



COE

Signals of collectivity from single
(or few) scattering

QM



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University of Jyväskylä, Centre of Excellence in Quark Matter



Introduction



QGP signals in small systems

Small systems: pp, pA...

→ Reference for AA with QGP

In **high-multiplicity** small systems...



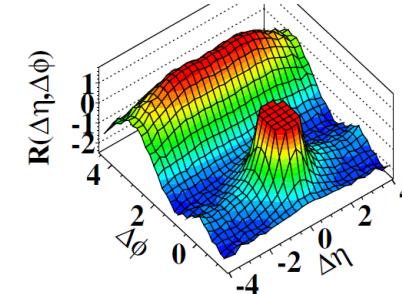
Thermal strange hadron productions
Hydro-like collectivity



Reviews: B. Schenke, Rept. Prog. Phys. 84 (2021) 8, 082301; J. L. Nagle and W. A. Zajc, Ann. Rev. Nucl. Part. Sci. 68 (2018) 211-235; K. Dusling *et al.*, Int. J. Mod. Phys. E 25 (2016) 01, 1630002

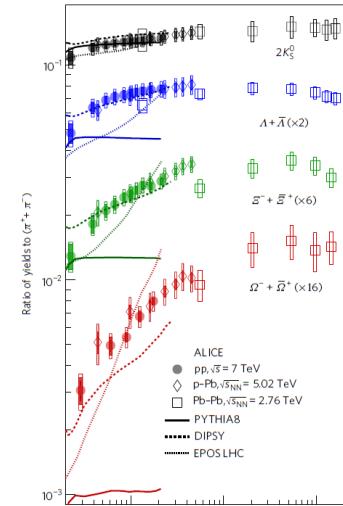
Challenge to interpret the universal behavior from pp to AA **in exp. data**

(d) CMS $N \geq 110$, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



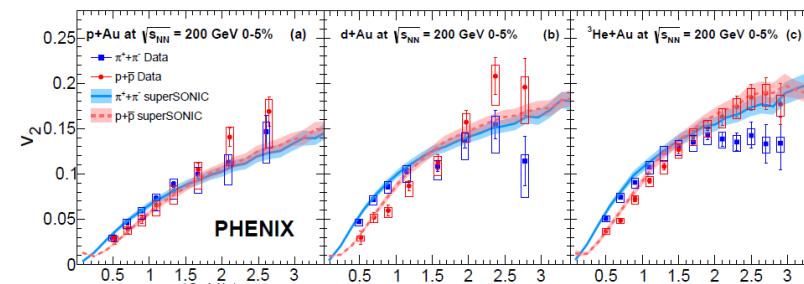
Long range correlation

CMS Collaboration, JHEP
09 091 (2010)



Strangeness enhancement

ALICE Collaboration, Nature
Phys. 13 535-539 (2017)



Flow harmonics

PHENIX Collaboration, Phys. Rev. C 97, 064904 (2018), Nature Phys. 15 (2019) 3, 214-220

New theoretical view opened by small systems



Studies on properties of
equilibrated matter

Relativistic hydrodynamics
+ lattice QCD EoS

$$E \sim T \sim \Lambda_{\text{QCD}}$$

Small
systems

pp

Studies on fundamental QCD
properties in vacuum

pQCD (+phenomenology)

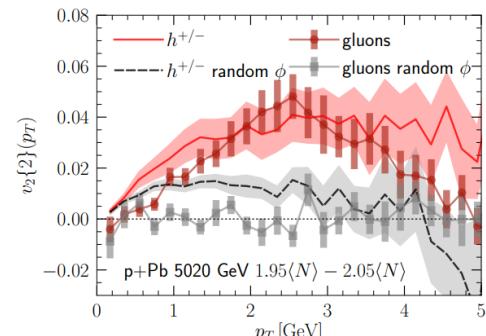
$$E \sim p_T \gg \Lambda_{\text{QCD}}$$

Experimental observation: universal behavior from pp to AA

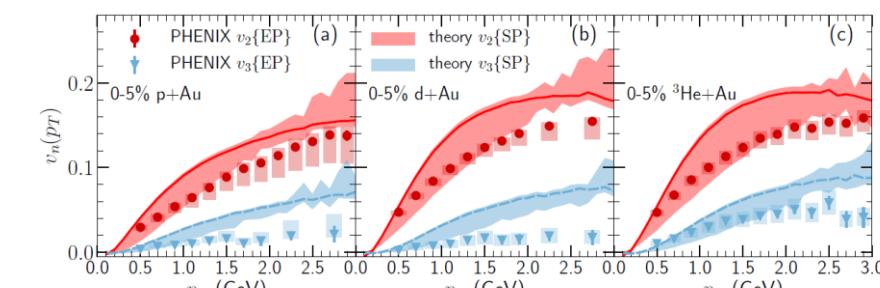
- Seamless connection
- Re-investigation of applicable range etc.

QCD challenges from pp to AA: J. Adolfsson *et al.*, Eur. Phys. J. A 56 (2020) 11, 288 Taxco (2016) Puebla (2017) Lund (2019) Padova (2023)

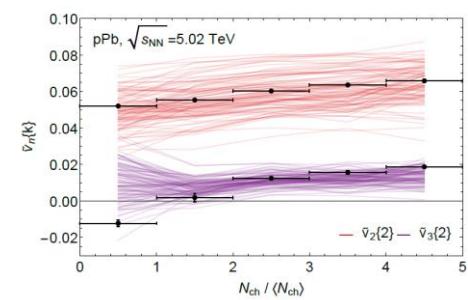
Discussions on origin of QGP signals



M. Greif et al., Phys. Rev. D 103 (2021) 5, 054011



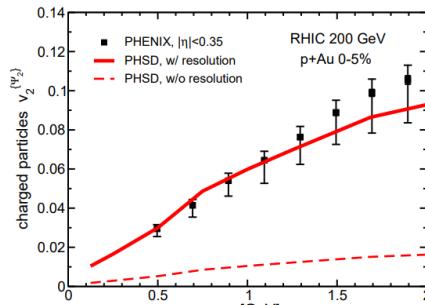
B. Schenke et al., Phys. Lett. B 803 (2020) 135322



G. Nijs et al., Phys. Rev. Lett. 126 (2021) 20, 202301

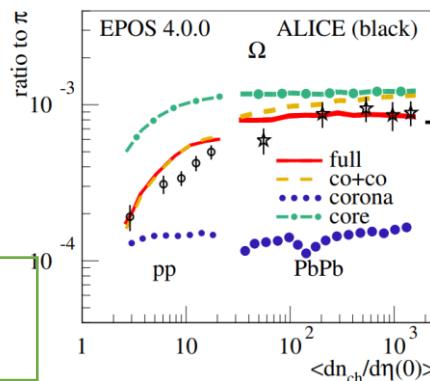
Talk by W. van der Schee, Wed. 15:00

L. Oliva et al., Phys. Rev. C 101 (2020) 1, 014917

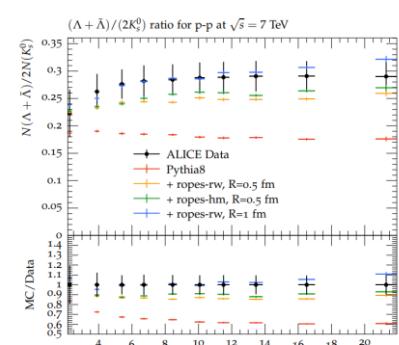
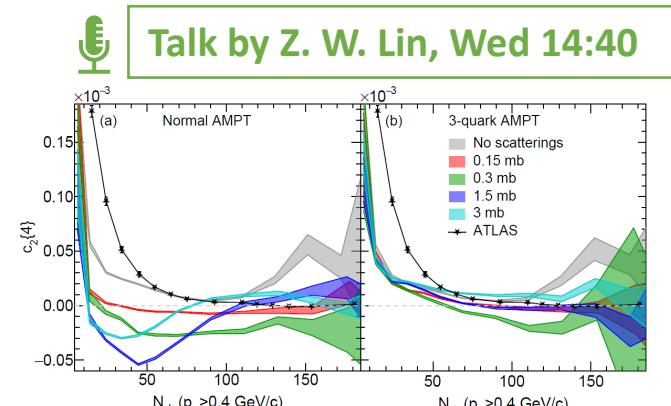


K. Werner, arXiv: 2301.12517

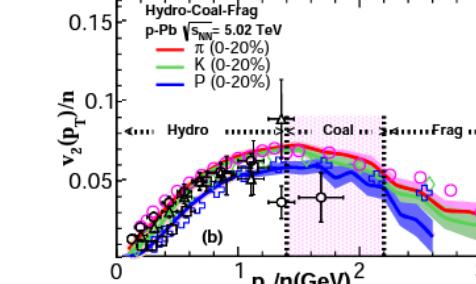
Plenary by K. Werner, Mon. 16:00



X. Zhao et al., Phys. Lett. B 839 (2023) 137799



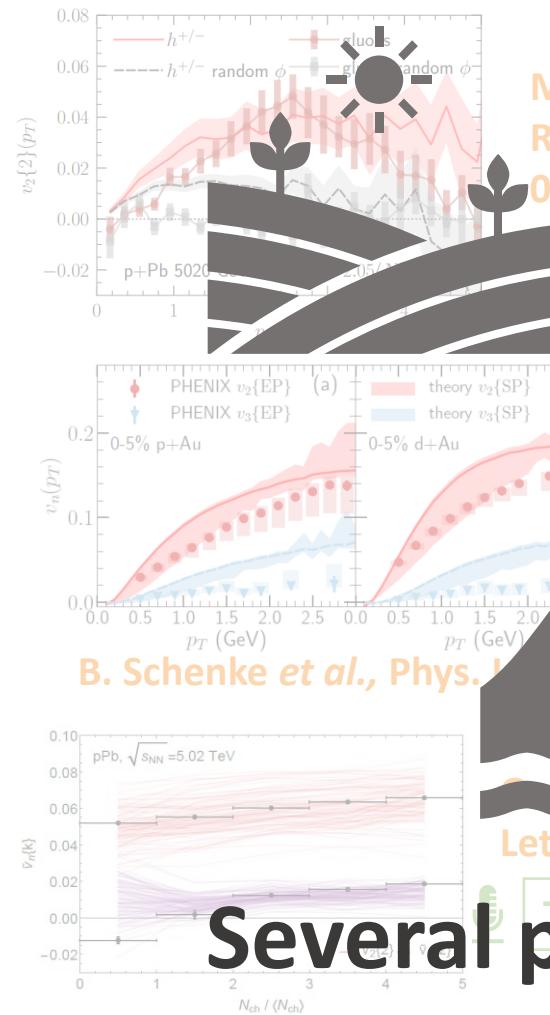
C. Bierlich et al., Phys. Lett. B 835 (2022) 137571



Talk by H. Song, Wed. 15:20

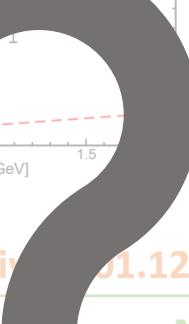
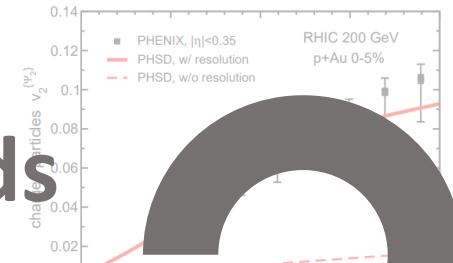
W. Zhao et al., Phys. Rev. Lett. 125 (2020) 7, 072301

Discussions on origin of QGP signals



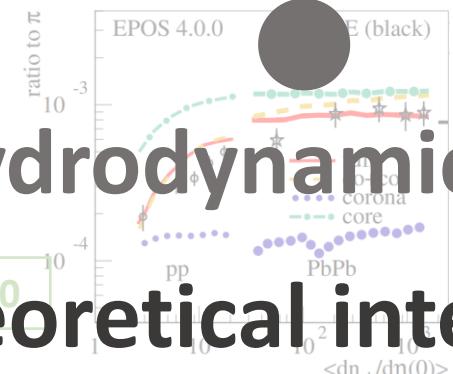
Color fields

L. Oliva *et al.*, Phys. Rev. C 101 (2020) 1, 014917



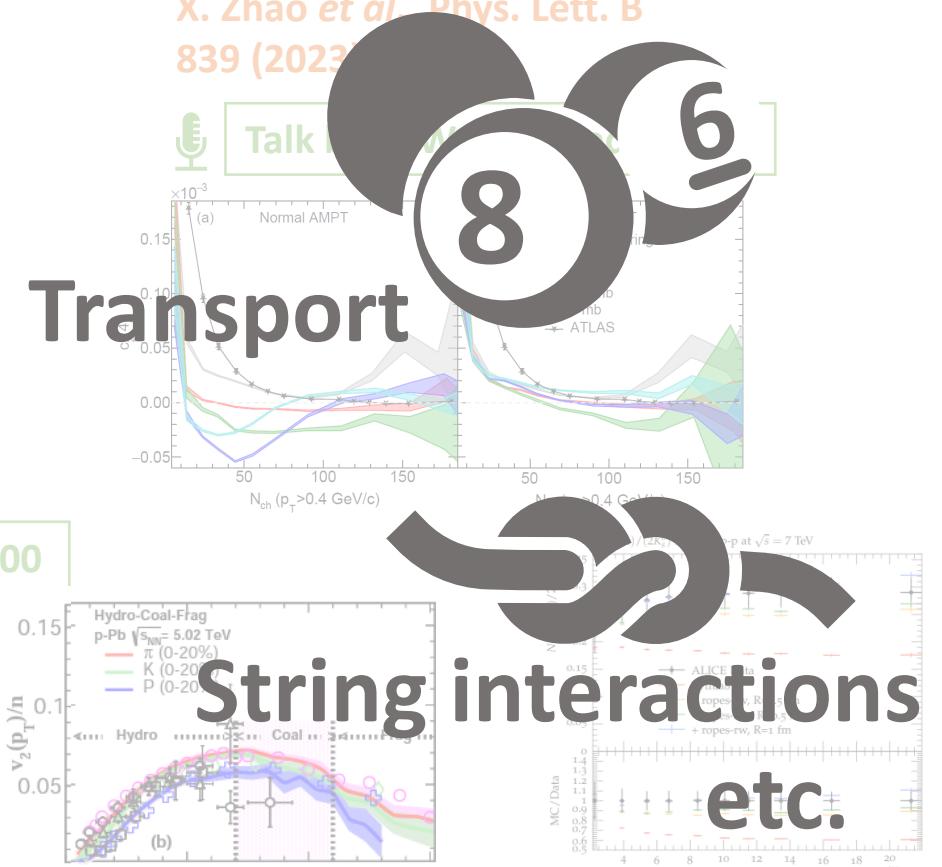
K. Werner, arXiv:201.12517

Plenary by K. Werner, Mon. 16:00



Several possible theoretical interpretations since 2010
→ Still remain open question...!

X. Zhao *et al.*, Phys. Lett. B 839 (2023) 137571



In this talk... Target: small systems at top RHIC to LHC energies

Highlights of recent studies from each
theoretical framework



Importance of multi-observable analysis with
Monte-Carlo event generators

How to address the open question
“What is the origin of collectivity in small systems?”

Recent works on small systems

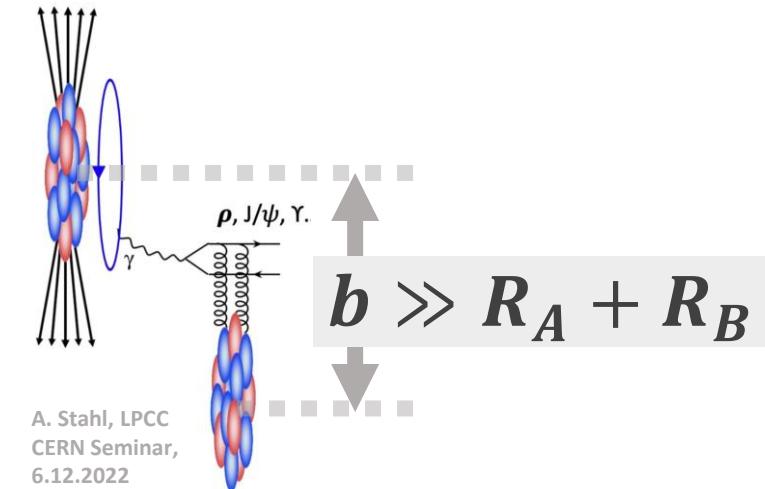


Ultra Peripheral Collisions (UPC)

AA \rightarrow pA
Go smaller...

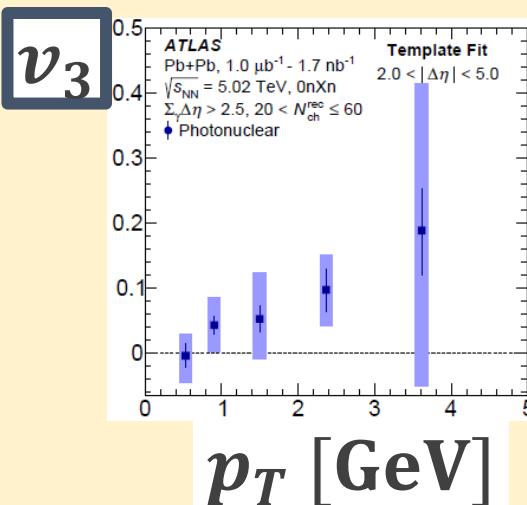
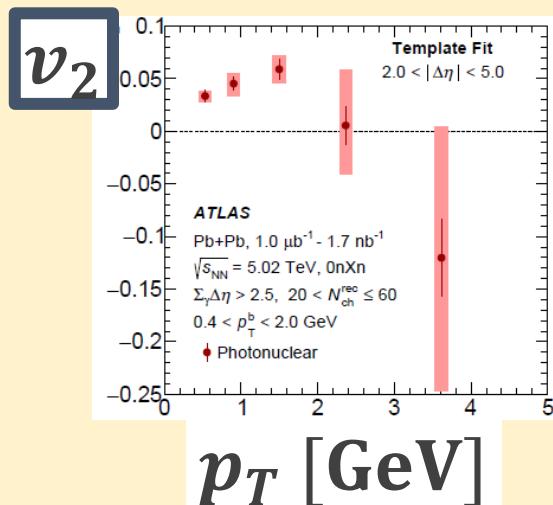
γA

Photon-induced reactions



A. Stahl, LPCC
CERN Seminar,
6.12.2022

Study on partonic structure of nucleus



Collectivity in high multiplicity UPC

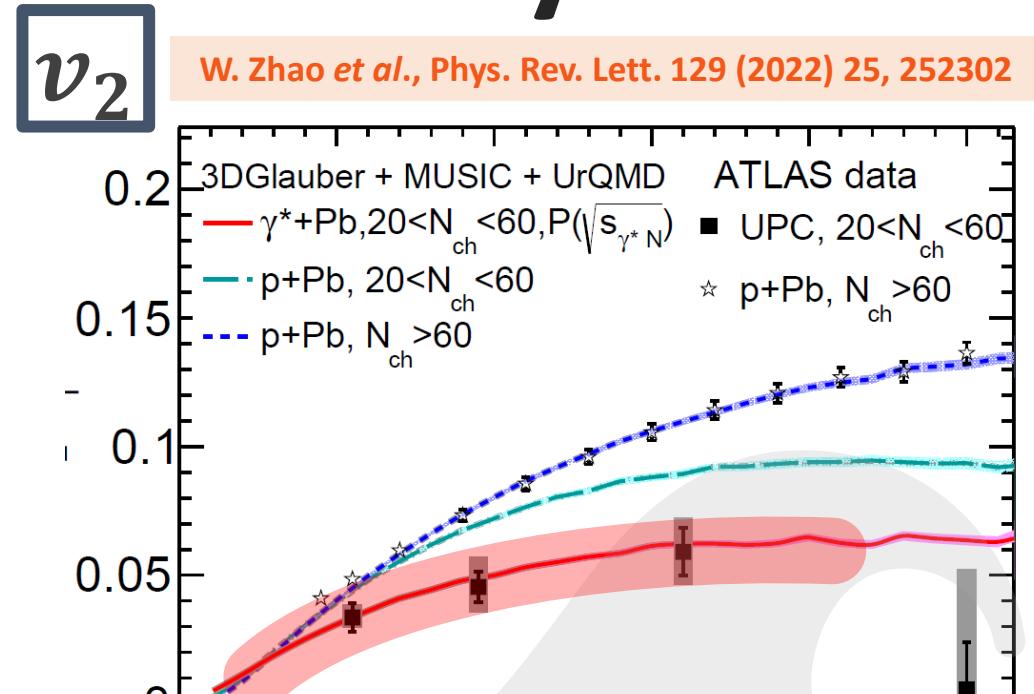
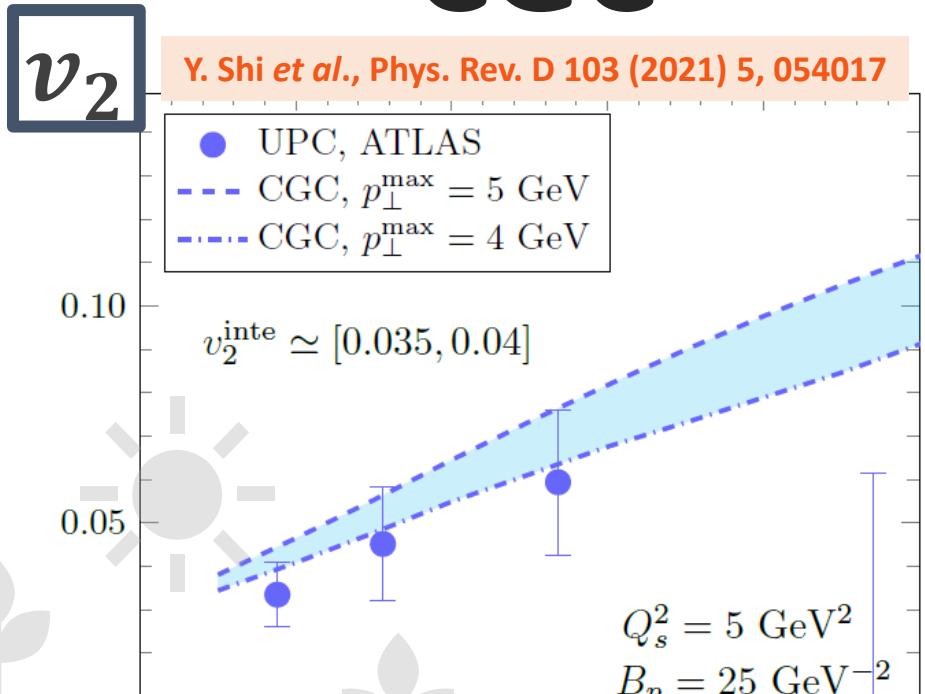
ATLAS collaboration: Phys. Rev. C 104 (2021) 1, 014903

Is it possible to understand with existing theoretical models?

*See also CMS collaboration 2204.13486 for two-particle correlation in γp

Ultra Peripheral Collisions (UPC)

CGC Hydro



Both CGC and hydro give reasonable description
→ Initial state or/and final state?

G. Giacalone *et al.*, Phys. Rev. Lett. 125 (2020) 19, 192301; S. H. Lim *et al.*, Phys. Rev. C 103 (2021) 6, 064906...

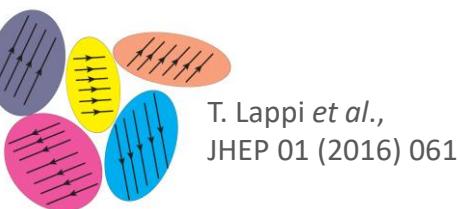
Origin of collectivity in initial states

Initial state or/and final state?

B. Schenke *et al.*, Phys. Rev. D 105 (2022) 9, 094023

Momentum anisotropy

Correlated gluons from
each colour field domain

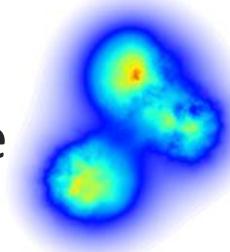


T. Lappi *et al.*,
JHEP 01 (2016) 061

OR

Geometrical anisotropy

Seeds for momentum
anisotropy in final state
evolution



H. Mäntysaari
and B. Schenke,
Phys. Rev. Lett.
117, 052301

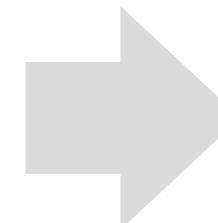
→ Both effects in initial stages can contribute to v_2 or $C(\Delta\phi, \Delta\eta)$

Which is significant?

IP-
Glasma
initial
condition

JIMWLK
evolution

Classical
Yang-Mills
evolution



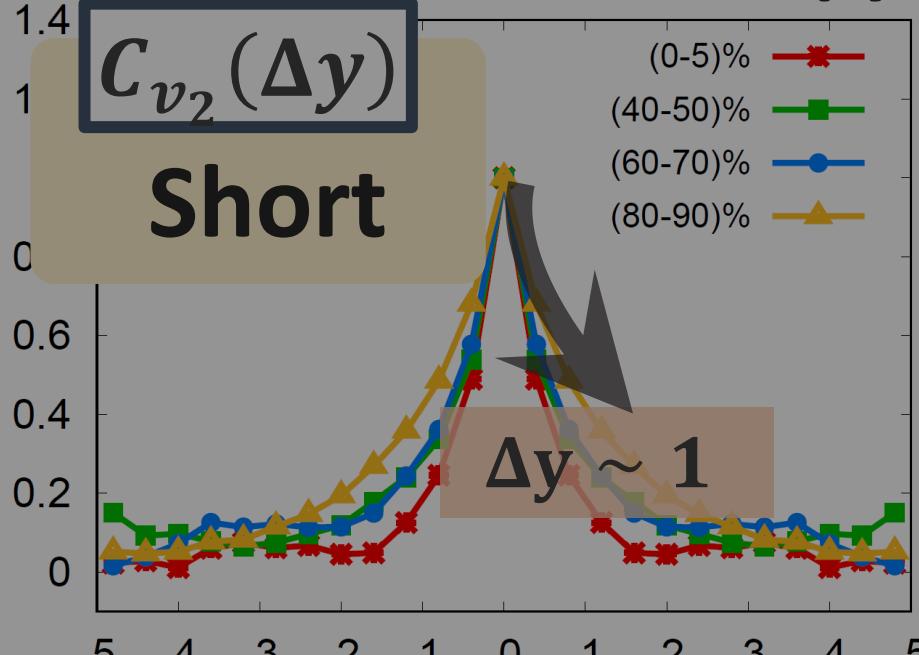
Full 3D
glasma

Origin of collectivity in initial states

pPb

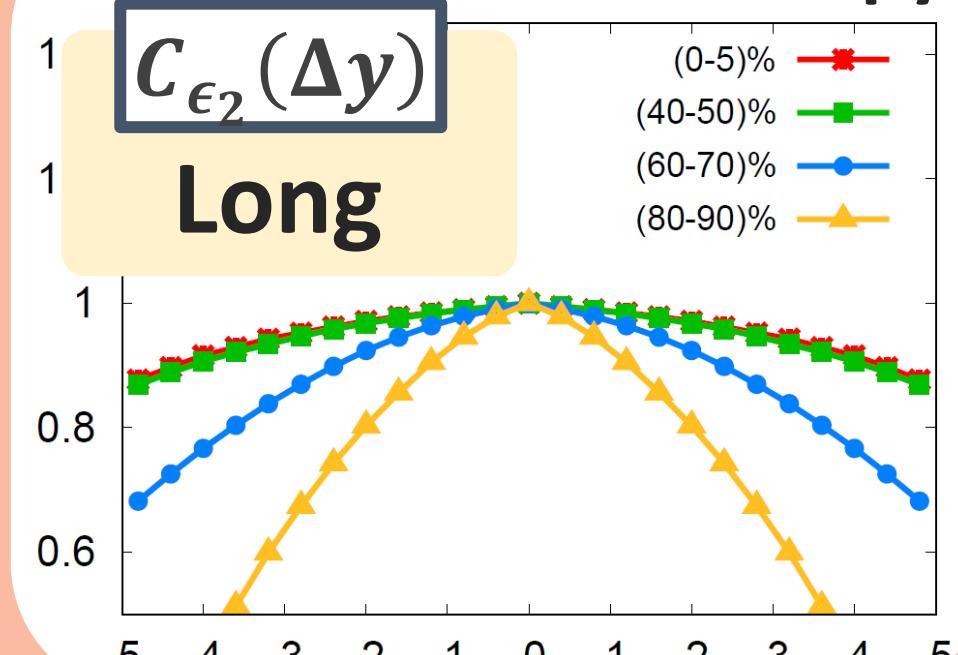
B. Schenke *et al.*, Phys. Rev. D 105 (2022) 9, 094023

Momentum anisotropy



Short

Geometrical anisotropy



OR

Longitudinal correlation: Geometrical anisotropy

Importance to go full 3D in IP-Glasma



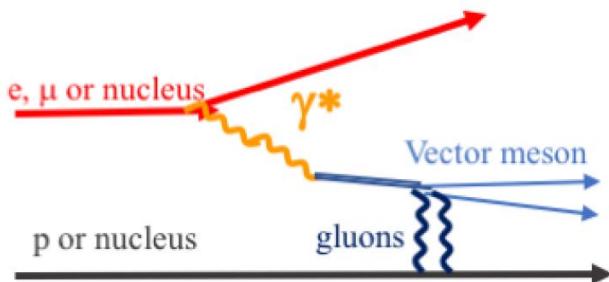
Plenary by C. Shen, Wed 13:20

Accessing proton profile

Diffractive vector meson production

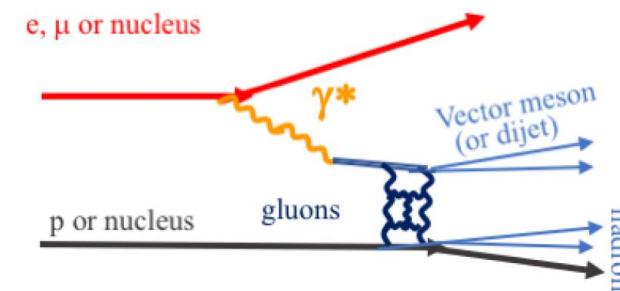
→ Access to spatial structure of proton

S. R. Klein and H. Mäntysaari, Nature Rev. Phys. 1 (2019) 11, 662-674



Coherent

$$\frac{d\sigma_{coh}}{dt} \propto |\langle A \rangle|^2$$



Incoherent

$$\frac{d\sigma_{inc}}{dt} \propto \langle |A|^2 \rangle - |\langle A \rangle|^2$$

Fourier-transformation: $t \leftrightarrow b^2$

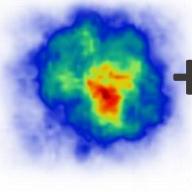
Geometrical structure of proton

Incoherent → sensitive to geometrical fluctuations

Accessing proton profile

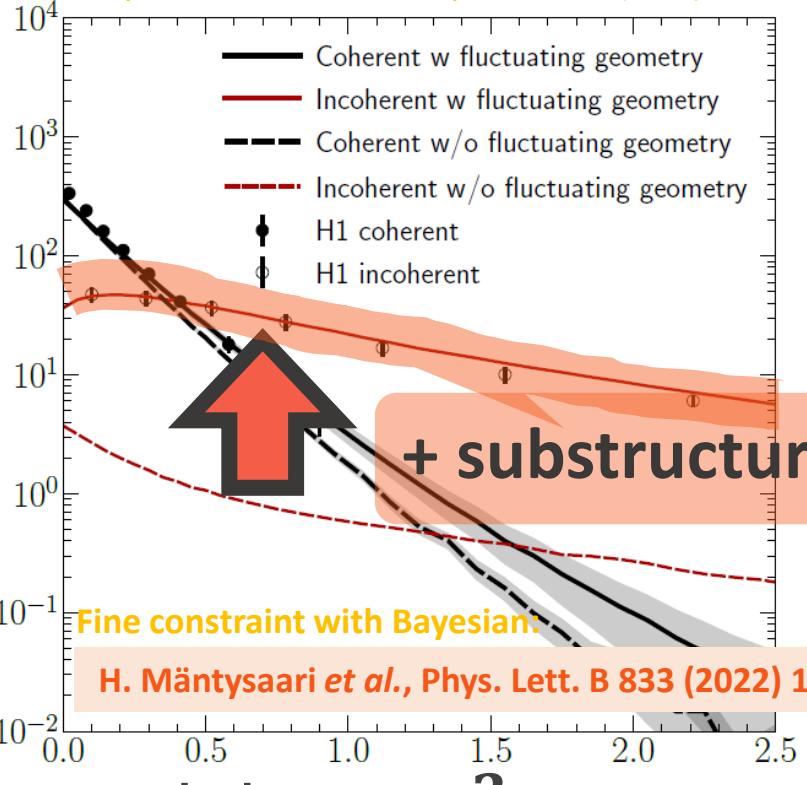
1. Round proton

+ colour charge fluctuation



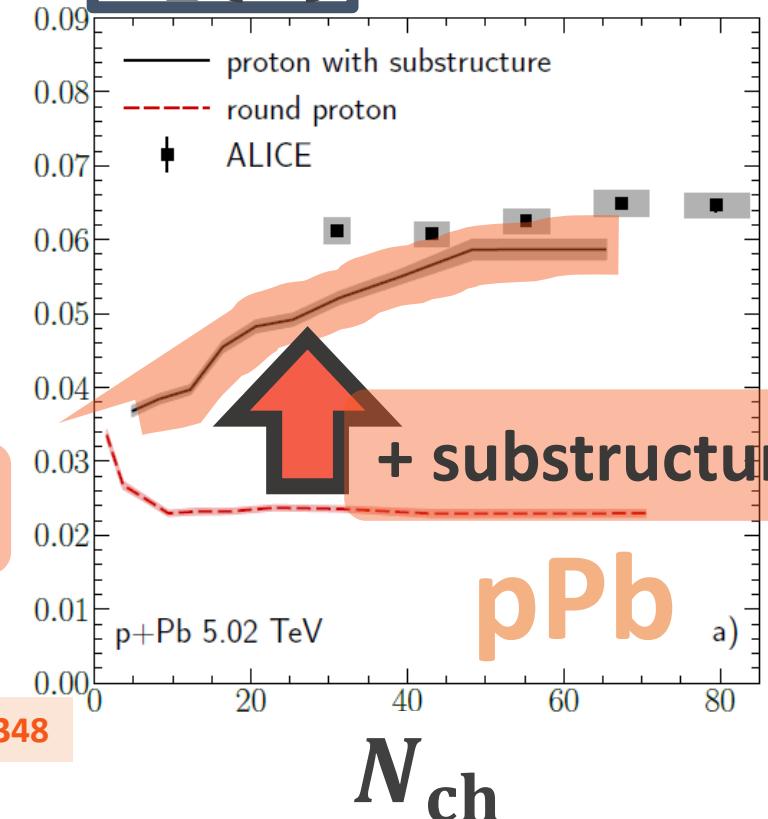
$$d\sigma_{J/\Psi}/dt \text{ [nb/GeV}^2]$$

H. Mäntysaari and B. Schenke, Phys. Rev. D 94 (2016) 3, 034042



$$v_2\{2\}$$

B. Schenke, Rept. Prog. Phys. 84 (2021) 8, 082301



2. Proton w/ substructure

+ colour charge fluctuation
+ substructure

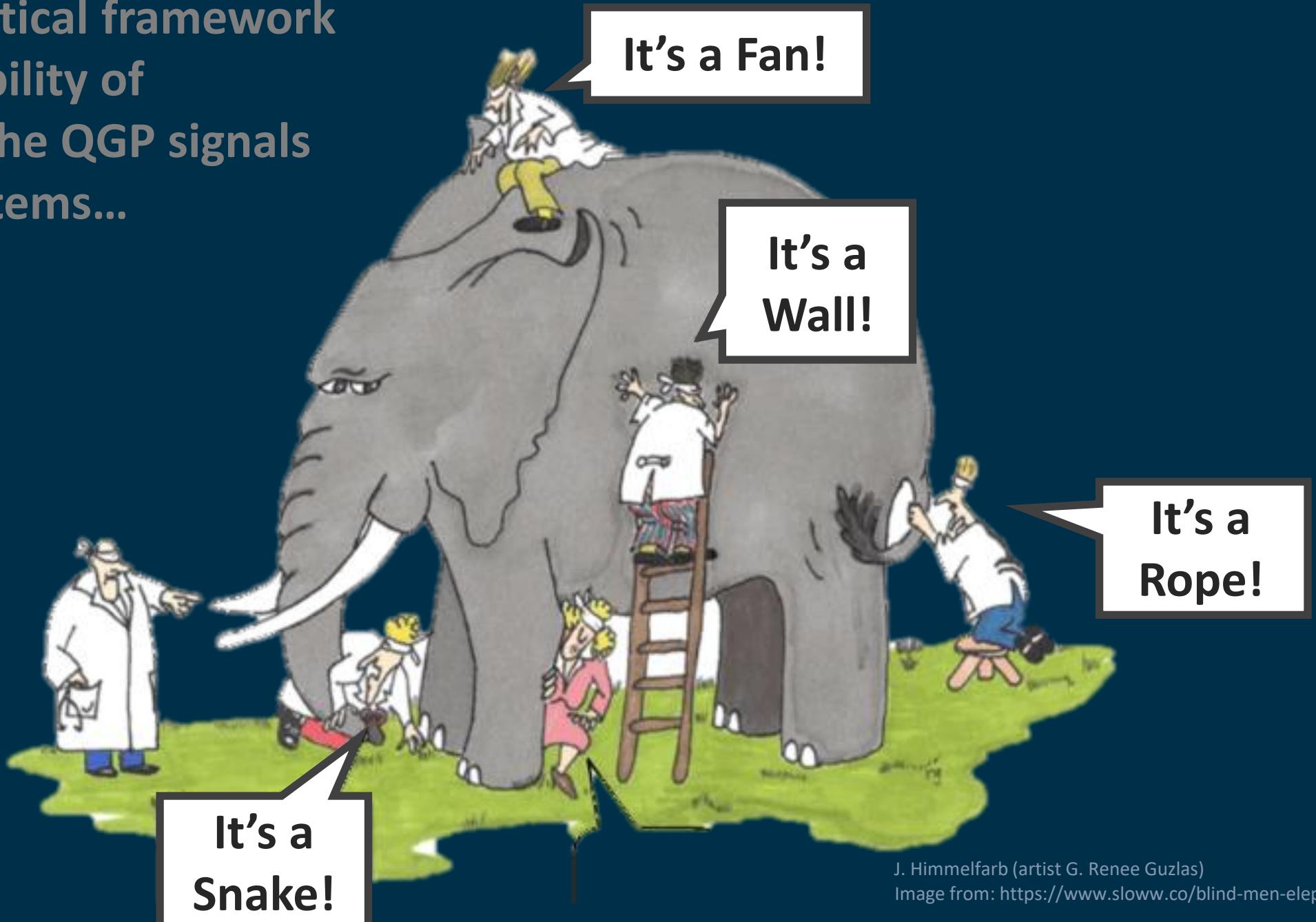


→ Seed of collectivity

Initial state → substantial contribution in final state

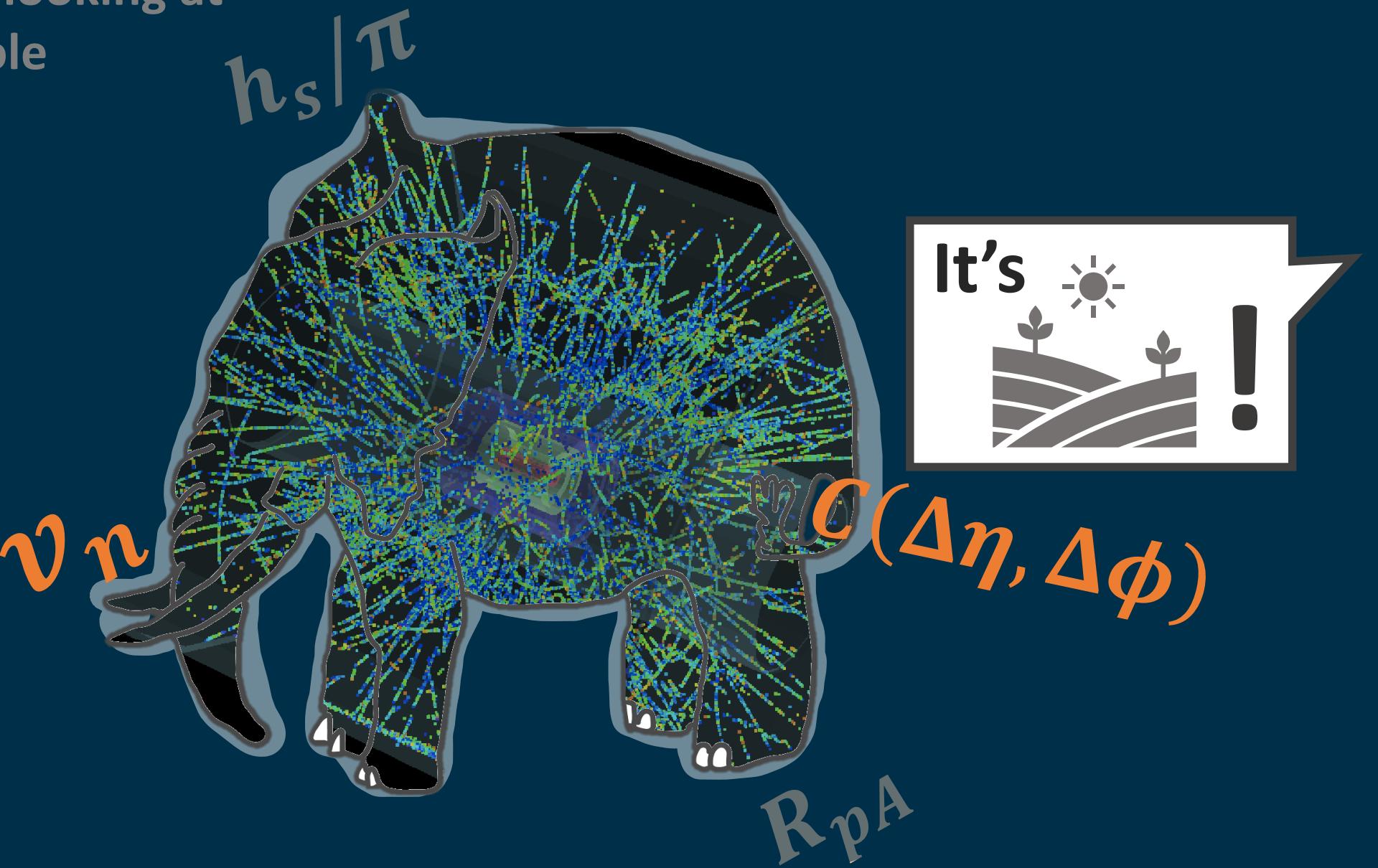
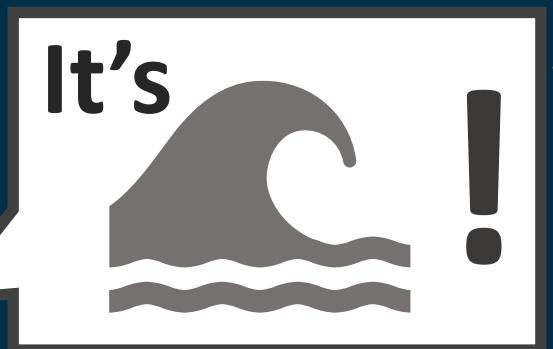
See also: Mäntysaari, Schenke, Shen, Tribedy (2017)

Each theoretical framework
show possibility of
explaining the QGP signals
in small systems...



J. Himmelfarb (artist G. Renee Guzas)
Image from: <https://www.sloww.co/blind-men-elephant/>

We might be just looking at
one side of a whole
phenomenon





Multi-observable analysis with

Monte-Carlo Event Generators

A. Buckley *et al.*, Phys. Rept. 504 (2011) 145-233

PYTHIA/PYTHIA Angantyr: T. Sjöstrand *et al.*, Comput. Phys. Commun. 178, 852 (2008), C. Bierlich *et al.*, JHEP 10 (2018) 134..., HIJING: X. N. Wang *et al.*, Phys. Rev. D 44 (1991) 3501-3516..., EPOS: K. Werner *et al.*, Phys. Rev. C 74 (2006) 044902..., AMPT: Z. W. Lin *et al.*, Phys. Rev. C 72 (2005) 064901...

Weak signals in small systems!
quantitative investigation required (ex. non-flow subtraction...)

J. Jia *et al.*, Phys. Rev. C 96 (2017) 3, 034906; H. Song *et al.*, Nucl. Sci. Tech. 28 (2017) 7, 99; P. Huo *et al.*, Phys. Lett. B 777 (2018) 201-206; S. H. Lim *et al.*, Phys. Rev. C 100 (2019) 2, 024908; J.L. Nagle *et al.*, Phys. Rev. C 105 (2022) 2, 024906...

String fragmentation

PYTHIA8

- Colour confinement **in vacuum**
- Successful description of pp measurements

T. Sjöstrand *et al.*, Comput. Phys. Commun. 178, 852 (2008)

PYTHIA8 Angantyr

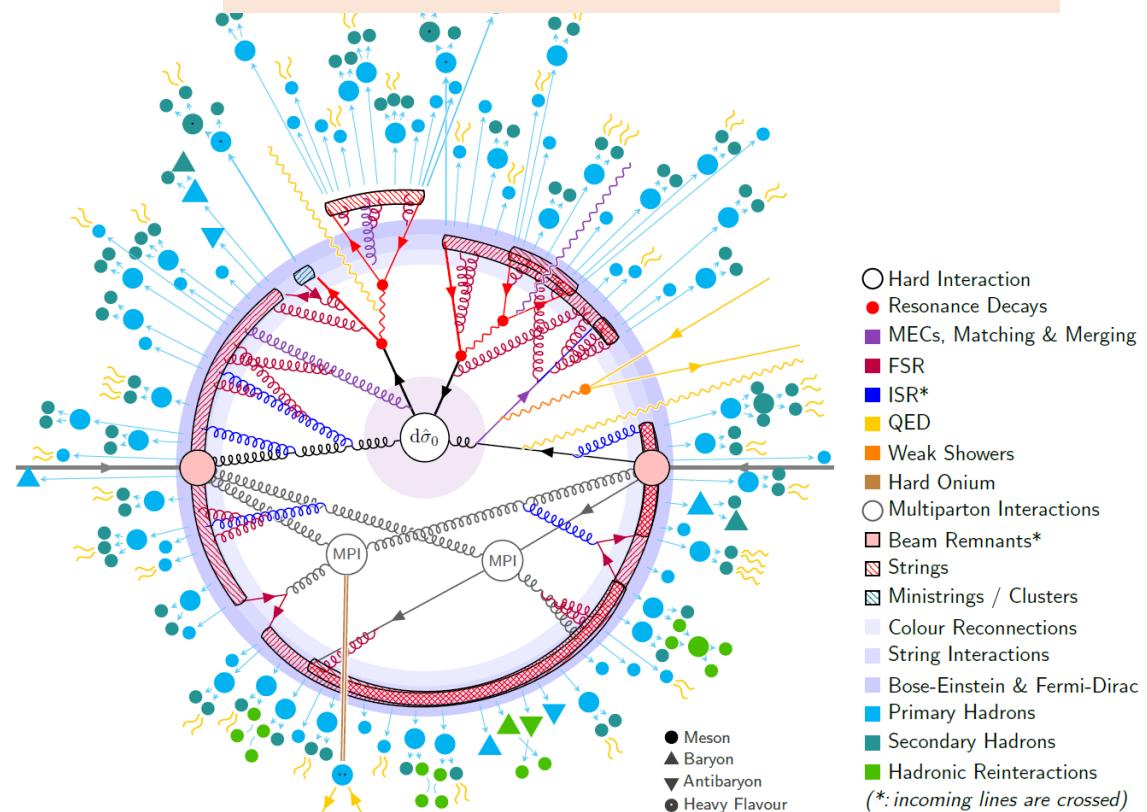
- Extrapolation to pA, AA

→ No QGP

A comprehensive guide to the physics and usage of PYTHIA 8.3

Christian Bierlich¹, Smita Chakraborty¹, Nishita Desai², Leif Gellersen¹, Ilkka Helenius^{3,4}, Philip Ilten⁹, Leif Lönnblad¹, Stephen Mrenna⁵, Stefan Prestel¹, Christian T. Preuss^{6,7}, Torbjörn Sjöstrand¹, Peter Skands⁶, Marius Utheim^{1,3}, and Rob Verheeven⁸

C. Bierlich *et al.*, SciPost Phys. Codebases 8 (2022)



String fragmentation

PYTHIA8

- Colour confinement **in vacuum**
- Successful description of pp measurements

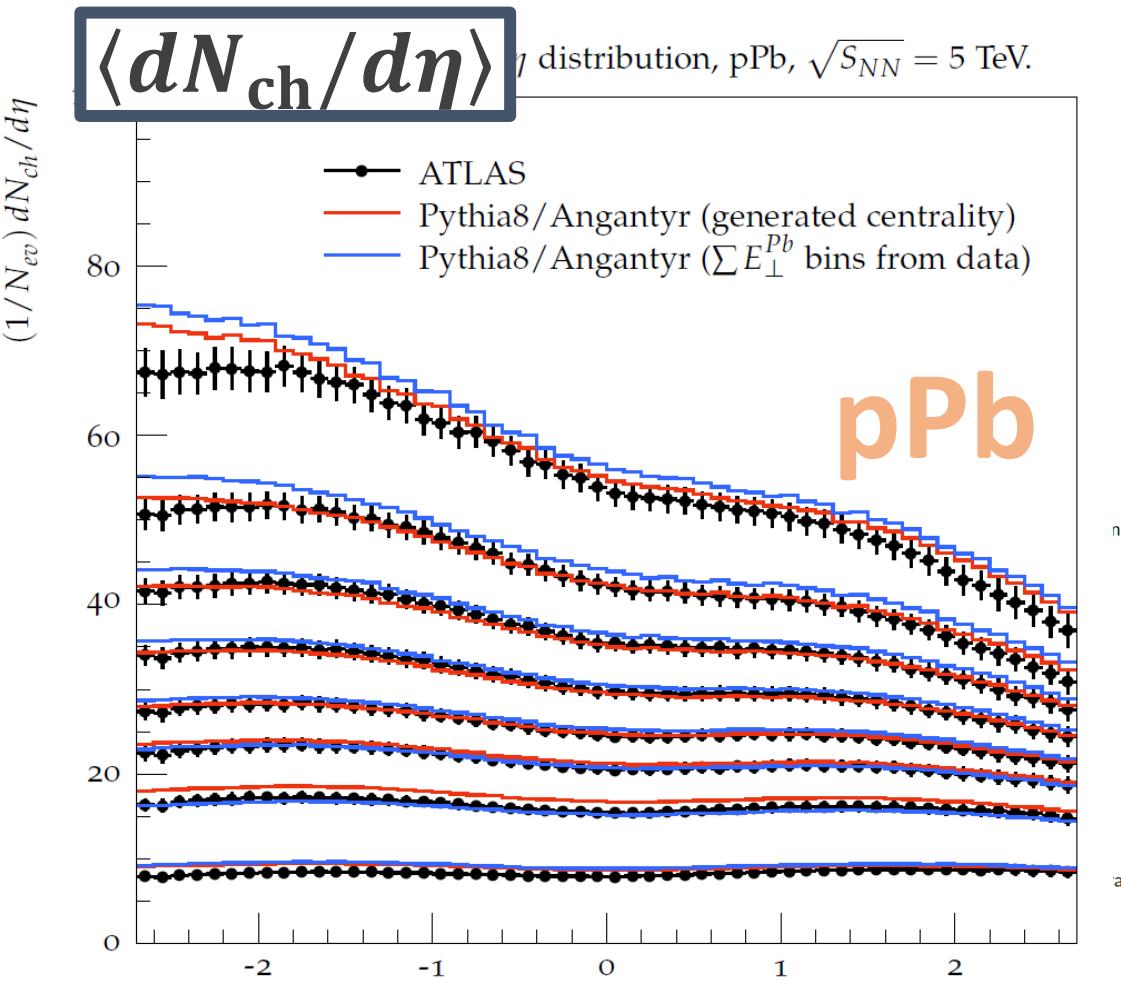
T. Sjöstrand *et al.*, Comput. Phys. Commun. 178, 852 (2008)

PYTHIA8 Angantyr

- Extrapolation to pA, AA

→ No QGP

What about strangeness enhancement & collectivity?



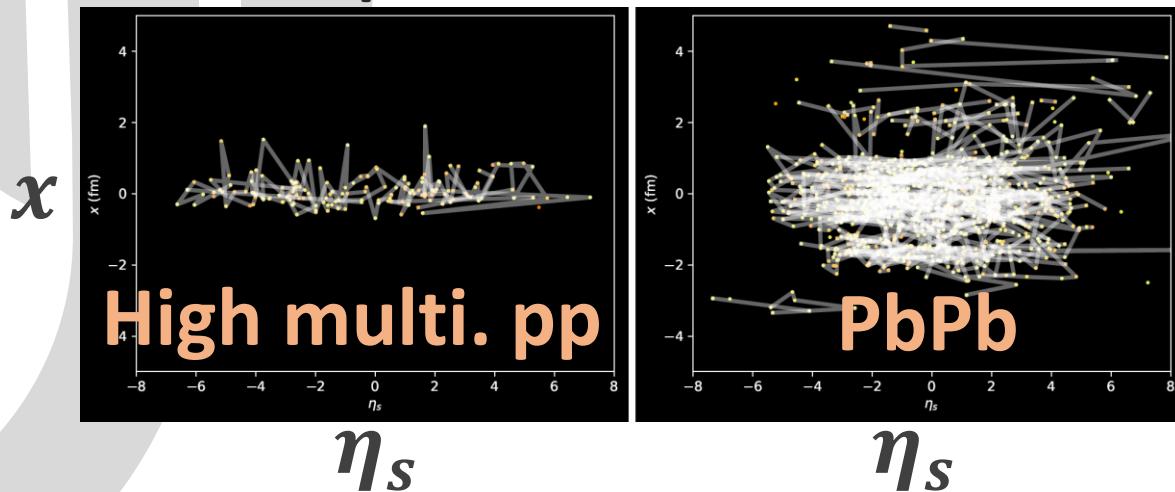
String fragmentation

Rope hadronisation

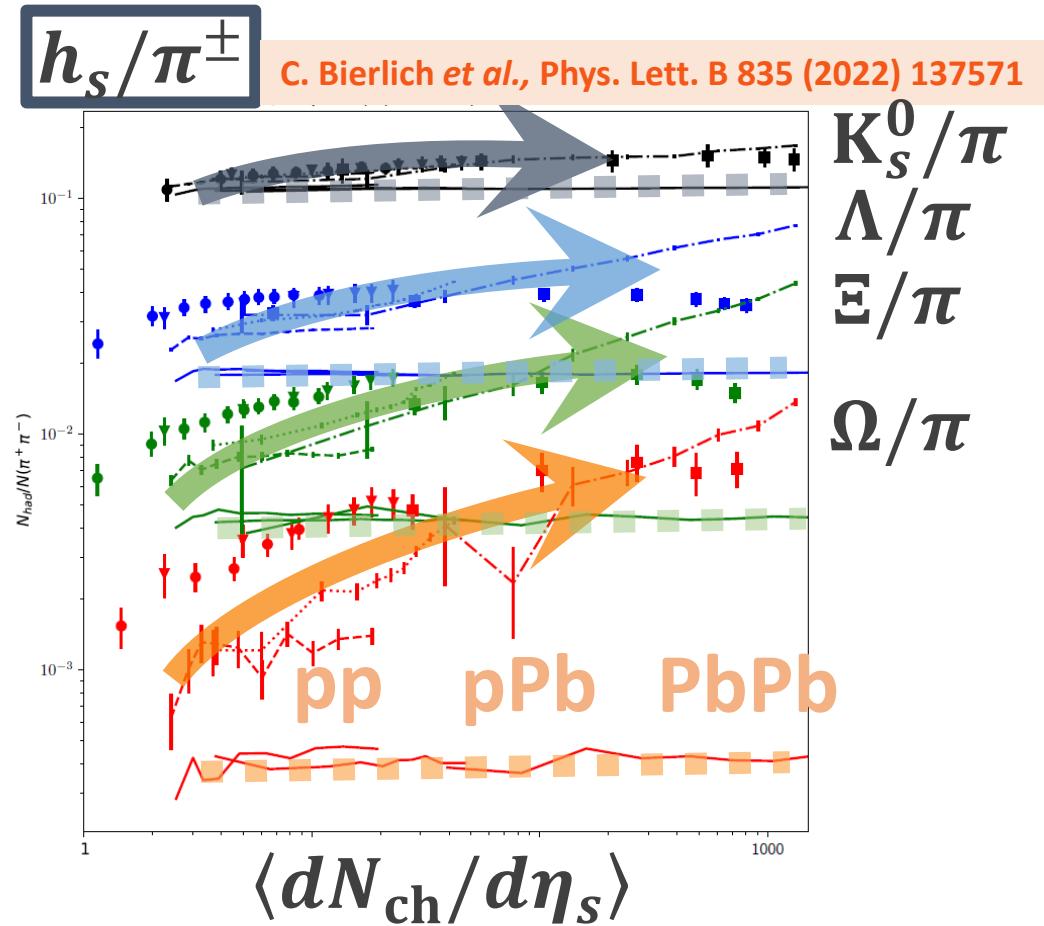
Modification of **string tension**
due to spatial overlap

$$P \propto \exp(-\pi m_T^2 / \kappa)$$

Colour string configuration
in spatial coordinate



V. Kanakubo, PhD thesis, 2208:07029

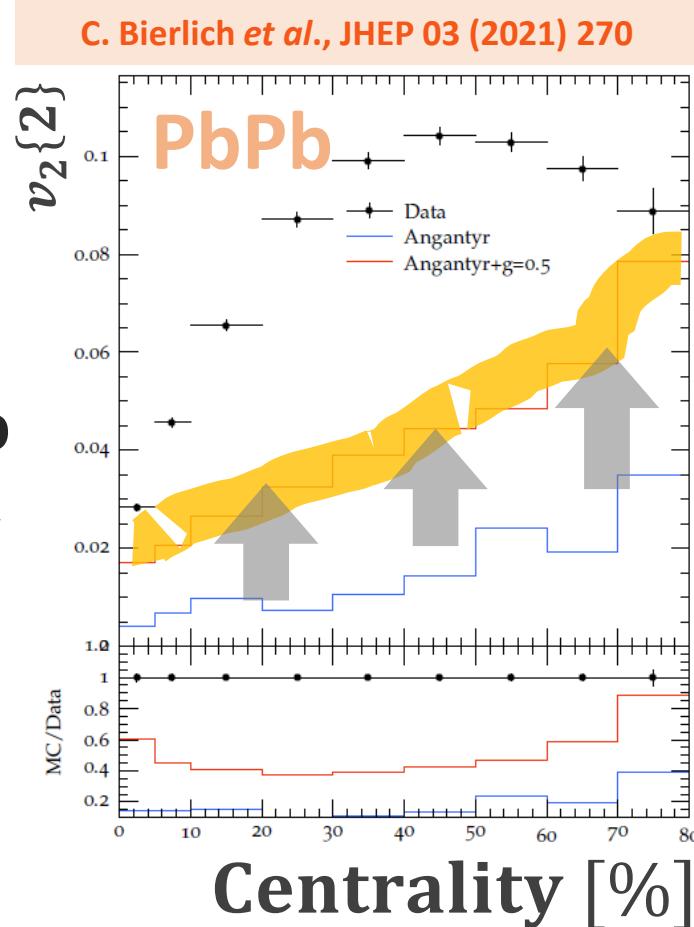


$v_2\{2\}$

String shoving
Push to transverse
direction according to
distance of strings d_T

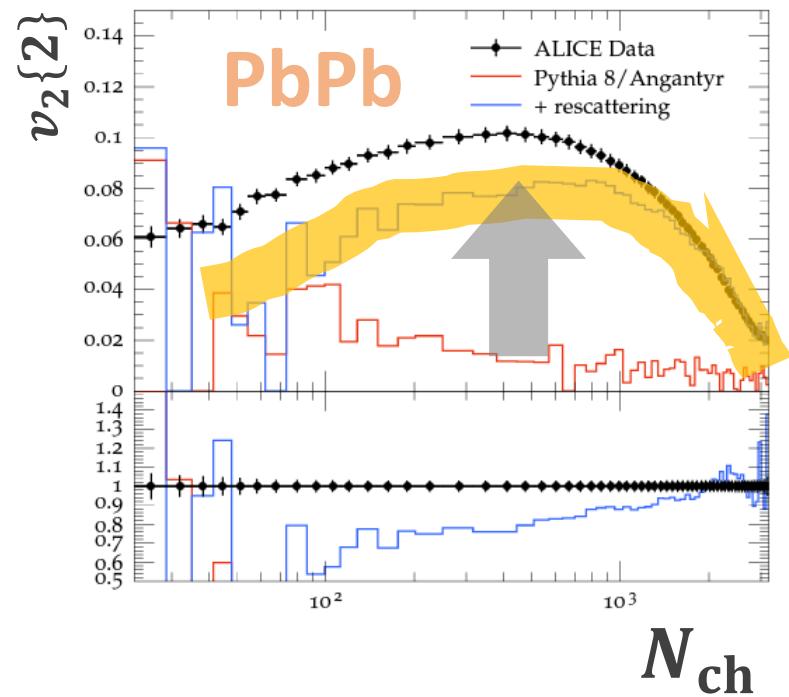
String fragmentation

8
16



Hadronic rescatterings

C. Bierlich *et al.*, Eur. Phys. J. A 57 (2021) 7, 227



How far can we go without picture of equilibrated matter?

Core-corona picture

EPOS4

K. Werner, arXiv: 2301.12517 [hep-ph]

New papers appeared on arXiv yesterday! 2306.10277, 2306.02396

- Both in and out-of equilibrium

in equilibrium: QGP hydro (core), out-of equilibrium: strings (corona)

- Initial: factorization at high p_T

+ saturation at low p_T

- Microcanonical particlisation of hydro

- Hadronic rescatterings

Talk by K. Werner at QCD challenges from pp to AA collisions 2023



Plenary by K. Werner, Mon. 16:00-

<https://klaus.pages.in2p3.fr/epos4>

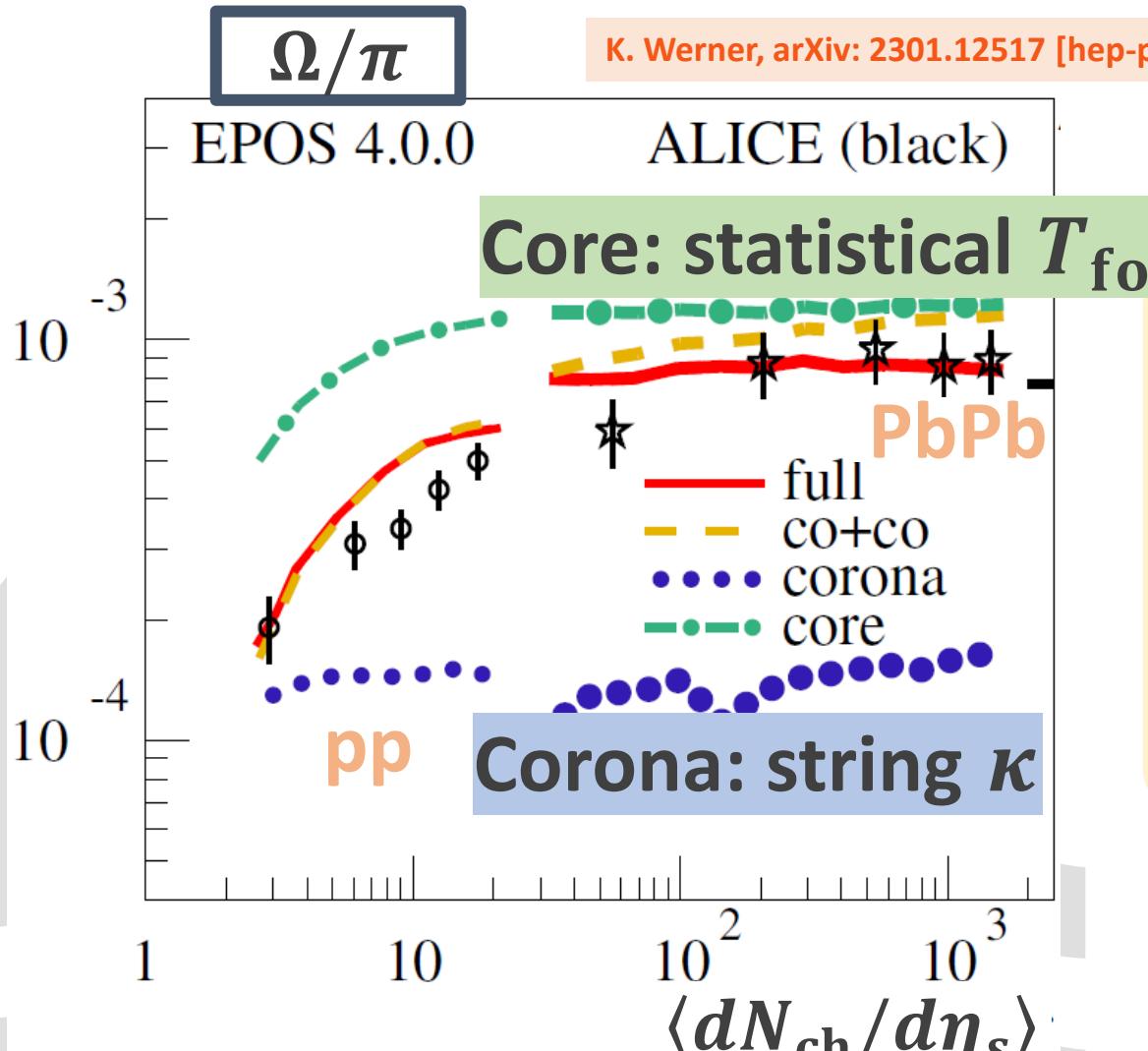
eBye energy-momentum
conservation
with hydro

allows (for the first time!) to accommodate simultaneously

E_nergy conservation + P_{ar}allel scattering + fact O_rization + S_aturation

Now we can do in one single ("general purpose") approach
"multi-observable analysis" concerning

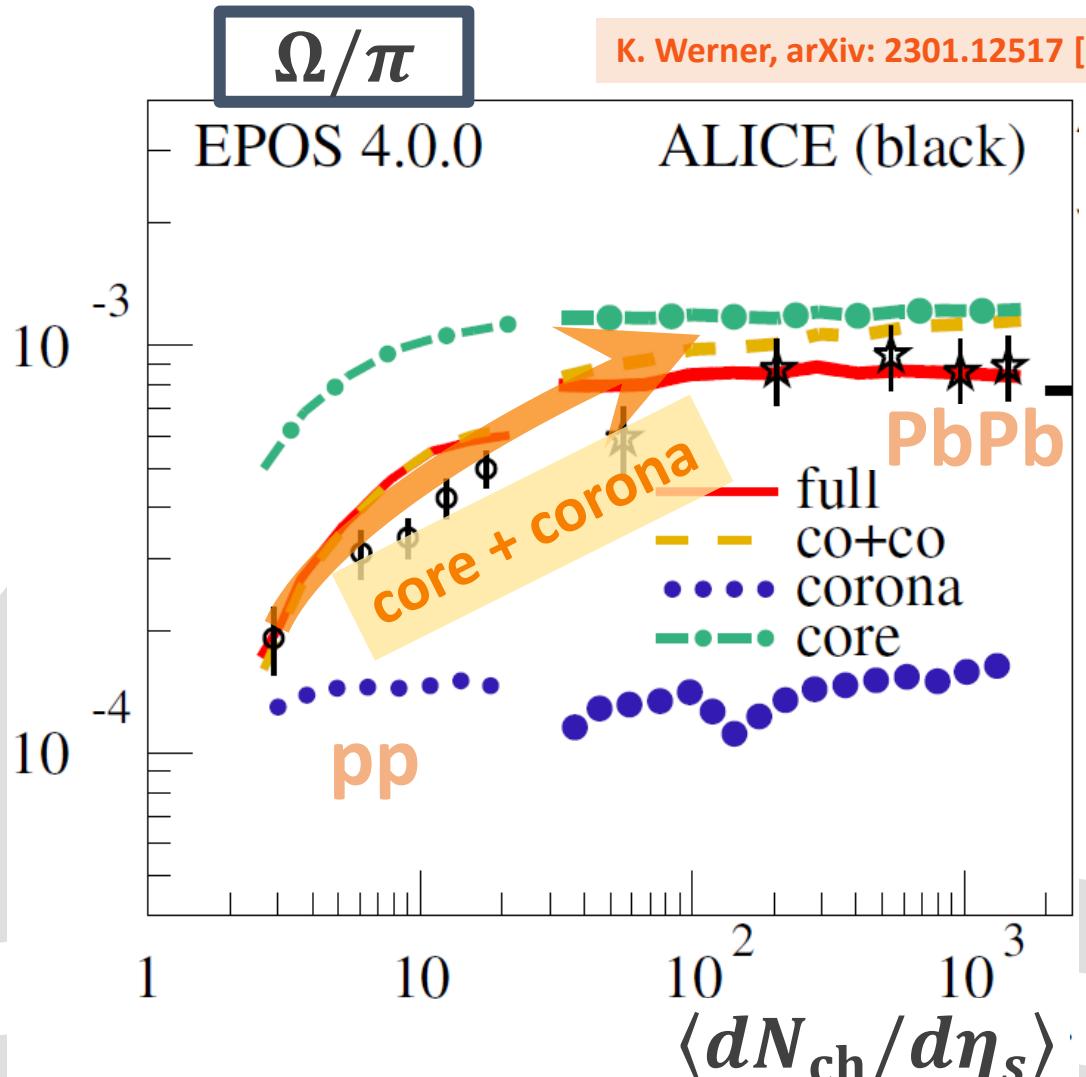
Core-corona picture



Strangeness enhancement

→ Multiplicity dependent
QGP formation in initial stage

Core-corona picture



Strangeness enhancement

→ Multiplicity dependent
QGP formation in initial stage

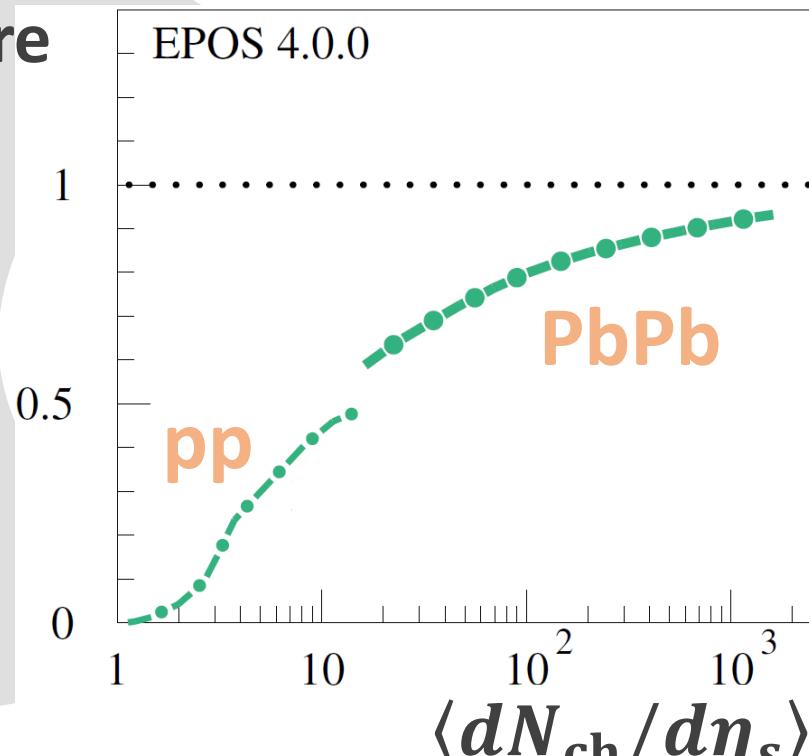
Core-corona picture

EPOS4

Fraction of particle
productions from core

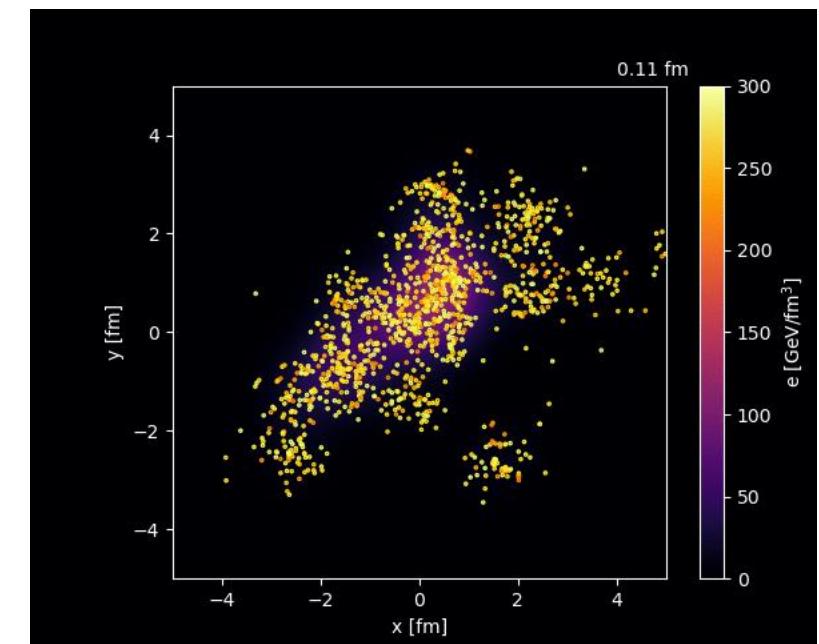
$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

K. Werner, arXiv: 2301.12517 [hep-ph]



DCCI2

Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905



Dynamical initialisation
based on core-corona

Core-corona picture

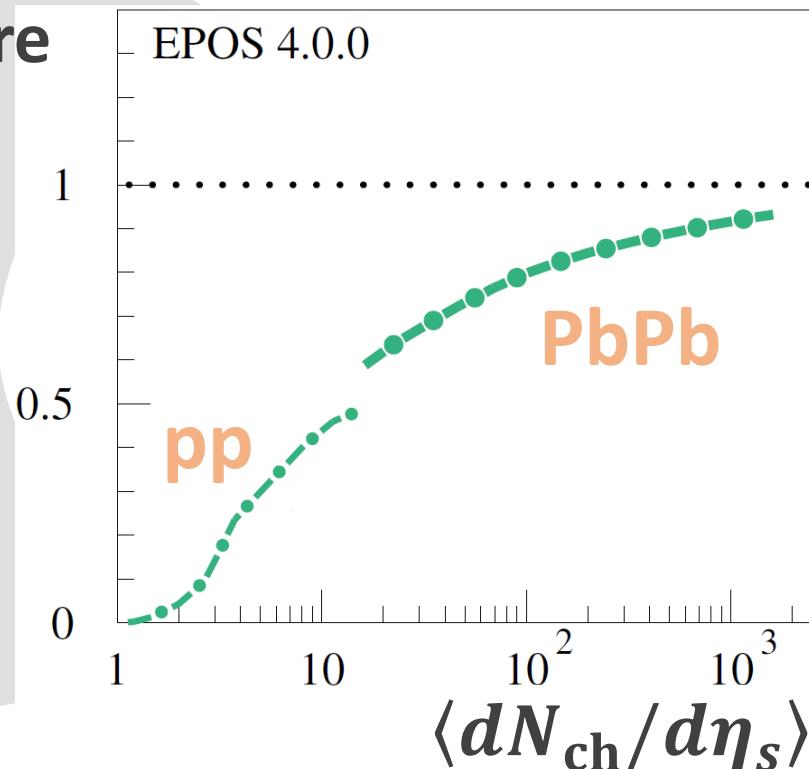
EPOS4

Fraction of particle
productions from core

$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

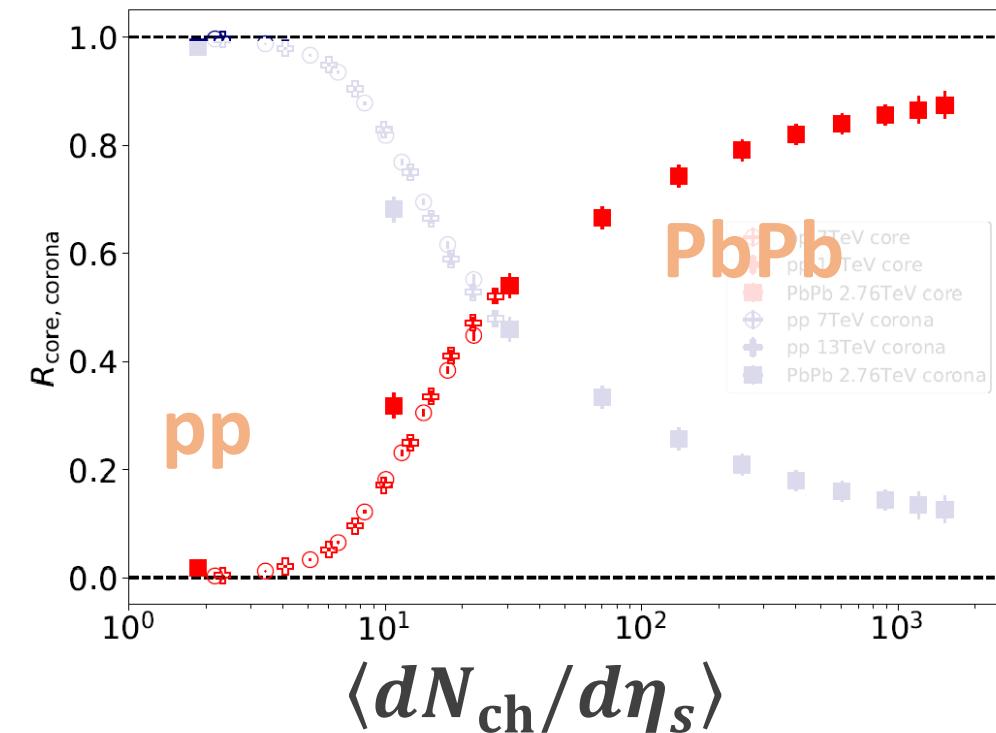
→ Reasonable
consistency

K. Werner, arXiv: 2301.12517 [hep-ph]



DCC12

Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905



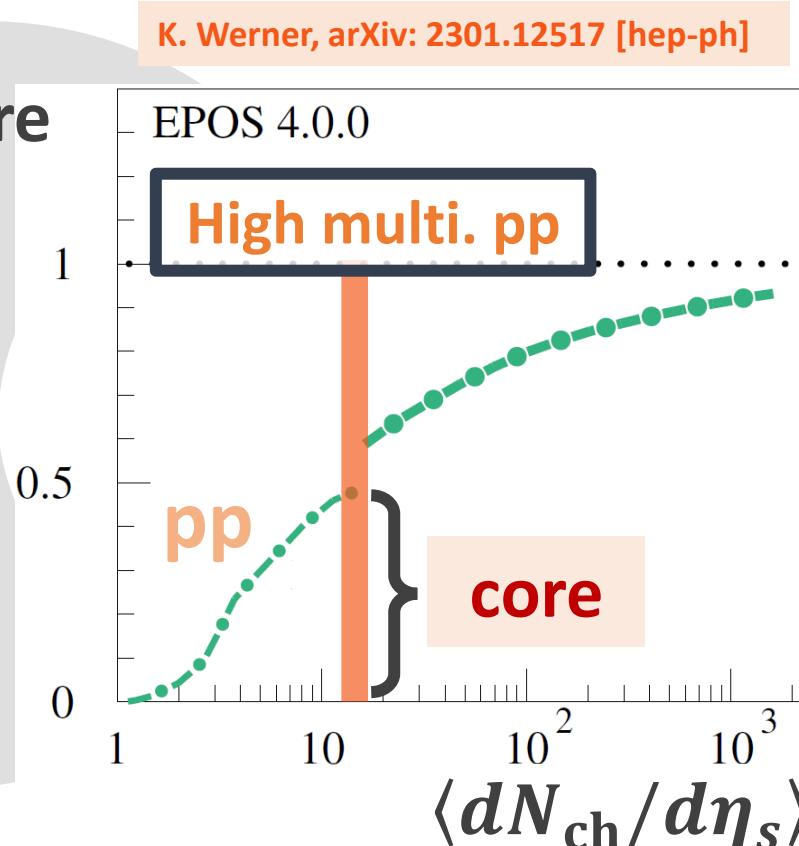
Core-corona picture

EPOS4

Fraction of particle
productions from core

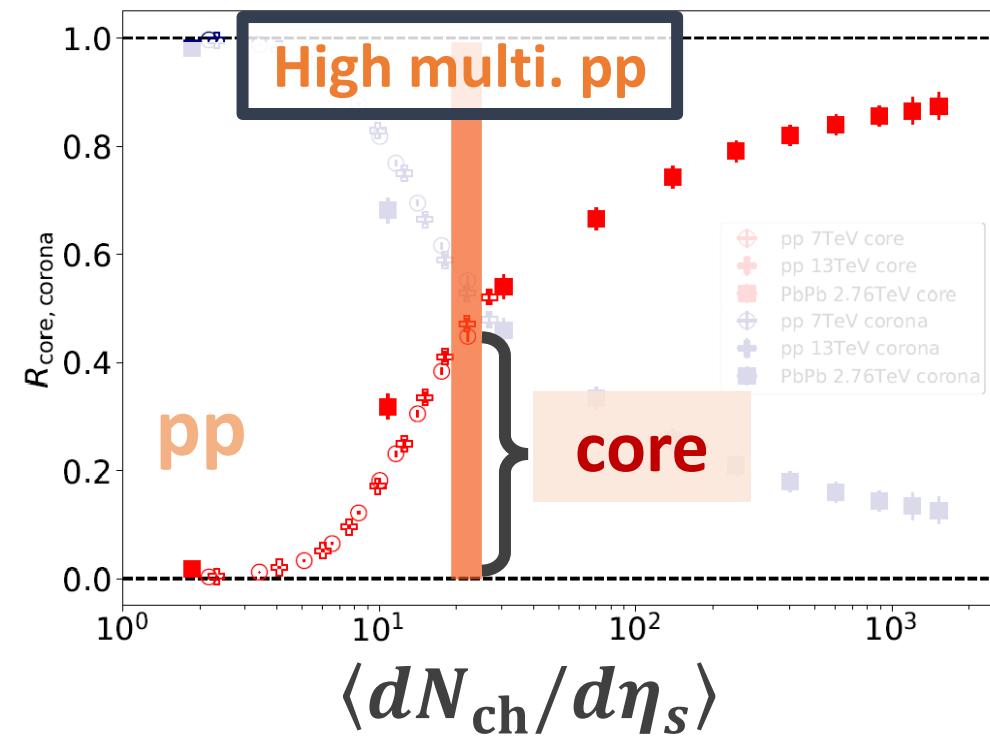
$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

→ Reasonable
consistency



DCC12

Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905



High multi. pp: **core contribution $\sim 50\%$**

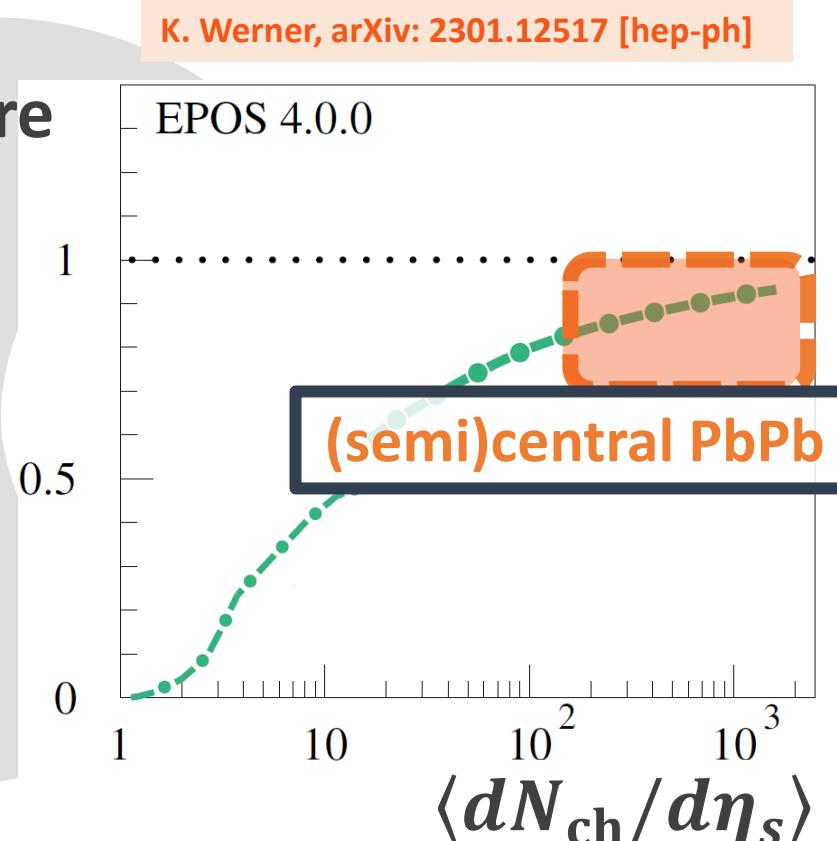
Core-corona picture

EPOS4

Fraction of particle
productions from core

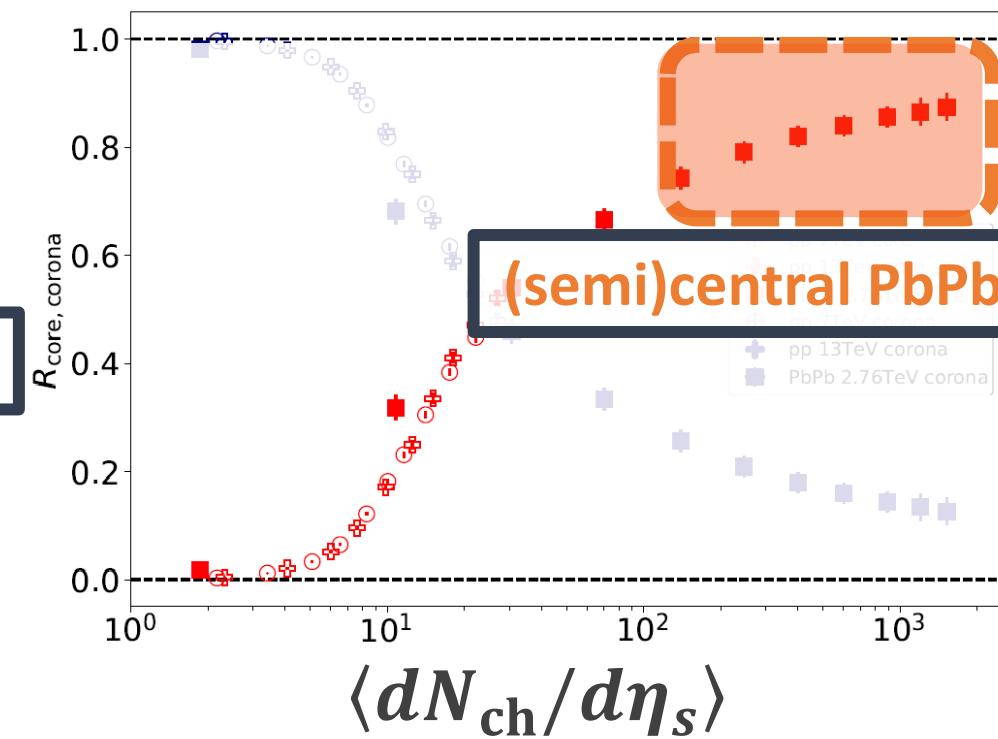
$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

→ Reasonable
consistency



DCC12

Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905



(Semi-)central PbPb: non-negligible corona contribution

Effect on collectivity: Y. Kanakubo *et al.*, Phys. Rev. C 106 (2022) 5, 054908

Core-corona picture

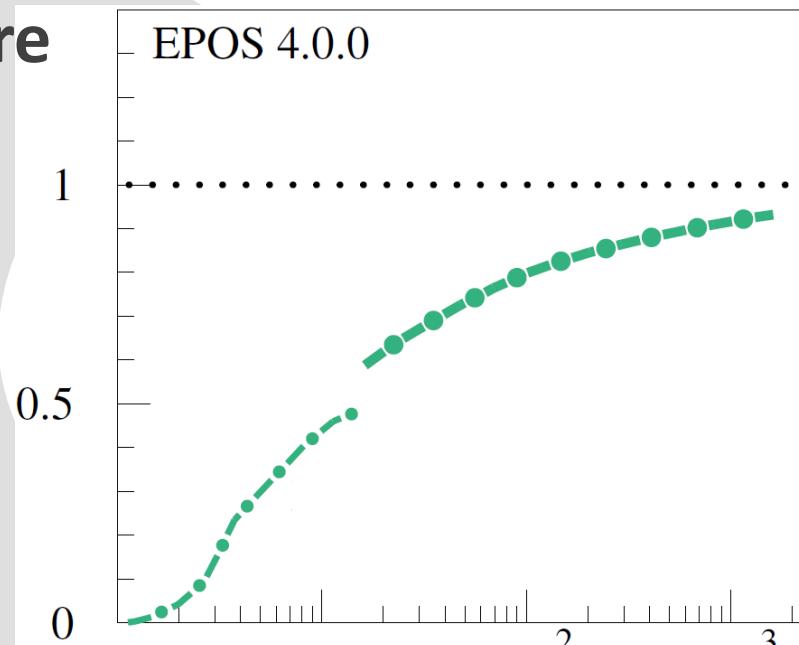
EPOS4

Fraction of particle
productions from core

$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

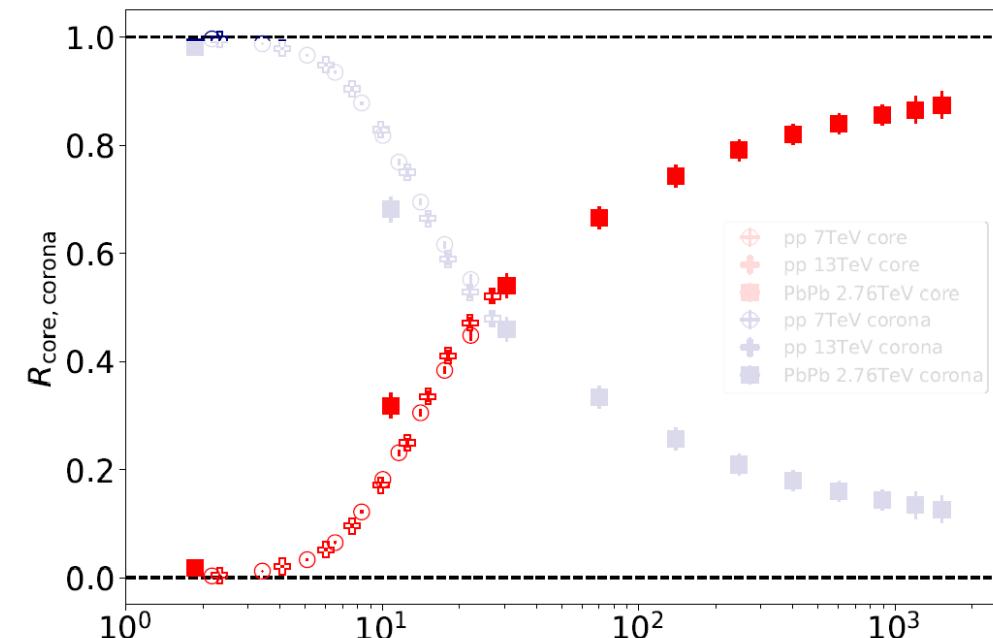
→ Reasonable
consistency

K. Werner, arXiv: 2301.12517 [hep-ph]



DCC12

Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905



Hadron chemistry (e.g. strange hadron yield ratios)

→ Both equilibrated and non-equilibrated from pp to AA

**Different pictures?
Should we discriminate them,
or should we find compatibility?**

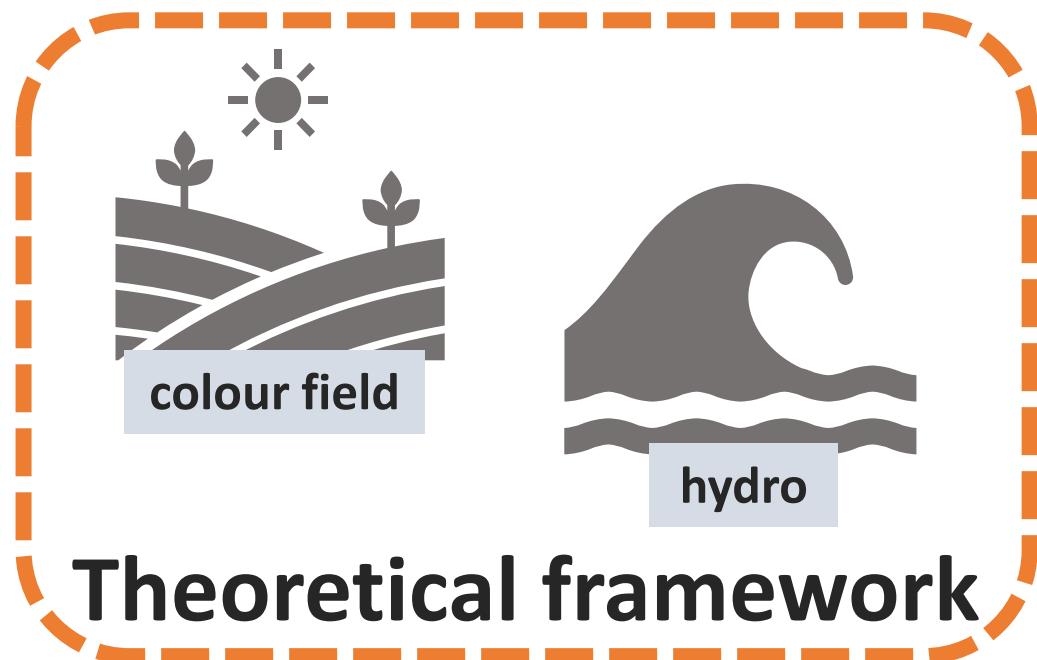


Comparison among different descriptions

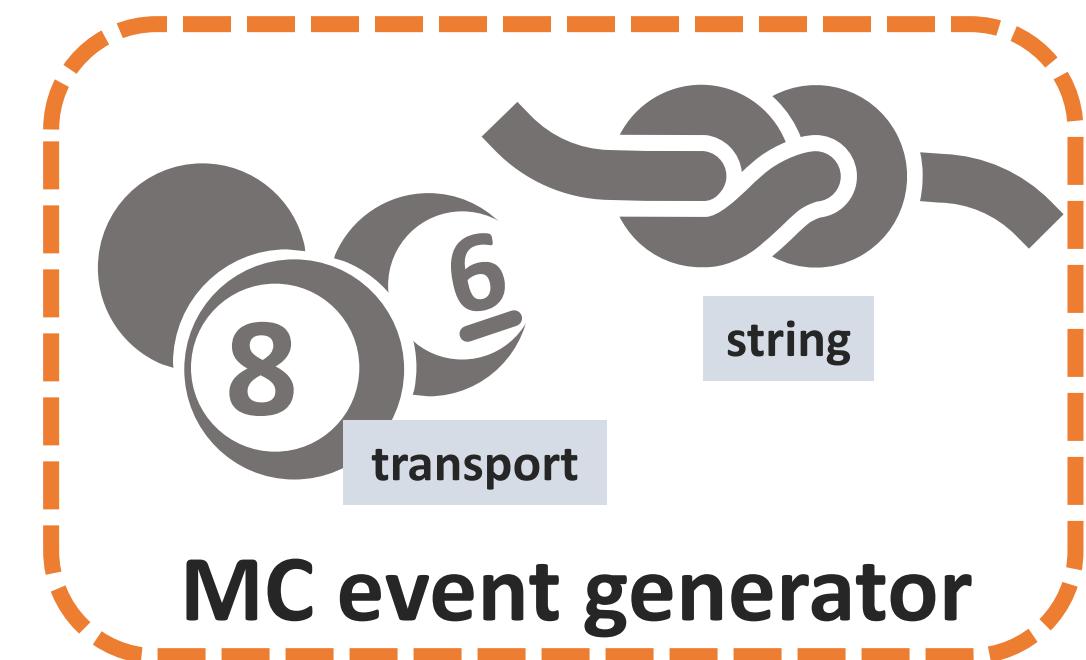
Which is better?

Ex. Transport vs. hydro: investigation of non-equilibrium effects in pPb with PHSD

L. Oliva *et al.*, Phys. Rev. C 106 (2022) 4, 044910



Theoretical framework



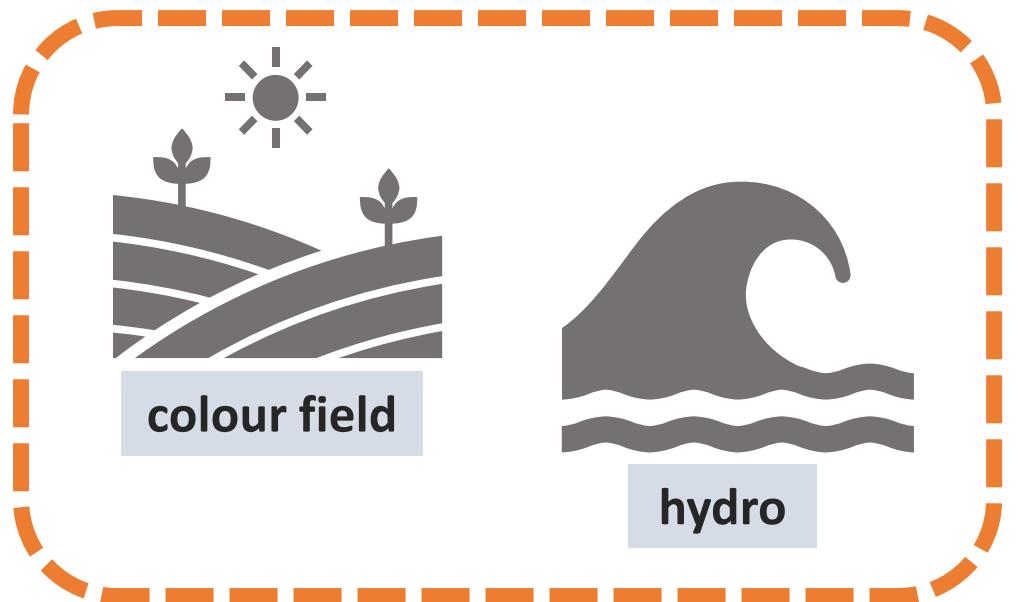
MC event generator

*Not necessary to be exclusive (different description can be applied for each stage of a collision)

*Above classification is not true for every model

→ Apple to apple comparison is challenging

MC event generator with CGC and/or hydro



Problems to consider

- Energy-momentum conservation of incoming beam energy
- Entire momentum space (from low to high p_T , from forward to backward rapidity)

Fermion productions: N. Tanji *et al.*, Phys. Rev. D 97 (2018) 3, 034013; V. Kasper *et al.*, Phys. Rev. D 90 (2014) 2, 025016...

Glasma+jets: D. Avramescu *et al.*, arXiv:2303.05599;
A. Ipp *et al.*, Phys. Lett. B 810 (2020) 135810; M. E.
Carrington *et al.*, Phys. Rev. C 105 (2022) 6, 064910... etc.

Full 3D MC EKRT initial condition: M. Kuha *et al.*, in progress

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Core-corona: K. Werner, arXiv: 2301.12517 [hep-ph]; Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905 etc.

Quantitative discussions based on model-data comparisons

Summary



Summary

Origin of collectivity in small systems?
→ No common consensus yet



hydro



colour field



string



transport

Hadron chemistry should be discussed too

Quantitative discussion is required in small systems!

To address the open question from model-data comparisons

Multi-observable analysis

within Monte-Carlo event generator under unified description

Special thanks for discussions

Heikki Mäntysaari, Lucia Oliva, Pragya Singh, Olga Soloveva, Marius Utheim

and all members of Centre of Excellence in Quark Matter

Oskari Saarimäki for CoE logo

Thank you



Core-corona picture

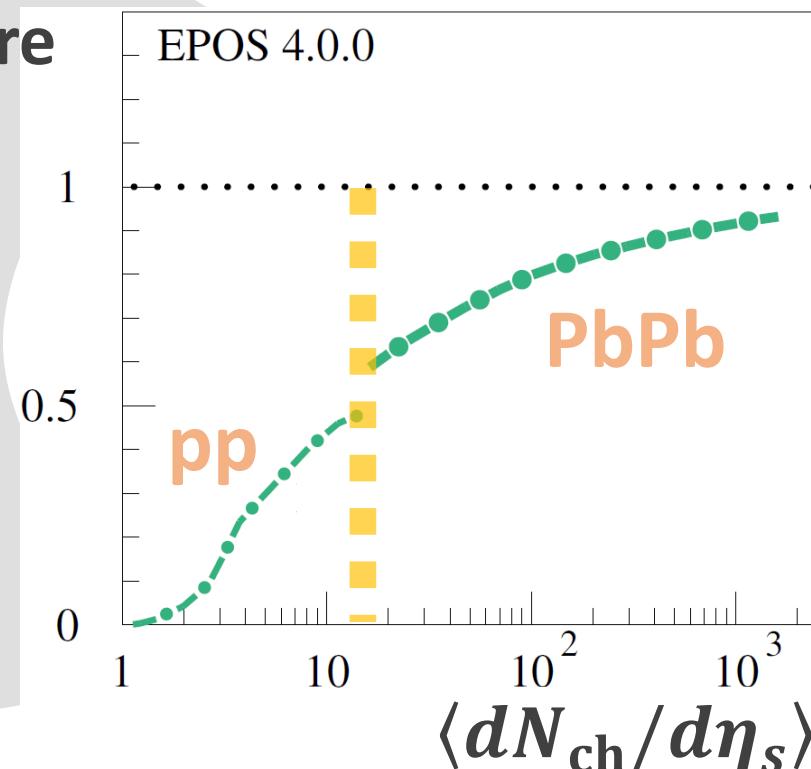
EPOS4

Fraction of particle
productions from core

$$\frac{dN_{\pi(\text{ch})}/d\eta \text{ (core)}}{dN_{\pi(\text{ch})}/d\eta \text{ (tot)}}$$

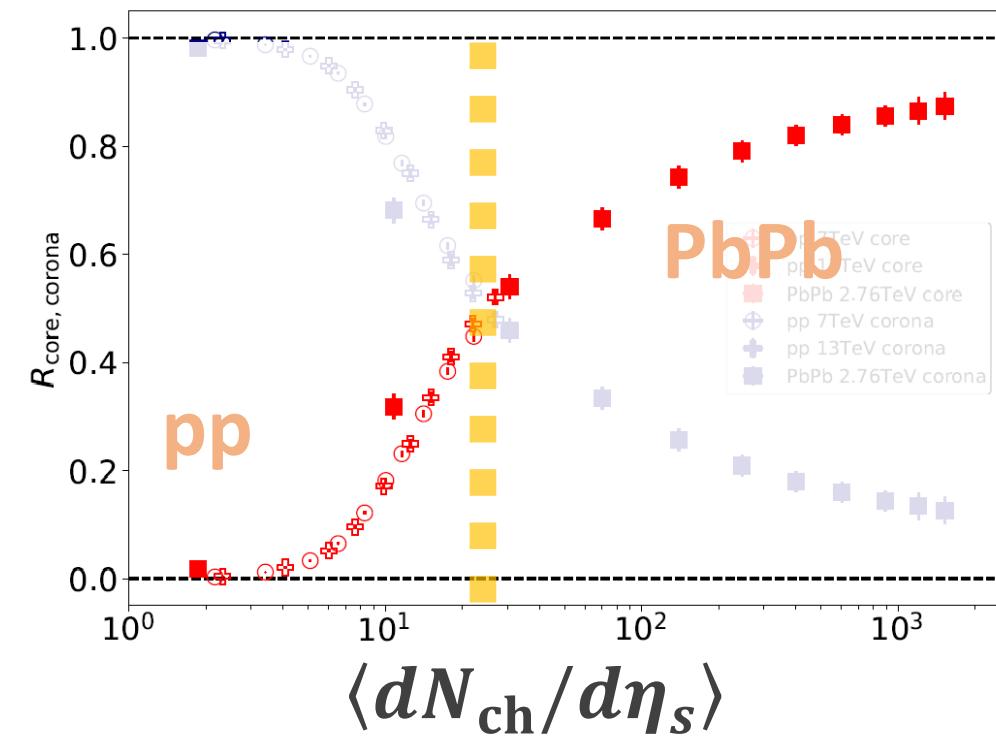
→ Reasonable
consistency

K. Werner, arXiv: 2301.12517 [hep-ph]



DCC12

Y. Kanakubo et al., Phys. Rev. C 105 (2022) 2, 024905



Core dominates above $\langle dN_{\text{ch}}/d\eta_s \rangle \sim 10\text{-}20$

Transport (in and out-of equilibrium)

PHSD (Parton-Hadron-String Dynamics)

W. Cassing and E.L. Bratkovskaya, Nucl. Phys. A 831 (2009) 215-242

- Microscopic description of partonic and hadronic matter

- Both in and out-of equilibrium

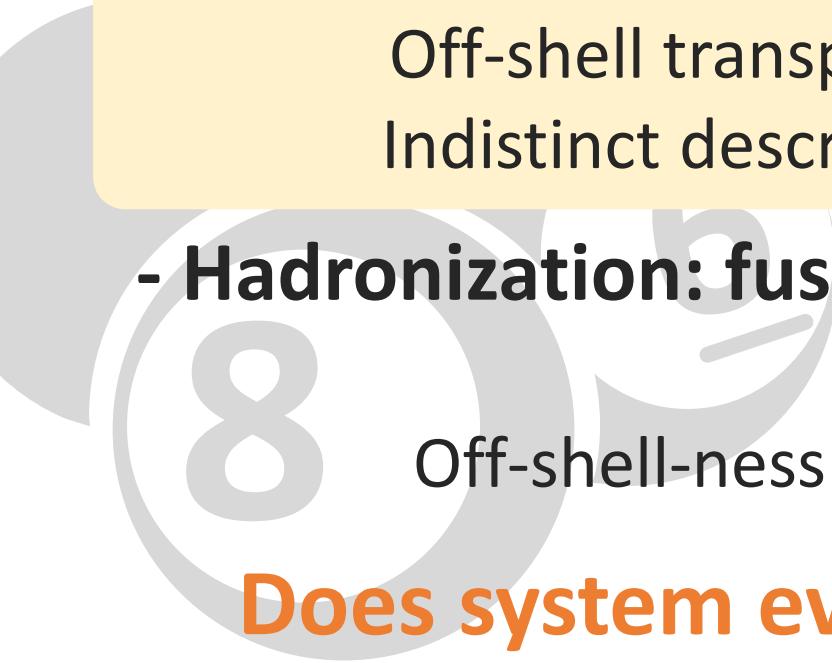
- Off-shell transport equations: interacting quasi-particles

- Indistinct description between in and out-of equilibrium

- Hadronization: fusion of quark and anti quark → meson
 - three (anti-)quarks → (anti-)baryon

- Off-shell-ness keeps four-momentum conservation

Does system evolve differently compared to hydro?



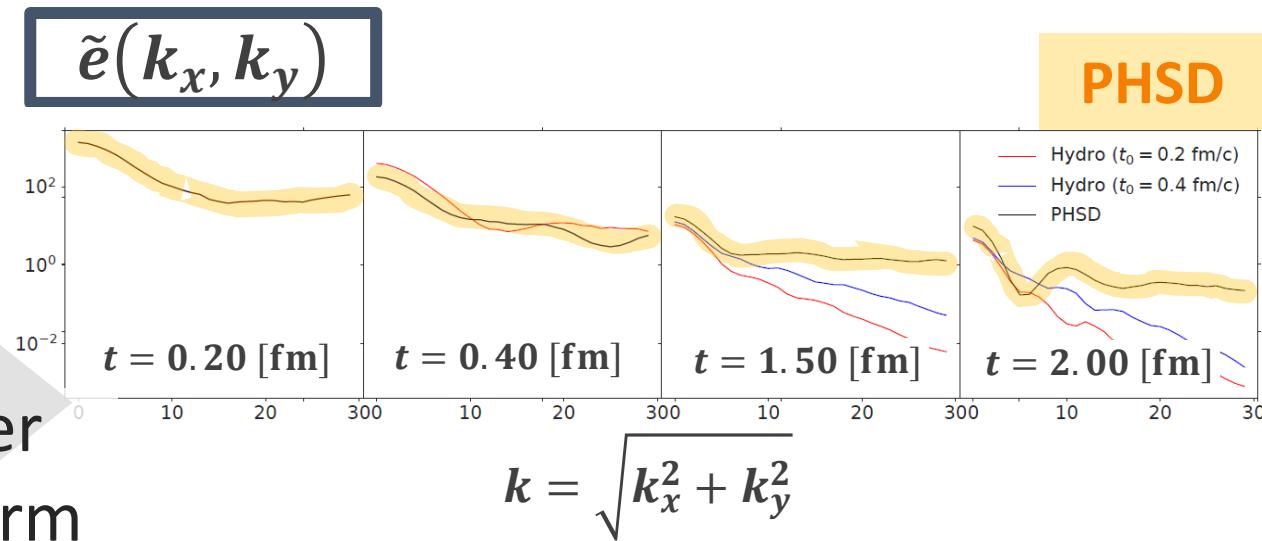
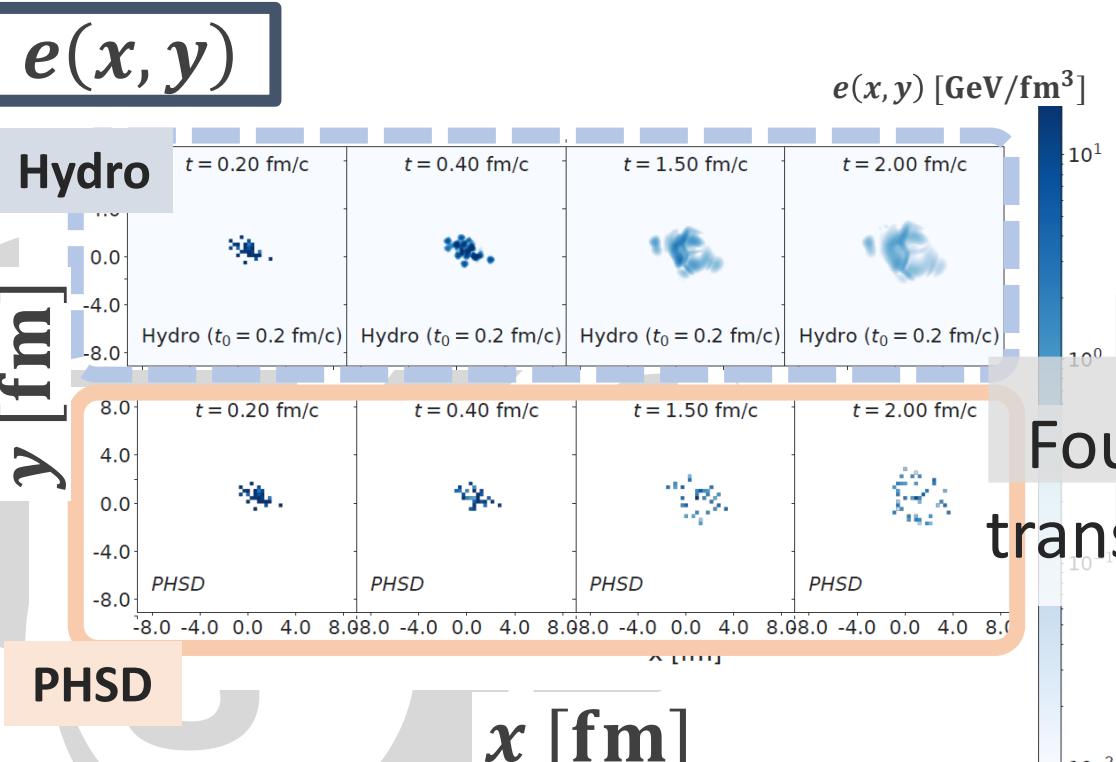
Transport (in and out-of equilibrium)

Transport vs. hydro: investigation of non-equilibrium effects in pPb with PHSD

W. Cassing and E.L. Bratkovskaya, Nucl. Phys. A 831 (2009) 215-242

Does system evolve differently?

L. Oliva *et al.*, Phys. Rev. C 106 (2022) 4, 044910



Essential difference: shorter wavelength modes survives in PHSD

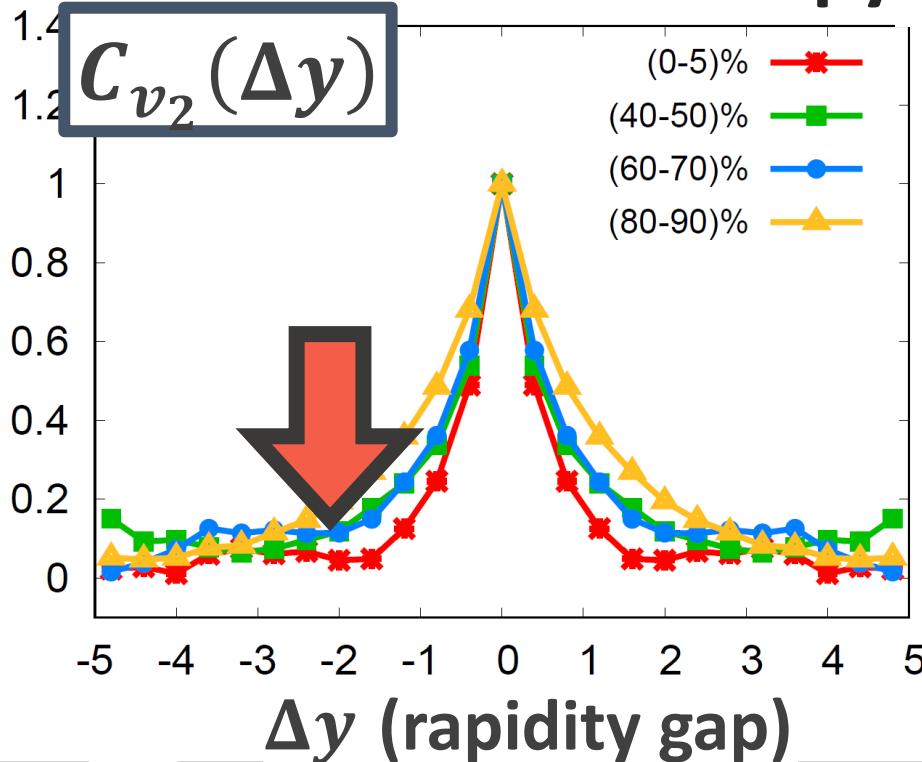
Macroscopic vs. microscopic

Origin of correlation in initial states

pPb

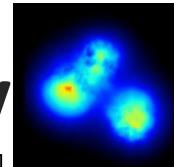
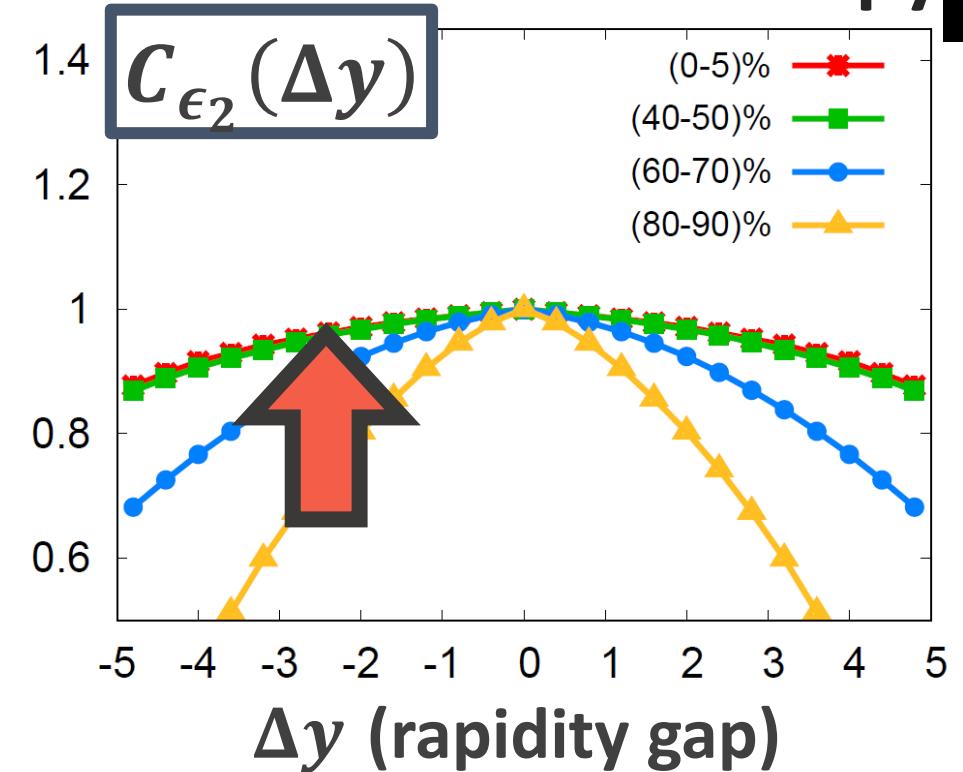
B. Schenke, S. Schlichting, and P. Singh, Phys. Rev. D 105 (2022) 9, 094023

Momentum anisotropy



OR

Geometrical anisotropy

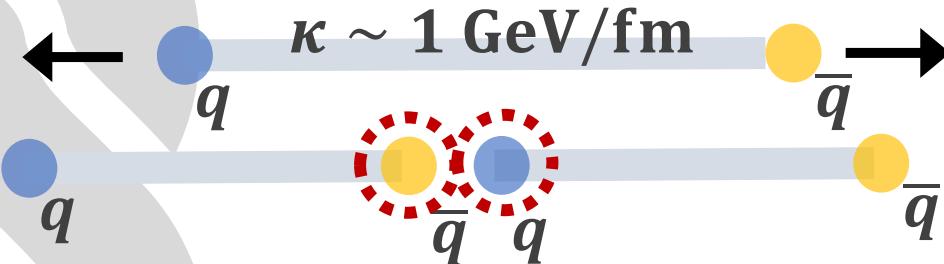


Opposite centrality dependence

String fragmentation

PYTHIA8/PYTHIA8 Angantyr

- Colour confinement **in vacuum**



- Successful description of pp measurements

T. Sjöstrand *et al.*, Comput. Phys. Commun. 178, 852 (2008)

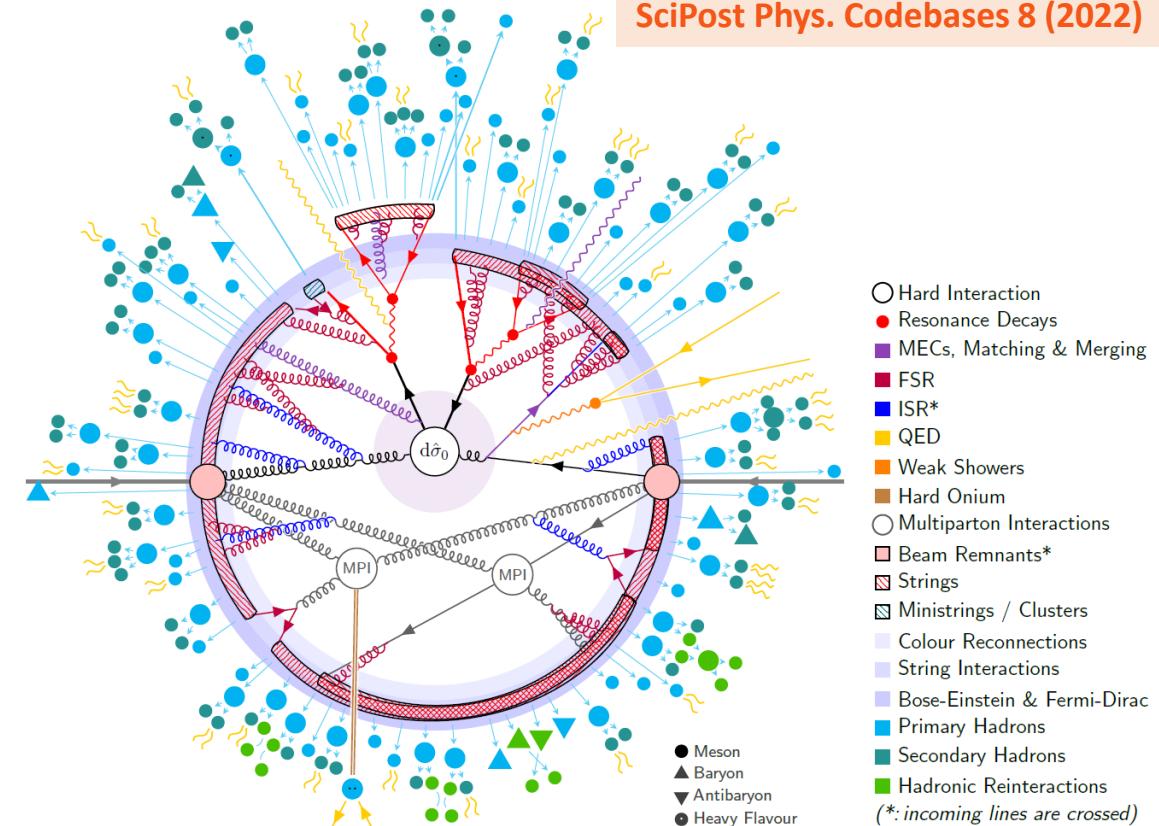
- Extrapolation to pA, AA

→ No QGP

A comprehensive guide to the physics and usage of PYTHIA 8.3

Christian Bierlich¹, Smita Chakraborty¹, Nishita Desai², Leif Gellersen¹, Ilkka Helenius^{3,4}, Philip Ilten⁹, Leif Lönnblad¹, Stephen Mrenna⁵, Stefan Prestel¹, Christian T. Preuss^{6,7}, Torbjörn Sjöstrand¹, Peter Skands⁶, Marius Utheim^{1,3}, and Rob Verheyen⁸

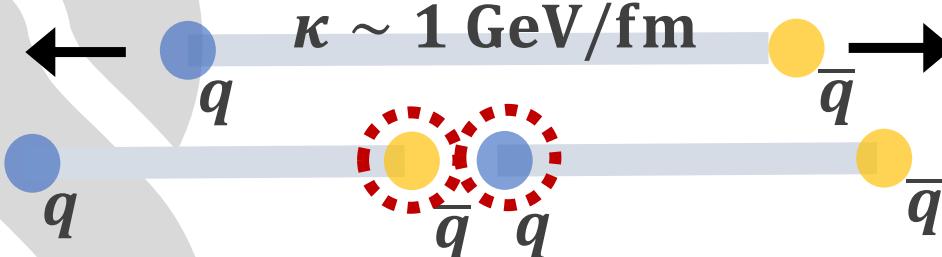
SciPost Phys. Codebases 8 (2022)



String fragmentation

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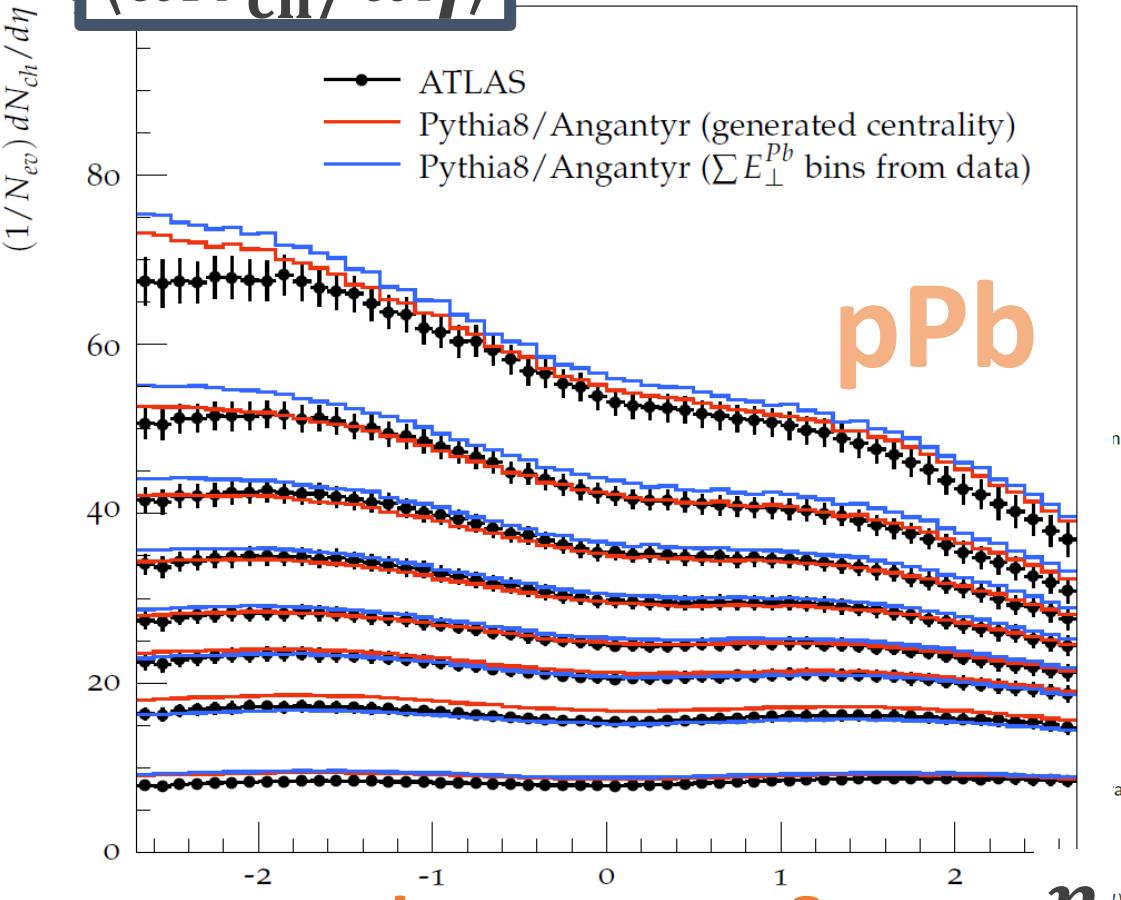
- Extrapolation to pA, AA

→ No QGP

What about collectivity & strangeness enhancement?

A comprehensive guide to the physics and usage of PYTHIA 8.3

$\langle dN_{\text{ch}}/d\eta \rangle$



ng

ac

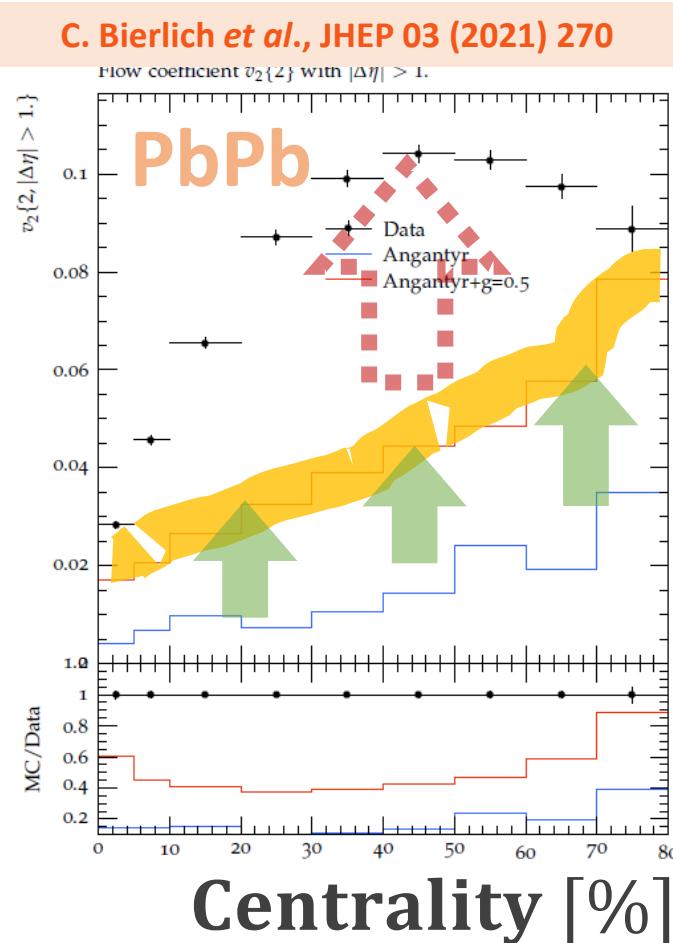
\eta

$v_2\{2\}$

String shoving
Push to transverse
direction according to
distance of strings d_T

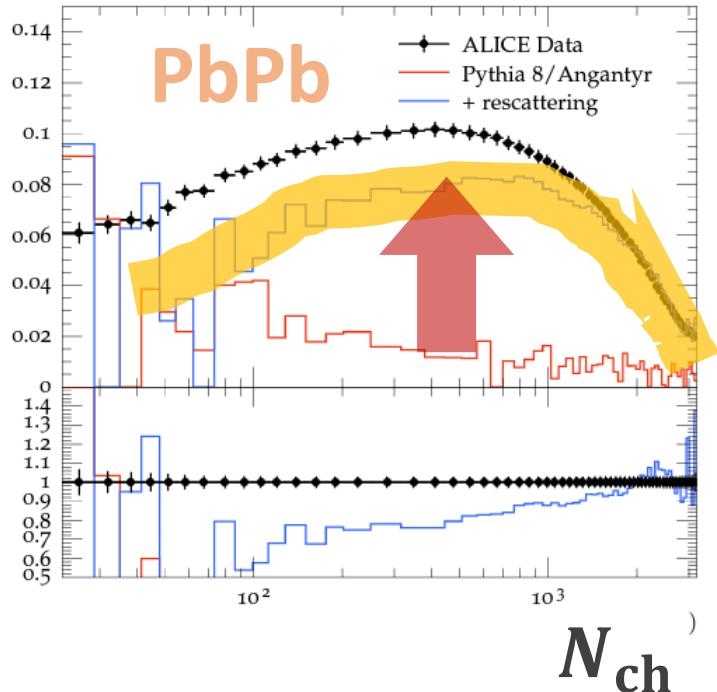
String fragmentation

8
6



Hadronic rescatterings

C. Bierlich *et al.*, Eur. Phys. J. A 57 (2021) 7, 227



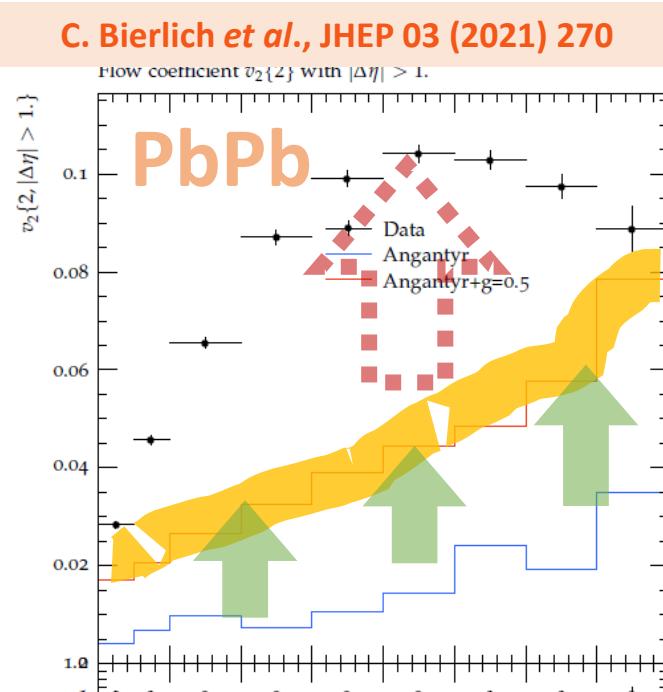
Expected compensation of each effect

$v_2\{2\}$

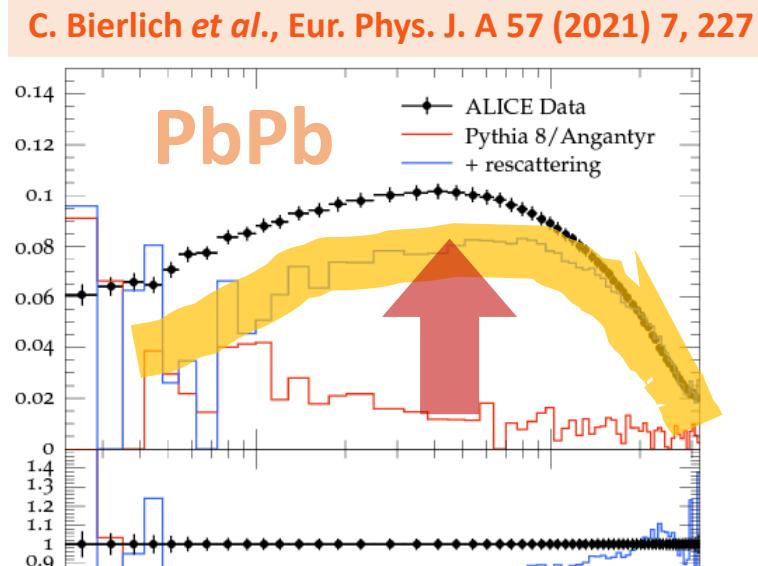
String shoving
Push to transverse
direction according to
distance of strings d_T

String fragmentation

8
6



Hadronic rescatterings



Strangeness enhancement & collectivity
→ String interactions (+ hadronic interactions)
Interplay of those effects (rope, shoving, rescattering) is expected

Monte-Carlo Event Generators

- Energy-momentum conservation of incoming beam energy
- Entire momentum space (from low to high p_T)



Target: all observables

Small systems.... weak signals, quantitative investigation required

→ Same analysis technique as experiment (e.g. non-flow subtraction...)

MC event generators from pp to AA:

X. L. Zhao *et al.*, Phys.Lett.B 839 (2023) 137799

PYTHIA8 Angantyr

C. Bierlich *et al.*, JHEP 10 (2018) 134...

HIJING

X. N. Wang *et al.*, Phys. Rev. D 44 (1991) 3501-3516...

EPOS

T. Pierog *et al.*, Phys. Rev. C 92 (2015) 3, 034906...

AMPT...

Z. W. Lin *et al.*, Phys. Rev. C 72 (2005) 064901...

Comparison among different descriptions



Glasma+jets: D. Avramescu *et al.*, arXiv:2303.05599;
A. Ipp *et al.*, Phys. Lett. B 810 (2020) 135810; M. E.
Carrington *et al.*, Phys. Rev. C 105 (2022) 6, 064910...

Fermion productions: N. Tanji *et al.*, Phys. Rev. D 97
(2018) 3, 034013; V. Kasper *et al.*, Phys. Rev. D 90 (2014) 2,
025016...
etc.

Problems to consider

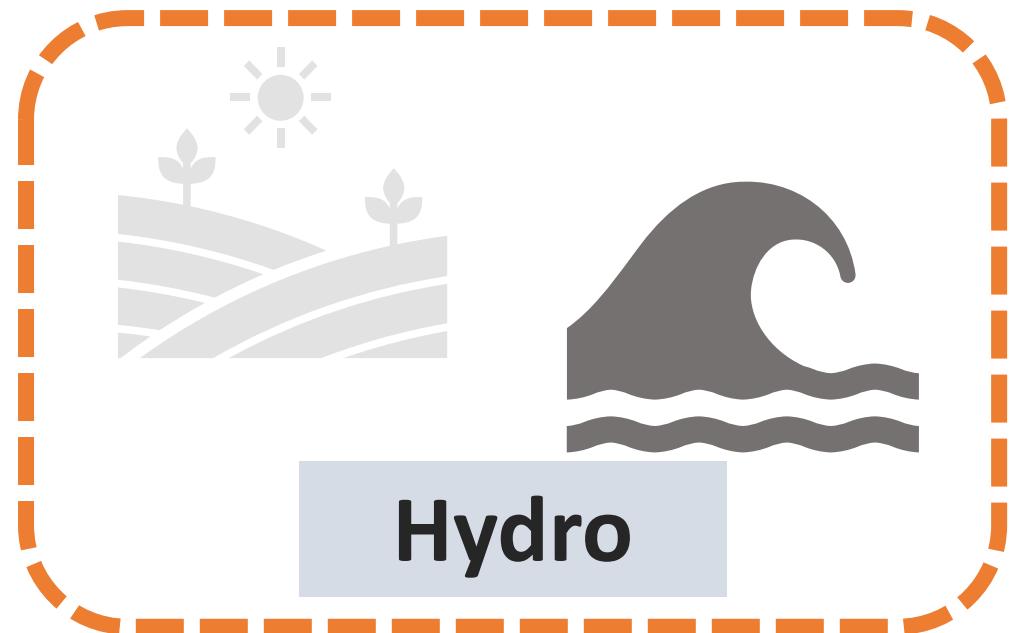
Energy-momentum conservation of incoming beam energy

Only gluon fields
→ Missing q and \bar{q} carrying energy-momentum

Entire momentum space (from low to high p_T)

Effective description at small x
→ Jets are missing

Comparison among different descriptions



Full 3D MC EKRT initial condition: M. Kuha *et al.*, in progress

Microcanonical Particlisation: D. Oliinychenko *et al.*, Phys. Rev. Lett. 123 (2019) 18, 182302, Phys. Rev. C 102 (2020) 3, 034904

Core-corona: T. Pierog *et al.*, Phys. Rev. C 92 (2015) 3, 034906; Y. Kanakubo *et al.*, Phys. Rev. C 105 (2022) 2, 024905

etc.

Problems to consider

Energy-momentum conservation of incoming beam energy

- Initial condition: parametrized or scaled to describe final state multiplicity
- Cooper-Frye: grand canonical

Entire momentum space (from low to high p_T)

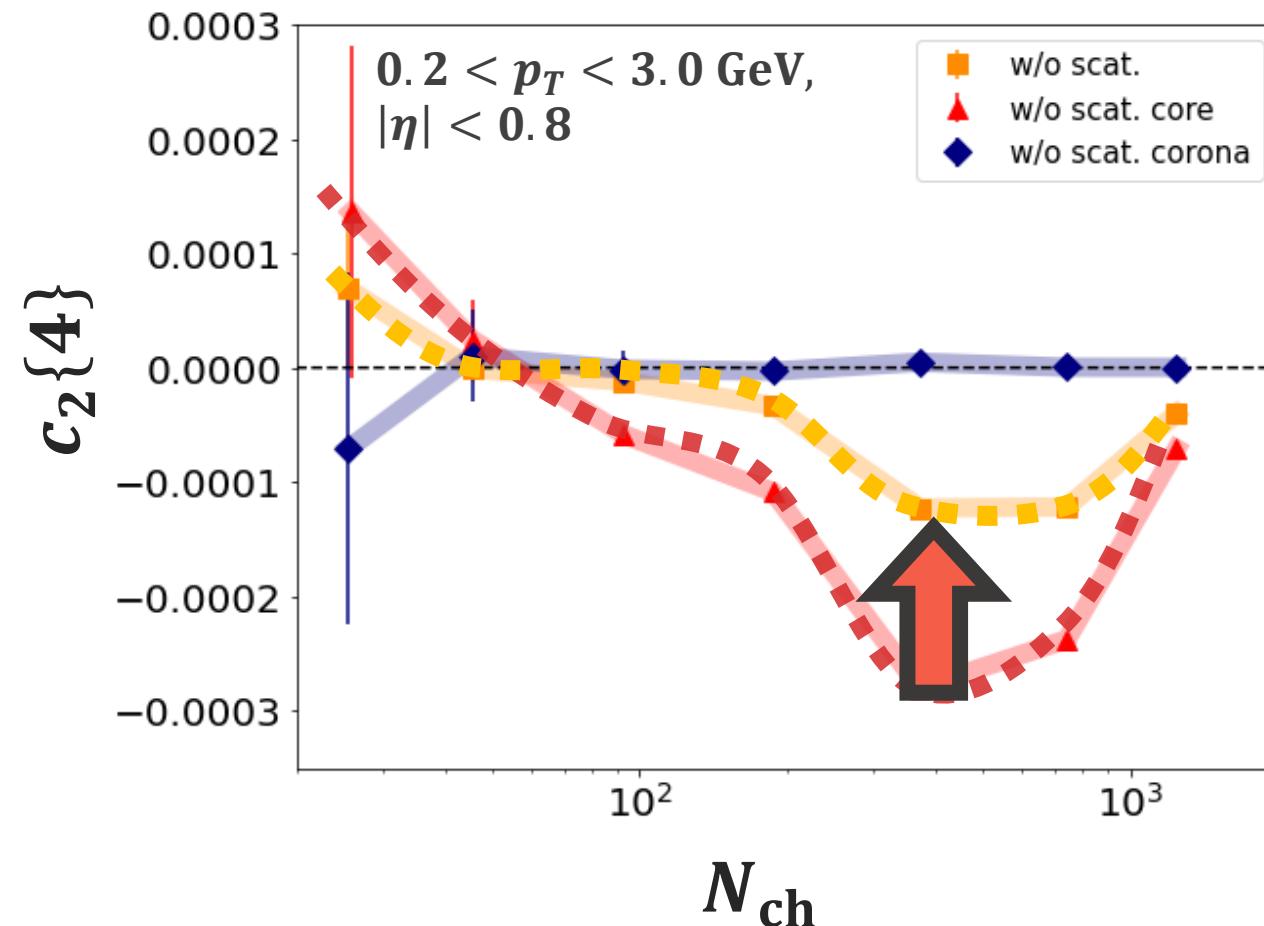
Effective theory in long wavelength limit

→ Jets are missing

Assume local equilibrium for entire system

Corona corrections to flow

$c_2\{4\}$ from PbPb 2.76 TeV



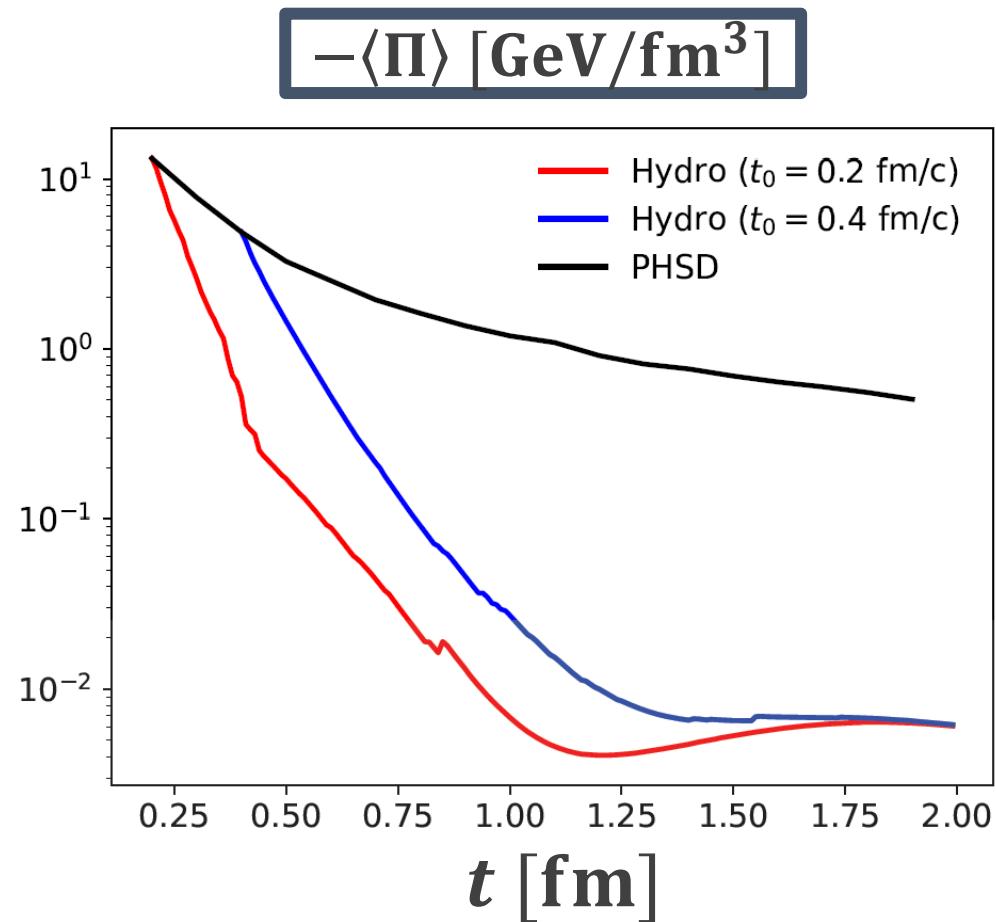
$c_2\{4\}_{\text{core}} \neq c_2\{4\}_{\text{tot}}$
→ Diluted by corona

Conventional Hydro model

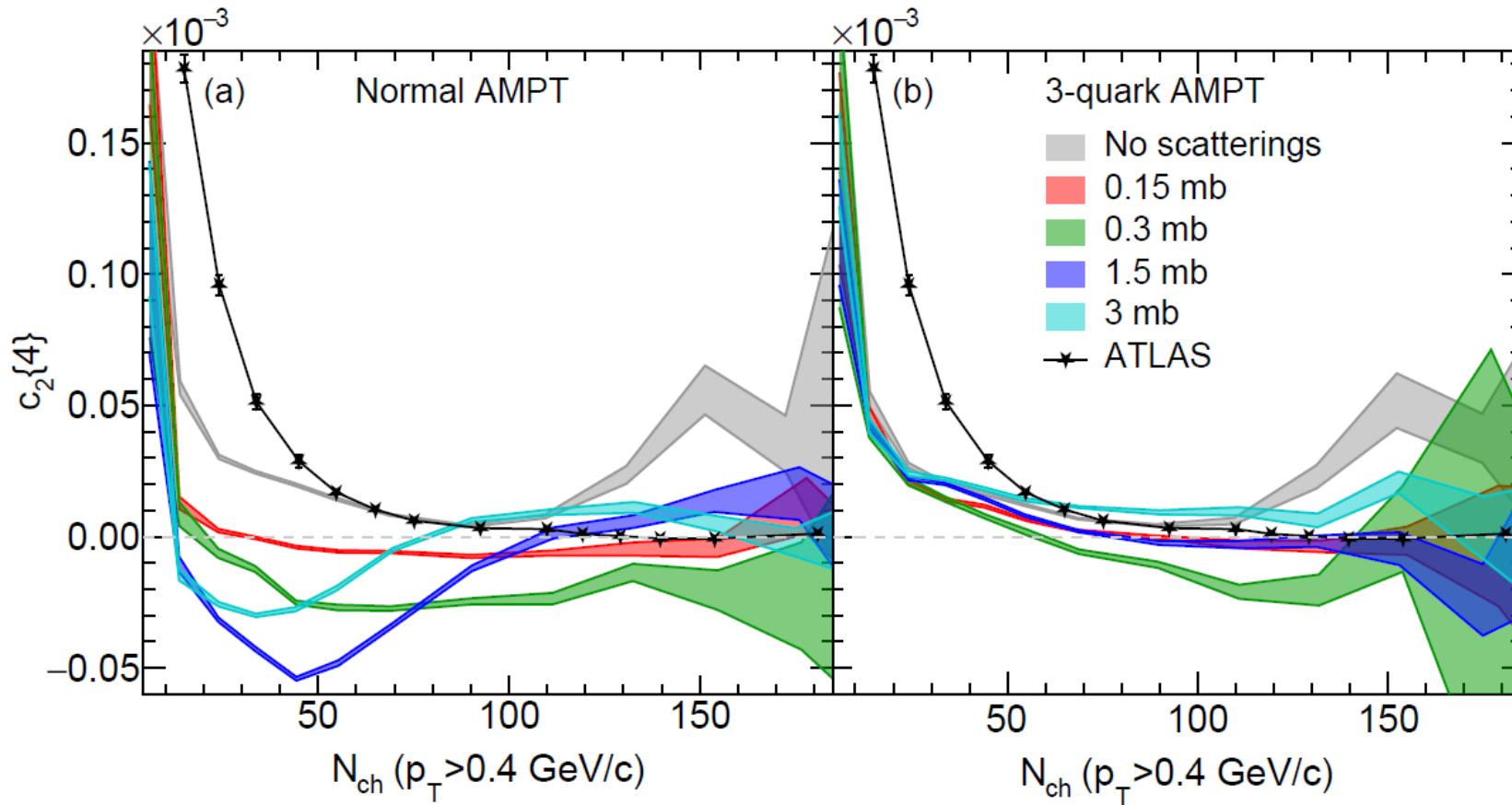
Comparison

Experiment

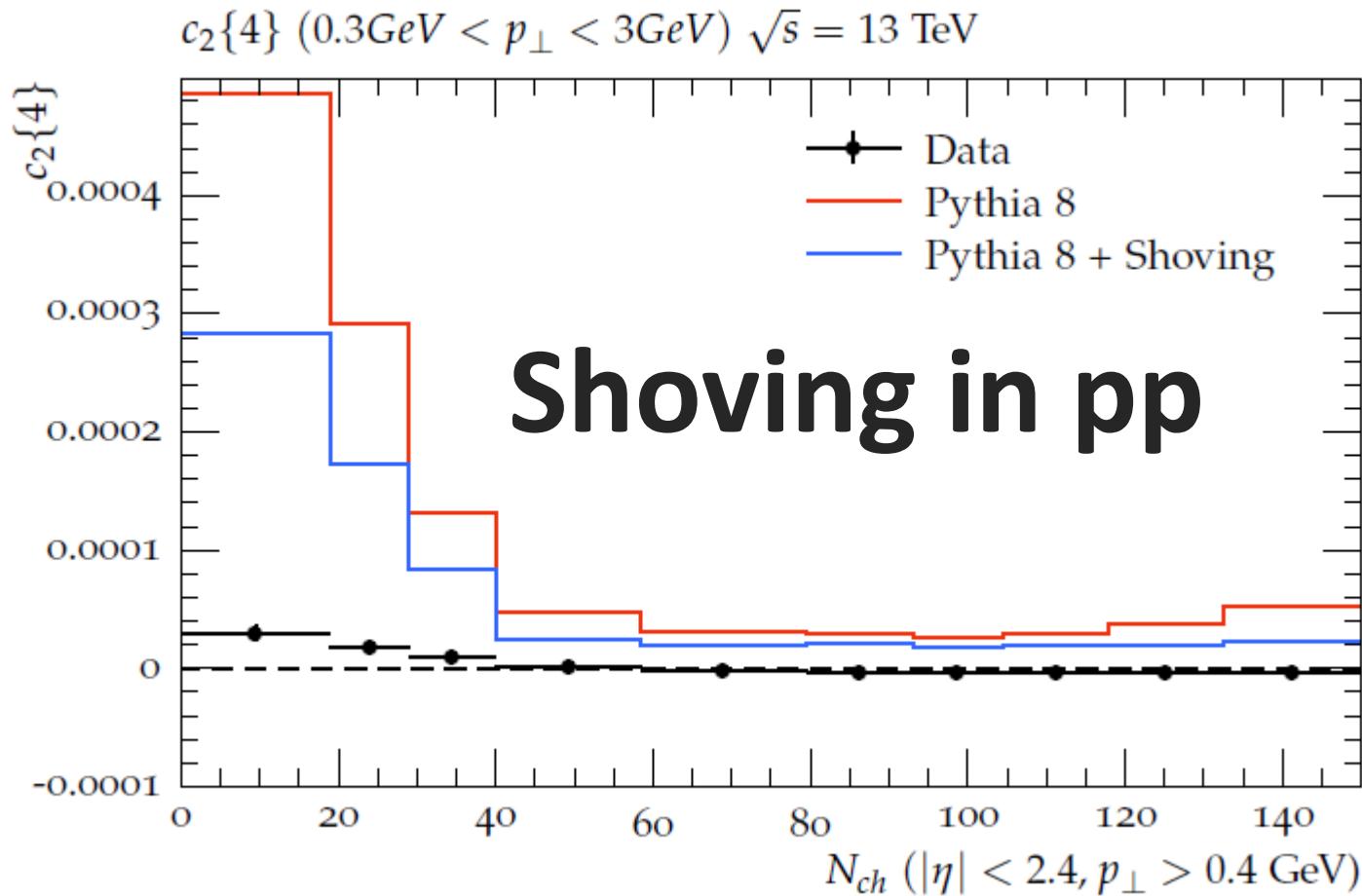
Comparisons between hydro and PHSD



$c_2\{4\}$ from AMPT

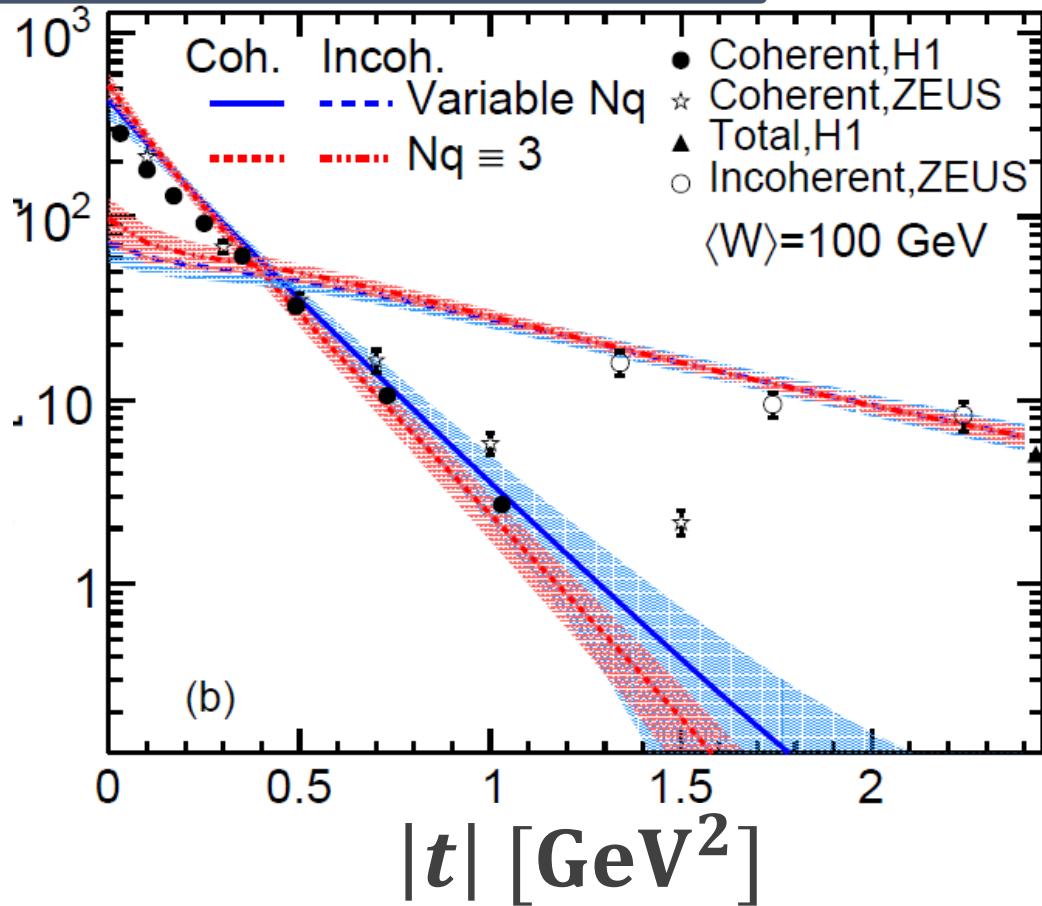


$c_2\{4\}$ from PYTHIA



Accessing proton profile

$d\sigma_{J/\Psi}/dt$ [nb/GeV 2]



H. Mäntysaari *et al.*, Phys. Lett. B 833 (2022) 137348

Systematic constraint with
Bayesian analysis

→ Reveal fluctuating
proton shape

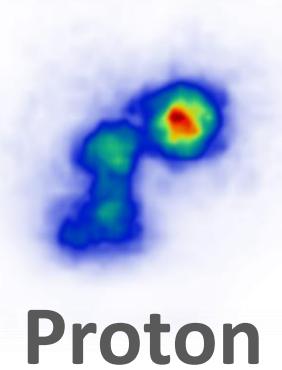
Case of 3 hotspots: $N_q = 3$

Proton size

$$B_{qc} \sim 4.45 \text{ [GeV}^{-2}\text{]}$$

Hot spot size

$$B_q \sim 0.346 \text{ [GeV}^{-2}\text{]}$$



Proton

Constrained proton shape

Heikki Mäntysaari, Björn Schenke, Chun Shen, and Wenbin Zhao,
Phys. Lett. B 833 (2022) 137348

https://arxiv.org/abs/2201.07001

Parameter	Description	Prior range	MAP (variable N_q)	MAP ($N_q \equiv 3$)
m [GeV]	Infrared regulator	[0.05, 2]	$0.506^{+1.12}_{-0.356}$	$0.246^{+0.162}_{-0.103}$
B_{qc} [GeV $^{-2}$]	Proton size	[1, 10]	$4.02^{+1.73}_{-0.728}$	$4.45^{+0.801}_{-0.803}$
B_q [GeV $^{-2}$]	Hot spot size	[0.1, 3]	$0.474^{+0.434}_{-0.286}$	$0.346^{+0.282}_{-0.202}$
σ	Magnitude of Q_s fluctuations	[0, 1.5]	$0.833^{+0.194}_{-0.441}$	$0.563^{+0.143}_{-0.141}$
$Q_s/(g^2\mu)$	Ratio of color charge density and saturation scale	[0.2, 1.5]	$0.598^{+0.230}_{-0.264}$	$0.747^{+0.0704}_{-0.0930}$
$d_{q,\text{Min}}$ [fm]	Minimum 3D distance between hot spots	[0, 0.5]	$0.257^{+0.221}_{-0.231}$	$0.254^{+0.222}_{-0.229}$
N_q	Number of hot spots	[1, 10]	$6.79^{+2.93}_{-4.83}$	3