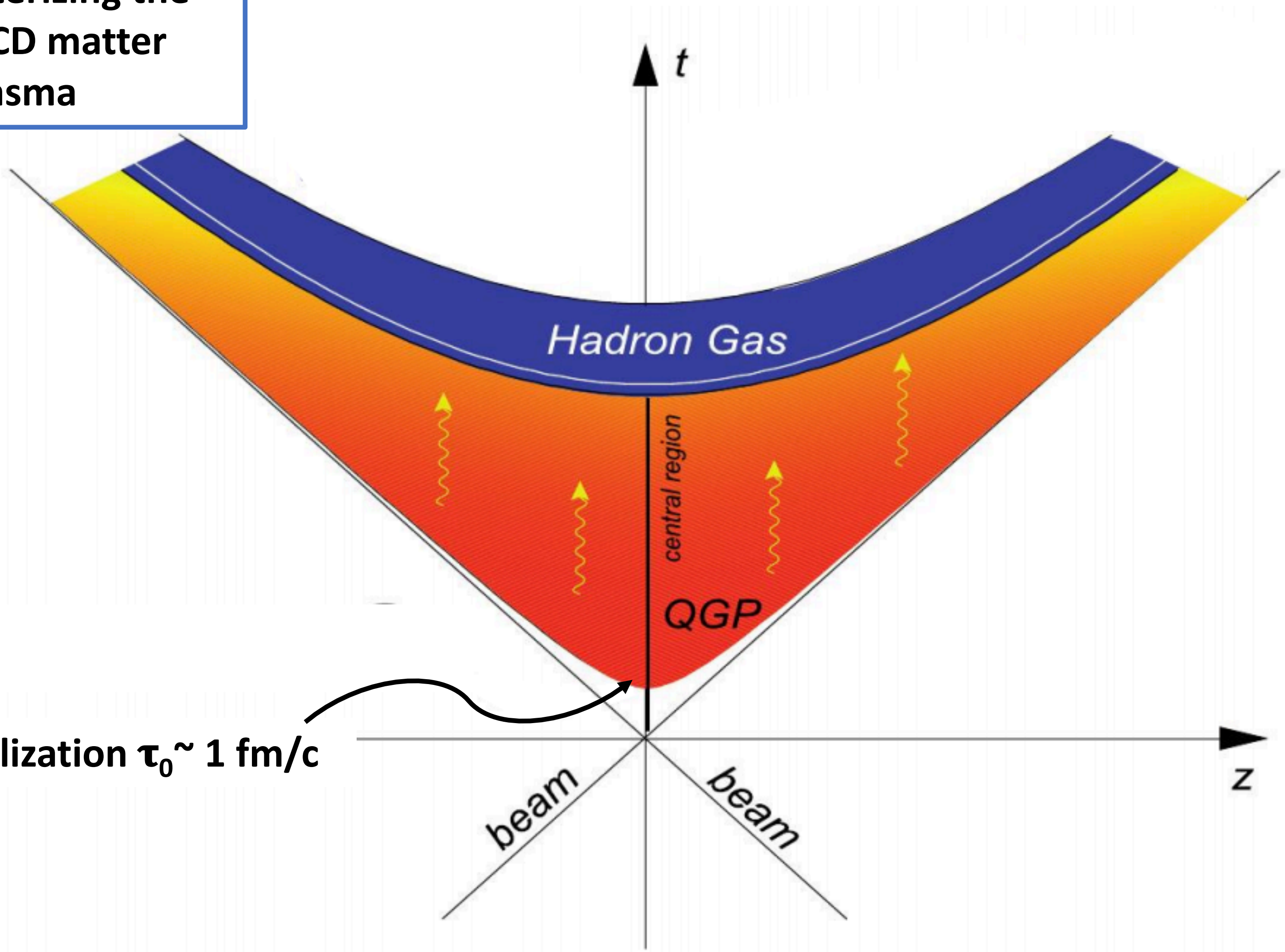
Spectra Measurements with MRPC based Time Of Flight system in ALICE

Marco Toppi, on behalf of the ALICE Collaboration

Laboratori Nazionali di Frascati - INFN

Introduction

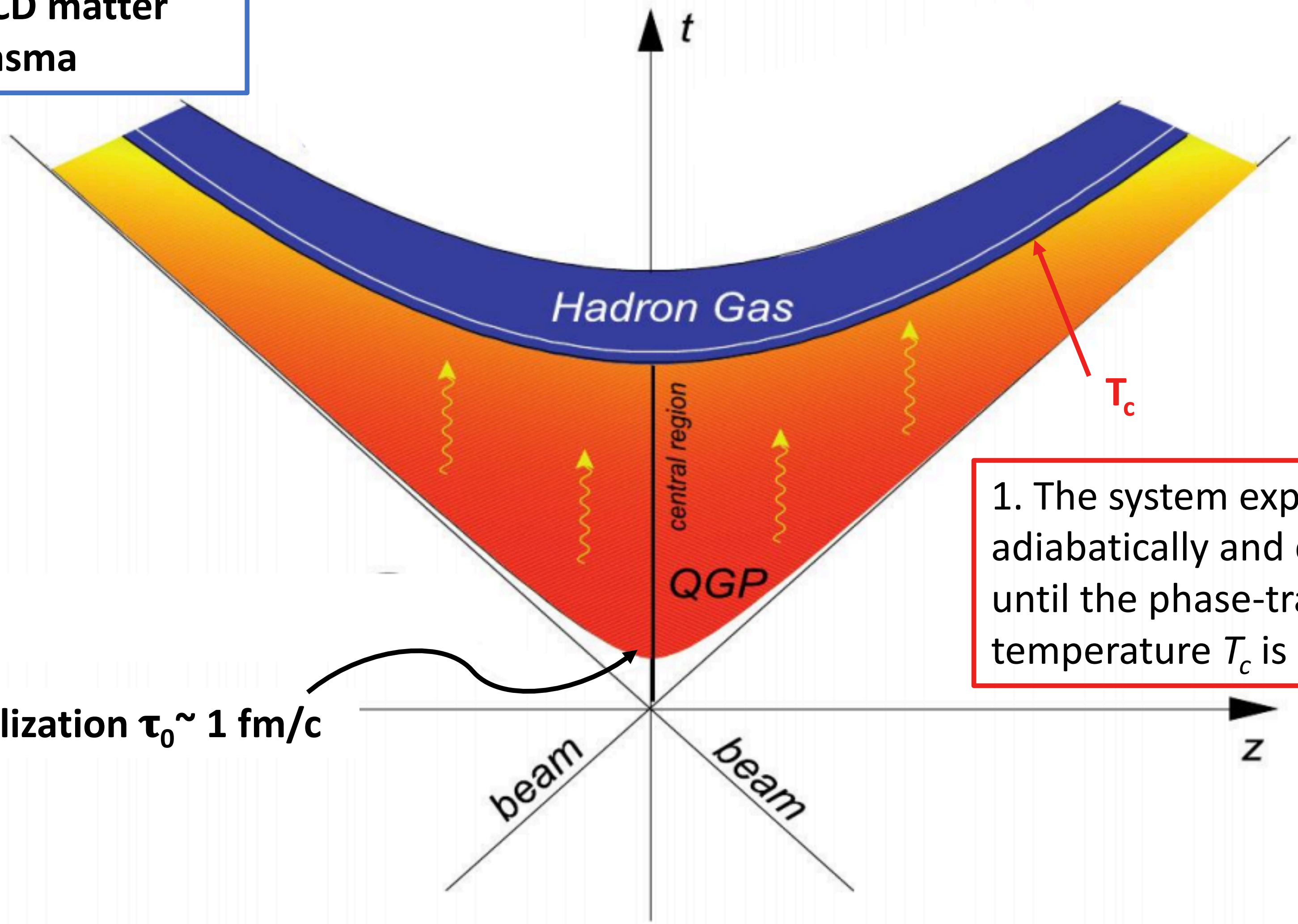
ALICE Main Goal: To study strongly interacting matter, characterizing the deconfined state of the QCD matter known as **Quark Gluon Plasma**



Thermalization τ_0~ 1 fm/c

Introduction

ALICE Main Goal: To study strongly interacting matter, characterizing the deconfined state of the QCD matter known as Quark Gluon Plasma

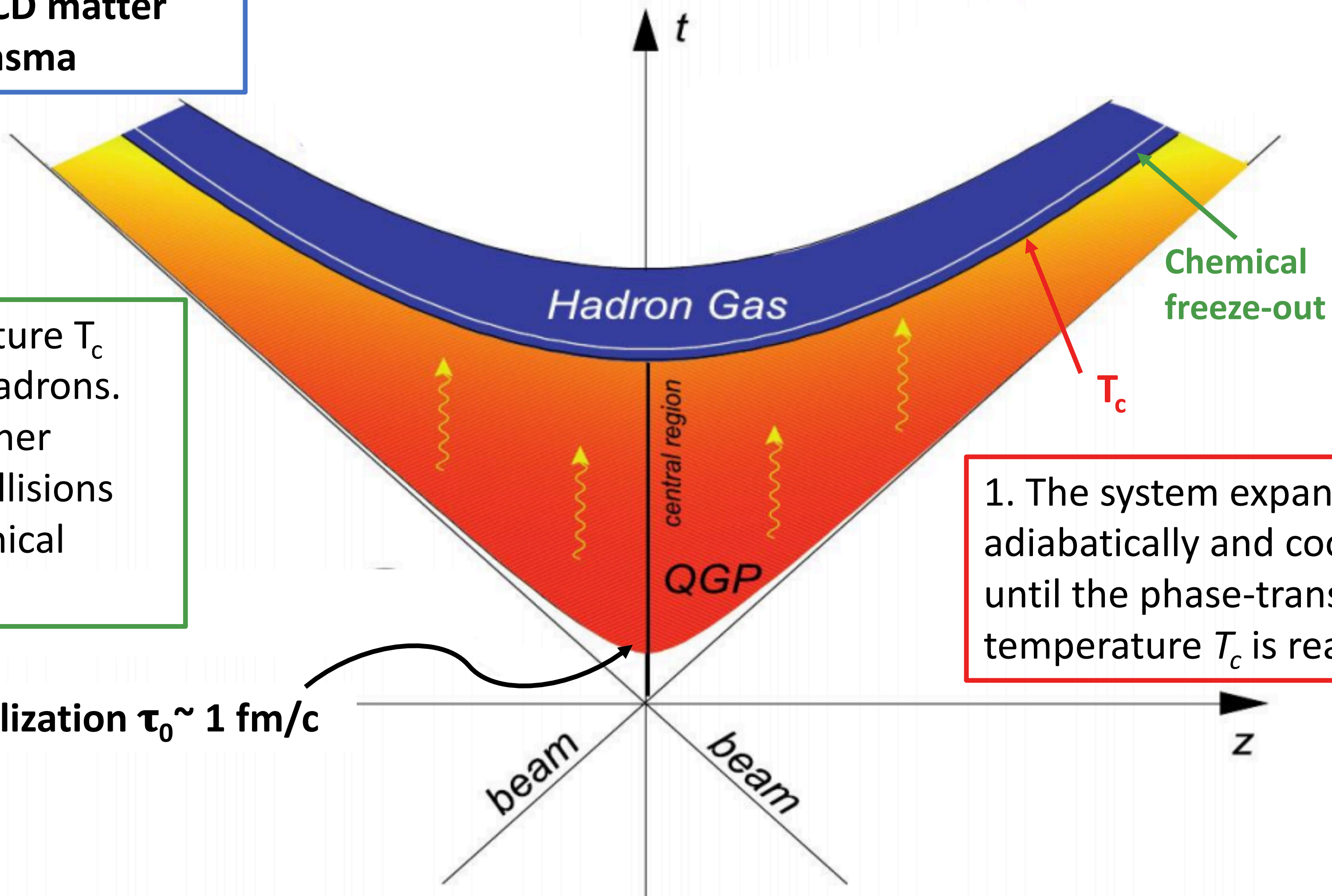


Thermalization τ_0~ 1 fm/c

1. The system expands adiabatically and cools down until the phase-transition temperature T_c is reached.

Introduction

ALICE Main Goal: To study strongly interacting matter, characterizing the deconfined state of the QCD matter known as Quark Gluon Plasma



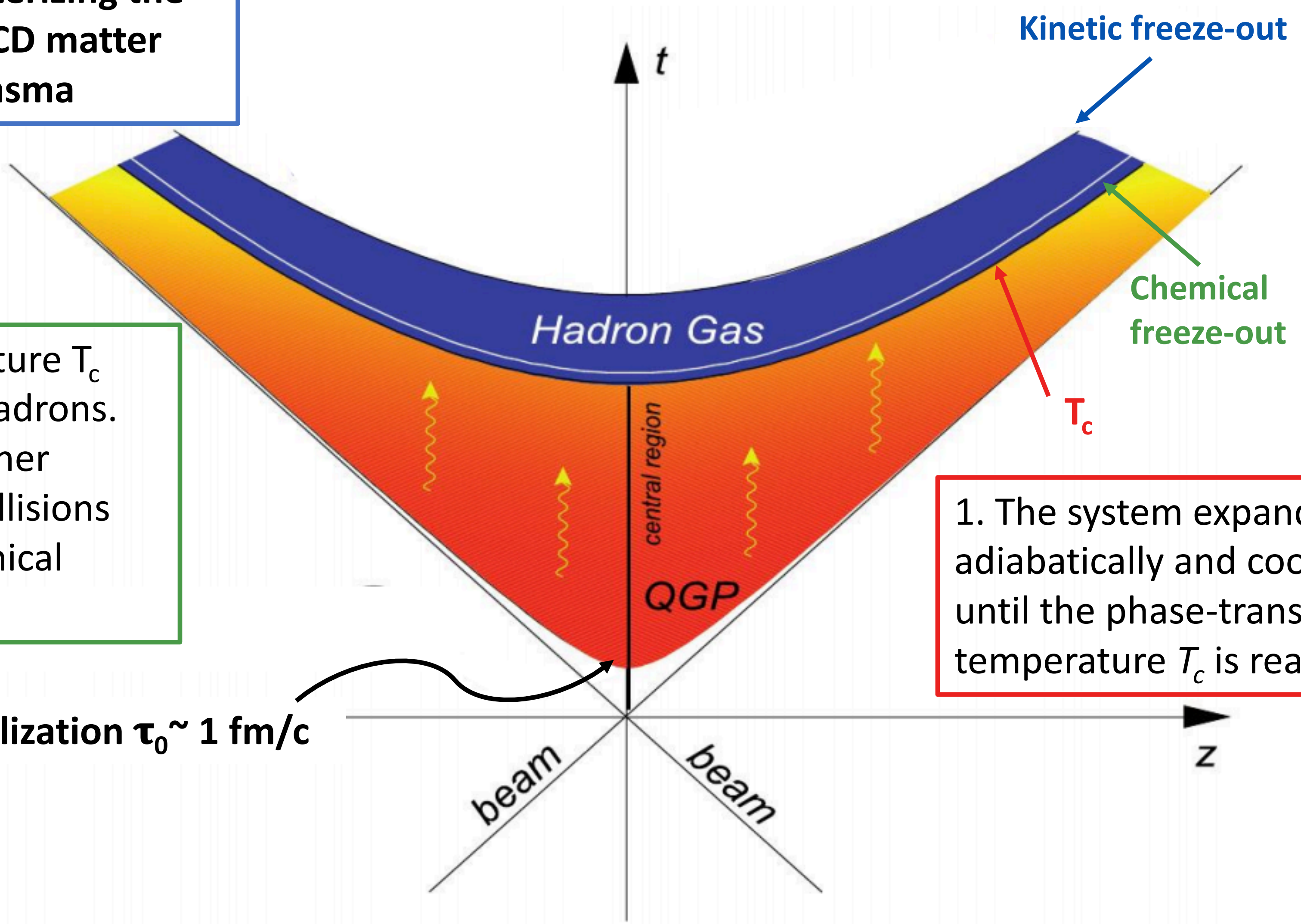
2. At the critical temperature T_c partons freeze out into hadrons. The hadron gas then further expands until inelastic collisions stop to occur at the chemical freeze-out

1. The system expands adiabatically and cools down until the phase-transition temperature T_c is reached.

Thermalization τ_0~ 1 fm/c

Introduction

ALICE Main Goal: To study strongly interacting matter, characterizing the deconfined state of the QCD matter known as Quark Gluon Plasma



2. At the critical temperature T_c partons freeze out into hadrons. The hadron gas then further expands until inelastic collisions stop to occur at the chemical freeze-out

3. The particle yields are frozen. The momentum spectra can still change until elastic collisions stop to occur and the kinematic freeze-out is reached.

1. The system expands adiabatically and cools down until the phase-transition temperature T_c is reached.

Thermalization τ_0~ 1 fm/c

Introduction

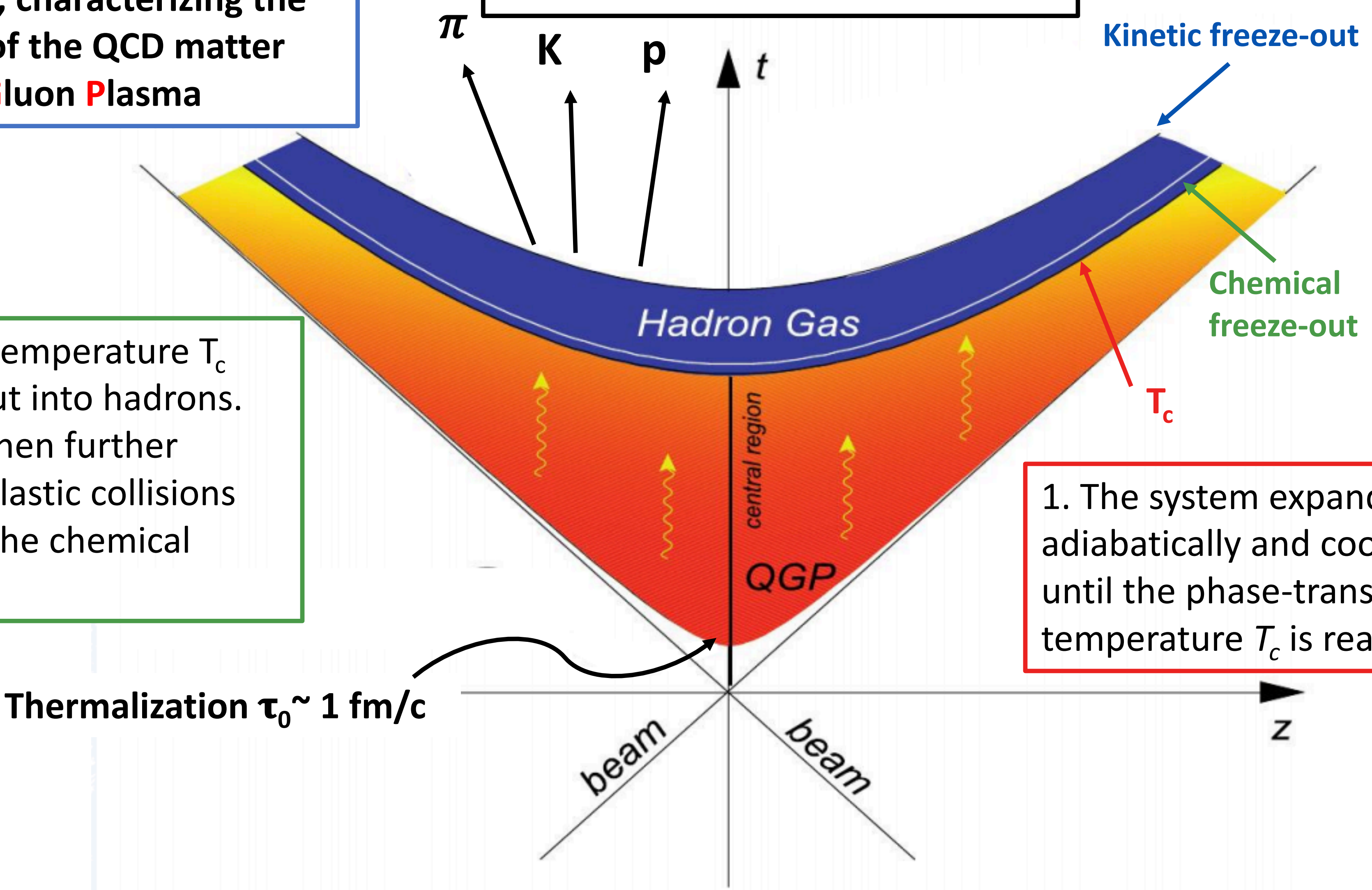
ALICE Main Goal: To study strongly interacting matter, characterizing the deconfined state of the QCD matter known as Quark Gluon Plasma

4. Produced particles leave the collision area and can be detected

3. The particle yields are frozen. The momentum spectra can still change until elastic collisions stop to occur and the kinematic freeze-out is reached.

2. At the critical temperature T_c partons freeze out into hadrons. The hadron gas then further expands until inelastic collisions stop to occur at the chemical freeze-out

1. The system expands adiabatically and cools down until the phase-transition temperature T_c is reached.



ALICE detector

A Large Ion Collider Experiment

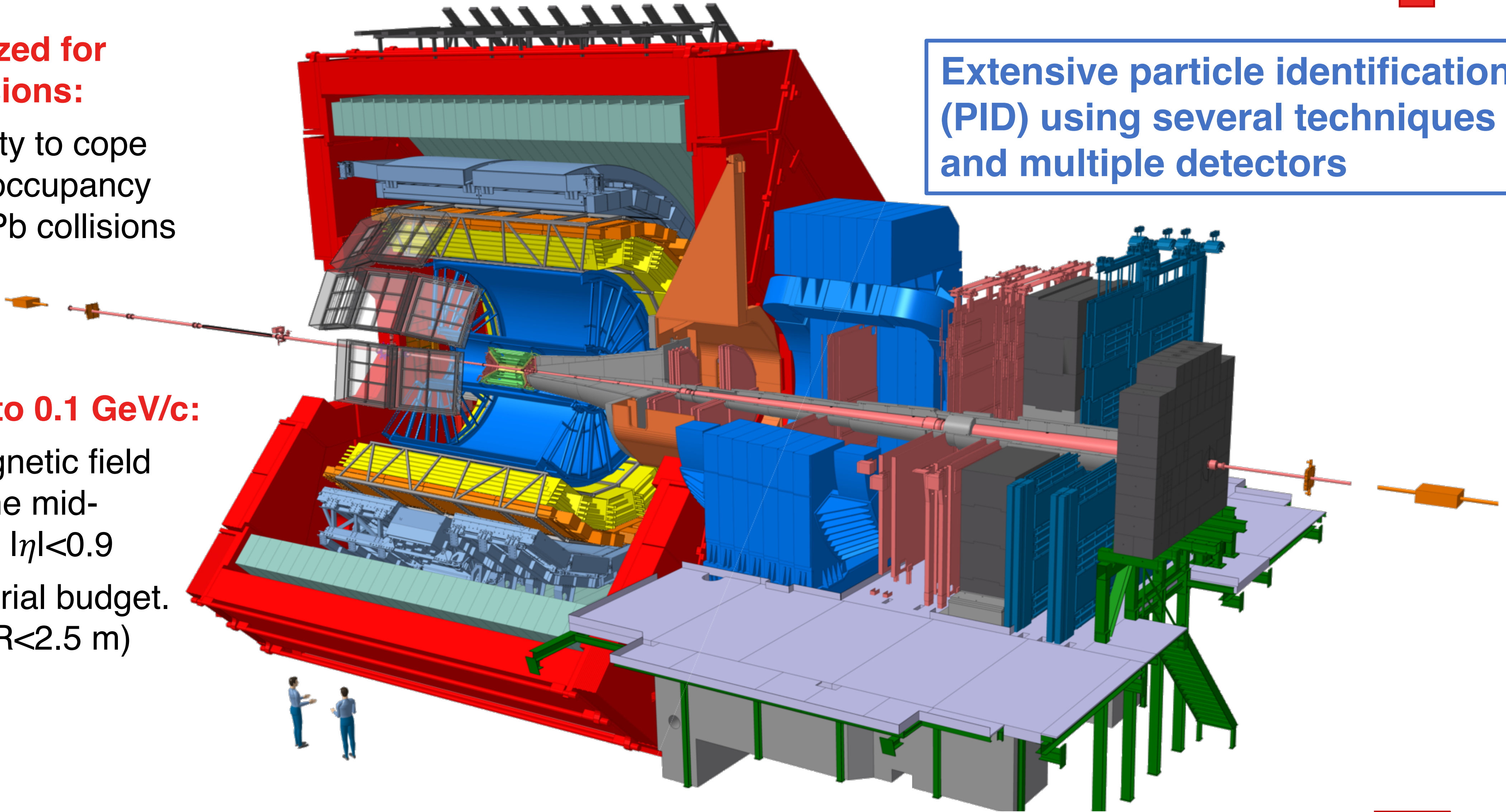
Detector optimized for Heavy Ion collisions:

- High granularity to cope with the high occupancy events in Pb-Pb collisions

Tracking down to 0.1 GeV/c:

- Moderate magnetic field (B=0.5 T) in the mid-rapidity region $|\eta|<0.9$
- Very low material budget. (<10% X_0 for R<2.5 m)

Extensive particle identification (PID) using several techniques and multiple detectors



ALICE detector

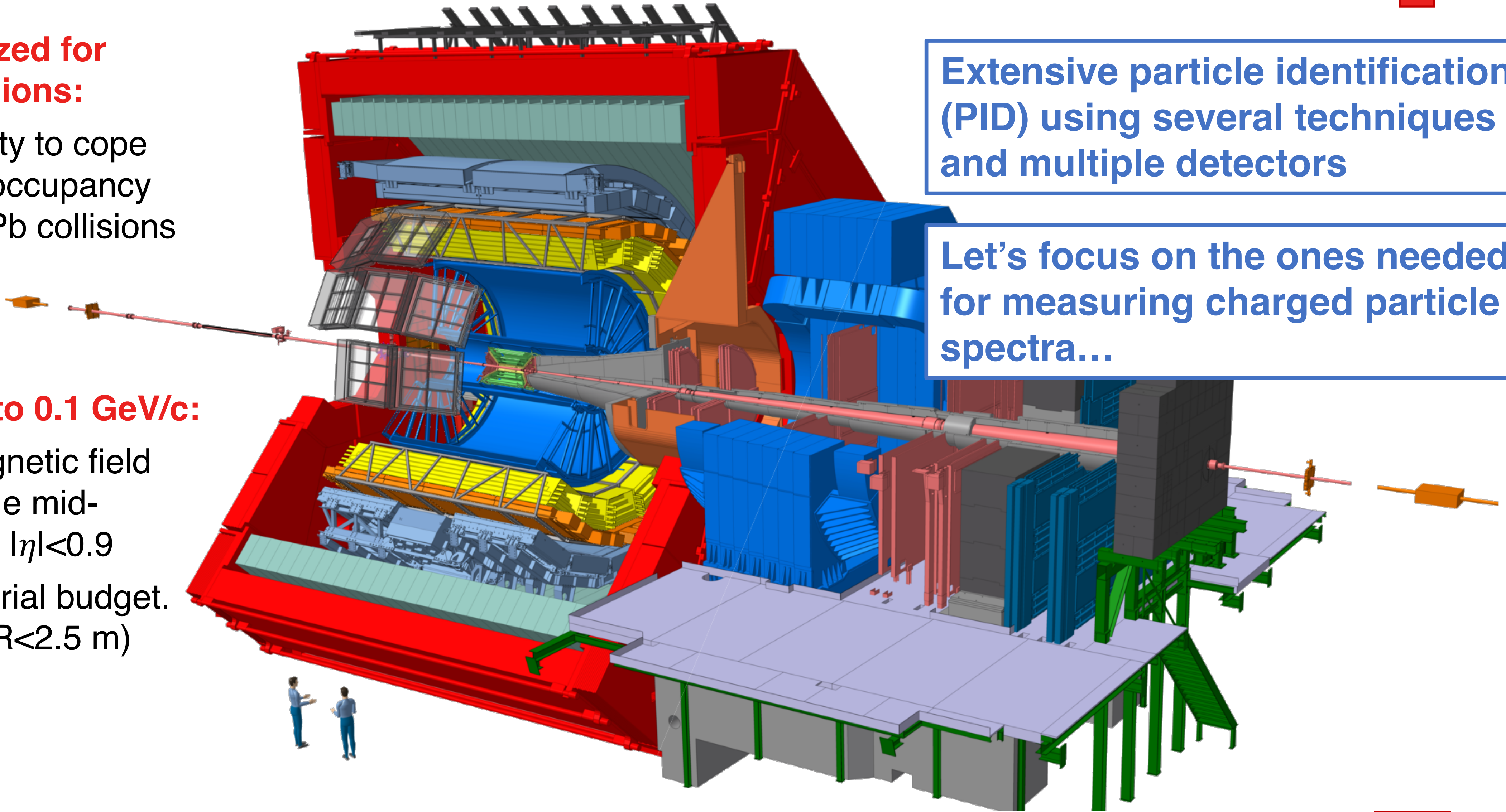
A Large Ion Collider Experiment

Detector optimized for Heavy Ion collisions:

- High granularity to cope with the high occupancy events in Pb-Pb collisions

Tracking down to 0.1 GeV/c:

- Moderate magnetic field (B=0.5 T) in the mid-rapidity region $|\eta|<0.9$
- Very low material budget. (<10% X_0 for R<2.5 m)

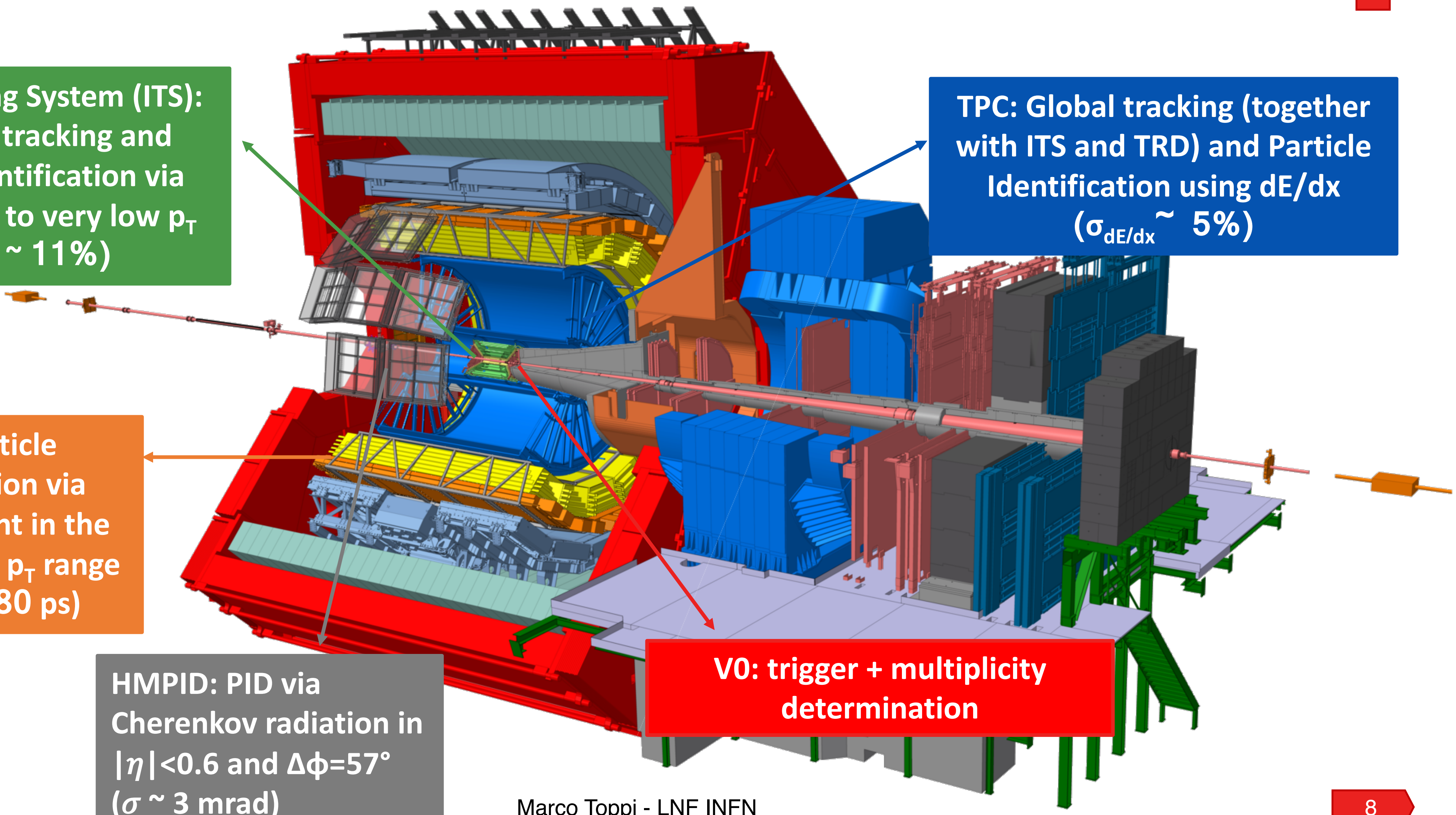


Extensive particle identification (PID) using several techniques and multiple detectors

Let's focus on the ones needed for measuring charged particle spectra…

A Large Ion Collider Experiment

ALICE detector



Inner Tracking System (ITS): Vertexing, tracking and Particle identification via dE/dx down to very low p_T ($\sigma_{dE/dx}$ ~ 11%)

TPC: Global tracking (together with ITS and TRD) and Particle Identification using dE/dx ($\sigma_{dE/dx}$ ~ 5%)

TOF: Particle Identification via Time-of-Flight in the intermediate p_T range (σ_{TOF} ~60-80 ps)

HMPID: PID via Cherenkov radiation in $|\eta|<0.6$ and $\Delta\phi=57°$ (σ ~ 3 mrad)

V0: trigger + multiplicity determination

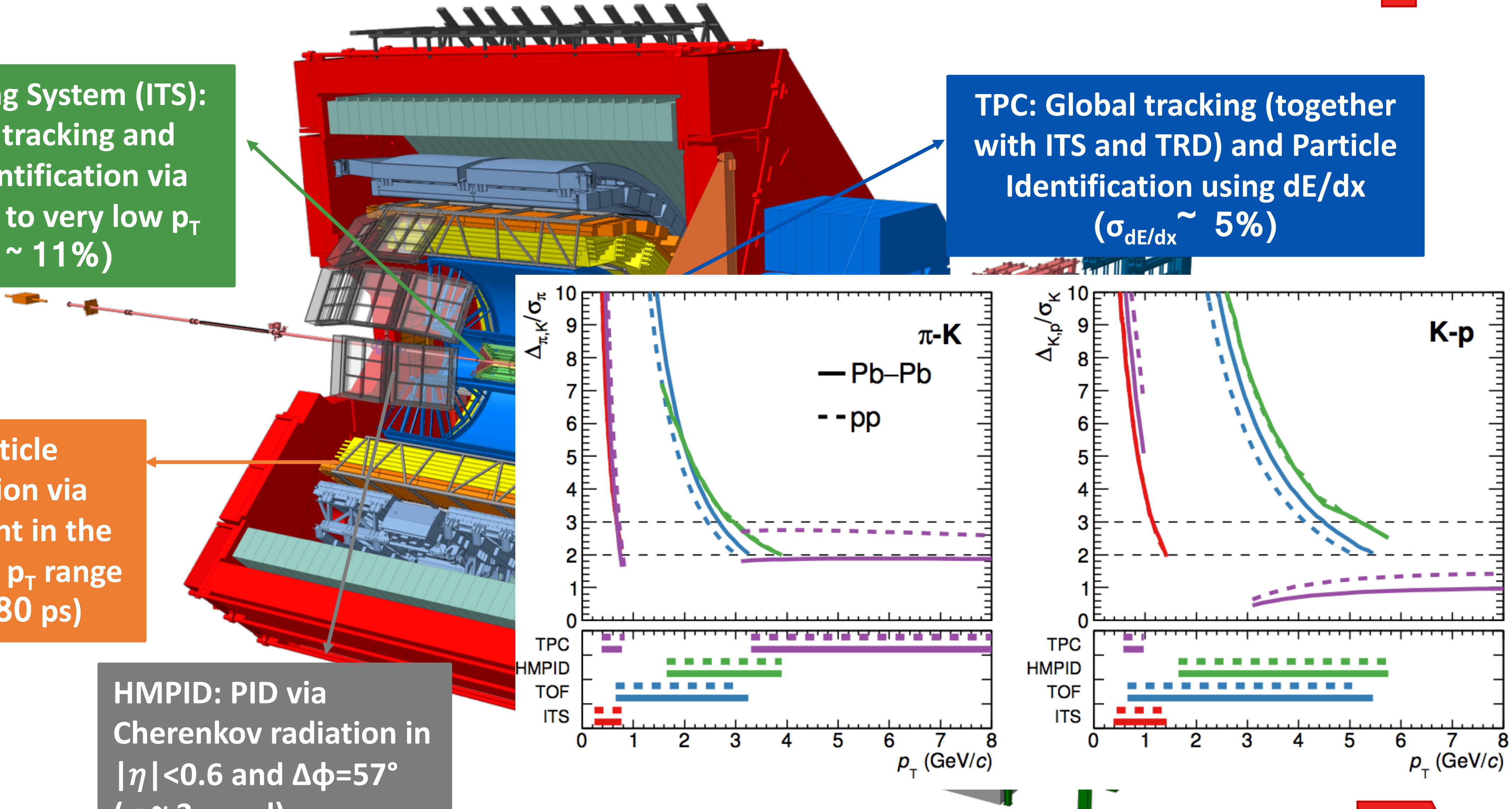
ALICE detector

Inner Tracking System (ITS): Vertexing, tracking and Particle identification via dE/dx down to very low p_T ($\sigma_{dE/dx}$ ~ 11%)

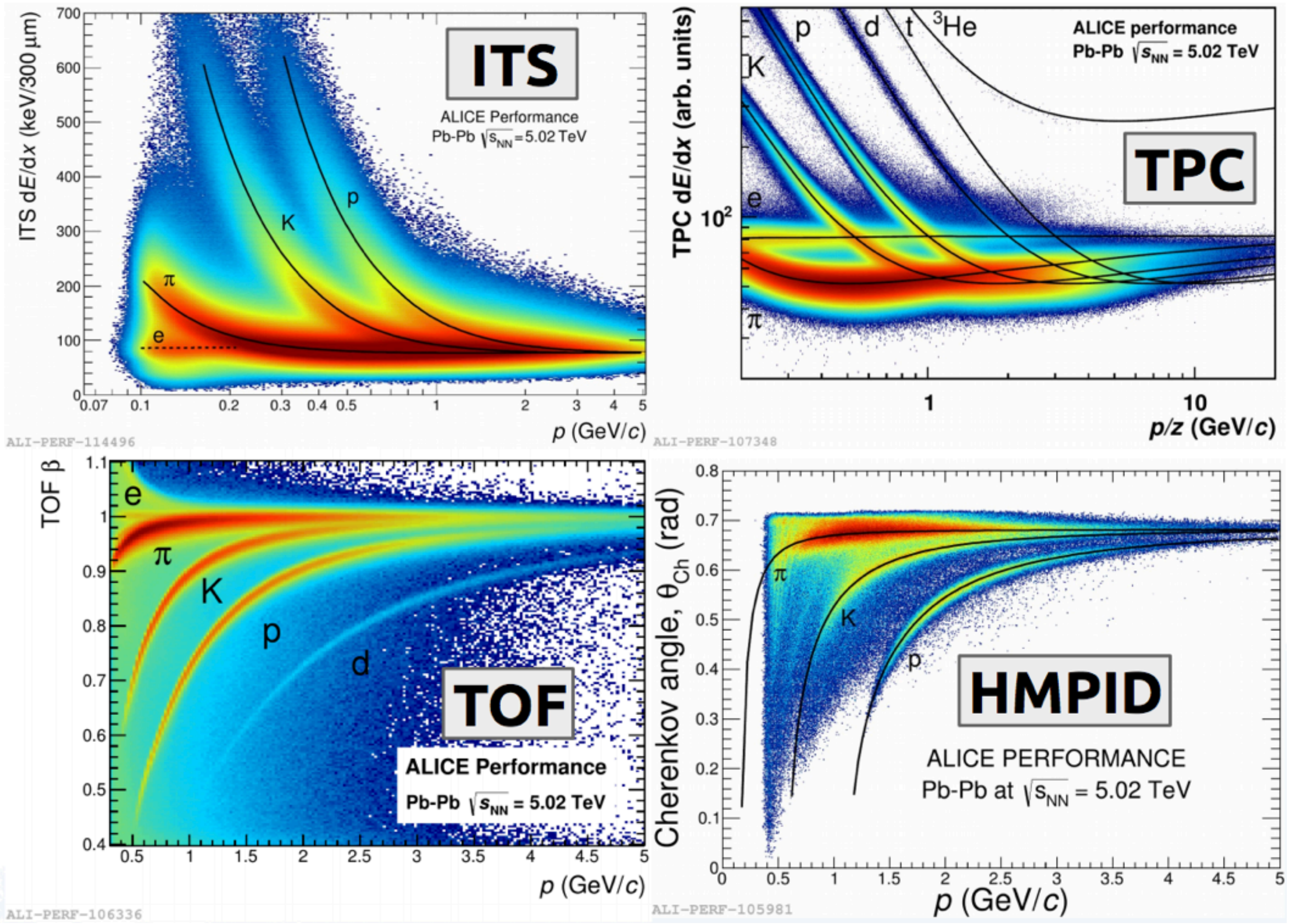
TPC: Global tracking (together with ITS and TRD) and Particle Identification using dE/dx ($\sigma_{dE/dx}$~ 5%)

TOF: Particle Identification via Time-of-Flight in the intermediate p_T range (σ_{TOF}~60-80 ps)

HMPID: PID via Cherenkov radiation in $|\eta|$<0.6 and $\Delta\phi$=57° (σ ~ 3 mrad)

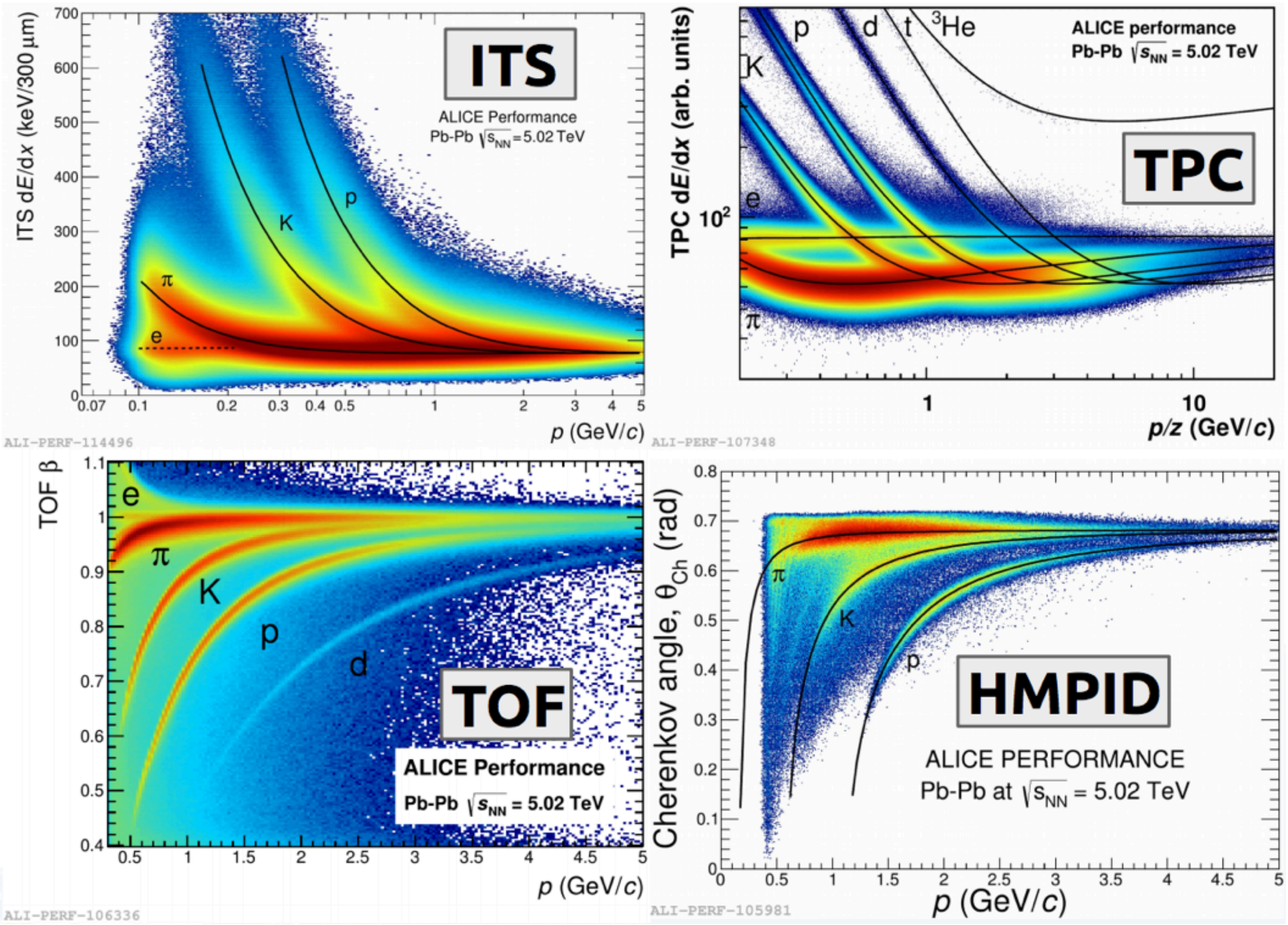


Particle identification

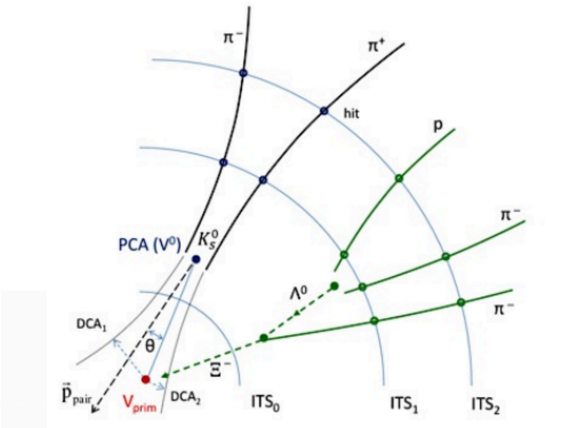


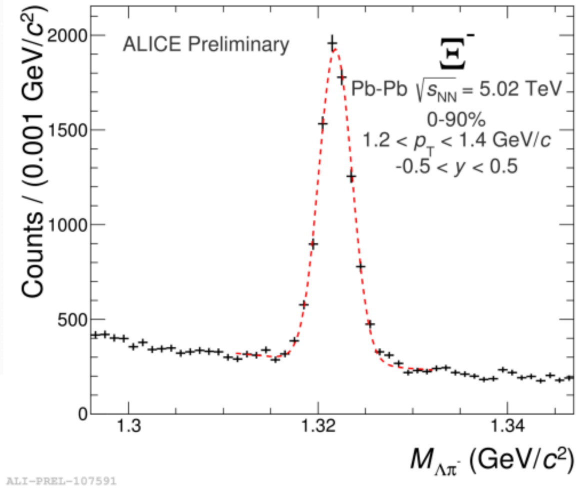
- Distribution of dE/dx, TOF and Cherenkov angle vs p_T quantifies the separation of different particle species
- Stable hadrons and light (anti-) nuclei are directly identified via specific energy loss, time-of-flight, and Cherenkov radiation
- Weakly decaying hadrons and hyper-nuclei are reconstructed via their decay topology by combining their daughter tracks which are displaced from the primary vertex…

Particle identification



Decay topology
secondary vertex reconstruction +
invariant mass analysis

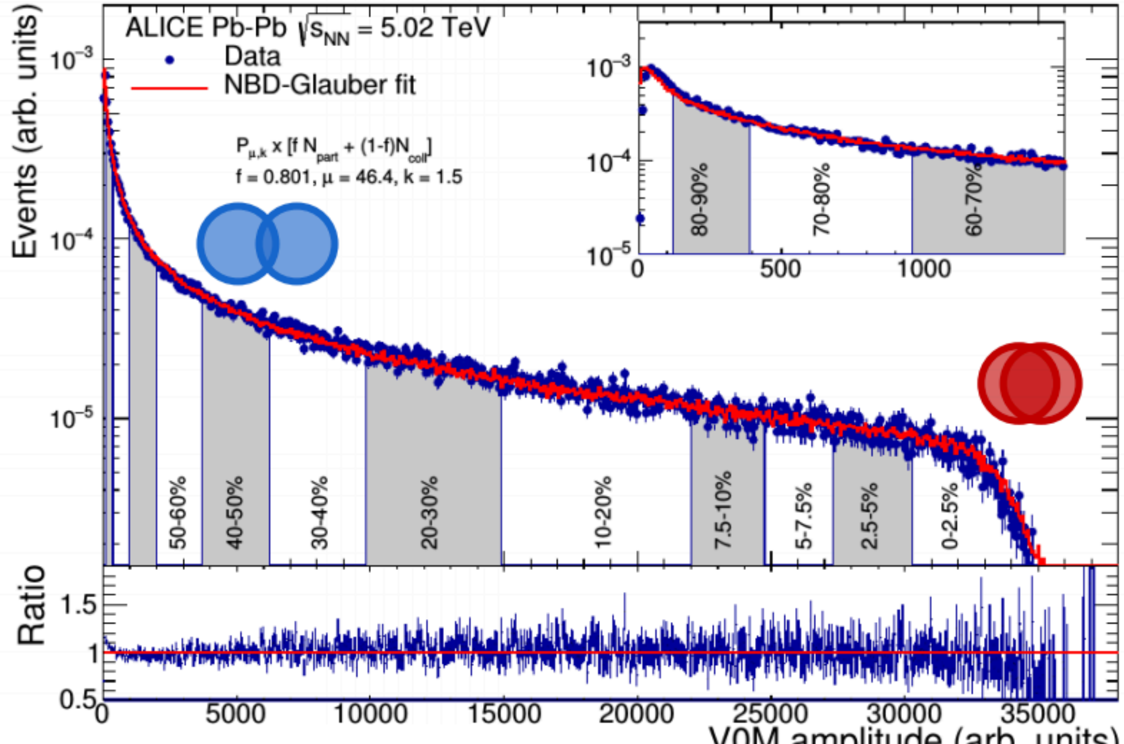




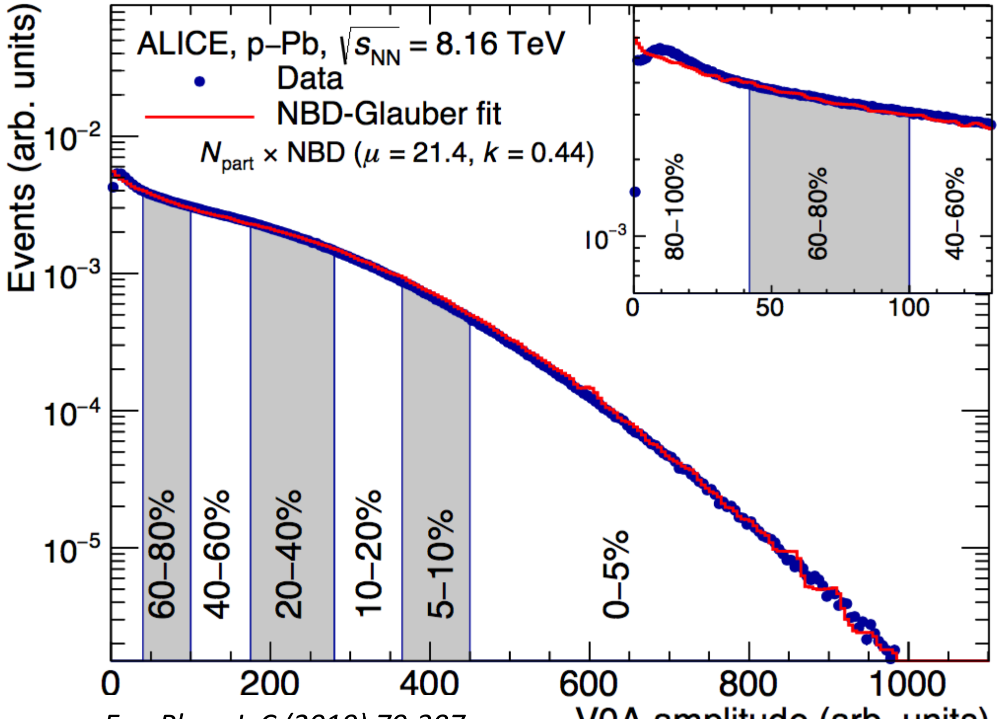
Event multiplicity and centrality

A Large Ion Collider Experiment

- Multiplicity is defined as the number of charged particles per event
- Linked through the impact parameter to the collision centrality in Pb–Pb
- ALICE measures the event activity at forward rapidity with the V0 detector
- Wide range of measured multiplicities from ≈ 2 in pp to ≈ 1600 in central Pb–Pb



ALICE-PUBLIC-2018-011



Eur. Phys. J. C (2019) 79:307

Particle spectra: motivations

Why study identified charged particle p_T -spectra of π, K and p, in pp, p-A and A-A collisions at different energies?

- Light flavor (u, d, s) hadrons produced at low p_T (soft probes) constitute more than 99% of the produced hadrons: **the bulk of particle production is composed of π (~80%), K (~13%) and p (~4%)**
- Such particles probe the system as a whole, giving the opportunity to study **collective behavior**
- In high-energy particle collisions the p_T distributions of identified hadrons carry much information about the system evolution, including:
  - Radial flow -> comparison of p_T spectra to hydrodynamic models
  - Kinetic freeze-out -> Blast-wave model fit
  - Chemical freeze-out -> thermal model fit to particle yields

Particle spectra: motivations

Why study identified charged particle p_T -spectra of π, K and p, in pp, p-A and A-A collisions at different energies?

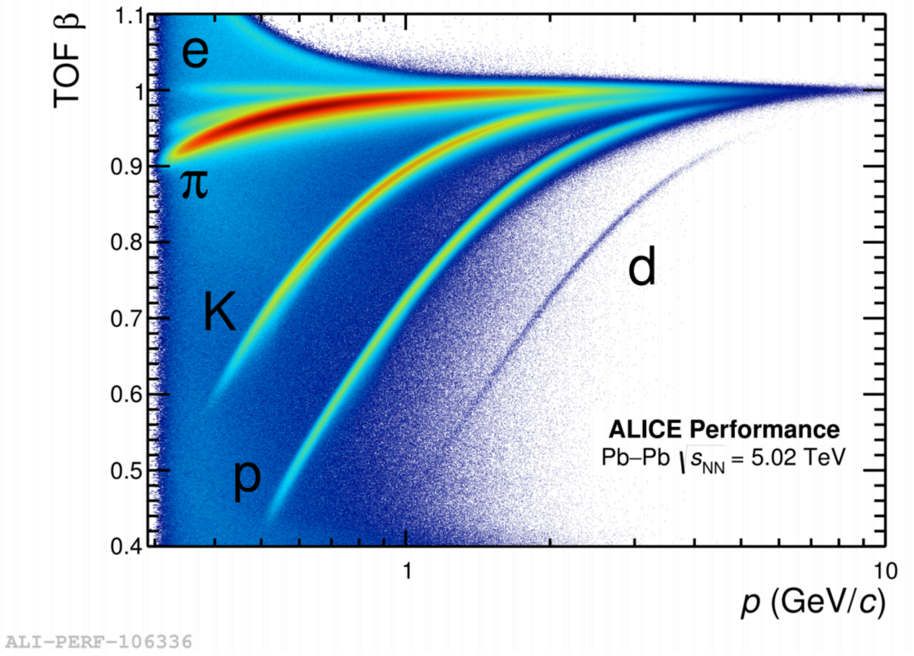
Strategy to measure p_T-particle spectra for π, K and p:

- The production of π, K and p is measured at midrapidity via independent analyses, each one focusing on a subrange of the total p_T distribution, with emphasis on the individual detectors (ITS, TPC, TOF and HMPID) and specific techniques to optimize the signal extraction.
- Finally the different analyses are combined in order to get the spectra over a wide p_T range

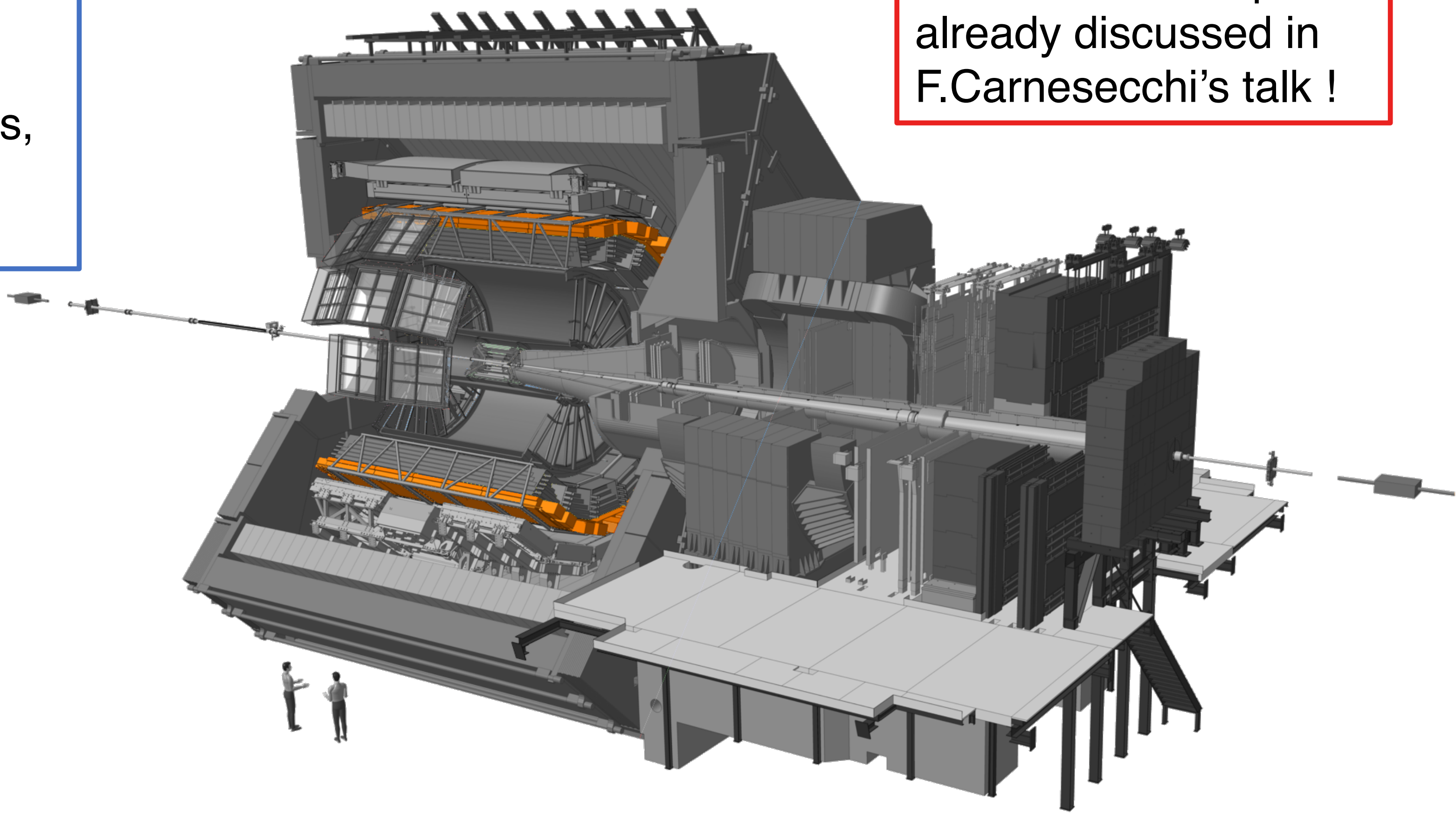
A **L**arge **I**on **C**ollider **E**xperiment

Measuring p_T-spectra with TOF

The measurements of π, K and p spectra with **TOF detector standalone** is performed using a statistical unfolding procedure to identify the different species, in order to extend the measurement beyond the region of clear separation



TOF technical aspects already discussed in F.Carnesecchi's talk !



Extraction of the TOF signal

The measurements of π, K and p spectra with **TOF detector standalone** is performed using a statistical unfolding procedure to identify the different species, in order to extend the measurement beyond the region of clear separation

Used a data-driven approach, fitting pions $n_\sigma = \Delta t / \sigma_{TOF}$ distribution in a region of clear separation in p_T (~1GeV/c) and extracting the TOF time response to be used as **template for the fitting procedure**

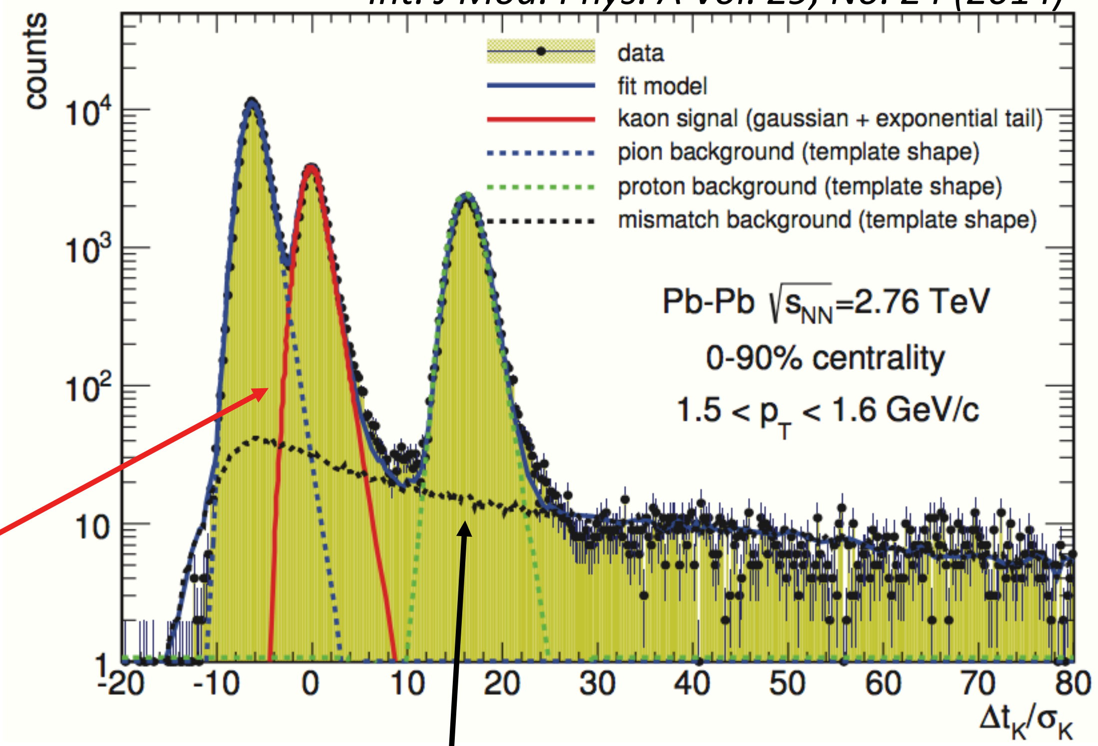
$\Delta t = t_{meas} - t_{exp}$

t_{meas} --> measured TOF

t_{exp} --> expected TOF

σ_{TOF} is the total TOF resolution

Int. J Mod. Phys. A Vol. 29, No. 24 (2014)



An additional template is needed to account for the tracks which are associated to a wrong hit in the TOF (mismatch background)

Spectra corrections

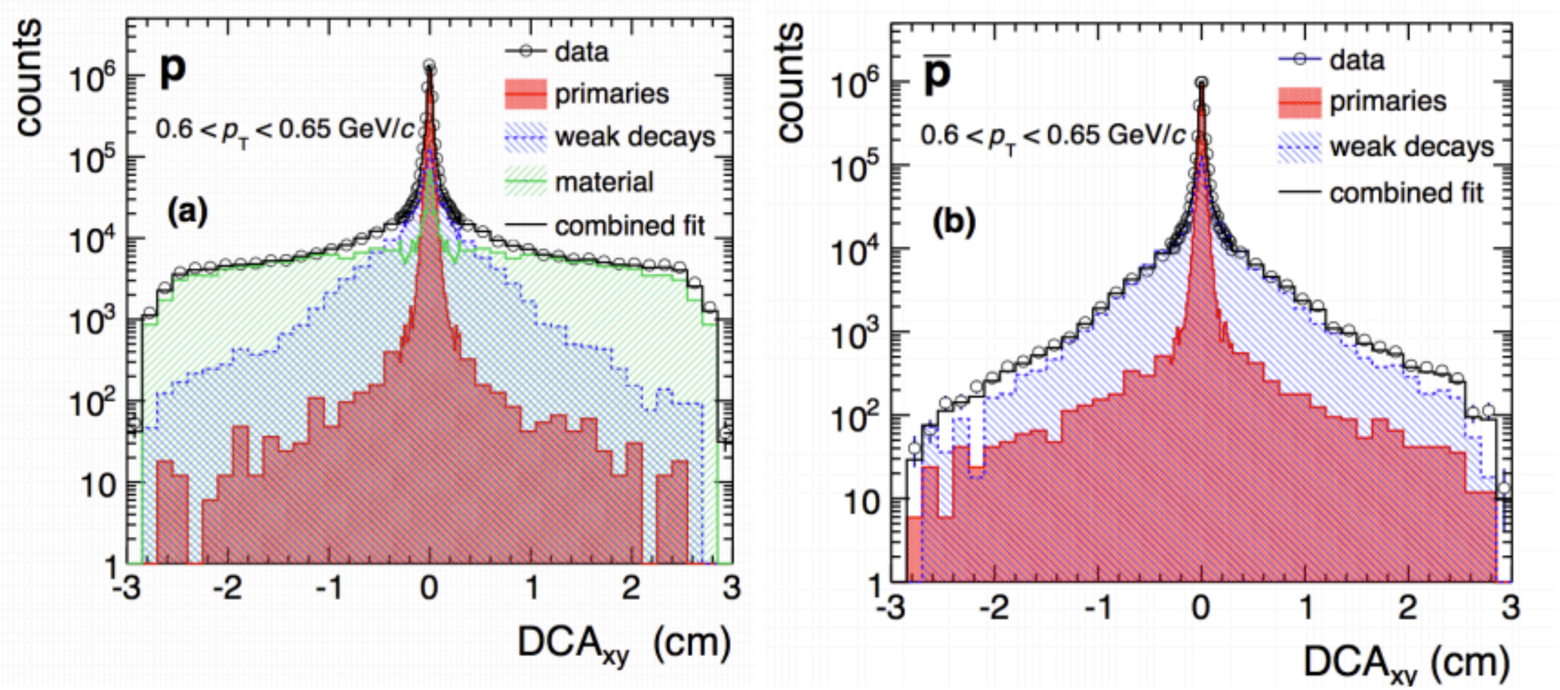
A Large Ion Collider Experiment

Decays of strange particles feed into the states with lower mass and need to be carefully subtracted for consistent data/model comparisons

In ALICE primary particles are defined as prompt particles produced in the collision including all decay products, except products from weak decays of light flavor hadrons and of muons.

Secondaries are subtracted based on their distance of closest approach to the primary vertex using MC templates

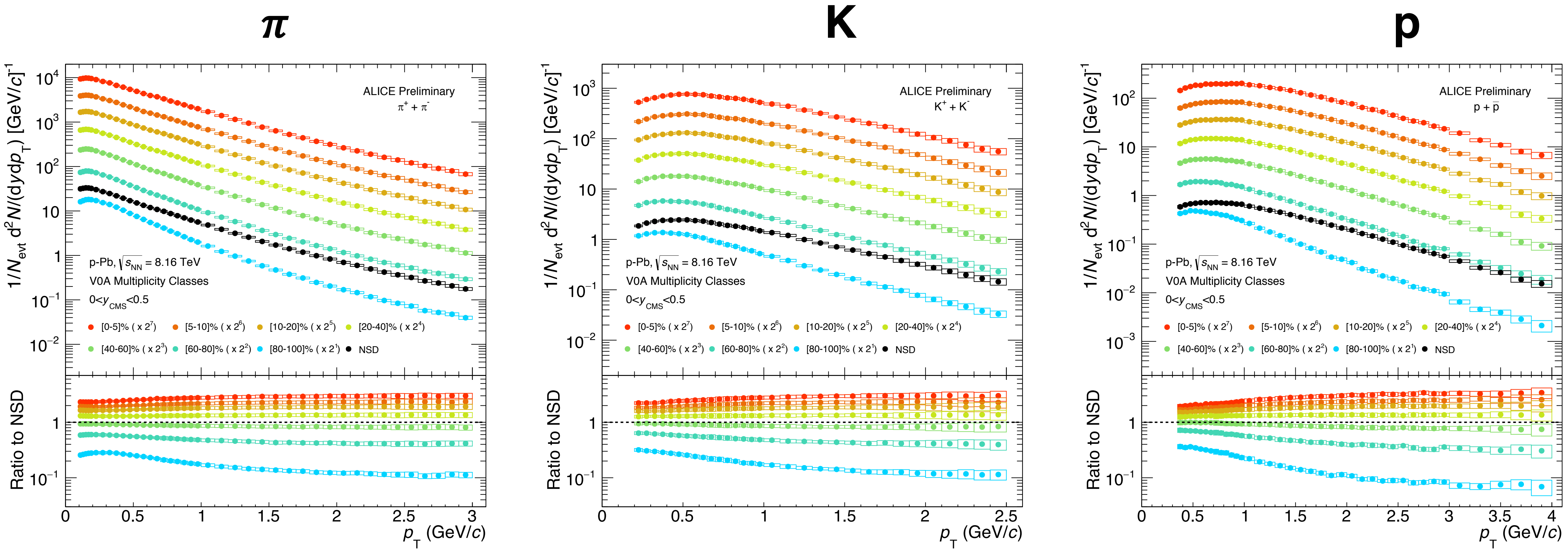
Phys. Rev. C 88, 044910 (2013)



Spectra are further corrected for acceptance and efficiency (computed from MC for each particle specie) and normalized to the number of events

Final p_T-spectra [New p-Pb 8.16 TeV]

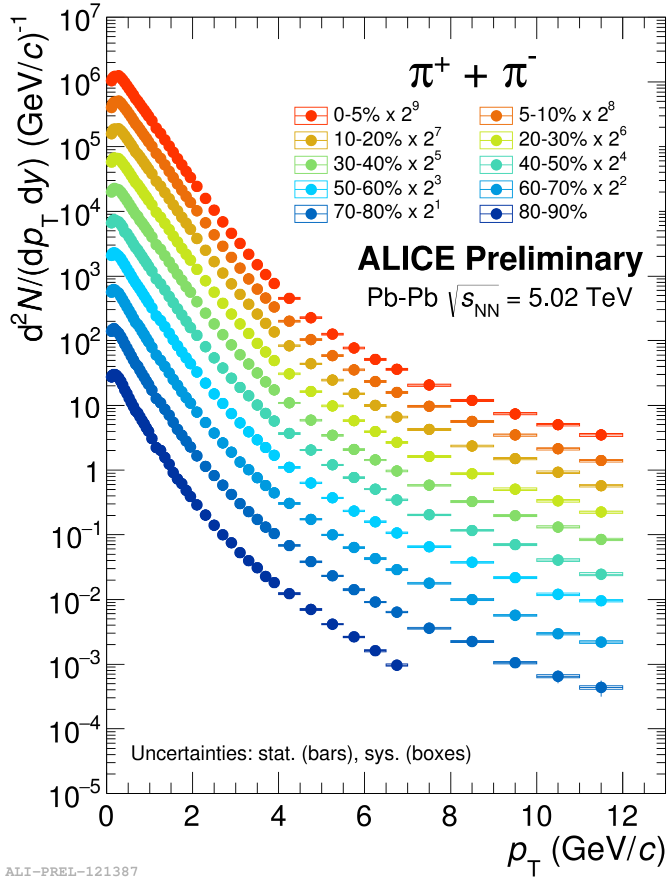
A Large Ion Collider Experiment

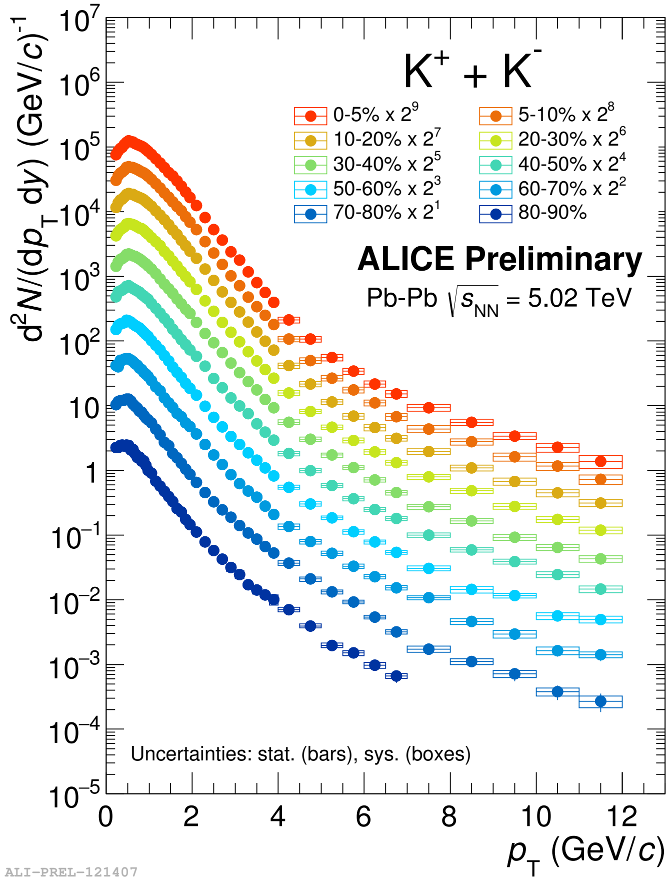


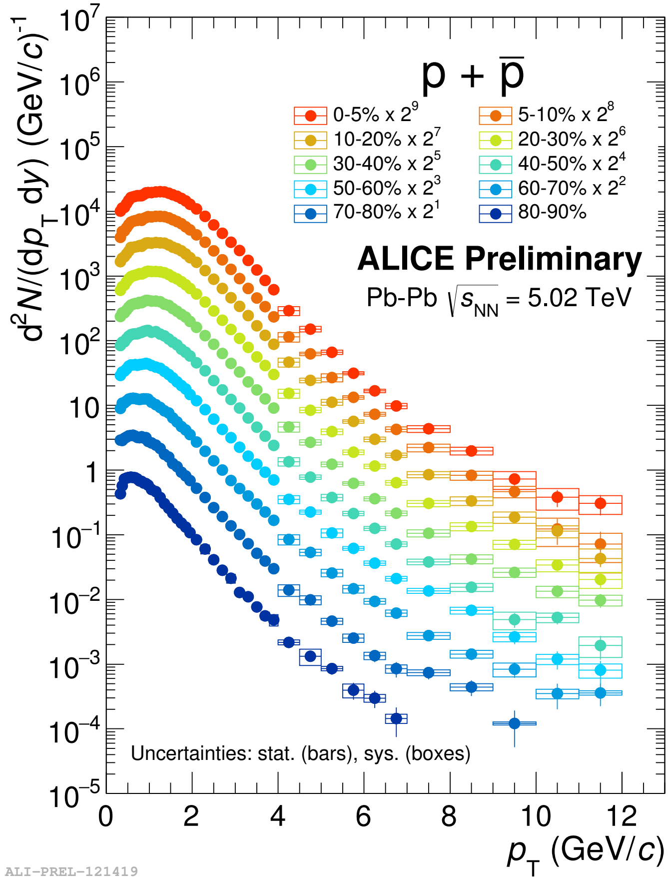
- Spectra become harder as the multiplicity increases (flattening visible at low p_T)
- Mass-dependent hardening of the soft part with increasing centrality due to the collective evolution (radial flow): the change is most pronounced for heavier particles

A Large Ion Collider Experiment

Final p_T-spectra [Pb-Pb 5.02 TeV]



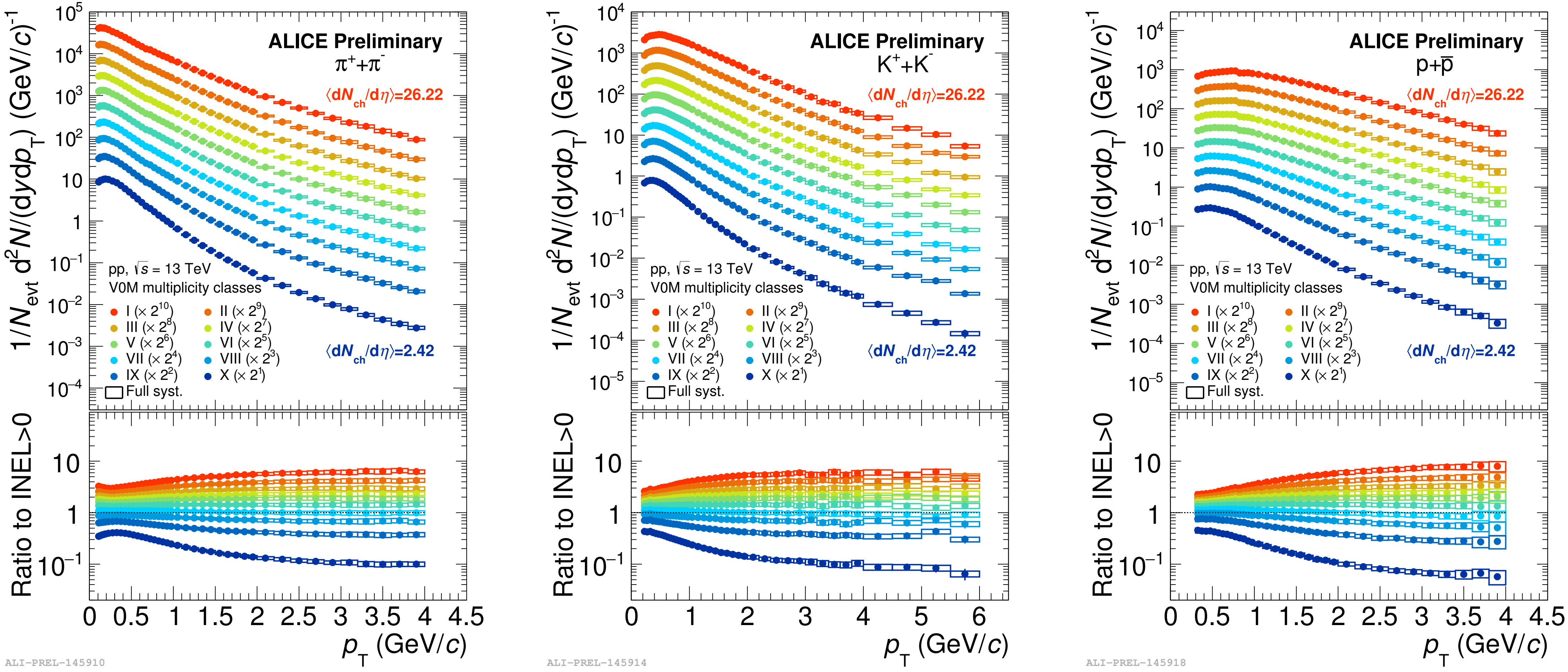




- Spectra become harder as the multiplicity increases (flattening visible at low p_T)
- Mass-dependent hardening of the soft part with increasing centrality due to the collective evolution (radial flow): the change is most pronounced for heavier particles

A Large Ion Collider Experiment

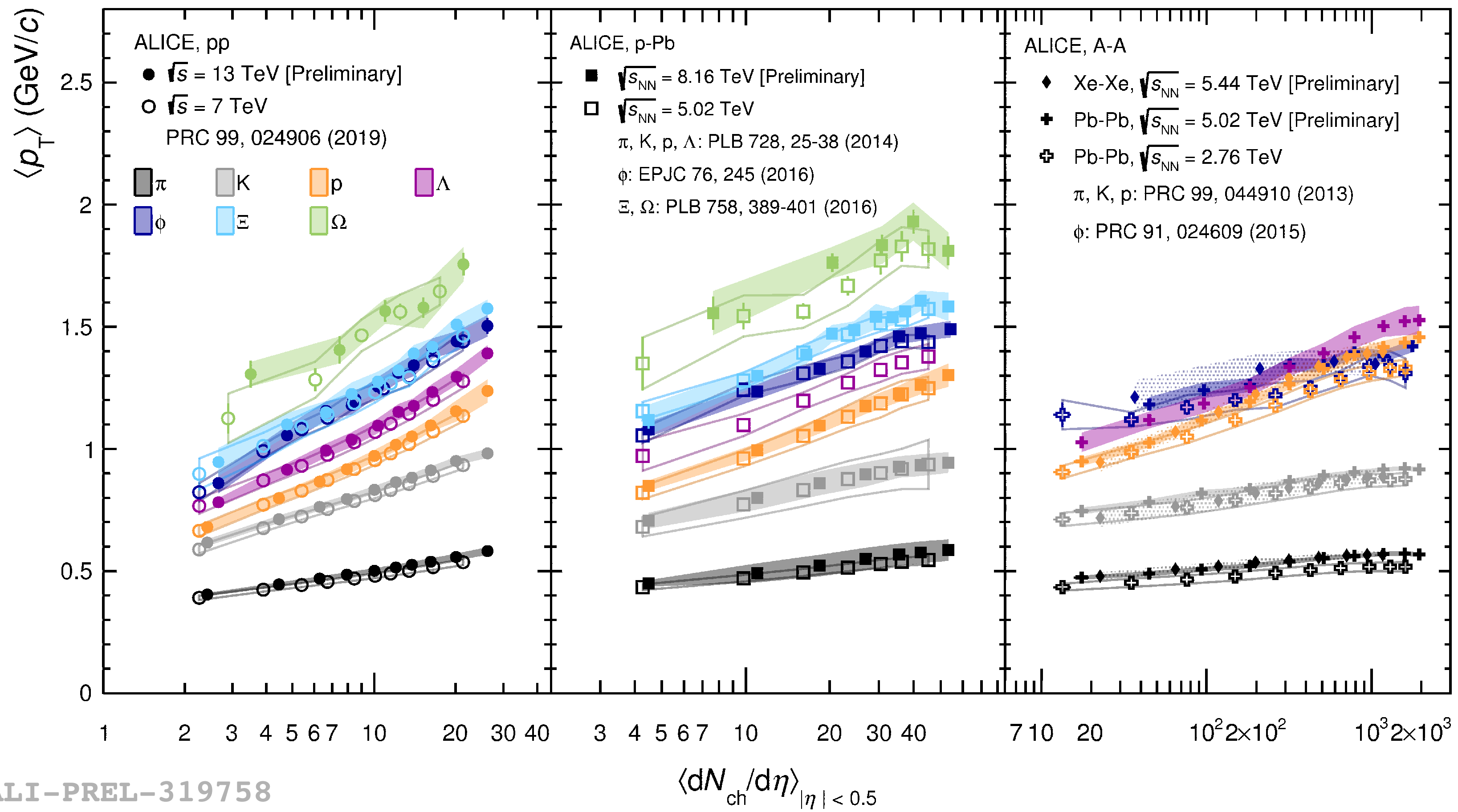
Final p_T-spectra [pp 13 TeV]



- Spectra become harder as the multiplicity increases
- Hints of radial flow in a limited p_T range in high multiplicity pp collisions

Mean transverse momenta $<p_T>$

A Large Ion Collider Experiment



The moderate increase is usually attributed to increasing collective radial flow

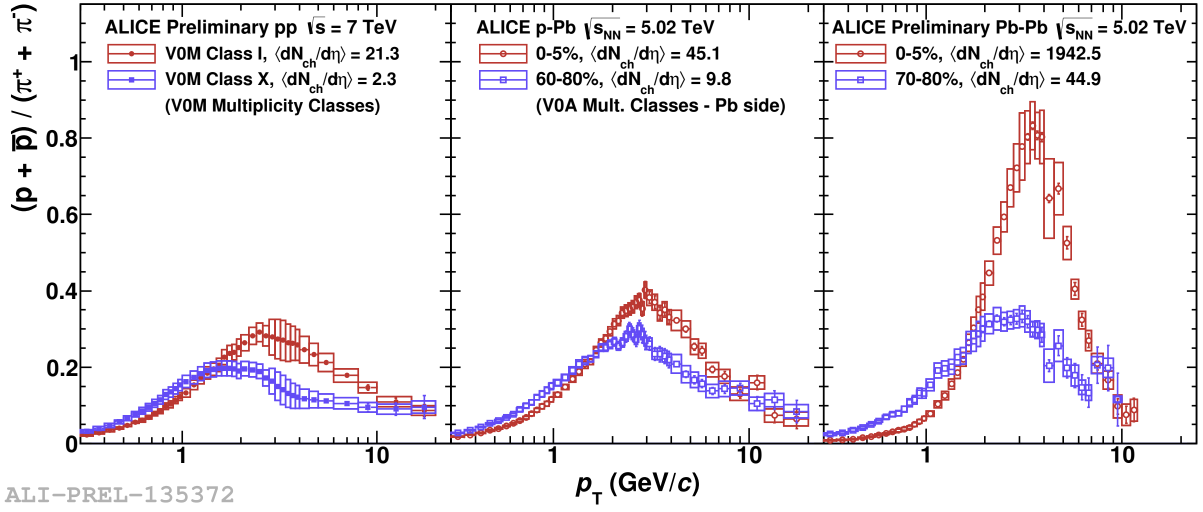
- **Spectra get harder with increasing centrality**, according to mass ordering (violated by ϕ)
- Similar hierarchy is observed in pp, p-Pb and peripheral A-A
- Particles with similar mass have similar $<p_T>$ in central AA collisions
- Small hardening of the spectra with increasing $\sqrt{s}$

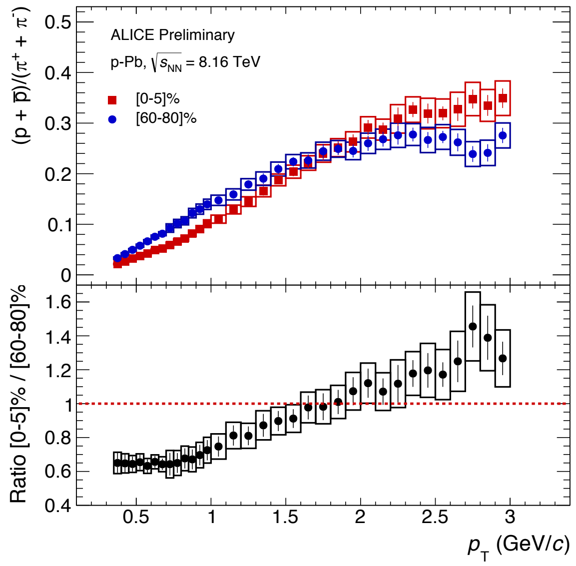
Mass ordering expected in presence of collective hydrodynamic expansion:

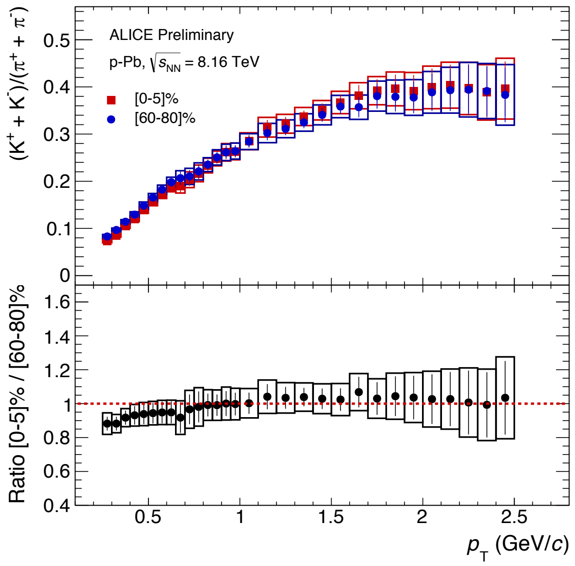
➢ Consistent with radial flow

A Large Ion Collider Experiment

Particle ratios

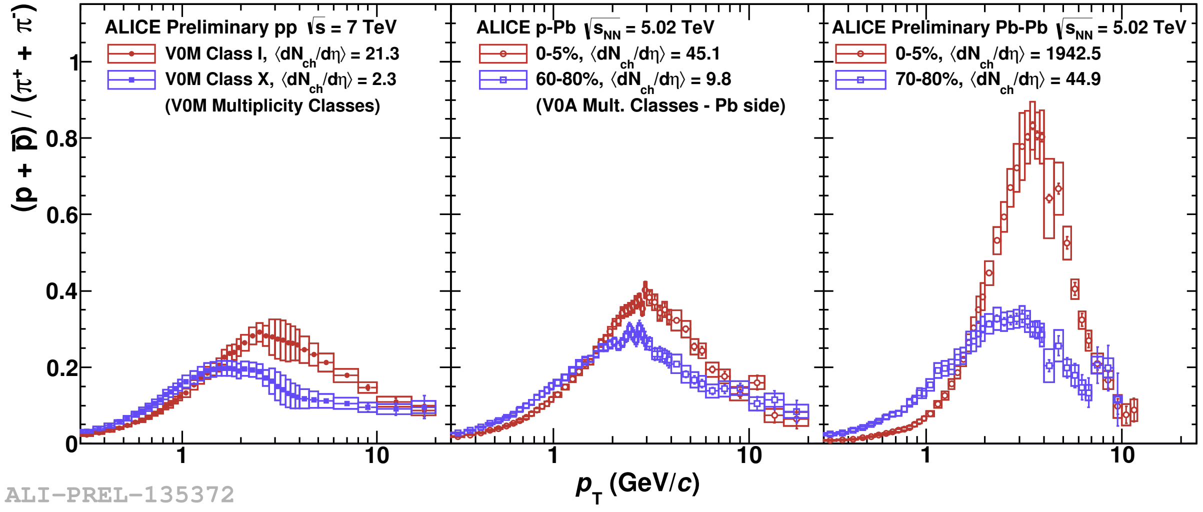


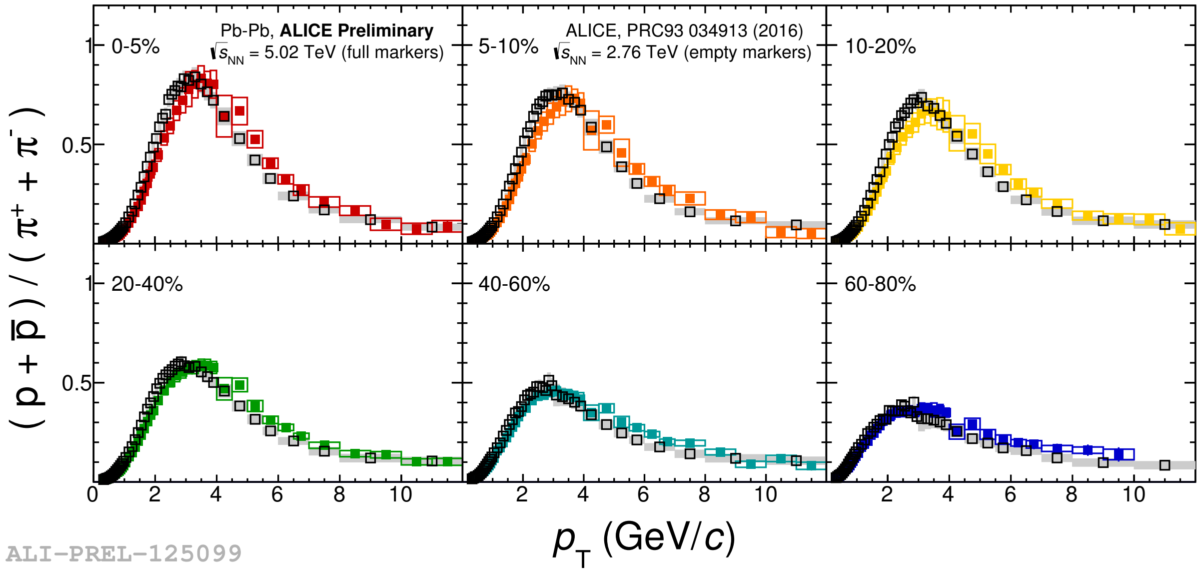




- Peripheral Pb-Pb collision are similar to pp and p-Pb collisions (smaller charged particle multiplicity)
- Significant evolution with the size of the collision system (large differences in multiplicity)
- Evolution of the baryon/meson ratio also in small systems
- p/π: similar flow-like features for pp, p-Pb and Pb-Pb systems
- Smaller enhancement in the K/π

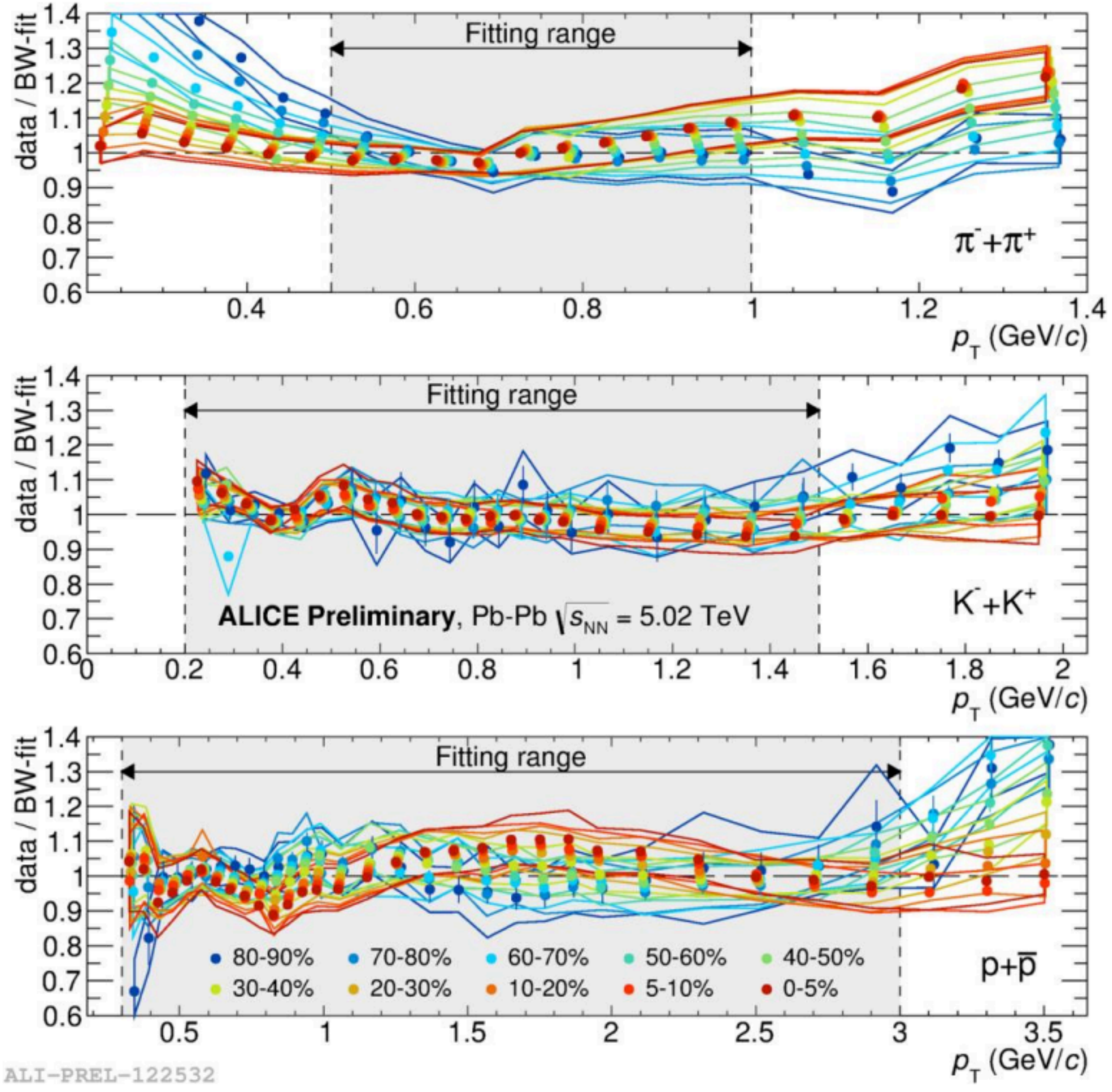
Particle ratios





- Peripheral Pb-Pb collision are similar to pp and p-Pb collisions (smaller charged particle multiplicity)
- Significant evolution with the size of the collision system (large differences in multiplicity)
- Evolution of the baryon/meson ratio also in small systems
- p/π: similar flow-like features for pp, p-Pb and Pb-Pb systems
- Smaller enhancement in the K/π
- Indication of a slightly higher radial flow in central collisions compared to lower energies.

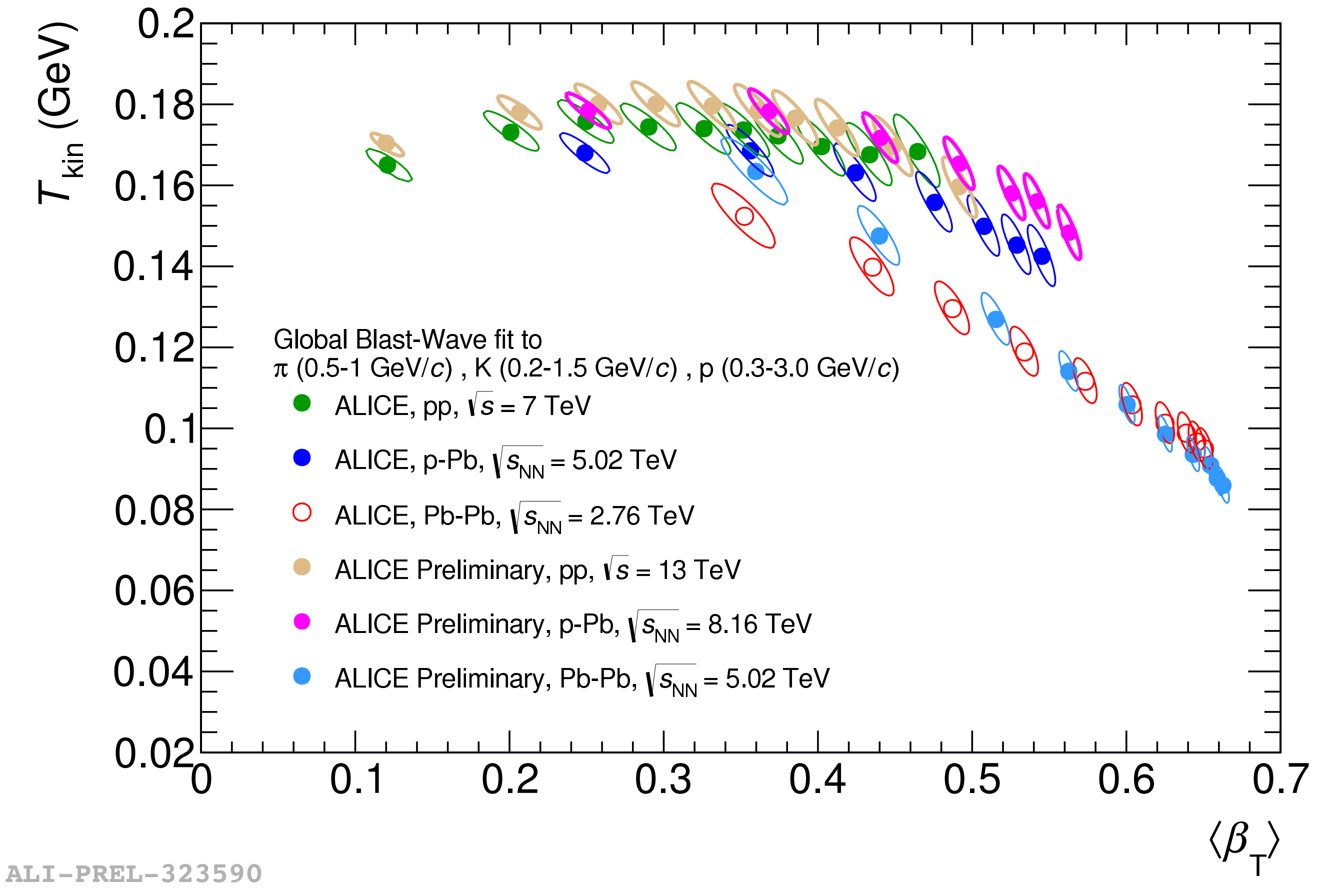
Radial flow and Blaste-wave model



- Full hydro models describe spectra fairly well.
- A combined **blast-wave fit** to the data (simplified hydrodynamic model, *Phys. Rev. C 48, 2462*) gives also a reasonable description allowing a systematic study of the **evolution of the spectral shape versus centrality**

- **Baste-wave model**: Locally thermalized medium, collective expansion with common expansion velocity β_T and freeze-out temperature T_{kin}
- Describes the particle distribution at kinetic freeze-out as a result of the expansion of a thermalized source
- Boltzmann-Gibbs statistics is used as an initial thermal distribution
- Free parameters are obtained with a simultaneous fit to the measured π/K/p distributions

Blaste-wave results



Large systems (AA collisions):

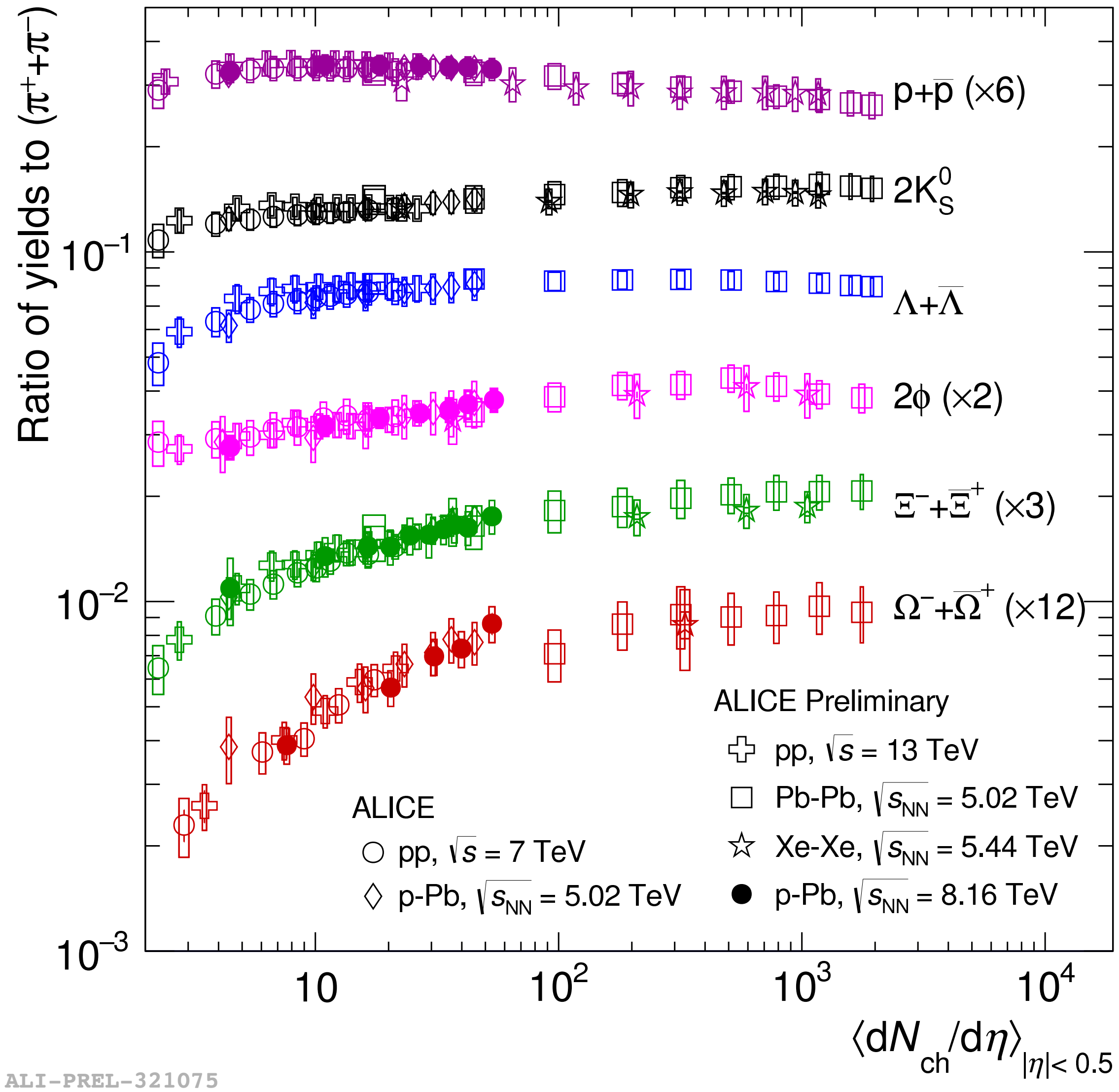
- Largest β_T and lowest T_{kin} for central Pb-Pb collisions (comparable β_T and T_{kin} at similar <$dN_{ch}/d\eta$> values)
- The expansion velocity slightly increases with the collision energy

Small systems (pp and p-Pb)

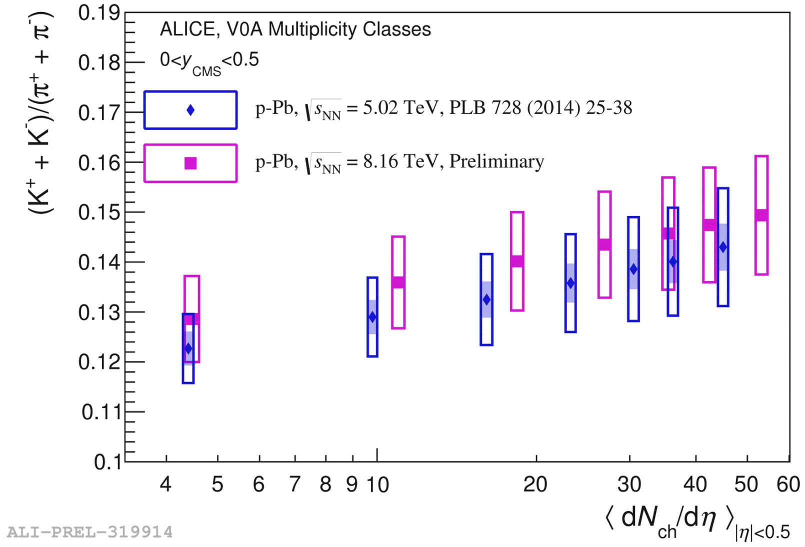
- Continuous evolution as a function of the event multiplicity is found in small systems
- pp and p-Pb show a similar trend and values are comparable: higher T_{kin} in p-Pb 8.16 TeV wrt 5.02 TeV
- Larger decoupling temperature with respect to heavy-ion collisions

Anyhow is necessary to be careful: It has been observed that other effects can mimic flow-like patterns!

Integrated particle yields



- The integrated particle yields exhibit a **continuous evolution with the charged particle multiplicity** independent of the collision system
- At large multiplicities small systems reach the values observed in heavy-ions



Chemical composition independent of collision system at same $\langle dN_{ch}/d\eta \rangle$

Summary

- Identified particle spectra (π/K/p/...) have been measured by ALICE in all collision systems provided by the LHC, allowing excellent systematic studies to be performed as a function of the collision energy and of the collision system
- TOF system is the key detector for the identification of particles in the intermediate p_T range
- Several similarities between pp, p-Pb, and Pb-Pb collisions have been reported – collectivity, baryon/meson ratio, strangeness production
- Some conclusions:
  - ➢ Radial flow effects are measurable in the hadron distributions (hardening)
  - ➢ Hints of radial flow in small systems
  - ➢ Hadron chemistry driven by multiplicity and not by collision energy nor system
  - ➢ Importance of hydrodynamical models which go beyond an incoherent superposition of parton-parton scatterings in the description of the measured data

Thank you!

INFN
Istituto Nazionale di Fisica Nucleare

ALICE

CERN

STVDIVM VRBIS

ITS Monopixel

Ministero degli Affari Esteri
e della Cooperazione Internazionale
FARNESINA

CENTRO FERMI
MUSEO
STORICO DELLA FISICA
E
CENTRO
STUDI E RICERCHE
ENRICO FERMI