System size dependence of particle production in pp, p-Pb and Pb-Pb collisions at 5.02 TeV

Outline

- Motivation
- ALICE detector
- Results
- Summary

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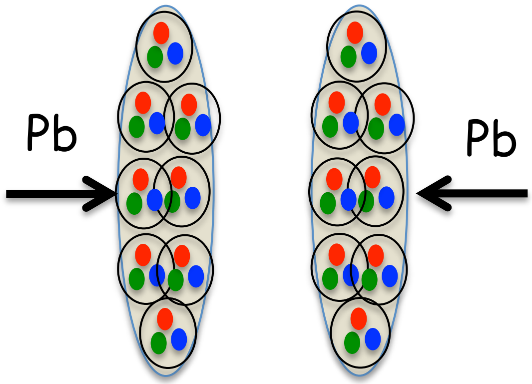
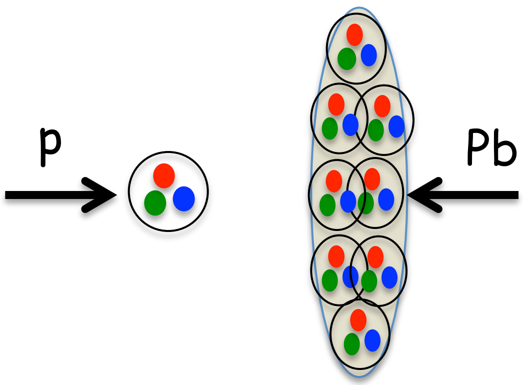
9th International Workshop on MPI at the LHC, Dec 11-15

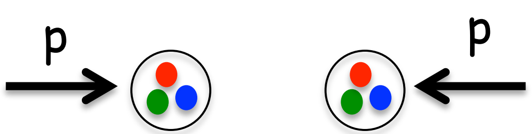
Motivation



- Deconfined/Hot QCD matter -> QGP
  - Chemical equilibrated particle production
  - Collectivity: radial and elliptic flow
  - Energy loss in strongly interacting medium
    -- Jet quenching



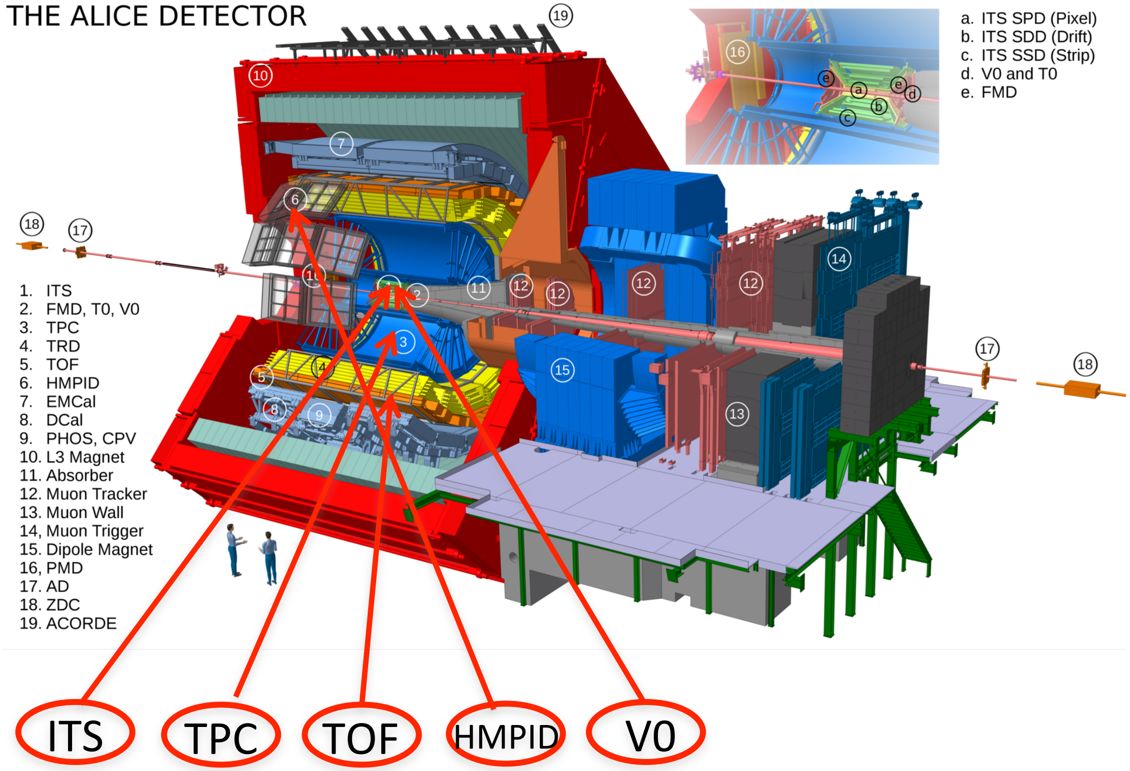
- Used to study the Cold Nuclear Matter effects
- Suited to explore the transition between Pb-Pb and pp collisions



- Testing pQDC calculation and tuning of MC generators

QCD medium in small system??

ALICE (A Large Ion Collider Experiment)



ITS (Inner Tracking System)

- ✓ Tracking and Vertexing
- ✓ Particle Identification (PID)

TPC (Time Projection Chamber)

- ✓ Primary vertex determination
- ✓ Main tracking device
- ✓ PID via dE/dx in gas

TOF (Time-Of-Flight)

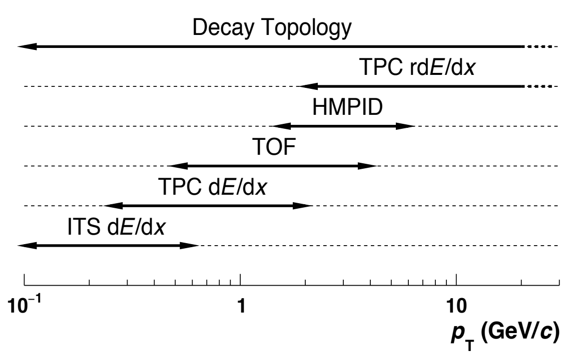
- ✓ PID via time-of-flight measurement

HMPID (High Momentum Particle Identification)

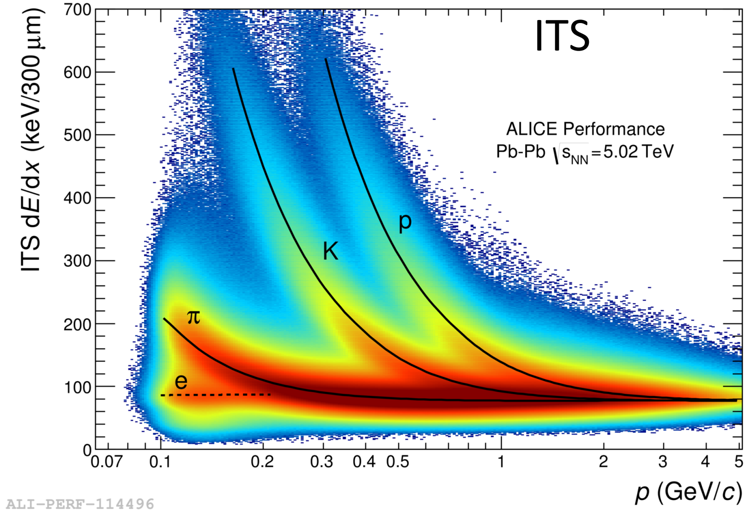
- ✓ PID via cherenkov angle measurement

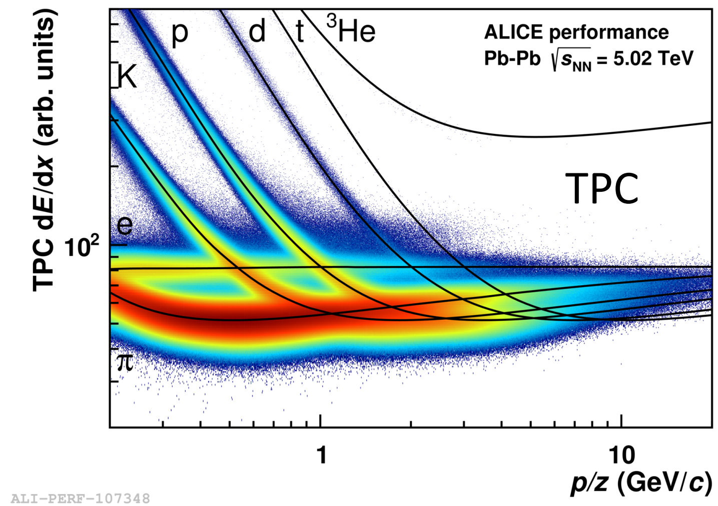
VZERO scintillator detectors:

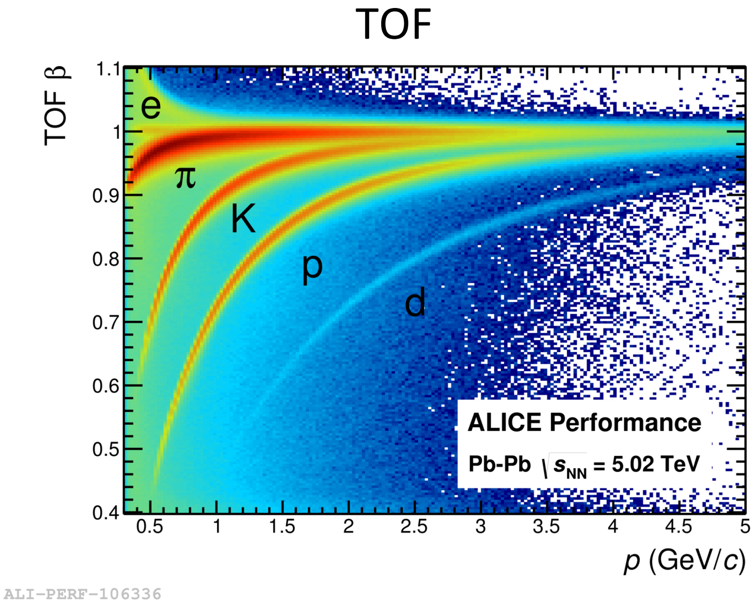
- ✓ Centrality definition in Pb-Pb (V0M)
- ✓ Multiplicity event classes in p-Pb and in pp (V0M) (V0M = V0A & V0C)

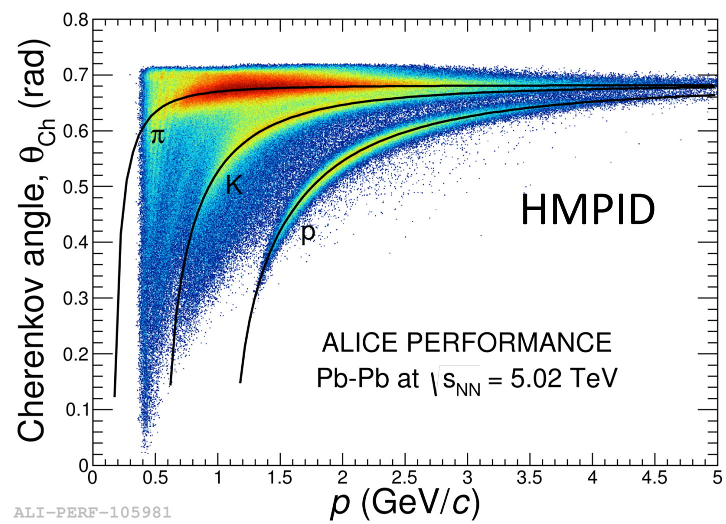


Particle identification

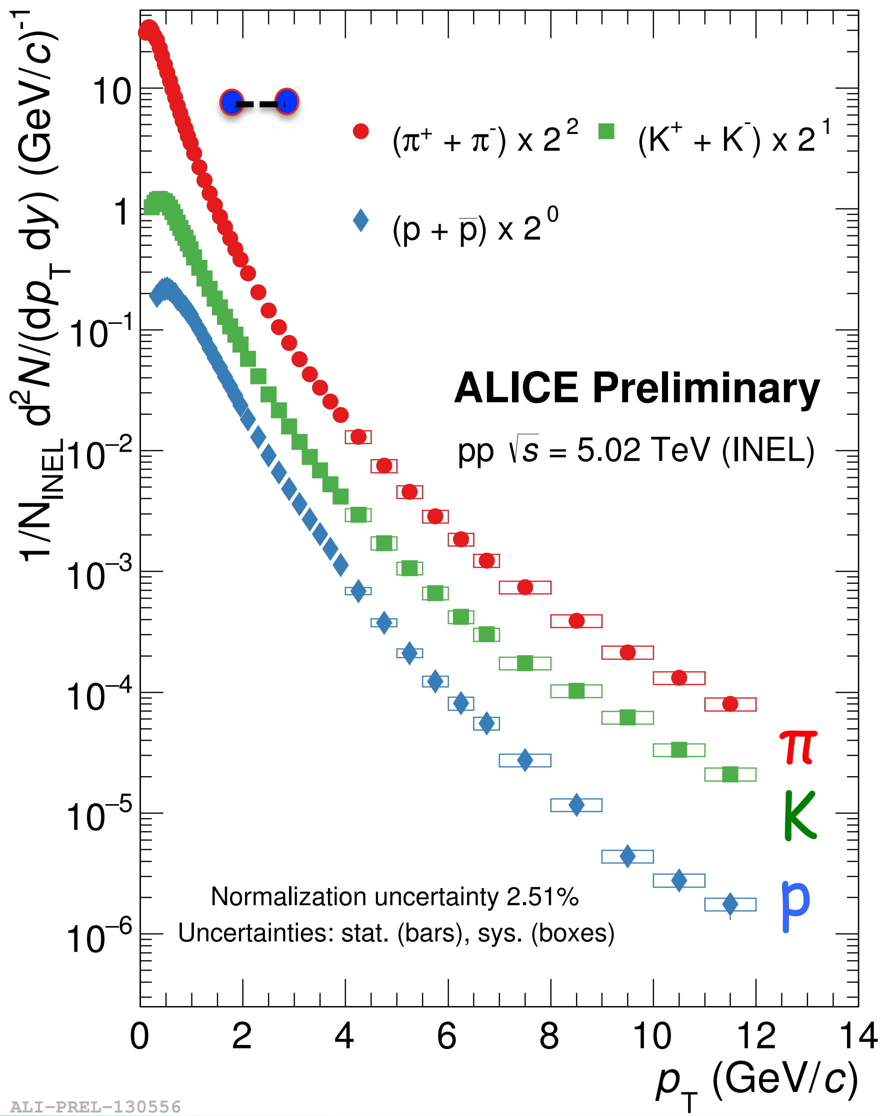


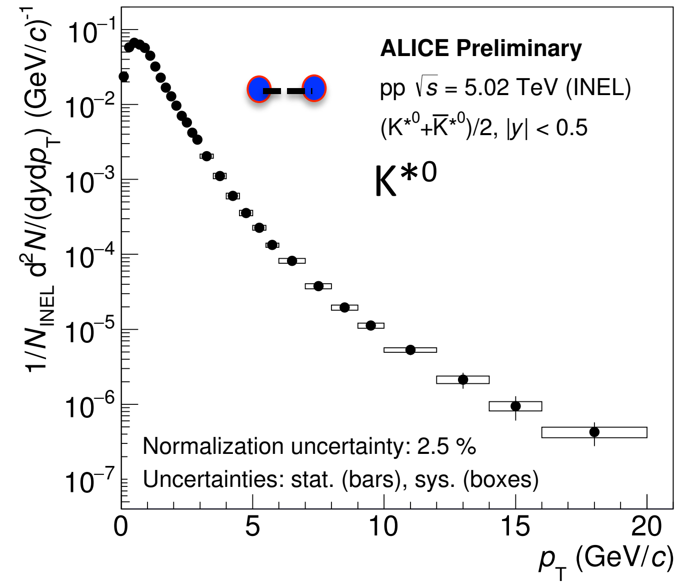


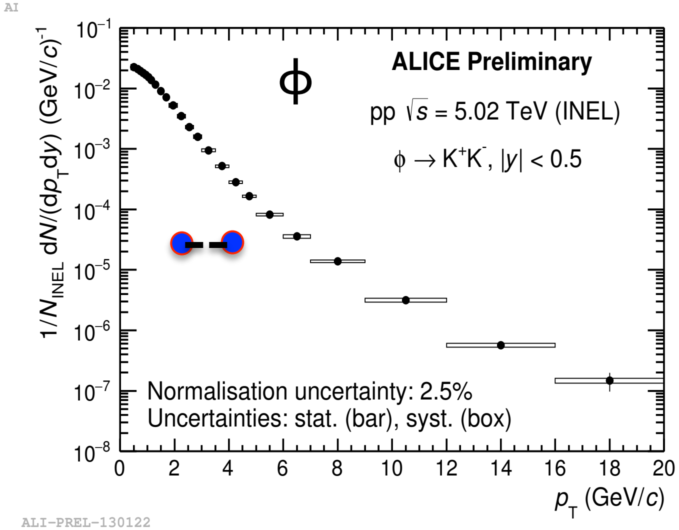




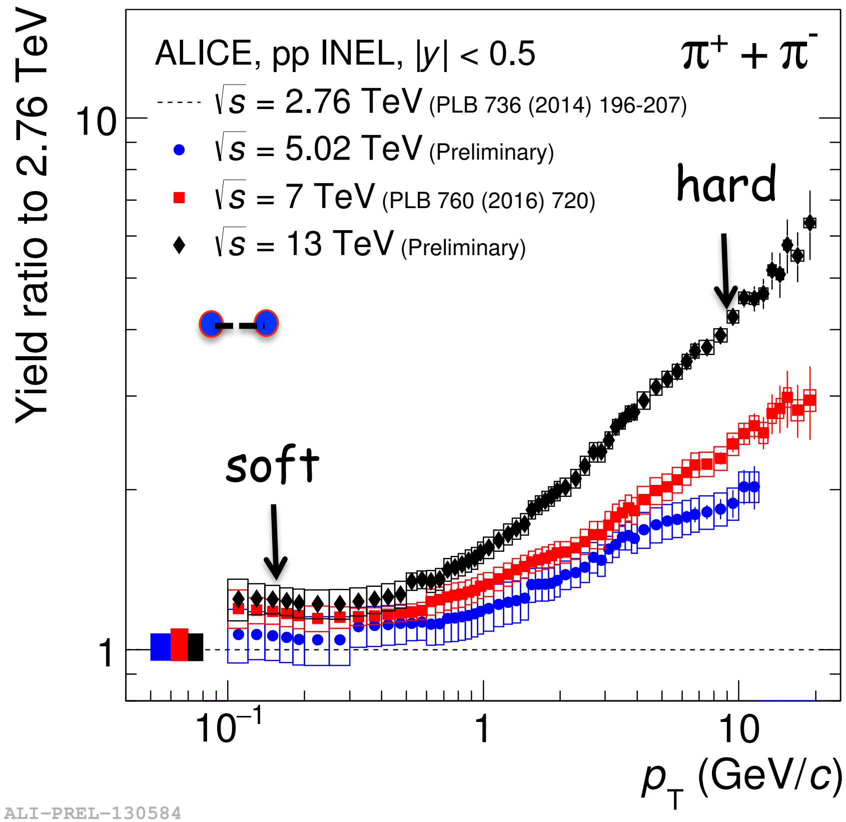
Transverse momentum spectra in pp

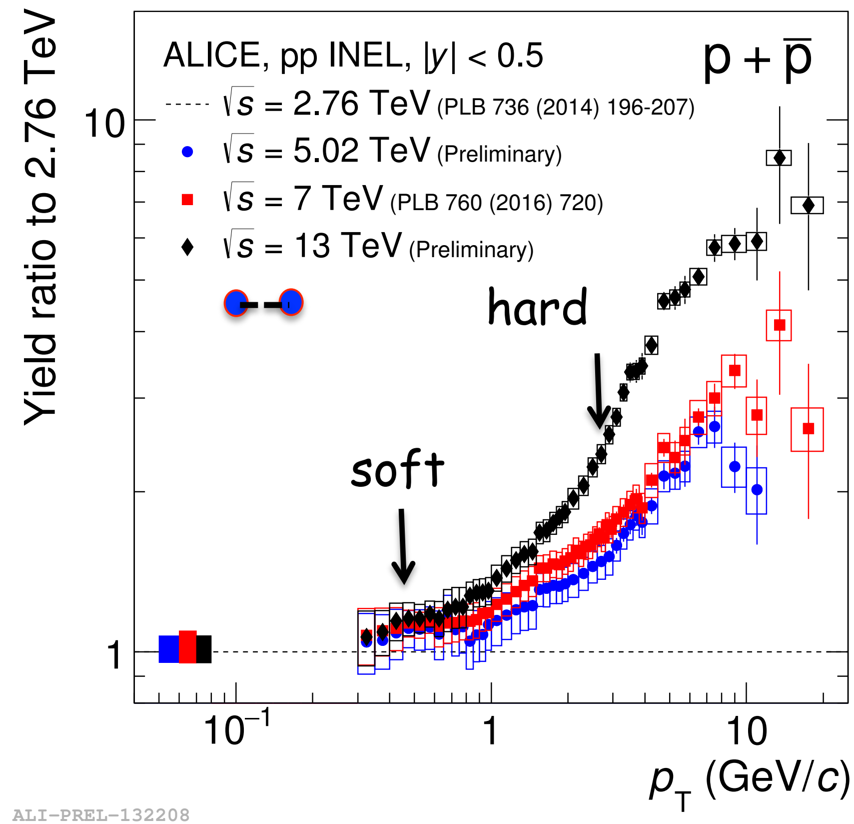






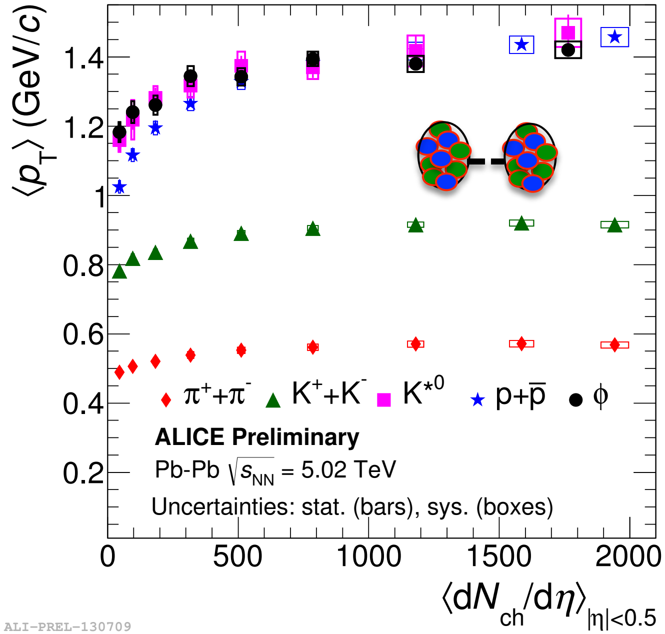
Energy dependence p_T spectra in pp





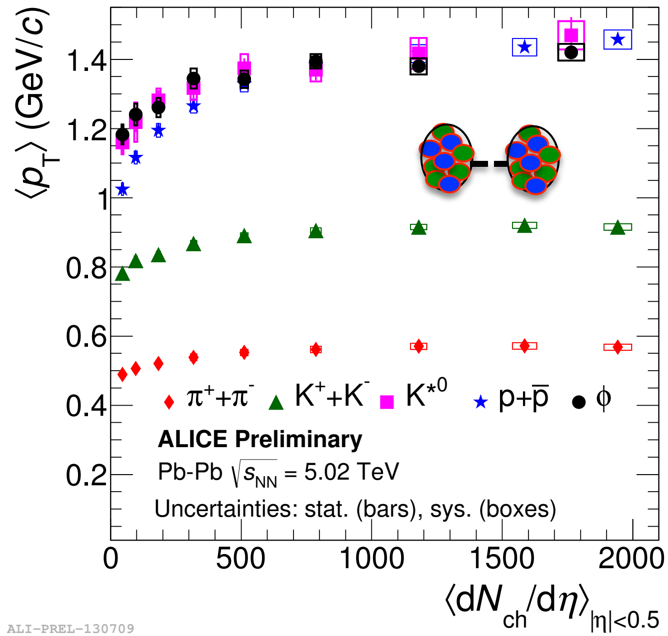
- ✓ Harder spectra with increasing center of mass energy ($\sqrt{s}$)
- ✓ Soft regime (< 1 GeV/c): no change
- ✓ Hard regime: significant dependence on $\sqrt{s}$

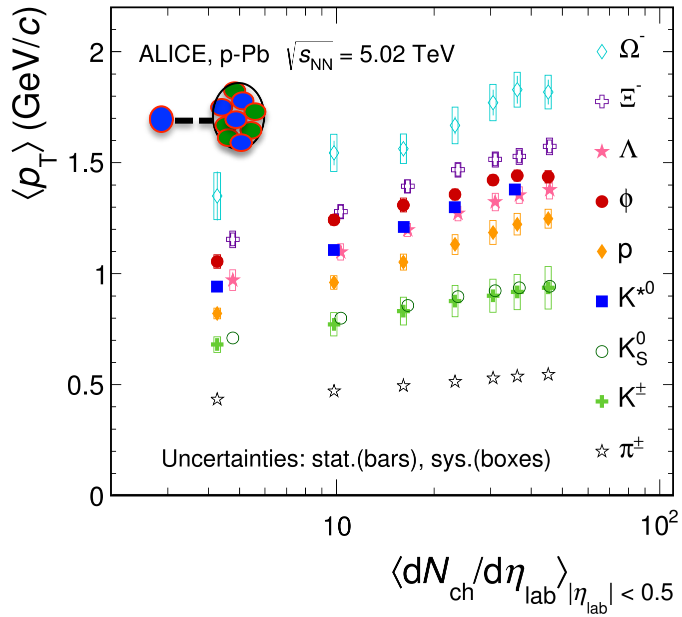
Mean p_T in Pb-Pb

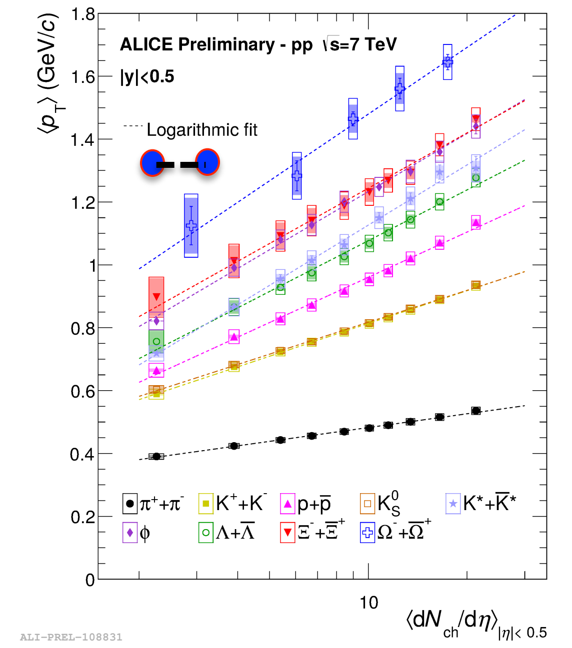


- ✓ Central Pb-Pb: $\langle p_T \rangle$ of K^{*0}, p, and ϕ is similar
  -- mass ordering -> Consistent with hydrodynamics

Mean p_T in pp, p-Pb and Pb-Pb

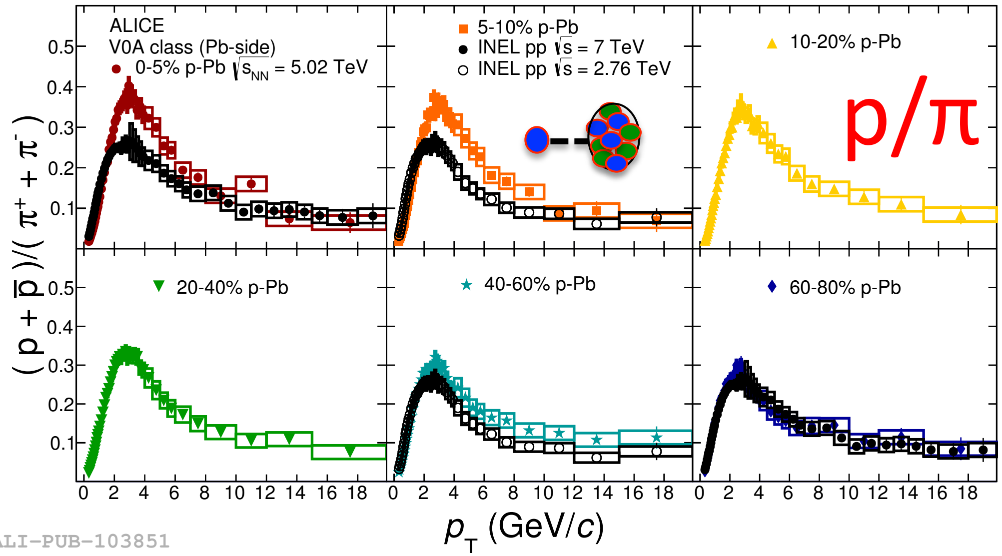






- ✓ Central Pb-Pb: <p_T> of K*0, p, and ϕ is similar
  -- mass ordering -> Consistent with hydrodynamics
- ✓ Mass ordering only approximate for peripheral Pb-Pb, p-Pb, and pp
  -- Resonances behave differently from long-lived particles? Baryon/meson difference?

Differential particle ratio in p-Pb



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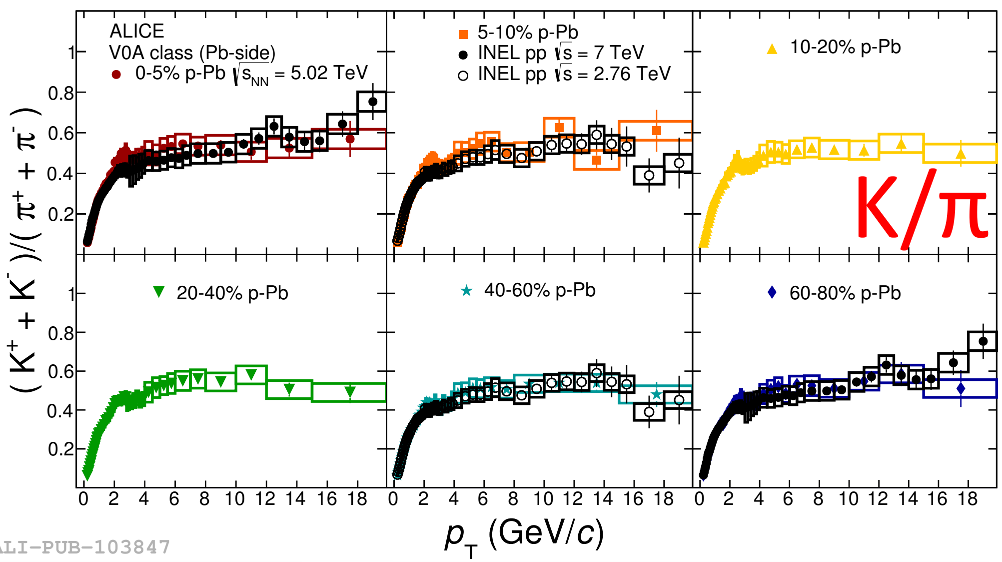

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Compared with ratios from pp

✓ p/π:

-- Multiplicity dependence at low and intermediate p_T

-- No system and energy dependence at high p_T

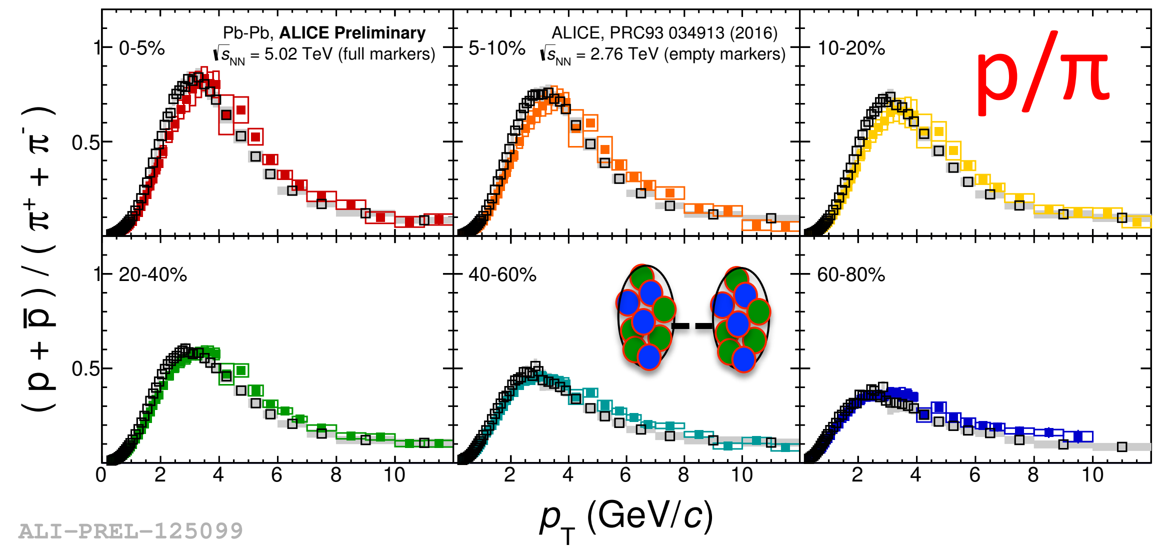
-- 60-80 % is similar to pp

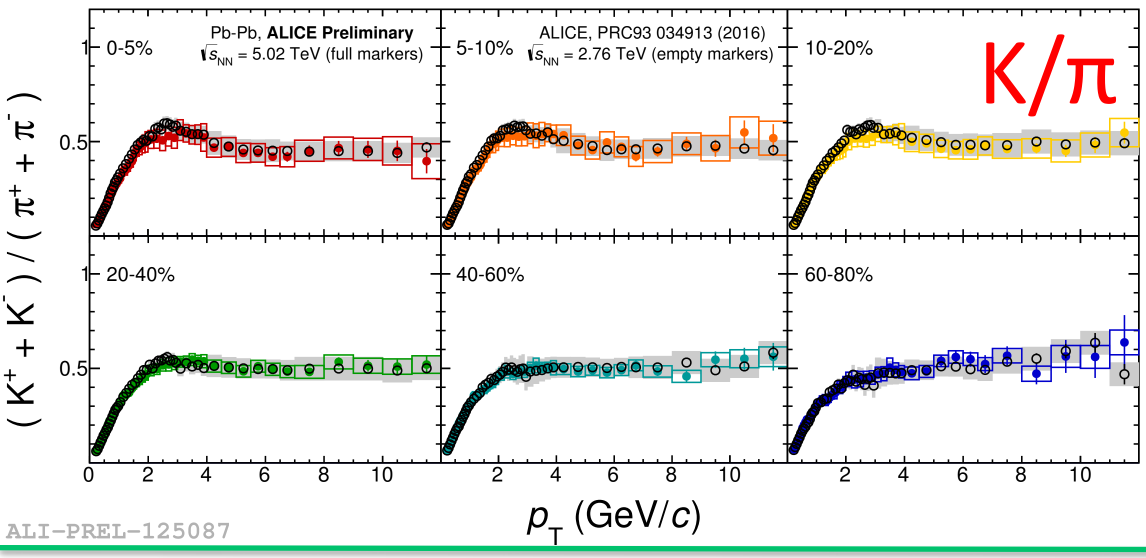
✓ K/π:

-- No multiplicity dependence

-- Similar to pp

Differential particle ratio in Pb-Pb





Comparison of 2.76 TeV and 5.02 TeV

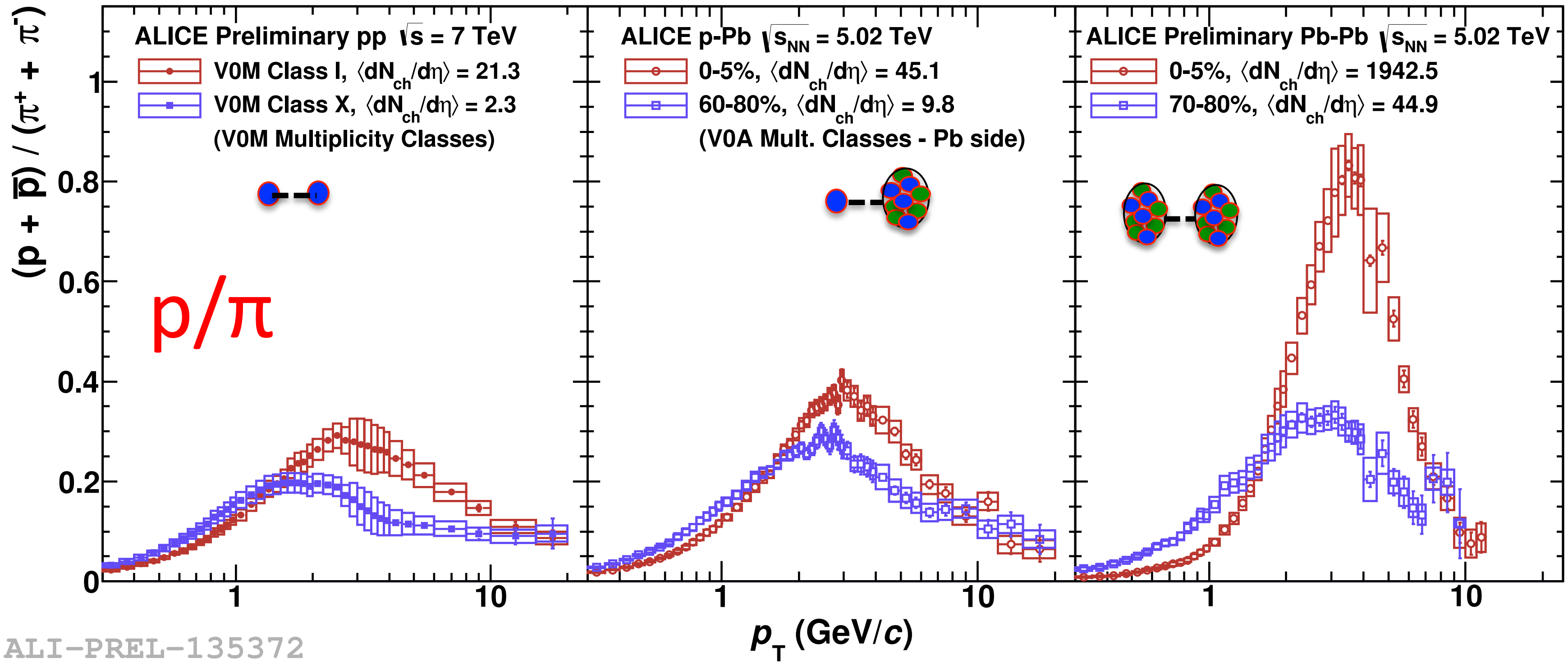
p/π:

- ✓ Indication of a slightly higher radial flow in central collisions compared to lower energy
- ✓ Enhanced at intermediate p_T in central w.r.t peripheral Pb-Pb

K/π:

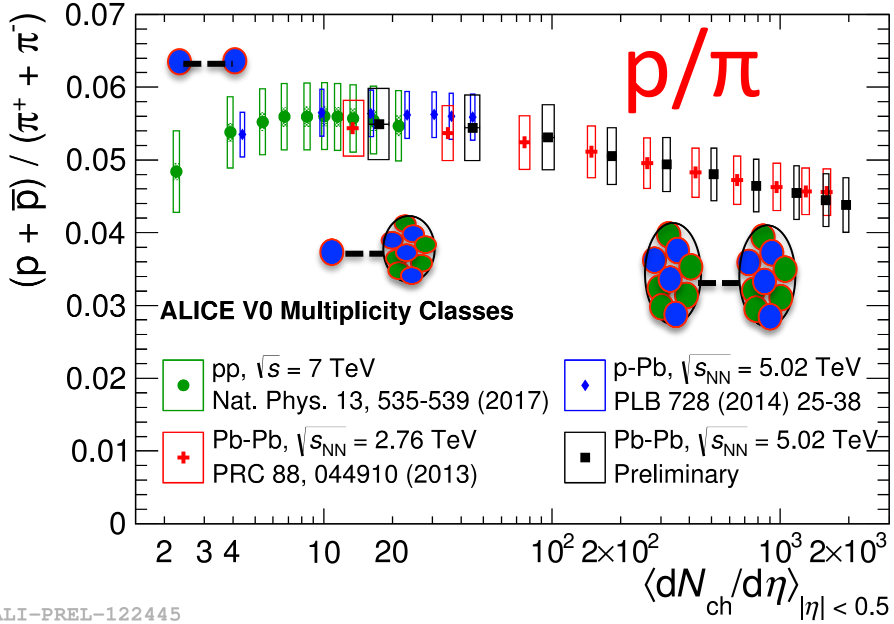
- ✓ No significant change observed between both energies

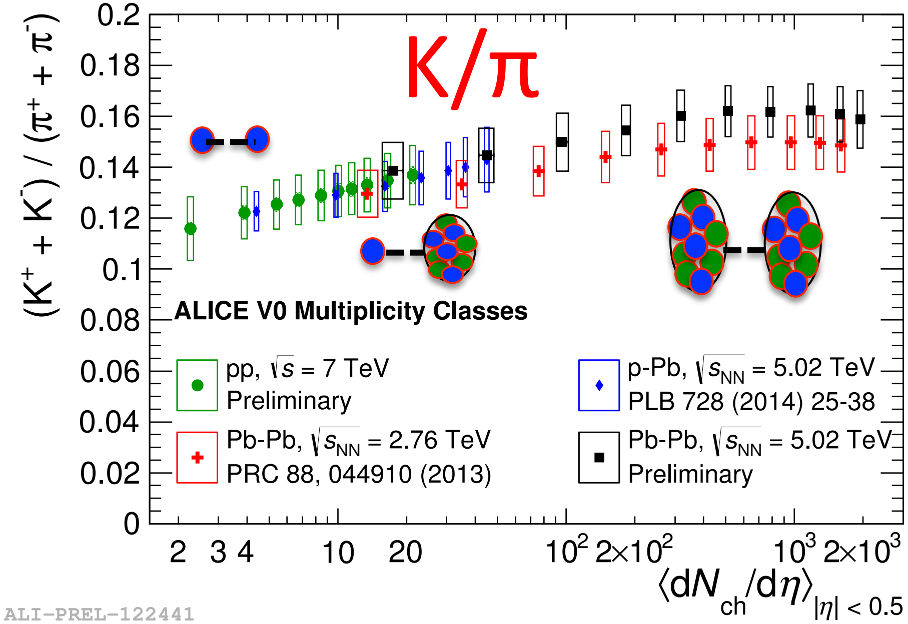
Proton to pion ratio: System dependence



- ✓ p/π: qualitatively similar flow-like features in pp, p-Pb and Pb-Pb systems
- ✓ For $2 < p_T < 10$GeV/c, ratios increase with event multiplicity
- ✓ At high p_T (>10 GeV/c) the ratios in pp, p-Pb and Pb-Pb are independent of event multiplicity

p_T integrated particle ratios





- ✓ A smooth transition is observed from pp to p–Pb and Pb-Pb
- ✓ No significant energy dependence is observed as a function of $\langle dN_{ch}/d\eta \rangle$
- ✓ The chemical composition is independent of the collision system at same $\langle dN_{ch}/d\eta \rangle$

Blast-Wave Model

Simplified hydrodynamics model

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

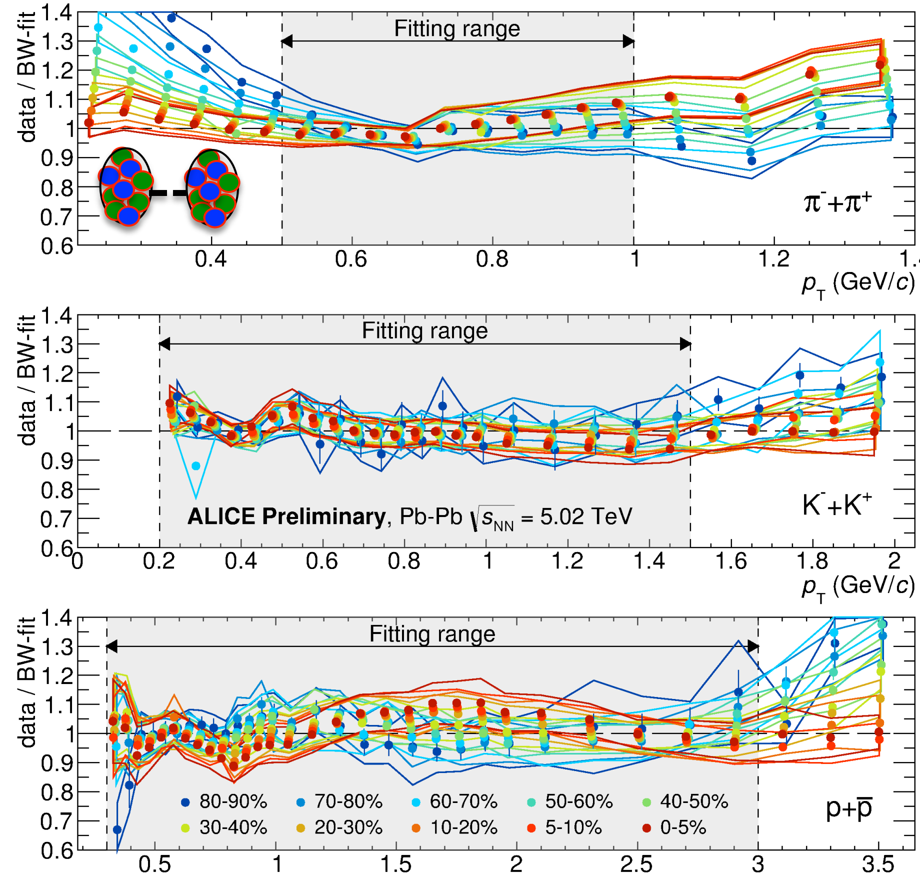
$$m_T = \sqrt{m^2 + p_T^2}, \quad \rho = \tanh^{-1}(\beta_T), \;\; \beta_T(r) = \beta_s\left(\frac{r}{R}\right)^n$$

β_T → radial expansion velocity
T_{kin} → kinetic freeze-out temperature
n → velocity profile

Caveats

results sensitive to fit range, particles included and uncertainties considered

Simultaneous fit to the π, K, p spectra with The Boltzmann–Gibbs Blast-Wave model
-- Good description of data



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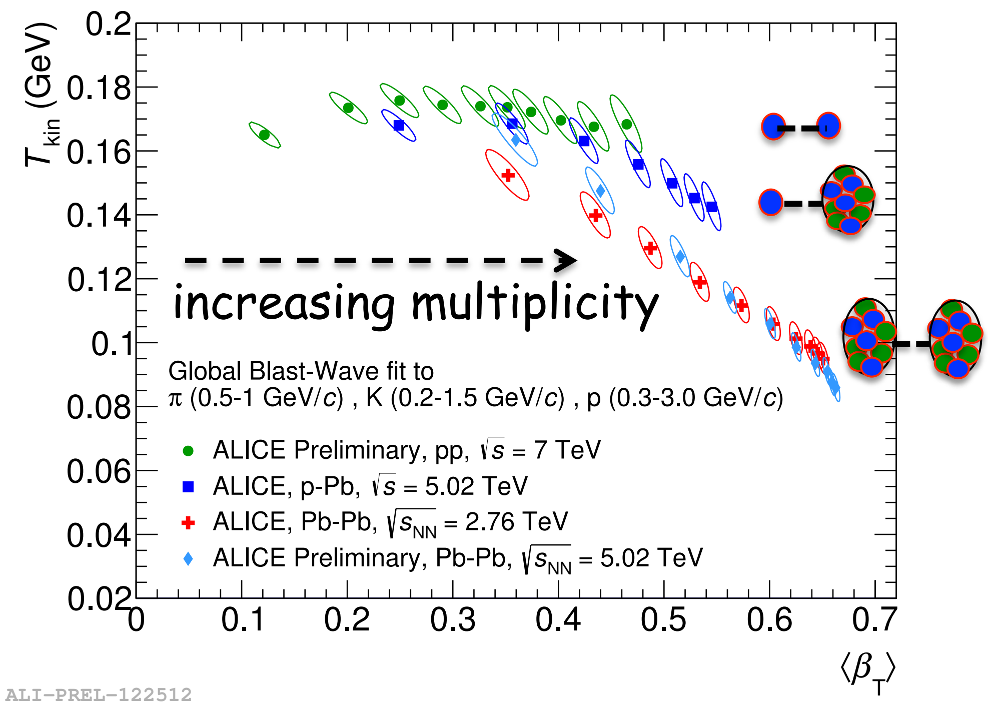
Blast-Wave Model

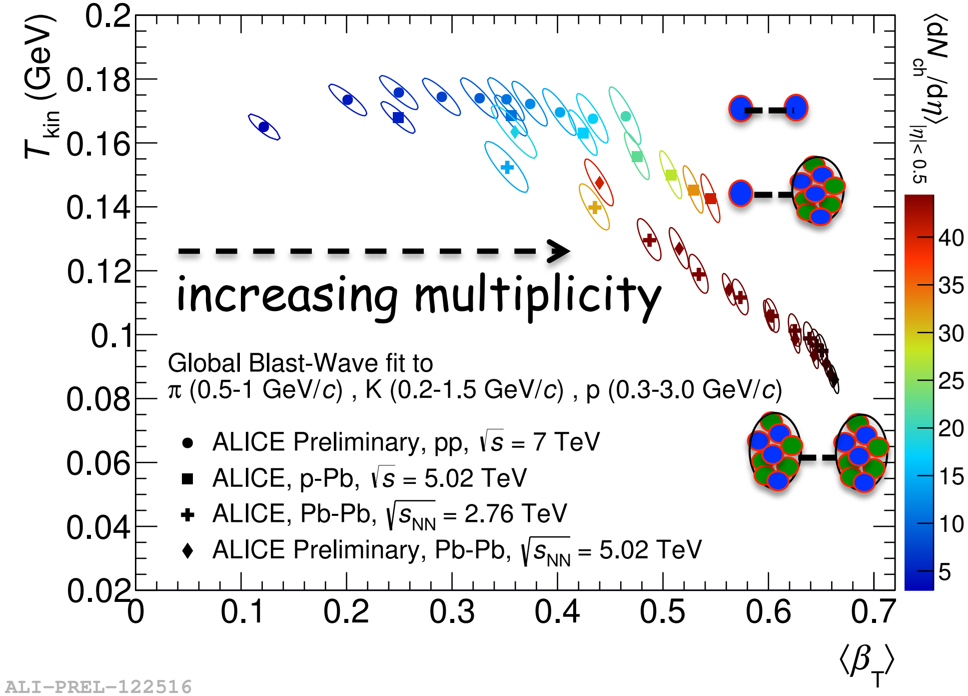


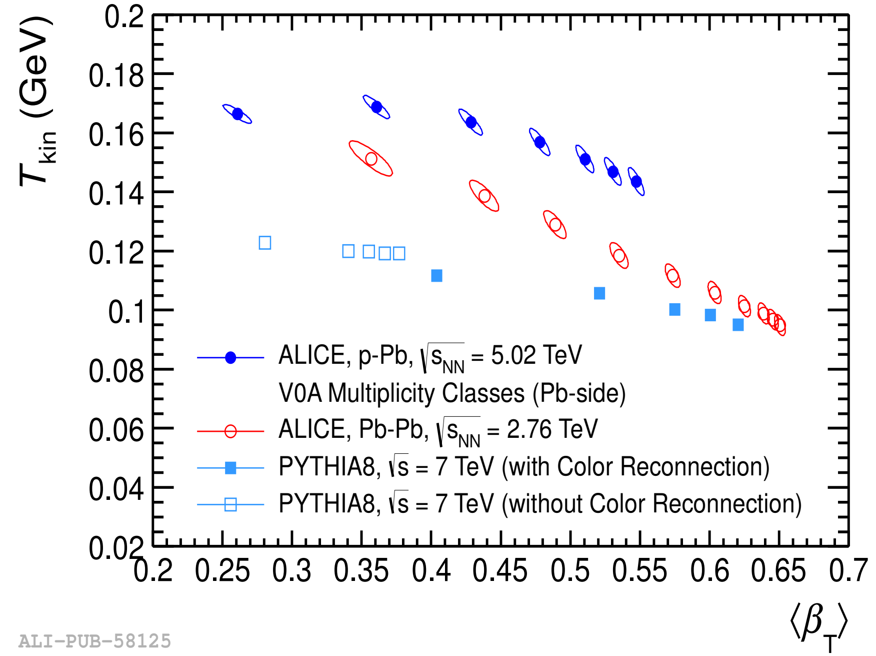
Combined fits of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ in pp, p–Pb, and Pb–Pb

- ✓ T_{kin} nearly constant for pp, small decrease in p–Pb
- ✓ Radial flow <β_T> increases with multiplicity/centrality
- ✓ High multiplicity p–Pb vs Pb–Pb: parameters show a similar trend

-- Consistent with the presence of radial flow in p–Pb collisions

Blast-Wave Model

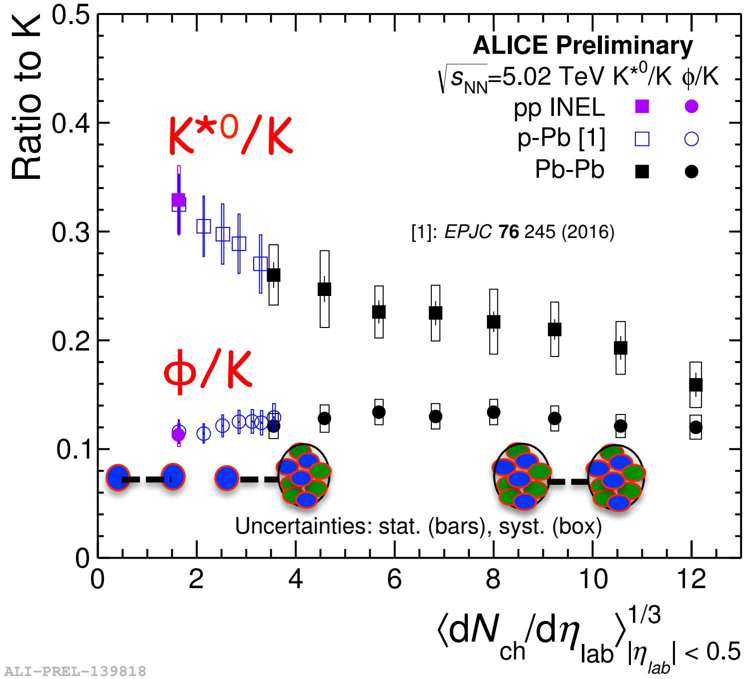




Combined fits of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$ in pp, p-Pb, and Pb-Pb

- ✓ At similar $\langle dN_{ch}/d\eta \rangle$, T_{kin} is similar for the two system, whereas $\langle \beta_T \rangle$ is significant higher for p-Pb collisions
- ✓ Color reconnection in pp models can mimic the increase in radial flow

p_T integrated particle ratio



K^{*0}/K:

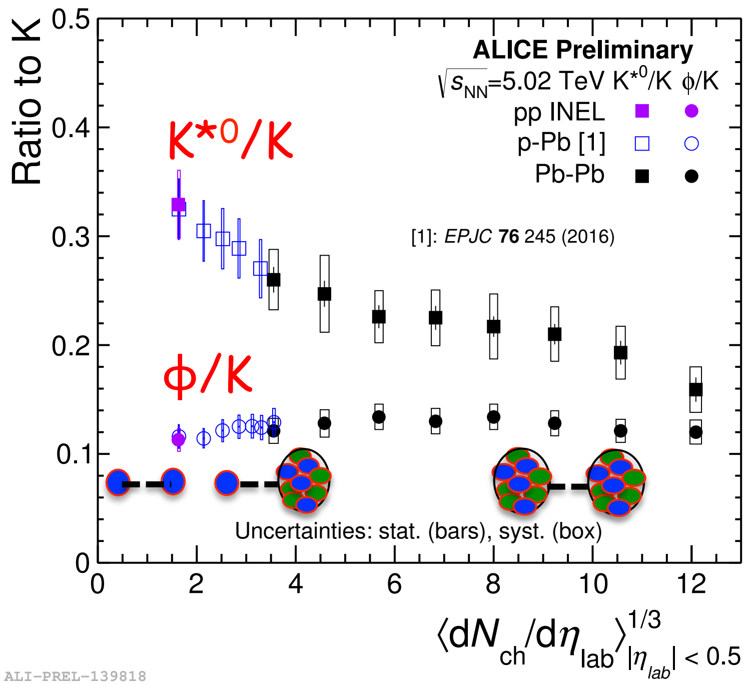
- ✓ Decreases with increase in centrality
- ✓ Significant suppression in central Pb-Pb collisions w.r.t. peripheral Pb-Pb, pp and p-Pb
  - -> consistent with K^{*0} rescattering as the dominant effect
  - -> lifetime of K^{*0} ~ lifetime of the hadronic phase

Thermal model predictions
$K^{*0}/K \sim 0.29$, $\phi/K \sim 0.12$

	Life time (fm/c)
K^{*0}	~ 4.16
ϕ	~ 46.3

Phys. Rev. C 91 024609 (2015)
Thermal Model: J. Stachel et al., SQM 2013

p_T integrated particle ratio



Thermal model predictions
K*0/K ~ 0.29, ϕ/K ~ 0.12

Phys. Rev. C 91 024609 (2015)
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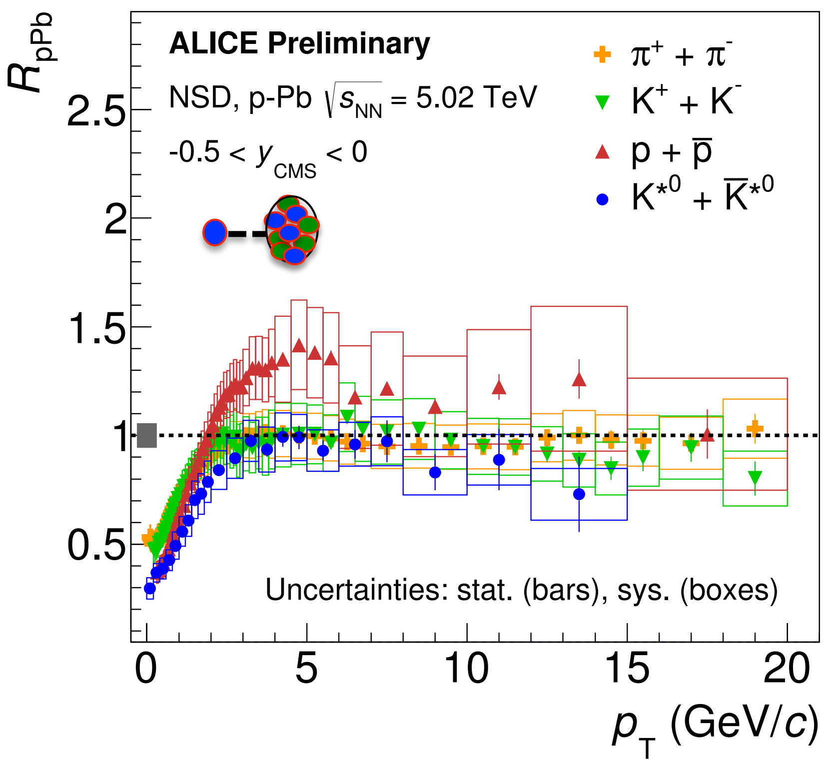
K*0/K:

- ✓ Decreases with increase in centrality
- ✓ Significant suppression in central Pb-Pb collisions w.r.t. peripheral Pb-Pb, pp and p-Pb
  -> consistent with K*0 rescattering as the dominant effect

ϕ/K:

- ✓ Independent of collision centrality / multiplicity event class in Pb-Pb, p-Pb and pp
- ✓ Ratios for central Pb-Pb collisions consistent with thermal model prediction
- ✓ No re-scattering effects is observed
  -> due to longer ϕ lifetime

Nuclear modification factor (R_{AA})



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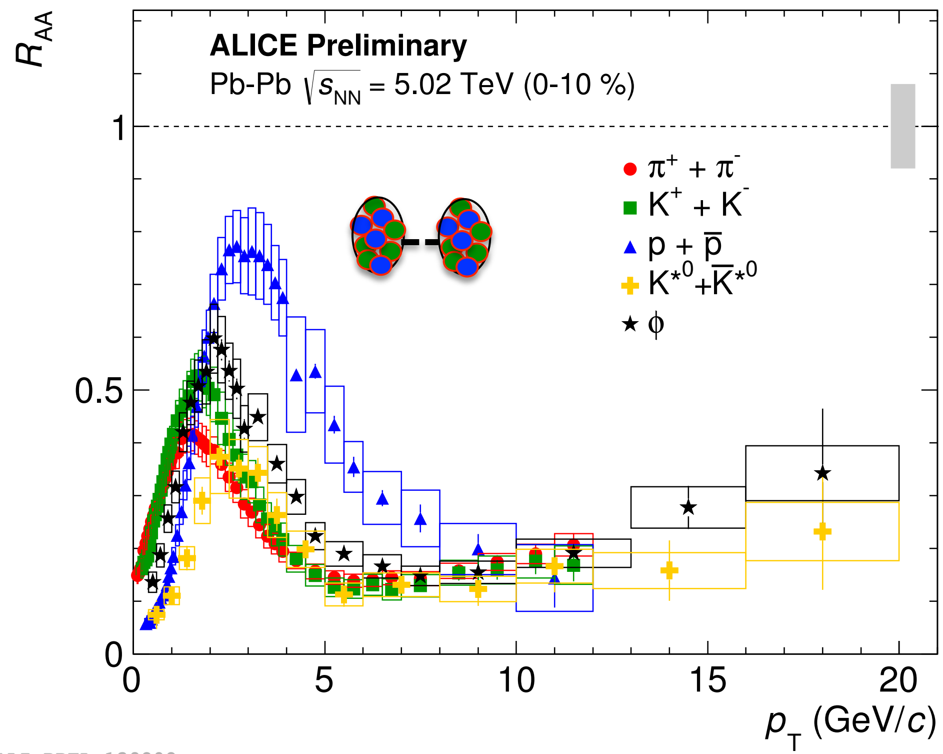

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$$R_{AA}(p_T) = \frac{Yield_{AA}(p_T)}{Yield_{pp}(p_T) \times \langle N_{coll} \rangle}$$

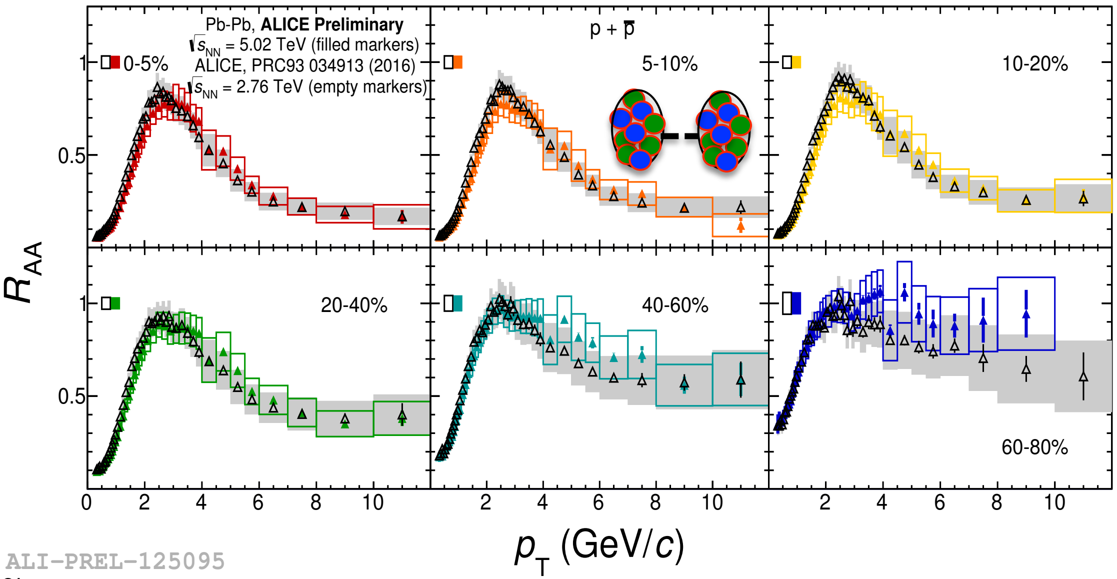
R_{pPb}

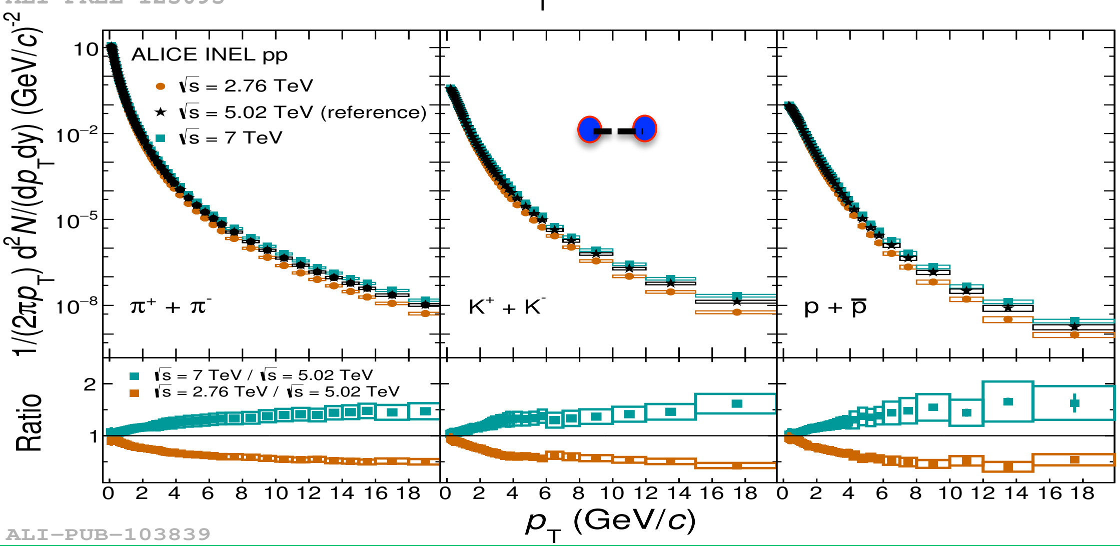
- ✓ High p_T: no modification
- ✓ Intermediate p_T: Cronin peak

R_{AA}

- ✓ Similarly suppression at p_T > 8 GeV/c
- ✓ Species dependence of R_{AA} at intermediate p_T
- ✓ The difference of R_{AA} for ϕ and p is governed by the difference of pp references

R_{AA} energy dependence





- ✓ No significant evolution with the collision energy is found
  - ->Similar observations for pions, kaons, K^{*0} and ϕ
- ✓ Significant hardening of the reference spectra with respect to $\sqrt{s}$ = 2.76 TeV
  - ->Does similar R_{AA} suggest larger energy loss in medium at $\sqrt{s_{NN}}$ = 5.02 TeV ?

Summary

ALICE

- Particle spectra and ratios

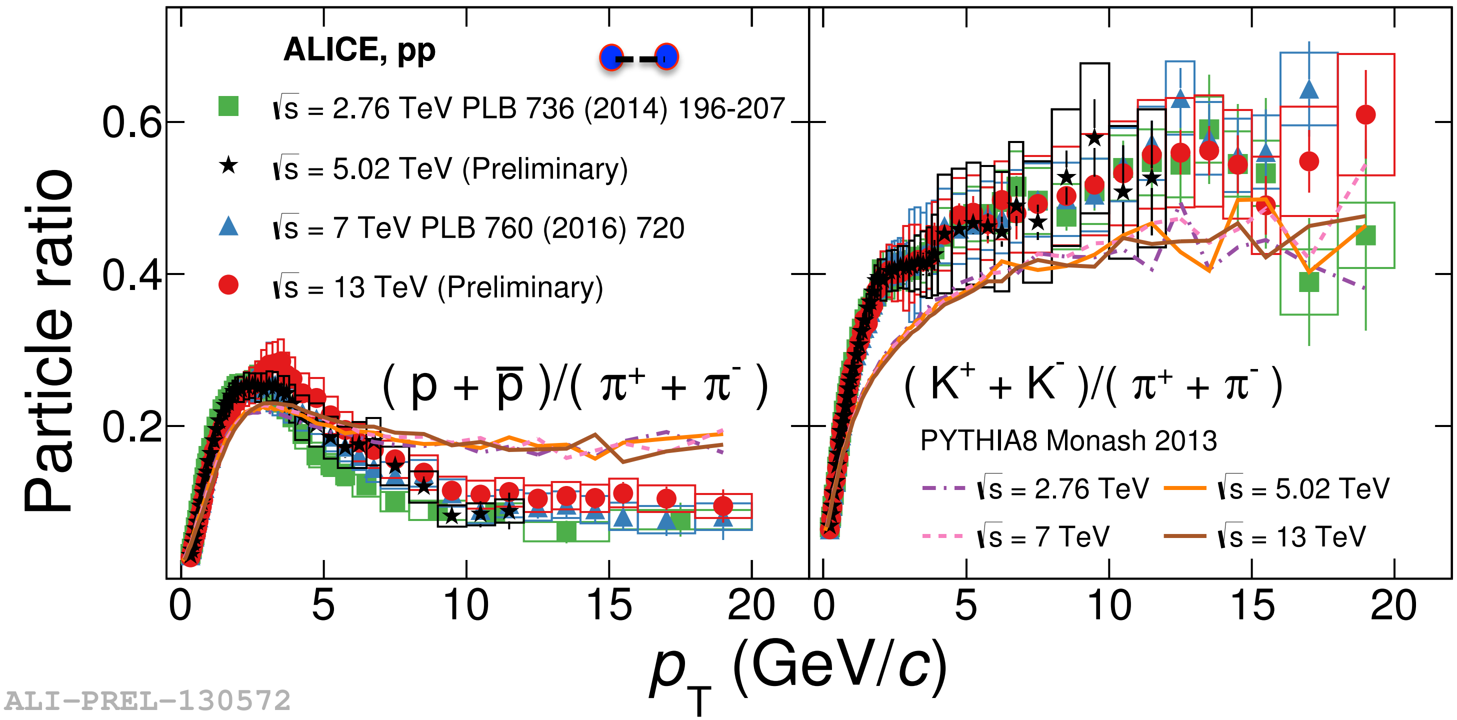
-- Spectra become harder (mass dependent effect)
-- Central Pb–Pb: <p_T (K^{*0})> ≈ <p_T (p)> ≈ <p_T (ϕ)> → consistent with hydrodynamics
-- Deviation from mass ordering observed in small systems and peripheral Pb–Pb
→ Baryon/meson difference or resonances do not follow?
-- Depletion (enhancement) at low (high) p_T in the p/π ratio
-- Chemical composition hint to be independent of collisions system at same <dN_{ch}/d η>
-- Central Pb–Pb: K^{*0} suppressed (→ re-scattering), ϕ not suppressed (longer lifetime)
-- Rescattering (and regeneration) in the hadronic phase can affect yield of short-live hadronic resonances such as K^{*0}.
-- <p_T> and <β_T> larger in small systems at similar multiplicities
→ Radial flow in small system? or QCD final state mechanism (Color reconnection) ?
-- Strong hydrodynamic collective expansion in Pb-Pb at 5.02 and 2.76 TeV

- Nuclear modification factor

Similar suppression for all the light hadron considered at high p_T in central Pb–Pb
Baryon/meson differences at intermediate p_T?
→ Does similar R_{AA}(in $\sqrt{s_{NN}}$ = 2.76 and 5.02) suggest larger energy loss in medium at $\sqrt{s_{NN}}$ = 5.02 TeV ?

Thank you

Differential particle ratios in pp



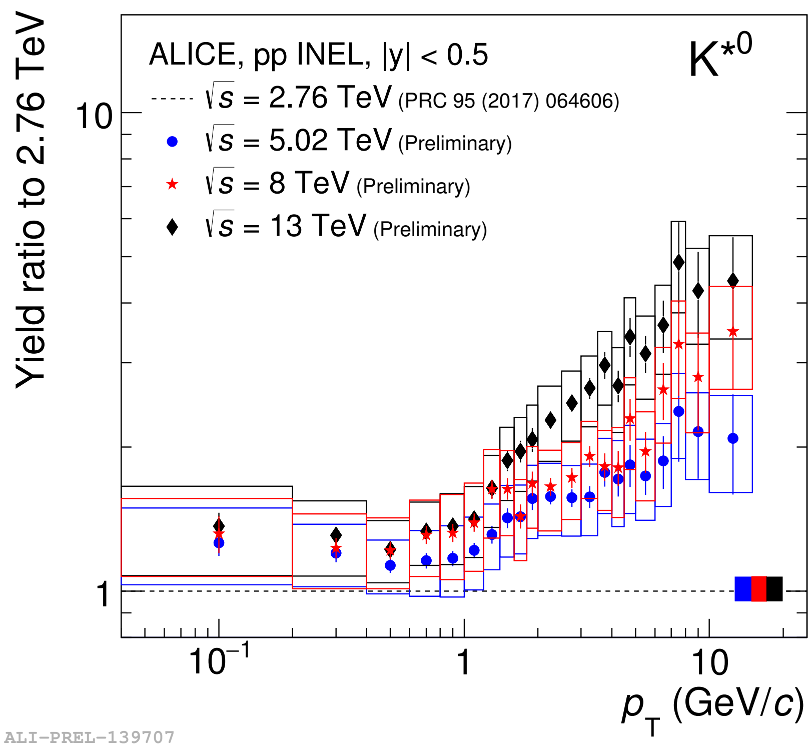
p/π:

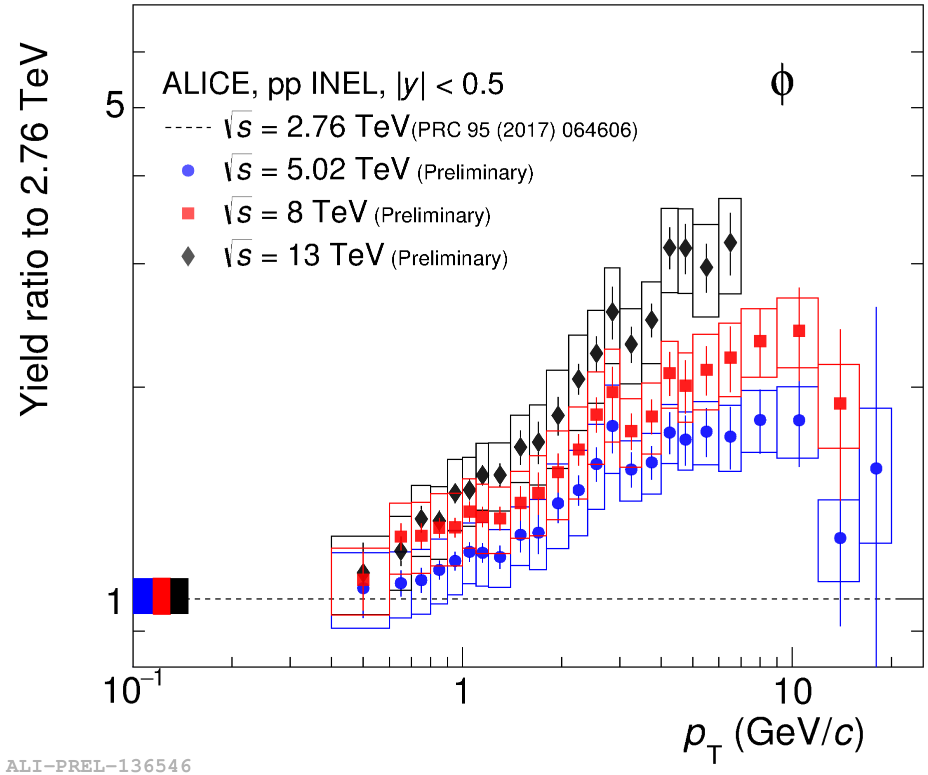
- ✓ The peak shifts to higher p_T with increase in energy
- ✓ PYTHIA describe at low p_T and over estimate at high p_T

K/π:

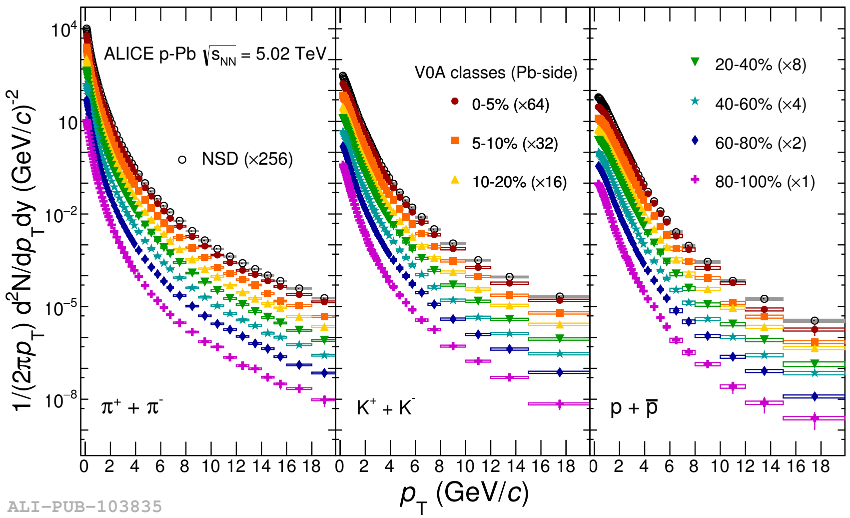
- ✓ No significant energy dependence
- ✓ PYTHIA describe at low p_T and under estimate at high p_T

K^{*0} and ϕ spectra comparison with energy





p_T spectra in p-Pb and $\langle p_T \rangle$ comparison



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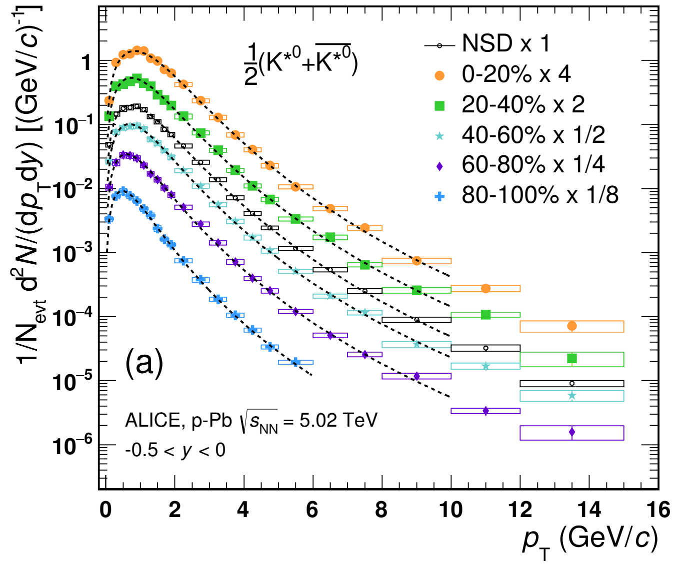

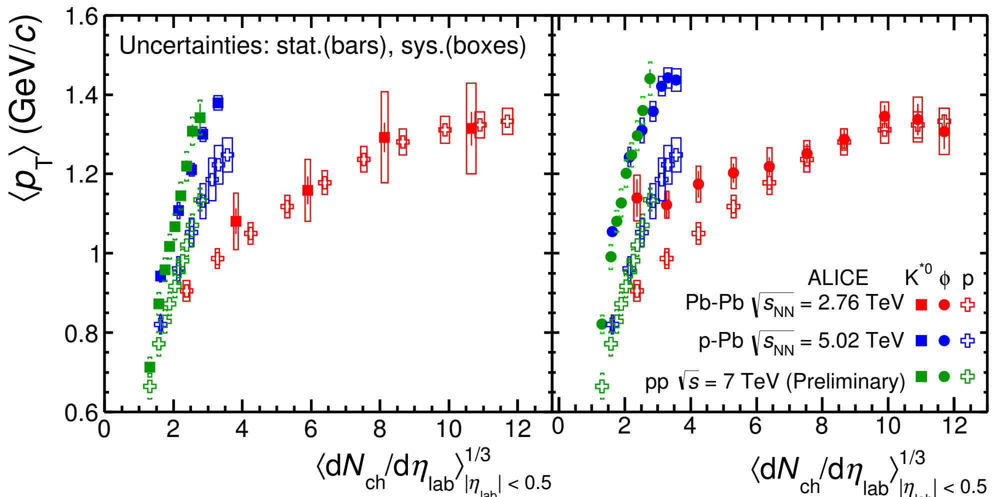

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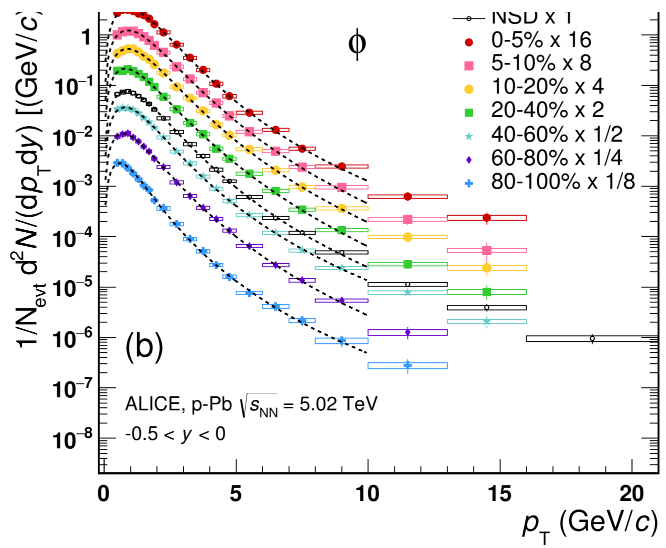
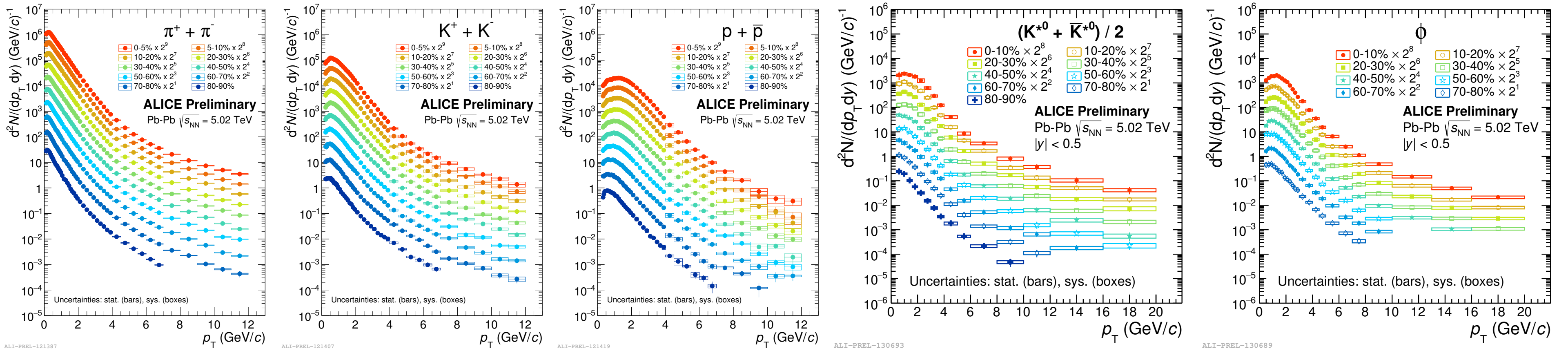


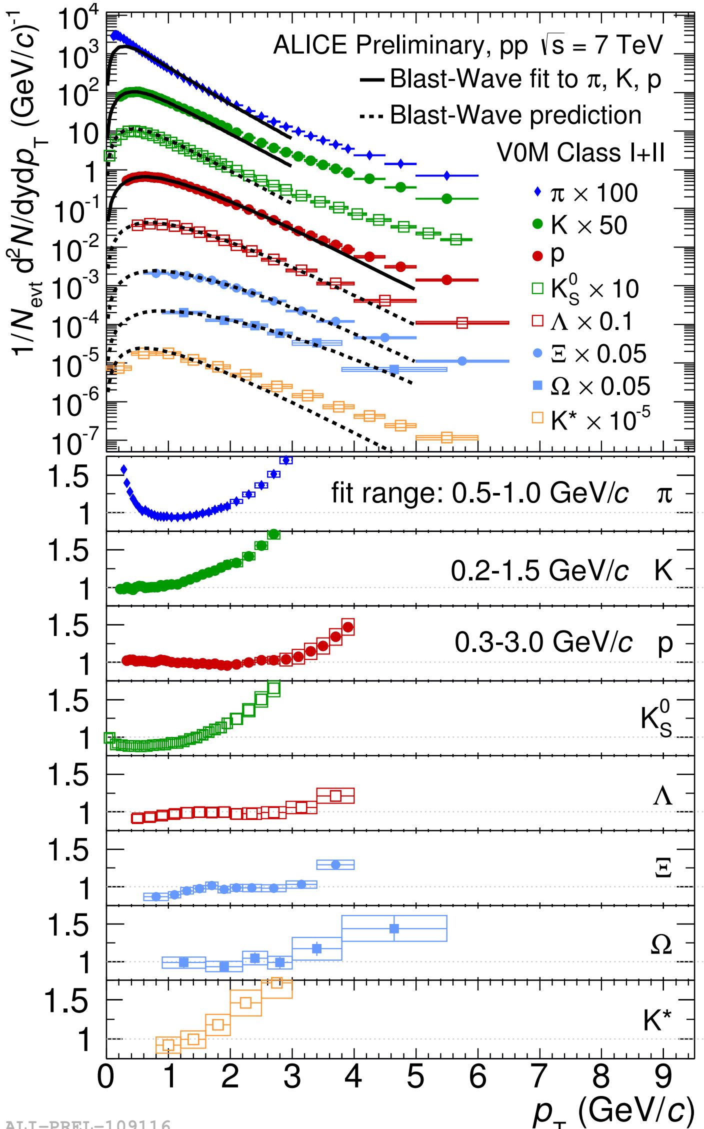
p_T spectra in Pb-Pb

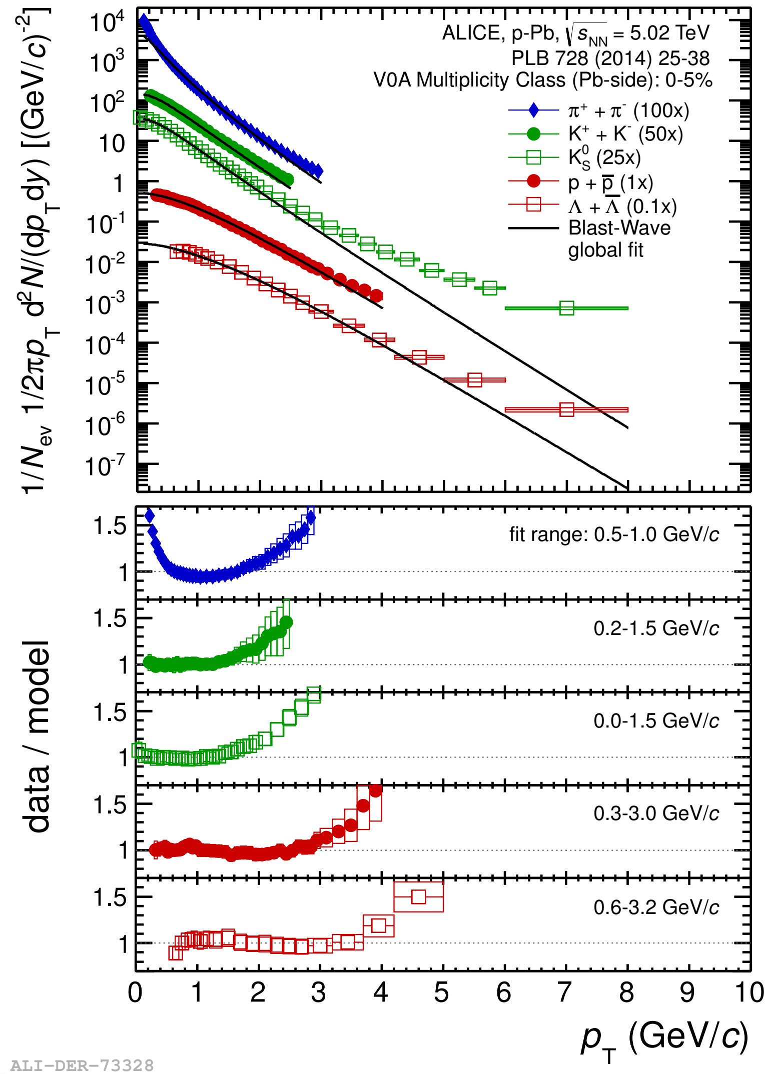


✓ Spectra become harder as the multiplicity increases

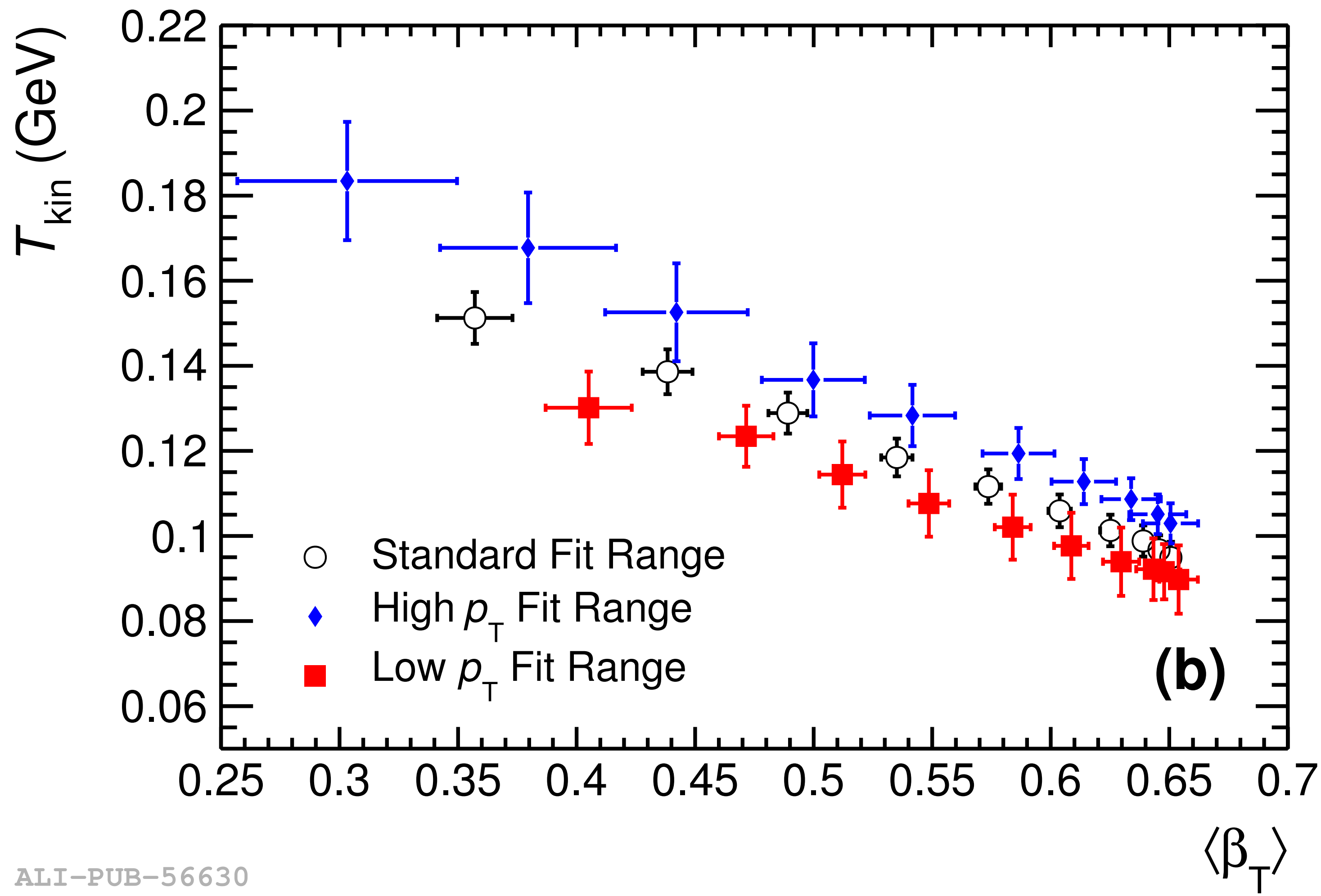
✓ Change is most pronounced for heavier particles
-> Effect of radial flow

Blast-Wave Model in pp and p-Pb





Blast-Wave parameter: diff. fitting range



Motivation

Resonances can decay inside the hot and dense matter due to their short lifetimes (few fm/c) and can be regenerated by final state interactions -> sensitive to the evolution dynamics

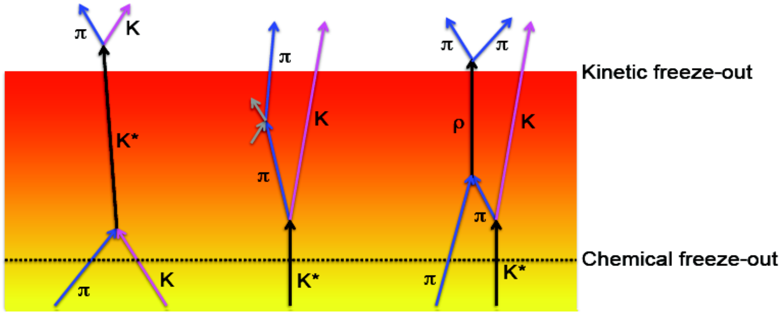
✓Modification of yields and particle ratios as hints of regeneration/rescattering effects

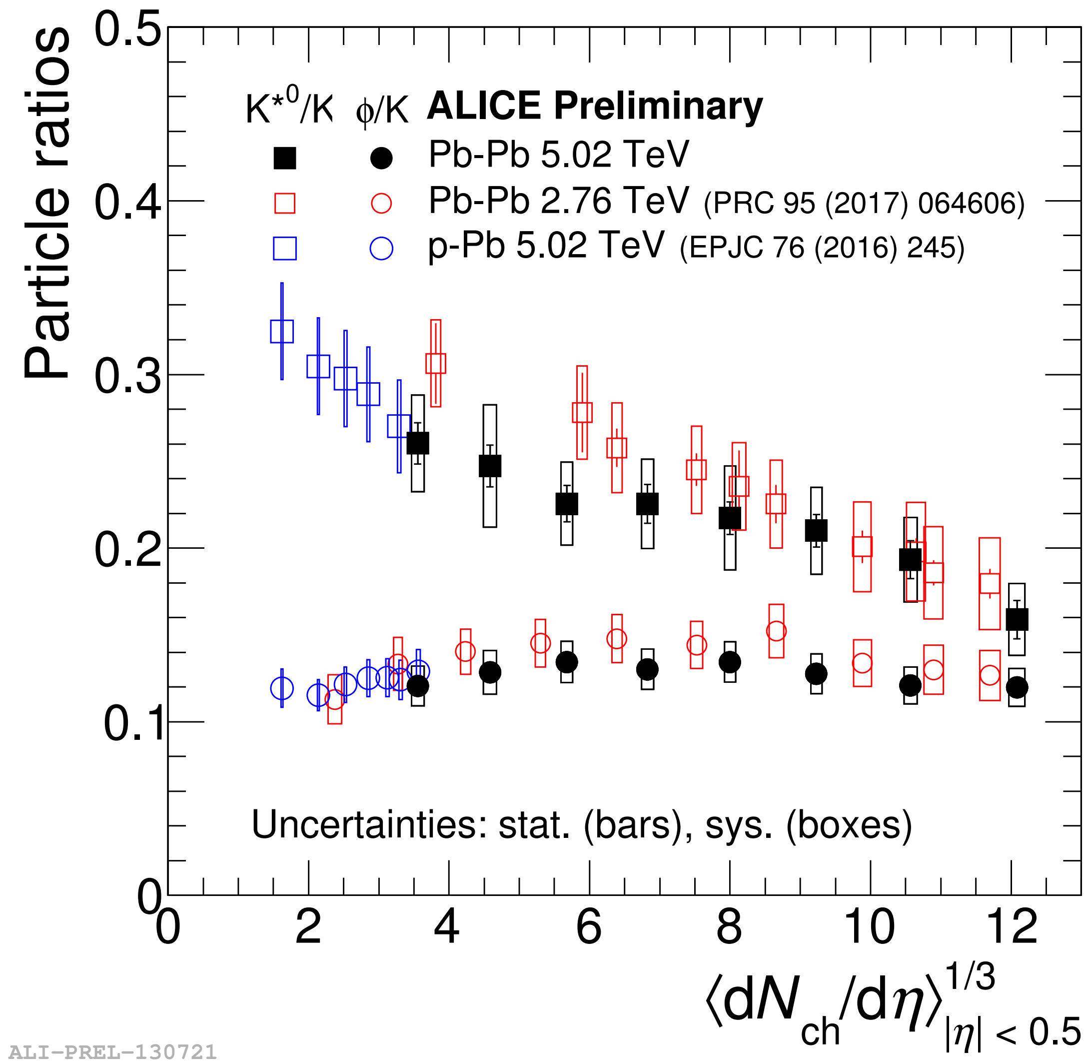
– **Regeneration:** Pseudo-elastic scattering of decay products e.g., $\pi K \rightarrow K^* \rightarrow \pi K$
– **Re-scattering:** resonance decay products undergo elastic scattering or pseudo-elastic scattering through a different resonance (e.g. ρ) resonance not reconstructed through invariant mass

✓Comparison of hadrons that differ by mass, baryon number and strangeness content can help to understand particle production mechanisms

✓Study of the nuclear modification factor provides information about in-medium energy loss

Measurement in pp is a reference:
✓ for the nuclear modification factor
✓ for tuning QCD-inspired event generators





Particle ratios
0.5
0.4
0.3
0.2
0.1
0
K*0/K ϕ/K ALICE Preliminary
Pb-Pb 5.02 TeV
Pb-Pb 2.76 TeV (PRC 95 (2017) 064606)
p-Pb 5.02 TeV (EPJC 76 (2016) 245)
Uncertainties: stat. (bars), sys. (boxes)
0 2 4 6 8 10 12
⟨dNch/dη⟩1/3 |η| < 0.5
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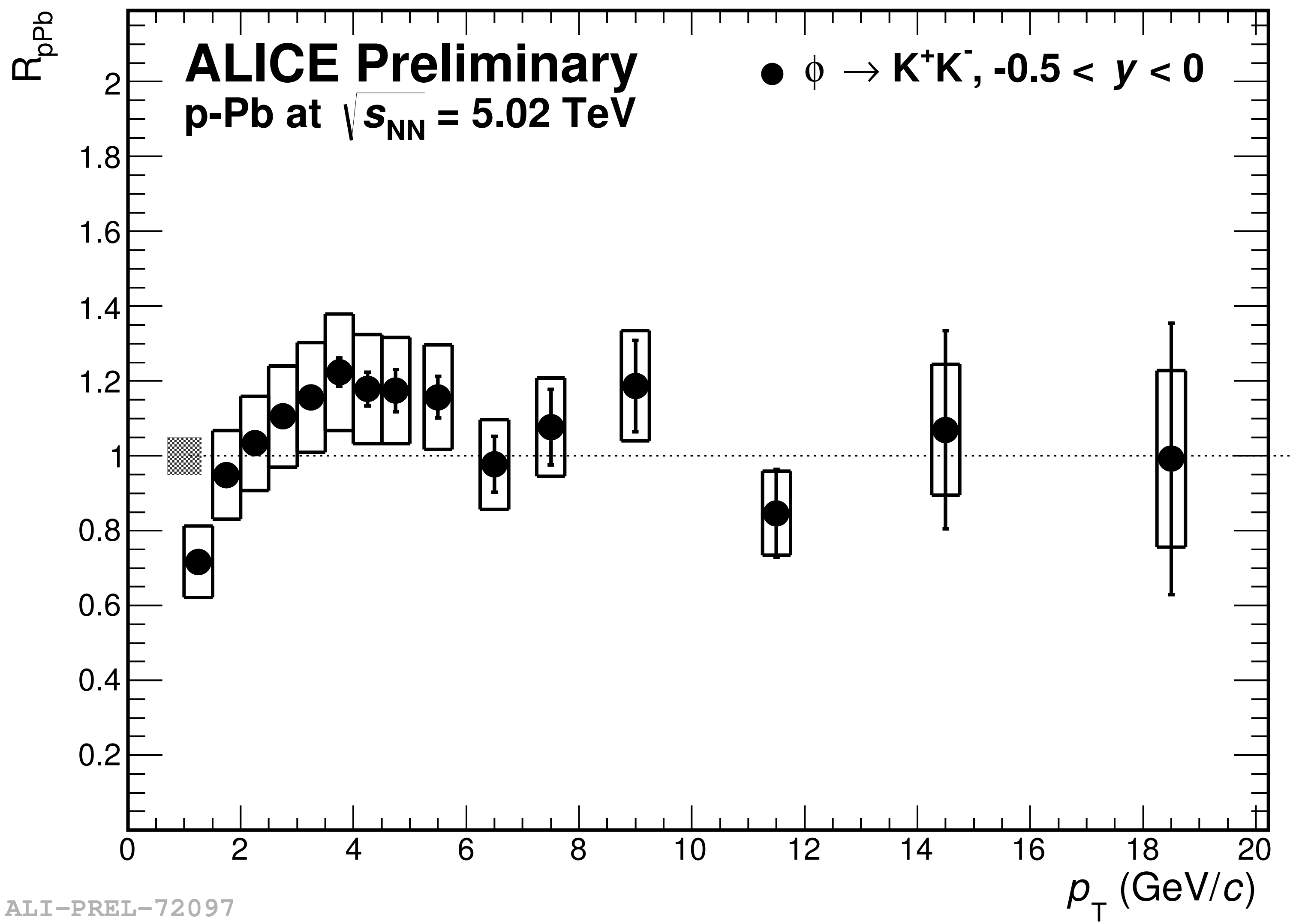
$R_{p\text{-}Pb}$ ϕ at 5.02 TeV



R_{AA} centrality dependent 5.02 TeV