Collective dynamics of heavy ion collisions in ATLAS

Dominik Derendarz on behalf of the ATLAS collaboration
PANIC 2021 (Virtual)
08/09/2021

Heavy ion physics program in ATLAS

Complex program of measurements covering

- ➡ Collective flow in small & large systems
- ➡ Colorless probes - electroweak bosons (W/Z) in Pb+Pb
- ➡ Colored probes - jets & heavy flavour quarks
- ➡ Ultra Peripheral Collisions (UPC)

Christopher McGinn
Sun, 14:50

Benjamin Gilbert
Wed, 14:12

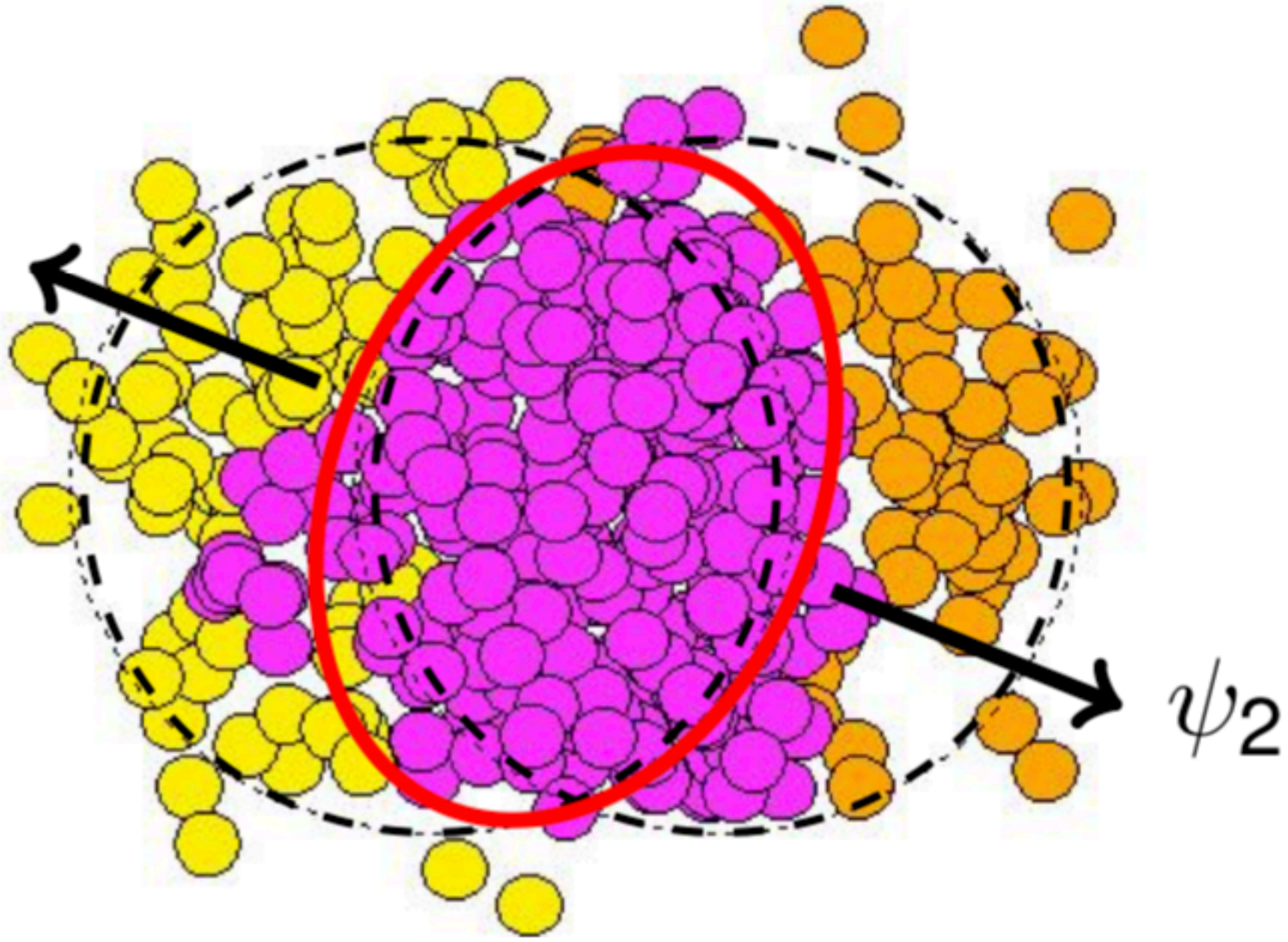
Recorded datasets

System	Year	sqrt(s_{NN}) [TeV]	L_{int}	
Pb+Pb	2010	2,76	7 μb^{-1}	Run 1
Pb+Pb	2011	2,76	0.14 nb^{-1}	Run 1
pp	2012	8	19.4 fb^{-1}	Run 1
pp	2013	2,76	4 pb^{-1}	Run 1
p+Pb	2013	5,02	29 nb^{-1}	Run 1
low <μ> pp	2015-16	13	0.9 pb^{-1}	Run 2
pp	2015	5,02	28 pb^{-1}	Run 2
Pb+Pb	2015	5,02	0.49 nb^{-1}	Run 2
p+Pb	2016	5,02	0.5 nb^{-1}	Run 2
p+Pb	2016	8,16	0.16 pb^{-1}	Run 2
Xe+Xe	2017	5,44	3 μb^{-1}	Run 2
pp	2017	5,02	270 pb^{-1}	Run 2
Pb+Pb	2018	5,02	1.76 nb^{-1}	Run 2

Global observables of heavy ion collision: collective flow

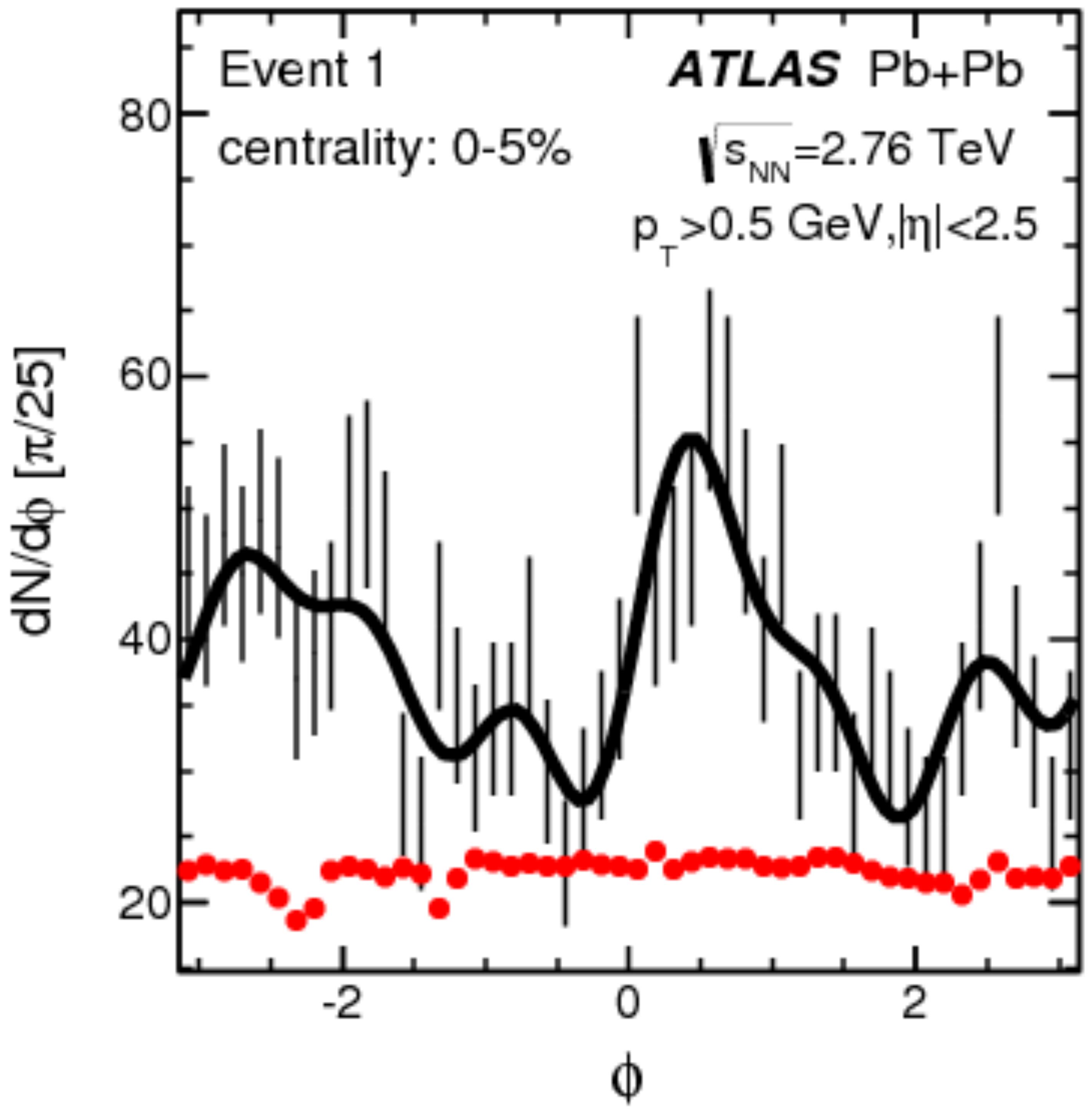
➡ 3D hydro description of QGP expansion

➡ Role of the initial conditions?



Initial asymmetry in the colliding nucleons distribution

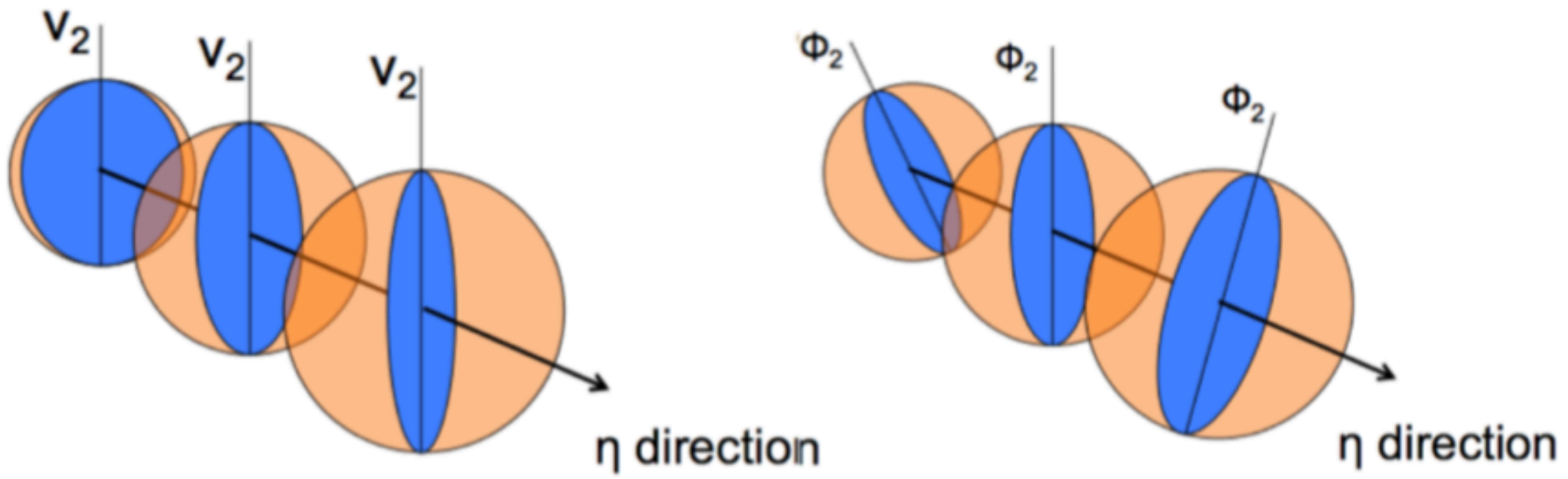
JHEP11(2013)183



Final state particles seen in the detector

Longitudinal flow decorrelation Xe+Xe & Pb+Pb

Phys. Rev. Lett. 126 (2021) 12230

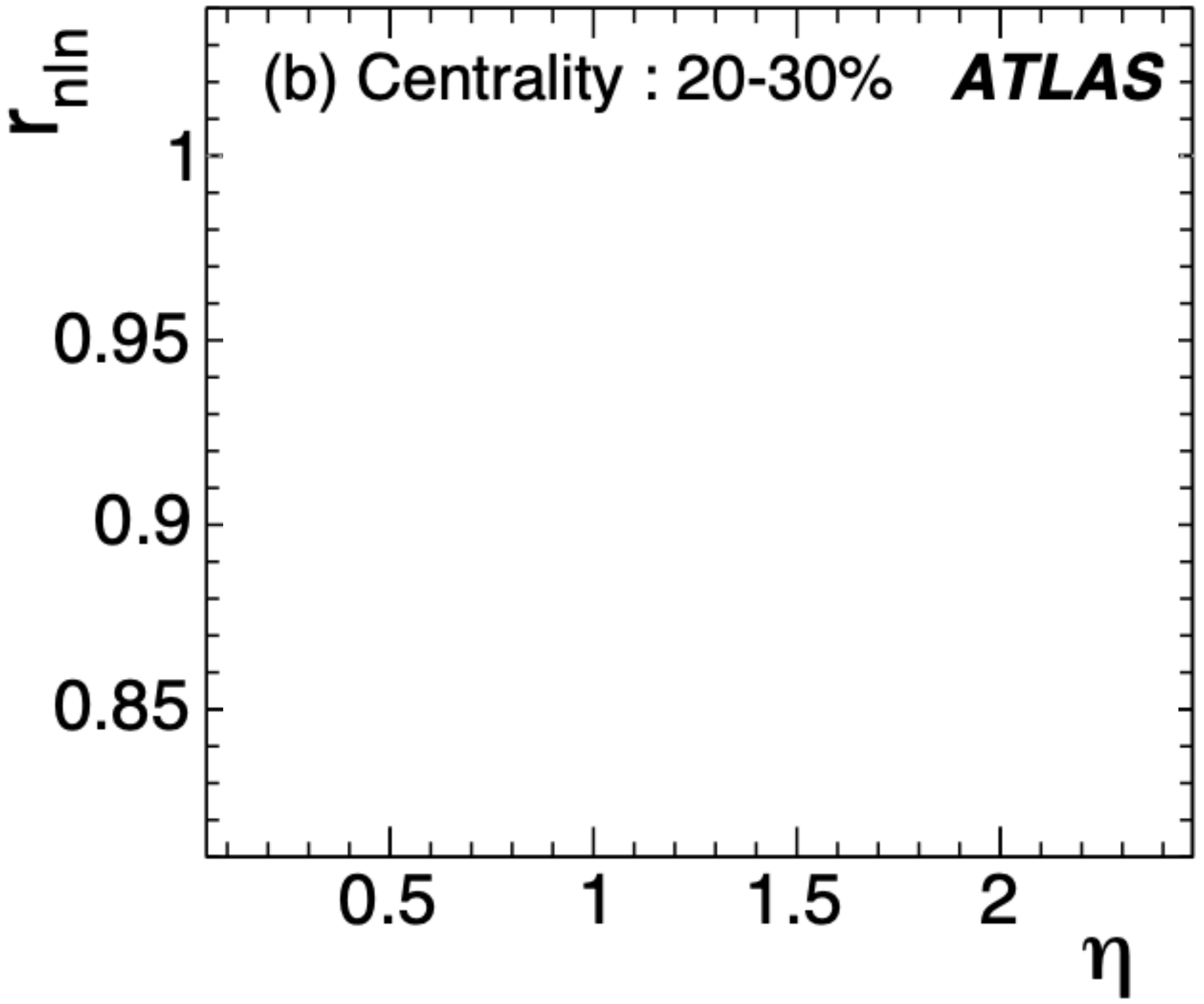


$v_n(\eta_1) \neq v_n(\eta_2)$ $\Psi_n(\eta_1) \neq \Psi_n(\eta_2)$

ID (|η|<2.5)

$$r_{n|n}(\eta) = \frac{\langle q_n(-\eta) q_n^*(\eta_{\rm ref})\rangle}{\langle q_n(\eta) q_n^*(\eta_{\rm ref})\rangle}$$

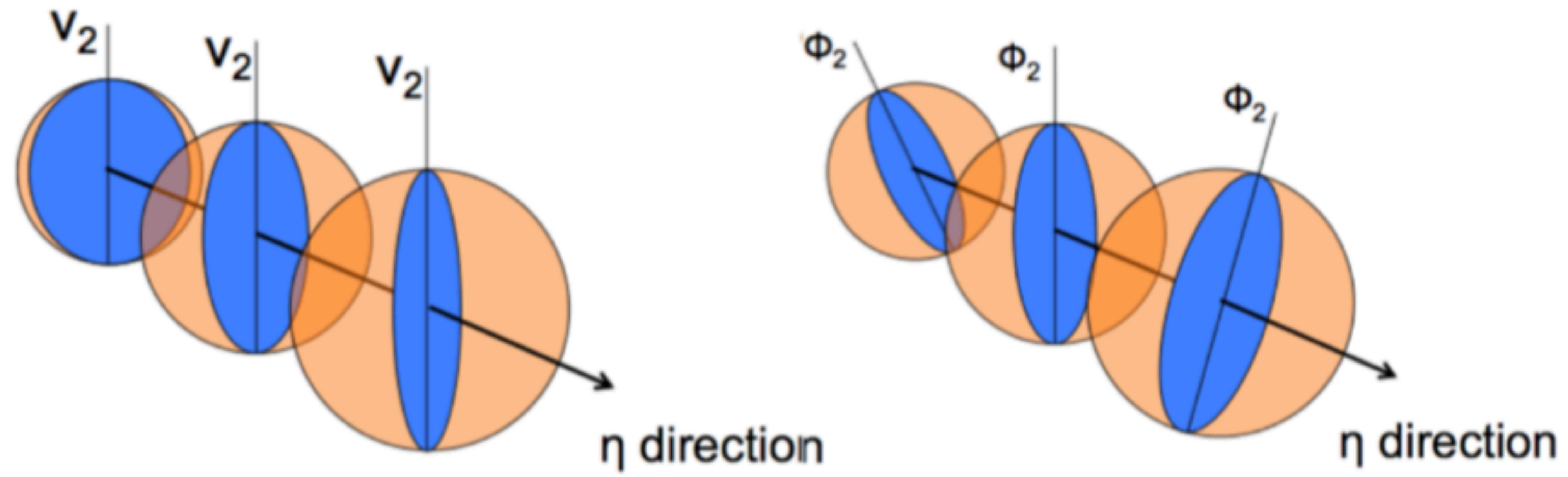
FCal (3.2 <|η|< 4.9)



$r_{n|n;2}$ at 1
no decorrelation effect

Longitudinal flow decorrelation Xe+Xe & Pb+Pb

Phys. Rev. Lett. 126 (2021) 12230



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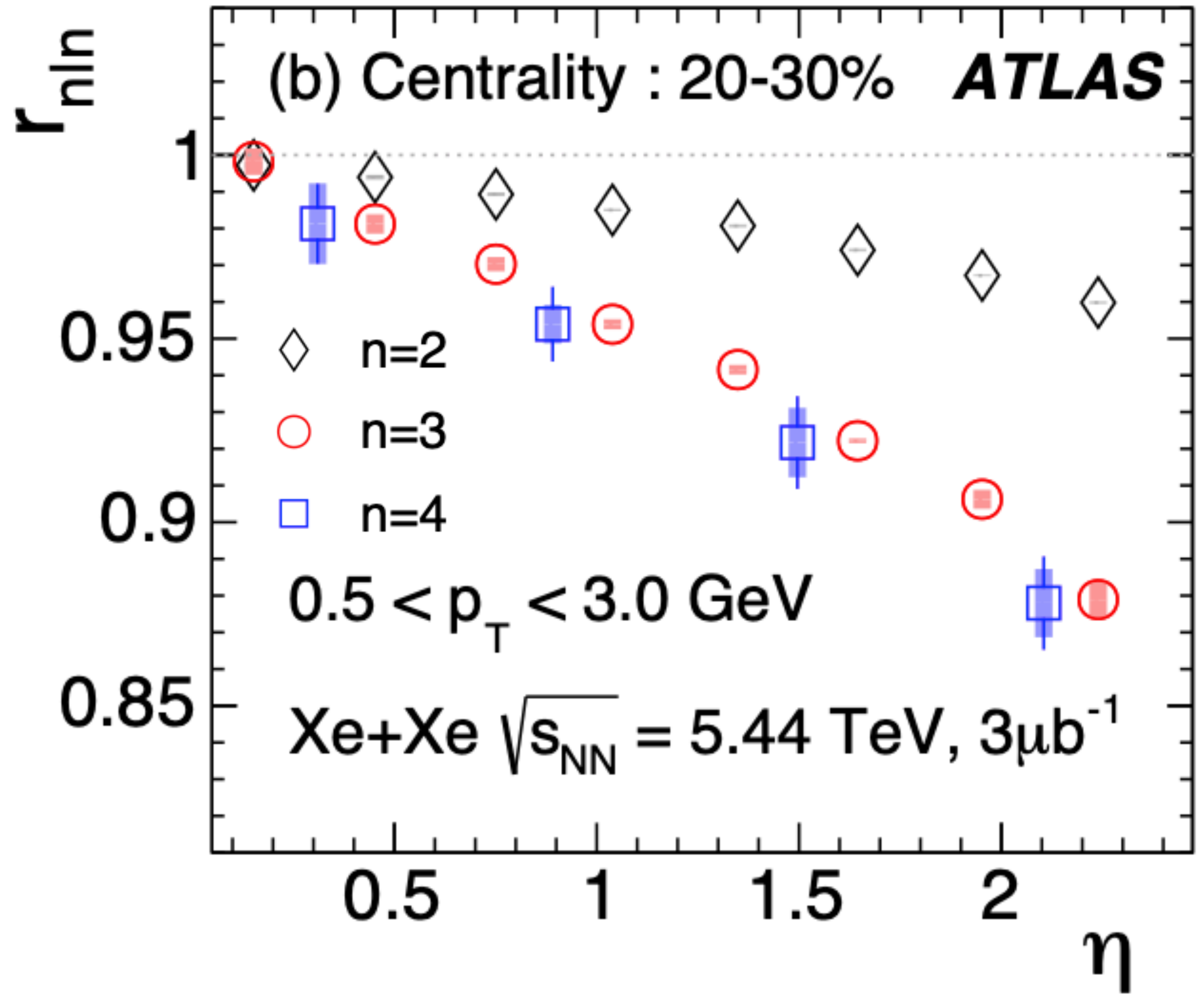


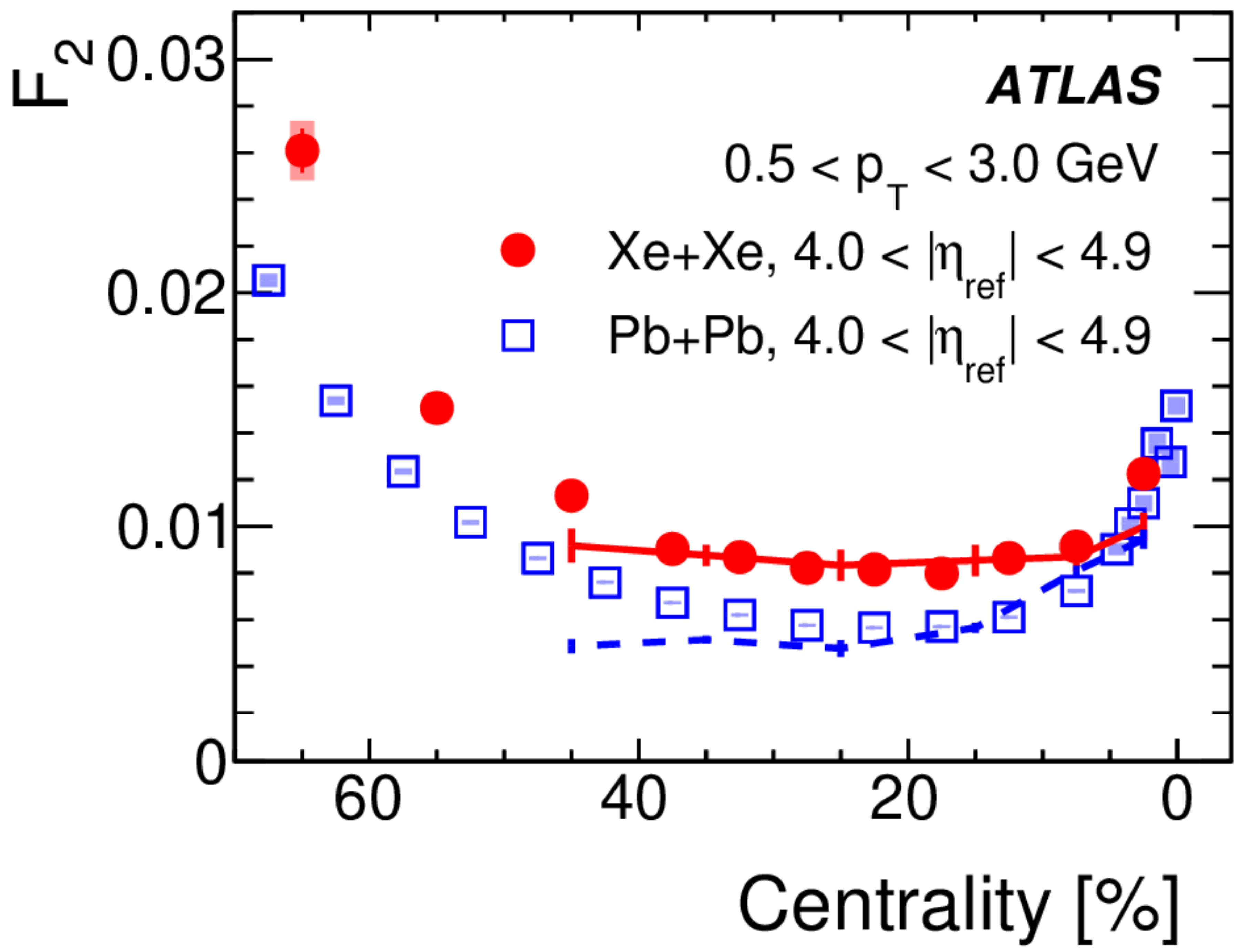
$r_{n|n;2}$ at 1 no decorrelation effect

F_n - slope of the $r_{n|n;2}$

Measured decorrealtion for v_2, v_3 and v_4 harmonics in Xe+Xe and compared to that in Pb+Pb.

Longitudinal flow decorrelation Xe+Xe & Pb+Pb

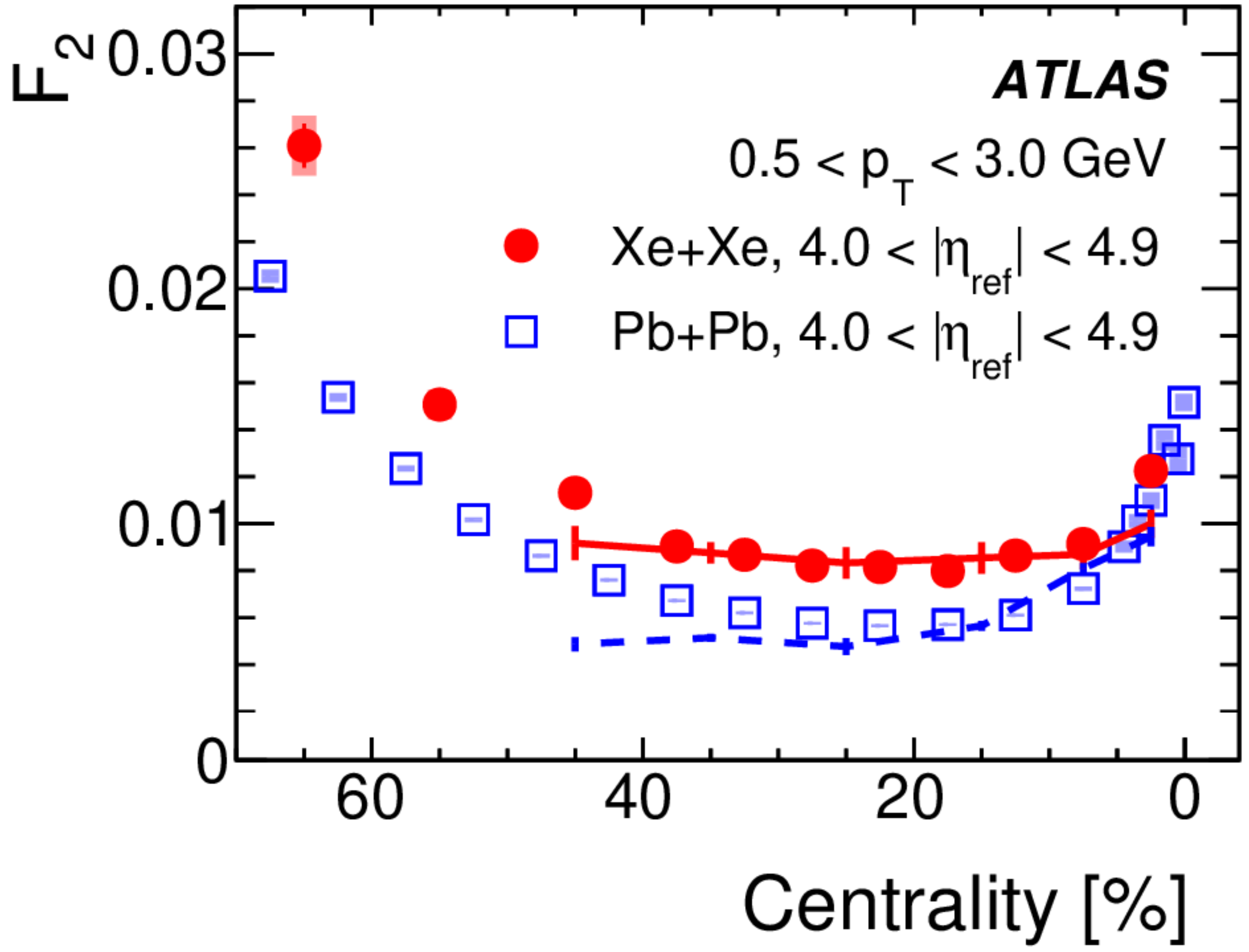
Phys. Rev. Lett. 126 (2021) 12230

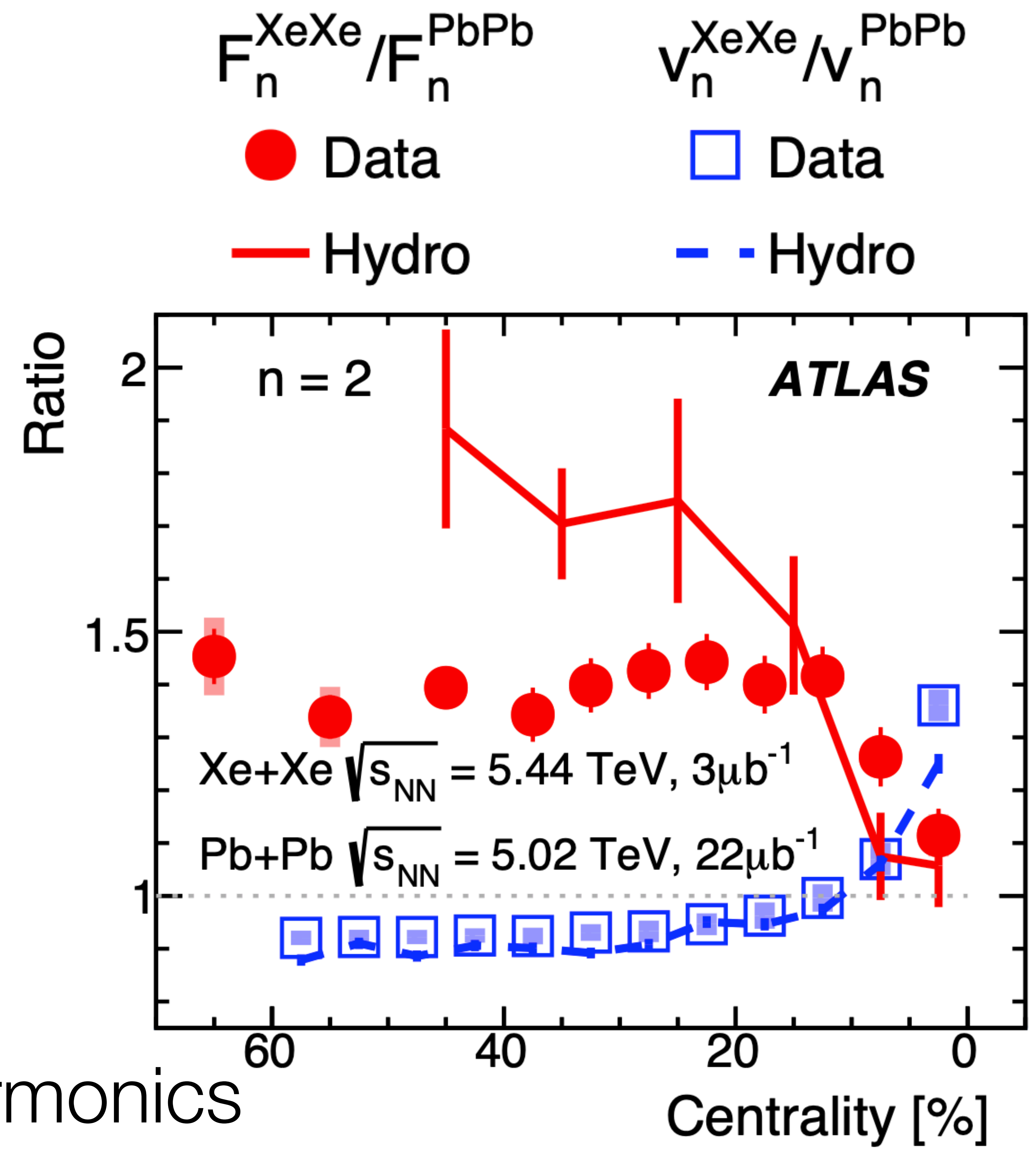


System size dependence of ***longitudinal flow*** harmonics ***decorrelation***

Longitudinal flow decorrelation Xe+Xe & Pb+Pb

[Phys. Rev. Lett. 126 (2021) 12230](https://doi.org/)



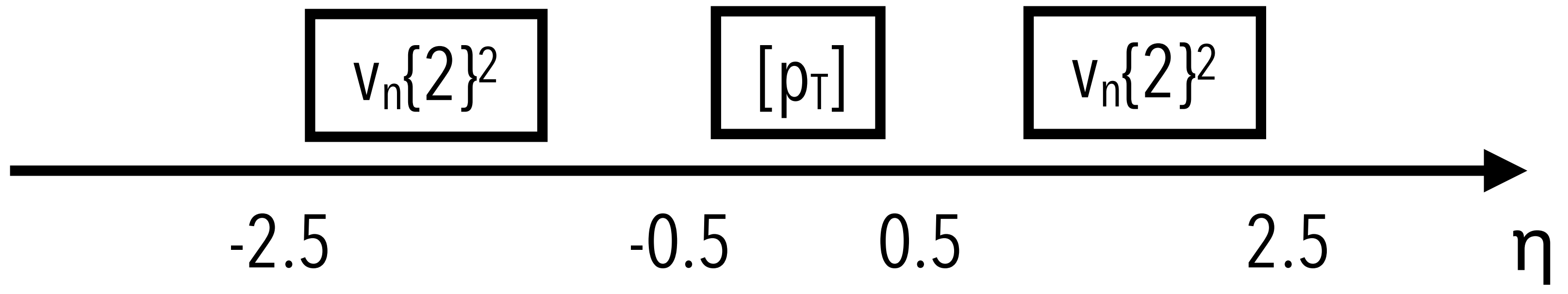


System size dependence of ***longitudinal flow*** harmonics ***decorrelation*** and ***transverse flow*** provides strong constraints for modeling of heavy-ion collisions.

vn-[pT] correlation in Xe+Xe & Pb+Pb

Correlation between "radial" (mean p_T) and "transverse" evolution of the system (v_n harmonics)

$$\rho = \frac{\mathrm{cov}(v_n\{2\}^2, [p_\mathrm{T}])}{\sqrt{\mathrm{Var}\left(v_n\{2\}^2\right)_\mathrm{dyn}}\sqrt{c_k}}$$



v_n-$[p_T]$ correlation in Xe+Xe & Pb+Pb

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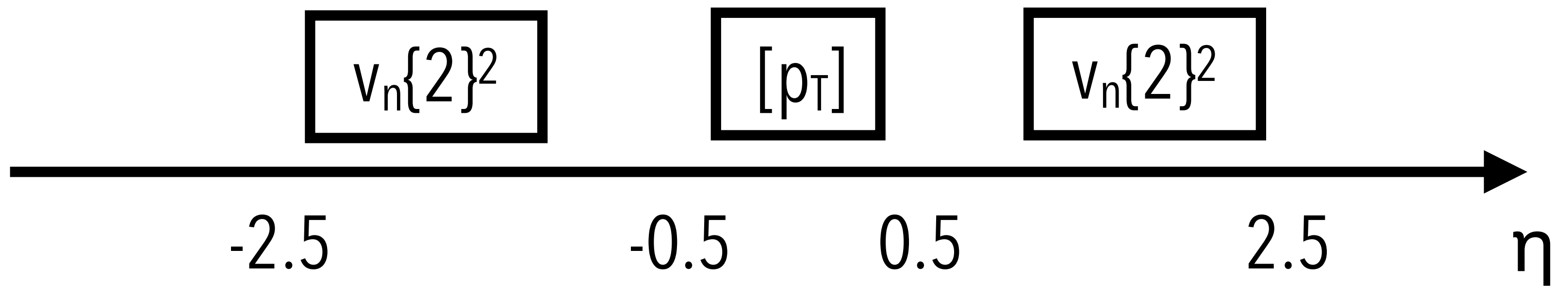

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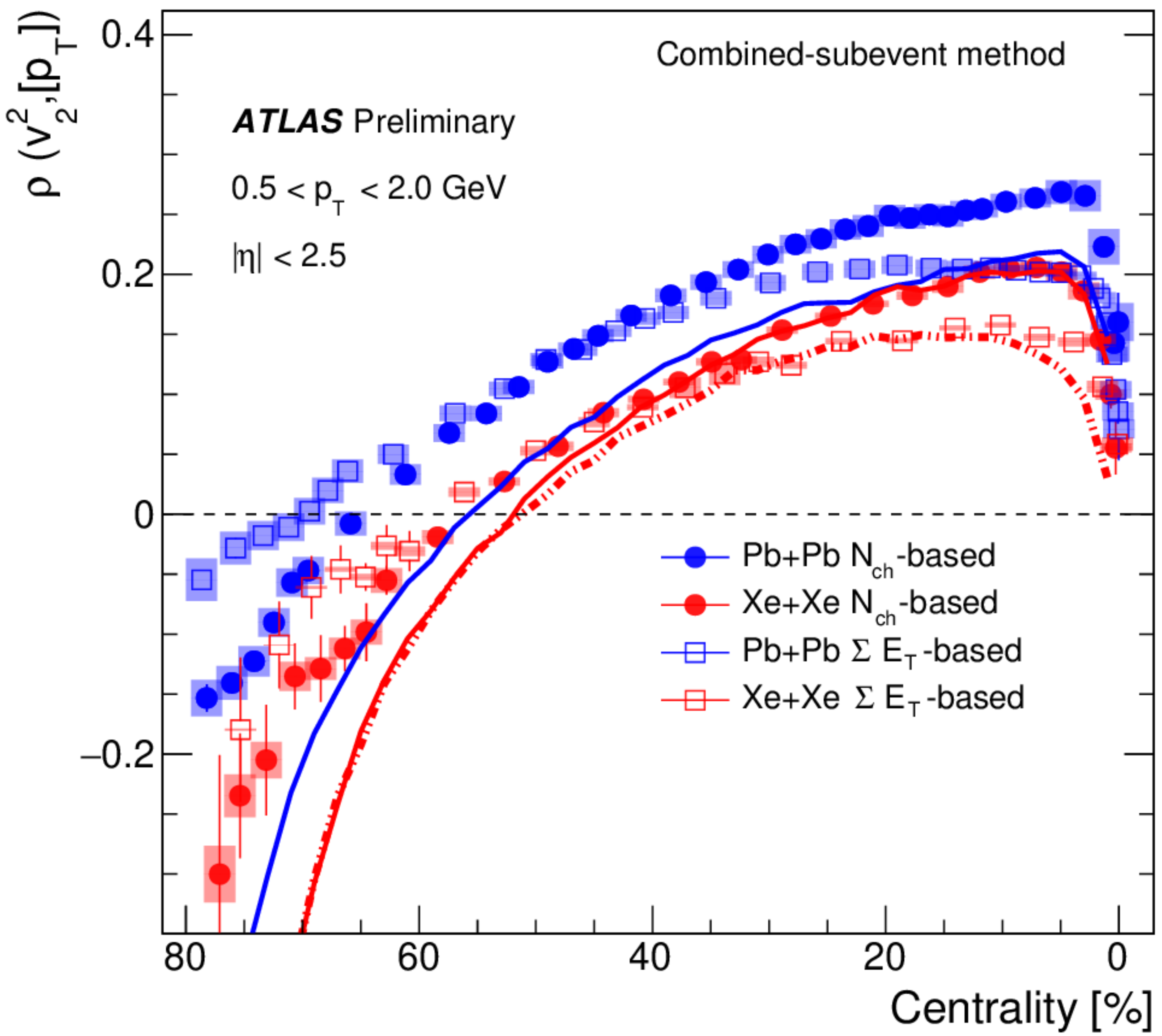

Strong centrality dependence and sensitivity to the event class definition.

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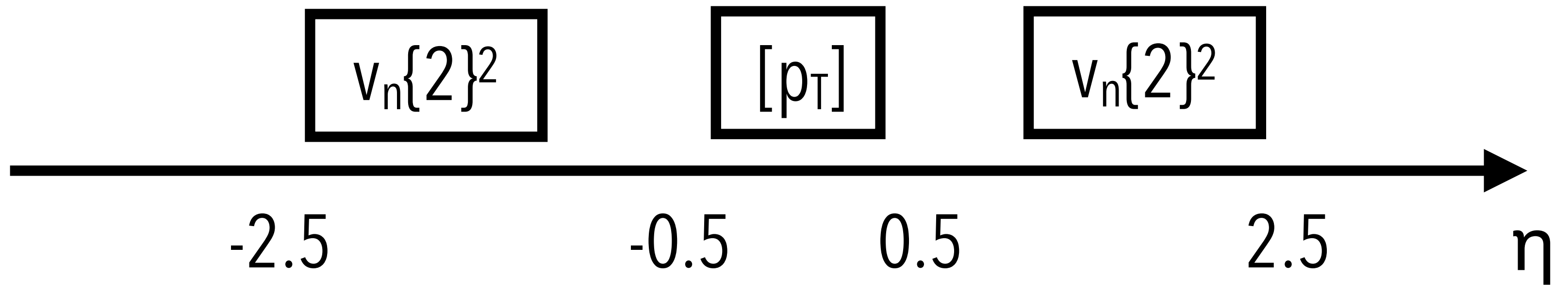
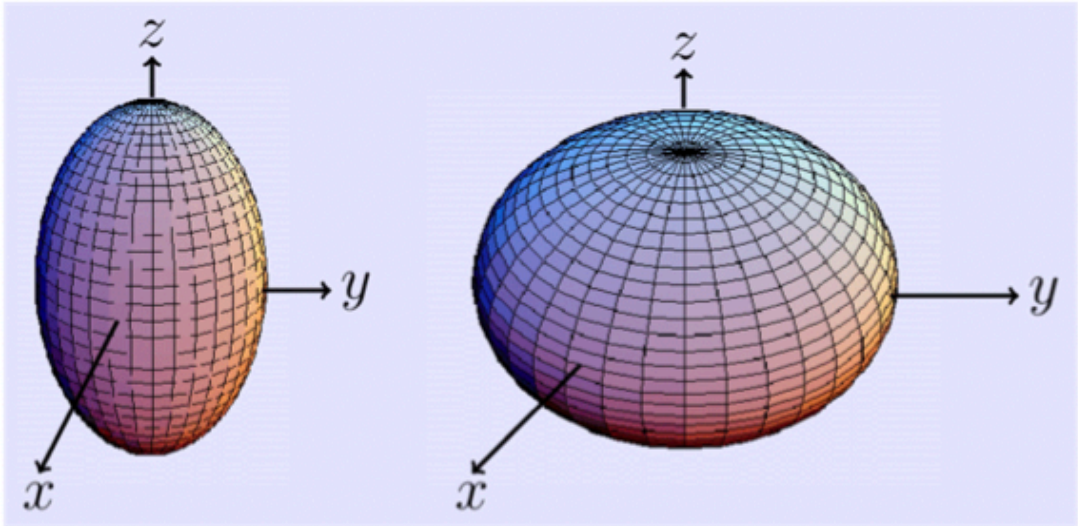


Nuclear deformation:



$\beta_2 > 0$ Prolate $\qquad \beta_2 < 0$ Oblate

- RHIC - Au+Au ($\beta_2 \simeq -0.13$) , U+U ($\beta_2 \simeq 0.3$)
- LHC - Pb+Pb ($\beta_2 \simeq 0$) , Xe+Xe ($\beta_2 \simeq 0.16$)

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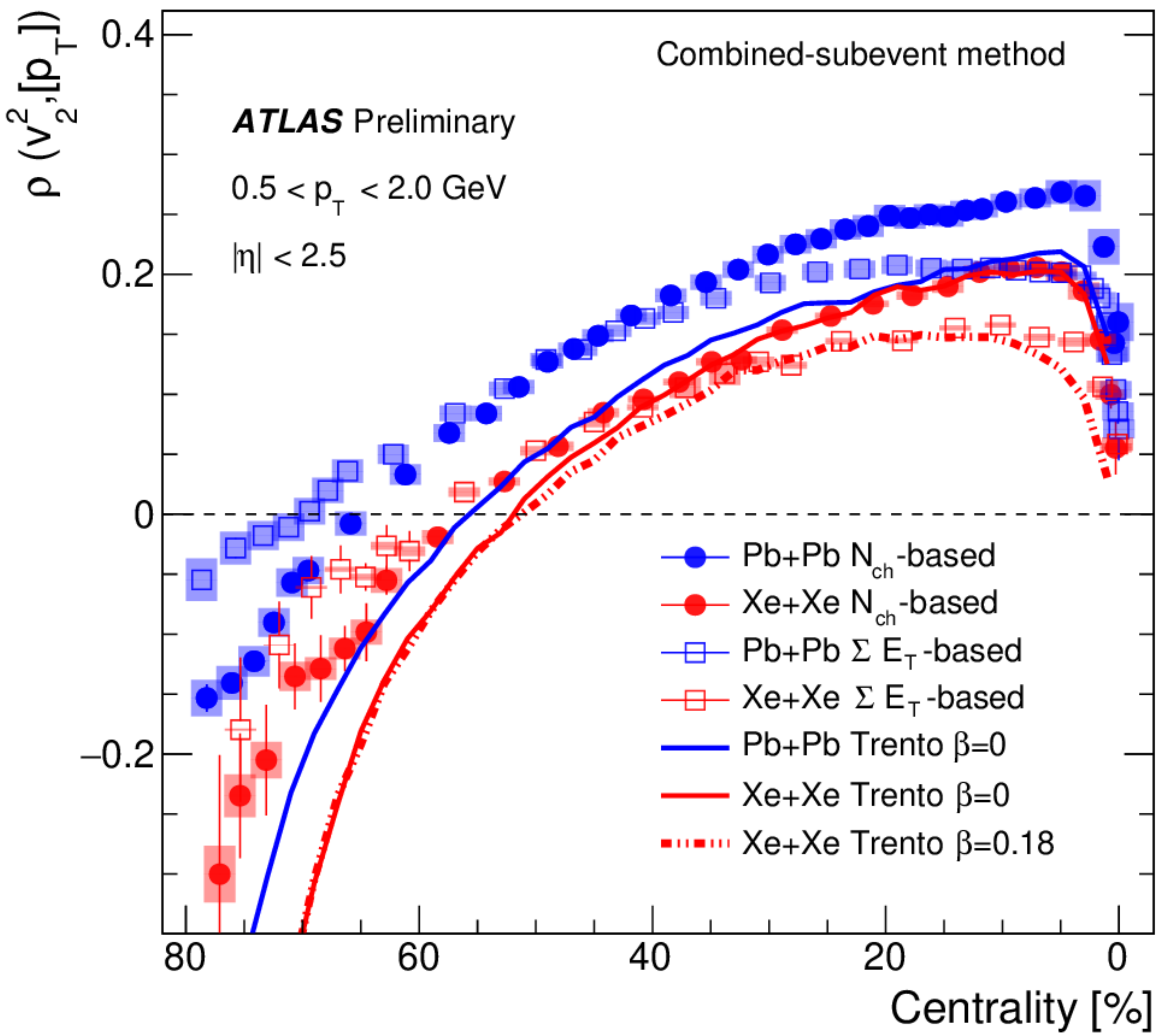

Same data compared to hydro with ***Trento initial conditions …***

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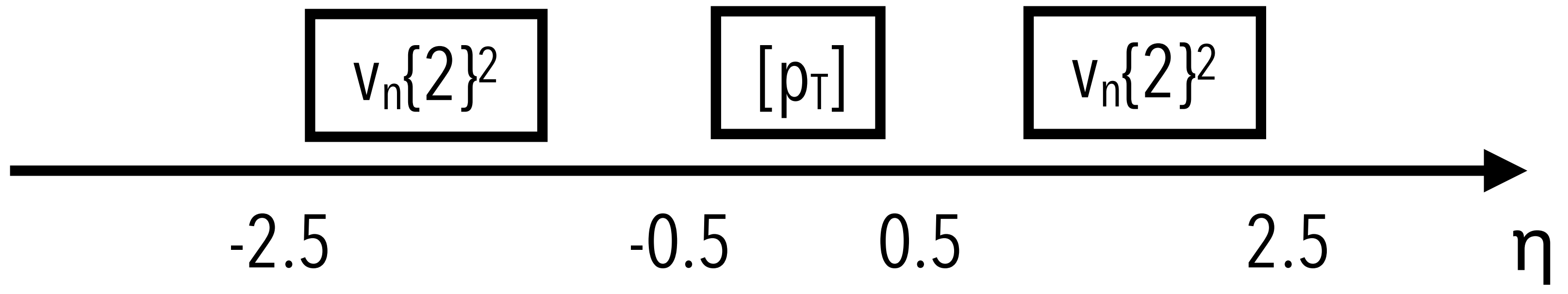

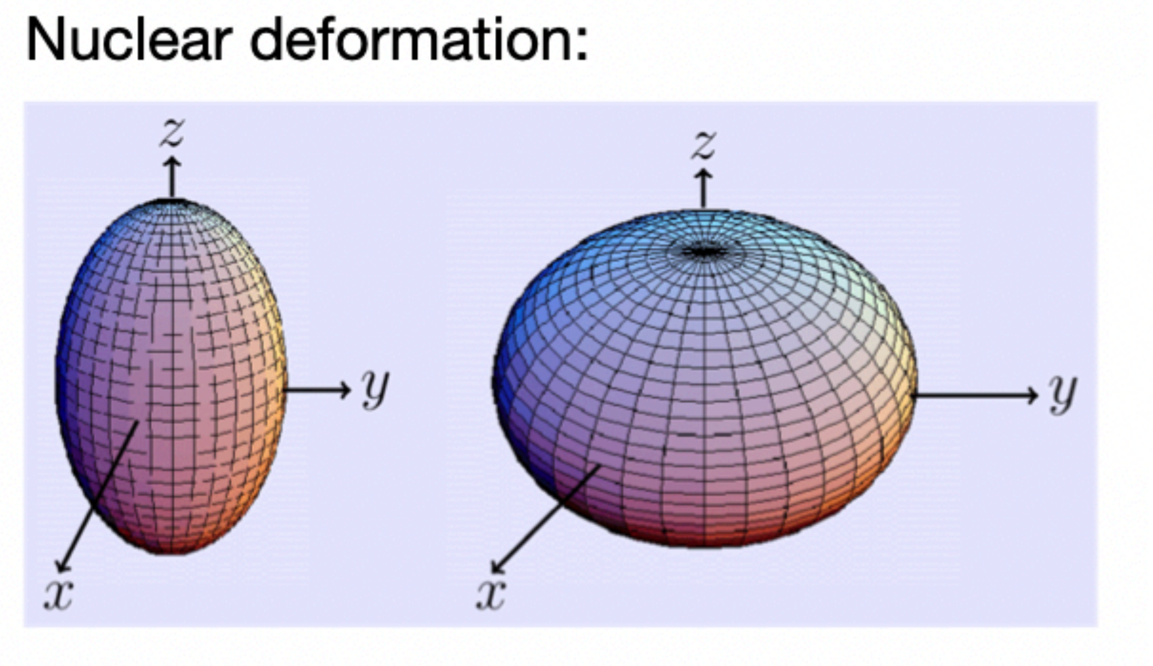

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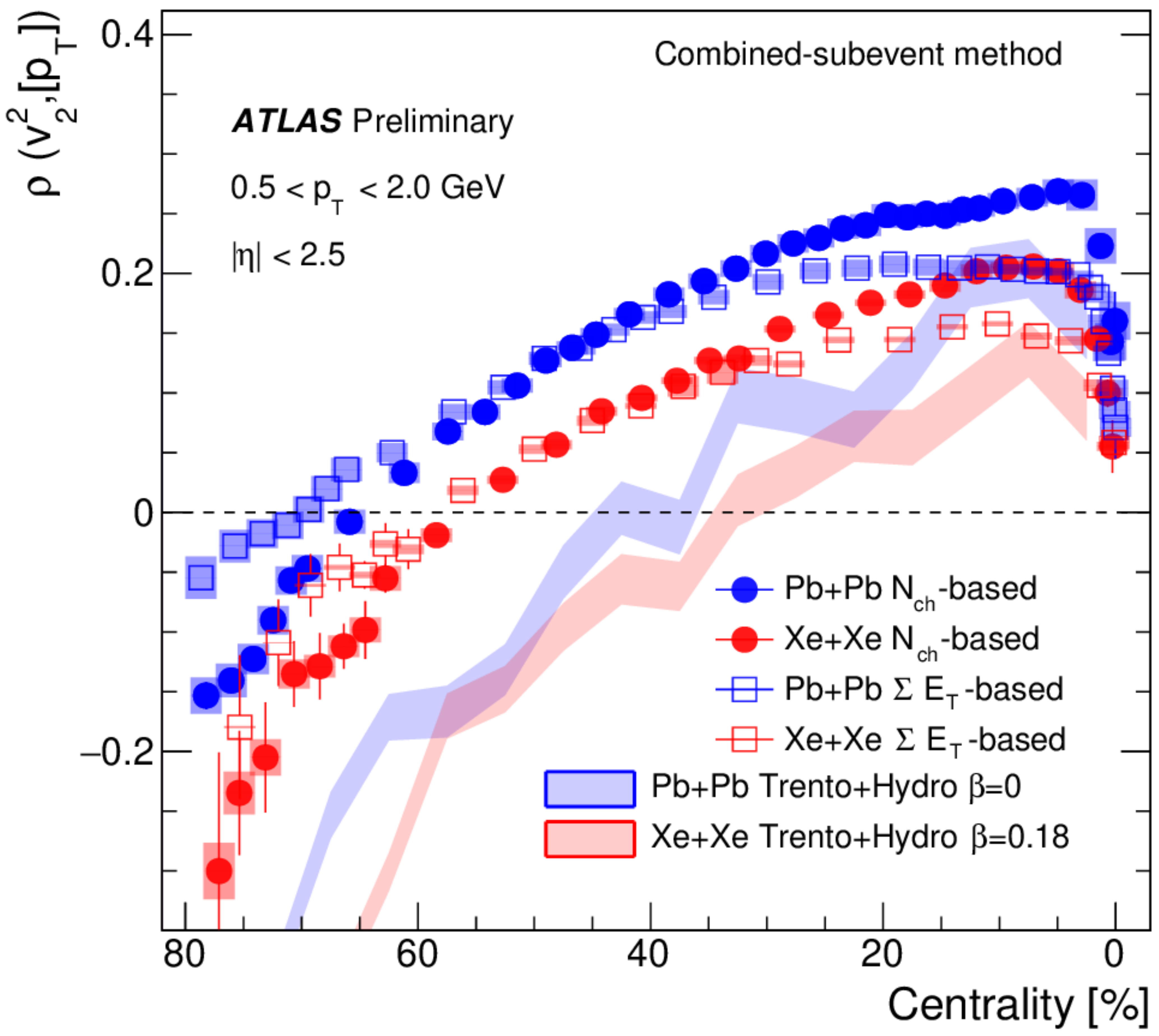

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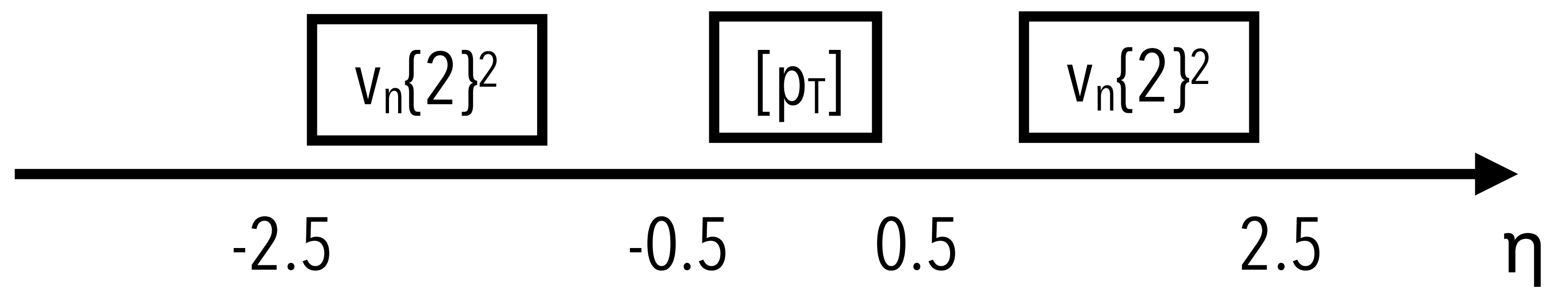

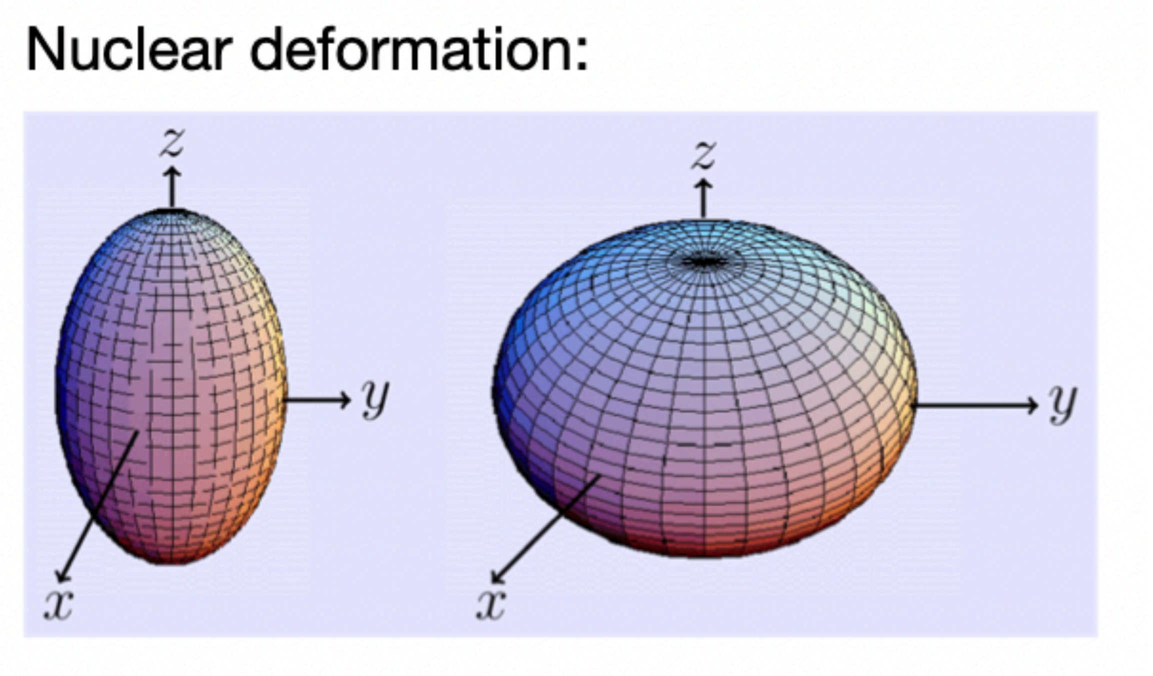

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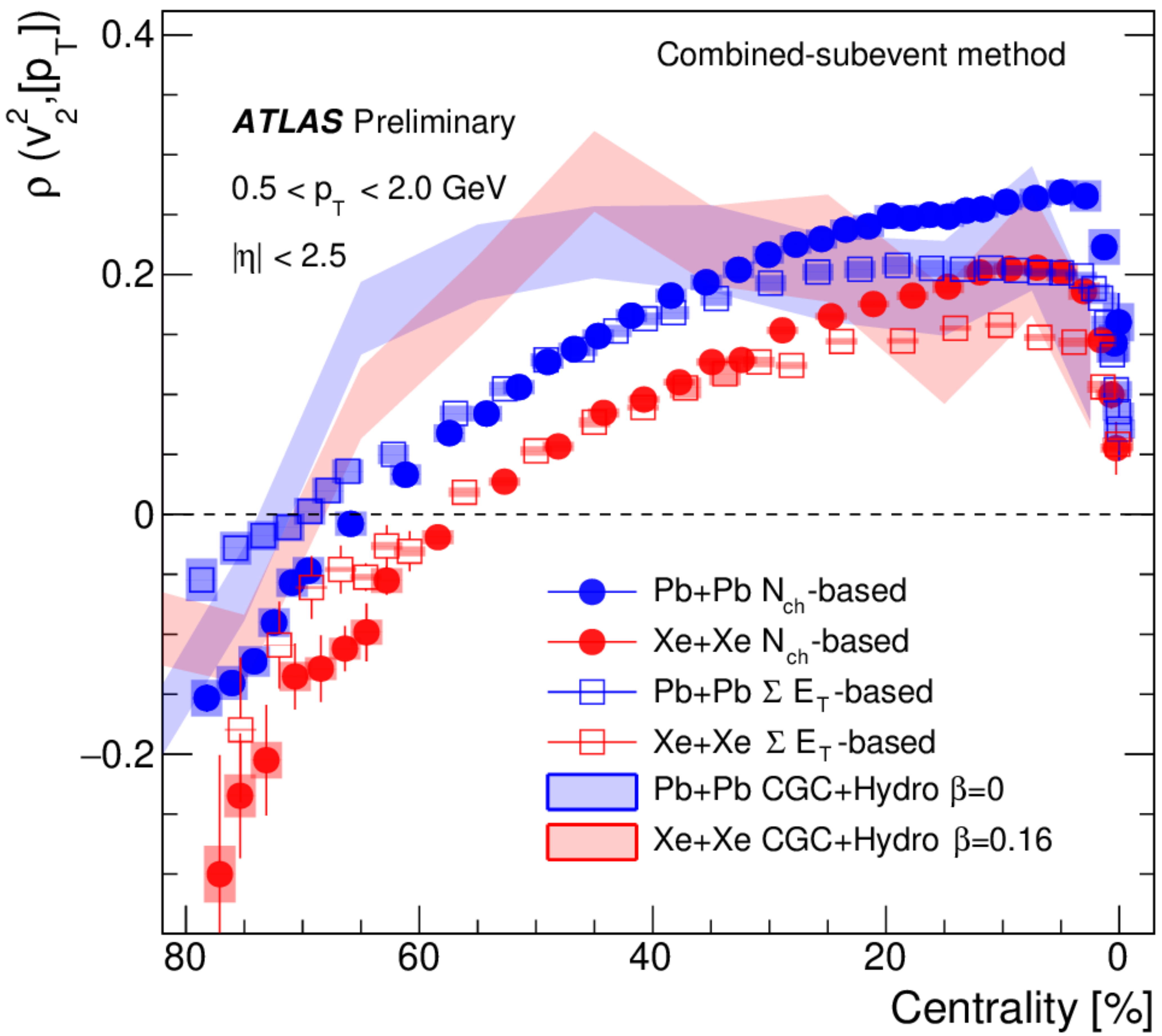


and ***CGS + hydro …***
not yet able to constrain nuclear deformation

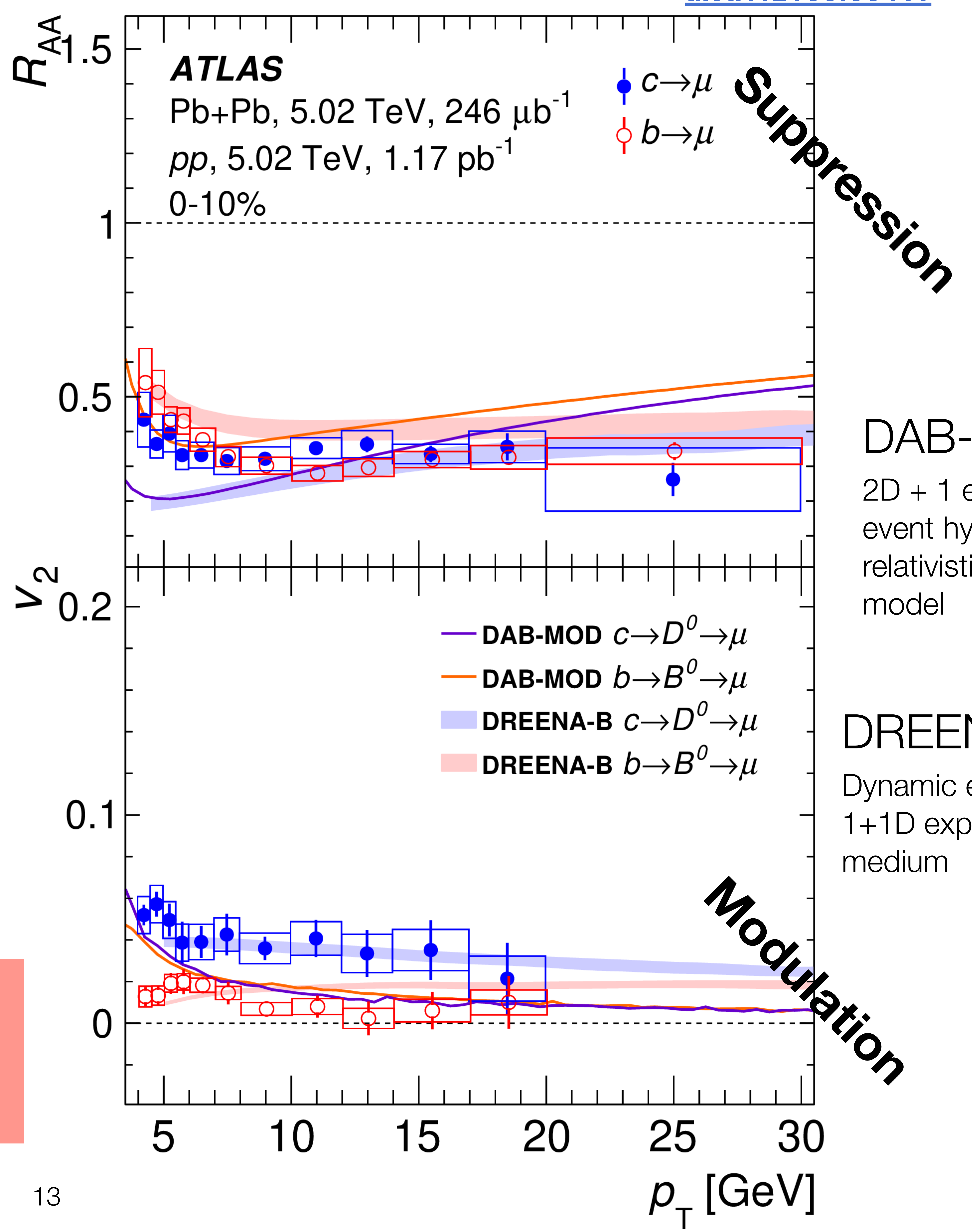
arXiv:2109.00411

Heavy flavour (charm and bottom) quarks flow and suppression in Pb+Pb

Simultaneous measurement of R_{AA} and v_2 of muons from charm and beauty decays test the balance between energy loss mechanism and the QGP expansion

- ➡ At lower muon p_T, clear mass effect in overall suppression and flow magnitude
- ➡ Similar level of suppression at higher p_T, while still significantly different flow

Christopher McGinn
Sun, 14:50



DAB-MOD

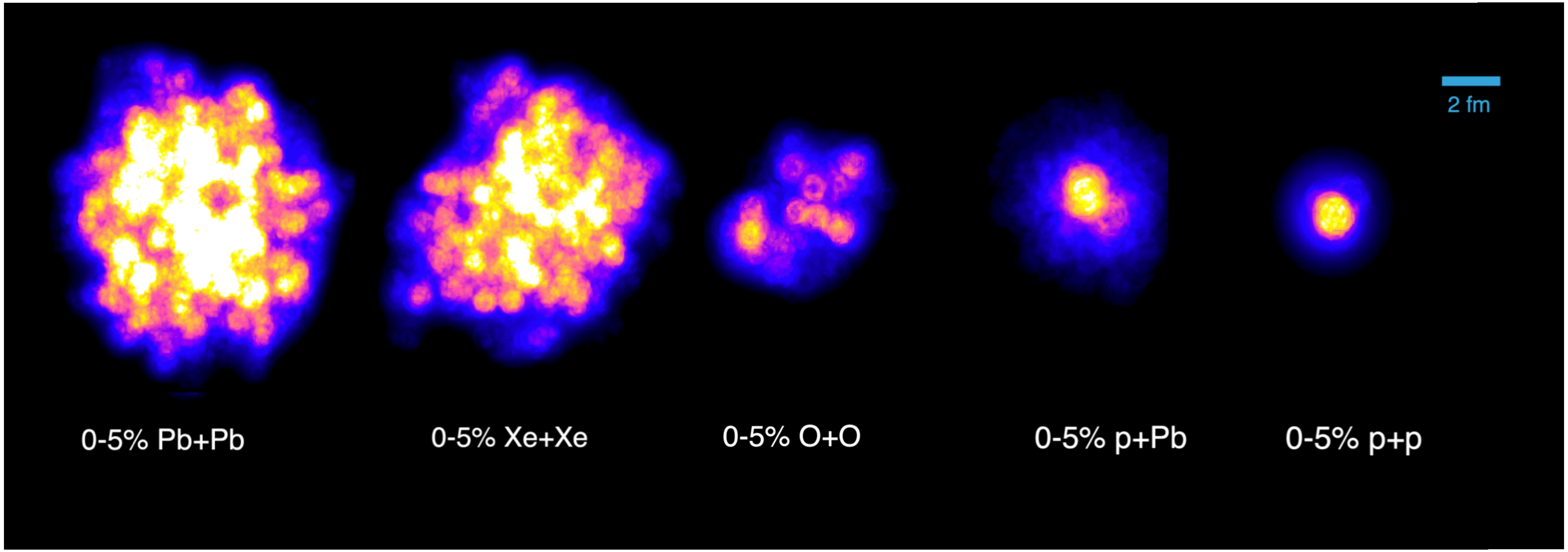
2D + 1 event-by-event hydro with relativistic Langevin model

DREENA-B

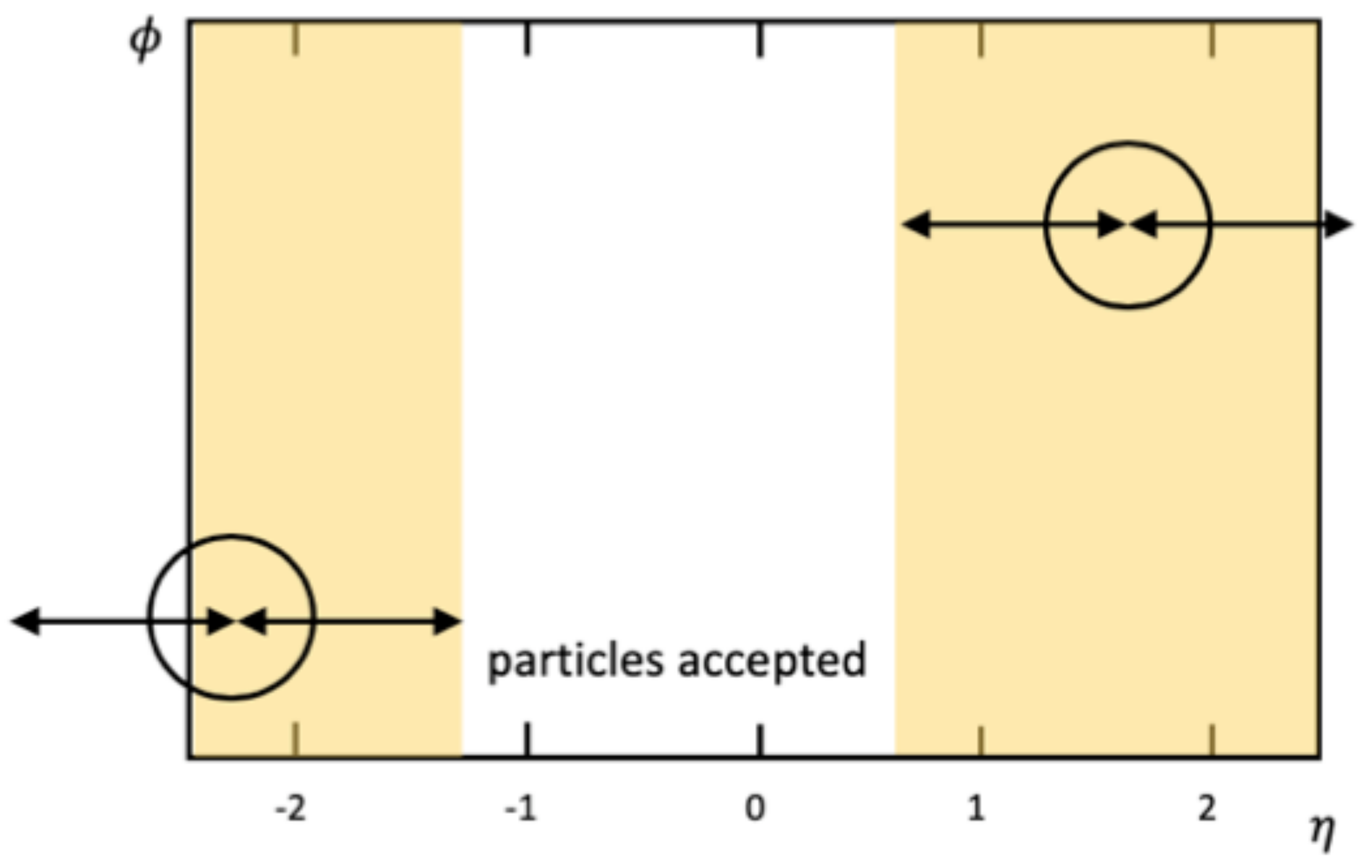
Dynamic energy loss in 1+1D expanding QCD medium

Flow in small systems

- ➡ How the flow in pp collision is affected by hard processes?
- ➡ Can we constrain the geometry of the pp collision?

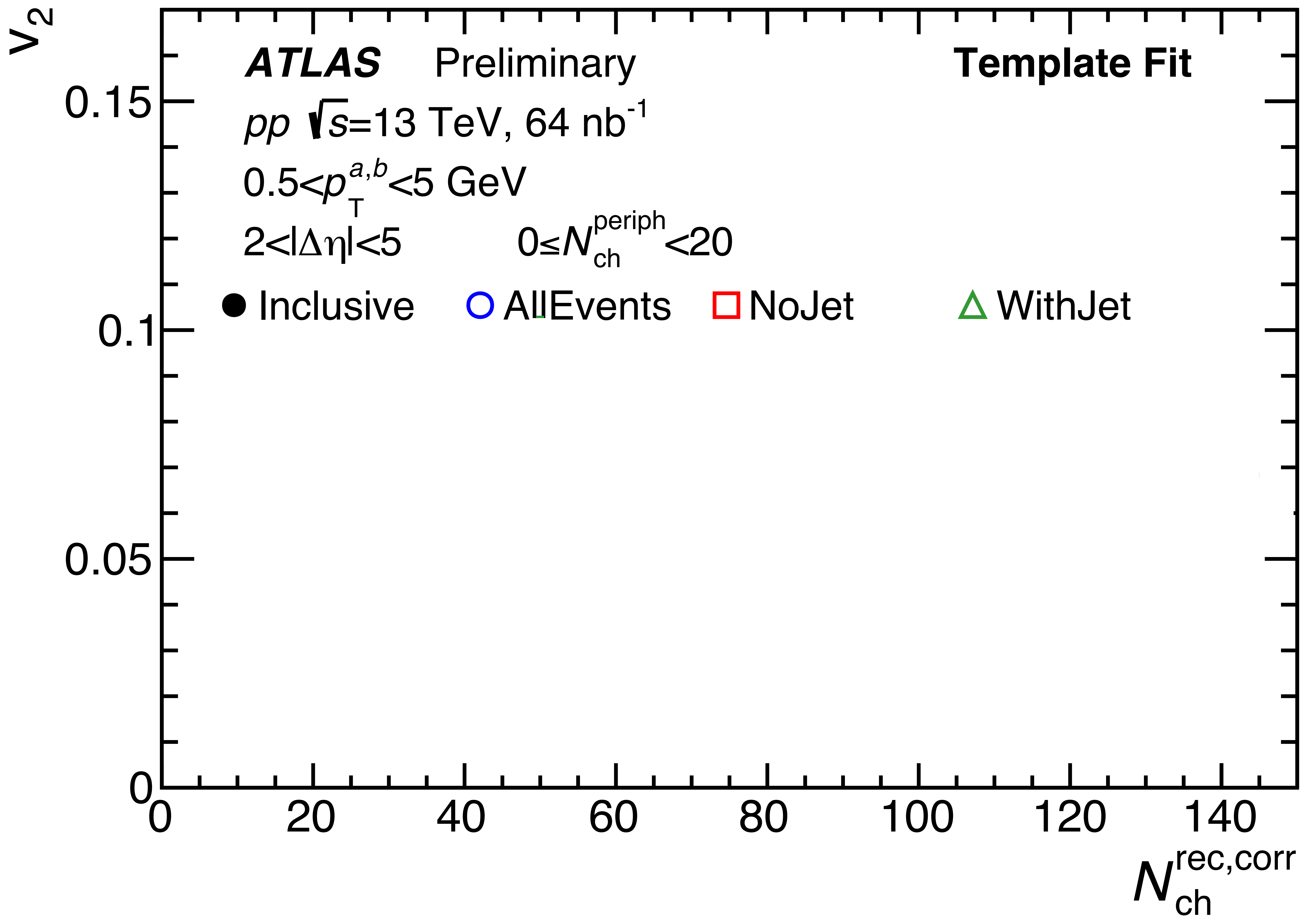


Flow in pp with jet particle rejection



Charged particles close (|Δη|<1) to the jet (track jet with p_T > 10 GeV) removed from the 2PC (both trigger and associated)

ATLAS-CONF-2020-018



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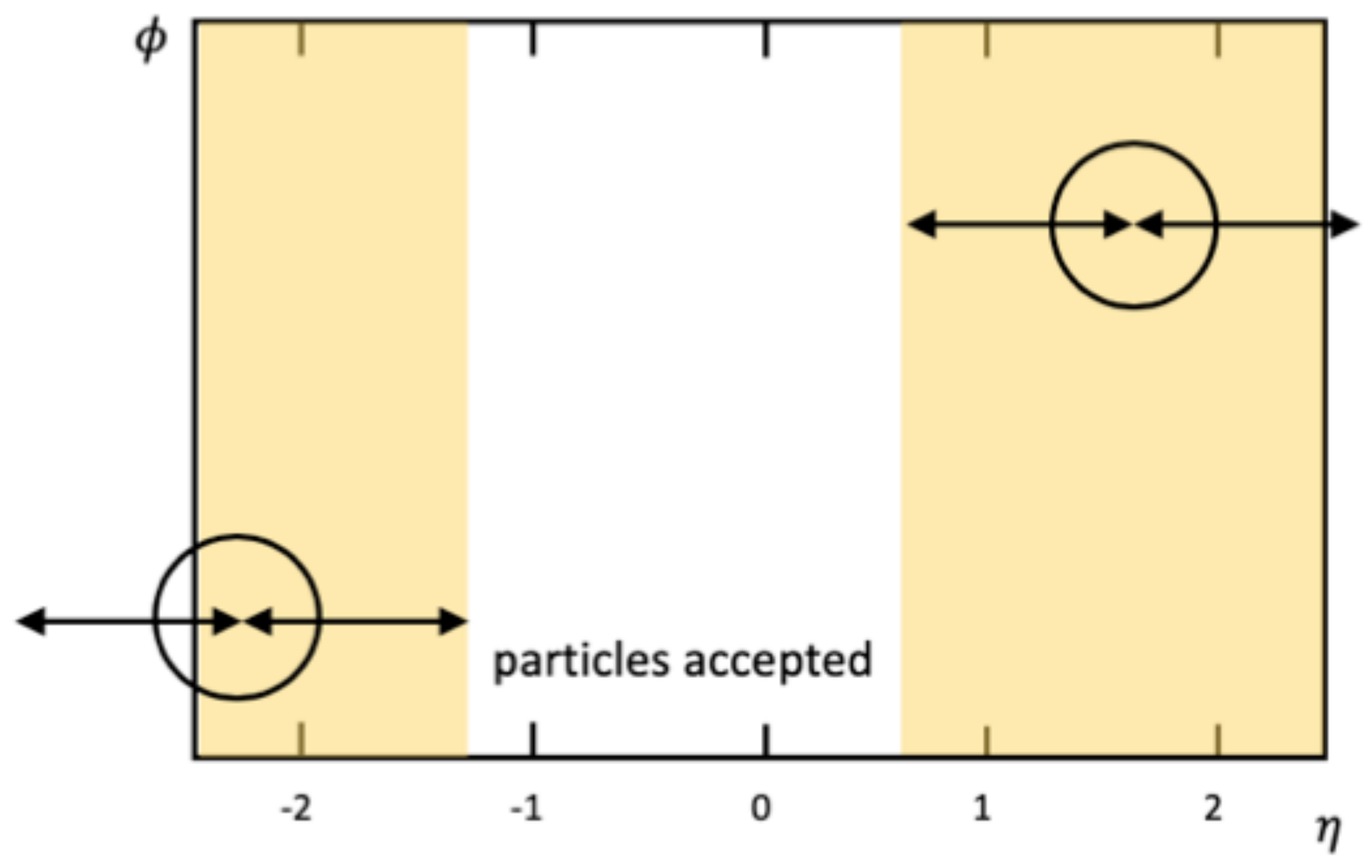

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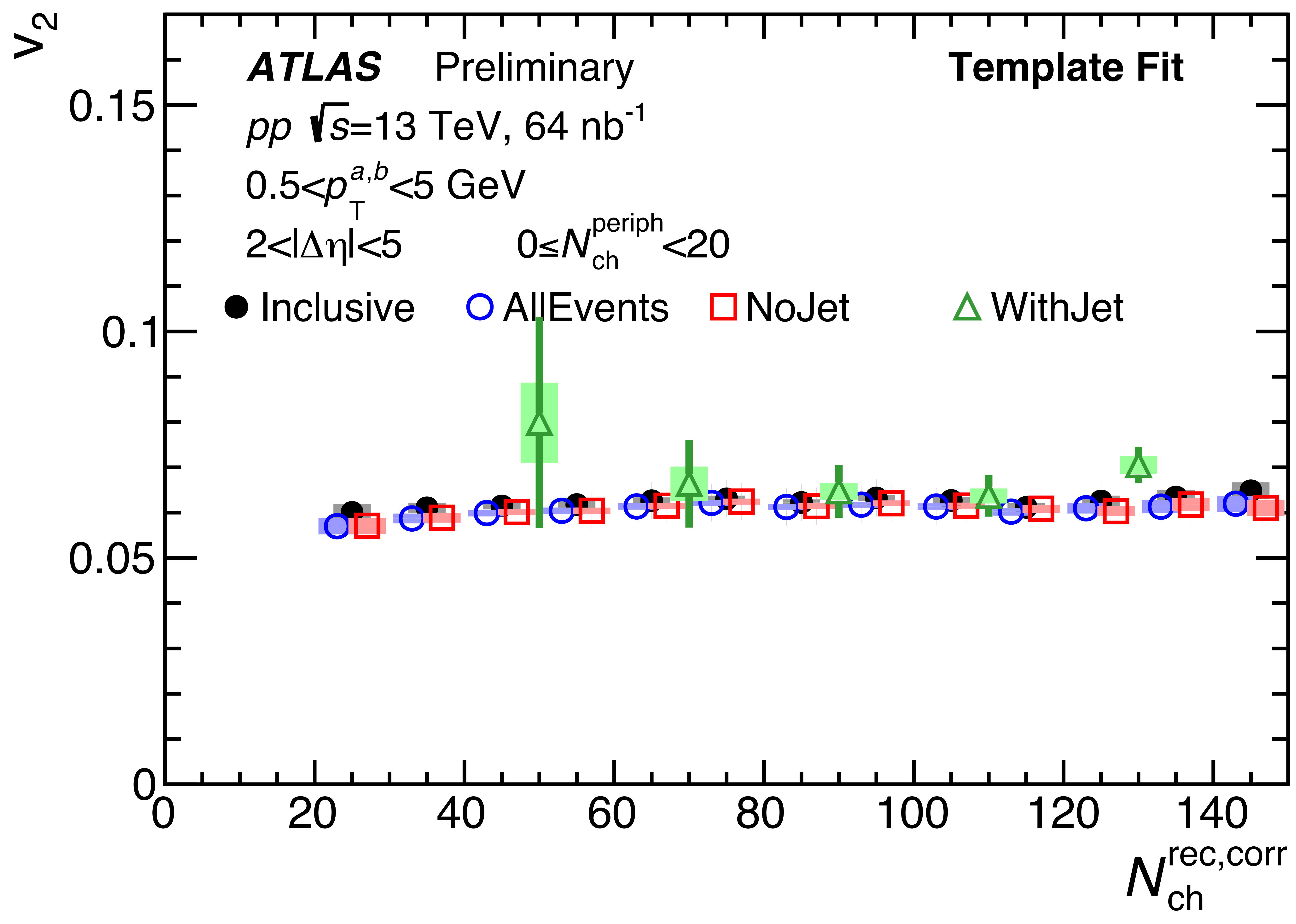

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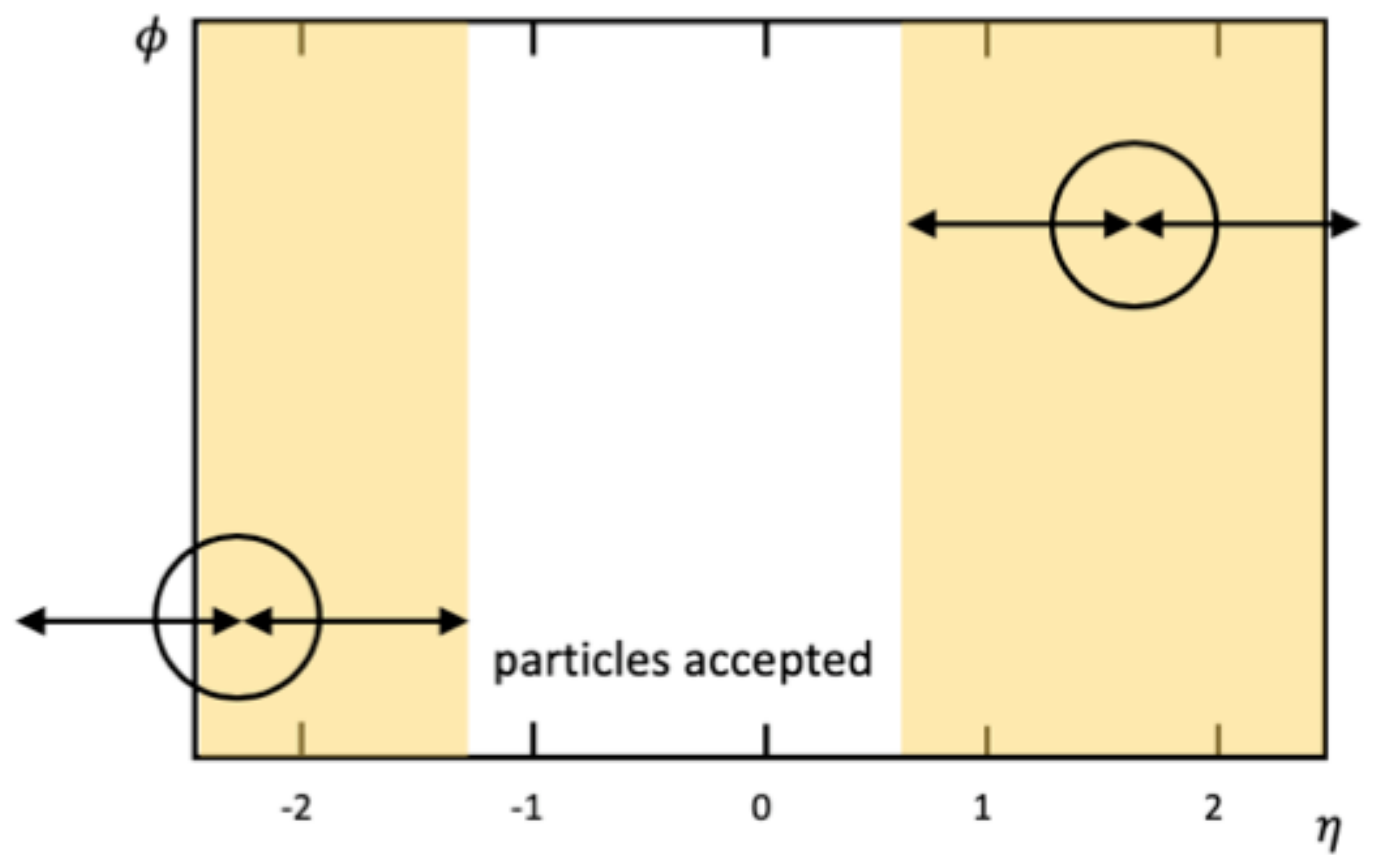
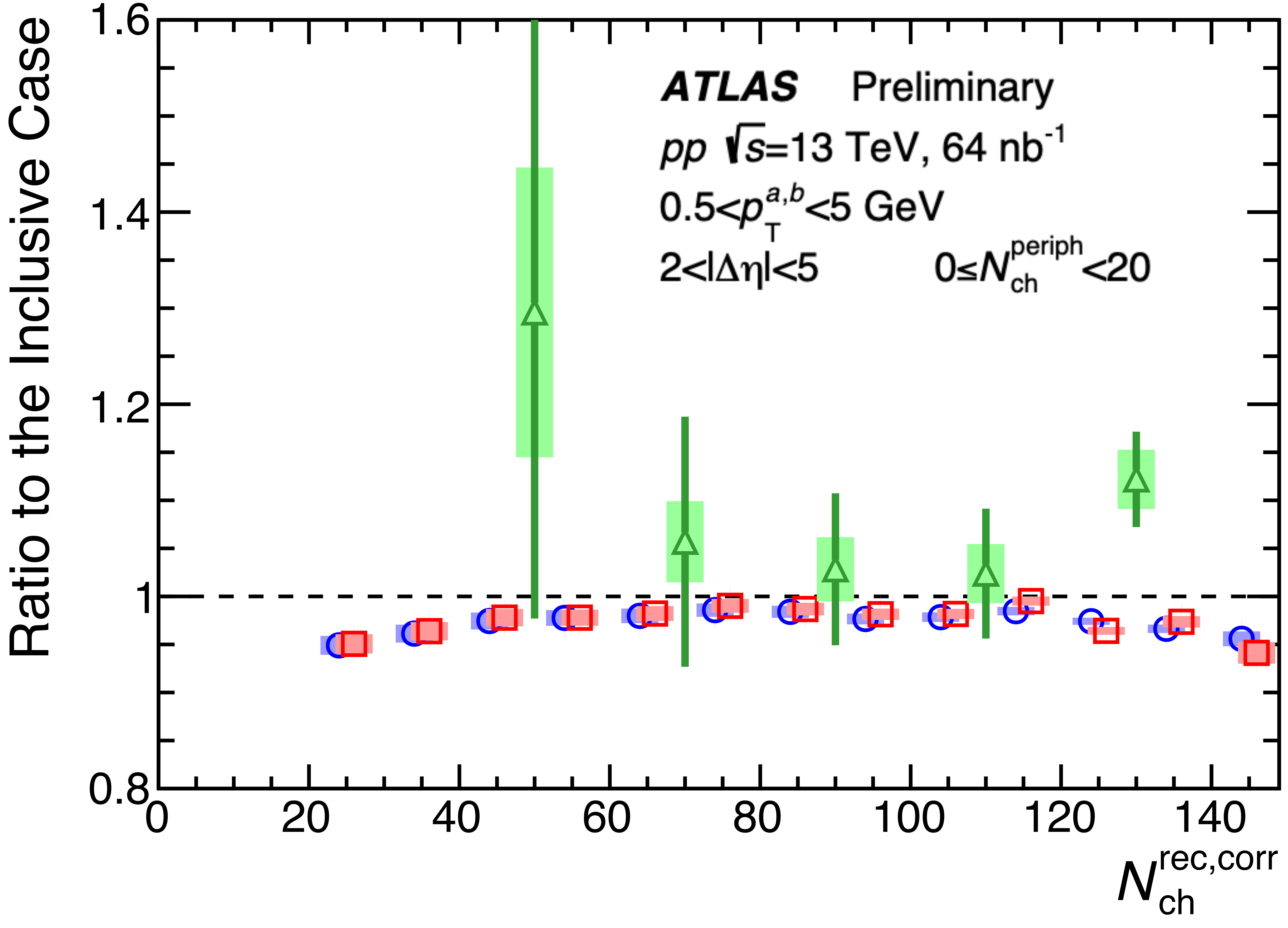


Charged particles close (|Δη|<1) to the jet (track jet with p_T > 10 GeV) removed from the 2PC (both trigger and associated)

The v_2 integrated over the 0.5–5 GeV p_T range decreases only marginally (2-5%) when applying jet particle rejection

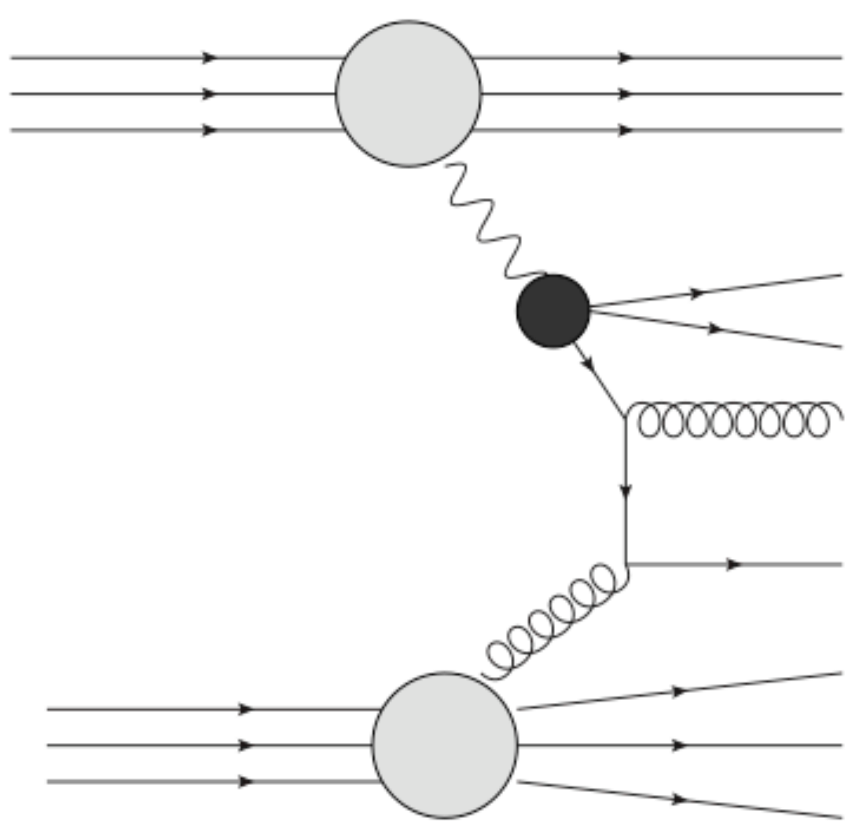
ATLAS-CONF-2020-018

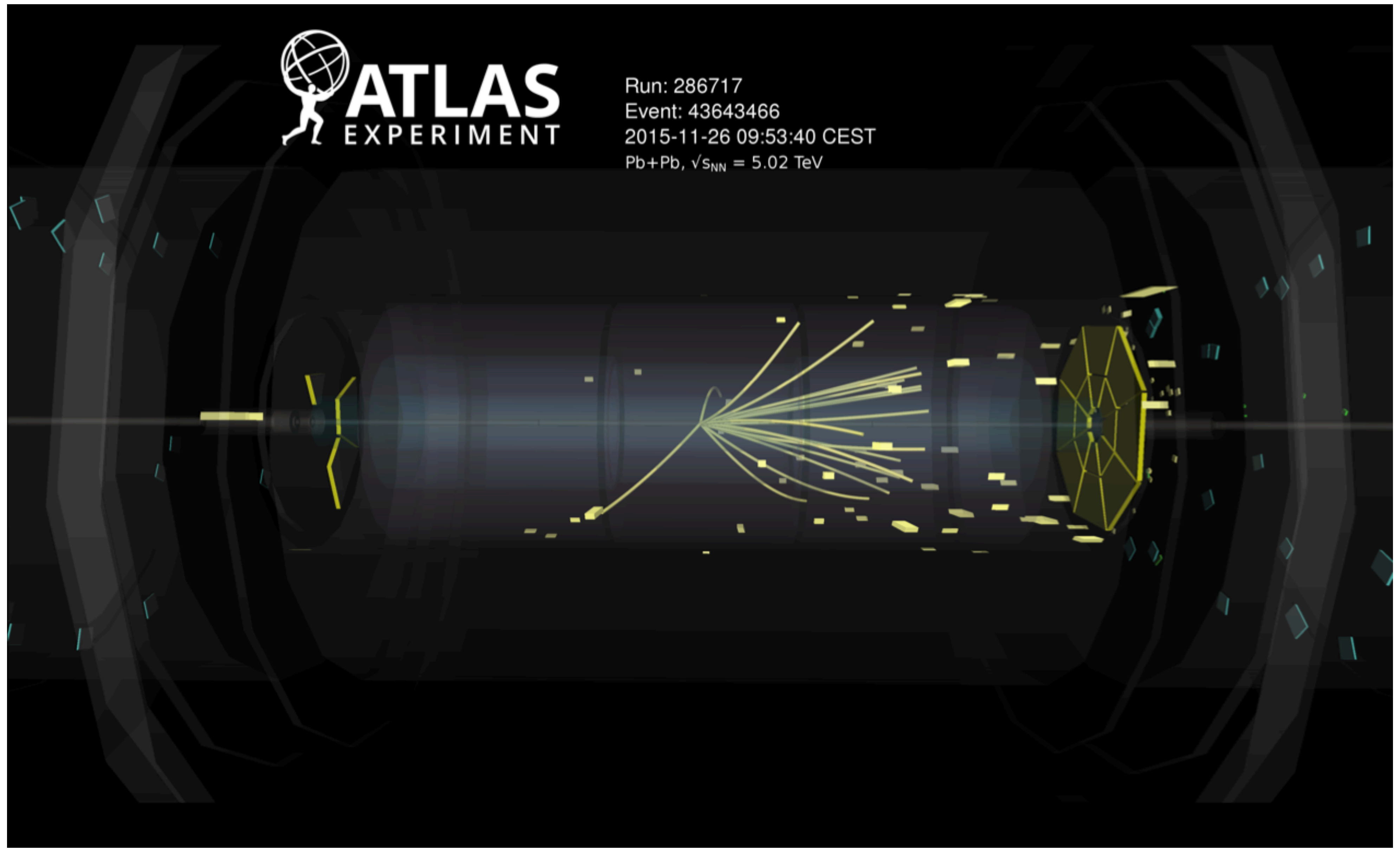


Flow in UPC

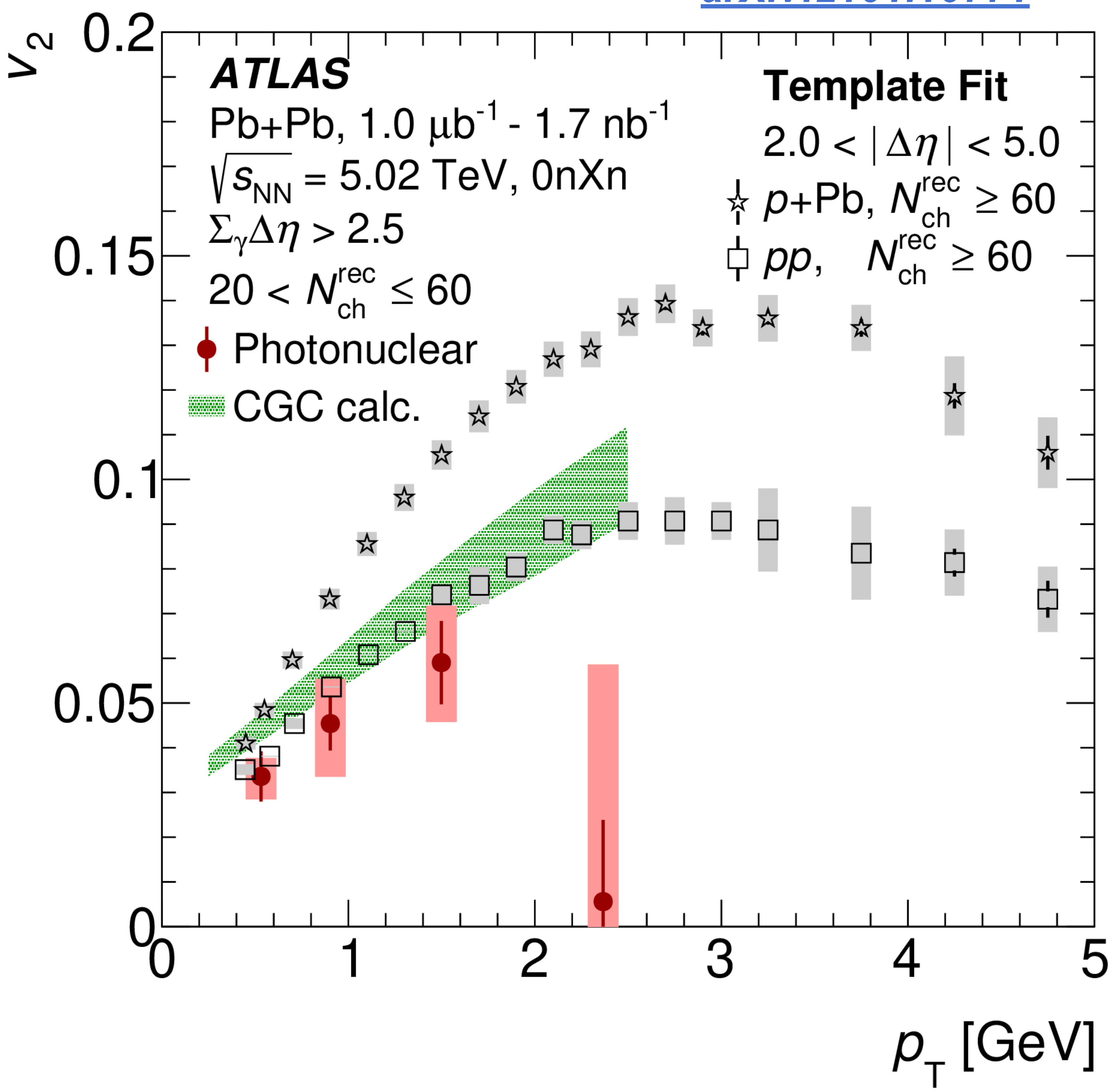
Benjamin Gilbert
Wed, 14:12

UPC γ+Pb (ρ+Pb)





arXiv:2101.10771

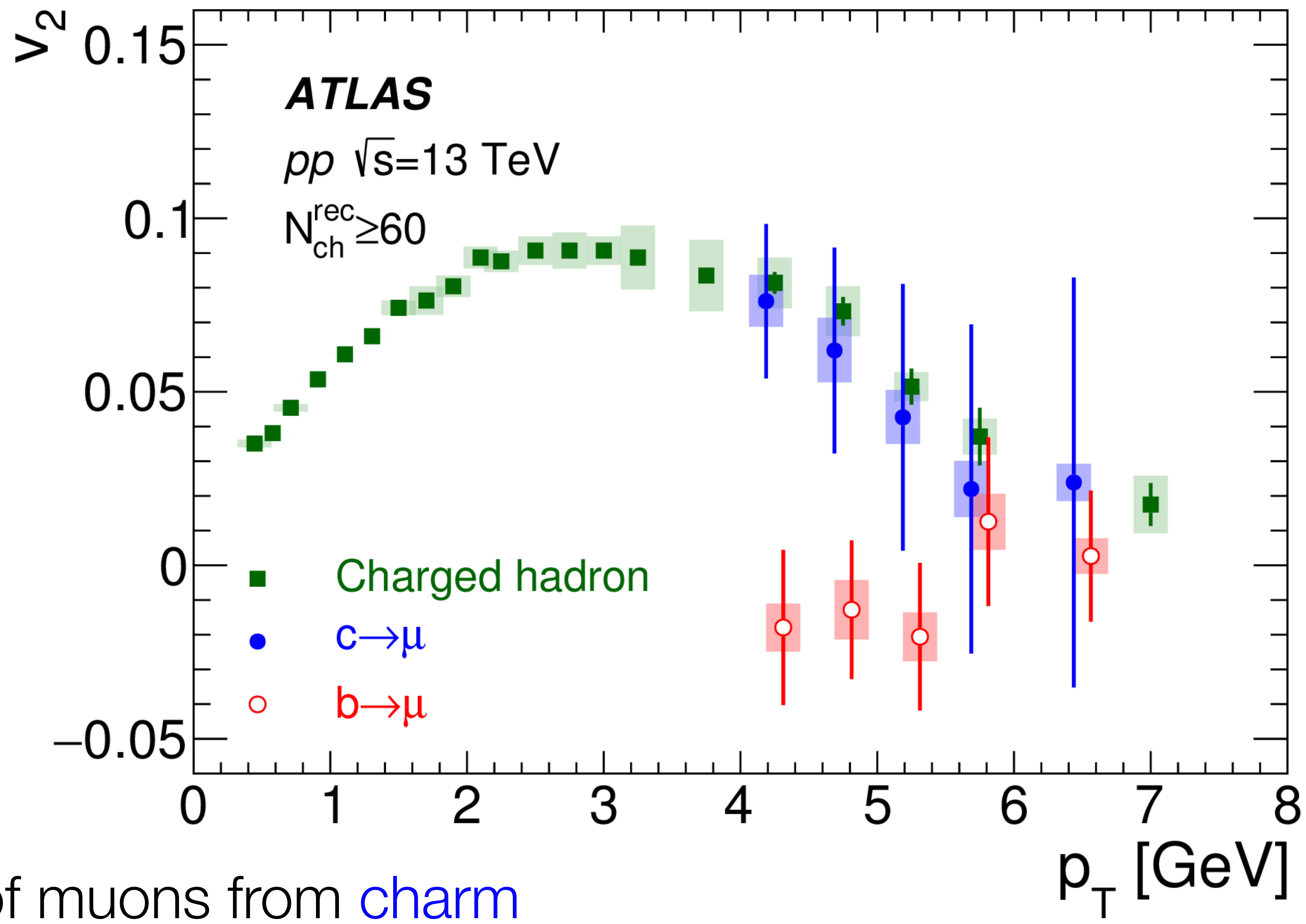


- ➡ Looking in the class of high multiplicity photo-nuclear collision
- ➡ Good separation from peripheral Pb+Pb due to the characteristic asymmetric topology

Observed significant v_2, but smaller than p+Pb and pp

Heavy flavour flow in pp

Phys. Rev. Lett. 124 (2020) 082301

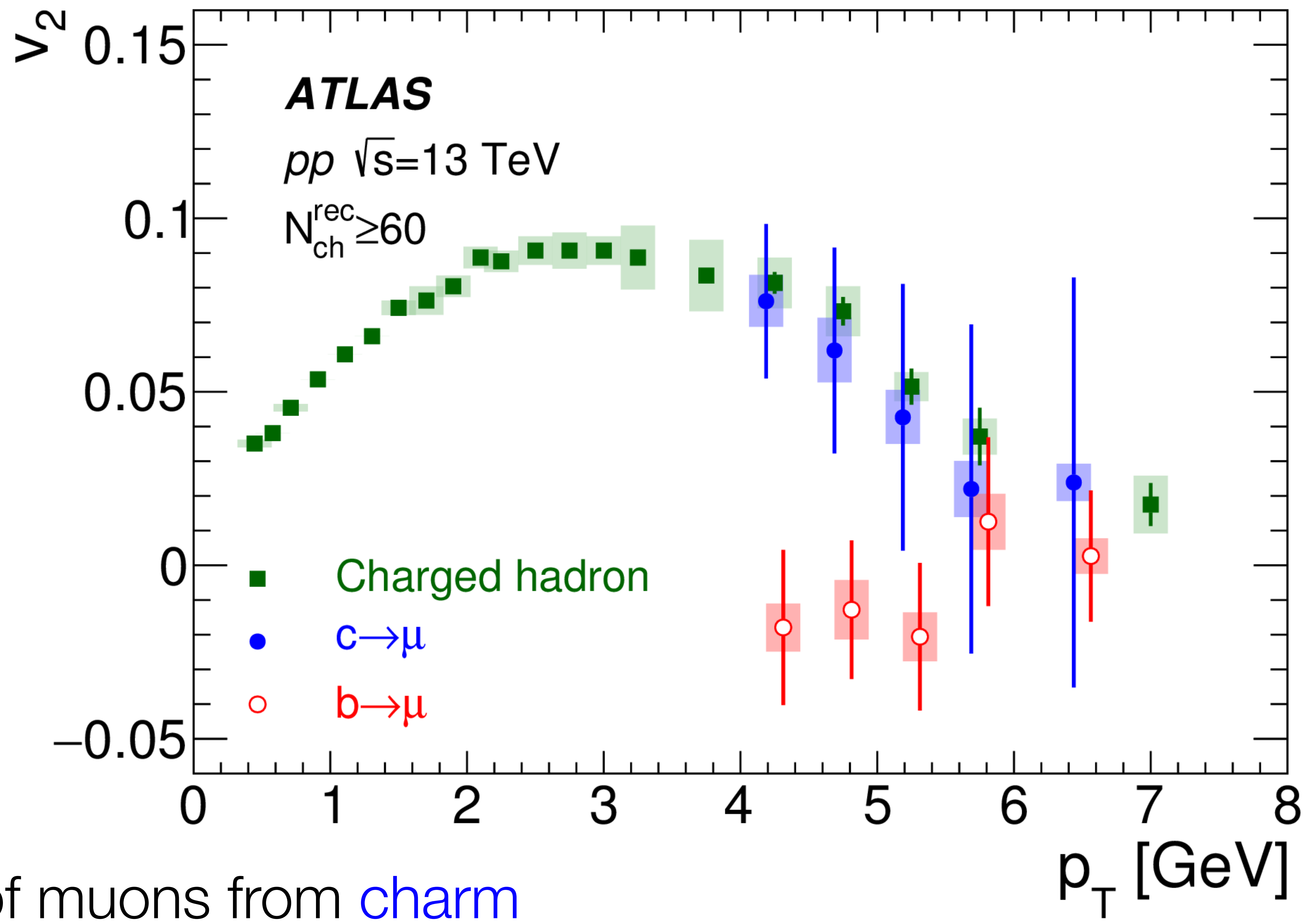


v_2 of muons from charm decays consistent with light hadrons flow

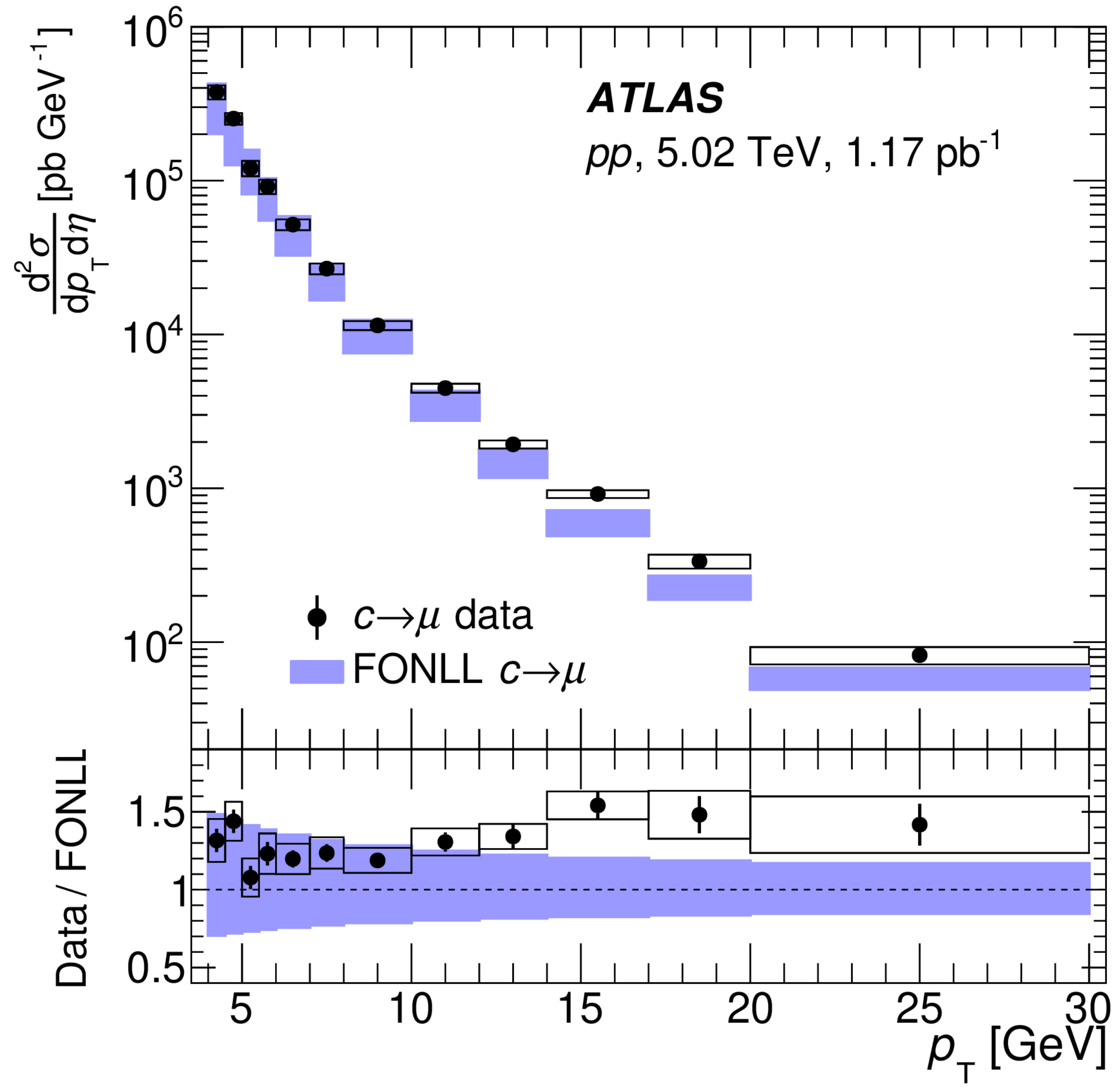
v_2 of muons from beauty decays consistent with 0

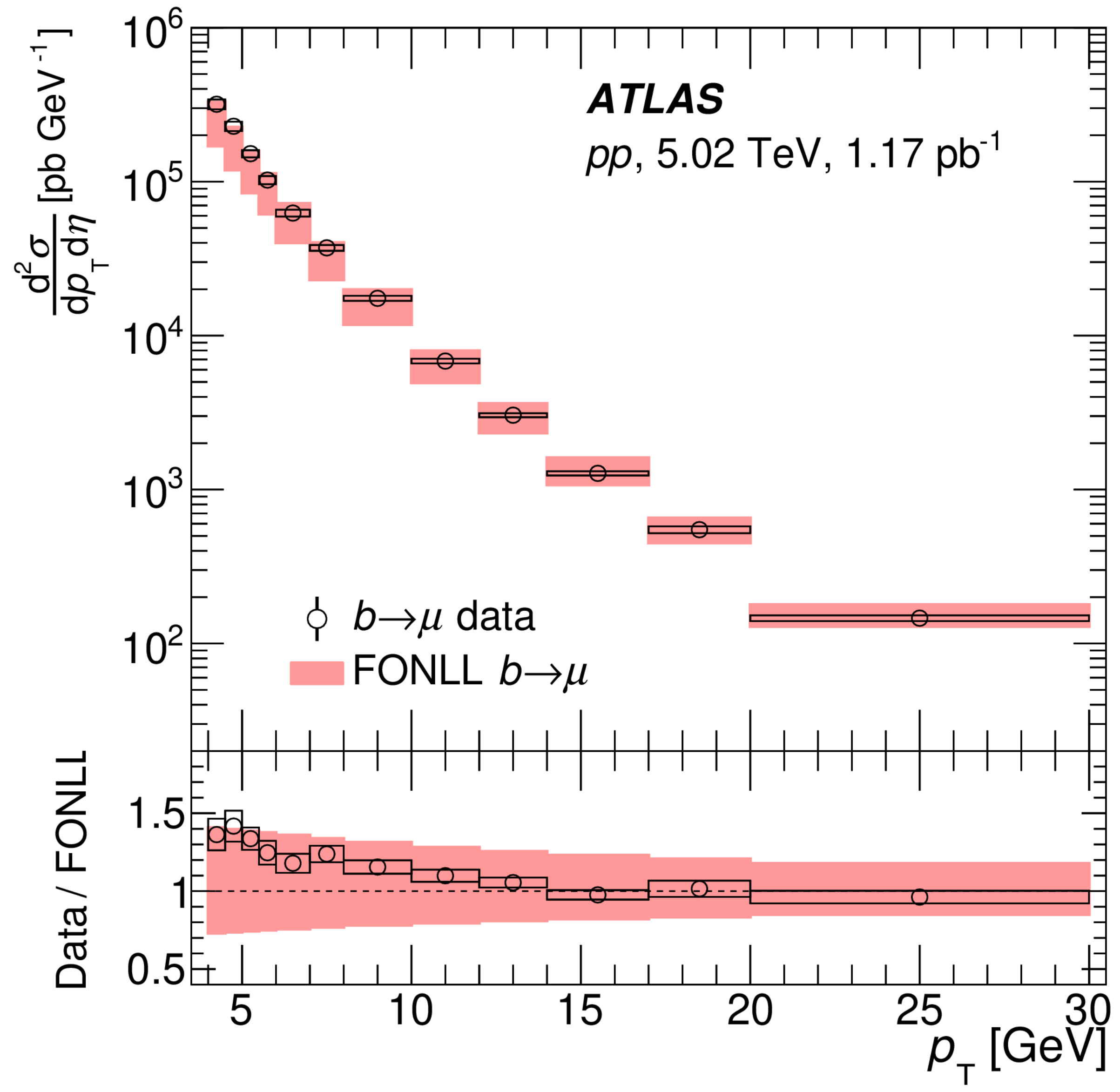
Heavy flavour flow in pp

[Phys. Rev. Lett. 124 (2020) 082301]



[arXiv:2109.00411]





v_2 of muons from charm decays consistent with light hadrons flow

v_2 of muons from beauty decays consistent with 0

Minimal if any modification to yield of muons from charm decays in pp

Summary

Lots of results based on the Run2 data

- ➡ Full list of ATLAS heavy ion results

Good prospects for the future:

Run	Year	Systems, $\sqrt{s_{NN}}$	Time	L_{int}
Run 3	2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
		pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
	2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
		O–O, p–O	1 week	500 μb^{-1} and 200 μb^{-1}
	2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
		pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
Run 4	2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
		pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
	2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
		pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
	2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
	Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
		pp reference	1 week	

From HL/HE-LHC Physics Workshop Working Group 5 report

Run 1 L_{int} 0.17 nb-1
Run 2 L_{int} 2.2 nb-1
Run 3 & 4 L_{int} ~ 13 nb-1 !!!

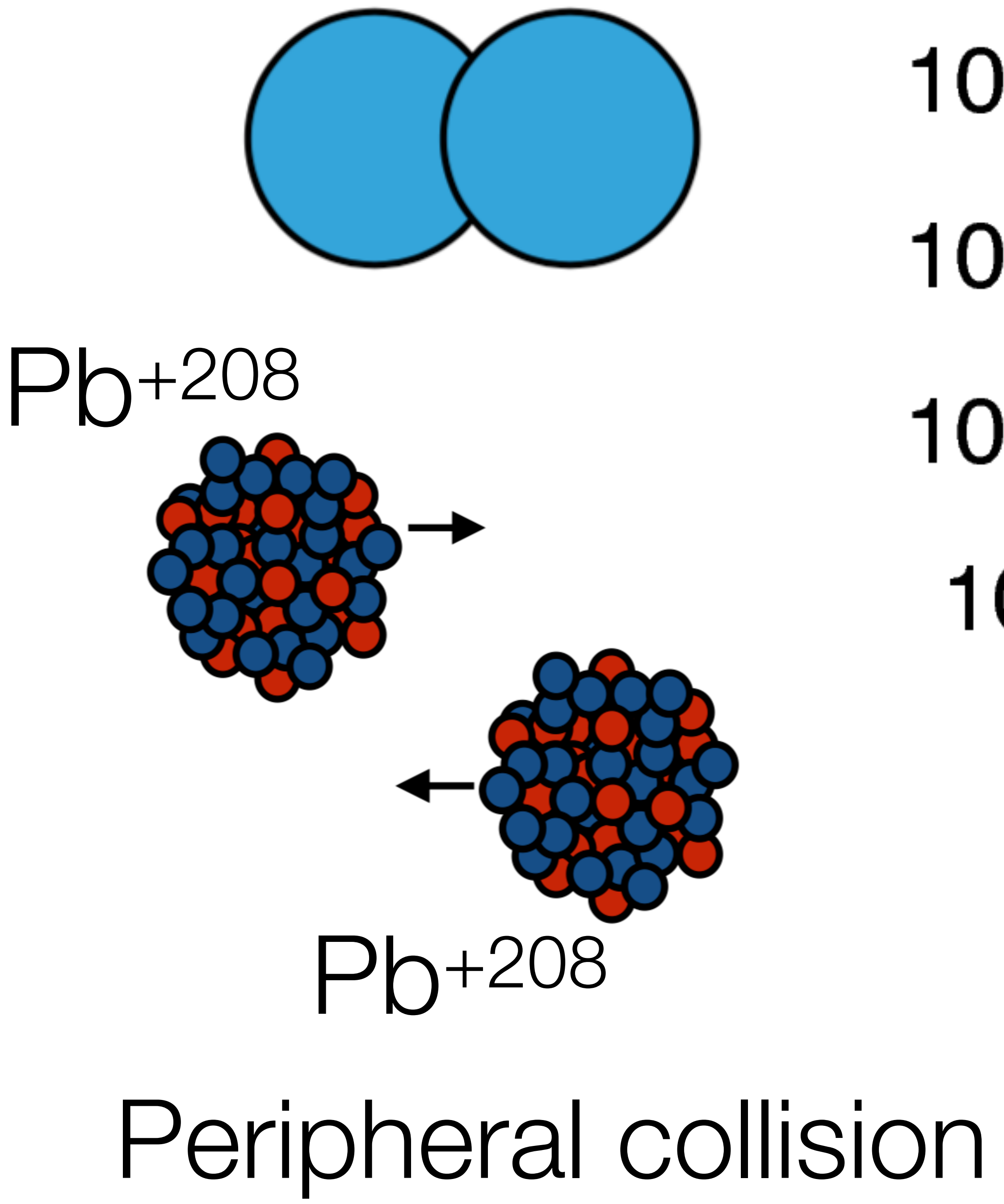
Possibility of using lighter ion species (test of O-O configuration in Run 3).

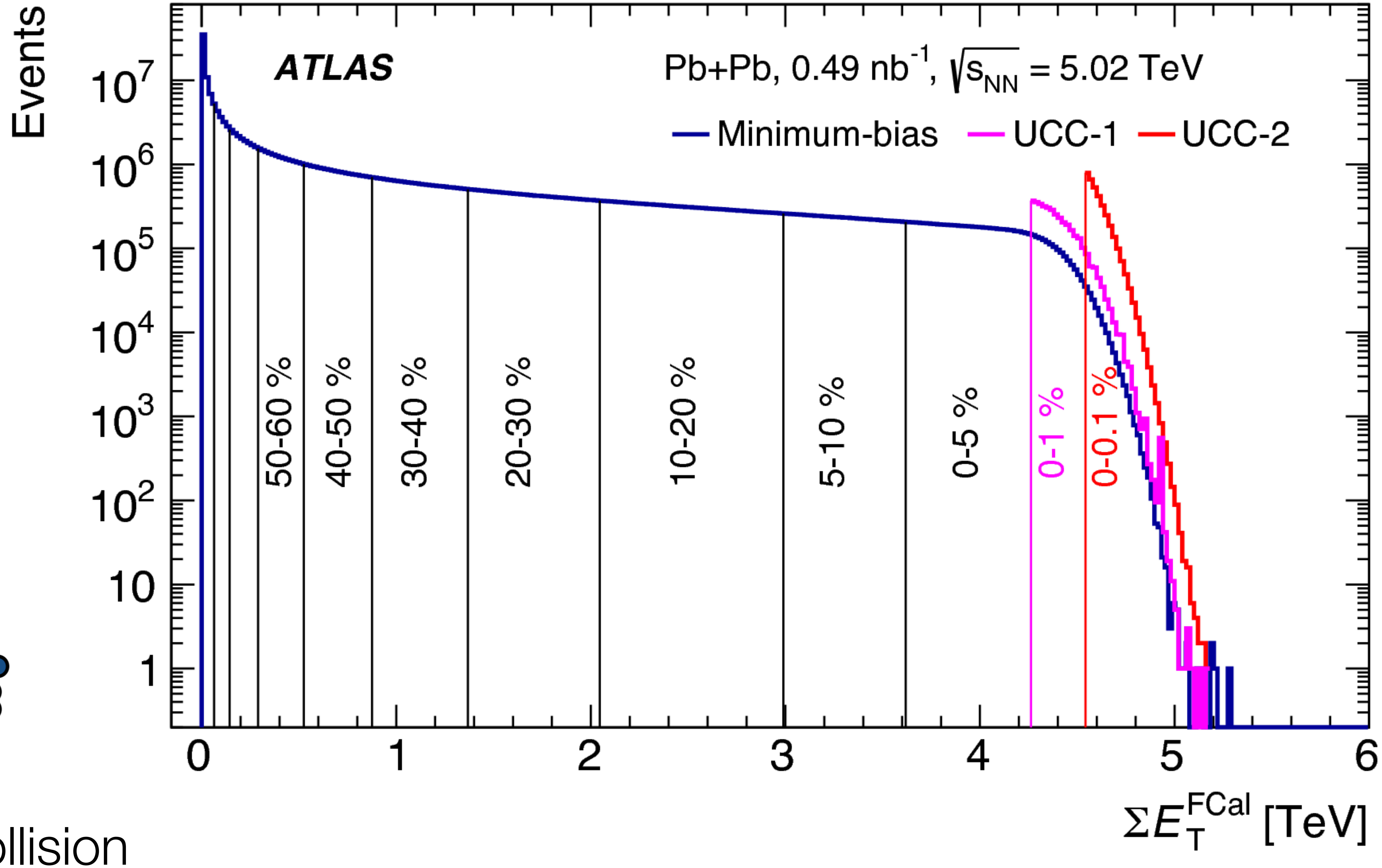
Nucleon nucleon luminosity equivalent to:
Pb-Pb @ L_{int} 75-250 nb^{-1}.

Backup

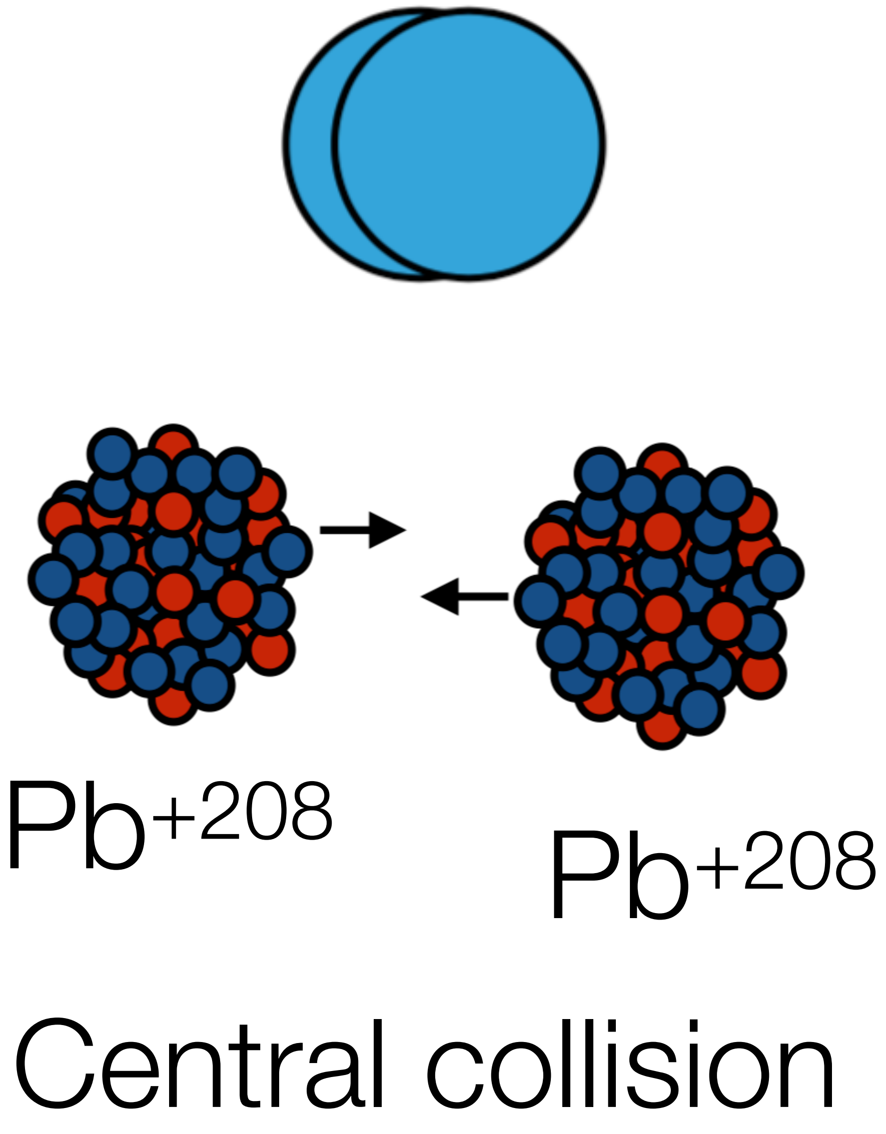
Centrality in Heavy Ion collisions

2015 Pb+Pb data





Negligible pile-up!



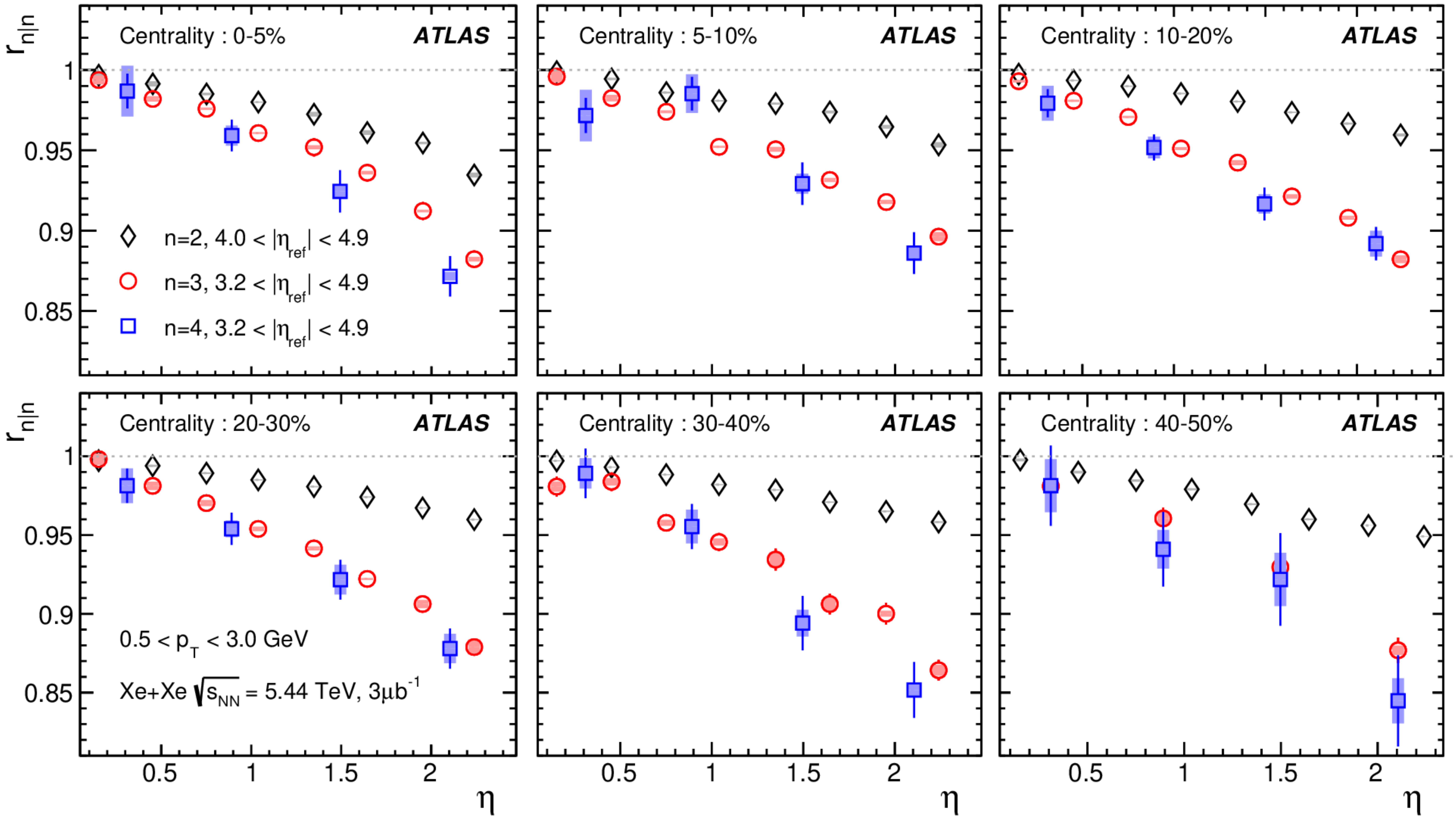
Centrality is parametrized using the energy deposited in the Forward calorimeter (|η|>3.2)

Centrality intervals and their corresponding geometric quantities

Centrality [%]	$\langle N_{part} \rangle$	$\langle T_{AA} \rangle$ [mb^{-1}]	Centrality [%]	$\langle N_{part} \rangle$	$\langle T_{AA} \rangle$ [mb^{-1}]
0–2%	399.0 ± 1.6	28.30 ± 0.25	20–25%	205.6 ± 2.9	9.77 ± 0.18
2–4%	380.2 ± 2.0	25.47 ± 0.21	25–30%	172.8 ± 2.8	7.50 ± 0.17
4–6%	358.9 ± 2.4	23.07 ± 0.21	30–40%	131.4 ± 2.6	4.95 ± 0.15
6–8%	338.1 ± 2.7	20.93 ± 0.20	40–50%	87.0 ± 2.4	2.63 ± 0.11
8–10%	317.8 ± 2.9	18.99 ± 0.19	50–60%	53.9 ± 2.0	1.28 ± 0.07
10–15%	285.2 ± 2.9	16.08 ± 0.18	60–80%	23.0 ± 1.3	0.39 ± 0.03
15–20%	242.9 ± 2.9	12.59 ± 0.17	80–100%	4.80 ± 0.36	0.052 ± 0.006
			0–100%	114.0 ± 1.1	5.61 ± 0.06

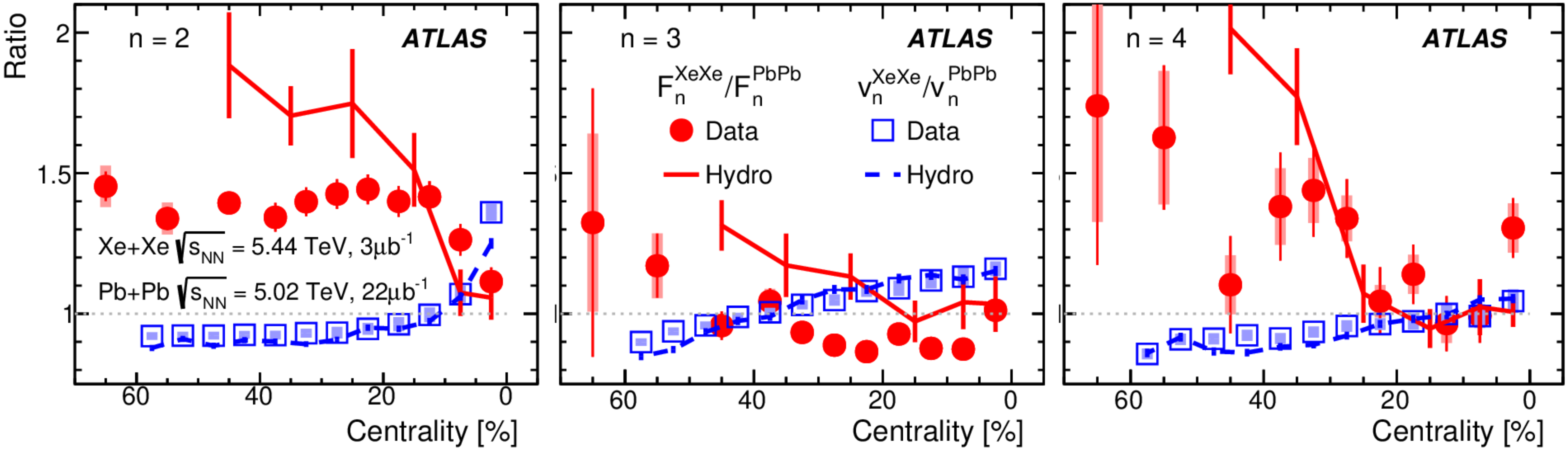
Flow decorrelation

[Phys. Rev. Lett. 126 (2021) 12230]



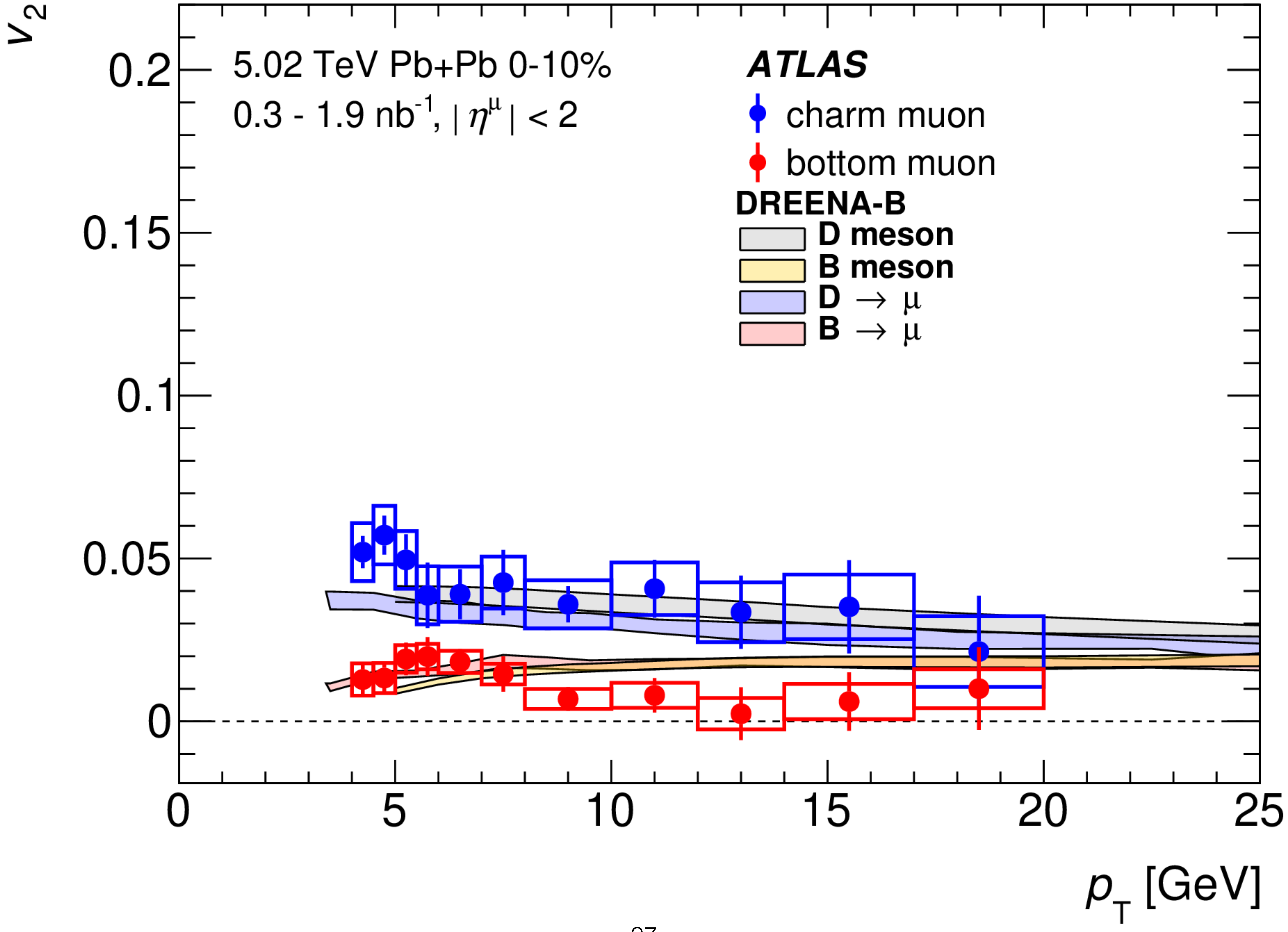
Flow decorrelation and flow harmonics ratios all harmonics

[Phys. Rev. Lett. 126 (2021) 12230]



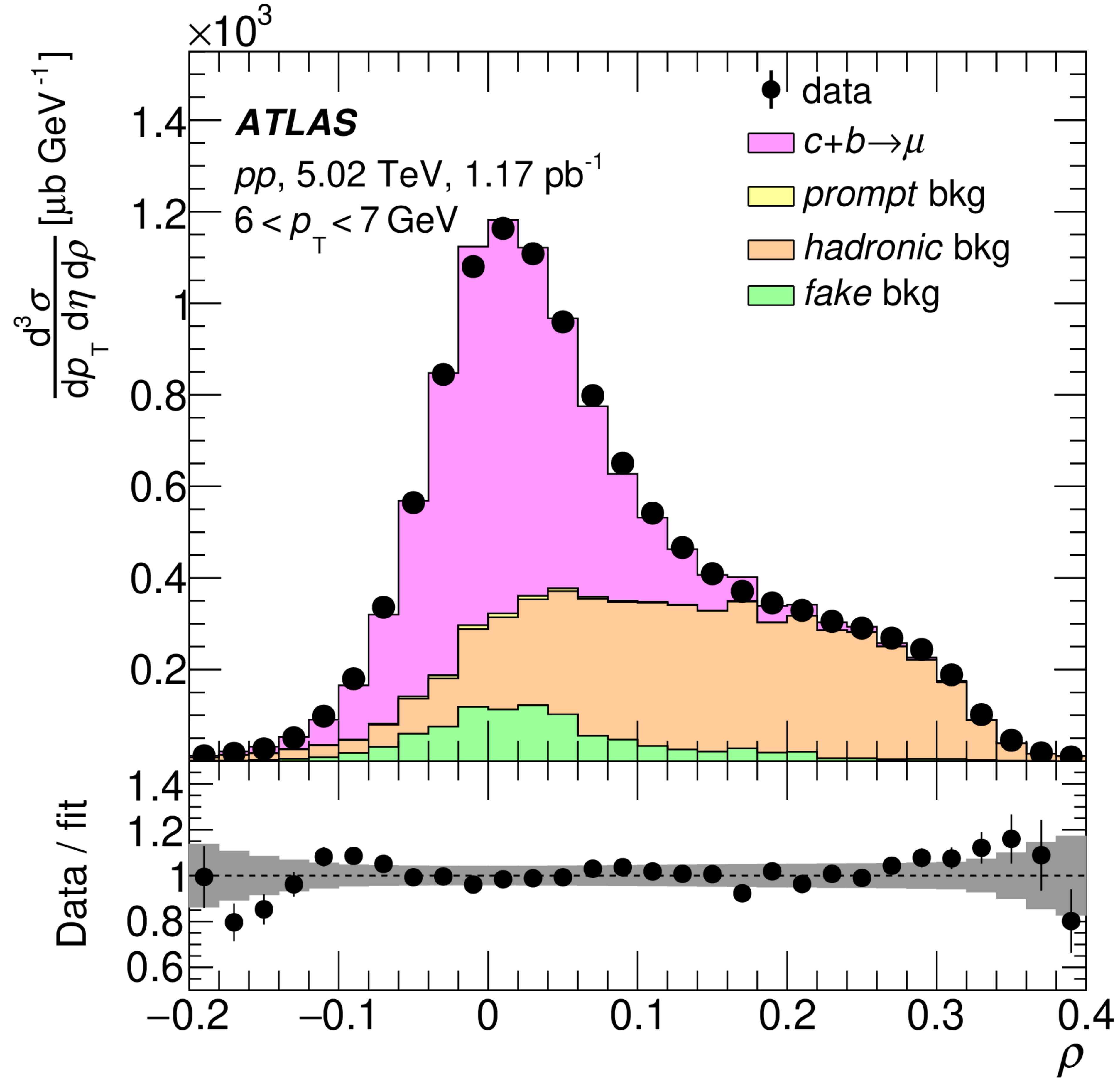
Heavy flavor muon versus heavy flavor meson flow

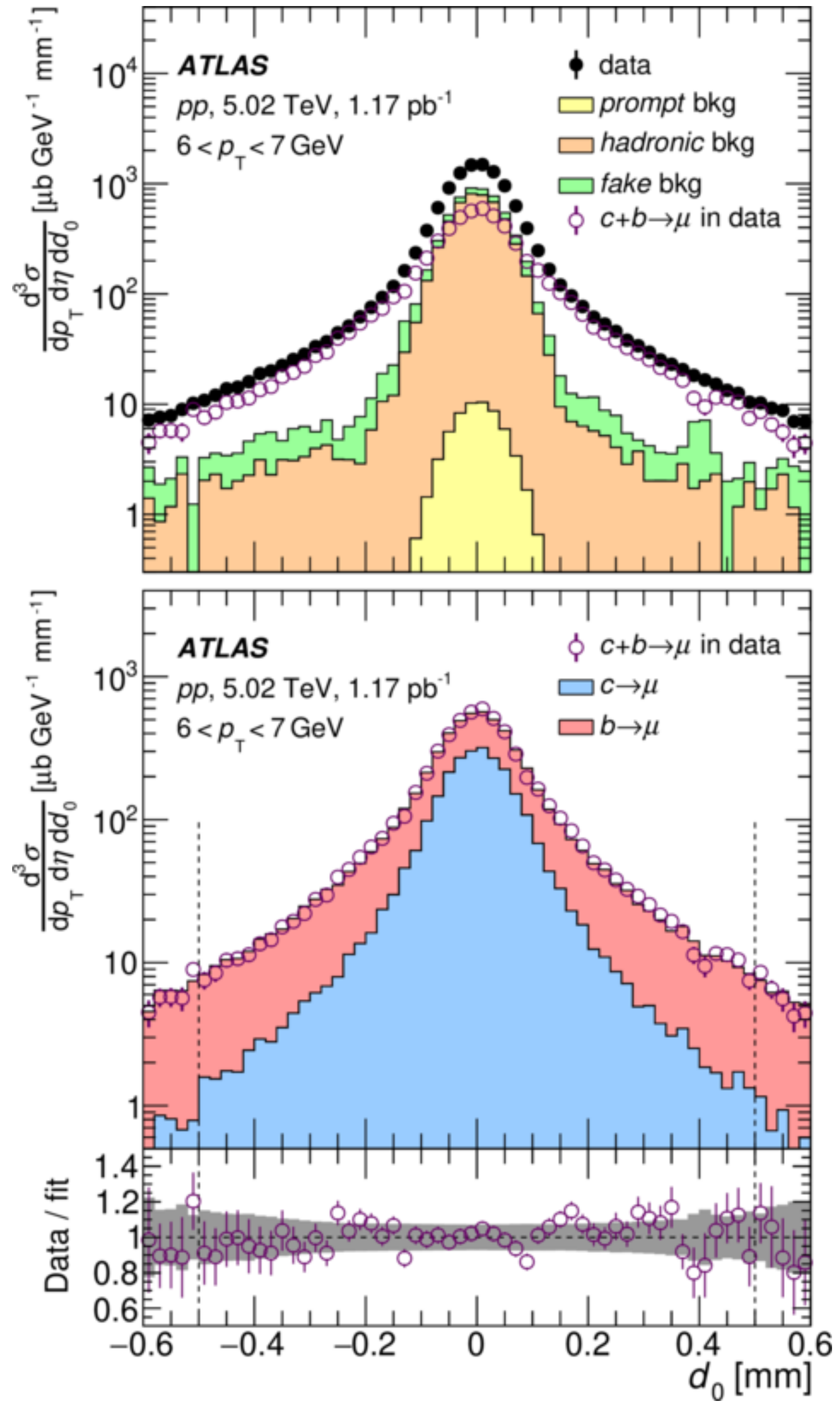
arXiv:2003.03565



Muons from heavy flavour decay

[Phys. Rev. Lett. 124 (2020) 082301](https://doi.org/10.1103/PhysRevLett.124.082301)





Events with and without track jet of certain threshold in pp

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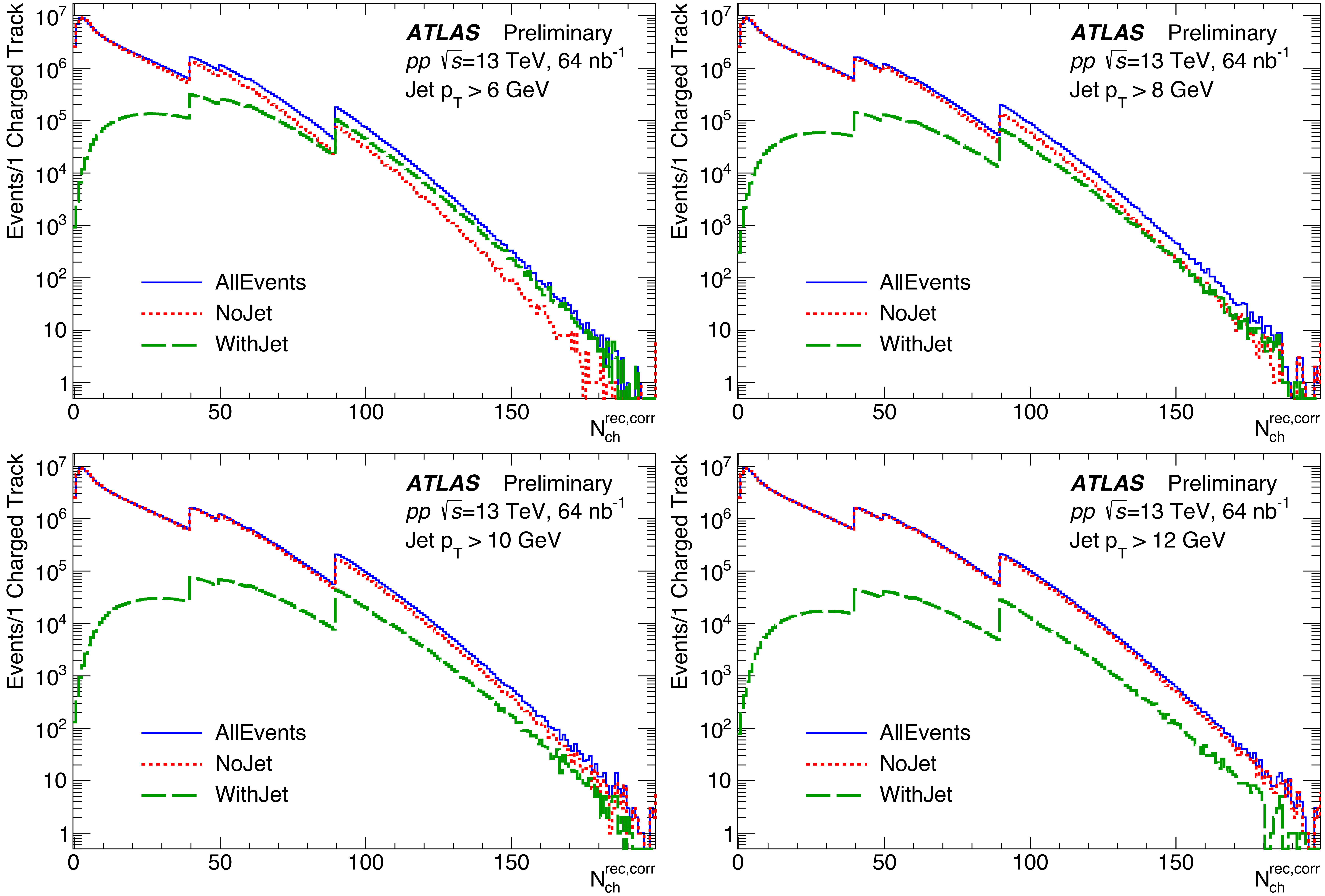

Flow in pp with jet particle rejection - p_T dependence

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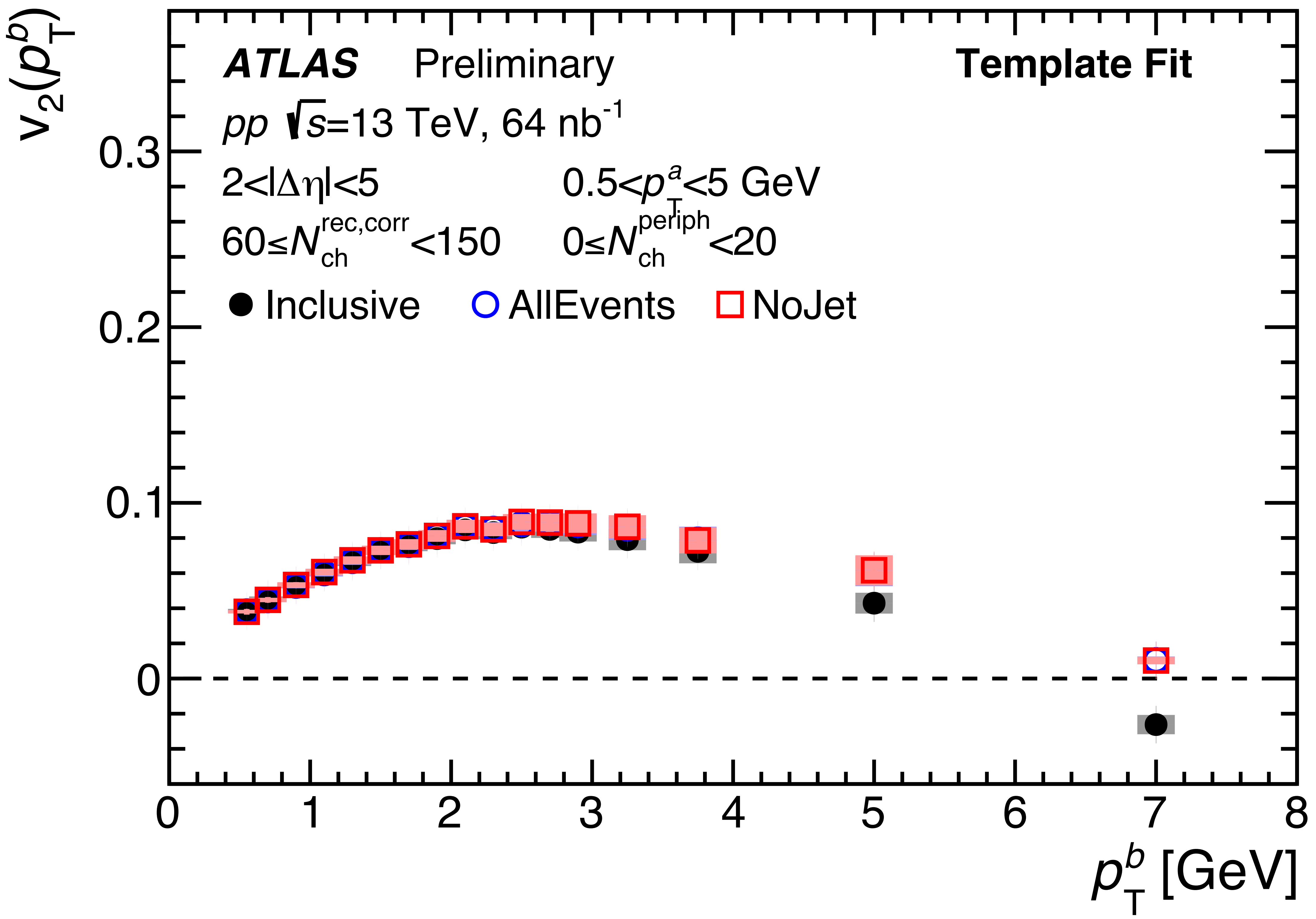

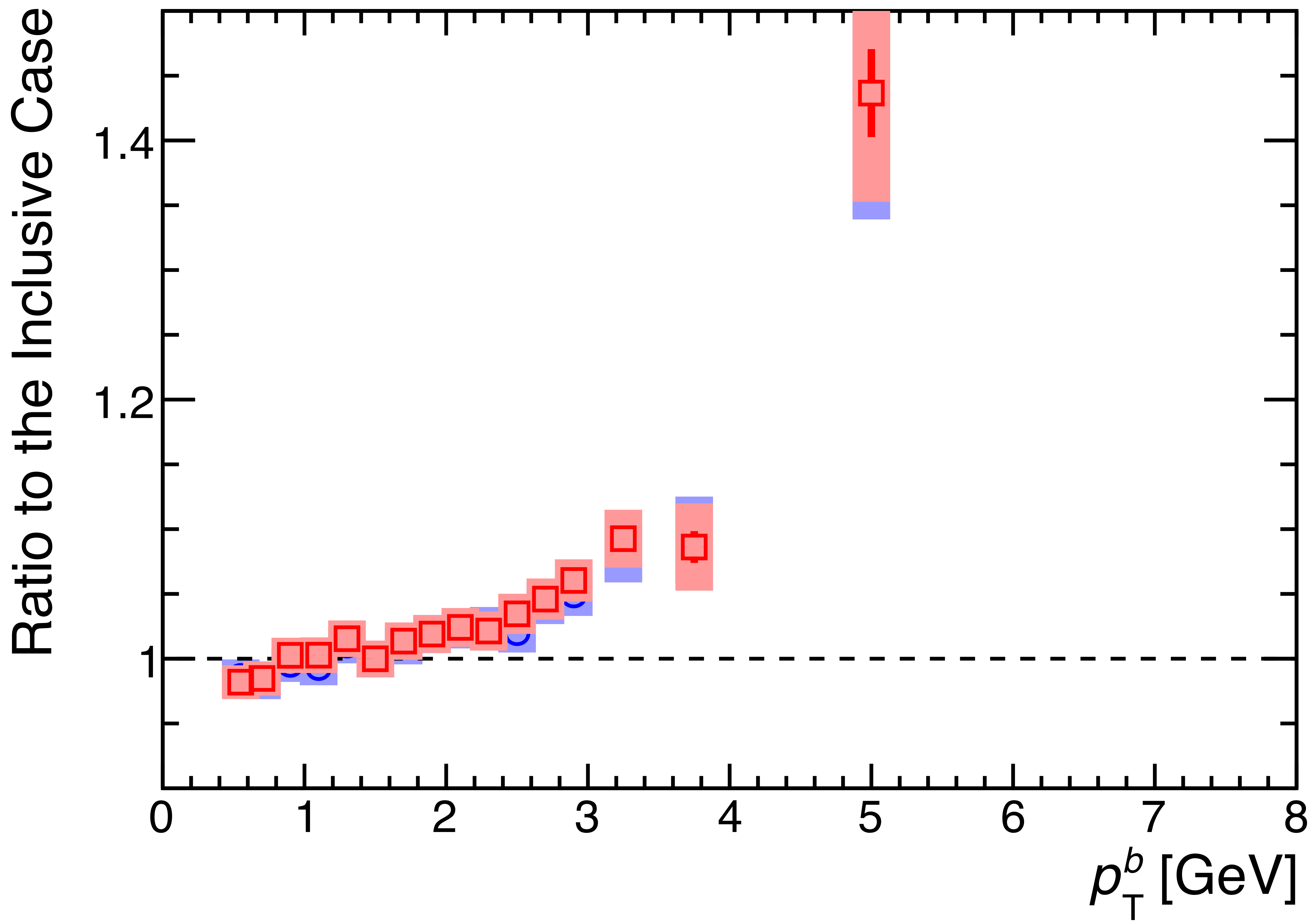

Flow in pp with jet particle rejection - jet threshold

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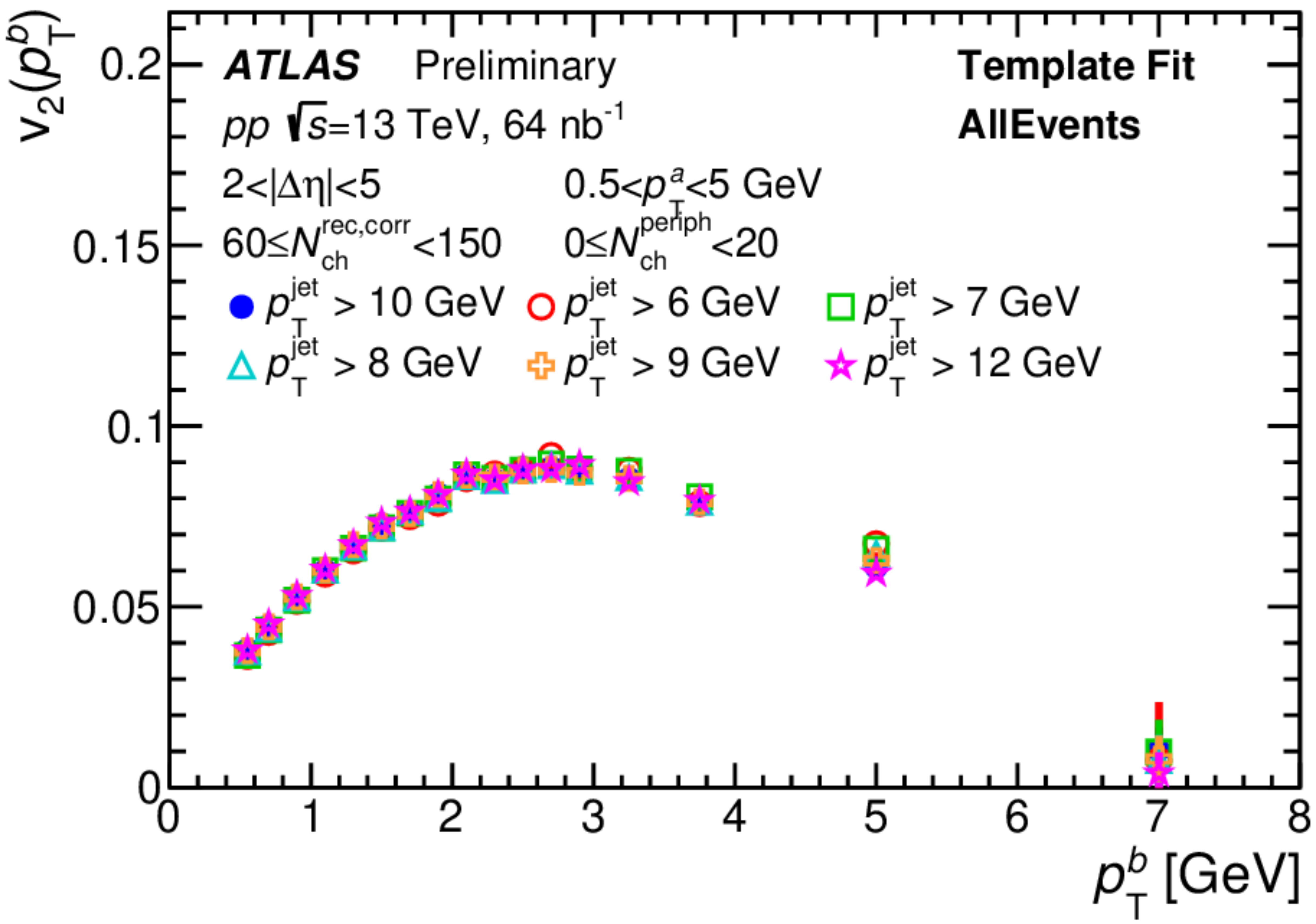
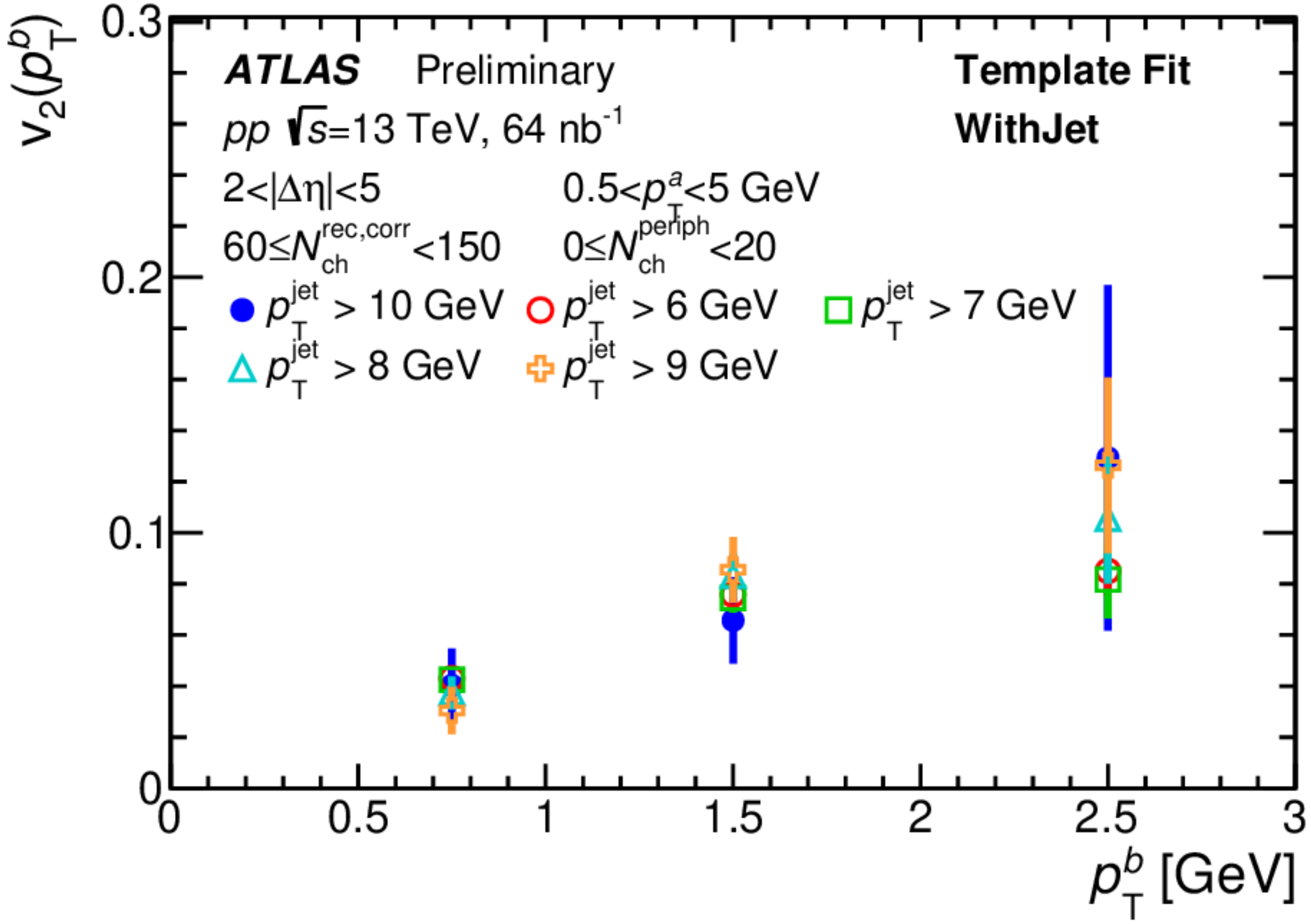
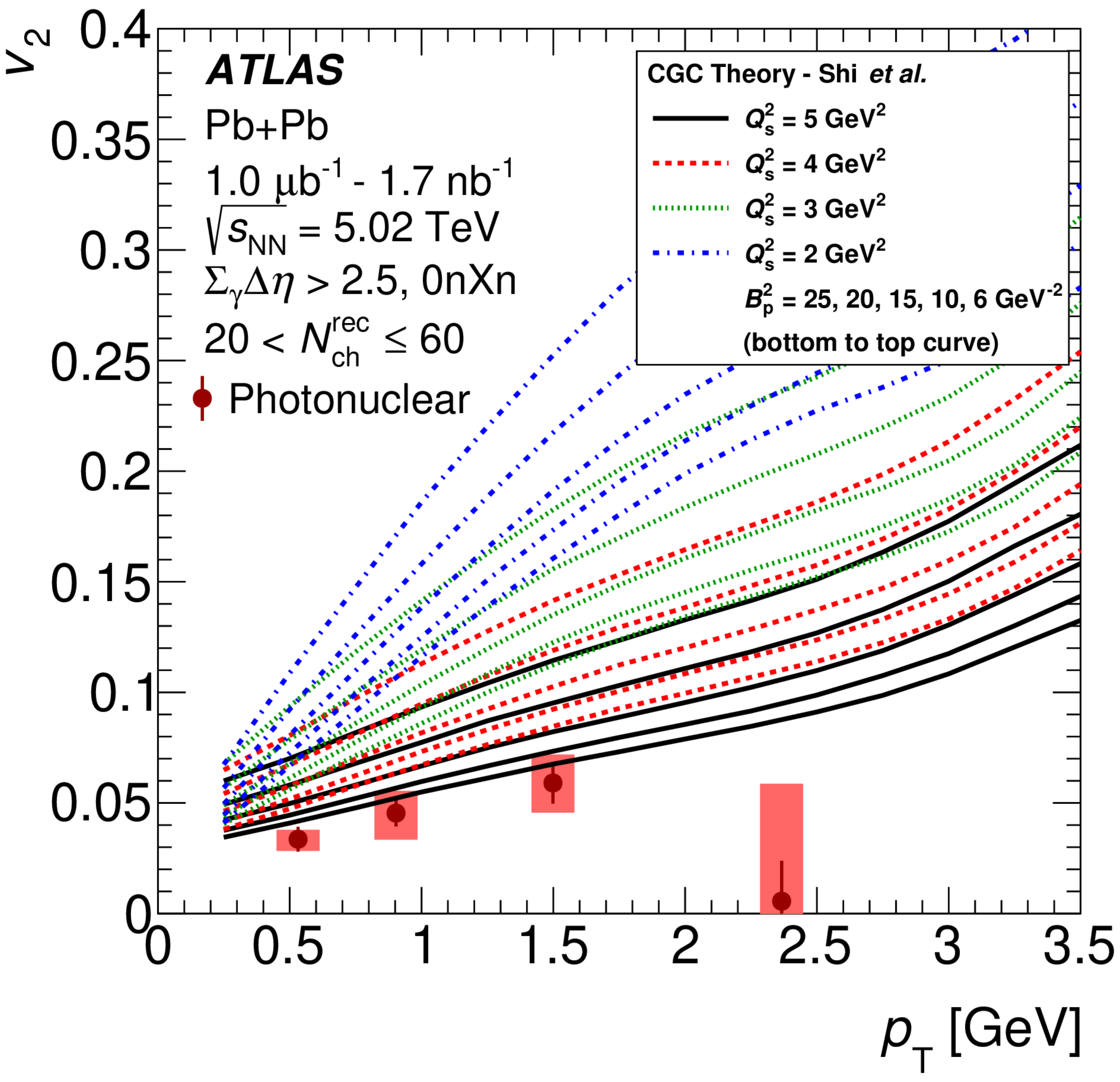




Flow in UPC - details of the CGC calculations

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-27/

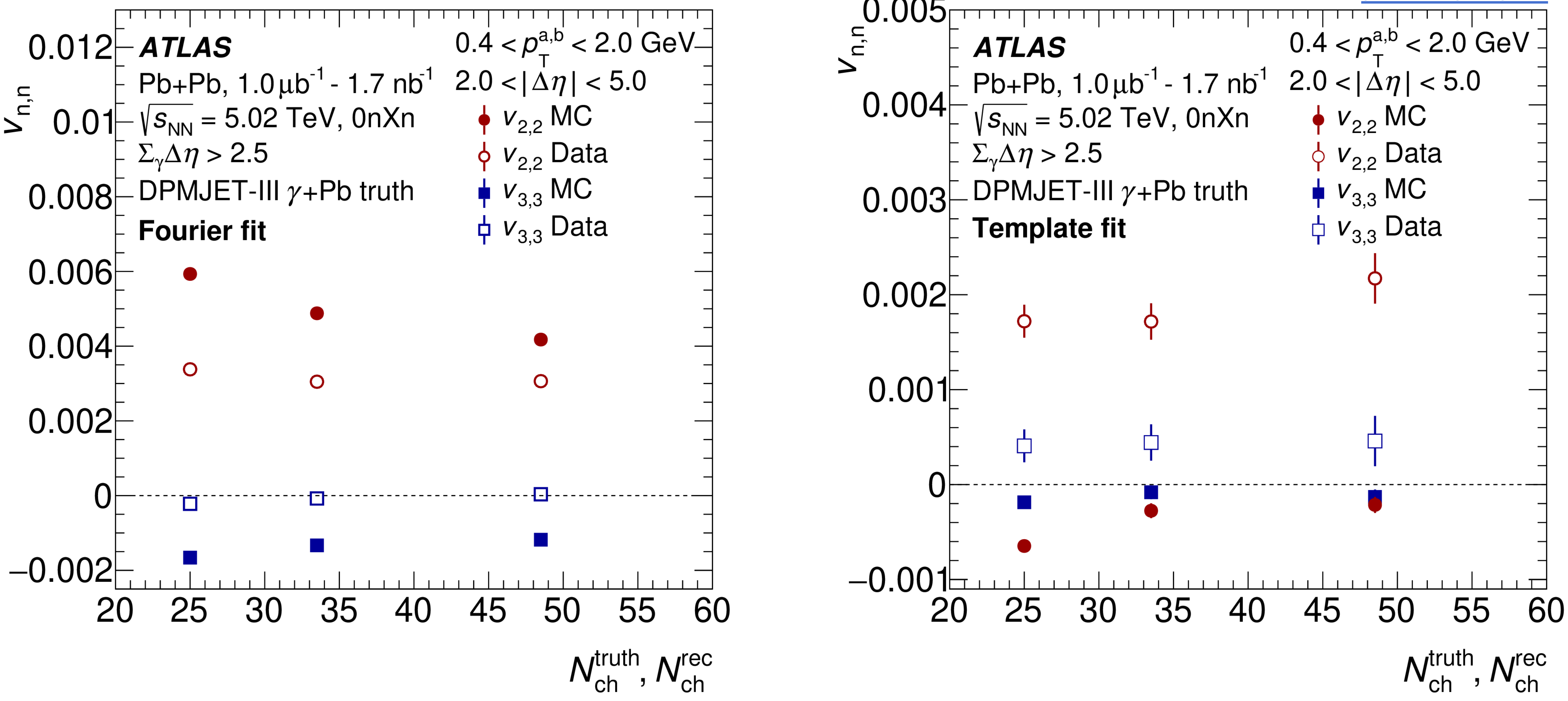


Q_s^2 - saturation scale
B_p^2 - controls the transverse area of the interaction

Flow in UPC - pure photonuclear MC

Without (left) and with (right) non-flow subtraction

arXiv:2101.10771



ATLAS detector

Tracker $|\eta| < 2.5$

Calorimeters $|\eta| < 4.9$

➡ And forward detectors located far far away from the interaction point ZDC (140m), AFP & ALFA (~240m)