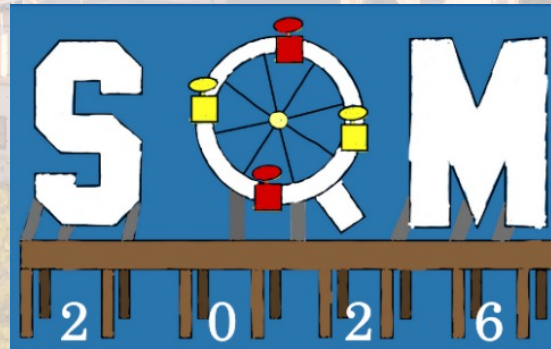


# ALICE highlights: recent results on light flavors

Chiara Pinto on behalf of the ALICE Collaboration  
(CERN)

March 23<sup>rd</sup>, 2026

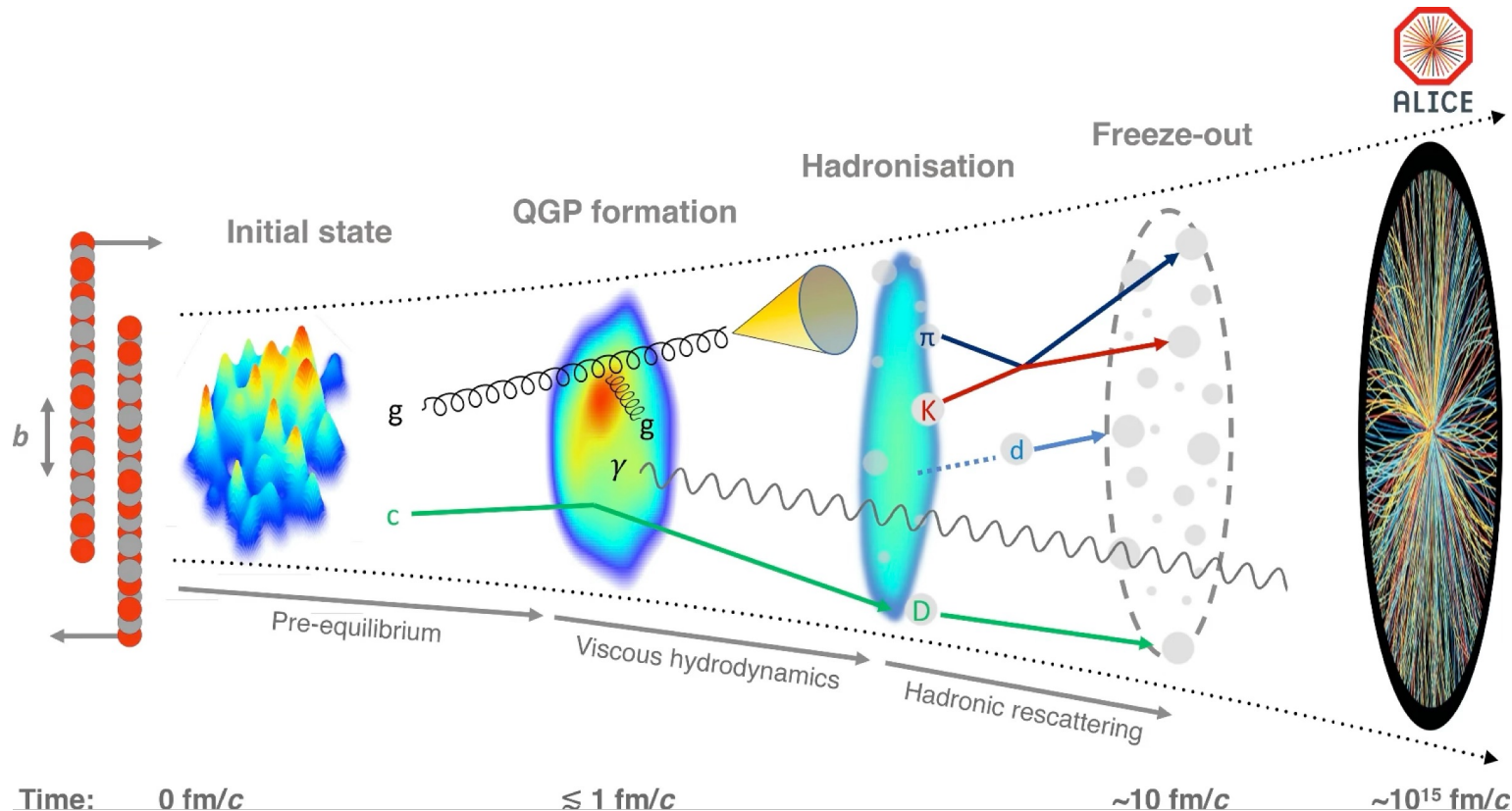


*Los Angeles, USA*  
*March, 23-27<sup>th</sup> 2026*

ALICE investigates the **QGP** and the **stages of heavy-ion collisions** using final-state observables

- Hadronization, hadrochemistry and bulk properties of the medium
- Medium interactions with hard probes
- Hadron spectral shapes and collective effects

**Small systems** serve as both reference and probes of collective-like effects

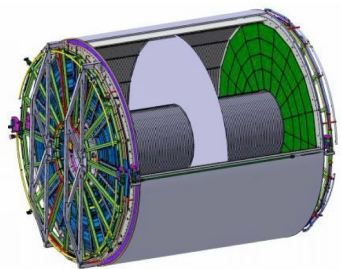


*With LF probes:*

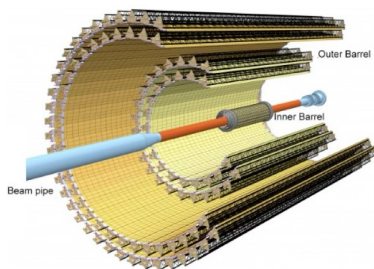
- *How does the system remember its initial geometry and angular momentum?*
- *How do collective flow and bulk medium properties influence flavor-dependent hadron production?*
- *How do the most weakly bound objects, i.e., (hyper)nuclei, form?*

## Major upgrades during LS2

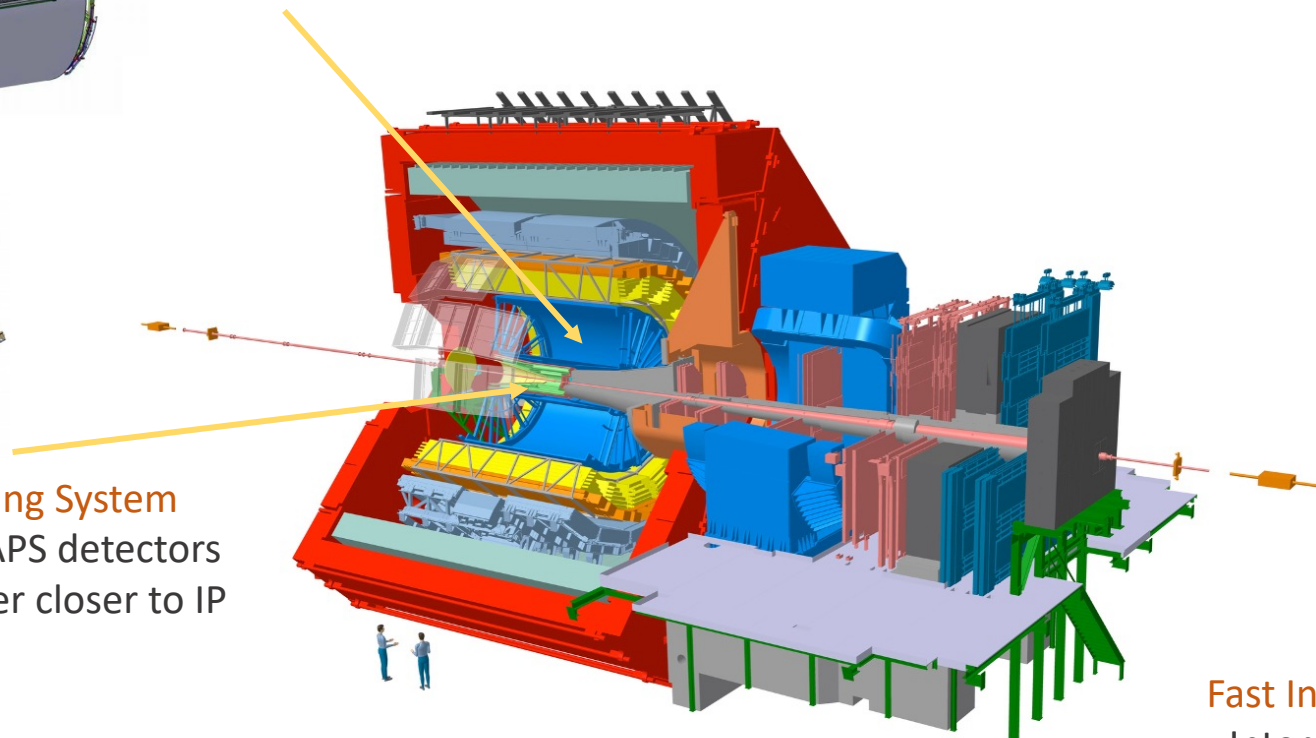
Readout upgraded for all key detectors to allow continuous readout



Time Projection Chamber (TPC)  
GEM readout chambers



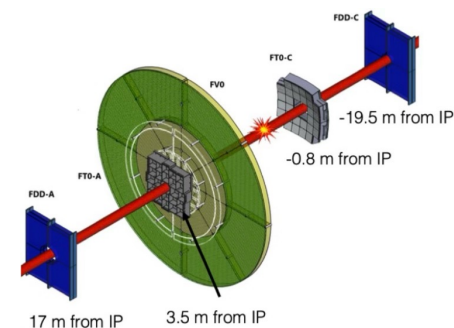
Inner Tracking System  
7 layers of MAPS detectors  
Innermost layer closer to IP



- excellent tracking & PID capabilities over a broad  $p$  range
- low material budget

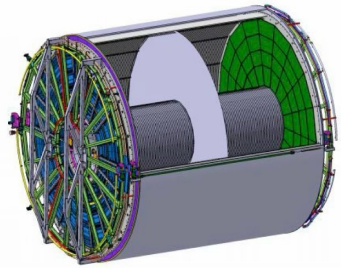
→ *ideal detector at the LHC for light-flavor particle measurements*

Fast Interaction Trigger (FIT)  
Interaction trigger, online  
luminometer  
Forward multiplicity  
estimator

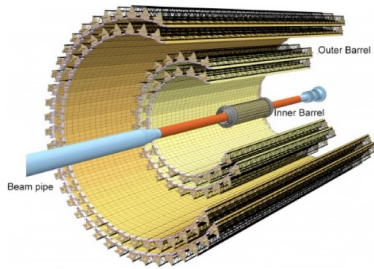


## Major upgrades during LS2

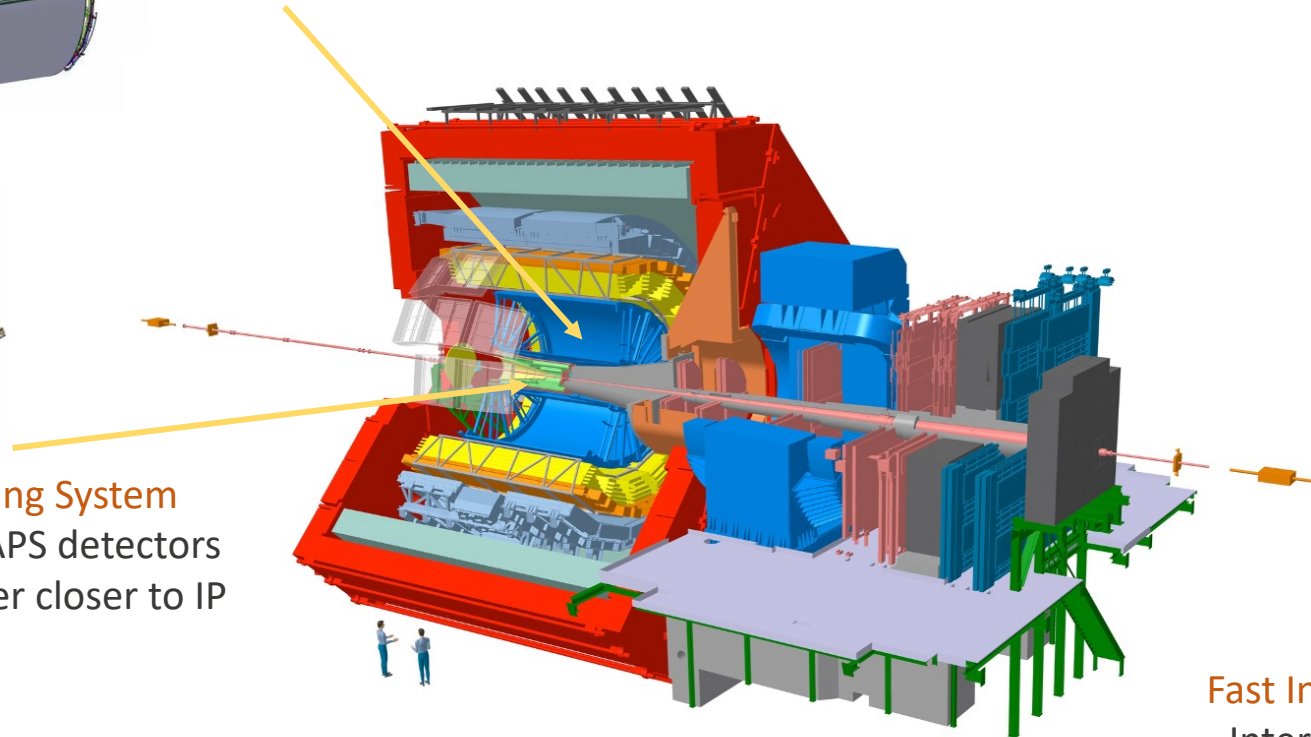
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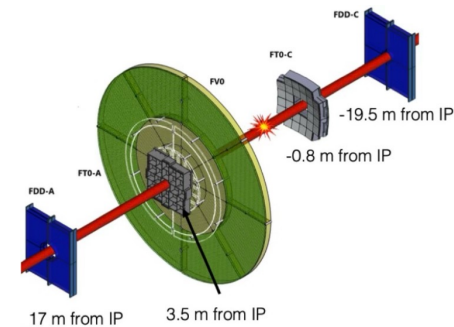
	MB events	
	Run 3	Run 3 wrt Run 1+2
pp	$\sim 8 \times 10^{12}$	$\times 10^2 - 10^3$
Pb—Pb	$\sim 40 \times 10^9$	$\times 120$

+ first light ion runs in 2025!  
(pO, OO, Ne—Ne)

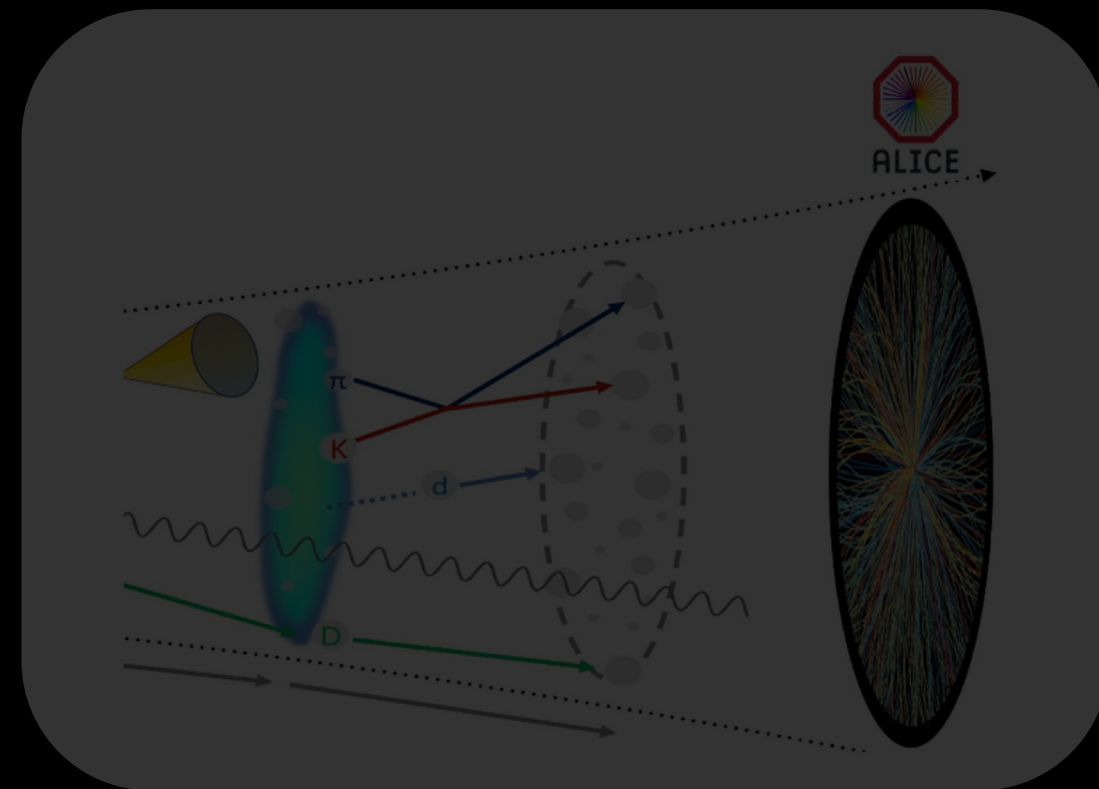
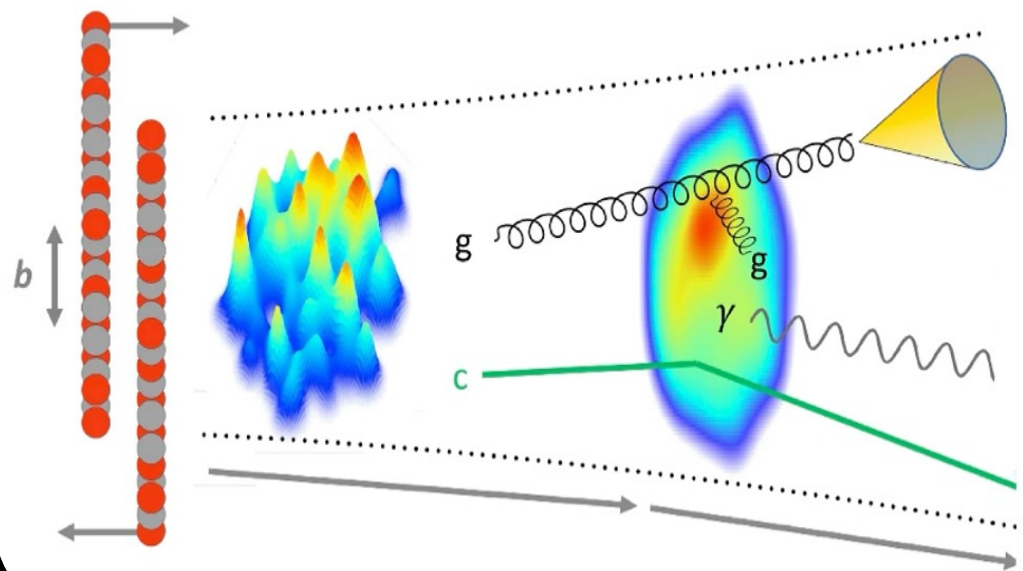
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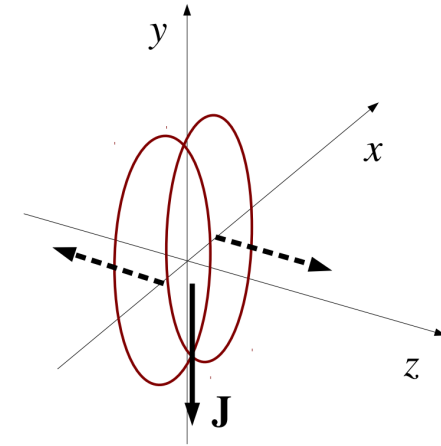


### Initial state and QGP evolution



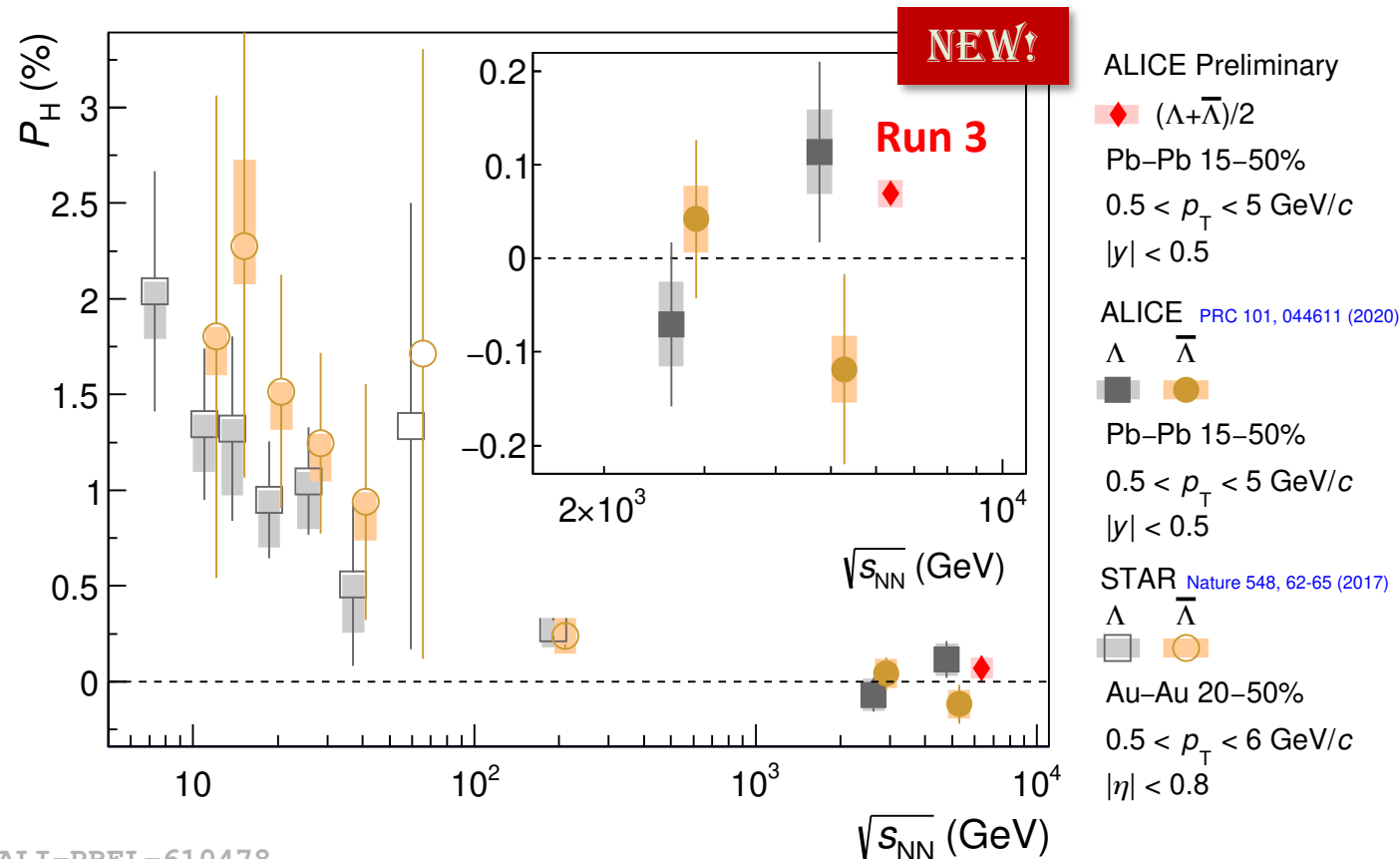
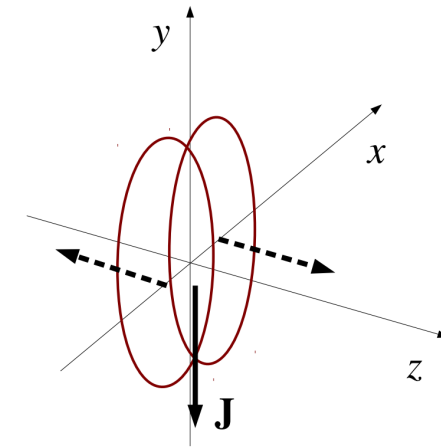
- Non-central heavy-ion collision  $\rightarrow$  overlap region carries **large orbital angular momentum**
- If the produced QCD matter is vortical, part of that initial orbital angular momentum can be transferred to **final-state particle spin**
- **$\Lambda$  hyperons** are ideal because their parity-violating weak decay allows for the reconstruction of their spin orientation experimentally

 Becattini et al., *EPJC* 75 (2015) 9, 406



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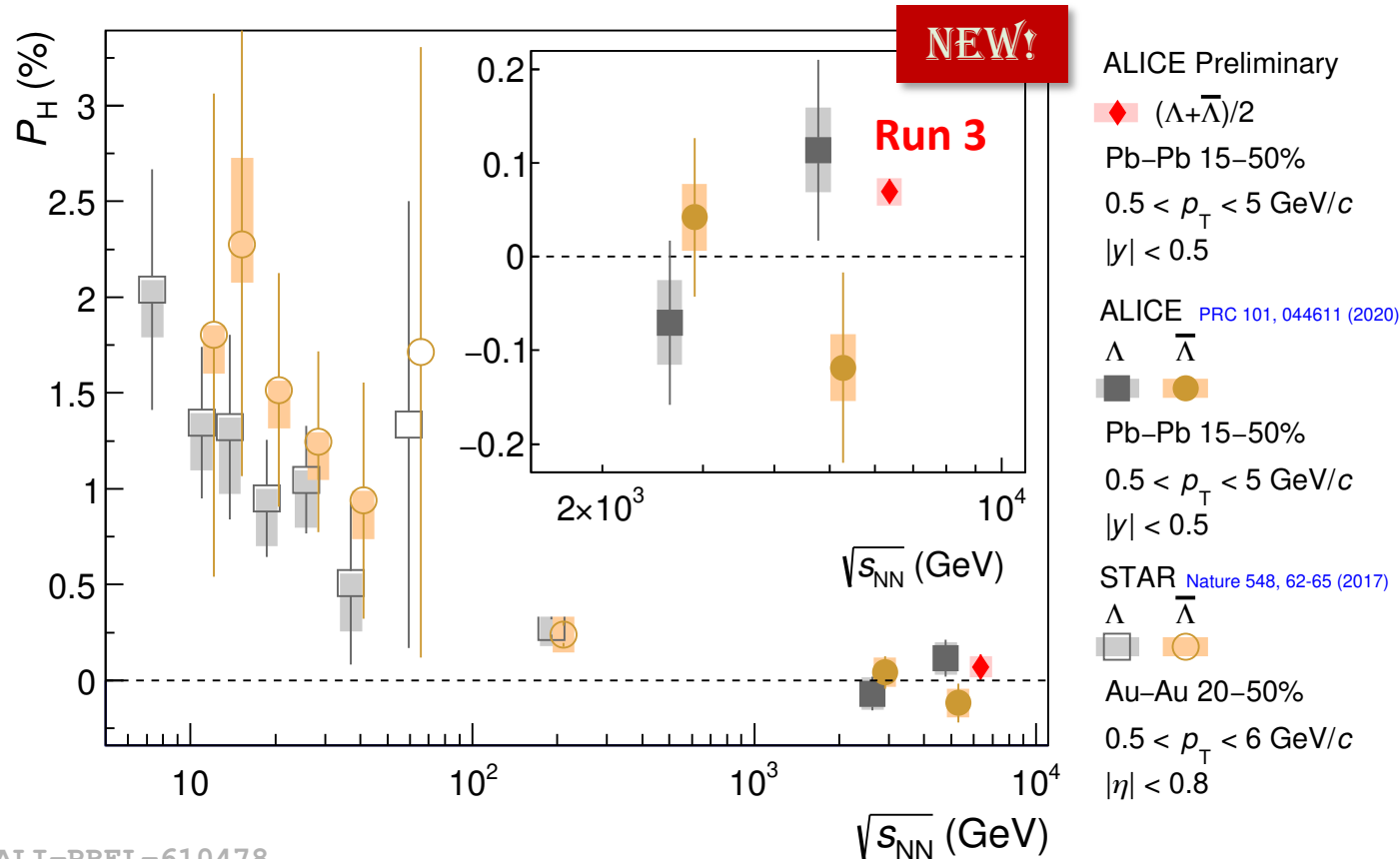
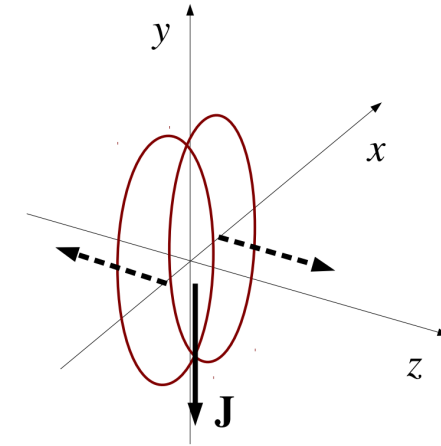
 Becattini et al., *EPJC* 75 (2015) 9, 406



- Global polarization of average (anti) $\Lambda$  is **positive**
- Global polarization decreasing with increasing collision energy (due to higher baryon transparency at higher collision energies)

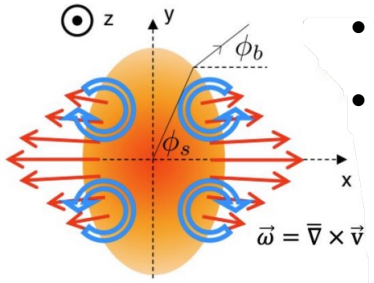
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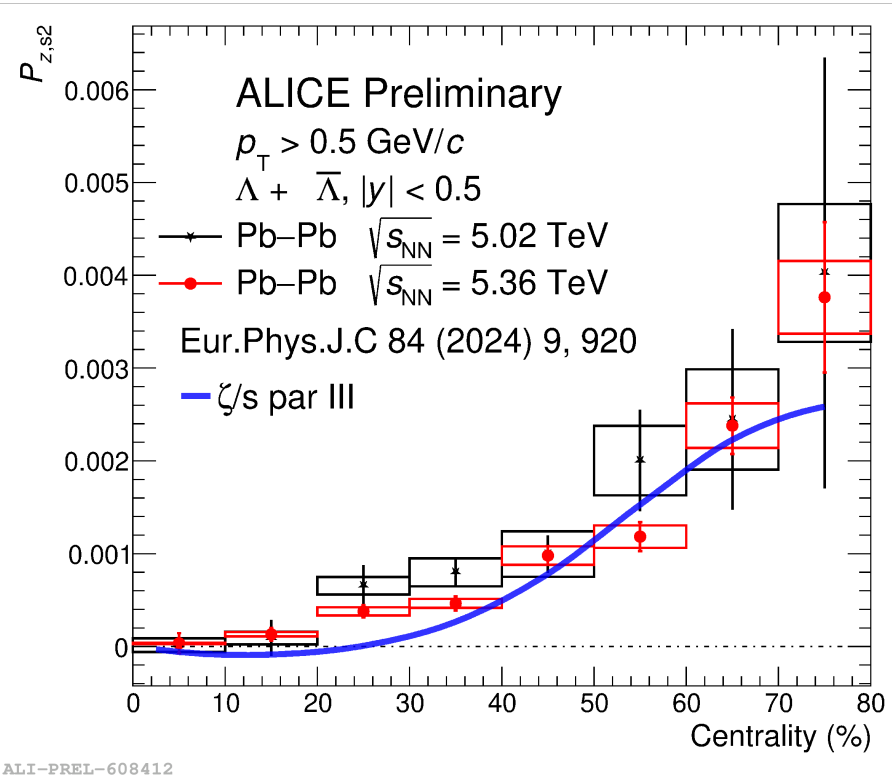
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What else can we learn from polarization?

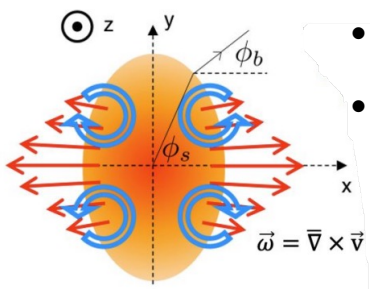


→ Expansion velocity  
↻ Local vorticities induced by elliptic flow

- Local asymmetries in velocity fields—driven by elliptic flow—generate non-zero longitudinal polarization
- ALICE has measured the  $\Lambda$  longitudinal polarization ( $P_{z,s2}$ ) in Pb–Pb collisions in Run 2 & Run 3



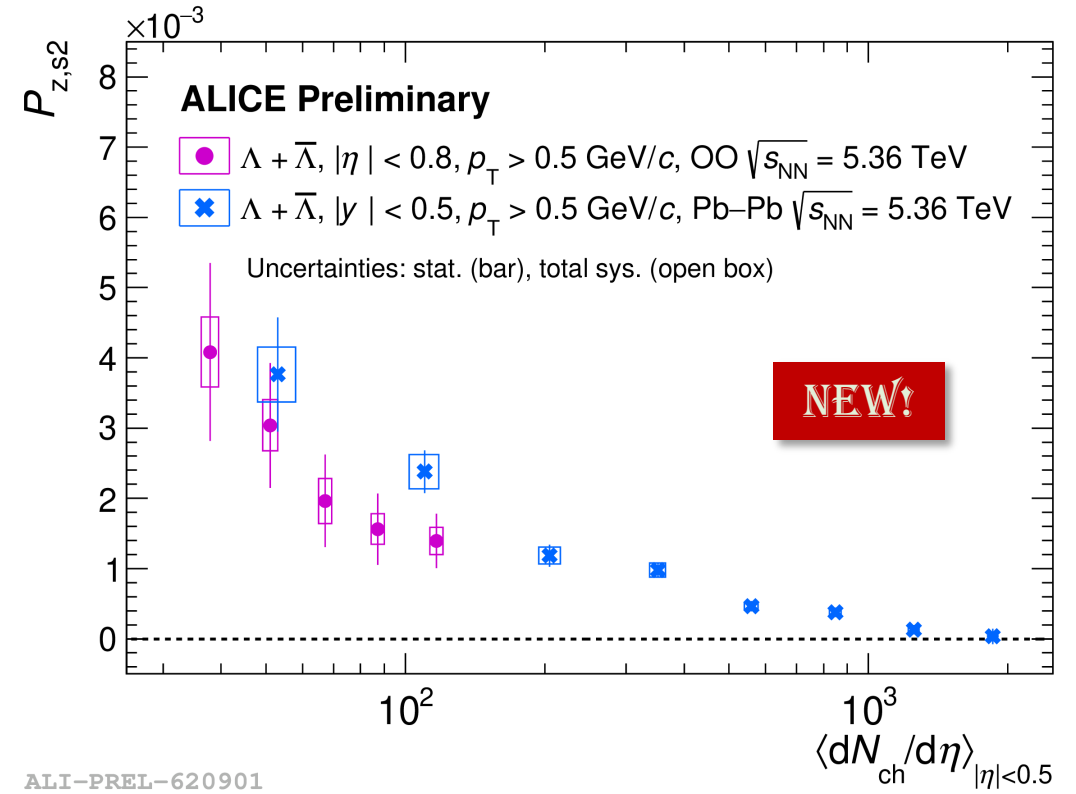
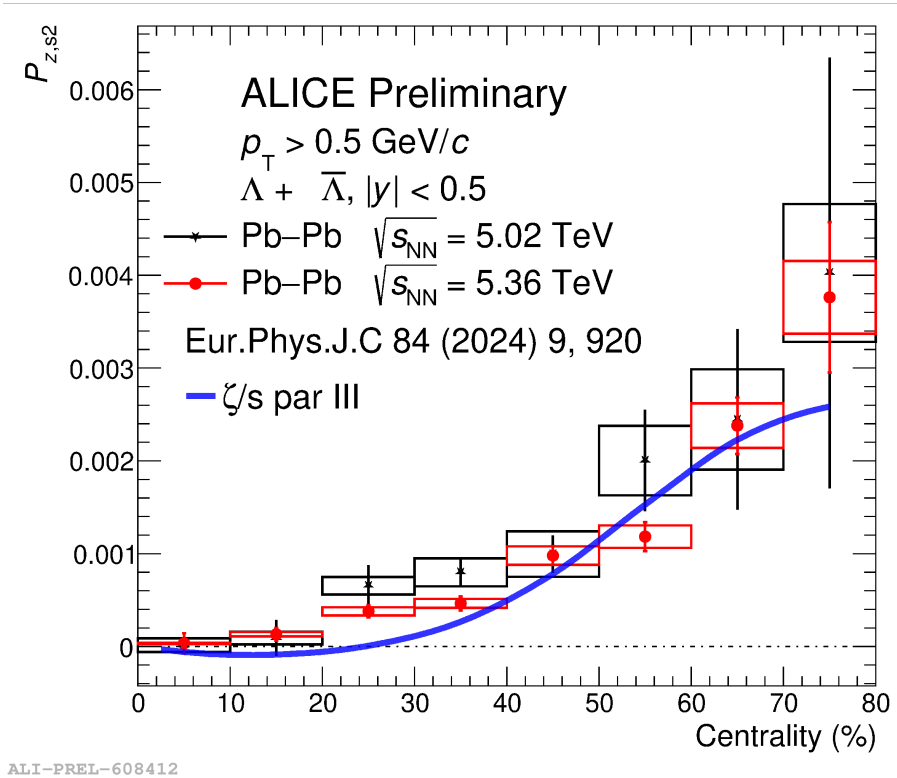
ALI-PREL-608412



→ Expansion velocity  
 ↻ Local vorticities induced by elliptic flow

First measurement of  $P_{z,s2}$  of  $\Lambda$  in OO collisions  
 → pending model comparison to infer bulk viscosity of the medium

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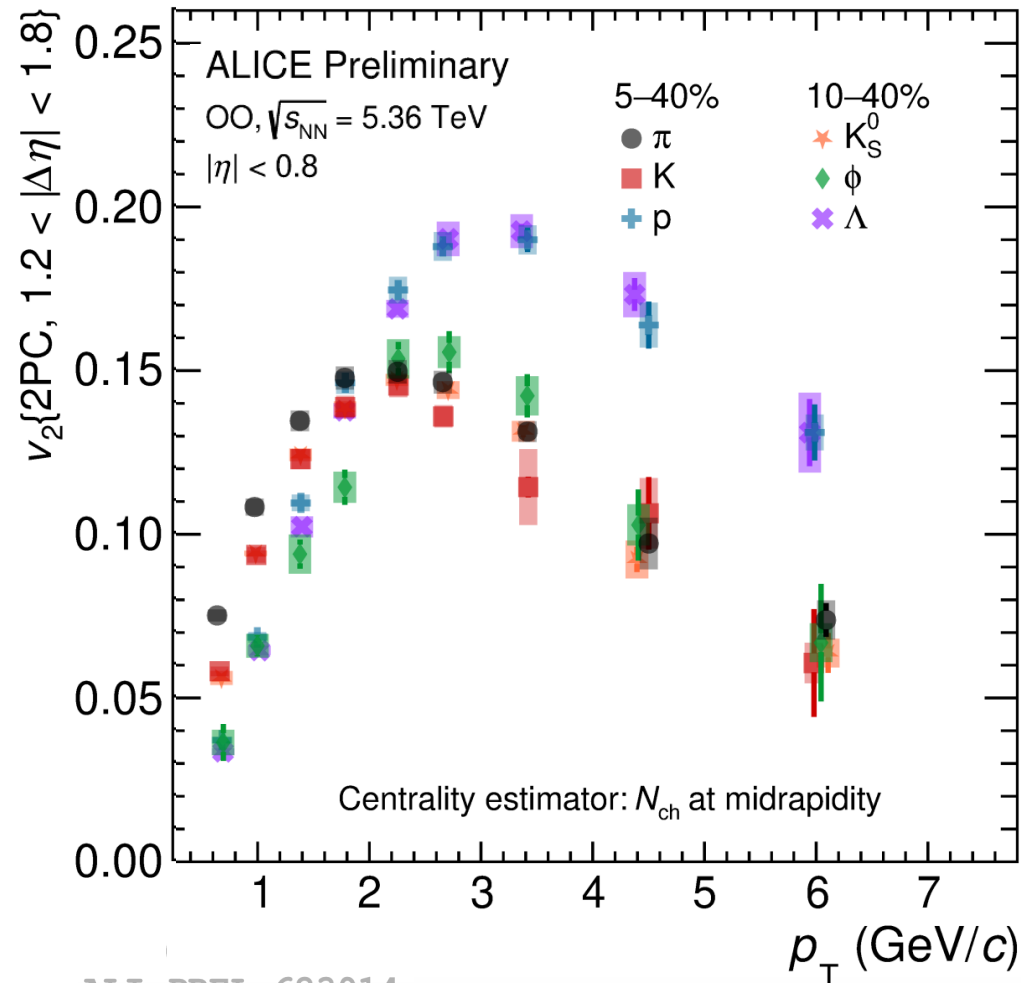


In OO collisions a **positive  $\Lambda$  longitudinal polarization** is observed

- significantly different from zero up to centrality 50% (combined significance of  $\sim 6\sigma$ )
- similar to that in Pb–Pb collisions at similar multiplicity values

S. Voloshin and T. Niida, Phys. Rev. C 94 (2016) 021901(R)

- Initial spatial anisotropy translates into final-state momentum anisotropy
- Second term of the Fourier expansion of the particle azimuthal distribution is the  $v_2$

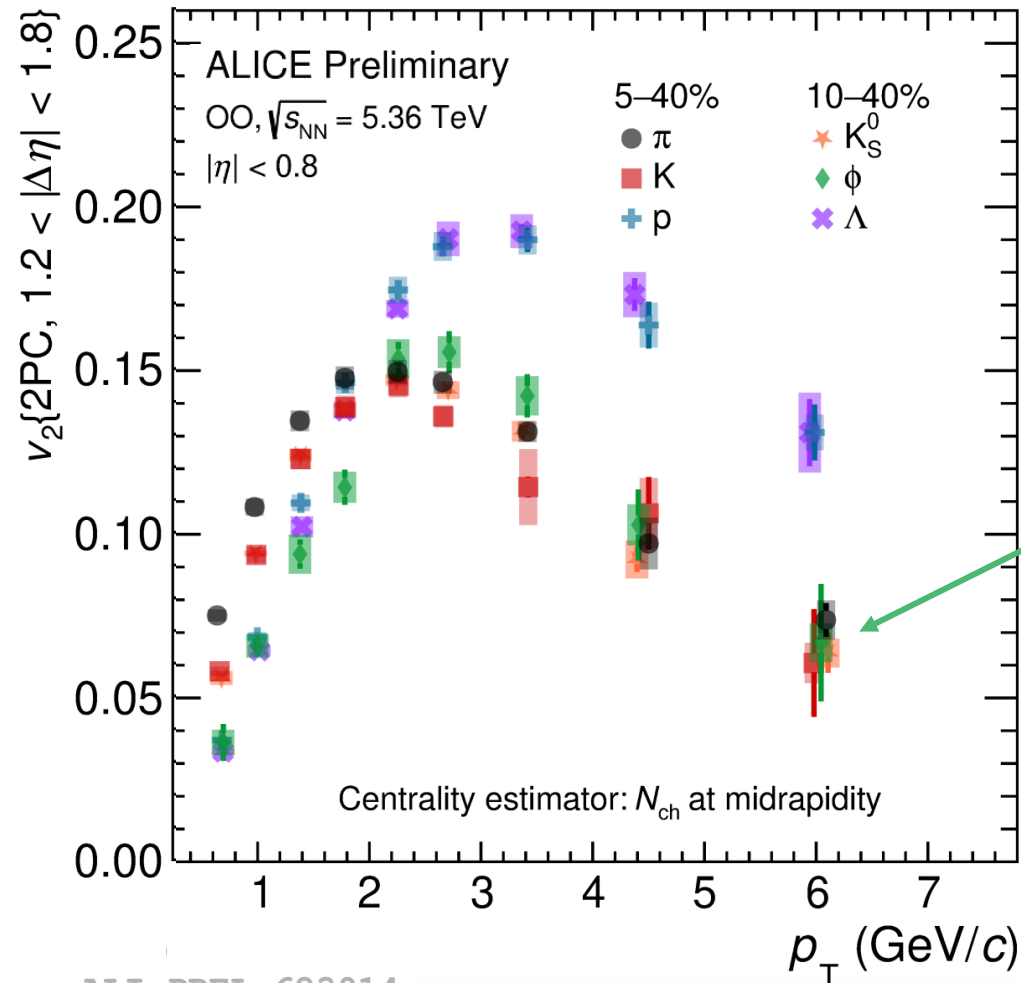


- Low  $p_T$ : **Mass ordering** → consistent with collective expansion of the medium
- Intermediate  $p_T$ : Significant **baryon-meson splitting**
  - $\phi$  flows as mesons despite its mass close to the p and  $\Lambda$  baryons;
  - Splitting between  $\Lambda$  and  $\phi$  at high  $p_T$  is  $5\sigma$

ALI-PREL-623914

Check out our new  
**Nature Communication Paper on Run 2 results**  
<https://www.nature.com/articles/s41467-025-67795-1>

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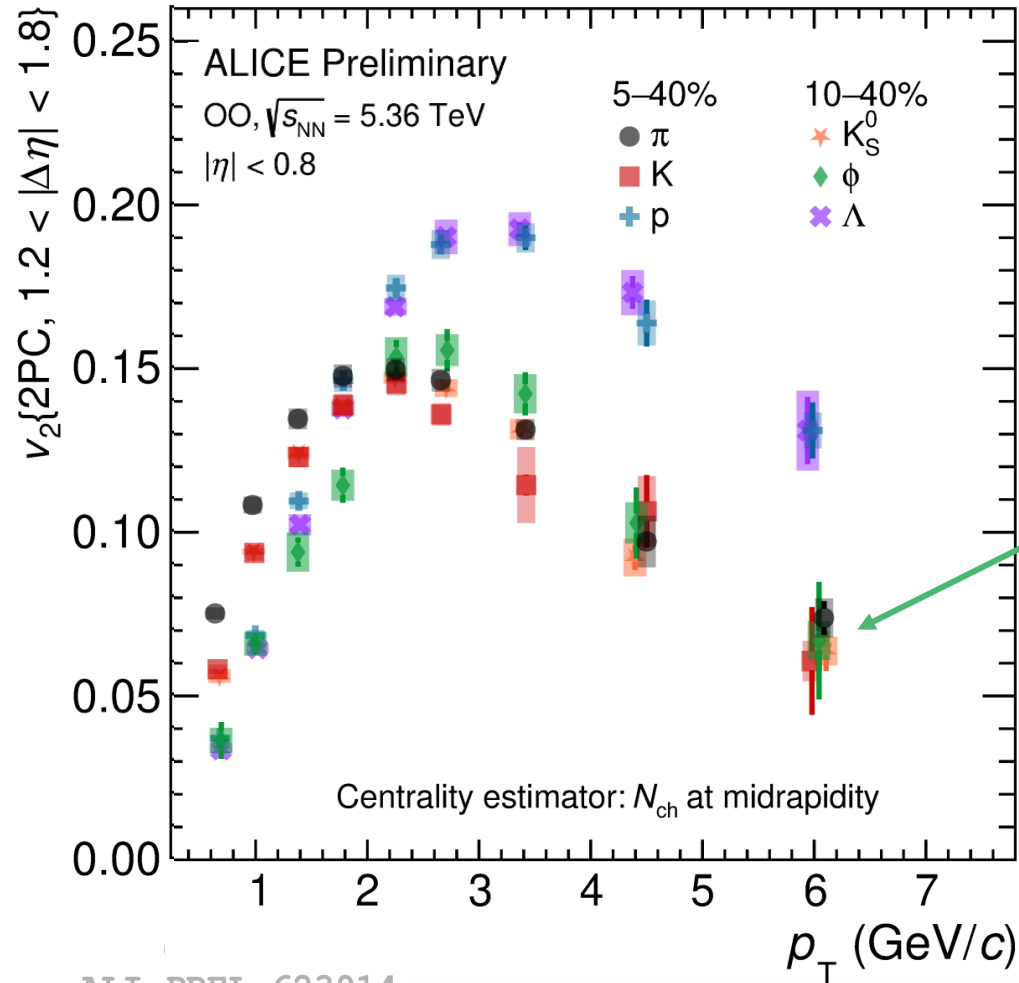
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**Meson-like behavior of  $\phi$**  supports hadronization via quark recombination from a collectively flowing partonic medium

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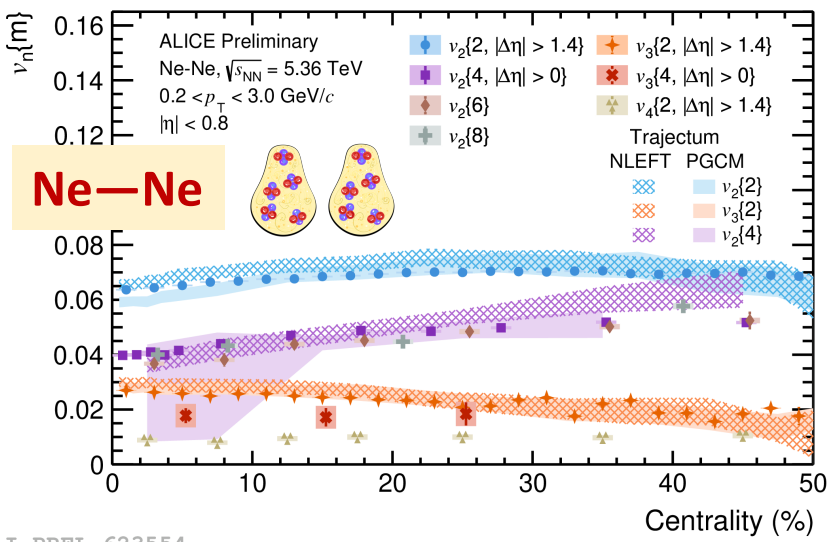
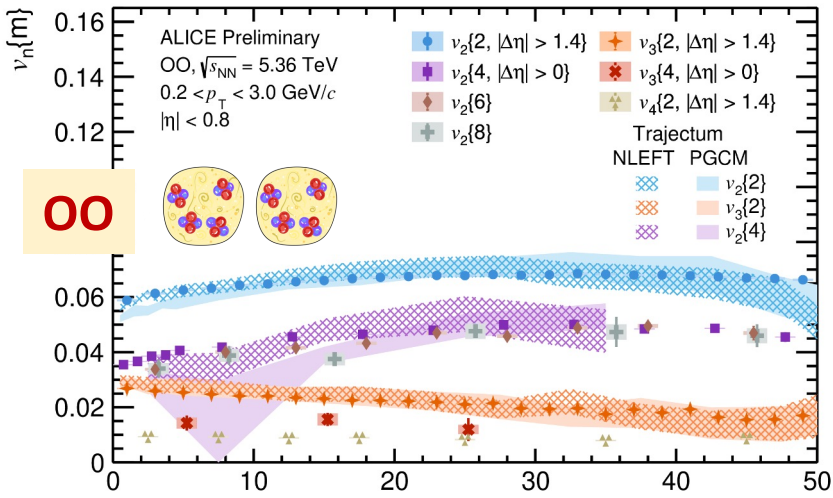
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Key signatures of partonic collectivity persist in light-ion collisions

ALI-PREL-623914

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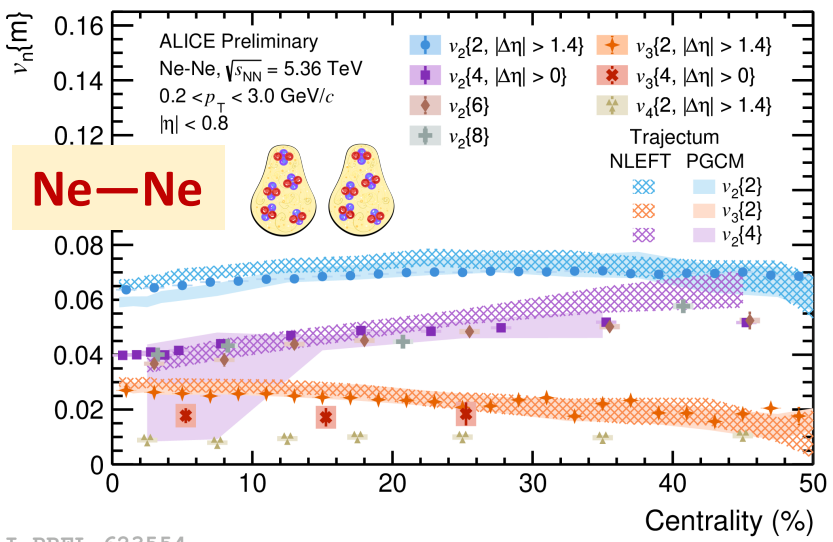
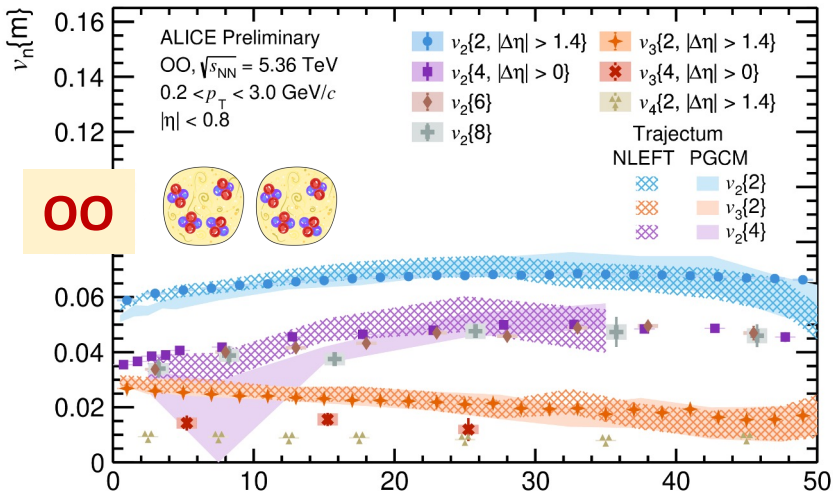


- Deeper insight into geometry driven elliptic flow in OO and Ne-Ne collisions in central collisions
- Measurements of higher order harmonics and cumulants
  - $v_2 > v_3 > v_4$
  - $v_2\{2\} > v_2\{4\} \approx v_2\{6\} \approx v_2\{8\}$
  - expected ordering from collective expansion
- Good agreement with Trajectum + NLEFT
  - hydrodynamics with realistic initial conditions works well

ALI-PREL-623554

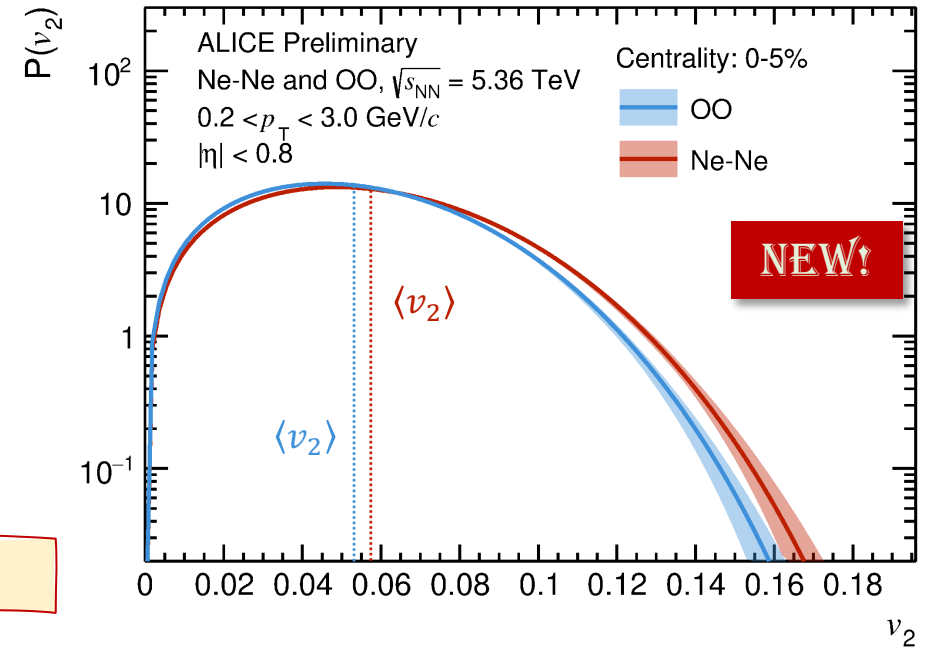
**NEW!**

Sketch credits: D. Stryger [arXiv:2509.06428](https://arxiv.org/abs/2509.06428)



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- Good agreement with Trajectory + NLEFT
  - hydrodynamics with realistic initial conditions works well

- First ever measurement of  $P(v_2)$  in small systems
- Mean elliptic flow  $\langle v_2 \rangle^{OO} < \langle v_2 \rangle^{Ne-Ne}$ 
  - connected to different multi-nucleon correlation of nuclei



ALI-PREL-623554

**NEW!**

Confirmation of hydrodynamic flow in light-ion collisions

Sketch credits: D. Stryger [arXiv:2509.06428](https://arxiv.org/abs/2509.06428)

ALI-PREL-623559

- At the LHC the crossover region of QCD at  $\mu_B \approx 0$  can be probed through fluctuation observables
- Net-baryon number susceptibilities  $\rightarrow$  related to the cumulants of the net-baryon number distribution
- Net-proton cumulants  $\rightarrow$  experimental proxies of susceptibilities

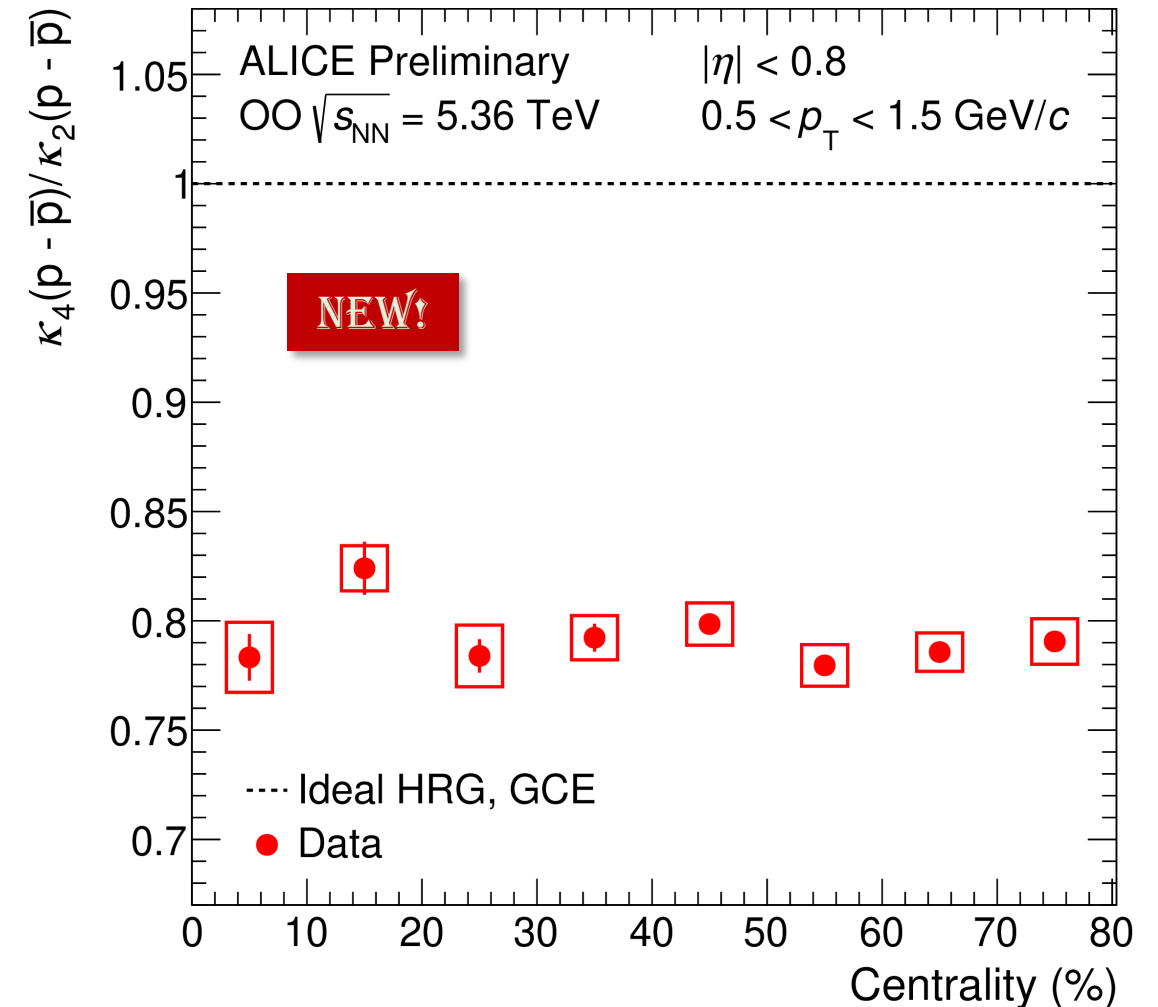
First measurement of net-proton fluctuations in OO collisions

- Normalized fourth-order net-proton cumulant shows a deviation with respect to the Grand Canonical limit of the ideal hadron resonance gas (HRG)



$$\kappa_2 = \mu_2$$

$$\kappa_4 = \mu_4 - 3\mu_2^2$$

$\mu_i \rightarrow i$ -th moment of net-proton number distribution



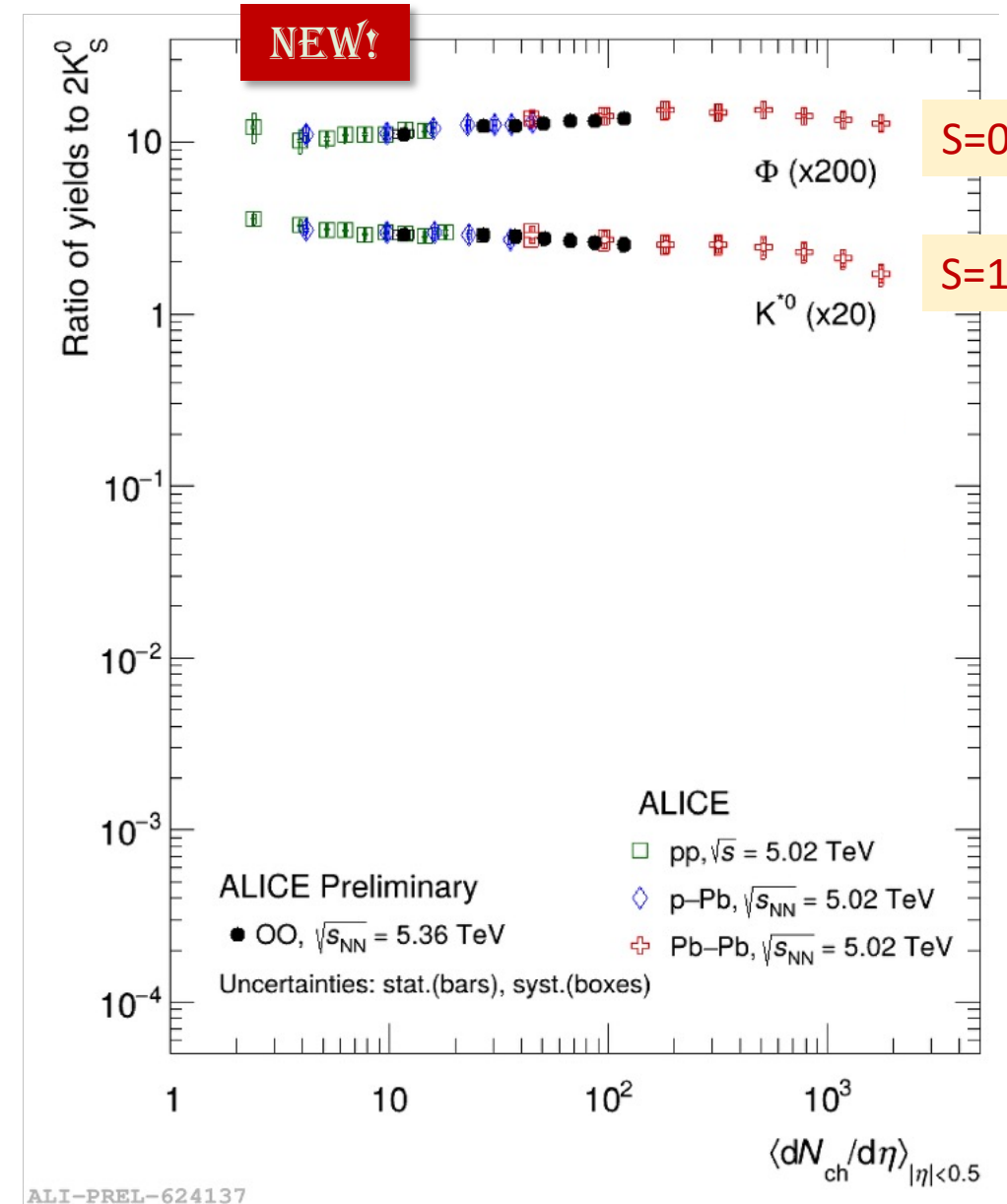
ALI-PREL-623597

 Koch, Vovchenko [arXiv:2512.04288](https://arxiv.org/abs/2512.04288)  
 Bazavov et al., Phys. Rev. D 101, 074502 (2020)

First measurement of resonances ( $\Phi$ ,  $K^*$ ) in OO collisions

- $K^*/K_s^0$  ratio shows decreasing trend
  - suppression of short-lived resonances due to **rescattering** in the hadronic phase
- $\Phi/K_s^0$  meson remains unaffected
  - longer-lived resonances remains largely unaffected by **hadronic phase** effects

Effects of the hadronic phase



# Resonances and strangeness in OO



First measurement of resonances ( $\Phi$ ,  $K^*$ ) in OO collisions

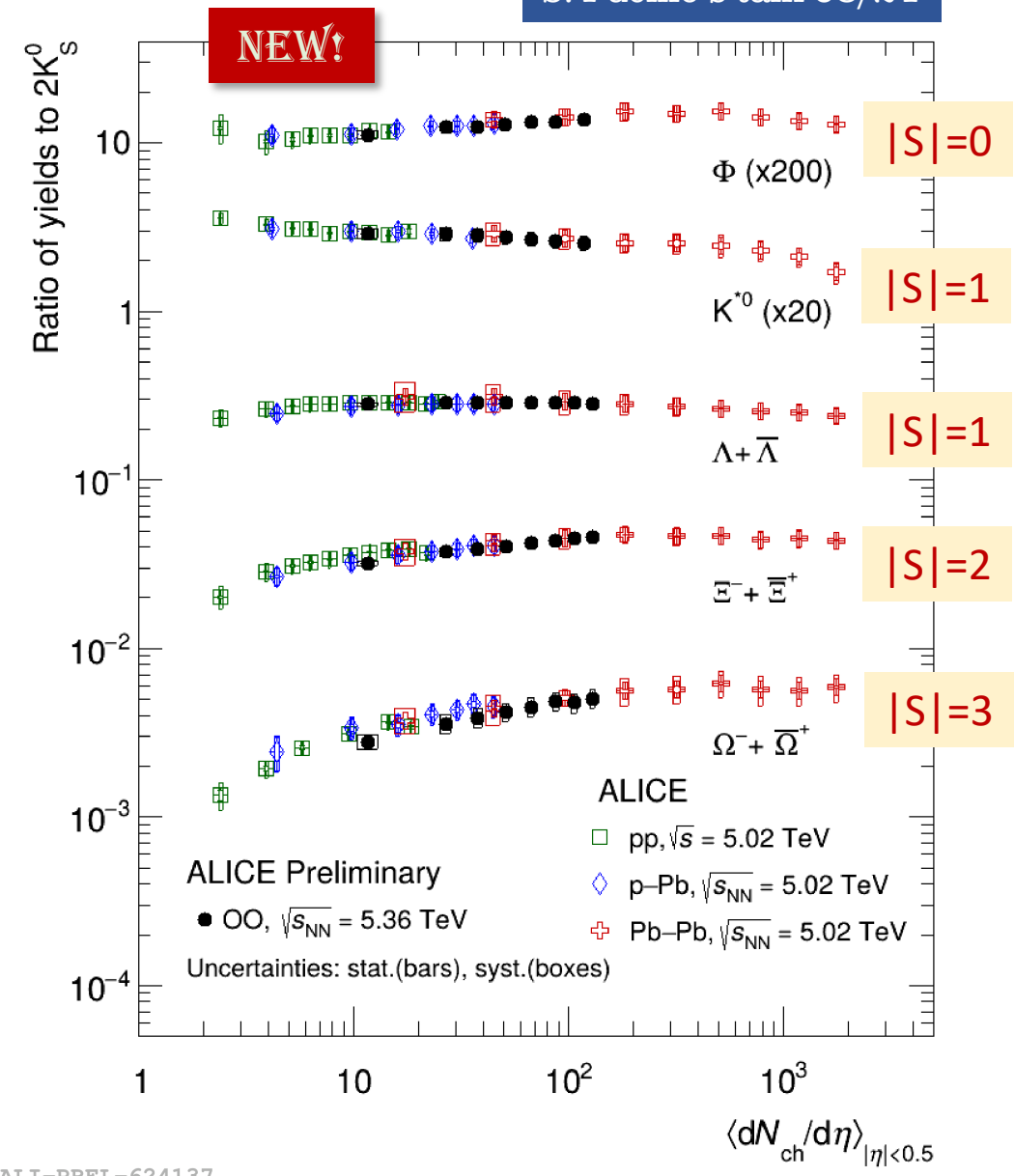
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Effects of the hadronic phase

First measurement of strange and multi-strange particles ( $\Lambda$ ,  $K_s^0$ ,  $\Xi$ ,  $\Omega$ ) in OO collisions

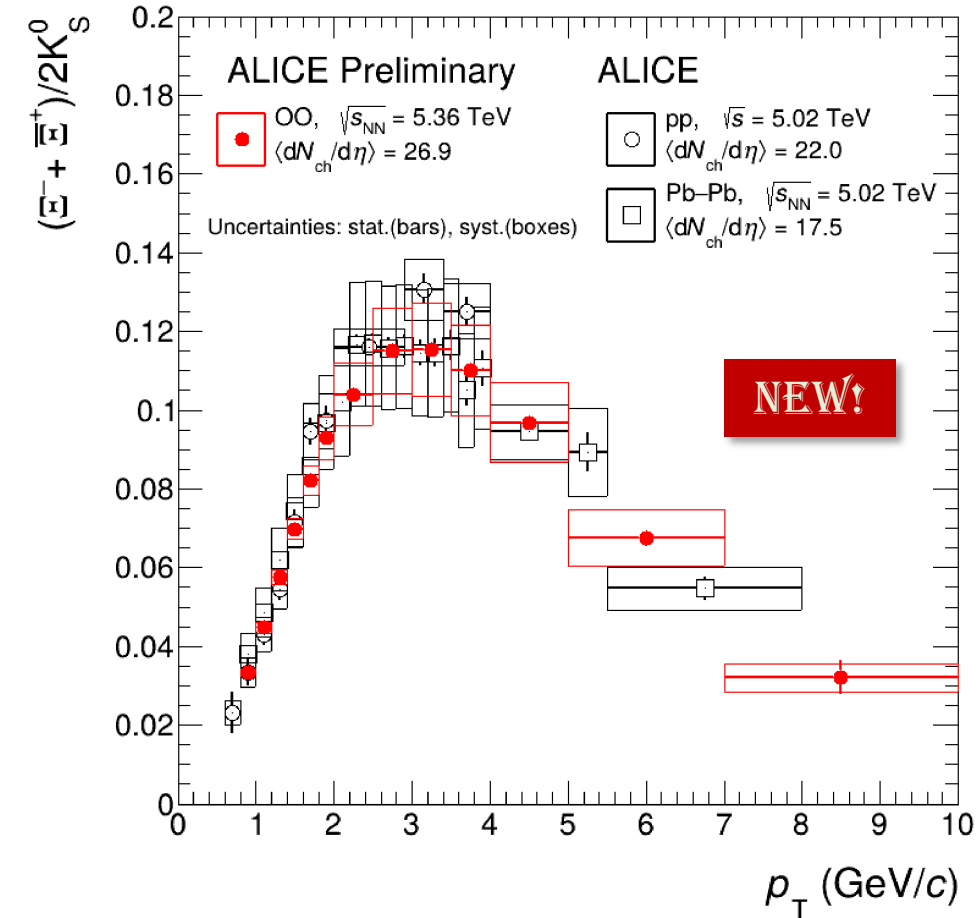
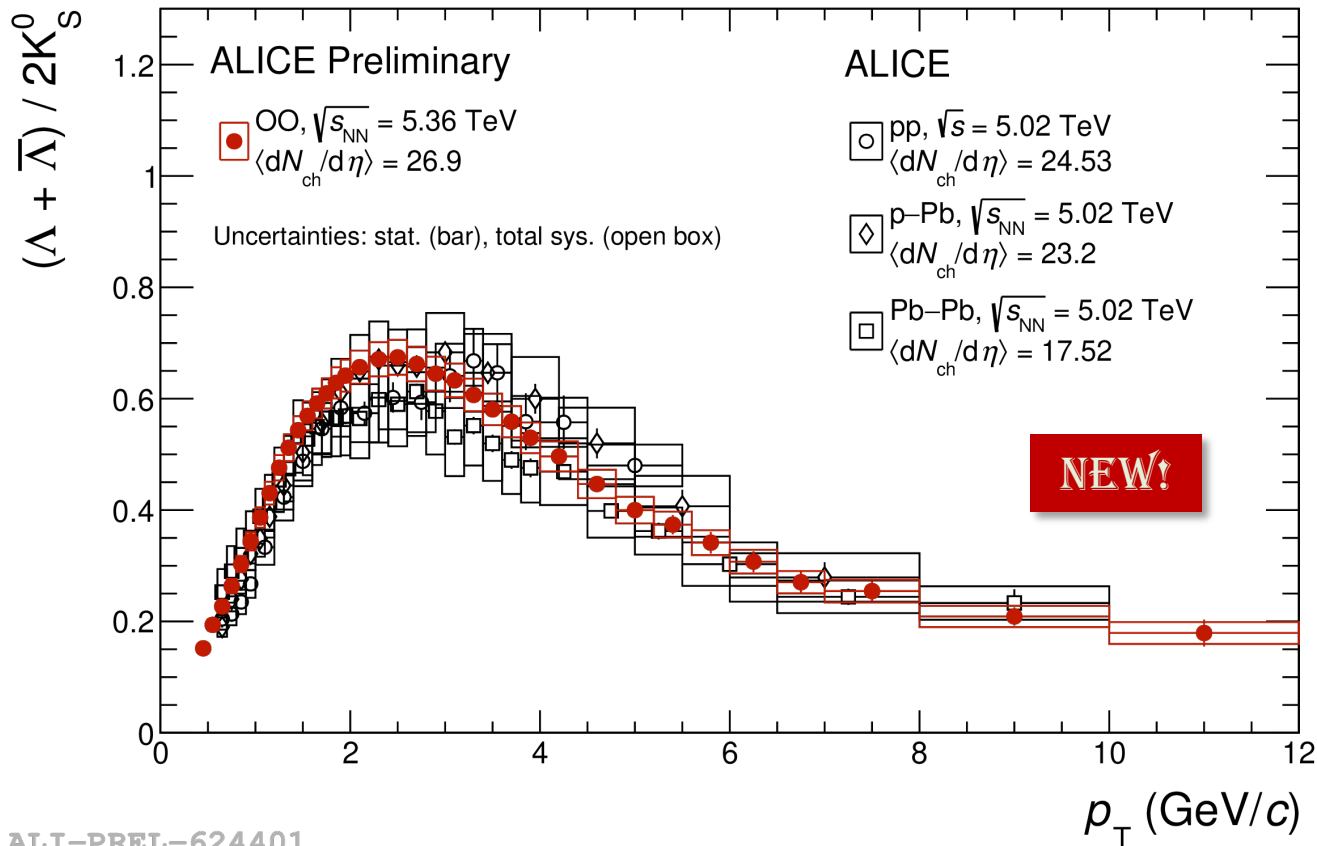
- Production yields in light-ion collisions agree with the common smooth increase with multiplicity

Common strangeness-driven scaling across collision systems, with a stronger enhancement for higher strangeness content



# Baryon-to-meson ratio in OO

- Baryon-to-meson ( $\Lambda/K^0_s$ ,  $\Xi/K^0_s$ ) ratio in OO collisions
  - increase at intermediate  $p_T$
  - baryon-meson splitting (larger magnitude in OO than in Pb-Pb)
- Similar behavior as in pp and Pb-Pb collisions



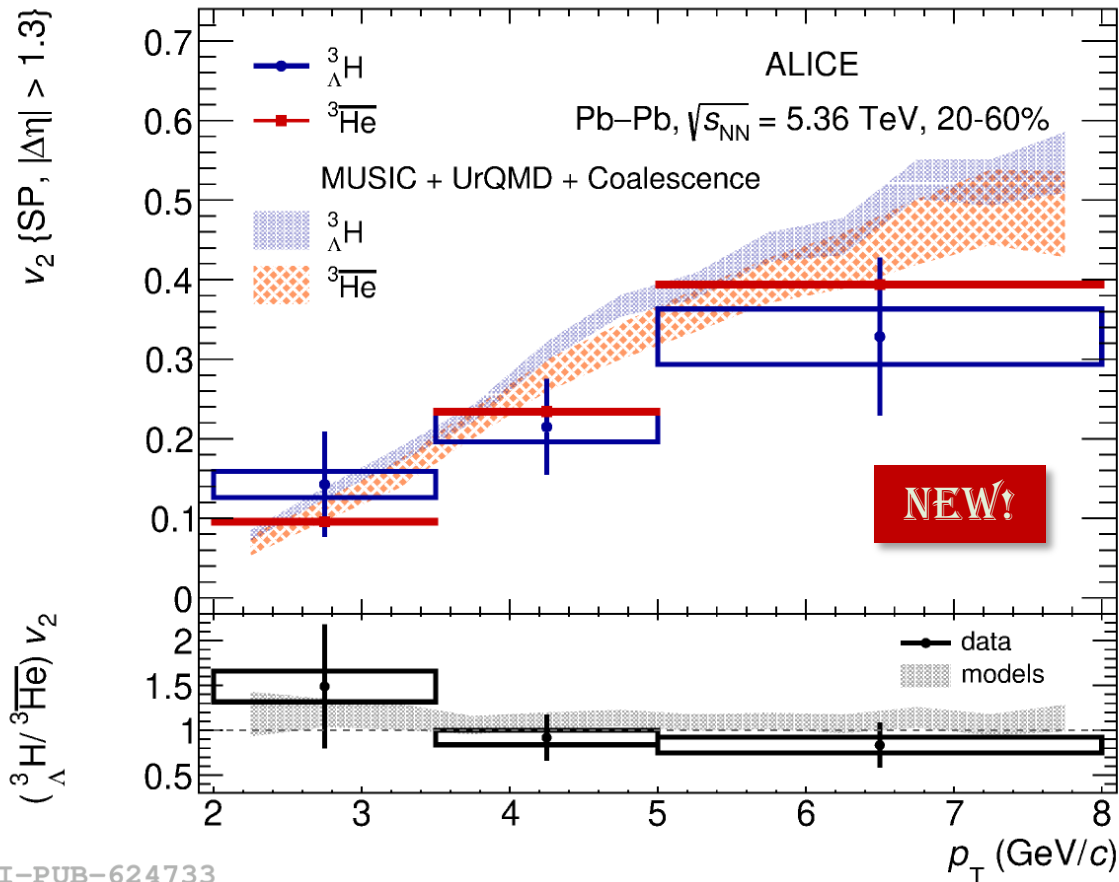
ALI-PREL-624122

Low  $p_T \rightarrow$  radial flow boosts baryons more efficiently than mesons  
 Intermediate  $p_T \rightarrow$  coalescence inside a collectively expanding medium

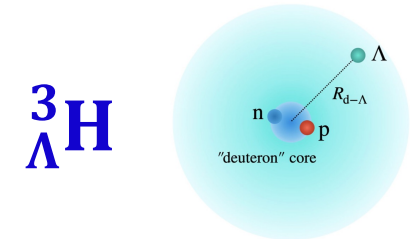
ALI-PREL-624401

- The elliptic flow of  ${}^3\overline{\text{He}}$  &  ${}^3_{\Lambda}\text{H}$  is measured using the scalar product method
- ${}^3_{\Lambda}\text{H}$   $v_2$  compatible with  ${}^3\overline{\text{He}}$   $v_2$ , due to their similar masses; different sizes don't play a role in elliptic flow

$$v_2^{\text{Tot}} = \frac{\langle\langle \vec{u}_2 \cdot \vec{Q}_2 \rangle\rangle}{R_2}$$



	${}^3\text{He}$	${}^3_{\Lambda}\text{H}$
mass (GeV/c <sup>2</sup> )	2.809	2.991
radius (fm)	1.8	10



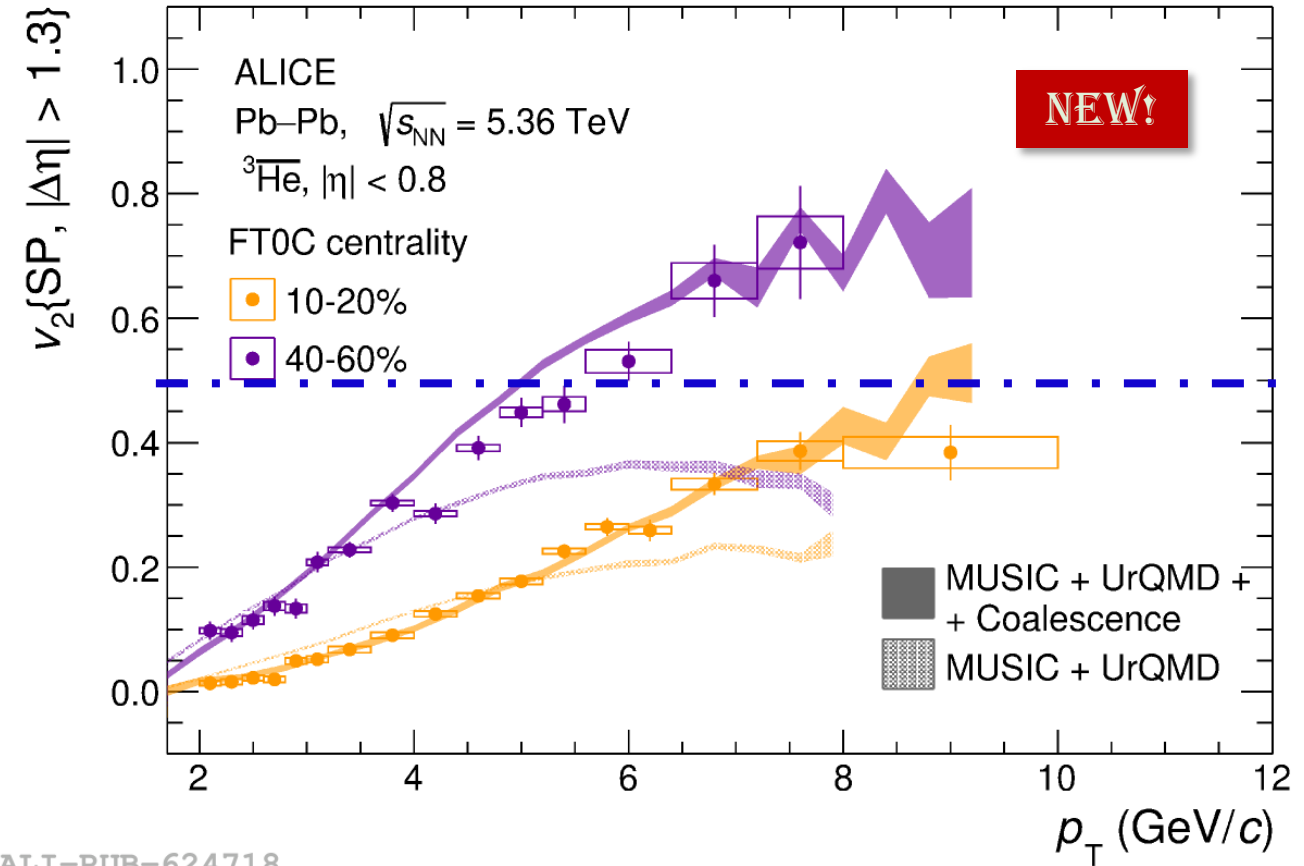
The elliptic flow of hypertriton is measured for the first time at the LHC

# A sign of coalescence in ${}^3\text{He } v_2$

- Focusing only on  ${}^3\text{He } v_2$ : new feature observed at high  $p_T$  for peripheral events:  $v_2 > 0.5$
- Values above 0.5 imply negative yields in certain azimuthal regions  $\rightarrow$  unphysical
- Higher-order harmonics may play a significant role

${}^3\text{He}$

$$\frac{dN}{d(\phi - \Psi_2)} \propto 1 + 2v_2 \cos[2(\phi - \Psi_2)] + 2a \cos[4(\phi - \Psi_2)] + 2b \cos[6(\phi - \Psi_2)] + \dots$$



ALI-PUB-624718

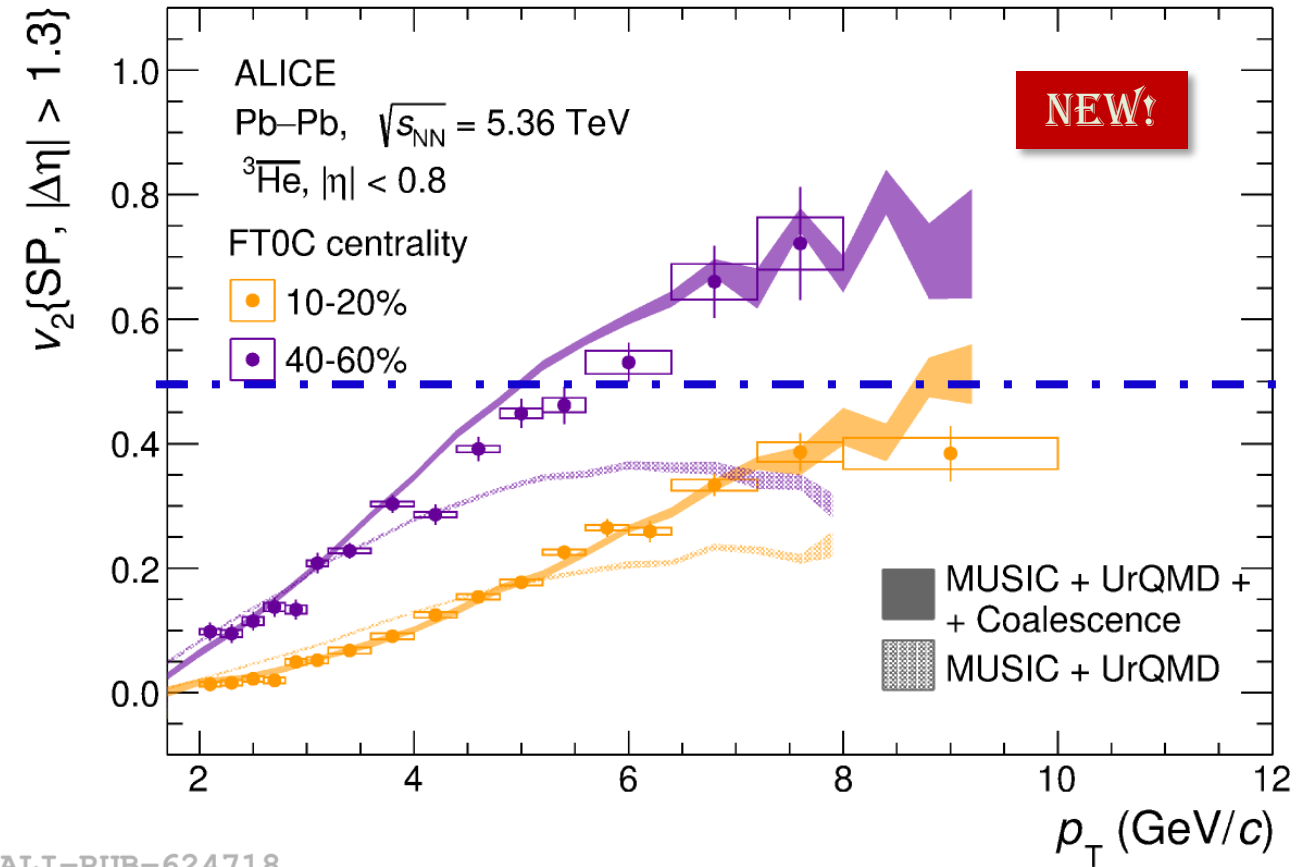
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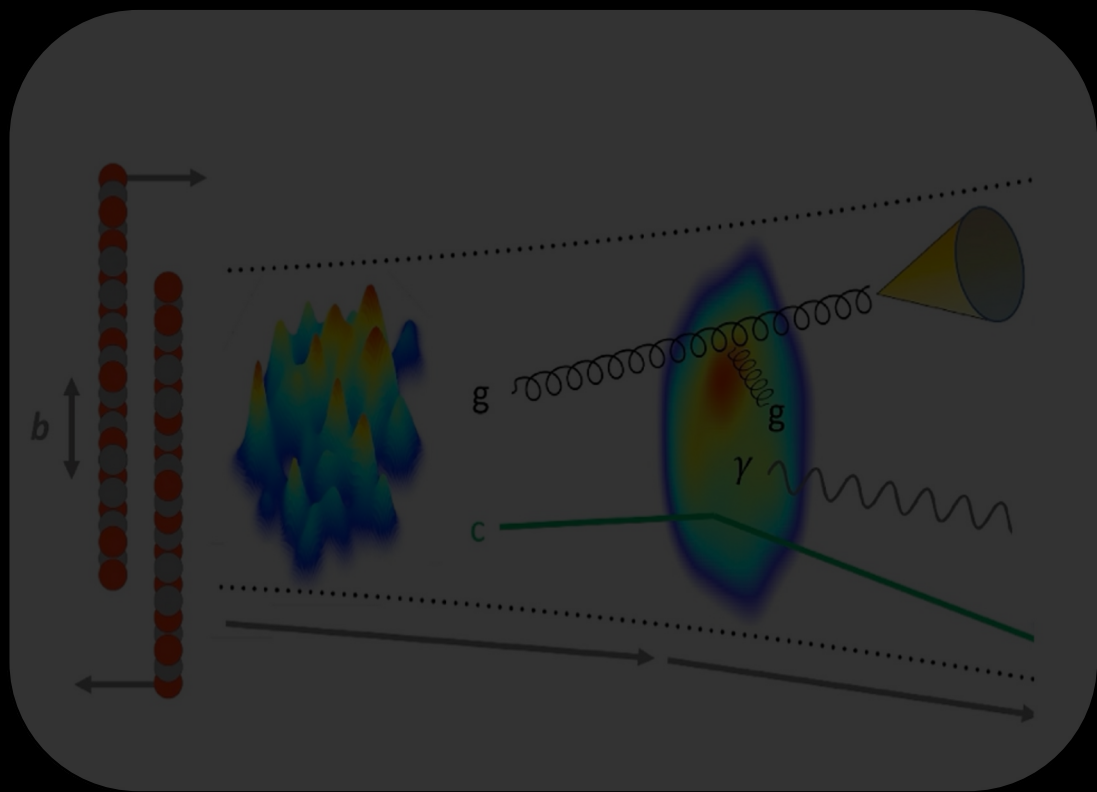
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- $v_2 > 0.5$  predicted also by **coalescence** model
- Effect not present in hydrodynamical models
- As for quark coalescence, nucleon coalescence introduces a modulation in the  $(\phi - \psi_2)$  distribution!

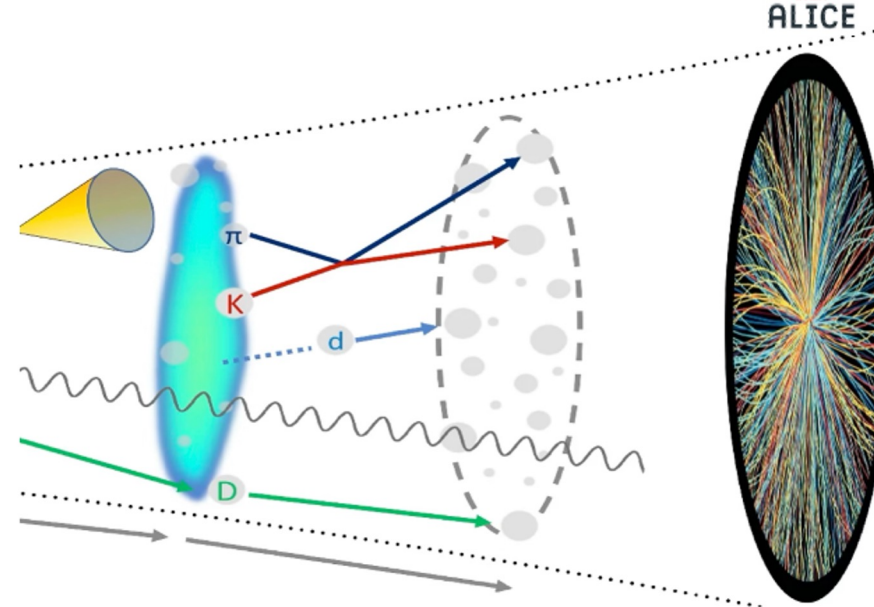
$\rightarrow$  large  $v_2$  values observed for  ${}^3\text{He}$  may originate from coalescence-induced effects



ALI-PUB-624718



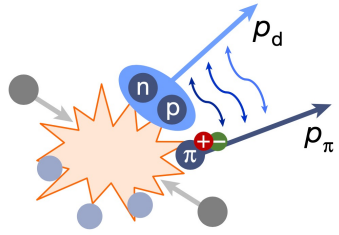
## Hadronization and freeze-out



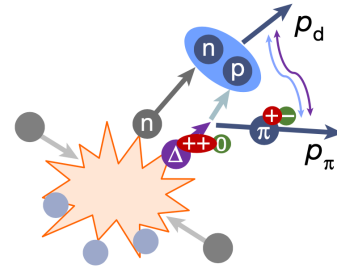
Use **femtoscopy** to understand the formation mechanism in pp collisions

$$c(k^*) = \int s(\vec{r}^*) |\psi(\vec{k}^*, \vec{r}^*)|^2 d^3\vec{r}^* = \mathcal{N}(k^*) \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

theory experiment



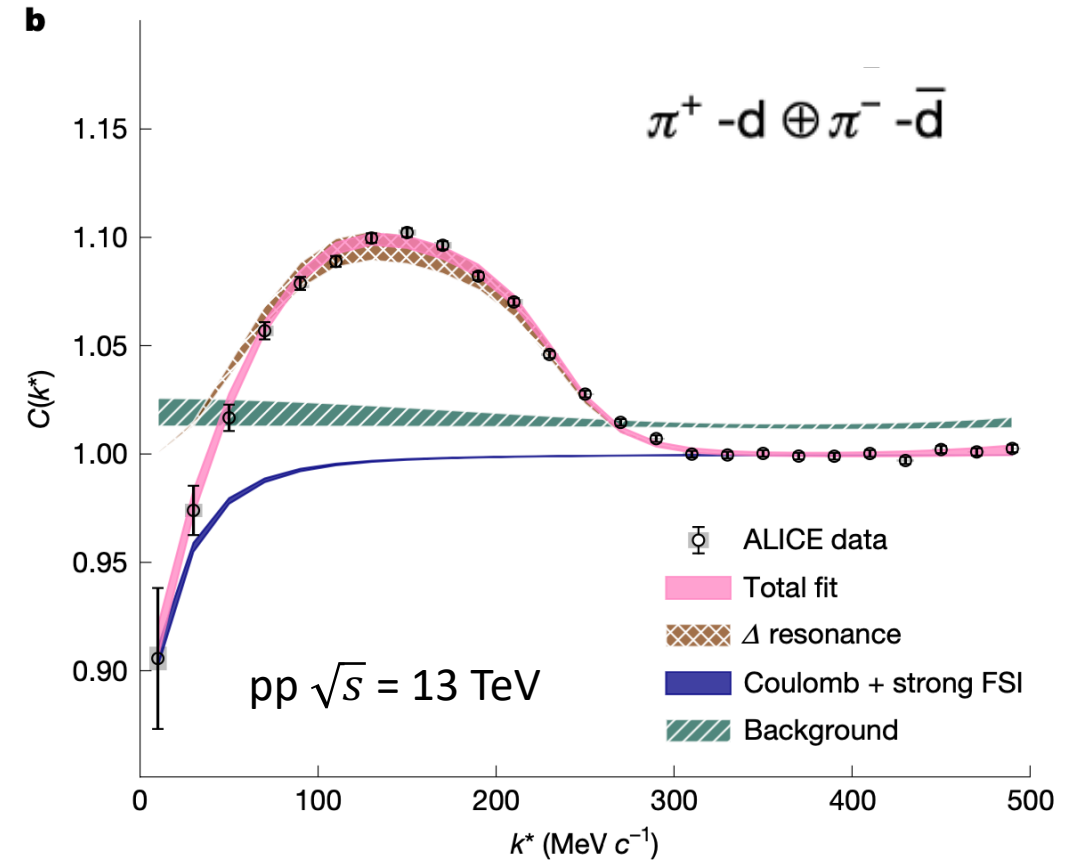
Scenario I:  
prompt production



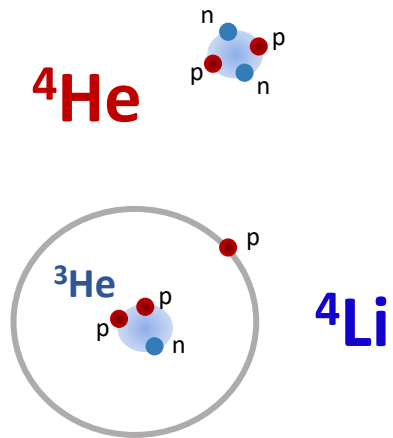
Scenario II:  
resonance decay + coalescence

- Observation of  $\Delta$  resonance contribution in pion-deuteron correlation functions
  - **Deuterons must be formed from pre-existing nucleons** (possibly from Delta decay)
  - **Dominant process**  $\rightarrow$   $\sim 89\%$  of deuterons have at least one nucleon coming from a resonance

Direct evidence of the deuteron formation from **fusion of resonance-decay nucleons**

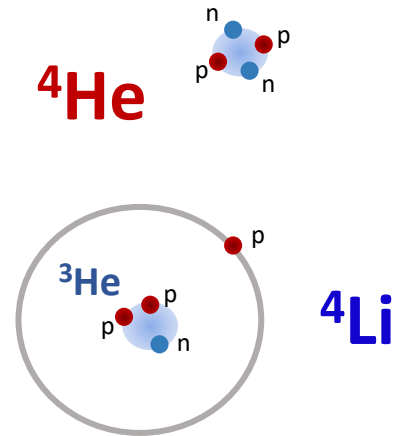


- Search for (anti) $^4\text{Li}$  signal (antimatter never observed to date)
- Resonant state ( $\tau \sim 9 \cdot 10^{-23}$  s)
- Test **nucleosynthesis models**, in comparison to  $^4\text{He}$  nuclei, given their different size and structure and similar masses



	$^4\text{He}$	$^4\text{Li}$
mass ( $\text{GeV}/c^2$ )	3.727	3.749
radius (fm)	1.68	>2
spin ( $J^\pi$ )	$0^+$	$2^-$

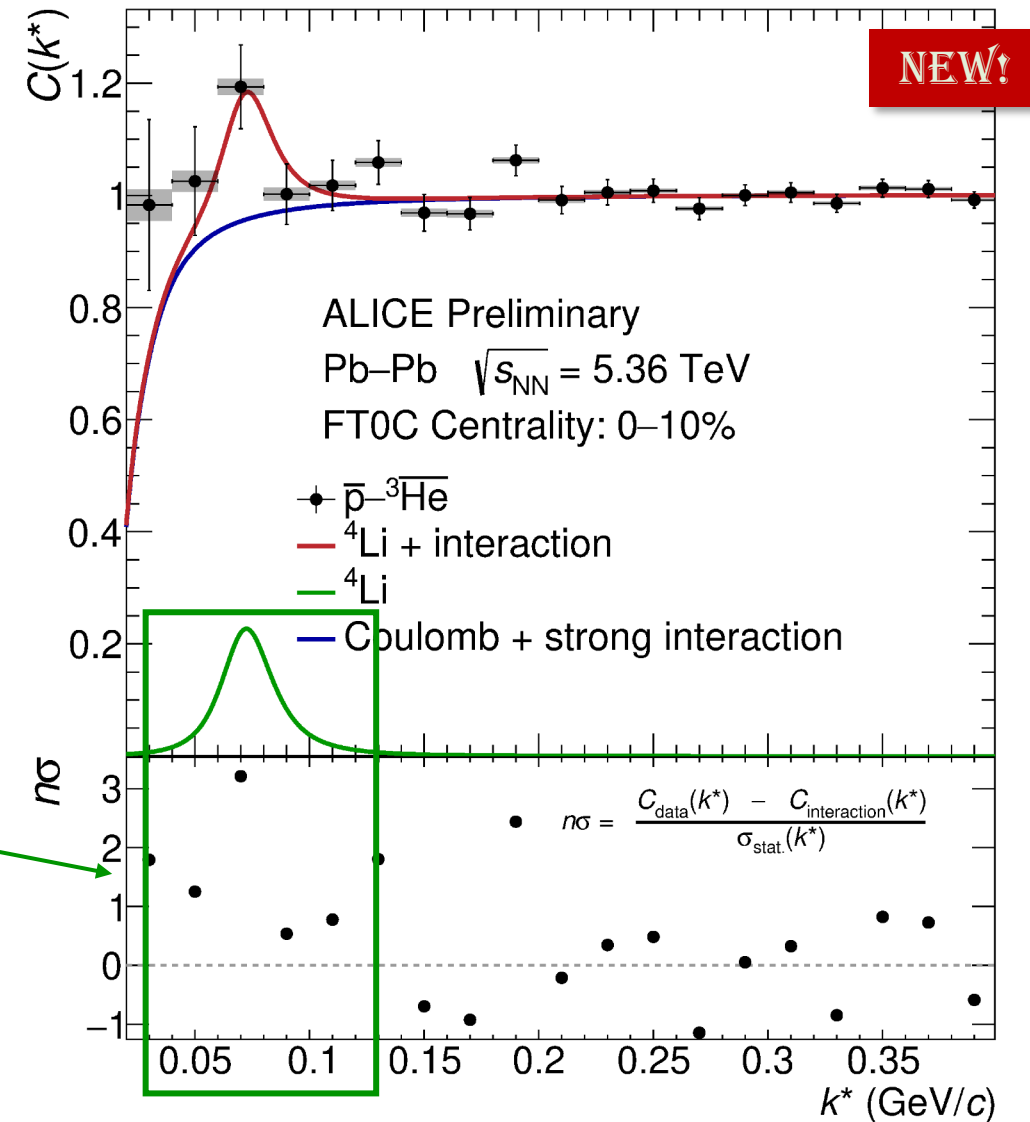
- Search for (anti) $^4\text{Li}$  signal (antimatter never observed to date)
- Resonant state ( $\tau \sim 9 \cdot 10^{-23}$  s)
- Test **nucleosynthesis models**, in comparison to  $^4\text{He}$  nuclei, given their different size and structure and similar masses



	$^4\text{He}$	$^4\text{Li}$
mass (GeV/c <sup>2</sup> )	3.727	3.749
radius (fm)	1.68	>2
spin (J <sup><math>\pi</math></sup> )	0 <sup>+</sup>	2 <sup>-</sup>

Significance in the signal region  $2.1\sigma$

First upper limit on the production yield of  $^4\bar{\text{Li}}$  using the correlation function of  $\bar{p}+^3\bar{\text{He}}$



ALI-PREL-621440

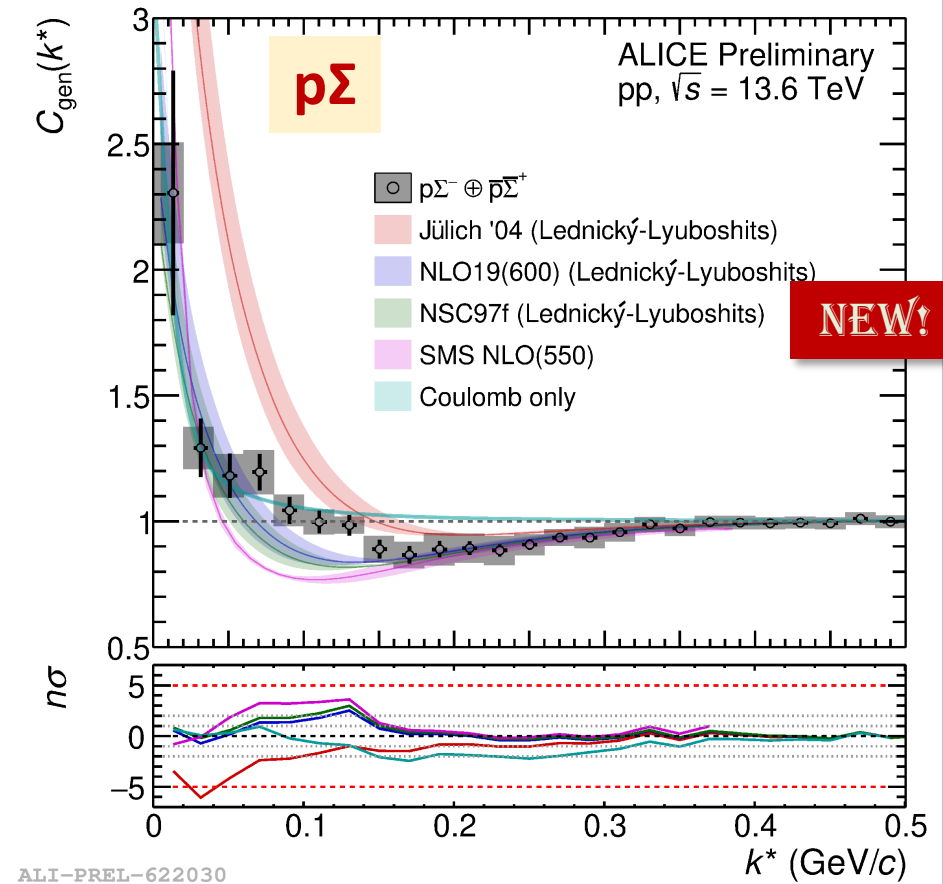
# 2- and 3-body interactions involving strangeness

New high-precision femtoscopy measurements by ALICE in the strangeness sector

H. Fribert's talk 03/25

## TWO-BODY

- Data favor a shallow repulsive interaction
- Tension observed with available models tuned to scattering data



# 2- and 3-body interactions involving strangeness



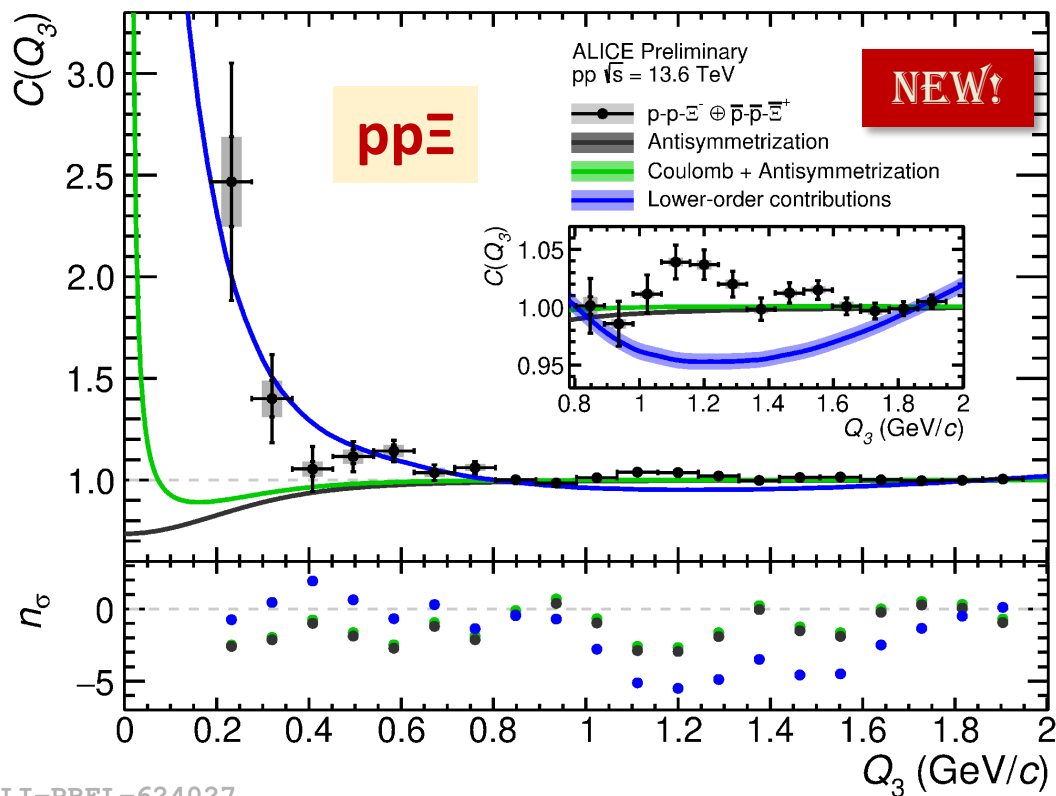
R. Del Grande's talk 03/25

H. Friberg's talk 03/25

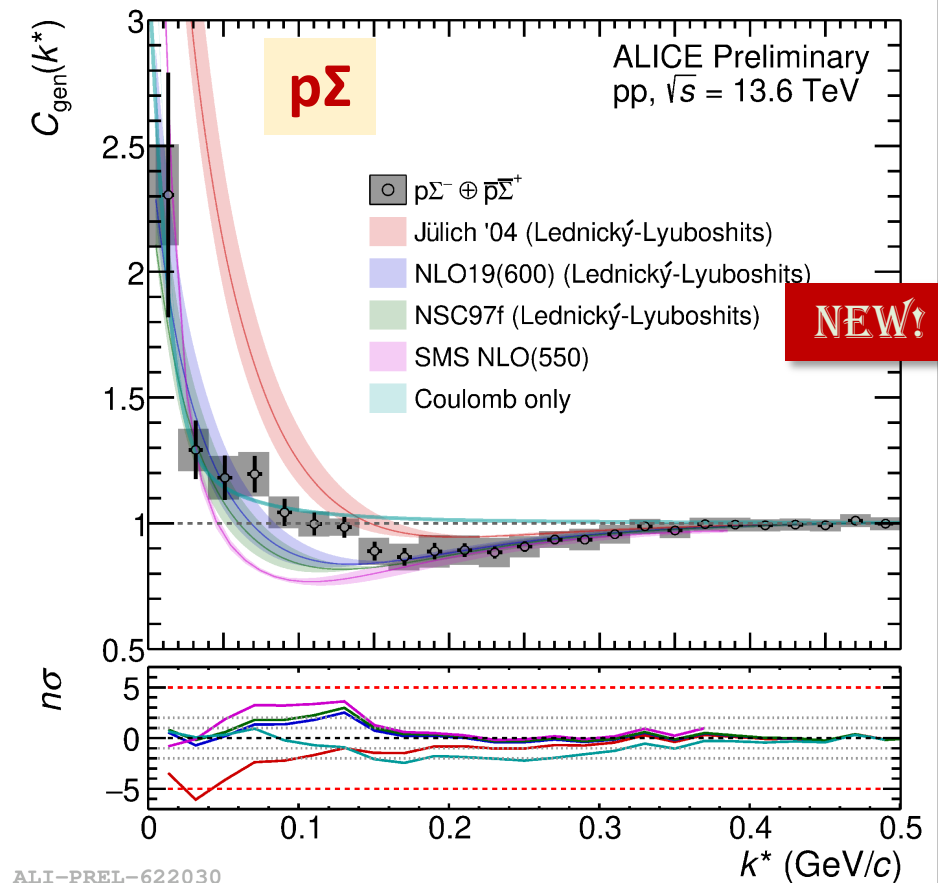
New high-precision femtoscopy measurements by ALICE in the strangeness sector

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- Data favor a shallow repulsive interaction
- Tension observed with available models tuned to scattering data



ALI-PREL-624027



ALI-PREL-622030

## THREE-BODY

- First 3-body measurement in the  $S=-2$  sector
- Final state interaction observed with  $3.5\sigma$  significance at low  $Q_3$

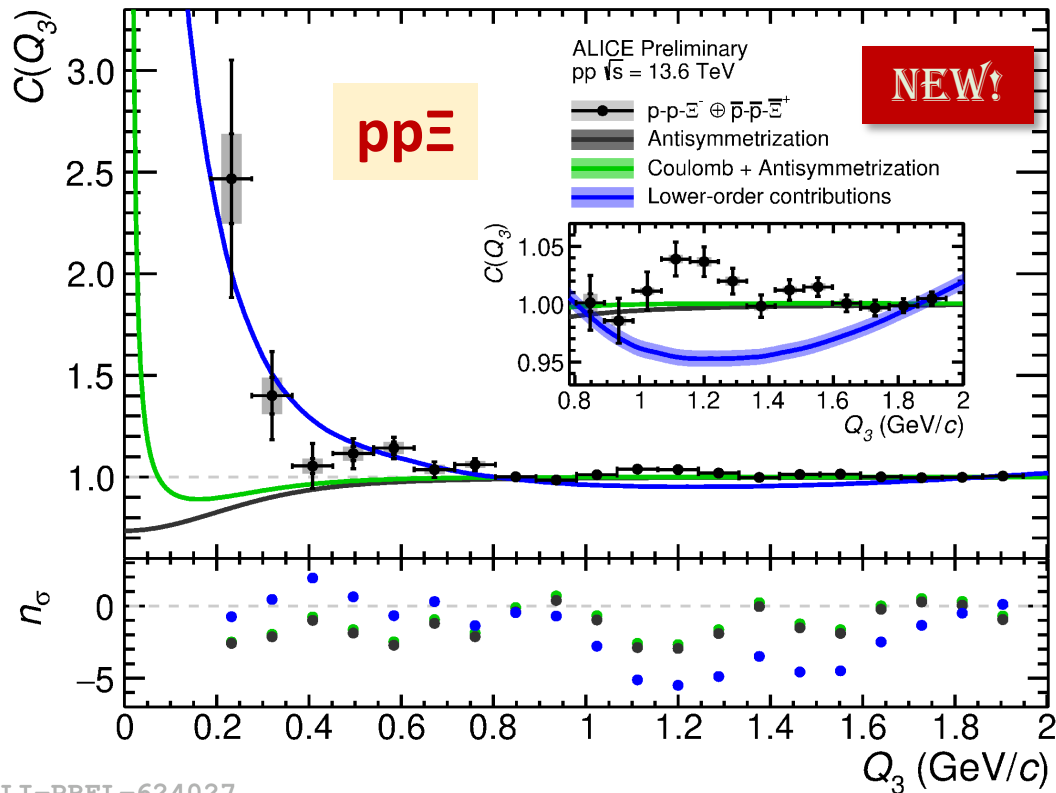
# 2- and 3-body interactions involving strangeness



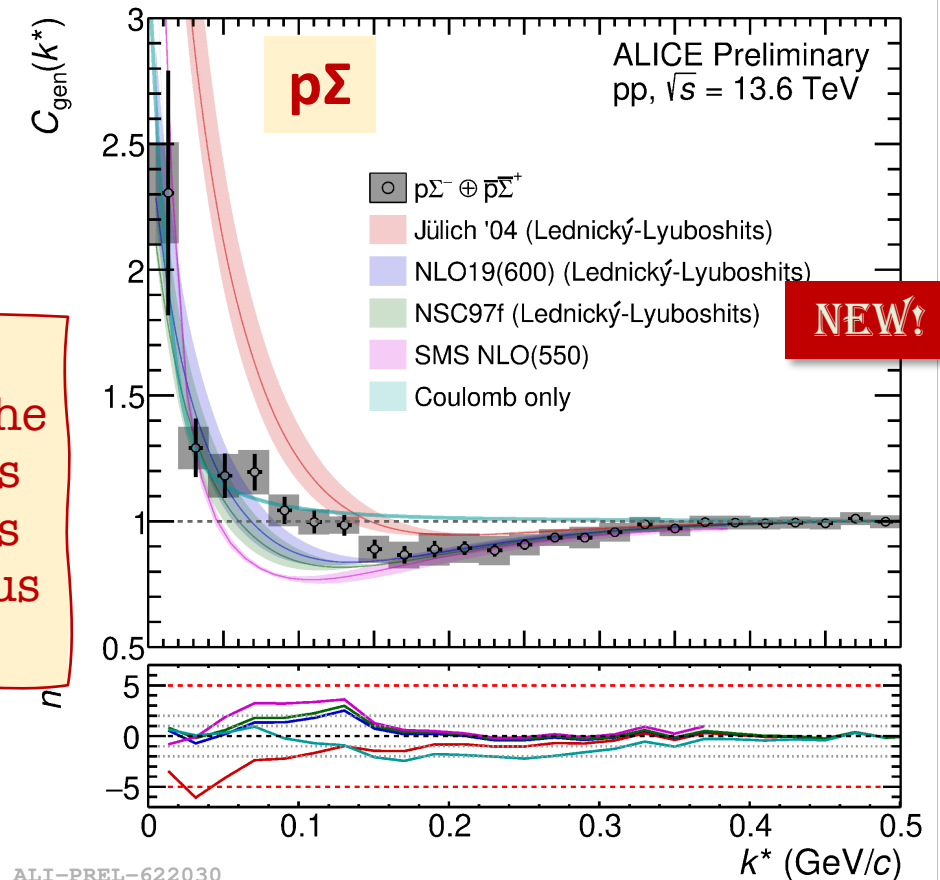
New high-precision femtoscopy measurements by ALICE in the strangeness sector

## TWO-BODY

- Data favor a shallow repulsive interaction
- Tension observed with available models tuned to scattering data



Crucial for understanding the role of hyperons in neutron stars and hypernucleus properties



## THREE-BODY

- First 3-body measurement in the  $S=-2$  sector
- Final state interaction observed with  $3.5\sigma$  significance at low  $Q_3$

ALI-PREL-622030

- **Light-flavor observables** map the full space-time evolution of the collision
- Light-ion collisions extend the study of collectivity and strangeness into a **critical intermediate system size**
- **QGP features** are clearly observed in light ions
- Nuclei, hypernuclei, correlations, and rare-state limits characterise **nuclear formation with unprecedented precision**

...and more to come with the future upgrades for **Run 4 and 5!**

S. Siddhanta's talk 03/25

J. Gumprecht's talk 03/25

*Don't miss highlights from HF later today!*

F. Catalano's talk 03/24

*Thank you!*

# Talks and posters on LF this week



Evidence of anti-Li4 signal from p+3He femtoscopy	G.A. Lucia	24 March, 17:45	Parallel I
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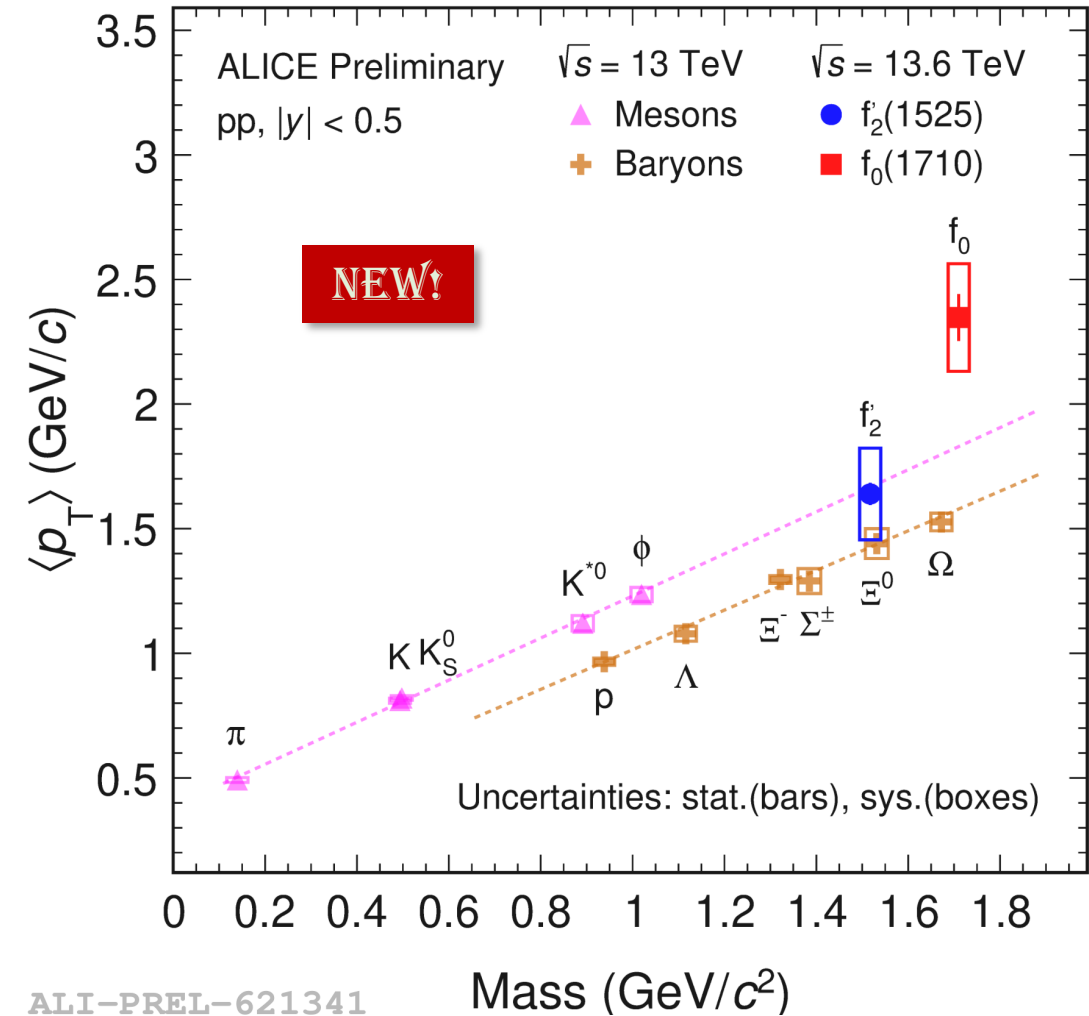


- Glueball is a bound state composed entirely of gluons
- Lattice QCD: Lightest scalar glueball mass range 1550–1750 MeV/c<sup>2</sup>
- Lightest scalar glueball candidate  $f_0(1710)$ <sup>1</sup>:
  - Quantum numbers  $J^{PC} = 0^{++}$
  - Mass in the predicted range
  - Partonic content has yet to be established

## State-of-the-art

- HERA (e-p collisions):  $f_0(1710)$  observed in  $K_s^0 K_s^0$  channel<sup>2</sup>
- Measured by ALICE in pp collisions in  $K_s^0 K_s^0$  channel

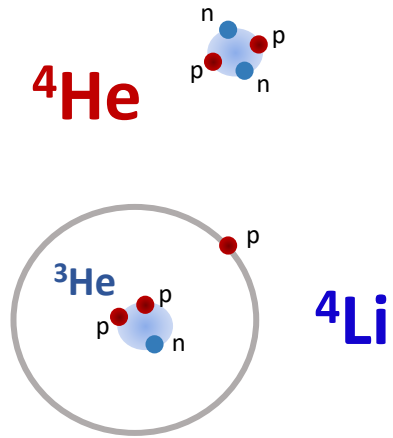
Mean  $p_T$  of  $f_0$  deviates from the apparent scaling of baryon-meson splitting  
 → further studies are needed to investigate the nature and structure of  $f_0$



<sup>1</sup> Y. Chen et al., [Phys. Rev. D73, 014516 \(2006\)](#)

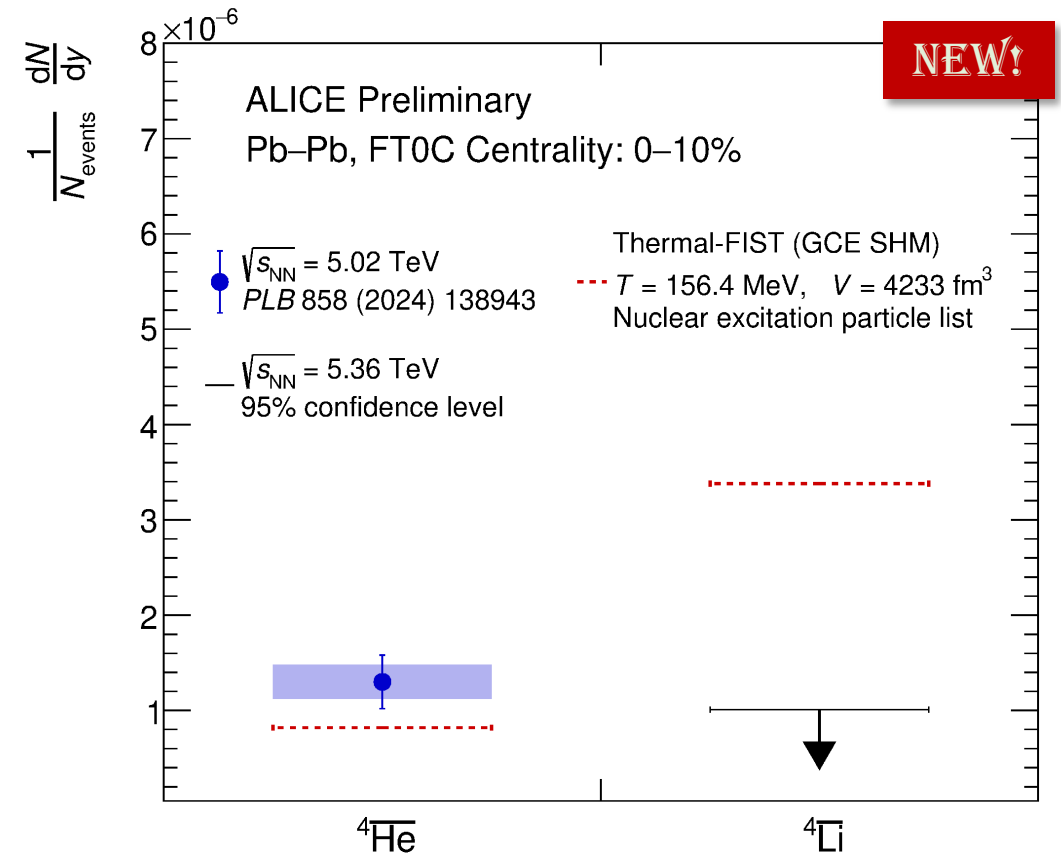
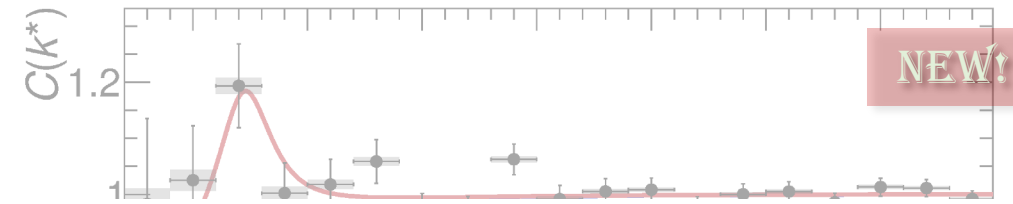
<sup>2</sup> ZEUS Coll., [PRL 101, 112003 \(2008\)](#)

- Search for (anti) $^4\text{Li}$  signal (antimatter never observed to date)
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- Test **nucleosynthesis models**, in comparison to  $^4\text{He}$  nuclei, given their different size and structure and similar masses

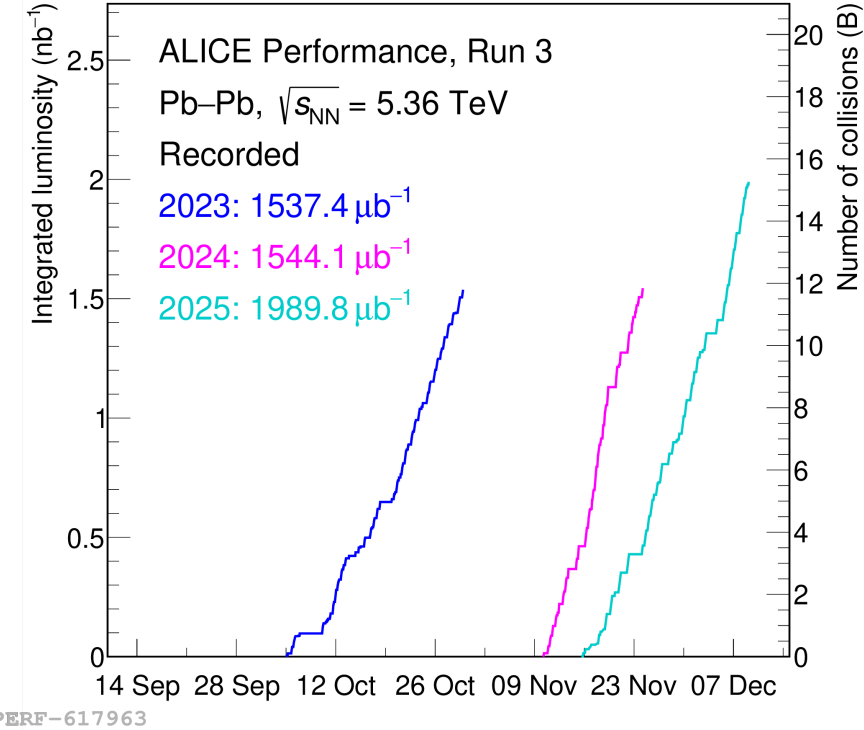
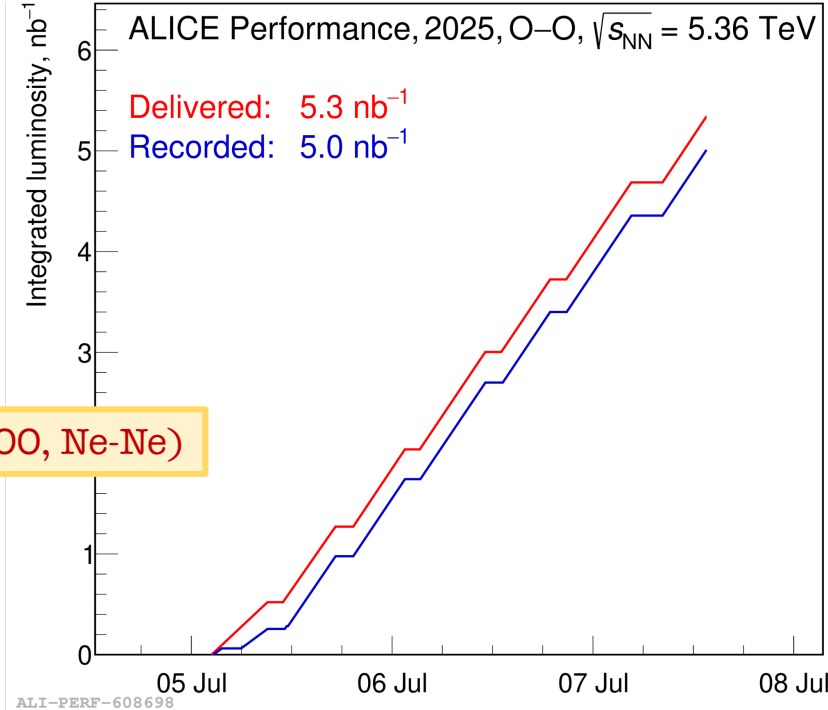
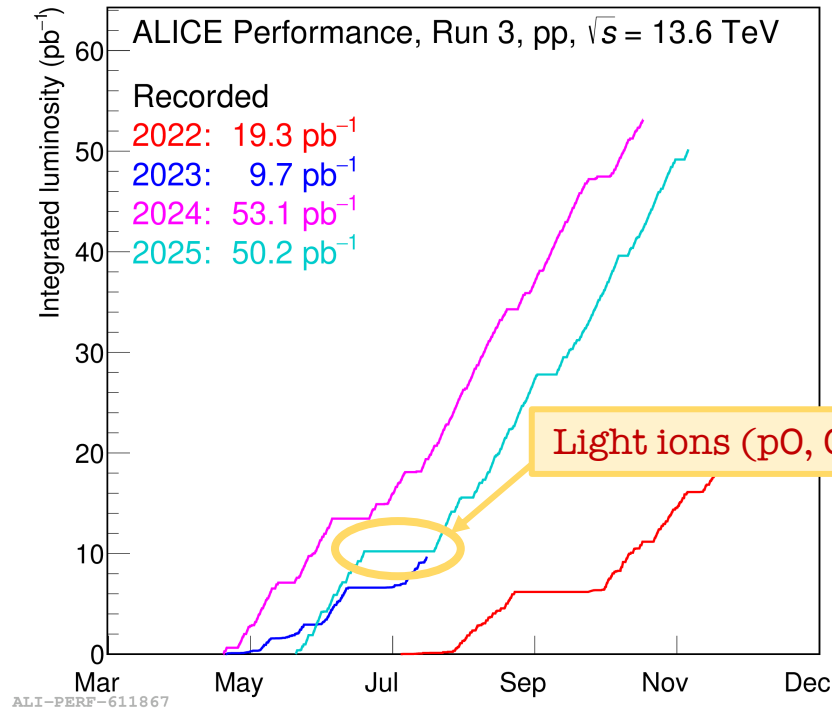


	$^4\text{He}$	$^4\text{Li}$
mass (GeV/c <sup>2</sup> )	3.727	3.749
radius (fm)	1.68	>2
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First upper limit on the production yield of  $^4\bar{\text{Li}}$  using the correlation function of  $\bar{p}+^3\bar{\text{He}}$



# Run 3 data taking



~8 x 10<sup>12</sup> MB pp events  
x10<sup>2</sup>-10<sup>3</sup> more MB than Run 1+2

First OO collisions at the LHC!

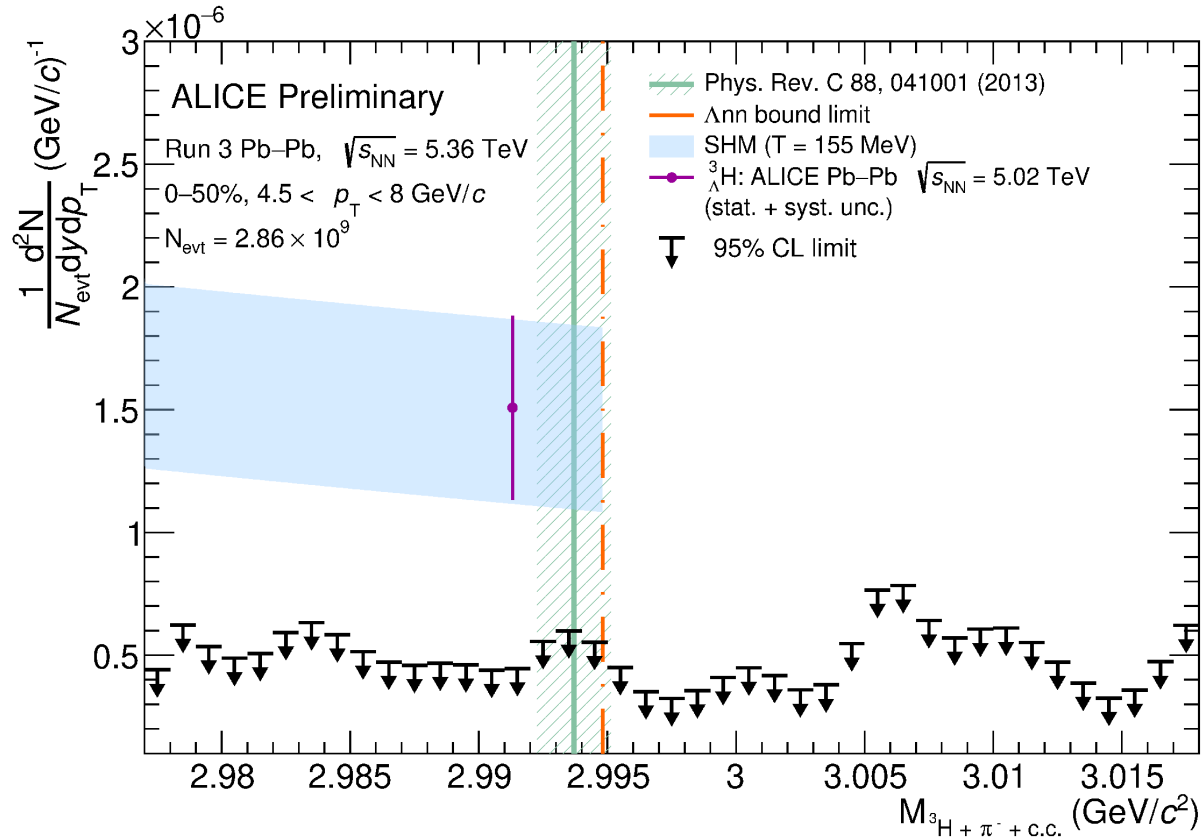
<https://alice-collaboration.web.cern.ch/2025-LHC-Oxygen-Run>

~40 x 10<sup>9</sup> MB Pb-Pb events  
x120 more MB than Run 1+2  
x20 more central than Run 1+2





→ Enabling searches for rare states previously not accessible

Accessing intermediate systems (light ions) ←

Possible two-body channel decay  
 $\Lambda$ nn  $\rightarrow$   ${}^3\text{H} + \pi^- + \text{charge conjugate (c.c.)}$



First estimate of  $\Lambda$ nn yield

- observed?  $\rightarrow$   $d+\pi^-$  and  ${}^3\text{H}+\pi^-$  final states in  ${}^6\text{Li}+{}^{12}\text{C}$  at 2A GeV reactions  HypHI Coll., [Phys. Rev. C 88, 041001\(R\) \(2013\)](#)
- unbound?  $\rightarrow$   Downs and Dalitz, [Phys. Rev. 114, 593 \(1959\)](#),  Gal and Garcilazo, [Phys. Lett. B 736 \(2014\) 93-97](#)
- bound?  $\rightarrow$  IQCD calculations  Beane et al., [Phys. Rev. D 87, 034506 \(2013\)](#)

- In the region with the highest sensitivity to a potential  $\Lambda$ nn signal - corresponding to an expected significance of  $4.6\sigma$ : no statistically significant signal observed
  - $\Lambda$ nn upper limit distribution does not agree with the SHM predictions in the region mass below the expected bound state threshold
- $\rightarrow$  Different production mechanism wrt  ${}^3\Lambda\text{H}$  or unbound system?



# Glueball searches in pp collisions

- Glueball is a bound state composed entirely of gluons
- Lattice QCD: Lightest scalar glueball mass range 1550–1750 MeV/c<sup>2</sup>
- Lightest scalar glueball candidate f<sub>0</sub>(1710)<sup>1</sup>:
  - Quantum numbers J<sup>PC</sup> = 0<sup>++</sup>
  - Mass in the predicted range
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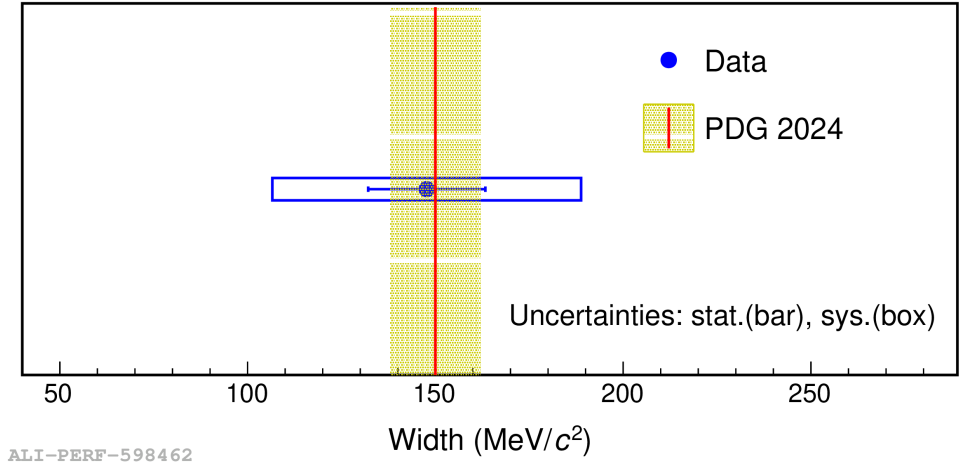
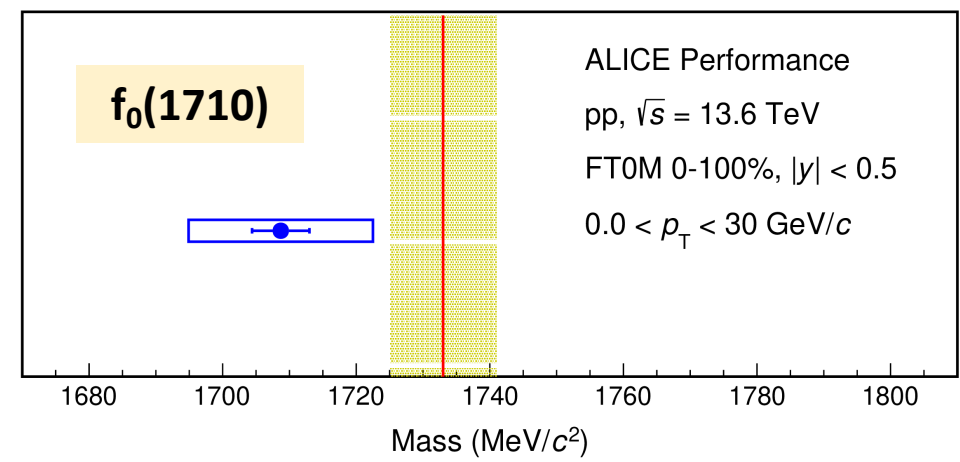
## State-of-the-art

- HERA (e-p collisions): f<sub>0</sub>(1710) observed in K<sub>s</sub><sup>0</sup>K<sub>s</sub><sup>0</sup> channel<sup>2</sup>
- Seen in EM environment (ep), needs validation in hadronic environment

First measurement of f<sub>0</sub>(1710) in ALICE in pp collisions in K<sub>s</sub><sup>0</sup>K<sub>s</sub><sup>0</sup> channel

- Mass and width consistent with that quoted by the PDG 2024 (Γ ~ 150 ± 12 MeV, m = 1733 ± 8 MeV/c<sup>2</sup>)

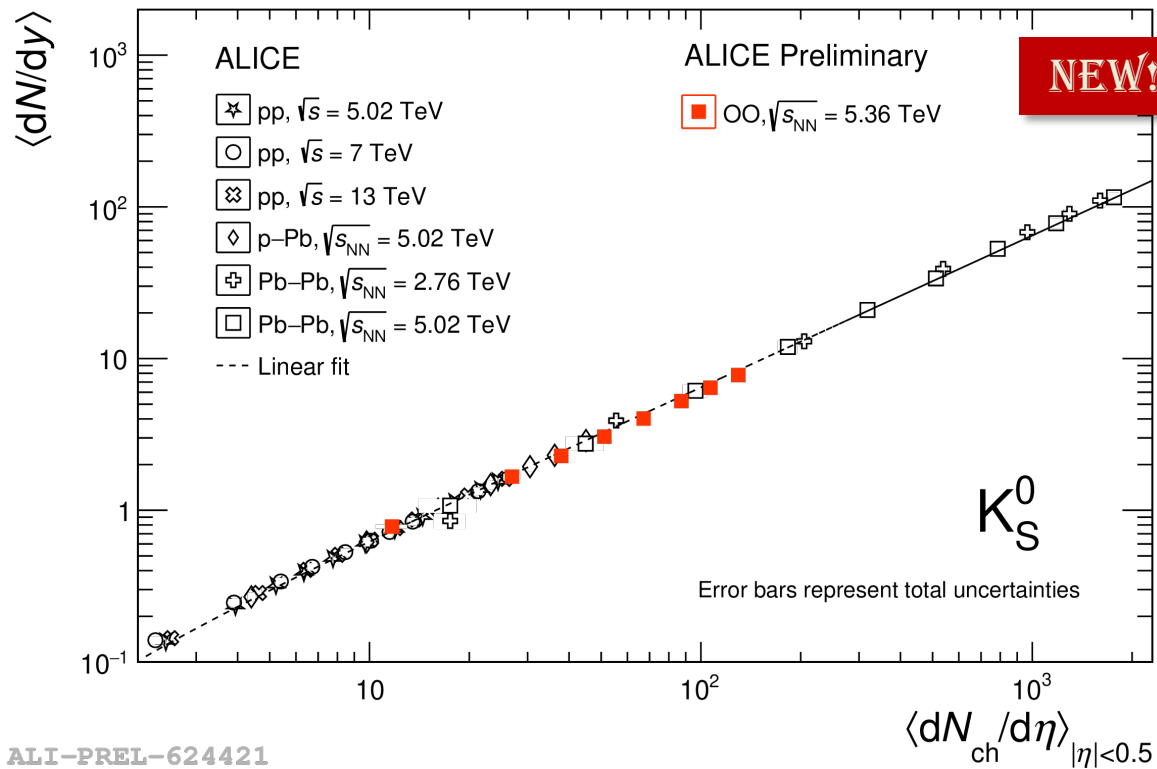
## Corrected spectra of f<sub>0</sub>(1710)



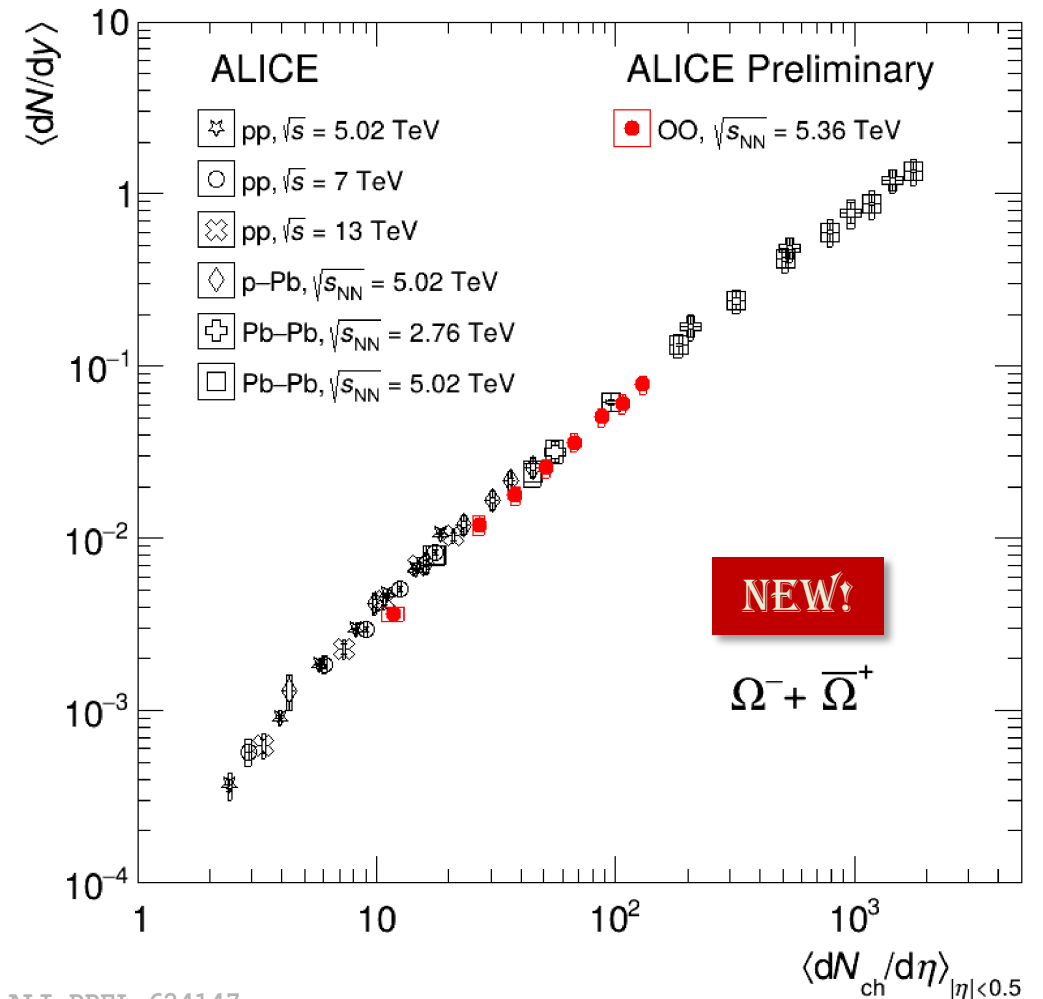
<sup>1</sup> Y. Chen et al., [Phys. Rev. D73, 014516 \(2006\)](#)

<sup>2</sup> ZEUS Coll., [PRL 101, 112003 \(2008\)](#)

- Strange and multi-strange particles ( $\Lambda$ ,  $K_s^0$ ,  $\Xi$ ,  $\Omega$ ) measured in OO collisions
  - integrated yields in light-ion collisions agree with the common picture established from pp to Pb—Pb collisions
  - linear evolution from low to high multiplicity



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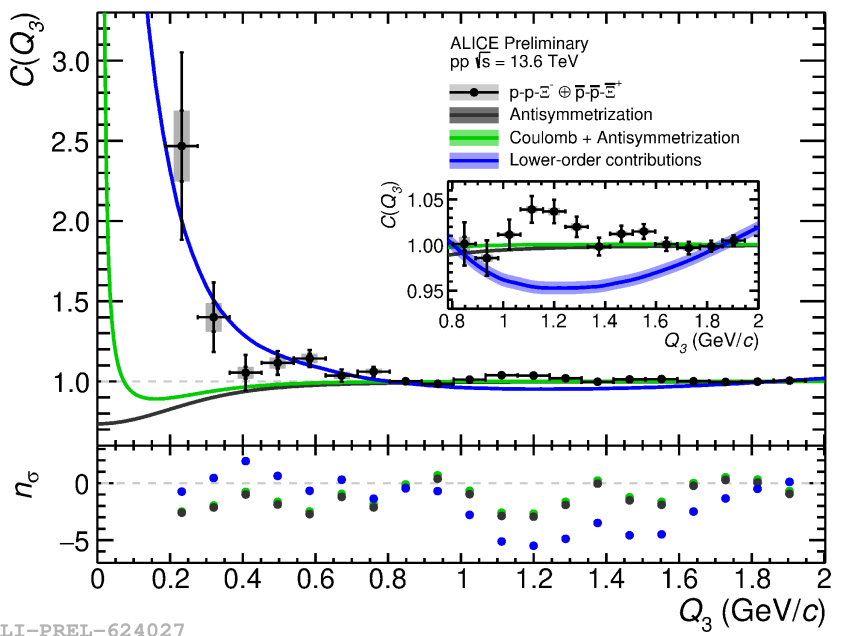


ALI-PREL-624147

**TWO-BODY**

$p\Xi$  correlation function from Run 3

- Evidence of an attractive strong interaction
- Coulomb attraction cannot describe the data
- Clear signal of the  $\Lambda$ - $\Sigma^0$  channel coupling visible in data
- Full  $p\Xi$ - coupled channel dynamics improves the description of data
- Deviation at large  $k^*$
- $\Lambda$ - $\Sigma^0$  coupling is too weak
- p-wave interaction is not included yet
- HAL QCD Coll. NPA 998 (2020)

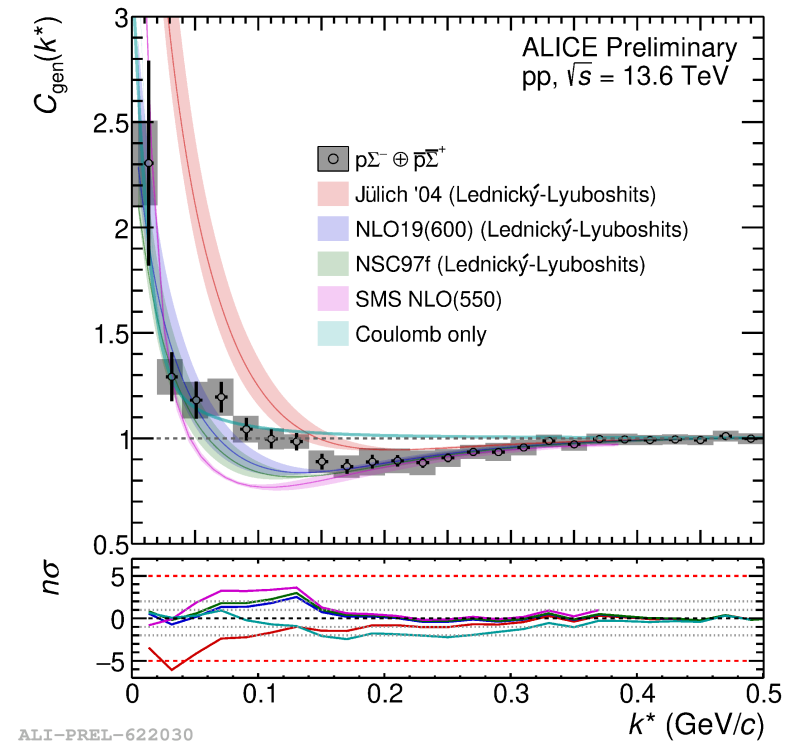


ALI-PREL-624027

**THREE-BODY**

p-p- $\Xi$ - correlation function

- First measurement of p-p- $\Xi$ - final state interaction: 3.5  $\sigma$  significance at  $Q_3 < 1$  GeV/c
- Coulomb improves the agreement with data
- Strong interaction with cumulant expansion method (no 3-body dynamics) provides 0.6  $\sigma$  agreement at  $Q_3 < 1$  GeV/c
- Significant deviation observed in the range (1.0, 1.8) GeV/c



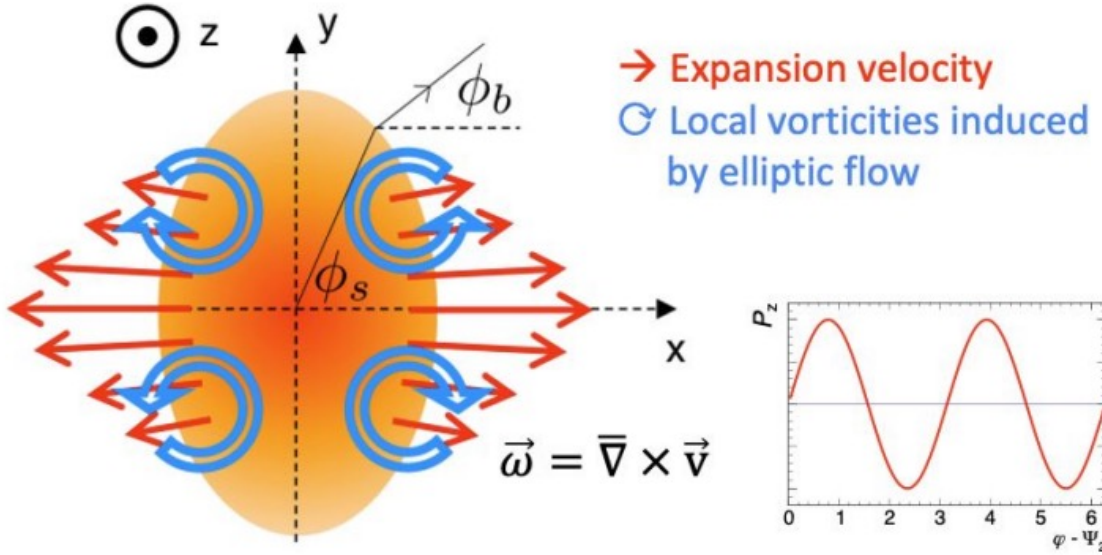
ALI-PREL-622030

# Longitudinal polarization

- Local asymmetries in velocity fields—driven by elliptic flow—generate non-zero longitudinal polarization
- Longitudinal spin polarization
  - degree to which the spin of a particle is aligned with the beam axis
  - sensitive to the bulk viscosity of the QGP

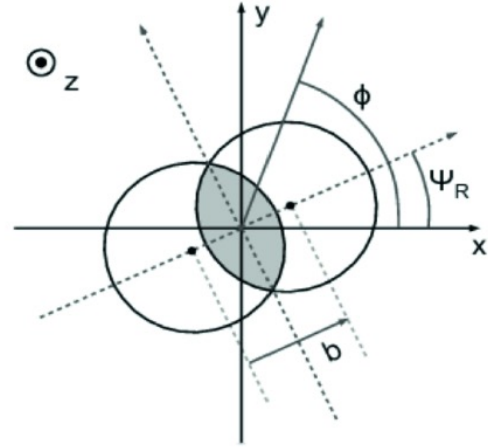
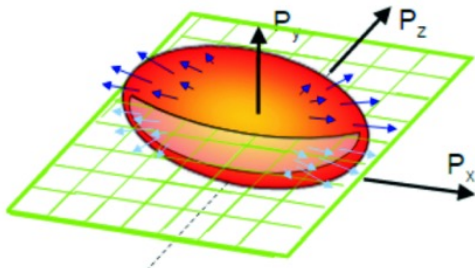
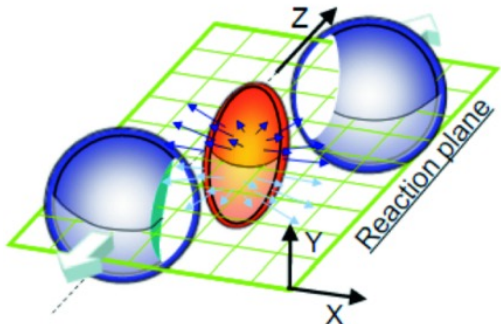
The polarization along the beam axis  $P_z$  is sensitive to:

- the bulk viscosity  $\zeta/s$  of the QGP at the LHC energies → bulk viscosity can change the sign of the polarization
- the contribution from shear-induced polarization (SIP), whose origin is the motion of particles in anisotropic fluid, and which competes with the effect of thermal vorticity



# Elliptic flow

non-central heavy-ion collisions



transverse plane

$\phi$ : azimuthal angle of outgoing particle  
 $\Psi_R$ : reaction plane angle  
 $b$ : impact parameter

Initial spatial anisotropy translates into final-state momentum anisotropy

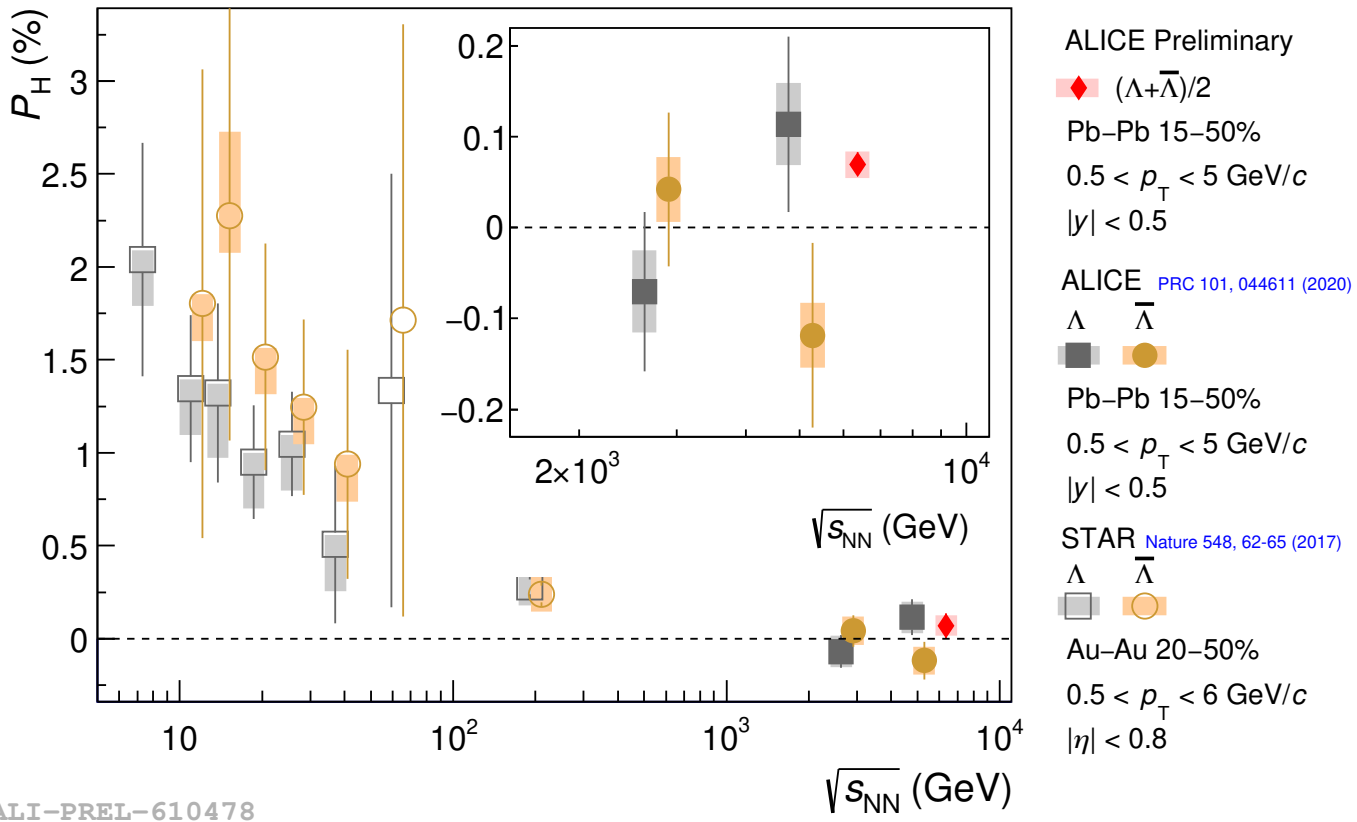
Particle azimuthal distribution can be expressed as a Fourier series

$$\frac{dN}{d\phi} \propto 1 + 2 \sum_{n \geq 1} v_n \cos(n(\phi - \Psi_R))$$

flow coefficients

the second term of the Fourier expansion is the elliptic flow  
 $v_2 \rightarrow$  quantifies the initial anisotropy of the collision

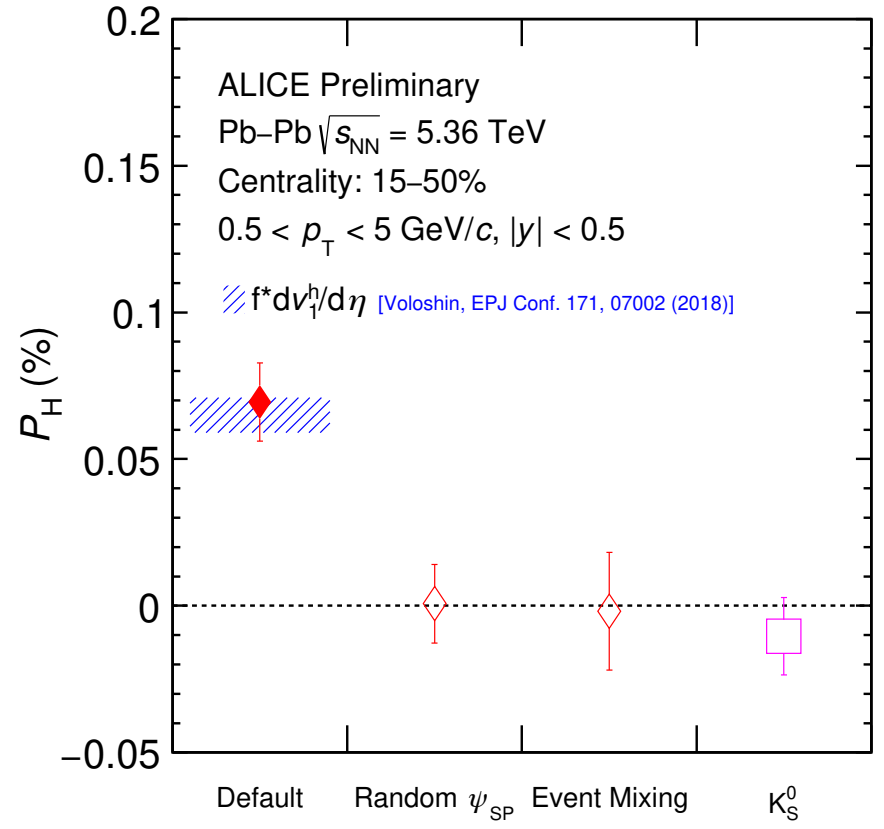
# Global polarization of Lambda



ALI-PREL-610478

- In agreement with empirical theoretical calculations
- Tested against null-hypotheses

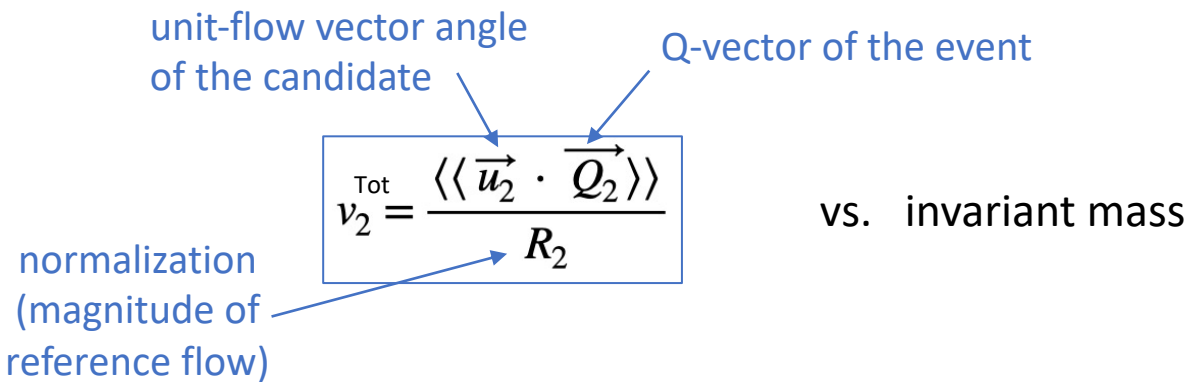
- Global polarization of average (anti) $\Lambda$  is positive
- Common trend of the global polarization decreasing with increasing collision energy



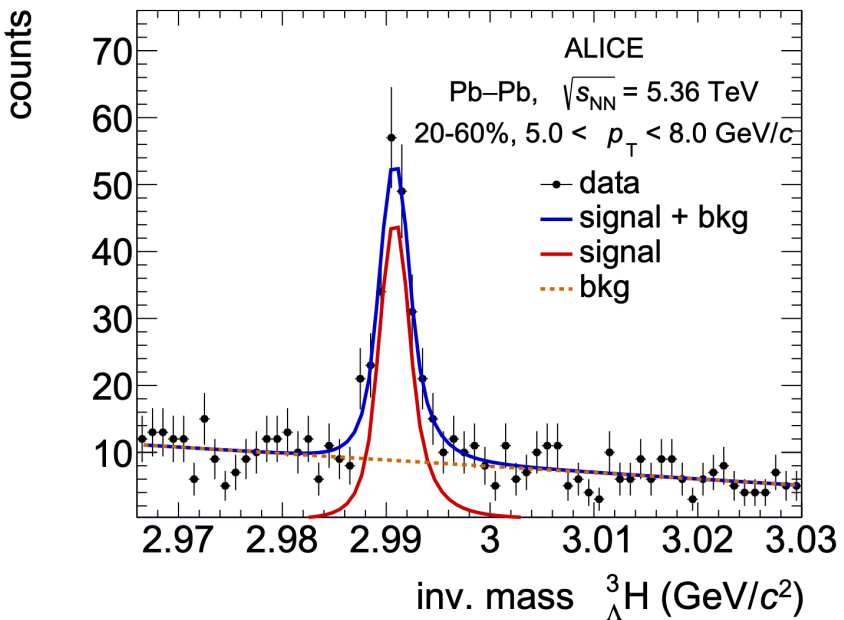
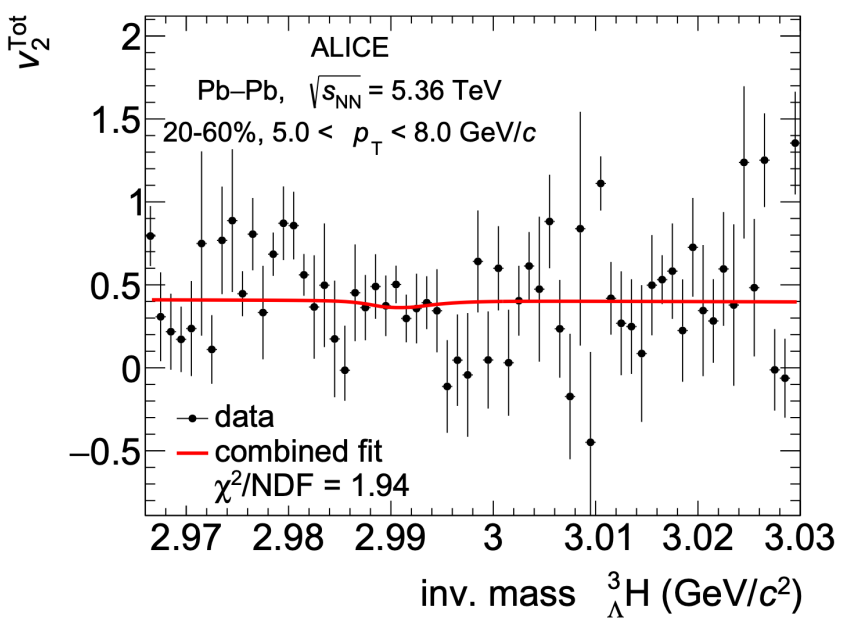
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# Analysis technique

The elliptic flow of  ${}^3\text{He}$  & Hypertriton is measured using the scalar product method



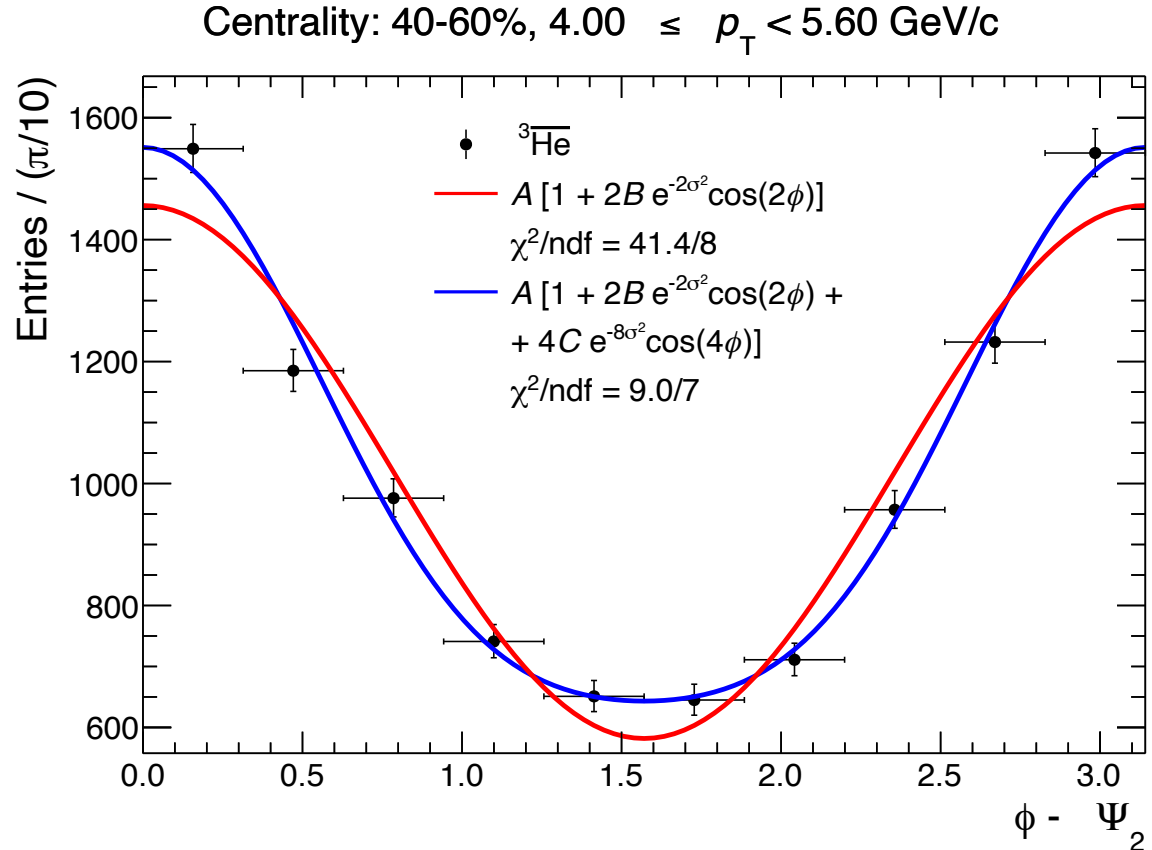
$\rightarrow$  For each  $p_T$  and centrality interval, the  $v_2$  of  ${}^3\text{H}$  is obtained from a **combined fit** of the  $v_2^{\text{Tot}}$  and the invariant mass distributions



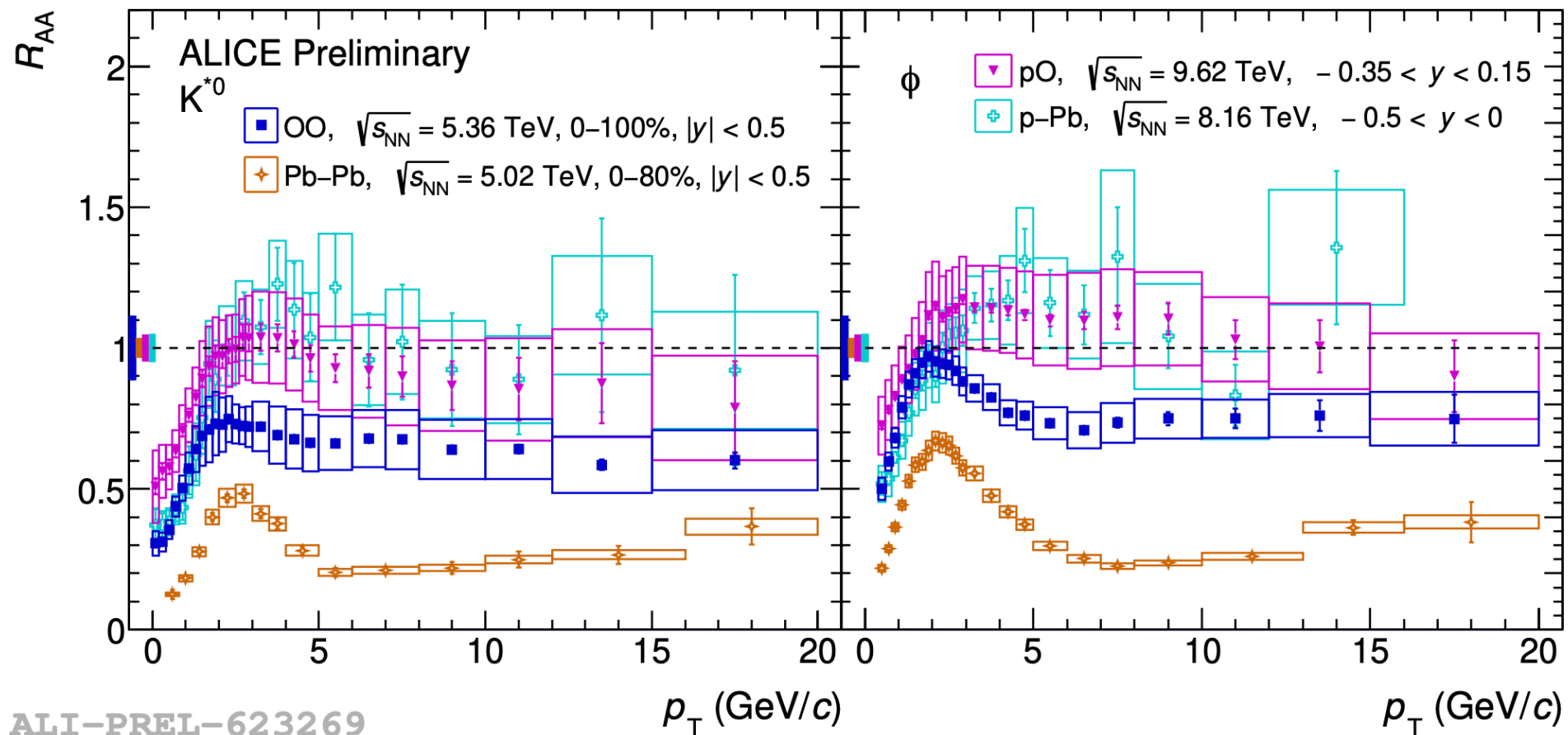
# $v_2 > 0.5 \rightarrow$ a sign of coalescence?

- Similar effect in quark coalescence  $\rightarrow$  non-linear mapping from quark to hadron momentum introduces higher-order harmonics in the azimuthal distribution  
 [Kolb et al., Phys. Rev. C 69 (2004) 051901,  
 Fries et al., Ann. Rev. Nucl. Part. Sci. 58 (2008) 177–205]
- These contributions become significant when the constituent quark  $v_2$  is large
- By analogy, in nucleon coalescence  $\rightarrow$  formation of  $^3\text{He}$  from nucleons at high  $p_T$ , where proton flow reaches its maximum, can introduce higher-order modulations in the azimuthal structure

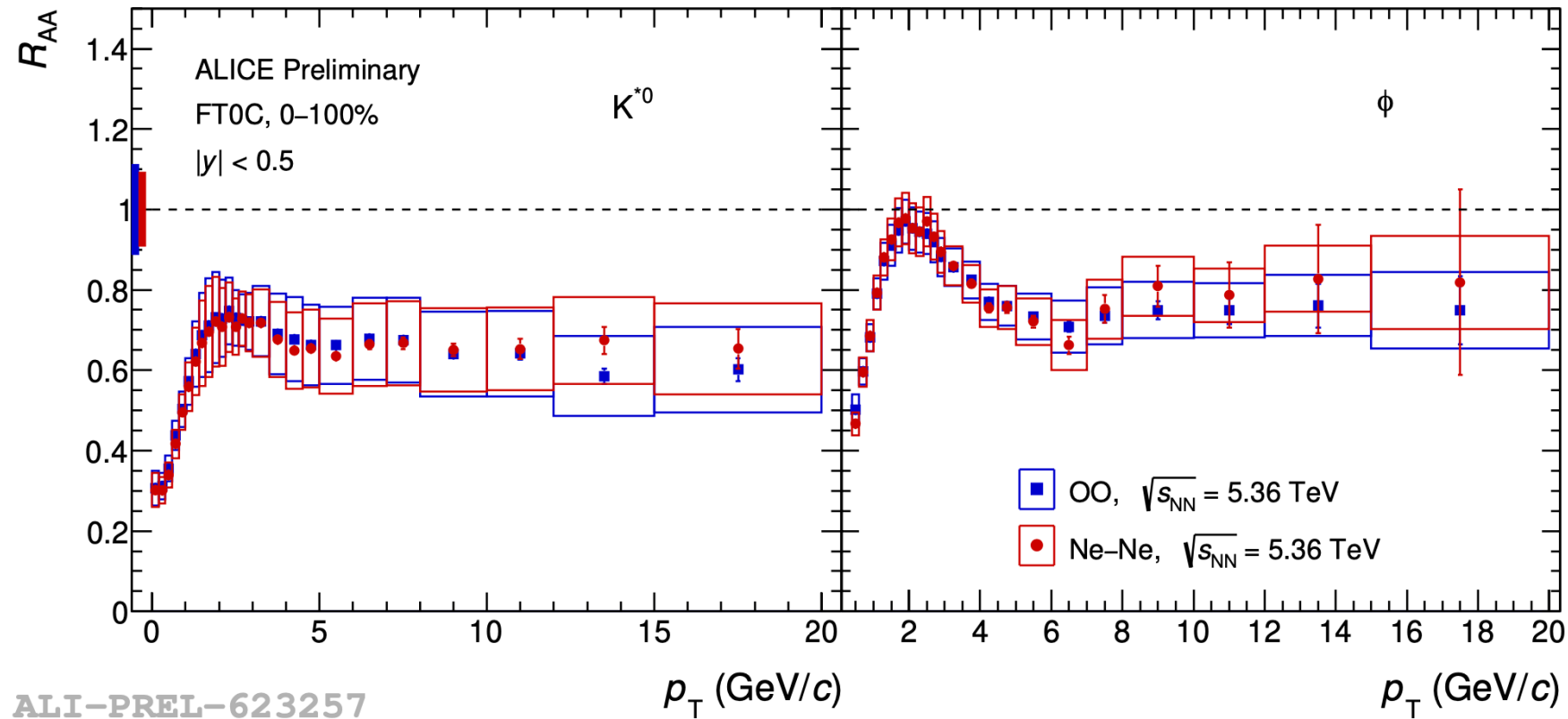
$\rightarrow$  large  $v_2$  values observed for  $^3\text{He}$  may originate from coalescence-induced effects



Coalescence introduces a modulation in the  $(\phi - \psi_2)$  distribution!

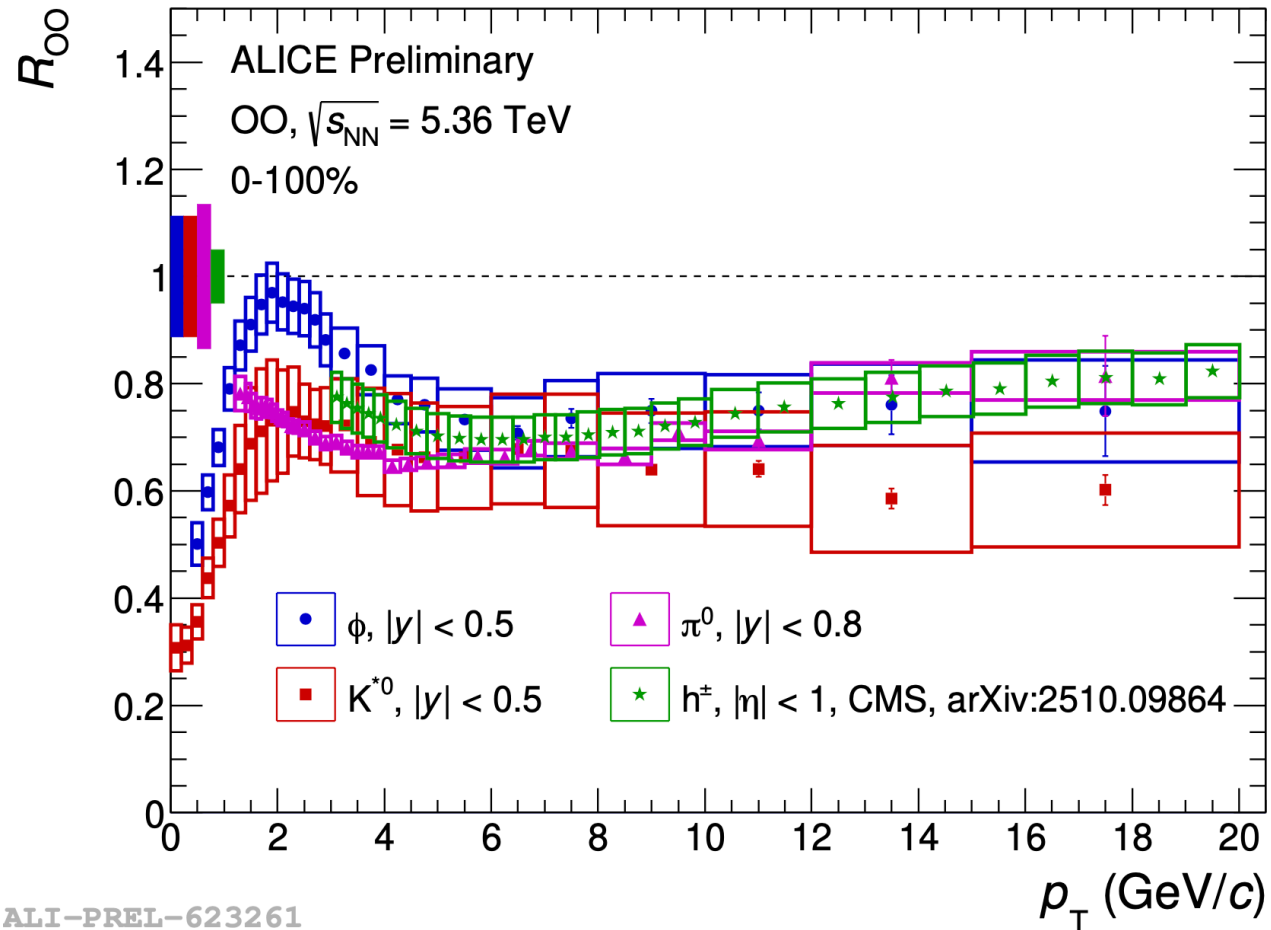


$R_{AA}$  in different collision systems



ALI-PREL-623257

OO & Ne–Ne collisions shows similar  $R_{AA}$  values, indicating comparable parton energy loss at high  $p_T$  in these light-ion systems



Similar high-  $p_T$ , suppression across different hadron species suggests that partonic energy loss is largely independent of the final hadron species.

# Talks on LF this week...



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