Baryon production from small to large collision systems at ALICE

Omar Vázquez,

on behalf of the ALICE Collaboration

LUND UNIVERSITY

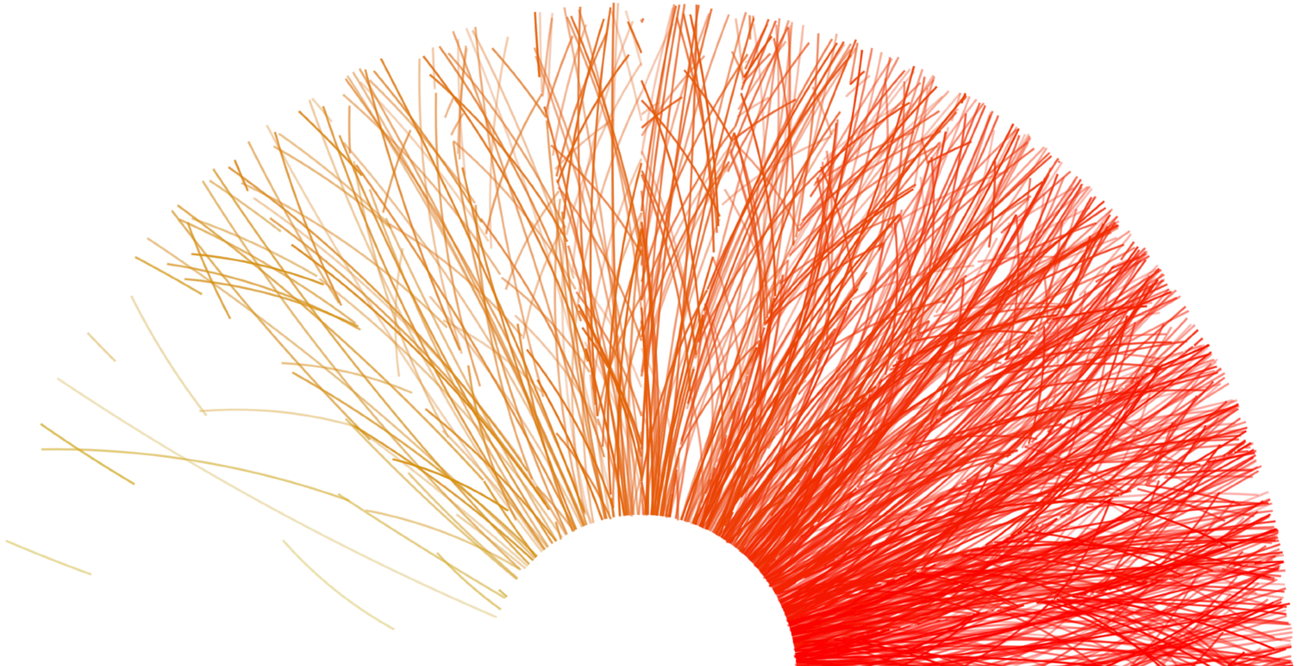
ALICE

Outline

- Introduction
- ALICE at the LHC
- Particle production across system size
- Baryon-to-meson ratios
- Particle chemistry and model predictions
- Summary

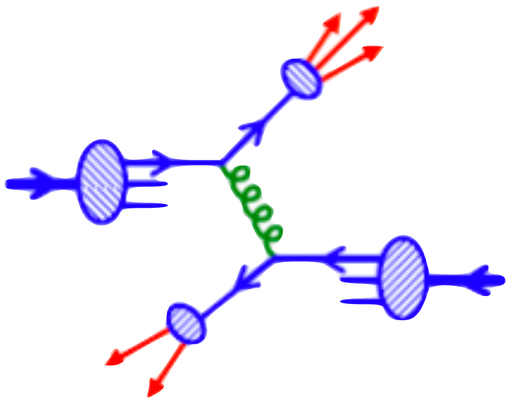
Introduction

High-multiplicity pp
& p-Pb collisions



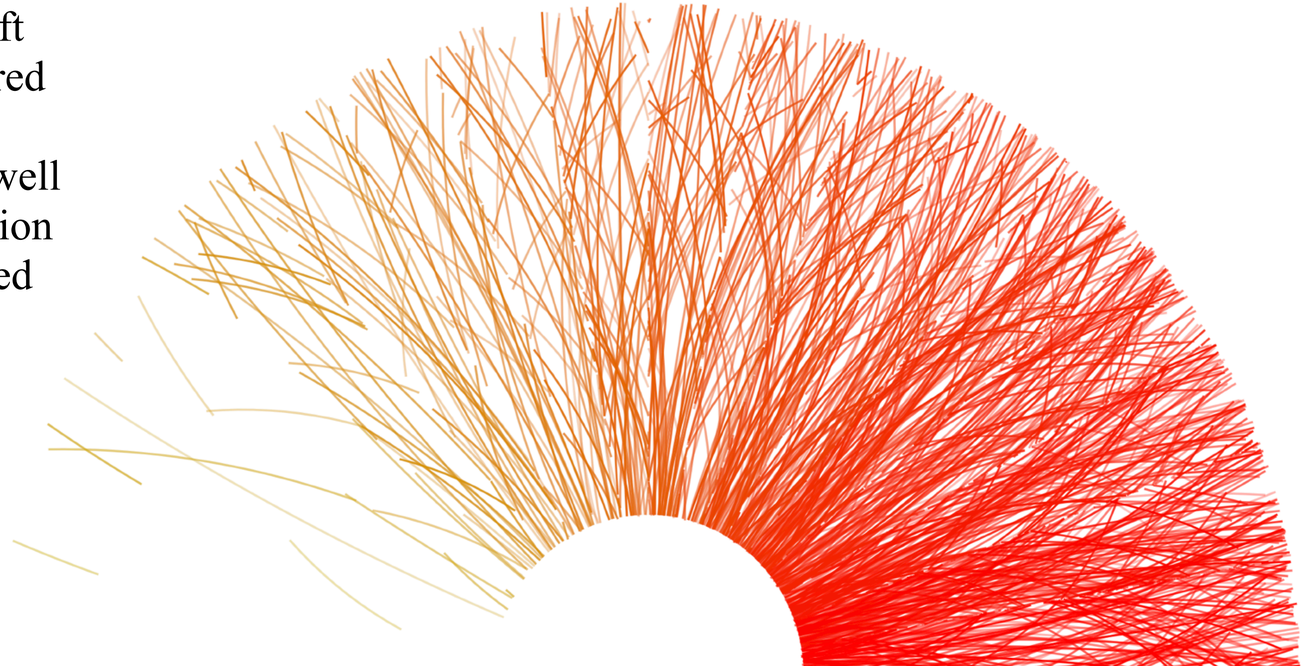
pp
collisions

Pb-Pb
collisions



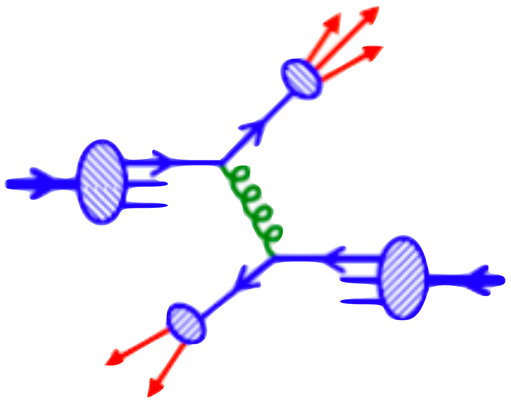
High-multiplicity pp
& p-Pb collisions

- Low-p_T particle production: Soft processes, MPI $\longrightarrow$ QCD inspired phenomenological models
- High-p_T particle production is well described by pQCD+fragmentation
- No jet quenching effects observed

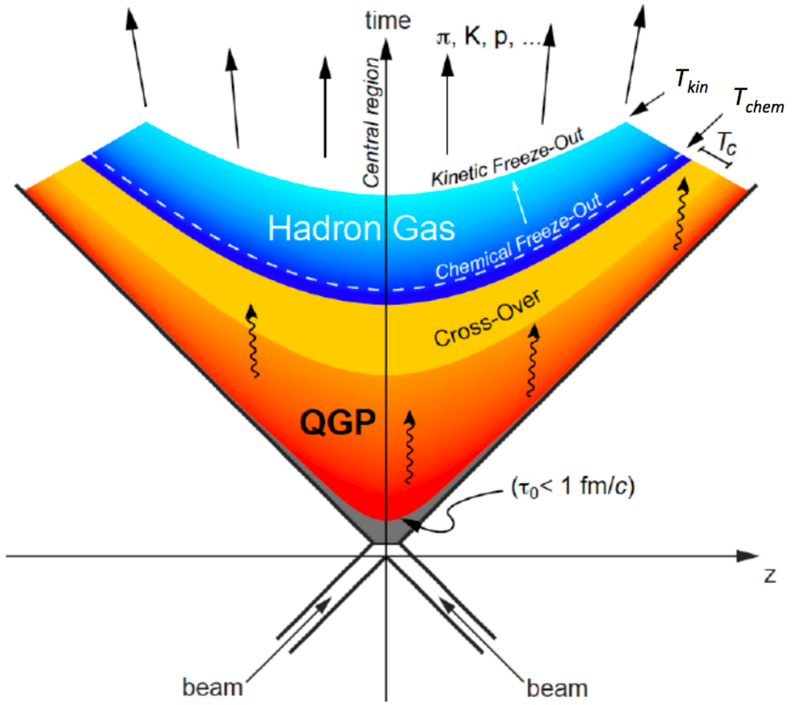


pp
collisions

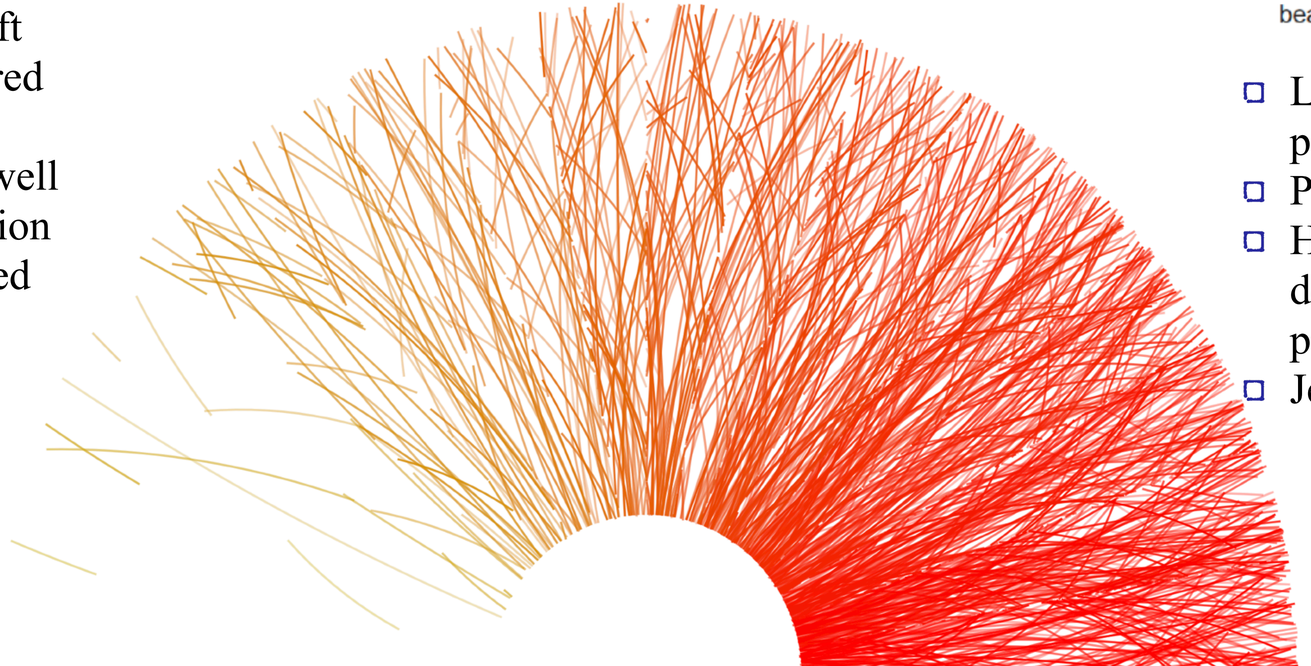
Pb-Pb
collisions



High-multiplicity pp & p-Pb collisions



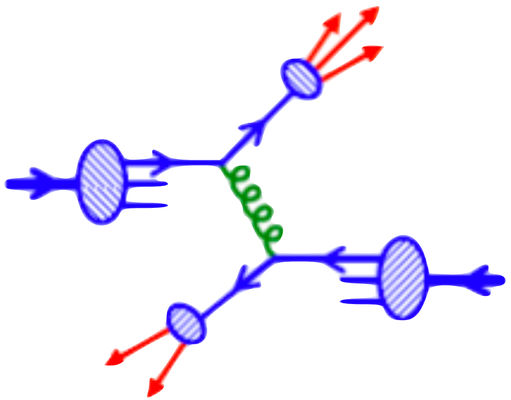
- Low-p_T particle production: Soft processes, MPI ⟶ QCD inspired phenomenological models
- High-p_T particle production is well described by pQCD+fragmentation
- No jet quenching effects observed



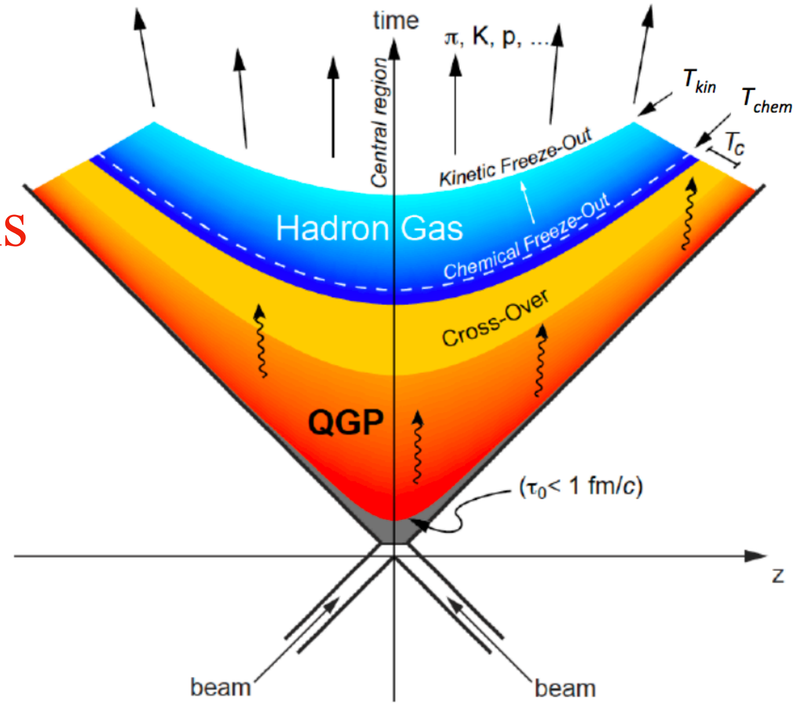
- Low-p_T particles from bulk production
- Phenomenological models
- High-p_T particle production is well described by pQCD+fragmentation
- Jet quenching

pp collisions

Pb-Pb collisions

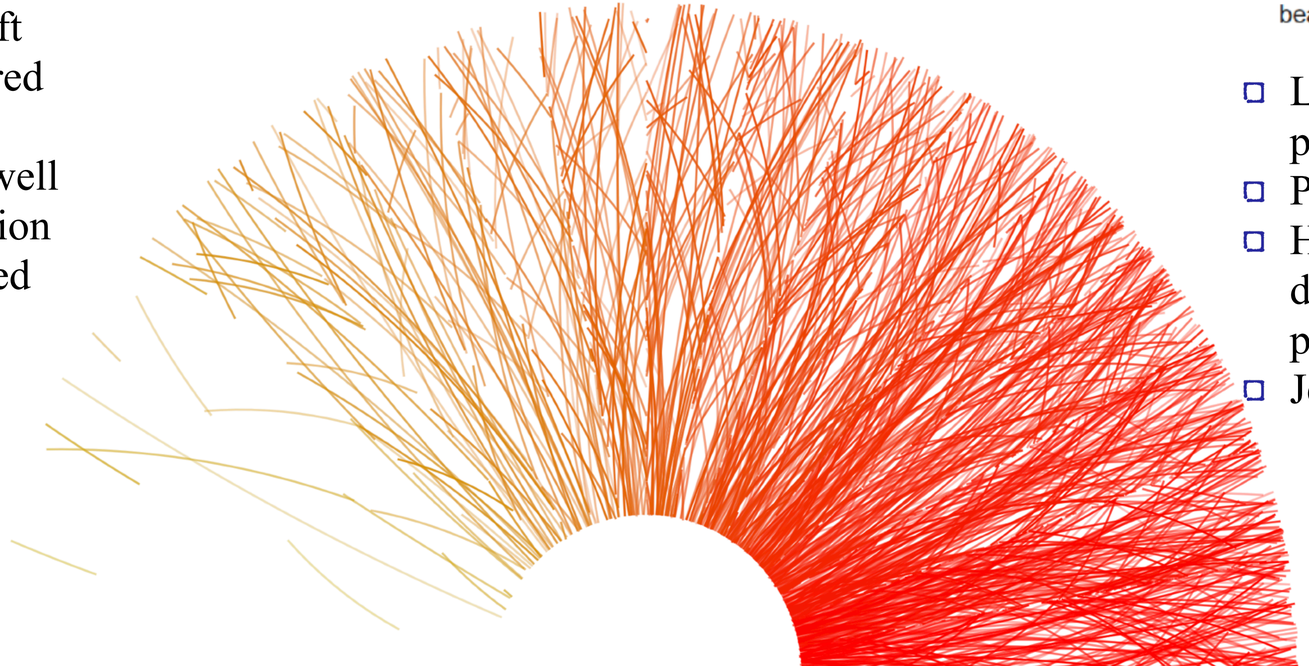


Is the chemistry in hadronic collisions driven by the system size/energy/ charged particle multiplicity…?



High-multiplicity pp & p-Pb collisions

- Low-p_T particle production: Soft processes, MPI ⟶ QCD inspired phenomenological models
- High-p_T particle production is well described by pQCD+fragmentation
- No jet quenching effects observed



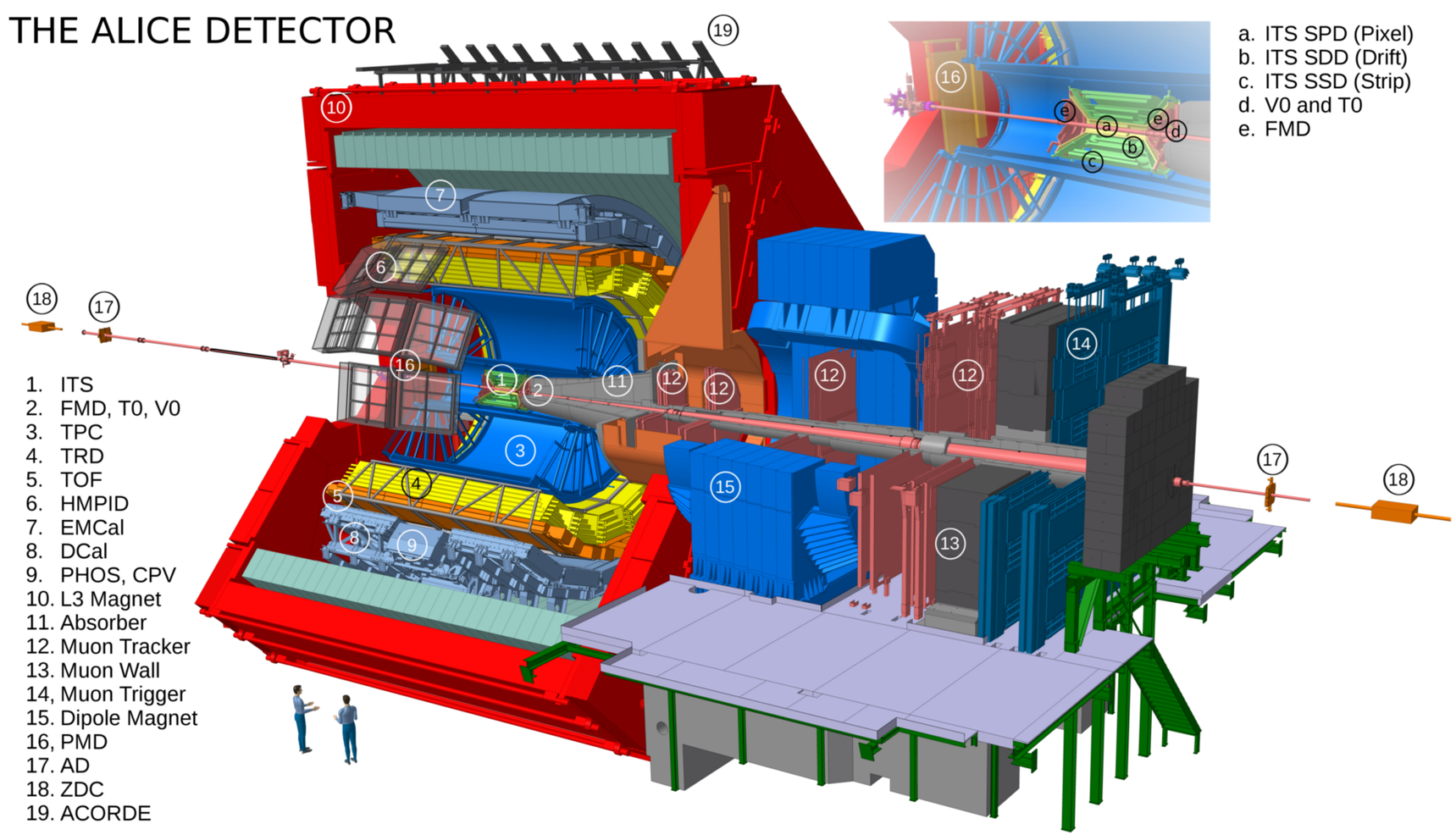
- Low-p_T particles from bulk production
- Phenomenological models
- High-p_T particle production is well described by pQCD+fragmentation
- Jet quenching

pp collisions

Pb-Pb collisions

ALICE at the LHC

ALICE at the LHC

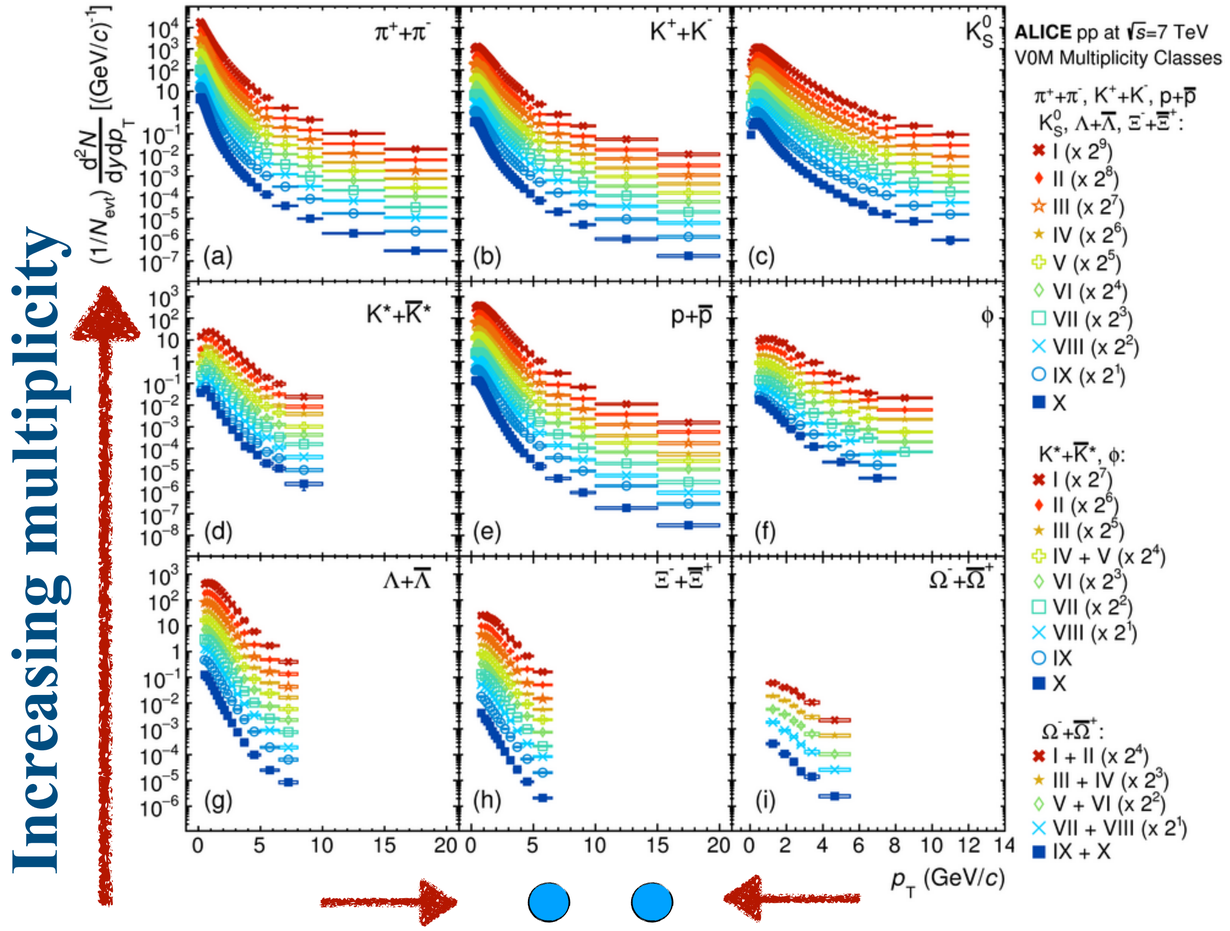


- The dedicated detector at the LHC for tracking and low-momentum PID in high-multiplicity environments
  - V0
    - V0A $(2.8 < \eta < 5.1)$
    - V0C $(-3.7 < \eta < -1.7)$
    - Triggering, background suppression and event classification
  - ITS
    - $|\eta| < 0.9$
    - Tracking, triggering and PID
  - TPC
    - $|\eta| < 0.9$
    - Tracking and PID
  - TOF
    - $|\eta| < 0.9$
    - PID

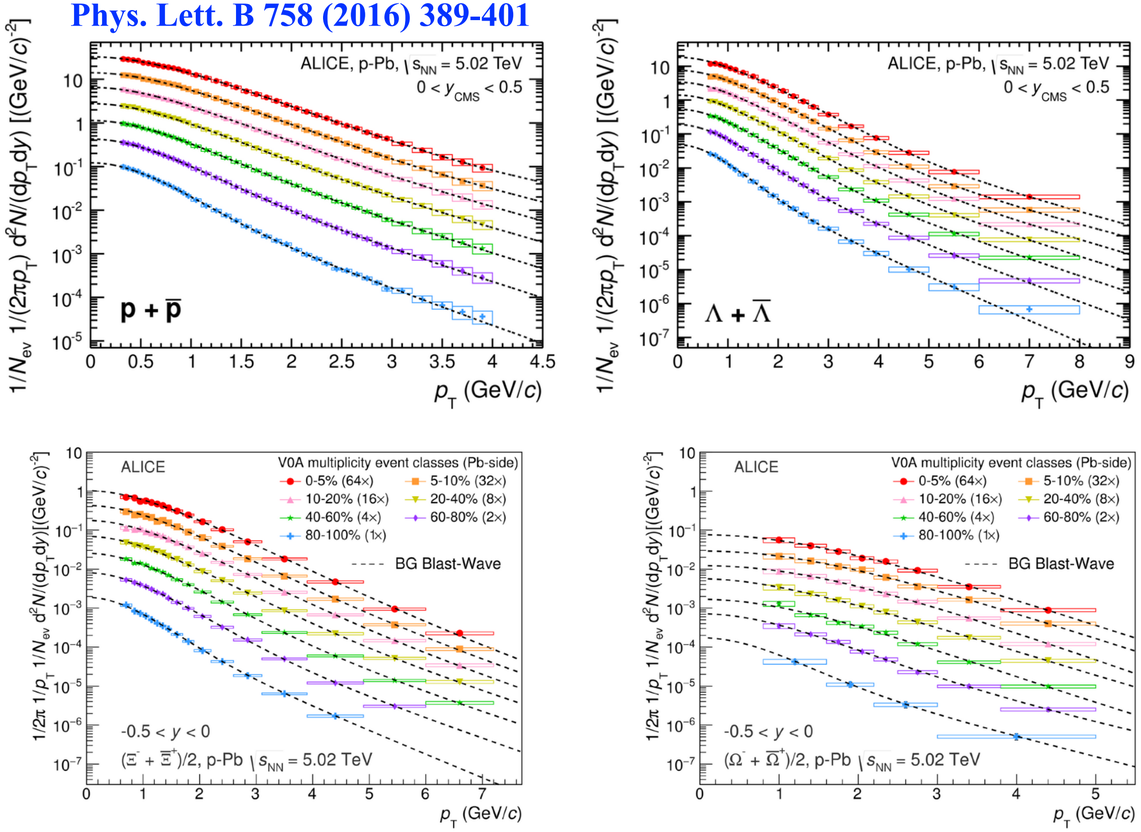
Particle production across system size

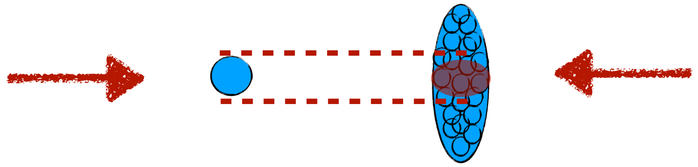
p_T-spectra in small collision systems

Phys. Rev. C 99, 024906



Phys. Lett. B 728 (2014) 25-38
Phys. Lett. B 758 (2016) 389-401

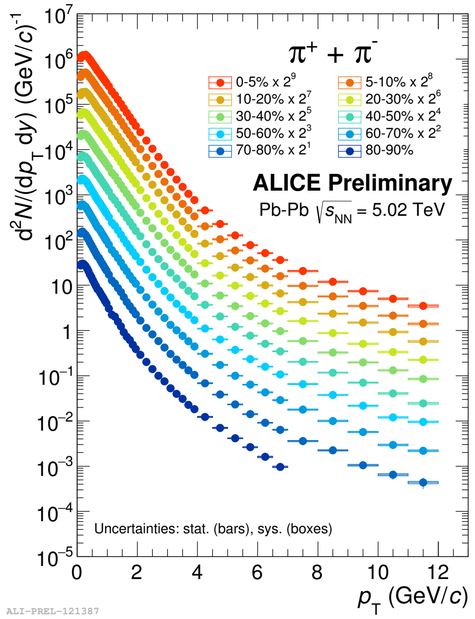


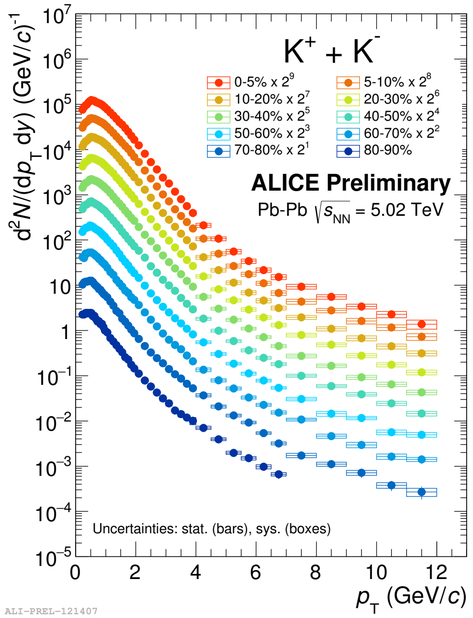


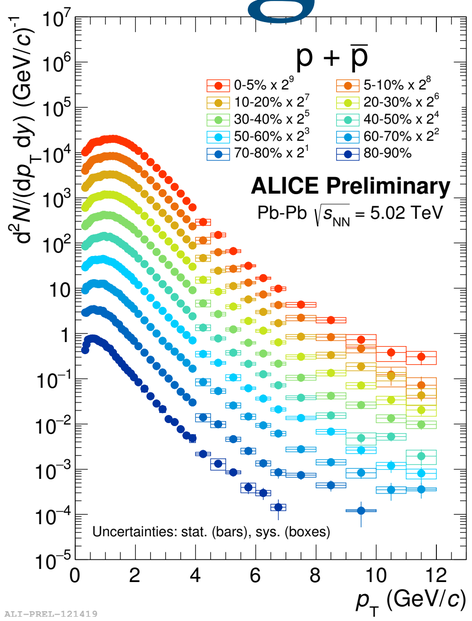
Available collision systems & energies
pp: 0.9, 2.76, 5.02, 7, 8 and 13 TeV
p-Pb: 5.02 and 8 TeV

… and in large systems

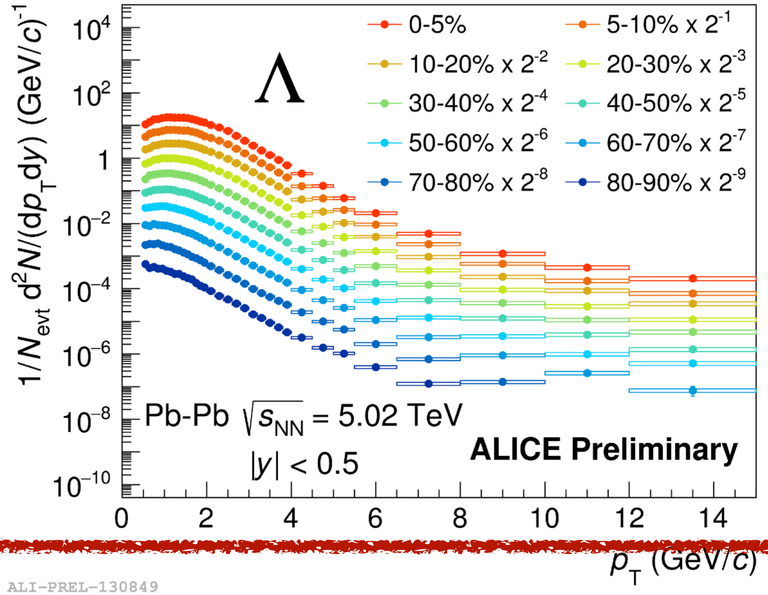
Increasing multiplicity

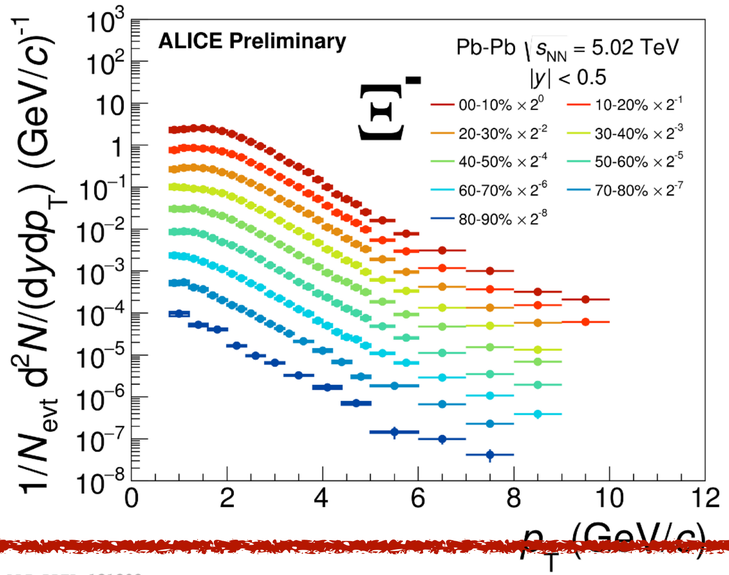


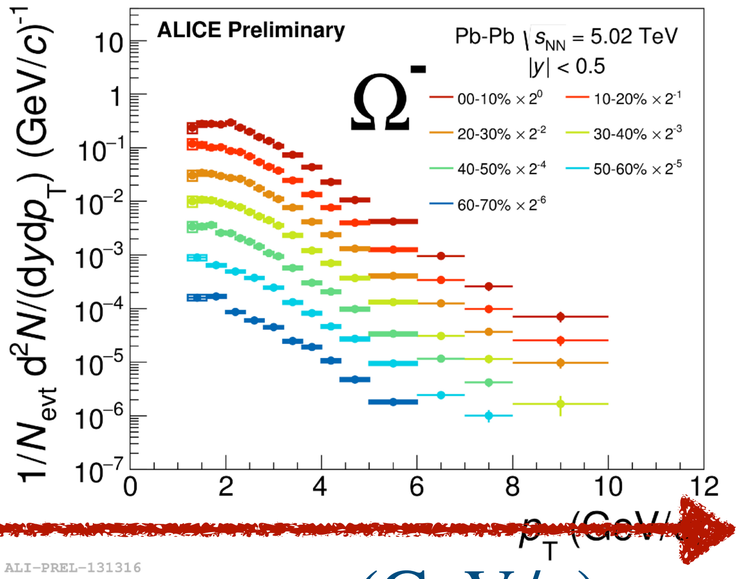




- Mass dependent flattening of the spectra around $p_T \approx 1$ GeV/c with increasing multiplicity
- Within the hydrodynamical picture this is understood as a progressively stronger radial flow with increasing centrality
- Particle and antiparticle are compatible

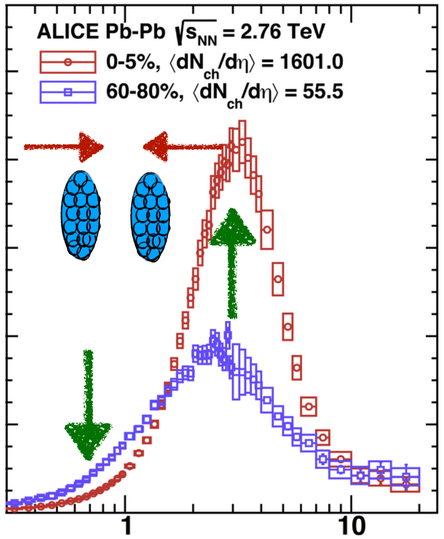






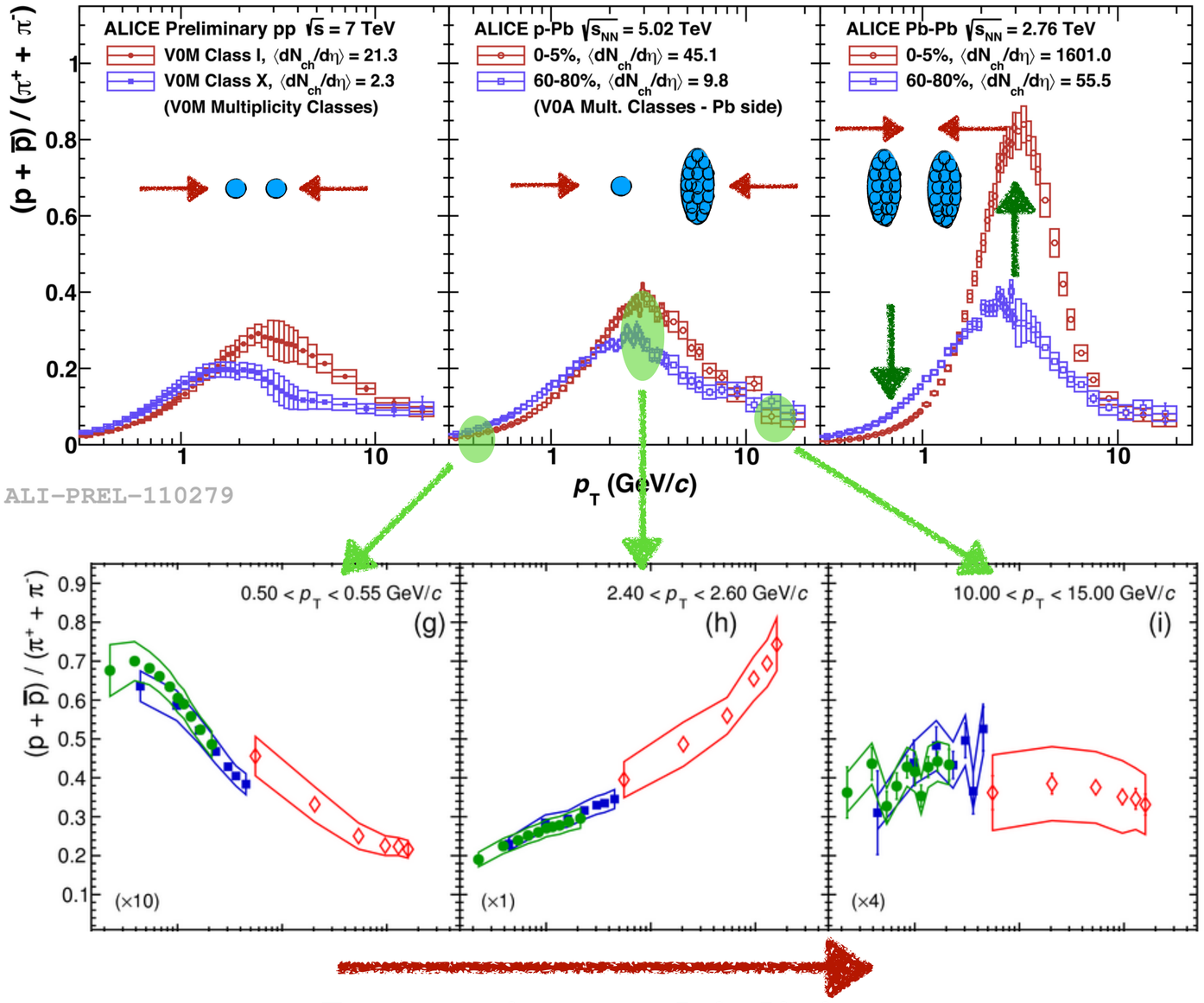
p_T (GeV/c)

Baryon-to-meson ratio (light-flavour)



- In heavy-ion collisions the creation of a QGP takes place, which evolves with progressively stronger radial flow with increasing centrality
- This acts differentially with mass as a function of p_T

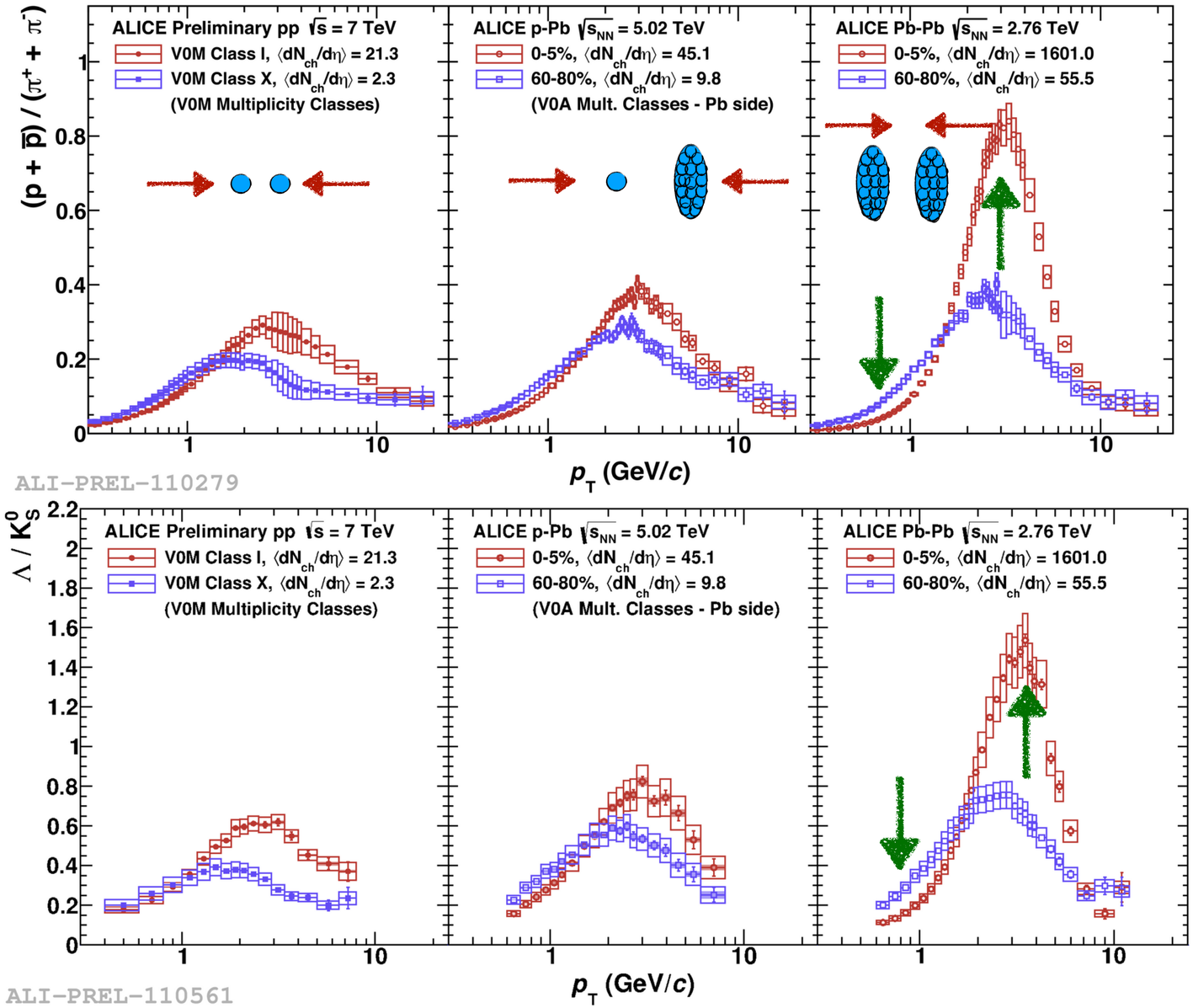
Baryon-to-meson ratio (light-flavour)



- In heavy-ion collisions the creation of a QGP takes place, which evolves with progressively stronger radial flow with increasing centrality
- This acts differentially with mass as a function of p_T
- Unexpected flow-like effects in small systems with increasing multiplicity

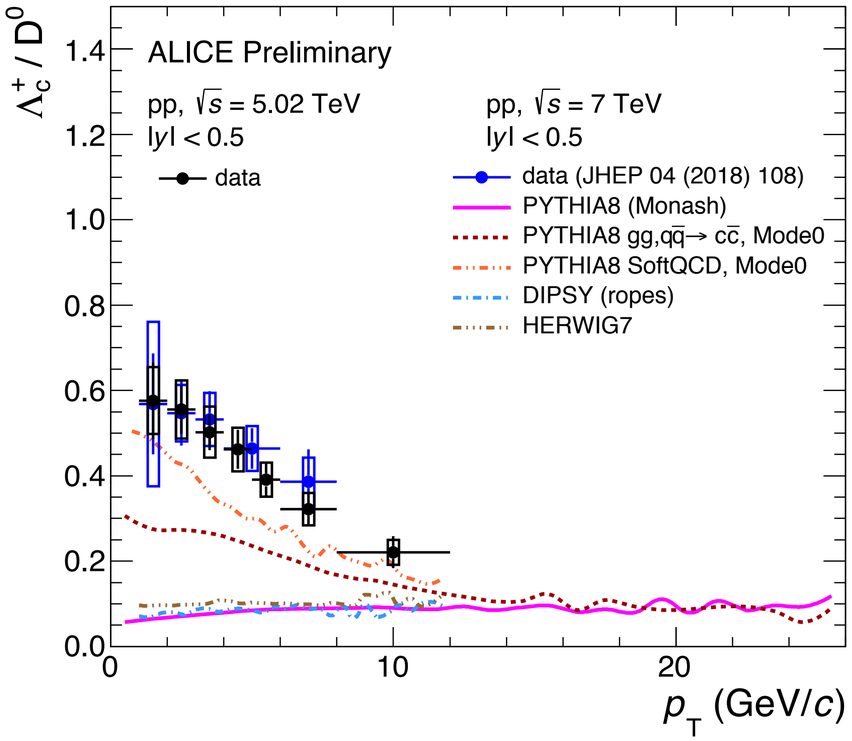
Increasing multiplicity

Baryon-to-meson ratio (light-flavour)



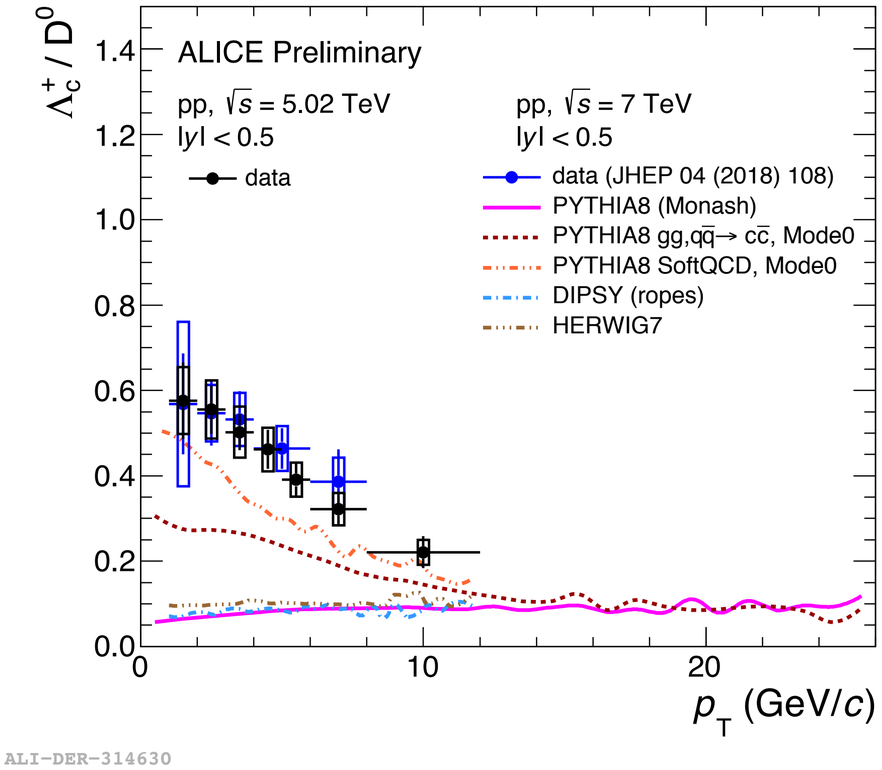
- In heavy-ion collisions the creation of a QGP takes place, which evolves with progressively stronger radial flow with increasing centrality
- This acts differentially with mass as a function of p_T
- Unexpected flow-like effects in small systems with increasing multiplicity
- Similar behaviour is observed in the Λ/K_s^0 ratio

Baryon-to-meson ratio (heavy-flavour)



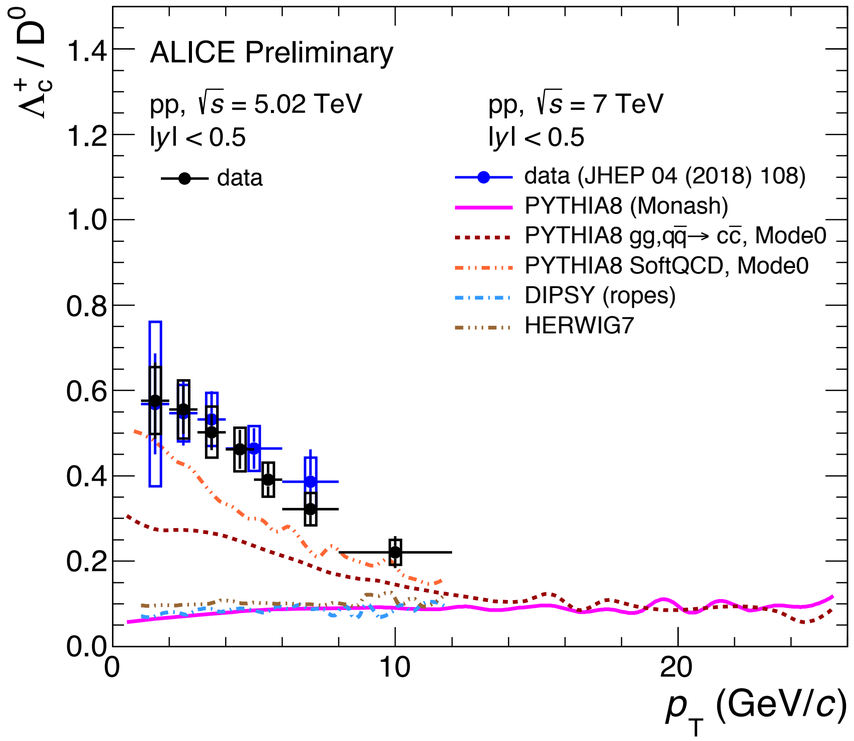
ALI-DER-314630

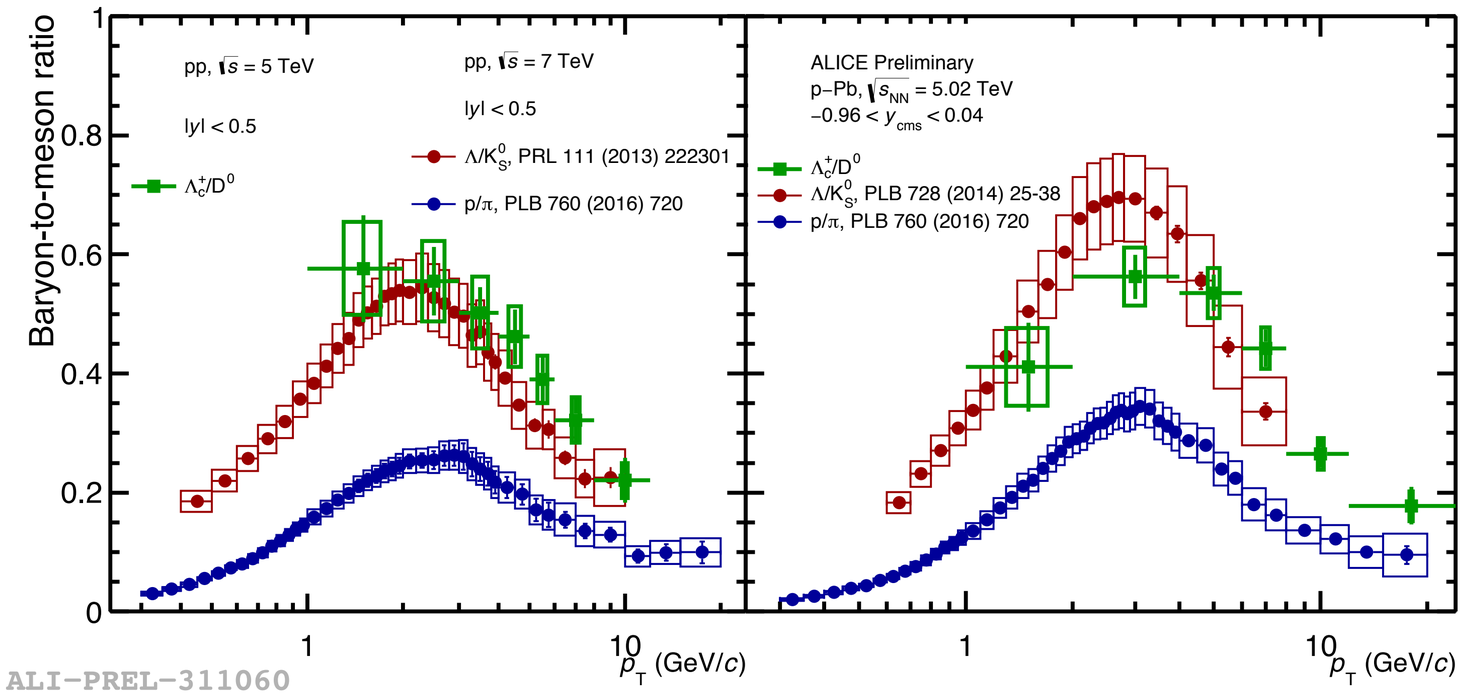
Baryon-to-meson ratio (heavy-flavour)



- The p_T-differential Λ_c^+/D^0 ratio measured in pp collisions showed that it is significantly larger than the expected from the fragmentation parameters for these model derived from e^+e^- collision data
- The colour reconnection mechanism in PYTHIA enhances flow-like effects, bringing the prediction closer to the data

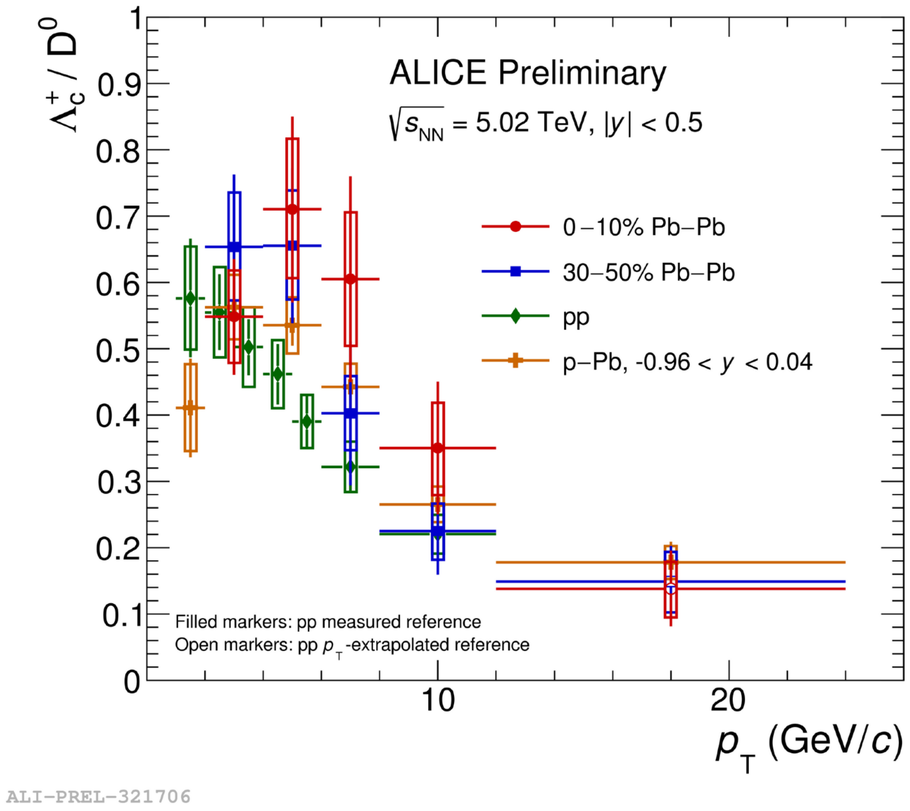
Baryon-to-meson ratio (heavy-flavour)





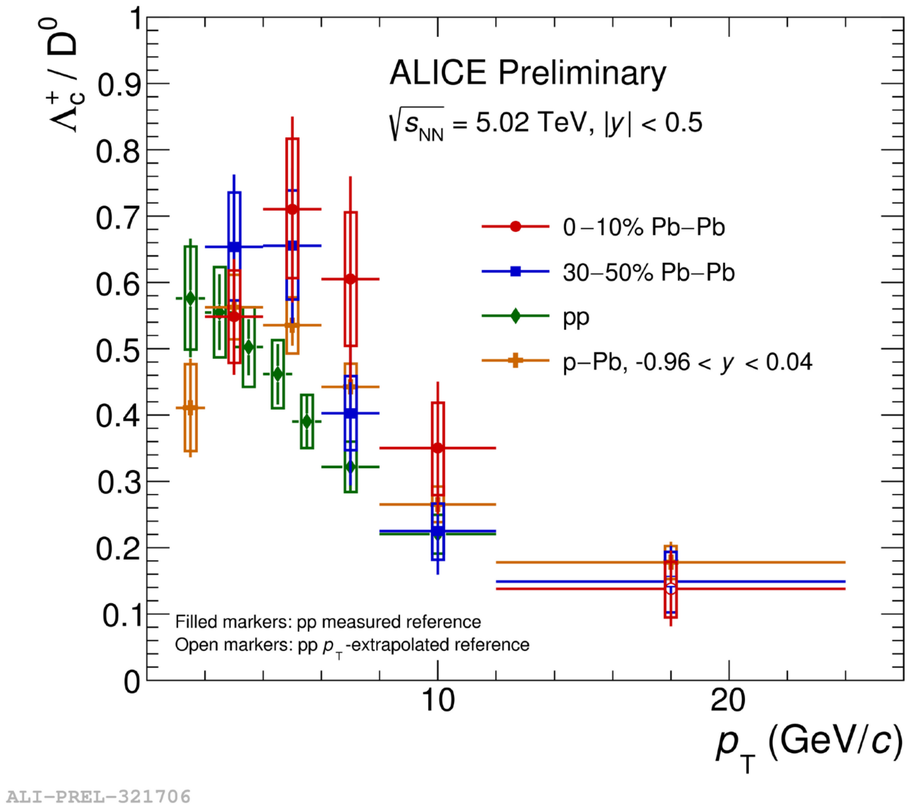
- The p_T-differential Λ_c^+/D^0 ratio measured in pp collisions showed that it is significantly larger than the expected from the fragmentation parameters for these model derived from e^+e^- collision data
- The colour reconnection mechanism in PYTHIA enhances flow-like effects, bringing the prediction closer to the data
- Similar qualitative behaviour of the Λ_c^+/D^0 ratio to the one of the p/π and Λ/K_s^0 ratios from pp to p-Pb collisions
- Although the height of the maximum increases from pp to p-Pb collisions in the light-flavour sector, the one from heavy-flavour does not increase significantly

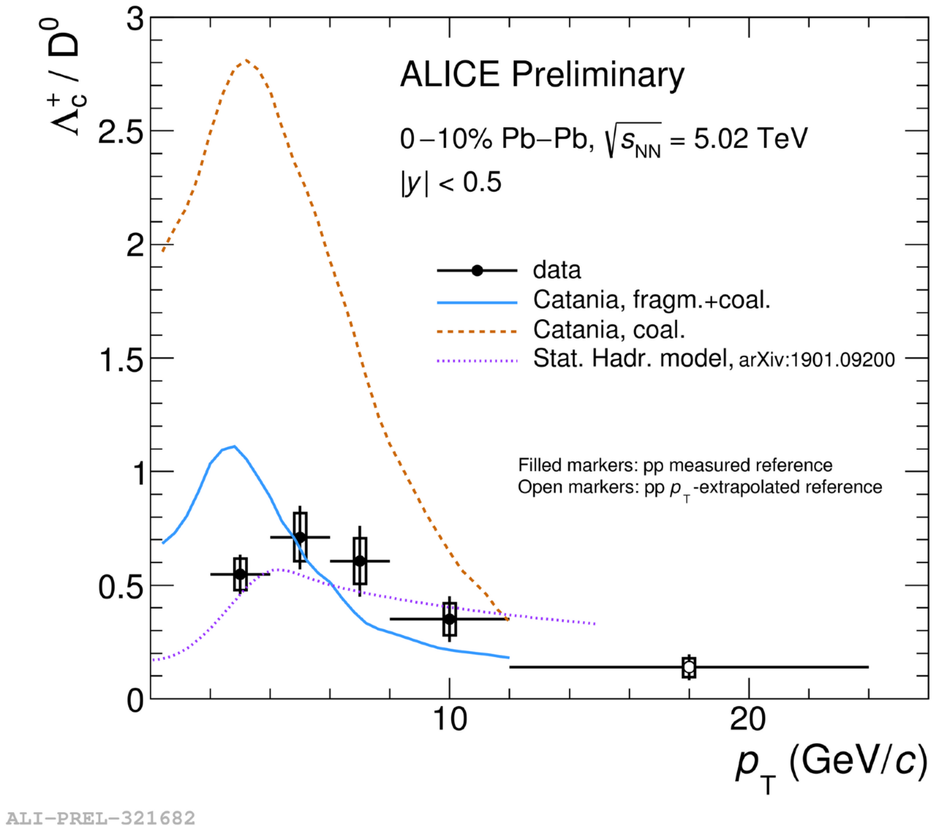
Baryon-to-meson ratio (heavy-flavour)



- Charm-baryons in HI collisions allow charm-quark hadronization mechanisms to be studied inside the QGP
- At intermediate p_T the Λ_c^+/D^0 ratio is higher in central collisions than in peripheral ones

Baryon-to-meson ratio (heavy-flavour)

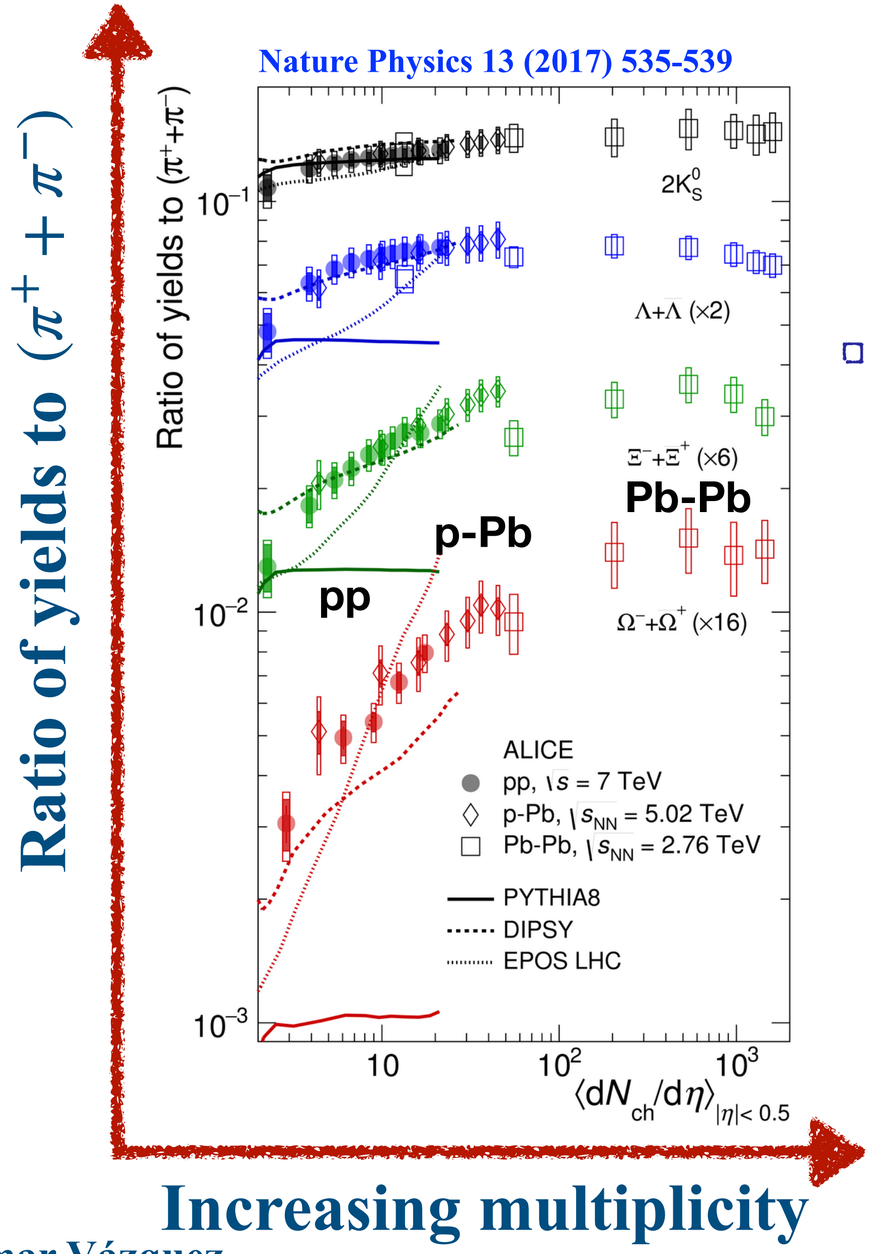




- Charm-baryons in HI collisions allow charm-quark hadronization mechanisms to be studied inside the QGP
- At intermediate p_T the Λ_c^+/D^0 ratio is higher in central collisions than in peripheral ones
- For $p_T \gtrsim 4$ GeV/c, models in which coalescence and fragmentation are present can qualitatively describe the data
- Good agreement with statistical hadronization model

Particle chemistry

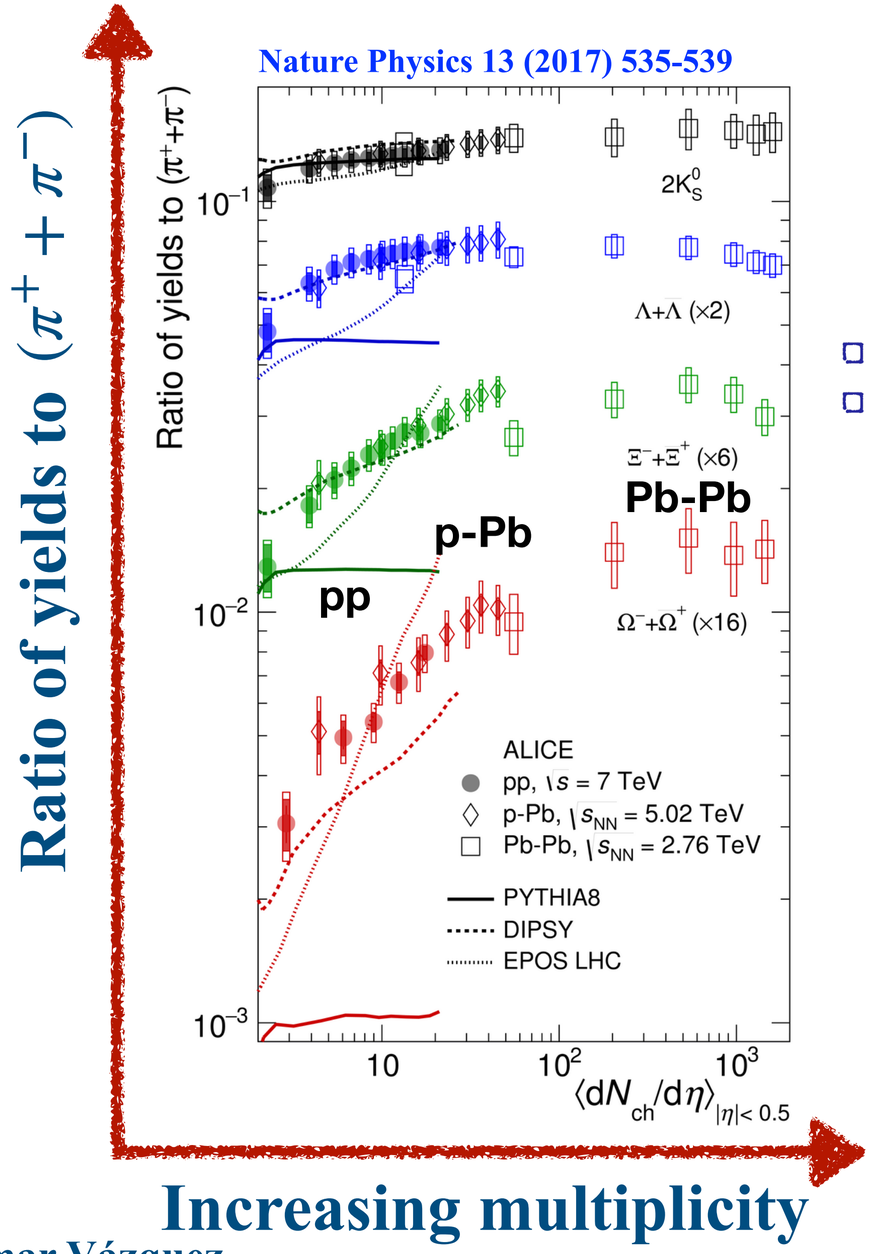
Nature Physics 13 (2017) 535-539



- Enhanced production of (multi-)strange hadrons as a function of $\langle dN_{ch}/d\eta \rangle$

Particle chemistry

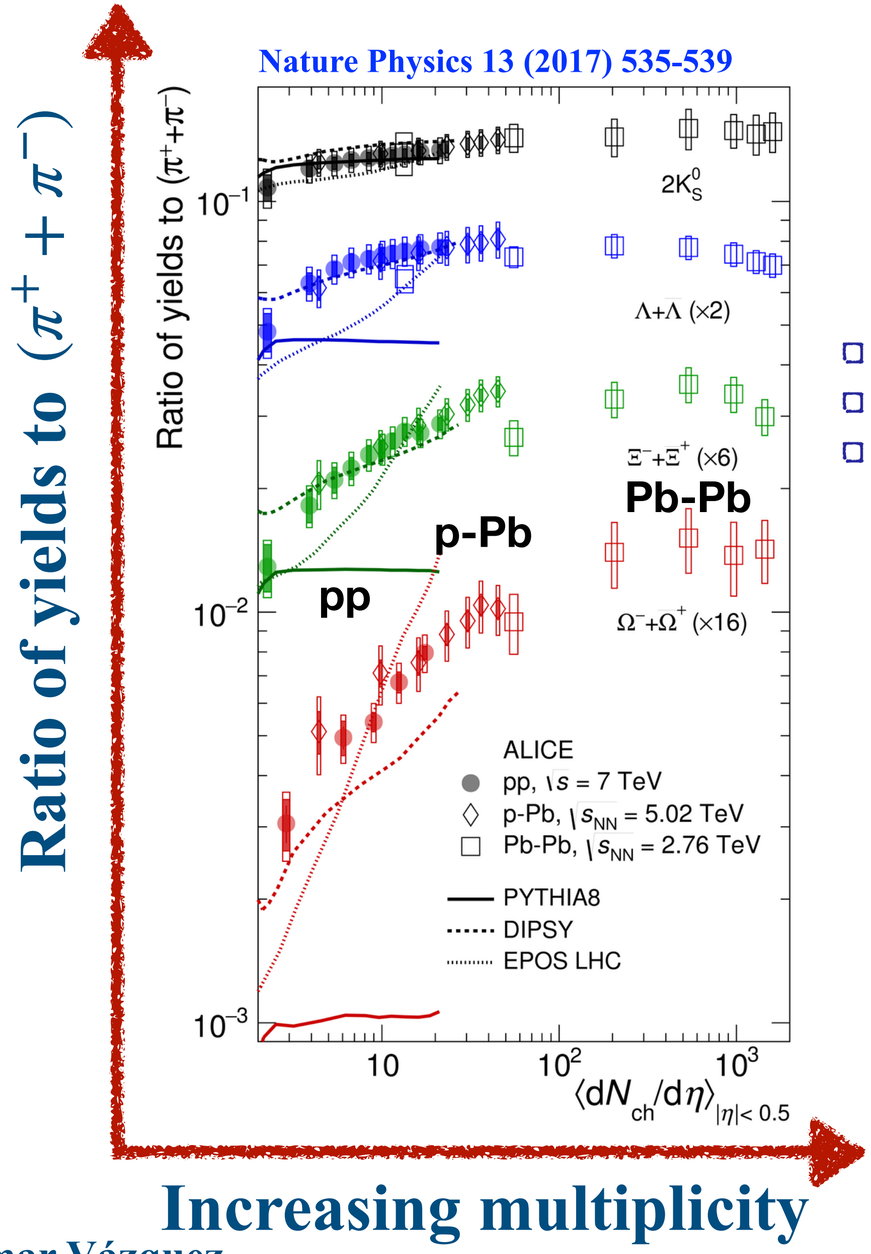
Nature Physics 13 (2017) 535-539



- Enhanced production of (multi-)strange hadrons as a function of $\langle dN_{ch}/d\eta \rangle$
- The rate increases with strange-quark content

Particle chemistry

Nature Physics 13 (2017) 535-539

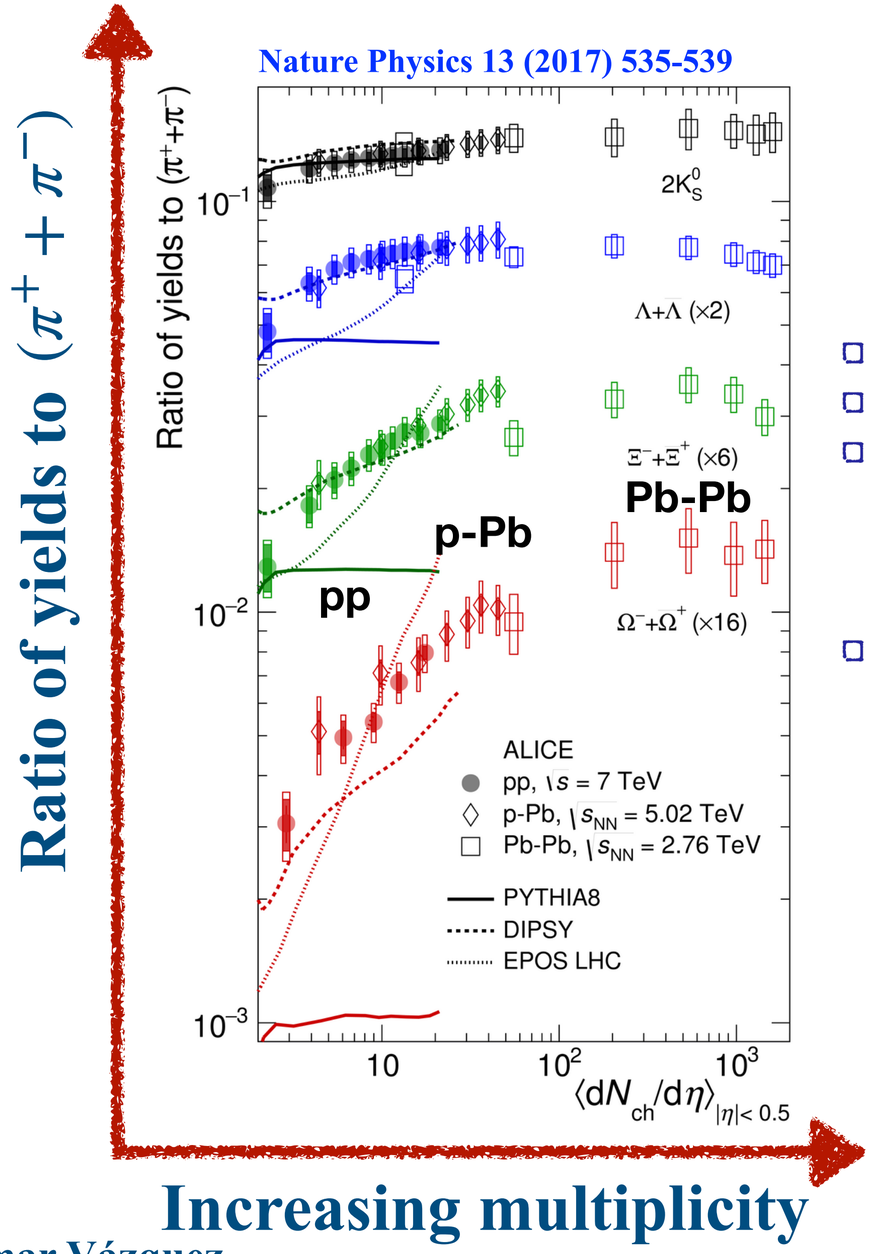


- Enhanced production of (multi-)strange hadrons as a function of $\langle dN_{ch}/d\eta \rangle$
- The rate increases with strange-quark content
- DIPSY describes the data best
  - In this model the interaction between strings allows the formation of 'colour ropes', which are expected to produce more strange particles

JHEP 1503 (2015) 148

Particle chemistry

Nature Physics 13 (2017) 535-539

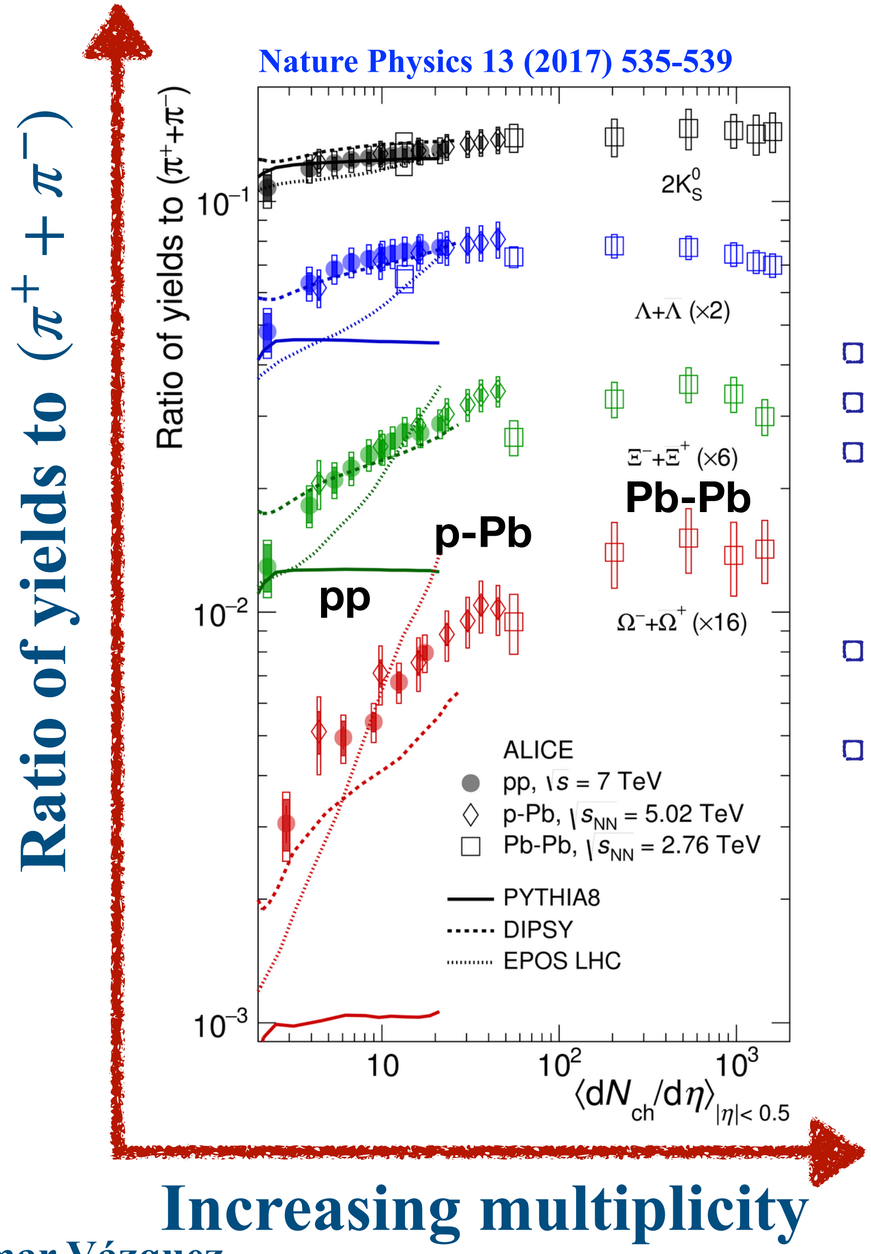


- Enhanced production of (multi-)strange hadrons as a function of $\langle dN_{ch}/d\eta \rangle$
- The rate increases with strange-quark content
- DIPSY describes the data best
  - In this model the interaction between strings allows the formation of 'colour ropes', which are expected to produce more strange particles

    JHEP 1503 (2015) 148
- In Pb-Pb collisions no significant change beyond $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5} \approx 200$ (grand-canonical plateau)

Particle chemistry

Nature Physics 13 (2017) 535-539

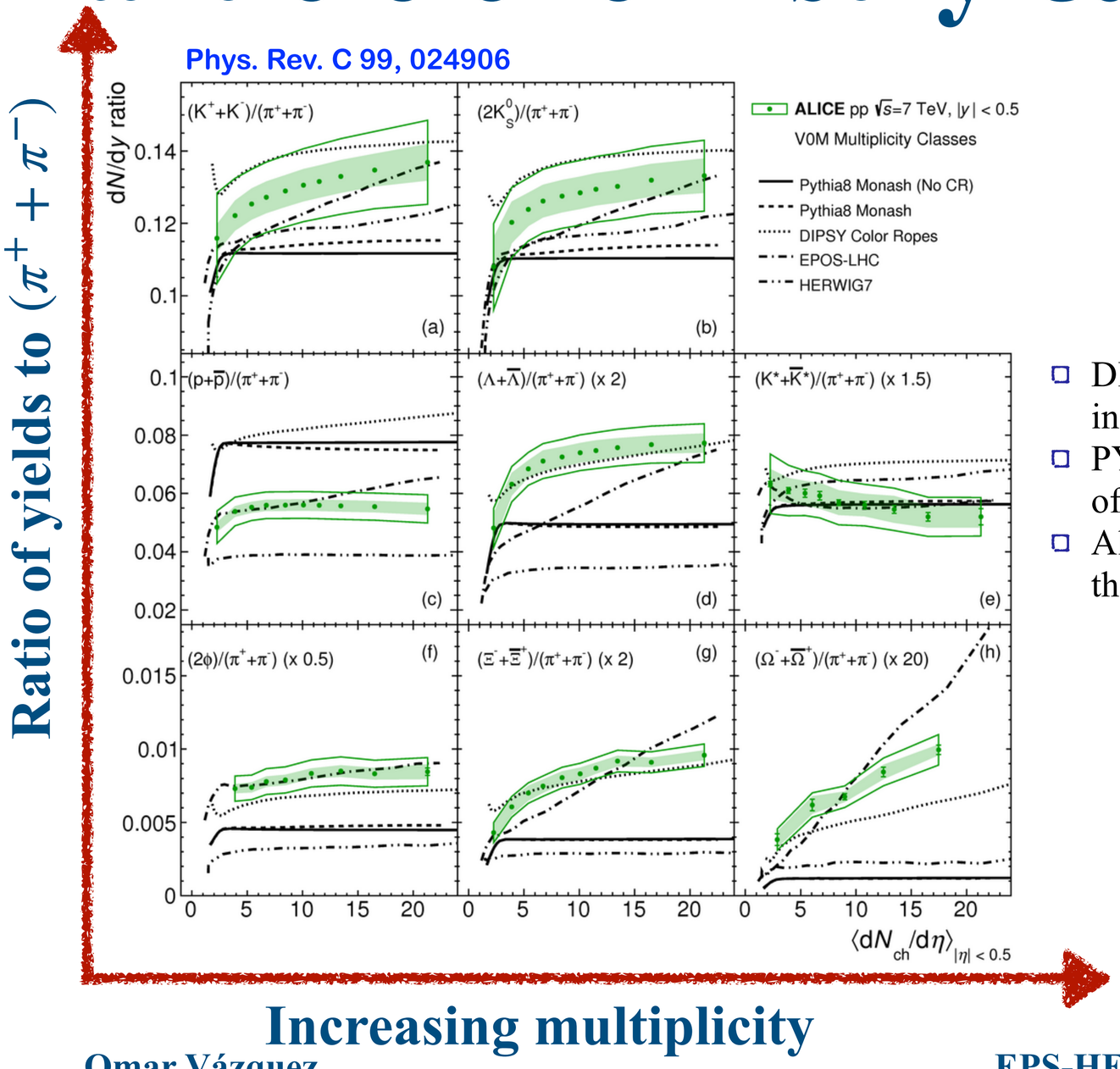


- Enhanced production of (multi-)strange hadrons as a function of $\langle dN_{ch}/d\eta \rangle$
- The rate increases with strange-quark content
- DIPSY describes the data best
  - In this model the interaction between strings allows the formation of 'colour ropes', which are expected to produce more strange particles

    JHEP 1503 (2015) 148
- In Pb-Pb collisions no significant change beyond $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5} \approx 200$ (grand-canonical plateau)
- Hadrochemistry is predominately driven by the charged particle multiplicity density and not by the colliding system or collision energy

Particle chemistry & model predictions

Phys. Rev. C 99, 024906



- DIPSY and EPOS-LHC mimic the increased strangeness with increasing multiplicity but fail to predict a constant p/π ratio
- PYTHIA8 and HERWIG7 fail to describe the multiplicity dependence of relative strangeness production
- All the MC generators fail to describe the multiplicity dependence of the K^{*0}/π ratio, which is observed to decrease slightly

Summary

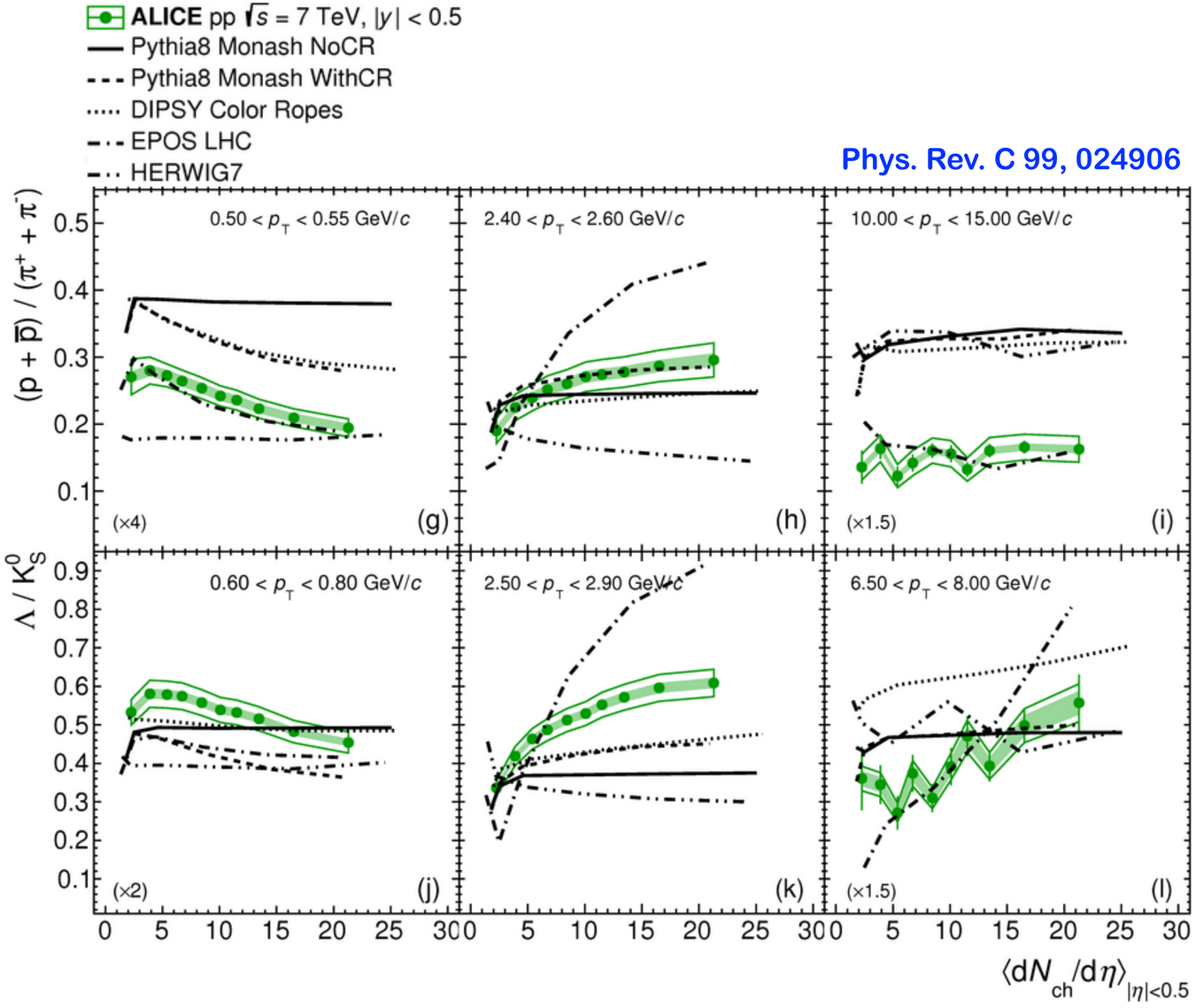
- The ALICE experiment has made precise measurements of PID down to $p_{\mathrm{T}} \approx 100$ MeV/c in pp, p-Pb and Pb-Pb collisions over a broad range of collision energies allowing the exploration of the non-perturbative QCD regime

- The light-flavour baryon-to-meson ratio in small systems showed qualitative similarities to the ones in HI collisions. Moreover, these effects were also observed in the $\Lambda_{\mathrm{c}}^{+}/\mathrm{D}^{0}$ ratio

- Precise measurements of the production of identified charged particles showed that the charged particle multiplicity is a key variable that controls the relative particle abundances (hadrochemistry)

Backup

Baryon-to-meson ratio (MC)



Phys. Rev. C 99, 024906

- **PYTHIA (String-model-based)**
  - Strings: colour-flux tubes between $q - \bar{q}$ end-points
  - Pythia with CR enhances flow-like patterns

    Phys. Rev. Lett 111, 042001
  - Successful in describing the qualitative features

- **EPOS LHC (Core-corona approach)**
  - Core: high-density of strings (QGP droplet)
  - Hadronization happens statistically
  - Predicts the baryon-to-meson ratio at intermediate p_T but overestimates the multiplicity dependence

    Phys. Rev. Lett. 98, 152301