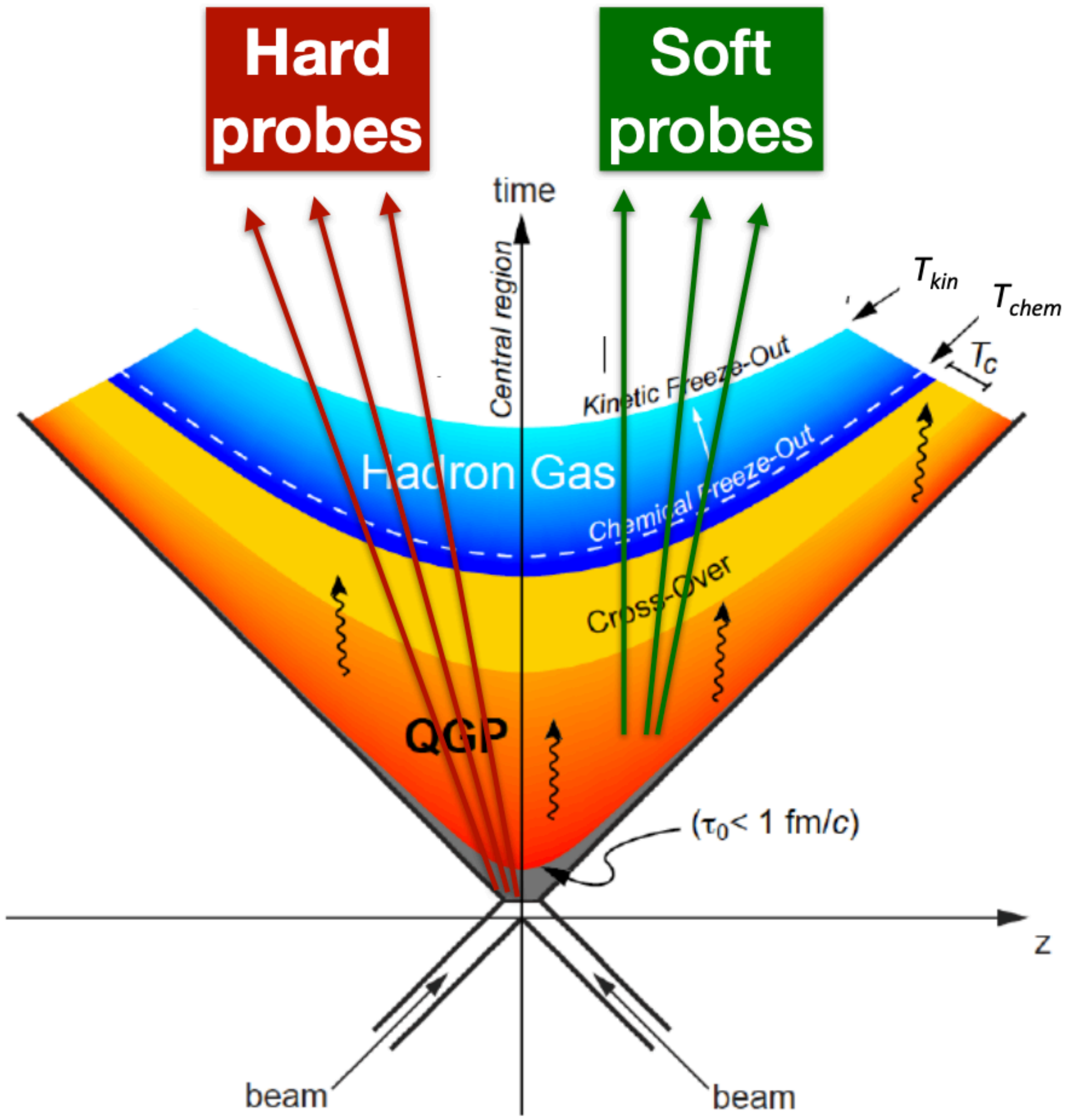
- Motivation
- Experimental setups & analysis approach
- Results
- Summary



Quark-gluon plasma



- Heavy-ion collisions probe the strongly-interacting matter — the quark-gluon plasma (QGP) under extreme conditions of high temperature and energy density
- **Hard probes** created at the initial stage of the collision
  - ➡ Jet, heavy-flavor quarks
- **Soft probes** created in the "fireball"
  - ➡ Collective expension

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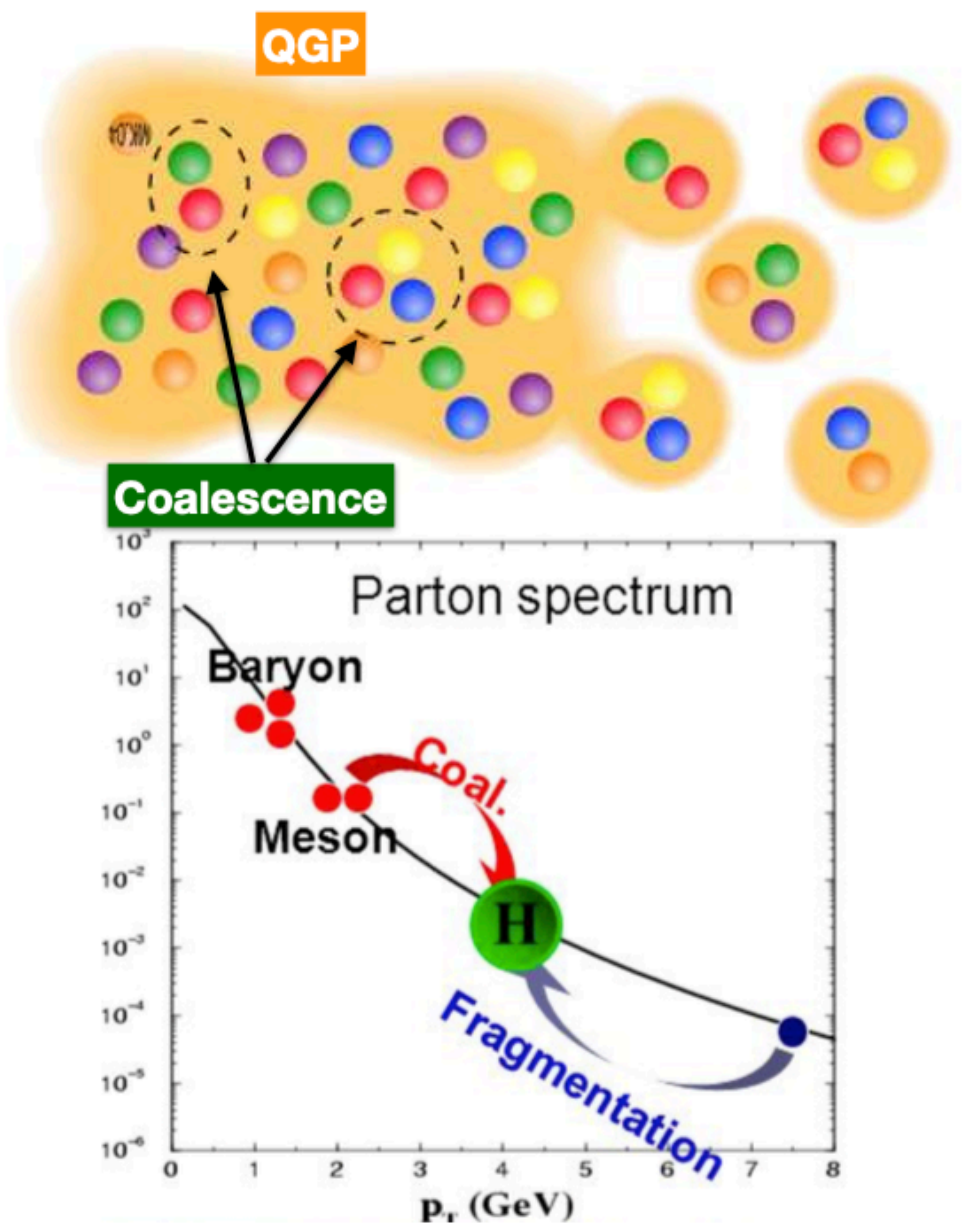
The hadronization in QGP

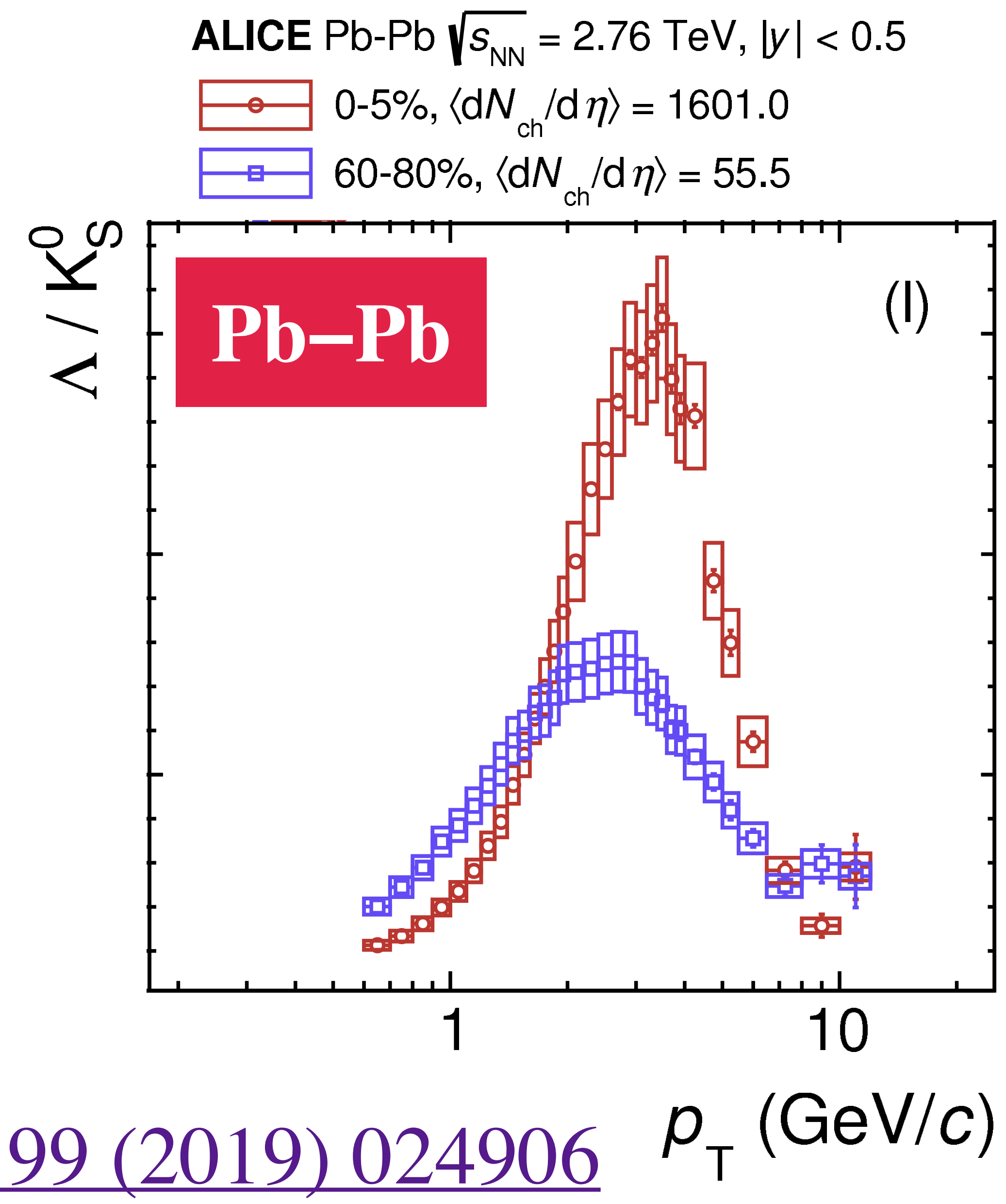


Rapp *et al. Phys. Lett.* **B655** (2007) 126
Greco *et al. Phys.Rev.* **C92** (2015) 054904
Ko *et al. Phys. Lett.* **B792** (2019) 132

- **Fragmentation** — hadrons from high p_T (hard) partons

- Coalescence/recombination — hadrons formation via (di-)quark combination in the QGP medium
  - $p_{T,\mathrm{hadron}} \simeq n\, p_{T,\mathrm{parton}}$, n = 2 (meson), 3(baryon)
  - Sensitive to baryon and meson species
  - Baryons from lower momenta partons (denser)

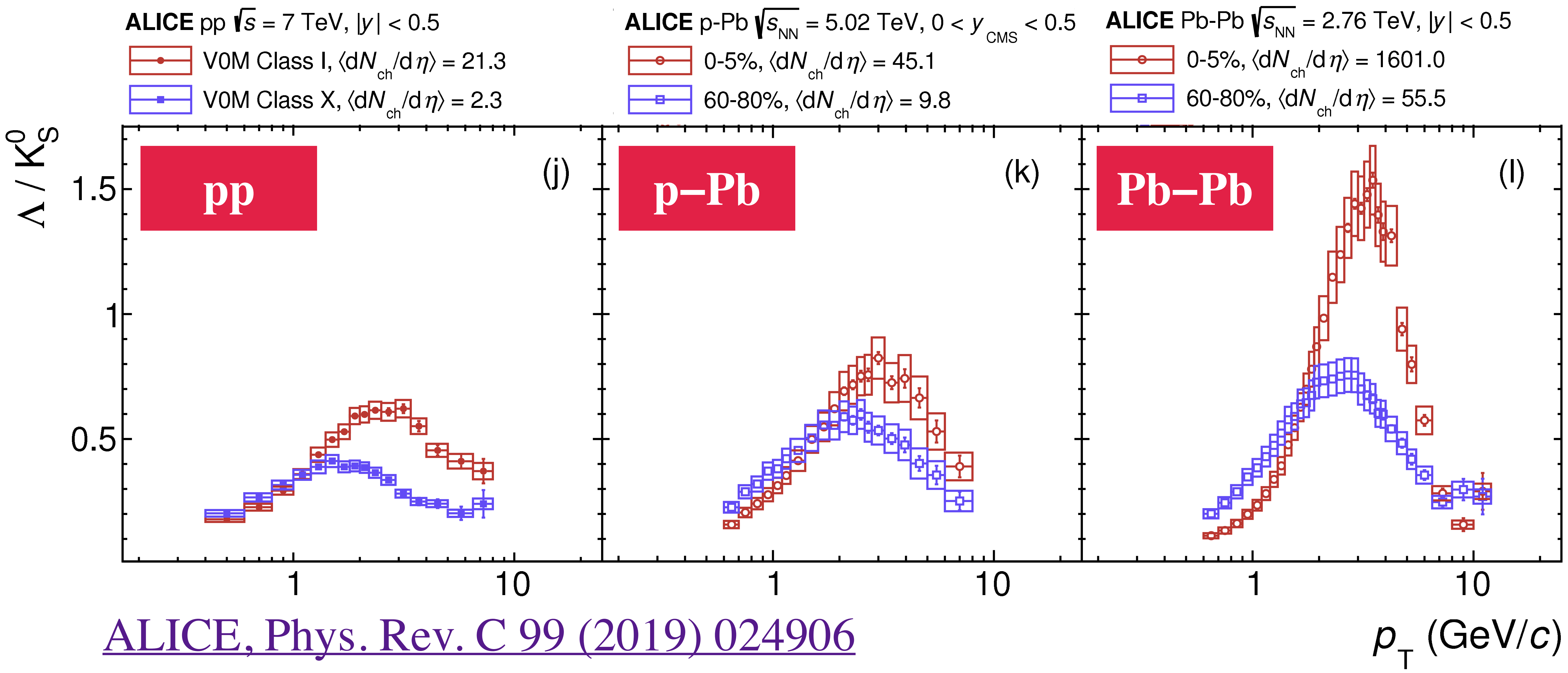
Strange baryon-to-meson enhancement



[ALICE, Phys. Rev. C 99 (2019) 024906]

- Baryon-to-meson ratio (Λ/K^0_S) increases at intermediate p_T in central Pb–Pb collisions compared to peripheral ones
  - ➡ Interplay of radial flow and quark coalescence
  - ➡ Reflect QGP effects in heavy-ion collisions

Strange baryon-to-meson enhancement



ALICE, Phys. Rev. C 99 (2019) 024906

- Baryon-to-meson ratio (Λ/K^0_S) increases at intermediate p_T in central Pb–Pb collisions compared to peripheral ones
- Λ/K^0_S ratio enhancement is observed in small collision systems (pp, p–Pb) at high multiplicity
- To constrain hadronization mechanisms in all systems, it's important to separate particles from hard and soft processes ☞ Using jets to tag the hard processes

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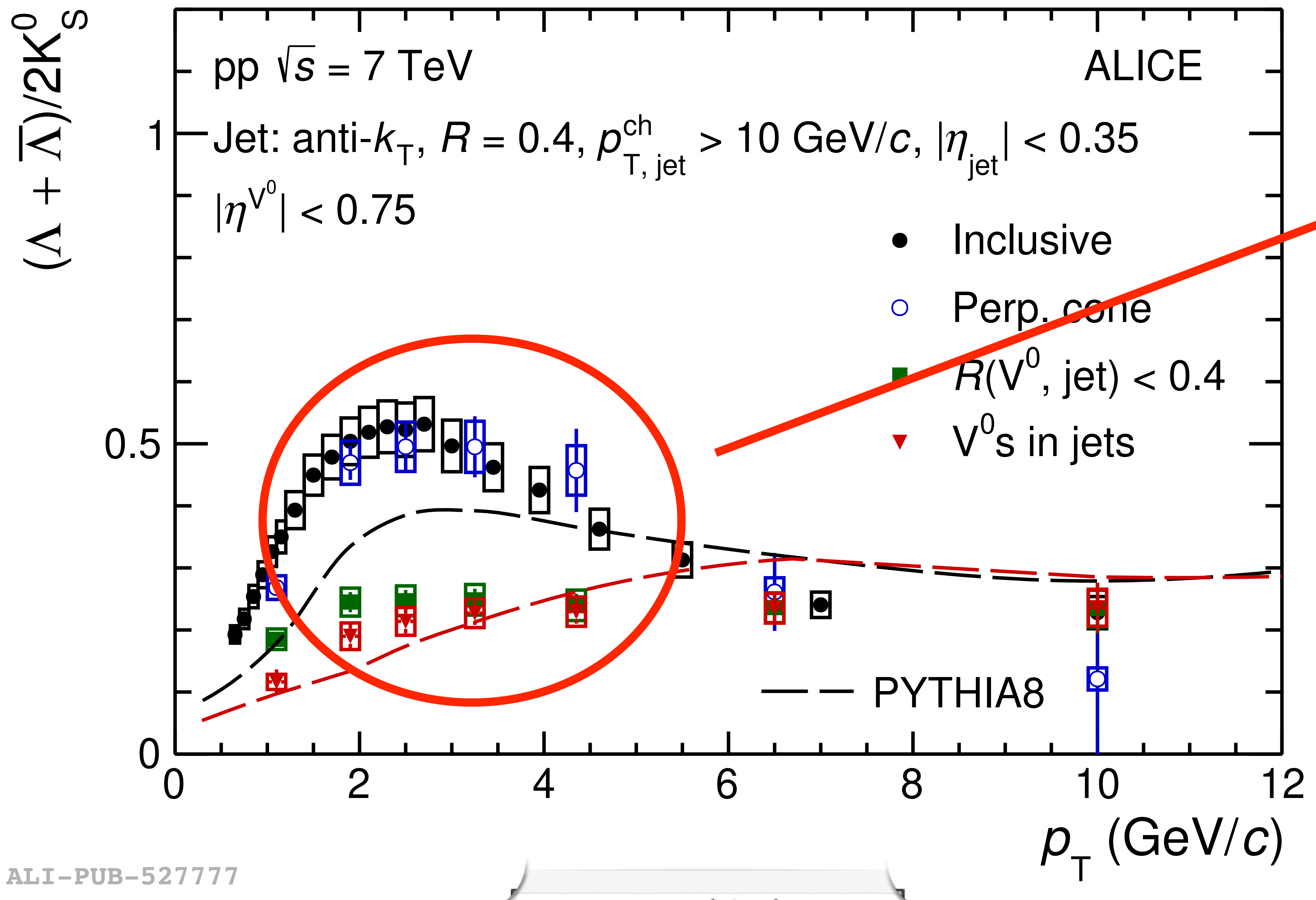
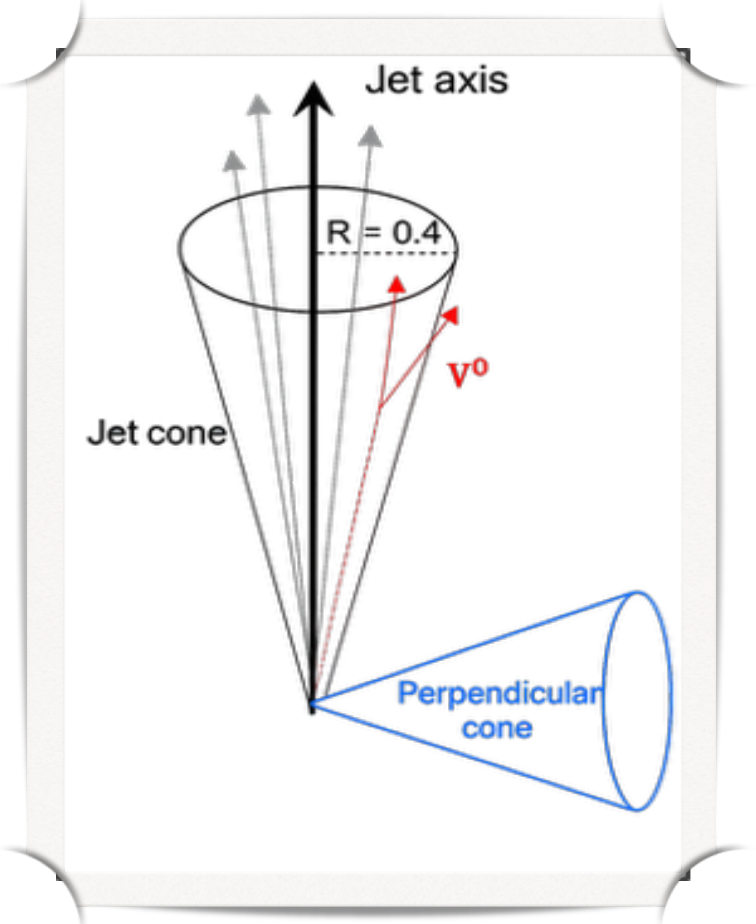
Strange particle production in jet

ALICE, Phys. Lett. B 827 (2022) 136984





- Strange baryon-to-meson ratio enhancement observed in UE (compared to in jet production) at intermediate p_T in small systems
  - ➡ Suggests that the enhancement is not attributed to the jet fragmentation
  - ➡ However, particles produced in the hard process don't necessarily be within high energy jets

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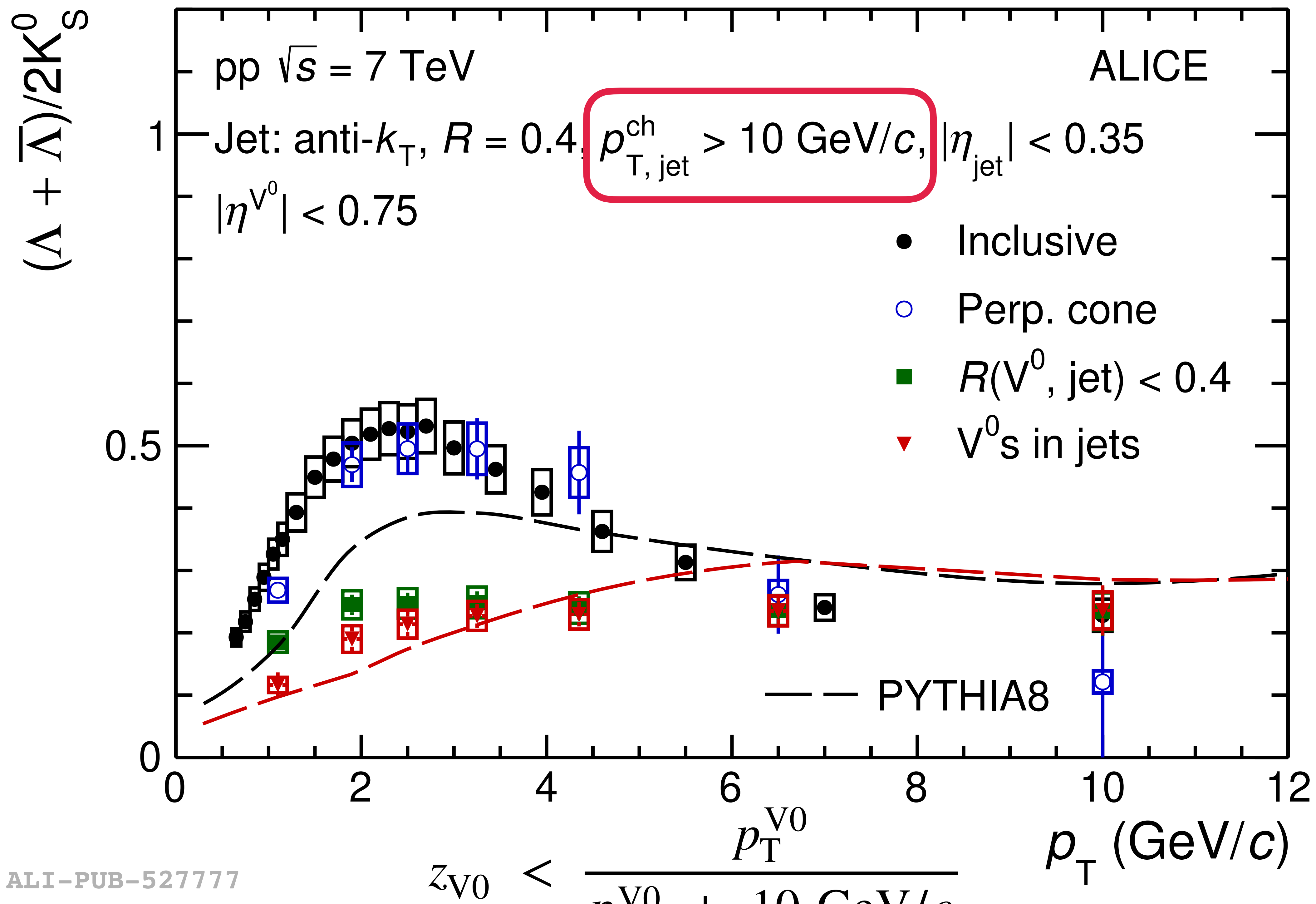
Strange particle production in jet

ALICE, Phys. Lett. B 827 (2022) 136984



$$z_{V0} < \frac{p_T^{V0}}{p_T^{V0} + 10\ \mathrm{GeV}/c}$$

$z < 0.09$ → $z < 0.5$

- Strange baryon-to-meson ratio enhancement observed in UE (compared to in jet production) at intermediate p_T in small systems
  - ➡ Suggests that the enhancement is not attributed to the jet fragmentation
  - ➡ However, particles produced in the hard process don't necessarily be within high energy jets

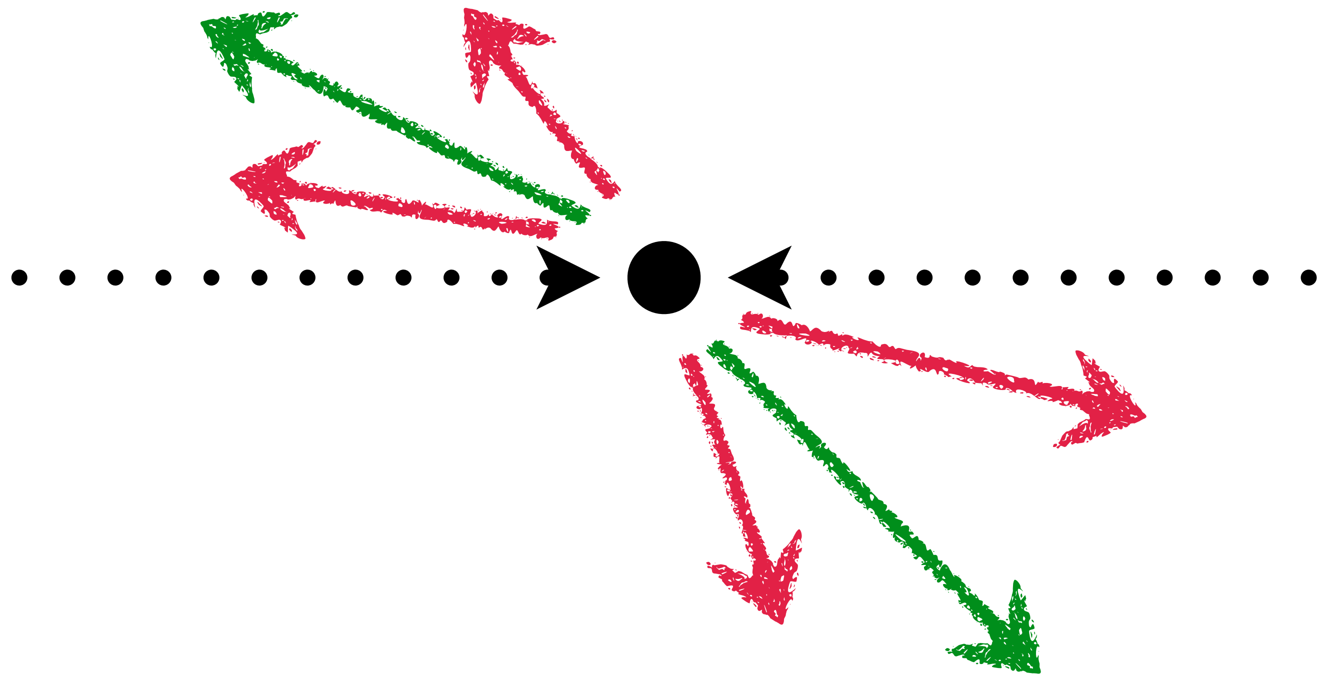
$$z = \frac{p_T^S}{p_{T,jet}}$$

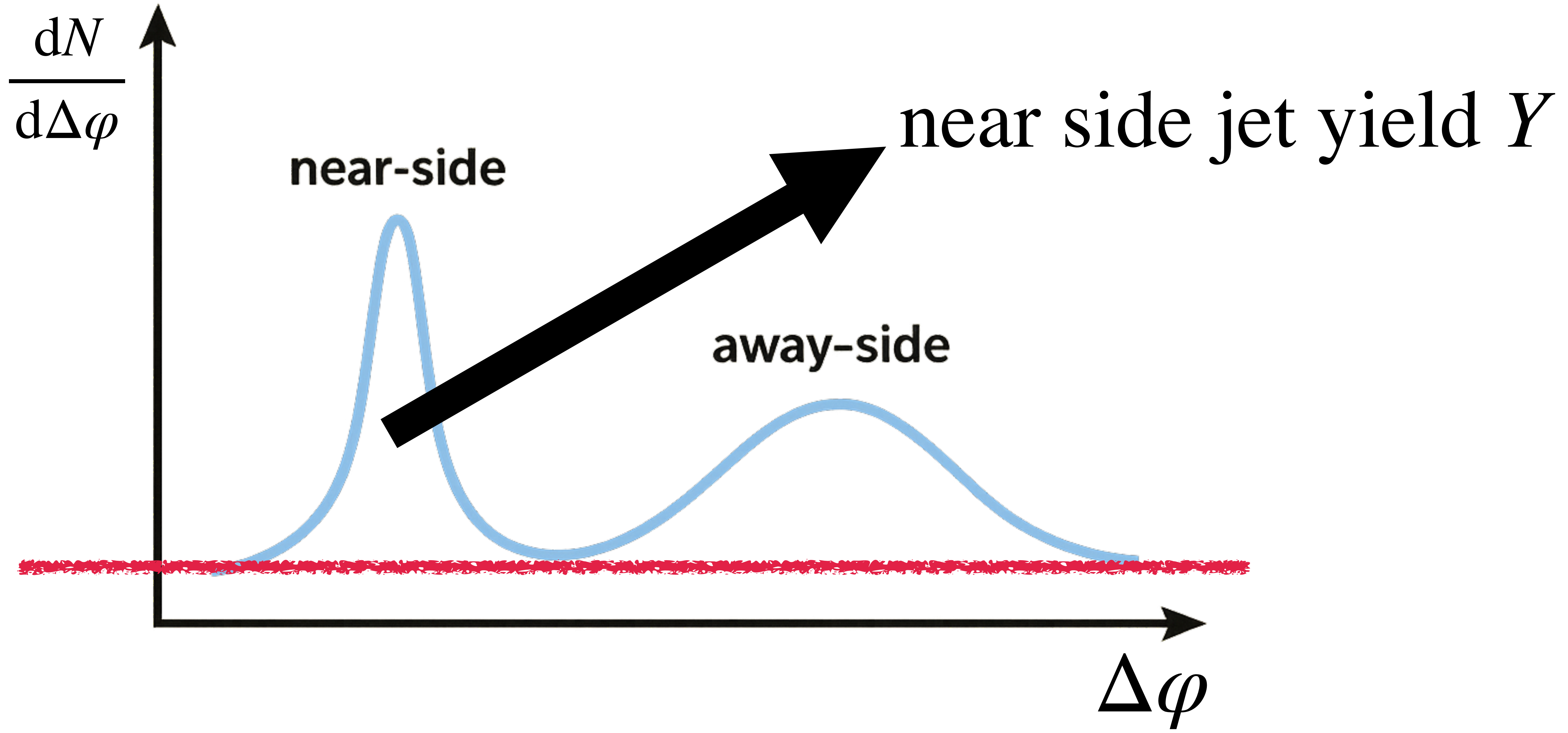
- Strange particle-jet association depends also on momentum fraction z
- Using a two-particle angular correlations method

Two particle angular correlation

- **Correlation function:**

$$C\left(\Delta\eta,\ \Delta\varphi\right) = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N}{\mathrm{d}\Delta\varphi\mathrm{d}\Delta\eta}$$





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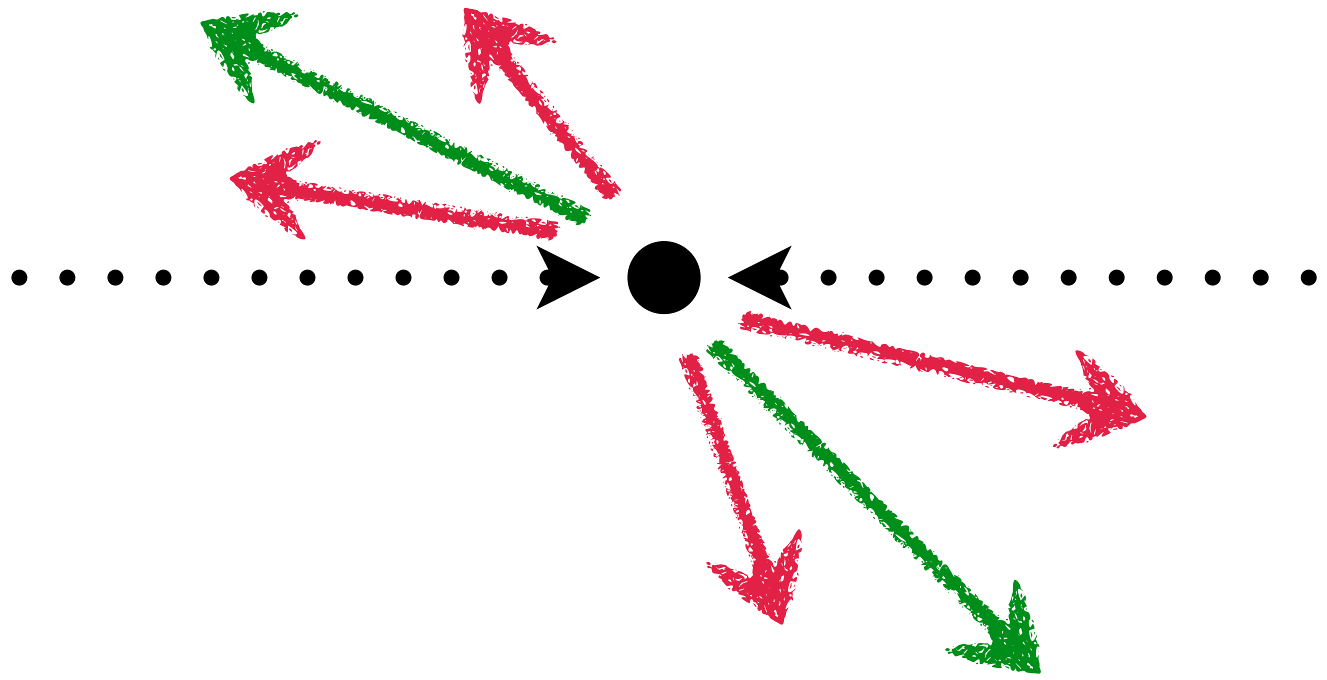
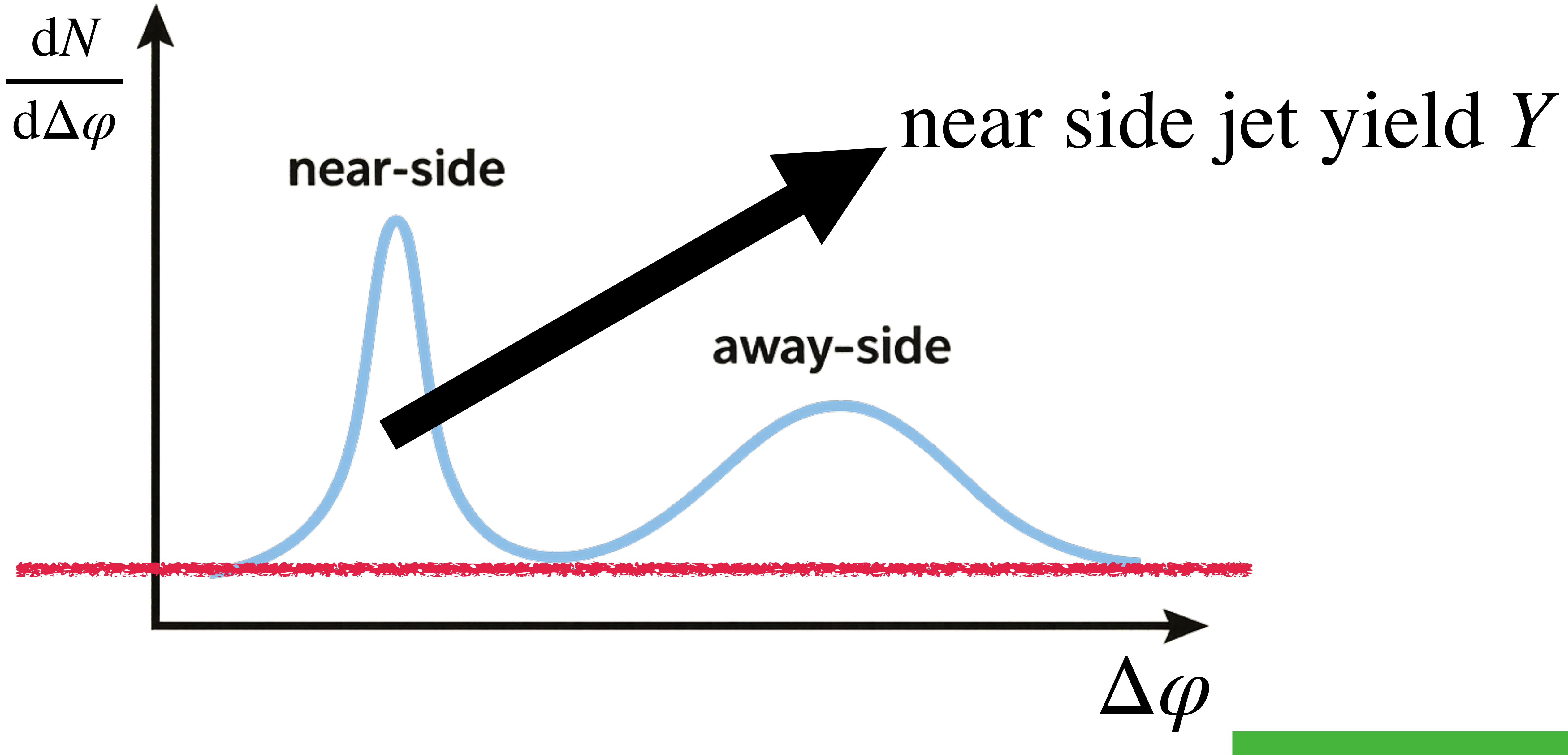
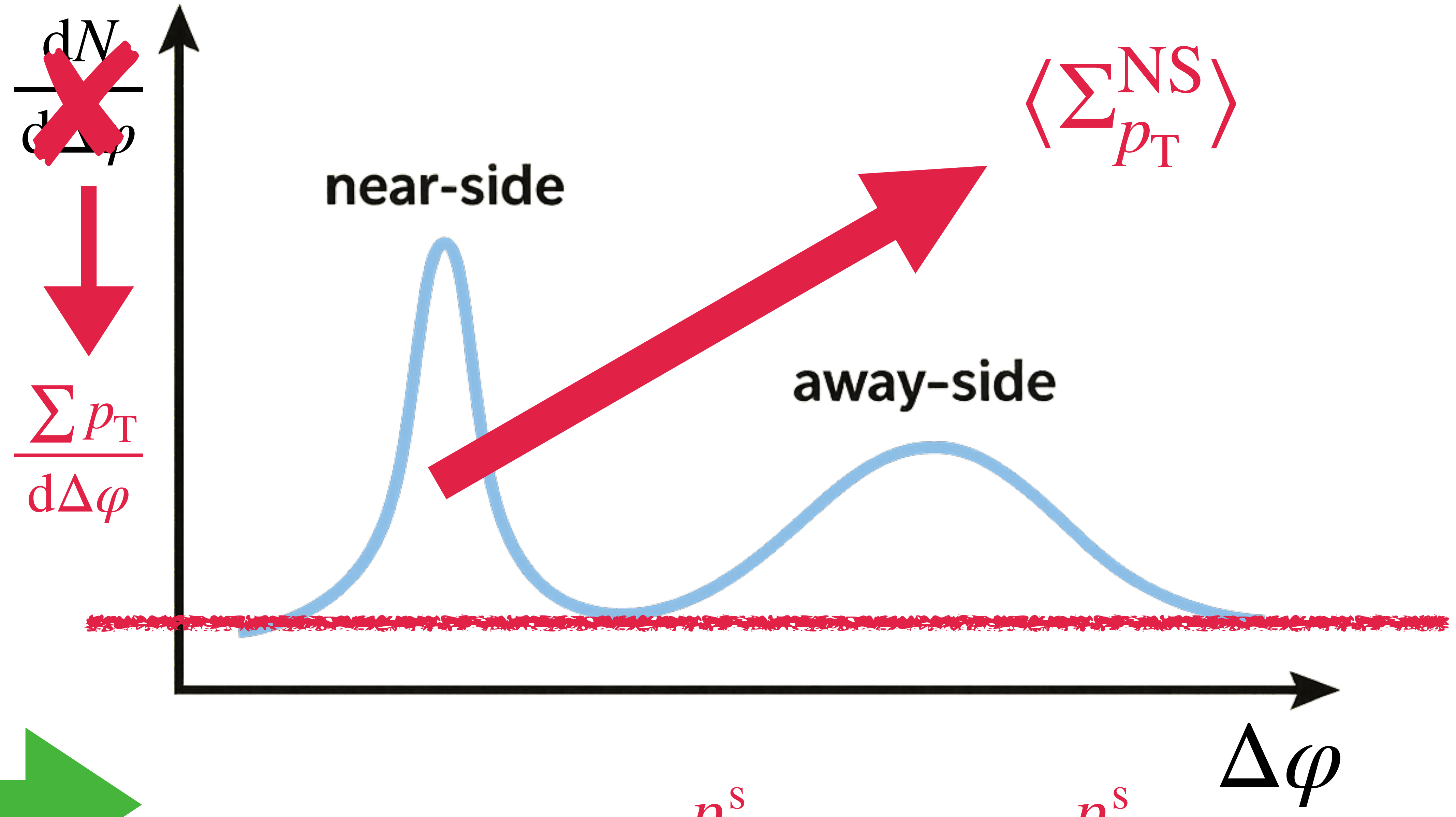
p_T-weighted two particle angular correlation

- **p_T weighted correlation function:**

$$C_{p_T-\text{weighted}}(\Delta\eta,\ \Delta\varphi) = \frac{1}{N_{\text{trig}}}\frac{d^2\sum p_T}{d\Delta\varphi d\Delta\eta}$$







introducing $p_{T,\text{assoc}}$ weight

$$\langle z \rangle = \frac{p_T^S}{p_{T,\text{jet}}} = \frac{p_T^S}{p_T^S + \langle \Sigma_{p_T}^{NS} \rangle}$$

Experimental setup

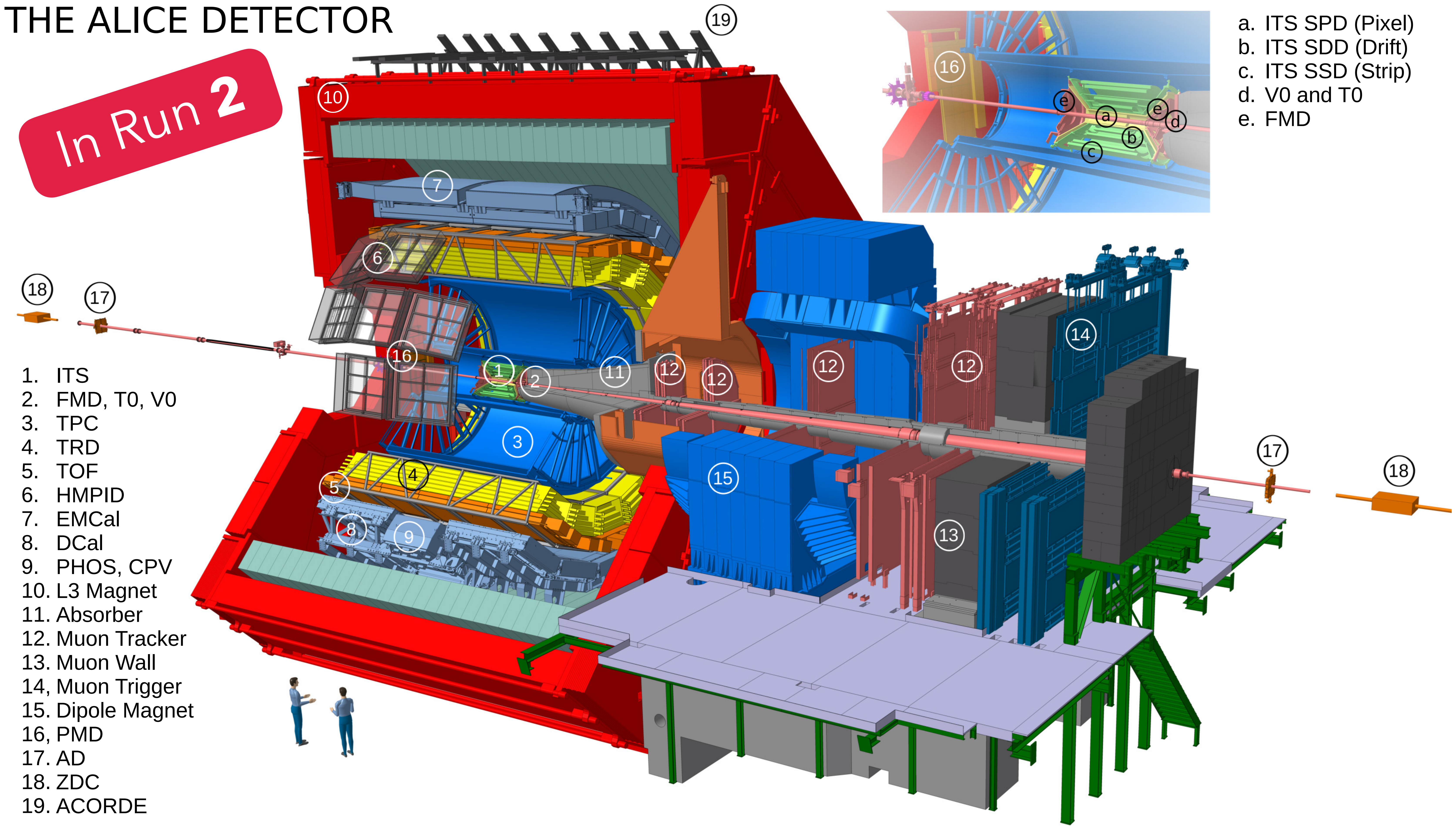
- **V0A and V0C (V0)**
  - V0A: $2.8 < \eta < 5.1$, V0C: $-3.7 < \eta < -1.7$
  - Event trigger and multiplicity determination
- **Inner Tracking System (ITS)**
  - $|\eta| < 0.9$
  - Vertex and track reconstruction
- **Time Projection Chamber (TPC)**
  - $|\eta| < 0.9$
  - Charged-particle tracking and identification
- **Time Of Flight (TOF)**
  - Charged-particle identification

Data samples & analysis setup

- pp at $\sqrt{s}$ = 13 TeV
- Standard event selections, $|z_{vtx}| < 10$ cm, IB and OOB pileup rejected

In Run 2

THE ALICE DETECTOR



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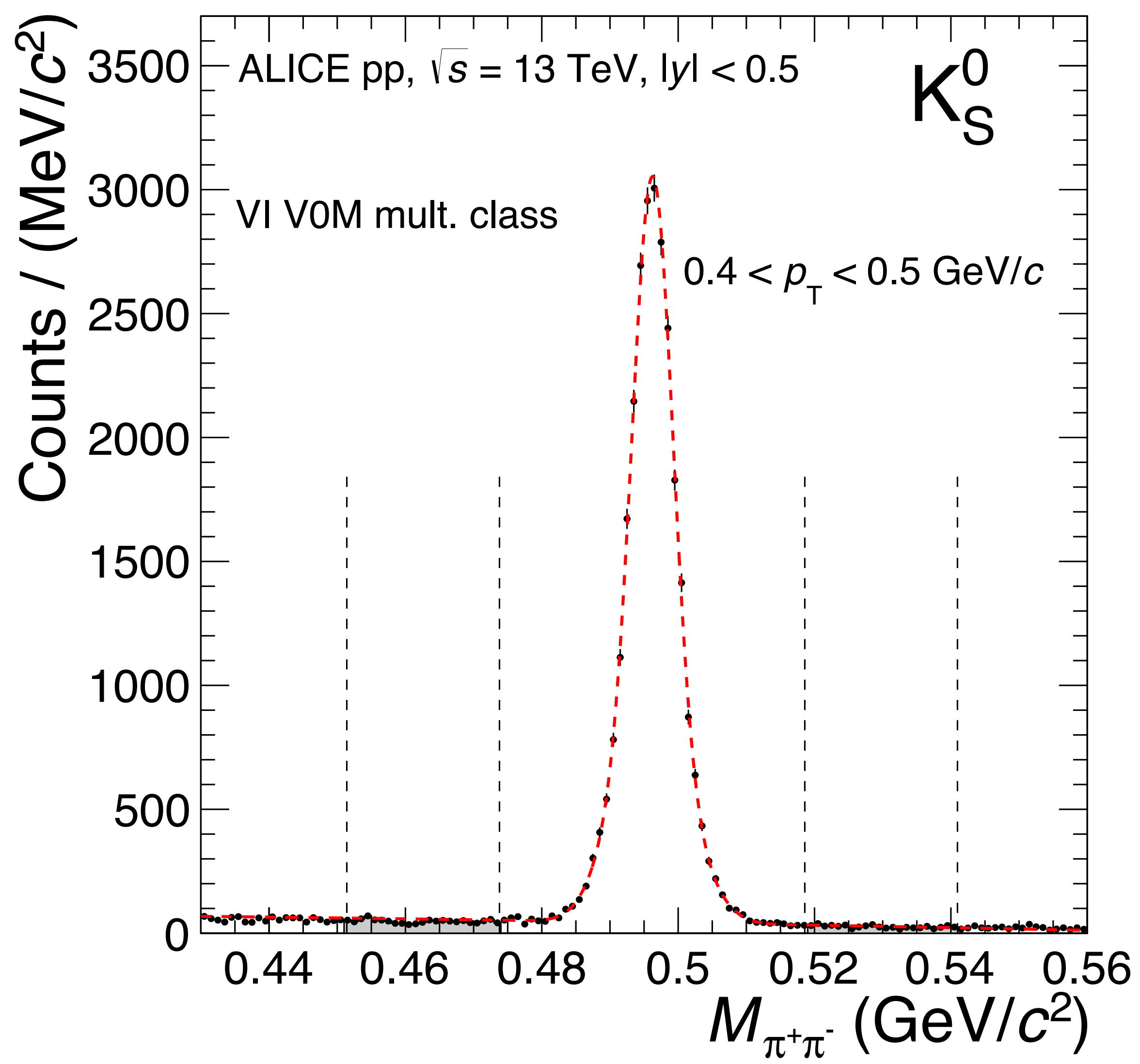
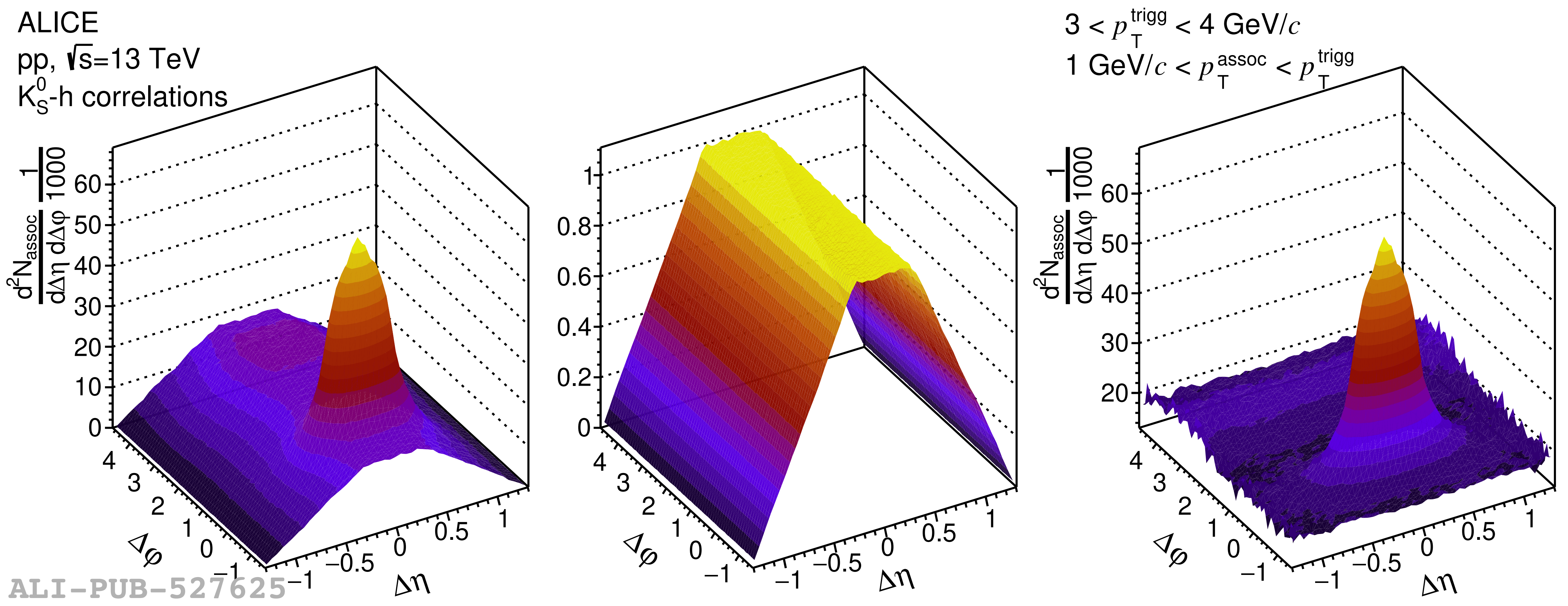
Analysis approach

- **Trigger particles**: strange particles (K^0_S, Λ, $\overline{\Lambda}$, Ξ^-, $\overline{\Xi}^+$)
  - Tracks with proper charge-sign combination and PID
  - Topological and kinematical selections (e.g., DCA, η,…)
- **Associated particles**: charged primary tracks
- Raw correlation function
  - ➡ Jet yield ($\langle \Sigma^{NS}_{p_T} \rangle$) obtained by applying acceptance and inefficiency corrections, and uncorrelated bkg subtraction

ALICE, Eur. Phys. J. C80 (2020) 167



ALICE, Eur. Phys. J. C 81 (2021) 945



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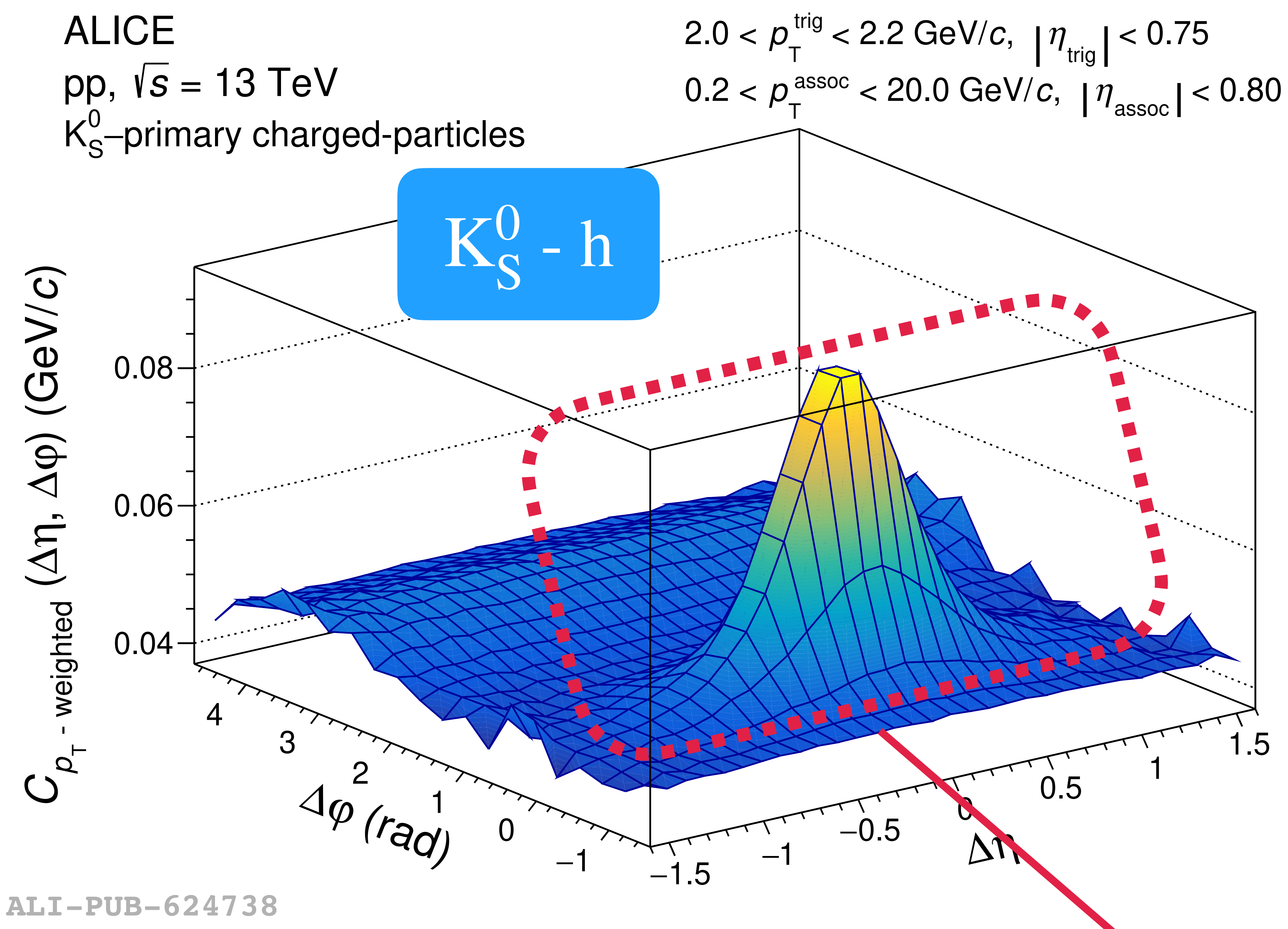
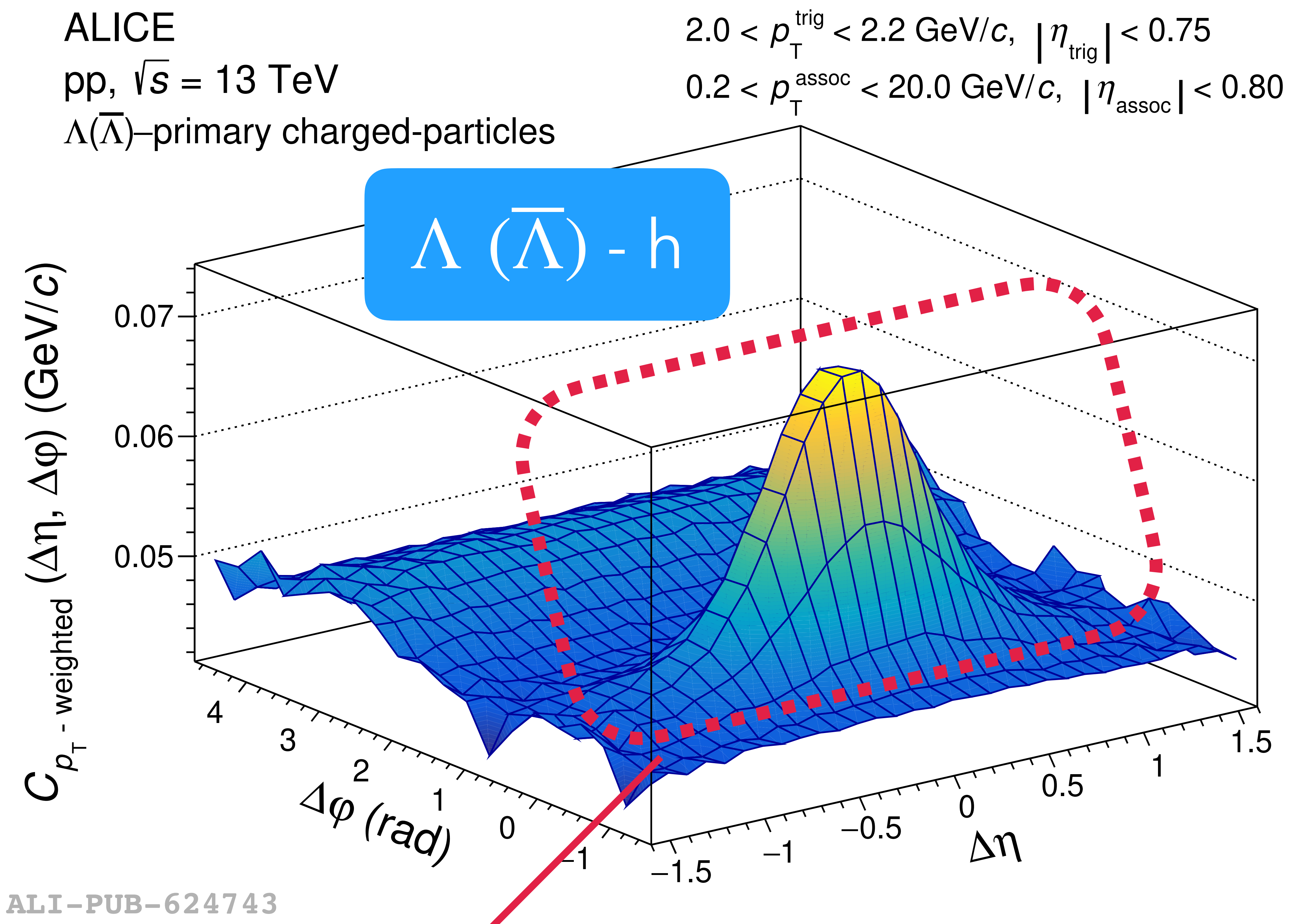
Combined p_T weighted correlation function

ALICE, arXiv:2603.19387





Fully corrected p_T weighted correlation function for strange meson K^0_S (left) and baryon $\Lambda(\overline{\Lambda})$ (right)

$$\langle z \rangle = \frac{p_T^s}{p_{T,\mathrm{jet}}} = \frac{p_T^s}{p_T^s + \left\langle \Sigma_{p_T}^{NS} \right\rangle}$$

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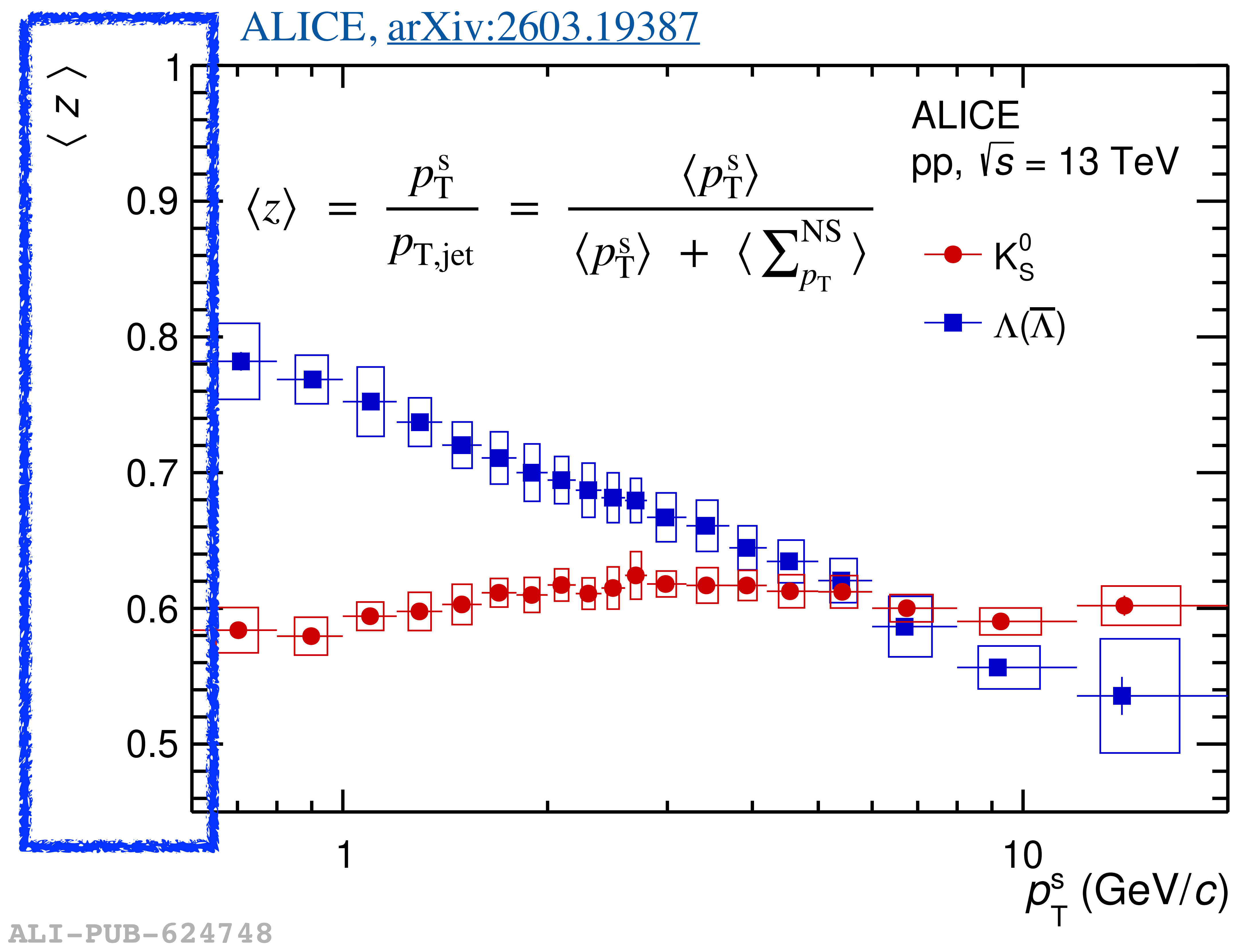
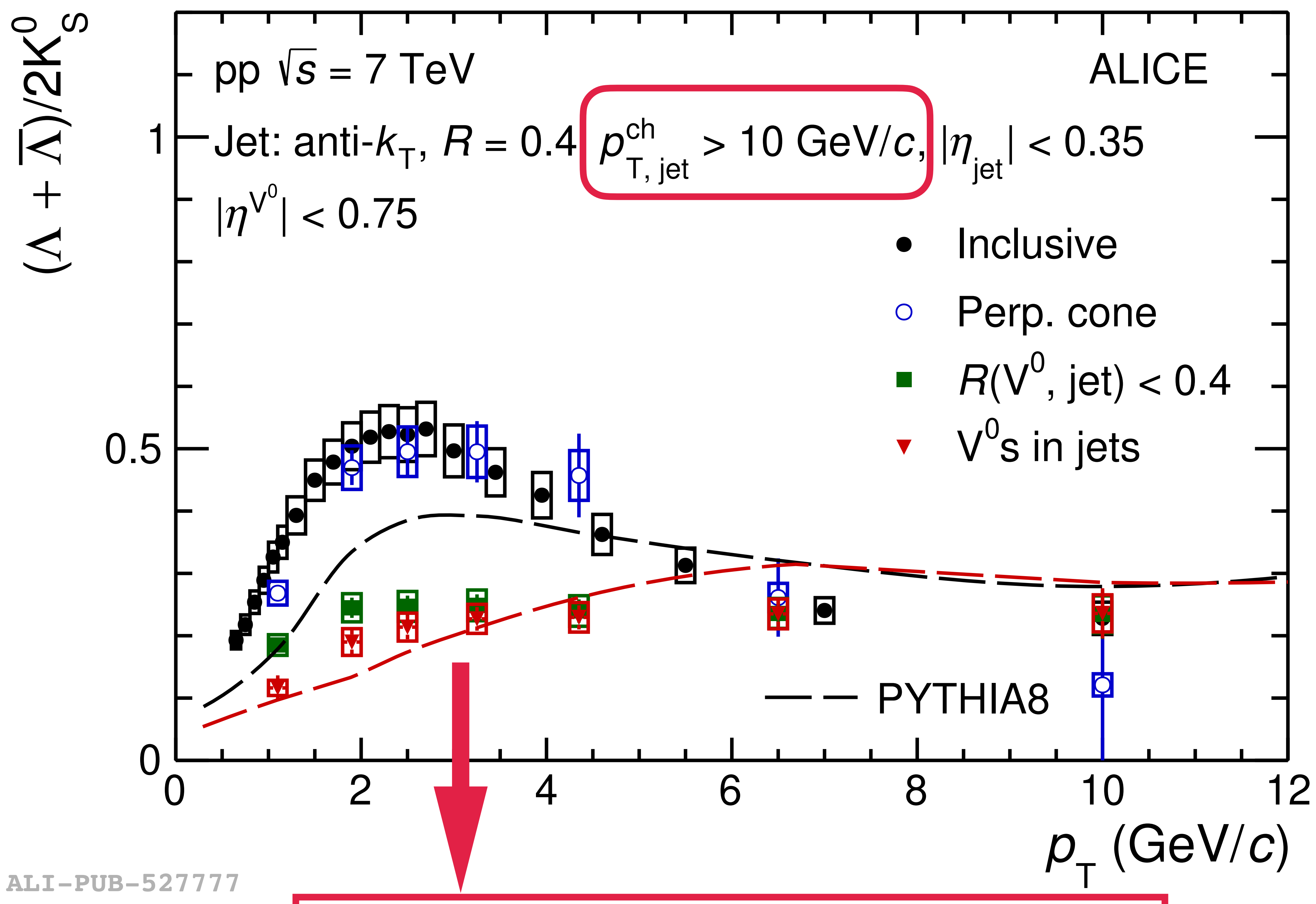
Results - <z>





$p_{T,jet} \sim 3/0.6\ \text{GeV}/c = 5\ \text{GeV}/c$

- Results suggest that the strange particles take large fraction (high $< z >$) from the originated (relative) low energy partons
  - When comparing the in-jet and out-of-jet strange particles production, we are actually measuring particles with different $<z>$

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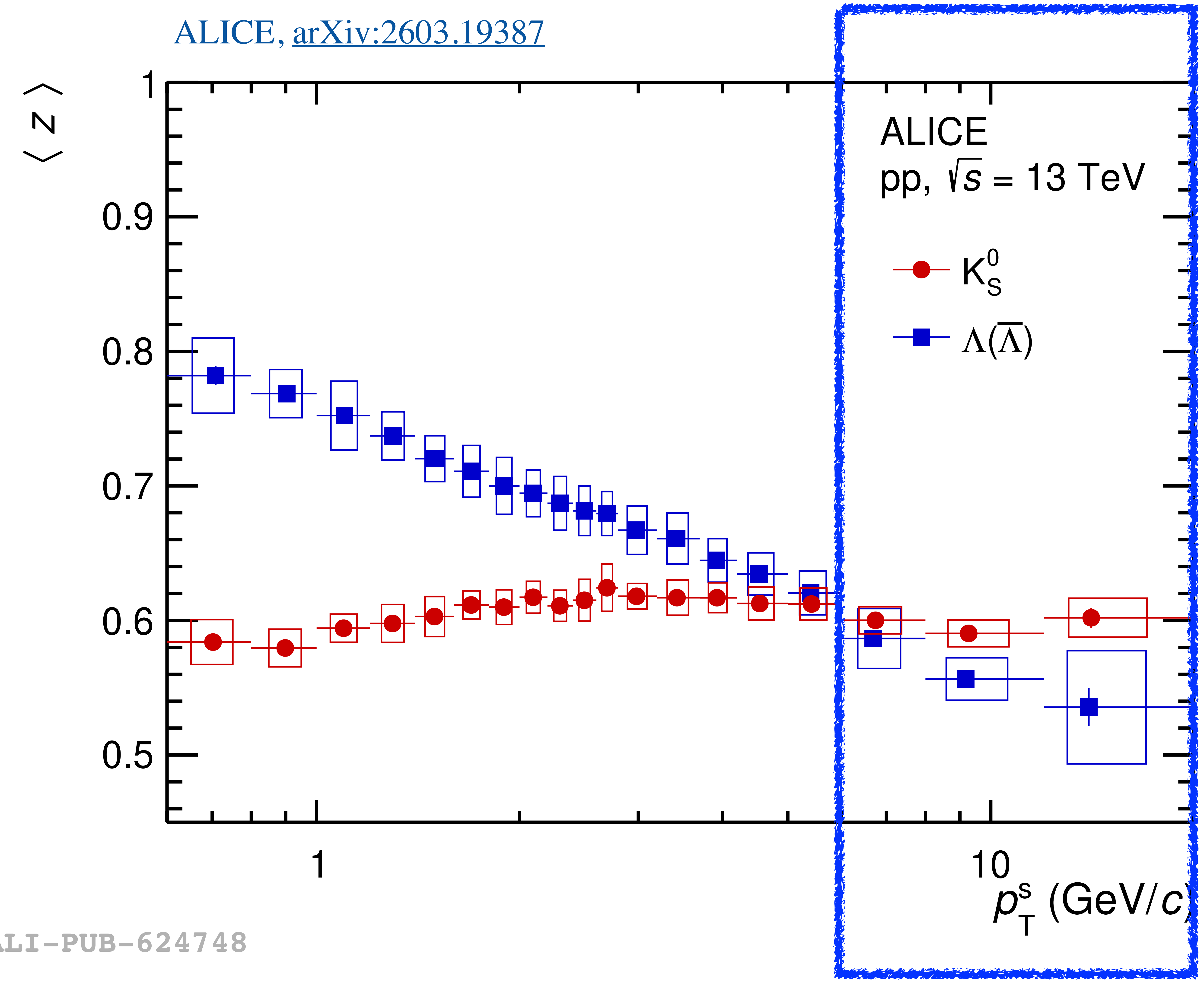
Results - <z>

ALICE, arXiv:2603.19387



ALI-PUB-624748

- At high p_T, expected due to the trigger bias

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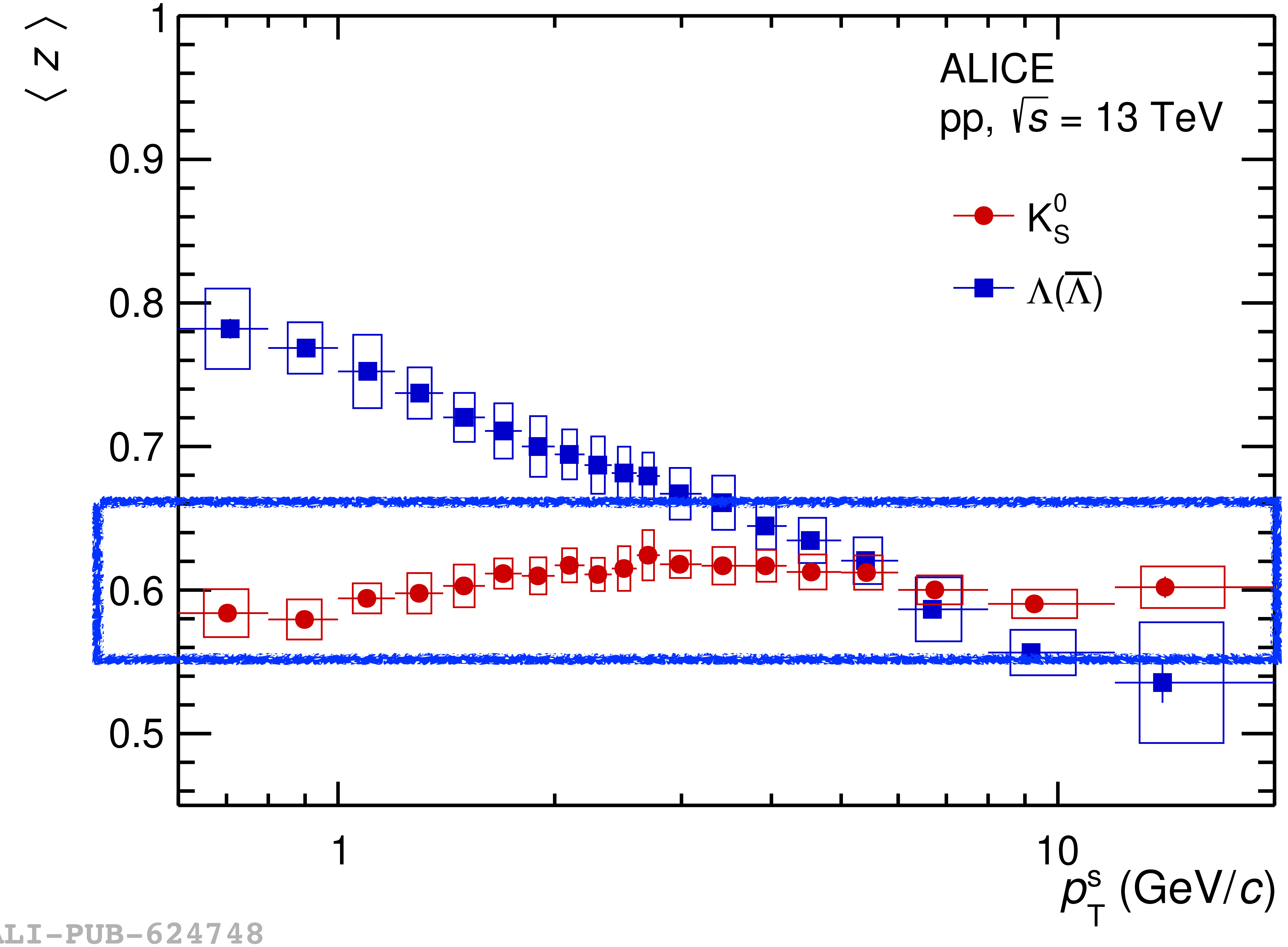
Results - <z>

ALICE, arXiv:2603.19387

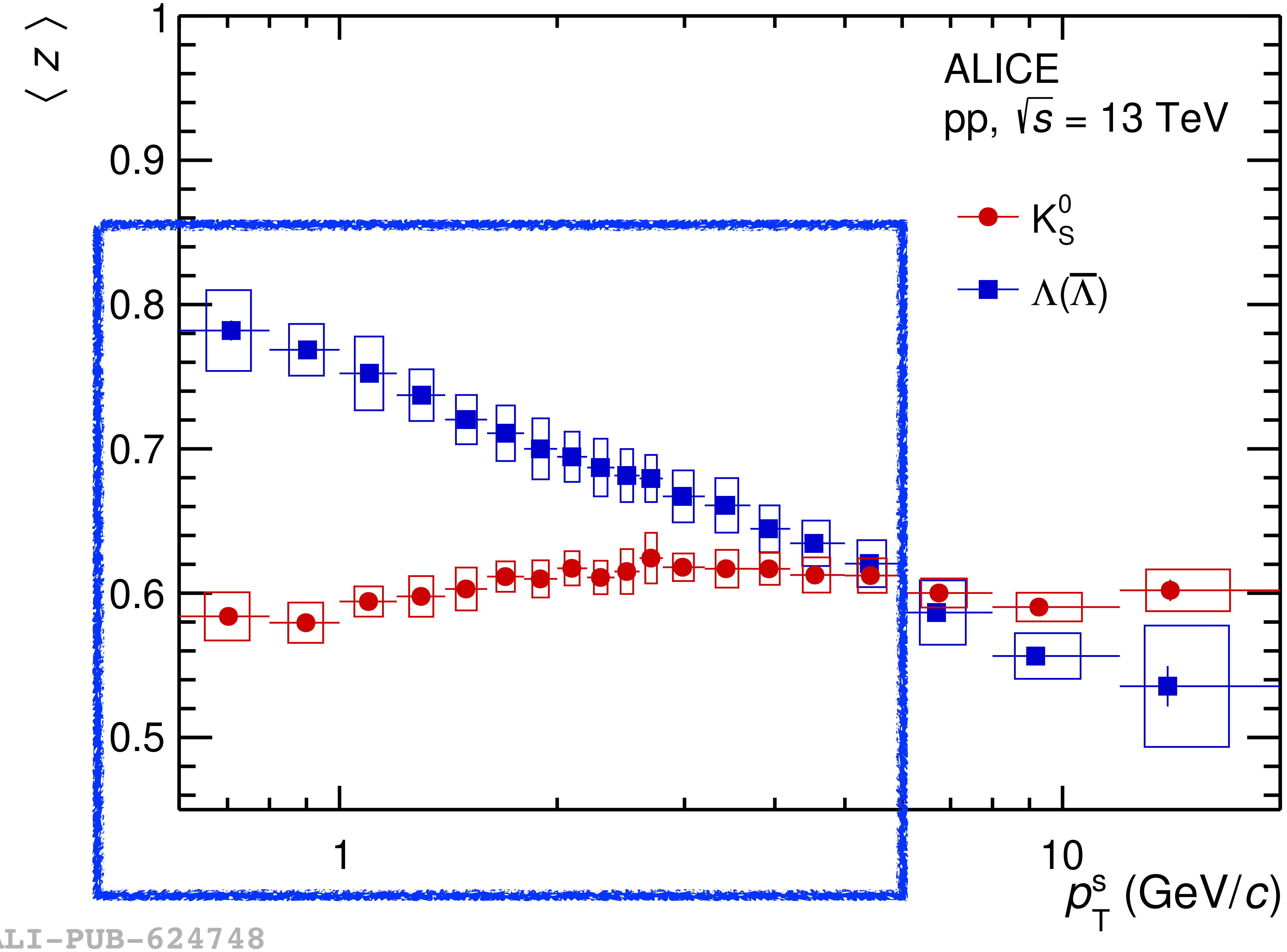


ALI-PUB-624748

- At high p_T, expected due to the trigger bias
- $< z >$ doesn't change too much, no indication of a significant change in the production mechanism
  - ➡ Strange particles are more likely to come from the fragmentation of a lower-energy parton

Results - <z>

ALICE, arXiv:2603.19387



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- $< z >$ doesn't change too much, no indication of a significant change in the production mechanism
  - ➡ Strange particles are more likely to come from the fragmentation of a lower-energy parton
- Increase for Λ with decreasing p_T
  - ➡ The fragmentation is harder in this region (?)
  - ➡ More isolated Λ $(\overline{\Lambda})$ production ($z = 1$) contribution in this region (?)
  - ➡ Motivating study <z> in different multiplicities

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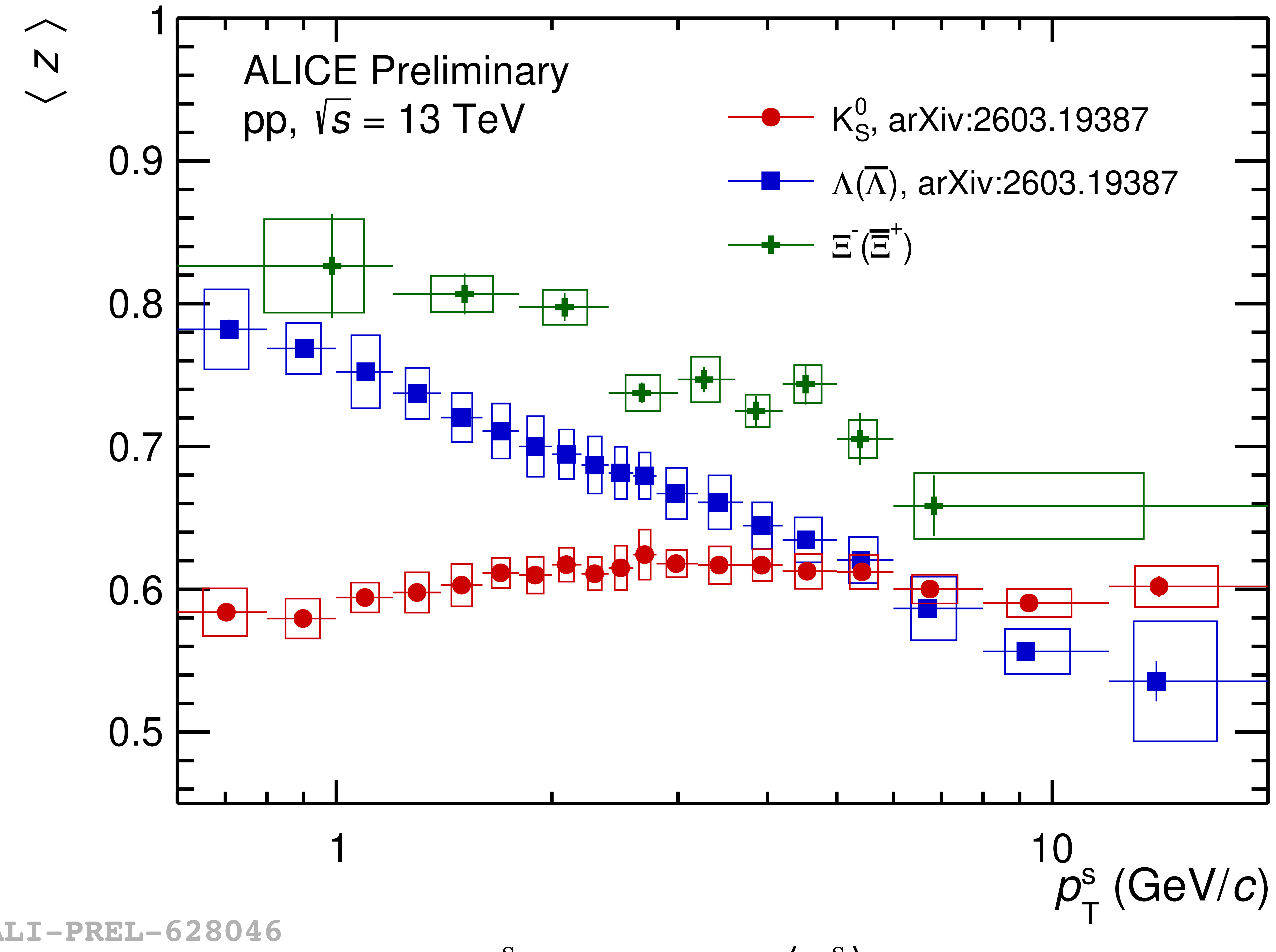
Including multi-strange baryon



$$\langle z \rangle = \frac{p_T^s}{p_{T,jet}} = \frac{\langle p_T^s \rangle}{\langle p_T^s \rangle + \langle \sum_{p_T}^{NS} \rangle}$$

- At high p_T, expected due to the trigger bias
- $< z >$ doesn't change too much, no indication of a significant change in the production mechanism
  - ➡ Strange particles are more likely to come from the fragmentation of a lower-energy parton
- Increase for Λ with decreasing p_T
  - ➡ The fragmentation is harder in this region (?)
  - ➡ More isolated Λ ($\overline{\Lambda}$) production ($z = 1$) contribution in this region (?)
  - ➡ Motivating study $<z>$ in different multiplicities
- Similar behavior between Ξ and Λ

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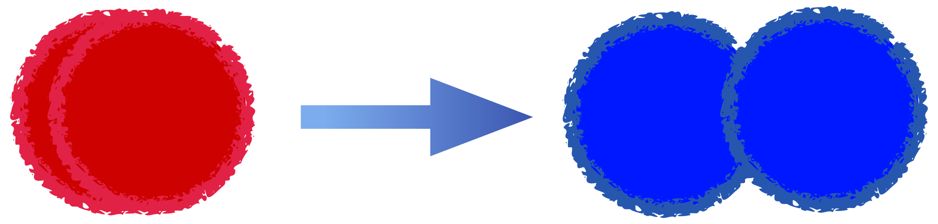
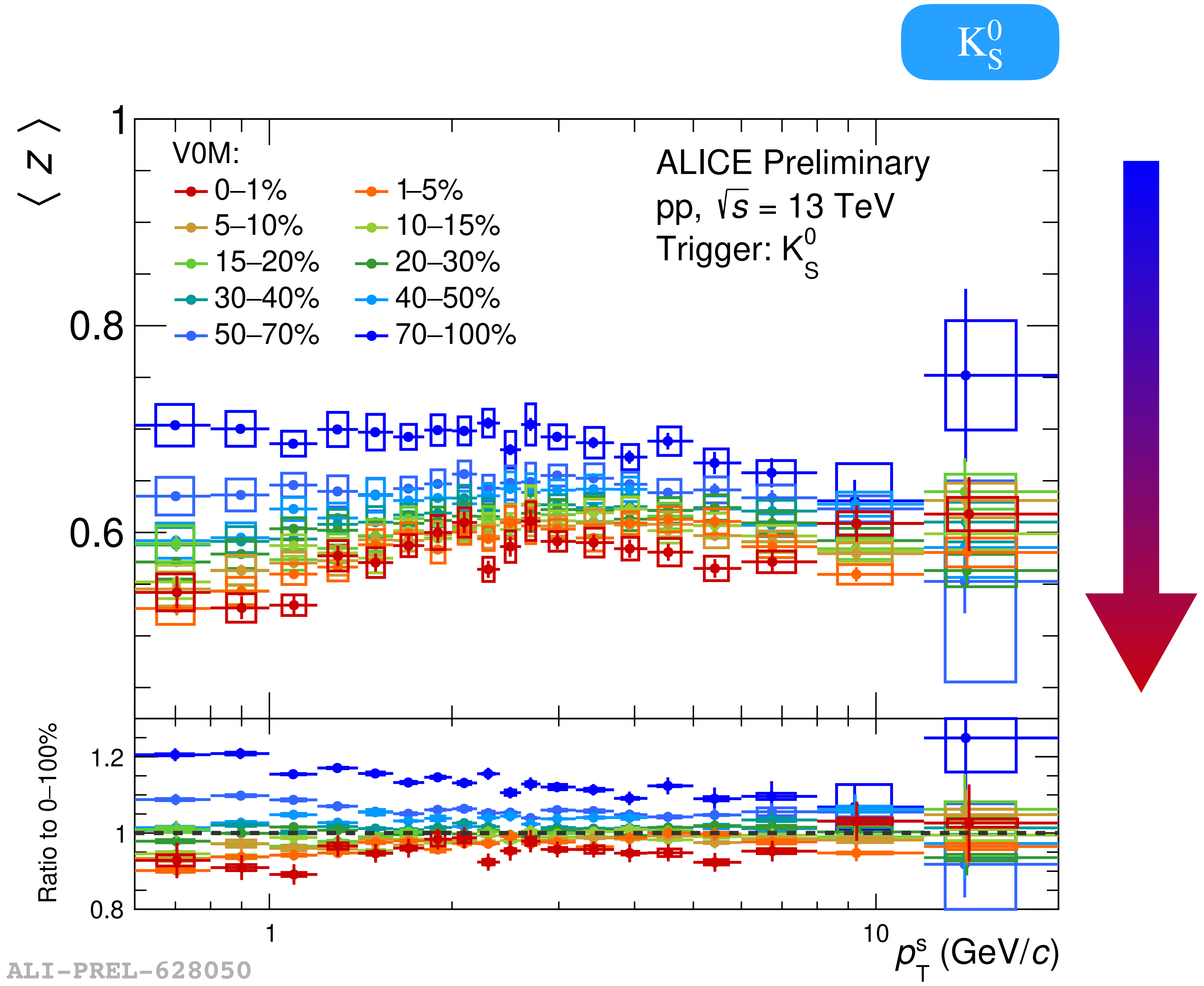
Multiplicity dependence of <z>





- For K^0_S, $<z>$ is clearly multiplicity dependent, larger $<z>$ with more peripheral collisions

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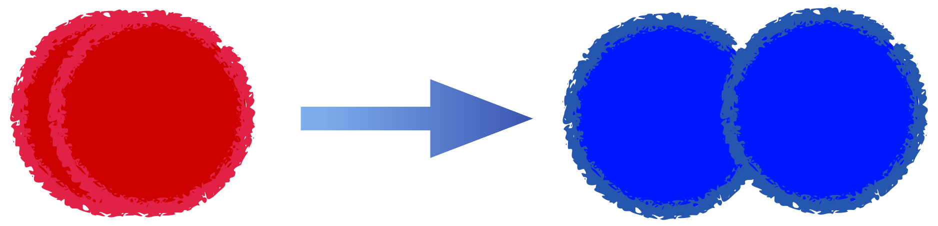
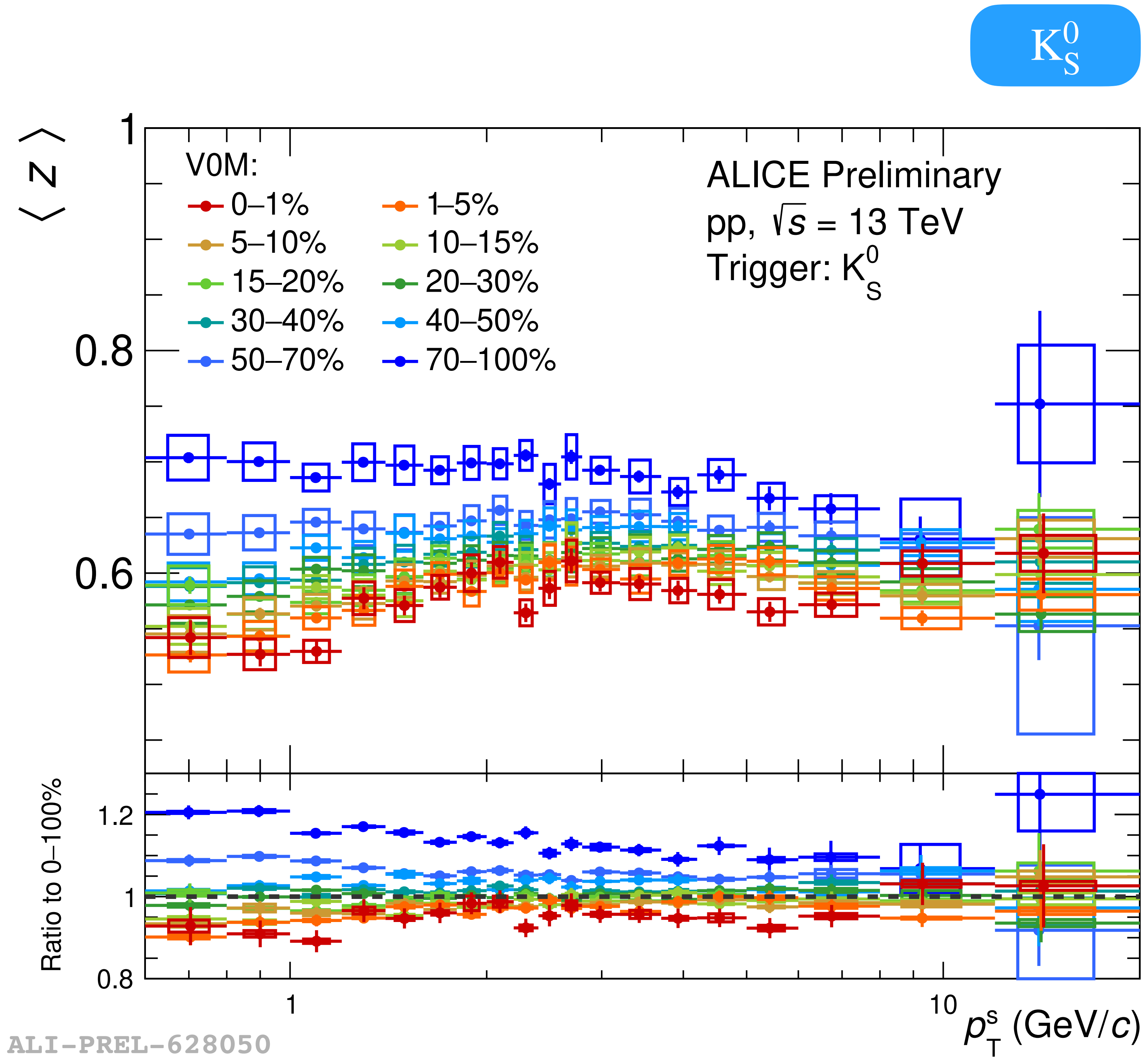
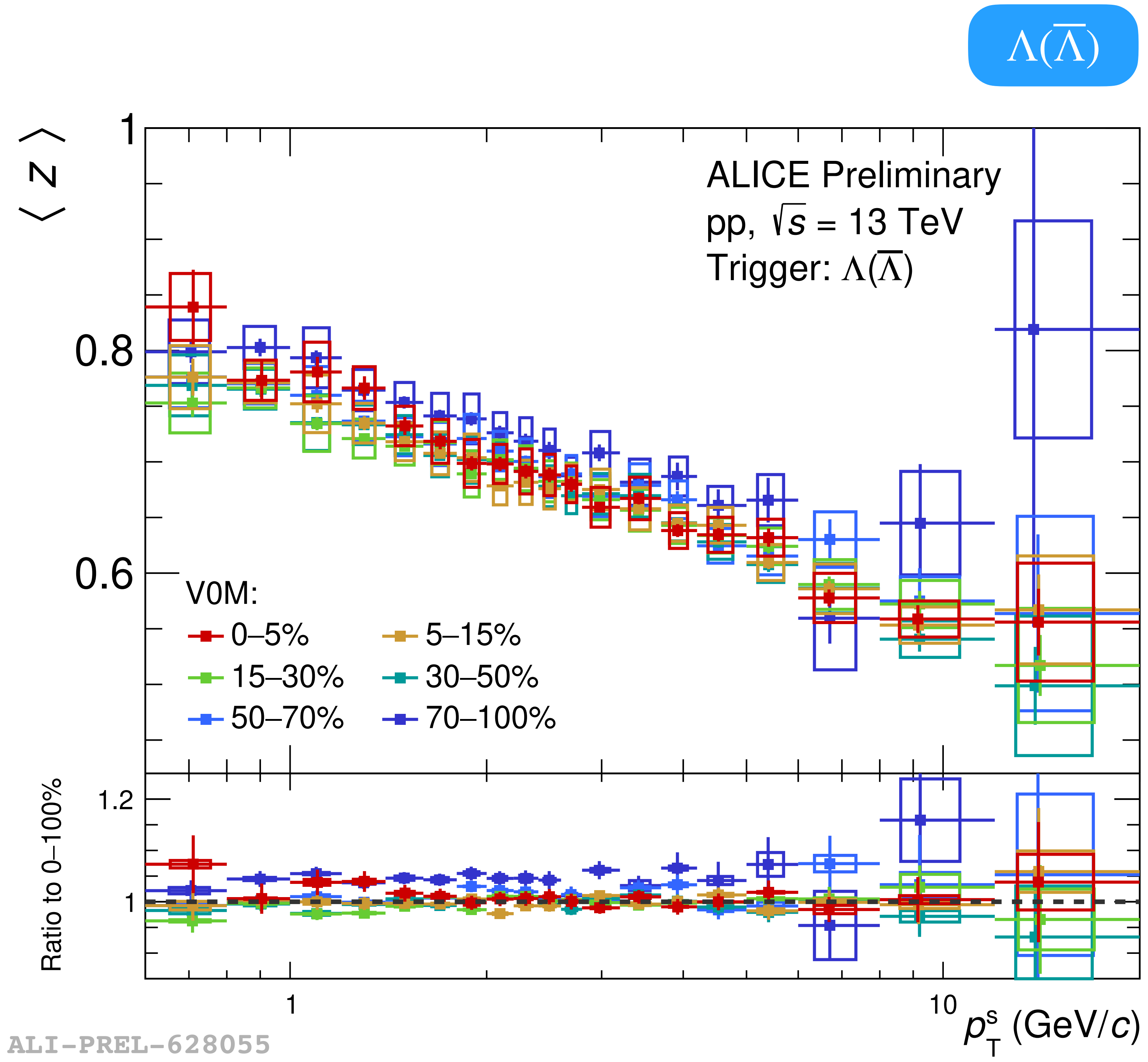
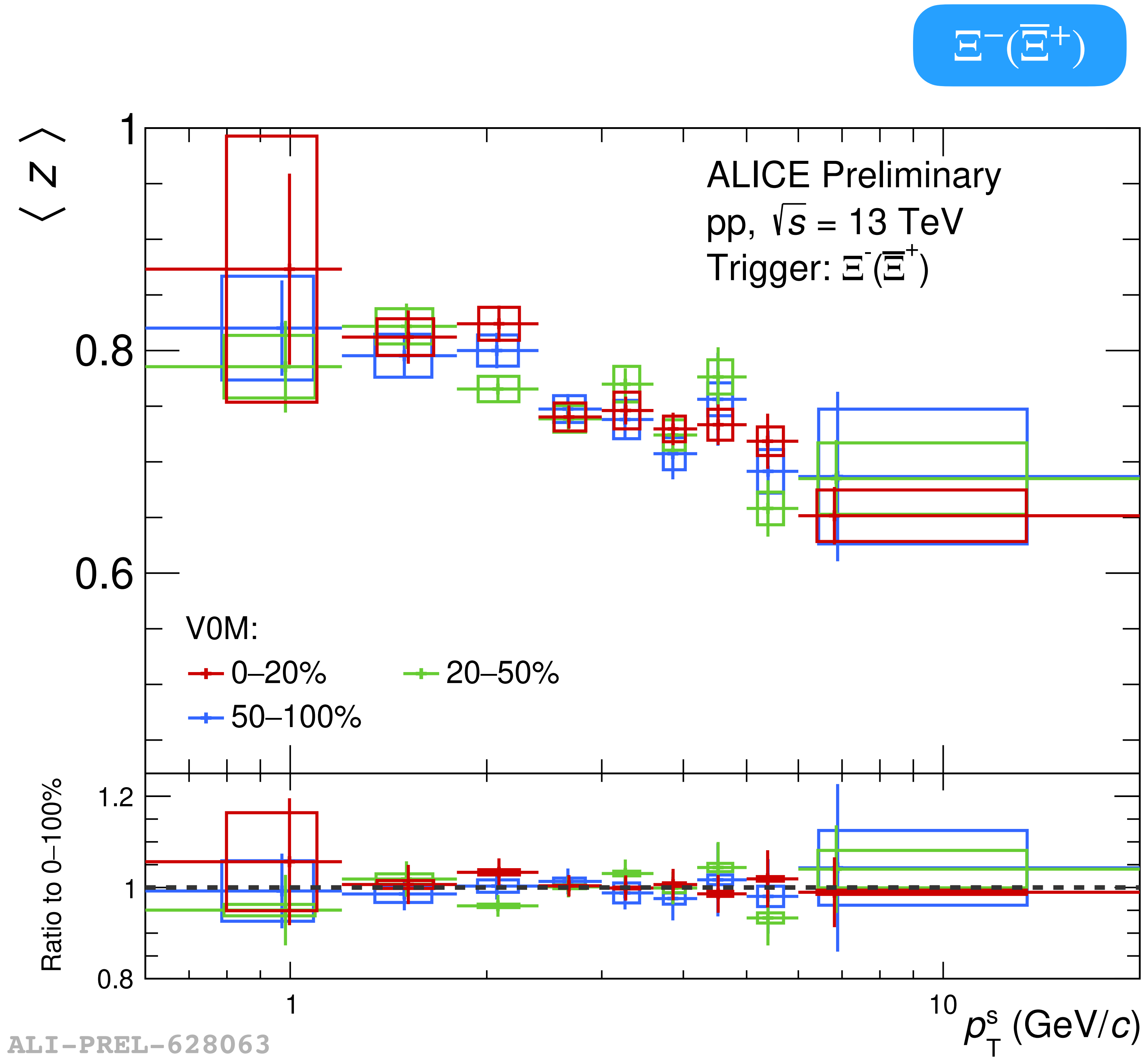
Multiplicity dependence of <z>



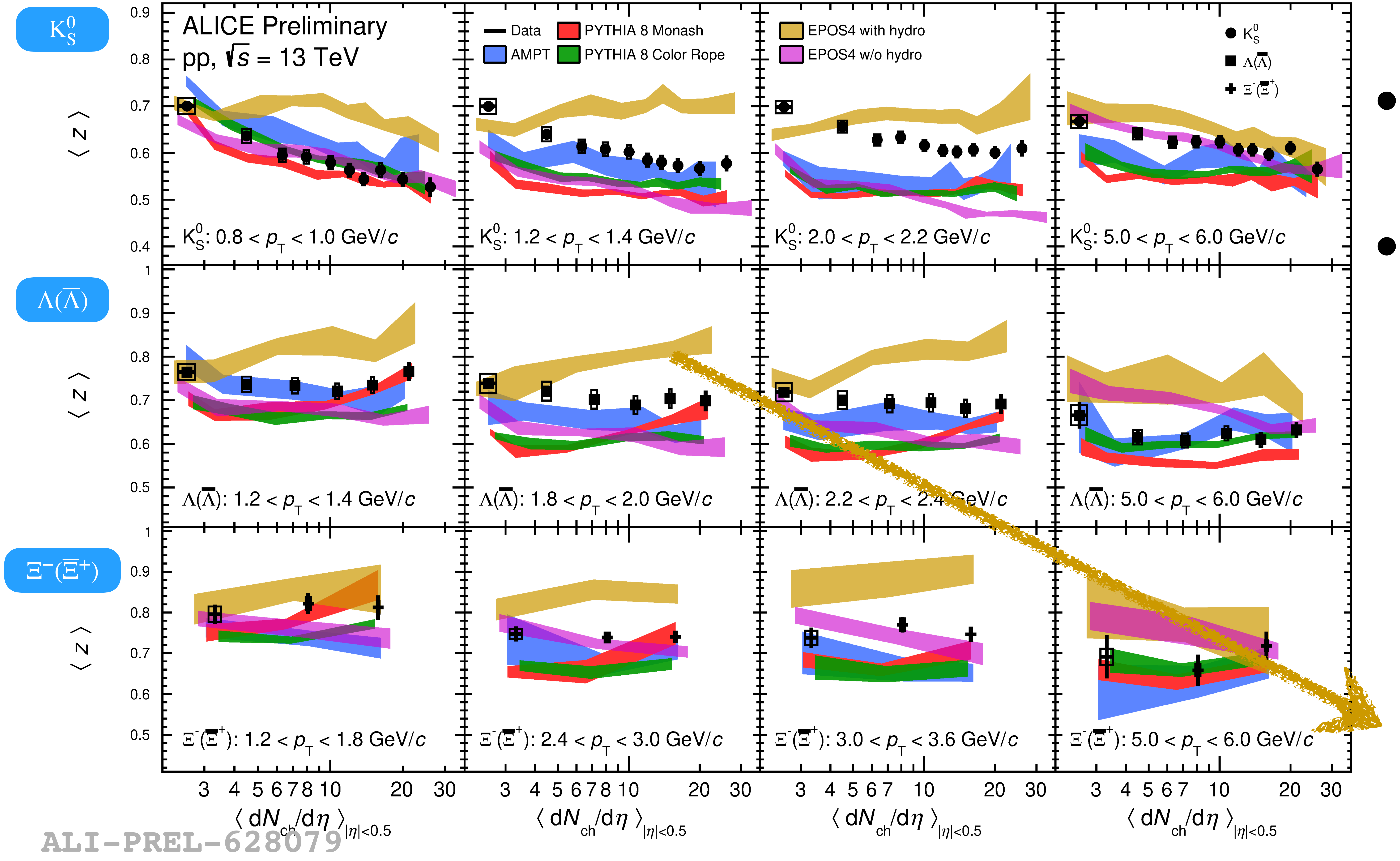






- For K^0_S, <z> is clearly multiplicity dependent, larger <z> with more peripheral collisions
- No multiplicity dependence observed for strange baryons
  - ➡ Challenging the scenario where coalescence is assumed to dominate the production in high-multiplicity hadronic collisions

<z> vs. <dN$_{ch}$/dη> and model comparison



- String-based models reproduce the trend within uncertainties
- Hydrodynamic increases <z>
  - ➡ Jet correlations are “diluted”
  - ➡ <z> increases with higher multiplicity, stronger effect at higher multiplicity

Rough estimation on $\langle \Sigma^{NS}_{p_T} \rangle$:

- $\gtrsim$ 0.8 GeV/c at the lowest multiplicity
- $\lesssim$ 0.4 GeV/c left at the highest multiplicity

$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$ values for each V0M class in the data taken from ALICE Eur. Phys. J. C 81 (2021) 630

Summary

- The first measurement of the strange particle's p_{T} fraction in mini-jets ($\langle z \rangle$) in pp collisions at $\sqrt{s}$ = 13 TeV, and a novel p_{T} weighted correlation method is presented
- Strange particles are more likely to come from (relatively) lower-energy partons with high z
- Different behaviors between strange meson and baryons
- The multiplicity dependence of $\langle z \rangle$ is studied using the V0M percentile
  - ➡ $\langle z \rangle$ is larger when the collision is more peripheral for $\mathrm{K}^0_{\mathrm{S}}$
  - ➡ No multiplicity dependence for $\Lambda(\overline{\Lambda})$ and $\Xi^-(\overline{\Xi}^+)$
  - ➡ Disfavoring the picture where coalescence dominates hadron production in high-multiplicity hadronic collisions
- String-based models reproduce the multiplicity trend within uncertainty
- Hydrodynamic dilutes jet correlations and is more pronounced at higher multiplicity

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Special thanks to FCPPN/L

A CSC funded joint-PhD program
ongoing smoothly ~

Between
IOPP, Central China Normal University
and
IP2I, Université Claude Bernard Lyon 1

PhD candidate:
- Lang XU

Thesis title:
- Study of strange particle production in jets with ALICE at the LHC

Thesis supervisors:
- Cvetan Valeriev Cheshkov from IP2I, UCBL; Xiaoming Zhang from IOPP, CCNU

Topics:
- The novel measurement of the transverse-momentum fraction of (multi-) strange particle in (mini-)jets

Thanks for listening!

Backup

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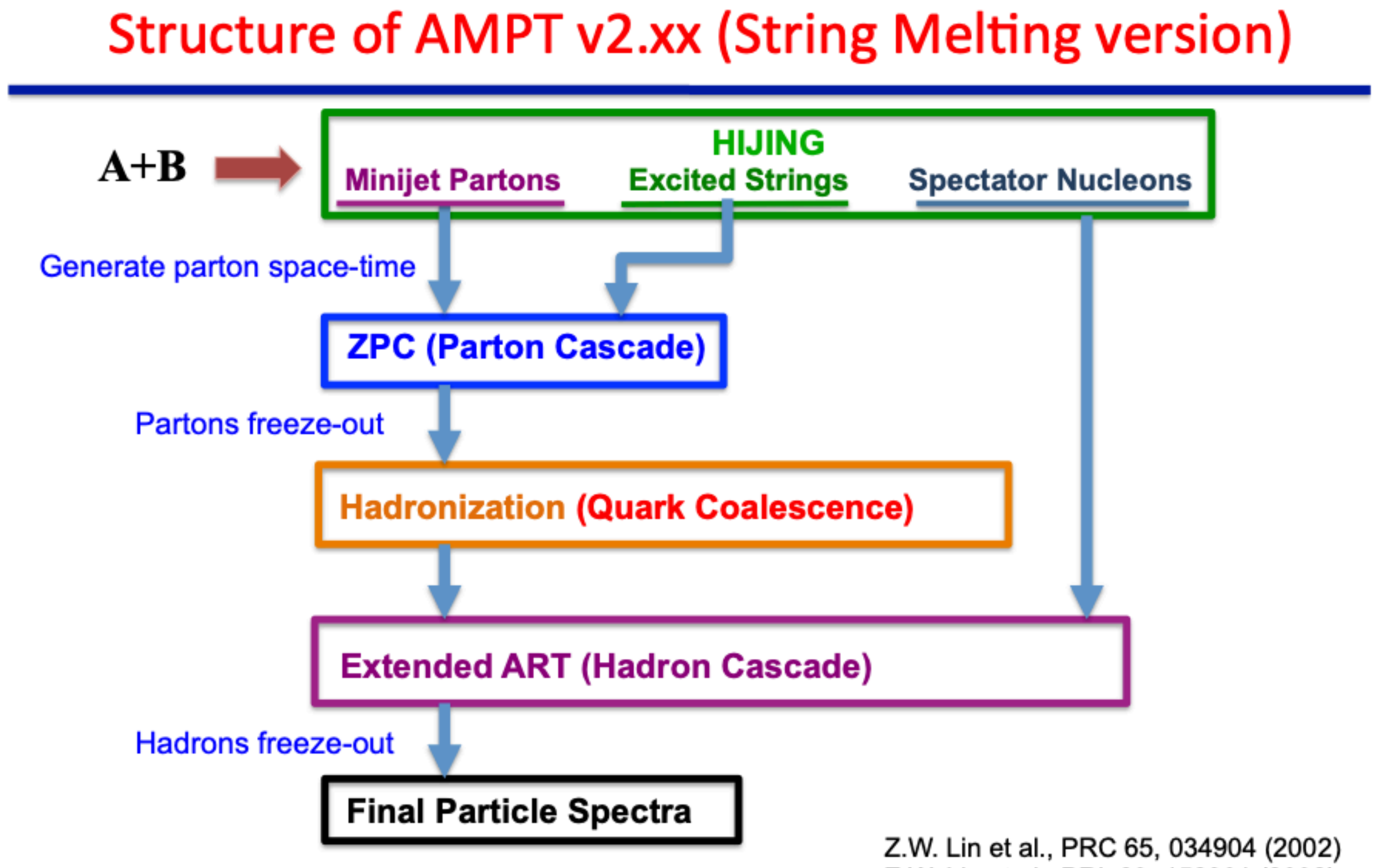
MC models

PYTHIA8.3

Monash

Color Rope

A Multi-Phase Transport (AMPT) model



Z.W. Lin et al., PRC 65, 034904 (2002)
Z.W. Lin et al., PRL 89, 152301 (2002)

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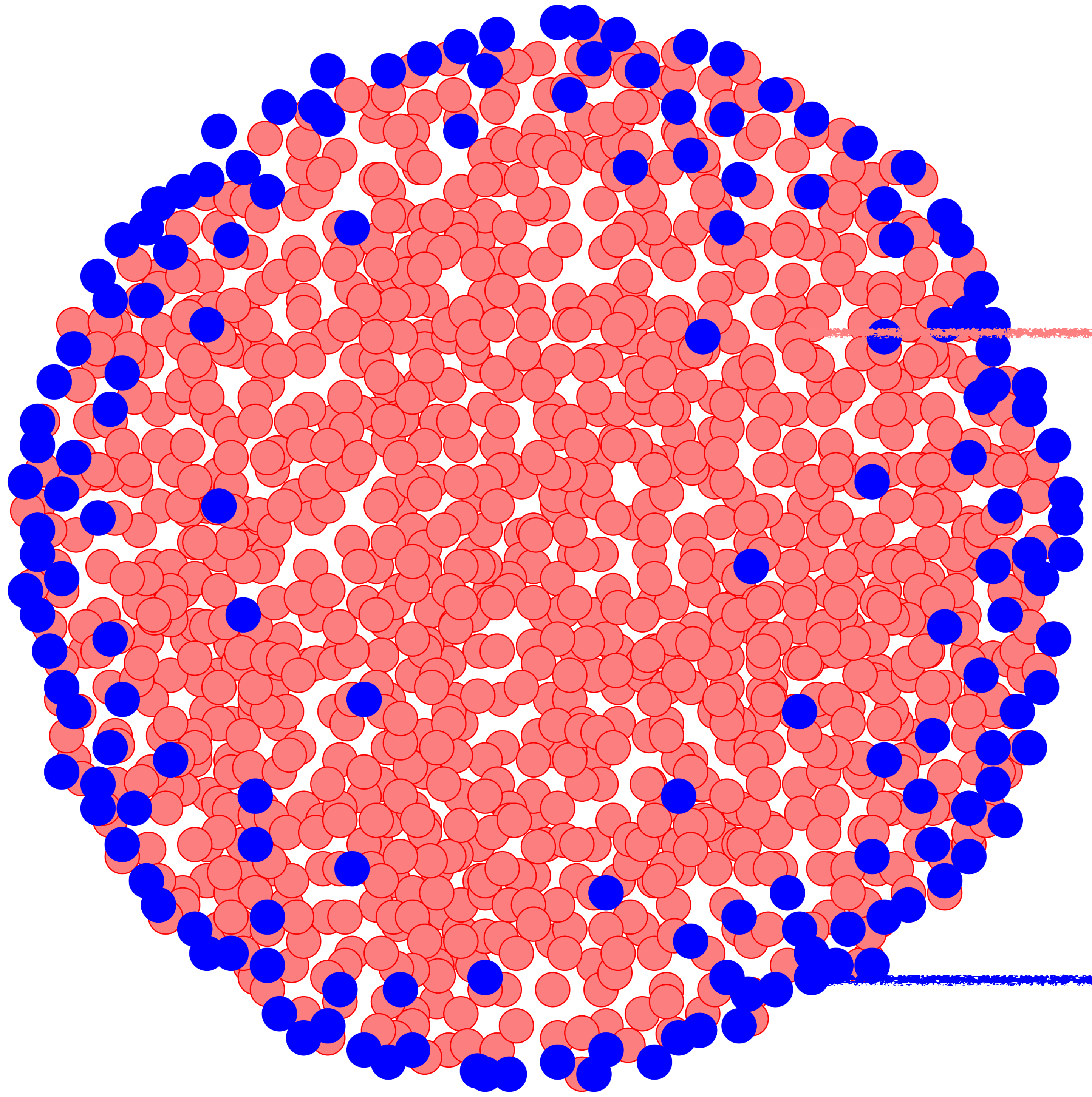
MC models

EPOS4

with hydro

w/o hydro



dense Core

High energy density, go through hydrodynamic. then hadronize

dilute Corona

Created at early stage or near the surface, string-fragmentation

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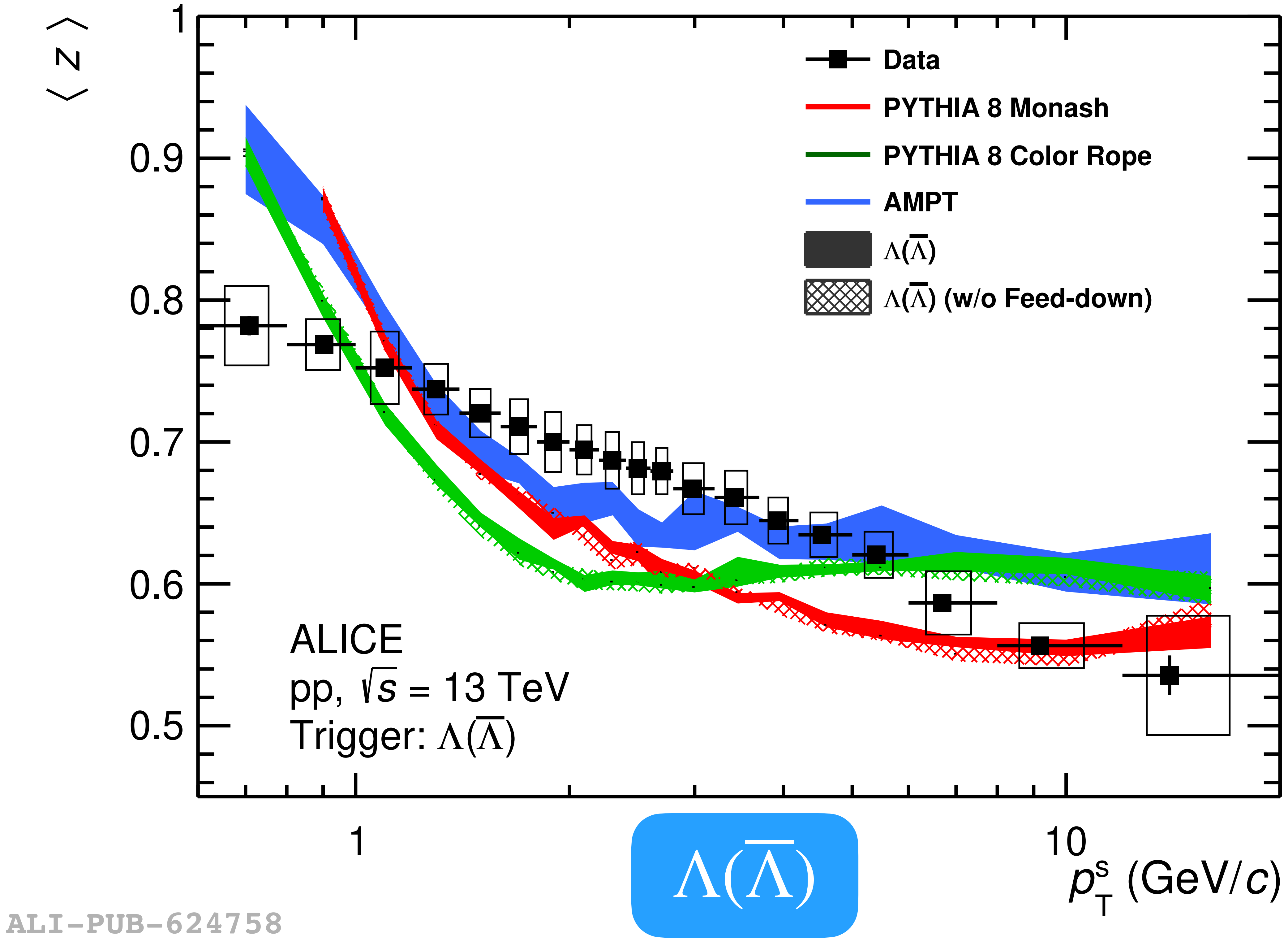
Results - <z> compared with predictions

ALICE, arXiv:2603.19387

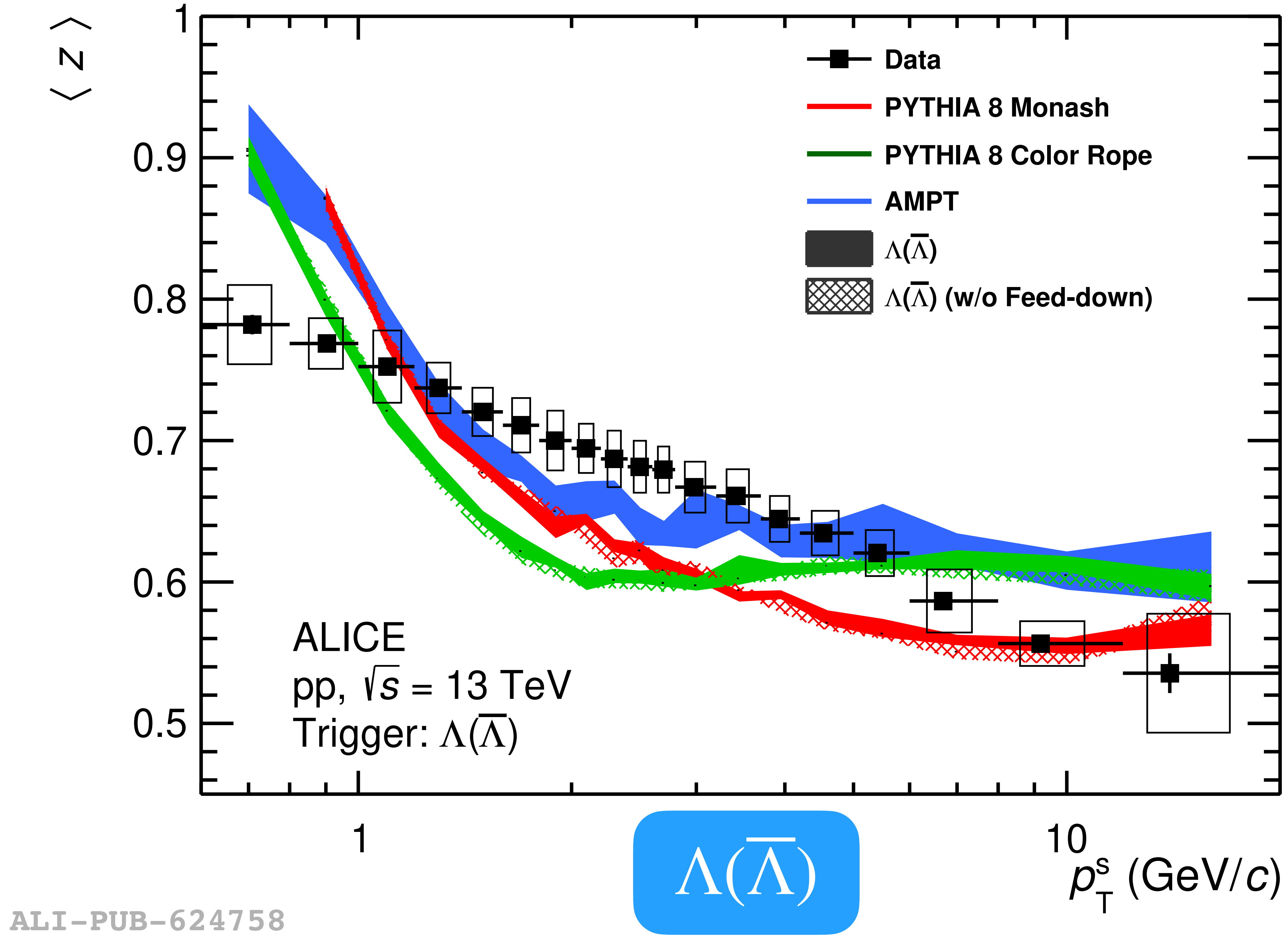


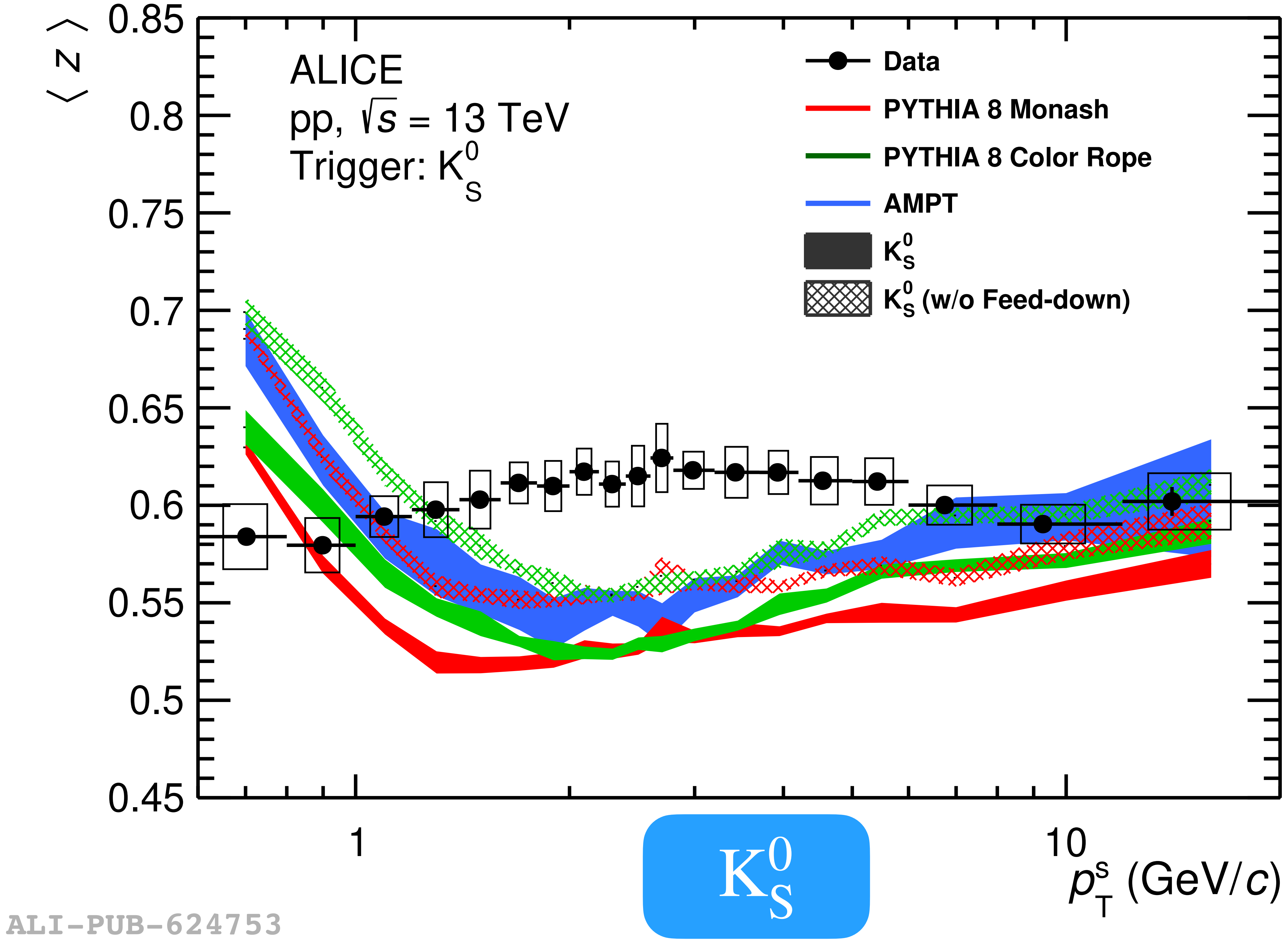
Λ ($\overline{\Lambda}$):

- Models catch the shape for Λ ($\overline{\Lambda}$), not able to describe the magnitude
- No significant effect from feed-down from Ξ

Results - <z> compared with predictions

ALICE, arXiv:2603.19387





K^0_S:

- Models can NOT even catch the shape
- ~ 10% decrease when including resonance (K*, ϕ) feed-down

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