

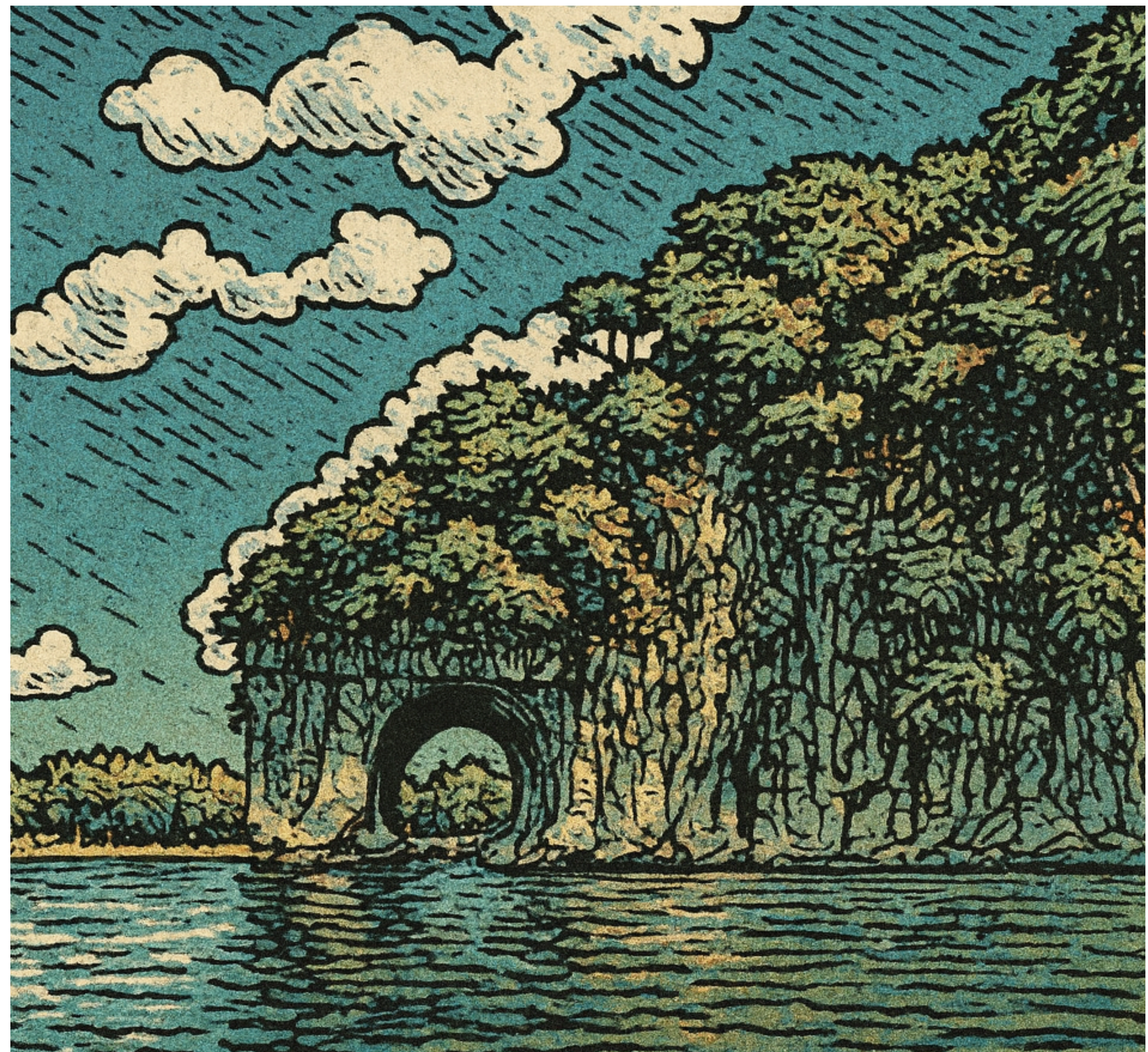
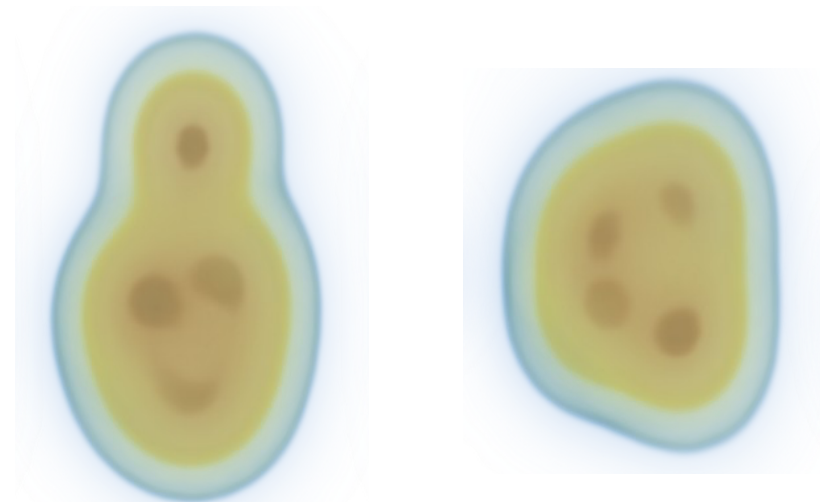


Recent flow results from ATLAS

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University of Science and Technology of China

October 26, 2025

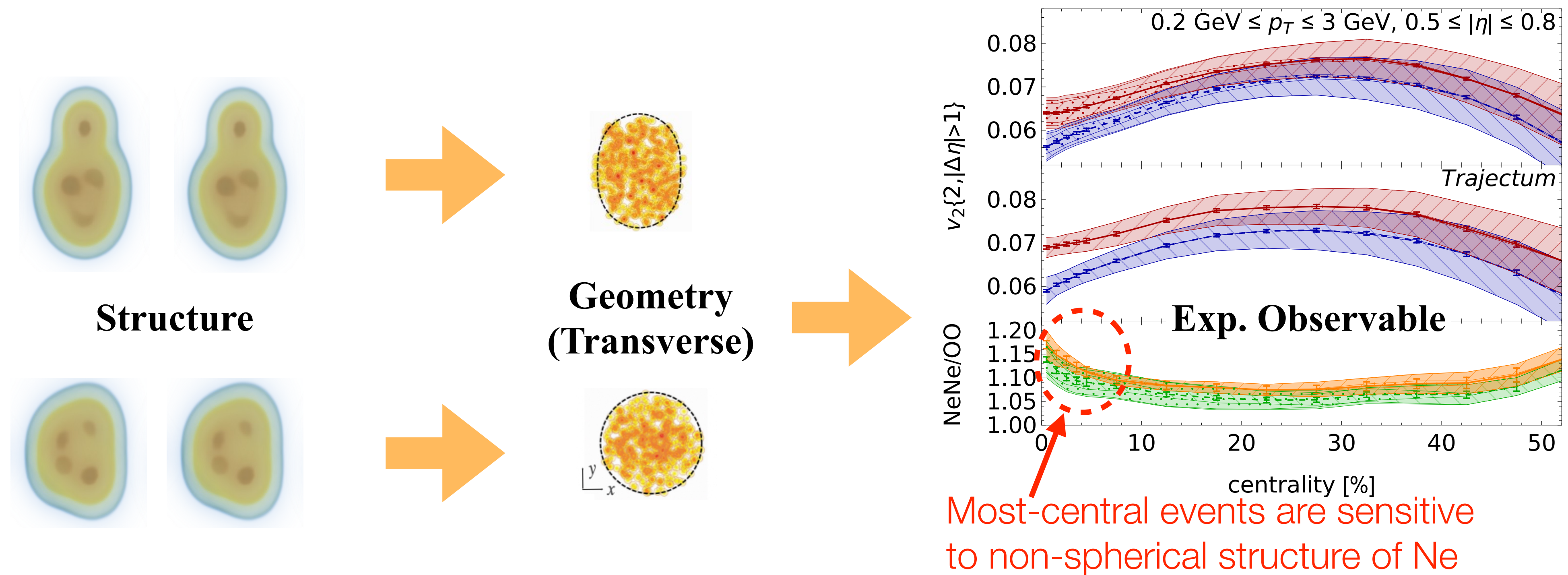


The 16th Workshop on QCD Phase Transition and Relativistic Heavy-Ion Physics (QPT 2025)

Oct. 24-28, 2025, Guilin

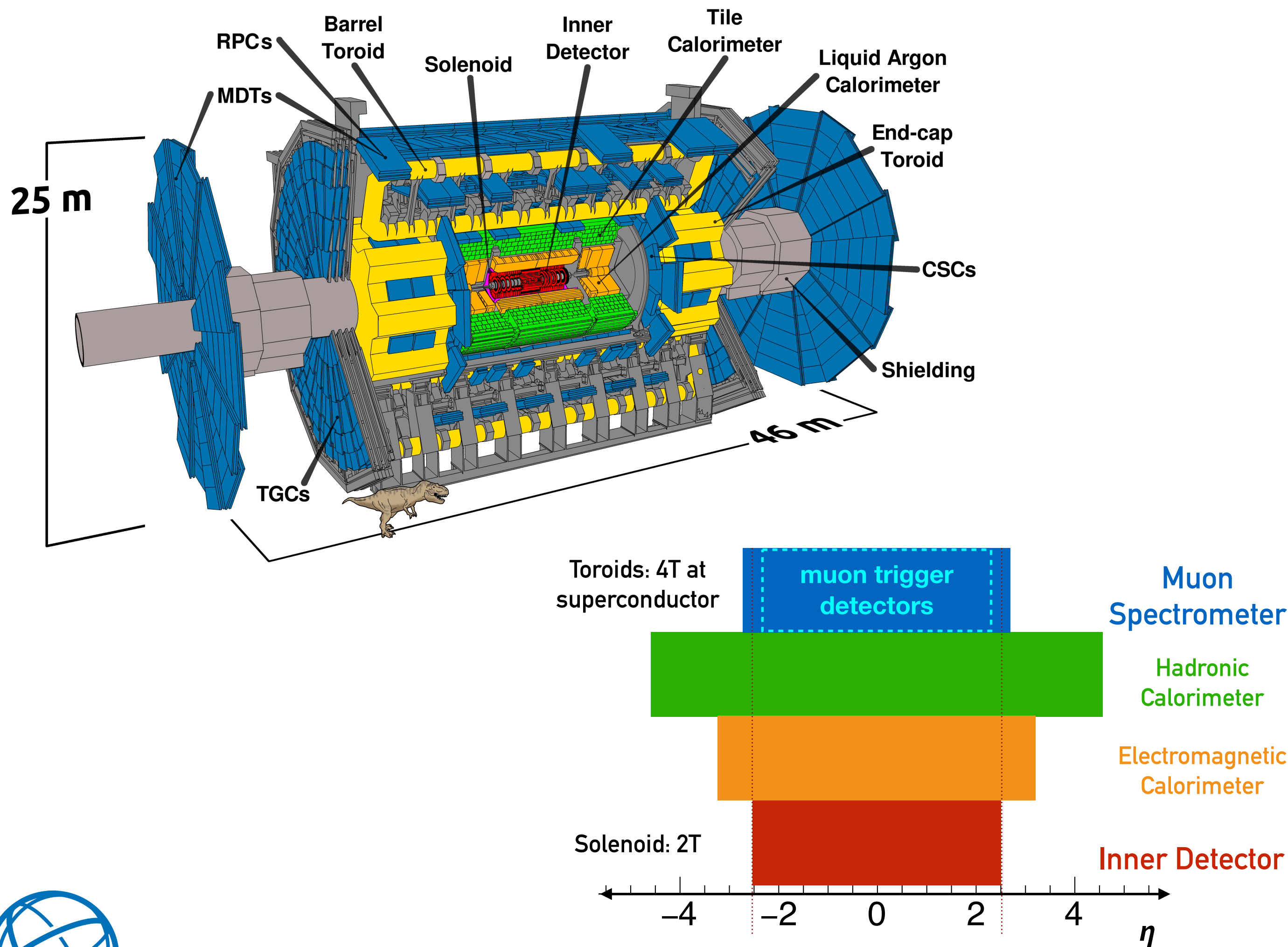
Why light ions collisions at LHC

- Bridge the gap between pp and Pb+Pb/Xe+Xe to test QGP formation in light-ion collisions
- If QGP is formed, use most-central ^{20}Ne (deformed) vs ^{16}O (spherical) collisions to probe nuclear structure



Giuliano Giacalone et al. PRL 135 (2025) 012302
Jiangyong Jia, arXiv:2501.16071

ATLAS heavy-ion physics program



System	Year	$\sqrt{s_{NN}}$ [TeV]	L_{int} [nb ⁻¹]
Pb+Pb	2010	2.76	0.007
Pb+Pb	2011	2.76	0.14
pp	2013	2.76	4000
p+Pb	2013	5.02	29
pp	2015	5.02	28000
Pb+Pb	2015	5.02	0.49
p+Pb	2016	5.02	0.5
p+Pb	2016	8.16	160
Xe+Xe	2017	5.44	0.003
pp	2017	5.02	270000
Pb+Pb	2018	5.02	1.76
Pb+Pb	2023	5.36	1.71
pp	2024	5.36	425000
Pb+Pb	2024	5.36	1.73
p+O	2025	9.62	12.48
O+O	2025	5.36	8.63
Ne+Ne	2025	5.36	1.05
Pb+Pb	2025	5.36	To be taken
??	2026	??	??

Run1

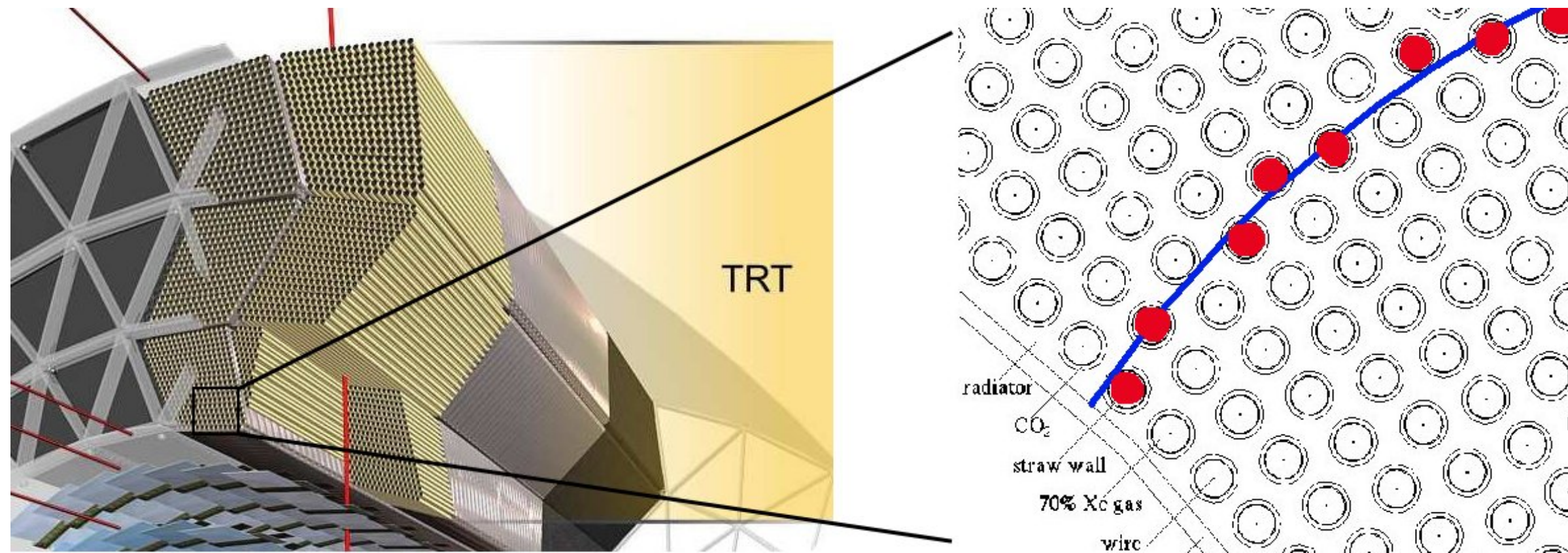
Run2

Run3

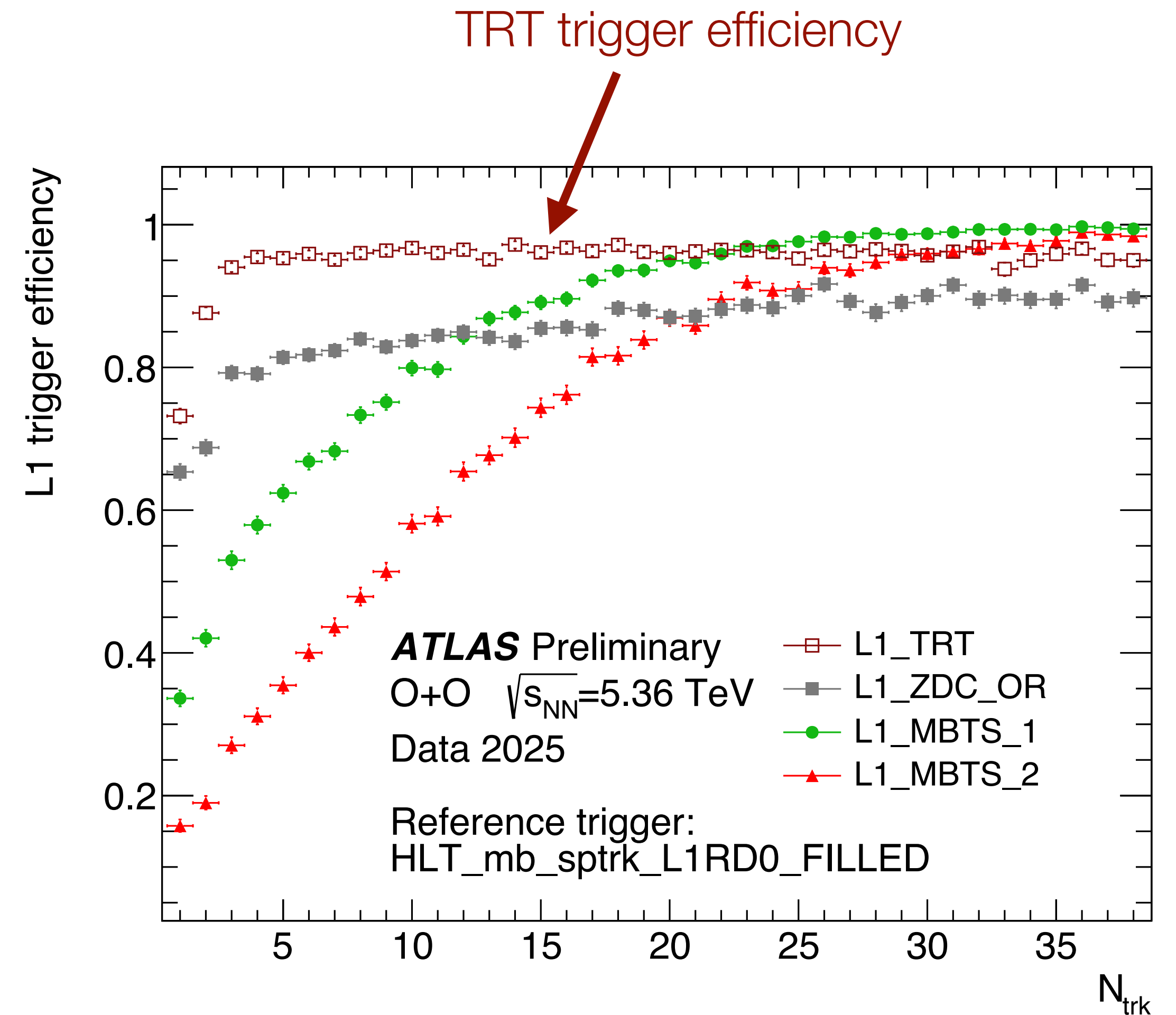
All ATLAS HI public results: <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults>



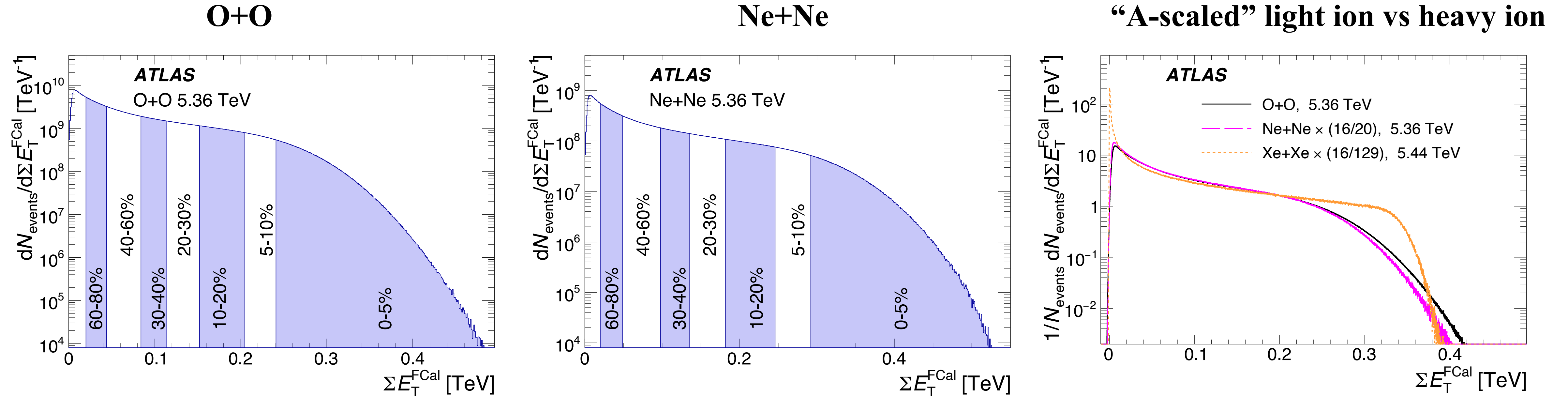
Trigger strategy



- Minimum-bias event triggering with TRT
- Unbiased down to very low multiplicities
- Significantly better performance than other ATLAS minimum-bias triggers (MBTS, ZDC, etc.)



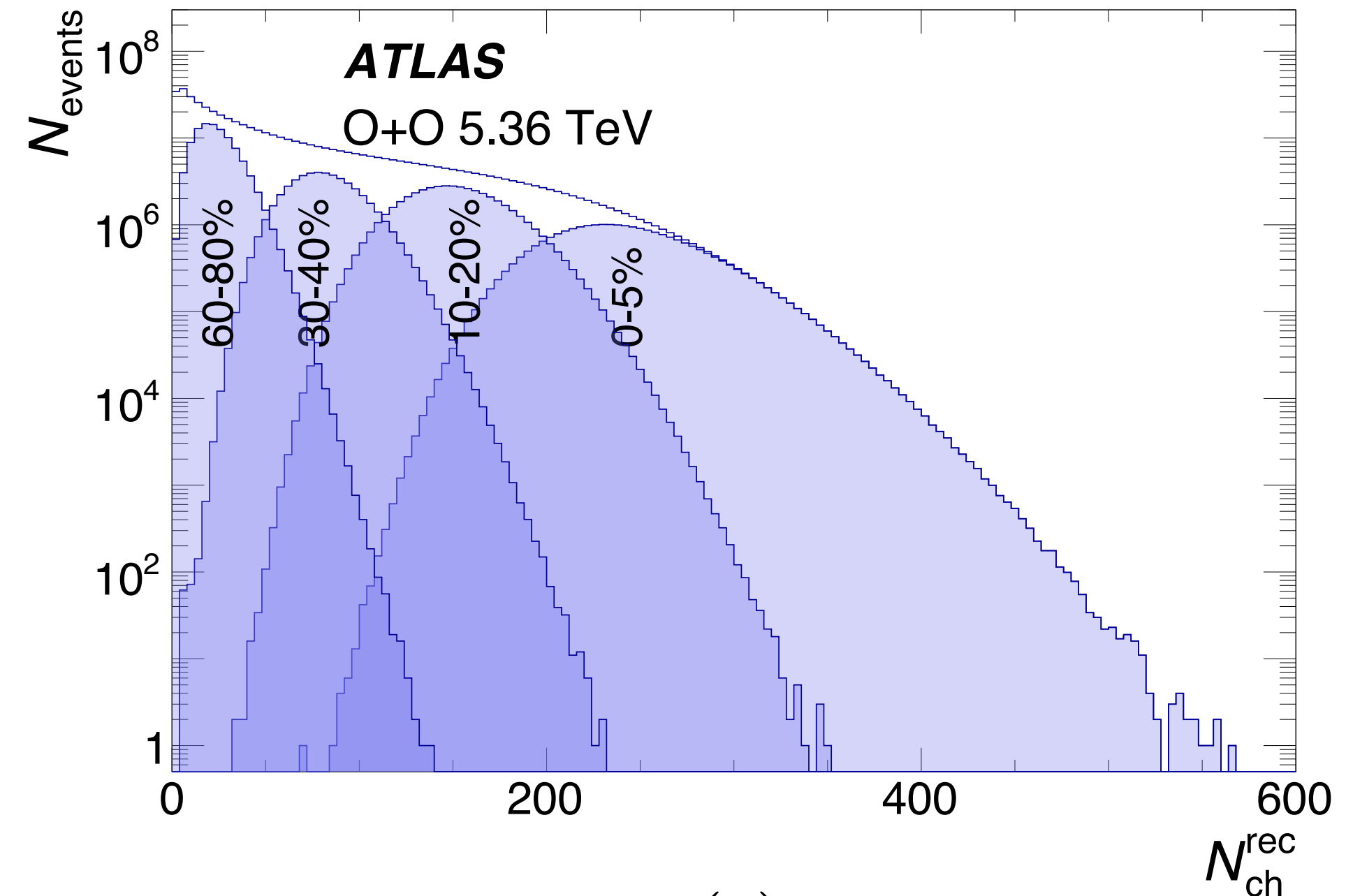
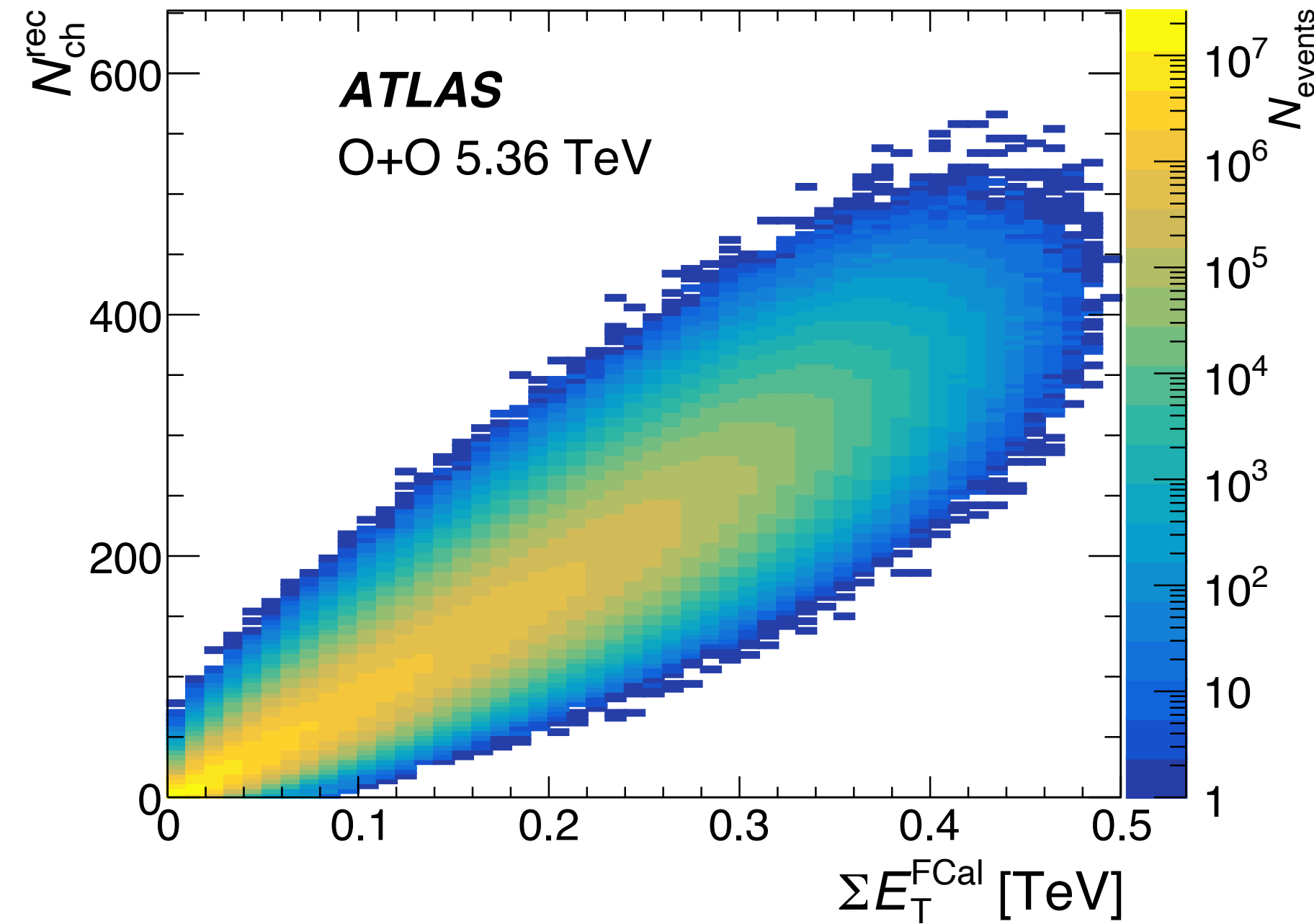
O+O and Ne+Ne Centrality



- Centrality from Forward Calorimeter energy sum (0–80%)
- Glauber analysis with improved light-ion geometry and fluctuations (Loizides, arXiv:2507.05853)
- Event-by-event fluctuations play a larger role in light-ion collisions in most central collisions (long tails)



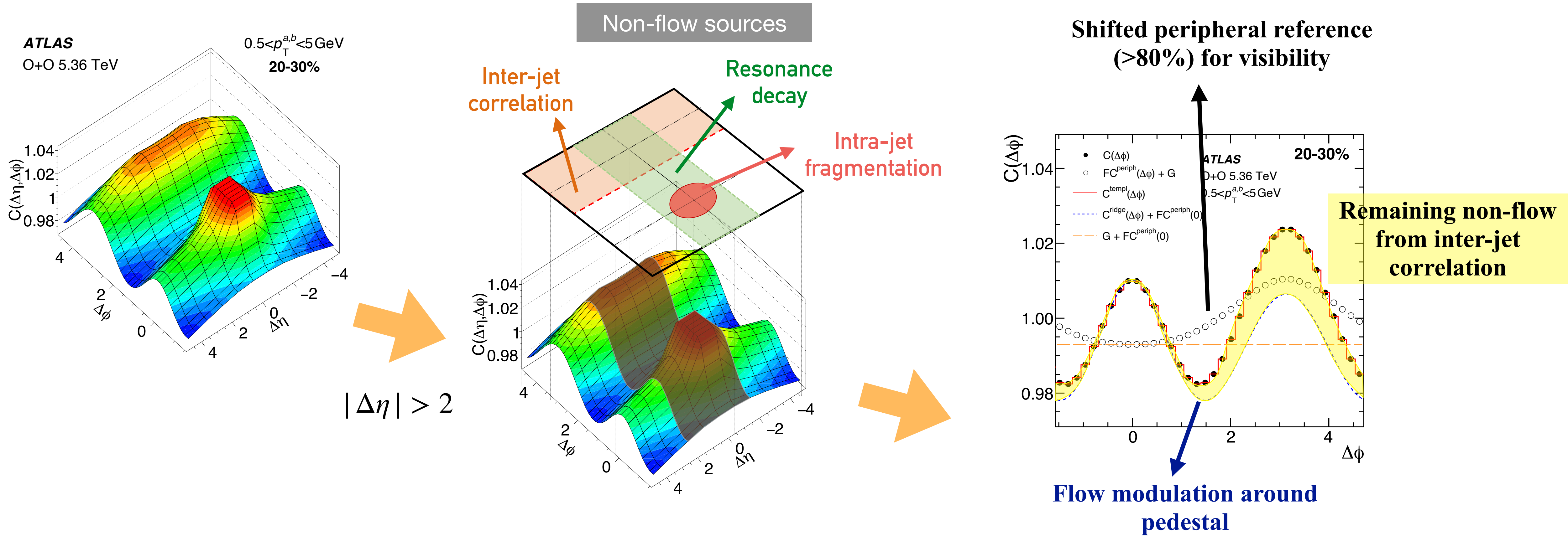
Centrality definitions: forward energy vs. multiplicity



- Correlation between forward energy and mid-rapidity multiplicity in O+O (Ne+Ne is similar)
- When comparing model using multiplicity-based centrality to data, one should account for bin migration between different centrality definitions



Two particle correlation



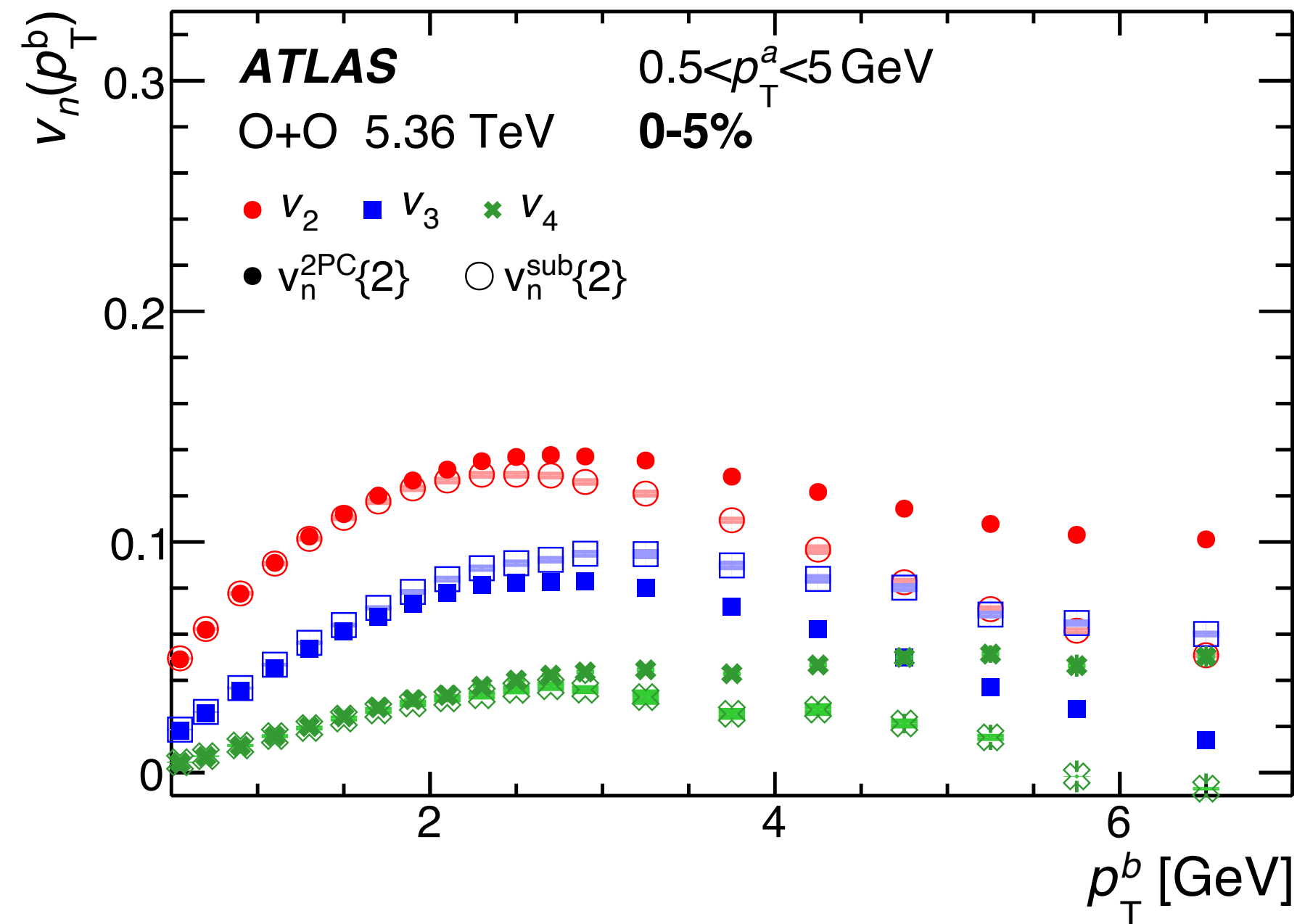
$$v_n(p_T^b) = \frac{v_{n,n}(p_T^a, p_T^b)}{v_n(p_T^a)} = \frac{v_{n,n}(p_T^a, p_T^b)}{\sqrt{v_{n,n}(p_T^a, p_T^a)}}$$

$$C(\Delta\phi) = FC^{\text{periph}}(\Delta\phi) + G \left\{ 1 + 2 \sum_{n=2}^5 v_{n,n}(p_T^a, p_T^b) \cos(n\Delta\phi) \right\}$$

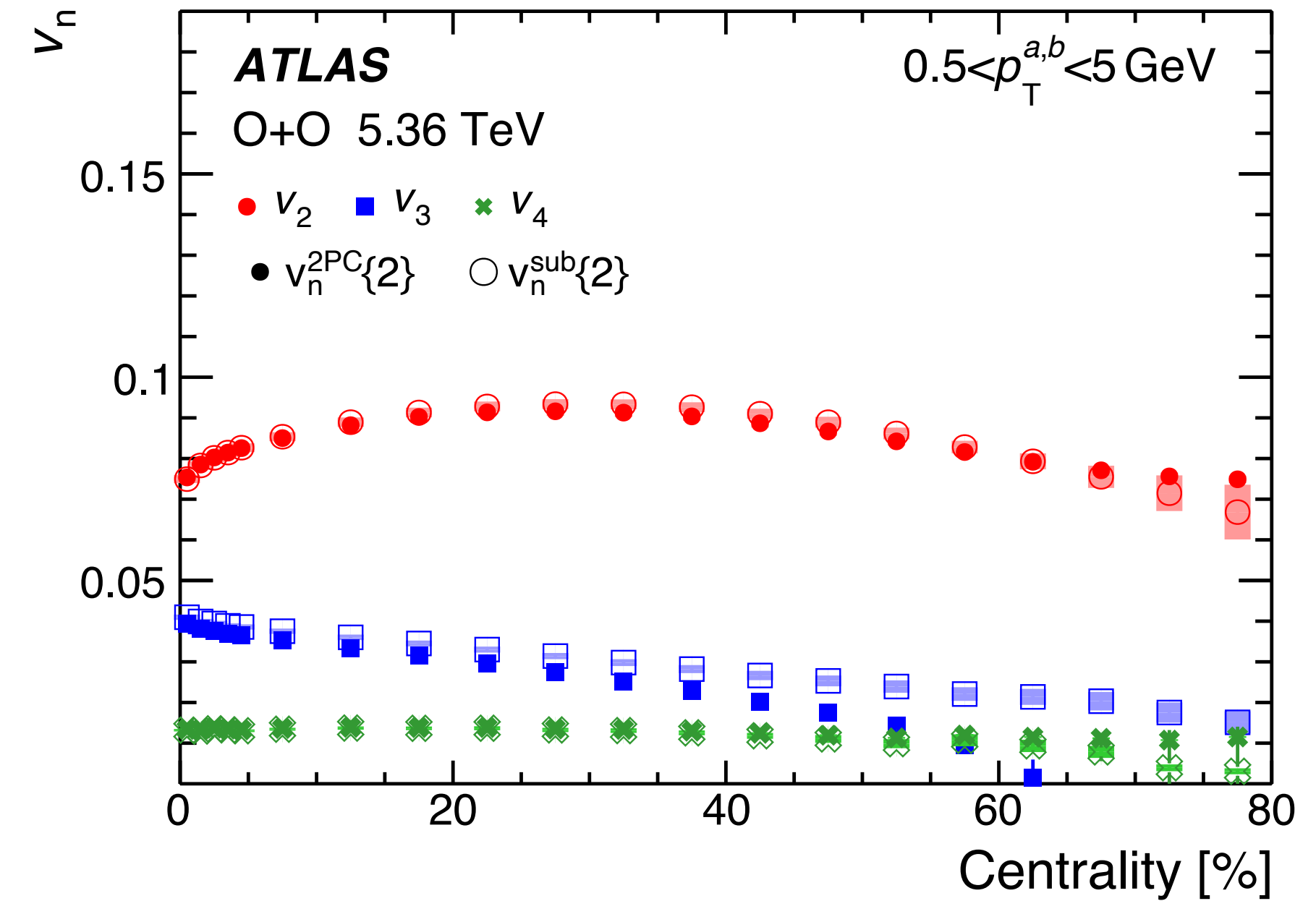
$$= FC^{\text{periph}}(\Delta\phi) + Y^{\text{ridge}}(\Delta\phi).$$



p_T dependence



Centrality dependence



● Direct Fourier decomposition: $v_n^{2PC}\{2\}$

○ Template fit: $v_n^{sub}\{2\}$

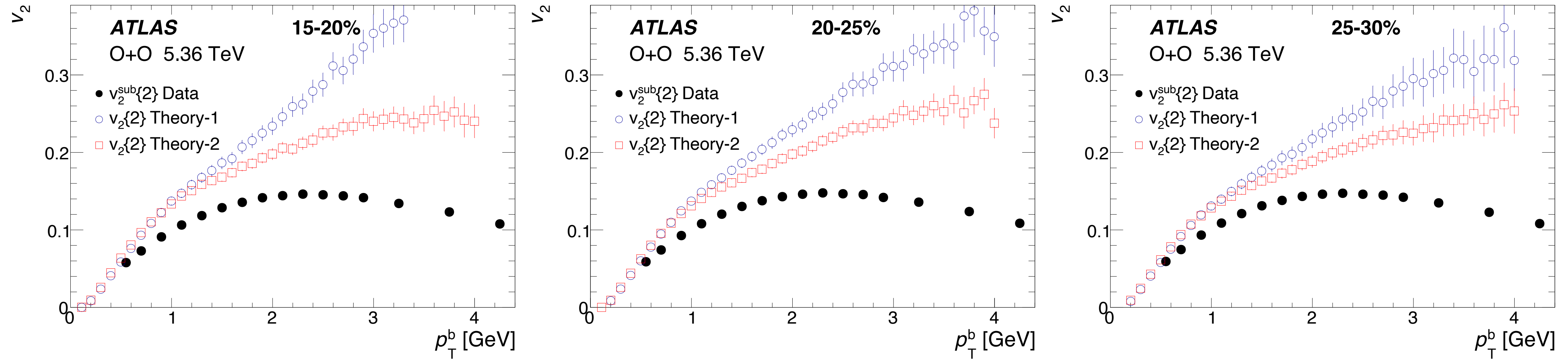
Effect of subtraction (strongly p_T dependent):

$v_2\{2\} \downarrow, v_3\{2\} \uparrow, v_4\{2\} \downarrow$

• $v_n^{sub}\{2\}$ is chosen as the central results

• When integrated over wide p_T range (0.5 ~ 5 GeV), the impact of non-flow is small



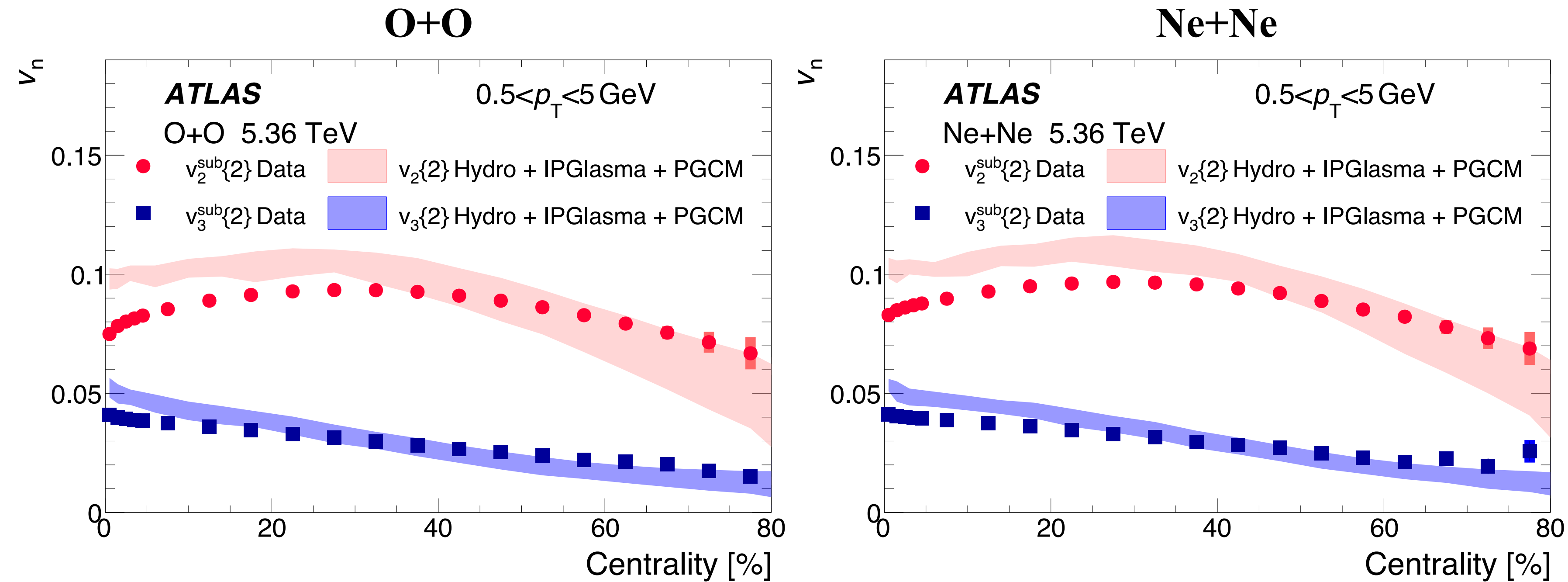


IPGlasma+Hydro+PGCM:

- “Theory-1” vs “Theory-2” correspond to how much anisotropy from the glasma stage is retained in the hydro initialization
- ATLAS data provide input to further improve models



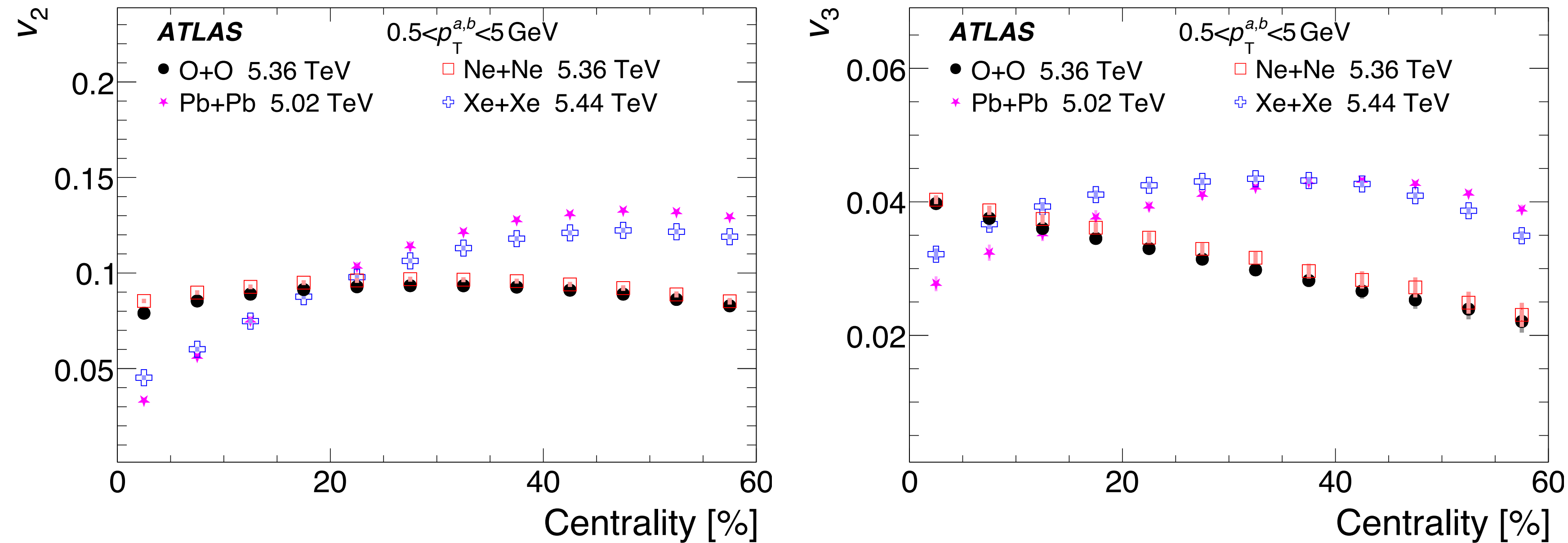
Other aux figures of the paper can be found at <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2025-02/>



- Flow signals in O+O and Ne+Ne resemble those seen in heavy-ion collisions
- Characteristic ordering observed: $v_2 > v_3$
- Comparison with **Hydro+IPGlasma+PGCM** models clearly indicates a collective (hydrodynamical) response



Comparison of different ion collisions



- Flow in Ne+Ne consistently larger than in O+O
- Light ions vs. heavy ions in centralities:
 - Light ion v_2 is much flatter
 - Light ion v_3 decreases from central to peripheral
 - Stronger fluctuation contributions in light ions

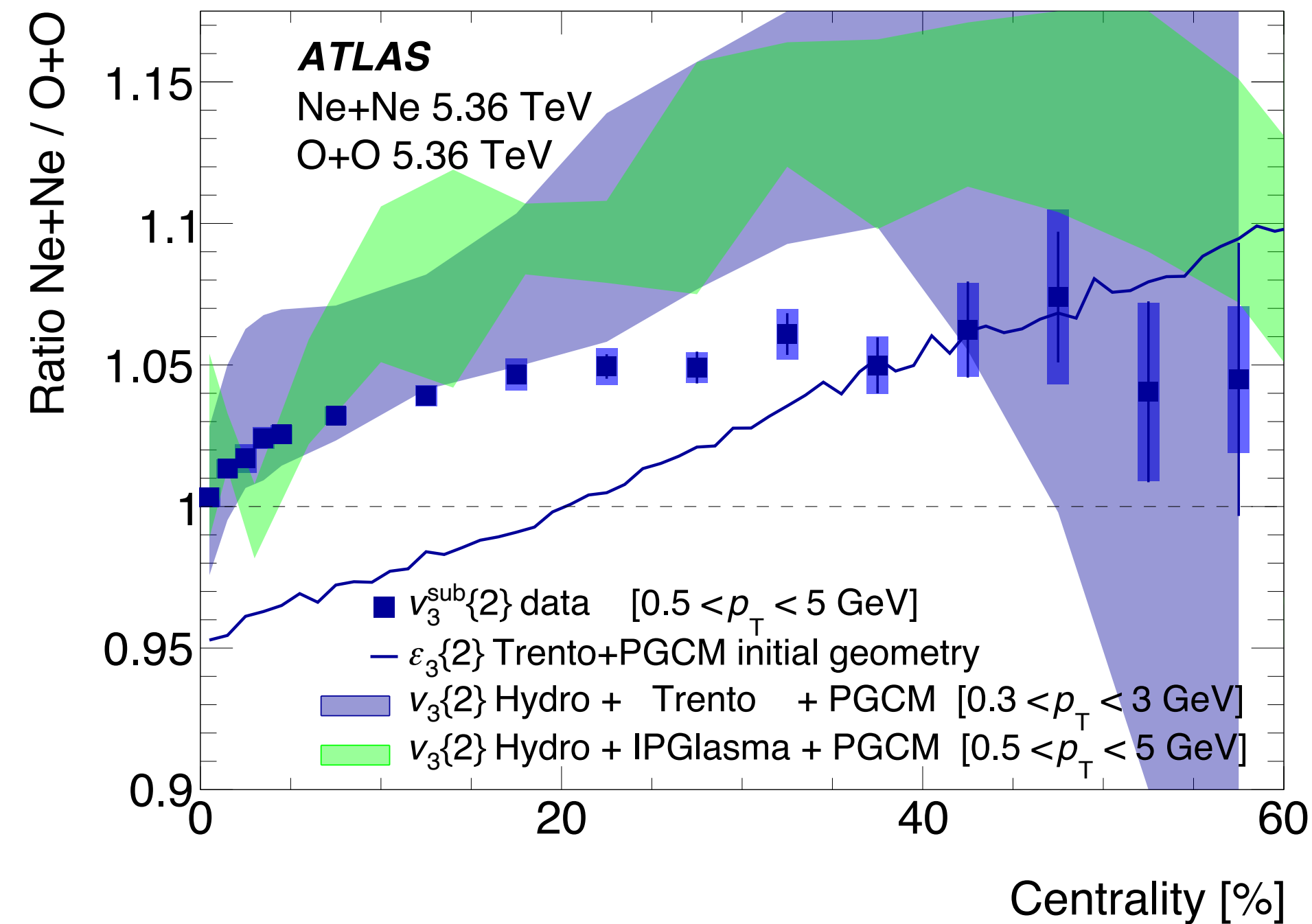
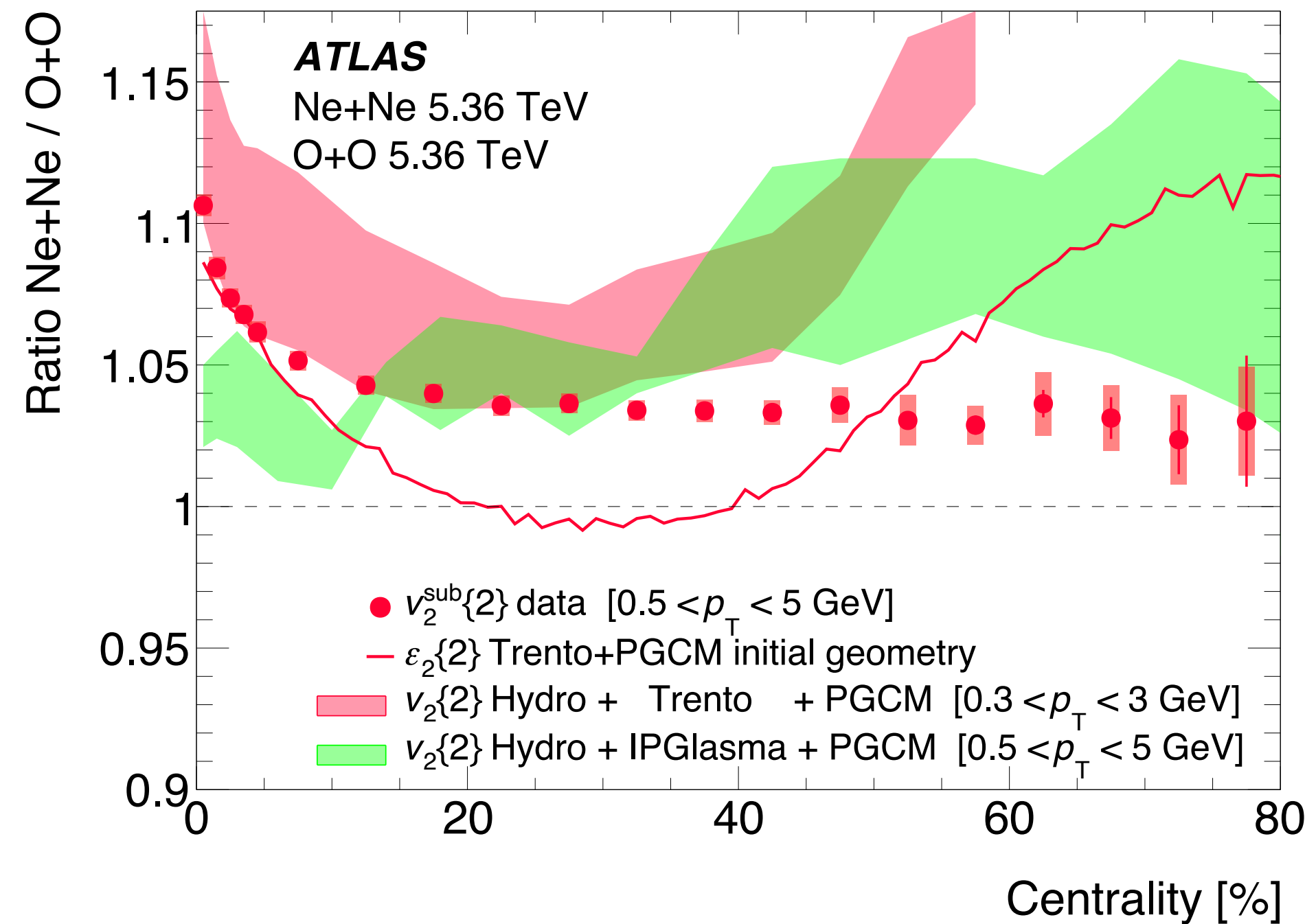


Ne+Ne/O+O vs. model calculations

ATLAS: arXiv:2509.05171

Hydro+Trento+PGCM, PRL 135 (2025) 012302

Hydro+IPGlasma+PGCM: PRL 135 (2025) 022302



Compare to PGCM (initial conditions) + **different** pre-equilibrium evolution + Hydro (QGP phase):

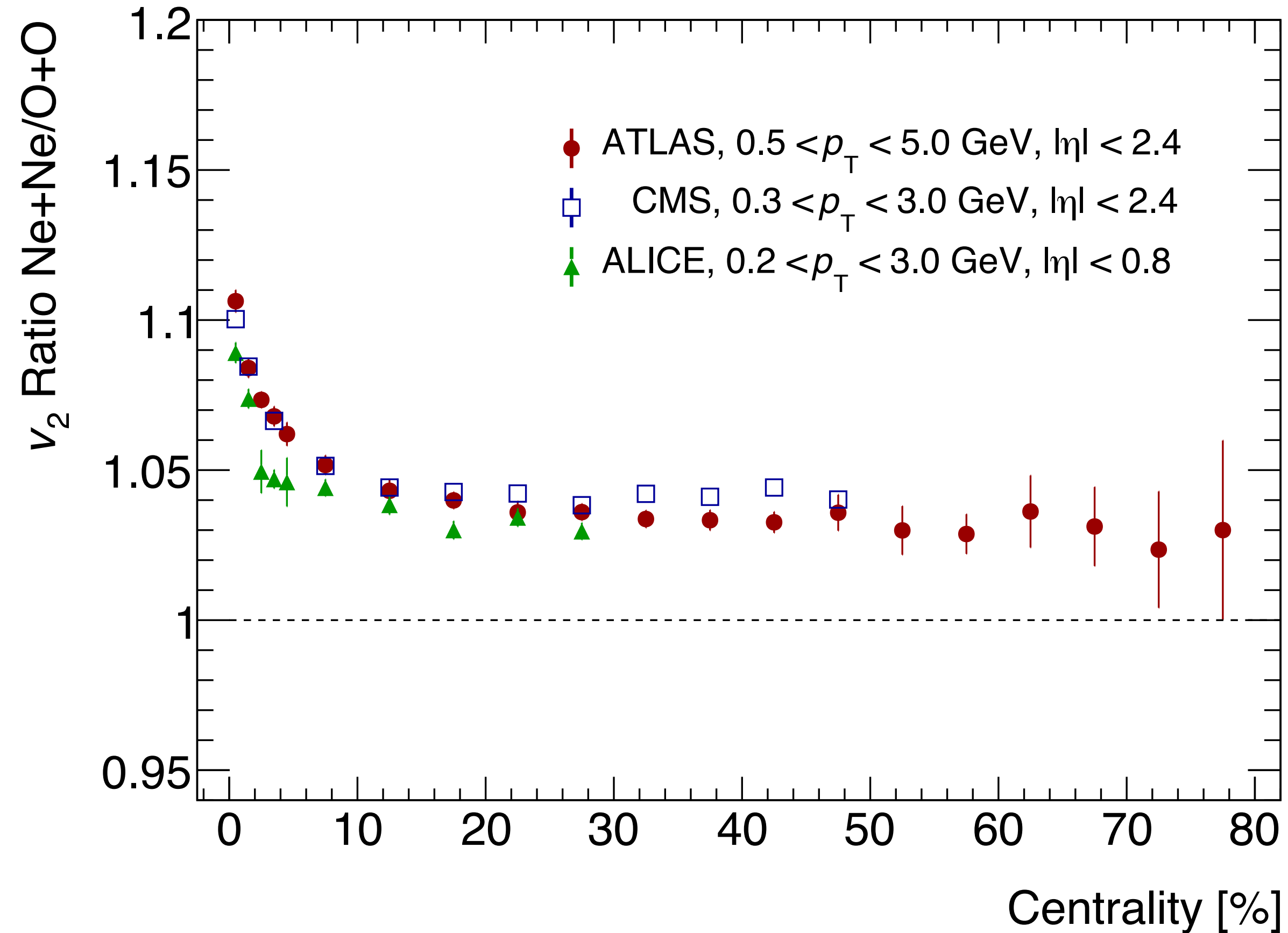
- **Trento**: provides a better description of centrality dependence in central events
- **IPGlasma**: fails to reproduce the observed central-event trend



Giacolone et al, PRL 135 (2025) 012302

Mantysaari et al, PRL 135 (2025) 022302

Cross-experiment comparison



- Overall good consistency across experiments
- Small difference between experiments could arise from different selections

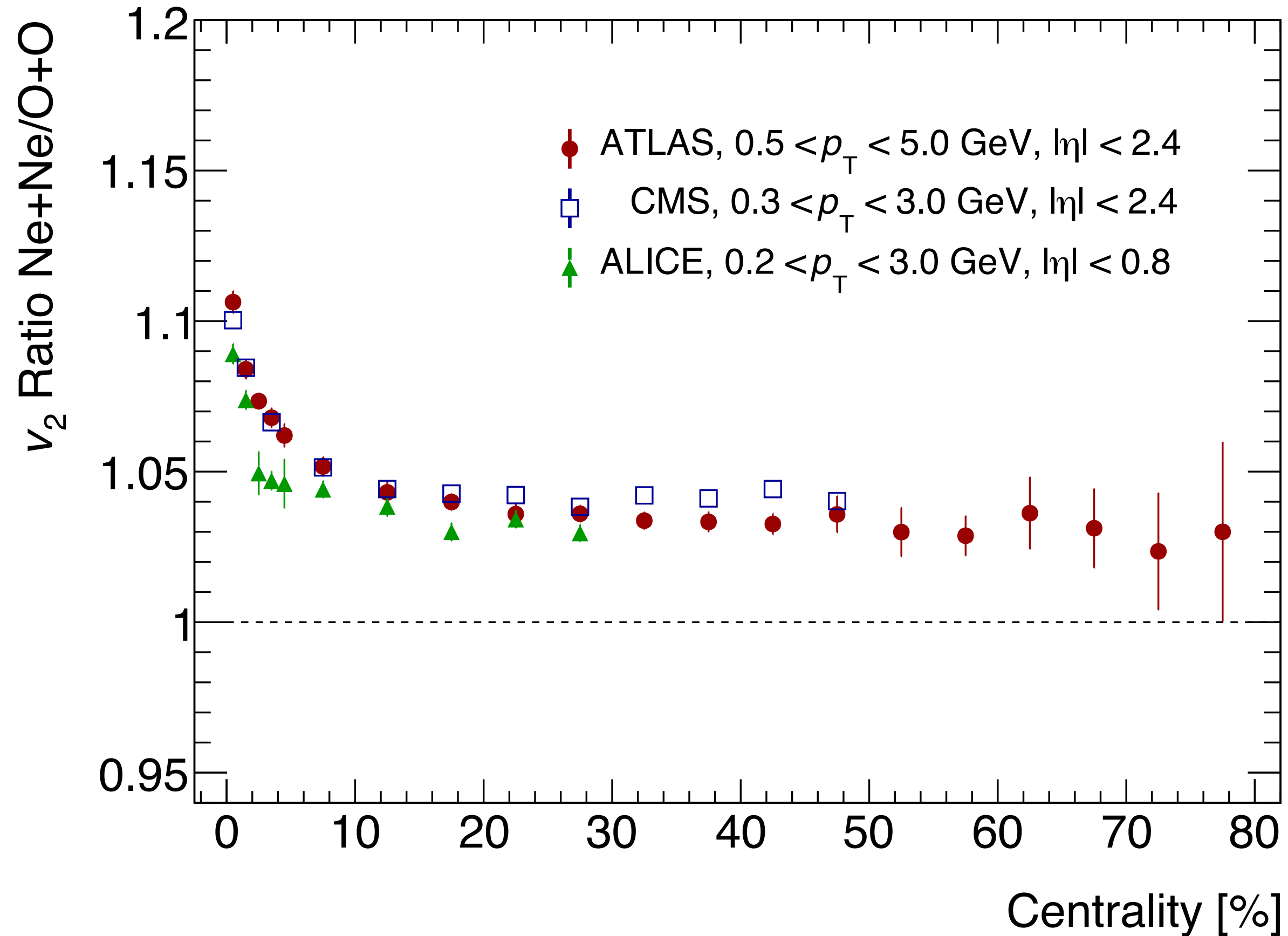
ATLAS: [arXiv:2509.05171](#) (submit to PRC)

ALICE: [arXiv:2509.06428](#) (submit to PRL)

CMS: [arXiv:2510.02580](#) (submit to PRL)

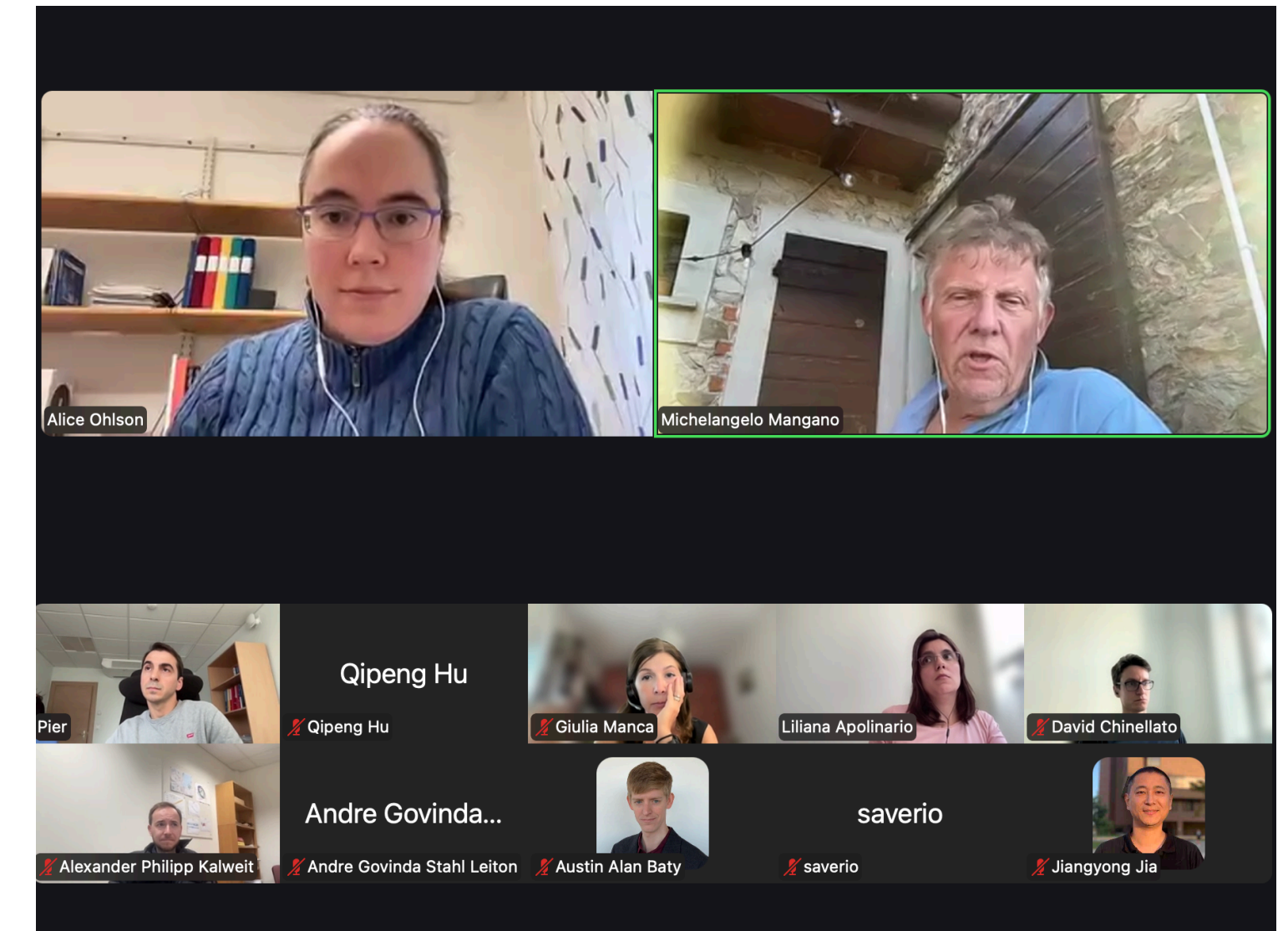


Cross-experiment comparison



LHC HI working group:

- Bridge experimental and theoretical HI communities ...
- Improve the uniformity of analysis choice ...
- ...



Conveners:

ALICE: Alice Ohlson, Alexander Kalweit

ATLAS: Qipeng Hu, Martin Rybar

CMS: Austin Baty, Andre Stahl

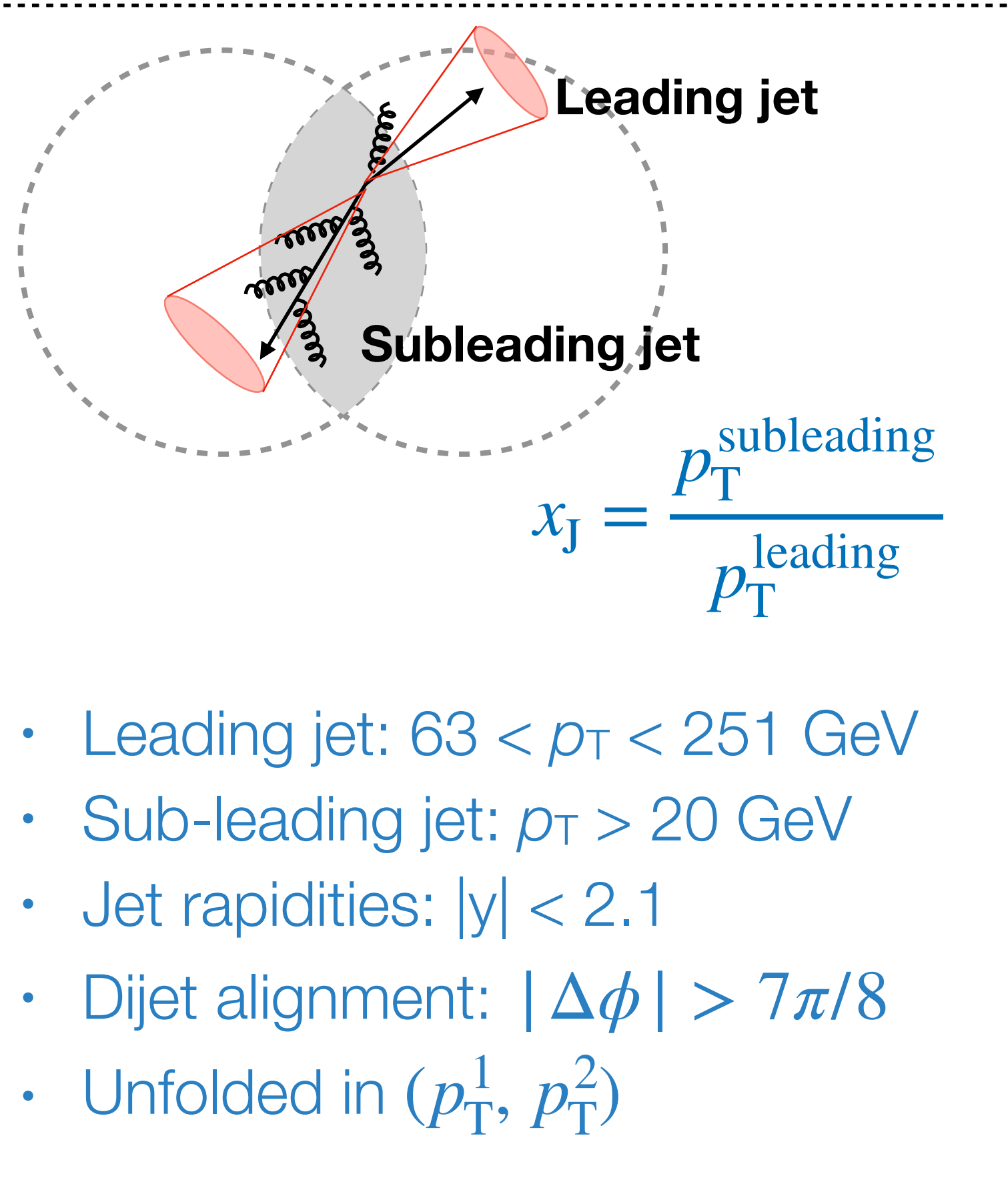
LHCb: Giulia Manca, Saverio Mariani

Theory: Liliana Apolinario, Urs Wiedemann

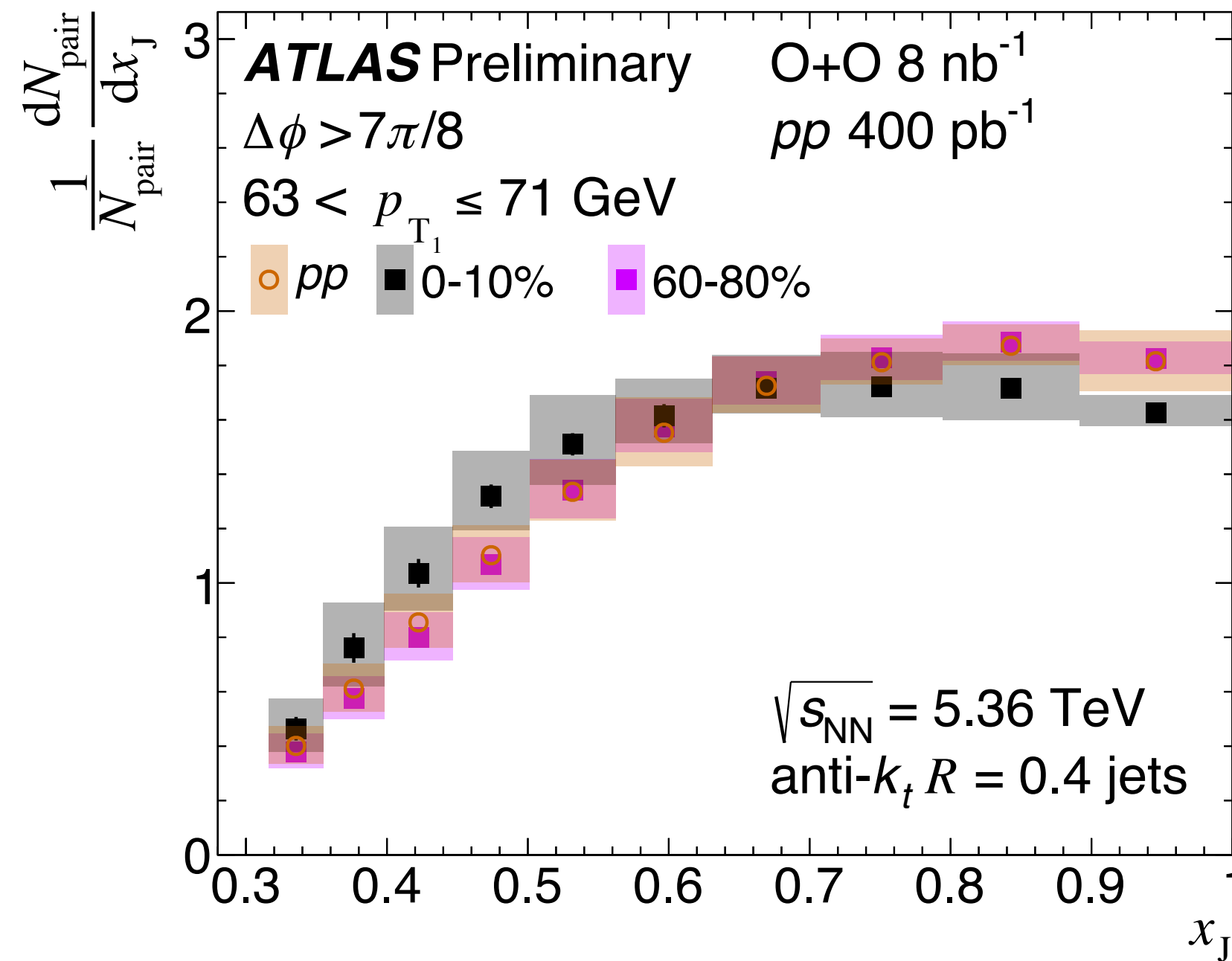
Reach all through ihc-hiwg-admin@cern.ch



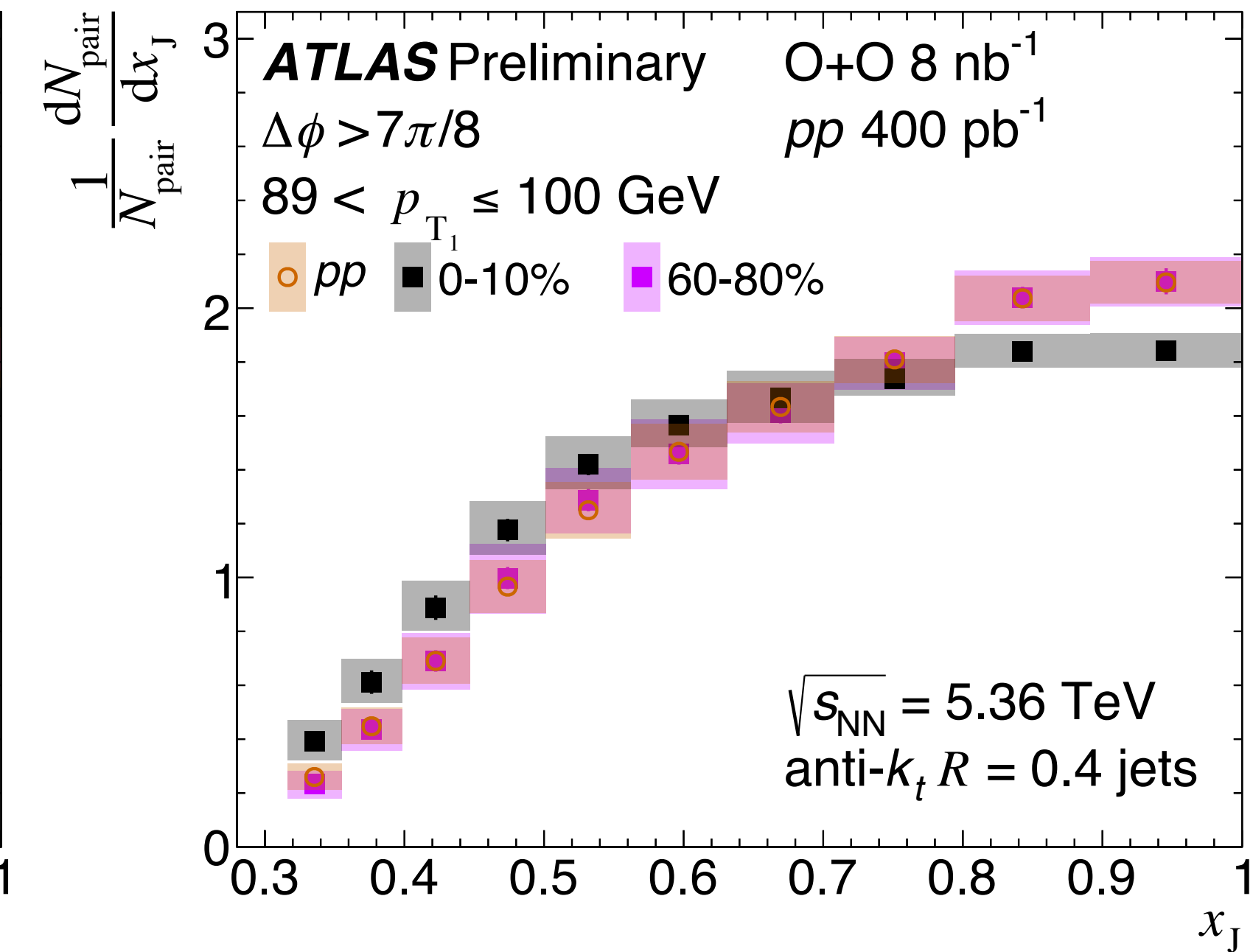
Dijet asymmetry in O+O collisions



Lowest leading p_T



Intermediate leading p_T

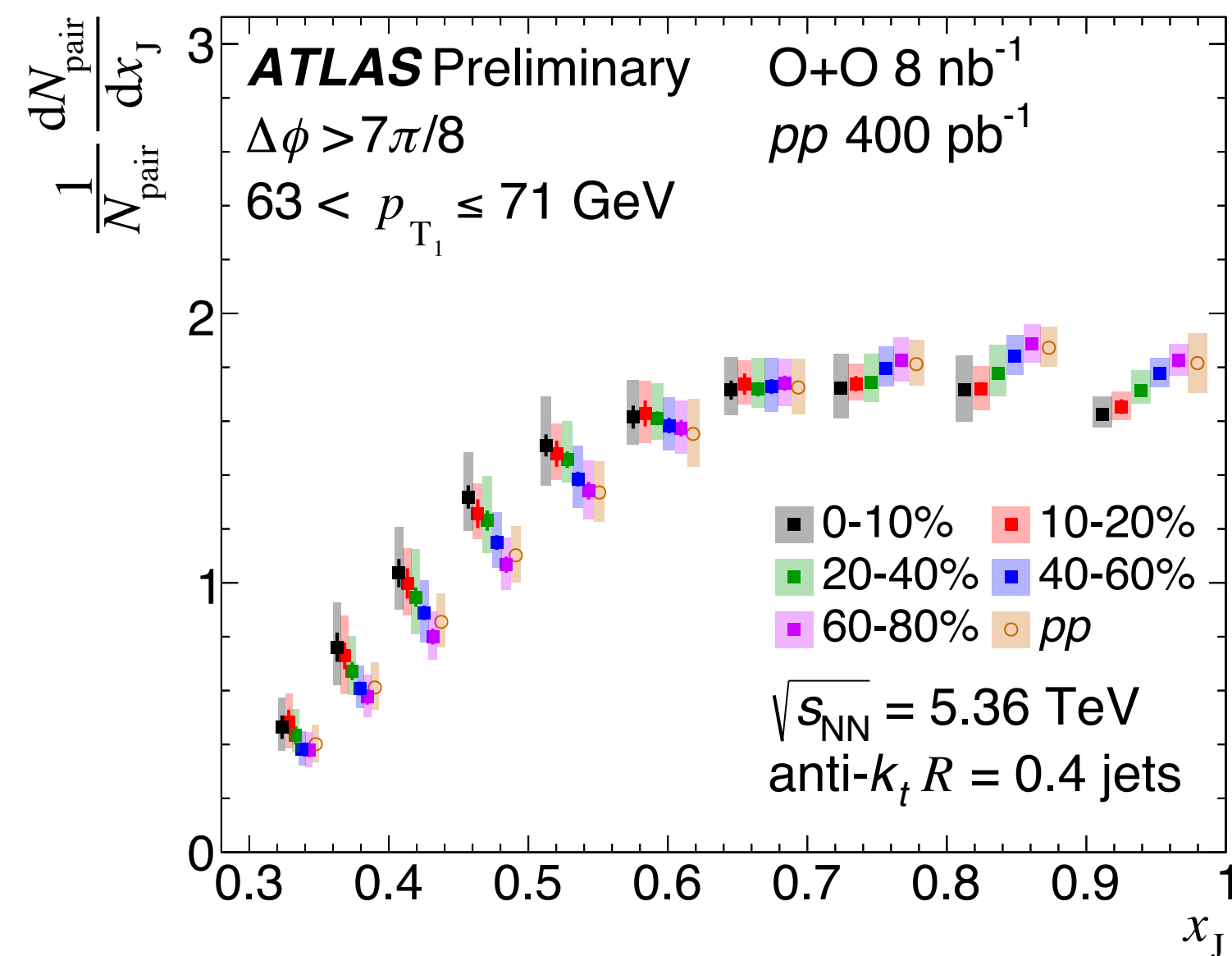


- pp and peripheral O+O (60–80%) show similar distributions
- Central O+O (0–10%) events exhibit clear differences compared to pp and peripheral O+O

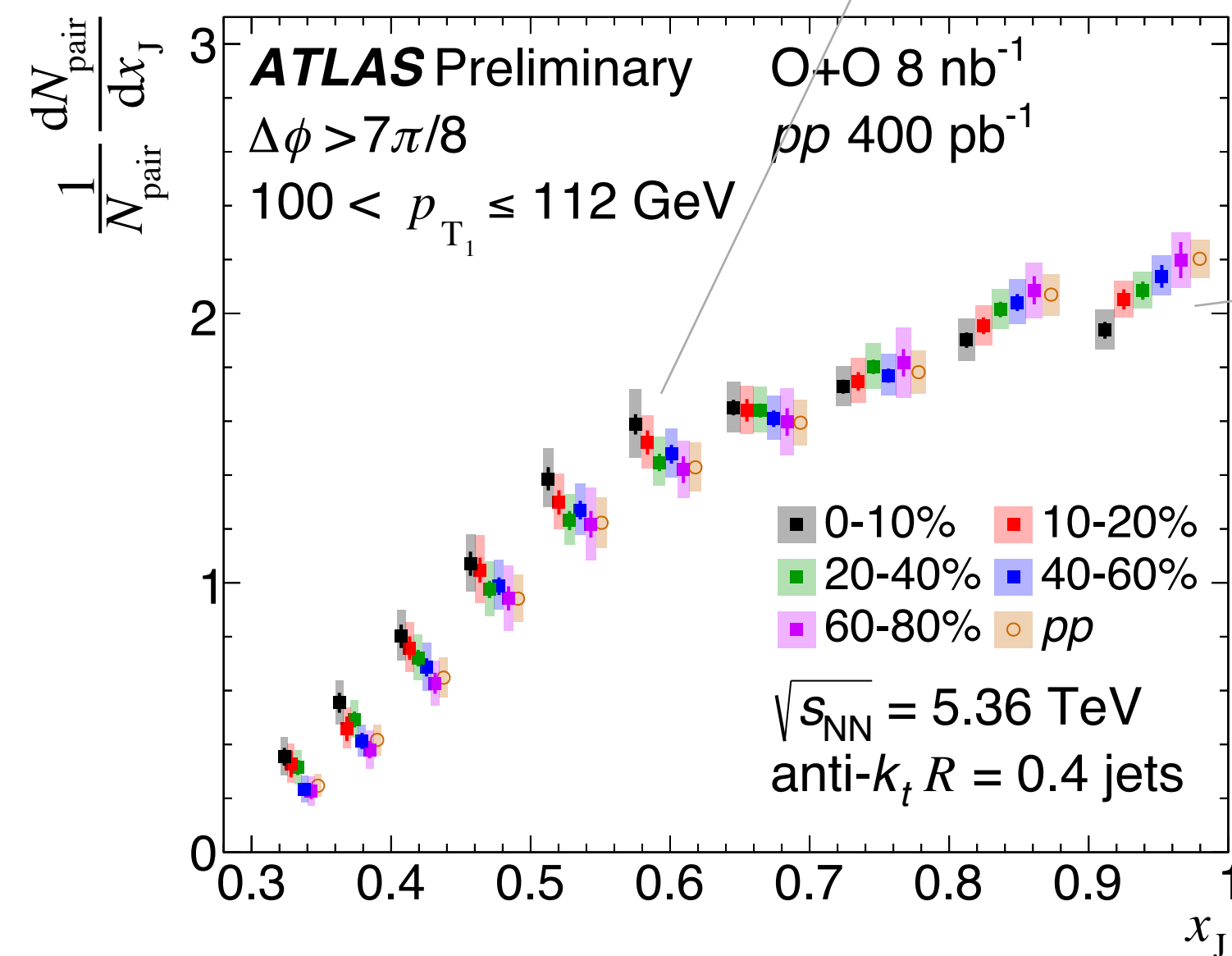


Centrality dependence

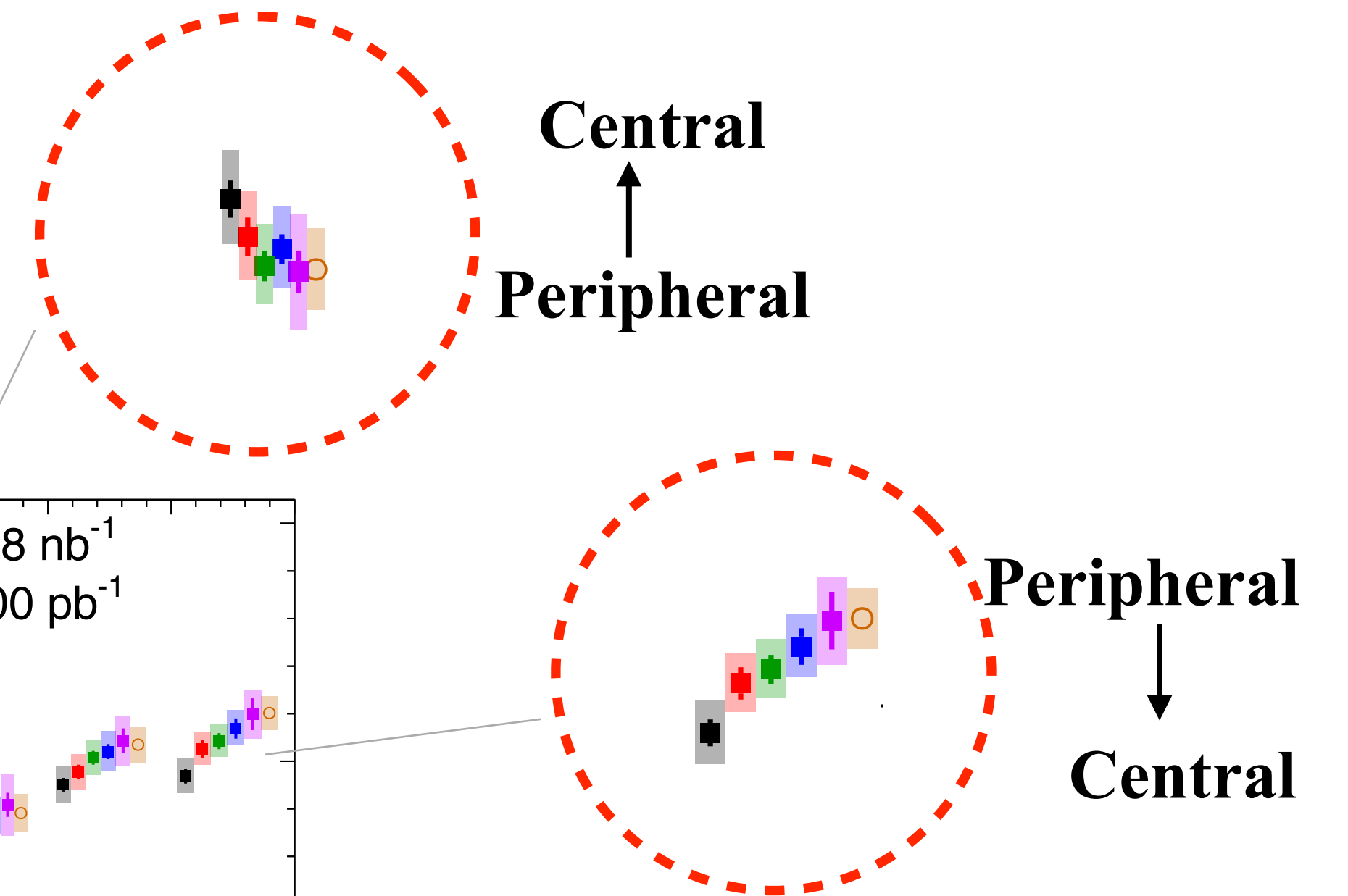
- In each x_J interval, data points are laterally shifted by centrality for visibility
- A smooth, systematic centrality dependence is observed from low p_T to high p_T



Low leading p_T



High leading p_T

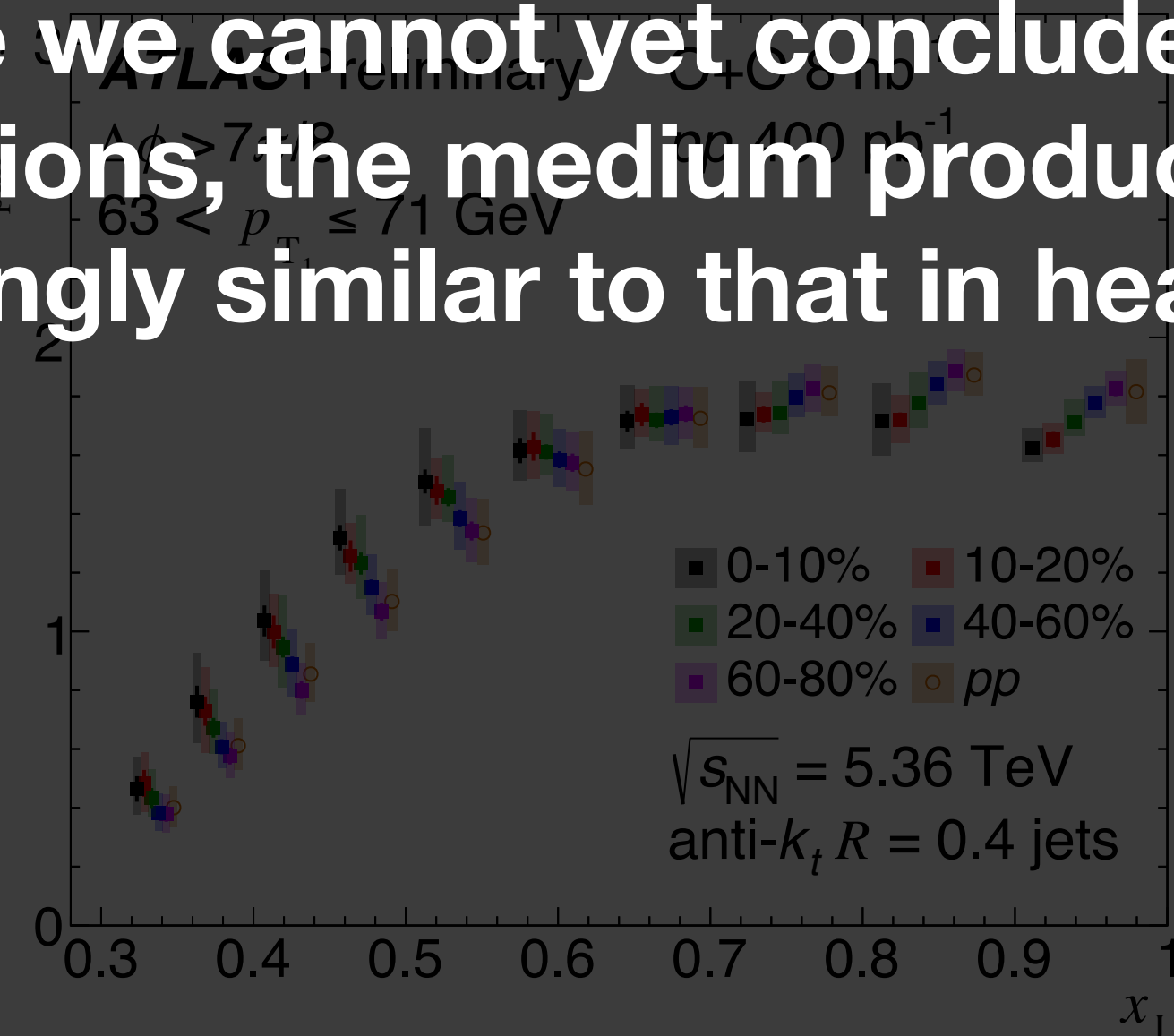


Centrality dependence

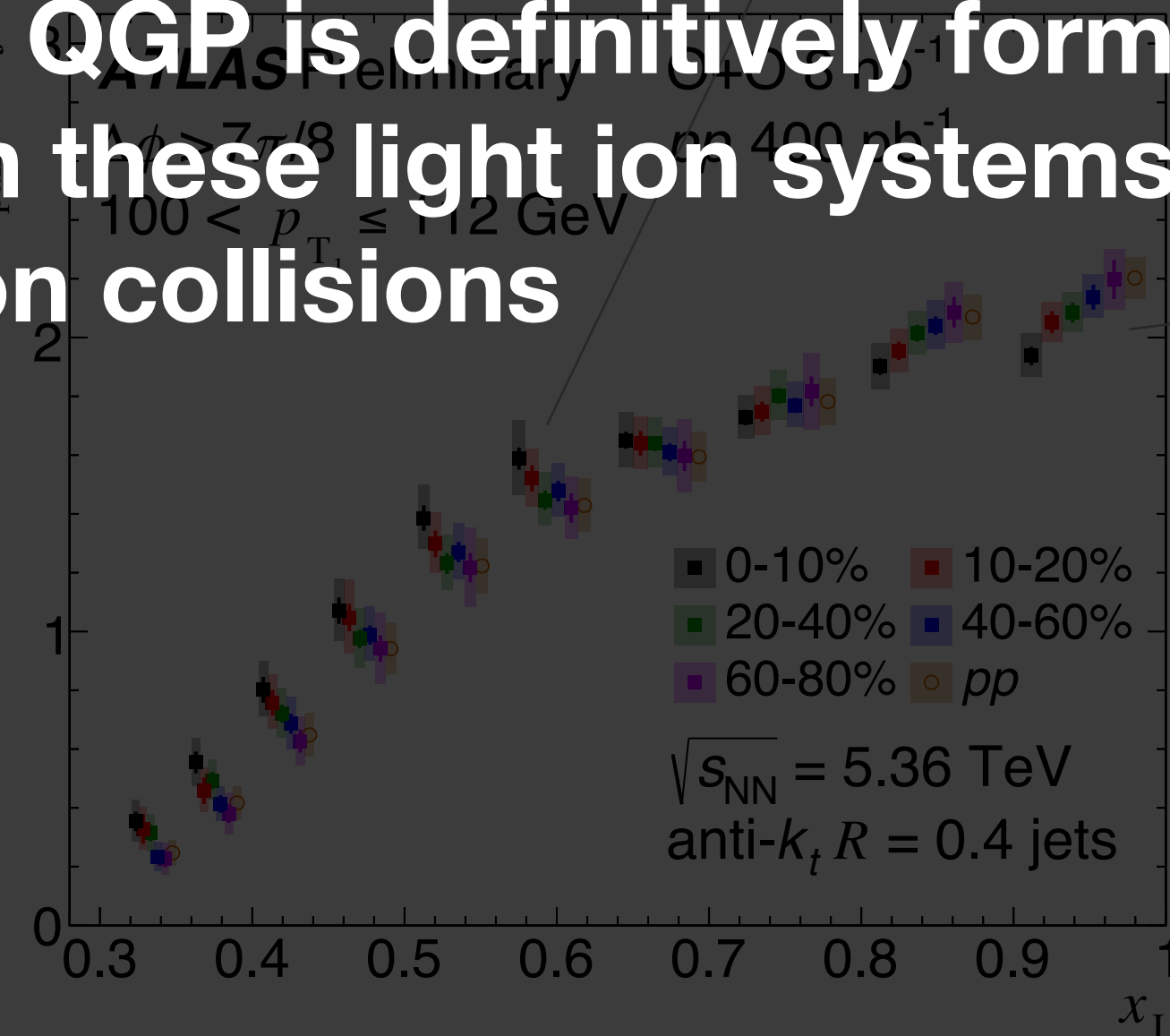
- In each x_J interval, data points are laterally shifted by centrality for visibility
- A smooth, systematic centrality dependence is observed

Qualitatively consistent with hydrodynamical response, confirmed also by dijet measurements; v_n ratios reveal sensitivity to nuclear geometry (^{20}Ne vs ^{16}O)

While we cannot yet conclude that QGP is definitively formed in O+O and Ne+Ne collisions, the medium produced in these light ion systems exhibits behavior strikingly similar to that in heavy ion collisions



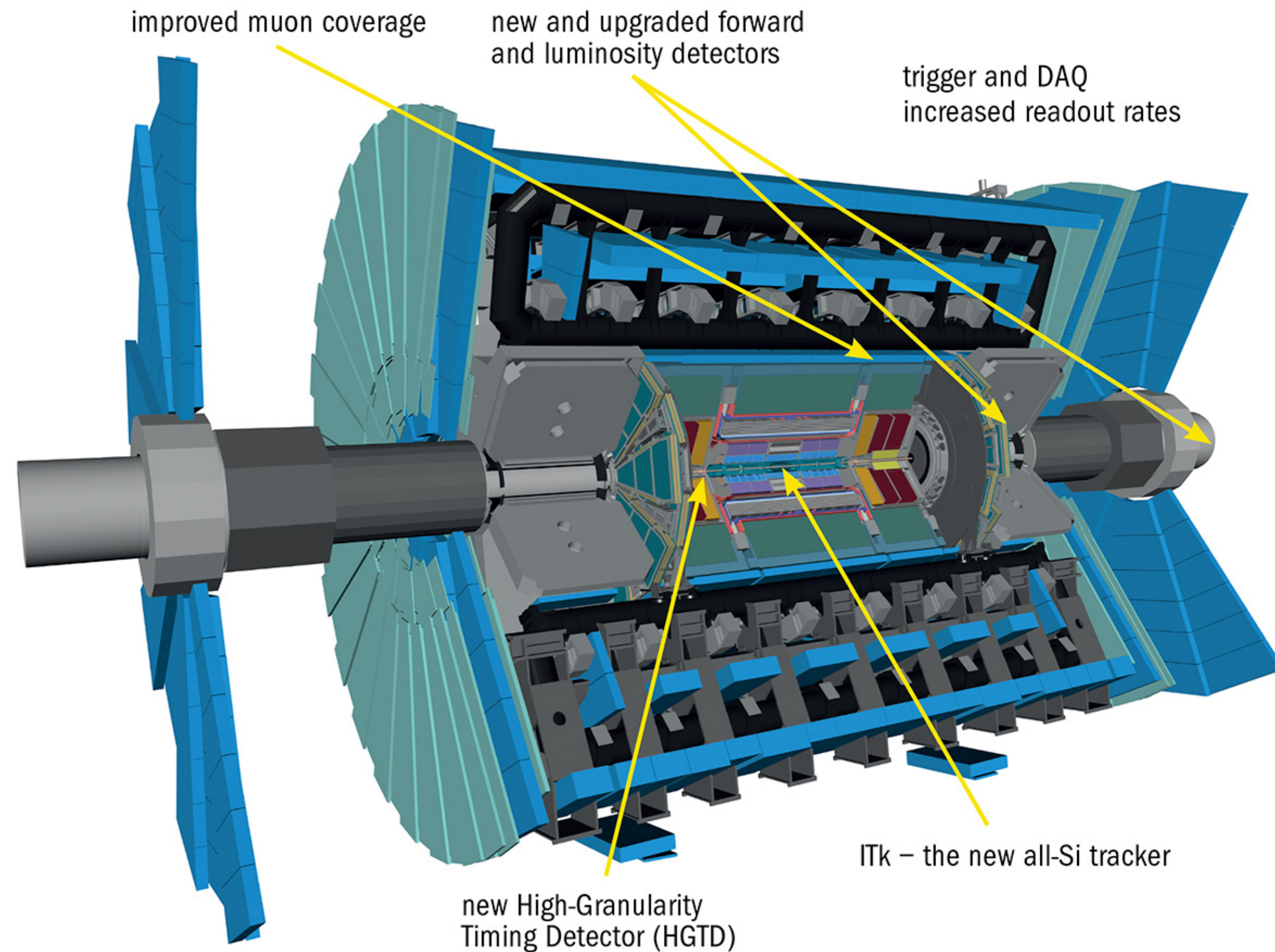
Low leading p_T



High leading p_T



Future ATLAS and runs



LHC Run3 will end in 2026. An upgraded ATLAS will be used in Run4 (~ 2030s)

- **High-granularity, high-coverage tracker (2.5 → 4.0)**
- **New ZDC (same as CMS Phase-II ZDC)**
- **High-granularity timing detector**
- Replaced muon chambers
- New and upgraded forward and luminosity detector
- Improved trigger, high-performance software & computing, deeply embedded machine learning

ATLAS (maybe also CMS) has a strong preference to place p+Pb run in Run4 and dedicate 2026 to lighter ion runs (Ar, Kr, O, Ne)

First respond from LHC program committee: **“this is not impossible”**



Light ion workshop 2025

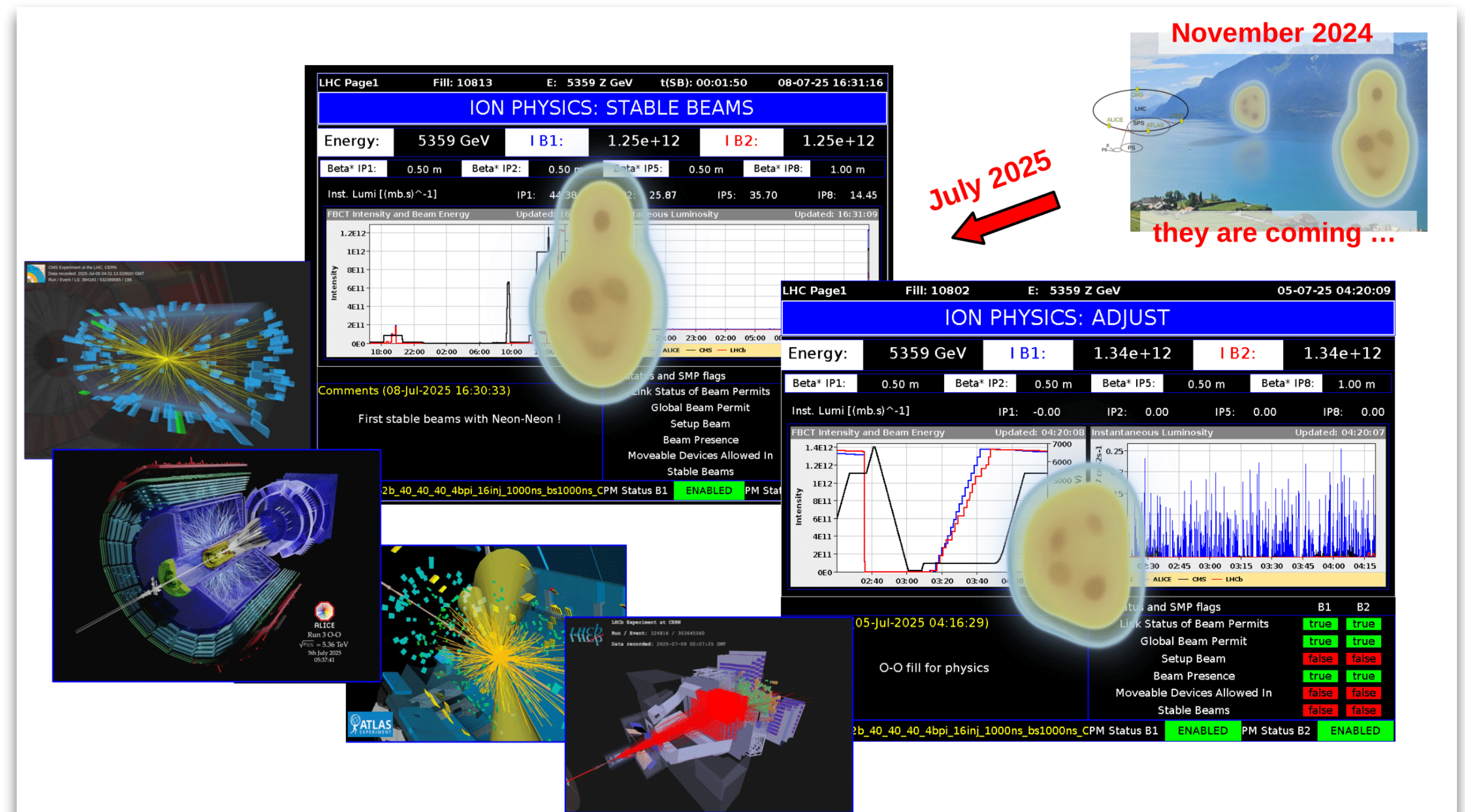
Light Ion workshop 2025

Dec 1 - 3, 2025, CERN

<https://indico.cern.ch/event/1597414/>

Organization:

Reyes Alemany Fernandez (CERN)
Giuliano Giacalone (CERN)
Qipeng Hu (USTC Hefei)
Gian Michele Innocenti (MIT)
Georgios Krintiras (University of Kansas)
Saverio Mariani (CERN)
Aleksas Mazeliauskas (ITP Heidelberg)
Dennis Perepelitsa (CU Boulder)
Anthony Timmins (University of Houston)
Wilke van der Schee (CERN)
Urs Wiedemann (CERN)
You Zhou (NBI Copenhagen)

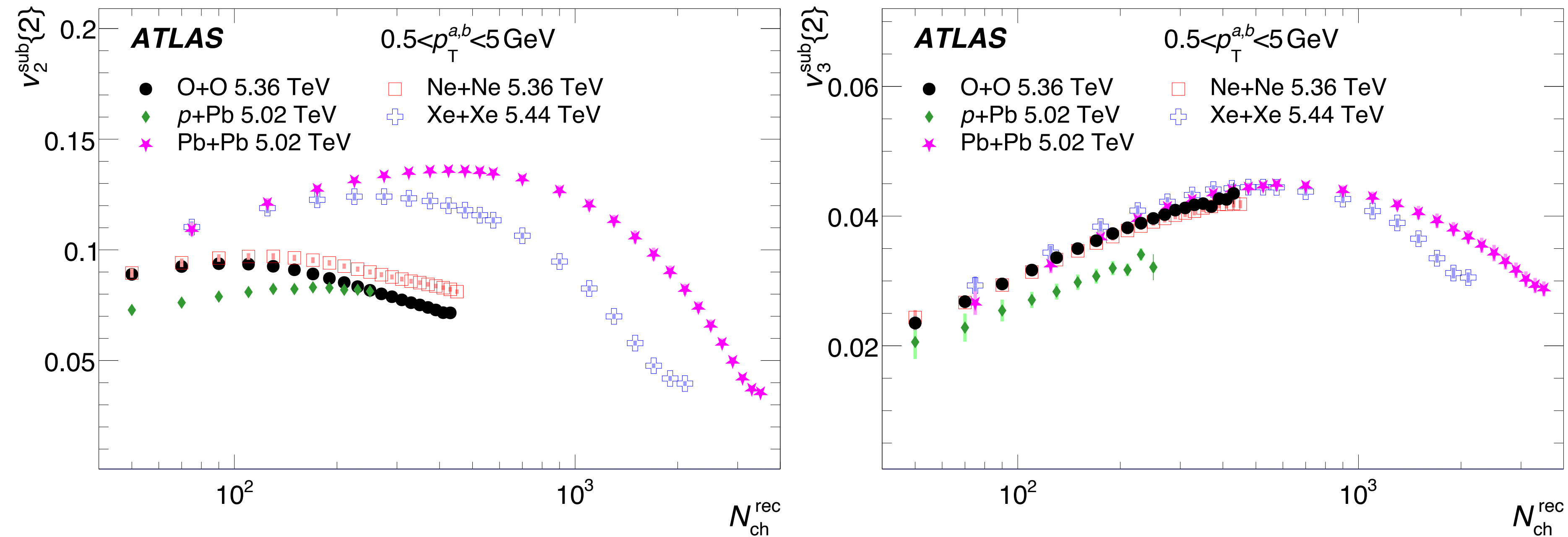


Workshop topics:

- Experimental overviews of collectivity and energy loss
- Hydrodynamics and non-equilibrium dynamics
- Jet quenching in small systems
- nPDFs of light ions
- Synergies with nuclear structure physics and other areas
- Accelerator and experiments perspectives for future light-ion runs

Backup Slides

Comparison of different ion collisions — multiplicity bins



- Light ions vs. heavy ions in multiplicities:
 - O+O v_2 converges with p+Pb
 - Light ion v_3 align with heavy ion



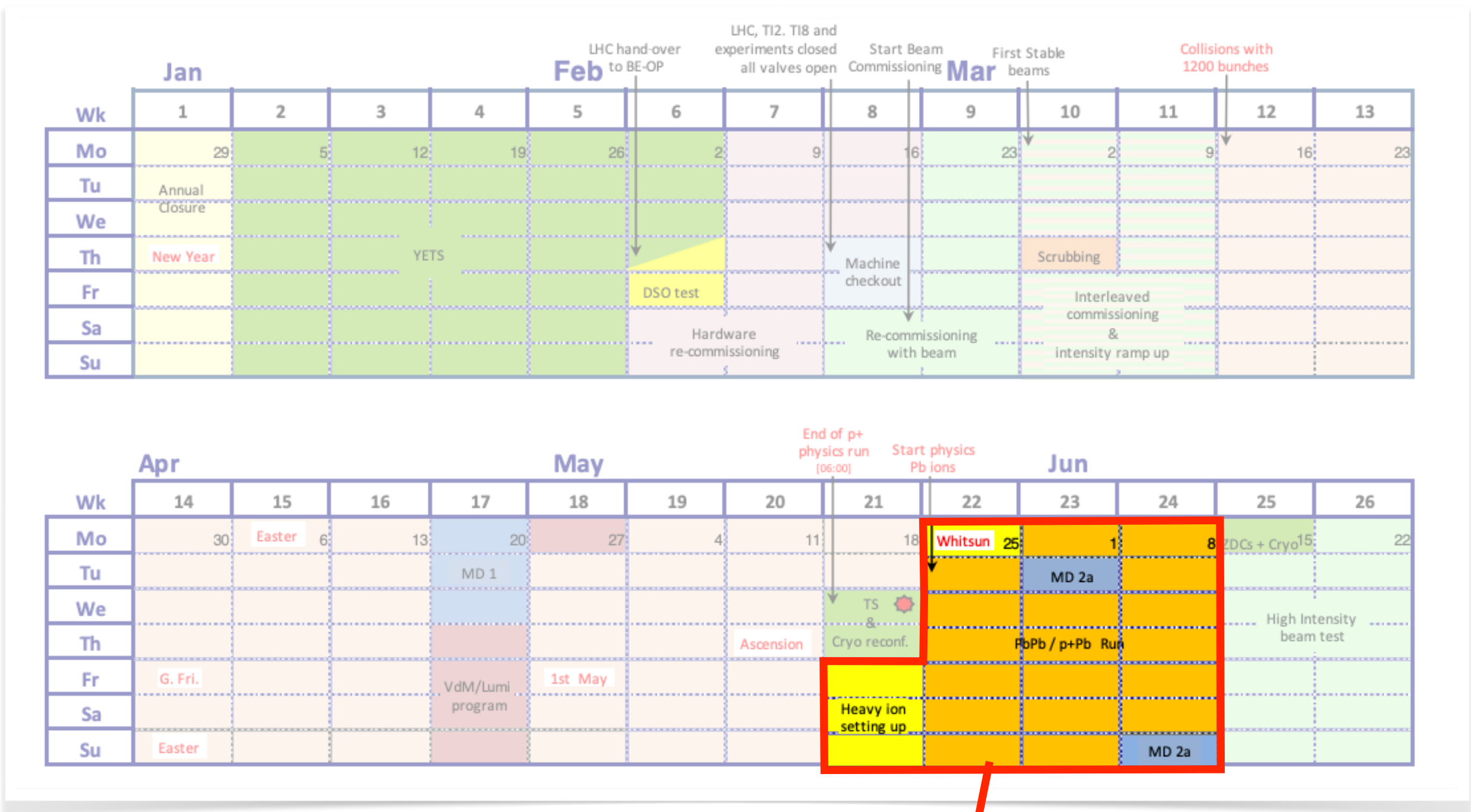
Flow systematics

Source	harmonic order	0–40% [%]	40–70% [%]
1. MC closure	v_2-v_4	1	1
2. Track selection	v_2	0.5	0.5
	v_3	0.75	0.75
	v_4	1.5	1.5
3. Tracking efficiency	v_2-v_4	0.25	0.25
4. Centrality definition	v_2	0.2	0.2–0.6
	v_3	0.2–1.0	1–2
	v_4	0.2	0.2–0.6
5. Residual pileup	v_2-v_4	0.2	0.2
6. Event-mixing	v_2	0.25	0.25
	v_3	0.5	0.5
	v_4	1	1
7. Peripheral reference	v_2	0.5	0.5–3
	v_3	0.75–3.5	3.5–12
	v_4	1.0–4.5	4.5–20
8. Flattening procedure	v_2-v_3	0.25	0.25



LHC heavy ion run schedule in 2026

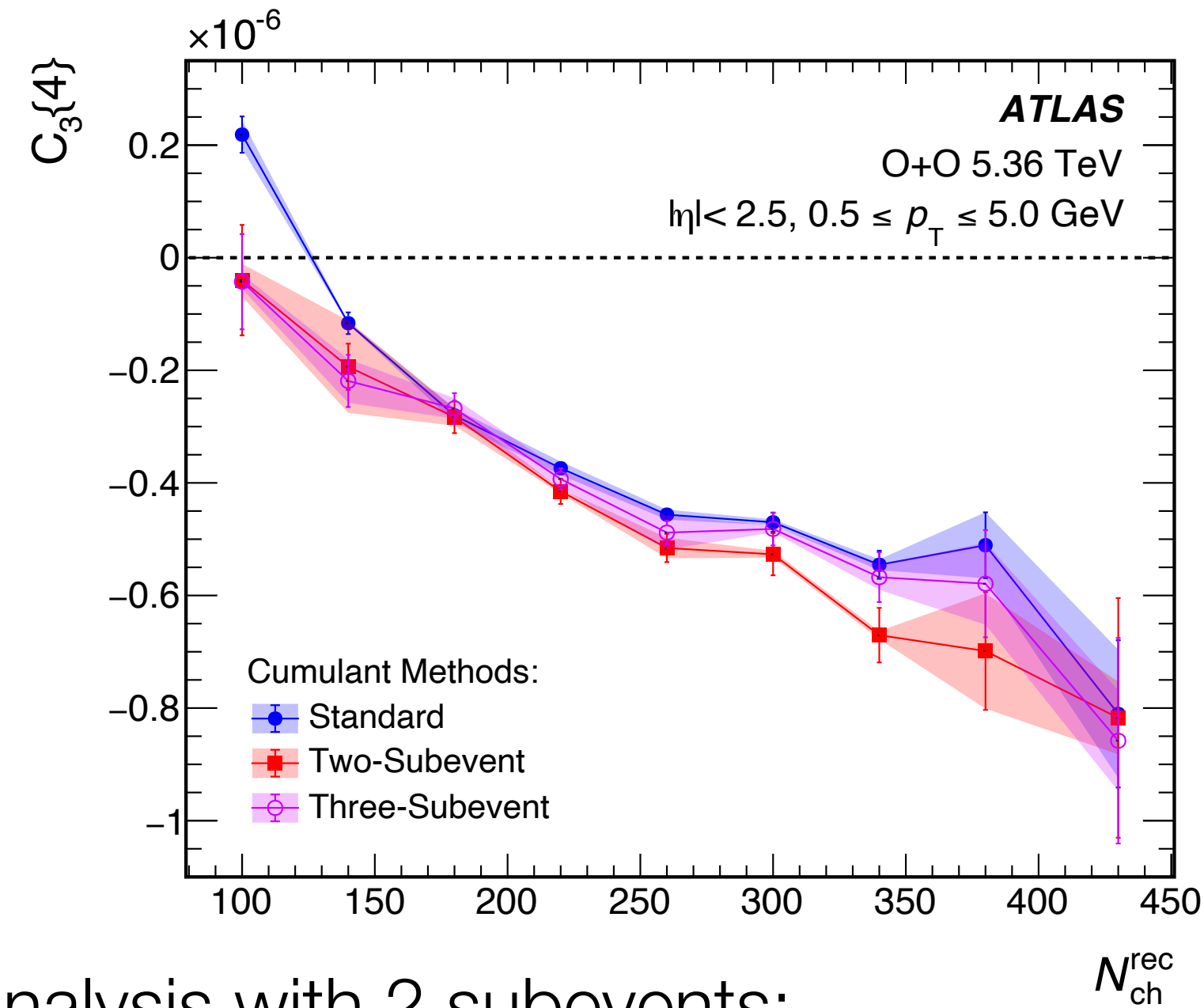
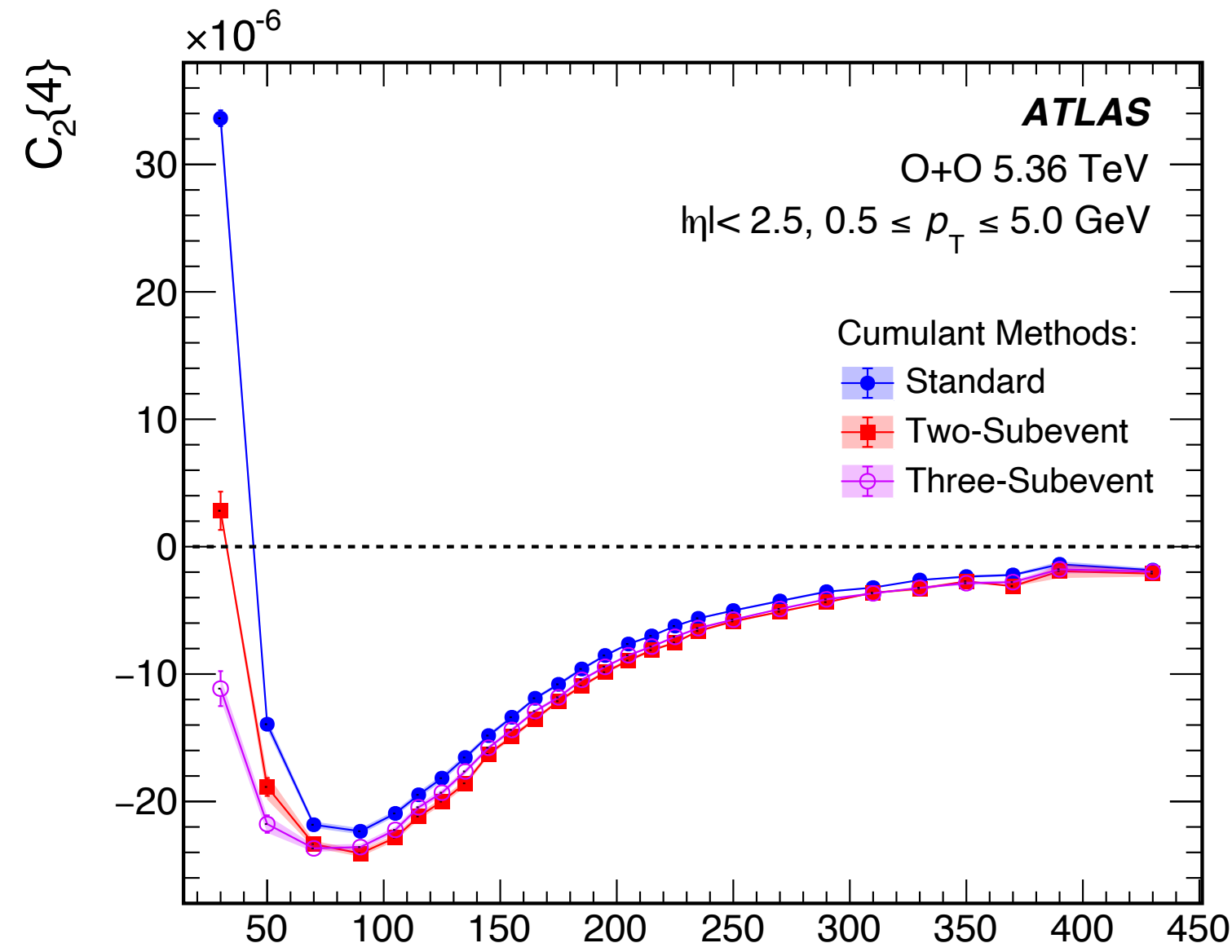
2026-LHC-v0.5



Another heavy ion run (~3 weeks)
at LHC scheduled in summer 2026
Pb+Pb or p+Pb



Non-flow in 4 particle cumulant — subevent method

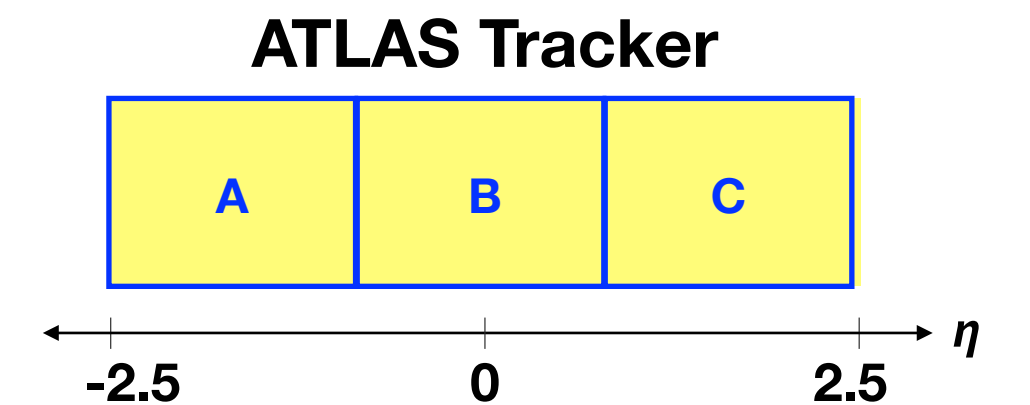
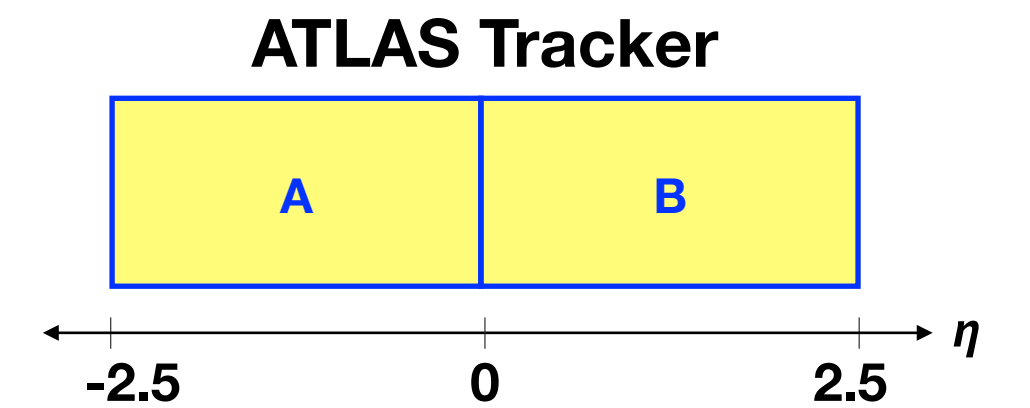
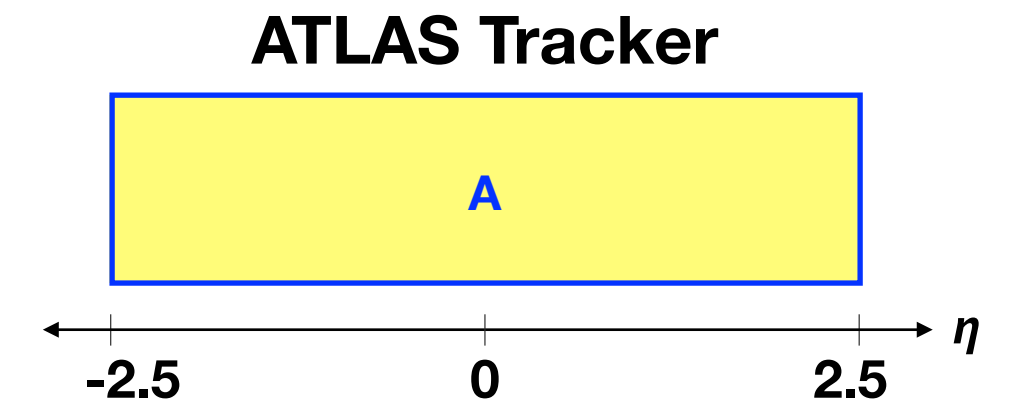


Standard 4-particle cumulant analysis with 2 subevents:

$$c_n\{2\} = \langle\langle\{2\}_n\rangle\rangle,$$

$$c_n\{4\} = \langle\langle\{4\}_n\rangle\rangle - 2\langle\langle\{2\}_n\rangle\rangle^2$$

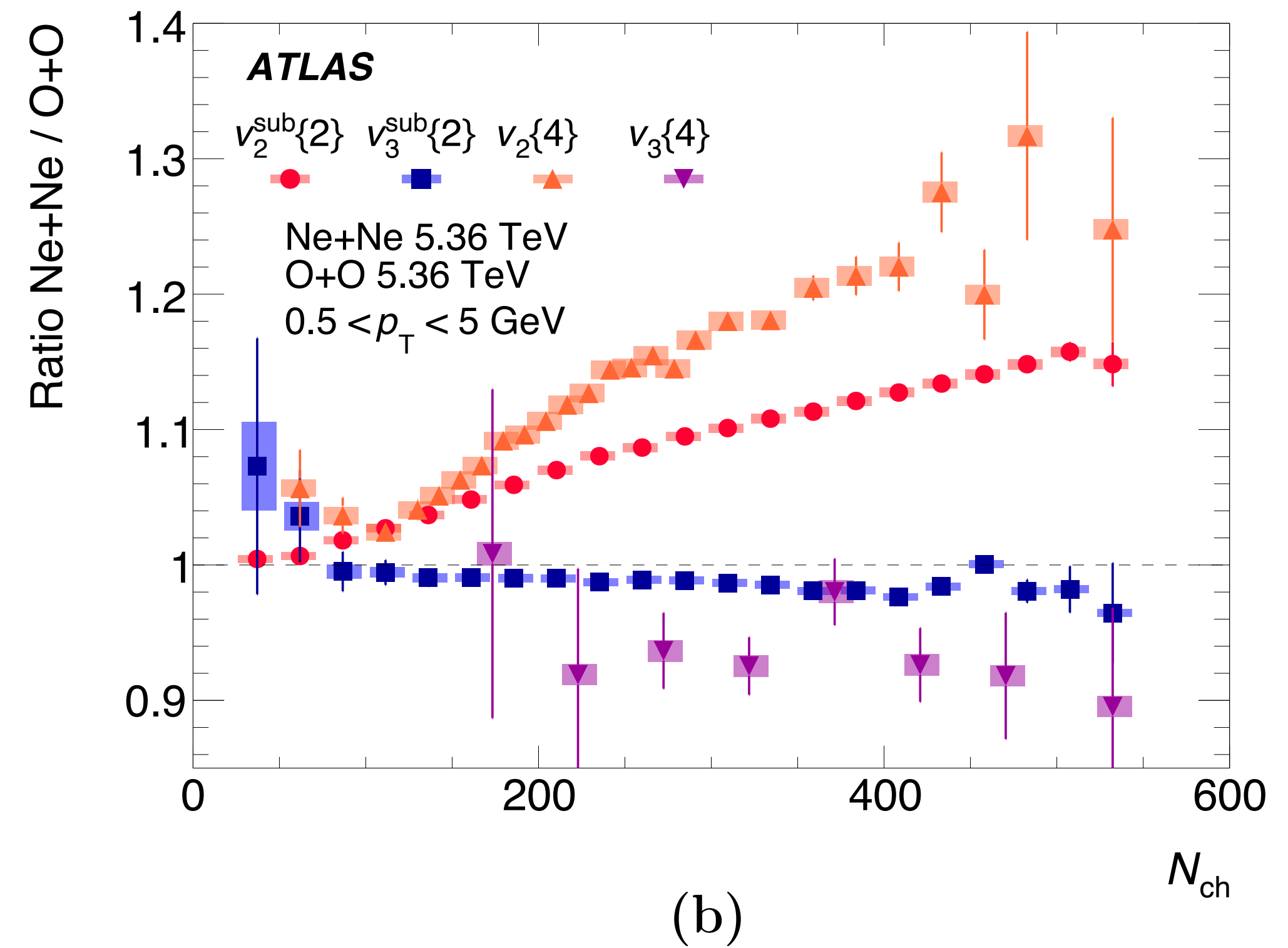
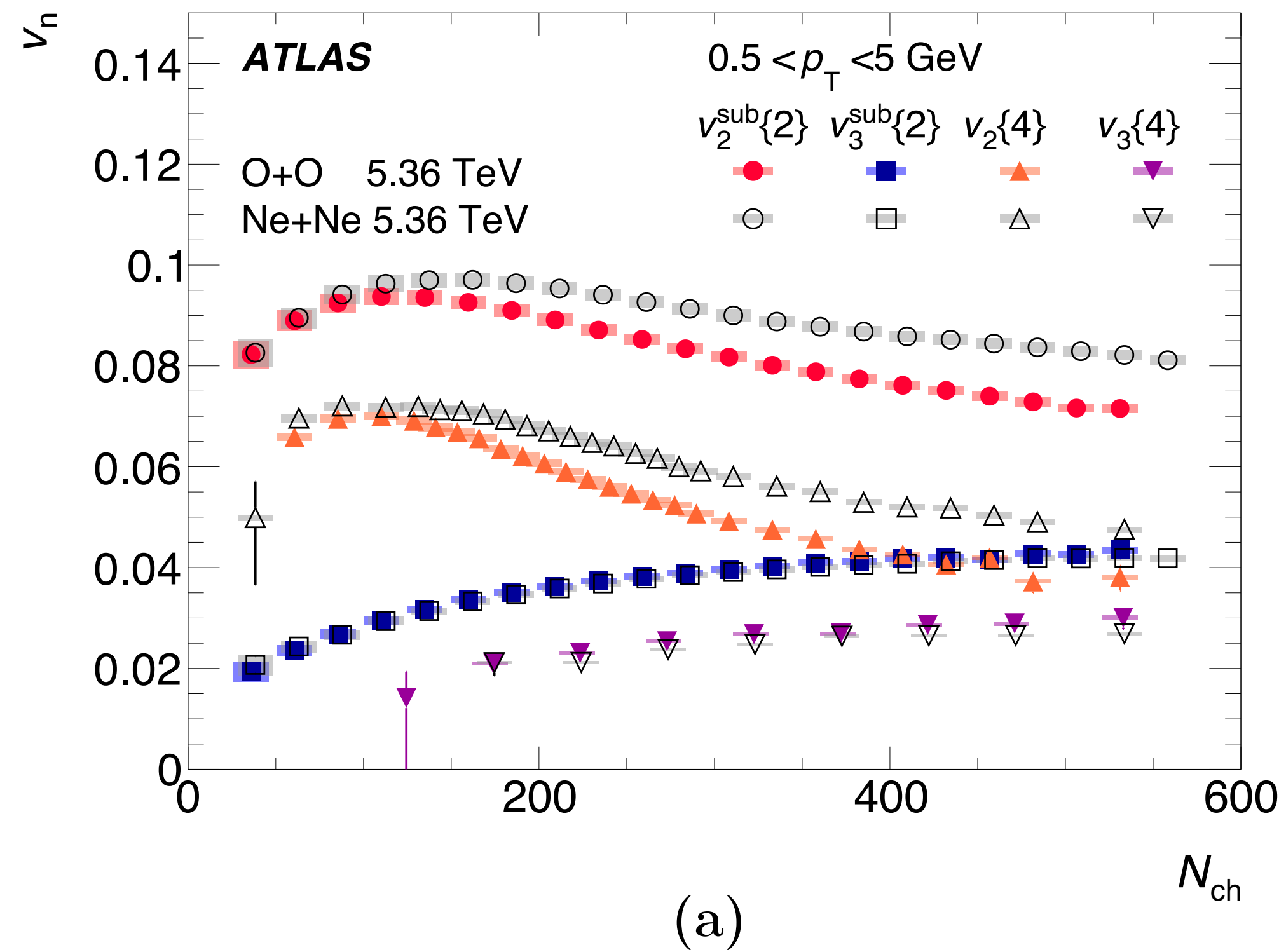
$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$



- Additional event division further reduce non-flow, but with only small impact for p_T -integrated results
- Two subevent results are taken as nominal

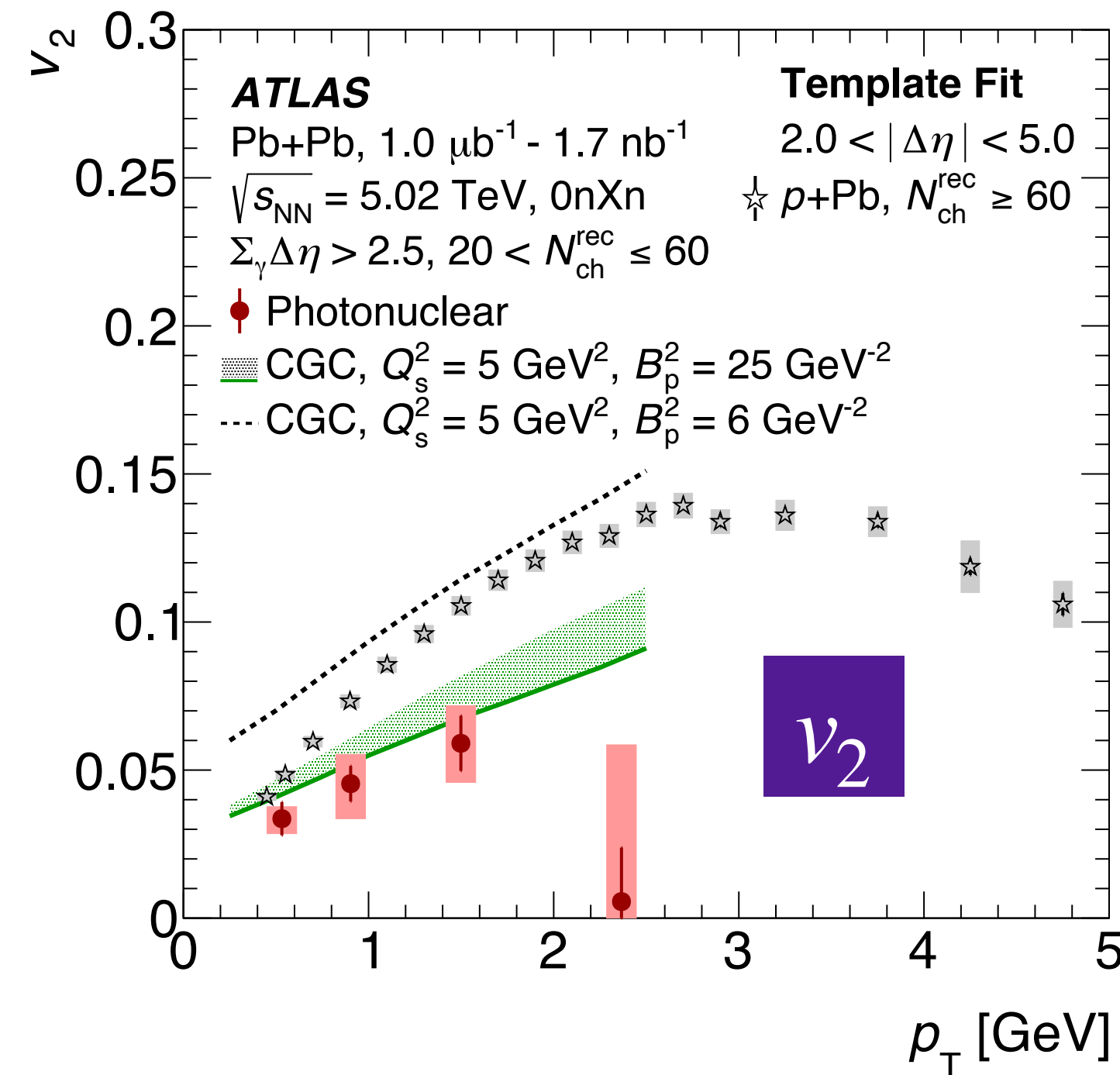


Two particle correlation vs. four particle cumulant

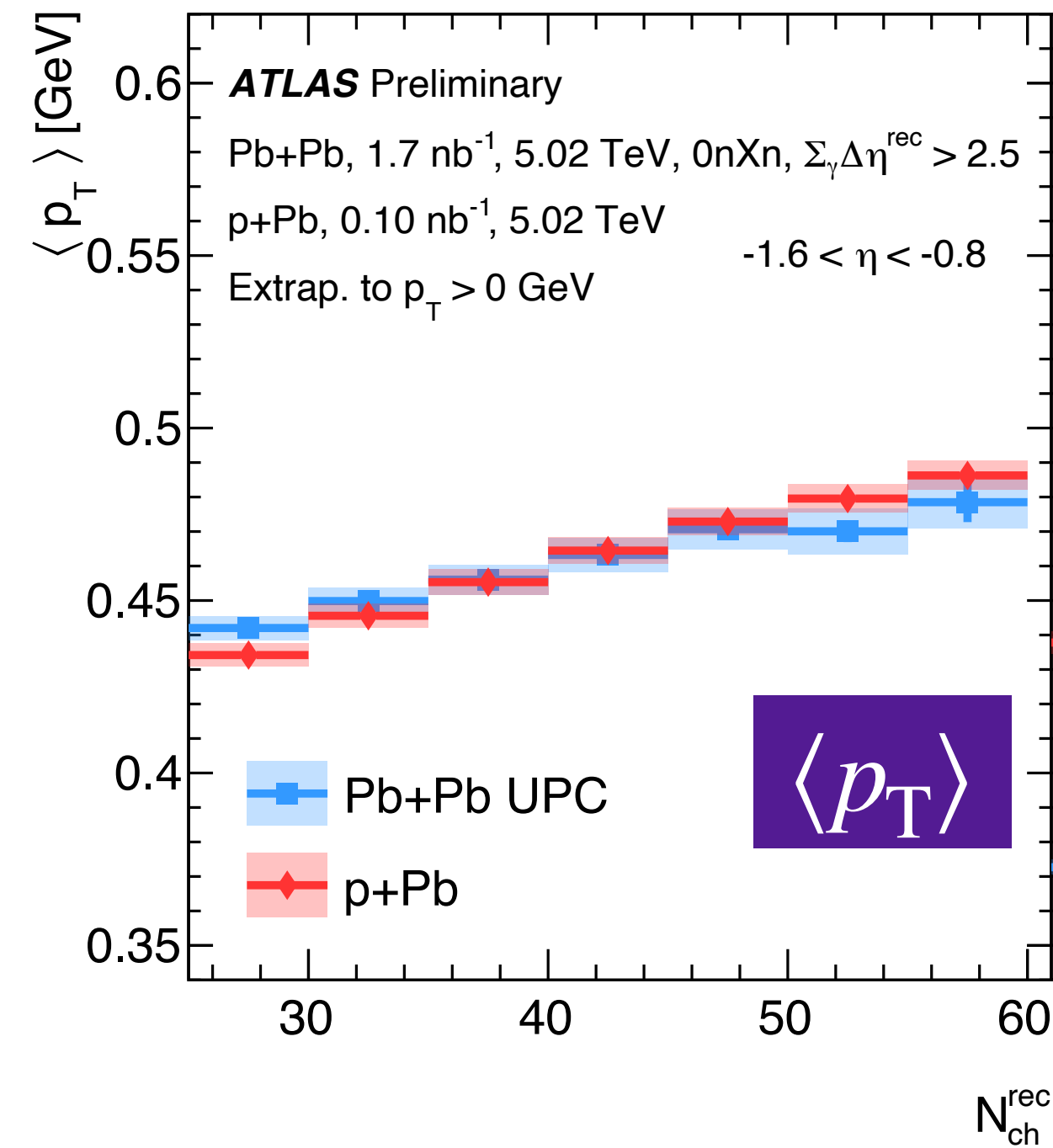


v_2 and $\langle p_T \rangle$ in photonuclear interactions

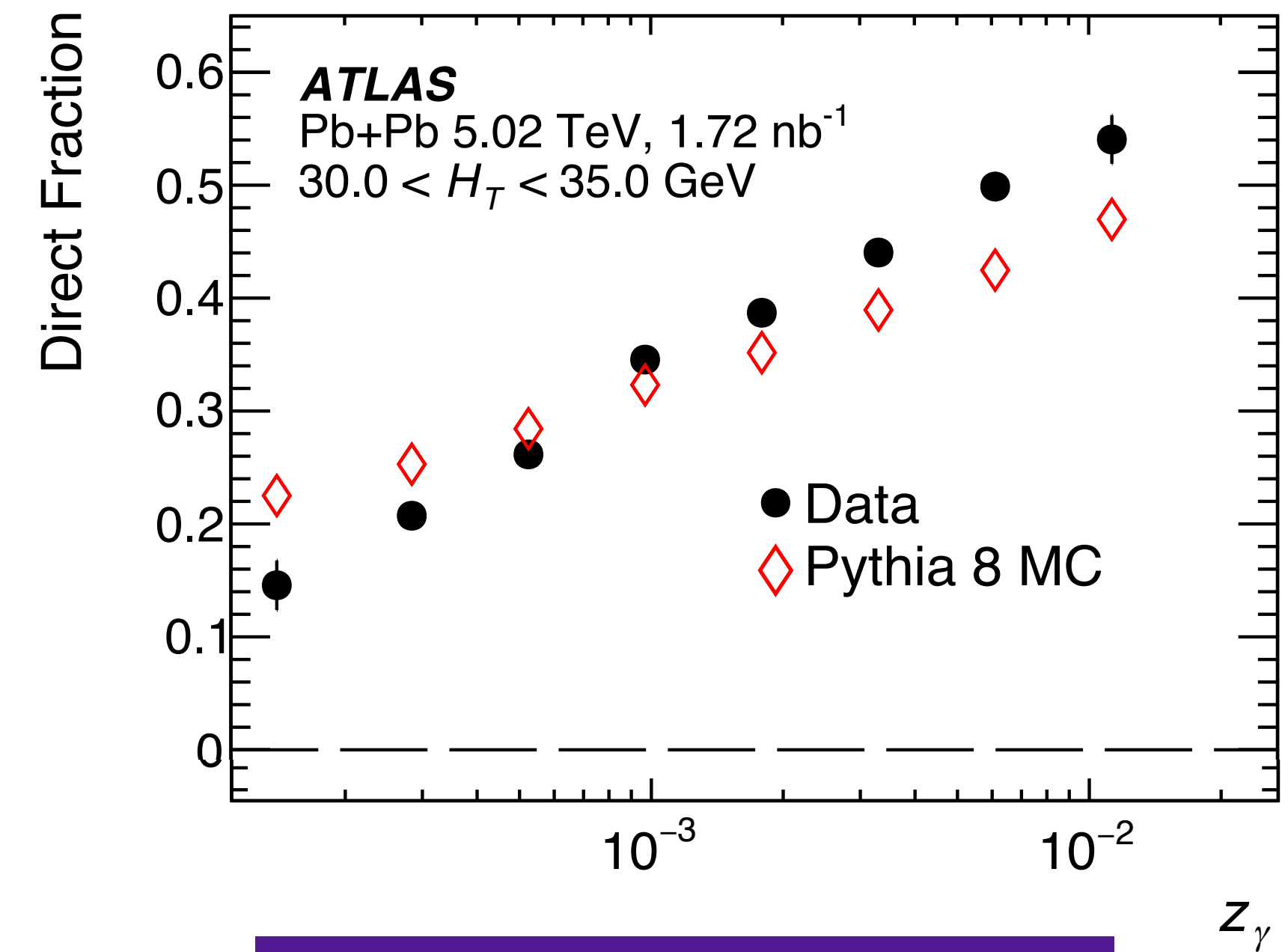
PRC 104 (2021) 014903
ATLAS-CONF-2023-059



$$v_2 (p + \text{Pb}) > v_2 (\gamma + \text{Pb})$$



$$\langle p_T \rangle (\gamma + \text{Pb}) \approx \langle p_T \rangle (p + \text{Pb})$$

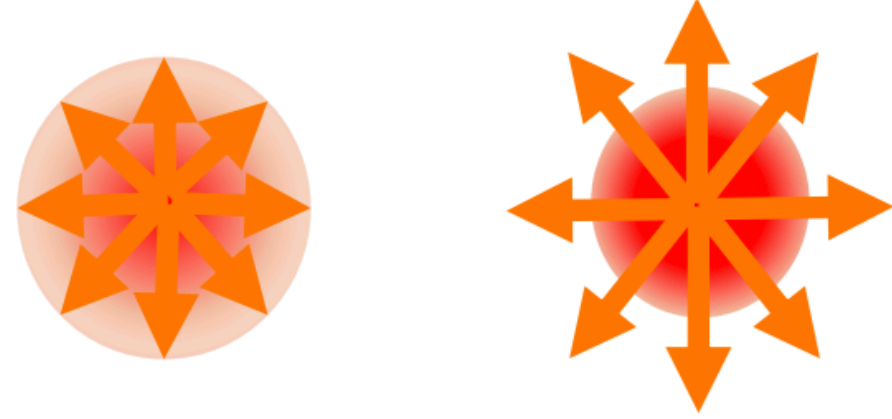


- Could be understood as different longitudinal decorrelation and similar radial flow in the hydro picture (Zhao et al PRL 129 (2022) 252302)
- However, direct and resolved processes should be studied separately and it becomes possible

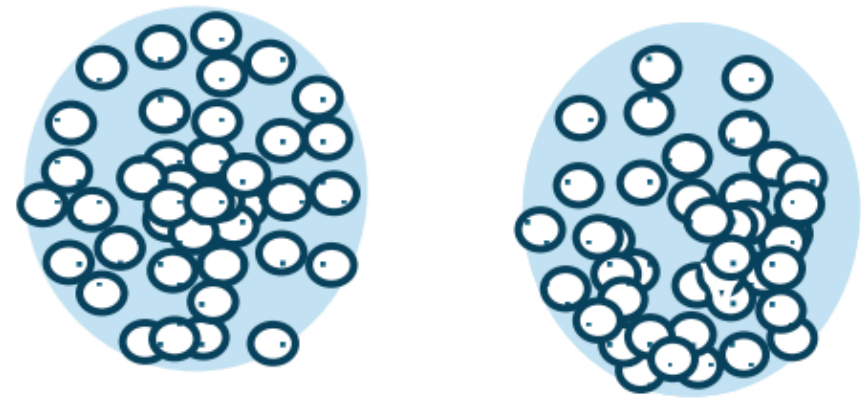


Disentangling sources of initial fluctuations

arXiv:2407.06413



“Geometric Component”



“Intrinsic Component”

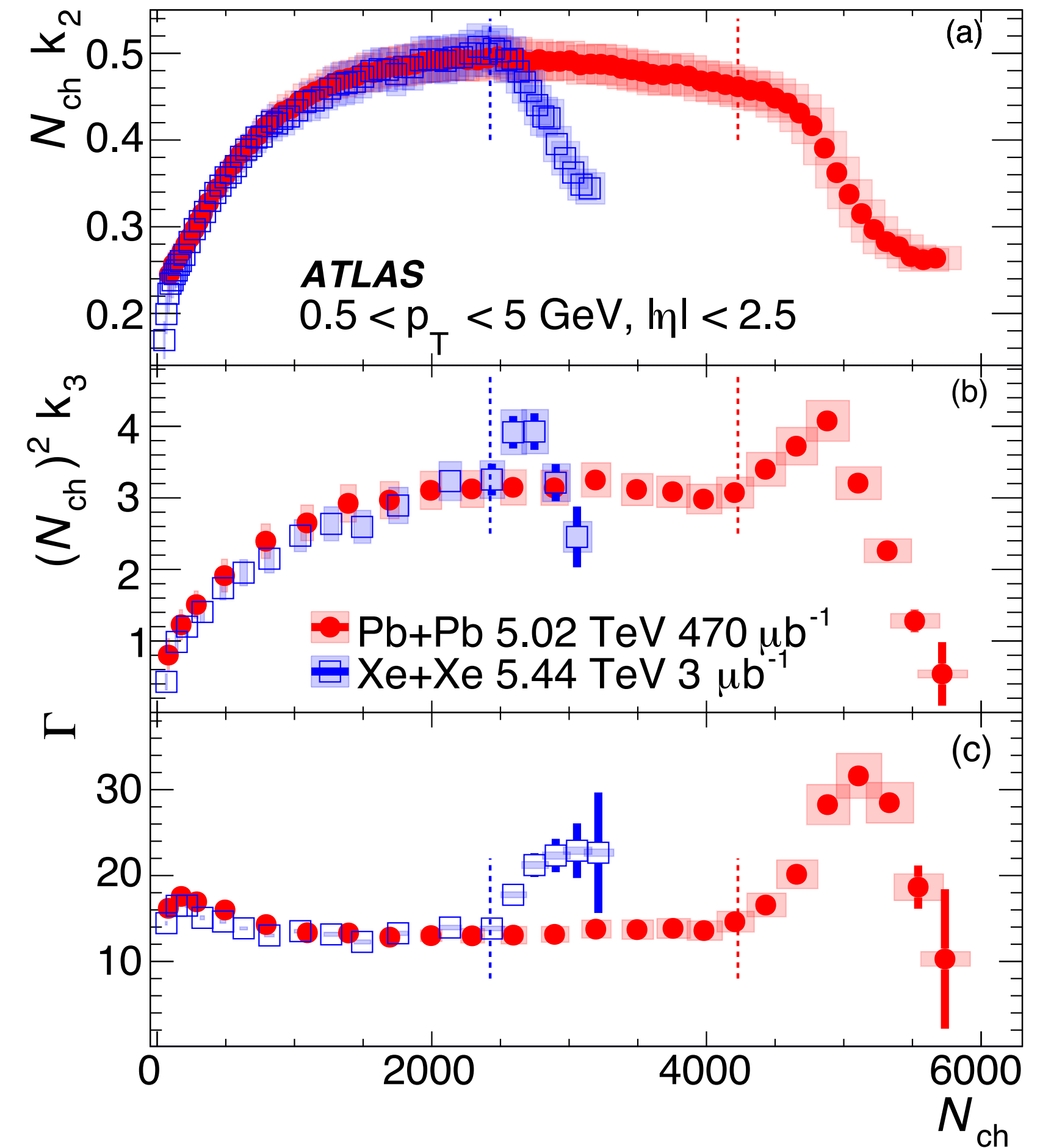
Understand roles of fluctuations in initial conditions:

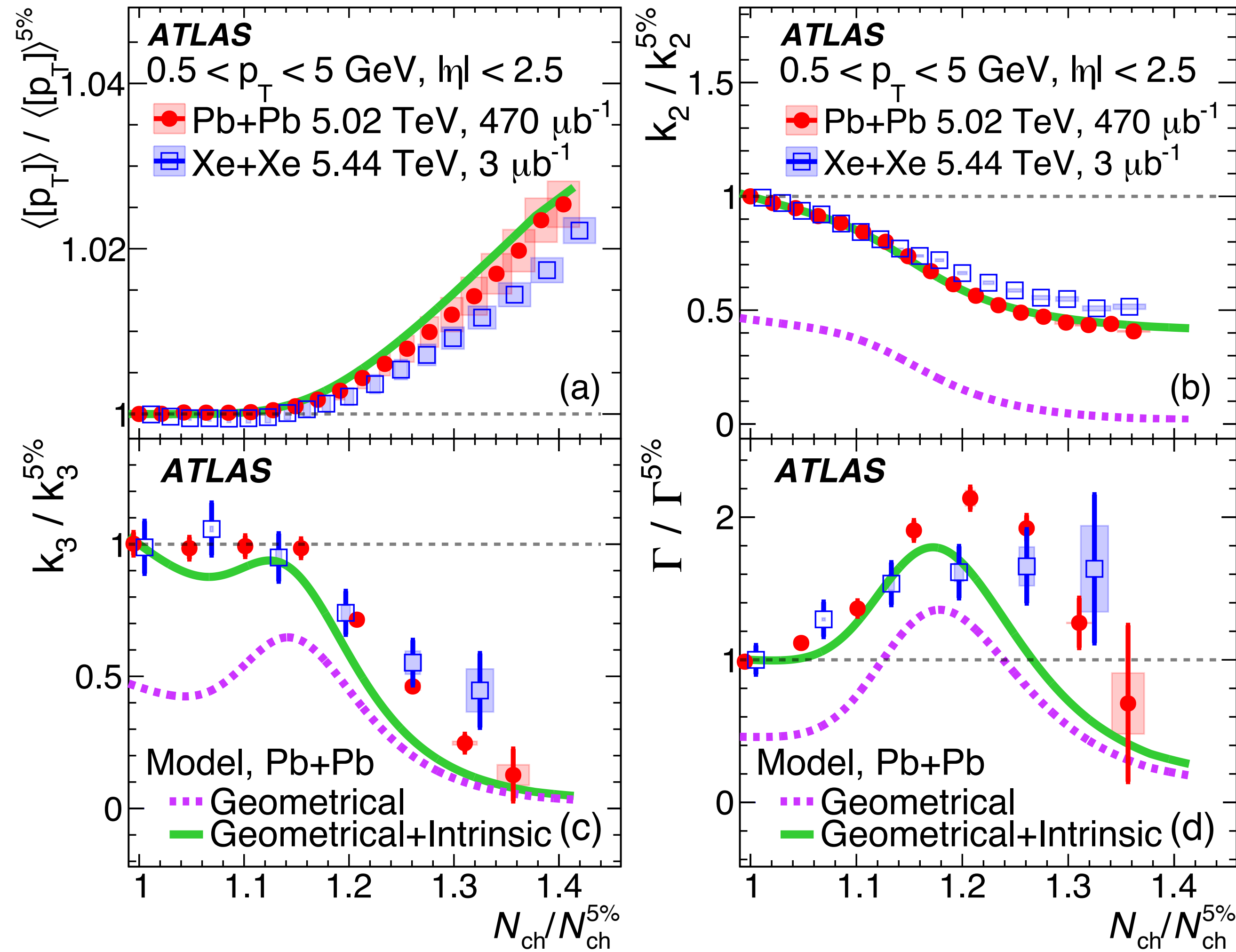
- Geometric fluctuations
- Intrinsic fluctuations

Moments of event-wise average p_T distribution in **ultra-central** Pb+Pb and Xe+Xe via n-particle momentum correlators:

$$c_n = \frac{\sum_{i_1 \neq \dots \neq i_n} w_{i_1} \dots w_{i_n} (p_{T,i_1} - \langle [p_T] \rangle) \dots (p_{T,i_n} - \langle [p_T] \rangle)}{\sum_{i_1 \neq \dots \neq i_n} w_{i_1} \dots w_{i_n}}$$

$$k_2 = \frac{\langle c_2 \rangle}{\langle [p_T] \rangle^2}, \quad k_3 = \frac{\langle c_3 \rangle}{\langle [p_T] \rangle^3}, \quad \gamma = \frac{\langle c_3 \rangle}{\langle c_2 \rangle^{3/2}}, \quad \Gamma = \frac{\langle c_3 \rangle \langle [p_T] \rangle}{\langle c_2 \rangle^2}.$$





- A phenomenological 2D Gaussian fluctuations predicts the trends well (R. Samanta et al. Phys. Rev. C 109 (2024) L051902)

