The small size limit of QGP

2023 CMS heavy ion workshop

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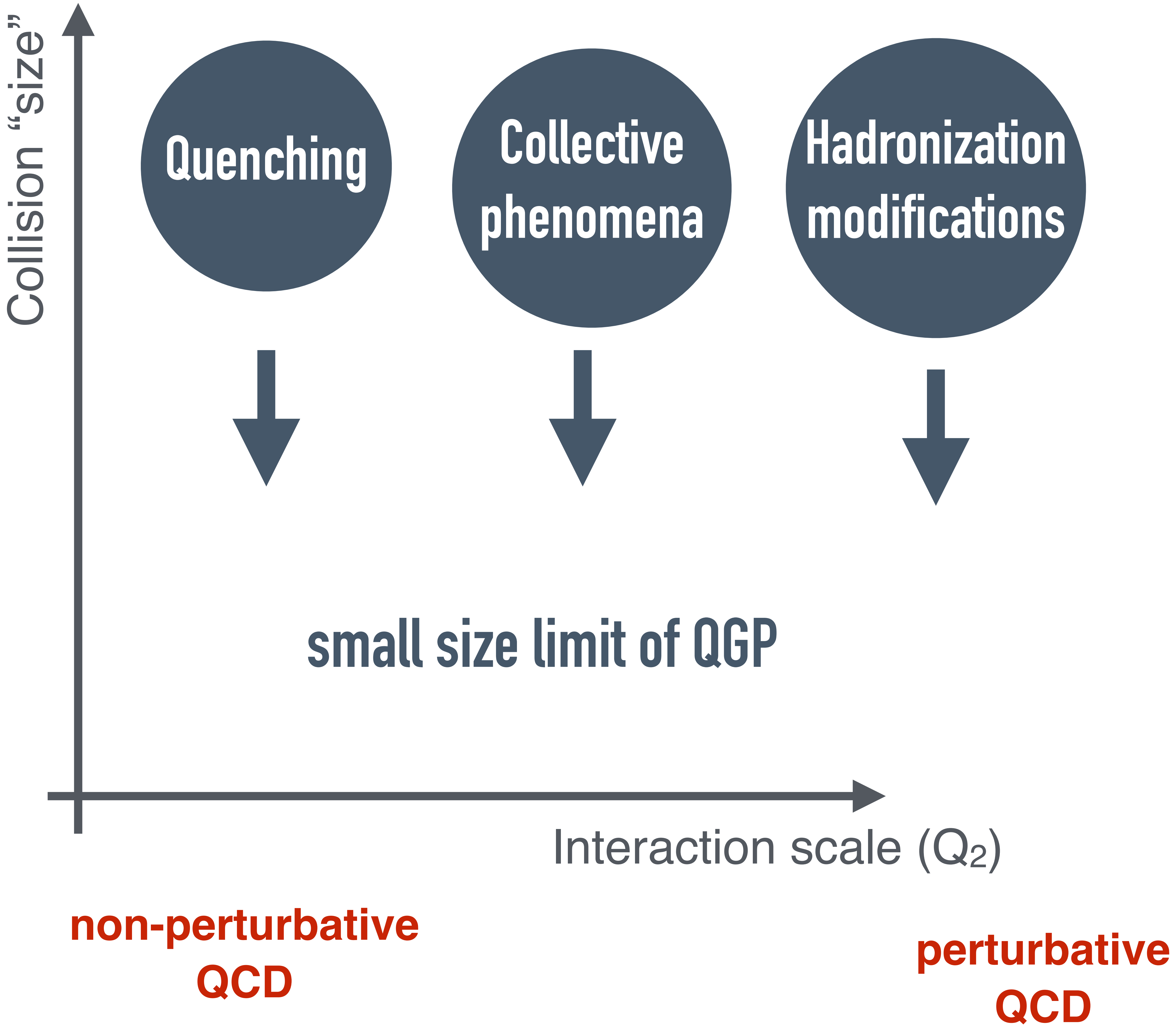
Introduction and outline

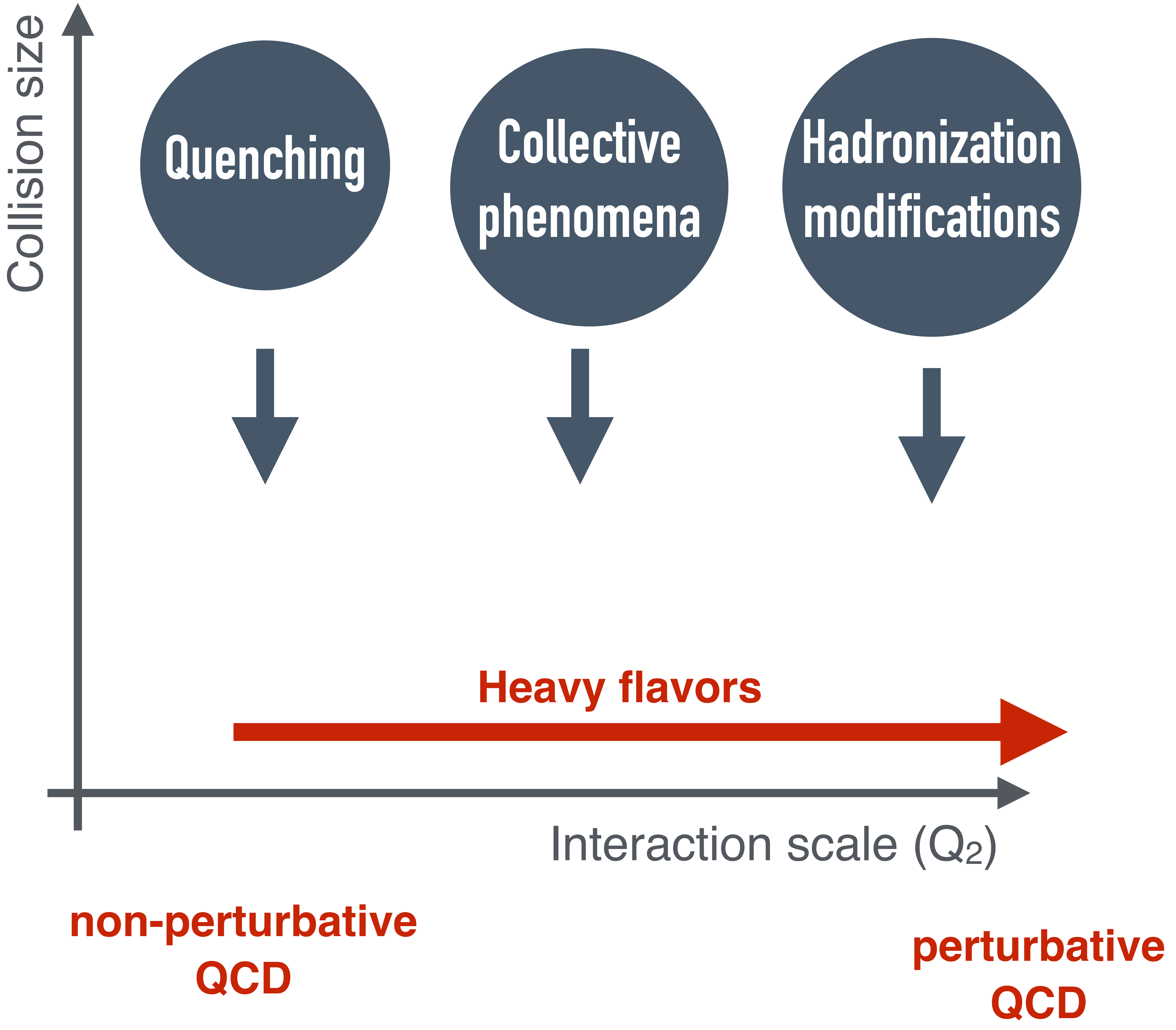


A (very limited) experimental overview:

- Characterize the properties of small systems exploiting the "classic" QGP signatures
- Focus on heavy-flavor observables

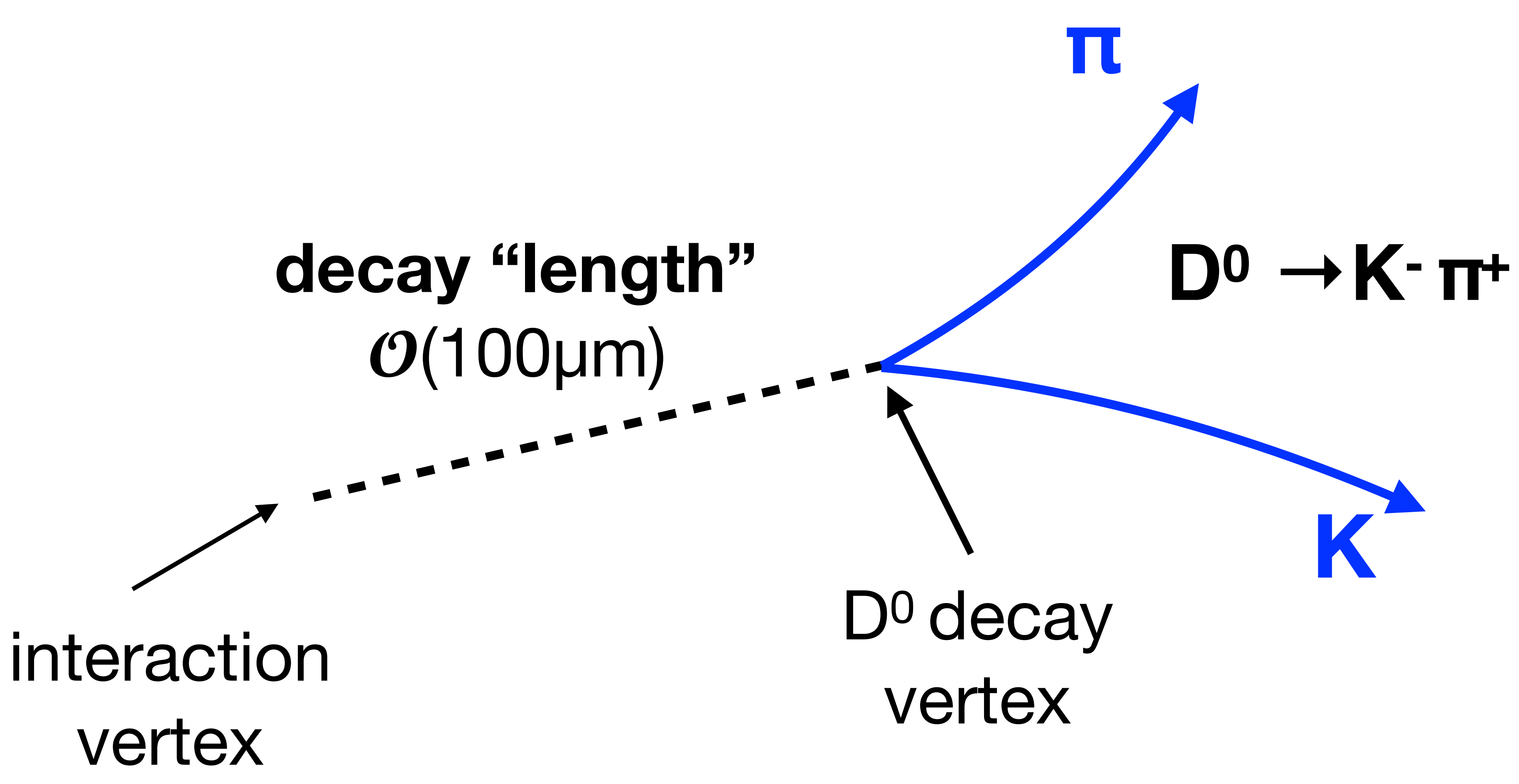
Why heavy-flavors are relevant?

$m_c \sim 1.5$ GeV
$\Lambda_{QCD} \sim 200$ MeV
$T_{QGP} \sim 300$ MeV
$m_{u,d,s} \lesssim T_{QGP}$



Heavy quarks in small systems:

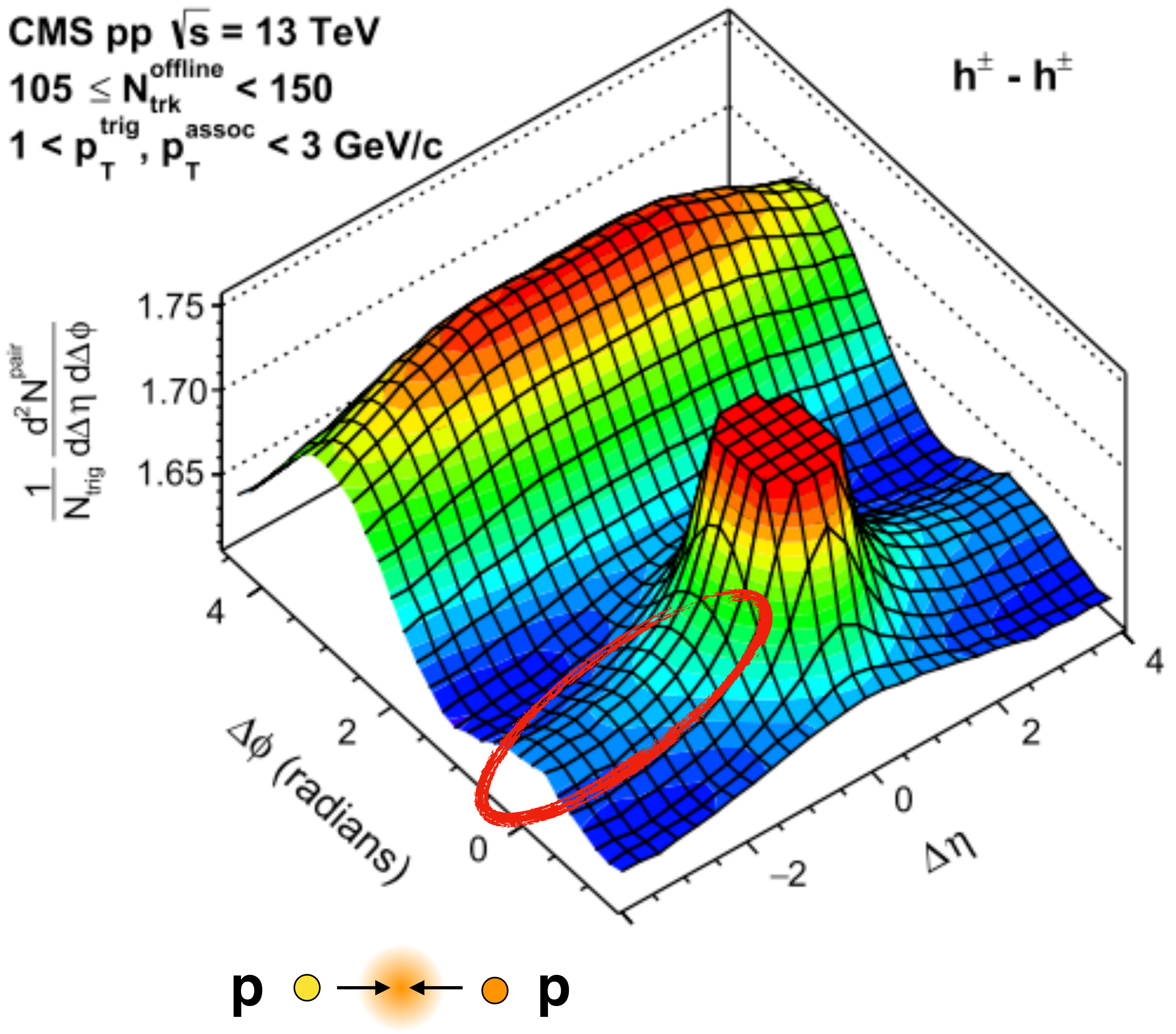
- experimentally "traceable"
- connect non perturbative and perturbative QCD
- "out-of-equilibrium" probe ($m_c > T_{QGP}$)
- controlled formation time



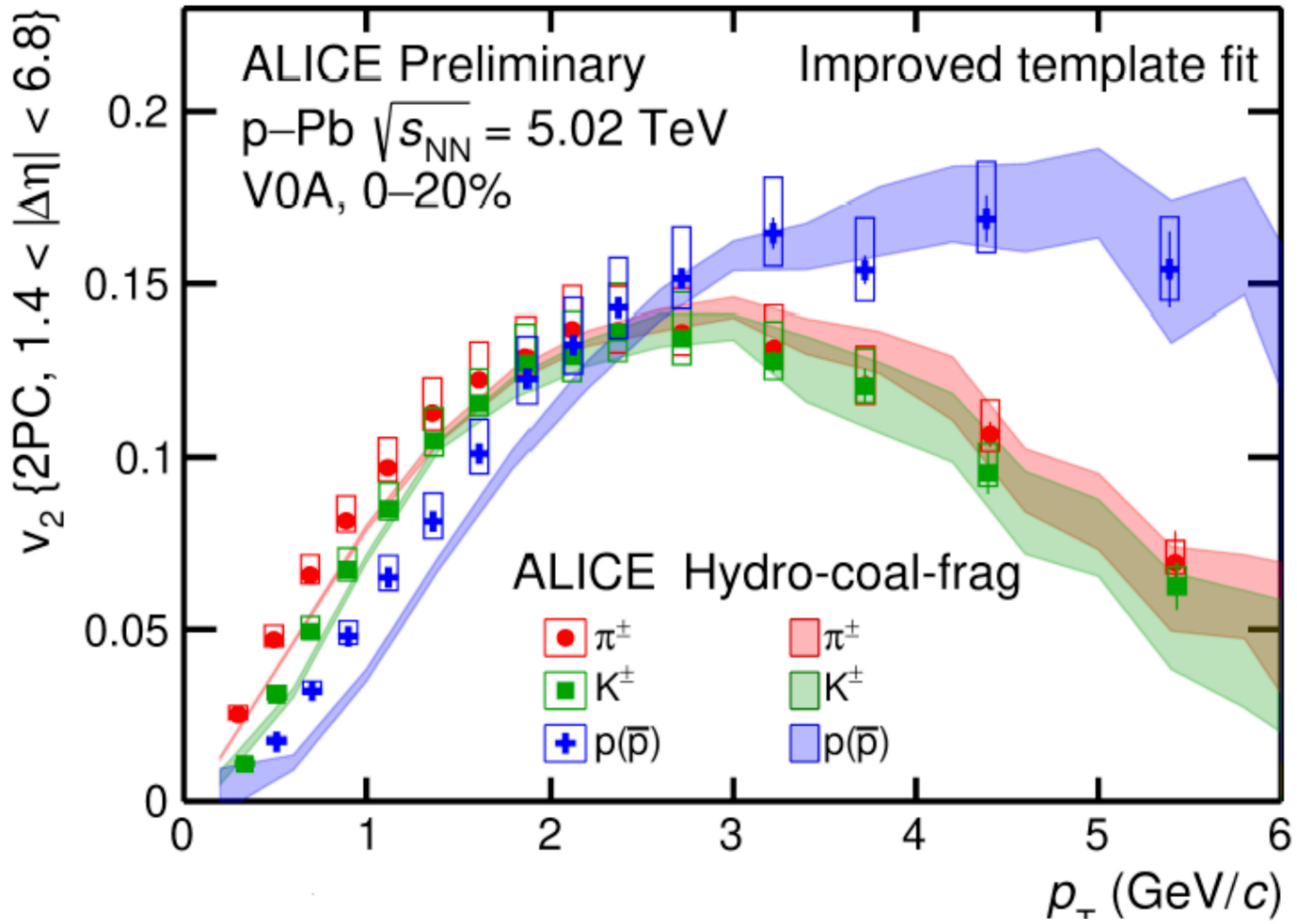
Collective properties in small systems

Collectivity in high-multiplicity pp

CMS, PLB 765 (2017) 193



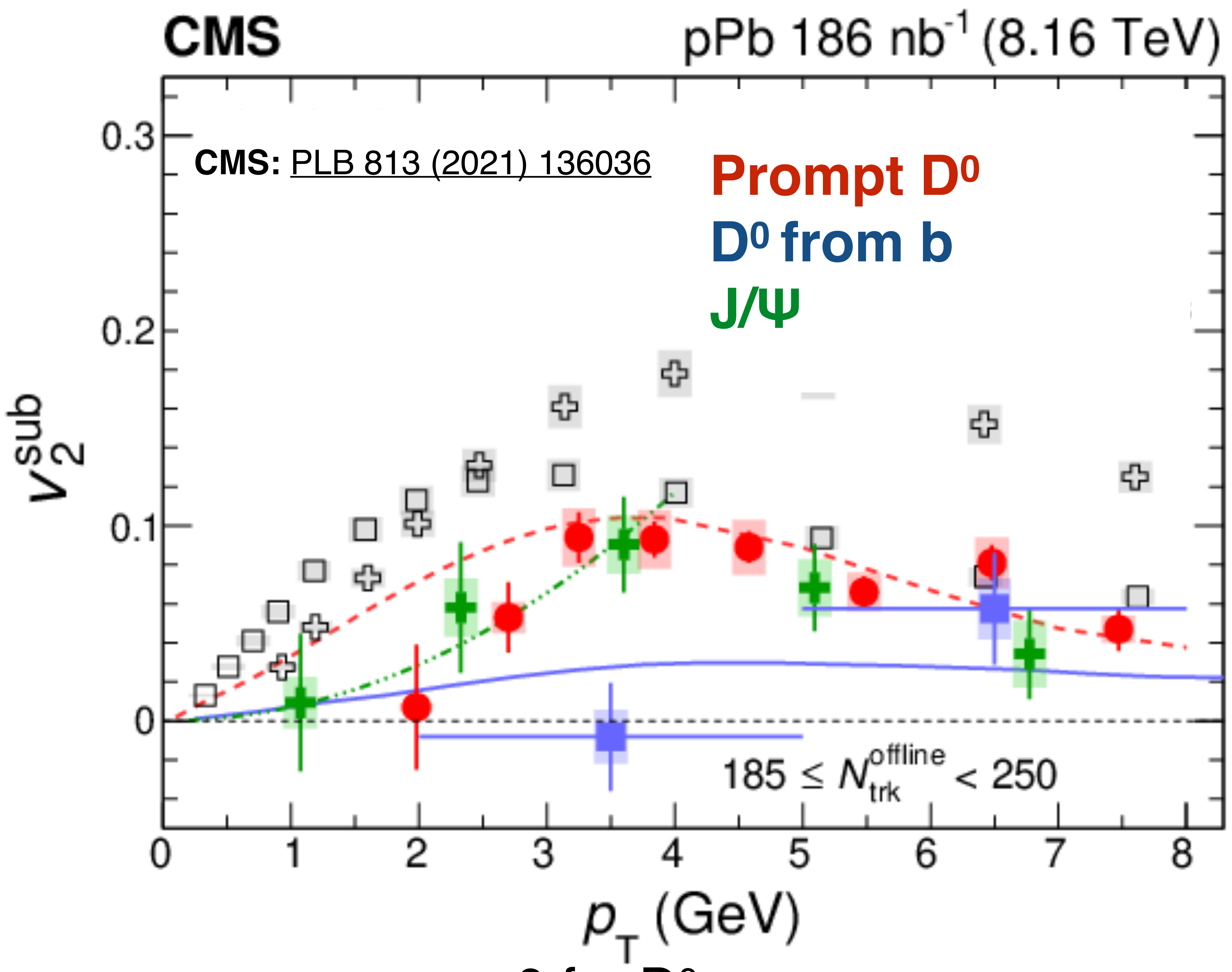
Near-side long-range ridge in azimuthal correlations between two particles

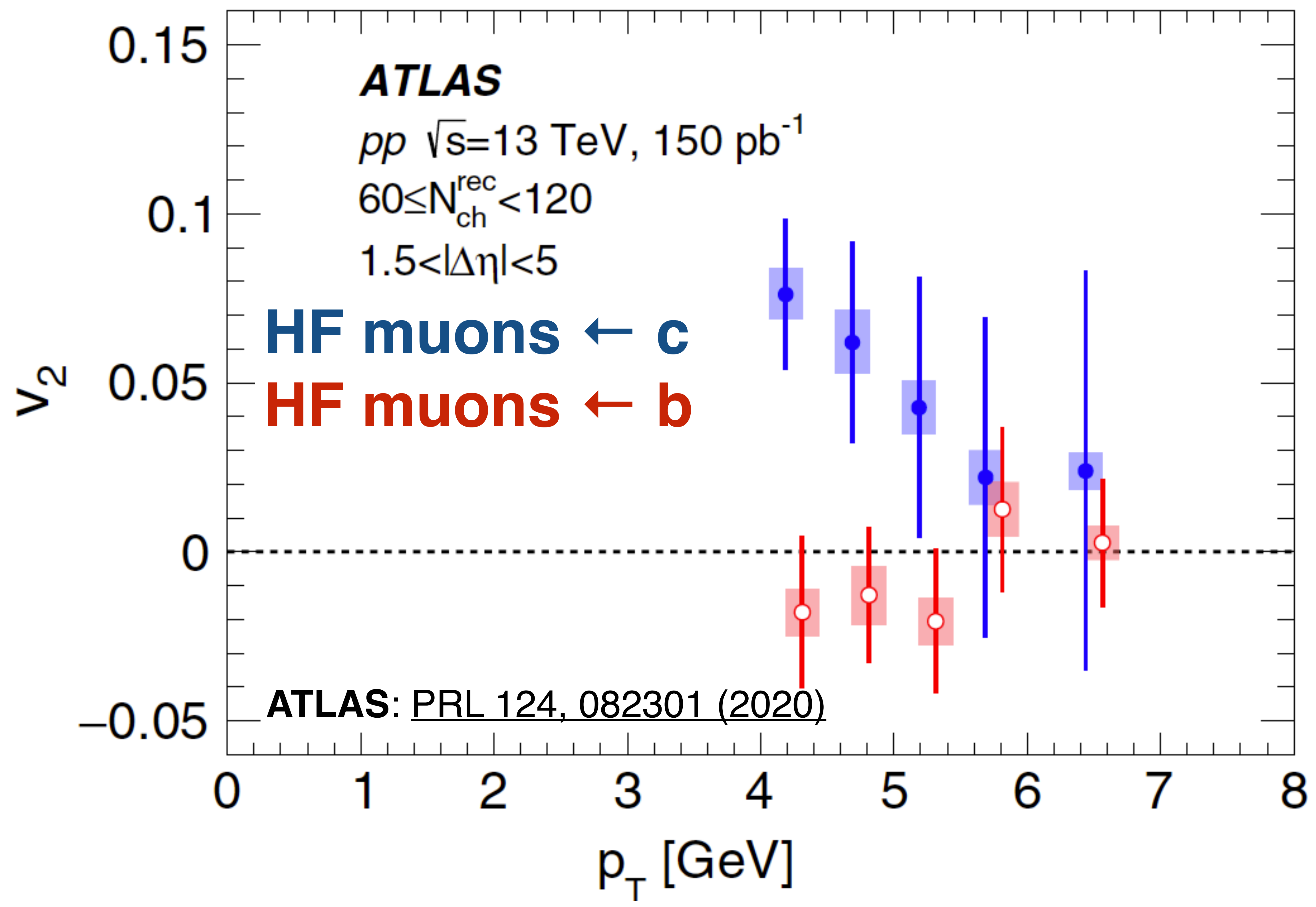


Mass ordering and particle type grouping observed in p-Pb and in pp collisions

- **Common dynamic origin for collective behaviors in small and large systems?**
- **Is "QGP" a misleading concept for small systems?**

Heavy-flavour collectivity in high-multiplicity pPb and pp





pPb

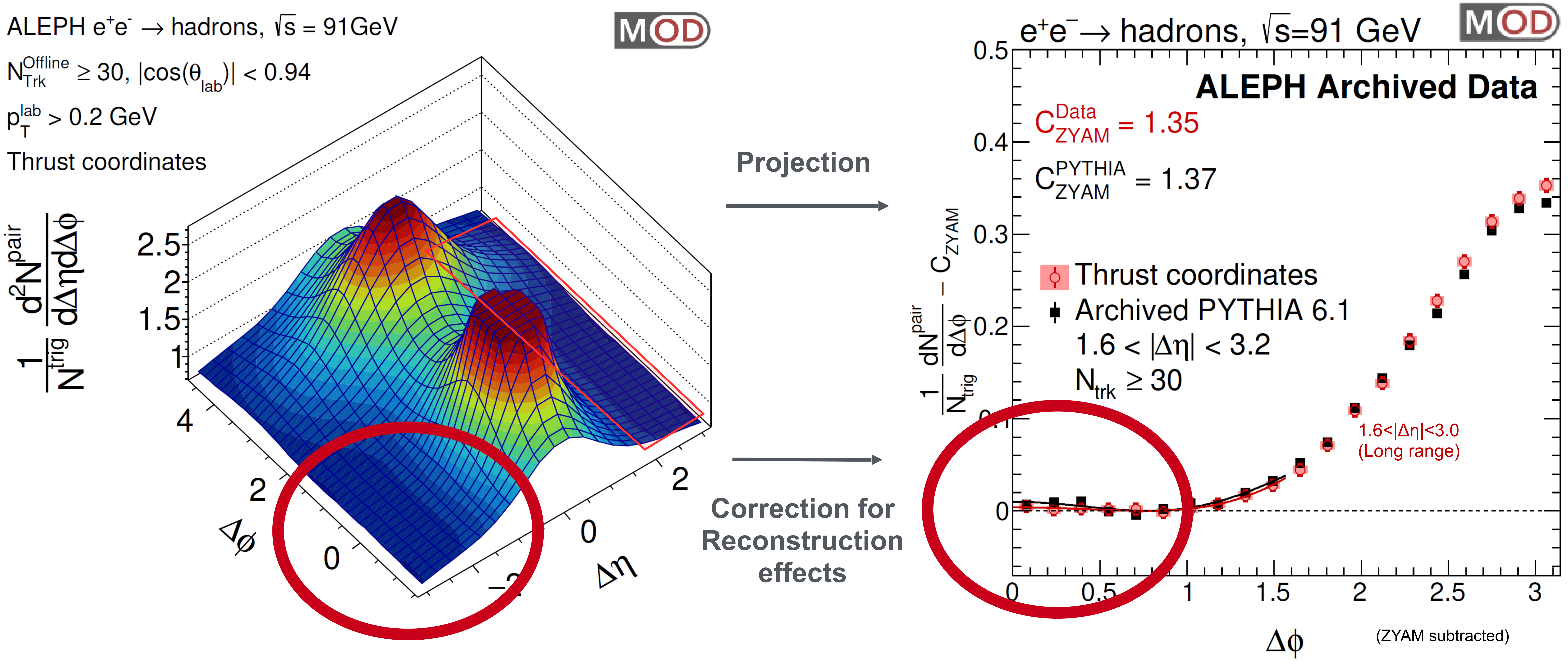
- $v_2 > 0$ for D^0 mesons
- $v_2 \sim 0$ for b hadrons

pp

- $v_2 > 0$ for c hadrons
- $v_2 \sim 0$ for b hadrons

- **What does the observation of a sizeable charm v_2 tell us about pp collisions?**
- **Does it favour a initial-state interpretation?**

Collectivity in e+e- collisions with ALEPH LEP1 open data

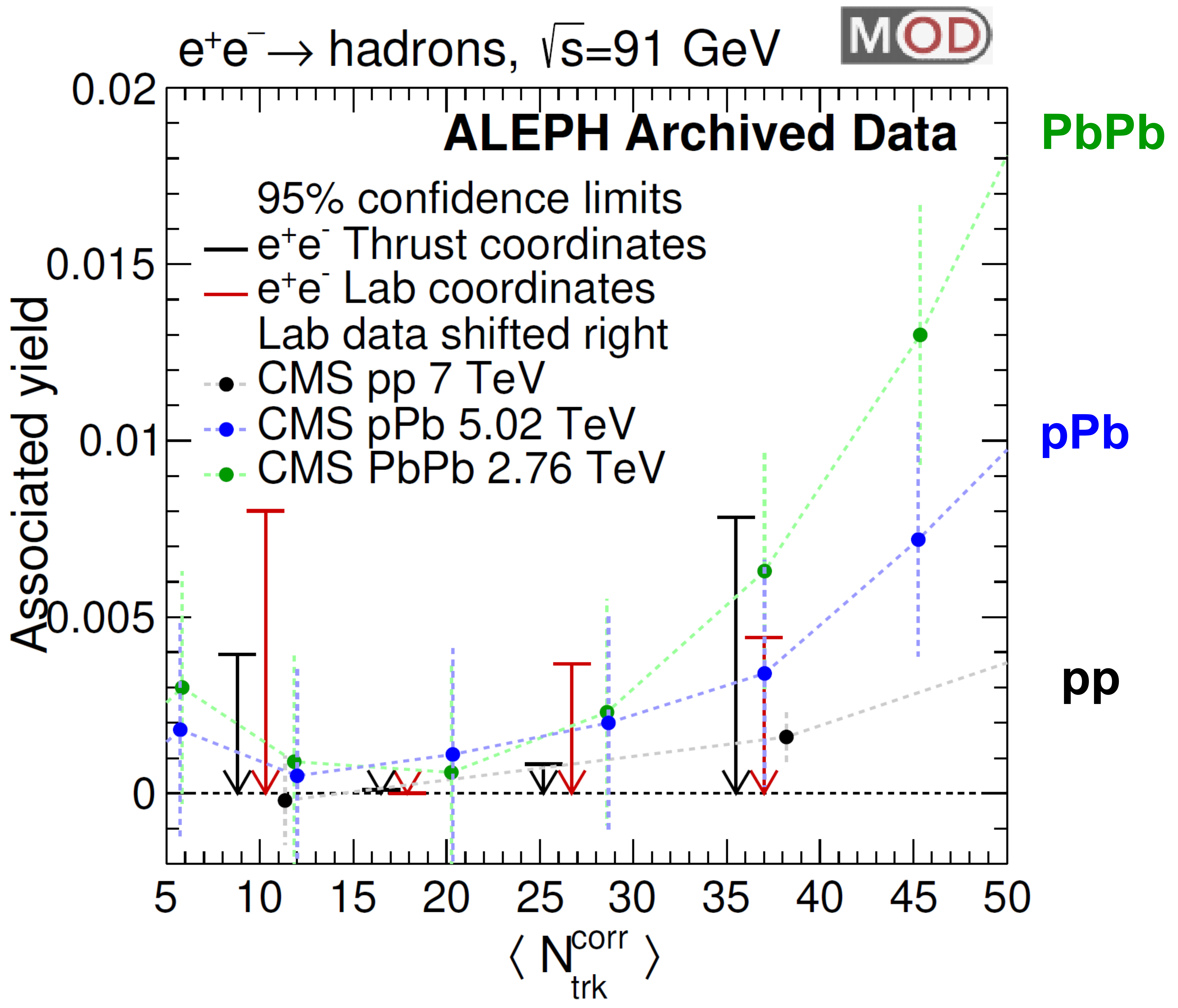


No significant near-side ridge from corrected data

- Consistent with PYTHIA6 without additional final-state effects

A. Badea, Y.J. Lee et al. Phys. Rev. Lett. 123, 212002 (2019)

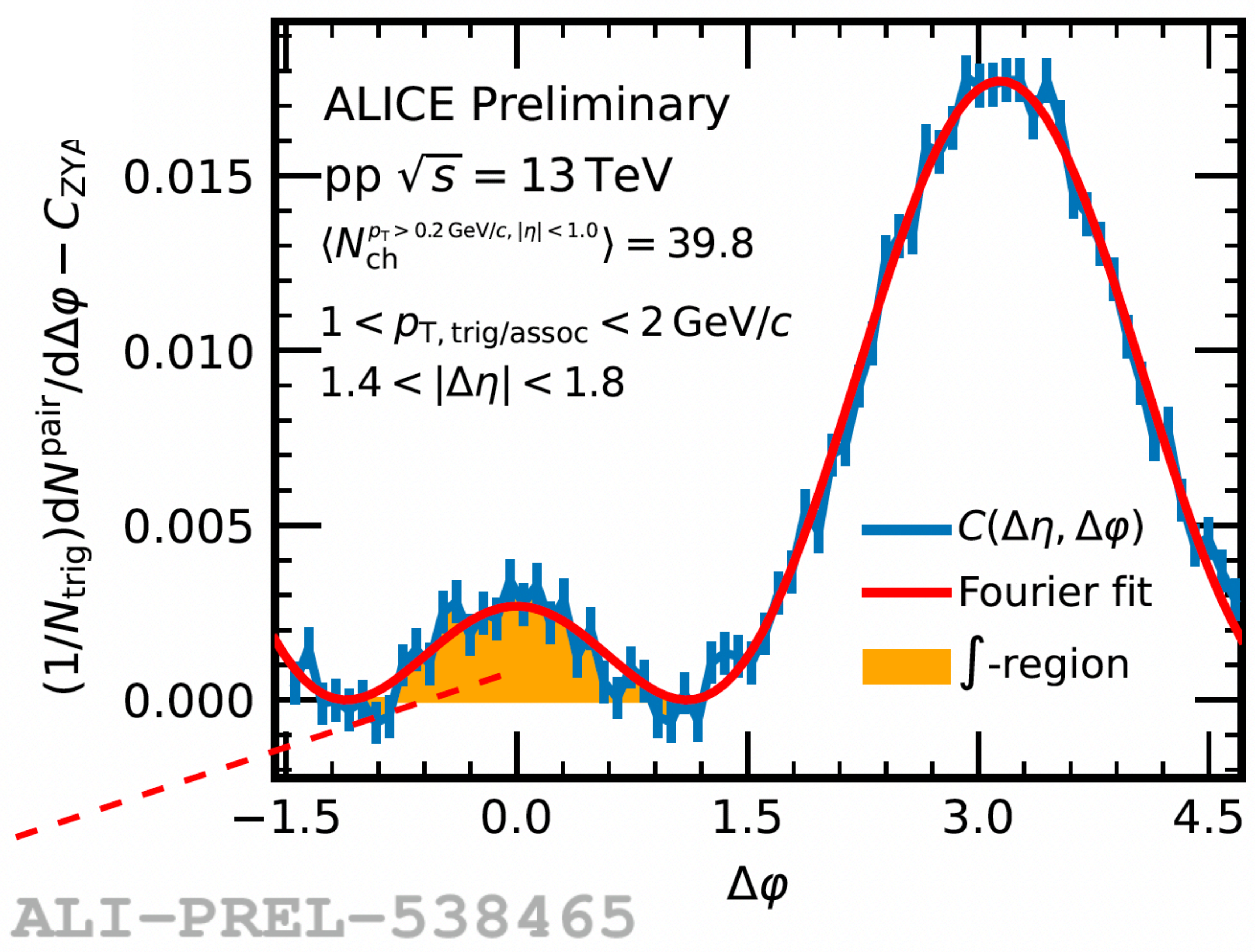
Collectivity in e+e- vs CMS pp collisions

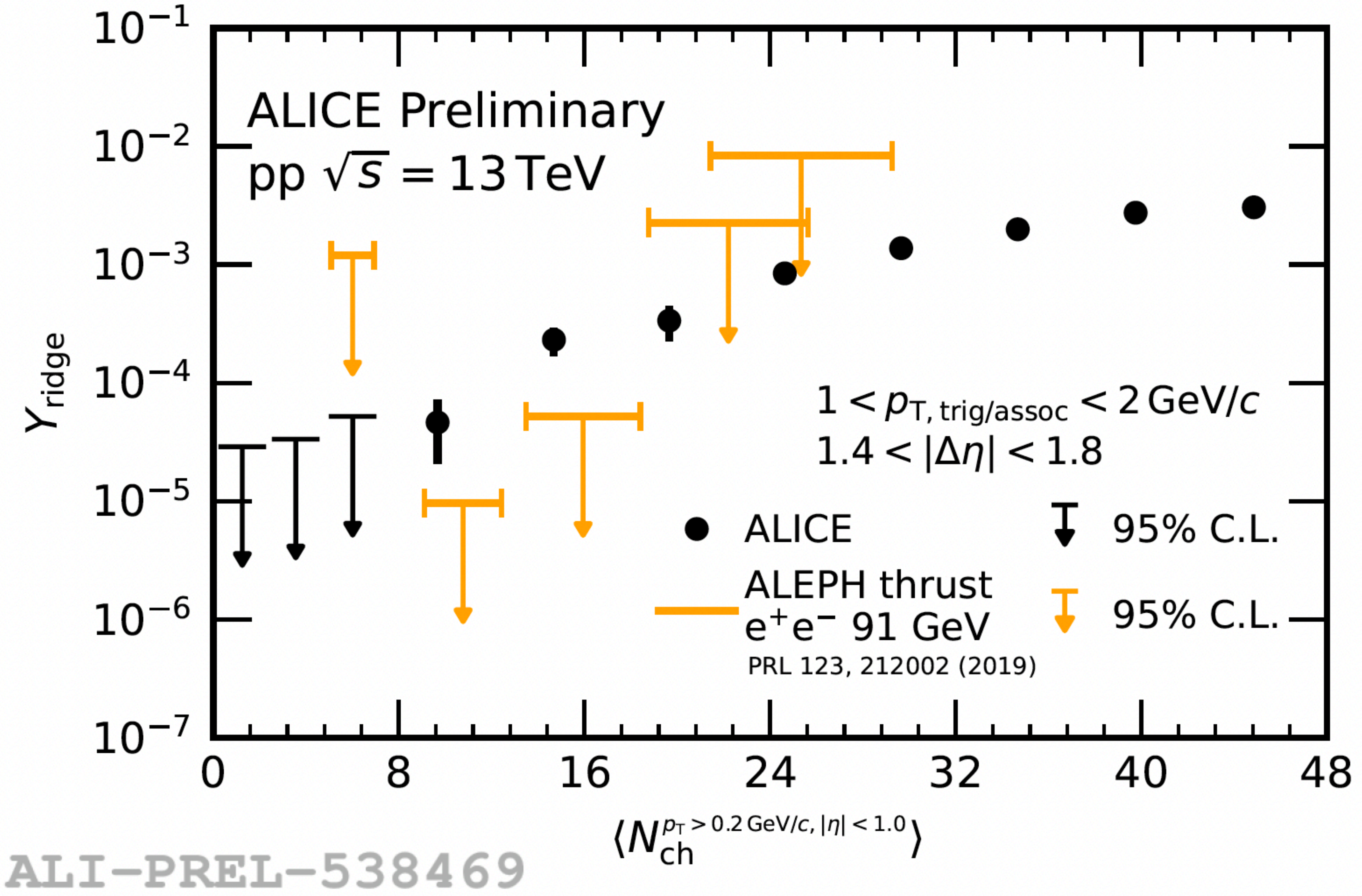


A. Badea, Y.J. Lee et al. Phys. Rev. Lett. 123, 212002 (2019)

Collectivity in e+e- vs new ALICE pp data

→New measurement of near-side ridge yield in 13 TeV pp collisions down to low multiplicity with increased accuracy

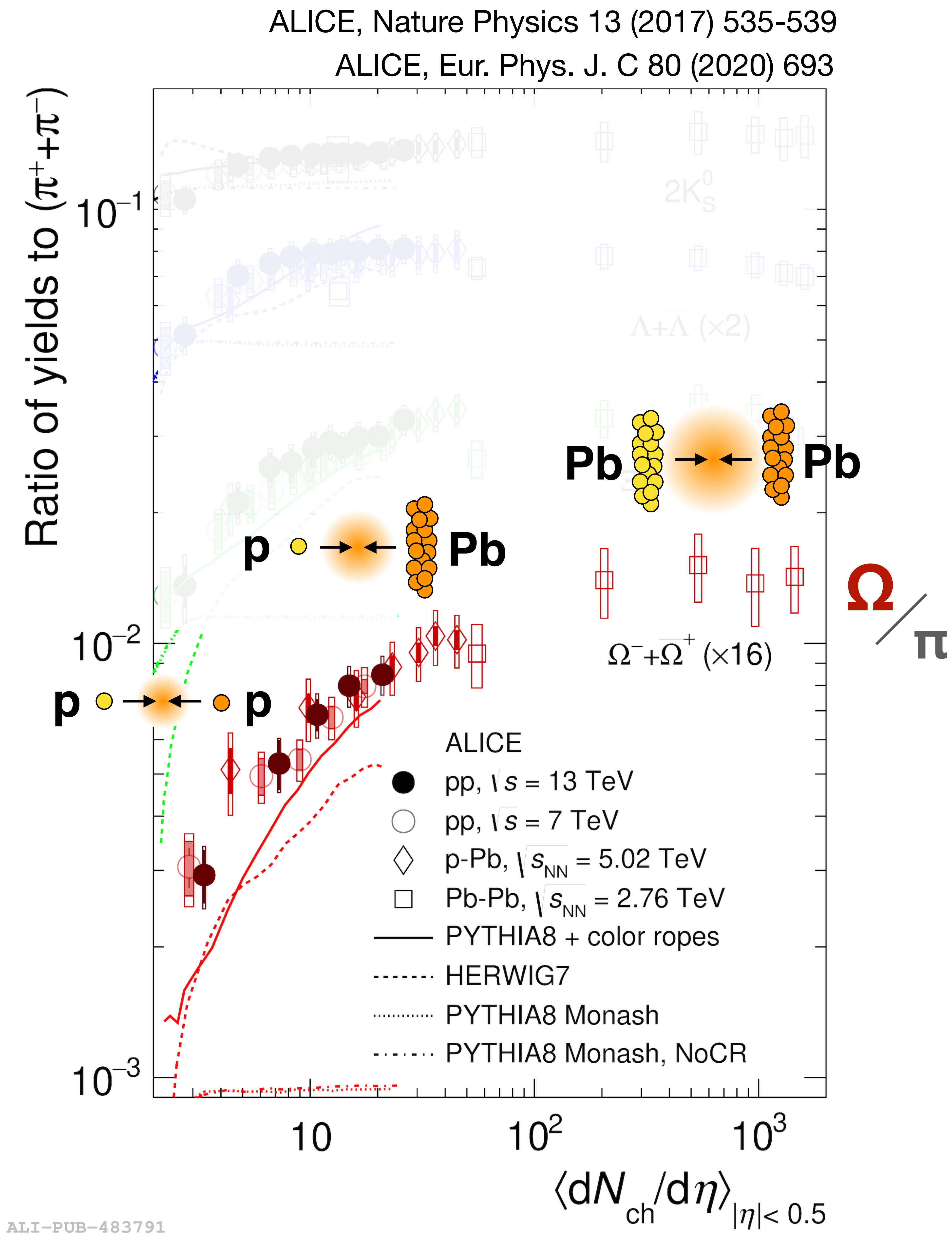


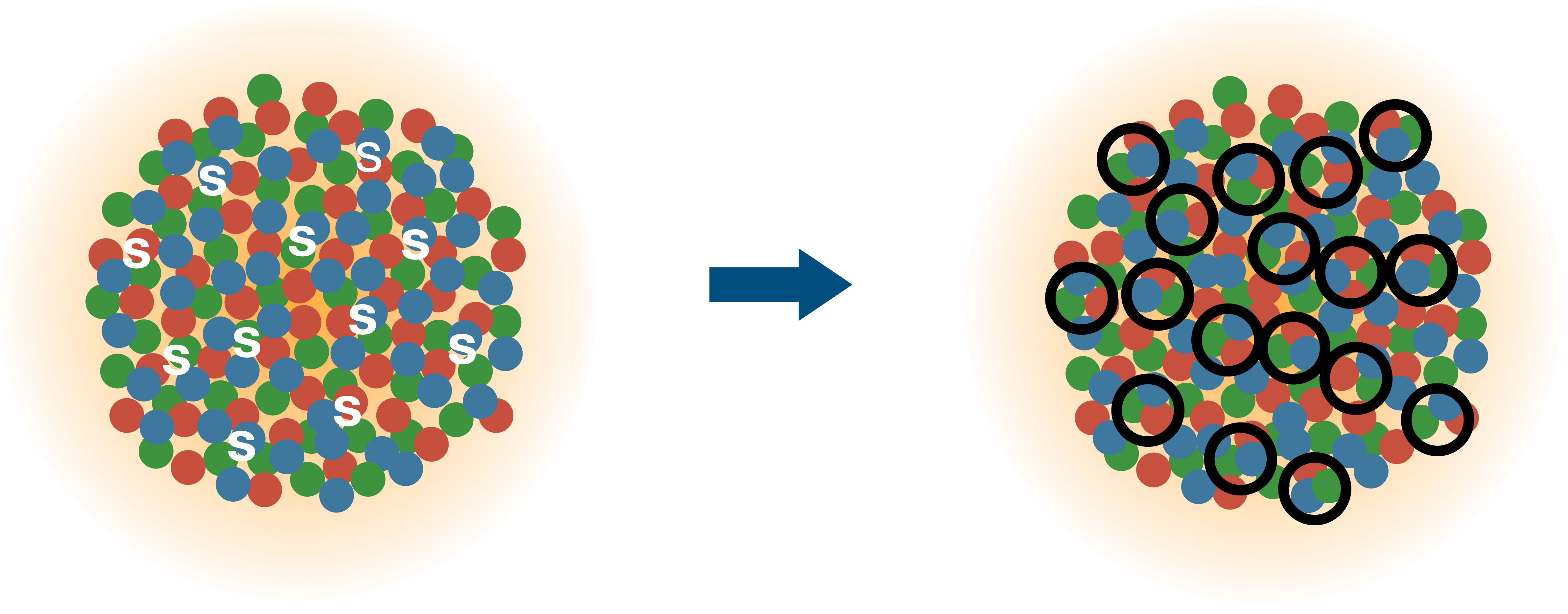


- Compatible with previous CMS results (and significantly smaller uncertainties)
- **pp ridge larger than e+e− by ≳ 3.2σ in ⟨N⟩ = 10~20**

Hadronization modifications in small systems

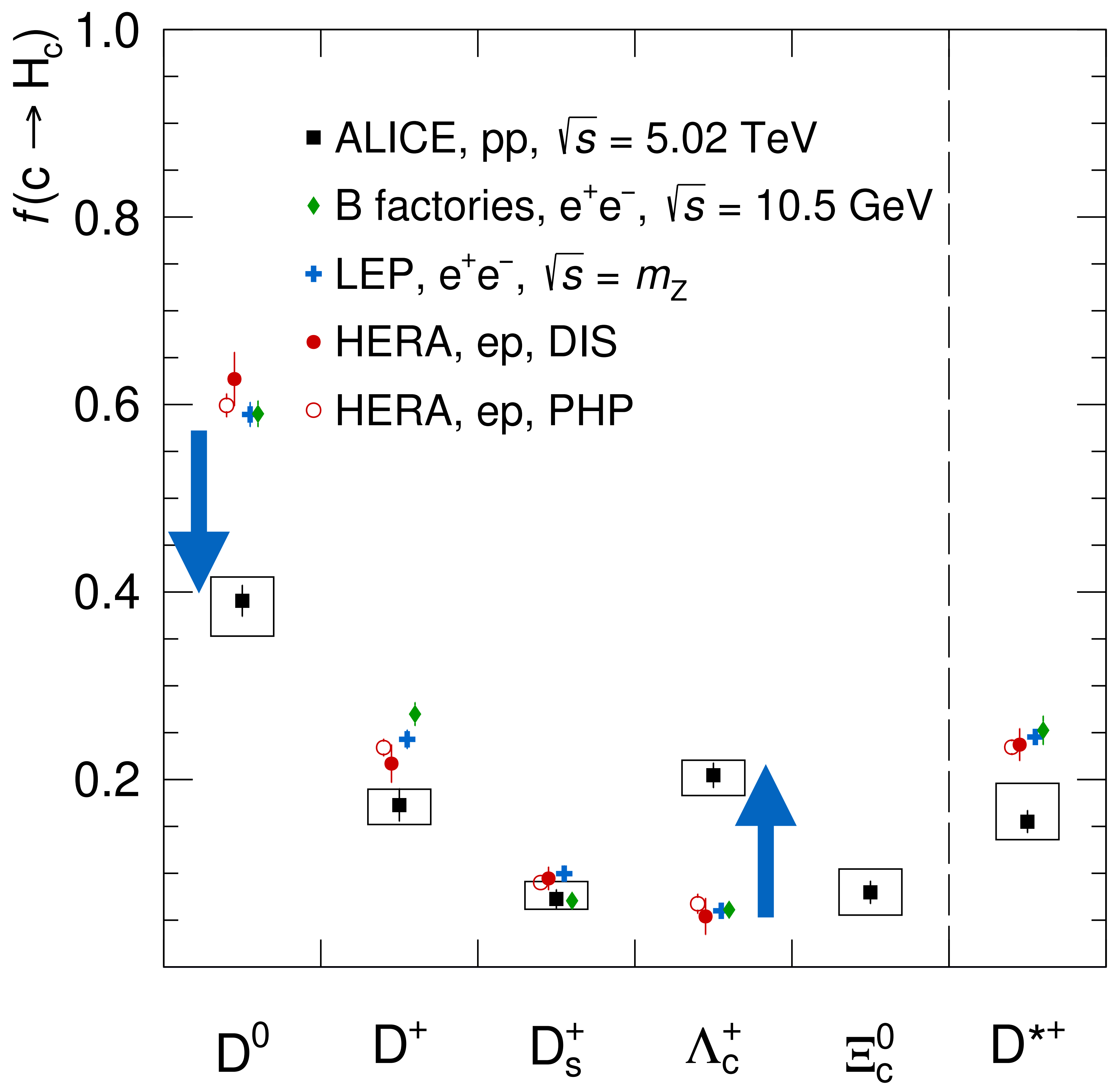
Strangeness enhancement in small systems





Strangeness enhancement observed to smoothly increase with particle multiplicity from pp to Pb-Pb collisions

Λ_c/D^0 ratio in pp collisions



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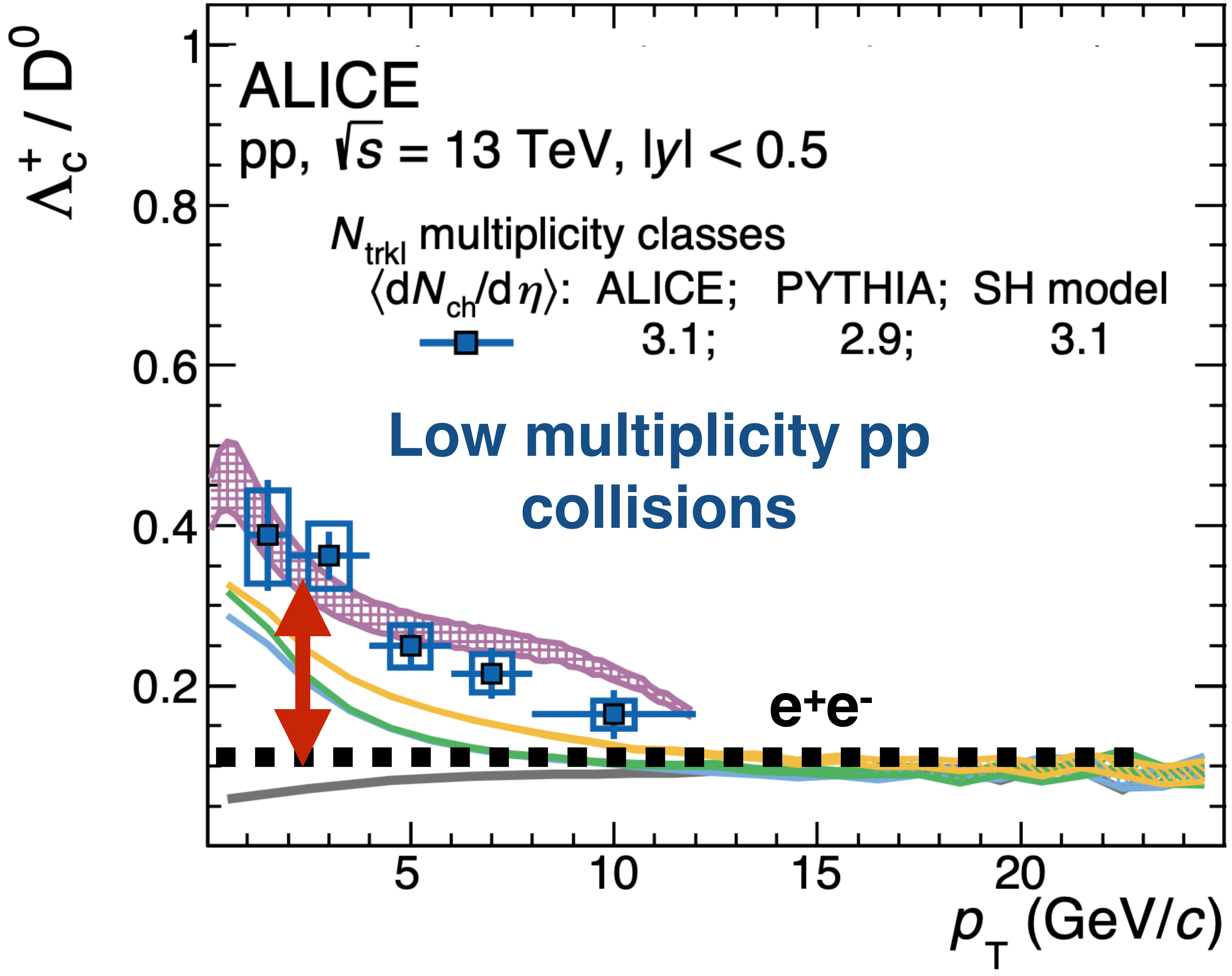


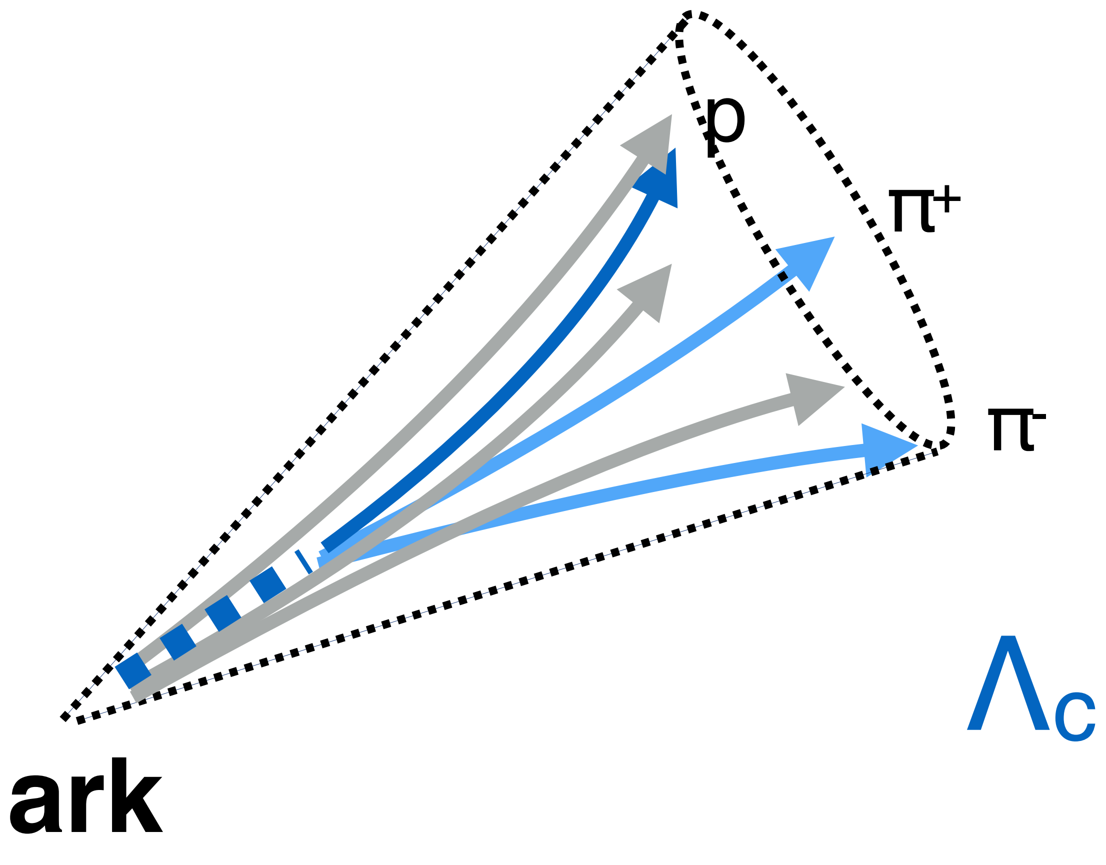
Fragmentation fractions are modified:
"Redistribution" of charm quarks
from mesons to baryons

Λ_c/D^0 always higher in pp than e^+e^- at low p_T!
→ **Hadronization modified compared to vacuum (e^+e^-) already in low-multiplicity pp**

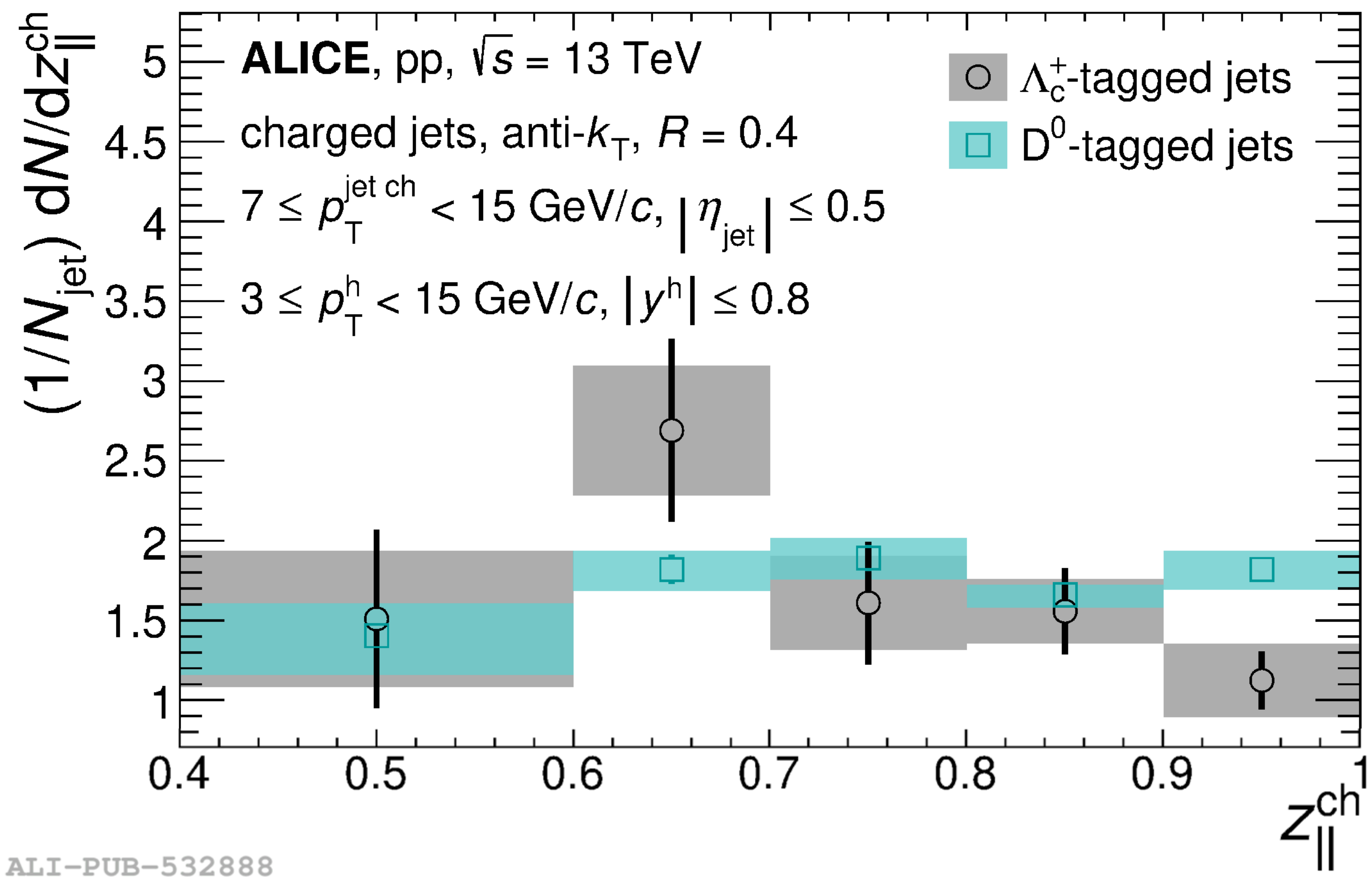
Searches for "new" hadronization in pp collisions with HF jets

$$z_{\parallel}^{ch} = \frac{\boldsymbol{p}^{\text{jet ch}} \cdot \boldsymbol{p}^{\text{HF}}}{\boldsymbol{p}^{\text{jet ch}} \cdot \boldsymbol{p}^{\text{jet ch}}}$$

Longitudinal momentum fraction carried by the Λ_c



NEW! ALICE collaboration, arXiv.2301.13798



→ Hint of softer fragmentation for **Λ_c (baryon)** w.r.t. **D^0 (meson)**

→ **Not consistent with in-vacuum fragmentation**

Hadronization universality is broken already in pp!

$\sigma(pp \to H_Q X)$ = PDF ⊗ **σ(pQCD)** ⊗ **$D^{vacuum}(z,Q^2)$**

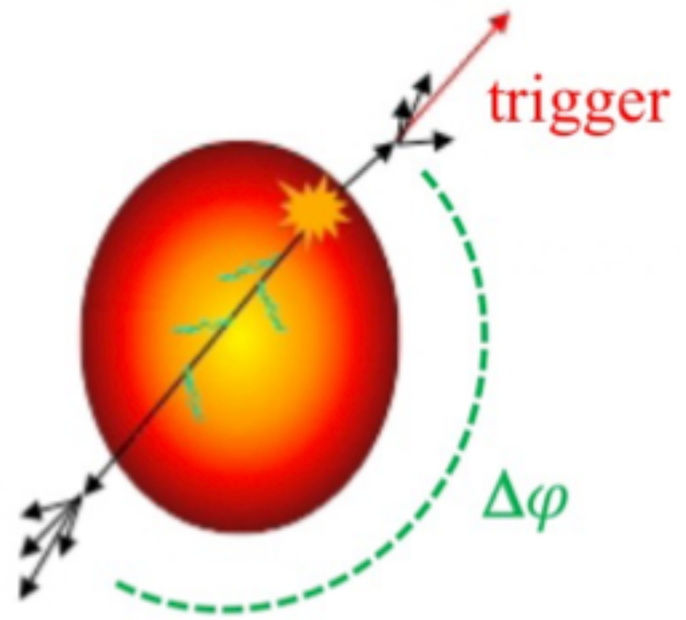
- what is the connection between hadronization modifications and the HQ degree of equilibration?

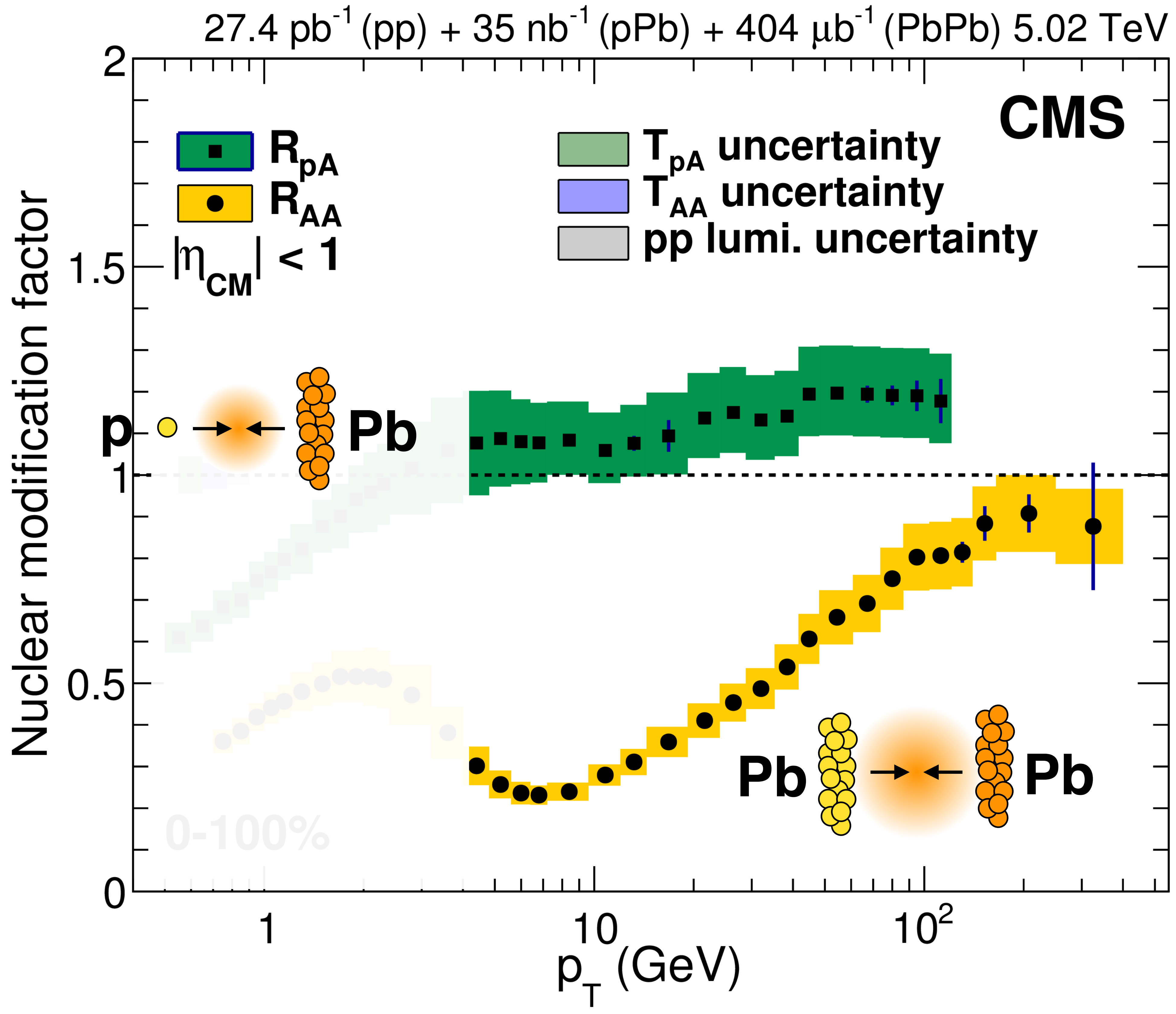
E_{loss} mechanisms (quenching) in pp and pN collisions

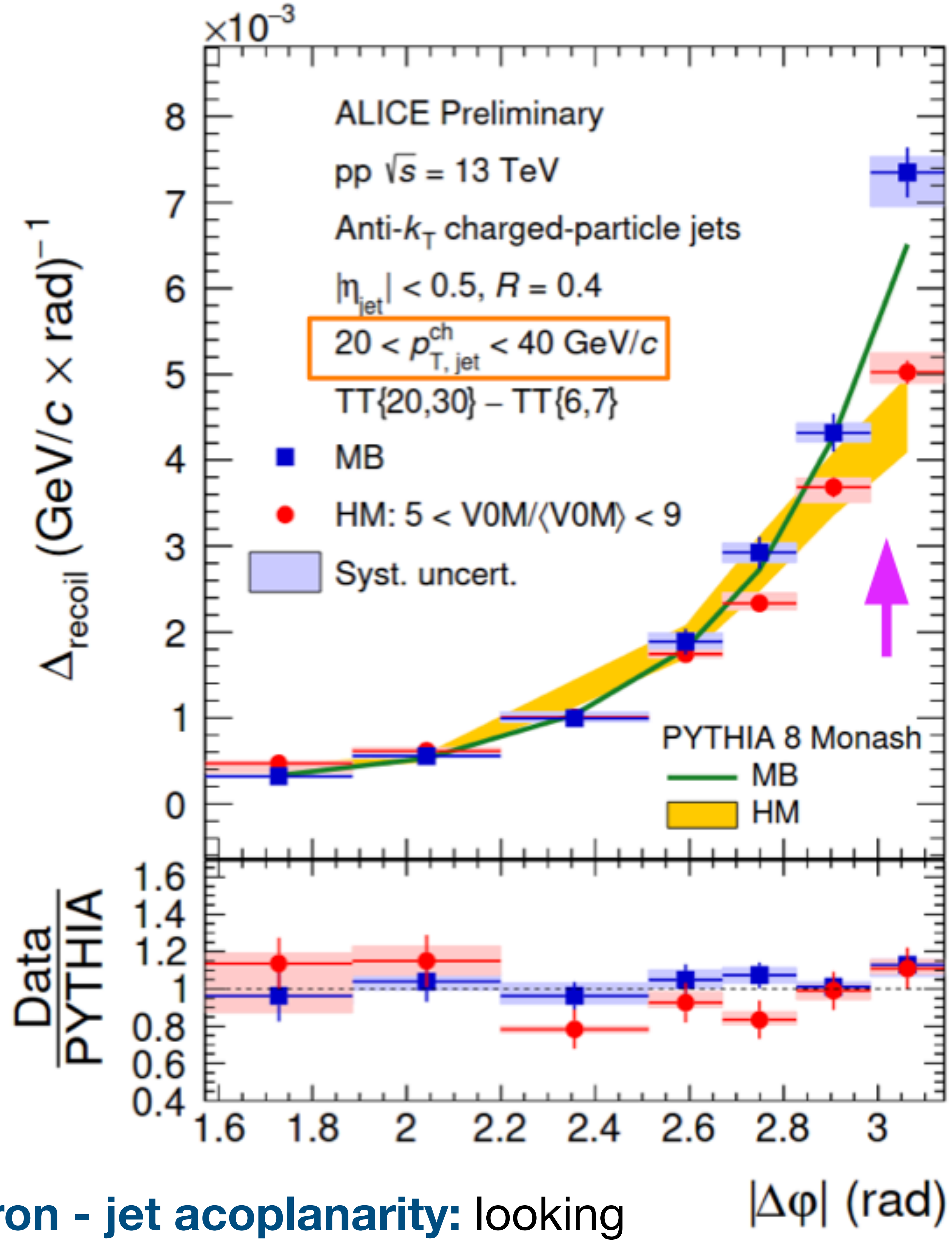
No evidence of jet quenching in small systems (so far)

$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle \, dN_{pp}/dp_T}$$

ALICE, PLB 793 (2019) 420
CMS, PRL 127 (2021) 102002







hadron - jet acoplanarity: looking at broadening of the recoiling jet w.r.t. trigger high-p_T hadron

No evidence of jet quenching in small systems (so far)

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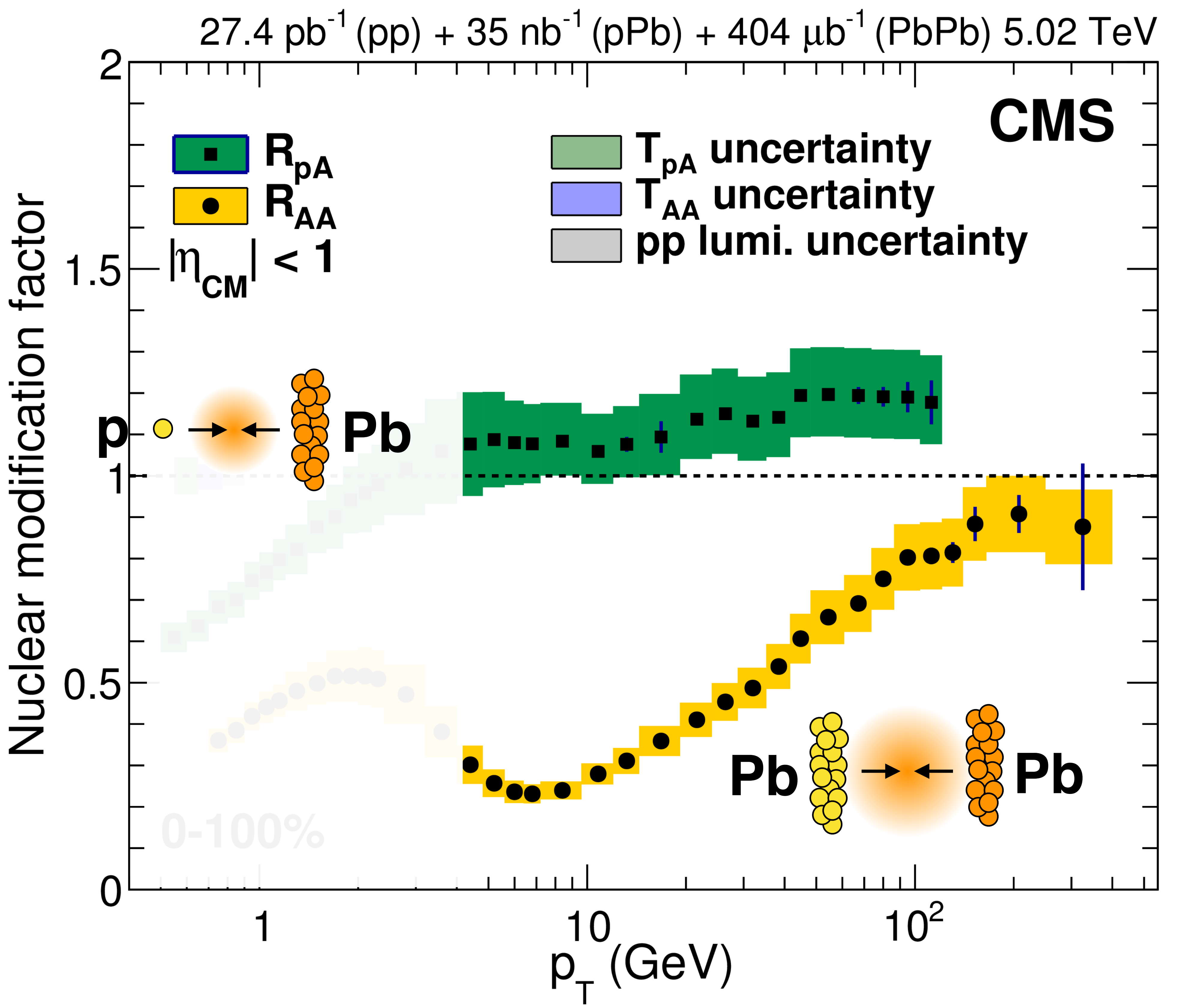

No clear evidence of jet quenching in small systems
despite the evidence for final state effects

- is this picture consistent?
- is quenching there but just too small?
- how much quenching (%) should be expect?

Summary and topics for discussion

Collectivity:

- Is there a common dynamic origin for collectivitiy in small and large systems?
  - Is “QGP” a misleading concept for small system?
- What does the observation of a sizeable charm v_2 tell us about the nature of the medium?
  - Does it favour a initial-state interpretation?

Modification of hadronization in all hadronic collisions (w.r.t. e^+e^-):

- what is the connection between hadronization modification and the HQ degree of equilibration?

No clear evidence of jet quenching in small systems:

- consistent with the evidence for the final-state interactions?
- is quenching there but it is just too small? how much quenching (%) would one expect?

thank you for your attention

BACKUP