



Probing deconfinement and related phenomena from small to large systems with Υ meson measurements with the CMS experiment

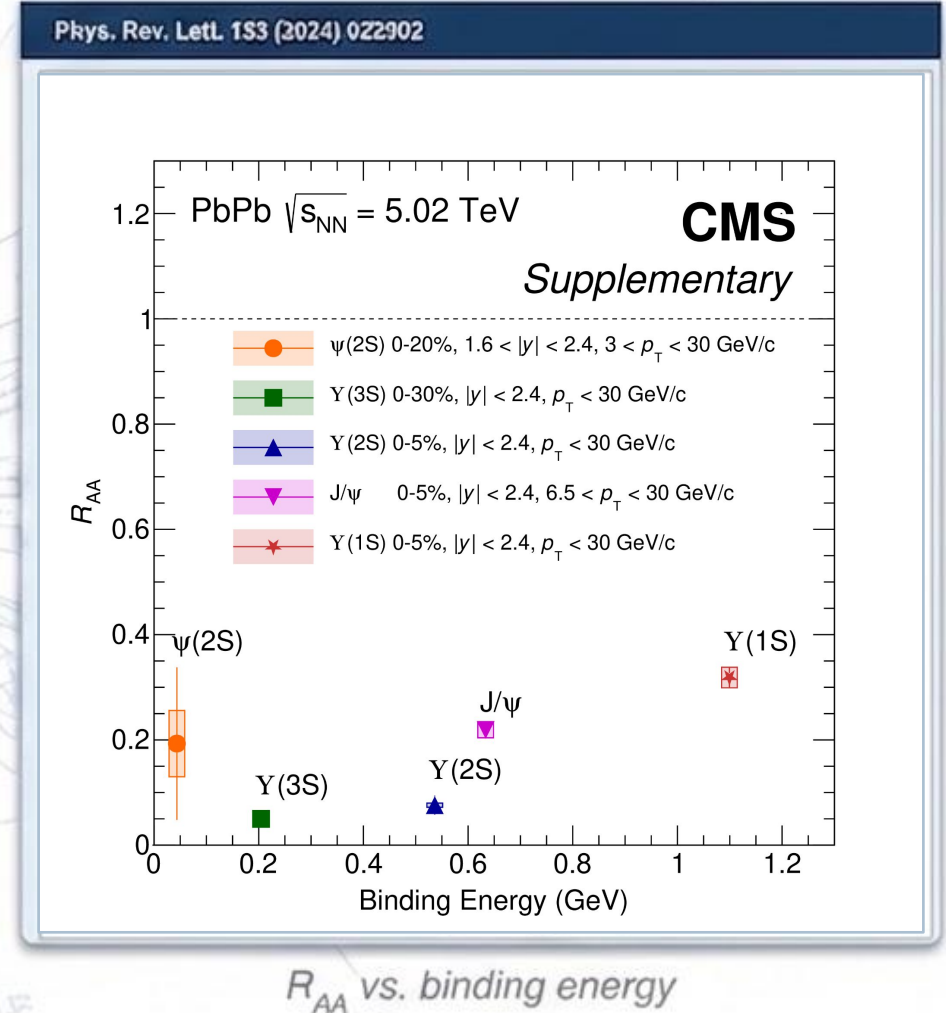
Evidence for Sequential Υ Suppression in Light Ion Collisions
(arXiv:2607.13758)

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The University of Kansas

EMMI Workshop: Light-ion collisions 2026 | Heidelberg University | 21–25 Sep 2026



- **Big Question:** Does a deconfined medium (QGP) form in systems smaller than PbPb?
- **Symmetric Systems:** OO and NeNe provide a bridge between pp/pPb and PbPb.
- **Sequential Y Suppression:**
 - Y(1S), Y(2S), Y(3S) have their R_{AA} 'ordered'.
- Hierarchy reflects the dissociation process: weaker states melt first ('Debye screening').
- **Modern descriptions** emphasize a complex in-medium potential for suppression via QGP.
 - Alternatively, could be induced by co-moving particles in the final state.



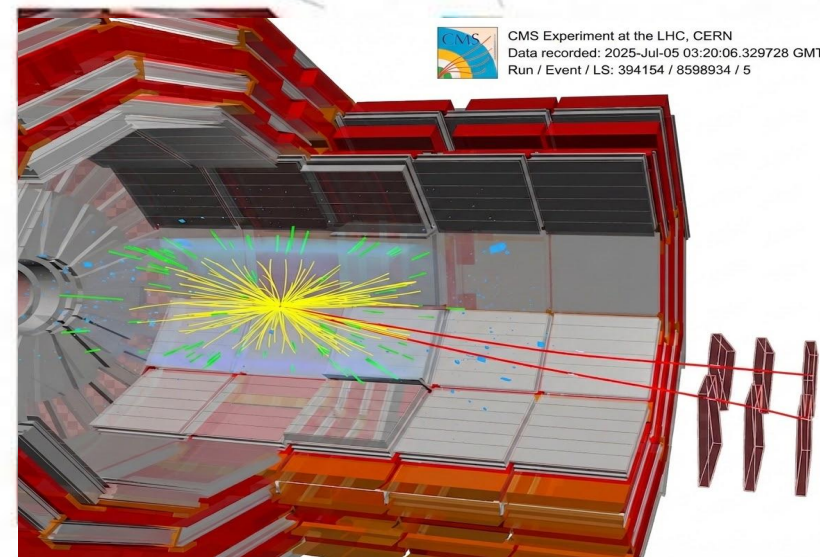
Experimental Setup

Datasets (LHC Run 3 at 5.36 TeV)

- OO ($8.4 \pm 0.3 \text{ nb}^{-1}$) and NeNe ($0.81 \pm 0.03 \text{ nb}^{-1}$)
- High-statistics pp reference ($456 \pm 14 \text{ pb}^{-1}$)

Analysis Strategy

- **pp**: Double muon trigger
- **ions**: Single muon trigger (for efficiency & systematic uncertainty)
- Opposite-sign “soft-ID” muons form $m_{\mu^+\mu^-}$ (fitting variable)
- Acceptance / efficiency from embedded PYTHIA8 + HIJING



CMS Experiment at the LHC, CERN
Data recorded: 2025-Jul-05 03:20:06.329728 GMT
Run / Event / LS: 394154 / 8598934 / 5

Large Acceptance

$\mu^+ \mu^-$

Particle-flow muons with

$$|\eta^\mu| < 2.4$$

$$p_T^\mu > 4.0 \text{ GeV}$$

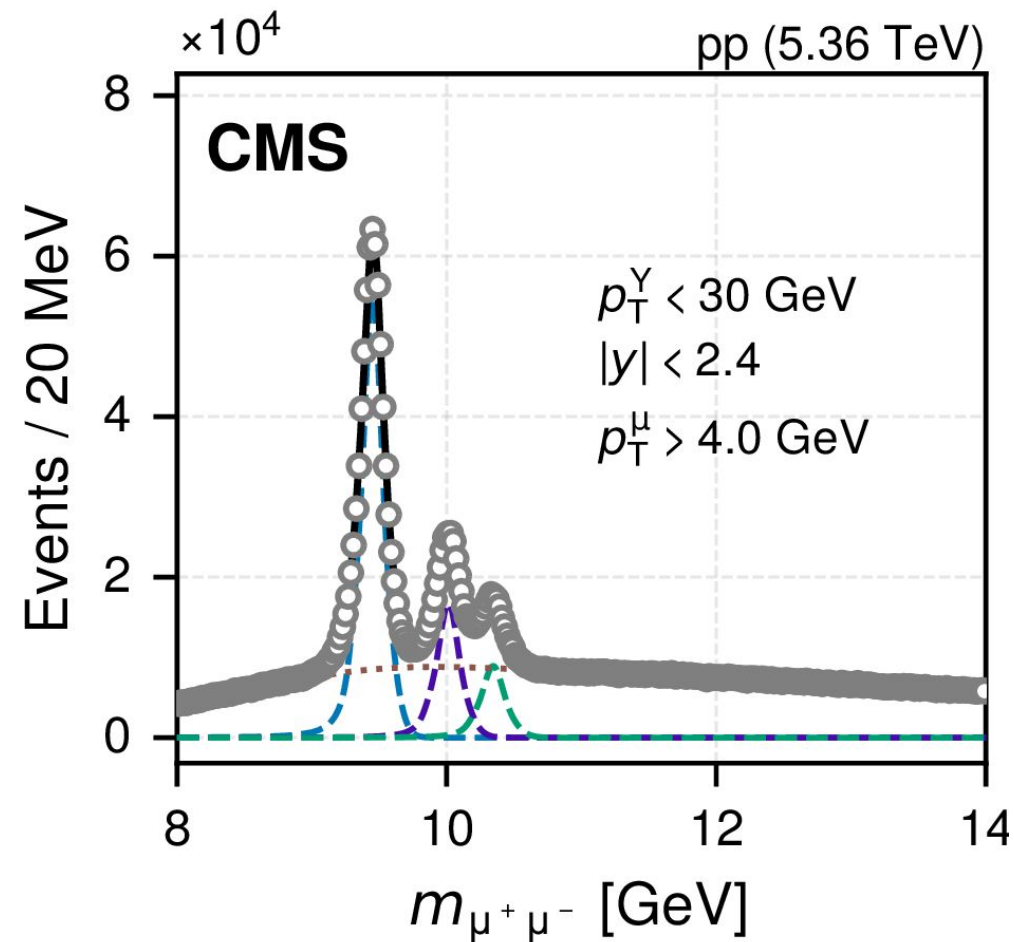
Offline muon selection is **kept identical** across reference and ion samples.

Dimuon channel and fit model

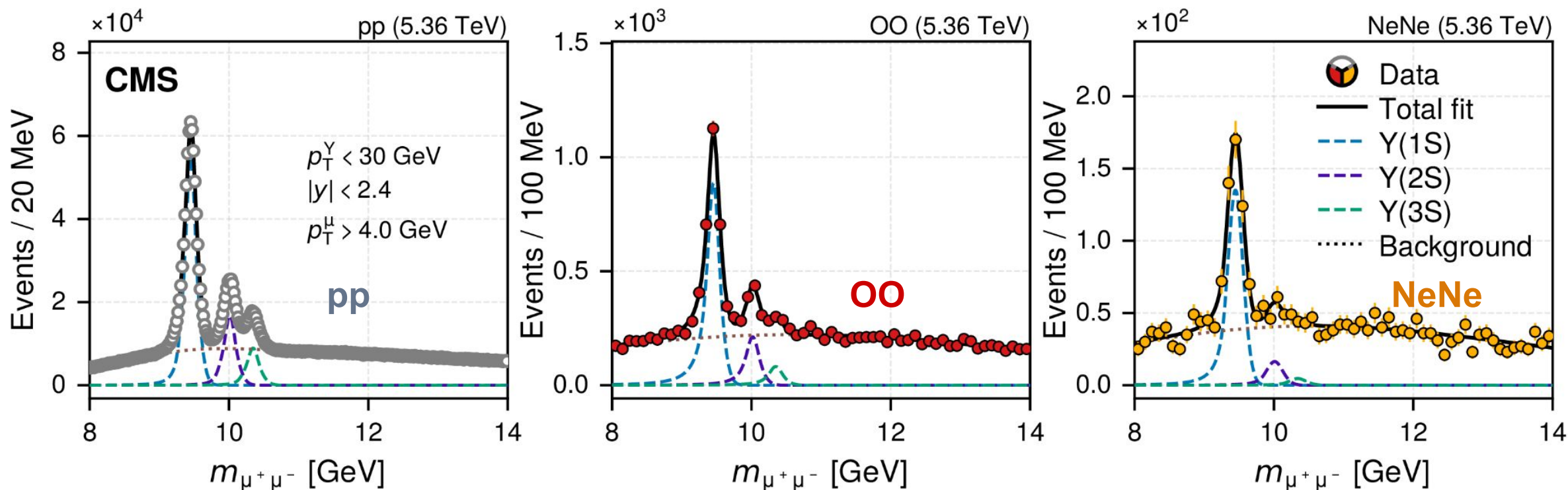
$$\Upsilon(nS) \rightarrow \mu^+ \mu^-$$

- **Signal Model:** Crystal Ball functions
- **Background:** Erf(m) $\times$ exp(m).
- **Excellent** description of data in $8 < m_{\mu^+\mu^-} < 14$ GeV.

arXiv: 2607.13758



Dimuon invariant mass and fit (pp)



Dimuon invariant mass and fit (pp, OO, NeNe)

- **Clear separation**

Separation of 1S, 2S, and 3S states in the OO system

- **NeNe System**

Impacted by lower statistics

Measurement Strategy: Double Ratios

To minimize initial-state effects & related uncertainties

Observable (double ratio)

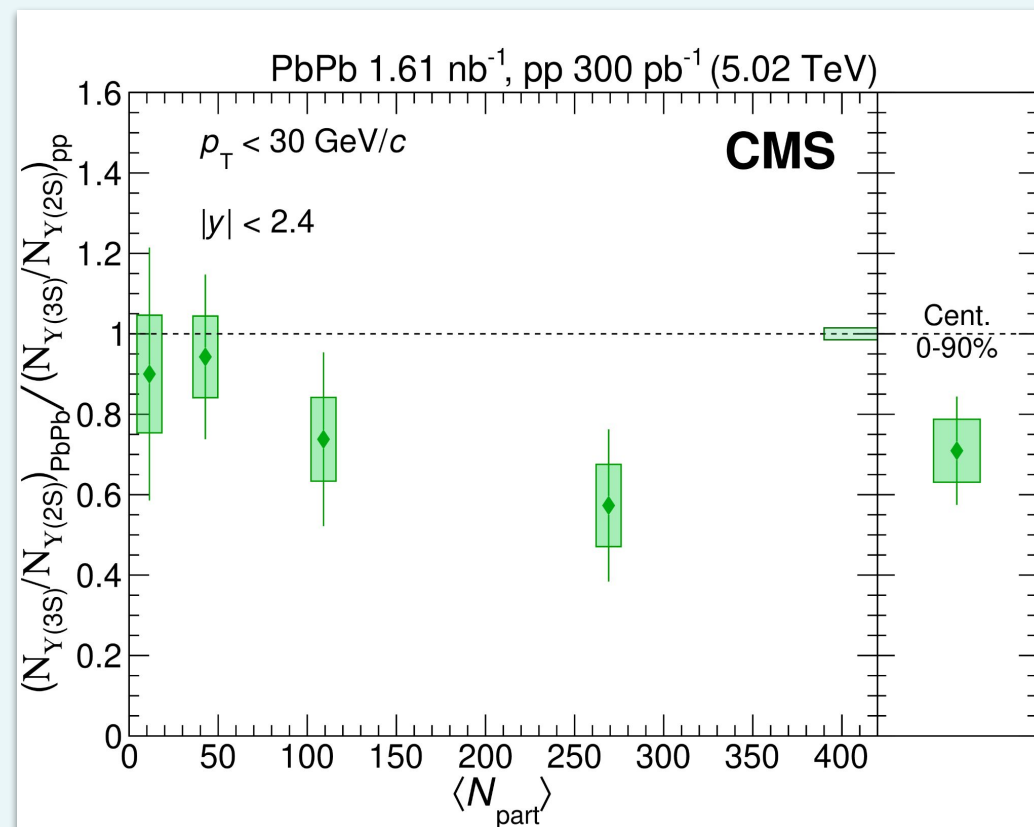
$$D_{nm} = \frac{[\Upsilon(nS)/\Upsilon(mS)]_{AA}}{[\Upsilon(nS)/\Upsilon(mS)]_{pp}} \quad \begin{matrix} n = 2, 3 \\ m = 1, 2 \end{matrix}$$

Cancels uncertainties related to

- Luminosity
- Modeling (nuclear PDFs, Glauber MC)
- Branching fraction

Phys. Rev. Lett. 133 (2024) 022302

Interpretation



$D_{nm} < 1$: final-state dependent modifications of excited states

Double ratio $Y(3S)/Y(2S)$ in PbPb

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Observable (double ratio)

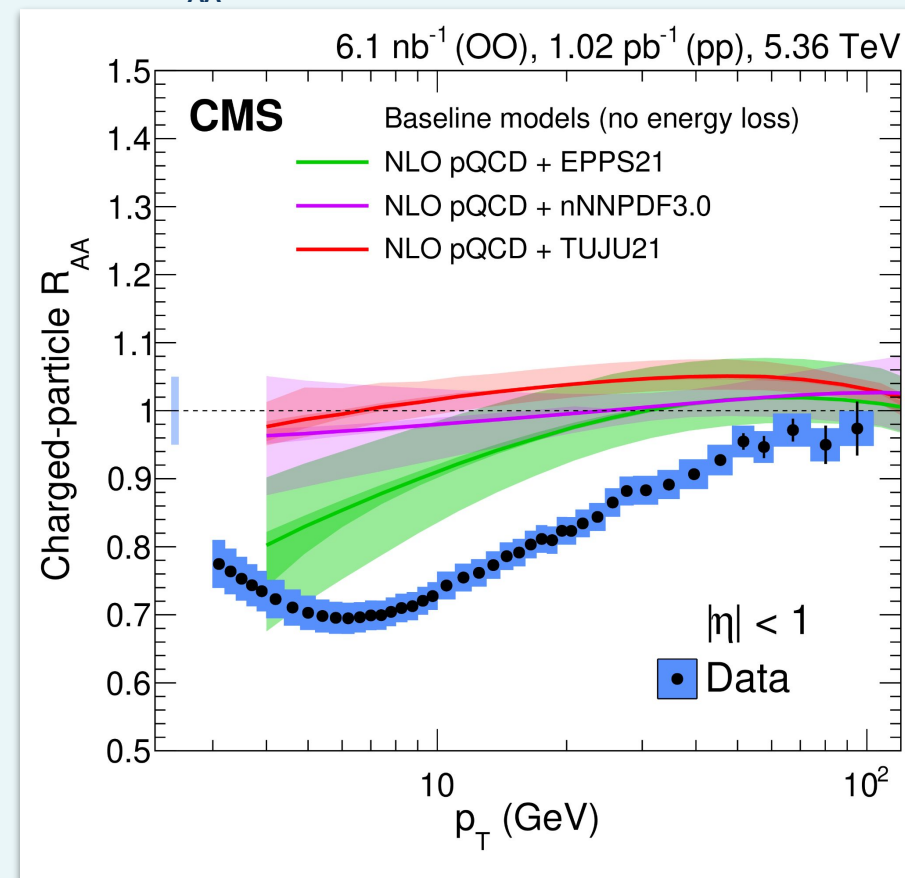
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- **Modeling** (nuclear PDFs, Glauber MC)
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arXiv: 2510.09864 (PRL editor's suggestion)

Interpretation in R_{AA}



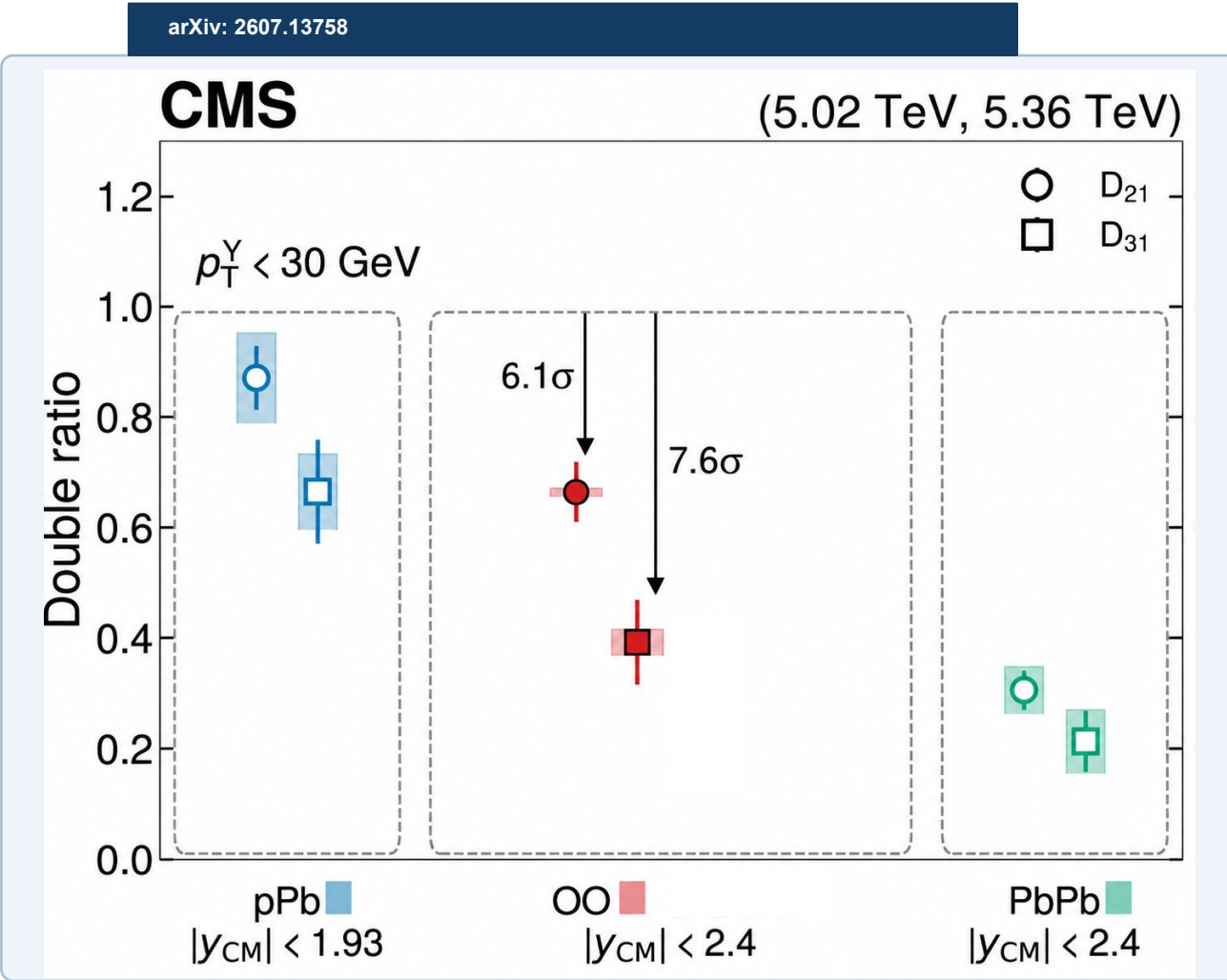
Complicated by the large uncertainties in nPDFs

Charged-particle R_{AA} in OO

Evidence of Sequential Suppression

- All double ratios are found significantly below unity.

Significance in OO		
Y(2S)/Y(1S)	$\phi \rightarrow$	6.1 σ
Y(3S)/Y(1S)	$\phi \rightarrow$	7.6 σ
Y(3S)/Y(2S)		3.2 σ



Demonstrates final-state modifications in AA systems smaller than PbPb.

Double ratios in pPb, OO, and PbPb

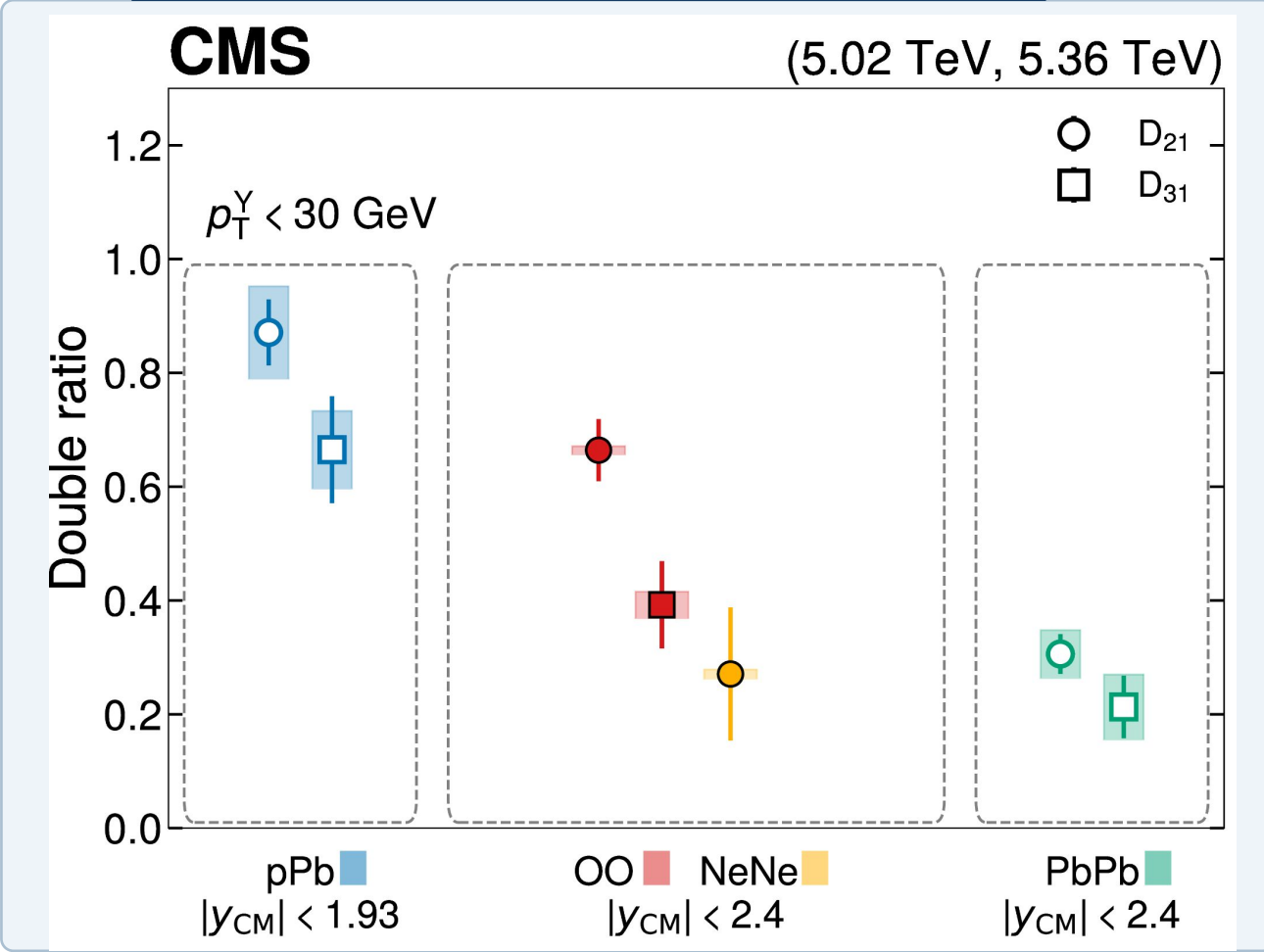
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Significance in NeNe	
• Comparable to OO • We only report Y(2S)/Y(1S) (smaller data sample)	

arXiv: 2607.13758



Demonstrates final-state modifications in AA systems smaller than PbPb.

Double ratios in pPb, OO, NeNe, and PbPb

Suppression vs. System Size ($\langle N_{\text{part}} \rangle$ and N_{trk})

Low Npart Limit

Suppression even down to $\langle N_{\text{part}} \rangle \sim 10$

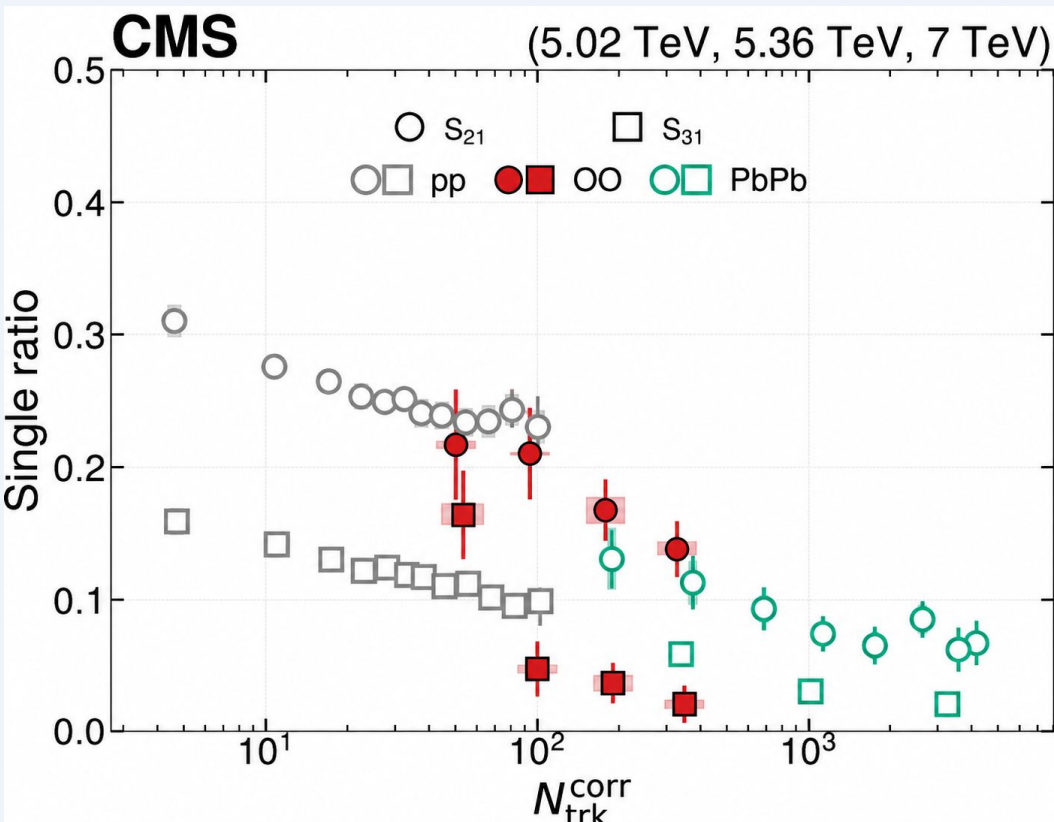
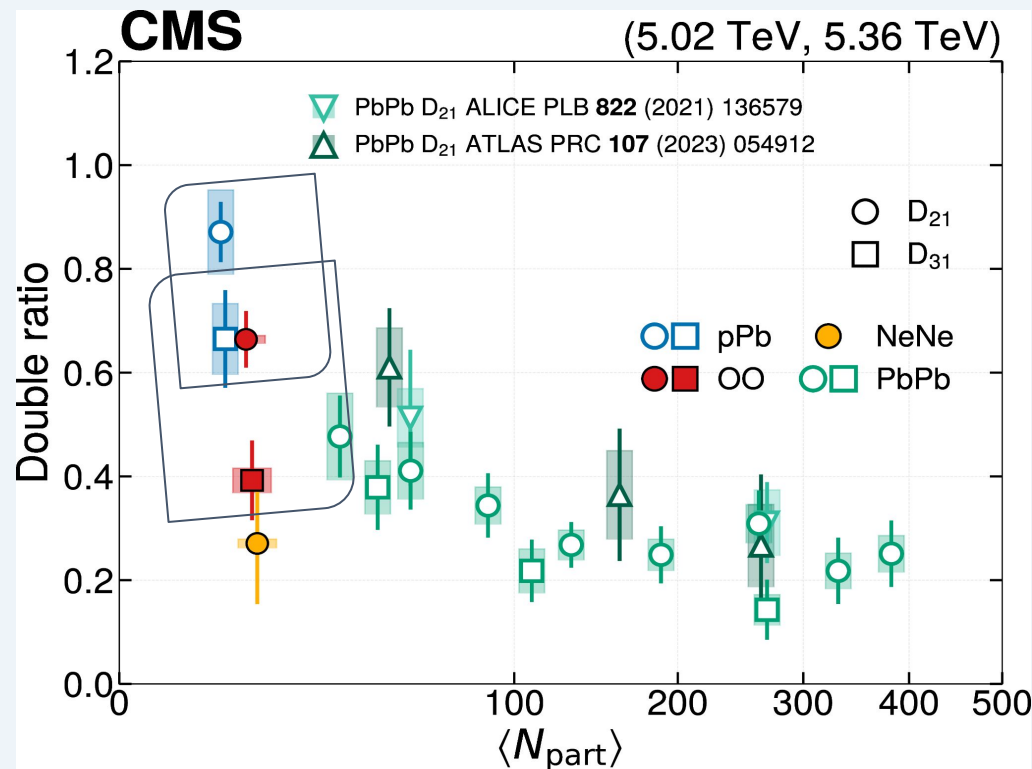
Multiplicity Trend

Decrease vs N_{trk} from pp $\rightarrow$ OO $\rightarrow$ PbPb

Global Consistency

Light ions can establish consistent global Y description

arXiv: 2607.13758



Double (left) and single (right) ratios vs system size

Possible indication of QGP formation with light nuclei!

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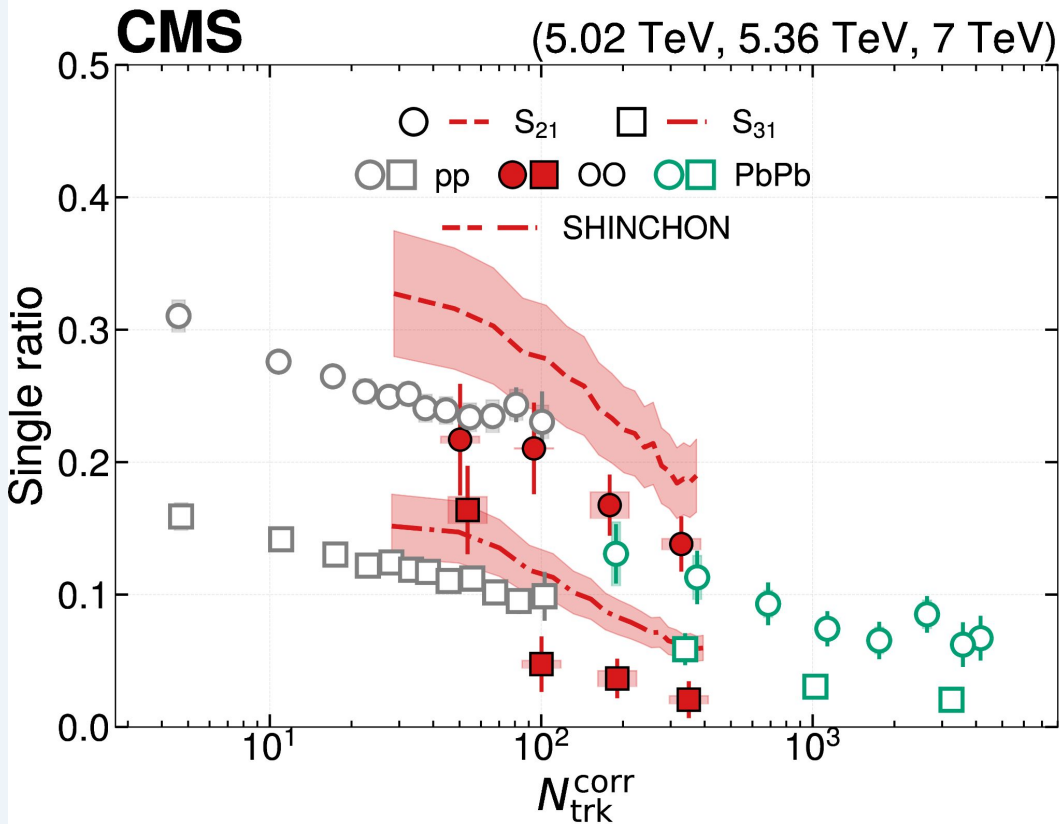
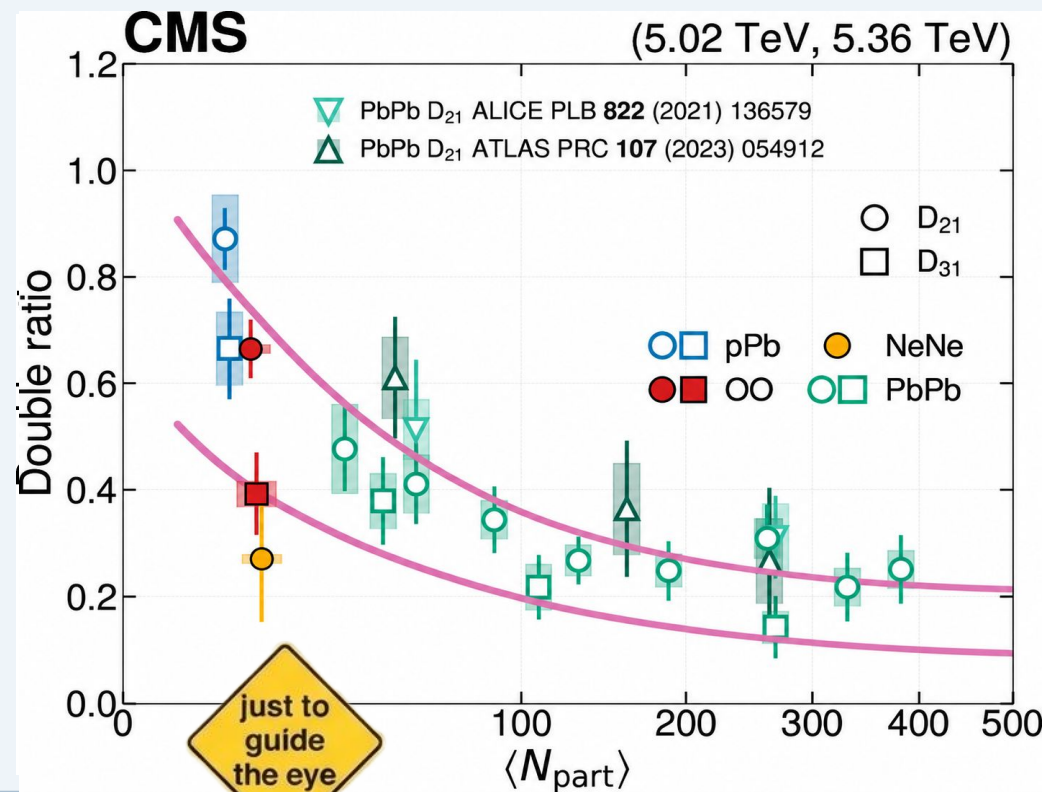
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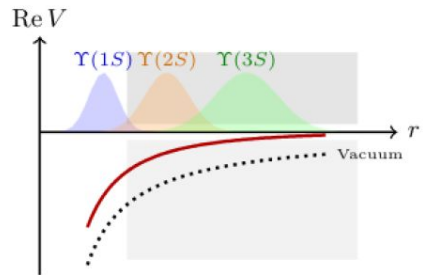
Suppression vs. Y Transverse Momentum

- **Similarity for $\Upsilon(3S)/\Upsilon(2S)$** → sensitivity to QGP temperature

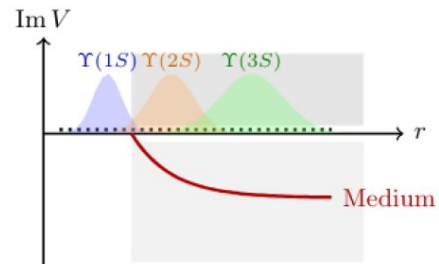
- **No significant p_T dependence** within the current precision

Complex In-Medium Potential

Real Potential: Color Screening

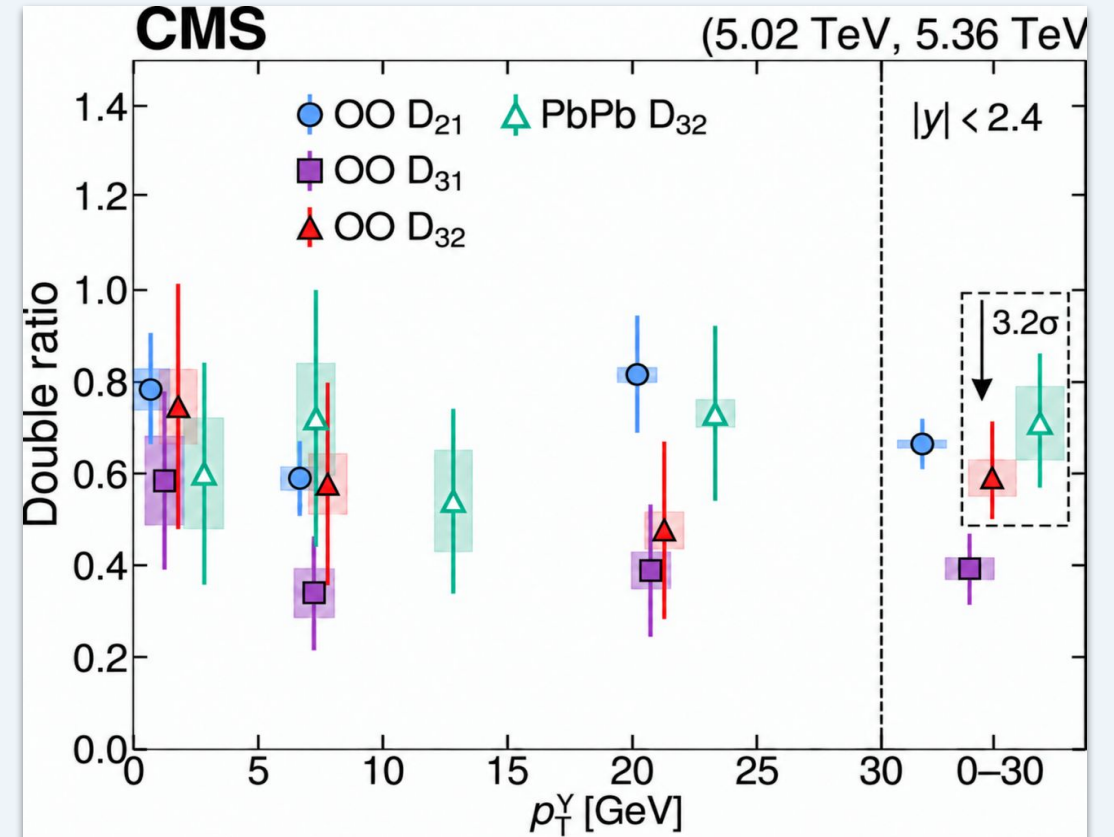


Imaginary Potential: Dissociation



New results can help constrain the Re and Im parts of the potential

arXiv: 2607.13758



Double ratios vs Y p_T in OO and PbPb

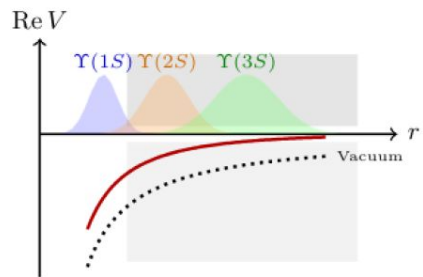
Suppression vs. Υ Transverse Momentum

- **Similarity for $\Upsilon(3S)/\Upsilon(2S)$** → sensitivity to QGP temperature

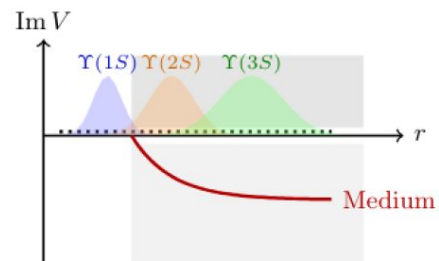
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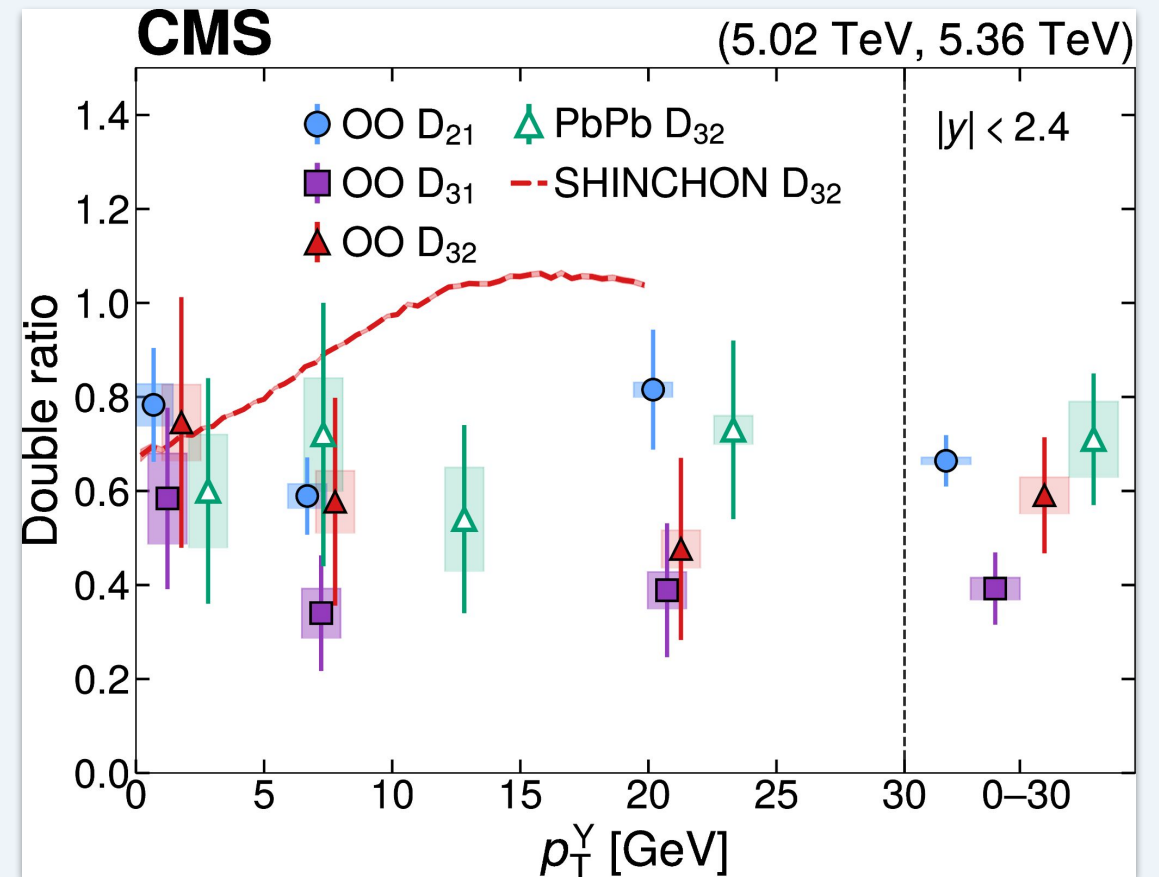


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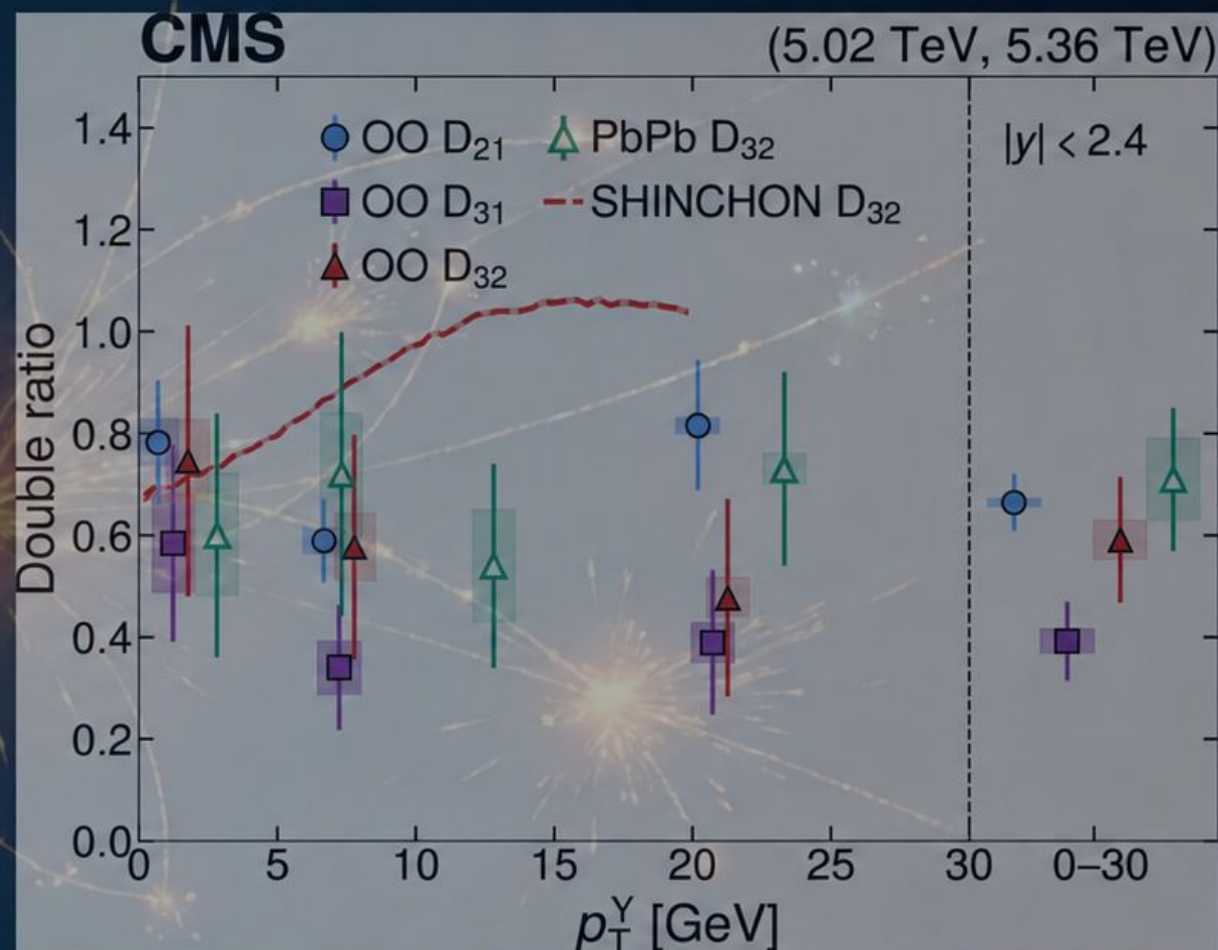


Double ratios vs Υ p_T in OO and PbPb

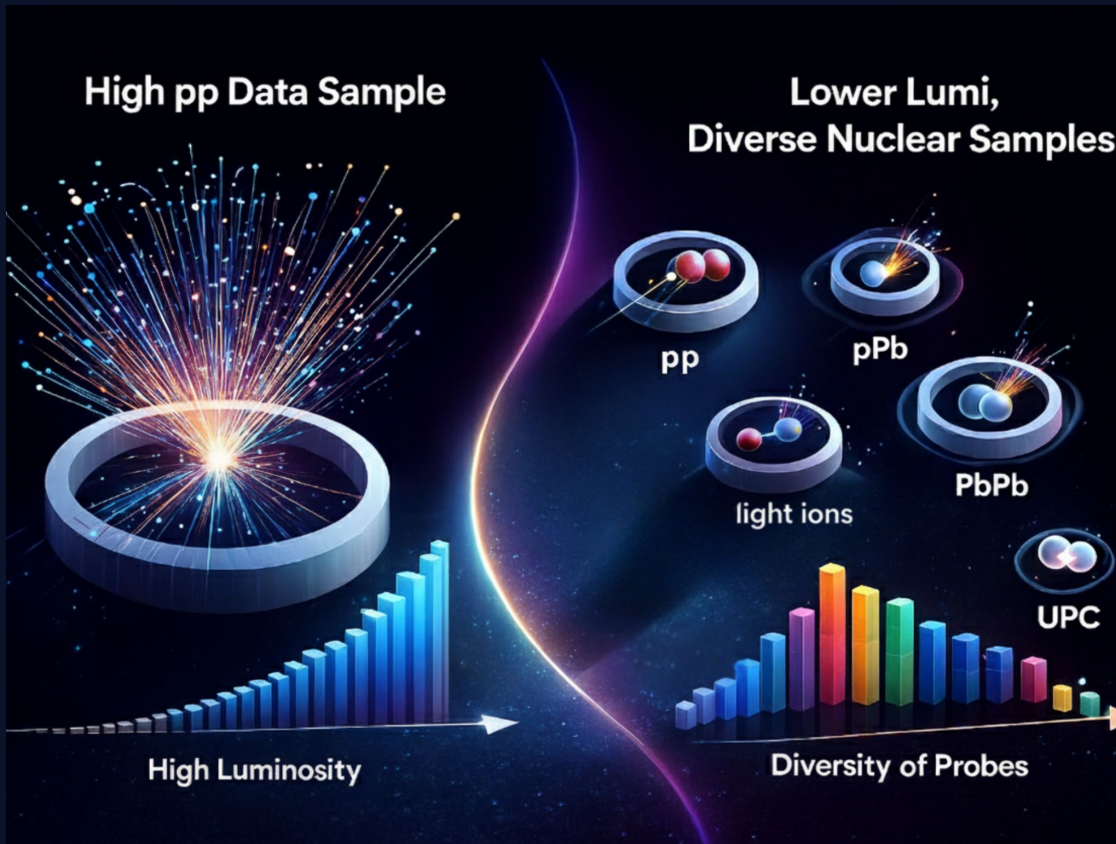


arXiv: 2607.13758: Sequential Y Suppression in Light Ions

- First measurement of Y suppression in OO and NeNe at 5.36 TeV.
- Observation:** significant suppression of excited states relative to pp.
- Hierarchy:** evidence for sequential Y suppression.
- Impact:** possible indications of deconfined-matter effects in intermediate-size systems



Novel insights on the emergence of bulk QCD matter.



PHYSICS PROGRAMS ON TWO DIFFERENT PREMISES

High Luminosity (HL-LHC)

By the end of the HL-LHC, *roughly* 3 ab^{-1} will have been collected, and the total value will not affect physics conclusions.

Diverse Ion Species

For ions, every additional run and every new species open qualitatively new physics.

Species Matter.

"Last time I checked, the N in CERN still stood for nuclear."

Three takeaways

1

Light ions are already a QGP laboratory

Collective flow, high- p_T suppression, and sequential bottomonium suppression are all present in the new data, characteristic of QGP.

2

Ion complexity is scientifically meant for AI

The high-dimensionality and transfer across controlled domains are unique features. Can they also help with xAI?

3

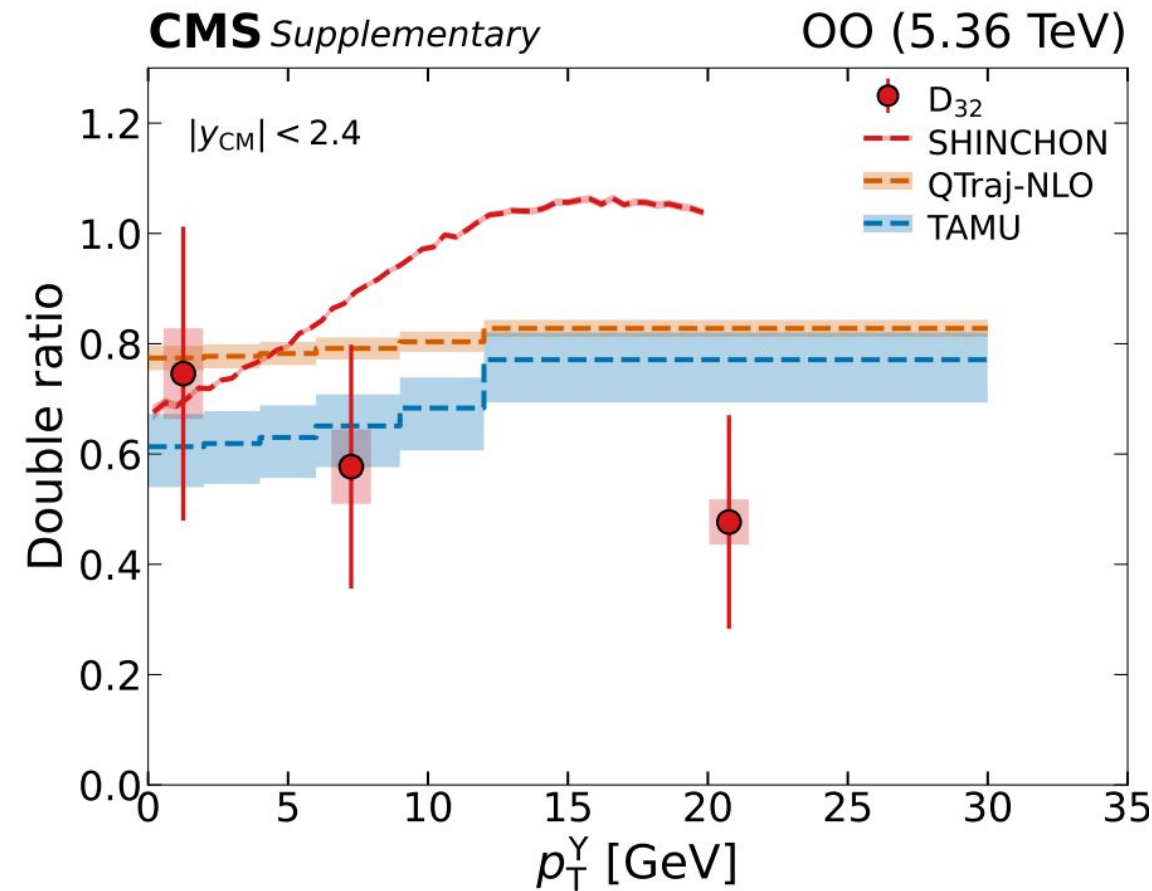
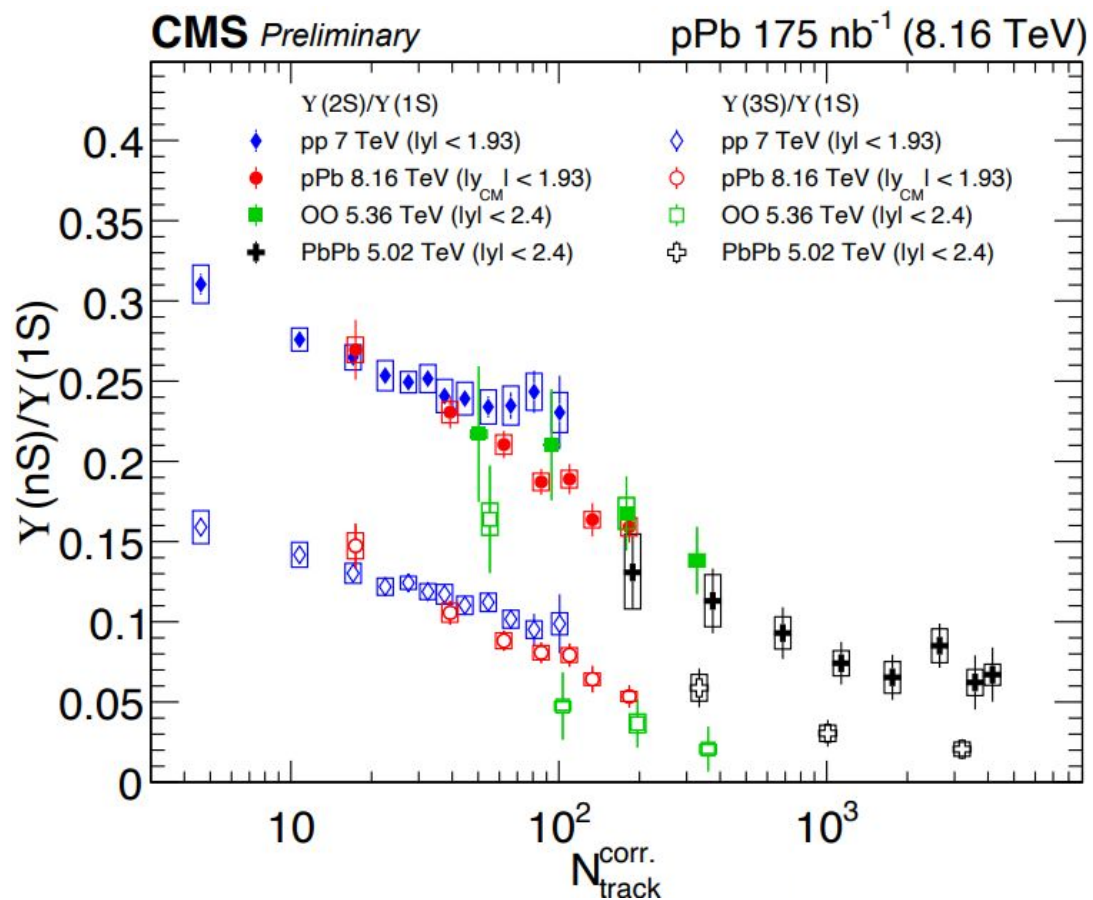
A flexible species program can reshape the field

NP community should reflect upon the “more of the same” approach and leave our best legacy behind (FCC-hh seems far-fetched).

"There has never been a better moment to reimagine the future of ion collisions."

Extra Comparisons

CMS-PAS-HIN-25-005
arXiv: 2607.13758



- **With high-statistics pPb data**

Smooth or more abrupt evolution?

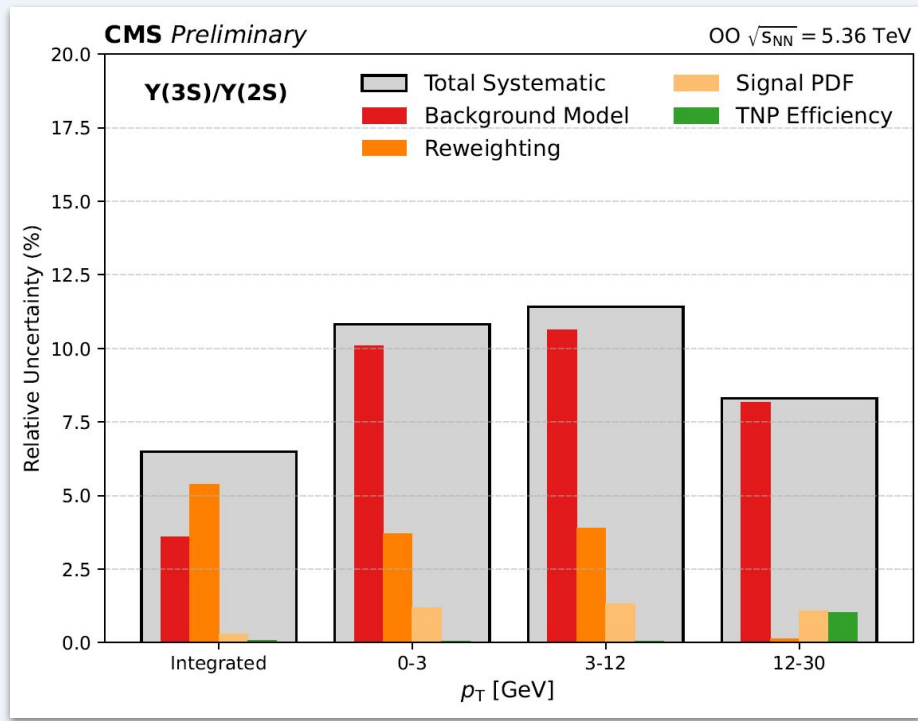
- **With more models**

Similar conclusions, the trend not well described

Systematic Uncertainties

Source	Typical Effect
Background Model	Up to $\approx 10\%$ for 3S
Signal PDF	Small ($< 2\%$)
Tag-and-Probe	Small ($< 2\%$)
Reweighting	$\approx 1\text{--}5\%$

CMS-PAS-HIN-25-015



Representative breakdown for $Y(3S)/Y(2S)$ vs p_T