35TH RENCONTRES DE BLOIS

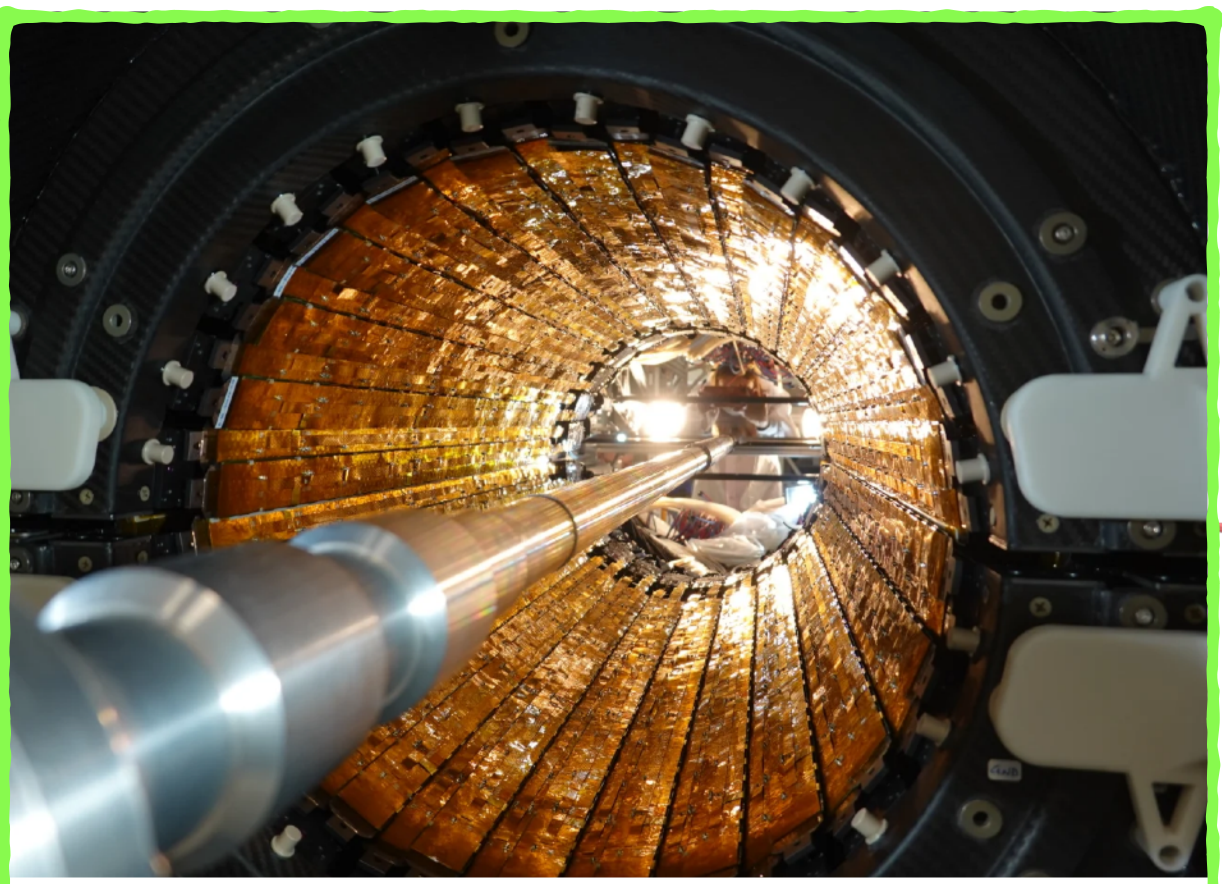
HIGHLIGHTS FROM THE ALICE EXPERIMENT

Chiara Oppedisano

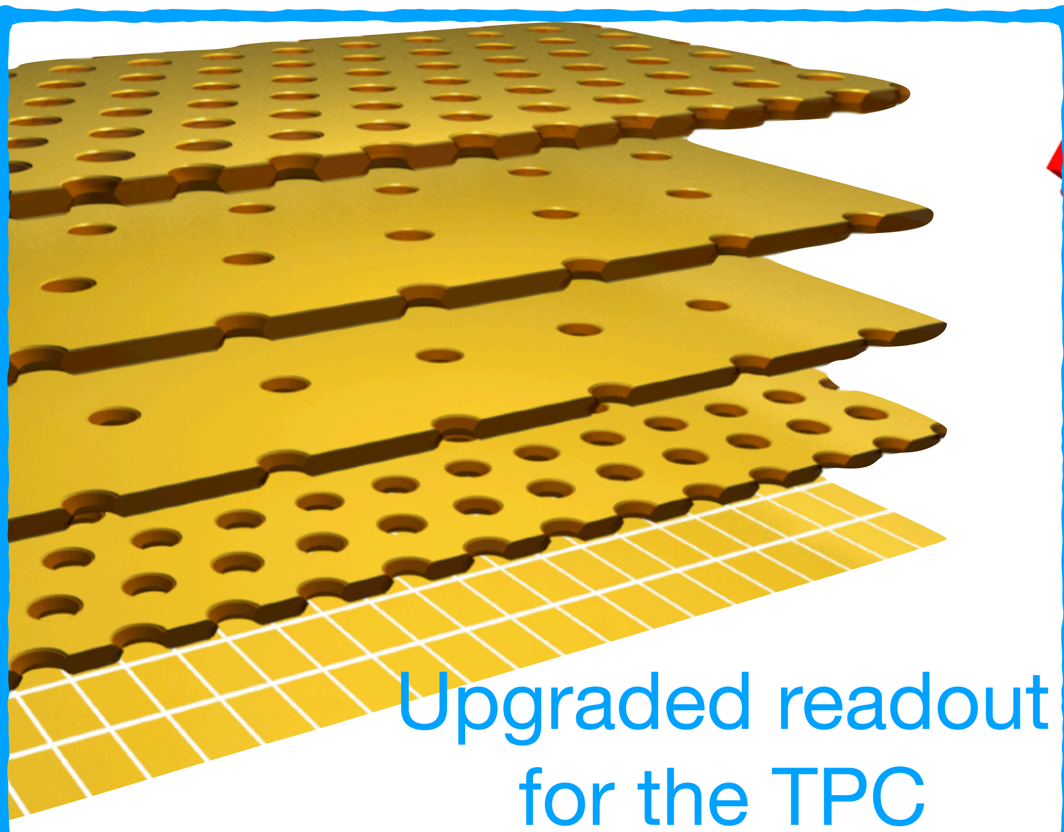
FOR THE ALICE COLLABORATION

ALICE IN RUN 3

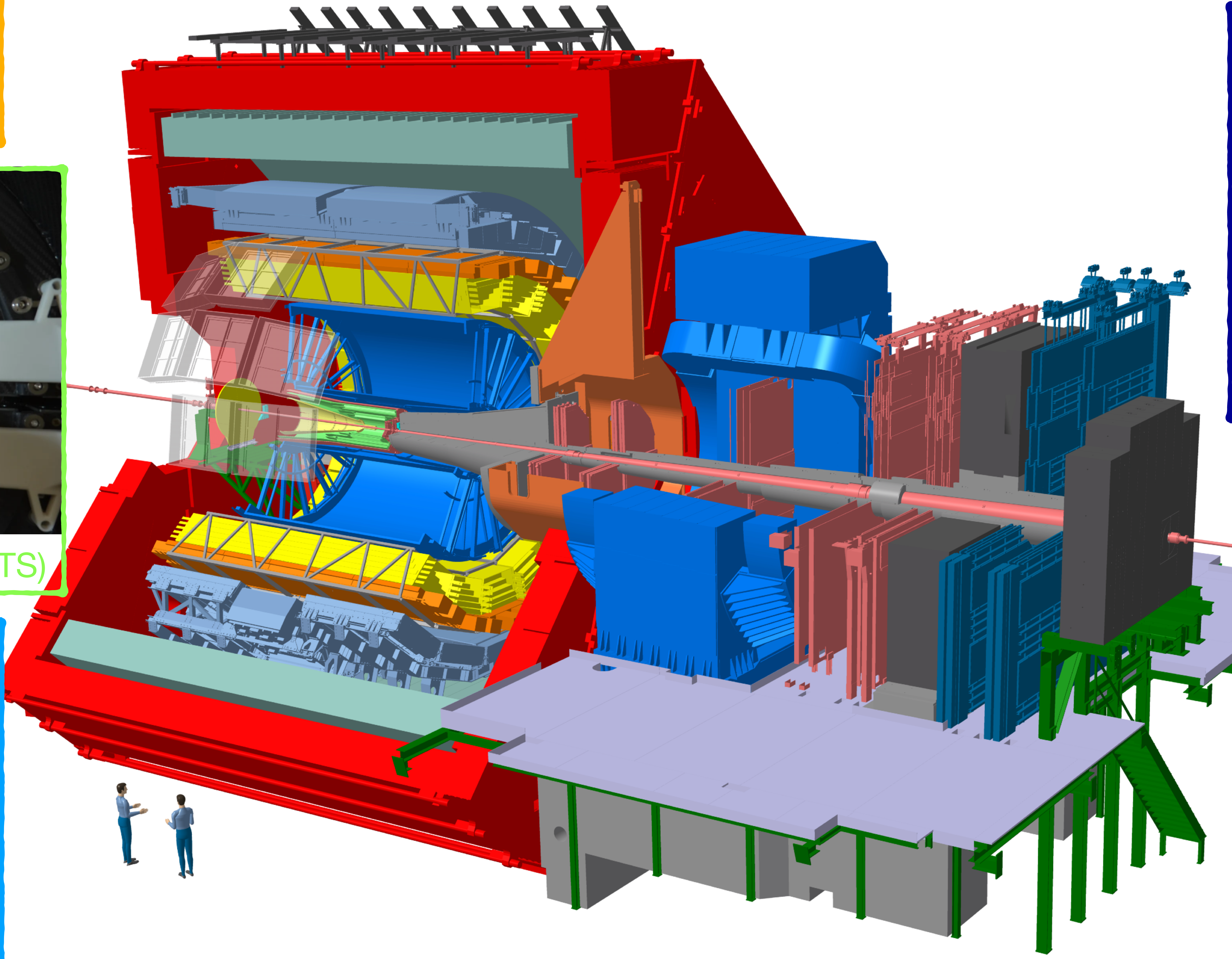
Beampipe closer to interaction point (diameter 36.4 mm)

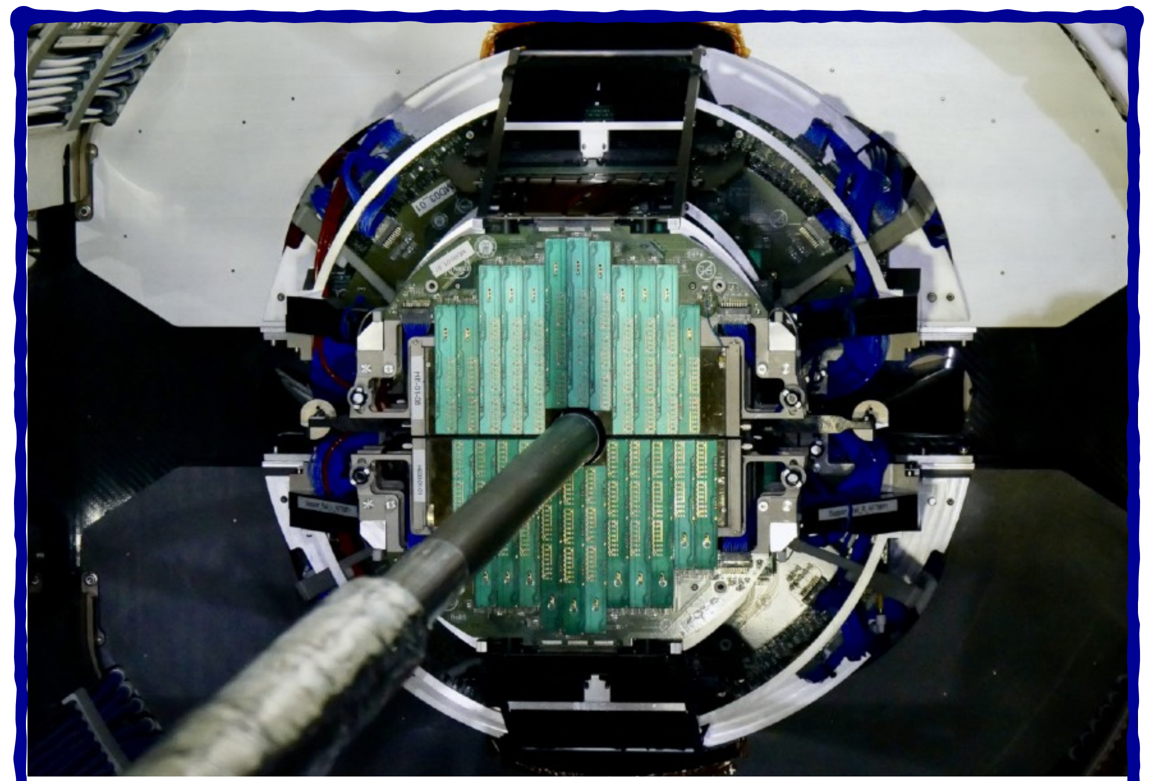


New Inner Tracking System (ITS)



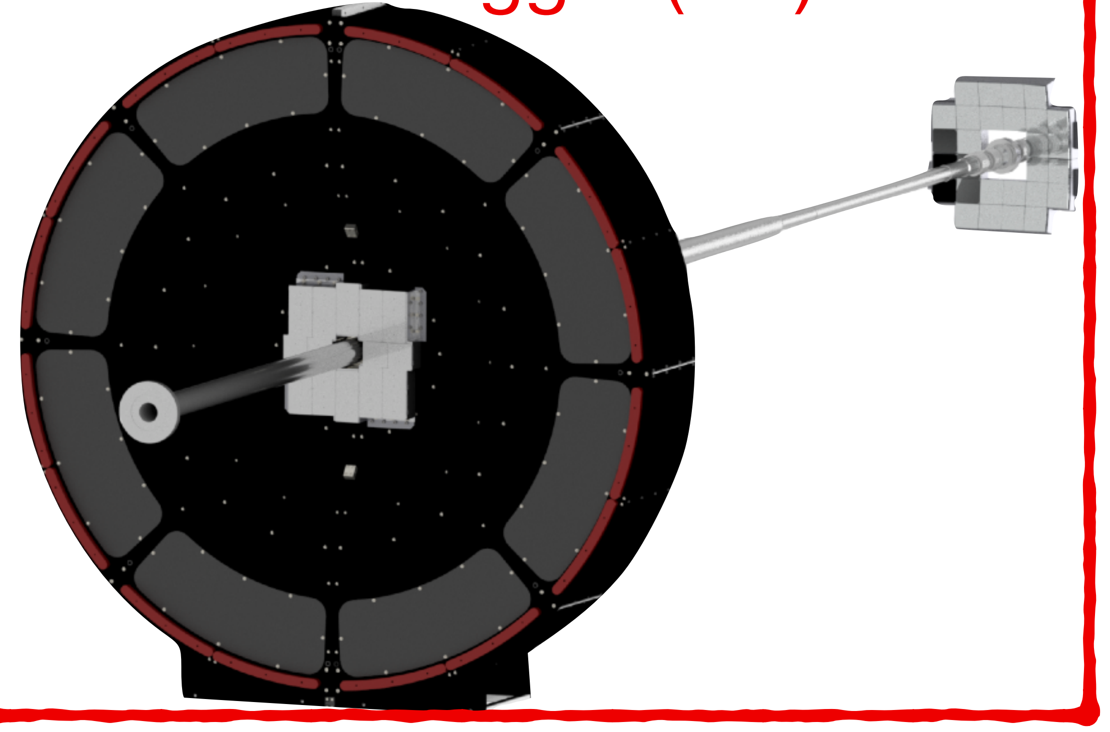
Upgraded readout for the TPC





New Muon Forward Tracker (MFT)

New Fast Interaction Trigger (FIT)



A LOOK AT RUN 3…

Pb-Pb collisions @ 50 kHz

Continuous readout
in triggerless mode

timeframe of 1 ms
Different colors are for tracks from different vertexes

ALICE AND THE QGP

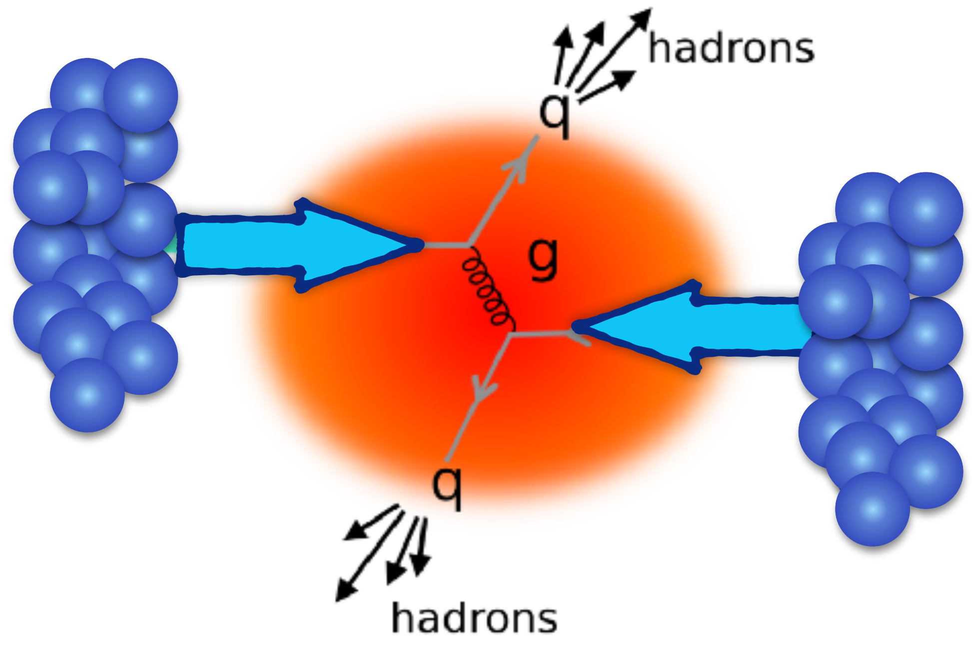
Ultra-relativistic heavy ion collisions ➧ formation of strongly interacting partonic medium (QGP)

HARD PROBES ➧ high p_T
produced in hard-partonic scattering processes, before QGP formation

SOFT PROBES ➧ low p_T
produced at late stages of the collision

COLLIDING SYSTEMS

AA

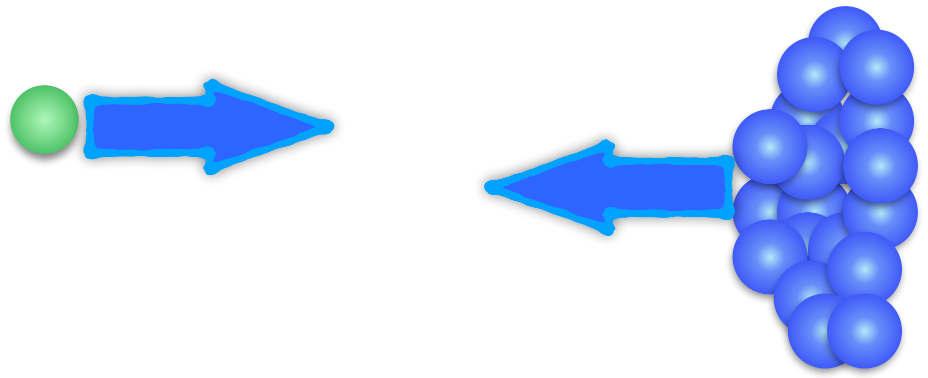


◗ formation of a strongly interacting state of partonic QCD matter (QGP)

SOFT PROBES ◗ collective effects observed, as expected in a strongly interacting medium

HARD PROBES ◗ high p_T particles and jets are modified by the interaction with the formed medium

pA

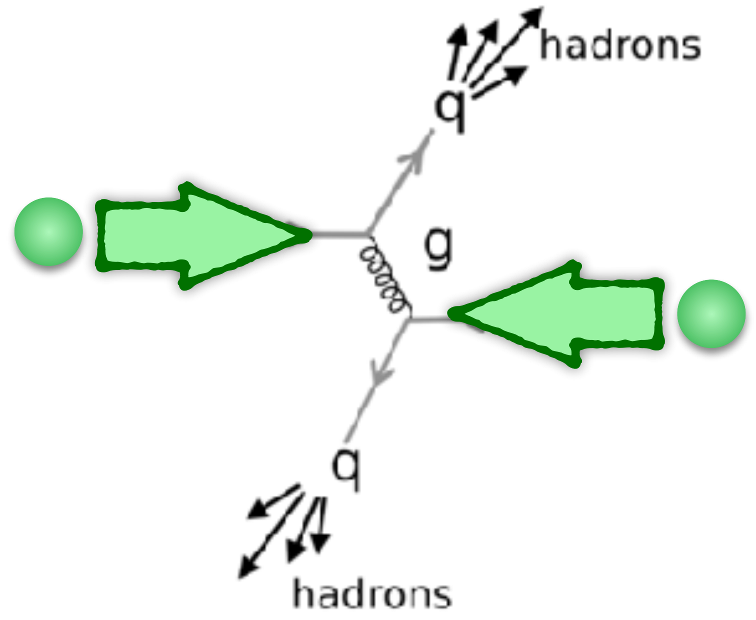


◗ Cold Nuclear Matter (CNM) effects due to the presence of the nucleus in the initial state

SOFT PROBES ◗ collective effects observed, not expected a priori

HARD PROBES ◗ no modification of high p_T particles nor jets

pp



◗ in-vacuum fragmentation

SOFT PROBES ◗ collective behaviour observed, unexpected

HARD PROBES ◗ no modification of high p_T particles nor jets

EVENT CHARACTERIZATION

CHARGED PARTICLE MULTIPLICITY

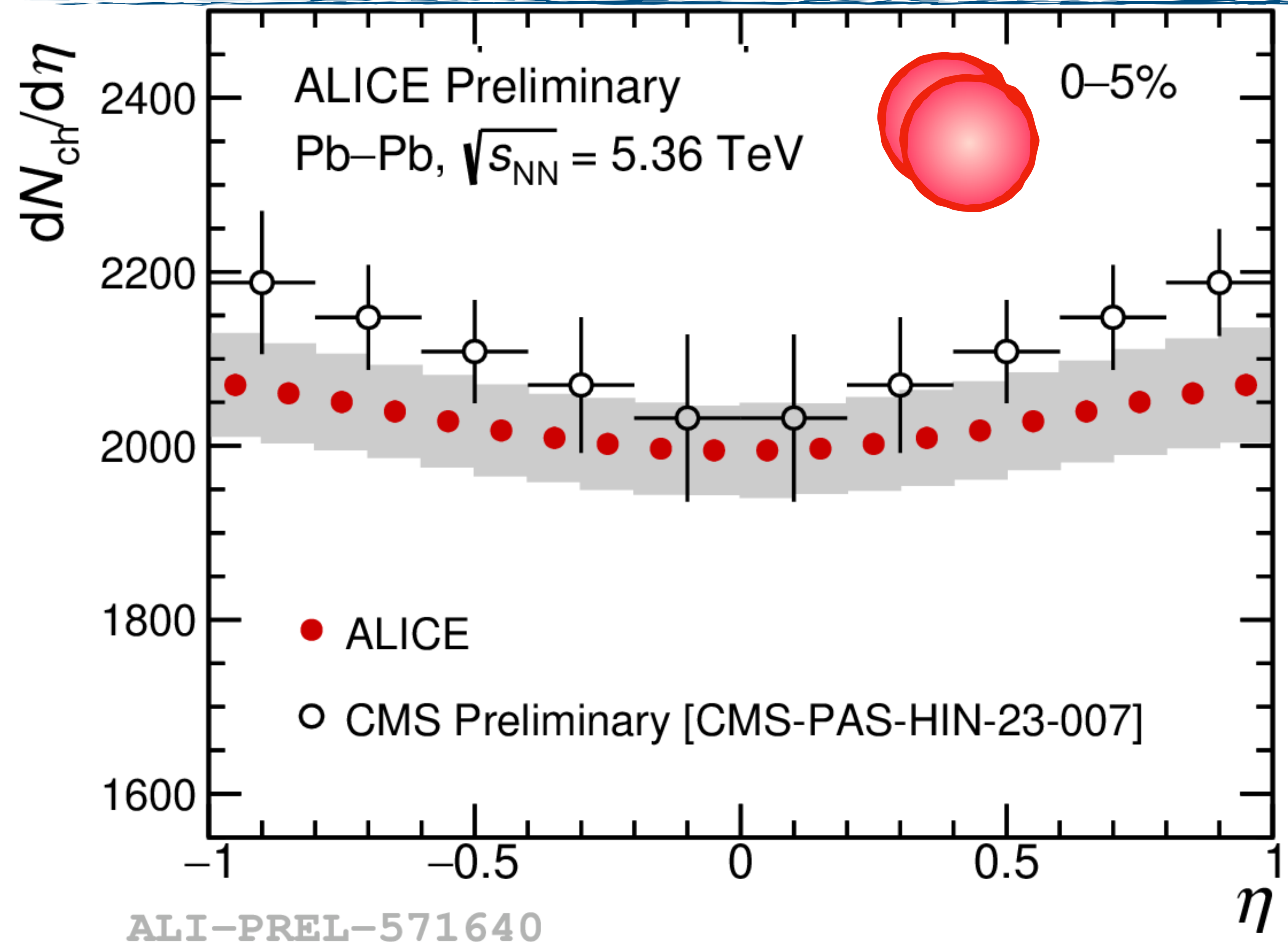
Run 3 results

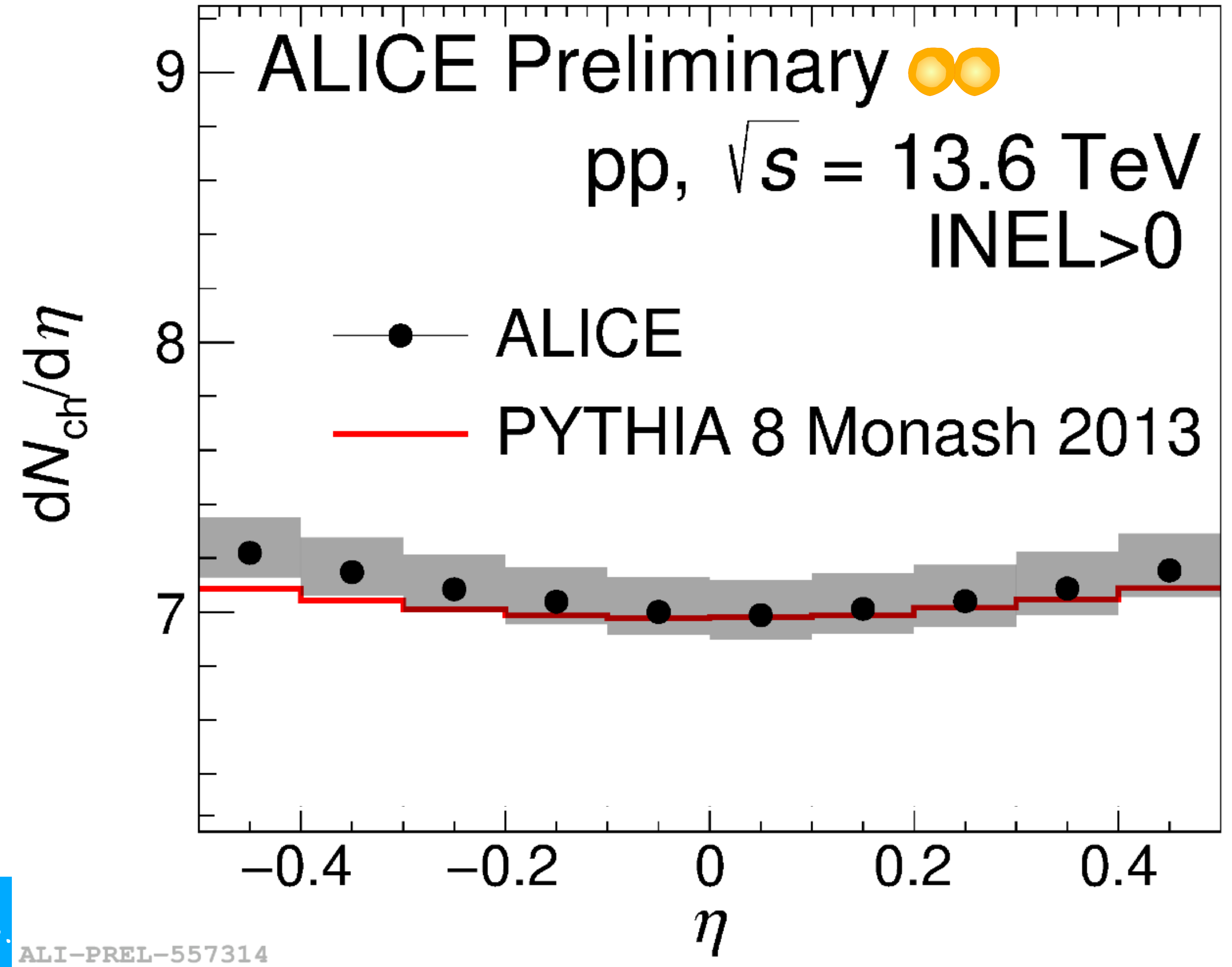
INFN ALICE

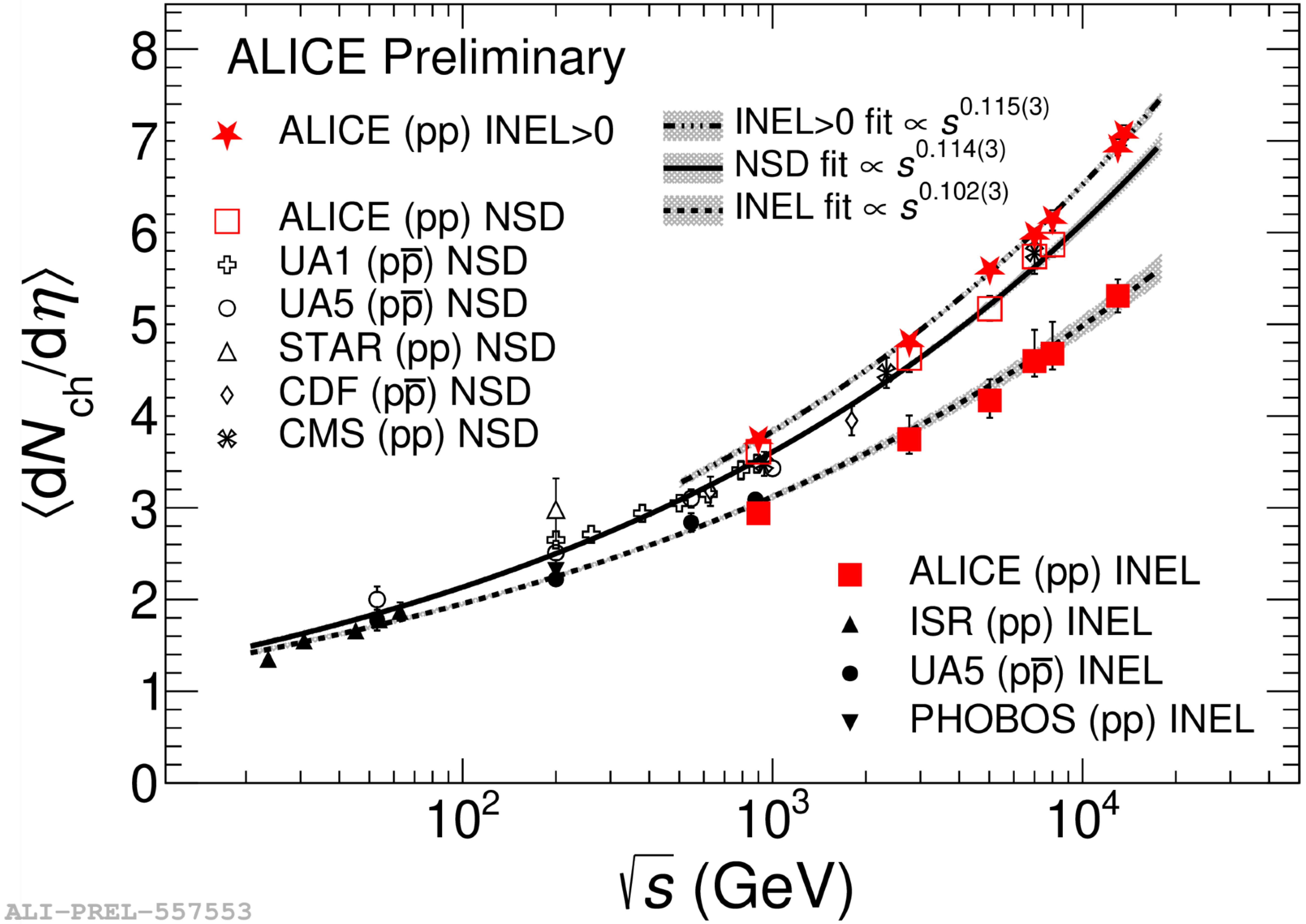
Fundamental observable, related to initial energy density

➧ study of its dependence on η, system energy and collision centrality

spans a large interval of √s and colliding systems





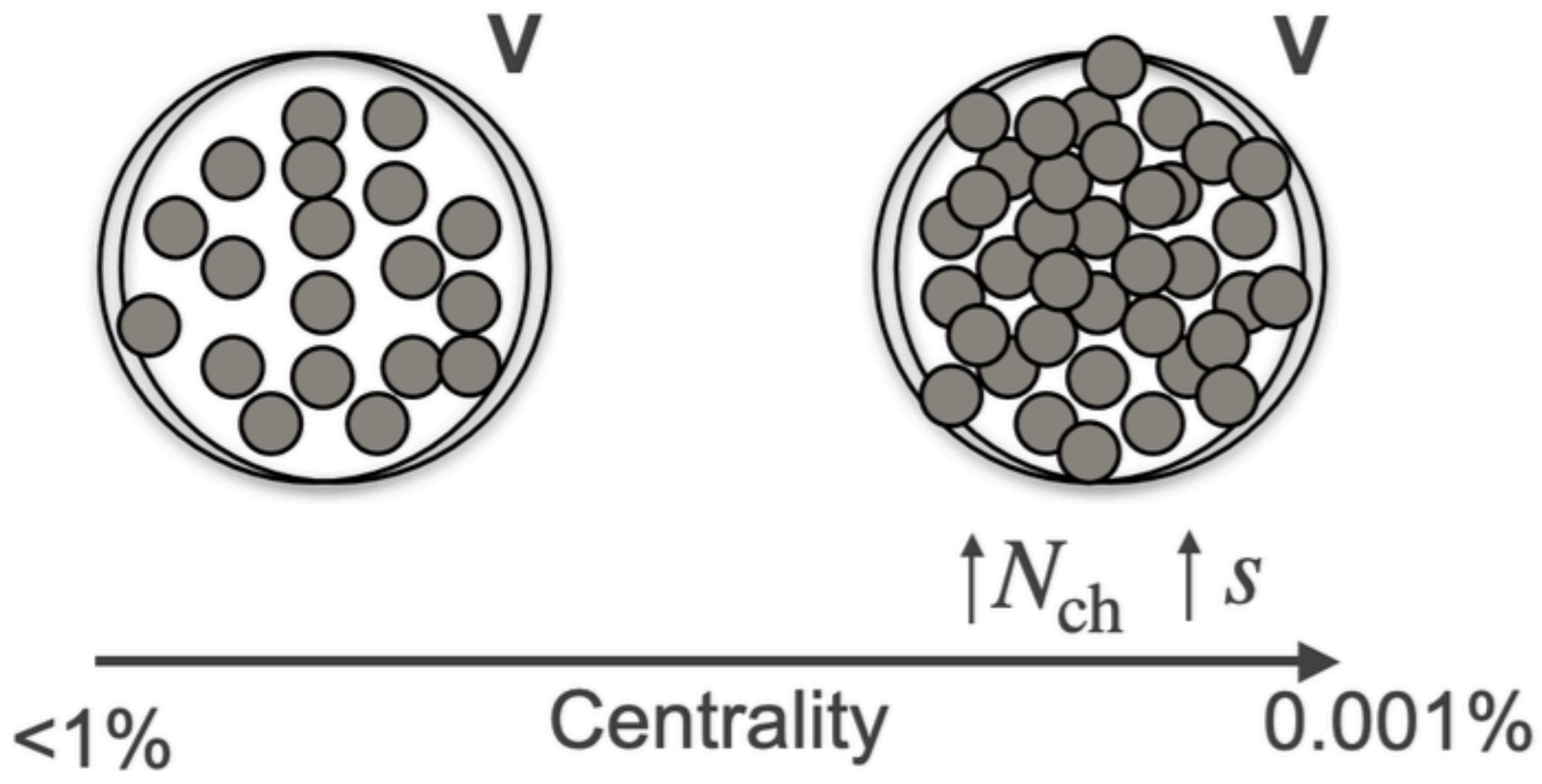


SPEED OF SOUND IN THE QGP

Run 2 results

In ultra-central events the volume is constant but entropy varies

F.G. GARDIM ET AL., NATURE PHYS. 16 (2020) 6, 615



➧ measure speed of sounds c_s that is related to the speed at which compression waves travel in the fluid (QGP)

$$c_s^2 = \frac{dP}{d\varepsilon} = \frac{s dT}{T ds} = \frac{d\langle p_T\rangle / \langle p_T\rangle}{dN_{ch}/N_{ch}}.$$

Experimentally, c_s^2 is extracted from <p_T> vs. <dN/dη> distributions

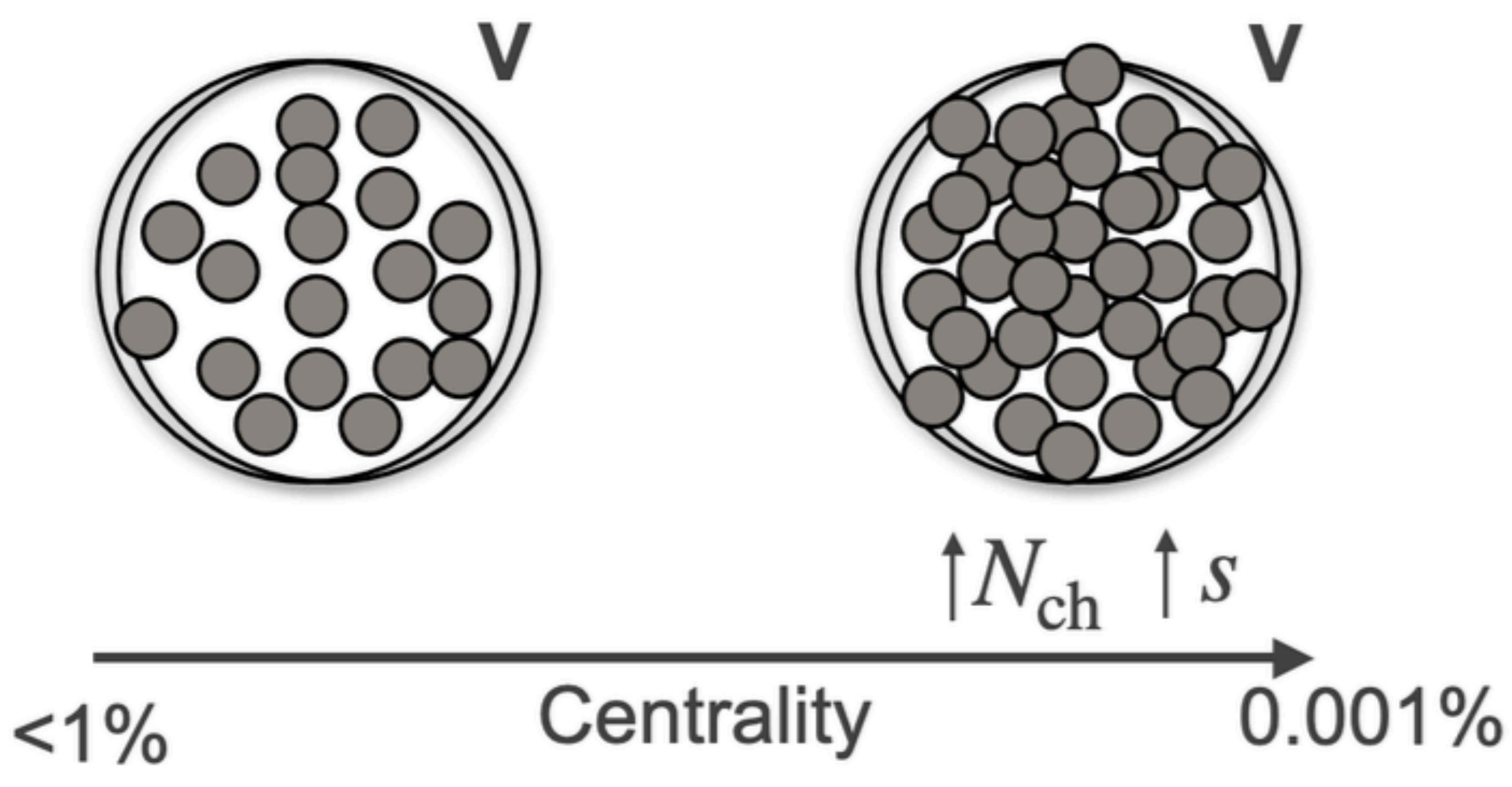
SPEED OF SOUND IN THE QGP

Run 2 results

ALICE PUBLIC-2024-002

In ultra-central events the volume is constant but entropy varies

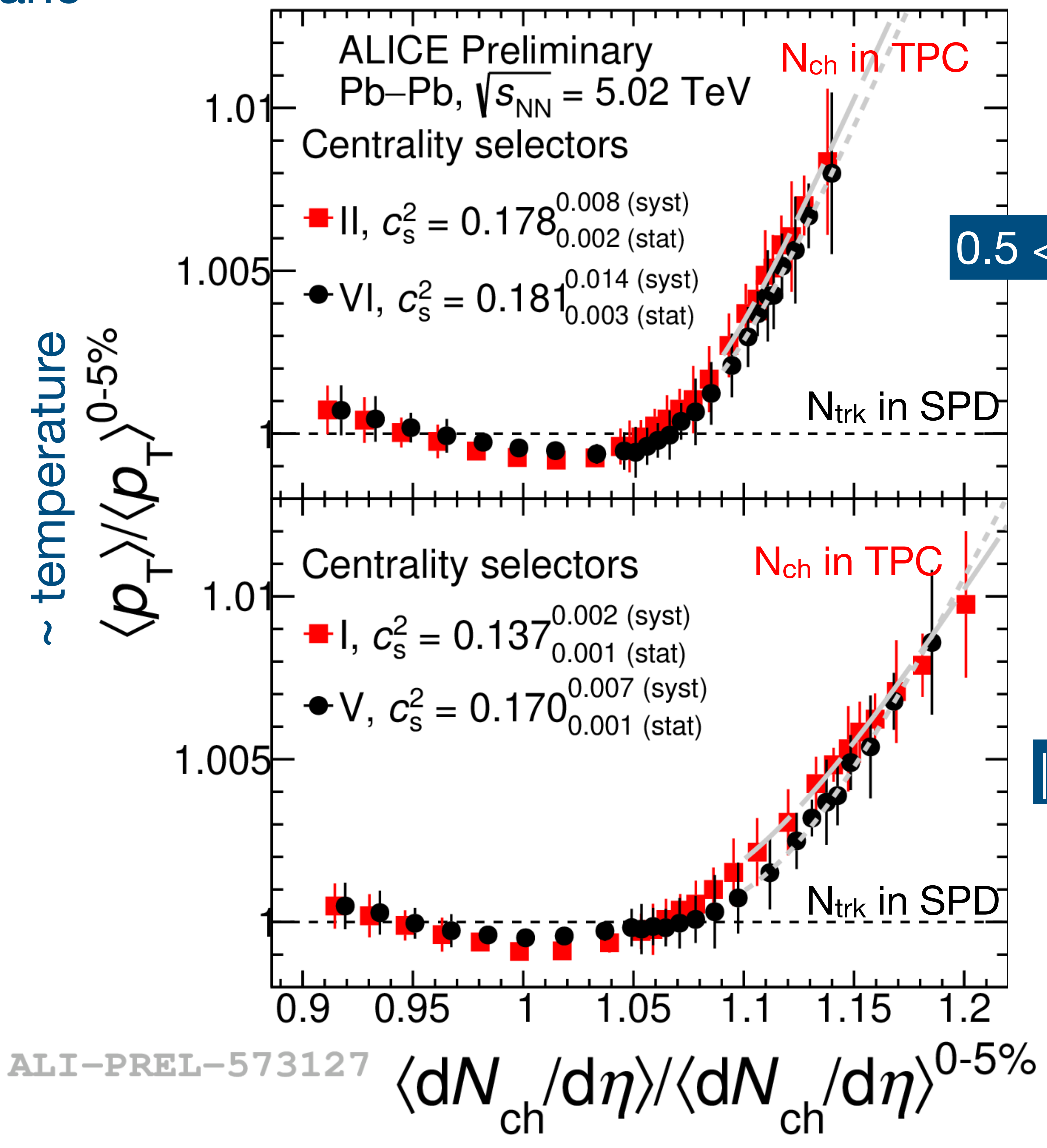
F.G. GARDIM ET AL., NATURE PHYS. 16 (2020) 6, 615



- measure speed of sounds c_s that is related to the speed at which compression waves travel in the fluid (QGP)

$$c_s^2 = \frac{dP}{d\varepsilon} = \frac{s dT}{T ds} = \frac{d\langle p_T\rangle / \langle p_T\rangle}{dN_{ch}/N_{ch}}.$$

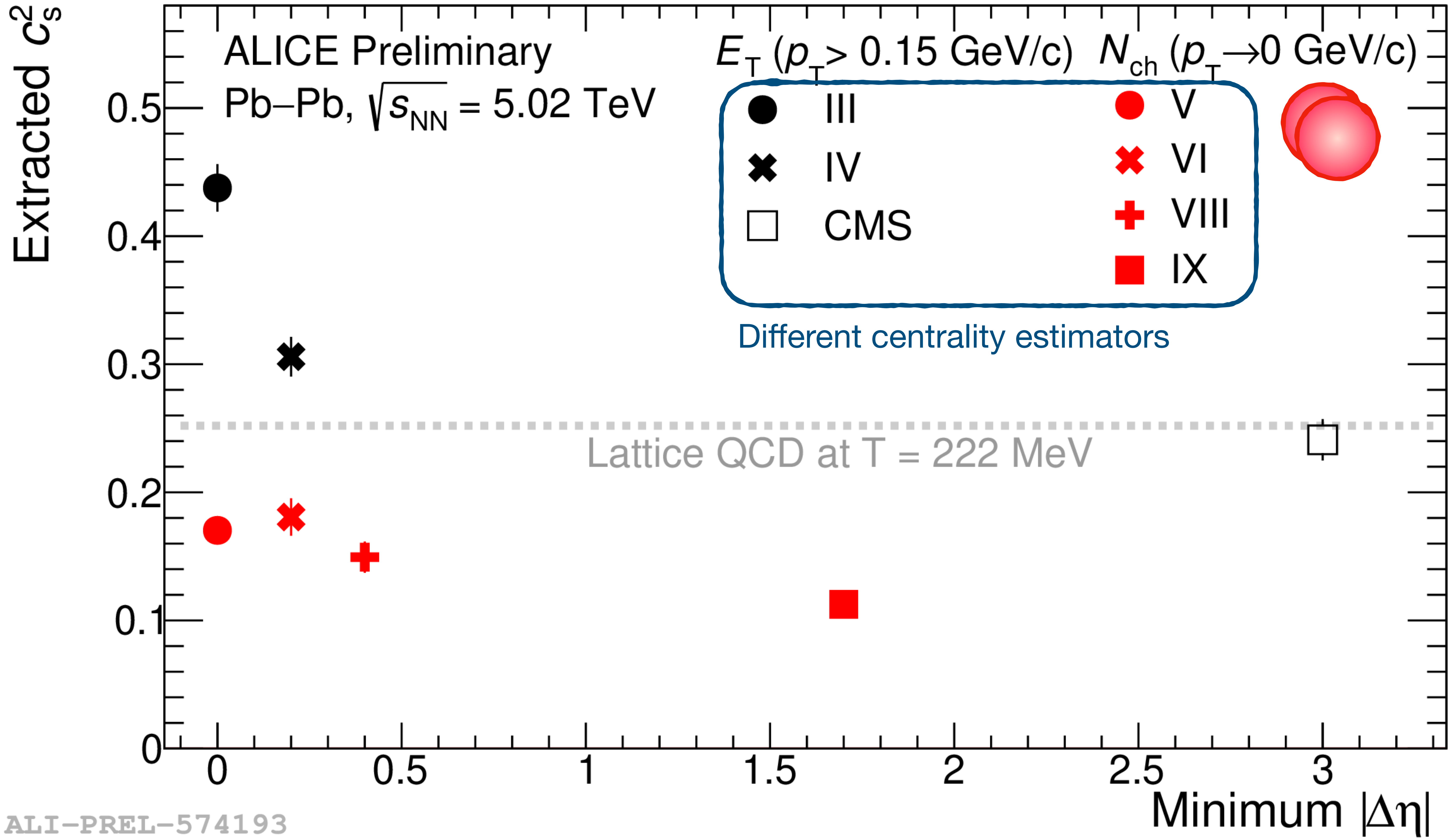
Experimentally, c_s^2 is extracted from $\langle p_T\rangle$ vs. $\langle dN/d\eta\rangle$ distributions



SPEED OF SOUND IN THE QGP

Run 2 results

ALICE PUBLIC-2024-002

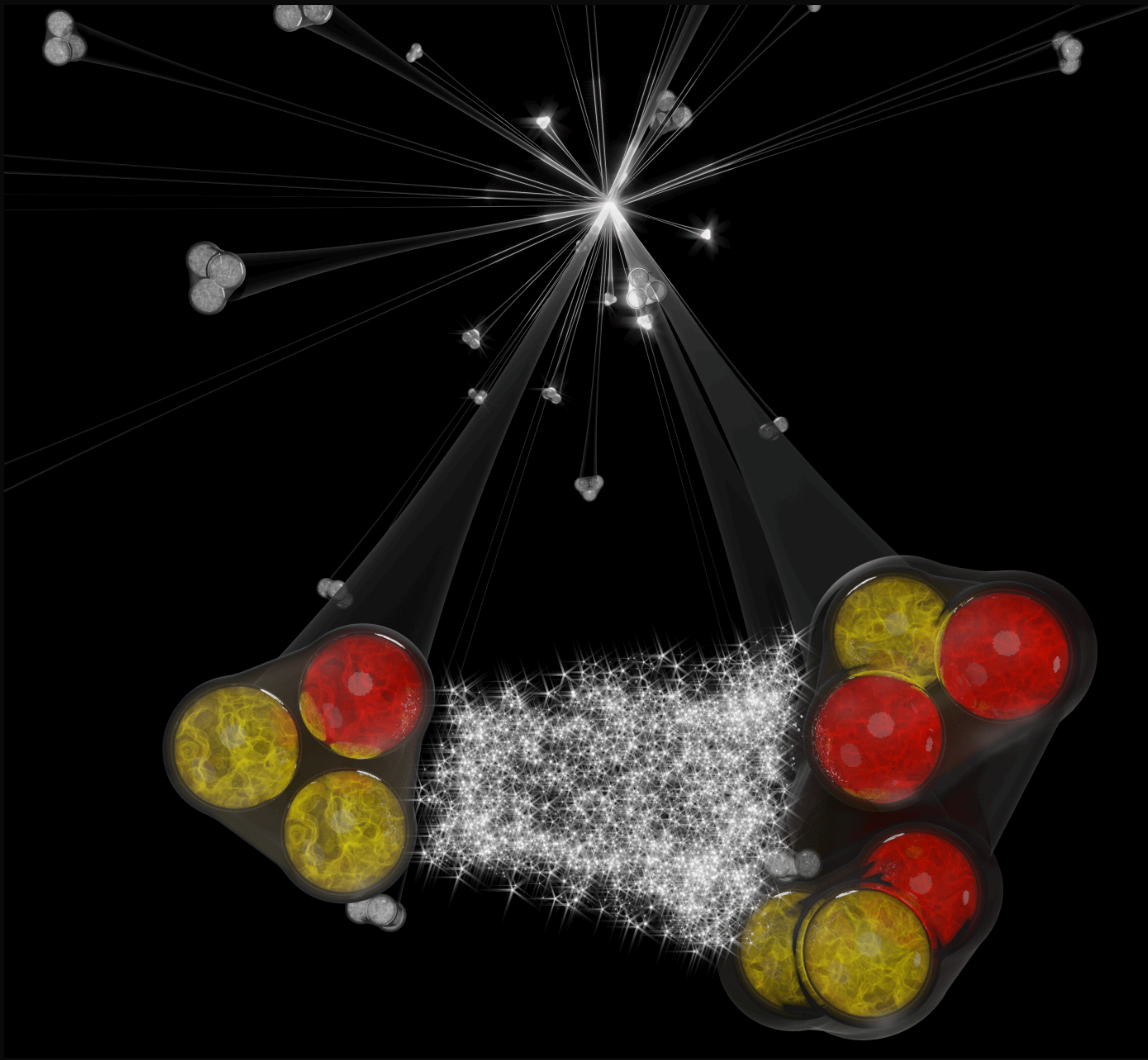


Different centrality estimators

η gap to avoid autocorrelations

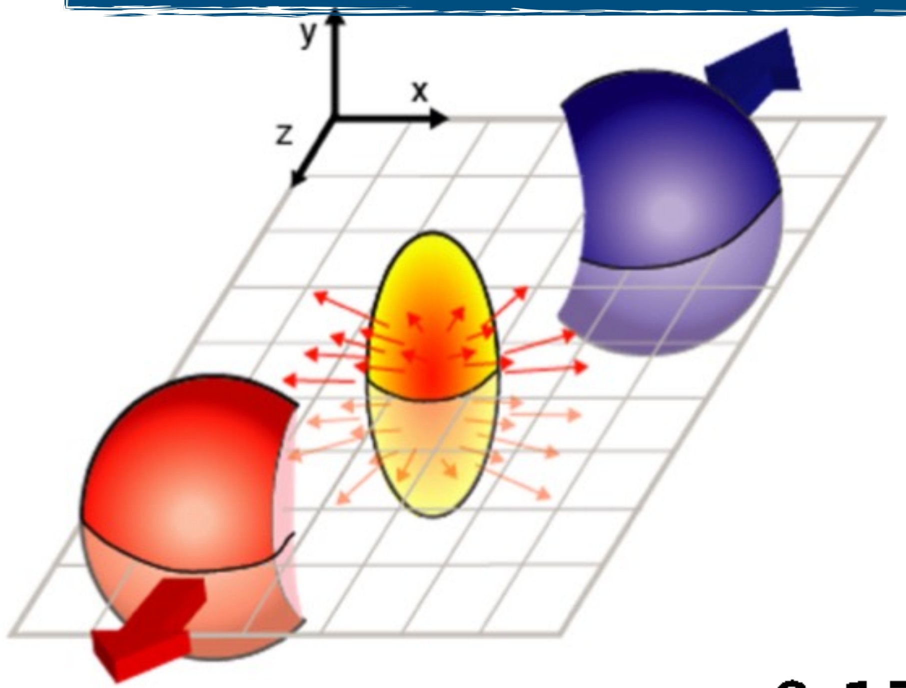
- the measured values strongly depend on the centrality estimator exploited as well as on the η gap
- a robust method to extract c_s from heavy ion data still to be developed

SOFT PROBES



COLLECTIVE EFFECTS IN SMALL SYSTEMS

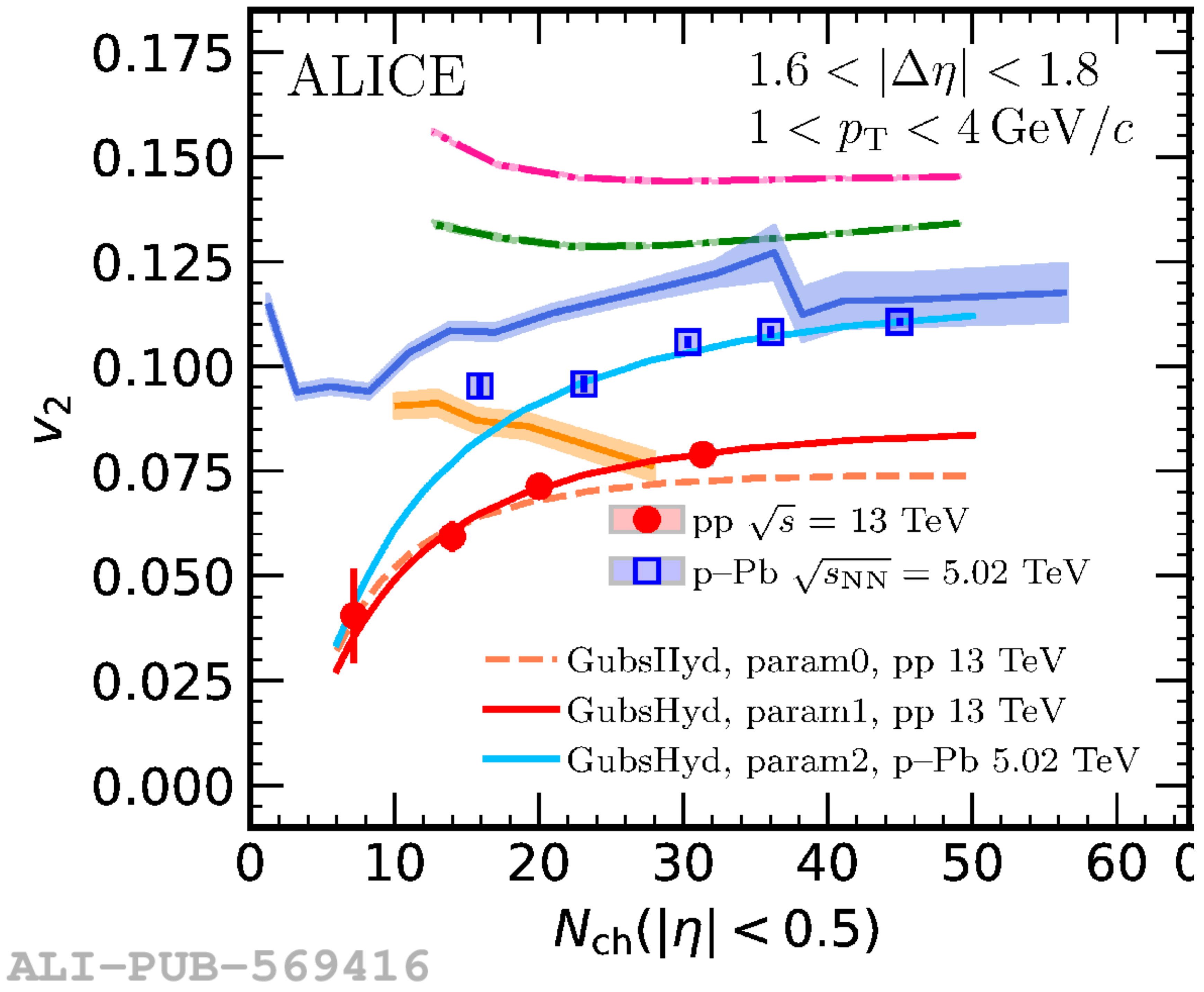
Run 2 results



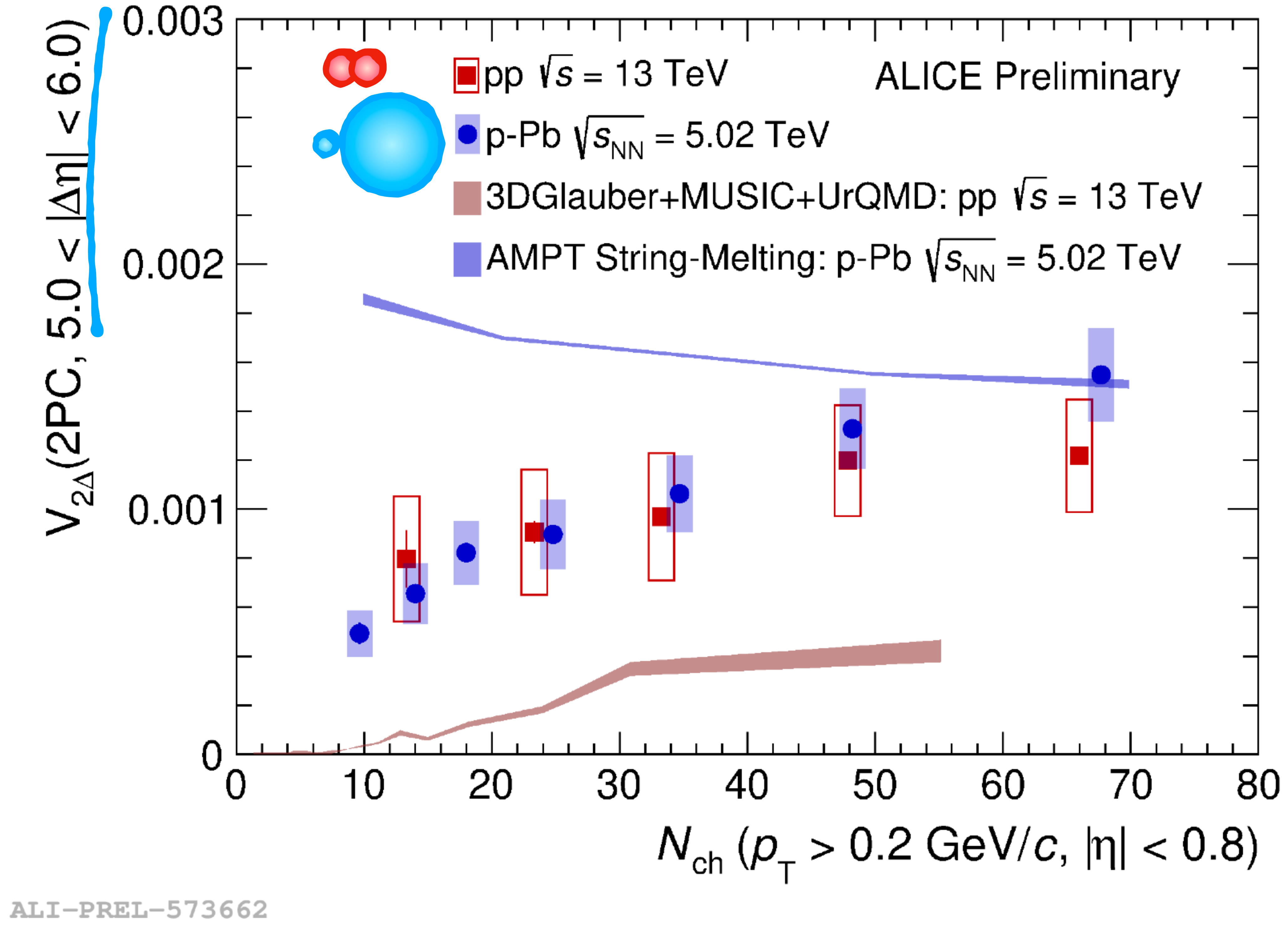
In AA collisions ➧ strong collective effects observed in momentum distributions in the final state quantified through Fourier coefficients v_n

Collective motion of the emitted particles reflects the collectivity of the initial medium

Removal of non-flow contribution



JHEP 03 (2024) 092



Larger η gap

➧ larger v_2 in p-Pb than in pp collisions

➧ v_2>0 down to low multiplicities

➧ collective effects are truly long-range

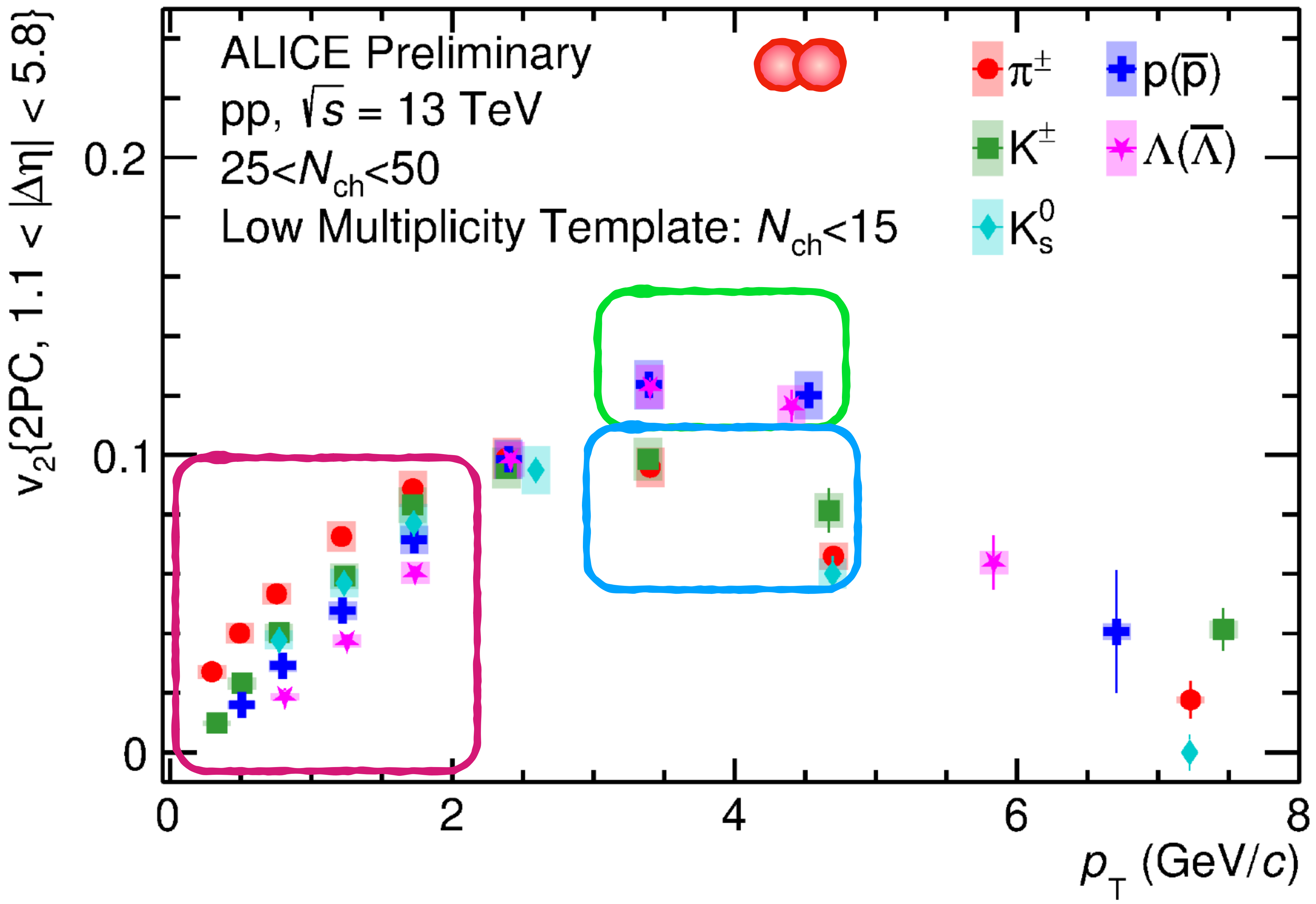
➧ unprecedented constraints to models

LOOKING FOR THE ONSET OF COLLECTIVITY

Run 2 results

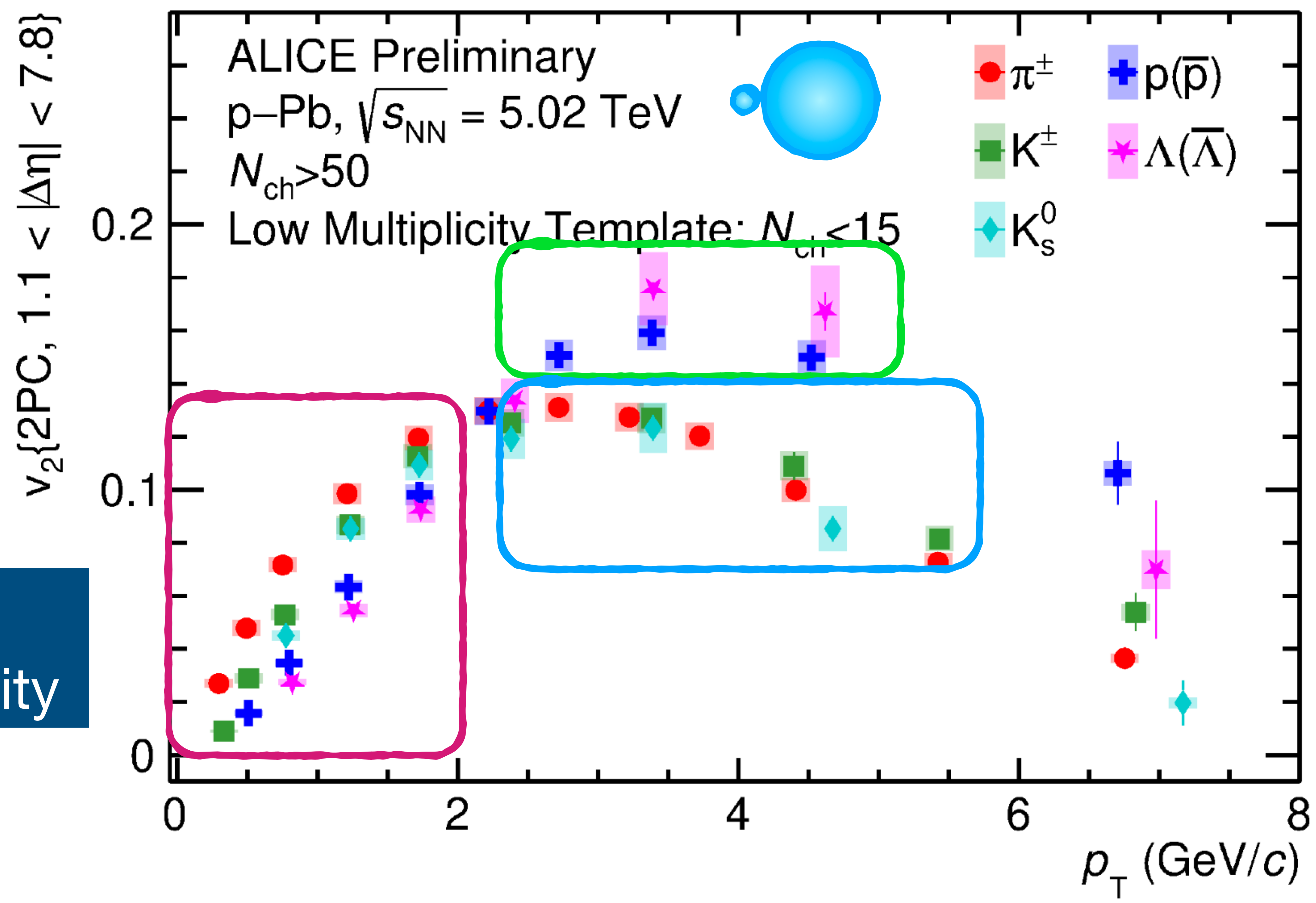
INFN ALICE

Elliptic flow for identified particles in small colliding systems in high multiplicity events
(two-particle correlation analysis including removal of non flow contributions)



ALI-PREL-573050

High multiplicity



ALI-PREL-573065

small p_T ➧ mass ordering consistent with expectations from hydrodynamics
intermediate p_T ➧ hadronization mechanisms drive baryon vs. meson grouping

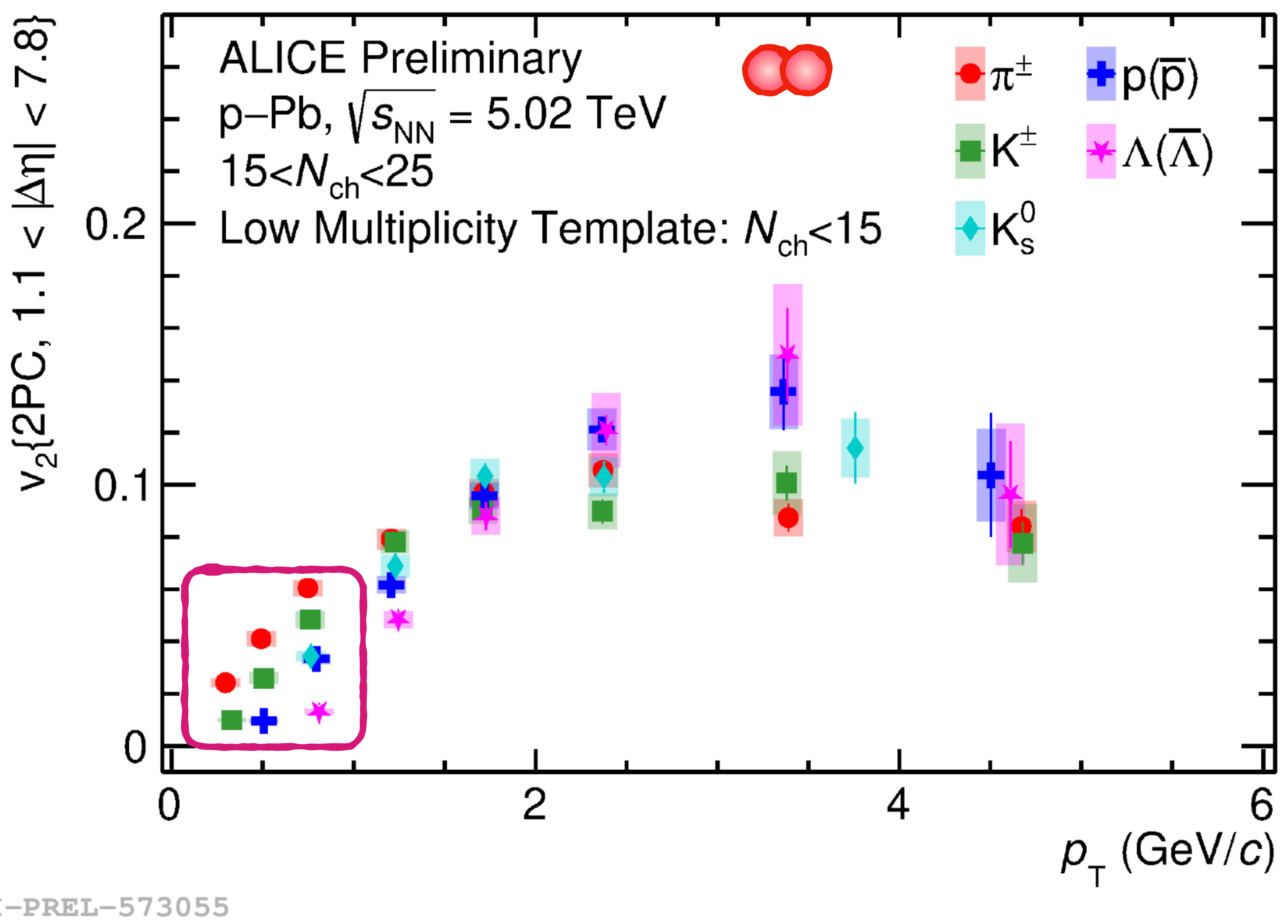
} Same features as in AA collisions

➧ mass ordering and baryon-meson grouping observed in high multiplicity pp and p-Pb collisions

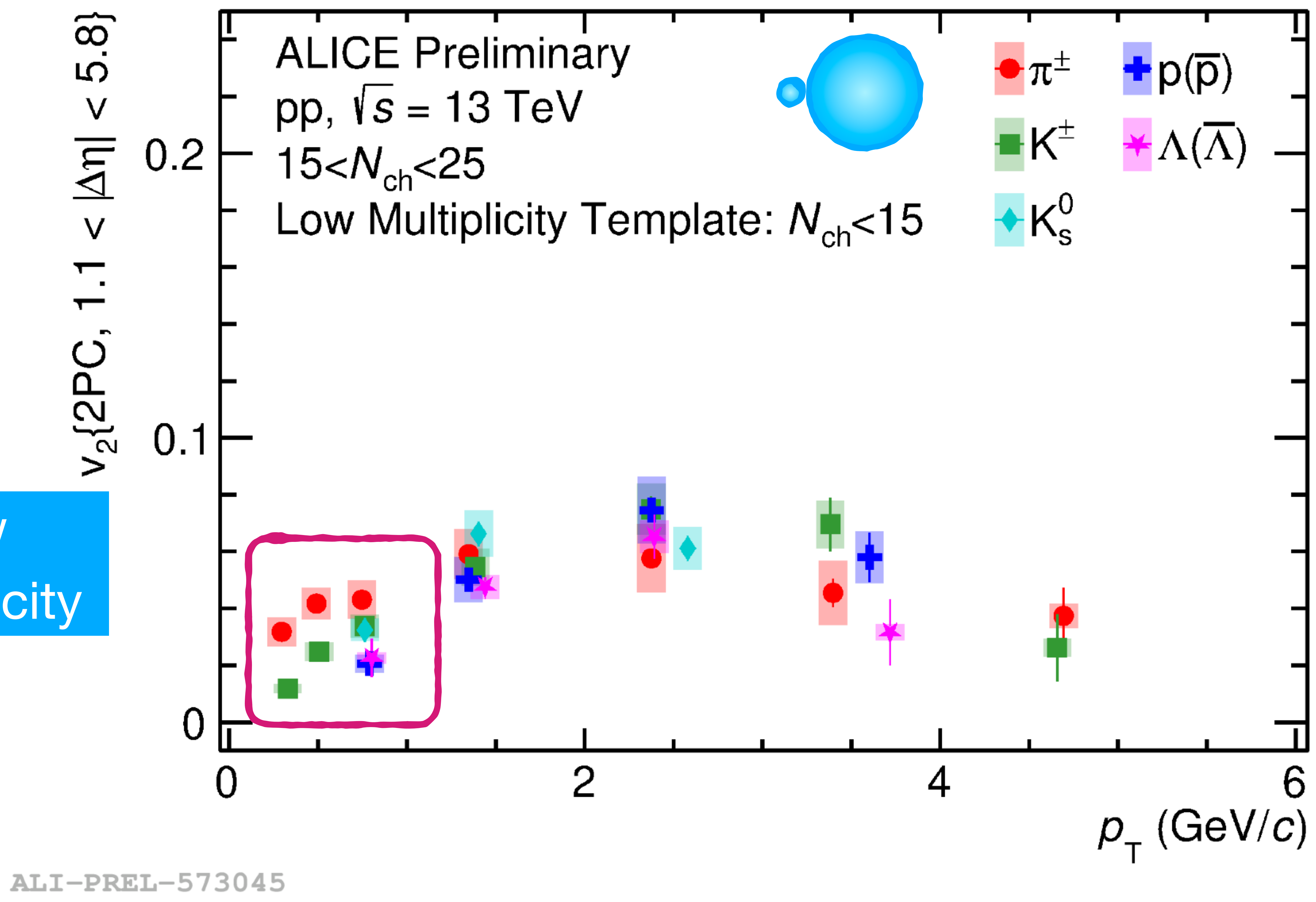
LOOKING FOR THE ONSET OF COLLECTIVITY

Run 2 results

Elliptic flow for identified particles in small colliding systems in high multiplicity events
(two-particle correlation analysis including removal of non flow contributions)



Low multiplicity

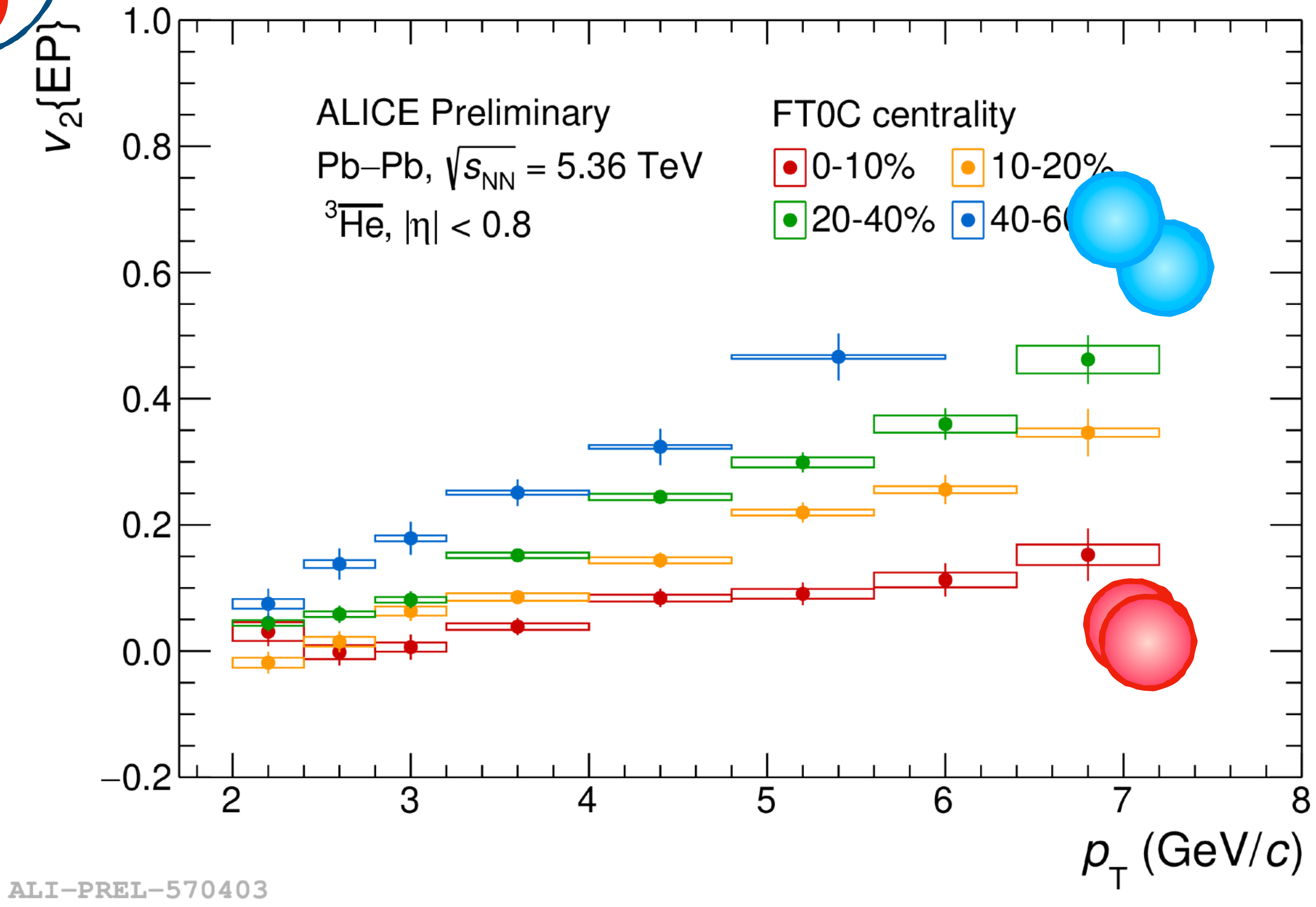


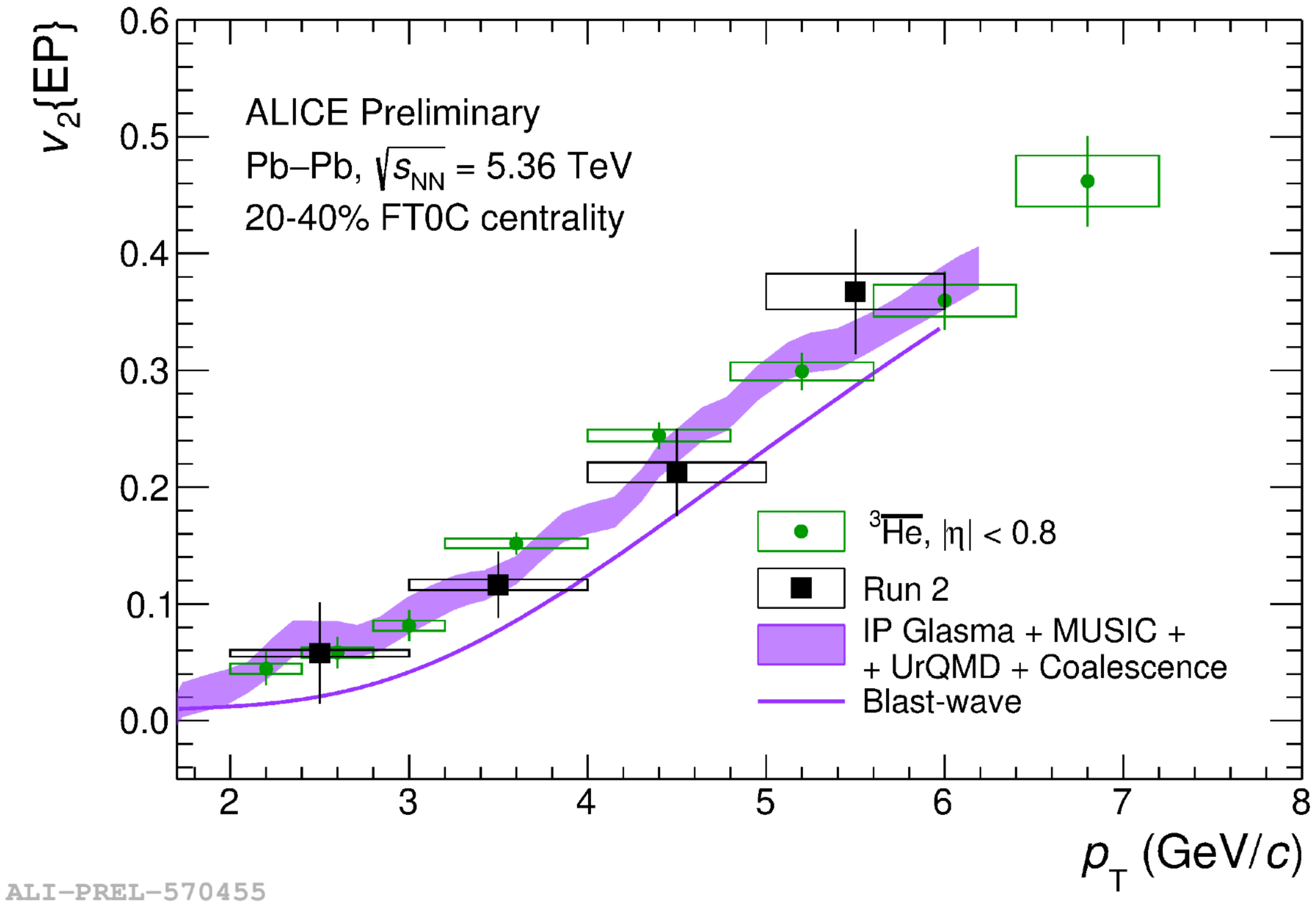
- v_2>0 and mass ordering, BUT baryon-meson grouping disappears in low multiplicity events
- hint of an onset in collective effects?

LIGHT NUCLEI AND COLLECTIVITY

Run 3 results

Elliptic flow of anti-He³ in Pb-Pb collisions





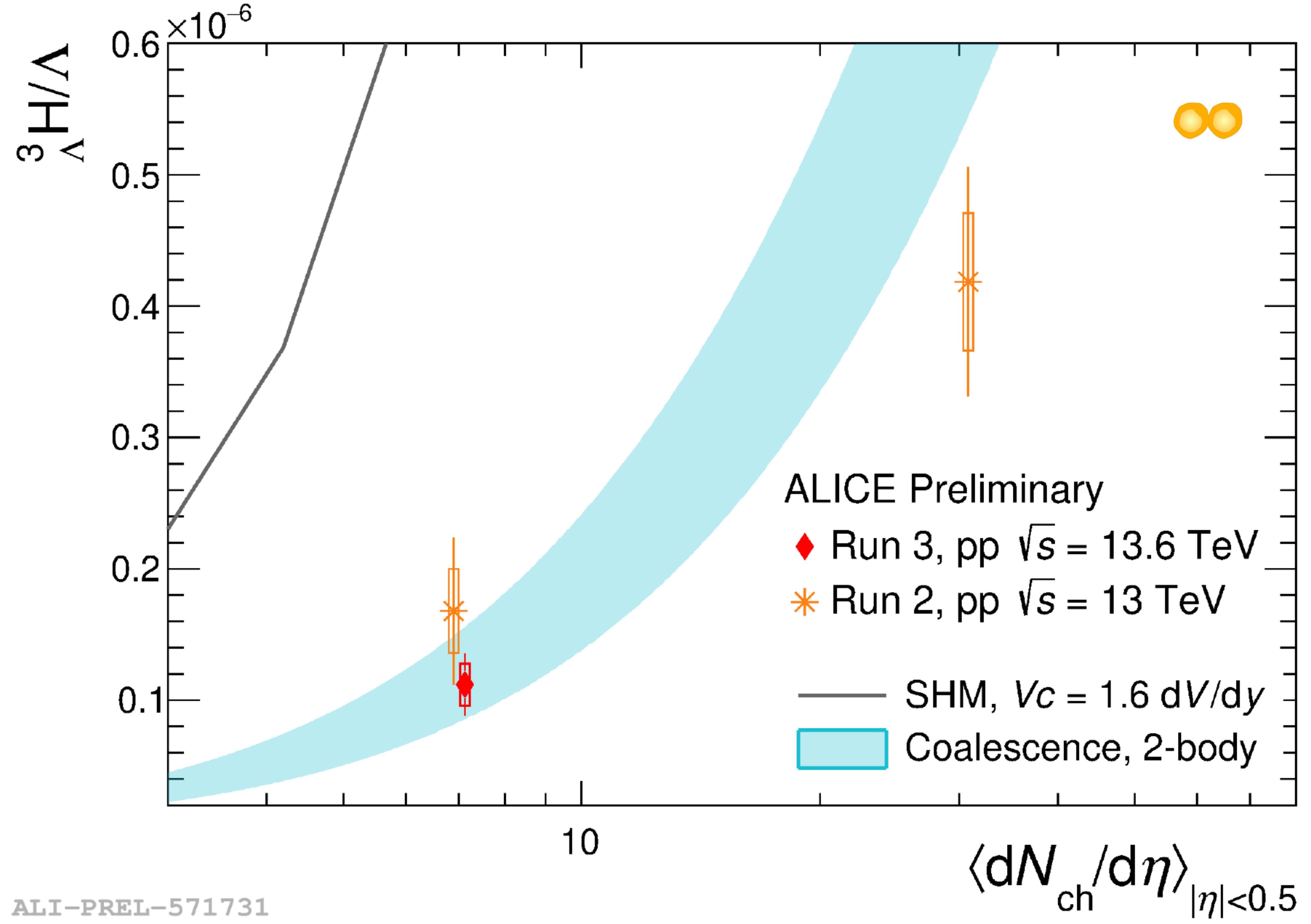
- v_2 reflects the collision geometry, being largest for mid-central collisions and small in central collisions
- Run 3 measurements allow to discriminate between model predictions ➧ coalescence model favoured

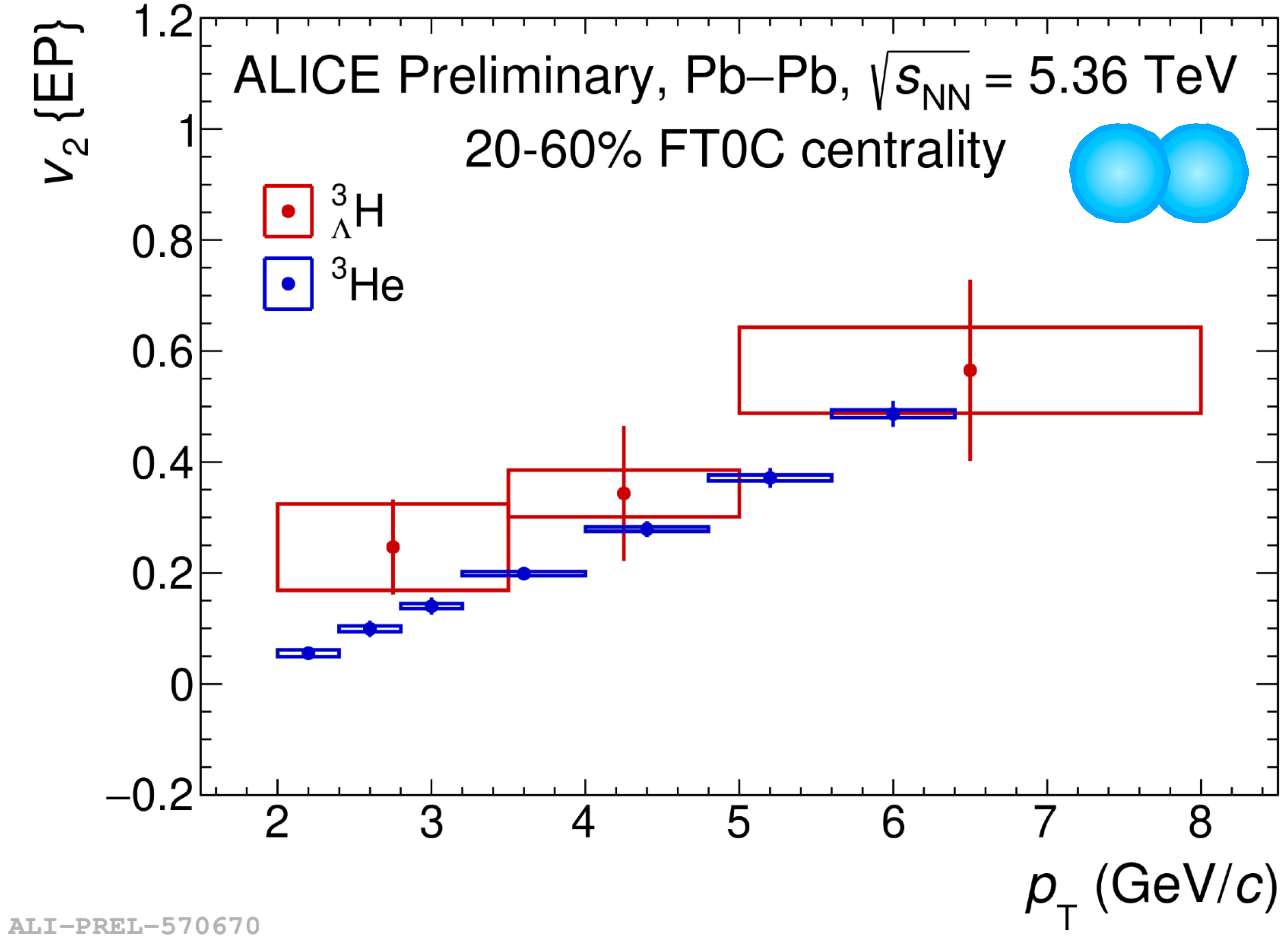
(ANTI)HYPER-TRITON PRODUCTION

Run 3 results

$^{3}_{\Lambda}H$ Investigate hyperon-nucleon interactions ➧ high-density cores of neutron stars

Models explaining anti-hypertriton productions: Statistical Hadronization Model (SHM) and coalescence model that have very different predictions at low multiplicity





➧ production consistent with 2-body coalescence model

➧ (anti)hyper triton flows with system in Pb-Pb collisions

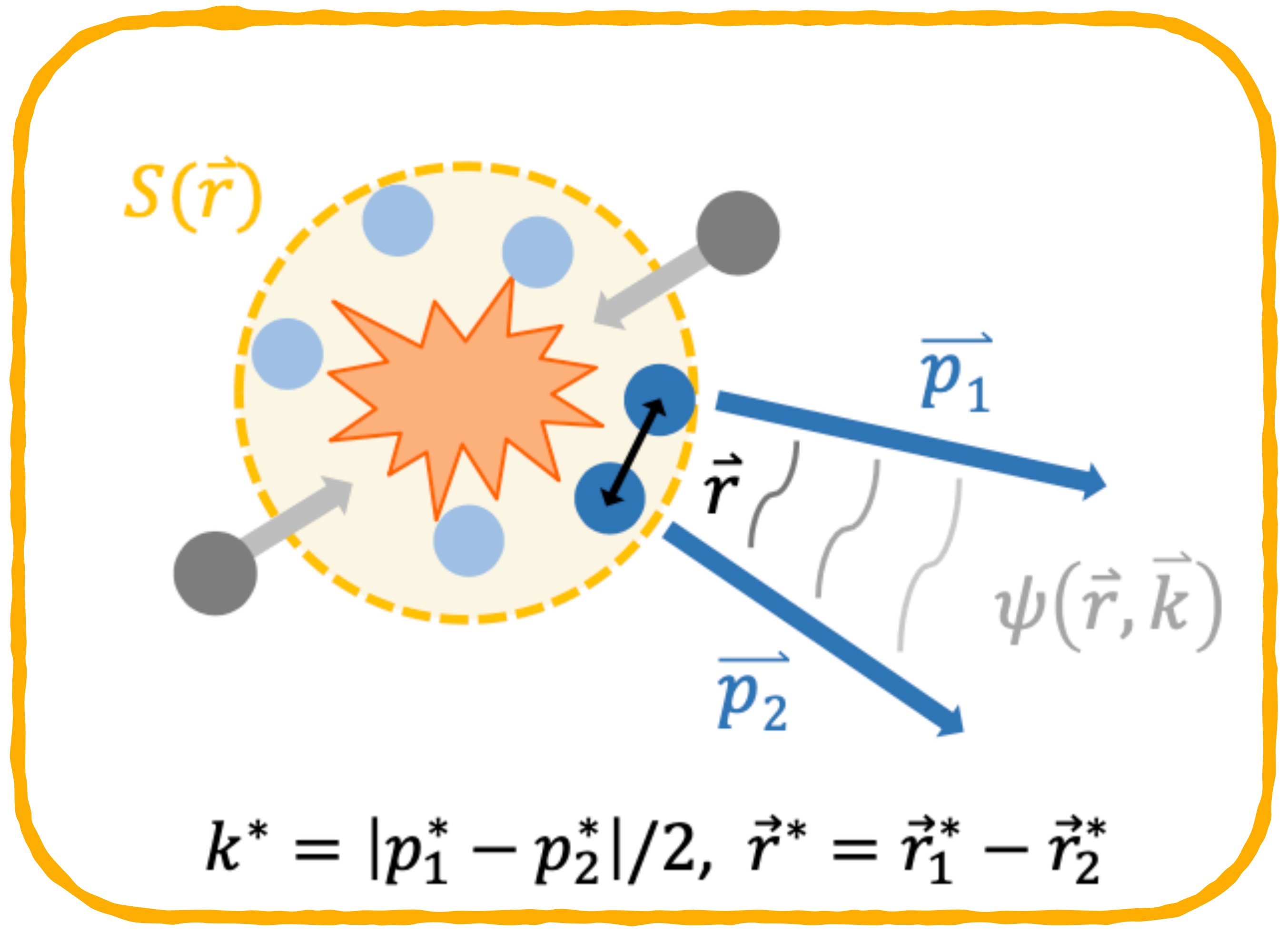
STRONG INTERACTION OF 3-BODY SYSTEMS

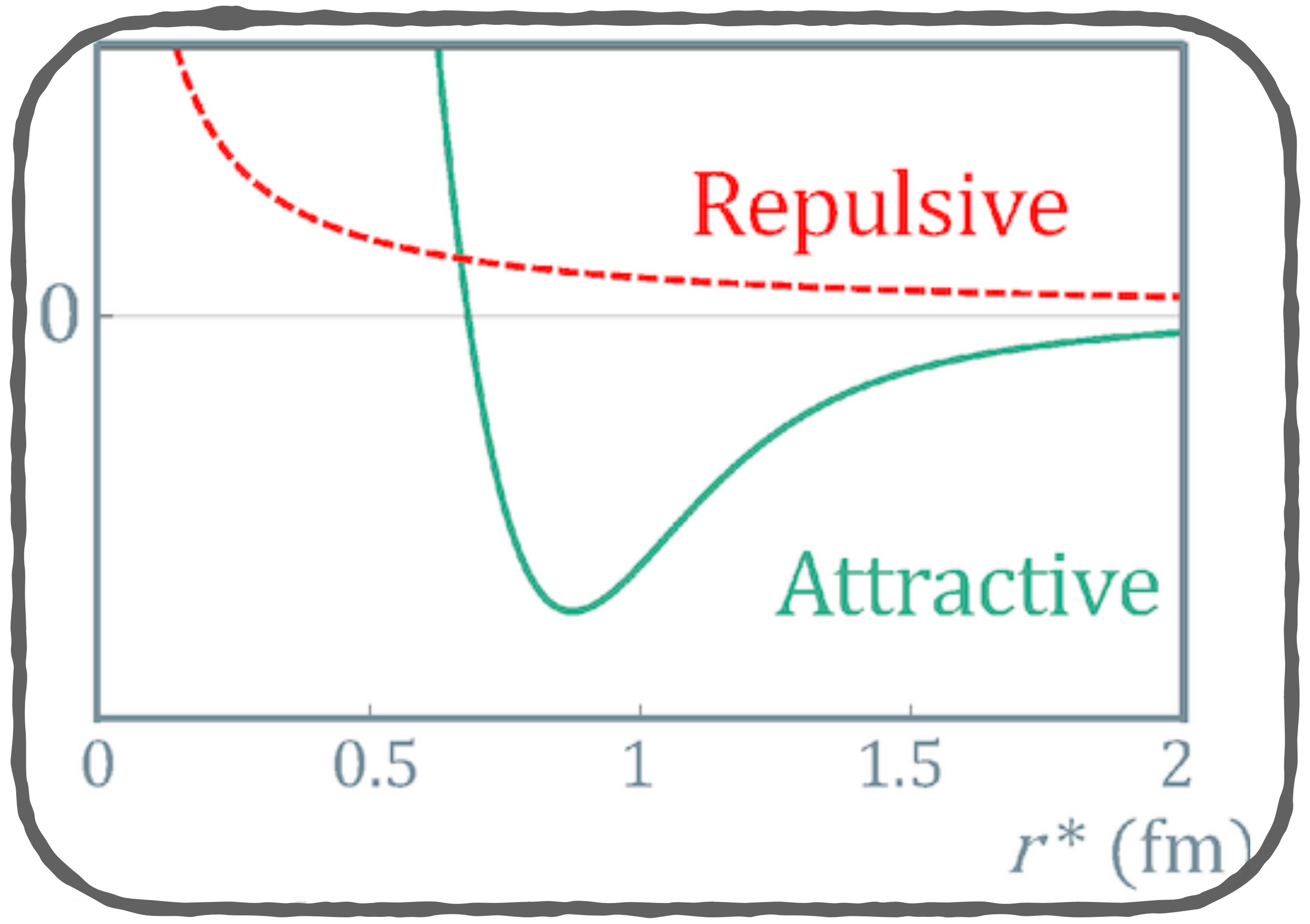
Study K^+-d and p-d interaction through femtoscopy ➧ build 2-particle correlation functions C(k*)

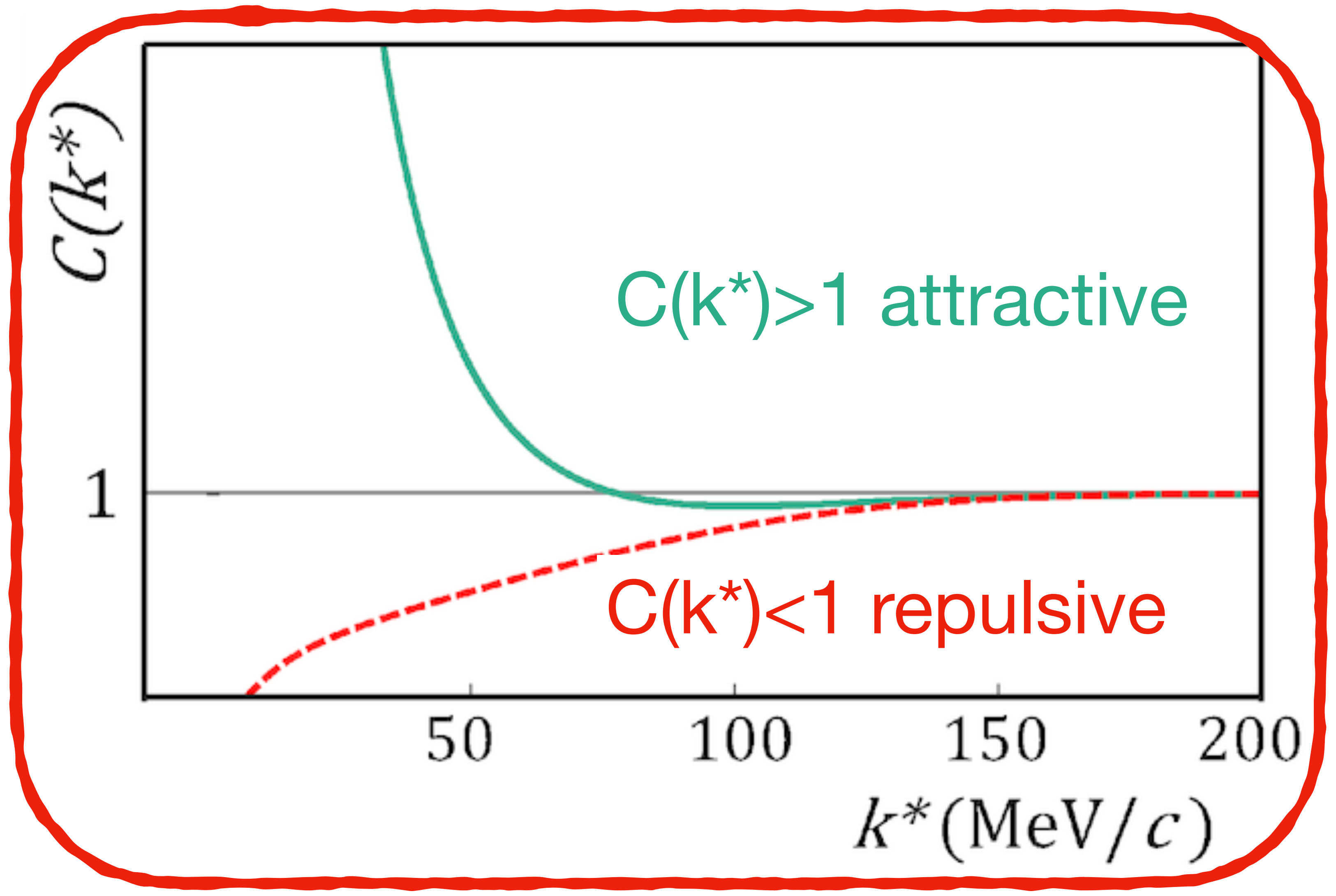
➧ measure the probability that two particles with certain relative momenta k* are correlated

$$C(k^*) = \int S(r^*) \, |\Psi(k^*, r^*)|^2 d^3r^* = \xi(k^*) \cdot \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

Model emitting source | Interaction potential | Measured correlation function



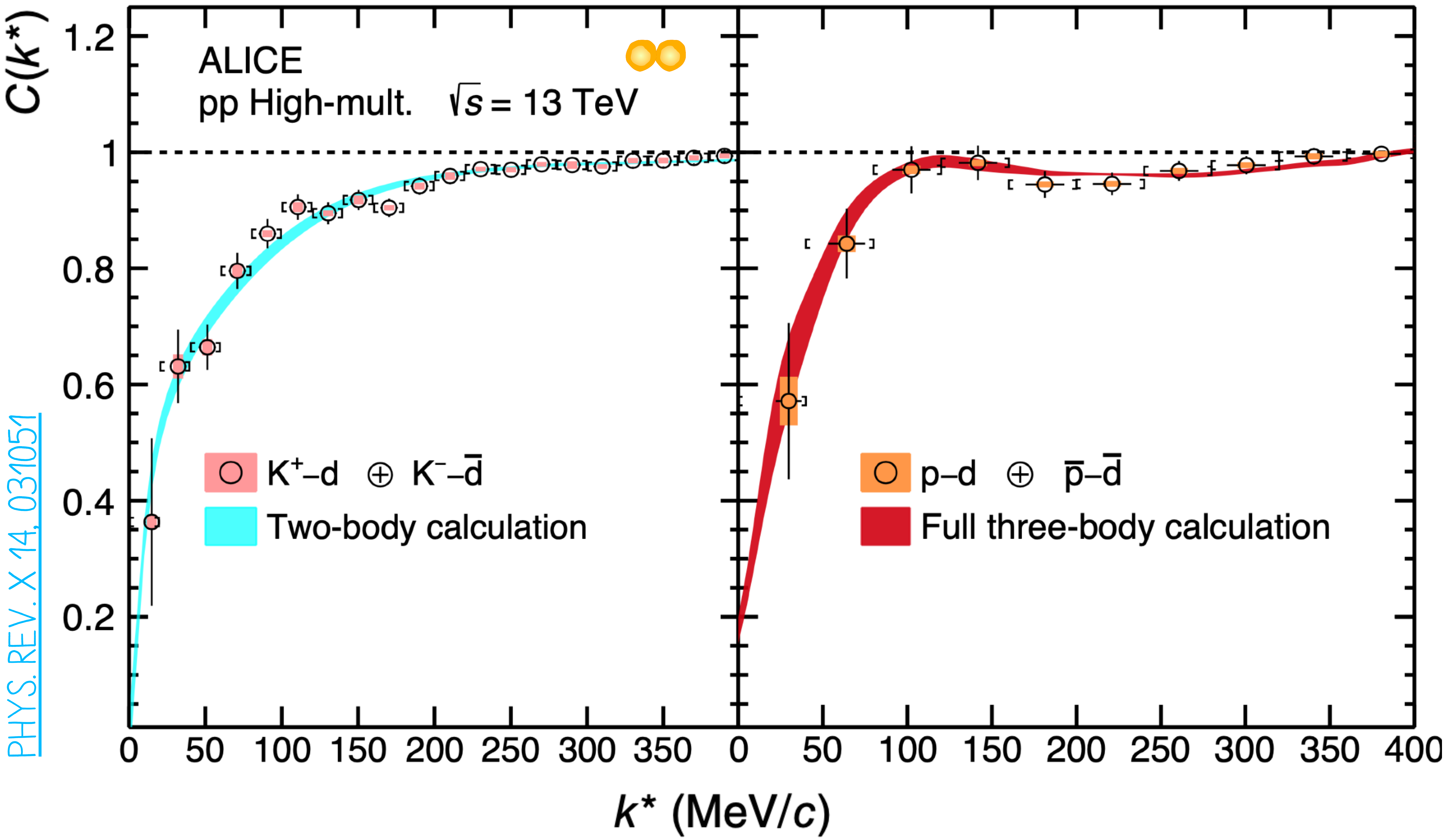




C(k*) =1 no interaction

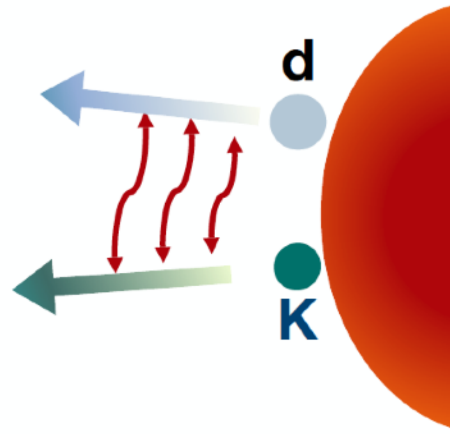
STRONG INTERACTION OF 3-BODY SYSTEMS

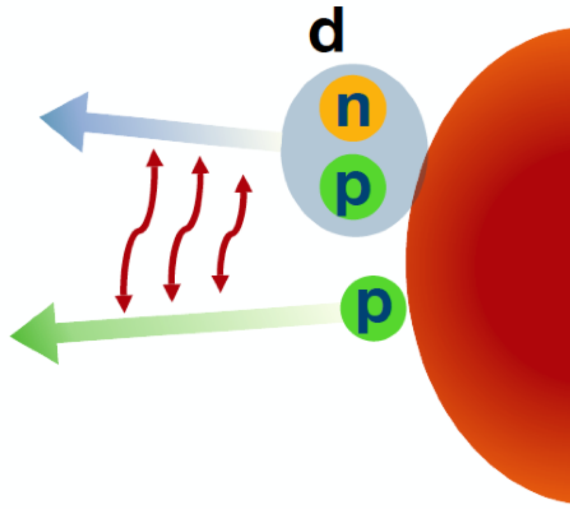
Run 2 results



PHYS. REV. X 14, 031051

- overall repulsive interaction
- K-d correlations are described with an effective two-body model including both the Coulomb and strong interaction
- p-d correlation can be described only with a full 3-body calculation where deuteron structure is considered

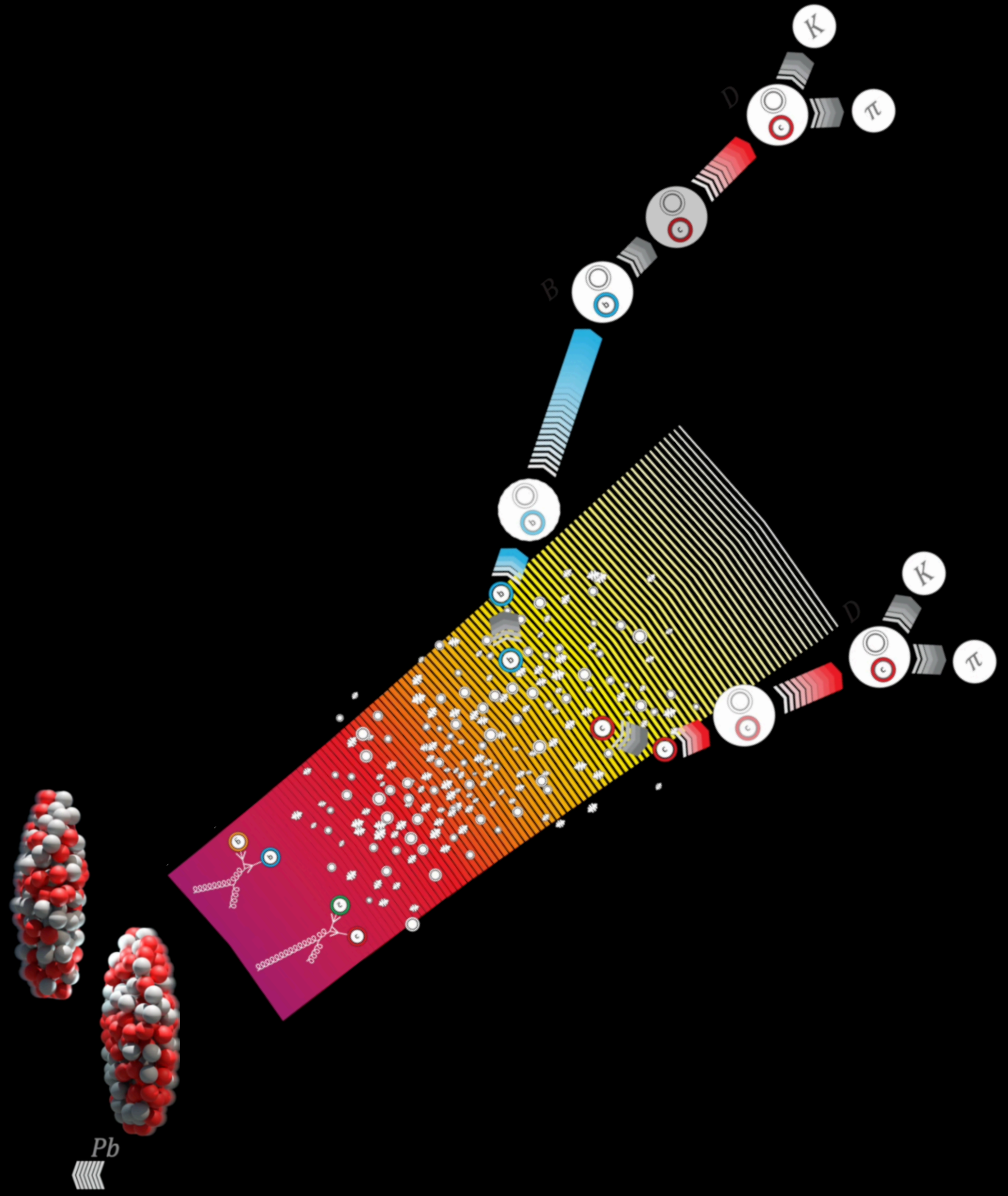




- precise studies of the forces in three-body nuclear systems with Run 3 data
- plan to extend measurements to charm and strange systems, implications for neutron star EoS

HARD PROBES

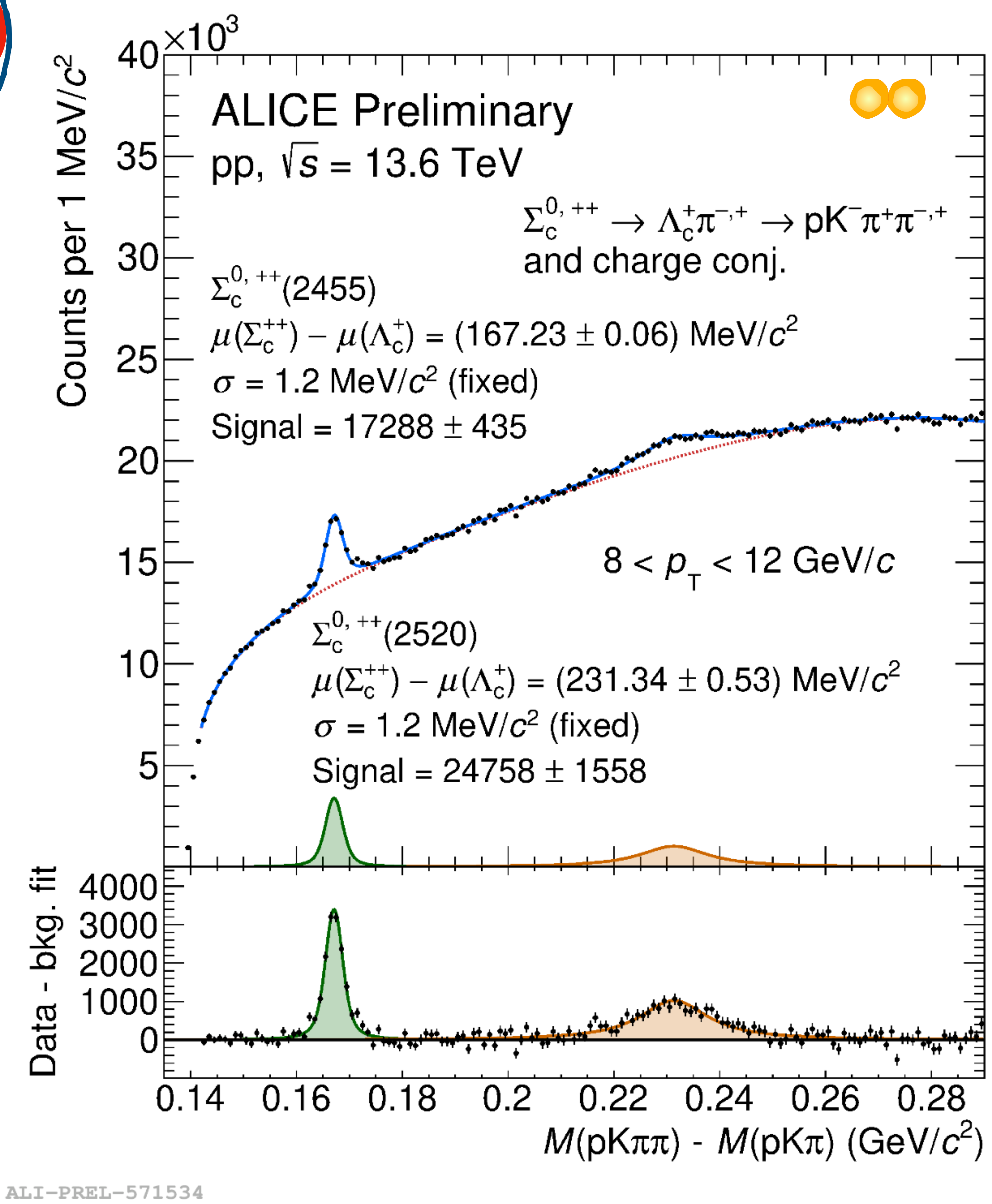
(CHARM SECTOR)

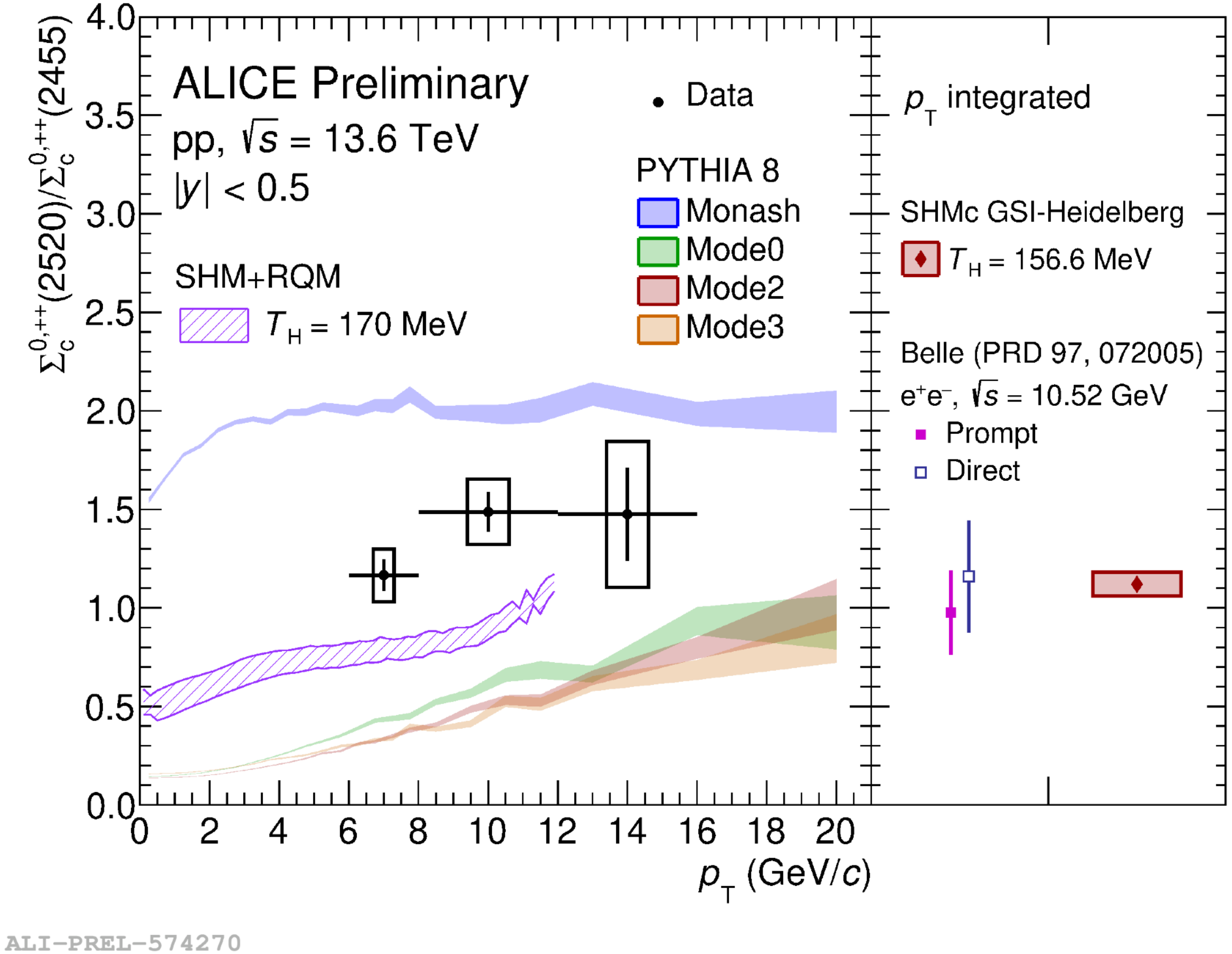


CHARMED BARYONS

Run 3 results

First measurement at LHC of the charm baryon resonances $\Sigma_c^{0++}(2520)$



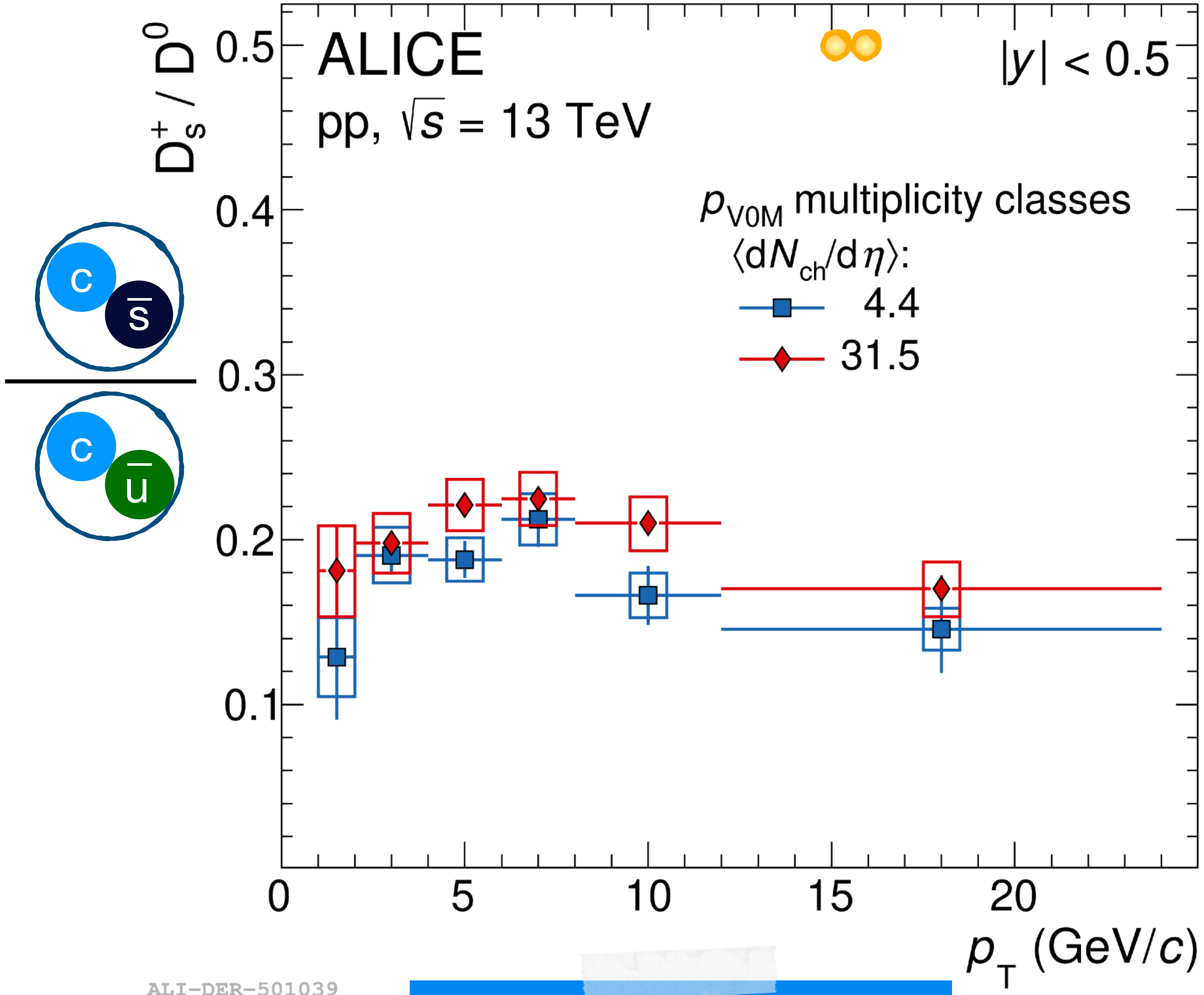


- integrated ratio consistent with result from e^+e^- collisions within uncertainties
- results put constraints to hadronization models that fail to describe the p_T dependence

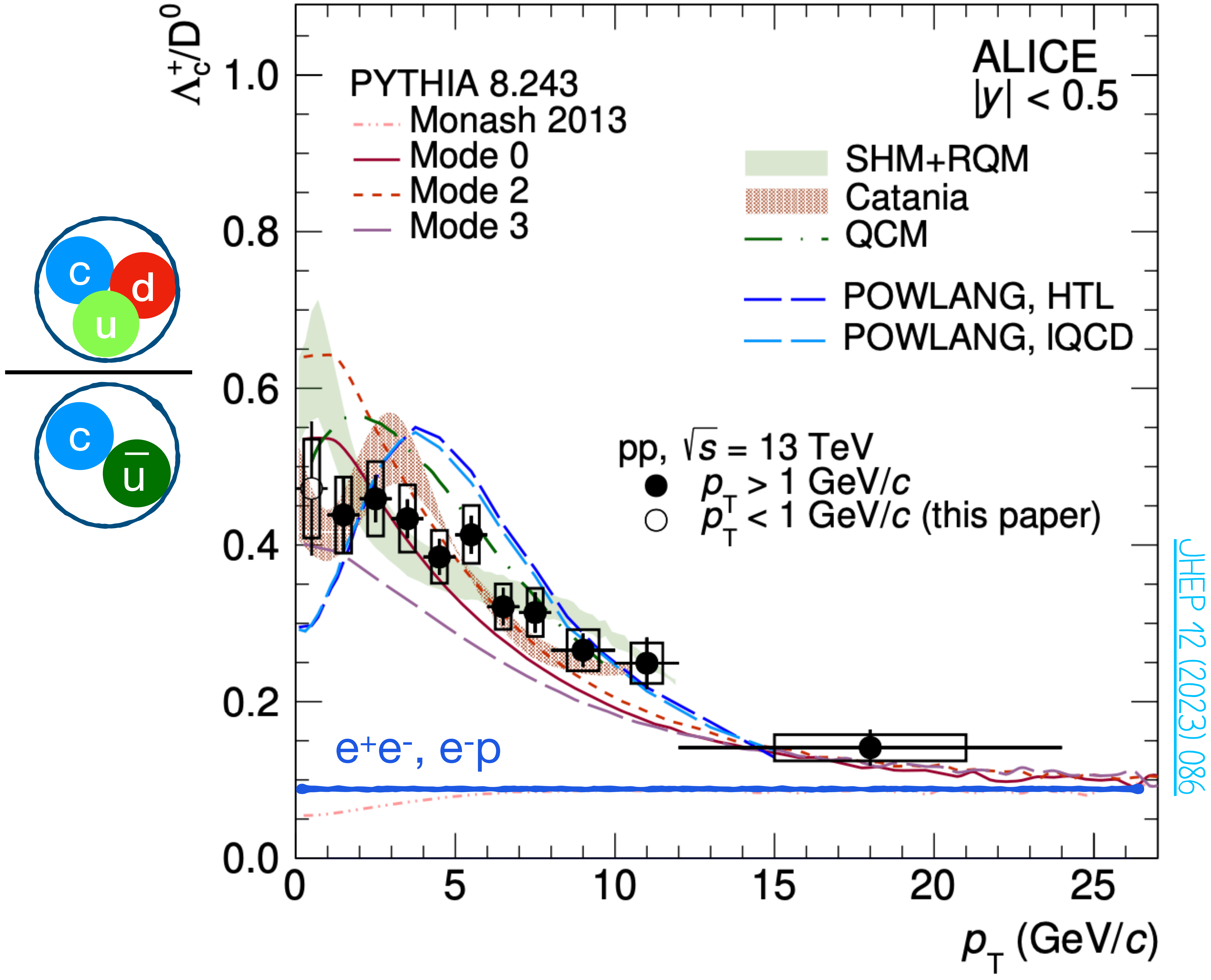
HADRONIZATION: BARYON VS. MESON

Run 2 results

- baryon-to-meson ratio is sensitive hadronization mechanisms



See M. Karwowska's talk Thu afternoon



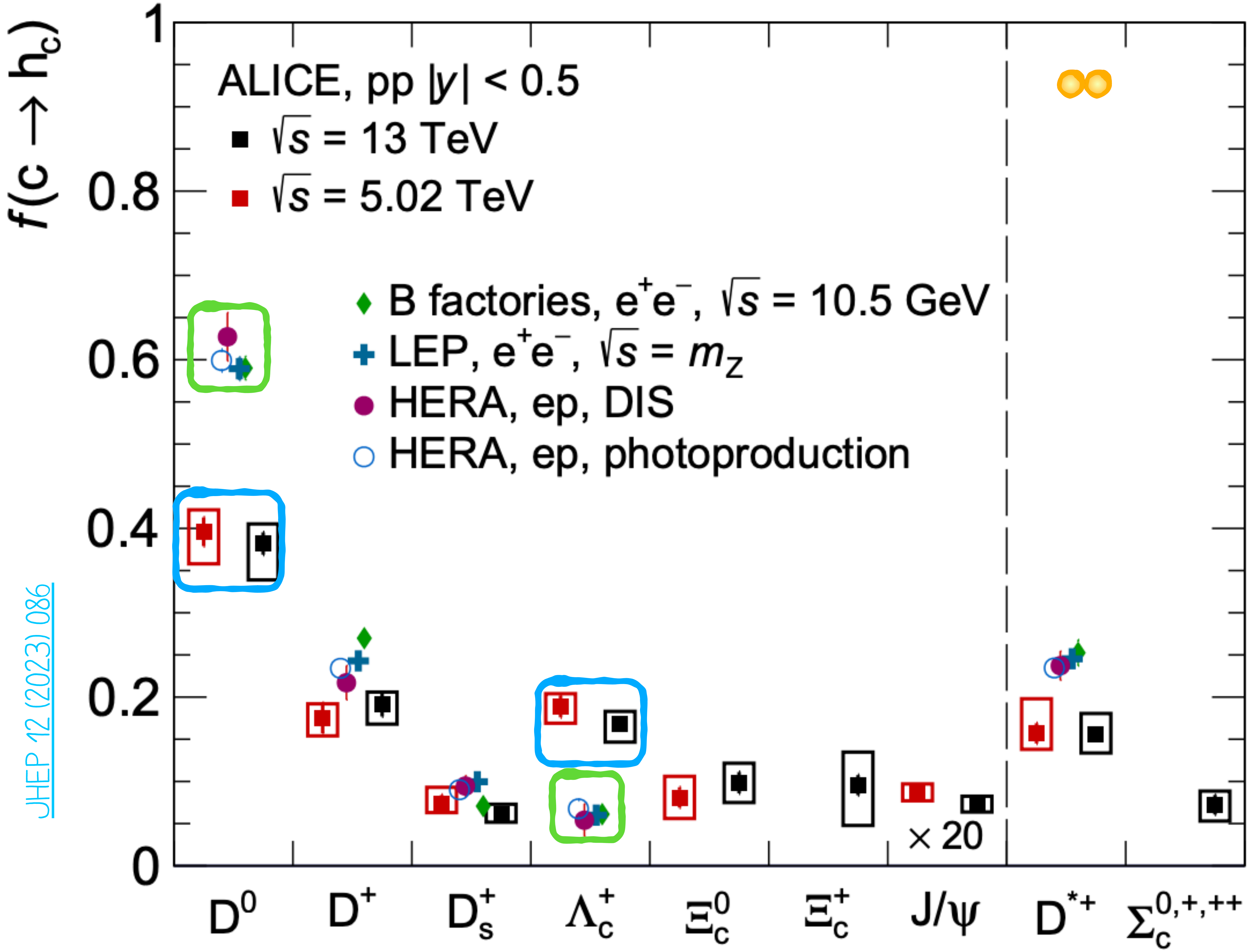
Sensitive larger Λ^+/D_0 in pp than in e^+e^- collisions

- baryon enhancement/modified fragmentation functions?

CHARM FRAGMENTATION FRACTION

Run 2 results

Charm-quark fragmentation fractions obtained from measurements of charm-hadron production cross sections



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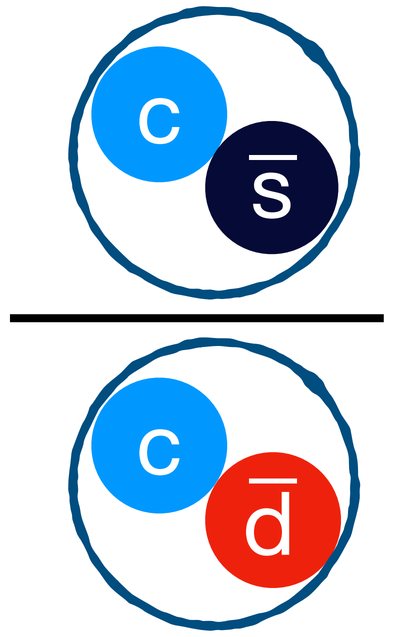
- no significant √s dependence
- clear dependence on collision system:
  - $f(c \rightarrow \Lambda_c)$ in pp larger than e^+e^-, e^-p by ×~ 3
  - $f(c \rightarrow D^0)$ in pp lower than e^+e^-, e^-p by ×~ 1.5

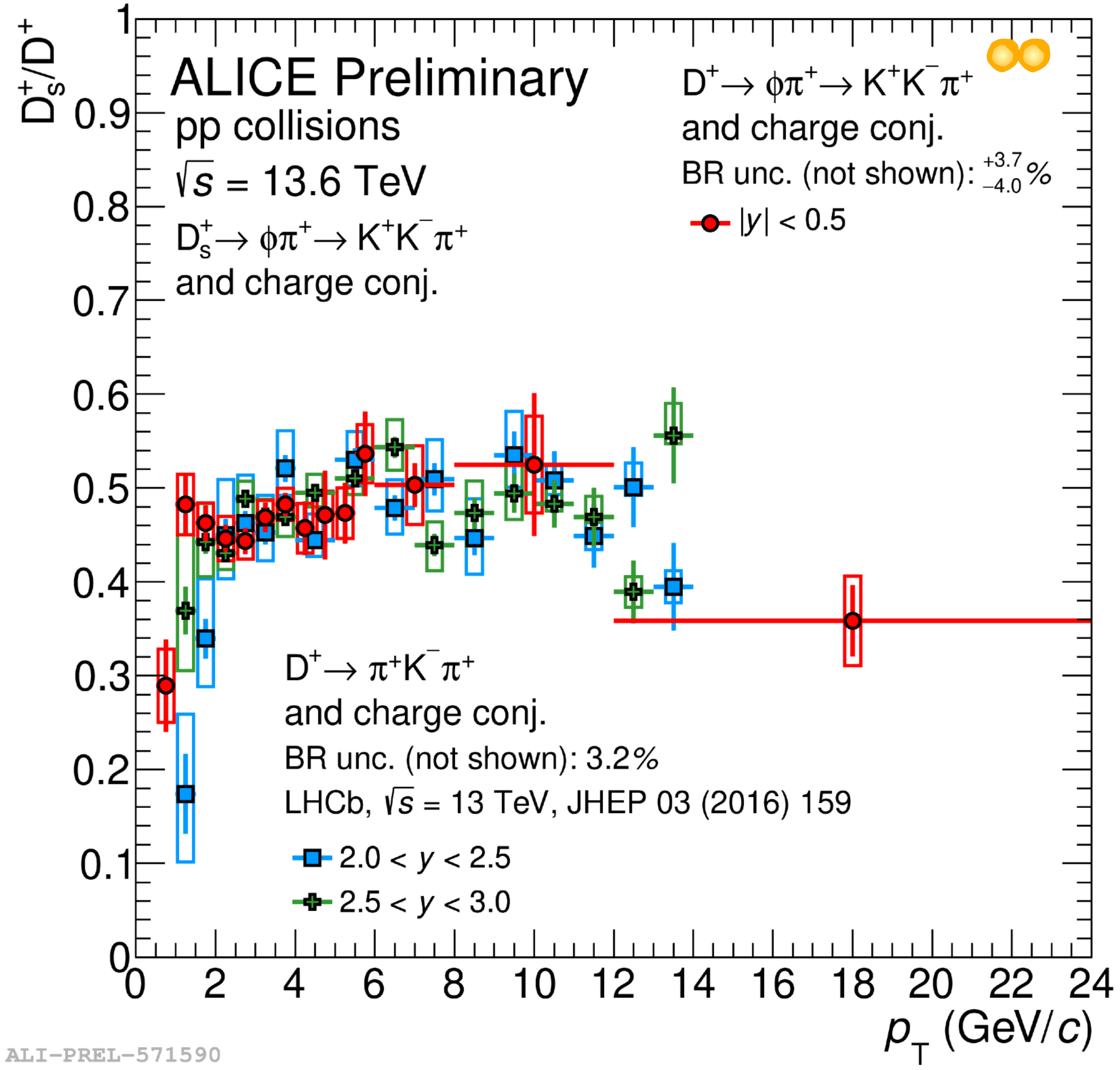
- baryon enhancement at the LHC caused by different hadronisation at play in the parton-rich environment produced in pp collisions

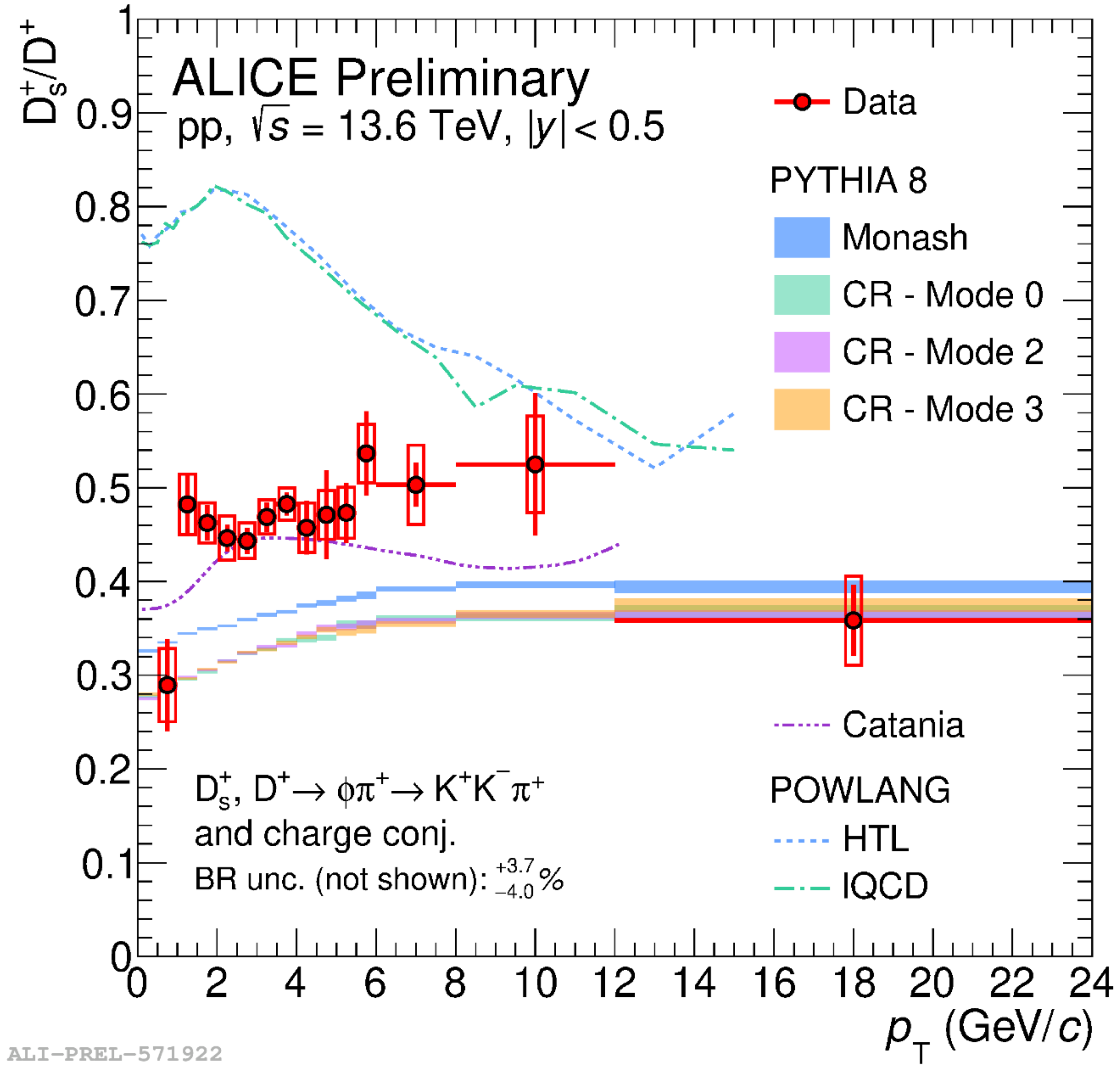
STRANGE AND CHARM MESONS

Run 3 results

First measurement of prompt D_s^+/D^+ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV s



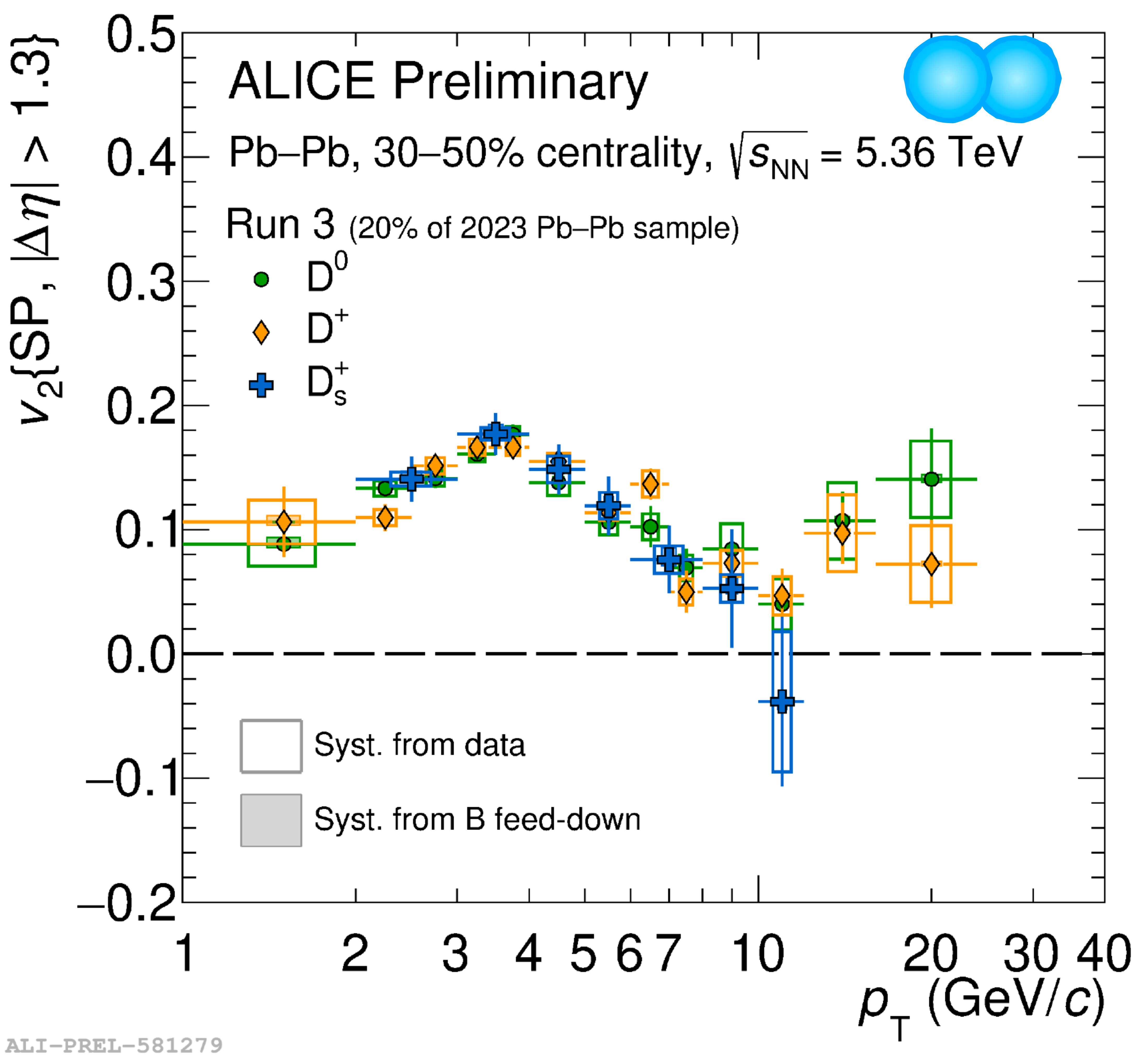




- measurements put constraints on existing models
- improved measurement granularity and p_T reach with Run 3 data

FLOW OF D MESONS

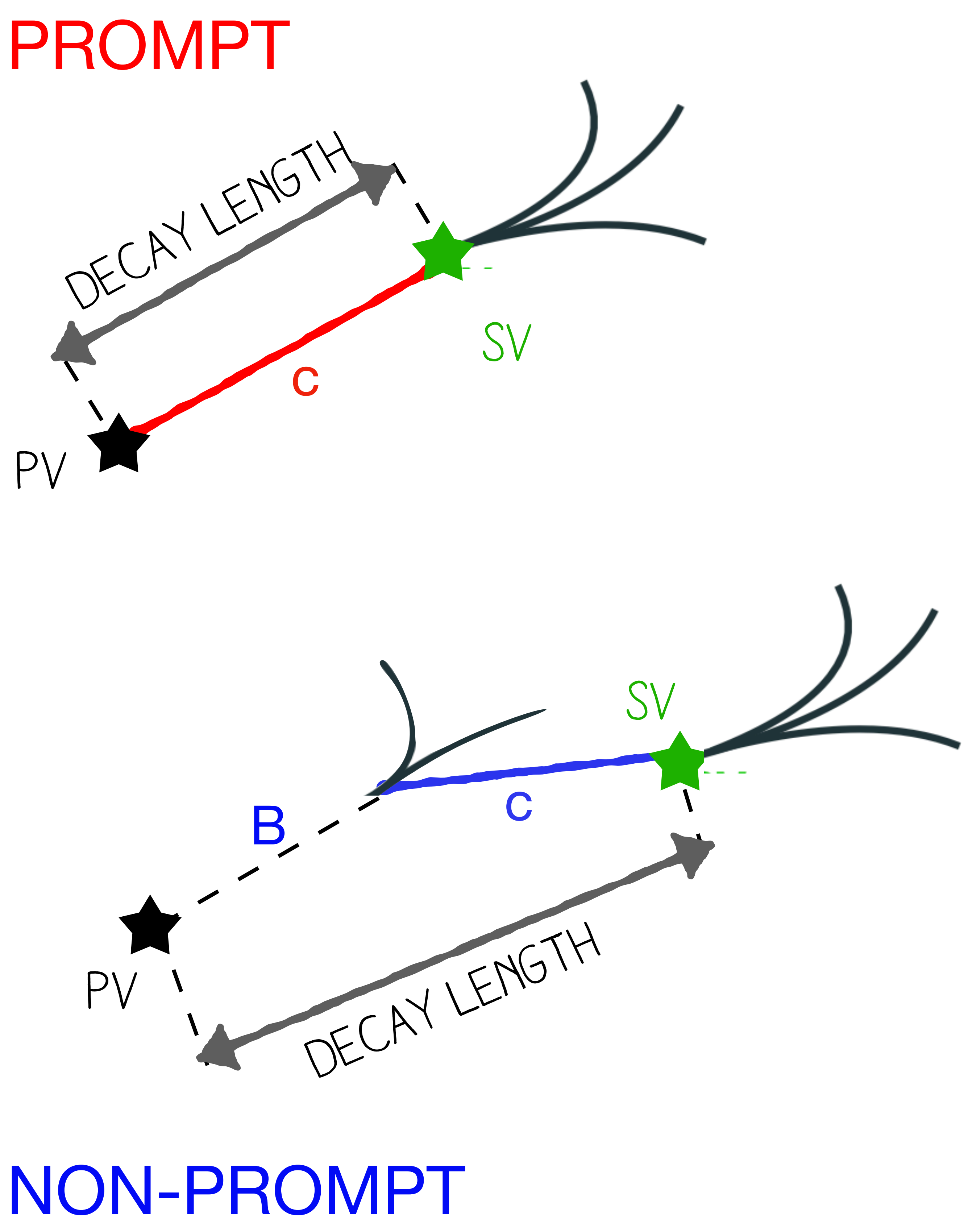
Run 3 results



➧ charm quarks participate in collective motion of the system

FLOW OF D MESONS

Run 3 results



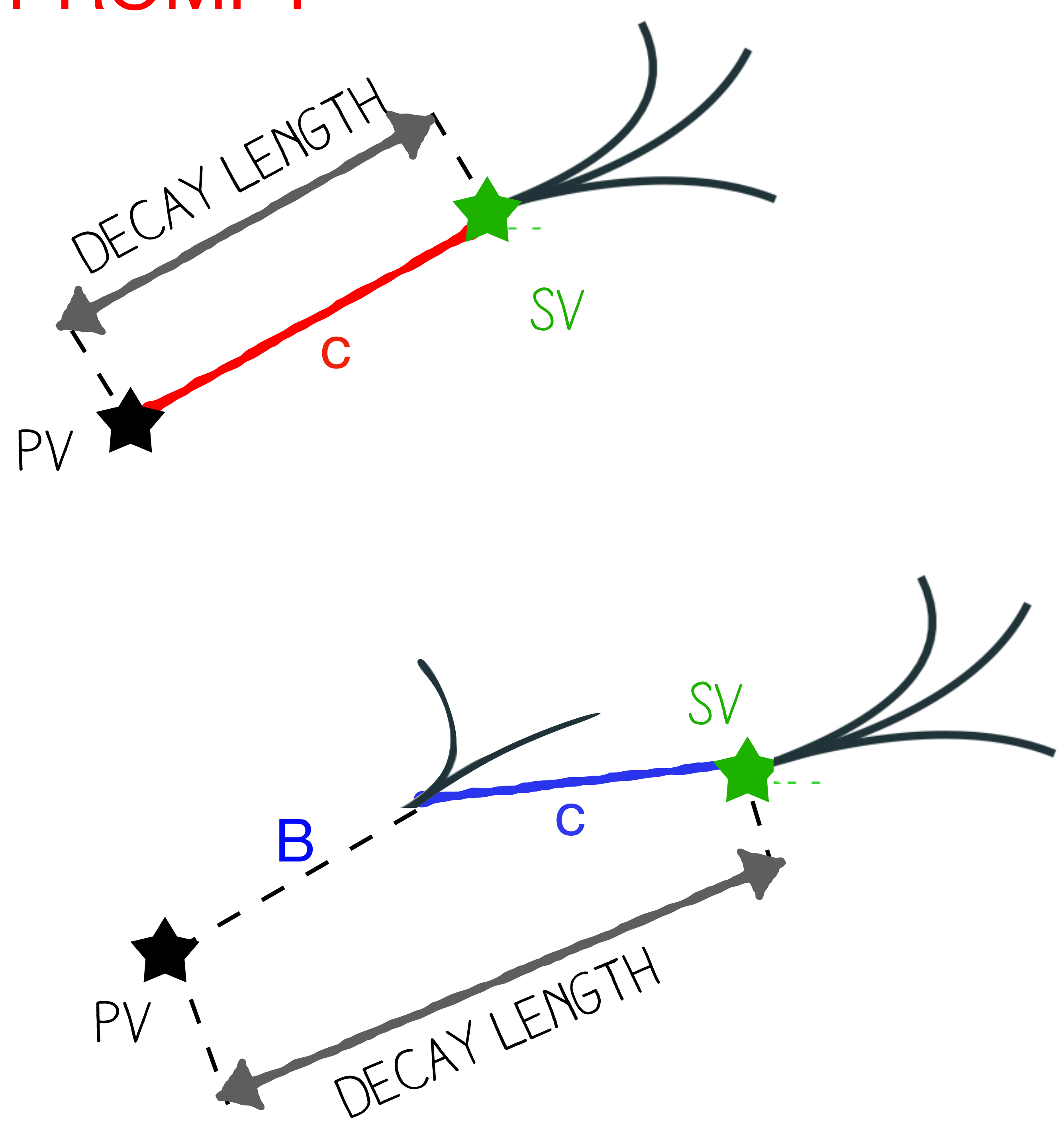
- charm quarks participate in collective motion of the system

FLOW OF D MESONS

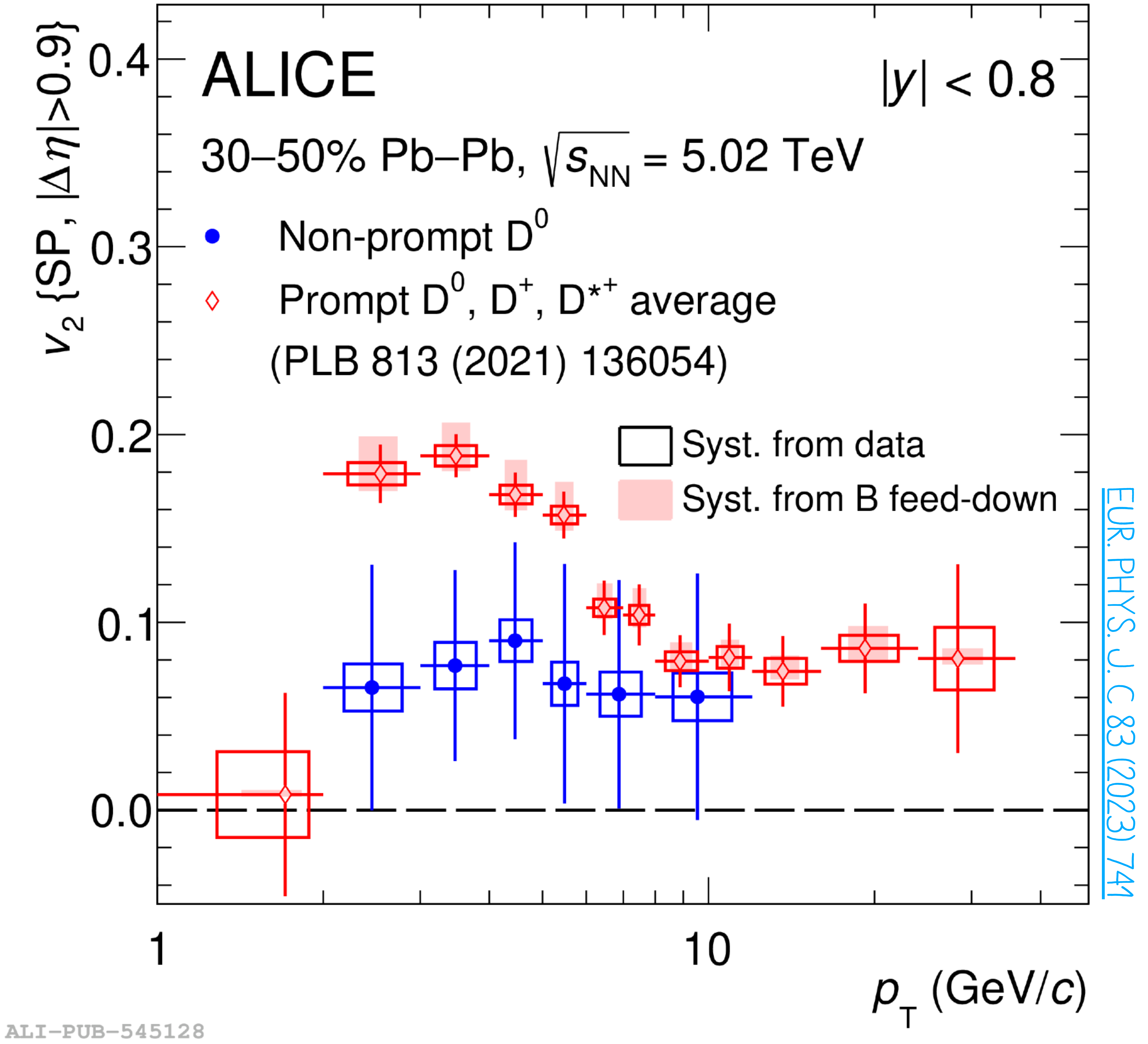
Run 3 results

Run 2 results

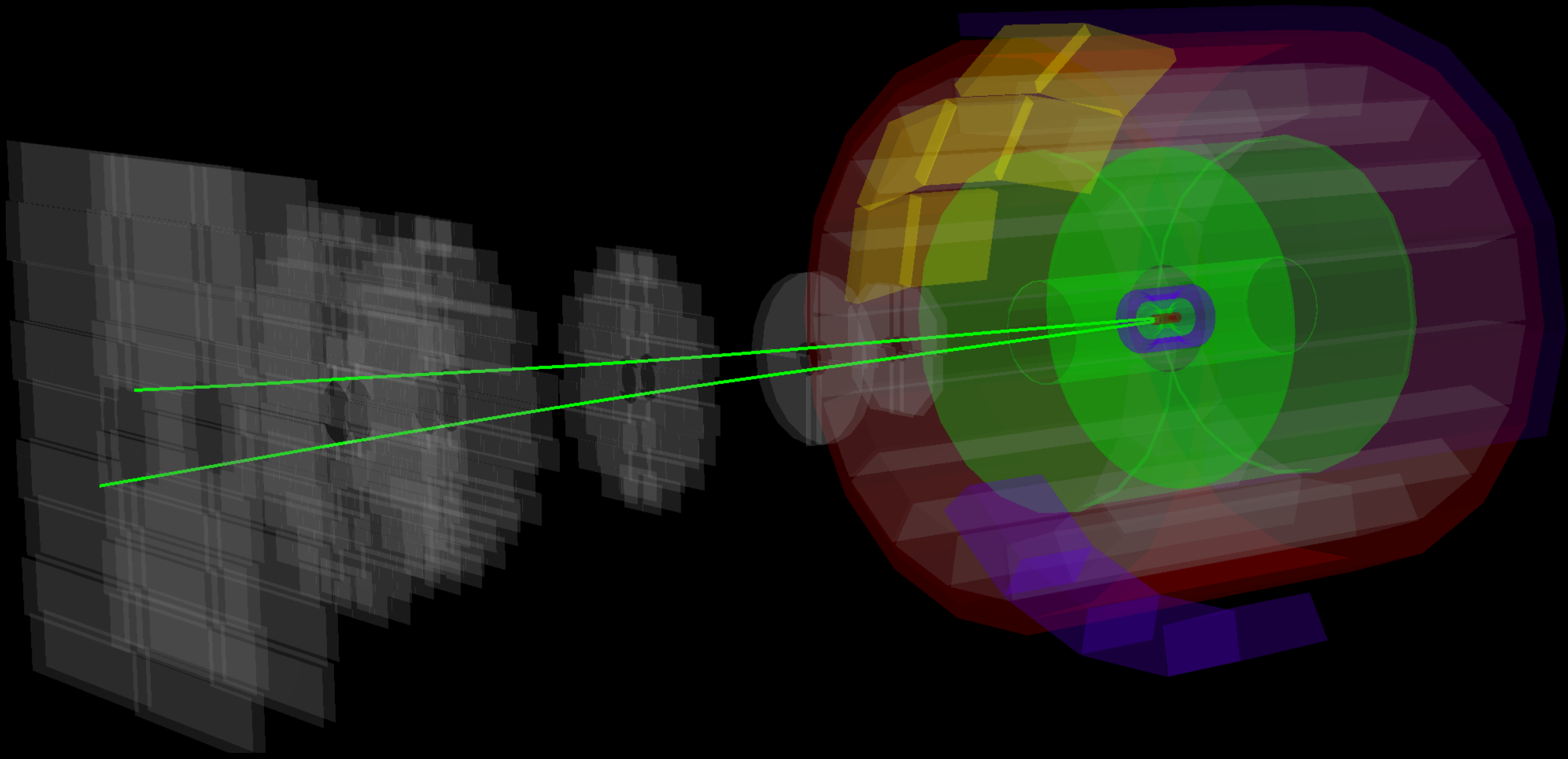
PROMPT



NON-PROMPT

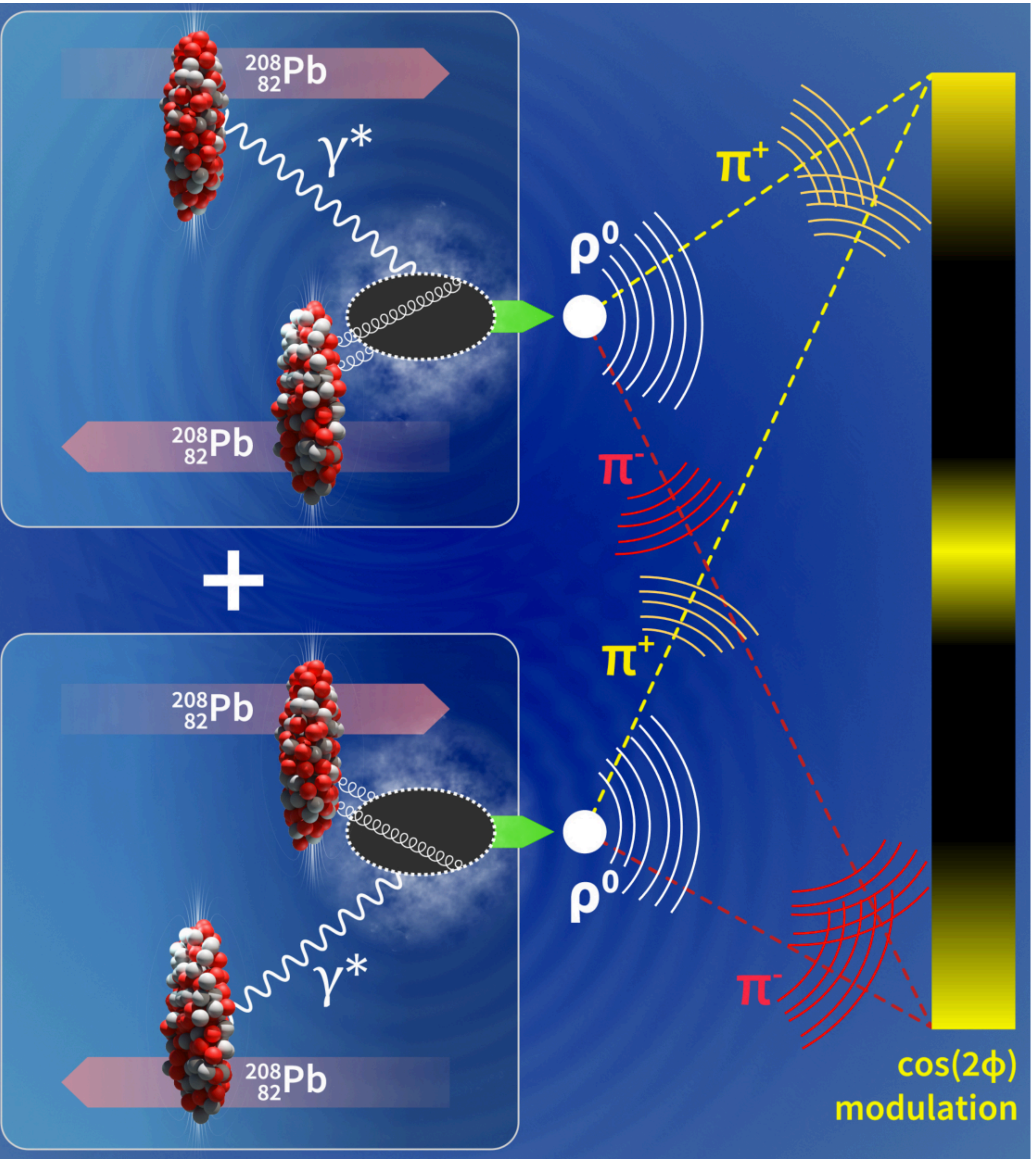


- charm quarks participate in collective motion of the system
- hint of quark flavour dependent flow



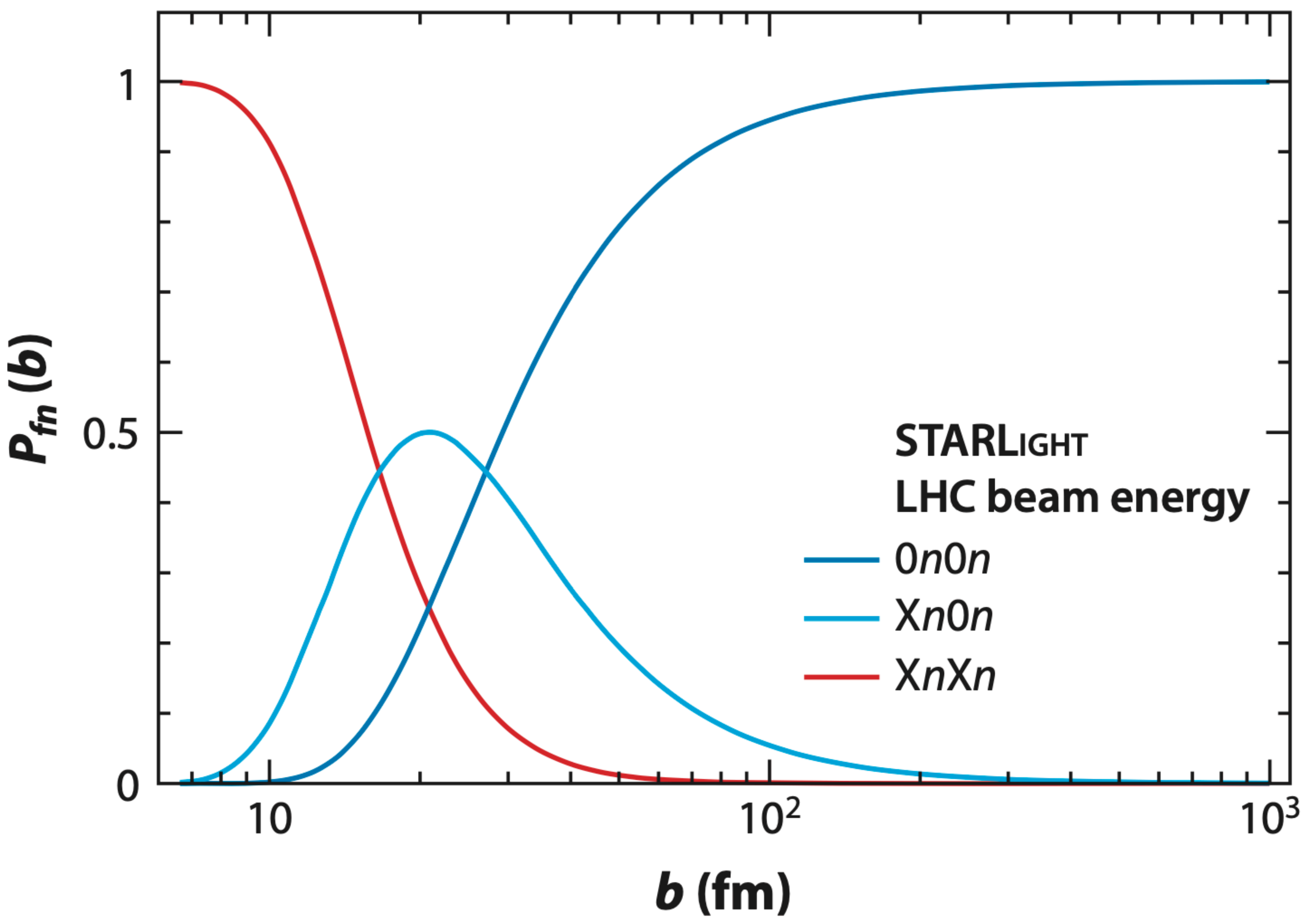
ULTRA-PERIPHERAL COLLISIONS

DOUBLE-SLIT ON FEMTOMETER SCALE



Vector meson (VM) photoproduction in UPC

- indistinguishable which of the interacting nuclei emits the photon and which emits the 2 gluons that goes in the neutral rho vector meson (ρ_0)
- the interference term gives rise to a cos(2ϕ) modulation in ρ_0 yield
- the strength of the modulation is expected to increase with decreasing impact parameter, estimated through neutron emission exploiting the ALICE ZDCs

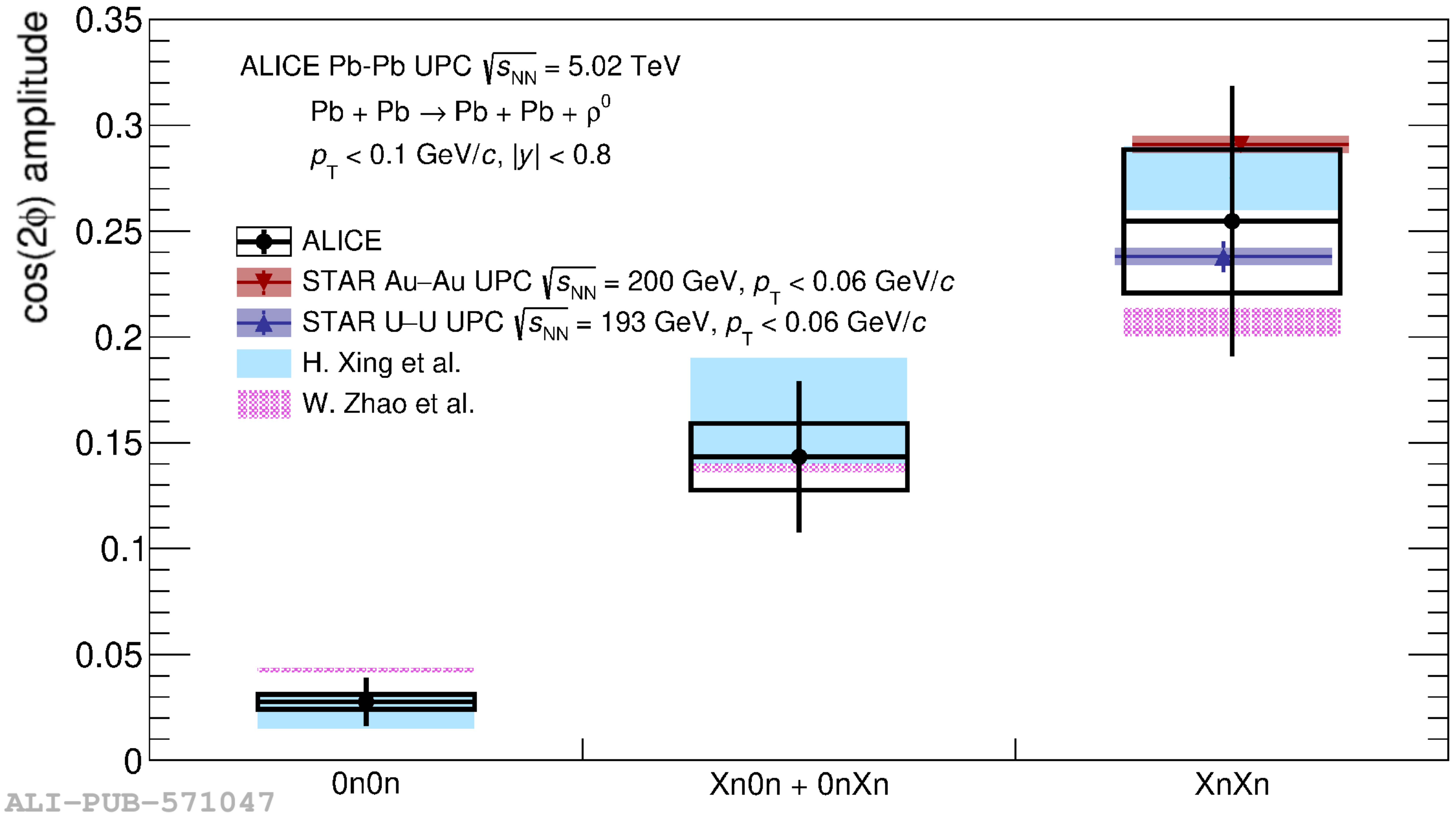


Ann. Rev. Nucl. Part. Sci. 70 (2020) 323

AZIMUTHAL ANISOTROPY IN VECTOR MESON PHOTO PRODUCTION

Run 2 results

First measurement of the impact-parameter dependent anisotropy in the decay of coherently photoproduced ρ_0



<b> ~ 49 fm <b> ~ 22.5 fm <b> ~ 18 fm

- the anisotropy comes from linearly polarized photons and quantum interference
- the modulation increases with decreasing impact parameter
- disentangle between different model predictions will be available with Run 3 data huge statistics

ARXIV 2405.14525

SUMMARY AND OUTLOOK

◗ large number of results from ALICE covering different areas: from medium characterization, to collectivity in small systems, hadronization mechanisms, up to fundamental interactions relevant for other fields of study (and many more results!!)

◗ Run 3 will broaden in an unprecedented way the precision of ALICE studies, allowing for more differential results as well as opening the field to new measurements

FUTURE ◗ In preparation for Run 4: new ITS3 ultra-light fully cylindrical tracking layers and a forward calorimeter

(FURTHER) FUTURE ◗ ALICE3 new designed experiment for Run5 and 6, compact silicon tracker with high-resolution vertex detector, widening the η coverage