Strangeness enhancement from dynamical core-corona initialisation model

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https://www.lonelyplanet.com/italy/puglia-basilicata-calabria/travel-tips-and-articles/bari-reinvented-why-you-should-visit-puglias-underrated-port/

Strangeness enhancement as a QGP signal

80s: Theoretical proposition

J. Rafelski, Phys. Lett. B 262 (1991) 333.
J. Rafelski and B. Muller, Phys. Rev. Lett., 48, 1066, (1982).

Thermal equilibrium → Strangeness abundance saturates within QGP lifetime

80s-90s: First report of strangeness enhancement

J. Bartke et al. [NA35 Collaboration], Z. Phys. C 48 (1990) 191.
S. Abatzis et al. [WA85 Collaboration], Phys. Lett. B 270 (1991) 123.
T. Alber et al. [NA35 Collaboration], Phys. Lett. B 366 (1996) 56.

Strange hadron yield ratios : A+A > p+p

2005: Press release "Nearly perfect fluidity of QGP"

https://www.bnl.gov/newsroom/news.php?a=110303

QGP formation in A+A

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.
.

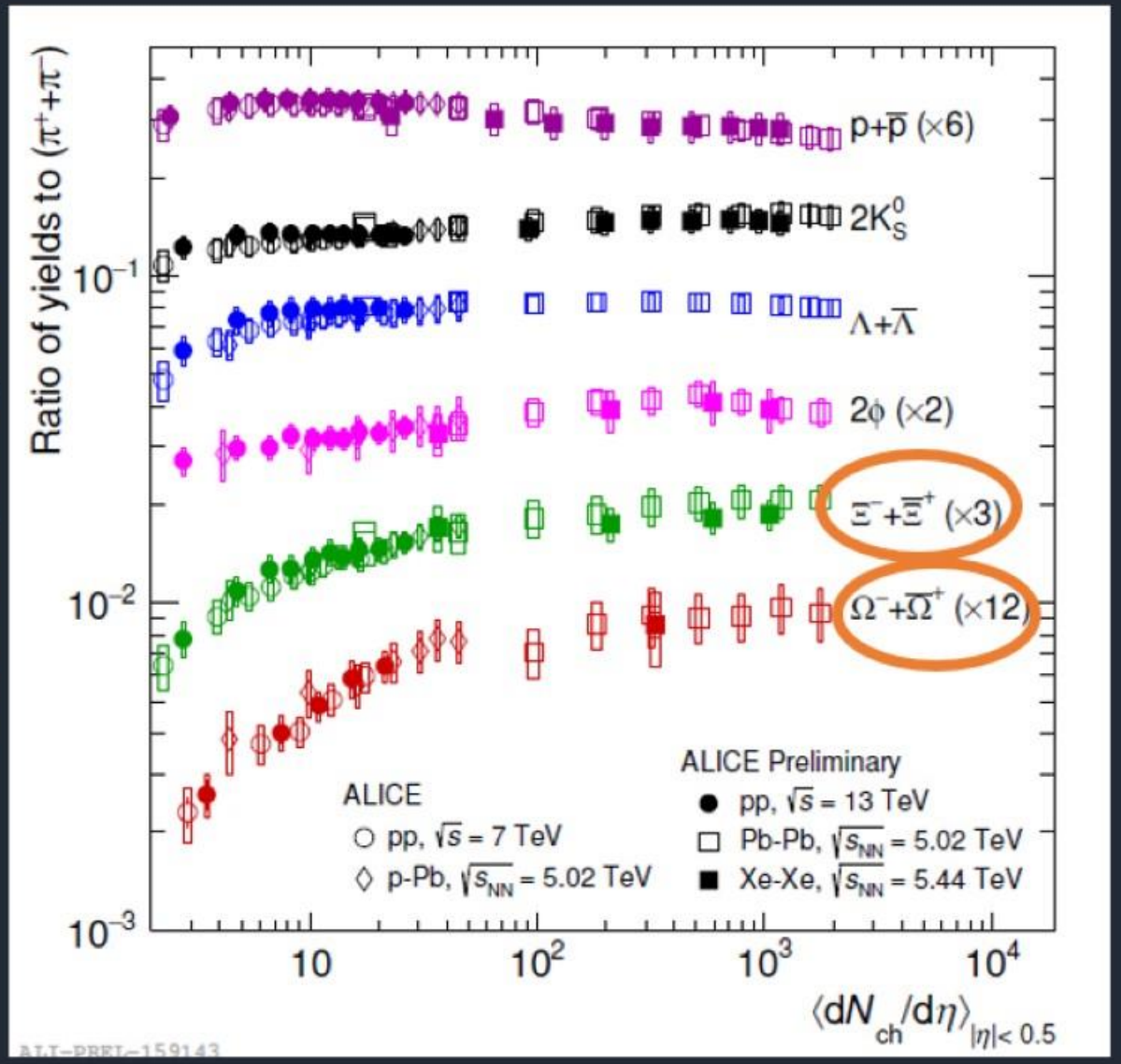
PARADIGM SHIFT!?

2017: Strangeness enhancement in small systems at high multiplicity

J. Adam et al. (ALICE), Nature Phys. 13, 535 (2017)

Indication of QGP formation in p+p and p+A as well

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 ?

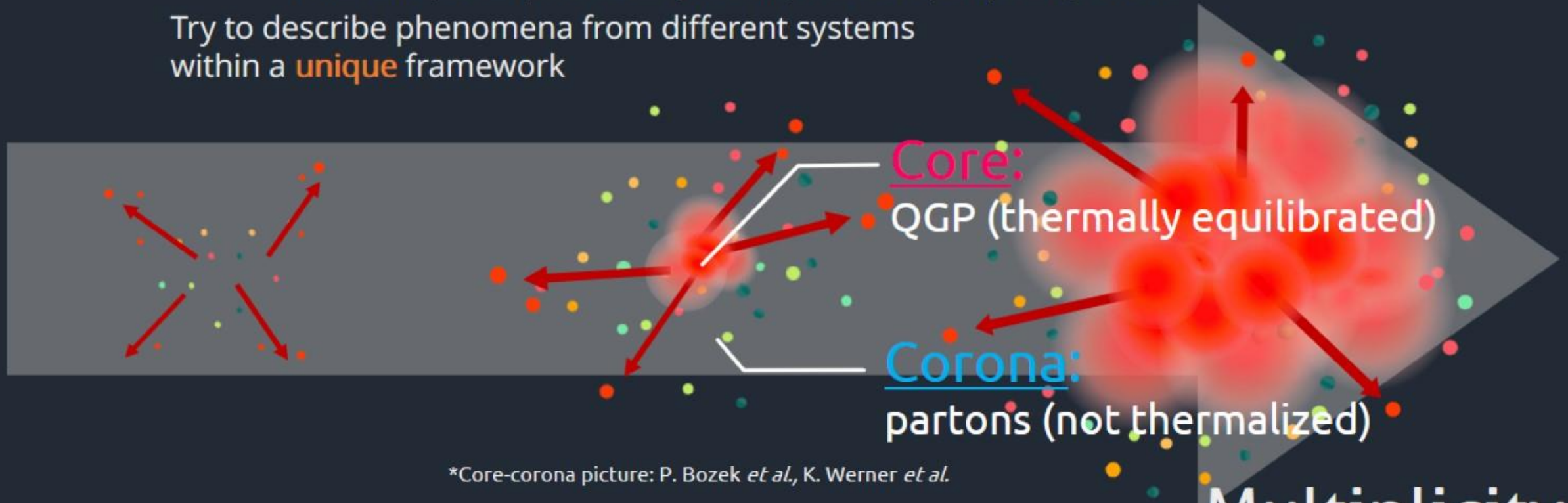
Motivation

Interpolation between p+p and heavy-ion collisions

→ "Dynamical core-corona initialisation model"

Y. Kanakubo, M. Okai, Y. Tachibana, T. Hirano, PTEP 2018 (2018) no.12, 121D01

Try to describe phenomena from different systems
within a **unique** framework



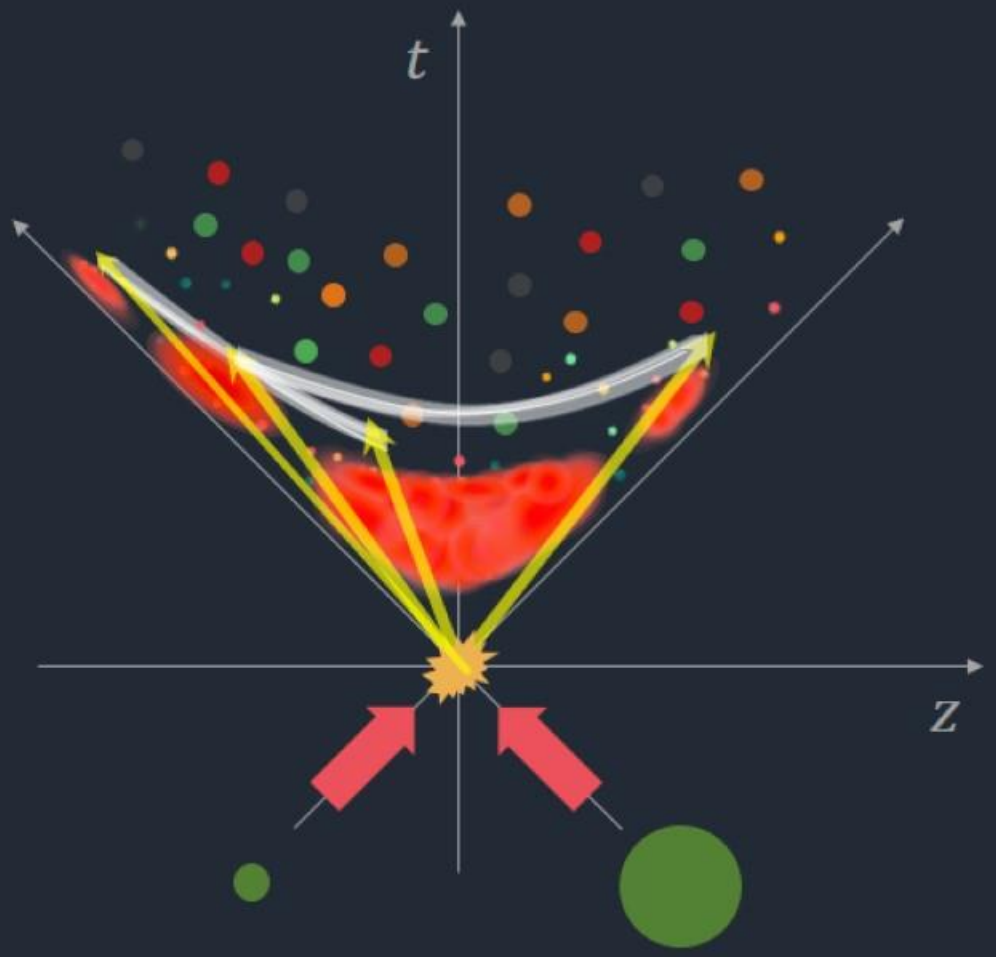
*Core-corona picture: P. Bozek *et al.*, K. Werner *et al.*

QGP signals in small system

→ **The same origin as ones observed in heavy-ion collisions?**

Model

Y. Kanakubo, M. Okai, Y. Tachibana, T. Hirano, PTEP 2018 (2018) no.12, 121D01



Hadronisation (particlisation)

Core → Freezeout at $T_{\mathrm{fo}} = 160$ MeV via Cooper-Frye formula

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

Dynamical core-corona initialisation

(3+1)-D ideal hydro, Lattice EoS (3 flavour)

Y. Tachibana and T. Hirano, Nucl.Phys. A904-905 (2013)

S. Borsanyi *et al.*, Phys. Lett. **B730**, 155 (2014).

Parton generation

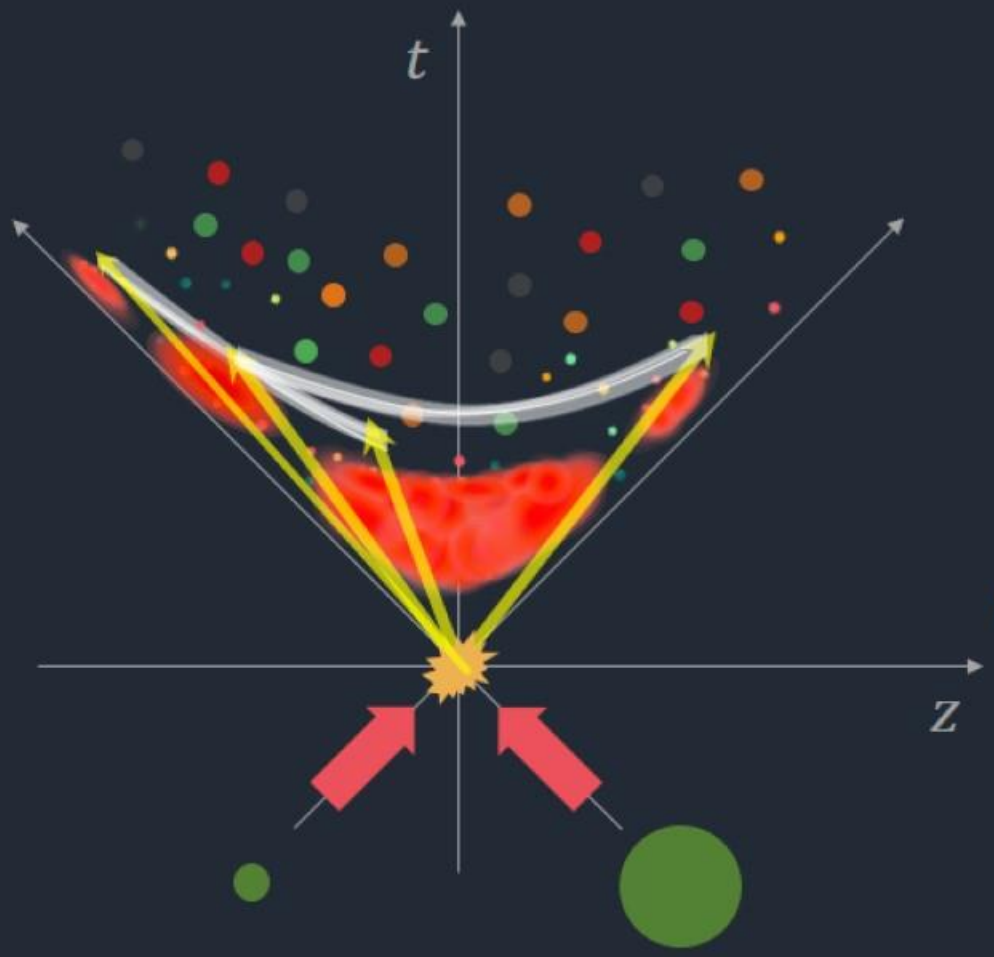
PYTHIA ver 8.230 (hadronization = off)

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

C. Bierlich *et al.*, JHEP 1610 (2016) 139.

Model

Y. Kanakubo, M. Okai, Y. Tachibana, T. Hirano, PTEP 2018 (2018) no.12, 121D01



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+ 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 initialisation**

(3+1)-D ideal hydro, Lattice EoS (3 flavour)

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 (hadronization = off)

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

C. Bierlich *et al.*, JHEP 1610 (2016) 139.

Dynamical initialisation

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

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

G: Gaussian function

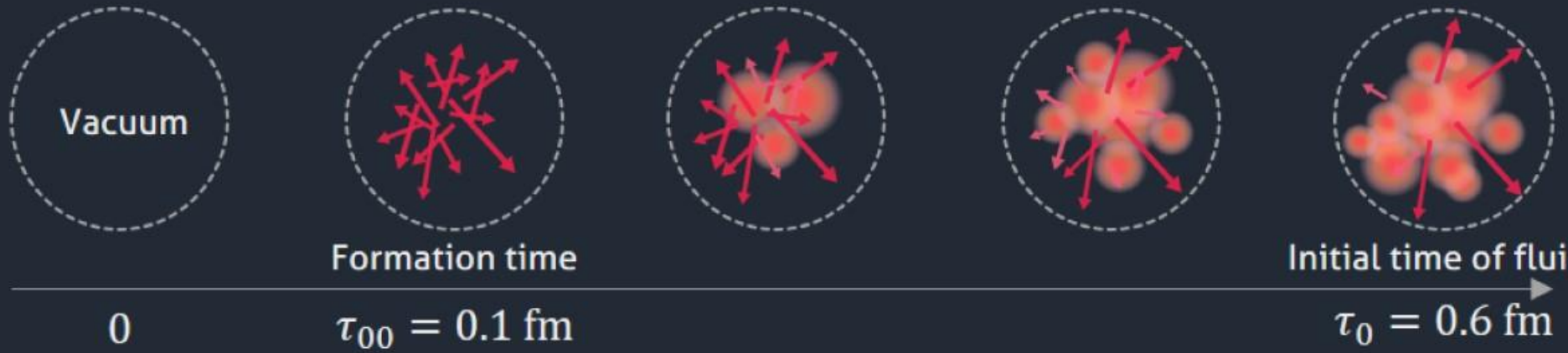
Energy & momentum conservation

→ Continuum eq. for QGP+parton

$$\partial_\mu [T^{\mu\nu}_{\text{QGP}} + T^{\mu\nu}_{\text{parton}}] = 0$$

Hydrodynamic eq. with source term:

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



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

Dynamical core-corona initialisation

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 distribution of partons

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

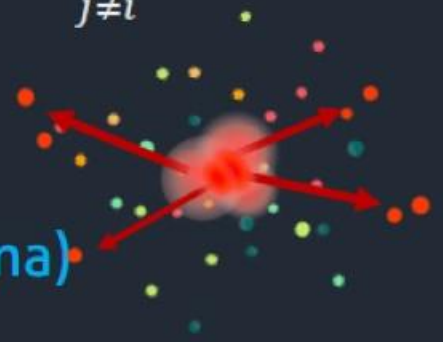
Vacuum

Partons

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

QGP fluids (core)

Surviving partons (corona)

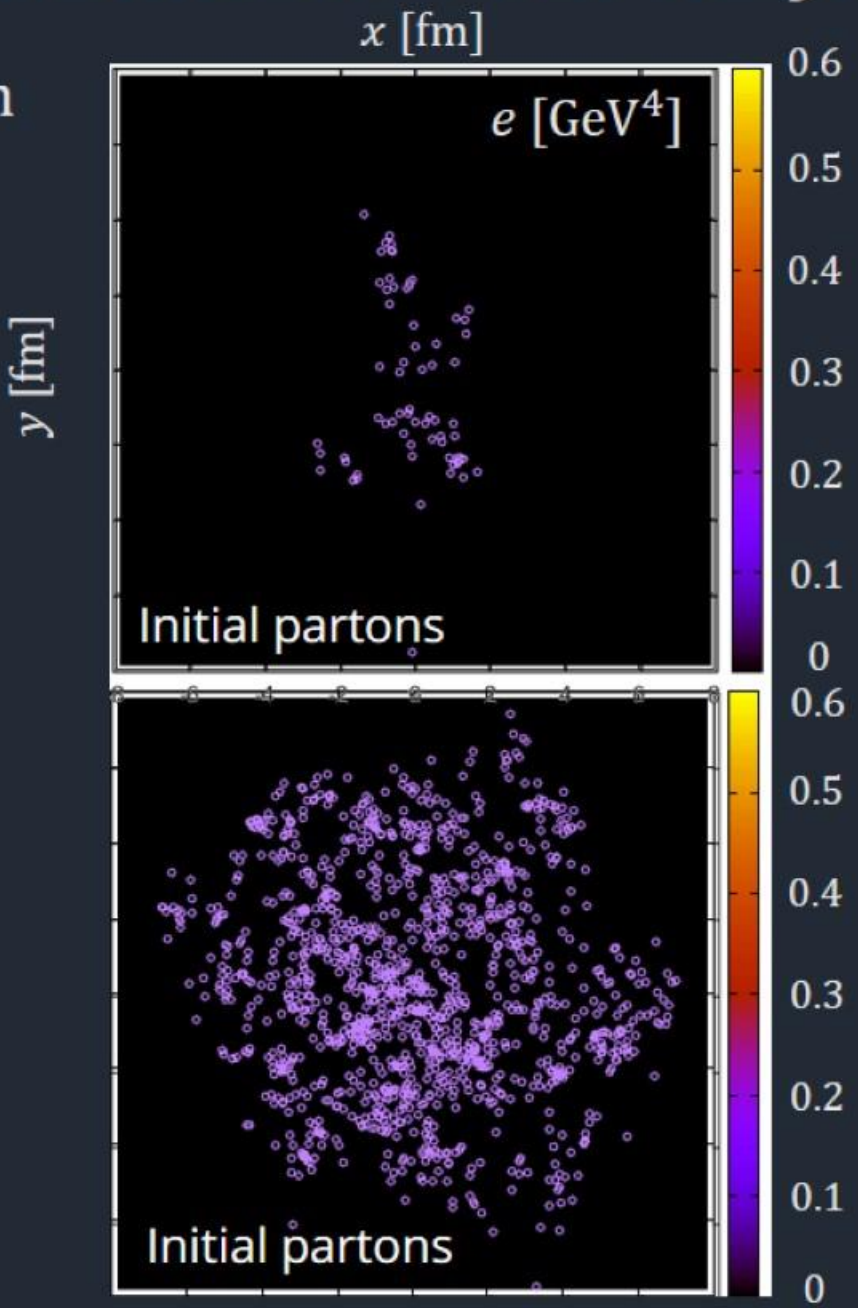


Result: Time evolution of dynamical core-corona initialisation

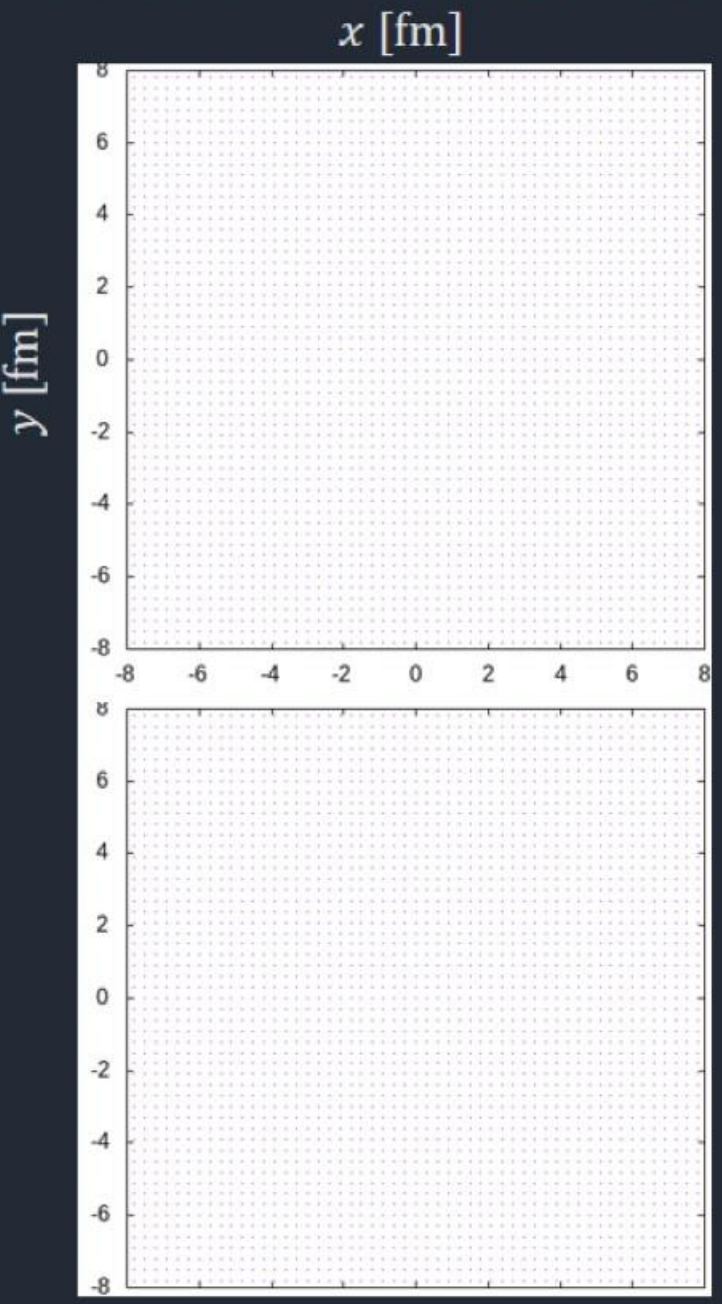
$\tau = 0.10$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central



$v_\perp$

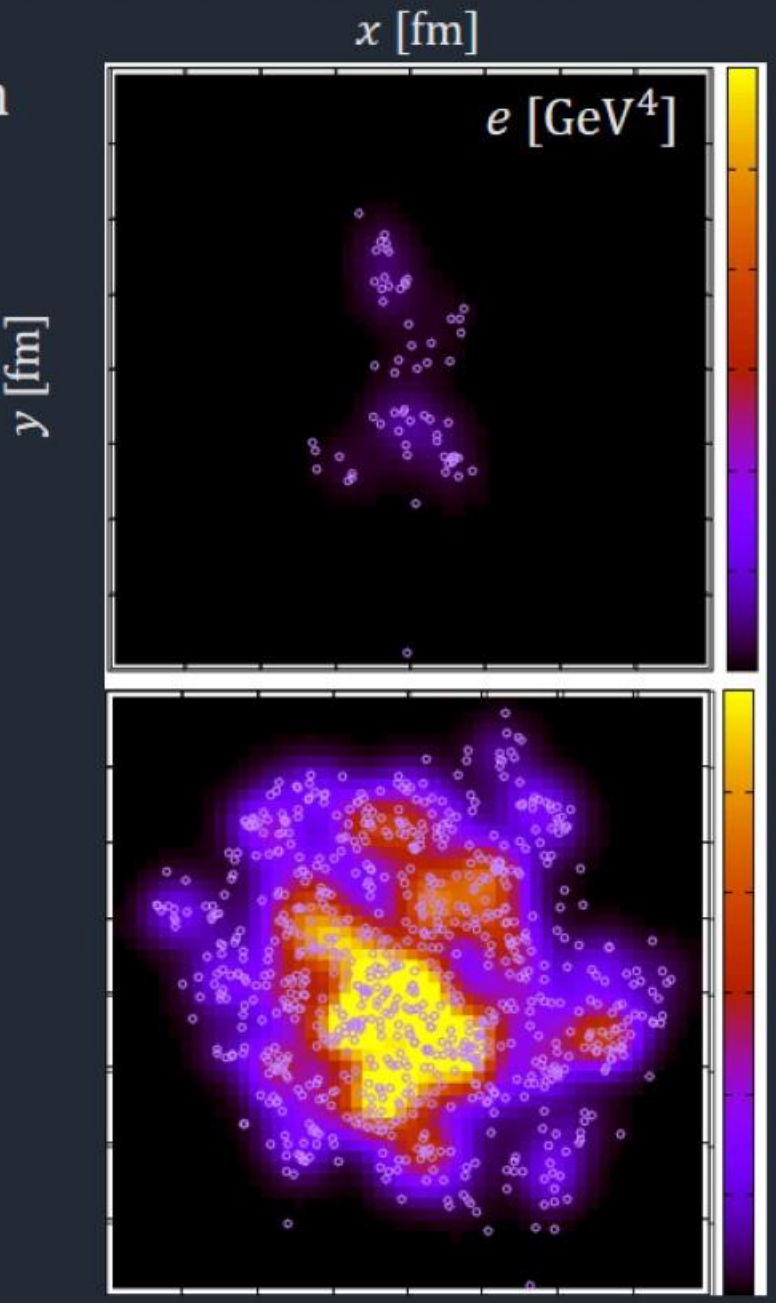


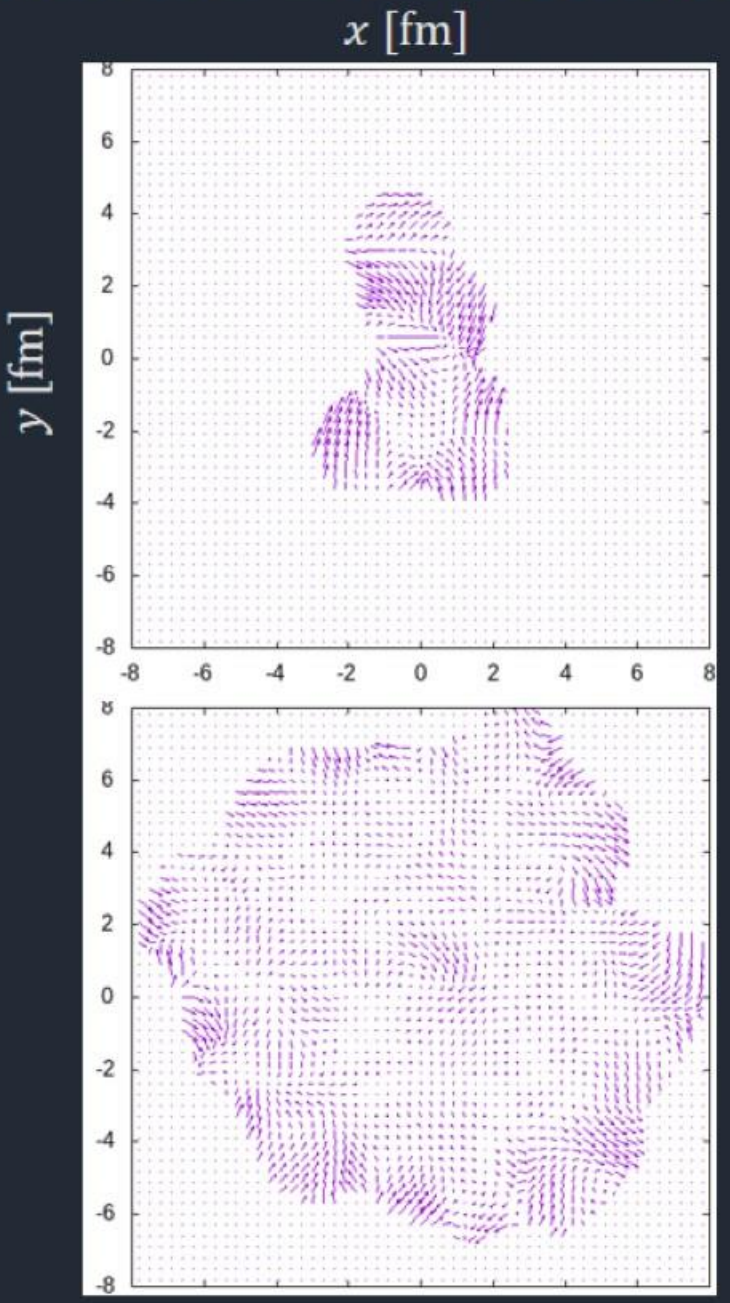
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.11$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





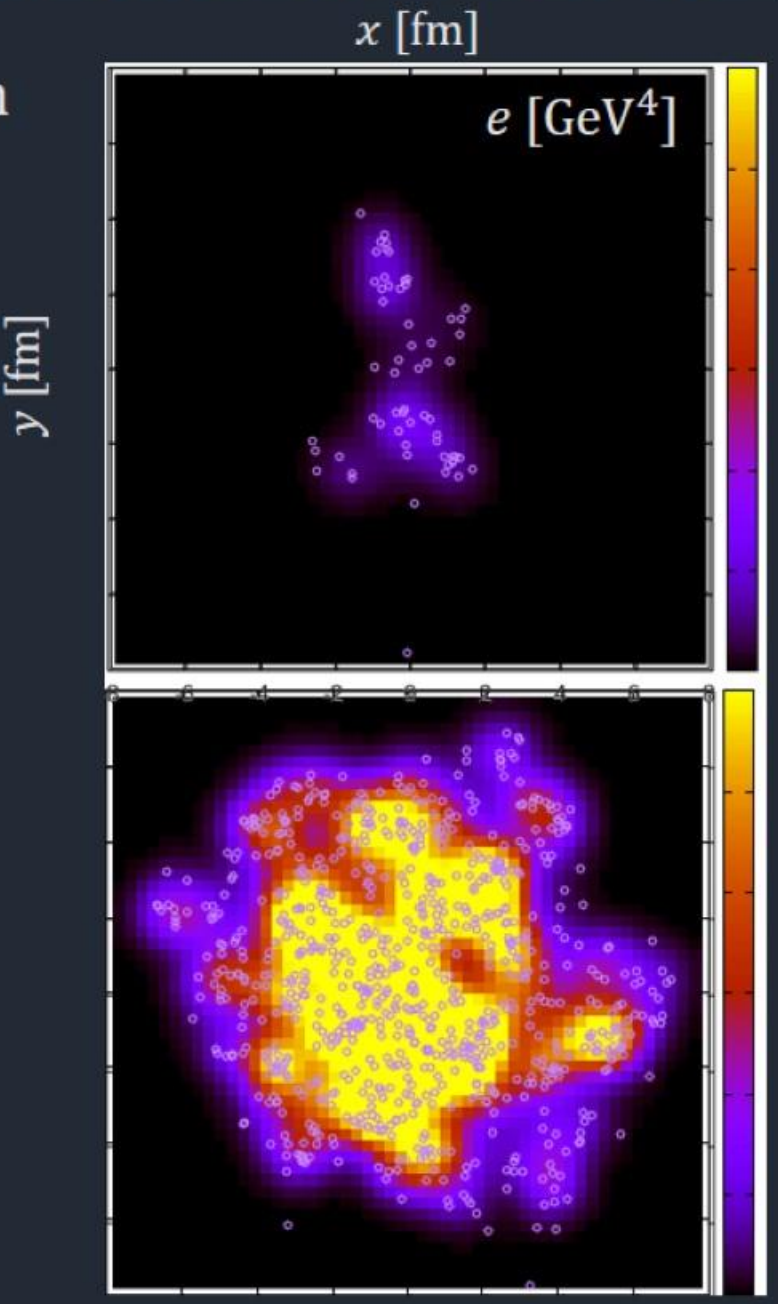
$v_\perp$

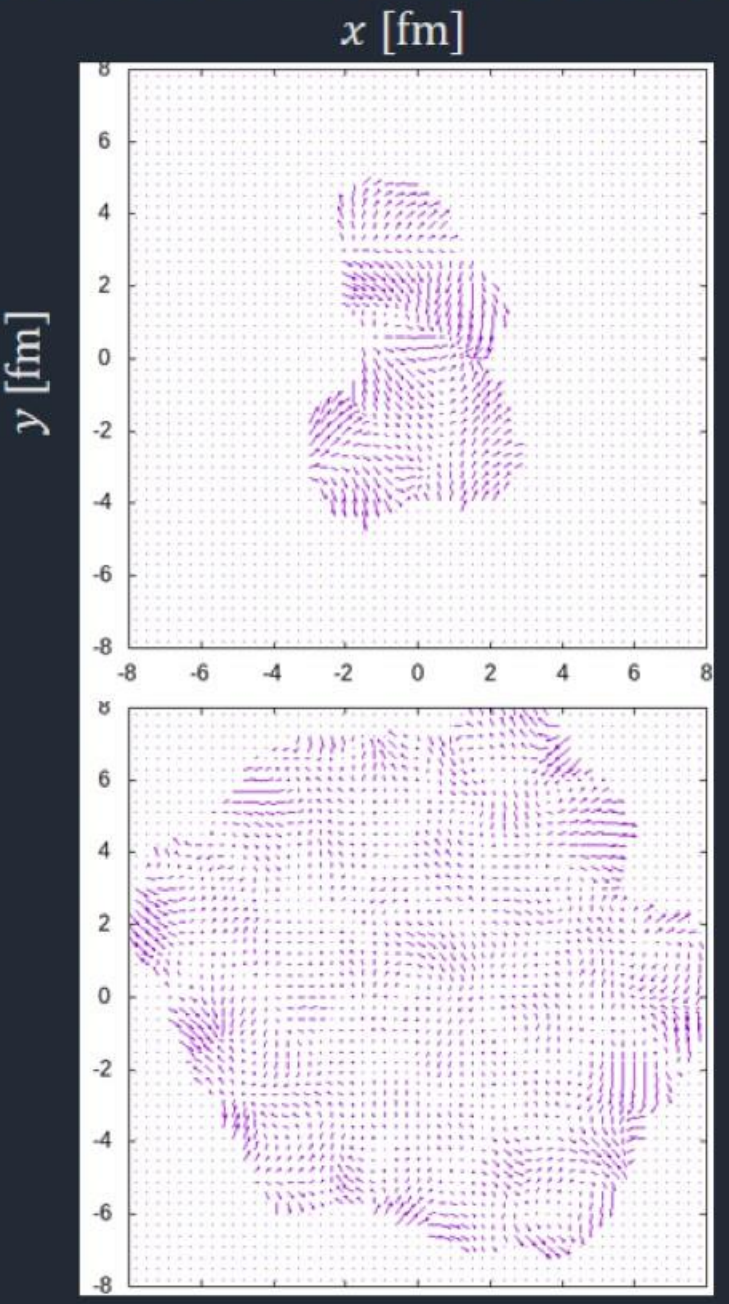
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.12$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





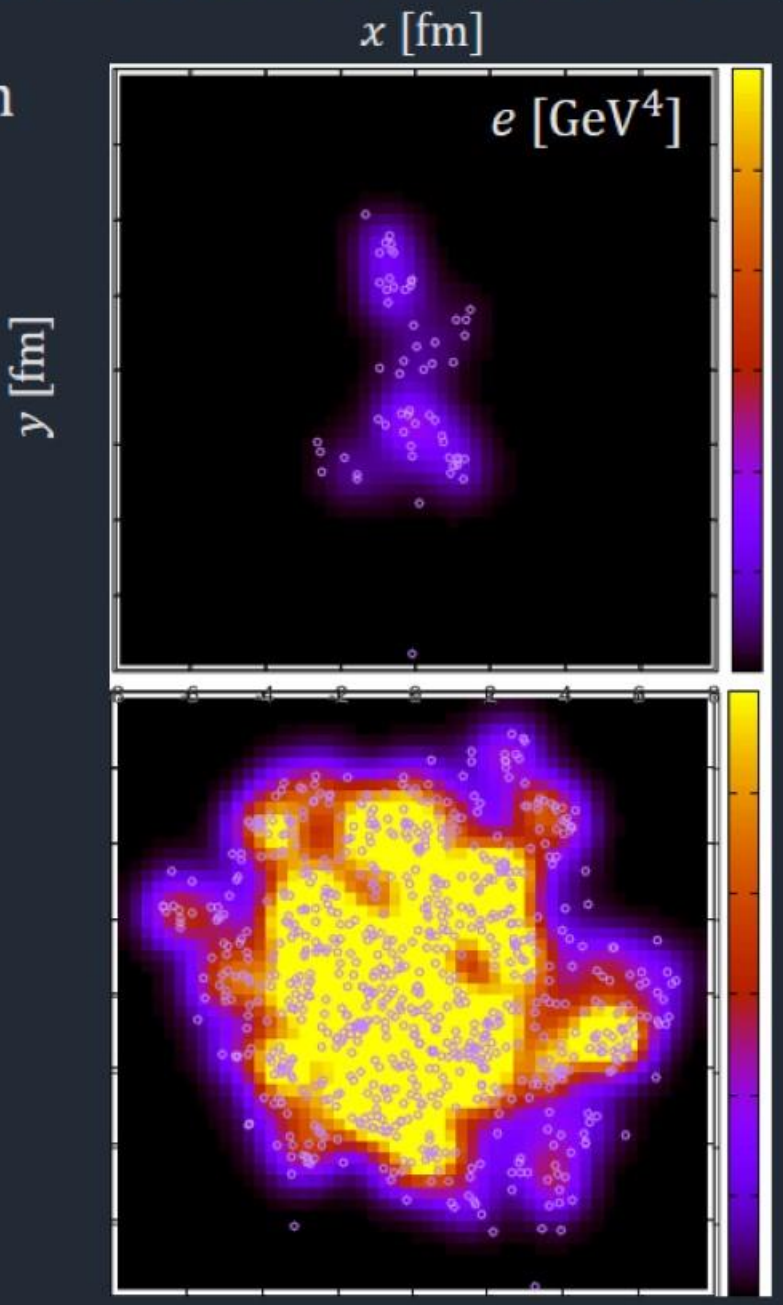
$v_\perp$

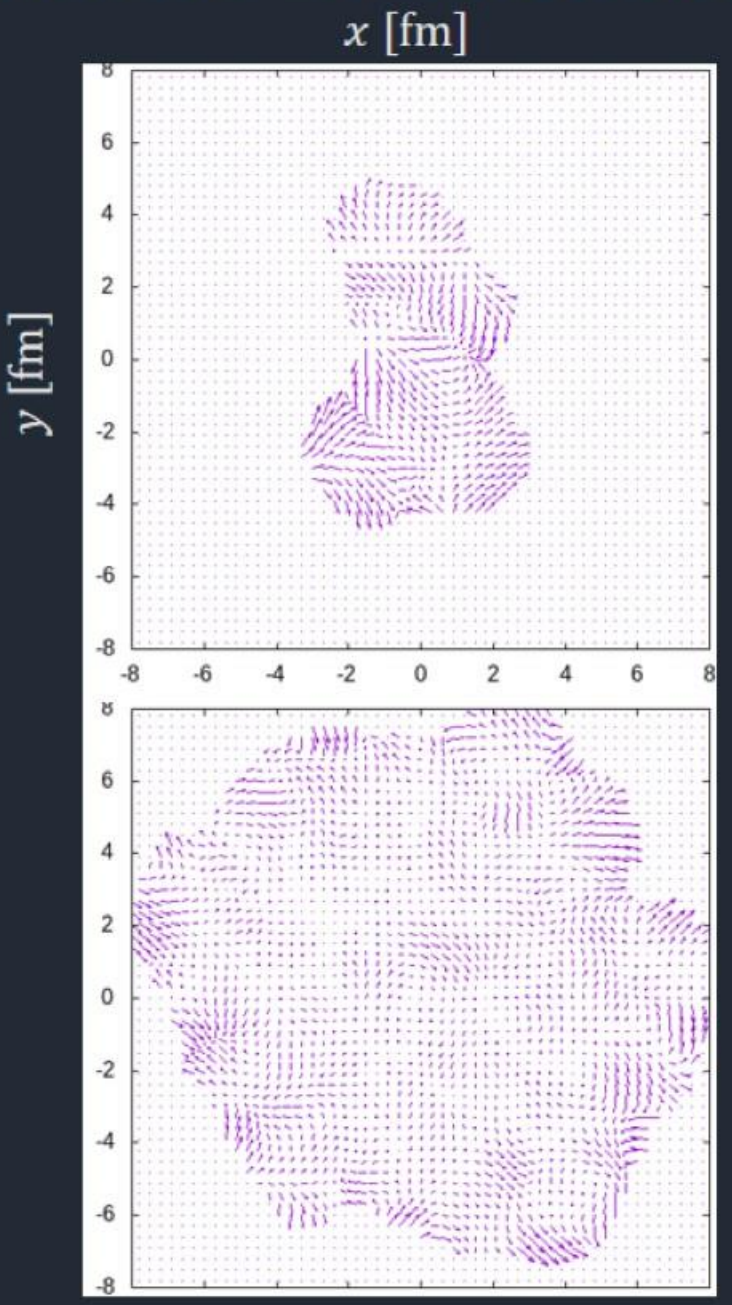
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.13$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





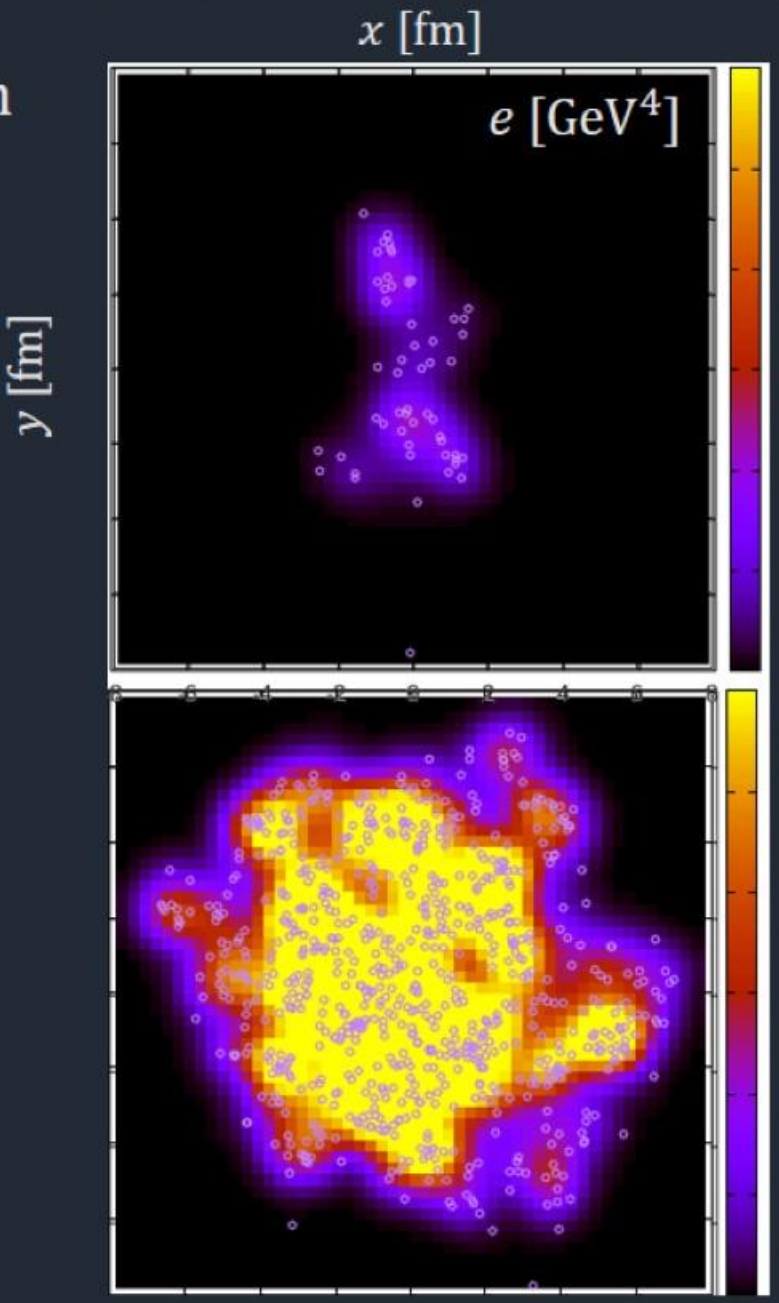
$v_\perp$

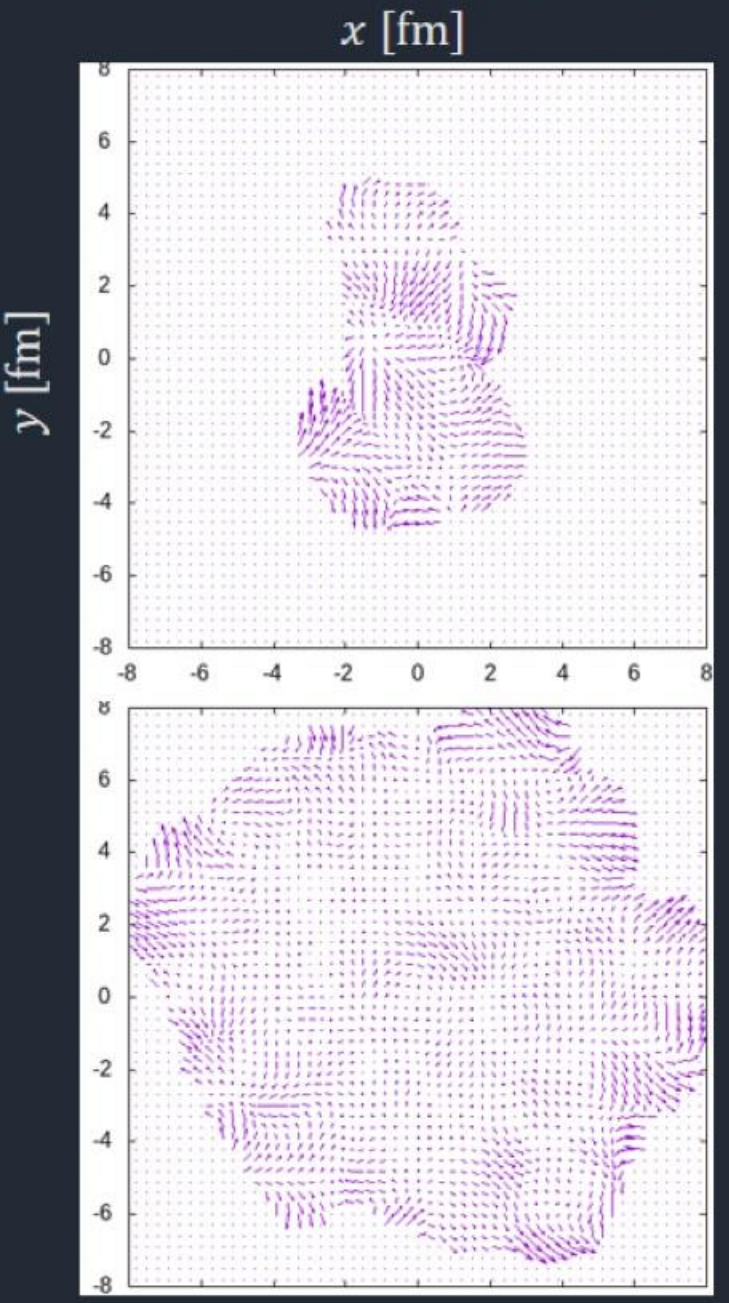
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.14$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





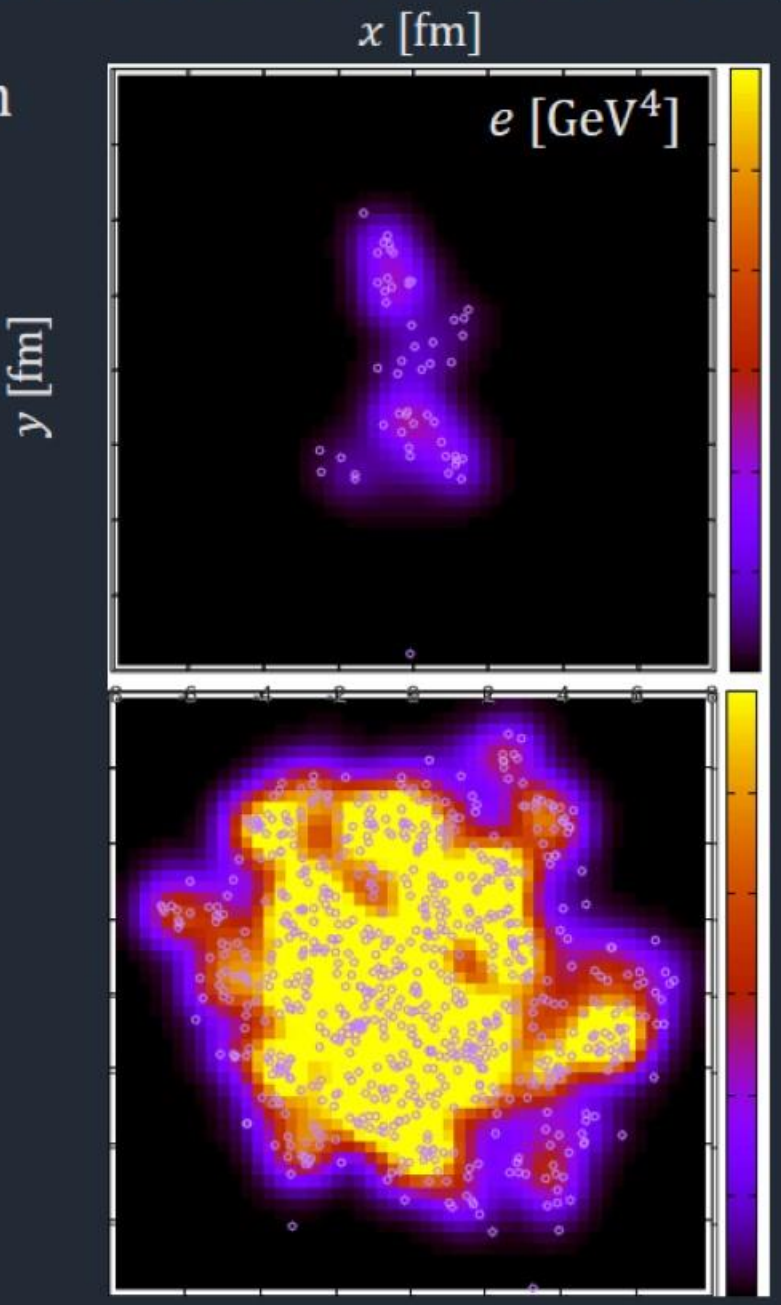
$v_\perp$

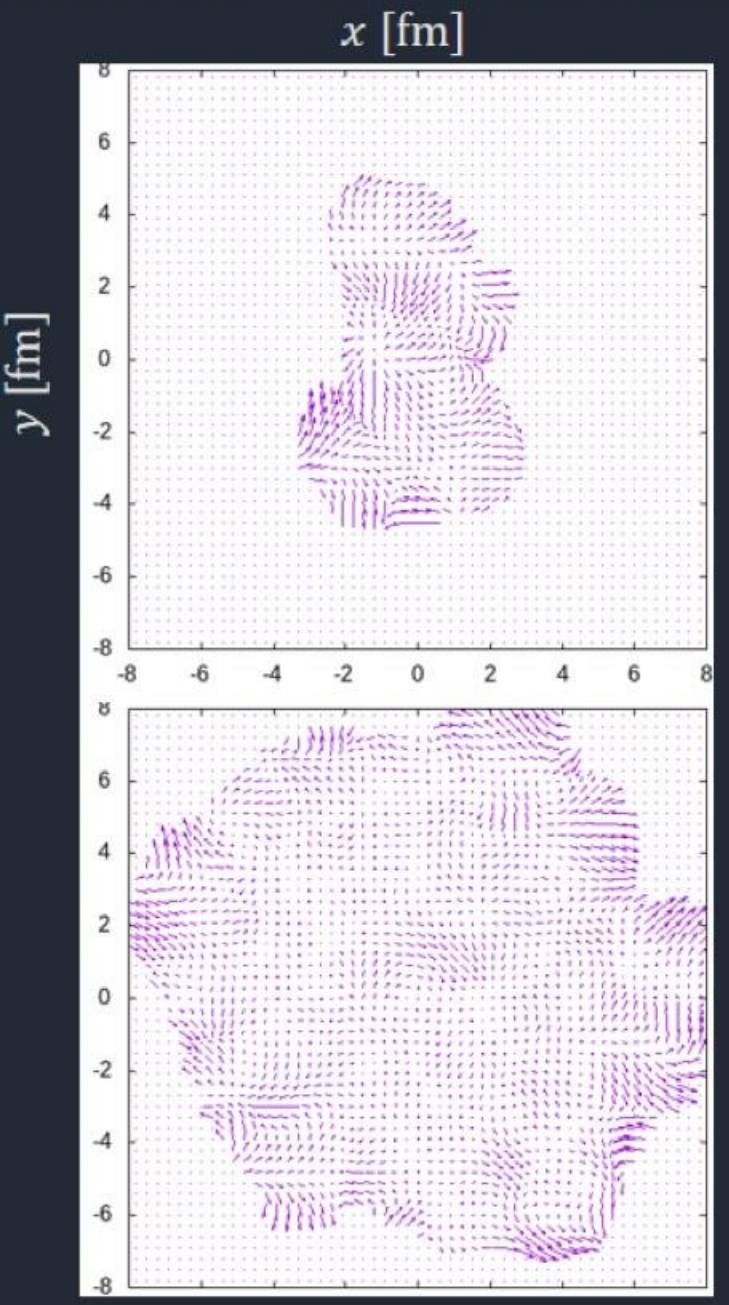
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.15$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





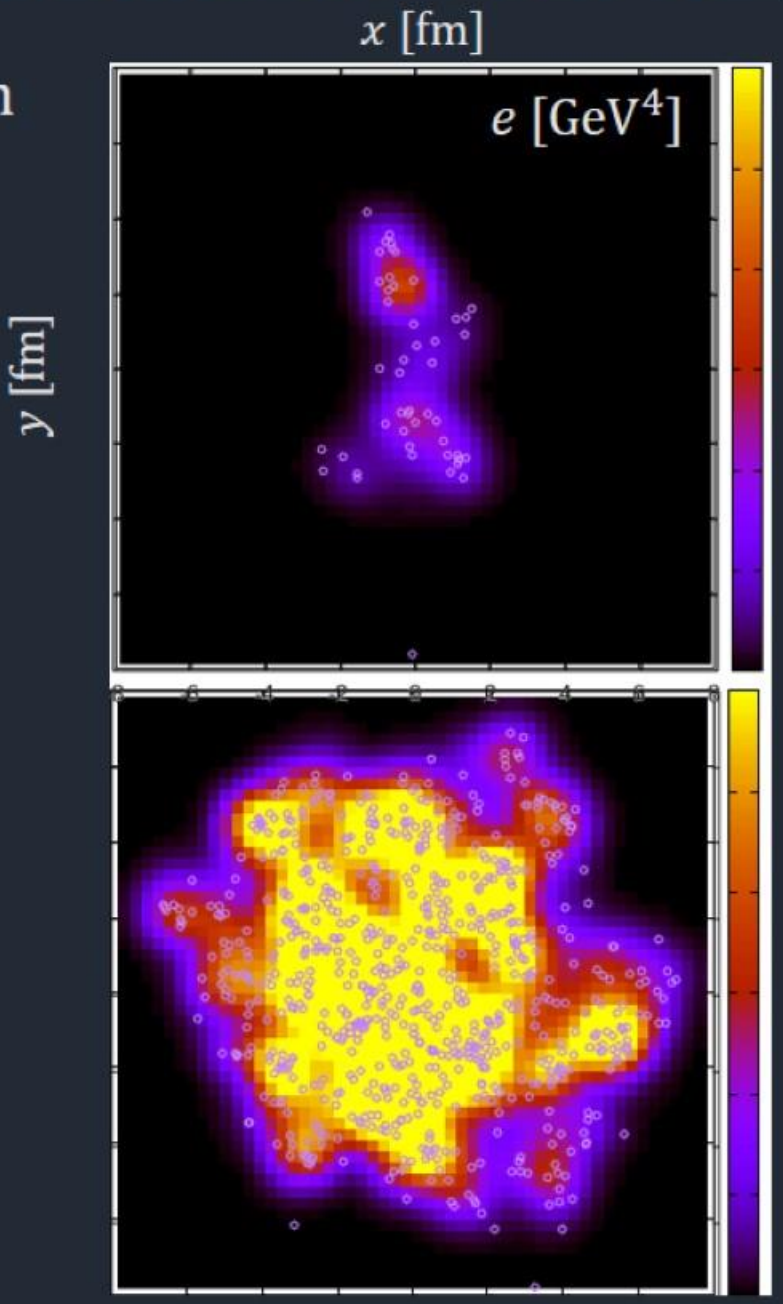
$v_\perp$

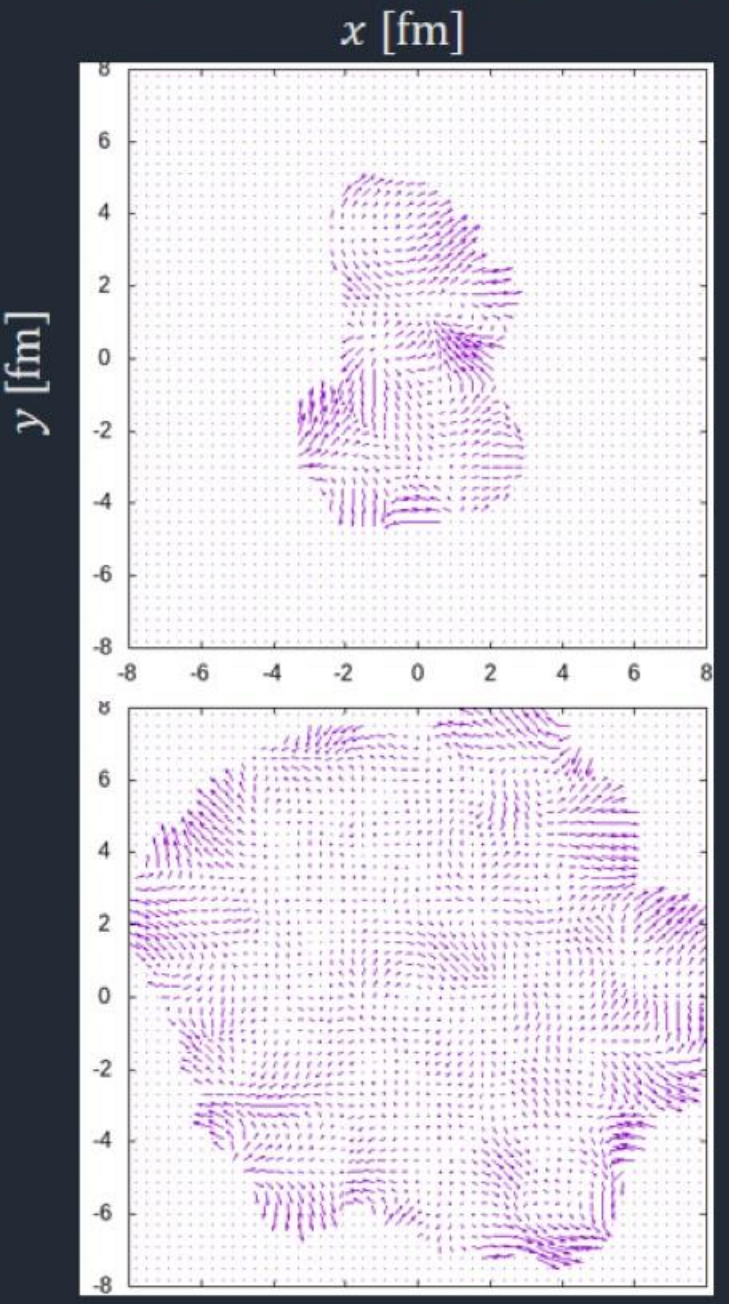
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.16$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





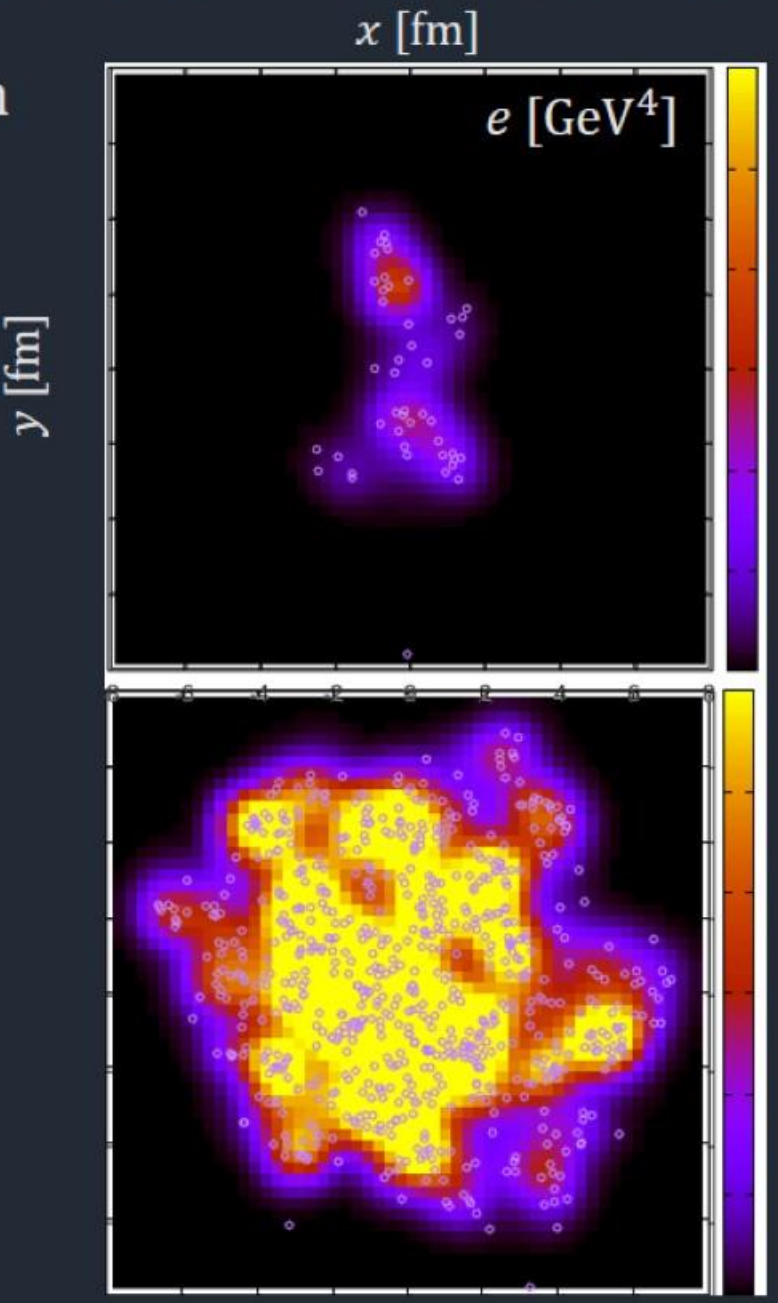
$v_\perp$

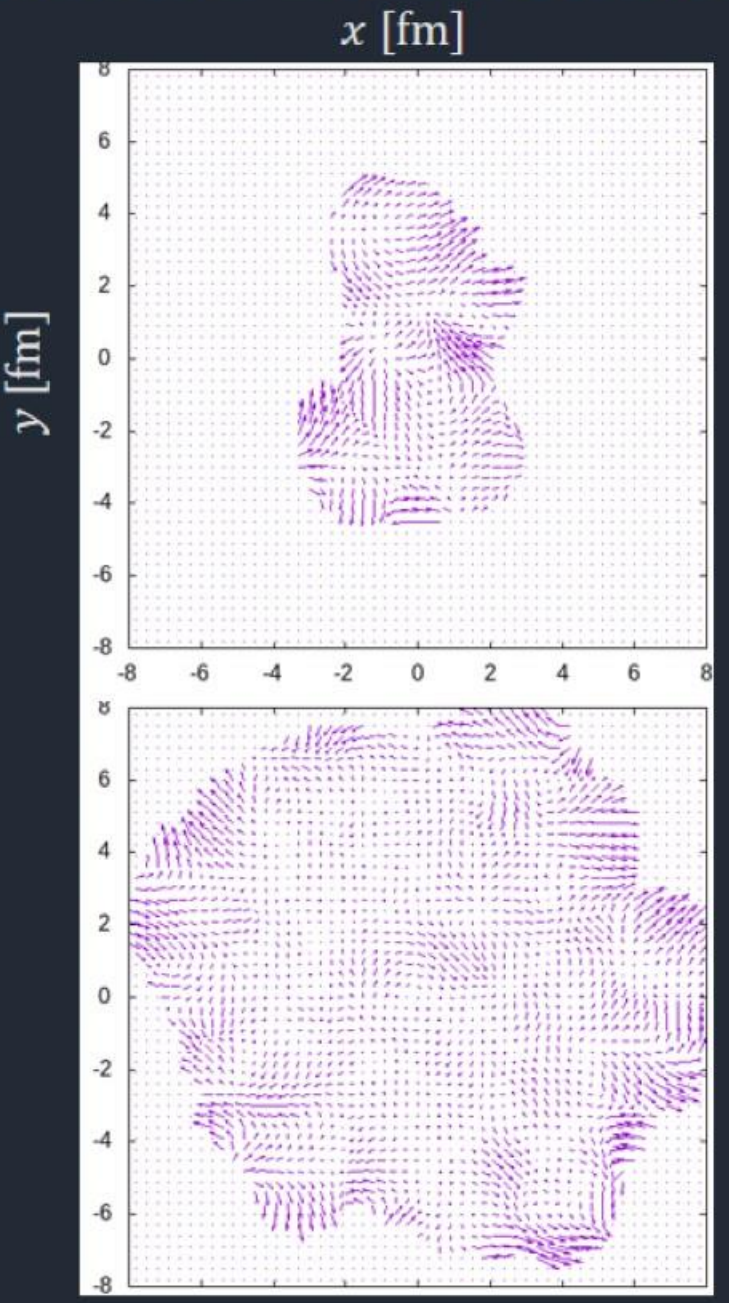
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.17$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central





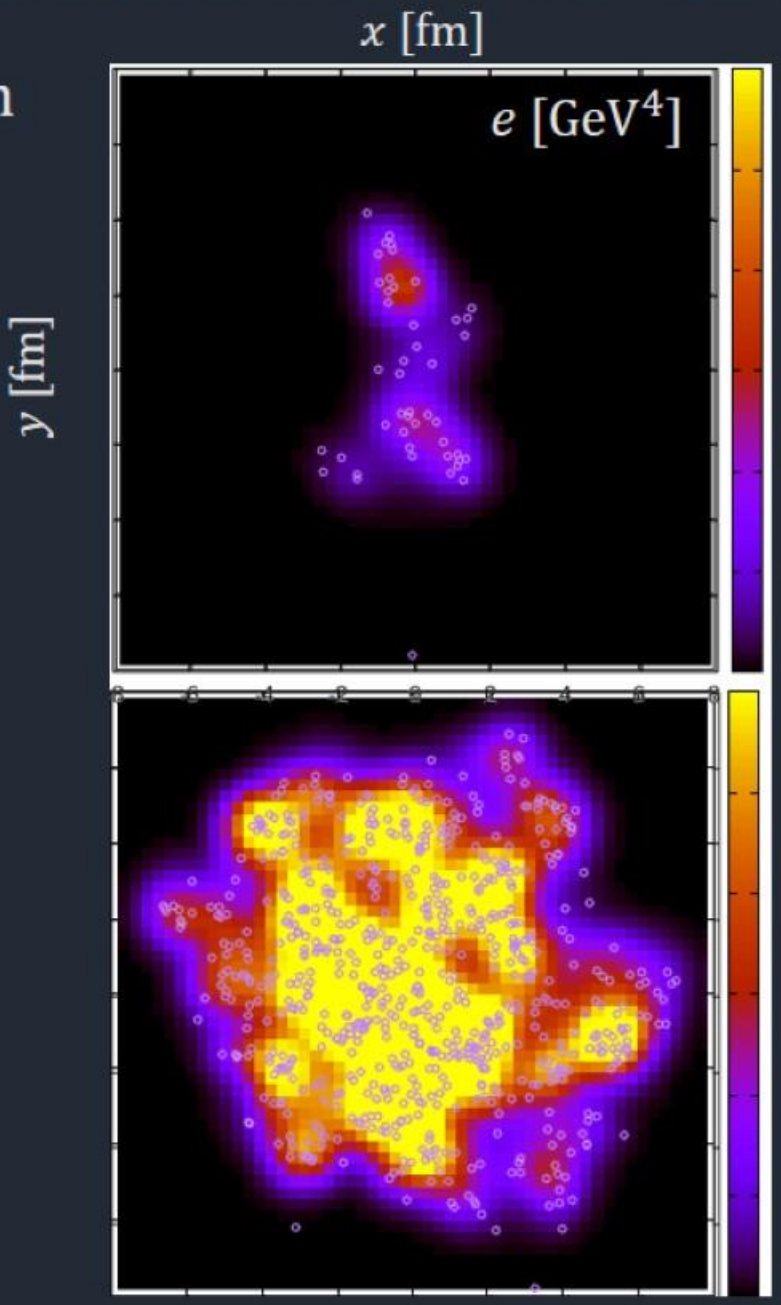
$v_\perp$

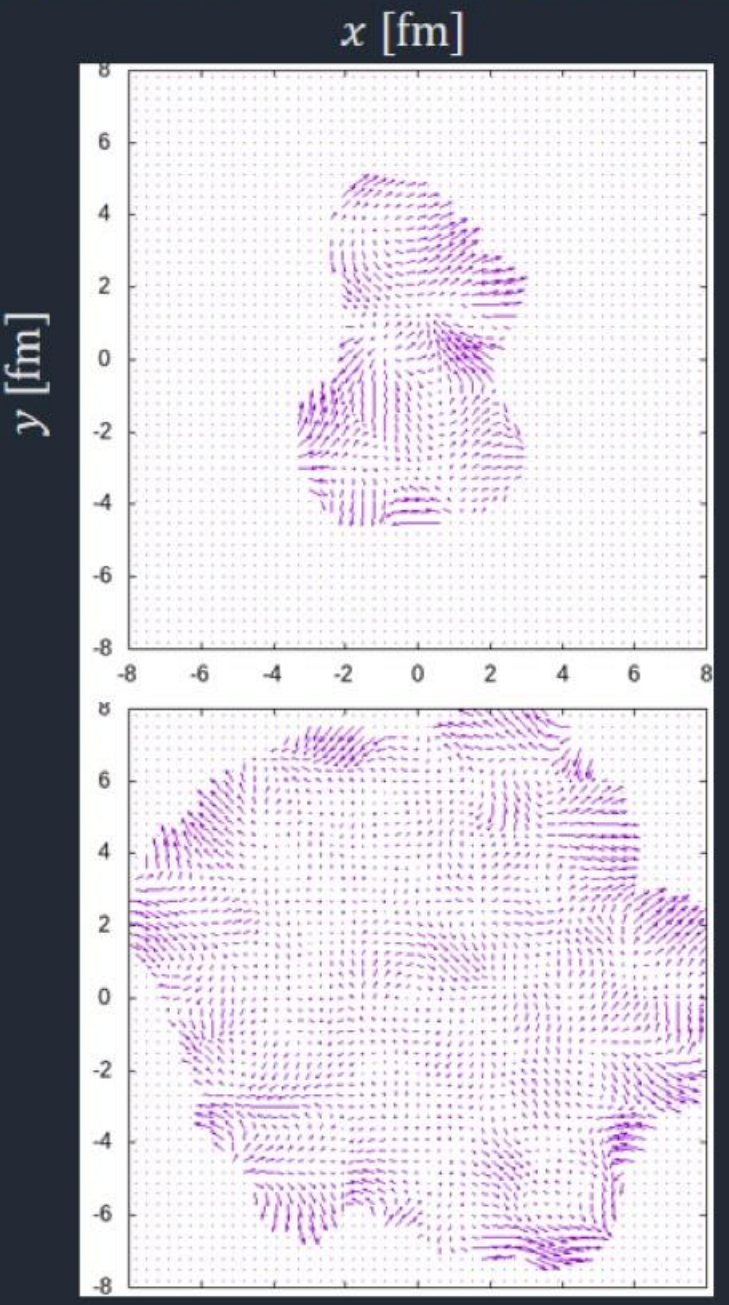
Result: Time evolution of dynamical core-corona initialisation

$\tau = 0.18$ fm

Pb+Pb
(2.76 TeV)
peripheral

Pb+Pb
(2.76 TeV)
central

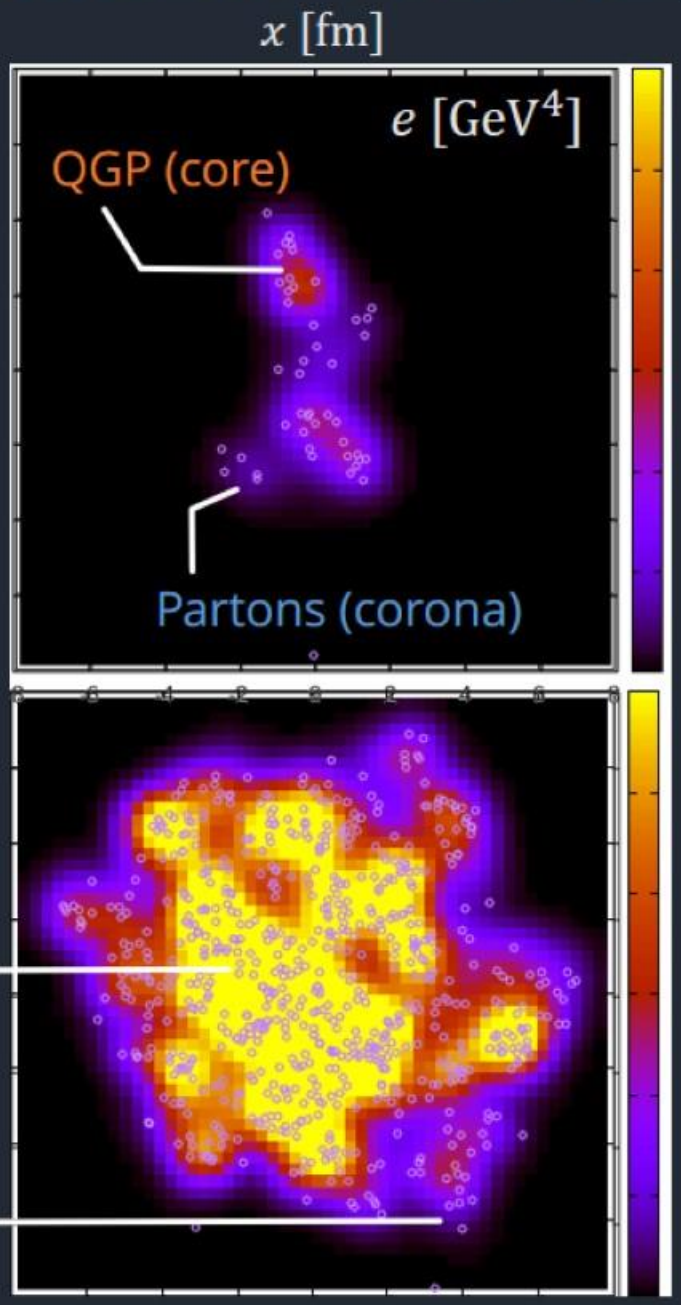




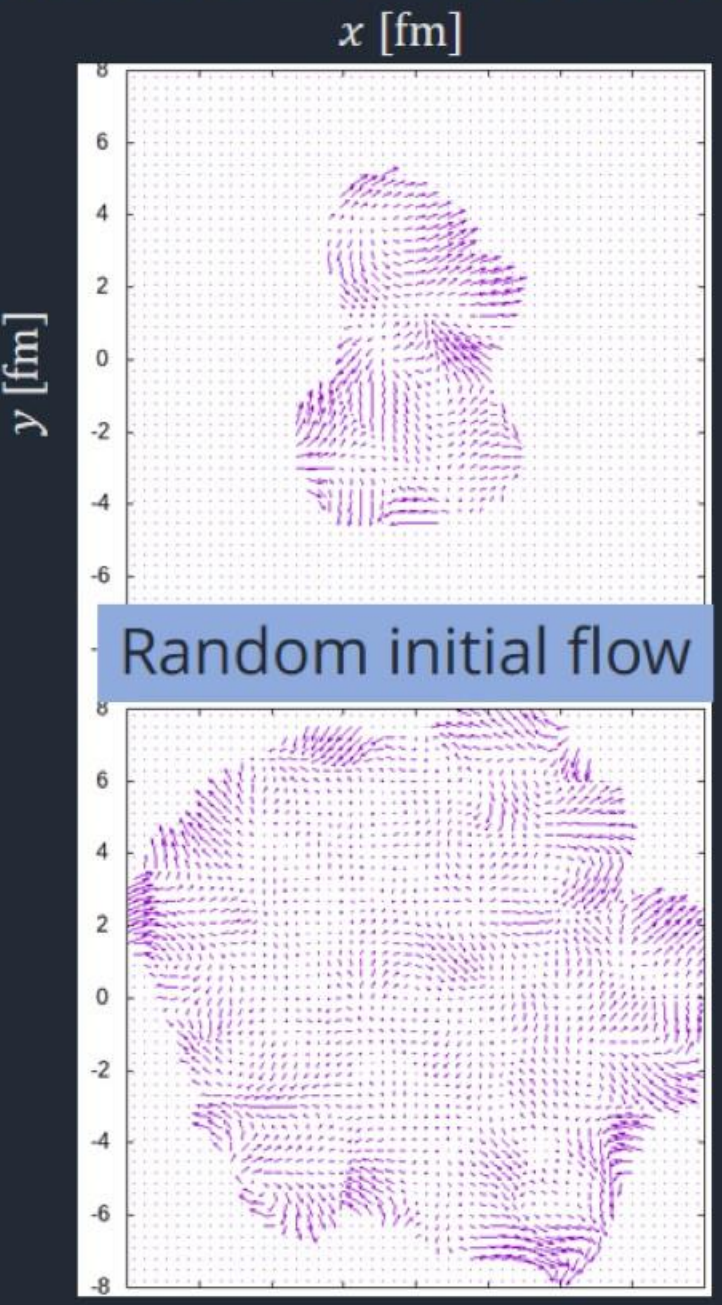
$v_\perp$

Result: Time evolution of dynamical core-corona initialisation

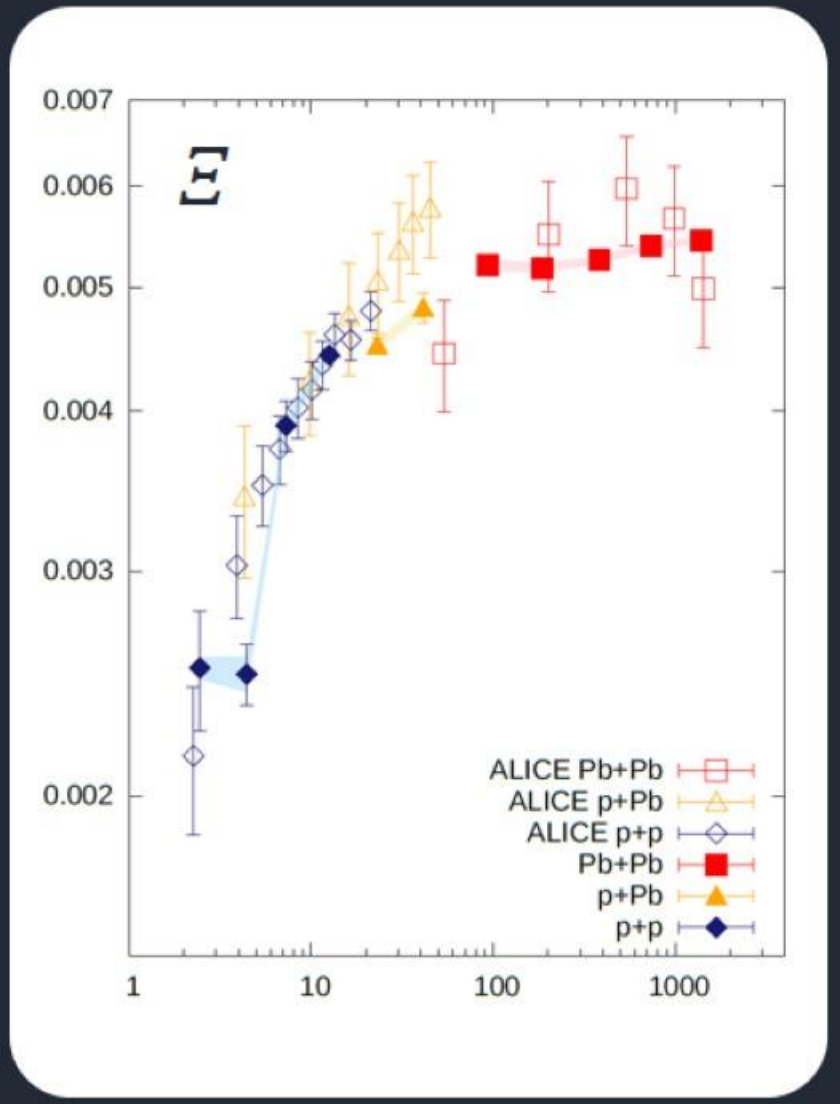
$\tau = 0.19$ fm

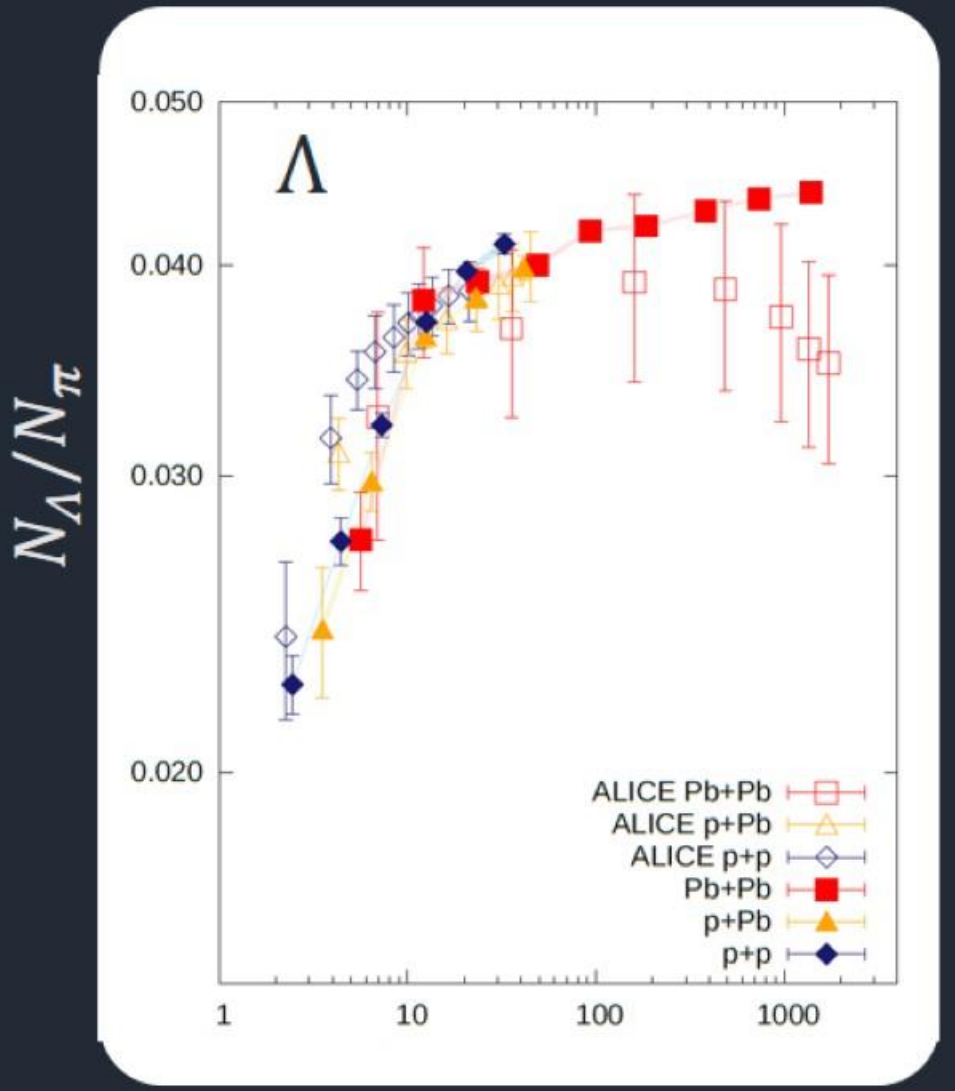


$v_\perp$



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)
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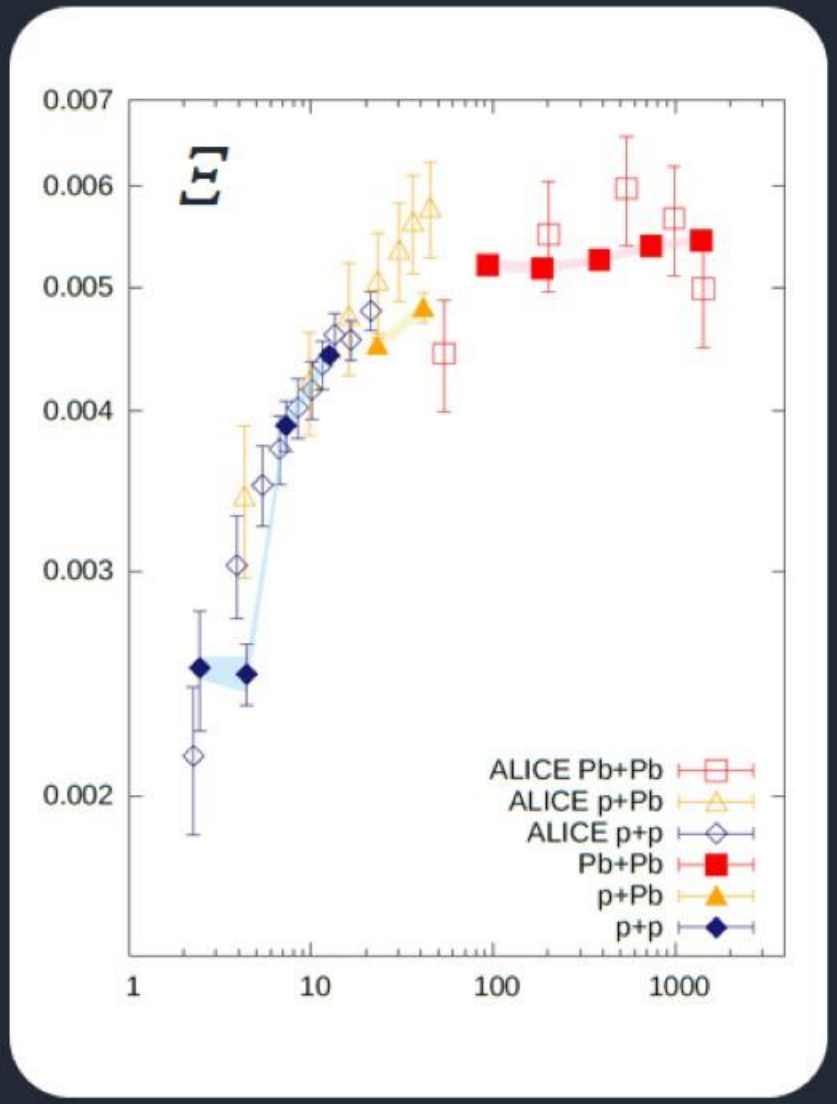

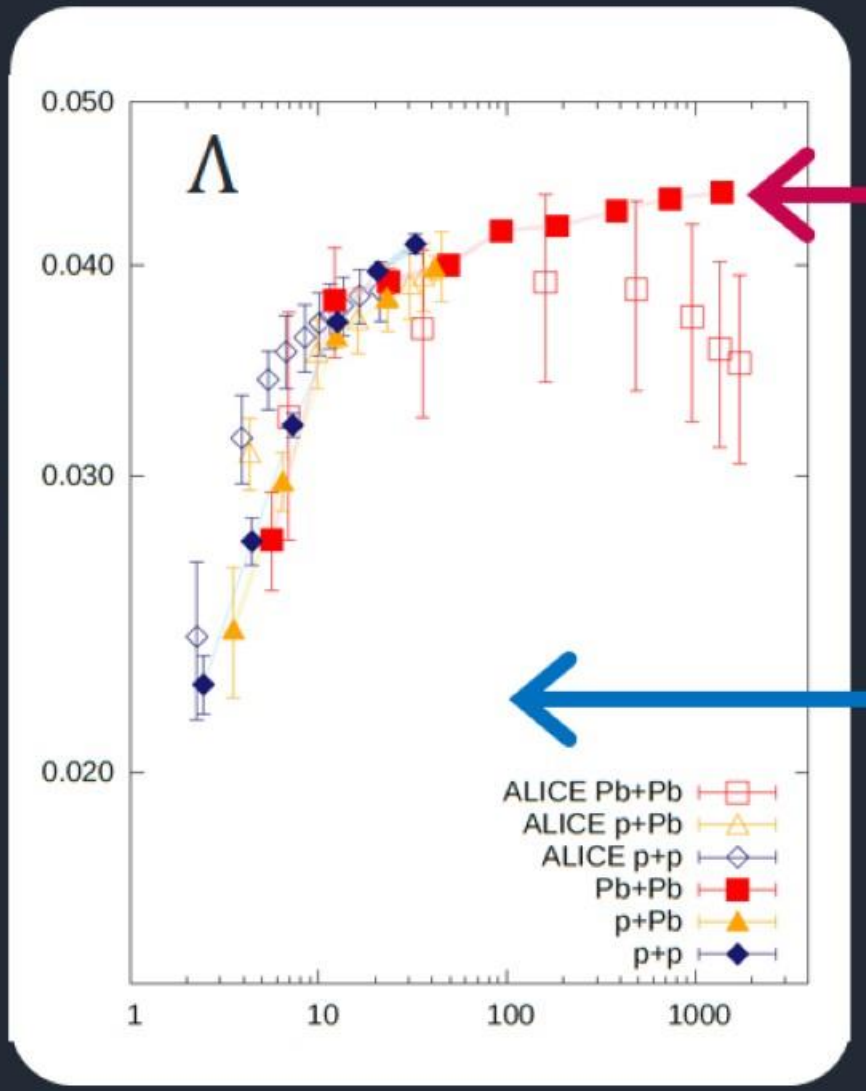

Core dominant reflects ratio from QGP

Corona dominant reflects ratio from string fragmentation

J. Adam et al. (ALICE), Nature Phys. 13, 535 (2017) J. Adam et al. (ALICE), Phys. Lett. B758, 389 (2016)
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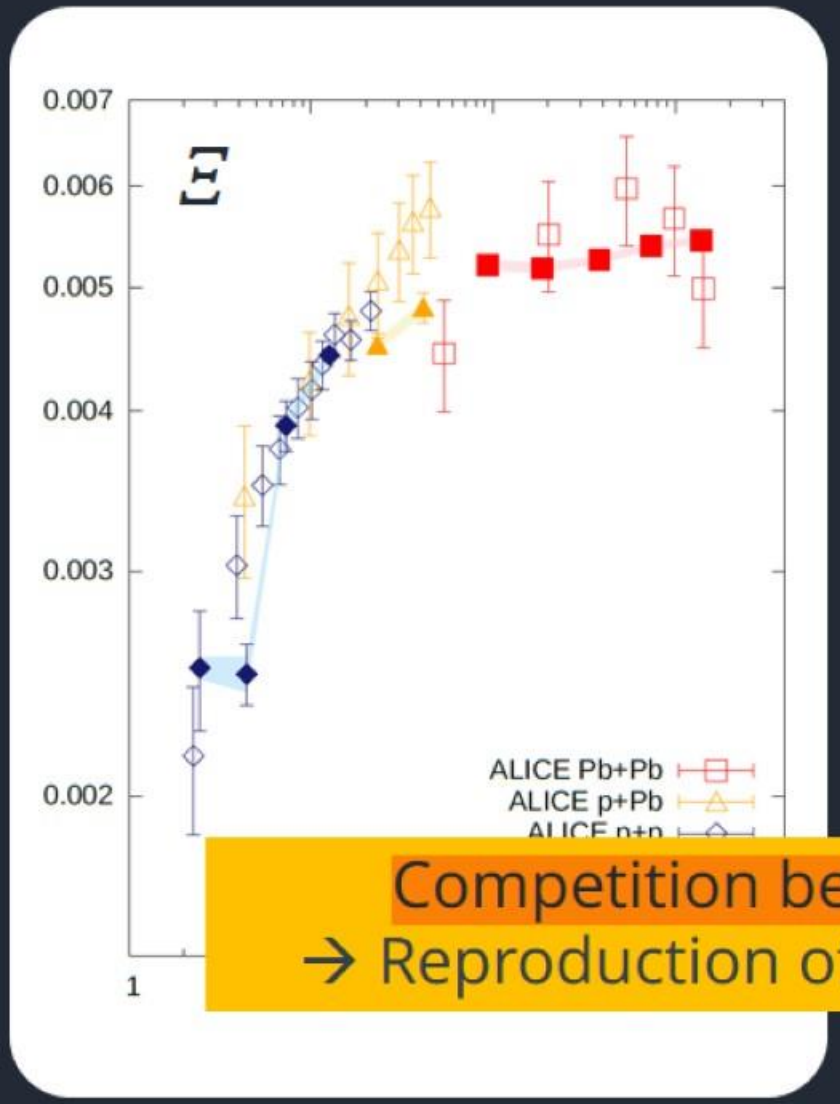
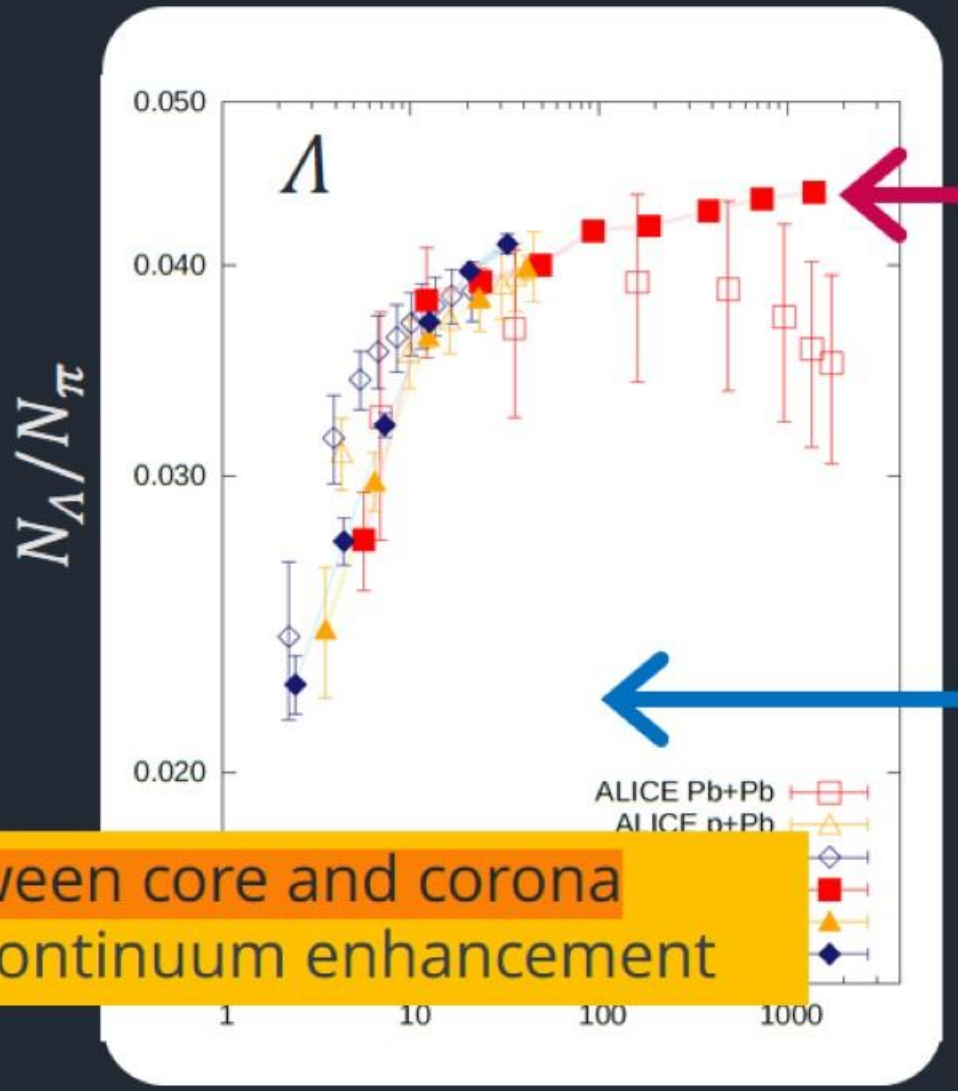




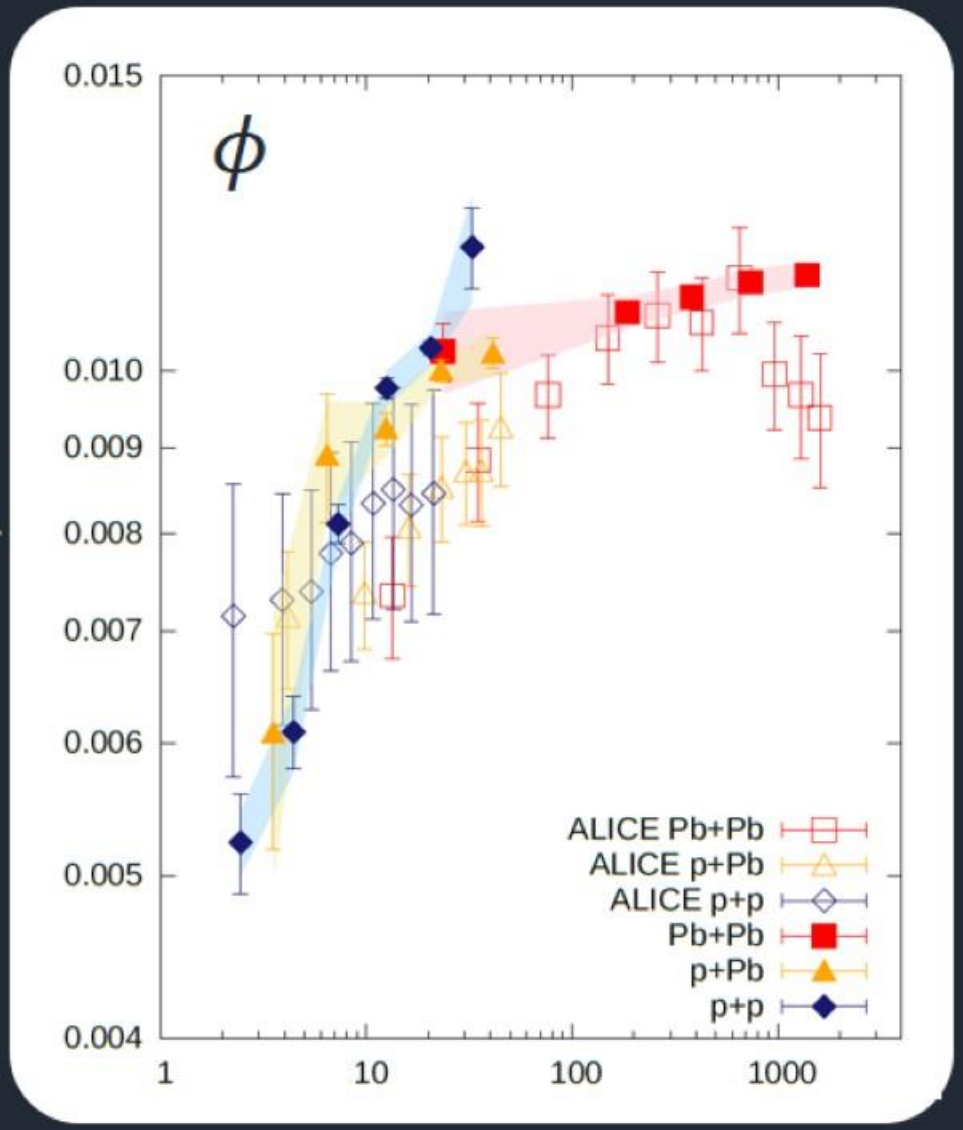
Core dominant reflects ratio from QGP

Corona dominant reflects ratio from string fragmentation

Competition between core and corona
→ Reproduction of continuum enhancement

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)

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
- Exp. data

→ Enhancement as multiplicity increases

ϕ: hidden strangeness
Canonical suppression → flat

J. Sollfrank, F. Becattini, K. Redlich and H. Satz, Nucl. Phys. A 638, 399C (1998)

V. Vislavicius *et al.*, arXiv:1610.03001v3

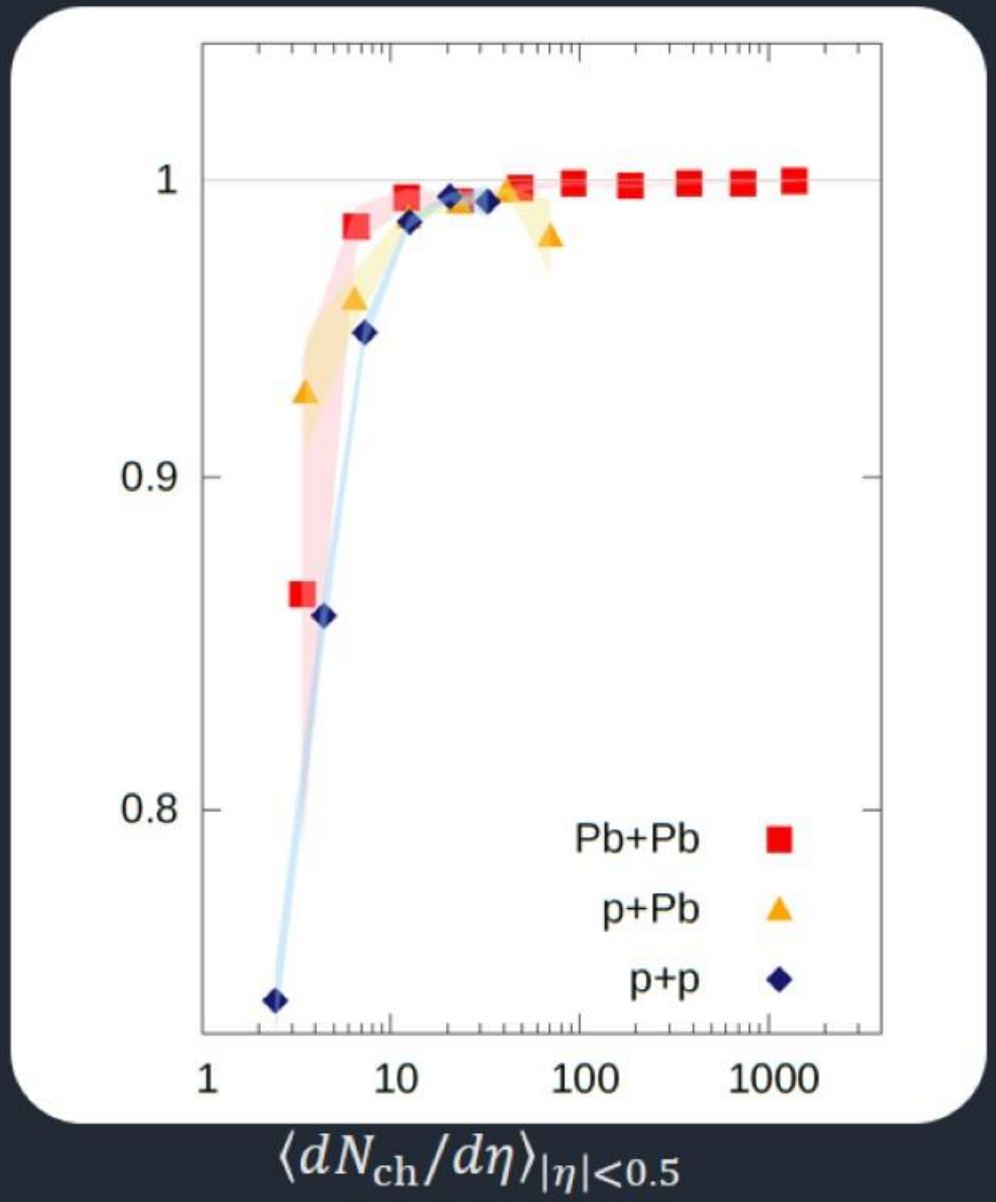
(Dynamical) core-corona

String fragmentation
+
Statistical Thermodynamics

→ Captures the essential characteristic of particle production

Not fully equilibrated, needs of string fragmentation

Result: Fraction of fluidized energy

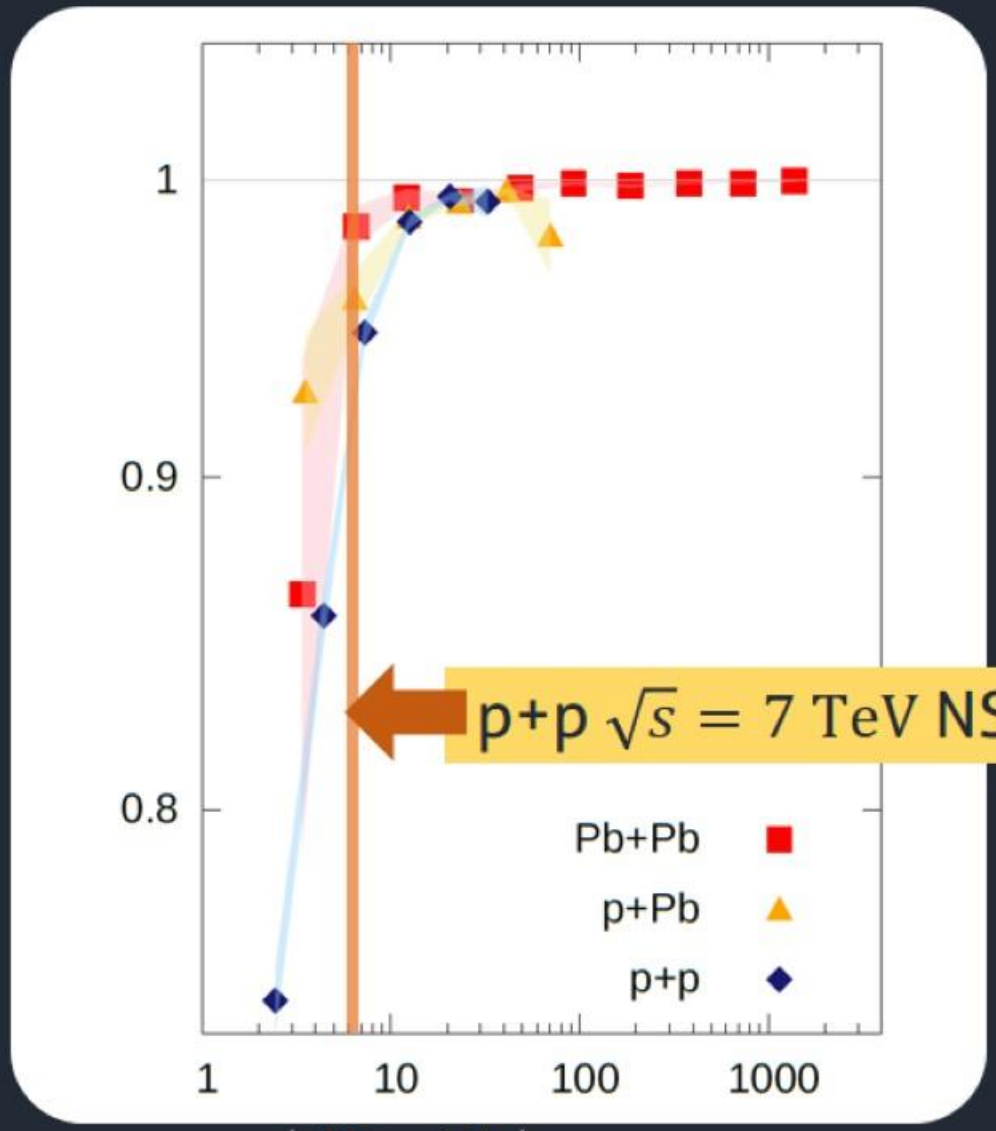


$$R = \frac{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau (\tau, x_\perp, \eta_s = 0)}{\int_{\tau_{00}}^{\tau_0} d\tau \int d\boldsymbol{x}_\perp \tau J^\tau_{\mathrm{tot}} (\tau, x_\perp, \eta_s = 0)}$$

$$\frac{\text{Core energy at midrapidity}}{\text{Total energy at midrapidity}}$$

→ Fraction of fluidized energy

Result: Fraction of fluidized energy



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

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

$$\frac{\text{Core energy at midrapidity}}{\text{Total energy at midrapidity}}$$

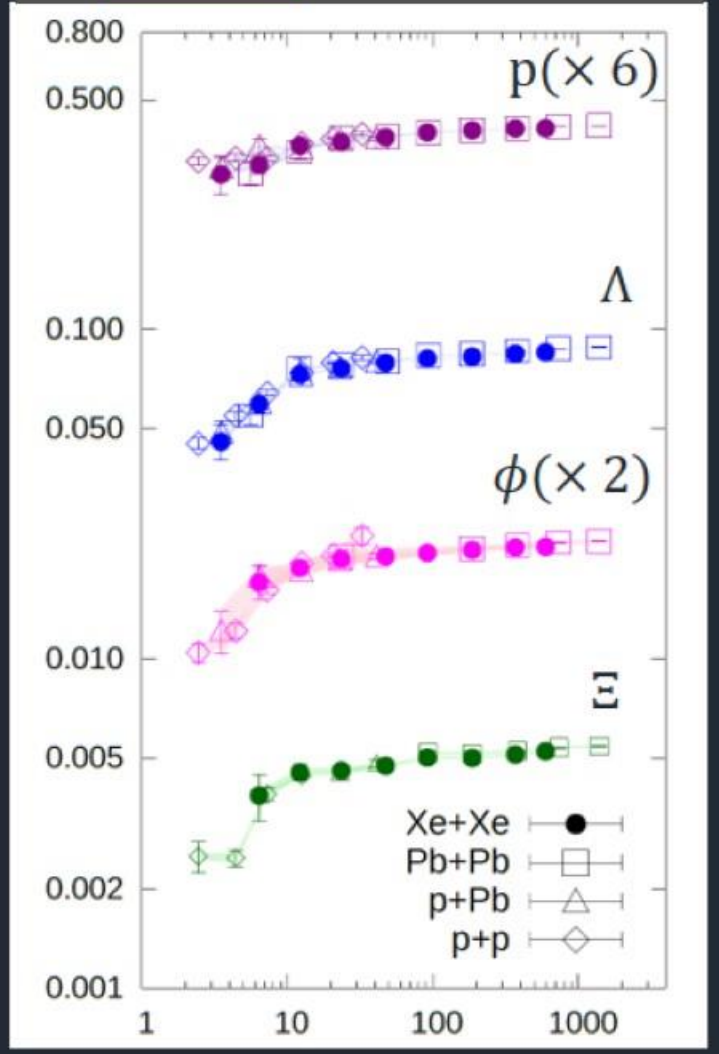
→ Fraction of fluidized energy

Reproduction of yield ratio
in the exp. data

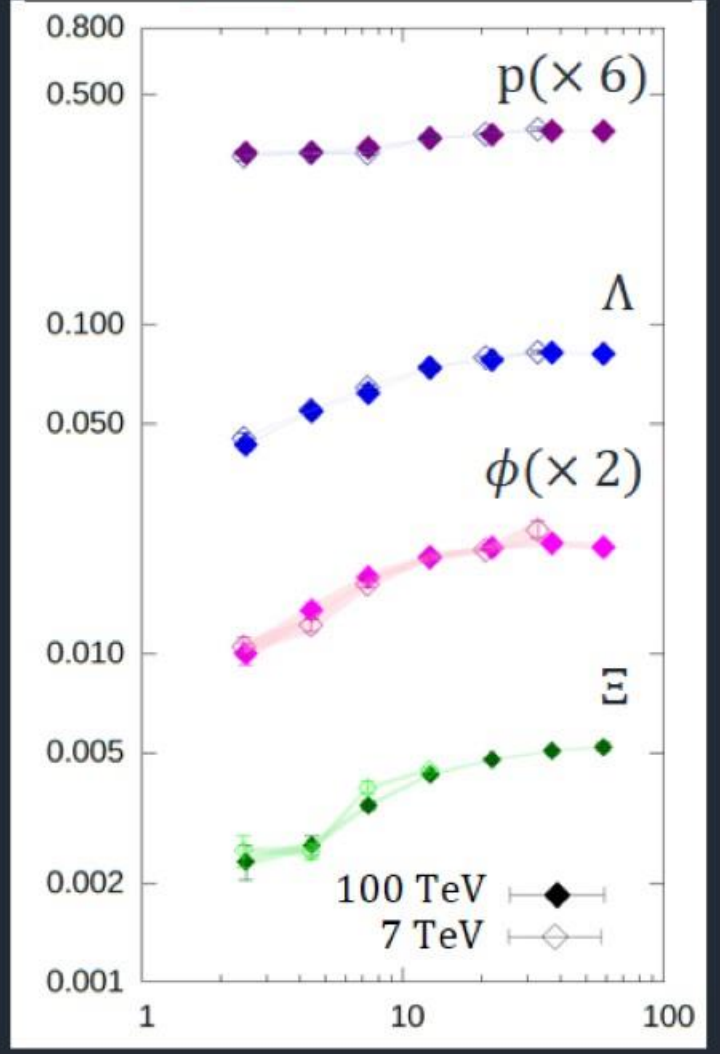
Need of QGP fluid (core) contribution
even in NSD p+p events

Result: Size & collision energy dependence

Xe+Xe vs others



FCC vs LHC



Clear scaling with multiplicity

→ Multiplicity plays an important role for thermalisation of partons

Summary & outlook

Dynamical core-corona initialisation

Continuous change of description considering initial geometry of partons
String fragmentation + hadronization from fluids

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 description from small to large systems

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

Need to discuss bulk property as well as flow components

*Future work: model sophistications... hadronic re-scatterings, viscosity, etc.
→ Towards understanding collectivity together with strangeness enhancement