Heavy ion physics experimental overview

裴 骅

华中师范大学

Many probes to study QGP medium

- In-medium parton energy loss
  - Jet
  - Strangeness
  - Heavy flavor hadrons
- Collective motion
  - Flow
- Smaller systems as reference

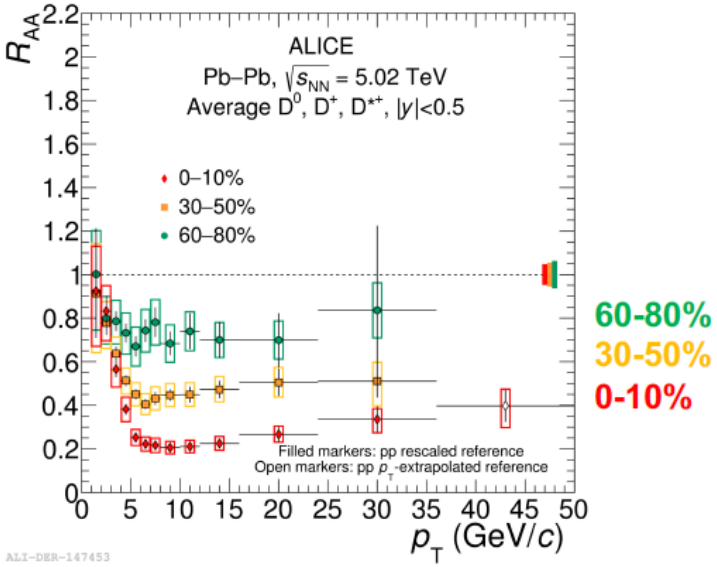
- What we need: a consistent implementation of experimental data, a full theory

Heavy flavours in medium

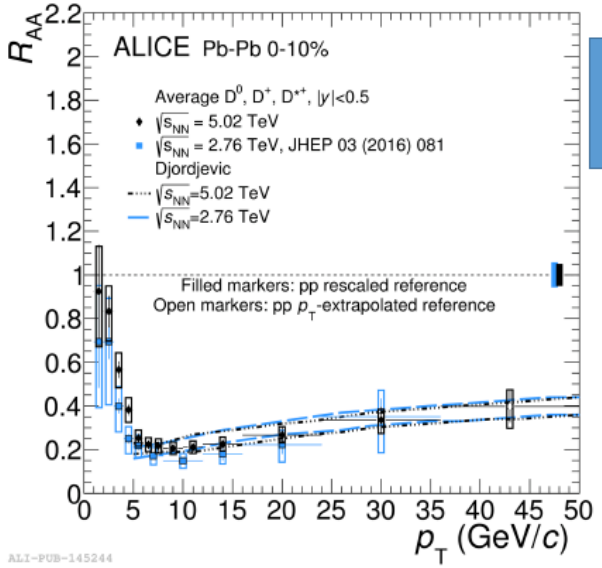
In-medium parton energy loss: gluon radiation and elastic collisions

By color charge (Casimir factor) and quark mass, it is expected that:

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ → $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?



60-80%
30-50%
0-10%



Improved precision in Run-2 with respect to Run-1 measurements

Published!

0-10%

Work of Xinye Peng

- Strong of suppression of non-strange D meson in Pb-Pb, increasing with centrality

JHEP 1810 (2018) 174

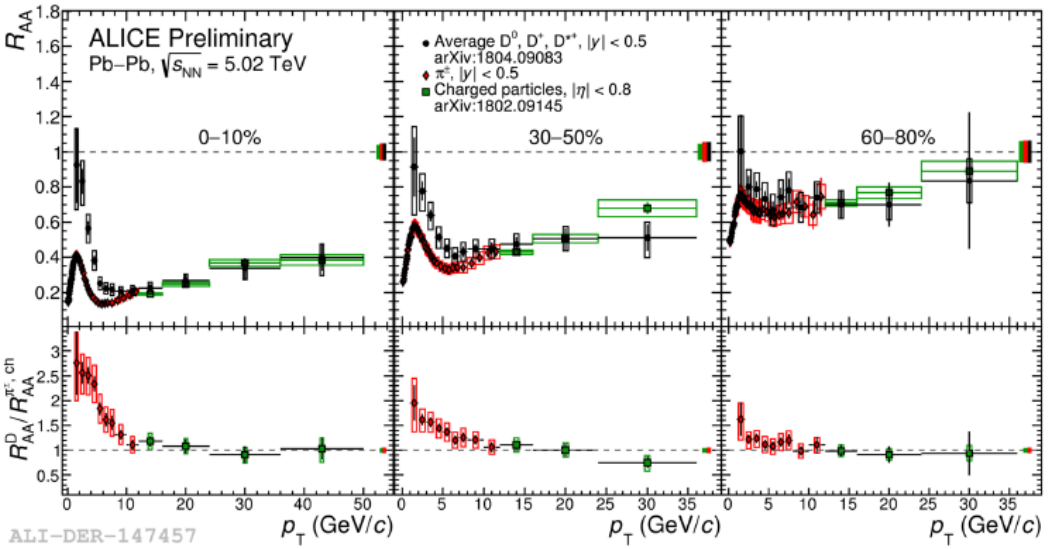
$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

Heavy flavours in medium

In-medium parton energy loss: gluon radiation and elastic collisions

By color charge (Casimir factor) and quark mass, it is expected that:

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ ⇒ $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?



Published!

$\pi^{\pm}$ ALICE preliminary

Charged-particle: arXiv:1802.09145

JHEP 1810 (2018) 174

Work of Xinye Peng

- Strong of suppression of non-strange D meson in Pb-Pb, increasing with centrality
- Similar as π and chaged-particle R_{AA} at high p_T

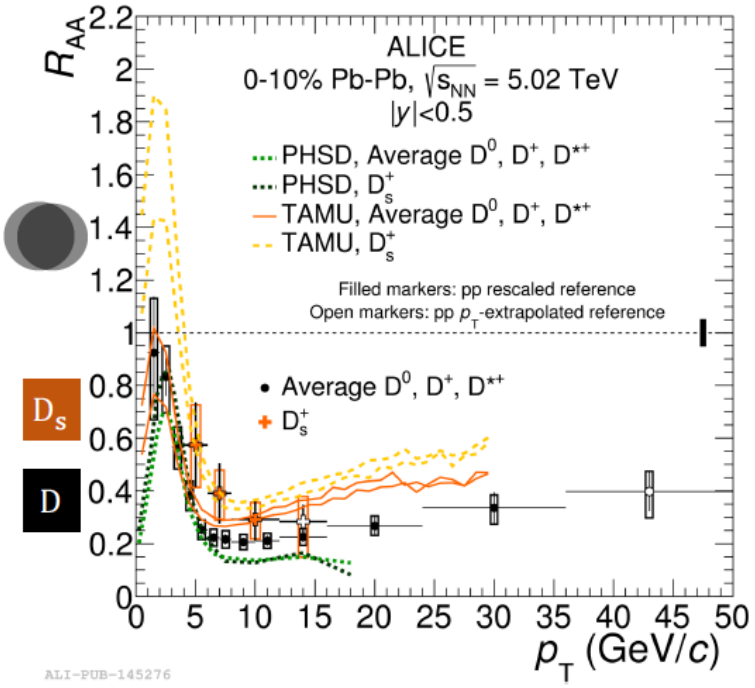
$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

Heavy and strange in medium

In-medium parton energy loss: gluon radiation and elastic collisions

By color charge (Casimir factor) and quark mass, it is expected that:

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ → $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?



JHEP 1810 (2018) 174

- Hint of enhanced Ds production vs. non-strange D mesons
- Effect of coalescence + strange enhancement ?

PHSD: Phys. Rev. C93 no. 3, (2016) 034906
TAMU: Phys.Lett. B735 (2014) 445–450
Catania: Eur.Phys.J.C (2018) 78:348

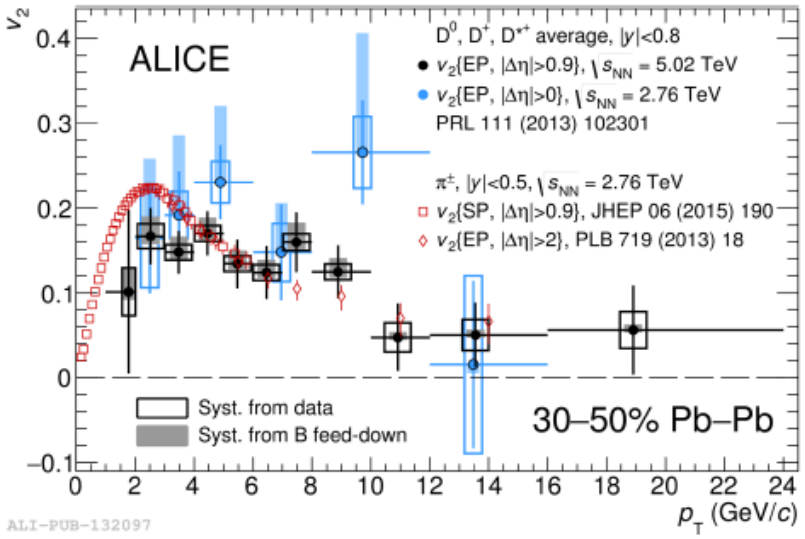
Work of Xinye Peng

$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

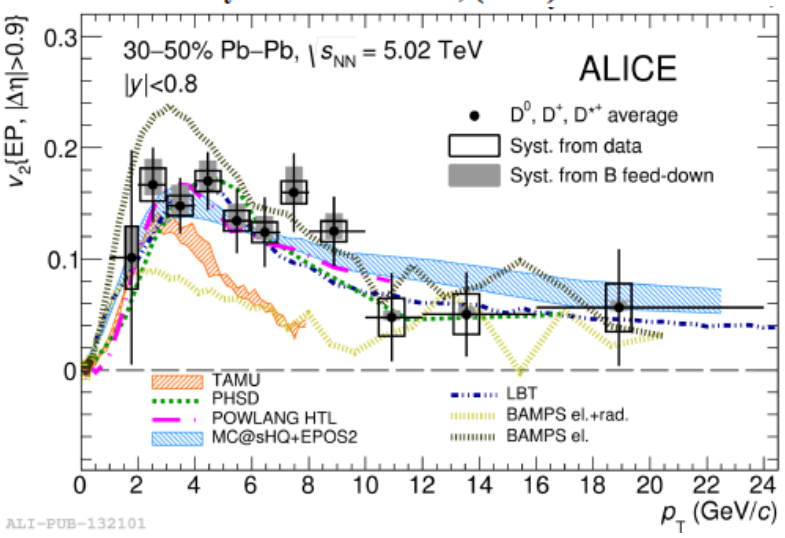
(Even) Heavy can flow in medium

Phys. Rev. Lett. 120 (2018) 102301

Work of Xinye Peng



POWLANG: Eur. Phys. J. C75 no. 3, (2015) 121
MC@sHQ: Phys.Rev. C89 no. 1, (2014) 014905
LBT: Phys. Lett. B777 (2018) 255–259
BAMPS: J. Phys. G42 no. 11, (2015) 115106
PHSD: Phys. Rev. C93 no. 3, (2016) 034906



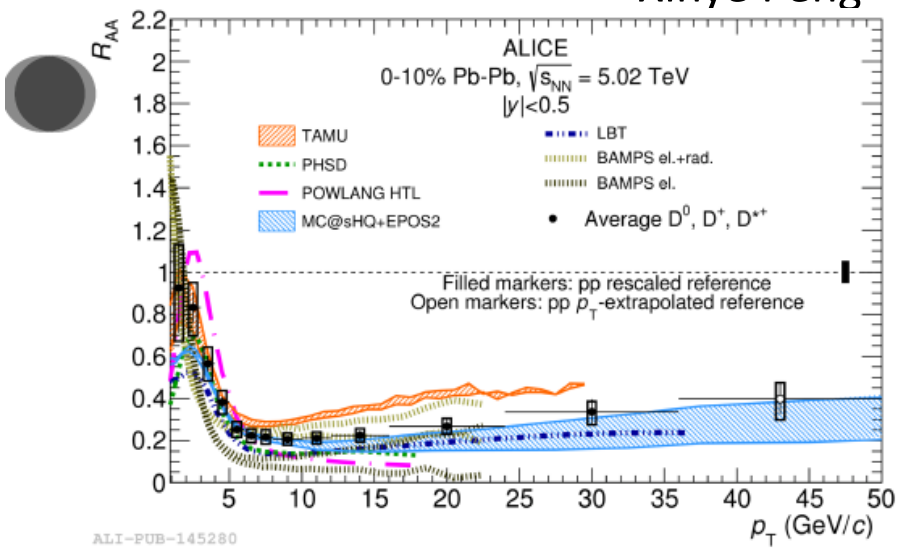
- Positive D-meson v_2
- Indication of charm quark sensitiveness to medium collective motion
- First measurement of D_s^+ v_2
- Similar to that of charged pions

$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

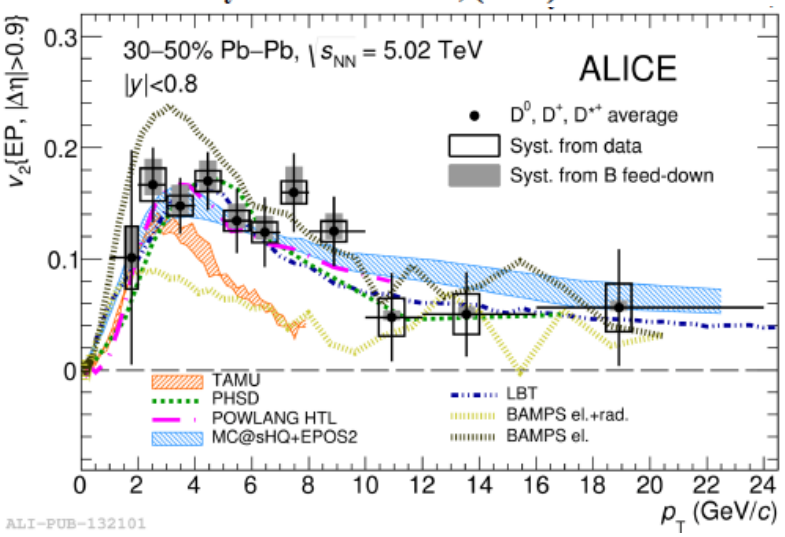
(Even) Heavy can flow in medium

Phys. Rev. Lett. 120 (2018) 102301

Work of
Xinye Peng



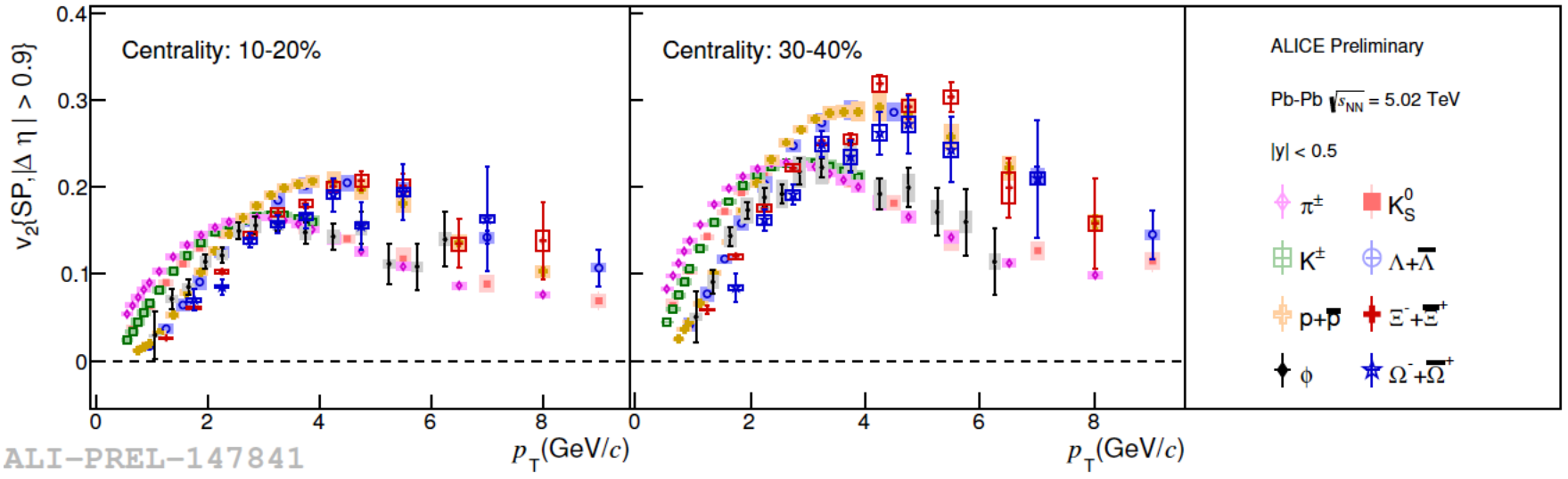
POWLANG: Eur. Phys. J. C75 no. 3, (2015) 121
MC@sHQ: Phys.Rev. C89 no. 1, (2014) 014905
LBT: Phys. Lett. B777 (2018) 255–259
BAMPS: J. Phys. G42 no. 11, (2015) 115106
PHSD: Phys. Rev. C93 no. 3, (2016) 034906



- R_{AA} and flow better described via
  recombination or subsequent elastic collisions in expanding medium

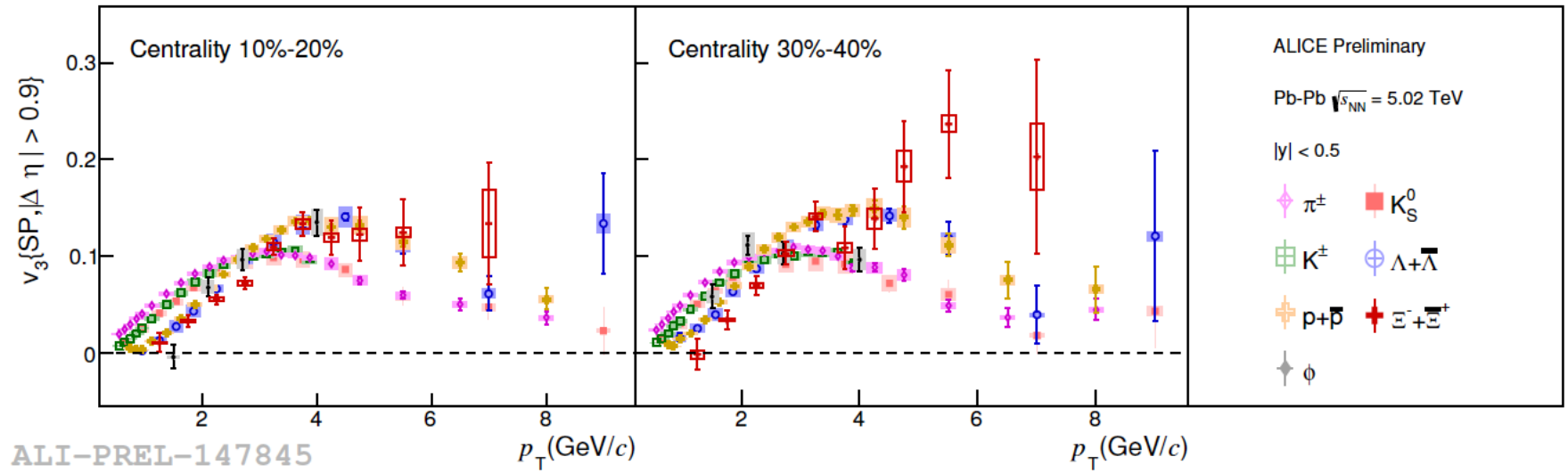
$D^0 \to K^-\pi^+$	BR ~ 3.93%	$c\tau \sim 123\ \mu m$
$D^+ \to K^-\pi^+\pi^+$	BR ~ 9.46%	$c\tau \sim 312\ \mu m$
$D^{*+} \to D^0(K^-\pi^+)\pi^+$	BR ~ 2.66%	-
$D_s^+ \to \phi(K^-K^+)\pi^+$	BR ~ 2.27%	$c\tau \sim 150\ \mu m$
$\Lambda_c^+ \to pK_s^0$	BR ~ 1.58%	"

In fact everybody flows in medium

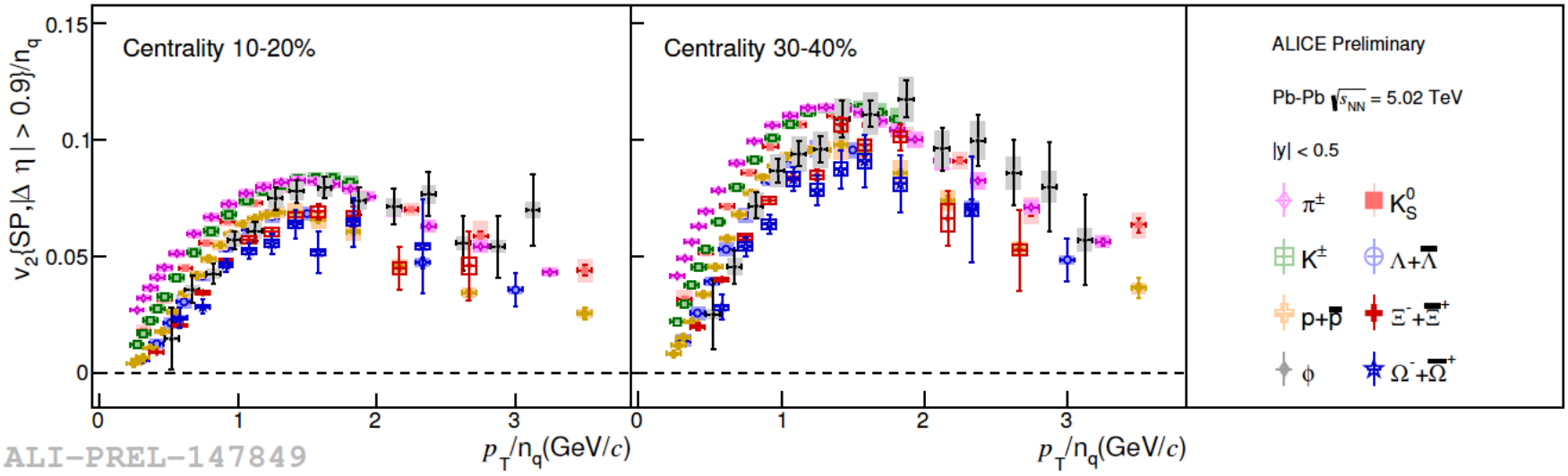


Work of Ya Zhu

- The p_T-differential v_2 (up) and v_3 (down) of π/K/p, ϕ, K^0_S, Λ and Ξ

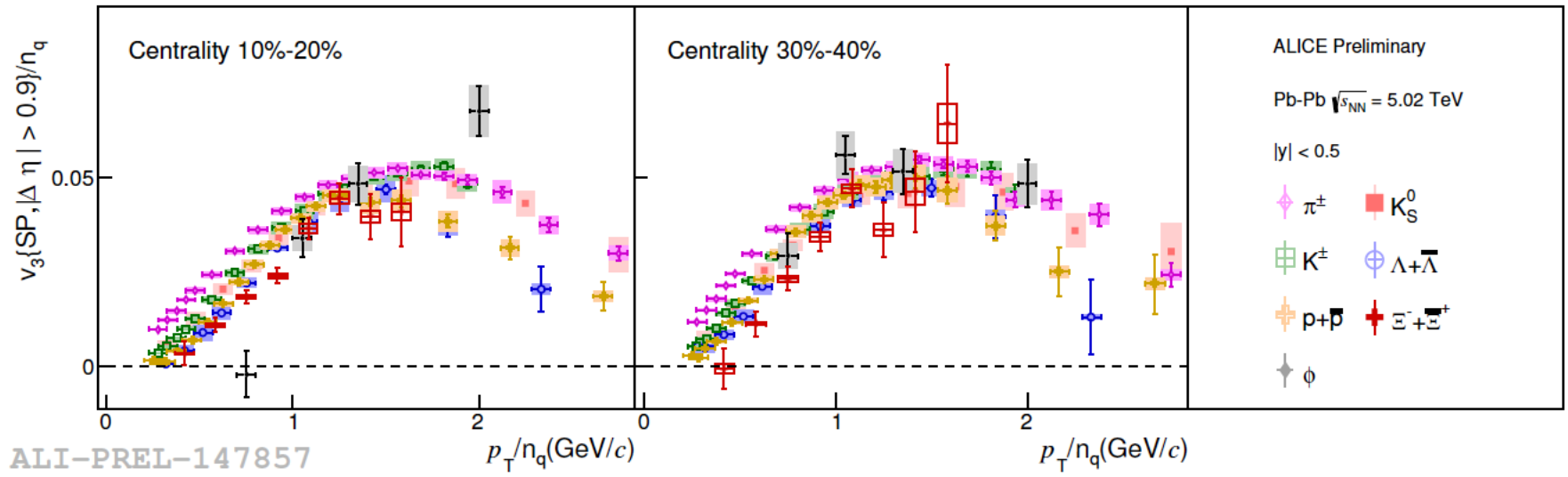


In fact everybody flows in medium

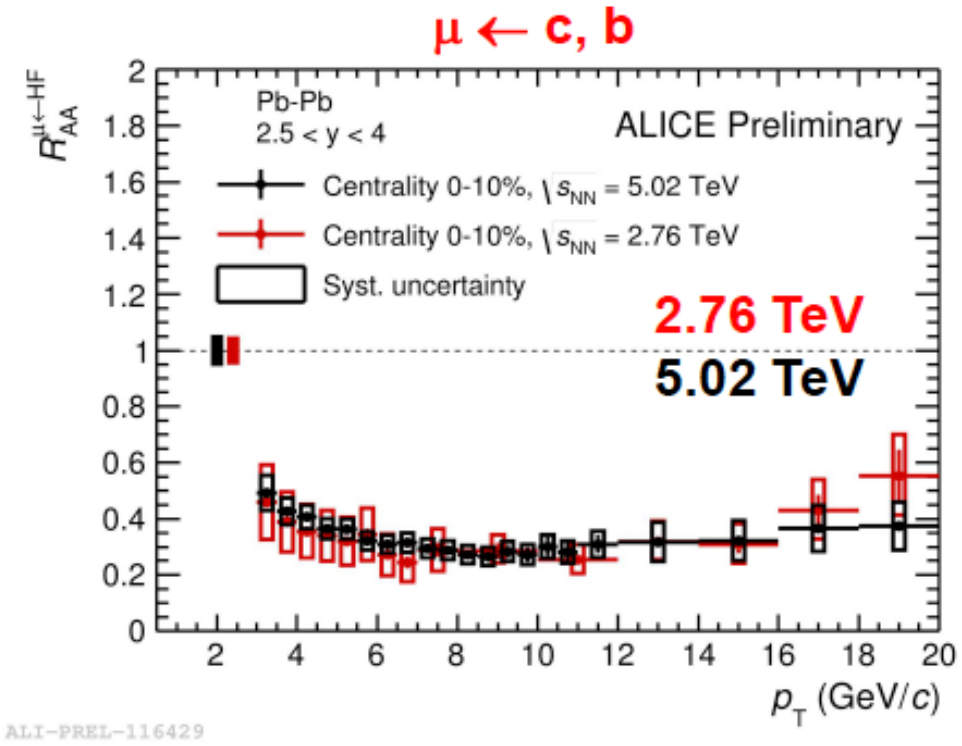


Work of Ya Zhu

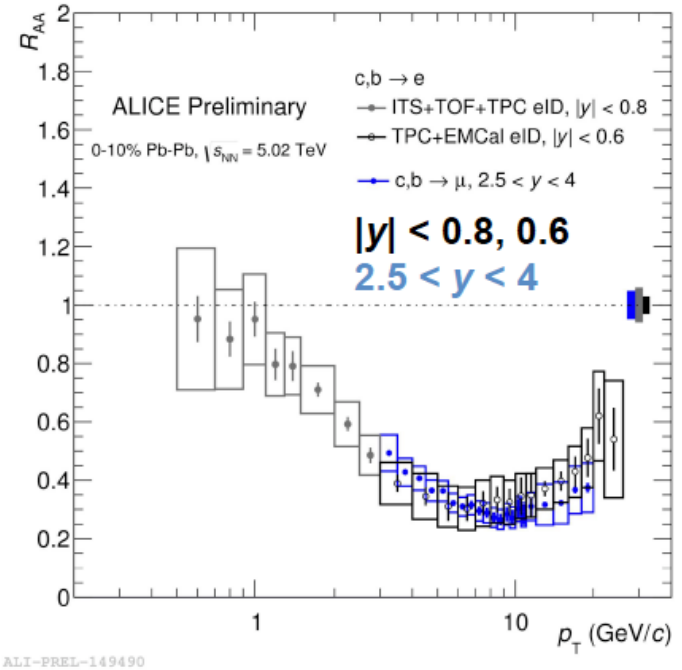
➢ The p_T/n_q scaled v_2 (up) and v_3 (down) of π/K/p, ϕ, K^0_S, Λ and Ξ



Heavy and go forward in medium

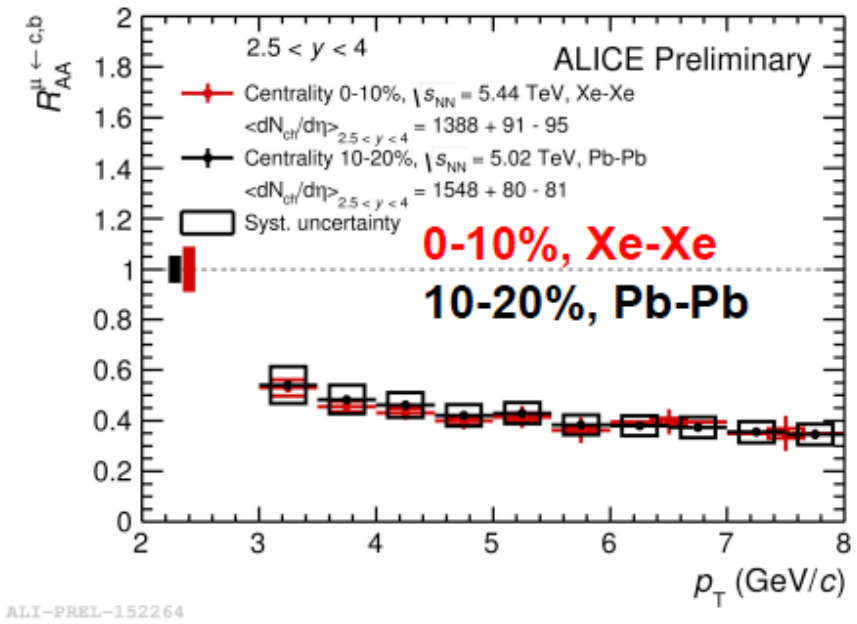


Work of
Zuman Zhang



- Strong suppression of heavy-flavour decay leptons
- And they are suppressed similarly at a wide rapidity interval

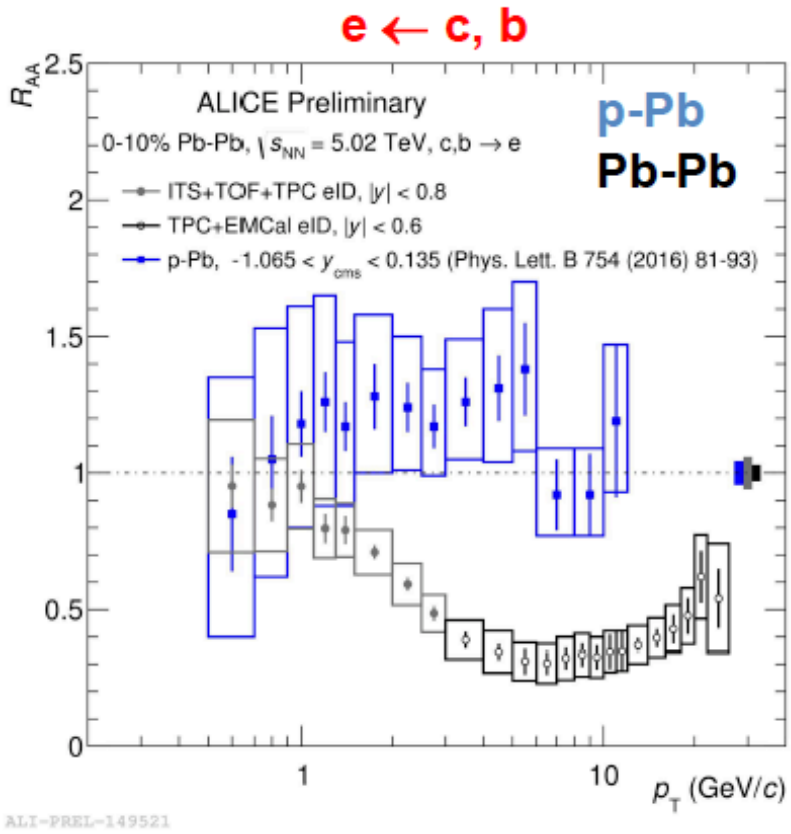
Heavy and go forward in medium

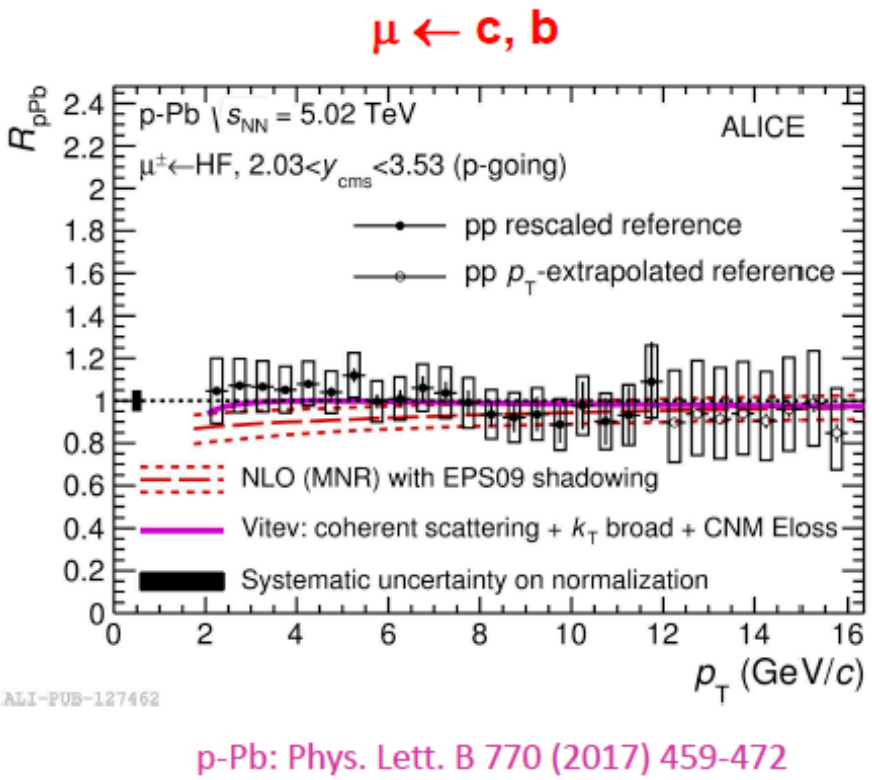


Work of
Zuman Zhang

- Strong suppression of heavy-flavour decay leptons
- And suppressed similarly at a wide rapidity interval
- Similar R_{AA} in 0-10% Xe-Xe vs. 10-20% Pb-Pb at similar <dN/dη>
- Possible interplay of geometry and path-length dependence

Initial-state and/or finial-state effect ?



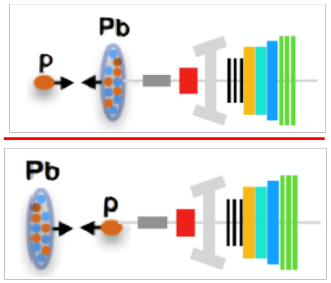


p-Pb: Phys. Lett. B 770 (2017) 459-472

- If the collision system is shifted to p-Pb, then the R_{pPb} become consistent with unity at both mid- and forward rapidity
- Indication of finial-state effects related to suppression / parton energy loss ?

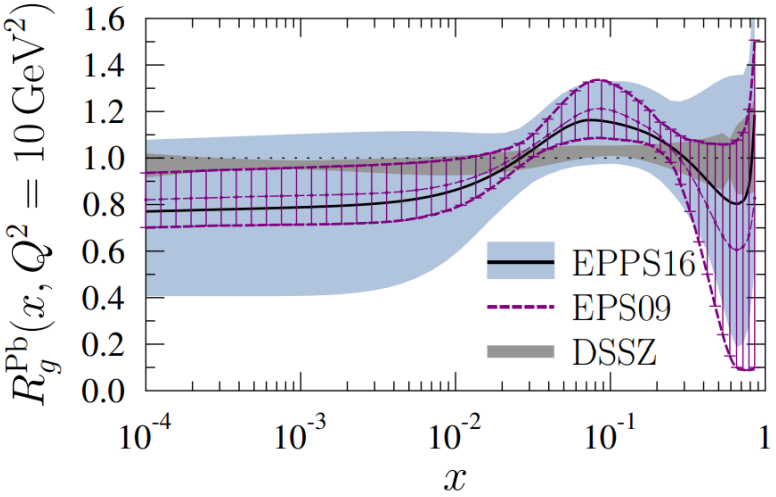
Initial-state and/or finial-state effect ?

$$R_{\mathrm{FB}} = \frac{\sigma(+|y^*|, p_{\mathrm{T}})}{\sigma(-|y^*|, p_{\mathrm{T}})}$$



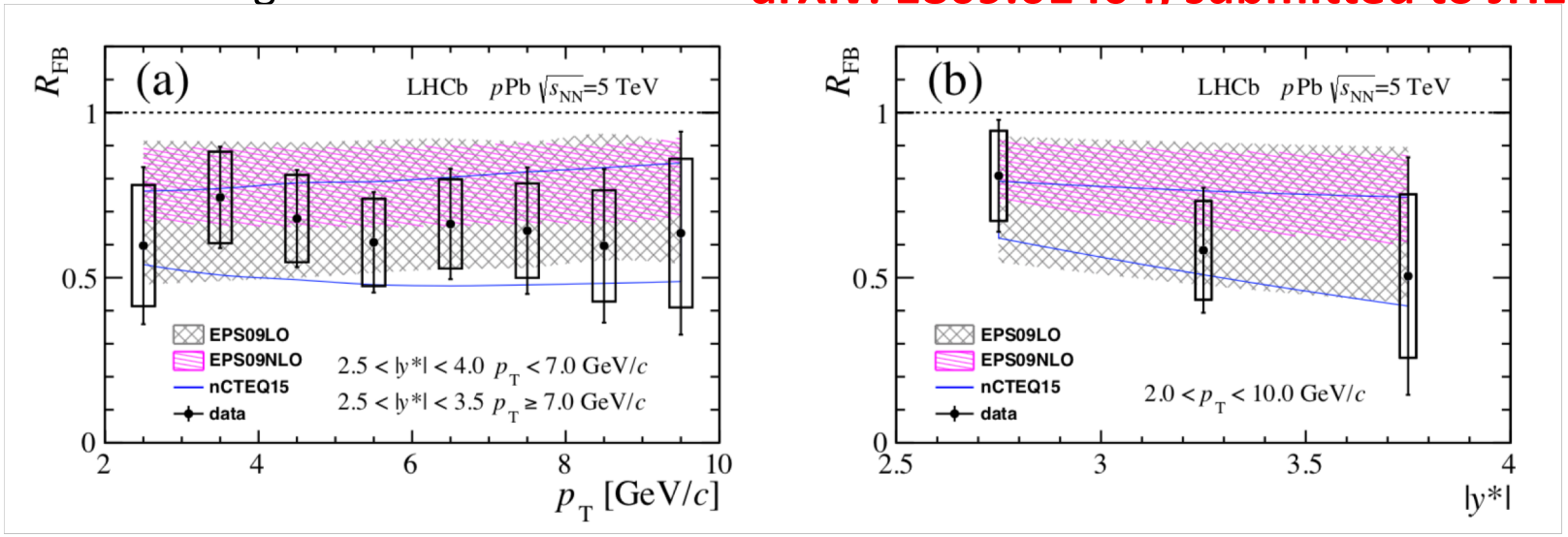
- Evident non-unity ratio of forward/backward of Λ_c^+
- Bottom decay subtracted
- Consistent with QCD calculation including nPDF

EPJ C10 (2017) 1140



Work of Jiayin Sun

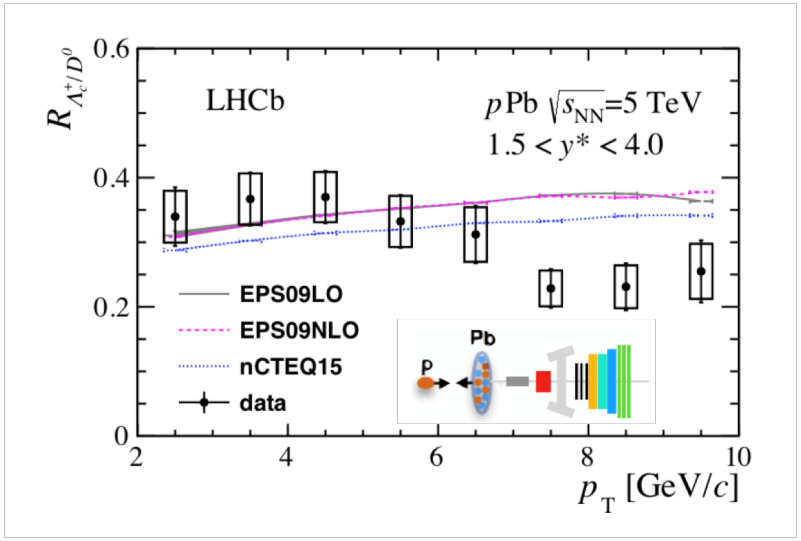
arXiv: 1809.01404. submitted to JHEP



Initial-state and/or finial-state effect ?

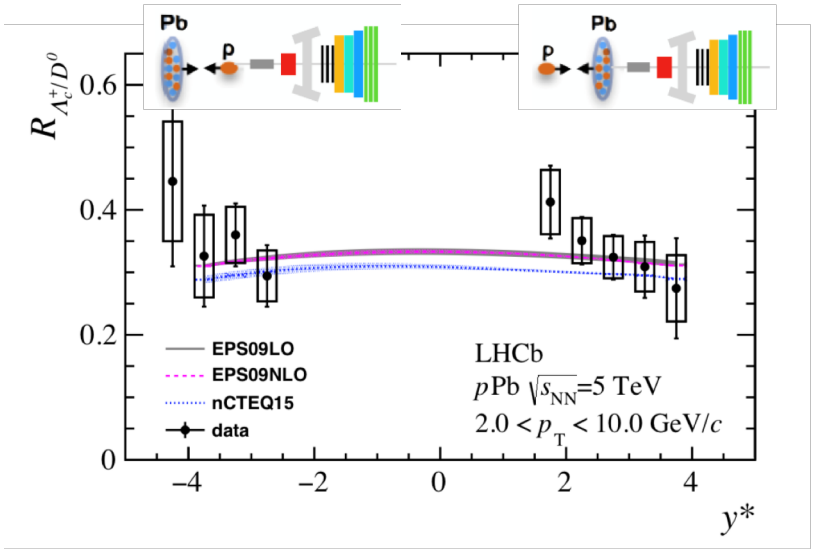
$$R_{\Lambda_c^+/D^0} = \frac{\sigma_{\Lambda_c^+}(y^*, p_{\mathrm{T}})}{\sigma_{D^0}(y^*, p_{\mathrm{T}})}$$

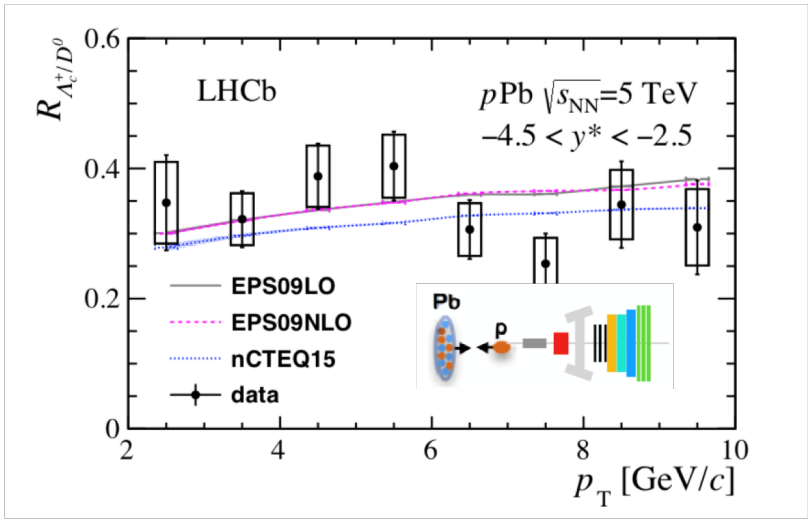
- Sensitive to charm hadronization mechanism
- Consistent with theory calculation based on pp cross section



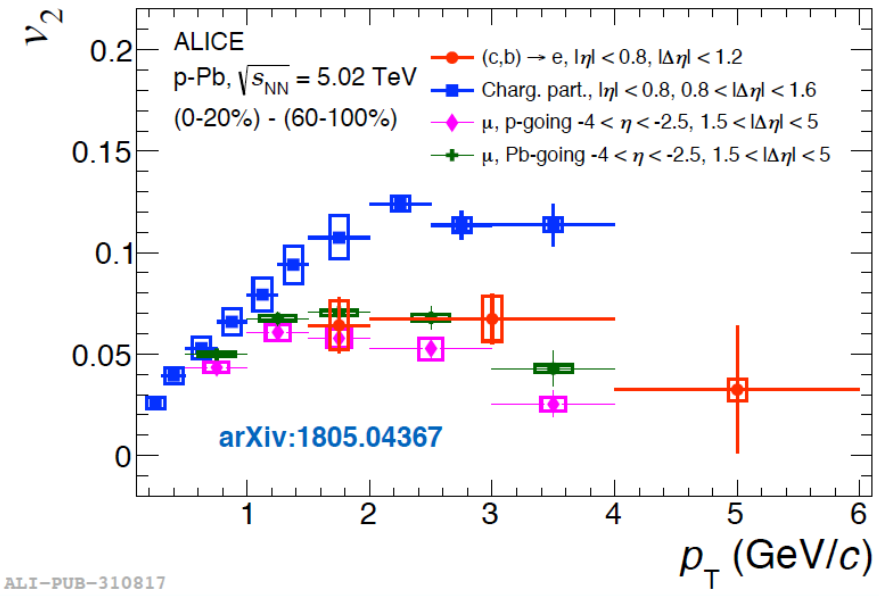
Work of Jiayin Sun

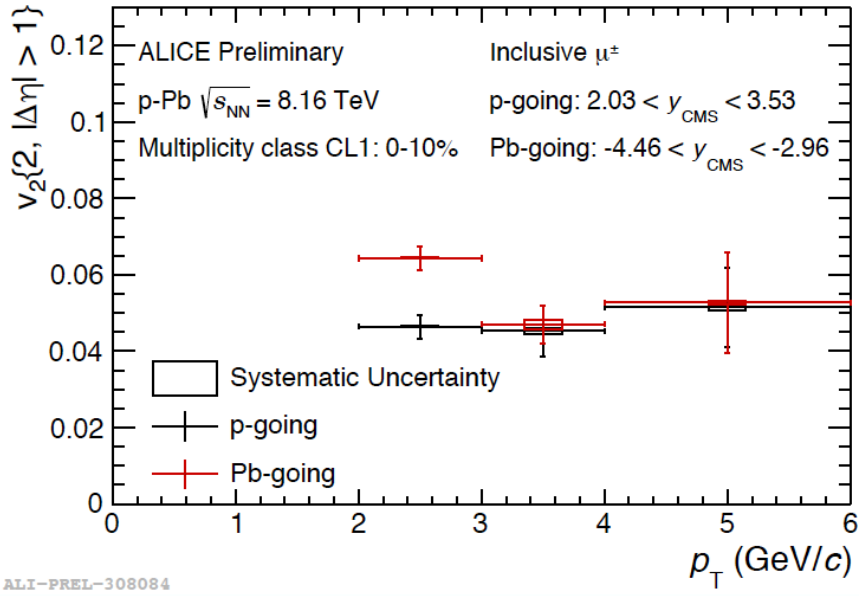
arXiv: 1809.01404, submitted to JHEP





Paradox of suppression vs. flow





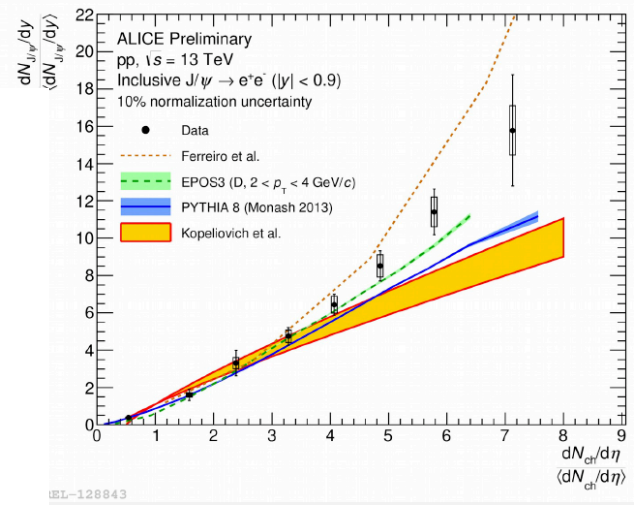
Work of Siyu Tang

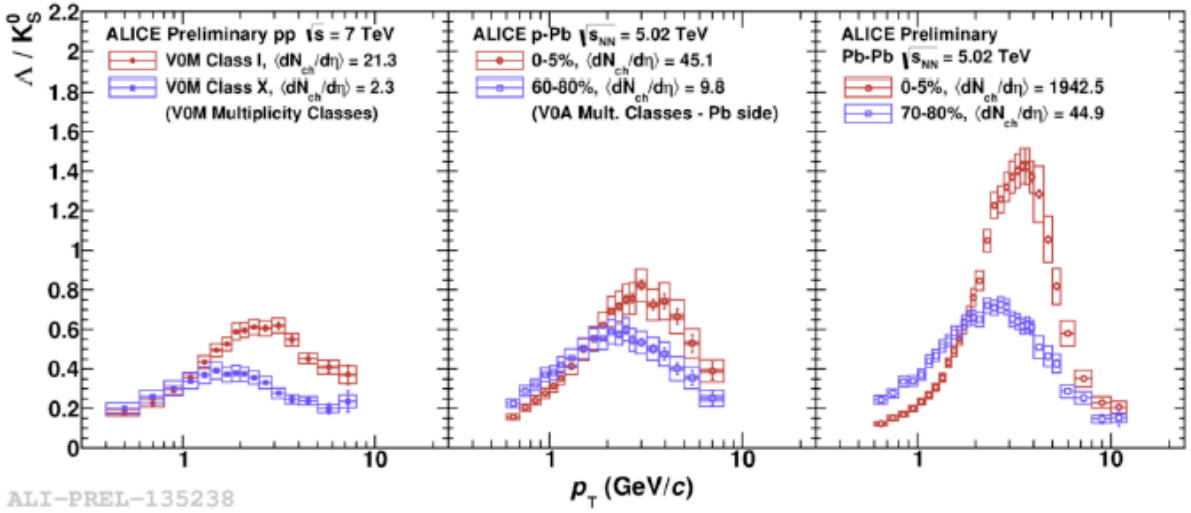
- Flow existed in p-Pb at multiple energies and different particles
- Fine model calculation necessary, if we believe both suppression and flow are mainly produced by final-state effects of medium

But is pp beyond the boundary of bulk media?

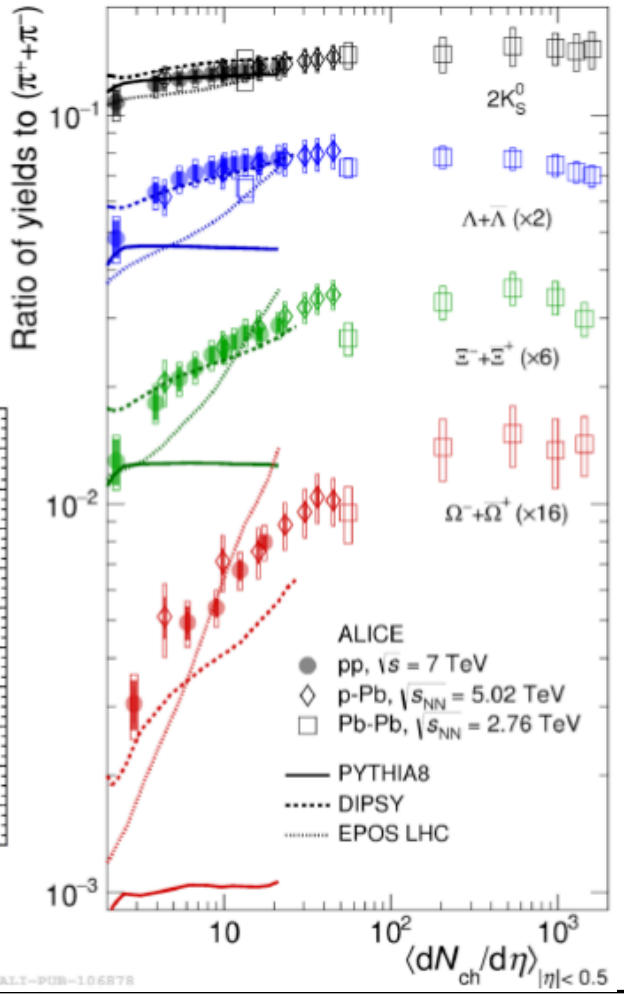
Hint of hot medium at high multiplicity in all systems?

Independent of original nuclei volume?

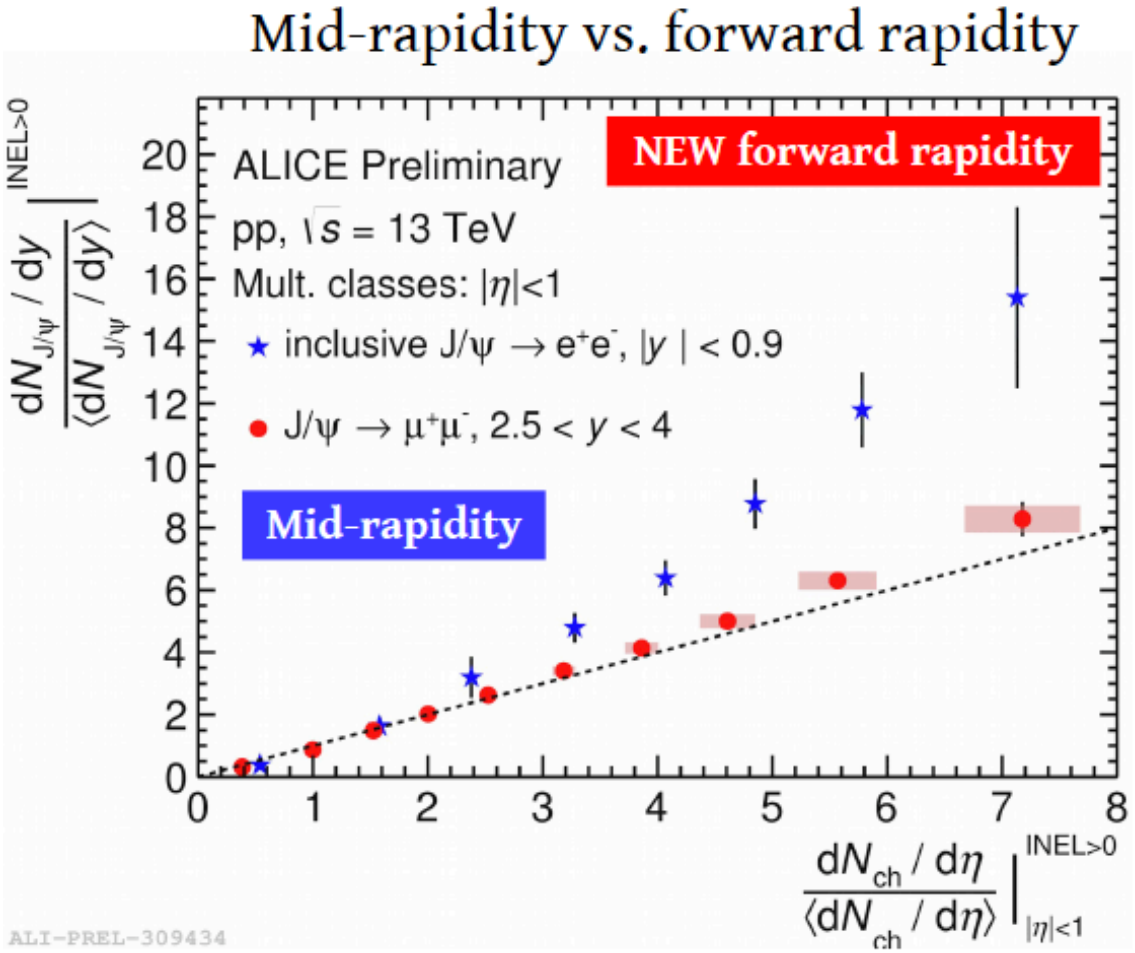


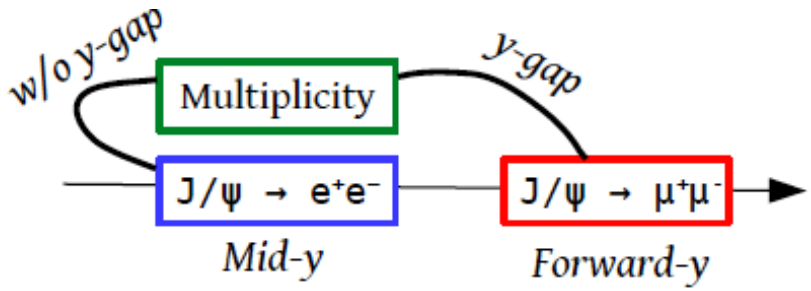


Nature Phys. 13 (2017) 535-539



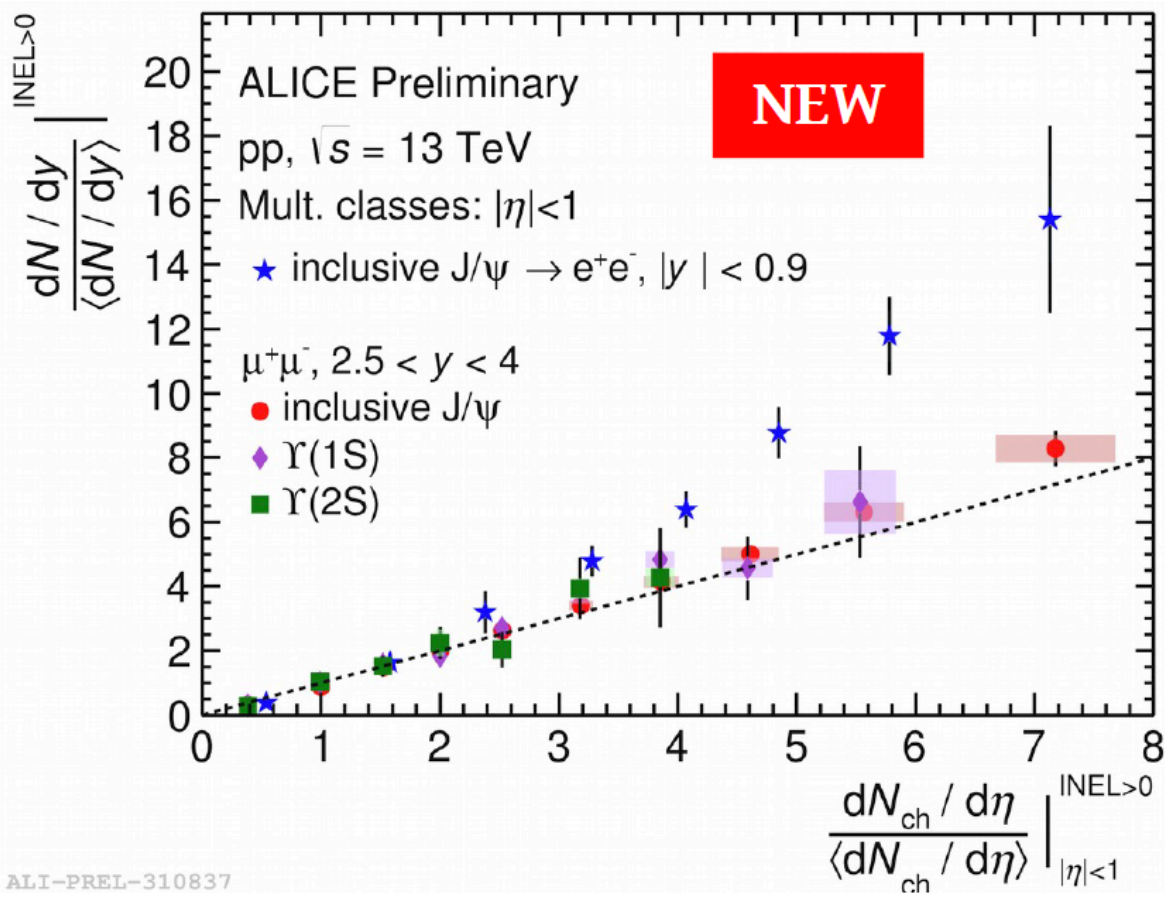
Quarkonium production vs. event multiplicity





- Faster than linear scaling with multiplicity at mid-rapidity
  - ➔ w/o rapidity gap between signal and multiplicity estimator
- Linear increase at forward rapidity
  - ➔ rapidity gap
- **Hint of auto-correlation bias**

Quarkonium production vs. event multiplicity

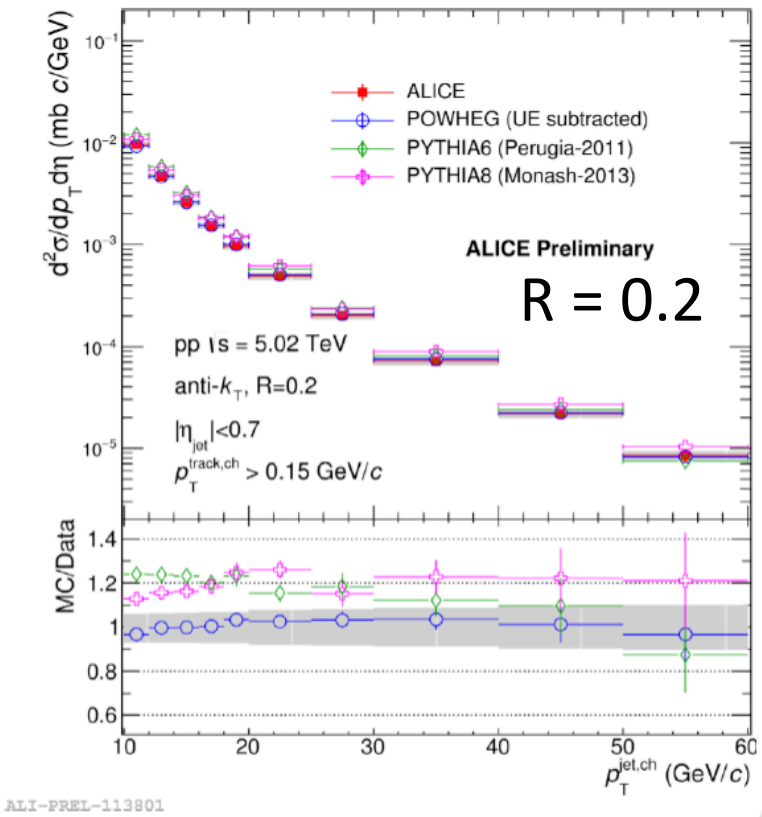


Work of
Yanchun Ding

Quarkonia:
Both J/ψ and ϒ(1S) ϒ(2S) yields increase linearly at forward rapidity, while evidently faster at mid-rapidity.

Open heavy flavours:
Similar enhancement of D-meson at mid-rapidity, slower increase of muons from HF at forward

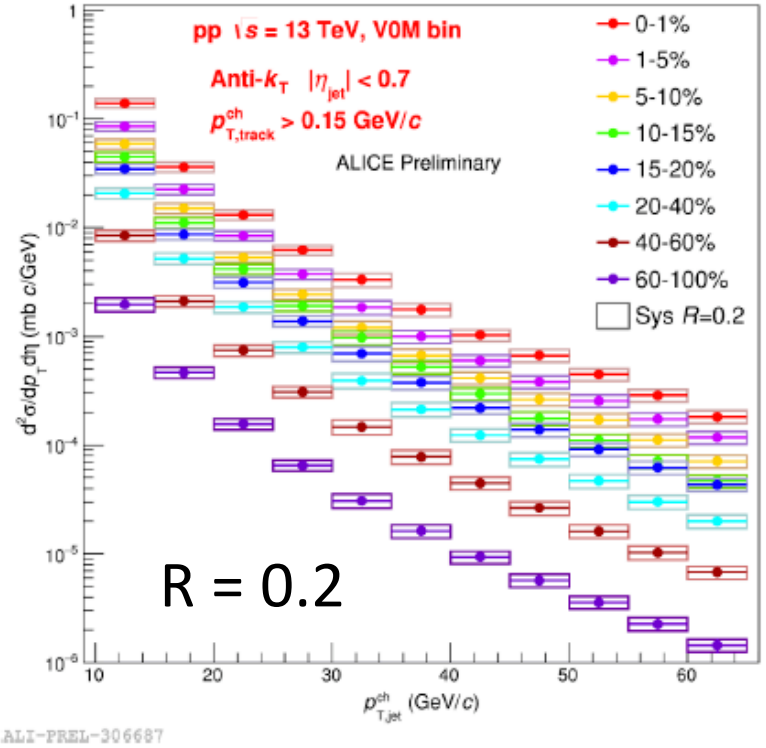
Jet vs. event multiplicity

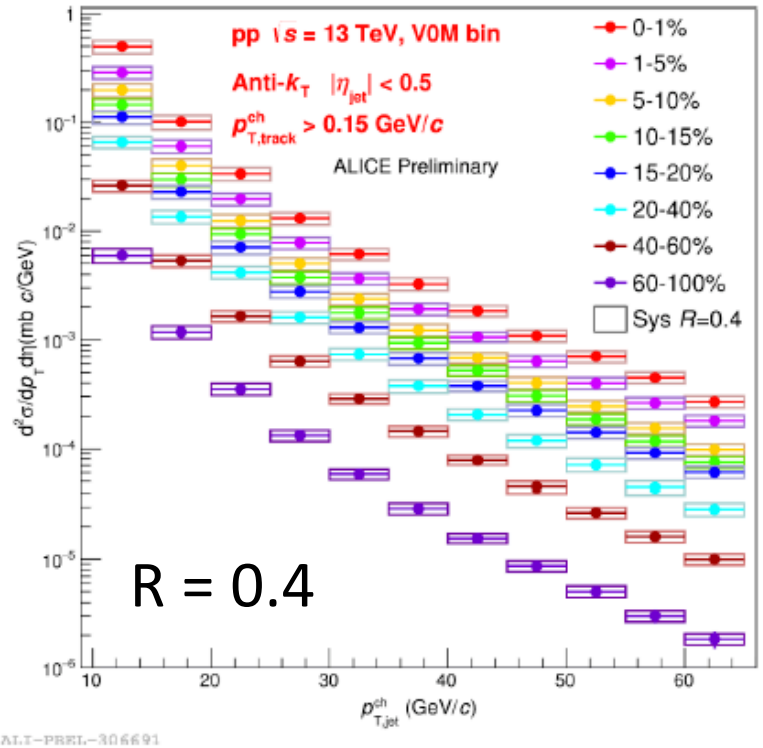


Work of
Yongzhen Hou

- Jets provide constraints to pQCD calculation, and reference to jet quenching effect in medium
- Jet cross section well described by POWHEG + PYTHIA8

Jet vs. event multiplicity

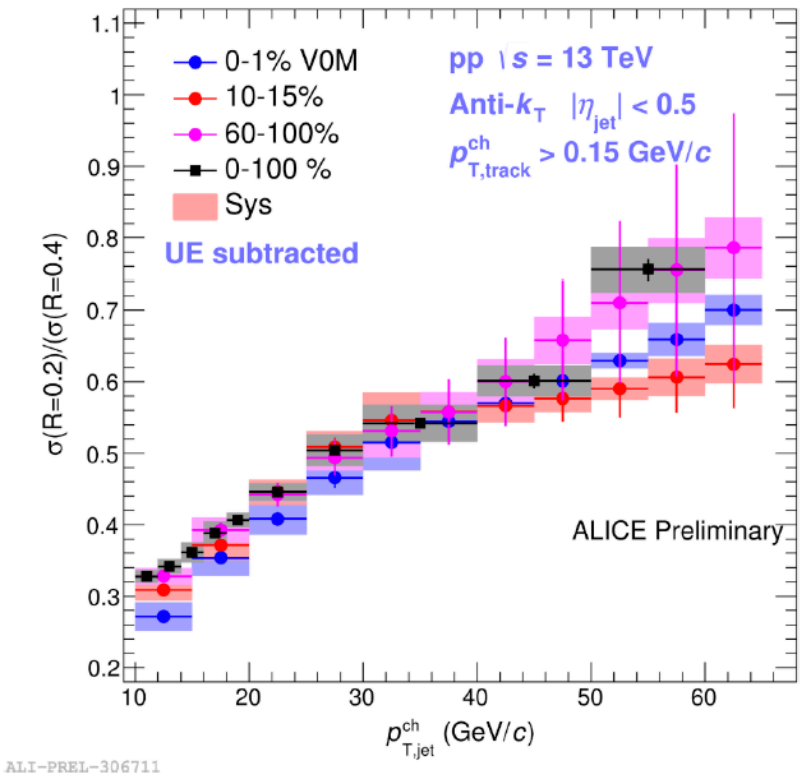


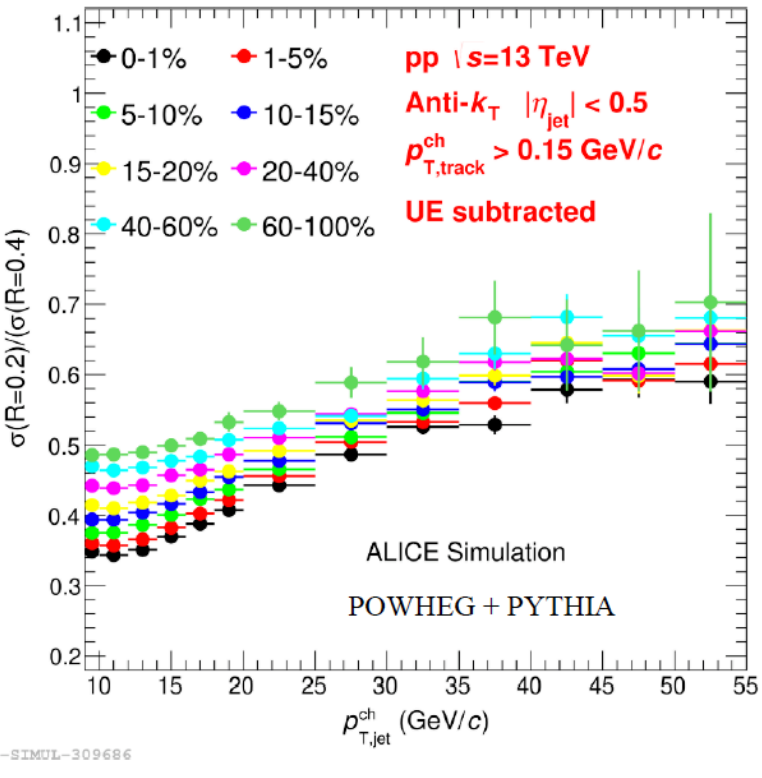


Work of Yongzhen Hou

- Jets provide constraints to pQCD calculation, and reference to jet quenching effect in medium
- Investigation of splitting function based on jet shape parameters

Jet vs. event multiplicity

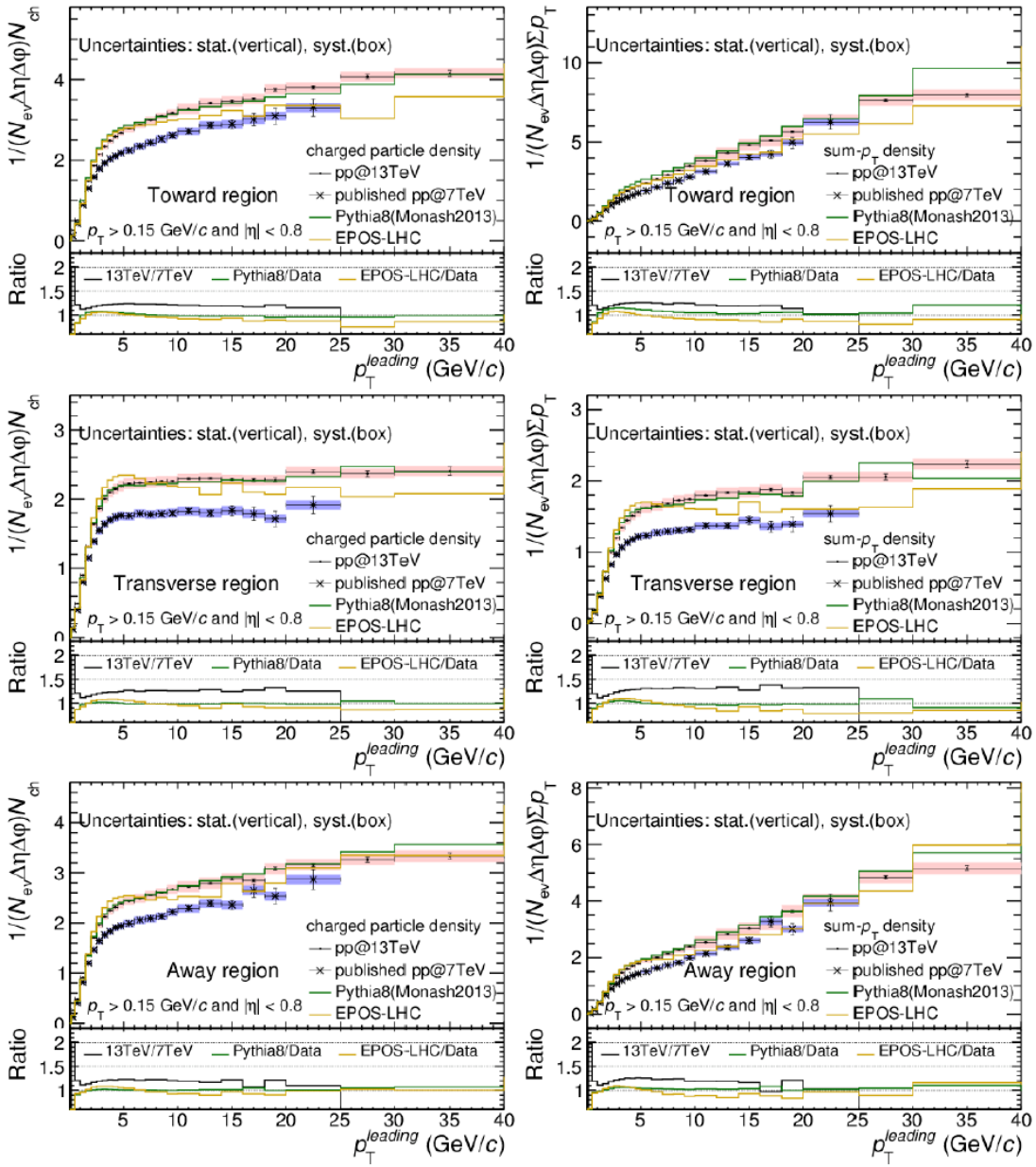




Work of Yongzhen Hou

- Jets provide constraints to pQCD calculation, and reference to jet quenching effect in medium
- Investigation of splitting function based on jet shape parameters
- MC shows bigger ”centrality” ordering than data

Jet and underlying event



Work of
Xiaowen Ren

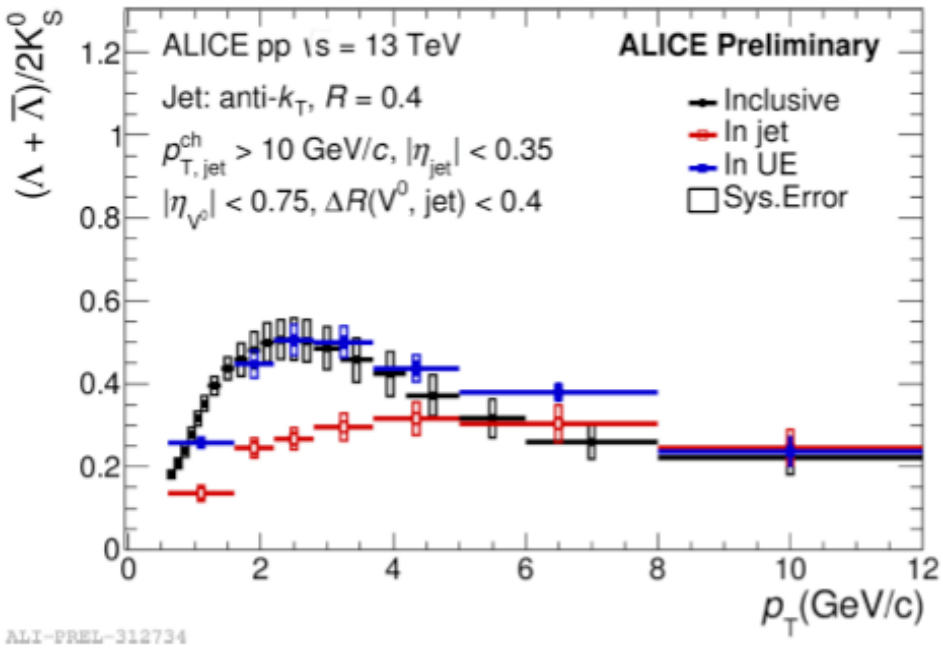
- Use high-p_T particle as proxy of jets
- The charged particle density and Σp_T are studied in three regions of jet / high-p_T:

❑ Toward (jet)

❑ Away (back-side jet)

❑ Transverse (underlying)

Strangeness in pp jets

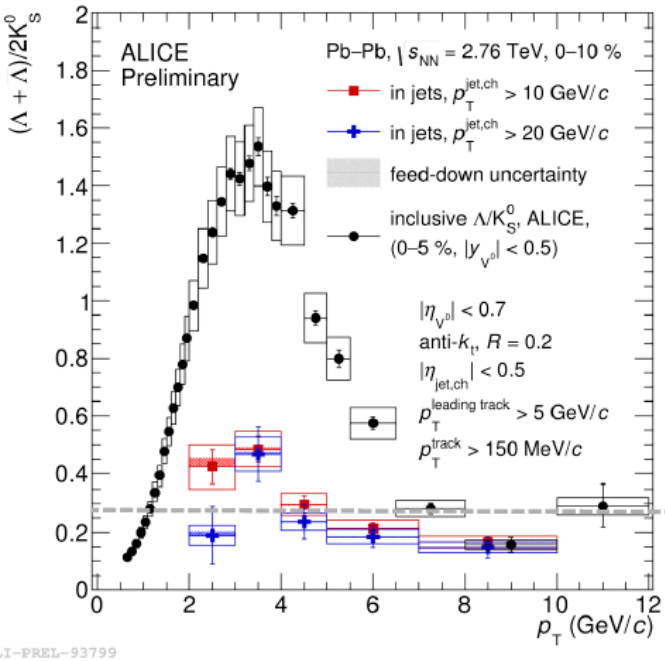


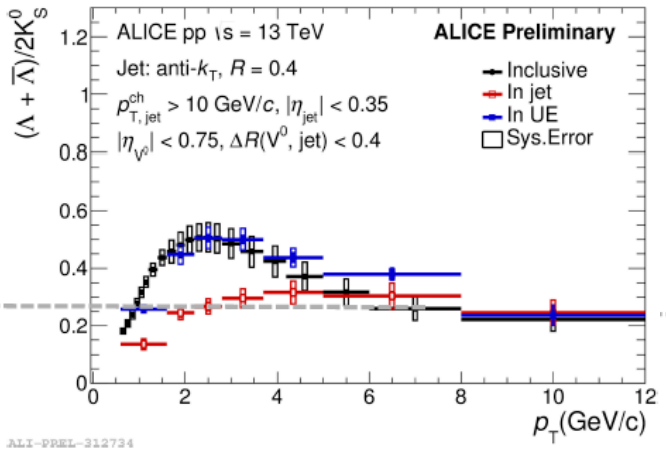
Work of
Pengyao Cui

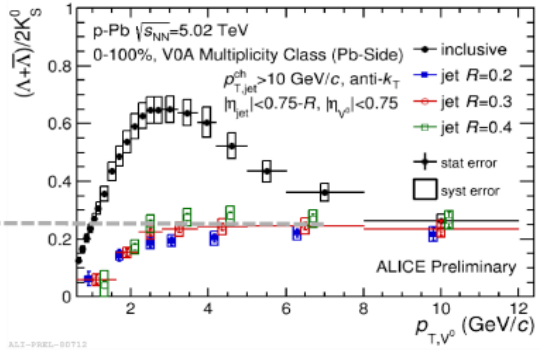
The Λ/K^0_S in underlying events is consistent with the ratio of inclusive V^0s

However, the ratio in jets is clearly different to inclusive at low and intermediate p_T

Strangeness in jets





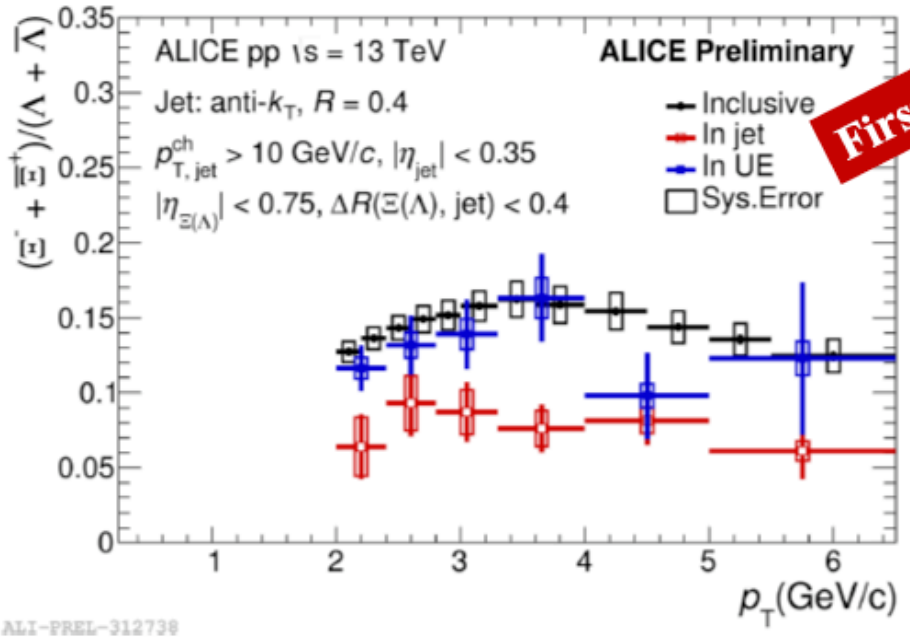


Pb-Pb pp p-Pb

The Λ/K^0_S in underlying events is consistent with the ratio of inclusive V^0s

However, the ratio in jets is clearly different to inclusive at low and intermediate p_T
And it is compatible with that in p-Pb and central Pb-Pb collisions.

Strangeness in pp jets



First Measurement

Work of
Pengyao Cui

Exploration of production mechanisms in jets and underlying events with multi-strange particles

Ξ/Λ is almost p_T independent in jets

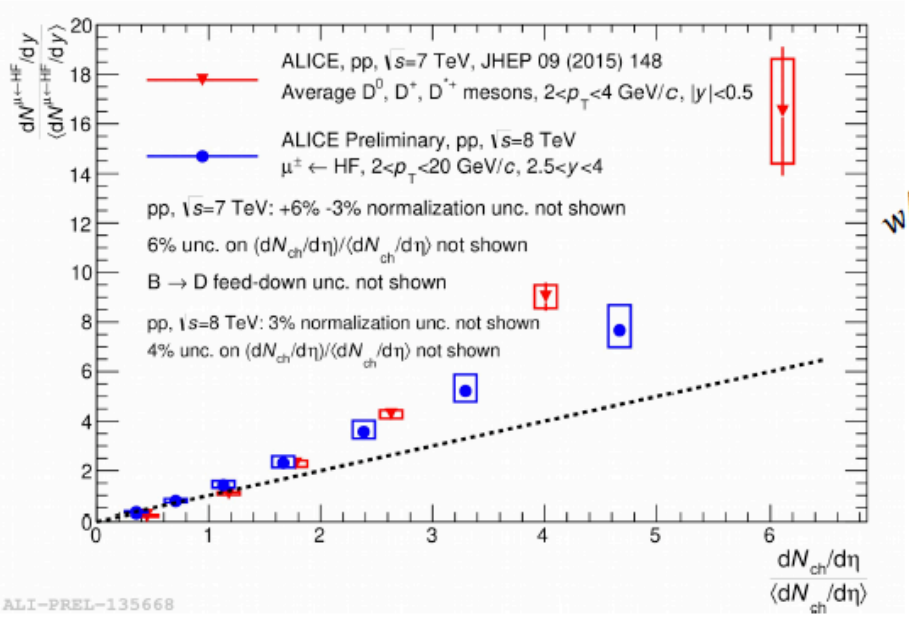
Summary

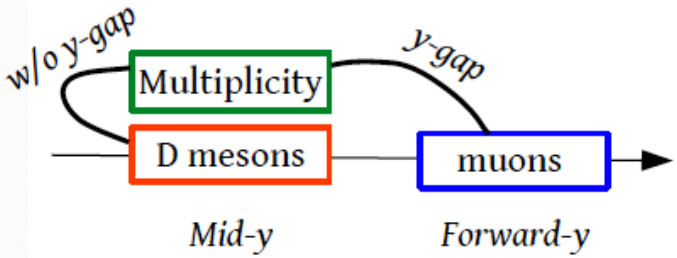
- Chinese institutes have made strong contributions to heavy-ion programs at LHC experiments
- Piece by piece, these results help to composite the medium effects, and propagate to QGP properties
- These results also indicate possible paradox, such as R_{AA} vs. flow in small systems
- Ongoing efforts of Run-2 data analysis shall help us find those missing pieces of jigsaw puzzle
- Theorists won't stand outside the game

Backup

Open heavy flavours production vs. event multiplicity

D mesons and muons from HF vs. event multiplicity



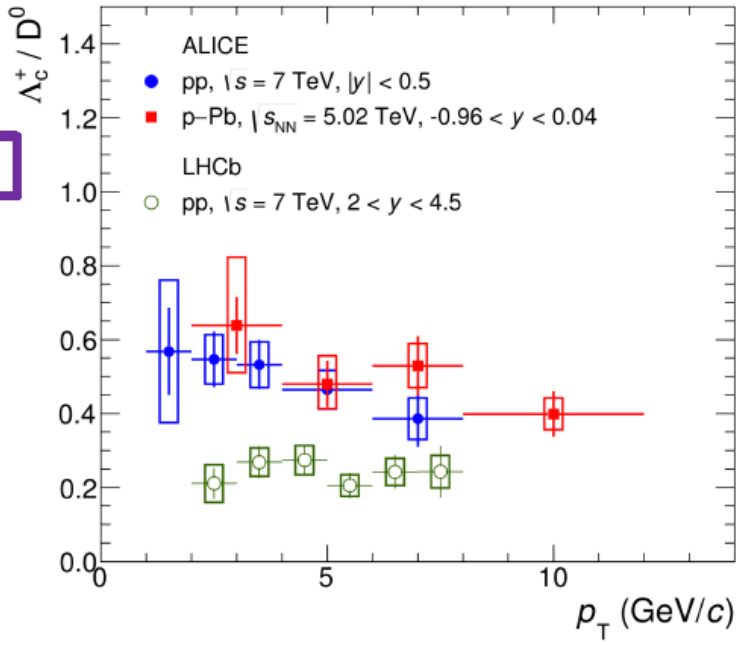


- Similar multiplicity dependence as J/ψ and ϒ at low multiplicity
- Stronger than linear increase at high multiplicity
- The increase appears slightly faster at mid-rapidity than at forward, which is similar to what is observed in J/ψ
- Need to study the role of jet fragmentation in J/ψ production

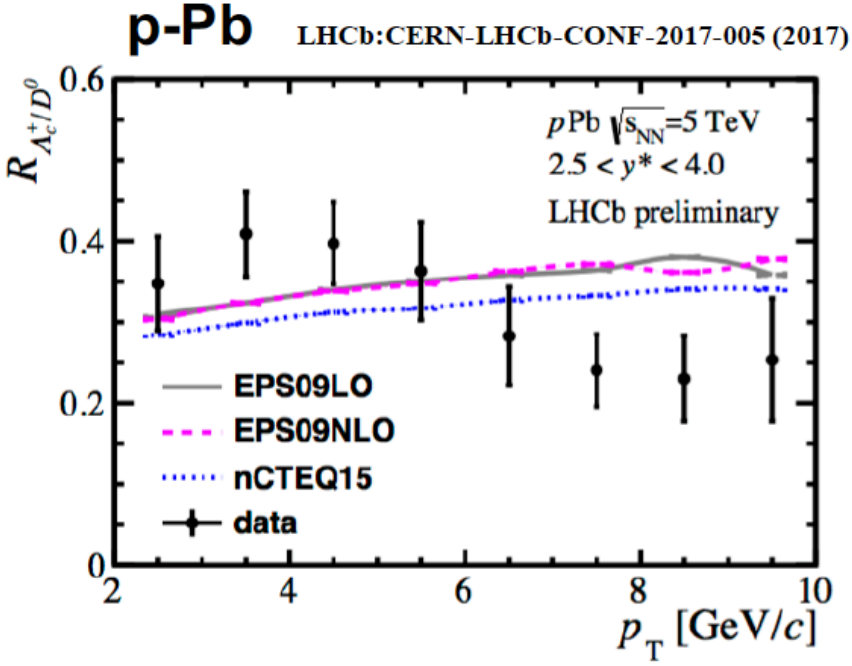
Λ_c^+/D^0 ratio compared with LHCb

Published!

arXiv:1712.09581



LHCb:Nucl. Phys. B871 (2013) 1–20

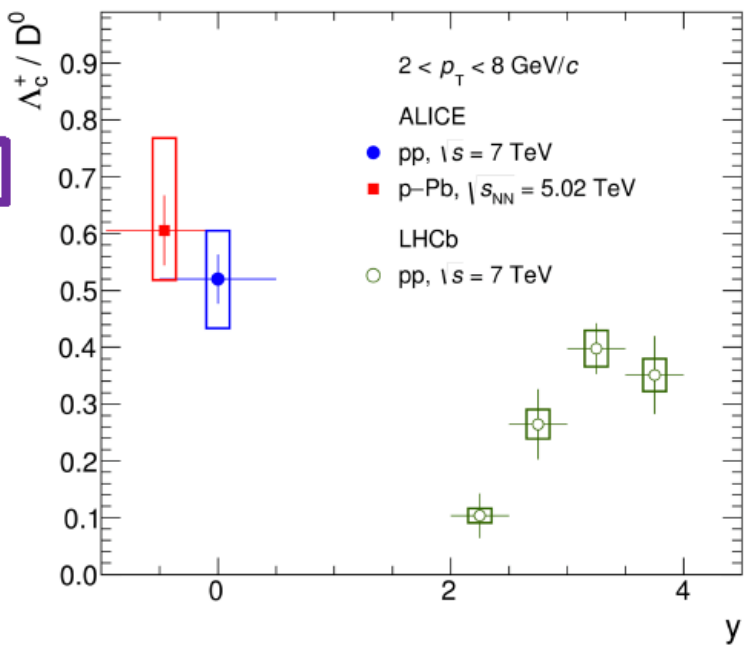


- ALICE measurement systematically **higher** than LHCb

Λ_c^+/D^0 ratio compared with LHCb

Published!

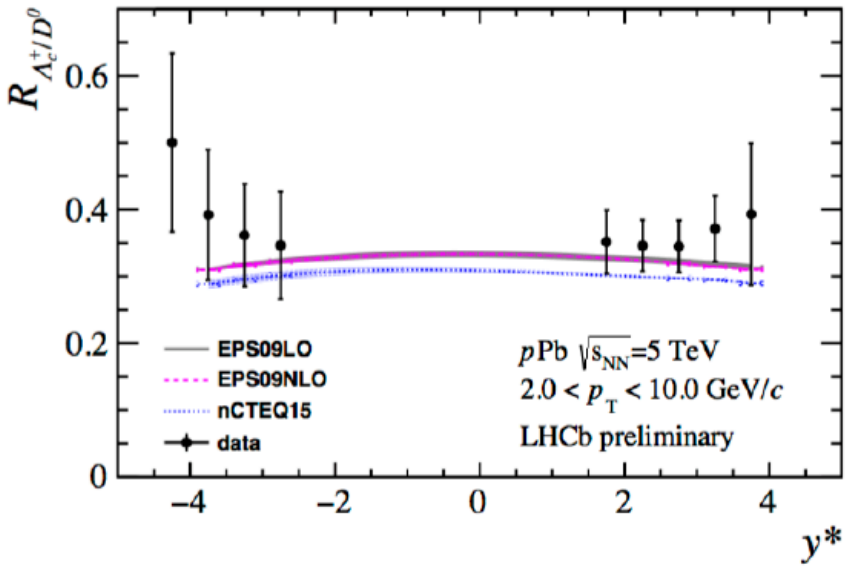
arXiv:1712.09581



ALI-PUB-141417

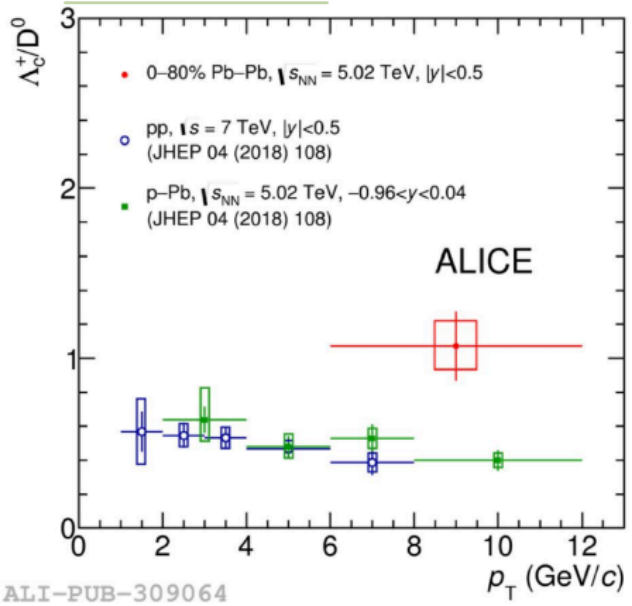
LHCb:Nucl. Phys. B871 (2013) 1–20

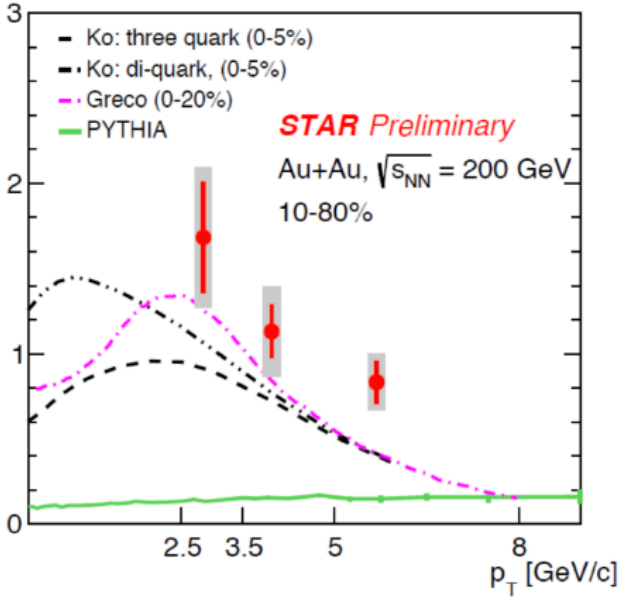
p-Pb LHCb:CERN-LHCb-CONF-2017-005 (2017)



- ALICE measurement systematically **higher** than LHCb

Λ_c^+/D^0 ratio in Pb-Pb

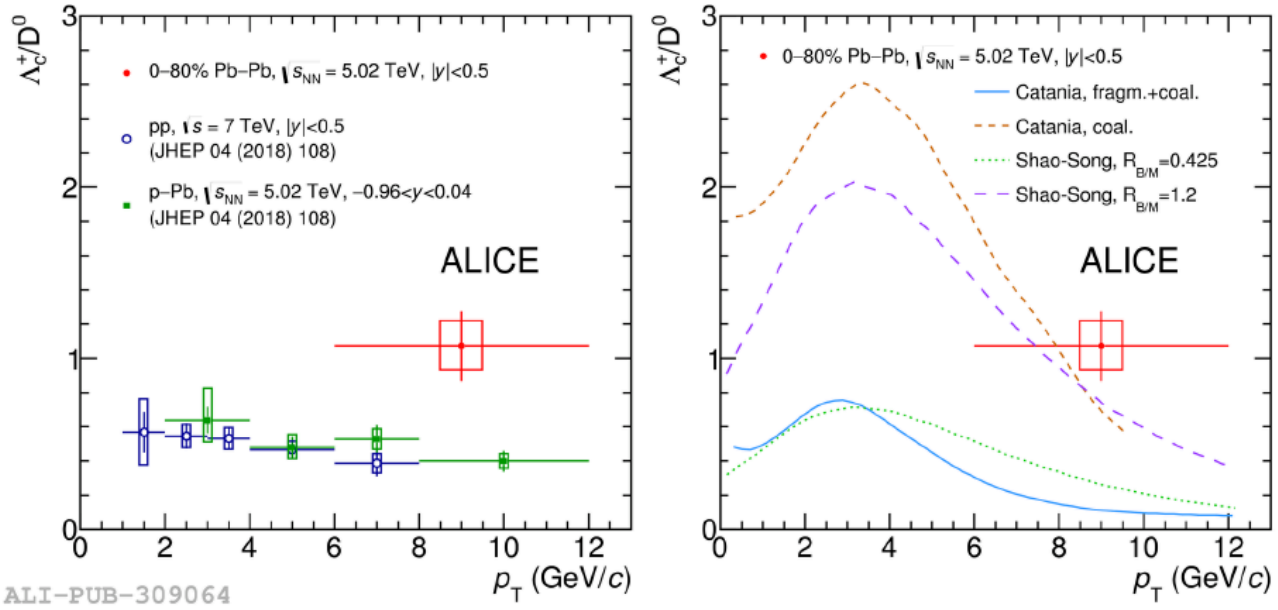




- Λ_c^+/D^0 ratio measured in Pb-Pb, hint of enhancement w.r.t pp and p-Pb
- Λ_c^+/D^0 results described by **model calculations including only coalescence**.
- Λ_c^+/D^0 in $6 < p_T < 12$ GeV/*c* is similar to STAR measurement in 3-6 GeV/*c*.

Catania: Eur.Phys.J.C (2018) 78:348

Λ_c^+/D^0 ratio in Pb-Pb

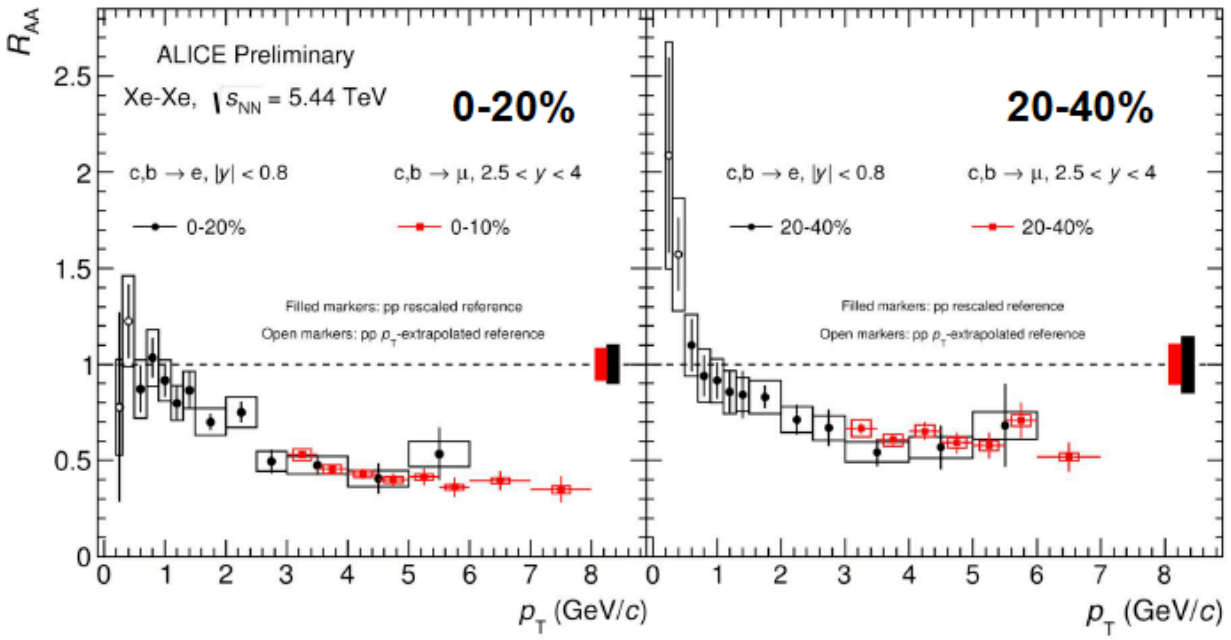


- Λ_c^+/D^0 ratio measured in Pb-Pb, hint of enhancement w.r.t pp and p-Pb
- Λ_c^+/D^0 **results described by model calculations including only coalescence.**

Shao-Song: Phys. Rev. C 97, 064915
Catania: Eur.Phys.J.C (2018) 78:348

p_T-differential R_{AA} of leptons ← c, b in Xe-Xe collisions: rapidity dependence

Heavy-flavour decay electron R_{AA} measured down to p_T = 0.2 GeV/c thanks to the low B field used during the Xe-Xe data taking!



- Compatible results within uncertainties for heavy-flavour decay electrons ($|y| < 0.8$) and heavy-flavour decay muons ($2.5 < y < 4$) R_{AA} in central and semi-central collisions