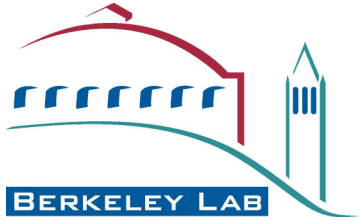
SELECTED

Multi-particle aspects of ~~heavy-ion~~ collisions with ALICE

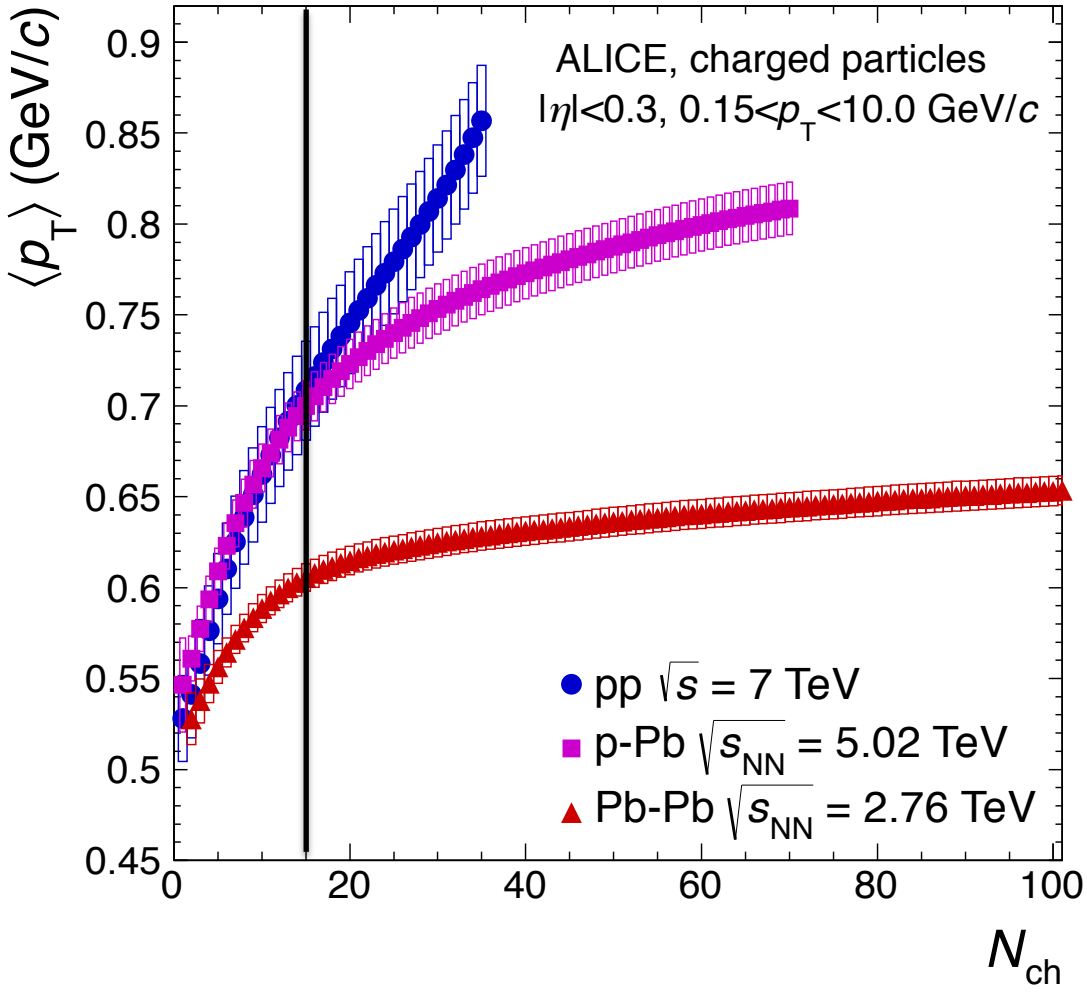
Mateusz Ploskon

ALICE Collaboration



Global event properties: mean p_T vs multiplicity

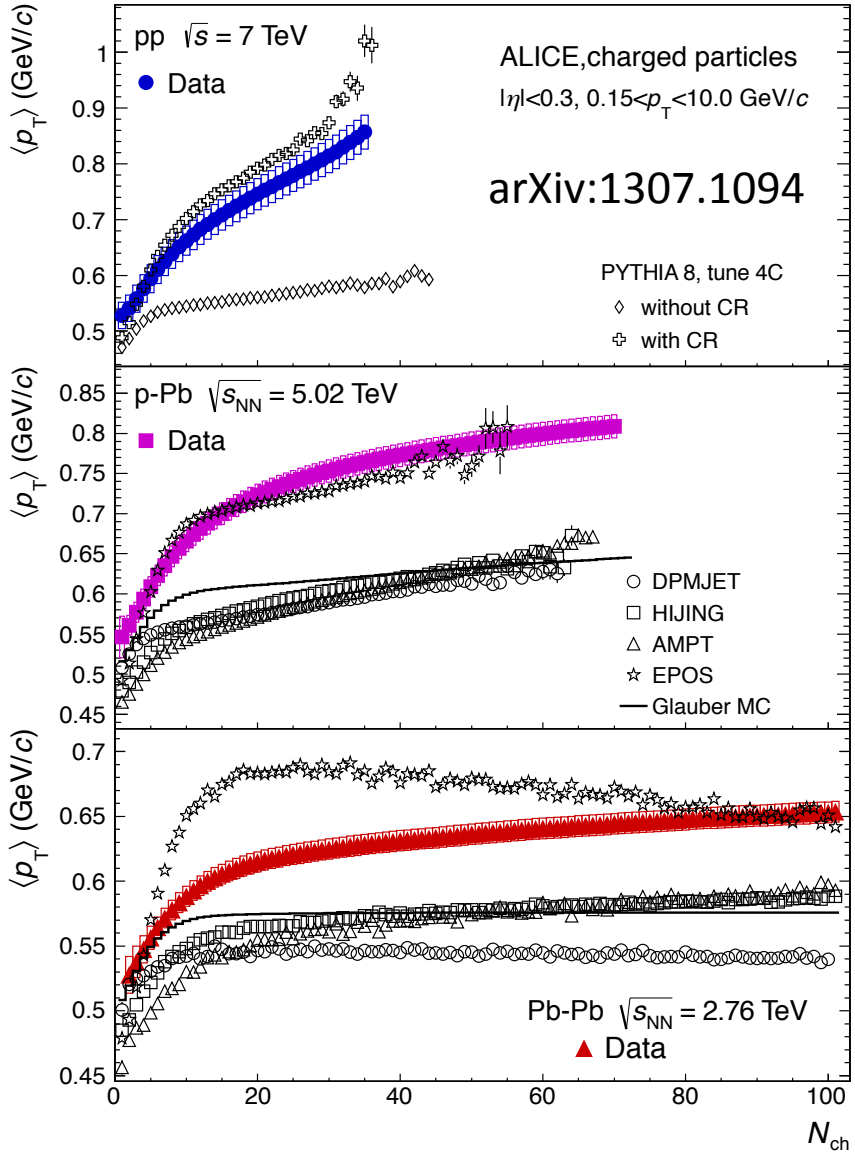
arXiv:1307.1094



Proton-proton and p-Pb follow the same trend up to **Nch~15**; however: this is **90% of pp x-section and 50% of p-Pb x-section** (different biases)

pp and p-Pb – much stronger increase than in Pb-Pb

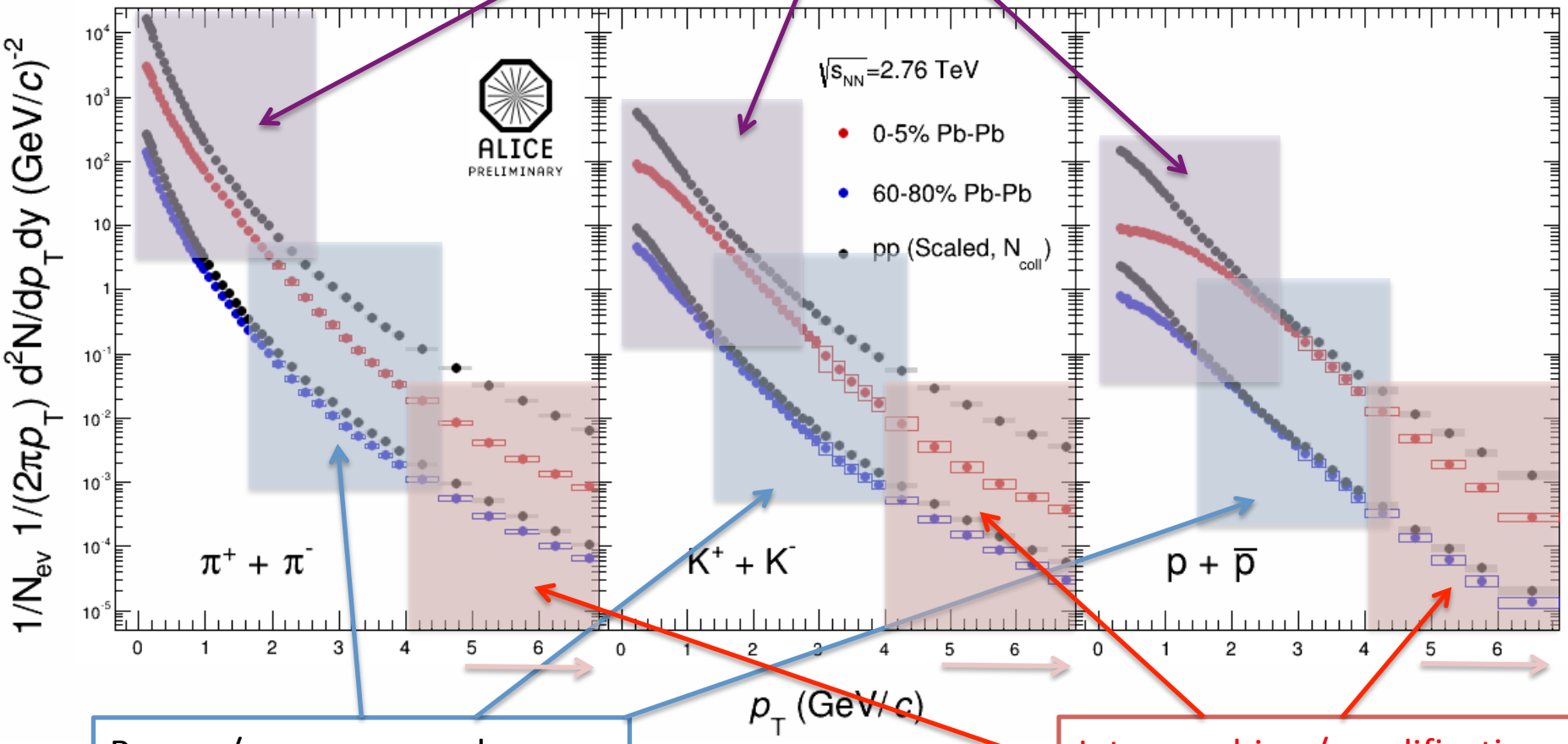
Global event properties: mean p_T vs multiplicity



- Proton-proton: PYTHIA - strong increase with N_{ch} attributed to **Color Reconnections** between hadronizing strings - a collective final state effect
- p-Pb:
  - Glauber MC (incoherent p-N's) using measured $\langle p_T \rangle$ in pp does not work
  - Coherent effects via strings from different pN?
  - EPOS includes collective effects.
- Pb-Pb: DPMJet gets trend right. EPOS has different shape for very peripheral collisions.

Pion/Kaon/Proton in pp and Pb-Pb

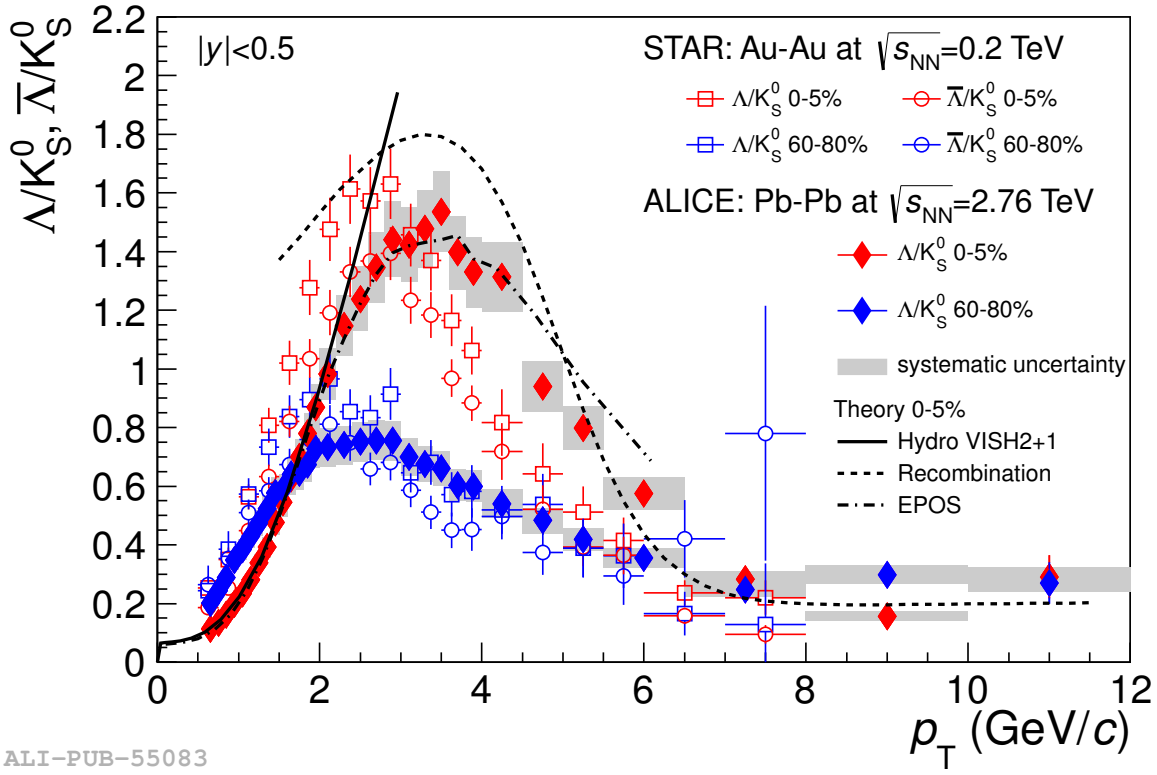
Radial flow (mesons – protons – mass dependence)



Baryon/meson anomaly
- Radial flow / recombination?

Jet quenching / modifications of jet fragmentation?

Λ/K^0 in Pb-Pb collisions

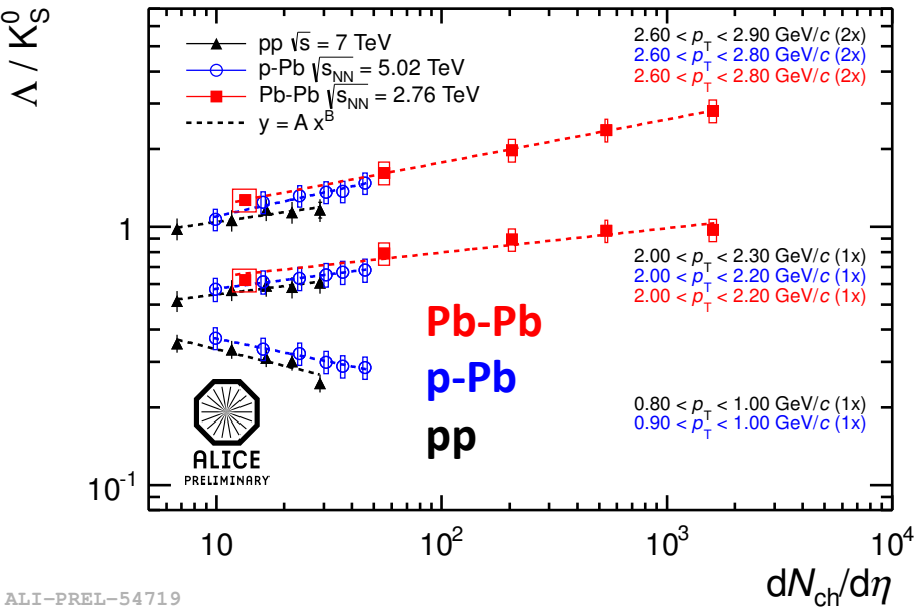


Submitted
arXiv 0764109

- Integrated ratio independent of centrality (Λ/K^0_s ~ 0.25)
- Intermediate p_T: Λ/K^0_s ratio enhanced in central Pb-Pb
  - consistent with radial flow
- High-p_T: ratio consistent with vacuum-like fragmentation.

NB: Identified particles in p-Pb

Lambda/Kaon ratio vs. charged particle multiplicity density $R = A(\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta)^{\mathrm{B}}$



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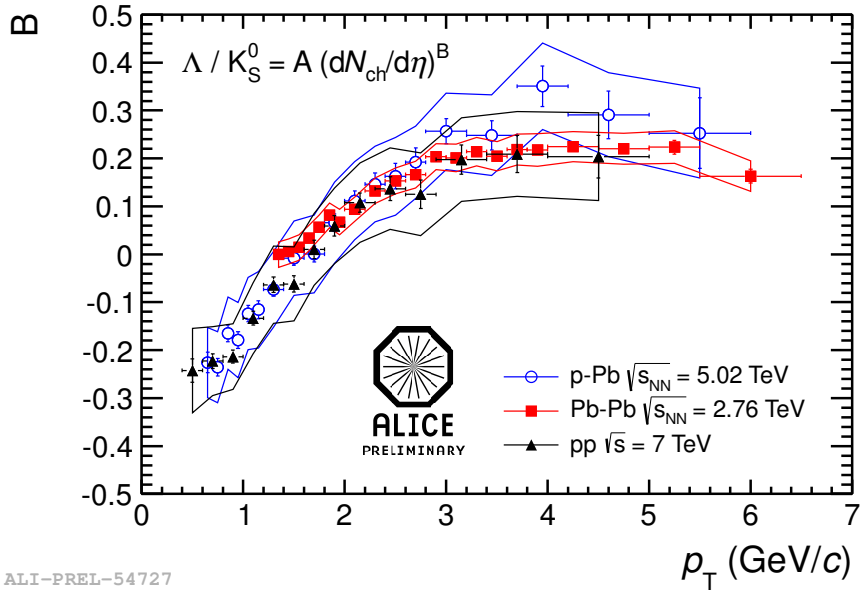

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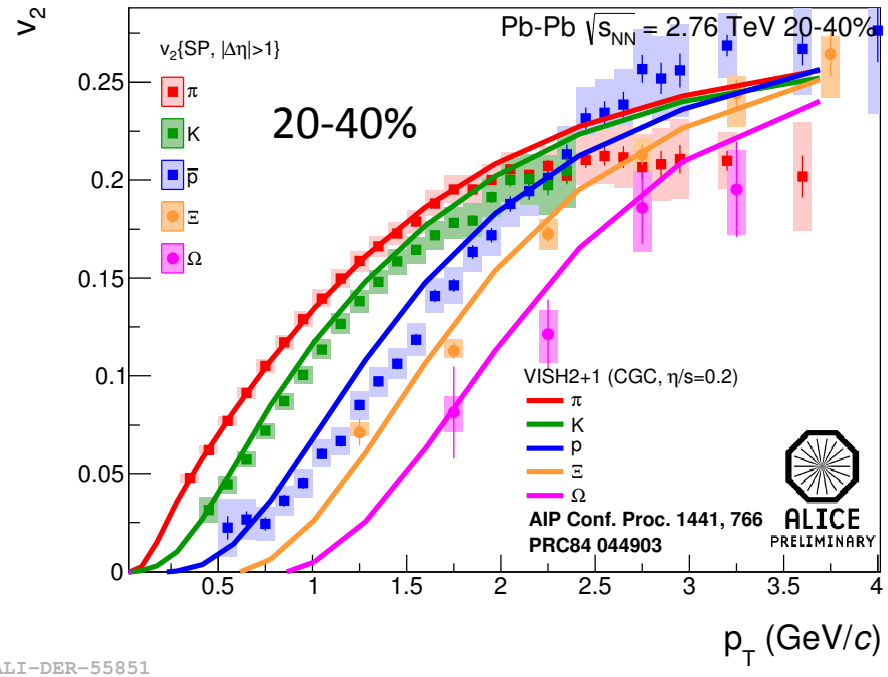
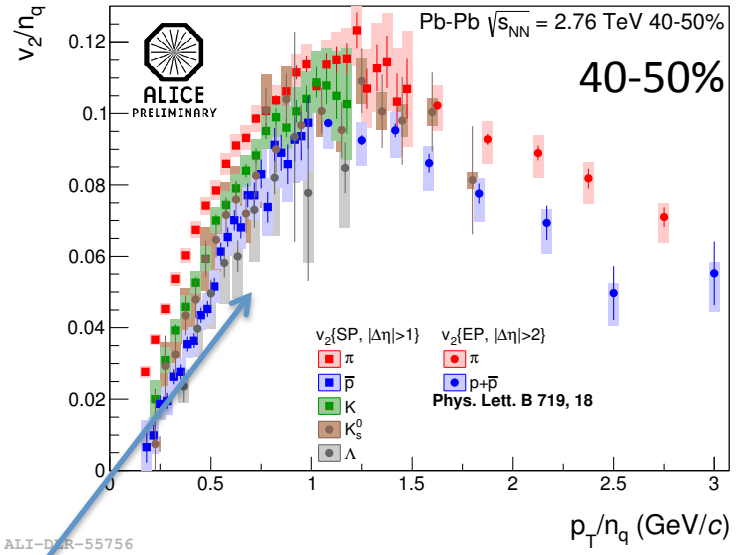
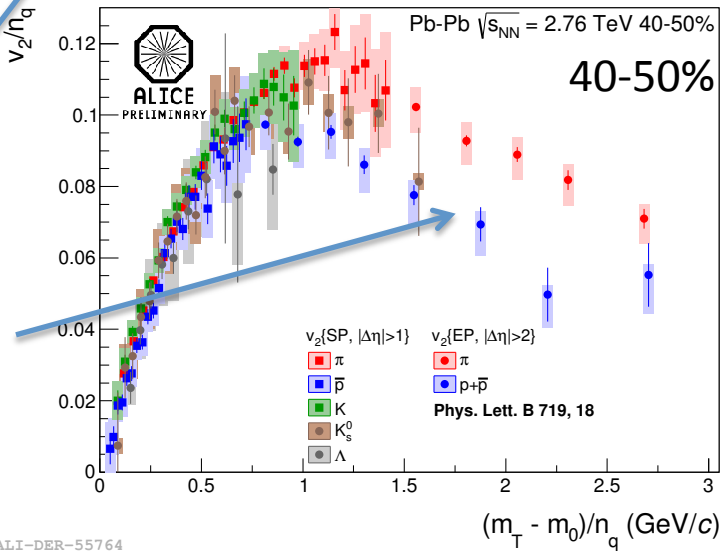
- Baryon to meson ratio:
  - **similar trend of p/pion ratio in p-Pb as in Pb-Pb per $dN_{ch}/d\eta$**
  - follows a **power-law with a same exponent B(p_T)** in two systems (although in p-Pb much smaller than in Pb-Pb case) - similar case for proton/pion ratio
  - **Same trend in proton-proton collisions**

Collective flow of identified particles

- Mass ordering for multi-strange baryons
  - Described by hydrodynamical model(s)







- v_2/n_q scaling at the LHC less obvious (within ~20%)
- For $(m_T-m_0)/n_q$>1 GeV/c v_2 of p is lower than of π

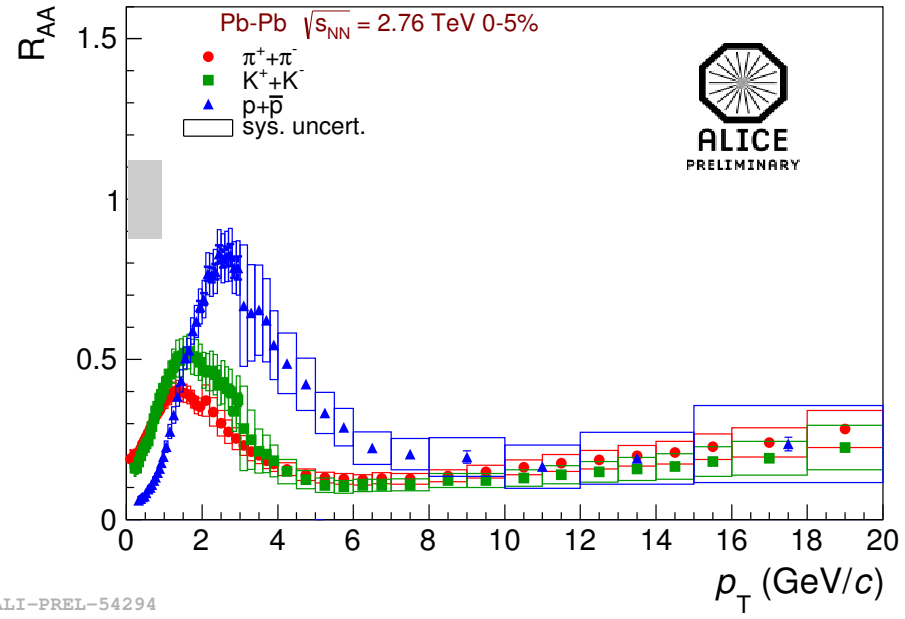
Not shown: v3(p_T) – mass ordering reproduced by hydro; pion-proton intersect – expected from coalescence

COLLECTIVE FLOW AND JET QUENCHING

v_2 at high-p_T and R_{AA}

Jet quenching and non-zero v_2 are closely related – signature of the physical properties of QGP:

- QGP is opaque to colored probes
- In-medium energy-loss depends on the path length



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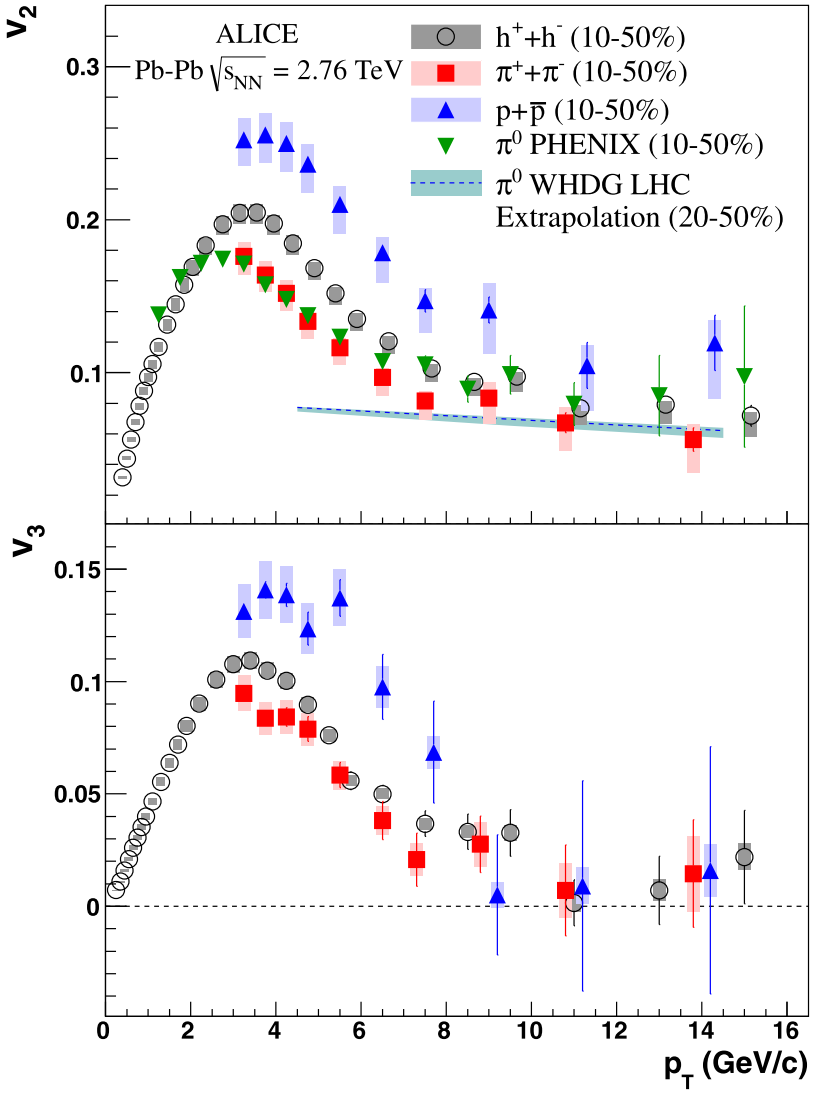
Physics Letters B 719 (2013) 18–28



News from R_{AA} of identified particles

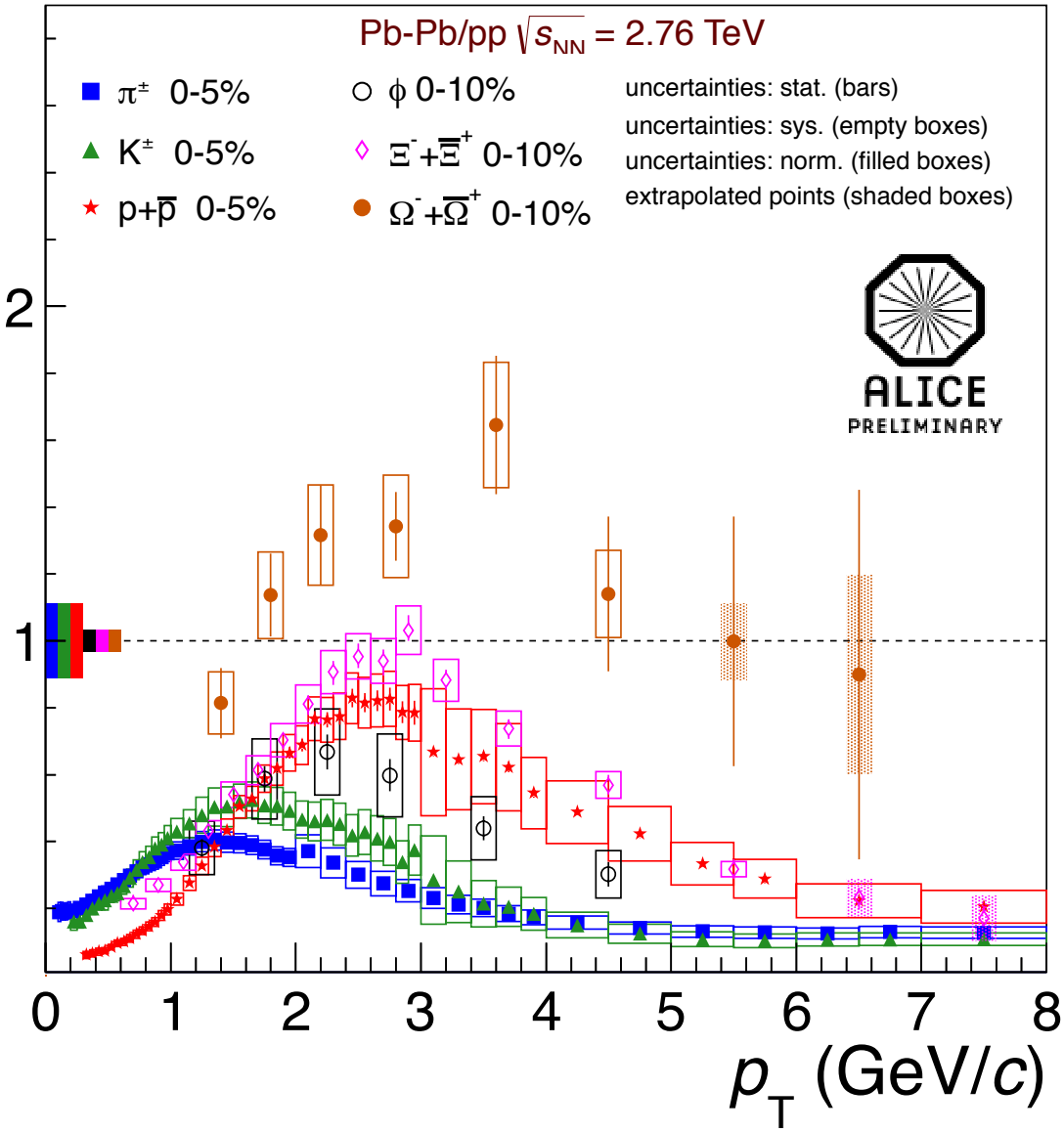
Same R_{AA} for π, K, p at high-p_T within uncertainties AND D-mesons

ϕ in 0-10%:

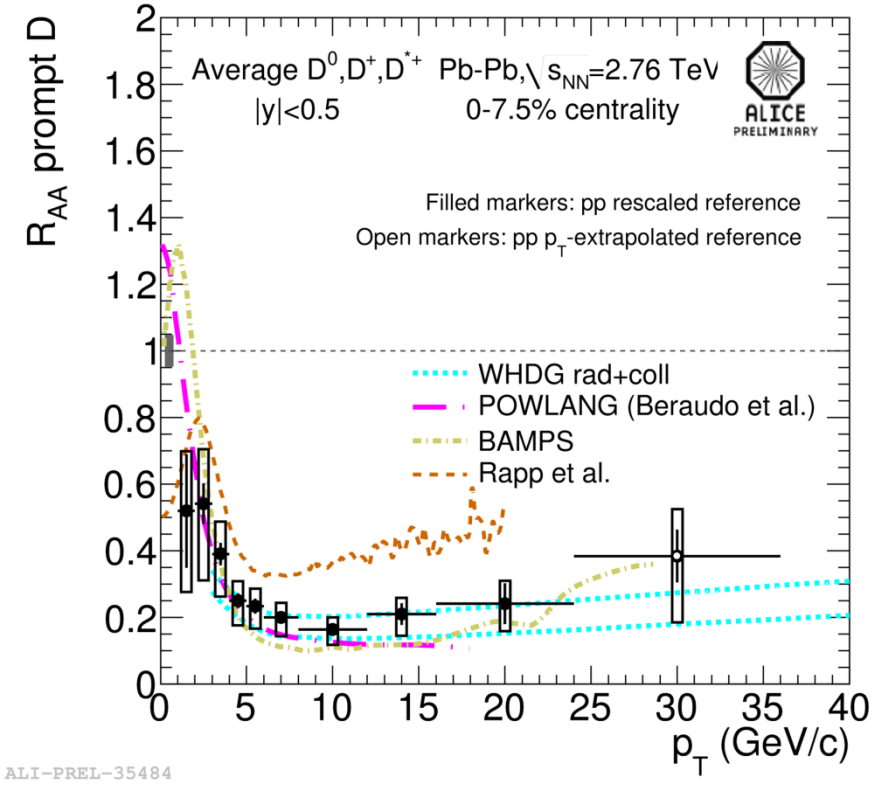
- **Similar to proton below 2 GeV/c**
- **Between pion and proton above 2 GeV/c**

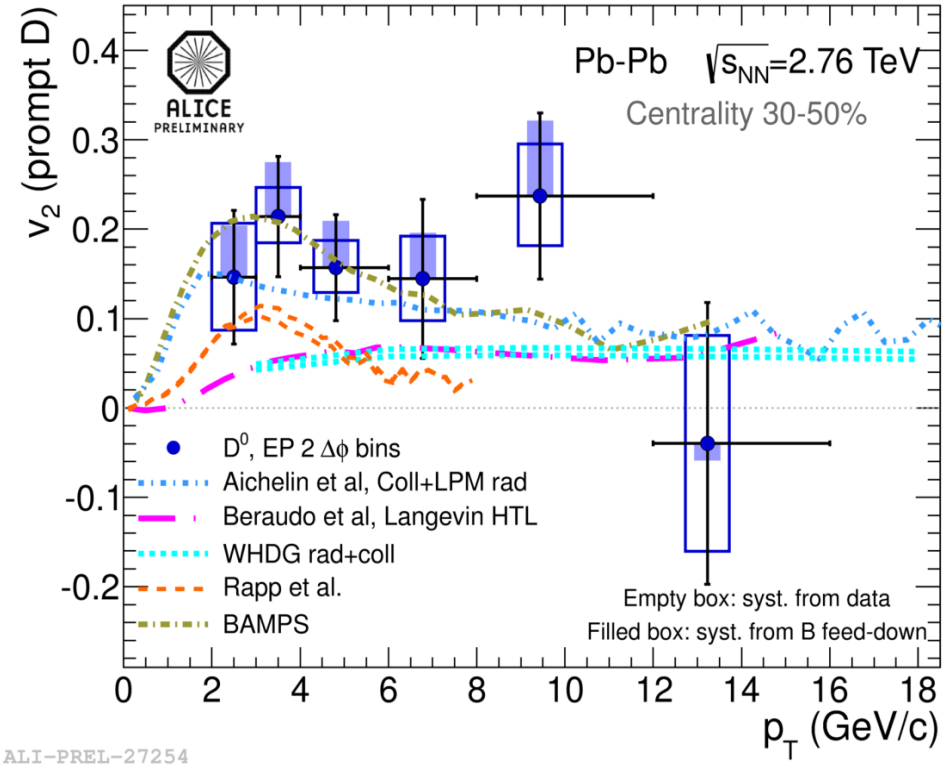
Ξ R_{AA} compatible with protons

Ω – large R_{AA} consistent with enhancement in HI collisions; however, largely due to the suppression in pp



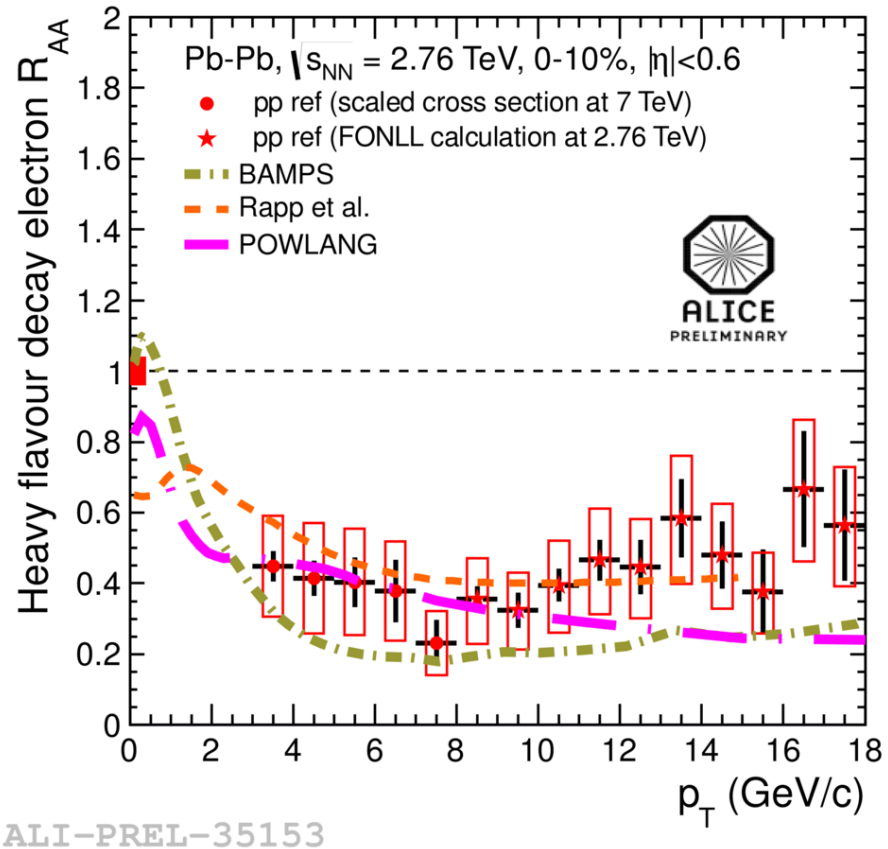
Challenge for theory – consistent description of charm production and its v_2

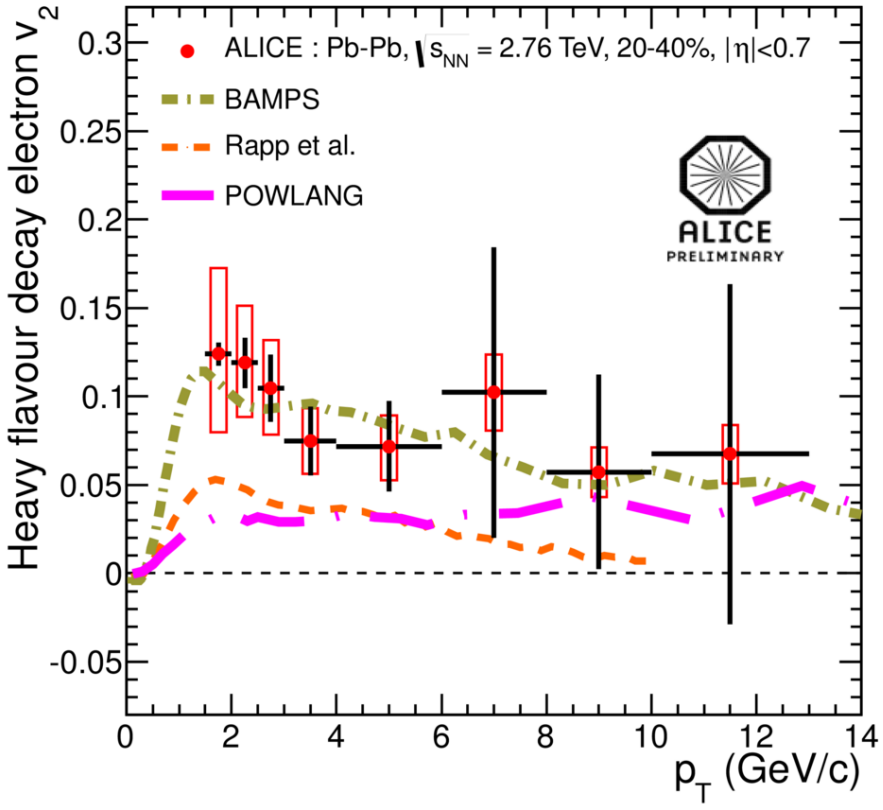




- **The simultaneous description of D meson R_{AA} and v_2 is a challenge to theoretical models**

Challenge for theory – consistent description of HFE and its v_2

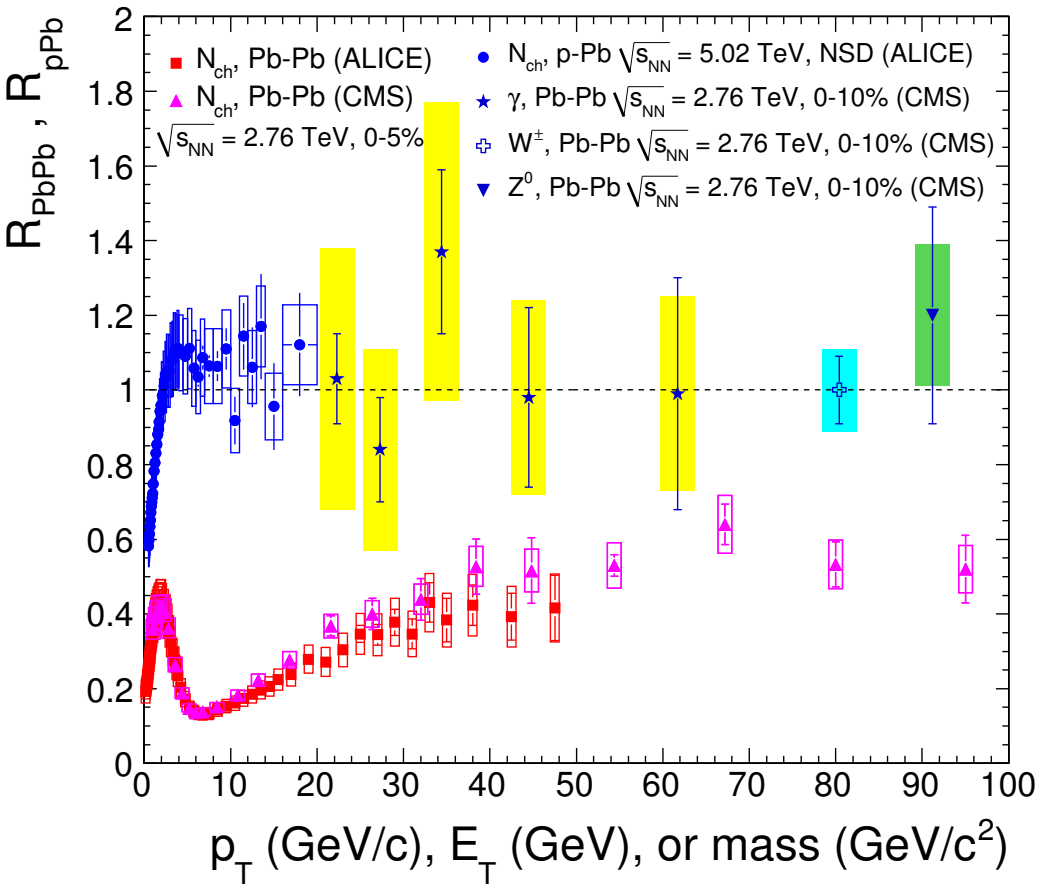




ALI-PREL-35153

- The simultaneous description of heavy flavor decay electrons R_{AA} and v_2 is a challenge to theoretical models
- Not shown: J/ψ: $v_2 > 0$ at LHC; R_{AA} LHC > R_{AA} RHIC for most central events

On the other hand: $R_{pPb} = 1$

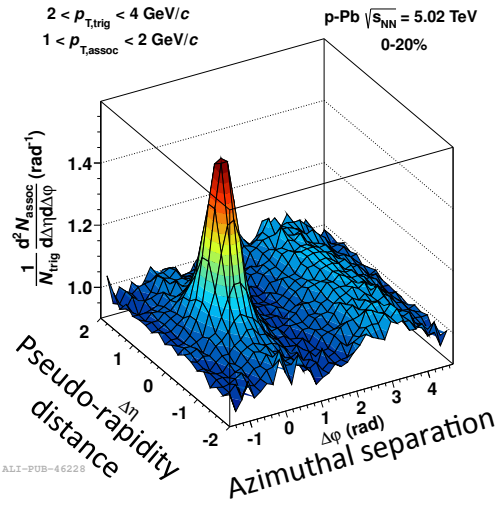


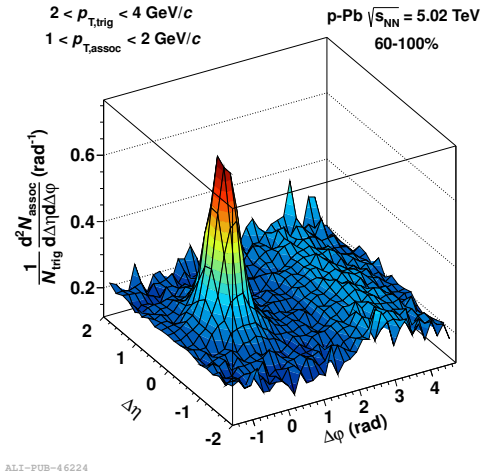
ALICE: Phys.Lett. B 720 (2013) 52-62; Phys.Rev.Lett. 110 (2013) 082302
CMS: Eur.Phys.J. C72 (2012) 1945; Phys.Lett. B710 (2012) 256-277;
Phys. Lett. B 715 (2012) 66-87; PAS HIN-13-004

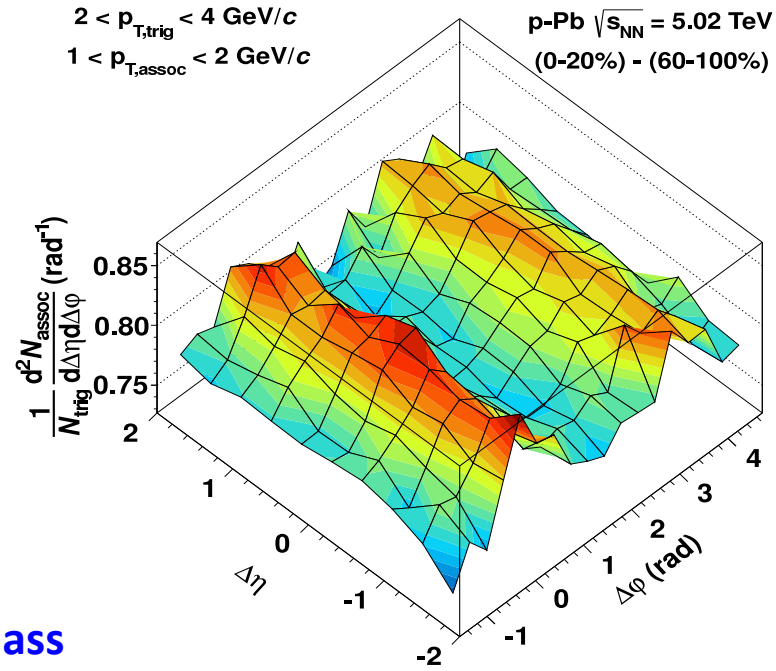
Two-particle correlations in p-Pb

ALICE: arXiv:1212.2001

The method: from the high-multiplicity yield subtract the jet yield in low-multiplicity events (no ridge)







High multiplicity event class

$\langle dN_{ch}/d\eta \rangle \sim 35$

Low multiplicity event class

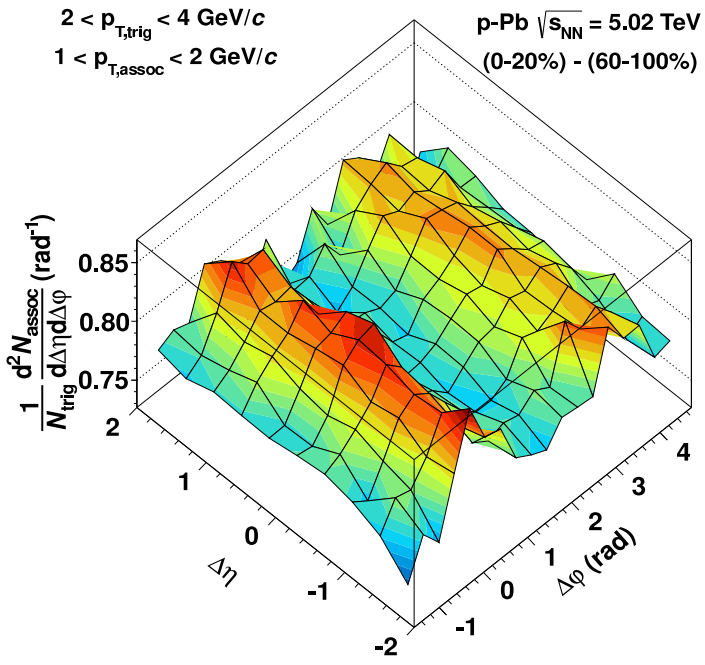
$\langle dN_{ch}/d\eta \rangle \sim 7$

Remaining correlation: two twin long range structures

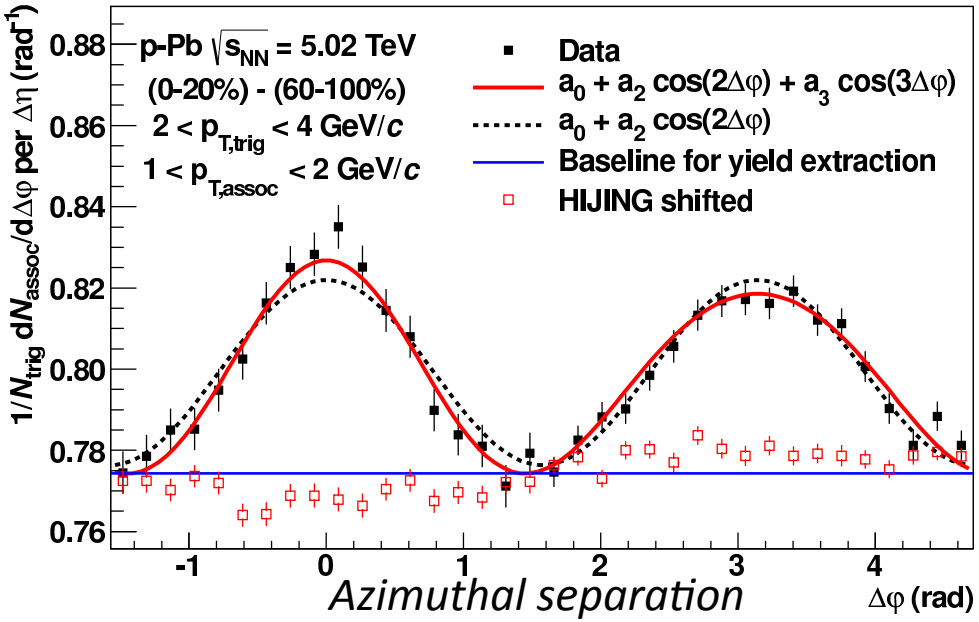
Analysis in multiplicity classes defined by the total charge in VZERO detector (away from the central region)

Twin ridge structure in p-Pb

ALICE: arXiv:1212.2001



Remaining correlation described by finite amplitudes of Fourier terms



Further investigations reveal:

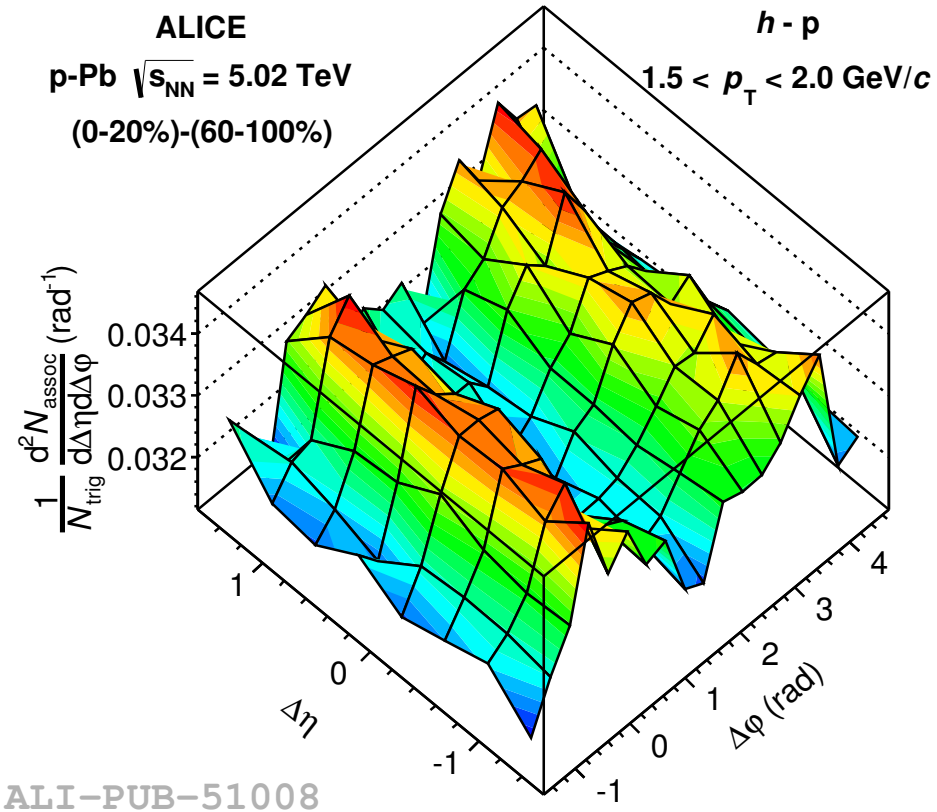
- the full modulation is (1) di-jets and (2) the double-ridge structure – nothing more
- Same yield near and away side for all classes of p_T and multiplicity suggest a common underlying process

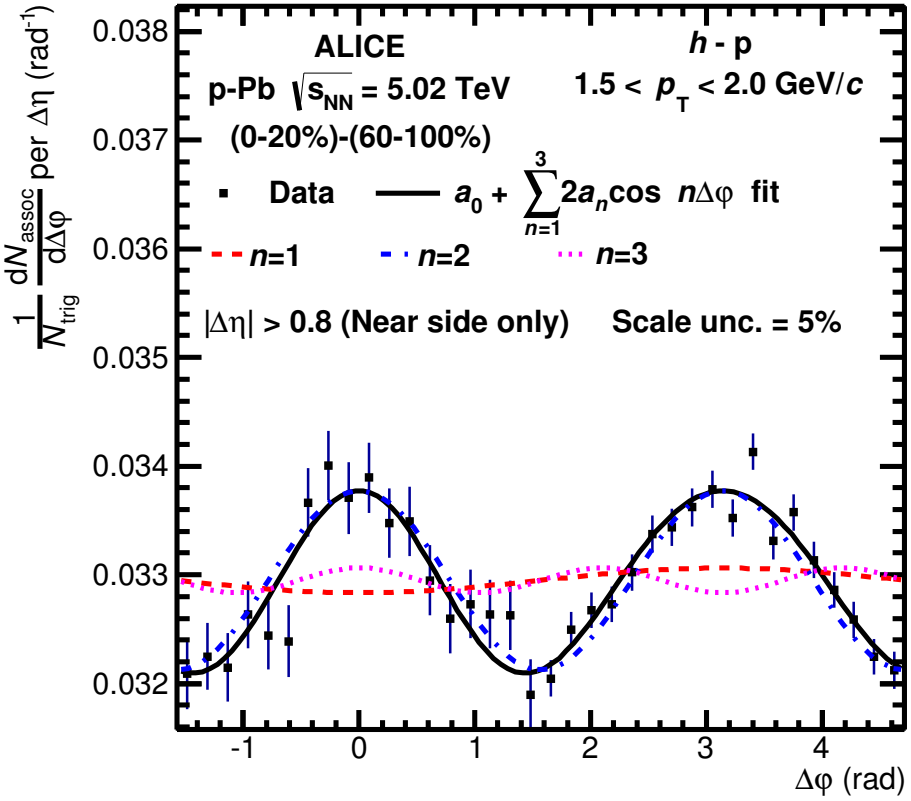
Similar observations in Pb-Pb are ascribed to collective effects!

Number of explanations put forward raging from hydrodynamic flow to CGC formalisms

Twin ridge structure in p-Pb with identified particles

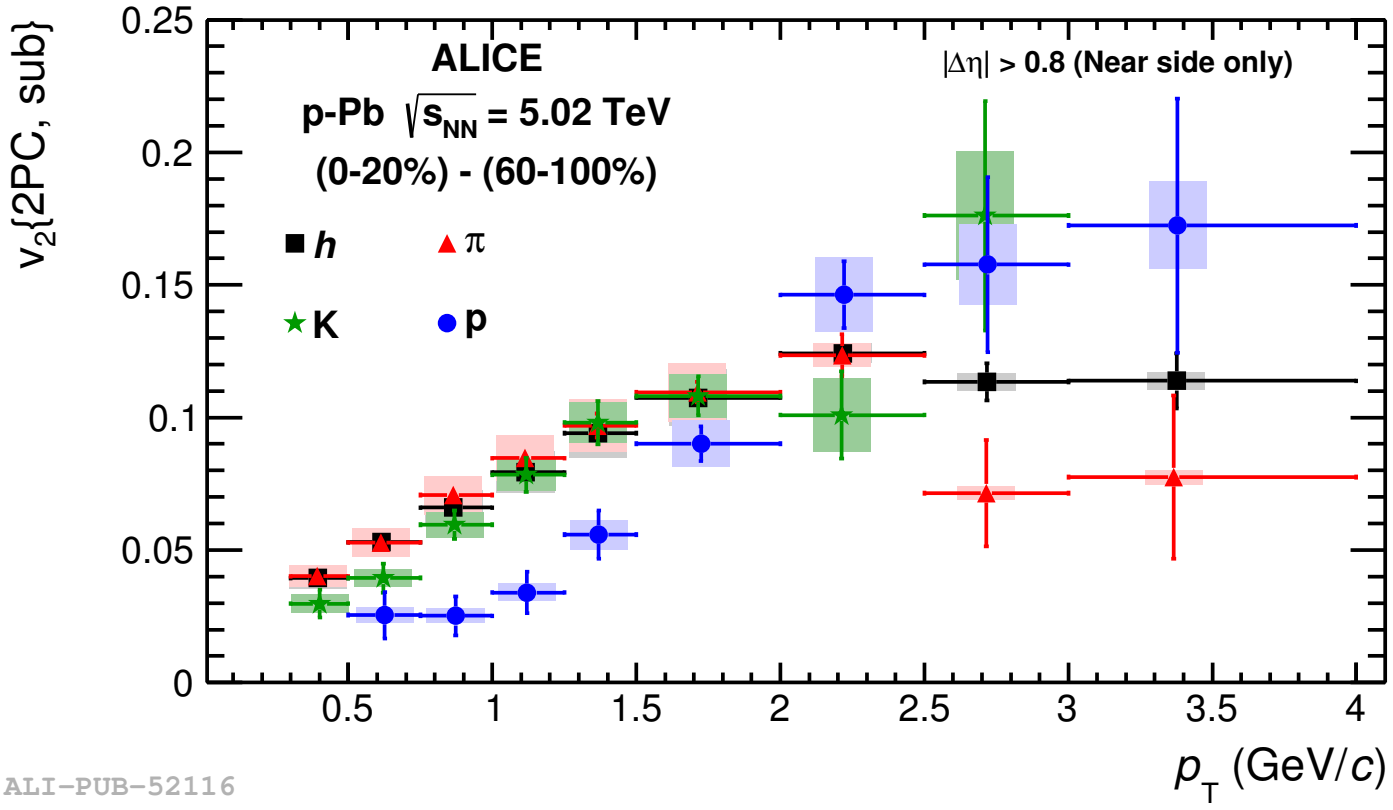
Shown here: hadron-proton correlation (high-low mult. percentile subtracted)





Jet peak excluded: $\Delta\eta < 0.8$

v_2 coefficient in p-Pb

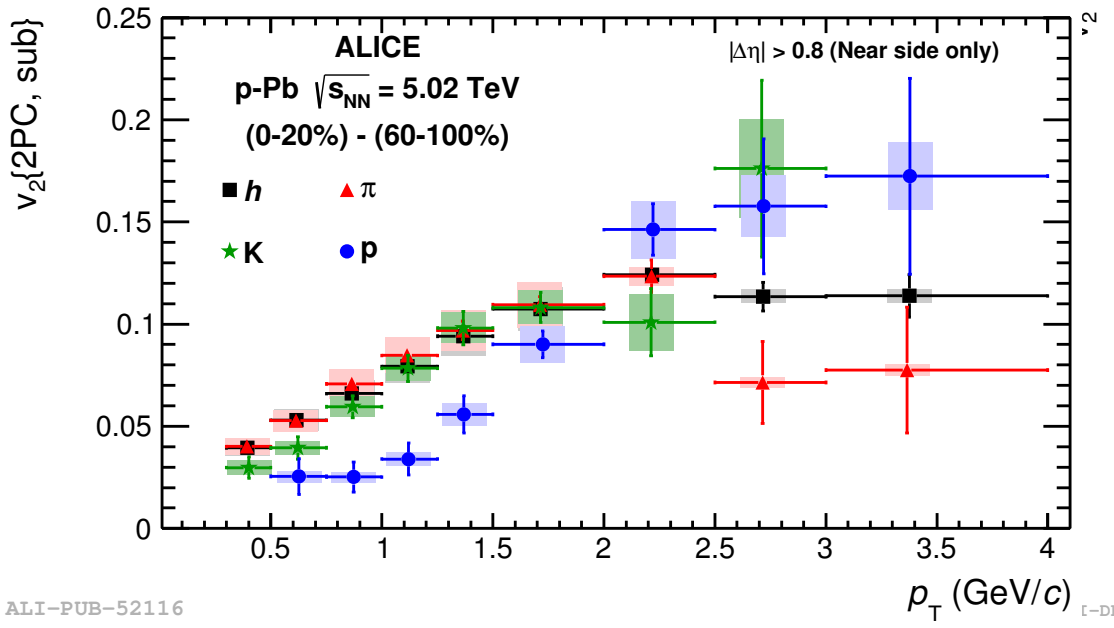


Mesons (pions and kaons) following the same trend (< 2.5 GeV/c)

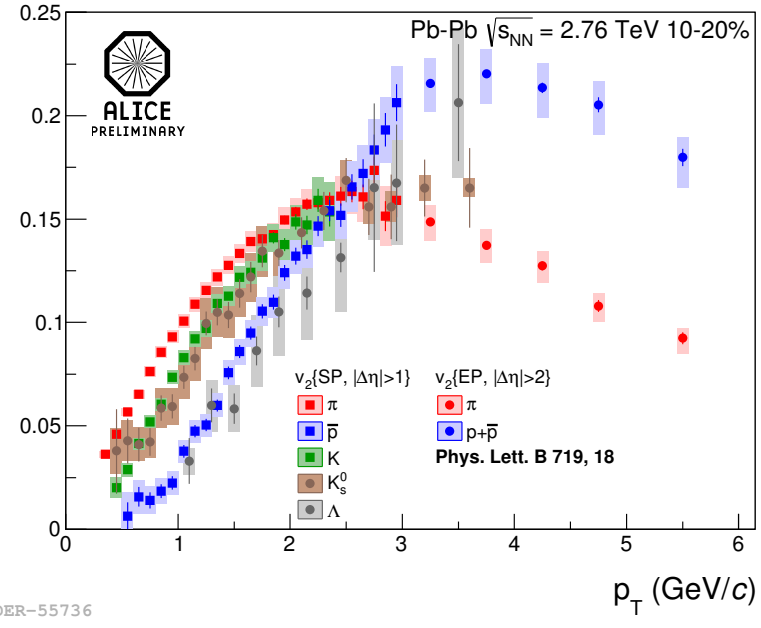
Intersection with protons ~2 GeV/c

Comparison of v_2 in Pb-Pb and p-Pb

High-multiplicity p-Pb collisions



10-20% Pb-Pb



Similar features in p-Pb and Pb-Pb: mass ordering at low-p_T
- in Pb-Pb ascribed to hydrodynamics

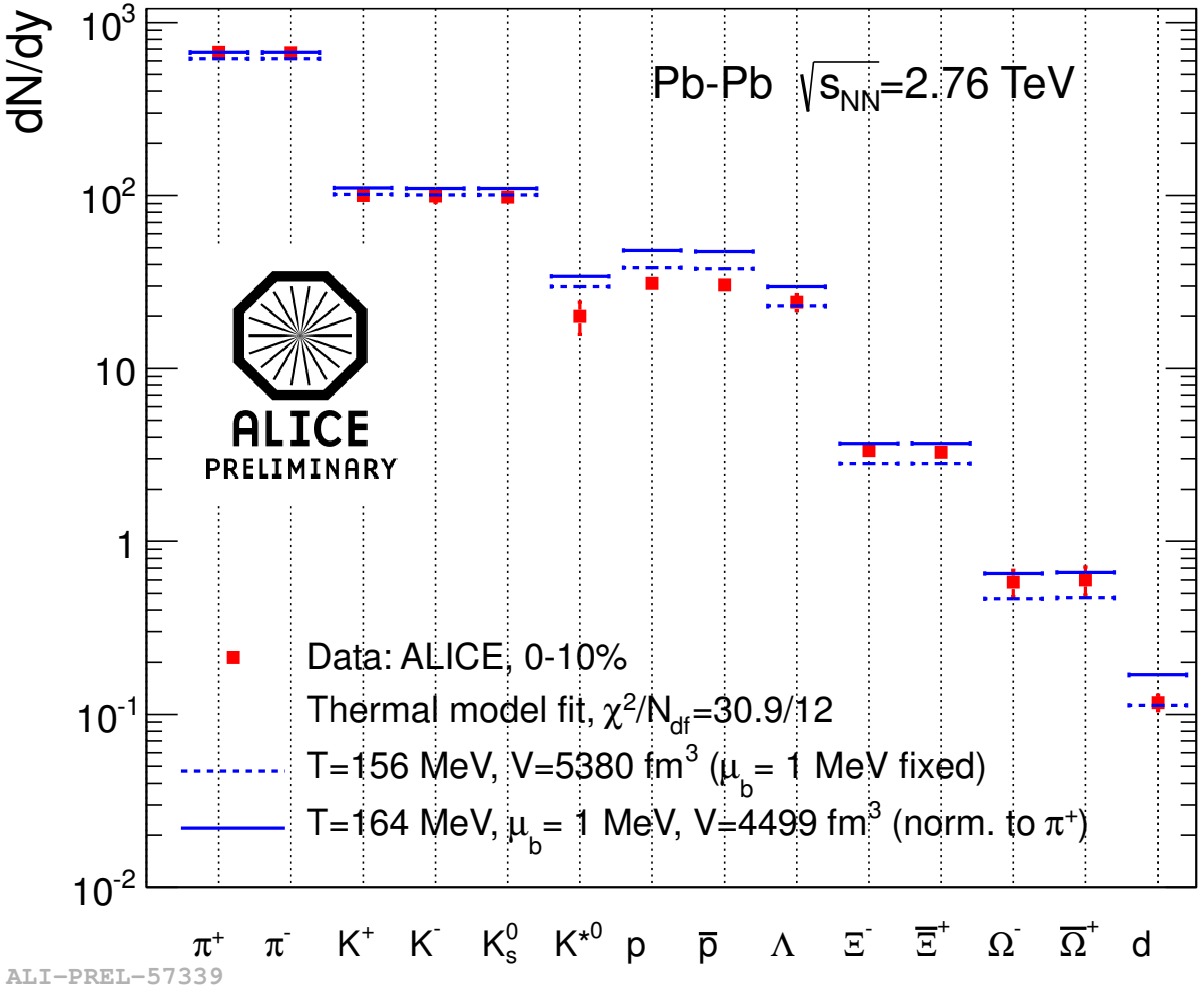
Summary & outlook

- QGP is opaque to colored probes
- Collective flow measured for identified particles in Pb-Pb collisions; features consistent with hydronynamical nature of QGP (RHIC: even at lowest $\sqrt{s_{NN}}$)
- Measurements of v_2 and R_{AA} – complementary observables – discriminating input to theory
- Min. bias collisions of p-Pb confirm jet quenching in Pb-Pb is a final state effect
- However, finite v_2 is found in most violent p-Pb collisions and v_2 for identified particles resembles findings from Pb-Pb collisions
- Similar features for particle ratios vs. p_T are found in pp p-Pb and Pb-Pb collisions – another universal feature?
- Wealth of results – interesting learning curve ahead!

ALICE

EXTRA SLIDES

Thermal fits



ALI-PREL-57339

Remaining data-fit tension – possible contributions:

- late stage baryon-antibaryon annihilation (specifically p-pbar)
- sequential freeze-out of different different quark flavours
- non-equiibrium freezeout conditions
- Unknown/unmeasured baryon resonance spectrum proton