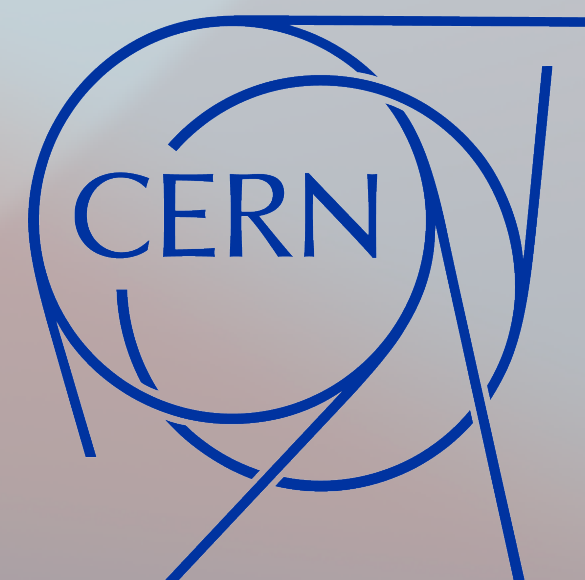




ALICE highlights

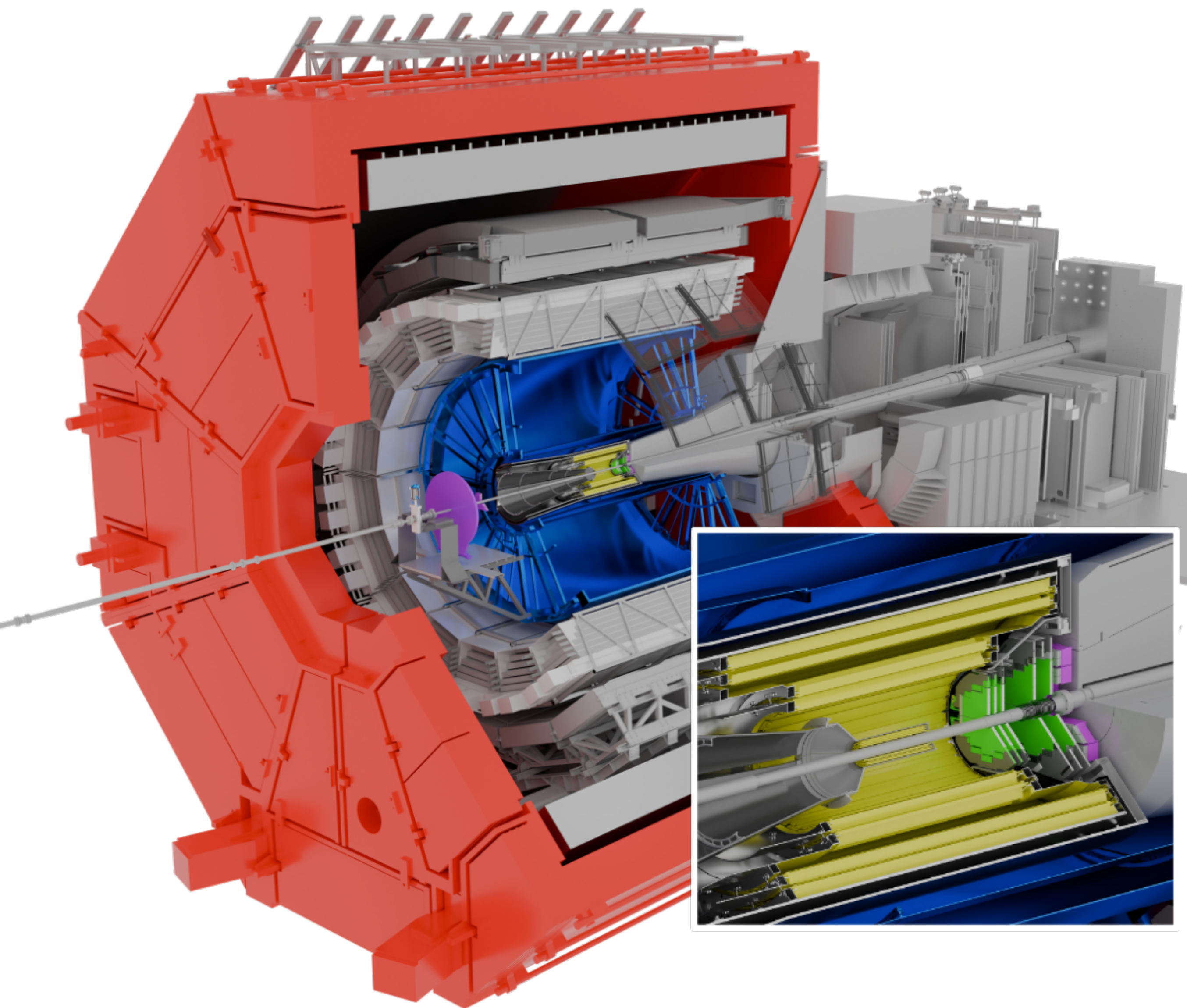
Maximiliano Puccio (CERN) on behalf the ALICE Collaboration

QCD@LHC 2026 - 2nd October 2026



The ALICE detector at the LHC

Detector sketches by D. Chinellato



Key characteristics:

- ➔ **PID with dE/dx and time of flight**
- ➔ **Global tracking** down to $p_T \sim 150$ MeV/c

Run 3 upgrades:

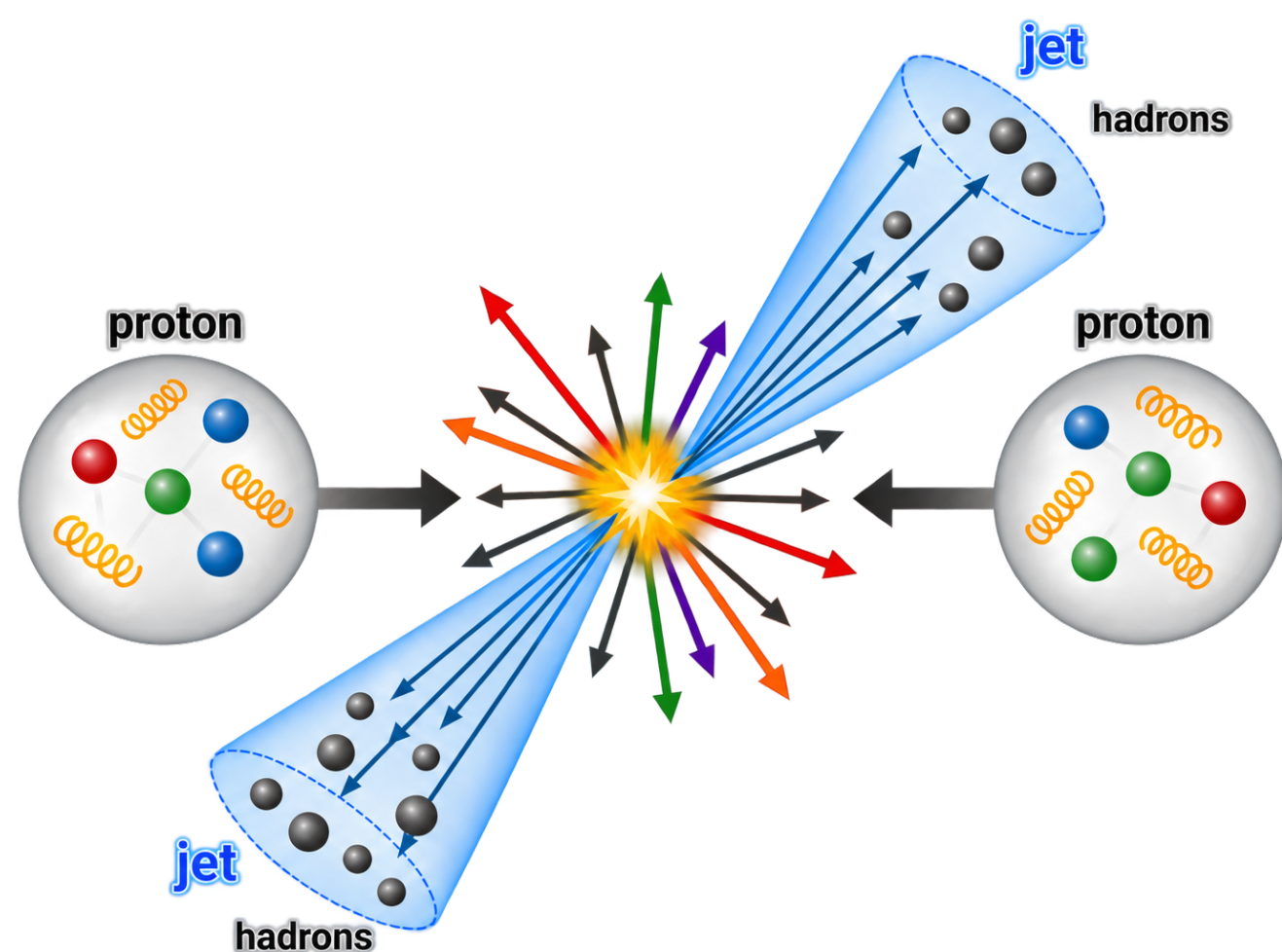
- ▶ **GEM-based TPC**: continuous readout
- ▶ **ITS2**: 35 μm pointing resolution at 1 GeV/c
- ▶ **MFT**: forward tracking and vertexing
- ▶ **FIT**: trigger and centrality estimation
- ▶ Integrated **Online-Offline compute** model

System	Luminosity in Run 3
Pb-Pb 5.36 TeV	6.9 nb ⁻¹ (collected) ~120x Run 1+2 total
pp 13.6 TeV	158.1 pb ⁻¹ inspected via software triggers ~1000x Run 1+2 total

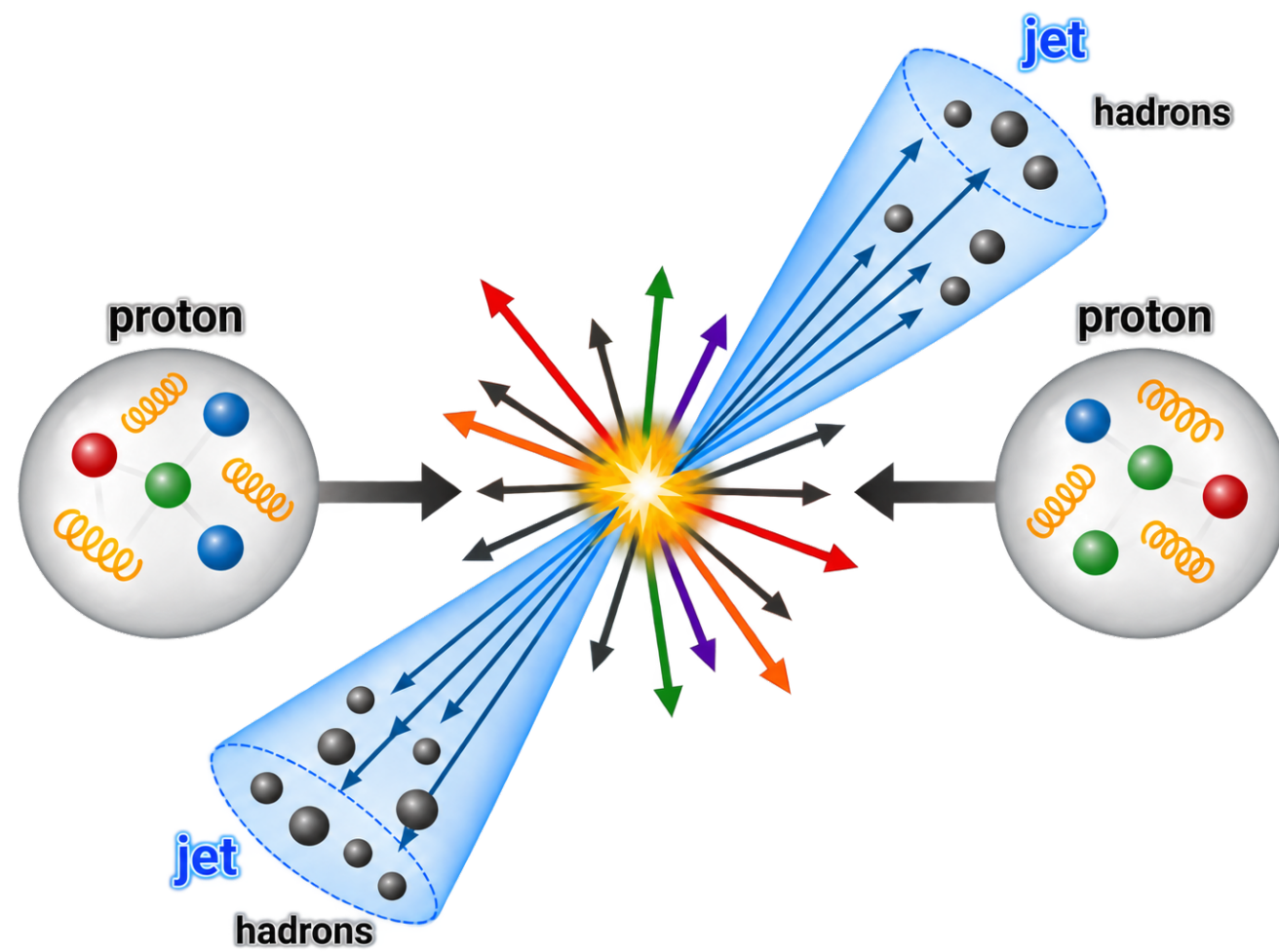
Extra: 5 nb⁻¹ OO, 0.8 nb⁻¹ Ne-Ne, 7.2 nb⁻¹ pO

Investigating QCD in different regimes with ALICE



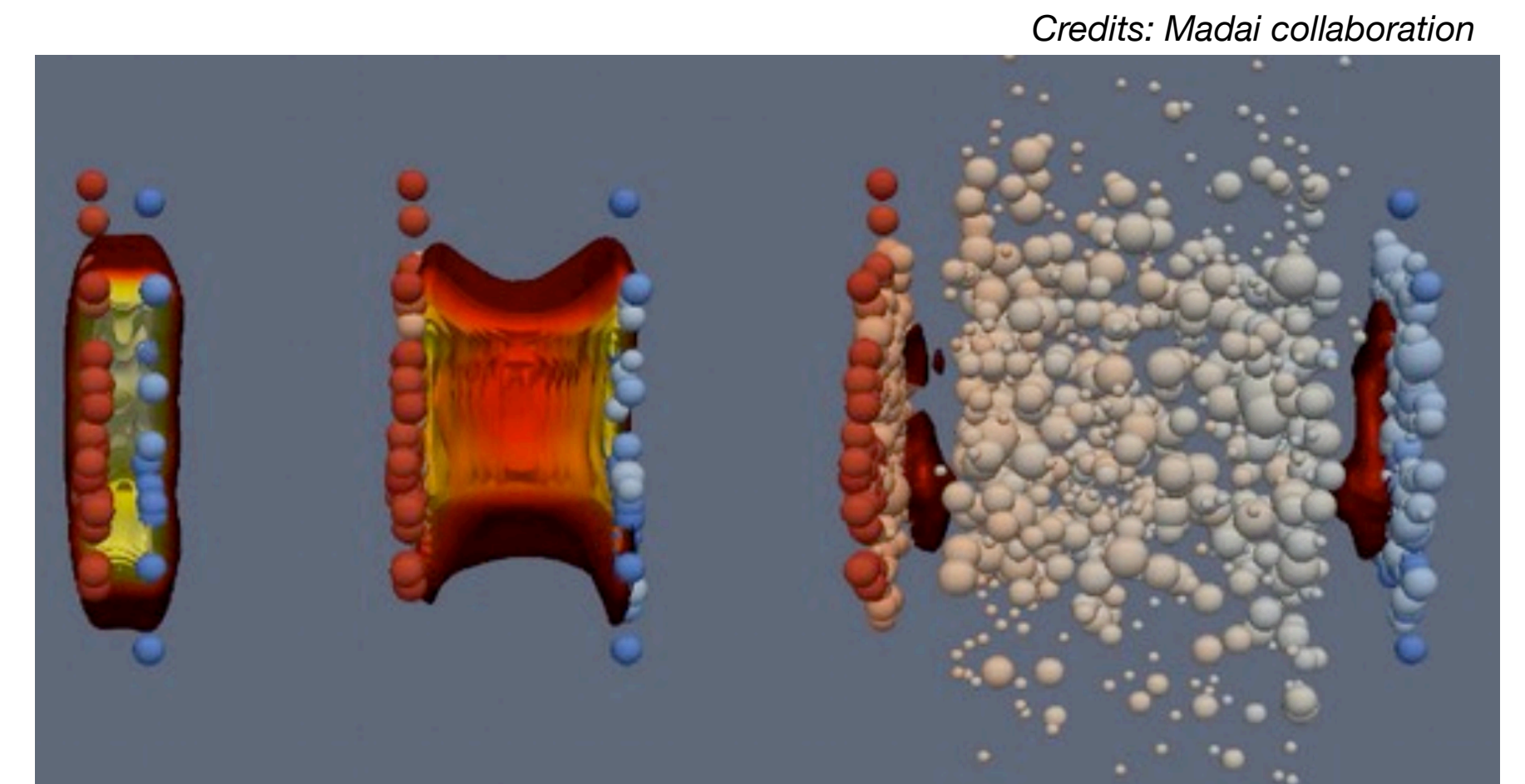


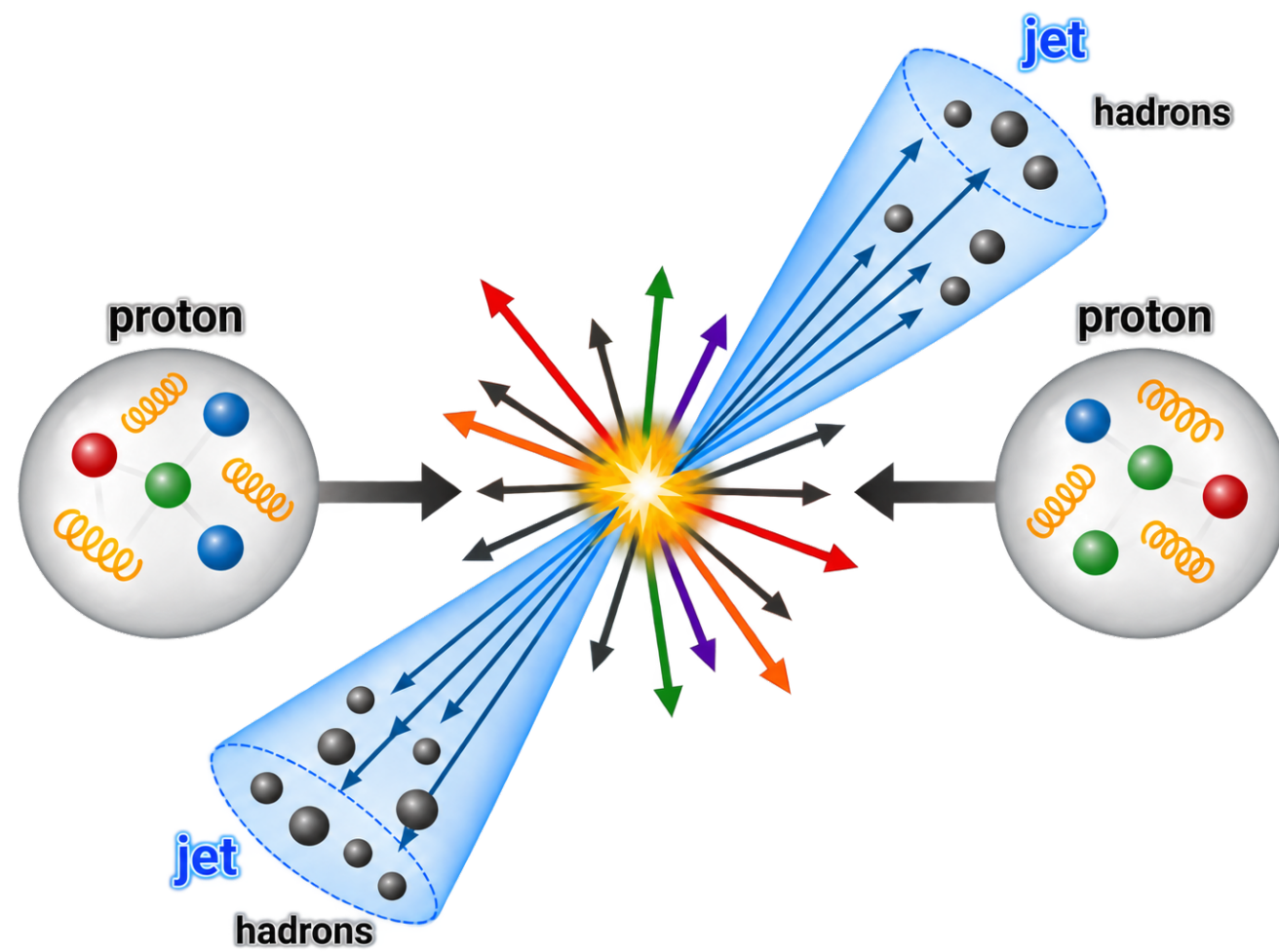
Partonic scale: jets and heavy flavour production



Partonic scale: jets and heavy flavour production

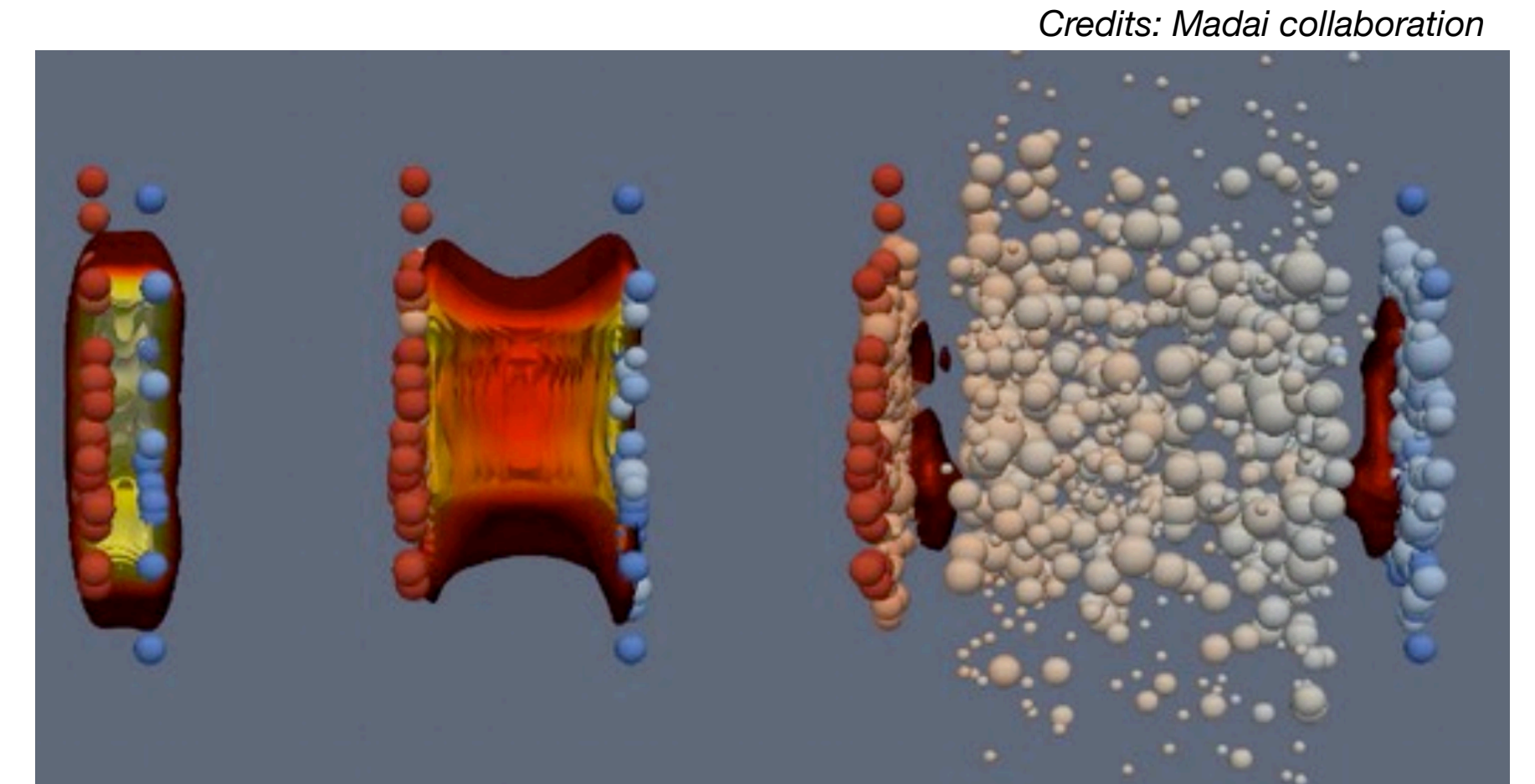
QCD matter dynamics at high temperature



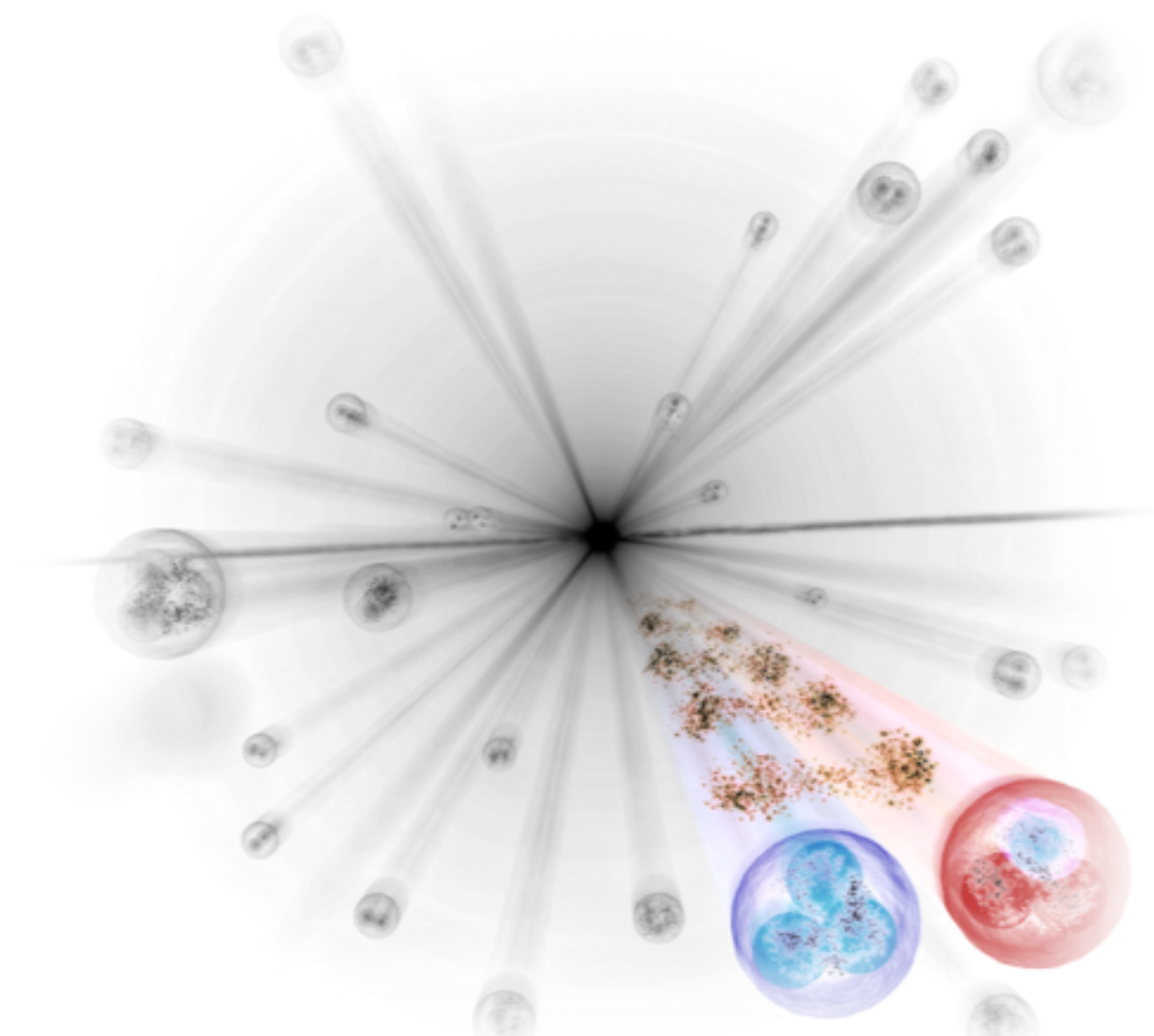


Partonic scale: jets and heavy flavour production

QCD matter dynamics at high temperature



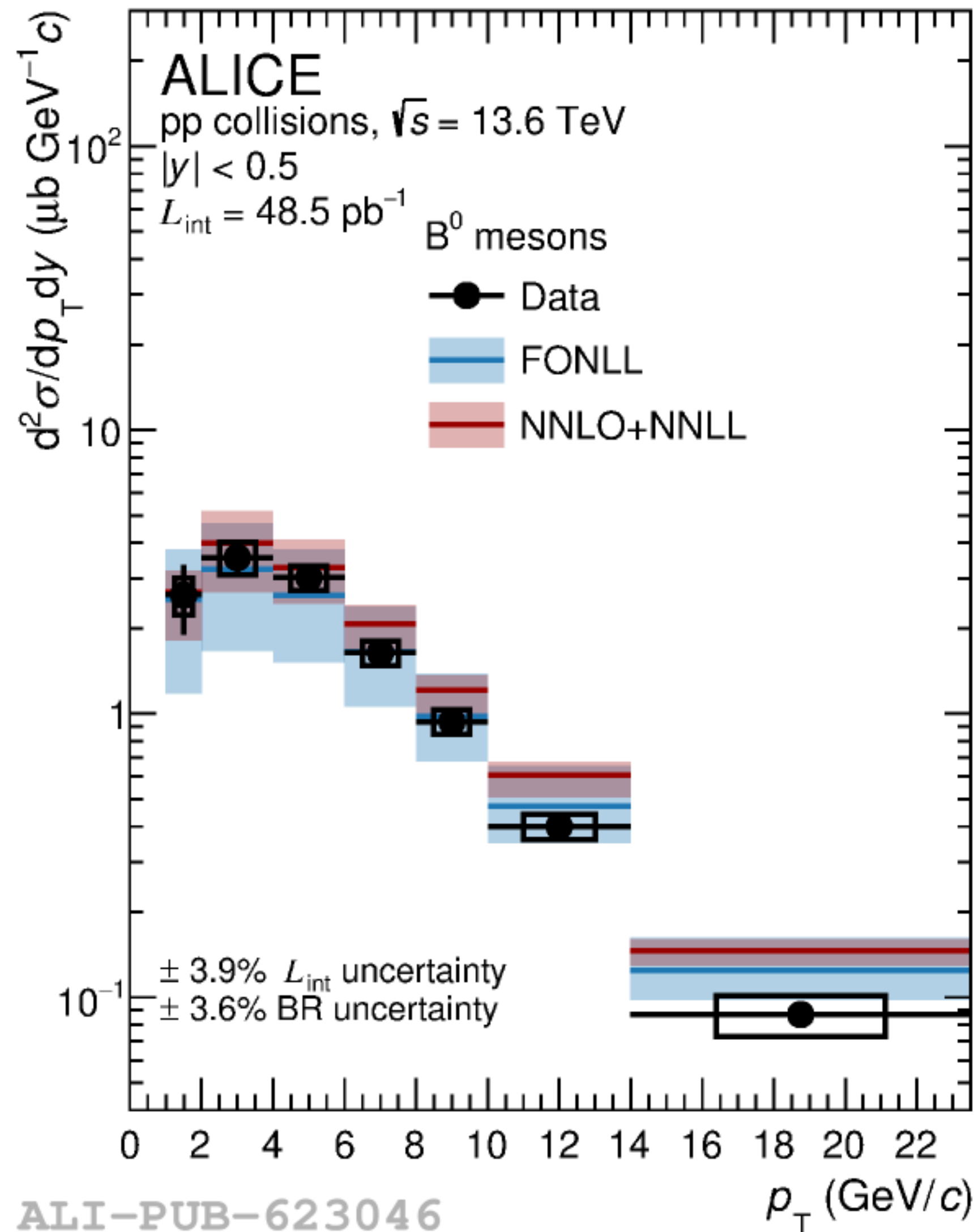
Hadronic scale: strong interactions between hadrons



Partonic scale: jets and heavy flavour production

B meson production in pp collisions

ALICE, arxiv:2603.18904

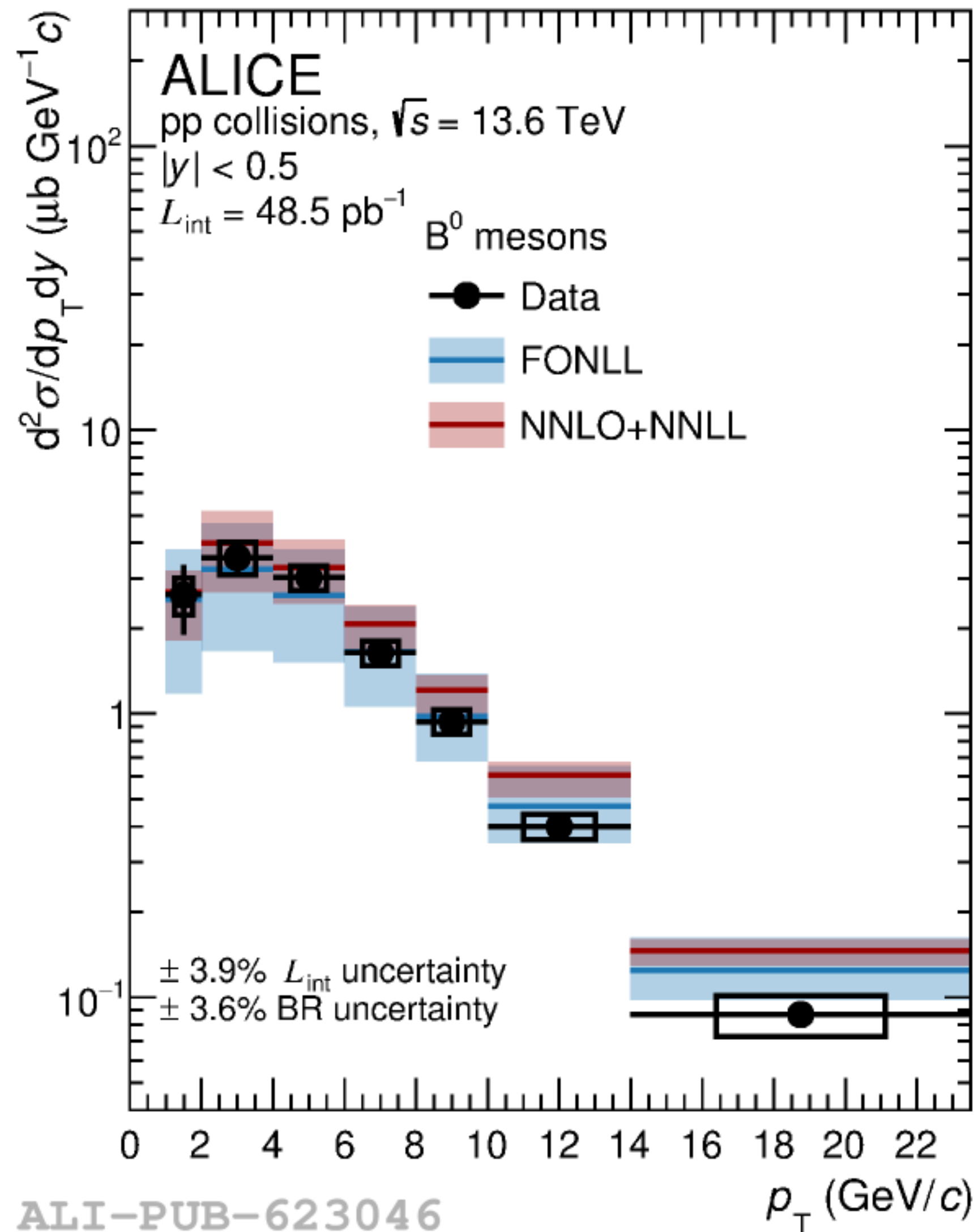


Measurements of open-beauty hadrons with ALICE in pp collisions using offline software triggers

- B^0 production cross sections measured down to low p_T at mid- y
- ▶ extension of kinematic region explored by CMS and LHCb

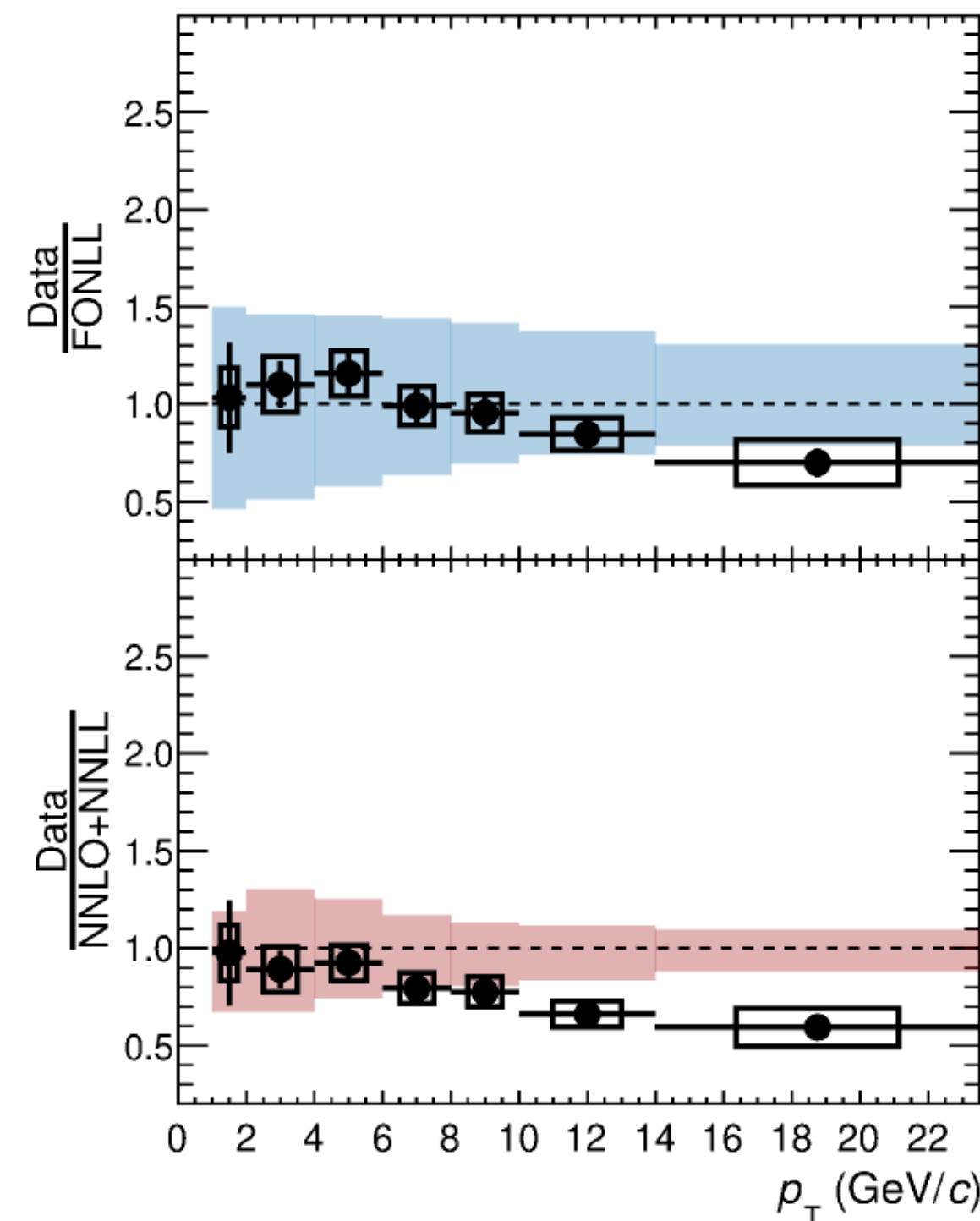
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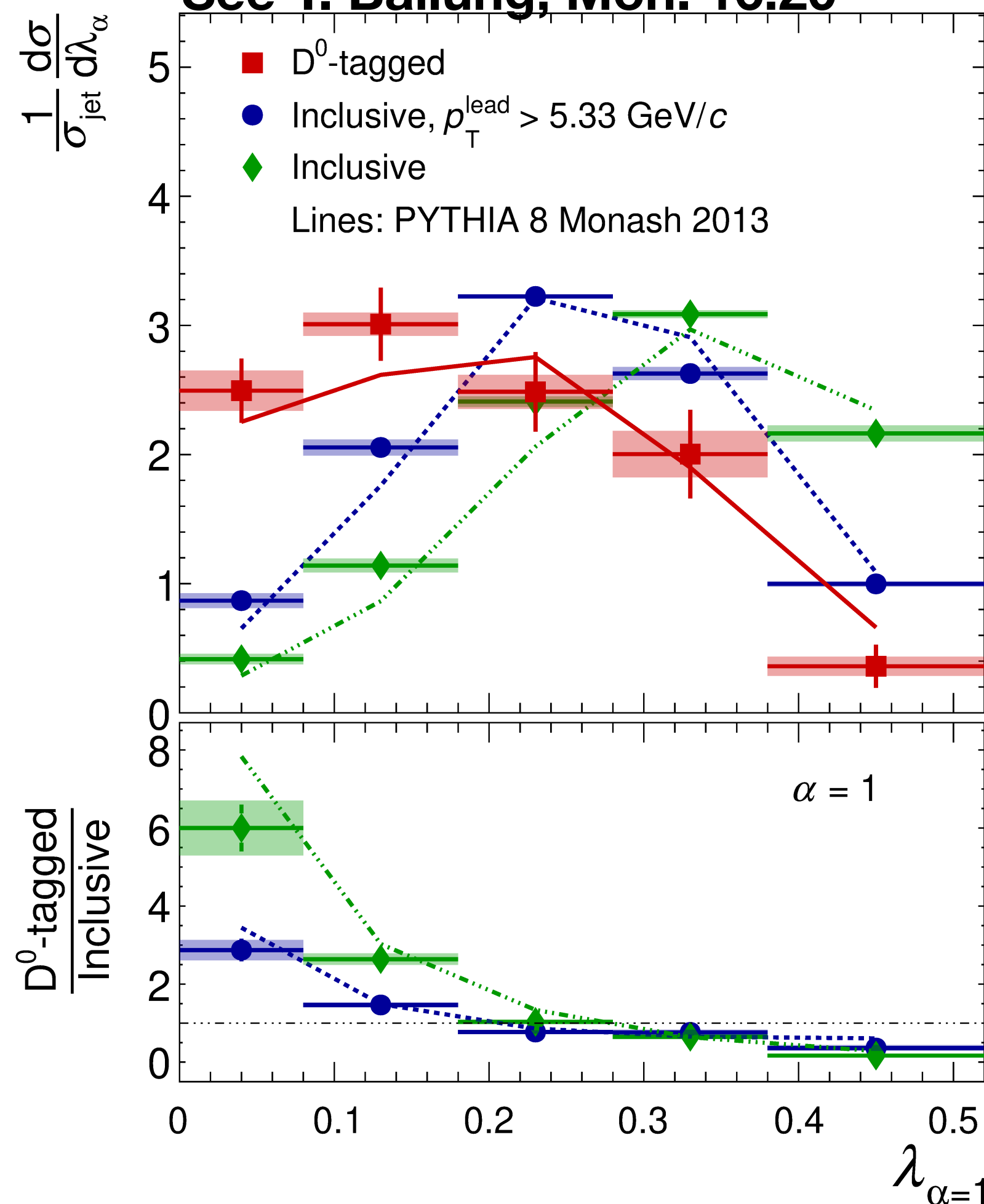


- ▶ Results overall compatible with FONLL and NNLO+NNLL predictions within uncertainties

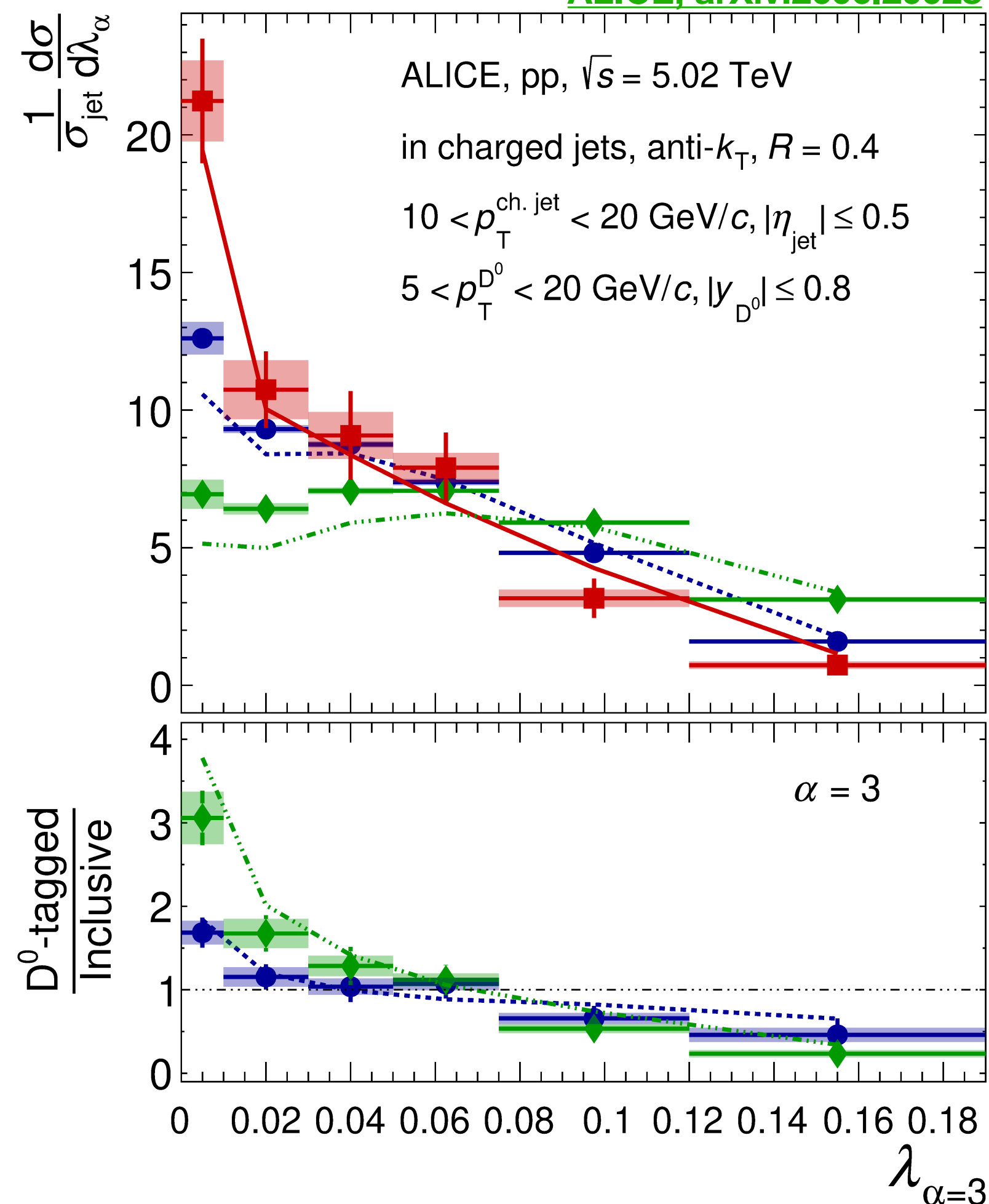
D meson tagged jets angularities

See Y. Bailung, Mon. 16:20

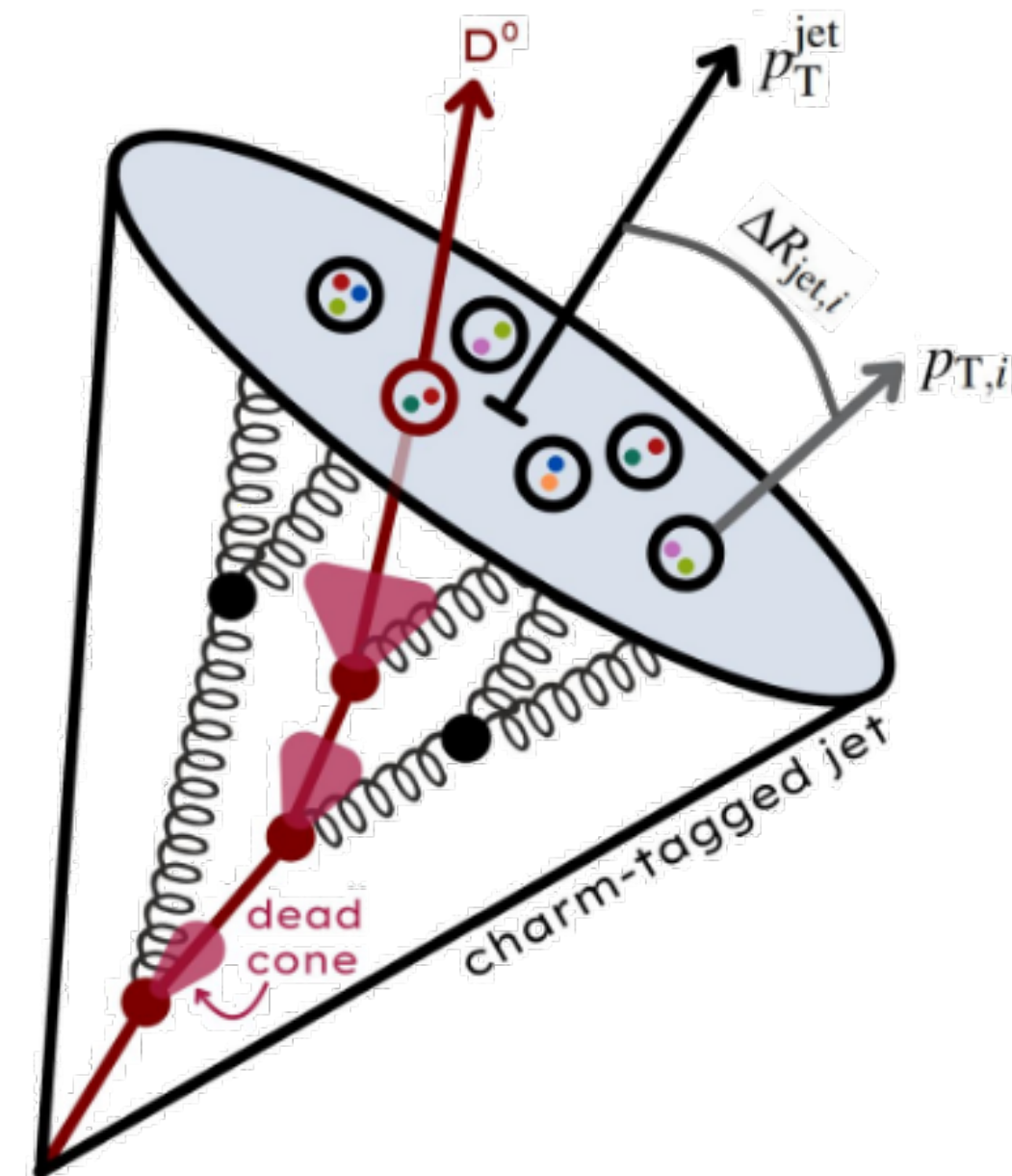
ALICE, arXiv:2606.20028



ALI-PUB-636124



ALI-PUB-636139



$$\lambda_\alpha = \sum_{i \in \text{jet}} \frac{p_{T,i}}{p_T^{\text{jet}}} \left(\frac{\Delta R_{i,\text{jet}}}{R} \right)^\alpha = \sum_{i \in \text{jet}} z_i \theta_i^\alpha$$

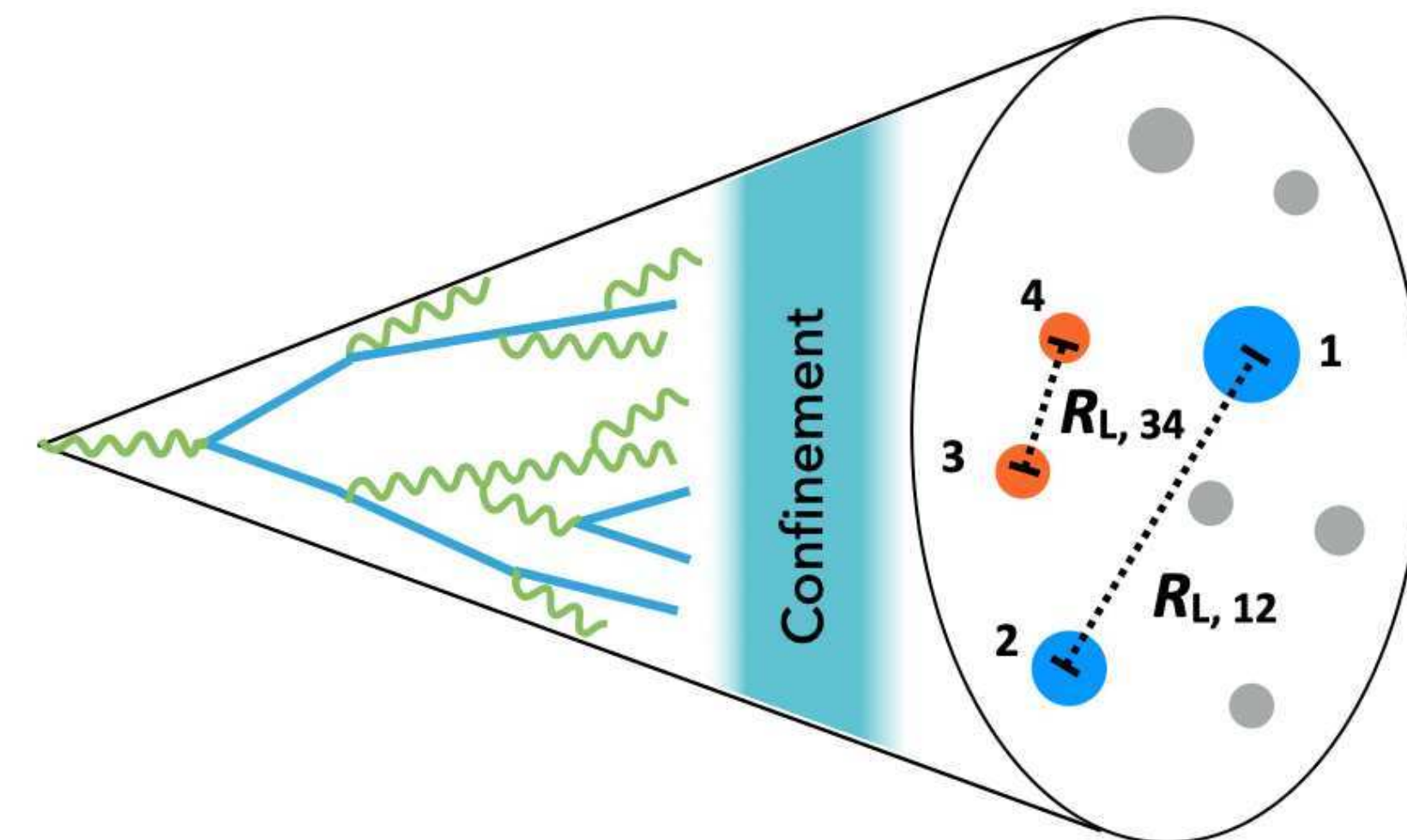
characterizes the **radial distribution of momentum within a jet**, with α controlling the relative sensitivity to collinear and wide-angle radiation.

- ▶ **$\alpha=1$** : focus on small $\theta_i \rightarrow$ strong sensitivity to **charm-mass / dead-cone effects** in the jet core.
- ▶ **$\alpha=3$** : focus on large $\theta_i \rightarrow$ charm-mass effects fade, while **quark-gluon colour-charge differences** dominate.
- ▶ Both effects are qualitatively reproduced by PYTHIA

Energy-Energy Correlators in pp, p-Pb, and Pb-Pb

$$\text{EEC}(R_L) = \frac{1}{N_{\text{jets}}} \sum_{\text{jets}} \sum_{i,j} \frac{p_{T,i} p_{T,j}}{p_{T,\text{jet}}^2} \delta(R_L - R_{L,ij})$$

EECs map the angular distribution of energy inside jets, probing their evolution from perturbative splittings to hadronization and medium modification.



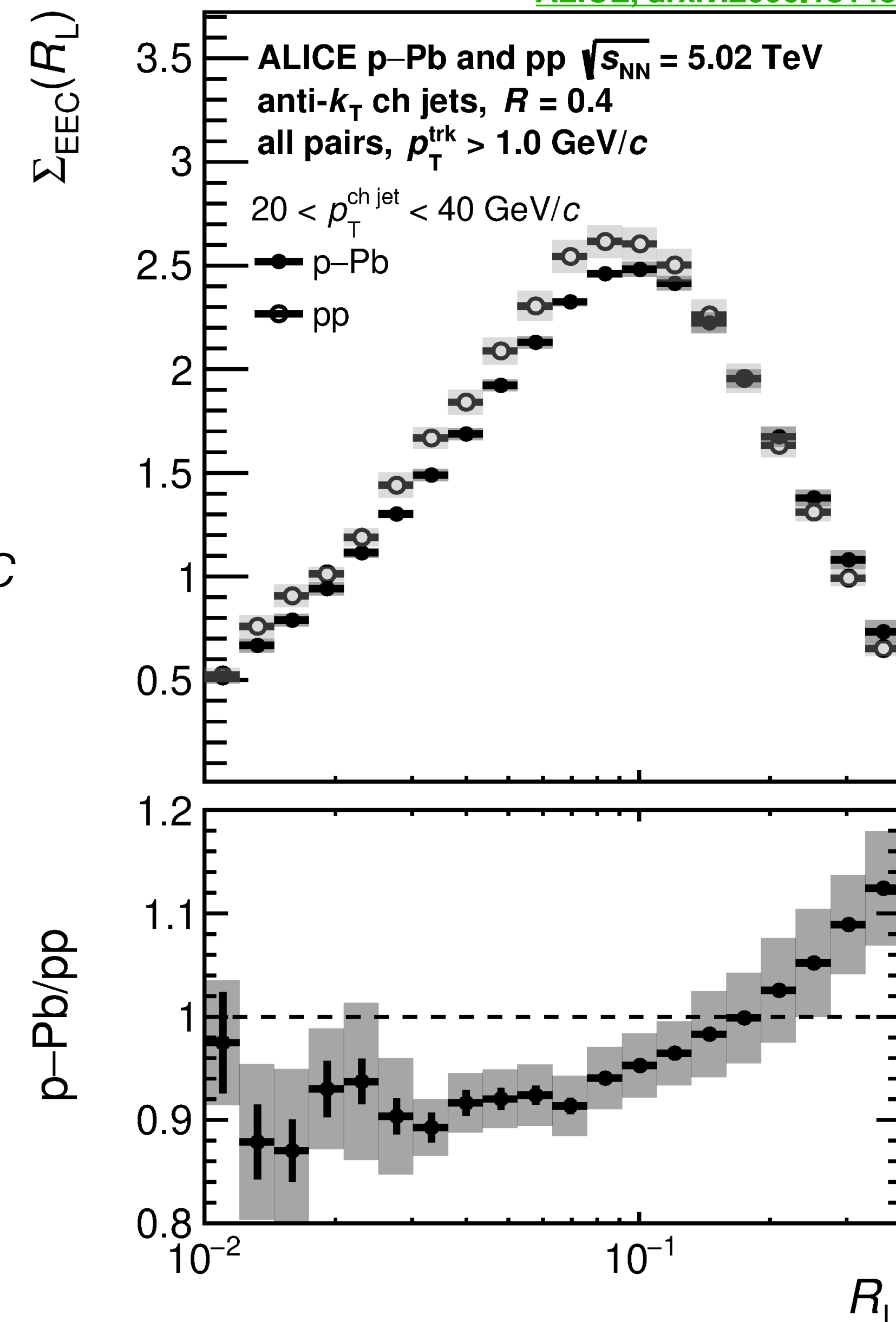
ALI-PUB-641856

Energy-Energy Correlators in pp, p-Pb, and Pb-Pb

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EECs map the angular distribution of energy inside jets, probing their evolution from perturbative splittings to hadronization and medium modification.

- ➔ Compared with pp, the EEC is modified in p-Pb at 20-40 GeV/c
 - shift toward larger angular scales → broadening of the jet energy flow?
- ➔ This establishes the p-Pb reference needed to disentangle nuclear effects from QGP-induced jet modification in Pb-Pb



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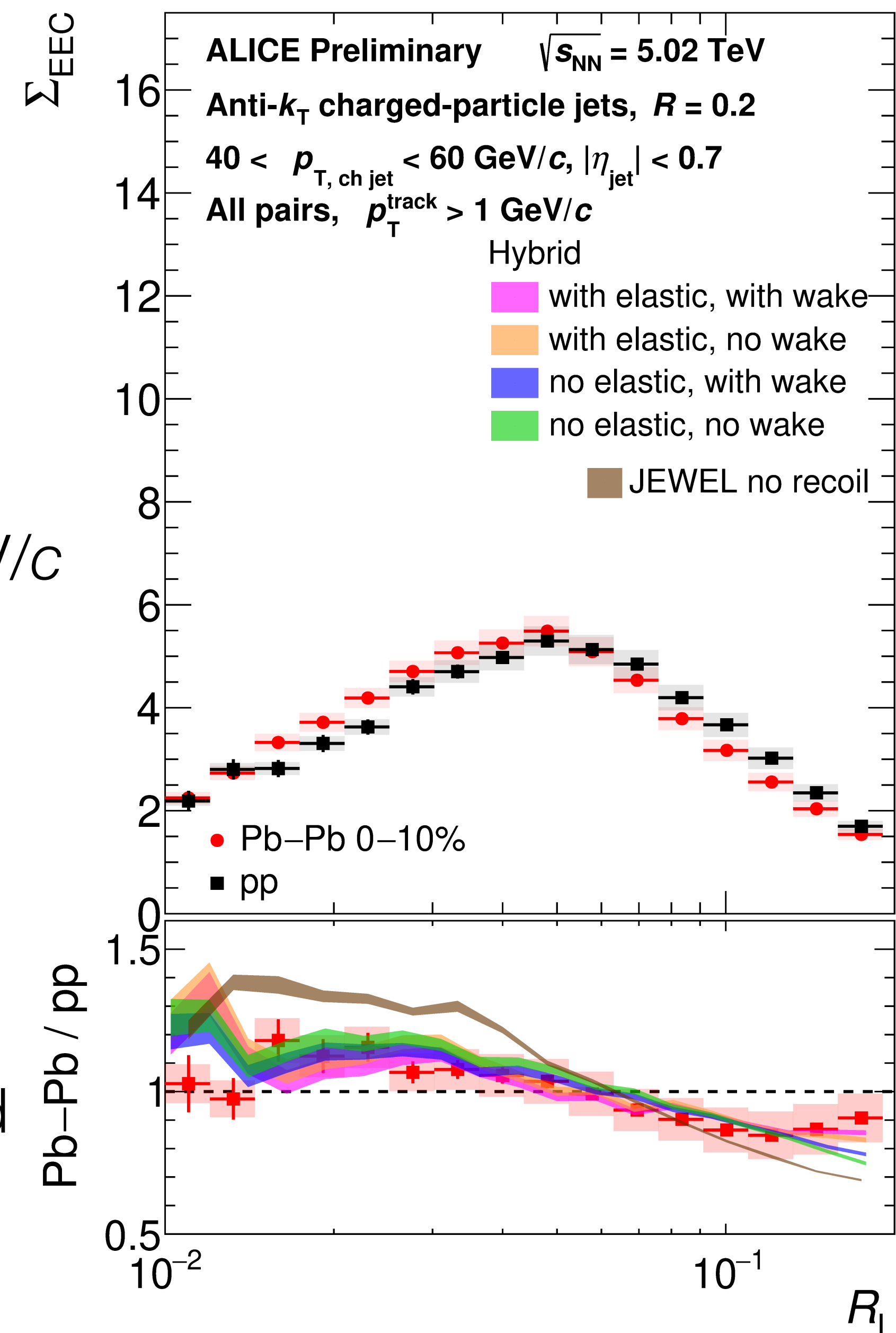
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Pb-Pb/pp shows a shift in the opposite direction

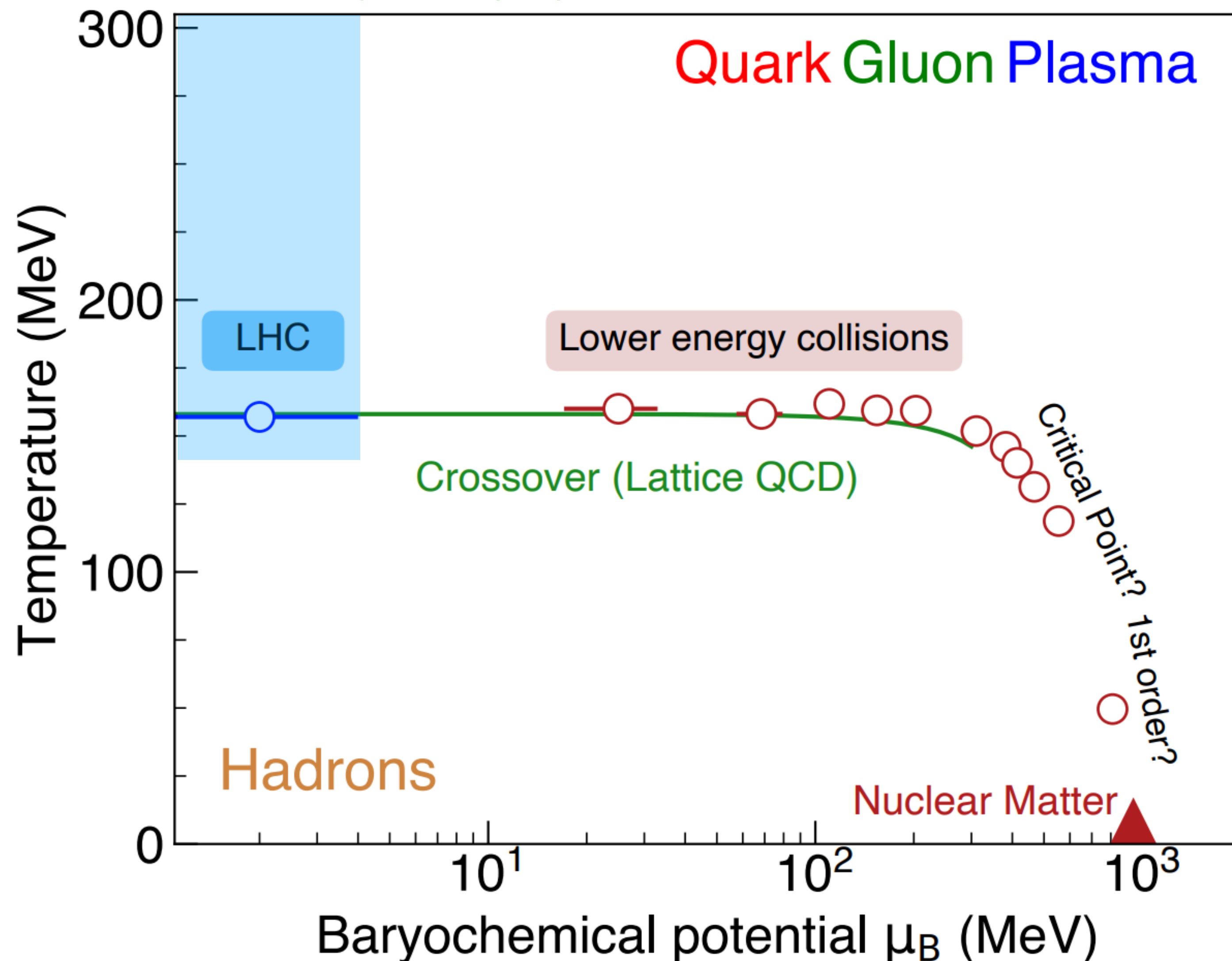
➔ **Not necessarily jet-focusing:** jet p_T selection biases toward initially higher-energy and more quark-like jets, both of which give narrower EECs.



QCD matter dynamics at high temperature

The LHC playground in the QCD phase diagram

ALICE, Eur. Phys. J. C 84 (2024) 813



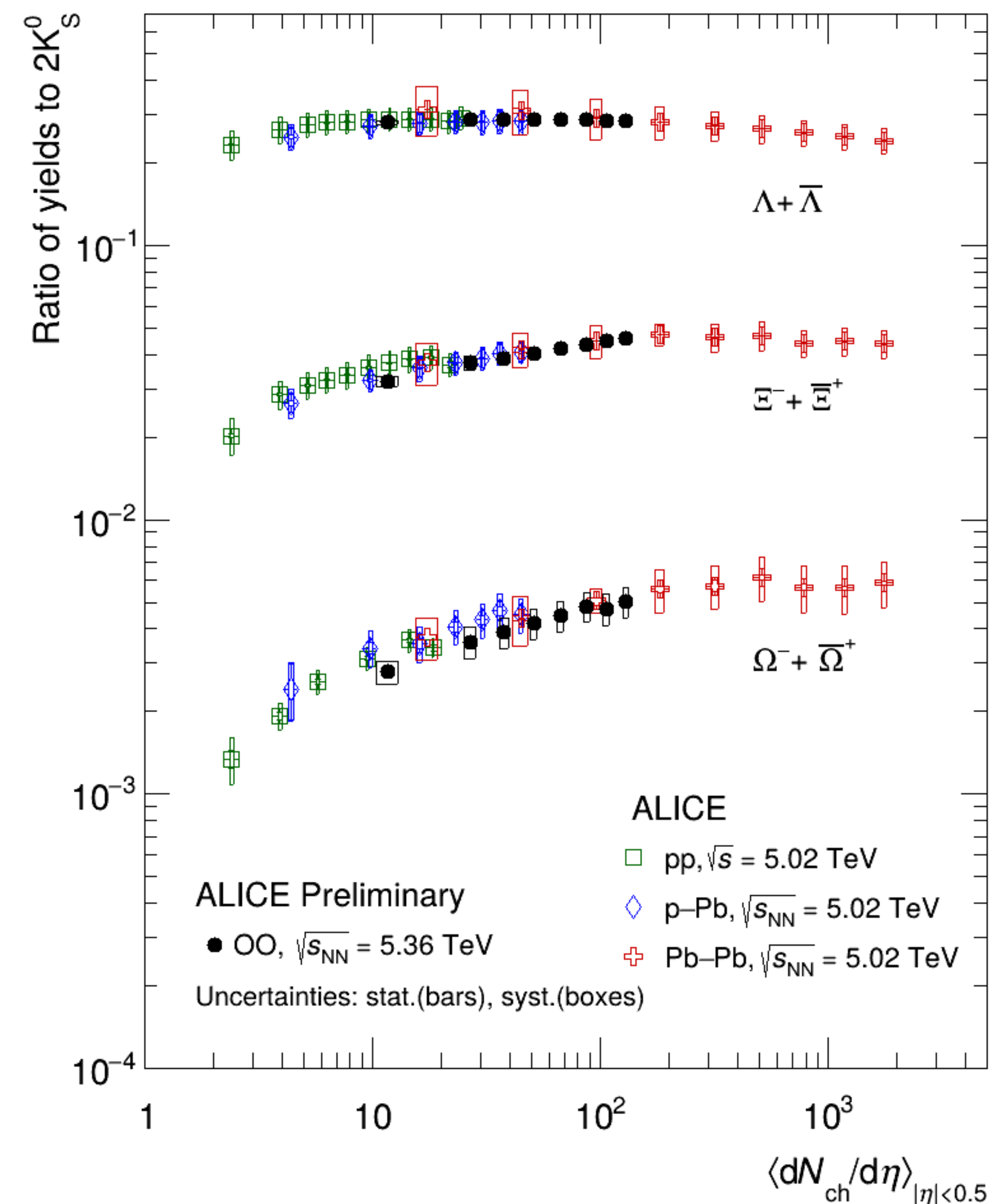
At high temperature, QCD matter forms a quark–gluon plasma (QGP), in which quarks and gluons are deconfined.

LHC: nearly zero net-baryon density at mid-rapidity, initial temperatures of a few hundred MeV

- Different probes access different stages of the system evolution
- Different observables are sensitive to different properties of the medium
- Together, they map the phenomena emerging in QCD matter at high T

Strangeness enhancement in hadronic collisions

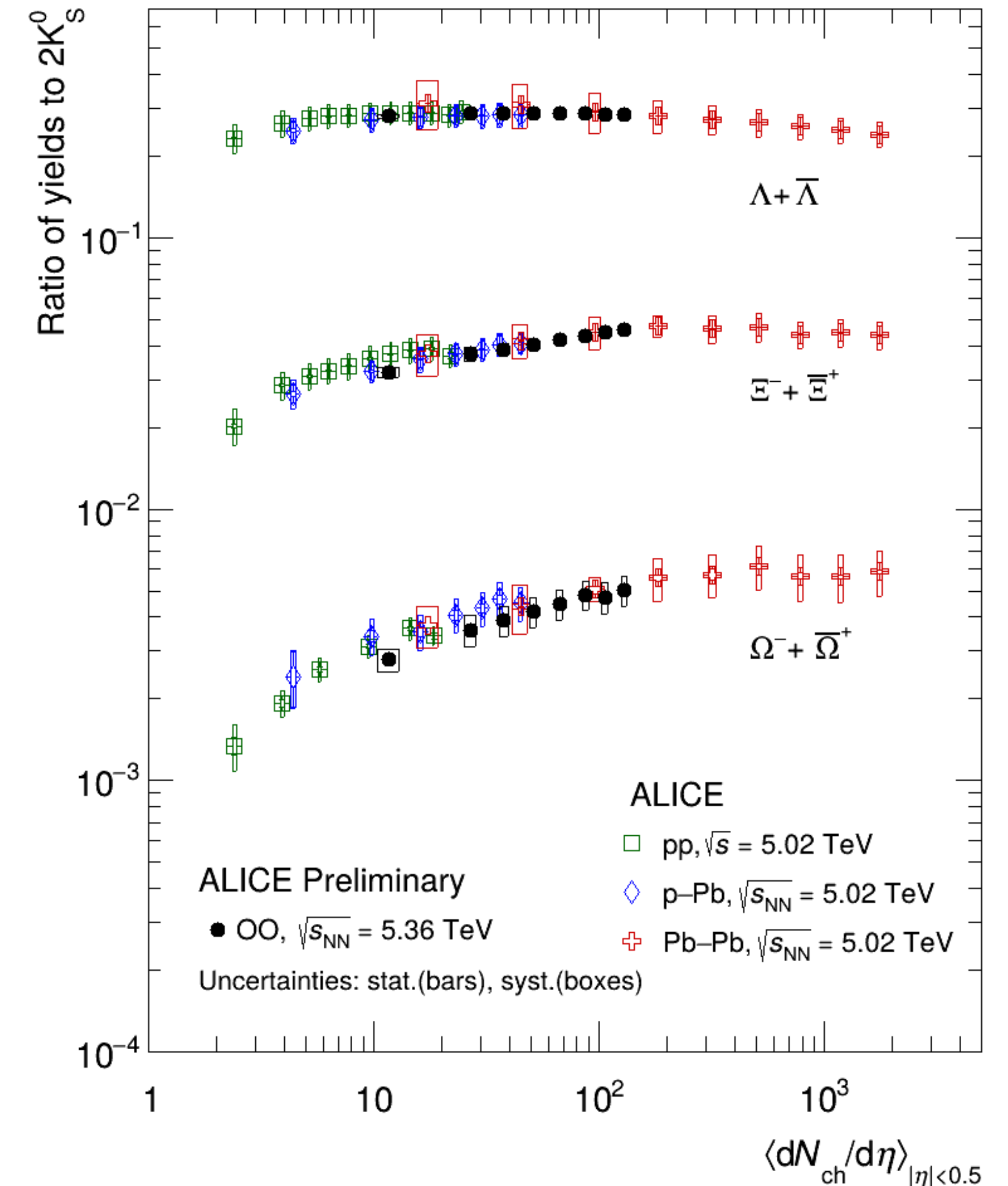
Historically: strangeness enhancement as one of the main signatures of a QGP due to larger production of strange quarks in the QGP



Strangeness enhancement in hadronic collisions

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- Continuous evolution of hadrochemistry with multiplicity, from pp to Pb–Pb

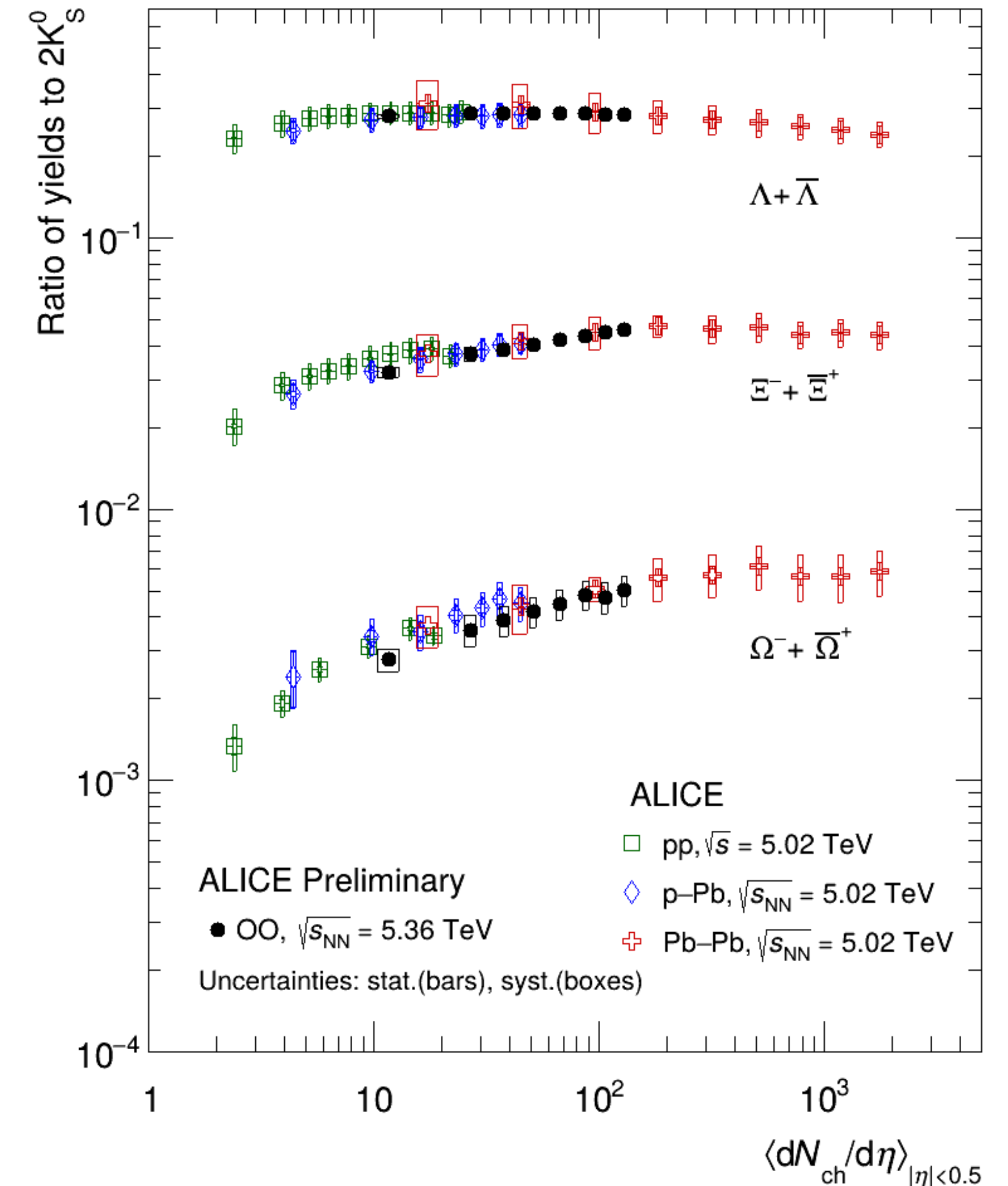


ALI-PREL-624132

Strangeness enhancement in hadronic collisions

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- New OO results connecting high mult. pp to Pb–Pb and overlapping with p–Pb

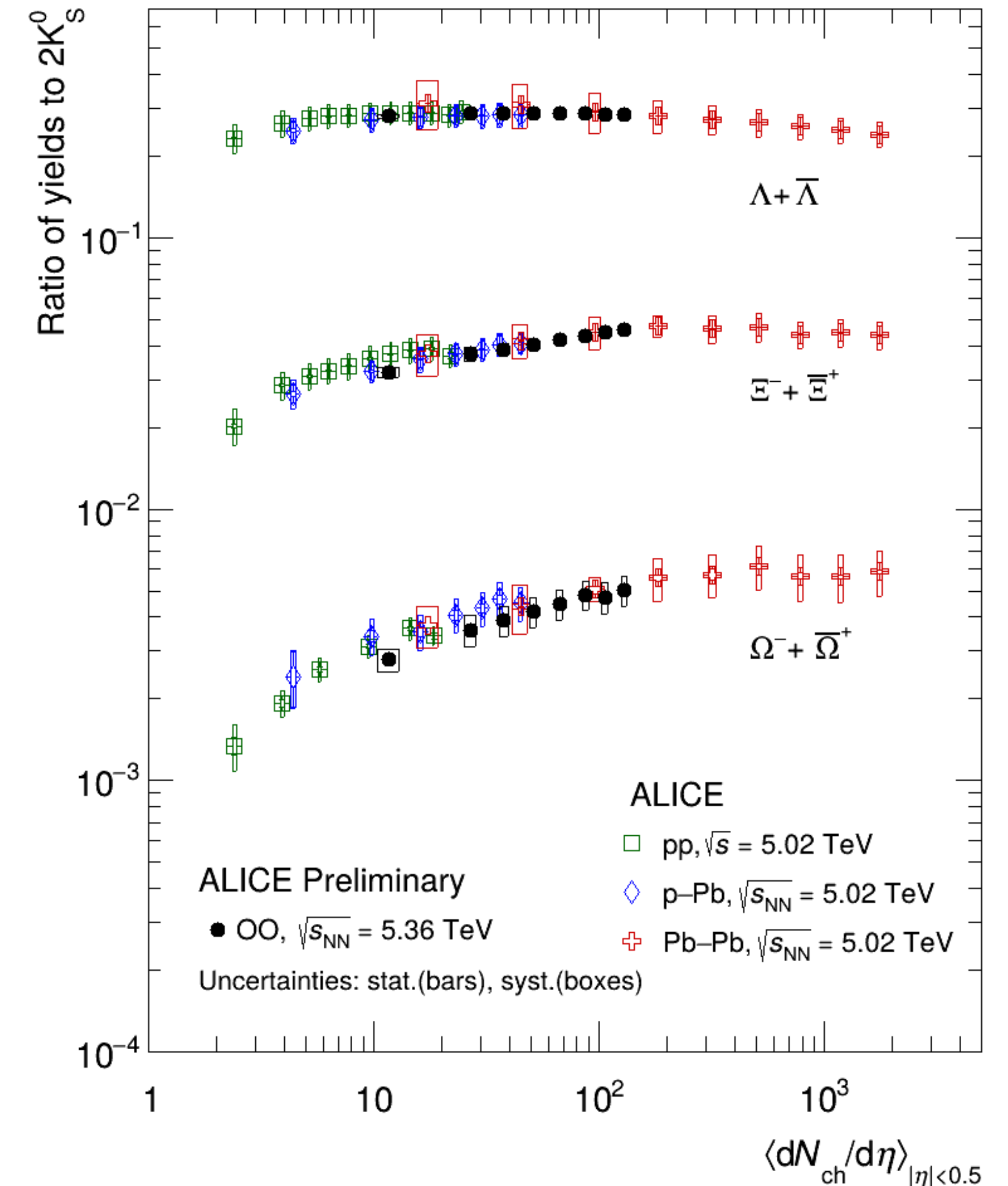


ALI-PREL-624132

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ALI-PREL-624132

Strangeness enhancement in hadronic collisions

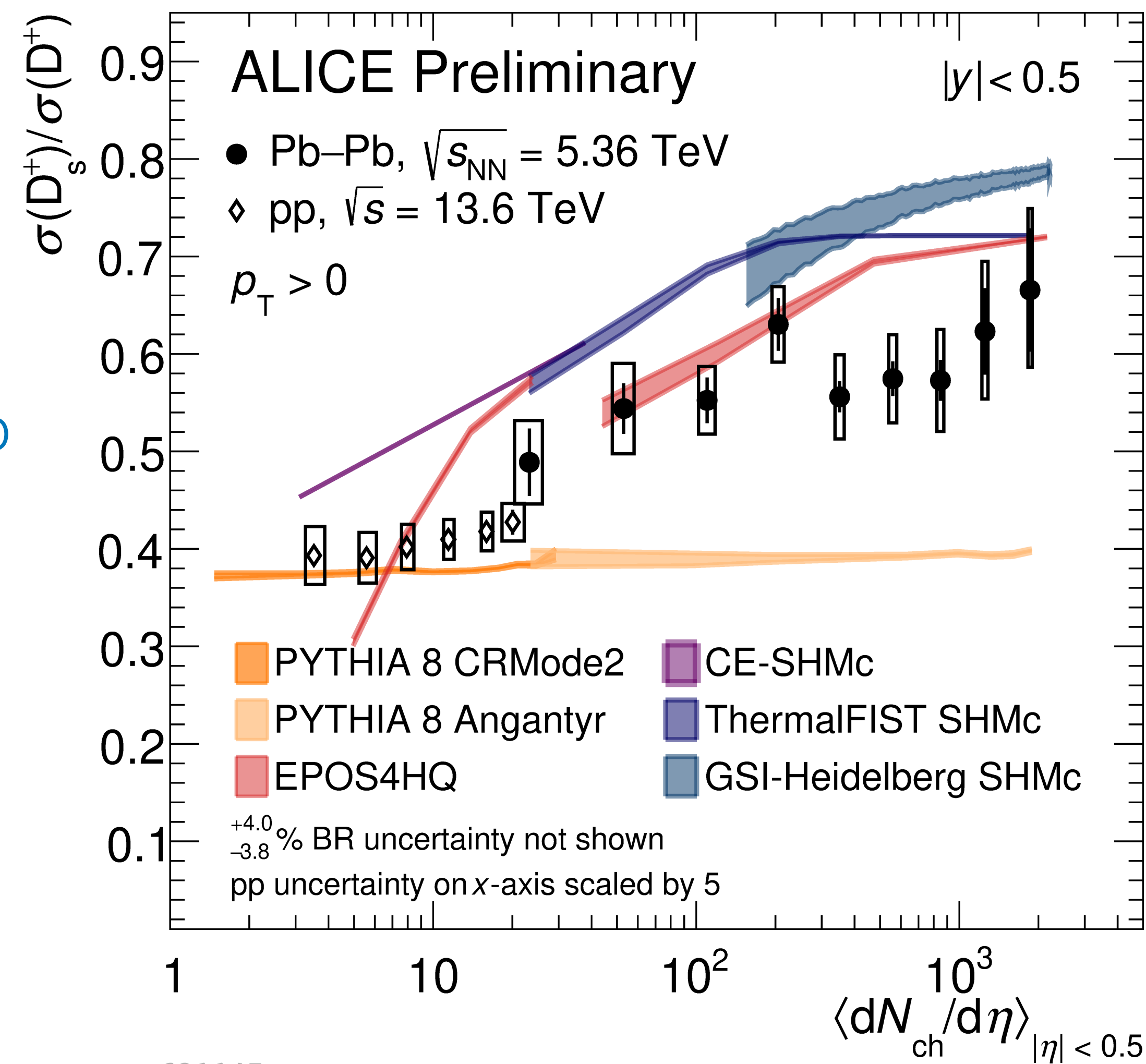
See L. Dello Stritto, Thu. 14:20

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D_s/D^+ yield ratio increasing from pp to Pb-Pb

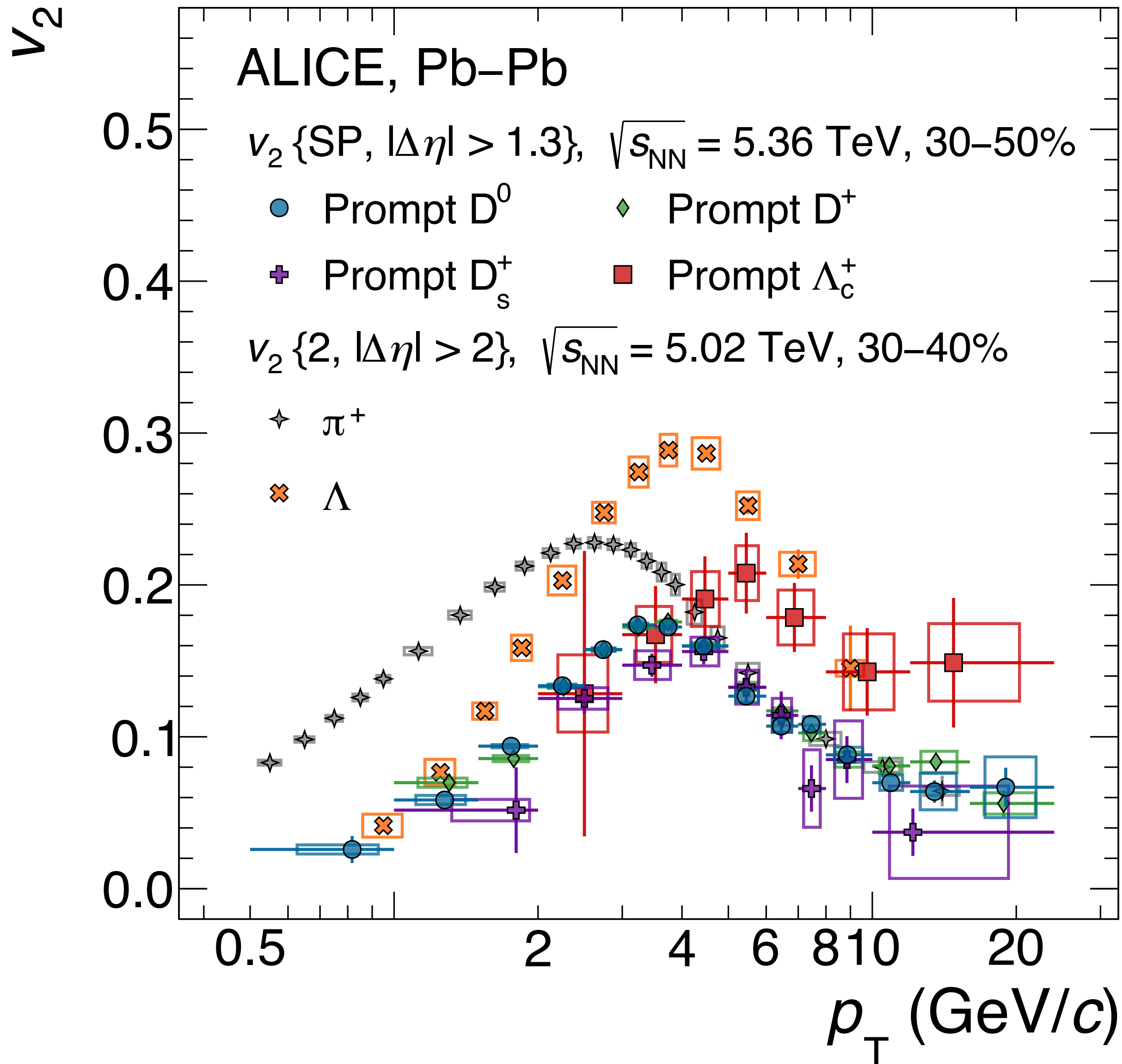
➔ Charm hadronisation influenced by the higher abundance of strangeness in the system



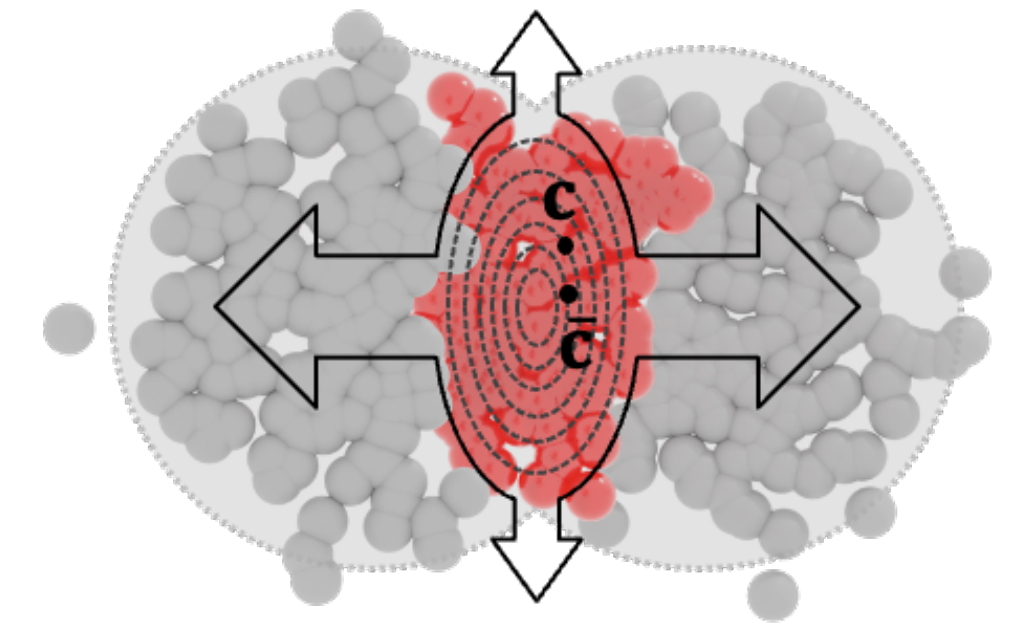
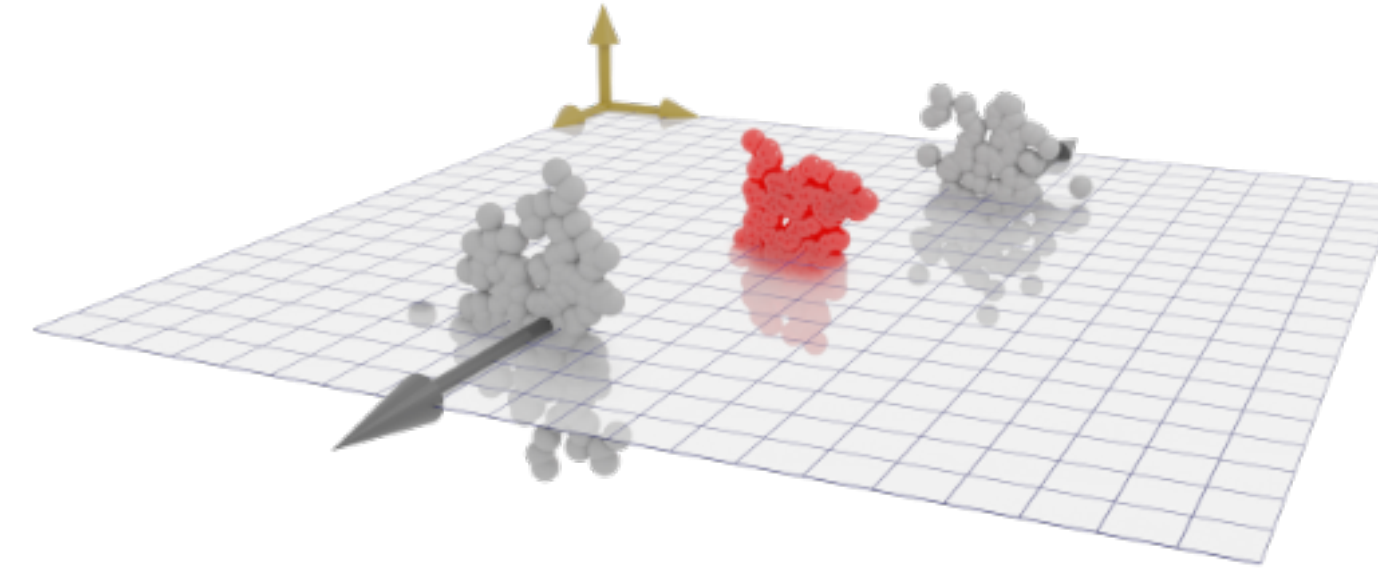
ALI-PREL-621147

Collective dynamics: Λ_c elliptic flow

ALICE, arXiv:2603.18966



Sketches by D. Chinellato



Spatial anisotropy creates anisotropic pressure gradients that build up a **collective momentum anisotropy**

$$\frac{dN}{d\varphi} \propto 1 + 2 \sum_{n=1}^{\infty} v_n \cos [n(\varphi - \Psi_n)]$$

Fourier analysis of the angular production

The second coefficient, v_2 , quantifies the resulting elliptic flow

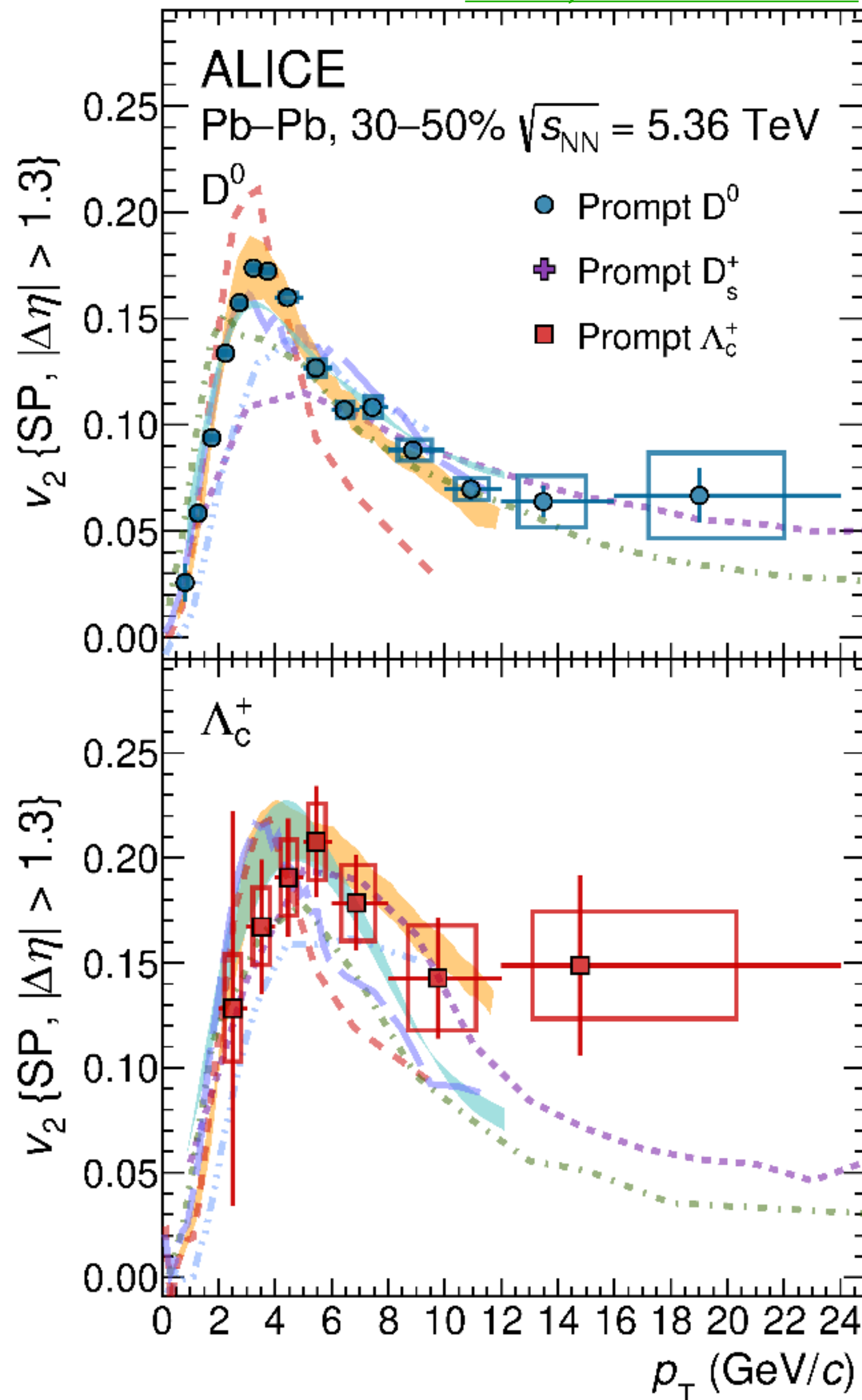
- ➡ Charm hadrons participate in the global expansion
- ➡ Intermediate p_T : D mesons follow pions, Λ_c follows the Λ

Collective dynamics: Λ_c elliptic flow

ALICE, arXiv:2603.18966

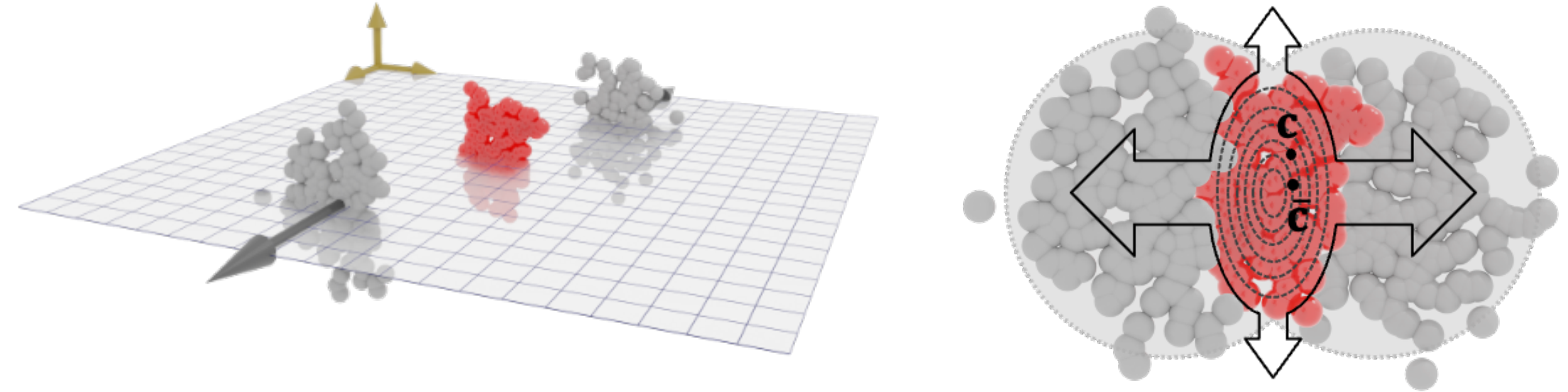
Models:

- TAMU
- Catania
- Langevin
- LBT-PNP
- POWLANG IQCD
- POWLANG HTL
- EPOS4HQ



ALI-PUB-623008

Sketches by D. Chinellato



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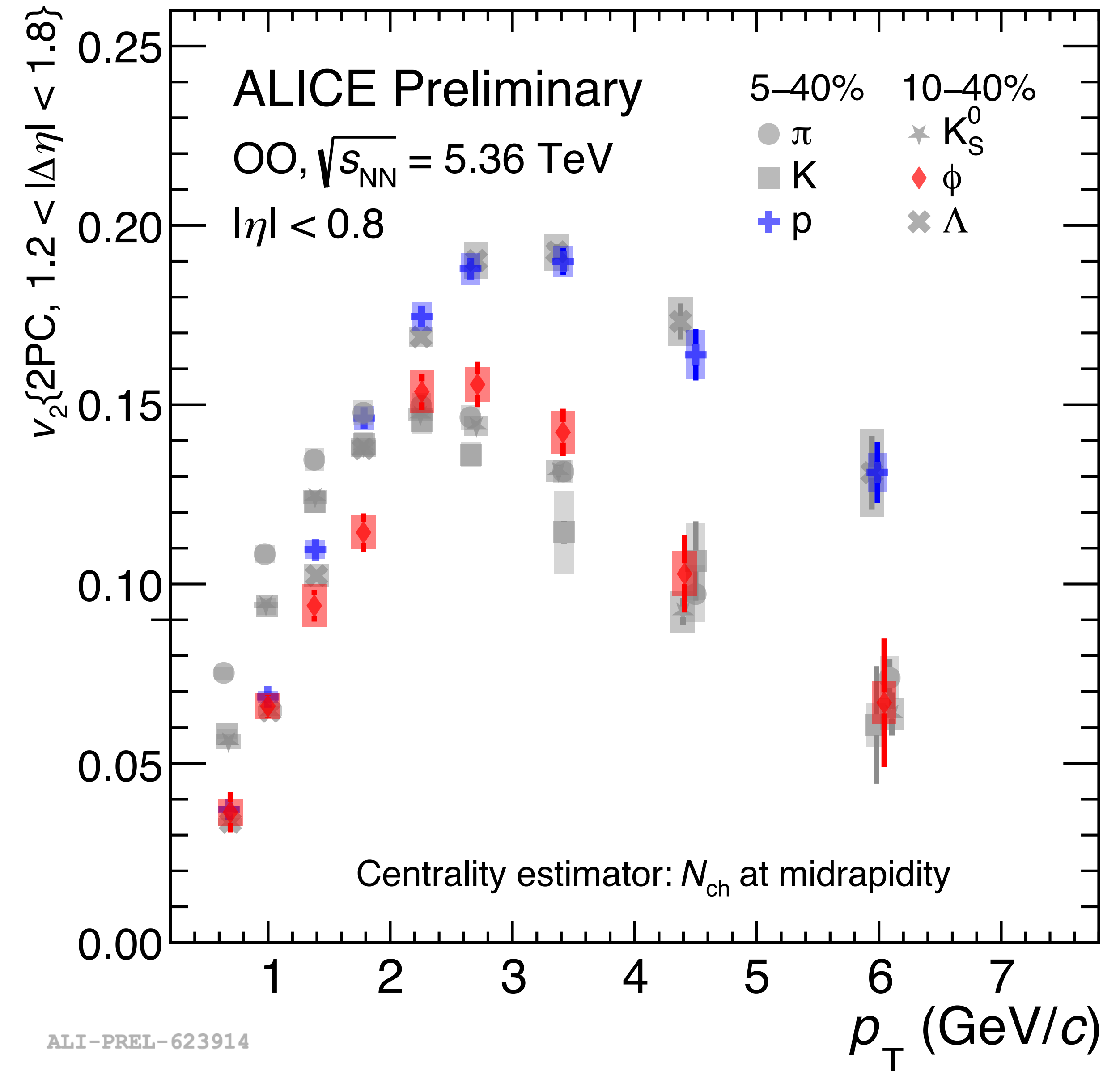
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- ➔ Charm hadrons participate in the global expansion
- ➔ Intermediate p_T : D mesons follow pions, Λ_c follows the Λ
- Models with coalescence describe the data

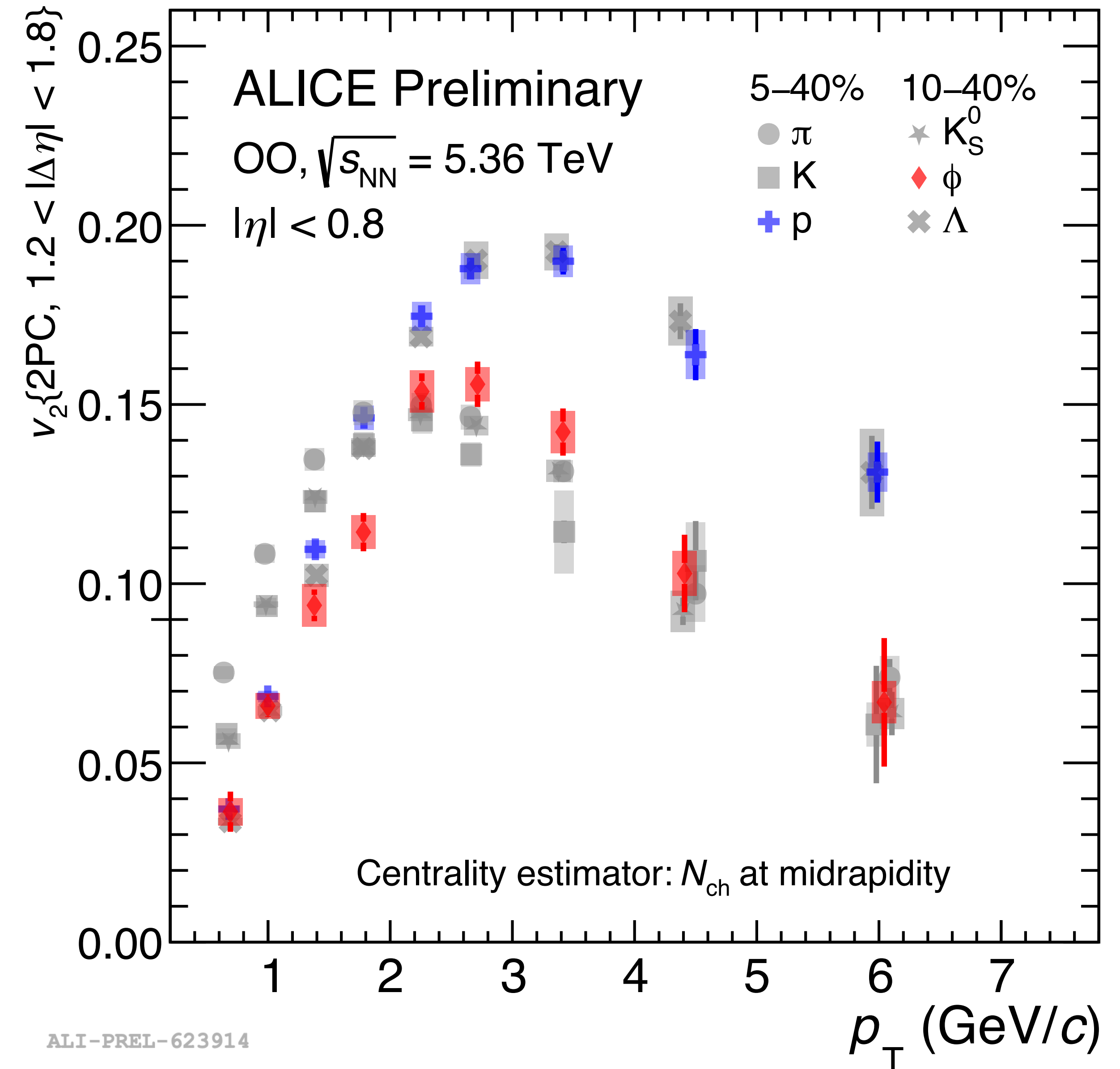
Elliptic flow in OO collisions



ALI-PREL-623914

Elliptic flow in OO collisions

First measurement of the elliptic flow of identified hadrons in OO collisions

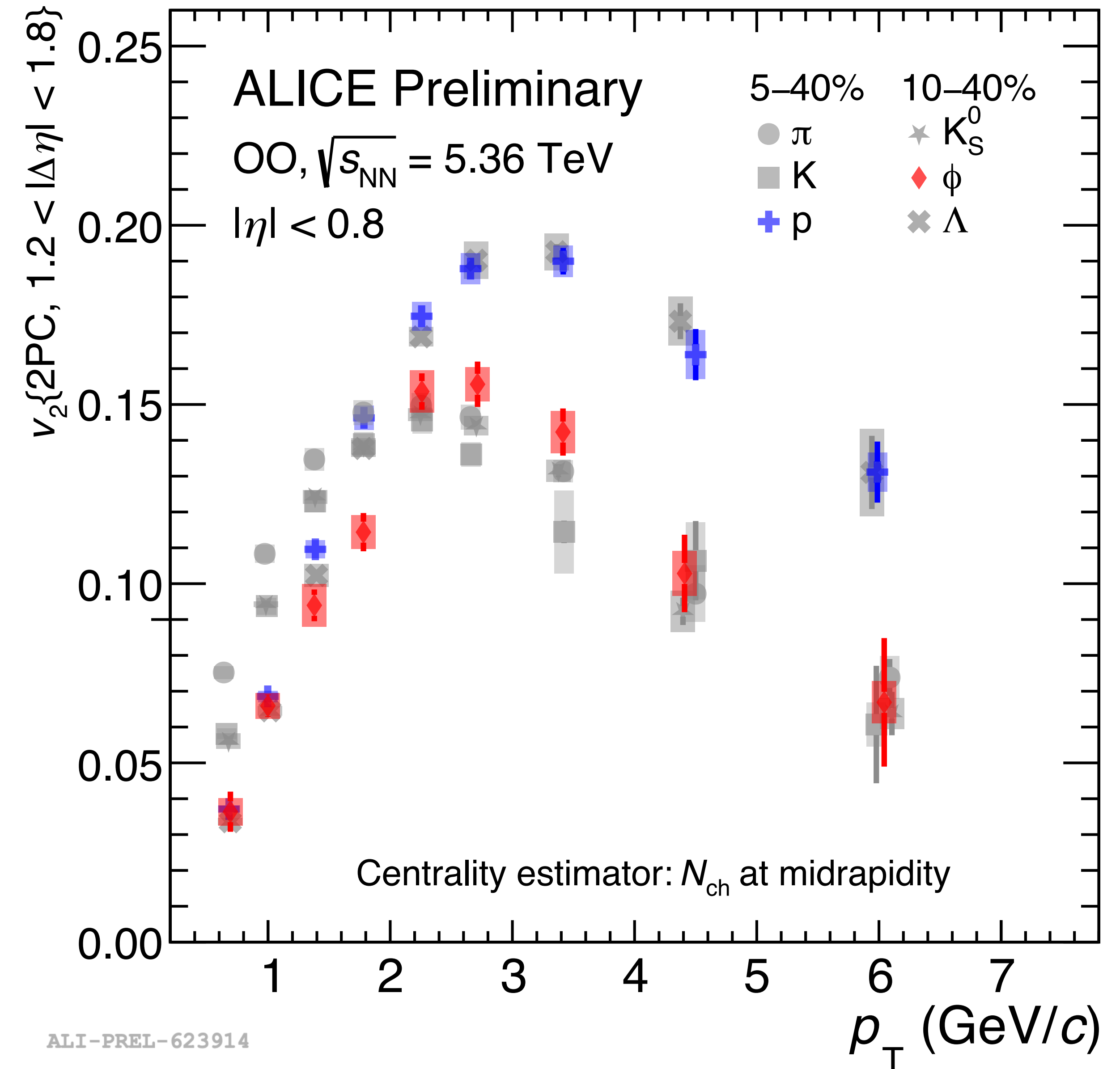


ALI-PREL-623914

Elliptic flow in OO collisions

First measurement of the elliptic flow of identified hadrons in OO collisions

→ Low p_T mass ordering: the larger the mass of the hadron, the smaller the v_2



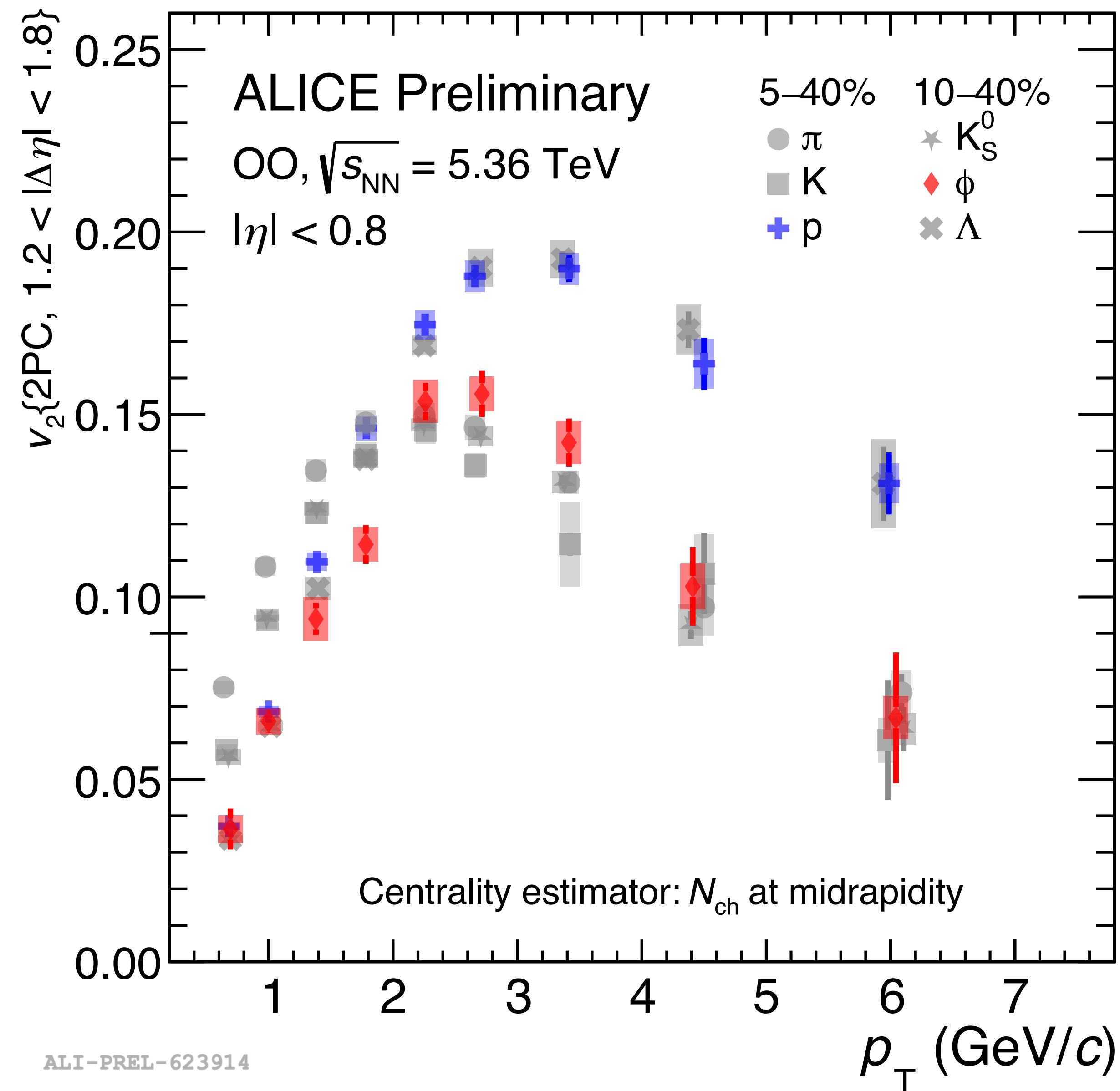
ALI-PREL-623914

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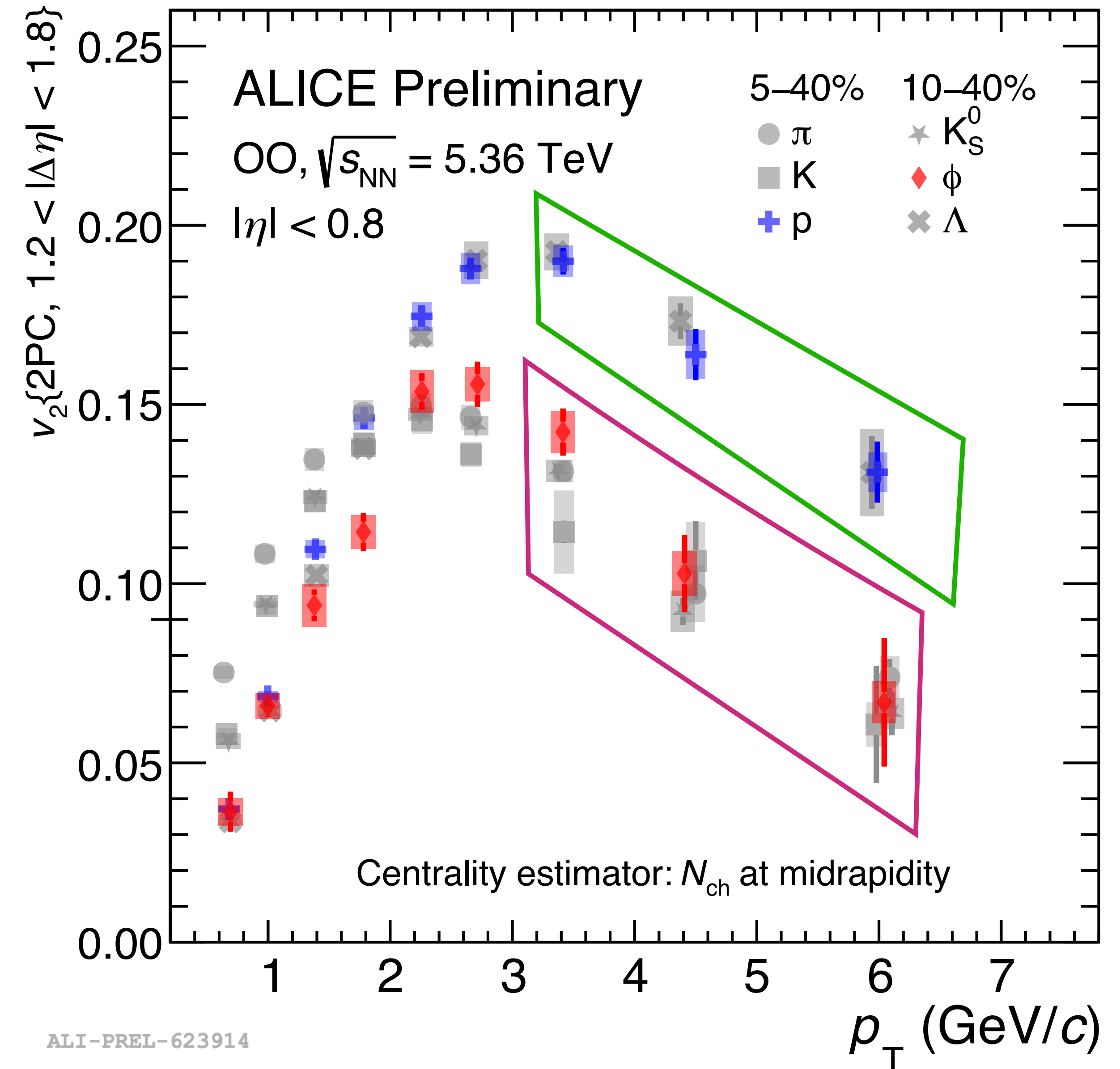
- Hadrons emitted from a common collective velocity field e.g. $v_2(p) \approx v_2(\phi)$



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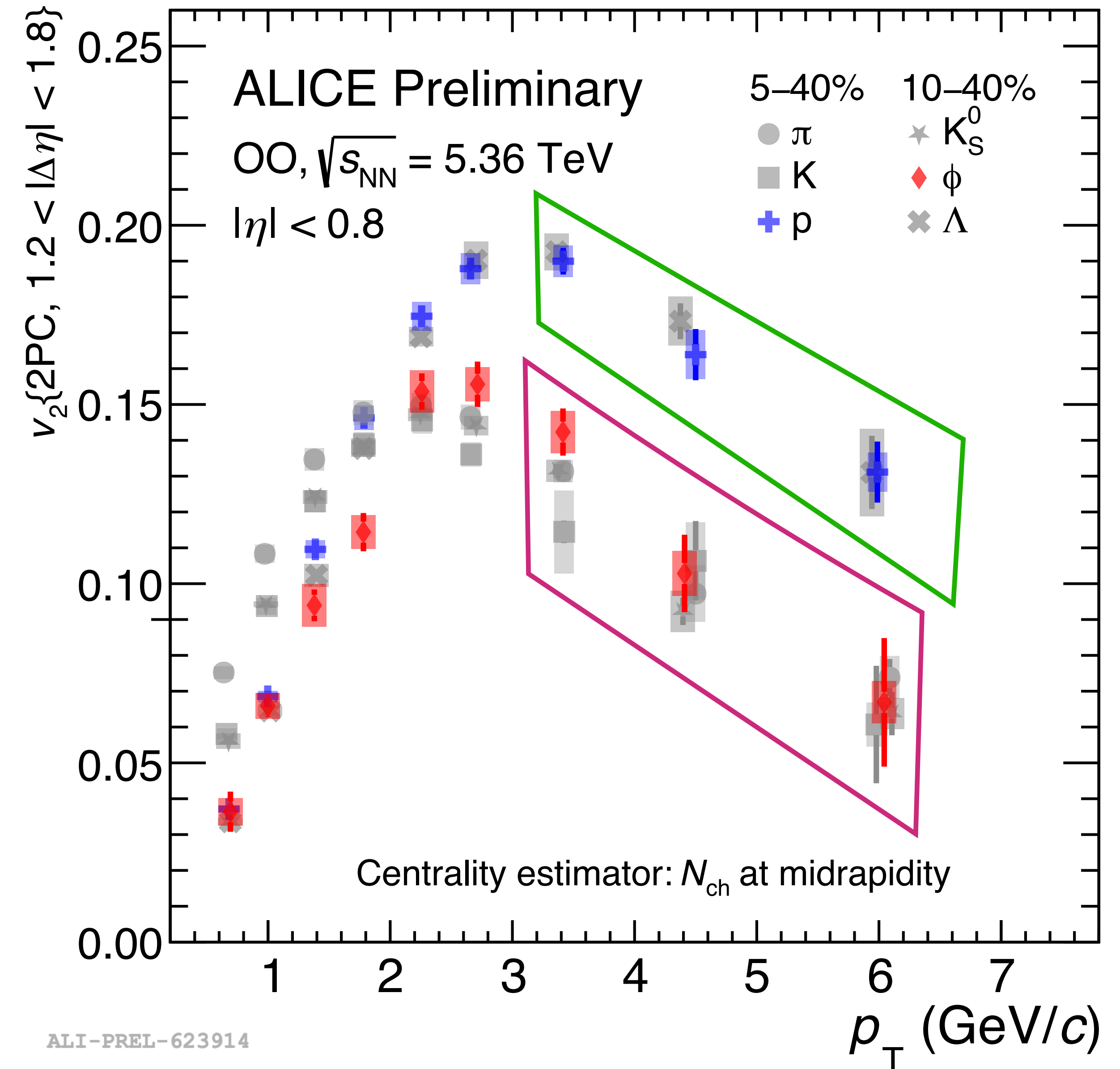
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- indication that partonic degrees of freedom carry collective flow before hadronization



ALI-PREL-623914

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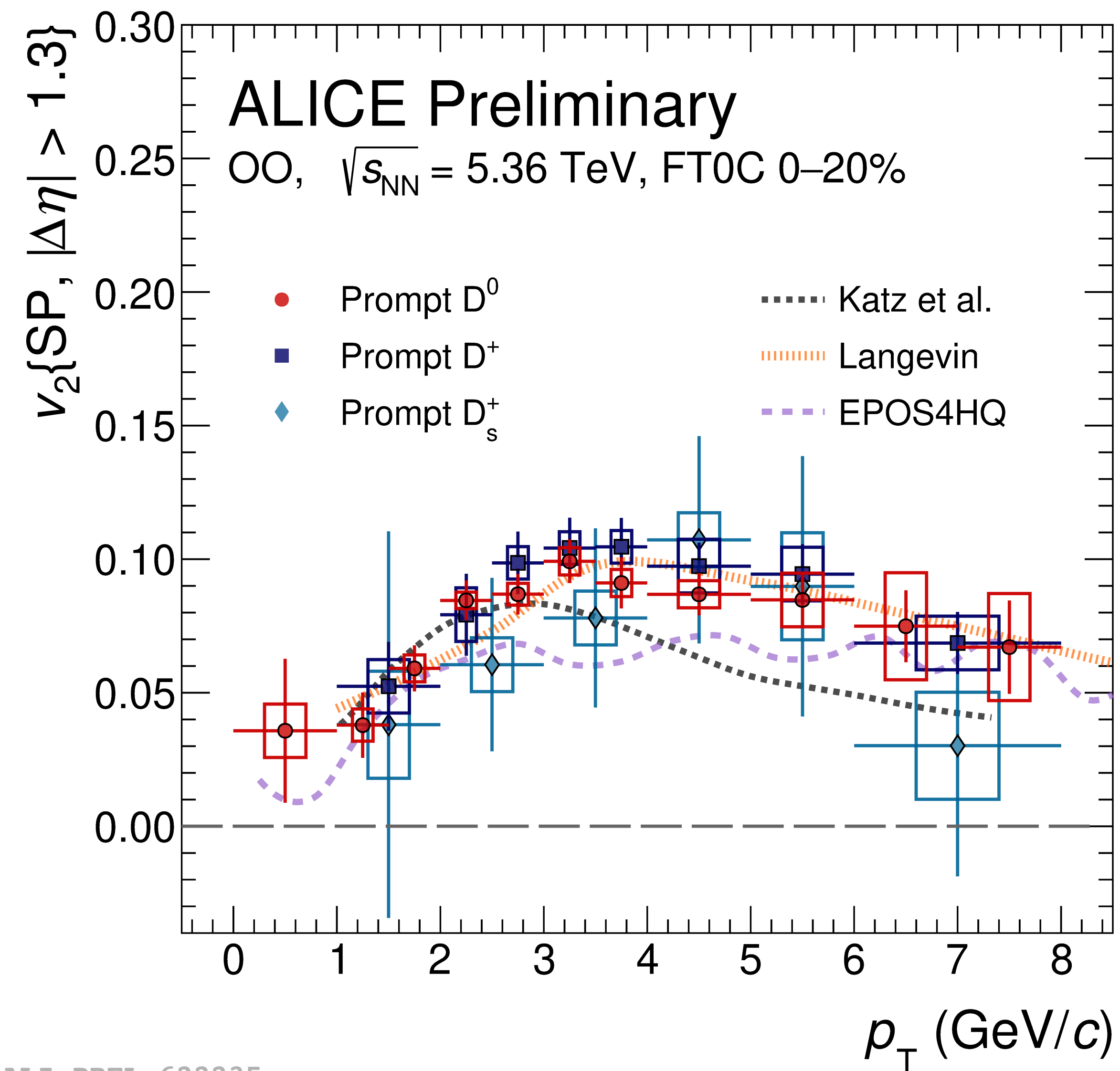
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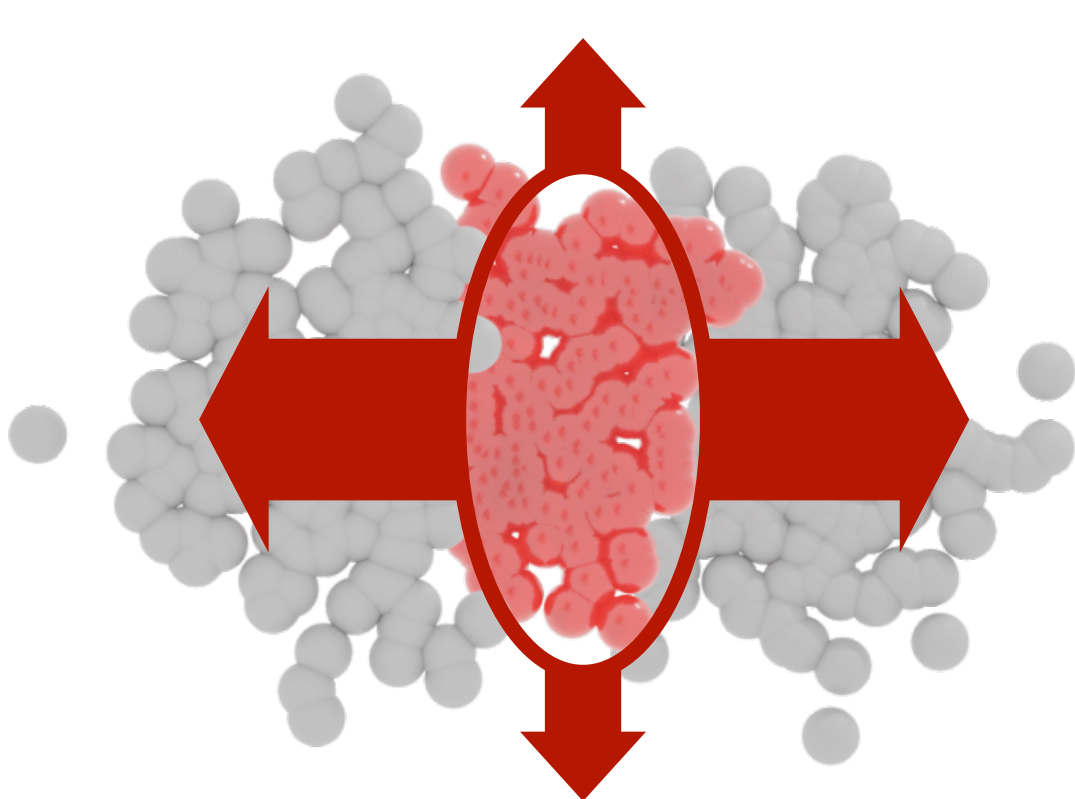
Extended to charm mesons as well confirming the same pattern

→ Consistent with transport models



ALI-PREL-622235

Λ longitudinal polarisation



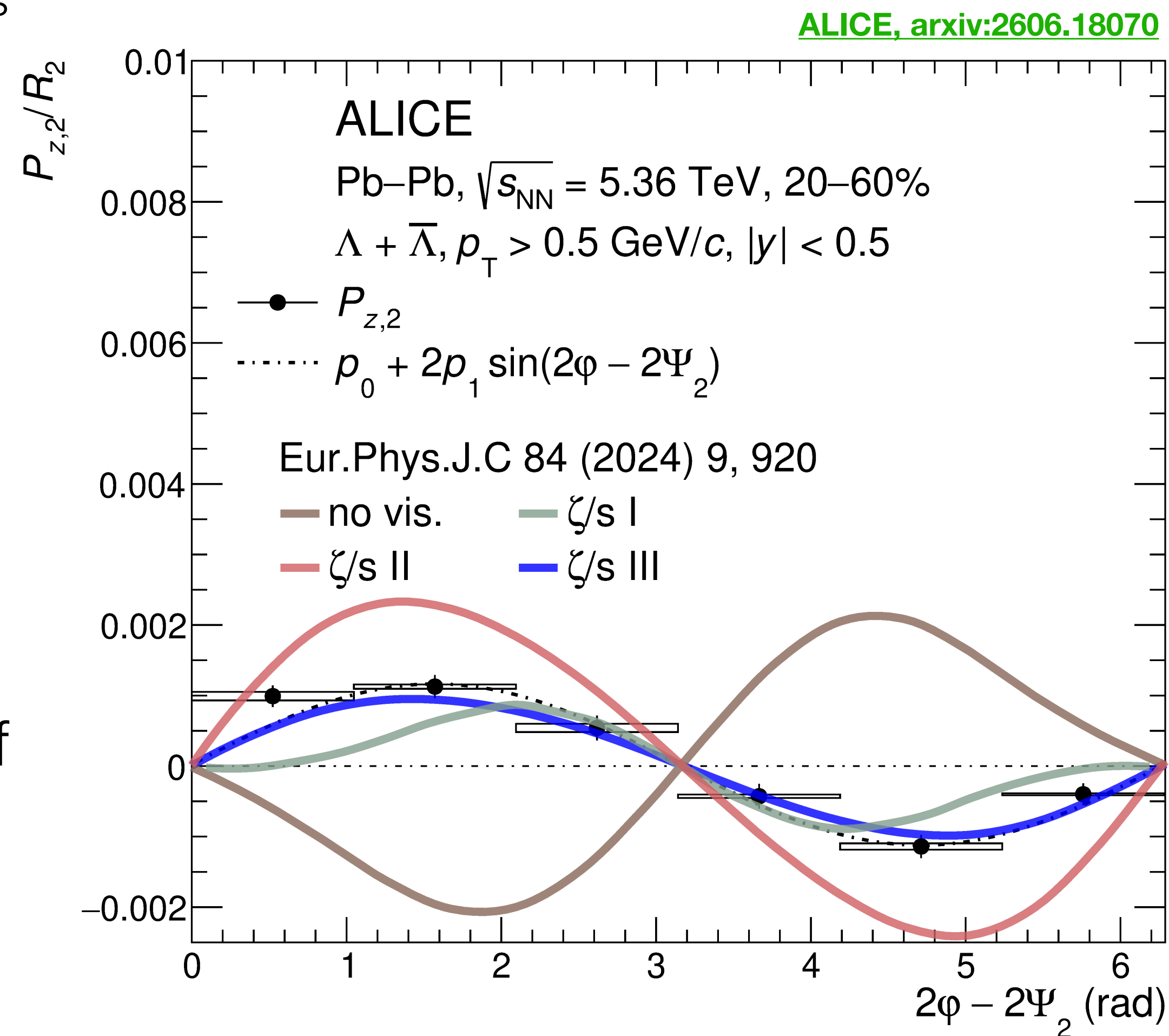
Momentum anisotropies (v_2) $\leftrightarrow$ velocity gradients

↓
This generates vorticity in the produced QGP

↓
Through **spin-vorticity coupling** the vorticity polarizes emitted hadrons

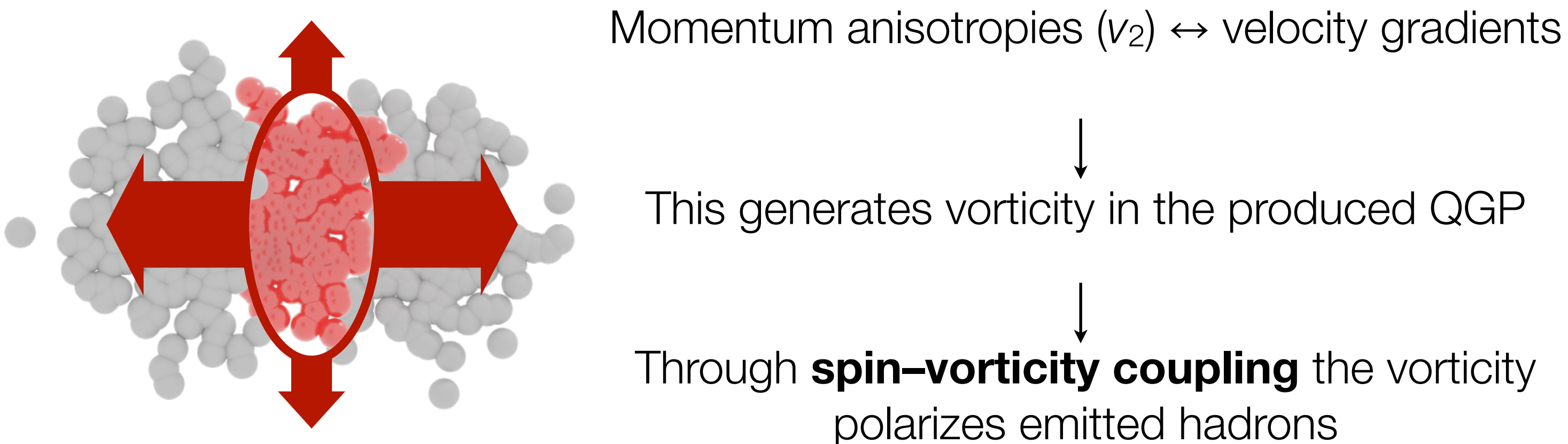
The magnitude of the measured polarization depends on the properties of the system

- ➔ New precise measurement longitudinal polarization of Λ and anti- Λ hyperons.
- Clear sine modulation vs. event plane, owing to the origin of the polarization
- ➔ **Constrains bulk viscosity (ζ/s)** beyond standard flow observables.



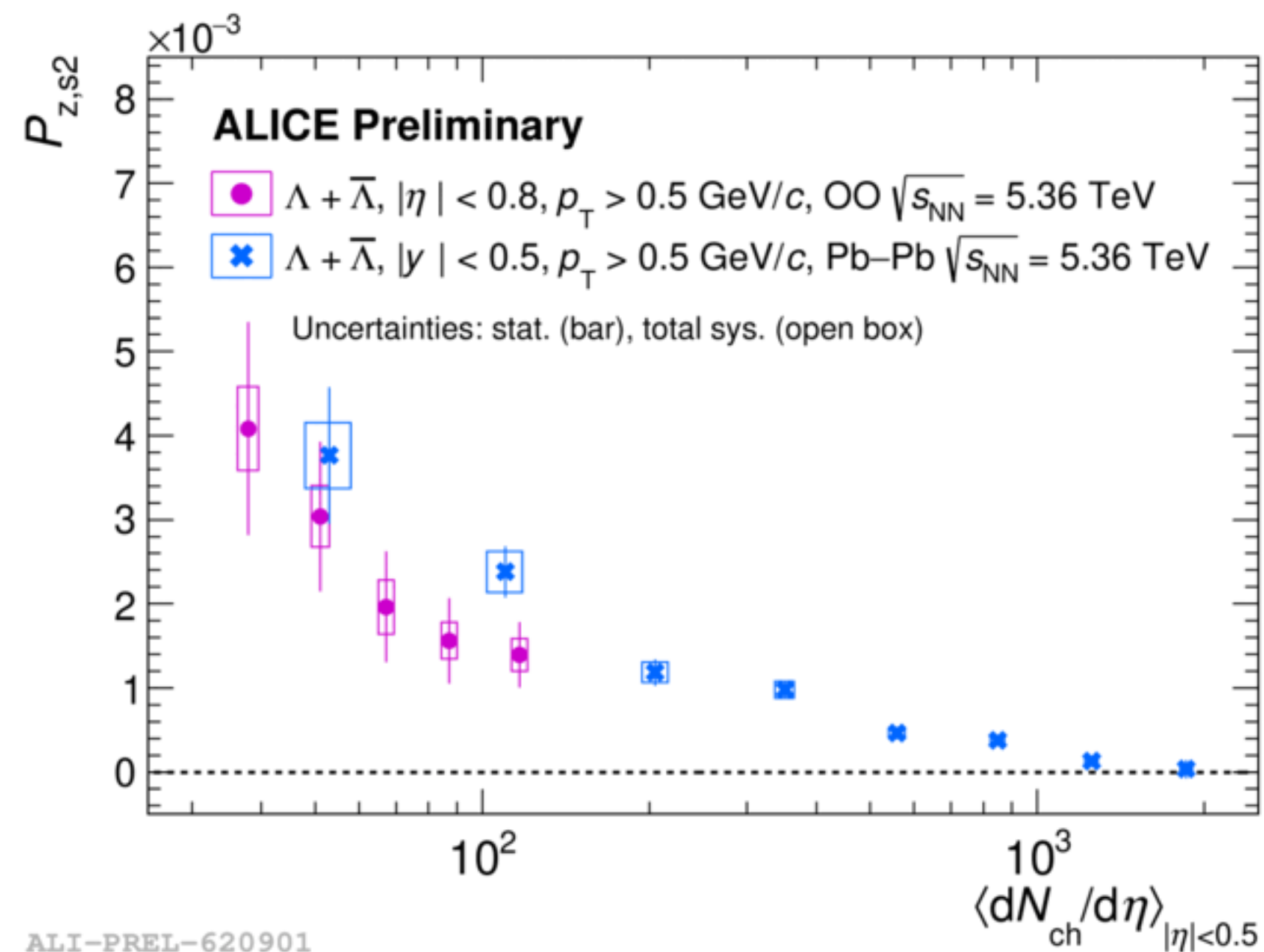
ALI-PUB-635098

Λ longitudinal polarisation



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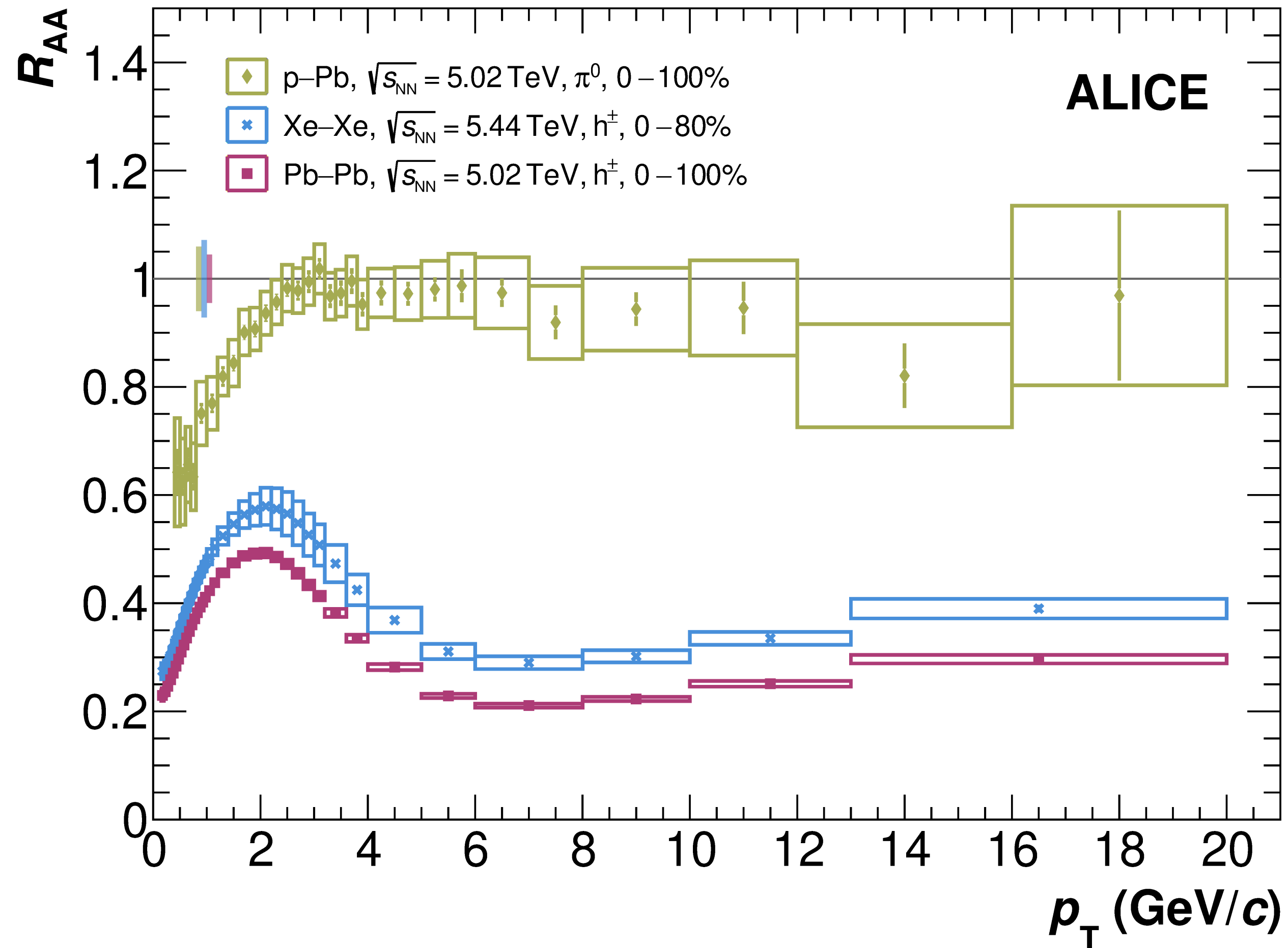
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Non-zero polarisation observed in OO collisions as well

Evidence of partonic energy loss in OO collisions

ALICE, arxiv:2606.19967



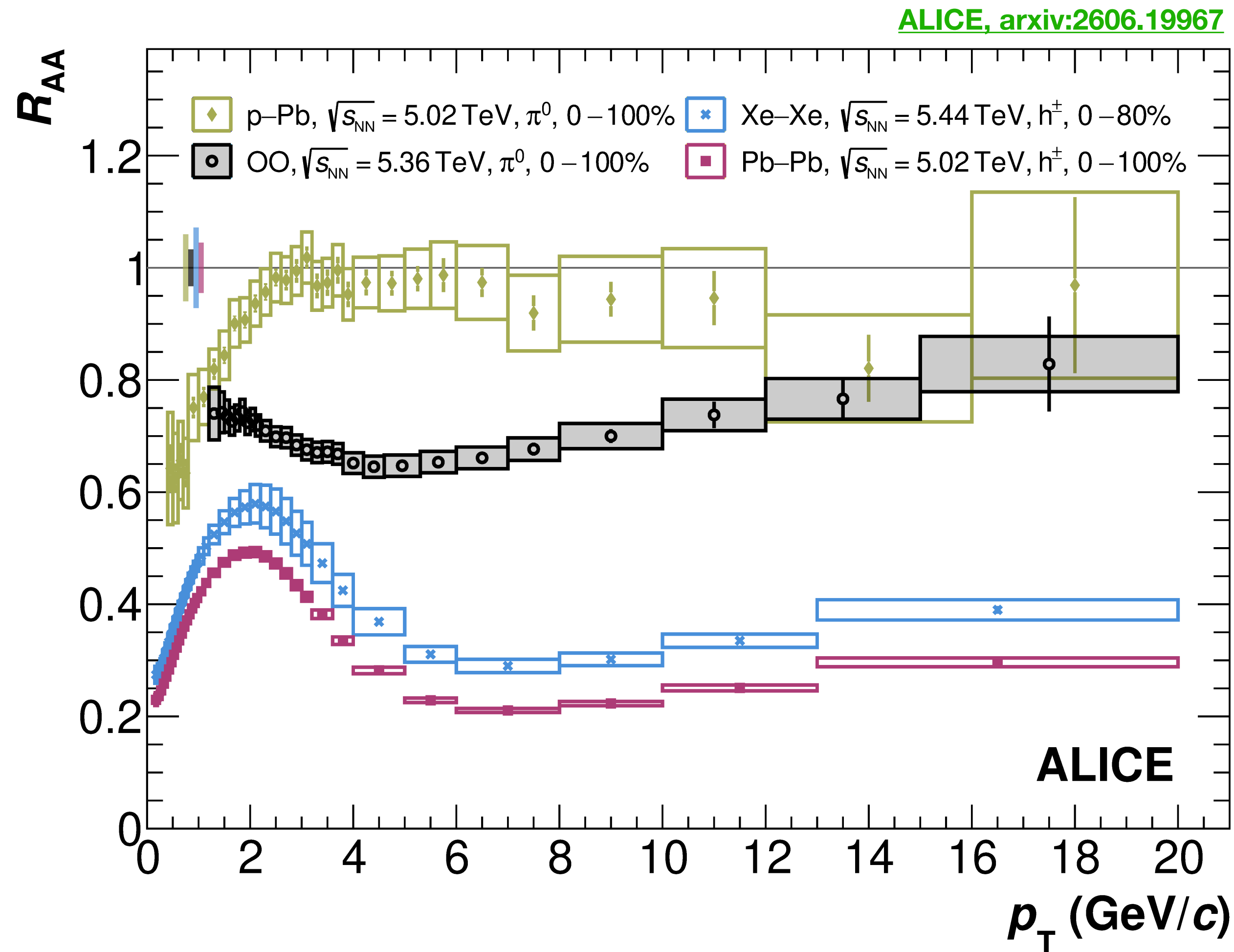
$$R_{AA}(p_T) = \frac{1}{\langle N_{\text{coll}} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

If collisions involving nuclei are simple incoherent superposition of NN collisions, $R_{AA}=1$

→ In Pb-Pb, large suppression not observed in p-Pb collisions

ALI-DER-638981

Evidence of partonic energy loss in OO collisions



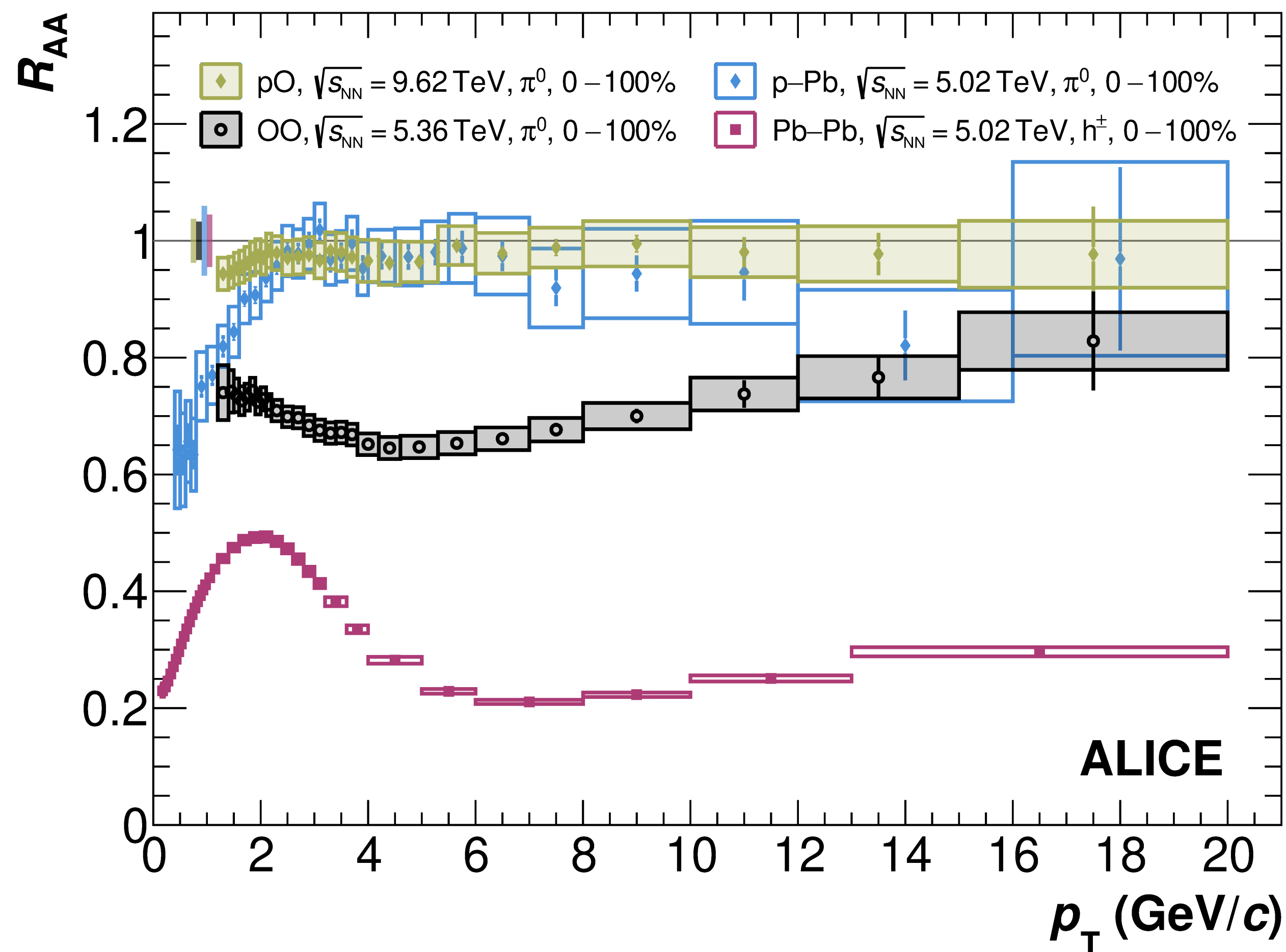
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- ➔ In OO collisions we observe as well a suppression wrt unity!
 - Is it real energy loss in a QGP or just cold nuclear matter effects? (e.g. NPPDF)

Evidence of partonic energy loss in OO collisions

ALICE, arxiv:2606.19967



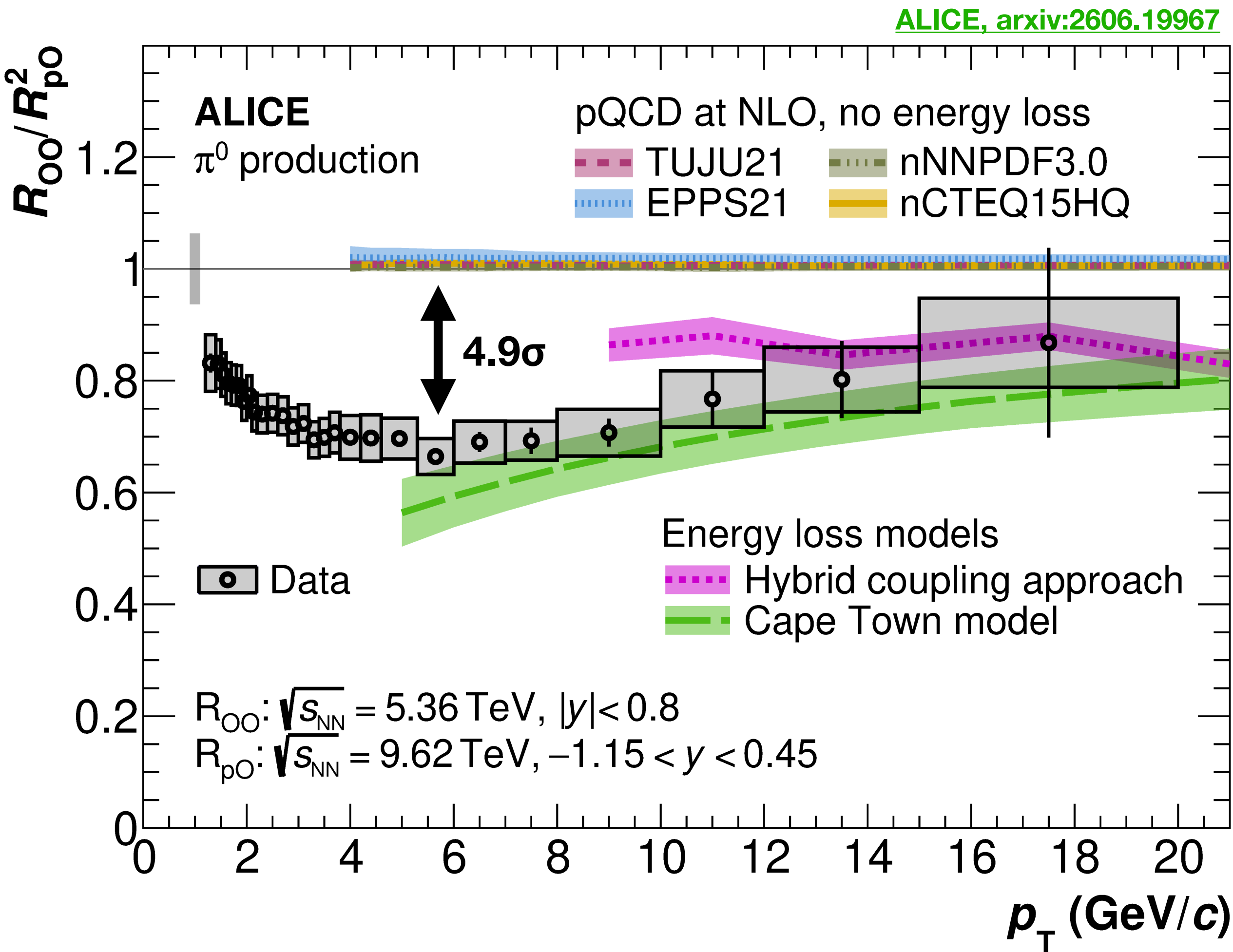
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- ➔ In pO, R_{AA} compatible with 1 above 2 GeV/c

ALI-DEP-639600

Evidence of partonic energy loss in OO collisions



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 - Is it real energy loss in a QGP or just cold nuclear matter effects? (e.g. NPDF)
- ➔ In pO, R_{AA} compatible with 1 above 2 GeV/c
- ➔ R_{OO}/R_{pO}^2 cancels cold-nuclear-matter effects, revealing that the **suppression in OO is consistent with partonic energy loss.**

Looking for the LQCD crossover signatures

In OO we have all the signals pointing to the formation of a QGP

→ We can look for the fluctuations of the baryon number expected by LQCD

$$\chi_B^n \equiv \frac{\partial^n (p/T^4)}{\partial (\mu_B/T)^n} = \frac{\kappa_B^n}{VT^3}$$

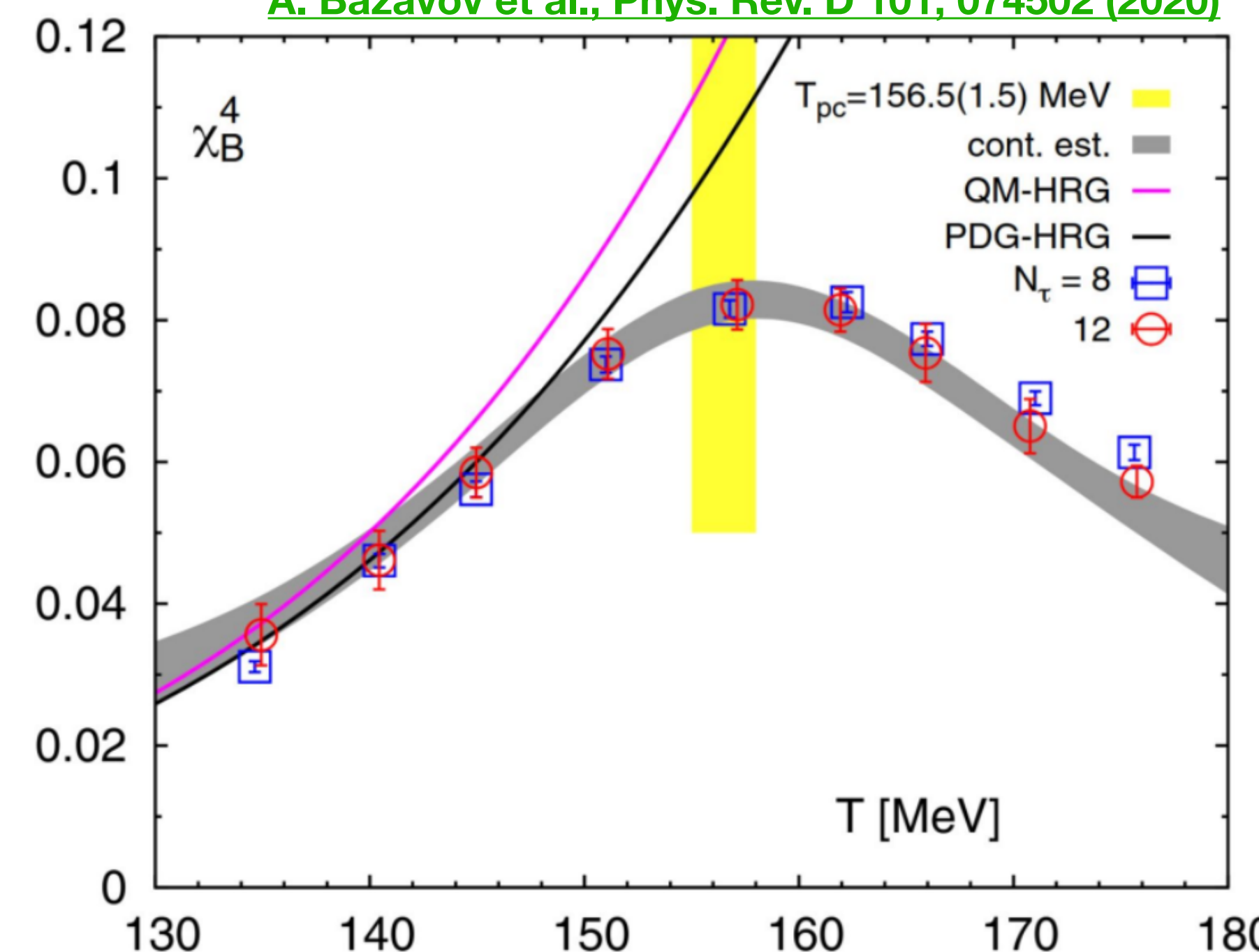
variance $\kappa_2 = \langle (\Delta N)^2 \rangle = \sigma^2$

skewness $\kappa_3 = \langle (\Delta N)^3 \rangle$

kurtosis $\kappa_4 = \langle (\Delta N)^4 \rangle - 3\langle (\Delta N^2) \rangle^2$

→ Experimentally we measure the high-order cumulants of the net number of proton measured event-by-event

A. Bazavov et al., Phys. Rev. D 101, 074502 (2020)



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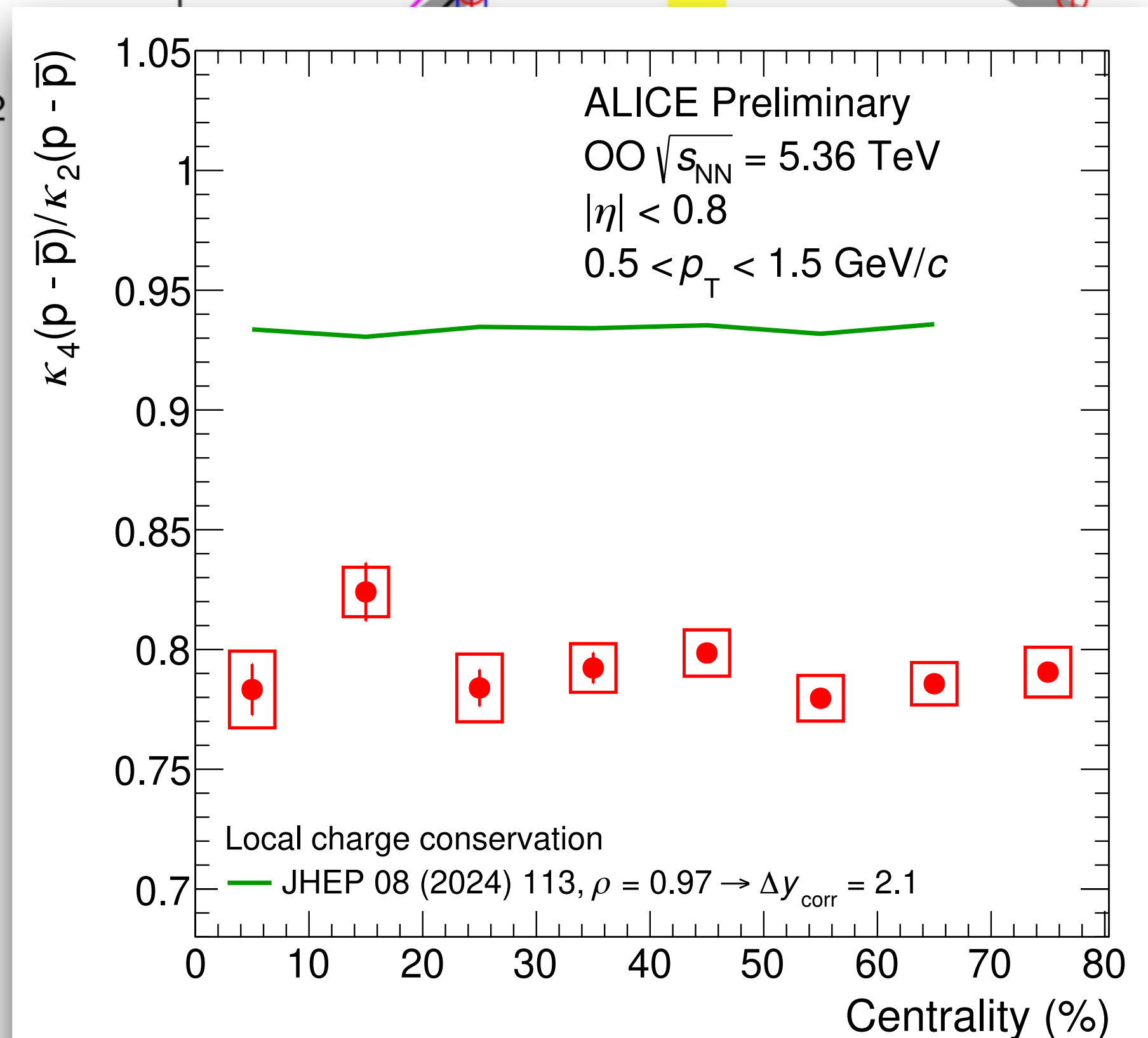
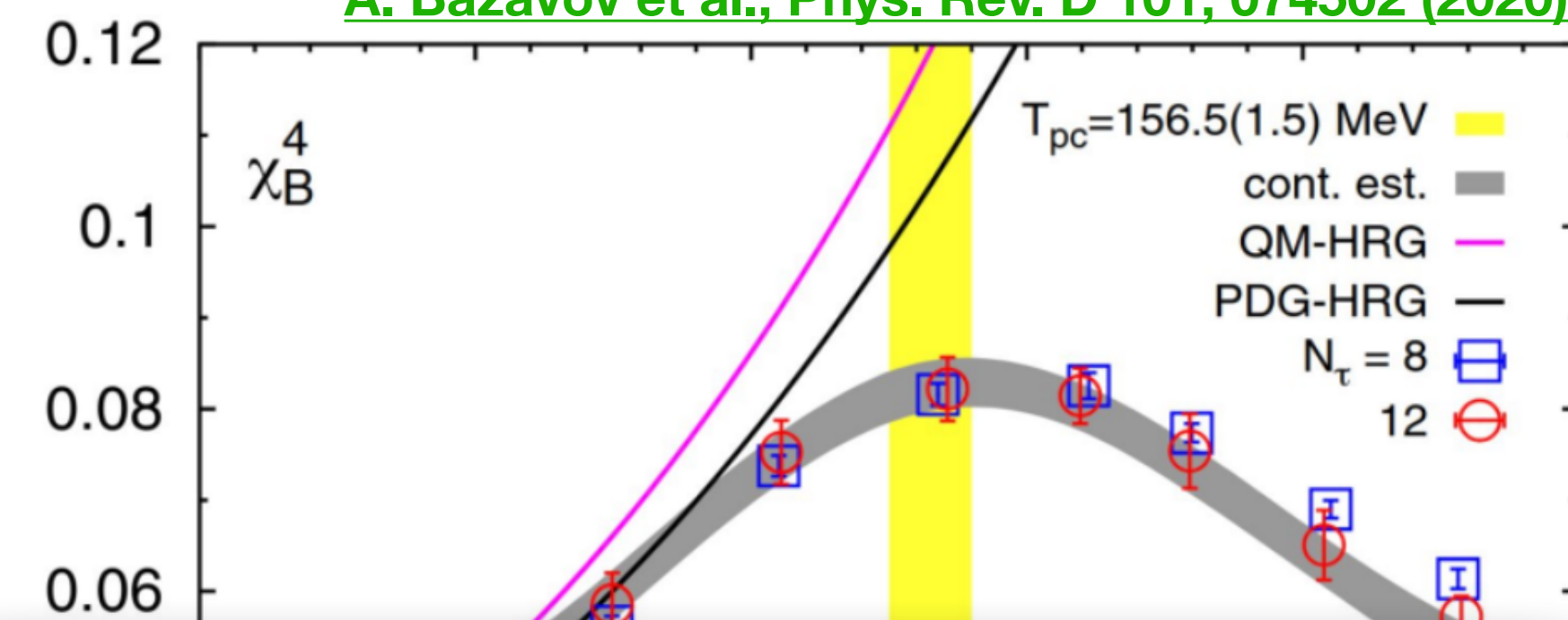
kurtosis $\kappa_4 = \langle (\Delta N)^4 \rangle - 3\langle (\Delta N^2) \rangle^2$

→ Experimentally we measure the high-order cumulants of the net number of proton measured event-by-event

- Significant tension with HRG models implementing local baryon-number conservation à la PYTHIA

→ Is this the discrepancy we are after?

A. Bazavov et al., Phys. Rev. D 101, 074502 (2020)



ALI-PREL-623329

Looking for the LQCD crossover signatures

In OO we have all the signals pointing to the formation of a QGP

→ We can look for the fluctuations of the baryon number expected by LQCD

$$\chi_B^n \equiv \frac{\partial^n (p/T^4)}{\partial (\mu_B/T)^n} = \frac{\kappa_B^n}{VT^3}$$

variance $\kappa_2 = \langle (\Delta N)^2 \rangle = \sigma^2$

skewness $\kappa_3 = \langle (\Delta N)^3 \rangle$

kurtosis $\kappa_4 = \langle (\Delta N)^4 \rangle - 3\langle (\Delta N^2) \rangle^2$

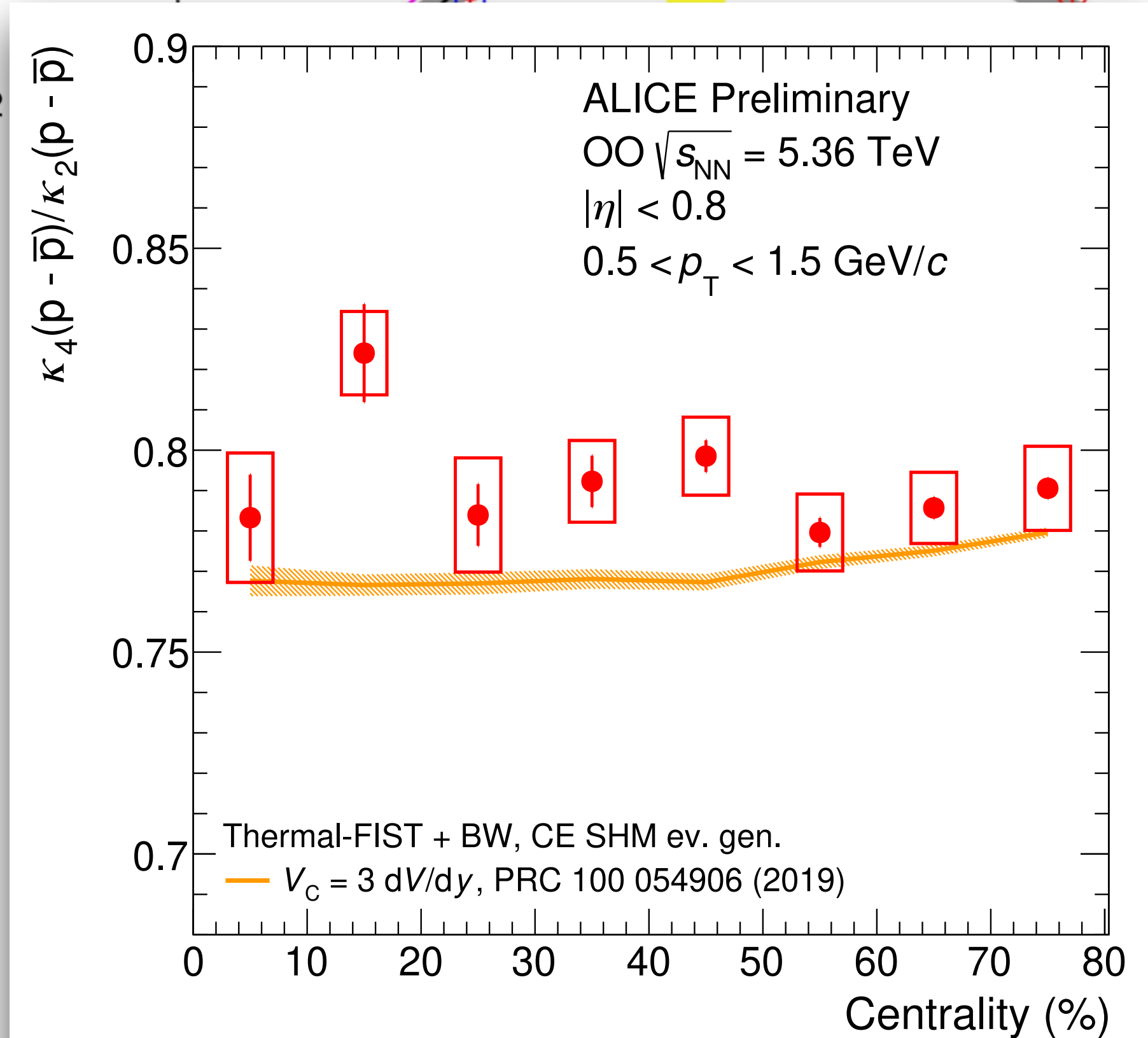
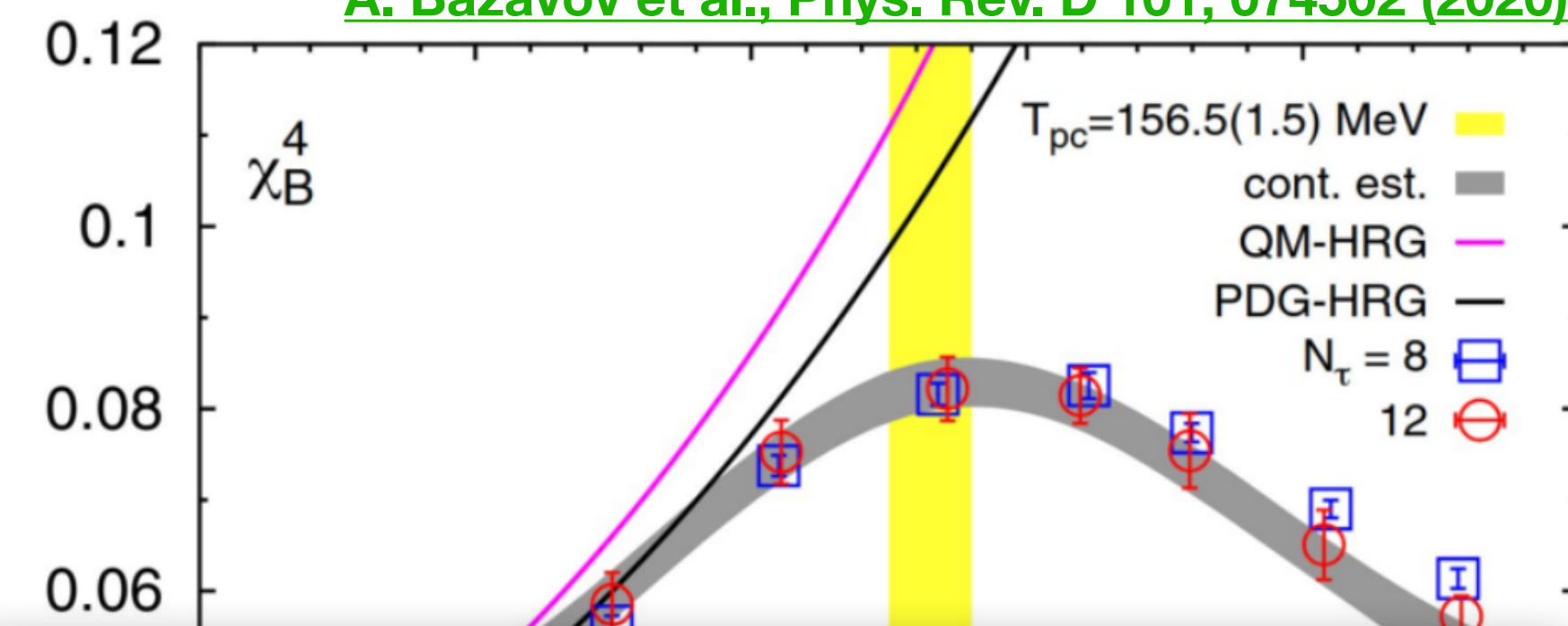
→ Experimentally we measure the high-order cumulants of the net number of proton measured event-by-event

- Significant tension with HRG models implementing local baryon-number conservation à la PYTHIA

→ Is this the discrepancy we are after?

- Other baryon number conservation models closer to data
- Work ongoing to have a direct comparison between LQCD EOS and the net-proton results

A. Bazavov et al., Phys. Rev. D 101, 074502 (2020)

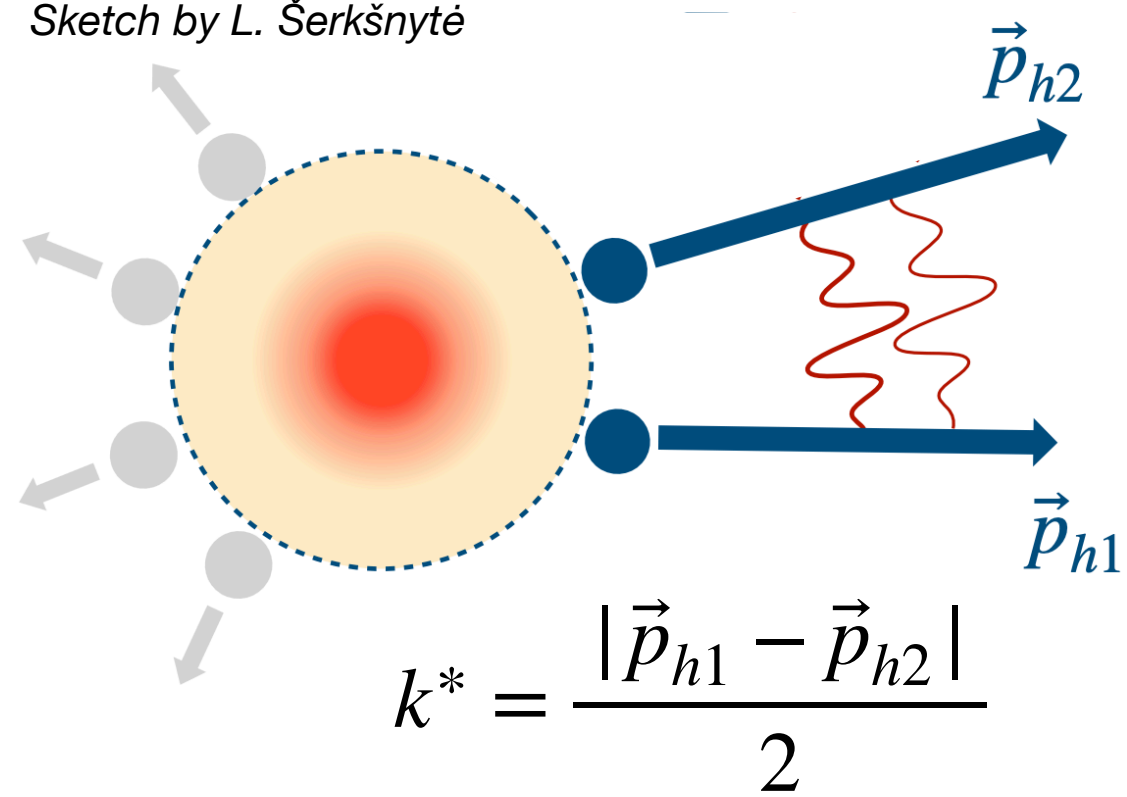


ALI-PREL-623357

Hadronic scale: strong interactions between hadrons

Momentum correlations as a gateway to interactions

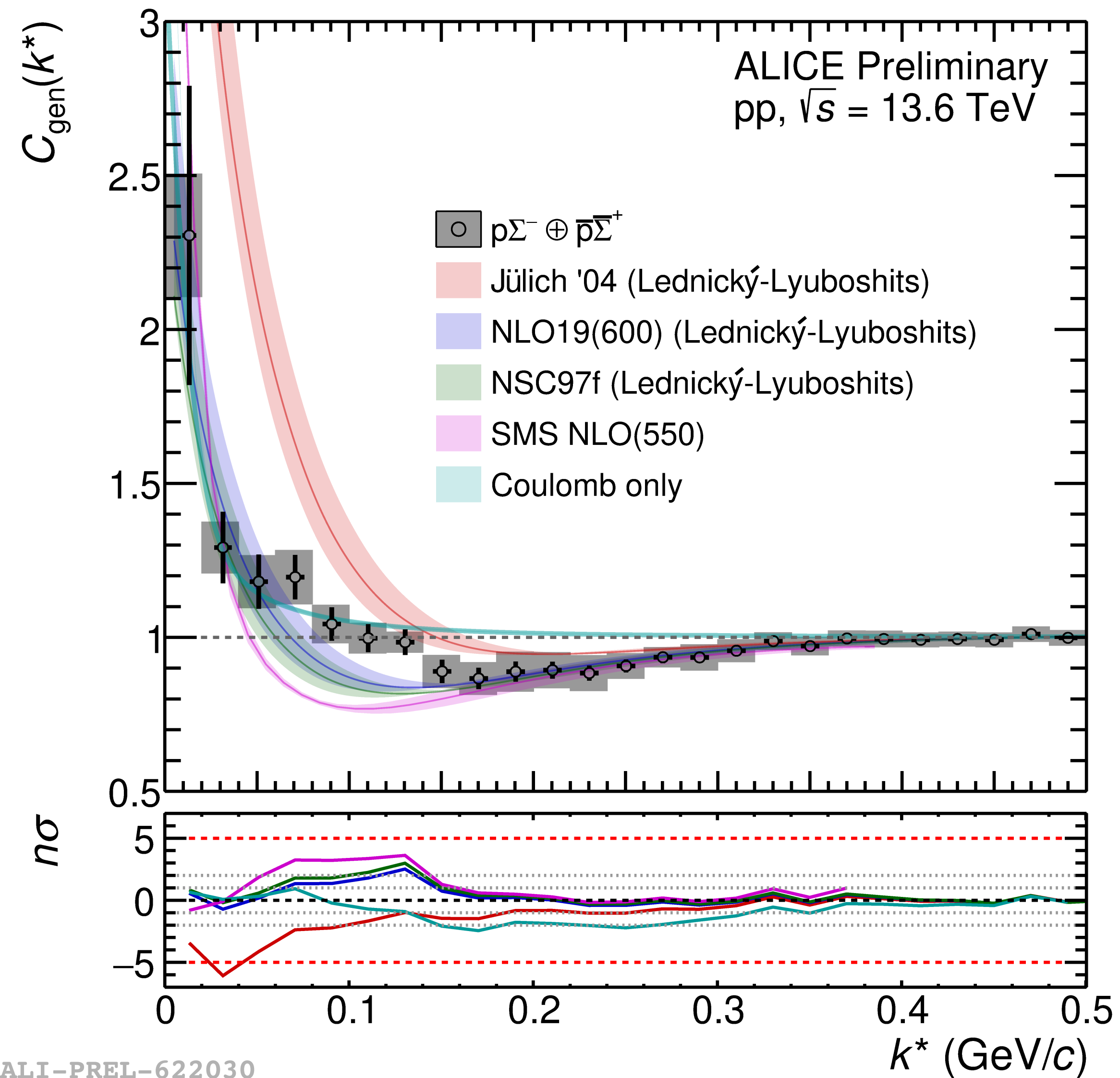
Sketch by L. Šerkšnytė



2-particle correlations are sensitive to the nature of the interactions among the particles:

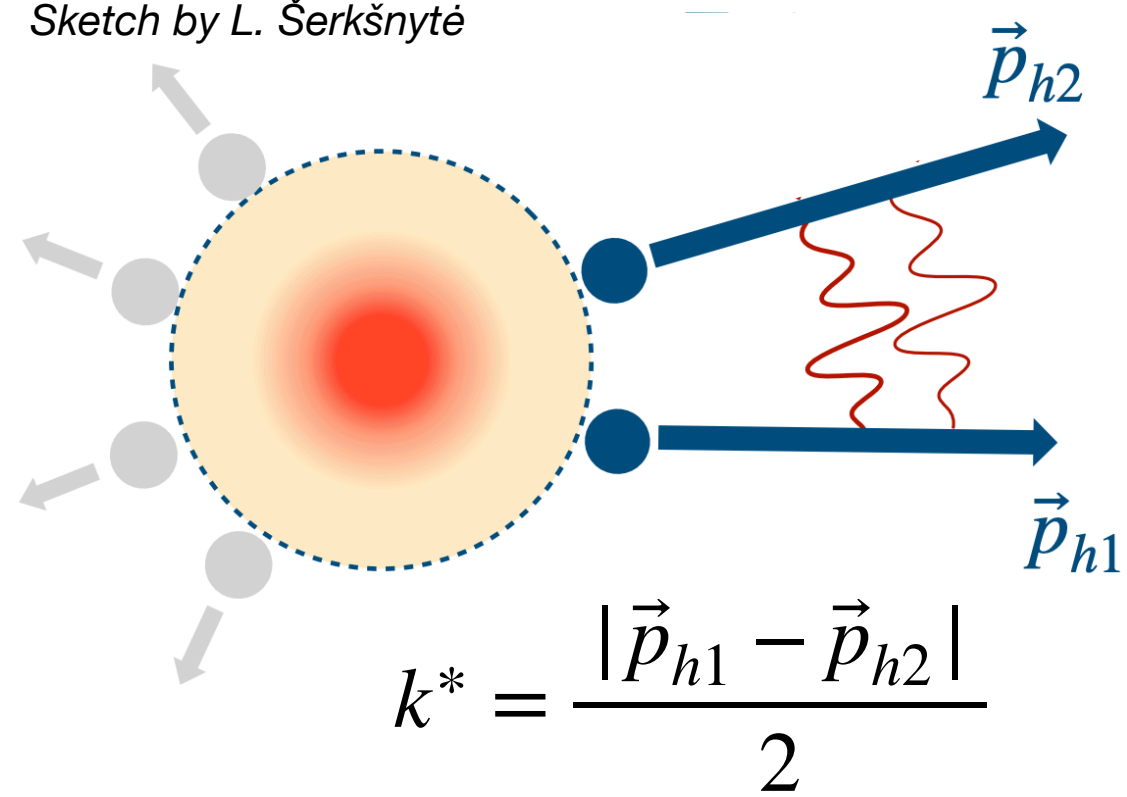
$$C(k^*) = \mathcal{N} \frac{N_{\text{same}}}{N_{\text{mixed}}} = \int S(r) |\Psi(k^*, r)|^2 d^3r$$

If $C(k^*) > 1$ attraction, otherwise repulsion



Momentum correlations as a gateway to interactions

Sketch by L. Šerkšnytė



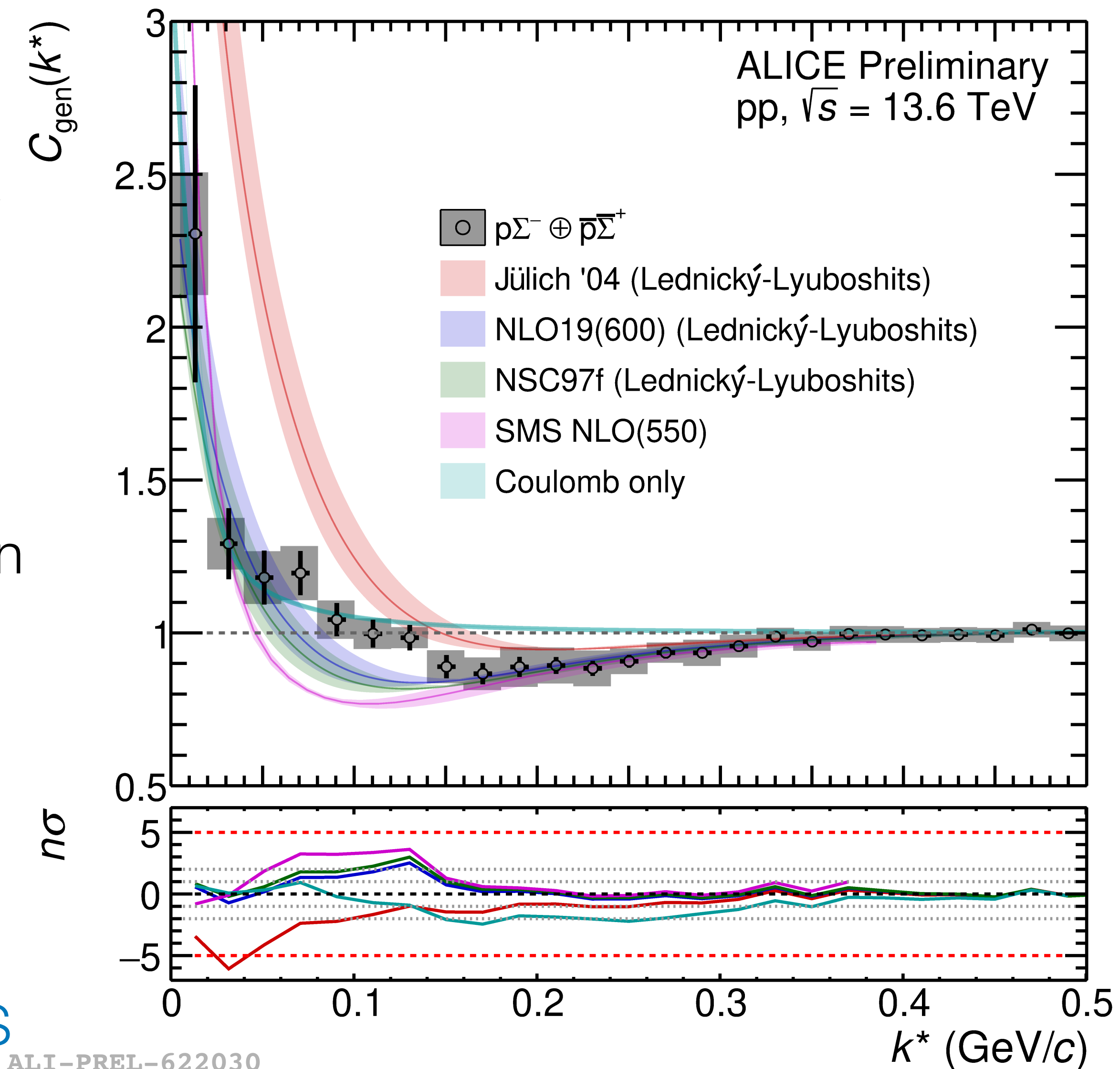
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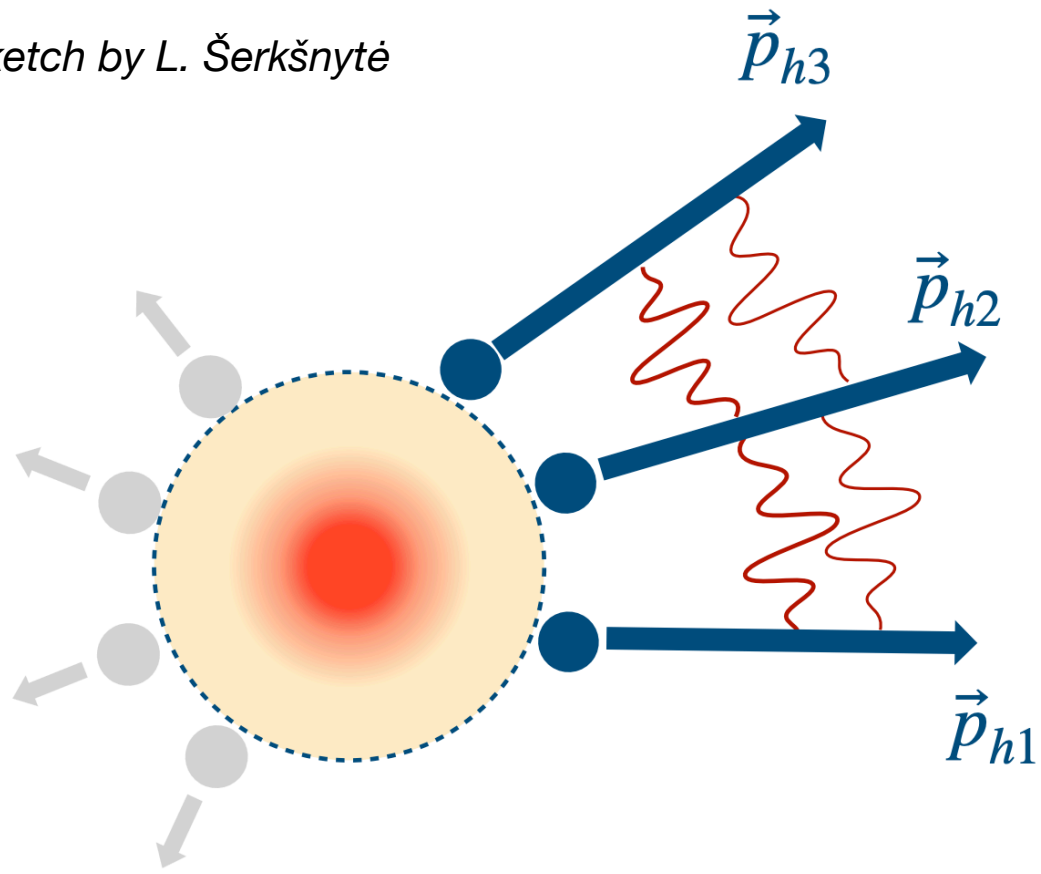
First measurement of the $p\Sigma^-$ correlation

- $\Sigma^- \rightarrow n\pi^-$ reconstructed from the kink topology in the ITS volume
- Shallow repulsion observed on top of the coulomb baseline
- Key input to the strong force modeling among these hadrons
- $N\Sigma$ interactions relevant for the **Neutron Star EOS**



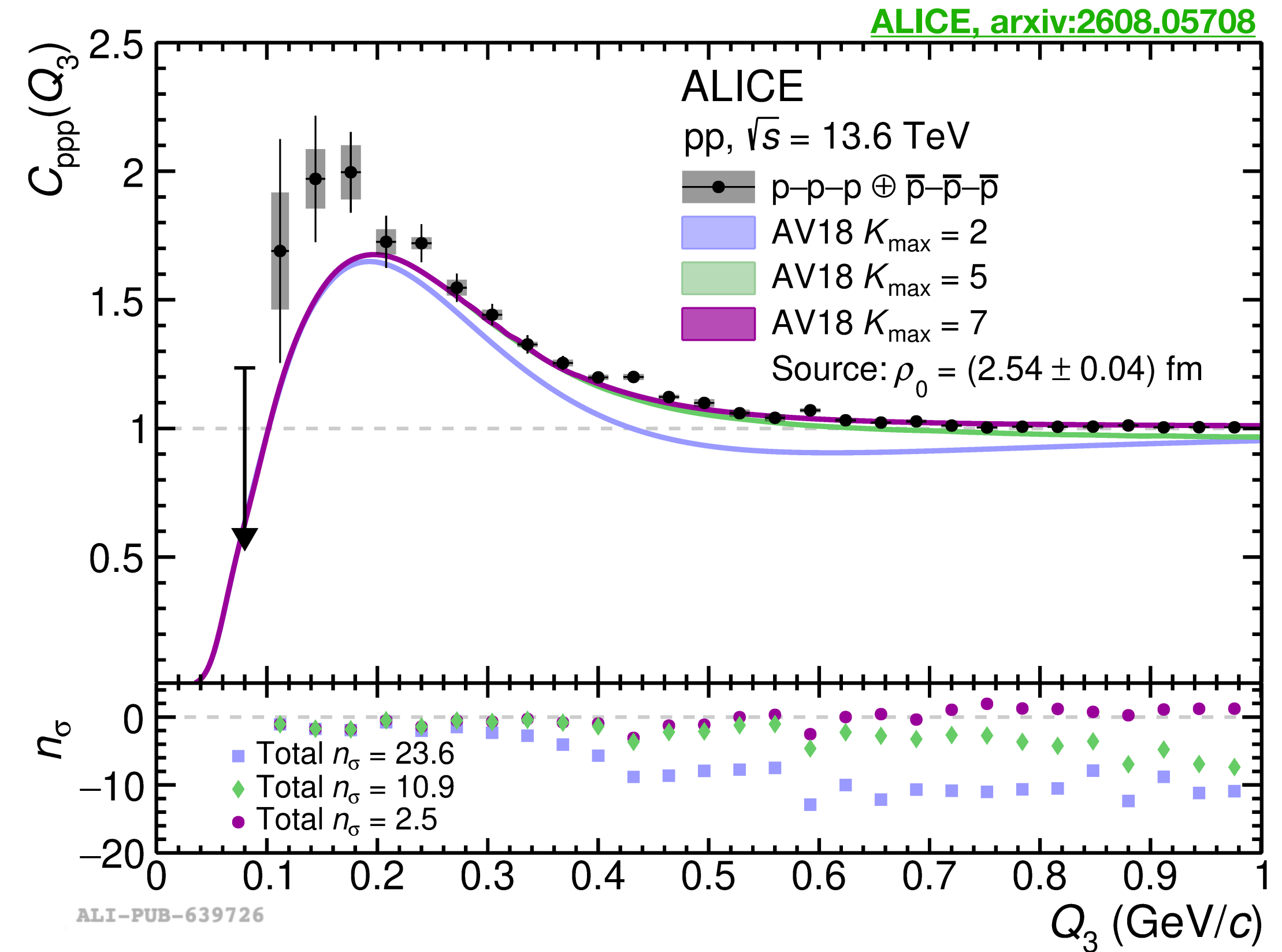
Extending interaction studies to 3-body interactions

Sketch by L. Šerkšnytė



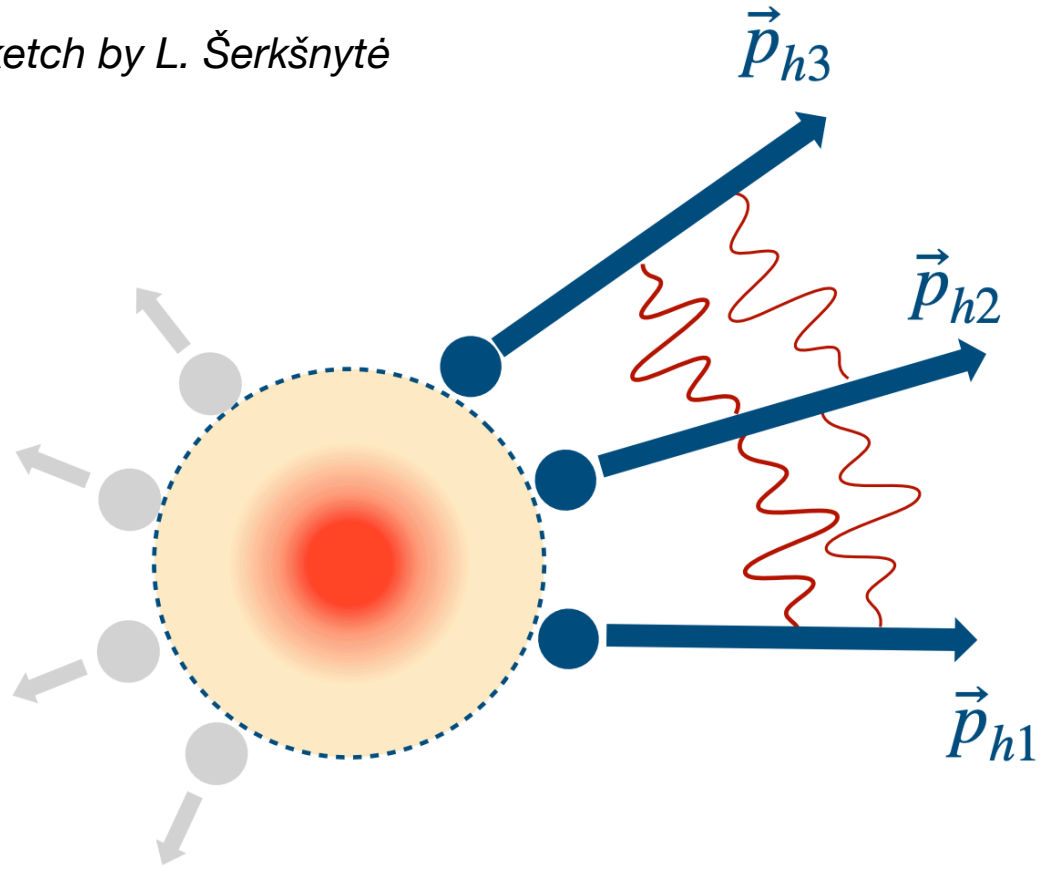
3-particle femtoscopy turns collisions at LHC into an effective $3 \rightarrow 3$ scattering experiment

$$Q_3 = \sqrt{-q_{12}^2 - q_{13}^2 - q_{23}^2}$$



Extending interaction studies to 3-body interactions

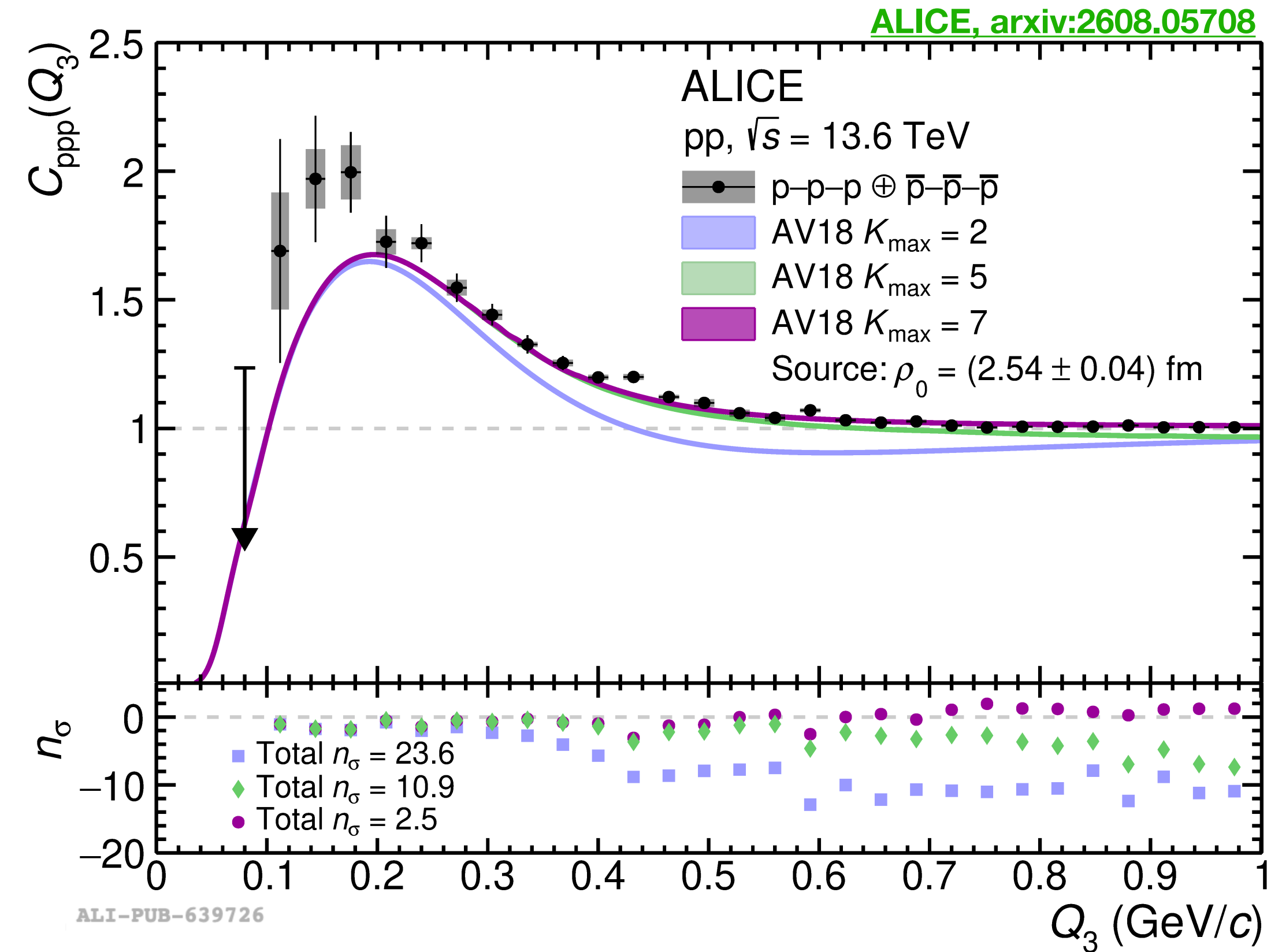
Sketch by L. Šerkšnytė



3-particle femtoscopy turns collisions at LHC into an effective $3 \rightarrow 3$ scattering experiment

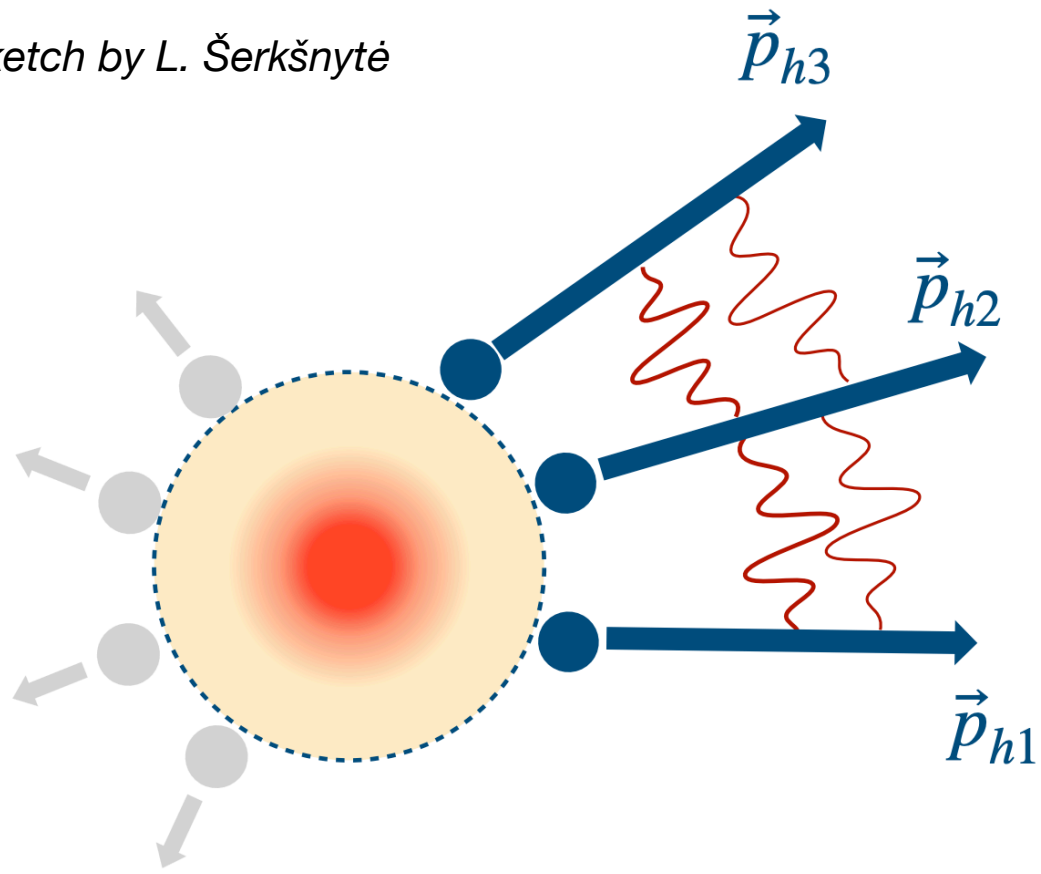
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Another poorly constrained ingredient in NS EOS modeling are the effective 3-body interactions



Extending interaction studies to 3-body interactions

Sketch by L. Šerkšnytė

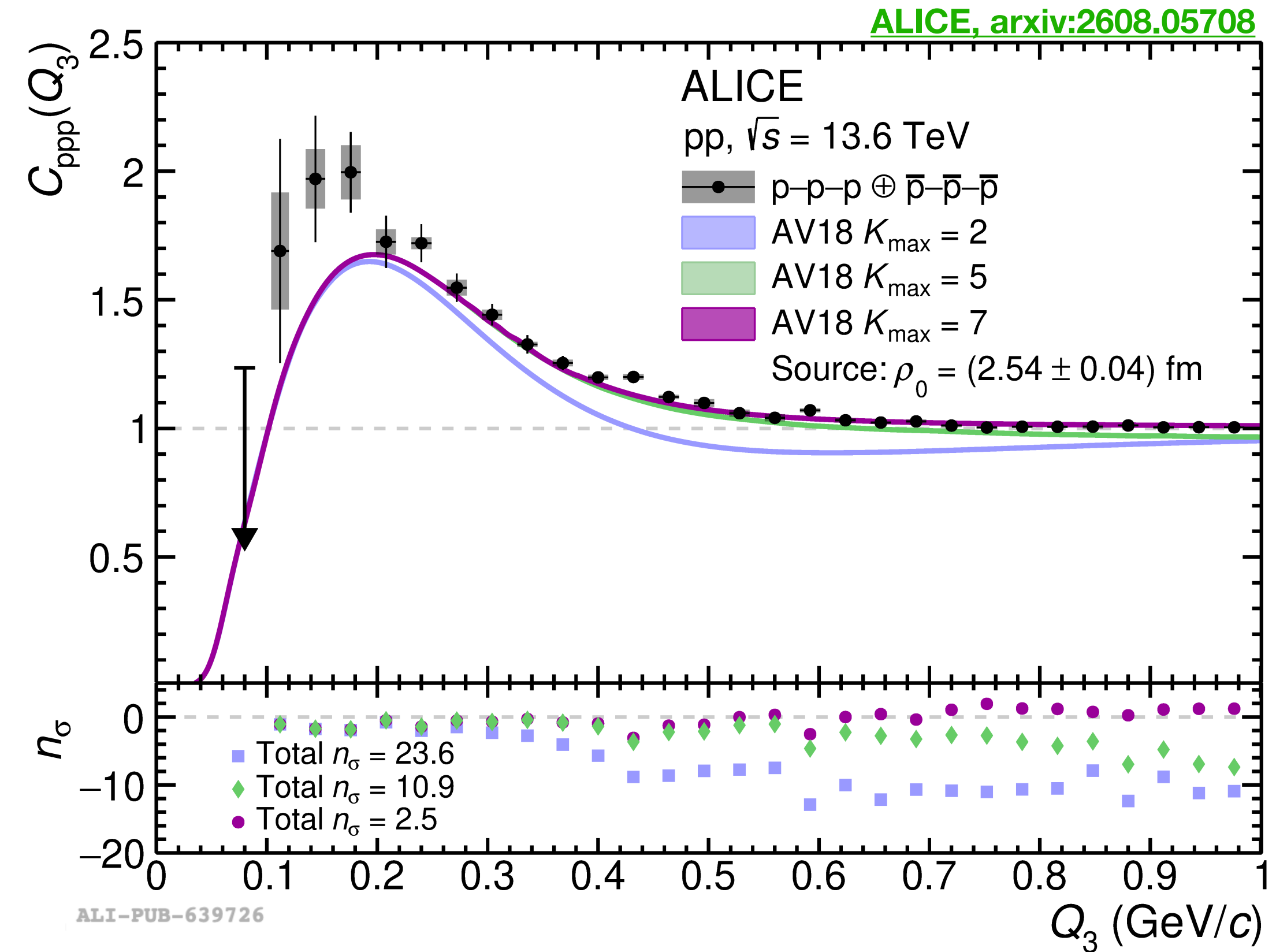


3-particle femtoscopy turns collisions at LHC into an effective $3 \rightarrow 3$ scattering experiment

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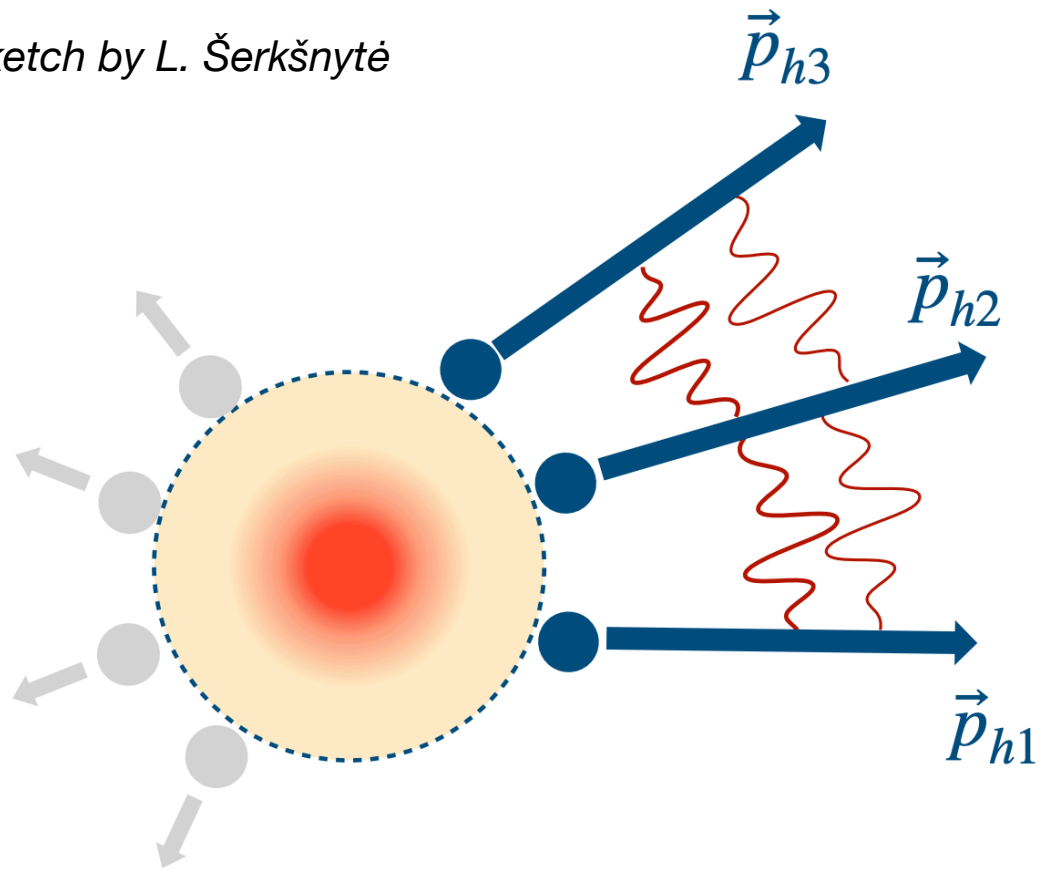
Another poorly constrained ingredient in NS EOS modeling are the effective 3-body interactions

- Direct access to $l=3/2$ component of the unbound 3 nucleons system



Extending interaction studies to 3-body interactions

Sketch by L. Šerkšnytė



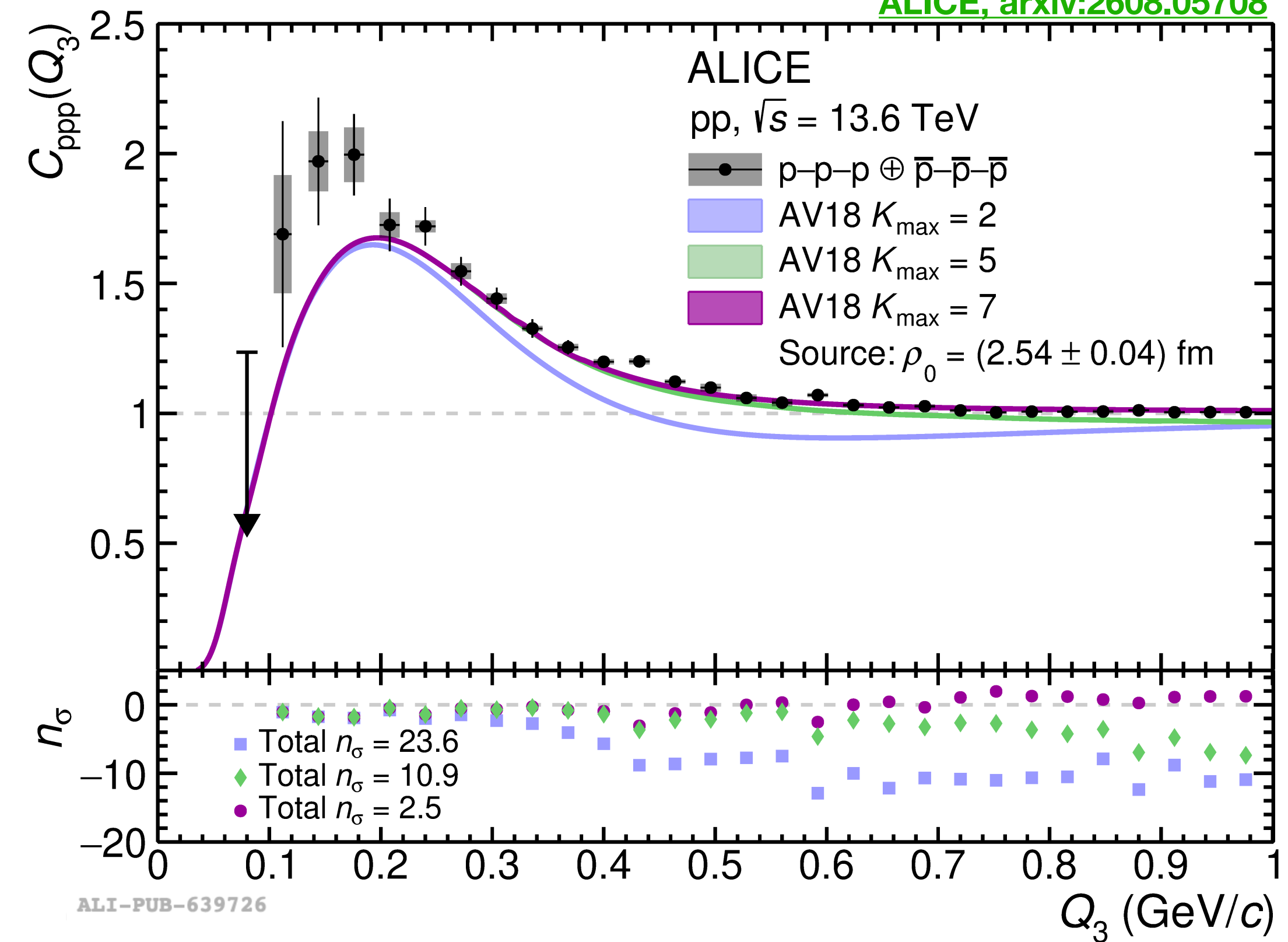
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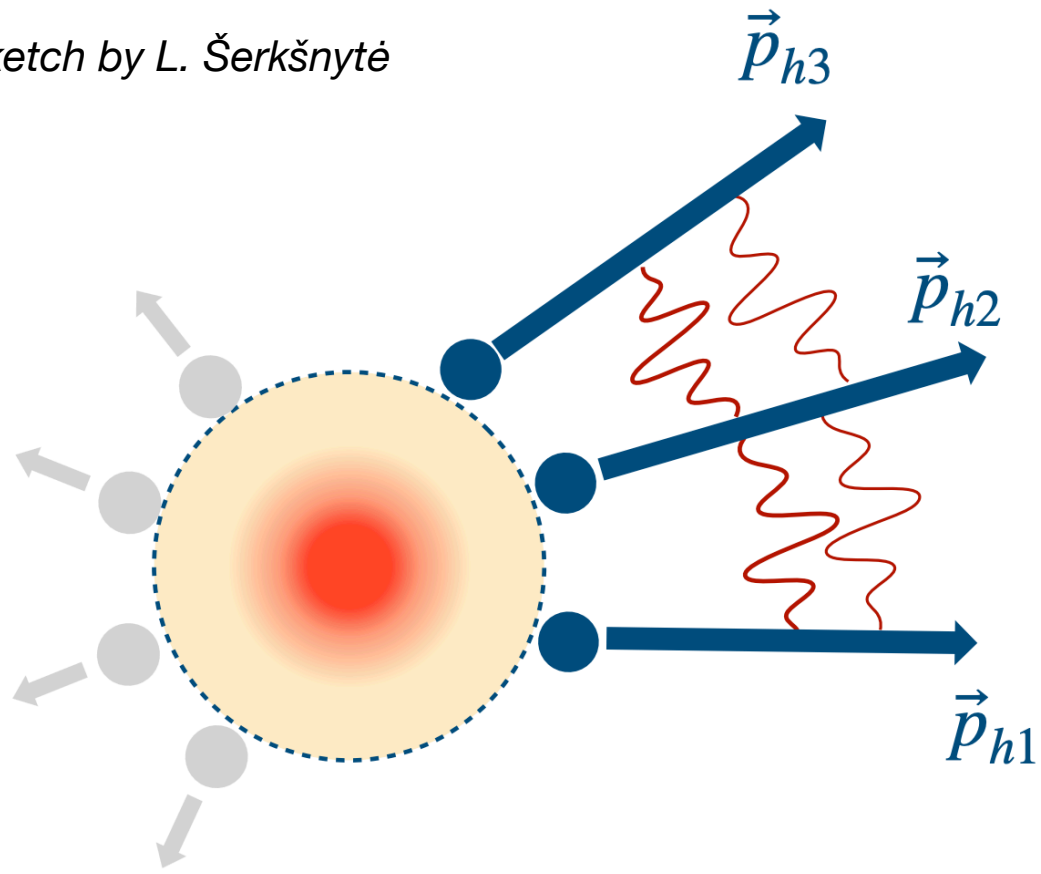
- Direct access to $l=3/2$ component of the unbound 3 nucleons system
- 3-particle attraction from pairwise interactions

ALICE, arxiv:2608.05708



Extending interaction studies to 3-body interactions

Sketch by L. Šerkšnytė

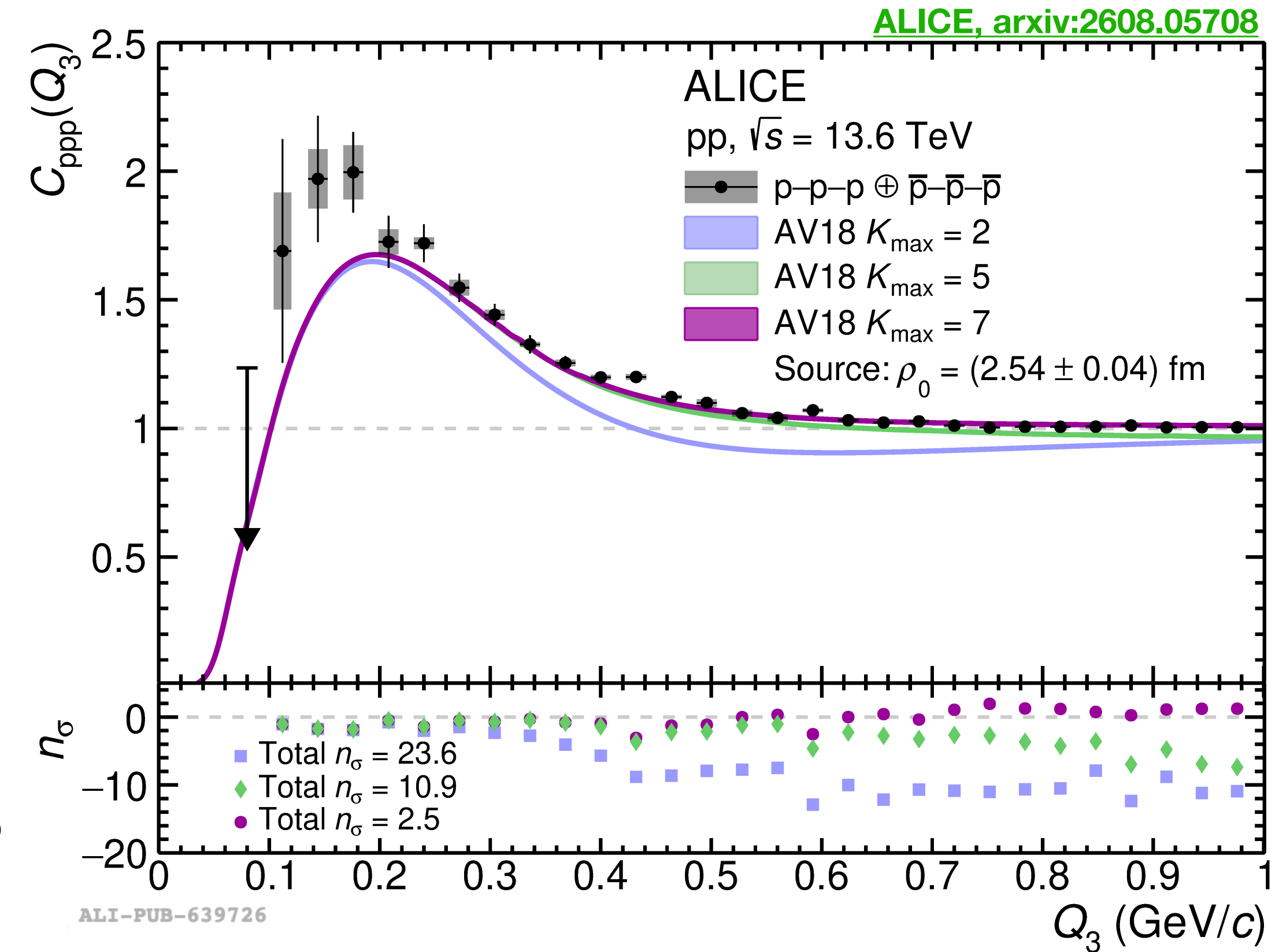


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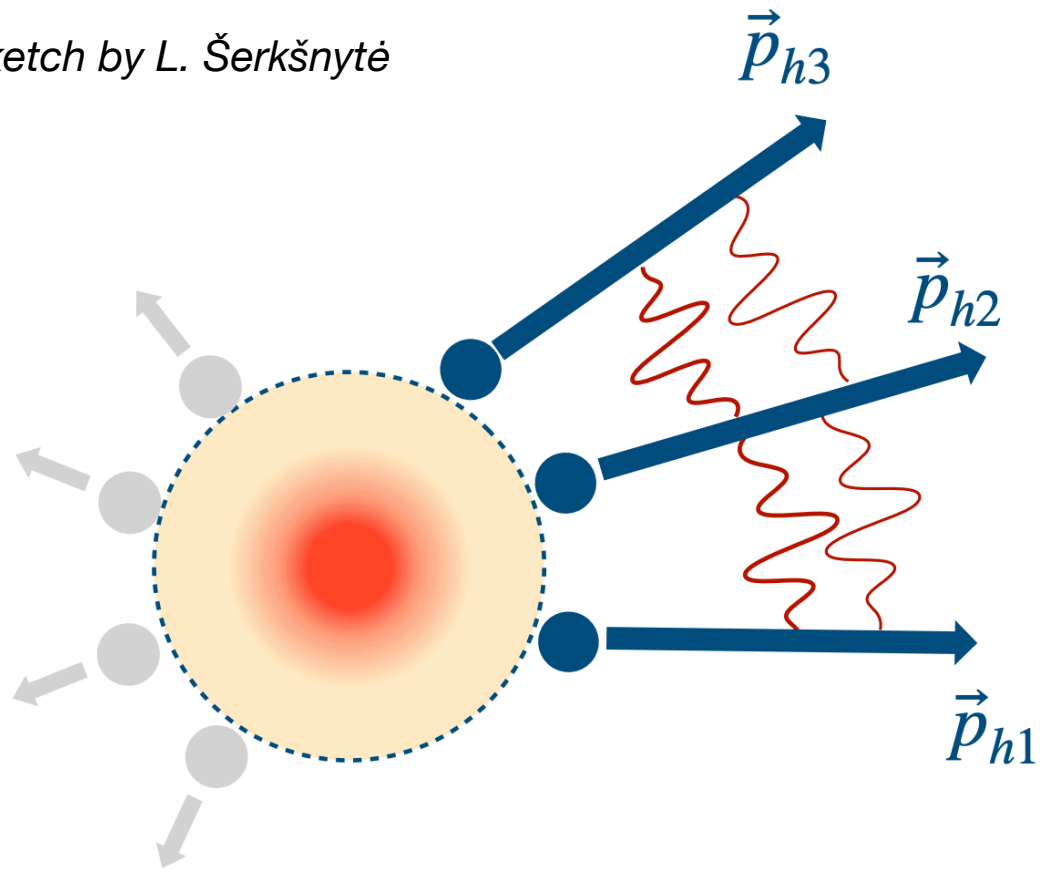
- Direct access to $l=3/2$ component of the unbound 3 nucleons system
- 3-particle attraction from pairwise interactions
 - High 3-body angular momenta are needed to reproduce the data



	$l = 0/K = 0$	$l = 1/K = 1$	$l = 2/K = 2$	$l > 2/K > 2$
Two body	 $J^P = 0^+$	 $J^P = 0^-, 1^-, 2^-$	 $J^P = 2^+$	...
Three body ($K = l_x + l_y + 2n$)	 $l_x=0, l_y=0$ Forbidden	 $l_x=0, l_y=1$ $l_x=1, l_y=0$ $J^P = 1/2^-, 3/2^-$	 $l_x=0, l_y=2$ $l_x=2, l_y=0$ $J^P = 1/2^+, 3/2^+, 5/2^+$	...

Extending interaction studies to 3-body interactions

Sketch by L. Šerkšnytė

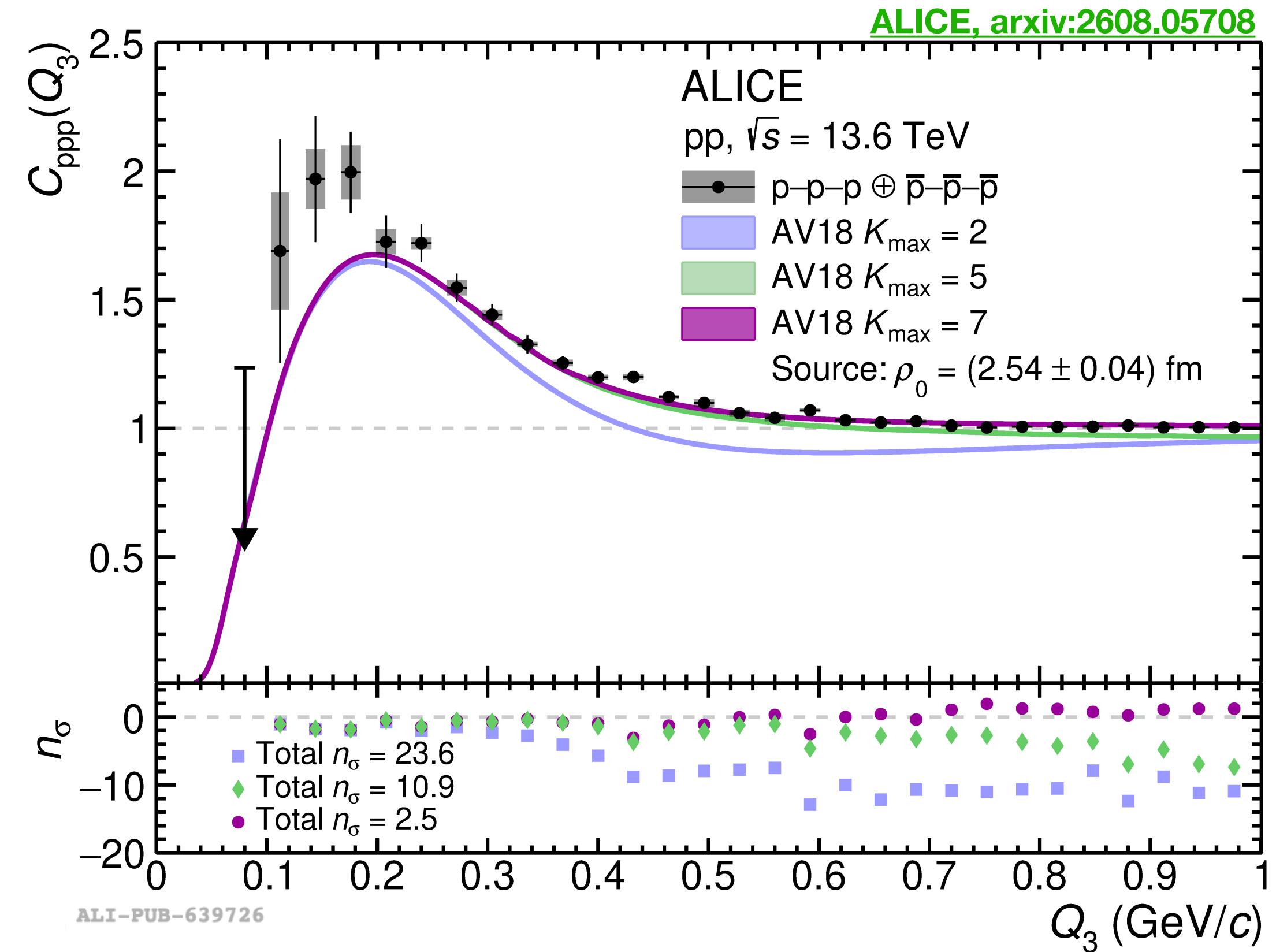


3-particle femtoscopy turns collisions at LHC into an effective $3 \rightarrow 3$ scattering experiment

$$Q_3 = \sqrt{-q_{12}^2 - q_{13}^2 - q_{23}^2}$$

Another poorly constrained ingredient in NS EOS modeling are the effective 3-body interactions

- Direct access to $l=3/2$ component of the unbound 3 nucleons system
- 3-particle attraction from pairwise interactions
 - High 3-body angular momenta are needed to reproduce the data
- Opens a route to constraining genuine three-body forces in future measurements.

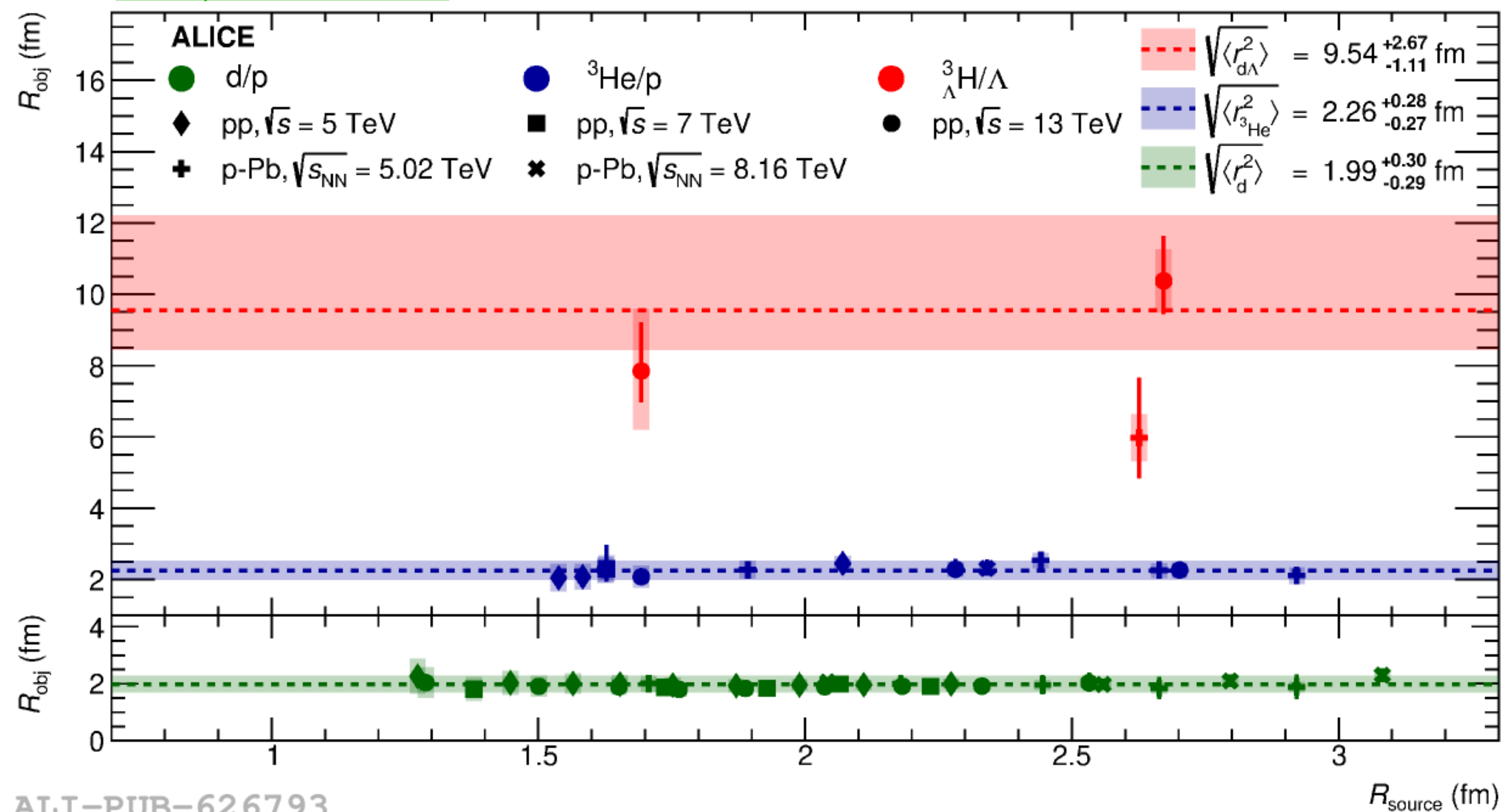


	$l = 0/K = 0$	$l = 1/K = 1$	$l = 2/K = 2$	$l > 2/K > 2$
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Sensitivity to (hyper)nuclear structure

Production cross section of hypernuclei at the LHC is sensitive to their structure

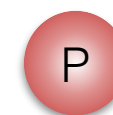
ALICE, [arxiv:2604.07949](https://arxiv.org/abs/2604.07949)



Fitting the production cross section with the RMS radius of the nucleus as a free parameter:

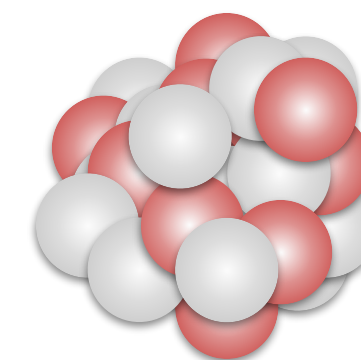
- ▶ Deuteron and ^3He charge radii are well reproduced with this technique
- ▶ First extraction of the $^3_\Lambda\text{H}$ radius

Proton



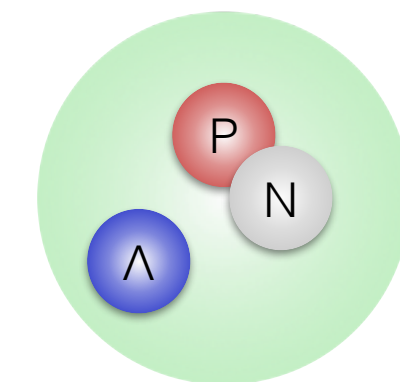
$R \sim 0.8$ fm

Copper



$R \sim 5$ fm

$^3_\Lambda\text{H}$

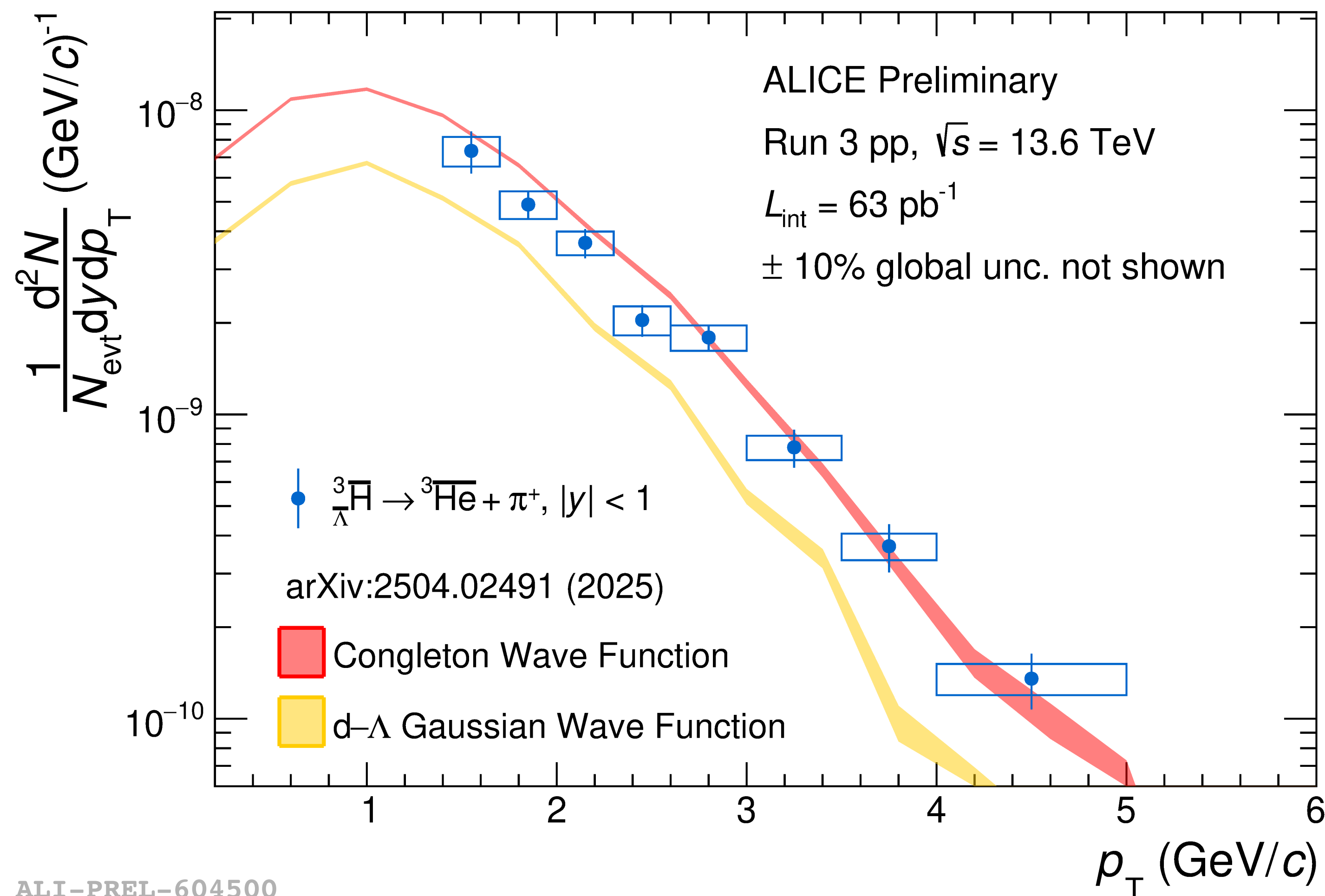


$R_{d\Lambda} \sim 9.5$ fm

Halo nucleus: wide $d\Lambda$ molecule

Sensitivity to (hyper)nuclear structure

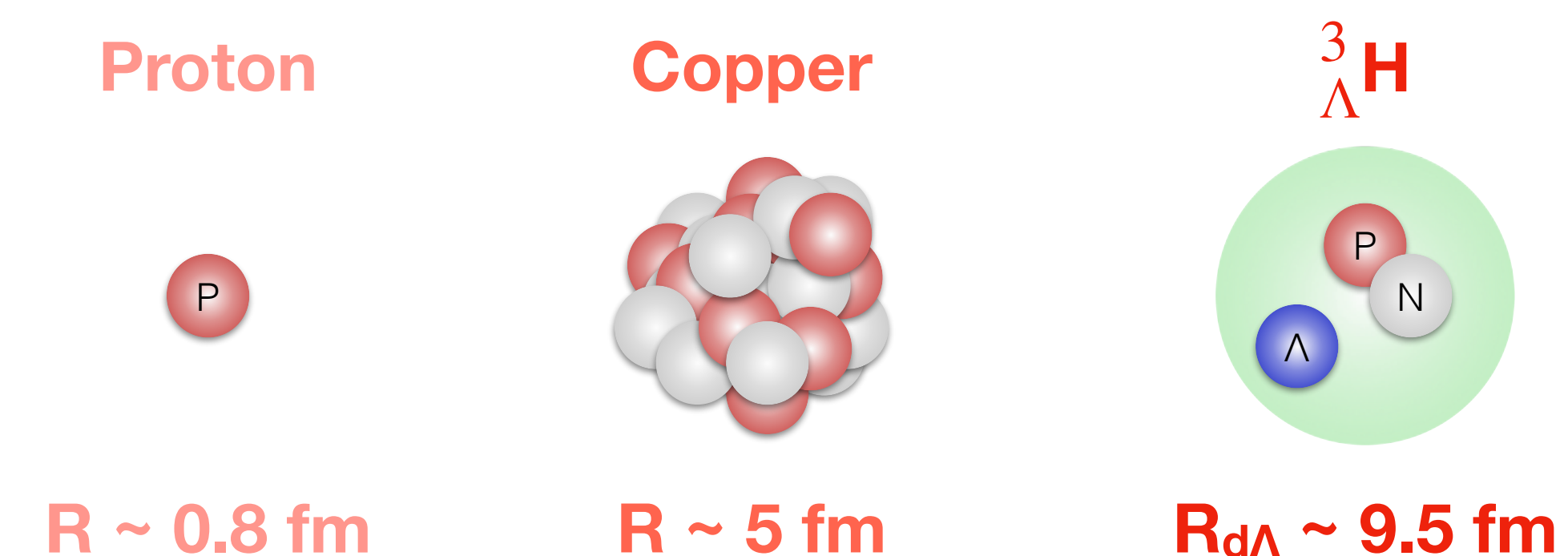
Production cross section of hypernuclei at the LHC is sensitive to their structure



ALI-PREL-604500

Fitting the production cross section with the RMS radius of the nucleus as a free parameter:

- Deuteron and ${}^3\text{He}$ charge radii are well reproduced with this technique
- First extraction of the ${}^3_{\Lambda}\text{H}$ radius



Sensitivity not only to the radius, but also to the wave-function shape through the p_T spectrum.

Halo nucleus: wide d Λ molecule

Summary

- ALICE is working across different scales and flavours of the characterization QCD in different regimes
 - Contributions to the study of hard processes
 - Precision QGP properties determination
 - Determination of the residual strong interaction among hadrons
- ▶ Harvest of the Run 3 results just started
- Stay tuned: upcoming upgrades for Run 4 and Run 5 will significantly widen the scope and performance of ALICE