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# Theoretical Review on Bulk Properties and Light/Strange Hadron Production in Heavy-Ion Collisions

Yuuka Kanakubo

RIKEN iTHEMS, LBNL, UC Berkeley

\*DISCLAIMER: this chronology is biased to the presenter's perspective

# Chronology

## Bulk-property study in soft sector

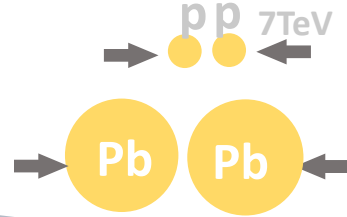
Elliptic flow  
→ Hydro model



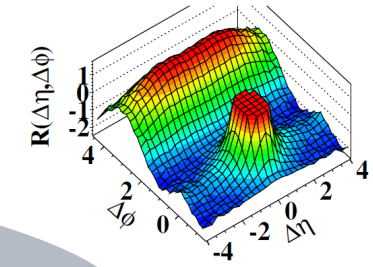
2005

Triangular flow 2010

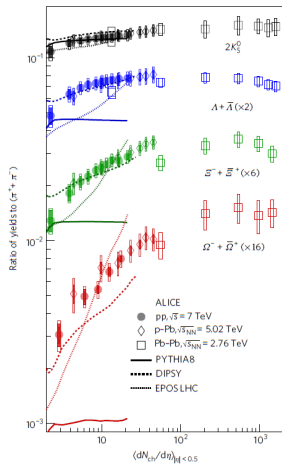
→ Fluctuation of nucleons in nucleus



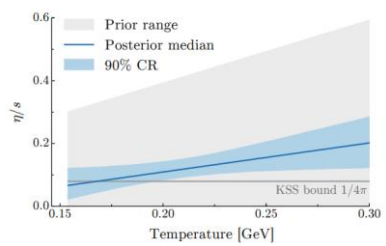
(d) CMS  $N \geq 110, 1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



Collectivity in small systems  
→ QGP in small system

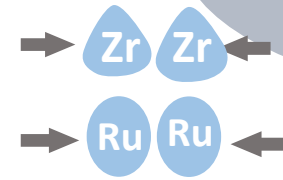


Viscosity extraction with Bayesian



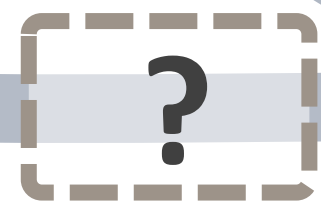
J. E. Bernhard et al., Phys. Rev. C 94, 024907 (2016)

Strangeness enhancement in pp



2020

Nuclear structure



See Jiayang Jia's overview on Mon

SQM 2026

# What's new in SQM2026?

*Bulk-property study in soft sector*

// from my perspective

**OO, pO results**  
System size scan

**Initial production**  
Effects on soft observables

**New observables**  
 $v_0$  and  $c_s$  from  $\langle p_T \rangle$  &  $N_{ch}$

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**OO, pO results**  
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[Voir en français](#)

## First-ever collisions of oxygen at the LHC

The Large Hadron Collider gets a breath of fresh air as it collides beams of protons and oxygen ions for the very first time. Oxygen-oxygen and neon-neon collisions are also on the menu of the next few days

1 JULY, 2025 | By Anais Schaeffer

First O+O run at  $\sqrt{s_{NN}} = 200$  GeV was taken in 2021. An additional O+O data taken early 2026 before shutdown.

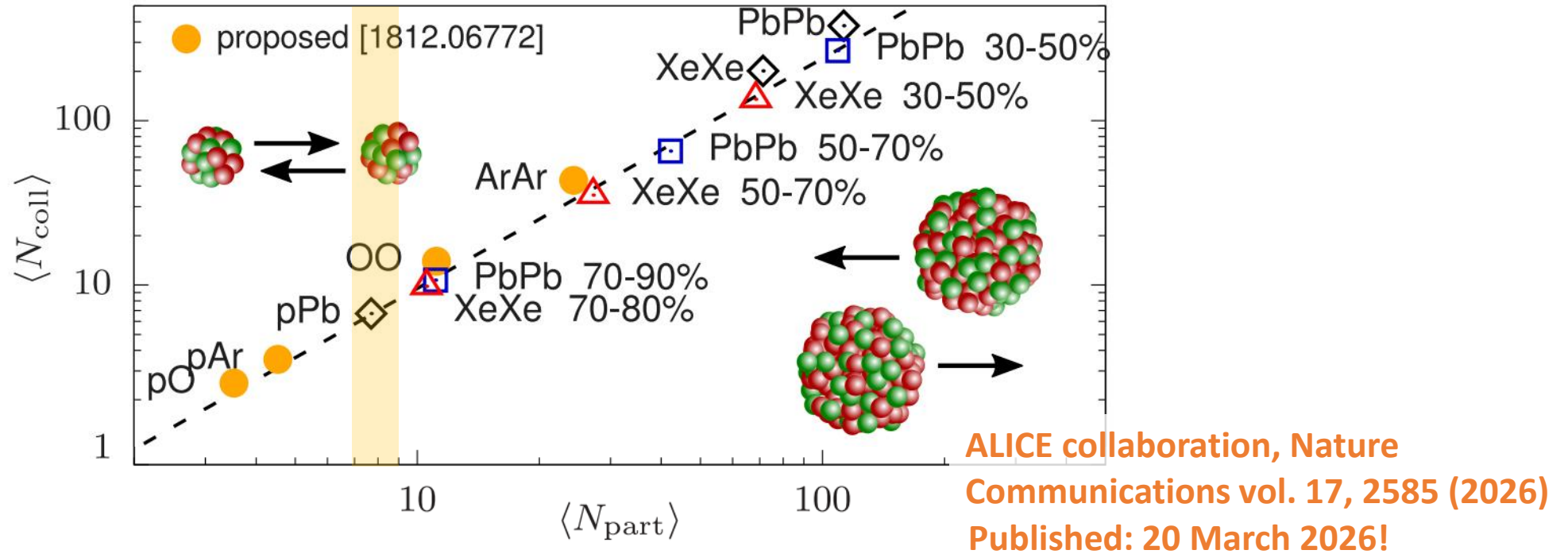
Taken from Iris Ponce's talk

**Initial production**  
Effects on soft observables

**New observables**  
 $v_0$  and  $c_s$  from  $\langle p_T \rangle$  &  $N_{ch}$

# System size scan of QGP signals

Oxygen-oxygen  $\Rightarrow$  sweet spot!



- AA central: clear QGP signals
- pp, pA (high-multiplicity): it looks like there are QGP signals

$\rightarrow$  OO: expected to be somewhere middle

# How does $^{16}\text{O}$ look like?

*The most abundant nucleus by weight in Earth's crust*

Structure and energy spectrum of  $^{16}\text{O}$

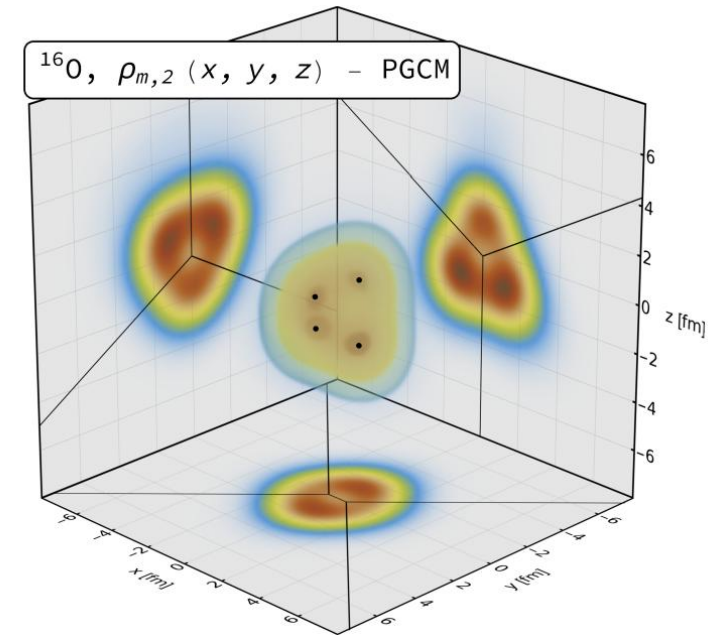
→ Long standing puzzle in nuclear physics

- Configuration of  $\alpha$ -clusters ( $^4\text{He}$ ) in  $^{16}\text{O}$

For reviews, see for instance: M. Freer et al., Rev. Mod. Phys. 90 (2018) 3, 035004

**Ab initio calculation:**

E. Epelbaum et al., Phys. Rev. Lett. 119, 222505

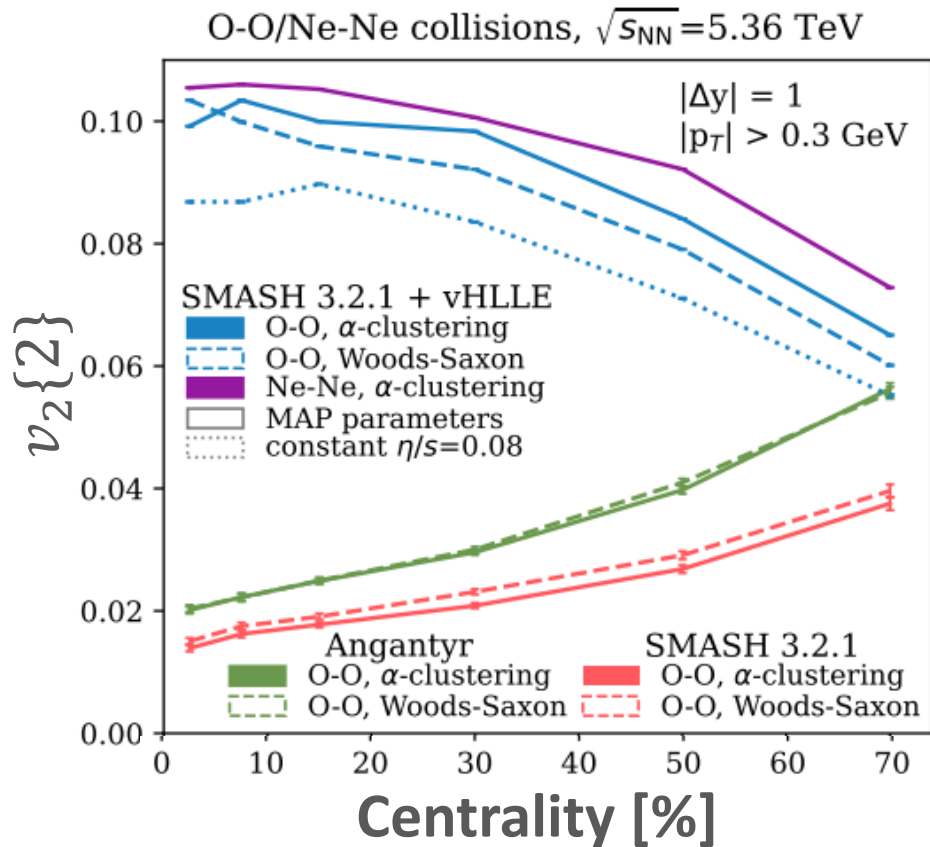


G. Giacalone et al., Phys.Rev.Lett. 135 (2025) 1, 012302  
Also see, C. Zhang et al., Phys.Lett.B 862 (2025) 139322;

Addressing the structure of  $^{16}\text{O}$  in relativistic nuclear collisions

# Footprint of $\alpha$ -clusters in flow

From hydro + hadronic transport model



L. Constantin et al., 2509.05613 [nucl-th]

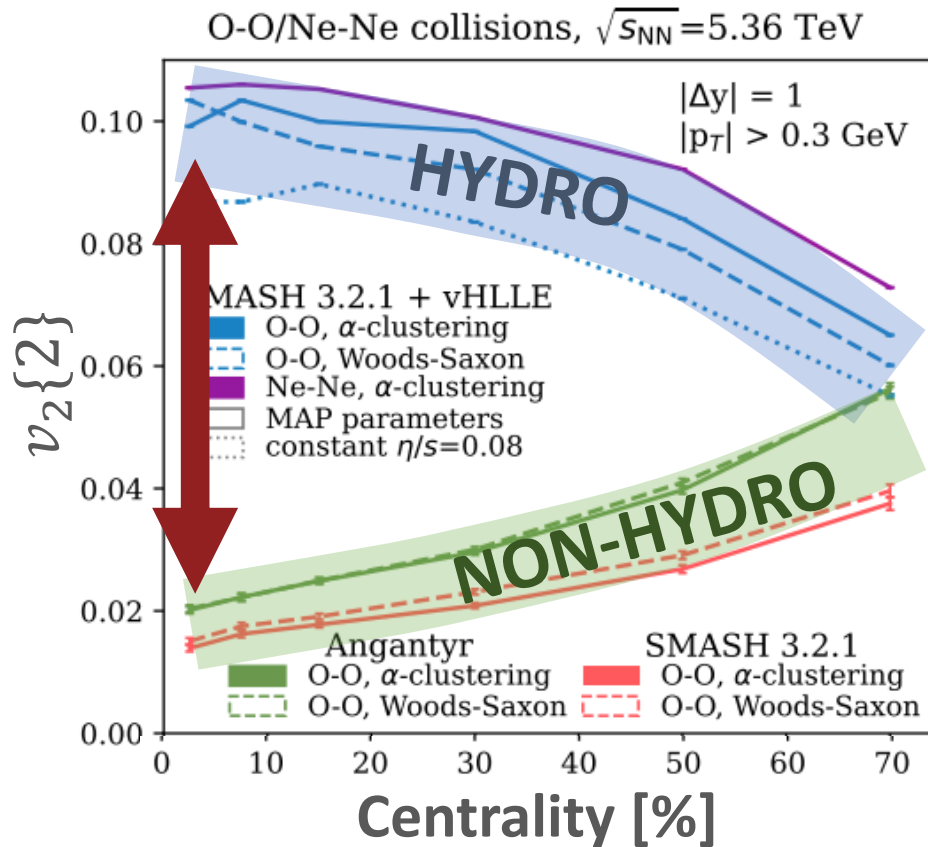
- Data favors hydro picture?

See also G. Barnaföldi's poster

S. Prasad et al., Phys.Lett.B 860 (2025) 139145

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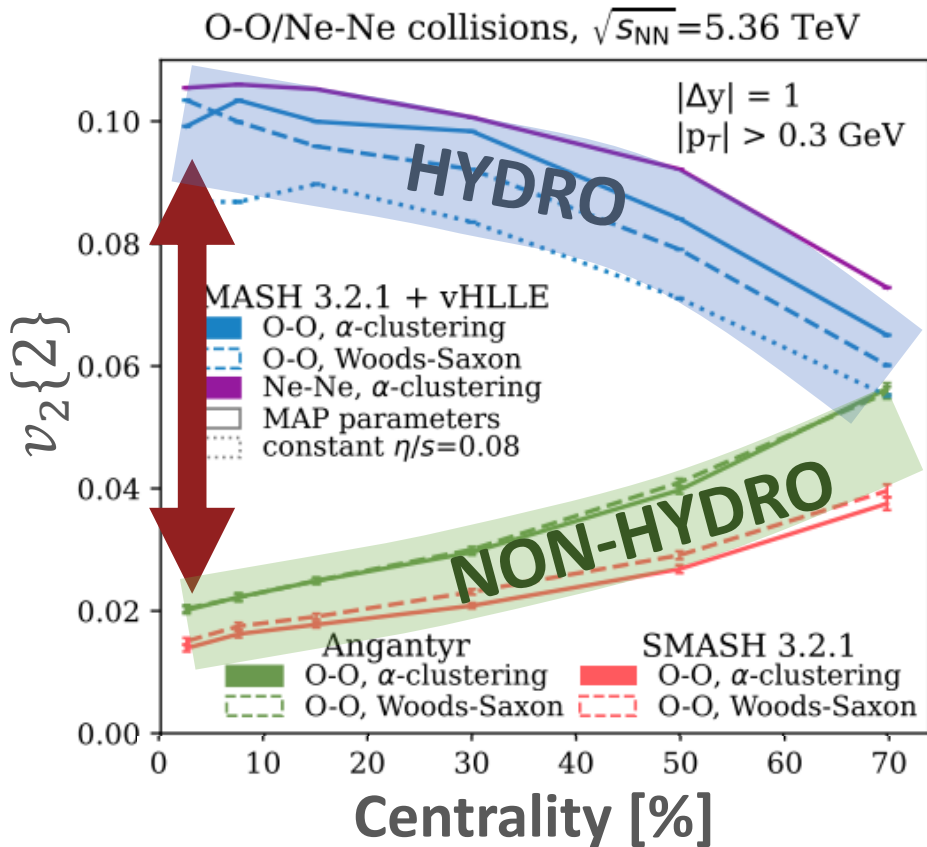
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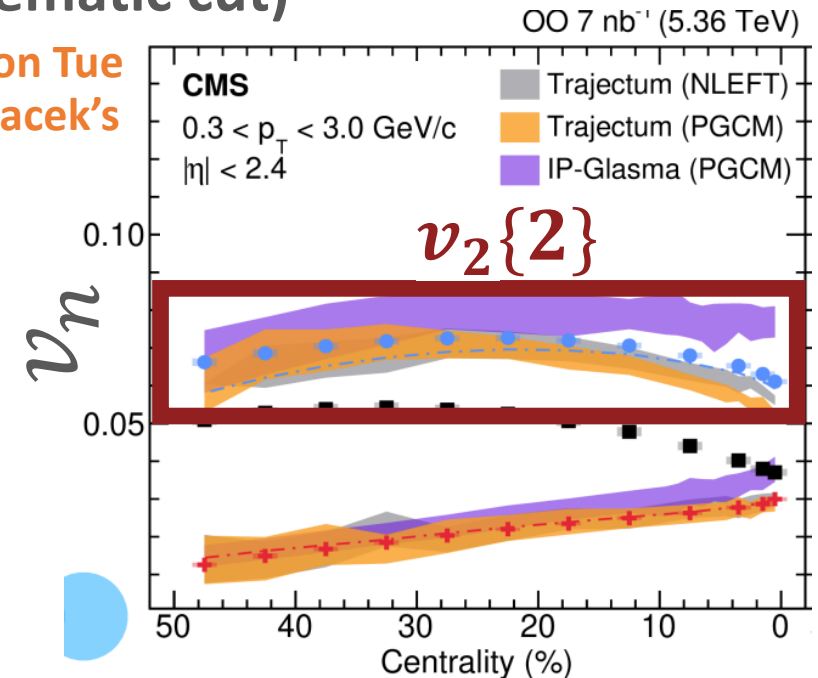
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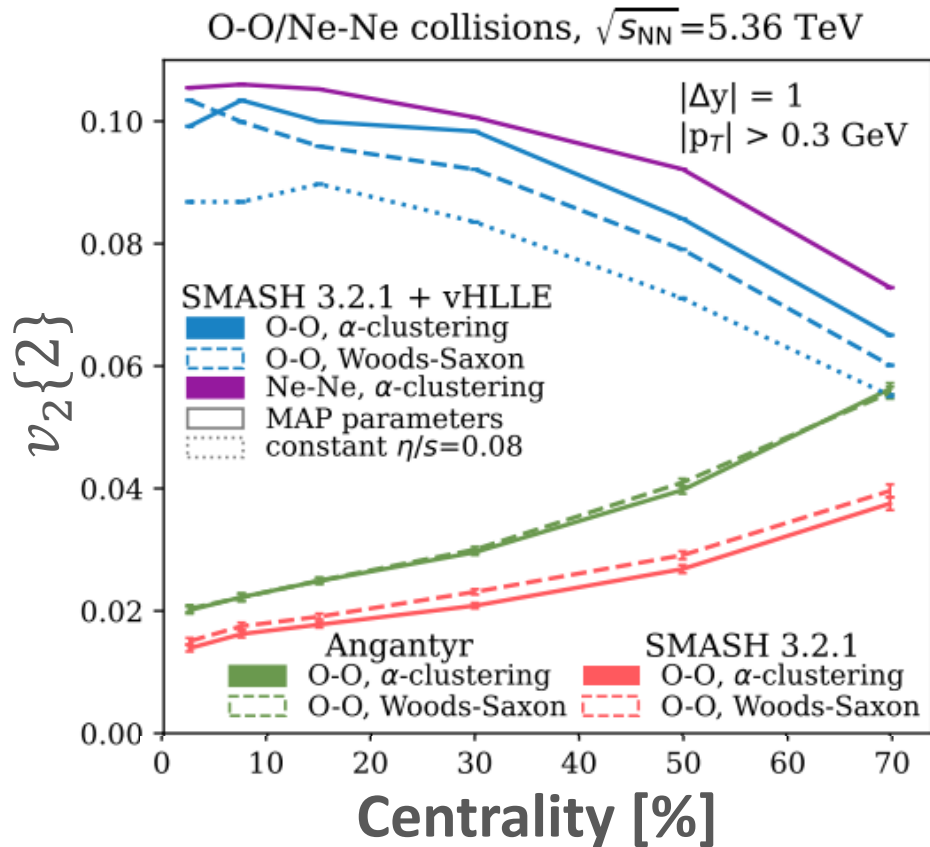
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See Austin Baty's talk on Tue  
 See also Vojtech Machacek's talk on Tue



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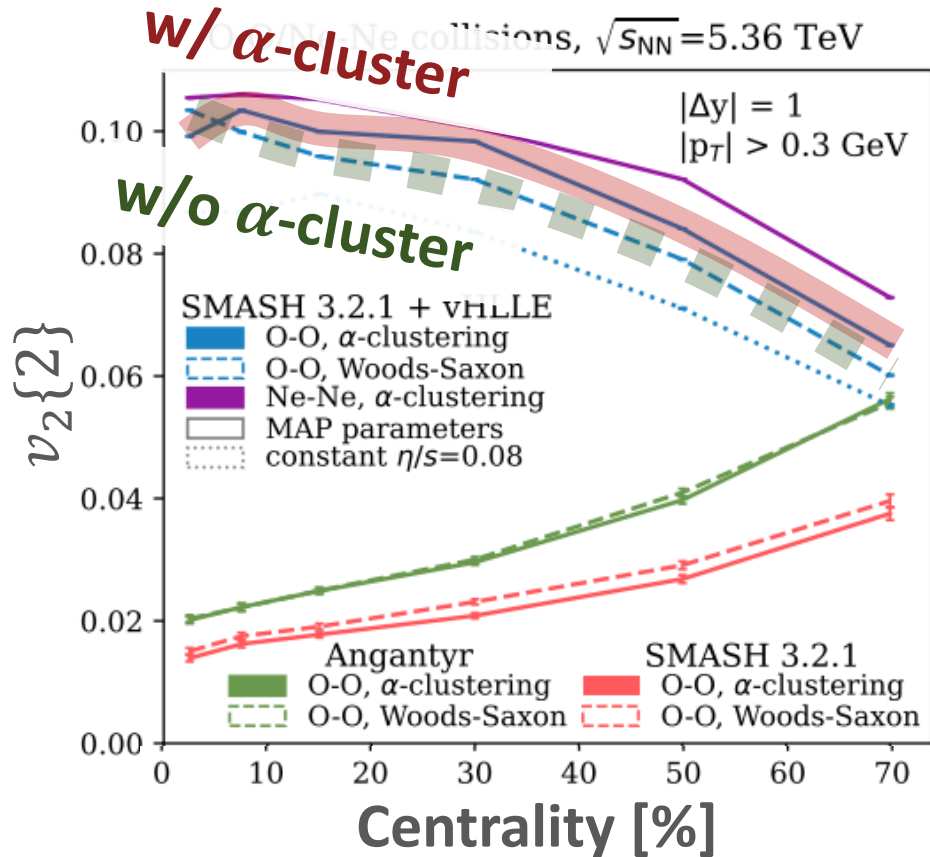
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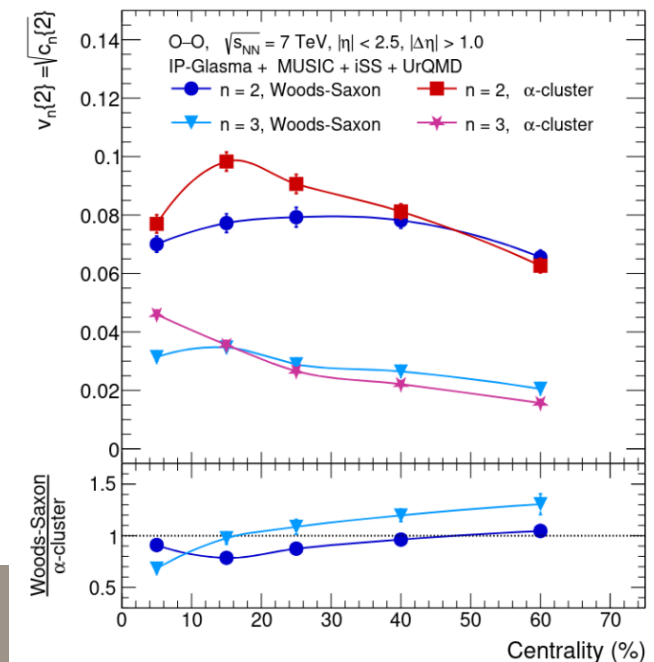


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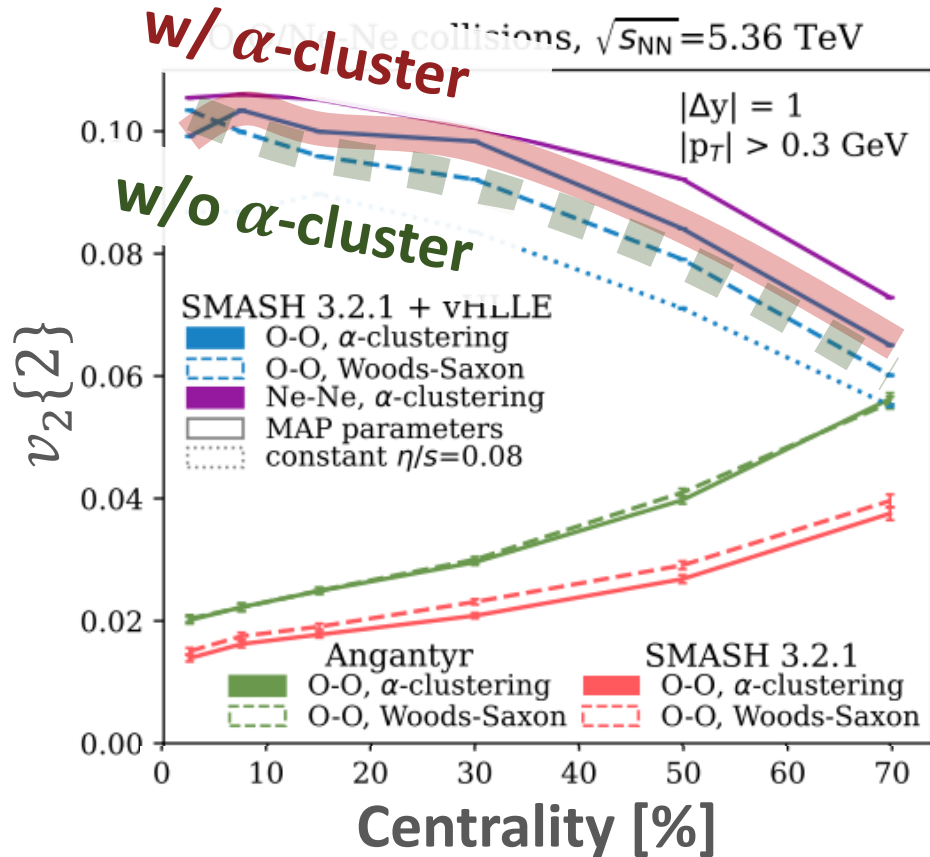
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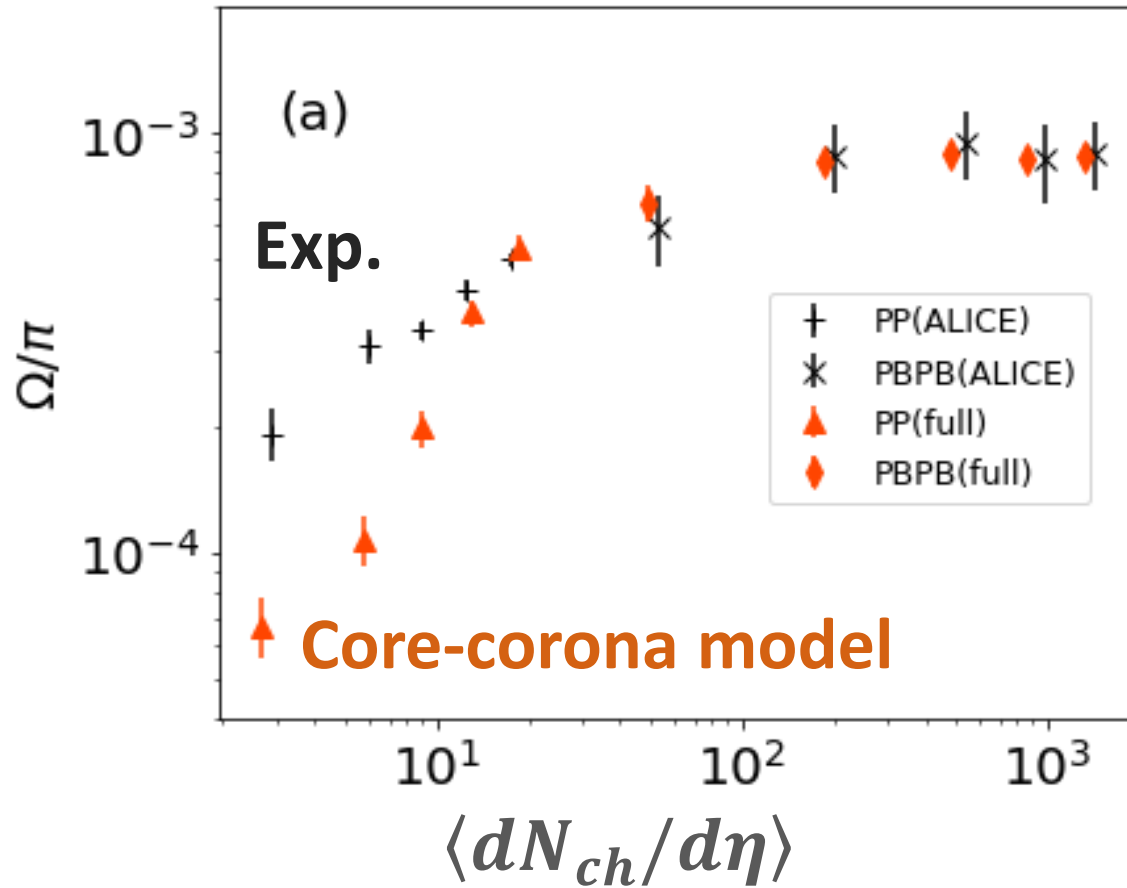
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S. Prasad et al., Phys.Lett.B 860 (2025) 139145

Need to pose same kinematic cut to get  $v_n$   
 Challenge is to access theoretical uncertainty

# Strangeness production in OO

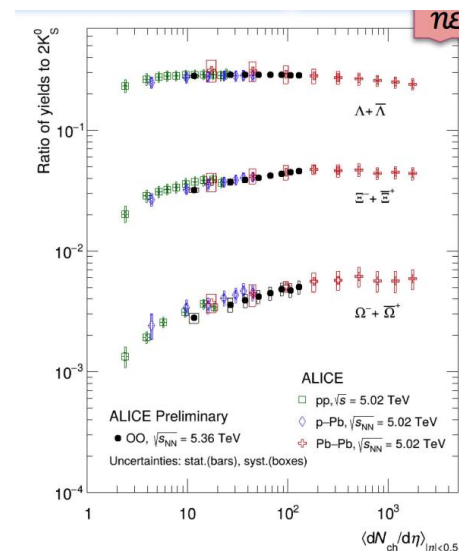
From 2-component model : equilibrium + non-equilibrium



Y. K, *et al.*, Phys. Rev. C 105 (2022) 2, 024905; Phys. Rev. C 106 (2022) 5, 054908

- Core-corona (hydro+string fragmentation) describes multiplicity dependence

K. Werner, Phys.Rev.C 109 (2024) 1, 014910  
See also, M.U. Ashraf et al., Chin.J.Phys. 98 (2025) 768-777 for OO results from EPOS4



See Sara Pucillo's talk on Tue

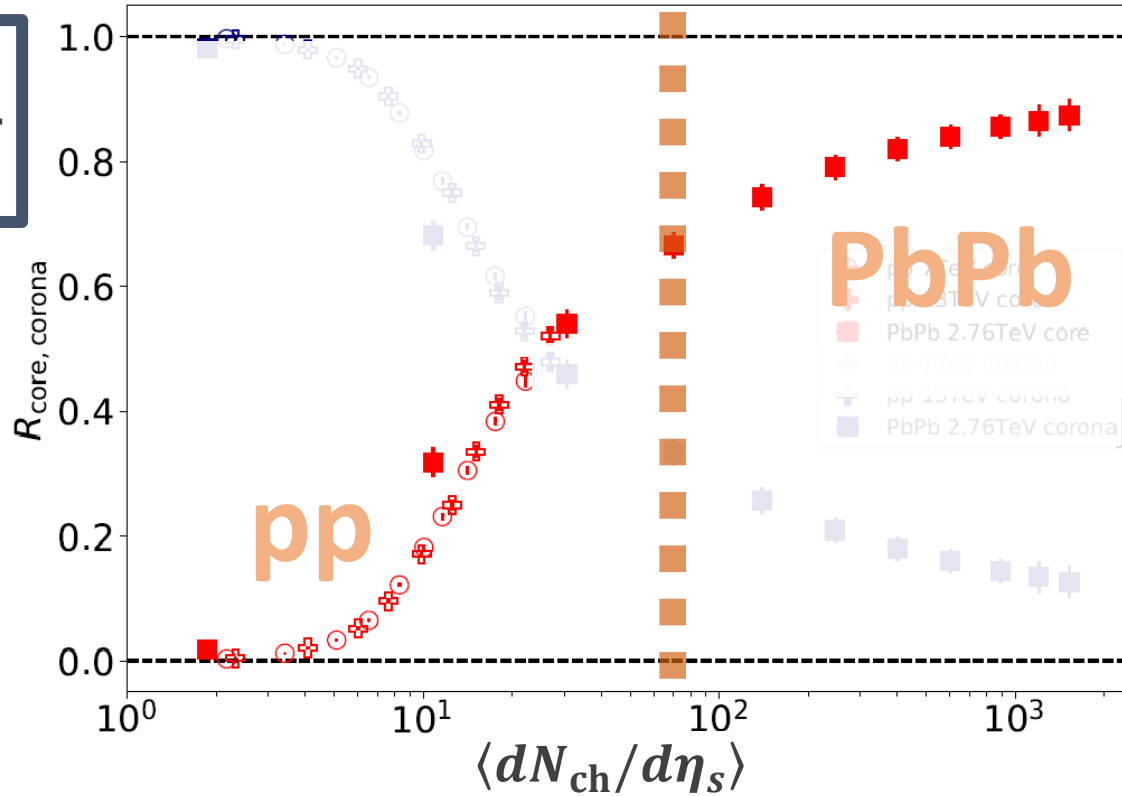
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# Strangeness production in OO

Fraction of particle productions from core

Y. K et al., Phys. Rev. C 105 (2022) 2, 024905; Phys. Rev. C 106 (2022) 5, 054908

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



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20-30% centrality in O-O



→  $\langle dN_{ch}/d\eta \rangle \sim 60-80$

→ Equilibrium  $\sim 70\%$  at mid-y

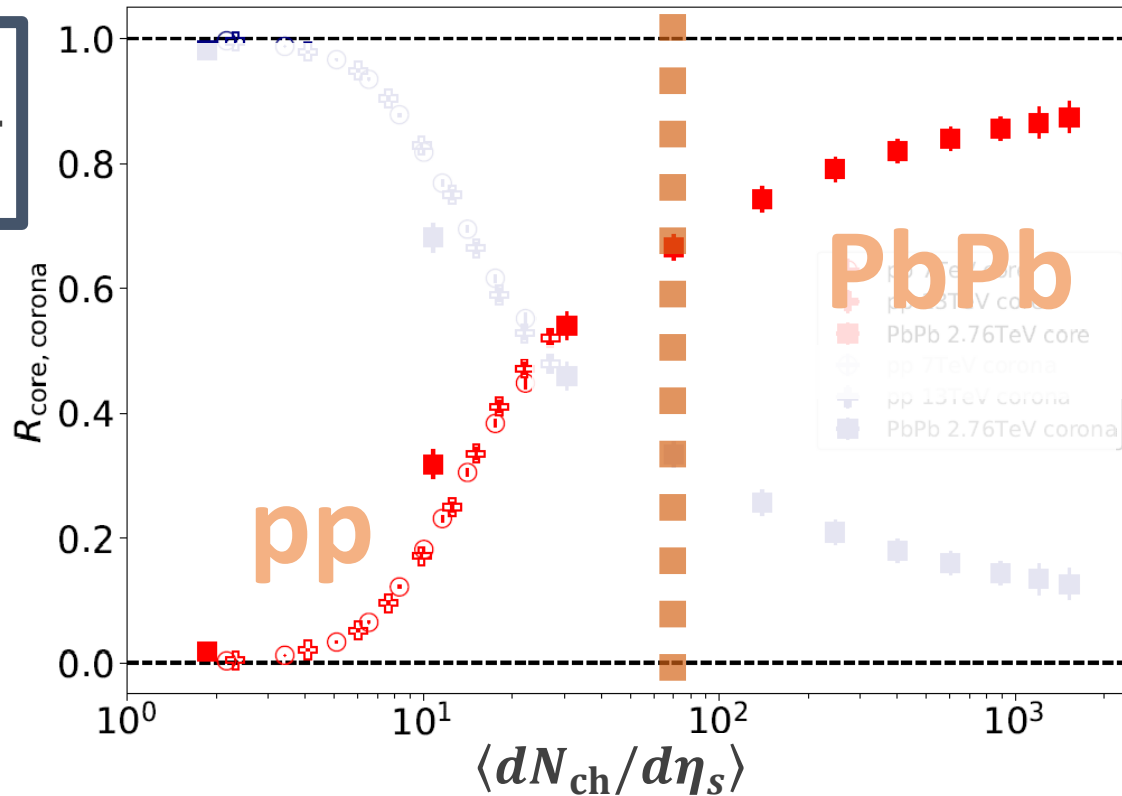
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**Sizable non-equilibrium contribution in OO**  
→ How reasonable is it to apply hydrodynamics to OO?

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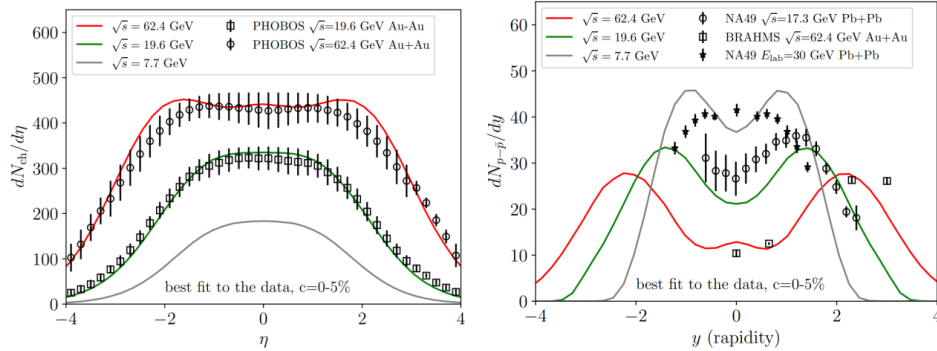
# Highlights

## Baryon stopping #1

C. Werthmann et al.,  
Phys.Rev.C 113 (2026) 3, 034908

See Iurii Karpenko's poster

- Charge transfer frictions in MUFFIN + SMASH

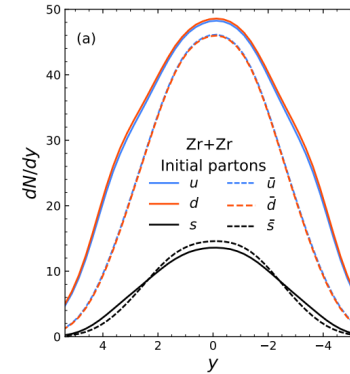


## Baryon stopping #2

M. A. Ross and Z-W Lin,  
Eur.Phys.J.C 86 (2026) 2, 143

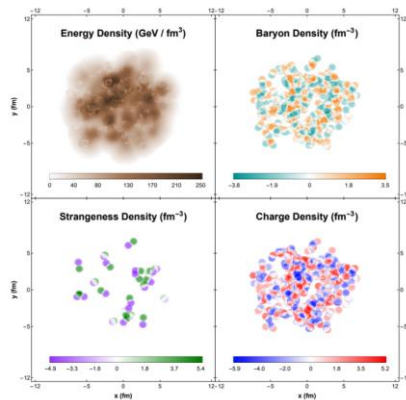
See Zi-Wei Lin's talk on Tue

- AMPT (string melting + partonic transport)



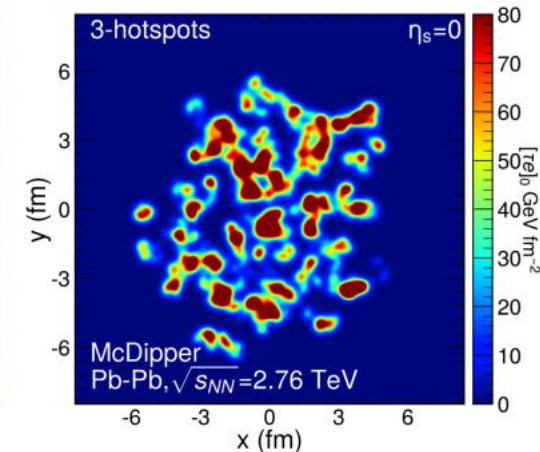
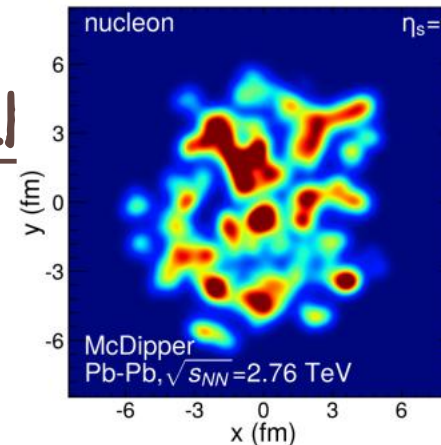
## Gluon splitting

Carzon et al., PRC 105,  
034908 (2022)



## CGC-based model

Garcia-Montero et al.,  
PRD 111 (2025) 7, 076029



# MC-EKRT: New 3D initial state model

M. Kuha, J. Auvinen, K. J. Eskola, H. Hirvonen, Y. K., H. Niemi,  
Phys.Rev.C 111 (2025) 5, 054914; Phys.Rev.C 110 (2024) 3, 034911

See H. Hirvonen's talk on Wednesday

pQCD (mini) jet : 
$$\frac{d\sigma_{\text{jet}}}{dp_T^2 dy_1 dy_2} = K \sum_{ijkl} x_1 f_i^{a/A}(\{\bar{s}_a\}, x_1, Q^2) x_2 f_j^{b/B}(\{\bar{s}_b\}, x_2, Q^2) \times \frac{d\hat{\sigma}^{ij \rightarrow kl}}{d\hat{t}}$$
  
snPDFs      LO pQCD

+ Energy - momentum conservation

Convention: Initial conditions of hydrodynamic simulations  
are parametrized to reproduce  $dN_{ch}/d\eta$

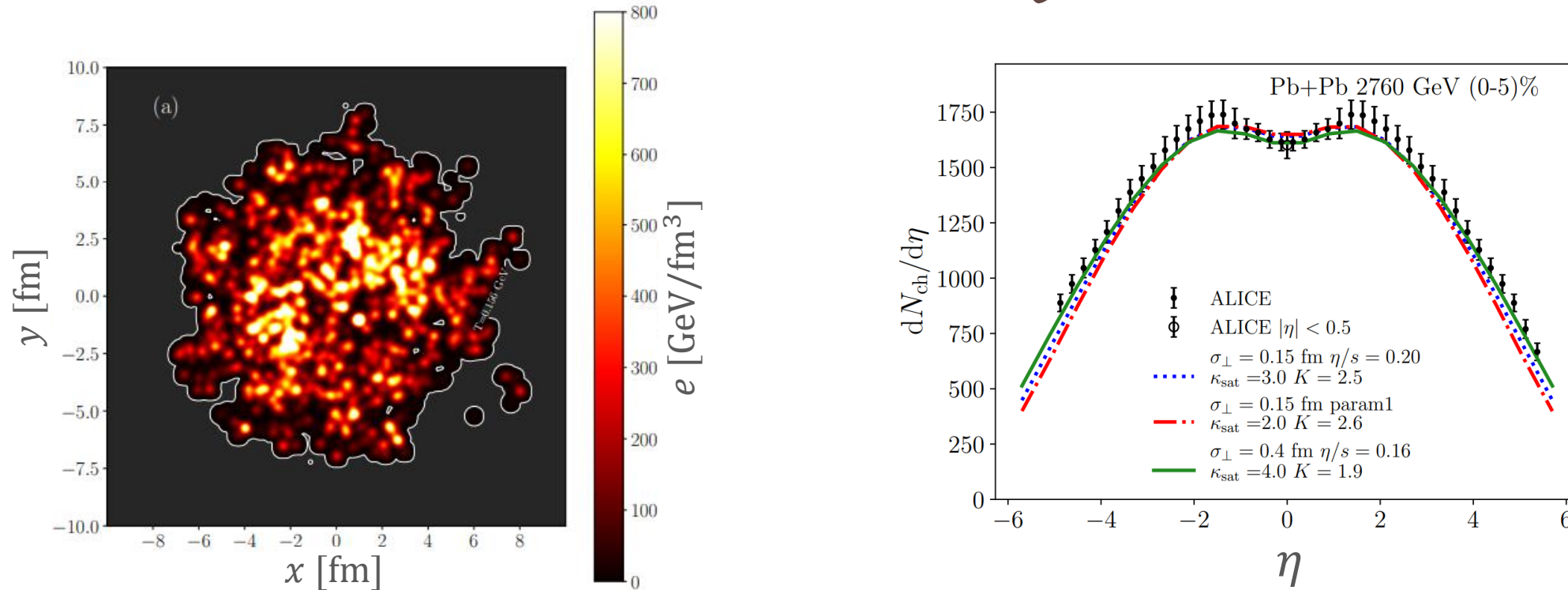
Goal: See if the MC-EKRT manages to describe  $dN_{ch}/d\eta$  with a  
few tunable parameters + energy-momentum constraints

Simple yet strong constraints

# MC-EKRT: New 3D initial state model

See H. Hirvonen's talk on Wednesday

MC-EKRT + Viscous hydro



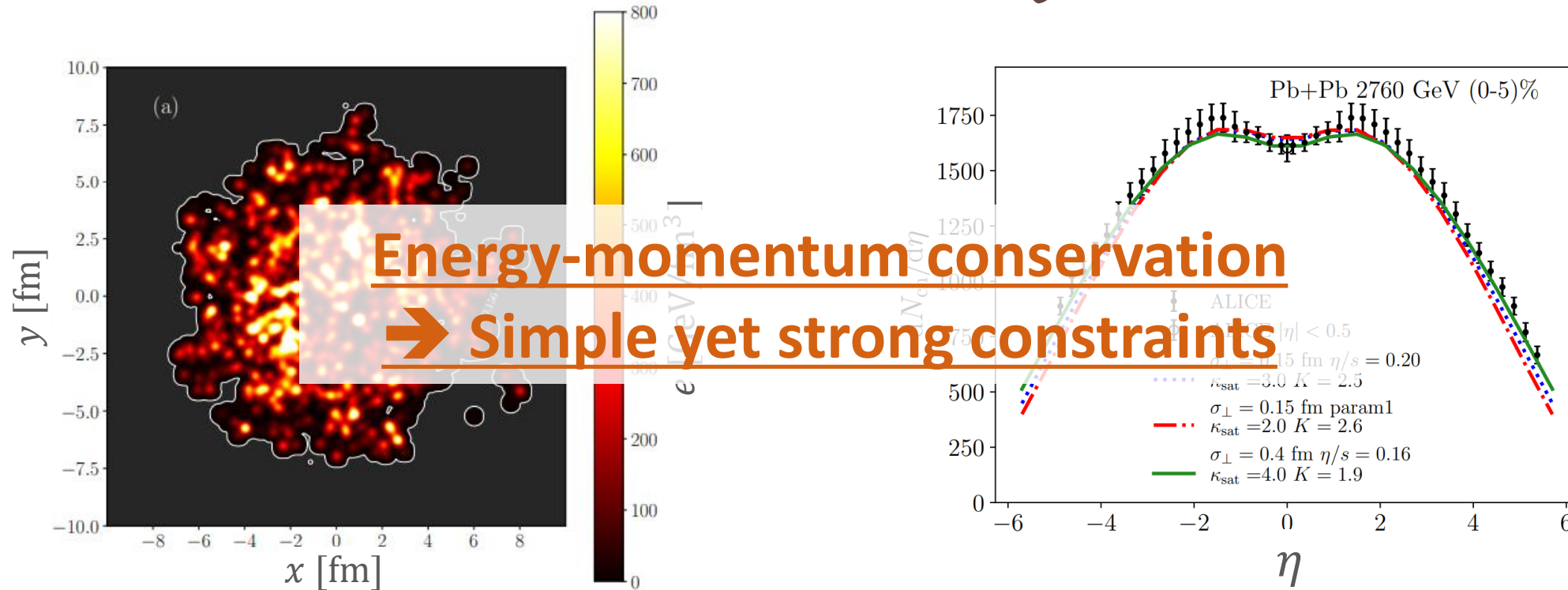
M. Kuha, J. Auvinen, K. J. Eskola, H. Hirvonen, Y. K., H. Niemi,  
Phys.Rev.C 111 (2025) 5, 054914; Phys.Rev.C 110 (2024) 3, 034911

- A few tunable parameters  $\rightarrow$  Nice agreement (not obvious)
- More constraints on bulk properties  $\rightarrow$  more constraints on initial state

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*Bulk-property study in soft sector*

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 $c_s$  and  $v_0$  from  $\langle p_T \rangle$  &  $N_{ch}$

# Speed of sound

CMS collaboration, Rept.Prog.Phys.  
87 (2024) 7, 077801

## EoS from soft observables

### Correction from non-equilibrium fluctuation

See also Yushan Mu's talk on Tuesday

Y. Mu, J-A. Sun, L. Yan, X-G Huang, Phys.Rev.Lett. 135 (2025) 16, 162301

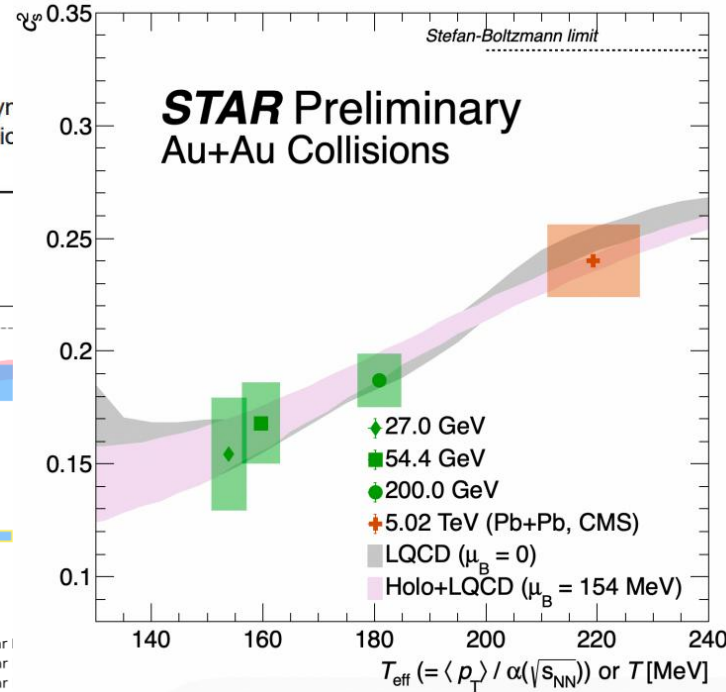
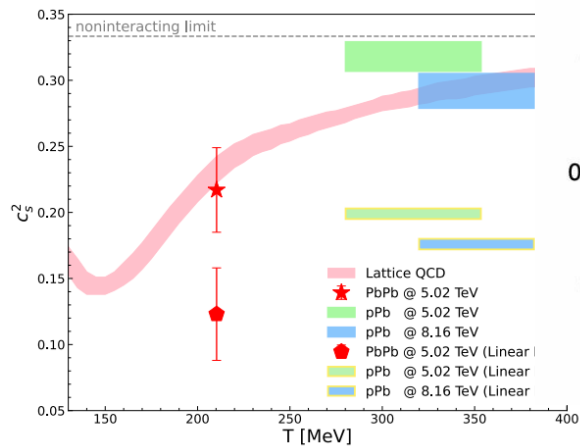
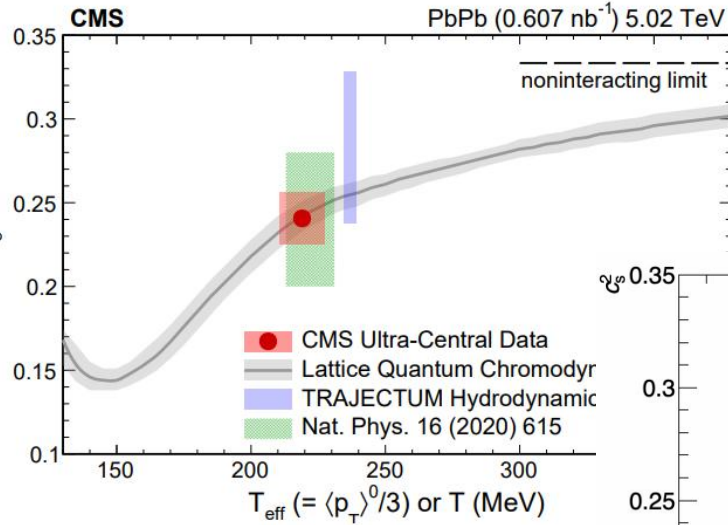
Also see, M. Alqahtani, T. Parida, J-Y. Ollitrault, 2603.09647

See also Caleb Broodo's talk on Tuesday

- EoS of QGP at  $\mu_B = 0$  is known from Lattice QCD

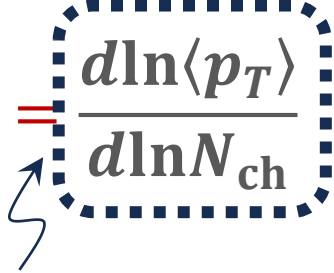
- "measurable speed of sound  $c_s$ "

$$c_s^2 = \frac{dP}{d\epsilon} = \frac{d\ln T}{d\ln s} \sim \frac{d\ln \langle p_T \rangle}{d\ln N_{ch}}$$



# Caveat on measurable $c_s$

L. Gavassino et al., Phys.Rev.C 112 (2025) 5, 054903

$$c_s^2 = \frac{d \ln T}{d \ln s} = \frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$


- $\langle p_T \rangle \propto T$  requires information of EoS

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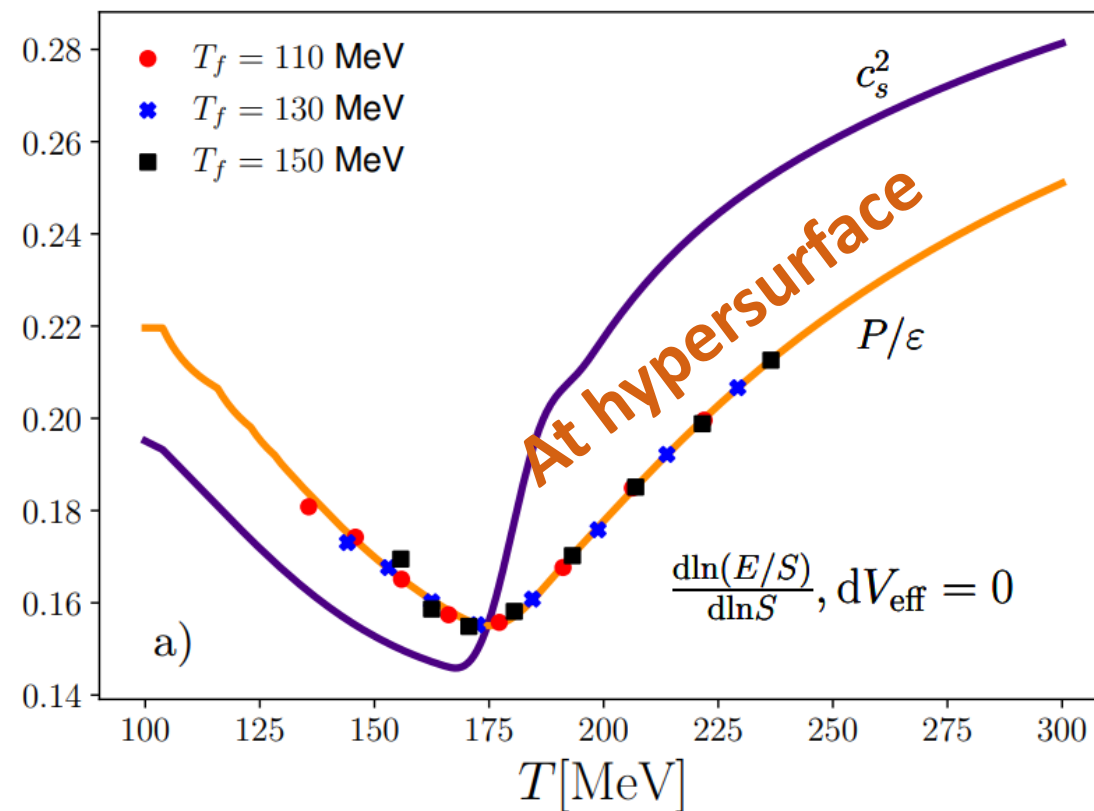
-  $\langle p_T \rangle \propto T$  requires information of EoS

- Coincident agreement?

1) Not  $\langle p_T \rangle \propto T$  but  $\langle p_T \rangle \propto E/S$

$$\frac{d \ln(E/S)}{d \ln S} = \frac{P}{\epsilon} \longrightarrow \frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$

$$\frac{d \ln(E/S)}{d \ln S}, dV_{\text{eff}} = 0$$



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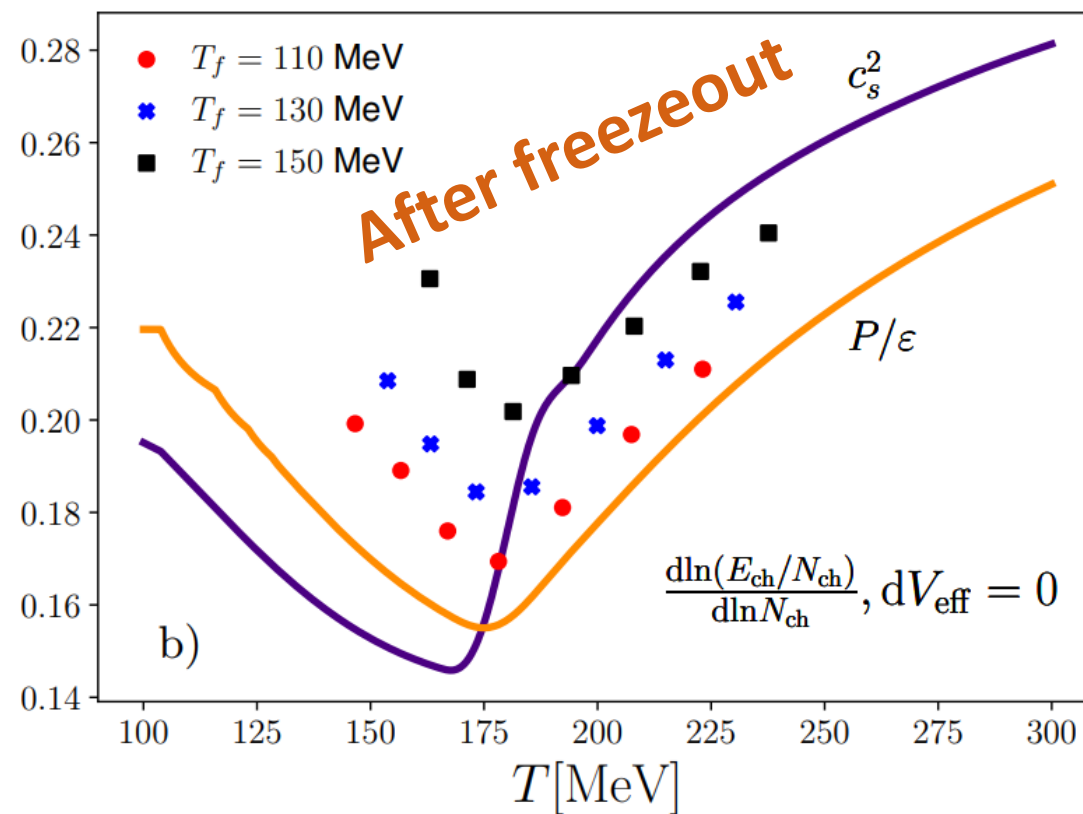
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2) Freezeout:  $E \Rightarrow E_{\text{ch}}$  and  $S \Rightarrow N_{\text{ch}}$   
+Kinematic cut

$$\frac{d \ln(E_{\text{ch}}/N_{\text{ch}})}{d \ln N_{\text{ch}}} \longrightarrow \frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$

$$\frac{d \ln(E_{\text{ch}}/N_{\text{ch}})}{d \ln N_{\text{ch}}}, dV_{\text{eff}} = 0$$



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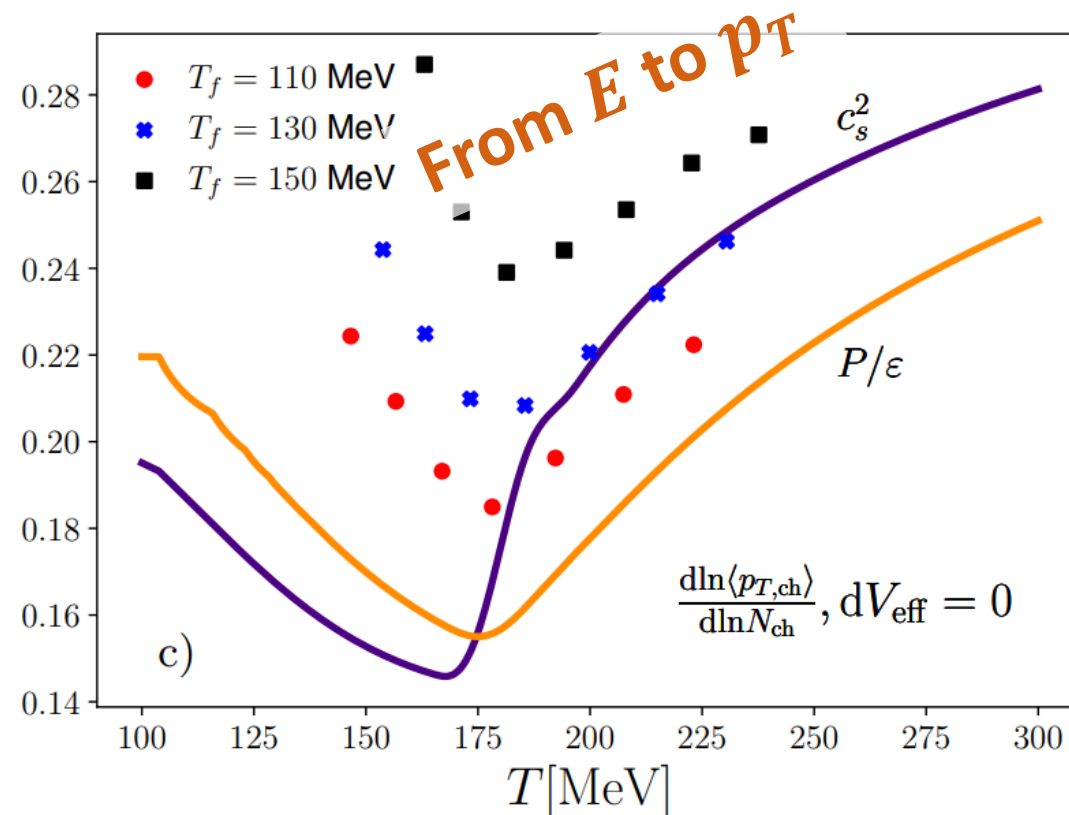
- Coincident agreement?

$$3) \langle E_{\text{ch}} \rangle \Rightarrow \langle p_{T,\text{ch}} \rangle$$

$$\frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}} \xrightarrow{dV_{\text{eff}} = 0}$$

$$\frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$

$$\frac{d \ln \langle p_{T,\text{ch}} \rangle}{d \ln N_{\text{ch}}}, dV_{\text{eff}} = 0$$



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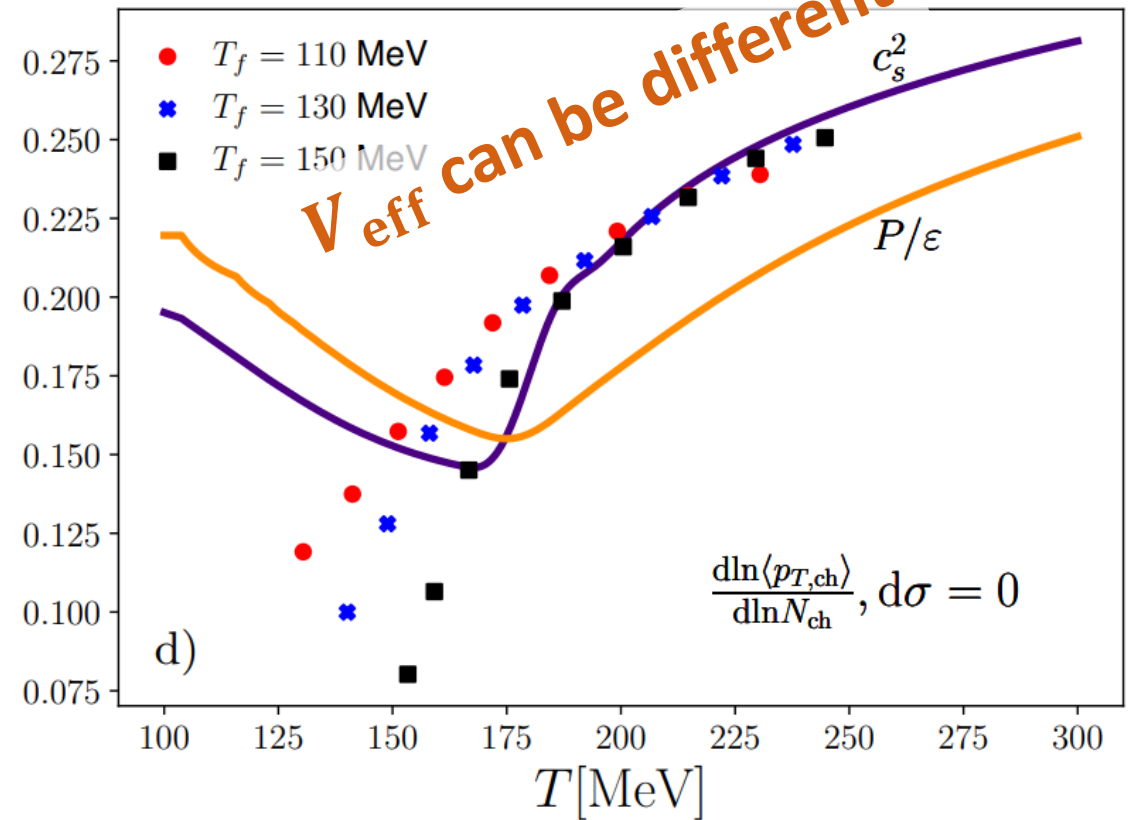
- Coincident agreement?

4) Relax  $dV_{\text{eff}} = 0$

Coincidental agreement...!

$$\frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$

$$\frac{d \ln \langle p_{T,\text{ch}} \rangle}{d \ln N_{\text{ch}}}, dV_{\text{eff}} \neq 0$$



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L. Gavassino et al., Phys.Rev.C 112 (2025) 5, 054903

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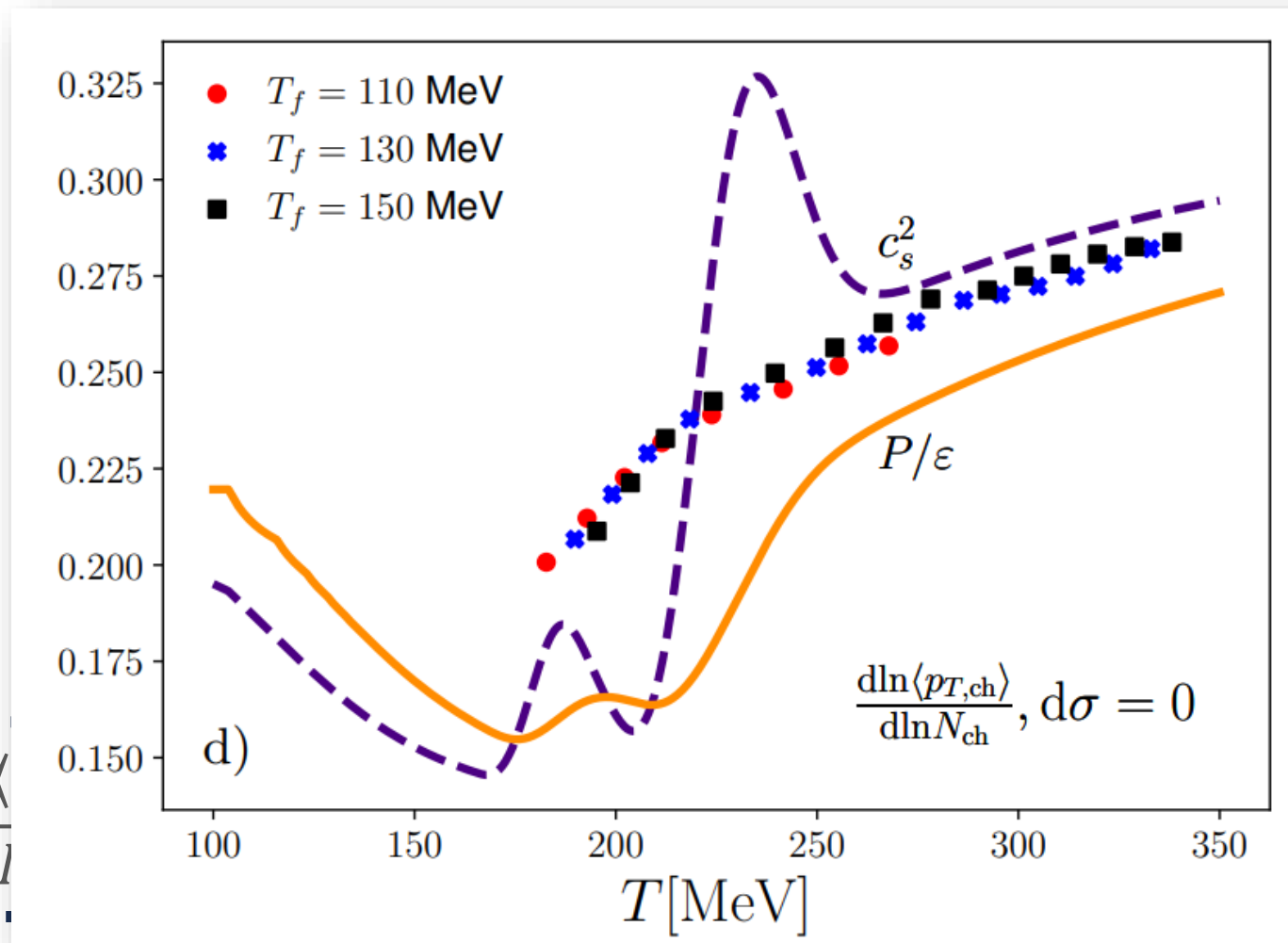
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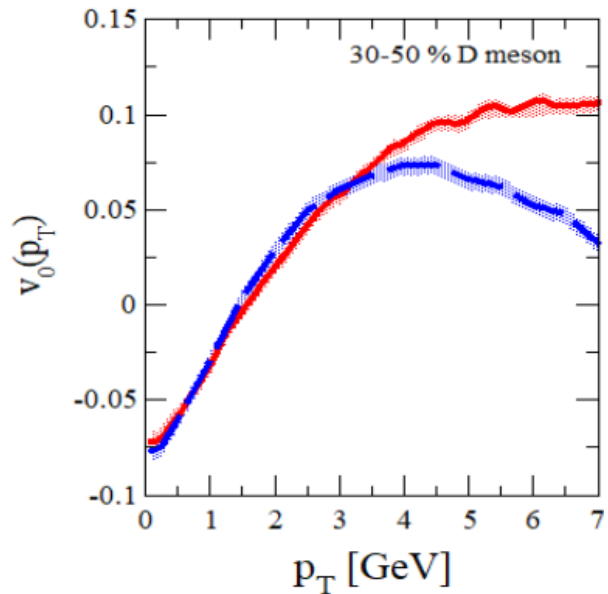
$$\frac{d \ln \langle p_T \rangle}{d \ln N_{\text{ch}}}$$



# $v_0(p_T)$ : radial flow fluctuation

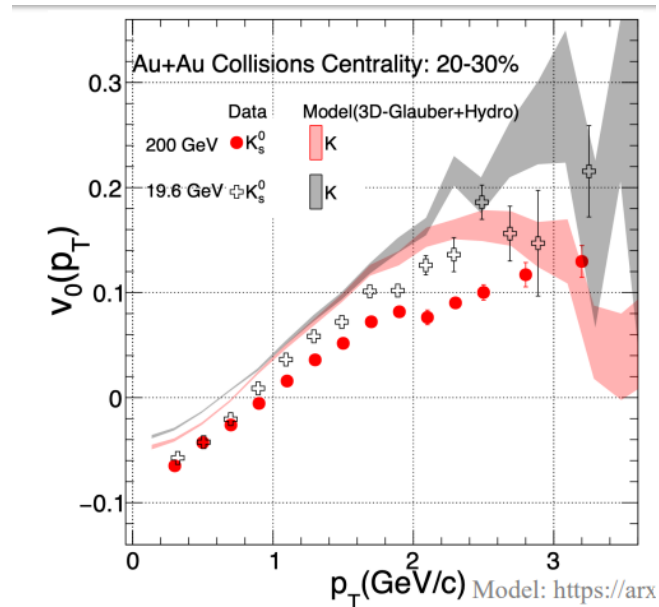
Lots of discussions at SQM2026!

Heavy-quark  $v_0$ : sensitive to hadronization



See Salvatore Plumari's talk on Tue

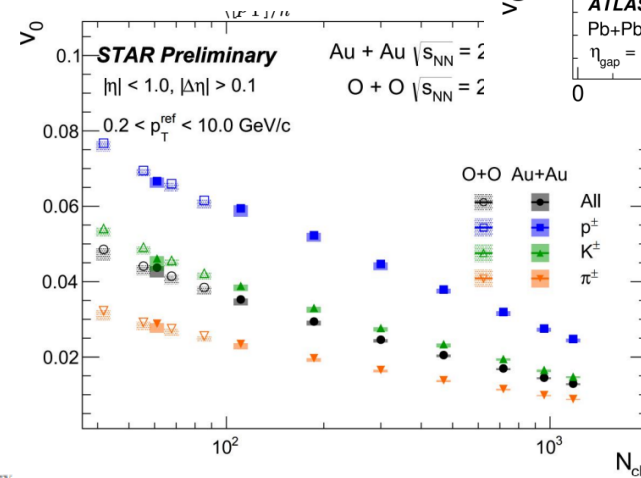
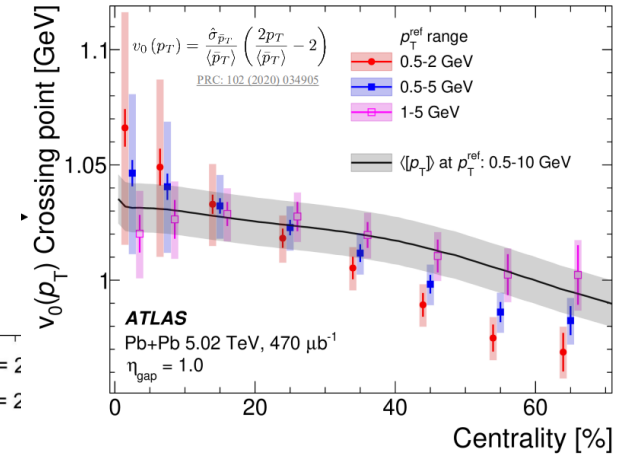
## STAR results



Yuli Kong's talk on Tue

## ATLAS results

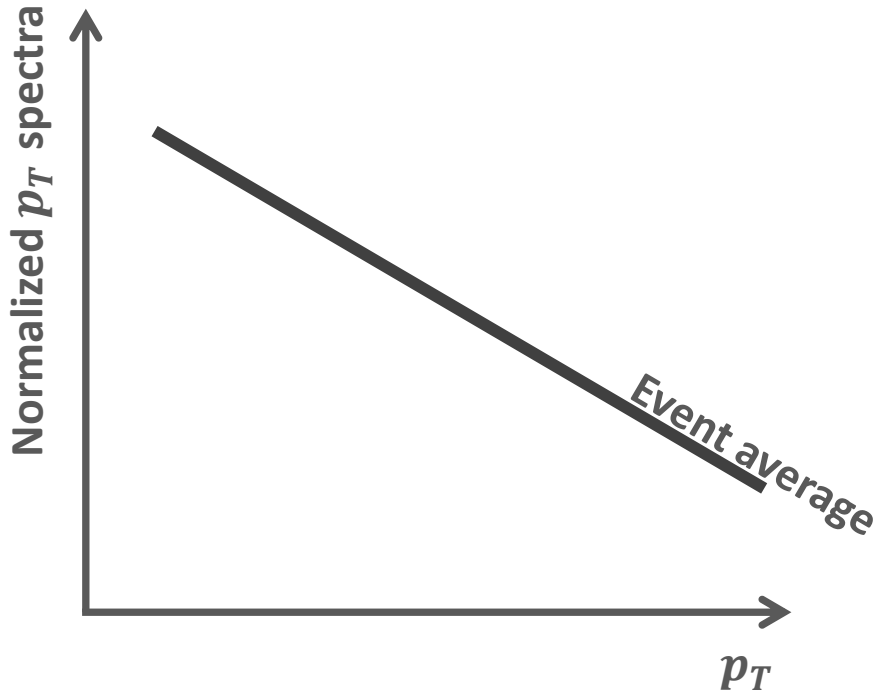
Aman Dimri's talk on Tue



Zaining Wang's talk on Tue

# $v_0(p_T)$ : radial flow fluctuation

$E$ -by- $E$  correlation between mean  $p_T$  and multiplicity in each  $p_T$



Covariance

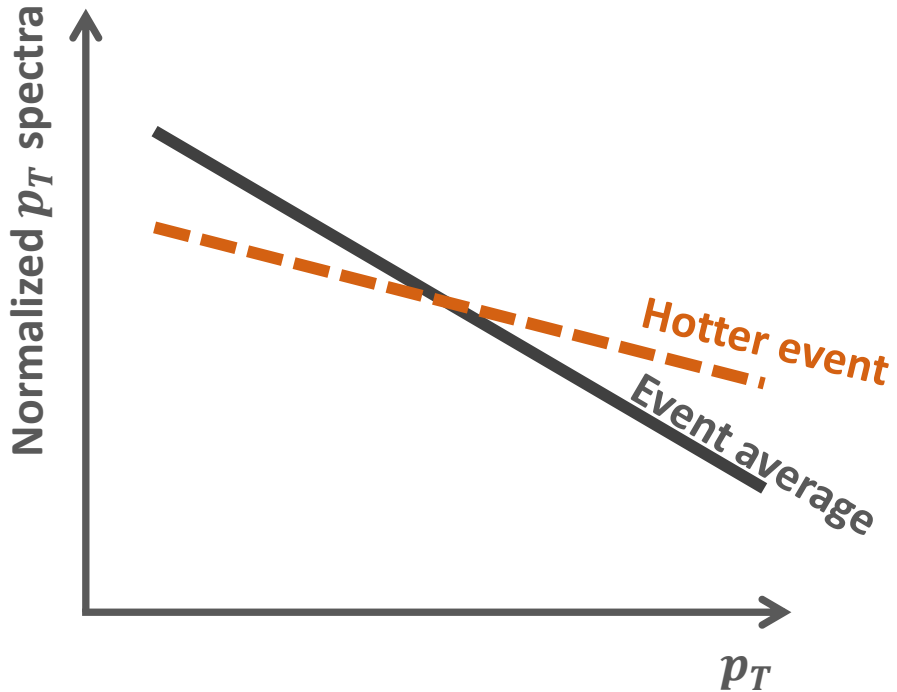
$$v_0(p_T) = \frac{\langle \delta n(p_T) \delta [p_T]_{\text{ref}} \rangle_{\text{ev}}}{\langle n(p_T) \rangle_{\text{ev}} \sigma_{[p_T]_{\text{ref}}}}$$

$n(p_T)$  : Normalized  $p_T$  spectra,  $n(p_T) = (1/N_{\text{norm}})dN / dp_T$

$\sigma_{[p_T]_{\text{ref}}}$  : Scaled SD of  $[p_T]_{\text{ref}}$  in event average

# $v_0(p_T)$ : radial flow fluctuation

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↑  $[p_T]_{\text{ref}}$  larger

Covariance

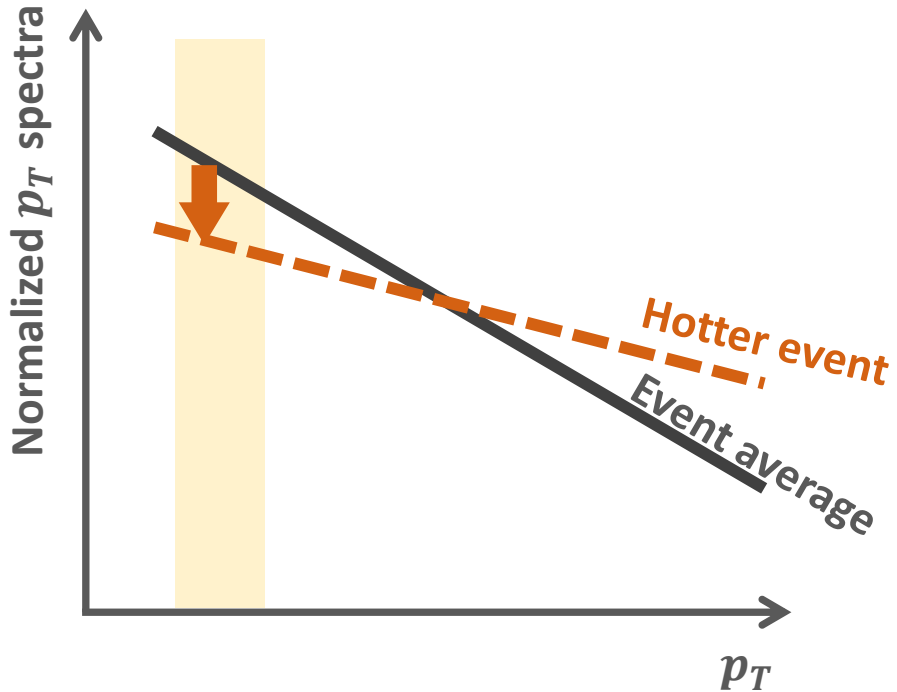
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# $v_0(p_T)$ : radial flow fluctuation

$E$ -by- $E$  correlation between mean  $p_T$  and multiplicity in each  $p_T$



↑  $[p_T]_{\text{ref}}$  larger  
 ↓  $n(p_T)$  smaller

▼  
 Negative  $v_0(p_T)$

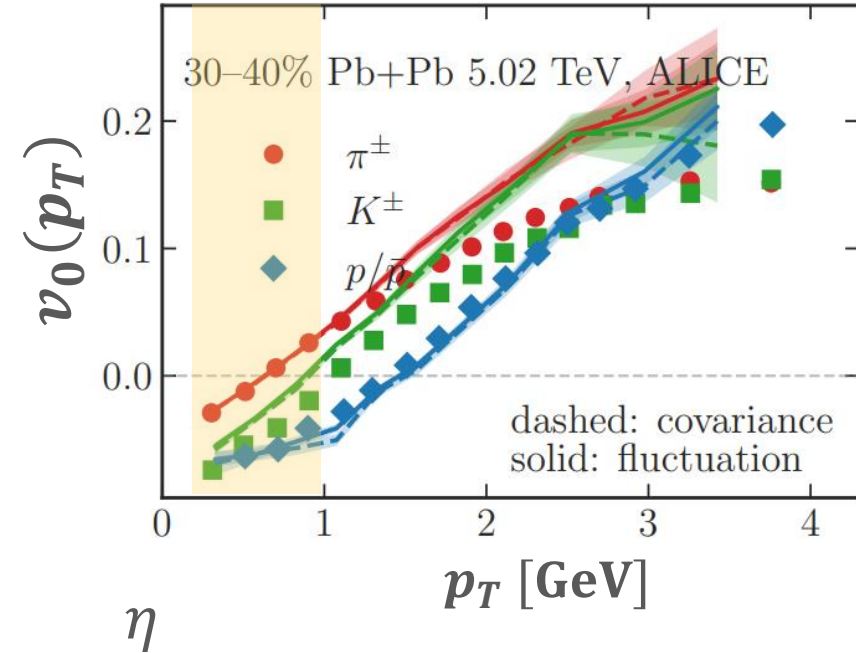
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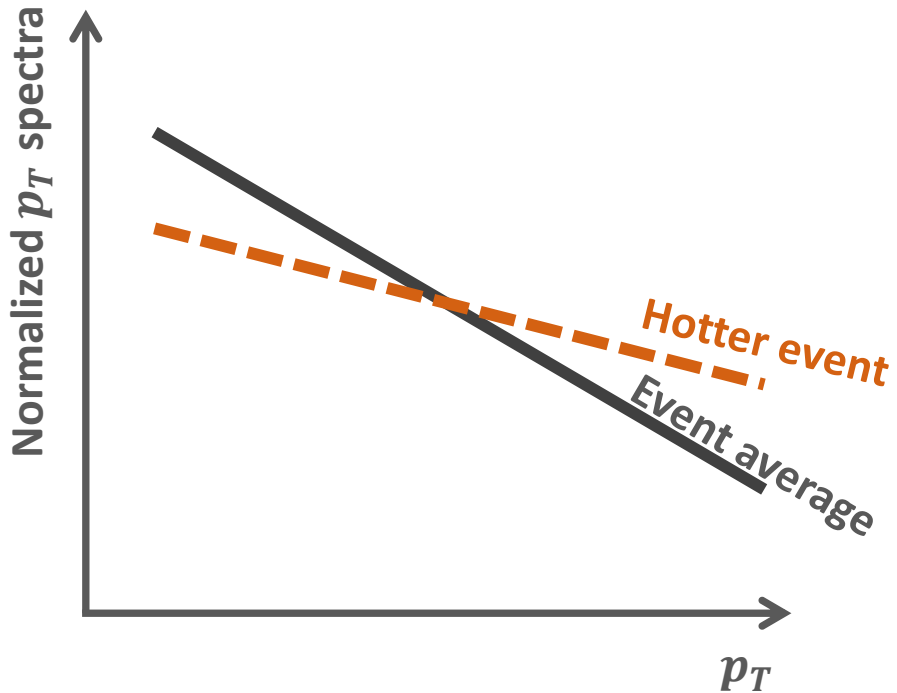
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L. Du, Phys.Rev.C 113 (2026) 1, 014901

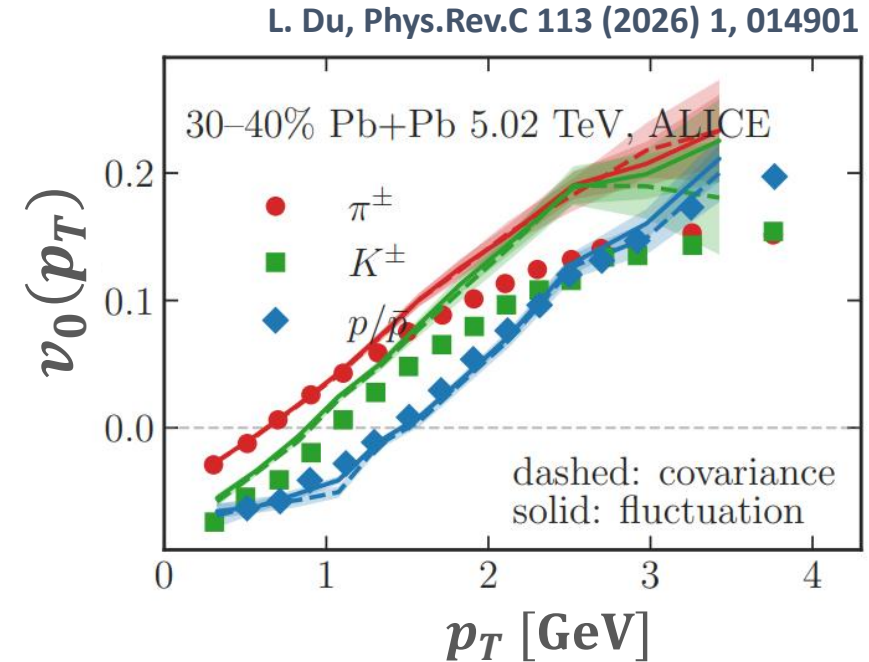


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Covariance

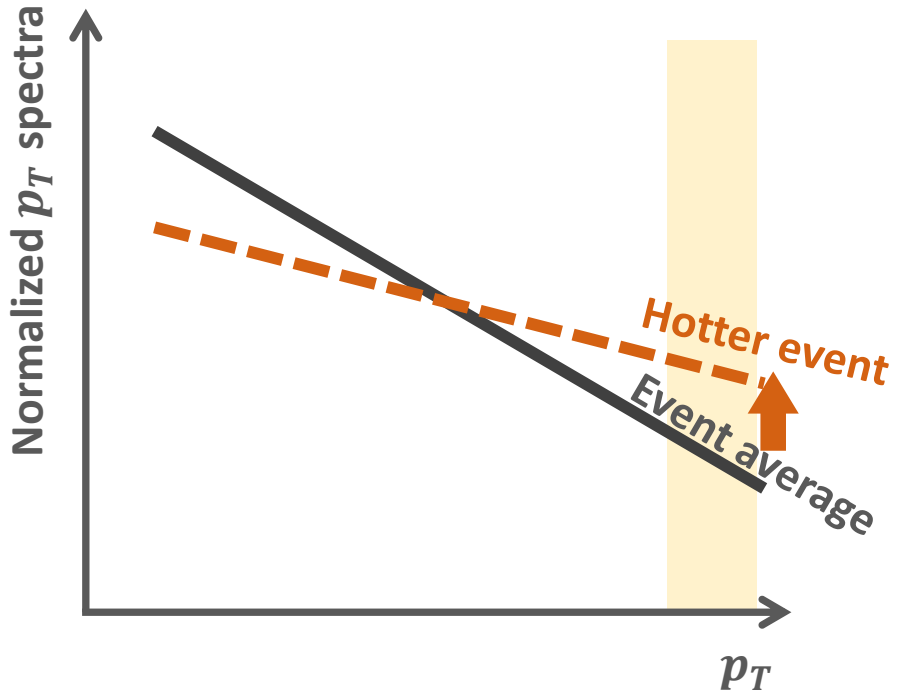
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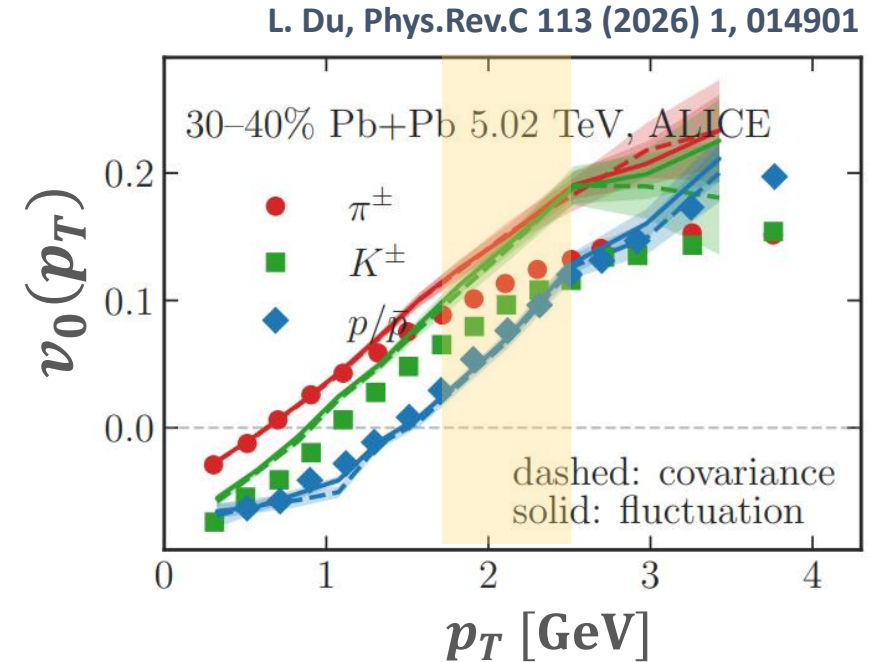
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↑  $[p_T]_{\text{ref}}$  larger

↑  $n(p_T)$  larger

Positive  $v_0(p_T)$



Covariance

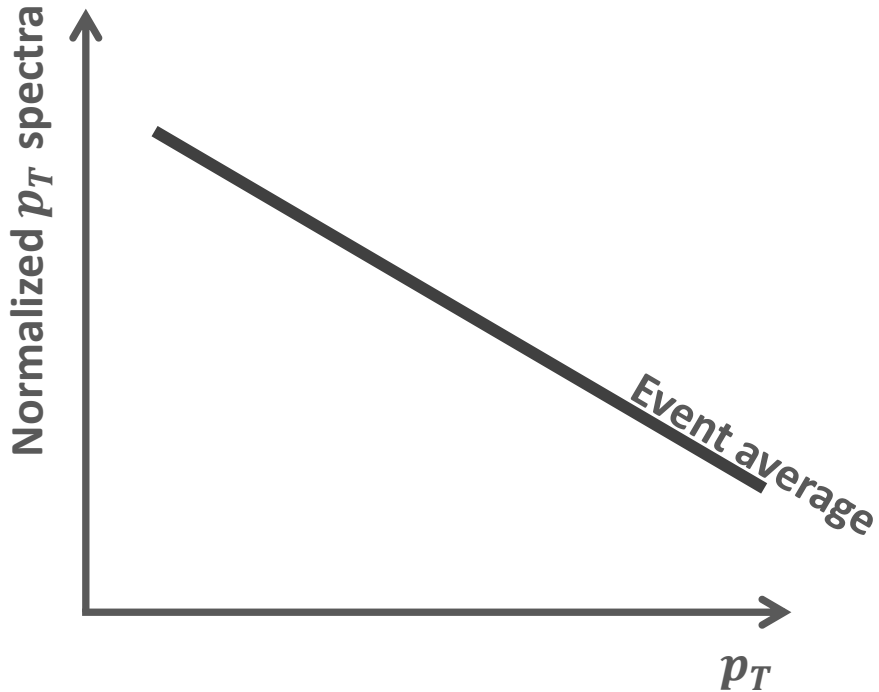
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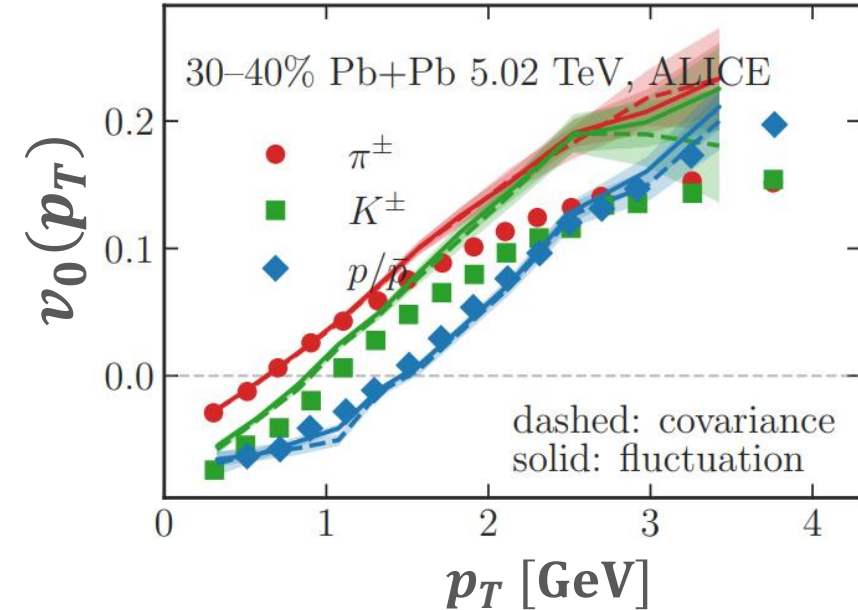
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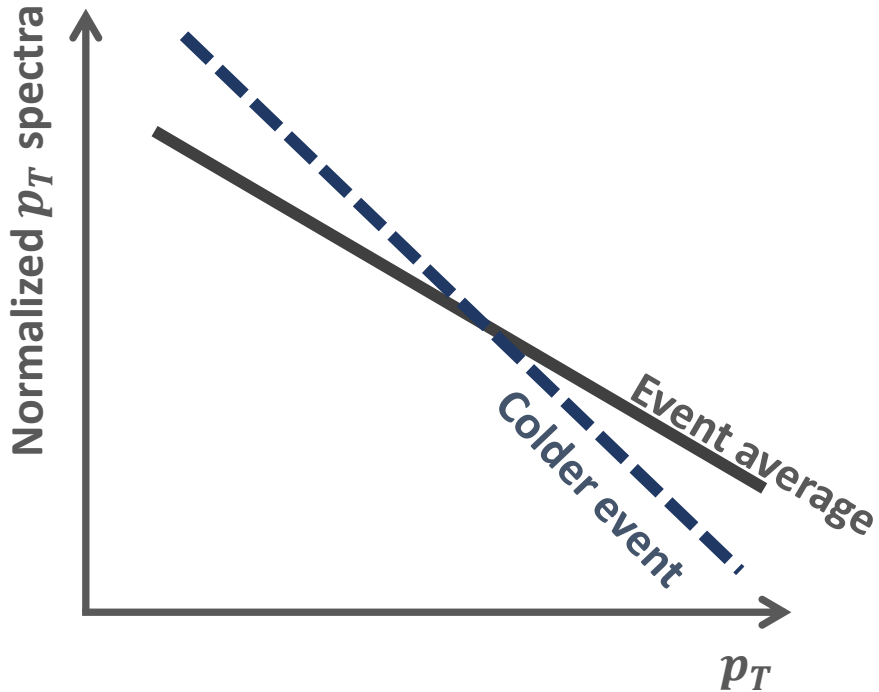
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L. Du, Phys.Rev.C 113 (2026) 1, 014901

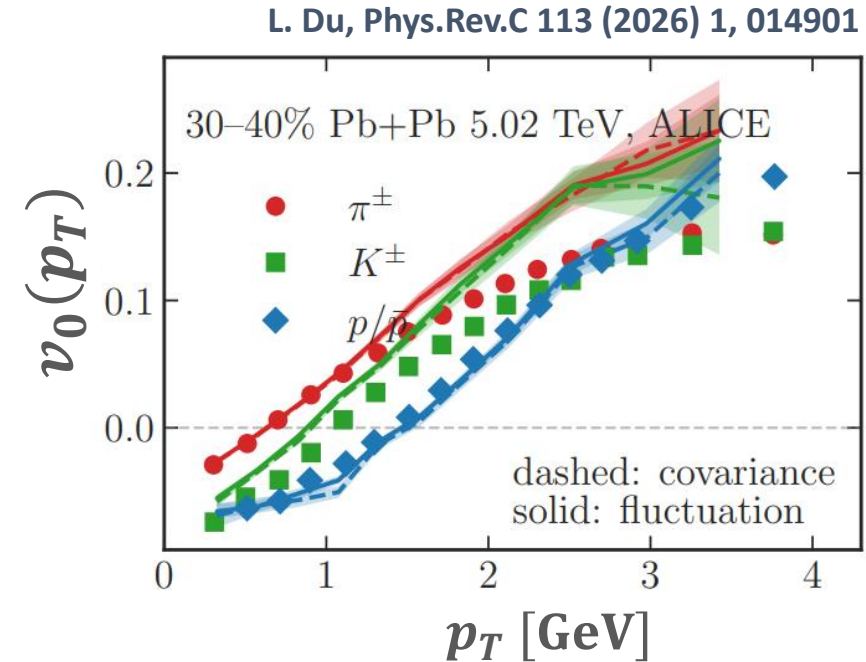


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↓  $[p_T]_{\text{ref}}$  smaller



Covariance

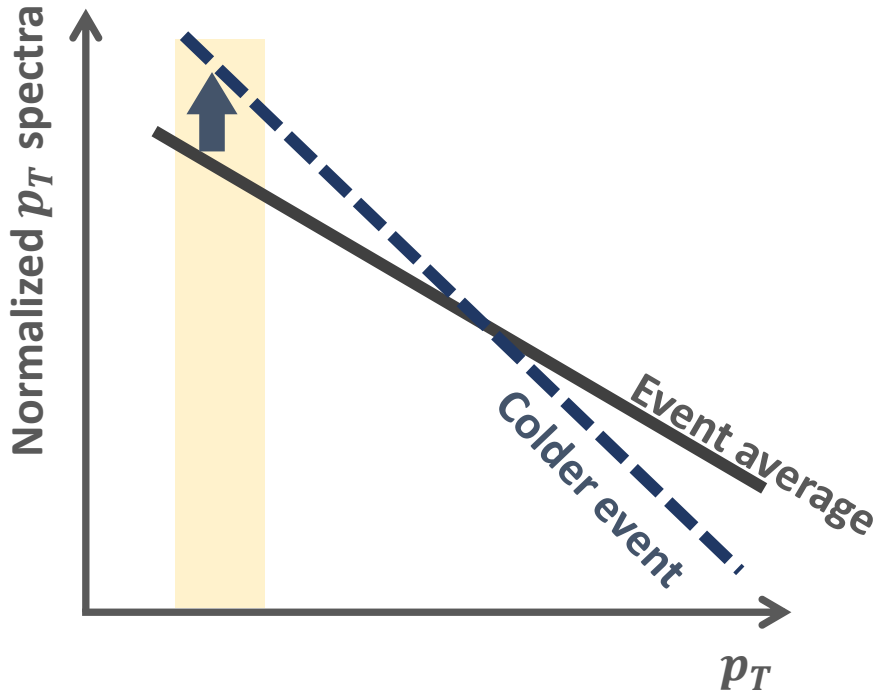
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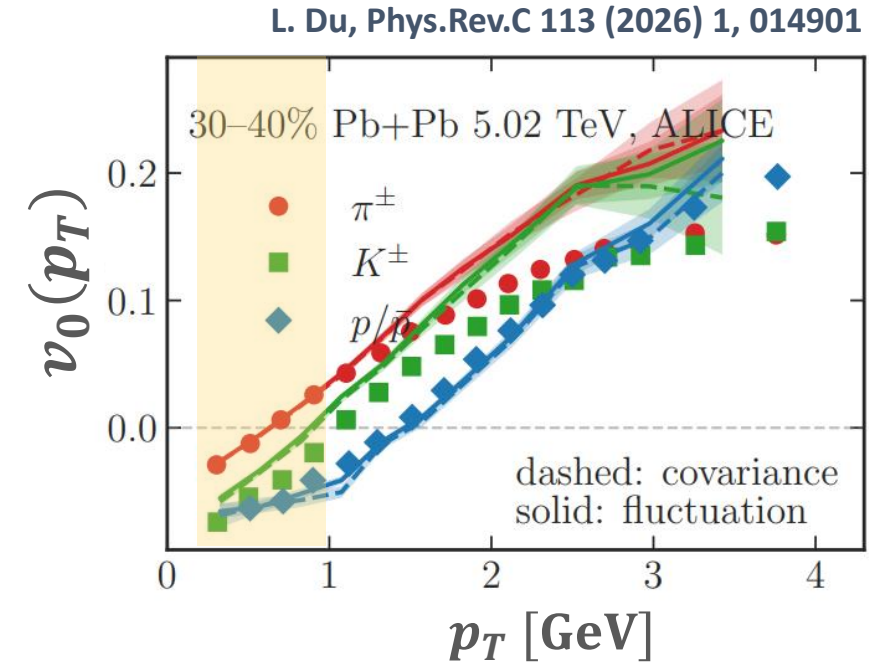
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↓  $[p_T]_{\text{ref}}$  smaller

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▽  
Negative  $v_0(p_T)$



Covariance

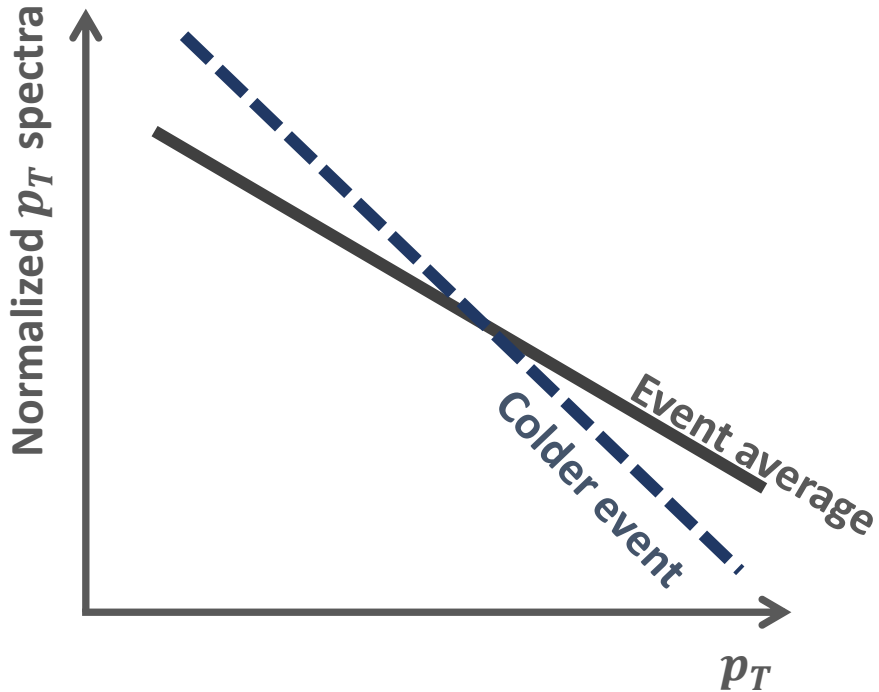
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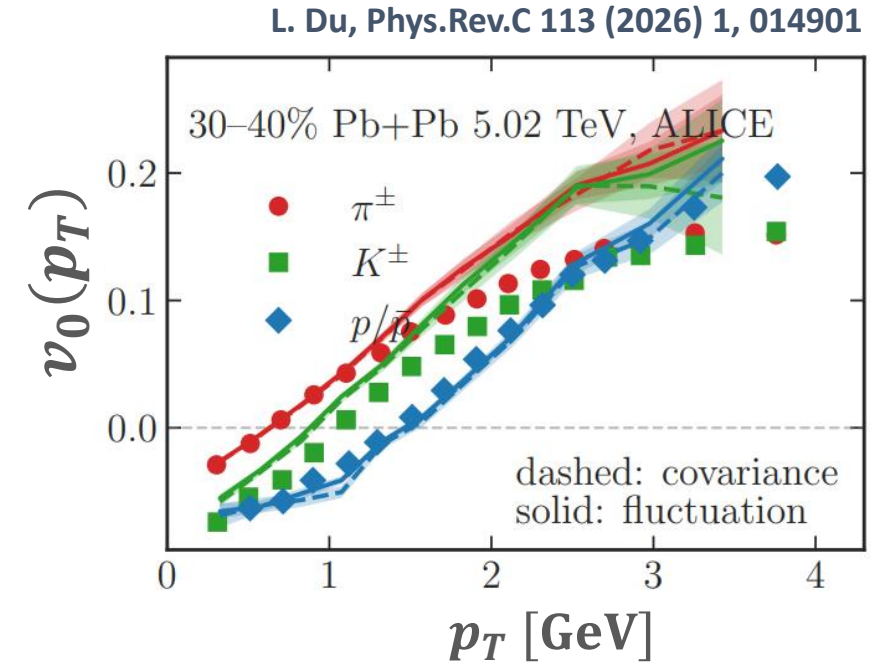
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Covariance

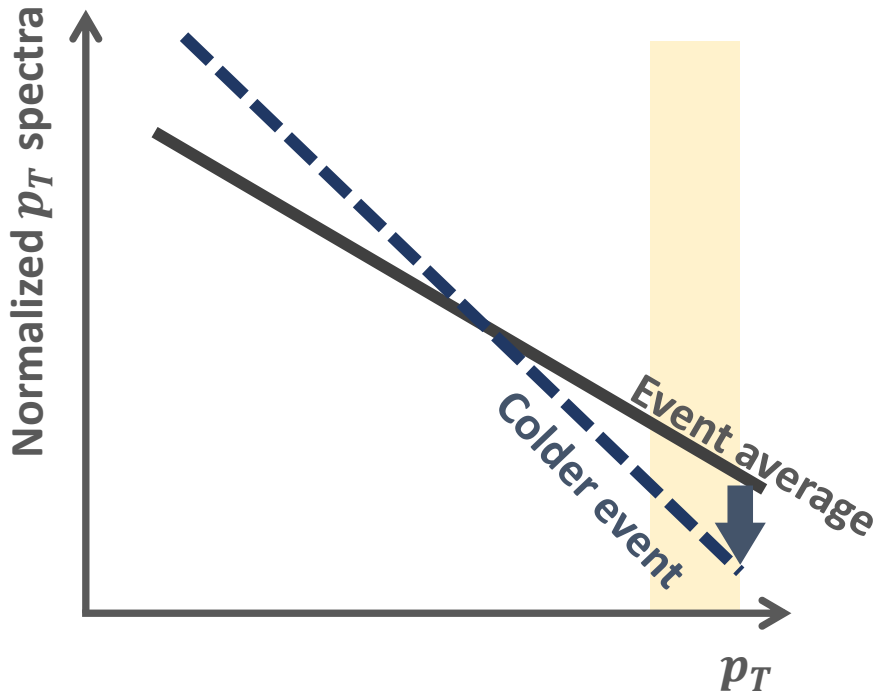
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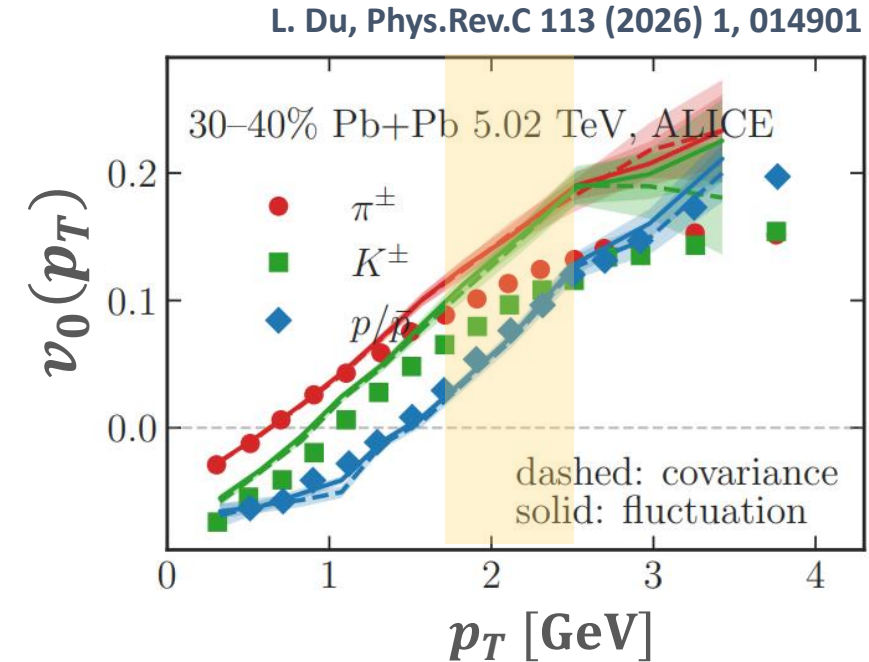
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Positive  $v_0(p_T)$



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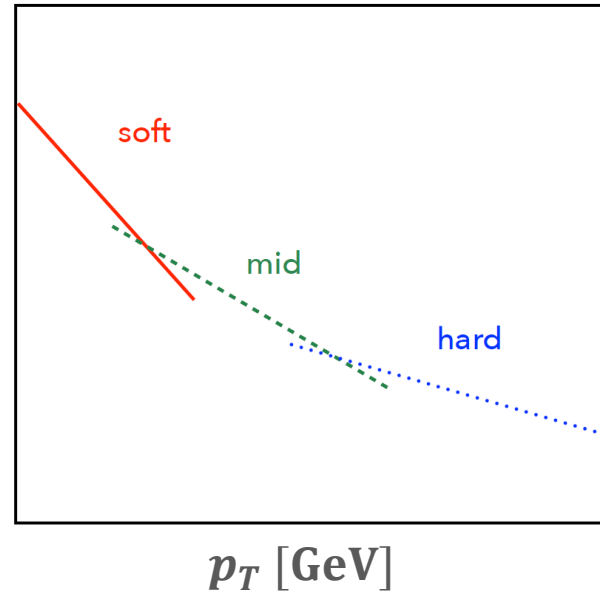
**Monotonic enhancement of  $v_0$ :  
described by a single soft component**

# $v_0(p_T)$ crossing different $p_T$

Towards intermediate  $p_T$  from soft

See L. Du's poster

L. Du, P.M. Jacobs,  
2512.10265 [nucl-th]



$$\frac{dN}{p_T dp_T} = [N_{\text{soft}} \mathbf{S}(p_T) + N_{\text{mid}} \mathbf{C}(p_T) + N_{\text{hard}} \mathbf{H}(p_T)]$$

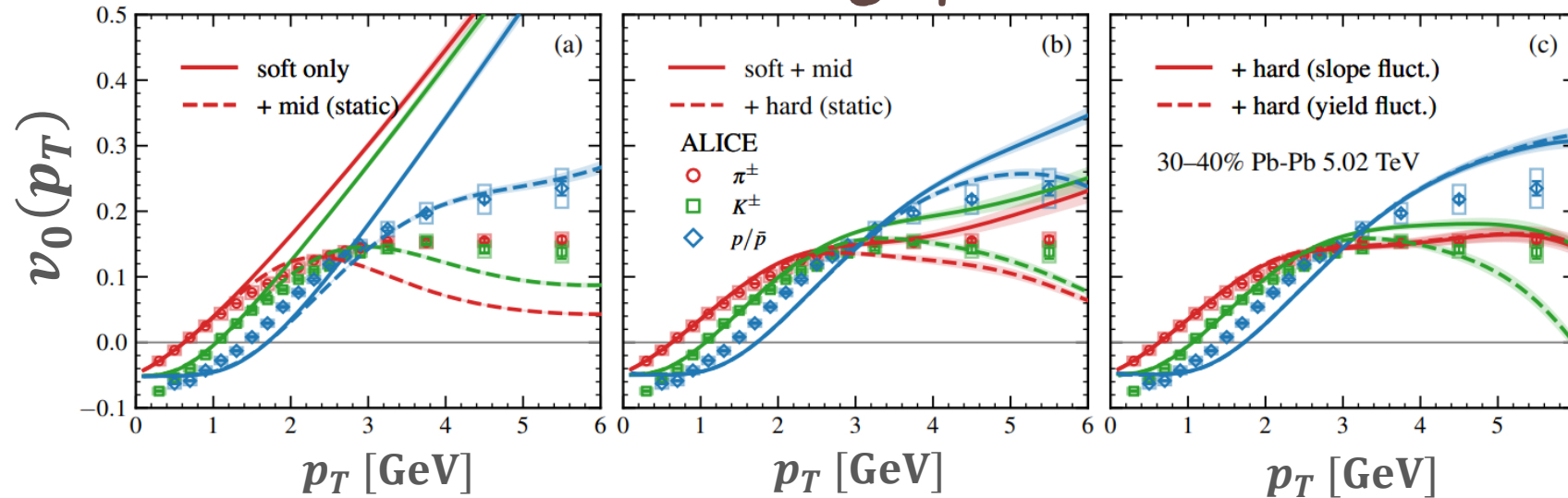
**Blast-wave**                      **Coalescence**                      **Fragmentation**

# $v_0(p_T)$ crossing different $p_T$

See L. Du's poster

Towards semi-high  $p_T$  from soft

L. Du, P.M. Jacobs,  
2512.10265 [nucl-th]



$$\frac{dN}{p_T dp_T} = [N_{\text{soft}} \mathbf{S}(p_T) + N_{\text{mid}} \mathbf{C}(p_T) + N_{\text{hard}} \mathbf{H}(p_T)]$$

Blast-wave      Coalescence      Fragmentation

- Enhancement of  $v_0$ : described by soft
- Decrease of  $v_0$ : described by +hard

- Good measure for E-by-E fluctuations of soft-hard interplay
- **Challenge for theoretical models** → **dynamics of intermediate energy scale...**

# Summary

*Bulk-property study in soft sector*

// from my perspective

## OO, pO results

System size scan

Highly likely to have QGP

$\alpha$ -clusters: need to address  
large theoretical uncertainty

## Initial productions

With more constraints

Energy-momentum conservation:  
strong constraints

Need more constraint in initial state

## New observables

$v_0$  and  $c_s$  from  $\langle p_T \rangle$  &  $N_{ch}$

$v_0$ : Fluctuation of radial flow

→ Interplay of soft-hard & EoS

Challenge: Dynamics of intermediate energy scale

# Summary

*Bulk-property study in soft sector*

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# Summary

Bulk-property study in soft sector

// from my perspective

## OO, p0 results

System size scan

Requires breakthrough

Highly likely to have QGP in theoretical works

$\alpha$ -clusters: need to address  
large theoretical uncertainty

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$v_0$ : Fluctuation of radial flow

→ Interplay of soft-hard

Challenge: Dynamics of intermediate energy scale

# See also...

Apology for not being able to cover // from my perspective

Novel Use of Generative AI See Shuhang Li talk on Wed

Bayesian inference of holographic transport and energy loss See Musa Rahim Khan's talk on Wed

Hard probe dynamics in QGP using EFT See Andreas Kirchner's talk on Tue

Deterministic AI Surrogate Modeling for Fast Hydrodynamic Evolution See Yeonju Go's talk on Wed

Quark flavor equilibrium See Andrew Gordeev's talk on Tue

Charm in hydro See Rossana Facen's talk on Wed R. Facen, F. Capellino, E. Grossi, A. Dubla, S. Masciocchi, 2510.25601 [hep-ph]

Etc.

# Thank you!

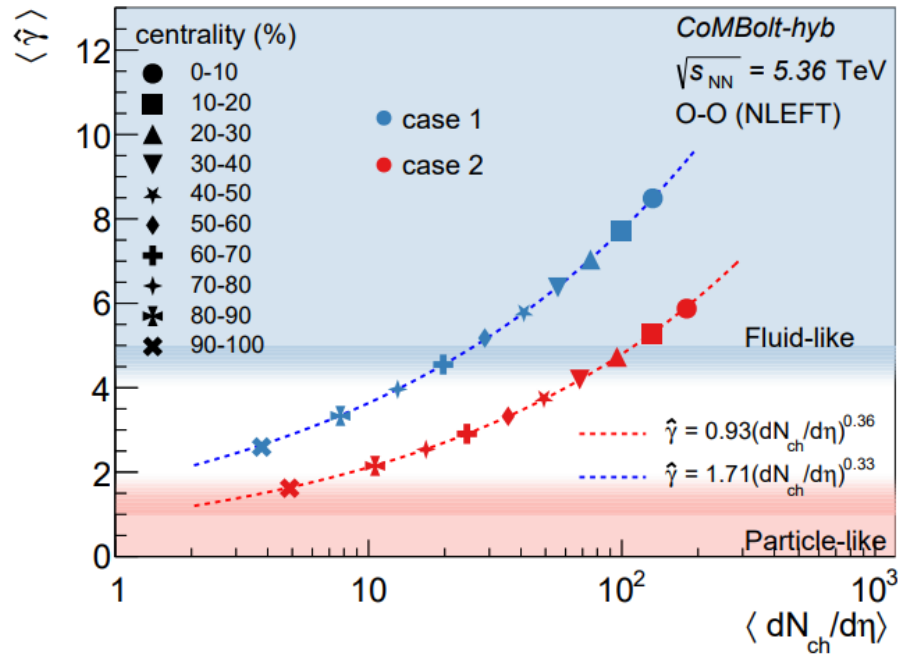
*Special thanks for discussion: Volker Koch, Lipei Du,  
Iurii Karpenko, NT group members at LBNL*



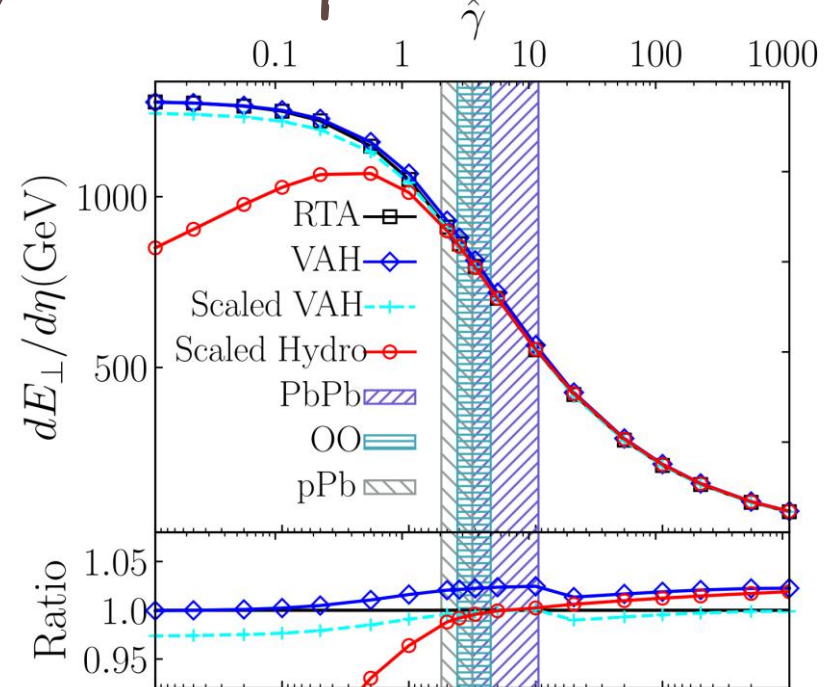
**Backup**

# Opacity in OO, pO

A way of measure how good hydro description would be



Yiyang Peng,<sup>1</sup> \* Victor E. Ambrus,<sup>2</sup>  
 † Clemens Werthmann,<sup>3</sup> ‡  
 Sören Schlichting,<sup>4</sup> § Ulrich Heinz,<sup>5</sup> ¶ and Huichao Song,  
 Phys.Rev.C 113 (2026) 2, 024918



Yiyang Peng,<sup>1</sup> \* Victor E. Ambrus,<sup>2</sup>  
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 Phys.Rev.C 113 (2026) 2, 024918



# QGP in small systems

Small systems (pp, pA...) used to be reference for AA with QGP

In **high-multiplicity** events...



Thermal hadron yield ratios  
Hydro-like collectivity

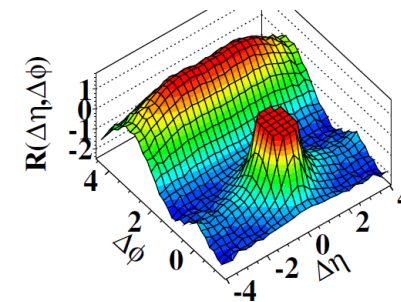


## QGP in pp and pA?

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

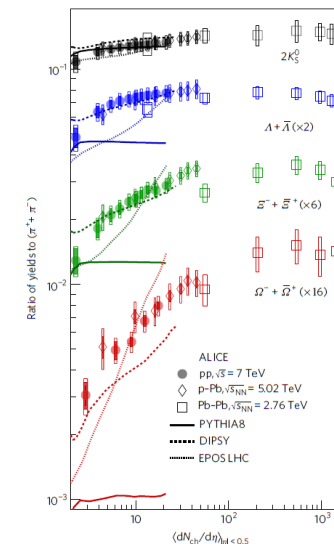
Needs comprehensive understanding

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



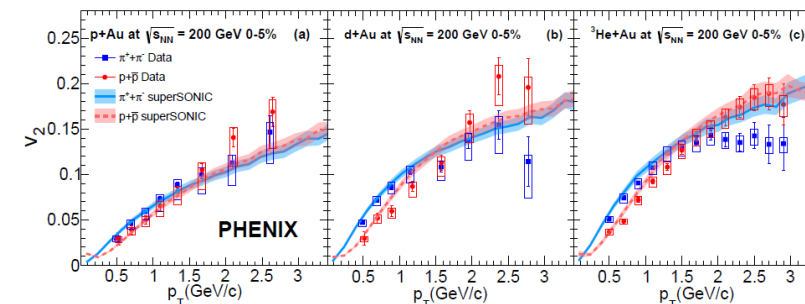
Long range correlation

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

# MC-EKRT

Factorization kept at high  $p_T$

Saturation  
regulating low  $p_T$

Thermalisation  
QGP

$$\sim \frac{1}{\kappa_{\text{sat}}} p_T$$

LO minijet production:

$$\frac{d\sigma_{\text{jet}}}{dp_T^2 dy_1 dy_2} = K \sum_{ijkl} x_1 f_i^{a/A}(\{\bar{s}_a\}, x_1, Q^2) x_2 f_j^{b/B}(\{\bar{s}_b\}, x_2, Q^2) \times \frac{d\hat{\sigma}^{ij \rightarrow kl}}{d\hat{t}}$$

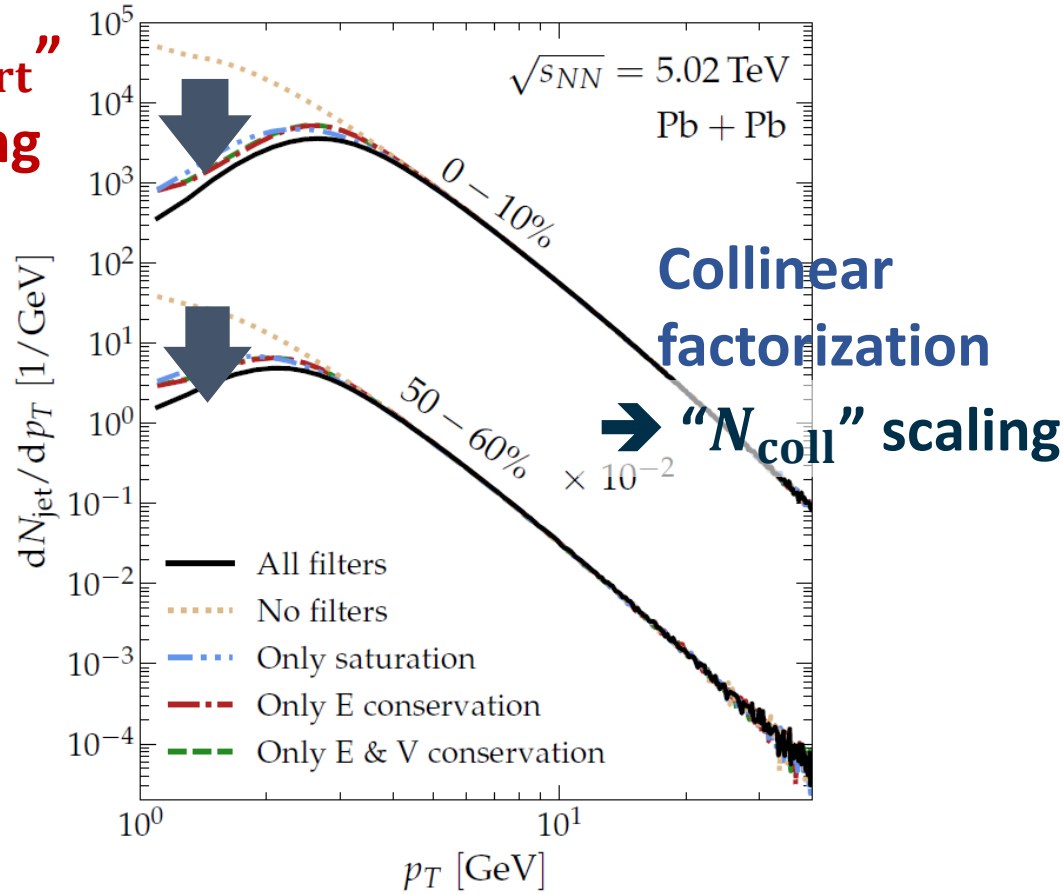
→ More nuclear effect in denser regions

$$\tau \sim 1/p_T$$

# Initial state from low to high $p_T$

For constraints of bulk properties!

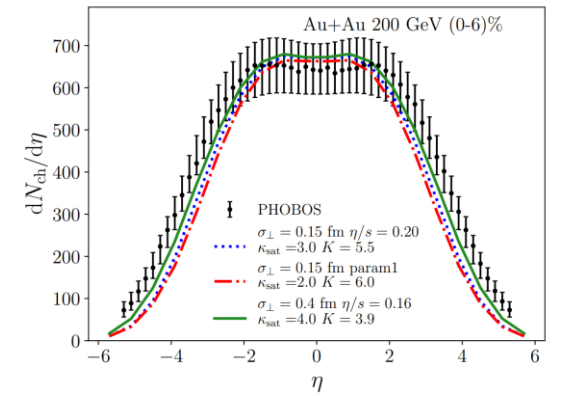
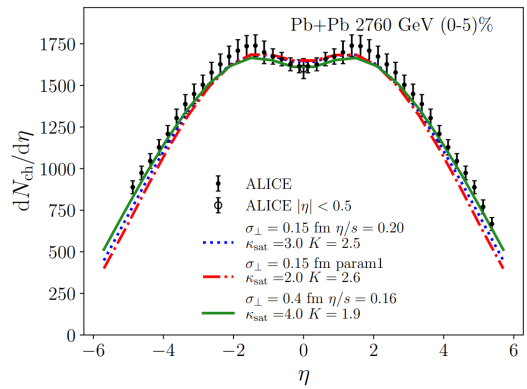
“ $N_{part}$ ”  
scaling



Minijets from nPDFs  $\otimes$  pQCD cross sections

Energy-momentum and charge conservation  
& saturation

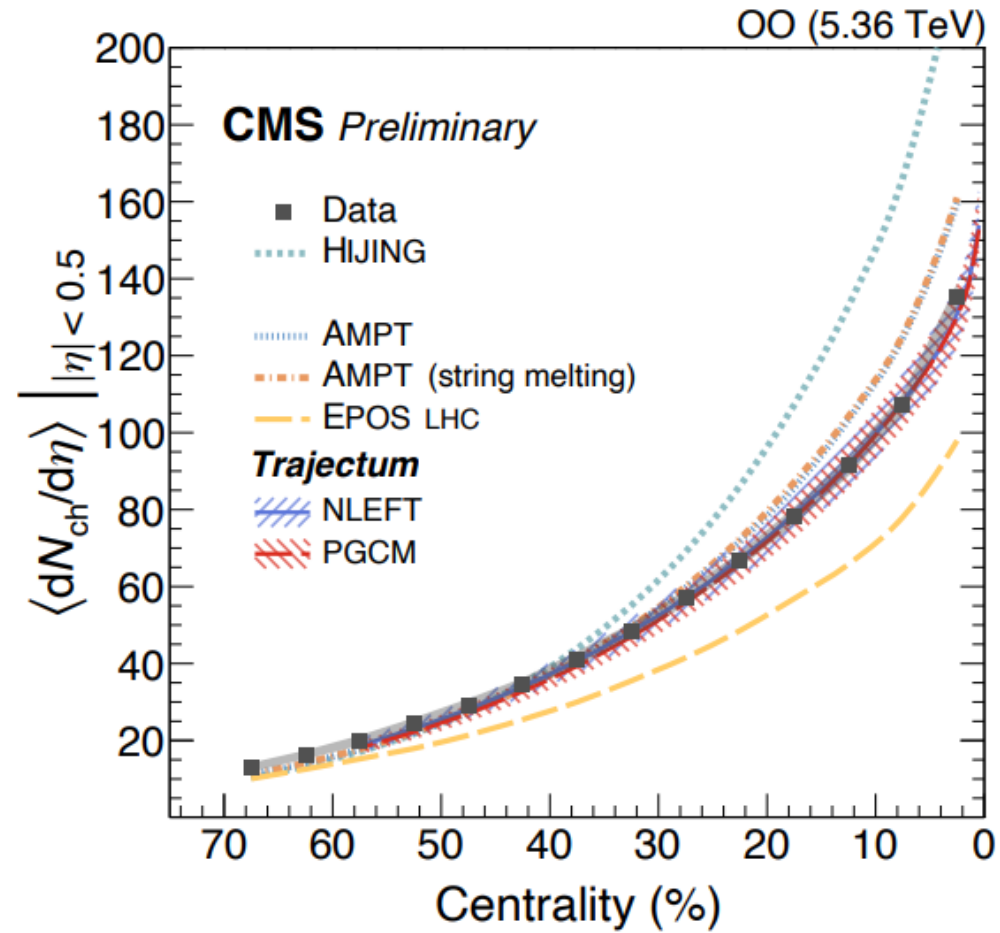
Partons from low to high  $p_T$



M. Kuha, J. Auvinen, K. J. Eskola, H. Hirvonen, Y. K. H. Niemi, Phys.Rev.C 111 (2025) 5, 054914; Phys.Rev.C 110 (2024) 3, 034911

Only 2 tunable parameters in initial state

# Multiplicity from OO 5.36 TeV



# About v0

## DEFINITION

4

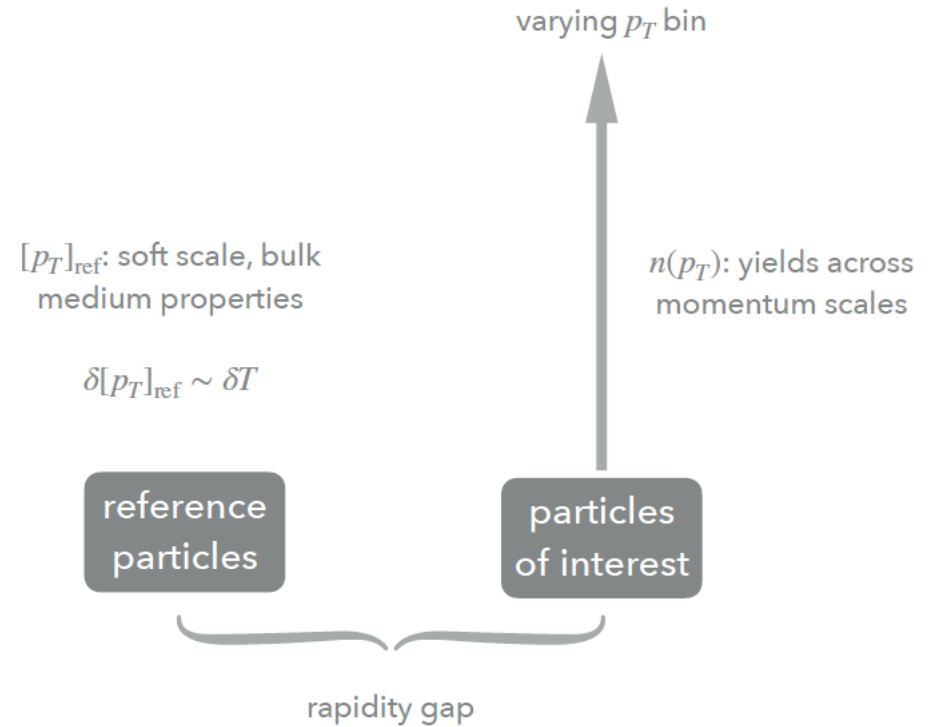
$$v_0(p_T) = \frac{\langle \delta n(p_T) \delta [p_T]_{\text{ref}} \rangle}{\langle n(p_T) \rangle \sigma_{[p_T]_{\text{ref}}}}$$

[...]: event-wise average;  $\langle \dots \rangle$ : ensemble average

- ▶  $n(p_T)$ : event-wise normalized spectrum

$$n(p_T) = dN/dp_T / \left( \int p_T dN/dp_T \right)$$

- ▶  $\delta n(p_T) = n(p_T) - \langle n(p_T) \rangle$ : fluctuation
- ▶  $[p_T]_{\text{ref}}$ : event-wise mean transverse momentum
- ▶  $\delta [p_T]_{\text{ref}} = [p_T]_{\text{ref}} - \langle [p_T]_{\text{ref}} \rangle$ : fluctuation
- ▶  $n(p_T)$  &  $[p_T]_{\text{ref}}$  are measured in separated pseudorapidity intervals



# Initial baryon production

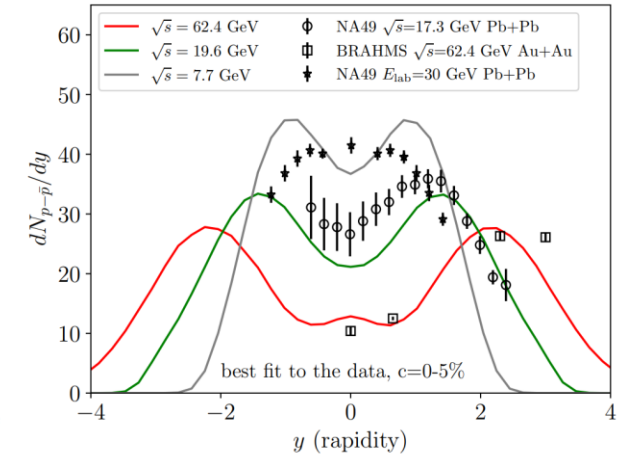
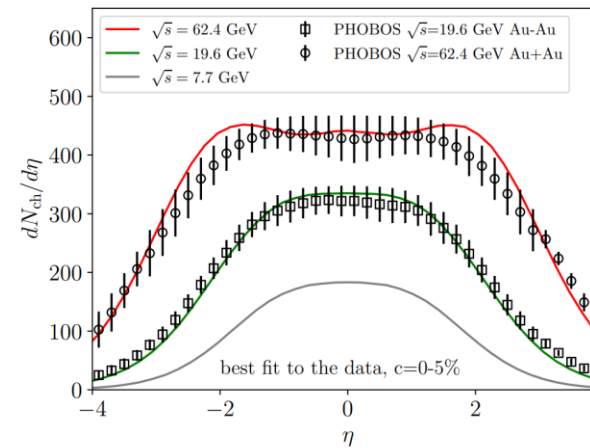
## Baryon stopping

Clemens Werthmann(Gent U.), Iurii Karpenko(Prague, Tech. U.), Pasi Huovinen, Phys.Rev.C 113 (2026) 3, 034908

See Iurii Karpenko's poster

- MUFFIN (3-fluid model) + SMASH
- Implementation of charge transfer frictions
- $\mu_B$ -dependent shear viscosity

→ Simultaneous description of charged and net-proton distribution



## Initial strangeness production

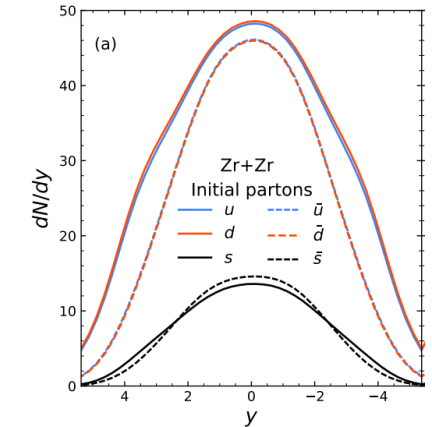
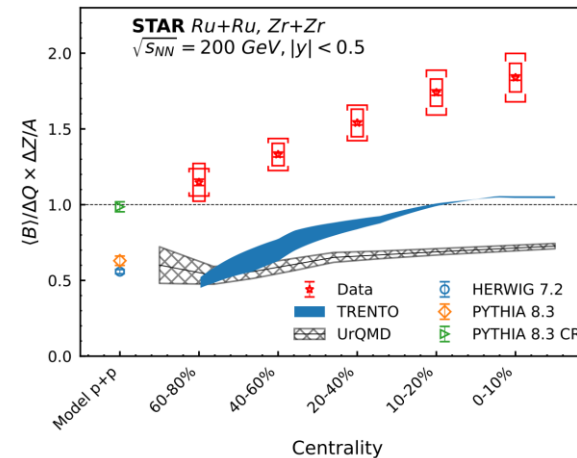
See Zi-Wei Lin's talk

- AMPT (string melting + partonic transport)
- Study role of  $s-s^-$  asymmetry and light-quark stopping

→ Midrapidity  $B/Q \times Z/A$  is highly sensitive to strangeness

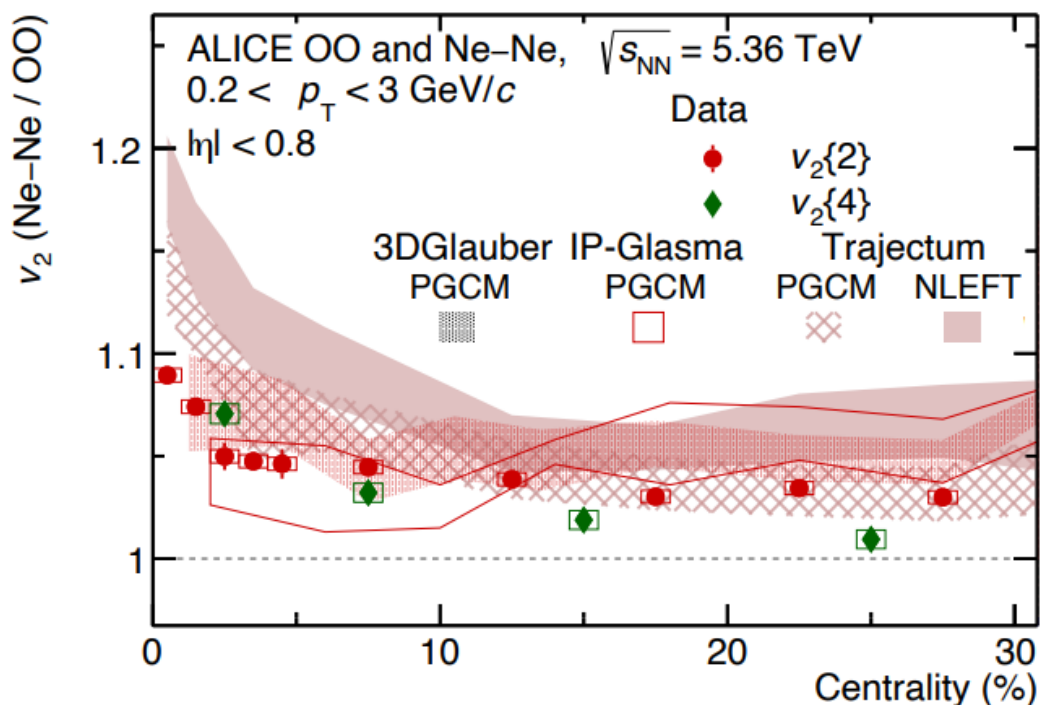
M. A. Ross and Z-W Lin, Eur.Phys.J.C 86 (2026) 2, 143

Also see G. Pihan, A. Monnai, B. Schenke, and C. Shen, Phys. Rev. Lett. 133, 182301 (2024).



Also see Siyuan Ping's talk: baryon stopping + AMPT

# Comparison of elliptic flow in light-ion collisions



ALICE, arXiv:2509.06428

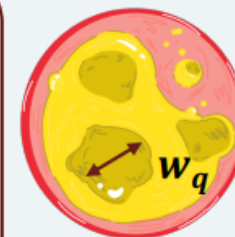
$v_2\{2\}$  (Ne-Ne/OO)

PGCM+Trajectum: **overestimate**  
 NLEFT+Trajectum: **overestimate**  
 PGCM+3DGlauber: **good description of data**  
 PGCM+IP-Glasma: **good description of data**

**Difference? Subnucleon width  $w_q$**

Trajectum:  $w_q \approx 0.4$  fm  
 3DGlauber:  $w_q \approx 0.11$  fm  
 IP-Glasma:  $w_q \approx 0.11$  fm

ALICE, arXiv:2509.06428

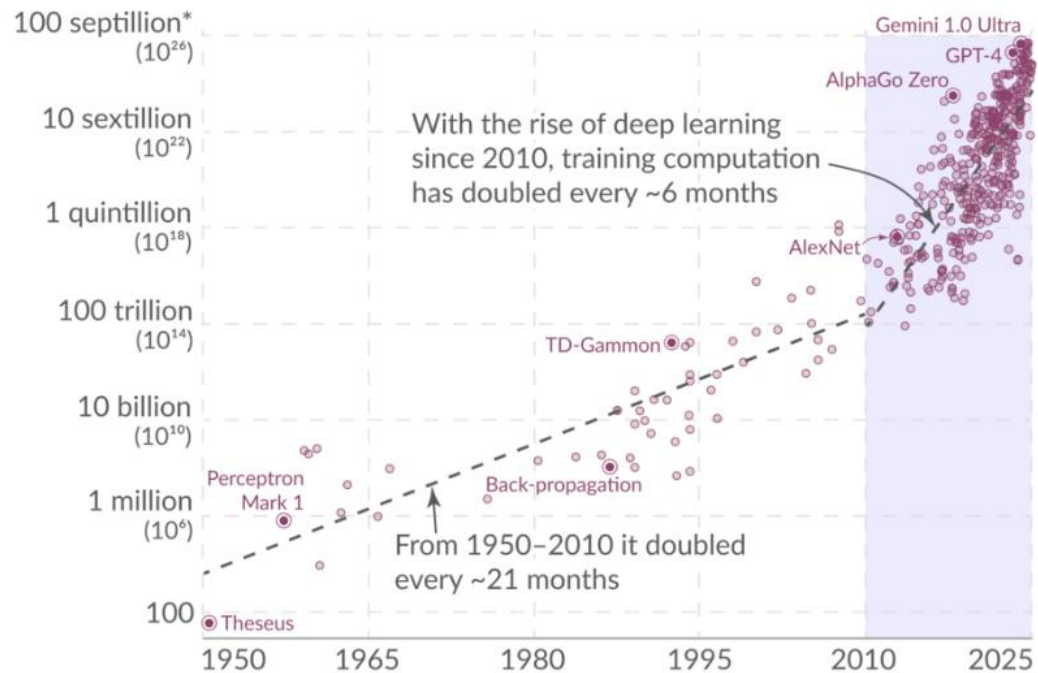


# ML/AI for high energy and nuclear physics

The computation used to train notable AI systems has doubled every ~6 months since 2010



Training computation is measured in total floating-point operations (FLOP). Each FLOP represents a single arithmetic calculation, such as multiplication. Shown on a logarithmic scale.



\*For comparison, 1 septillion (1,000,000,000,000,000,000,000,000) is the estimated number of stars in the universe.

Data source: Epoch (2024)

CC BY

*Social phenomena since 2025 autumn*

*Progresses in both "AI for physics"  
and "physics for AI"*

**It's the right time to think what we can  
do with ML/AI for QGP study.**

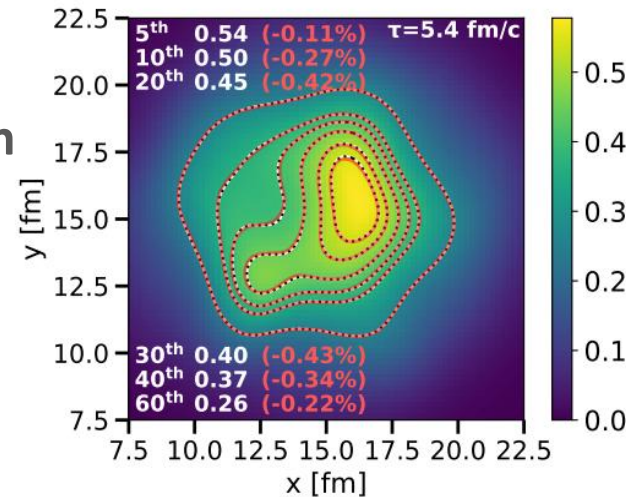
# ML/AI use in QGP study

- Impact parameter estimation
- determination of the QCD matter phase transition
- Prediction of flow from initial conditions ...

Berndt Müller et. al , 1995; C. David et al., Phys.Rev.C 51 (1995) 1453-1459; S.A. Bass et al., Phys.Rev.C 53 (1996) 2358-2363; L-G Pang et al., Nature Commun. 9 (2018) 1, 210; H. Huang et al., Phys.Rev.Res. 3 (2021) 2, 023256; N. Mallick et al., Phys.Rev.D 105 (2022) 11, 114022; H. Hirvonen et al., Phys. Rev. C 110 (2024) 3, 034911 etc.

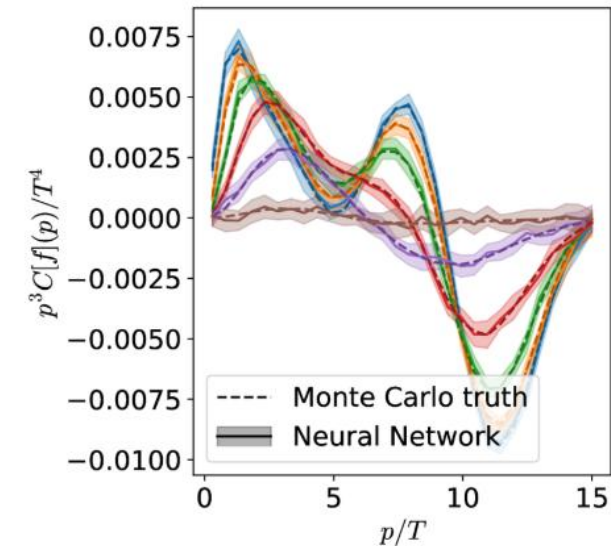
## Speeding up time-steps in simulations

As a replacement for the expensive collision kernel of QCD effective kinetic theory



- As a replacement for the hydrodynamic evolution step itself

Fourier Neural Operator (FNO)  
 → proven to emulate PDE solver well

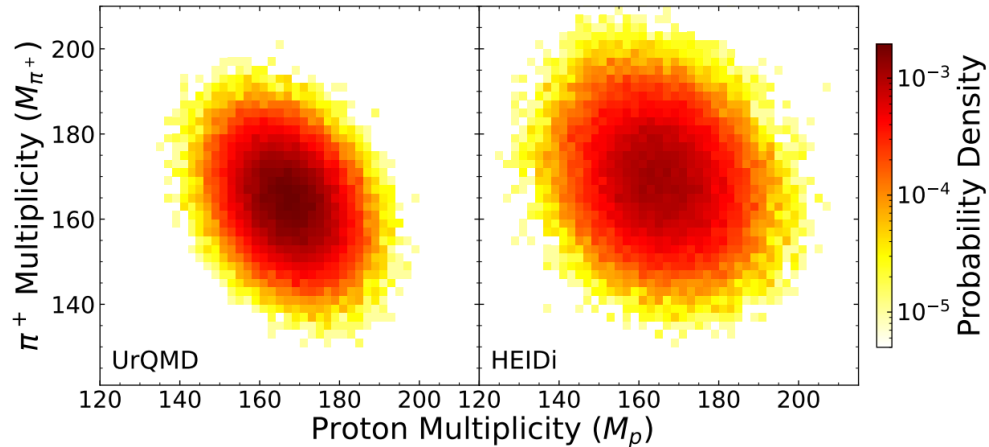


S. B. Cabodevila, A. Kurkela, F. Lindenbauer, Eur.Phys.J.C 85 (2025) 11, 1304

D. Stewart, J. Putschke, Phys.Rev.C 113 (2026) 1, 014904

# ML/AI talks in SQM2026

## Generative diffusion model



- HEIDI (Heavy-Ion Events through Intelligent Diffusion)
- Trained with UrQMD
- Generates full final hadron lists directly

M. O. Kuttan, K. Zhou, J. Steinheimer, H. Stoecker, Phys.Rev.C 112 (2025) 5, 5; Phys. Rev. C 112, 054907; Also see Kuttan's flash talk at QM2025

See also, J-A Sun, L. Yan, C. Gale, S. Jeon, Phys.Rev.C 112 (2025) 5, L051903

Also, see Jing-Zong Zhang, Shuang Guo, Li-Lin Zhu, Lingxiao Wang, Guo-Liang Ma, RIKEN-iTHEMS-Report-25, 2510.06691 [hep-ph]