Strangeness enhancement from dynamical initialization with core-corona picture

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Sophia Univ.

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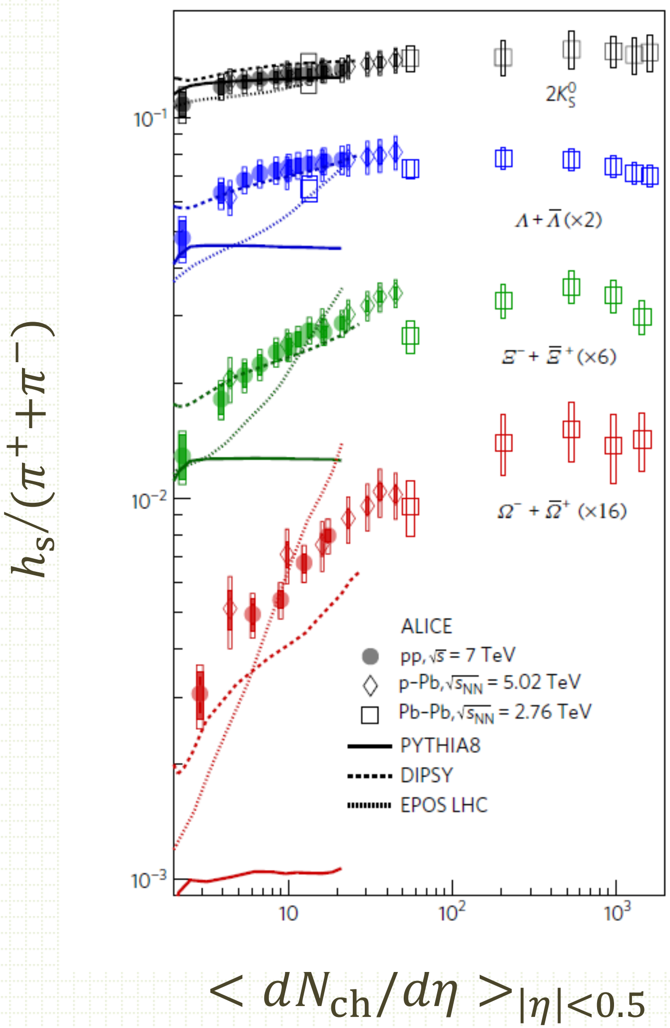
Yasuki Tachibana (Wayne state Univ.)
Tetsufumi Hirano (Sophia Univ.)

CSCS2018@Wuhan

Introduction & Motivation

Strangeness enhancement in small systems



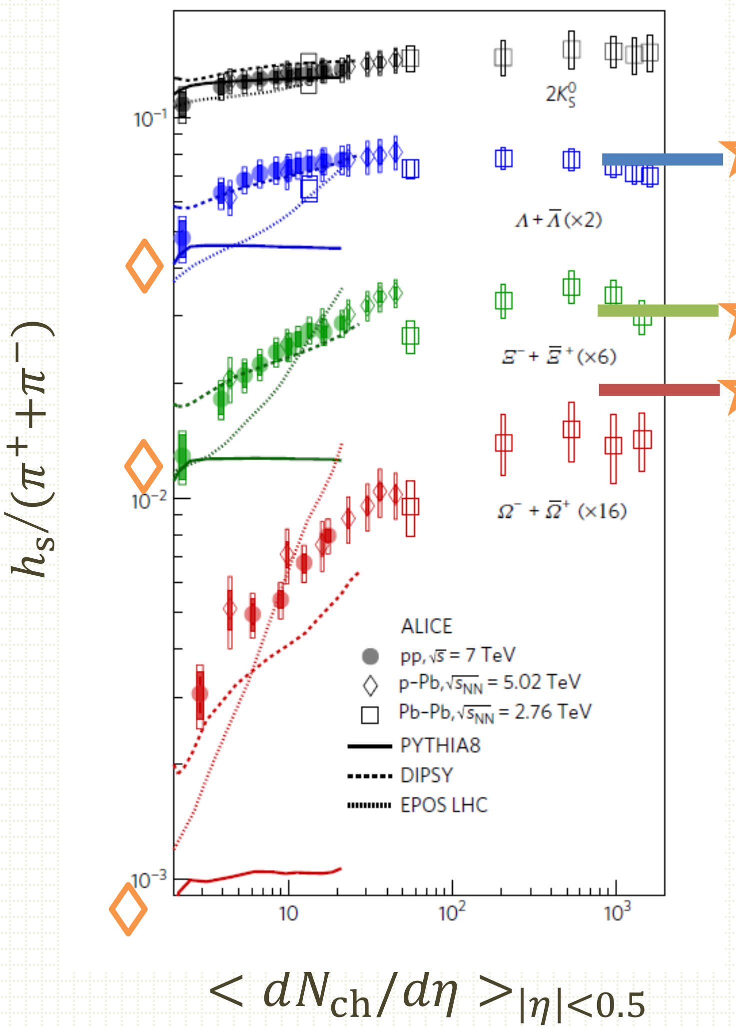
ALICE Collaboration: Nat. Phys. 13, (2017) 535.

- Rapid enhancement of multi-strange hadrons relative to charged pions in small systems
- Continuous increase as a function of multiplicity towards the ratio in Pb+Pb.

⇩

Indication of QGP creation in high multiplicity small colliding systems

Strangeness enhancement in small systems



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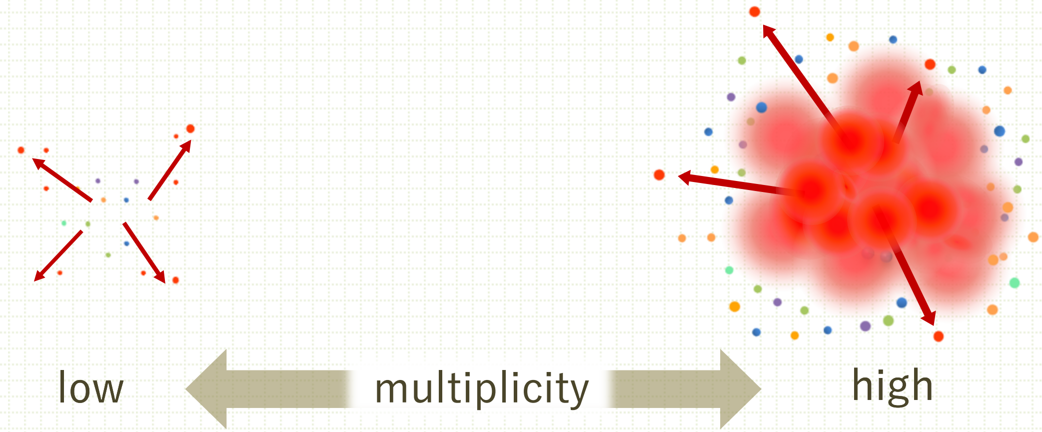


☆ Particlization from chemically equilibrated matter

A. Andronic *et al.*, (2017).

◇ String fragmentation

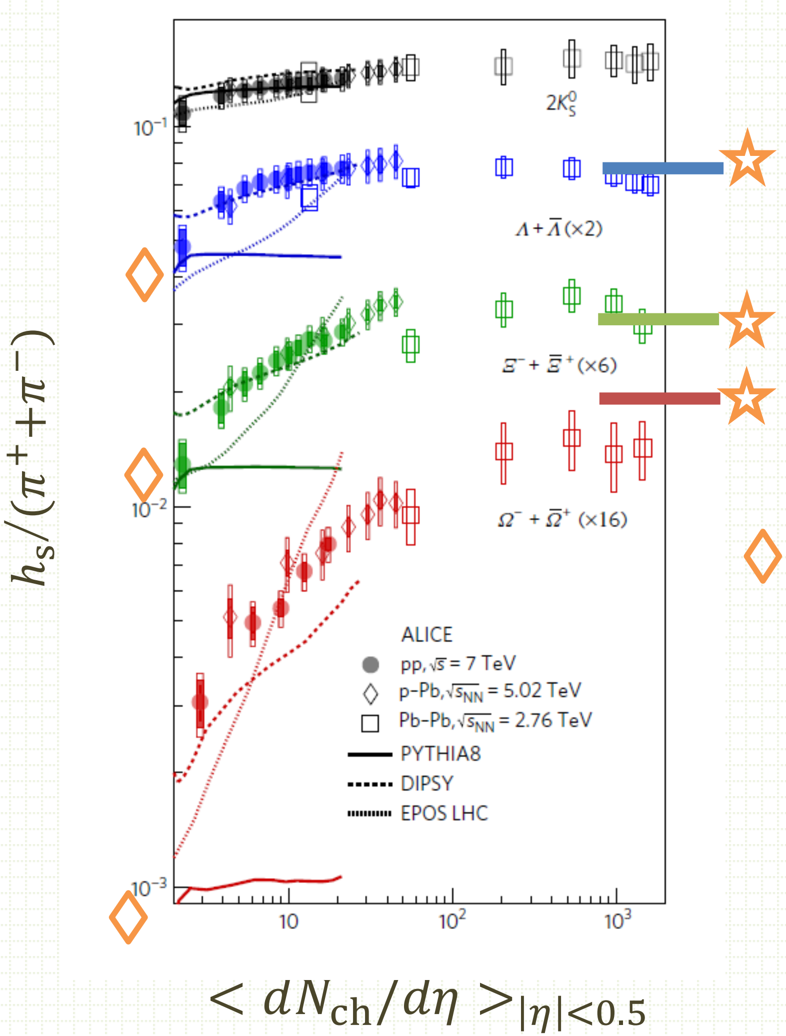
$$P \propto \exp\left(-\pi \frac{{m_q}^2}{\kappa}\right)$$

$$P \propto d_i \exp\left(-\frac{m_i}{T_{ch}}\right)$$

Different hadronization mechanism

➡ Two different ratios of strangeness products

Strangeness enhancement in small systems



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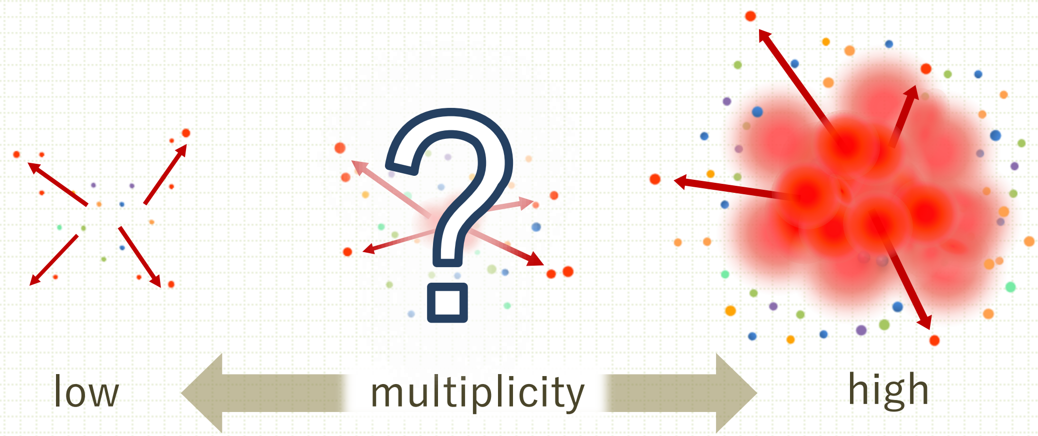

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Purpose

Interpretation of the strangeness enhancement from dynamical initialization with core-corona picture

⇩

Hydrodynamic equation with source terms

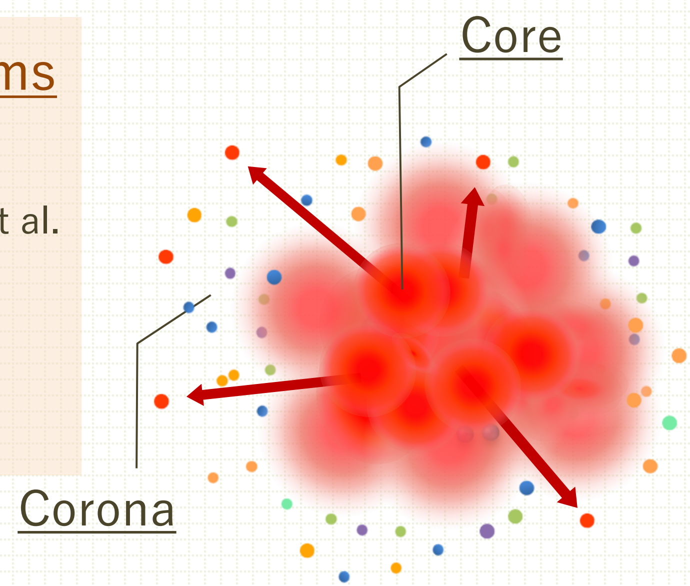
Dynamical initialization

M. Okai et al, C. Shen et al, Y.Akamatsu et al.

+

Core-corona picture

J. Aichelin et al, F. Becattini et al, T. Pierog et al



Final hadron products from "core" and "corona" separately

→ Final strangeness ratio from superposition of core and corona products

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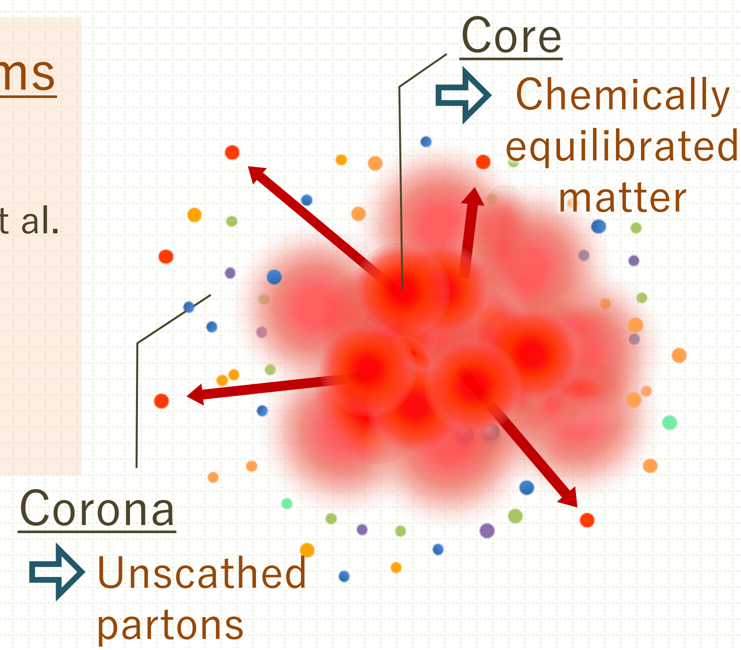

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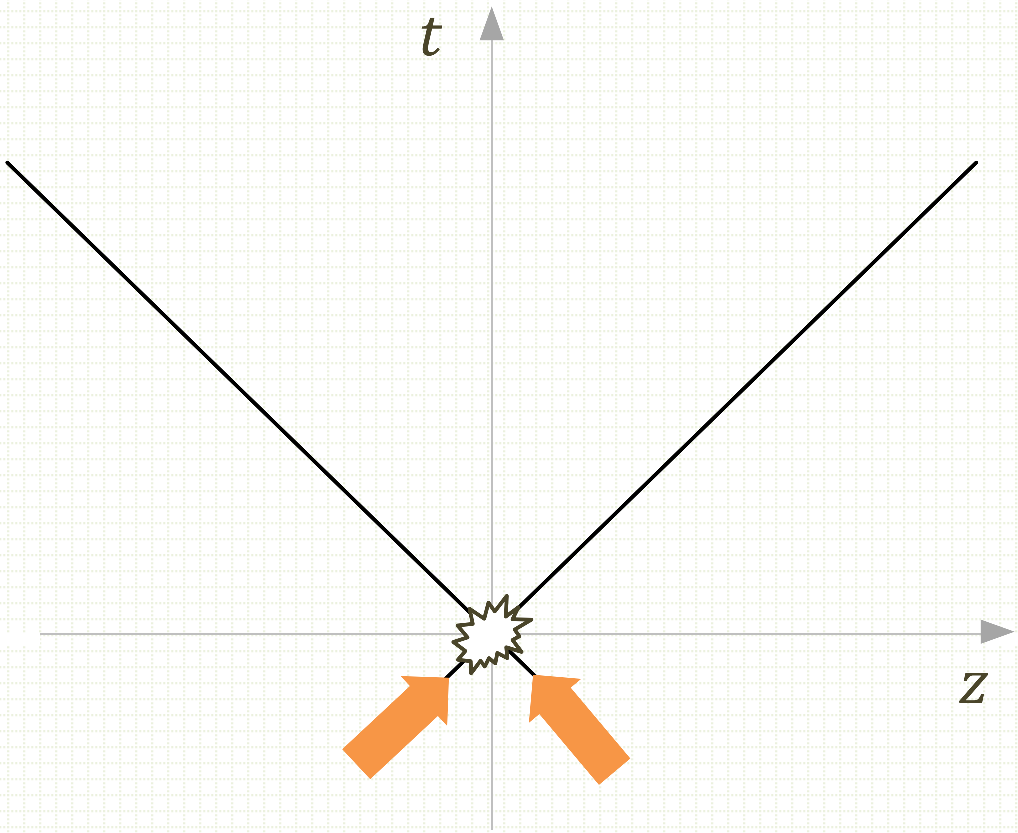
Model

Model

Time evolution of high energy nuclear collisions



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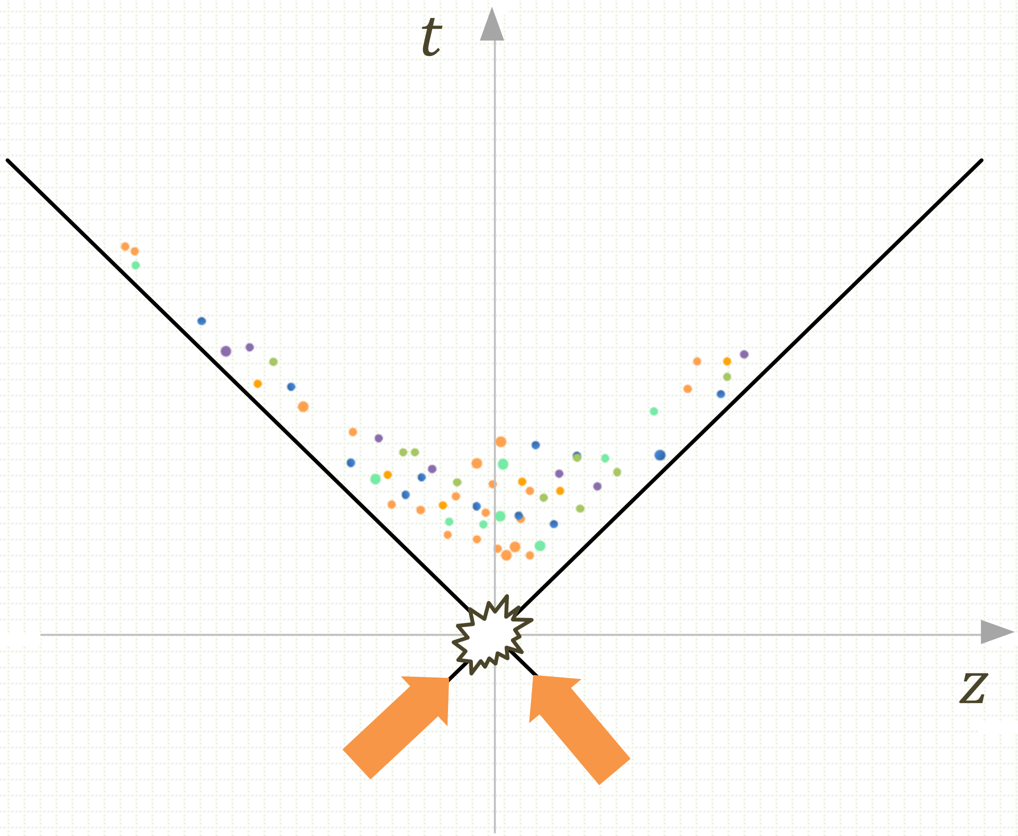


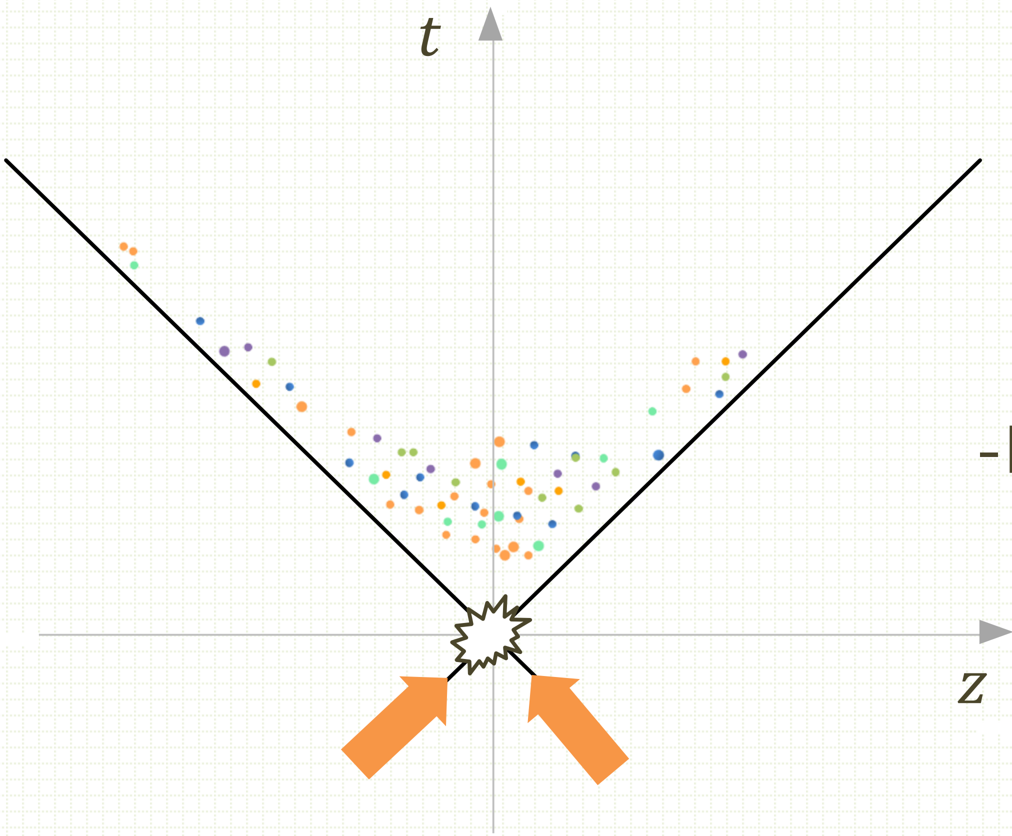
-Parton generation

PYTHIA ver 8.230

T. Sjöstrand *et al.*,
Comput. Phys. Commun. 191, 159 (2015).

Model

Time evolution of high energy nuclear collisions



-Evolution of QGP fluids

Dynamical initialization

Ideal hydro, Lattice EoS

M.Okai K.Kawaguchi, Y.Tachibana, T.Hirano,
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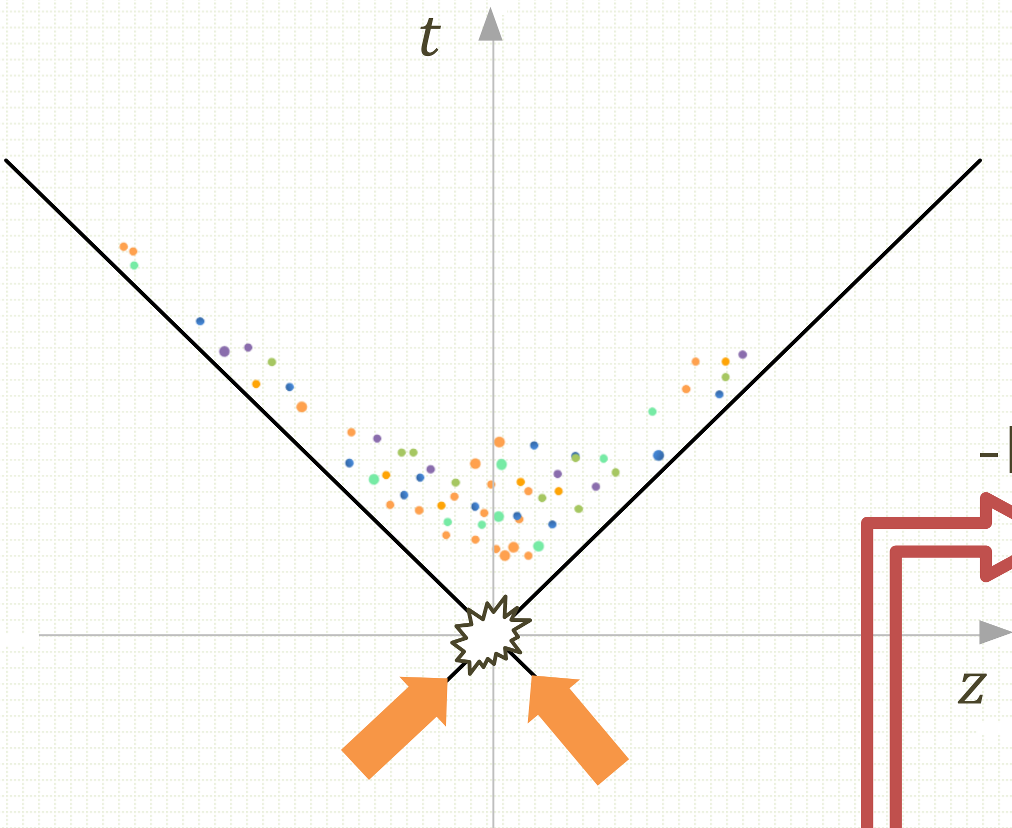

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+ Core-corona picture

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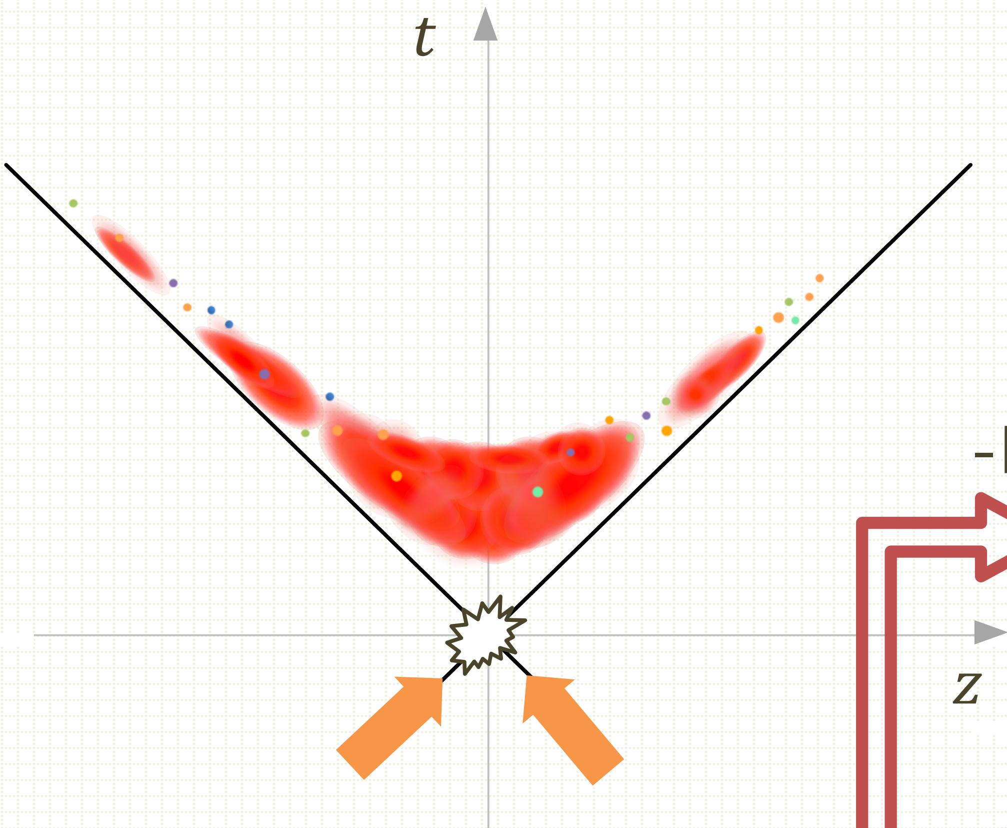

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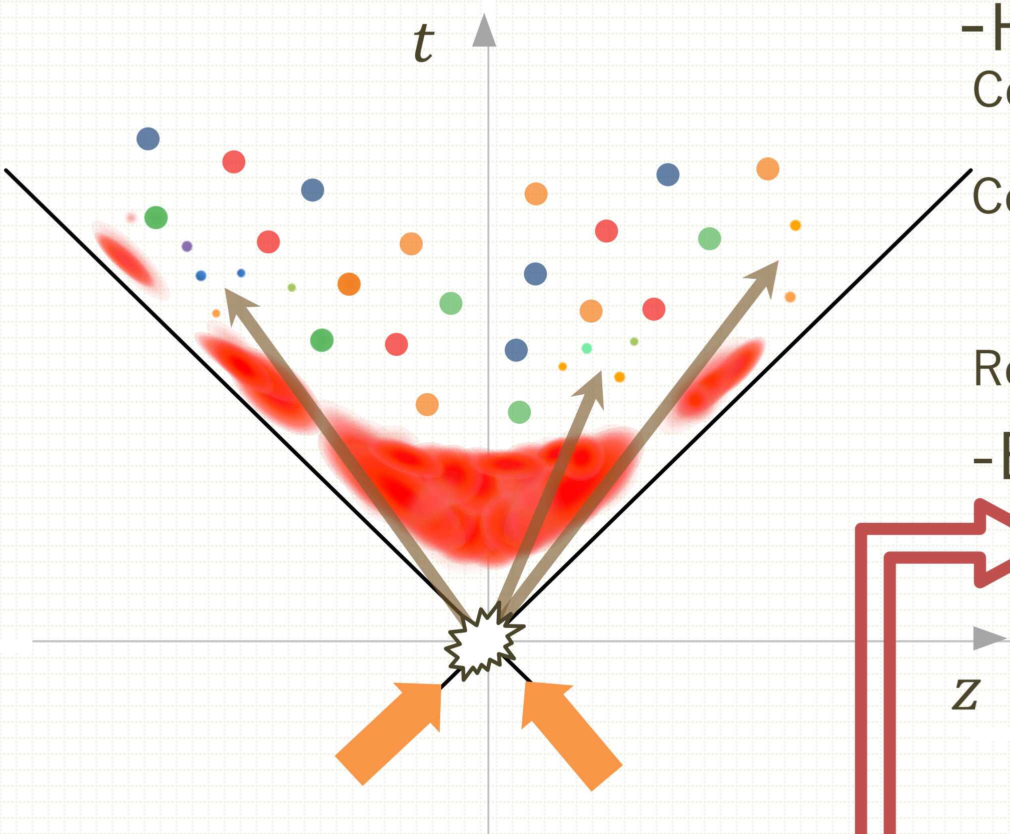

-Hadronization

Corona ➡ String fragmentation (PYTHIA)

Core ➡ Particlization at $T_{\mathrm{ch}} = 160\ \mathrm{MeV}$ with Cooper-Frye formula

F. Cooper and G. Frye, Phys. Rev. **D10**, 186 (1974).

Resonance factor: A. Andronic *et al.*, (2017).

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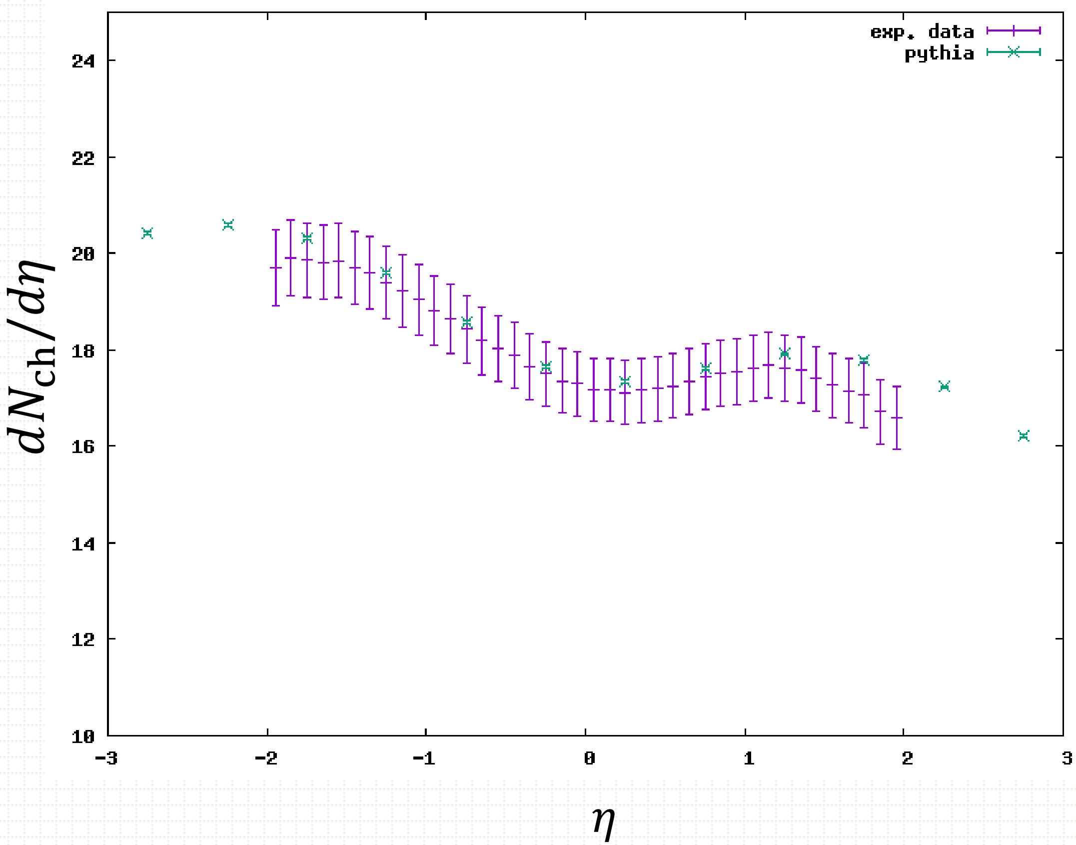
＋ Core-corona picture

Pseudo-rapidity distribution from PYTHIA

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



ALICE Collaboration.
Phys. Rev. Lett. 110 (2013) 032301

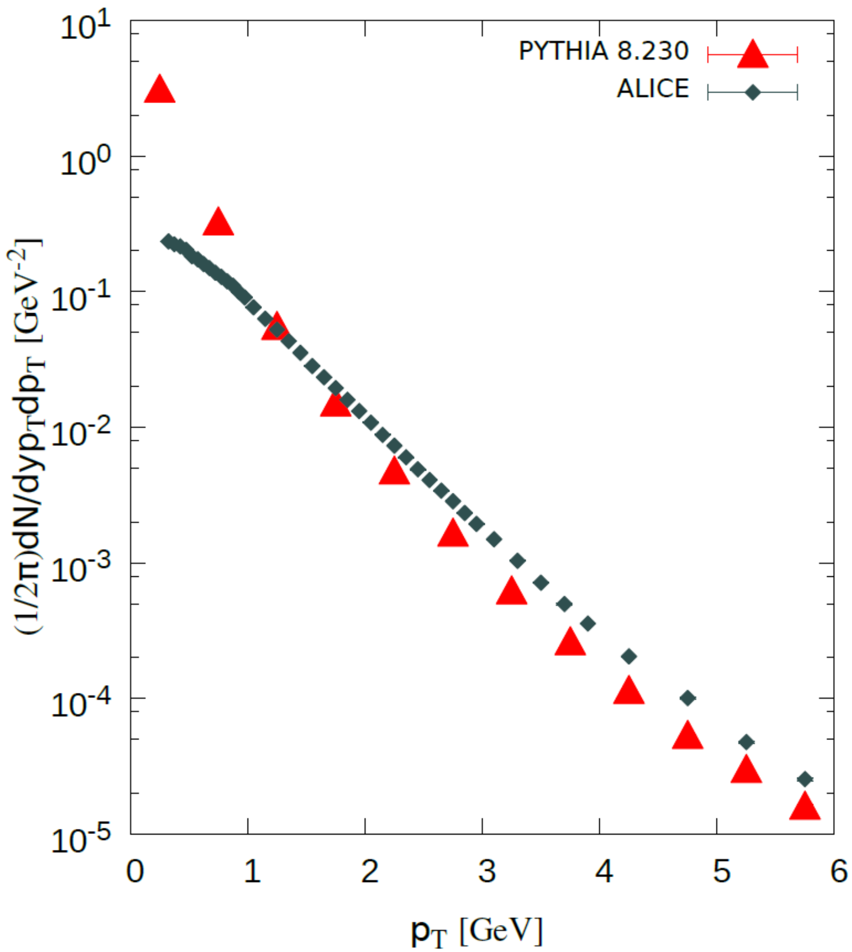
Simulation for heavy ion collision available.

C. Bierlich, G. Gustafson, L. Lönnblad, JHEP PoS DIS2016, 051 (2016)

Reproduction of $dN_{\mathrm{ch}}/d\eta$

Transverse momentum distribution from PYTHIA

p+Pb $\sqrt{s_{NN}} = 2.76$ TeV, NSD, mid rapidity



p_T spectra of $p + \bar{p}$

Exp. data → hard
PYTHIA → soft

No blue-shifts contrary to experimental data

Need of some transverse dynamics

ALICE Collaboration.
Phys.Lett. B760 (2016) 720-735 CERN-EP-2016-003

Dynamical initialization

M.Okai, K.Kawaguchi, Y.Tachibana, T.Hirano, Phys. Rev. C 95, no. 5, 054914 (2017).

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

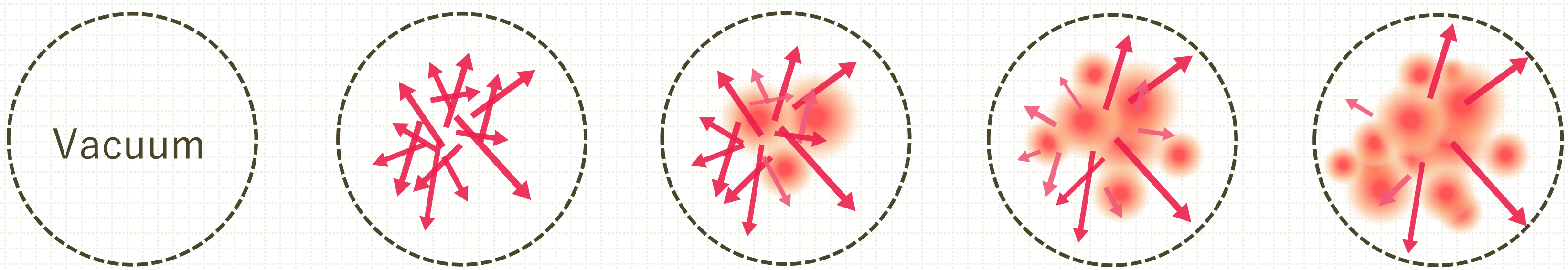
Energy-momentum tensor of QGP fluids

Energy and momentum deposited from initial partons

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

G: Gaussian function for smearing

"Fluidization rate"



Formation time

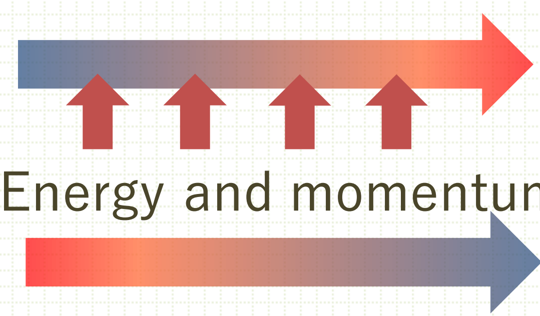
Initial time of fluids

0

$\tau_{00} = 0.1$ fm

$\tau_0 = 0.6$ fm

Vacuum



QGP fluids

Energy and momentum

Partons

Surviving partons

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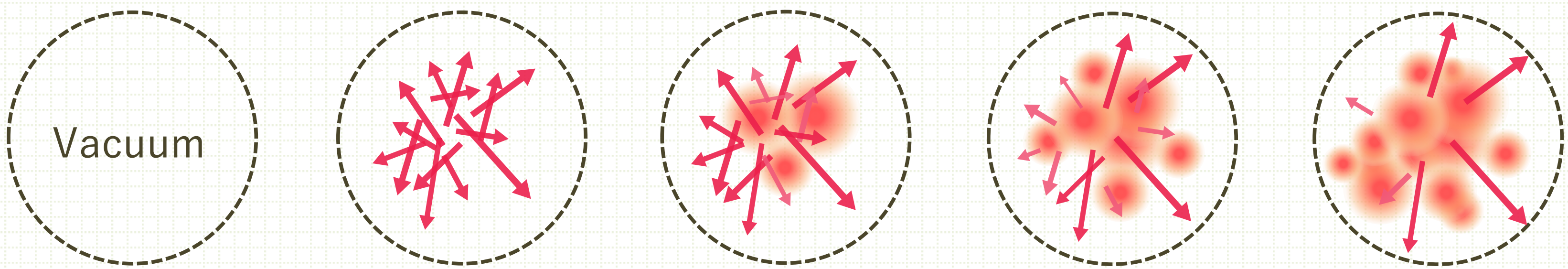


Formation time

Initial time of fluids

0 $\quad \tau_{00} = 0.1\ \mathrm{fm}$ $\quad \tau_0 = 0.6\ \mathrm{fm}$

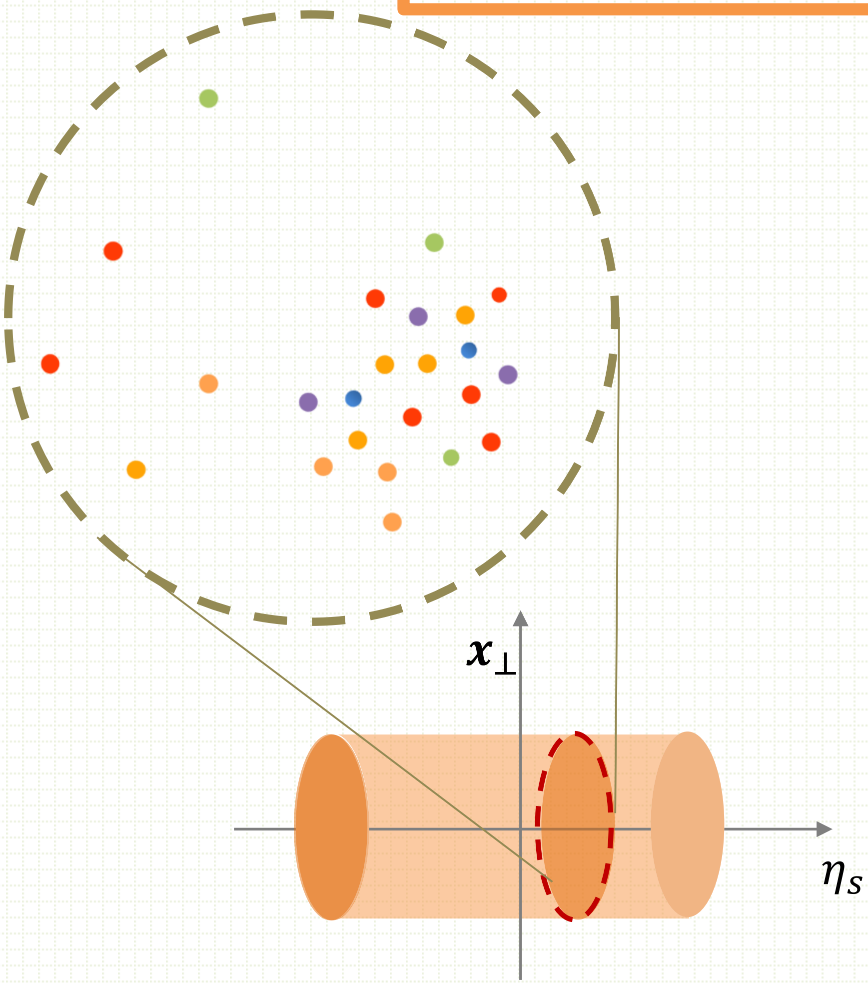
Vacuum → QGP fluids

Energy and momentum

Partons → Surviving partons

Fluidization rate with core-corona picture

$$\frac{dp_i{}^{\mu}(t)}{dt} = -a_0 \frac{\rho_i\left(x_i(t)\right)}{p_{\mathrm{T},i}{}^2} p_i{}^{\mu}(t)$$



- $\rho_i(x_i(t))$: Density distribution

$$\rho_i(x_i(t))d^3x = \sum_{j\neq i} G\left(\boldsymbol{x_i} - \boldsymbol{x}_j(t)\right) d^3x$$

- a_0: Free parameter to control core-corona picture

"Mean free path"

$$\frac{1}{\lambda_i} = \rho_i \sigma_i \approx \frac{\rho_i}{p_{T,i}{}^2}$$

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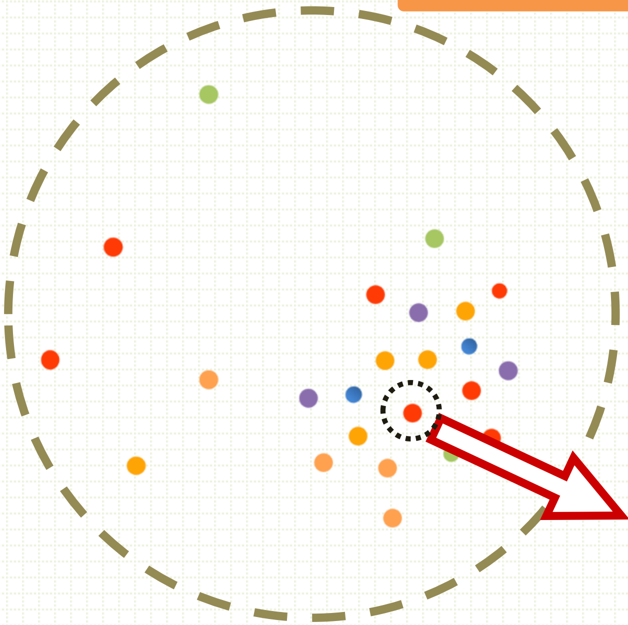

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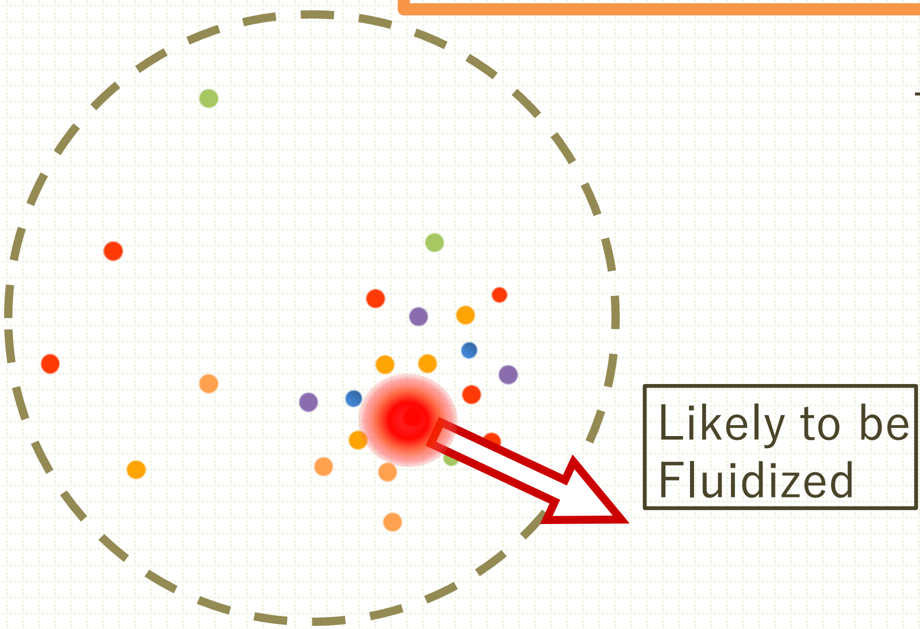

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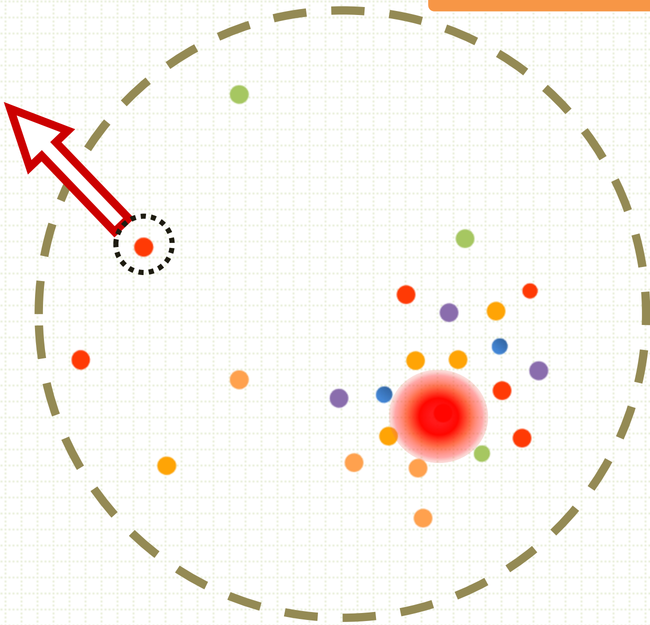

Likely to be Fluidized

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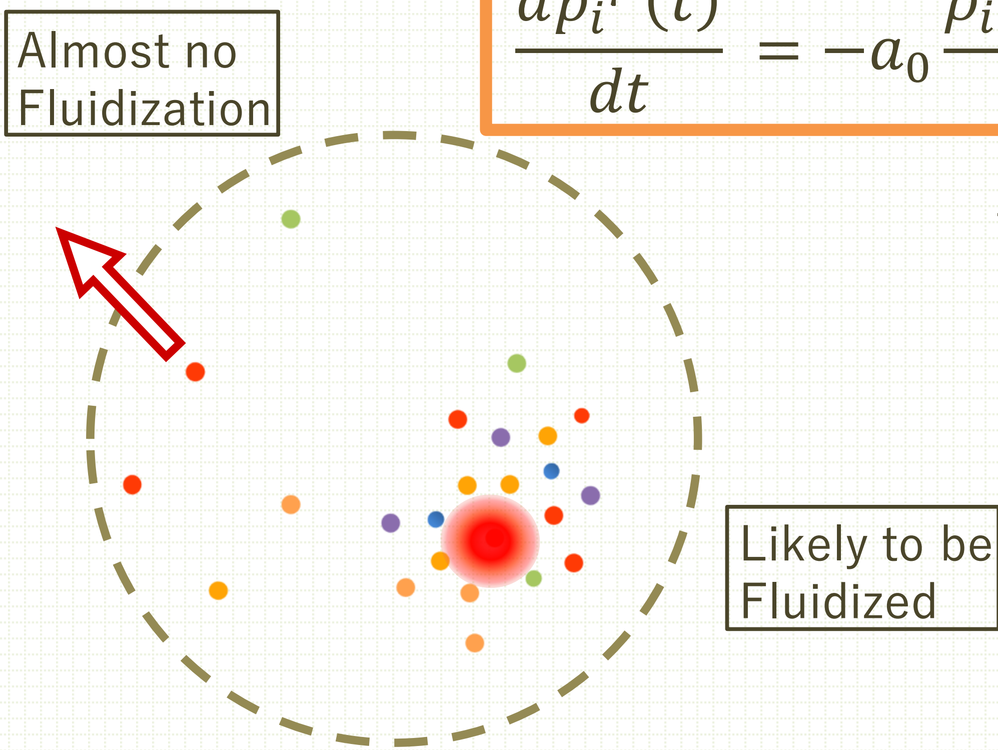

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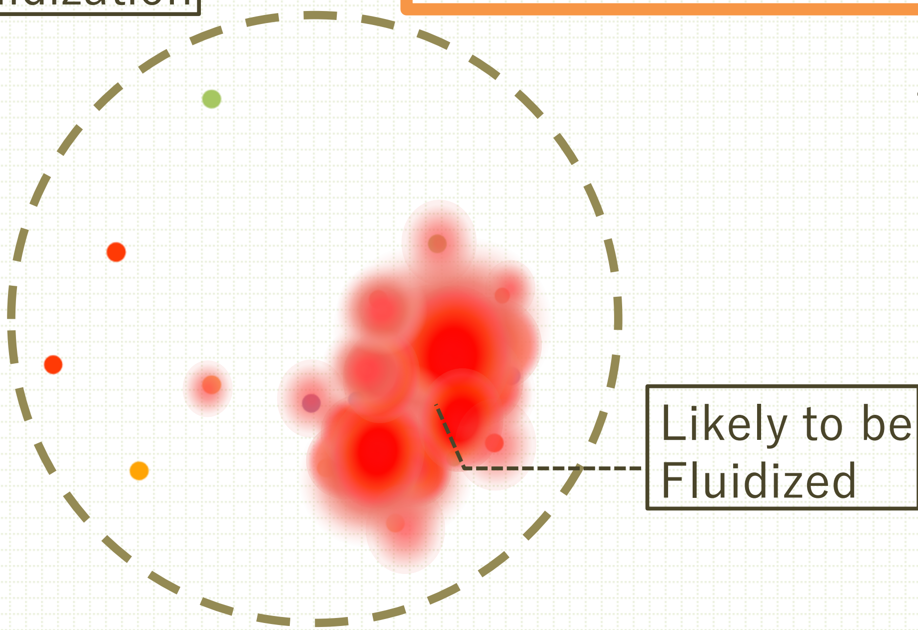
$$\frac{dp_i^{\mu}(t)}{dt} = -a_0 \frac{\rho_i\left(x_i(t)\right)}{{p_{\mathrm{T},i}}^2} p_i^{\mu}(t)$$

Almost no Fluidization



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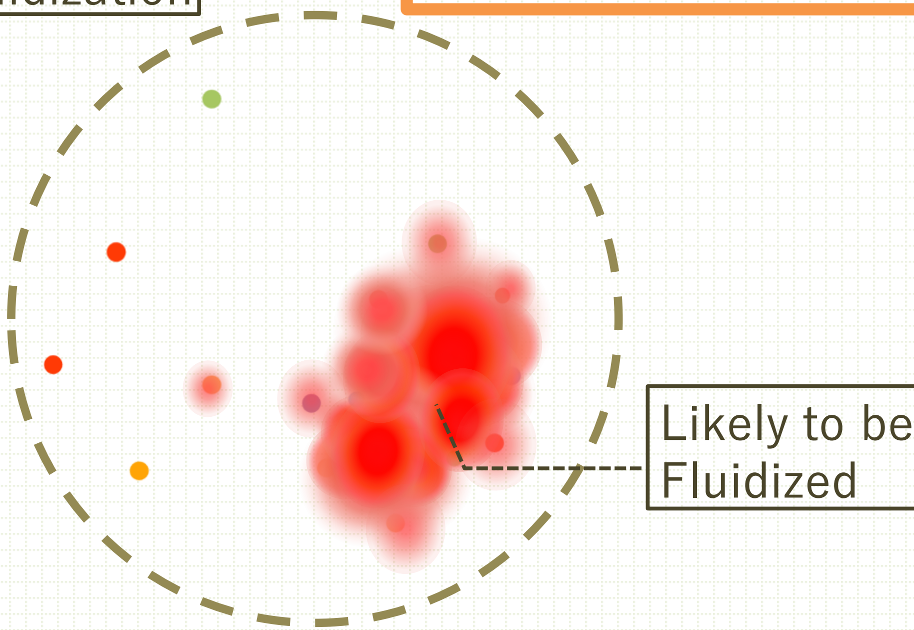

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"Mean free path"

$$\frac{1}{\lambda_i} = \rho_i \sigma_i \approx \frac{\rho_i}{p_{T,i}{}^2}$$

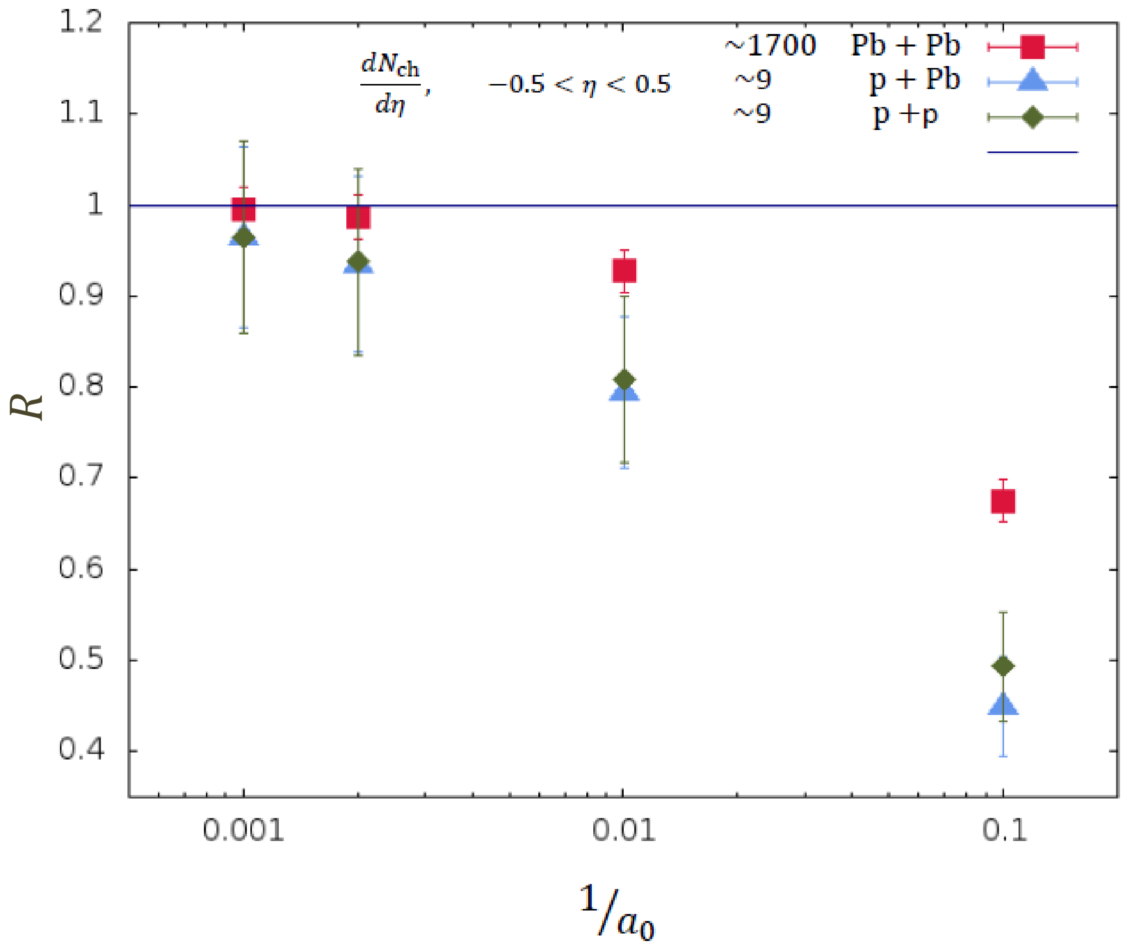
- Fluidization depends on the initial parton distribution.
- dense region ⇕ QGP fluids   dilute region ⇕ Surviving partons

Results

Estimation of $\boldsymbol{a_0}$

a_0 dependence of fluidized energy rate R in each system (typical multiplicity events)

$$R = E_{\text{generated fluid}}/E_{\text{input}}$$



a_0: Free parameter to control core-corona

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$$a_0 = 10^2$$

$R \approx 1$ Pb+Pb

→ Almost fluidized

$R < 1$ p+p, p+Pb

→ Supressed fluidization

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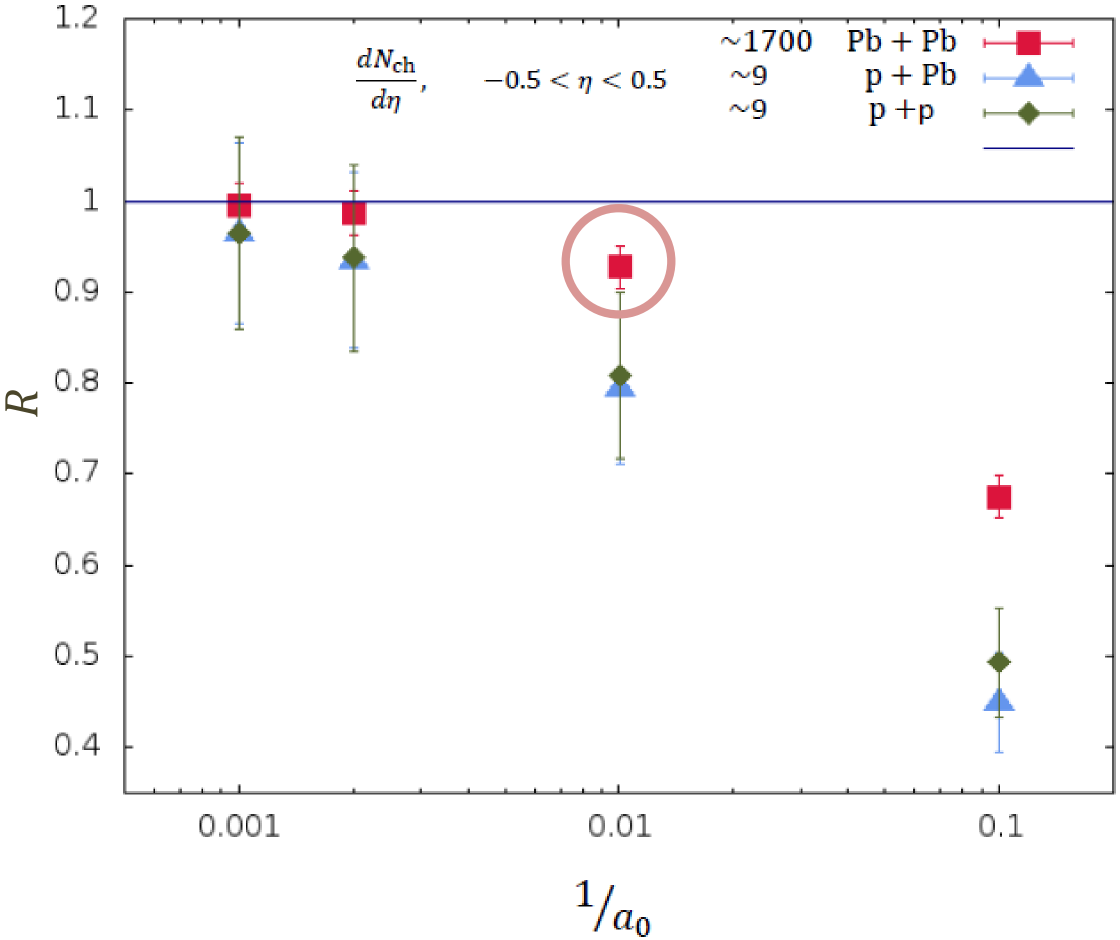

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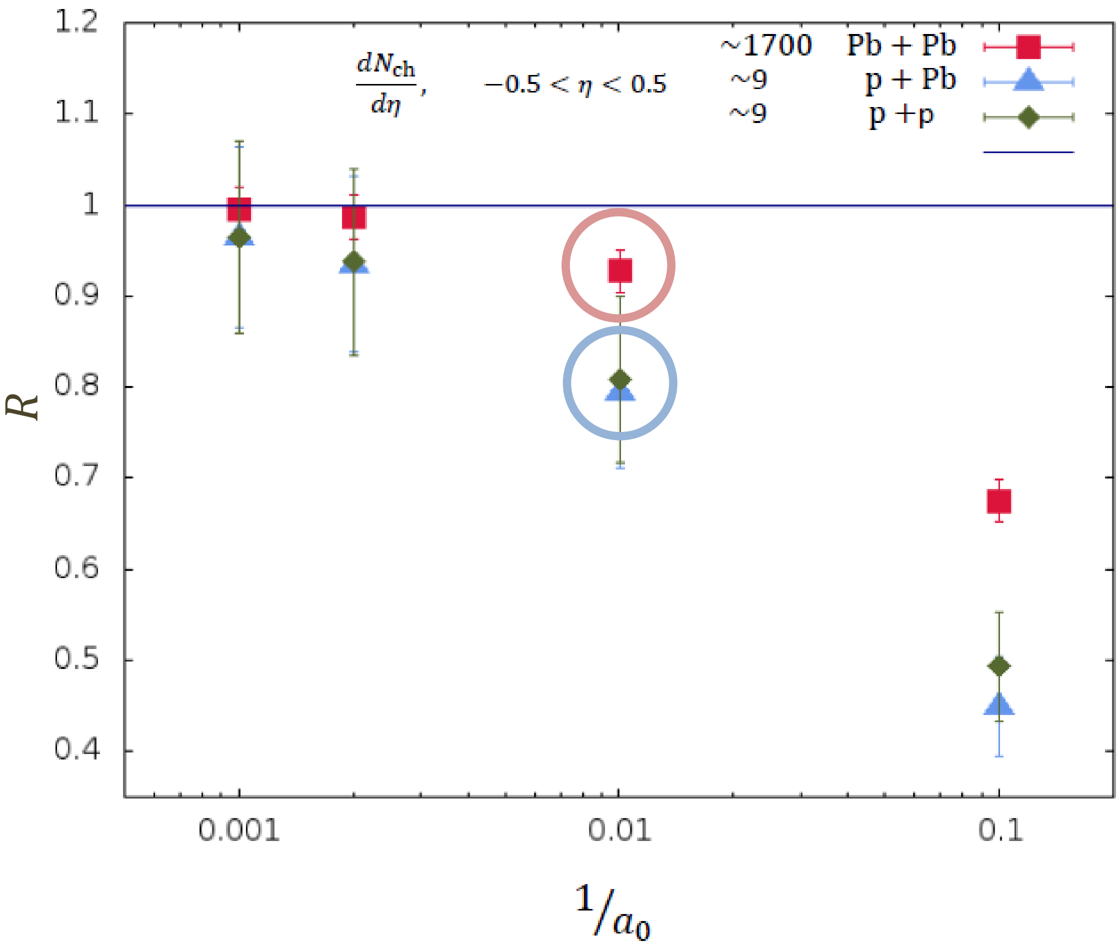

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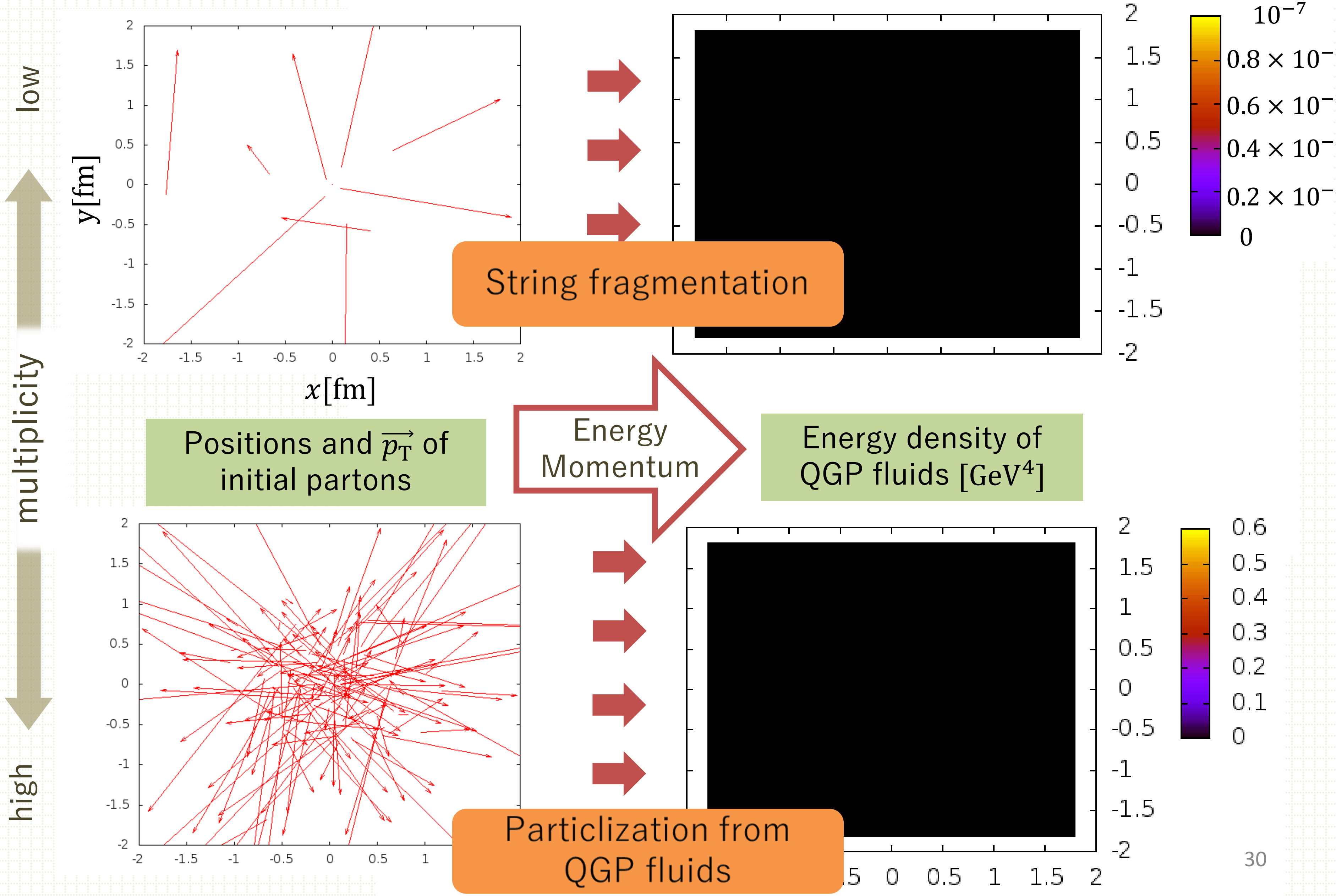
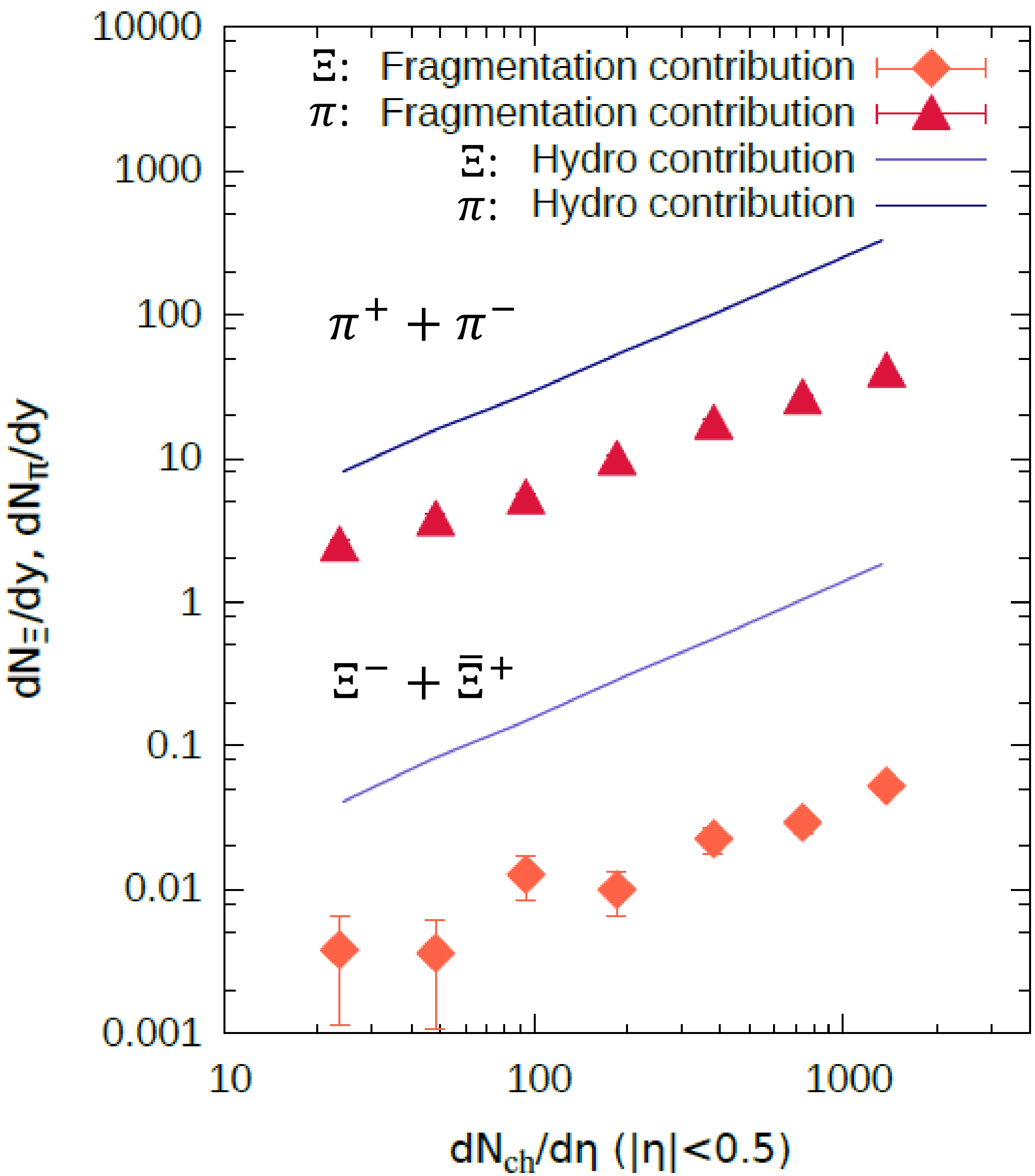
Dynamical initialization with core-corona in p+p



Yield vs multiplicity in Pb+Pb

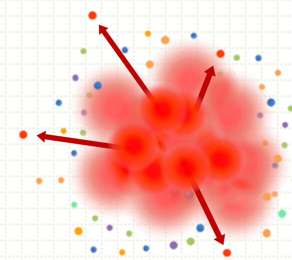


Pb+Pb, $\sqrt{s_{NN}} = 2.76$ TeV

⇩

Initial parton distribution:

Dense



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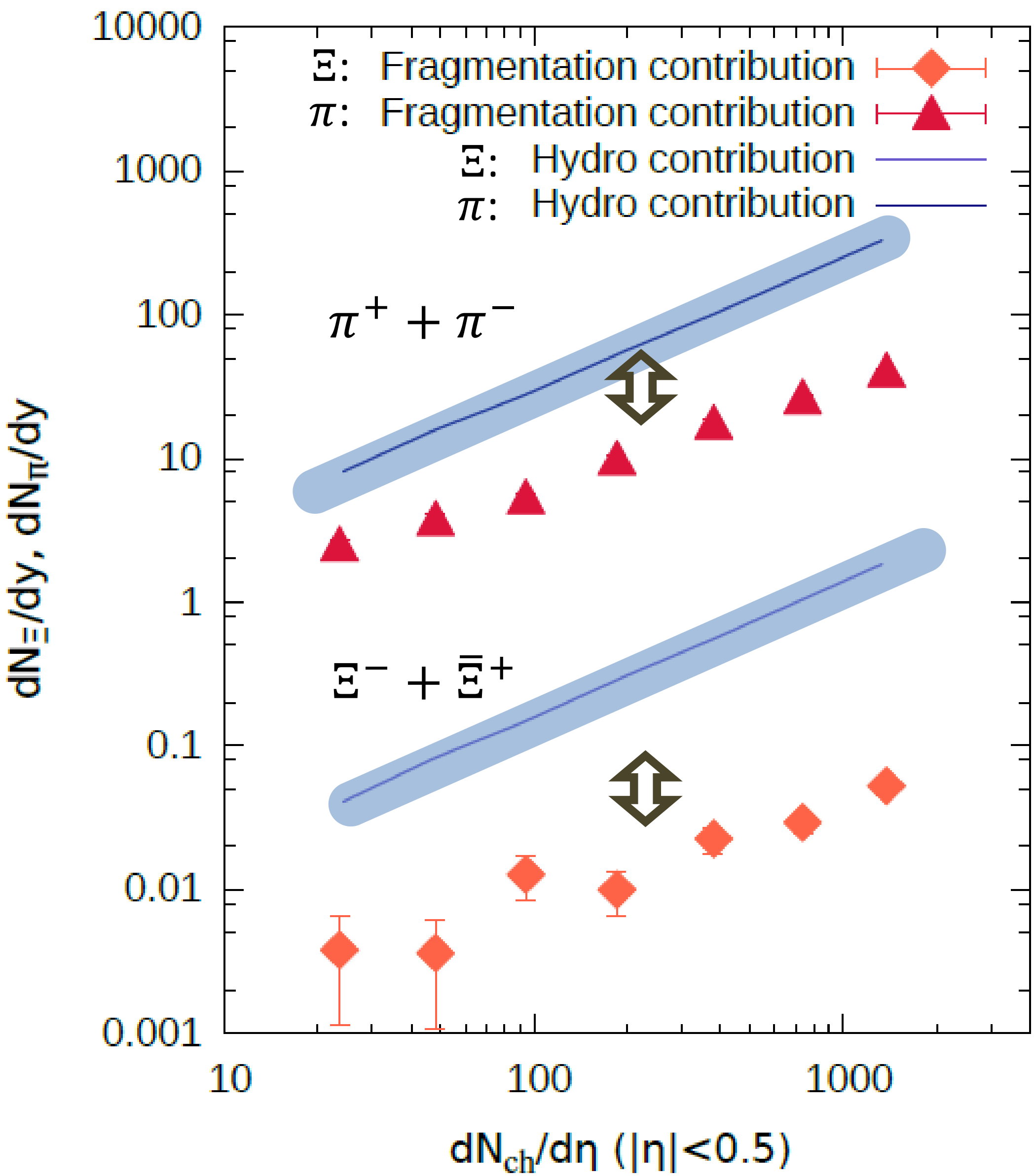

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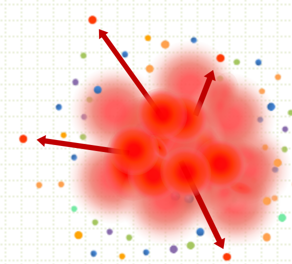
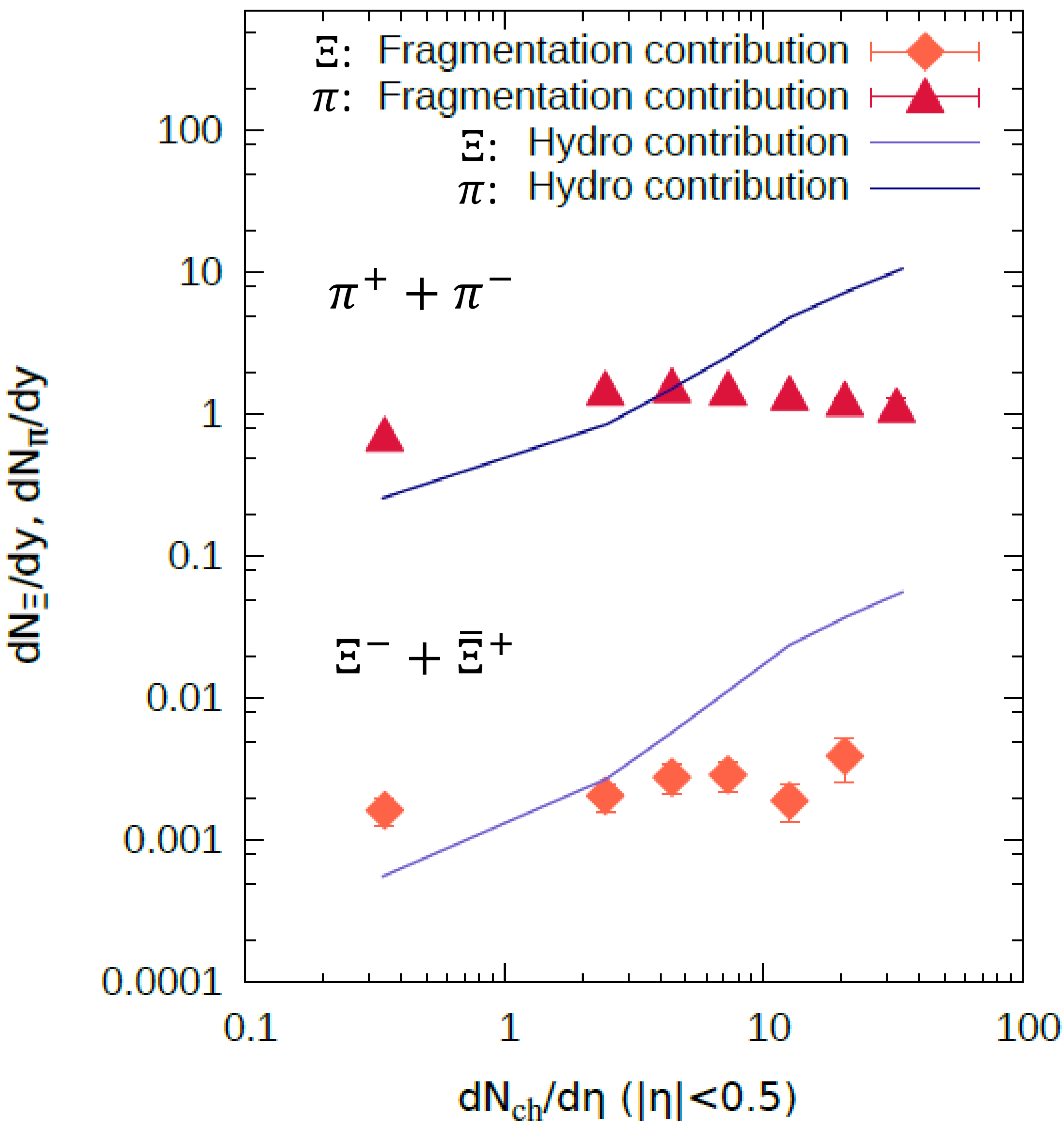


Fluids contribution is dominant in most events.

Yield vs multiplicity in p+p

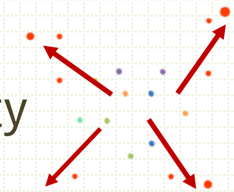


p+p $\sqrt{s_{NN}} = 2.76$ TeV

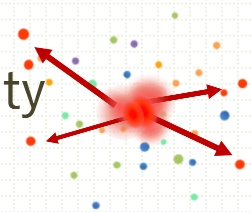
⇩

Initial parton distribution:

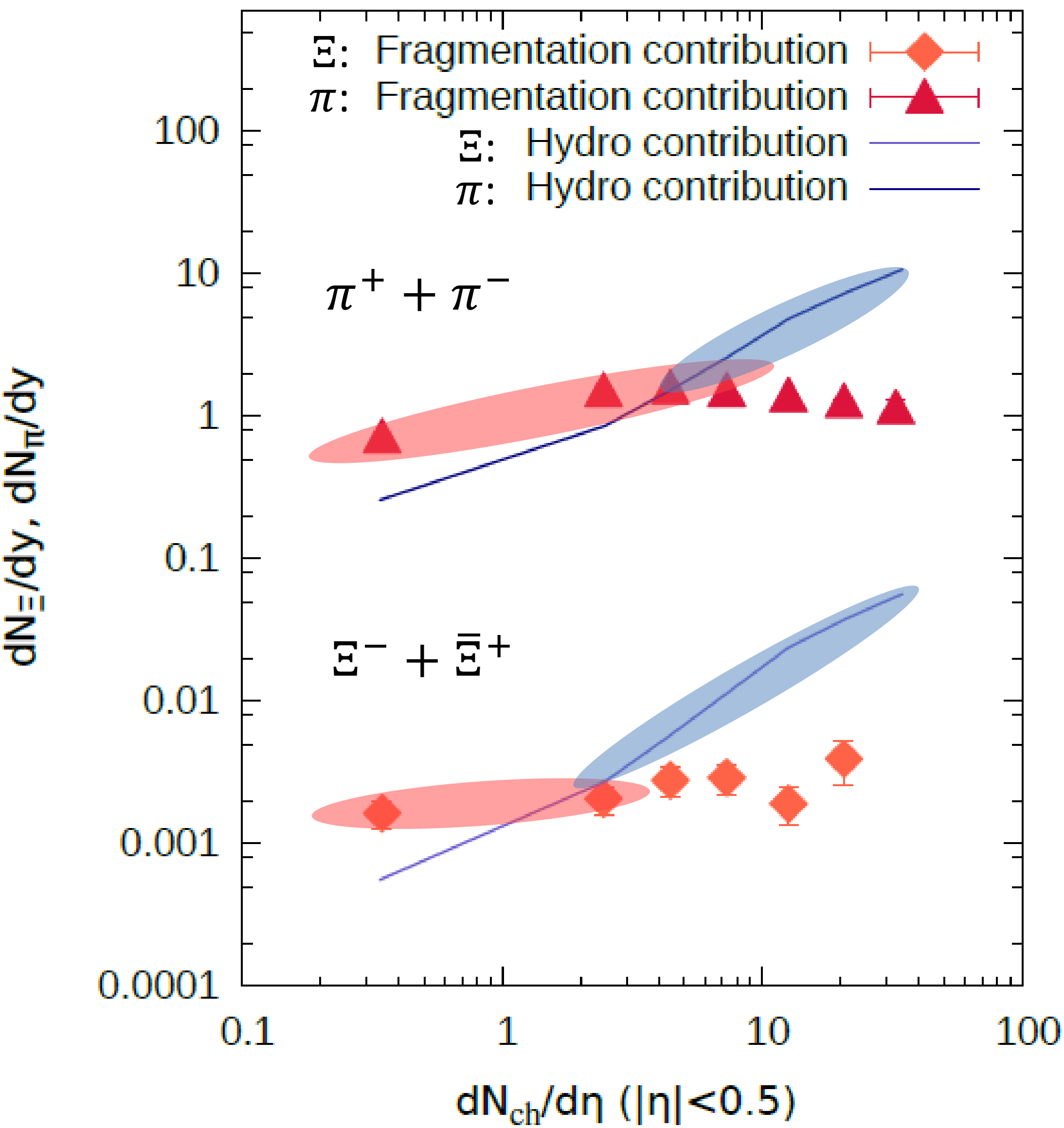
- Dilute in low multiplicity events.



- Dense in high multiplicity events.



Yield vs multiplicity in p+p



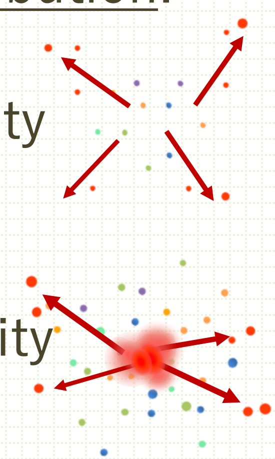
p+p $\sqrt{s_{NN}} = 2.76$ TeV

⇩

Initial parton distribution:

-Dilute
in low multiplicity
events.

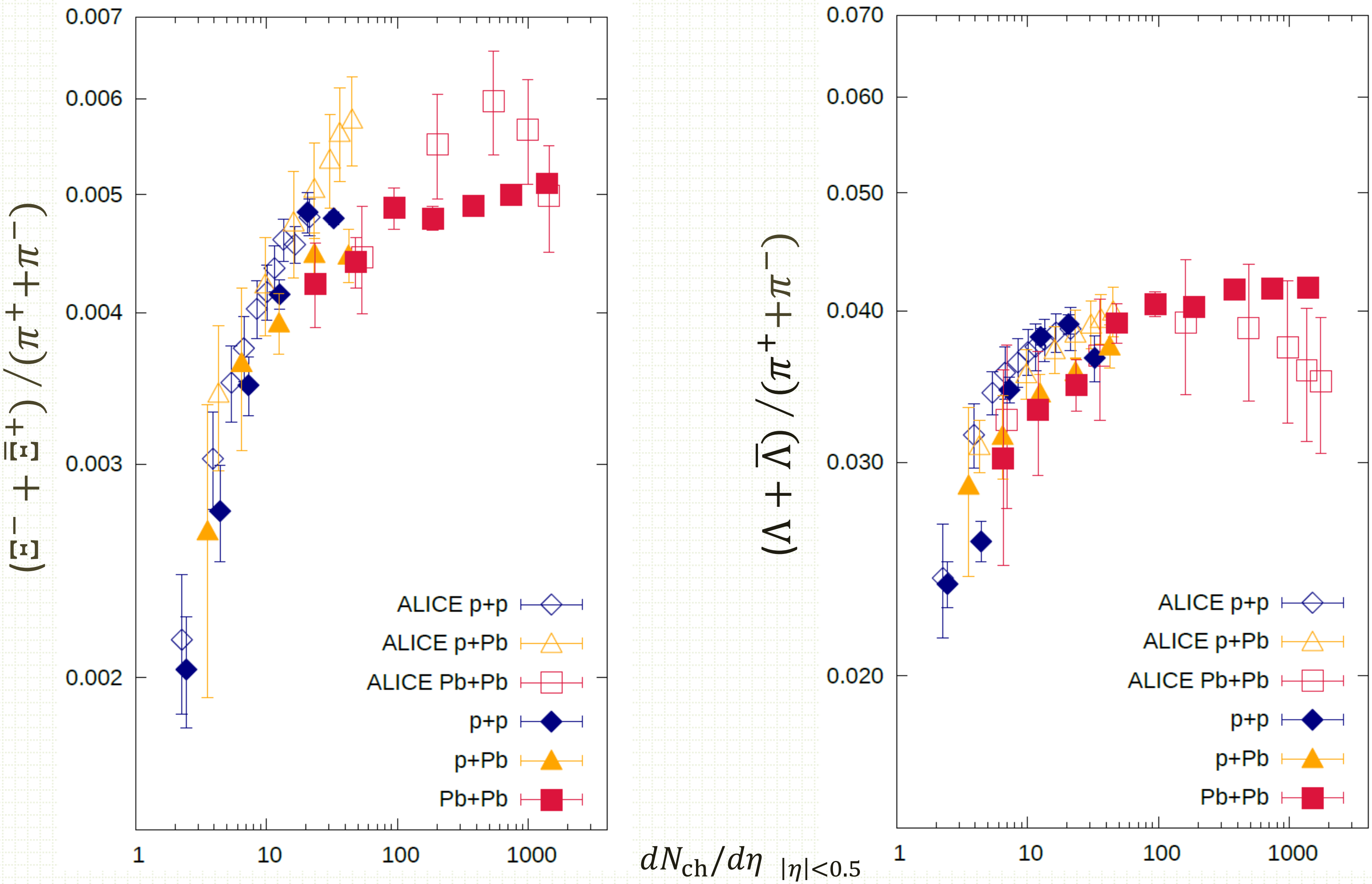
-Dense
in high multiplicity
events.



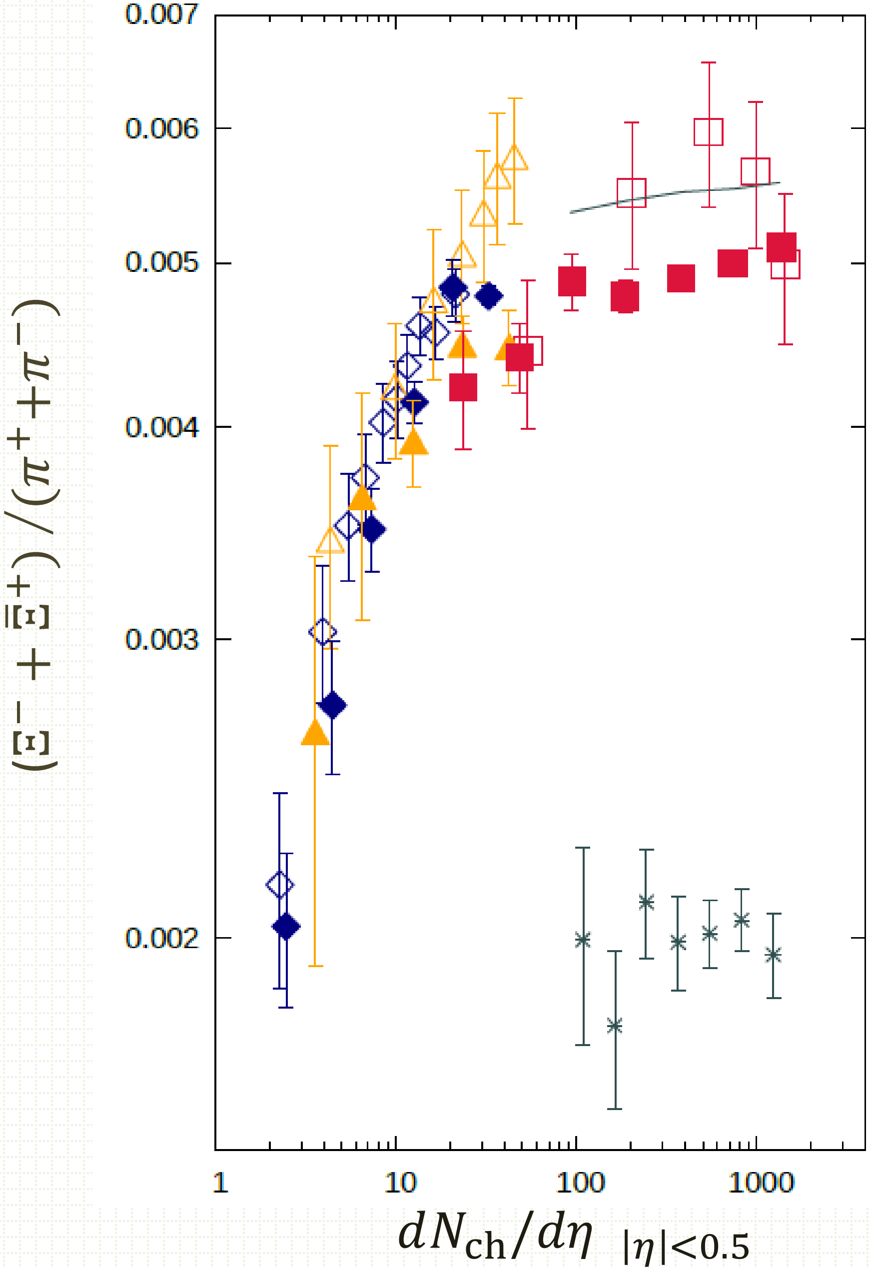
Competition between
fluids and fragmentation
→ depend on multiplicity

Ratio of yields to pions vs multiplicity

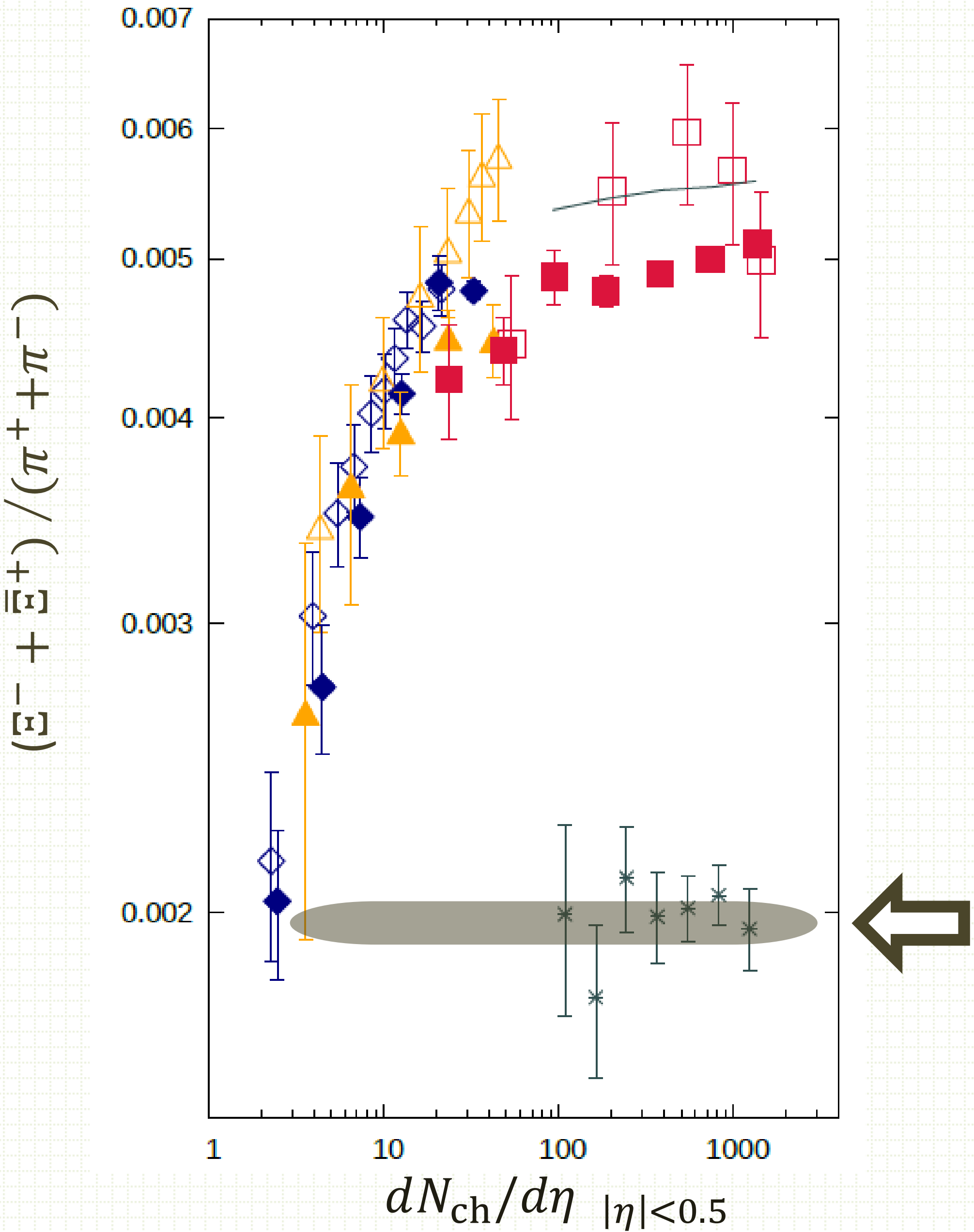
Results from dynamical initialization with core-corona picture



Continuous change of ratio

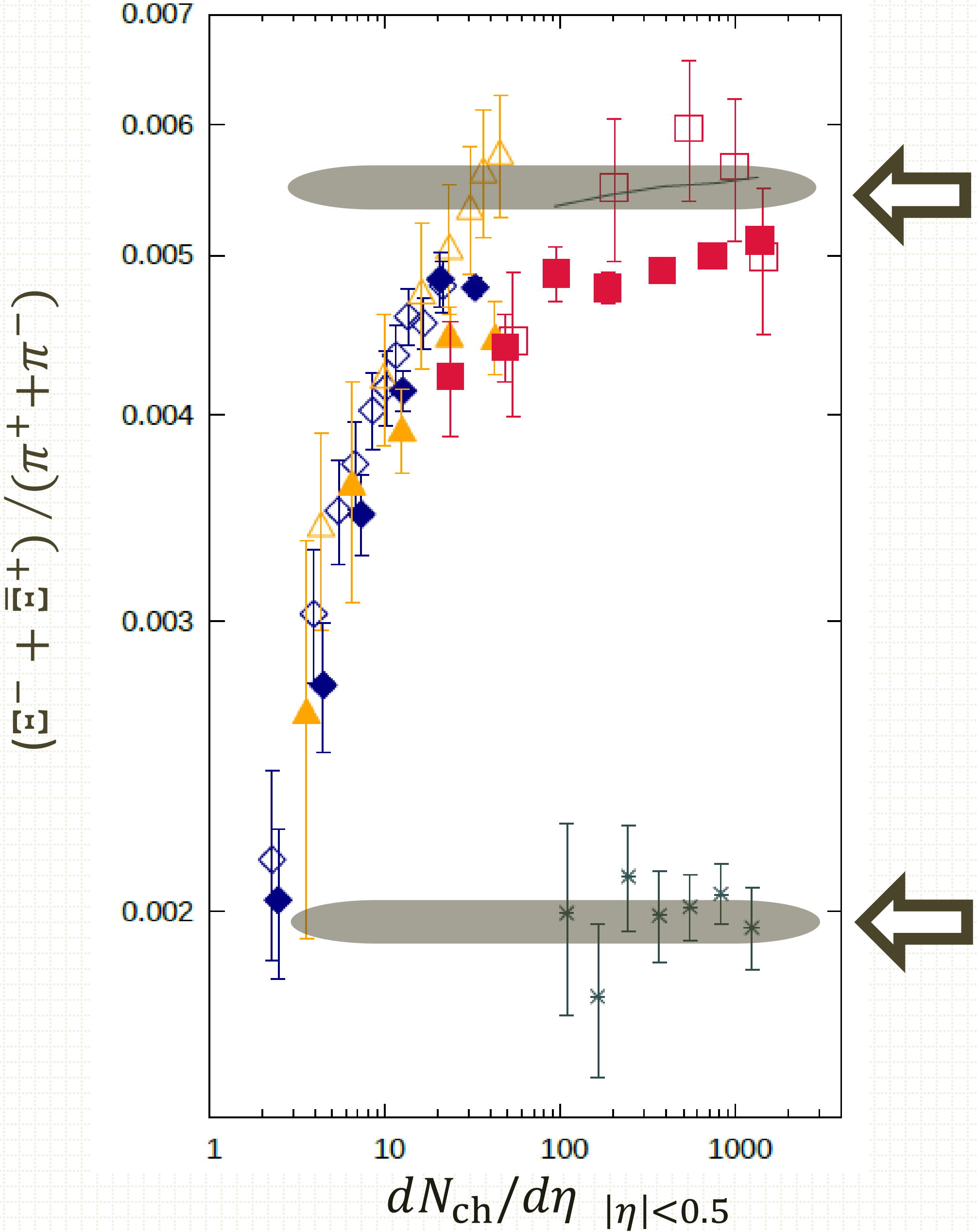


Continuous change of ratio



String fragmentation limit: hadron products only from string fragmentation

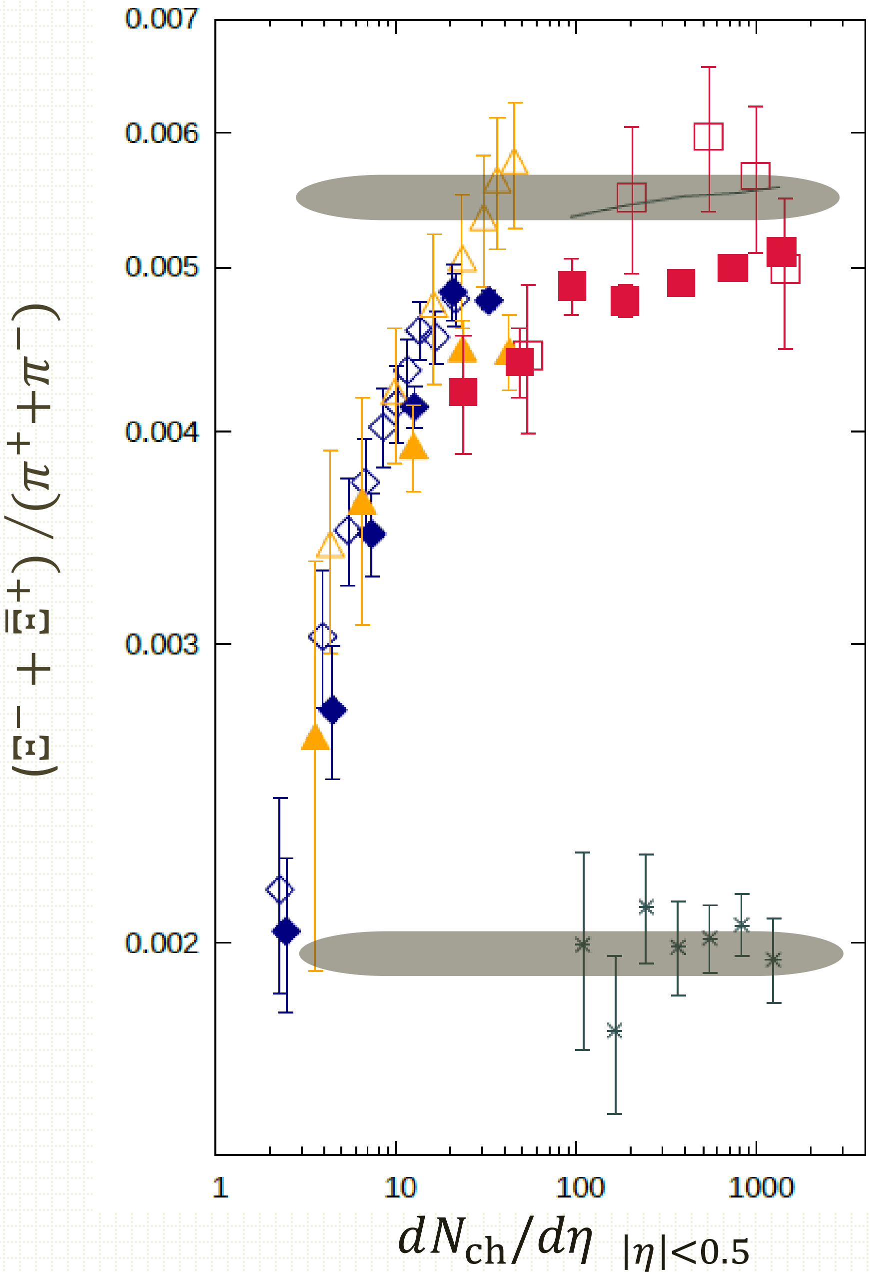
Continuous change of ratio



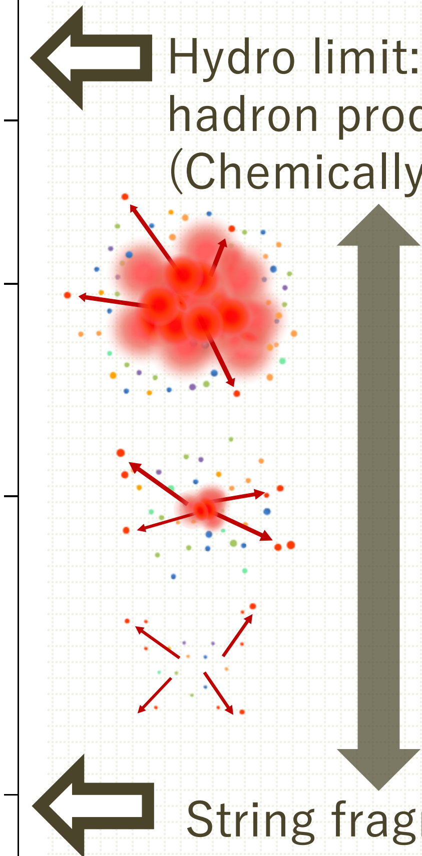
Hydro limit:
hadron products only from fluids
(Chemically equilibrated matter)

String fragmentation limit:
hadron products only from
string fragmentation

Continuous change of ratio



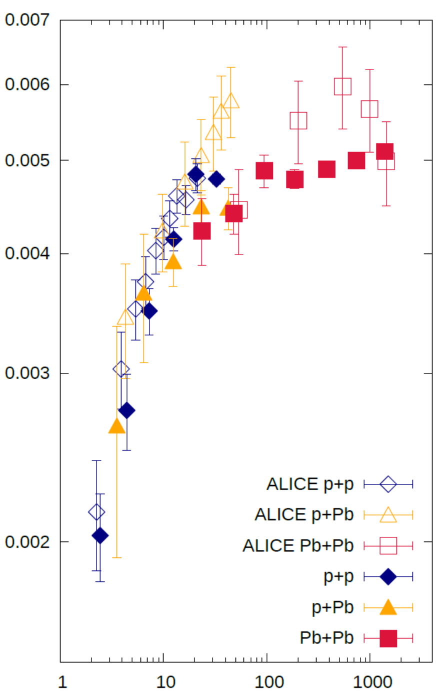
Hydro limit:
hadron products only from fluids
(Chemically equilibrated matter)

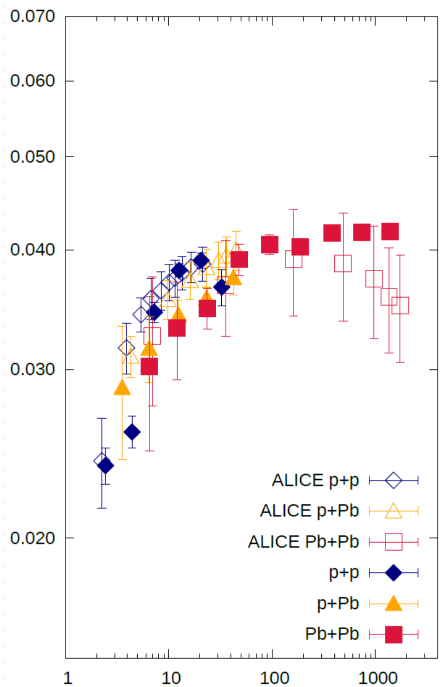


Continuous changes with multiplicity

String fragmentation limit:
hadron products only from string fragmentation

Interpretation of results





p+p $\sqrt{s_{NN}} = 7$ TeV

p+Pb $\sqrt{s_{NN}} = 5.02$ TeV

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

⇩

$dN_{\rm ch}/d\eta \ < \sim 100$:

→ Increase

$dN_{\rm ch}/d\eta \ \geq \sim 100$:

→ Saturation

Almost independent of collision energy and system size.

Strong implication:

QGP fluids are partly created even in small systems if multiplicity is high.

Summary & Outlook

Summary

- Dynamical initialization + core-corona picture
  - Low p_{T} partons in dense region tend to be fluids.
  - Two different hadronization processes
    - Particlization of chemically equilibrated matter (fluids)
    - String fragmentation
- Analysis of strangeness enhancement in p+p, p+Pb and Pb+Pb
  - Reproduced the tendency of ALICE data.
    - Continuous change of strangeness ratio with multiplicity
    - Almost no energy or system size dependence

→ **Multiplicity** is the key for QGP creation.
→ **Core-corona** picture is important for interpretation of strangeness enhancement in small systems.

Outlook

More possibilities to explain collectivity in small systems with dynamical initialization with core-corona picture

- Collective flow in small systems
  - Radial flow
  - Flow harmonics
  - Ridge structure
  - …
- Core-corona effects in large systems
  - Jet quenching
  - Collective flow in peripheral collisions
  - …

Future work: Sophistication of our model for more detailed study