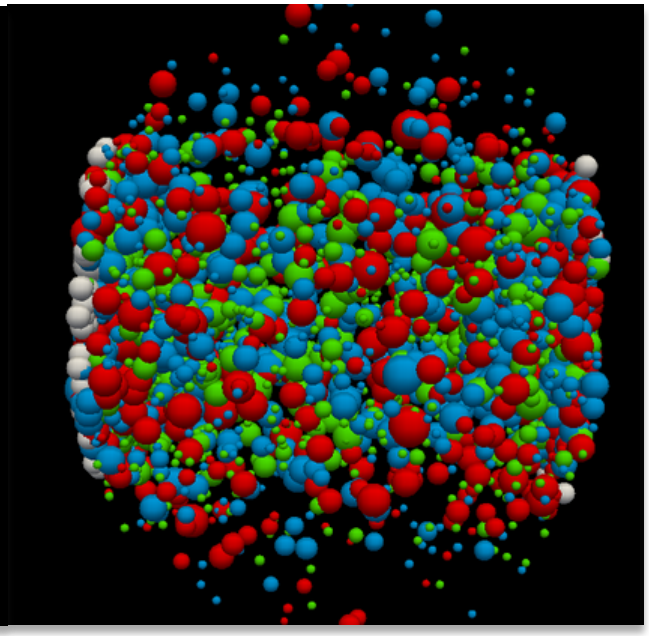
Bulk of the particle production and collective behavior study for searching QGP in small collision system



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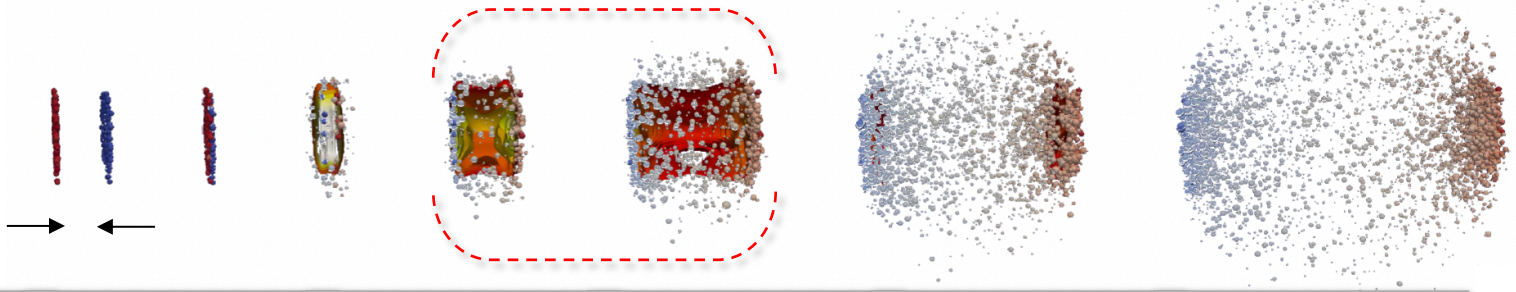
India - JINR workshop on elementary particle and nuclear physics, and condensed matter research

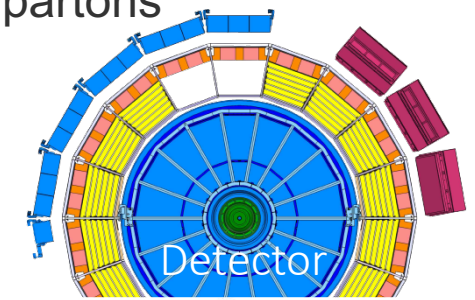
16-18 October, 2023, Dubna, Russia

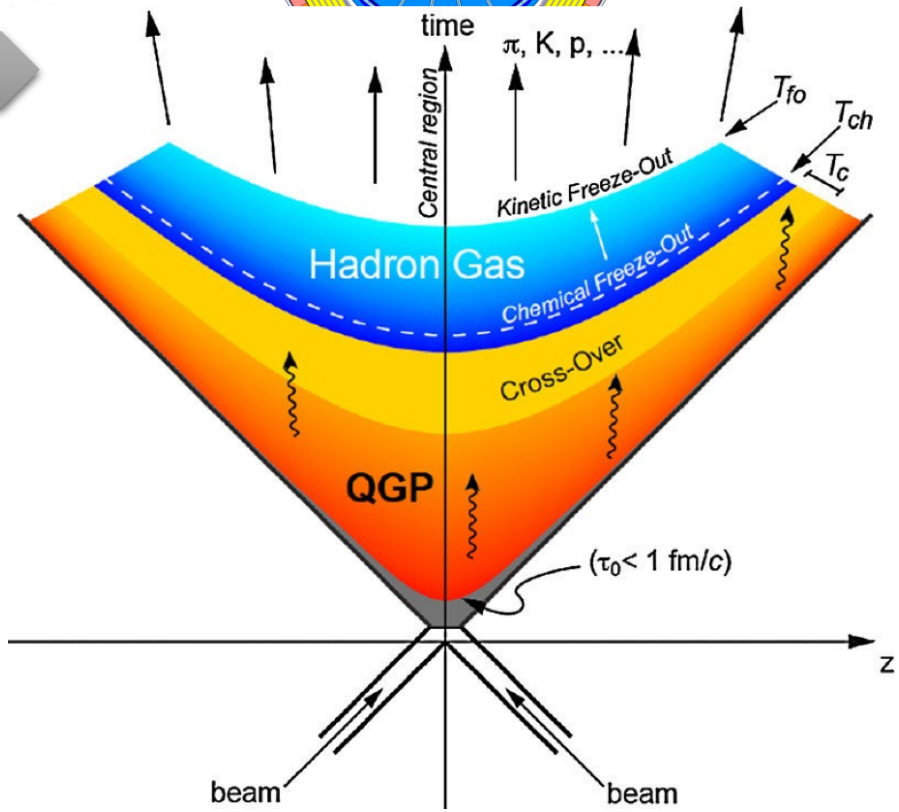
Introduction: Formation of the QGP

Quark-gluon plasma (QGP): A hot and dense medium of deconfined partons



Time	0 fm/c	1 fm/c	few fm/c	10 fm/c	20 fm/c
	Initial state	QGP formation	Hadronisation	Chemical freeze out	Kinetic freeze-out



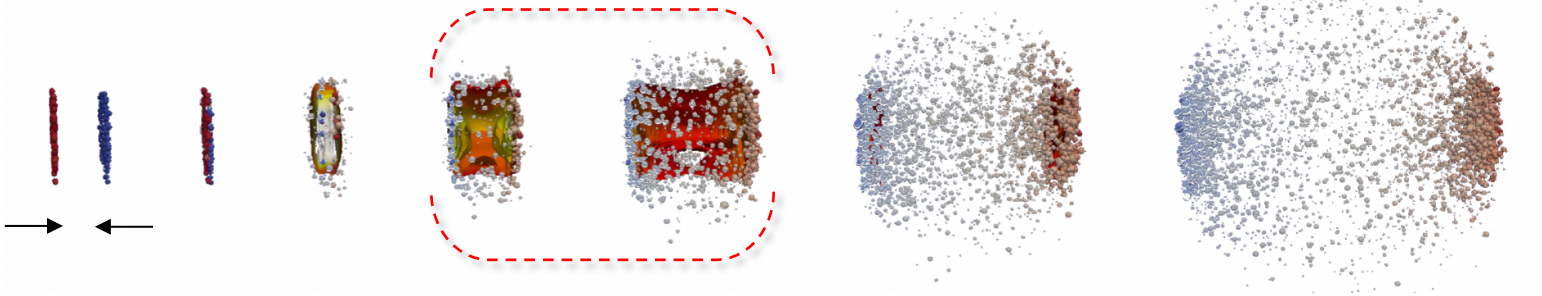


- **Initial state:** collision of two Lorentz-contracted nuclei
- **QGP formation:** fast thermalization, $\tau \approx 1$ fm/c
  → deconfined medium expanding hydrodynamically
- Phase transition (cross-over) to hadron gas
  (T_c = 156.5 +/- 1.5 MeV, Nucl. Phys. A 982 (2019) 847)
  → Color confinement: **hadronization**
- **Chemical freeze-out** ($T_{ch} \approx 153$ MeV)
  → inelastic collisions stop: particle abundances fixed
- **Kinetic freeze-out** ($T_{fo} \approx 100$ MeV)
  → elastic collisions stop: particle spectra fixed

•Particles fly towards detectors

Bulk of particles production in QGP study

Quark-gluon plasma (QGP): A hot and dense medium of deconfined partons



The bulk of the particle production at LHC constituting light-flavour (u, d, s) hadrons. They are more than 99% at low p_T region (< 2 GeV/c).

Study the thermodynamic property and explore the collective phenomena.

- p_T —spectra of the identified hadrons carry the information on radial flow, energy loss, chemical and kinetic freezeout temperature.

The particle ratio study helps to understand the hadron chemistry of the particle production.

- Strangeness enhancement

Azimuthal anisotropic behavior of particle production

- Anisotropic flow and long range correlation

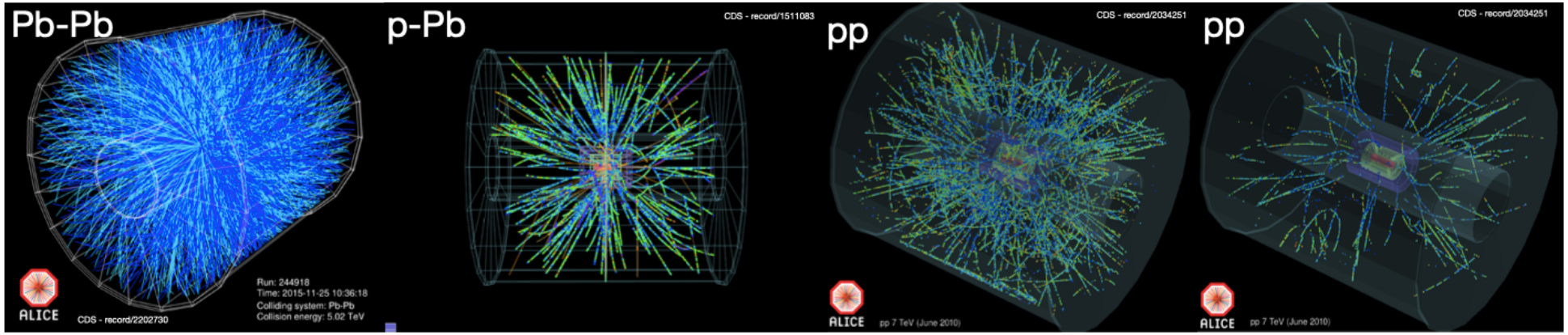
Useful in comparison among the colliding systems.

- **Hints of collectivity in in small system (pp and p—A).**

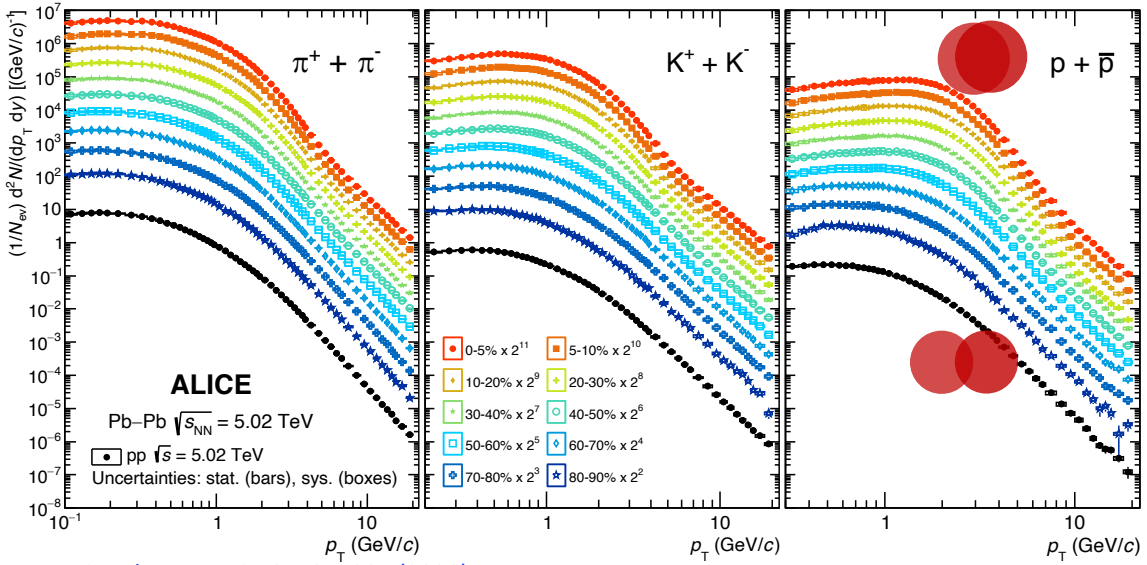
Searching of QGP: from large to small system

What is ‘small system’?

- In preLHC relativistic heavy-ion physics, a ‘small system’ is defined where QGP formation is not expected.
  - pp system as a reference for physics of A-A system.
- Recent studies show the collective phenomena in high multiplicity (HM) collisions in small system.
- Formation of QGP in small system? High multiplicity pp collisions are particularly important.
  - minimum bias pp system still holds as reference of A-A system.



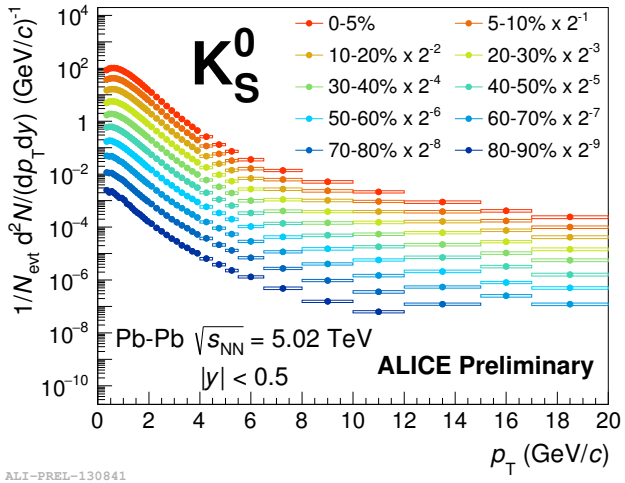
Light flavor spectra at A-A systems

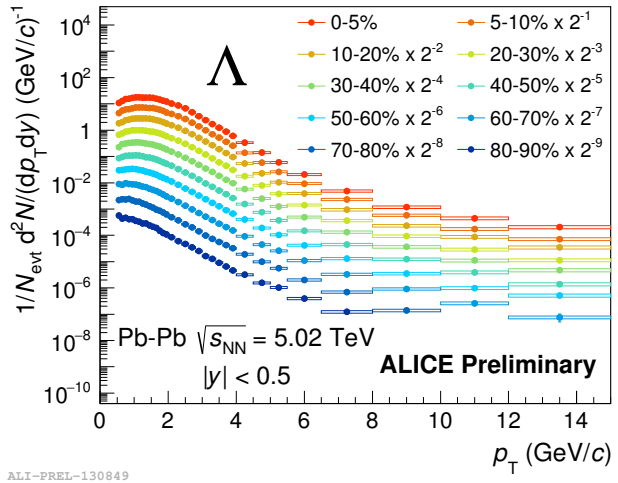


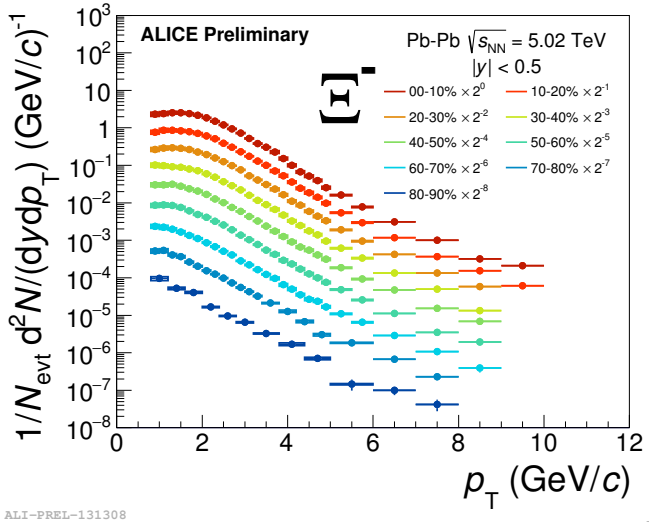
ALICE, Phys. Rev. C 101, 044907 (2020)

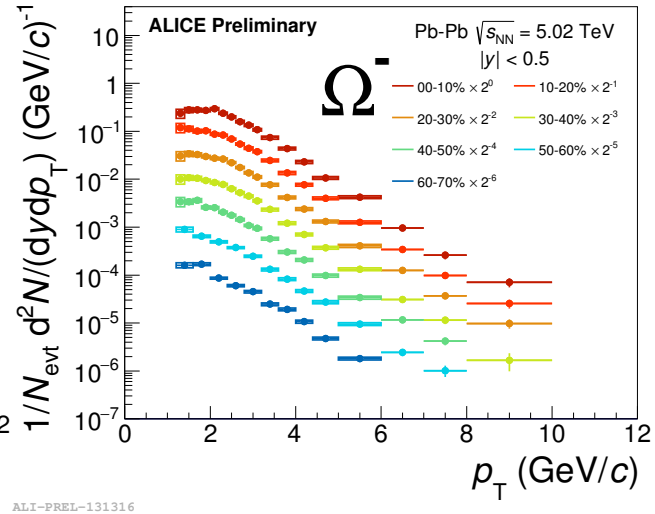
mass | Ω^- | Ξ^- | Λ | p | K^0_S | K | π

- Spectra shifted towards higher momenta from peripheral to central collisions – hardening of the spectra at low p_T .
- The effect is also mass dependent - heavier particles have more shifted towards large p_T (p=$\gamma\beta mc$).
- signature of the radial flow.

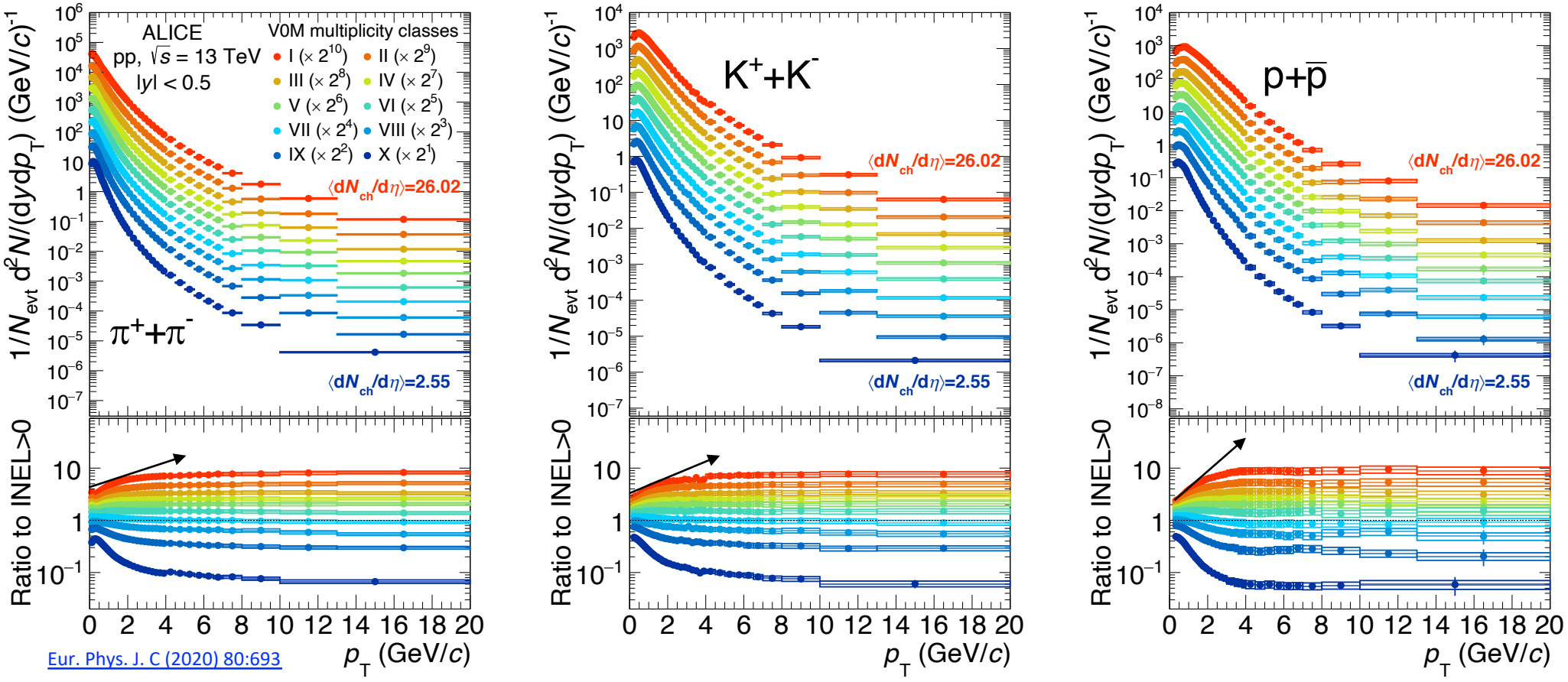








Light flavor spectra of pp 13 TeV published



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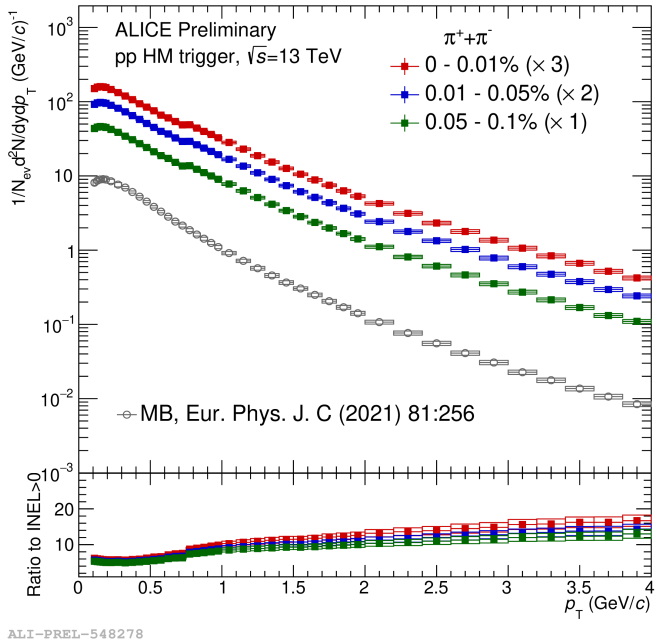
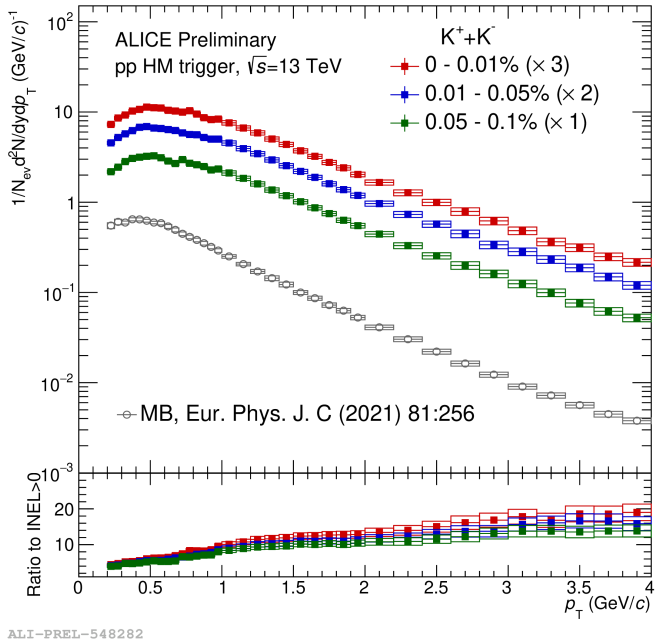
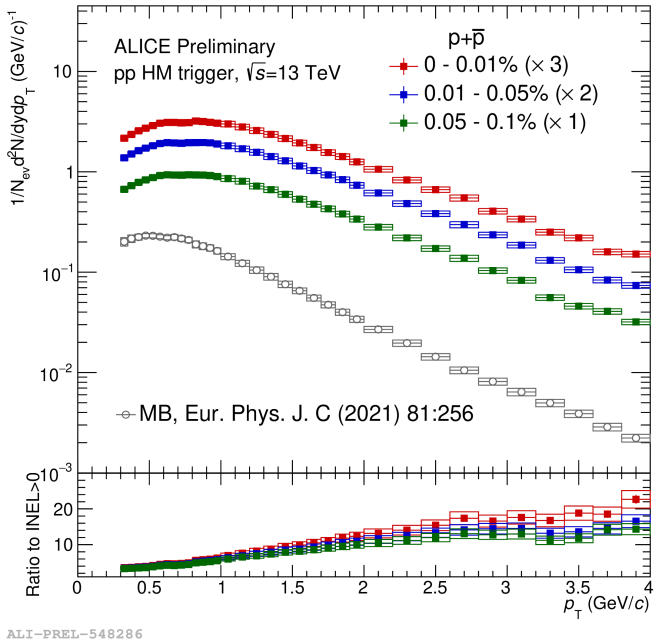
- At low p_T region mass dependent hardening of the spectra is observed.
- At higher p_T (> 8GeV/c) slope of the spectra are independent of the multiplicity class, as expected from pQCD.
- Multiplicity dependent hardening found.

Light flavor spectra in HM pp events

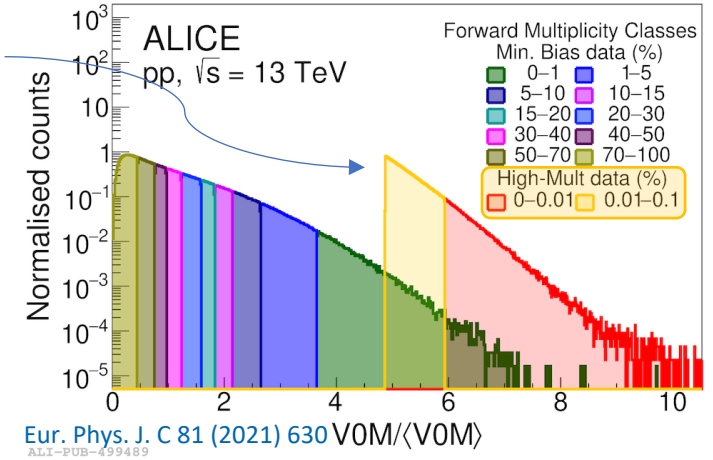






Talk in EPS-HEP 2023

High-multiplicity classes



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- High-multiplicity pp collisions: mass dependent hardening observed.
- Slight centrality dependent hardening.

- **Hint of the *radial flow* in high multiplicity pp collisions.**

Blast-wave model and radial flow as collectivity

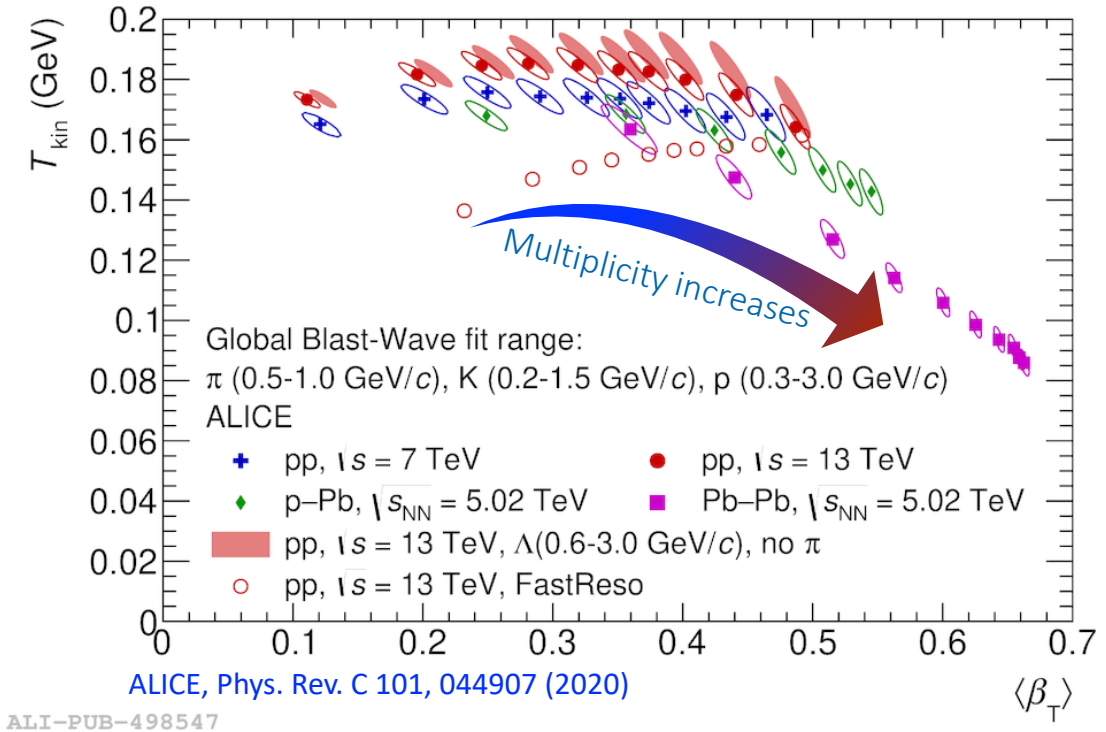
Boltzmann-Gibbs blast-wave model*: a three-parameter simplified hydrodynamical model -> calculate radial flow (β_T)

*Phys. Rev. C 48 (1993) 2462

$$E\frac{d^3N}{dp^3} \propto \int_0^R m_T I_0\left(\frac{p_T \sinh(\rho)}{T_{kin}}\right) K_1\left(\frac{m_T \cosh(\rho)}{\beta_T}\right) r\, dr$$

$$\rightarrow m_T = \sqrt{m^2 + p_T^2} \quad \rho = \tanh^{-1}(\beta_T) \quad \beta_T(r) = \beta_s\left(\frac{r}{R}\right)^n$$

- **Large systems:** **Largest β_T** and **lowest T_{kin}** for central Pb-Pb collisions
- **Small systems: pp and p-Pb show a similar trend** and
- values are comparable

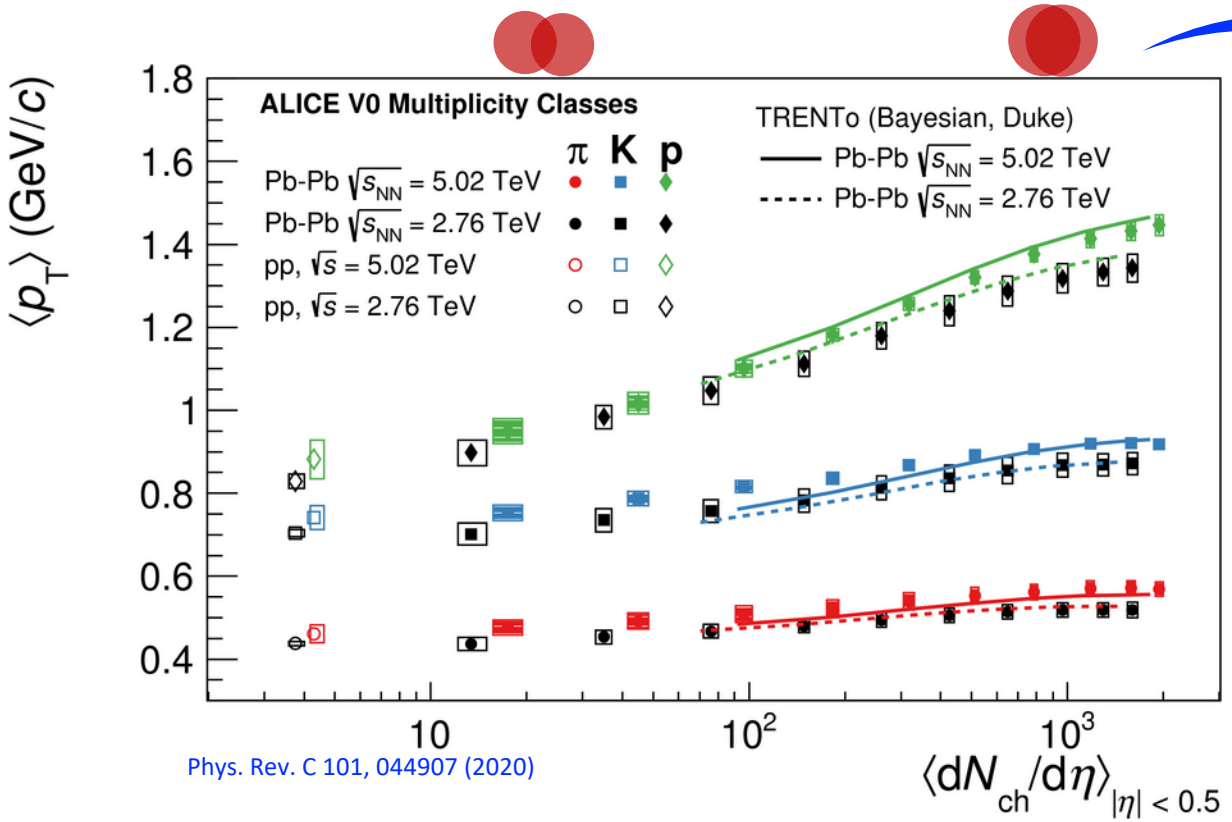


ALICE, Phys. Rev. C 101, 044907 (2020)

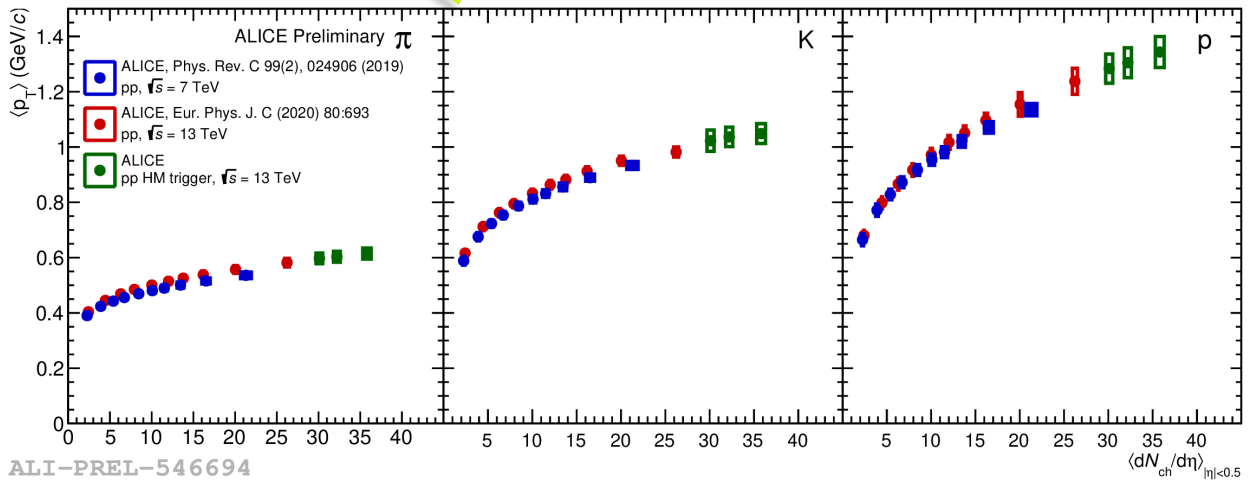
➢ Continuous evolution as a function of the event multiplicity is found in small systems.

➢ Radial flow effect can be observed in small system.

Signature of radial flow: $\langle p_T \rangle$ measurement in small and large systems



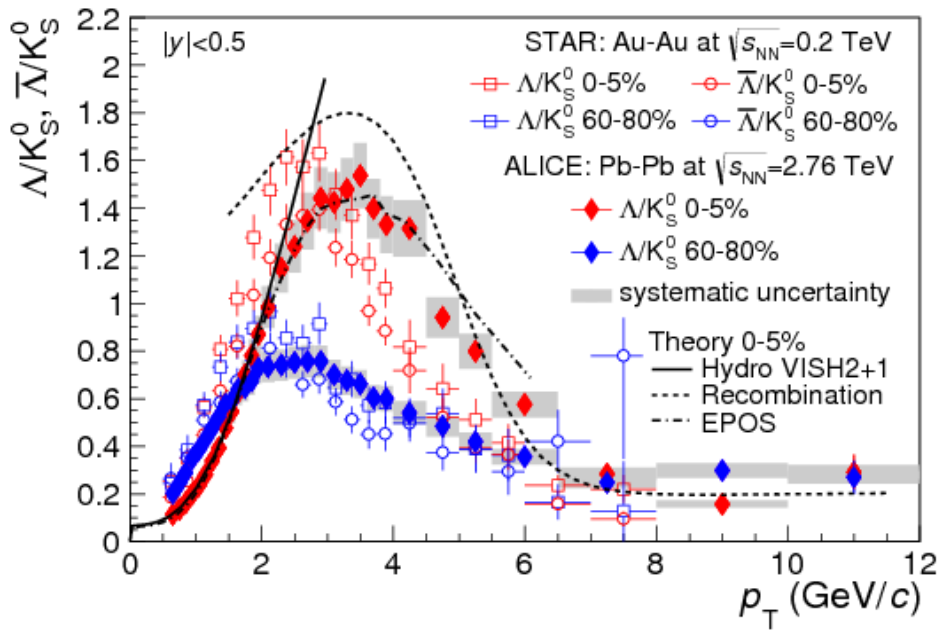
Phys. Rev. C 101, 044907 (2020)

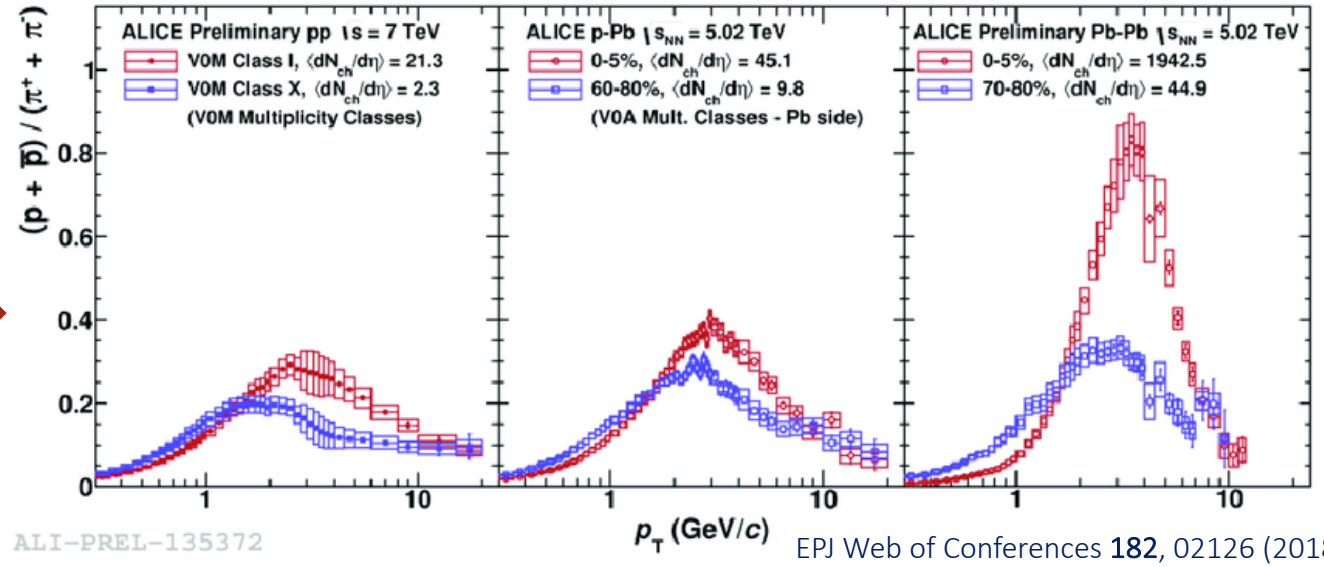


Talk in EPS-HEP 2023

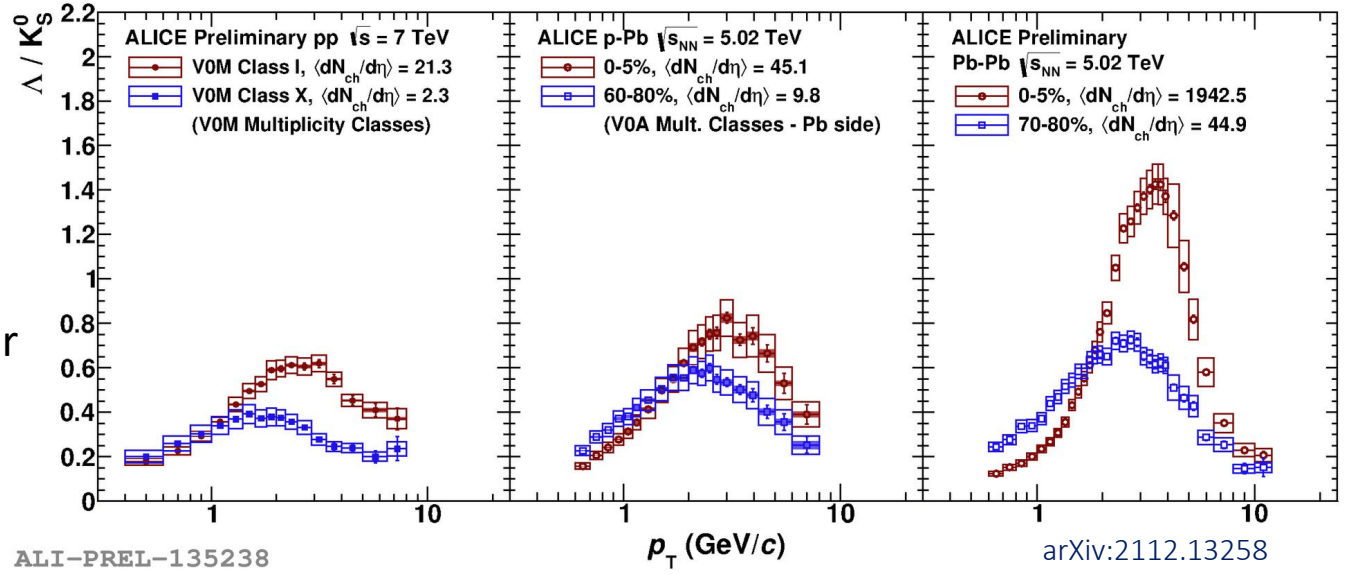
- $\langle p_T \rangle$ increases going from inelastic pp and peripheral Pb–Pb collisions to central Pb–Pb collisions.
- $\langle p_T \rangle$ increases continuously with multiplicity in pp collisions
- The increase is steeper with mass - supports the picture of common radial flow effect.
- At central Pb–Pb collision, $\langle p_T \rangle$ is slightly higher at 5.02 TeV than 2.76 TeV – low p_T part contribution in stronger radial flow.

Signature of radial flow as collective effect





EPJ Web of Conferences **182**, 02126 (2018)



arXiv:2112.13258

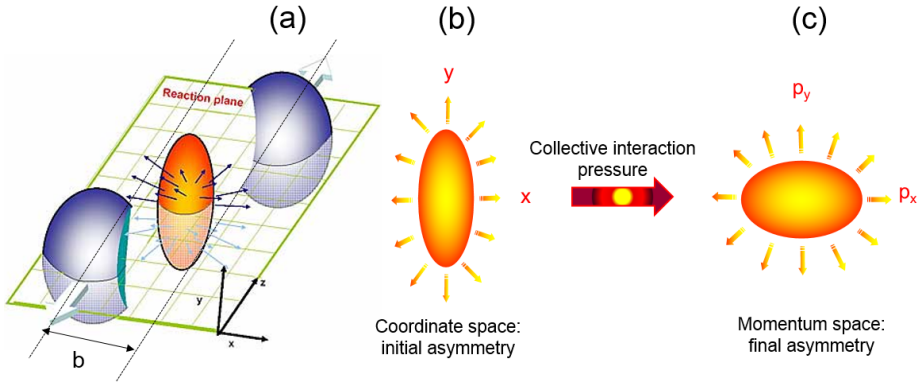
- Baryon-to-meson ratio shows qualitatively similar results in pp, p-Pb and Pb-Pb systems
- The peak at intermediate p_T is due to interplay between hydrodynamic flow and recombination.
- With increasing multiplicity the peak shifts towards higher p_T.

The results supports the radial flow is more effective to baryon than meson

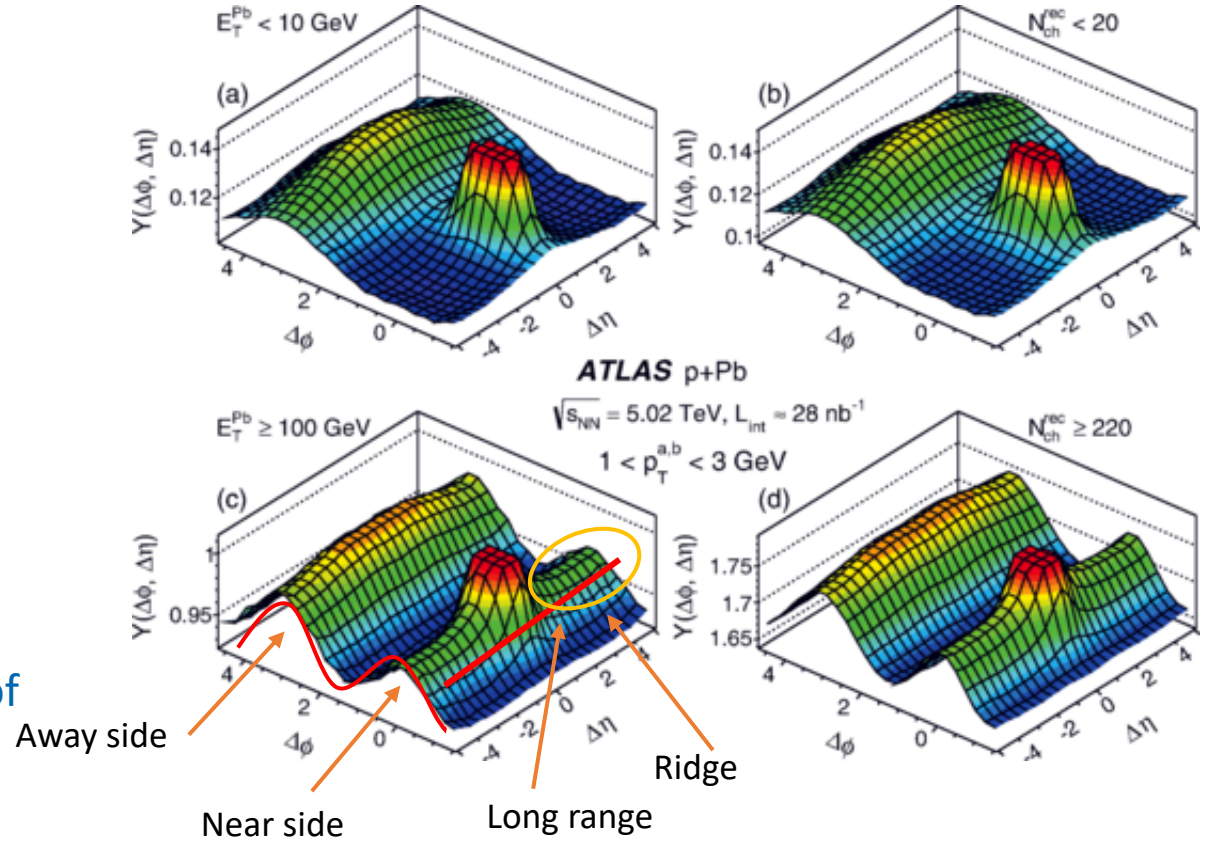
Angular correlation as collective evolution

Collective expansion translates into **long range** modulation of particle emission **in azimuth**

Correlations over a large range in pseudorapidity implies it originate from early times of collisions and thus suggest that hydrodynamic behavior.

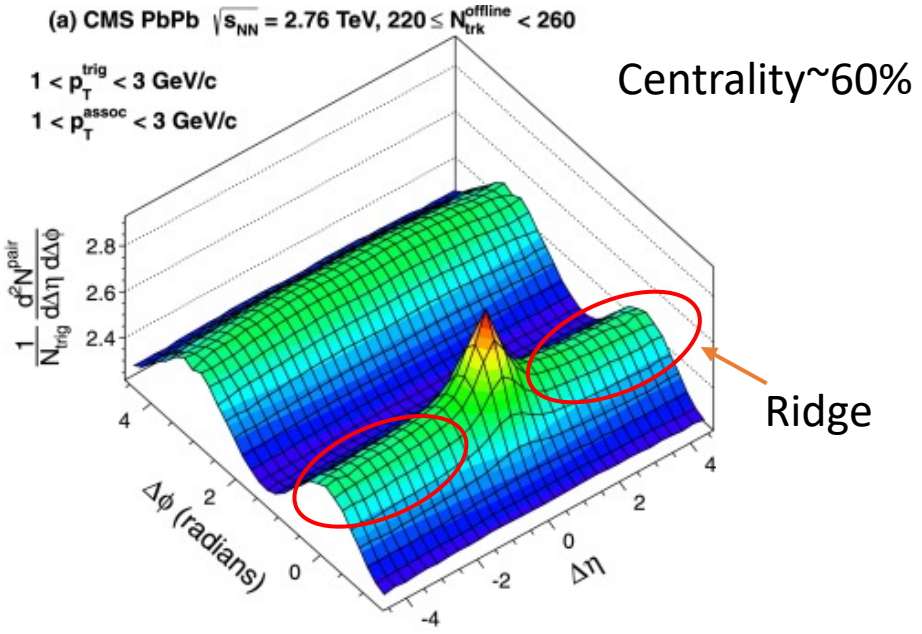


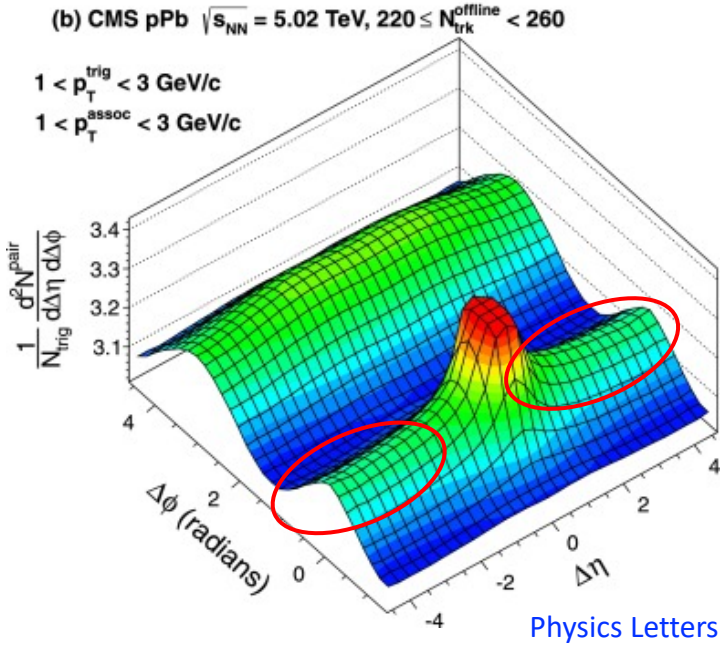
- Two particle correlation in $(\Delta\eta, \Delta\phi)$ plane shows a ridge like structure at near side $(\Delta\phi \approx 0)$ as a function of collision multiplicity because of long range correlation.
- Near ride ridge structure is because of collective effect of the medium.
- Away side $(\Delta\phi \approx \pi)$ ridge might be also seen, possible reason for that is elliptic flow and jet.



Phys. Rev. C **90**, 044906 (2014)

Angular correlation as collective evolution



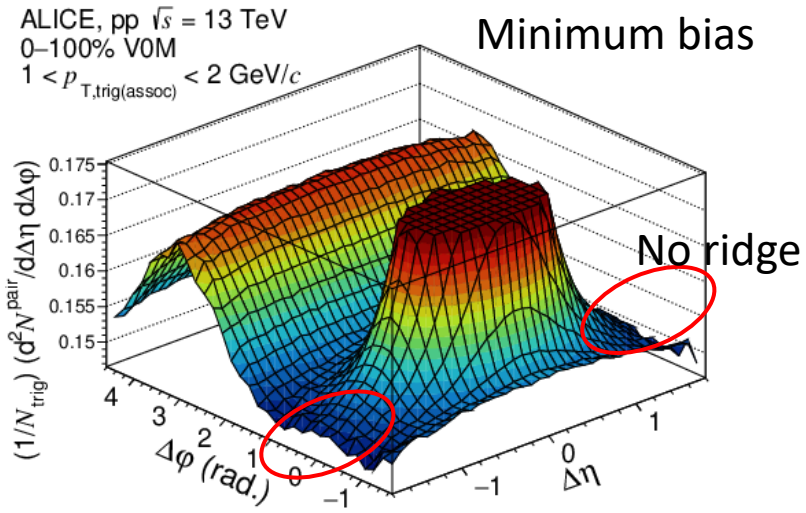


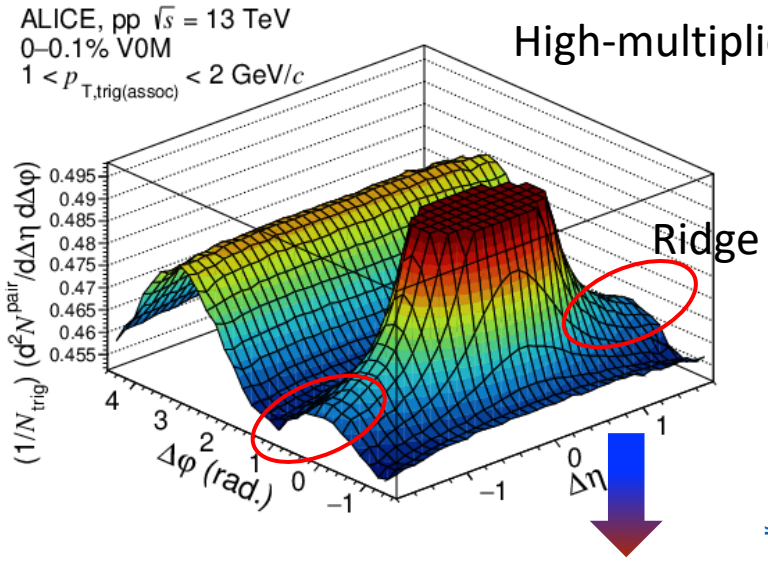
Physics Letters B 724 (2013) 213–240

- Near side ($\Delta\phi \approx 0$) ridge observed because of long range correlation in PbPb and pPb system
- Away side ($\Delta\phi \approx \pi$) ridge because of elliptic flow and also jet correlation

- So collectivity definitely observed in PbPb and pPb system
- Can we expect similar ridge like structure as a signal of collectiveness in pp system?

Angular correlation as collective evolution



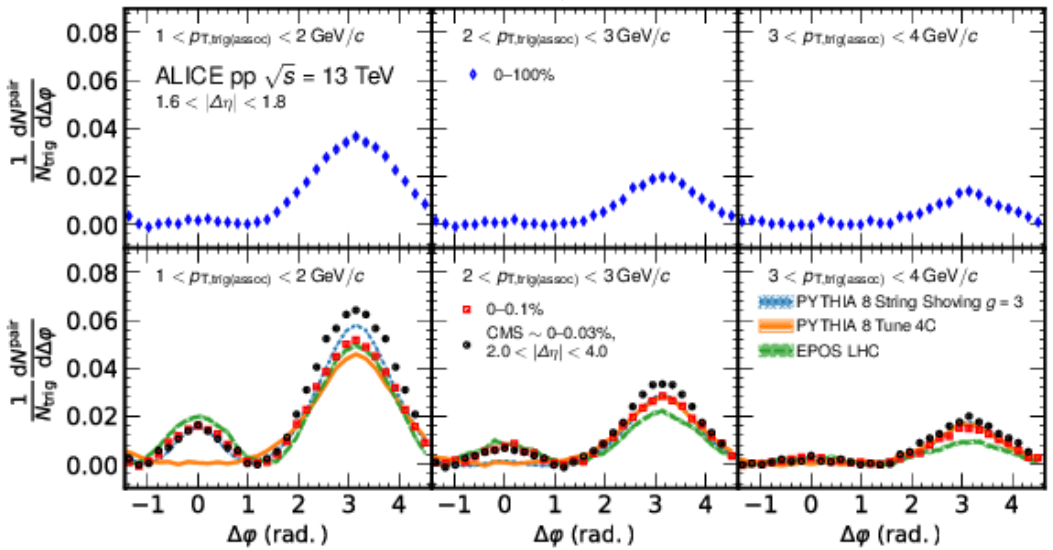


PRL 116, 172301 (2016)

JHEP 2105 (2021) 290

- In $\Delta\phi$ projected correlation shows clear near side ridge at high-multiplicity but no definitive signal at minimum bias pp events.
- Away side ridge structure is because of Jet correlation.
- The PYTHIA and EPOS LHC none models could explain the experimental observation exactly.

- High-multiplicity pp events shows hydrodynamical behaviour.



Summary

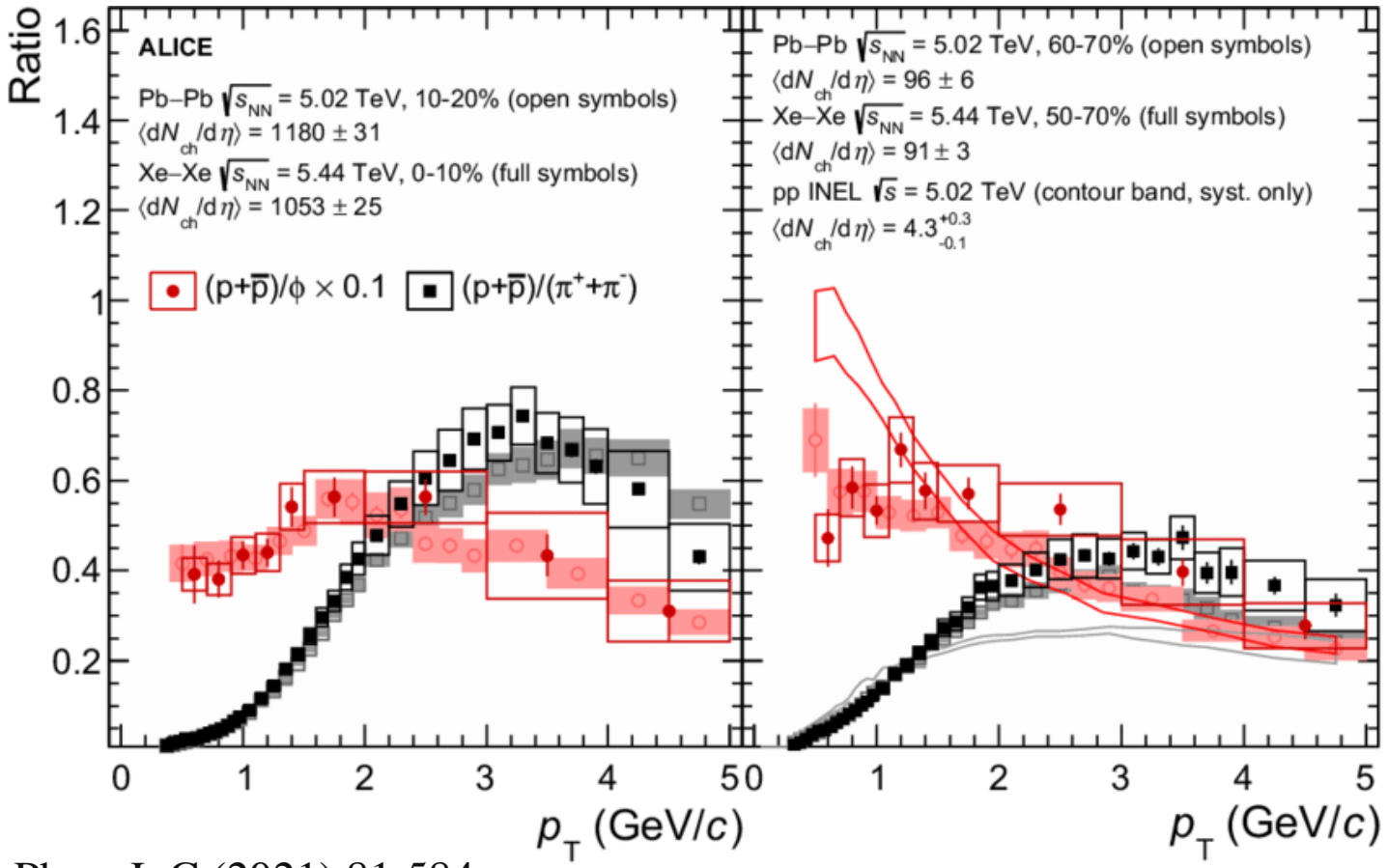
- High-multiplicity pp collisions show collectivity in particle production
  - Charged-particle multiplicity is driving force behind colliding physics irrespective of colliding systems and collision energy
- Radial flow effect in small system can found as in heavy-ion collisions
  - Mass ordered hardening of the p_T spectra
  - Multiplicity dependent mean p_T, mass ordering
  - Enhancement of baryon-over-meson at intermediate p_T
- Two particle long range correlation shows near side ridge structure in small system
  - Suggest hydrodynamical behaviour as found in large system

THANK YOU

for your kind attention!

Back-up

Particle ratio in Xe-Xe collisions



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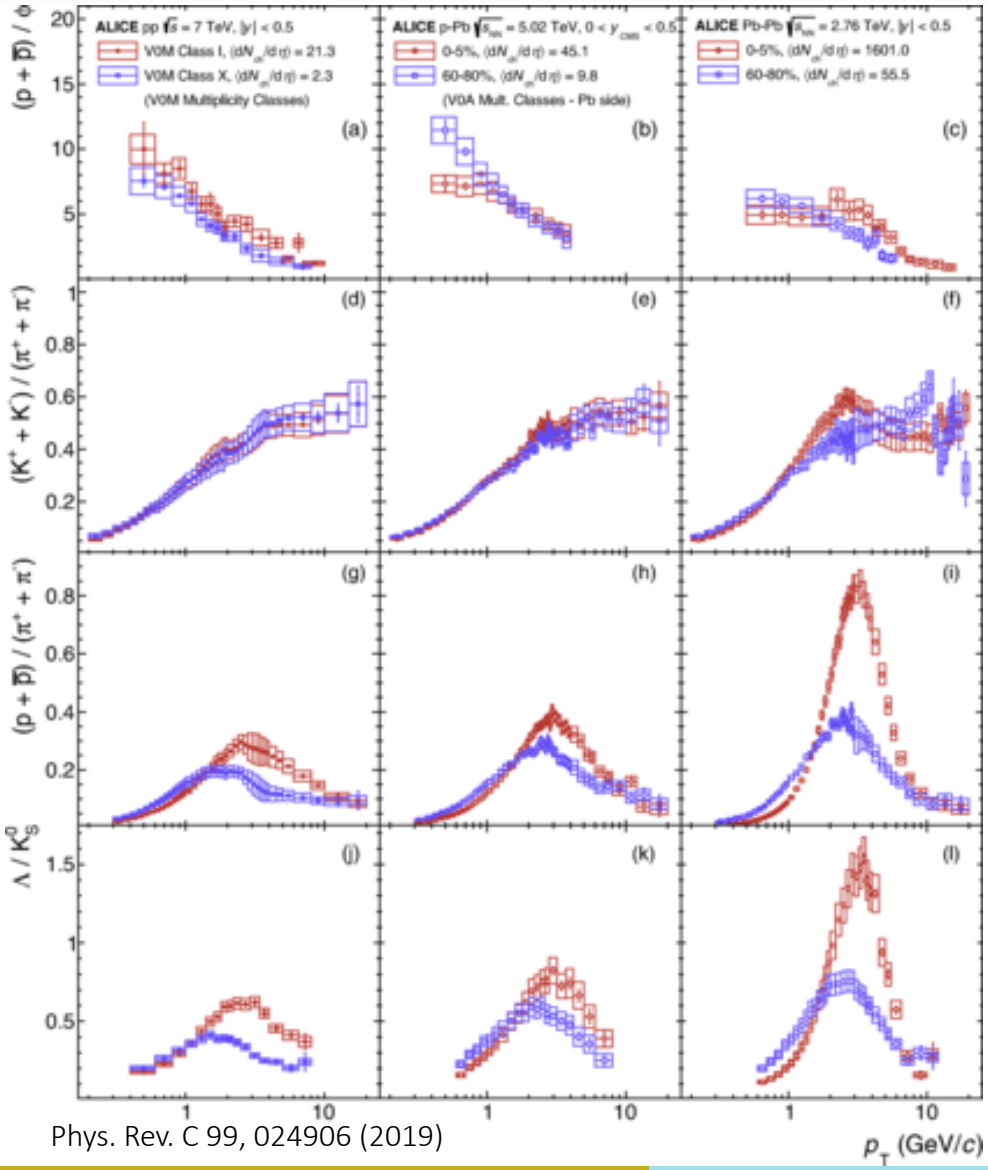
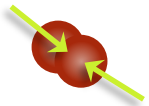
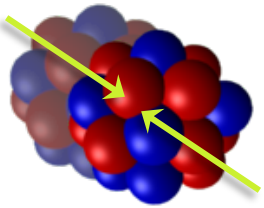
Back-up

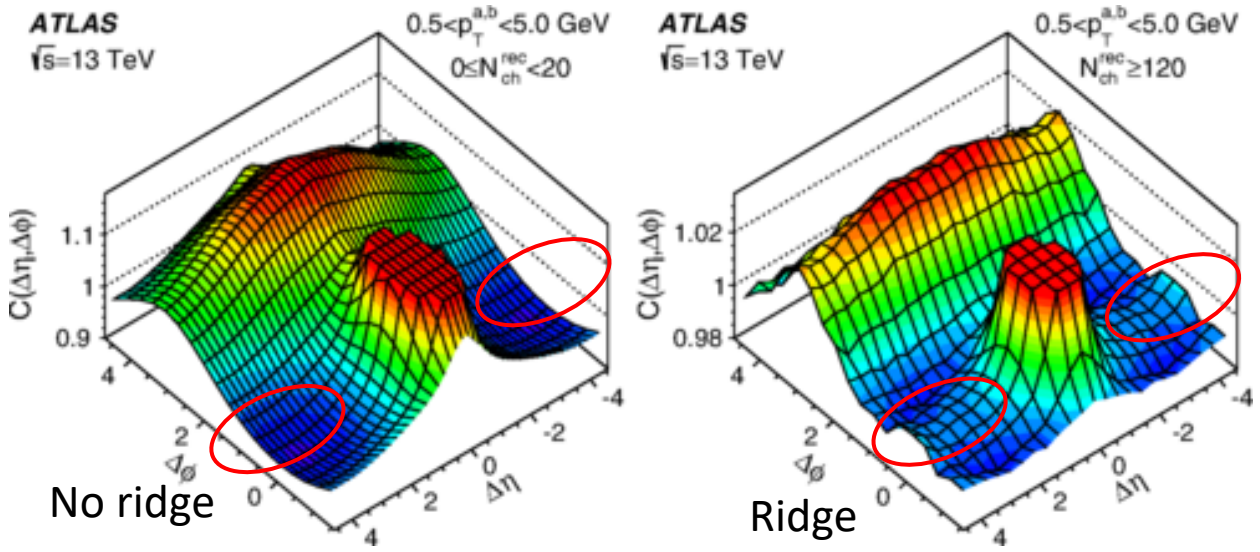


Phys. Rev. C 99, 024906 (2019)





Angular correlation as collective evolution



PRL 116, 172301 (2016)