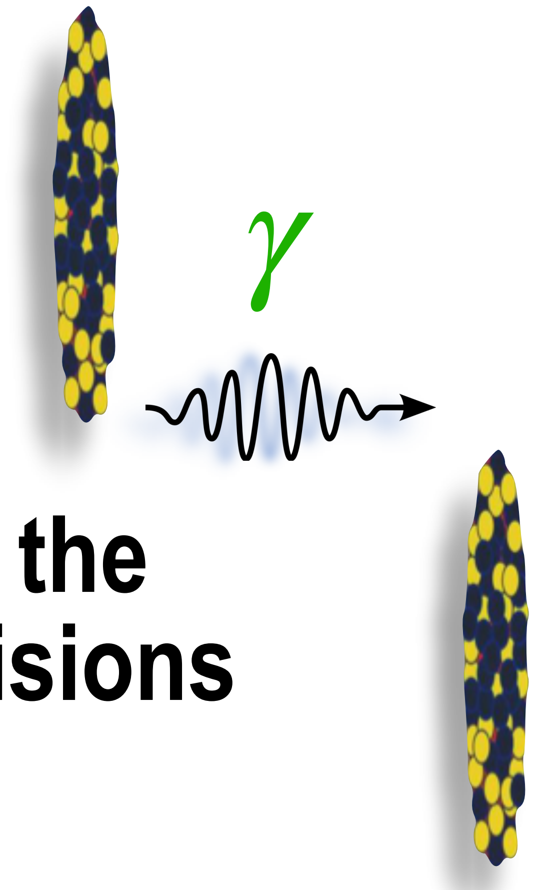
Measurements of the properties of photonuclear events in UPC with the ATLAS detector

ATLAS-CONF-2023-059



UPC 2023

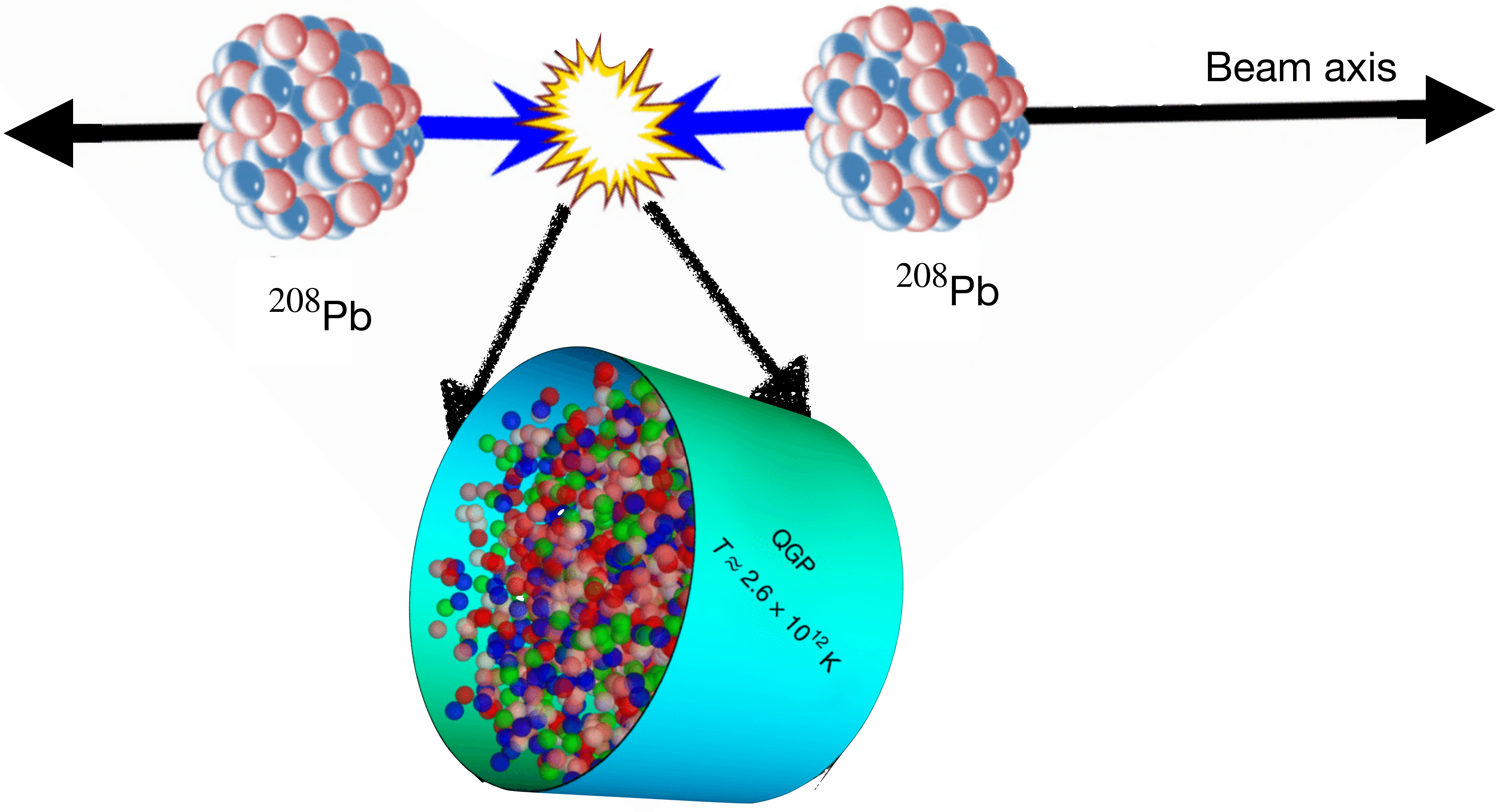
First international workshop on the physics of Ultra Peripheral Collisions

Sruthy Jyothi Das (University of Colorado Boulder)
for the ATLAS Collaboration

Playa del Carmen, Mexico | Dec 11-15, 2023

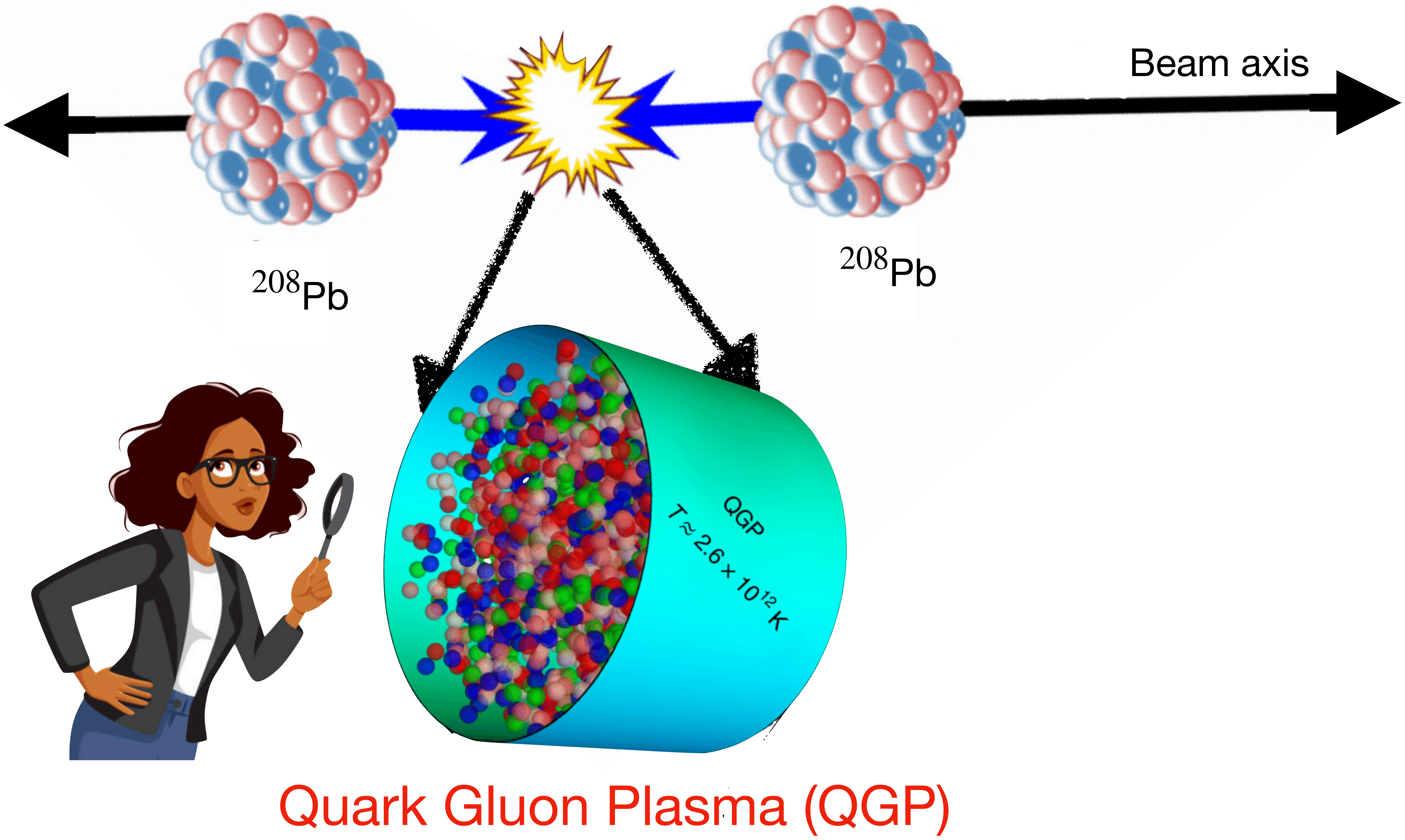
ATLAS EXPERIMENT

Overview



Quark Gluon Plasma (QGP)

Overview



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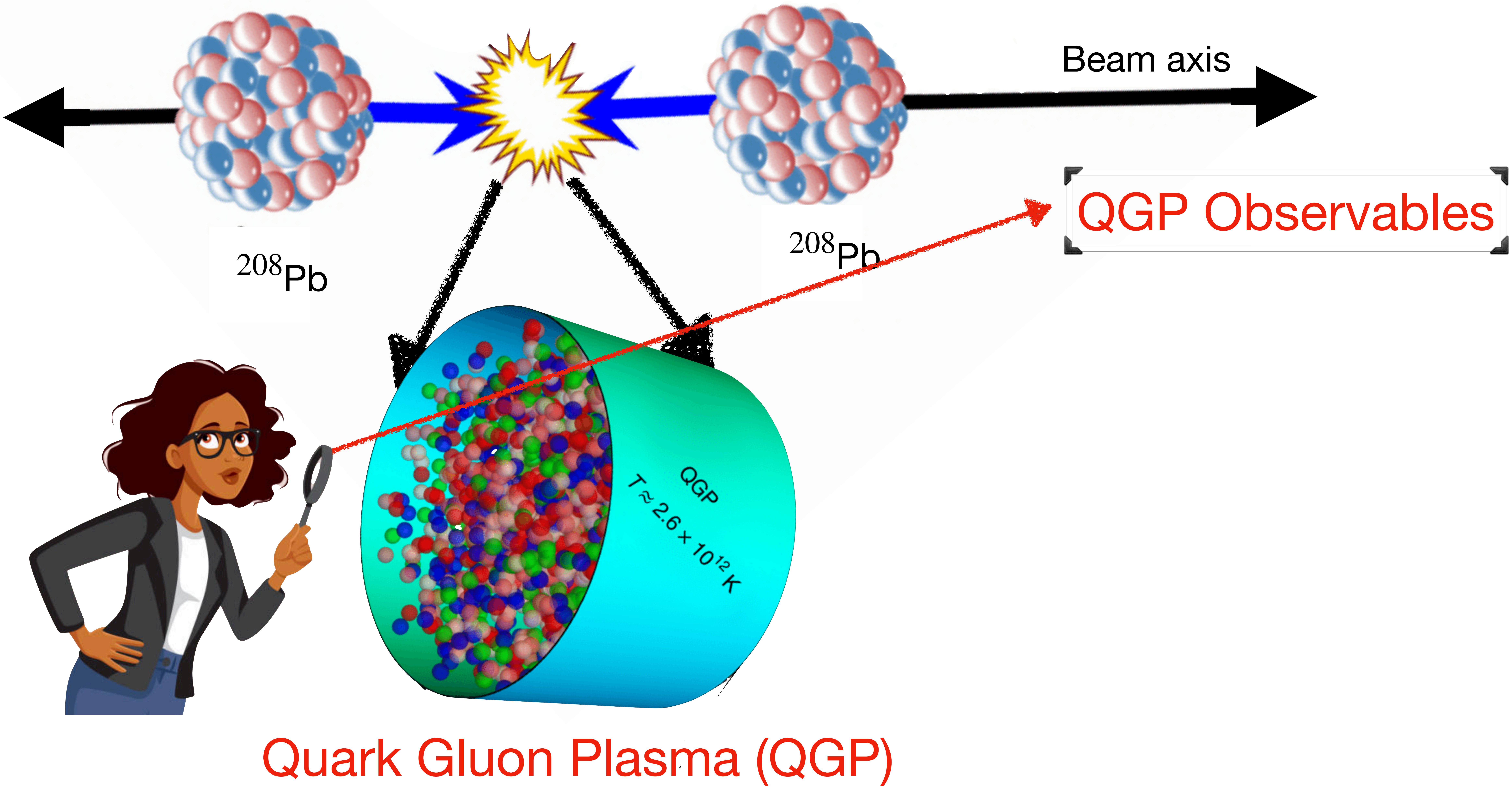
Beam axis
^{208}Pb
^{208}Pb
QGP Observables
QGP
$T \approx 2.6 \times 10^{12}$ K
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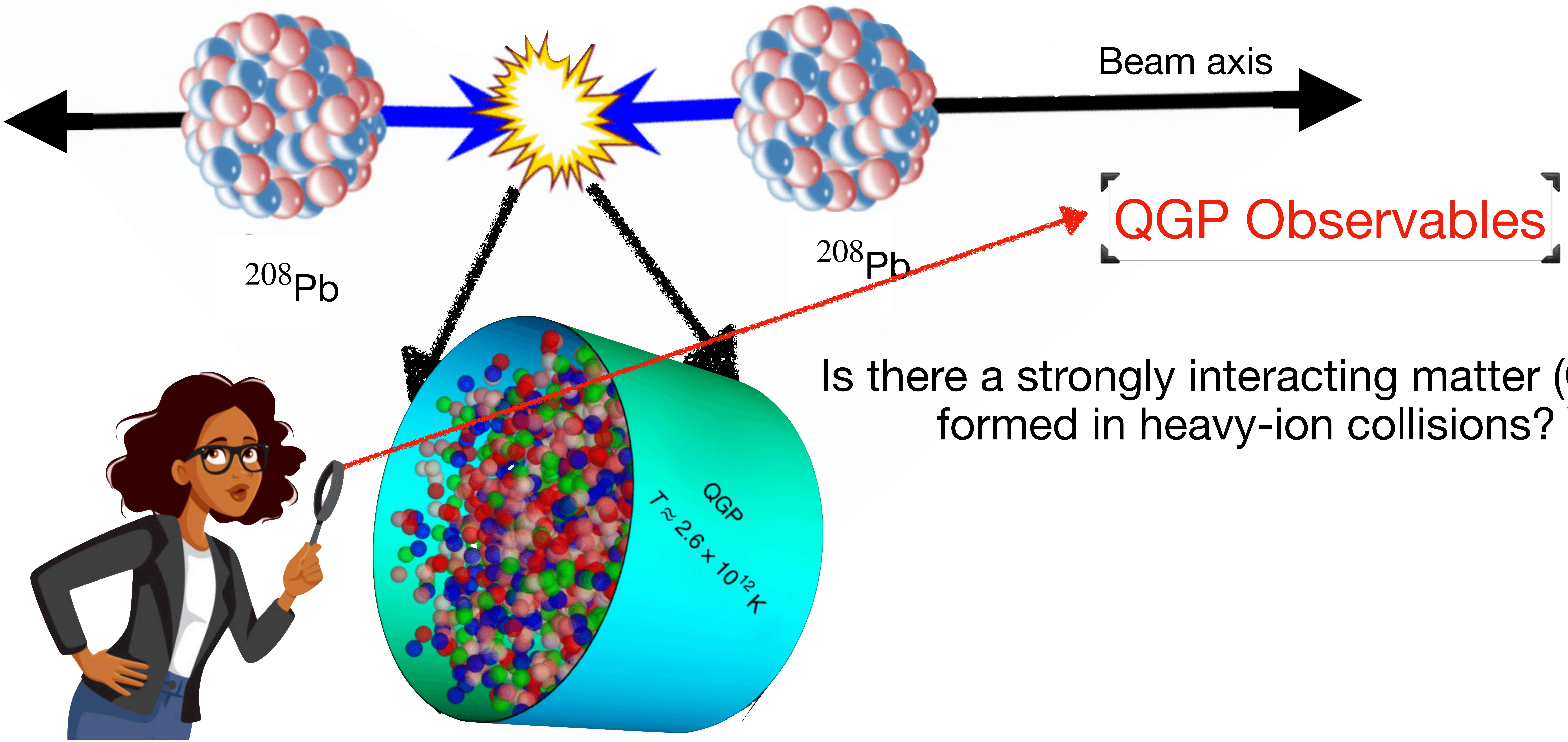

Is there a strongly interacting matter (QGP) formed in heavy-ion collisions? Yes!

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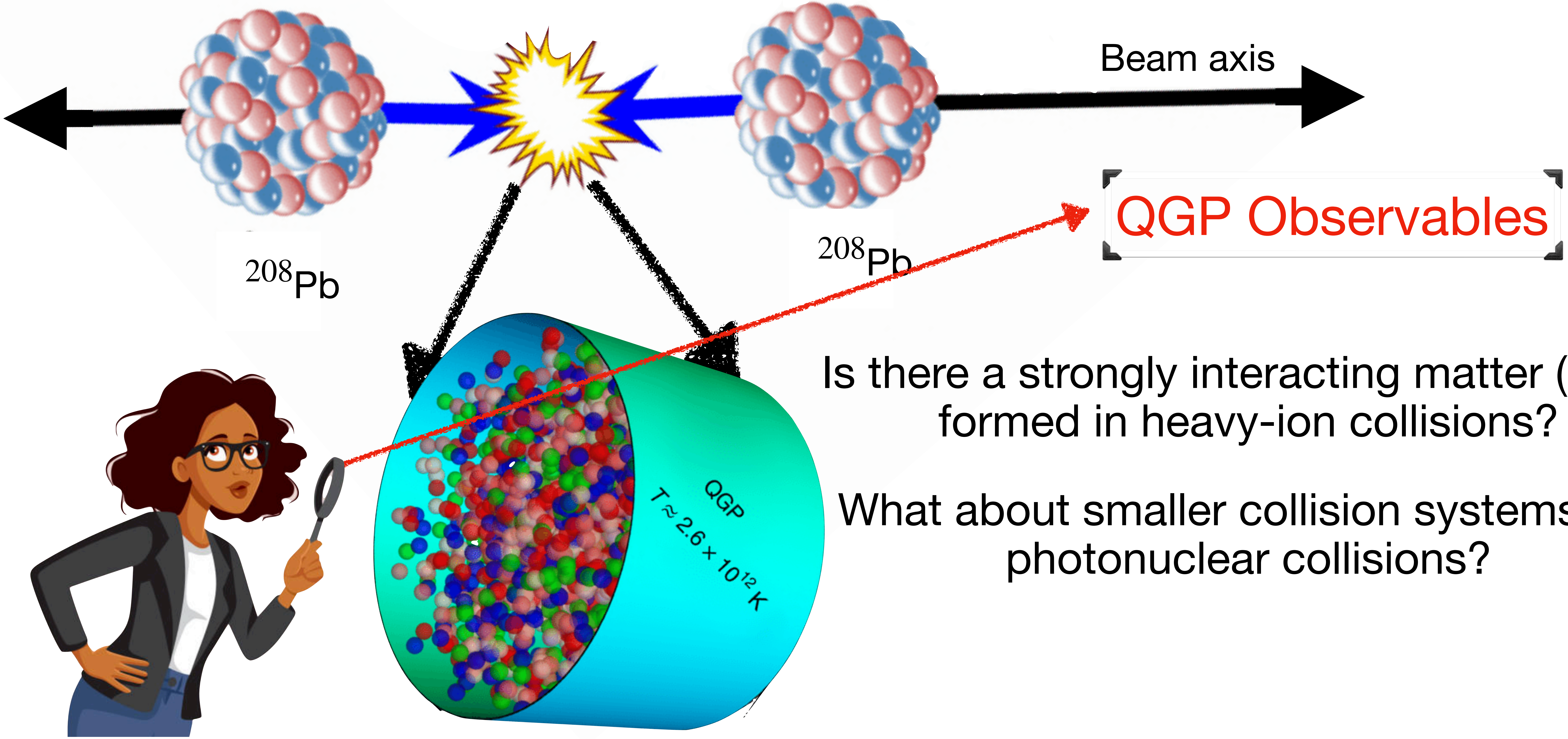

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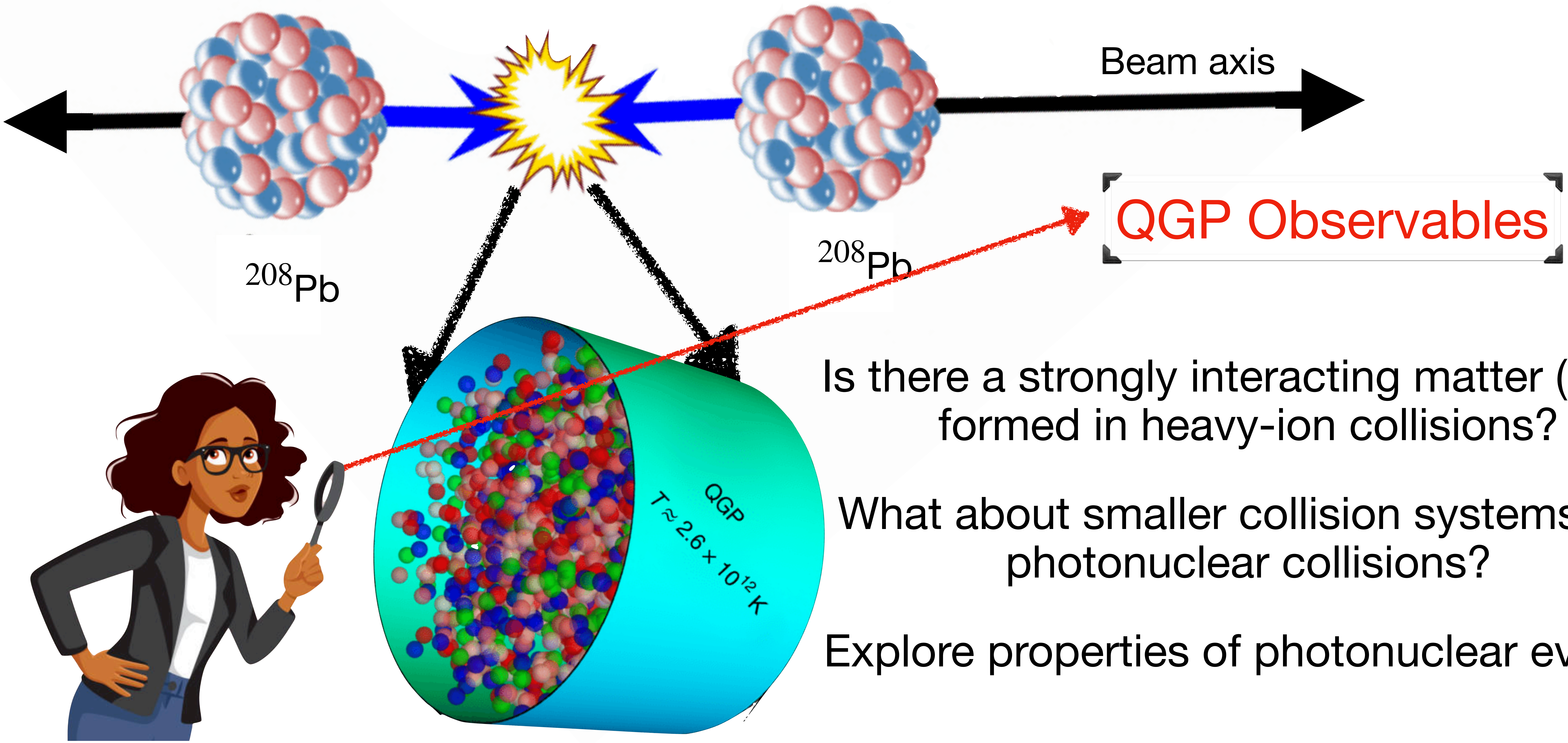

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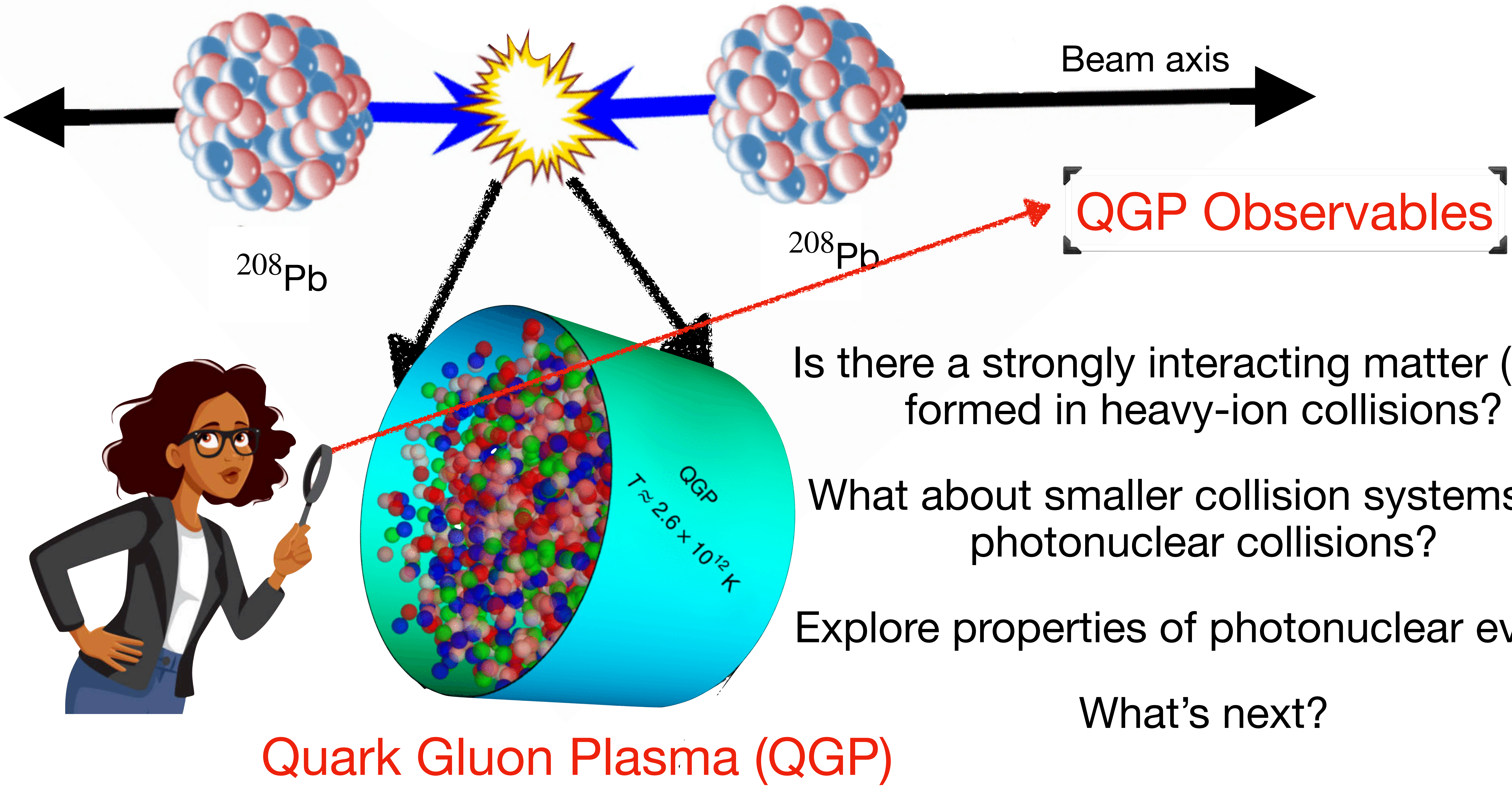

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What's next?

Quark-Gluon Plasma in Heavy-Ion collisions

Quark-Gluon Plasma (QGP) is the *state of matter formed in the early universe* where quarks and gluons are deconfined.

QGP is created by colliding large nuclei (eg: Pb+Pb *we call them "heavy-ions"*) at relativistic energies!

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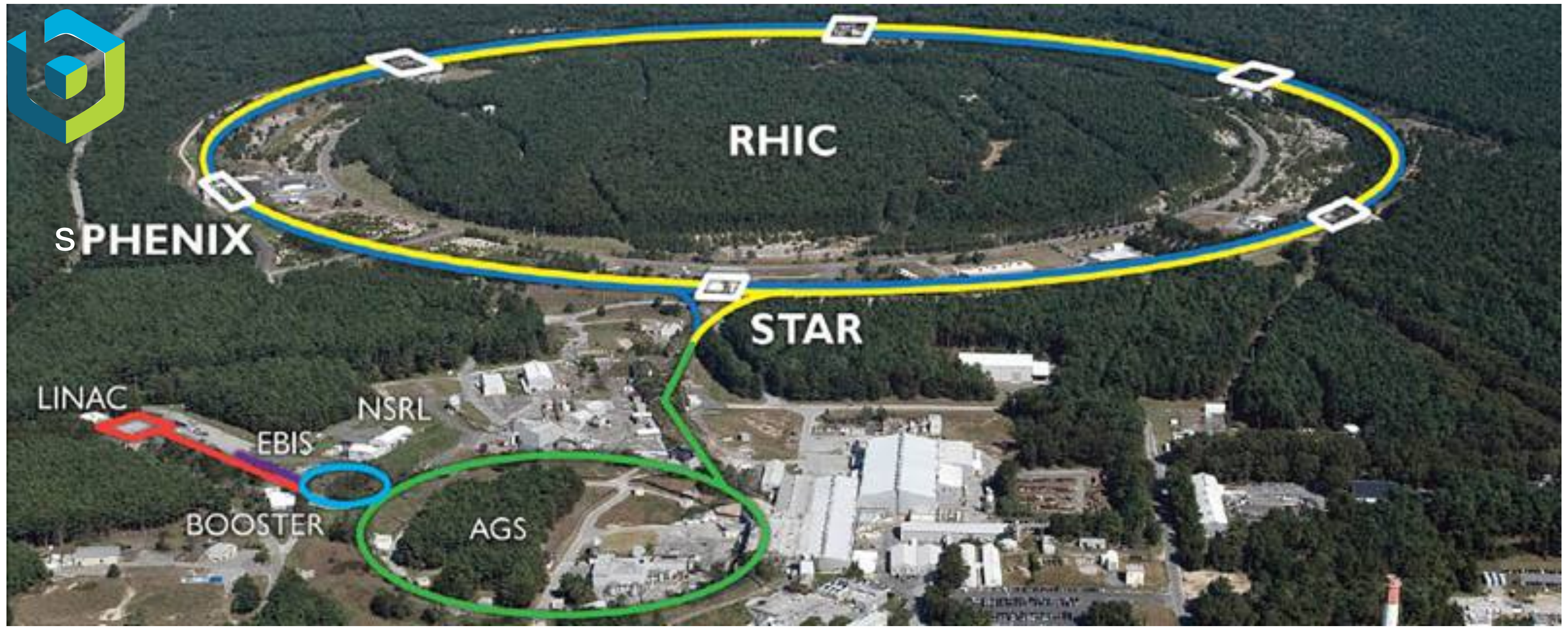
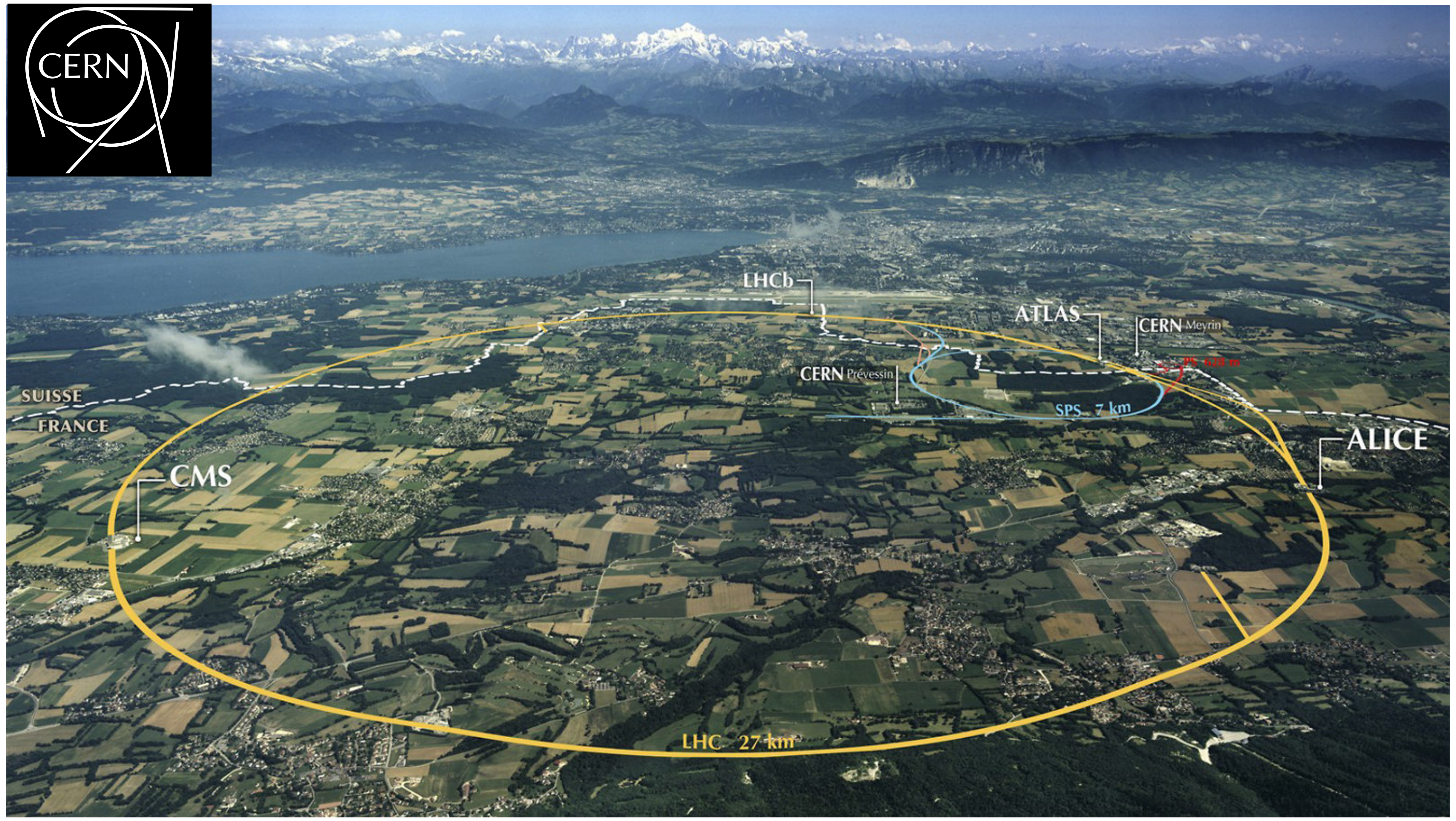


Relativistic Heavy Ion Collider (RHIC)



Large Hadron Collider (LHC)

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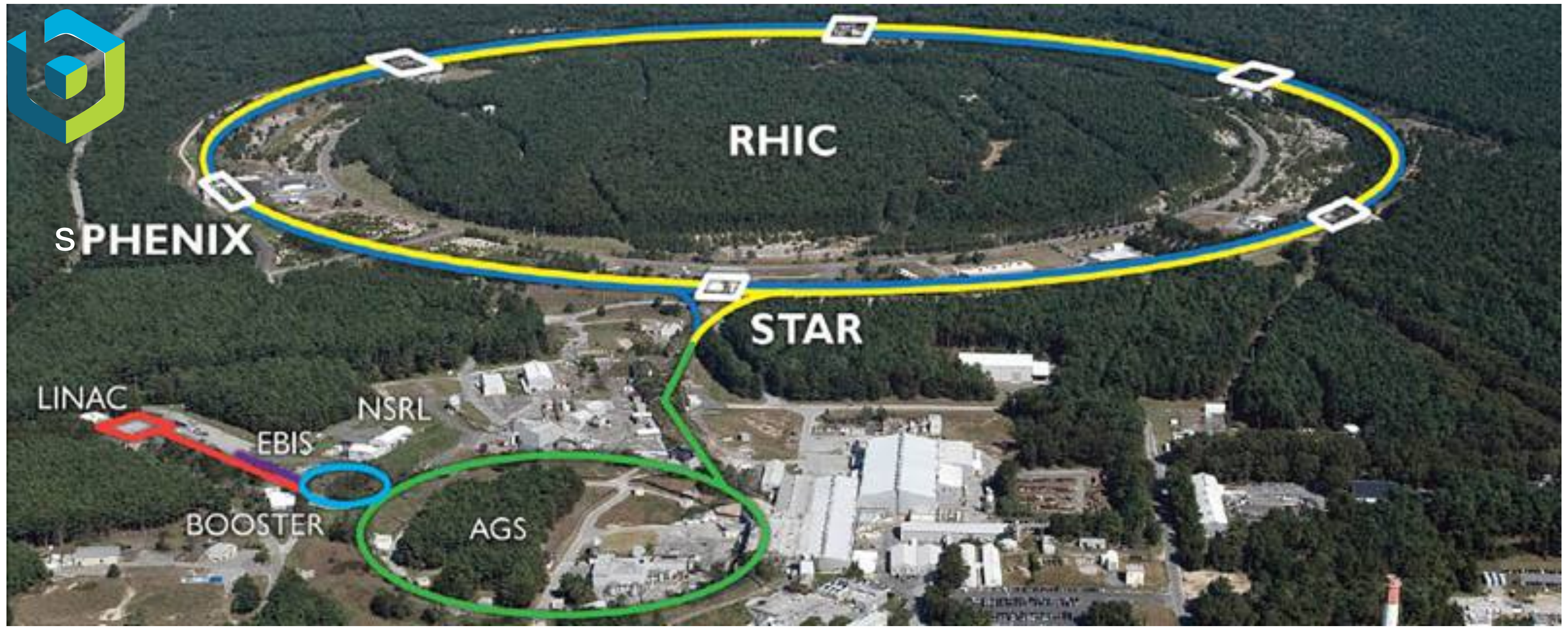

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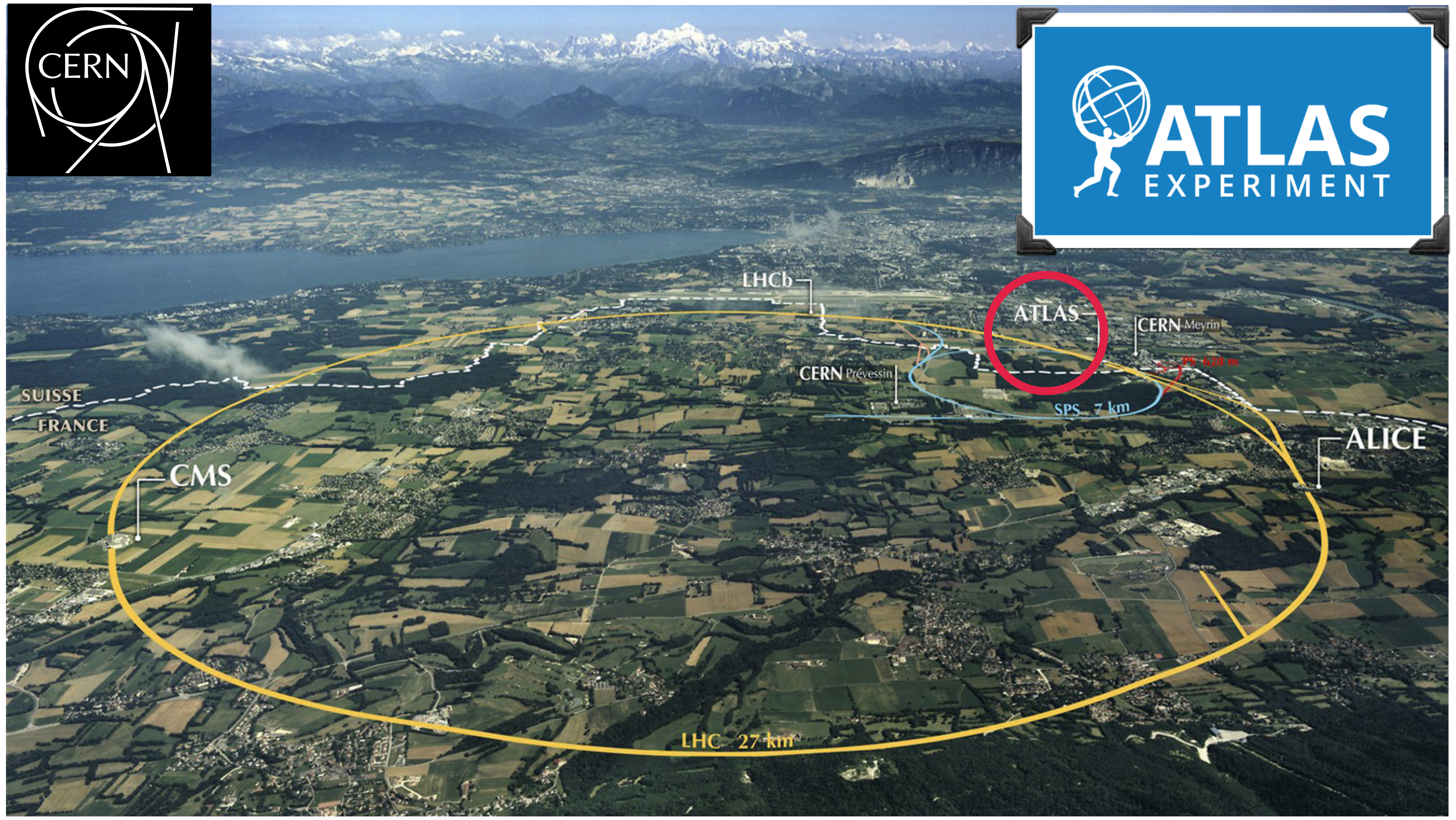

Large Hadron Collider (LHC)

A brief history of flow in heavy-ion collisions

Early results from RHIC program indicated that head on Au+Au collisions at 200 GeV behave as a nearly perfect fluid.

Subsequent measurements of **Pb+Pb** collisions at LHC shows similar *fluid nature*.

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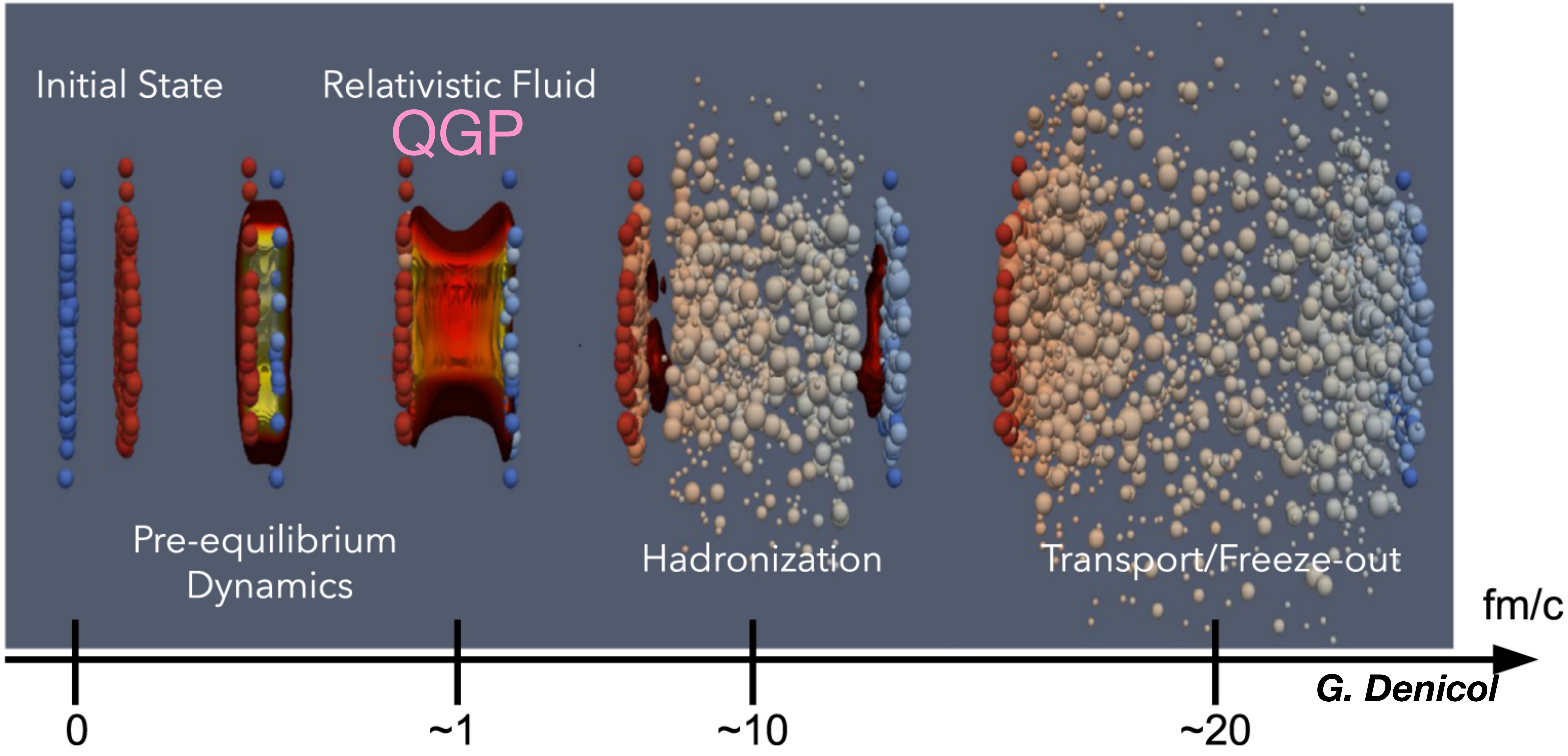
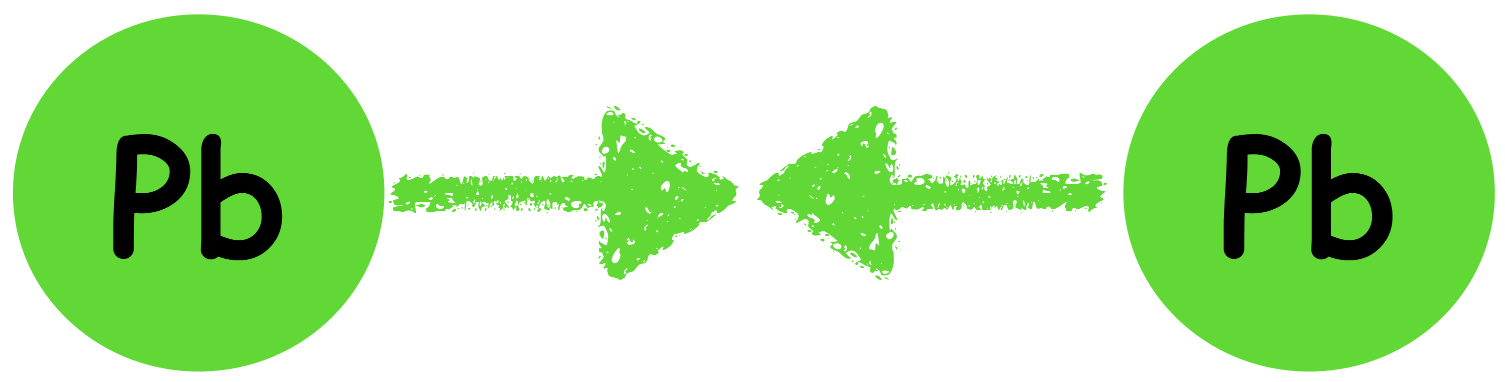


Visualization of the different stages of heavy-ion collisions in a hybrid approach based on *hydrodynamics and hadronic transport* for the initial and final stages.

Flow in heavy-ion collisions



A tiny drop of QGP is created in heavy-ion collisions and it expands like a fluid.

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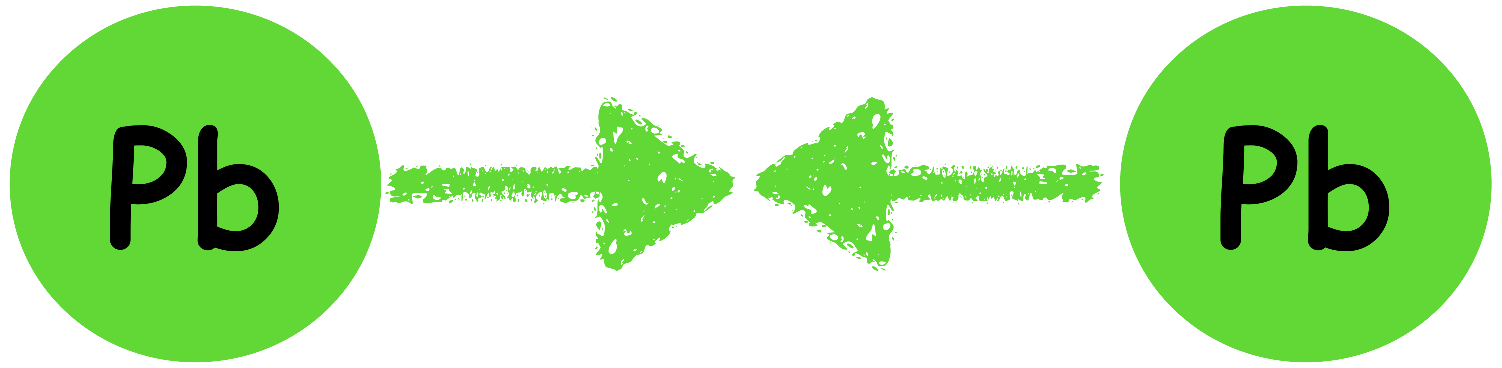

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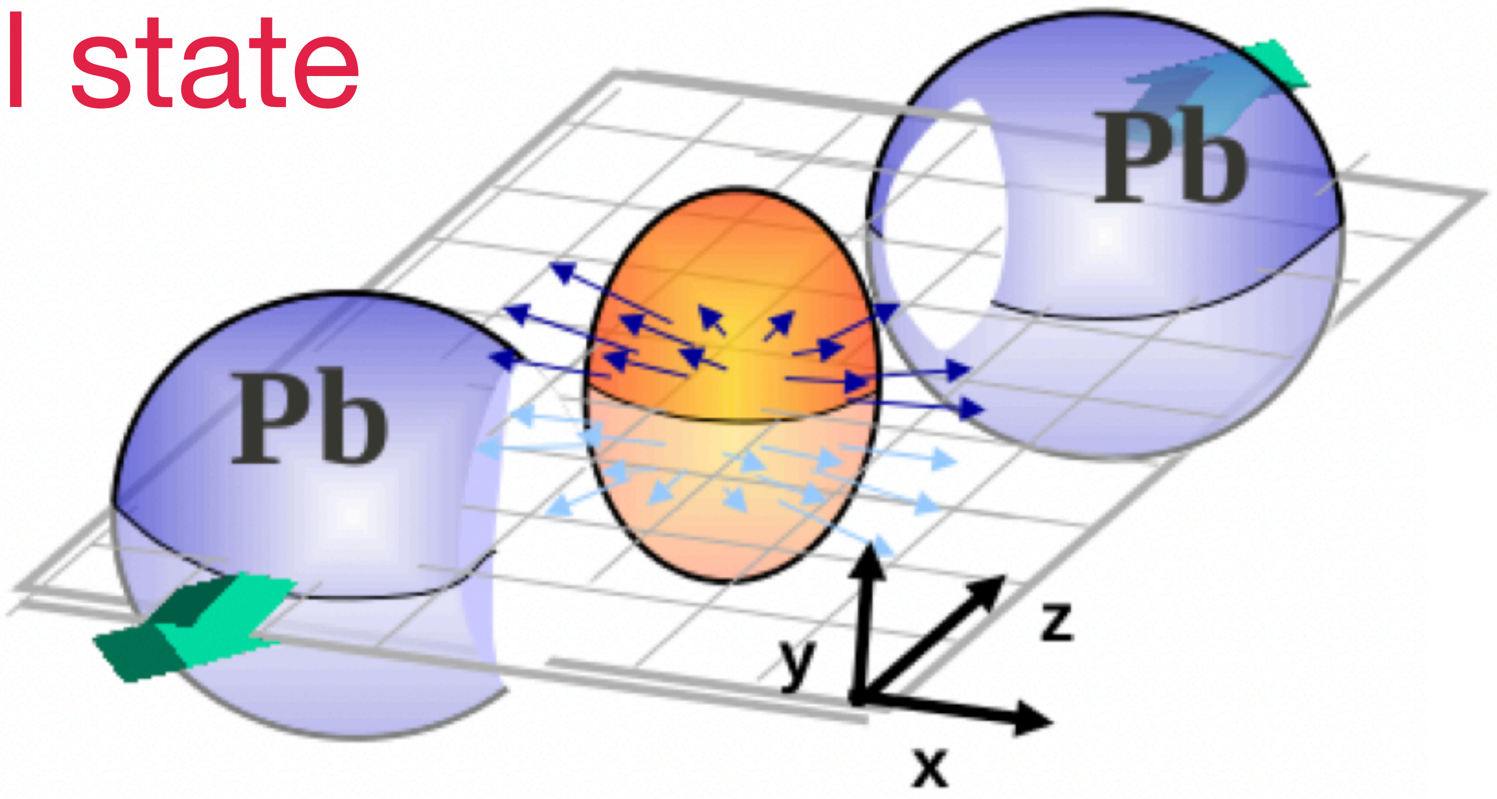
Initial state



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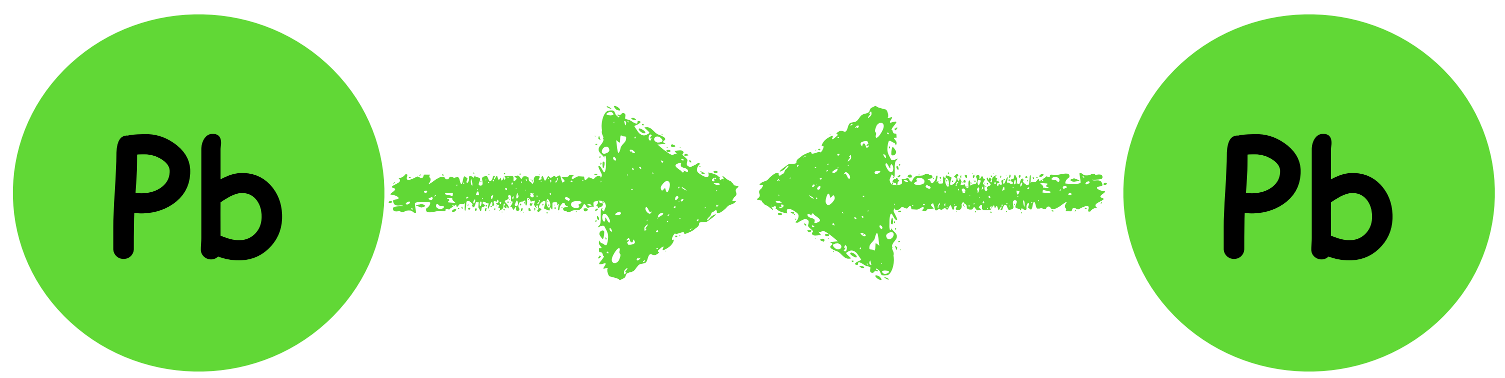

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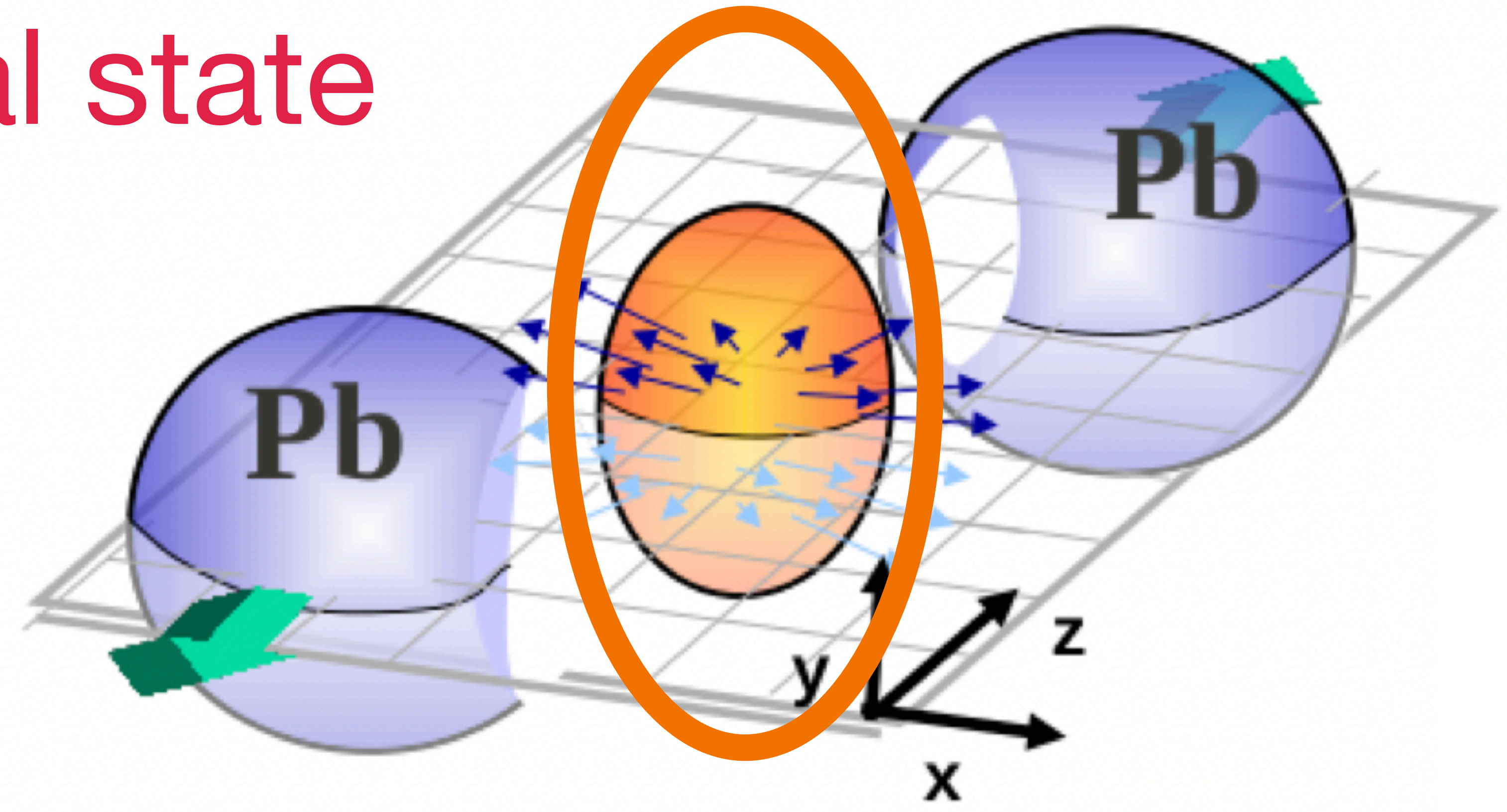

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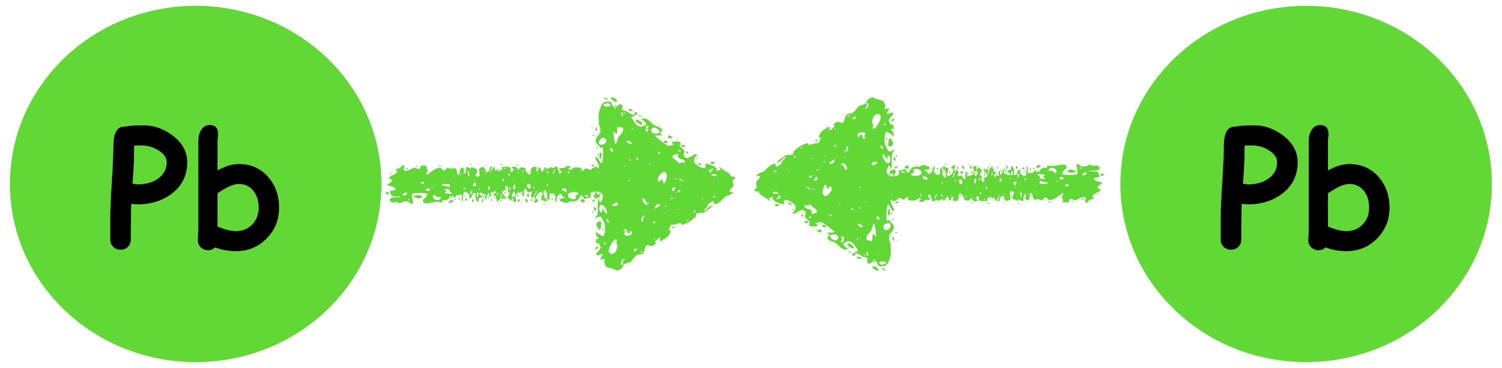

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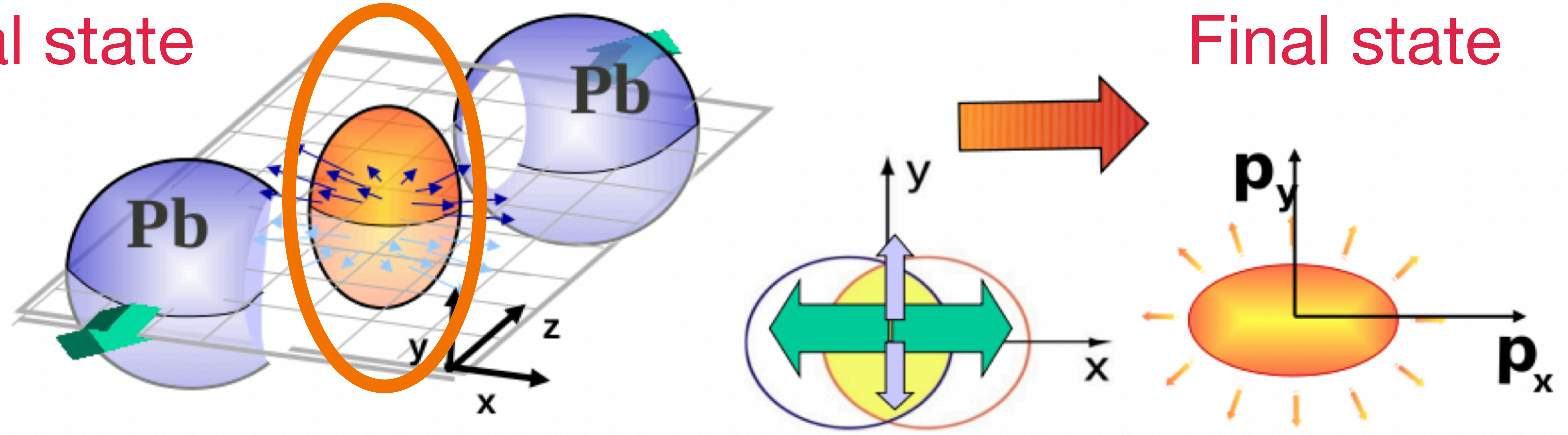
Final state



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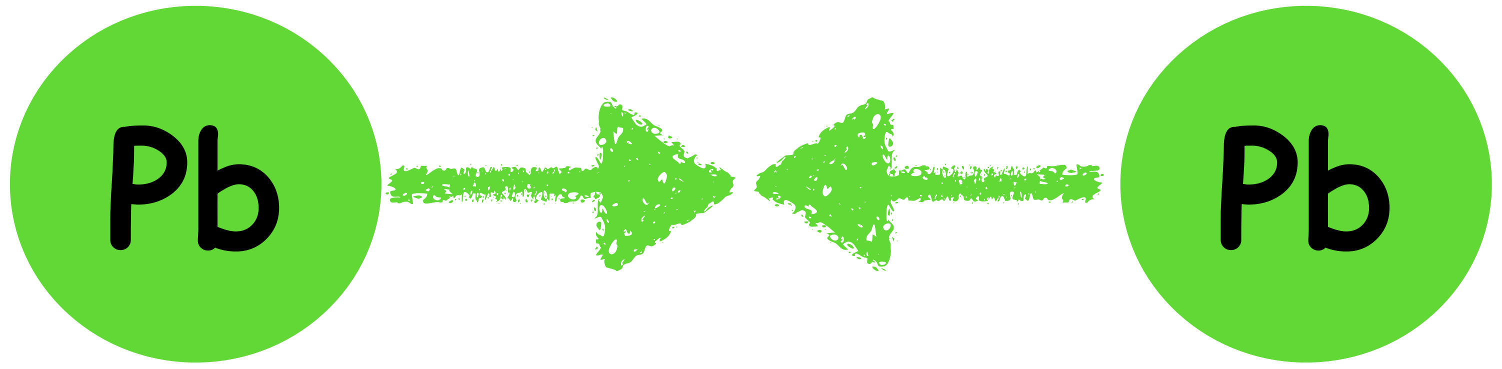

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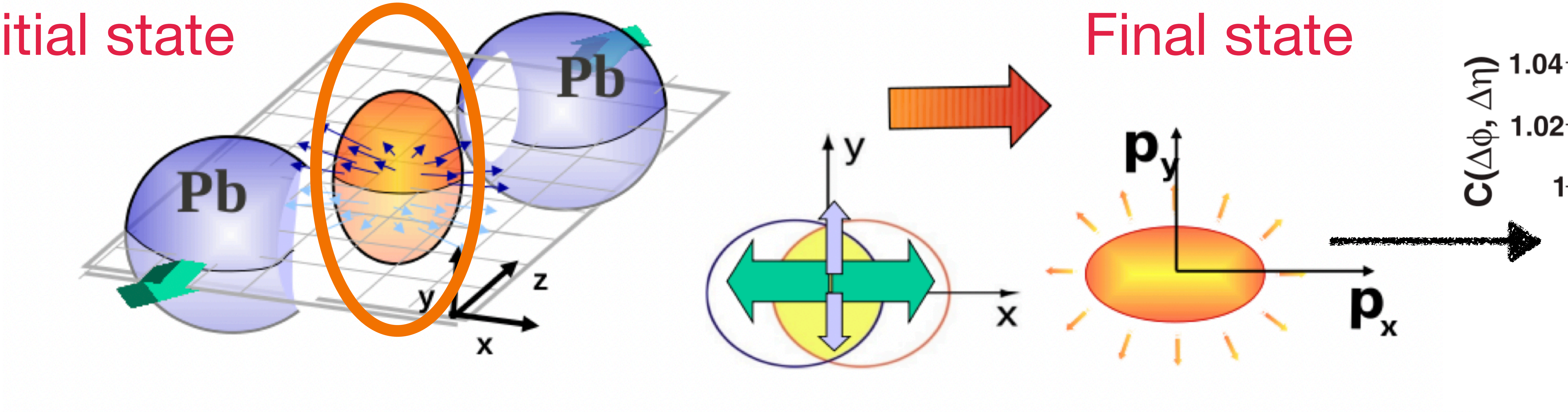
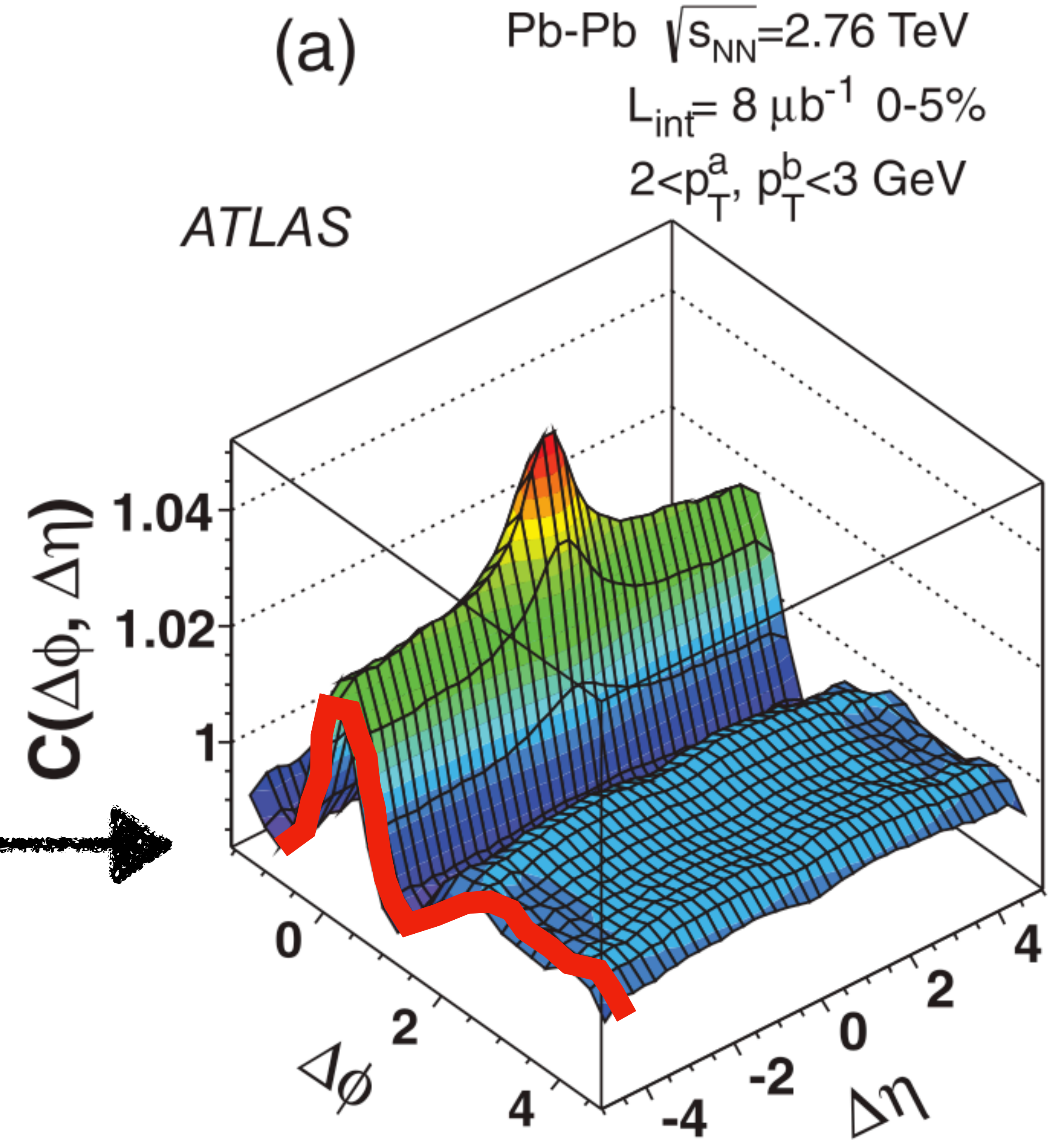
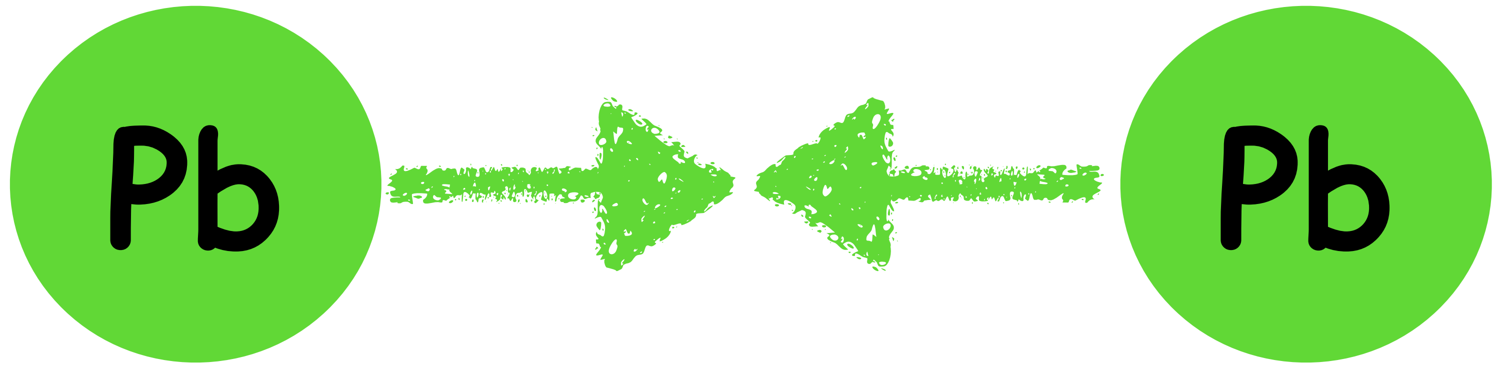




Phys. Rev. C 86, 014907 (2012)

Flow in heavy-ion collisions



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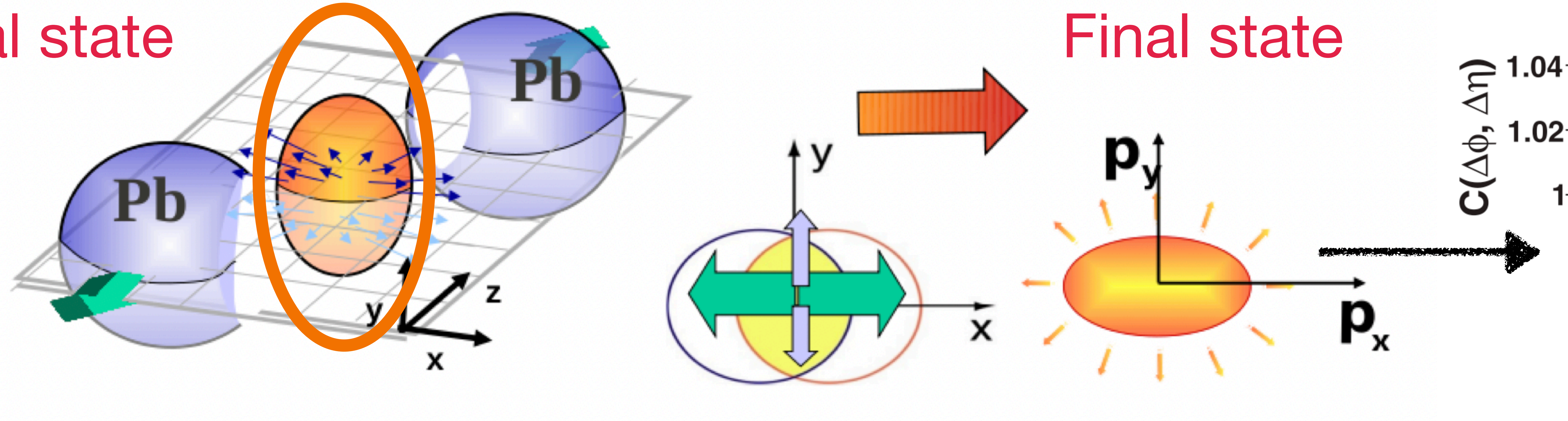

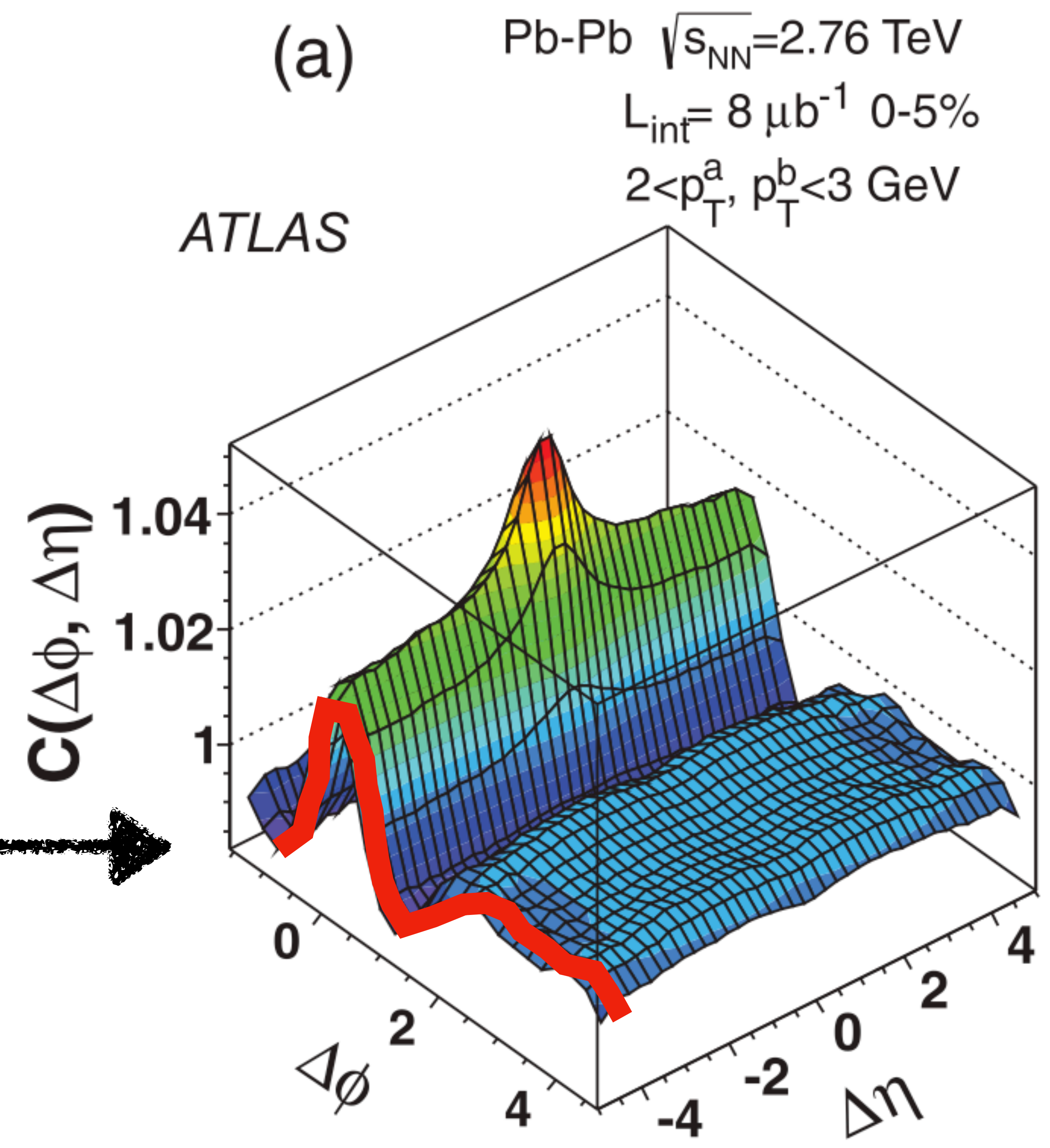

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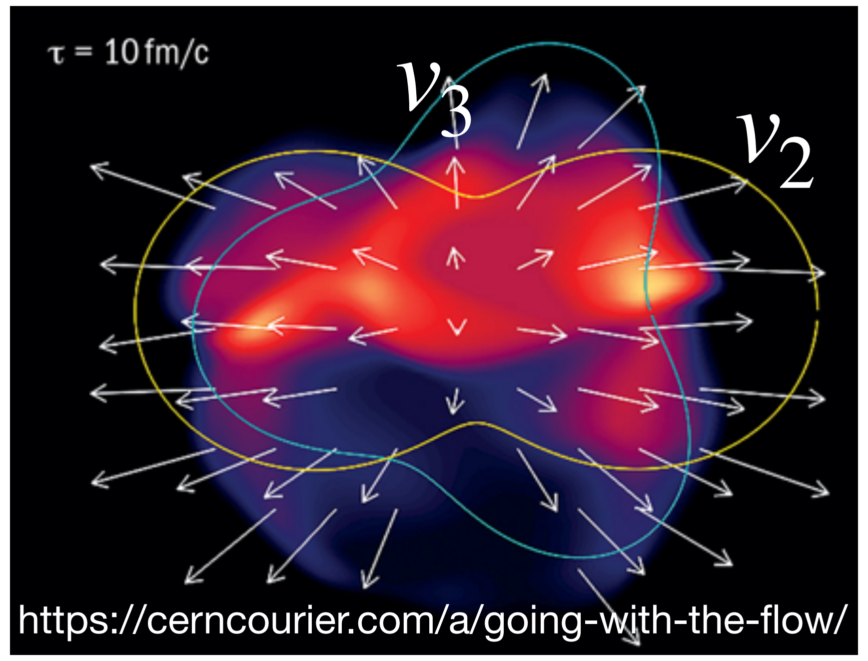
Spatial anisotropy in the initial state energy density translates into momentum anisotropy in the final state → v_2 *(Flow)*

Initial state fluctuations → v_3, v_4 …



Can we observe flow in small systems like *pp*, *p*Pb?

Theory: *Physics Letters B 774 (2017) 351–356*
ATLAS: *Physical Review C 90, 044906 (2014)*

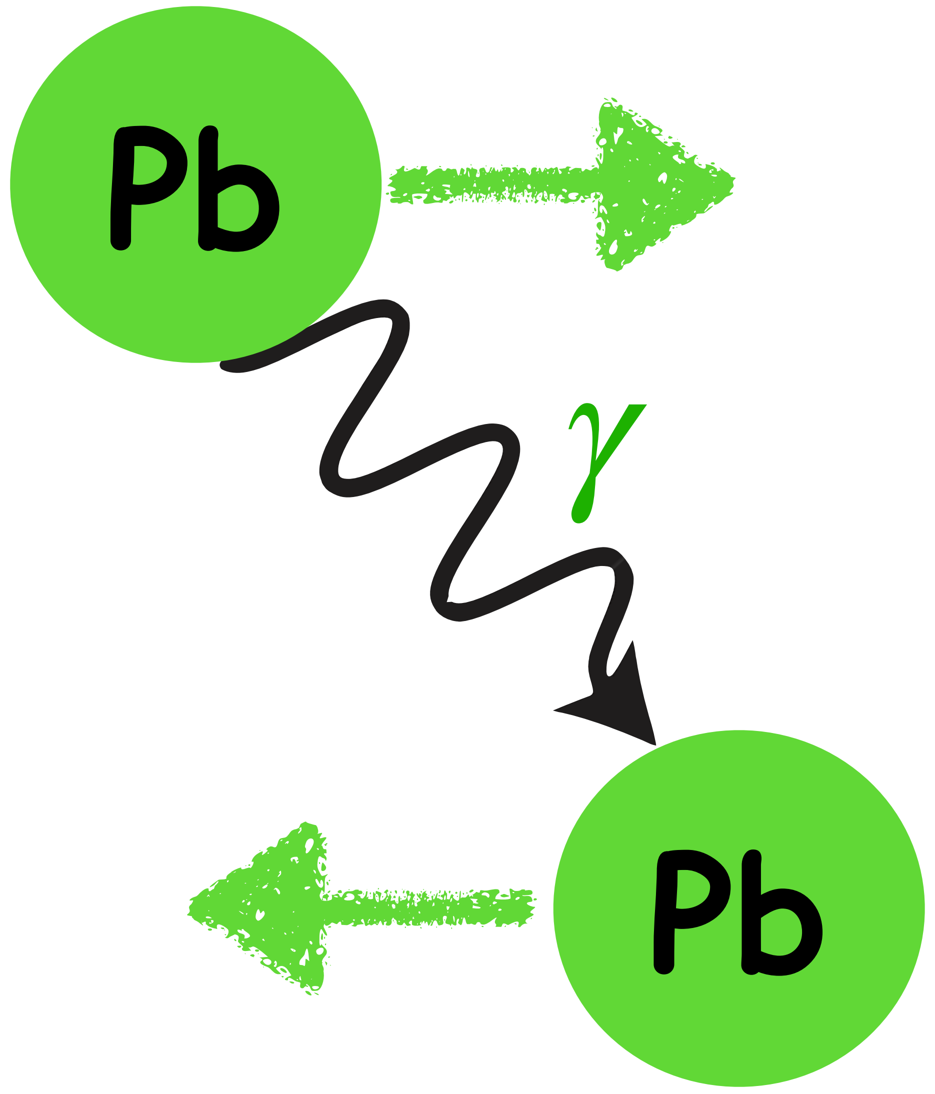
Hydrodynamic models can successfully describe v_2, v_3, v_4

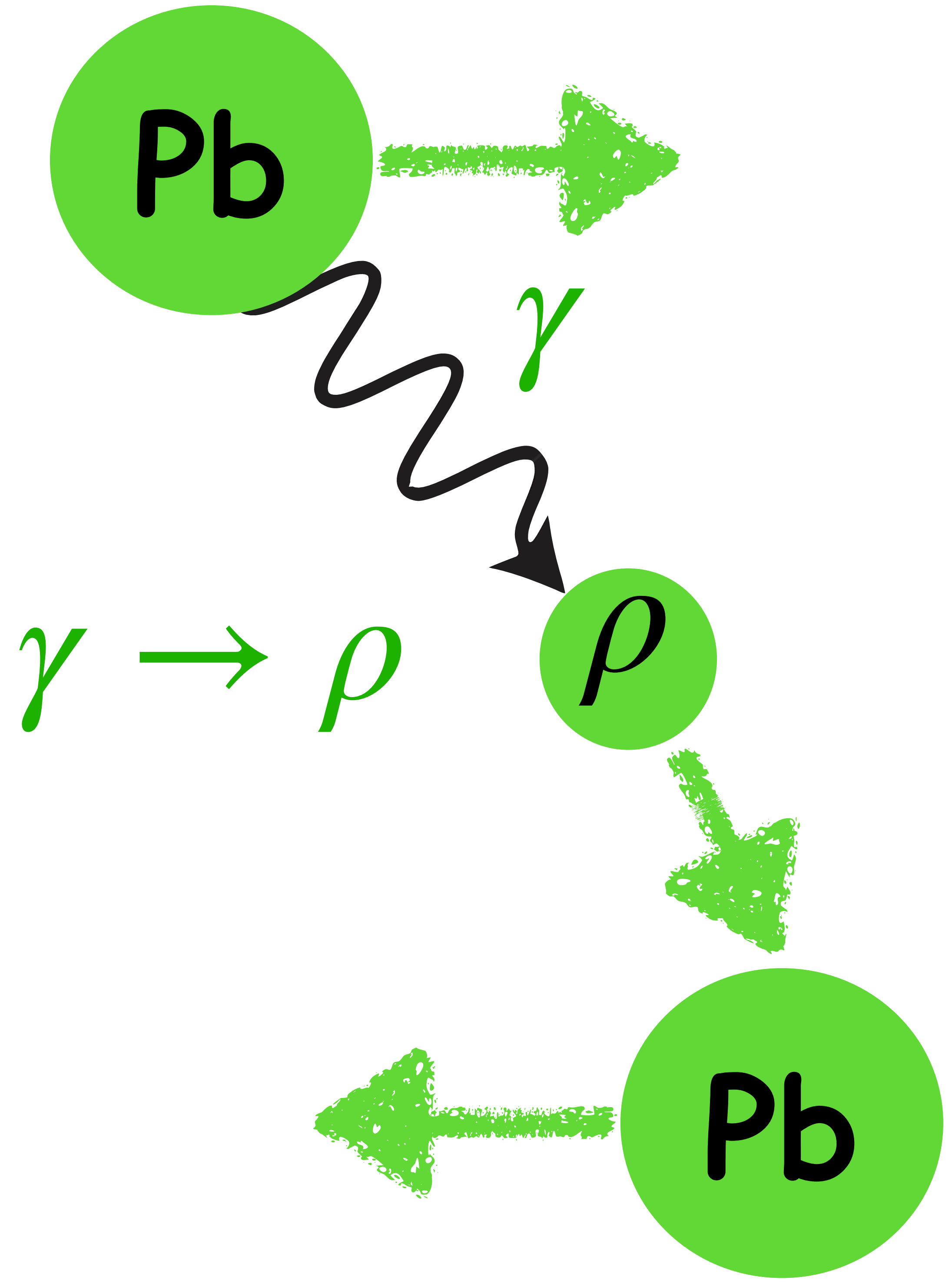
in systems of wide size ranges: *pp*, *p*Pb and Pb+Pb!

Can we look into other smaller systems like γ+Pb?

When two nuclei miss each other, EM field of one nucleus (photon) breaks up the other nucleus →Ultra Peripheral Collisions (UPC)

More specifically, photonuclear collisions.

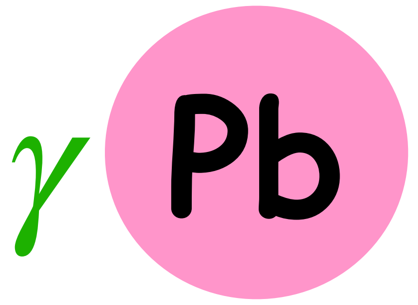




Can we observe flow-like signatures in smaller systems like γ+Pb?

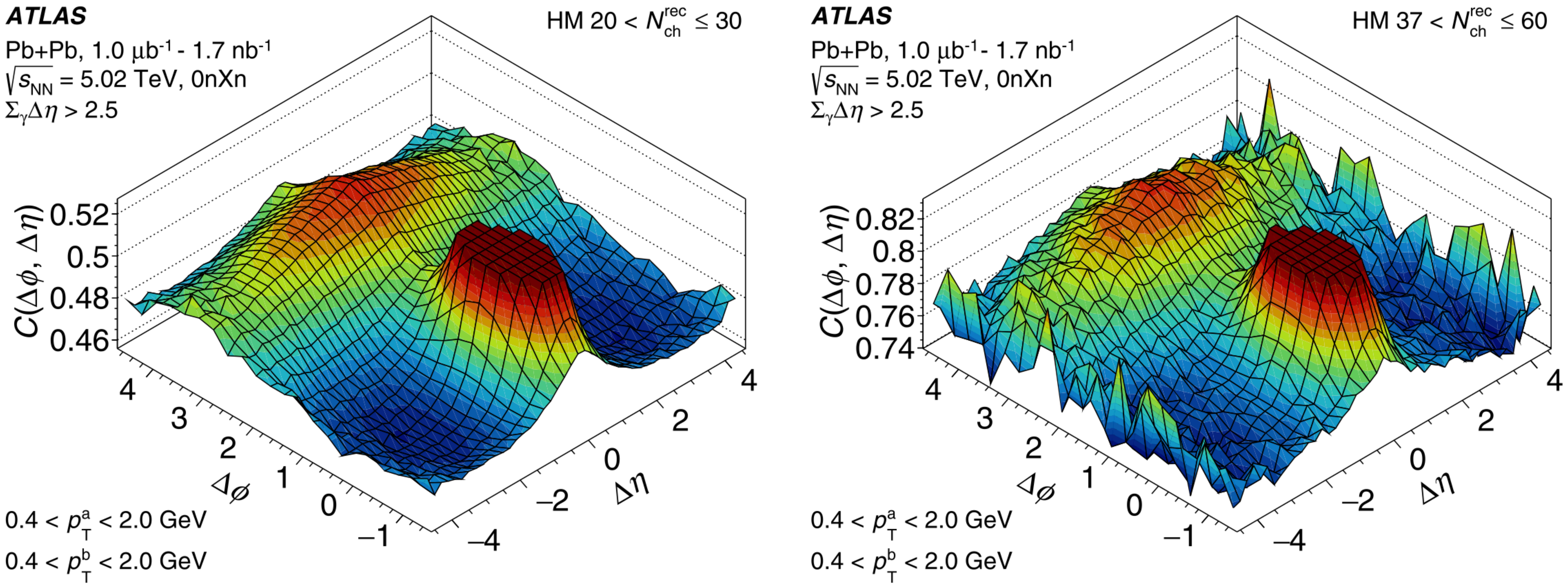
Do photo-nuclear events create QGP droplets?

Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at 5.02 TeV with ATLAS



G. Aad *et al.**
(ATLAS Collaboration)

(Received 27 January 2021; accepted 17 June 2021; published 12 July 2021)



[Physical Review C 104, 014903 (2021)]

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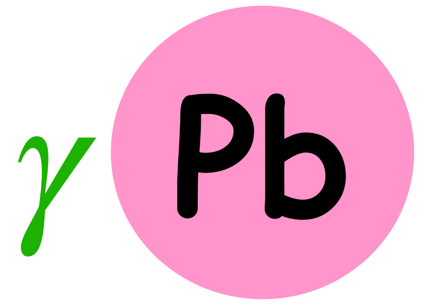

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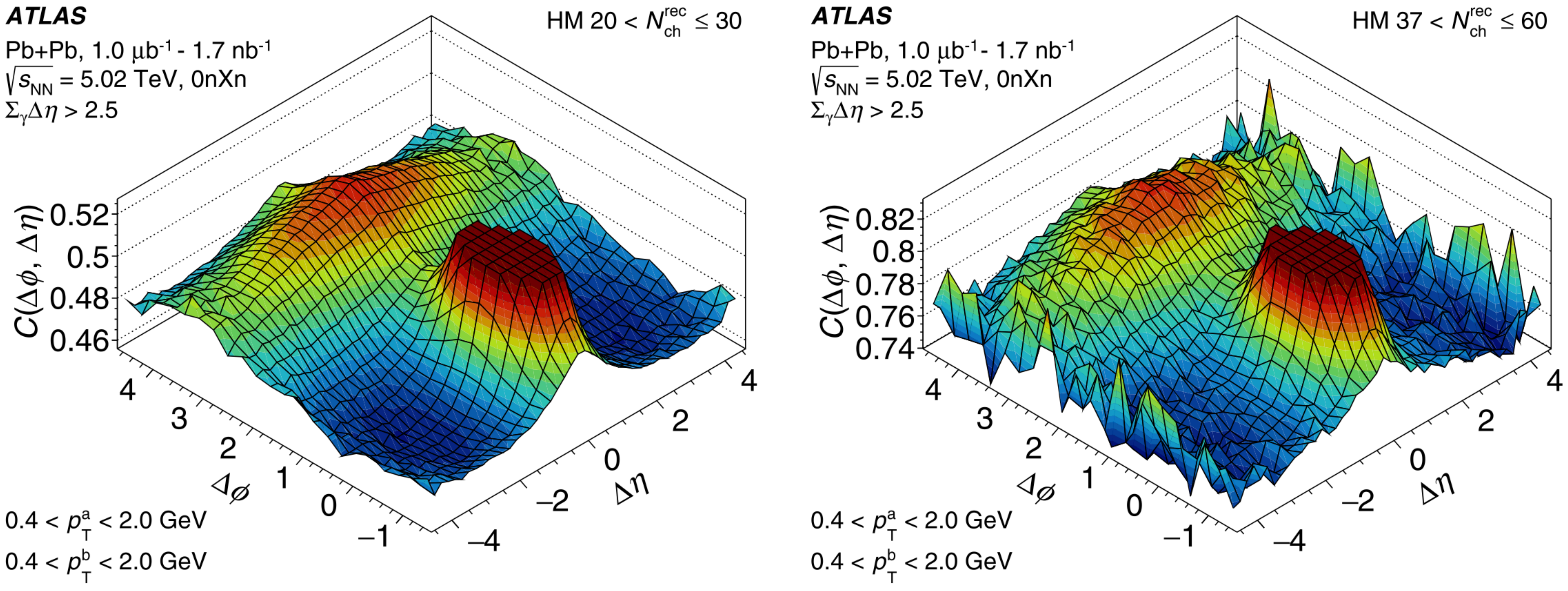
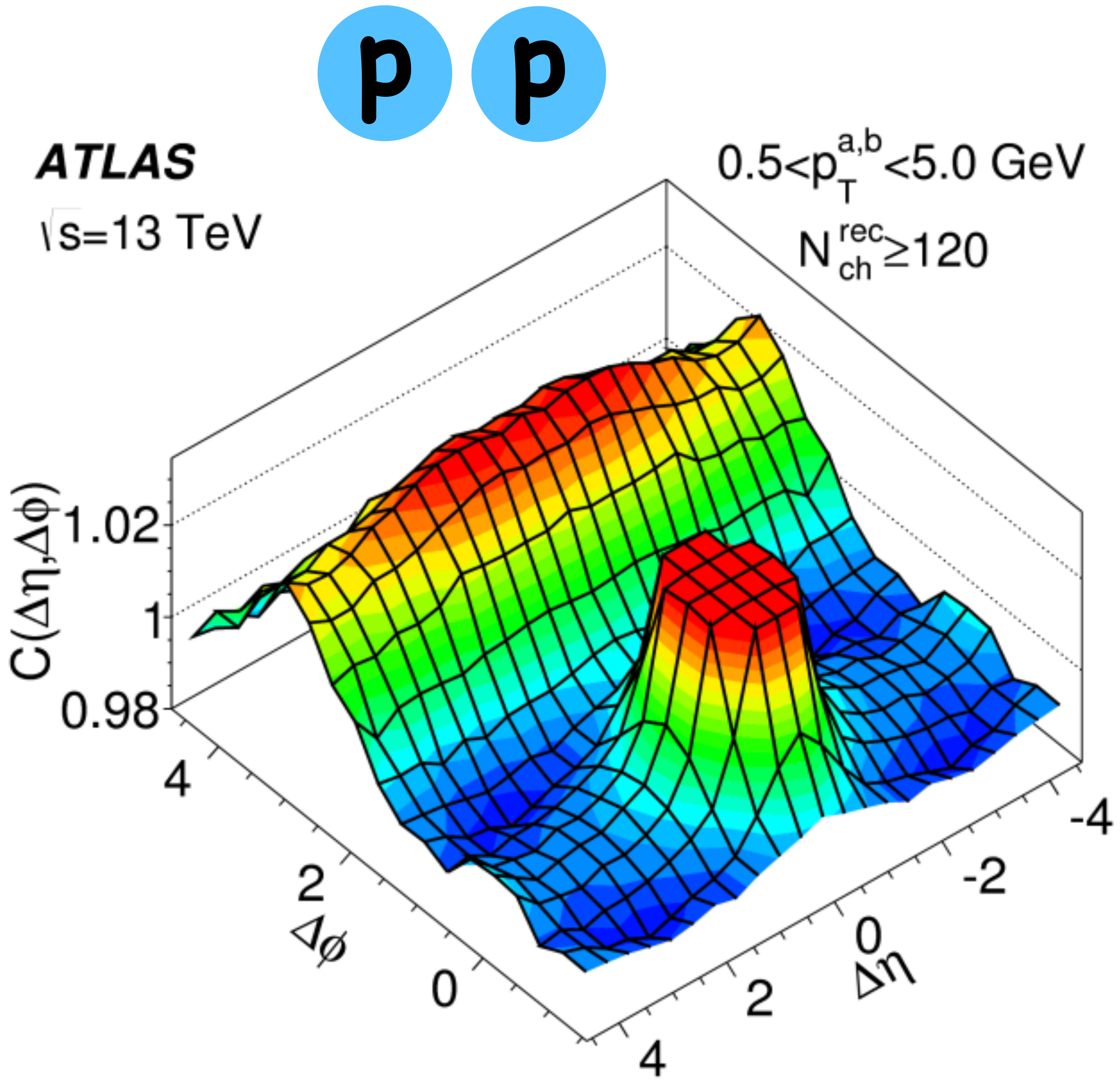


Physical Review C 104, 014903 (2021)



Phys. Rev. Lett. 116, 172301

Two-dimensional correlation functions in γ+Pb have features similar to those observed in *pp* collisions

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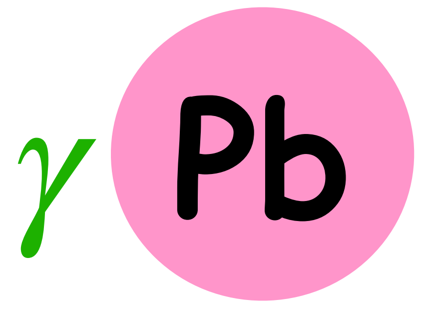

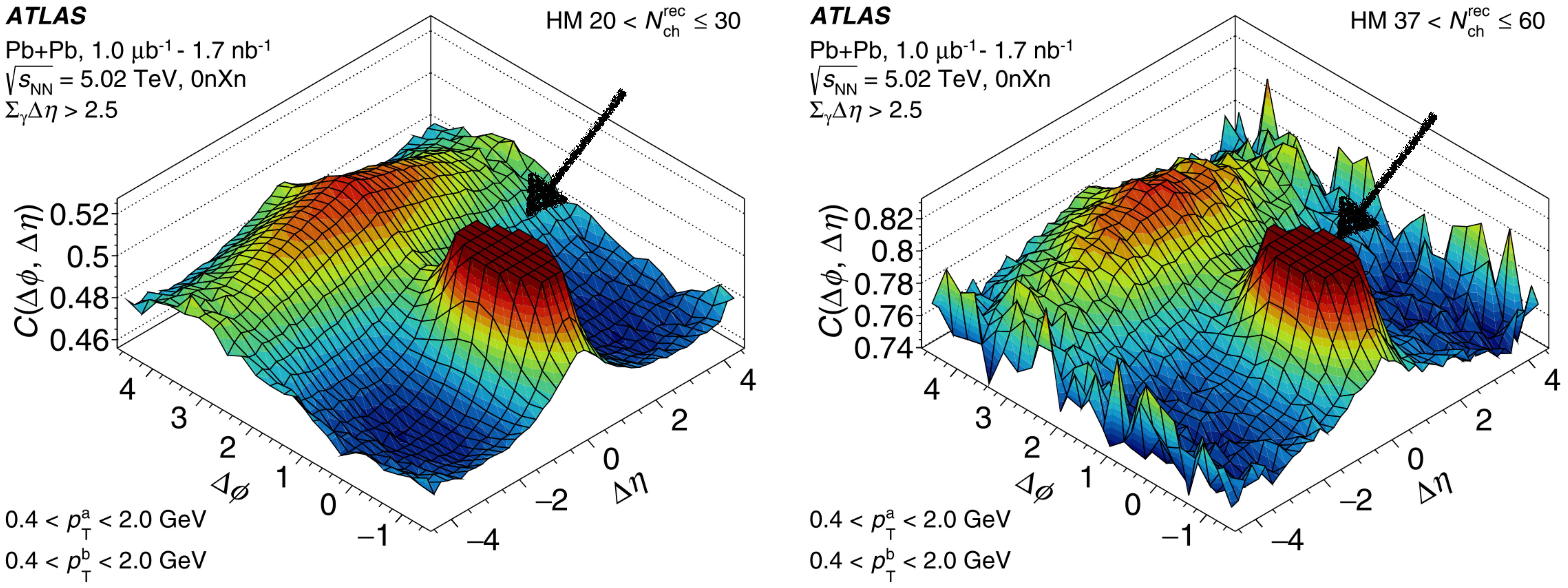

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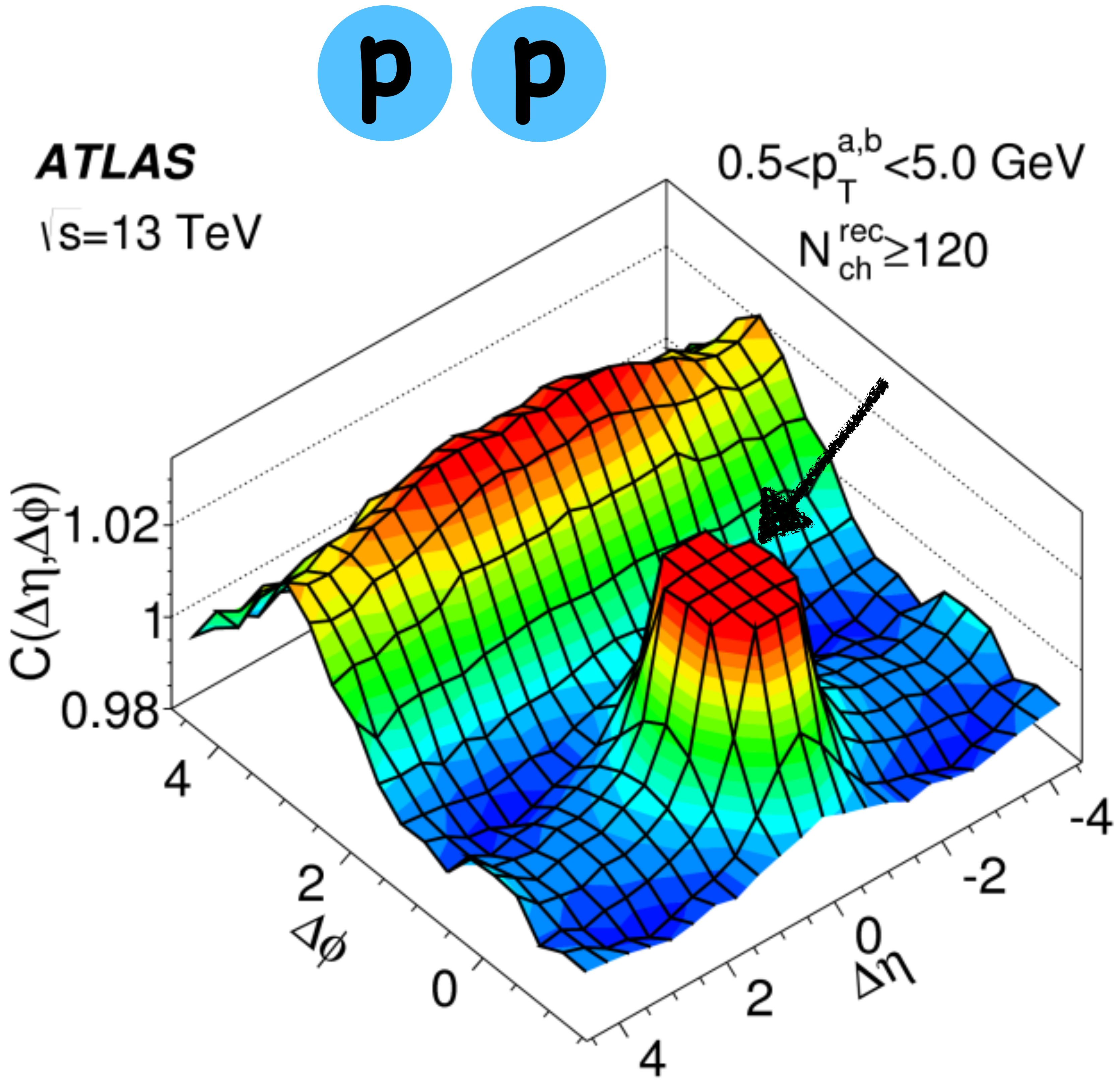

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γ Pb

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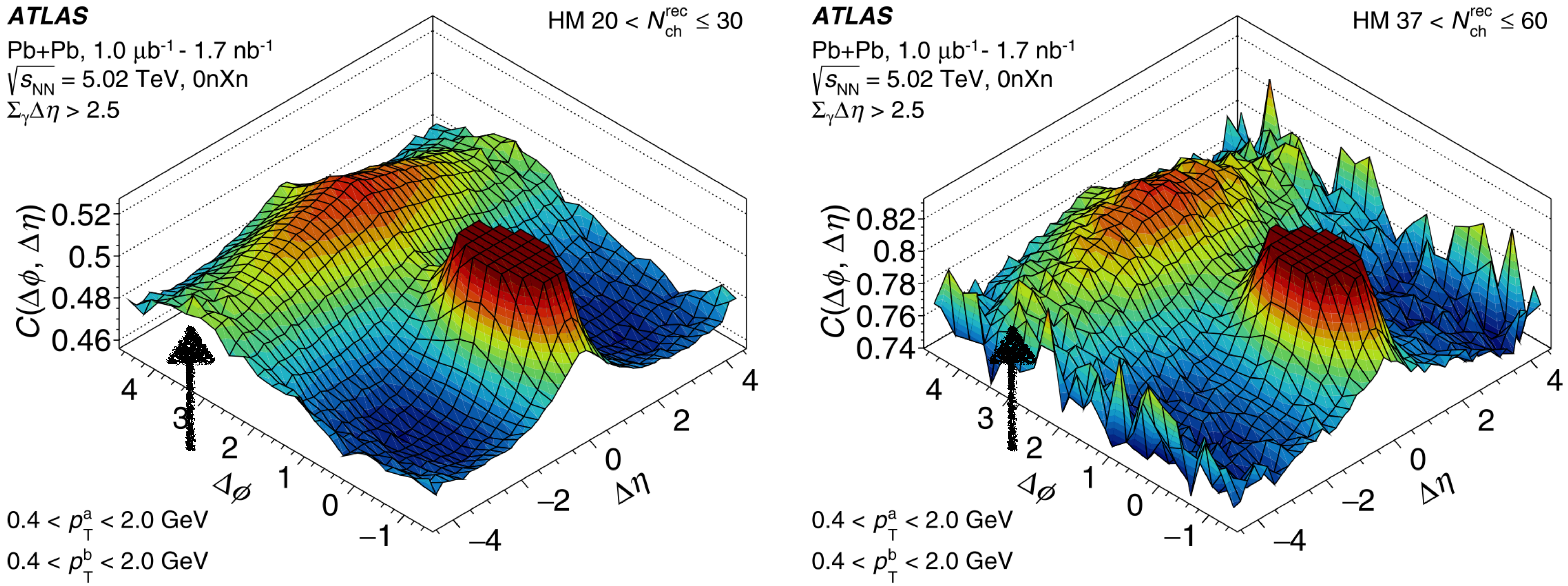

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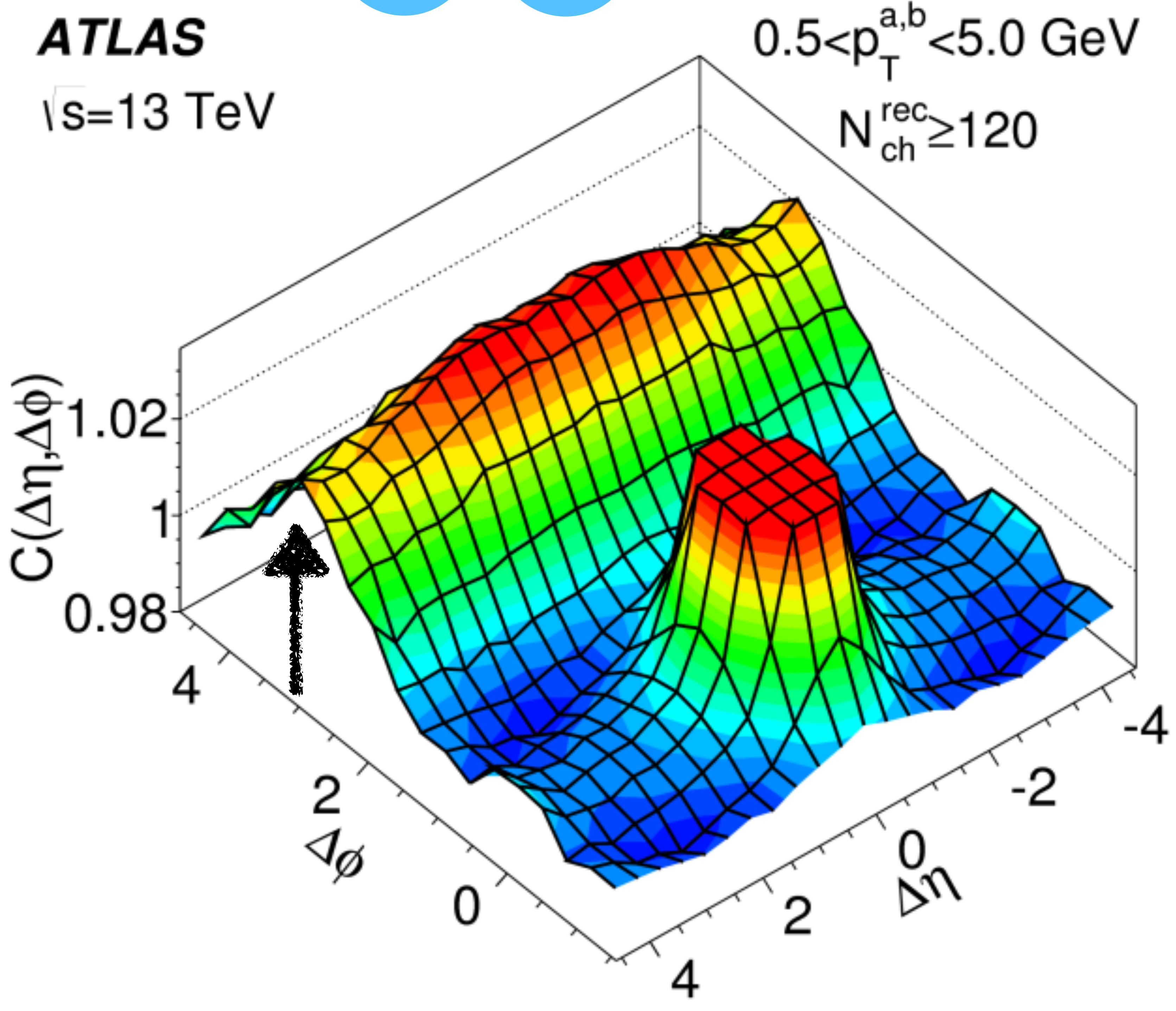
p p



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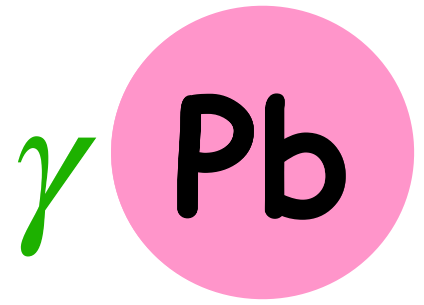

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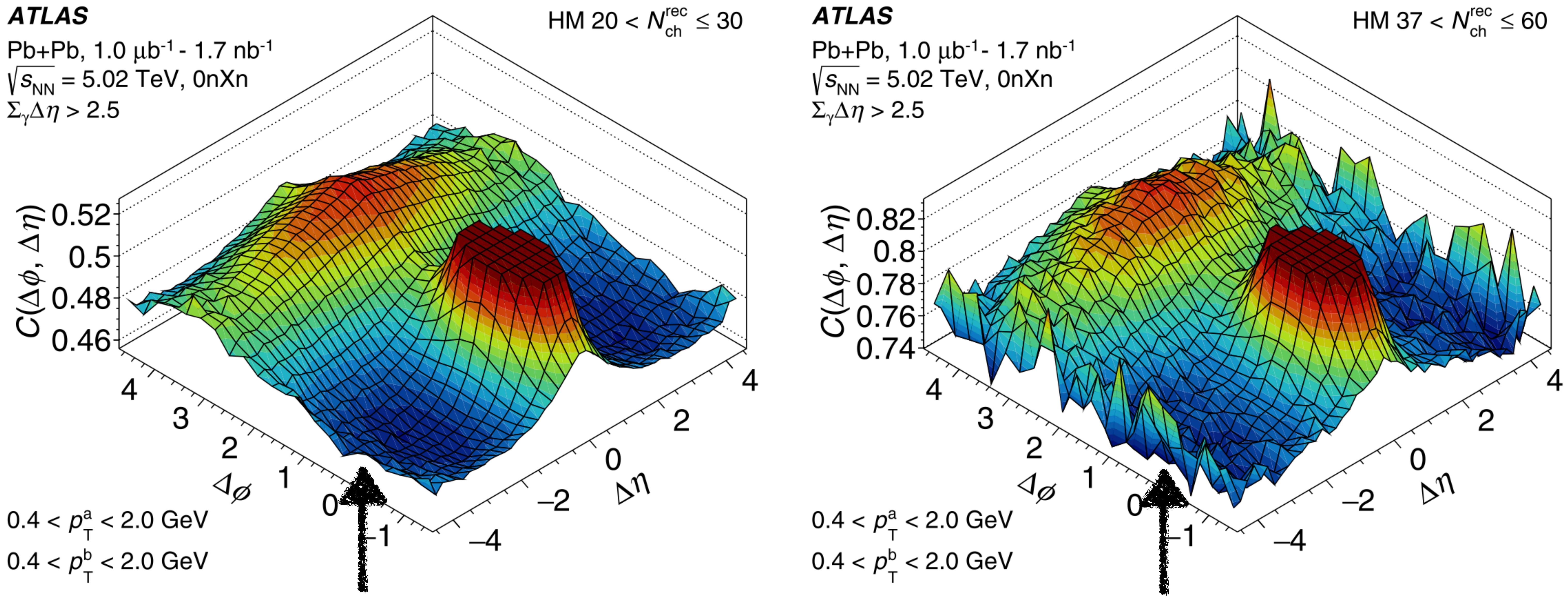

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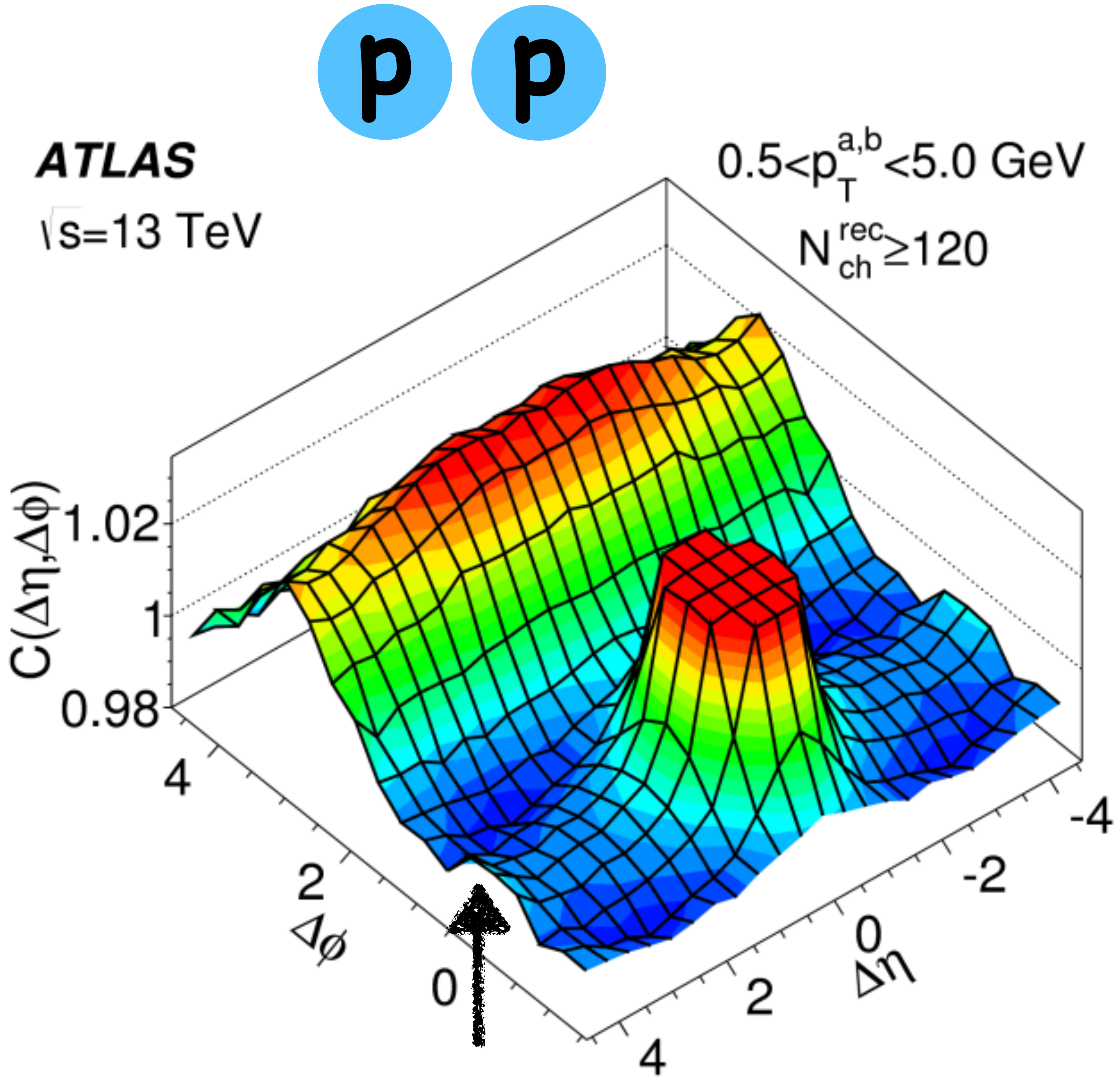

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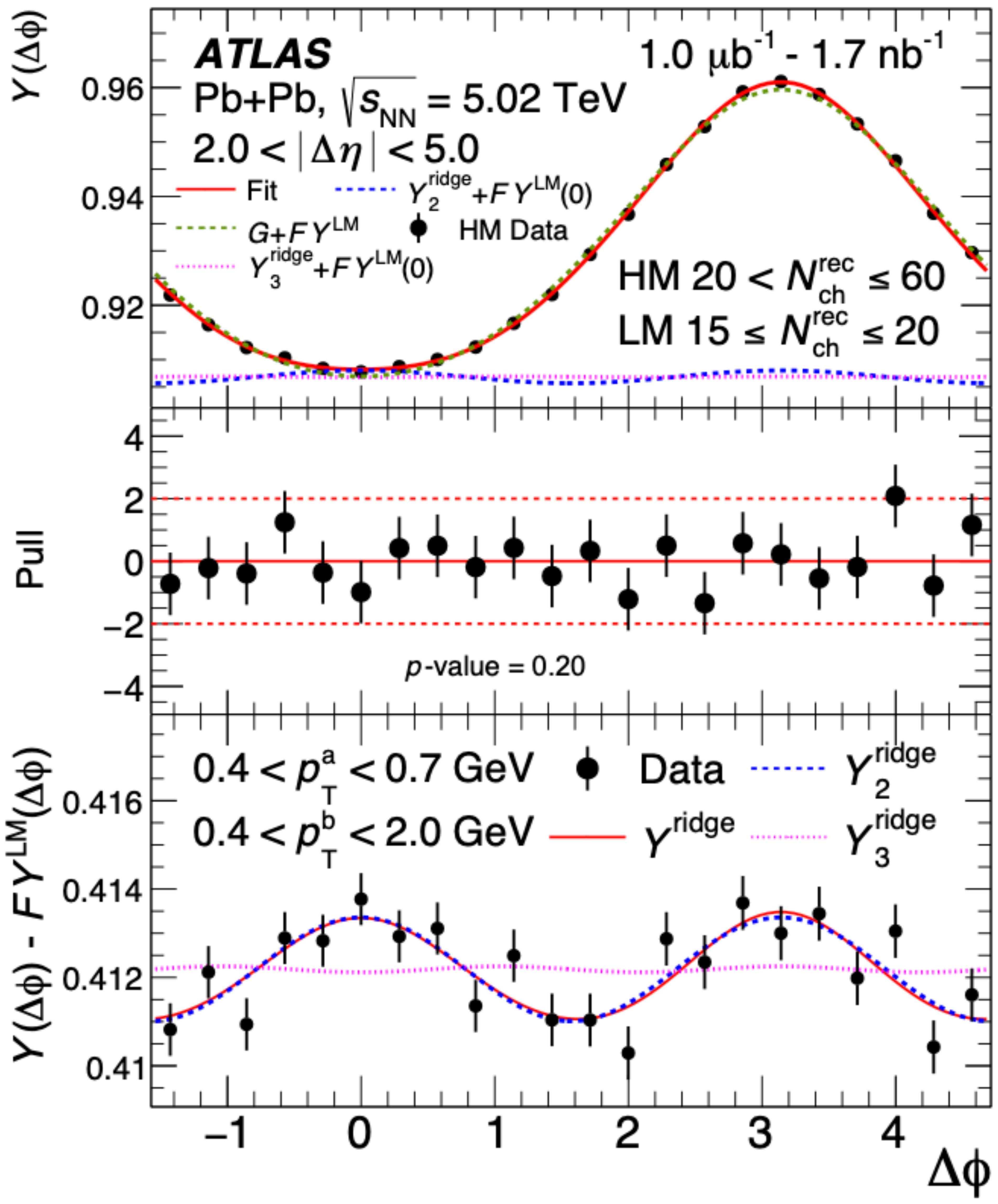

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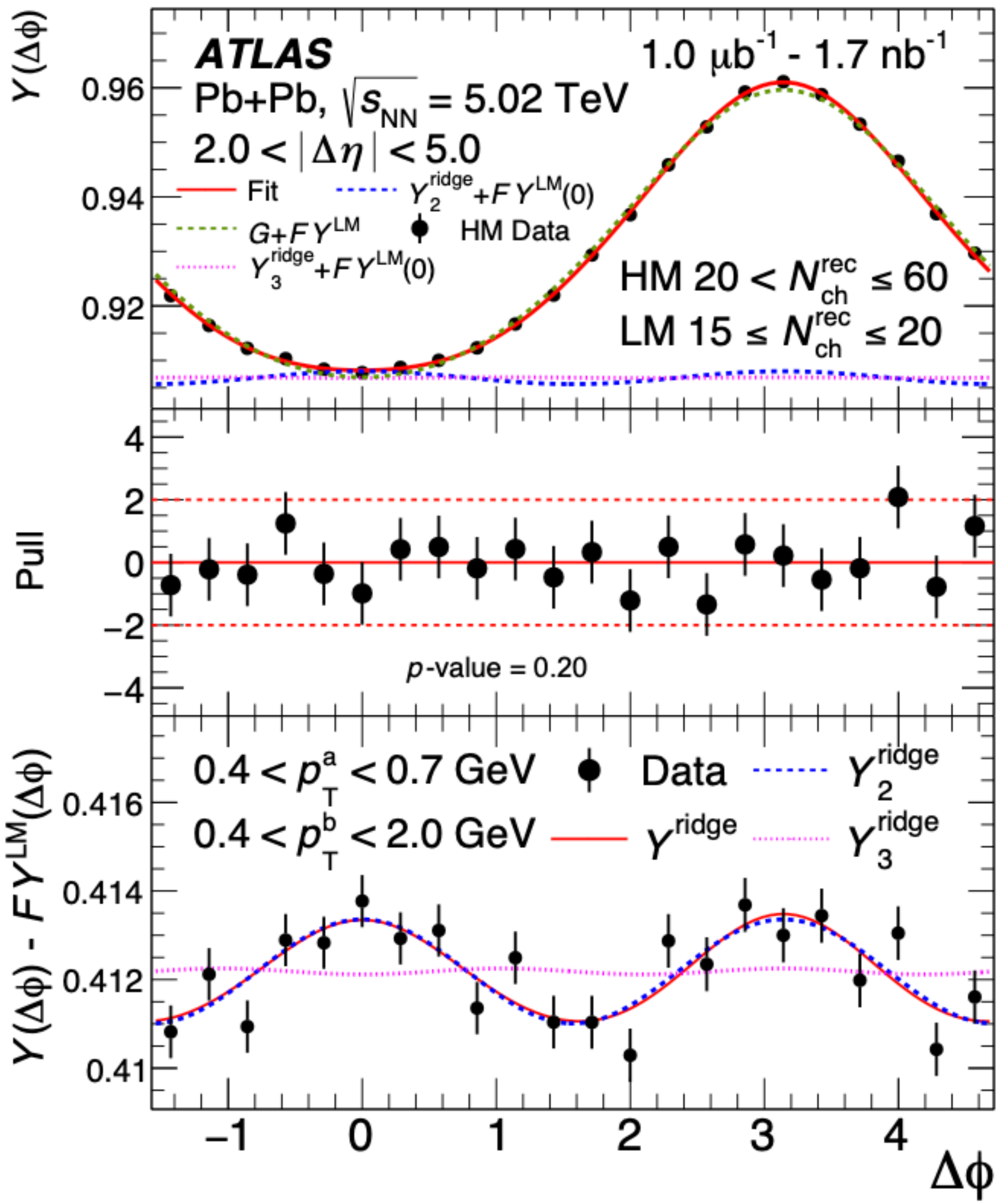

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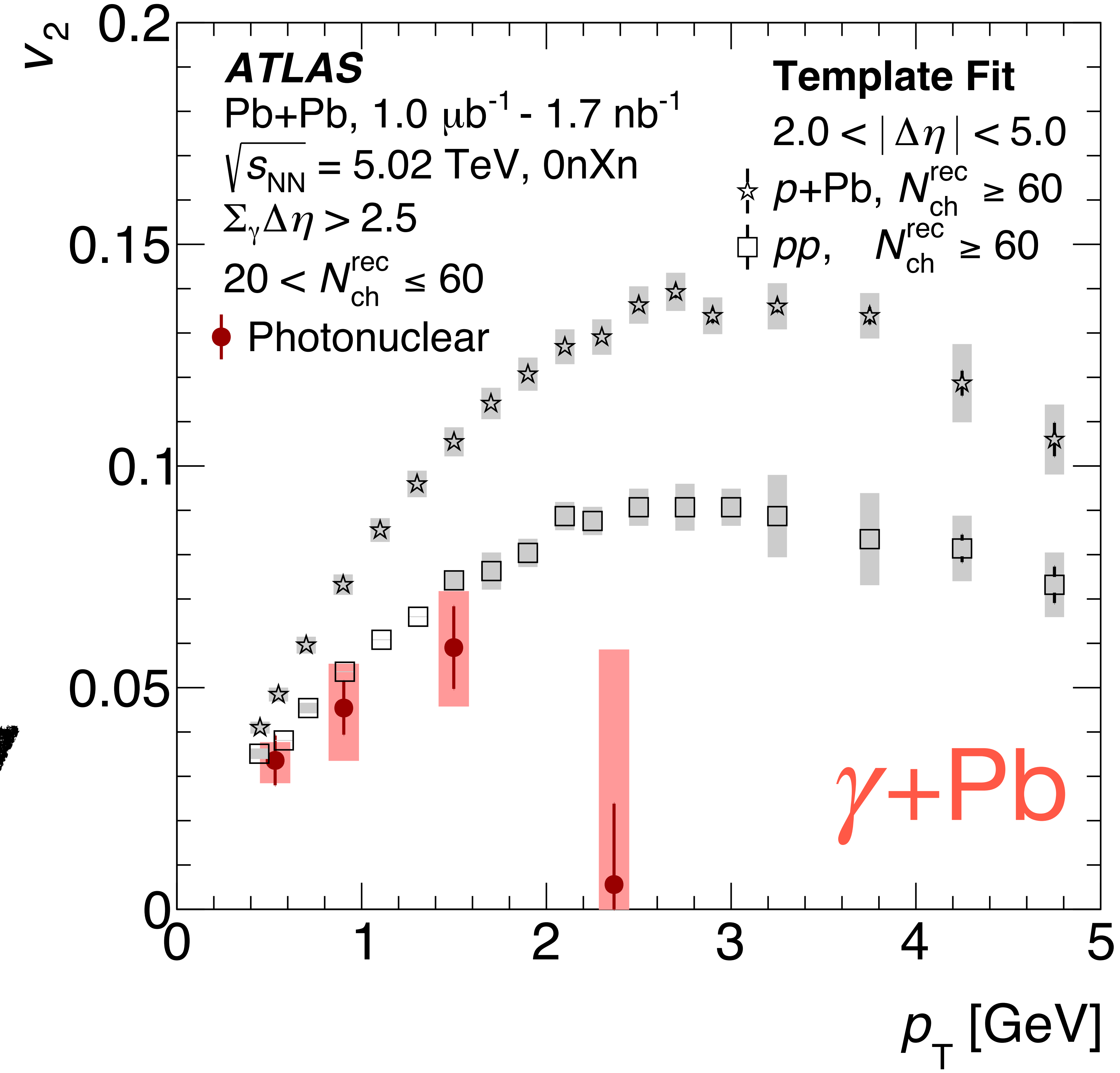
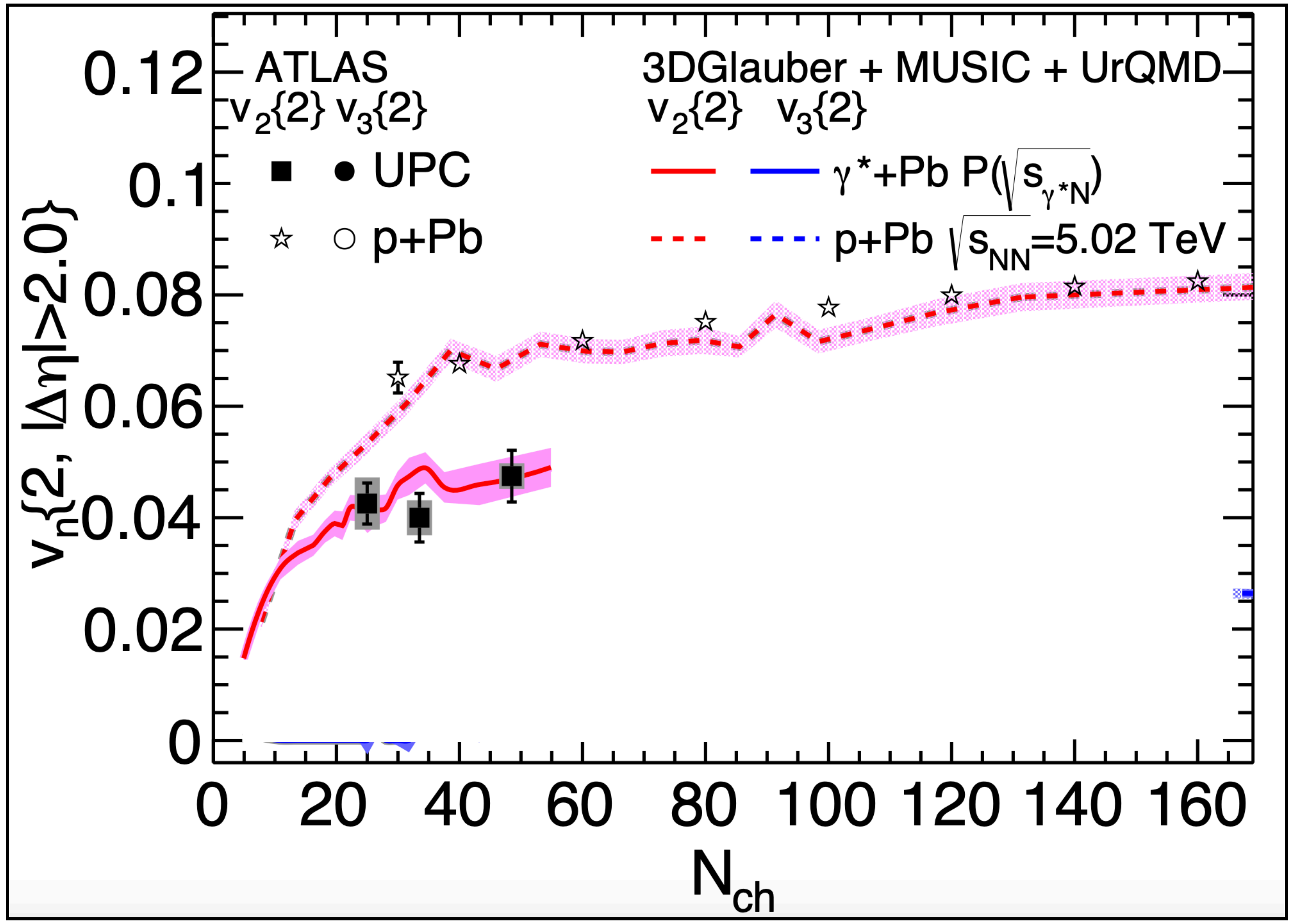


Collective flow (v_2) found by ATLAS in photo-nuclear collisions!

Motivation to look for more QGP-like signals!

Do photo-nuclear events create QGP droplets?

Phys. Rev. Lett. 129, 252302 Wenbin Zhao, Chun Shen, and Björn Schenke



3+1D hydrodynamics

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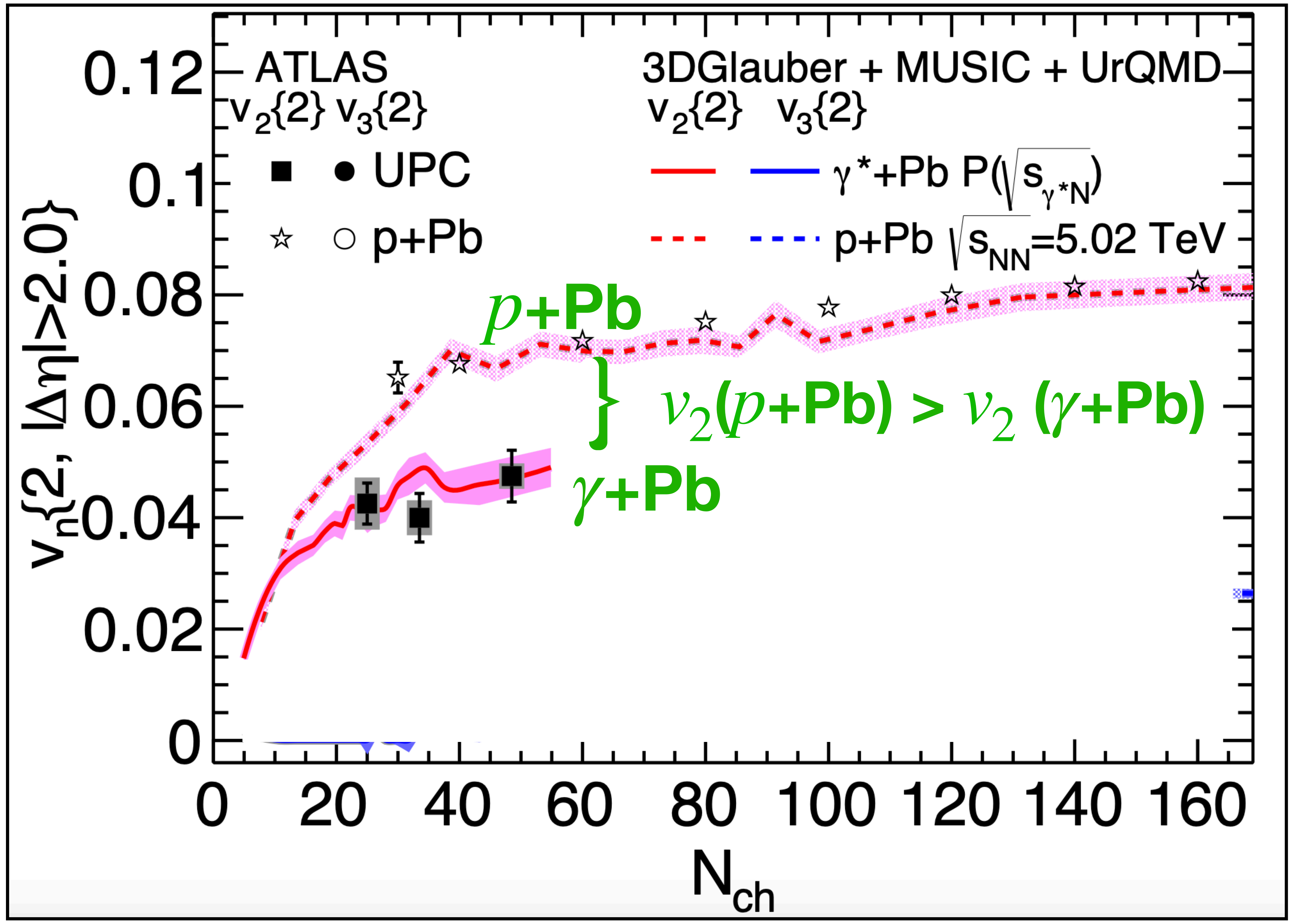
Phys. Rev. Lett. 129, 252302 Wenbin Zhao, Chun Shen, and Björn Schenke



3+1D hydrodynamics suggests

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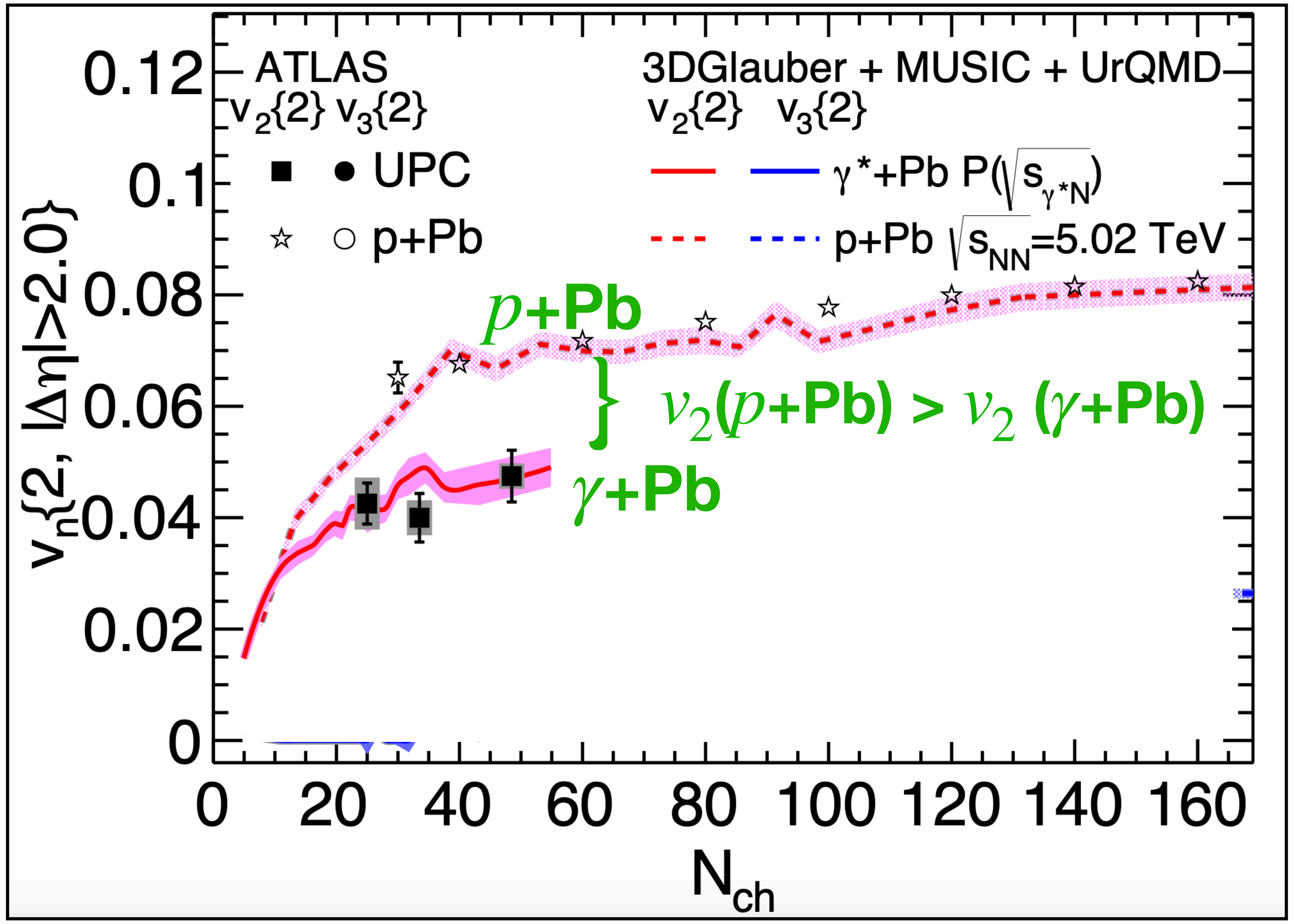

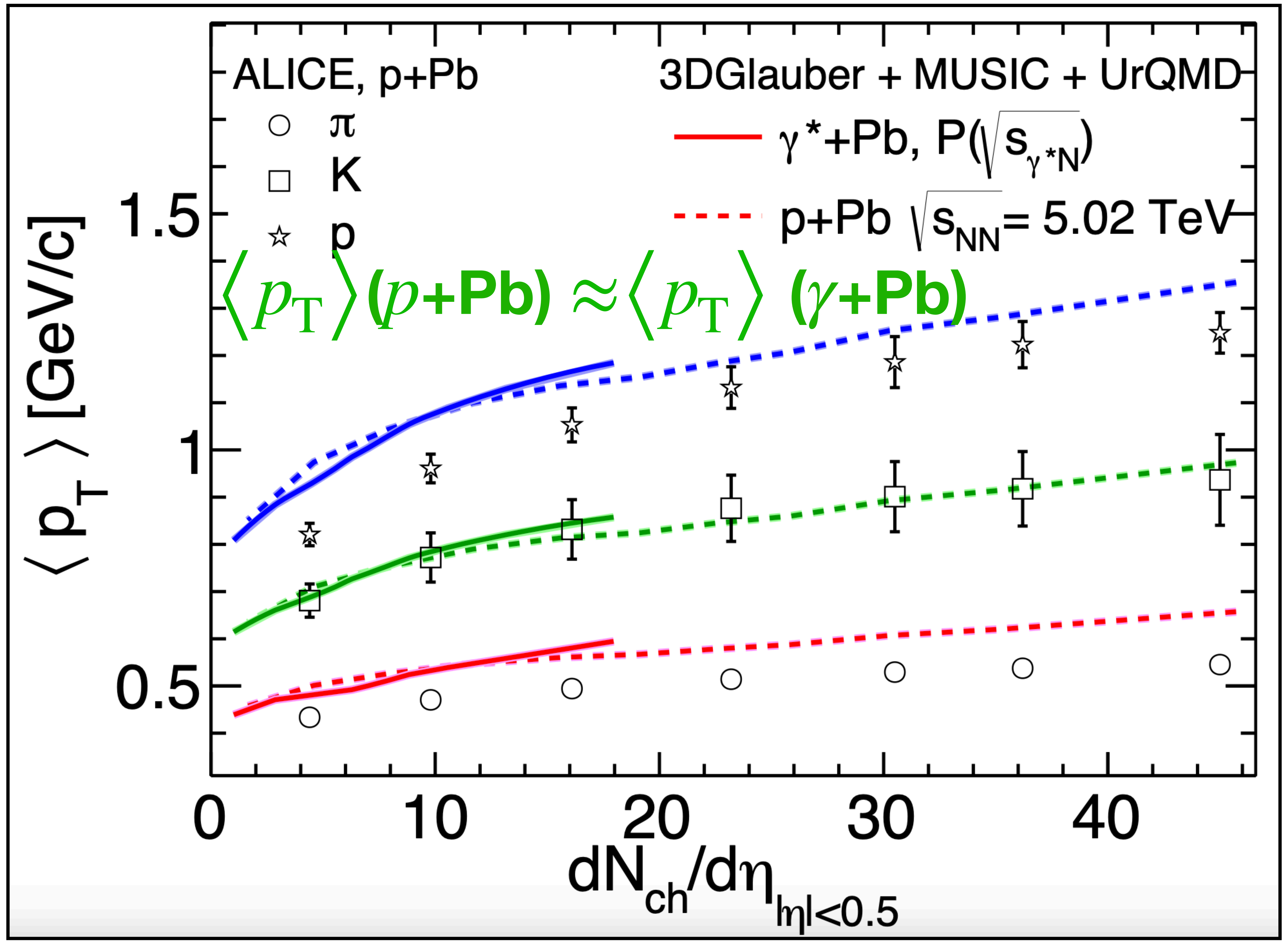

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Prediction is that both systems should have same radial flow, therefore the same $\langle p_T \rangle$

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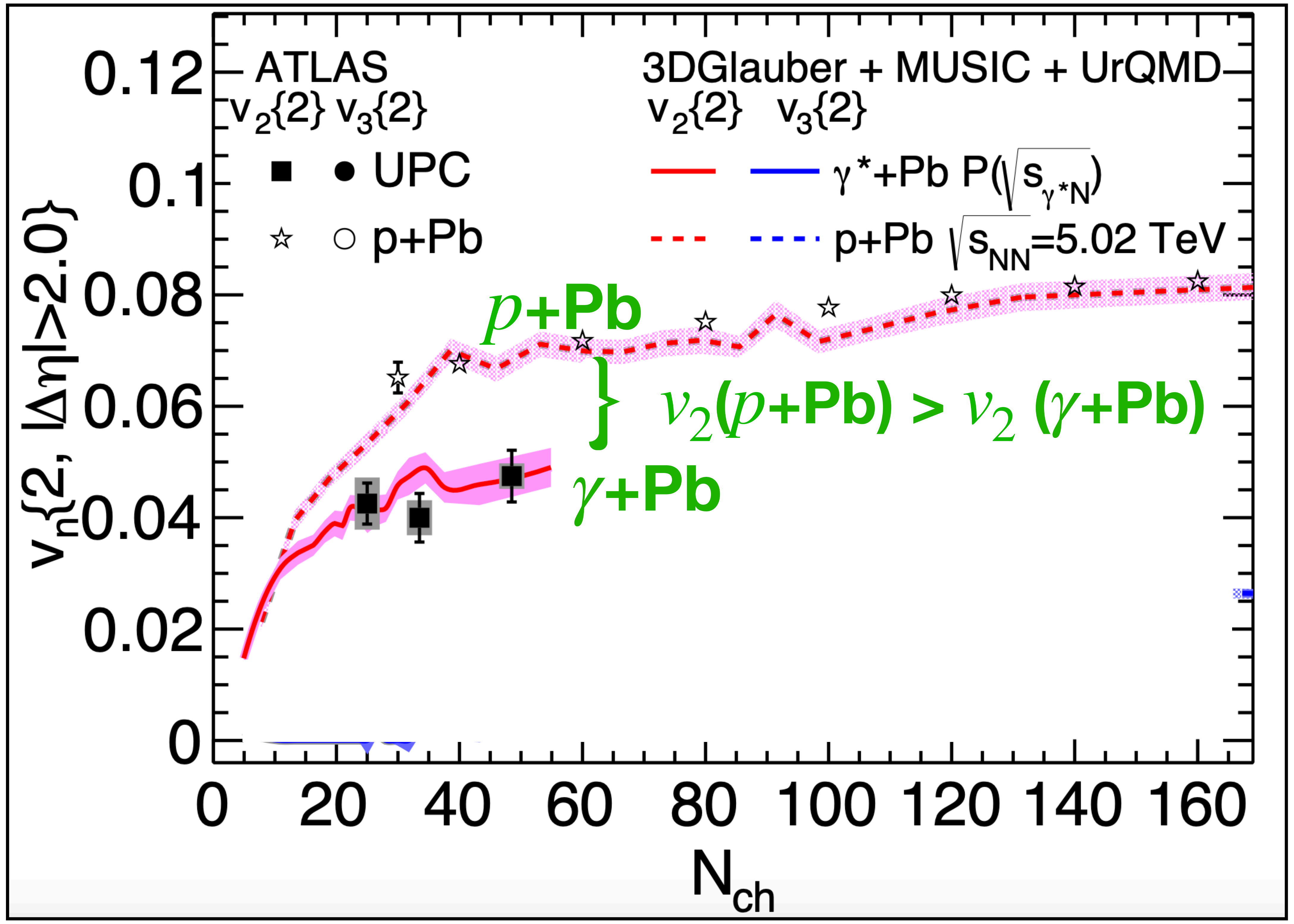
Phys. Rev. Lett. 129, 252302 Wenbin Zhao, Chun Shen, and Björn Schenke



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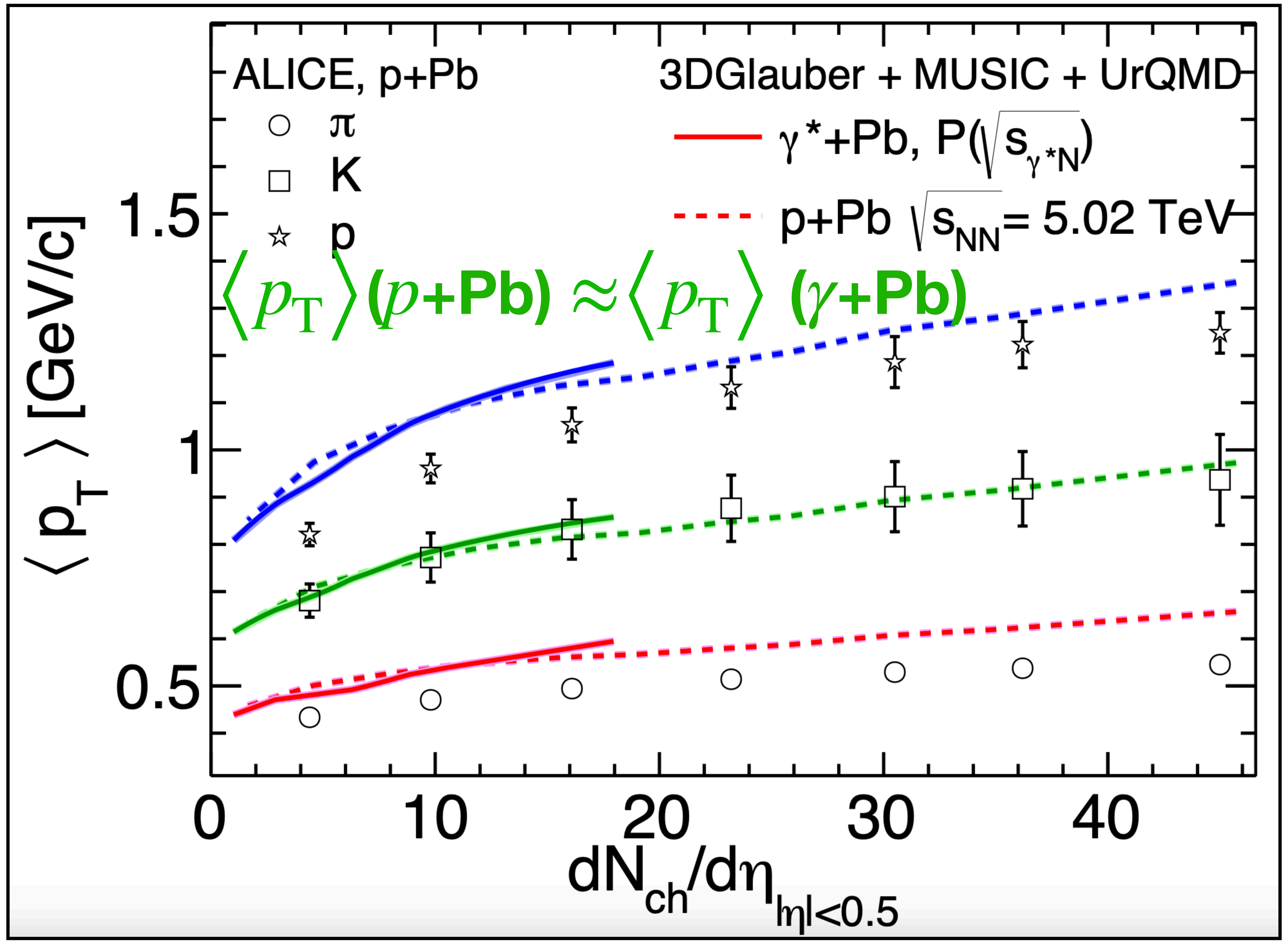

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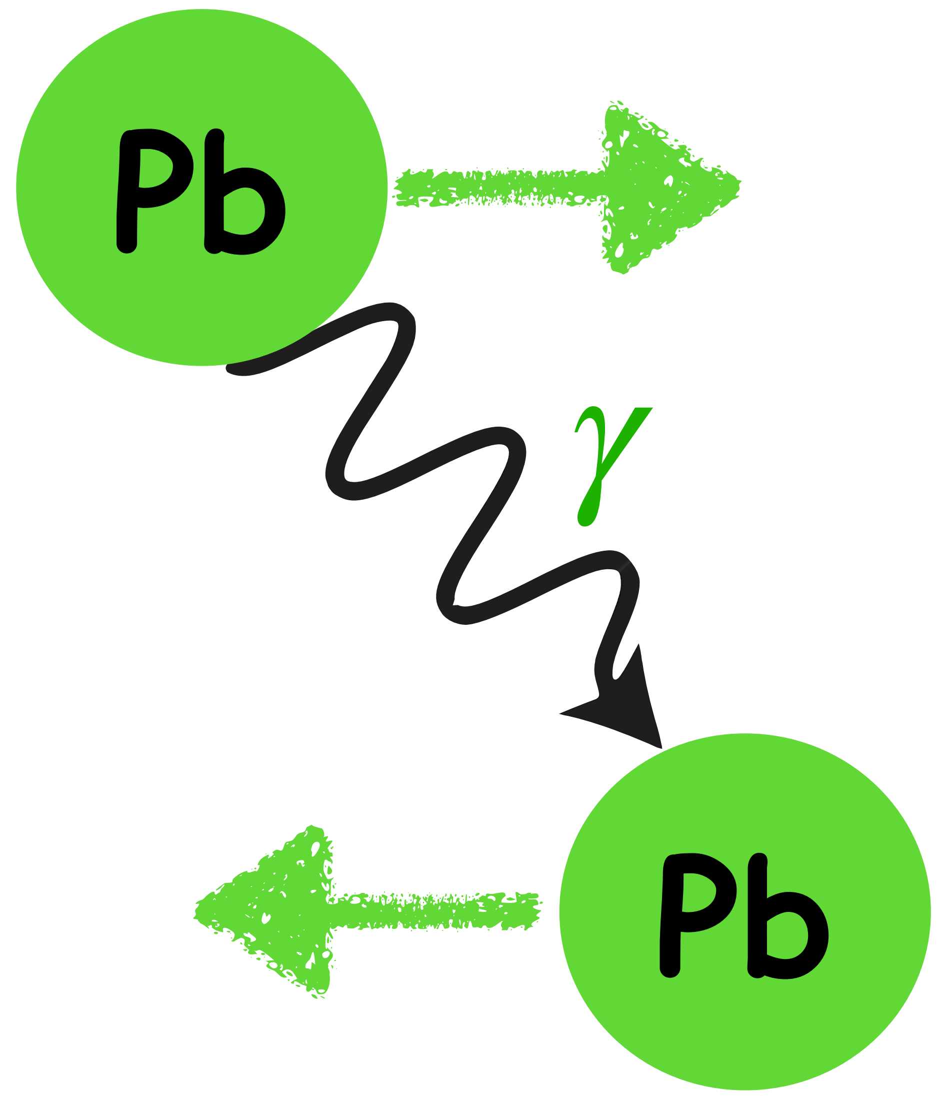
Relevant observables: $\langle p_T \rangle$ of charged hadrons

ATLAS-CONF-2023-059

Global characterization of photo-nuclear events

Characterizing photo-nuclear events places constraints on γA models



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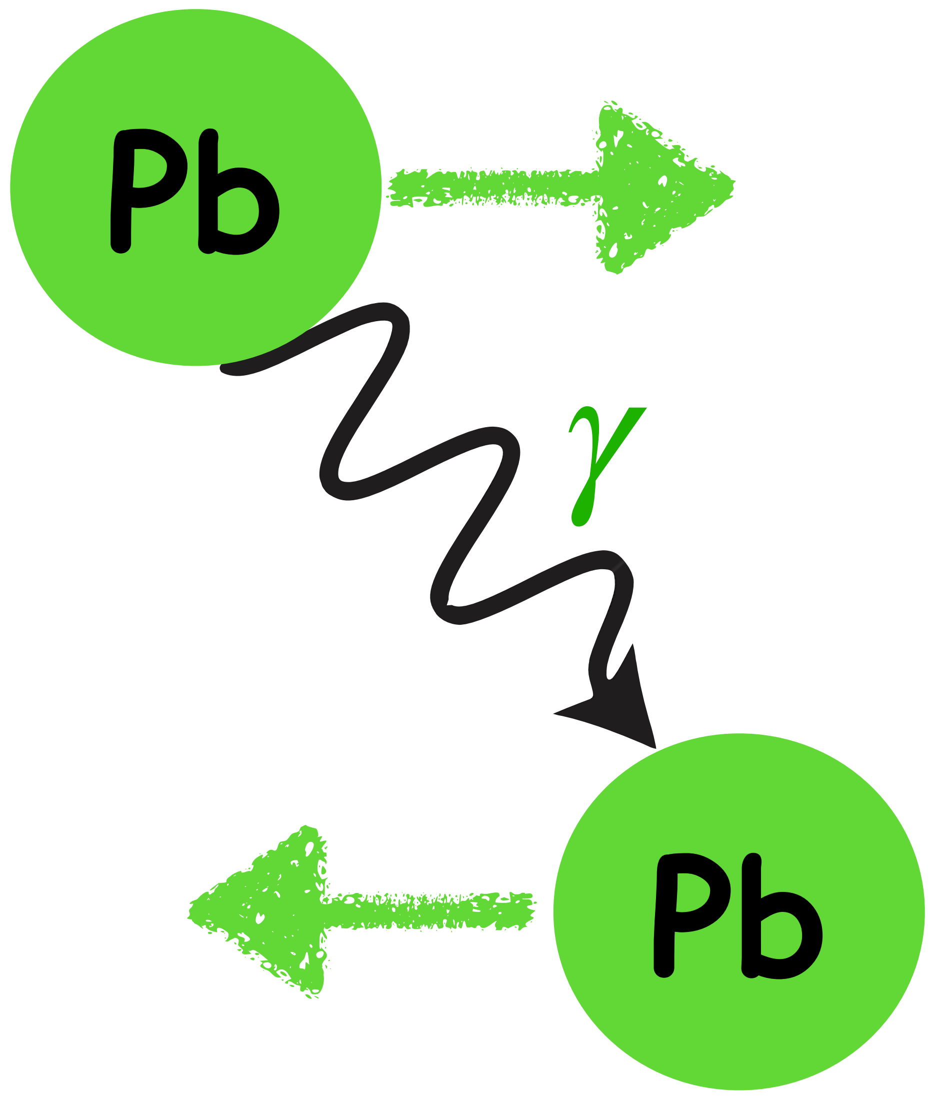

The Monte-Carlo model used:
DPMJET-III+STARLight γA

- Photon-flux from *STARLight*
- *DPMJET-III* collides γA

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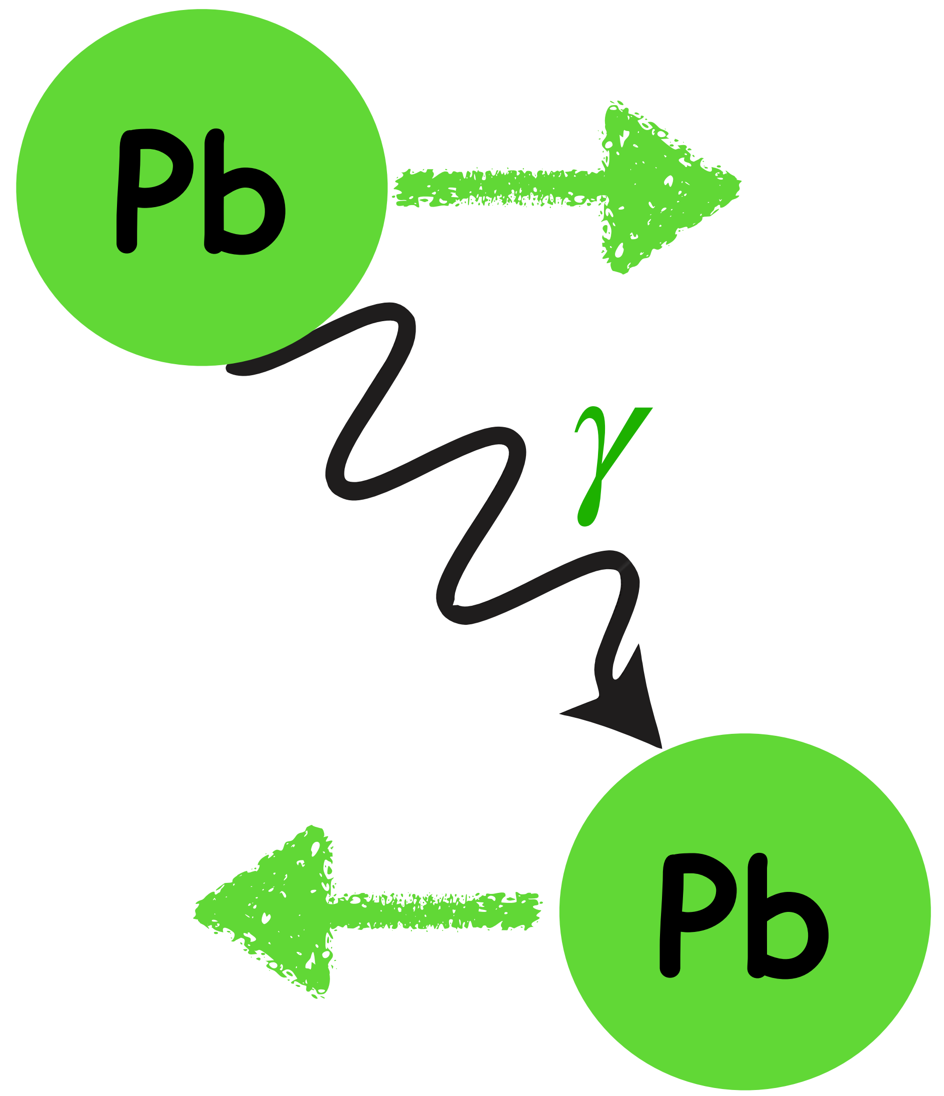

We look forward to Pythia γA!

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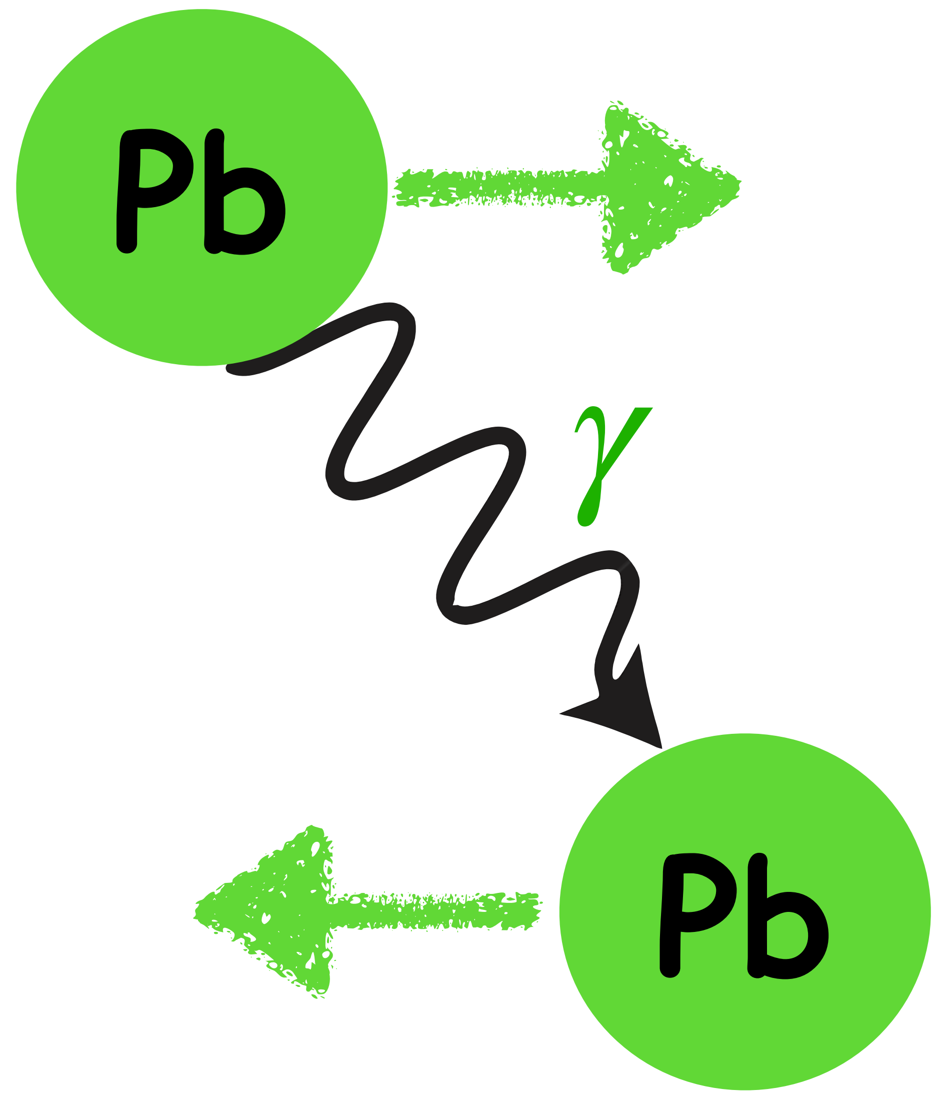
Global characterization of photo-nuclear events

Characterizing photo-nuclear events places constraints on γA models



We look forward to Pythia γA!

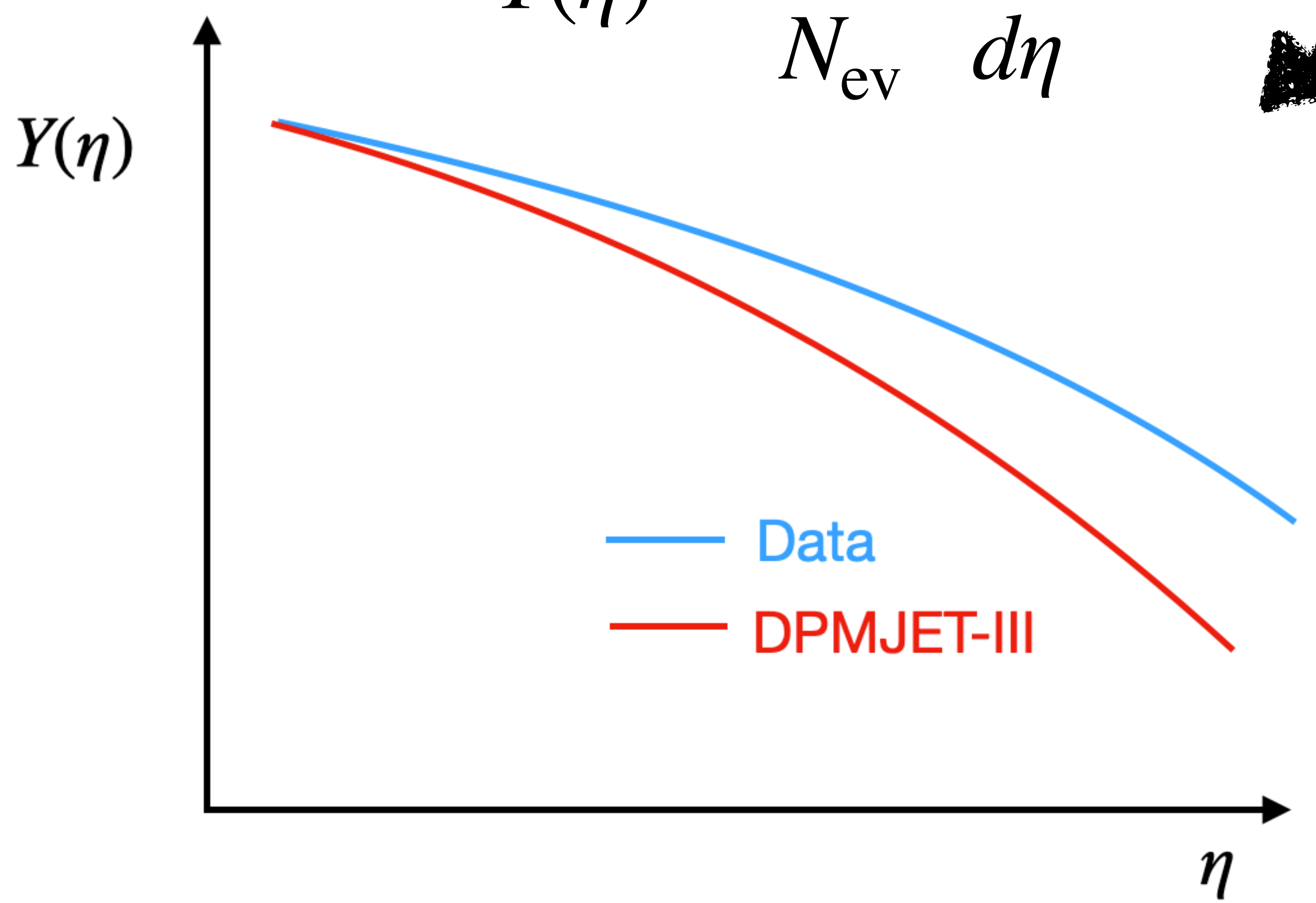
The Monte-Carlo model used: *DPMJET-III+STARLight γA*

- Photon-flux from *STARLight*
- *DPMJET-III* collides γA

Relevant observables: *ATLAS-CONF-2023-059*

Kinematic distributions

$$Y(\eta) = \frac{1}{N_{\mathrm{ev}}} \frac{dN_{\mathrm{ch}}}{d\eta}$$



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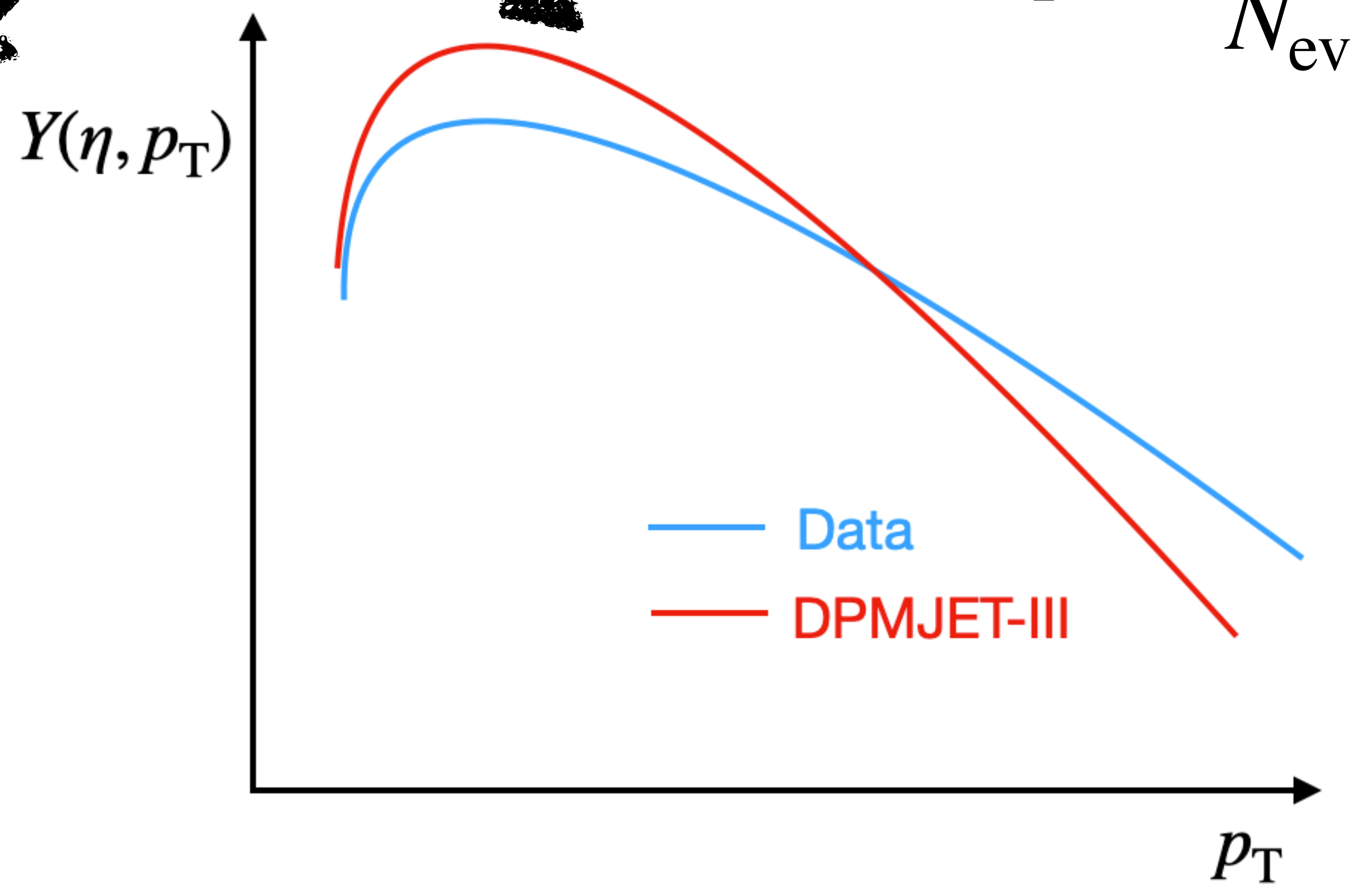

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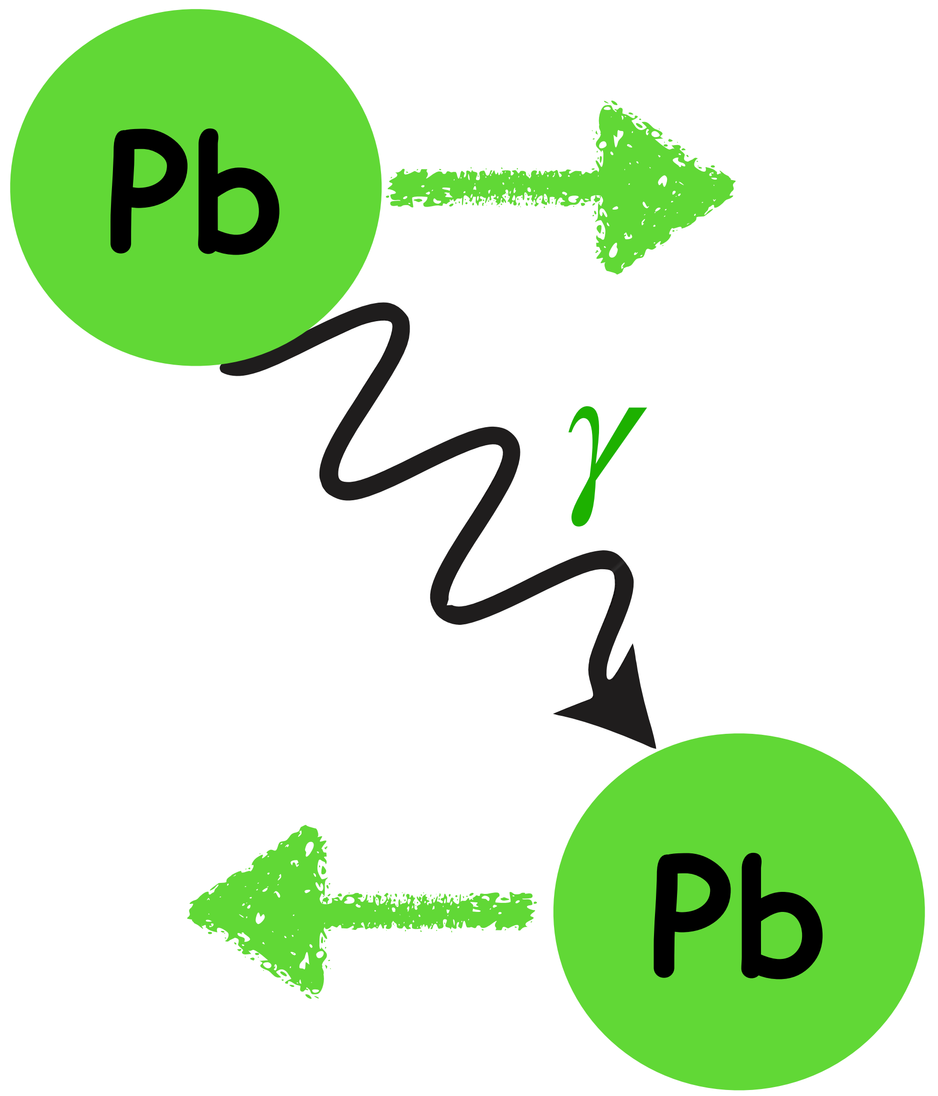

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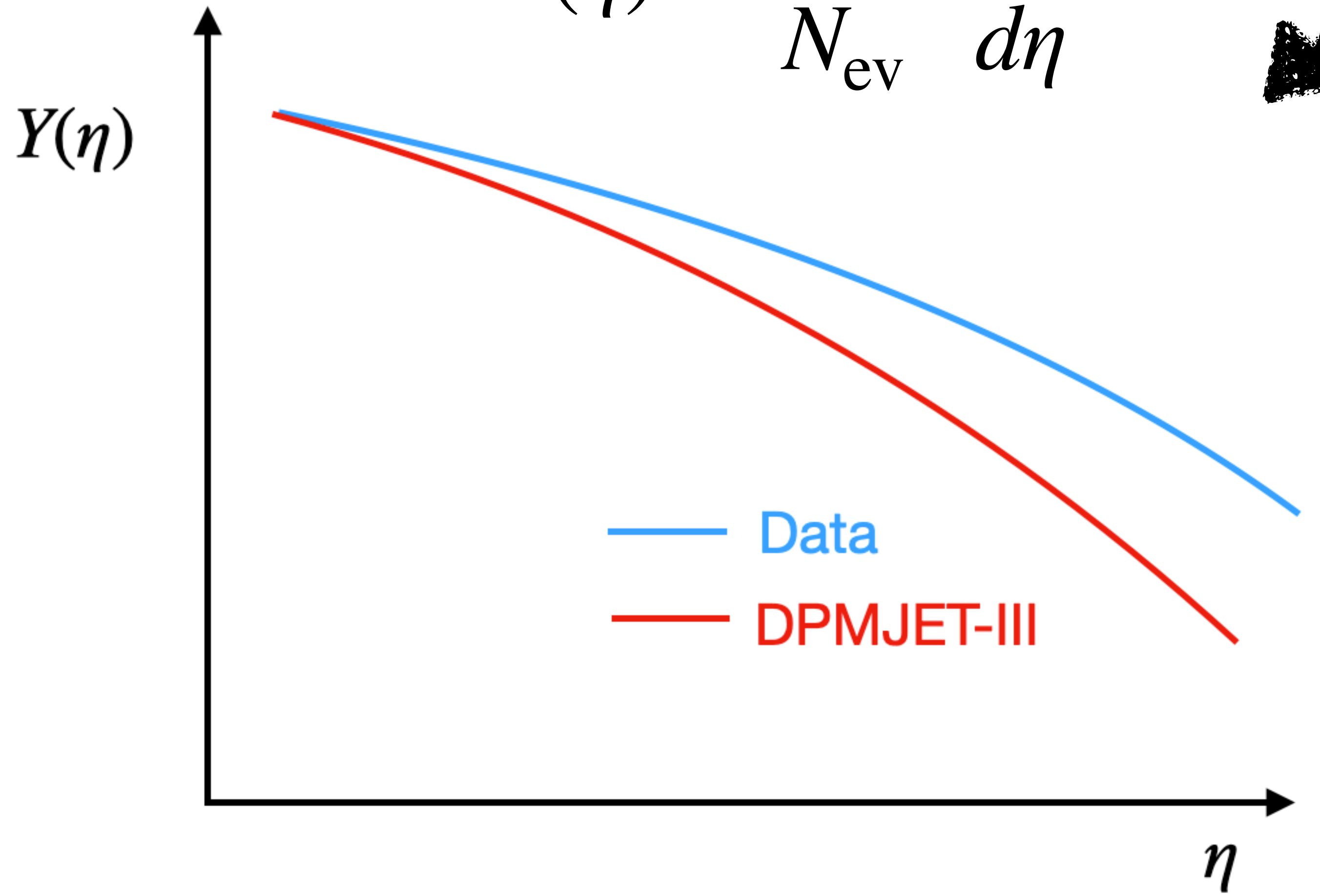

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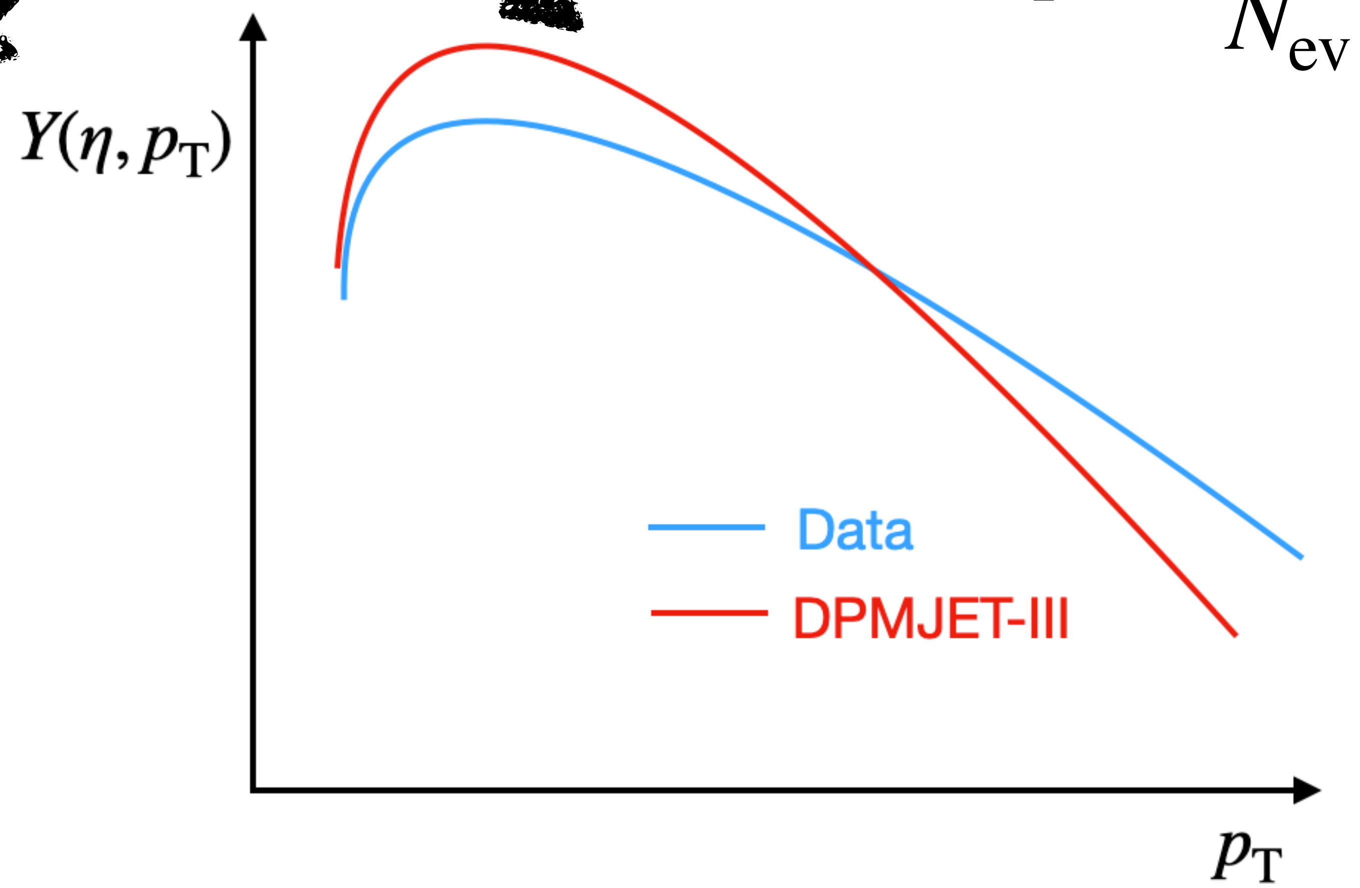


$\langle \eta \rangle$ - Photon energy and kinematics?

$\langle p_{\mathrm{T}} \rangle$ - Sensitive to radial flow

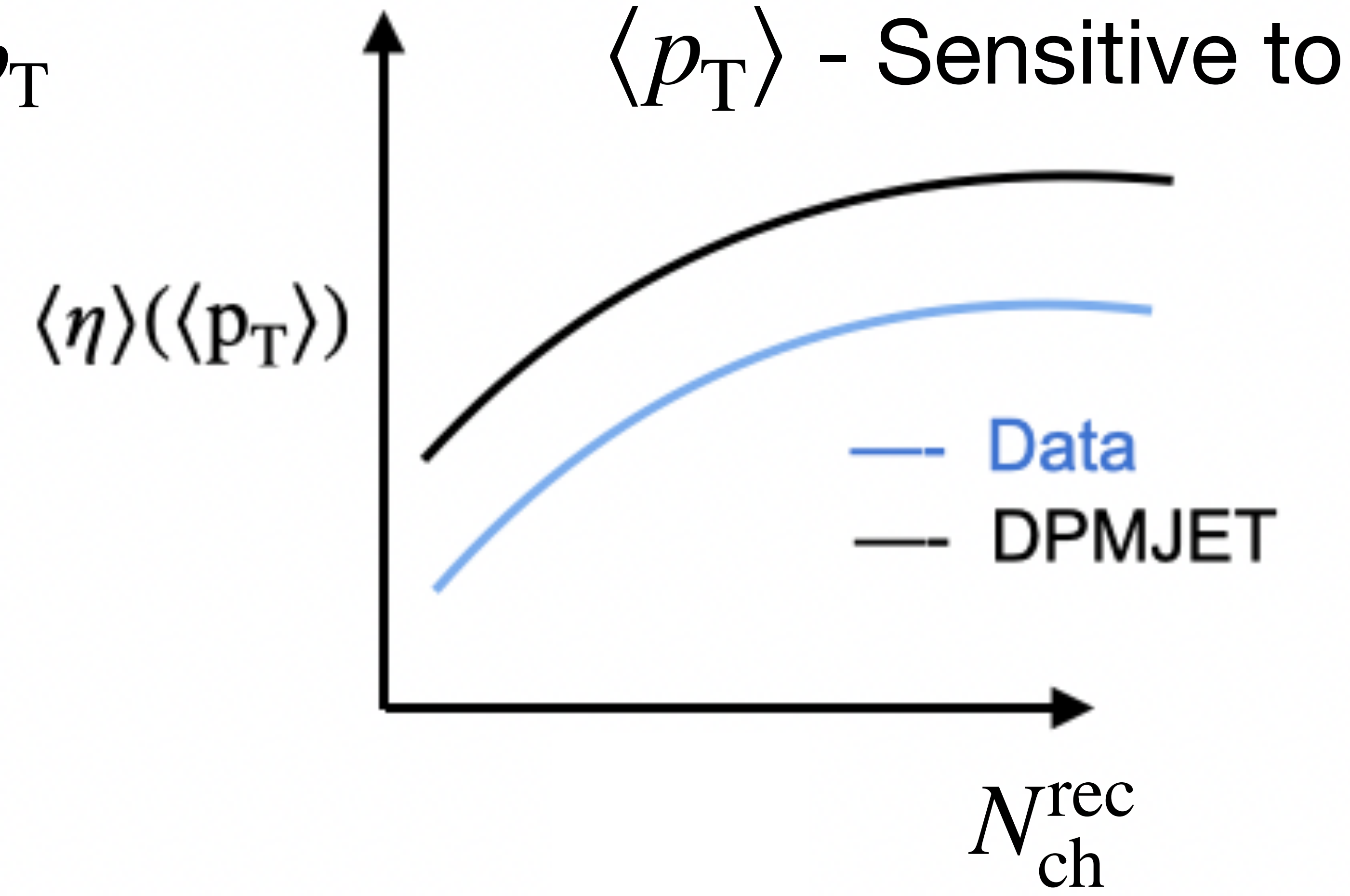
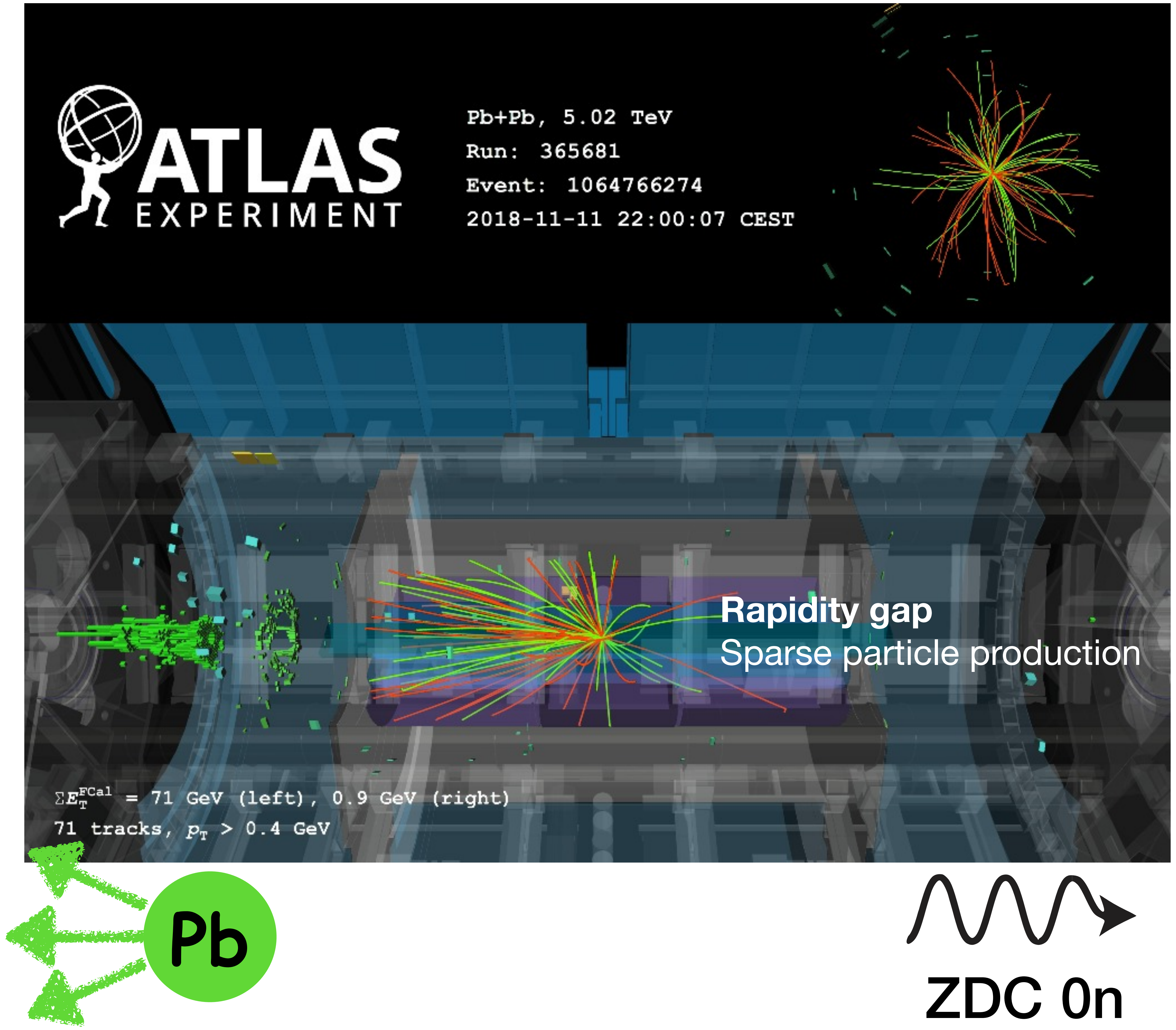


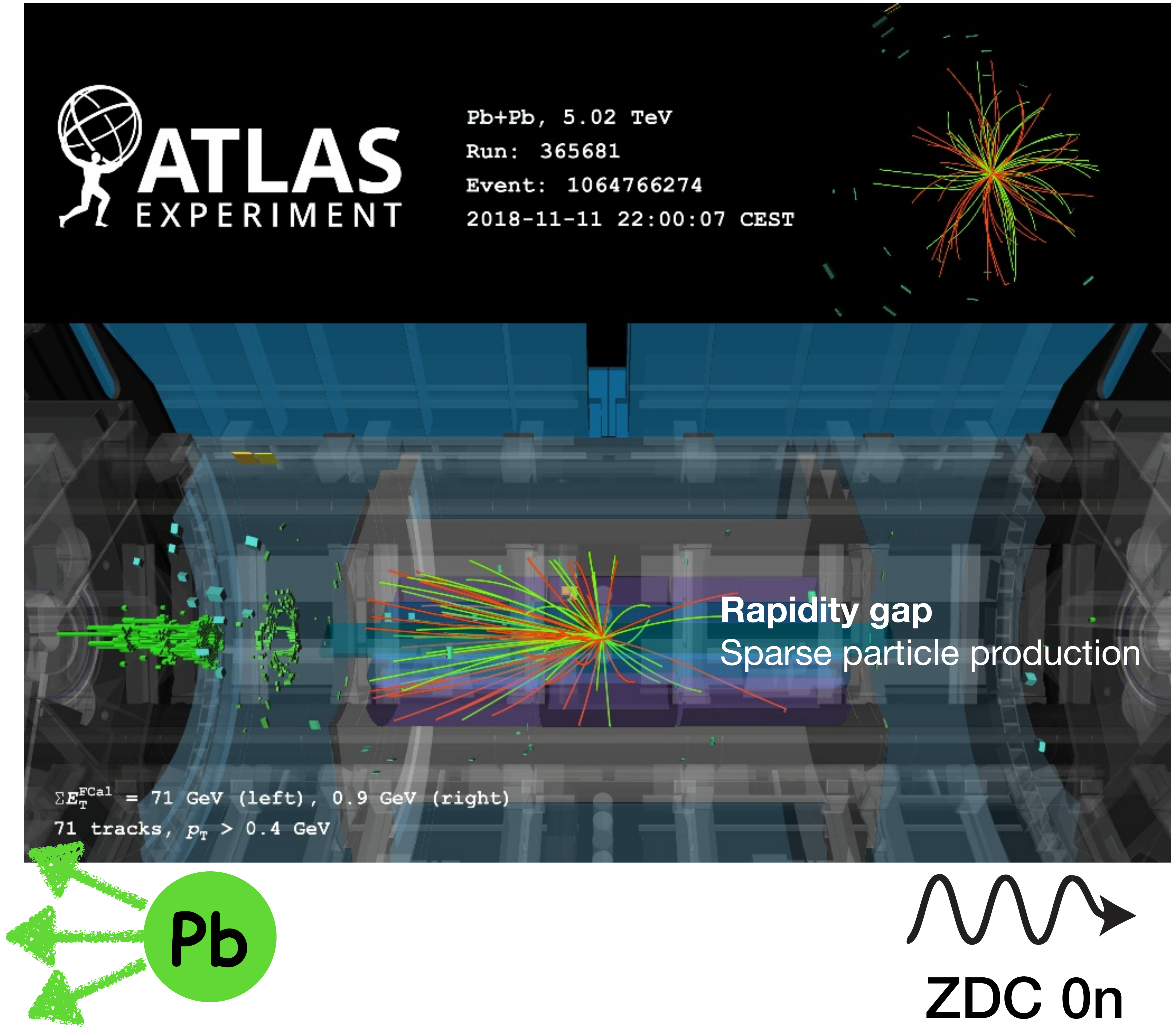
Photo-nuclear event selection

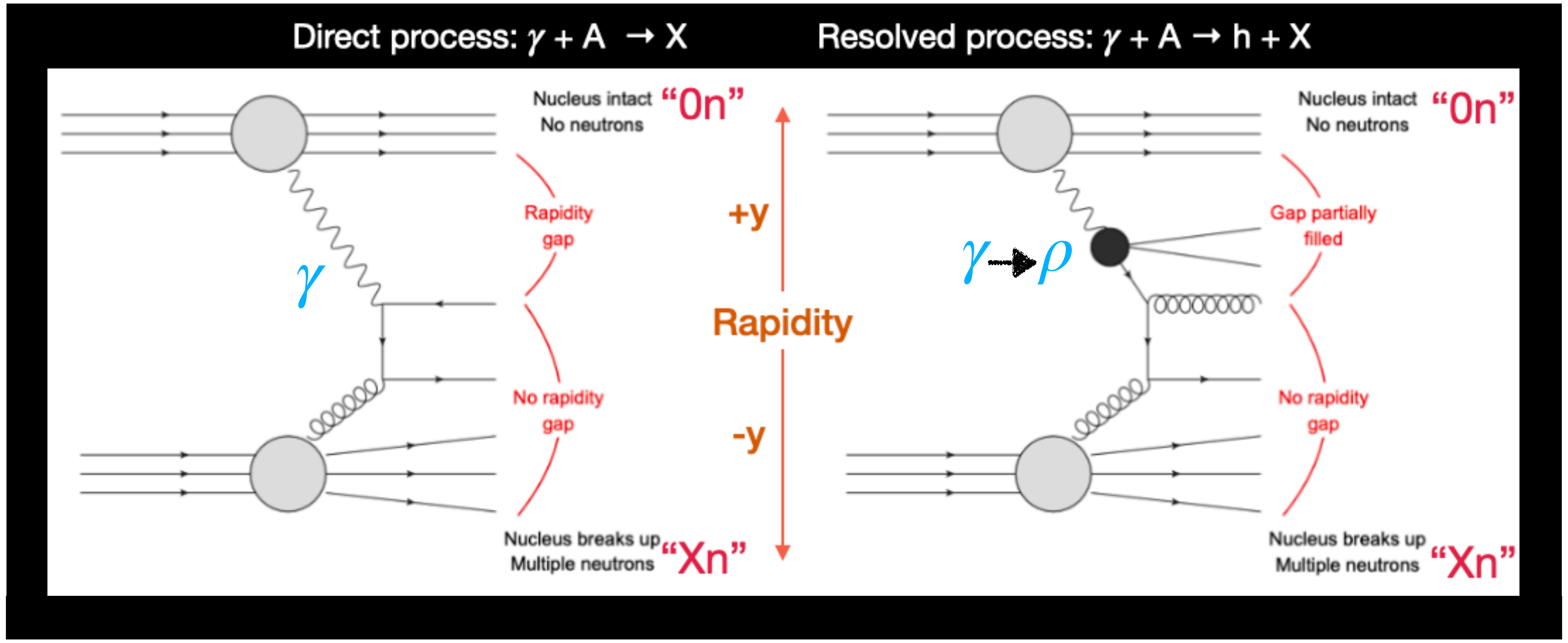


ZDC 0n

ZDC Xn

Photo-nuclear event selection





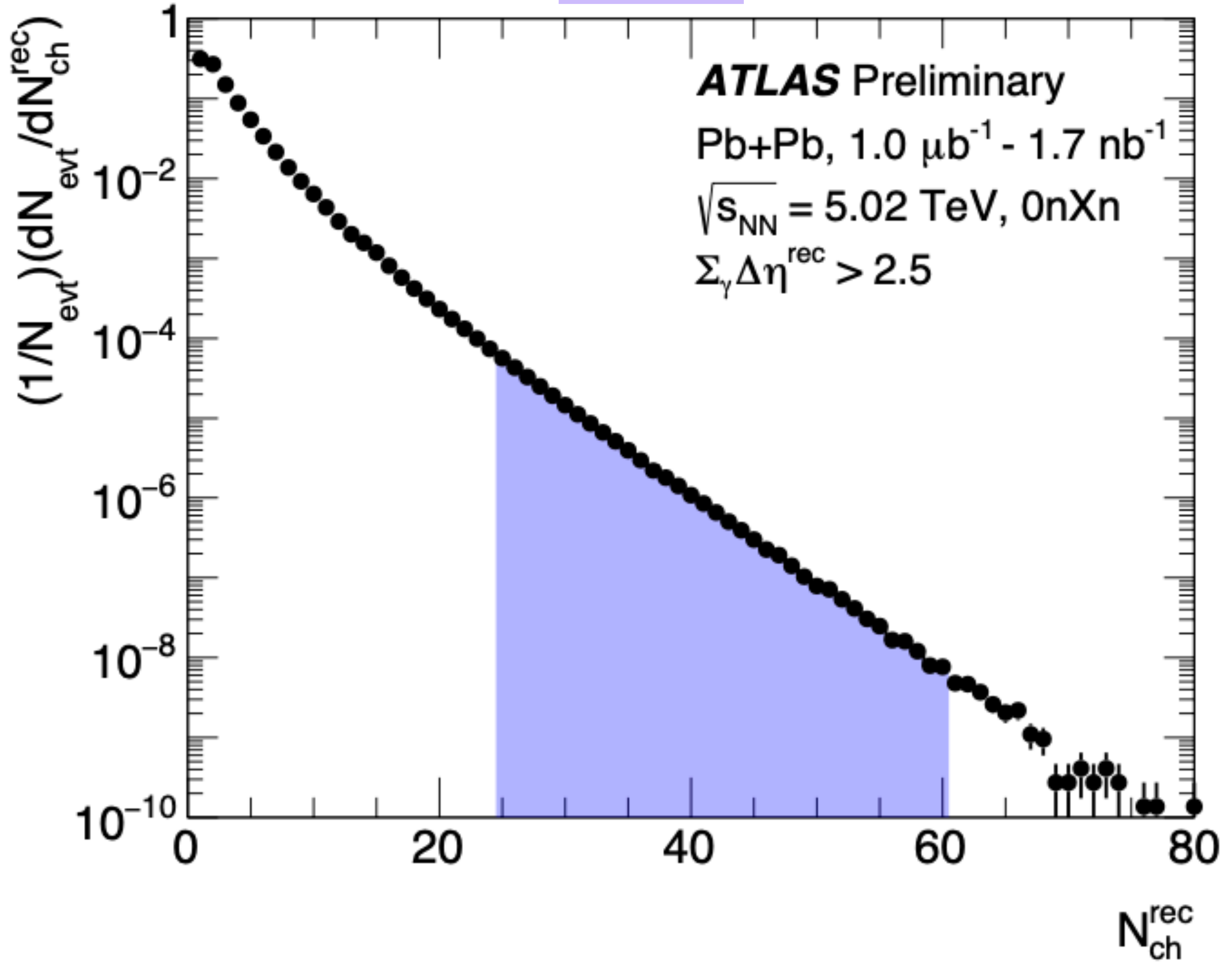
Single sided nuclear breakup "0nXn" &

$$\Sigma_{\gamma}\Delta\eta^{\rm rec} > 2.5$$

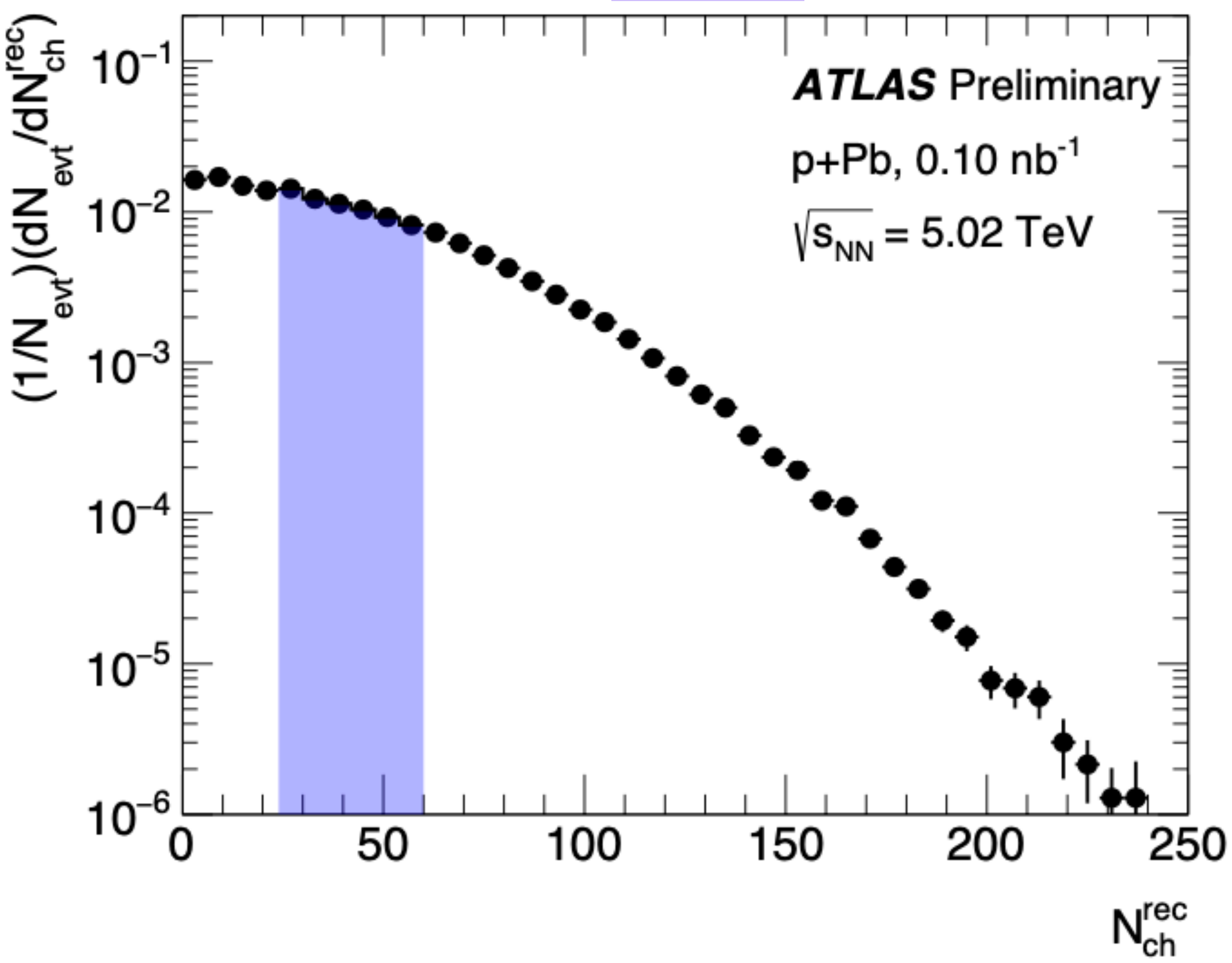
Multiplicity selection

ATLAS-CONF-2023-059

γ+Pb



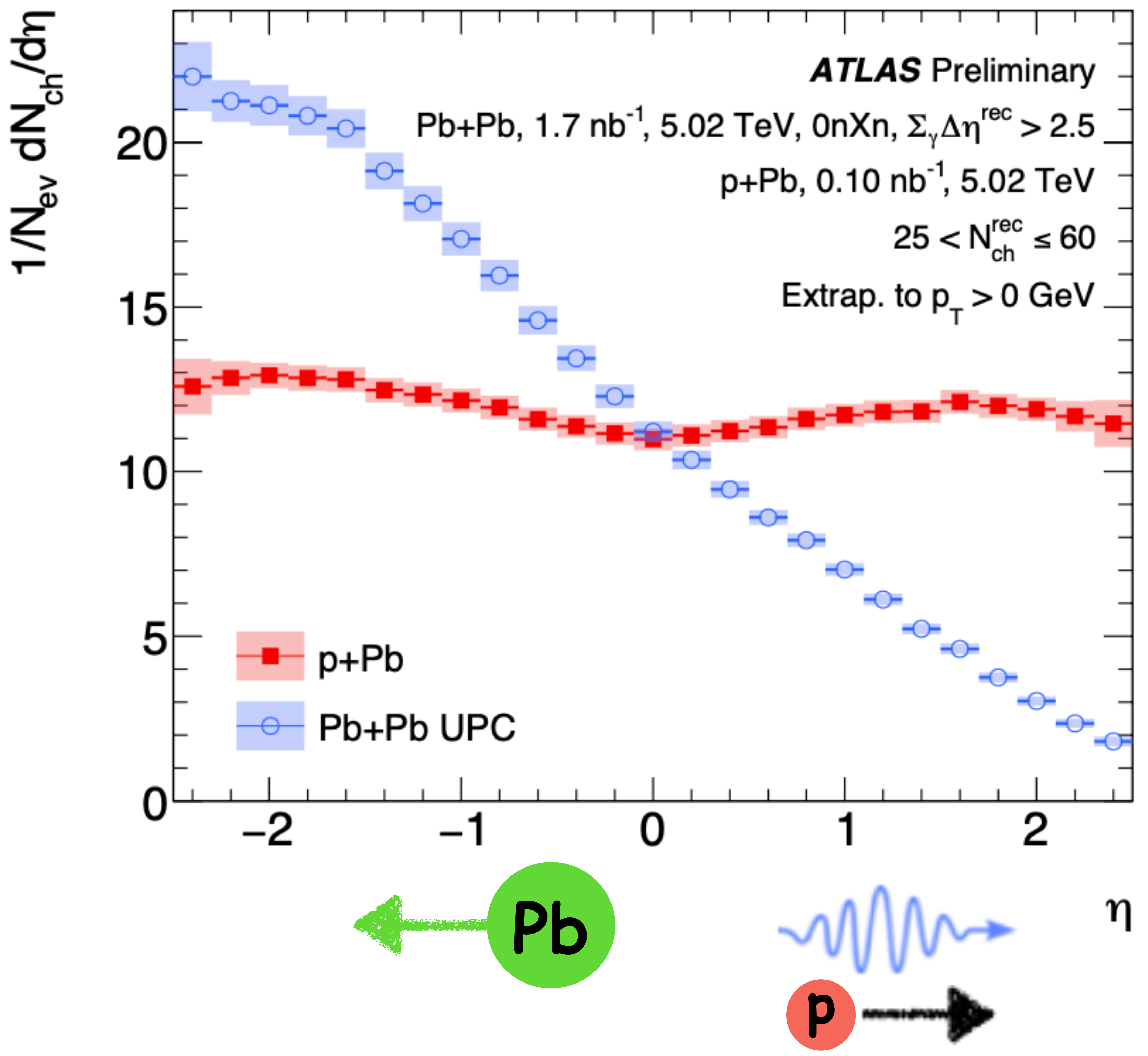
p+Pb



Analysis event class is chosen to have N_{ch}^{rec}: [25,60] and subdivisions

* For later comparisons, N_{ch}^{rec} distribution in p+Pb is re-weighted to match that of γ+Pb.

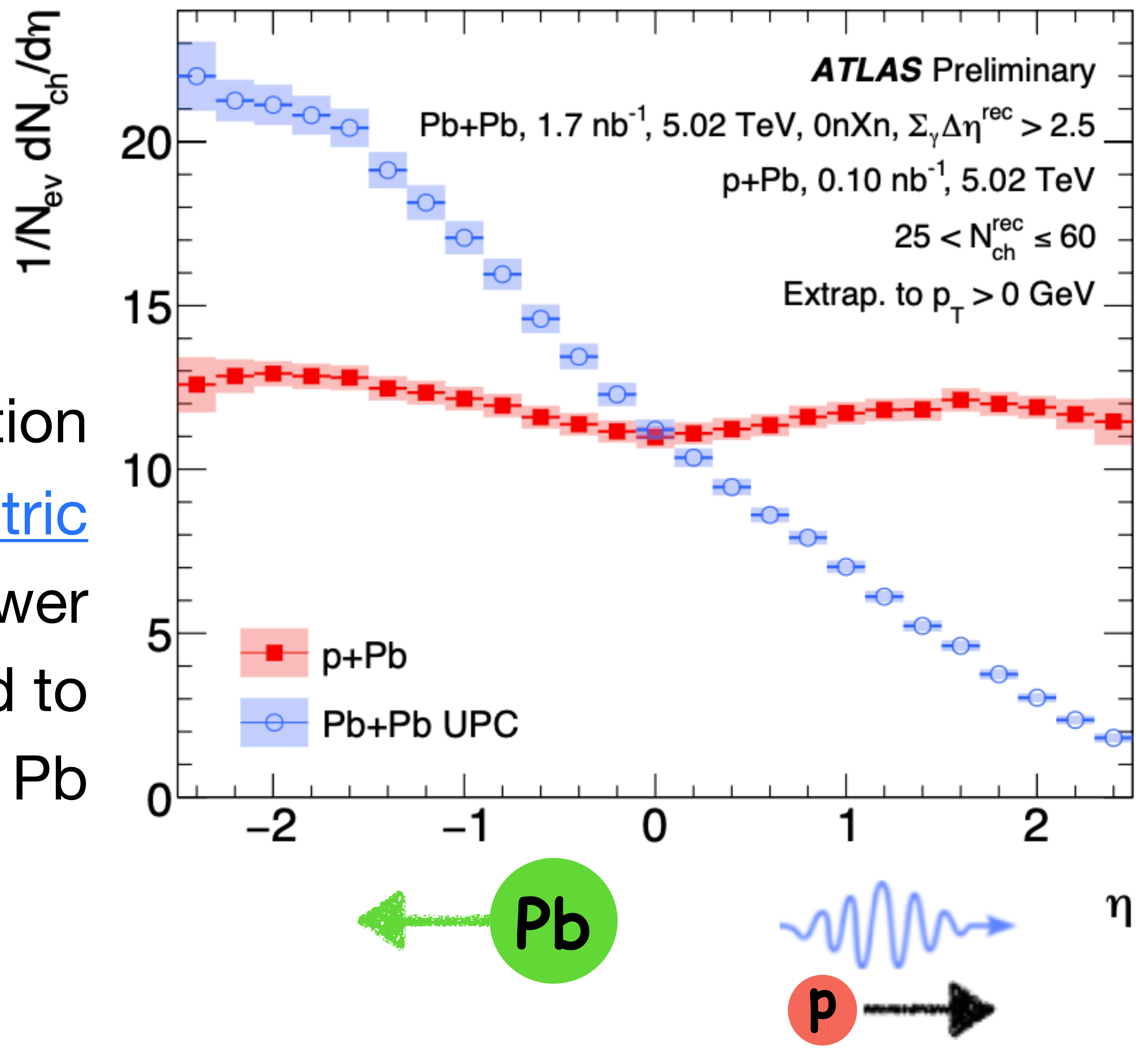
Results: γ+Pb vs p+Pb



Results: γ+Pb vs p+Pb

γ+Pb distribution is highly asymmetric

Photon energy lower compared to energy per nucleon in Pb



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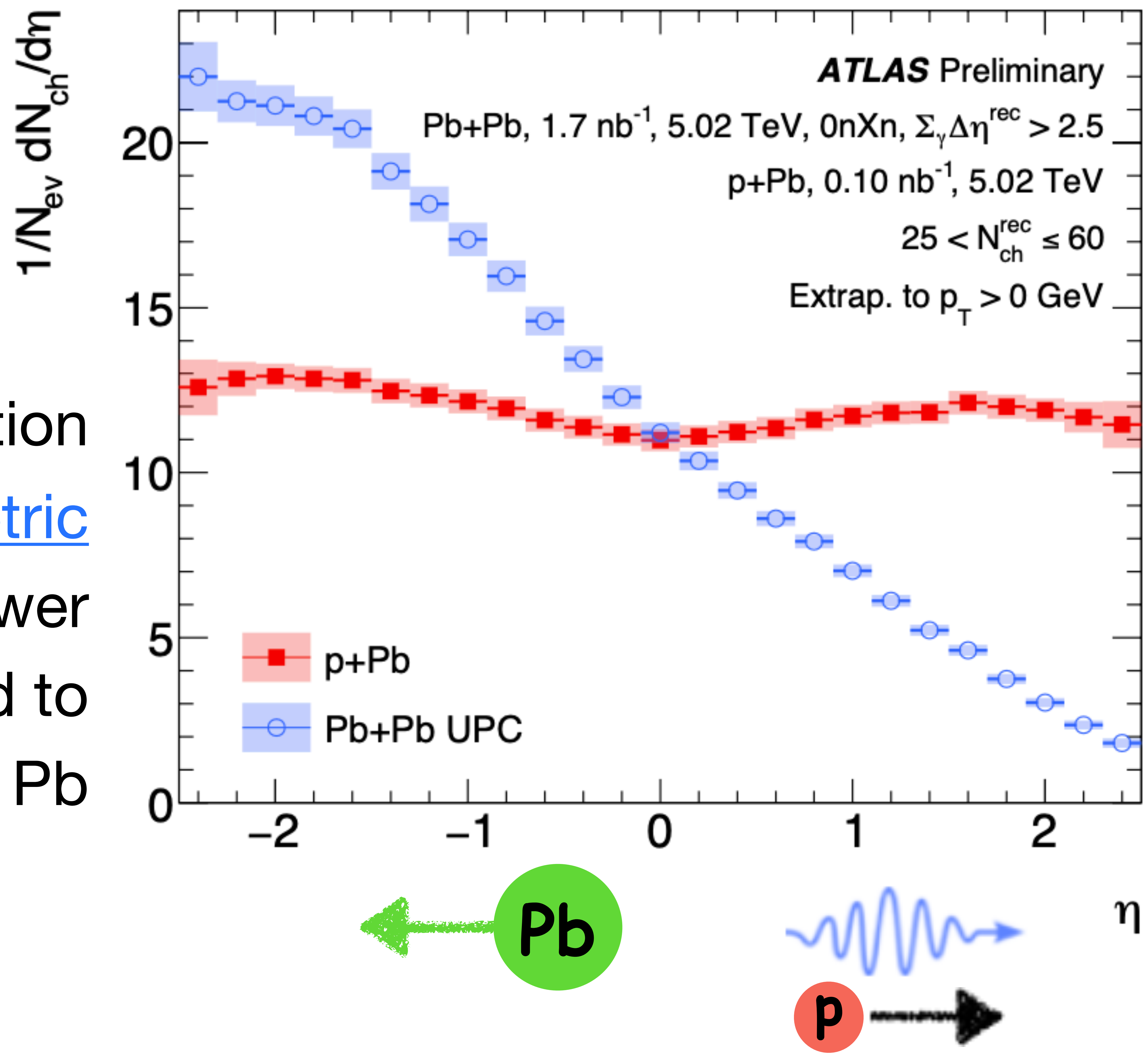
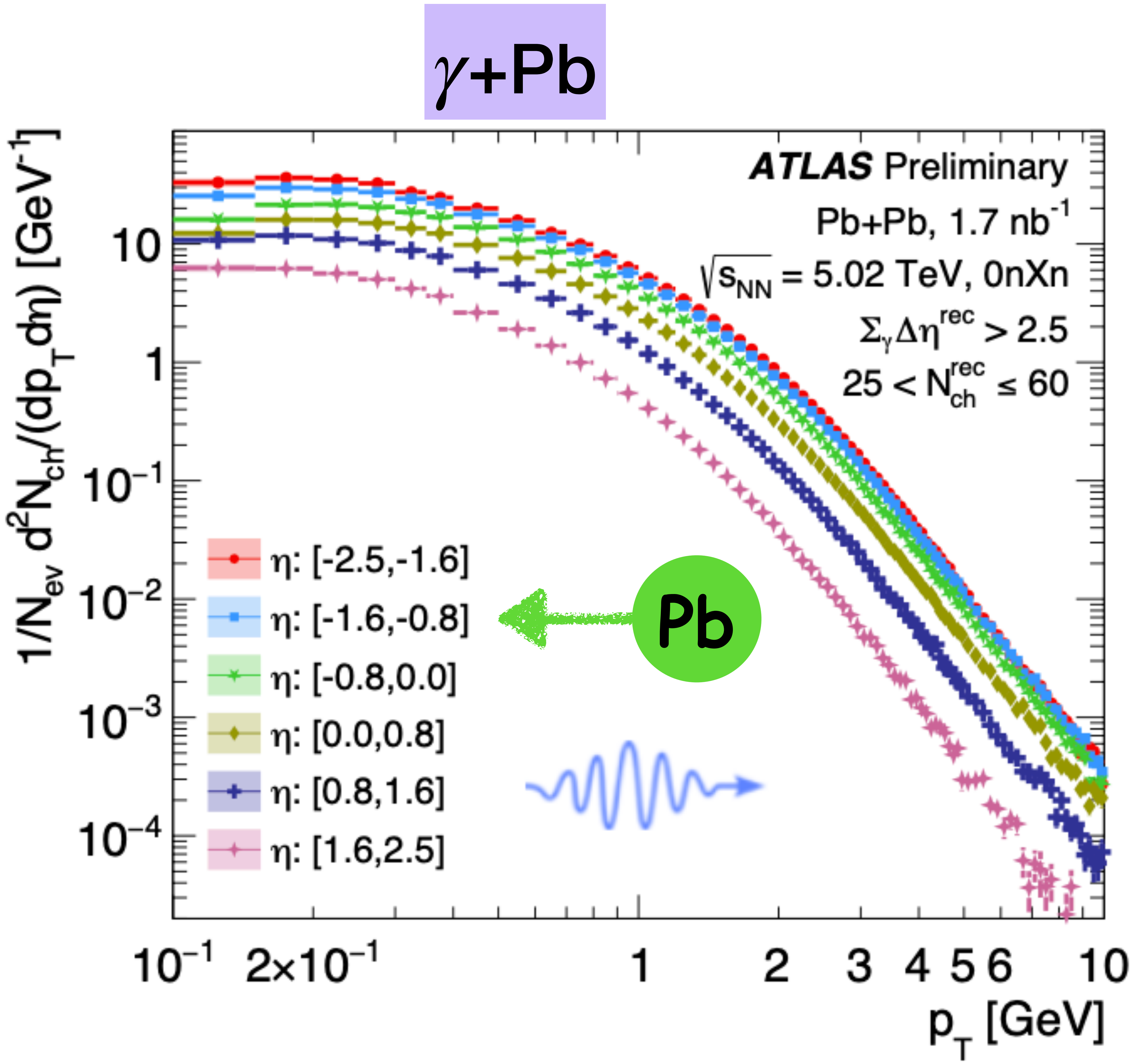


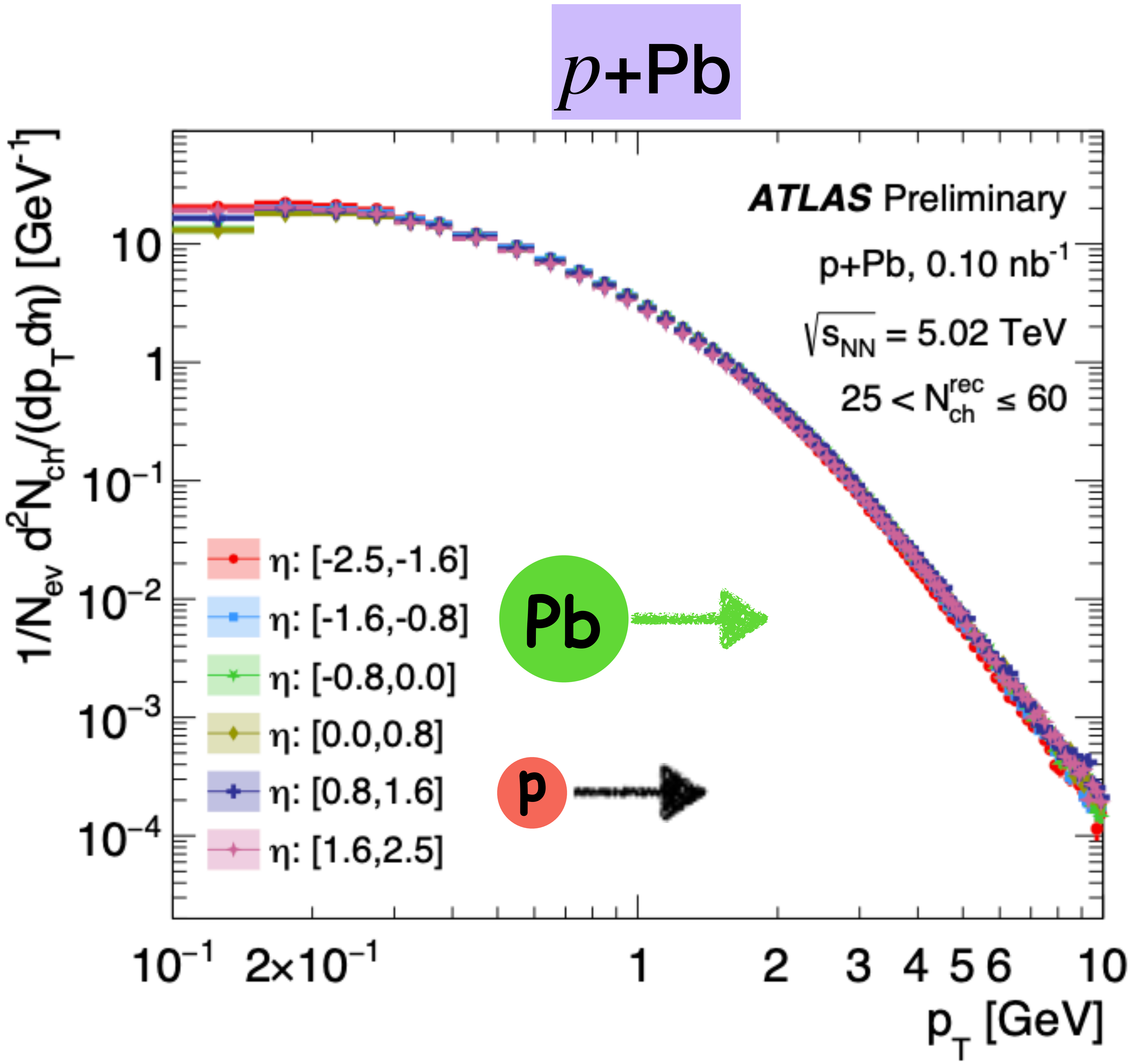
p+Pb distribution is nearly symmetric for selected low multiplicity events

Given the extreme asymmetry, it is important to study γ+Pb properties in different η regions separately!

ATLAS-CONF-2023-059

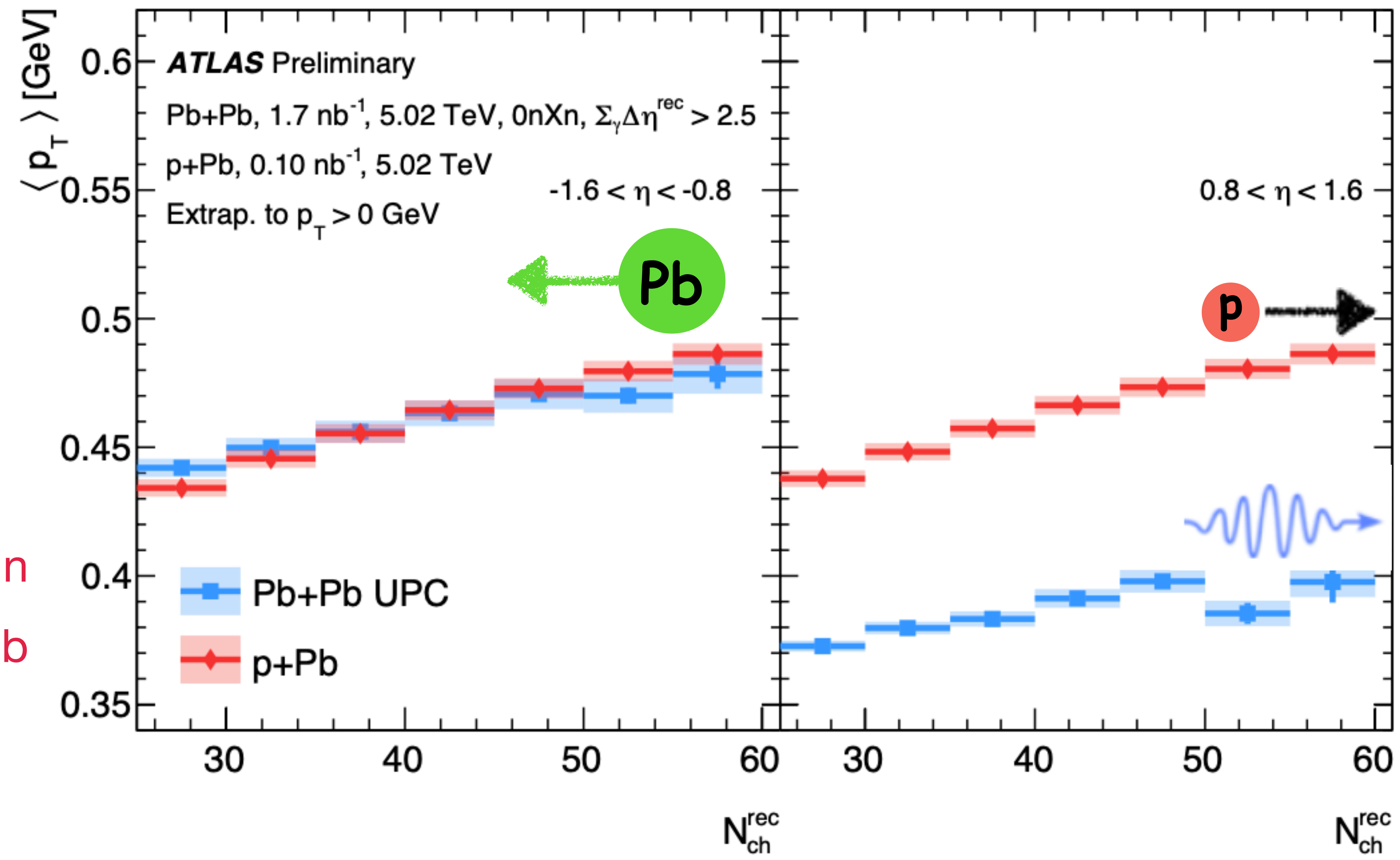
Results: γ+Pb vs p+Pb





Similarly falling momentum distributions. Further quantified via $\langle p_{\mathrm{T}} \rangle$

Results: γ+Pb vs p+Pb



$\langle p_T \rangle$ similar in γ+Pb and p+Pb

$\langle p_T \rangle$ lower in γ+Pb than p+Pb

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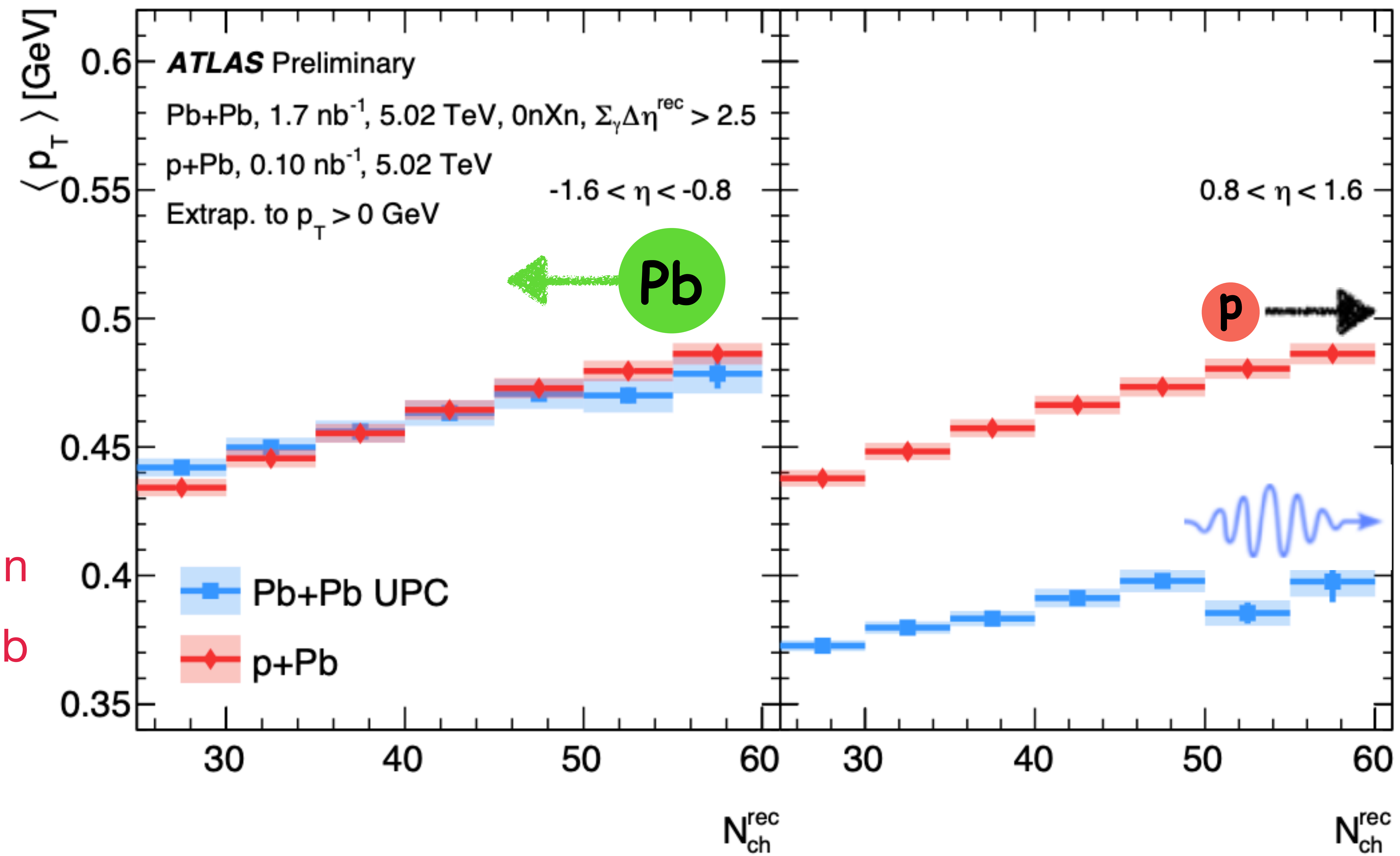

$\langle p_T \rangle$ similar in γ+Pb and p+Pb

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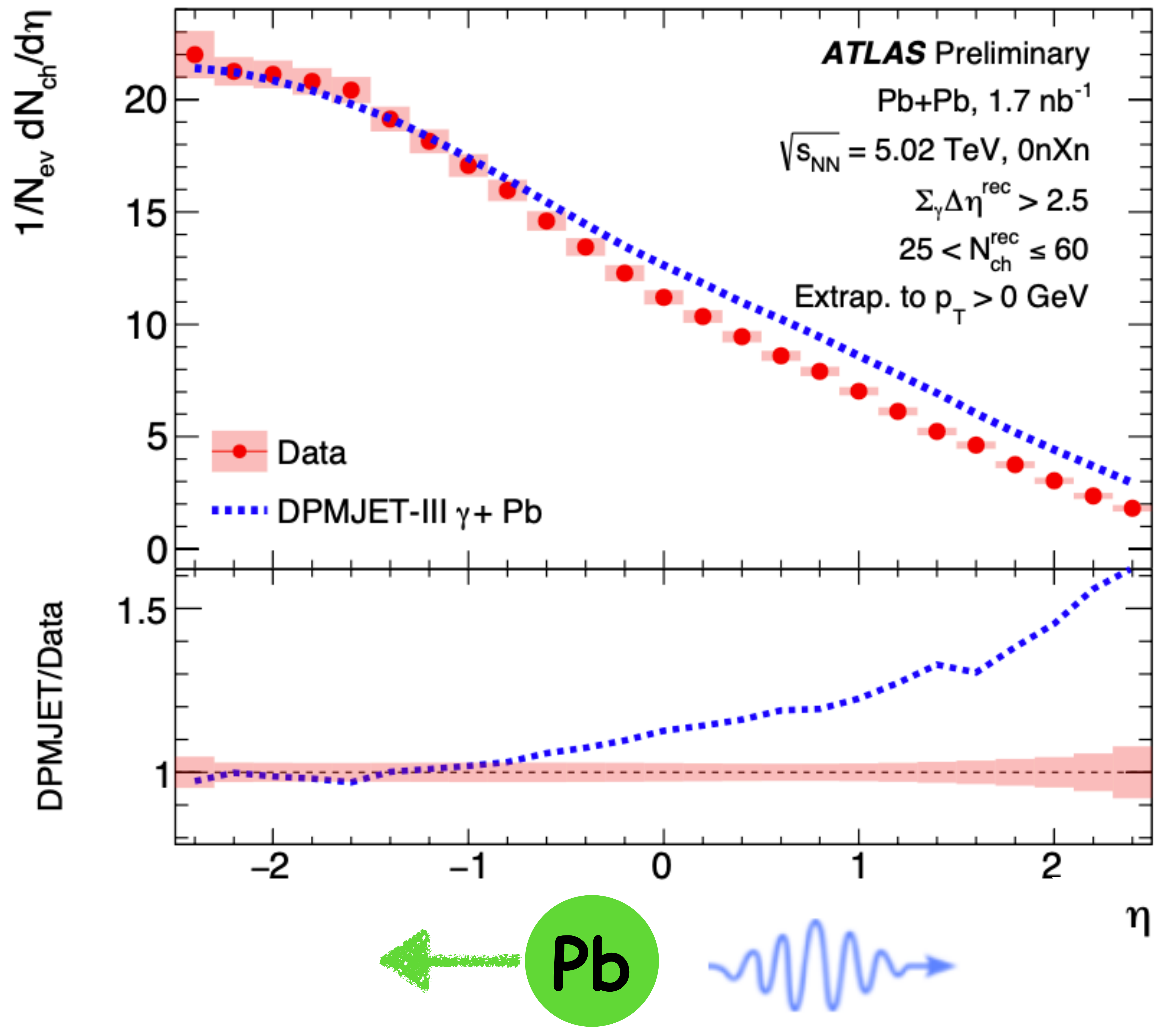
Theory (3+1D hydrodynamics) predicts both γ+Pb and p+Pb should have same radial flow, therefore same $\langle p_T \rangle$ (in backward rapidity). Phys. Rev. Lett. 129, 252302 Wenbin Zhao, Chun Shen, and Björn Schenke

K_S^0, Λ and Ξ^- are more sensitive to radial flow (ongoing work)

DPMJET-III comparison

ATLAS-CONF-2023-059



DPMJET agrees at backward rapidity

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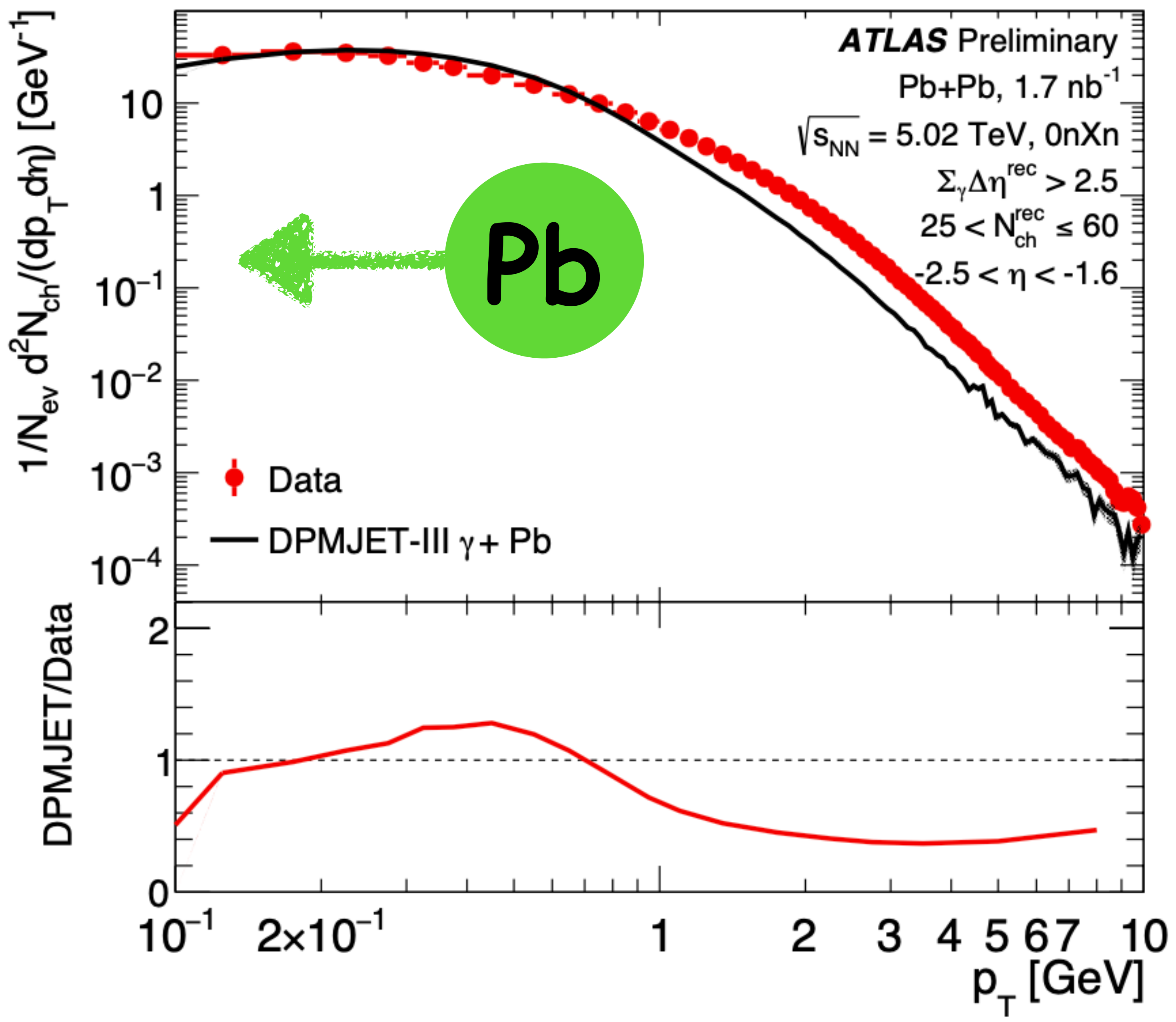

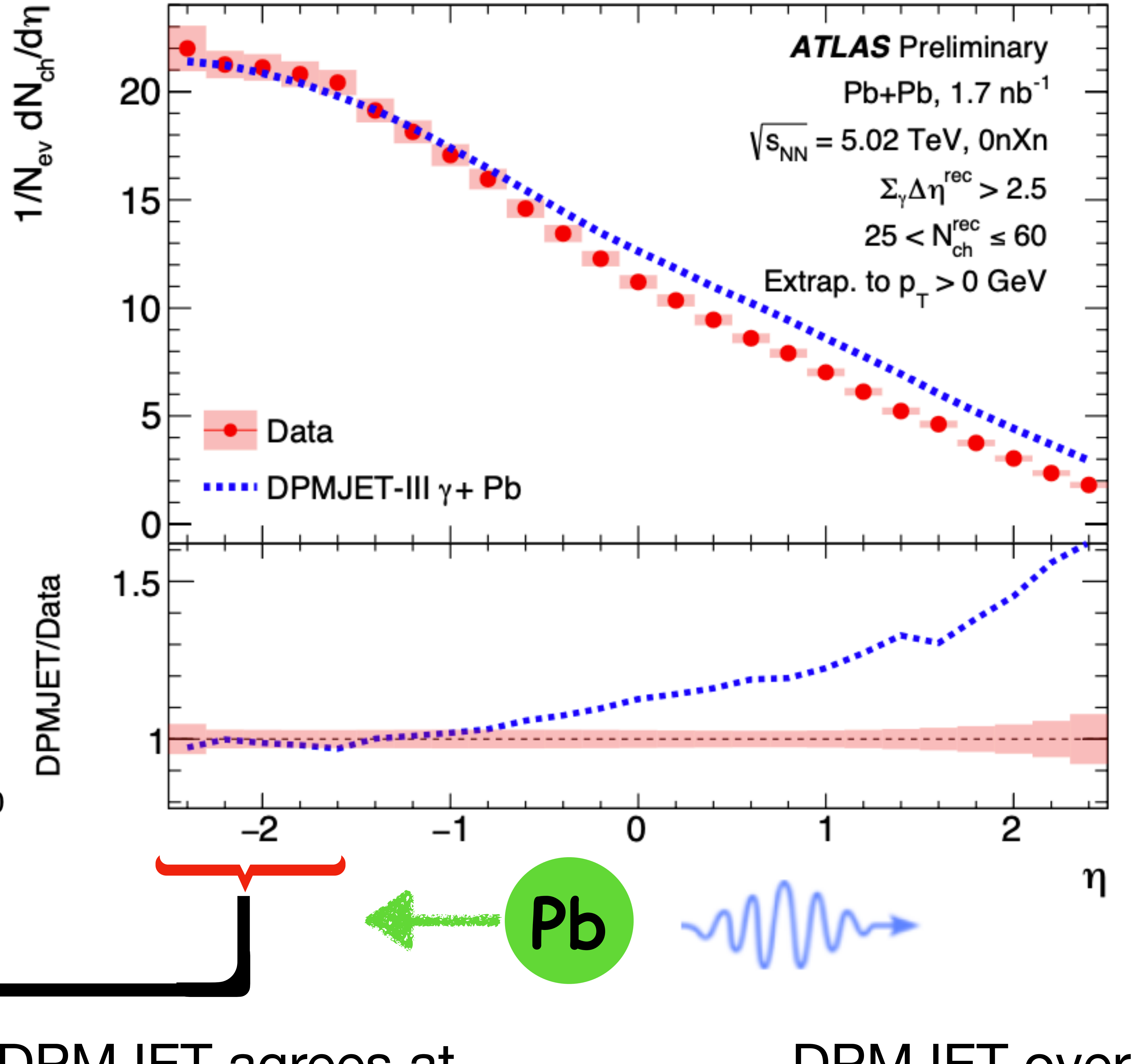

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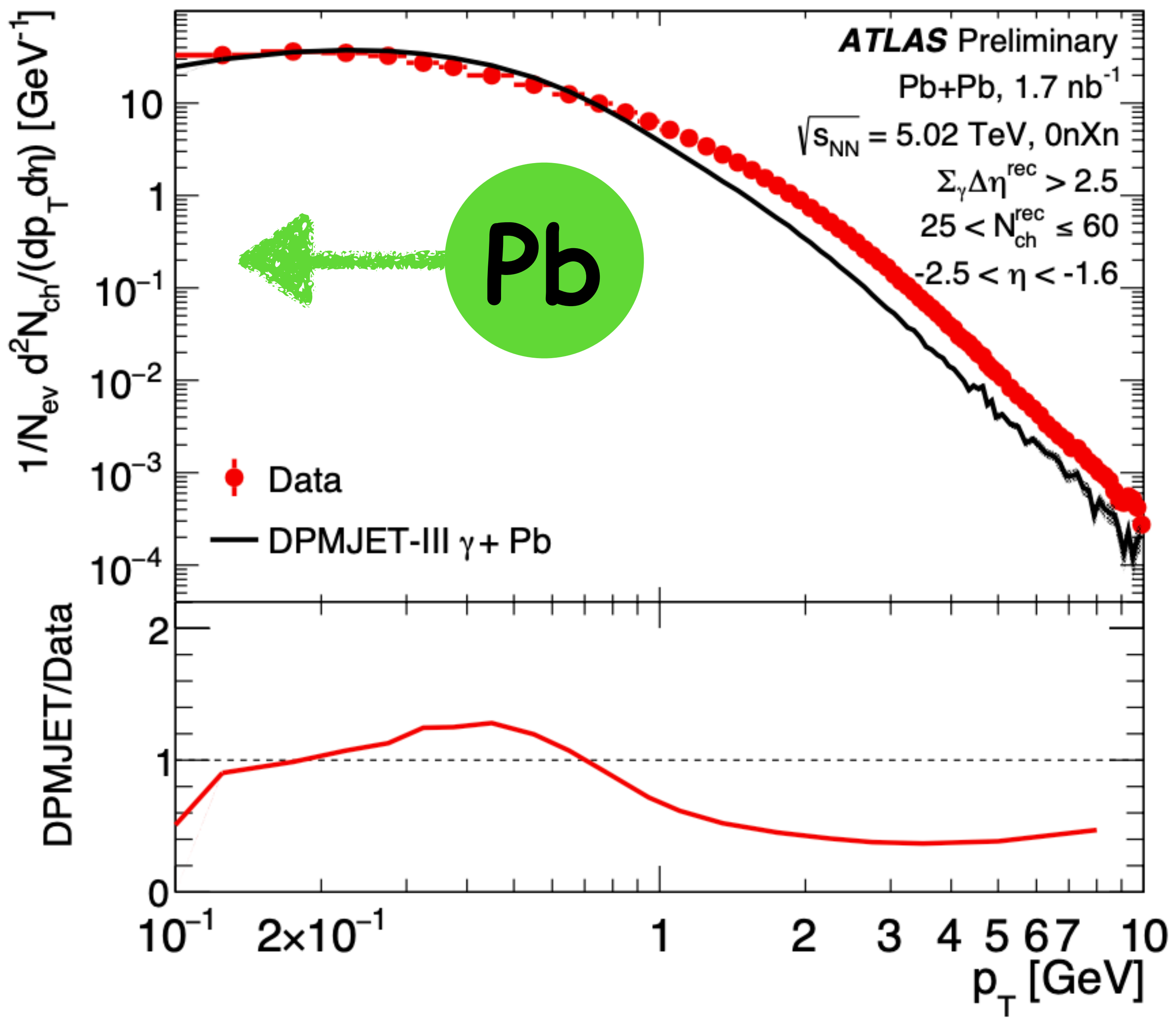

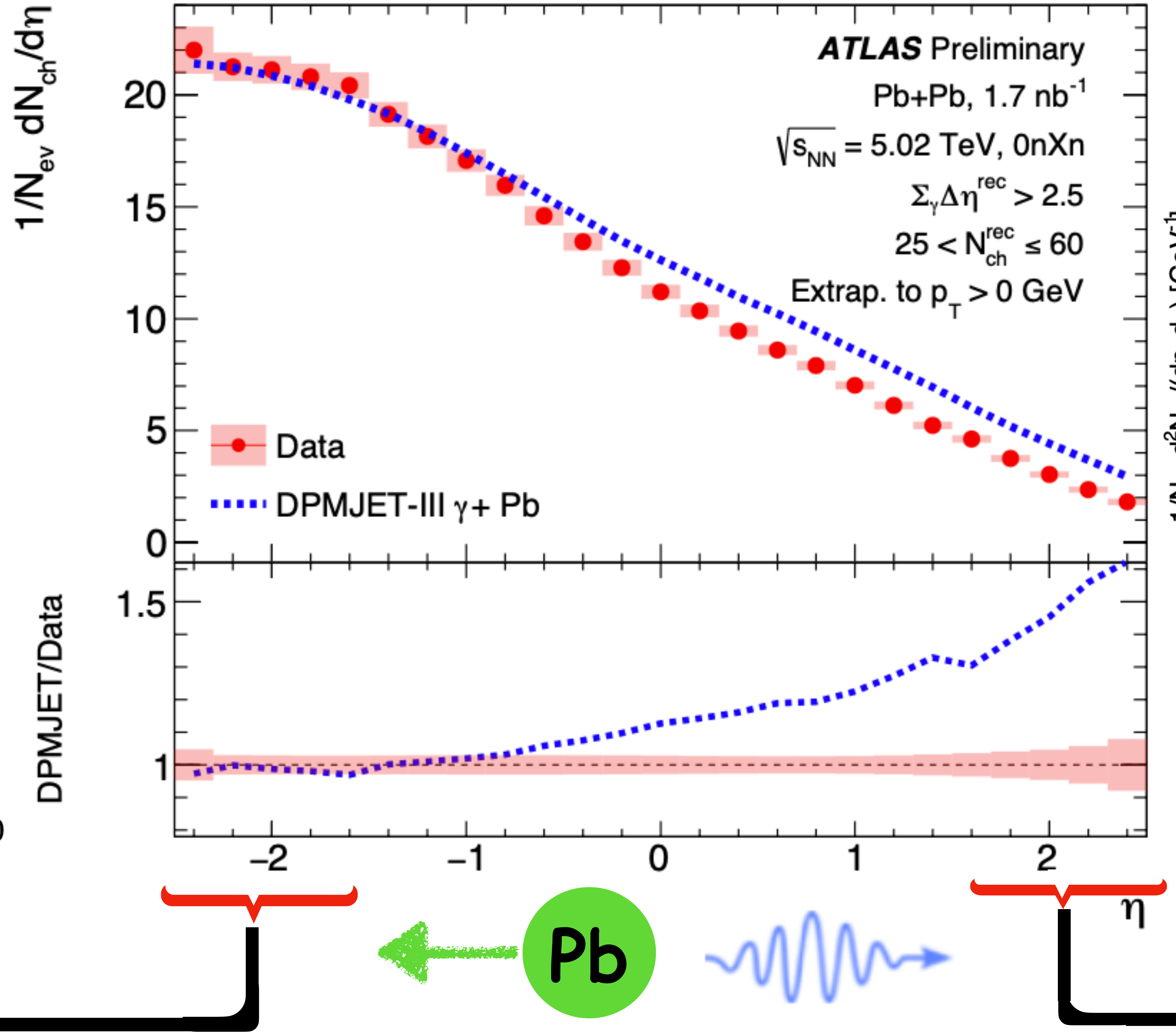

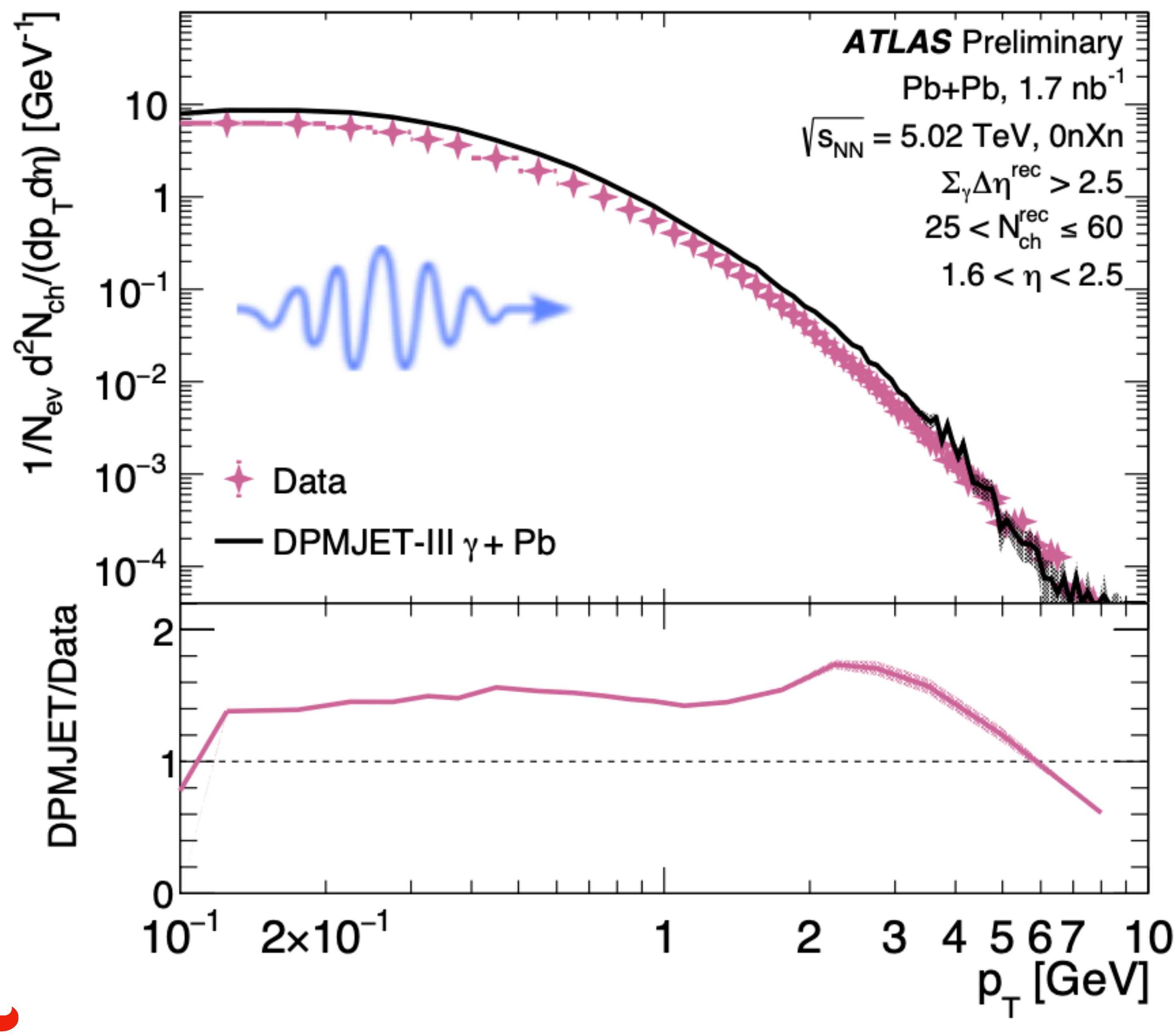

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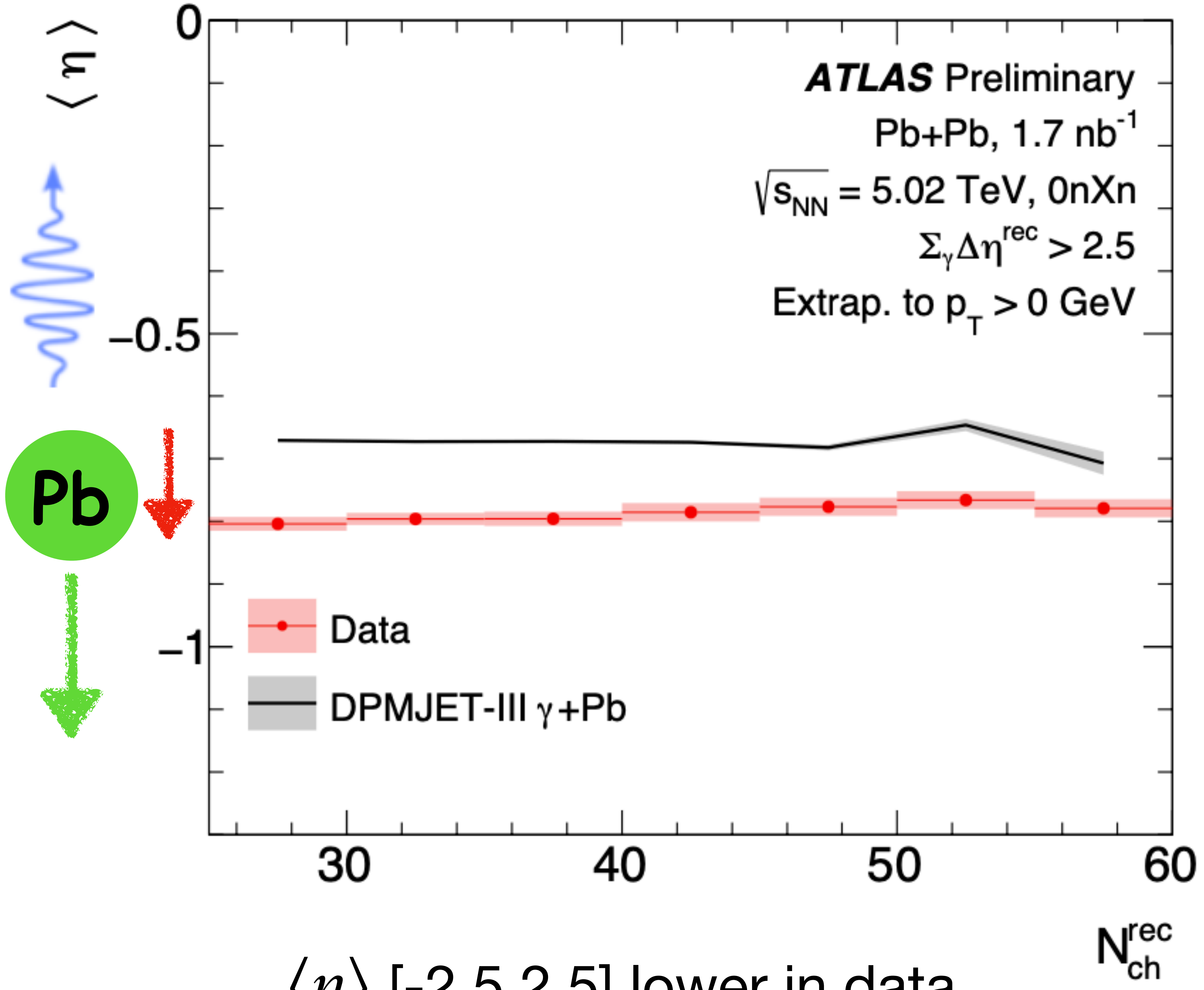

$\langle \eta \rangle$ [-2.5,2.5] lower in data

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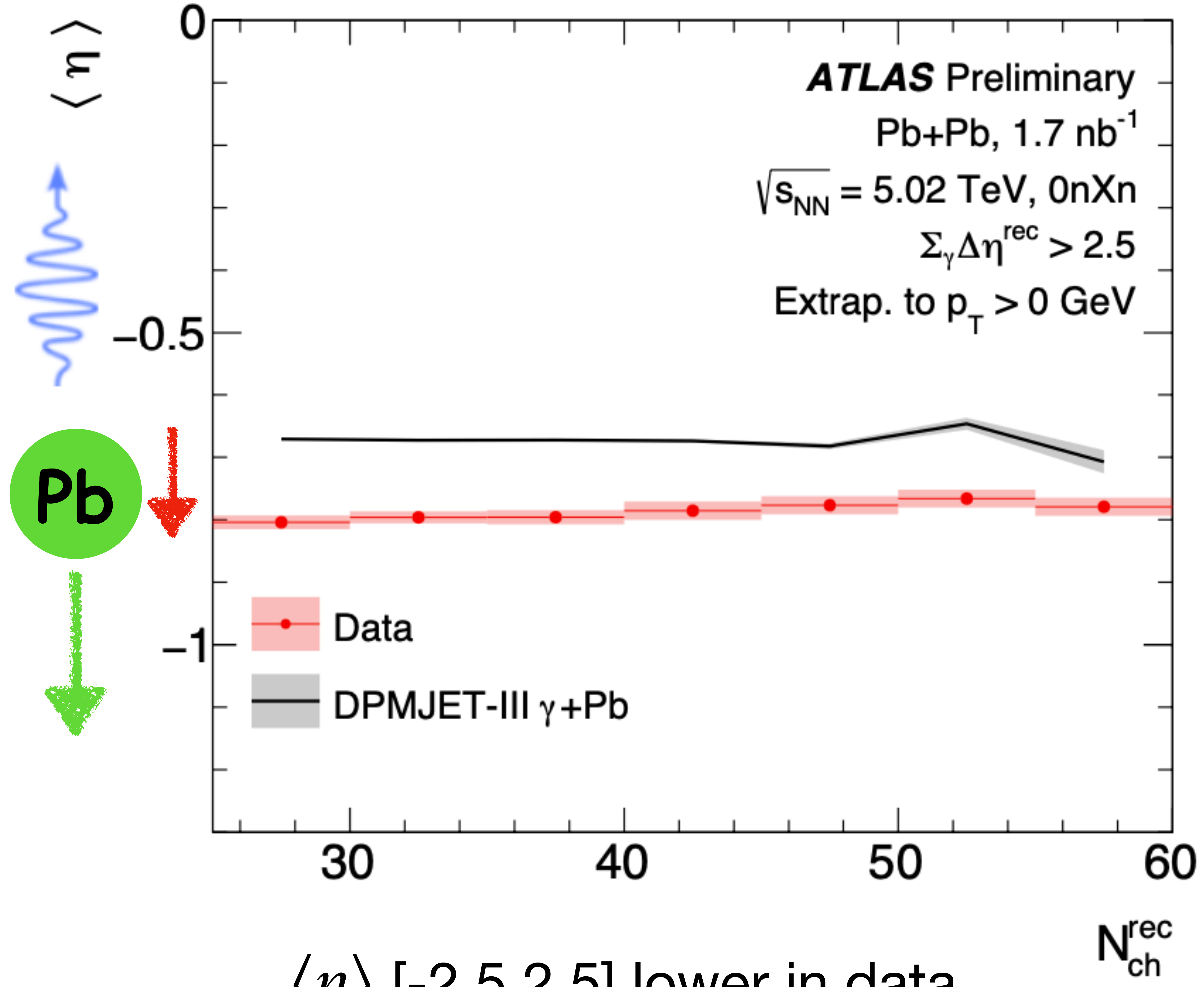

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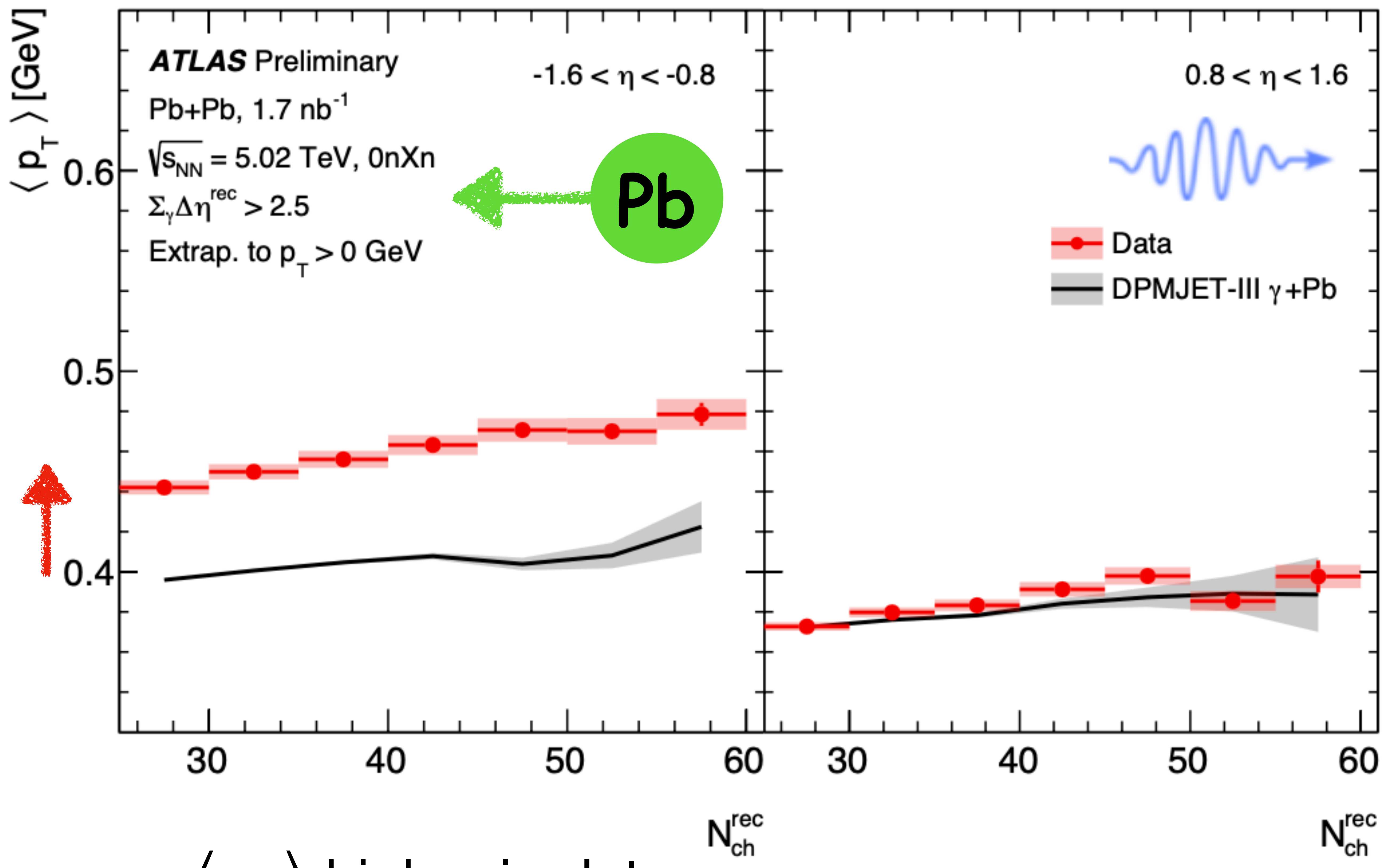
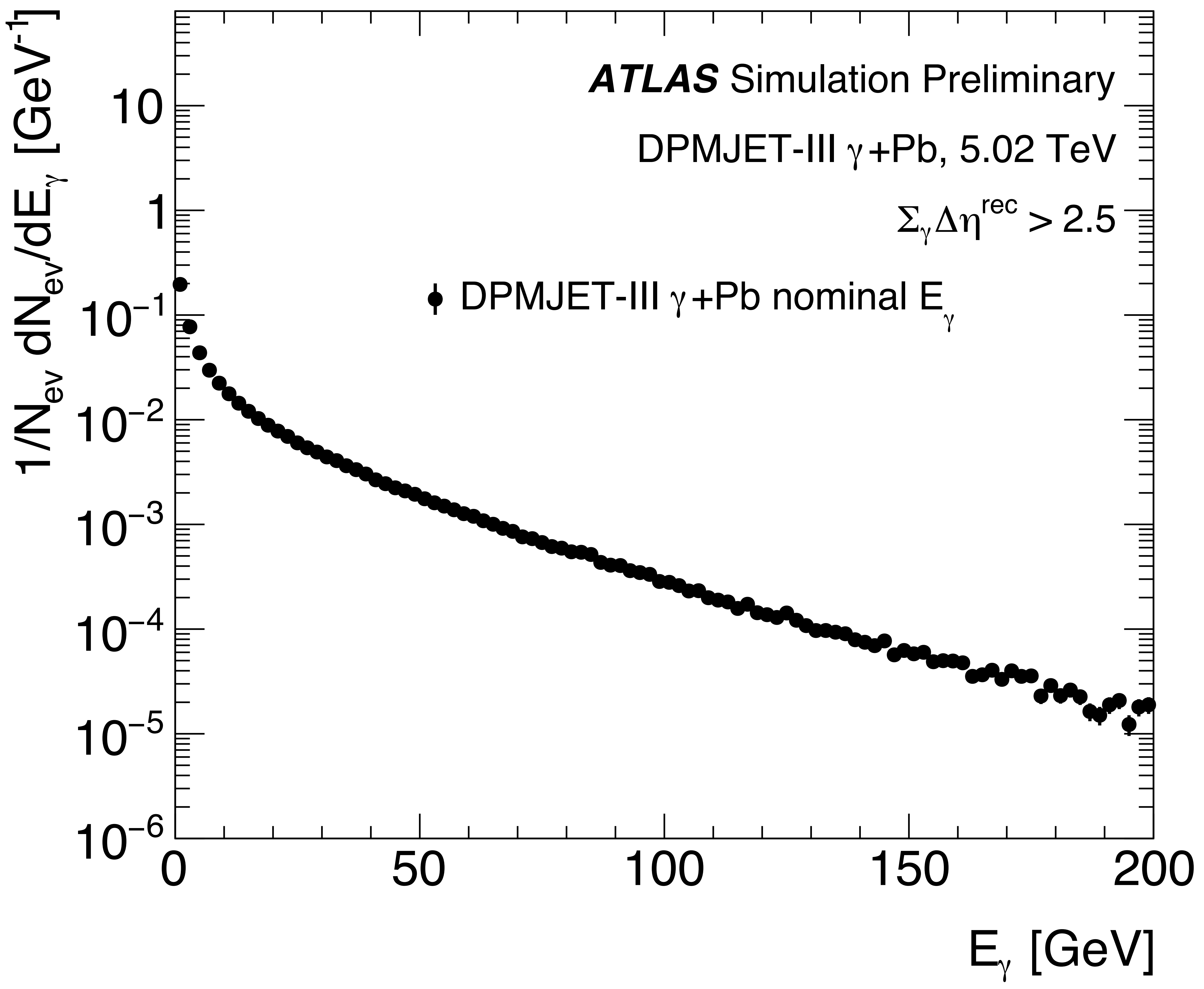


$\langle p_T \rangle$ higher in data

Radial flow?

Study of photon energy and particle production



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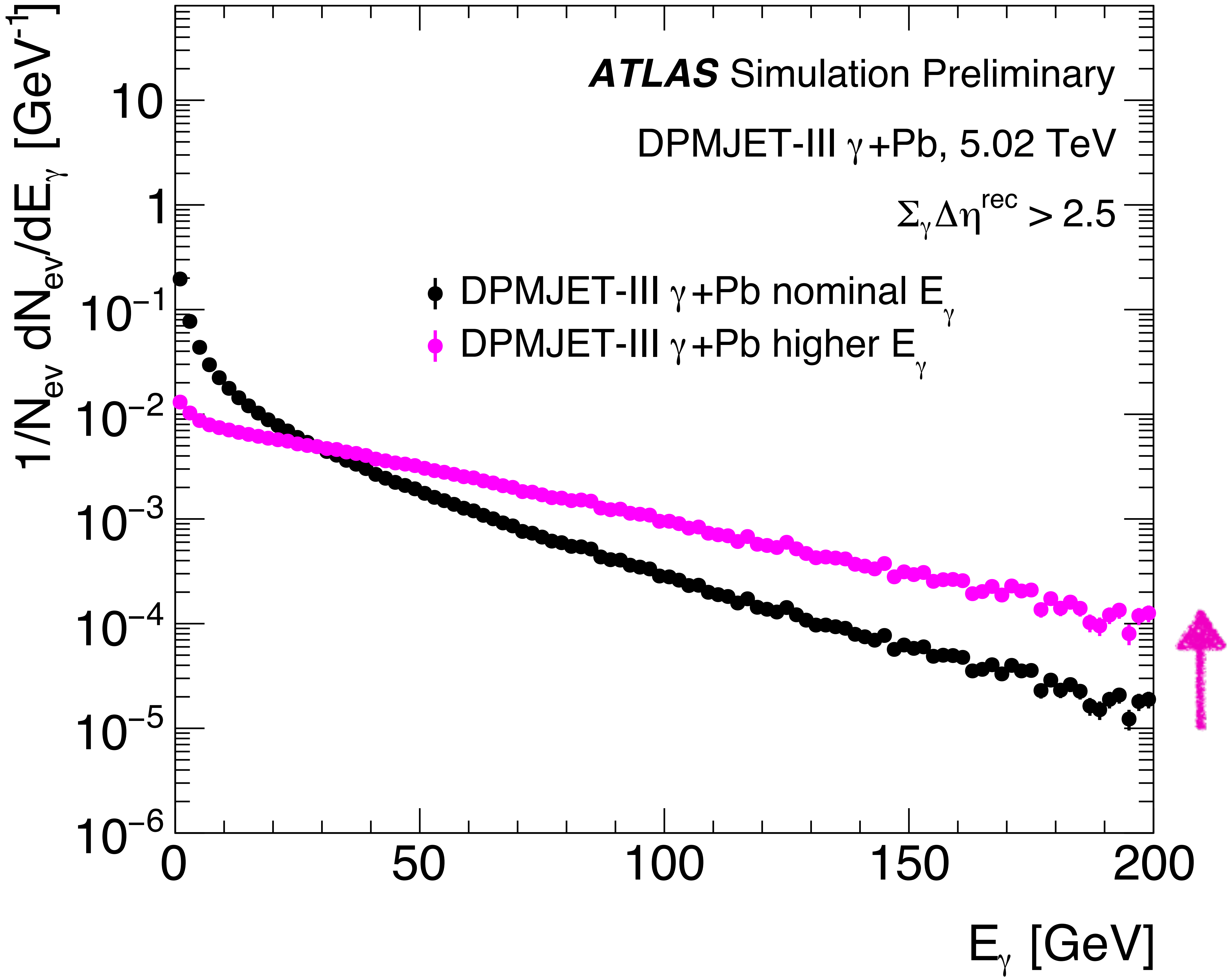

Arbitrarily re-weigh photon energy distribution
to relatively allow:
1) more high-energy photons

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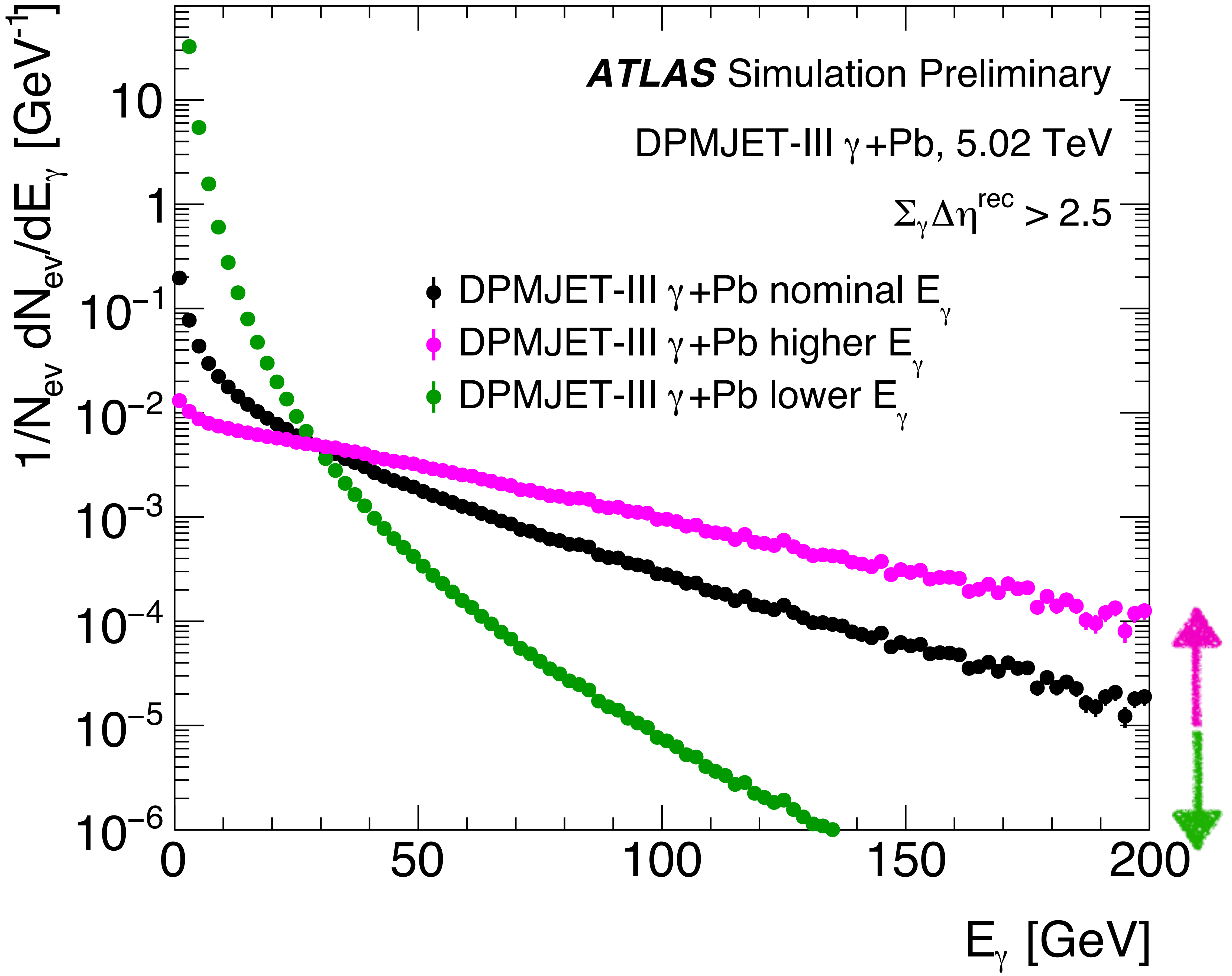

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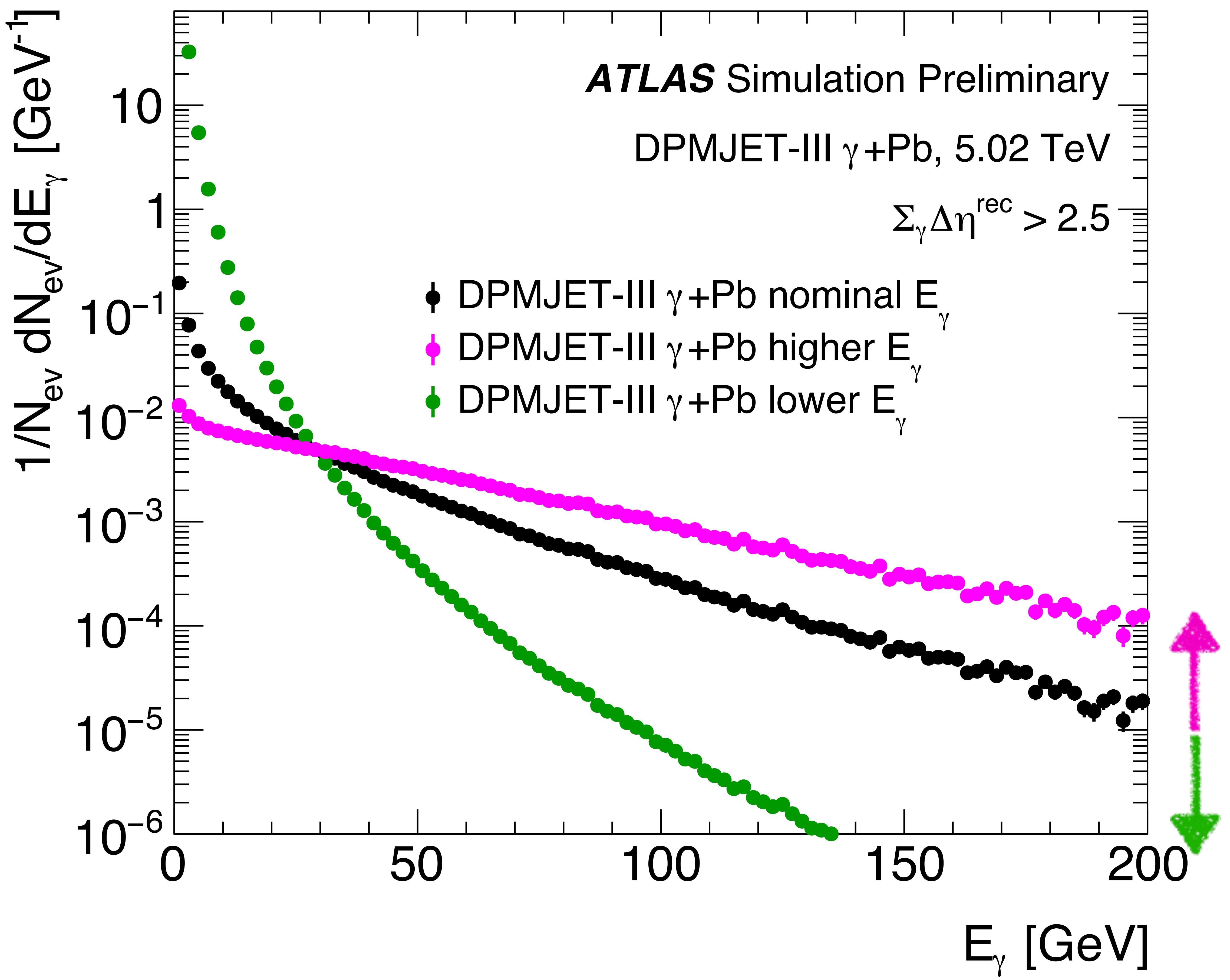
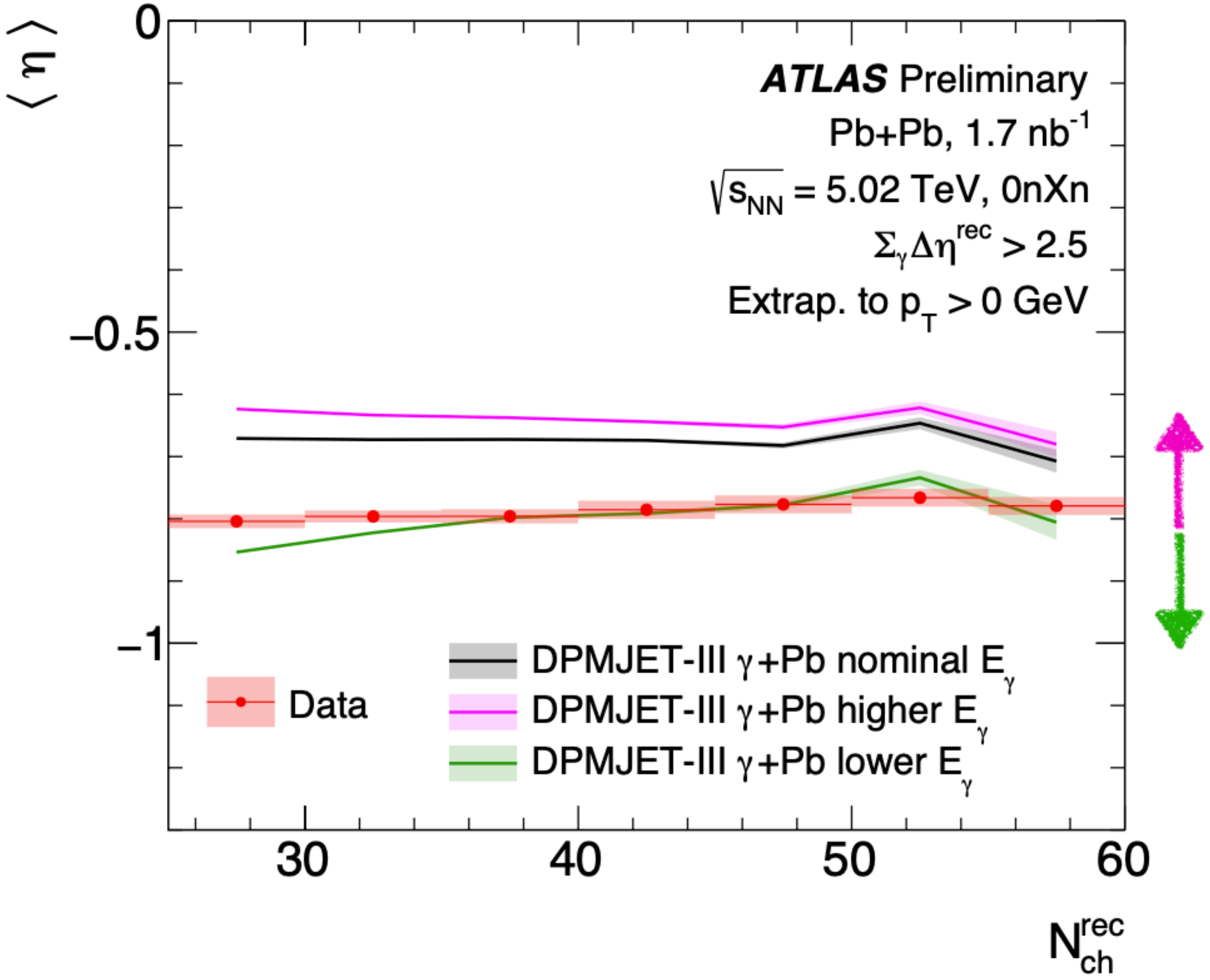
Study of photon energy and particle production





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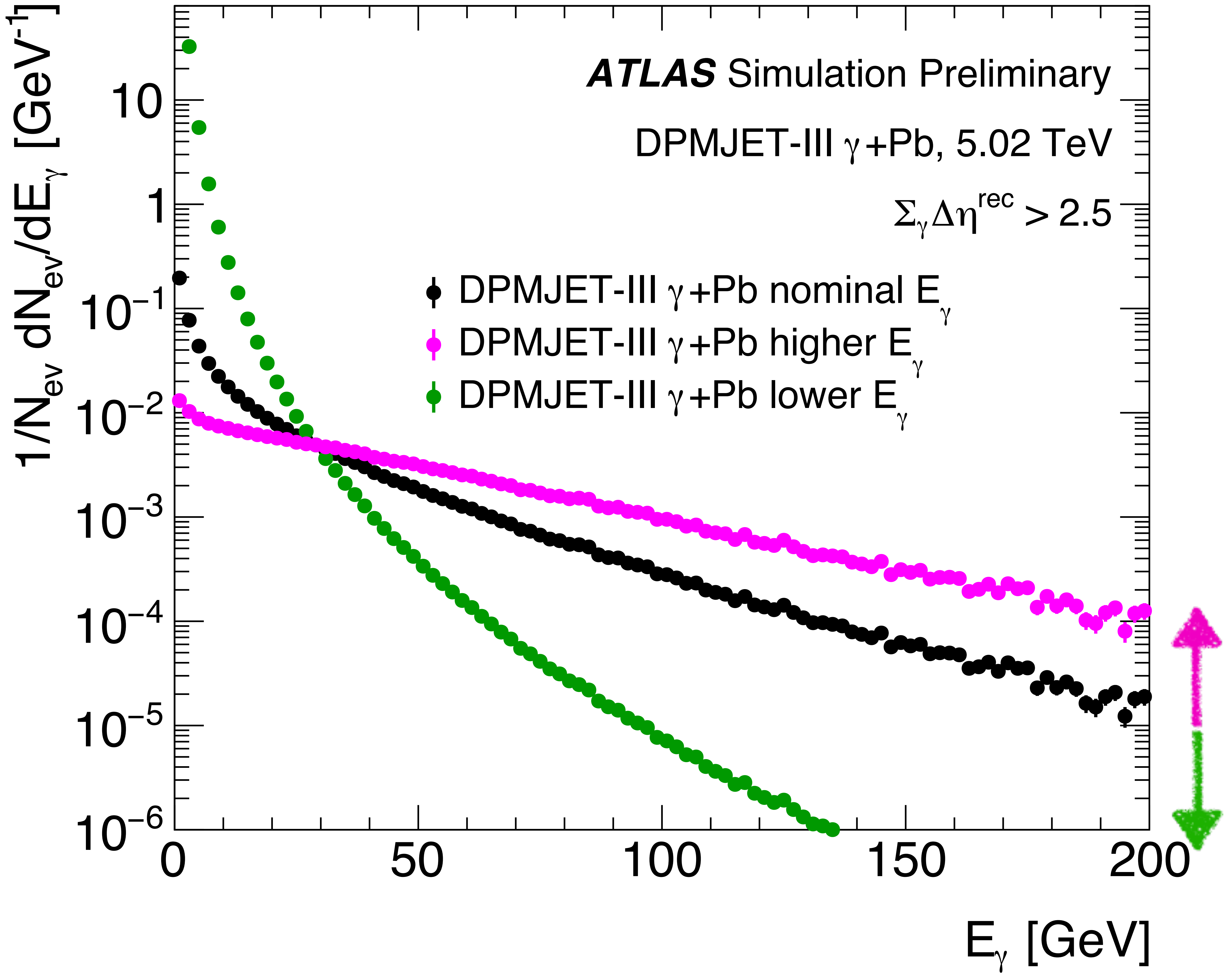

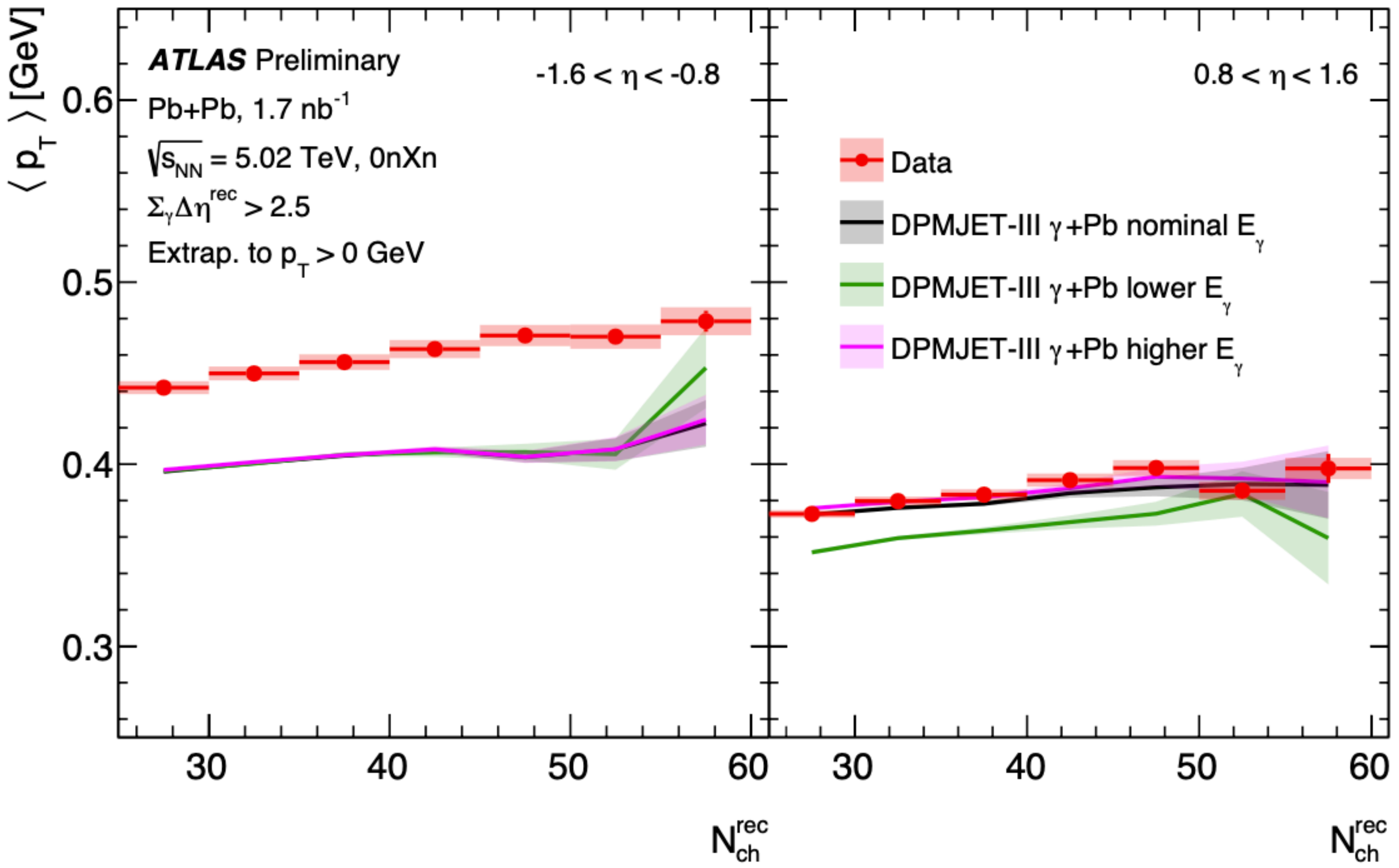

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ATLAS-CONF-2023-059

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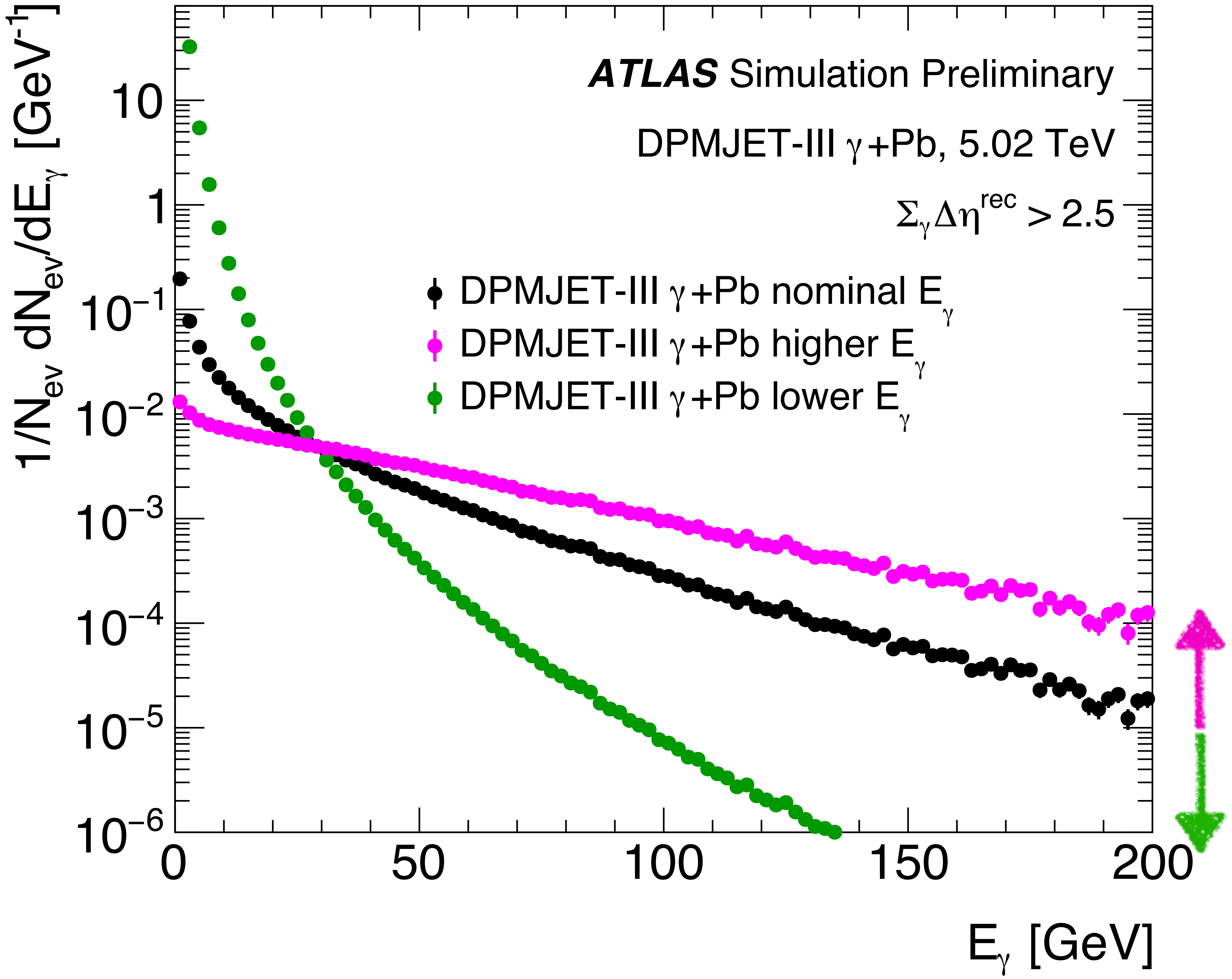

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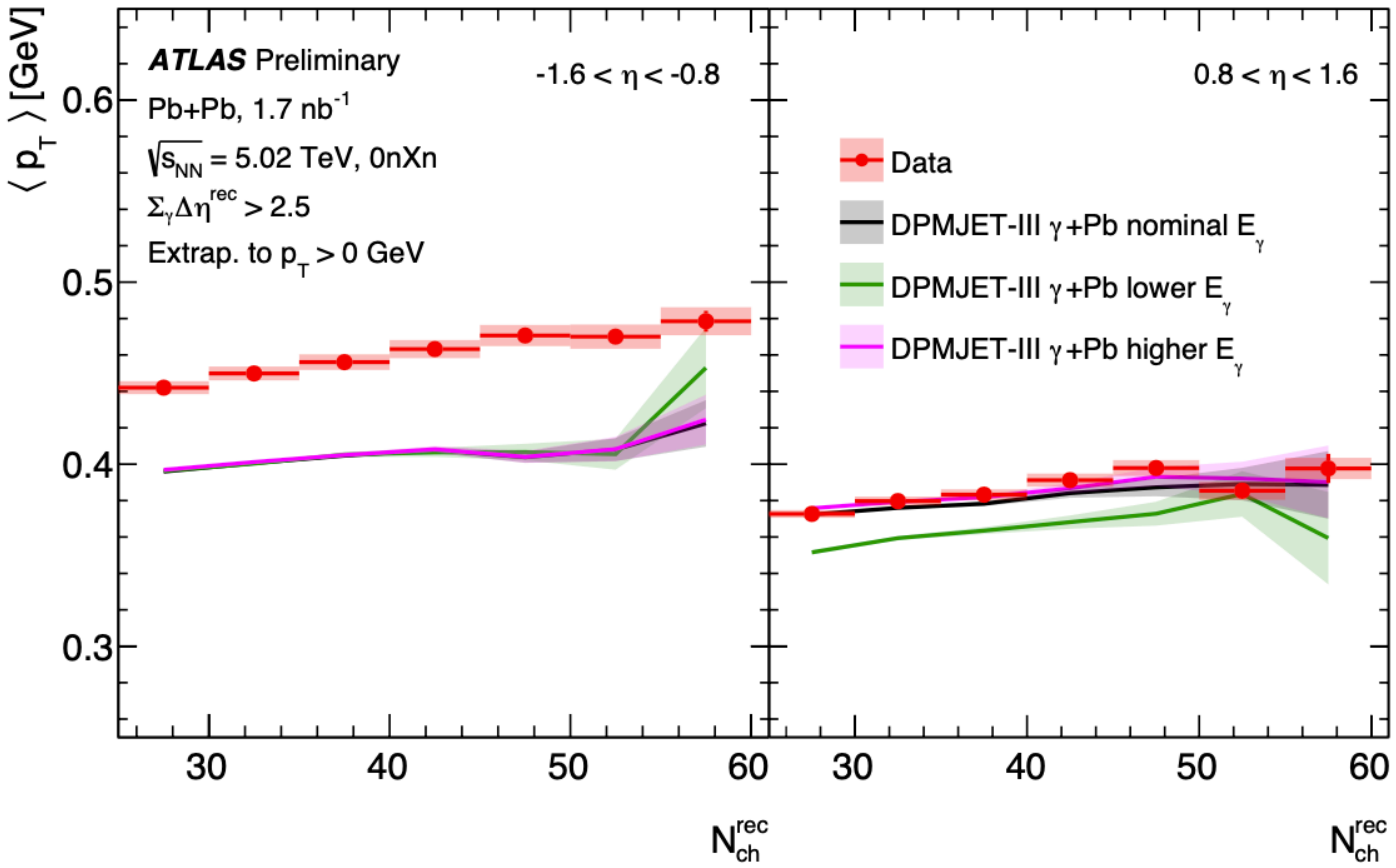

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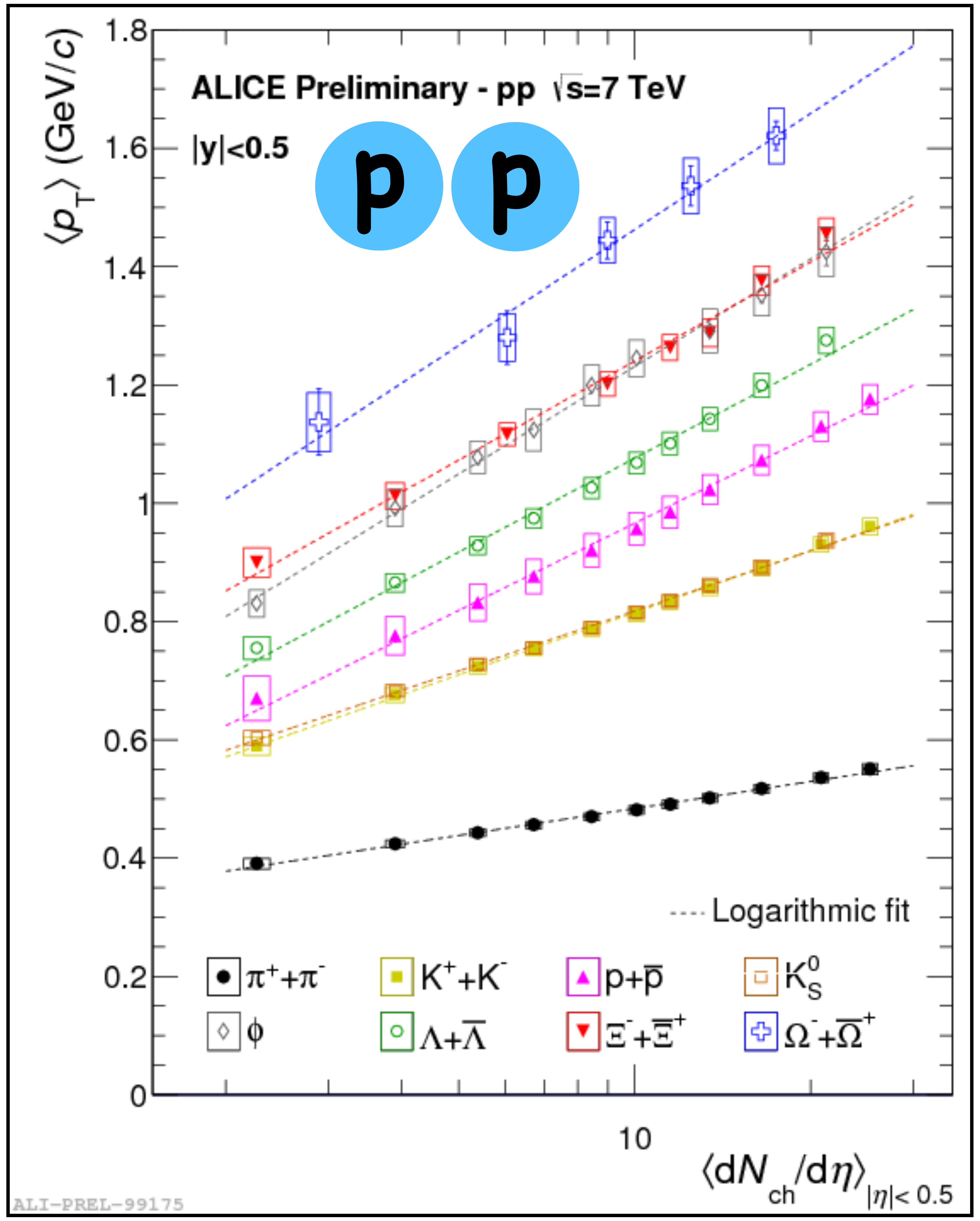
📍 However, the very substantial energy re-weighting is quite likely ruled out by other Pb+Pb UPC measurements.

Other QGP signatures



$\langle p_\mathrm{T} \rangle$ is sensitive to radial flow - is a QGP-like signal

Nuclear Physics A 956 (2016) 777-780

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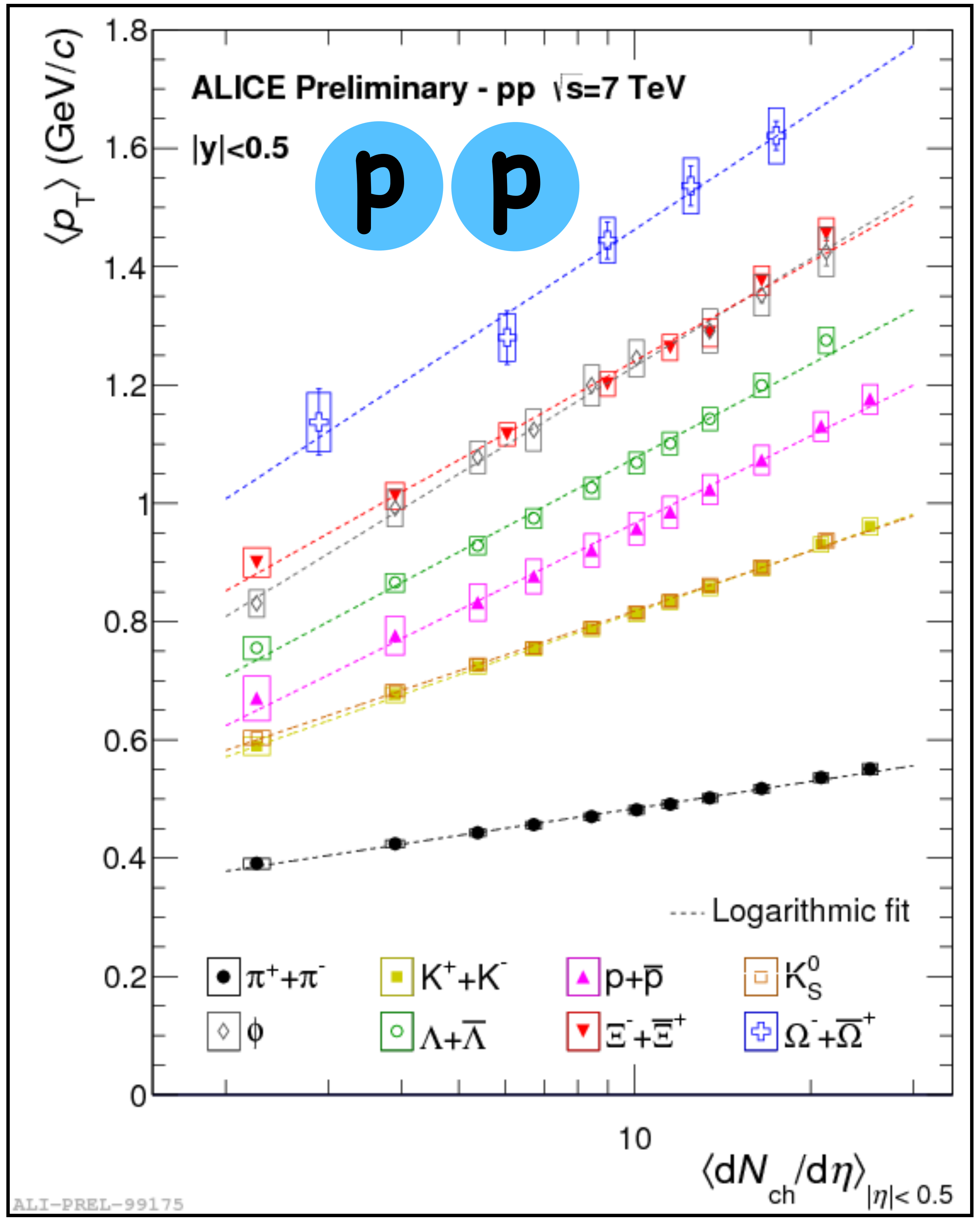

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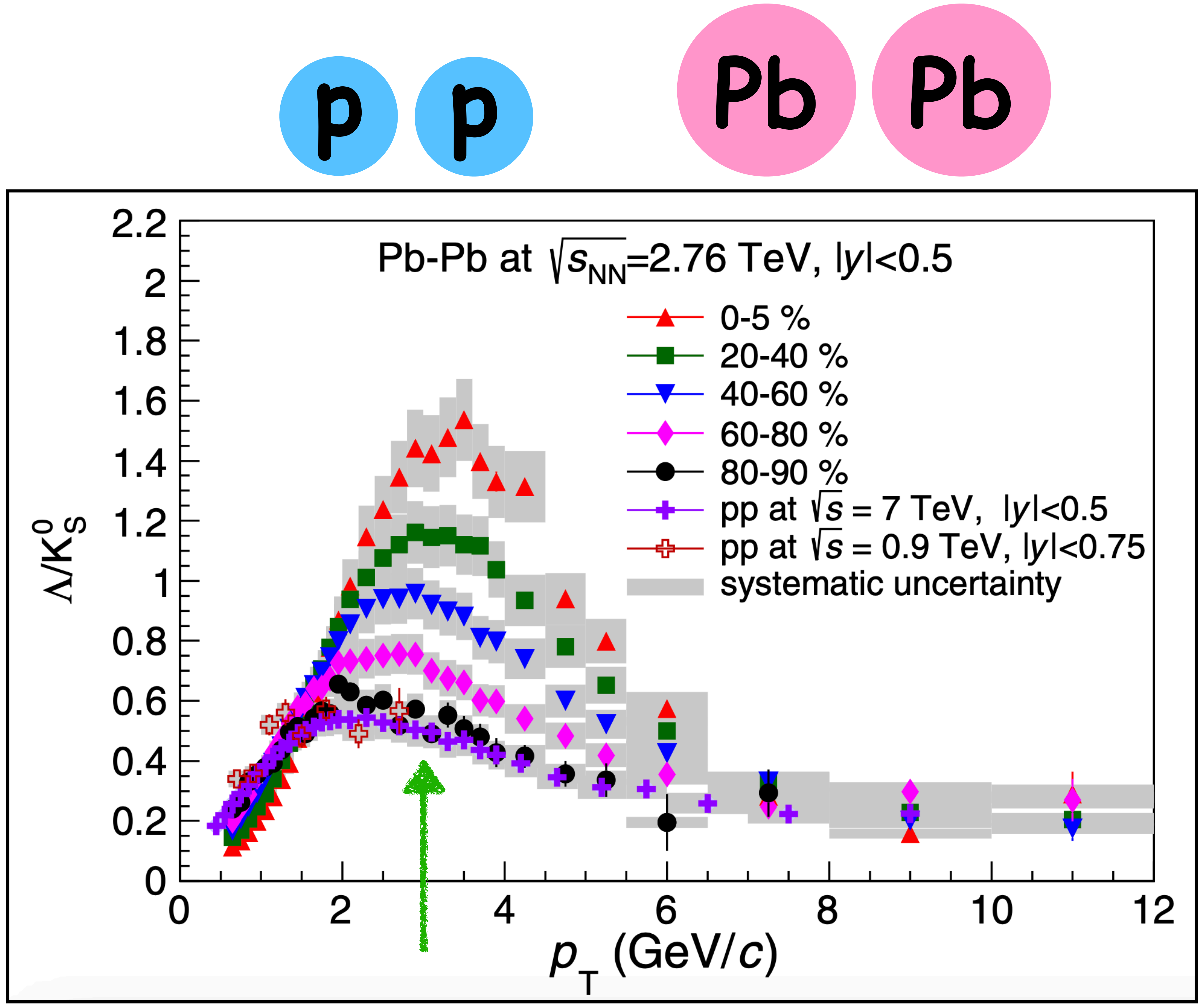

Baryon Anomaly

Enhanced baryon-to-meson ratio observed at intermediate p_T, is a QGP-like signal.

Phys. Rev. Lett. 111 (2013) 222301

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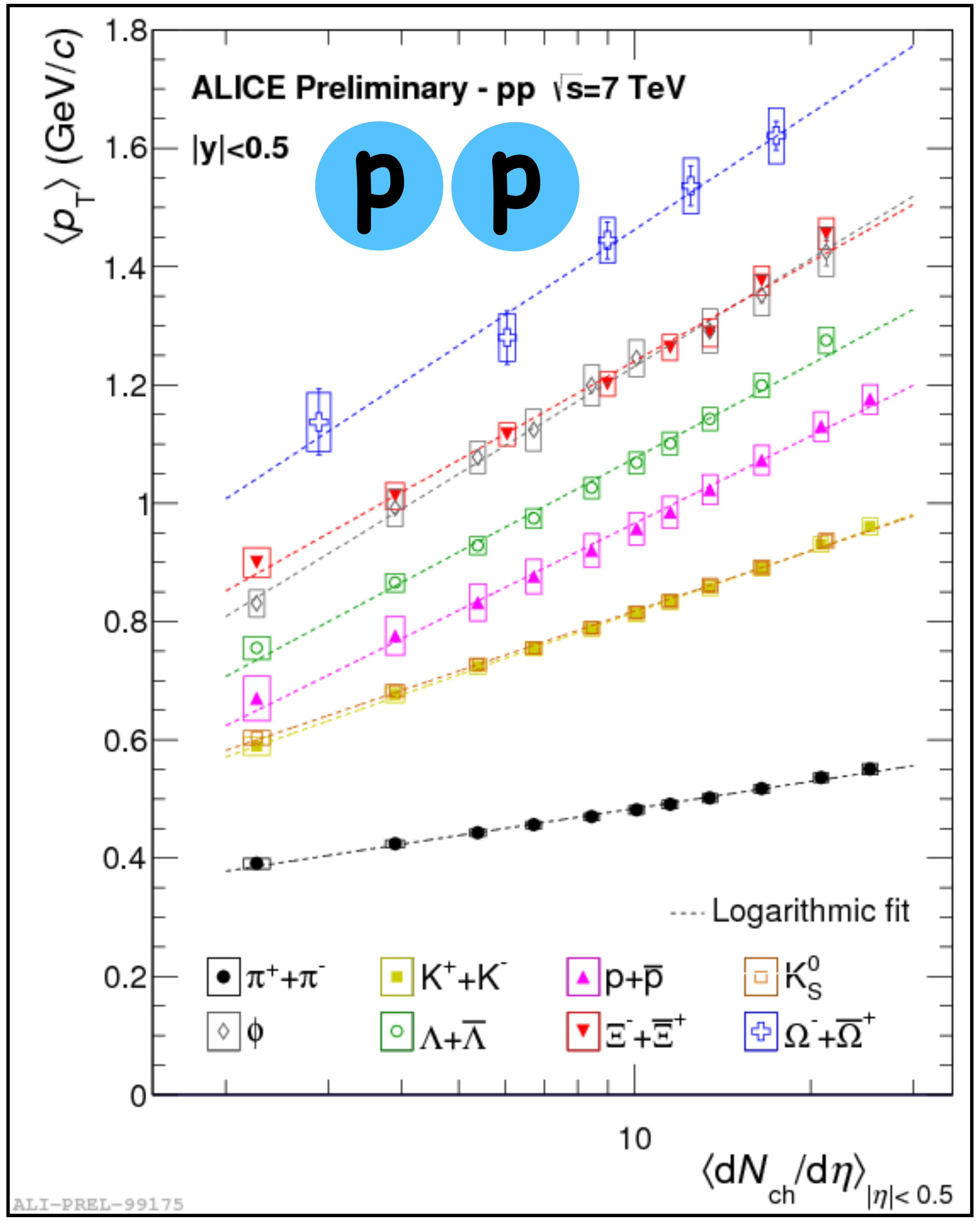

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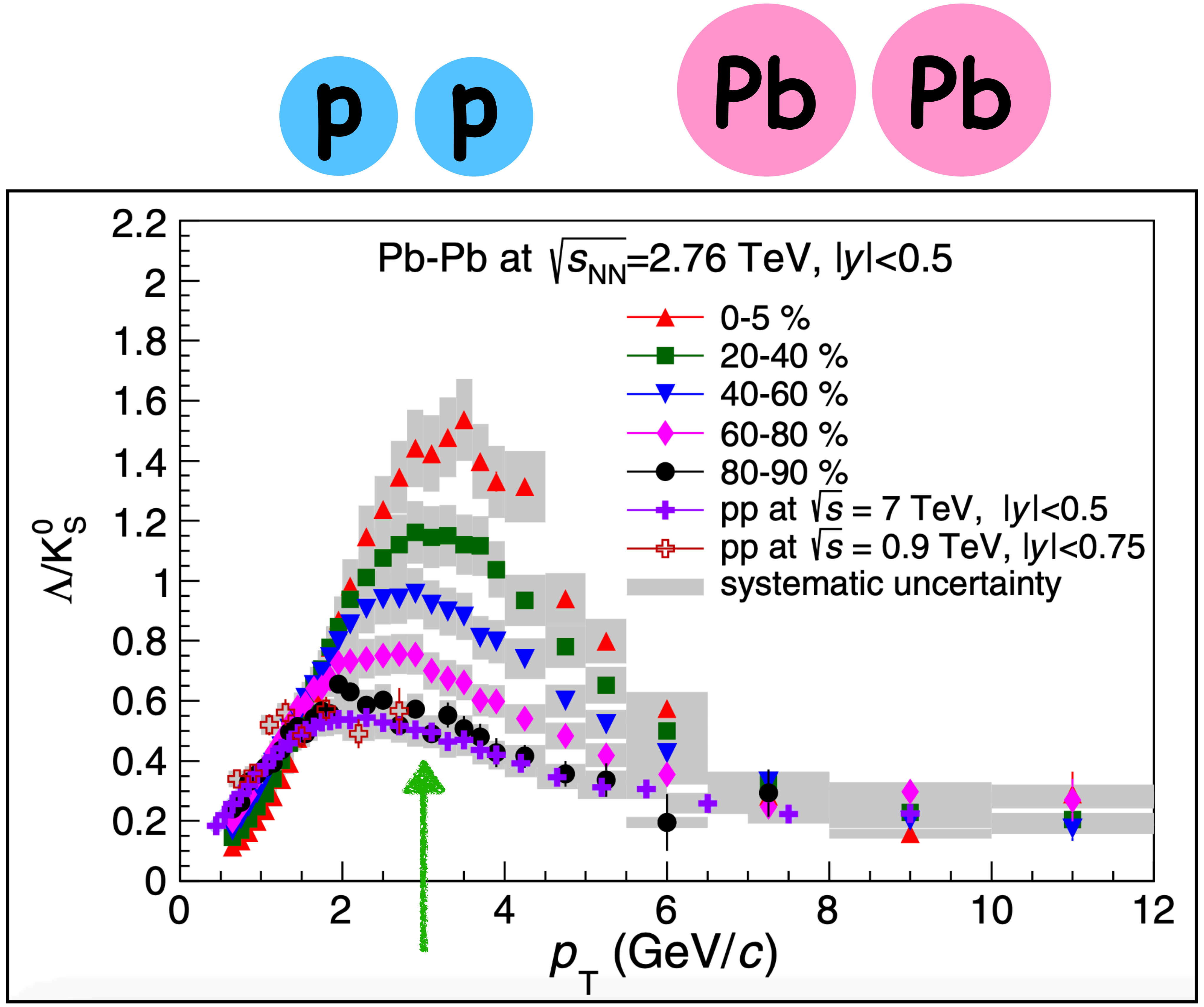

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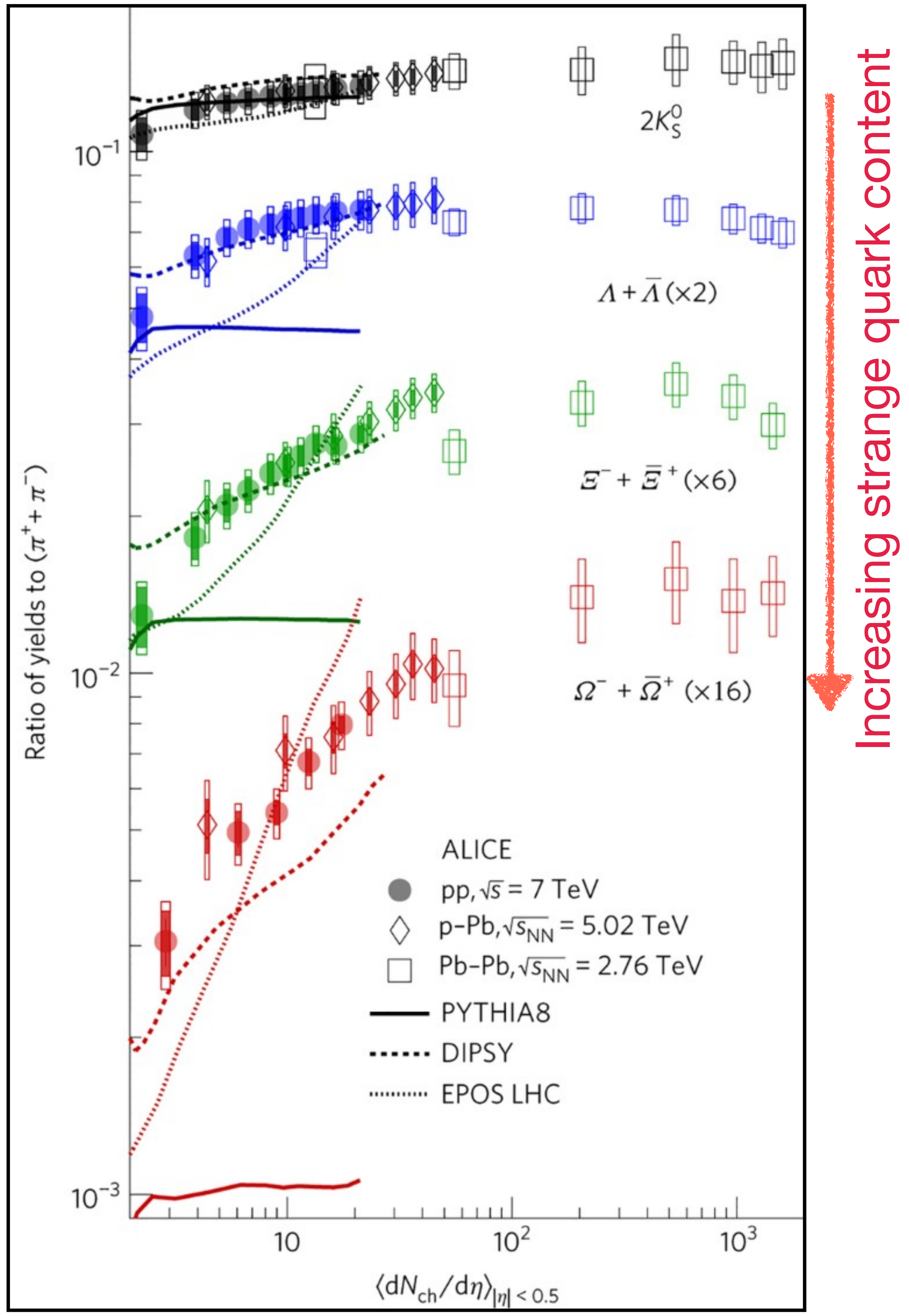

Strangeness enhancement is a signature of QGP.

Nature Physics 13 (2017) 535-539

Particle identification

ATLAS-CONF-2023-059

The yield measurements are being extended to particles

— in search of more QGP-like signals —

strangeness enhancement, baryon anomaly, radial flow etc.

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ATLAS-CONF-2023-059

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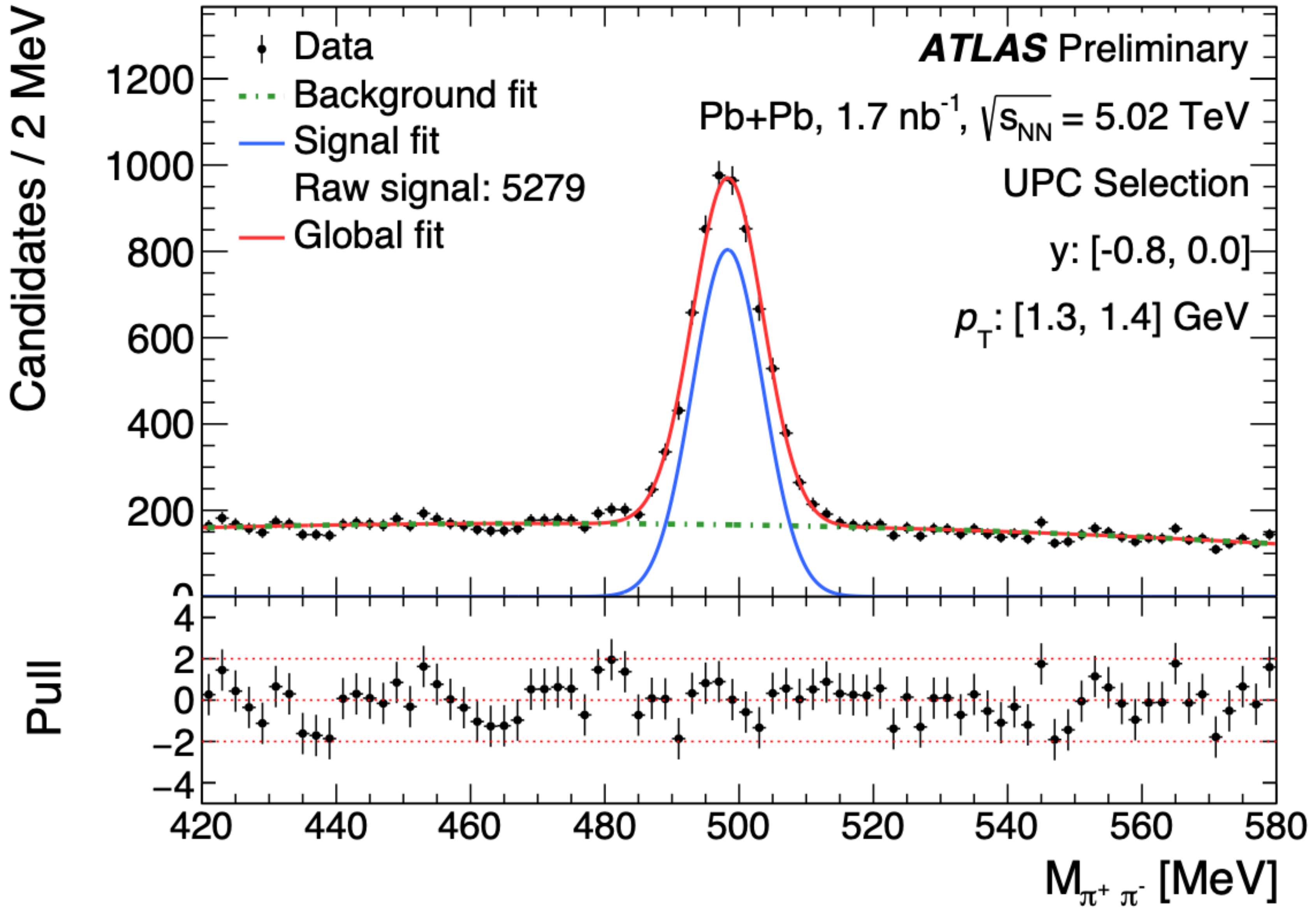
K_S^0



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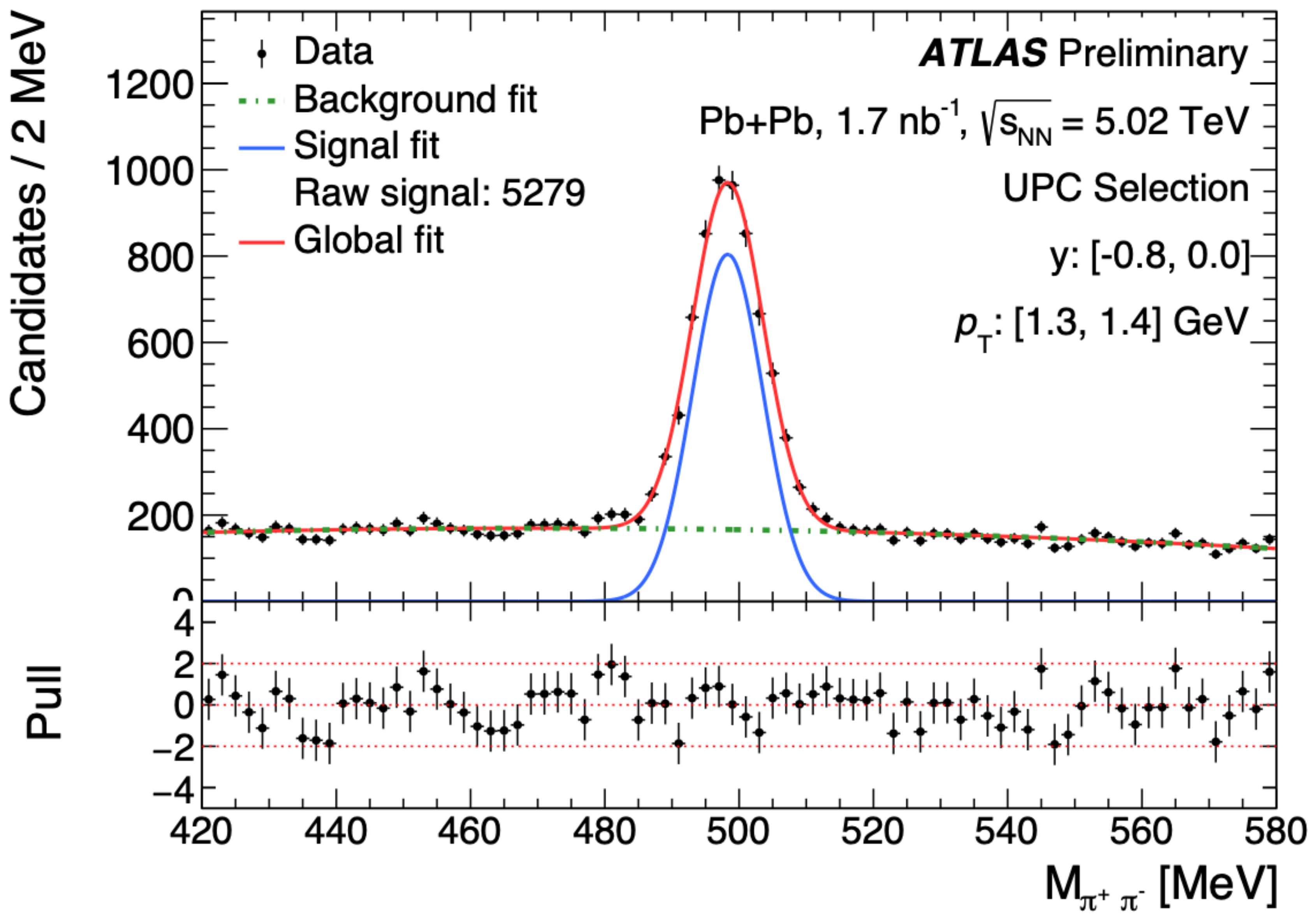
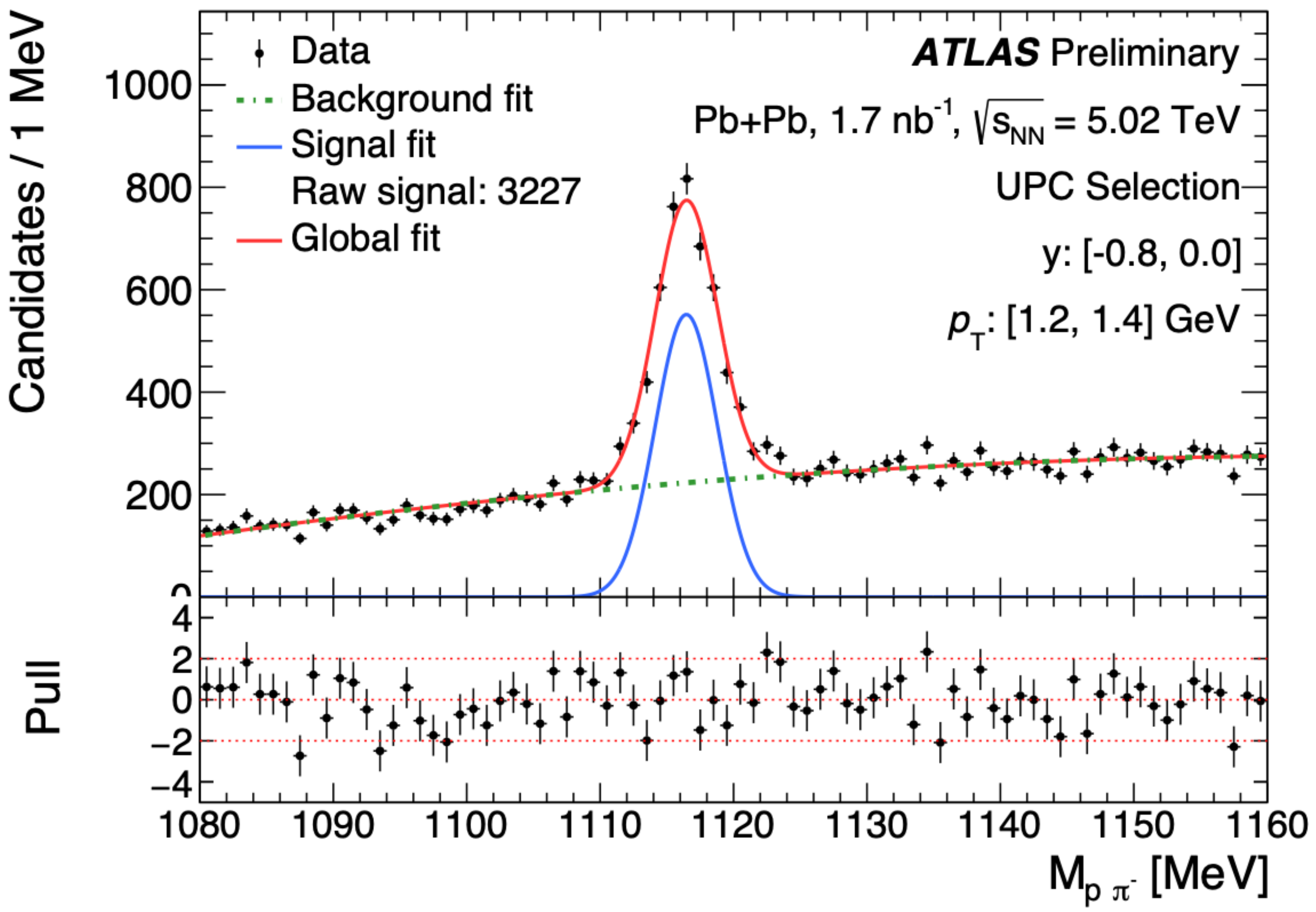


Λ



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K_S^0 Λ Ξ^-

Filling in the missing pieces

QGP signatures across all system-size

→ **smaller system-size**

QGP signatures	Pb Pb	p Pb	p p	γ Pb
1. Collective flow v_2	✅	✅	✅	✅
2. Radial flow $\langle p_{\mathrm{T}} \rangle$	✅	✅	✅	Charged hadrons ✅
3. Strangeness enhancement	✅	✅	✅	No measurement
4. Enhanced Baryon-to-Meson ratio	✅	✅	✅	No measurement

✅ : QGP signature present

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Summary

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- Small systems test the limit of Quark-Gluon Plasma (QGP) formation. UPCs are one of the smallest systems where QGP-like signals are found.

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- This measurement guides theoretical calculations of nuclear Deep Inelastic Scattering (DIS) which are relevant for future Electron-Ion Collider data.

Thank you for your attention