

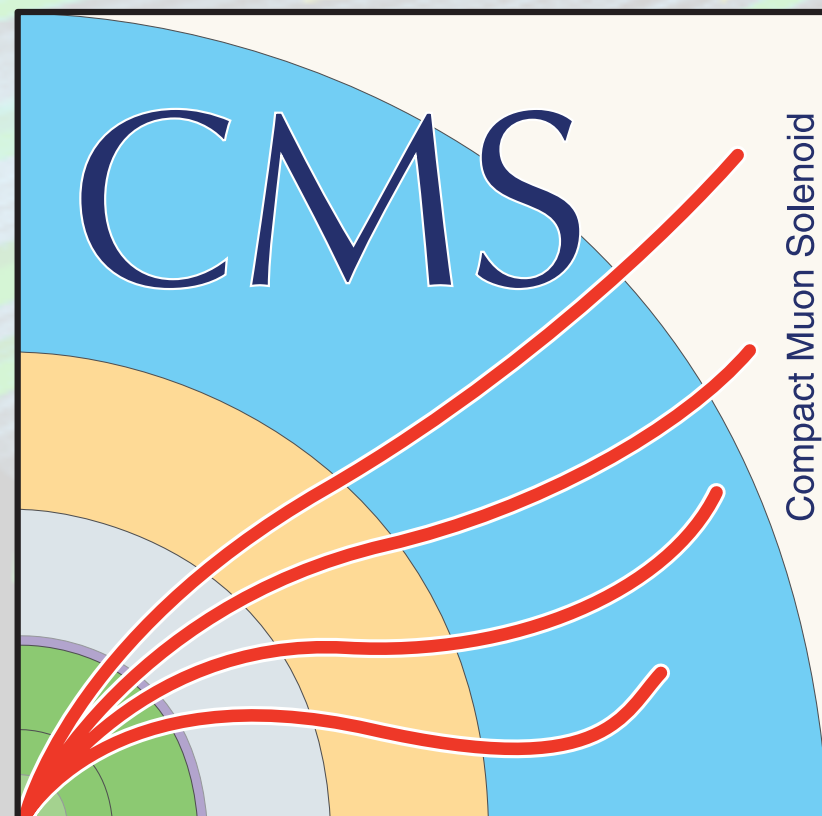
Overview of CMS Light Ion Collision Results

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On behalf of the CMS Collaboration

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EMMI Workshop: Light-Ion Collisions
2026
Heidelberg, Germany



UNIVERSITY OF
ILLINOIS CHICAGO



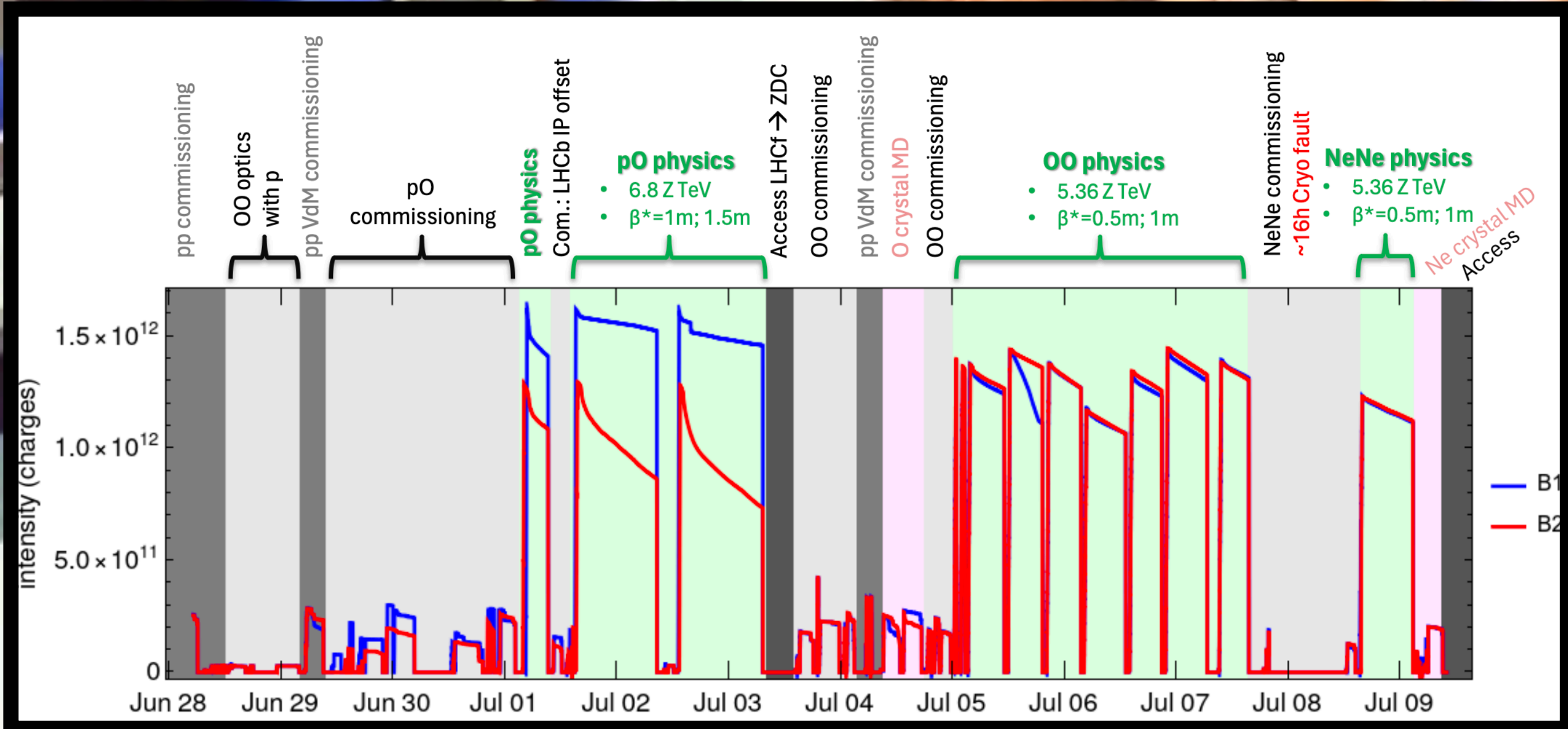
U.S. DEPARTMENT
of **ENERGY**

The UIC group is supported by the DoE Office of Science

CMS light ion crew: ~15 months ago



CMS light ion crew: ~15 months ago



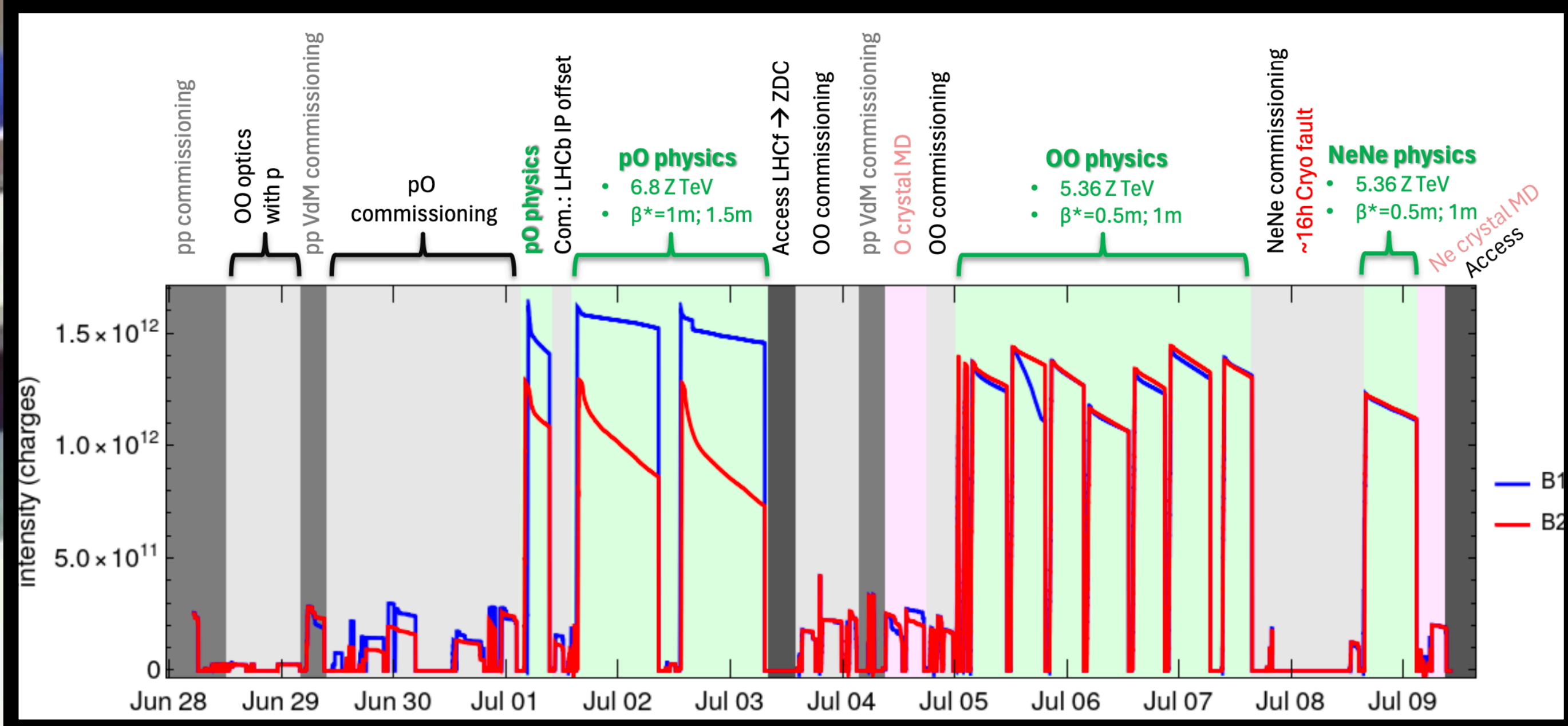
Oxygen-Oxygen Luminosities

(nb ⁻¹)	target	delivered	ratio
ATLAS	0.8	8.2	10.3
ALICE	0.5	5.15	10.3
CMS	0.8	9.4	11.8
LHCb	0.5	5.75	11.5

Figures from Roderik Bruce

CMS light ion crew: ~15 months ago

Thank you to the accelerator team for amazing datasets!



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Questions and motivation



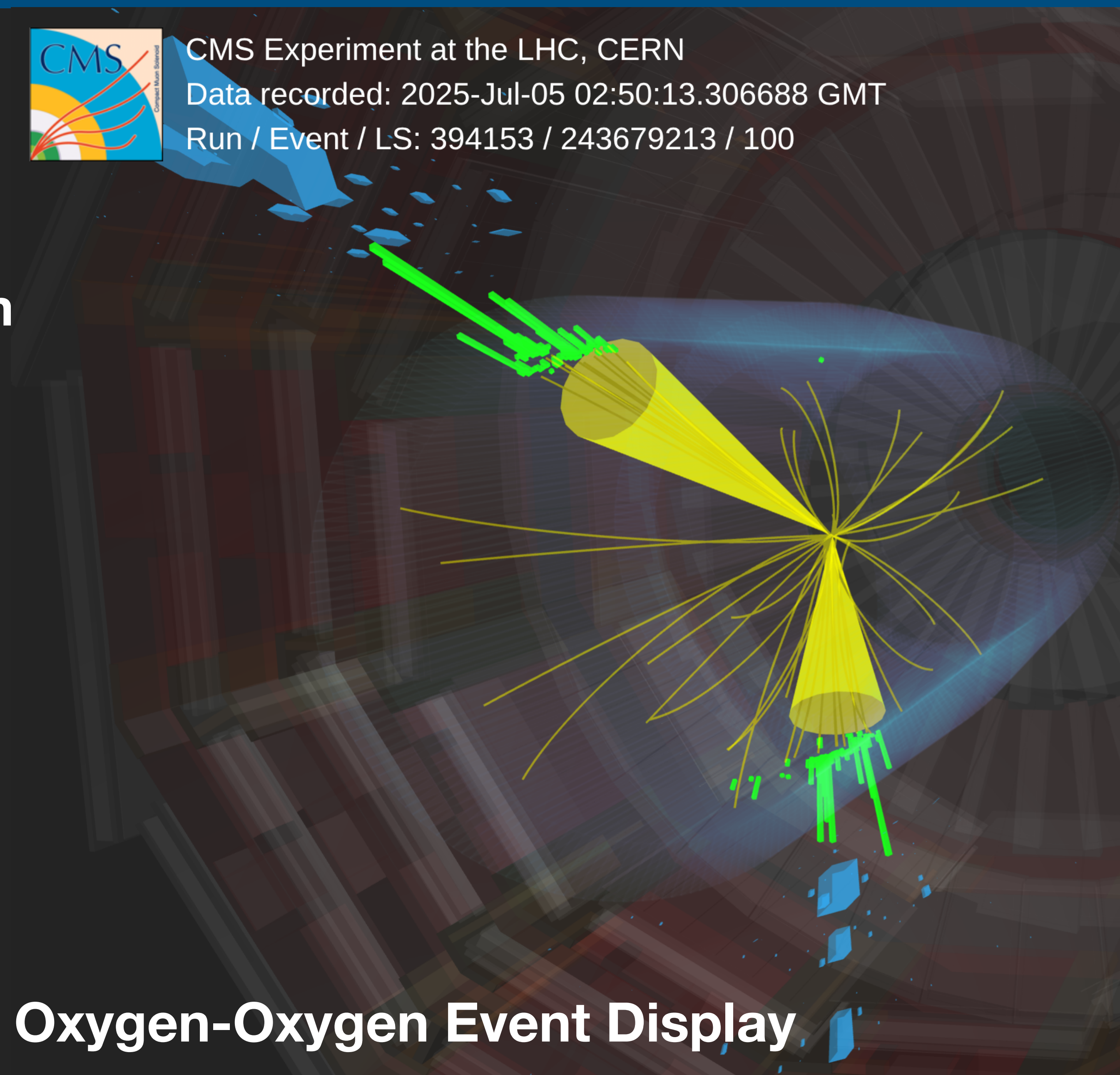
CMS Experiment at the LHC, CERN

Data recorded: 2025-Jul-05 02:50:13.306688 GMT

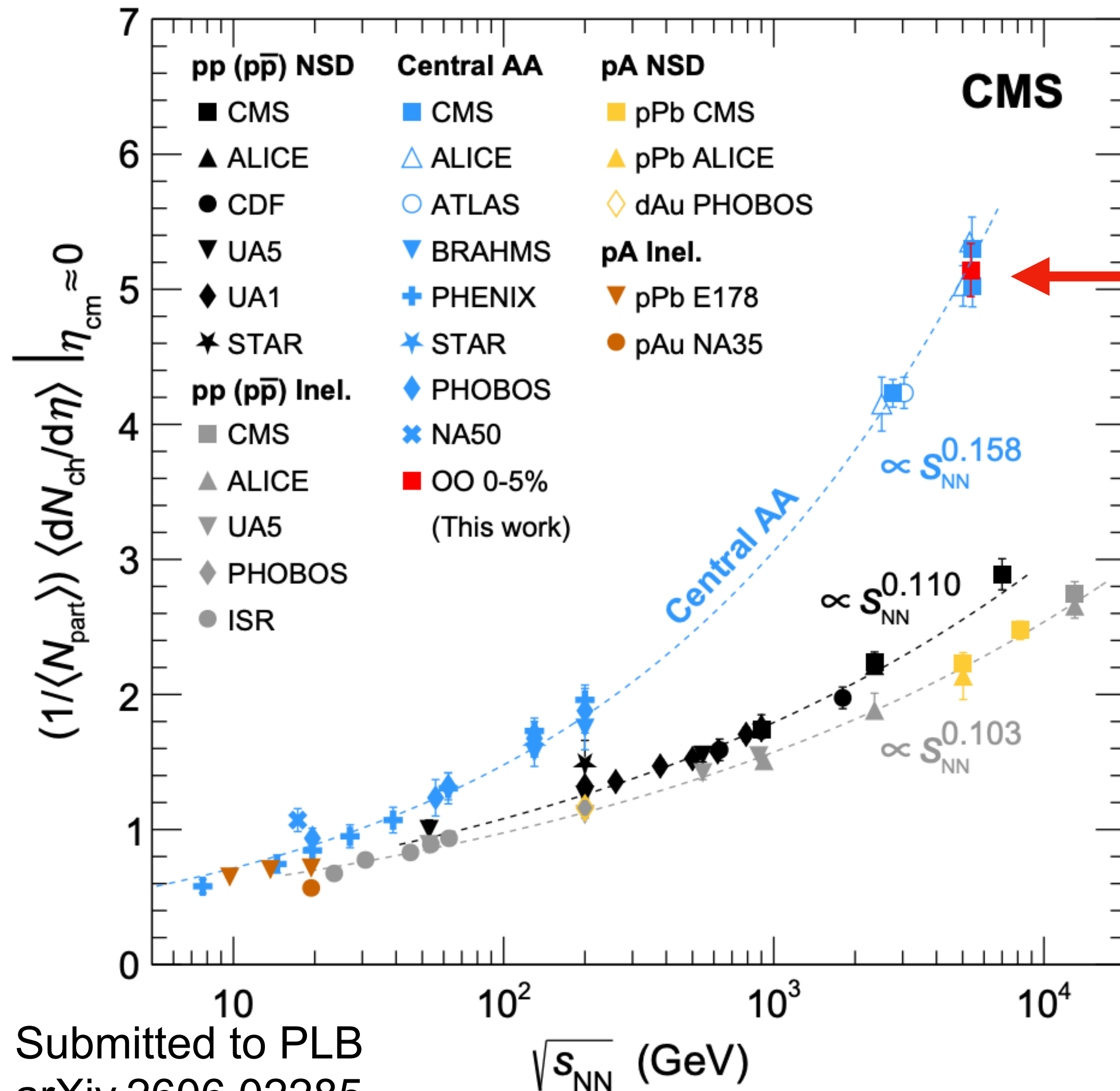
Run / Event / LS: 394153 / 243679213 / 100

- How do dynamics of heavy ions translate to intermediate-sized system
- OO/NeNe probe a similar multiplicity region as pPb
- Initial state more well-defined as compared to pPb
 - Less chance for selection biases
 - More likely to create a QGP?

Oxygen-Oxygen Event Display

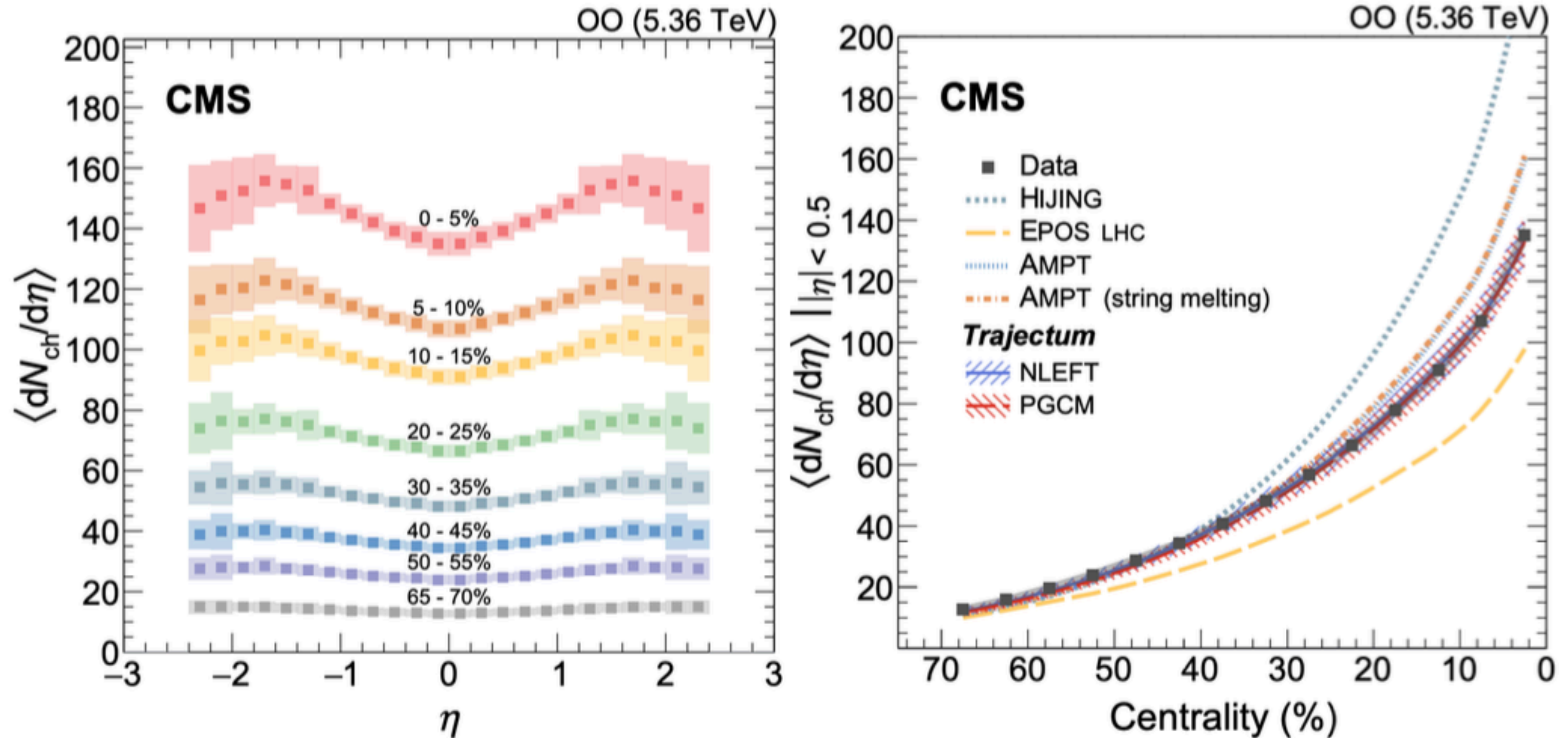


Particle production in OO



- **0-5% OO** on AA power law vs. $\sqrt{s_{NN}}$
- **Similar translation of energy to entropy**
- **Not a superposition of pp collisions!**
- **What about full centrality-dependence?**

Centrality dependence

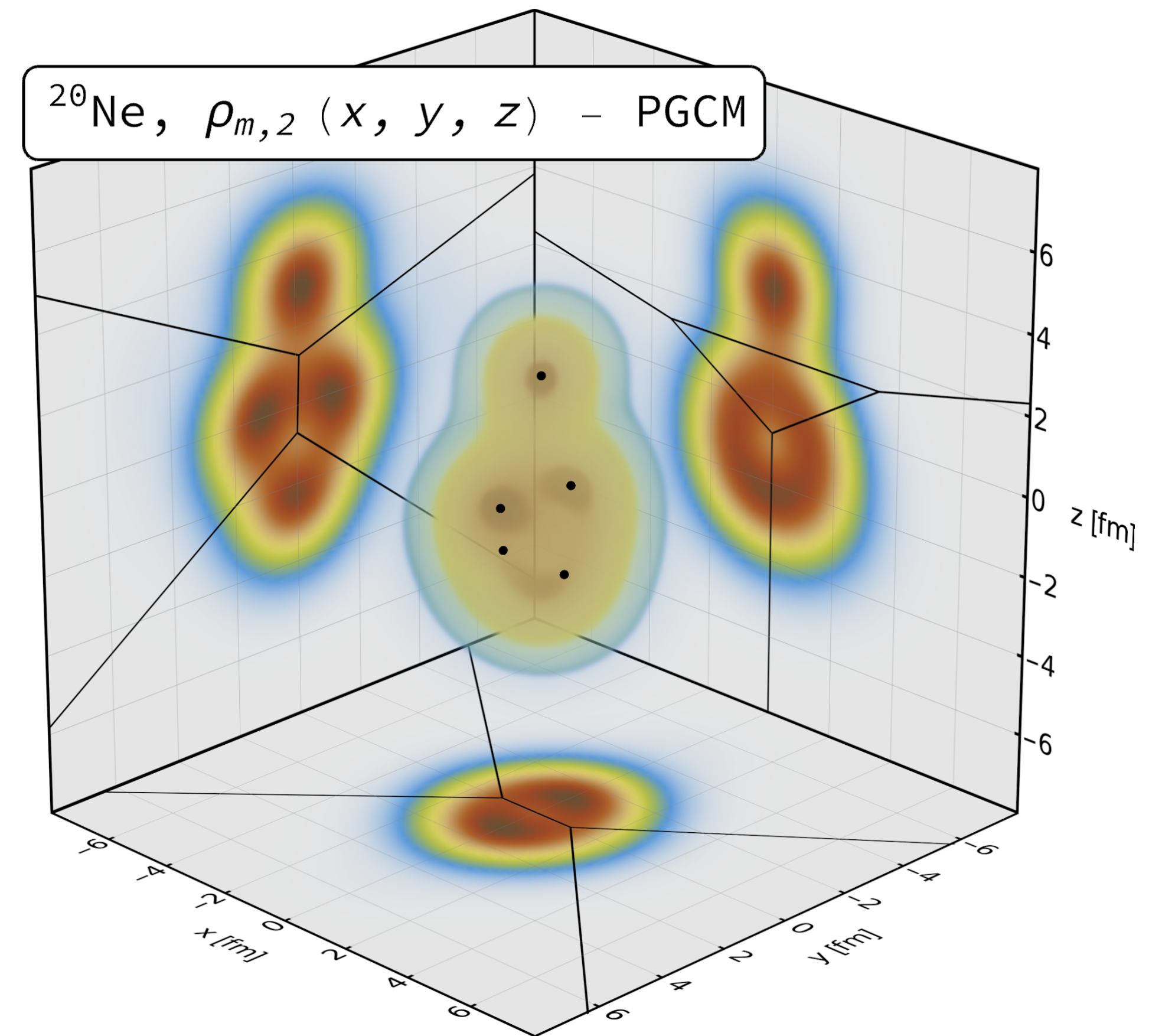
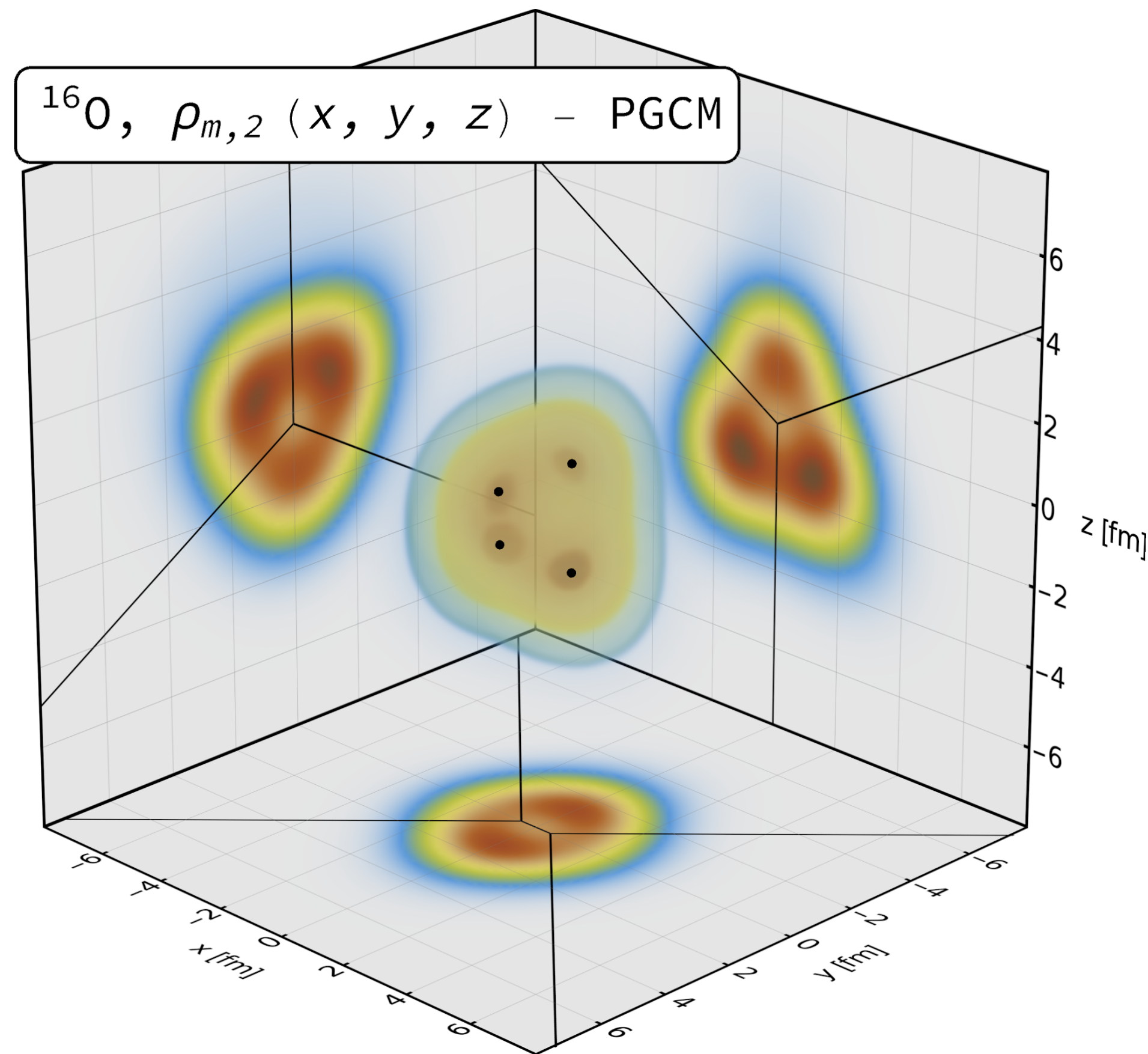


- Characterize the geometry and entropy density of OO collisions
- Centrality-dependence can be used to tune MC models

Submitted to PLB
arXiv.2606.02285

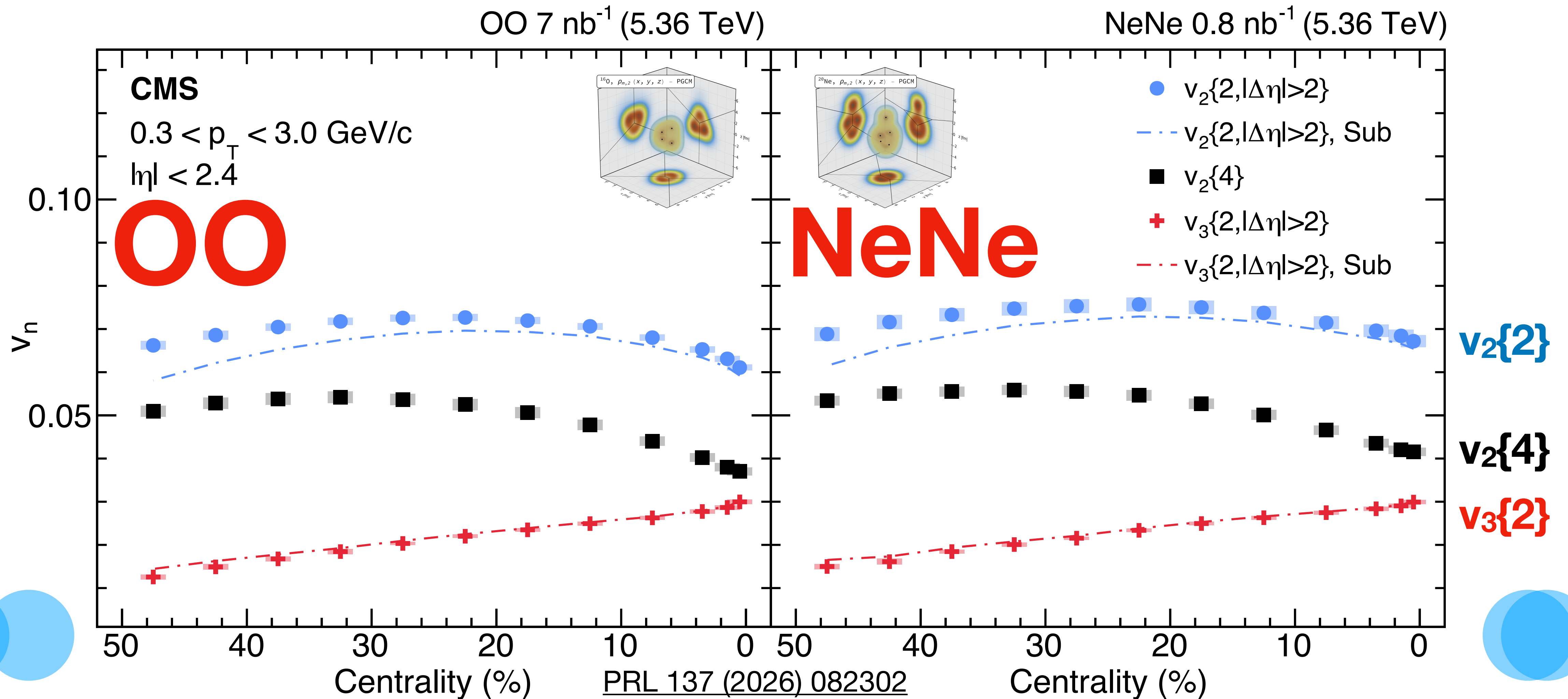
Azimuthal anisotropies in OO and NeNe

- Collectivity effects hypothesized to be present in OO/NeNe
- Proposed as a way to explore nuclear structure (i.e., bowling pin Ne)



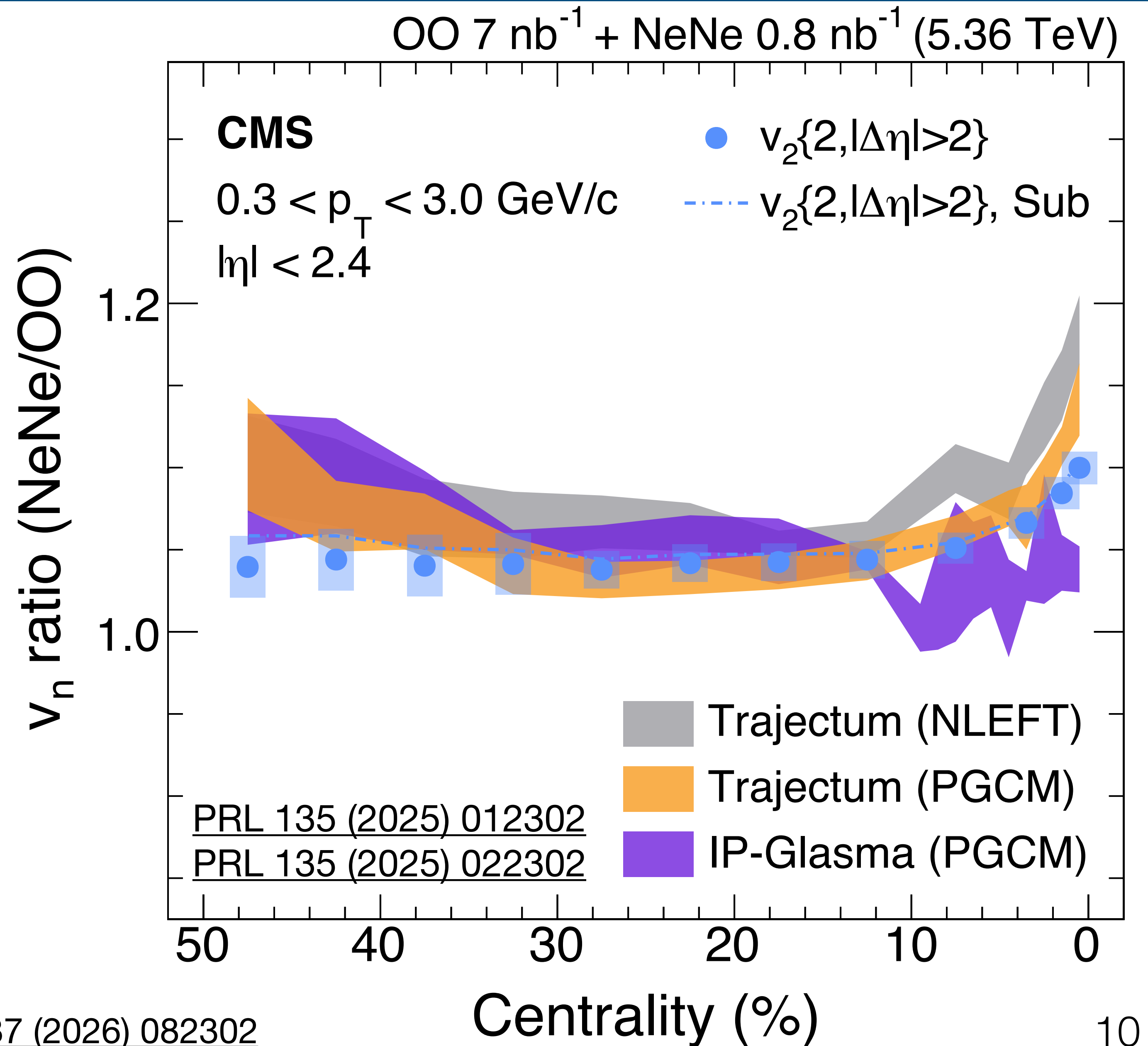
Azimuthal anisotropies in OO and NeNe

- Measured $v_2\{2\}$, $v_3\{2\}$, $v_2\{4\}$ in OO and NeNe collisions
- v_2 dips towards central events - geometry changes with impact parameter
- v_3 increases

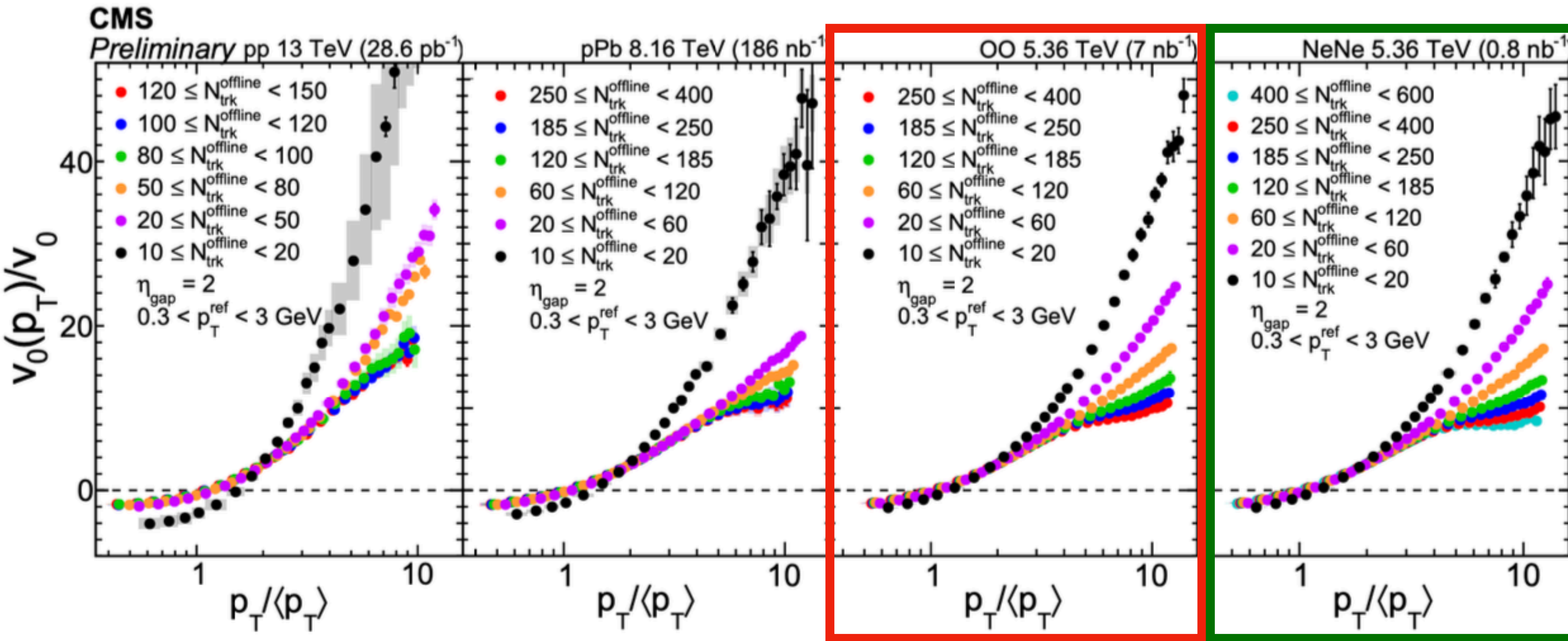


NeNe/OO v_2 ratios

- Ratio cancels hydrodynamic response: sensitive to geometry
- Clear uptick for central events
- Model differences from treatment of deformed nuclear geometry
- Having both NeNe and OO data valuable for nuclear structure



$v_0(p_T)$ in small systems



CMS-PAS-HIN-25-016

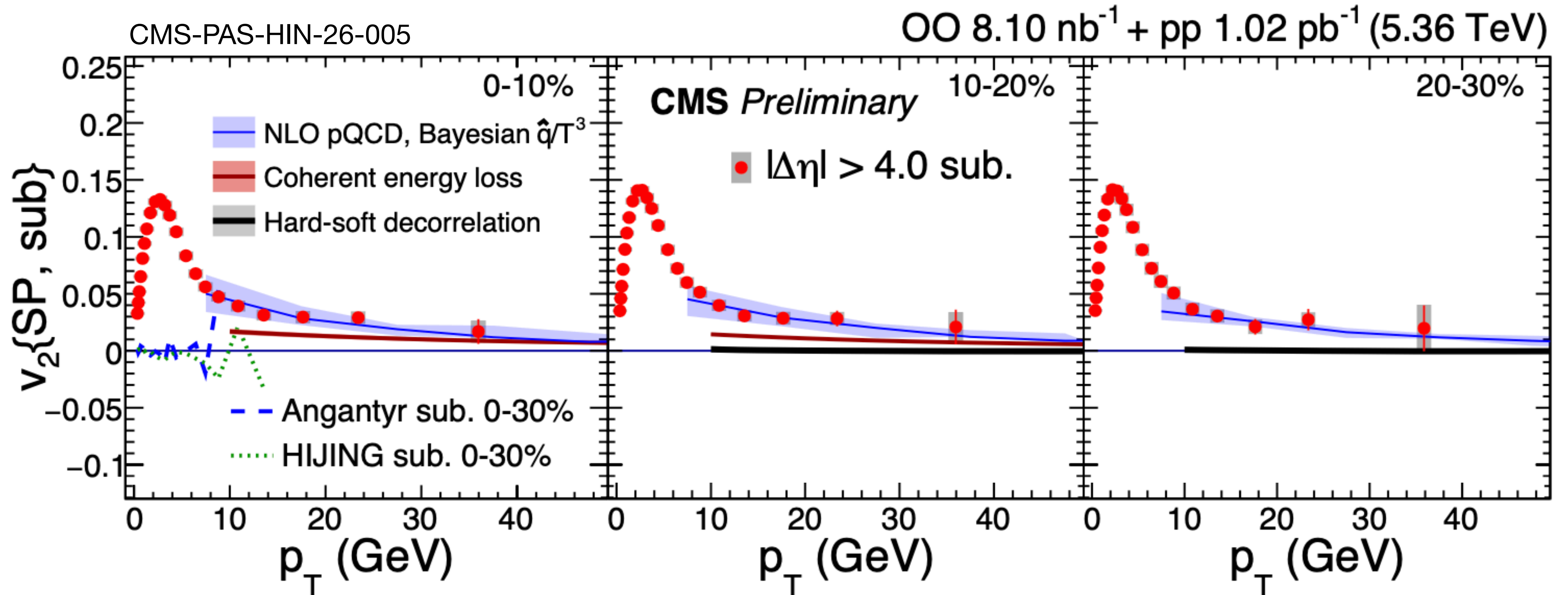
$$v_0(p_T) = \frac{\langle \delta n(p_T) \cdot \delta[p_T] \rangle}{\langle n(p_T) \rangle \cdot \sigma_{[p_T]}}$$

OO Data

NeNe Data

- Quantifying event-by-event radial flow fluctuations
- Comprehensive evaluation of $v_0(p_T)$ in small systems over large N_{trk} range
- Similar behavior across systems for $N_{\text{trk}} > 20$ and $p_T / \langle p_T \rangle < 2$
 - Potential signature of collective behavior, but to be discussed further
- Lots of data for Bayesian analyses!

High- p_T charged particle v_2

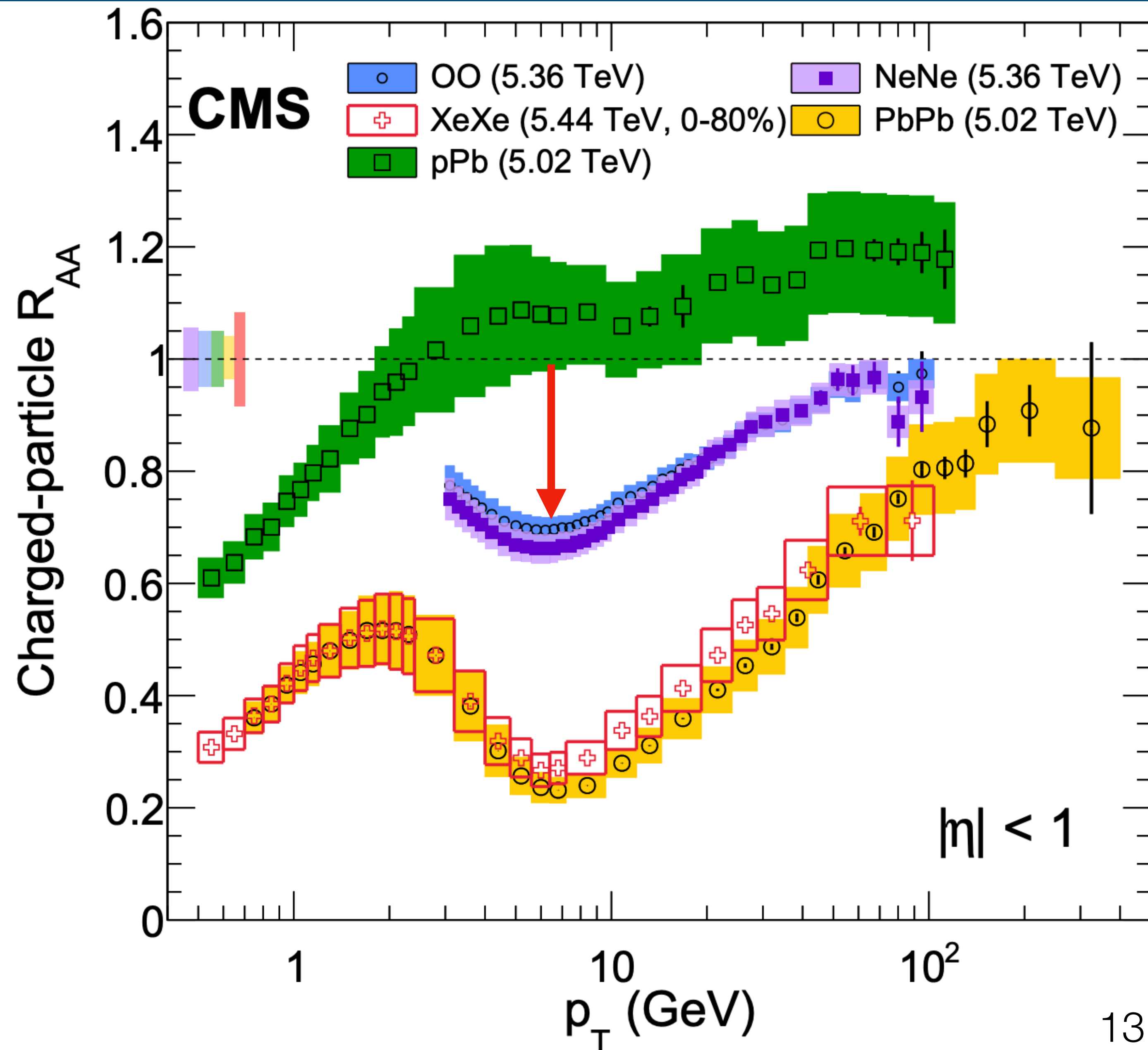


- Nonzero v_2 observed up to 50 GeV
- Consistent with pQCD parton model with T constraint and radiative energy loss
- Model with coherent energy loss is below data
- Energy-loss signature or continuation of small-systems high- p_T v_2 puzzle?

Charged particle R_{AA}

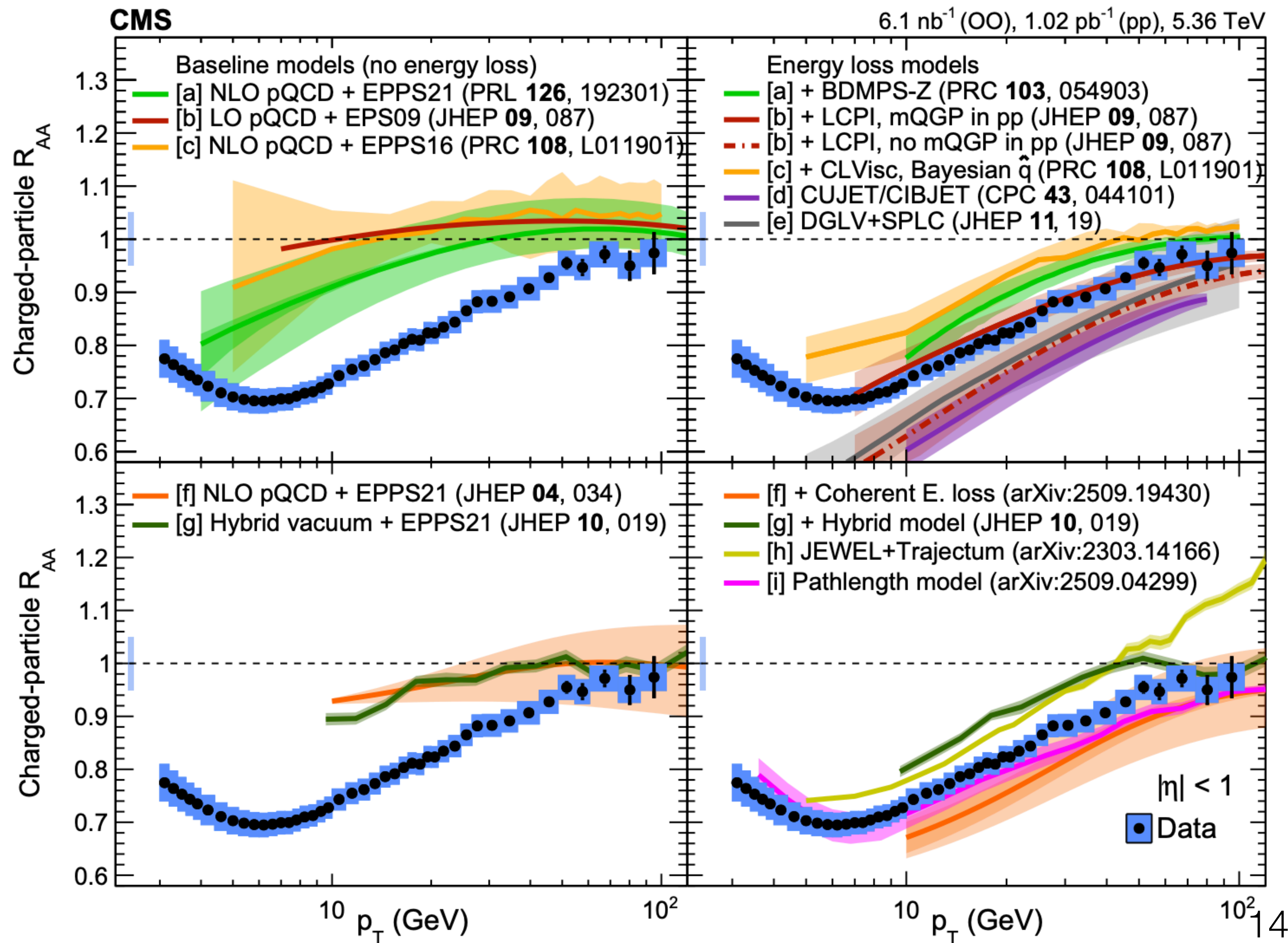
$$R_{AA} = \frac{1}{A^2} \frac{d\sigma_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- **Observation** of suppressed high- p_T particle production in OO/NeNe
- Clear hierarchy with system size
- Likely from parton energy loss, but nPDFs also important



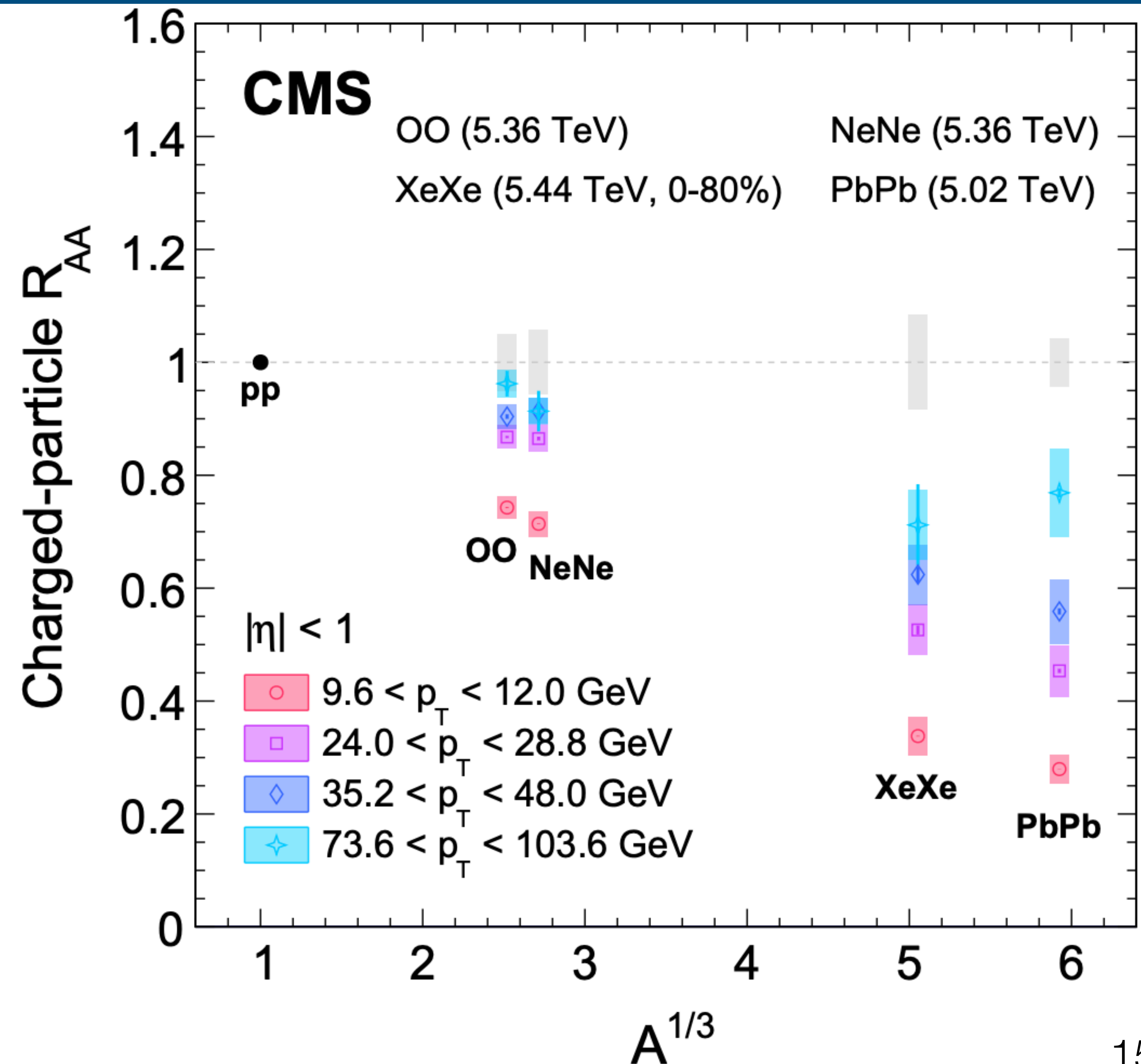
Comparison with Models

- Models with energy-loss describe the data better than baseline models
- But nPDFs important when interpreting the data!

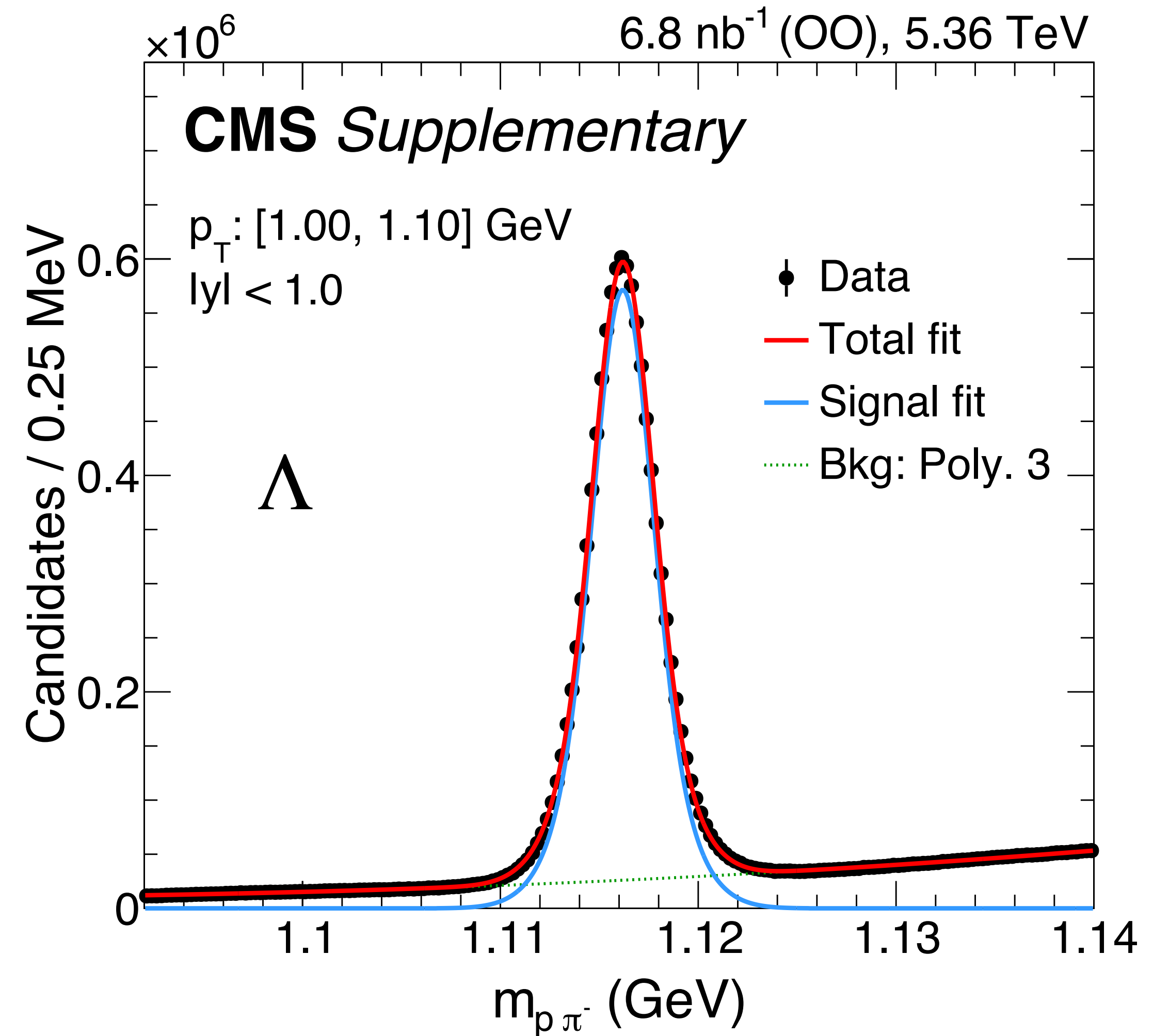
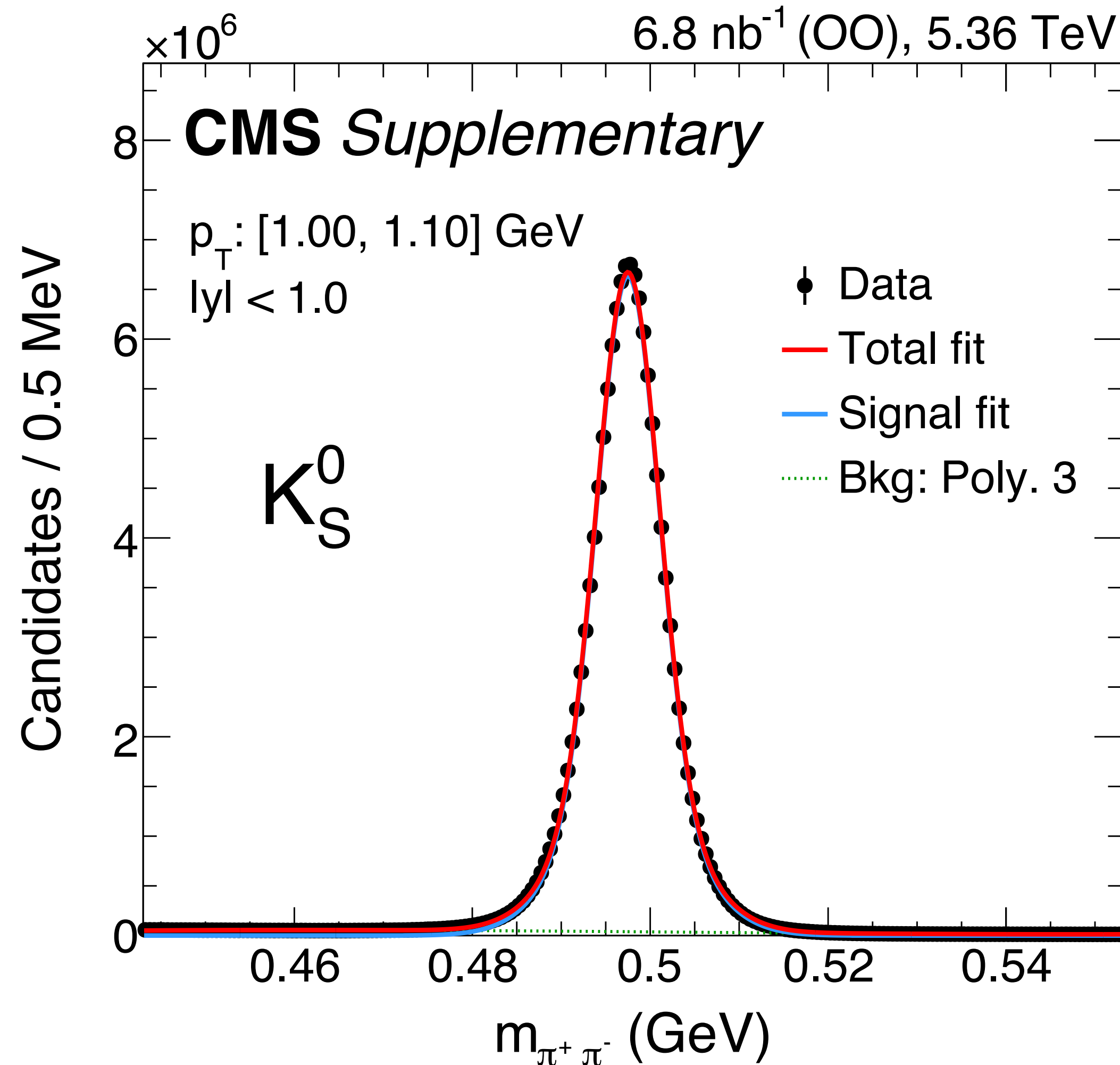


System-size scan without centrality

- $A^{1/3}$ as proxy for nuclear radius
- Clear evolution seen with size
- Provides an unbiased method to evaluate particle suppression vs. system size
- Greatly constraining on models of energy loss



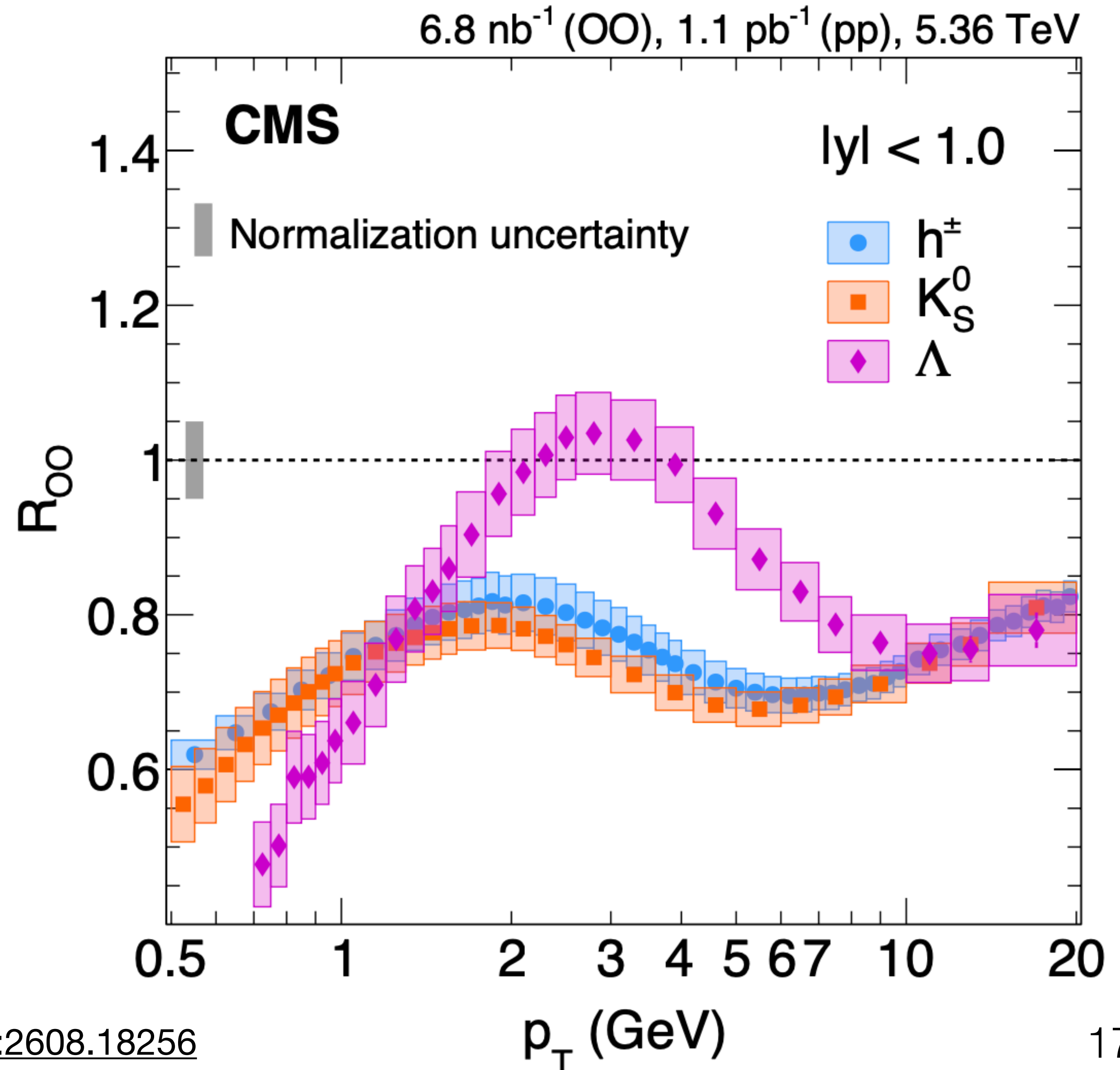
Identified neutral hadrons



- Low combinatorial backgrounds in light ions make V^0 's very clean
- Even without explicit PID

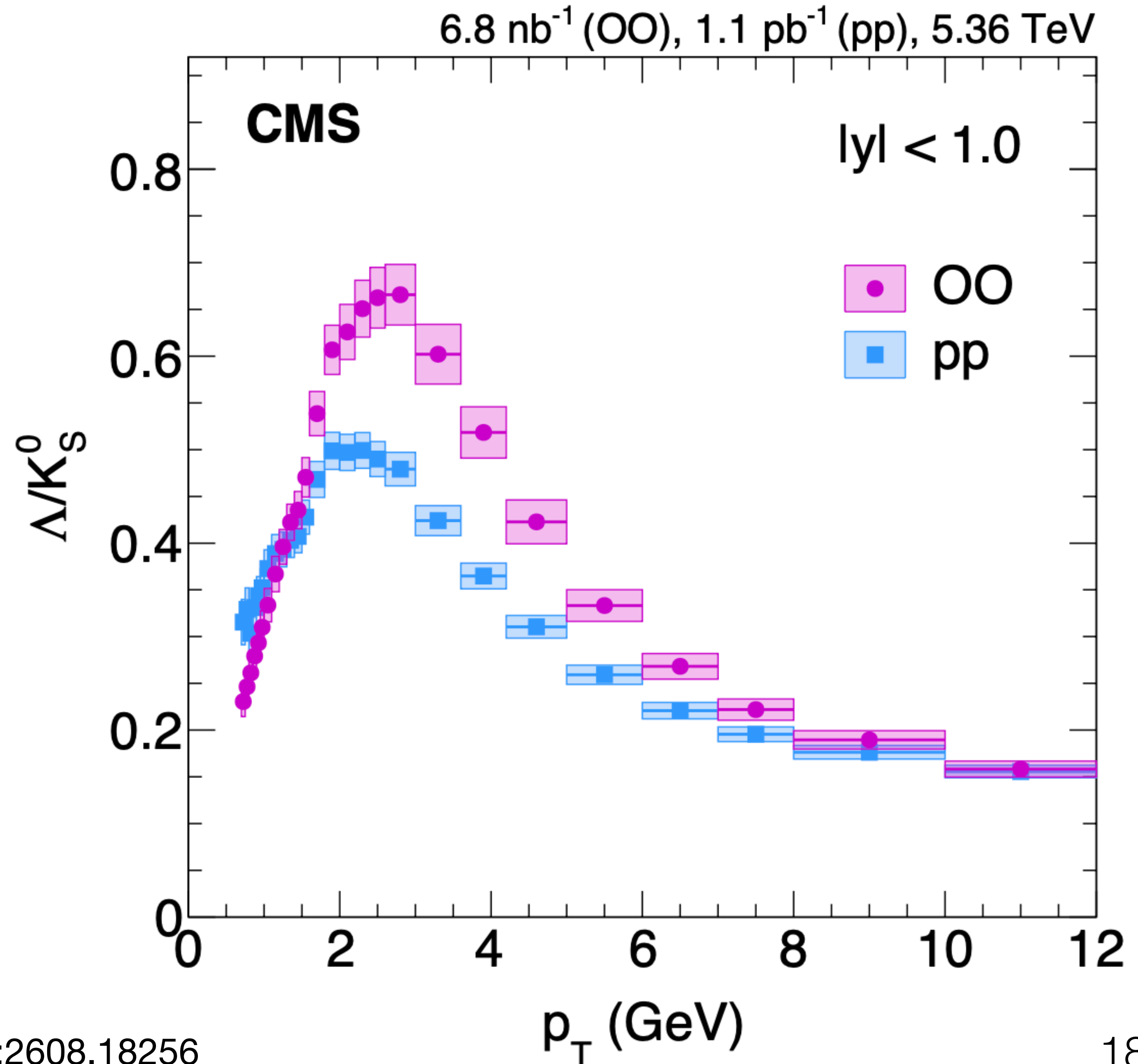
Identified neutral hadron R_{AA}

- Charged hadrons extended down to 500 MeV
- Clear radial flow bump
- K_s^0 similar to charged hadrons
- Λ less suppressed for 2-5 GeV
- All particles merge at $p_T > 10$ GeV
 - From energy loss + nPDFs

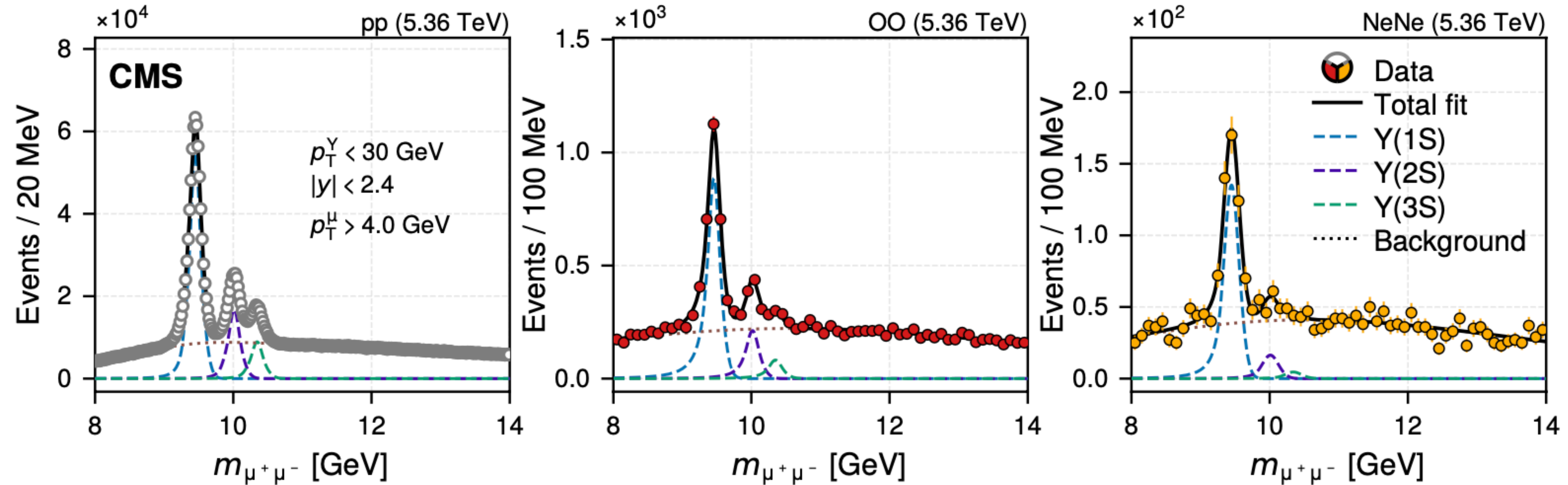


Identified neutral hadron R_{AA}

- Λ/K_s^0 ratio significantly enhanced in **OO** relative to **pp**
- Baryon anomaly likely related to radial flow + quark coalescence
- Roughly comparable to peripheral PbPb in nature

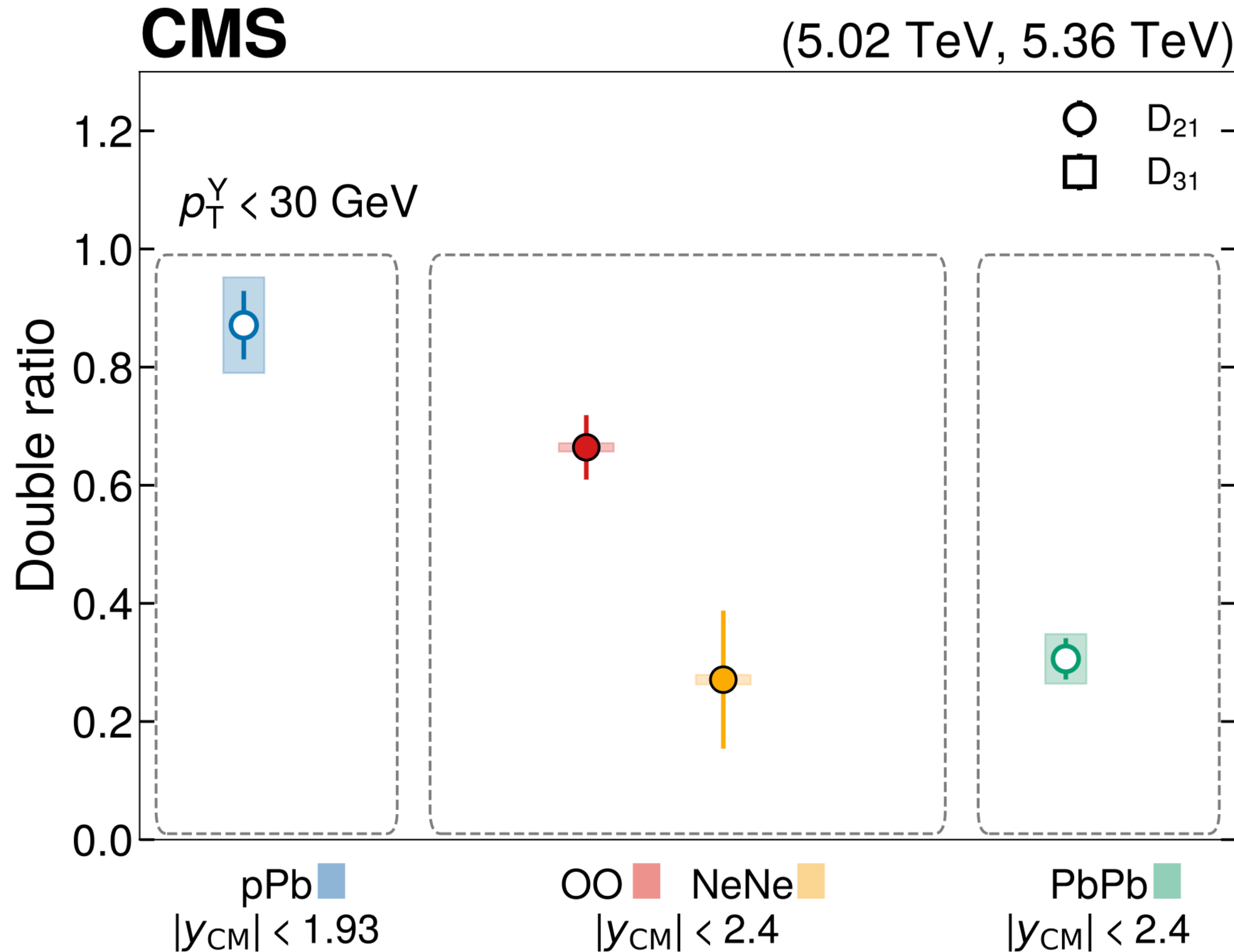


Upsilon Invariant Mass Peaks



- Clear $\Upsilon(3S)$ peak in OO collisions, but not visible for NeNe
- 5.36 TeV pp reference also analyzed

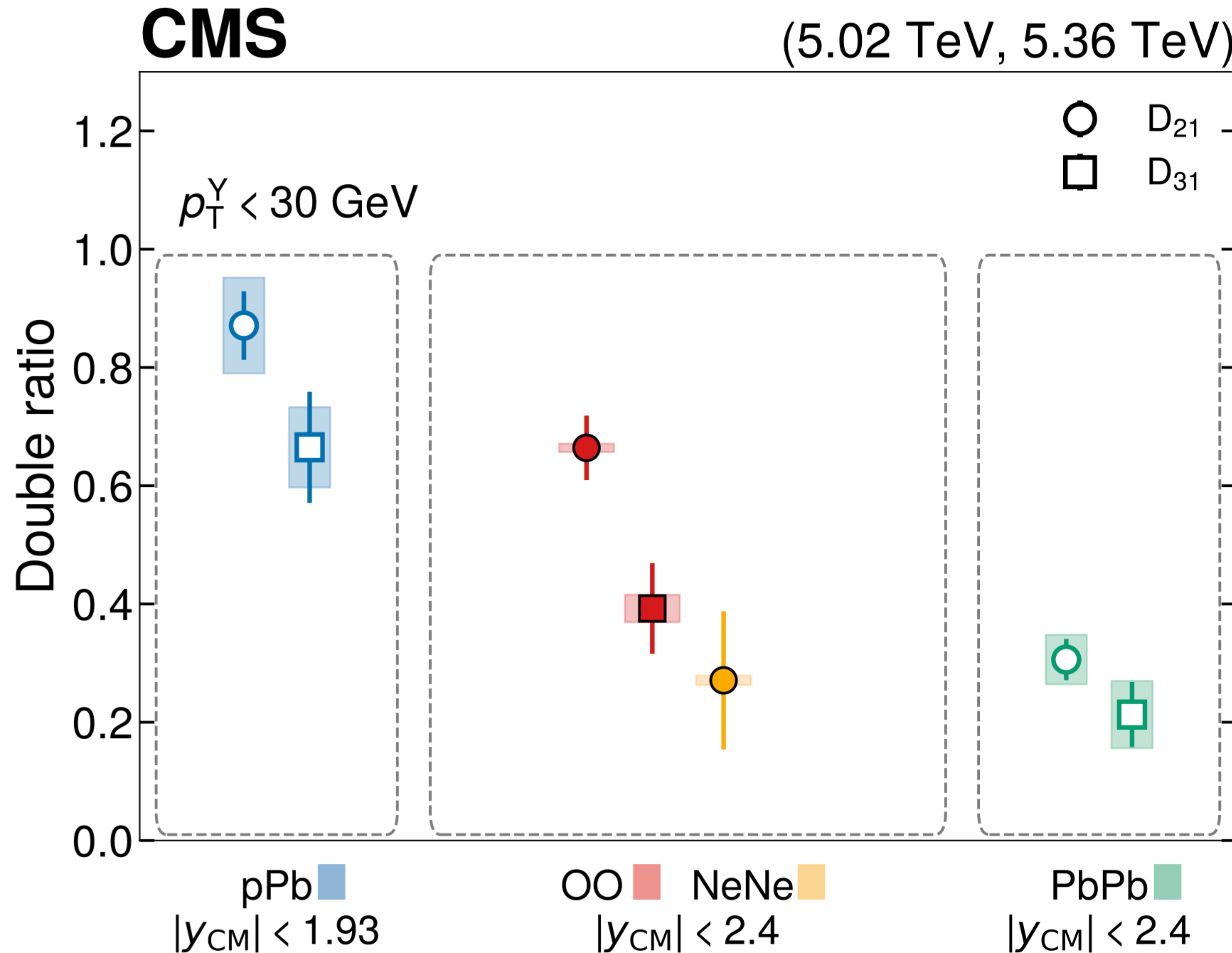
Double Ratio Results - 2S/1S



$$\left(\frac{N^{Y(nS)}}{N^{Y(mS)}} \right)_{AA} / \left(\frac{N^{Y(nS)}}{N^{Y(mS)}} \right)_{pp}$$

- **2S/1S:**
 - **OO between pPb and PbPb**
 - **NeNe lower, with large uncertainty**

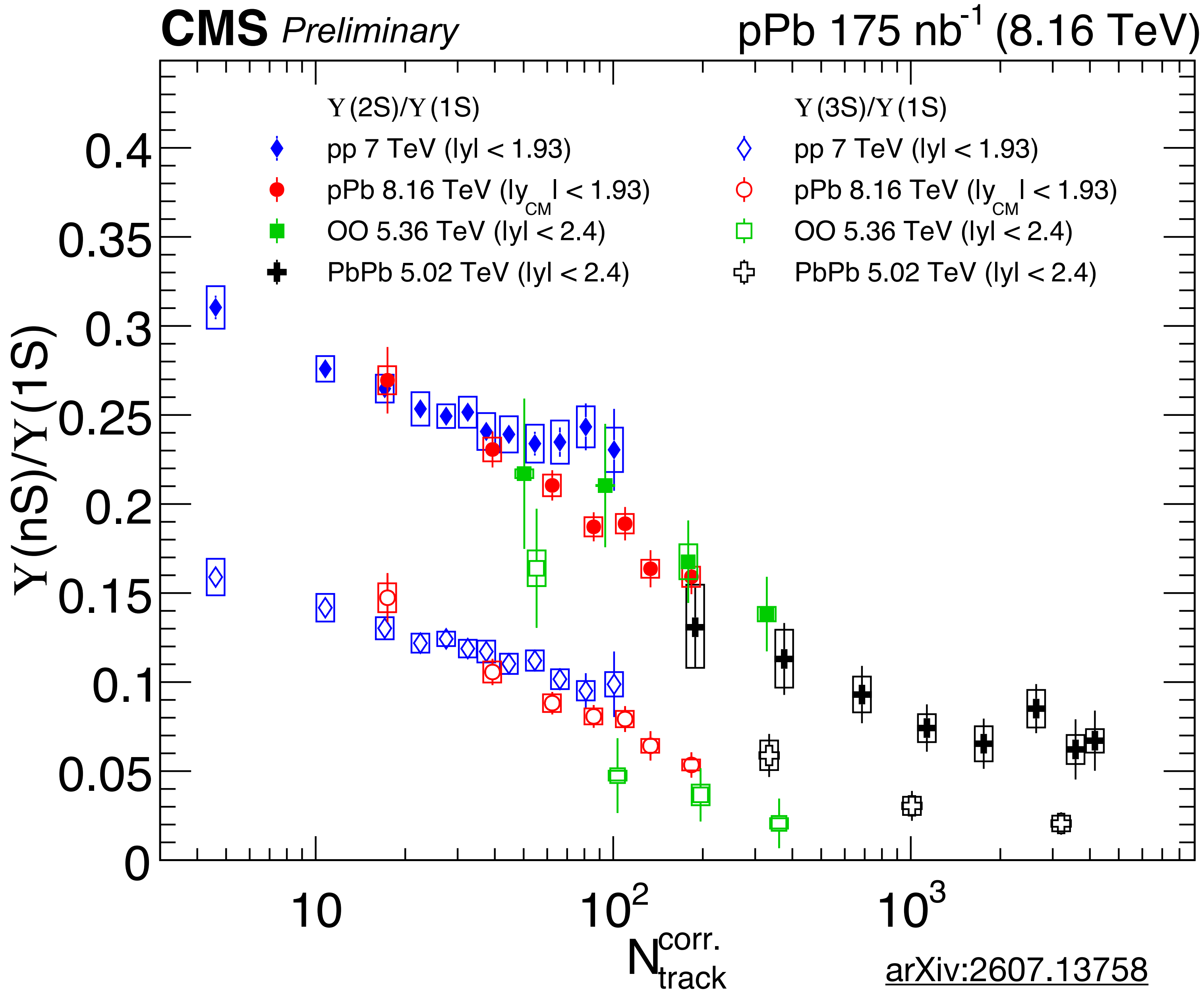
Double Ratio Results - 3S/1S



$$\left(\frac{N^{Y(nS)}}{N^{Y(mS)}} \right)_{AA} / \left(\frac{N^{Y(nS)}}{N^{Y(mS)}} \right)_{pp}$$

- **2S/1S:**
 - OO between pPb and PbPb
 - NeNe lower, with large uncertainty
- **3S/1S:**
 - Clear ordering seen with system size

Compilation of N_{trk}-dependent results

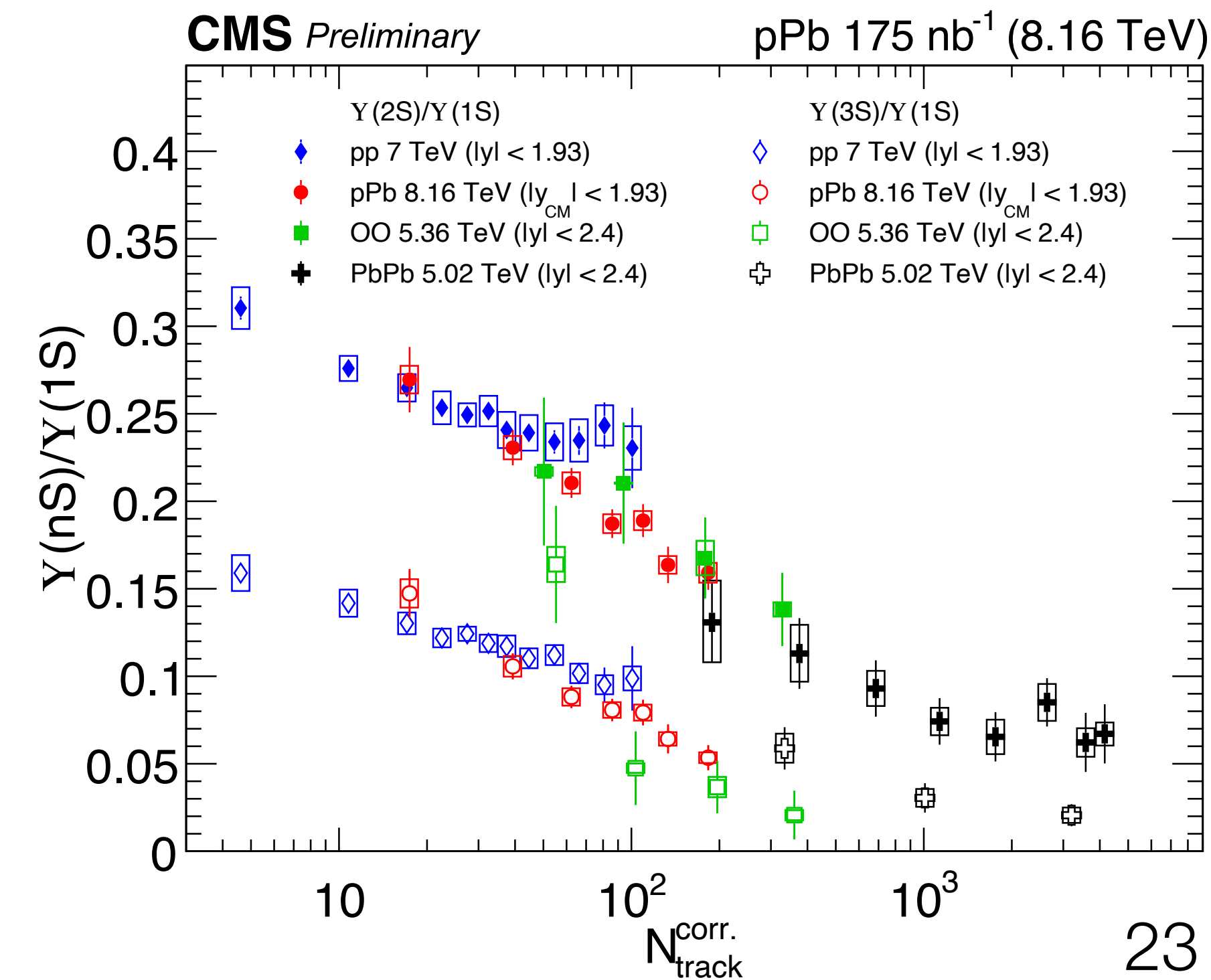
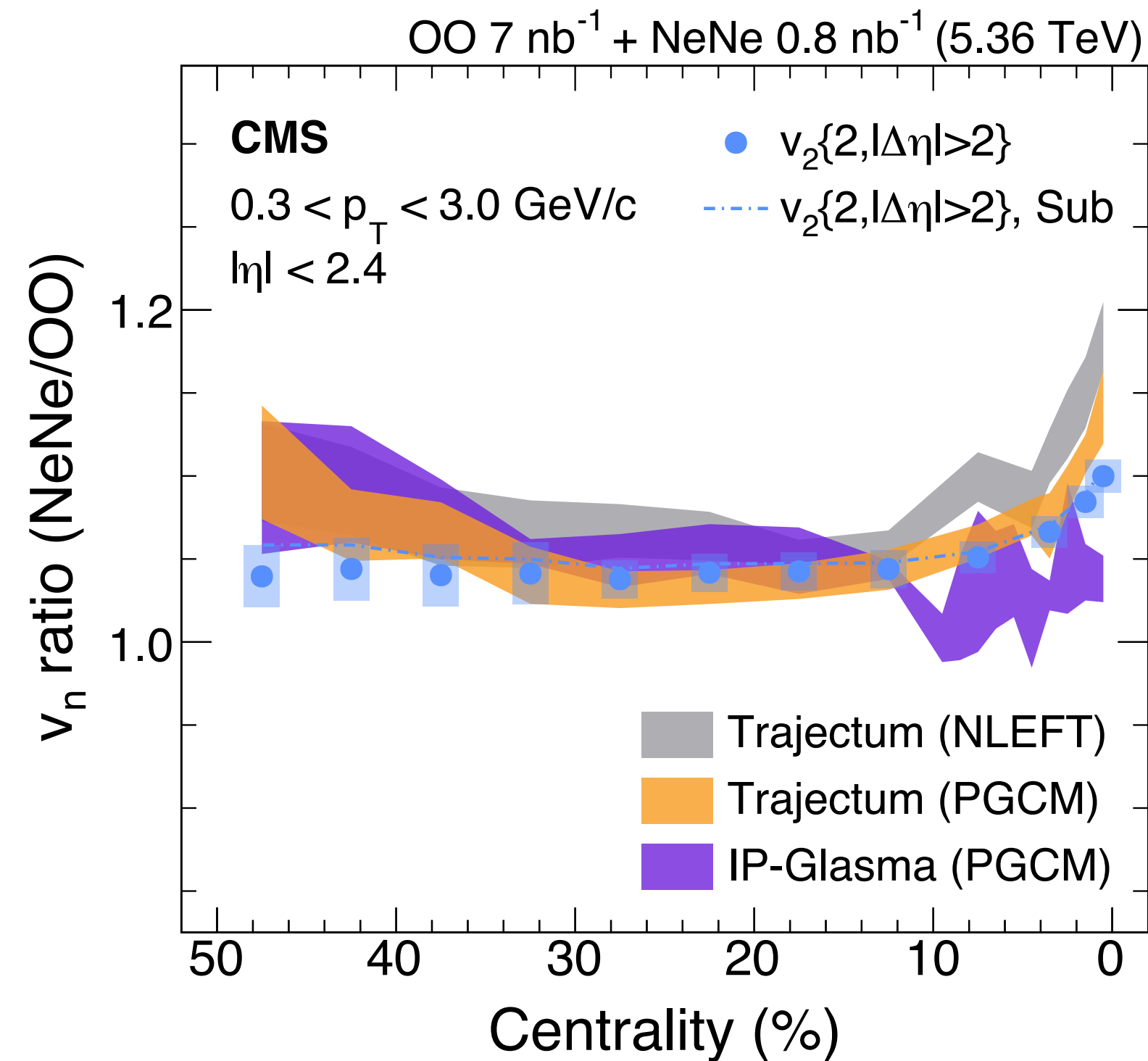
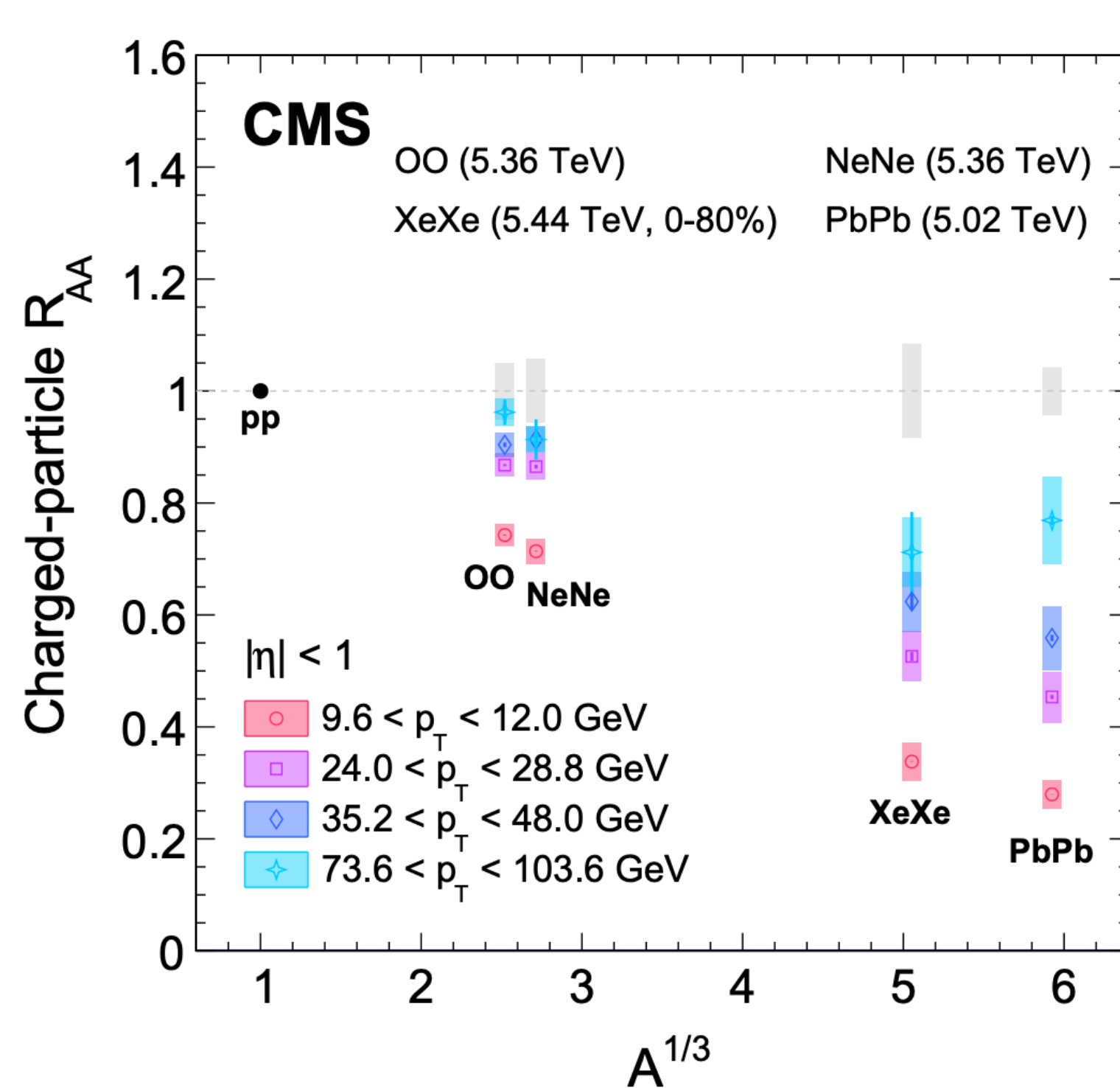


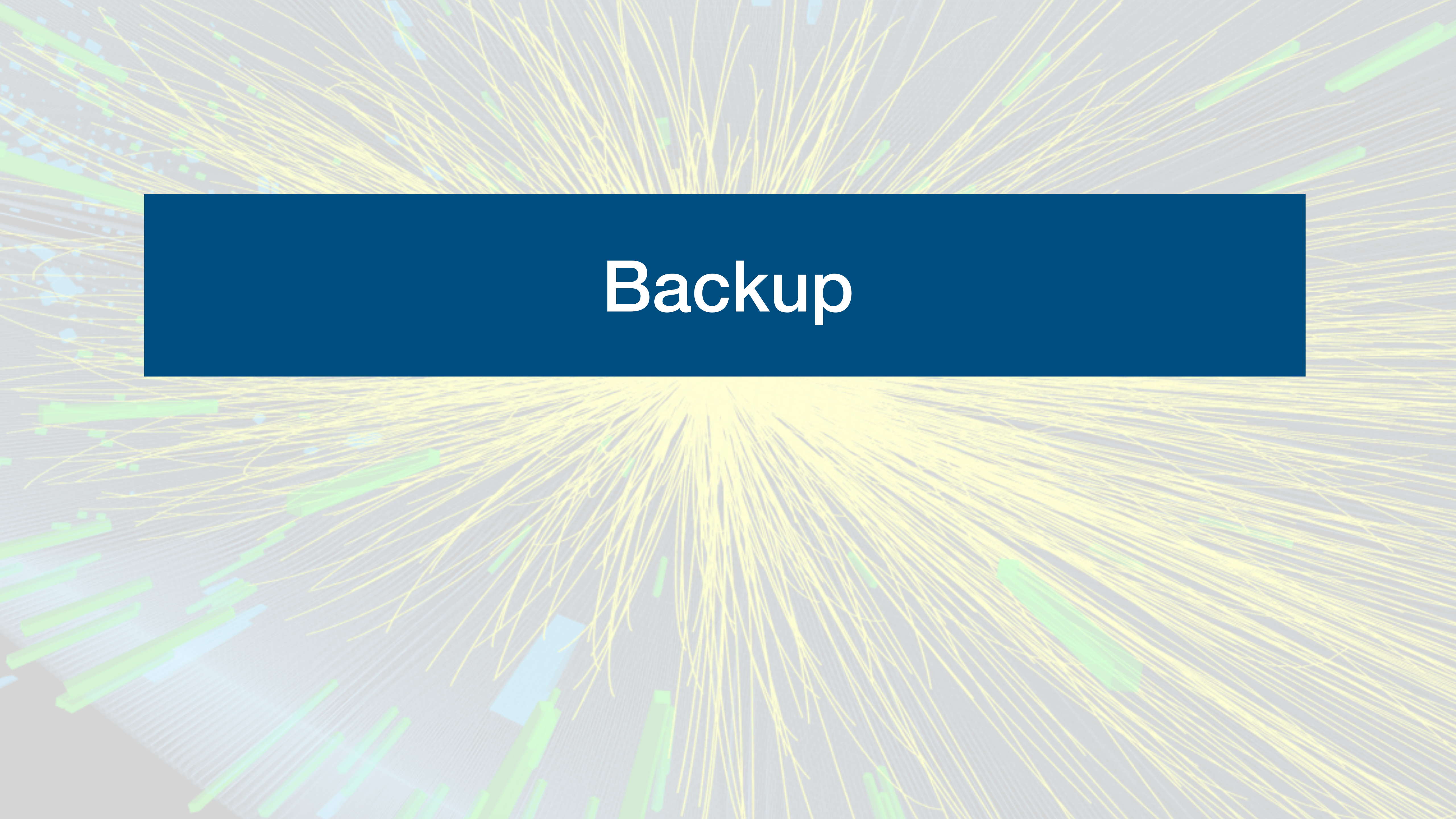
$$\left(\frac{N^{Y(nS)}}{N^{Y(mS)}} \right)_{AA}$$

- **OO 2S/1S single ratio follows pPb, PbPb trend**
- **OO 3S/1S tends to be lower than pPb, PbPb at higher N_{trk}**
- **Potentially creating a denser QGP for a fixed N_{trk}?**
- **But different volumes, temperature, lifetimes, etc.**
- **Need model guidance!**

Lessons learned and outlook

- Essentially every observable examined so far is qualitatively similar to larger systems
 - In particular, parton energy loss strongly indicated for smaller systems
- Measurements in the soft sector show a new avenue for studying nuclear deformations
- Wealth of data for further model constraints - likely highly valuable for Bayesian methods
- Just getting started!
 - To come: pO data, nPDF studies, jets + substructure, charm sector, UPCs.....



The background is a light gray field filled with a dense pattern of thin, yellow lines that radiate from a central point at the top, creating a sunburst or explosion effect. Scattered throughout the scene are numerous small, semi-transparent rectangles in shades of green and blue, some of which are oriented diagonally, giving the impression of floating particles or data points.

Backup

Azimuthal anisotropies in OO and NeNe

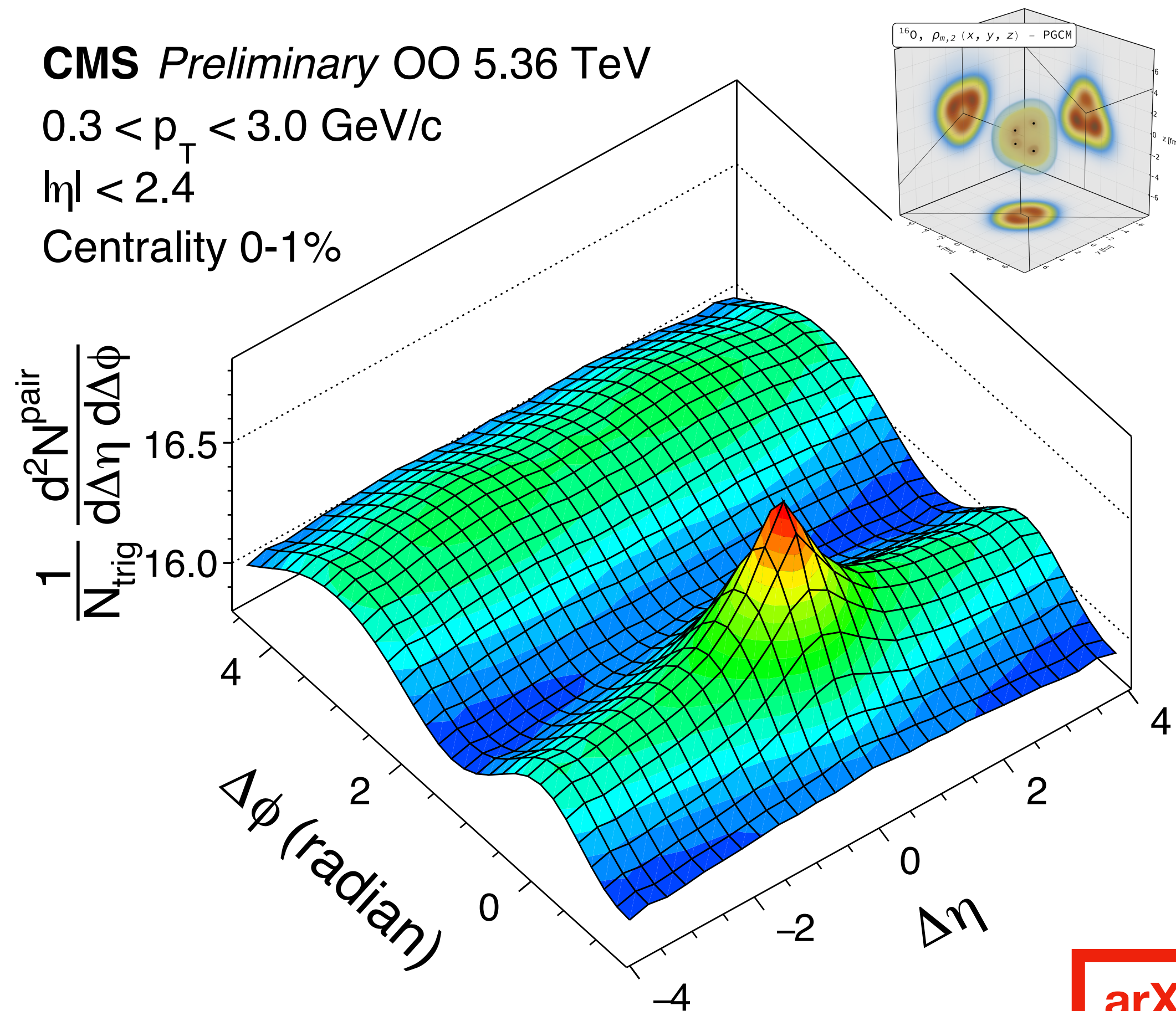
- Clear ridge structures seen in OO and NeNe collisions!

CMS Preliminary OO 5.36 TeV

$0.3 < p_T < 3.0$ GeV/c

$|\eta| < 2.4$

Centrality 0-1%

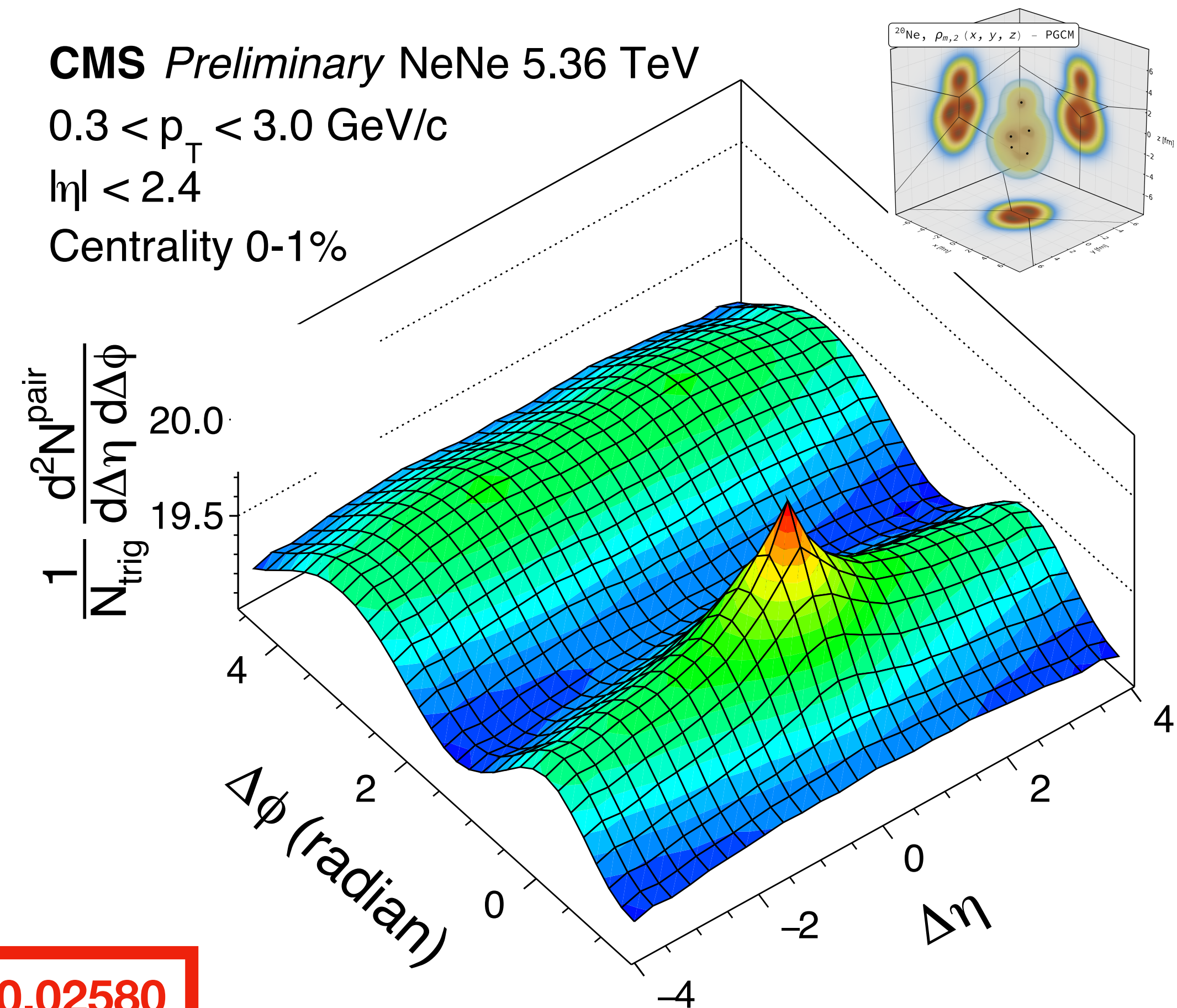


CMS Preliminary NeNe 5.36 TeV

$0.3 < p_T < 3.0$ GeV/c

$|\eta| < 2.4$

Centrality 0-1%



[arXiv:2510.02580](https://arxiv.org/abs/2510.02580)