Overview of Heavy-Flavour measurements in ALICE

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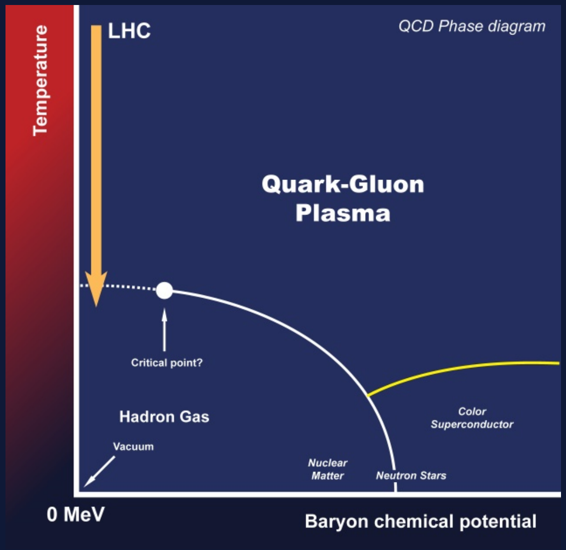
ALICE

The Quark-Gluon Plasma

- Particle colliders probe the high temperature region of the QCD phase diagram
- Ultra-relativistic heavy-ion collisions result in the creation of a Quark-Gluon Plasma (QGP)
- In this presentation we give an overview of heavy-flavour measurements of ALICE:
  - Open heavy-flavour
  - Quarkonia
  - Heavy-flavour jets



Collision systems

proton - proton

- Reference for studies of p-Pb and Pb-Pb collisions
- Determine particle production and test pQCD predictions

p-Pb

- Cold-nuclear-matter effects
- Test of collective effects

Pb-Pb

- In medium energy loss
- In medium hadronization
- Recombination effects

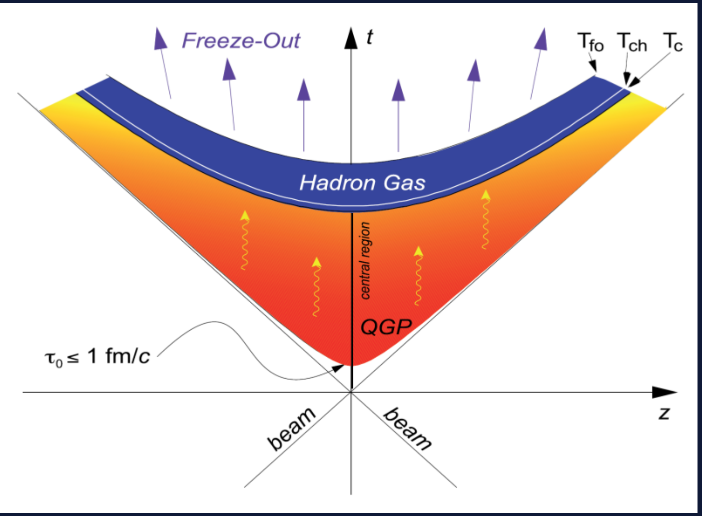
Open heavy-flavour

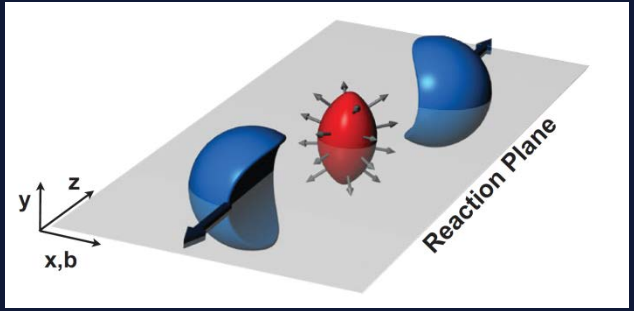
Physics Motivation

- Heavy quarks are created early during the collision so they experience the full evolution of the medium
- The quarks lose energy when they move through the created medium
  - Collisional
  - Radiative

- Energy loss is expected to depend on:
  - Particle path length and QGP density
  - Colour charge (Casimir factor)
  - Quark mass (dead cone effect)

- Heavy quarks are expected to be affected by the collective motion of the medium
- Provides insight in medium transport properties





ALICE

Inner tracker system

- Tracking
- Primary vertex reconstruction
- Particle identification

Time of Flight

- Particle identification

Electromagnetic calorimeter

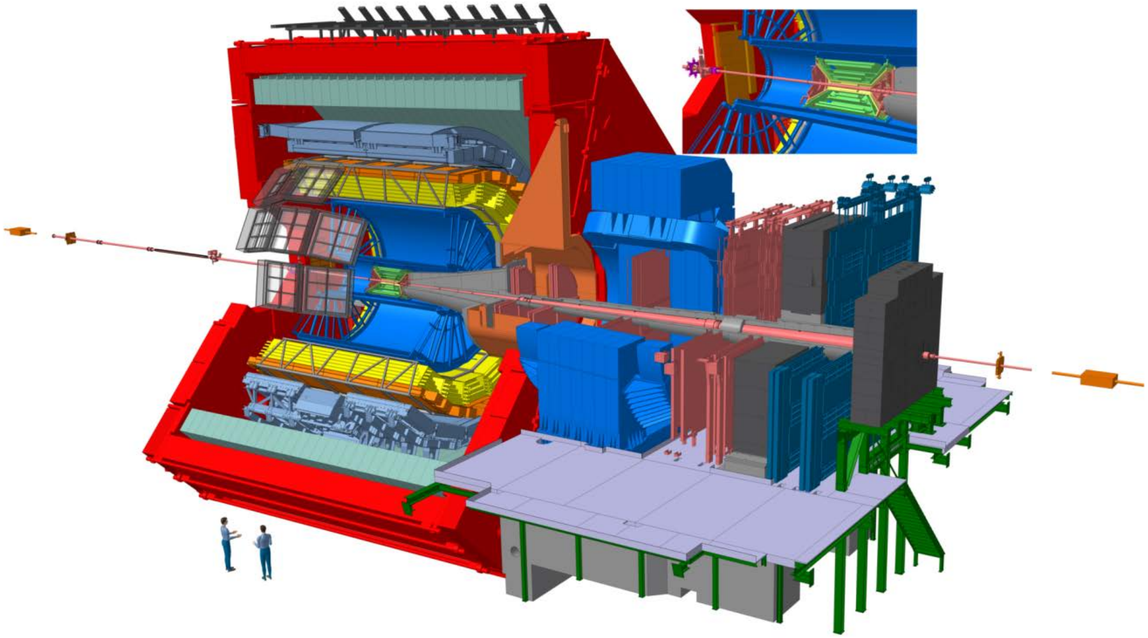
- Particle identification

Time projection chamber

- Tracking
- Particle identification

Muon spectrometer

- Tracking
- Muon identification



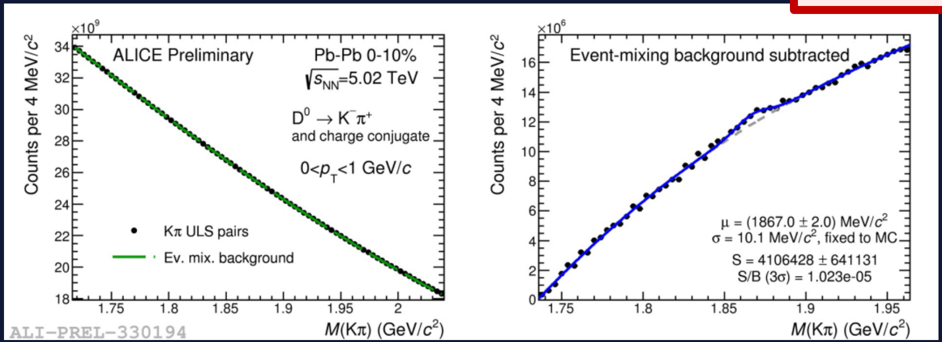
Central barrel: $-0.9 < \eta < 0.9$

Muon spectrometer: $-4 < \eta < -2.5$

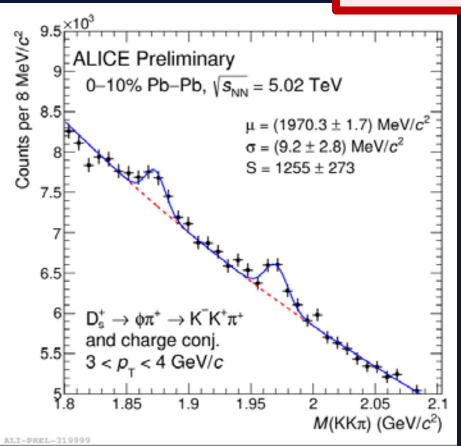
Open heavy-flavour

- Full hadronic reconstruction of heavy-flavour mesons and baryons down to low p_T

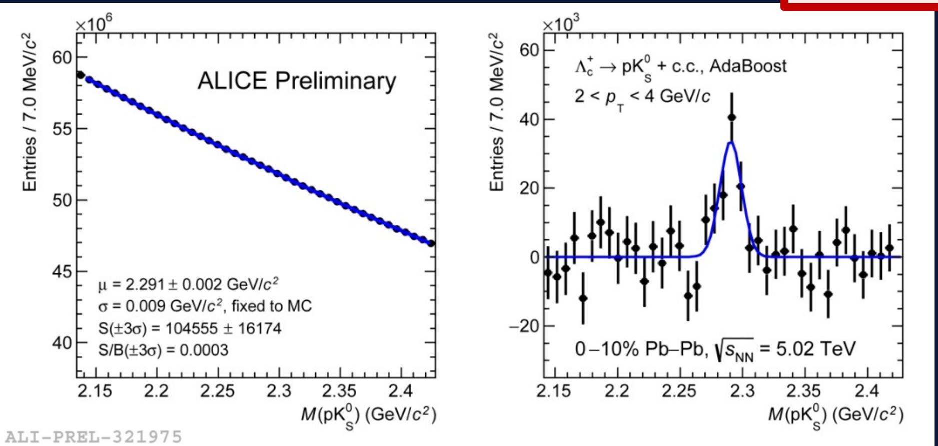
D^0 down to $p_T = 0$ GeV/c **Pb-Pb**



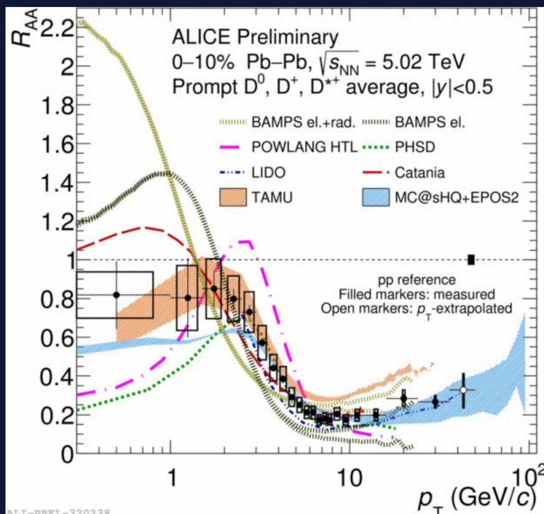
D_s^+ **Pb-Pb**

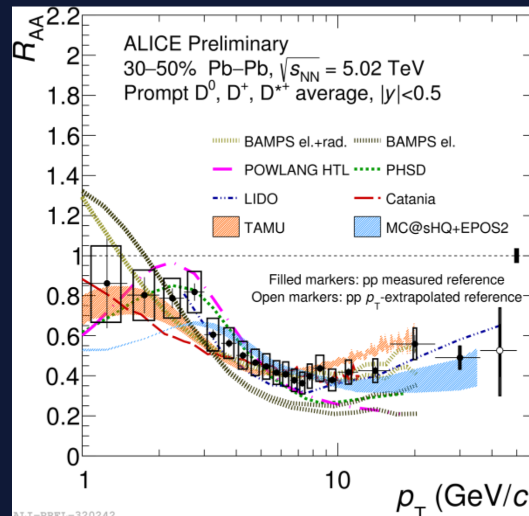


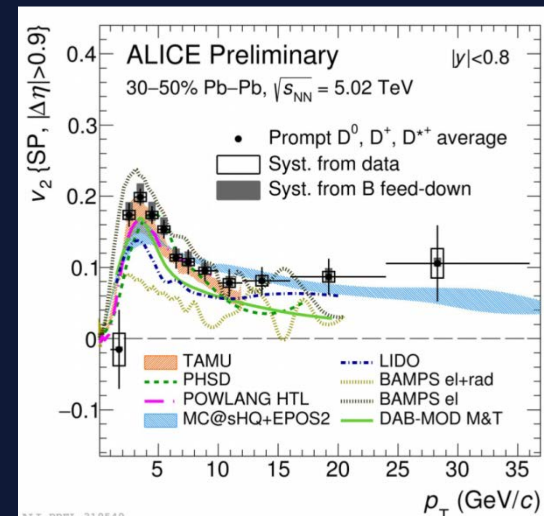
Λ_c^+ **Pb-Pb**



Charm quark energy loss and flow







- Strong discrimination between models from 0 to 1 GeV/*c* for central Pb-Pb collisions
- Models without shadowing overestimate low p_T

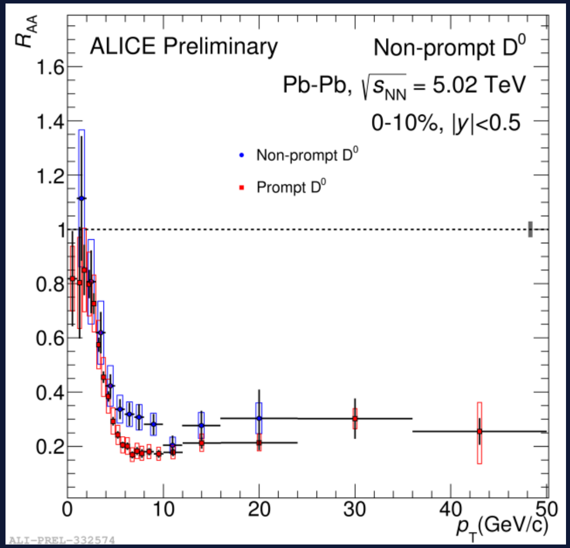
- Suppression decreases moving to peripheral collisions
- Most models show a good agreement with data

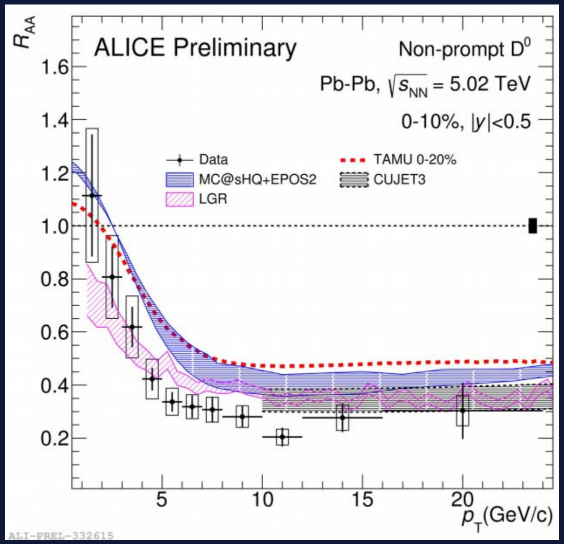
- Test the validity of models by comparing data and models for energy loss and flow at the same time

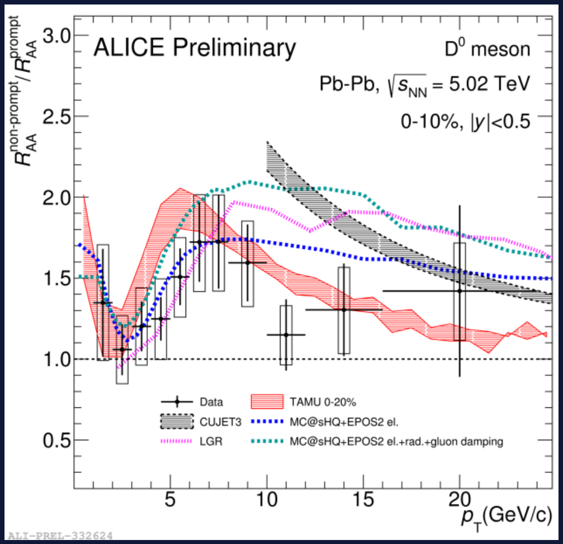
Accurate modeling of data requires combination of collisional + radiative energy loss, coalescence, cold-nuclear-matter effects, and medium evolution

Open heavy-flavour

Beauty quark energy loss



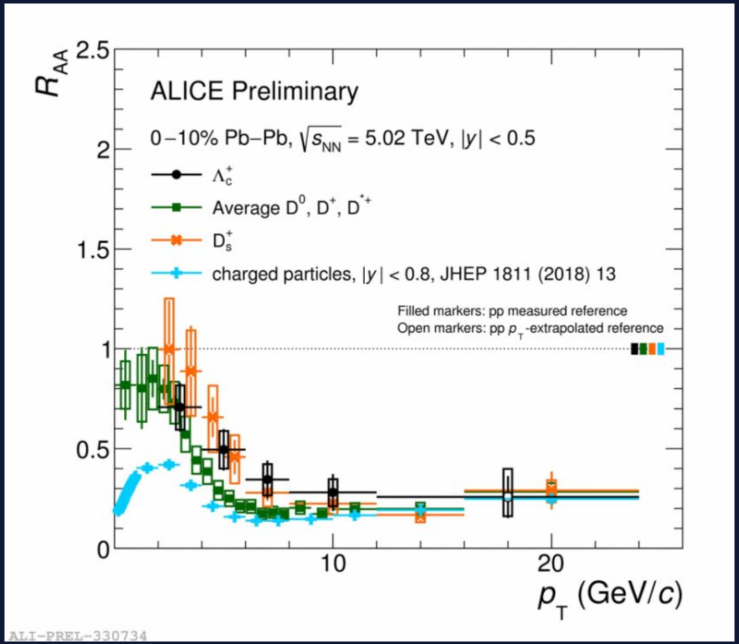


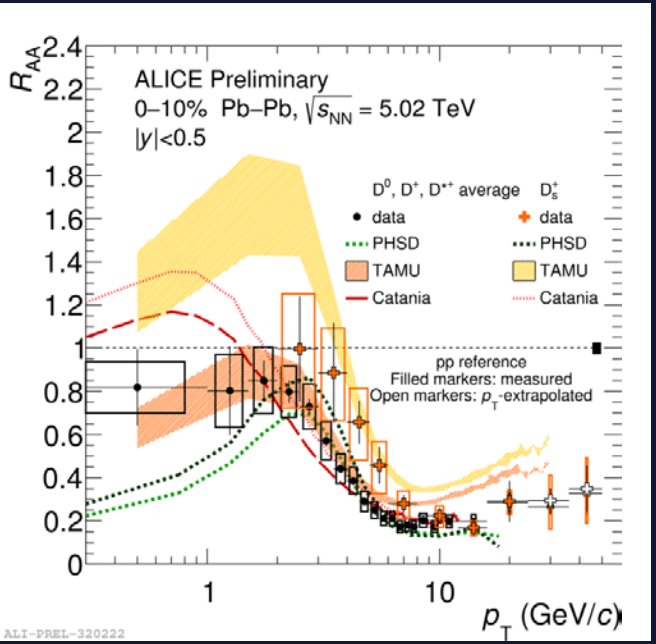


- Prompt and non-prompt D⁰ show different suppression at intermediate p_T
- Models with different energy loss for charm and beauty are compatible with data for the ratio of prompt over non-prompt D⁰

Indication of flavour dependent energy loss

Heavy-flavour R_{AA}



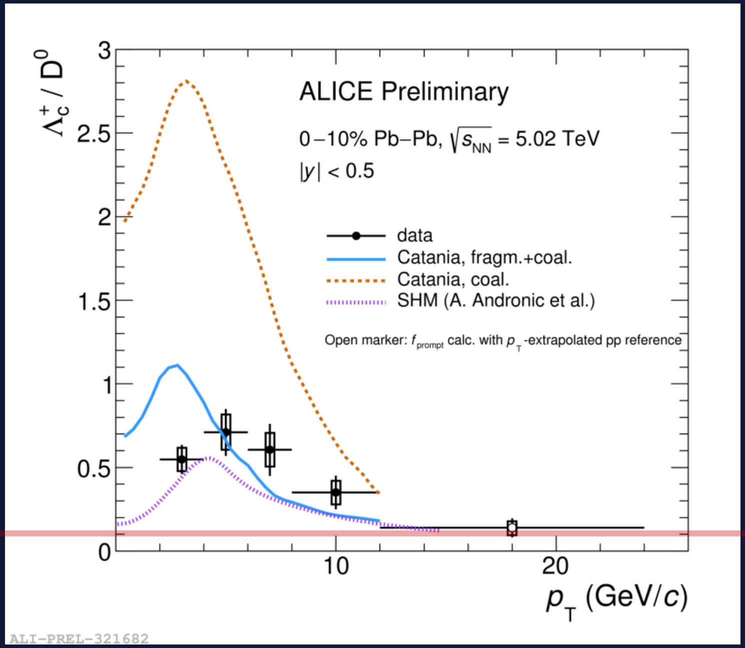


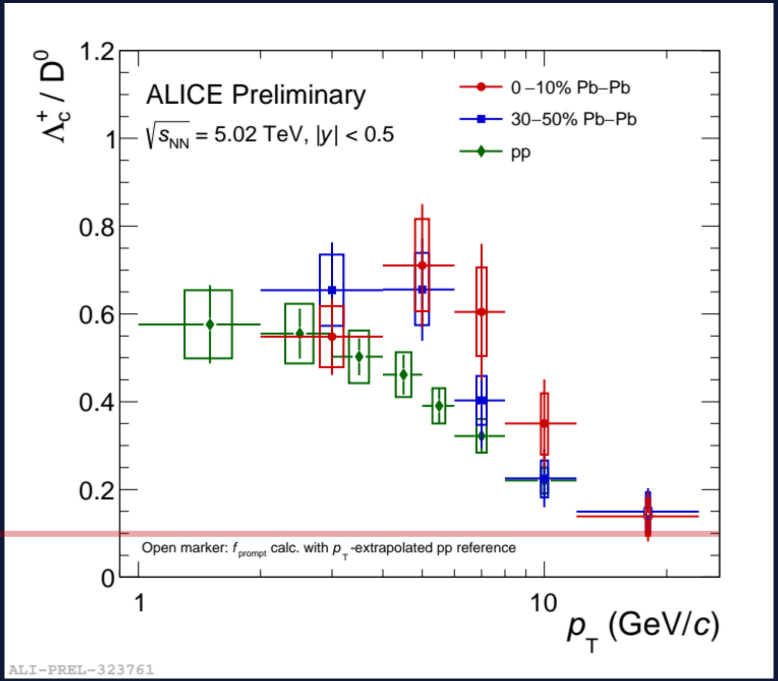
- ALICE provides a detailed picture of the nuclear modification factor for multiple particle species
- R_{AA} hierarchy consistent with expected energy loss for different partons:

$$\Delta E_{loss}(g) > \Delta E_{loss}(u,d) > \Delta E_{loss}(c) > \Delta E_{loss}(b)$$

- Strange D mesons and charm Λ baryons show a hint of lower suppression, compared to non-strange D mesons, that may point at recombination effects
- Data for D_S is consistent with models that show an enhancement due to hadronization via recombination

Heavy-quark hadronization





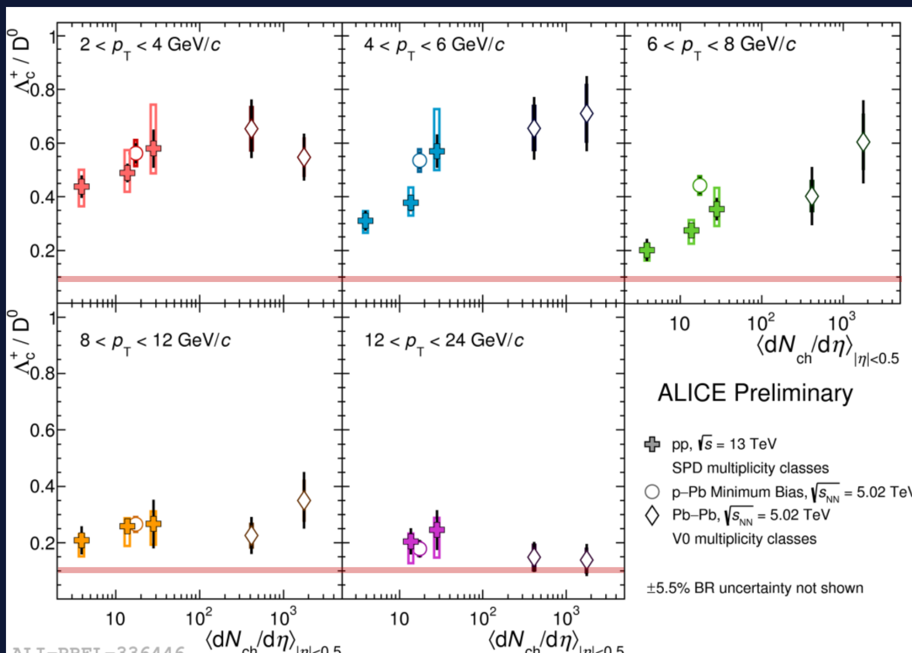
ee, ep colliders

Λ_c / D° ratio

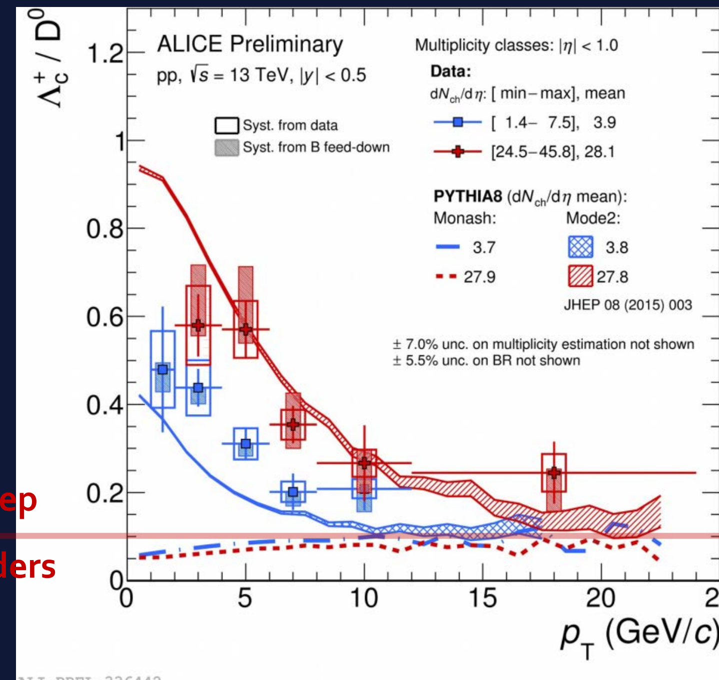
- Enhancement of Λ_c / D° ratio compared to ee and ep collider measurements
- Results favor models that use both coalescence and fragmentation
- Hint of an enhancement in Pb-Pb vs pp collisions in the intermediate p_T region -> need more data to conclude

ALICE

Heavy-quark hadronization



ee, ep colliders



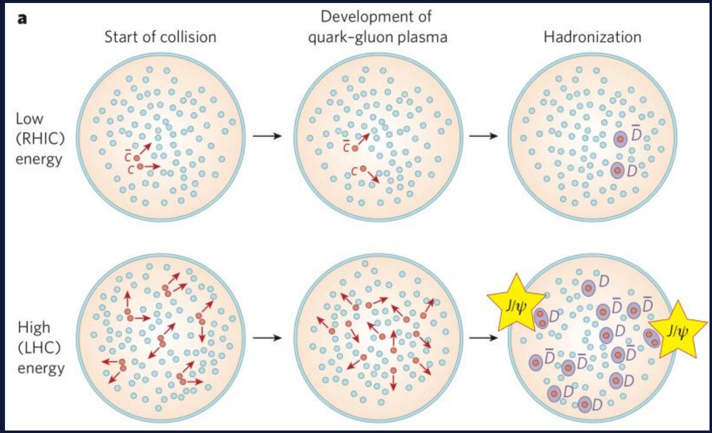
Λ_c / D⁰ ratio

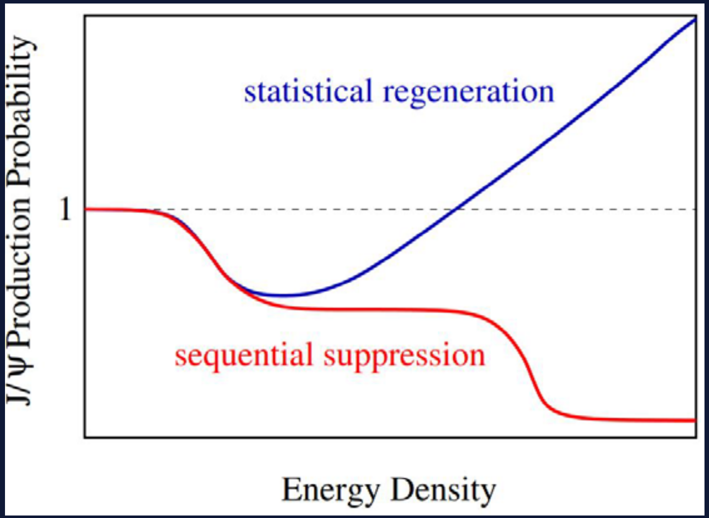
- Check the multiplicity dependence of the Λ_c / D ratio for a more detailed study of the enhancement
- Smooth increase from pp to p-Pb to Pb-Pb
- Even for low multiplicity pp events the Λ_c / D⁰ ratio remains higher than ee, ep measurements
- Indication of recombination which already occurs in pp
- PYTHIA including colour reconnection results in a good agreement with data

Quarkonium

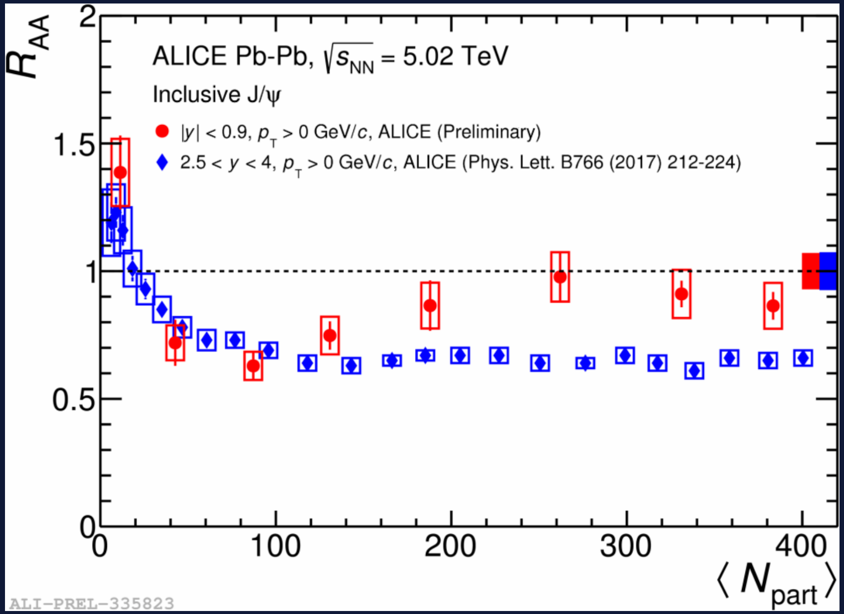
Physics Motivation

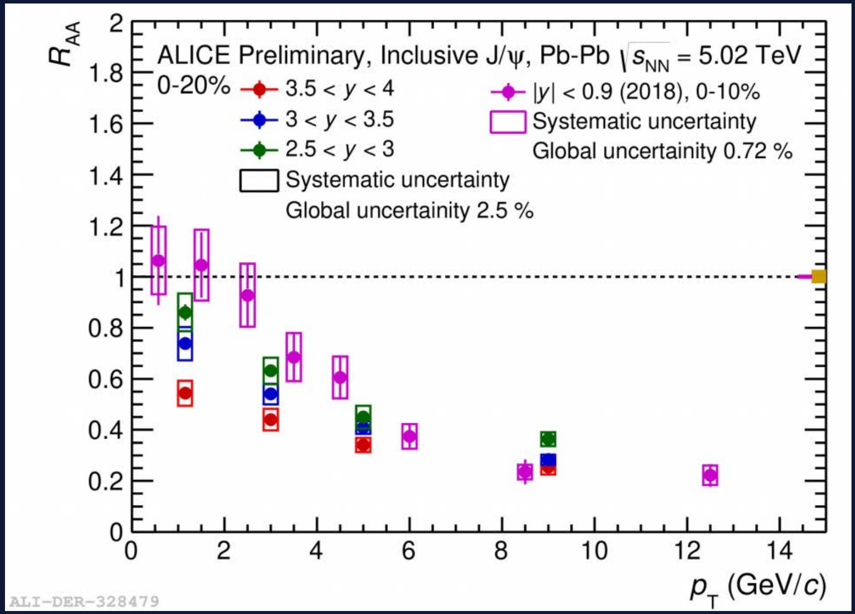
- At high temperatures colour screening in the QGP results in the suppression of quarkonium production
- Different quarkonium states have different binding energies -> **Sequential melting**
- At higher collision energies $c\bar{c}$ multiplicity increases leading to an enhanced quarkonia production via (re)combination at hadronization or during the QGP phase





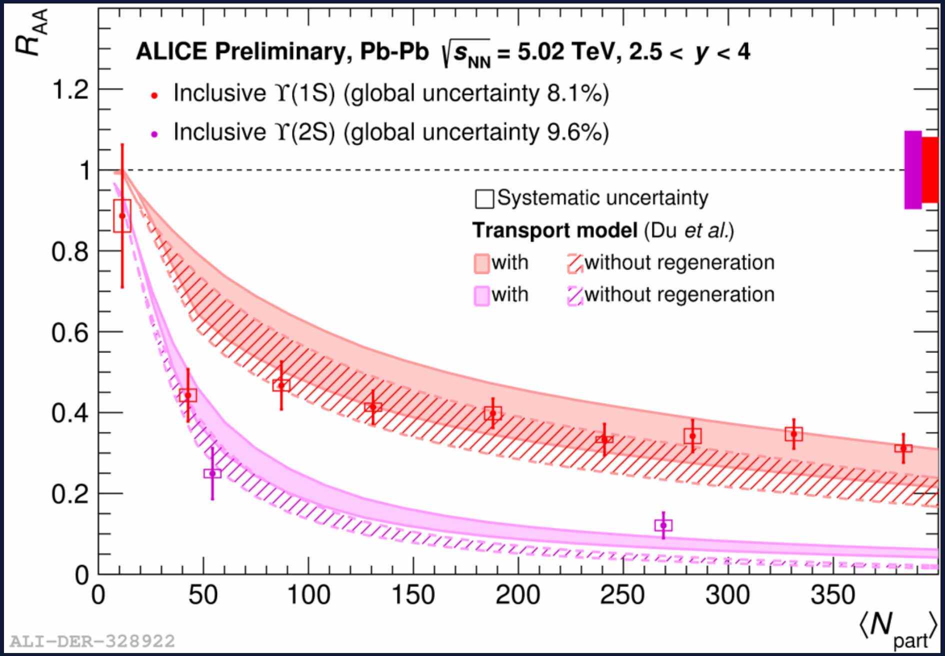
J/ψ R_{AA} in Pb-Pb collisions $\sqrt{s_{NN}}$= 5.02 TeV





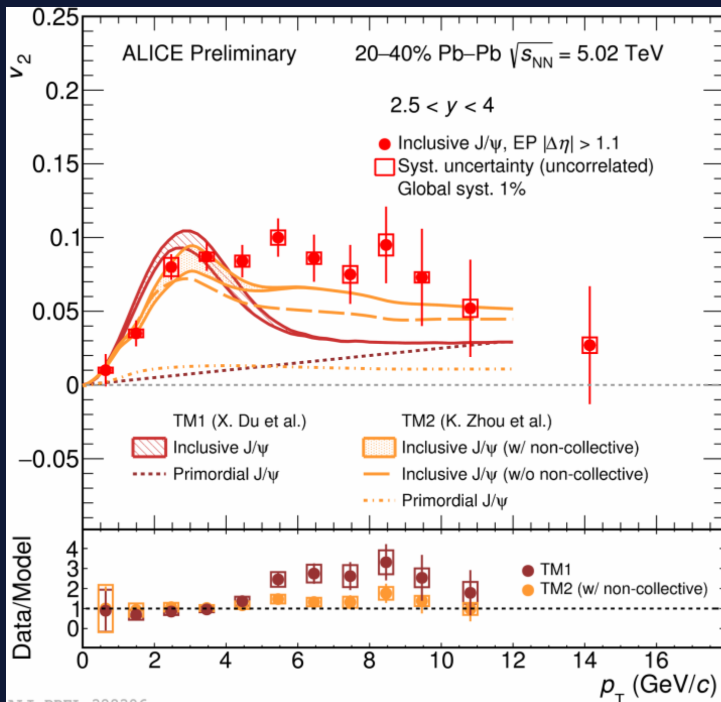
- Significantly improved precision and p_T reach compared to previous measurements
- Increasing charm-quark density towards mid rapidity -> recombination effects stronger at mid rapidity

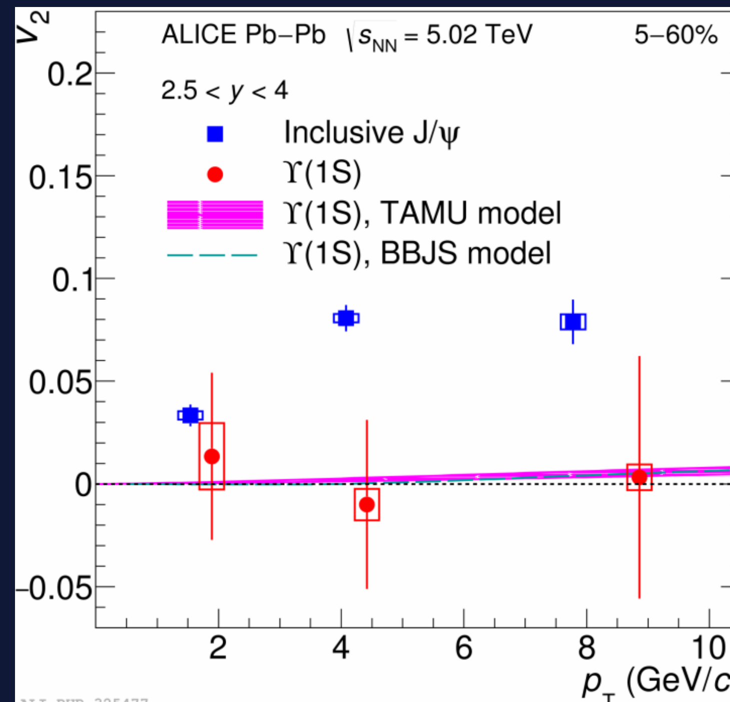
Υ R_{AA} in Pb-Pb collisions $\sqrt{s_{NN}}$= 5.02 TeV



- Slight bottomonium (Υ) centrality dependence
- Stronger suppression of Υ(2S) compared to Υ(1S)

J/ψ and Υ v_2 in Pb-Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV



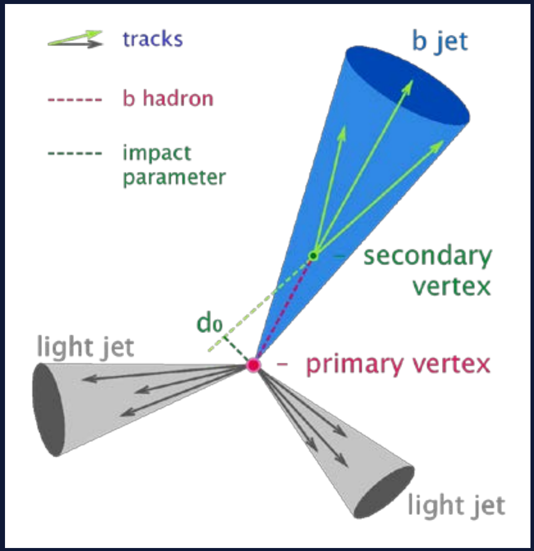


- Positive J/ψ v_2 in large p_T range at forward rapidity
- Bottomonium v_2 consistent with zero -> Need more data to make a conclusive interpretation on the difference between J/ψ and bottomonium v_2

Heavy-flavour jets

Physics Motivation

- Jets are produced in hard parton-parton collisions
- Heavy-flavour tagged jets are measured down to low jet p_T (5 GeV/c)
- Provide experimental data for gluon-to-hadron fragmentation functions and gluon PDF at low x
- Study the dependencies of energy loss in the QGP -> Jet quenching



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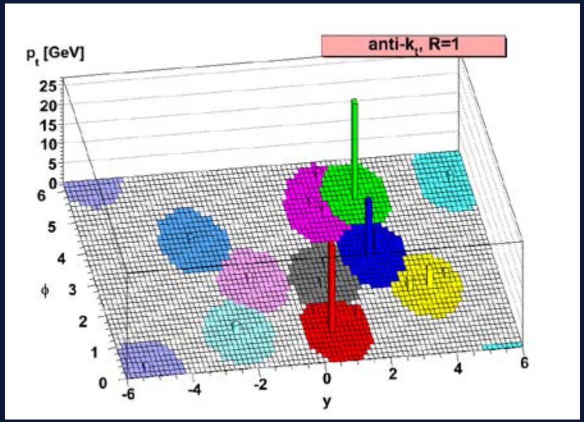

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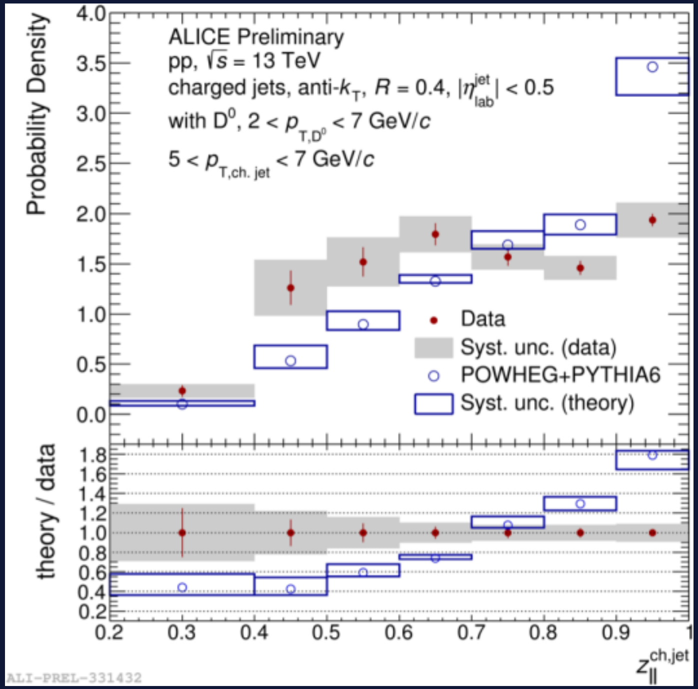
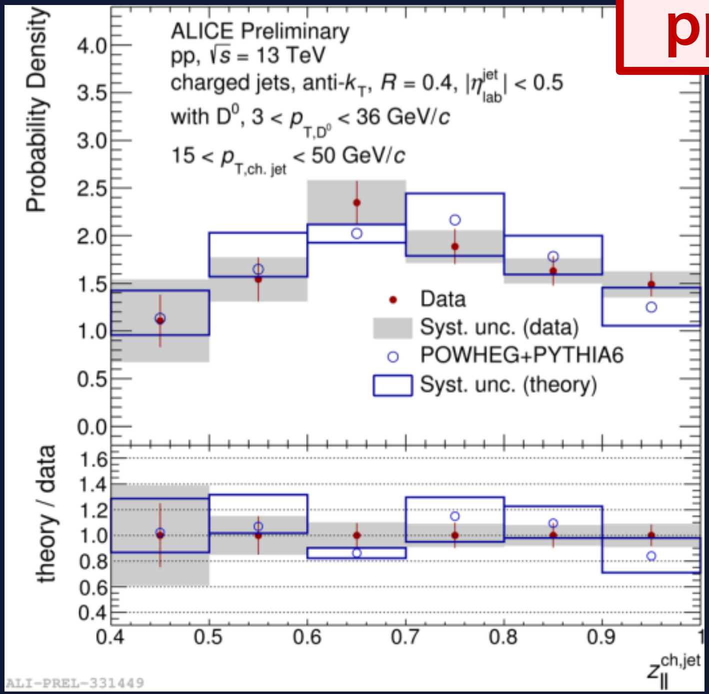
D^0-tagged jets - $z_{||}^{ch}$ probability density

pp





- Comparison of data to POWHEG for different momenta
- Results for different energies and *R* values in backup
- Data is comparable within uncertainty for high $p_{T,\text{jet}}$
- At low $p_{T,\text{jet}}$ data shows softer fragmentation

$$z_{||}^{ch} = \frac{\vec{p}_D \cdot \vec{p}_{\text{ch jet}}}{\vec{p}_{\text{ch jet}} \cdot \vec{p}_{\text{ch jet}}}$$

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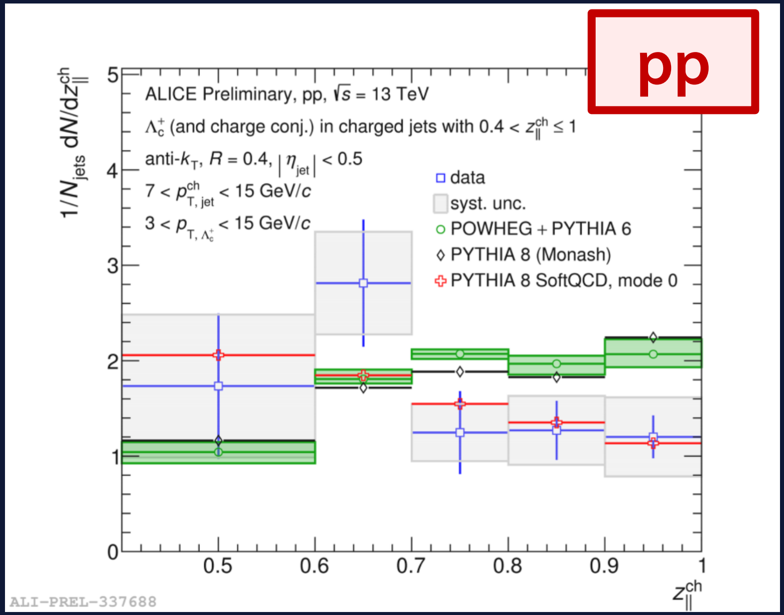
Λ_c^+-tagged jets - $z_{||}^{ch}$ probability density



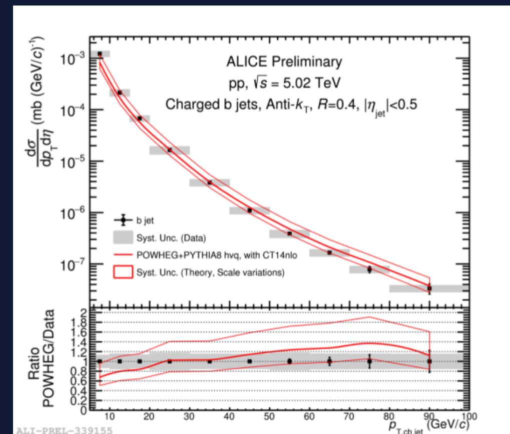
- First measurement of Λ_c^+ tagged jets at the LHC
- Higher precision measurements expected during next run

ALICE

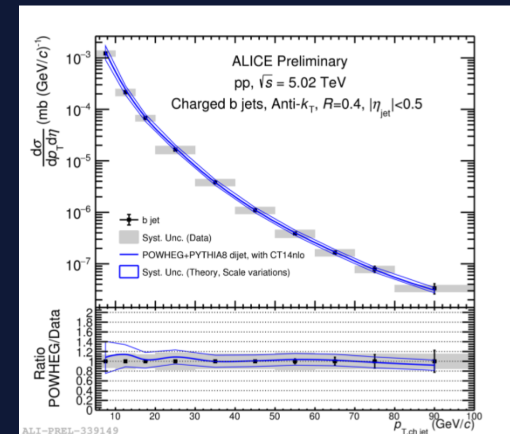
b-tagged jets

- Results consistent with POWEG
- No cold-nuclear-matter effects observed within uncertainties

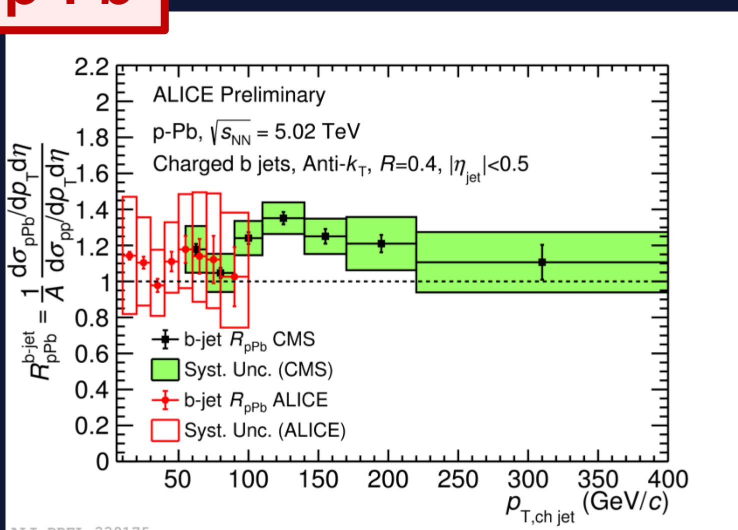
pp HVQ



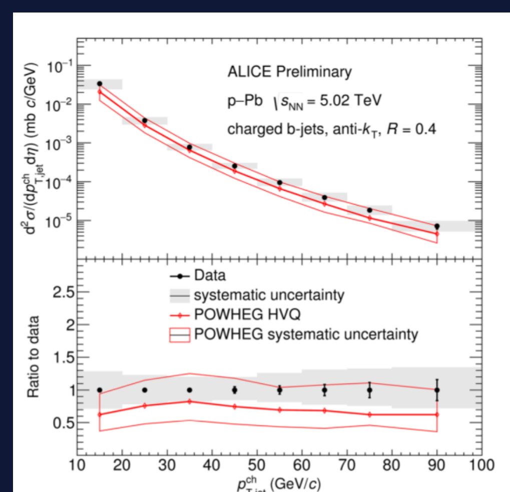
pp dijet



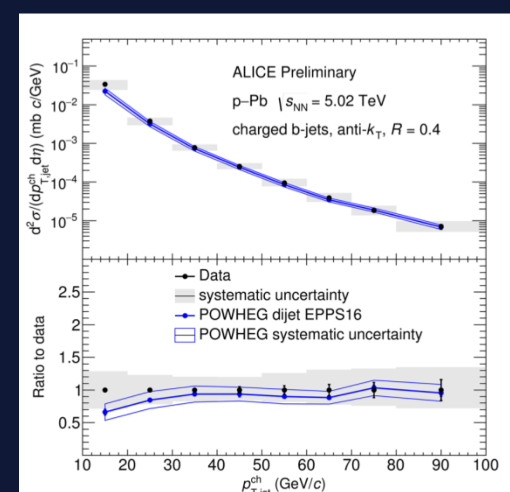
p-Pb



p-Pb HVQ

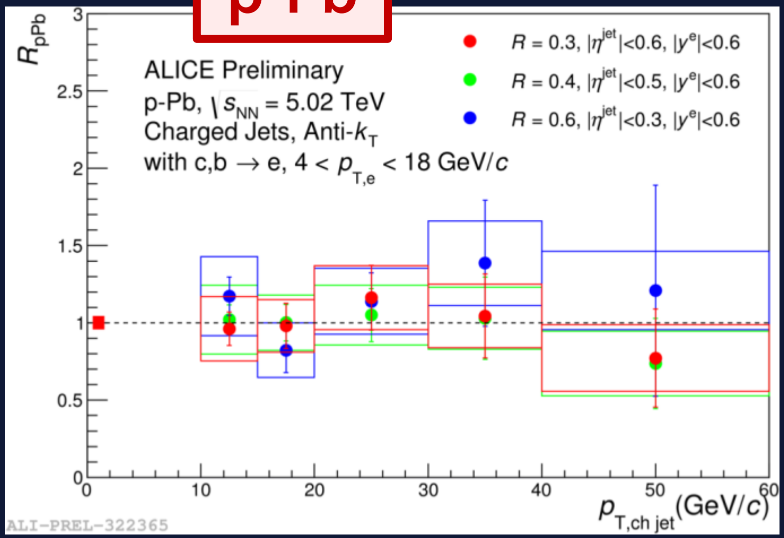


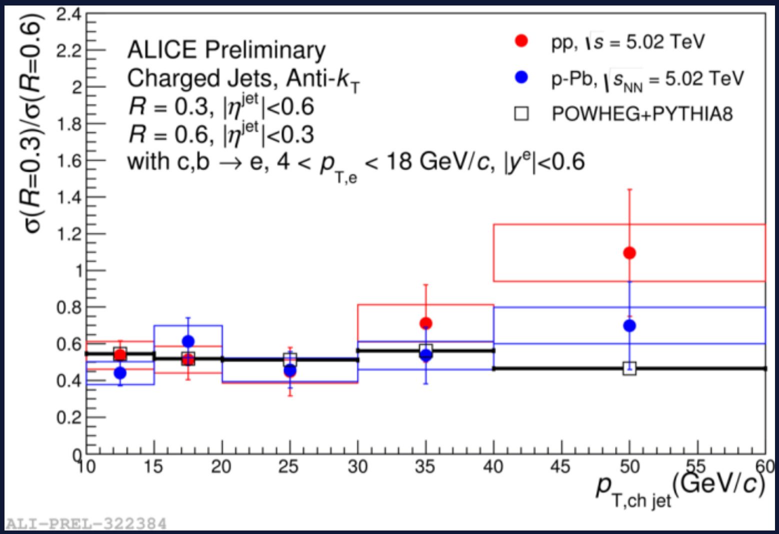
p-Pb dijet



Heavy-flavour decay lepton tagged jets

p-Pb





- Within uncertainties, no modification of the jet spectra observed in p-Pb

Summary and Conclusion

Large number of heavy flavour results from ALICE:

Open heavy flavour

- Measurements of heavy-flavour decay hadrons to low p_T
- Constraining models, can theory predict both R_{AA} and v_2?
- Indication of flavour-dependent energy loss
- Hint of strange D mesons and charm Λ baryon enhancement in Pb-Pb vs pp
- Indication of Λ_c recombination in pp

Quarkonium

- Precise J/ψ measurements
- J/ψ recombination effects stronger at central y
- J/ψ and ϒ R_{AA} and v_2 measurements in Pb-Pb collisions $\sqrt{s_{NN}}$= 5.02 TeV
- ϒ v_2 consistent with zero

Heavy-flavour jets

- D-tagged jet measurements consistent with POWHEG with softer fragmentation at low p_T
- First measurement of Λ_c^+ tagged jets at the LHC
- First b-jet measurements in ALICE: results consistent with theory
- Heavy-flavour decay lepton tagged jets show no modification of the jet spectra in p-Pb

Many more measurements are still to come! Exciting future ahead for ALICE!

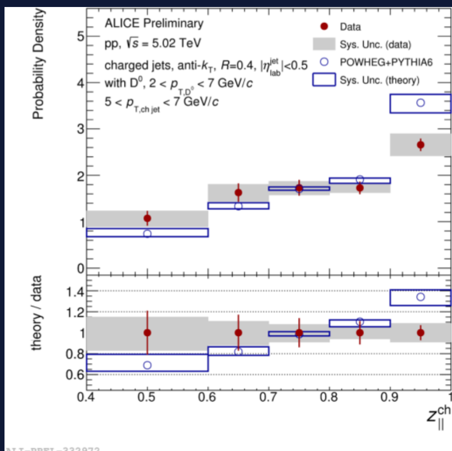
Backup

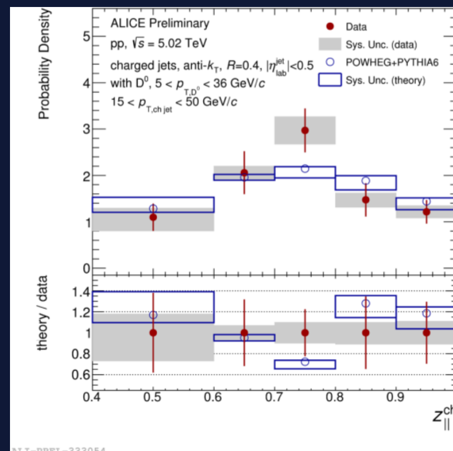
Backup

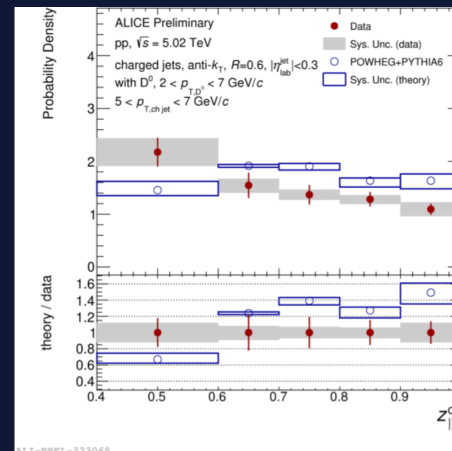
ALICE

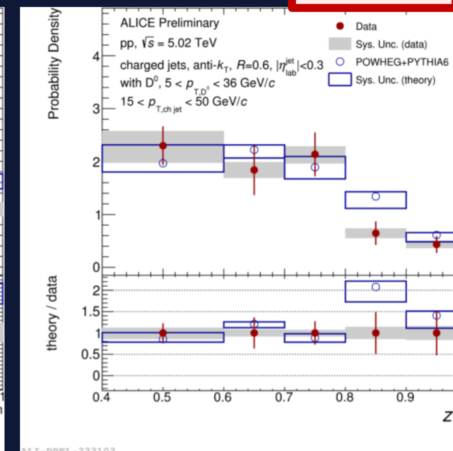
D^0-tagged jets - $z_{||}^{ch}$ probability density

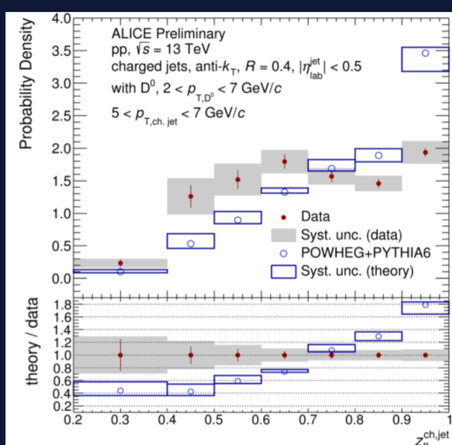
pp

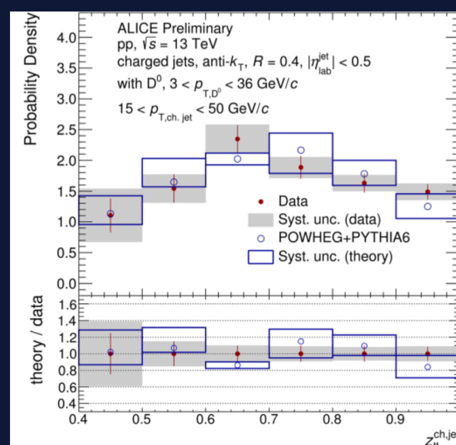












Comparison of data to POWHEG for different energies, momenta, and *R* values

- Data is comparable within uncertainty for high $p_{T,jet}$
- At low $p_{T,jet}$ data shows softer fragmentation

$$z_{||}^{ch} = \frac{\vec{p}_{D} \cdot \vec{p}_{ch\ jet}}{\vec{p}_{ch\ jet} \cdot \vec{p}_{ch\ jet}}$$