Hadron chemistry from dynamical core-corona initialization

Y. Kanakubo, Y. Tachibana, T. Hirano, arXiv:1910.10556 [nucl-th]
Y. Kanakubo, M. Okai, Y. Tachibana, T. Hirano, PTEP 2018 (2018) no.12, 121D01

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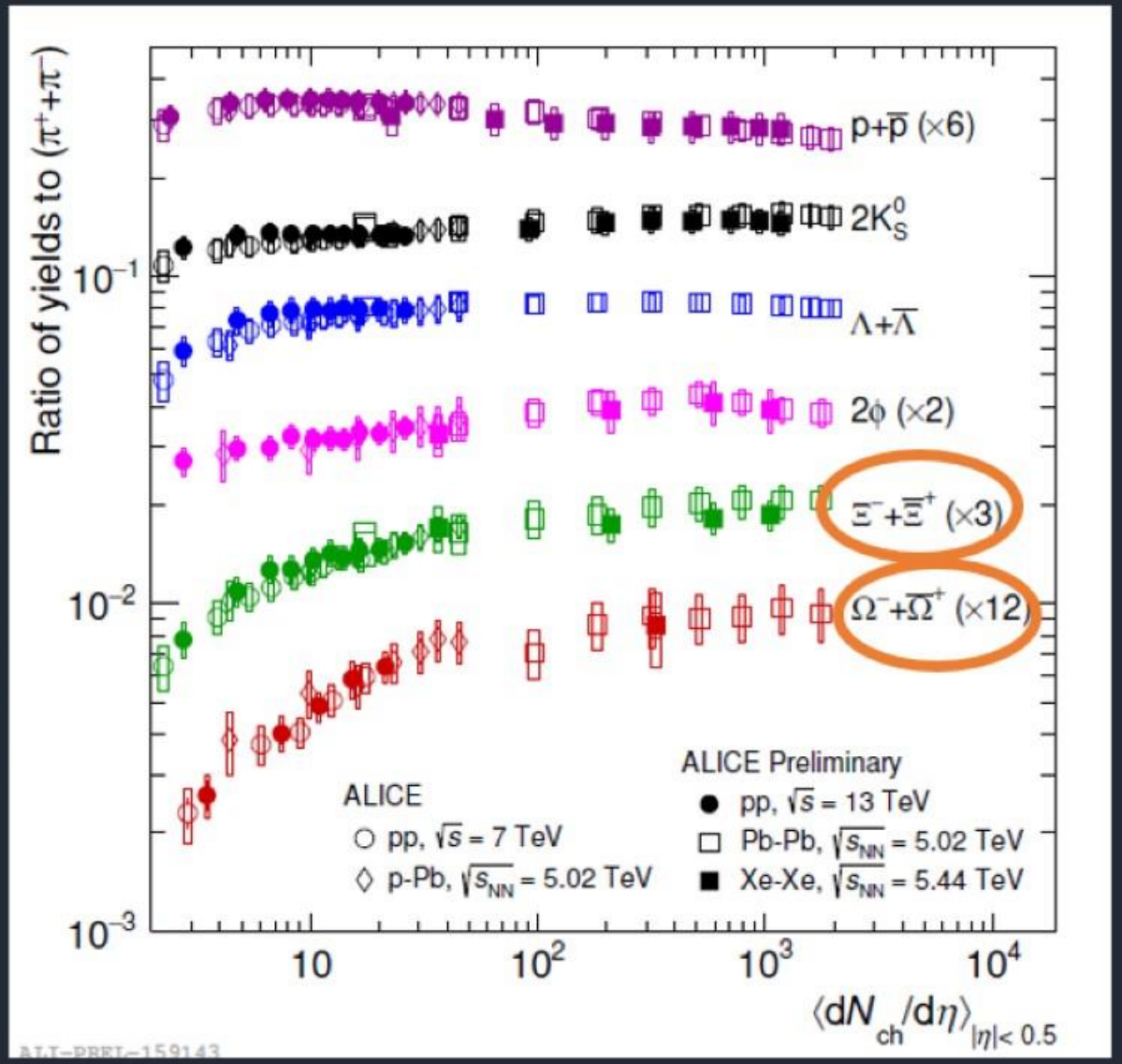
Yasuki Tachibana[2] and Tetsufumi Hirano[1]

Sophia University[1], Wayne State University[2]

Strangeness enhancement in small systems



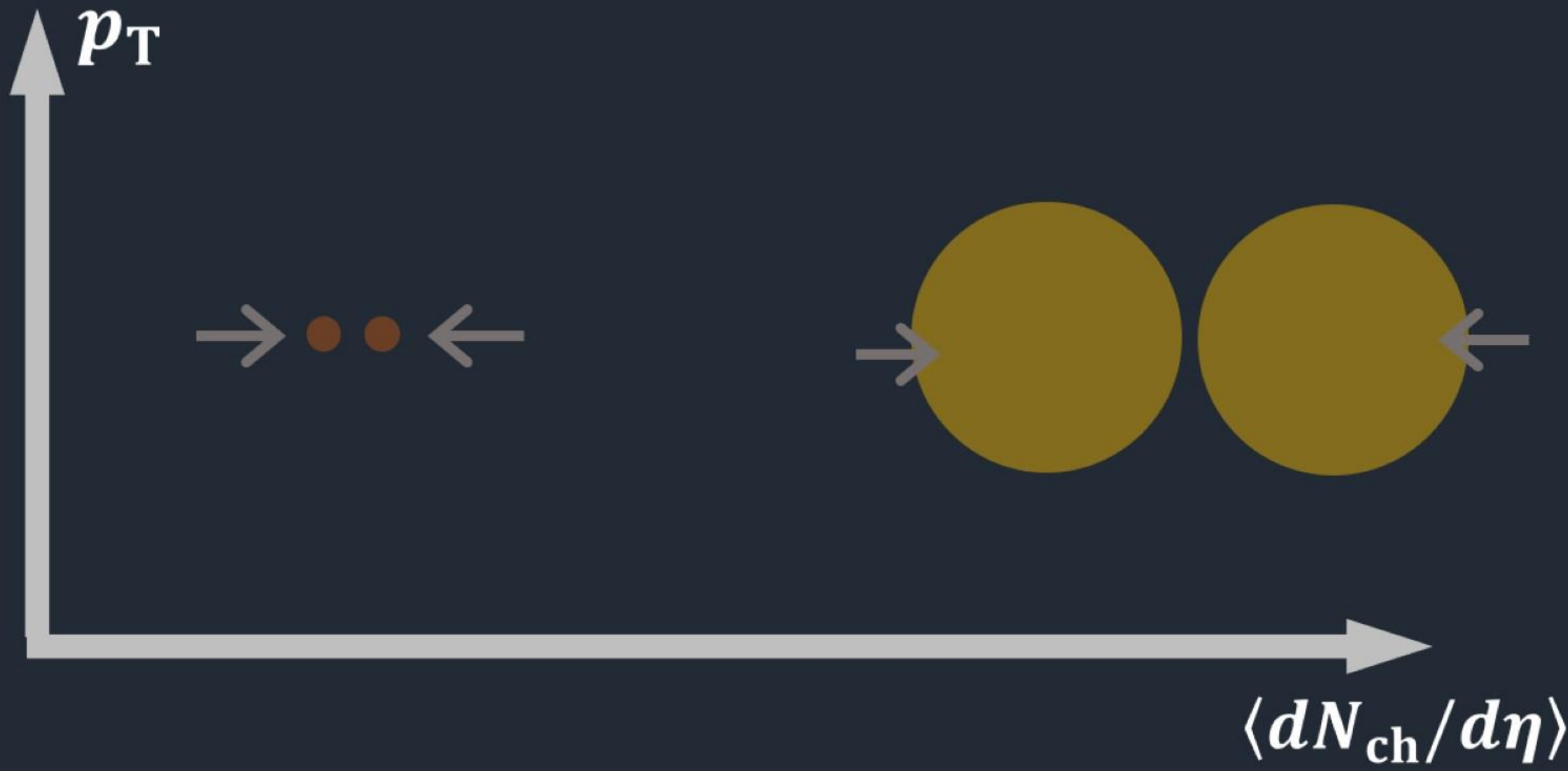
ALICE overview, talk at QM2018

Rapid enhancement of multi-strange hadron yield ratio in small systems

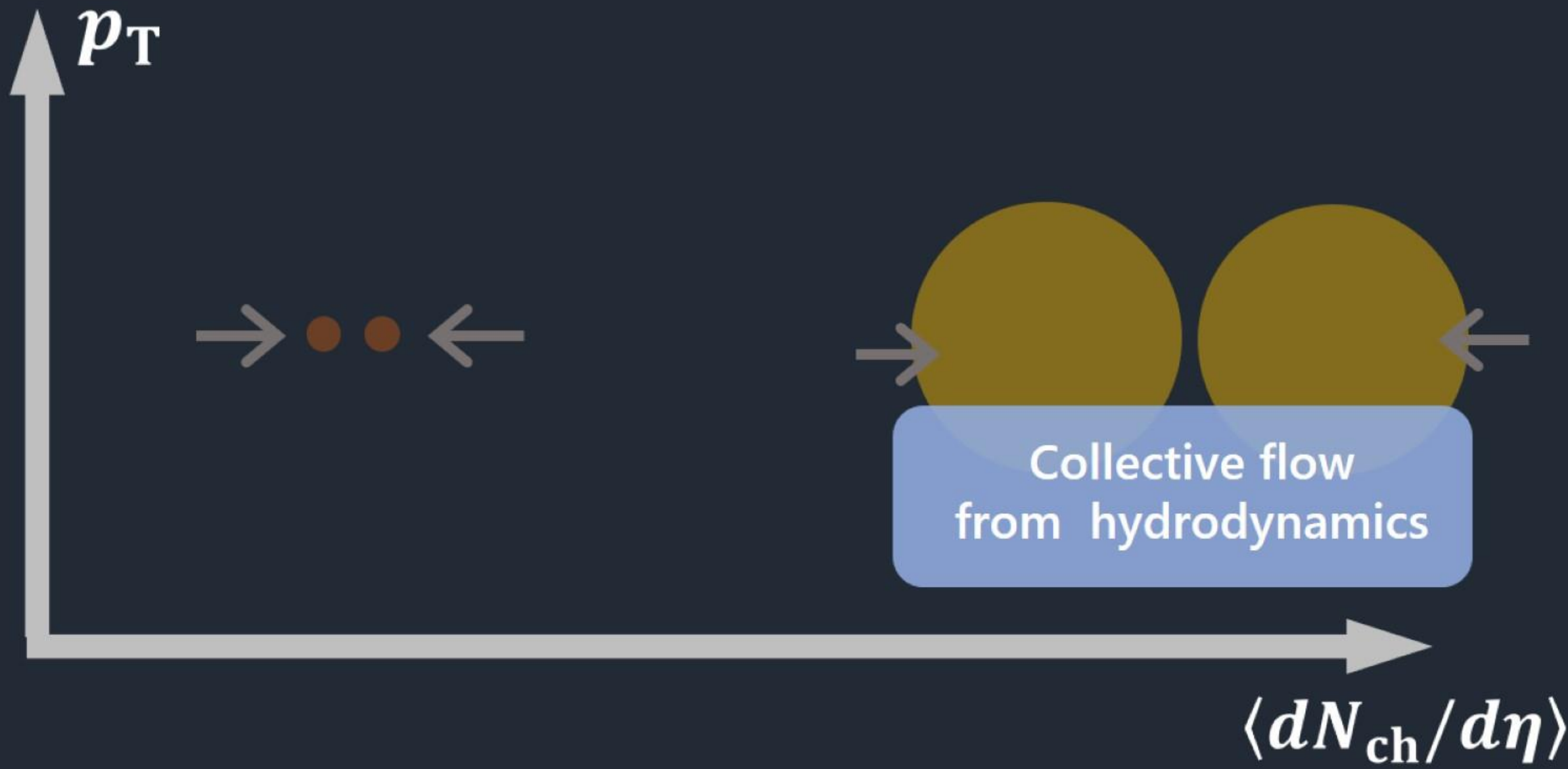
Indication of QGP formation in small systems

Continuous change of the description ?

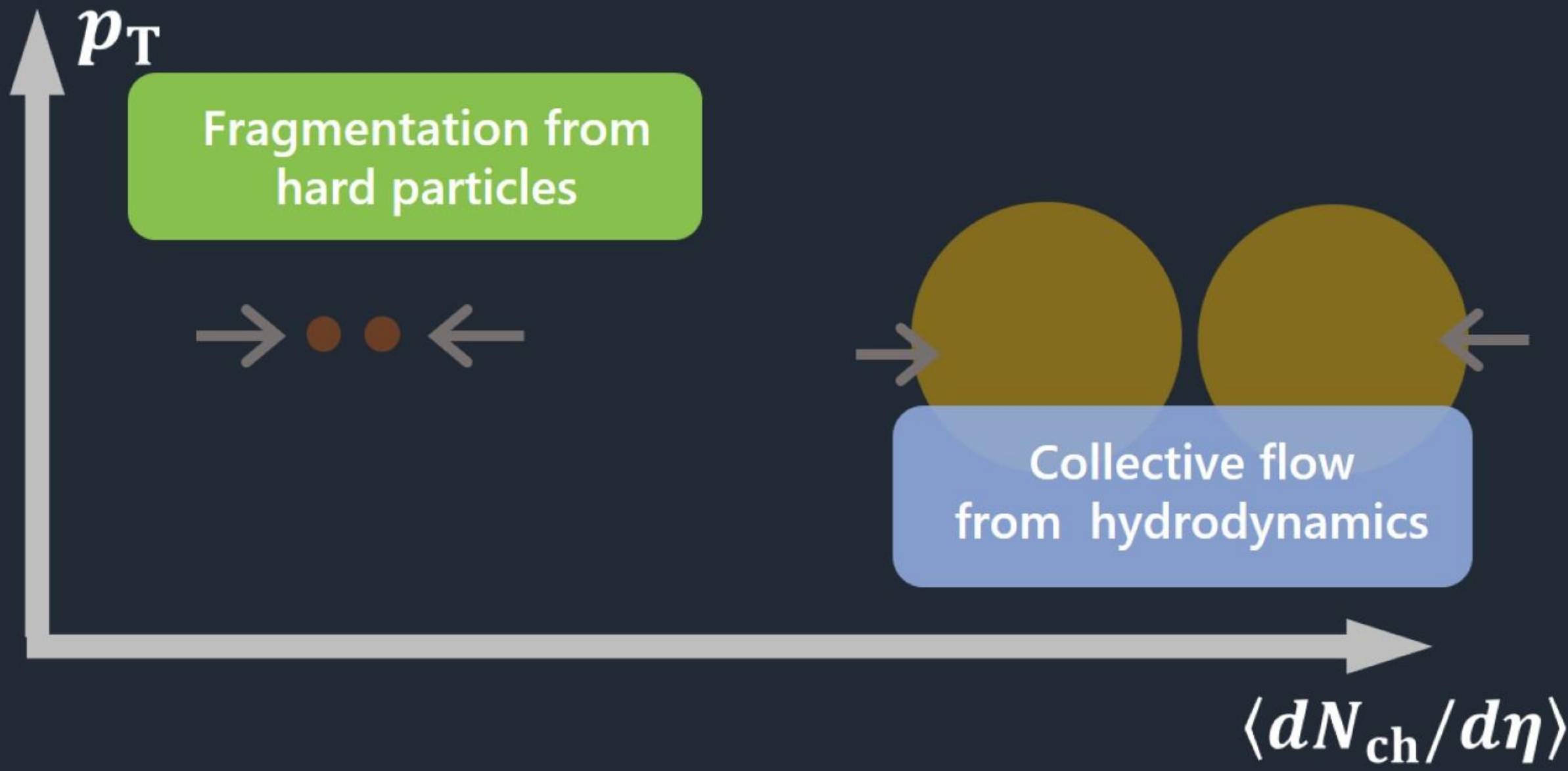
Towards a unified description



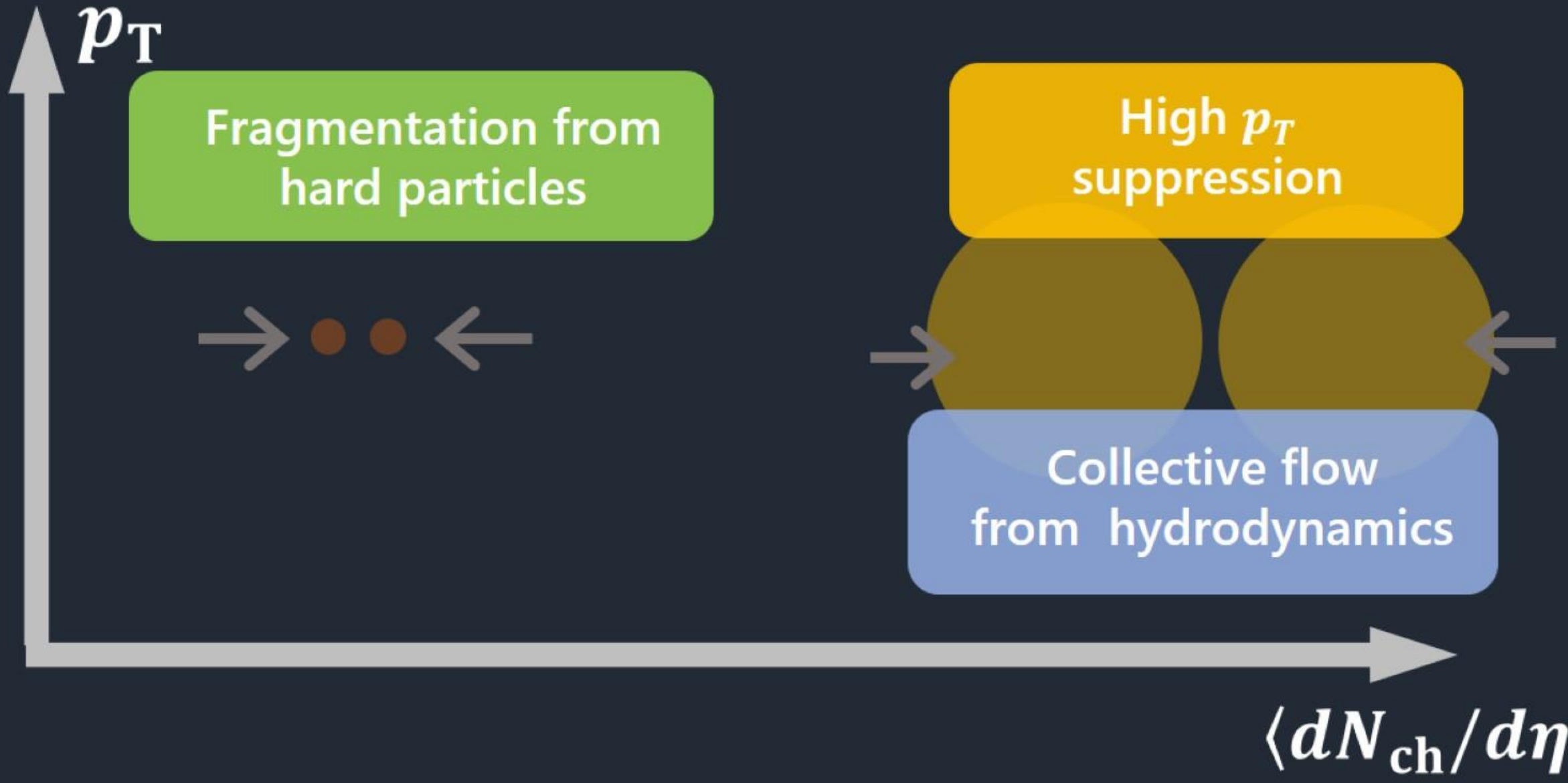
Towards a unified description



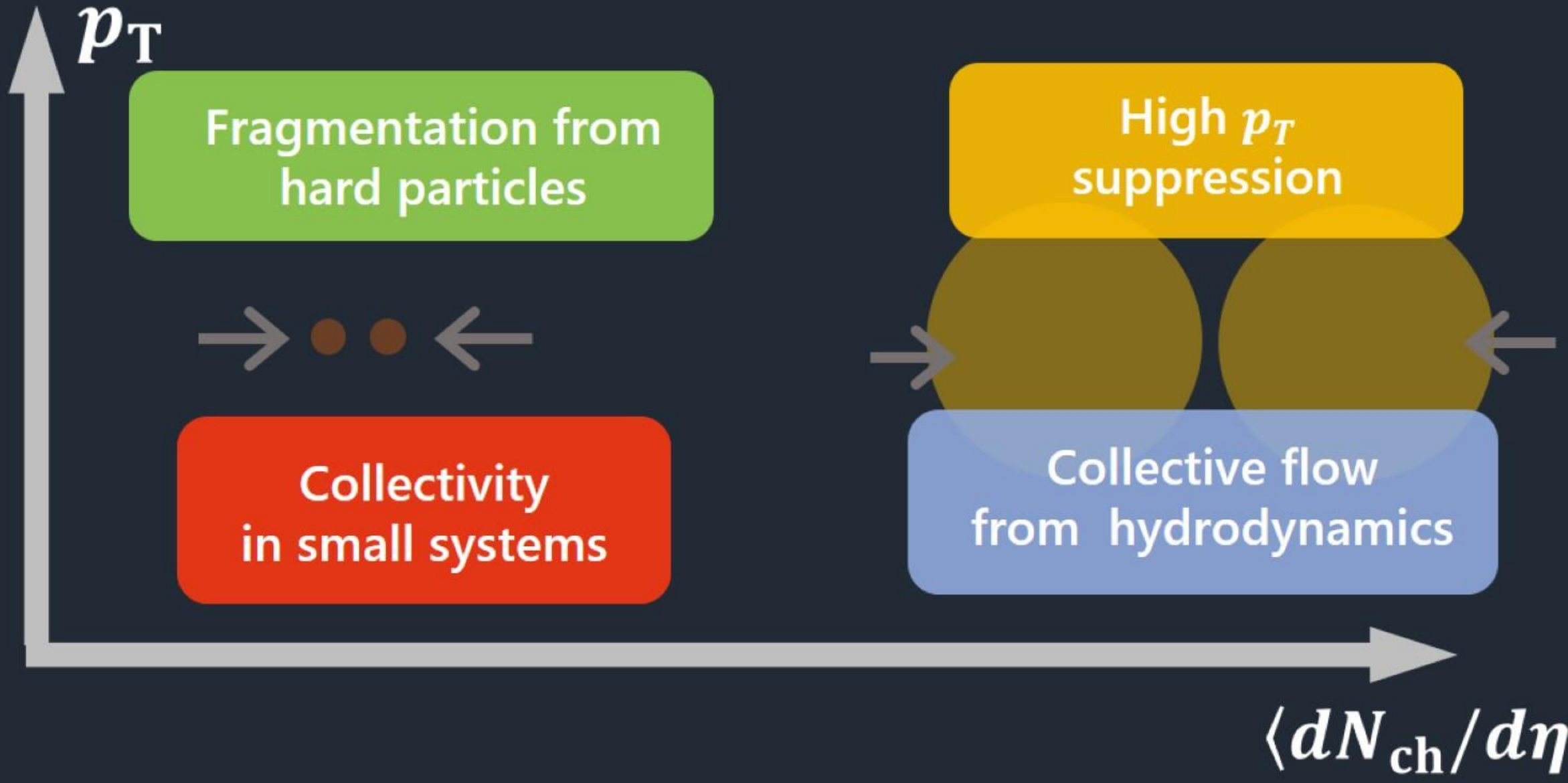
Towards a unified description



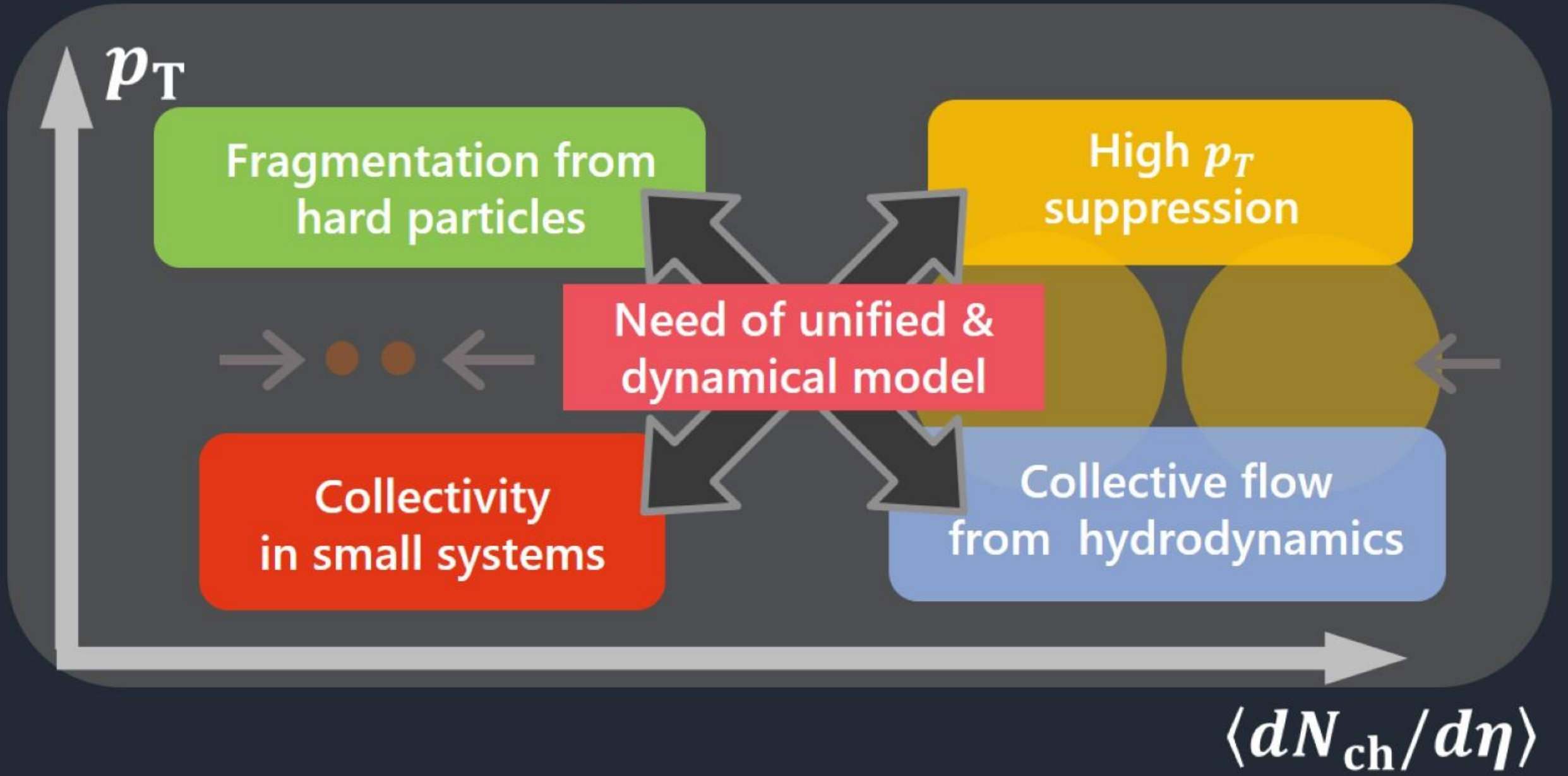
Towards a unified description



Towards a unified description



Towards a unified description

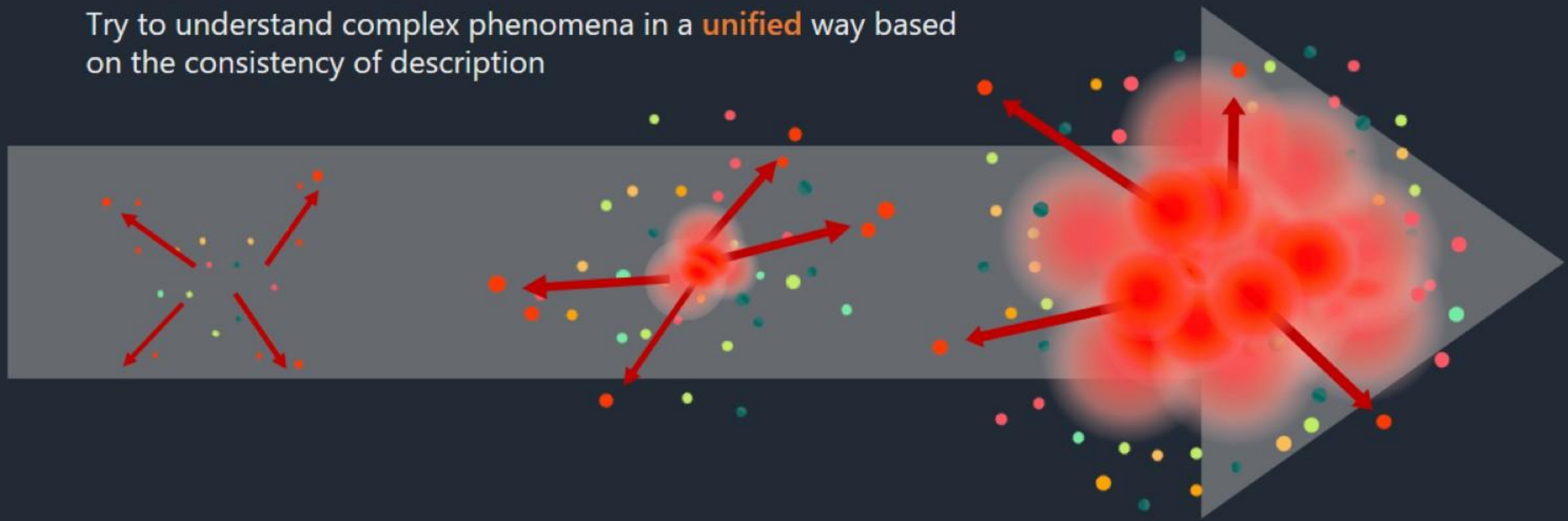


Motivation

Dynamical core-corona initialization model

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]
Y. Kanakubo, *et al.*, PTEP 2018 (2018) no.12, 121D01

Try to understand complex phenomena in a **unified** way based on the consistency of description



Current goal: To reveal the detail of QGP signals in small system
→ Have the same origin as ones observed in heavy-ion collisions?

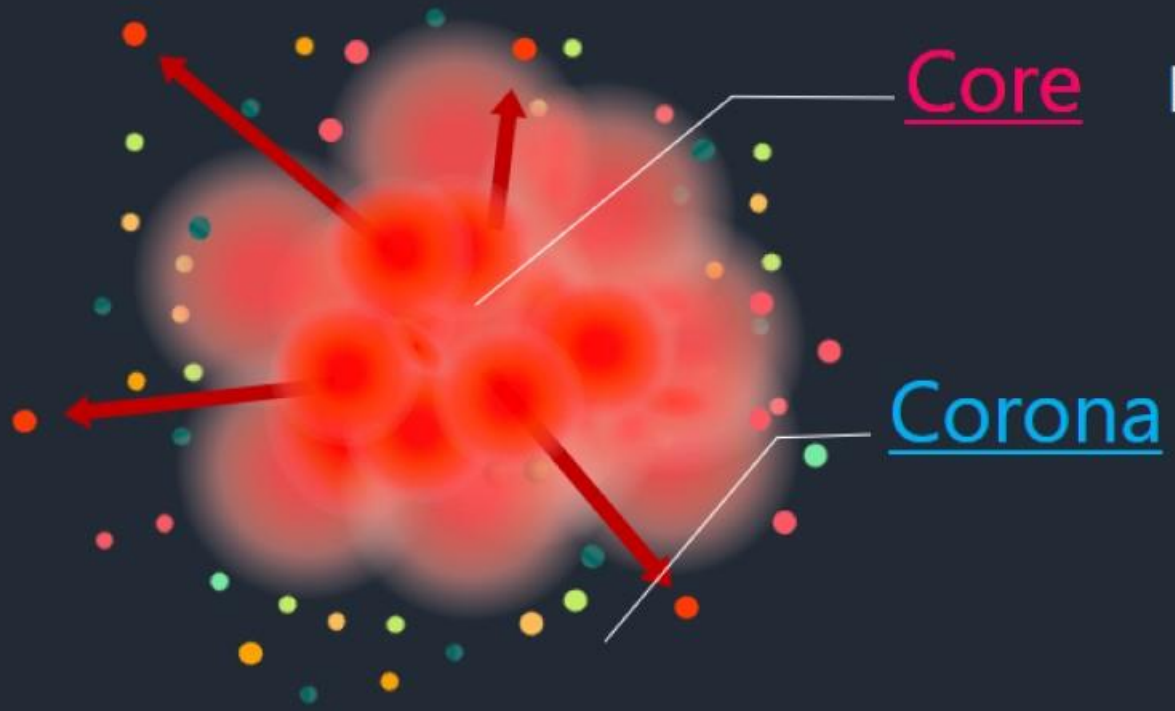
Core-corona picture

P. Bozek, Acta Phys. Polon. B36, 3071 (2005), K. Werner Phys. Rev. Lett. 98, 152301 (2007)

Our framework: Two-component model (QGP fluids + partons)

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]
Y. Kanakubo, *et al.*, PTEP 2018 (2018) no.12, 121D01

Initial parton geometry → separation of the system



Core

Enough secondary scatterings among partons
→ QGP (locally equilibrated)
→ Hadronization from QGP

Corona

Stay unscathed in few secondary scatterings
→ Partons (non-equilibrated)
→ String fragmentation

Dynamical initialization

M. Okai *et al.*, Phys. Rev. C 95, 054914 (2017)

Energy & momentum conservation → Continuum eq. for QGP+parton

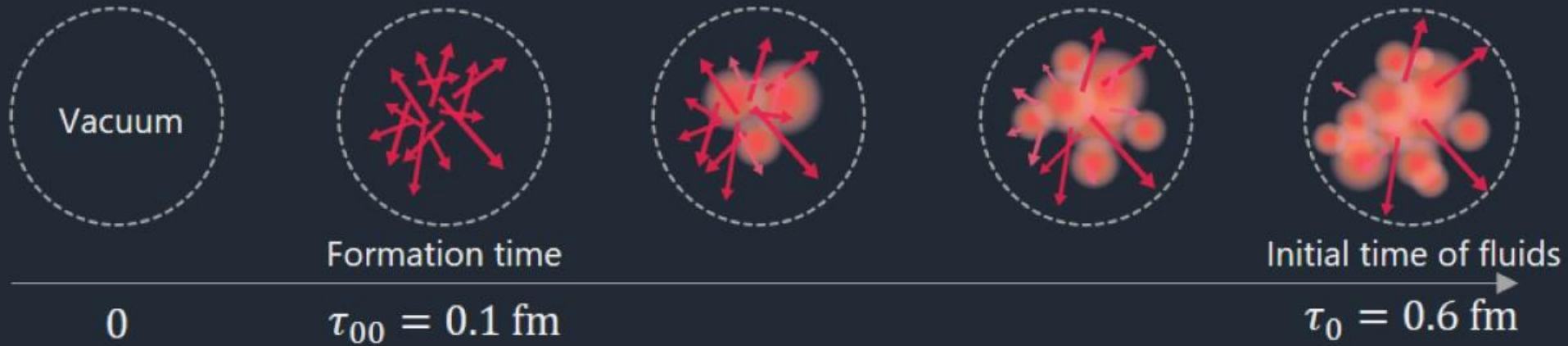
$$\partial_\mu \left(T^{\mu\nu}_{\mathrm{QGP}} + T^{\mu\nu}_{\mathrm{parton}} \right) = 0$$

p_i^μ: Four-momentum of the i^{th} parton

G: Gaussian function

Hydrodynamic eq. with source term:

$$\partial_\mu T^{\mu\nu}_{\mathrm{QGP}} = J^\nu , \qquad J^\nu = -\partial_\mu T^{\mu\nu}_{\mathrm{parton}} = -\sum_i \frac{dp_i{}^\nu(t)}{dt} G\big(\boldsymbol{x} - \boldsymbol{x}_i(t)\big)$$



4-momentum deposition from initial partons → Dynamical formation of initial condition

Dynamical core-corona initialization

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]
Y. Kanakubo, *et al.*, PTEP 2018 (2018) no.12, 121D01

$$J^{\nu} = -\sum_i \frac{dp_i{}^{\nu}(t)}{dt} G\big(\boldsymbol{x} - \boldsymbol{x}_i(t)\big)$$

New

4-momentum deposition based on core-corona picture

[Assumption] High density → Secondary scatterings → Local thermal equilibrium

$$\frac{dp_i{}^{\mu}(t)}{dt} \to -a_0 \frac{\rho_i\big(\boldsymbol{x}_i(t)\big)}{|\boldsymbol{p}_i|^2(t)} p_i{}^{\mu}(t)$$

a_0: Free parameter

ρ_i: Density of partons

$$\rho_i(\boldsymbol{x}) = \sum_{j \neq i} G\left(\boldsymbol{x} - \boldsymbol{x}_j(t)\right)$$

Vacuum

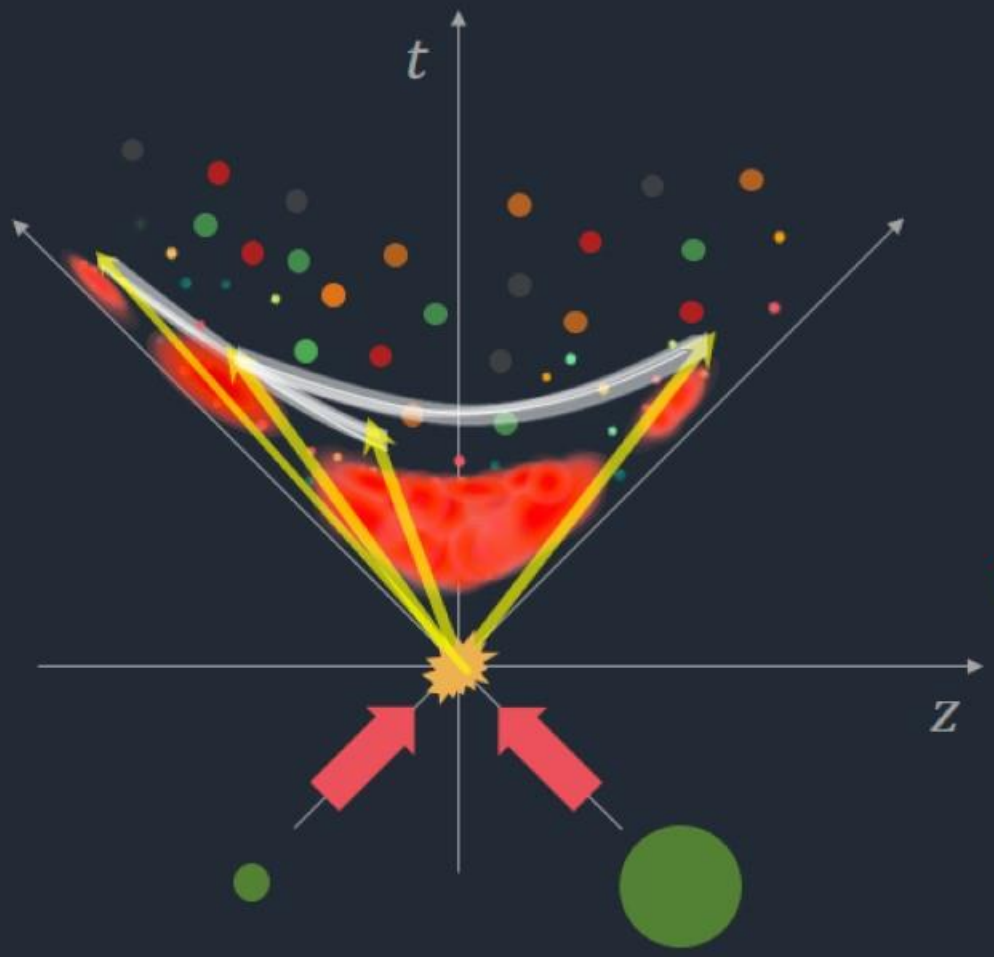
Partons

$J_i^{\mu} \propto \rho_i$

QGP fluids (core)

Surviving partons (corona)

Model



Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]
Y. Kanakubo, *et al.*, PTEP 2018 (2018) no.12, 121D01

Hadronization (particlization)

Core → Hadron distribution via
Cooper-Frye formula ($T_{\mathrm{fo}} = 160$ MeV)
F. Cooper and G. Frye, Phys. Rev. **D10**, 186 (1974).

+ Resonance correction
A. Andronic *et al.*, Nature 561 (2018) no.7723, 321-330 (2017).

Corona → String fragmentation (PYTHIA)

Evolution of QGP fluids

New **Dynamical core-corona initialization**

(3+1)-D ideal hydro, Lattice EoS (2+1 flavor)
Y. Tachibana and T. Hirano, Nucl. Phys. A904-905 (2013)
S. Borsanyi *et al.*, Phys. Lett. **B730**, 155 (2014).

Parton generation

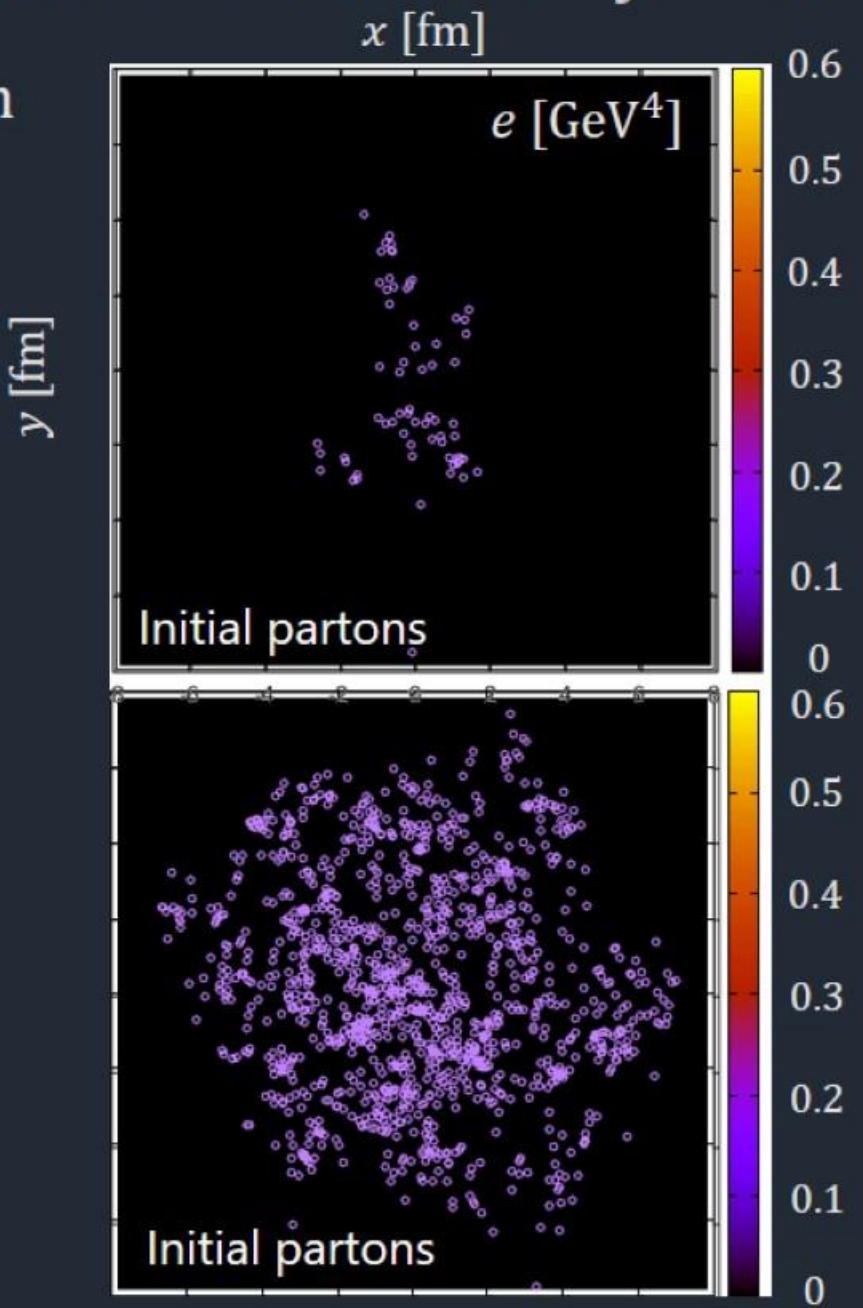
PYTHIA ver 8.230 (HadronLevel:all= off)
T. Sjöstrand *et al.*, Comput. Phys. Commun. 191, 159 (2015).
C. Bierlich *et al.*, JHEP 1610 (2016) 139.

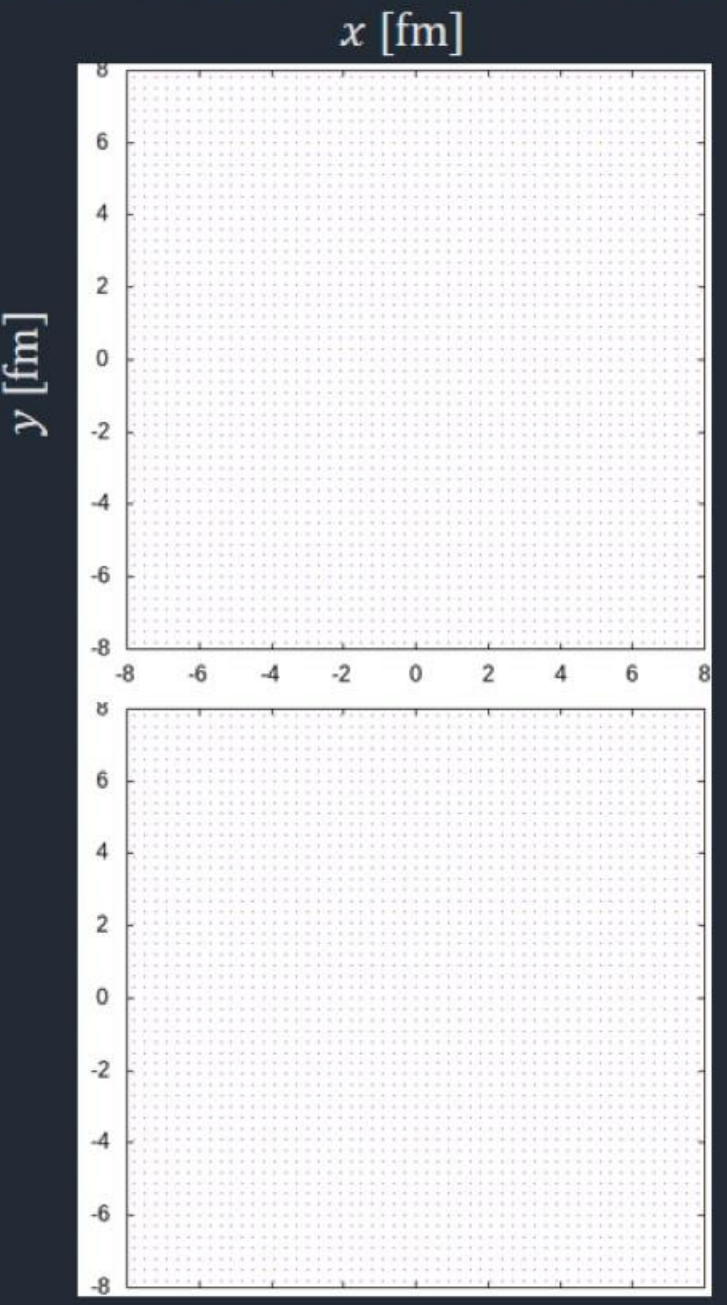
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.10$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





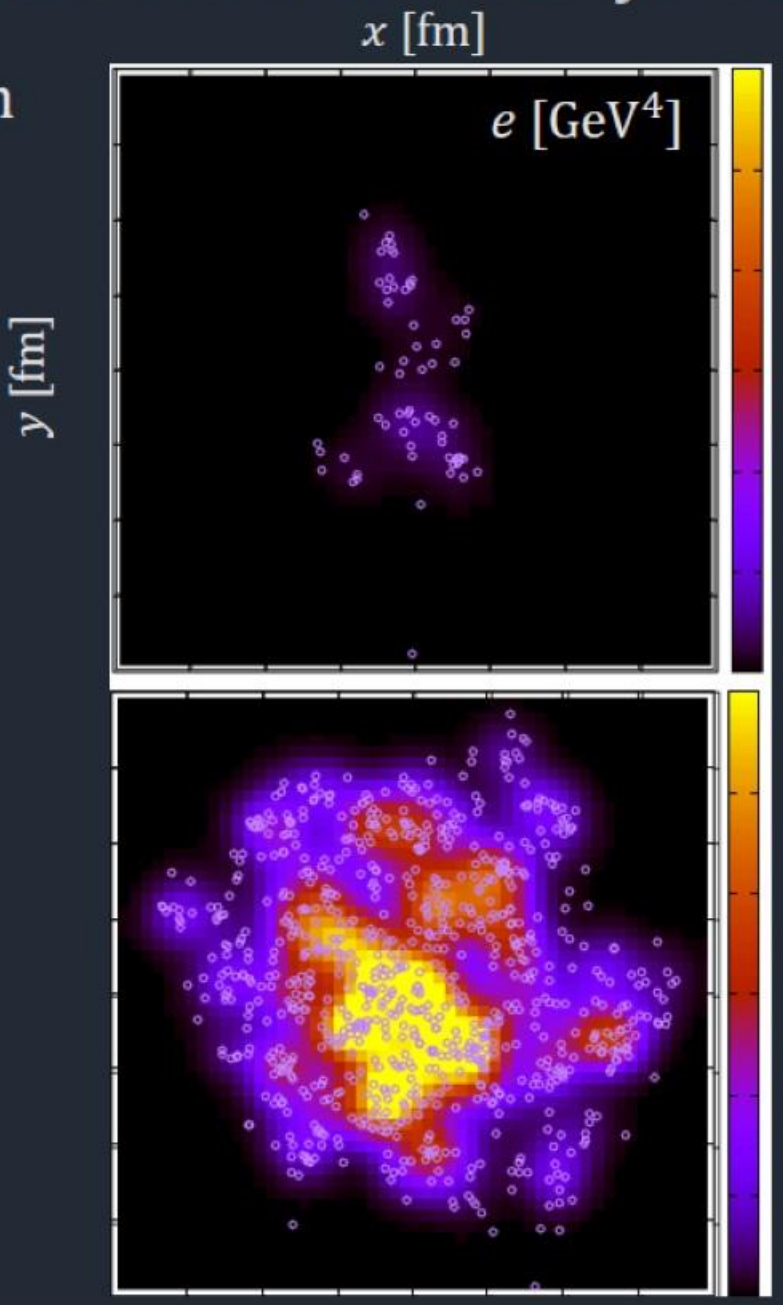
$v_\perp$

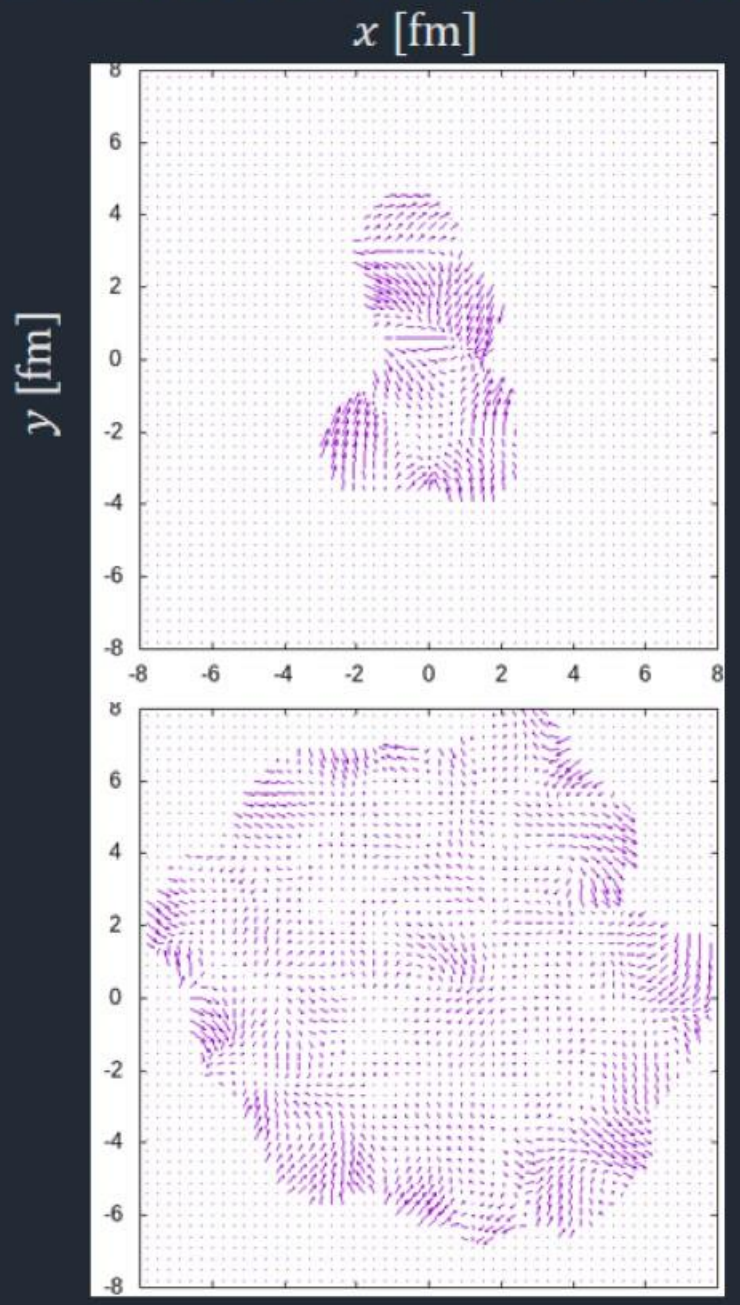
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.11$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





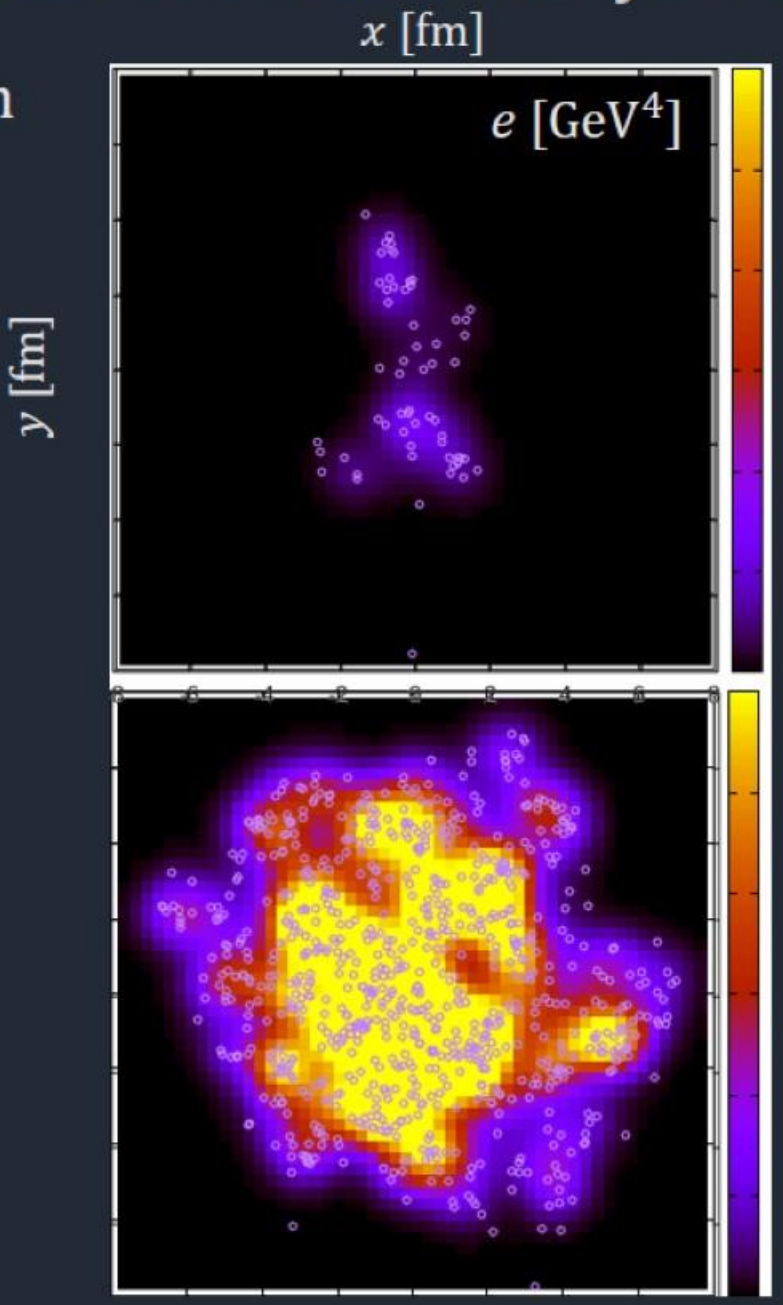
$v_\perp$

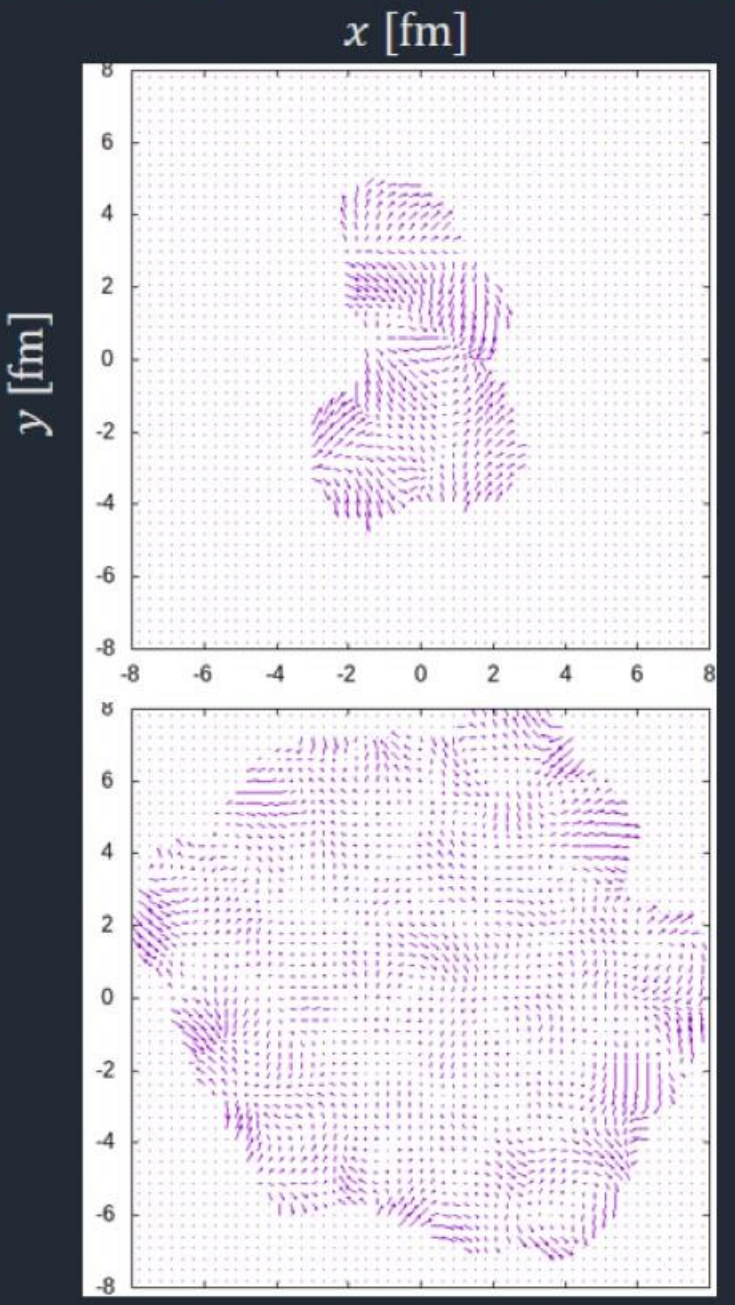
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.12$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central



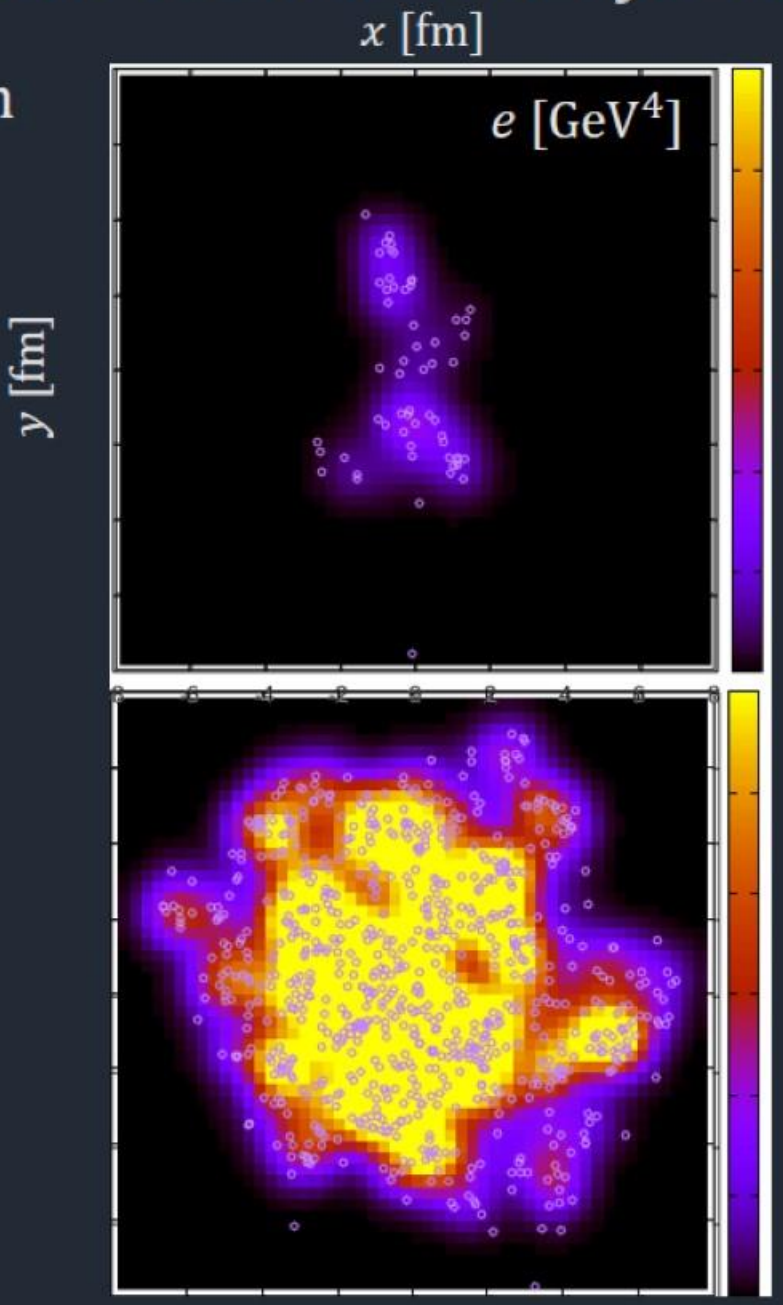


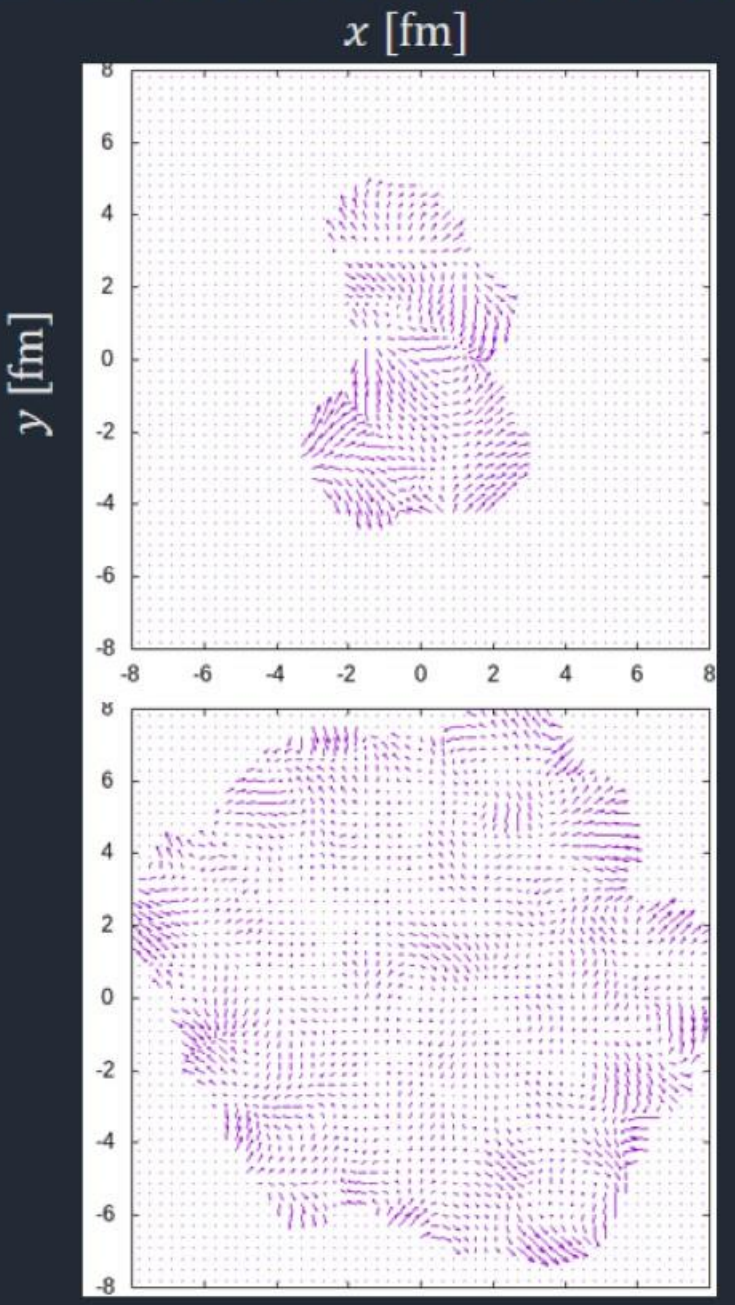
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.13$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central



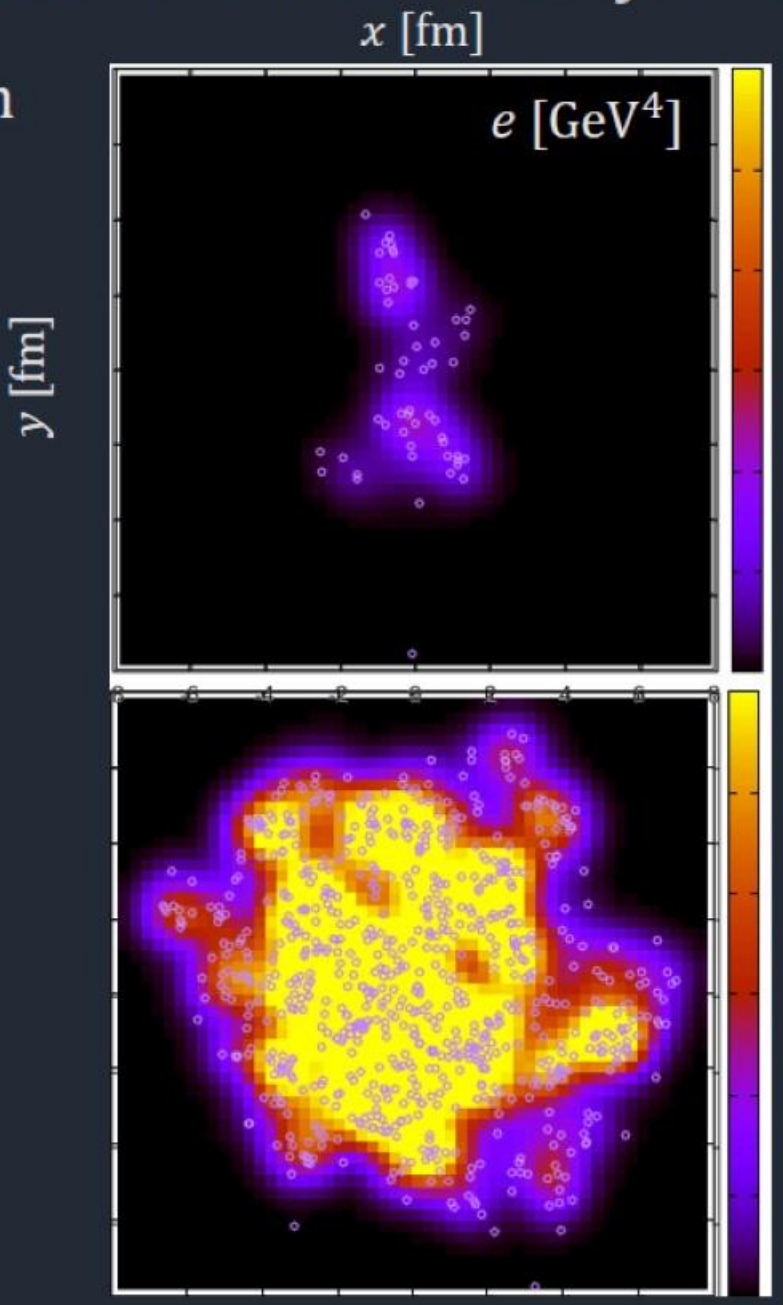


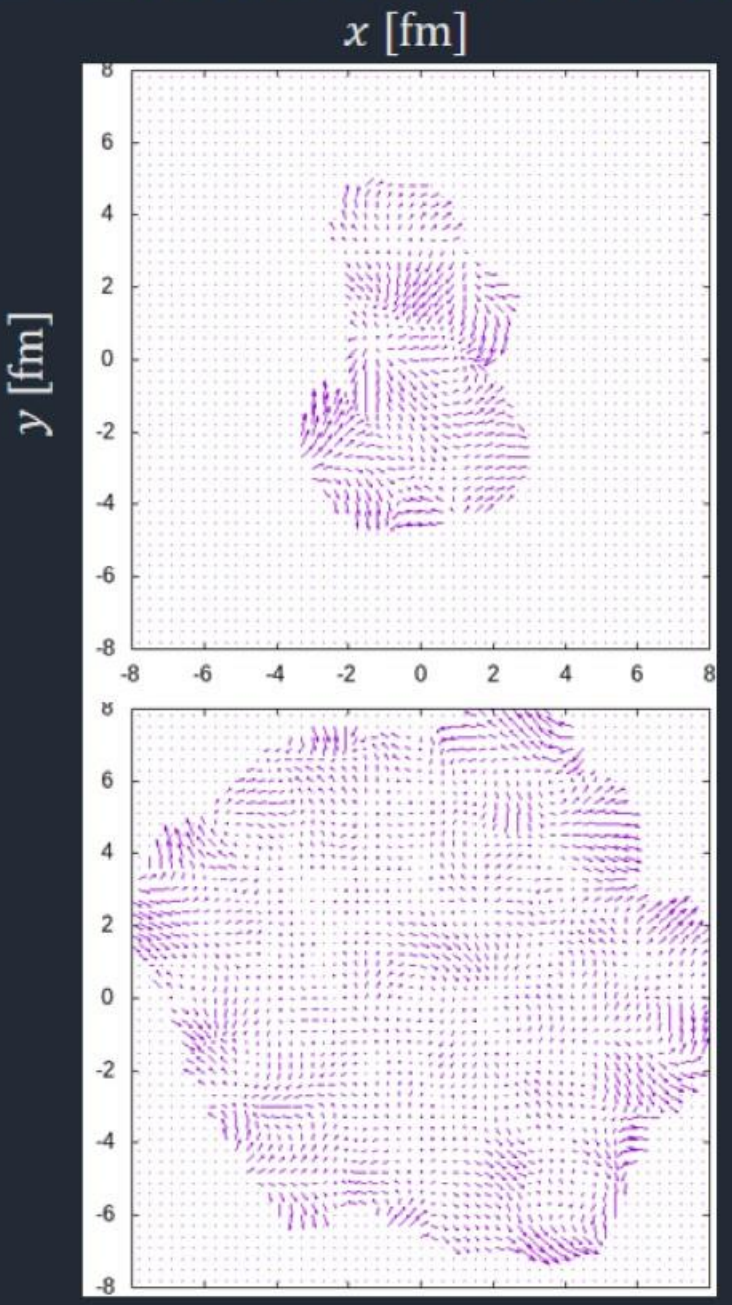
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.14$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





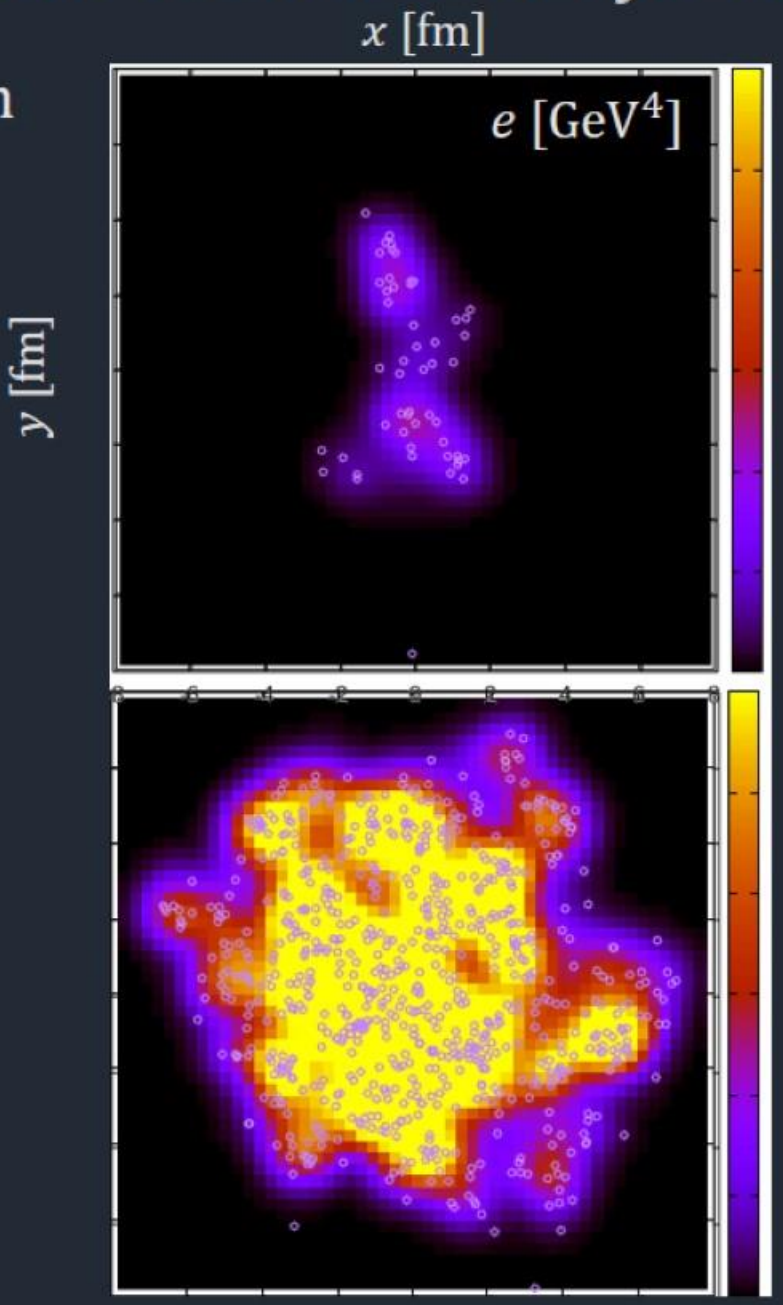
$v_\perp$

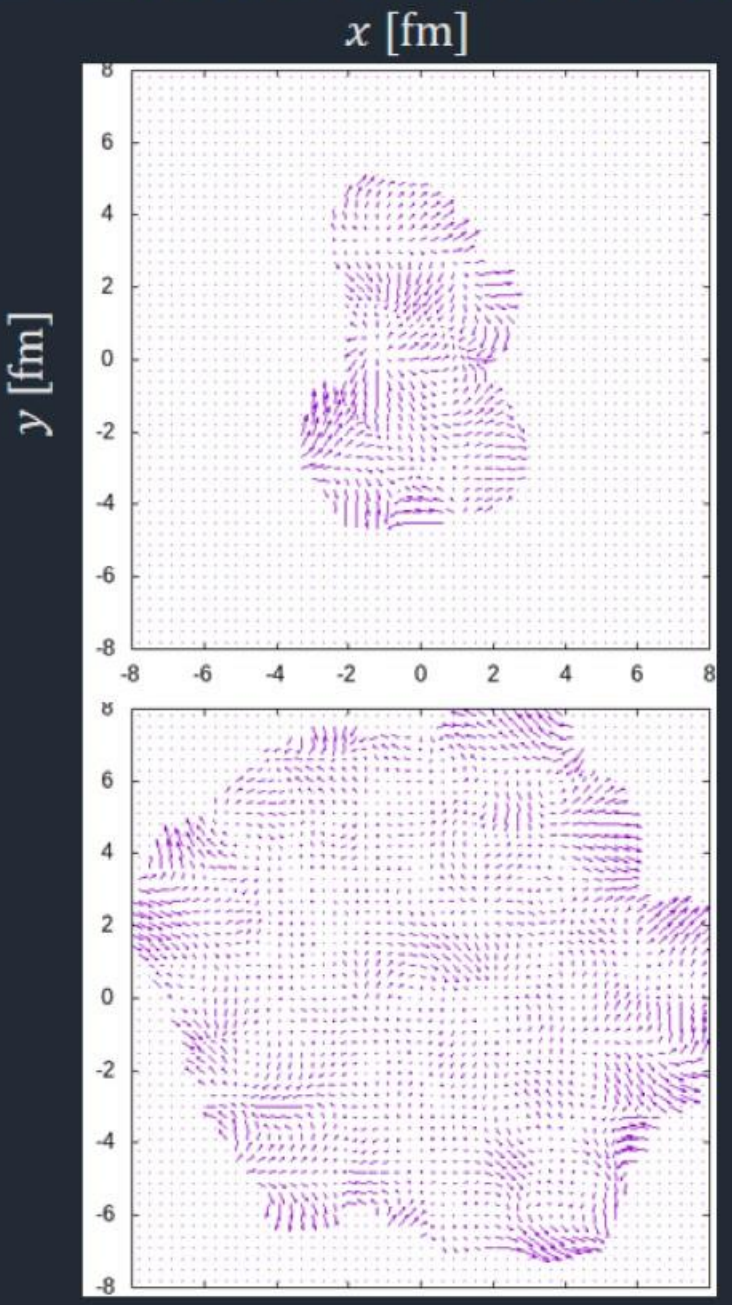
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.15$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





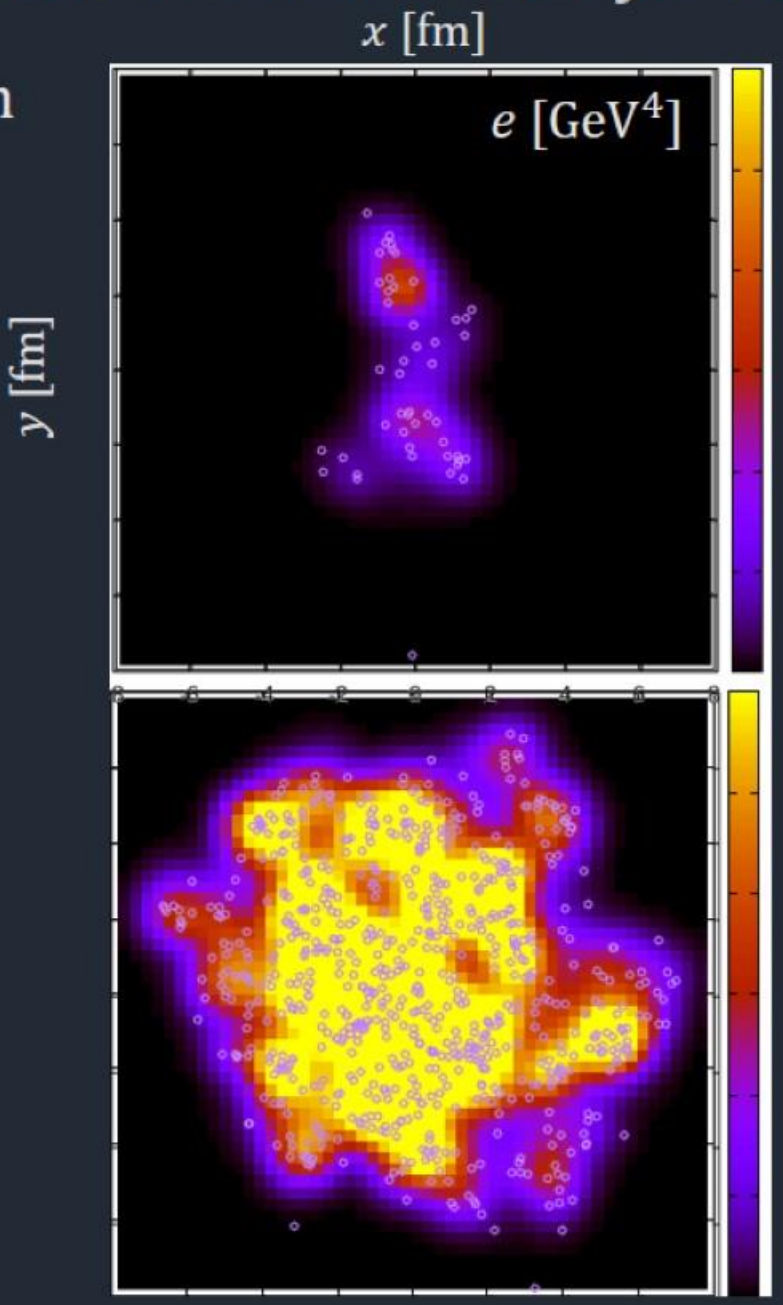
$v_\perp$

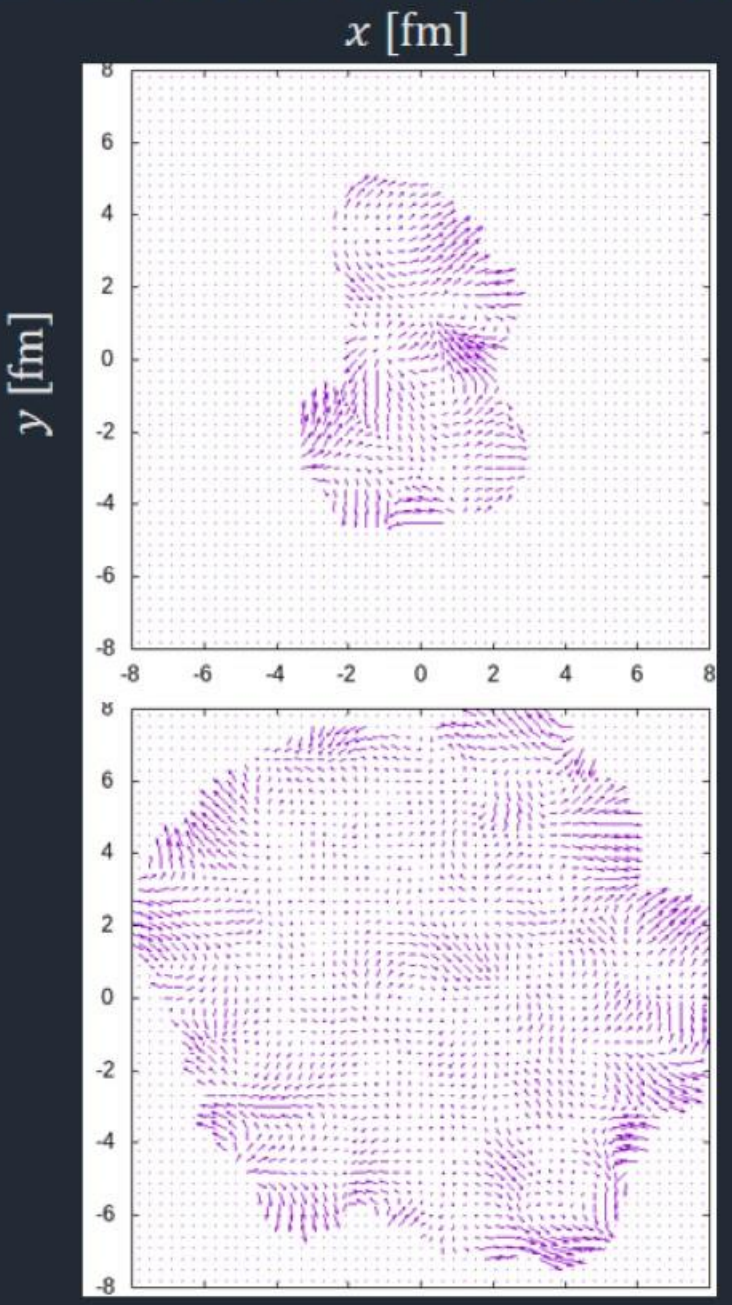
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.16$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





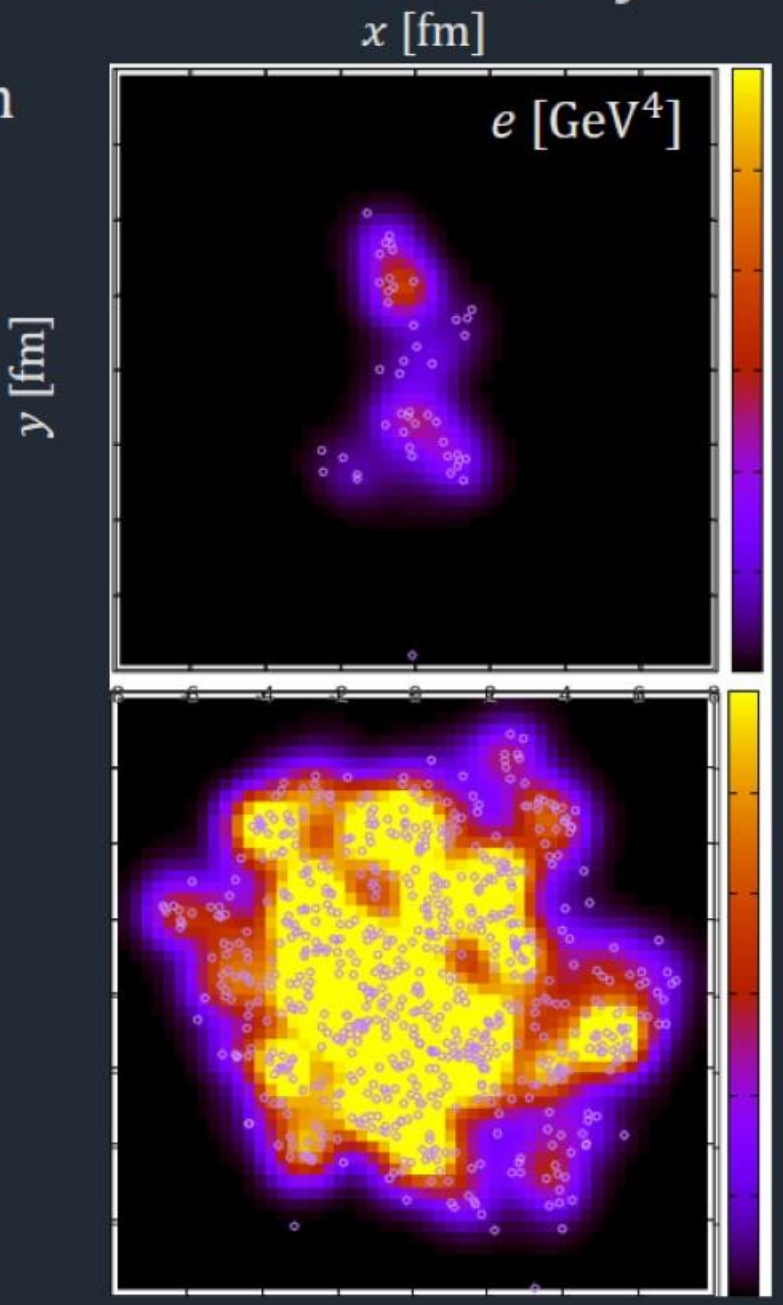
$v_\perp$

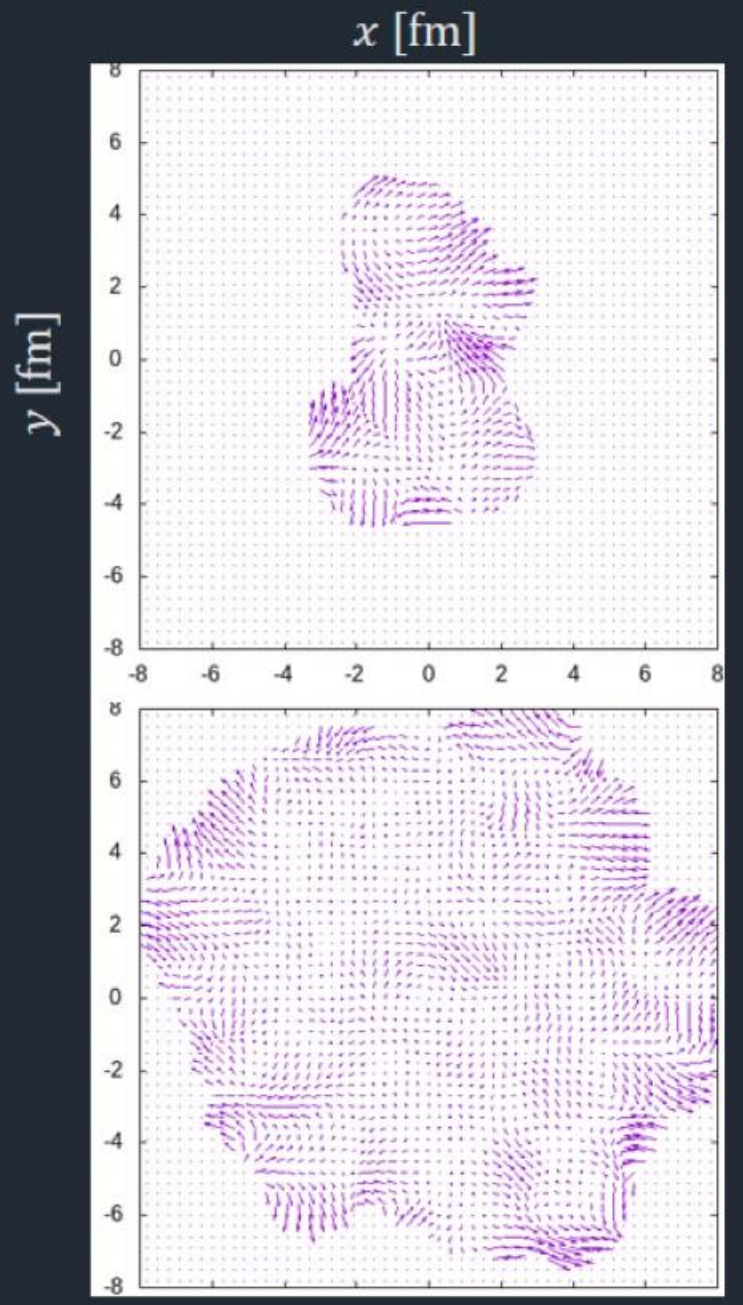
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.17$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





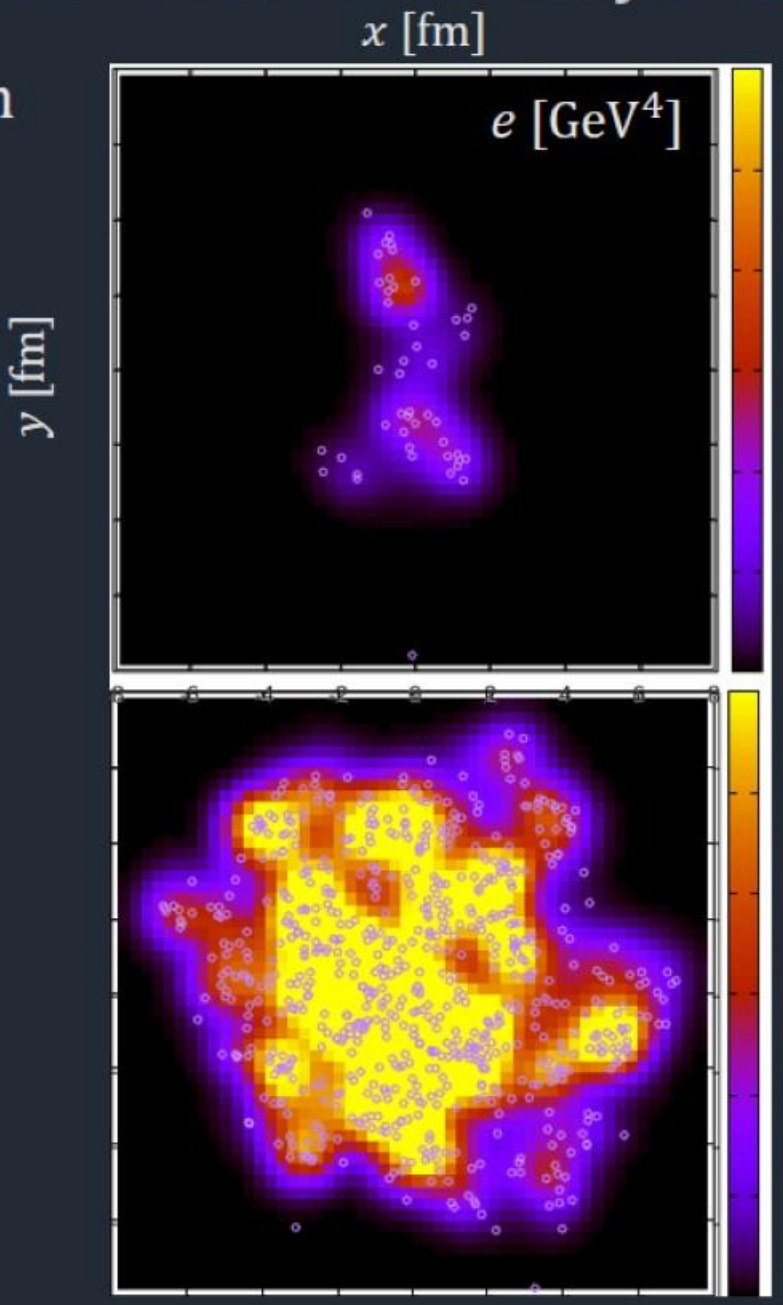
$v_\perp$

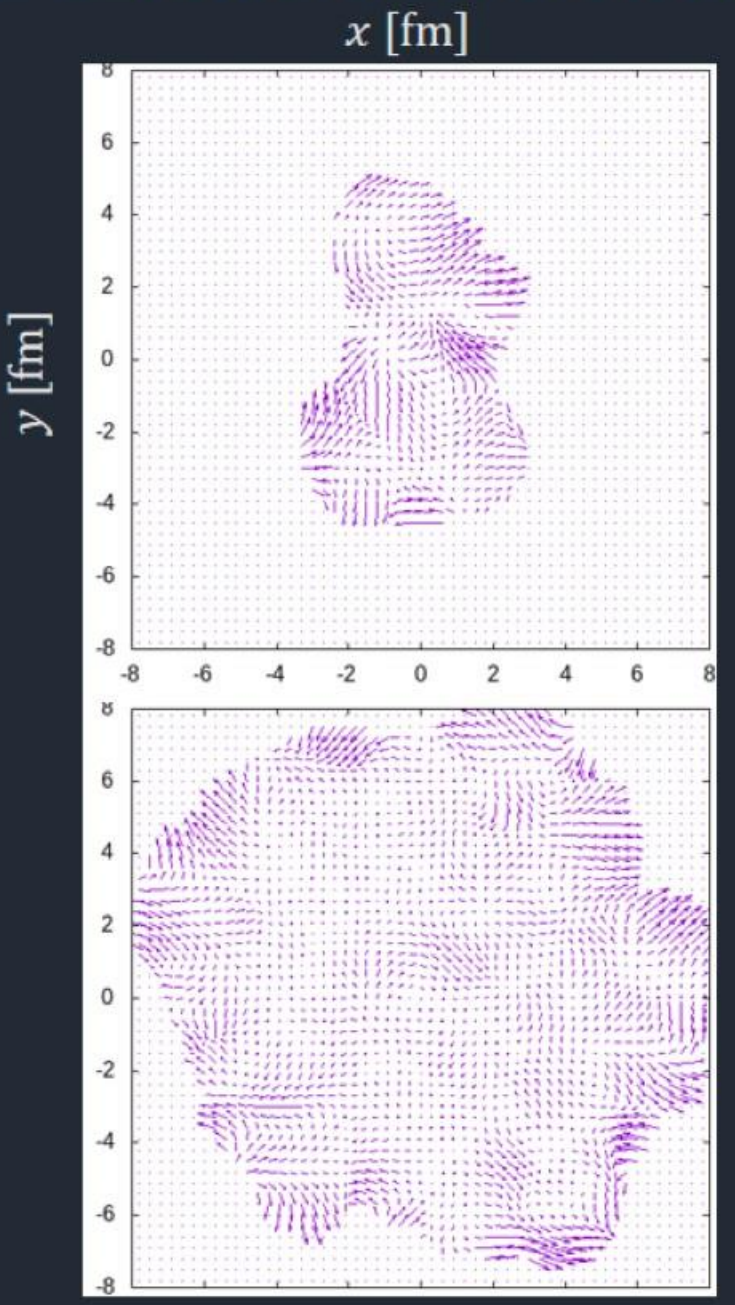
Result: Time evolution of dynamical core-corona initialization

$\tau = 0.18$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central

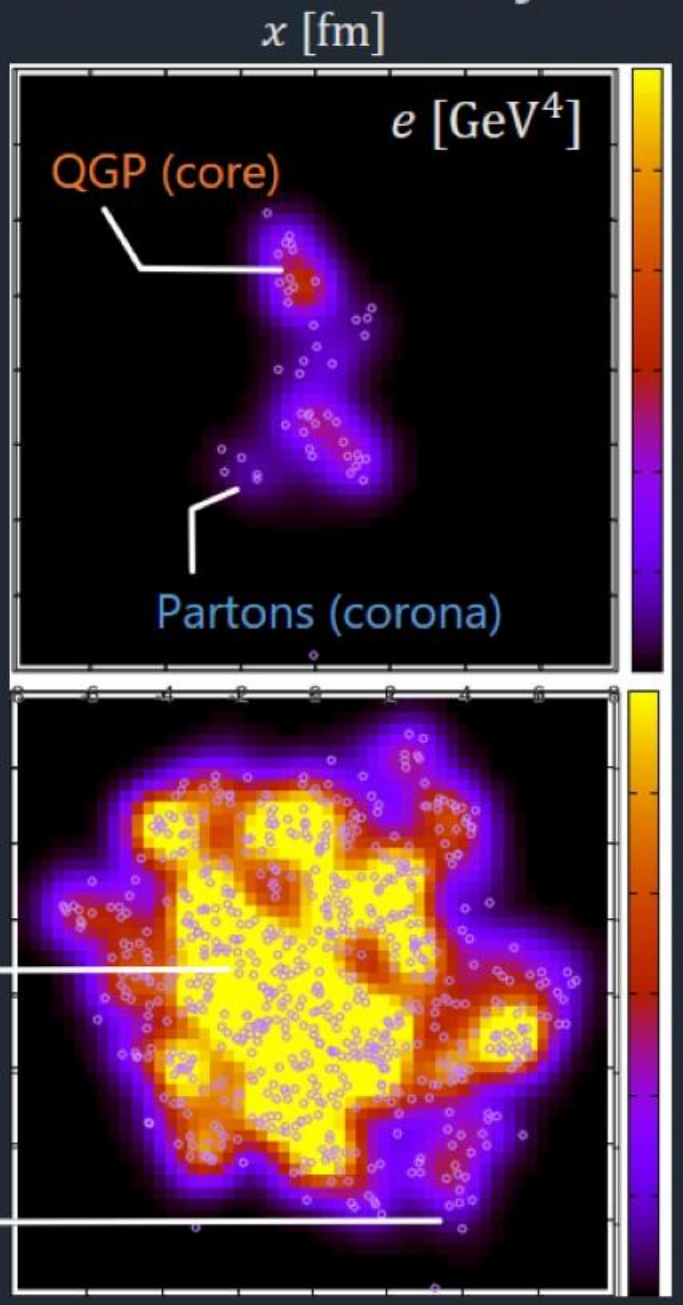


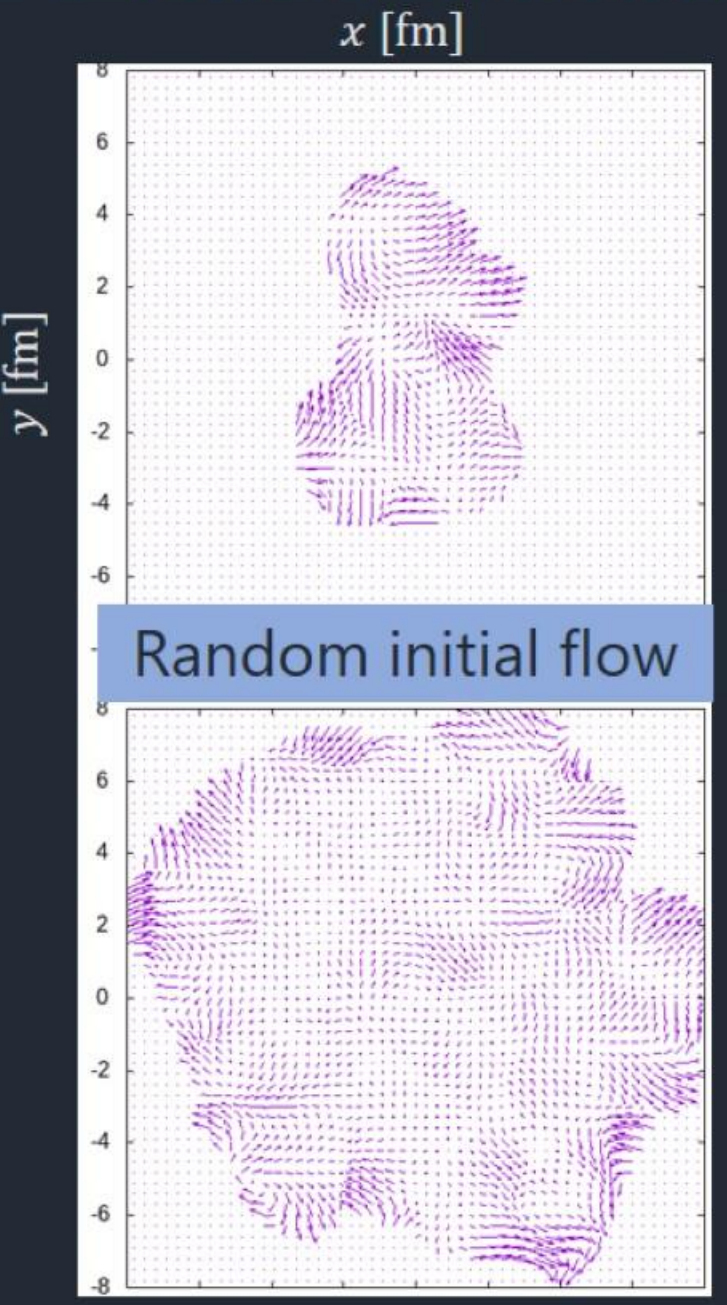


$v_\perp$

Result: Time evolution of dynamical core-corona initialization

$\tau = 0.19$ fm





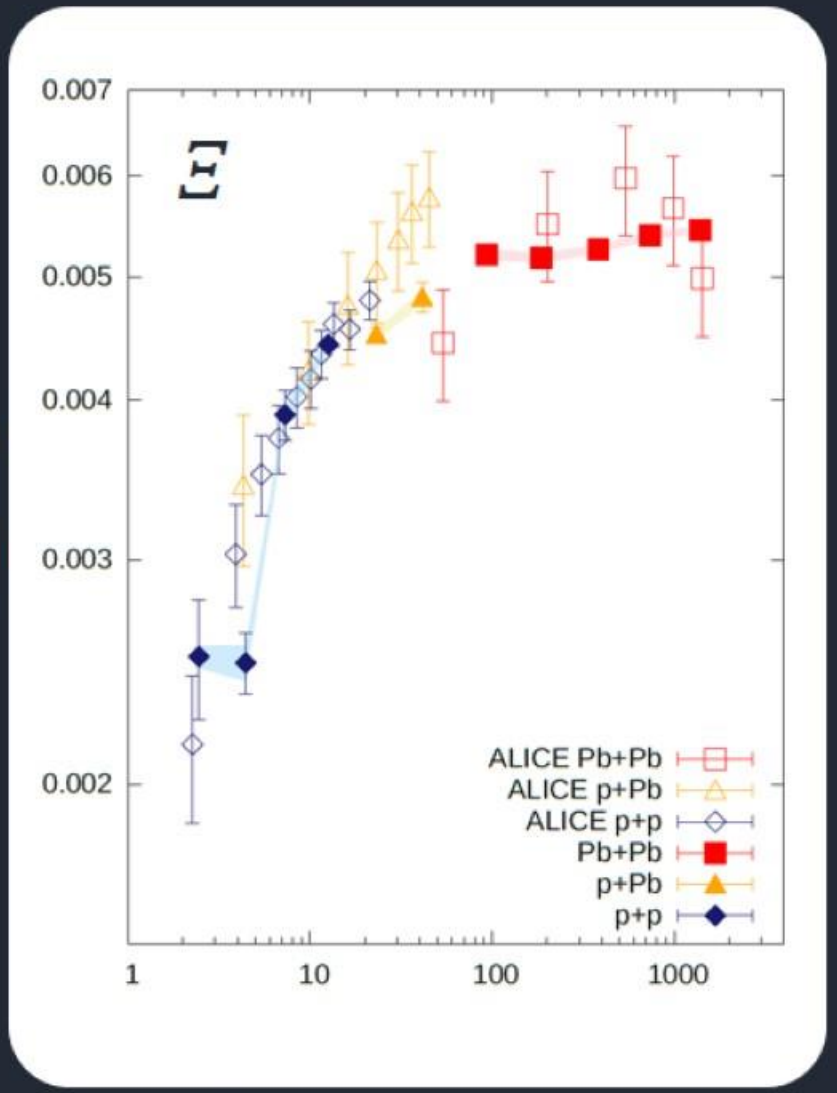
$v_\perp$

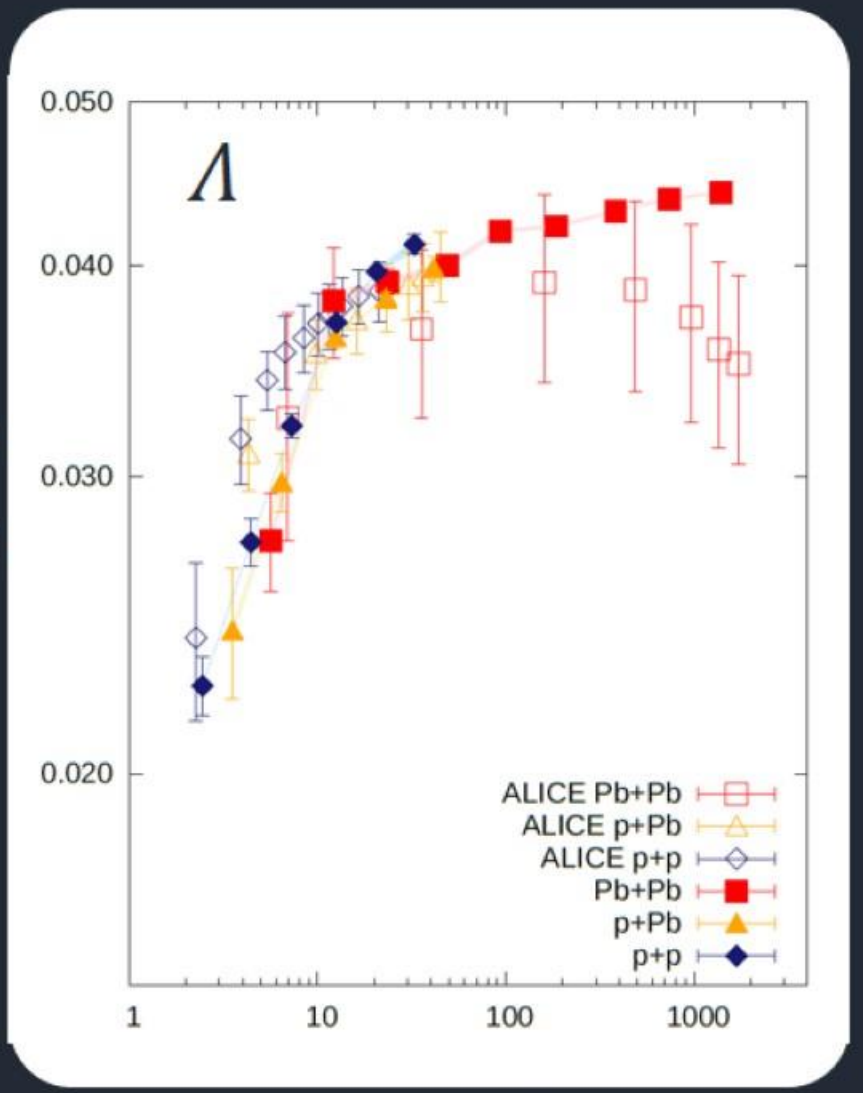
Random initial flow

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: Strangeness enhancement from dynamical core-corona

J. Adam et al. (ALICE), Nature Phys. 13, 535 (2017) J. Adam et al. (ALICE), Phys. Lett. B758, 389 (2016)
B. B. Abelev et al. (ALICE), Phys. Lett. B728, 25 (2014)



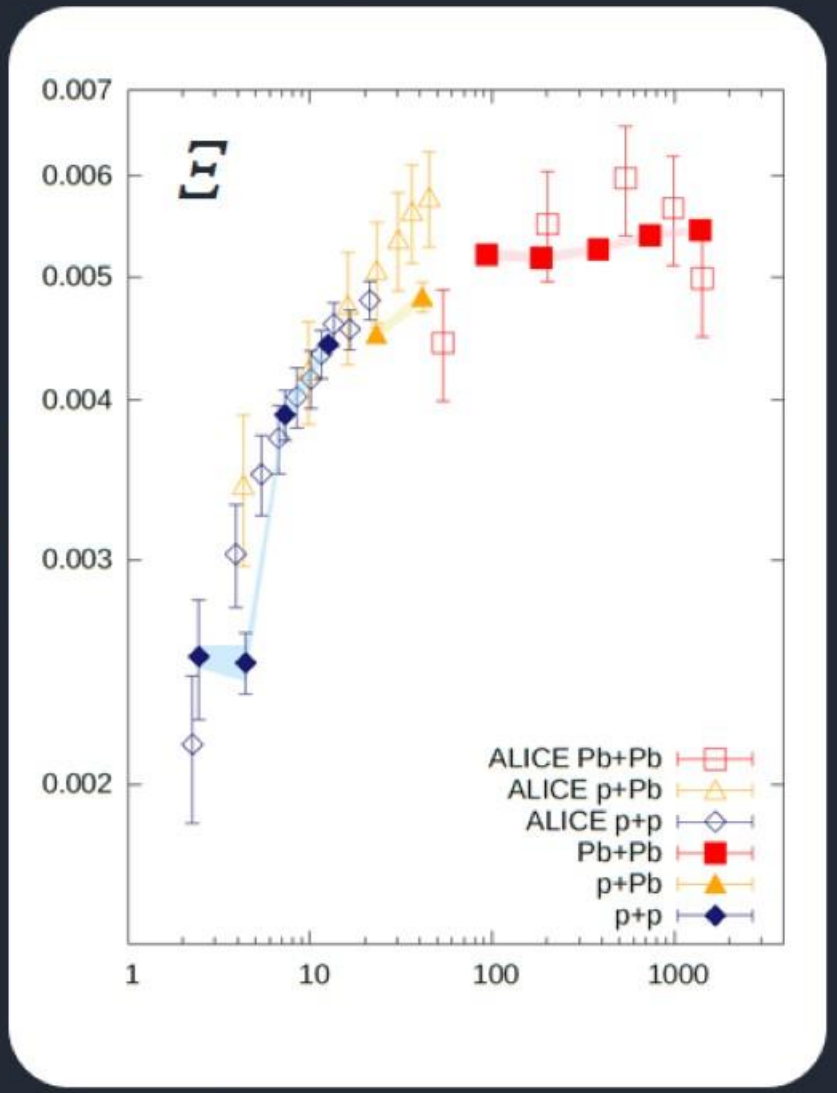


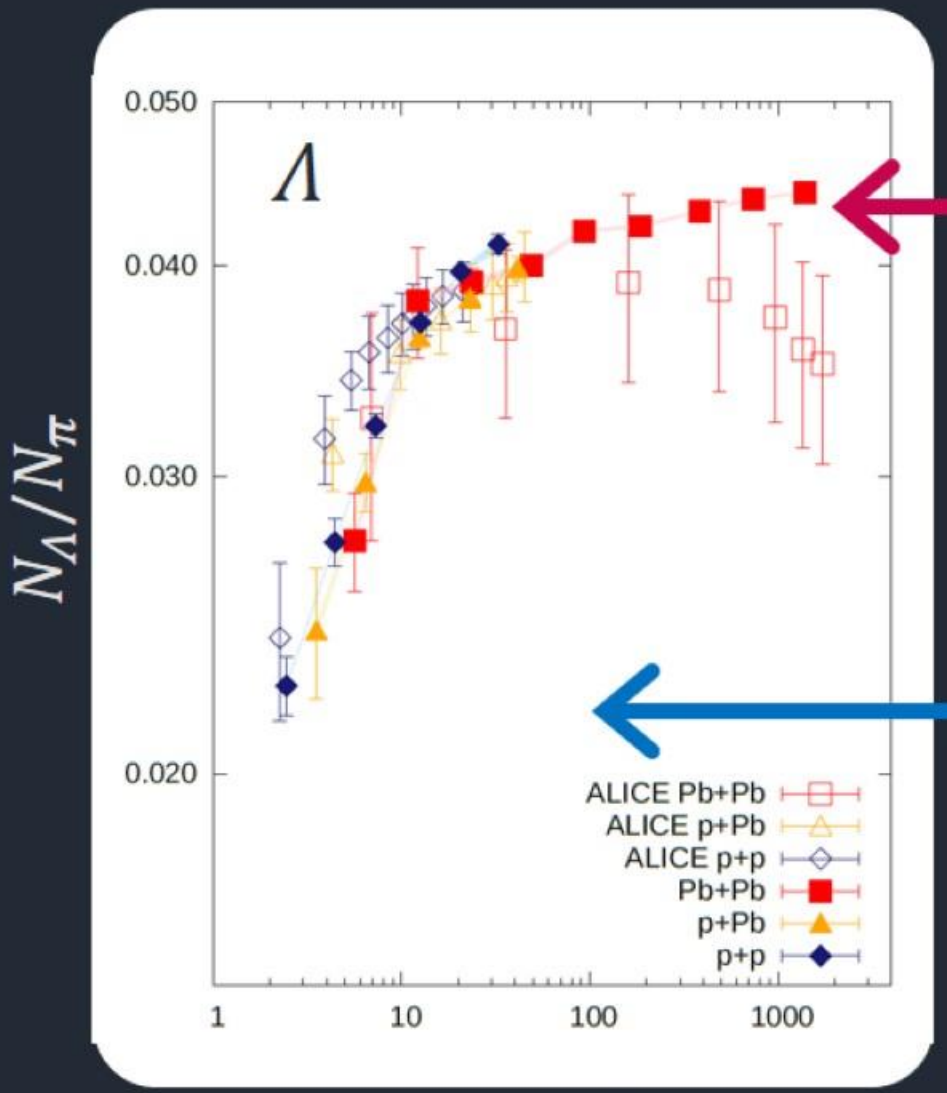
Competition between core and corona → Reproduction of continuous enhancement

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: Strangeness enhancement from dynamical core-corona

J. Adam et al. (ALICE), Nature Phys. 13, 535 (2017) J. Adam et al. (ALICE), Phys. Lett. B758, 389 (2016)
B. B. Abelev et al. (ALICE), Phys. Lett. B728, 25 (2014)





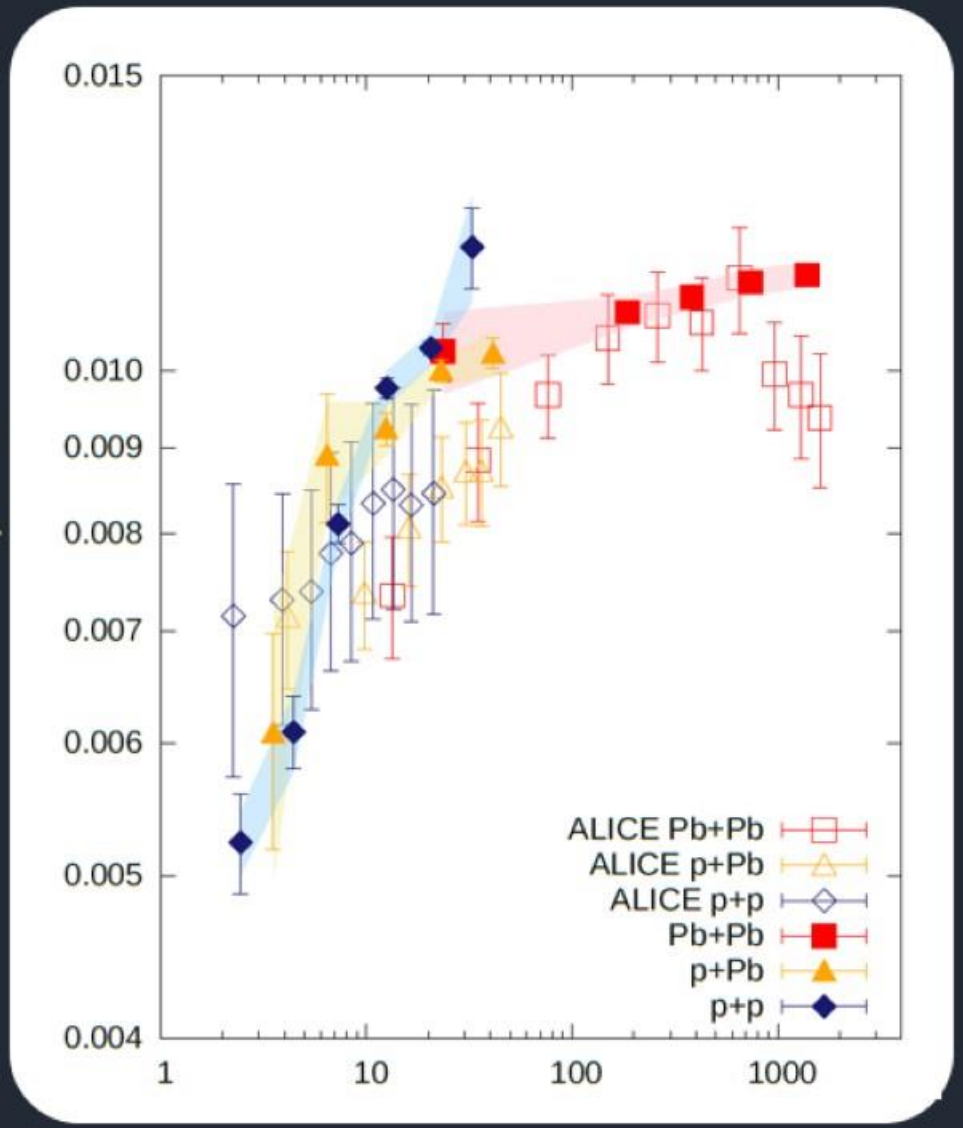
Core dominant reflects ratio from QGP

Corona dominant reflects ratio from string fragmentation

Competition between core and corona → Reproduction of continuous enhancement

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: phi / pi from dynamical core-corona



S. Acharya *et al.* (ALICE), Phys. Rev. C99, 024906 (2019)
B. B. Abelev *et al.* (ALICE), Phys. Rev. C91, 024609 (2015)
J. Adam *et al.* (ALICE), Eur. Phys. J. C76, 245 (2016)

Core-corona or canonical suppression?
→ ϕ: hidden strangeness

- Core-corona
- Exp. Data

→ enhancement

Canonical suppression
→ flat

J. Sollfrank, F. Becattini, K. Redlich and H. Satz, Nucl. Phys. A 638, 399C (1998)
S. Acharya et al. (ALICE), Phys. Rev. C99, 024906 (2019)

(Dynamical) core-corona

String fragmentation
+
Statistical Thermodynamics

Canonical suppression

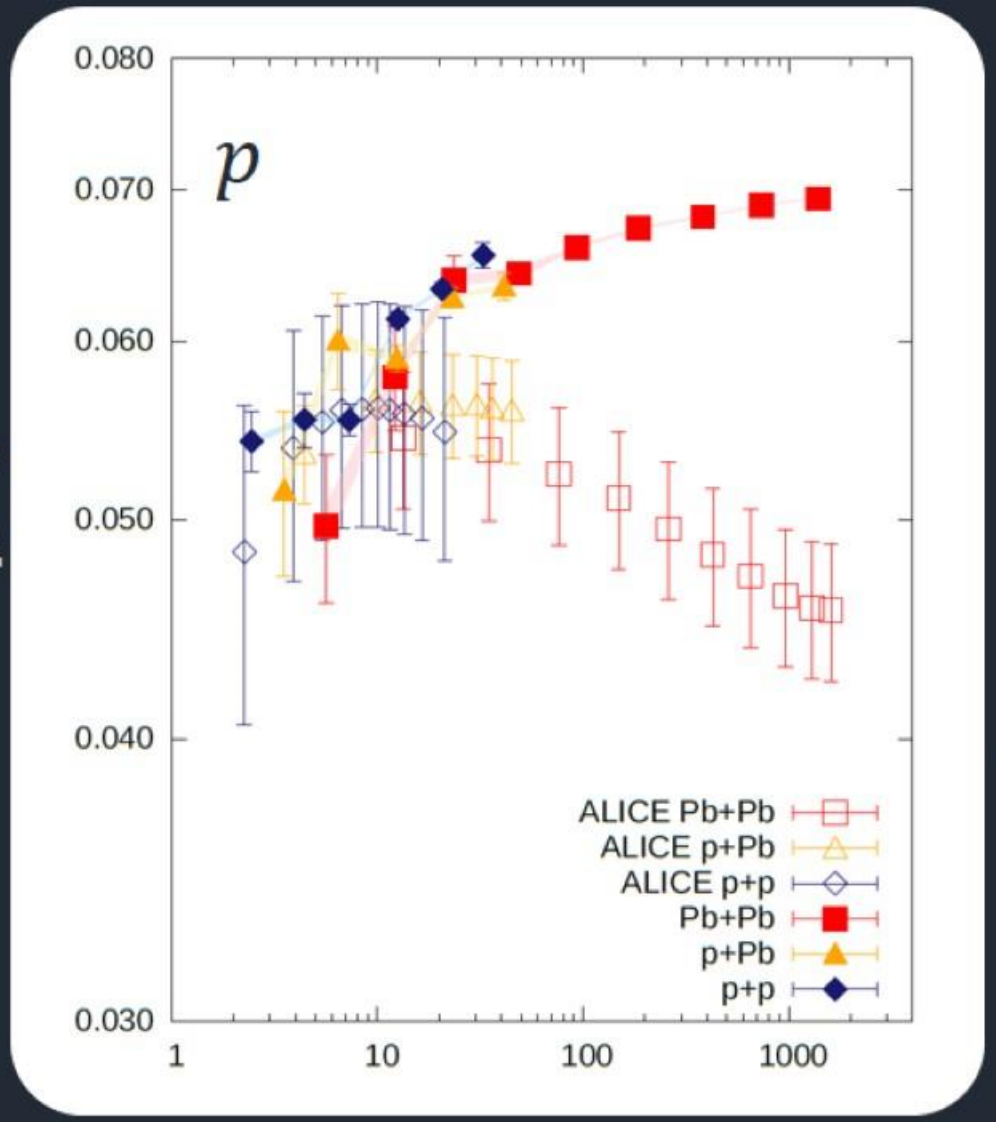
Statistical Thermodynamics
(canonical & grand canonical)

→ Captures the essential characteristic of particle production

Not fully equilibrated, needs of string fragmentation

Result: Proton / pi from dynamical core-corona

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

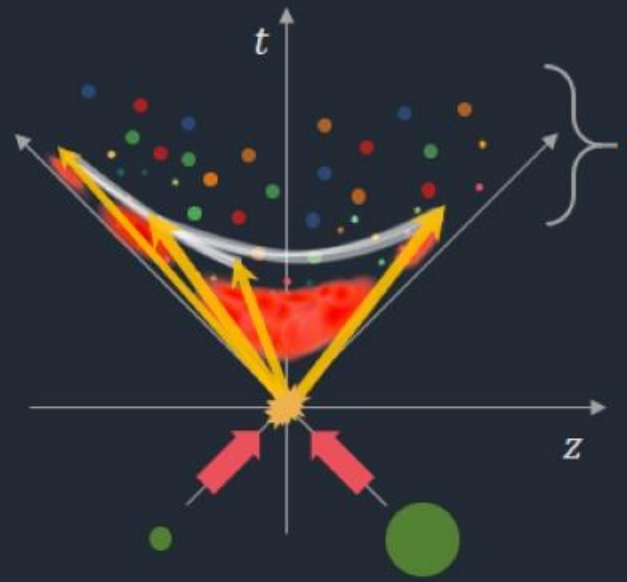


B. Abelev et al., Phys.Rev. C88 (2013) 044910
B. Abelev, et al. Phys.Lett. B728 (2014) 25-38, S. Acharya, et al. Phys. Rev., C99, 2, 024906, (2019).

Our results
→Enhancement with multiplicity

Exp. data
→Decrease in high-multiplicity events

$N_{\rm p}/N_{\pi}$ in high-multiplicity
→Deviation from statistical thermodynamics

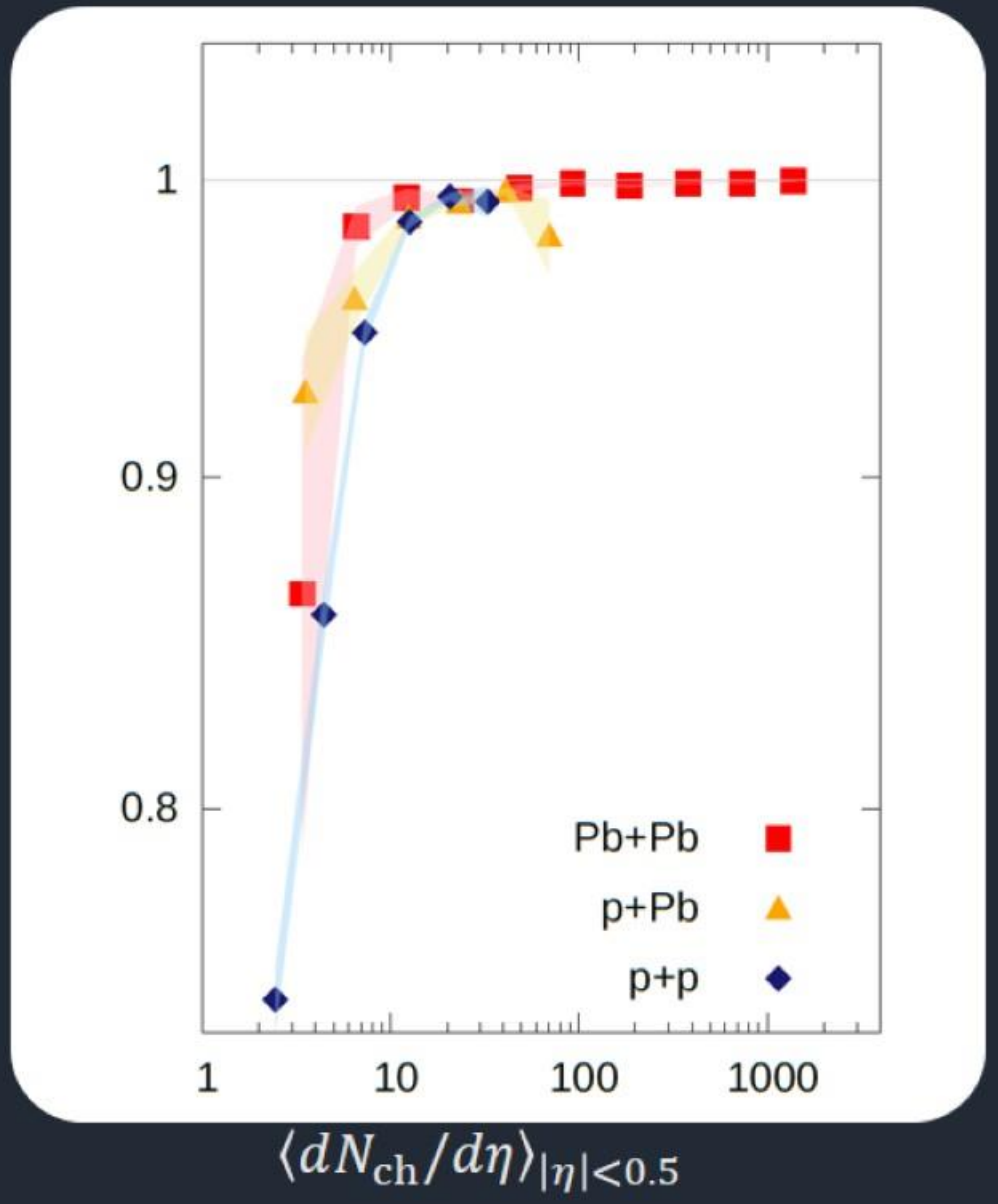


Effects of hadronic rescatterings

→baryon-antibaryon annihilation?

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: Fraction of fluidized energy



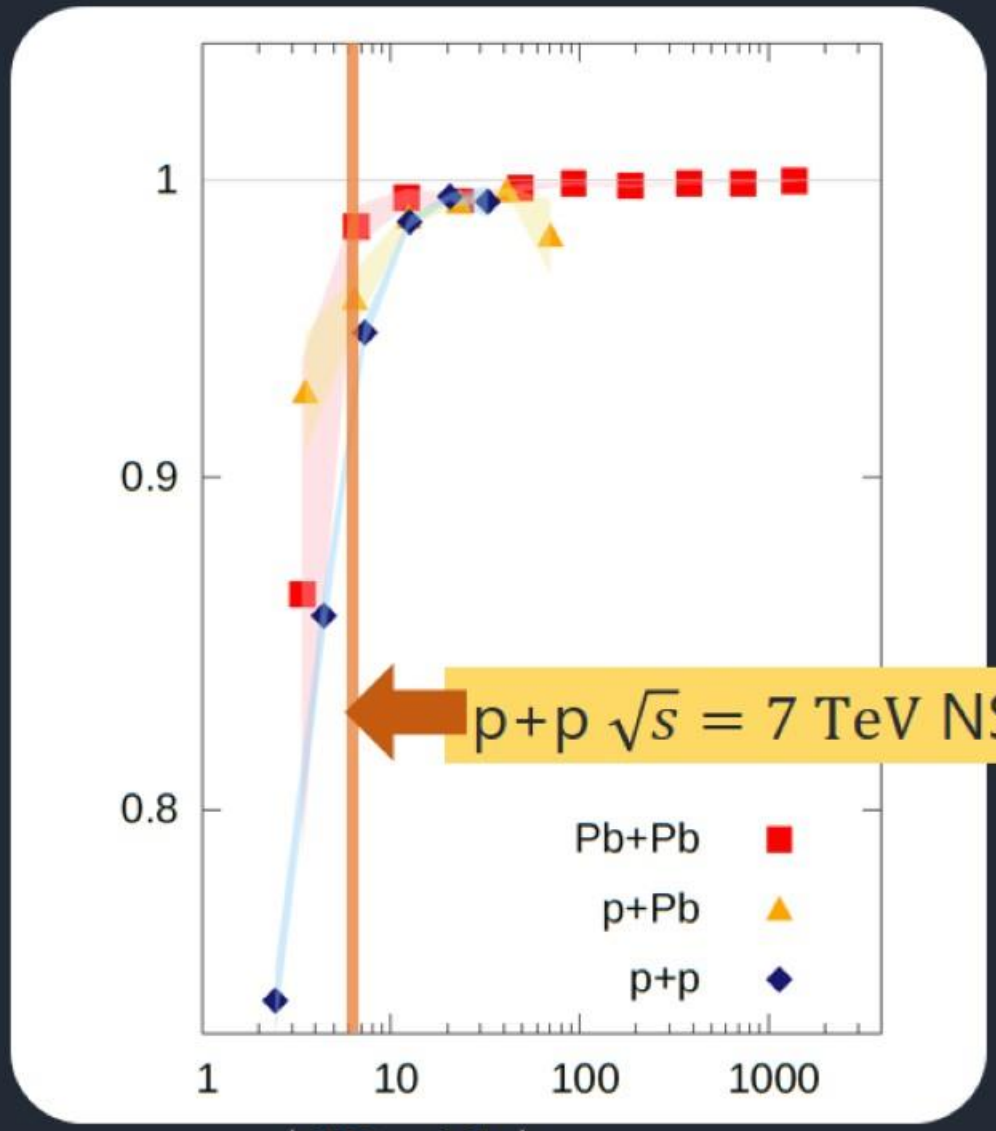
$$R = \frac{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau (\tau, x_\perp, \eta_s = 0)}{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau_{\rm tot} (\tau, x_\perp, \eta_s = 0)}$$

$$= \frac{\text{(Core energy at midrapidity)}}{\text{(Total energy at midrapidity)}}$$

→ Fraction of fluidized energy

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: Fraction of fluidized energy



*J. Adam *et al.* (ALICE), Eur. Phys. J. C77, 33 (2017)

$$R = \frac{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau (\tau, x_\perp, \eta_s = 0)}{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau_{\rm tot} (\tau, x_\perp, \eta_s = 0)}$$

$$= \frac{\text{(Core energy at midrapidity)}}{\text{(Total energy at midrapidity)}}$$

→ Fraction of fluidized energy

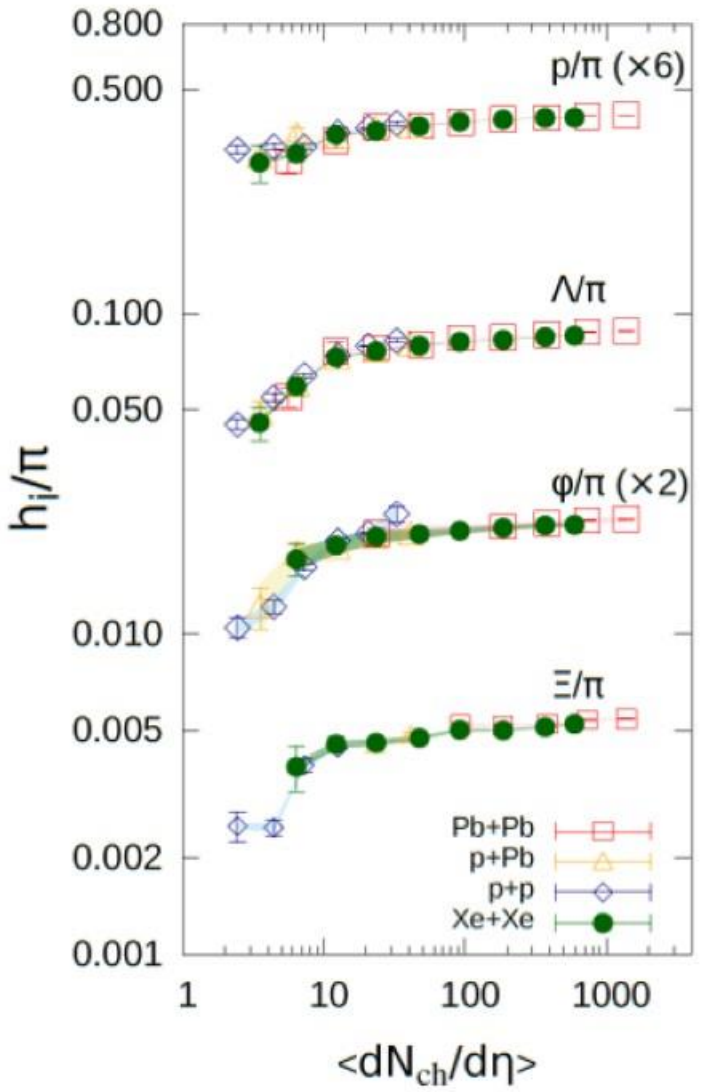
Reproduction of yield ratio
in the exp. data

Need of QGP fluid (core) contribution
even in NSD p+p events

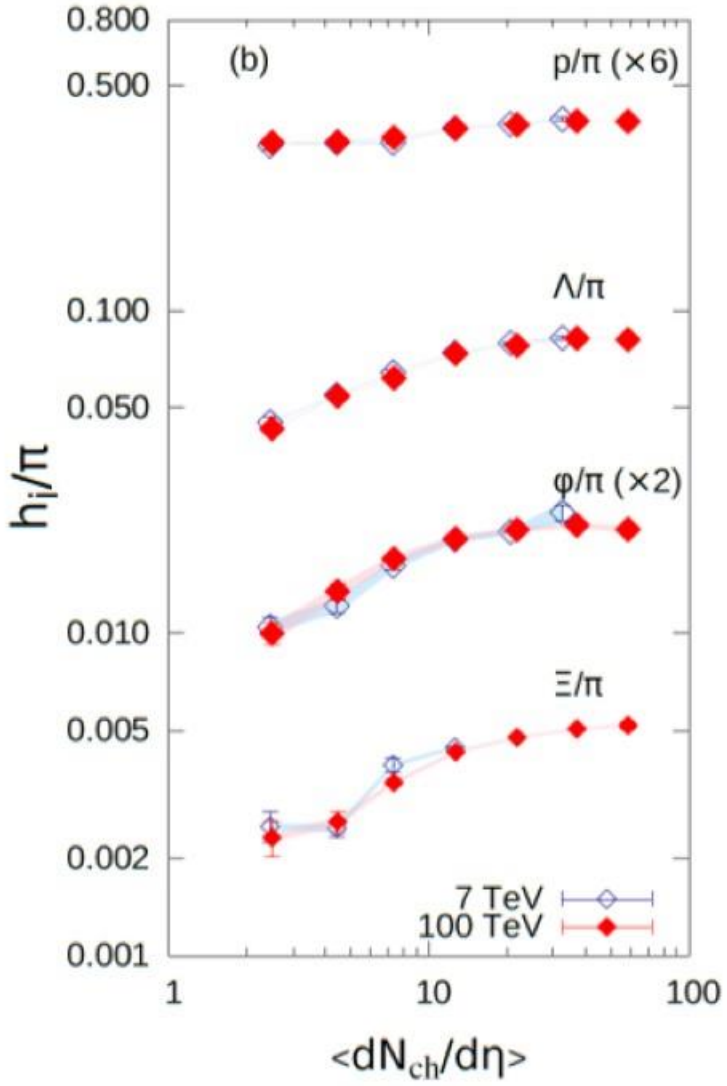
Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Result: Size & collision energy dependence

Xe+Xe vs others



FCC vs LHC



Clear scaling with multiplicity

→ Multiplicity plays an important role for thermalization of partons

<u>Prediction</u>: At FCC energy, saturation of multi-strangeness ratios are seen in high multiplicity events.

Summary & outlook

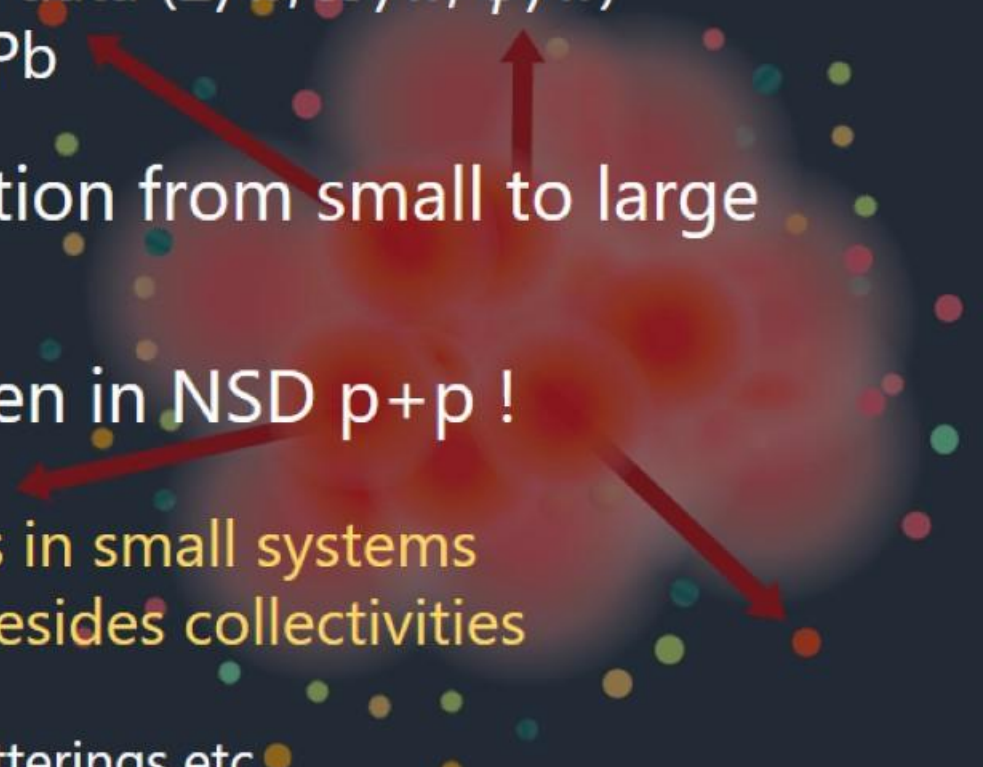
Dynamical core-corona initialization

Dynamical generation of initial condition of fluids considering initial parton distribution

Reasonable agreement with the ALICE exp. data (Ξ/π, Λ/π, ϕ/π)
in p+p, p+Pb, and Pb+Pb

→ First step for unified & dynamical description from small to large systems

→ Indication of partial QGP formation even in NSD p+p !



Towards understanding the dynamics in small systems
→ Need to discuss hadron chemistry besides collectivities

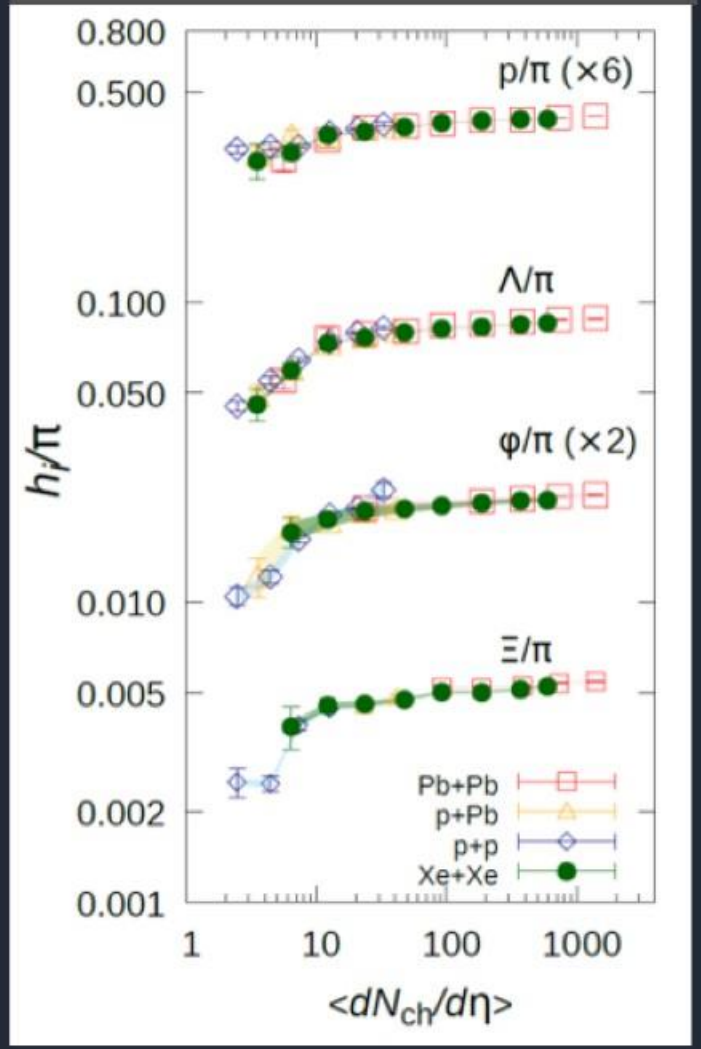
*Future work: collectivity → hadronic rescatterings etc.

Back up

Result: Collision energy dependence

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

RHIC vs LHC



$\langle dN_{\mathrm{ch}}/d\eta \rangle_{|\eta|<0.5}$

Au+Au $\sqrt{s_{NN}} = 200$ GeV

Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV

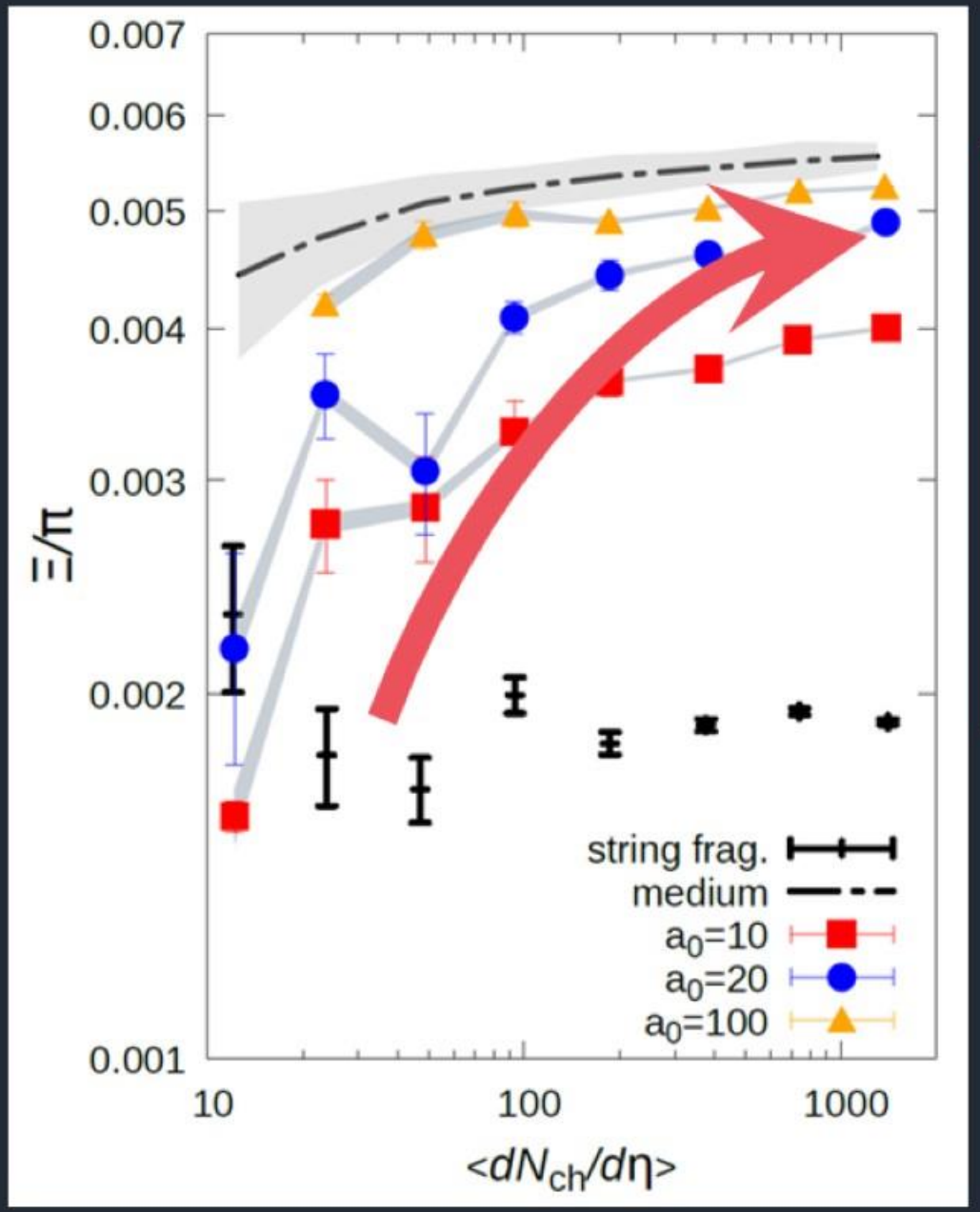
Determination of a_0

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

Check a_0 dependence of Ξ/π

Fitting with exp.data

Obtain the best a_0 to reproduce the experimental data.



$\langle dN/d\eta \rangle$ when Ξ/π reaches ~hydro limit

"Saturation multiplicity"

Determination of a_0 (Cont'd)

Y. Kanakubo *et al.*, arXiv:1910.10556 [nucl-th]

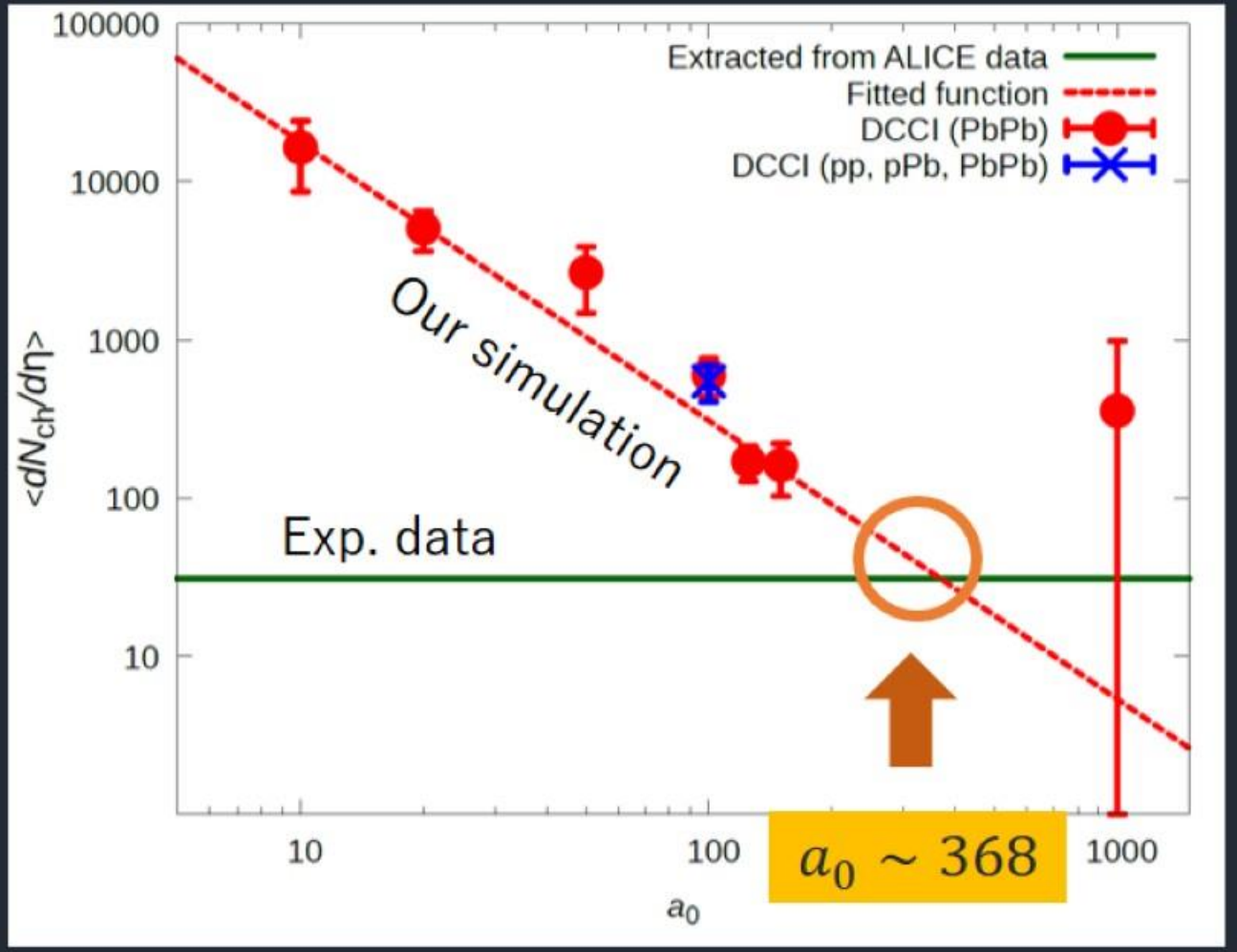
Check a_0 dependence of Ξ/π

Fitting with exp.data

Obtain the best a_0 to reproduce the experimental data.

$$a_0 \sim 368$$

$\langle dN/d\eta \rangle$ when Ξ/π reaches ~hydro limit



a_0 ↑ Saturation multiplicity ↓