

ALICE

Learning about the strong interaction from heavy-ion collisions with ALICE

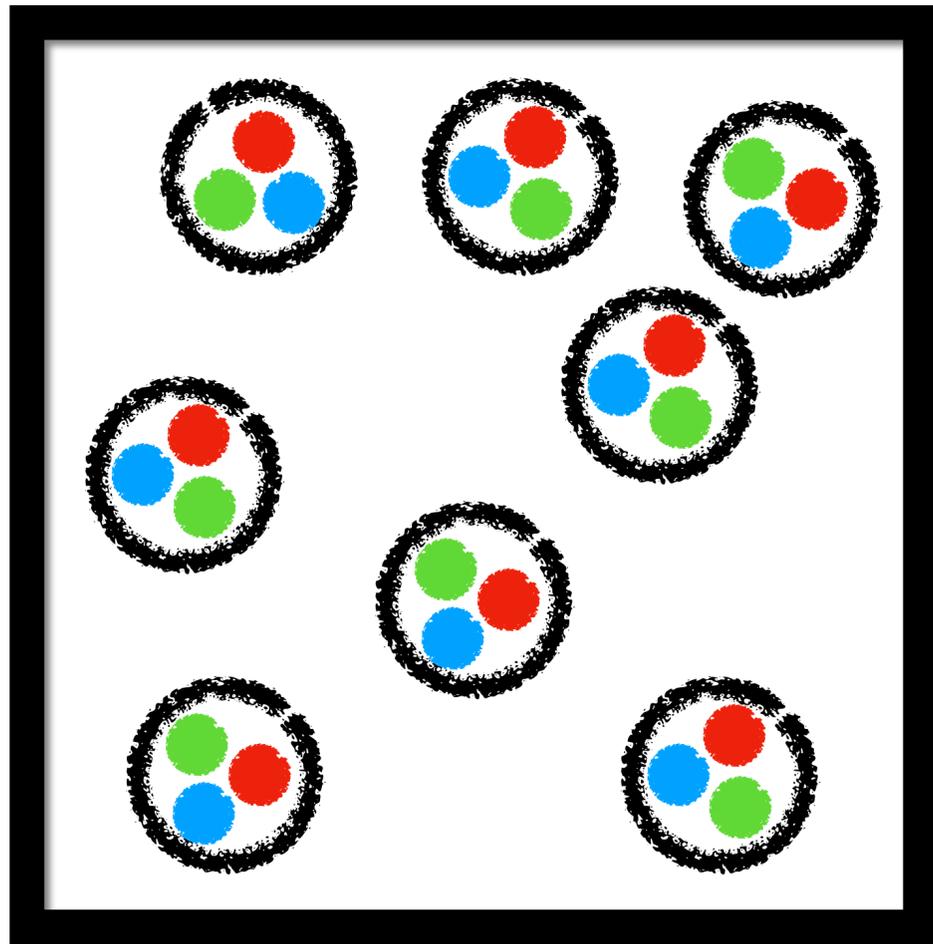
Nuclear Physics Community Meeting, January 2026
2026-01-08

Martin Völkl

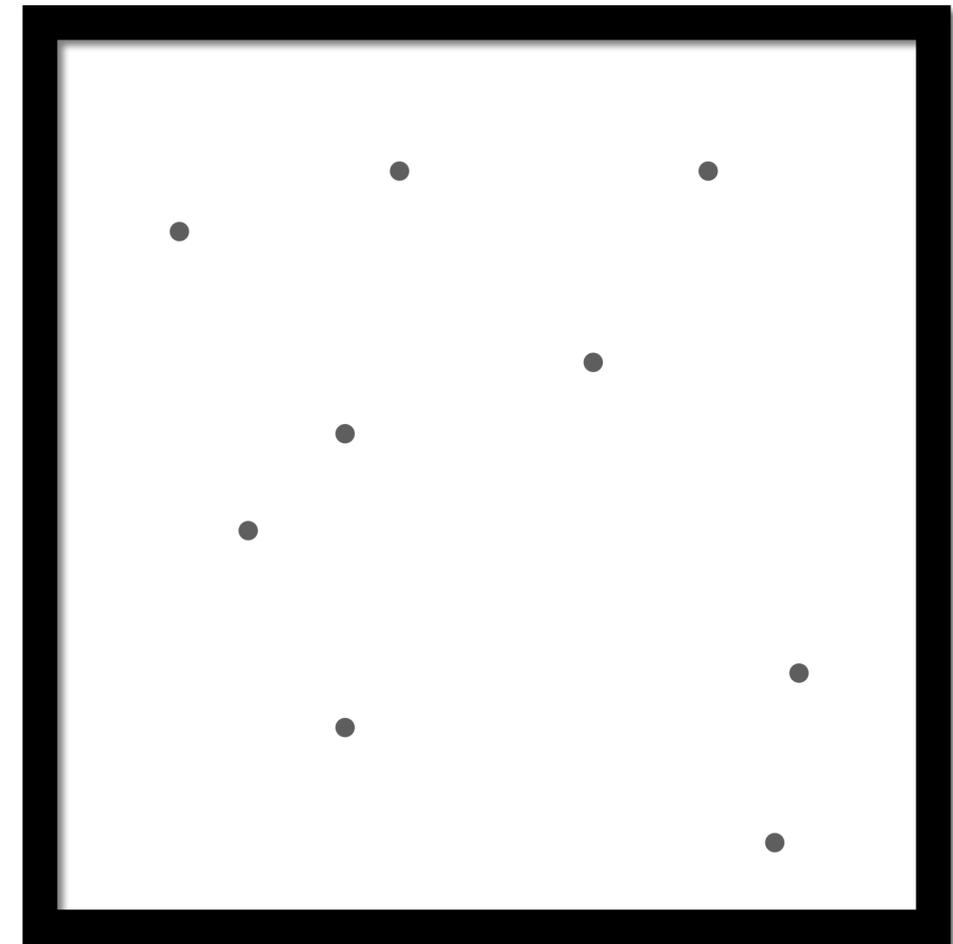


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BIRMINGHAM

Introduction

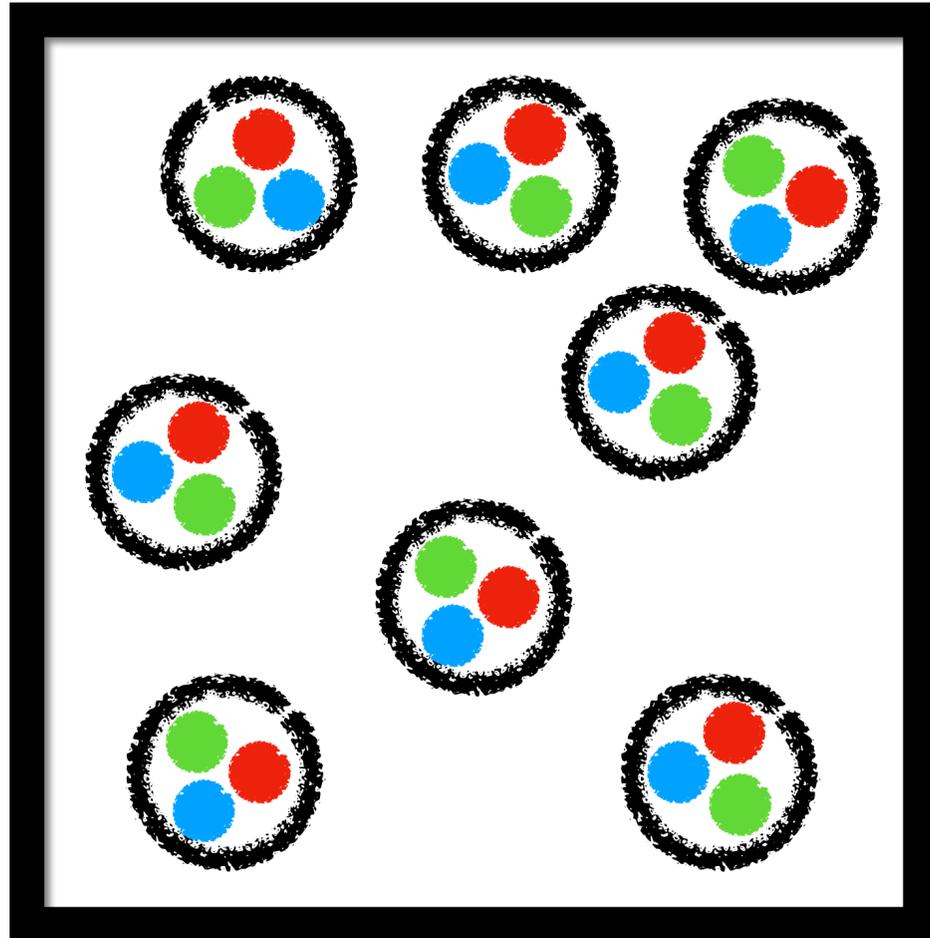


Hadrons in a box

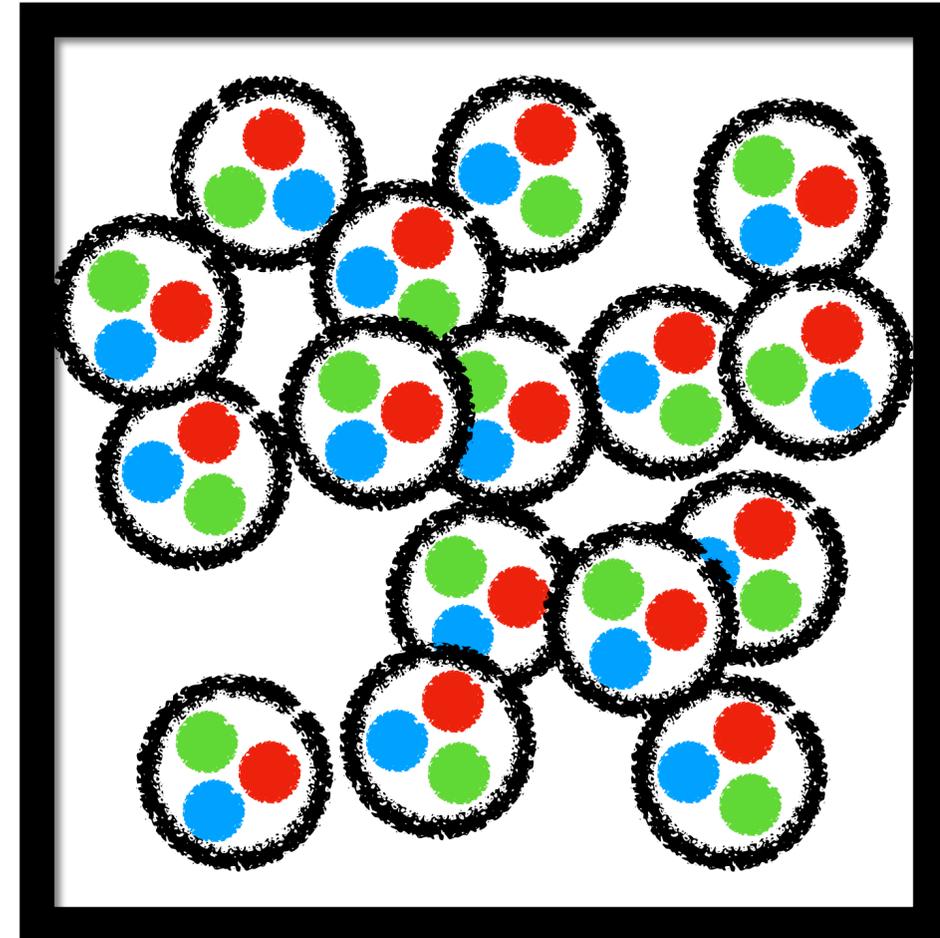


Point particles in a box

Percolation



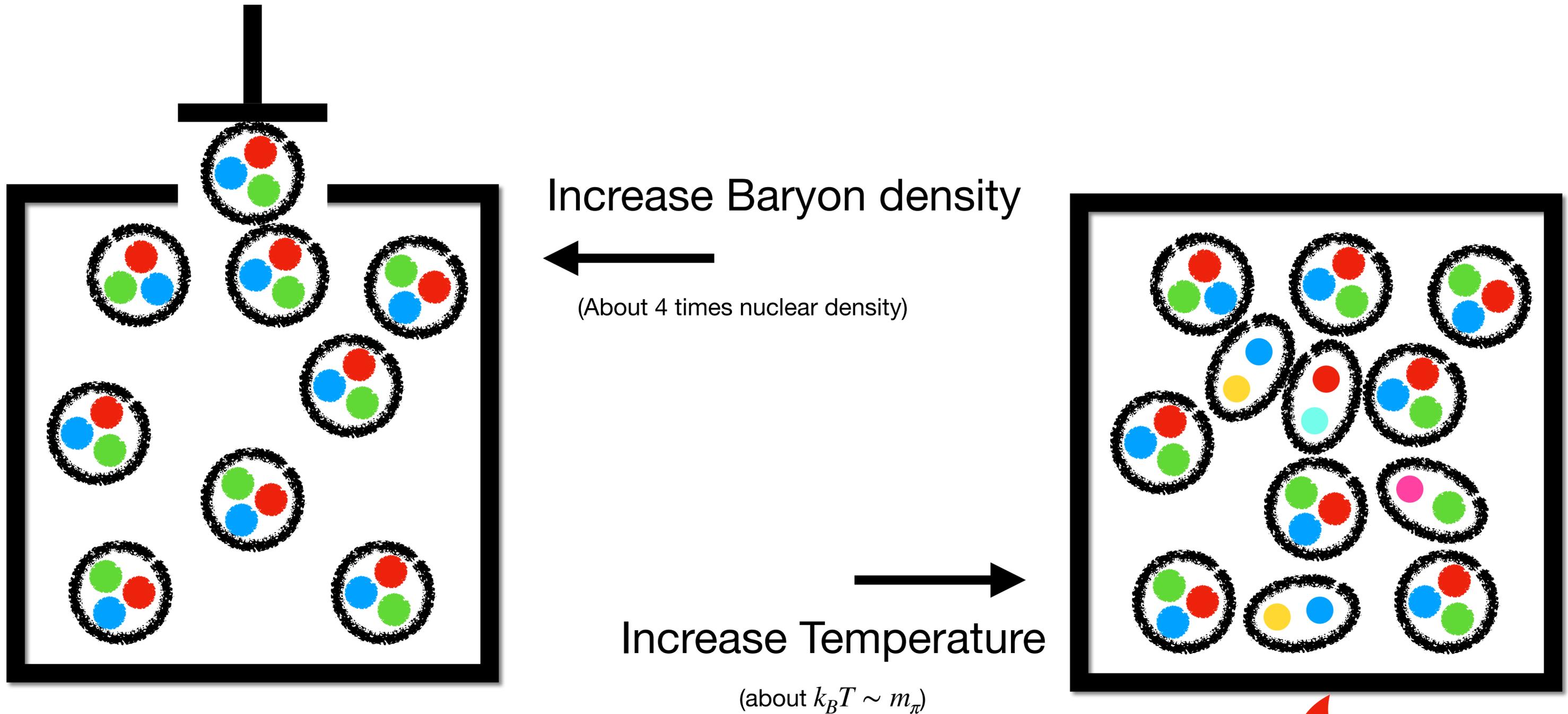
Confined matter



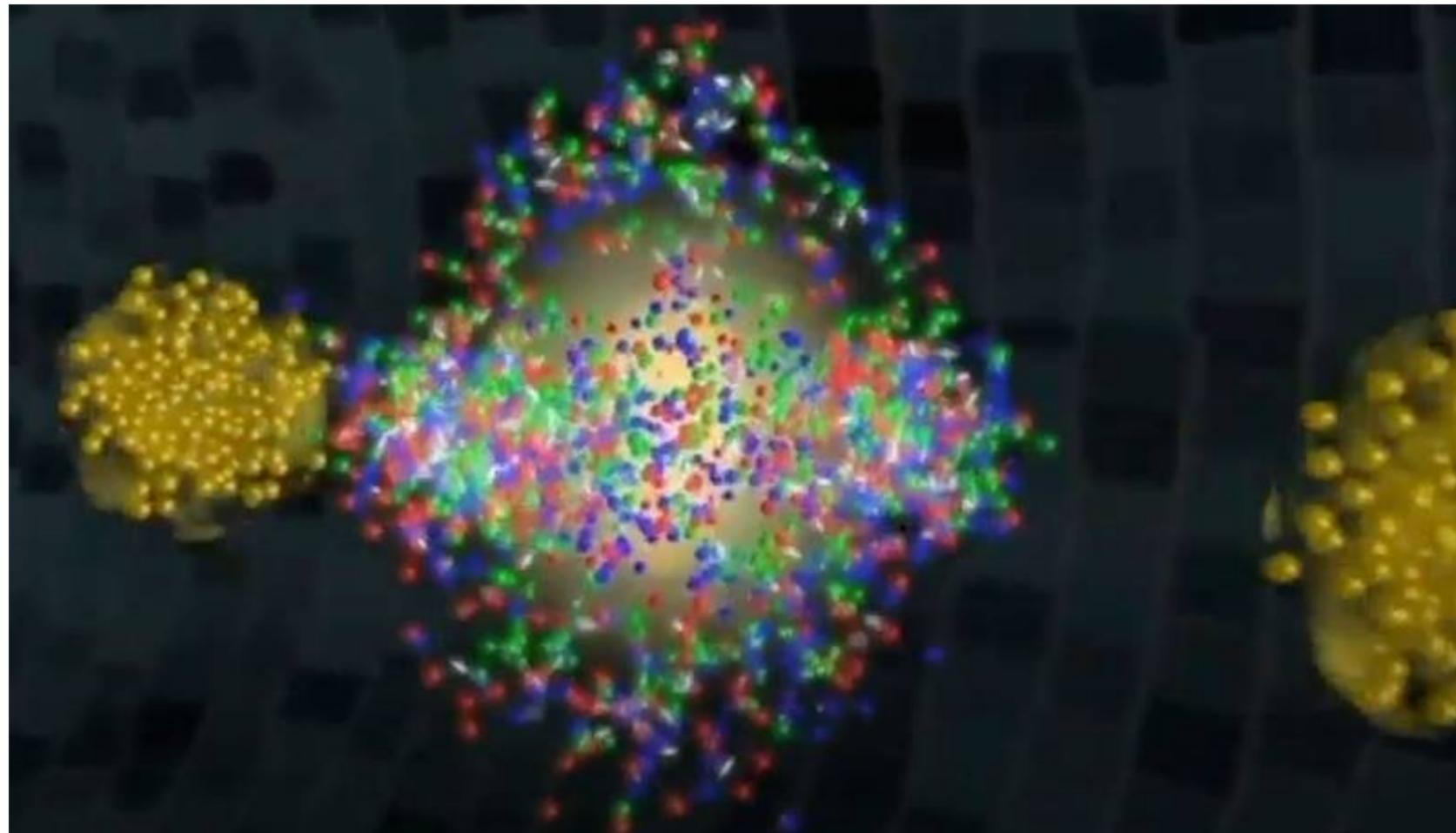
Deconfined matter

- Deconfined strongly interacting matter - the quark-gluon plasma

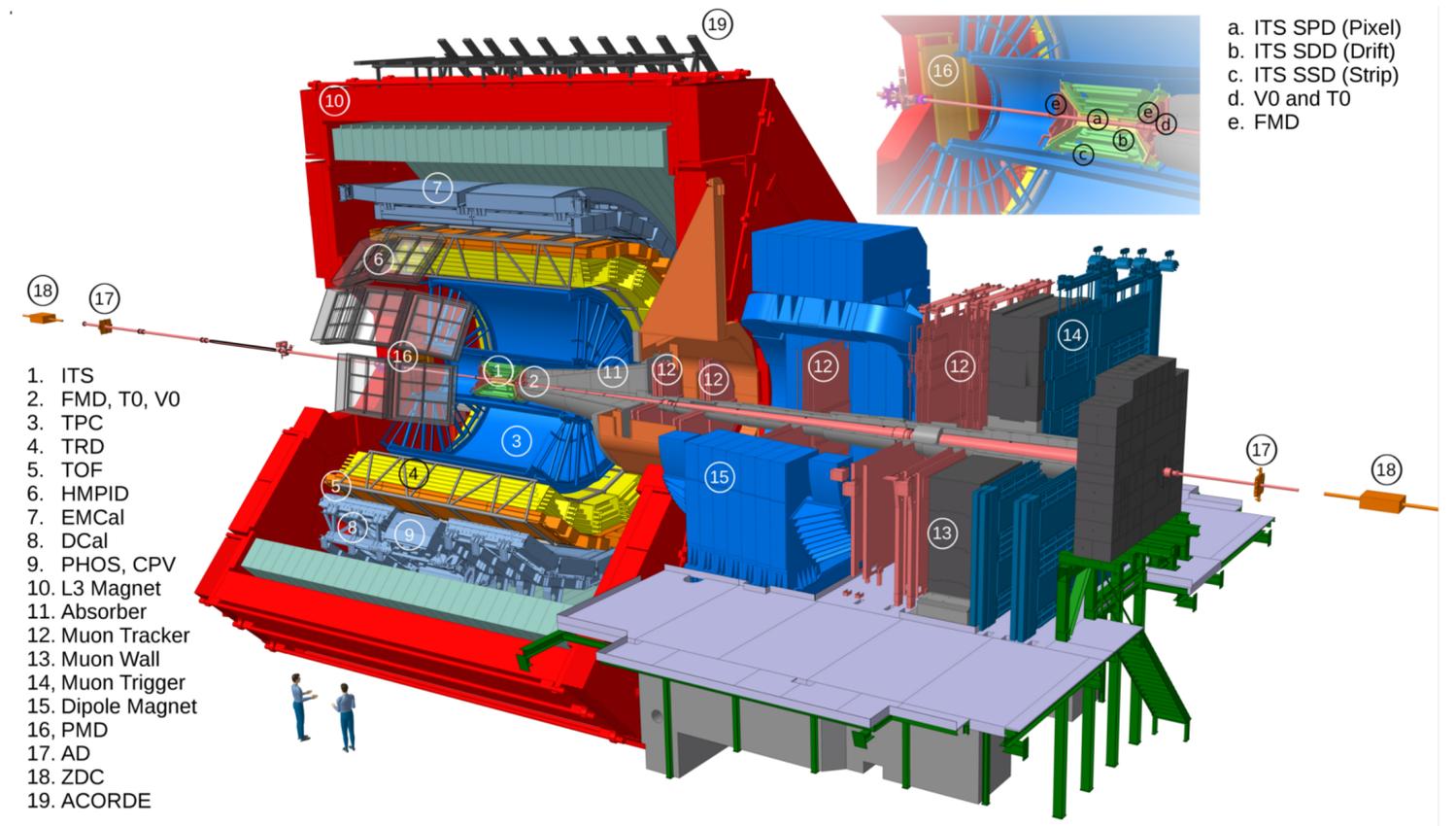
How do you make deconfined matter?



Where does such a transition happen?



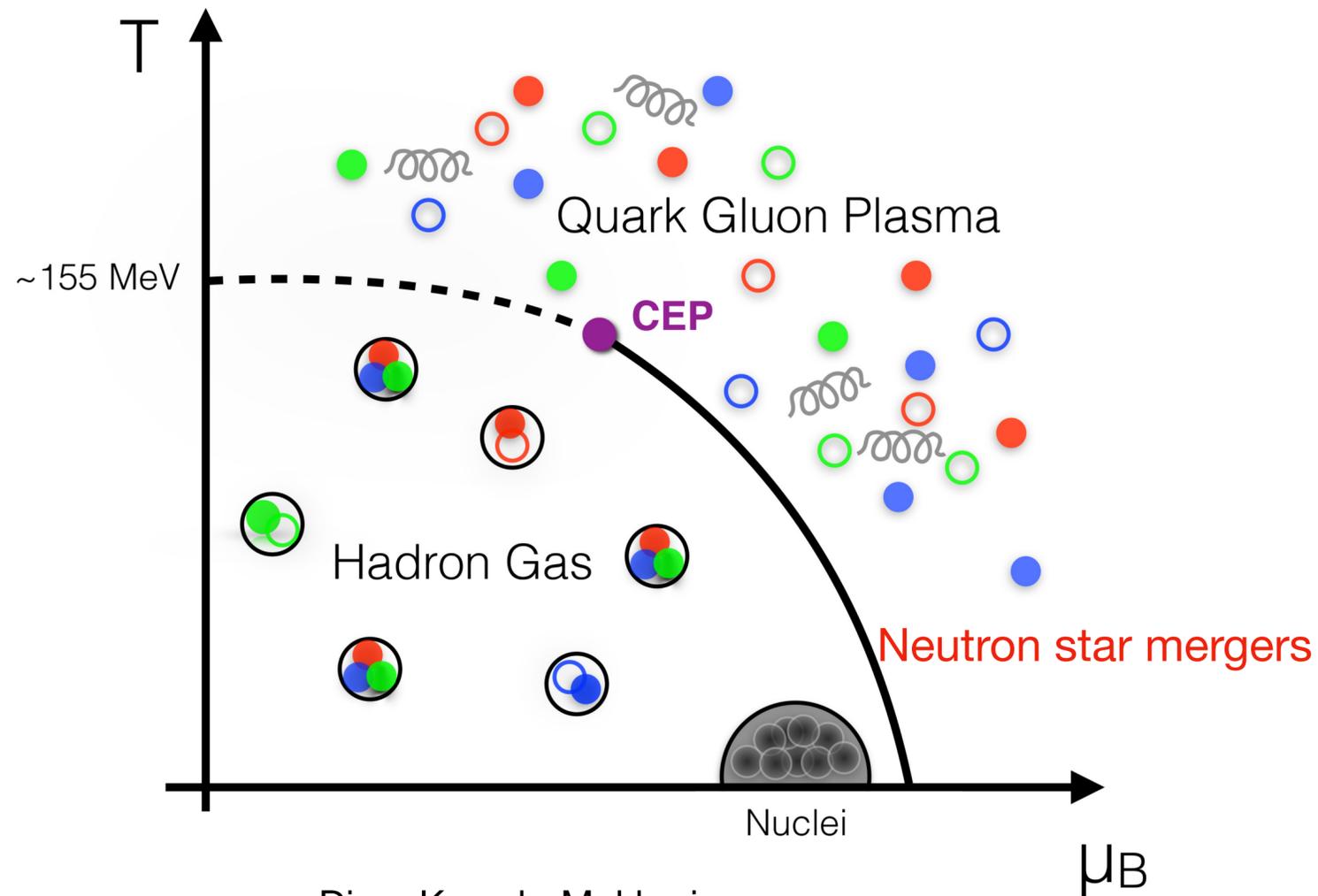
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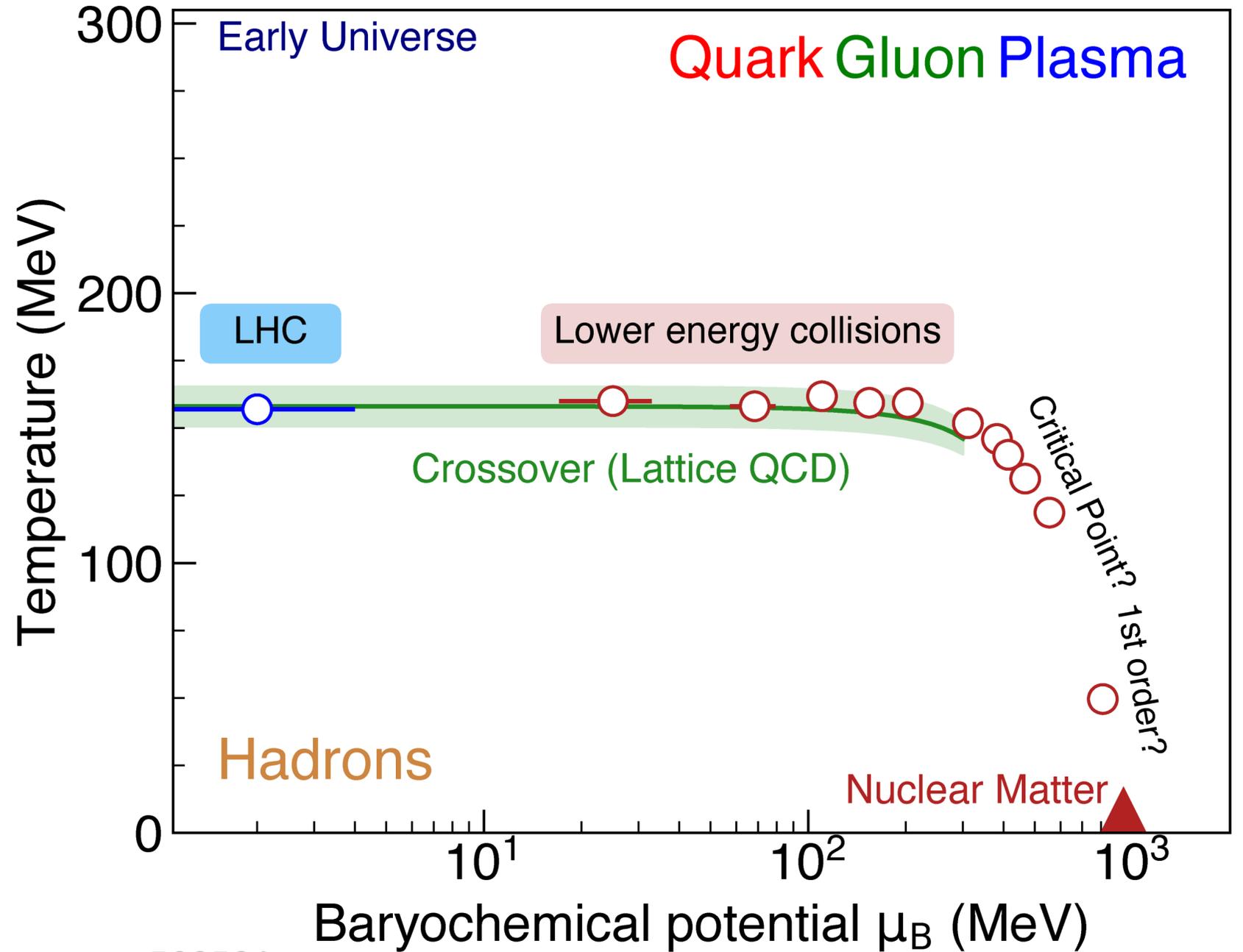
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- Nuclei essentially pass through each other and leave region of high energy density
- Enough time to thermalise

Phase diagram of strongly interacting matter



Ding, Karsch, Mukherjee
International Journal of Modern Physics E 2015 24:10



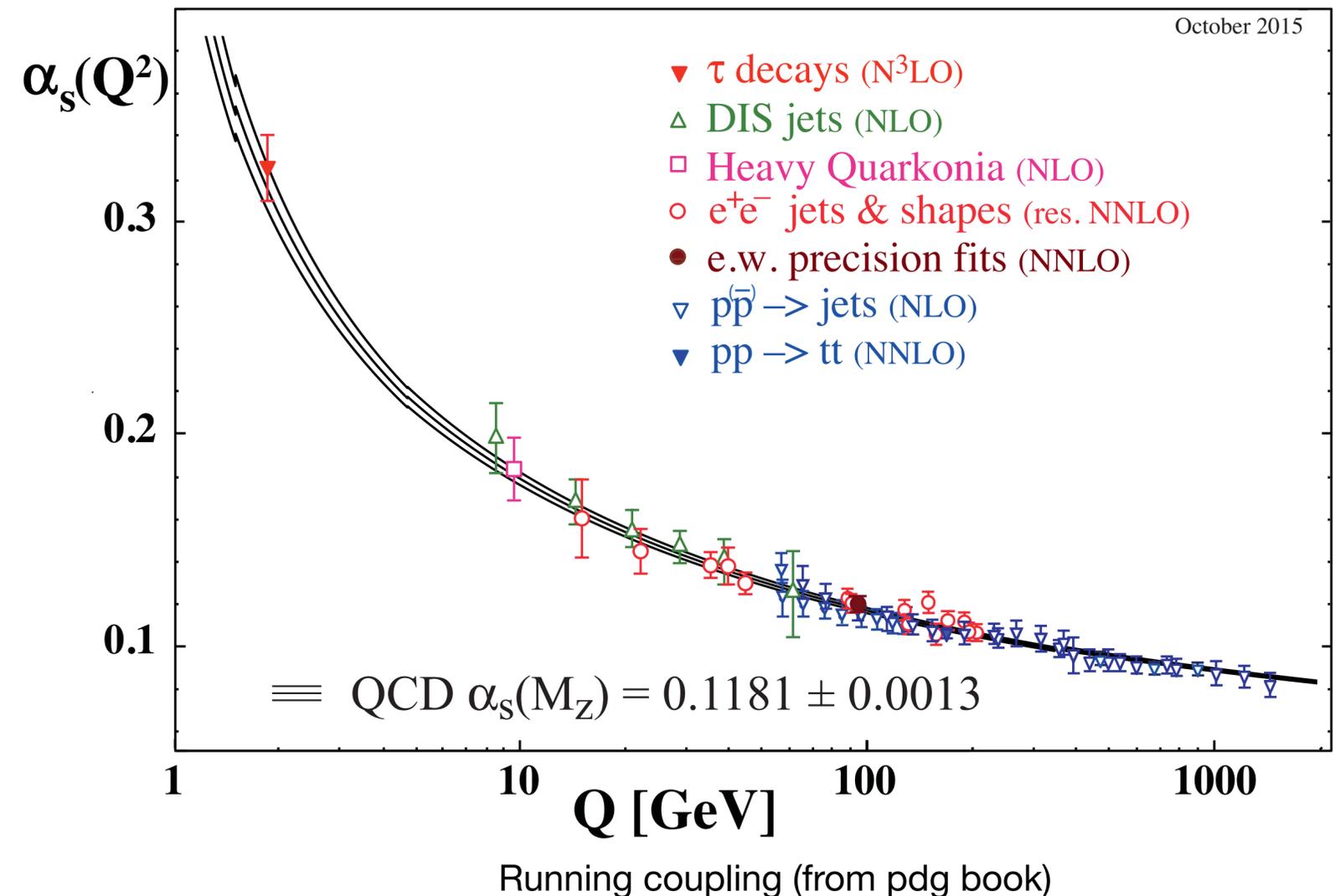
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Expectation

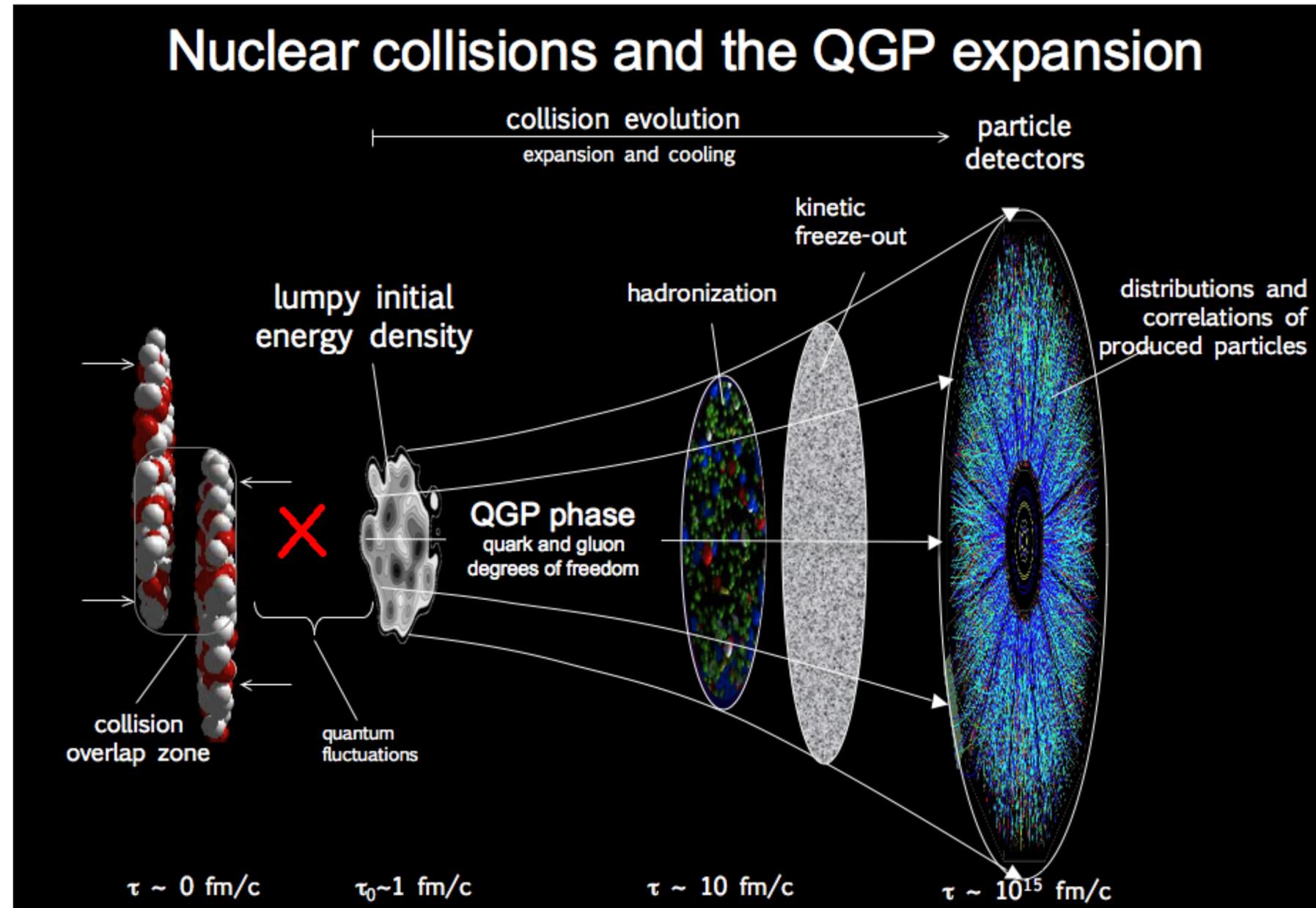
Measurement

Why do we care?

- QCD: non-Abelian gauge theory
- Running coupling
- Confinement
- Perturbative QCD: pQCD
- QGP: Laboratory for nonperturbative QCD in extreme conditions

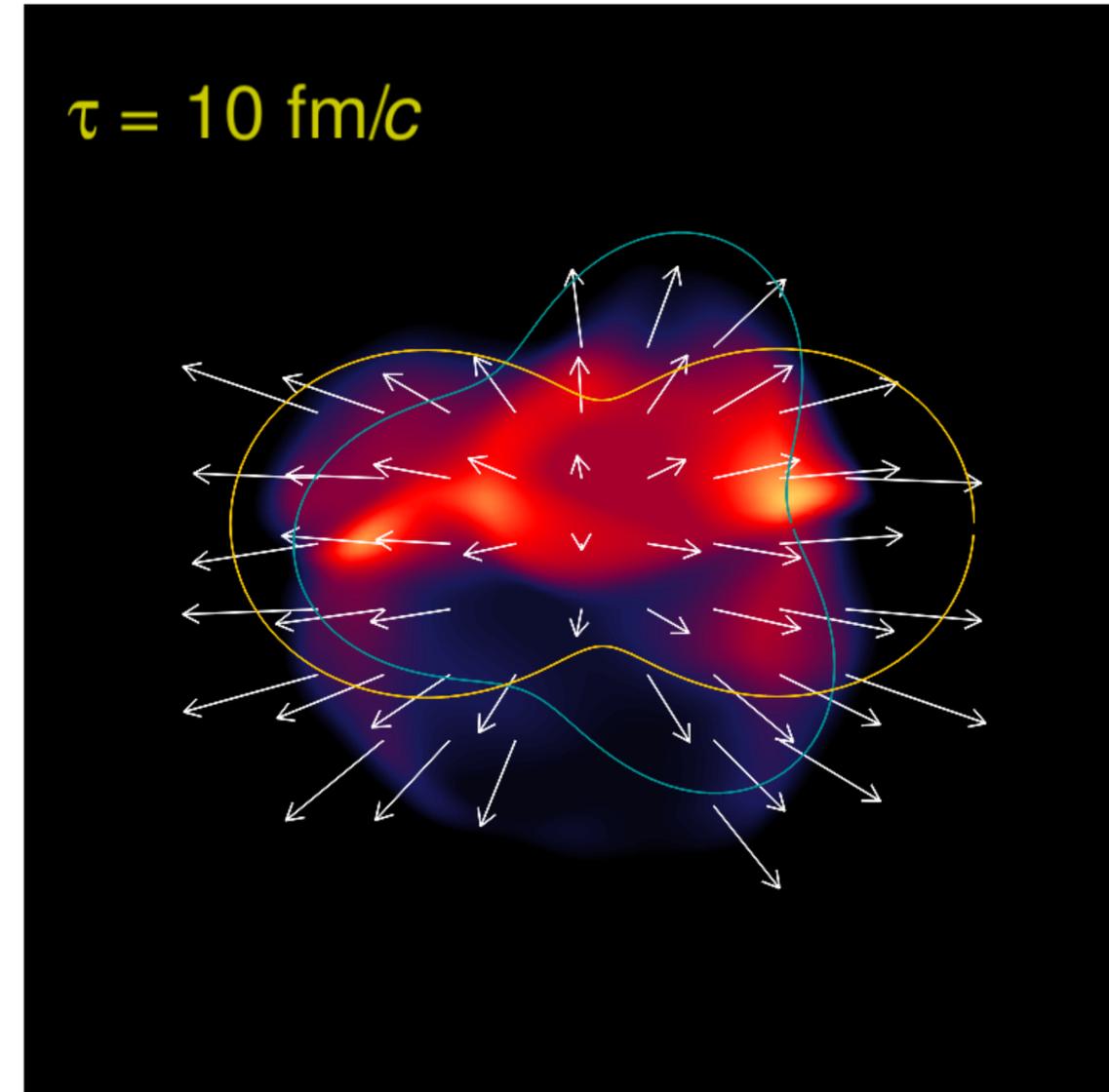
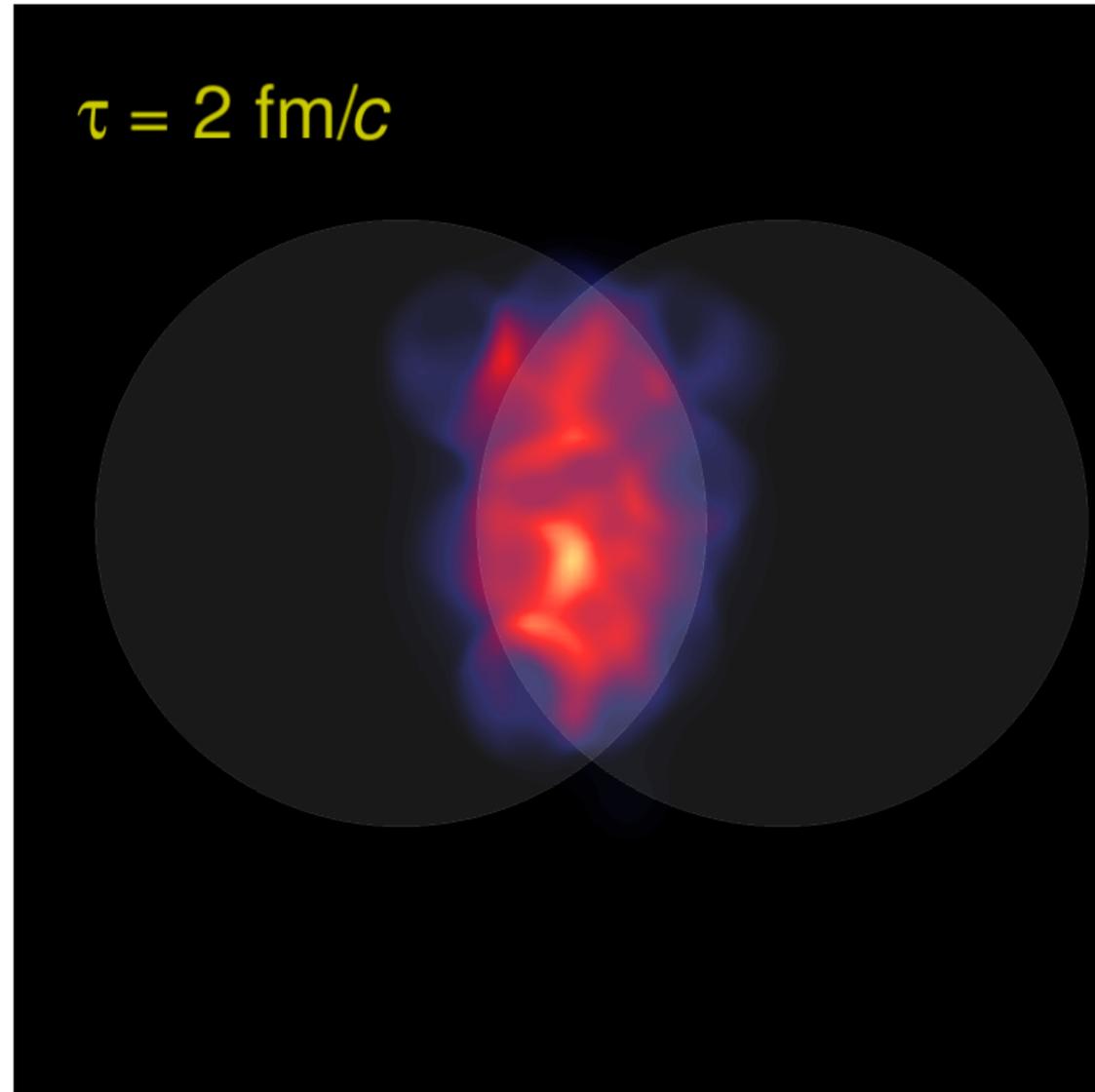


Stages of a heavy-ion collision



Nuclei \rightarrow Scattering processes \rightarrow Equilibration \rightarrow QGP evolution \rightarrow Hadronisation/Freeze-out \rightarrow (Decays)

Evolution of the QGP

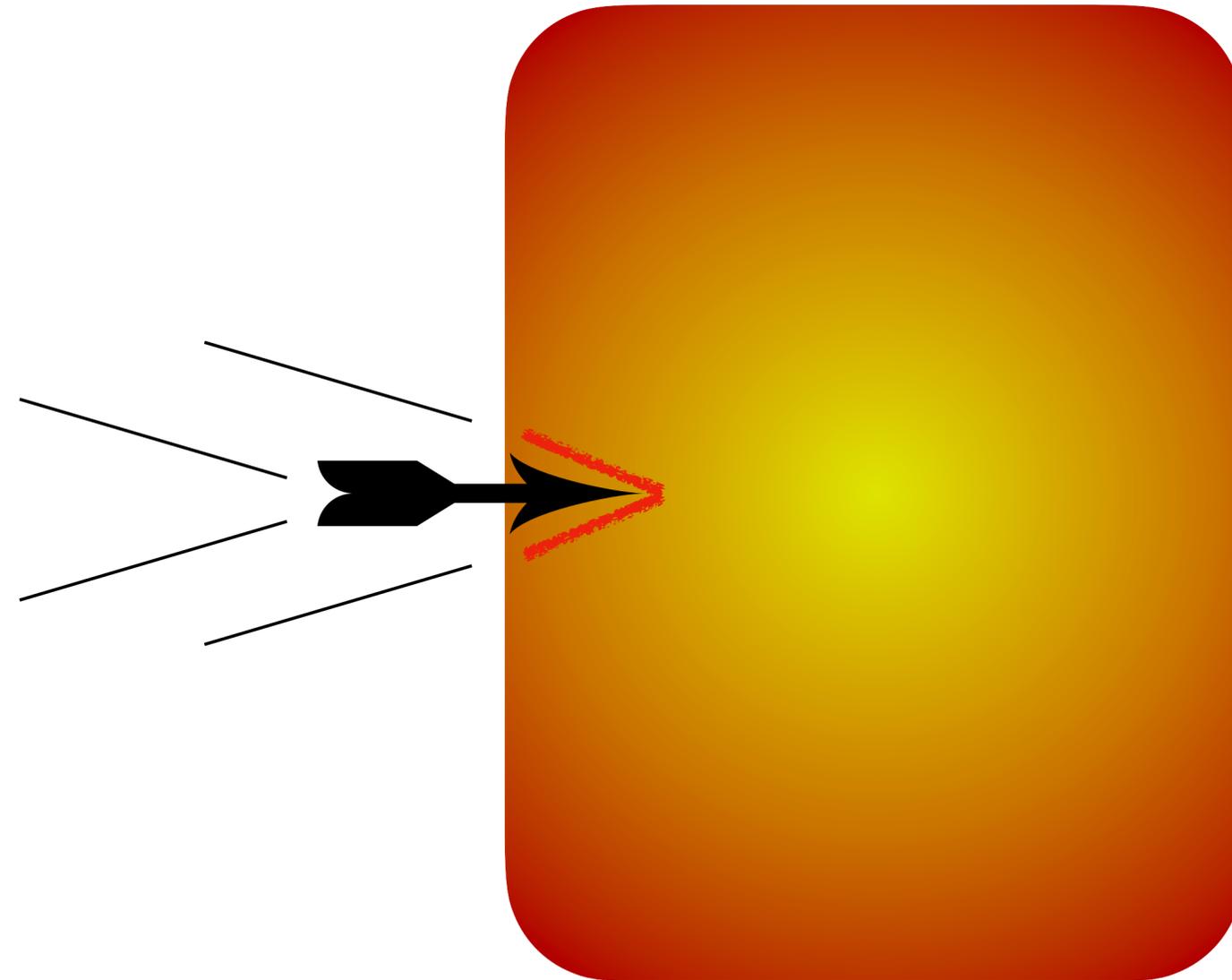


- Evolution described via relativistic hydrodynamics
- Medium expands and cools

Nuclei \rightarrow Scattering processes \rightarrow Equilibration \rightarrow **QGP evolution** \rightarrow Hadronisation/Freeze-out \rightarrow (Decays)

Heavy Flavour

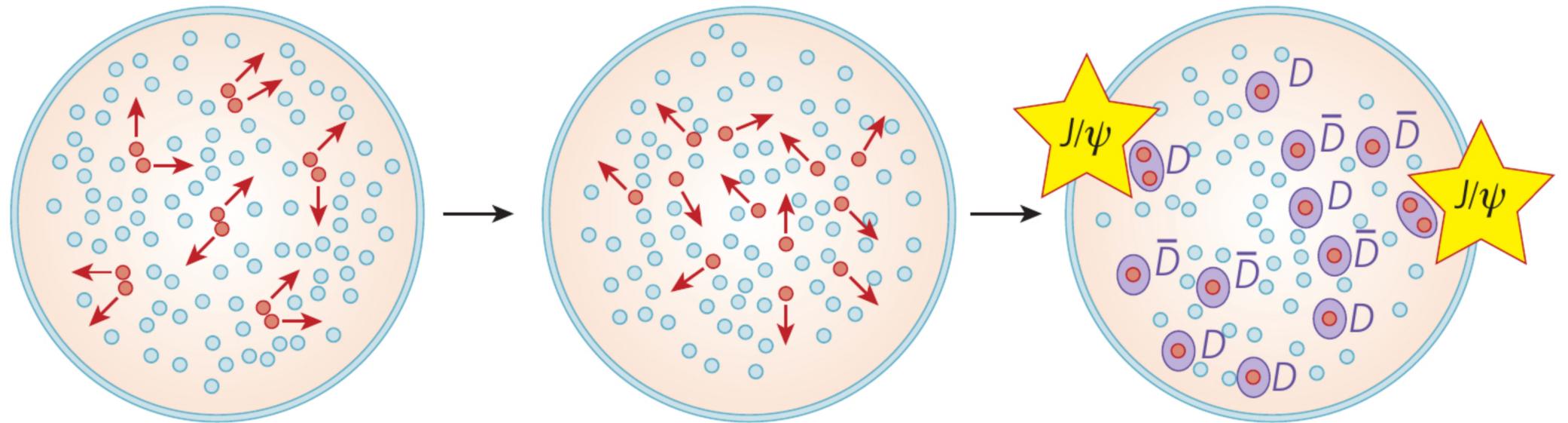
How do we learn about the QGP?



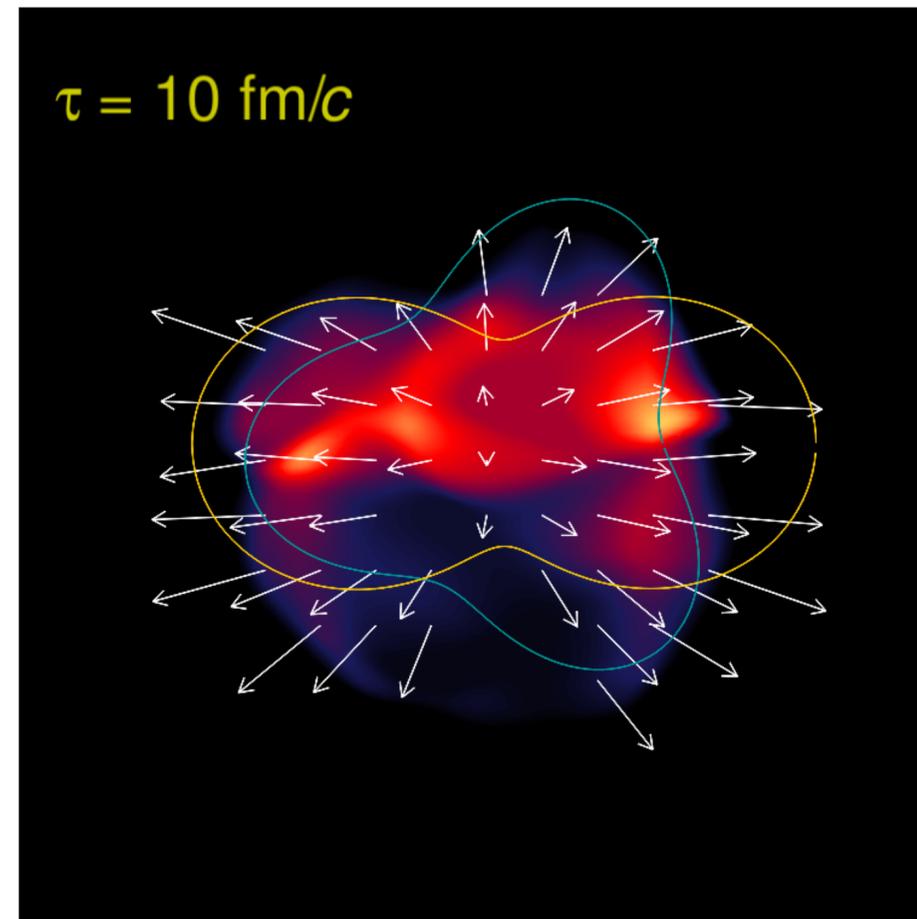
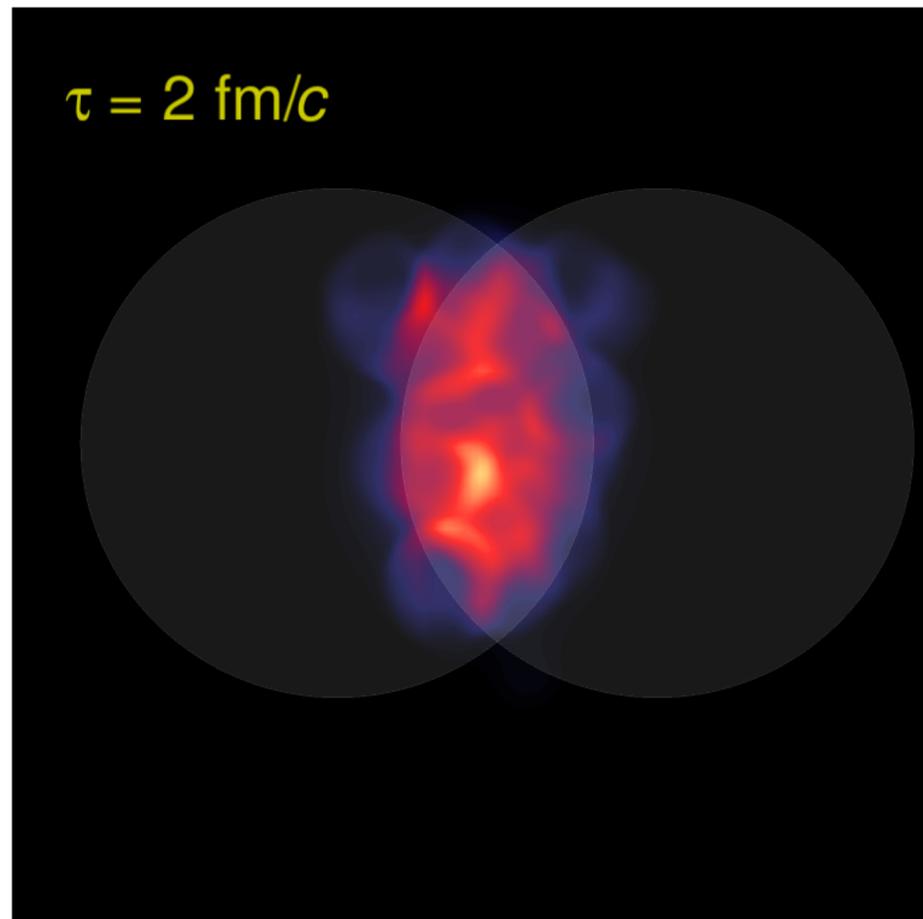
- “Transport properties” of the quark-gluon plasma
- What kind of projectile works best?

Why measure heavy flavours?

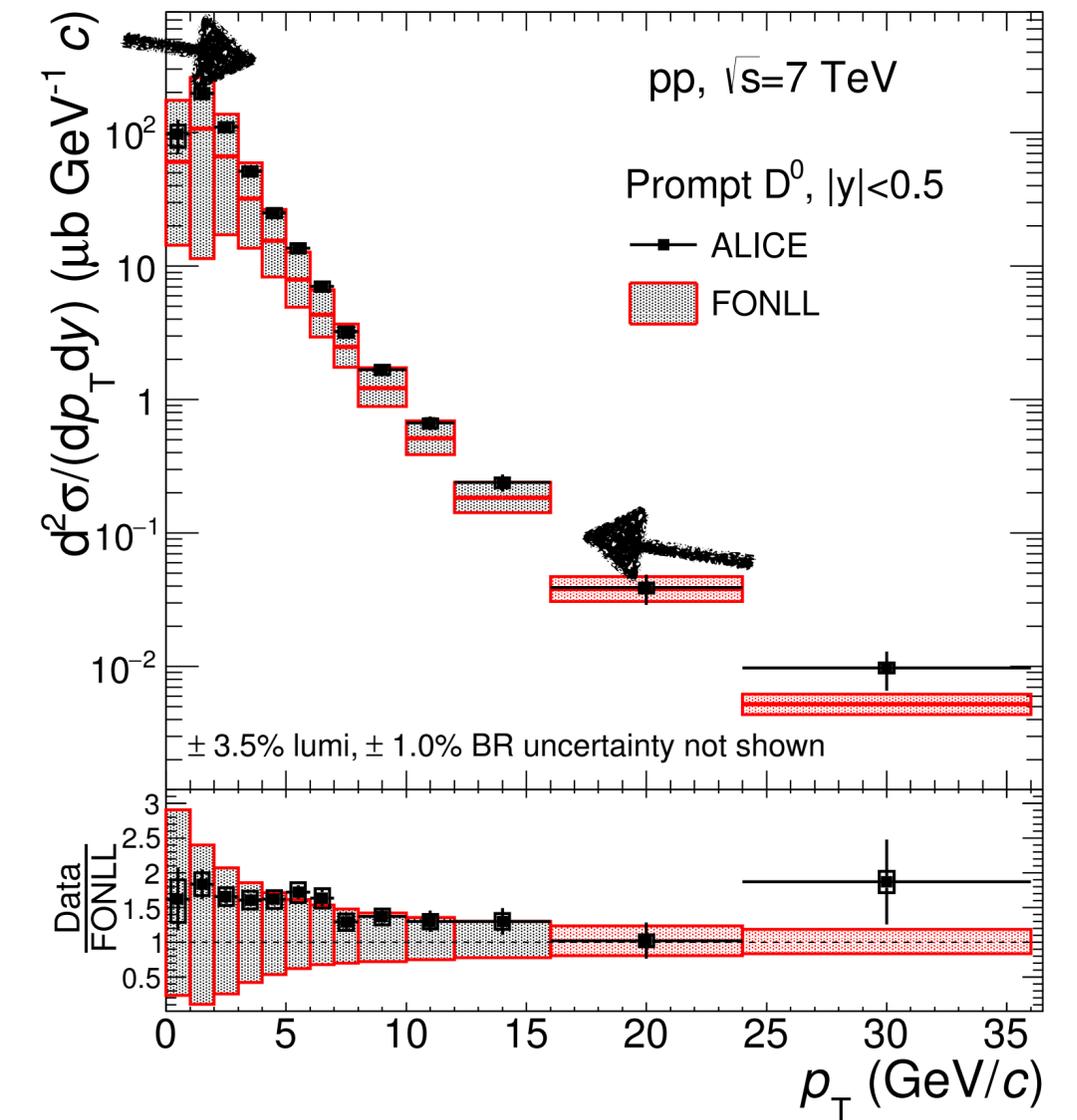
- $m_c \approx 1.3 \text{ GeV}/c$
 $m_b \approx 4.2 \text{ GeV}/c$
- Large compared to QGP temperatures ($T_c \approx 155 \text{ MeV}$)
- (Large compared to $\Lambda_{\text{QCD}} \approx 330 \text{ MeV}$)
- Clear association of quark and hadron



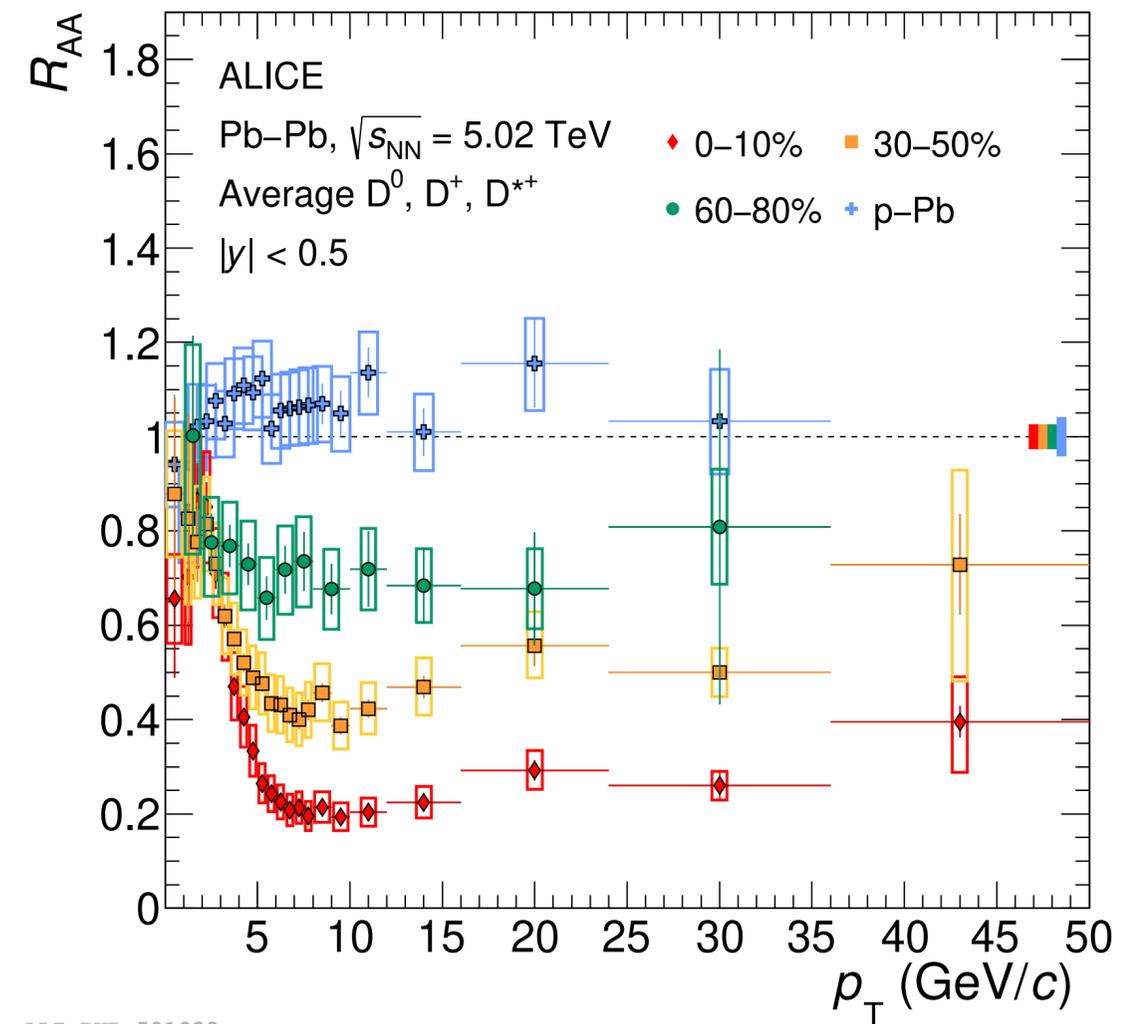
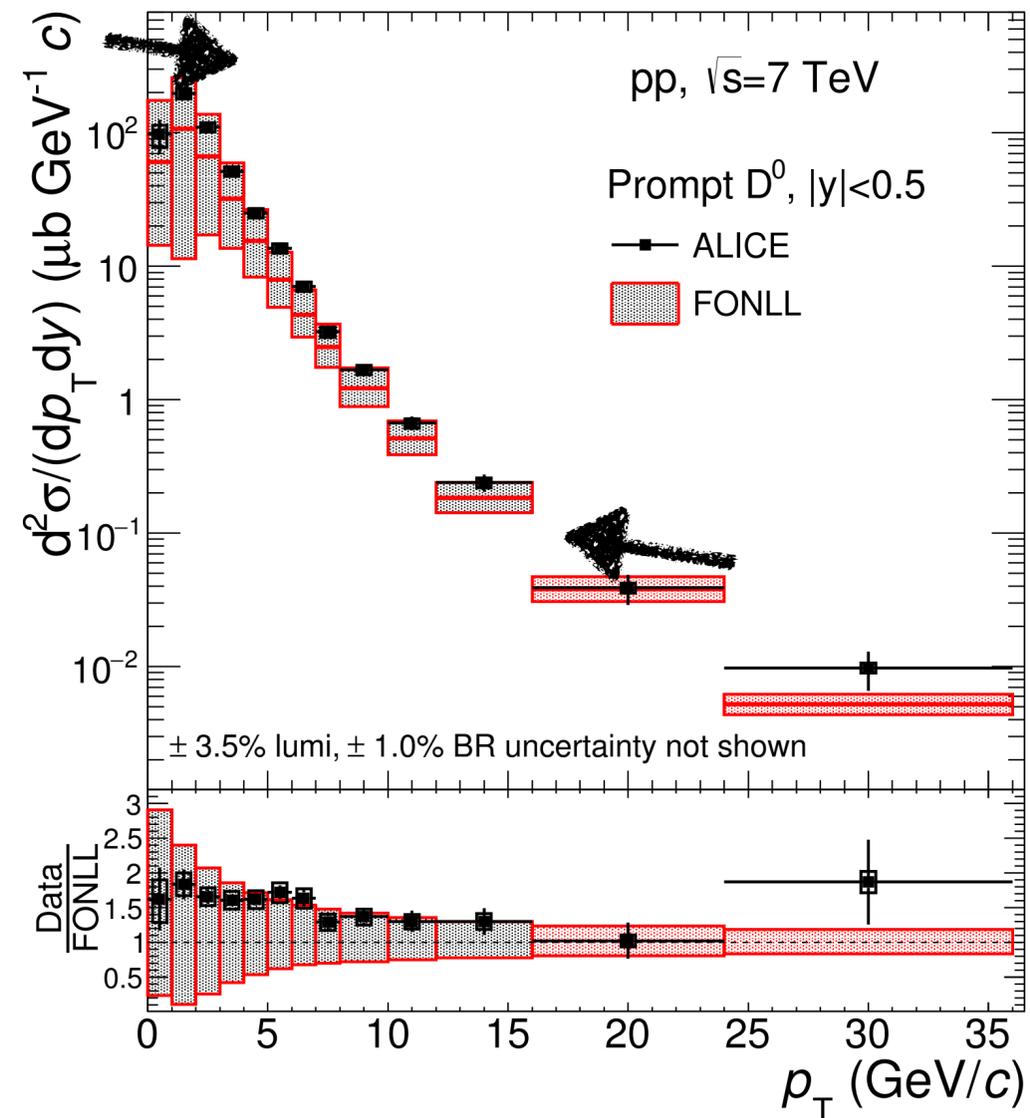
Qualitative expectation



- Measure momentum distributions and anisotropy

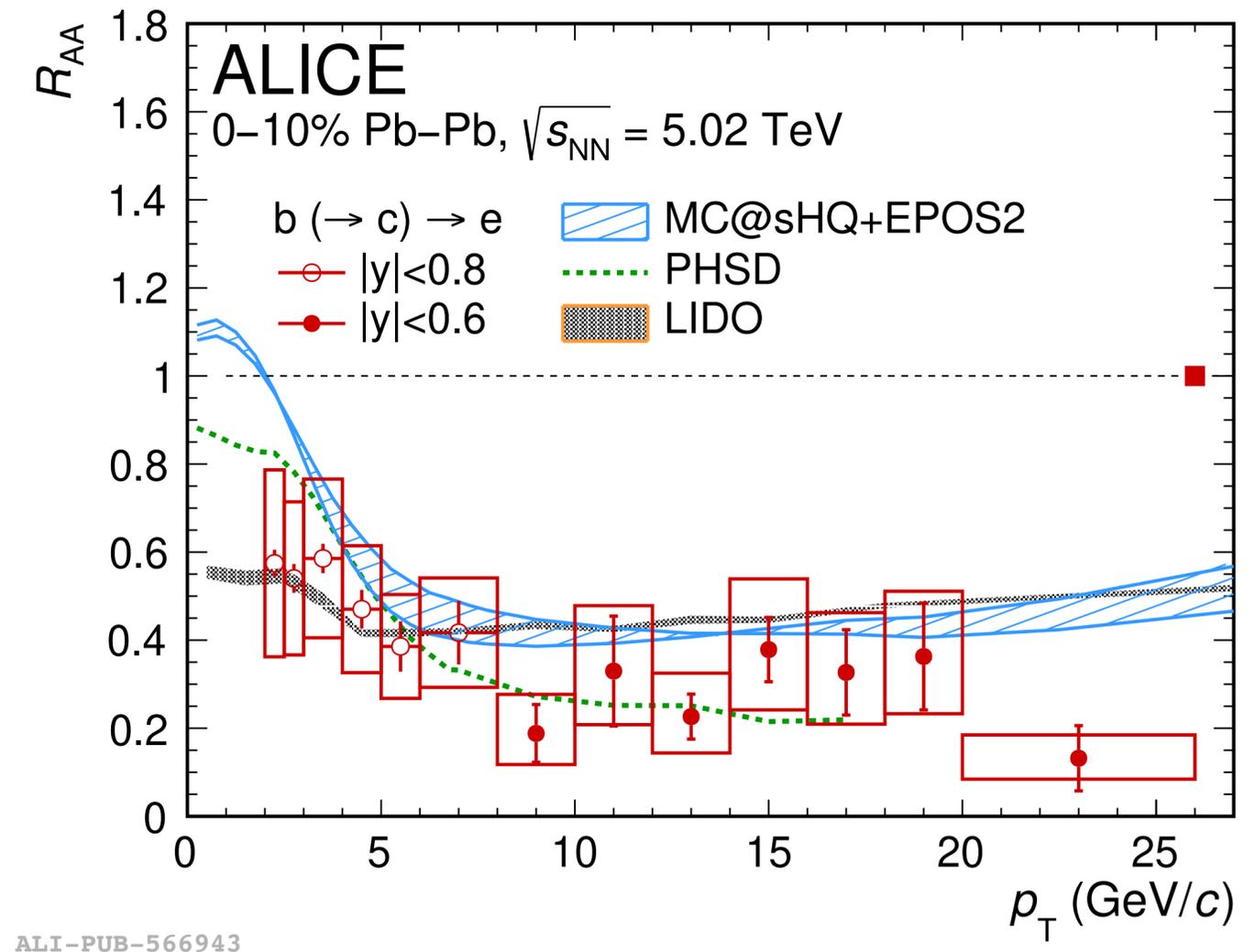
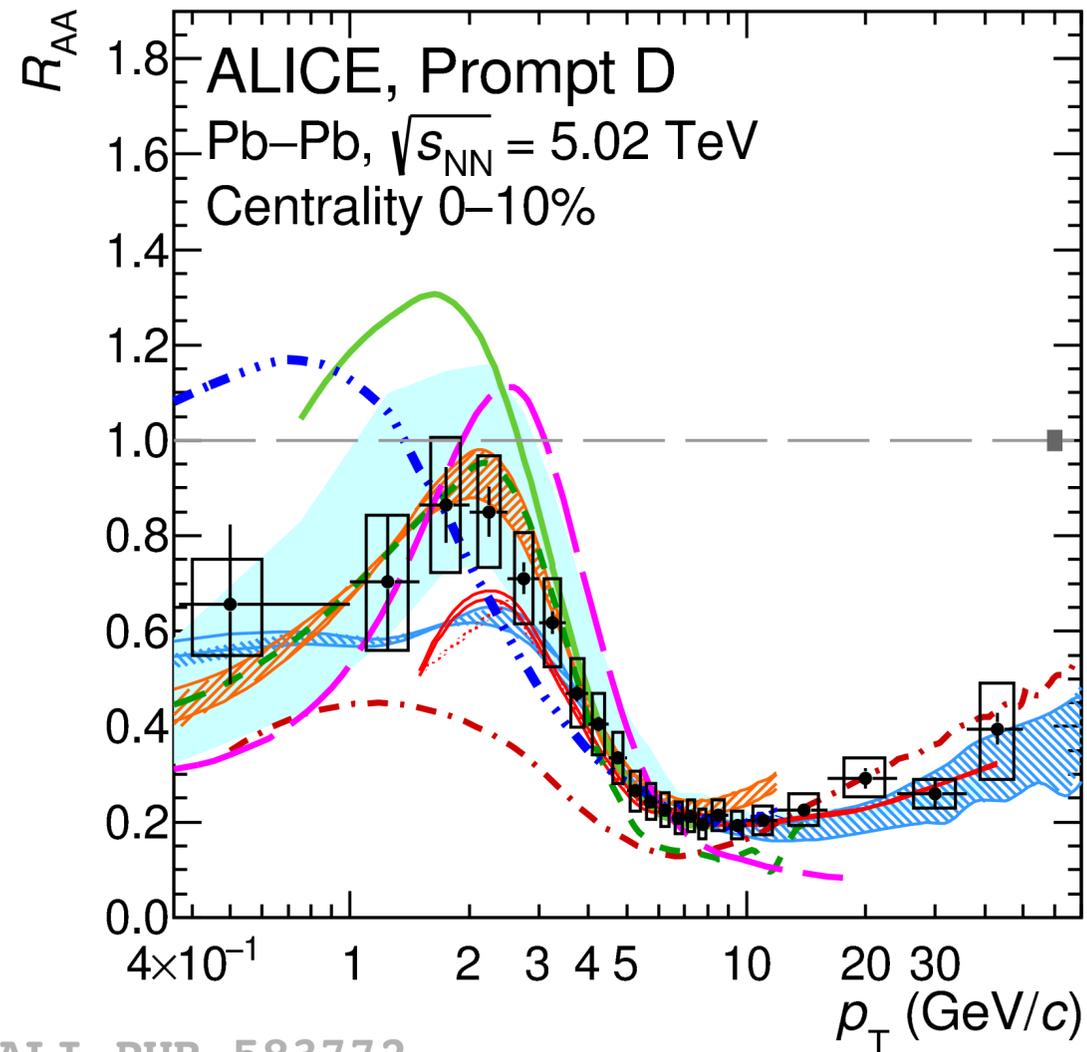


Observable: the nuclear modification factor



- If it is 1 \rightarrow no effect from QGP

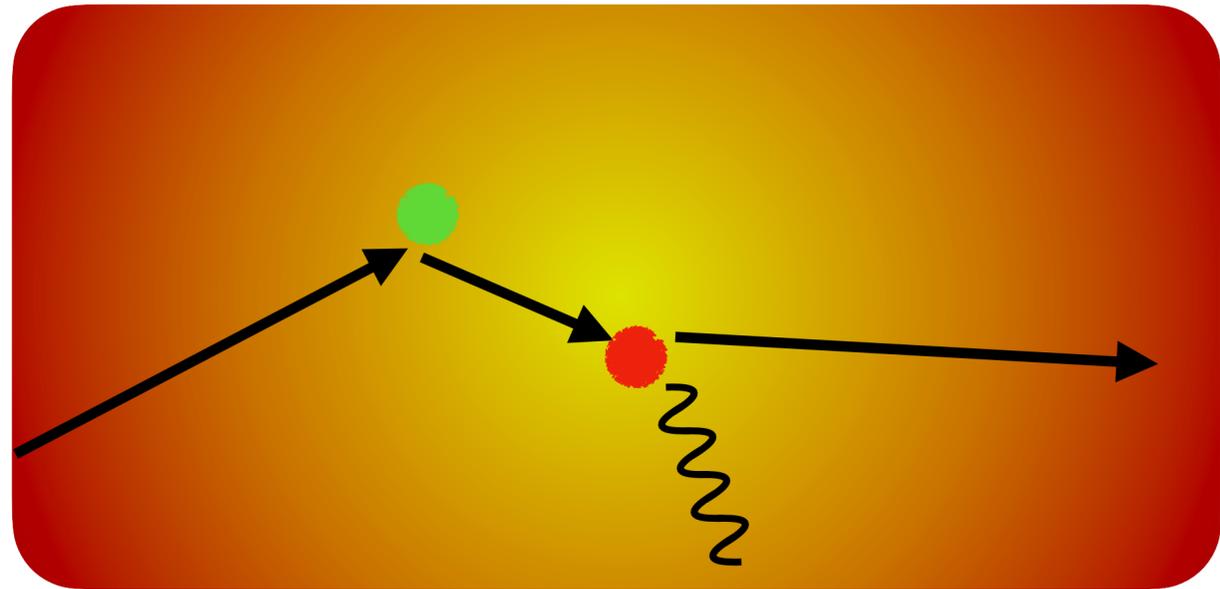
Nuclear modification for beauty and charm



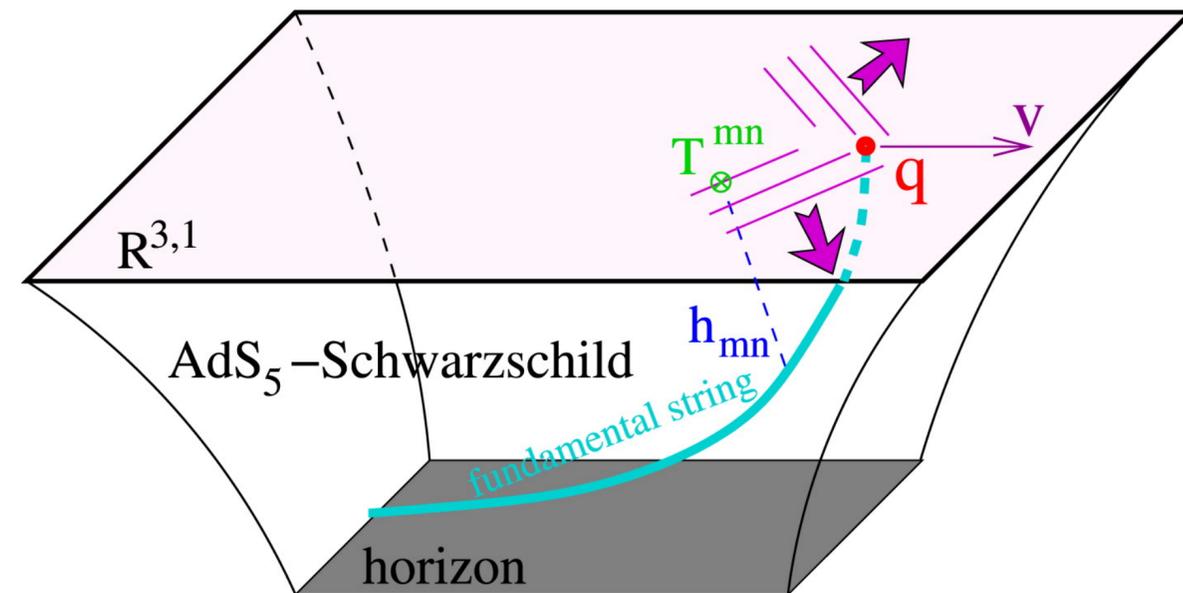
- What does this tell us about the strong interaction?

Modeling heavy quark interaction with the QGP

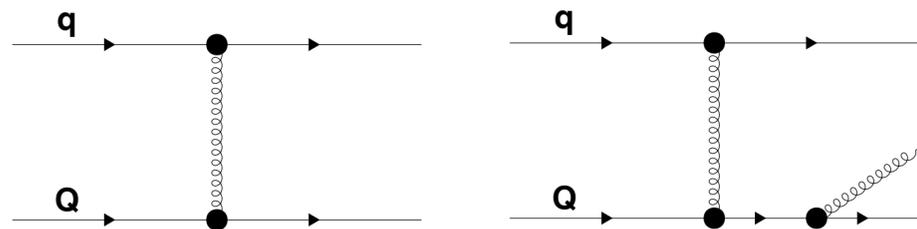
weak coupling



strong coupling



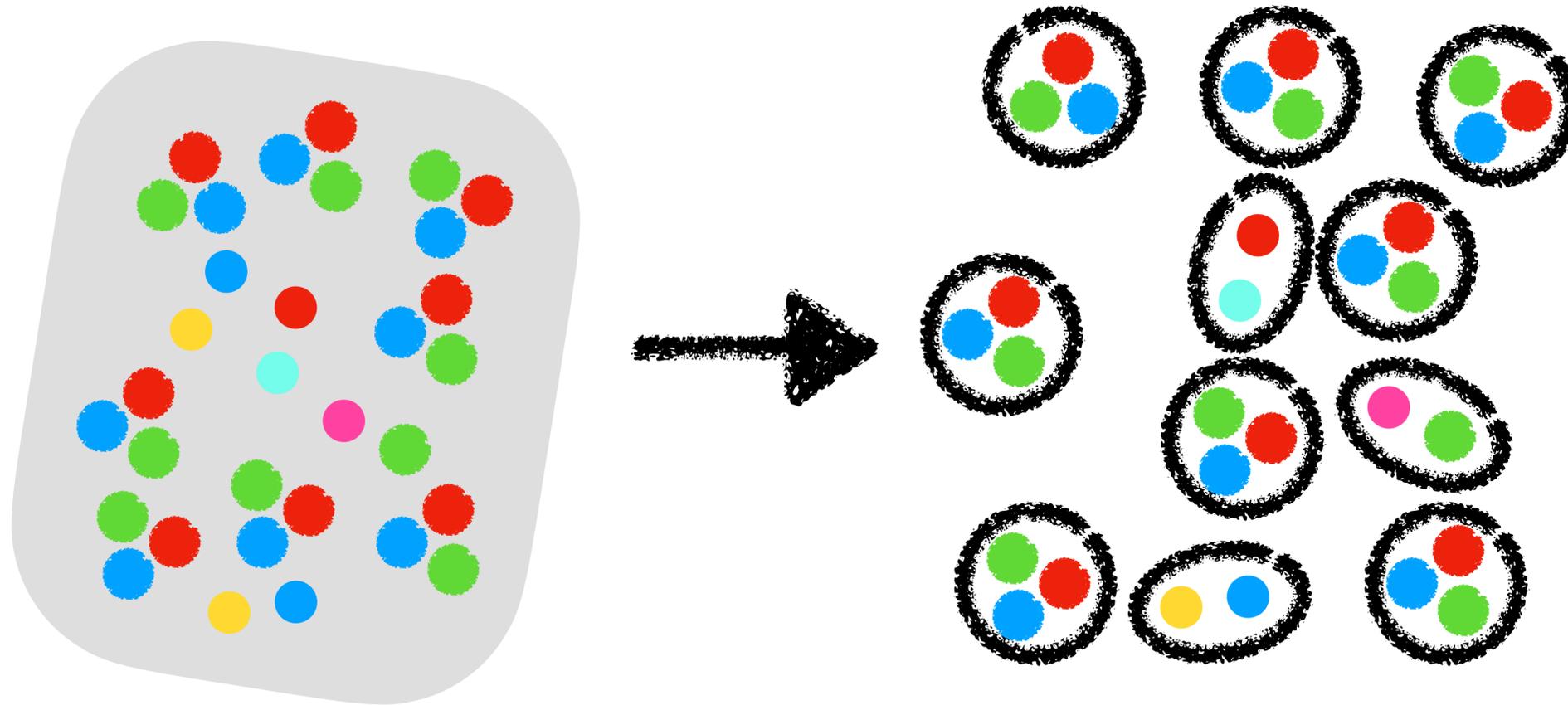
- Individual scattering events
- Almost all models in this paradigm



- But: interaction of quarks with the medium not the only relevant process

Hadronisation

Hadronisation

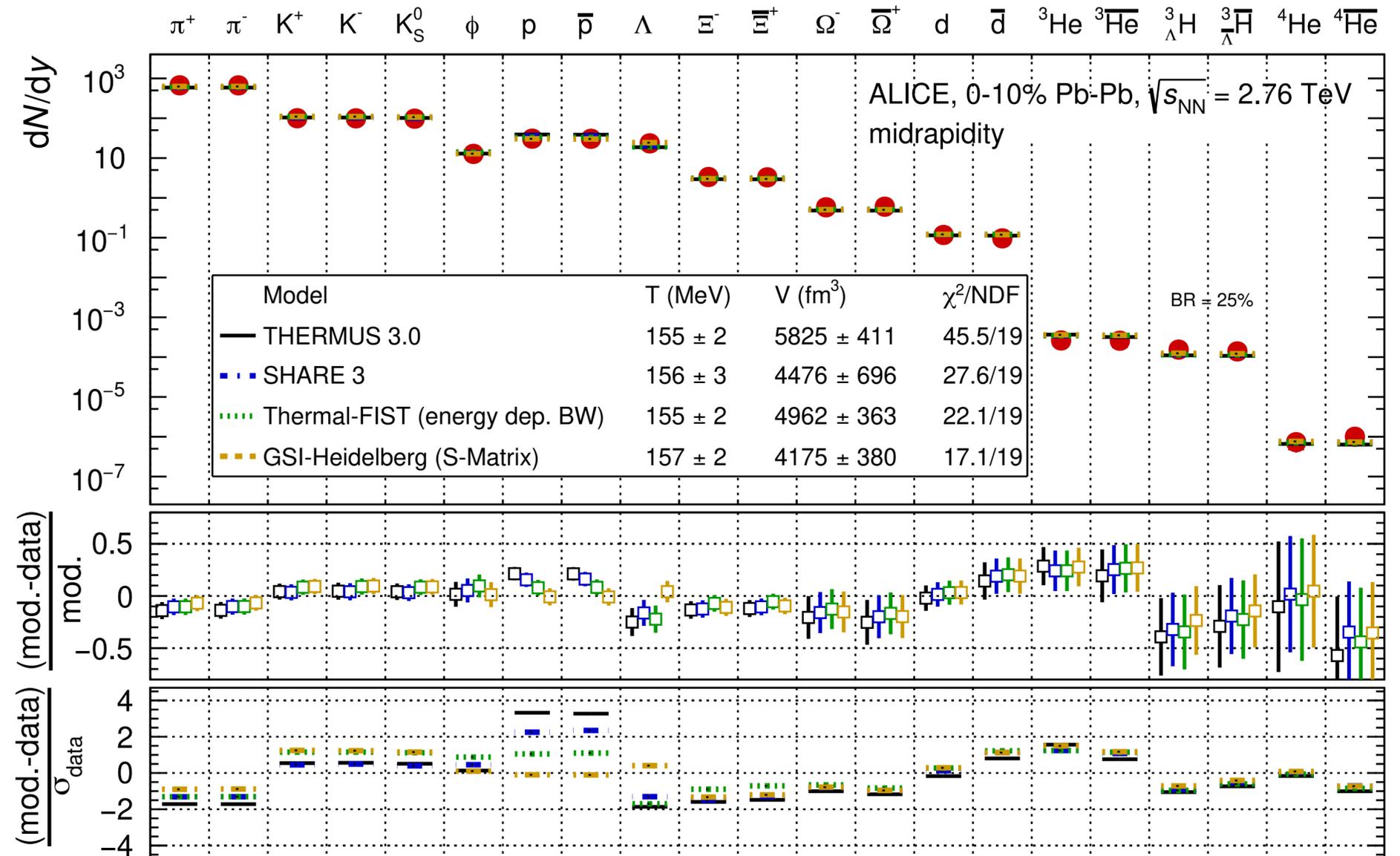


- Complex, nonperturbative process

Nuclei \rightarrow Scattering processes \rightarrow Equilibration \rightarrow QGP evolution \rightarrow **Hadronisation/Freeze-out** \rightarrow (Decays)

Statistical hadronisation

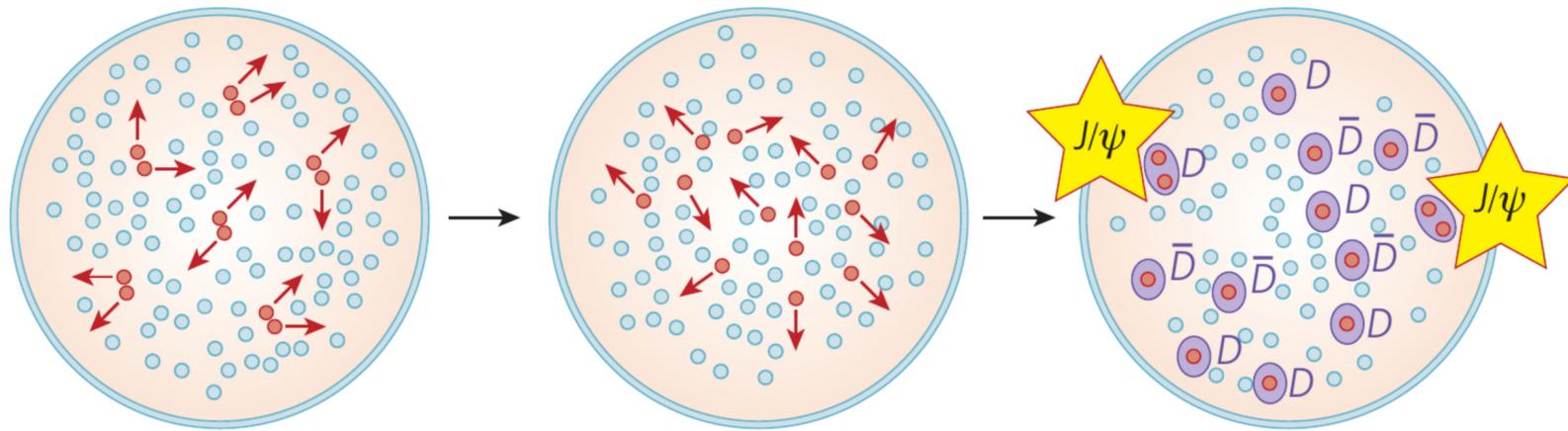
- Assuming a fully thermalised hadron gas after freeze out describes particle production
- Three parameters: volume, temperature, baryochemical potential
- This is how we measure the temperature of the phase crossover



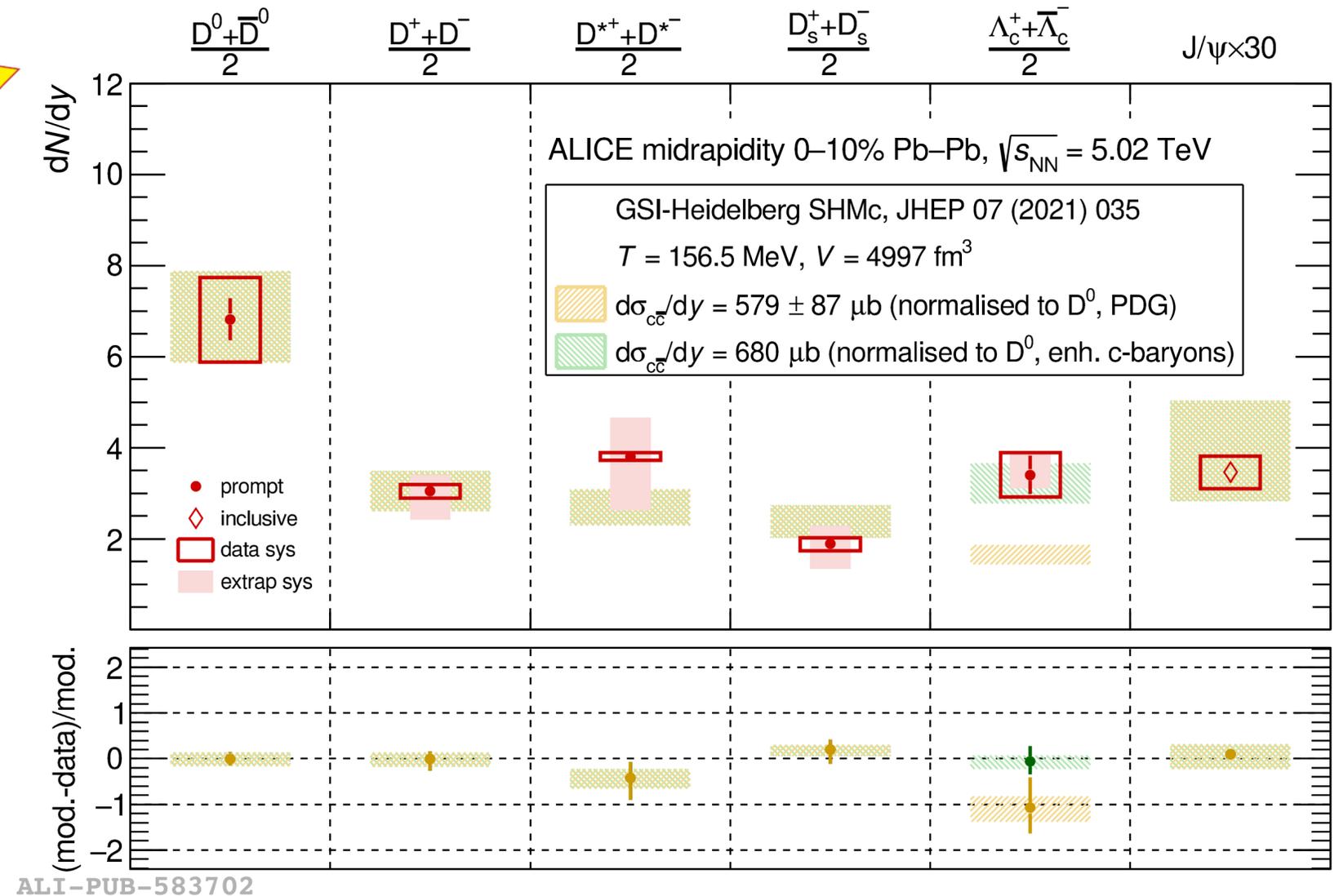
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Nuclei → Scattering processes → Equilibration → QGP evolution → **Hadronisation/Freeze-out** → (Decays)

Heavy flavour hadronisation

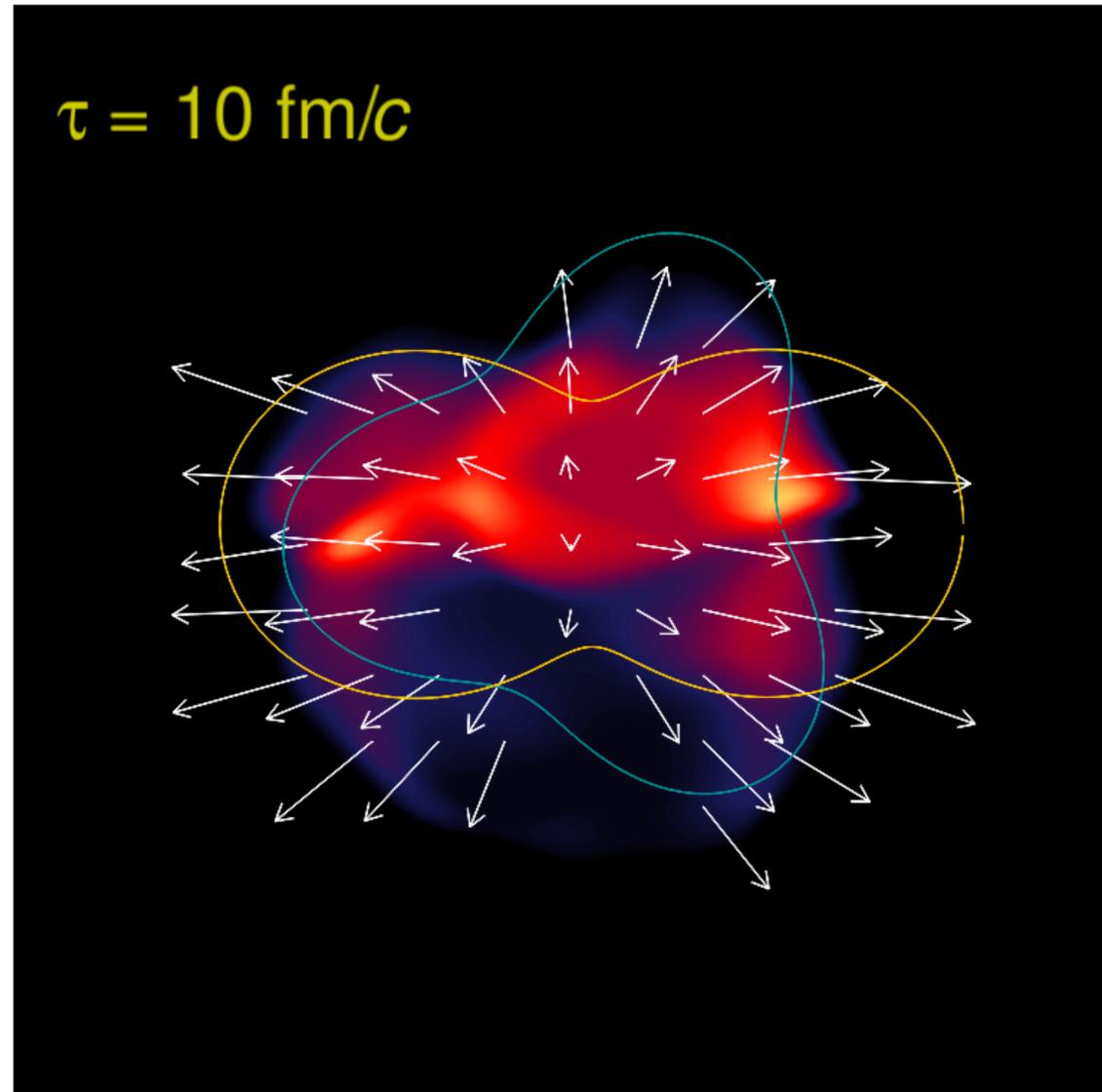


- Apply statistical hadronisation to heavy quarks
- SHMc: take into account that charm quarks are not produced thermally

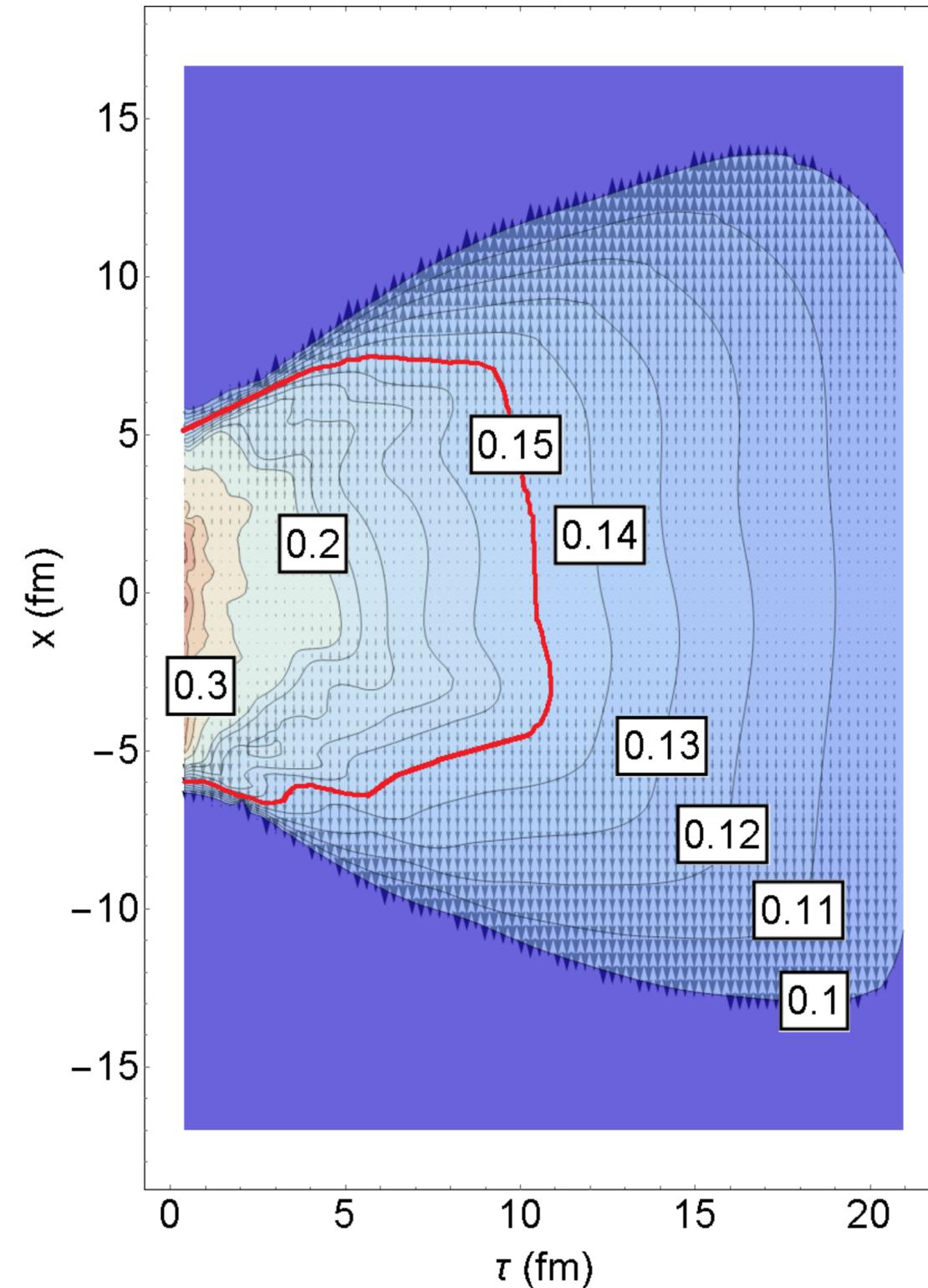


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What about the particle momenta?

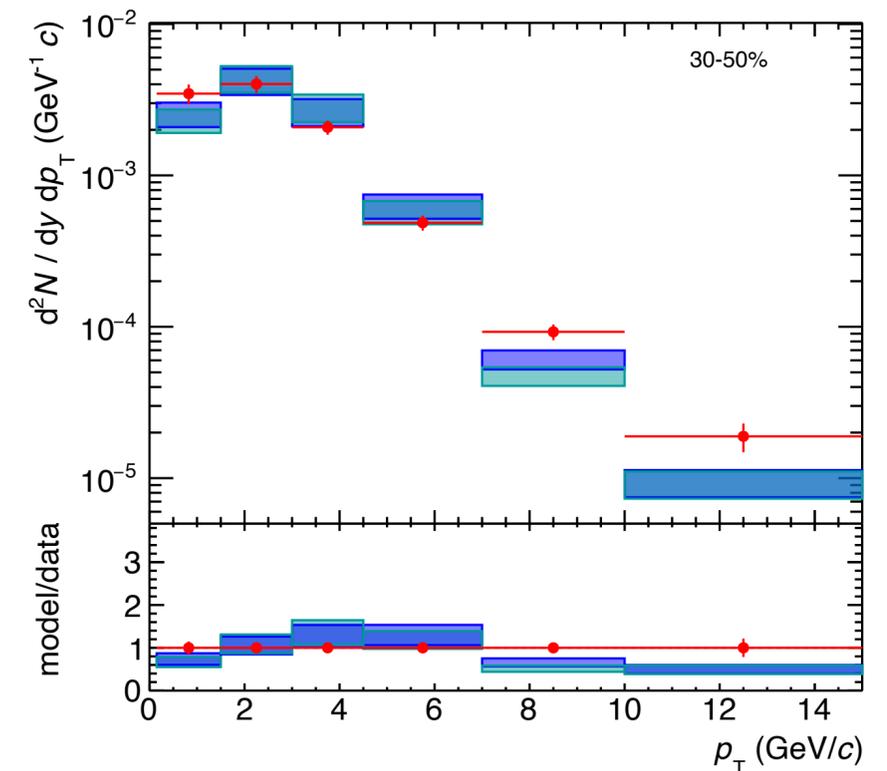
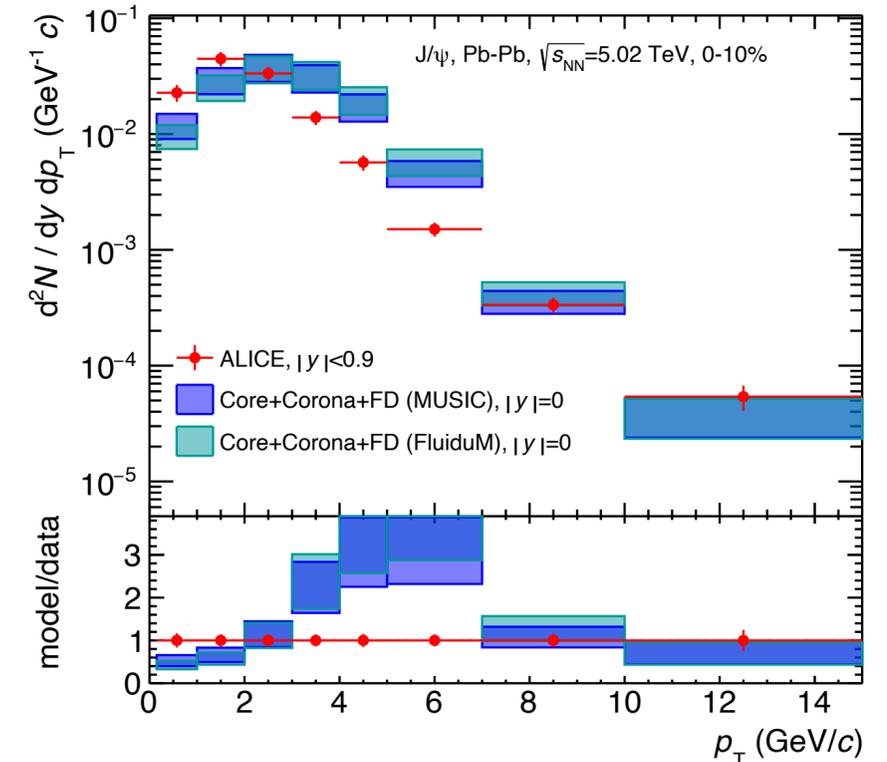
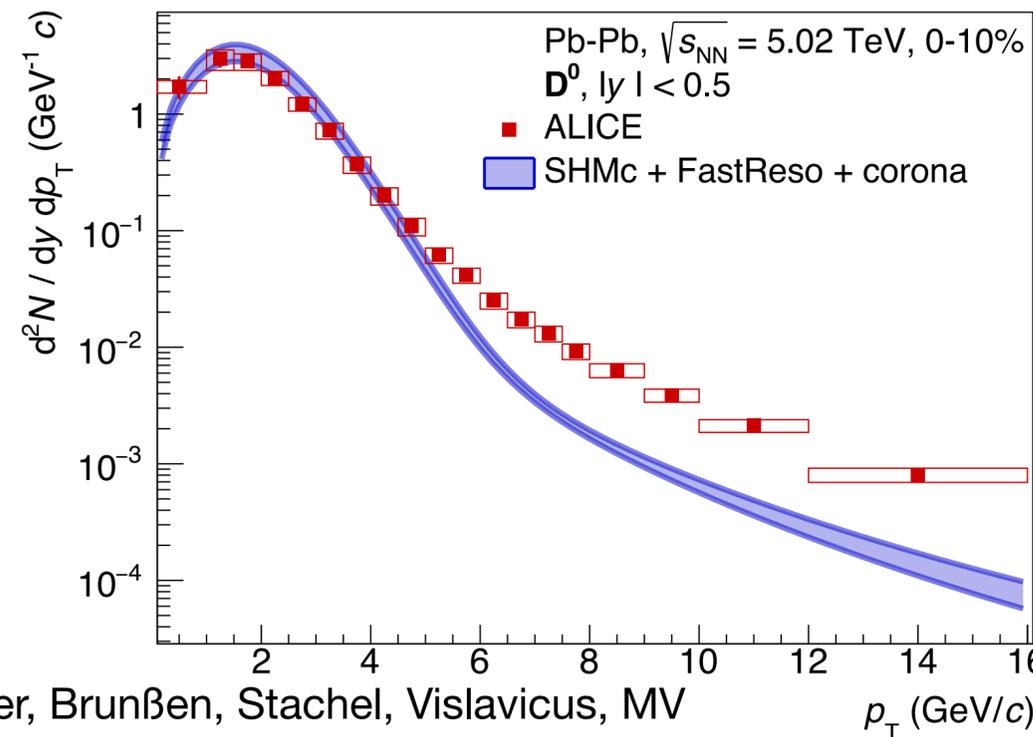
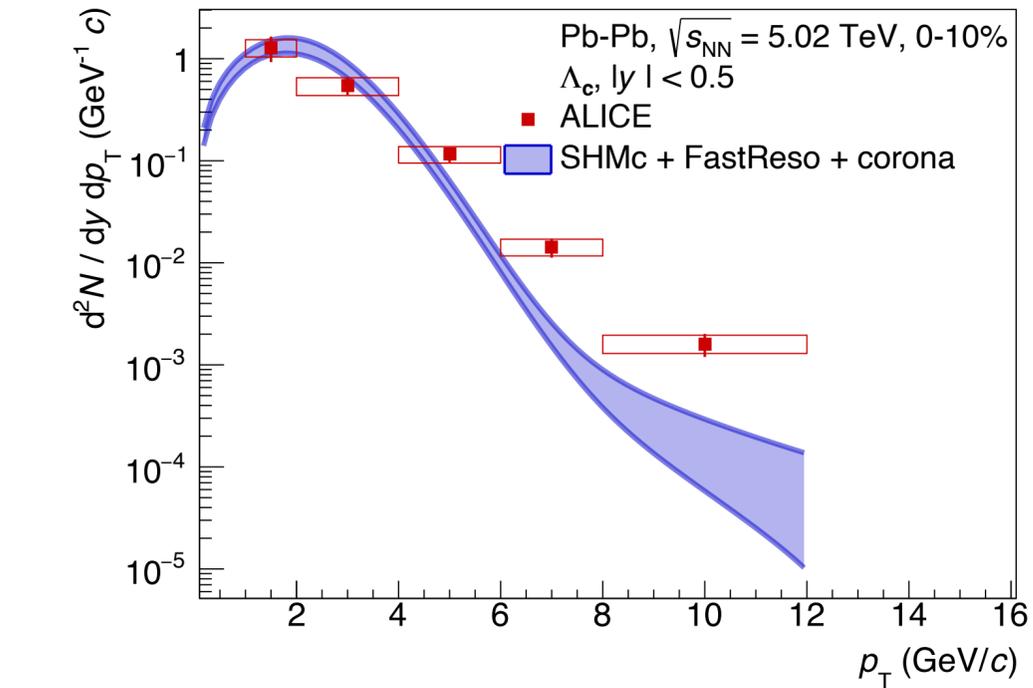


Add up the contributions from different parts of the fireball - hypersurfaces with different velocities

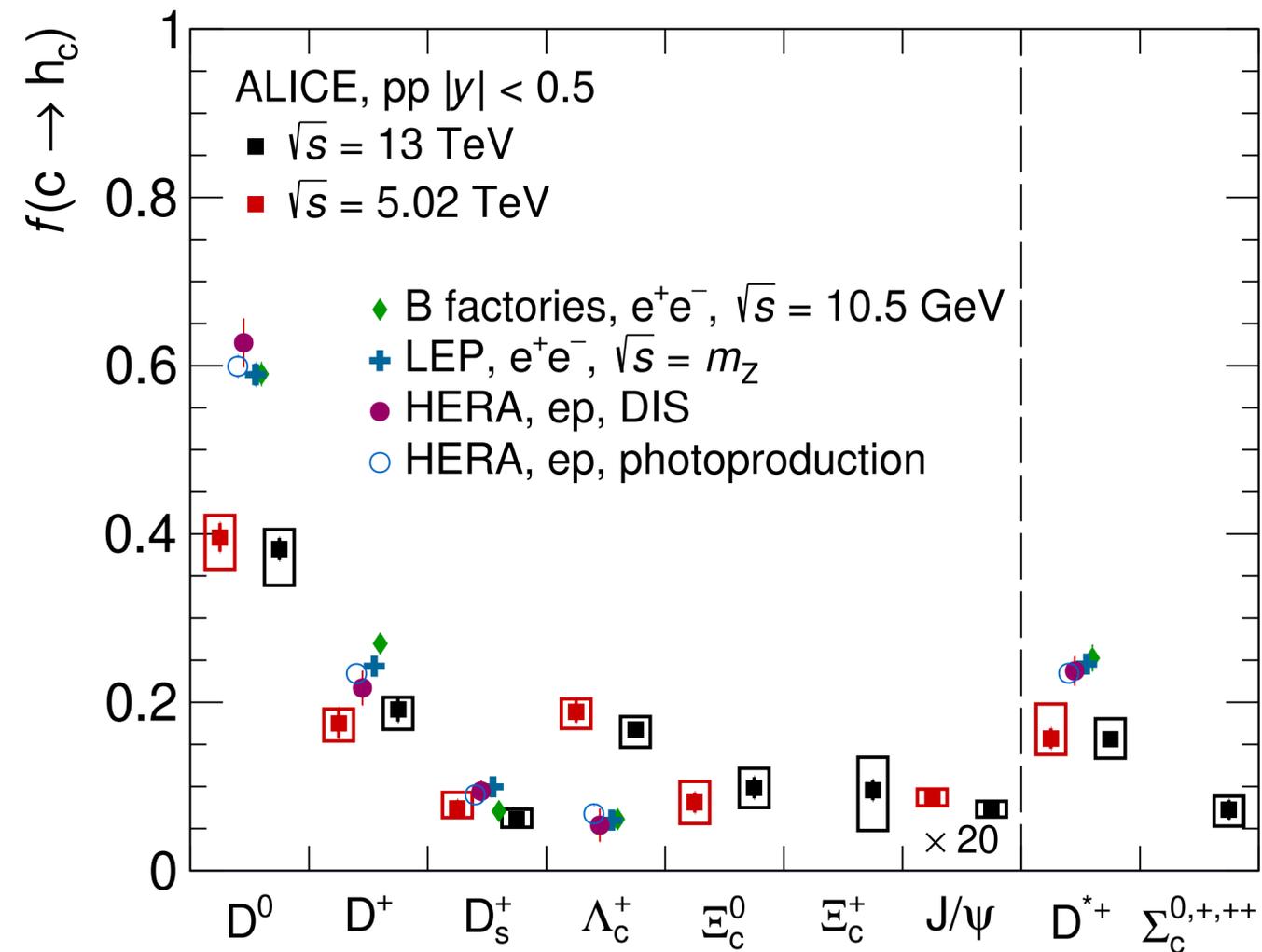


Thermalised charm spectra

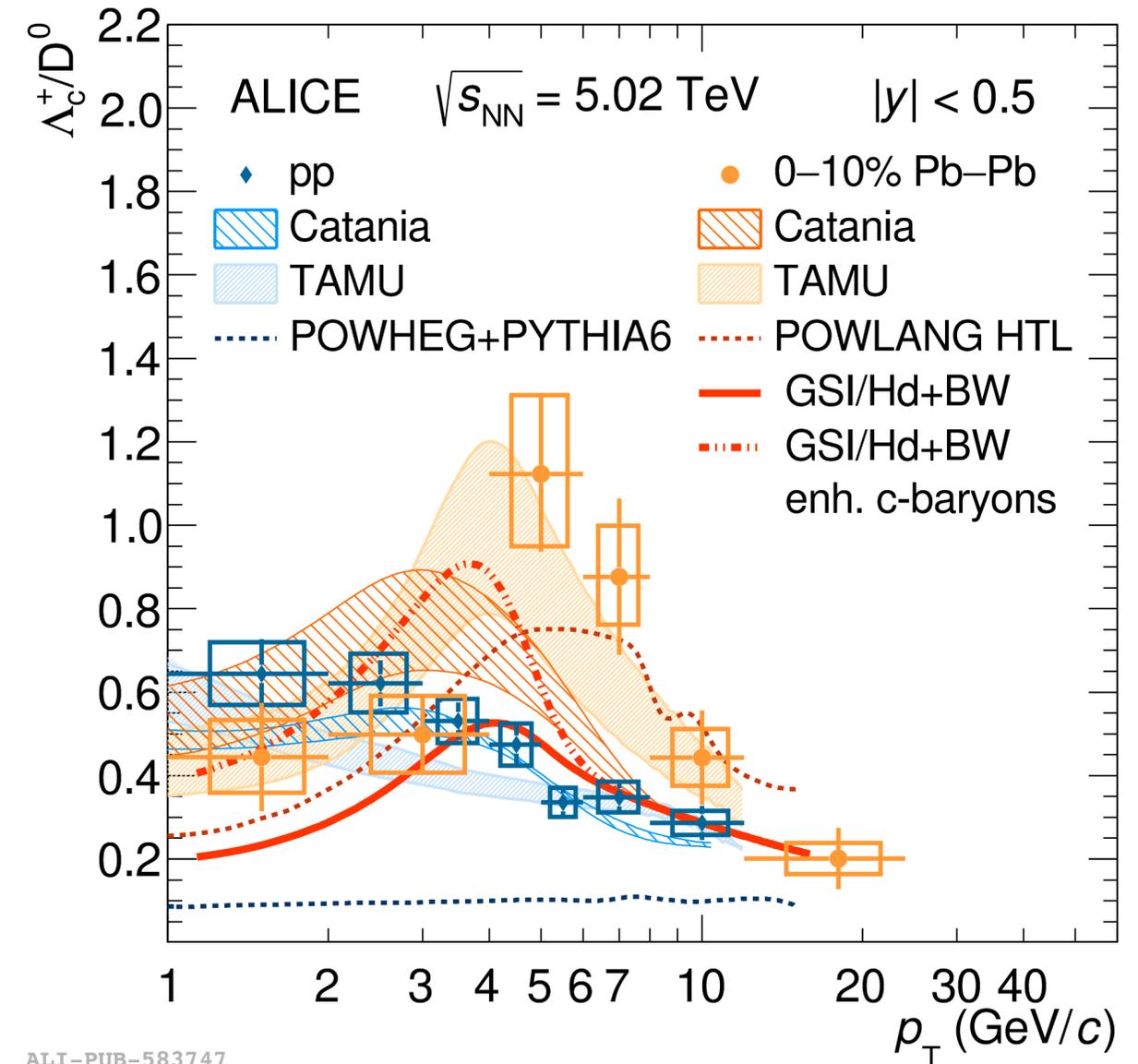
- Yields from statistical hadronisation
- Distributions based on hydrodynamic modelling
- Fair description of a variety of variables
- Non-thermal contributions at high momenta



Heavy flavour in small systems



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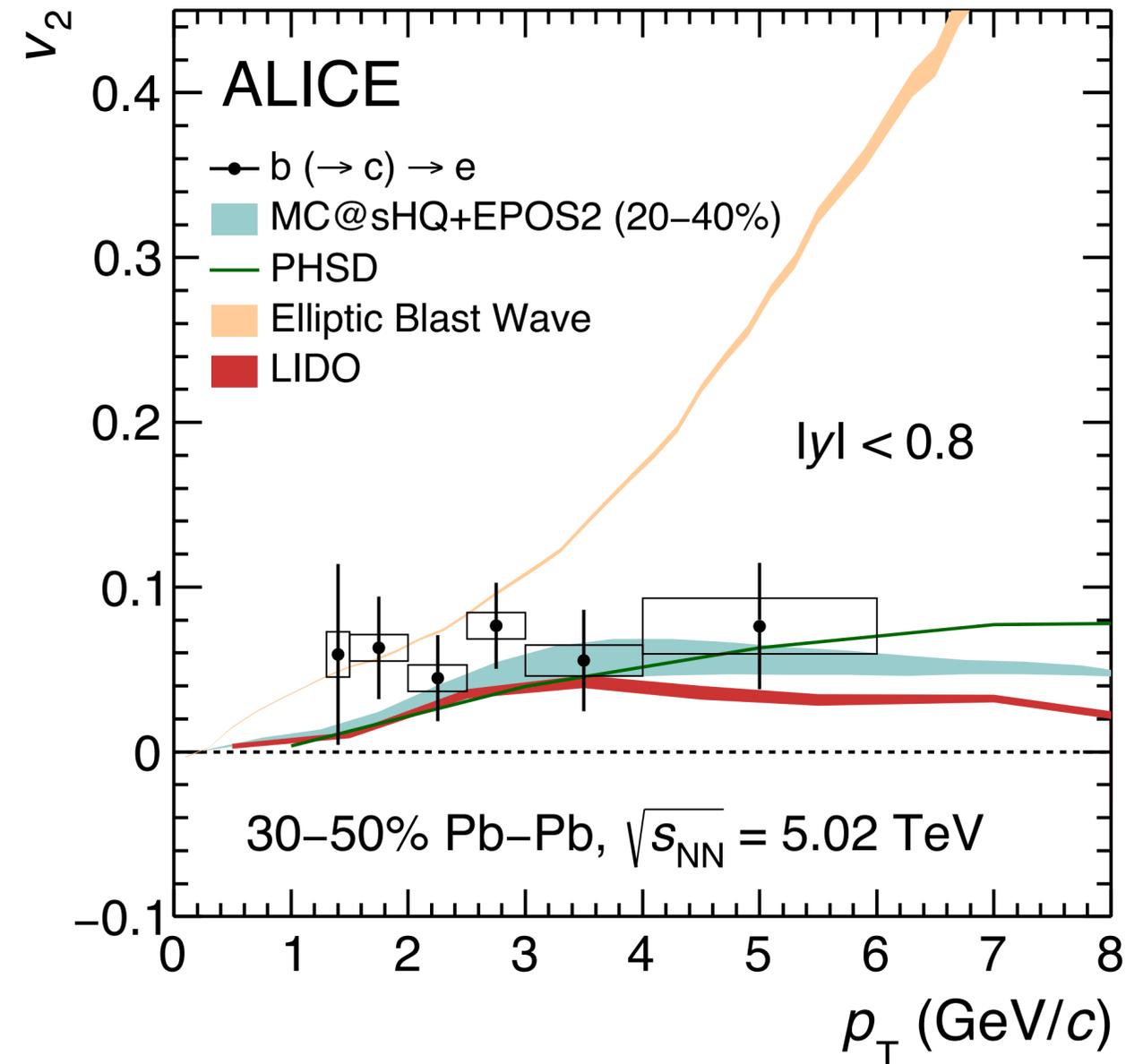
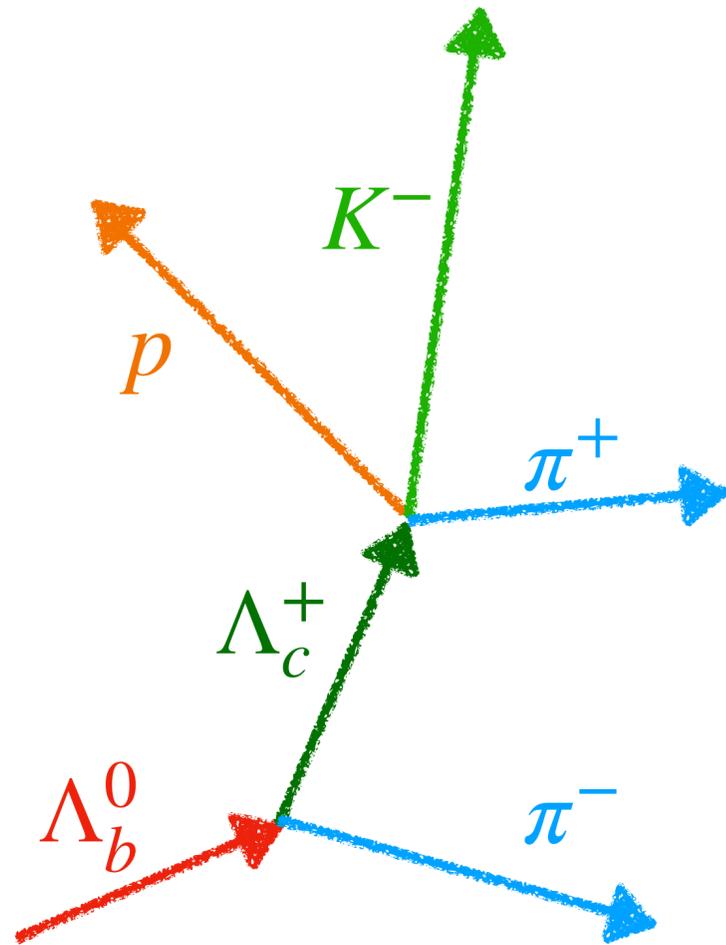


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- Surprise: Charm hadronisation in hadronic collisions more similar to Pb–Pb than e^+e^-
- What about beauty?

Measuring in the beauty sector

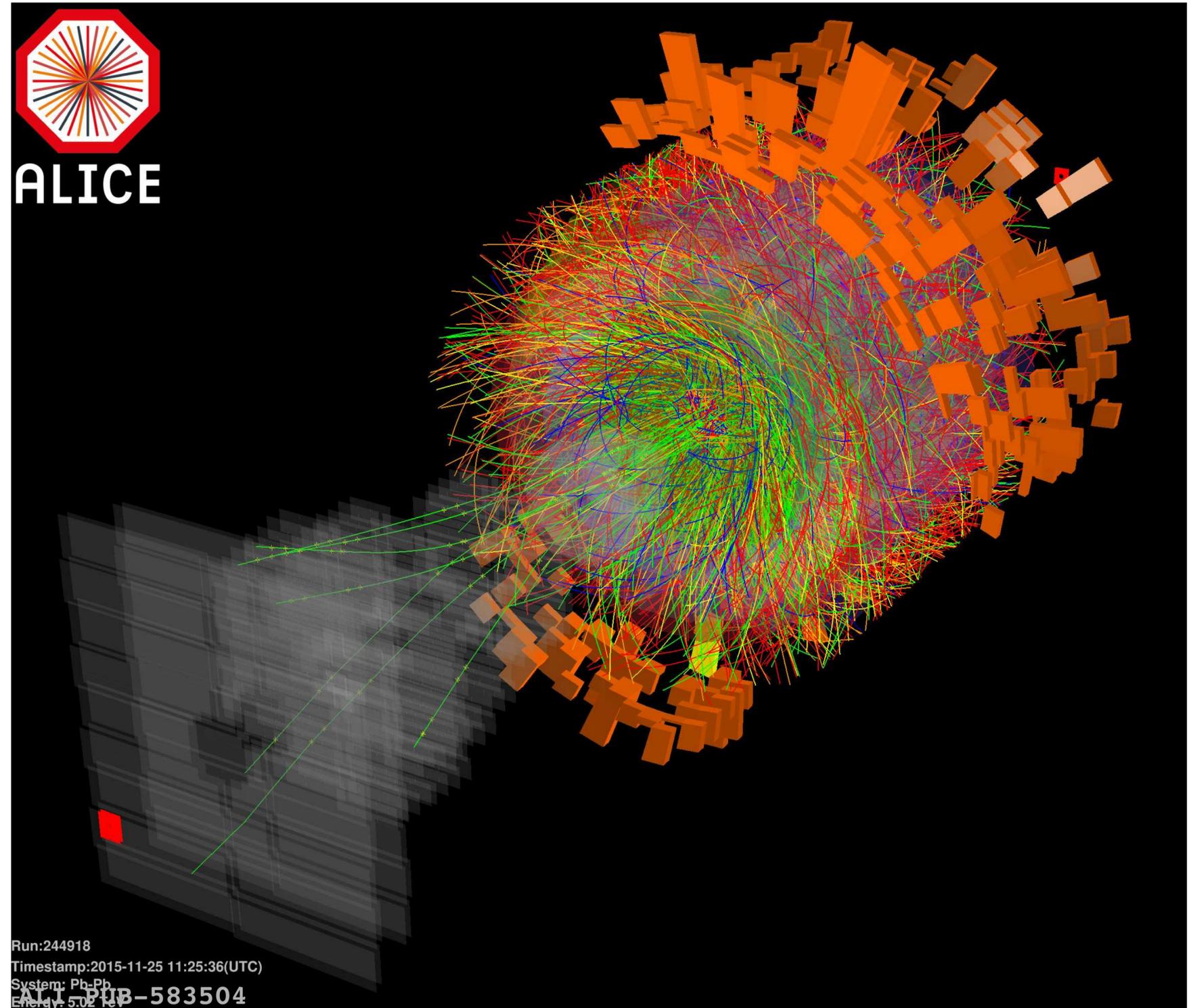
- Higher mass makes many assumptions more valid



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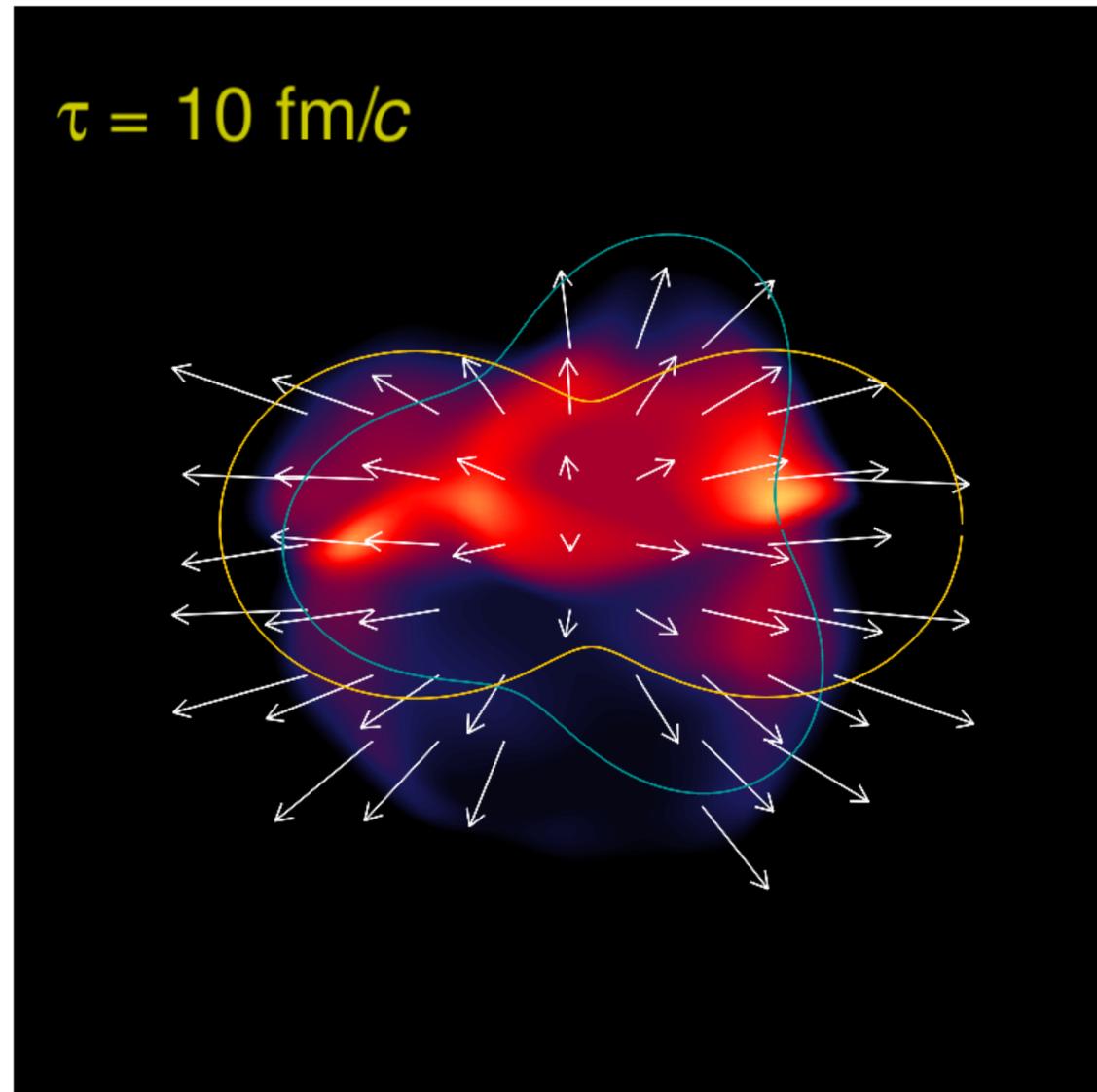
Summary

- Heavy ion collisions and the QGP give laboratory to understand QCD in extreme conditions
- Heavy flavour quarks are useful probes to understand the properties of QCD matter
- Hadronisation seems to hold secrets that we still need to explore



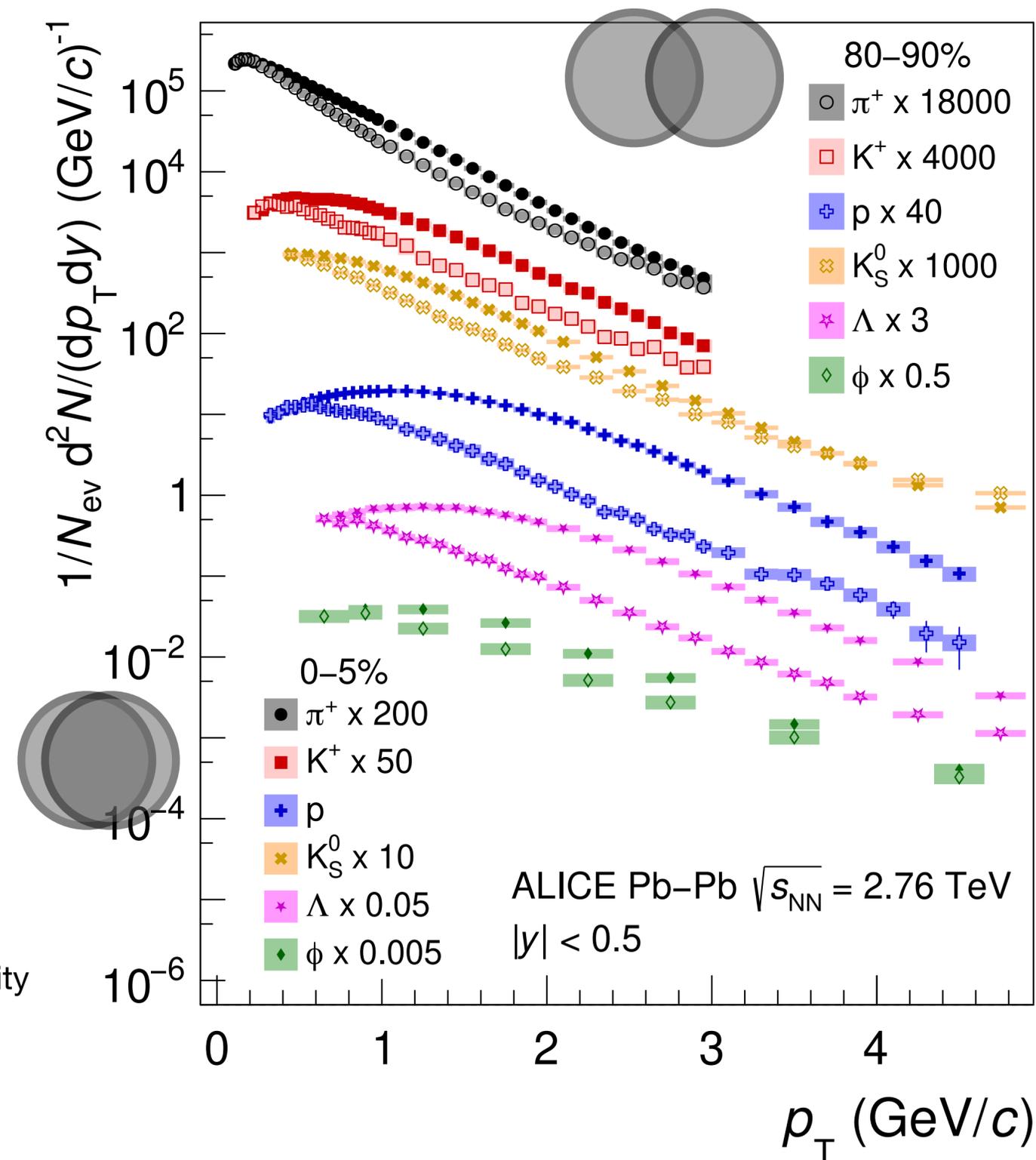
Appendix

Radial flow

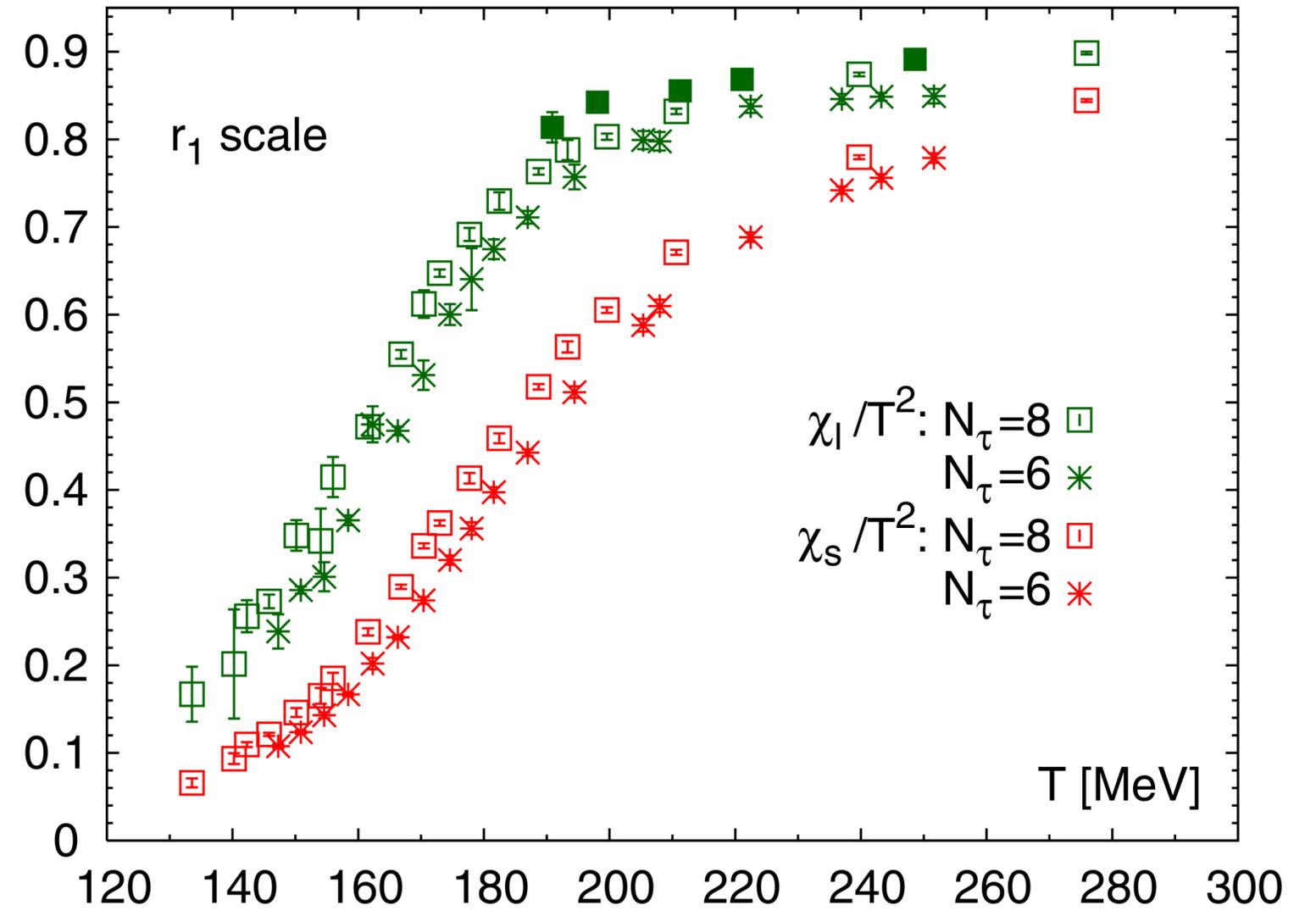
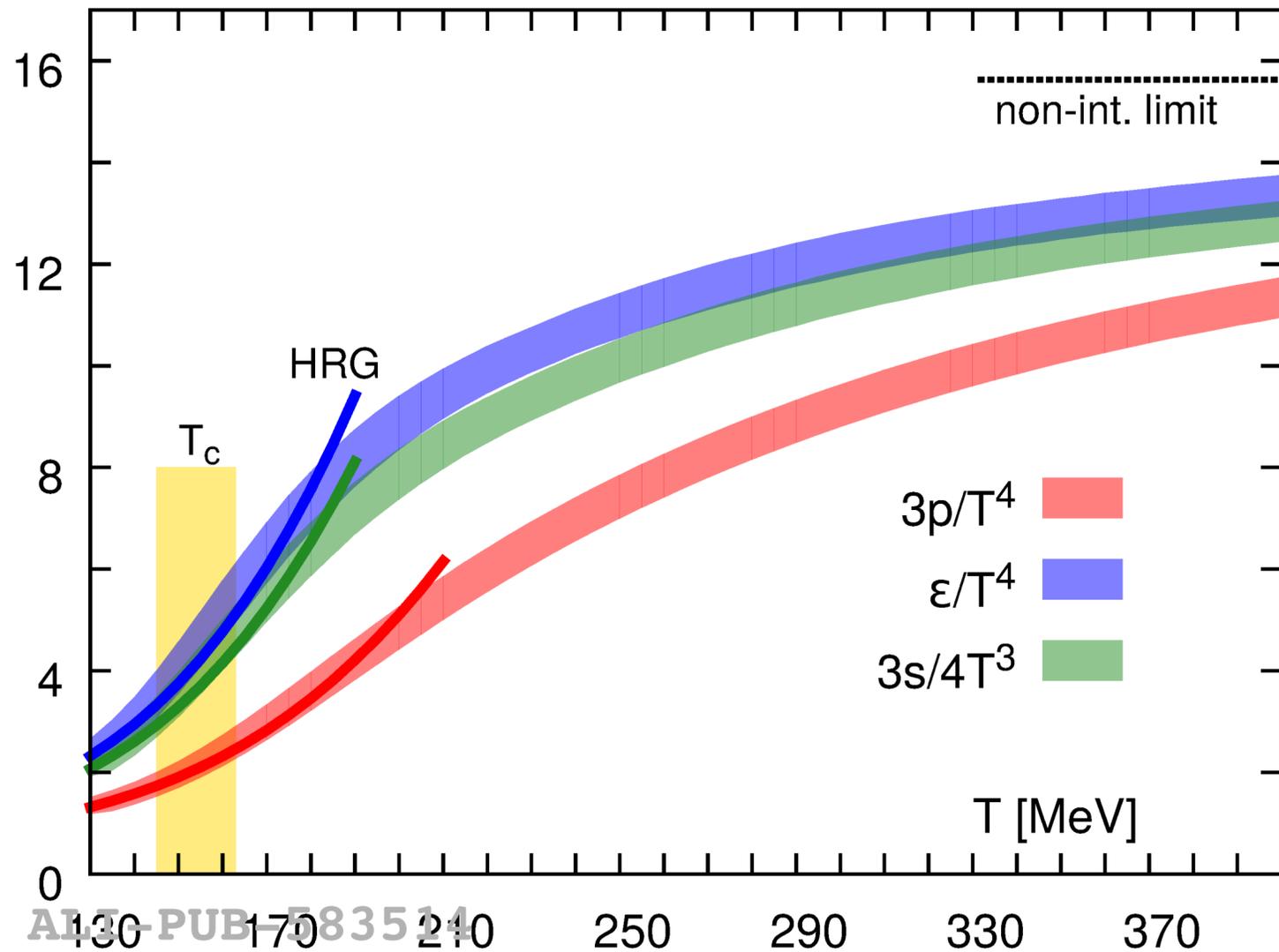


- When the QGP turns into particles, they have the same average velocity
- Central collisions \rightarrow more QGP, longer evolution \rightarrow higher velocities
- Heavier particles have a higher momentum for the same velocity

Nuclei \rightarrow Scattering processes \rightarrow Equilibration \rightarrow **QGP evolution** \rightarrow Hadronisation/Freeze-out \rightarrow (Decays)



IQCD



HotQCD Collaboration

- $T_c = 154 \pm 9 \text{ MeV}$

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