Goal and outline

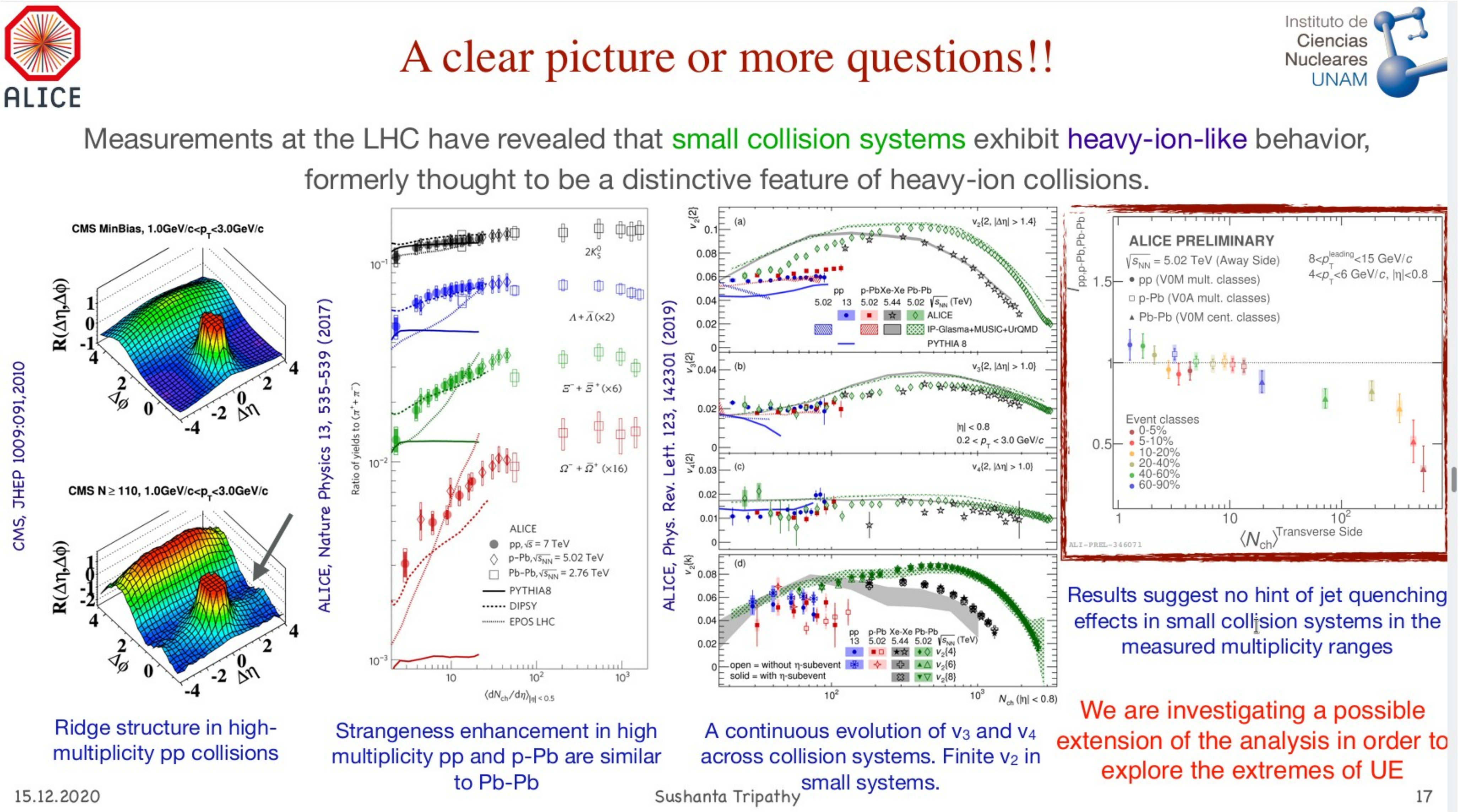
- Goal: motivate that the interplay of flow and non-flow could be sensitive to if the system is weakly or strongly coupled

- Intro to final state effects
- Weakly coupled example (kinetic theory)
- Fingerprints?
  - Idea: weakly coupled final-state interactions must modify non-flow (=standard) 2-particle correlations
- PYTHIA+Shoving (effectively strongly coupled ?)
- AMPT (effectively weakly coupled ?)

Why are final state effects so interesting

- Most pp models assume that for non-diffractive collisions one has for bulk processes
  - pp ~ ∑ parton-parton collisions
- No final state interactions means
  - Multiplicity dependence is more of the same
    - $\langle p_T \rangle$ is flat
    - Particle ratios are flat
    - System will look more and more isotropic in azimuthal angle with growing multiplicity

This is not what we observe



Final-state interactions are not a small thing

- In the world without final state interactions there are a lot of things you do not have to worry about:
  - How do strings form (pre-strings?)
    - Are there interactions?
    - What are the microscopic degrees of freedom?
  - Do strings interact?
  - Are strings still the relevant degrees of freedom for hadronization in dense systems
- This is of course what AA theorists have thought about for long
  - Let us have a look at how they could think

“Chemical Equilibration in Hadronic Collisions”, Aleksi Kurkela, Aleksas Mazeliauskas, PRL 122, 142301 (2019)
NB! Peter’s understanding

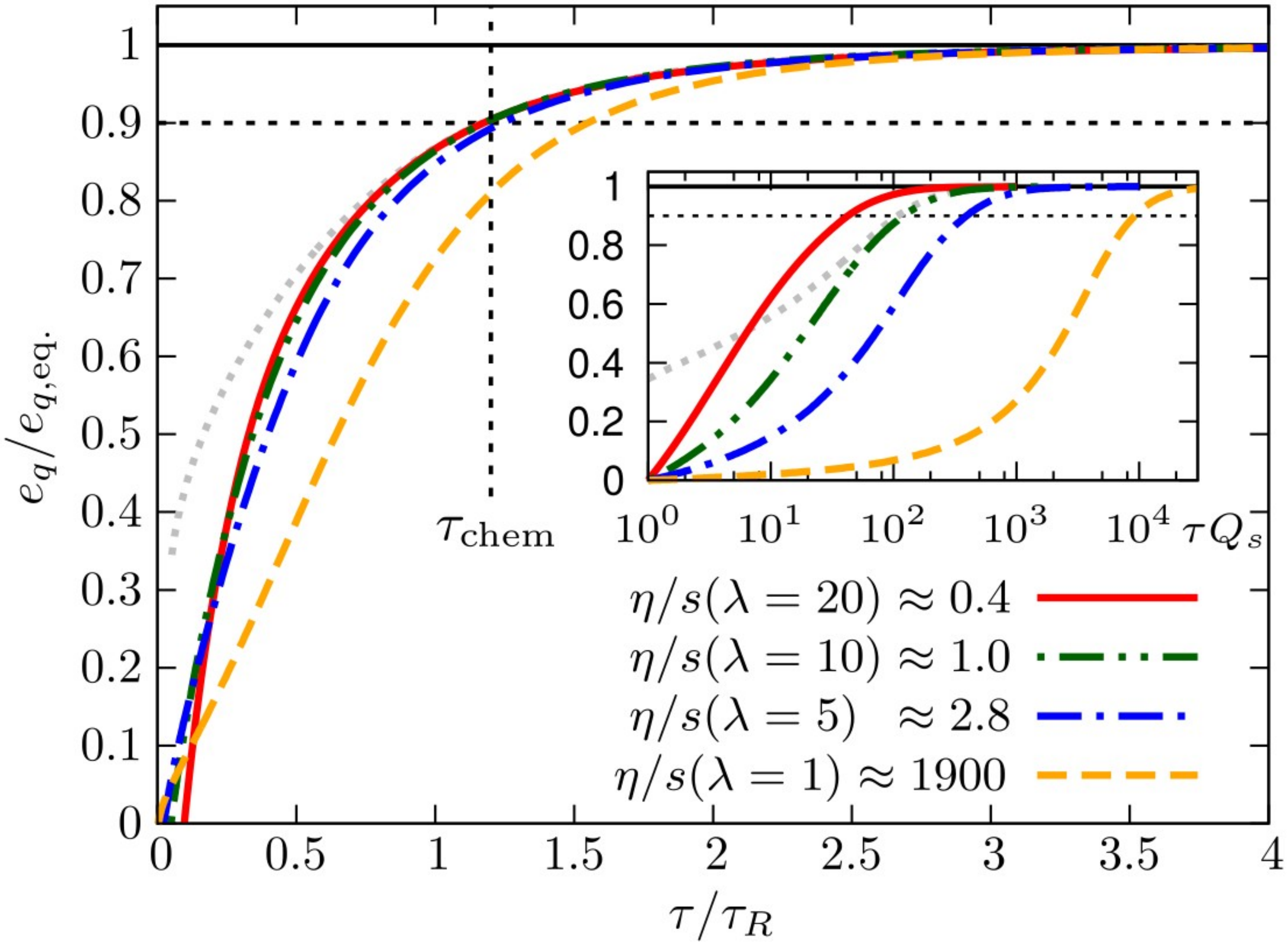
- Input: CGC initial state (only gluons!)
- Evolve this state using kinetic theory (2↔2 only: gg ↔ gg, gq ↔ gq, qq ↔ qq and gg ↔ q$\bar{q}$)
  - Peter’s understanding: Assume perturbative-like cross sections → Only need coupling

$$\tau_R = \frac{4\pi\eta}{sT} \sim \frac{1}{\lambda^2 T}.$$

$$\lambda \sim g^2 N_c \sim 4\pi\alpha_s N_c$$

  - If they know η/s from hydro measurements and initial “T”/energy density → they can get coupling lambda
  - Notice that $\lambda^2 \sim 1/(\eta/s)$

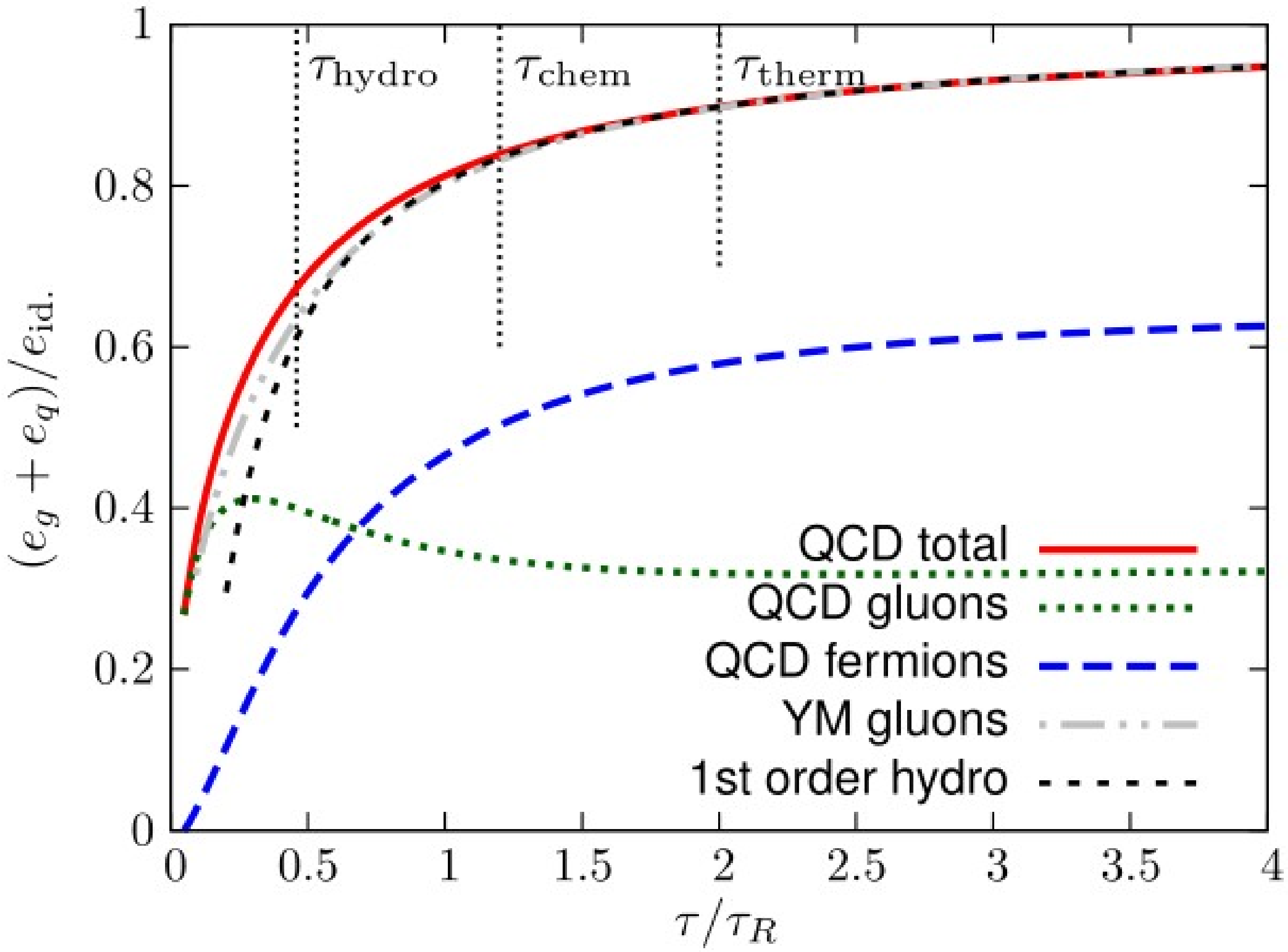
System evolves similar when time is normalized to τ_R



Note that the equilibrium definition of 0.9 is quite arbitrary

Main result is the "universal" behavior → Coupling dependence can be scaled away.

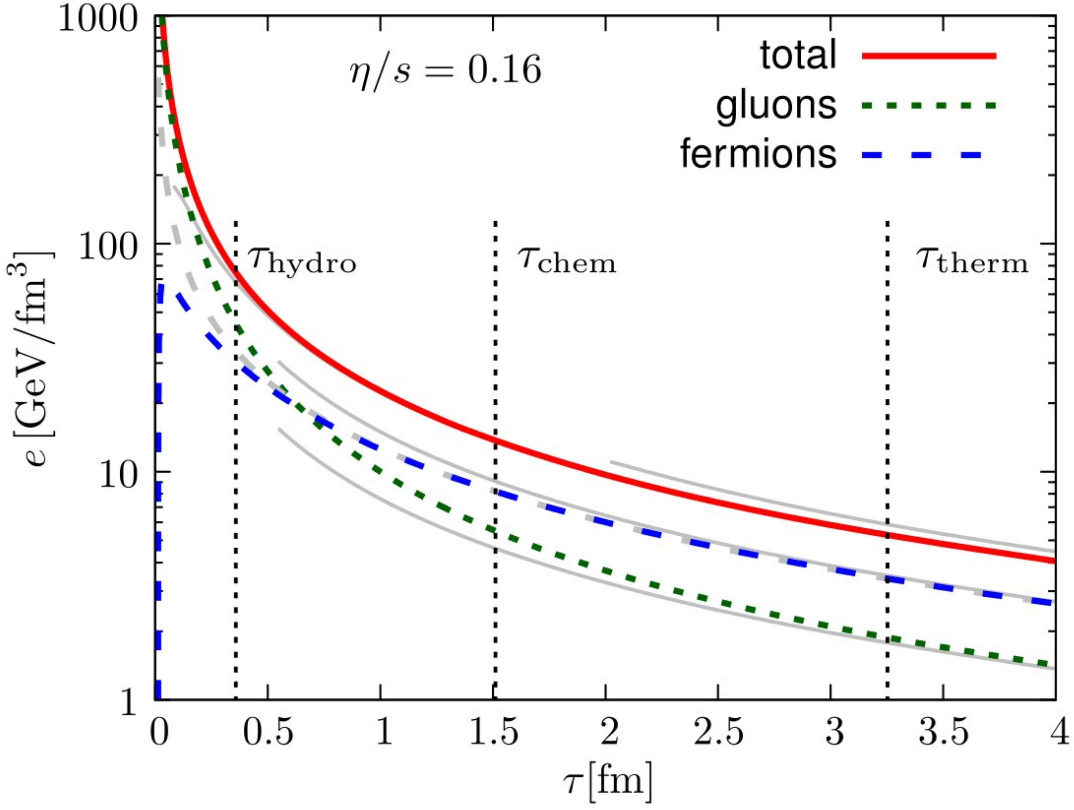
Compare evolution to that of viscous hydro



See paper for details

Two realistic examples

Central Pb-Pb at LHC



Small systems

Rewriting Eq. (12) as a bound on multiplicities, we get

$$\frac{dN_{\mathrm{ch}}}{d\eta} \gtrsim 110 \left(\frac{\tau_{\mathrm{chem}}}{1.2\tau_R}\right)^3 \left(\frac{\eta/s}{0.16}\right)^3 \left(\frac{\tau_{\mathrm{chem}}}{R}\right)^{-2}, \qquad (13)$$

where other constants were set to their nominal values [89]. That is, using the equilibration rates of QCD kinetic theory, we estimate that chemically equilibrated QGP with specific shear-viscosity $\eta/s = 0.16$ can be formed only for systems with multiplicity $dN_{\mathrm{ch}}/d\eta \gtrsim 10^2$ by the time it starts to freeze out at $\tau \sim R$.

Peter’s question: what are the finger prints of that?

- In what way does the non-chemically equilibrated small system look different from the chemically equilibrated one?
  - I want unique fingerprints I can measure

- CLASH angle: can we provide those?

One angle: measure quark decorrelations

- After you produce a s-sbar pair. Track what happens to each of those.

Event calendar at fysik.lu.se

Thesis defense: Jonatan Adolfsson, Particle Physics

Friday, 11 December 2020 from **13:15** to **16:00** (Europe/Stockholm)
at Fysiska institutionen-Physics Department (1-4-Rydbergsalen - Rydbergsalen)

Description **Jonatan Adolfsson** will defend the thesis "Study of Ξ-Hadron Correlations in pp Collisions at √s = 13 TeV Using the ALICE Detector" on December 11, 13.15 in Rydberg lecture hall

Faculty opponent: Prof. Nu Xu, Berkeley Lab

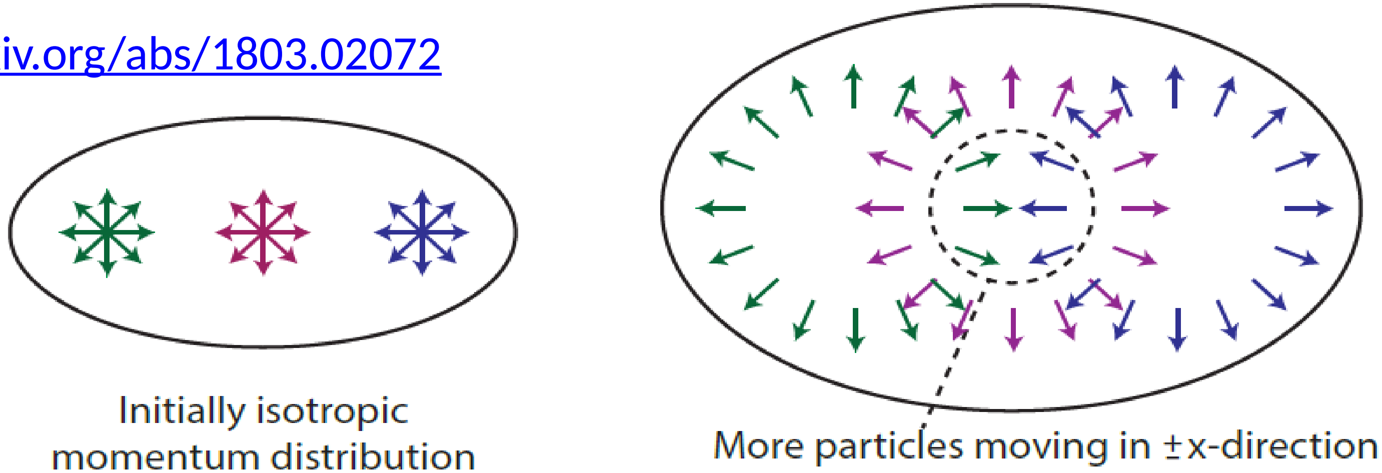
Follow via Zoom:
https://lu-se.zoom.us/j/68626552618?pwd=NUEzalJtdDJqcHB3L0U5Mk9QWXh1Zz09
Webinar ID: 686 2655 2618
Passcode: 251820

It will also be possible to ask question via zoom.

Another angle: go back to the flow story

Kinetic theory: flow in small systems

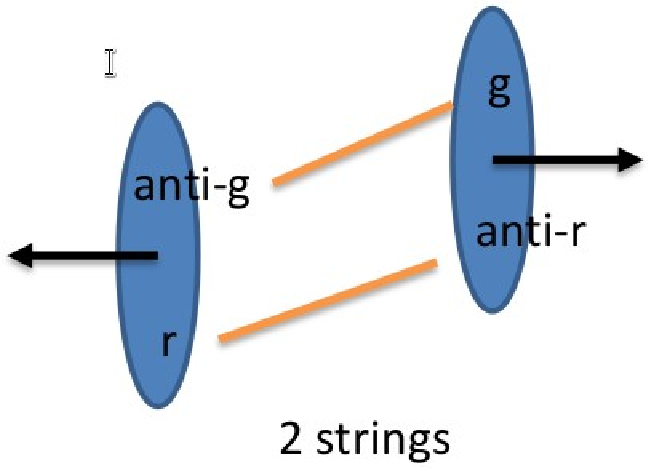
https://arxiv.org/abs/1803.02072

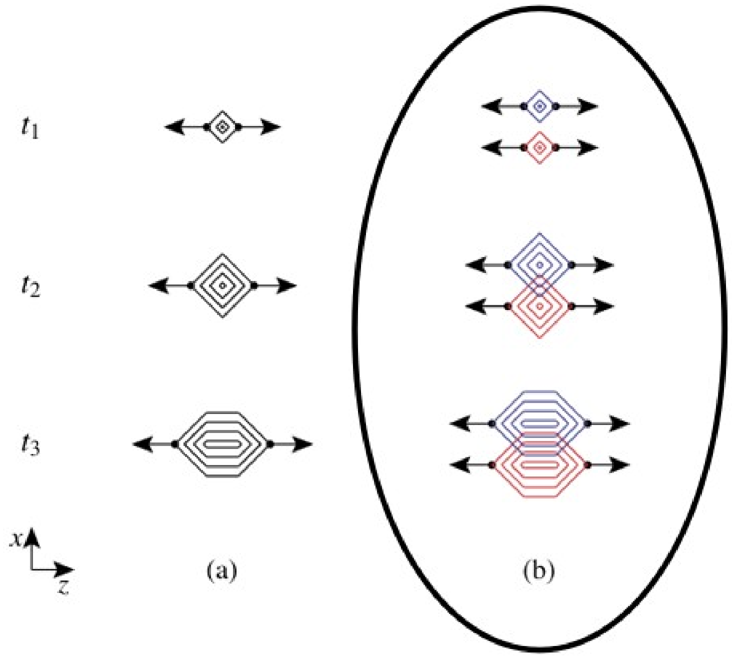


Caption: "Free-streaming particles move along the directions of their momentum vectors leading to local momentum anisotropies. In the central region where most collisions take place, there is an excess of particles moving horizontally compared to vertically moving ones. The interactions in the center region tend to isotropize the distribution function, and thus they reduce the number of horizontal movers and they add vertical movers."

Abstract: "Here, we demonstrate within the framework of transport theory that even the mildest interaction correction to a picture of free-streaming particle distributions, namely the inclusion of one perturbatively weak interaction ("one-hit dynamics"), will generically give rise to all observed linear and non-linear structures. ... As a non-vanishing mean free path is indicative of non-minimal dissipation, this challenges the perfect fluid paradigm of ultra-relativistic nucleus-nucleus and hadron-nucleus collisions."

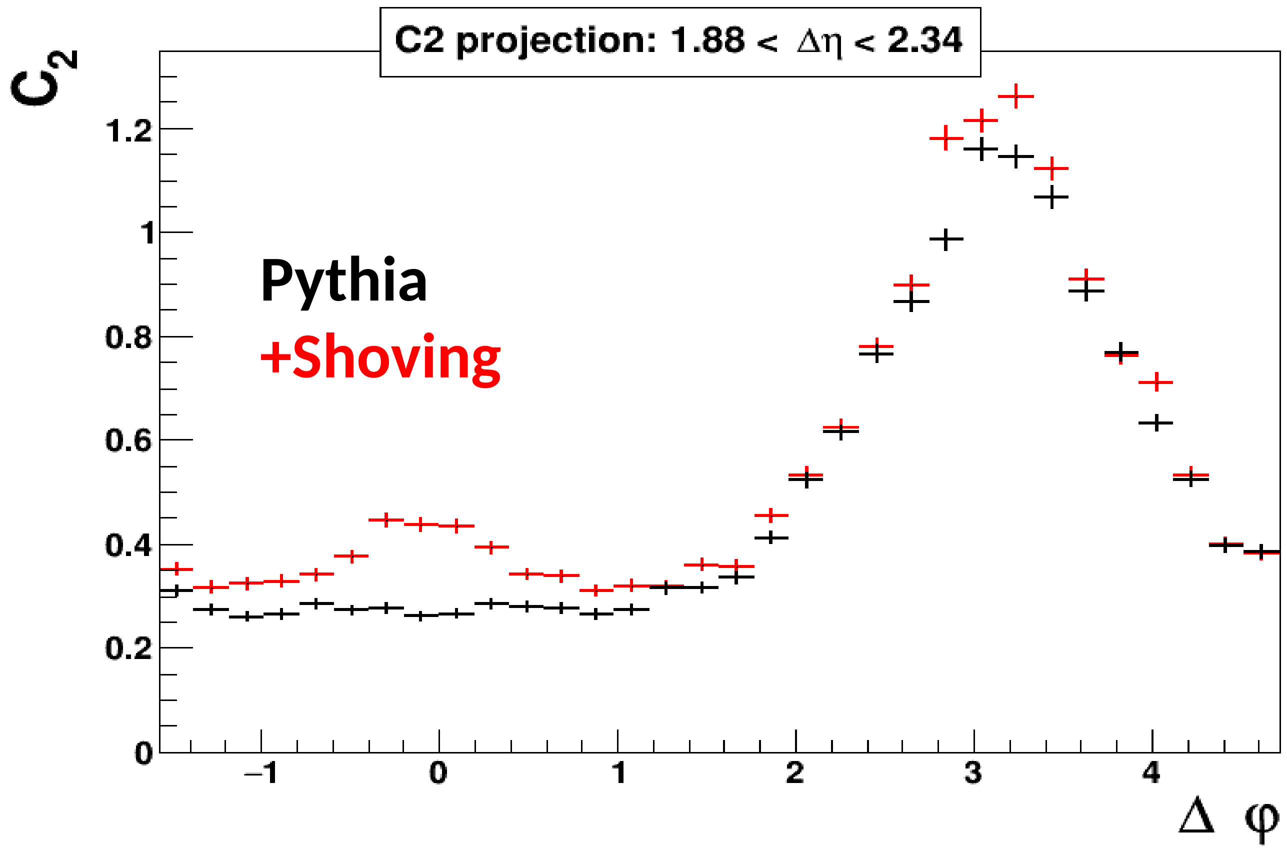
It does not have to be like that: PYTHIA+Shoving





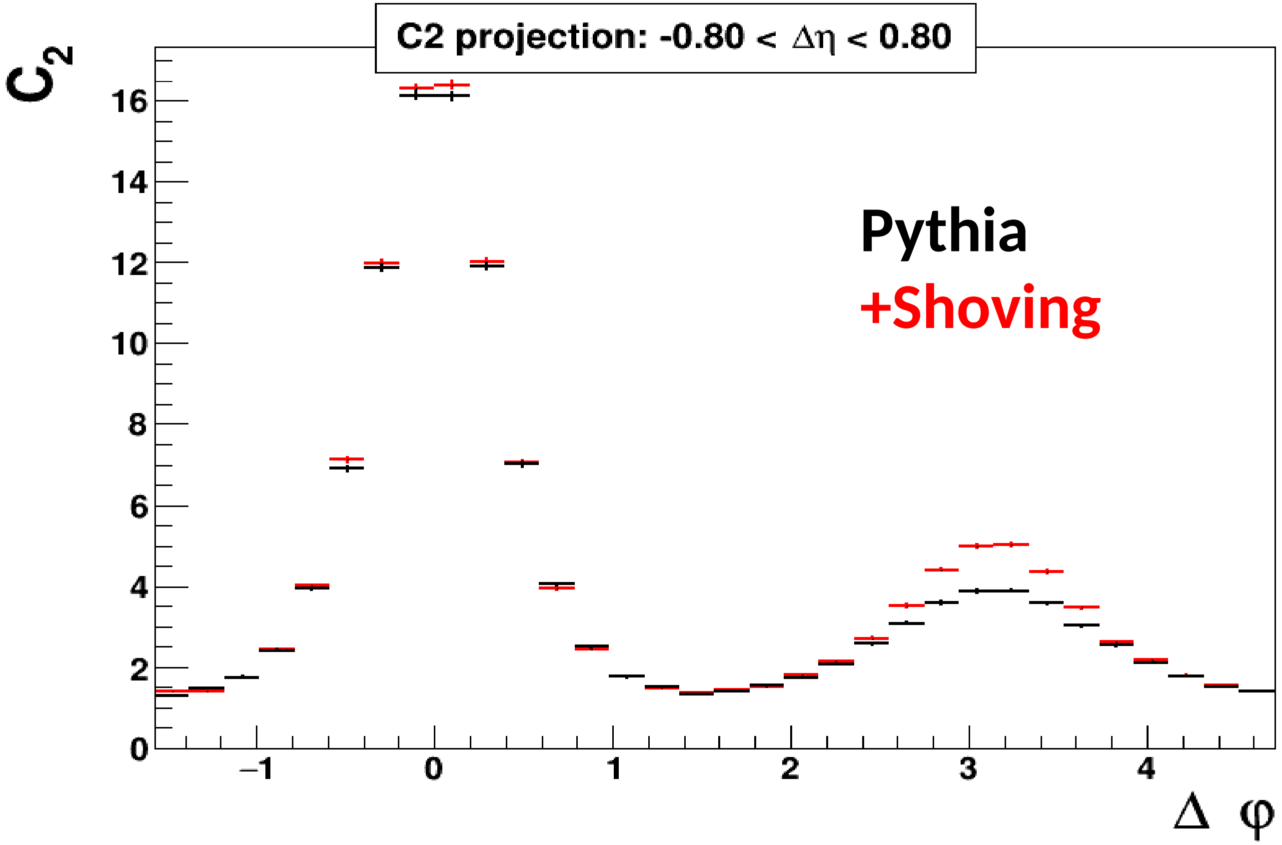
- Minimal colour to exchange is 1 gluon

Bulk: PYTHIA +Shoving



I get a ridge without changing the away side structure significantly

Jet: PYTHIA +Shoving



Also the jet structure is not changed significantly

Why is this a good fingerprint?

- Relatively clear why it is so
  - Strings shove but then decay as strings
    - One will preserve the fundamental correlations of string decays
    - But strings can change due to shoving and hadrons will be boosted by string “flow”

Is PYTHIA+shoving strongly coupled?

- Strings are strongly coupled
  - No individual quarks or gluons
- Shoving is calculated analytically and proportional to overlap = “continuous” process that is almost reversible

- Reminder of why I also like Pythia+shoving
  - String is equilibrated object (1st type of interaction = string formation – not modelled but must be there)
  - String shoving (2nd type of interaction)
  - I avoid limit of 2 ↔ 2 processes where one interaction has to solve both equilibration and flow

What is AMPT?

A Multi-Phase Transport Model for Heavy Ion Collisions

- Zi-Wei Lin, Che Ming Ko, Bao-An Li, Bin Zhang, and Subrata Pal, Phys. Rev. C 72, 064901 (2005)

- HIJING) for generating the initial conditions
- Zhang's Parton Cascade (ZPC) for modelling partonic scatterings,
- the Lund string fragmentation model or a quark coalescence model for hadronization,
- A Relativistic Transport (ART) model for treating hadronic scatterings,

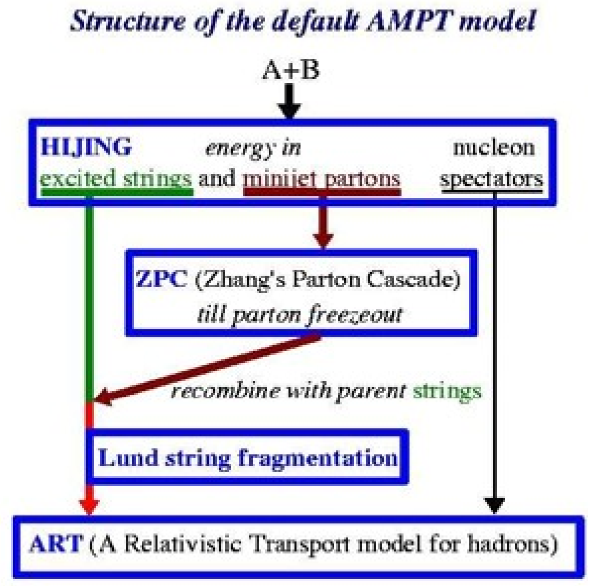


FIG. 1: (Color online) Illustration of the structure of the default AMPT model.

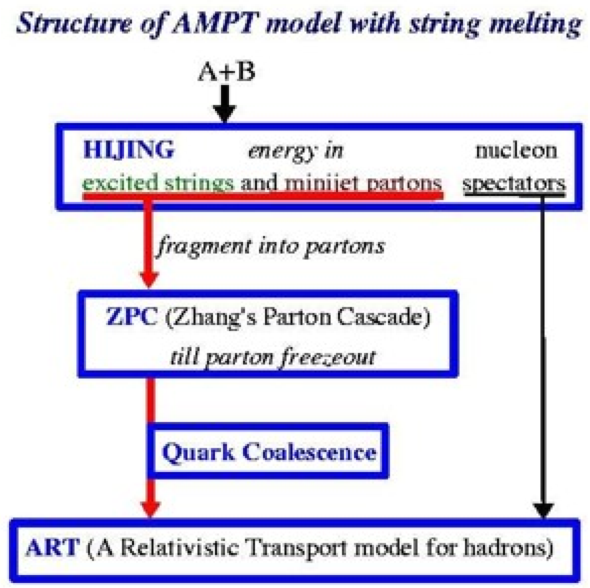


FIG. 2: (Color online) Illustration of the structure of the AMPT model with string melting.

AMPT – the good and the bad (Peter's opinion)

- Describes a lot of physics, e.g., v3/ridge was in AMPT before the origin was understood but is unclear how realistic the model is

- For a long time it was thought that it was hydrolike but then it was realized "Anisotropic parton escape is the dominant source of azimuthal anisotropy in transport models" Liang He, Terrence Edmonds, Zi-Wei Lin, Feng Liu, Denes Molnar, Phys.Lett.B 753 (2016) 506-510
  - It is found that the majority of vn comes from the anisotropic escape probability of partons, with no fundamental difference at low and high transverse momenta….Only when the parton–parton cross-section is set unrealistically large does this contribution start to take over.

Use AMPT as an example of a weakly coupled model

- Caveat: not clear how apples-to-apples it is with weakly coupled kinetic theory but I think it still shows my points are valid
  - And as far as I know it is currently the only non-hydro generator like this that I can get

- All the plots in the following are taken from another context

2 parallel strings in AMPT

Are minimal conditions for collectivity met in e+e- collisions?
J.L. Nagle, R. Belmont, K. Hill, J. Orjuela Koop, D.V. Perepelitsa, P. Yin, Z-W. Lin, D. McGlinchey
Phys. Rev. C 97, 024909 (2018)

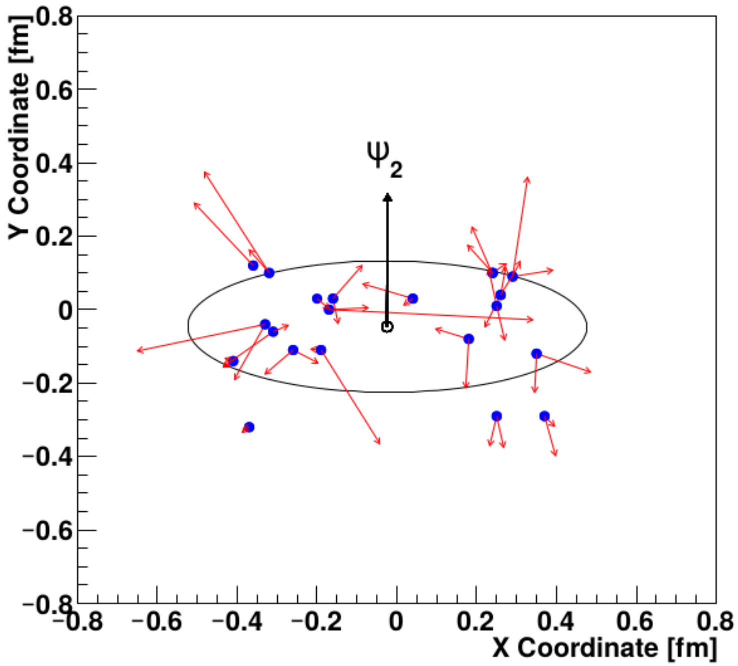


FIG. 3. Two color-string event with initial parton positions shown as blue points, and initial parton momentum vectors shown as red arrows. The center-of-mass coordinate for the set of partons is shown as the black open point and the spatial eccentricity shown as the drawn ellipse.

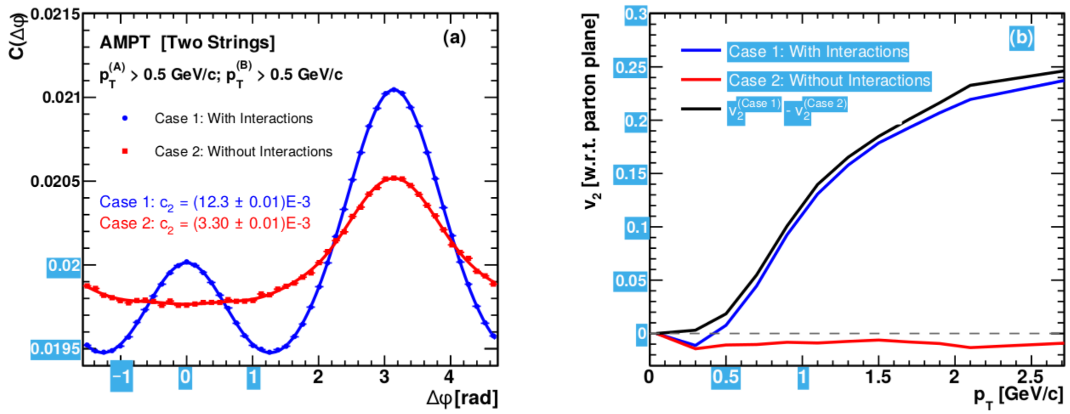
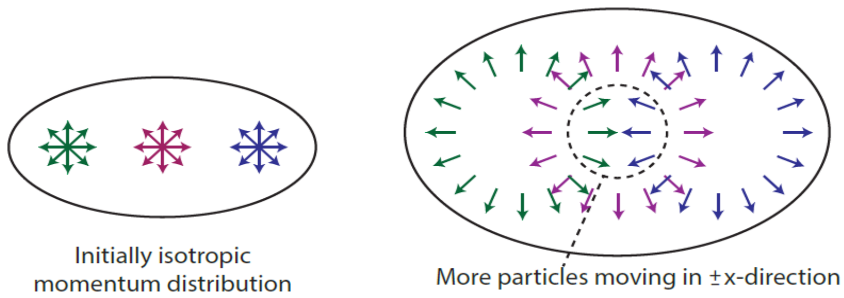
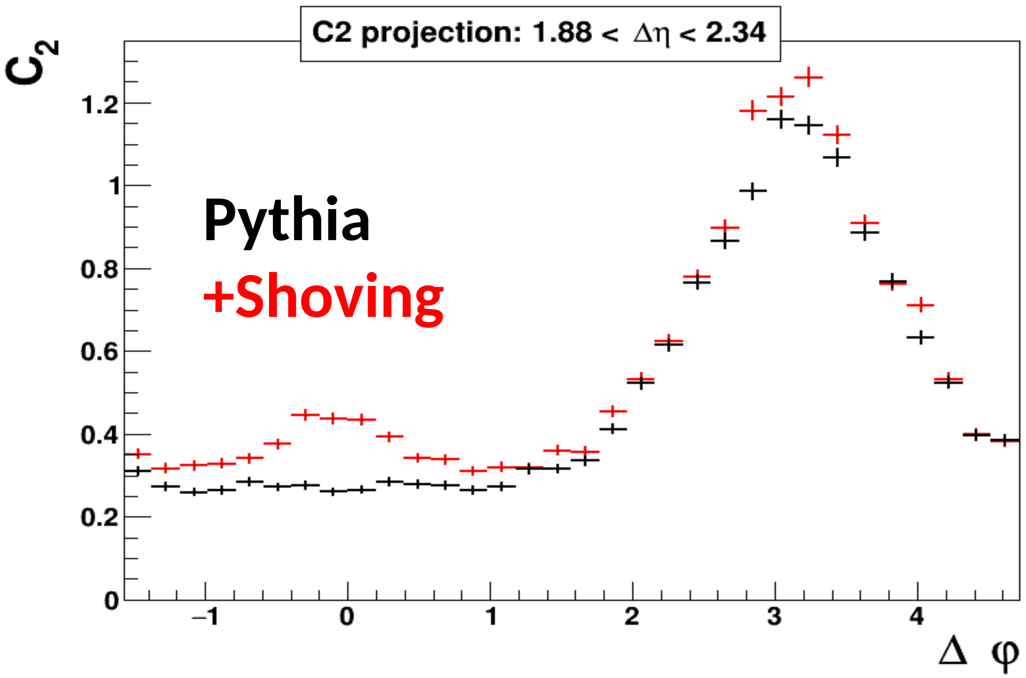
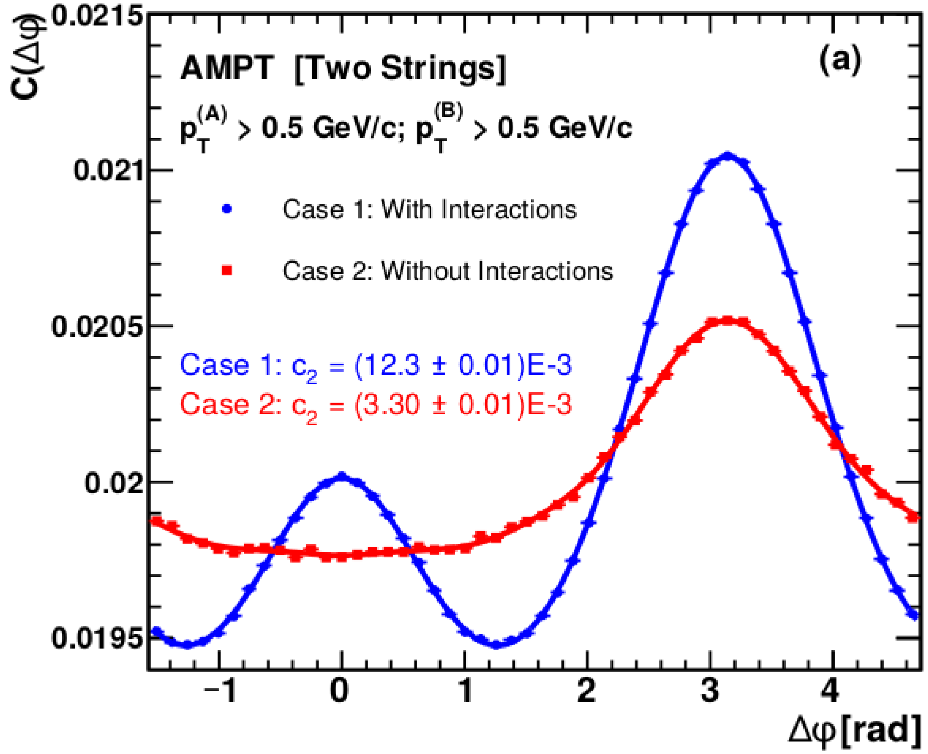


FIG. 4. AMPT events with two color strings. (Left) Long-range two-particle correlations $|\Delta\eta| > 2.0$ for hadrons with $p_T > 0.5$ GeV/c, with and without final-state interactions. Fourier fits are also shown as lines and the c_2 coefficients displayed. (Right) Azimuthal anisotropy (v_2) calculated with respect to the initial parton plane with and without final-state interactions, and then the net difference thus isolating the effects due to final-state interactions (black curve).



The difference seems to be “Push” vs “Reshuffle”





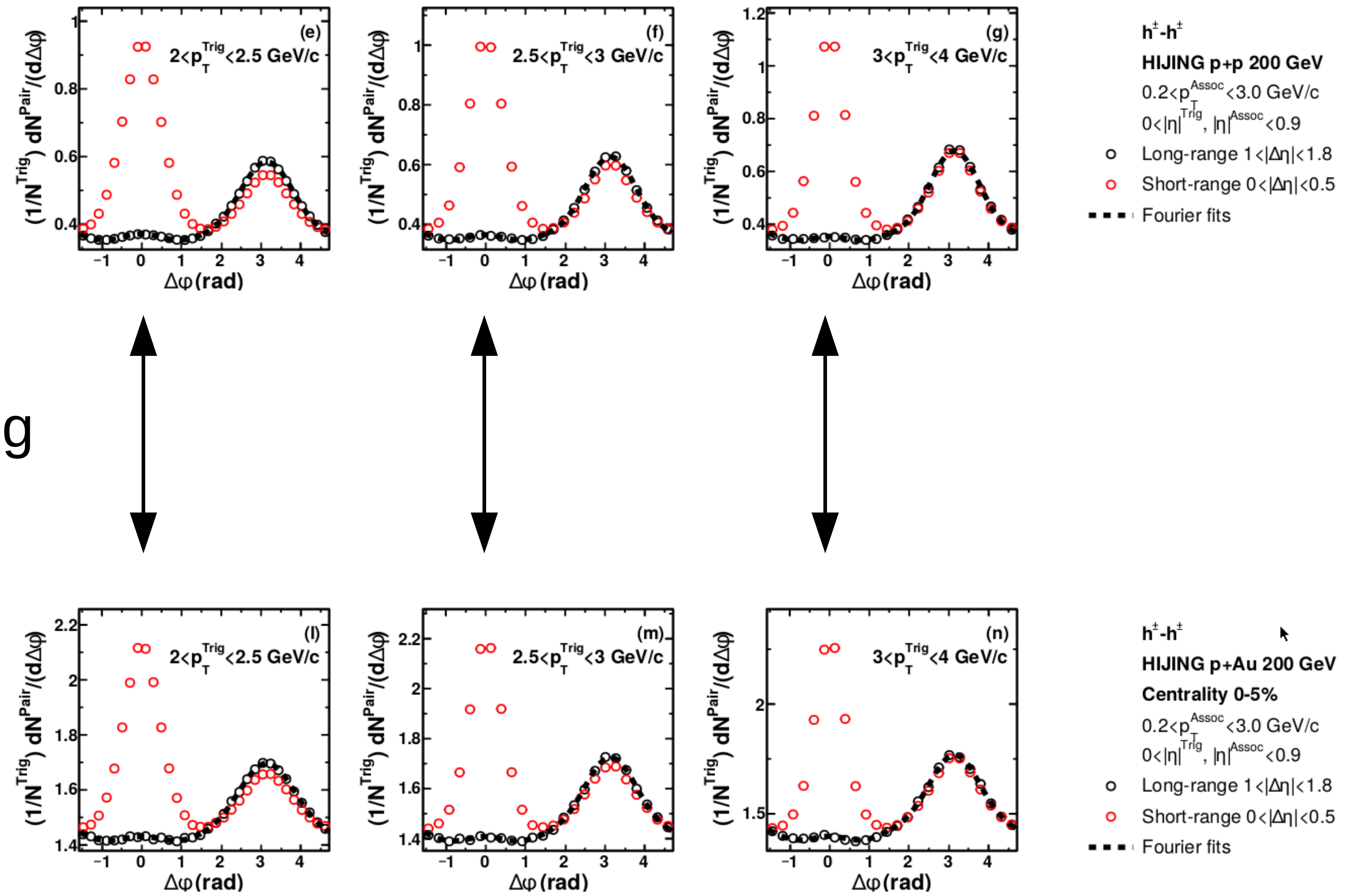
Study larger systems
HIJING (no flow) reference

Examination of Flow and Non-Flow Factorization Methods in Small Collision Systems
S.H. Lim, Q. Hu, R. Belmont, K.K. Hill, J.L. Nagle, D.V. Perepelitsa
Phys. Rev. C 100, 024908 (2019)

Small

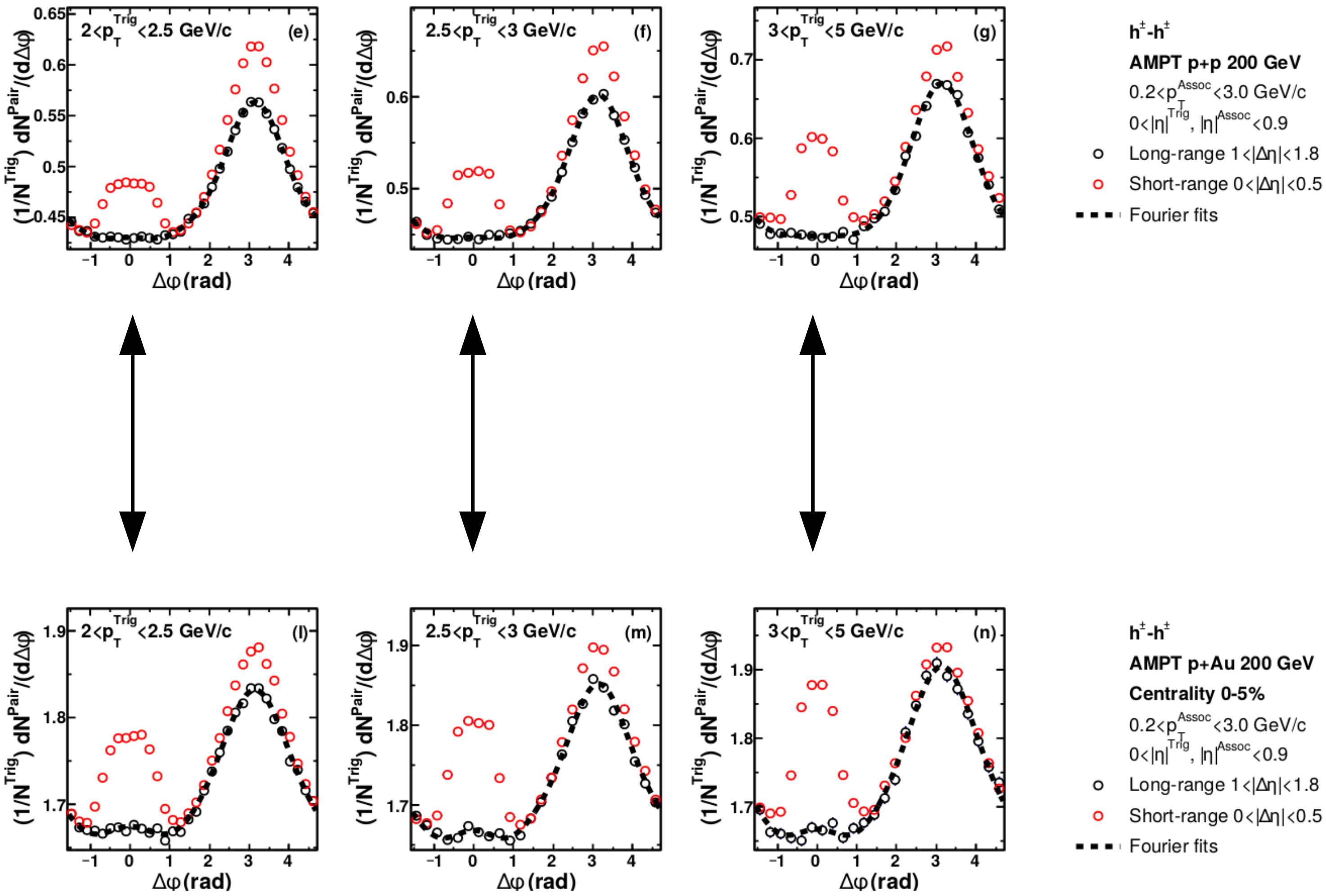
Non-flow:
Short – Long
is only
slightly
modified

Large

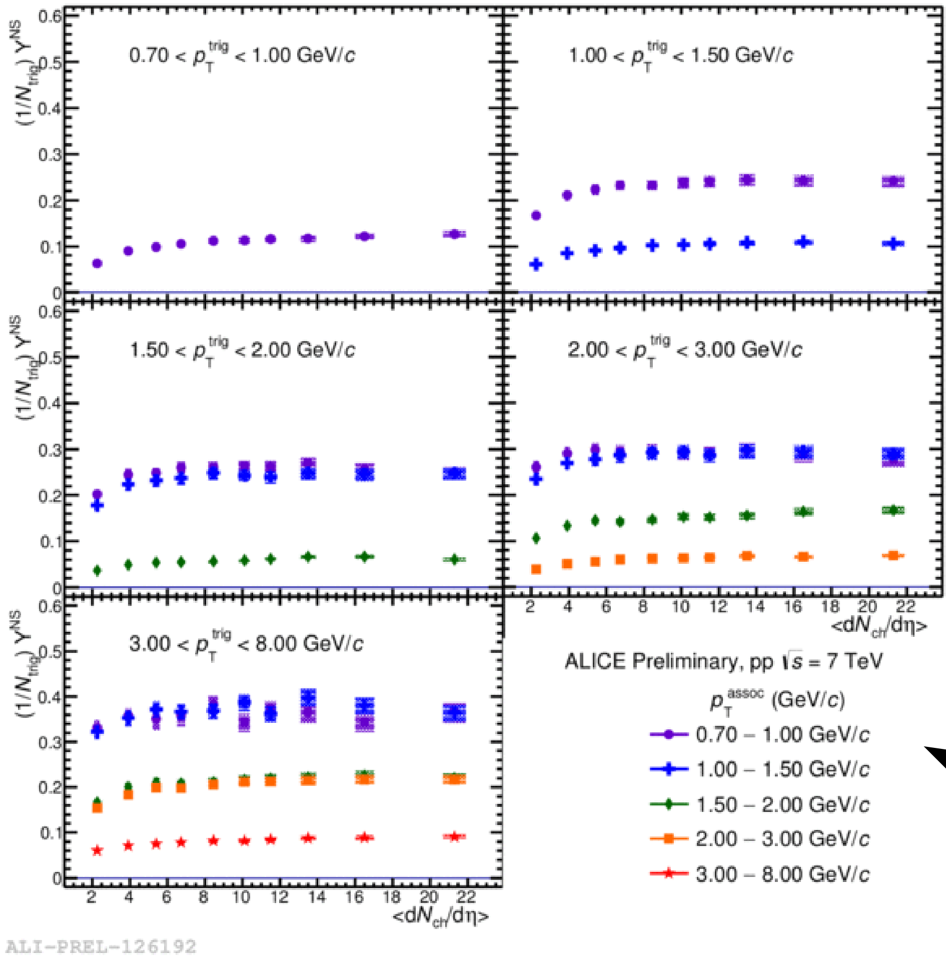


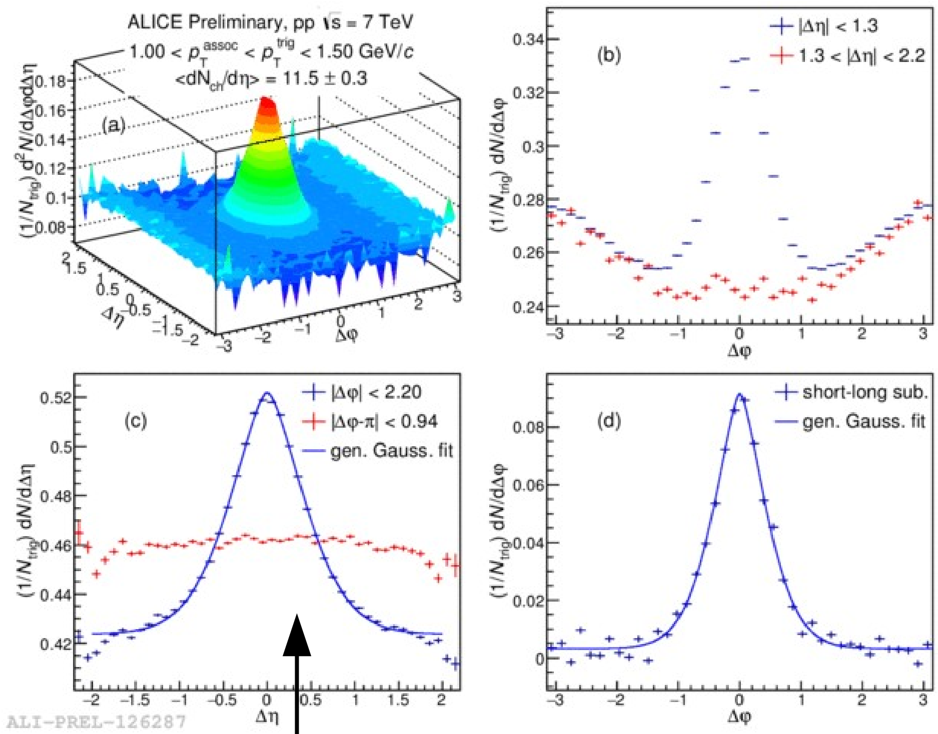
Study larger systems AMPT

Non-flow: Short – Long is significantly modified! Near side peaks in p-A is ~2 times larger than in pp!!! (?)



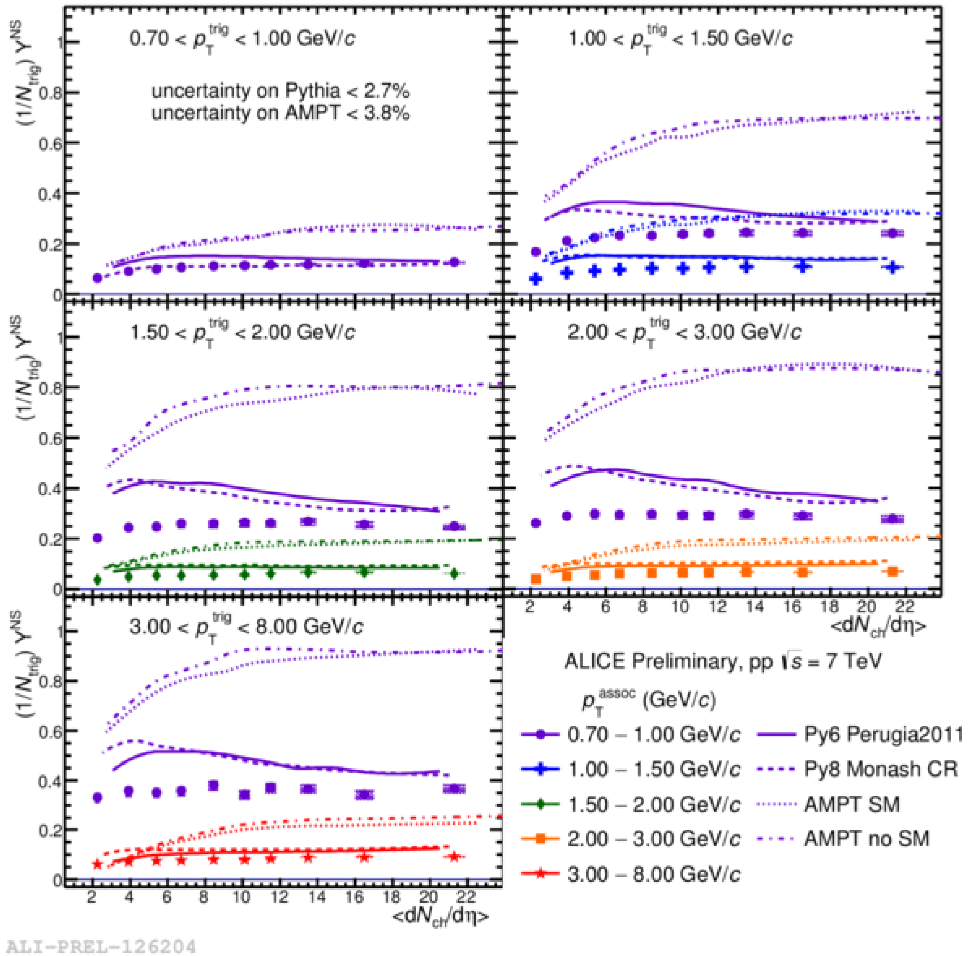
Some studies done in ALICE for pp of near-peak yield





Yield is integral of generalzied Gaussian (after flat background is subtracted)

Some studies done in ALICE for pp of near-peak yield



Data are quite flat while AMPT grows as we saw also in pp vs p-Au studies for RHIC.

Can of course get a much longer “arm” by going to p-Pb and Pb-Pb!

Could be a good fingerprint of AMPT if one understood origin!?

What I propose we should do

- Try to see if we can understood how shoving fits into this
  - Is it really strongly coupled?
  - Are the interactions leading to string formation and those giving string shoving different? It seems so and it seems smart but what is the QCD origin?
  - Can we develop extensions of PYTHIA that generates long range correlations a la Shoving/AMPT but that are weakly coupled?
    - And can we find fingerprints to clearly identify each mechanism?

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    - And can we find fingerprints to clearly identify each mechanism?

Merry Xmas and Happy New Year!