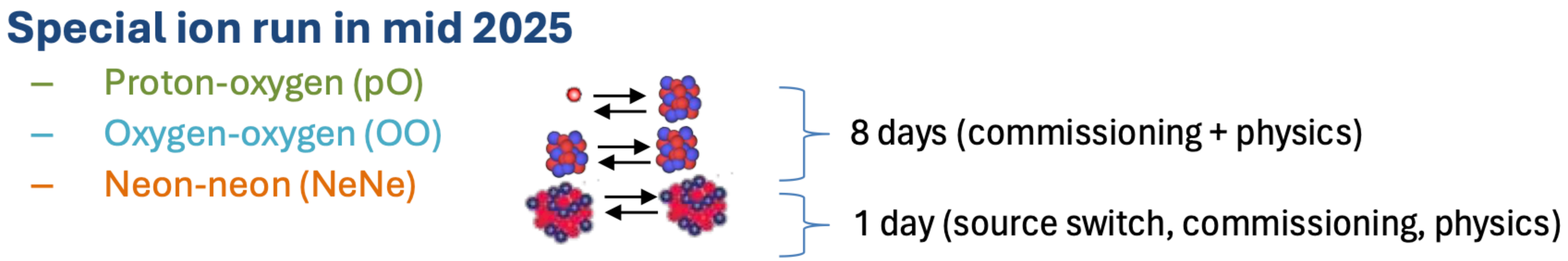
Results from the recent 2025 light ion LHC run by ALICE, ATLAS, CMS and LHCb — Sep 16, 2025

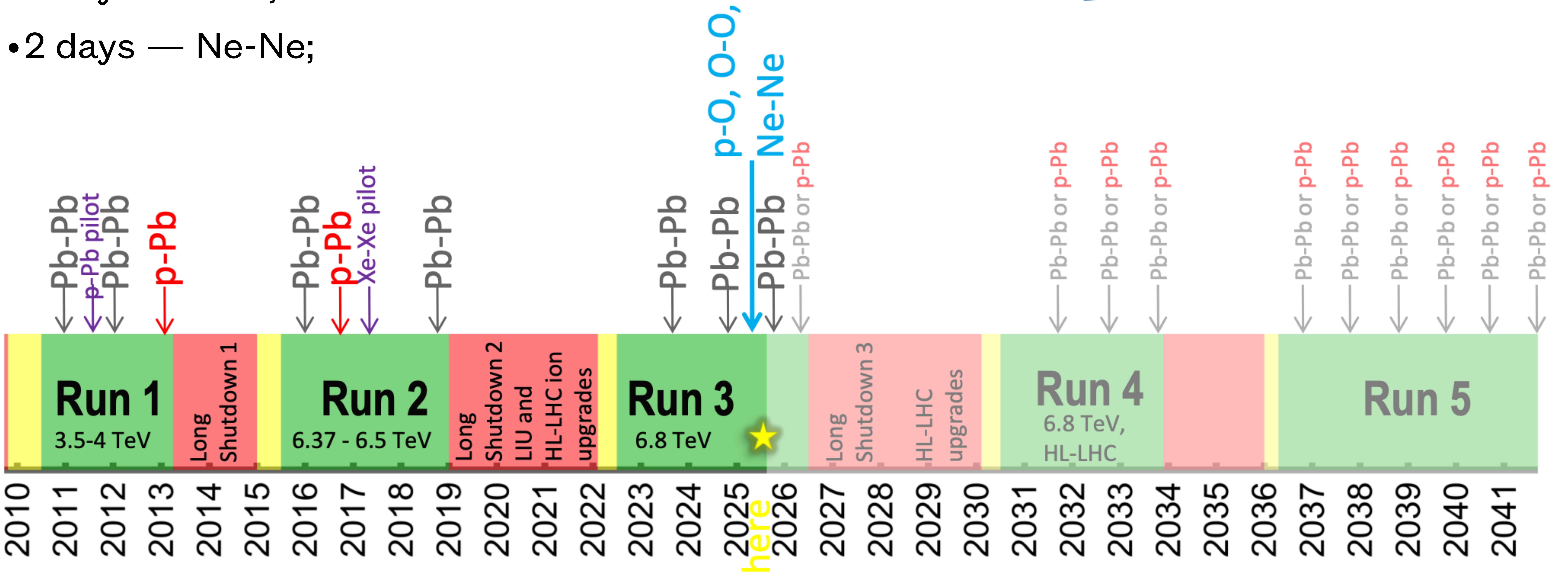
SIMAK SVETLANA

2025 LHC special run: p-O, O-O and Ne-Ne

From 29 June to 9 July:

- 2 days — p-O;
- 2 days — O-O;
- 2 days — Ne-Ne;





Goals and requests for the run

Luminosity targets in nb^{-1}

	p-O	O-O	Ne-Ne
ATLAS	1.5	0.8	0.1
ALICE	5	0.5	0.1
CMS	3	0.8	0.1
LHCb	2	0.5	0.1

(green) - official target

Beam energy:

- p-O: 6.8 TeV
- O-O, Ne-Ne: 5.36 TeV

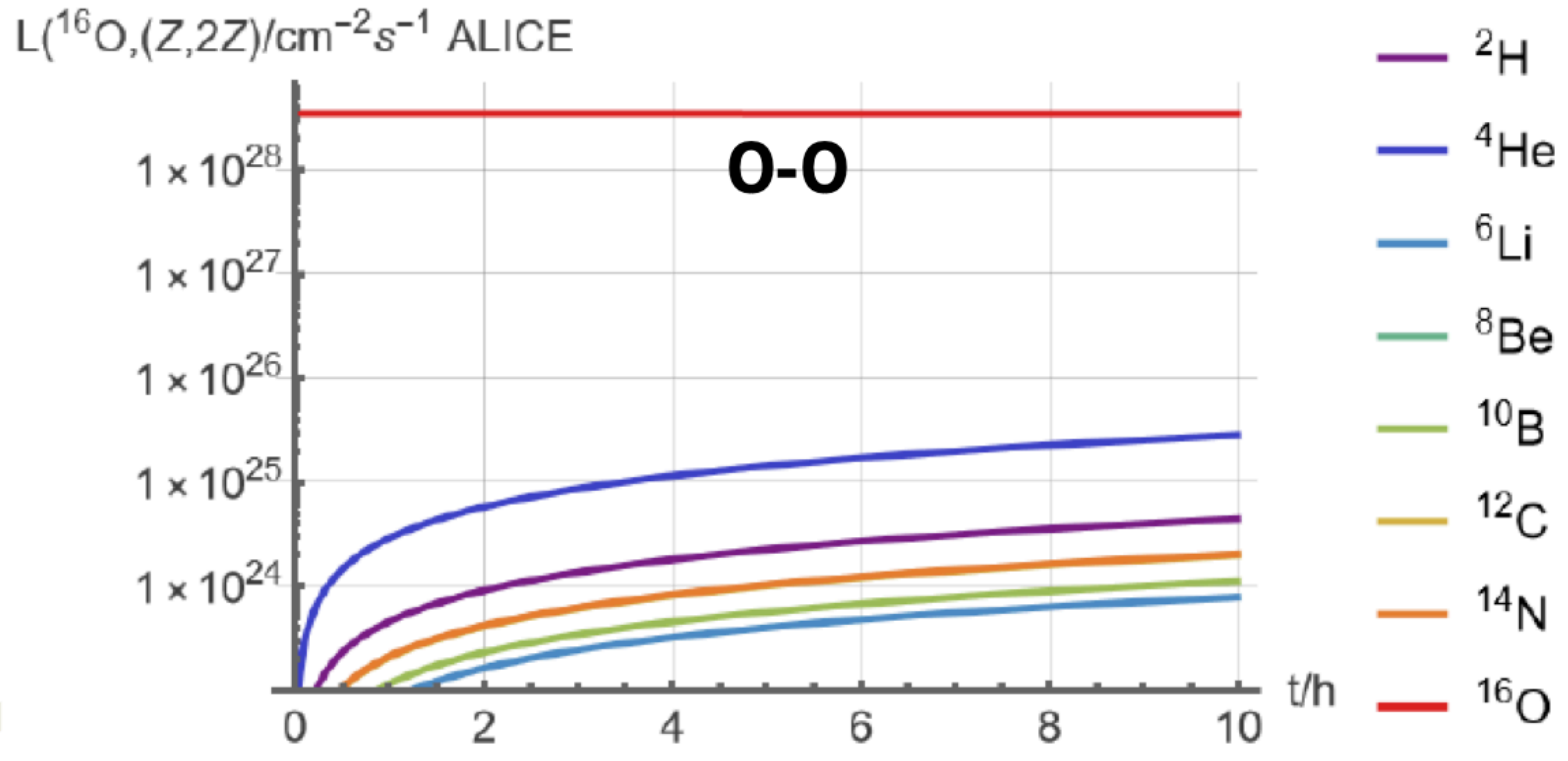
O-O and Ne-Ne beam transmutation

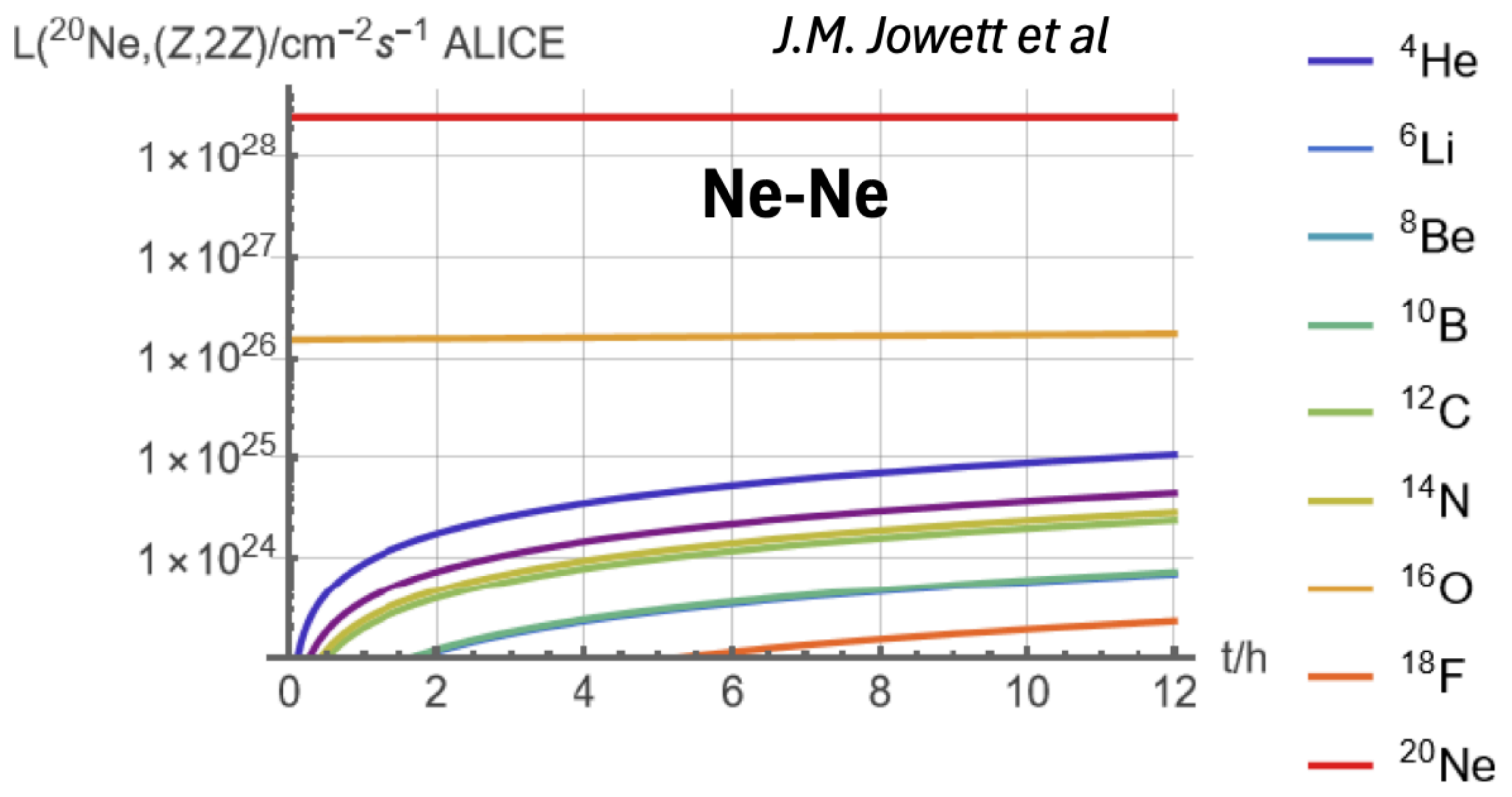
Colliding $^{16}O^{8+}$ also with other ions – “pollution”

– New beam physics effect not seen previously at LHC!

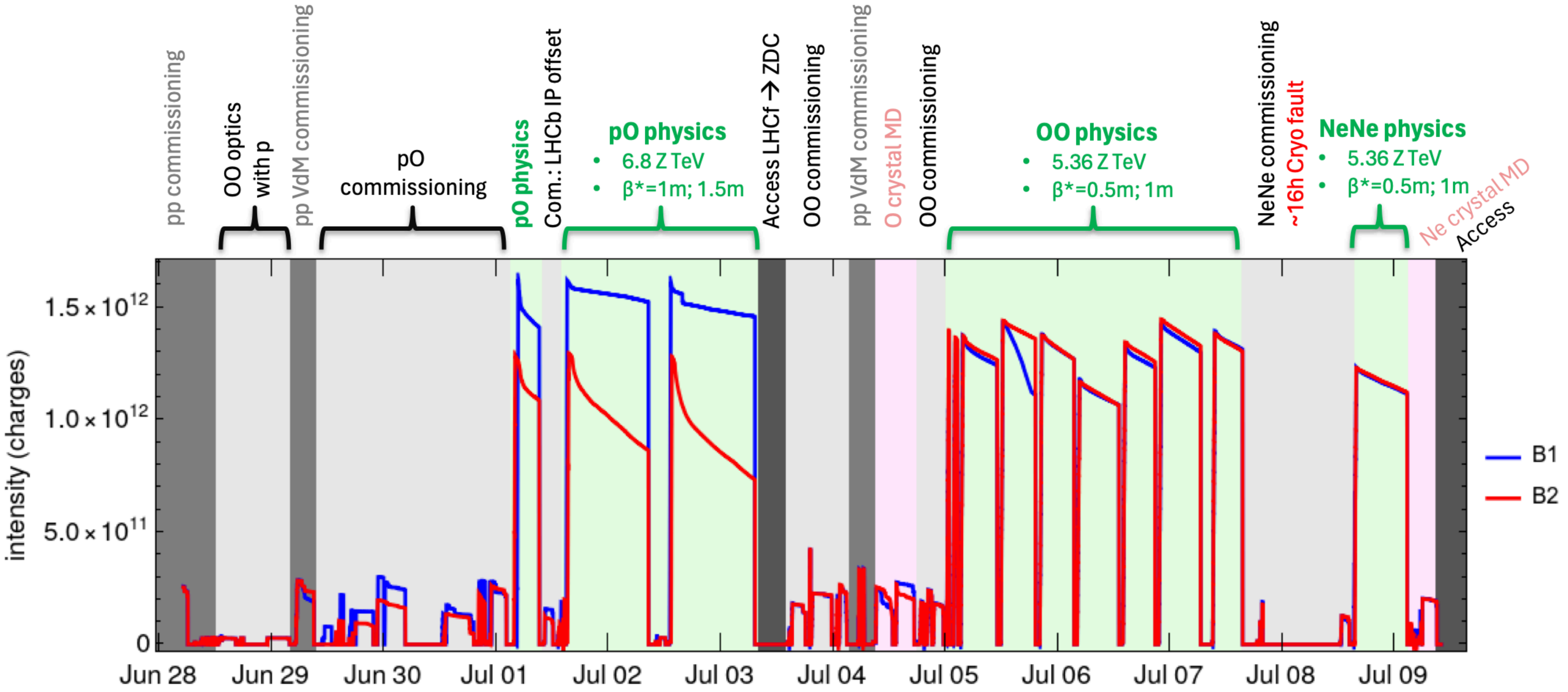
Simulations done to estimate contamination (J. Jowett et al.):

– From simulation, expect <<1% of total integrated luminosity from O-[other ion] or Ne-[other ion]





Overview of the Run



Luminosity

1/nb	p-O			O-O			Ne-Ne		
	target	delivered	ratio	target	delivered	ratio	target	delivered	ratio
ATLAS/ LHCf	1.5	1.8	1.2	-	-	-	-	-	-
ATLAS	-	6.9	-	0.8	8.2	10.3	0.1	1.0	10
ALICE	5	6.9	1.6	0.5	5.15	10.3	0.1	0.91	9.1
CMS	3	7.85	16	0.8	9.4	11.8	0.1	0.91	9.1
LHCb	2	33.1	16.6	0.5	5.75	11.5	0.1	0.61	6.1

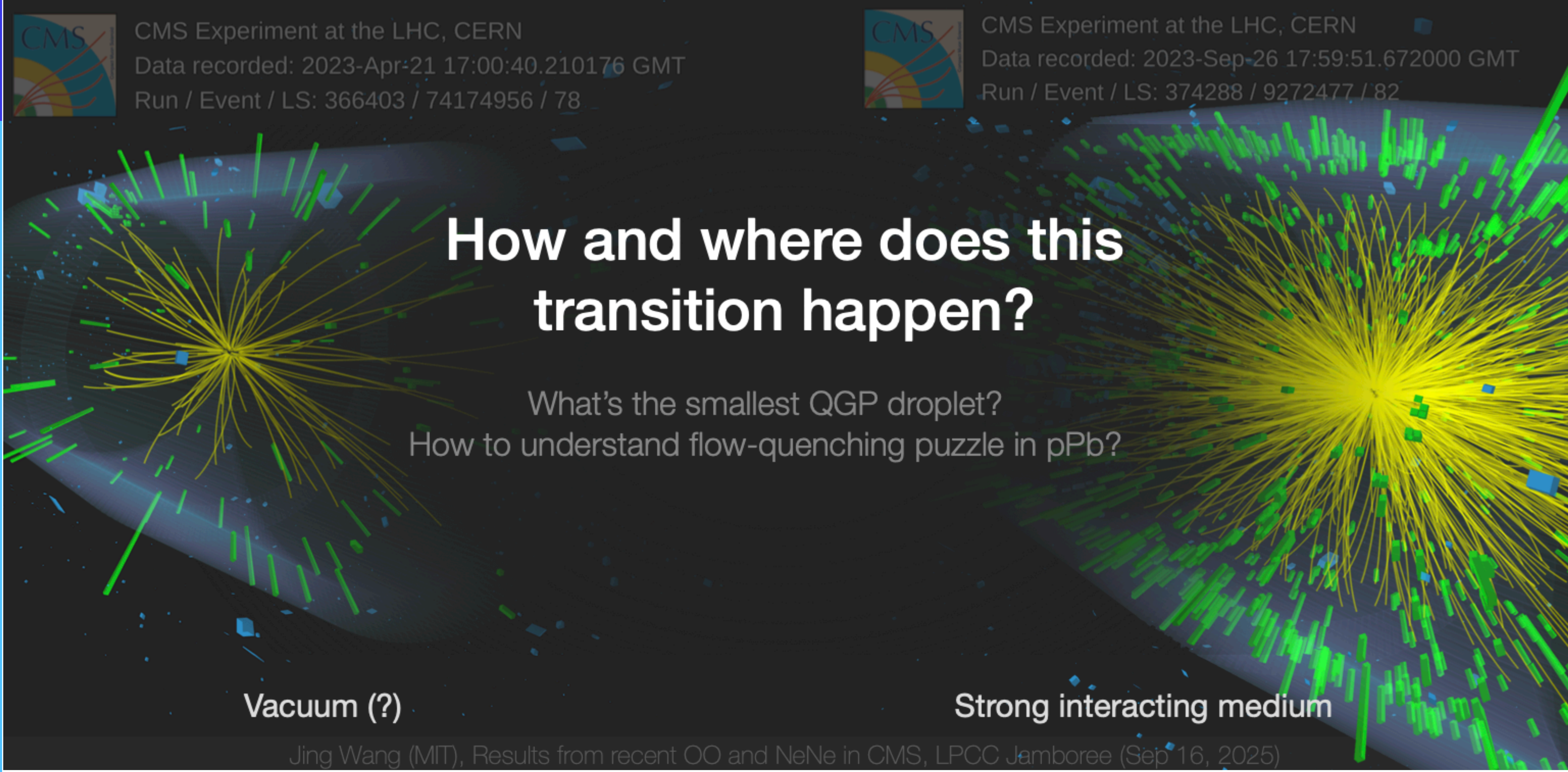
Summary 1/5

- First LHC runs with oxygen and neon done summer 2025
- 9 days assigned in total for p-O, O-O, Ne-Ne (commissioning + physics);
- Never switched particle species so quickly in LHC before;
- All luminosity targets met and most were exceeded by large factors;
- Now looking forward to seeing the physics results from these data sets!

From my LMC talk 18/6/2025
"Possibly, this run holds the record ratio of (preparation work) / nb^{-1}"

Update: It also has an impressive ratio of champagne / nb^{-1}

What About Less Extreme Conditions

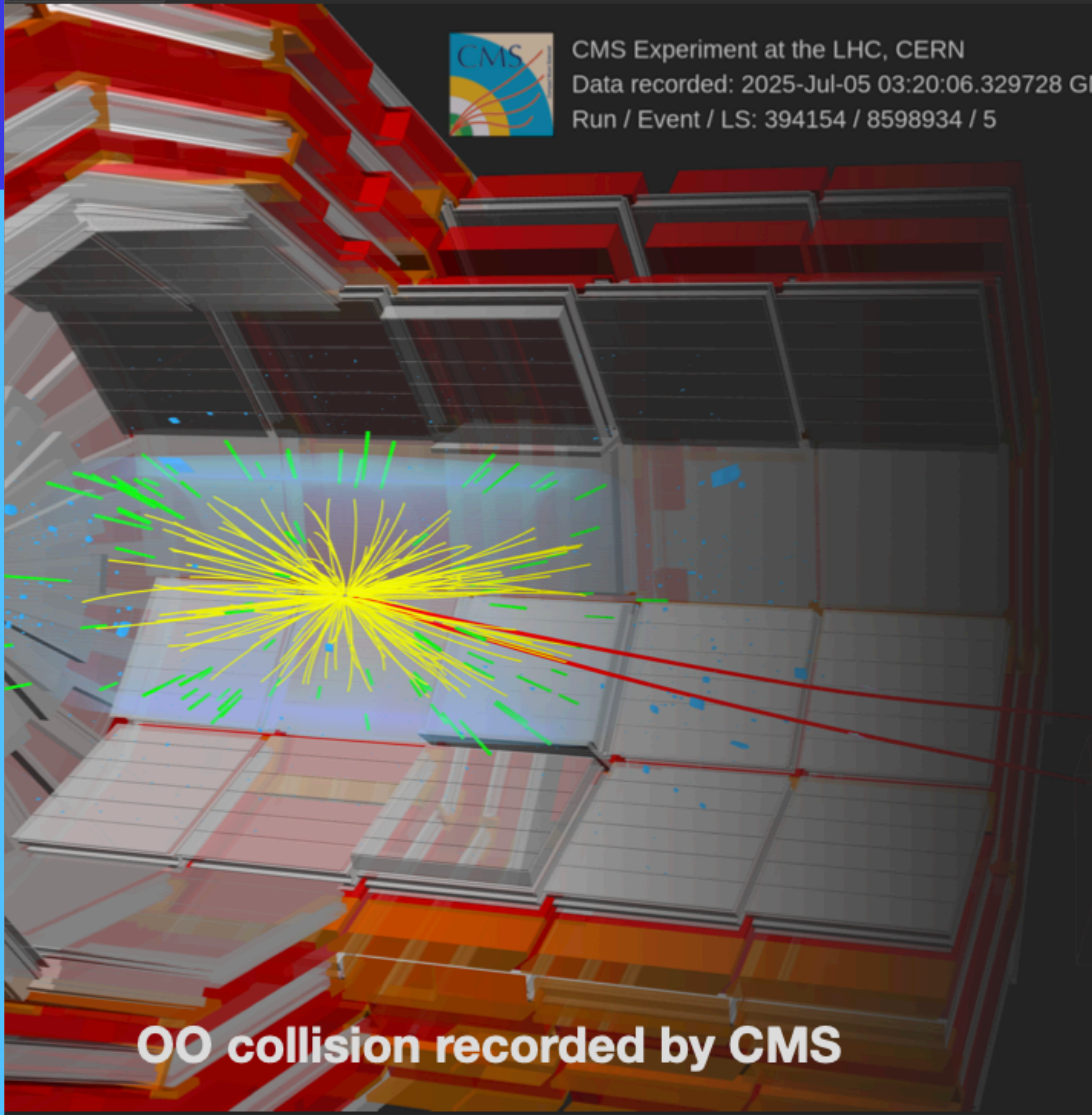


How and where does this transition happen?

What's the smallest QGP droplet?

How to understand flow-quenching puzzle in pPb?

Light Ions Will OO or NeNe Generate QGP?

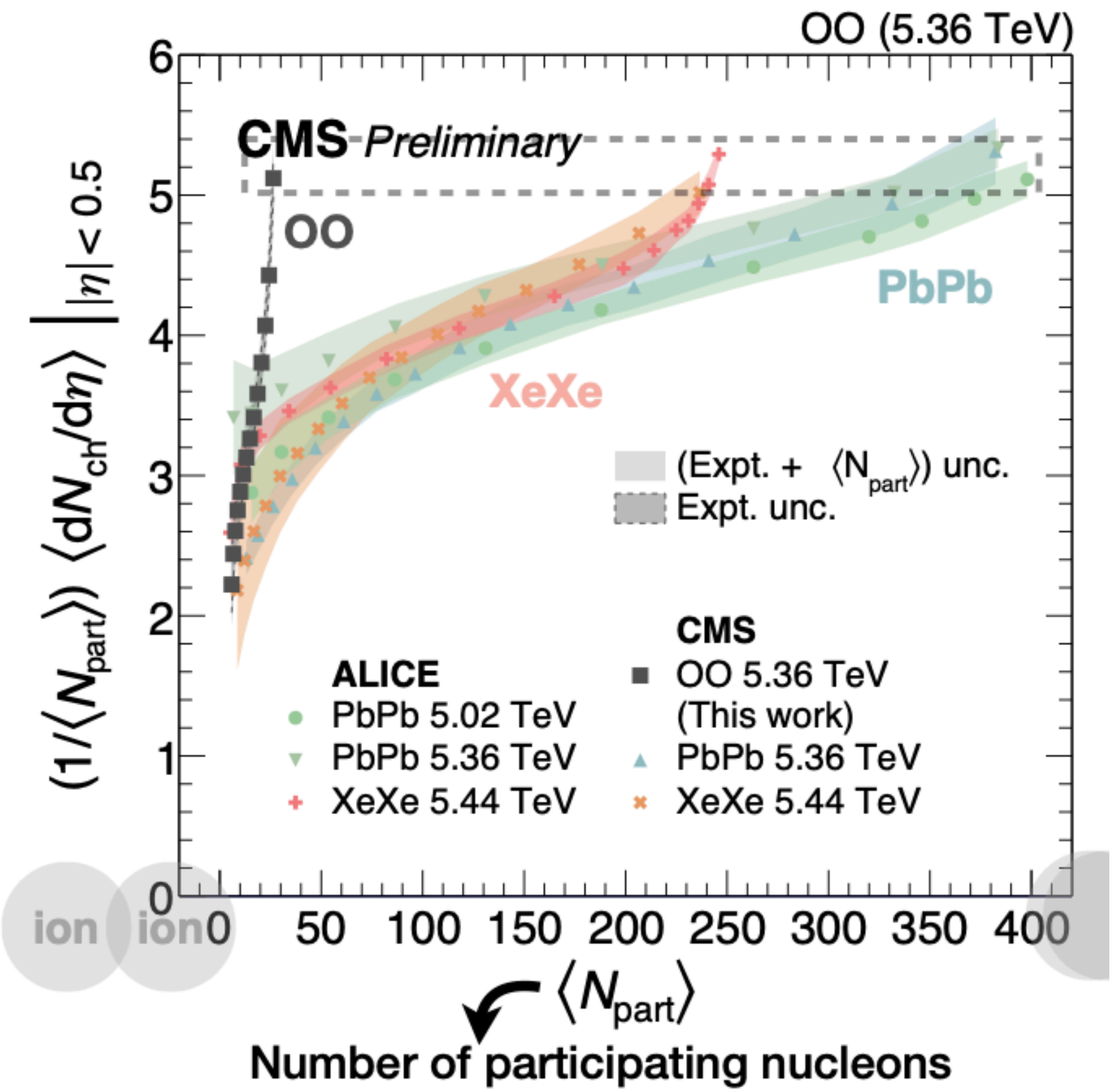


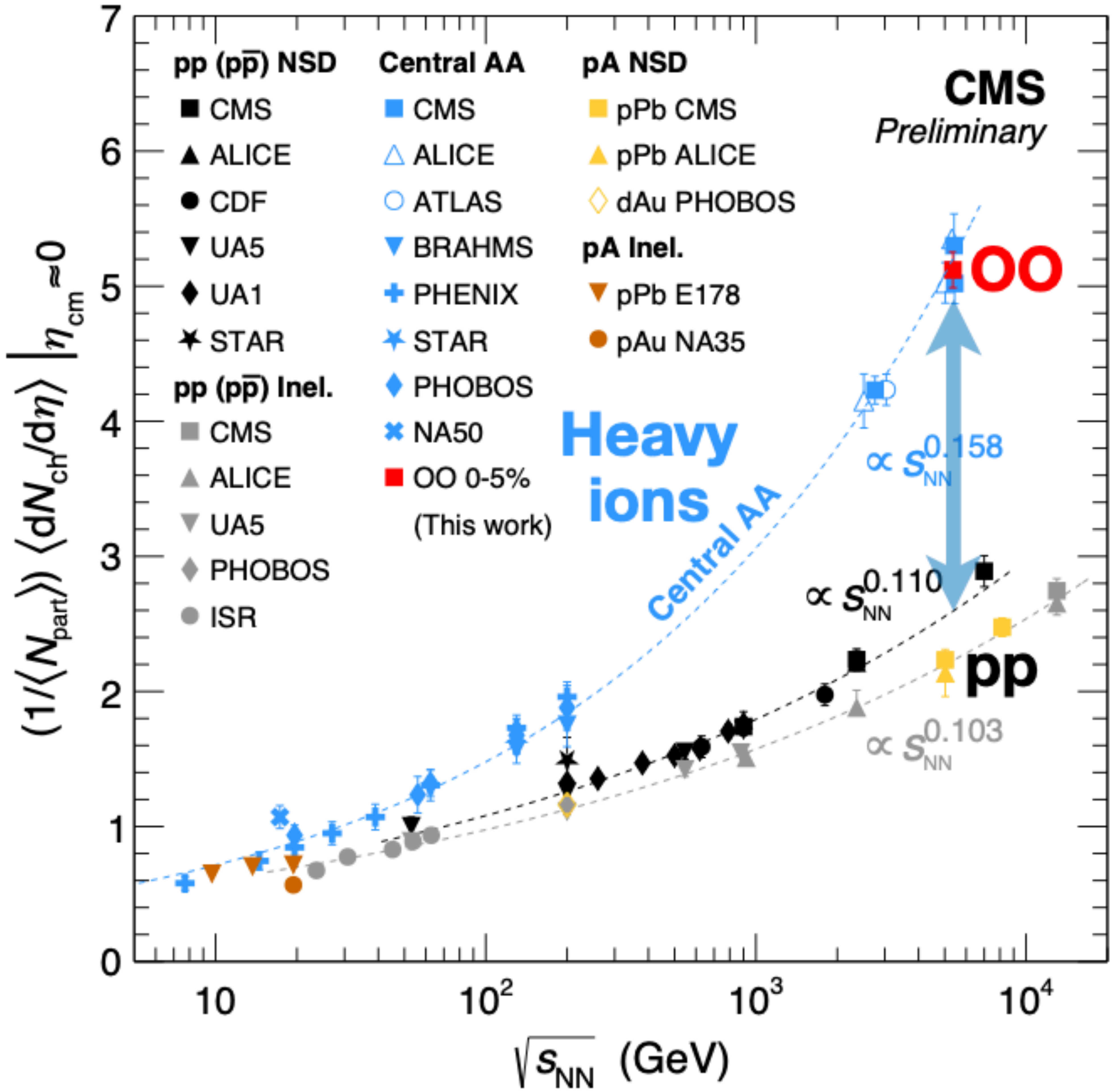
^{16}O and ^{20}Ne collisions

- Enable collision size scan along with pp, ^{129}XeXe and ^{208}PbPb collisions
  - Larger transverse size and more comparable longitudinal structure than pPb
  - Mitigate event selection bias in peripheral HI

Toward understanding of minimal conditions for QGP

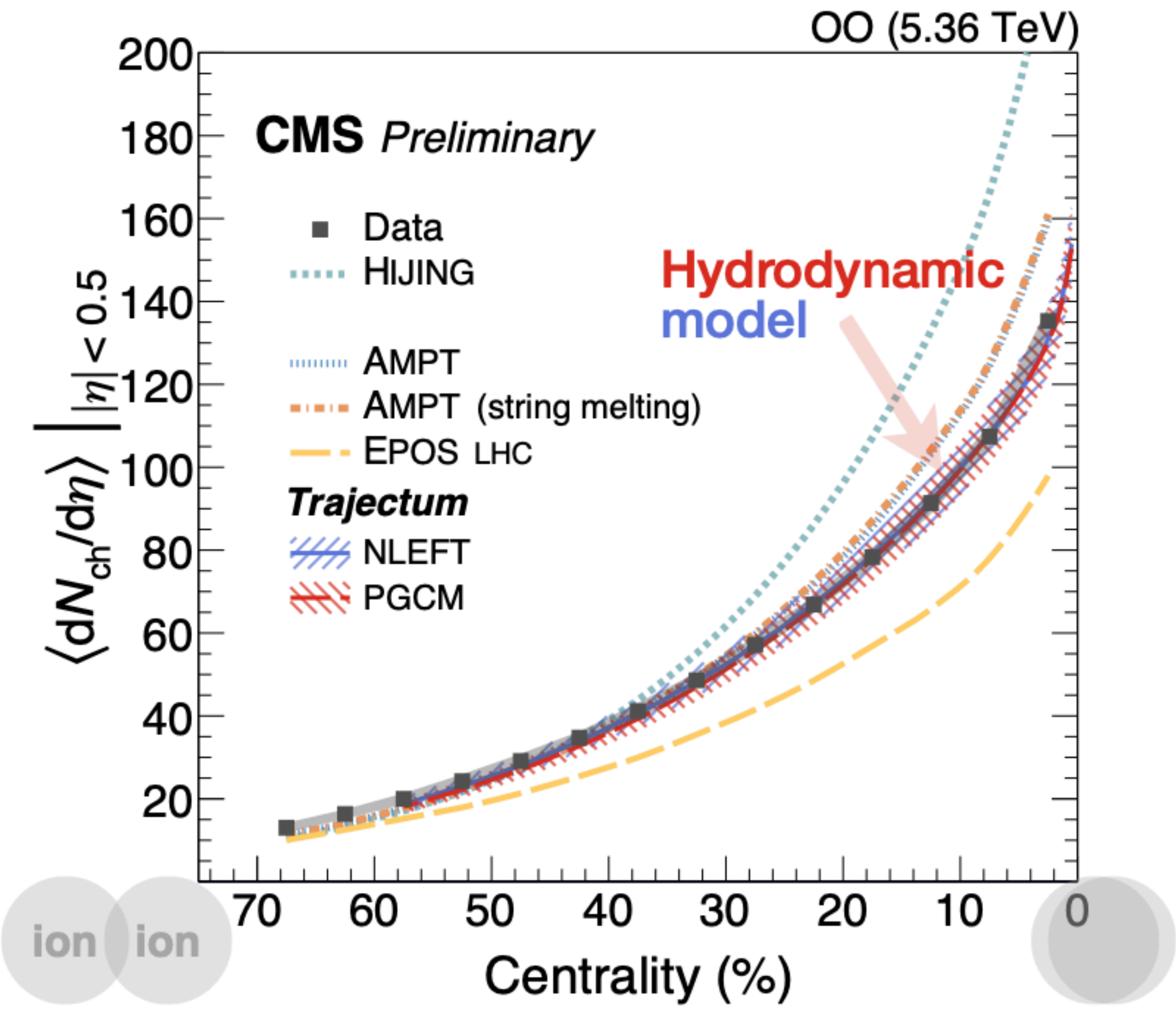
First results





Phenomenology Hydrodynamics

CMS-PAS-HIN-25-010



- Hydrodynamic model only tuned by heavy ion collisions **predicts** mid-rapidity data in OO

PRL 135 (2025) 012302

CMS

ALICE

ATLAS

LHCb

Collective flow v_2

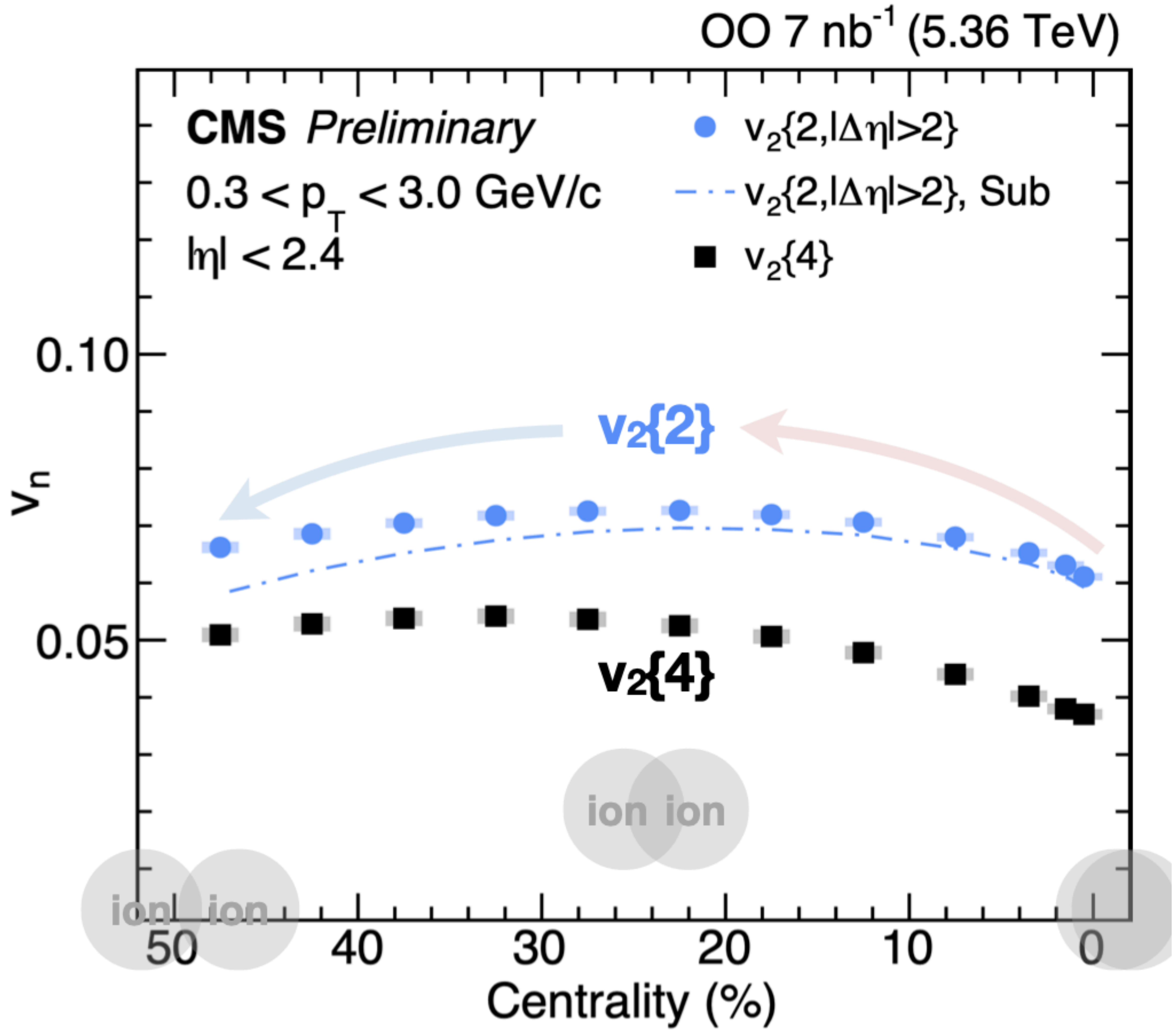
Final-state particle anisotropy in ϕ

$$\frac{dN}{d\phi} \propto 1 + 2v_n \cos 2(\phi - \Psi_2) + \dots$$

Existence of QGP → **non-zero v_2**

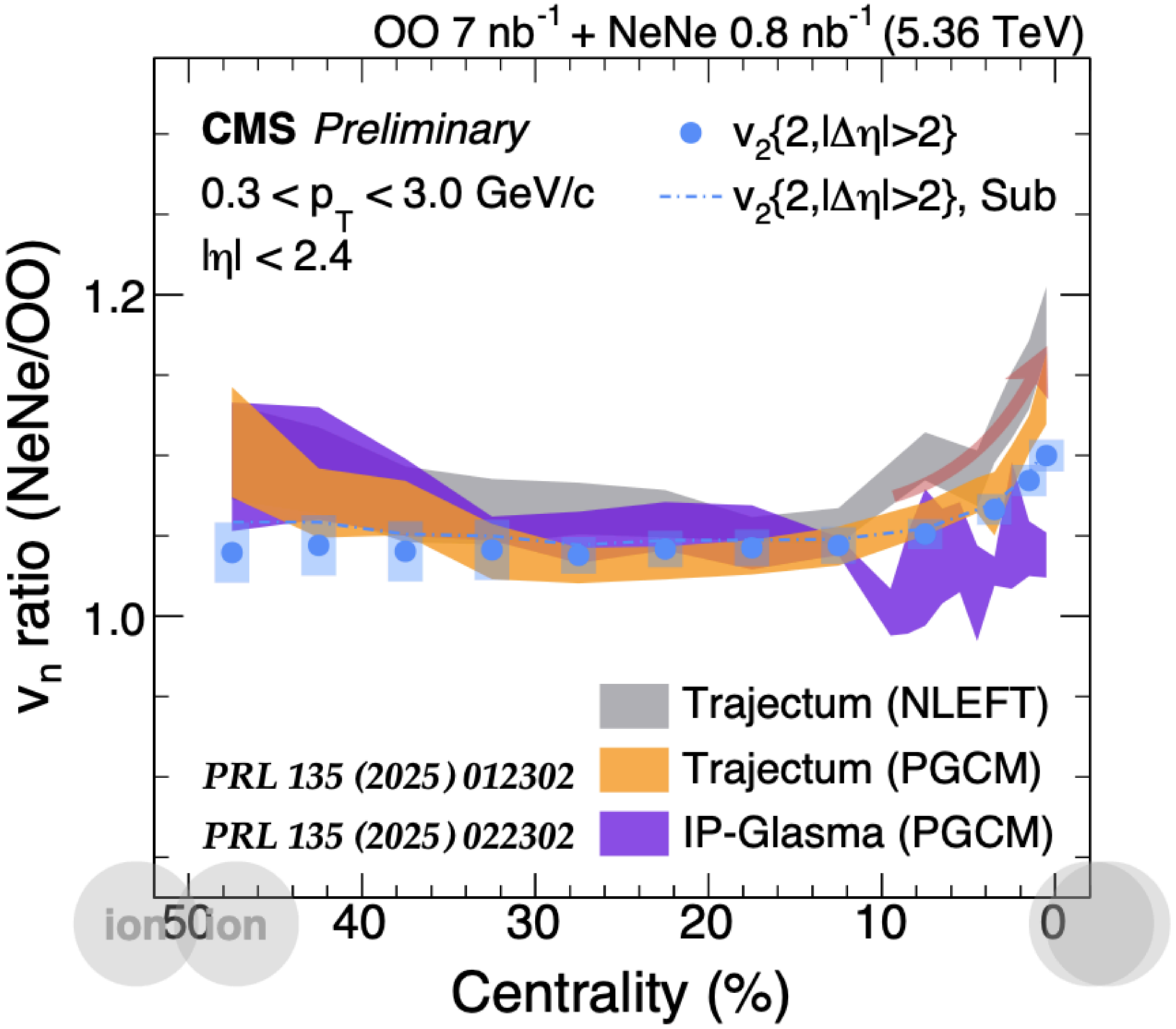
- Non-zero v_2 → Collective motion signal
  for 2-particle correlation $v_2\{2\}$ and 4-particle correlation $v_2\{4\}$ which largely suppresses non-flow effects
- Dependence of centrality follows the expectation of **hydrodynamics**
  - Increase to semi-central events
    - More anisotropic initial geometry
  - Decrease to more peripheral events
    - Smaller and diluter medium to flow
    - Higher viscosity

CMS-PAS-HIN-25-009



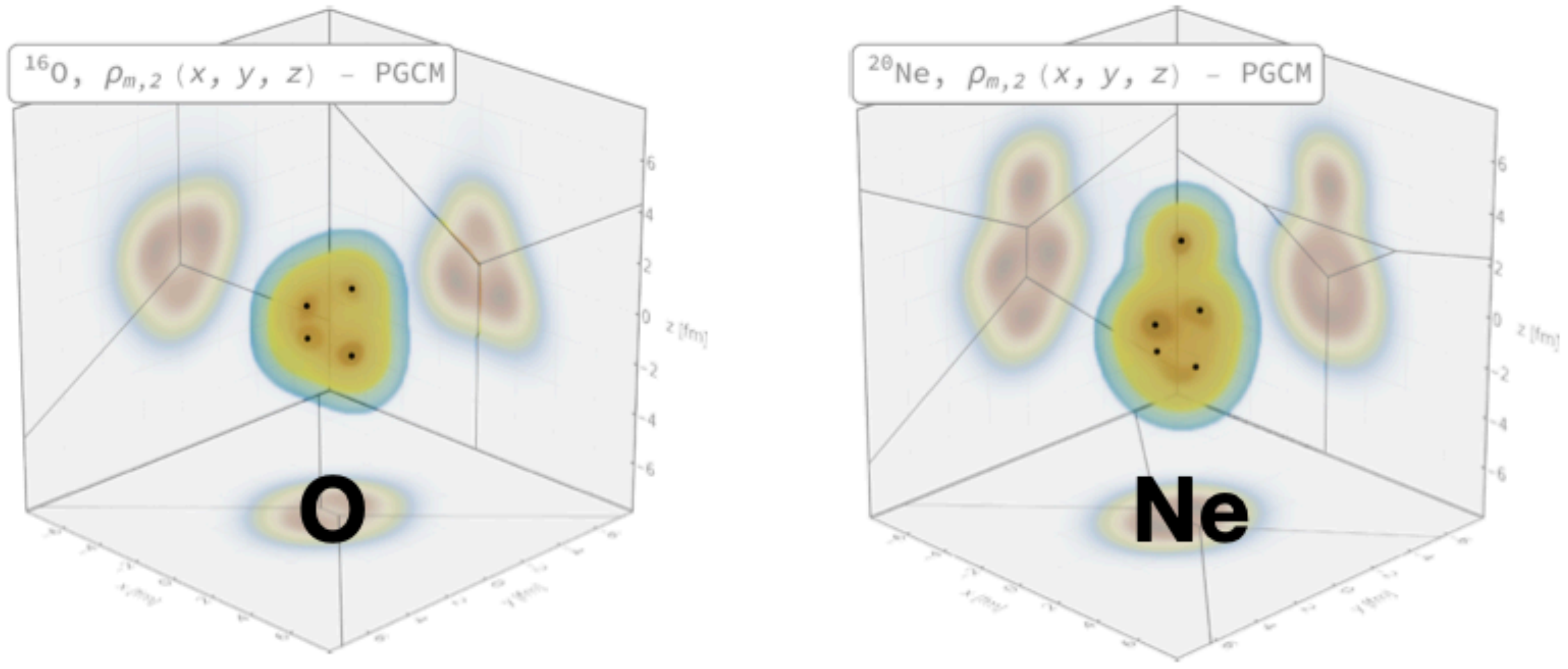
Nuclear Shape Imaging

CMS-PAS-HIN-25-009



Bowling shape of Ne enhances v_2 ratio in central events, predicted by hydro models

- Theoretical uncertainties from medium evolution are largely canceled in ratio due to comparable size of O and Ne
- Probed Ne deformation



PRL 135 (2025) 012302

CMS

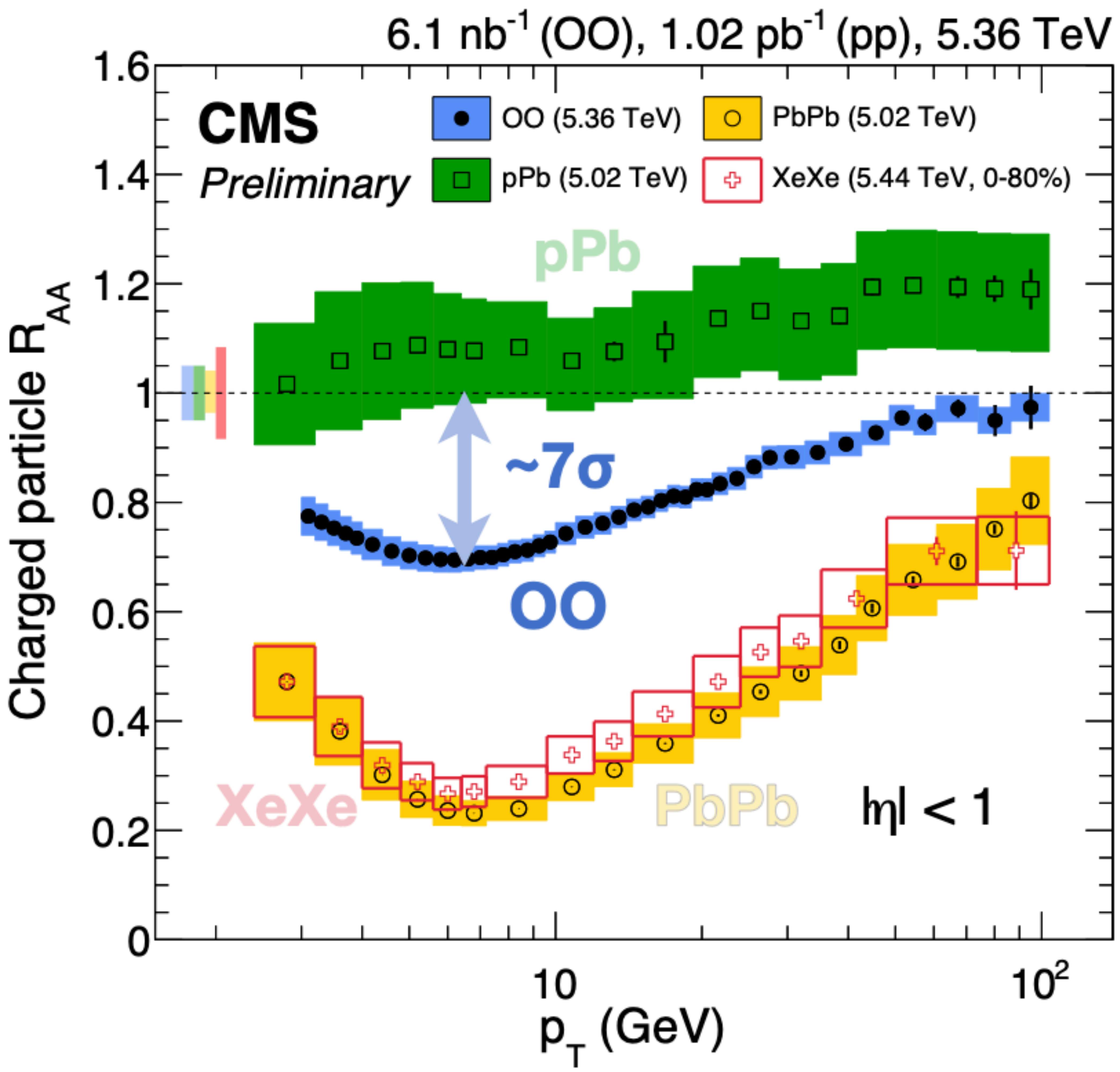
ALICE

ATLAS

LHCb

Quenching parton energy loss in medium

CMS-PAS-HIN-25-008



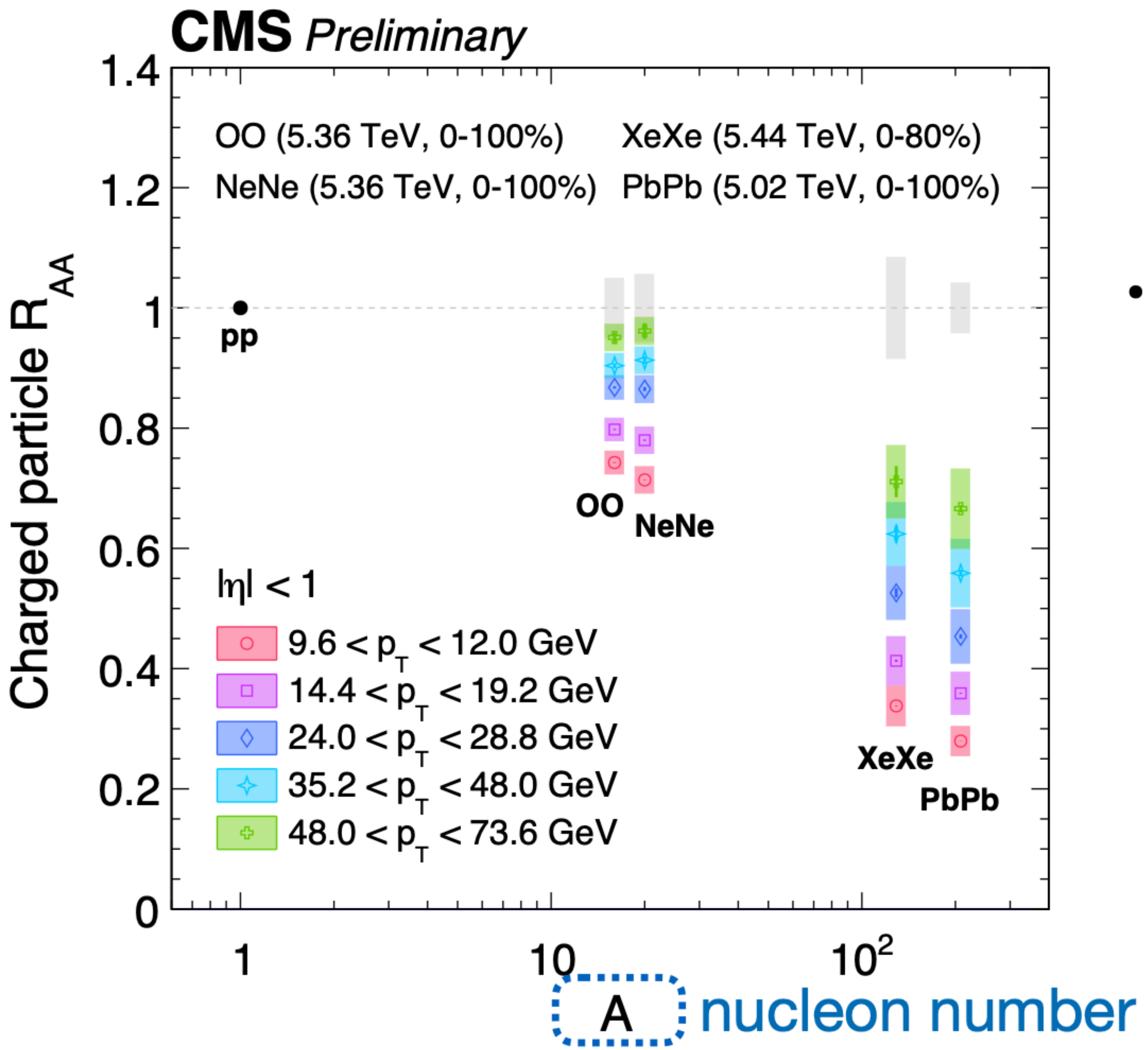
CMS **observes suppression** in OO

R_{AA} ~7σ smaller than 1

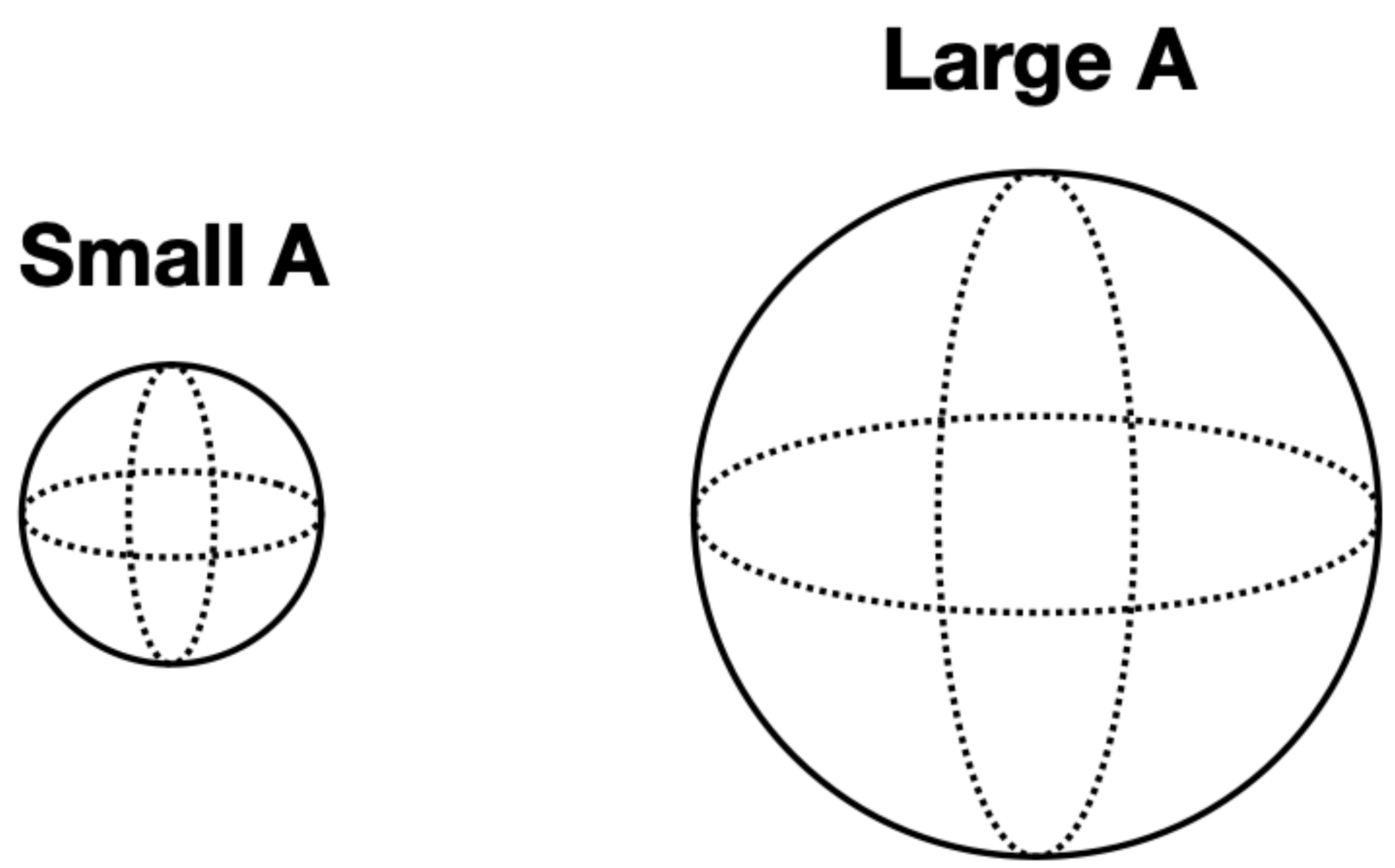
- Measured up to p_T 100 GeV/c
- The smallest collision system in which suppression is observed *up to now*

Test Knowledge of Quenching Across A

CMS-PAS-HIN-25-014



- Models can be tested across a wide A range from 16 to 208 simultaneously

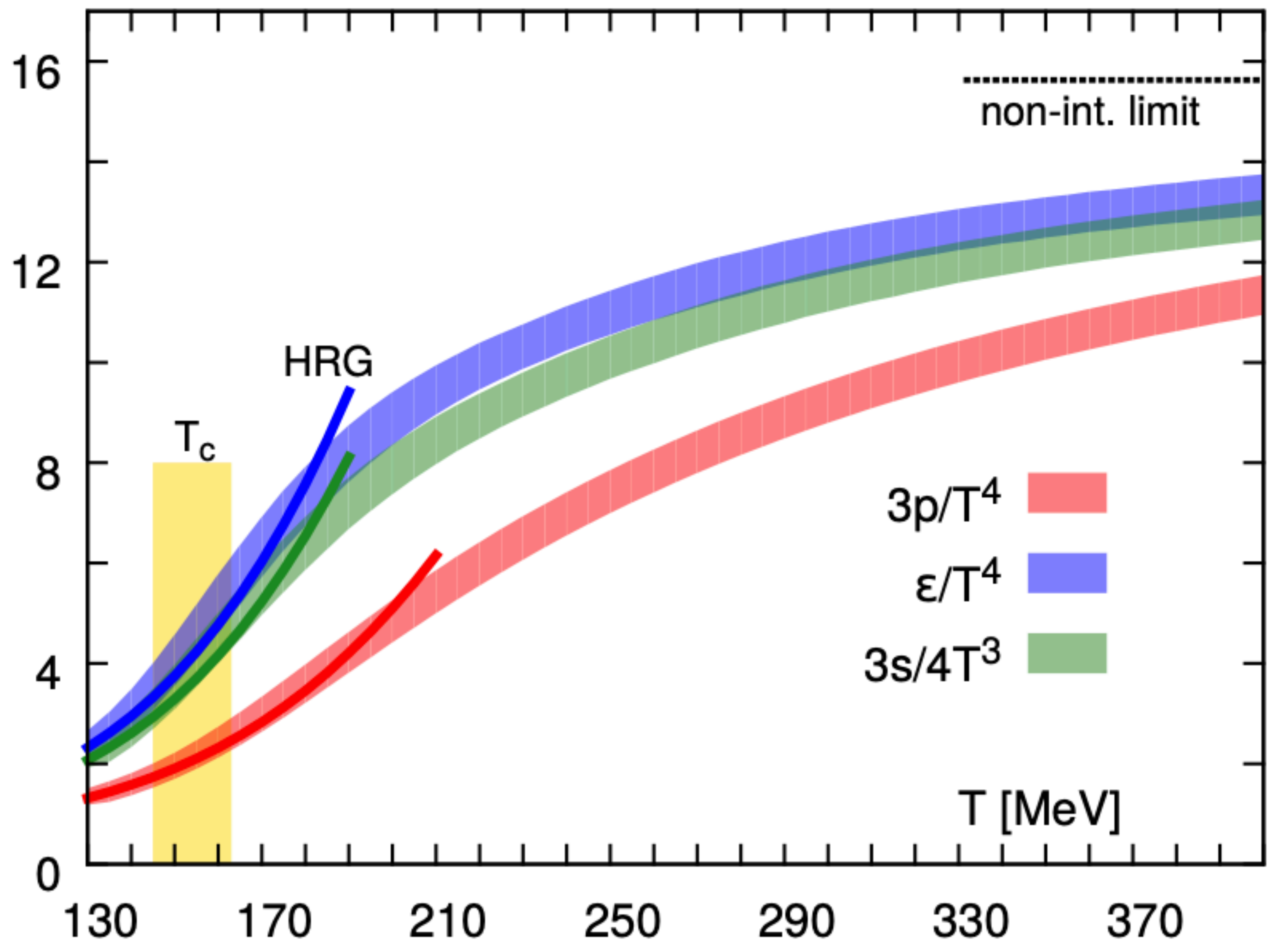


Summary 2/5

- Hydrodynamic models predict data;
- The smallest collision system where suppression is observed up to now;
- Central OO reaches multiplicity per participant nucleon comparable to heavy ions;
- Initial Ne nuclear shape probed by final-state particle correlation;

Emergence of the quark-gluon plasma

Hot QCD, PRD 90 (2014) 094503

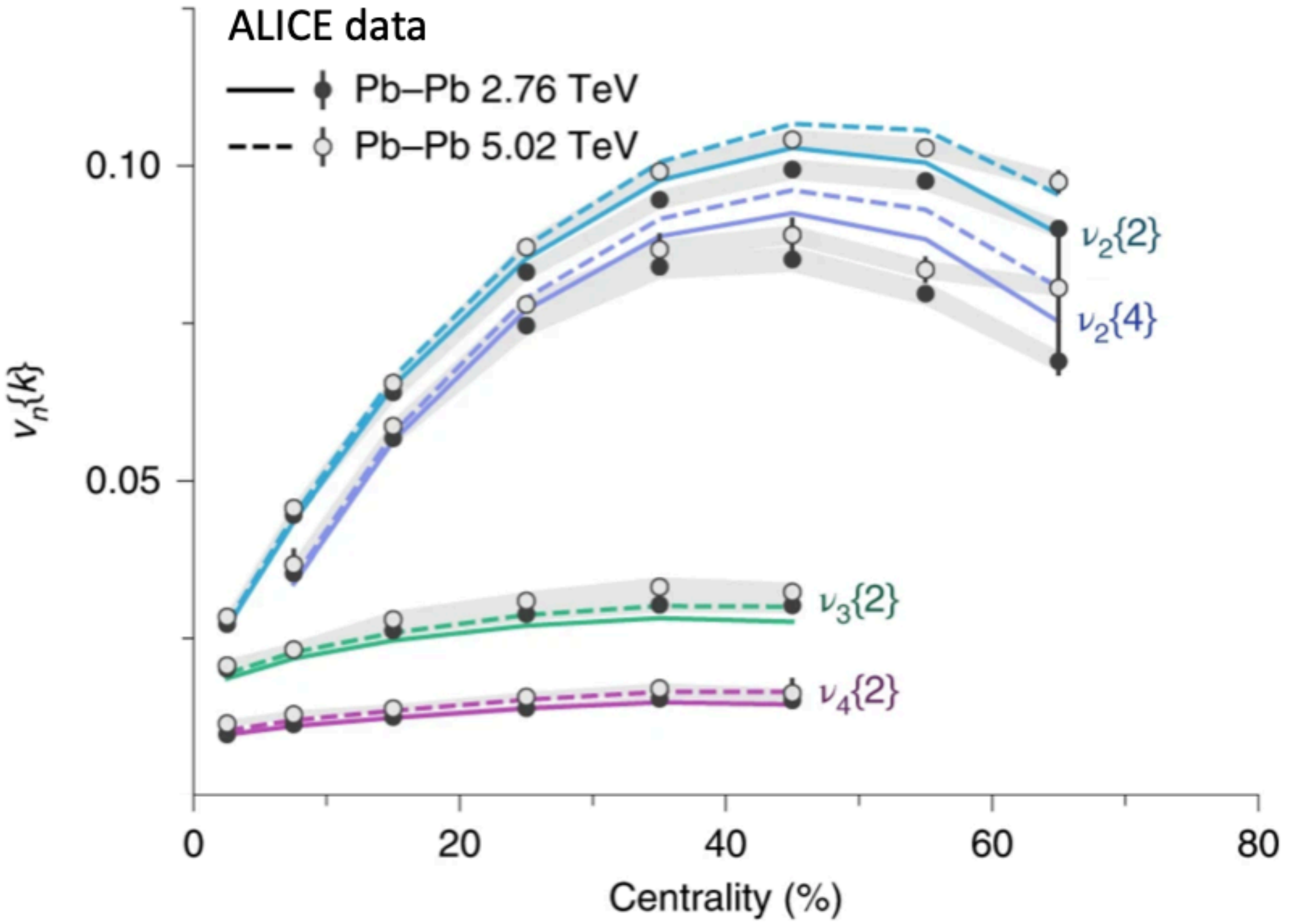


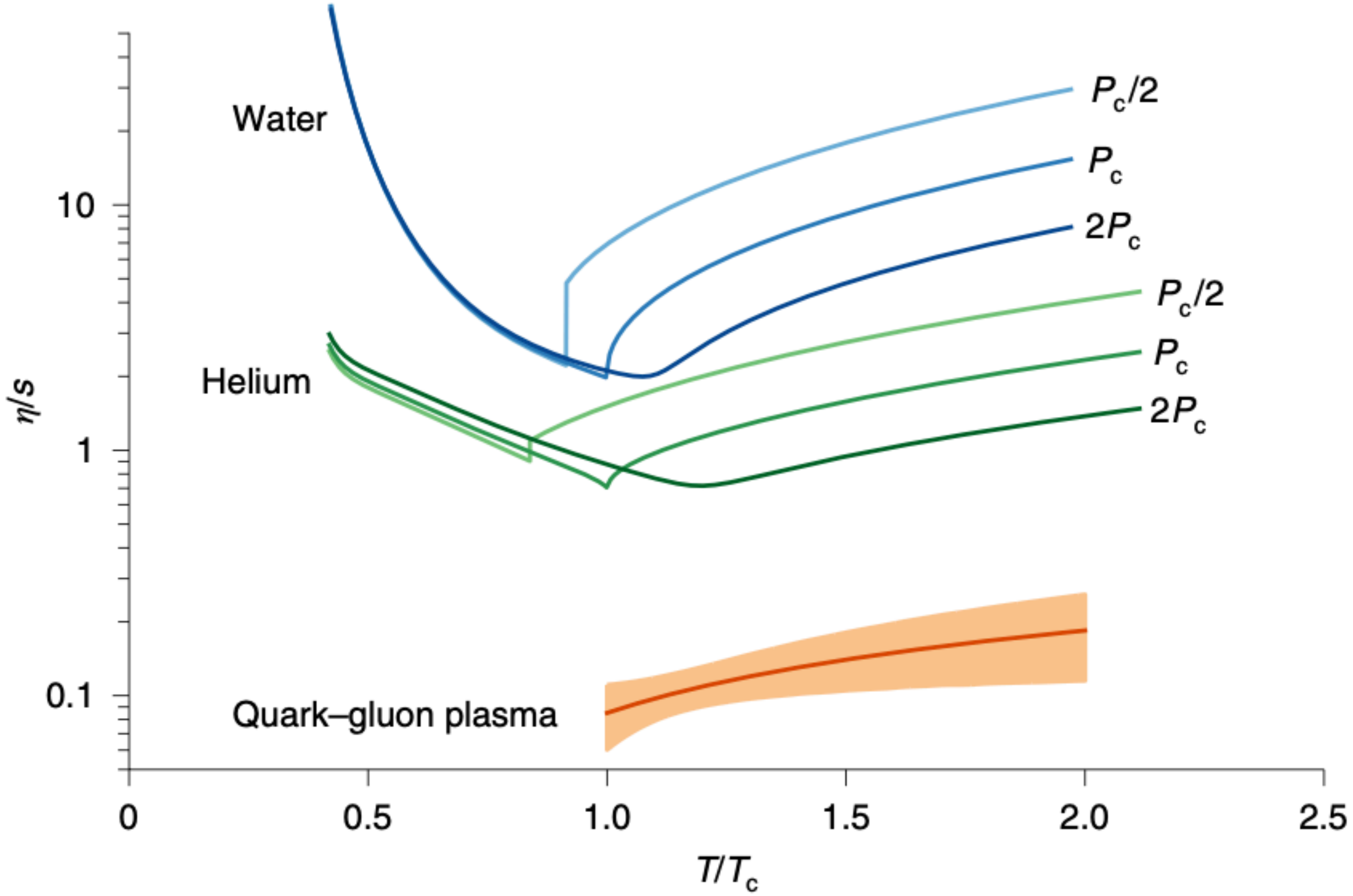
Lattice QCD predicts rapid change in thermodynamic properties at critical temperature $T_c \approx 155$ MeV

Formation of QGP — quarks and gluons are no longer confined

QGP in Pb+Pb

Nature Physics 15 (2019) 1113





Measured anisotropic expansion in Pb-Pb described by hydrodynamics for produced hadrons

✓Achieved with QGP equation of state and small but finite QGP viscosities

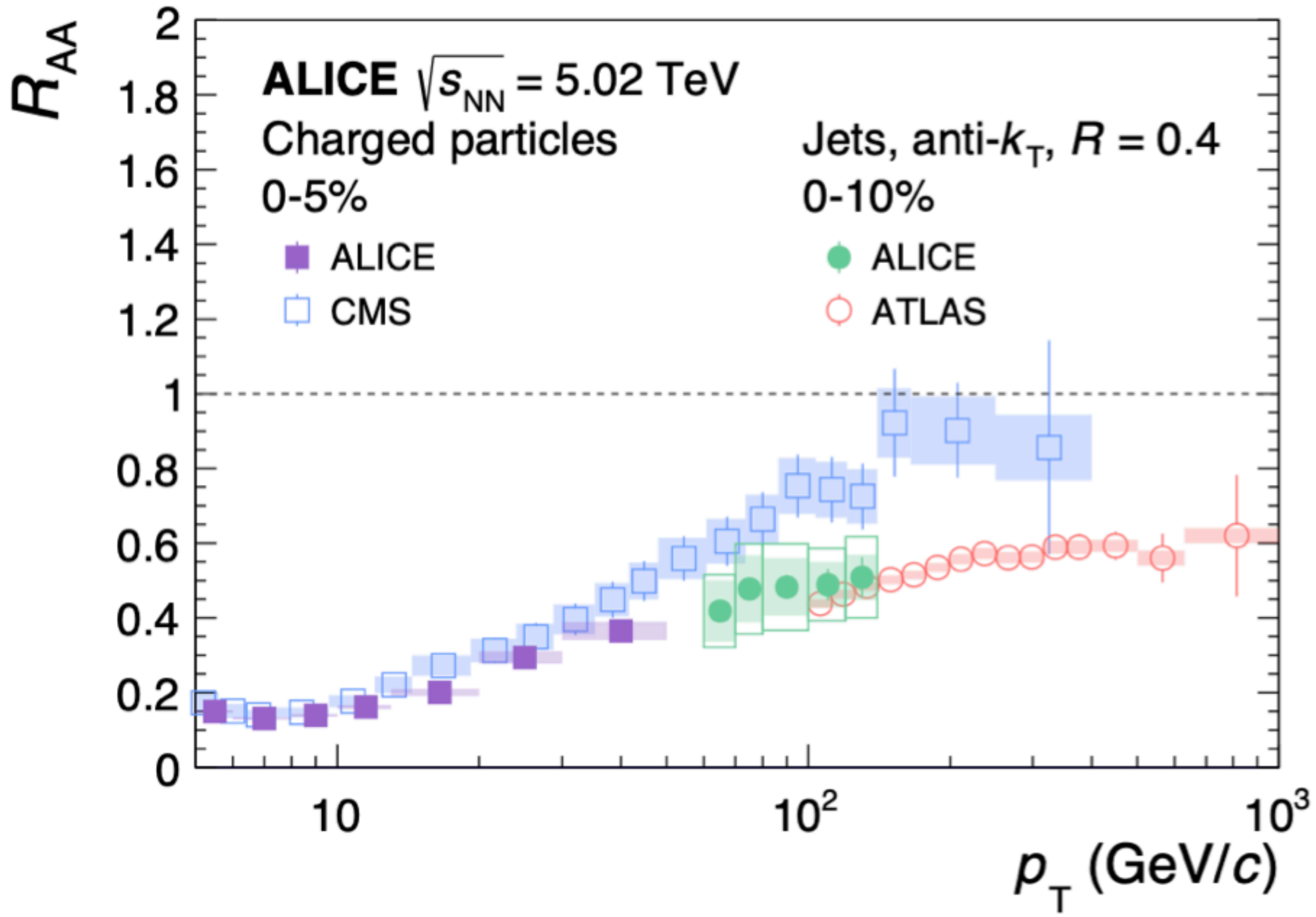
CMS

ALICE

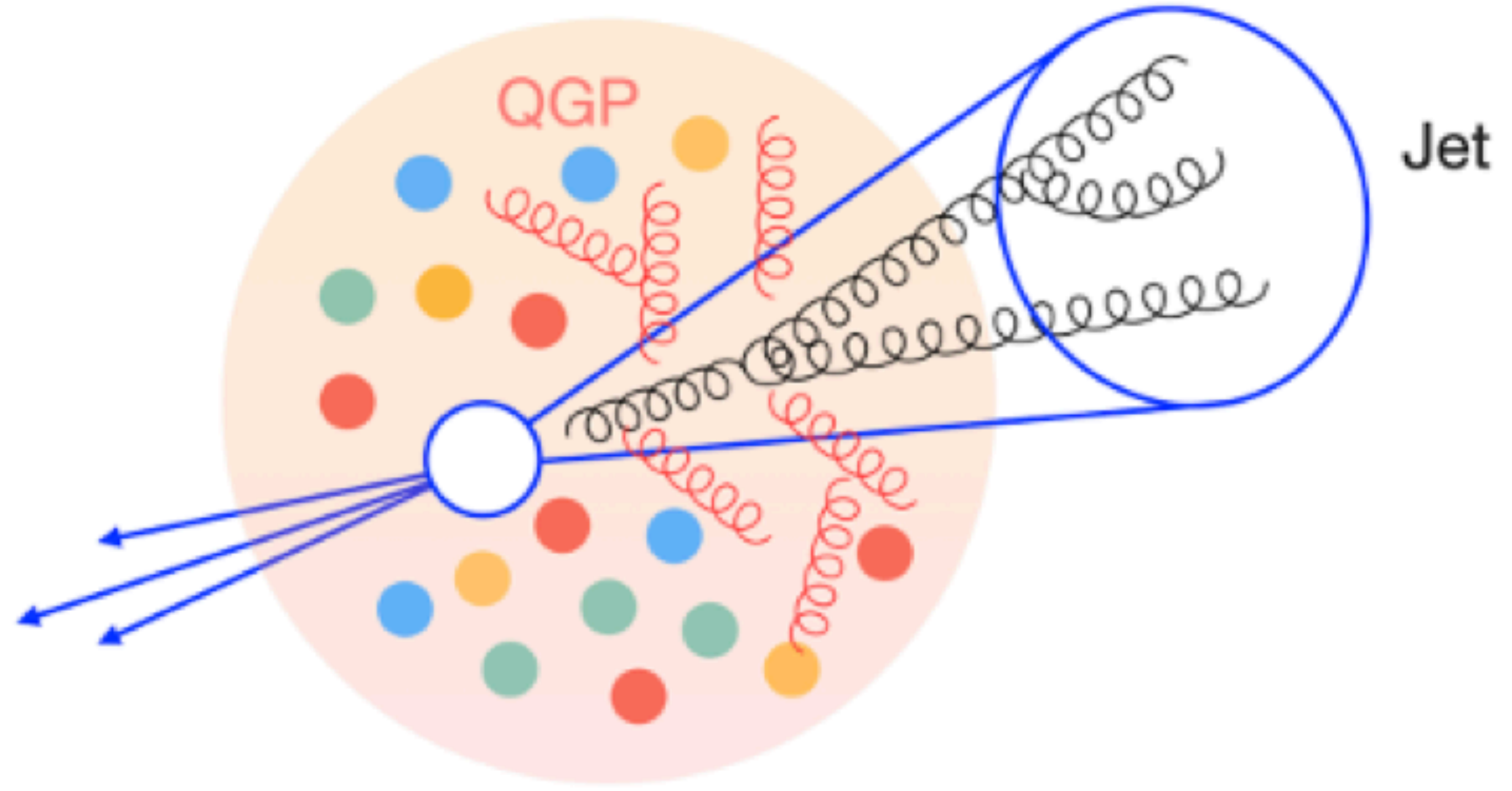
ATLAS

LHCb

Jet interactions with the QGP



Eur. Phys. J. C 84 (2024) 813



Measured anisotropic expansion in Pb-Pb described by hydrodynamics for produced hadrons

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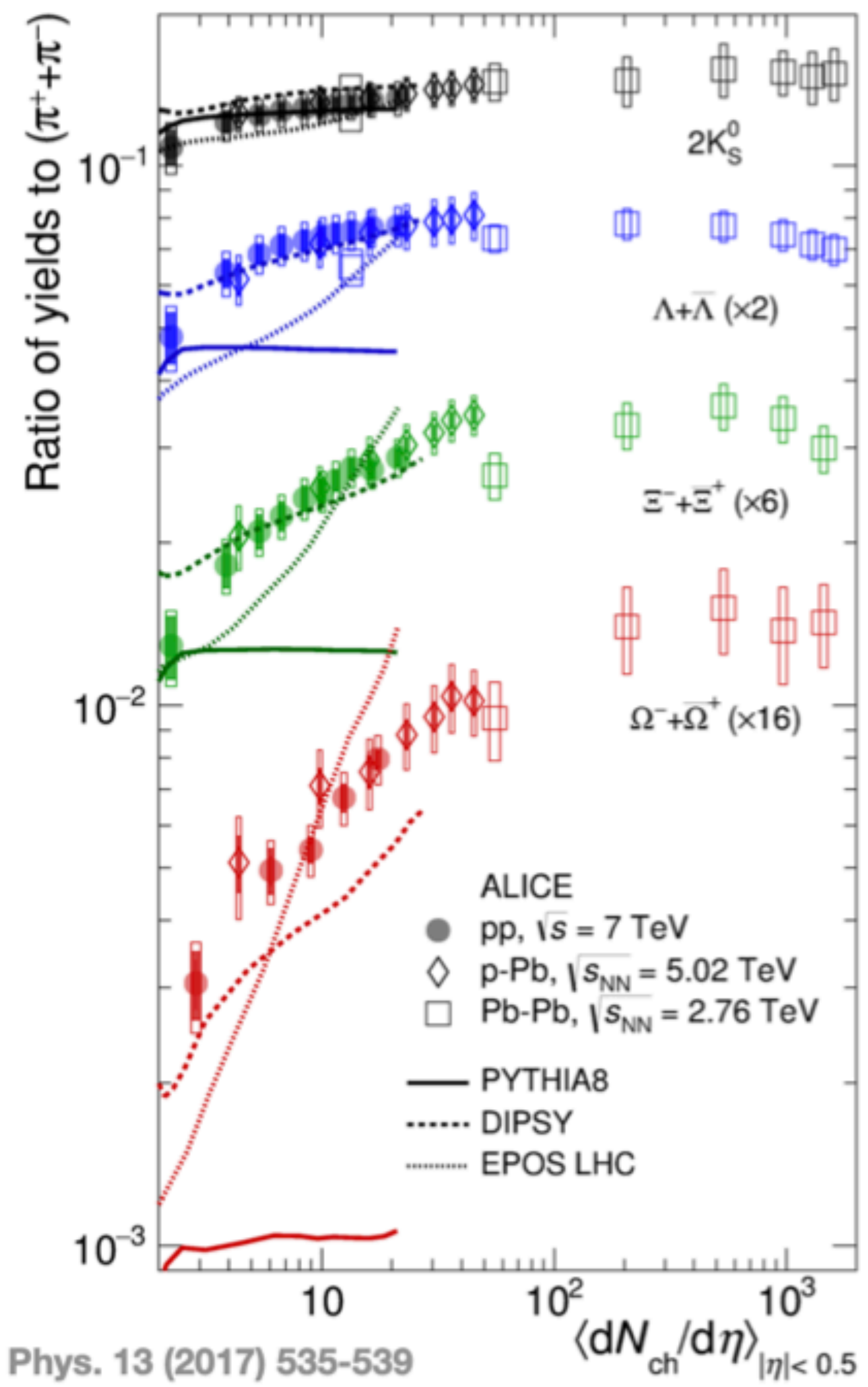
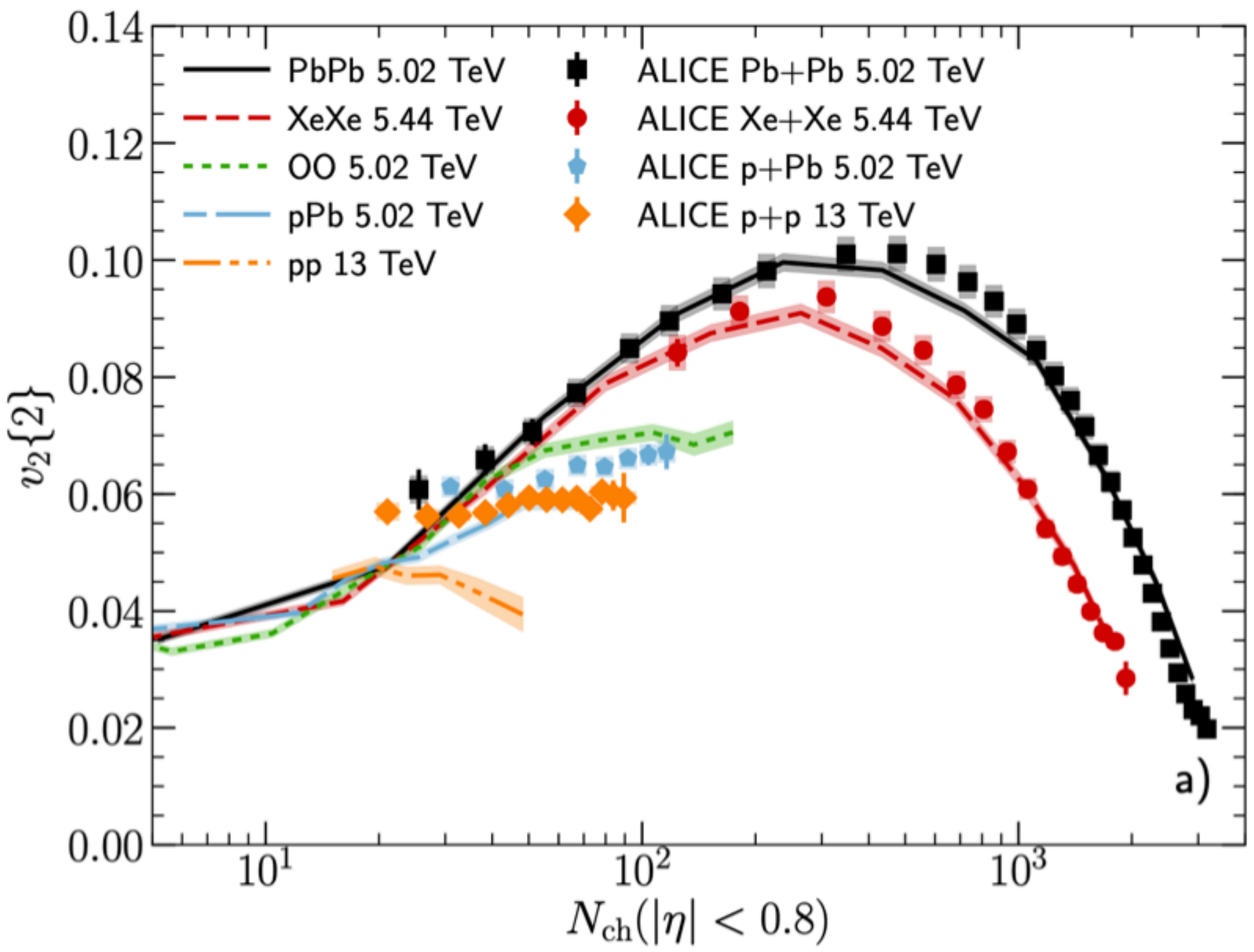
Features of QGP formation in pp and p-Pb



Nat. Phys. 13 (2017) 535-539



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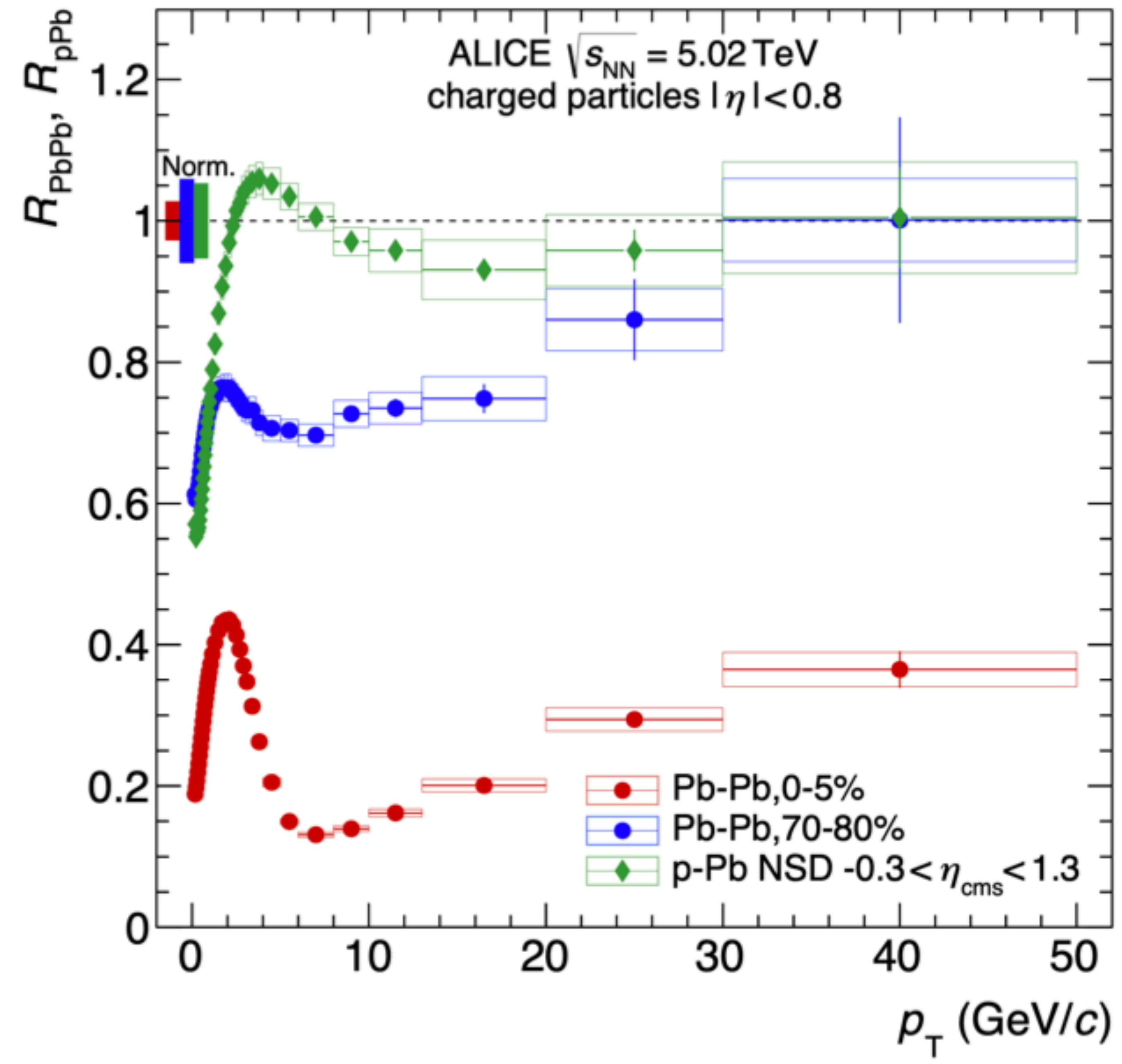


Strangeness enhancement

Reaches similar levels to Pb-Pb in high multiplicity p-Pb

Hydrodynamic description

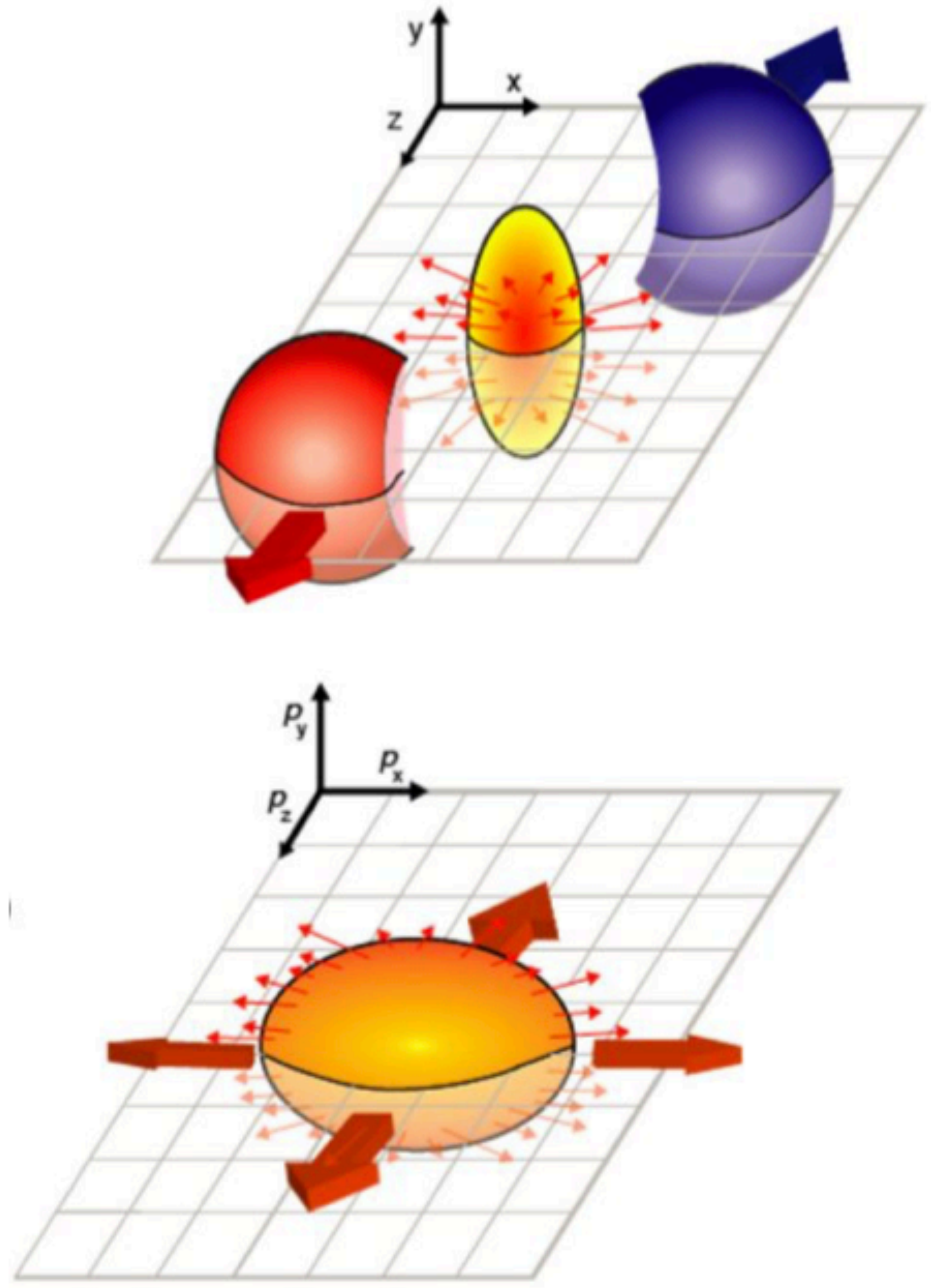
Qualitative agreement with pp and p-Pb flow measurements

Suppression of hard probes

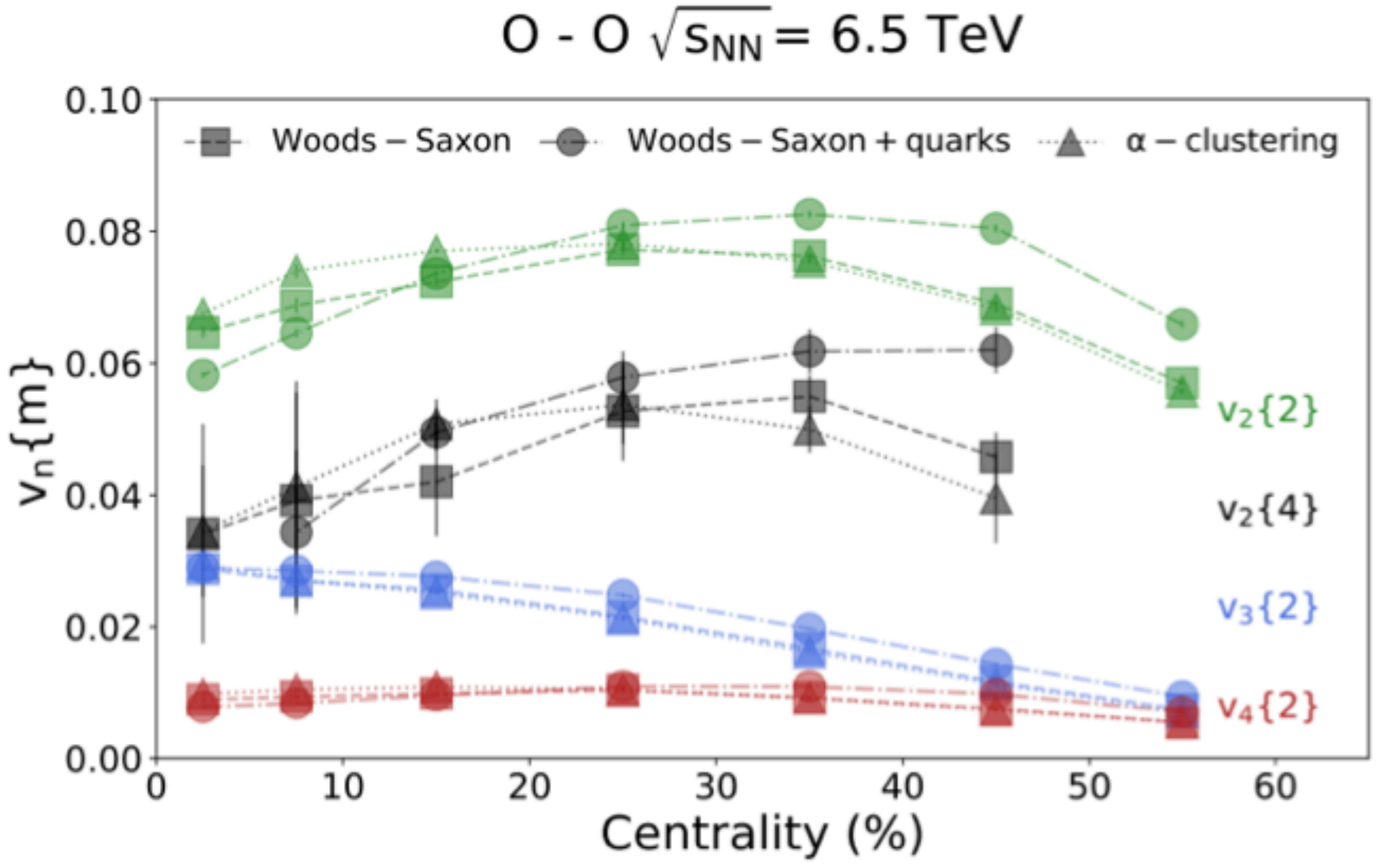
Absent in p-Pb within uncertainties

CMS
ALICE
ATLAS
LHCb

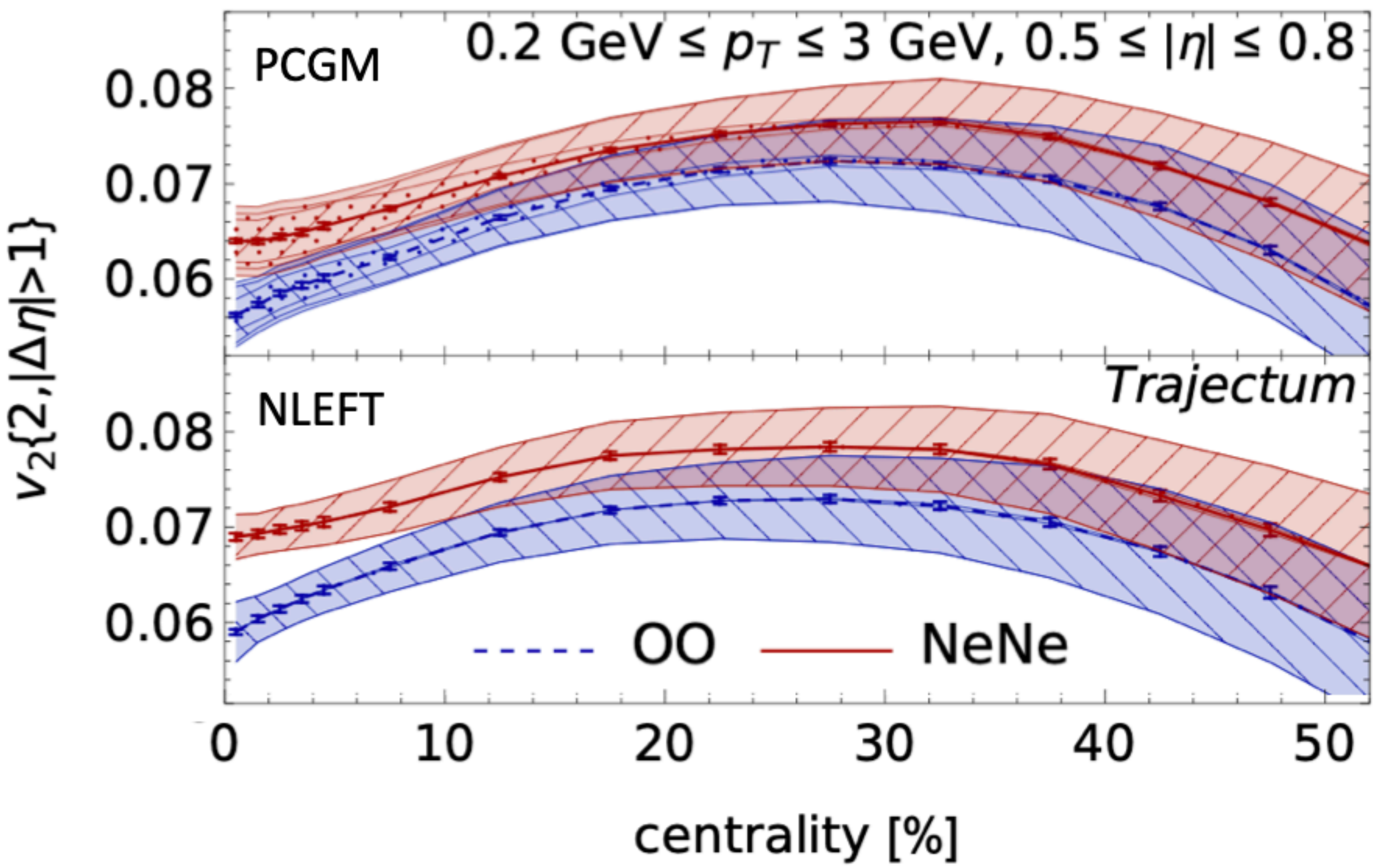
Jet interactions with the QGP



[Phys. Rev. C 104 (2021) 041901]



[Phys. Rev. Lett. 135 (2025) 012302]



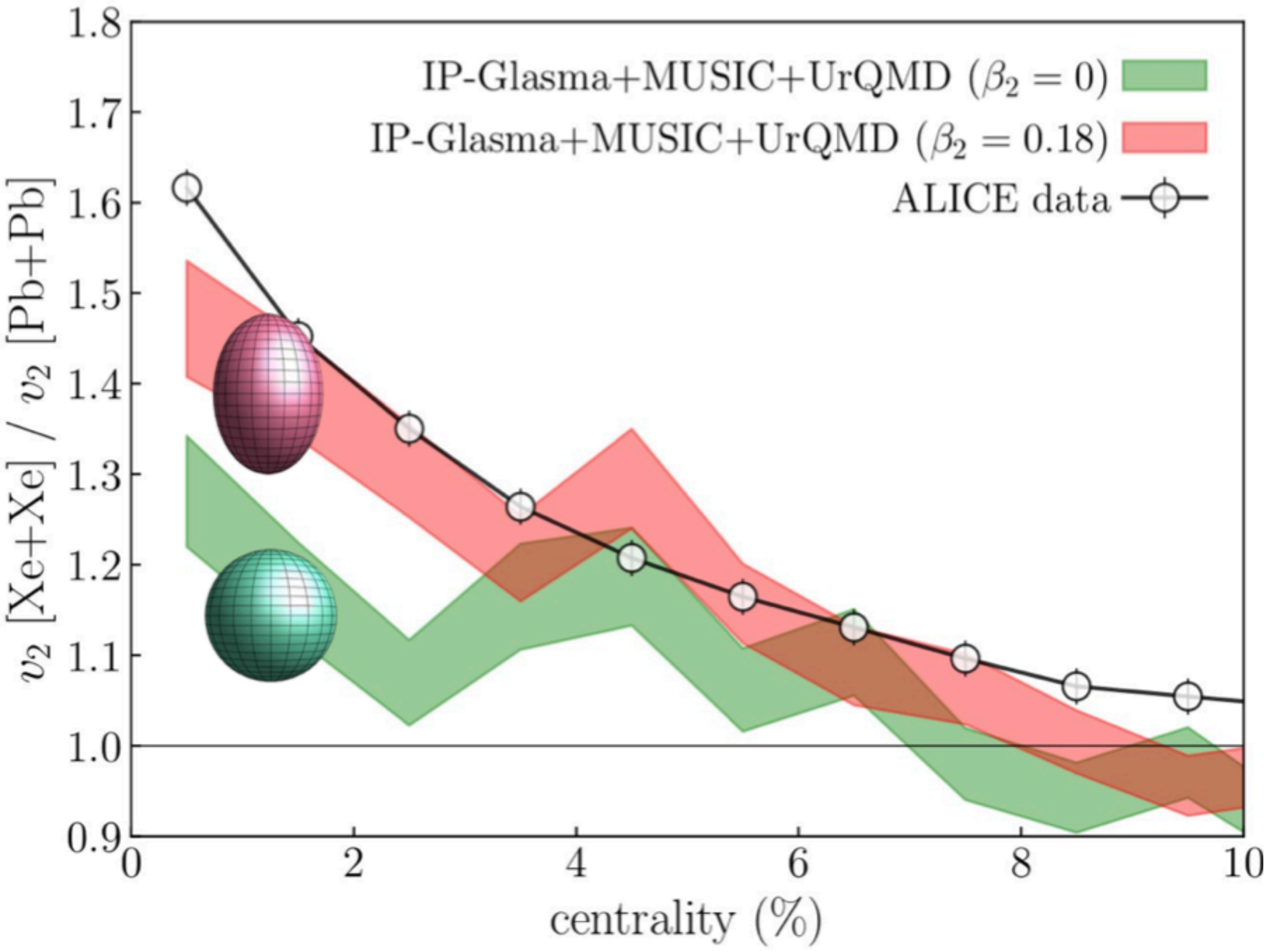
Hydrodynamic calculations employ QGP equation of state in OO and Ne-Ne to predict v_n

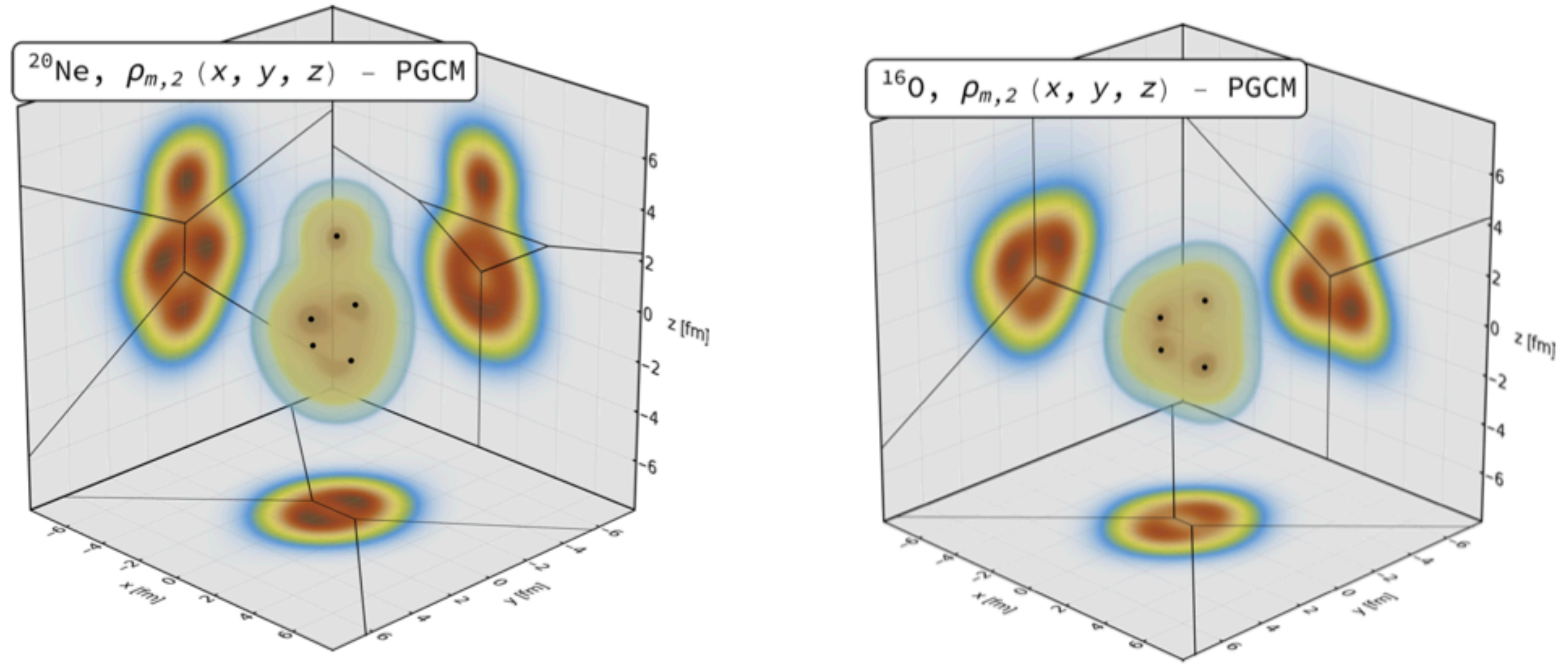
✓Modern low energy nuclear structure models e.g PCGM or NLEFT can be input

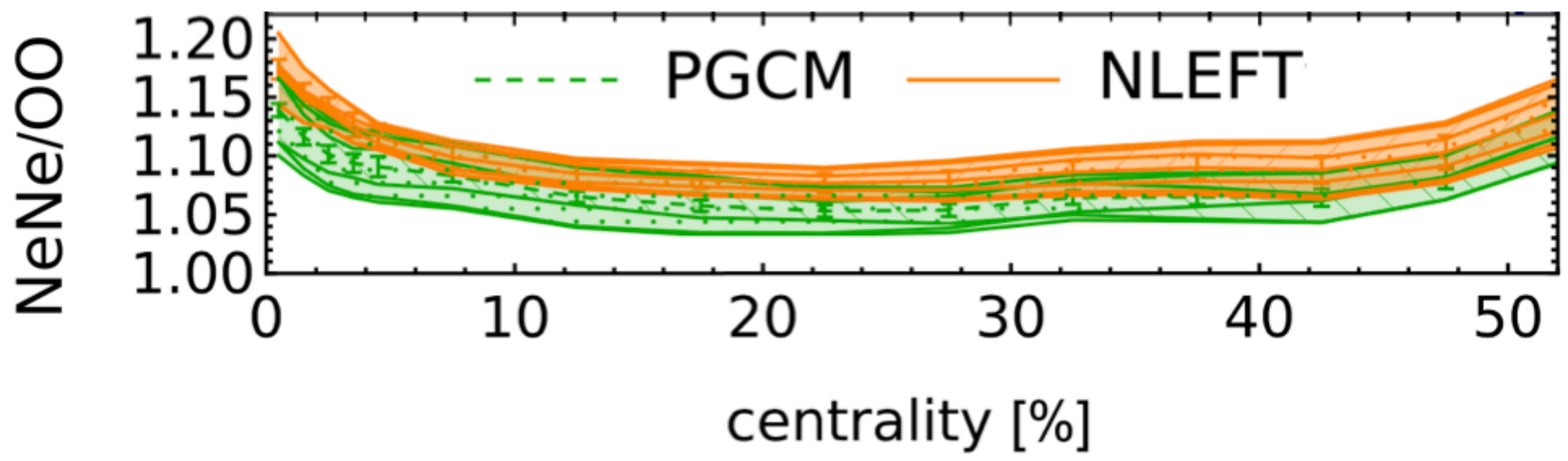
Imaging the ^{20}Ne nucleus

Phys. Rev. Lett. 135 (2025) 012302

NUCL SCI TECH 35 (2024) 220

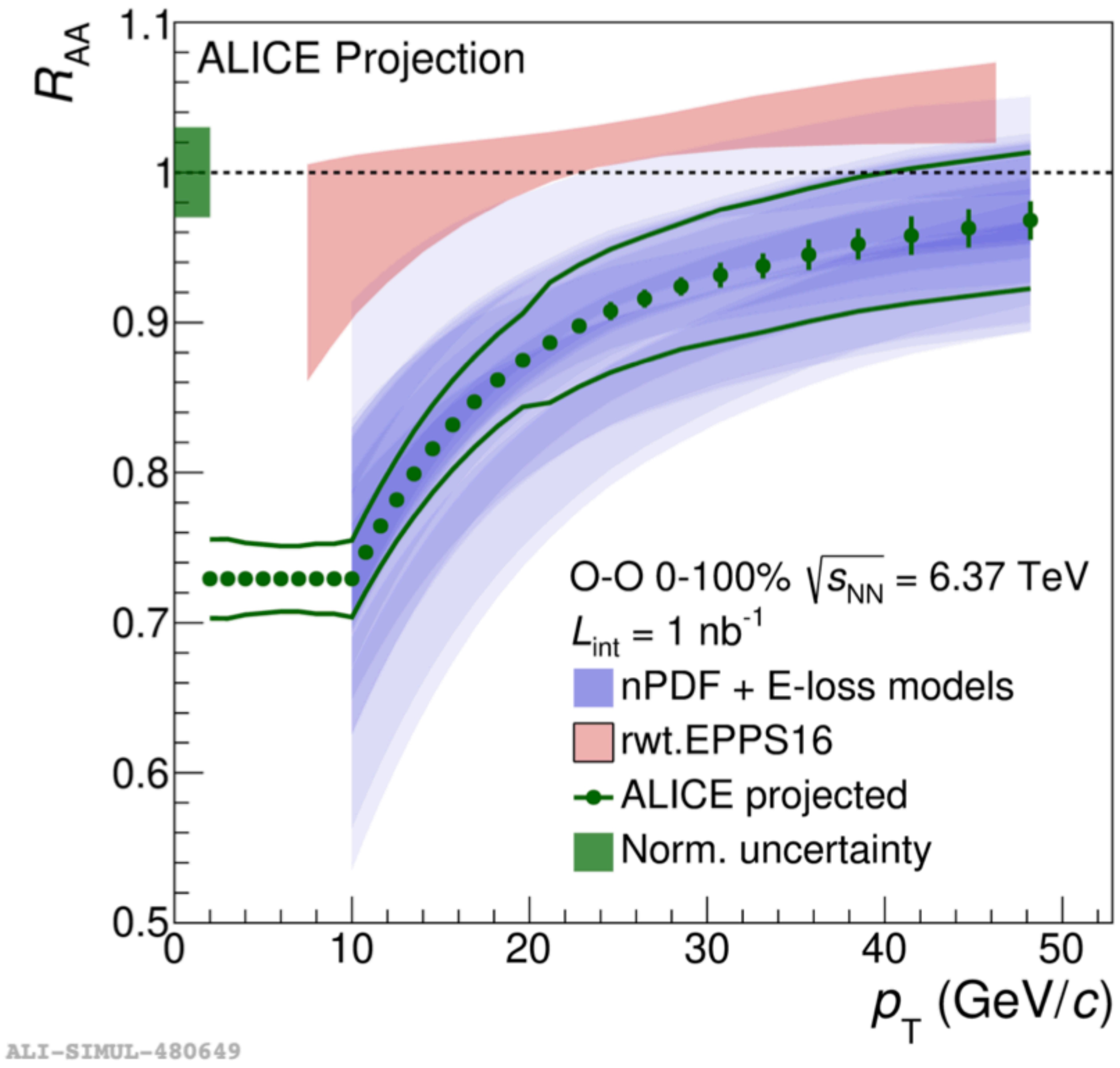




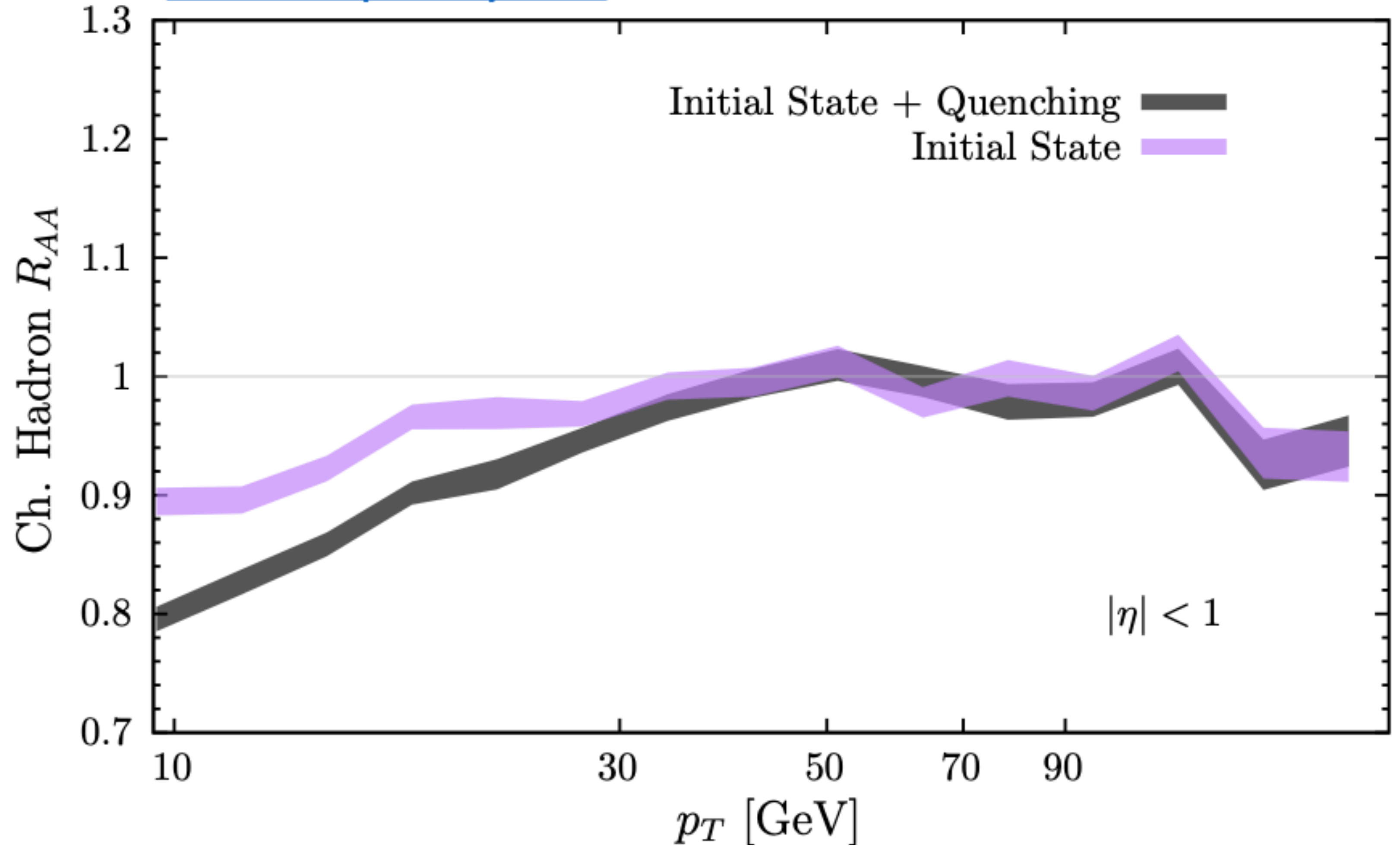


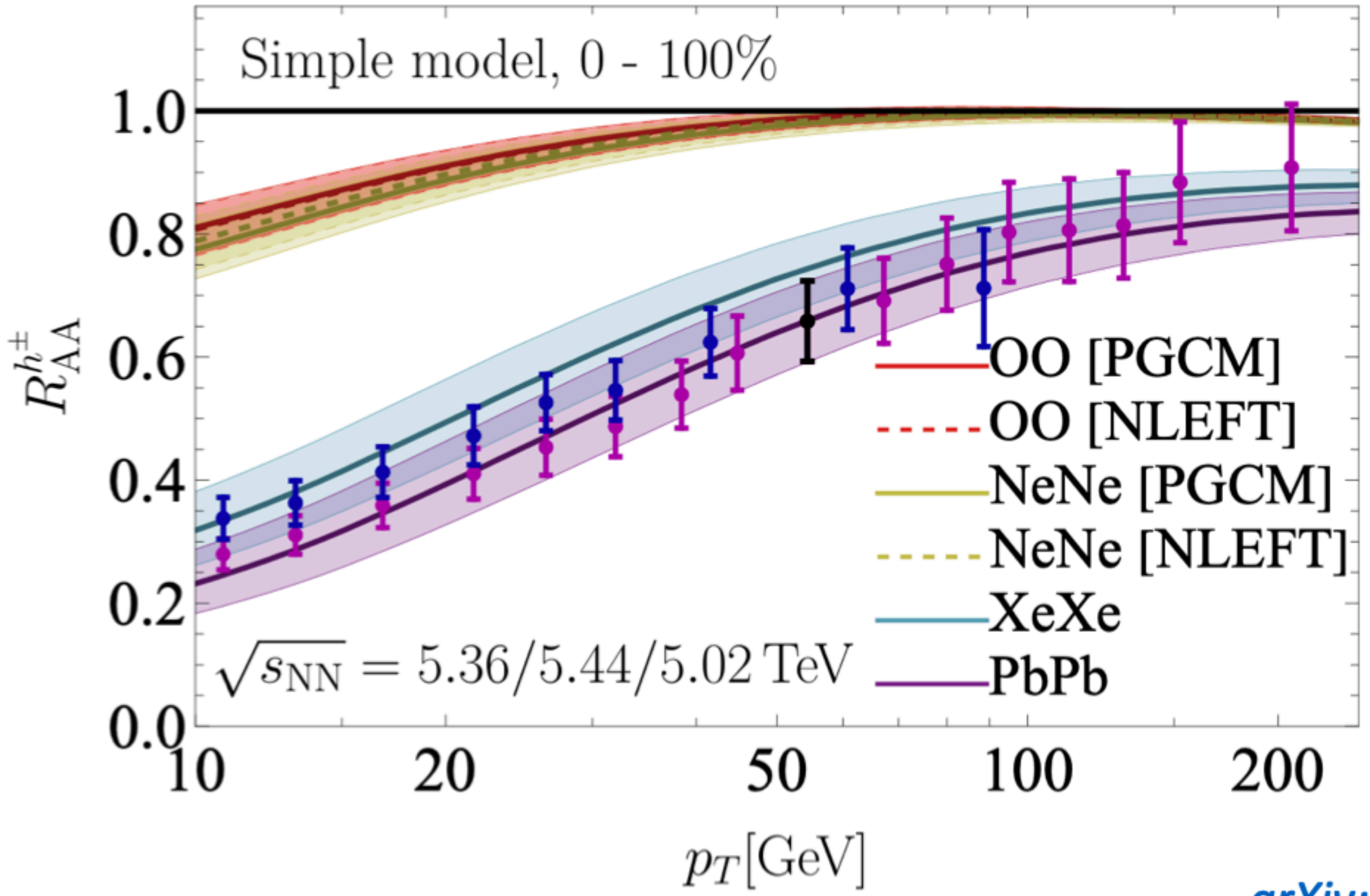
Jet quenching predictions

[Phys. Rev. Lett. 126 (2021) 192301](#)



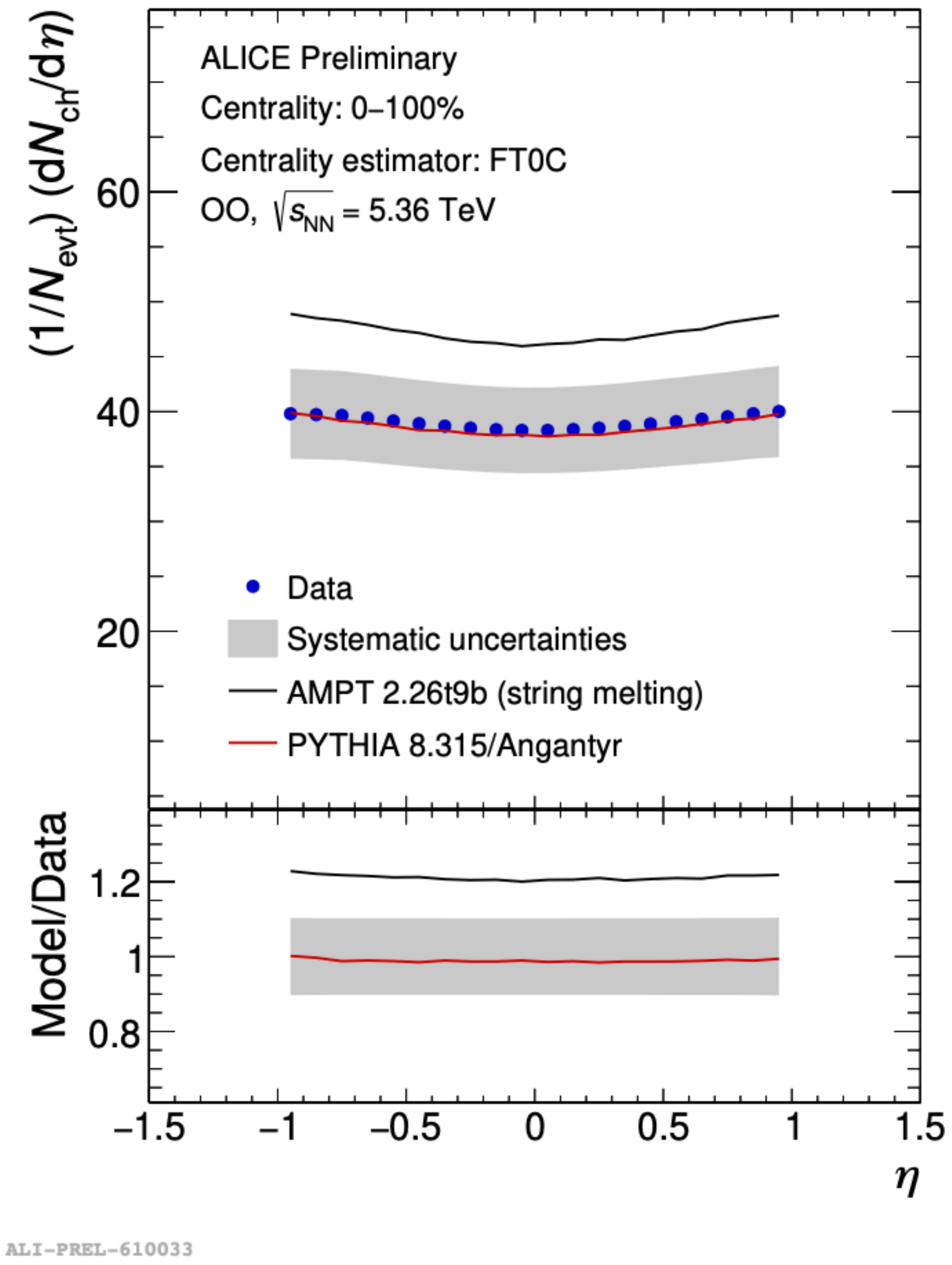
[JHEP 10 (2014) 019](#)

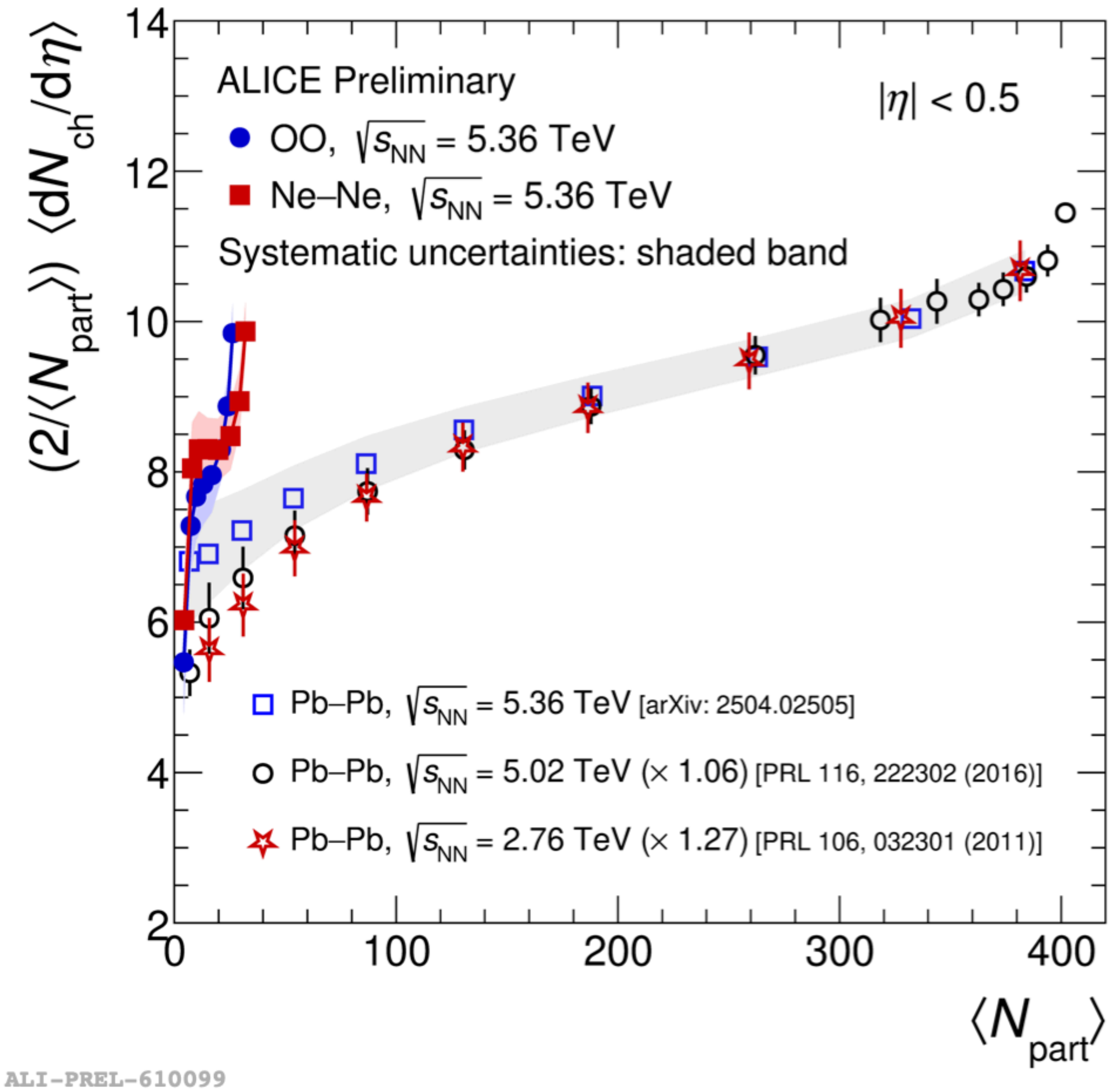




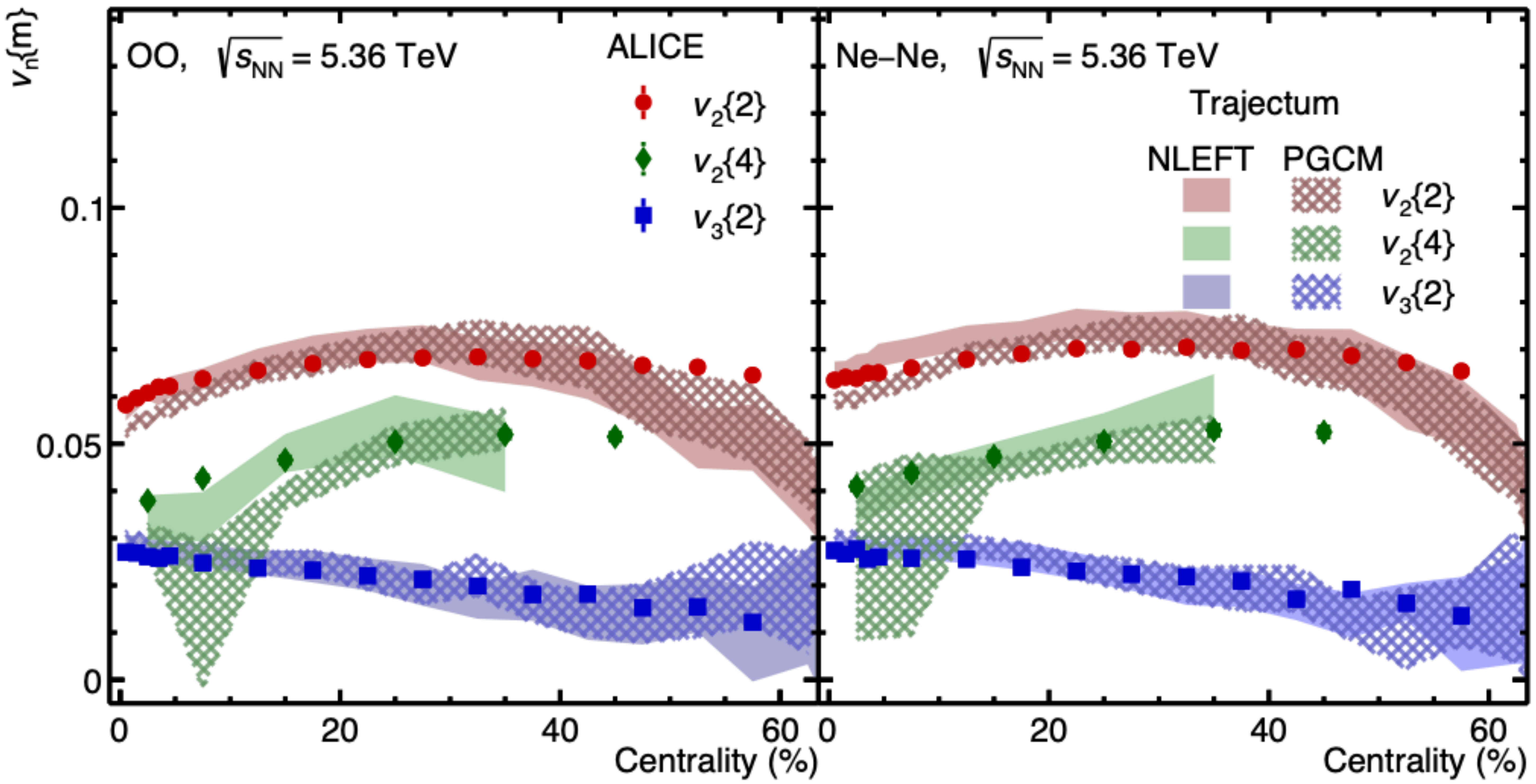
[arXiv:2509.04299](#)

Particle production in O+O and Ne+Ne collisions





Anisotropic flow in O+O and Ne+Ne collisions



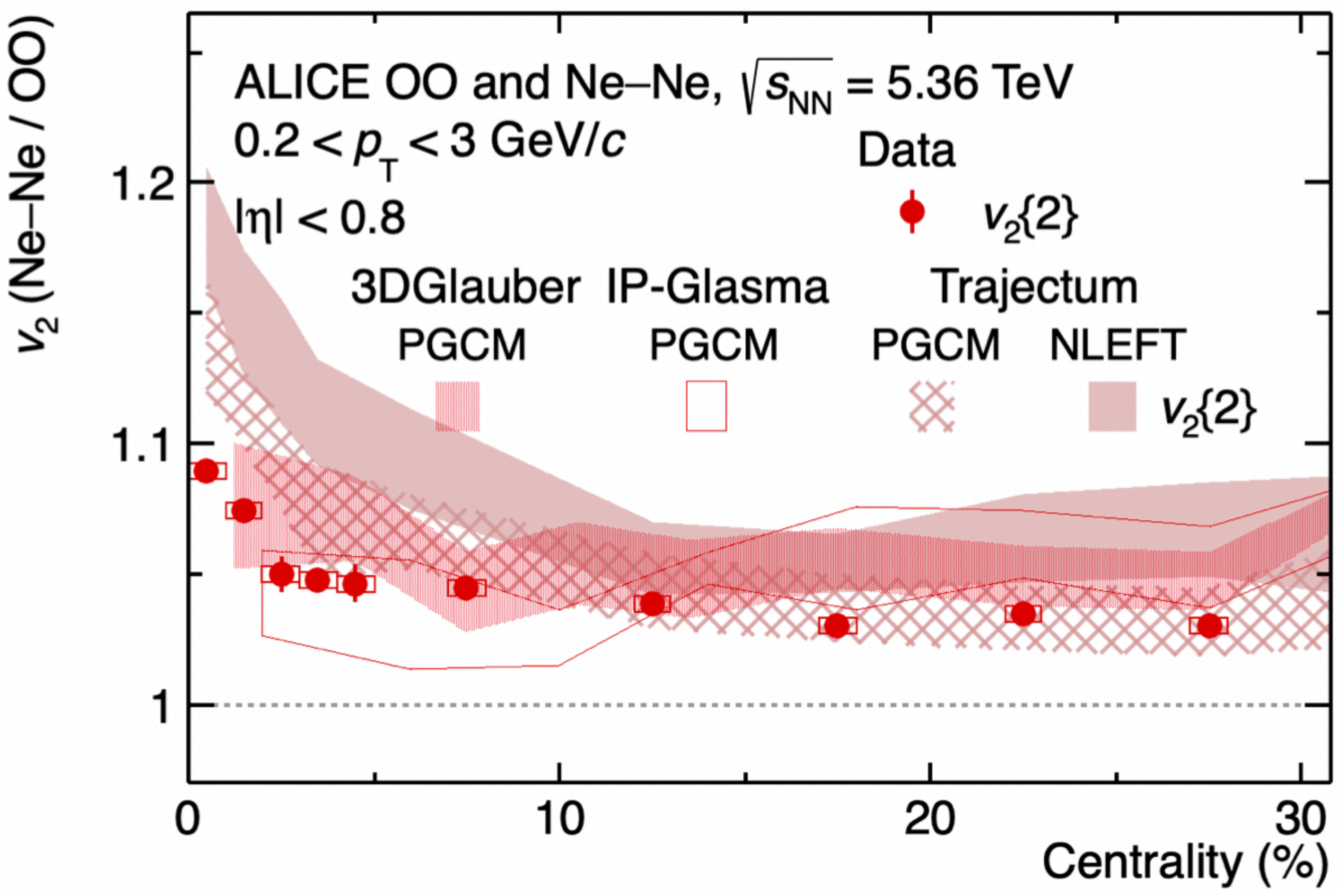
First O+O and Ne+Ne flow paper submitted for publication!

arXiv:2509.06428

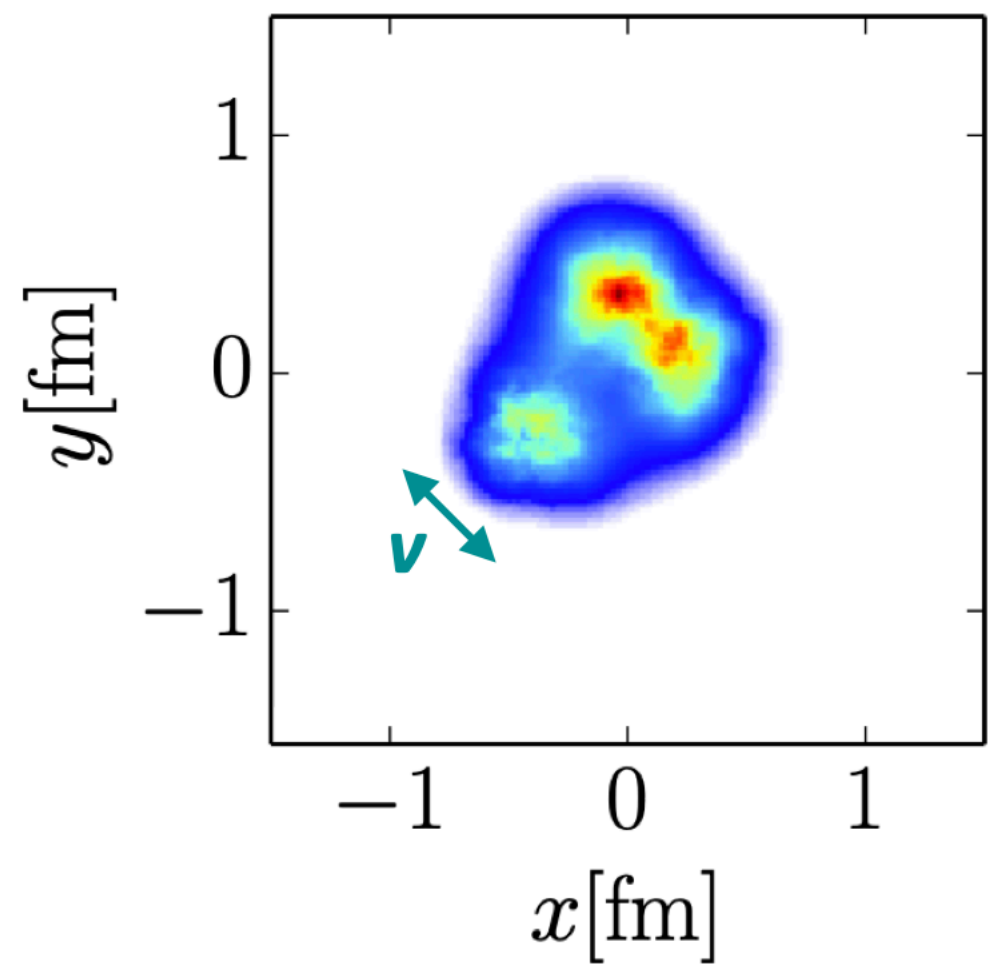
ALICE measurements well described by geometry-induced hydrodynamic flow predictions

✓NLEFT nuclear structure best favoured → some tension with other hydrodynamic implementations

Anisotropic flow in O+O and Ne+Ne collisions



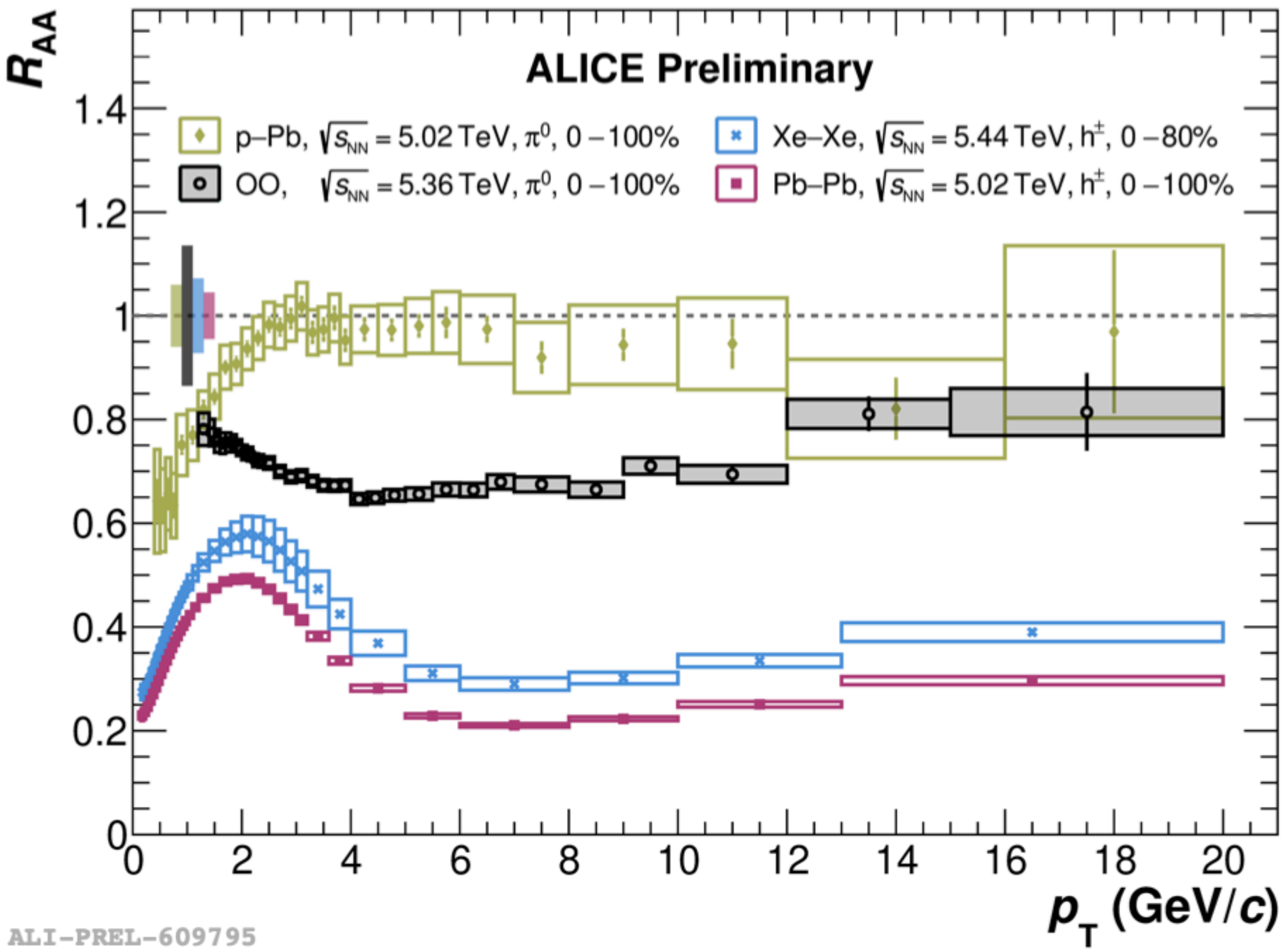
Phys. Rev. D 94 (2014) 034042



Models with PGCM ^{20}NeNe and ^{16}O nuclear structures favoured by ALICE data

✓Smaller sub-nucleon width gives best description $\rightarrow v \approx 0.1$ fm

Searches for jet-quenching in OO collisions



Nuclear modification factor R_{OO} of π_0 suppressed at higher momentum

R_{OO} shape similar to R_{PbPb} & R_{XeXe}

R_{OO} shape opposite to R_{pPb}

Searches for jet-quenching in O+O collisions

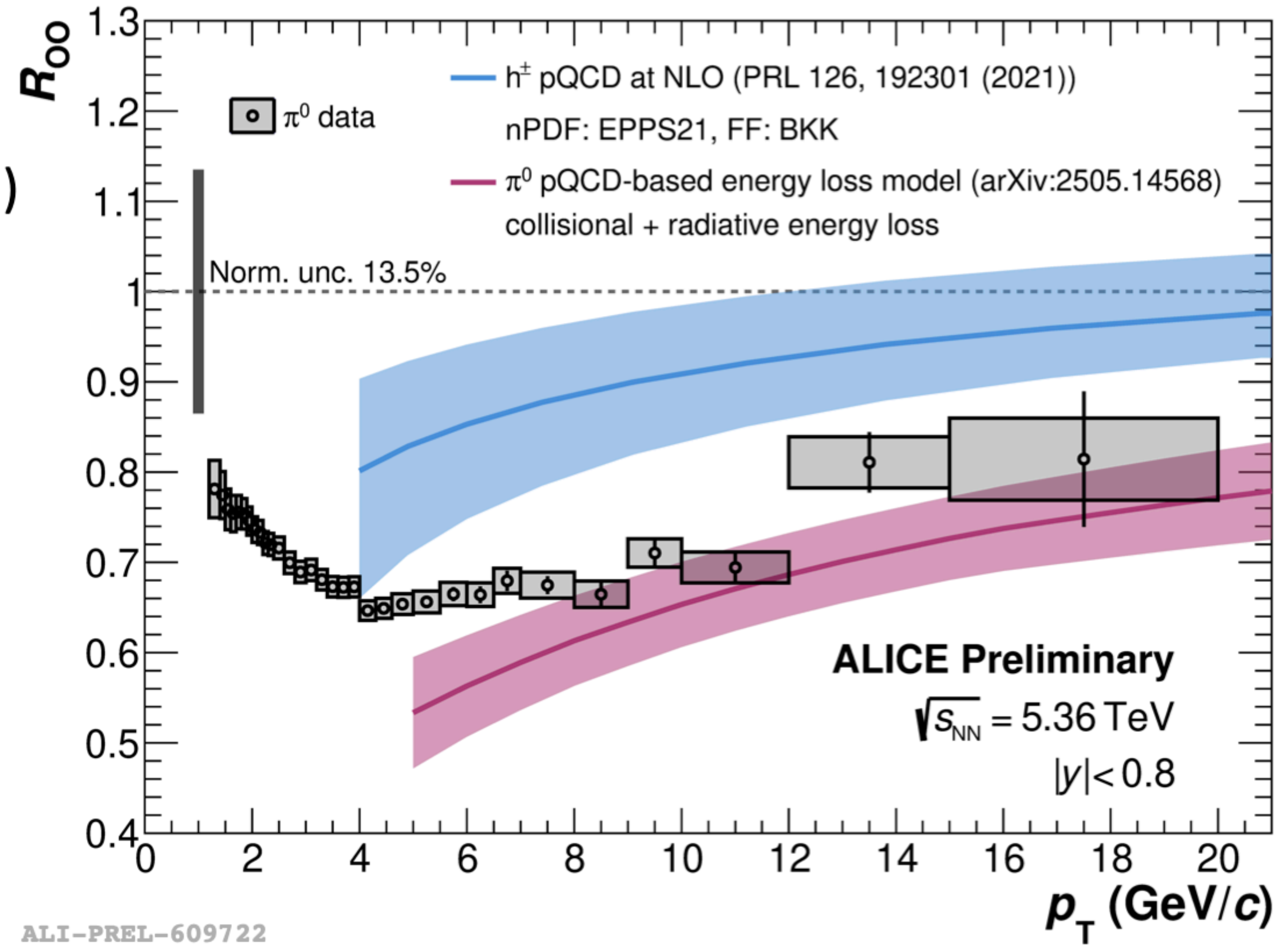
pQCD baseline calculation

✓Only cold nuclear matter effects (CNM) e.g. nuclear PDF modification

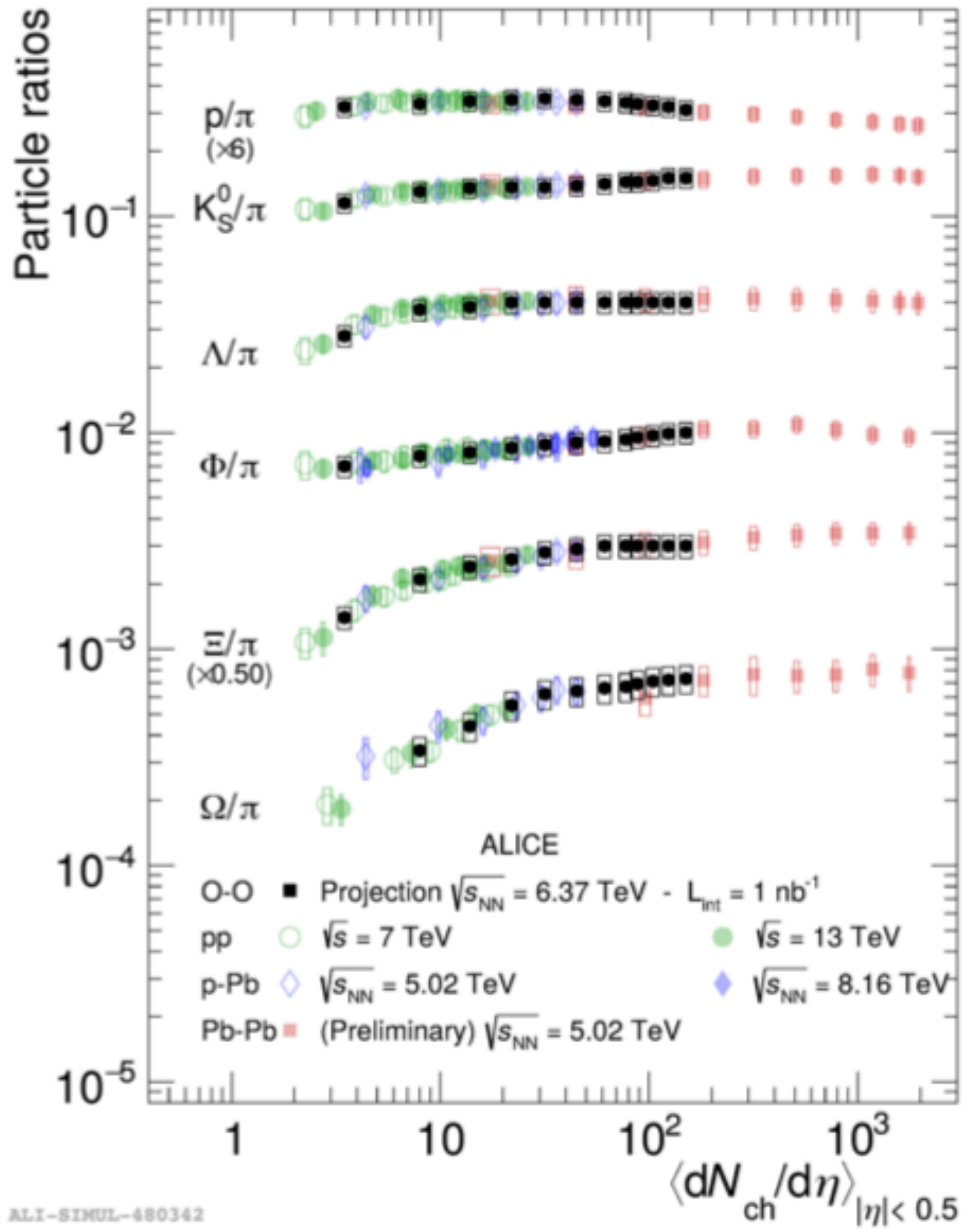
Energy loss calculation

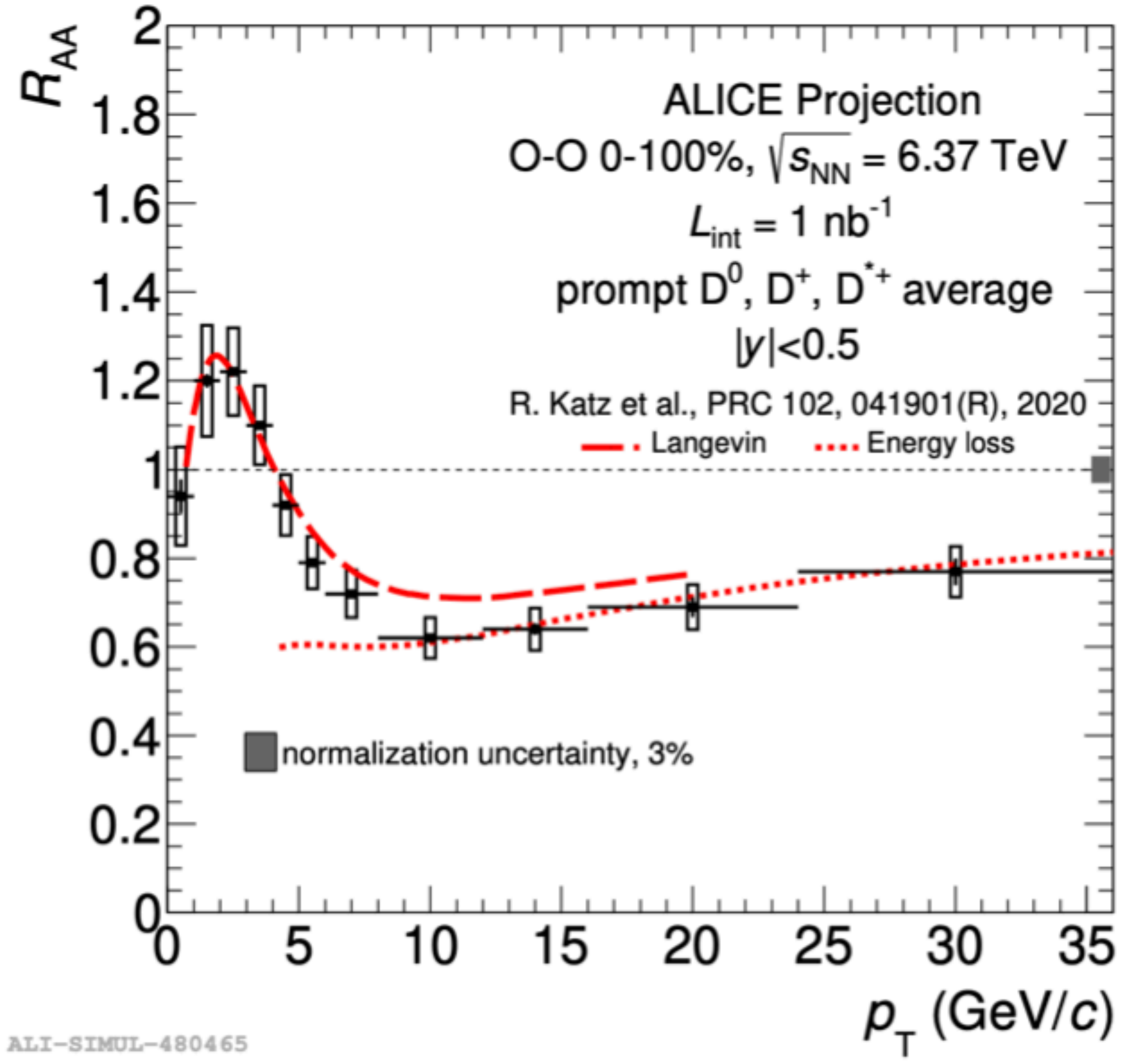
✓Only final state effects

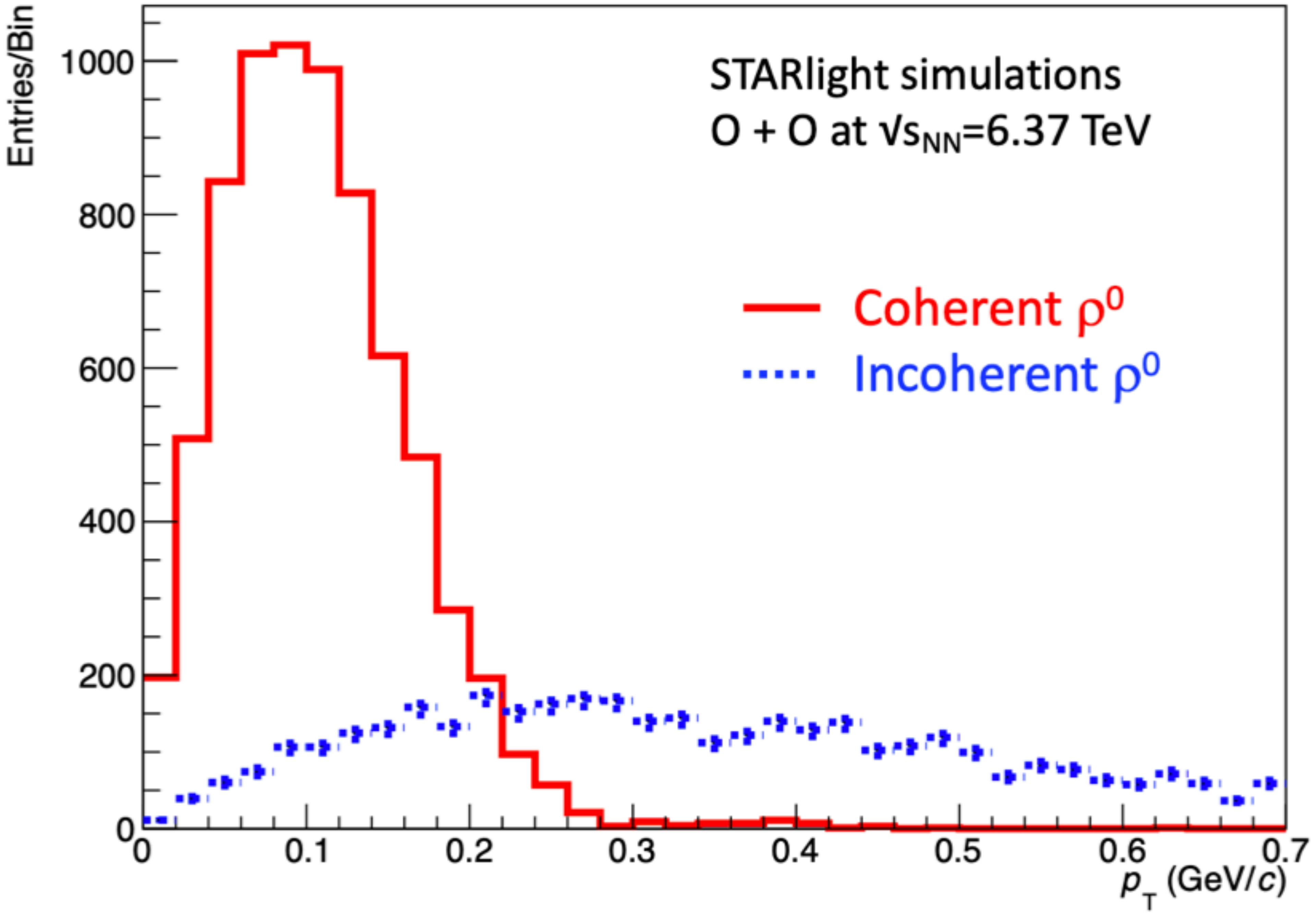
Expected reduction in Norm. Unc. after full VDM scan analysis...



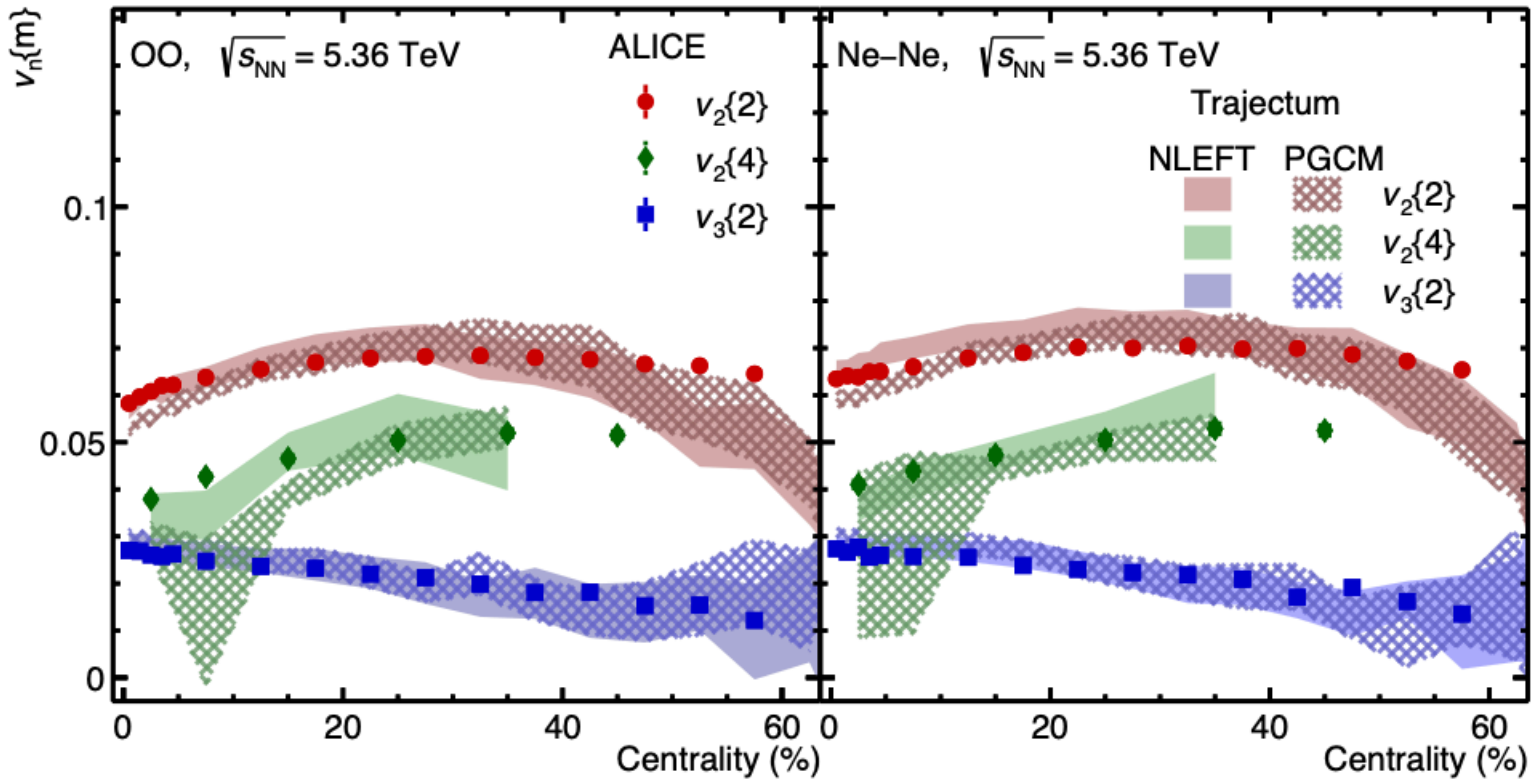
More to come...

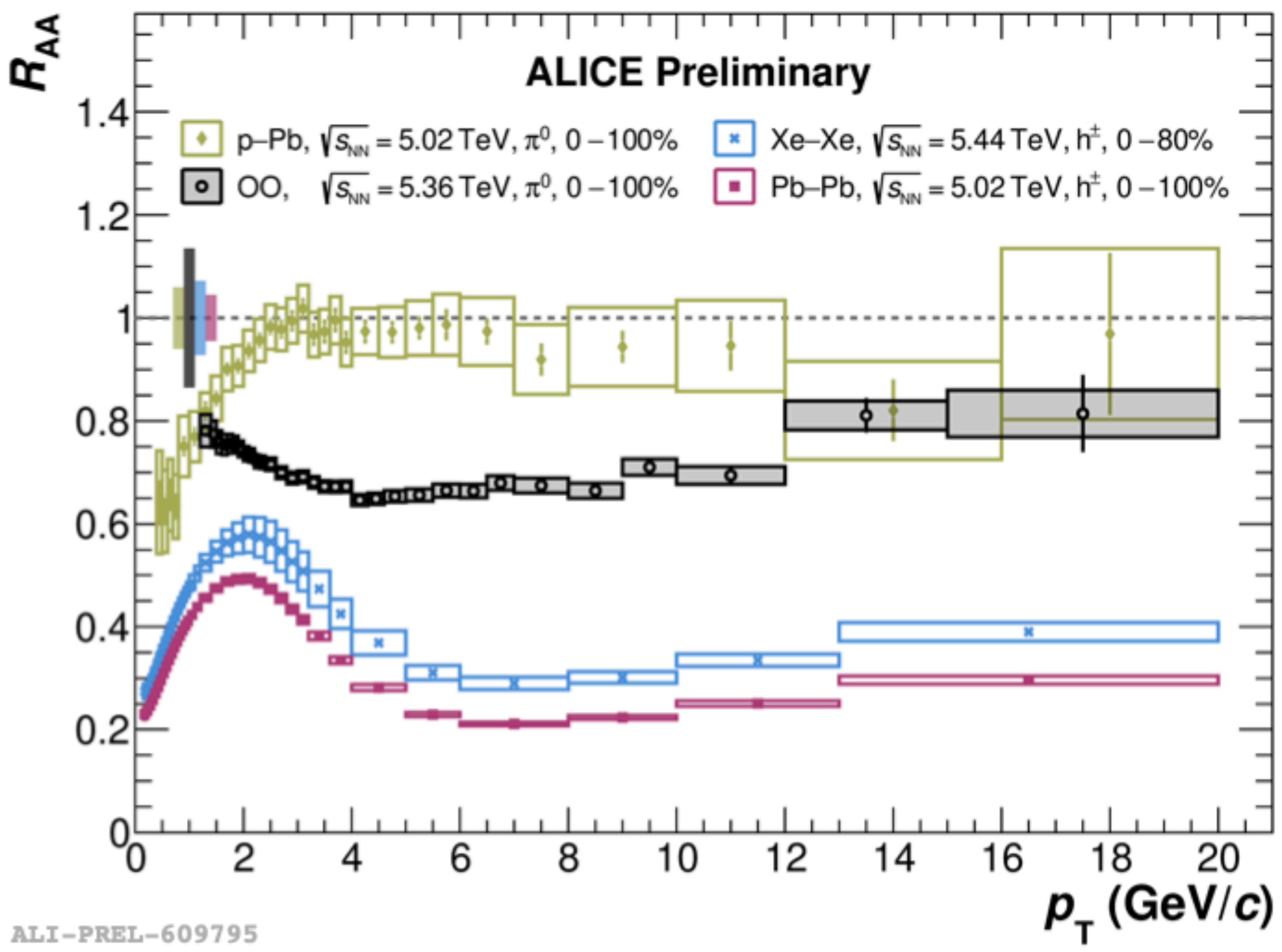

Particle ratios
p/π (×6)
K^0_S/π
Λ/π
Φ/π
Ξ/π (×0.50)
Ω/π
ALICE
O-O ■ Projection $\sqrt{s_{NN}}$ = 6.37 TeV - L_{int} = 1 nb^{-1}
pp ○ $\sqrt{s}$ = 7 TeV ● $\sqrt{s}$ = 13 TeV
p-Pb ◇ $\sqrt{s_{NN}}$ = 5.02 TeV ◆ $\sqrt{s_{NN}}$ = 8.16 TeV
Pb-Pb ■ (Preliminary) $\sqrt{s_{NN}}$ = 5.02 TeV
$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$
ALI-SIMUL-480342


R_{AA}
ALICE Projection
O-O 0-100%, $\sqrt{s_{NN}}$ = 6.37 TeV
L_{int} = 1 nb^{-1}
prompt D^0, D^+, D^{*+} average
|y|<0.5
R. Katz et al., PRC 102, 041901(R), 2020
Langevin
Energy loss
normalization uncertainty, 3%
p_T (GeV/c)
ALI-SIMUL-480465


Entries/Bin
STARlight simulations
O + O at $\sqrt{s_{NN}}$=6.37 TeV
Coherent ρ^0
Incoherent ρ^0
p_T (GeV/c)

Summary 3/5



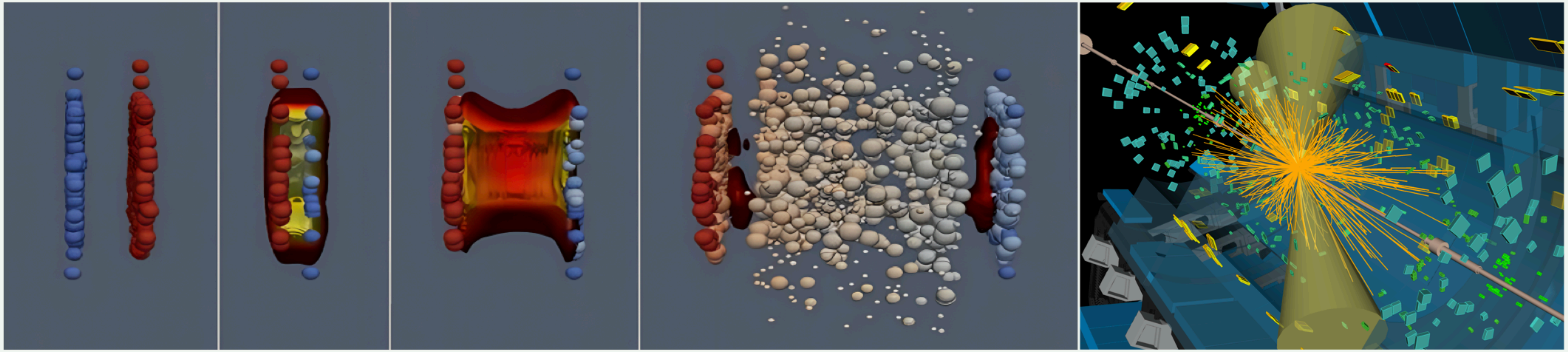


Initial ALICE results indicate **OO and Ne-Ne** collisions **look like a QGP**

Common picture emerging across LHC experiments from first measurements...

Heavy Ion collisions

Time $\tau = 0$ $\tau \sim 1$ fm/c $\sim 10^{-23}$ s $\tau \sim 10$ fm/c $\sim 10^{-22}$ s $\tau > 10$ cm/c $\sim 10^{-11}$ s

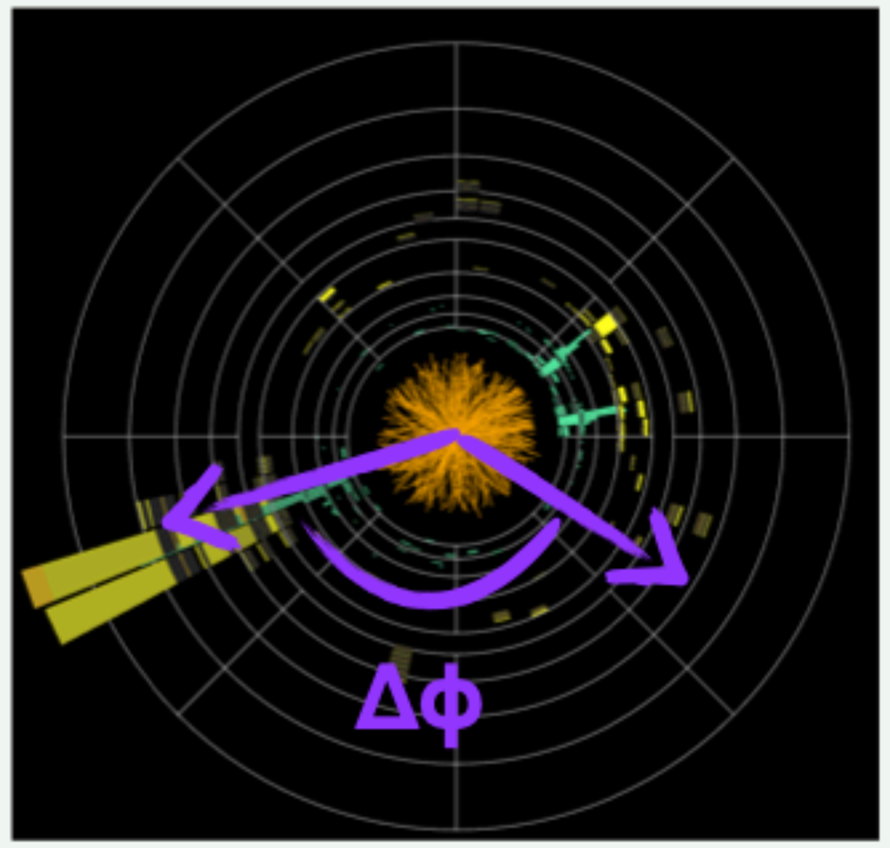


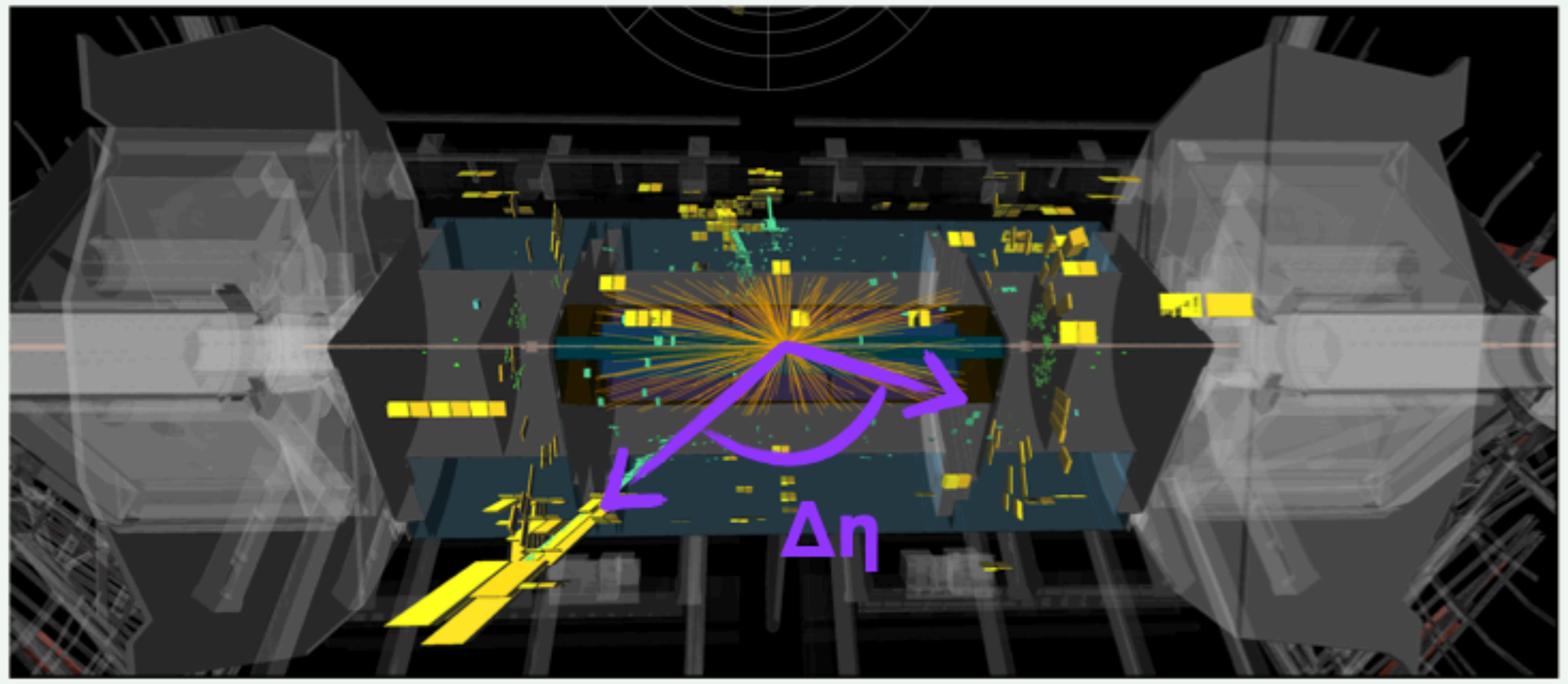
Collision evolution sketch from MADAI collaboration

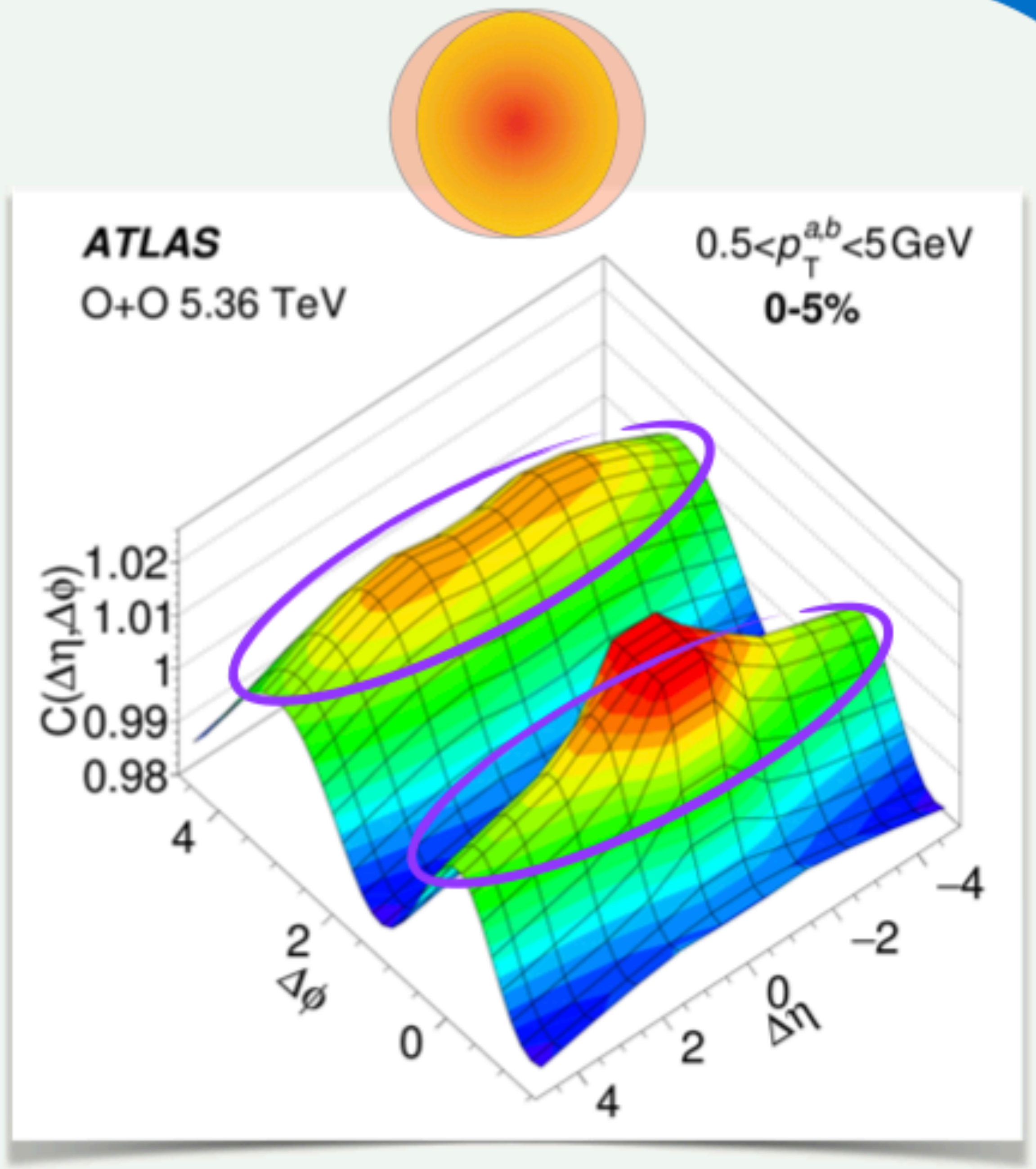
Initial state	Parton Scatterings	QGP formation & hydrodynamic expansion	Hadronization	Particle detection

2-Particle Correlation analysis

Standard **2–P**article **C**orrelation analysis, i.e. study of azimuthal (Δϕ) and longitudinal (Δη) correlations between pairs of particles





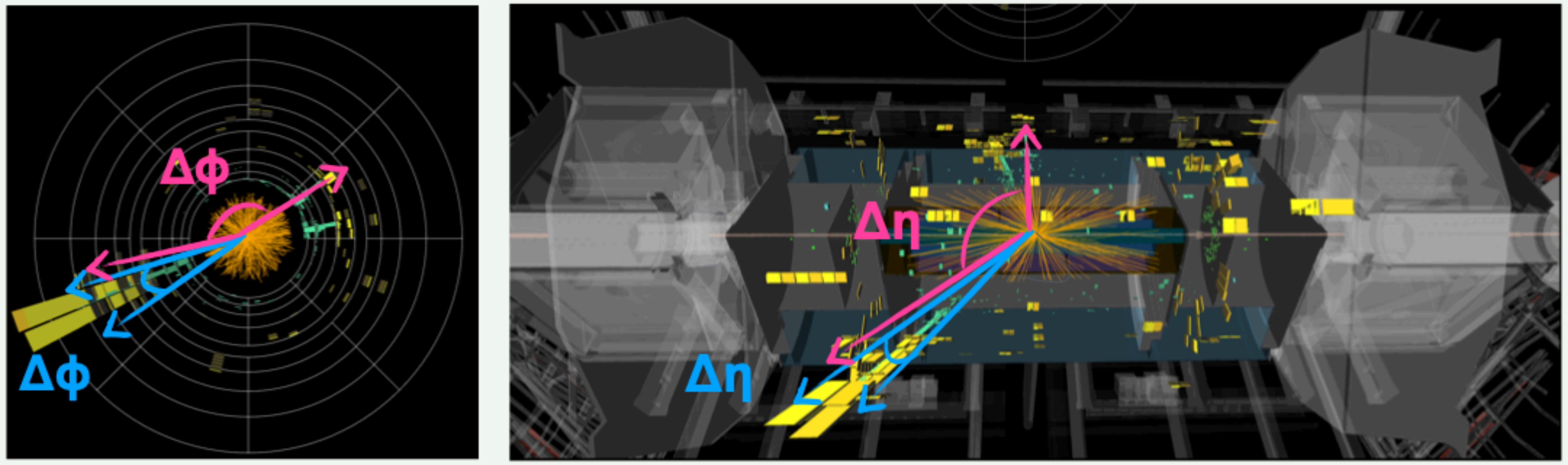


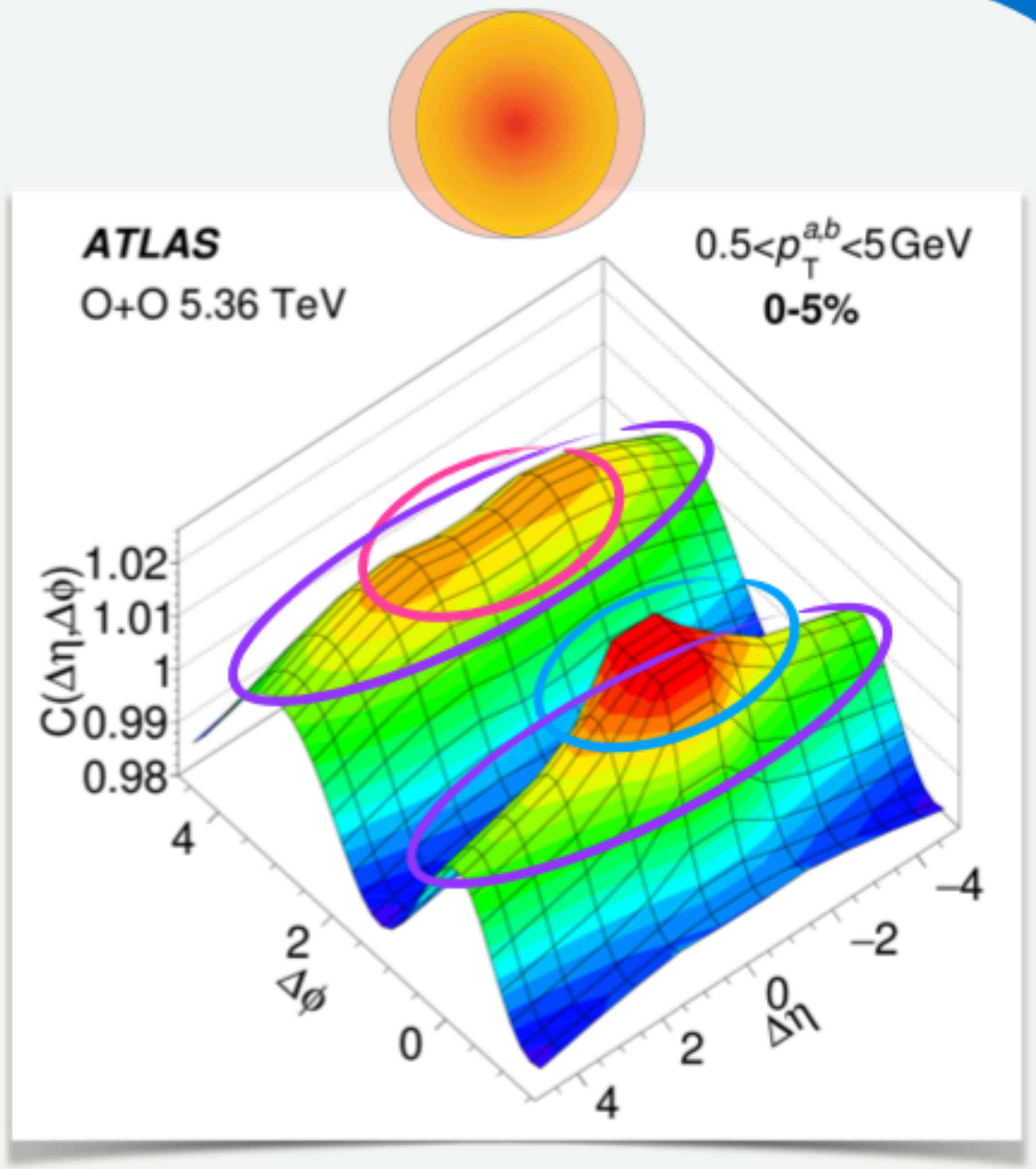
- Clear, **long–range correlations** observed ('the ridge')

2-Particle Correlation analysis

ATLAS EXPERIMENT

Standard **2**–**P**article **C**orrelation analysis, i.e. study of azimuthal (Δϕ) and longitudinal (Δη) correlations between pairs of particles





- Clear, **long-range correlations** observed ('the ridge')
- Non-flow contributions to be unraveled, for instance
  - Near-side contribution from **jets,** away-side contribution from **dijets** …

CMS
ALICE
ATLAS
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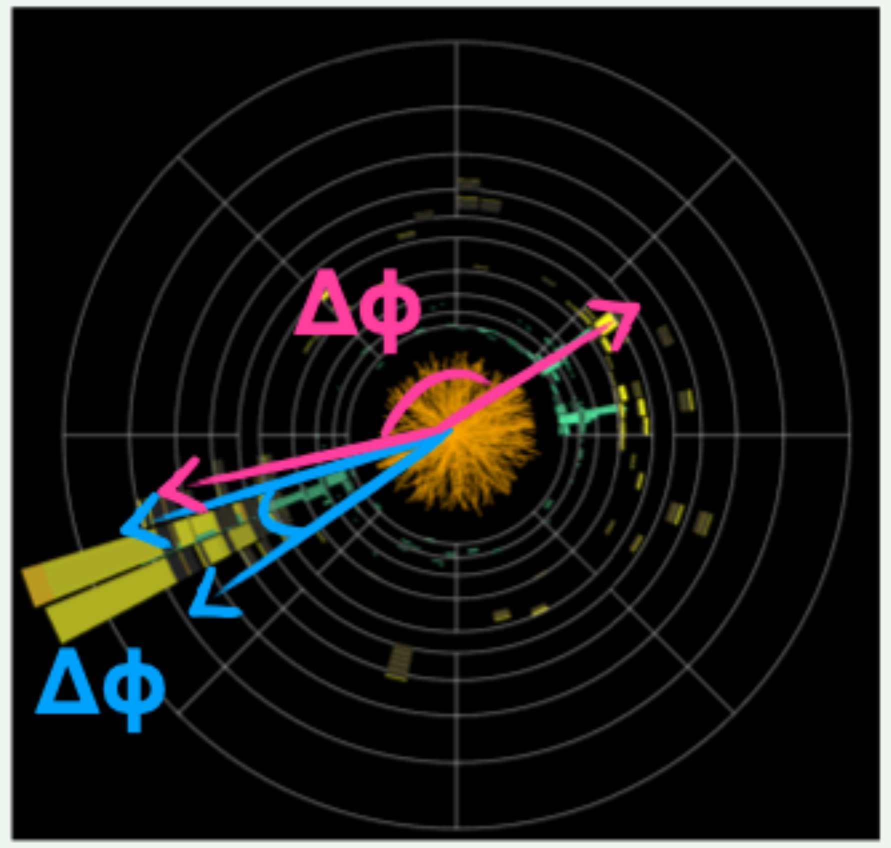
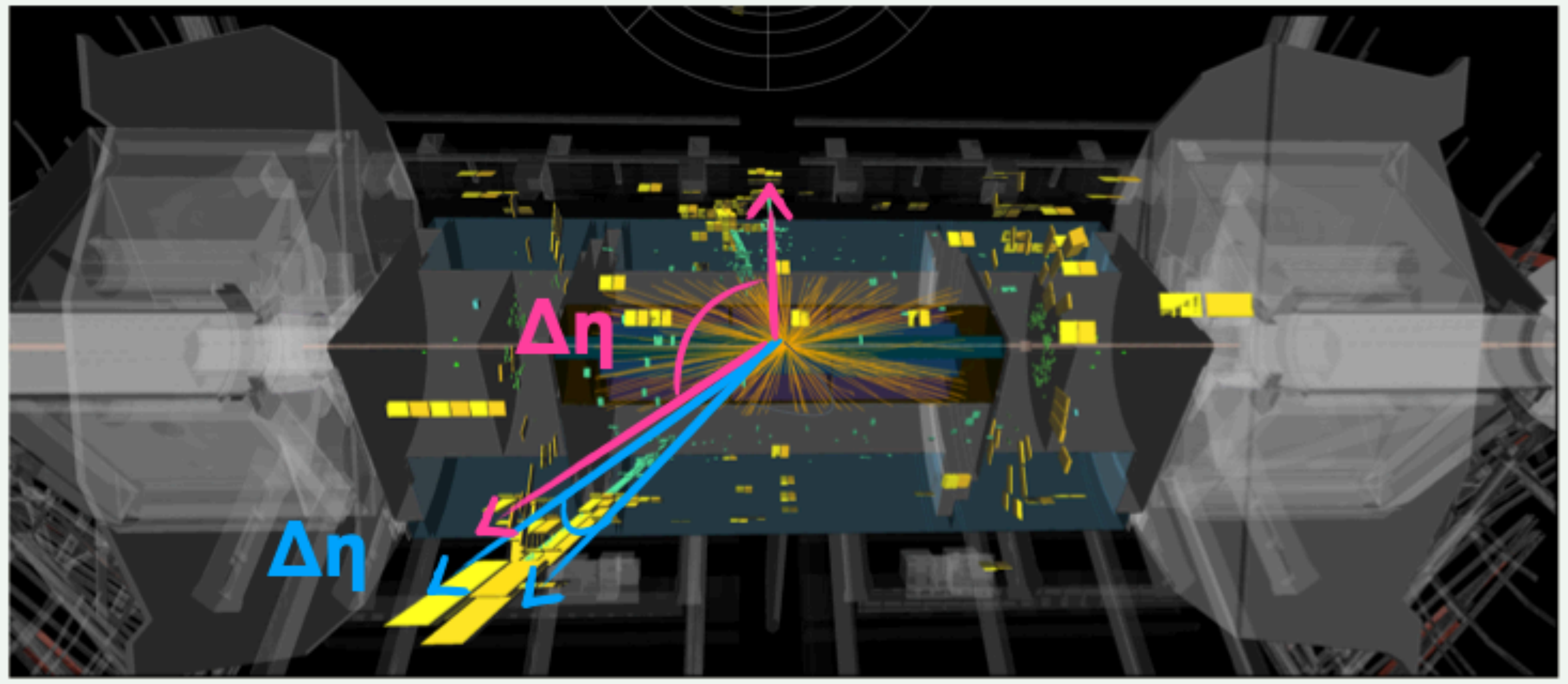
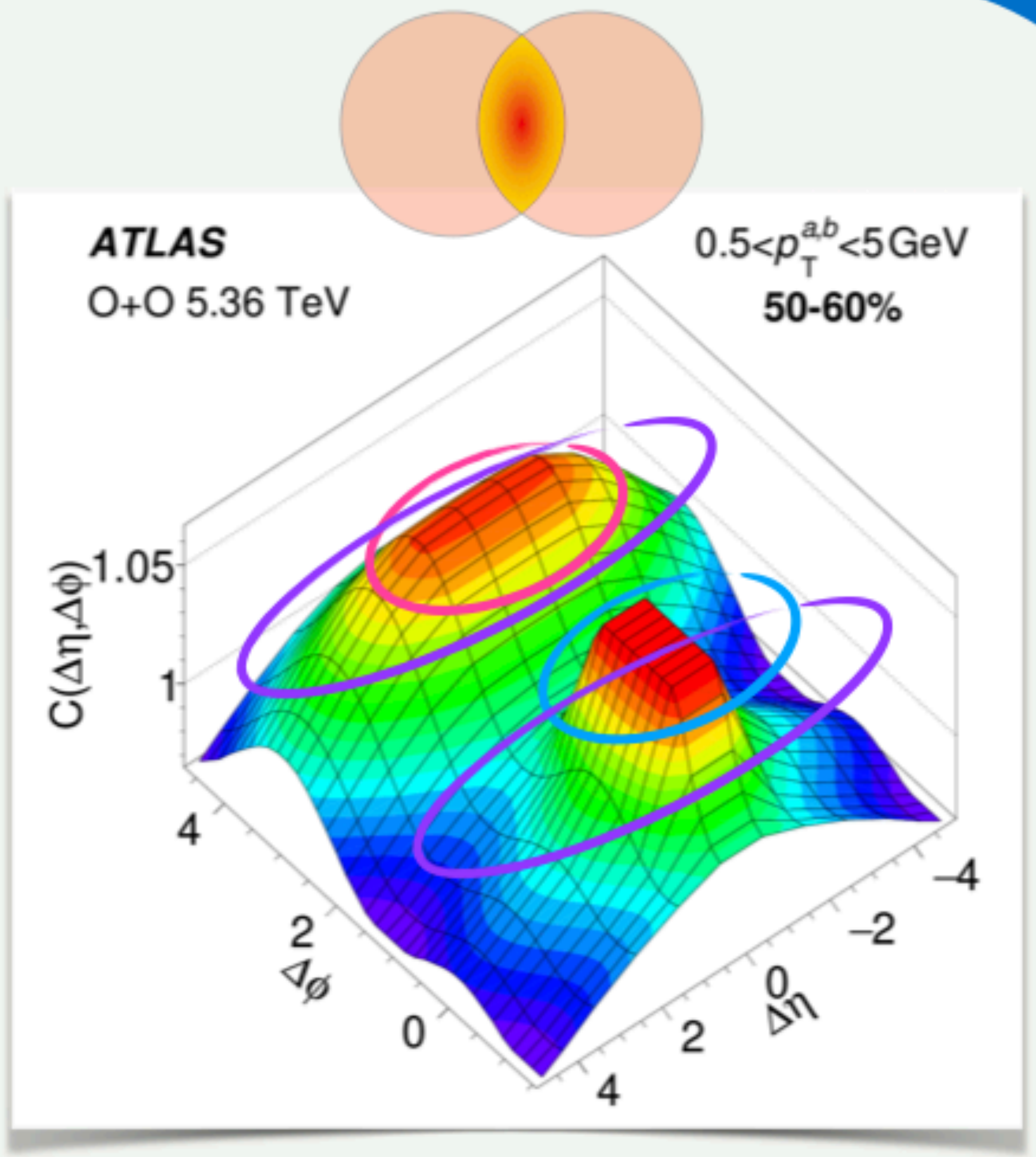
2-Particle Correlation analysis

ATLAS EXPERIMENT

Standard **2**–Particle **C**orrelation analysis, i.e. study of azimuthal (Δϕ) and longitudinal (Δη) correlations between pairs of particles







- Clear, **long-range correlations** observed ('the ridge')
- Non-flow contributions to be unraveled, for instance
  - Near-side contribution from **jets,** away-side contribution from **dijets** ...
- Even more pronounced in more peripheral collisions...

2-Particle Correlation analysis: non-flow

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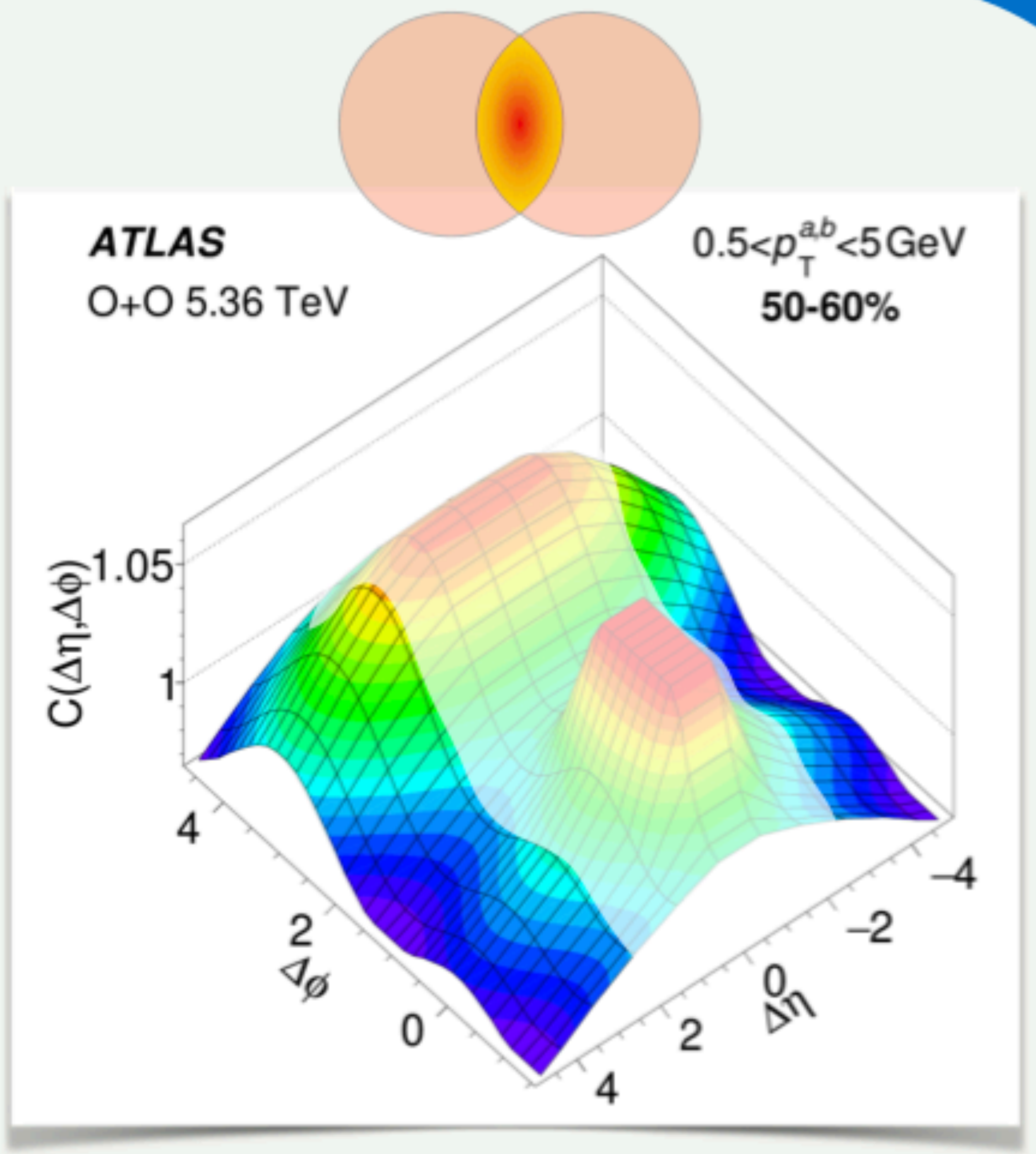
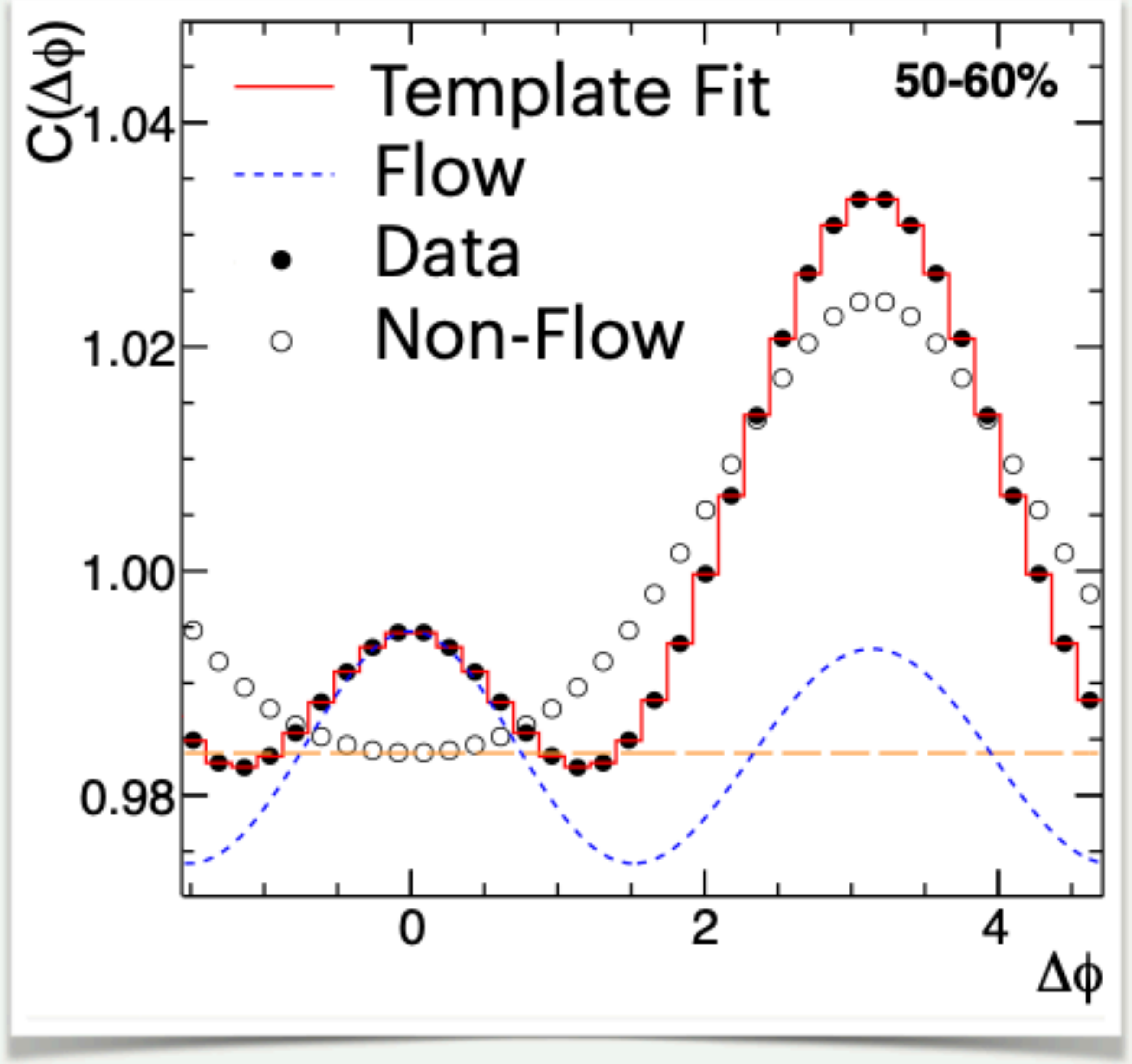
Project out the distribution on the $\Delta\phi$ axis while also selecting $|\Delta\eta| > 2$ to remove near-side correlations and fit the result with Fourier

$$C(\Delta\phi) = C_0\left(1 + 2\sum_{n=1}^{\infty} v_{n,n}(p_T^a, p_T^b)\cos(n\Delta\phi)\right)$$



Results still sensitive to residual non-flow contribution

➡ **Template fit method to remove it,** using peripheral (> 80%) O+O and Ne+Ne collisions to estimate the non-flow



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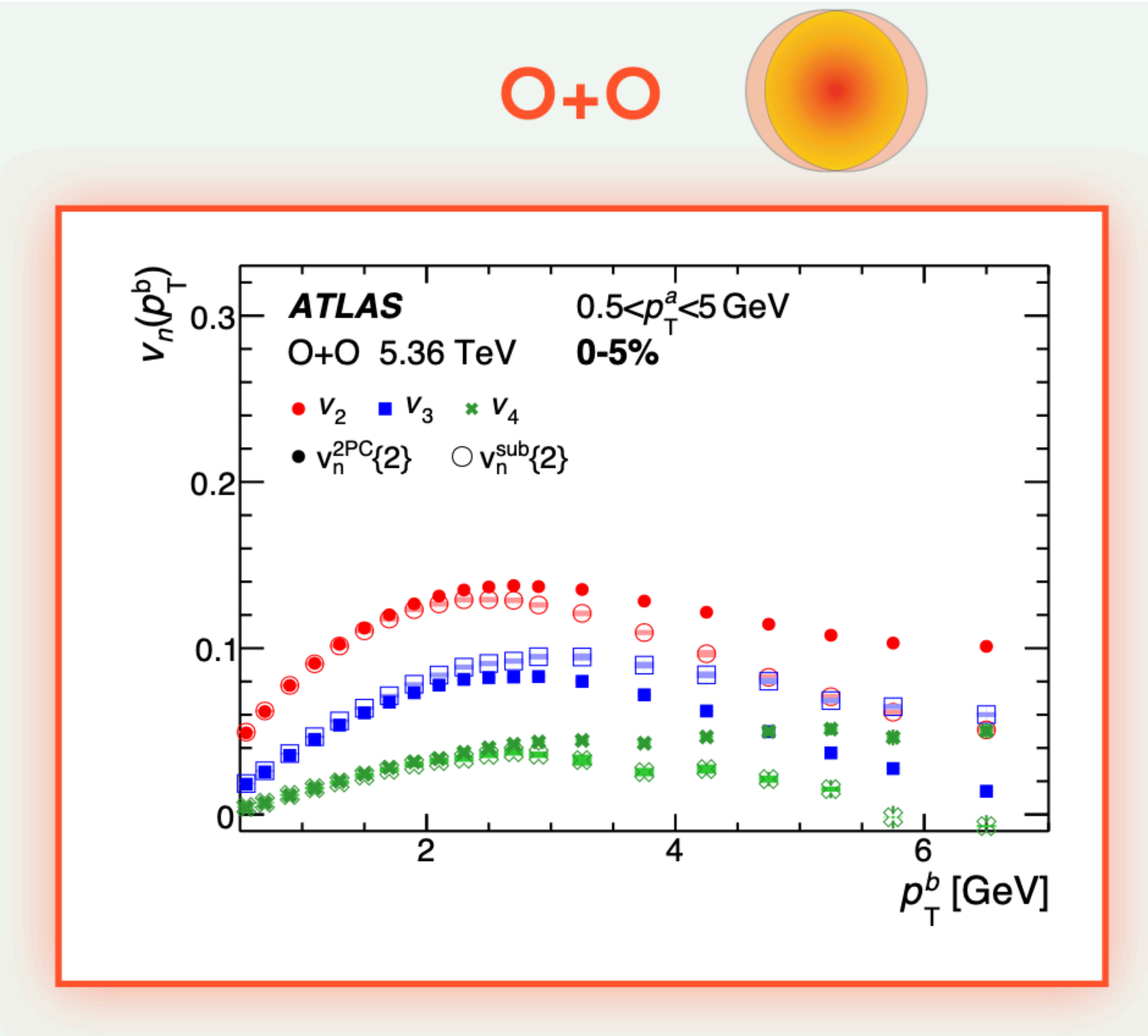
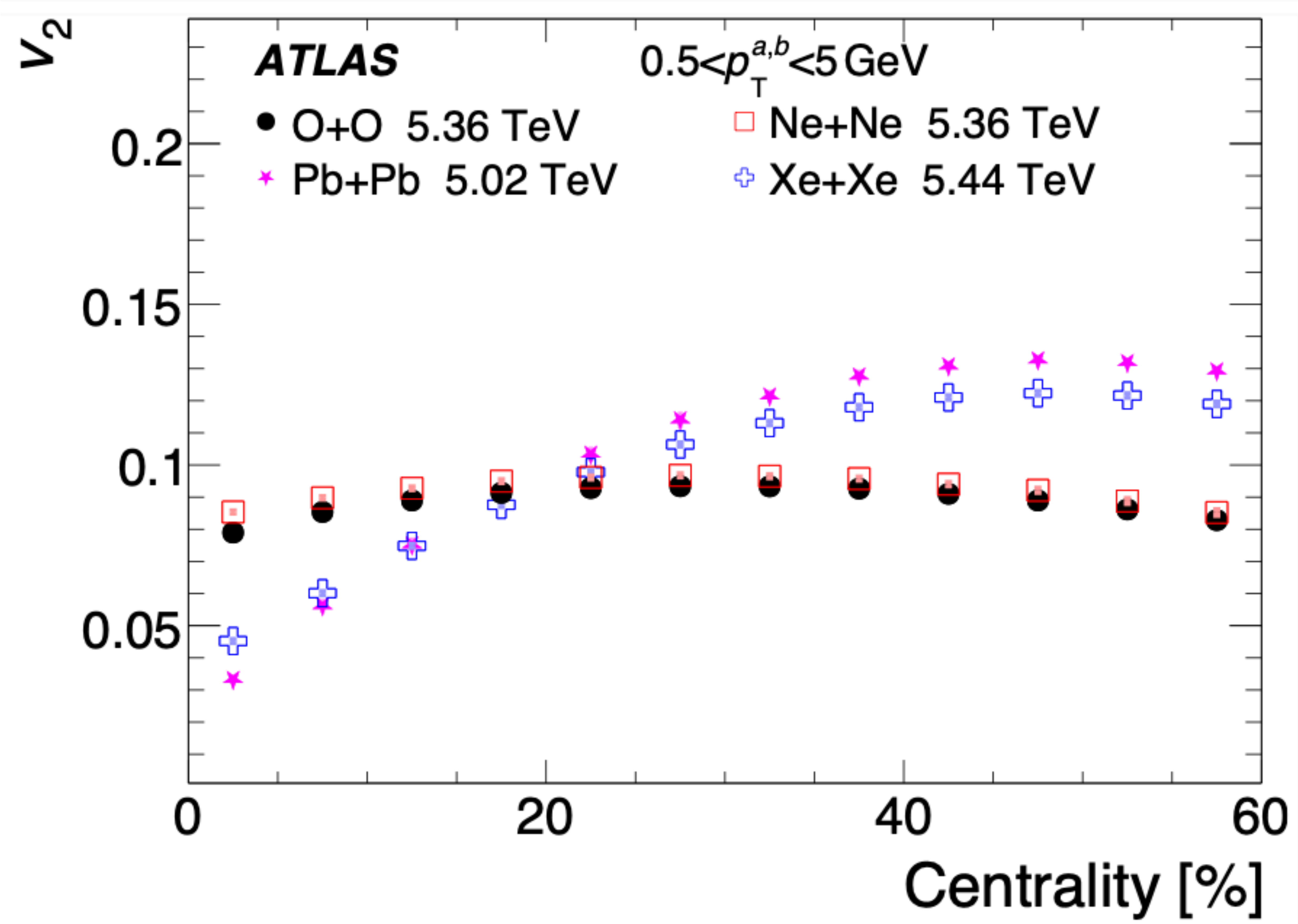
2-Particle Correlation analysis: results

$$v_2 > v_3 > v_4$$





Exposing the bowling-pin geometry of Ne

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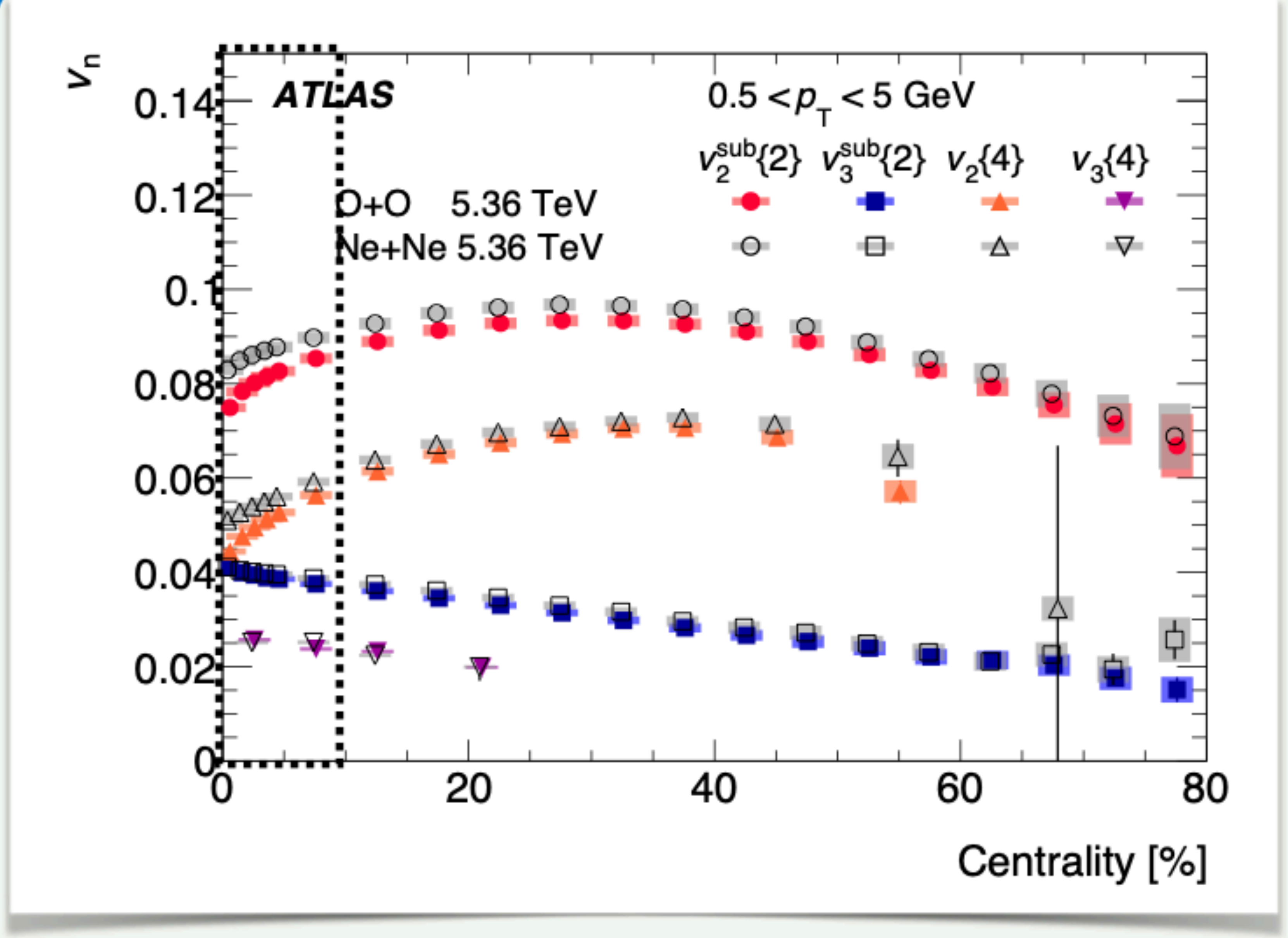
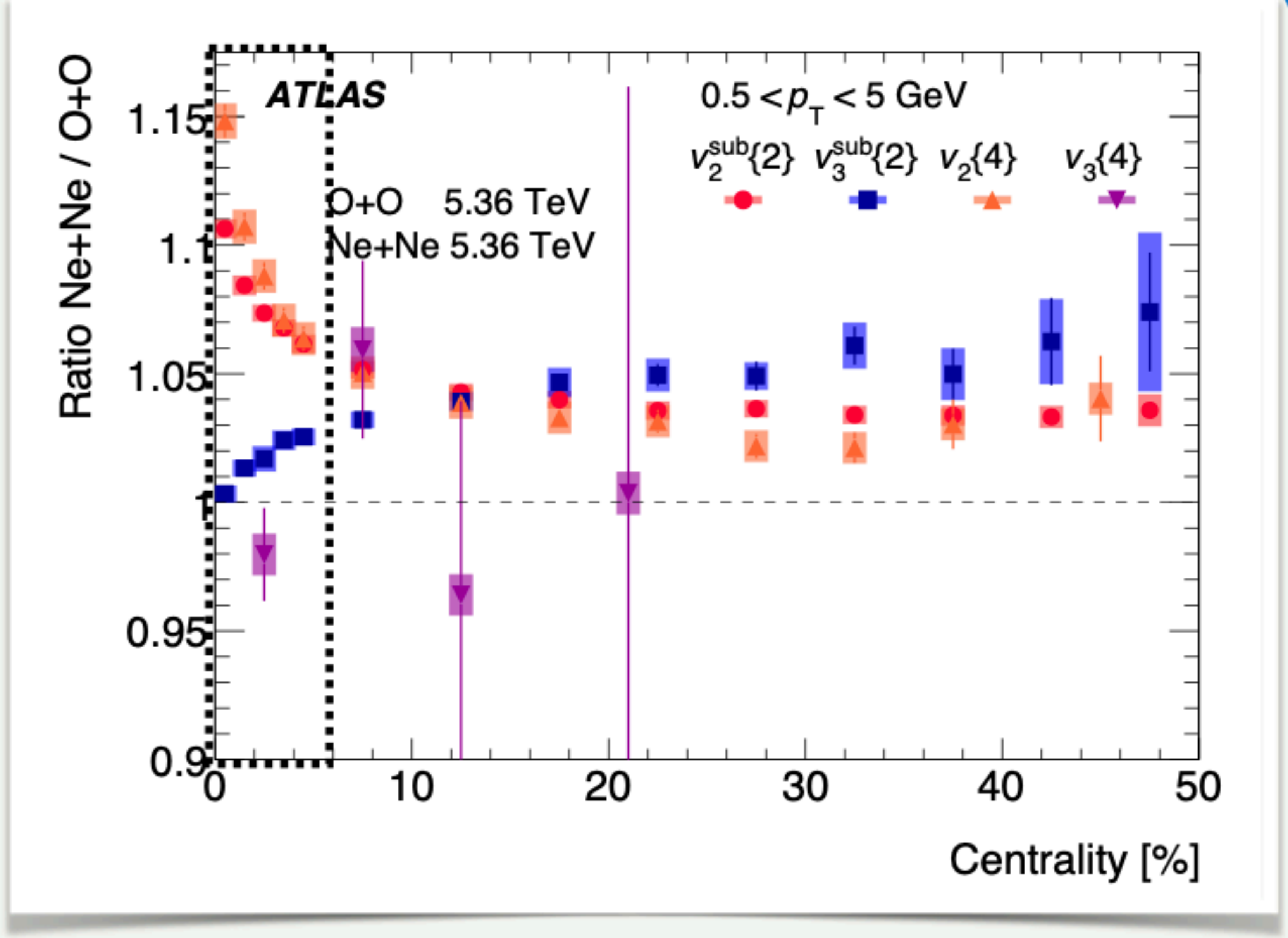
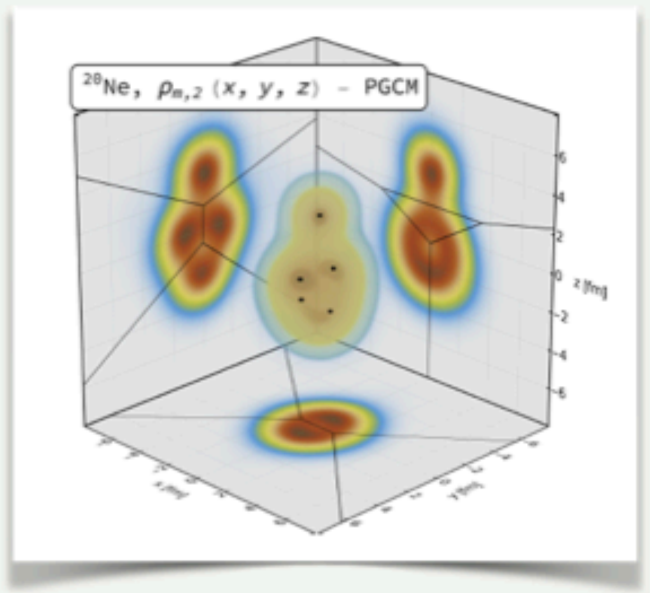
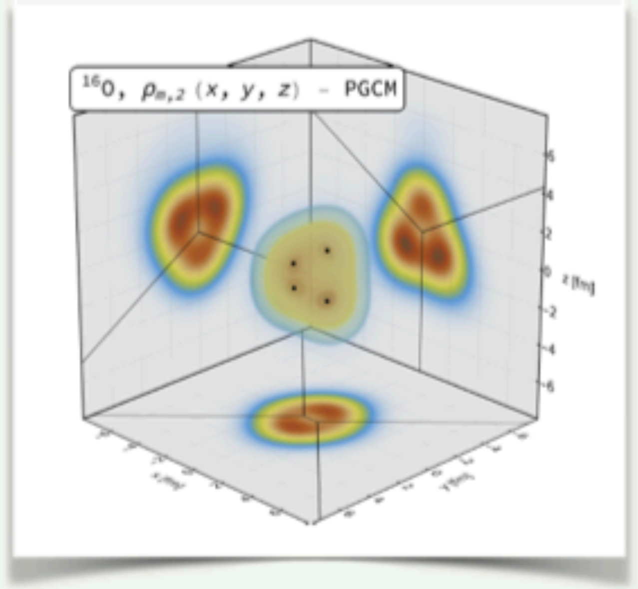


→ Ne+Ne / O+O →



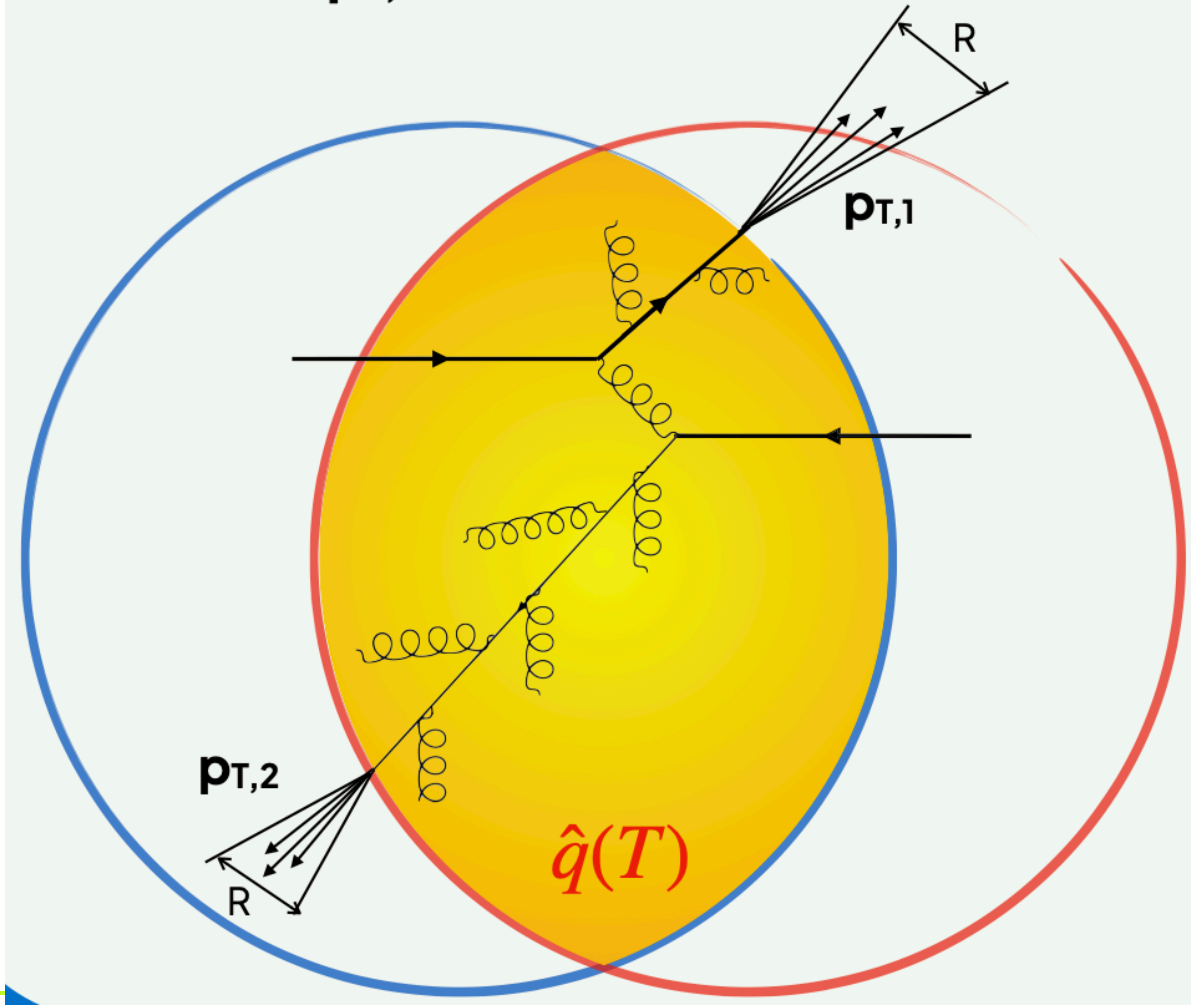
- Usual trend with centrality (e.g., v_2 reduced in more central collisions): trivial geometry?
- But O+O v_2 decreases more rapidly than Ne+Ne while approaching geometrical saturation: **nuclear geometry!**
- Similar triangular flow between the two systems
- Input for modeling?



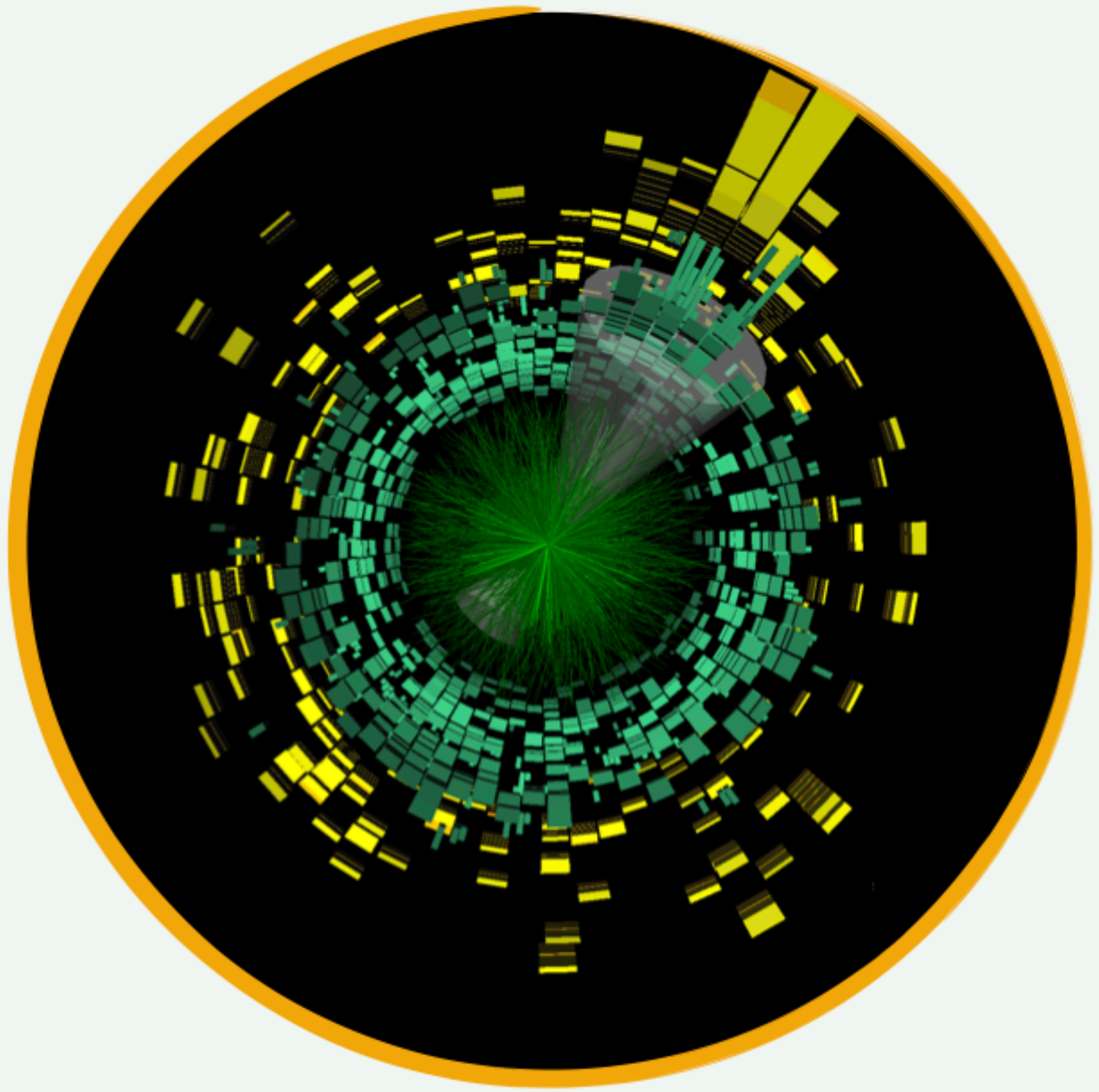


Dijet momentum imbalance - in a nutshell

$x_J = \frac{p_{T,2}}{p_{T,1}}$ **Dijet asymmetry**



In the presence of the medium, the picture significantly changes



Modification of the **dijet momentum balance** directly **probes the medium properties**

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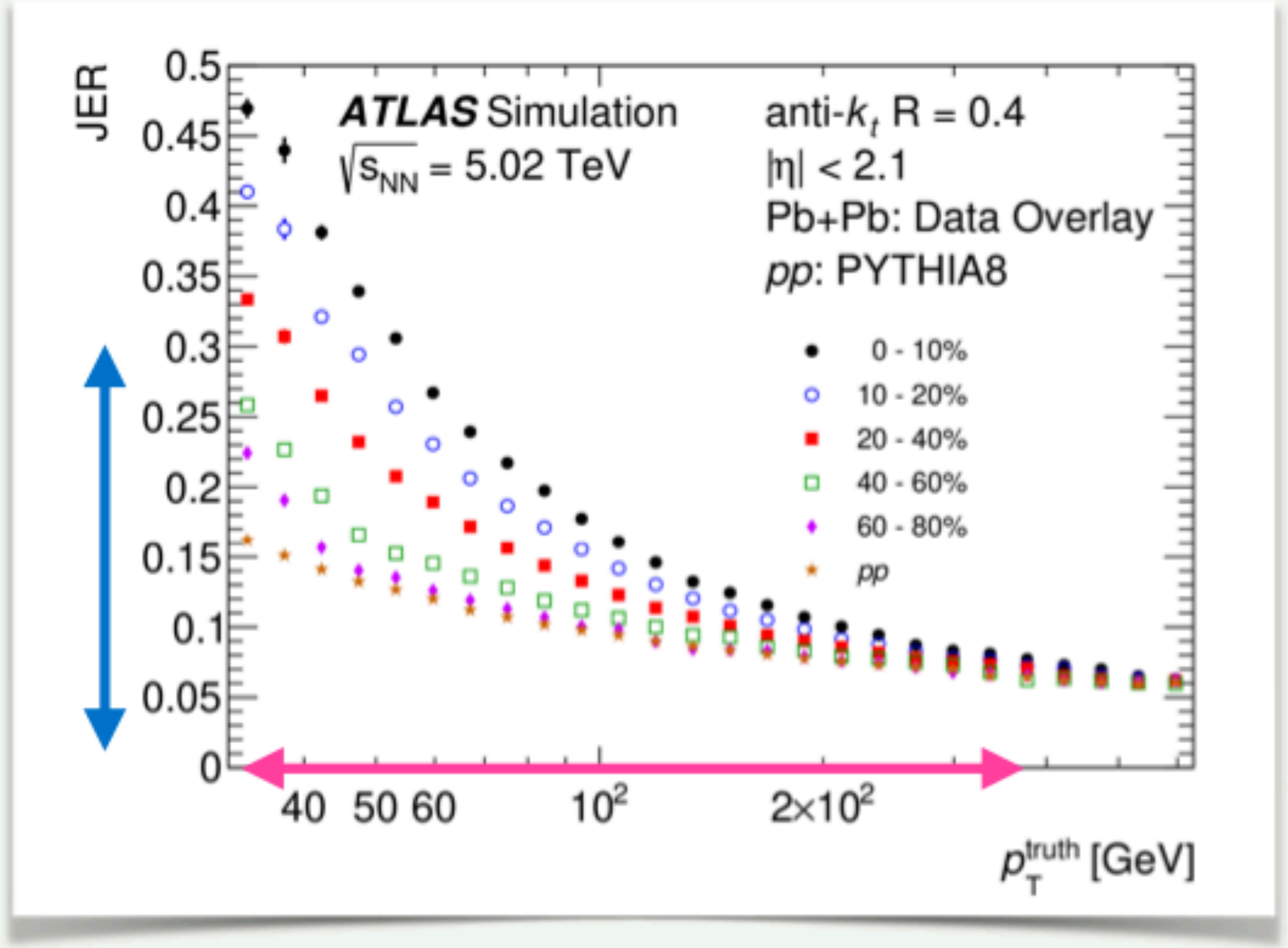
Jet reconstruction performance in O+O vs HI

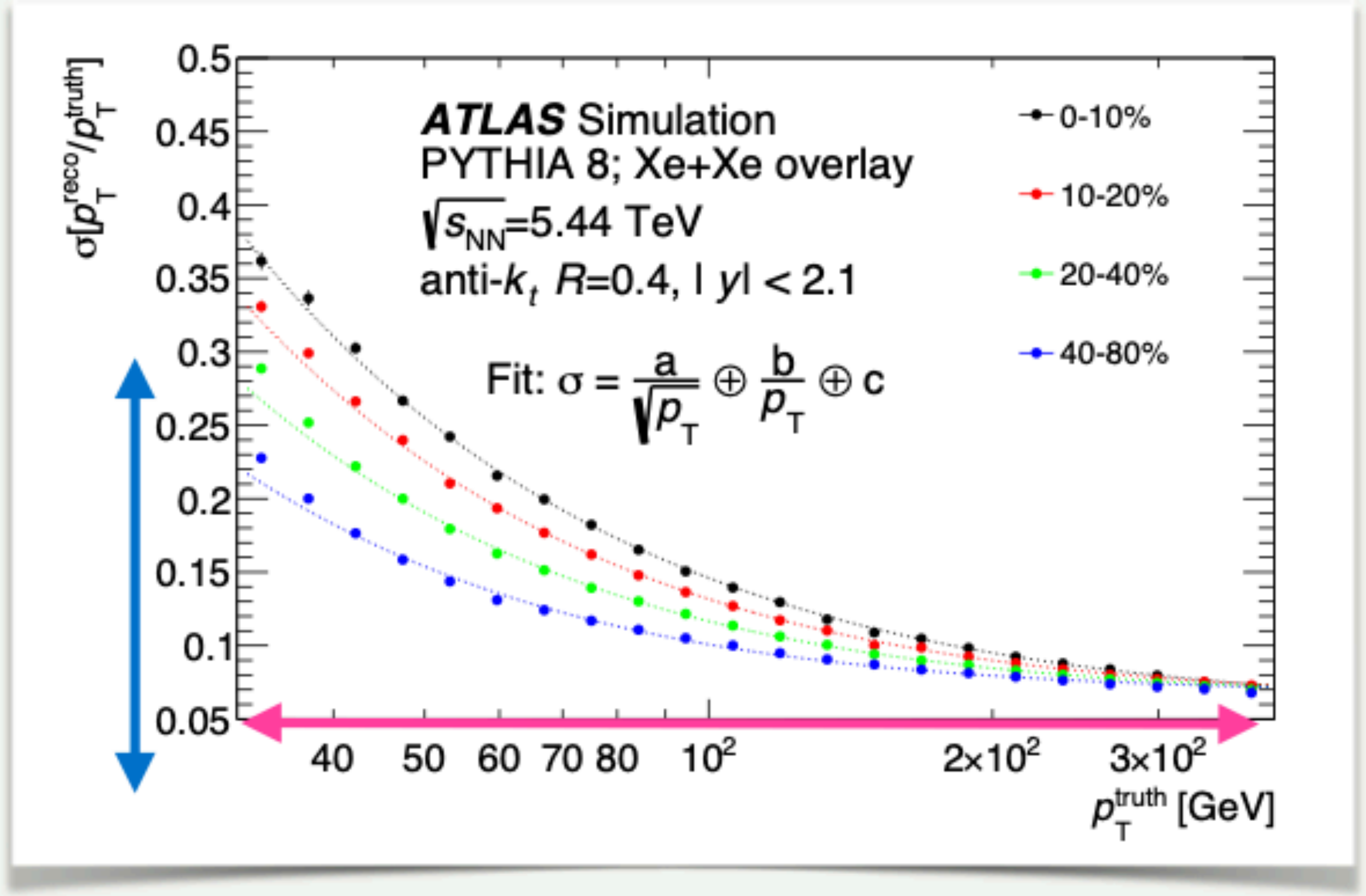
Significantly lower underlying event in O+O compared to Pb+Pb and Xe+Xe

Jet Energy Resolution vs jet p_T

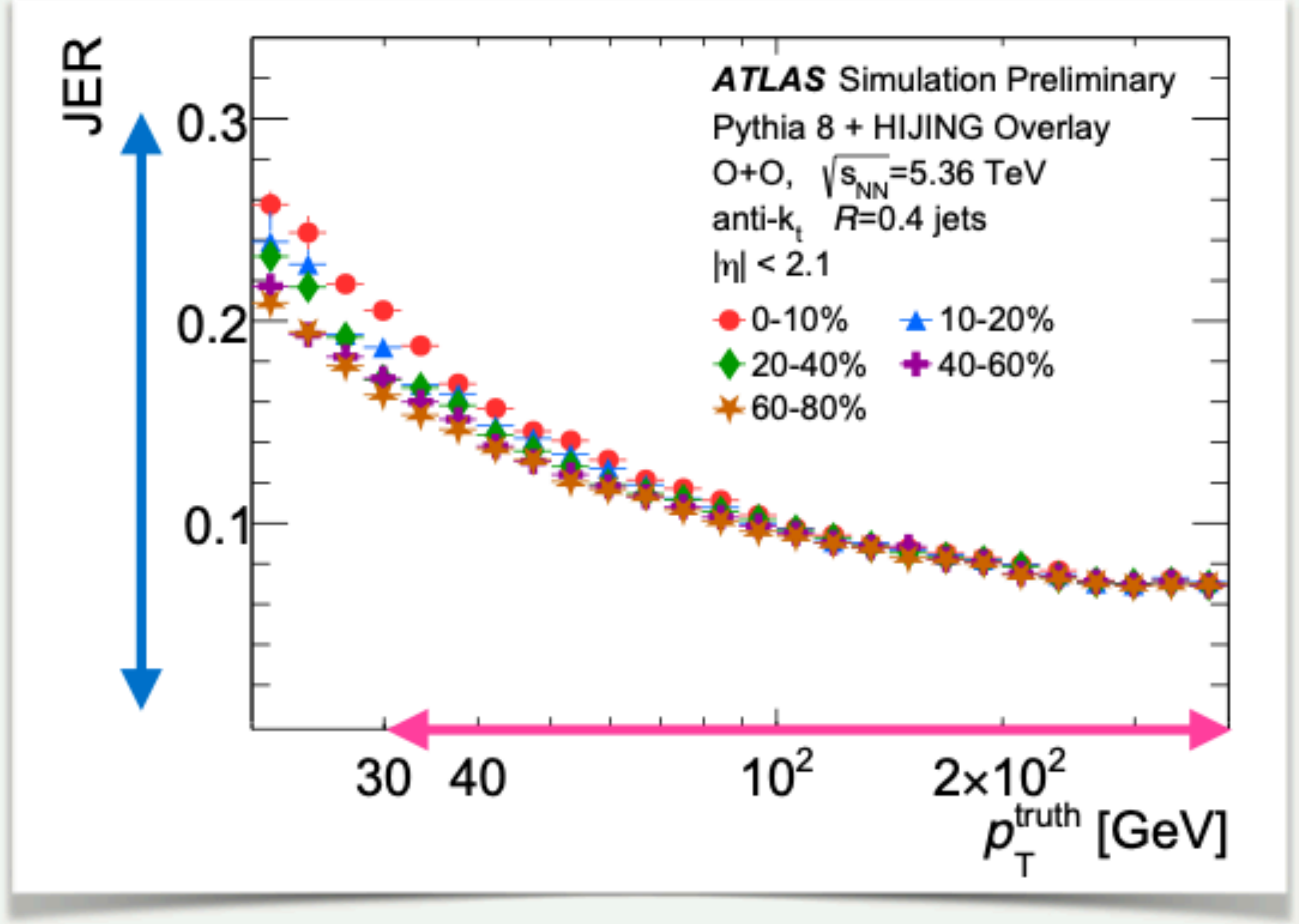
Phys. Rev. C 107 (2023) 054908



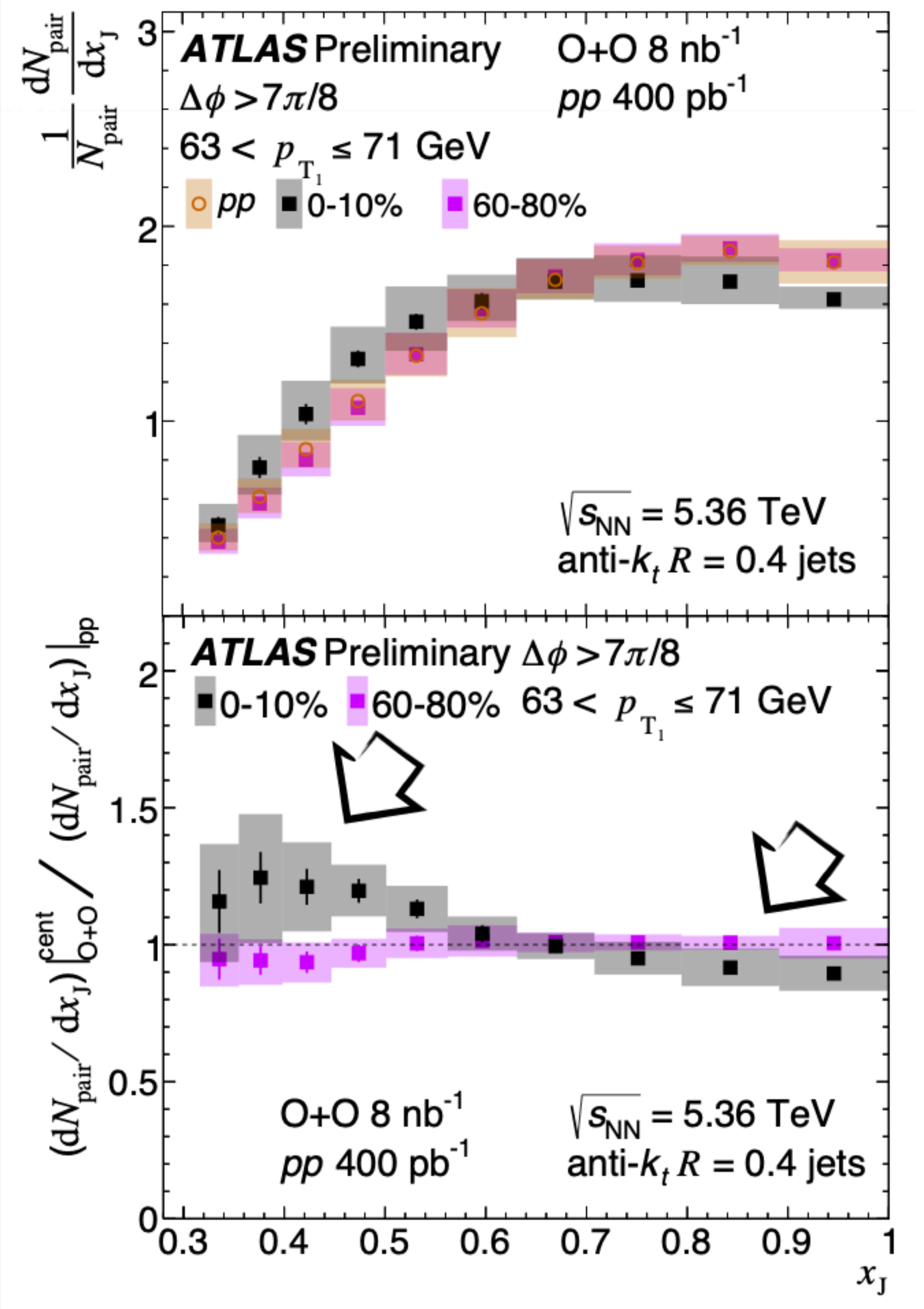
Phys. Rev. C 108 (2023) 024906



ATLAS-CONF-2025-010



Results



Ongoing effort to significantly reduce uncertainties for final results (jet calibration, data overlay)

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Results: $p_{T,1}$ dependence

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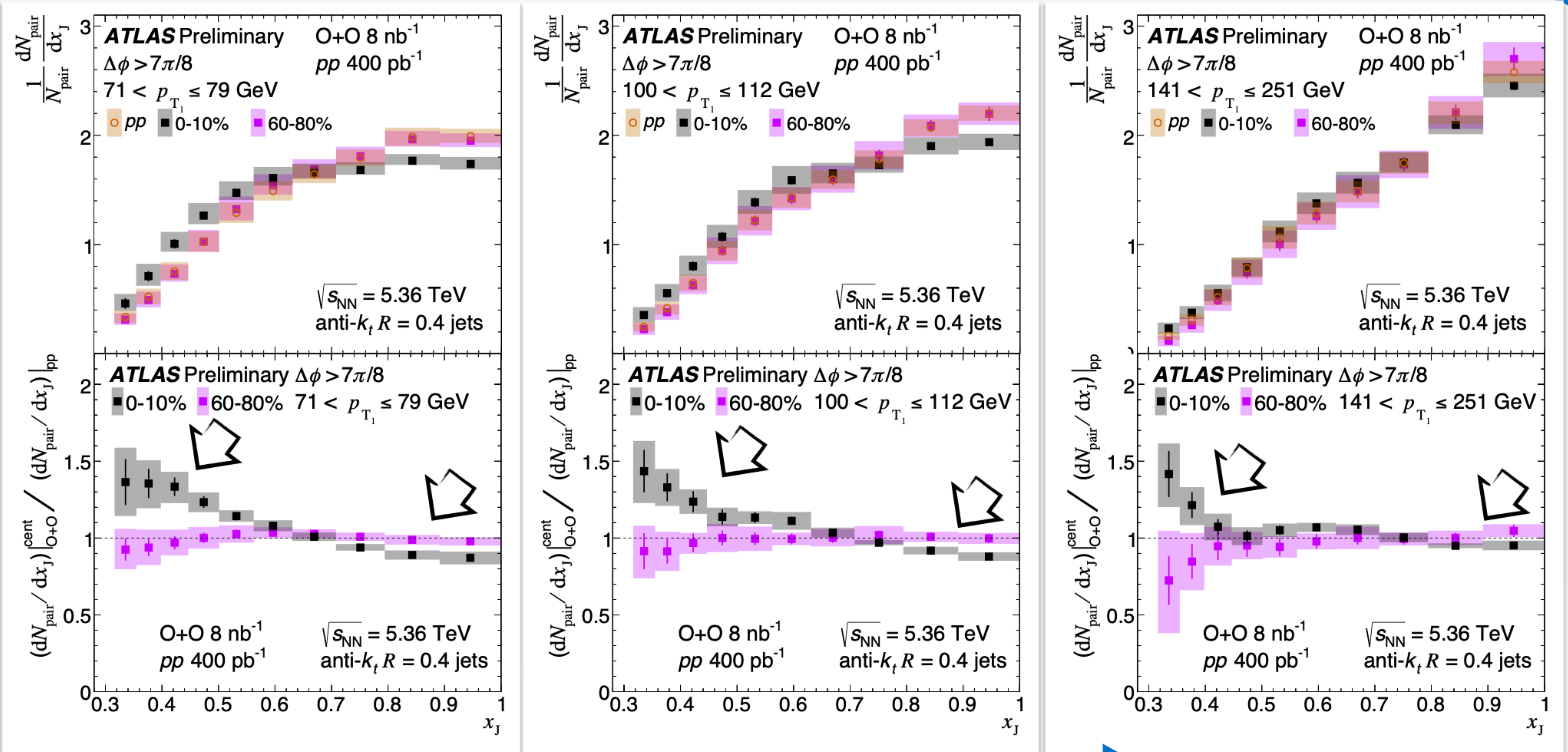
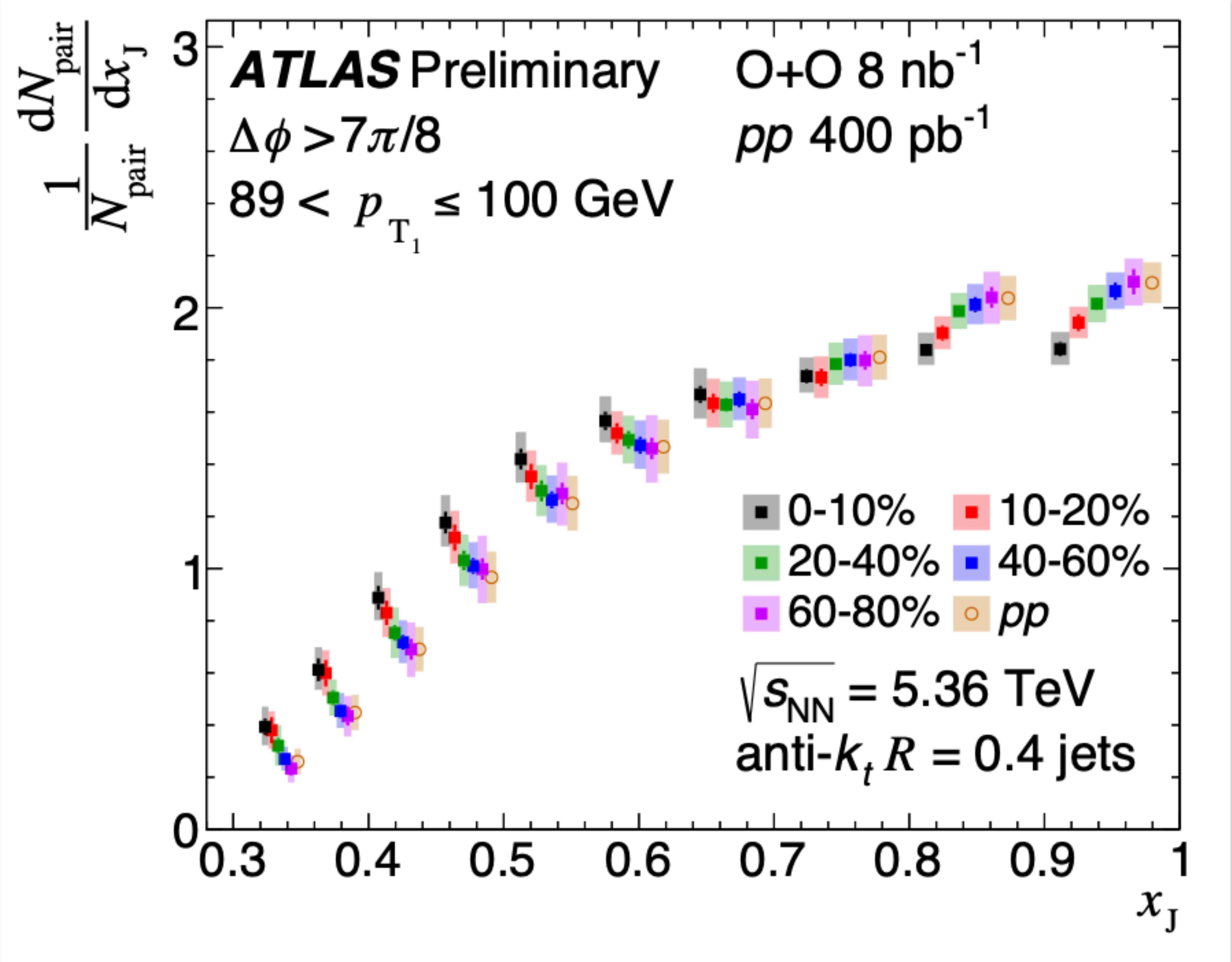


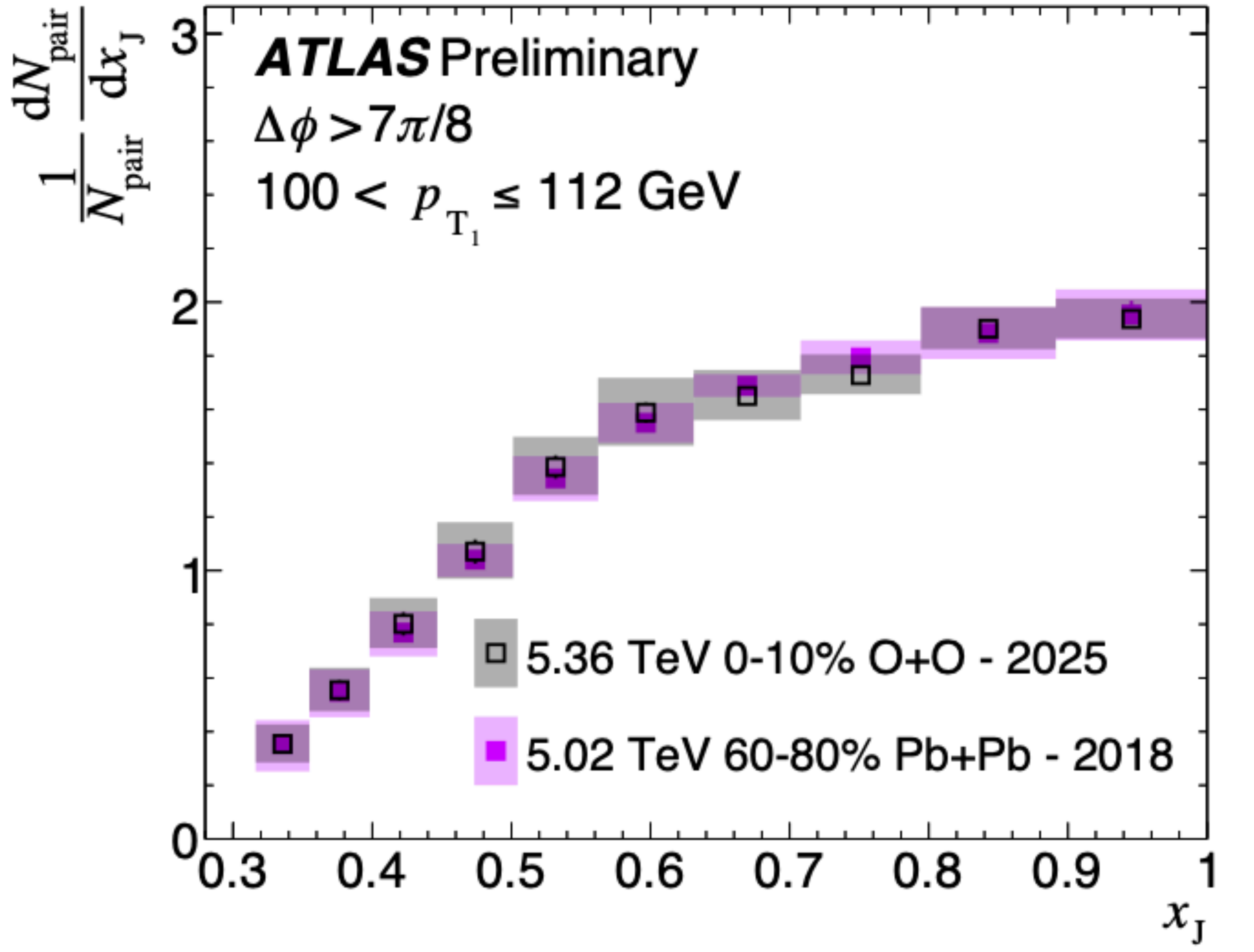
Increasing $p_{T,1}$

Results

ATLAS-CONF-2025-010



Centrality dependence 'evolution'
(Data points are shifted laterally for each centrality)

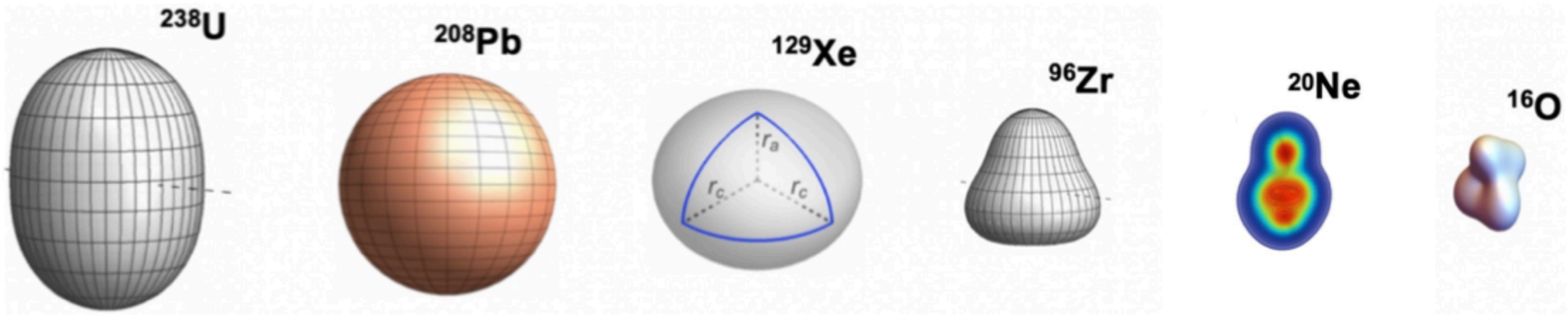


Summary 4/5

- The v_2 coefficients show clear evidence for a difference between Ne and O shapes, consistent with a bowling-pin structure of the Ne;
- Do initial state quantum fluctuations wash out the effects of the initial nuclear geometry? **No**;
- We see clear indications of quenching in O+O: significantly less than in central Pb+Pb, but compatible with peripheral.This is indicative of the path-length dependence of E_{loss};

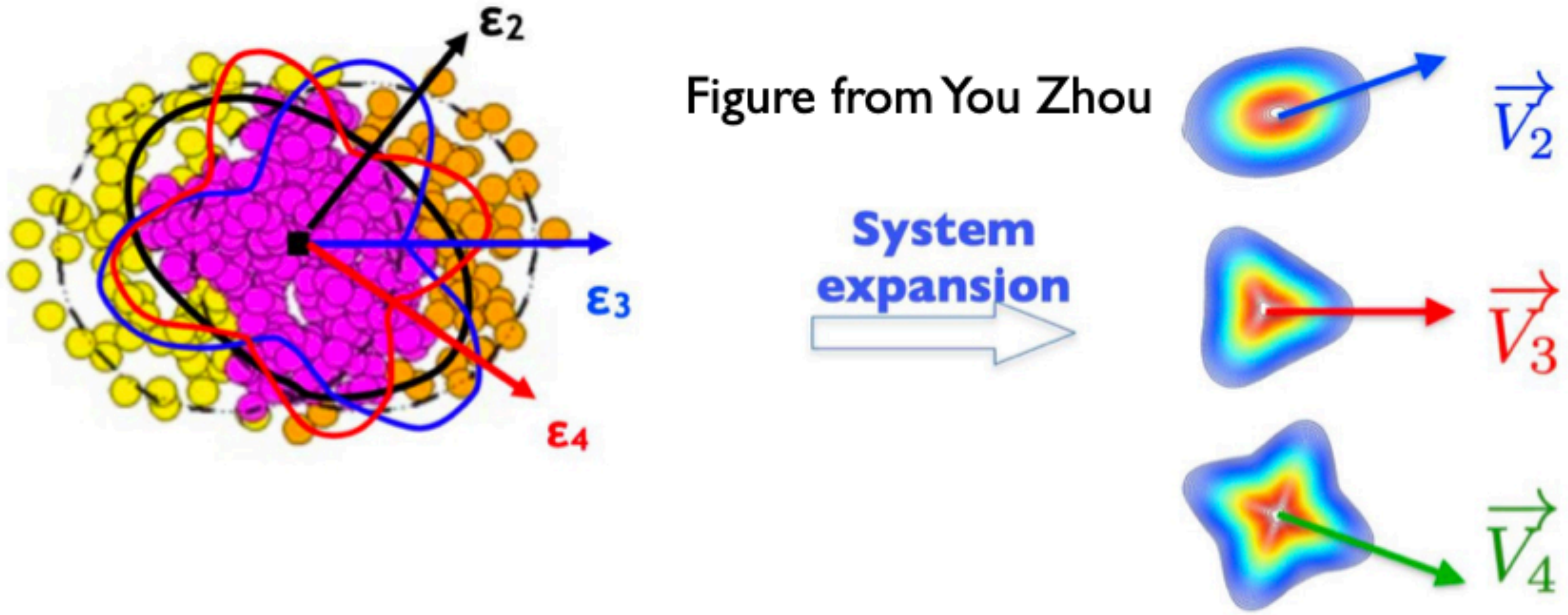
Motivation: Nuclear structure & medium properties in nuclear collisions

- Nuclei are not necessarily spherical
  - Well studied by many approaches: Woods-Saxon density profile, ab-initio calculation, …
  - Not directly observed at low energy experiments



- High-energy nuclear collisions
  - Can we see evidence that collective motion converts initial geometry into momentum space?

Initial state
anisotropic spatial distribution



Final state
anisotropic momentum distribution

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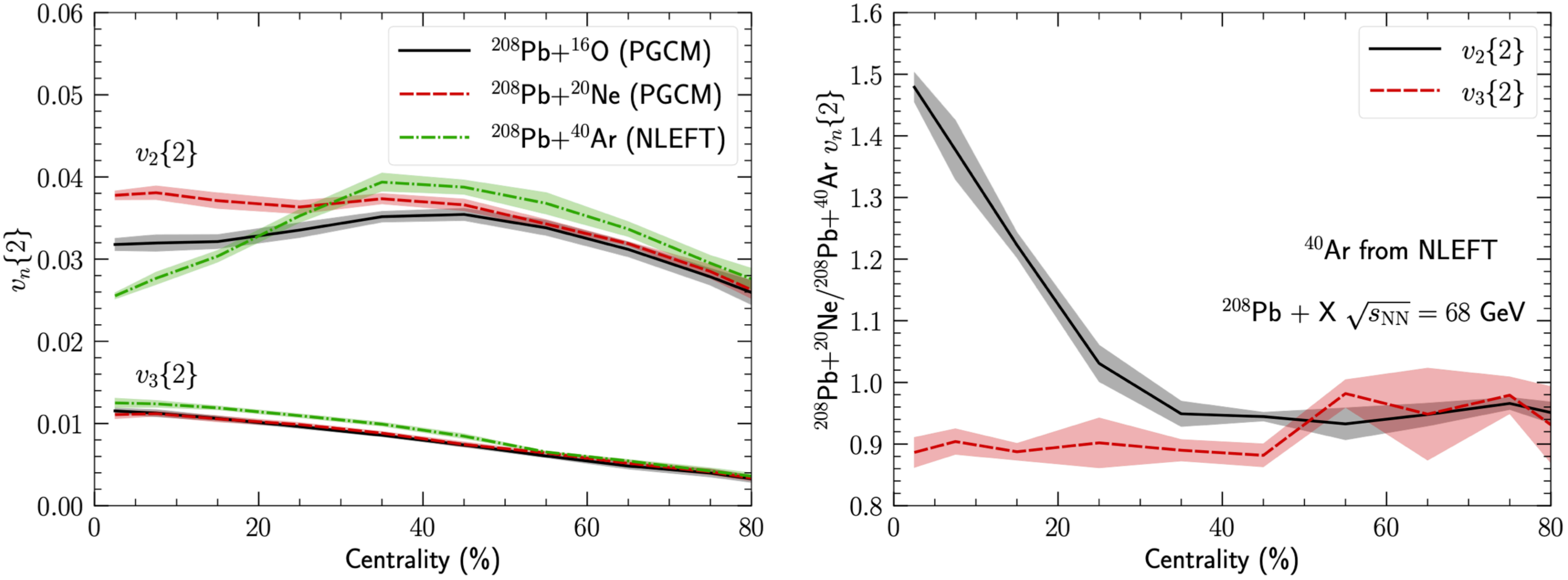
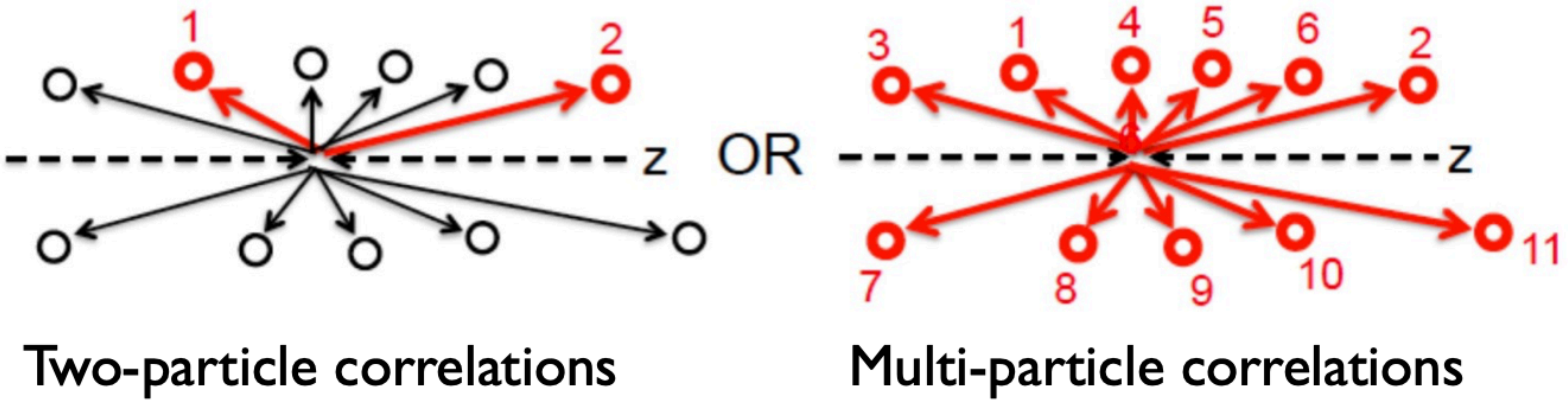
Motivation: Nuclear structure & medium properties in nuclear collisions



The theory predicts that the elongated shape of neon creates a larger elliptical flow v_2.
Therefore, a comparison of Pb+Ne and Pb+Ar may reveal the effect of nuclear deformation.

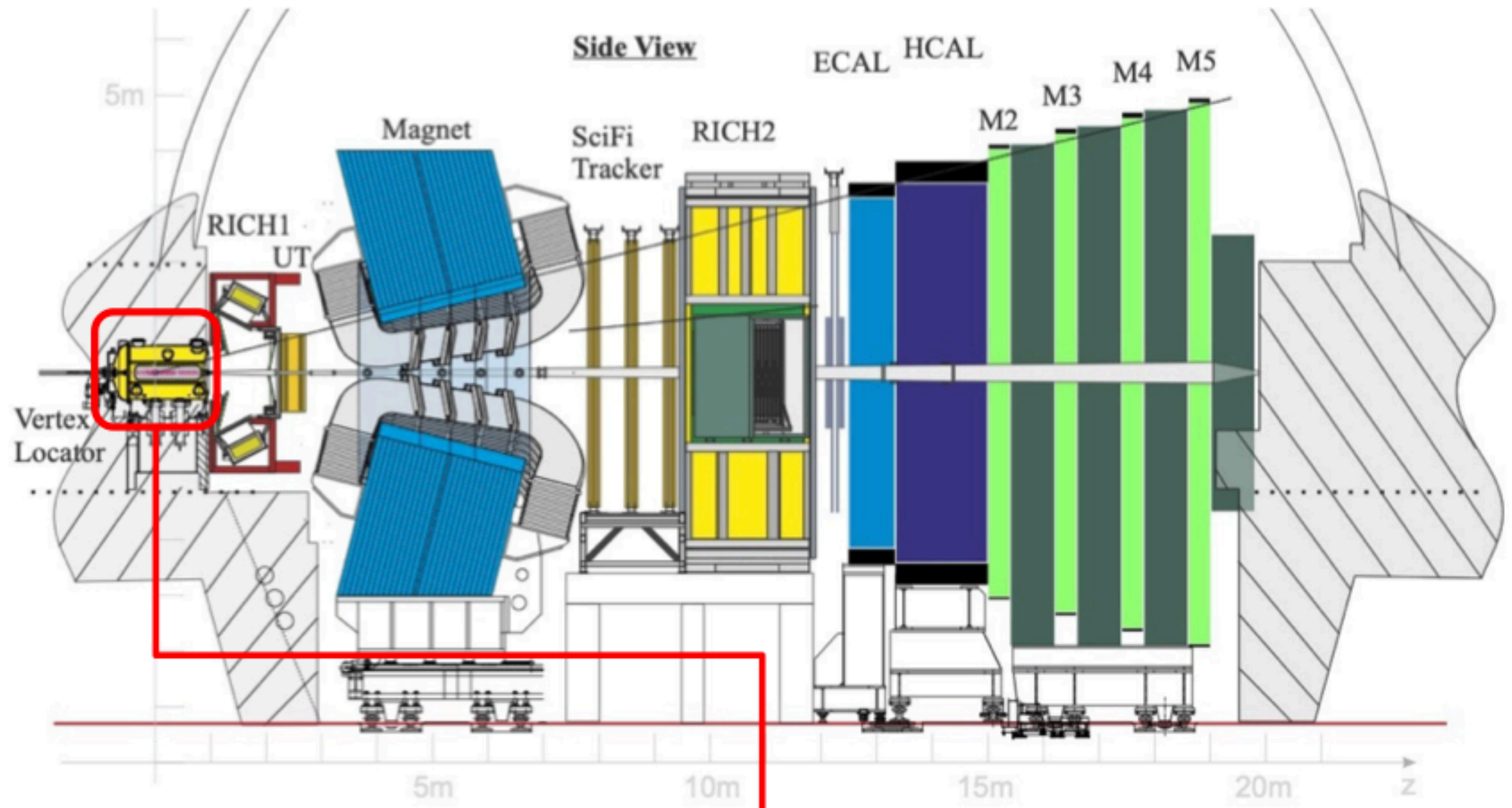
The cumulant method



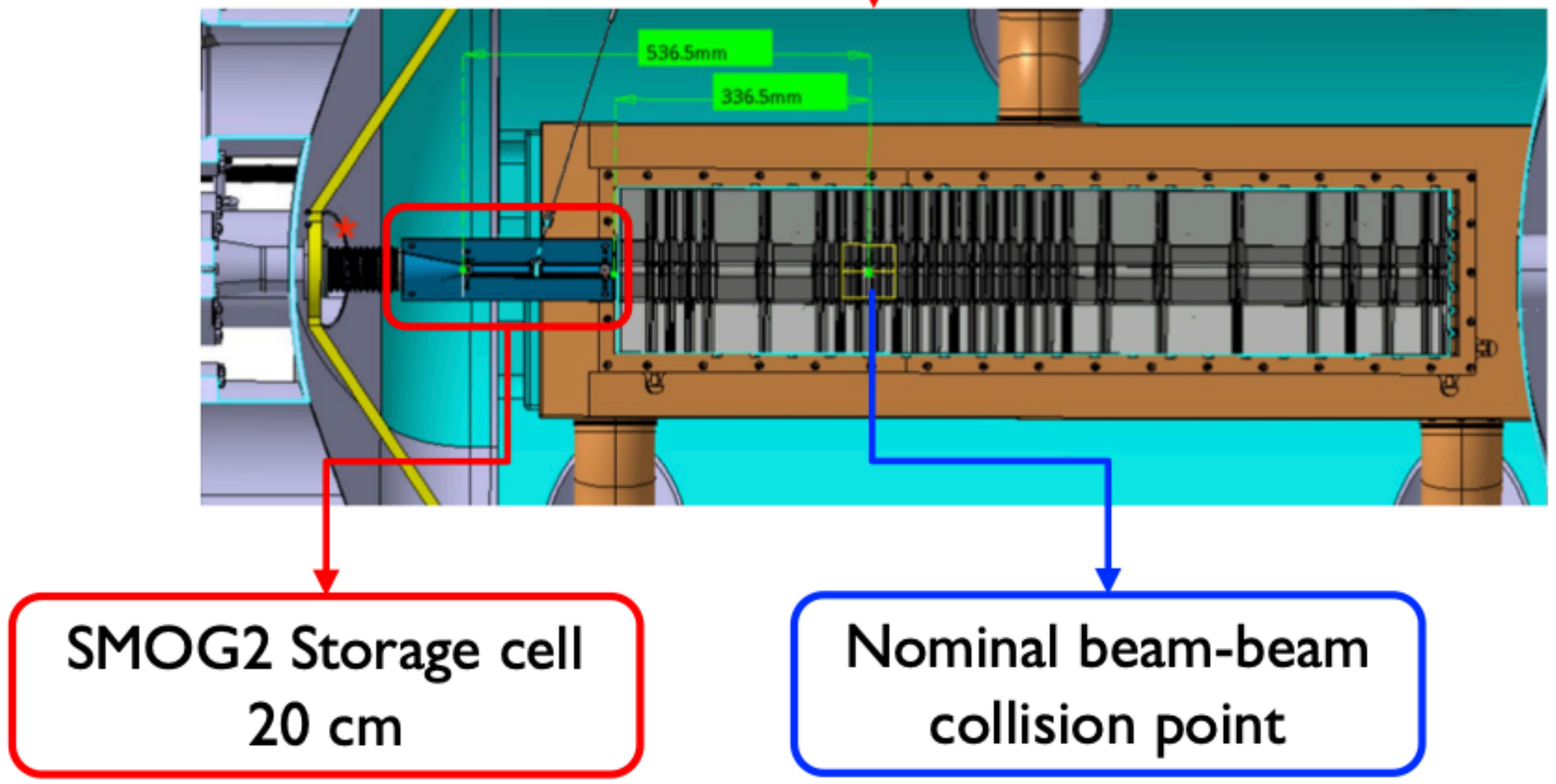
We measure the flow using cumulants, a method that reduces the contribution of the nonflow and uses multiple correlations. This was first applied at LHCb!

The LHCb experiment

JINST 19 P05065 (2024)

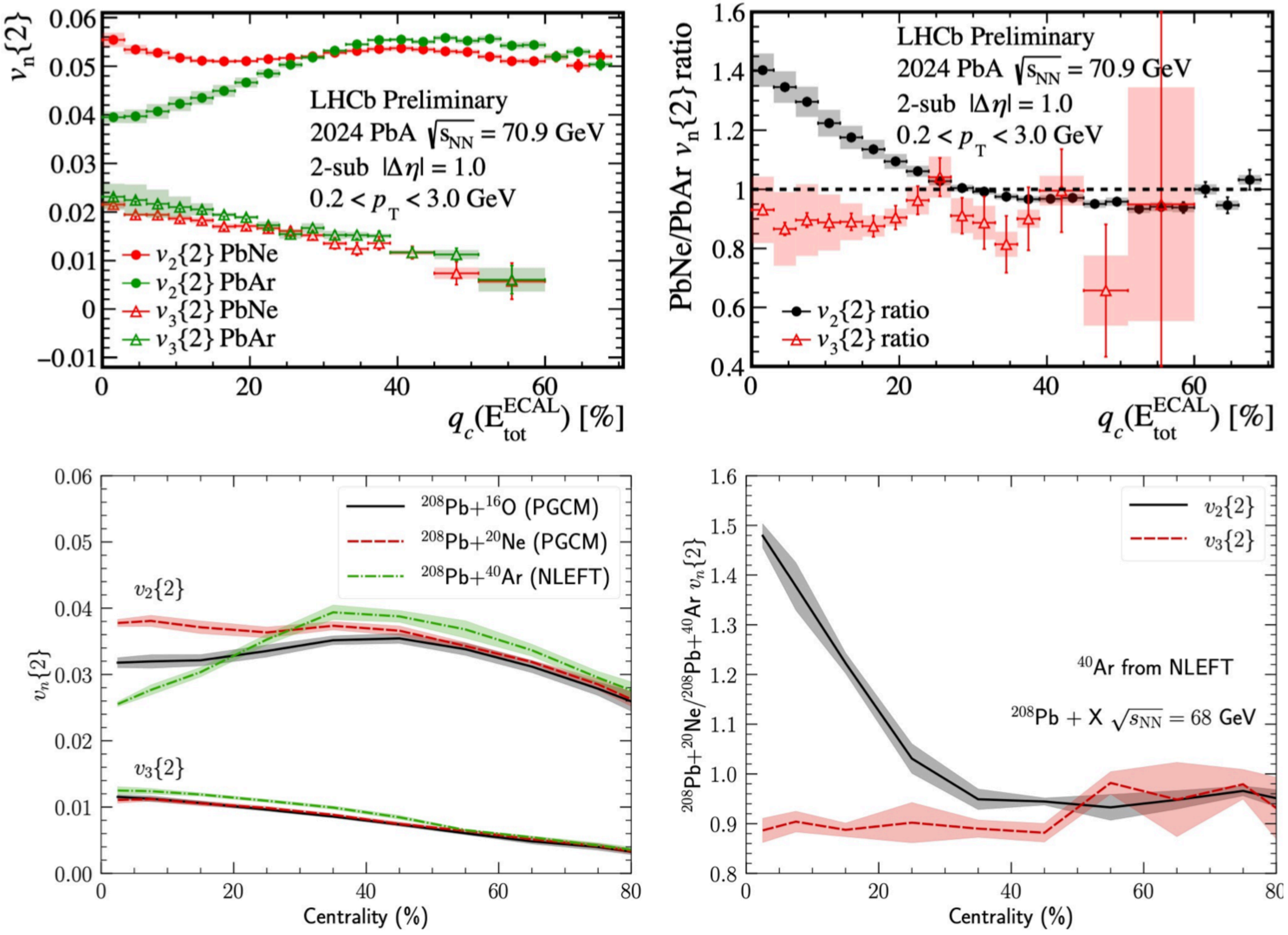


Phys. Rev. Accel. Beams 27 111001



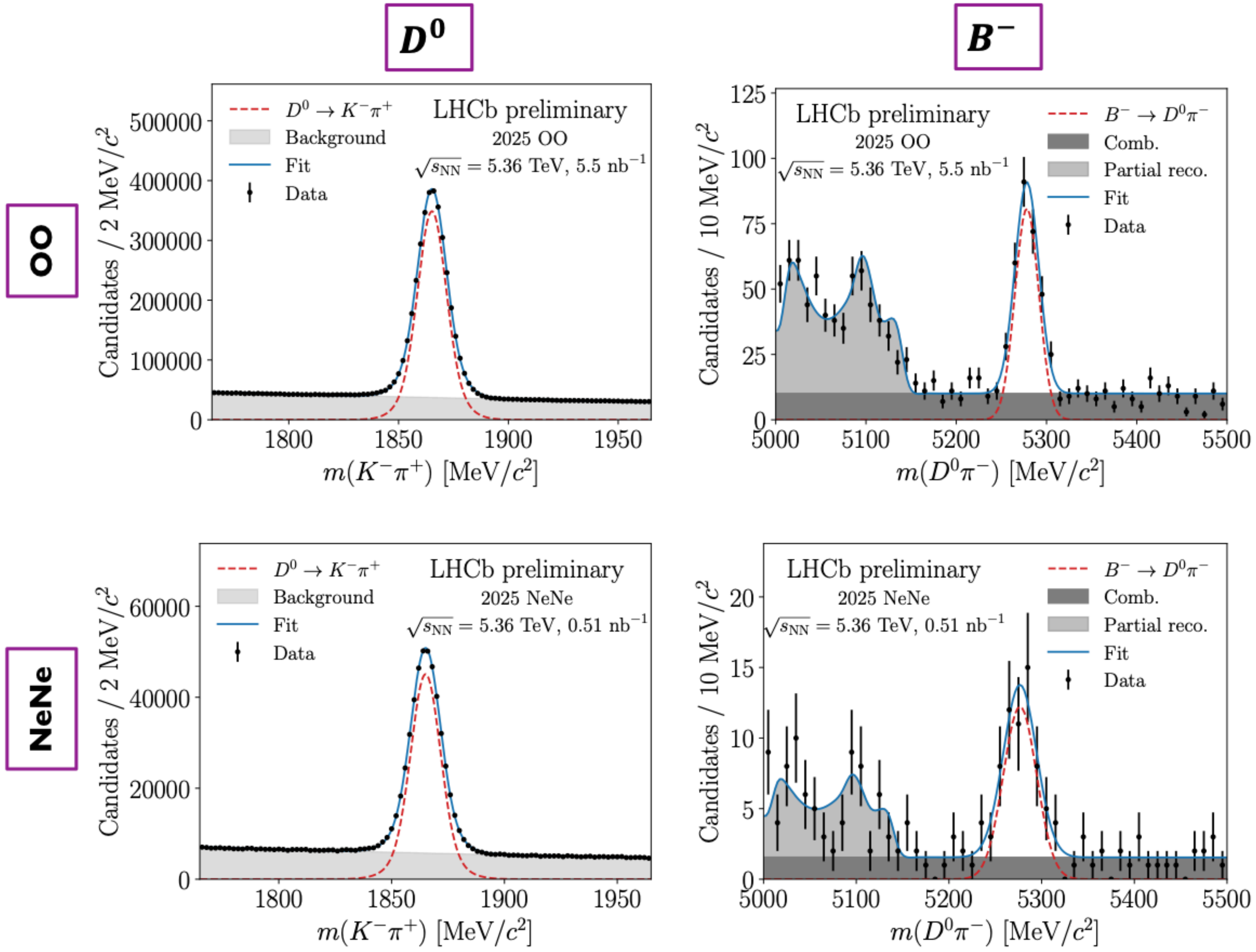
- SMOG2: The updated *System for Measuring Overlap with Gas*
  - A high density storage cell placed in the LHC primary vacuum
  - Wide choice of injectable gases: He, Ne, Ar, H_2, D_2, …
  - Unique physics opportunities at intermediate energies: $\sqrt{s_{NN}} \in [30, 115]$ GeV
  - Dataset for this analysis: PbNe(0.06 nb^{-1}) and PbAr(1.7 nb^{-1}) at $\sqrt{s_{NN}} = 70.9$ GeV
  - A primary vertex reconstructed within the SMOG2 cell

The LHCb experiment



We see that v_2 is higher for PbNe than for PbAr, especially in central collisions—this is consistent with hydrodynamic predictions taking into account the deformation of the neon nucleus.

NeNe/OO data-taking: Colliding mode



LHCb-FIGURE-2025-017

Very clean charm and beauty signal

With pO data, will enable providing very precise constraints to nPDF

With OO and NeNe data, studying plasma signatures in small systems (energy loss, collectivity, quarkonia suppression)

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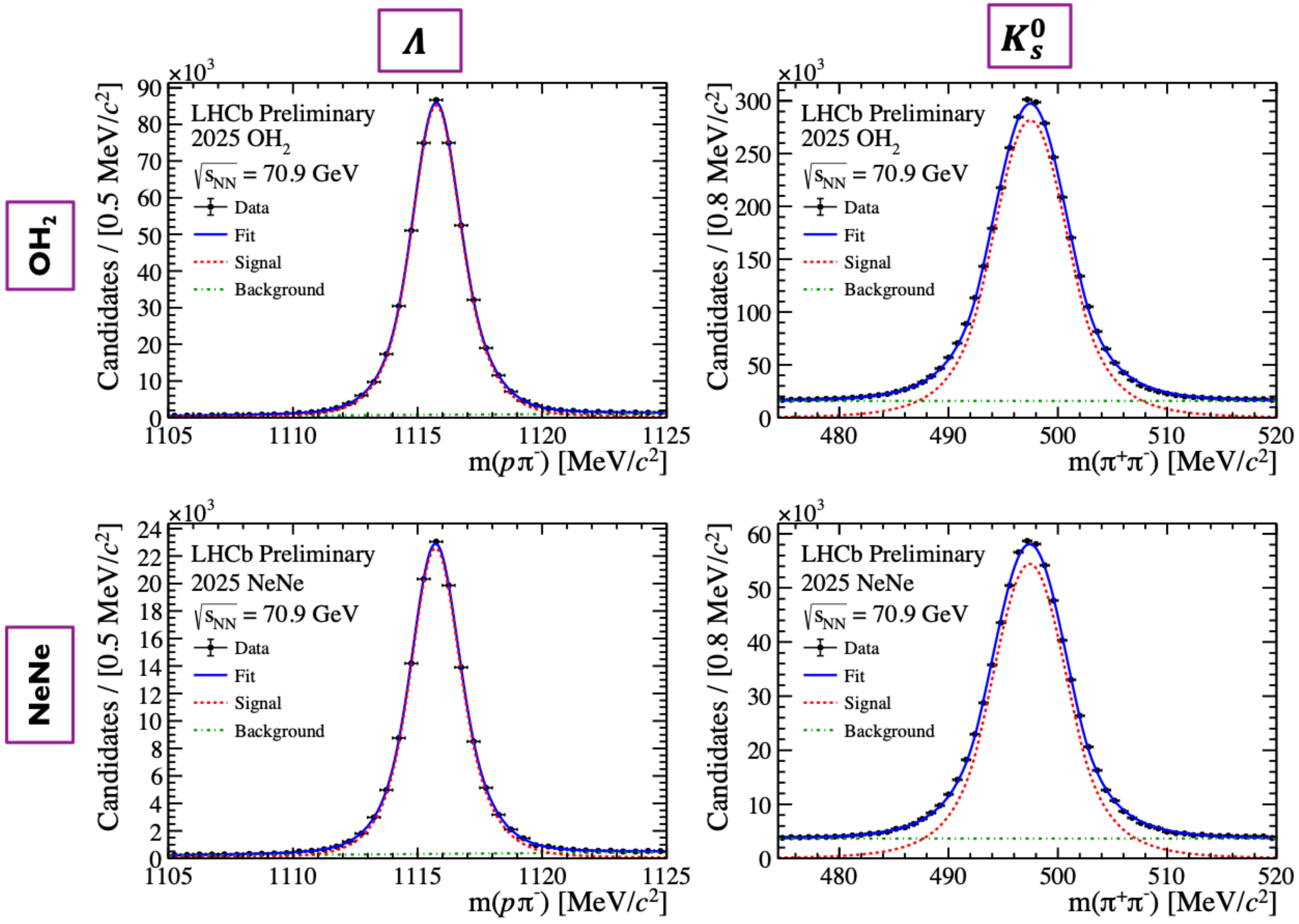
NeNe/OO data-taking: Fixed-target



LHCb-FIGURE-2025-019

Unique opportunities for cosmic-ray measurements (air showers and muon puzzle), as well as nuclear imaging and collective dynamics in small systems

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Summary 5/5

- Preliminary anisotropic flow measurements in PbNe and PbAr collisions
  - First result with the upgraded SMOG2 system
  - Evidence of the ^{20}Ne nucleus deformation and its effect on collective motions
  - Further measurements to reveal the possible cluster structures of light nuclei (e.g. $v_n - p_\mathrm{T}$ correlation) and tests of hydrodynamic predictions (e.g. $v_n(p_\mathrm{T})$) will follow soon
- In the 2025 light ions run, LHCb collected unique OH_2 and NeNe fixed-target samples as well as OO and NeNe samples in colliding mode
  - Opportunity for cosmic-ray measurements
  - Nuclear structure and collective dynamics in small systems


DANKE!
THANK YOU!
MERCI!
GRAZIE!
GRACIAS!
DANK JE WEL!
....

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