Interplay of equilibrium and non-equilibrium components from dynamical core-corona towards the RHIC isobar collisions

Y. Kanakubo *et al.*,
arXiv:2108.07943 (to appear in PRC)

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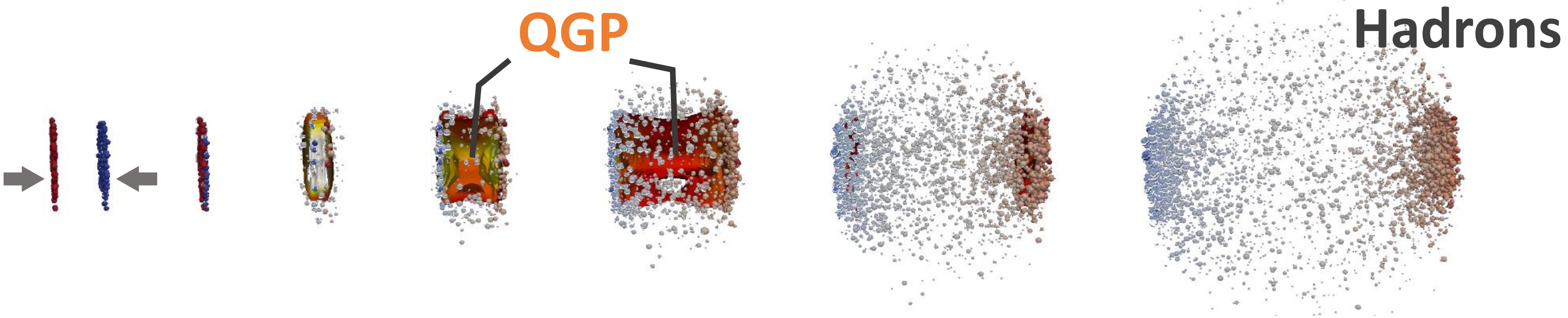
Introduction

Relativistic heavy-ion collisions

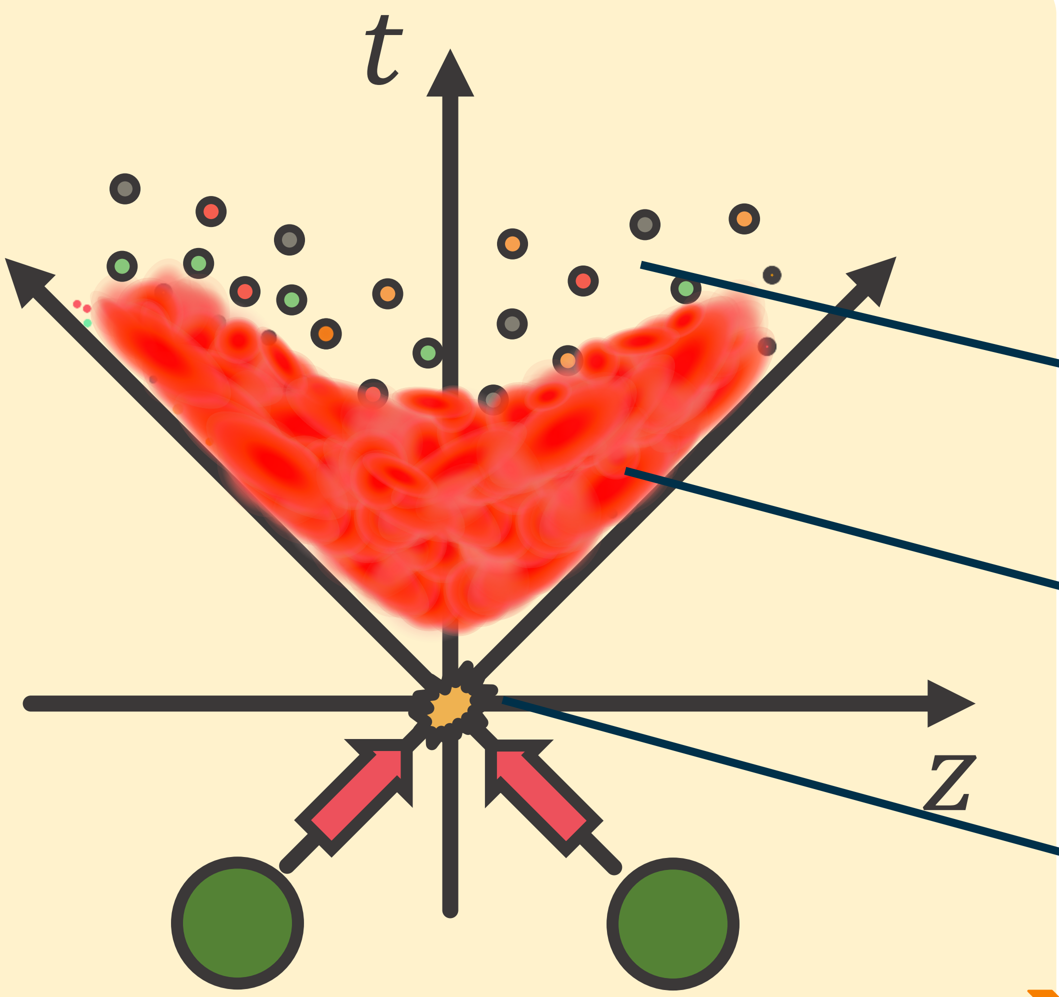


J. Bernhard, arXiv:1804.06469

How can we access the properties of QGP from HIC experimental data?

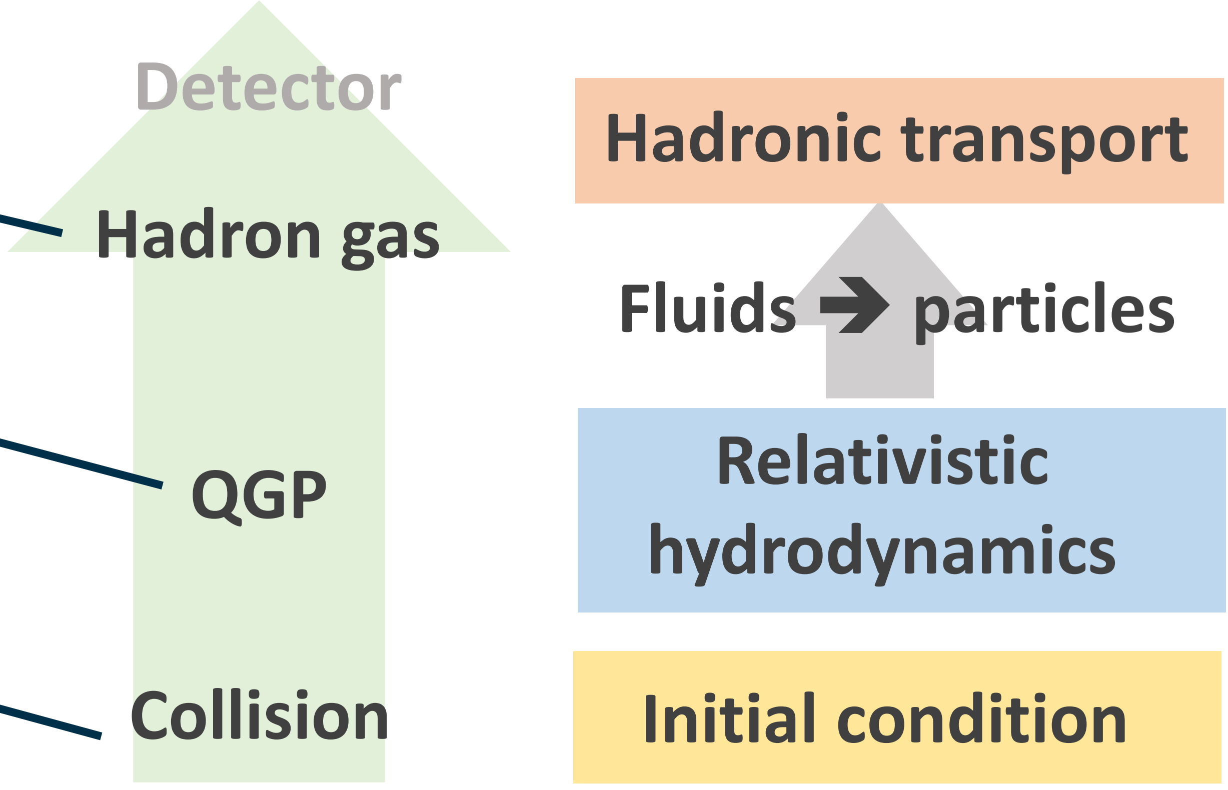
Dynamics of locally equilibrated matter
→ Relativistic hydrodynamics

Standard model of HIC



Space-time evolution of HIC

QGP is a transient state in HIC!
Different stage needs different picture



➔ Successful in describing HIC exp data

QGP signals in high-multiplicity small systems

pp collisions as a reference for HIC with QGP formation…

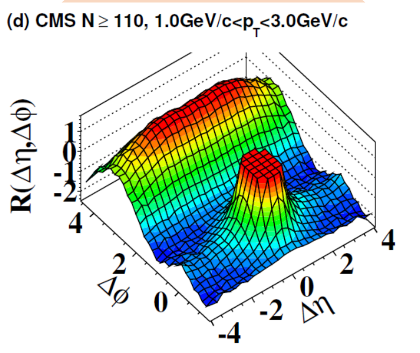
Paradigm shift (2010-)

Experimental data in high-multi. pp

- Thermal strange hadron productions
- Hydro-like collectivity

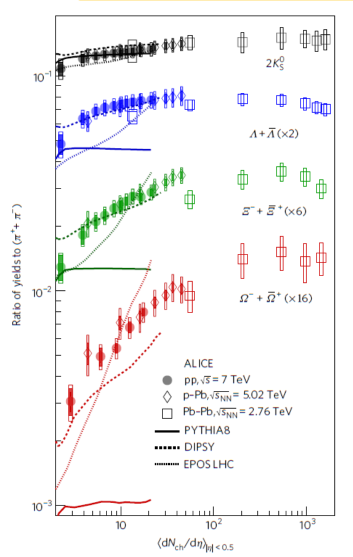
➔QGP signals observed in HIC

Comprehensive picture from pp to AA?



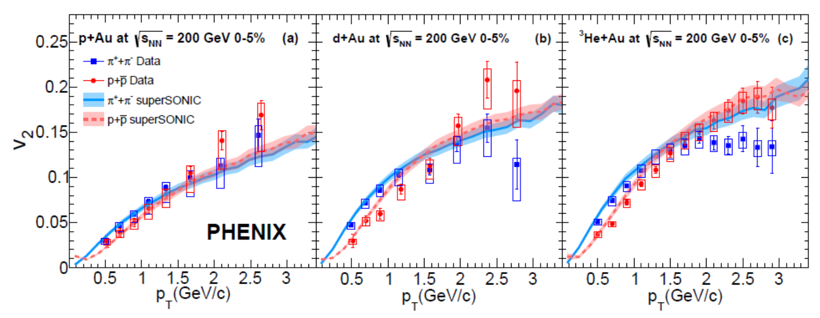
Long range correlation

JHEP 09 091 (2010)



Strangeness enhancement

Nature Phys. 13 535-539 (2017)

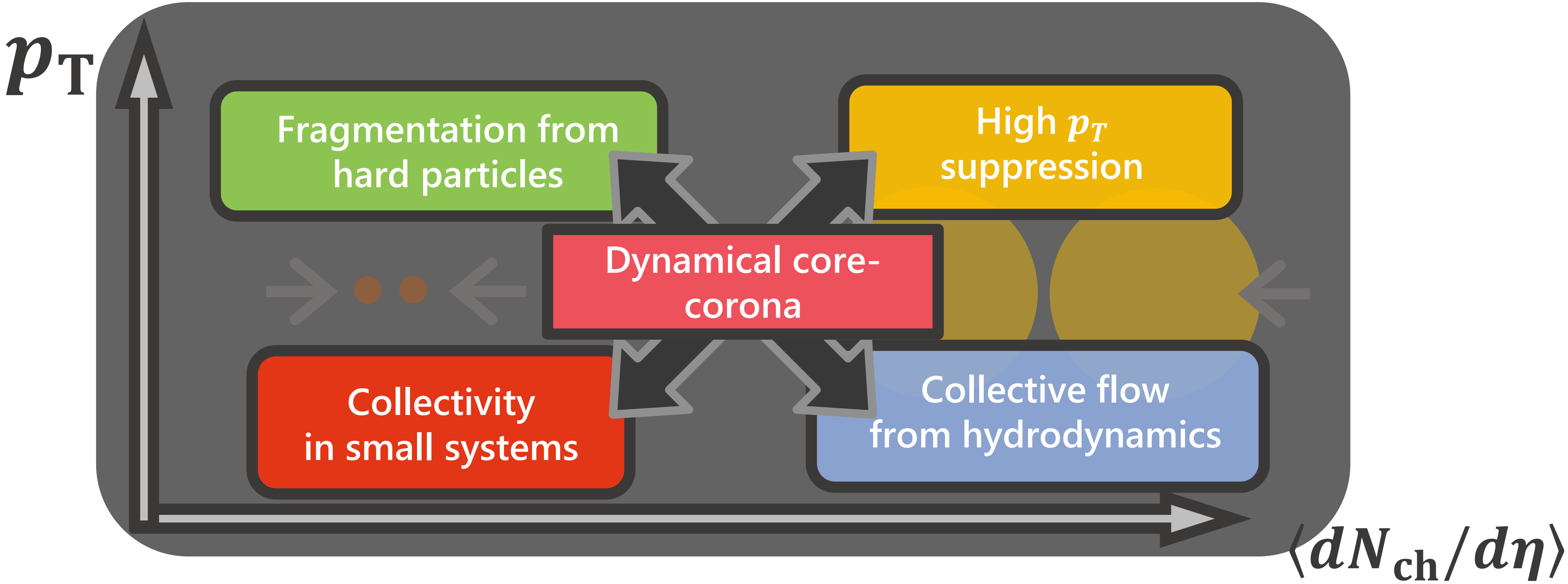


Phys. Rev. C 97, 064904 (2018)

Flow harmonics

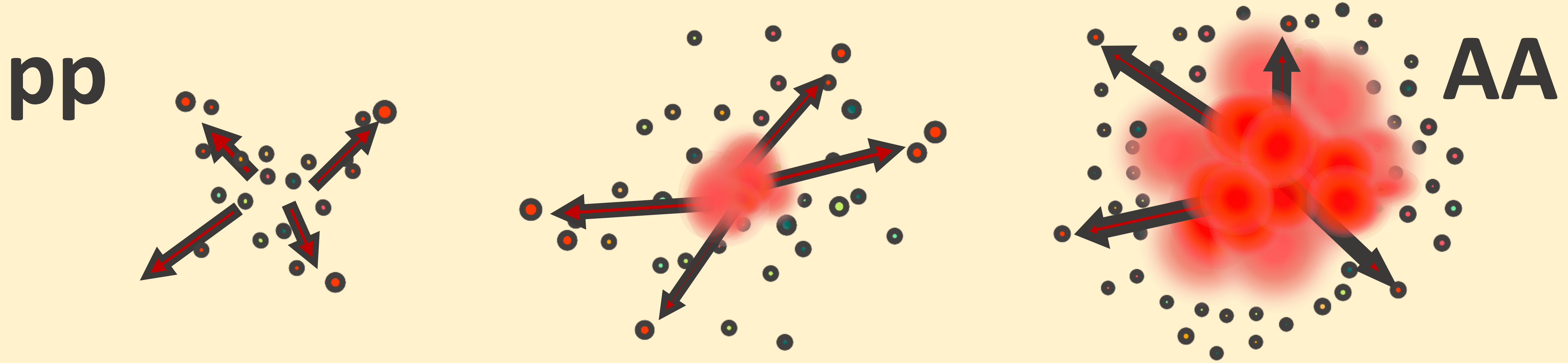
Towards unified description

Hydrodynamics works only in low p_T and high multiplicity



Right picture, right place!

Hydro-based MC event generator



Dynamical core-corona initialization (DCCI) model

Core: sufficient secondary scatterings
➔fluids (equilibrated matter)

Corona: few secondary scatterings
➔non-equilibrated partons

Goal: Understanding QCD dynamics from low to high p_T,
from forward to backward rapidity, and from pp to AA

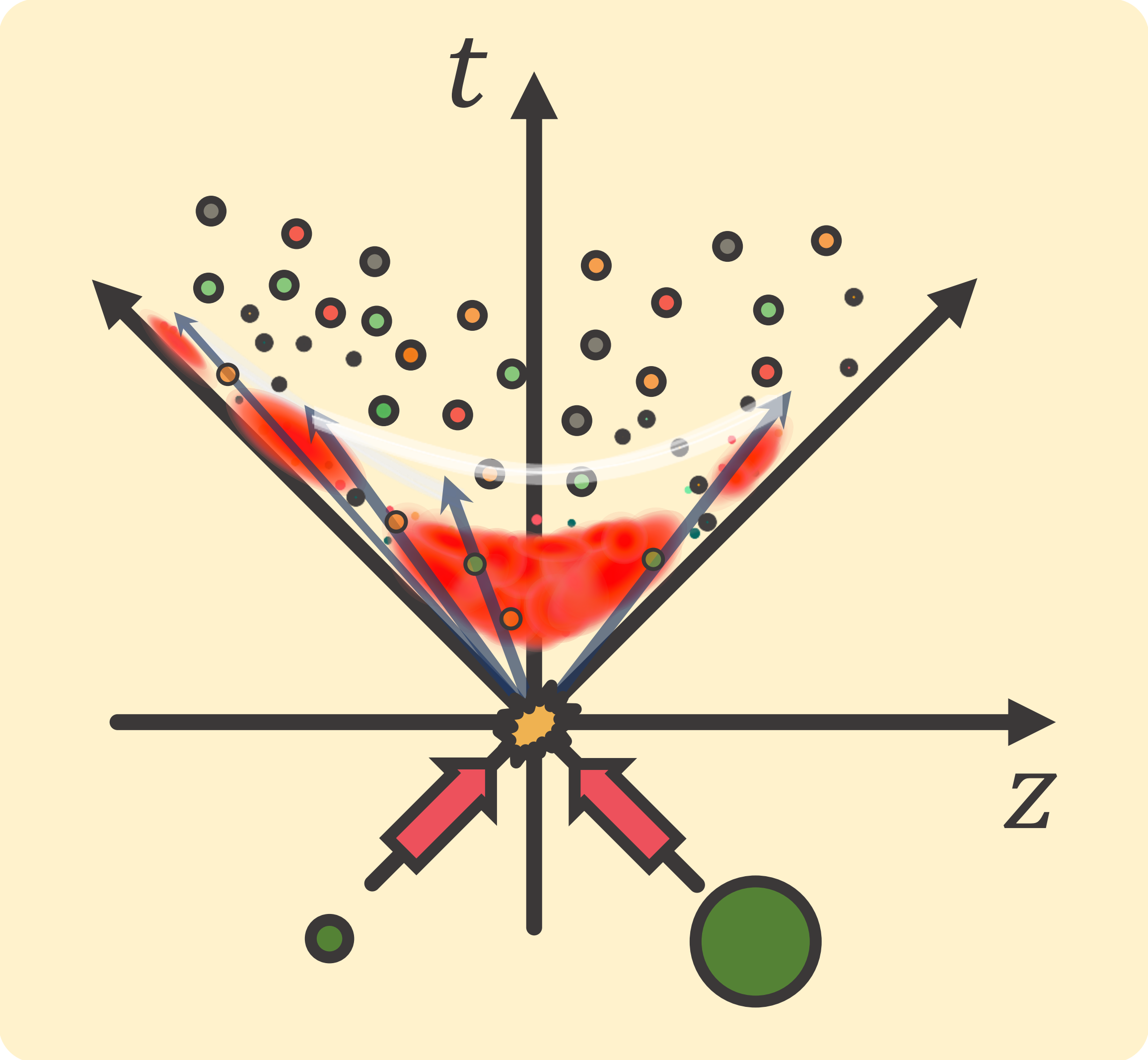
Y. Kanakubo *et al.*, PTEP 2018 12, 121D01 (2018);

Phys. Rev. C 101 2, 024912 (2020); arXiv:2108.07943

Dynamical Core-Corona Initialization model 2

Y. Kanakubo *et al.*, arXiv:2108.07943

Model flow of DCCI2



Hadronic afterburner

JAM Y. Nara *et al.*,Phys. Rev. C61, 024901 (2000)

Hadronization

PYTHIA8 (string fragmentation)
iS3D (thermal hadron sampling)
M. McNelis *et al.*, Comput. Phys.Commun.258, 107604 (2021)

Dynamics of QGP

(3+1)-D hydro with source terms

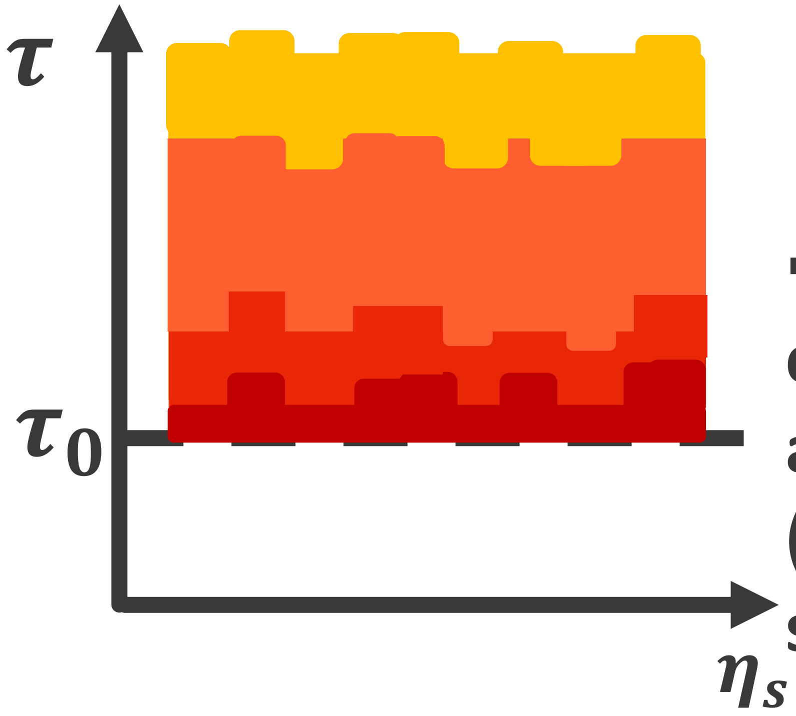
Initial partons

PYTHIA8/PYTHIA8 Angantyr
T. Sjöstrand *et al.*, Comput. Phys. Commun. 191, 159 (2015)
C. Bierlich *et al.*, JHEP 1610 139 (2016)

Dynamical initialization framework

➔ Dynamical generation of hydro initial conditions

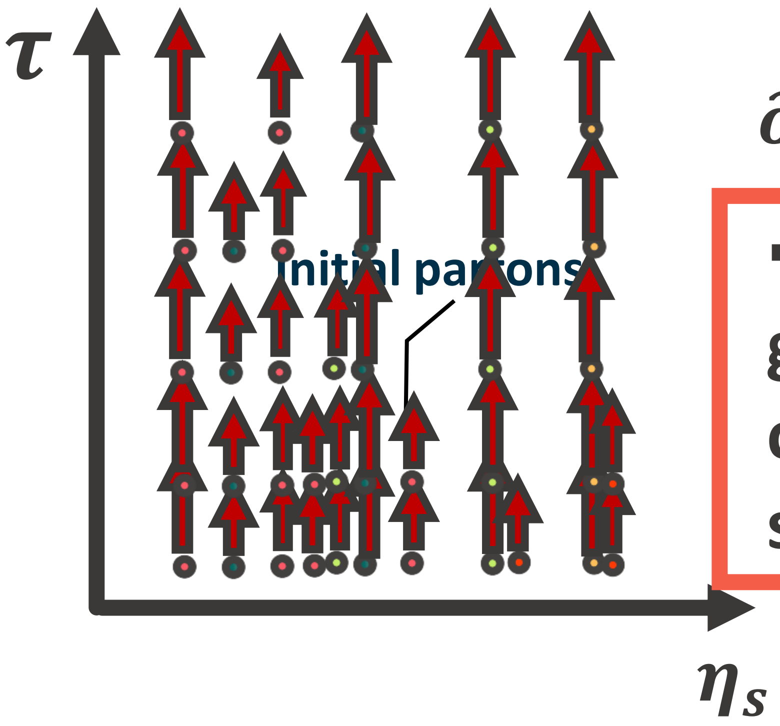
Conventional hydro



$\partial_\mu T^{\mu\nu} = 0$

➔ Put initial condition at fixed τ_0 (parametrized/scaled)

Hydro with dynamical initialization



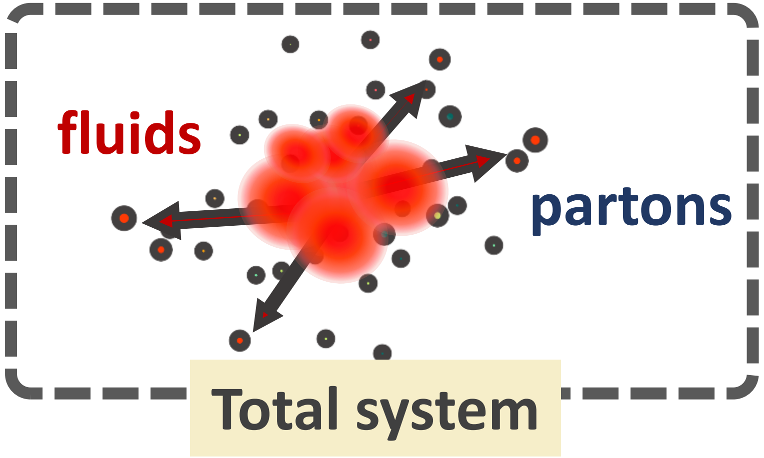
$\partial_\mu T^{\mu\nu} = J^\nu$

➔ Locally generate initial condition via sources J^μ

Dynamical initialization framework

Assumptions
- Sources of QGP ➔ partons
- Two-component picture

➔ fluids and partons



Continuum eq. for fluid+parton

$$\partial_\mu \boxed{\left(T^{\mu\nu}_{\text{fluid}} + T^{\mu\nu}_{\text{parton}}\right)} = 0$$

Hydrodynamic eq. with source term

$$\partial_\mu T^{\mu\nu}_{\text{fluid}} = J^\nu$$

Assuming Gaussian profile G and straight trajectory for a parton

$$J^\nu \rightarrow -\sum_i \boxed{\frac{dp_i{}^\nu(t)}{dt}} G\left(x - x_i(t)\right)$$

"Sources of fluids"

= "Four-momentum deposition from partons"

Dynamical core-corona picture

~ EoM with a drag force due to secondary scatterings

$$\frac{dp_i{}^{\mu}}{d\tau} = -\sum_{j}^{N_{\mathrm{scat}}} \rho_{i,j}\sigma_{i,j}\left|v_{\mathrm{rel},i,j}\right| p_i{}^{\mu}$$

Defined at a co-moving frame with $\eta_{s,i}$

*Note: Instant equilibration of deposited energy and momentum

- Collision criterion

$$b_{i,j} \leq \sqrt{\frac{\sigma_{i,j}}{\pi}}$$

- Parametrized cross-section

$$\sigma_{i,j} = \frac{\sigma_0}{s_{i,j}/[\mathrm{GeV}^2]}$$

- Density of partons

$$\rho_{i,j} = G(x_i - x_j)$$

G : Gaussian

of (non-equilibrated and equilibrated) partons scattered with *i*th parton

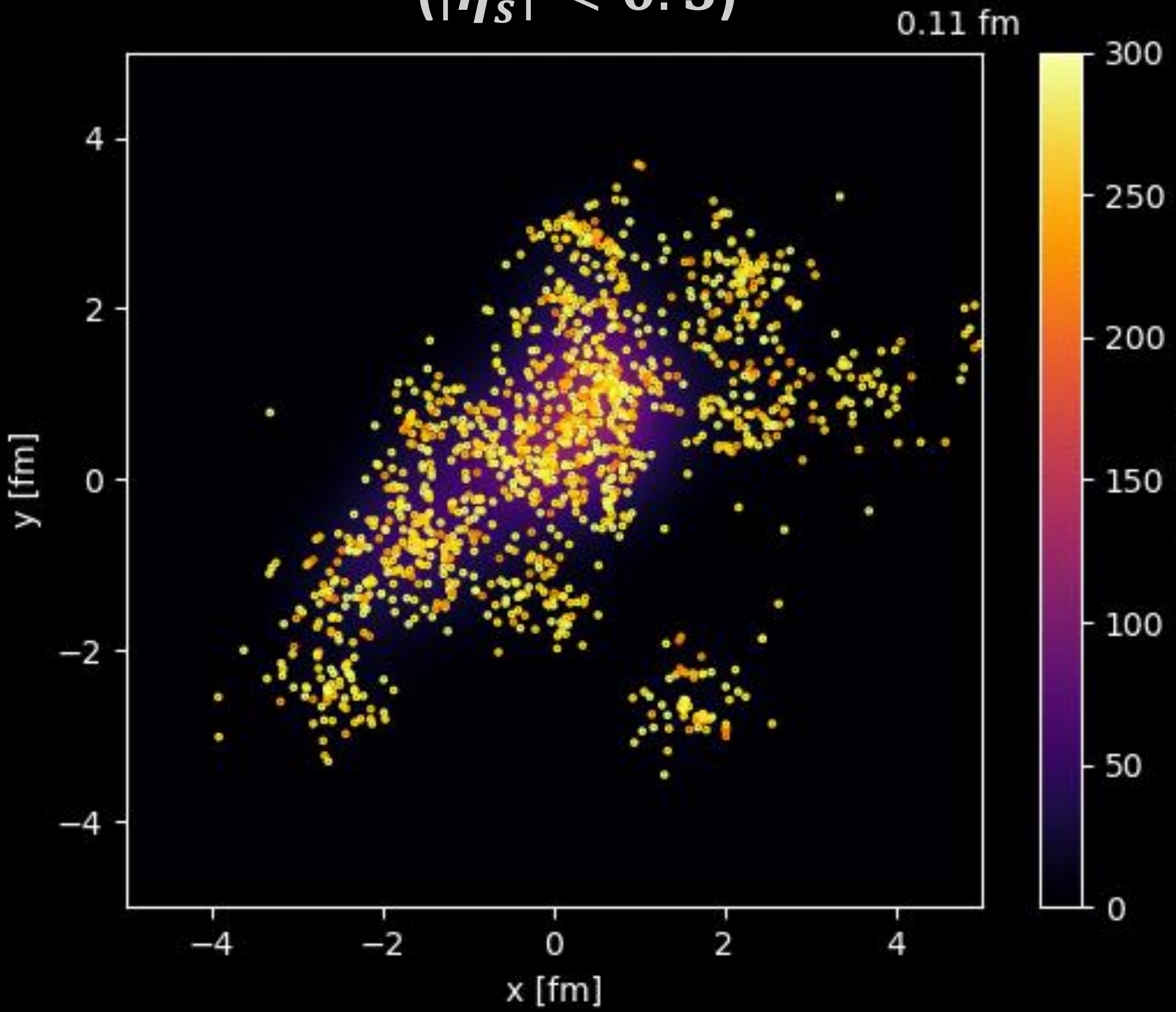
Low p_T and/or dense region ⇨ Core (fluids)

High p_T and/or dilute region ⇨ Corona (non-equilibrated partons)

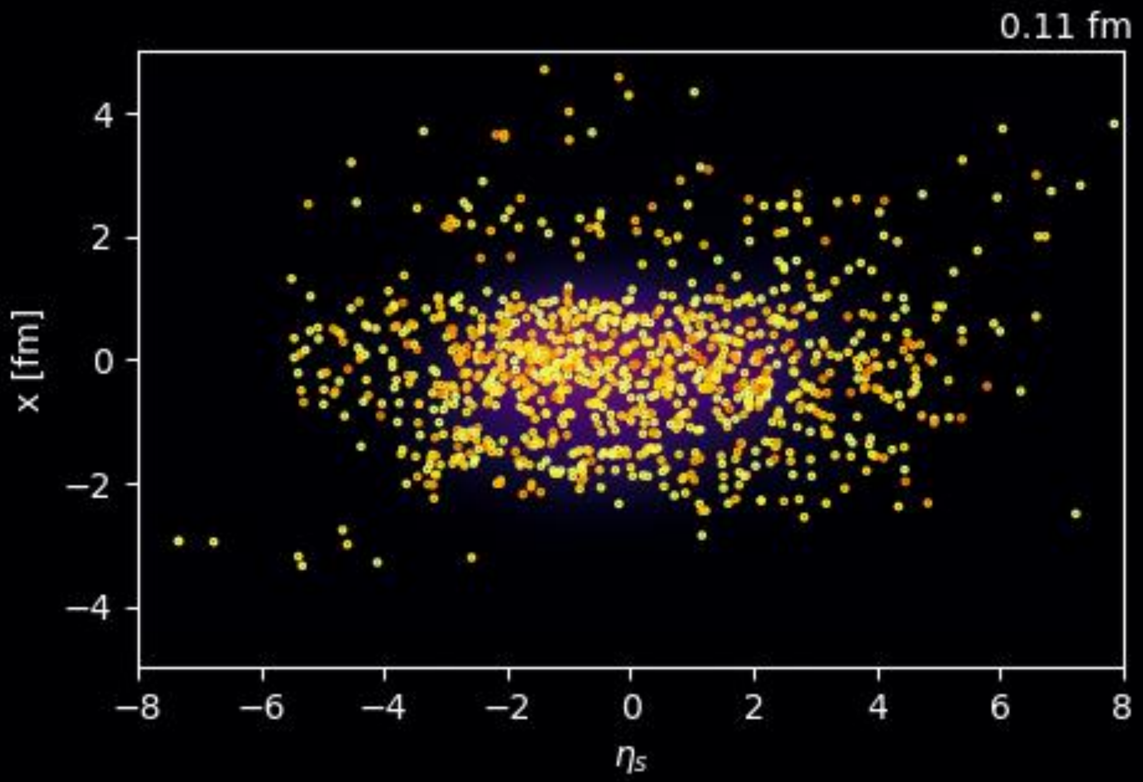
Dynamical core-corona initialization

PbPb 2.76 TeV

Transverse plane
($|\eta_s| < 0.5$)



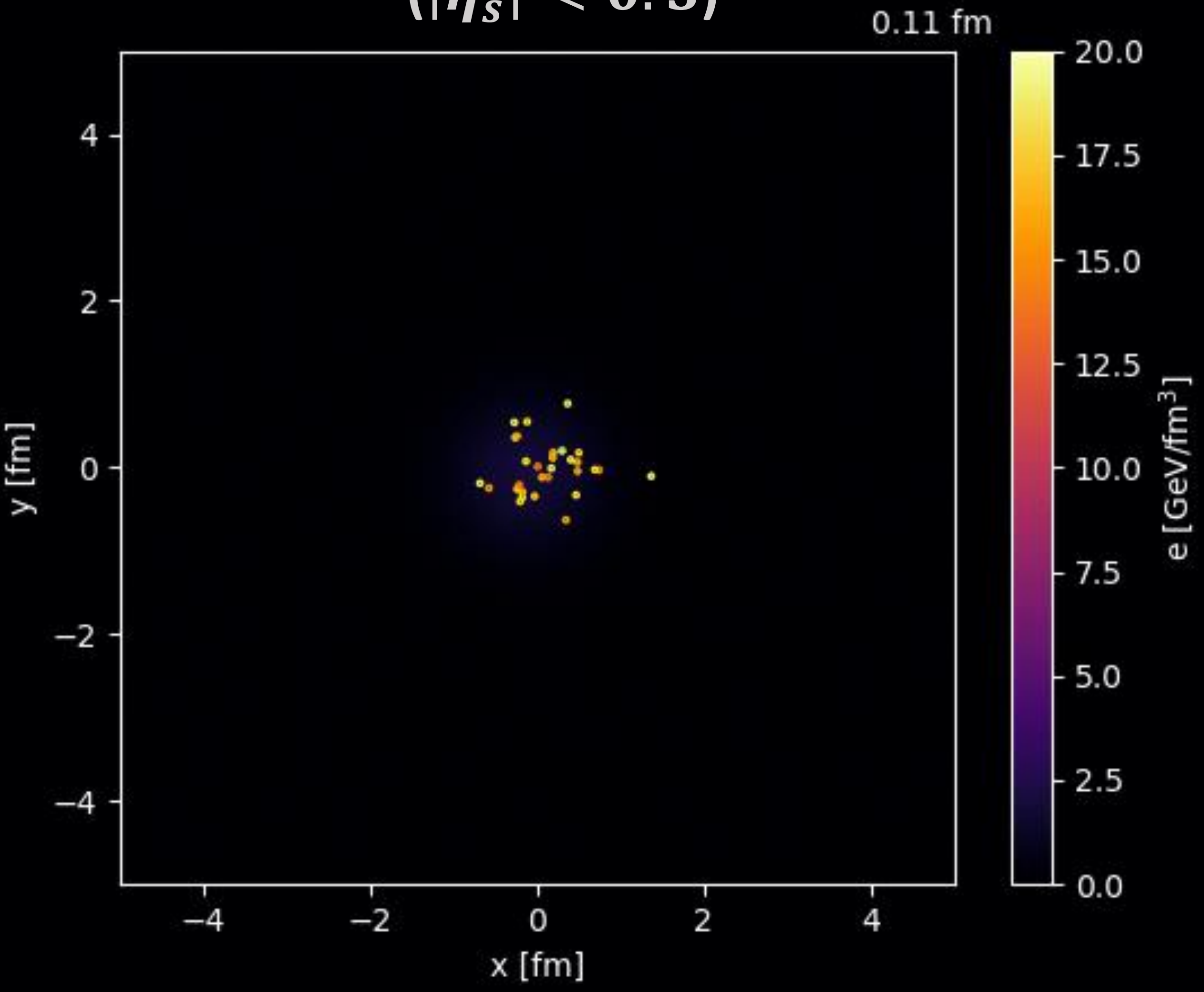
$x - \eta_s$ plane
($|y| < 0.5$)



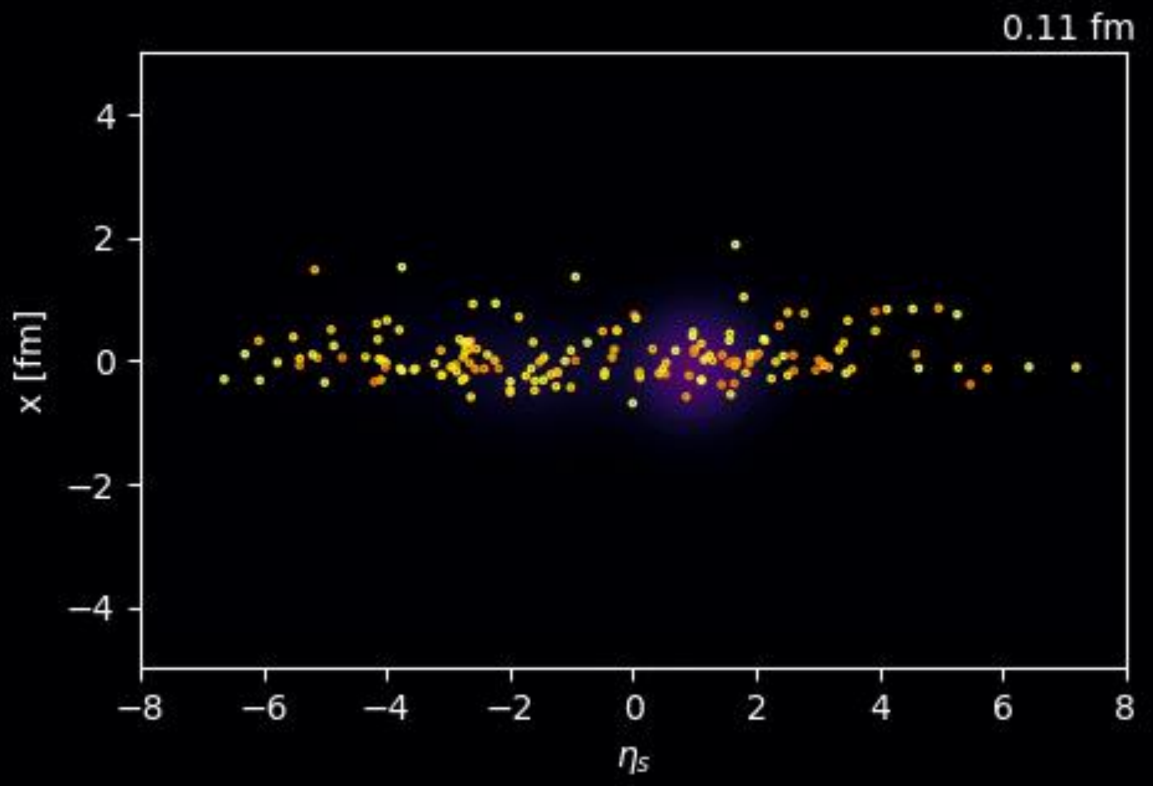
Dynamical core-corona initialization

pp 7 TeV

Transverse plane
($|\eta_s| < 0.5$)



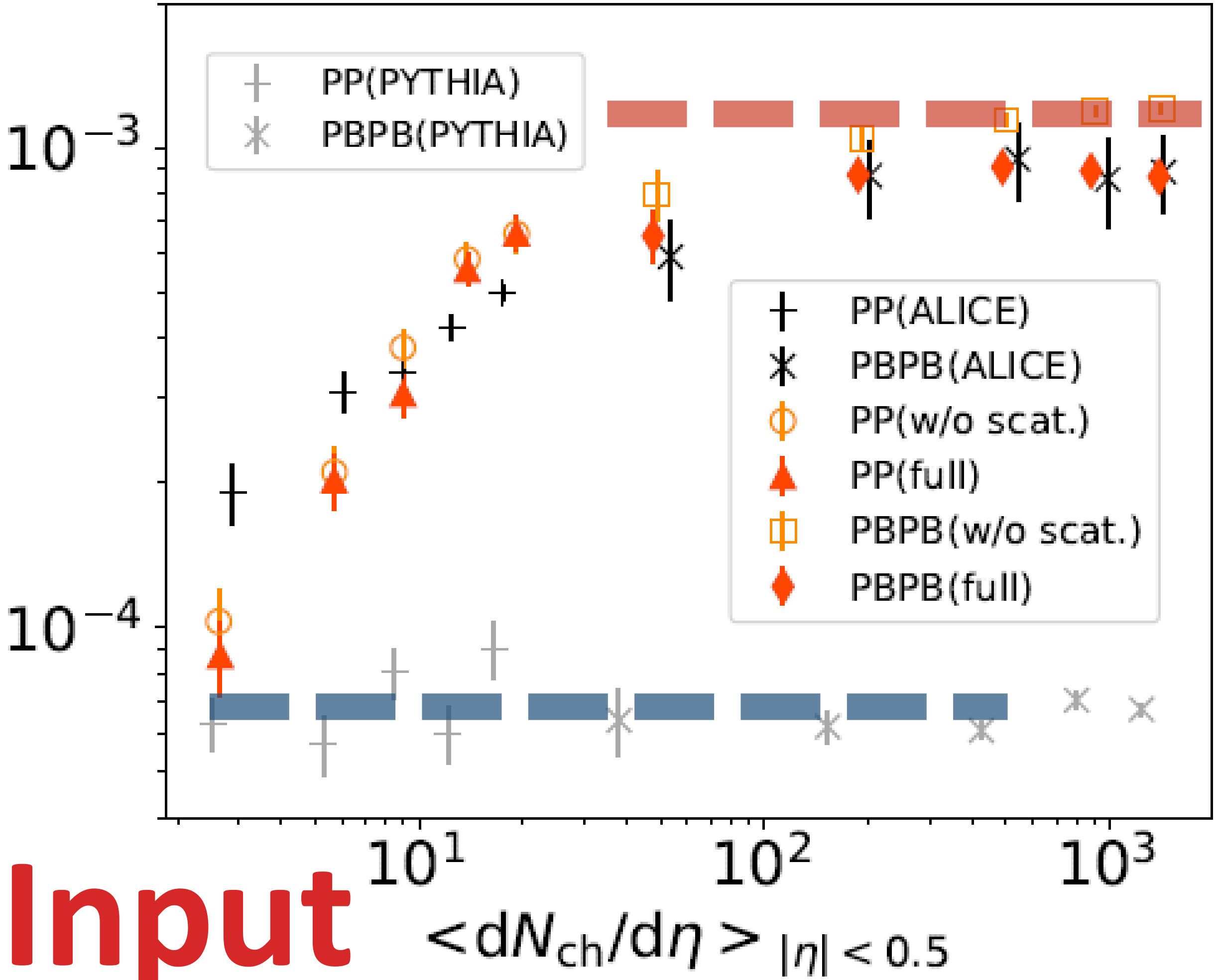
$x - \eta_s$ plane
($|y| < 0.5$)



Results from DCCI2

Parameter fit with Ω/π ratio from pp to PbPb

J. Adam *et al.*, (ALICE Collaboration), Nature Phys. 13 535-539 (2017)
B. Abelev *et al.* (ALICE Collaboration), Phys. Lett. B 728, 216-227 (2014); erratum 734, 409-410 (2014)



Input

Core (hydro): $T_{\mathrm{fo}} \sim 160$ MeV

Corona (string frag.): $\kappa \sim 1$ GeV/fm

➔ Constant particle ratios in each

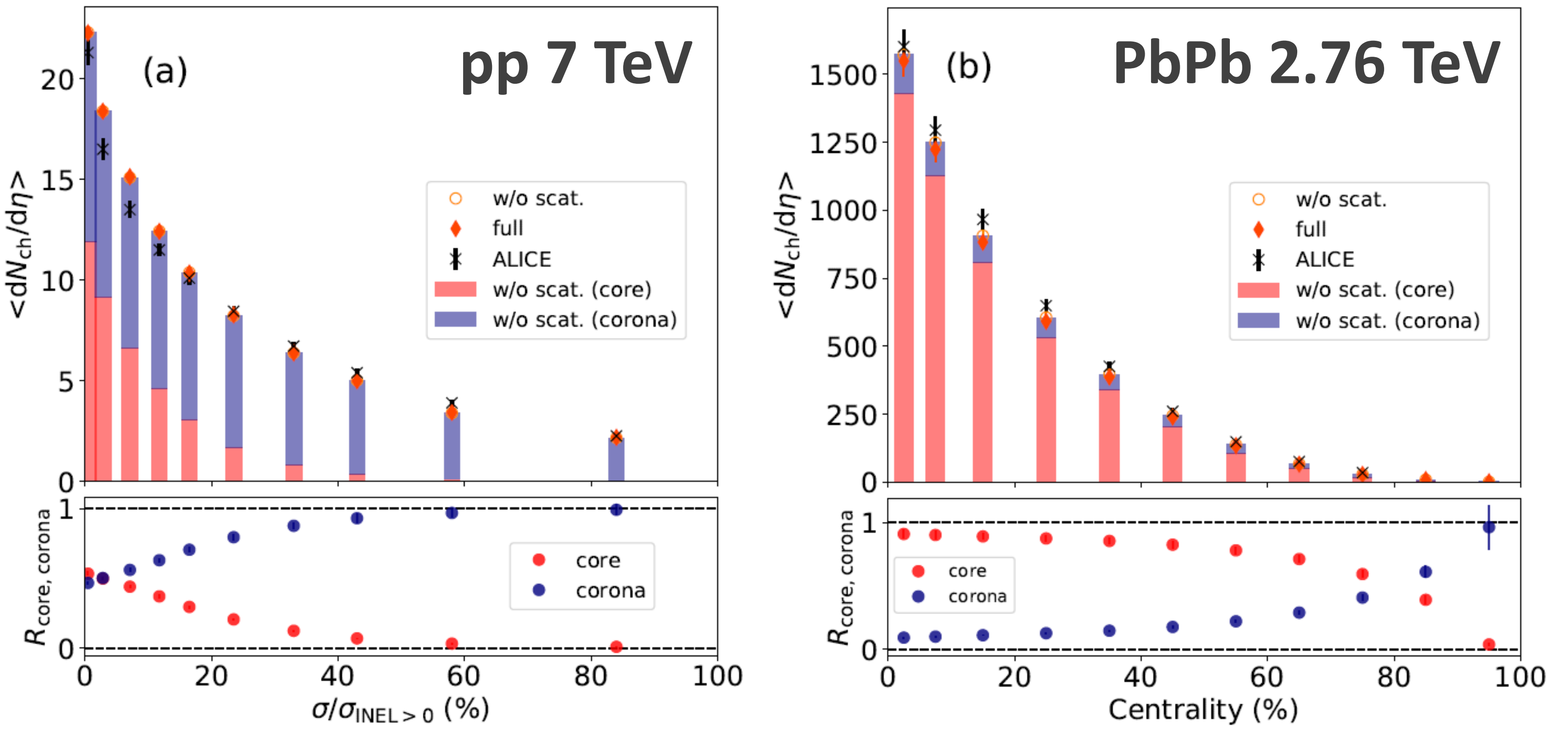
Partial QGP fluids are **forced to be generated**

➔ Description of strangeness enhancement from pp to PbPb

Starting point of our discussion!

Core/corona fraction vs. multiplicity/centrality class

J. Adam *et al.*, (ALICE Collaboration), Nature Phys. 13 535-539 (2017)



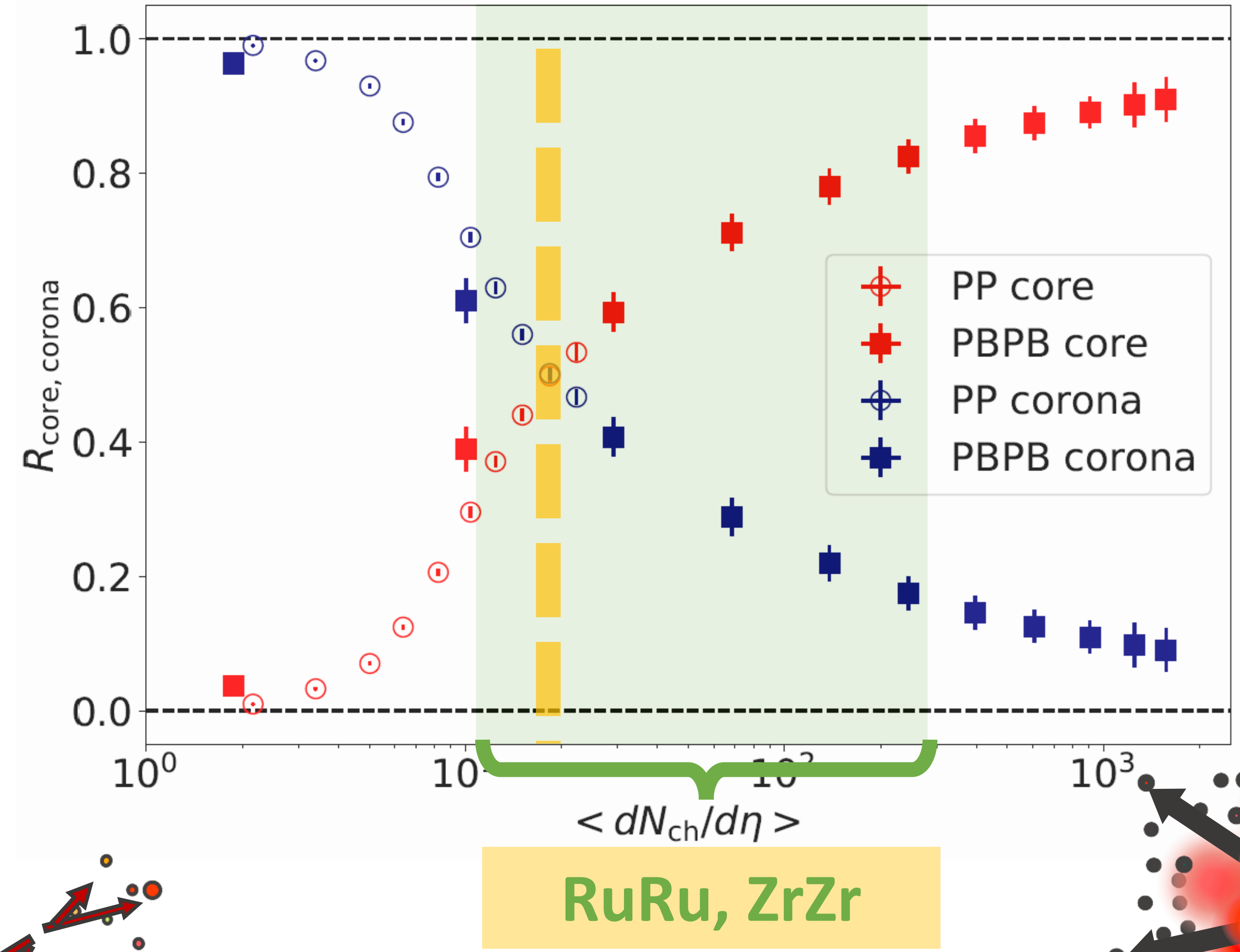
K. Aamodt *et al.*, (ALICE Collaboration), Phys. Rev. Lett. 106 032301 (2011)

pp: Excess of core contribution at the highest multiplicity class (0-0.95%)

PbPb: $\sim 20\%$ fraction of corona in intermediate central events (40-60%)

➔ Need both of core and corona in pp and AA!

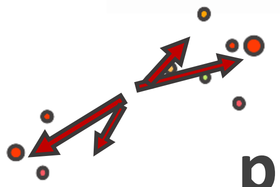
Fraction of core and corona vs. $\langle dN_{\mathrm{ch}}/d\eta \rangle$ from pp to PbPb

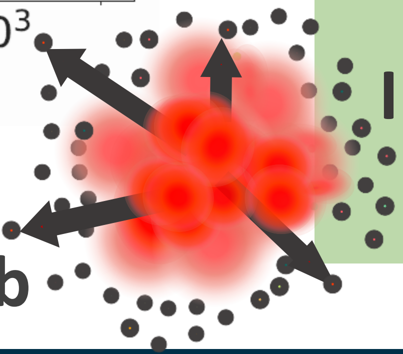


< 80% in centrality

STAR Collaboration, Phys.Rev.C 105 (2022) 1, 014901

B. Schenke *et al.*, Phys.Rev.C 102 (2020) 4, 044905





Clear scaling with multiplicity

Onset of core dominance at $\langle dN_{\mathrm{ch}}/d\eta \rangle \sim 18$

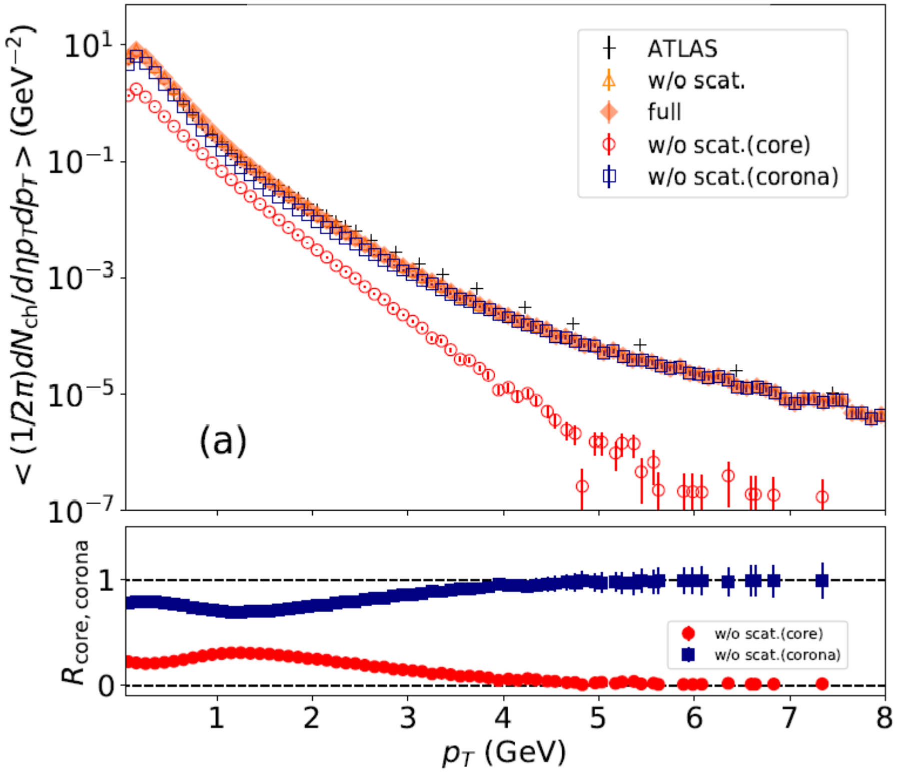
<u>RuRu, ZrZr</u>

- Covers the onset
- QGP fluids: $\sim 30-80\%$

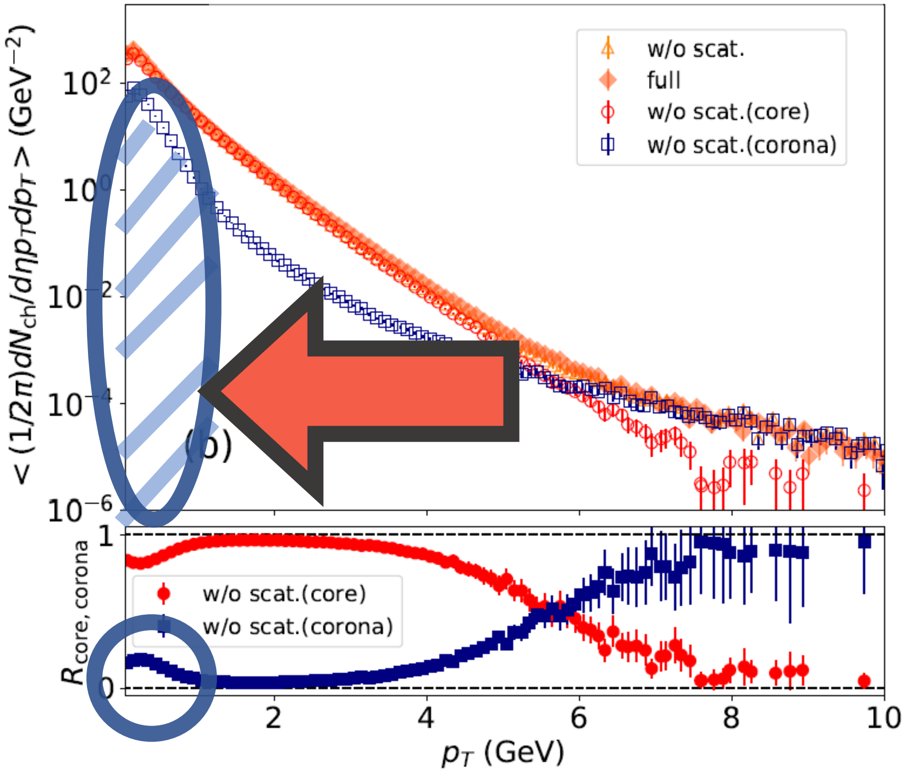
Important non-equilibrium (corona) contribution

Smooth description from low to high p_T

pp 7 TeV (MB)



PbPb 2.76 TeV (MB)



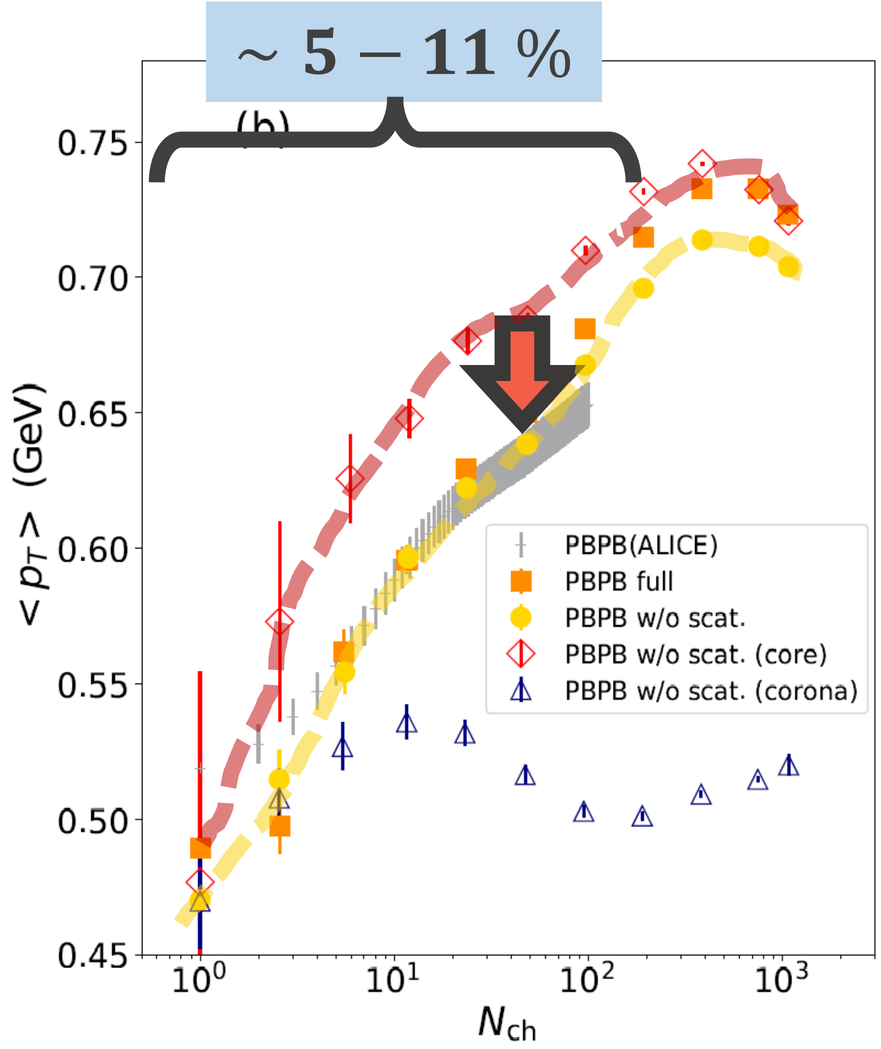
G. Aad *et al.*, (ATLAS Collaboration), New J. Phys. 13 053033 (2011)

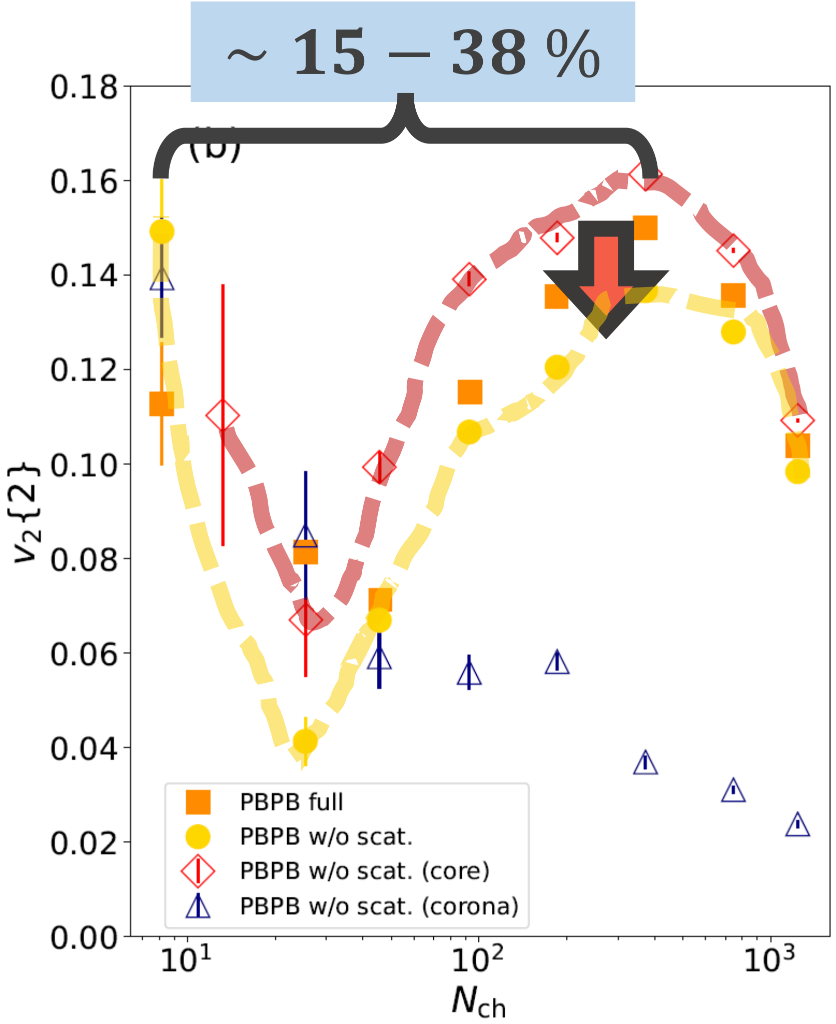
pp: Dominant corona contribution for all p_T range

PbPb: Dominant contribution flips at ~ 5.5 GeV

➔ Non-negligible corona contribution ($\sim 20\%$) at very low p_T (< 1 GeV)

Corona correction in PbPb





- Mean p_T and momentum anisotropy ➔ non-negligible effect of corona

- Pure hydro calculation can bring misinterpretation of exp. data even in PBPB

Why not for RuRu, ZrZr?

Summary

Dynamical core-corona initialization model (DCCI2)

- Respect beam energy (as a MC event generator)
- Both equilibrated and non-equilibrated matter

➔ From low to high p_T, from forward to backward, and from pp to AA

- Onset of core dominance, $\langle dN_{\rm ch}/d\eta \rangle \sim 18$
- Non-negligible corona correction even in PbPb

  ➔ Corona dilutes $\langle p_T \rangle$ by $\sim 5-11\%$ and $v_2\{2\}$ by $\sim 15-38\%$.

RuRu, ZrZr?

Core (QGP fluids) component in midrapidity: $\sim 30-80\%$

Extraction of nuclear structure from isobar collisions

➔ non-equilibrium (corona) contribution is necessary

Thank you!