Studying light flavour hadrons produced in the collision of different nuclei at the LHC

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for the ALICE collaboration

ALICE

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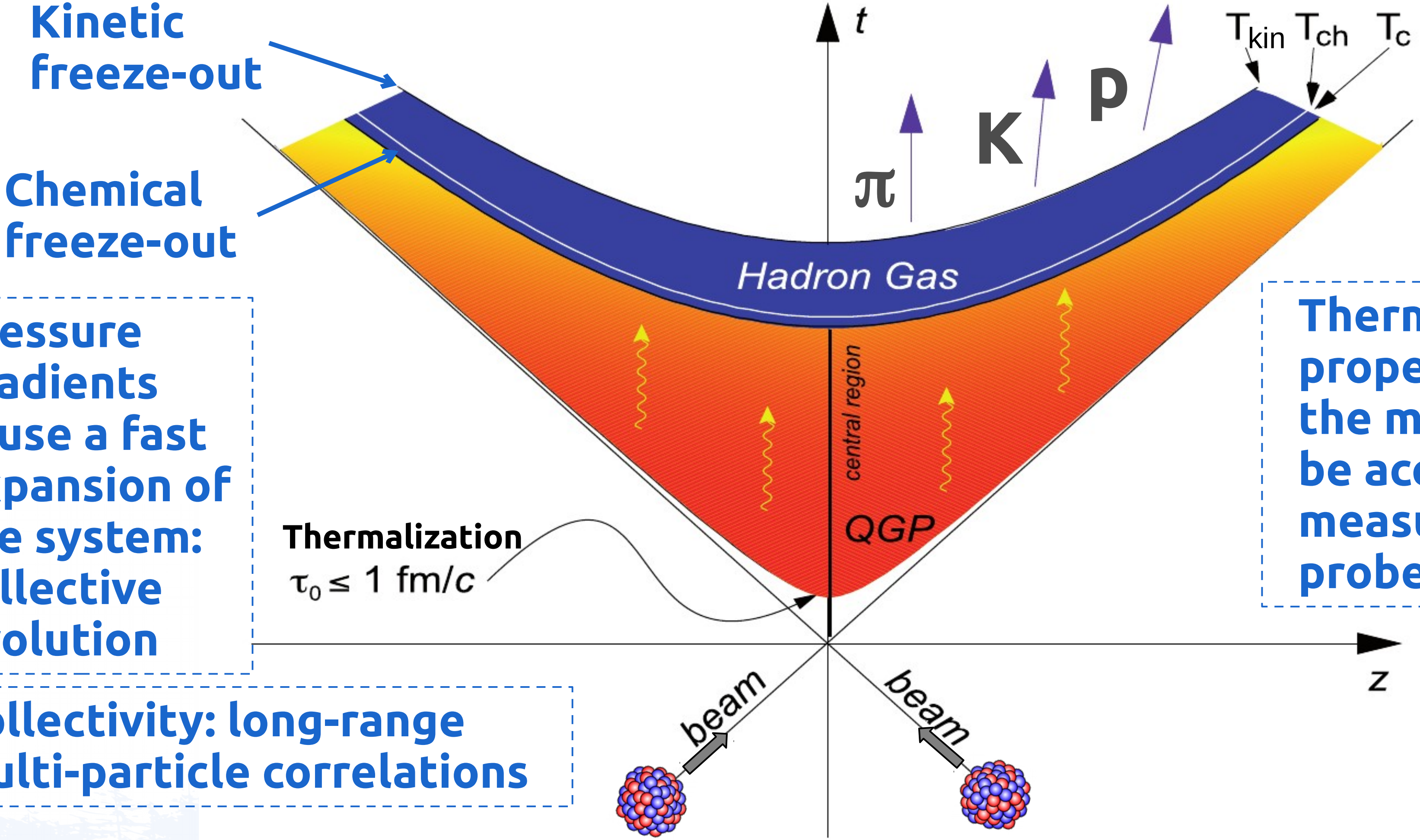
SQM2021

18/05/2021

CERN

Evolution of a heavy-ion collision

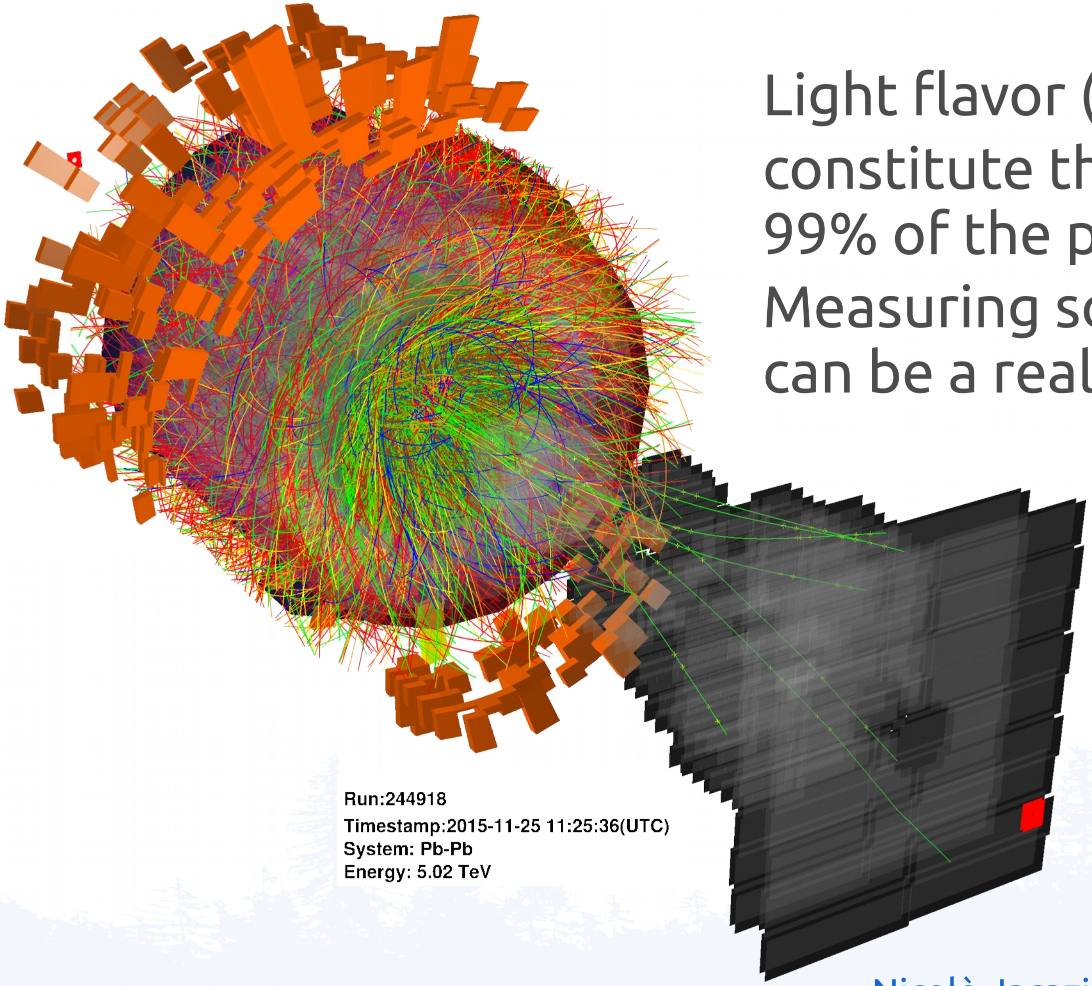


Pressure gradients cause a fast expansion of the system: collective evolution

Thermodynamic properties of the medium can be accessed by measuring soft probes

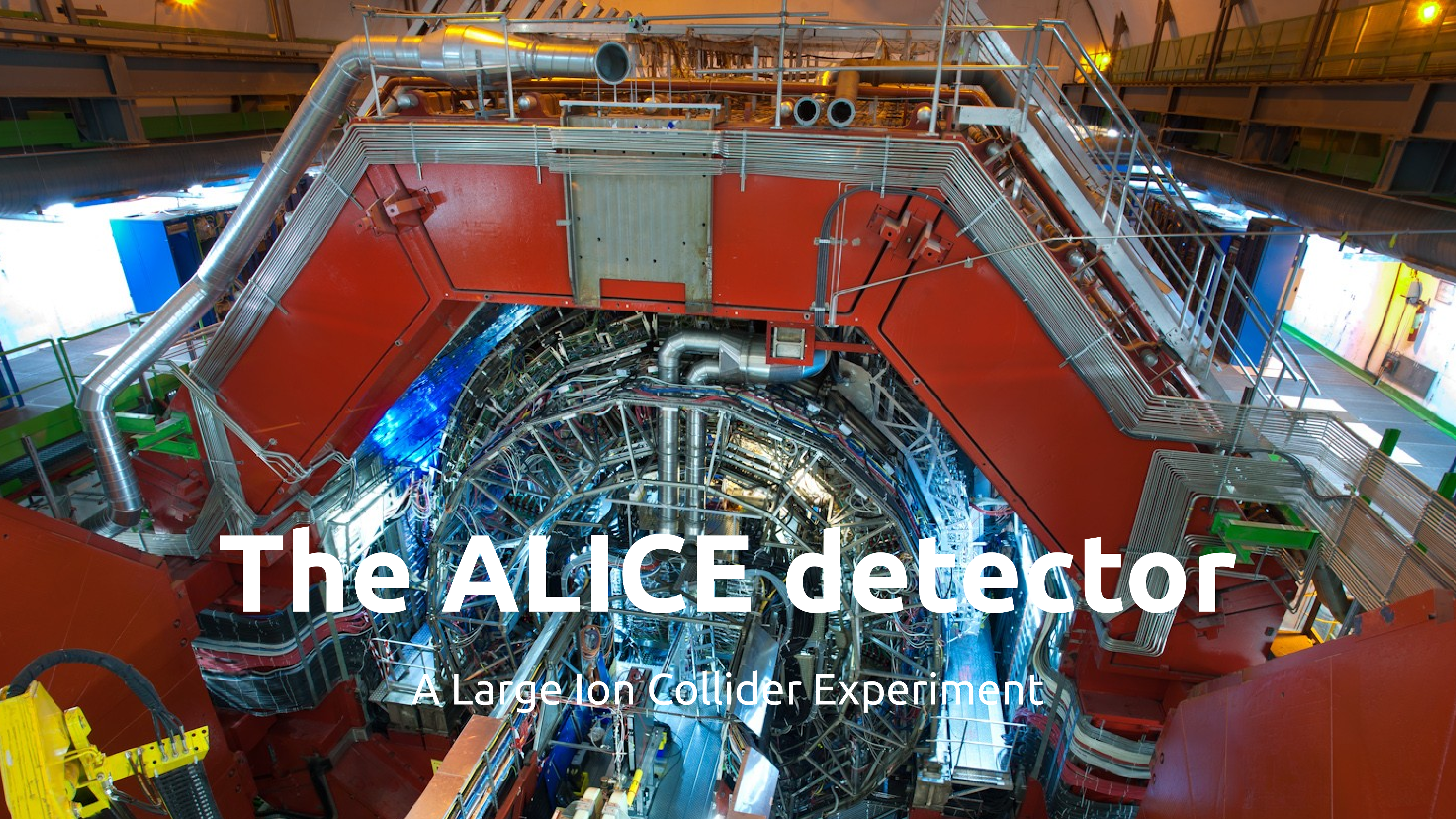
Collectivity: long-range multi-particle correlations

Soft probes from heavy-ion collisions

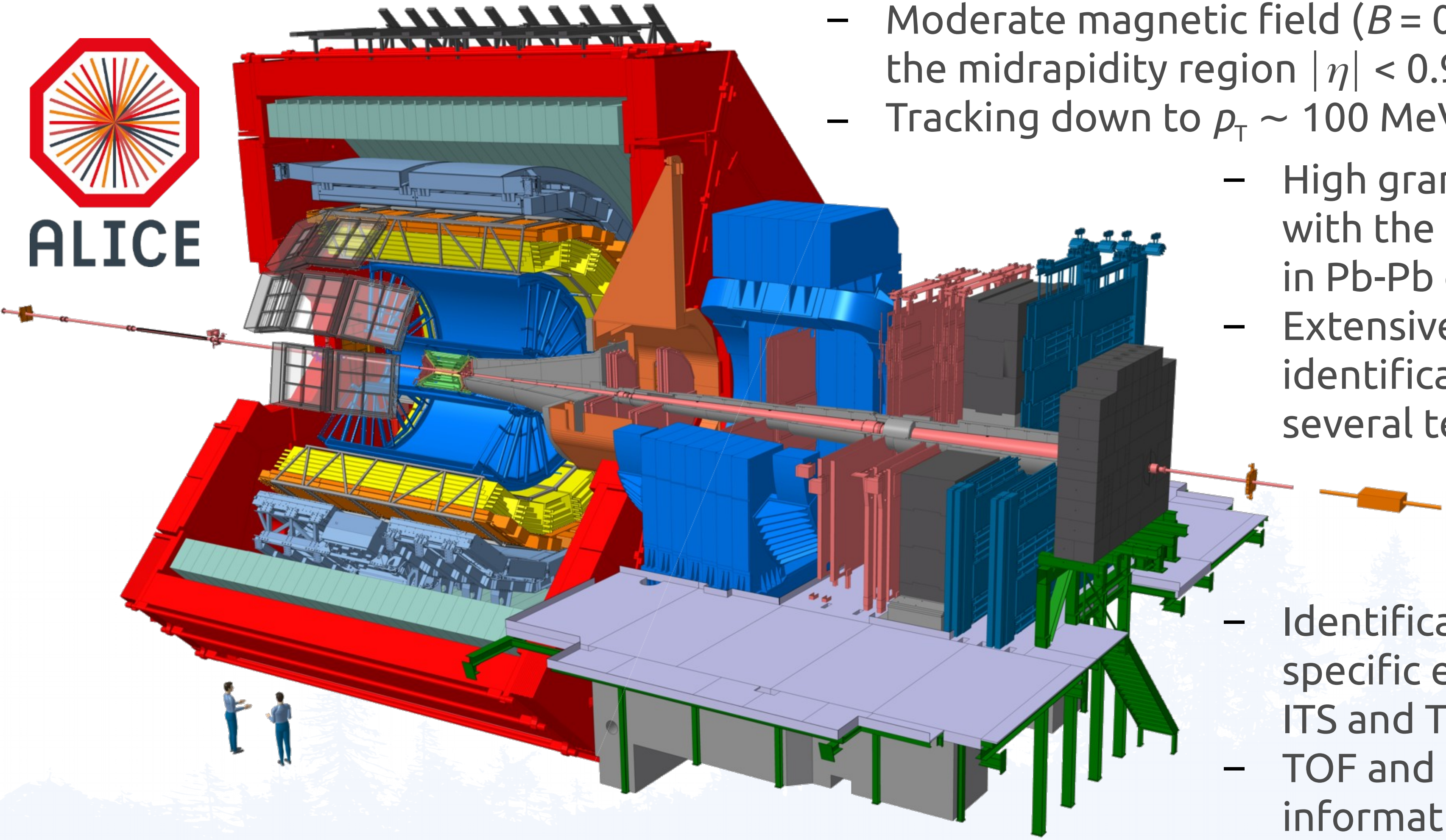


Light flavor (*u*, *d*, *s*) hadrons produced at low p_T constitute the *soft probes:* they are more than 99% of the produced hadrons (< 2 GeV/*c*).

Measuring soft probes in heavy ion collision can be a real challenge!


The ALICE detector
A Large Ion Collider Experiment

The ALICE detector

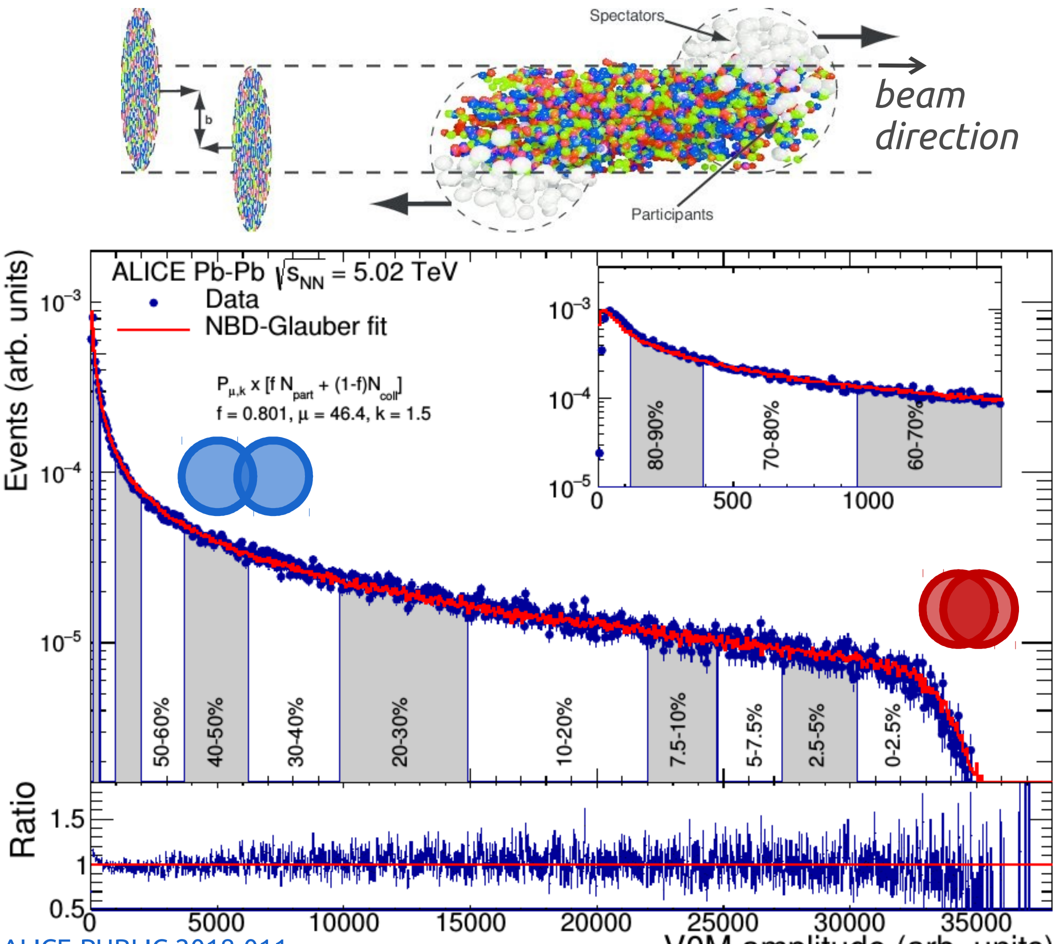


- Moderate magnetic field ($B = 0.5$ T, 0.2 T) in the midrapidity region $|\eta| < 0.9$
- Tracking down to $p_T \sim 100$ MeV/c

- High granularity to cope with the high occupancy in Pb-Pb collisions
- Extensive particle identification (PID) by several techniques

- Identification via the specific energy loss in the ITS and TPC
- TOF and Cherenkov information at intermediate p_T

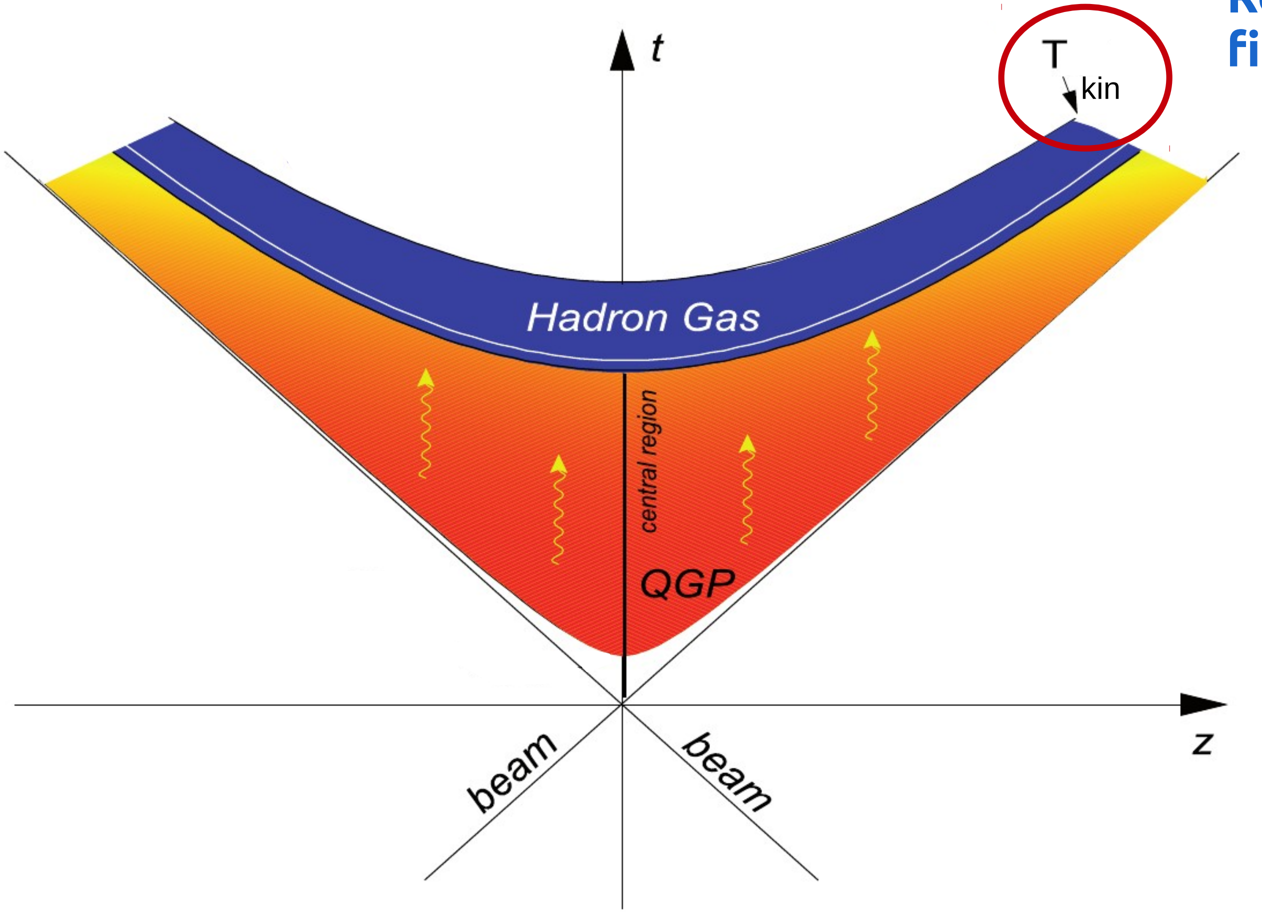
Heavy-ion collisions



ALICE-PUBLIC-2018-011

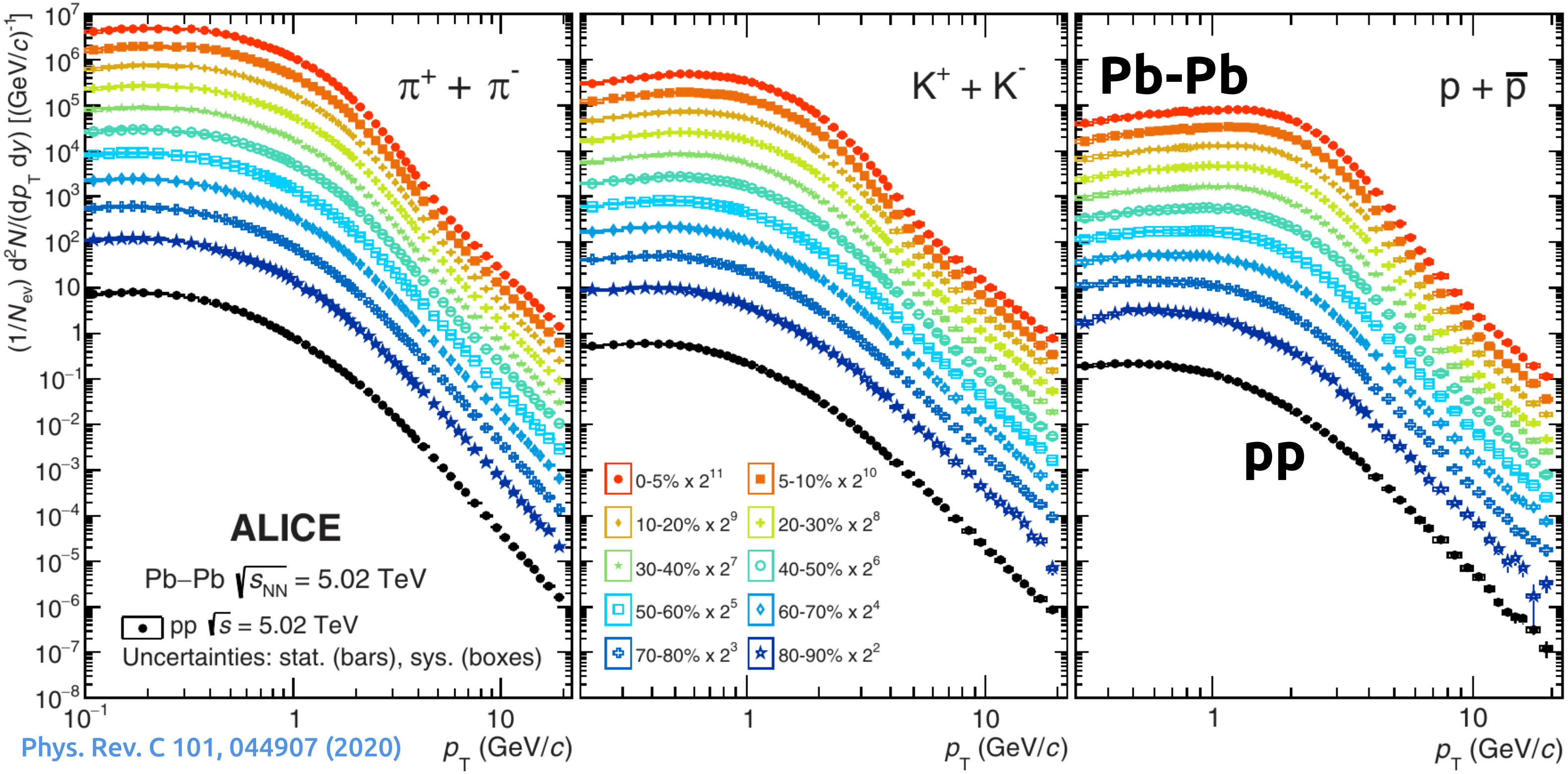
- The collision impact parameter defines how many nucleons interact in the collision (centrality)
- Centrality is expressed as **fraction of the total inelastic cross section**
- In ALICE it is measured by dedicated detectors at forward rapidity (V0)
- The **largest energy** density is achieved in the **most central collisions**

Investigating particle dynamics



Rewinding the fireball evolution

π/K/p in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV



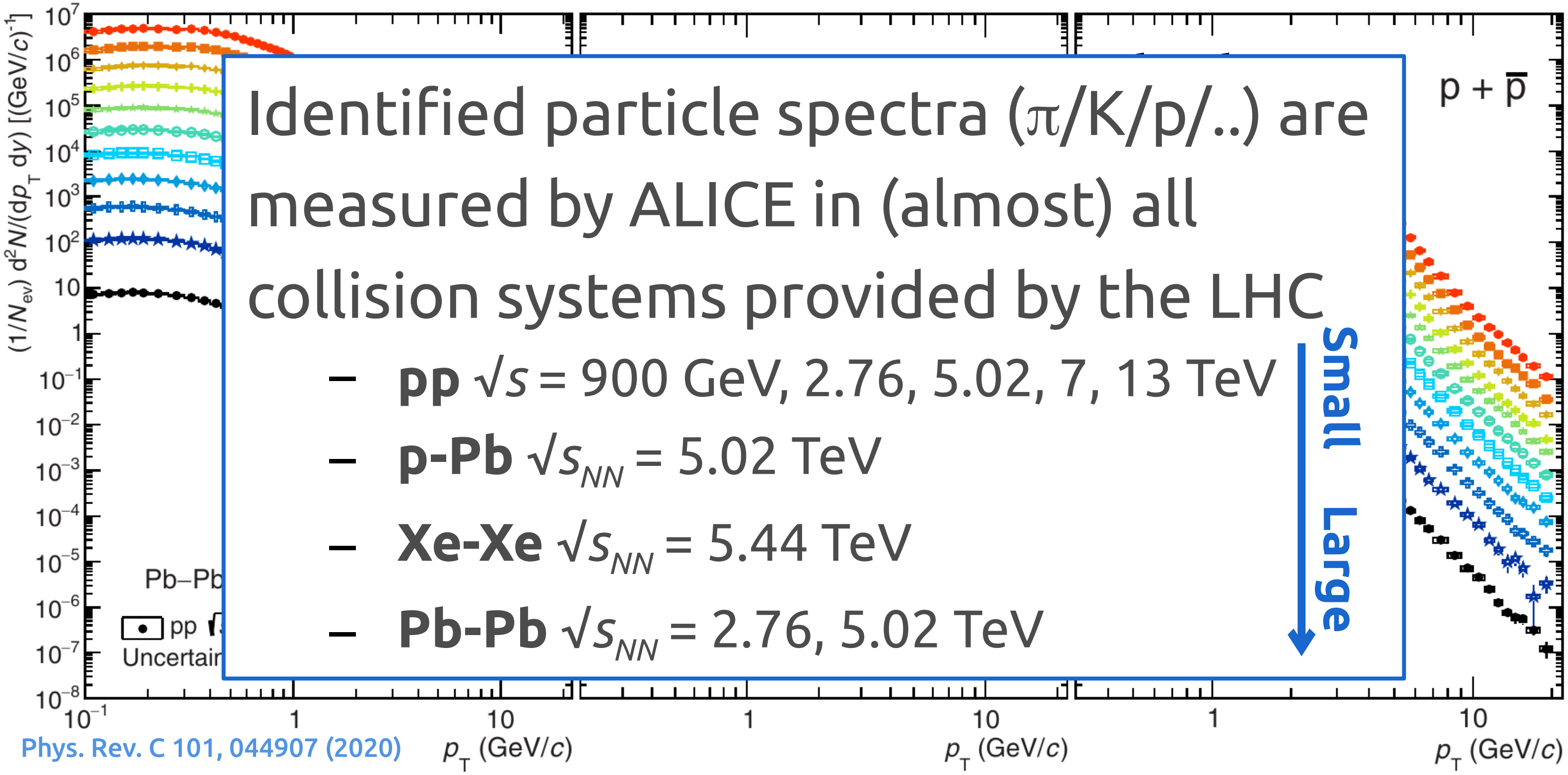
Phys. Rev. C 101, 044907 (2020)

Mass-dependent hardening of the soft part with increasing centrality due to the collective evolution (*radial flow*)

- Non – relativistic, $p_\perp \ll m_i$: $T_{i,\mathrm{slope}} \approx T_\mathrm{f} + \frac{1}{2} m_i \langle v_\perp \rangle^2$
- Relativistic, $p_\perp \gg m_i$: $T_\mathrm{slope} \approx T_\mathrm{f} \sqrt{\frac{1+v_\perp}{1-v_\perp}}$ (for all m_i)

arXiv:hep-ph/0407360

π/K/p in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV



Identified particle spectra (π/K/p/..) are measured by ALICE in (almost) all collision systems provided by the LHC

- **pp** $\sqrt{s}$ = 900 GeV, 2.76, 5.02, 7, 13 TeV
- **p-Pb** $\sqrt{s_{NN}}$ = 5.02 TeV
- **Xe-Xe** $\sqrt{s_{NN}}$ = 5.44 TeV
- **Pb-Pb** $\sqrt{s_{NN}}$ = 2.76, 5.02 TeV

Small → Large

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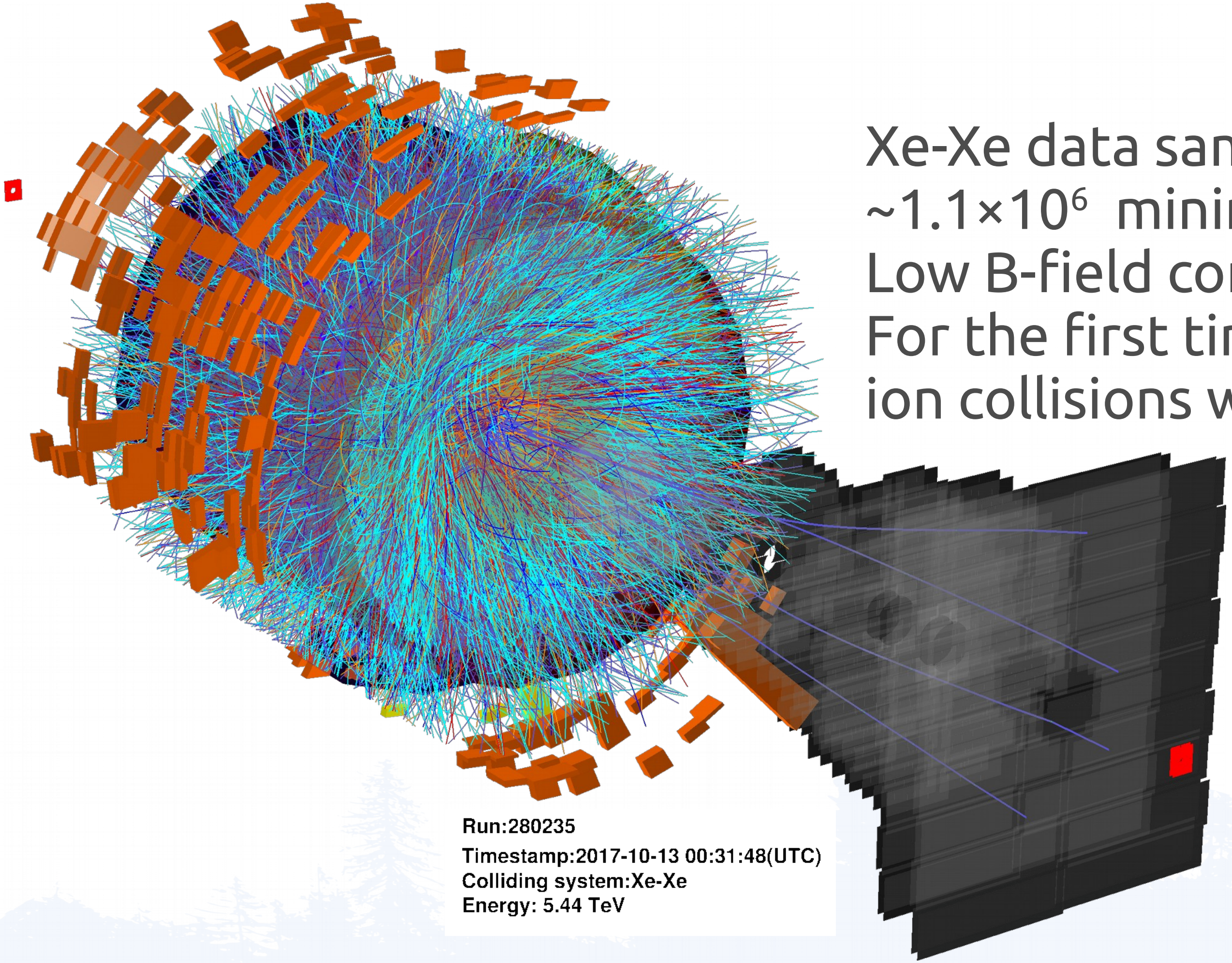
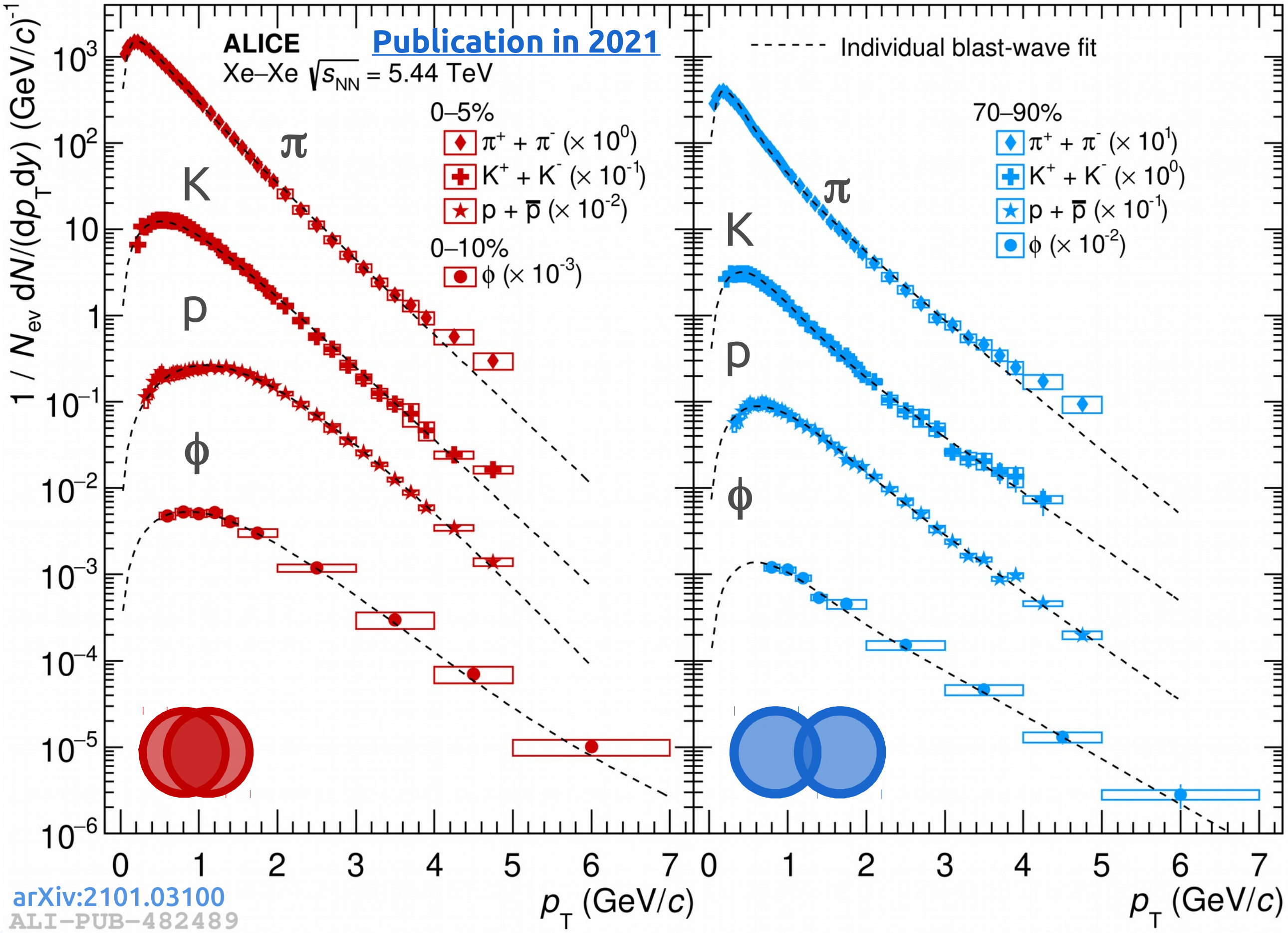
Soft probes from heavy-ion collisions



Xe-Xe data sample collected in 2017
~1.1×10^6 minimum bias events
Low B-field configuration: B = 0.2 T
For the first time at the LHC comparing heavy ion collisions with different nuclei

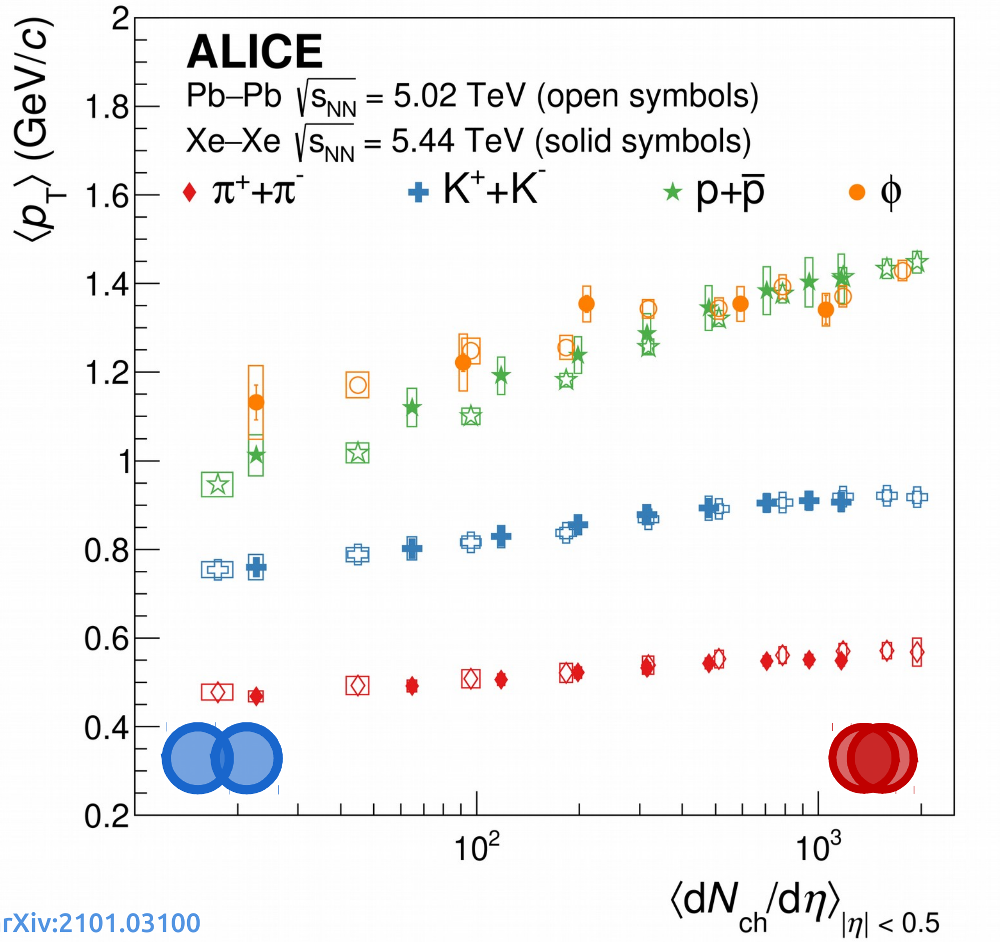
$\pi/K/p/\phi$ in Xe-Xe at $\sqrt{s_{NN}}$ = 5.44 TeV



arXiv:2101.03100
ALI-PUB-482489

- Low B-field configuration extends the measurement reach for the pion yields (from 100 MeV/*c* to 50 MeV/*c*)
- Same observation as in Pb-Pb collisions: **harder spectra in central collisions due to radial flow**
- Spectra hardening driven by particle mass: **heavier particles are more shifted towards higher p_T ($p = \gamma\beta mc$)**

<p_T> Pb-Pb vs Xe-Xe and mass dependence

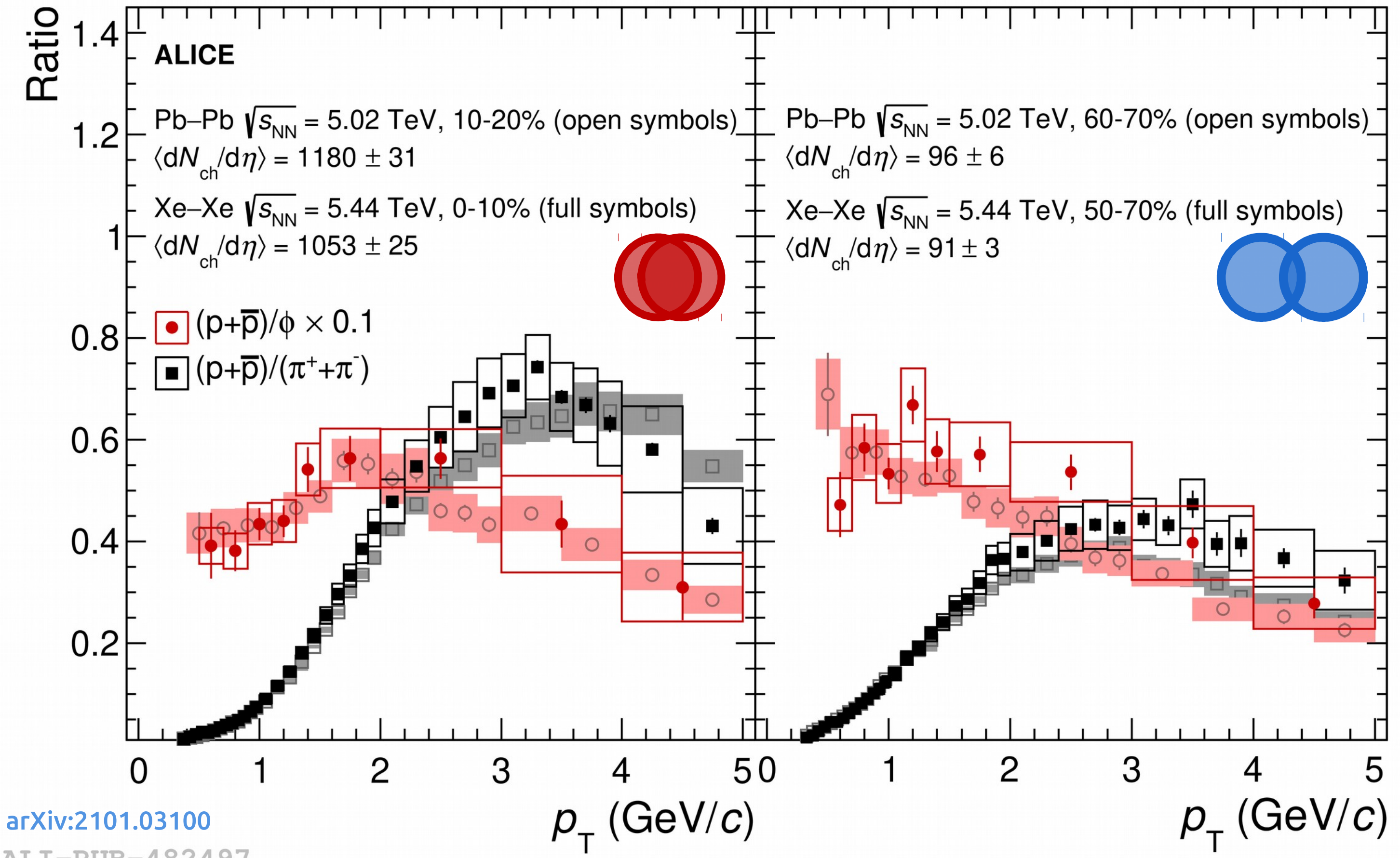


arXiv:2101.03100

ALI-PUB-482493

- <p_T> increases with charged particle multiplicity: **more radial flow at high multiplicity**
- Larger relative increase for heavier particles (steeper rise): **mass dependent hardening**
- Similar <p_T> trend for p and ϕ (m_p ~ 0.938 GeV/c^2; m_ϕ ~ 1.019 GeV/c^2)
- The comparison to Pb-Pb shows that charged particle multiplicity is the scaling property: **same dynamics in different systems**

Baryon/meson ratio: Pb-Pb vs Xe-Xe



arXiv:2101.03100

ALI-PUB-482497

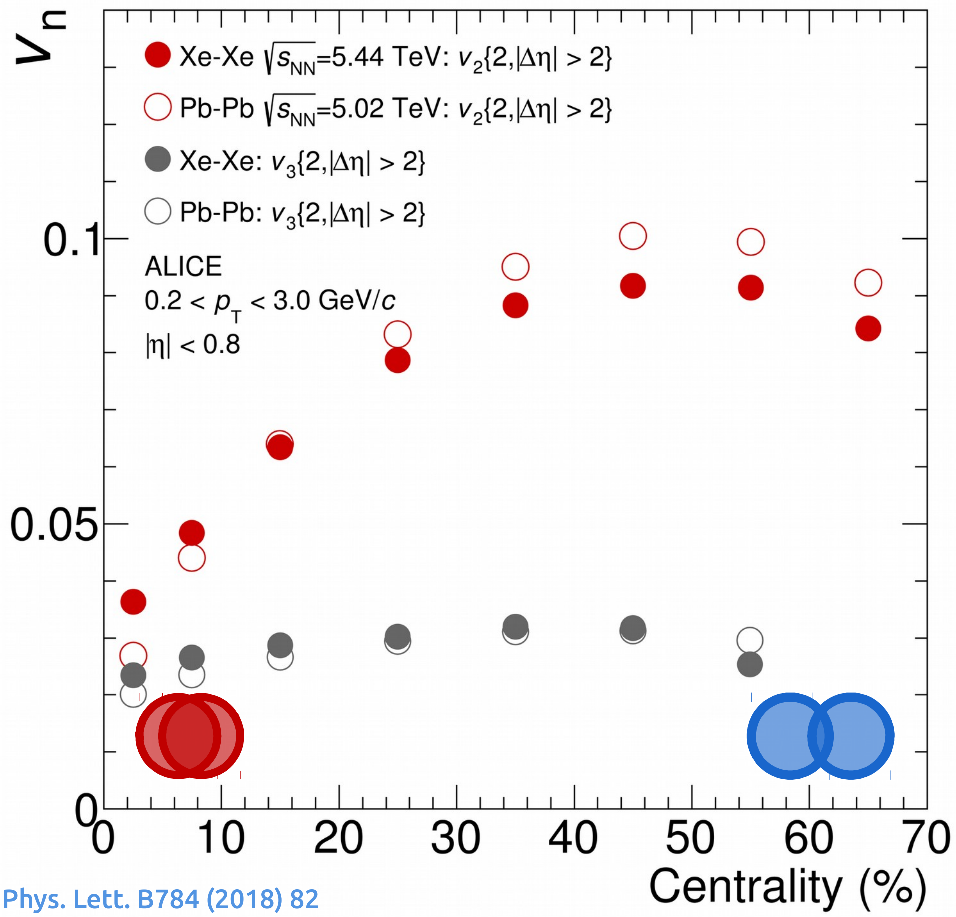
At the same multiplicity baryon/meson ratios agree in Pb-Pb and Xe-Xe

Radial flow independent of the collision system

Flat p/ϕ ratio: **radial flow driven by particle mass instead of quark content**

Radial flow magnitude decreases in peripheral collisions (lower multiplicity)

Anisotropic flow across different systems



Phys. Lett. B784 (2018) 82

ALI-PUB-150777

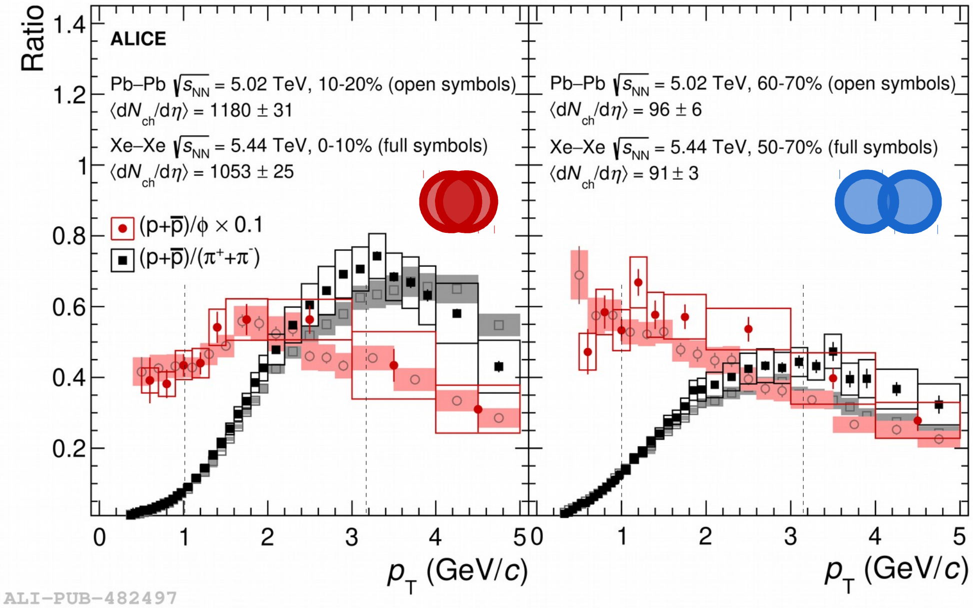
- The anisotropic flow in heavy-ion collisions at the LHC depends only weakly on the size of the colliding system (Pb-Pb vs Xe-Xe)

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1+2\sum_{n=1}^{\infty}v_n\cos[(\varphi-\Psi_n)]\right)$$

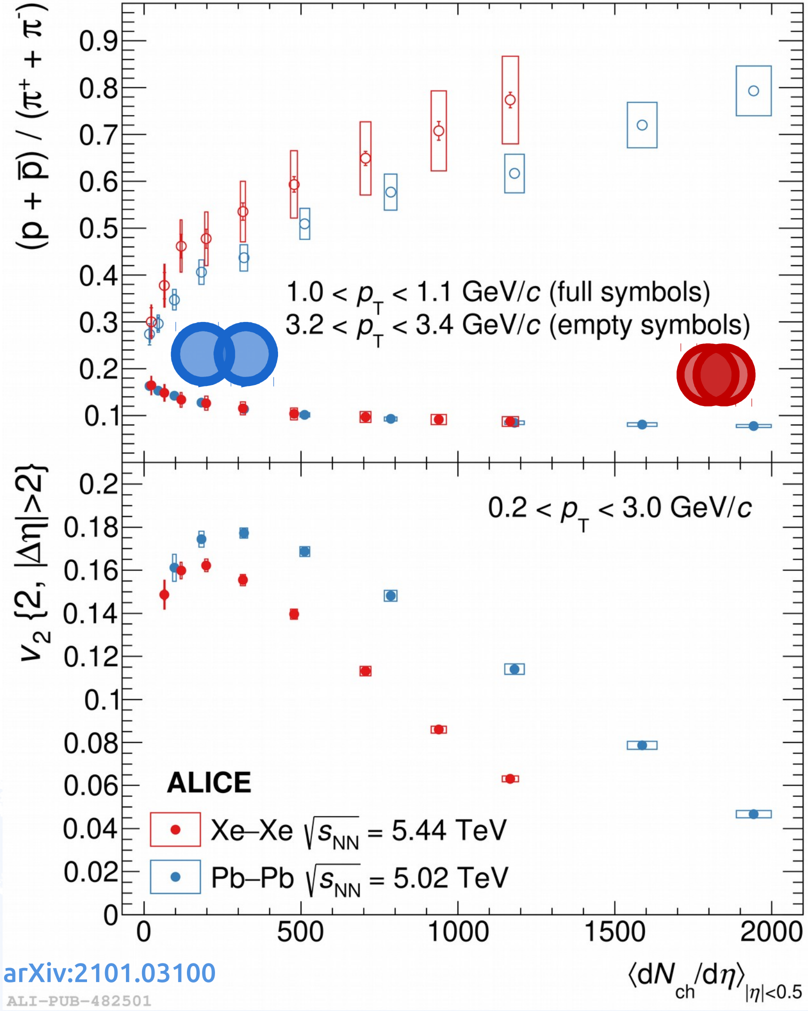
$$v_n(p_T,y)=\langle\cos[n(\varphi-\Psi_n)]\rangle$$

- **Centrality dependence of v_2 and v_3 shows similar trends in Pb-Pb and Xe-Xe** (note the different charged-particle multiplicities!)
- In peripheral collisions: increase in v_2 (mostly driven by collision geometry) is larger than for v_3 (mostly driven by fluctuations)

Testing elliptic vs radial flow



- Depletion/enhancement of the p/π ratio as a proxy to account for the radial flow
- **Radial flow in Xe-Xe and Pb-Pb at the same multiplicity is in agreement**
- Elliptic flow in the two systems at the same multiplicity is quite different (different geometry)



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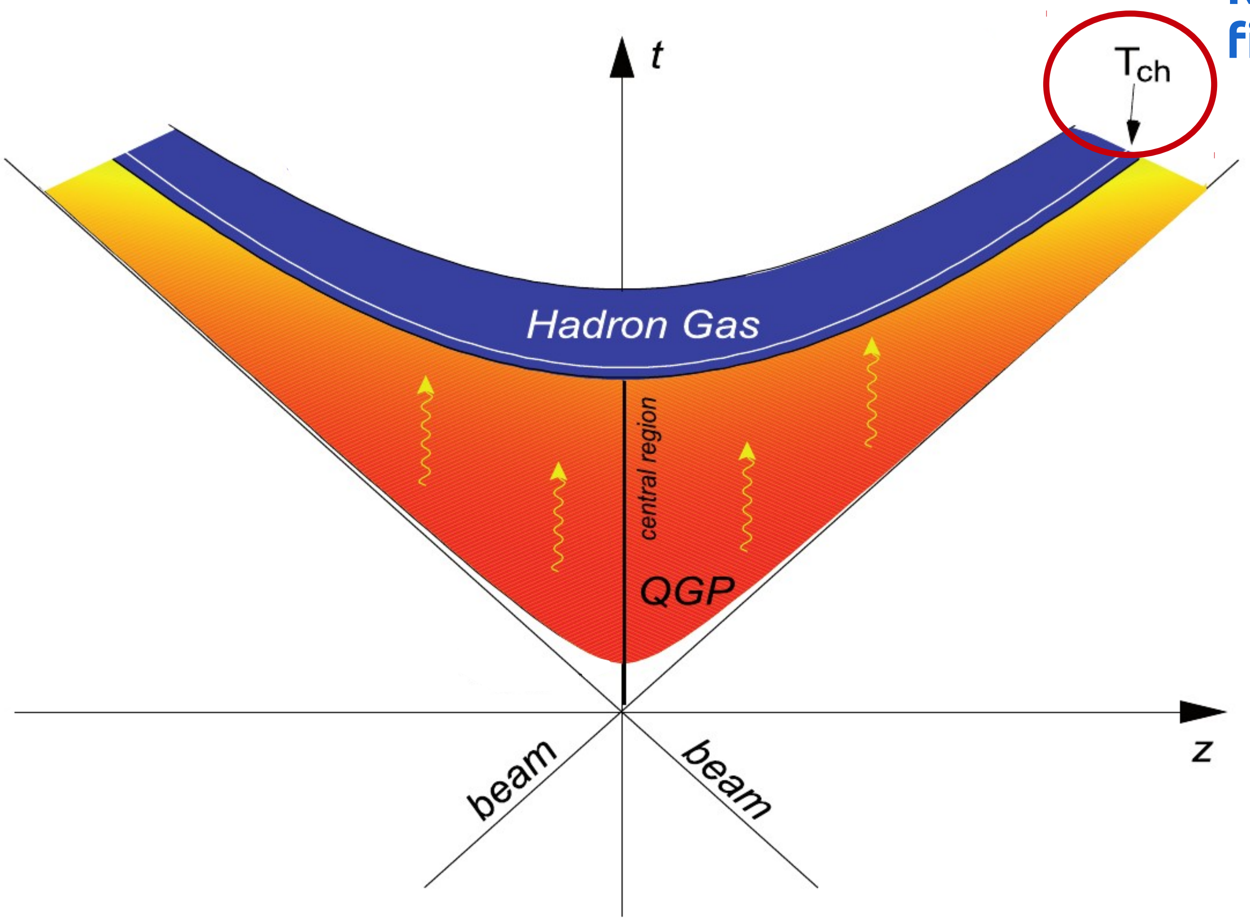
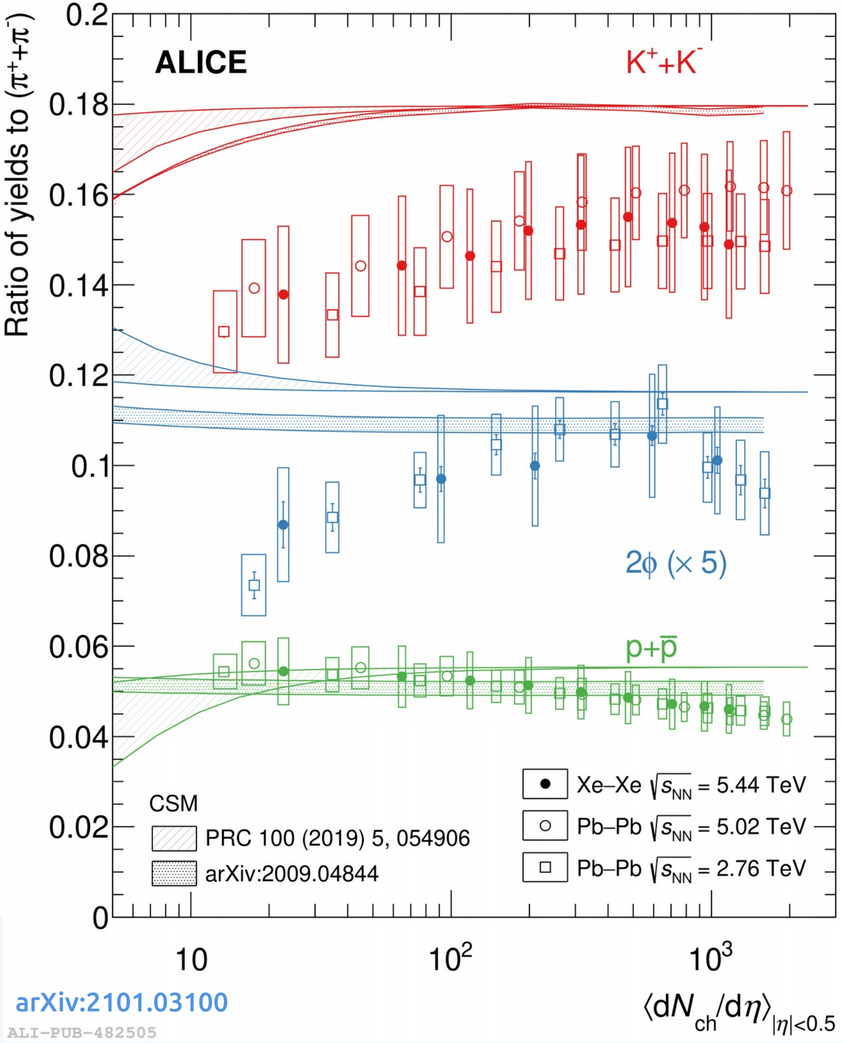
Investigating hadrochemistry



Rewinding the fireball evolution

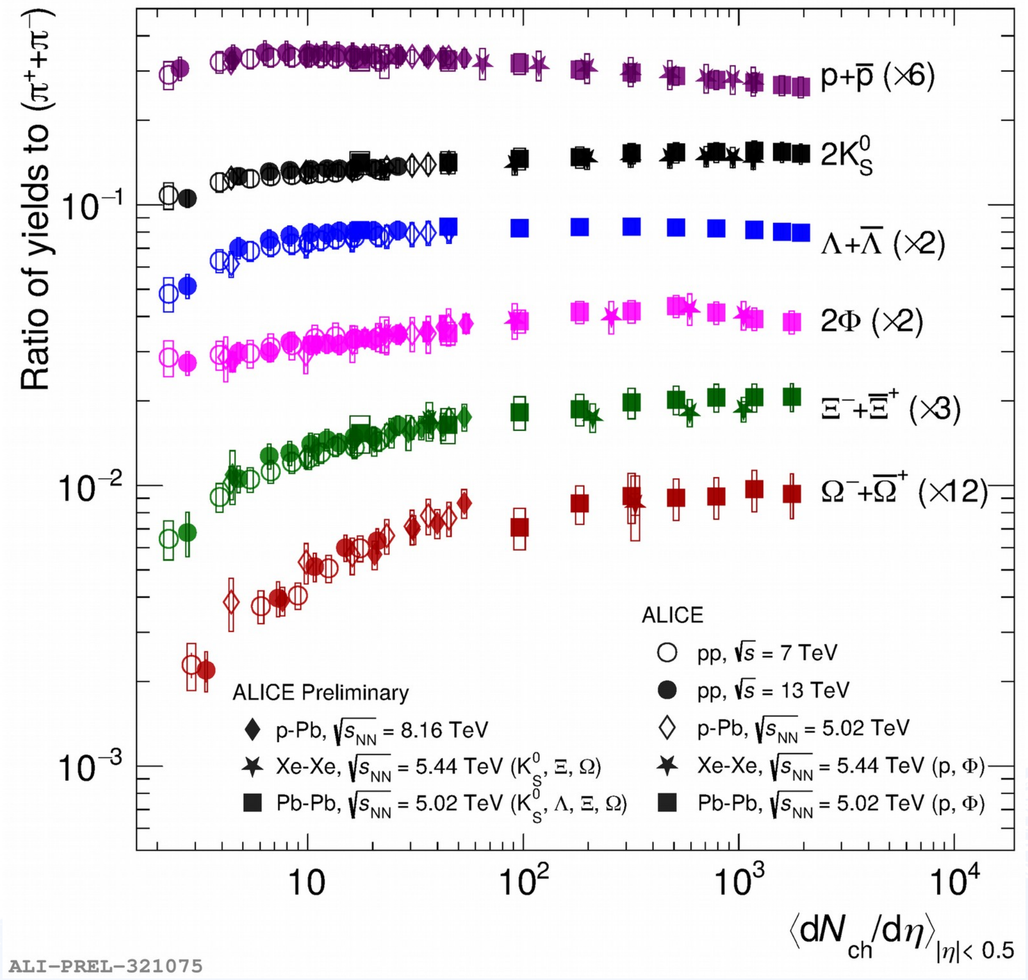
Hadrochemistry: Pb-Pb vs Xe-Xe



arXiv:2101.03100

- Integrated yield ratios exhibit a **continuous evolution with the charged-particle multiplicity**
- Limited energy dependence at the LHC scale
- Xe-Xe results are in agreement with Pb-Pb at similar energy
- Decreasing trend in the p/π interpreted as antibaryon-baryon annihilation
- Increasing trend in the φ/π not predicted by CSM
- **At LHC energies particle production is independent of the collision energy and collision system when studied as a function of the event multiplicity**

Hadrochemistry: from small to large systems



- At LHC energies continous evolution is observed also when considering small systems (pp and p-Pb)
- In pp, p-Pb, Xe-Xe and Pb-Pb the **charged particle multiplicity is a good scaling observable to describe particle production**
- Steeper increase in particles with more stangeness content indicating that the **strangeness enhancement starts at the charged-particle multiplicity reached in small systems**

Summary

- Soft probes allow us to investigate the fireball evolution and **how particle production changes with multiplicity and collision systems**
- Charged-particle multiplicity holds as a scaling property for the collective evolution, **independently of the system**
- **Radial flow** scales with charged particle multiplicity while **elliptic flow** depends on the collision geometry
- At the LHC energy **particle relative abundances** depend on the charged particle multiplicity and only weakly on the collision system or energy

More details in:

Production of pions, kaons, (anti-)protons and ϕ mesons in Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV

arXiv:2101.03100