



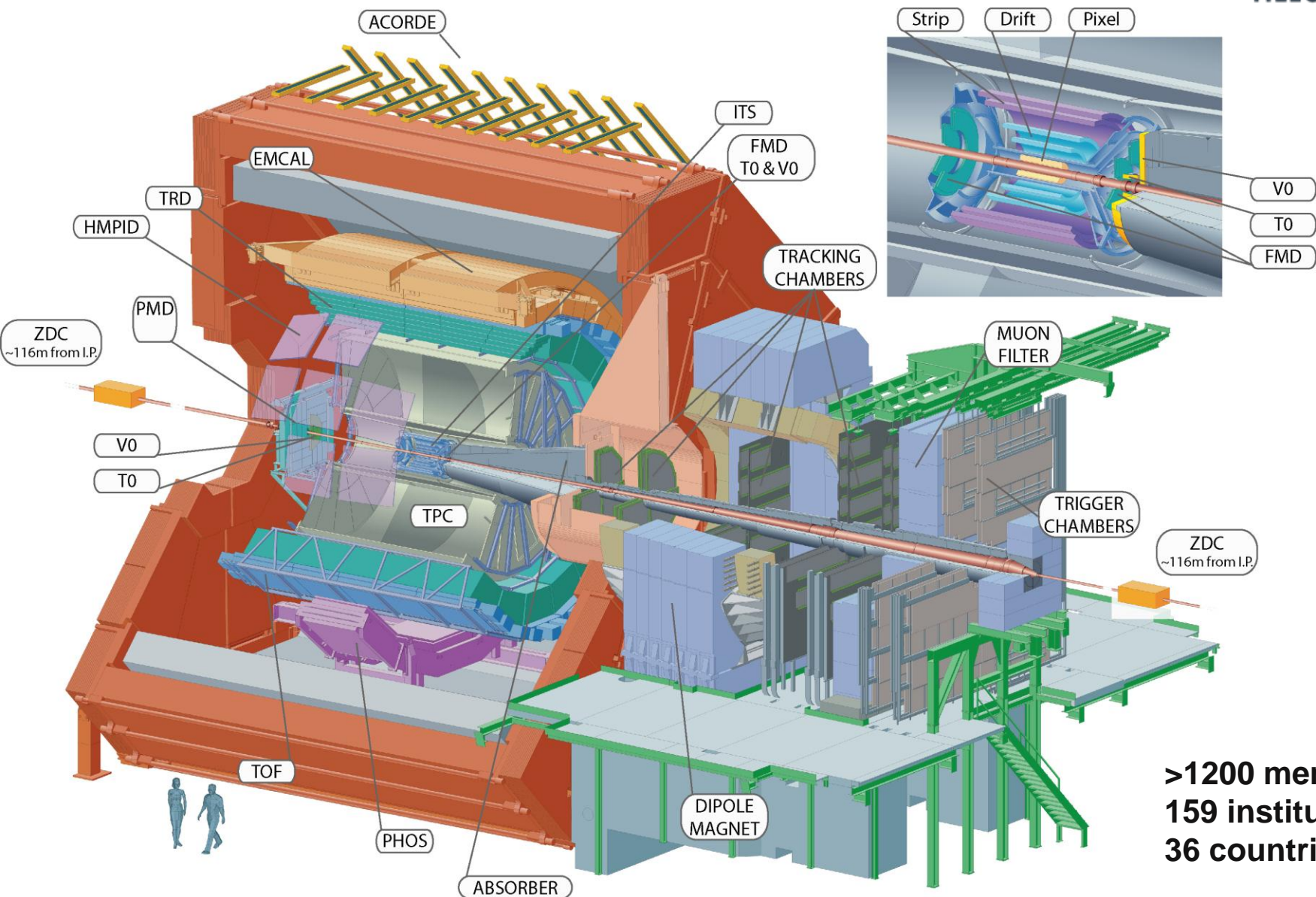
# Overview of ALICE results

Yuri Kharlov  
for the ALICE collaboration

# Outlook

- Global event properties
- Particle production
- Collective effects
- Hard probes
- Quarkonium
- ALICE in future

# ALICE in Run1



**>1200 members**  
**159 institutes**  
**36 countries**

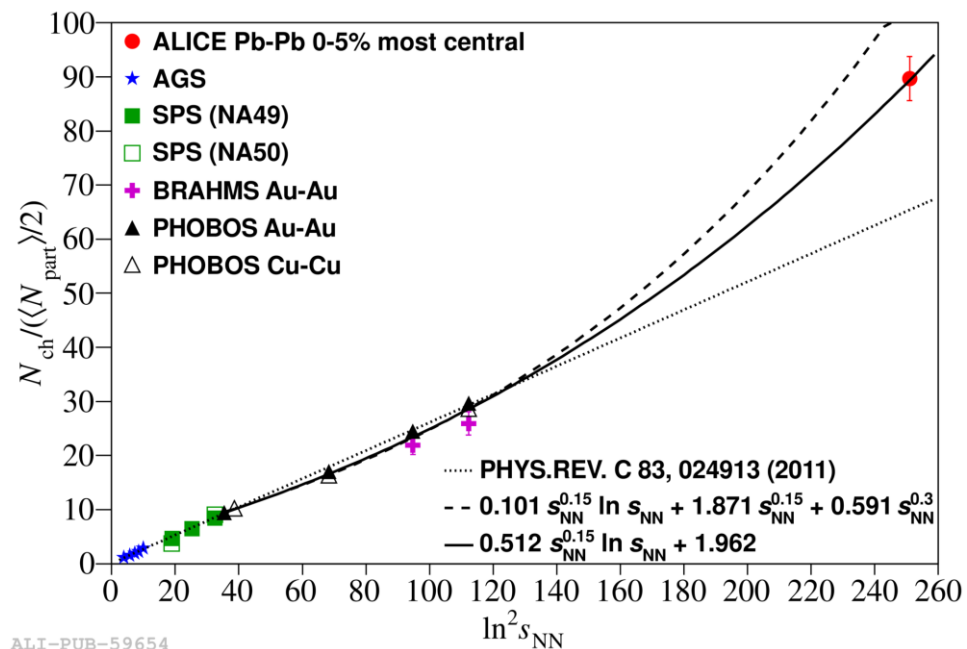
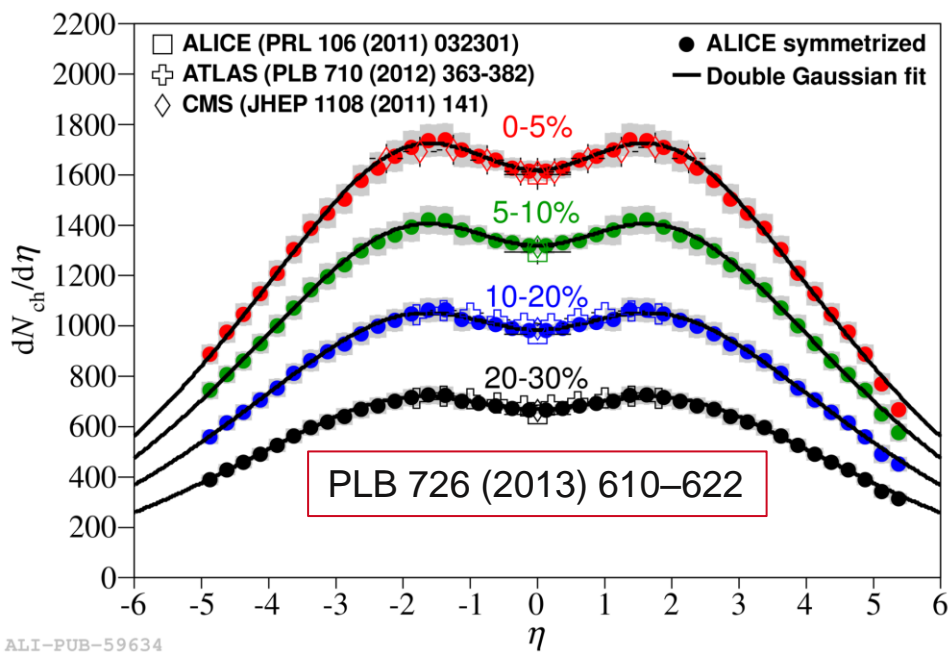


# Global event properties

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# Event multiplicity

Dependence of  $dN/d\eta$  on centrality of Pb-Pb collisions and on colliding system is essential for understanding the role of soft scattering processes in particle production

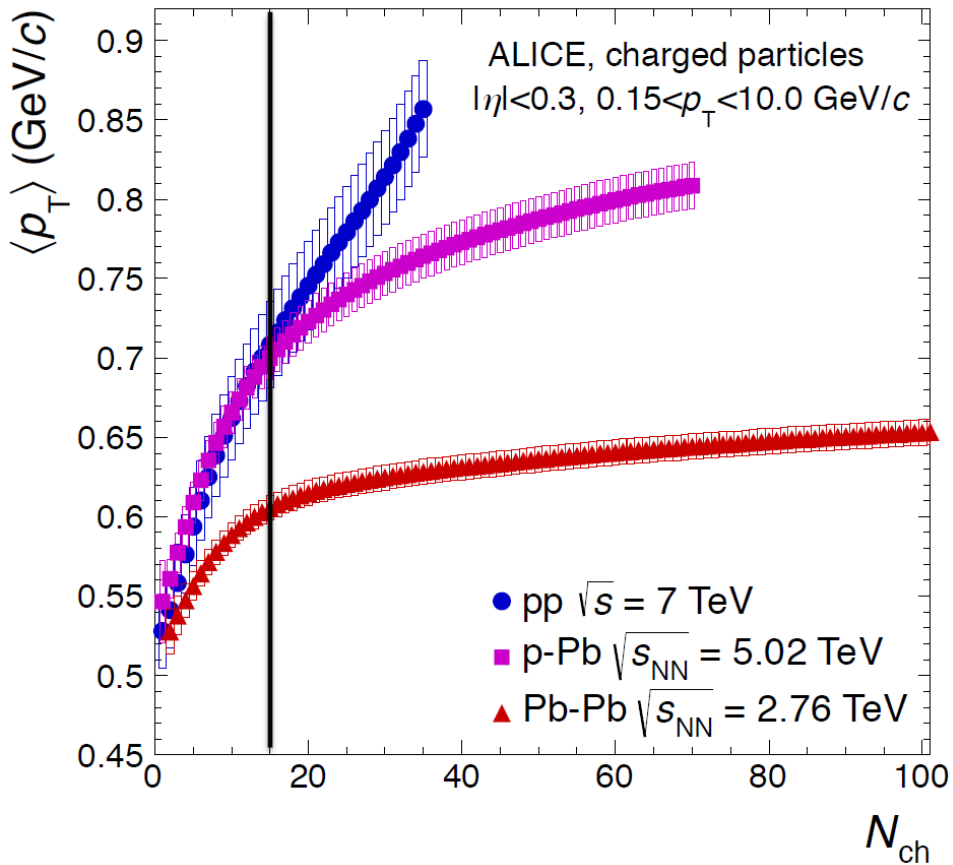


Total number of produced charged particles in 0-5% central Pb-Pb collisions:  $N_{ch} = 17165 \pm 772$

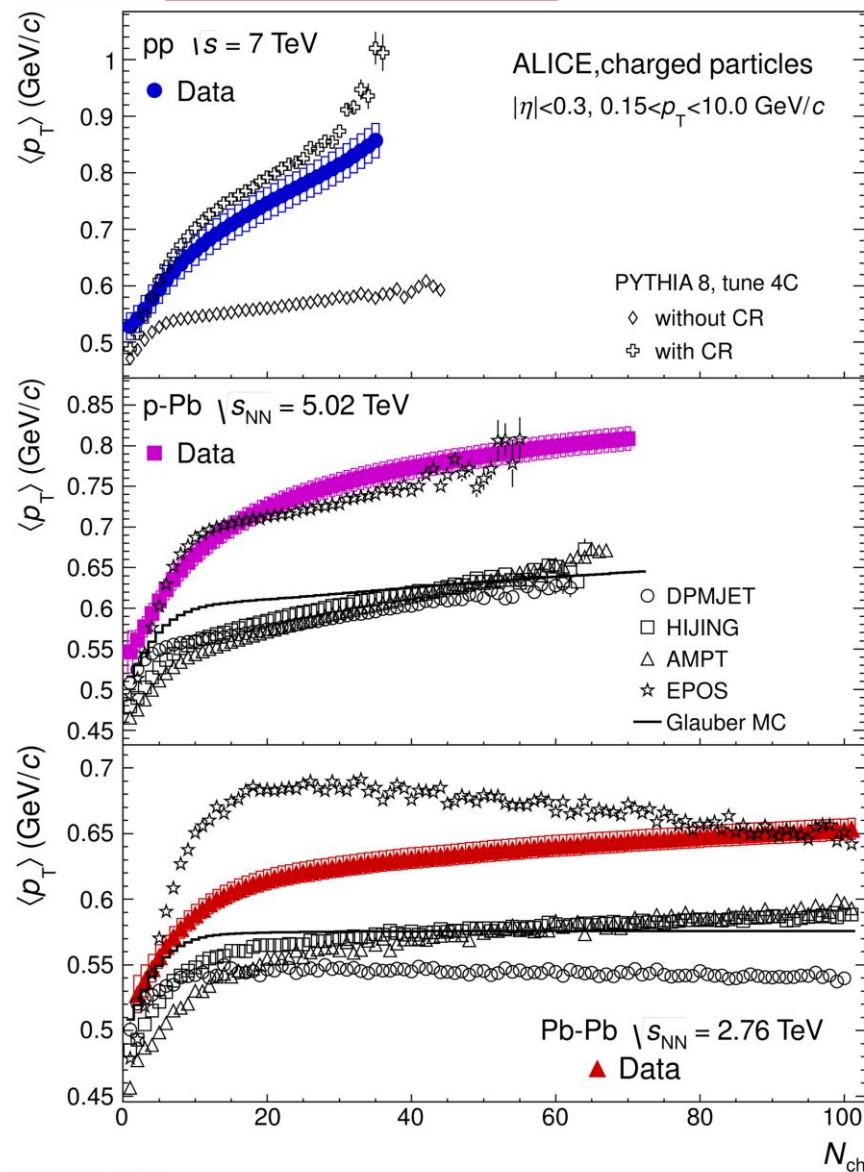
Linear trend from AGS to RHIC energies does not persist at LHC

# Mean $p_T$ vs multiplicity

arXiv:1307.1094



- pp and pPb – much stronger increase than in PbPb
- Color reconnection describes data better in pp
- None model can describe p-Pb and Pb-Pb consistently



ALI-PUB-55948

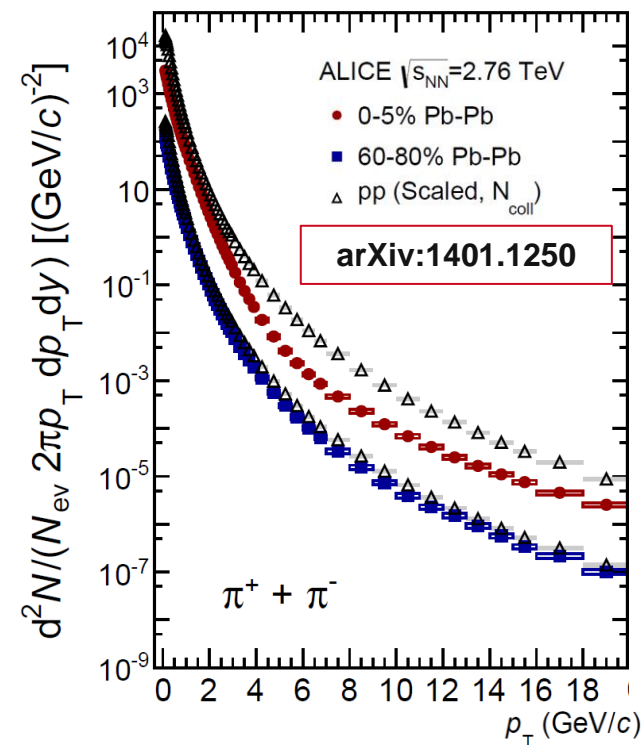
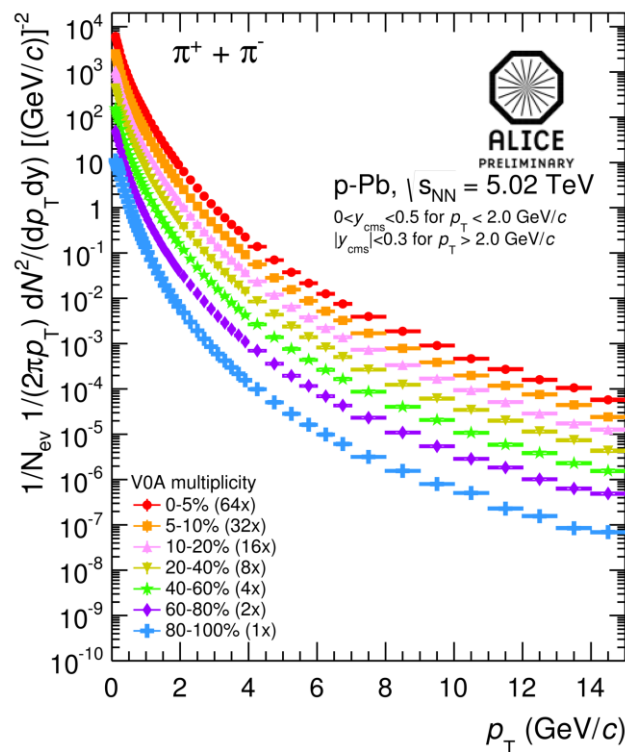
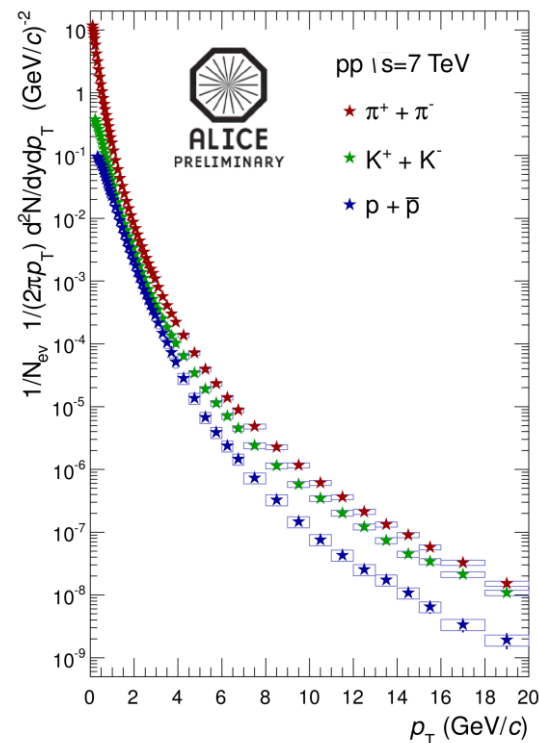


# Particle production

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# Pion, kaon, proton spectra

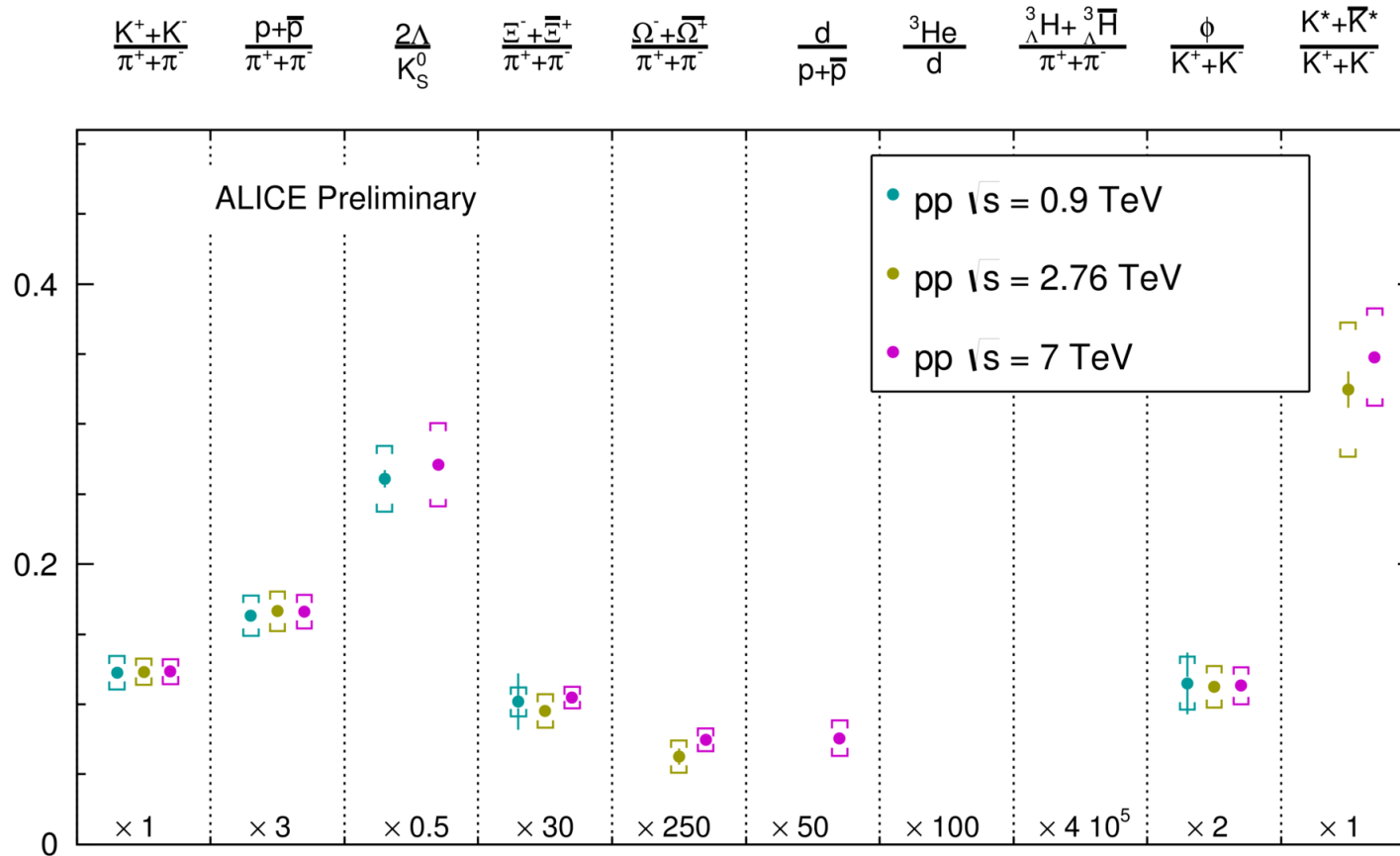


Combined measurements of all tracking detectors (ITS, TPC, TOF, HMPID) leads to identified charged hadron spectra in a wide  $p_T$  range in all collision systems.

- Input for flavor and mass dependence of particle yields
- Evolution with colliding system and centrality



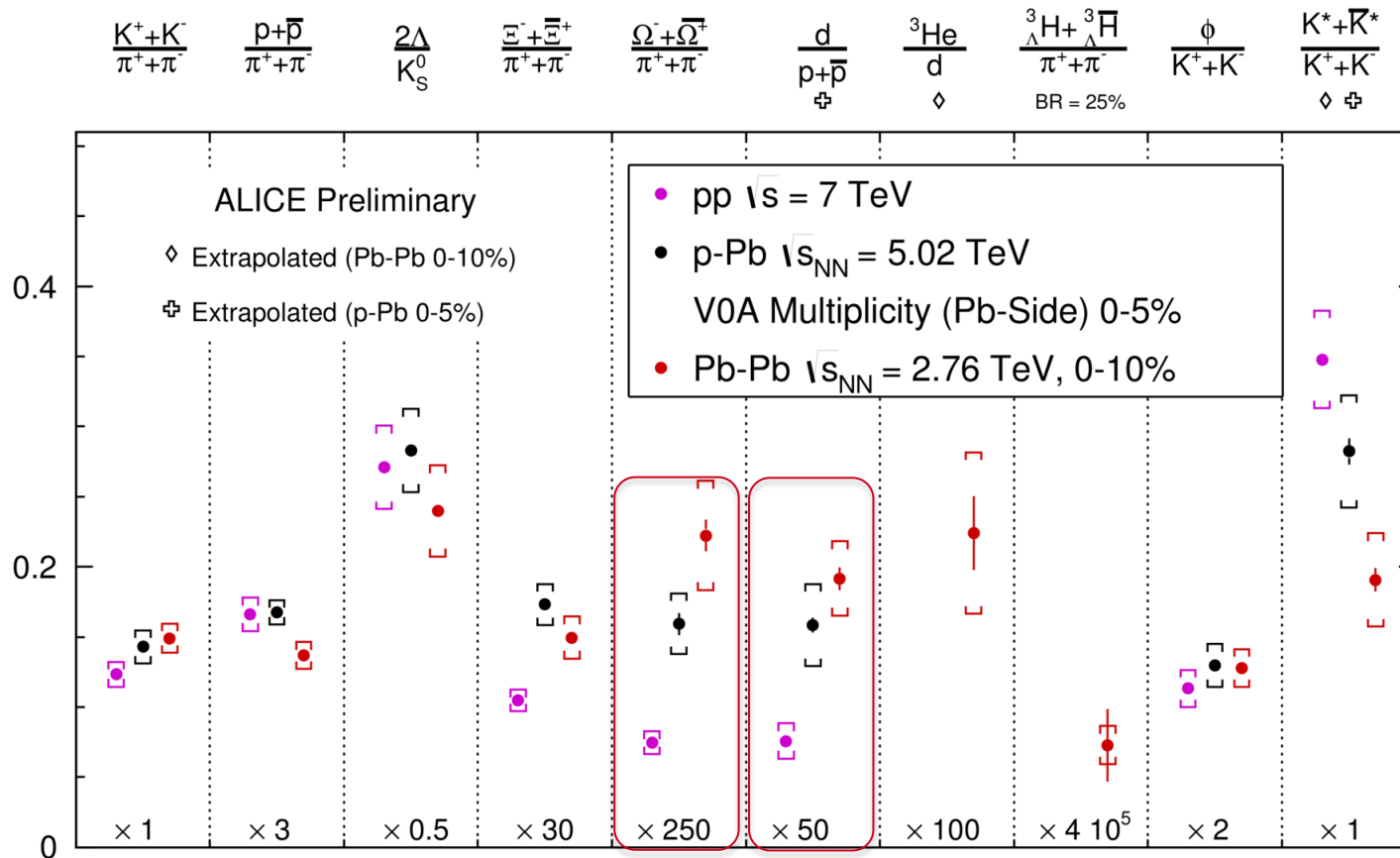
# Particle yields in pp vs $\sqrt{s}$



ALI-PREL-74045

Yield ratios of all measured hadrons in pp collisions show a very weak energy dependence in the range 0.9–7 TeV.

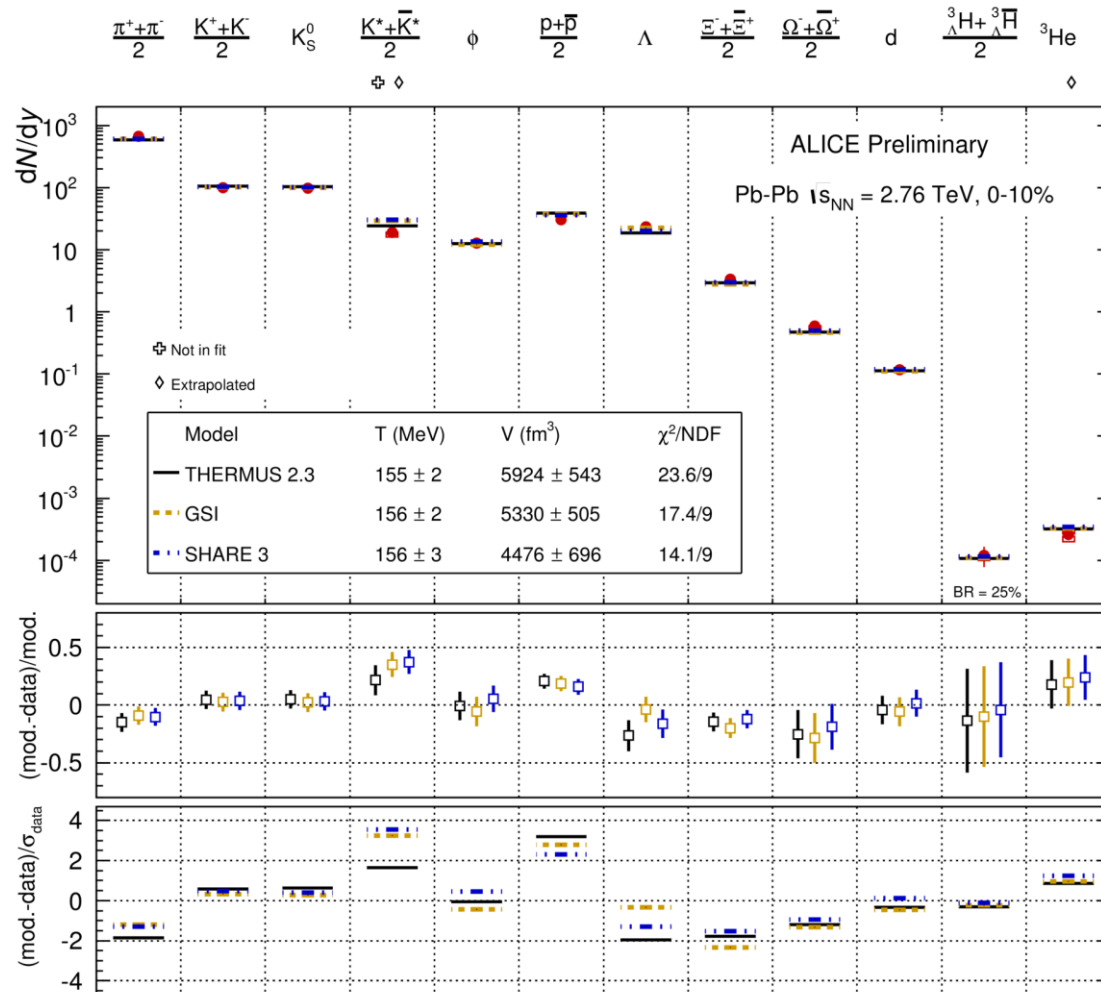
# Particle yields: pp, p-Pb, Pb-Pb



ALI-PREL-74423

- Yield ratios of all particles look similar in pp, p-Pb and Pb-Pb collisions
- A hint is enhancement of  $\Omega$  and  $p$  and a decrease of  $K^*$  in heavy-ion collisions

# Particle yields in Pb-Pb: data vs thermal model

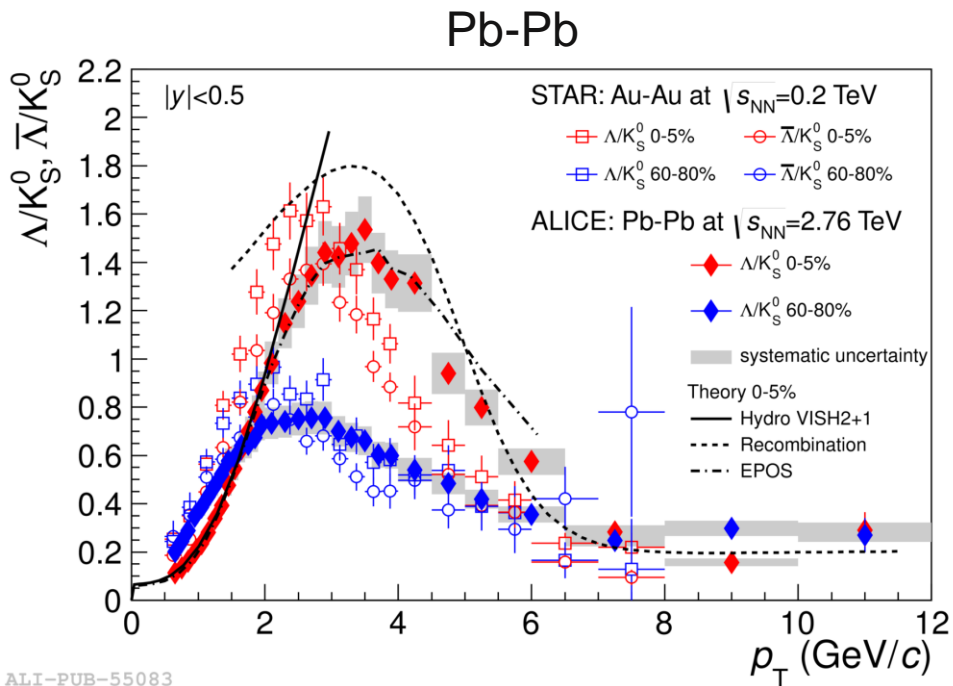


THERMUS: CPC 180 (2009) 84  
GSI: PLB 673 (2009) 142  
SHARE: arXiv:1310.5108

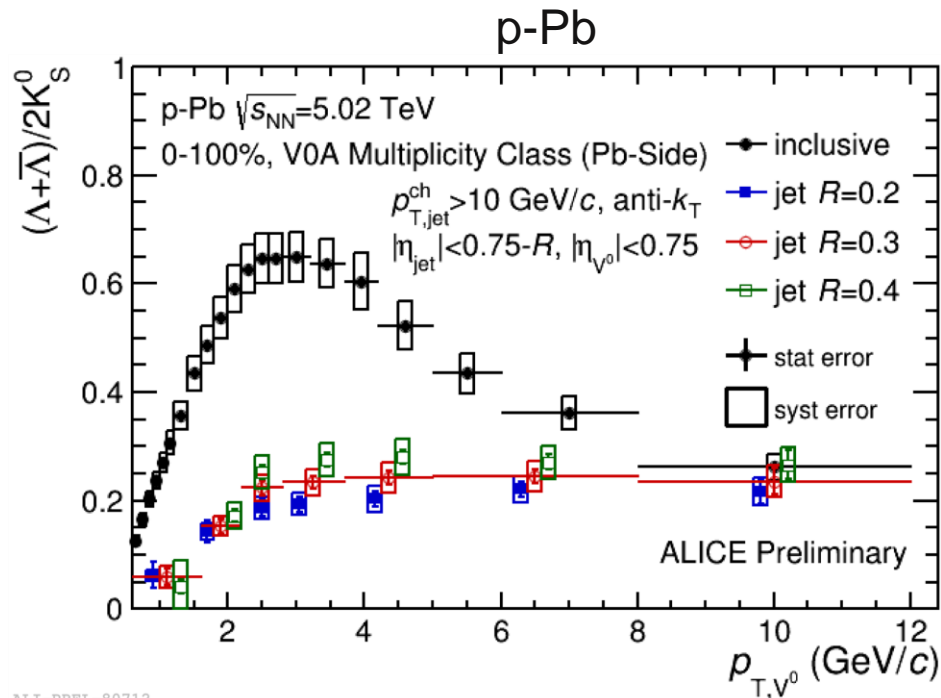
- Equilibrium models describe well the yields of all particles.
- Interesting to note that nuclei are also produced thermally.

ALI-PREL-74463

# Baryon anomaly



ALI-PUB-55083



ALI-PREL-80712

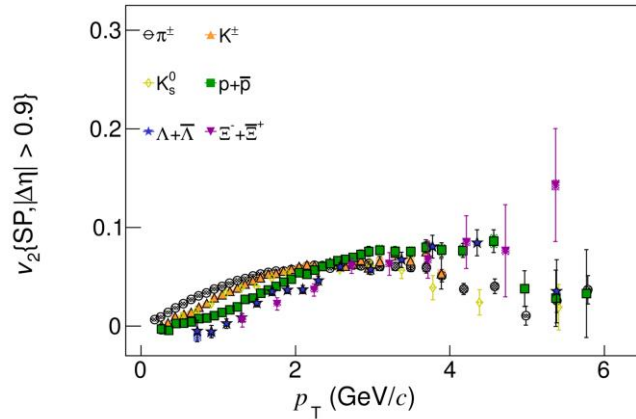
- $\Lambda$  production is strongly enhanced in central Pb-Pb collisions
- Clear centrality dependence
- Quantitatively the same effect as the one observed earlier at RHIC
- Ratio  $\Lambda/K_S^0$  in p-Pb collisions is similar to that in peripheral Pb-Pb collisions
- No  $\Lambda$  enhancement in jets



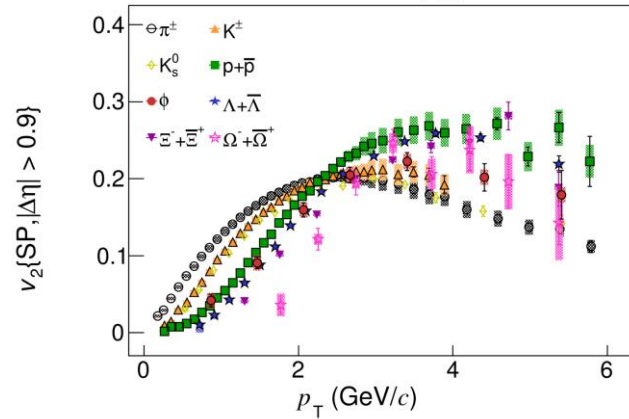
# Collective effects in QCD matter

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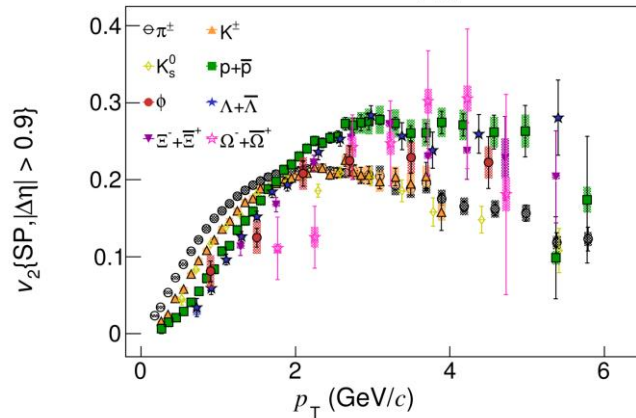
# Identified particle flow

ALICE 0-5% Pb-Pb  $\sqrt{s_{NN}} = 2.76$  TeV

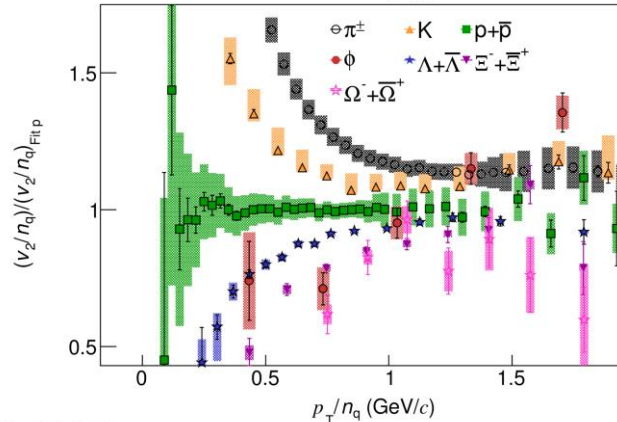
ALI-PUB-82646

ALICE 20-30% Pb-Pb  $\sqrt{s_{NN}} = 2.76$  TeV

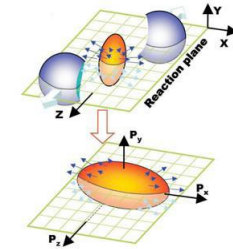
ALI-PUB-82677

ALICE 50-60% Pb-Pb  $\sqrt{s_{NN}} = 2.76$  TeV

ALI-PUB-82691

ALICE 20-30% Pb-Pb  $\sqrt{s_{NN}} = 2.76$  TeV

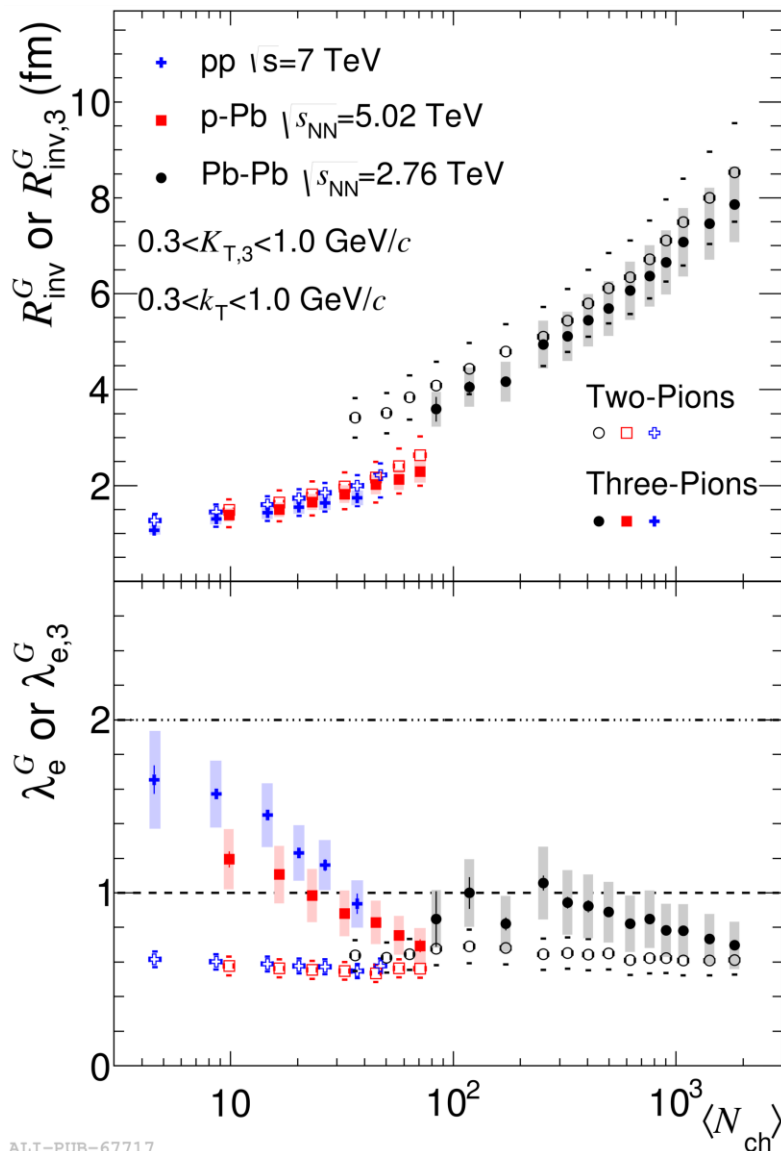
ALI-PUB-82768



- Spatial anisotropy → anisotropy in momentum space
- Mass ordering → attributed to common radial expansion velocity
- $\phi$  meson behaves like a baryon
- Mass ordering for multi-strange baryons
- $v_2/n_q$  scaling at the LHC less obvious
- Mass drives  $v_2$  rather than number of constituent quarks

arXiv:1405.4632

# Freeze-out radii in pp, p-Pb and Pb-Pb



- Femtoscopic radius: size of source at freeze-out
- Extracted radii in pp and p-Pb collisions at similar multiplicity are consistent
- pp and p-Pb are described by CGC initial conditions (IP-Glasma) without a hydrodynamic phase
- Pb-Pb can only be described with a hydrodynamic phase
- Significant collective expansion already in peripheral Pb-Pb collisions

arXiv:1404.1194

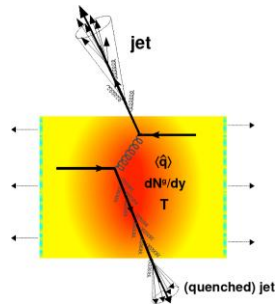




# Hard probes

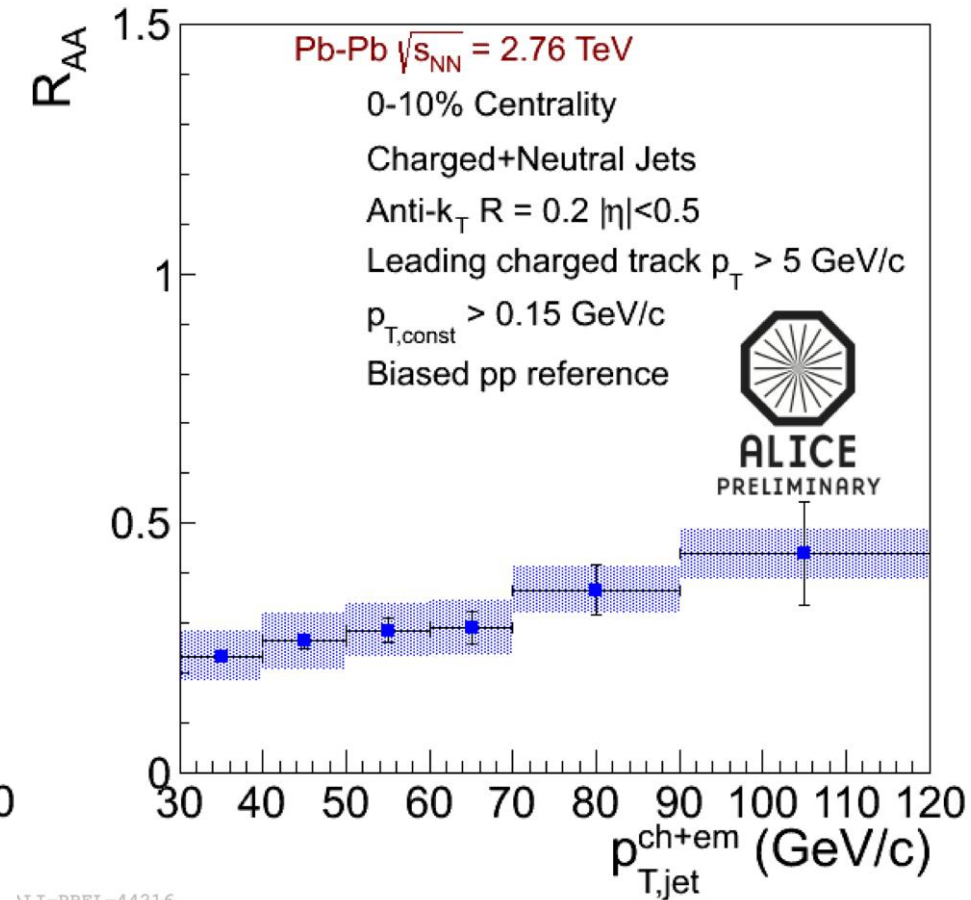
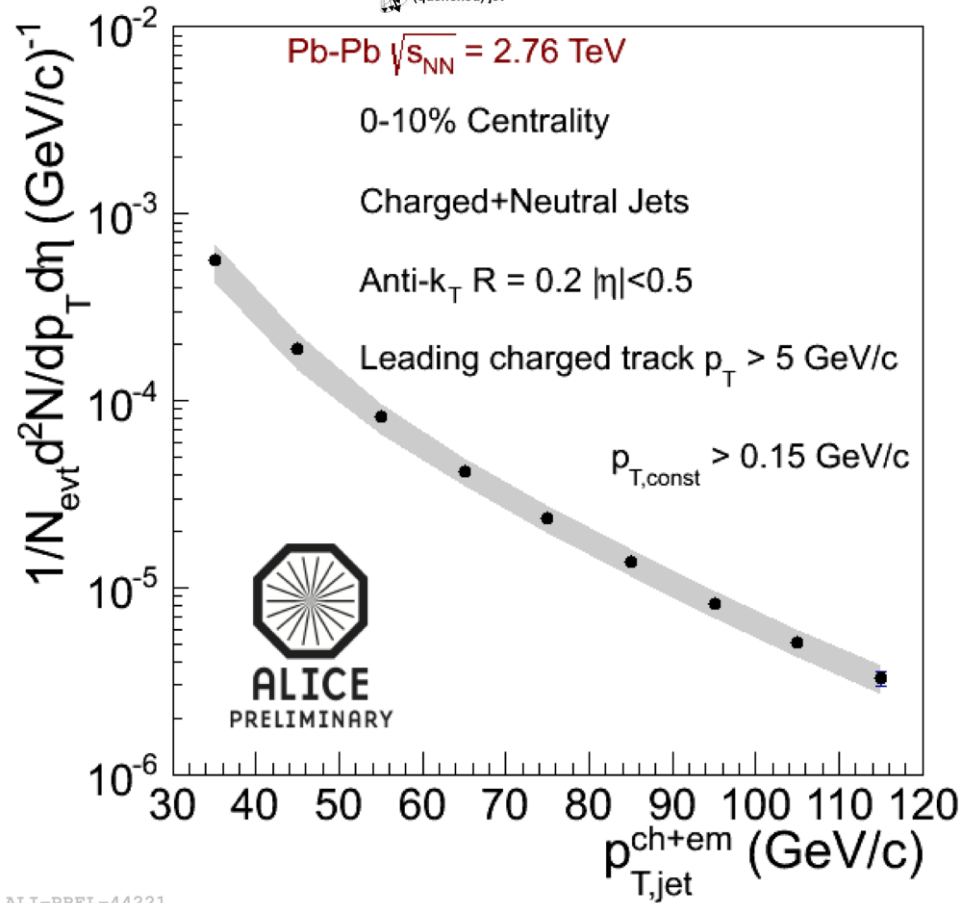
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# Jet suppression in Pb-Pb

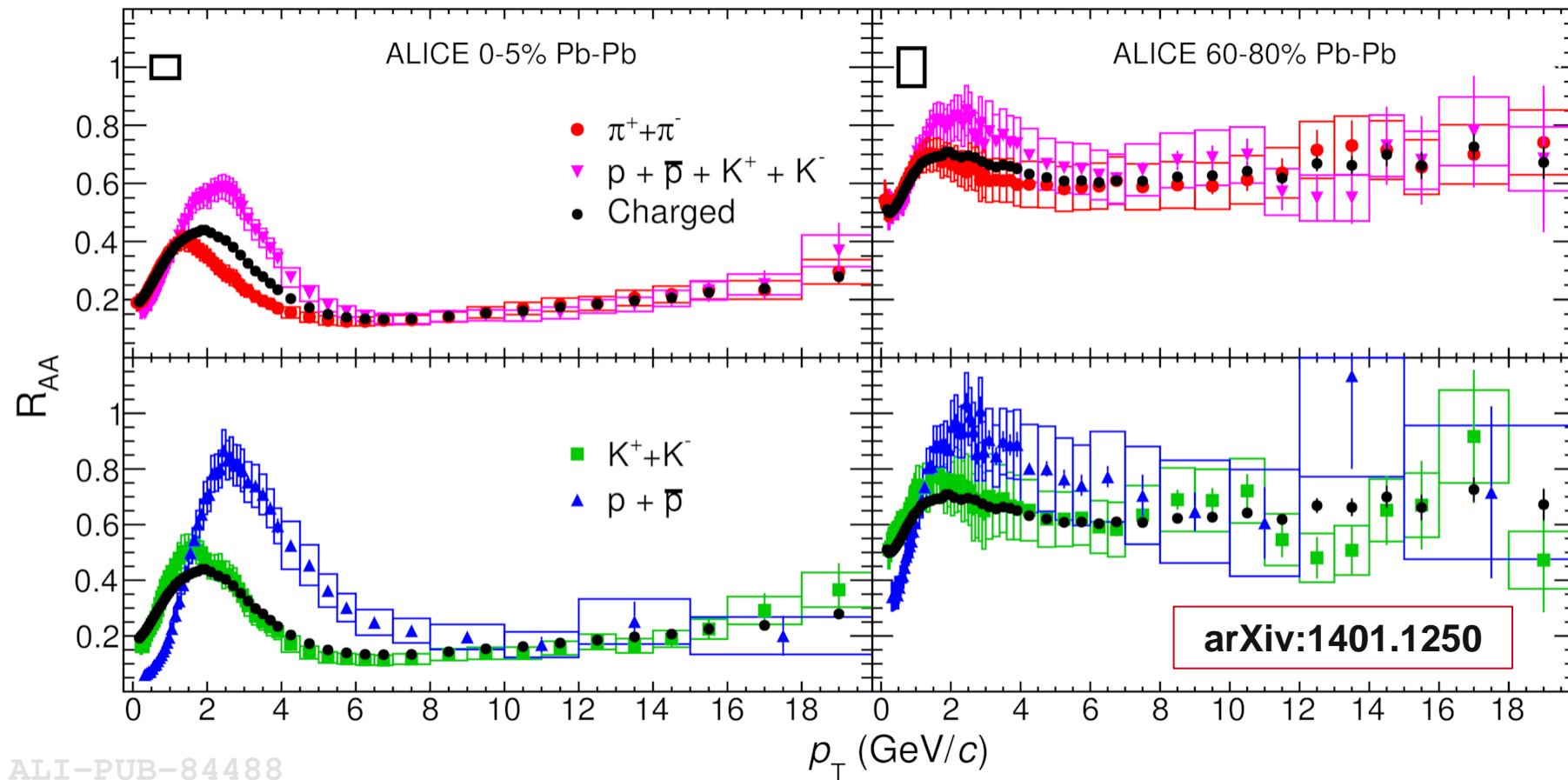


$$R_{AA} = \frac{\text{Spectrum in QCD medium}}{\text{Spectrum in QCD vacuum}}$$

$R_{AA}=1$ : no nuclear effects  
 $R_{AA}<1$ : suppression  
 $R_{AA}>1$ : enhancement



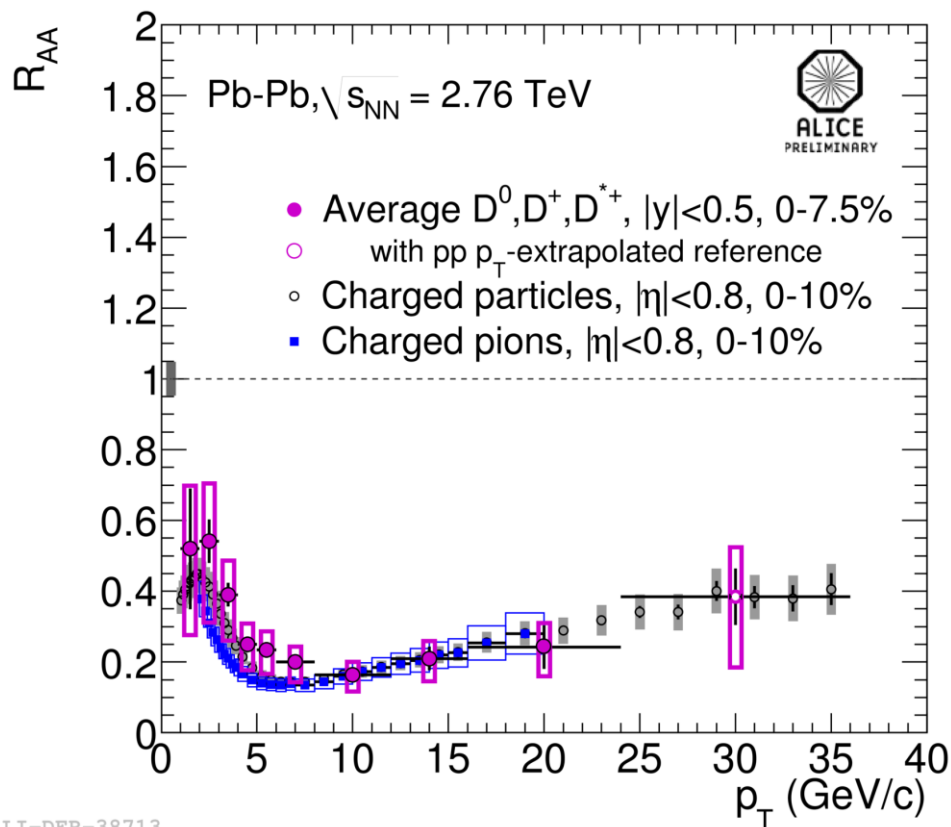
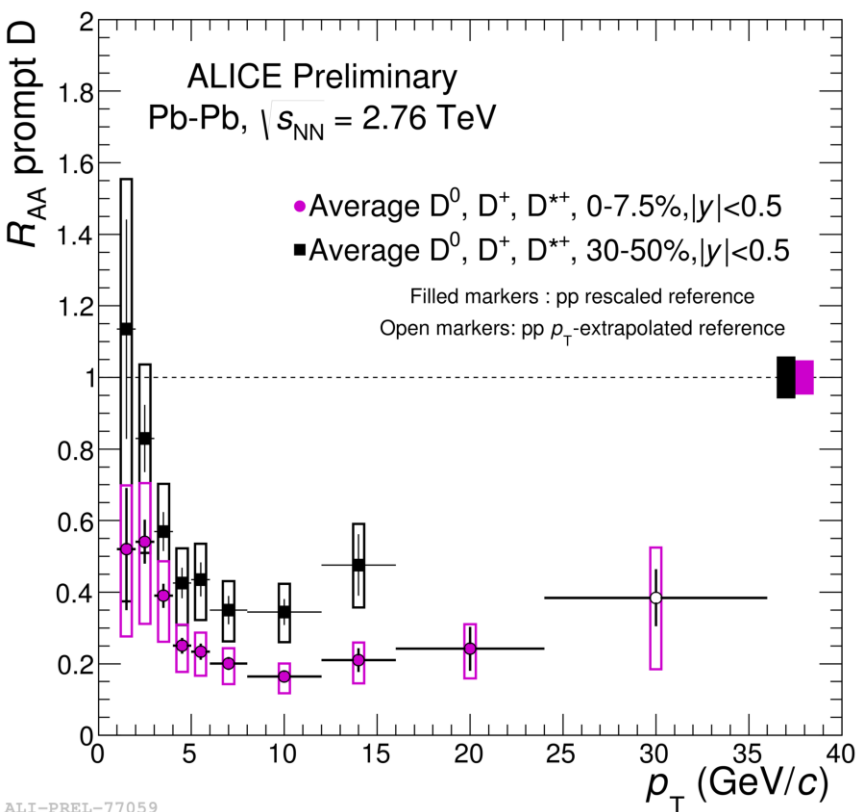
# Light flavor suppression in Pb-Pb



ALI-PUB-84488

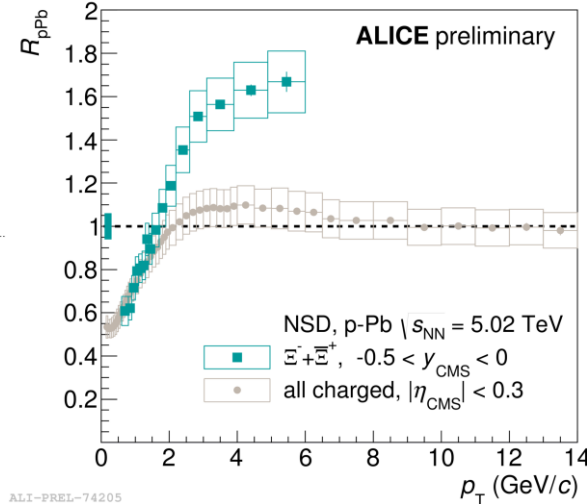
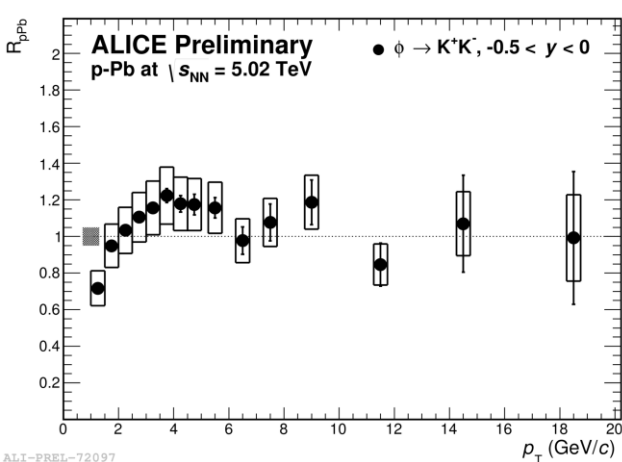
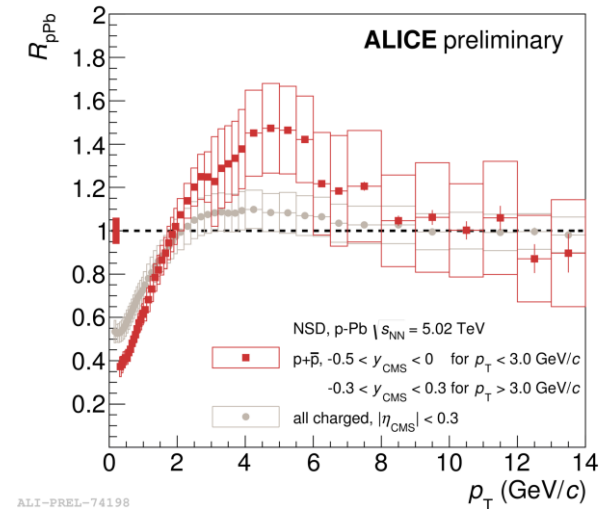
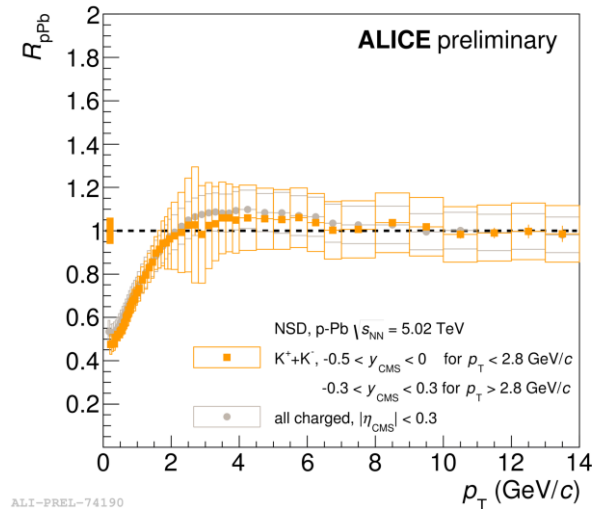
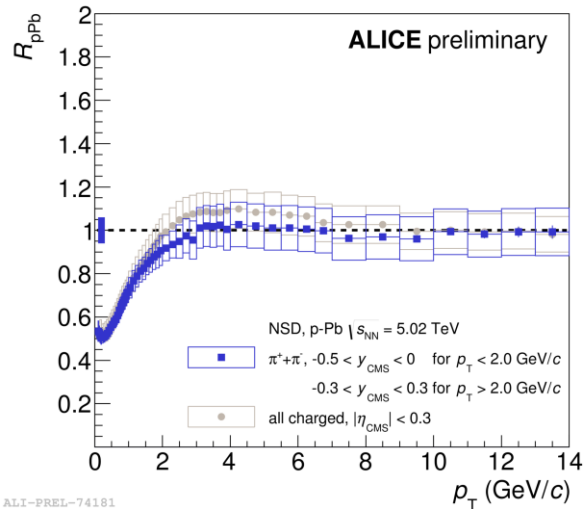
- $p_T < 3$  GeV/c: ratios  $K/\pi$  and  $p/\pi$  are in agreement with hydrodynamics
- $p_T > 10$  GeV/c: particle ratios in pp and Pb-Pb are similar
  - Particle composition of in-medium jets is the same as in jet in the vacuum

# Charm suppression in Pb-Pb



Charm suppression is similar to light flavor suppression

# Identified particle spectra in p-Pb



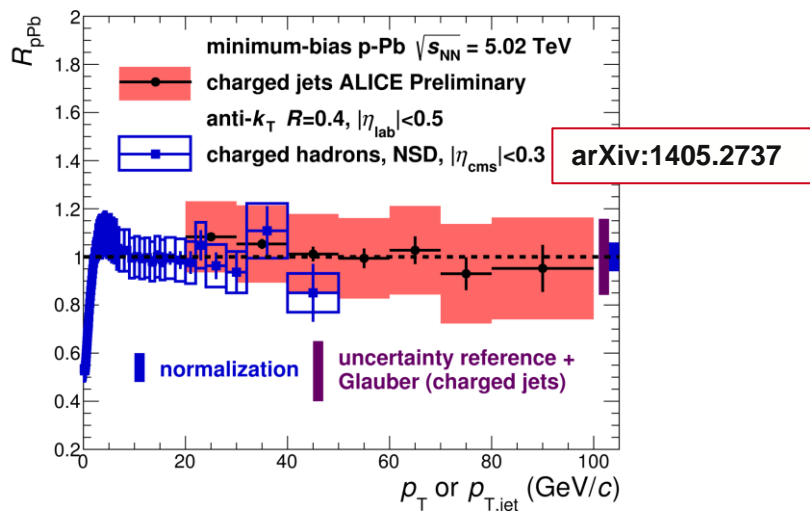
“Cronin enhancement” for baryons at  $p_T=3-5$  GeV/c

Mass dependence of  $R_{pPb}$ ?

$\phi$  meson is similar to  $\pi$  and  $K$

$R_{pPb} \rightarrow 1$  for all particles species: suppression observed in Pb-Pb is a hot matter effect

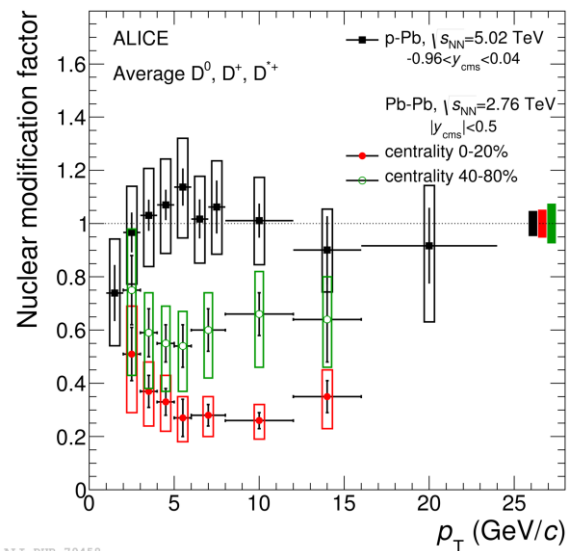
# More nuclear effects in p-Pb



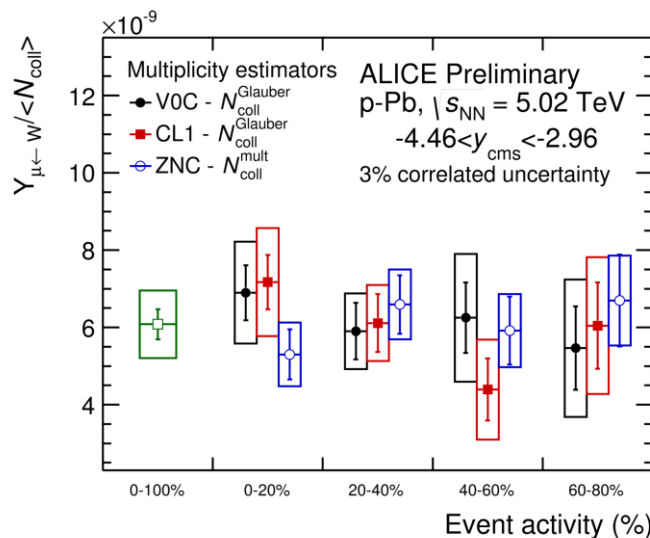
$R_{pPb} = 1$  at high  $p_T$ :

- for charged particles above 10 GeV/c
- for charged jets up to 100 GeV/c
- for open charm (D mesons)
- for heavy flavour lepton decays
- for  $W \rightarrow \mu$

ALI-PREL-80555



ALI-PUB-79458



ALI-PREL-80001

Particle production in p-Pb is scaled with binary collisions:

- no evidence of initial state effects
- spectra suppression in Pb-Pb is a final state effect (parton energy loss)

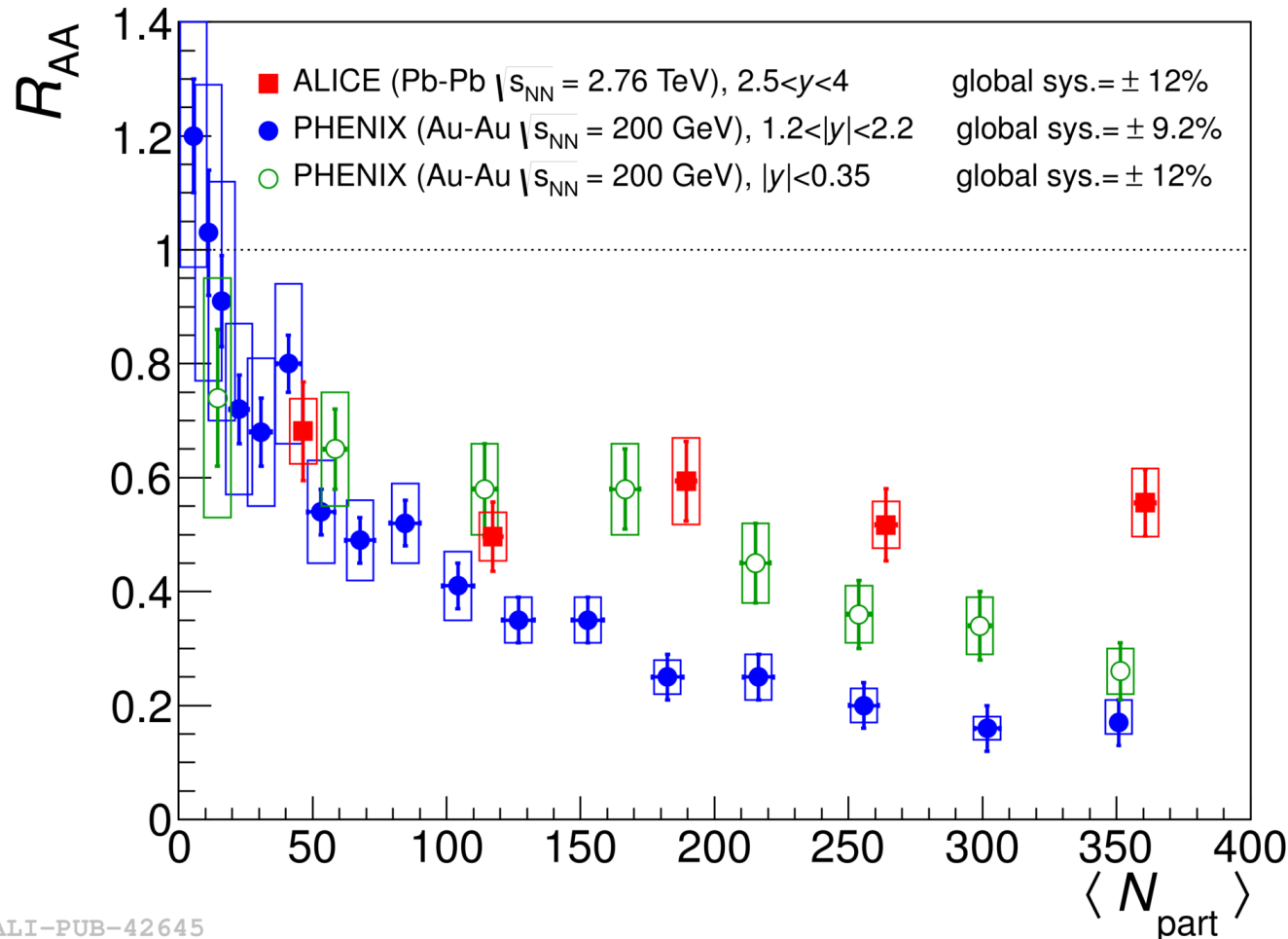


# Quarkonium

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# J/psi suppression in Pb-Pb

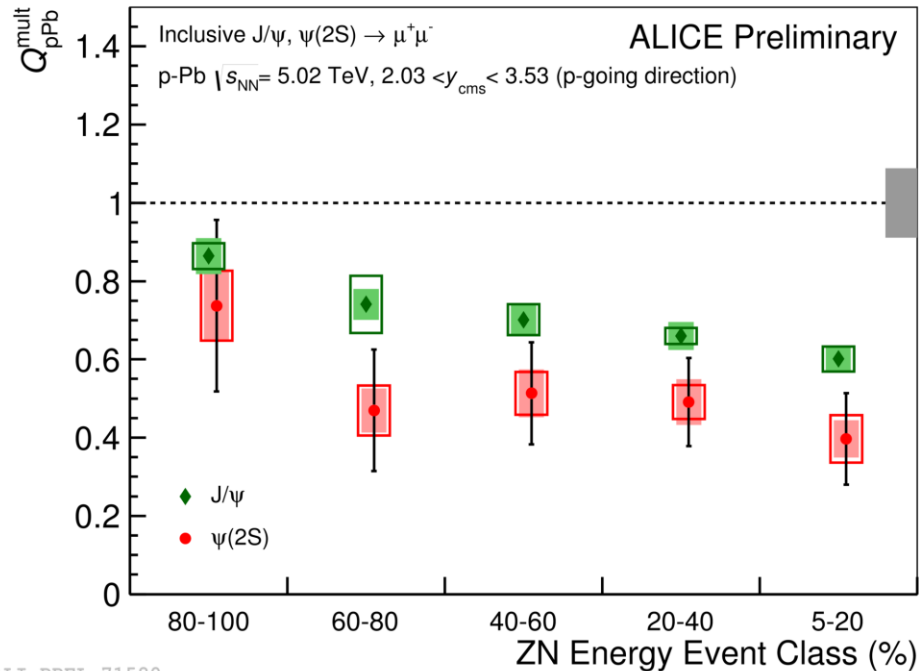


- J/psi “melts” in heavy-ion collisions from SPS to LHC
- However, suppression at LHC energy is less than at RHIC.
- In-medium  $c\bar{c}$  recombination?

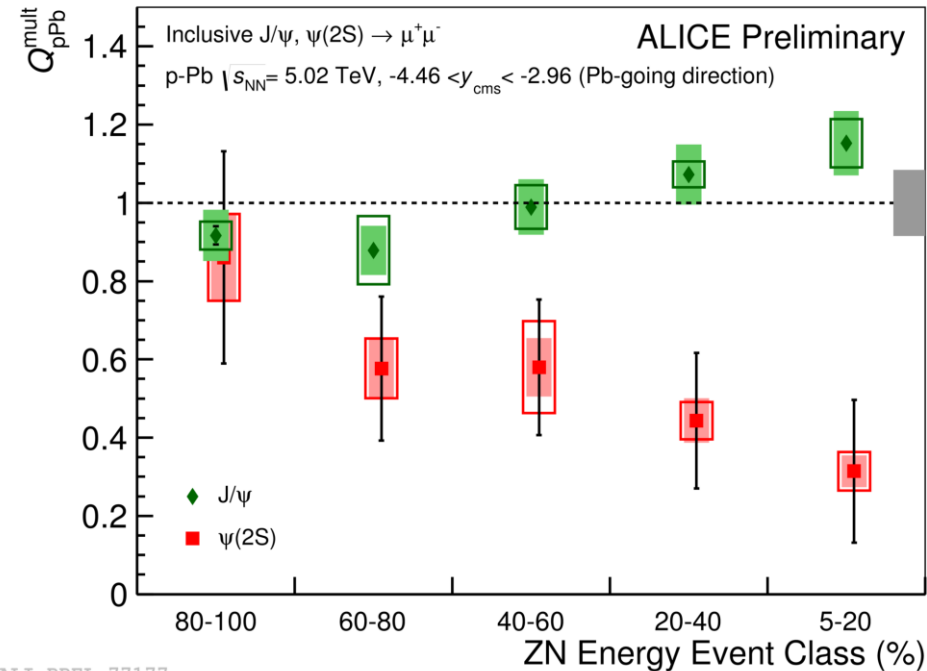
Phys. Rev. Lett. 109, 072301 (2012)

# J/ψ suppression in p-Pb

p-going direction



Pb-going direction



Multiplicity-dependent suppression for both  $J/\psi$  and  $\psi(2S)$

No suppression for  $J/\psi$ .  
 Multiplicity-dependent suppression  $\psi(2S)$ .



# Future ALICE

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# Plans for Run2 and Run3

- Run2 in 2015 – 2017
  - Complete geometry for all detectors
  - Upgraded detectors, readout, trigger
  - LHC energy up to 13 TeV for pp (~5.1 TeV for Pb-Pb)
  - Collect  $10 \text{ pb}^{-1}$  with pp rare triggers,  $70 \text{ nb}^{-1}$  with pp minimum bias trigger,  $1 \text{ nb}^{-1}$  with Pb-Pb.
- Run3 2020-2022 and beyond:
  - Major detector upgrade: new ITS and new TPC readout
  - Improvement in vertexing capability and tracking a low  $p_T$
  - Increase data-taking rate by factor 100! ( $\rightarrow 50\text{kHz}$  Pb-Pb)
  - Precision studies of charm and beauty mesons and baryons and quarkonia at low  $p_T$
  - Low mass lepton pairs and thermal photons
  - $\gamma$ -jet and dijets with particle identification in a large kinematic range
  - Heavy nuclear states

# Summary

## Hot QCD matter created in heavy ion collisions at LHC looks more and more interesting

- Particle yields in Pb-Pb are consistent with thermal model fit with  $T=156$  MeV
- Quantum statistics measurements extract size of the system at freeze-out: radial expansion in Pb-Pb, similarity in pp and p-Pb
- Significant progress in precision (spectra, PID  $v_2$ , D,  $J/\psi$ , ...)
- Better understanding of collective effects:  $v_2$  mass ordering for light and strange hadrons up to  $p_T < 2.5$  GeV/c. Flow is in agreement with hydrodynamics
- Mass seems to drive spectra and  $v_2$  up to  $\sim 4$  GeV/c in central collisions
- Wealth of new data of spectra suppression: LF, HF, jets

## **“Cold” nuclear matter in pA collisions is not so cold.**

- Similarity with Pb-Pb: thermal fits, radial expansion
- No indications of quenching at high  $p_T$  (charged hadrons, jets, open charm, heavy flavor electrons and muons).

More ALICE talks at this workshop:

- Diffraction physics with ALICE (S.Evdokimov, Tuesday)
- Direct photon and neutral pion production in pp and Pb-Pb with ALICE (D.Peressounko, Thursday)
- ALICE Fast Interaction Trigger detector (T.Karavicheva, Monday)