QPT 2025

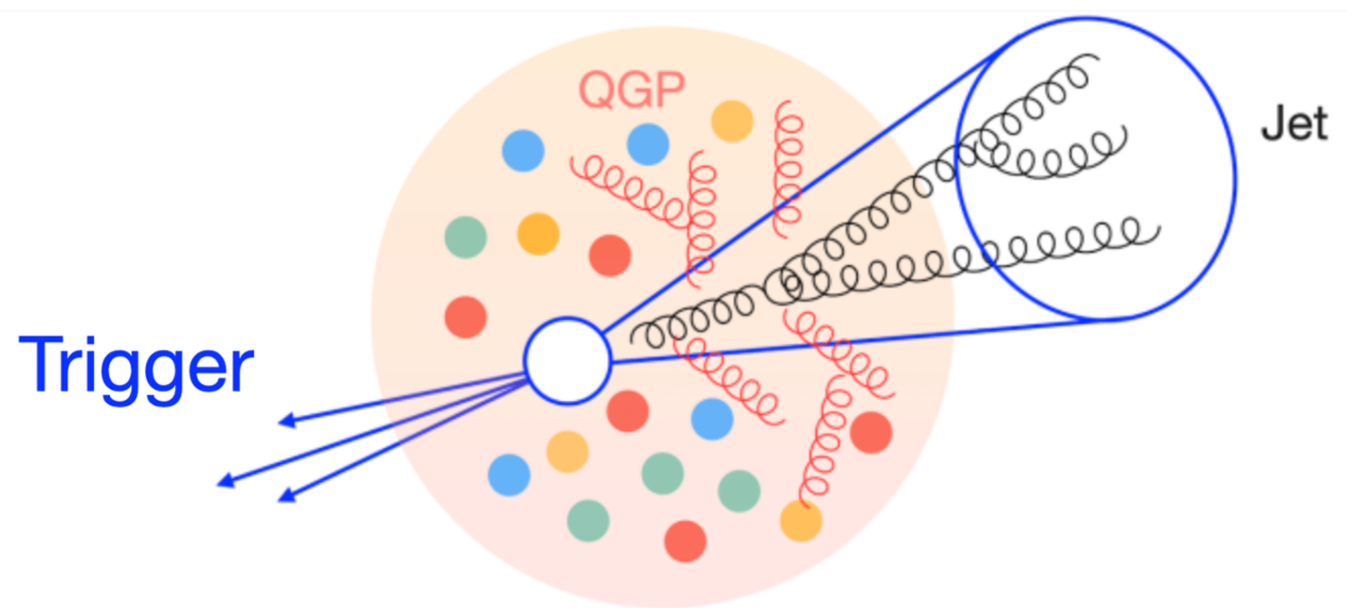
Guilin, China

Experimental search for medium response using jet correlations at the LHC

Yongzhen Hou (侯永珍，CUG&GSI)

The 16th Workshop on QCD Phase Transition and Relativistic Heavy-Ion Physics

Guilin, 24-28 October 2025



24-28, October

Jet probes

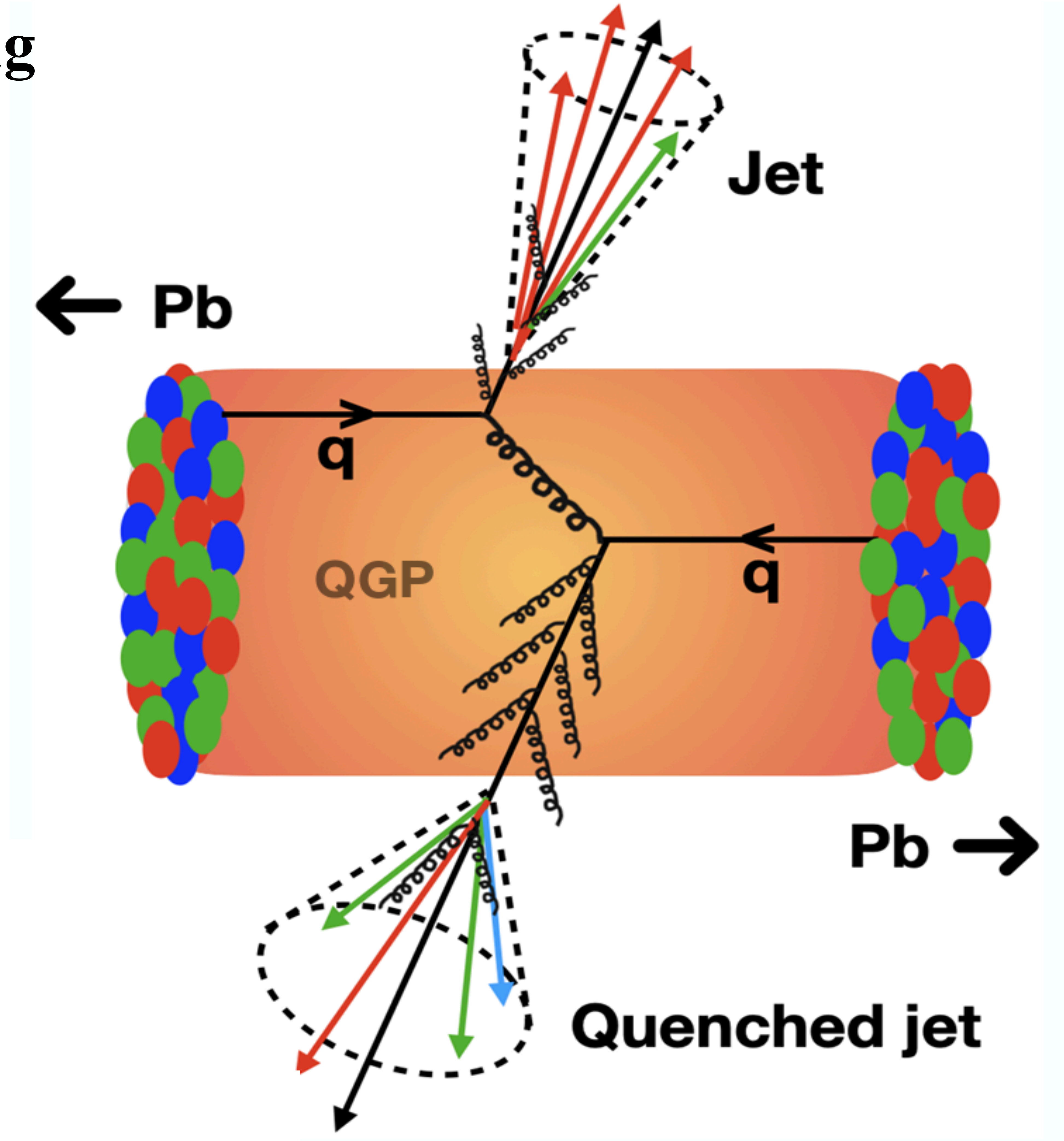
Jets are **proxies** of the **partons** produced in the **hard scattering**

- produced in the earliest phase of the collision

Jets in heavy-ion collisions → interact with the medium through the strong interaction, getting modified

- lose energy through medium-induced gluon radiations (inelastic) and collisions (elastic) with medium constituents

➡ $\mathrm{Jet}(E) \rightarrow \mathrm{Jet}(E' - \Delta E) + \text{soft particles}(\Delta \mathrm{E})$

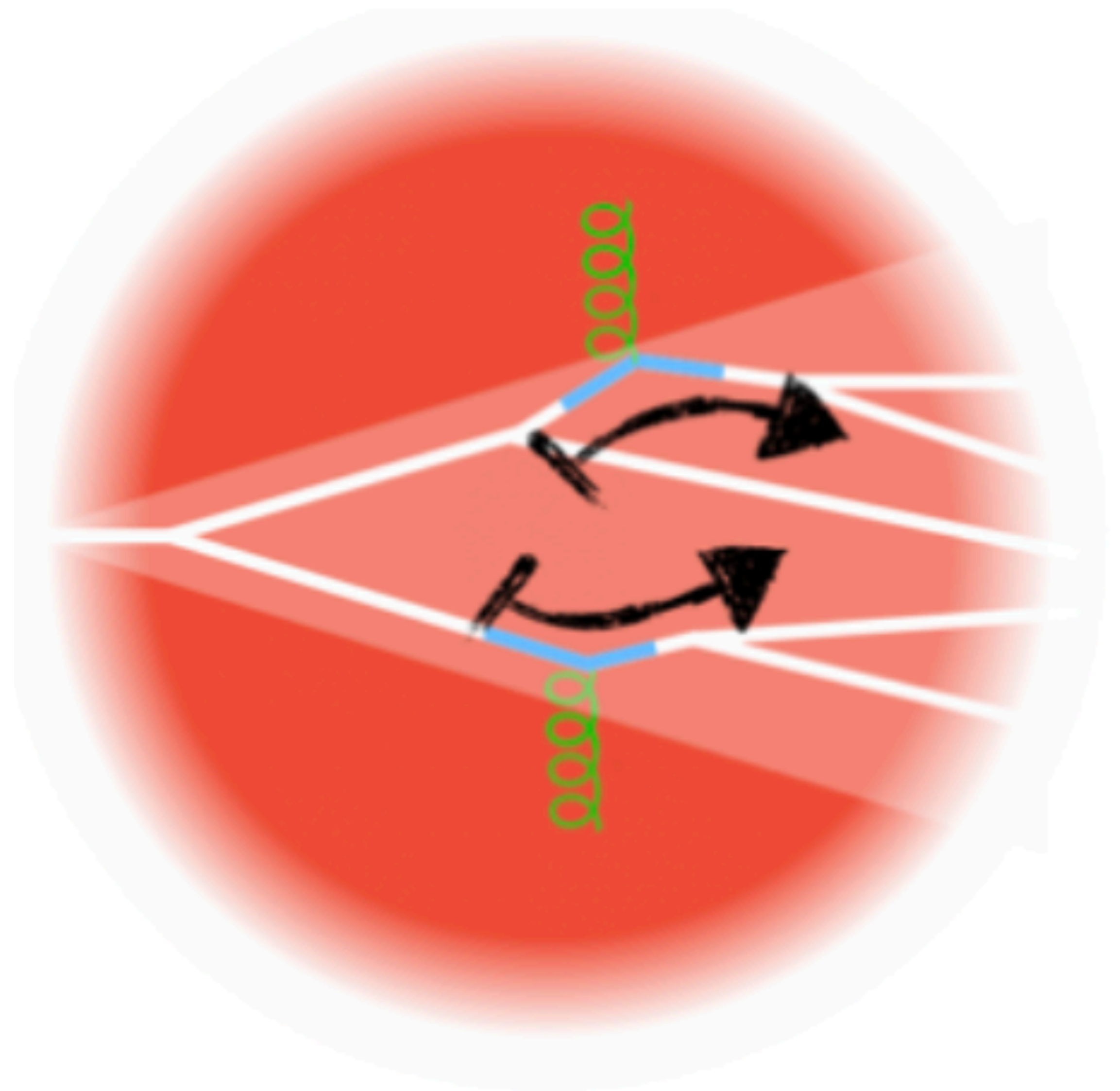


Jet quenching observables

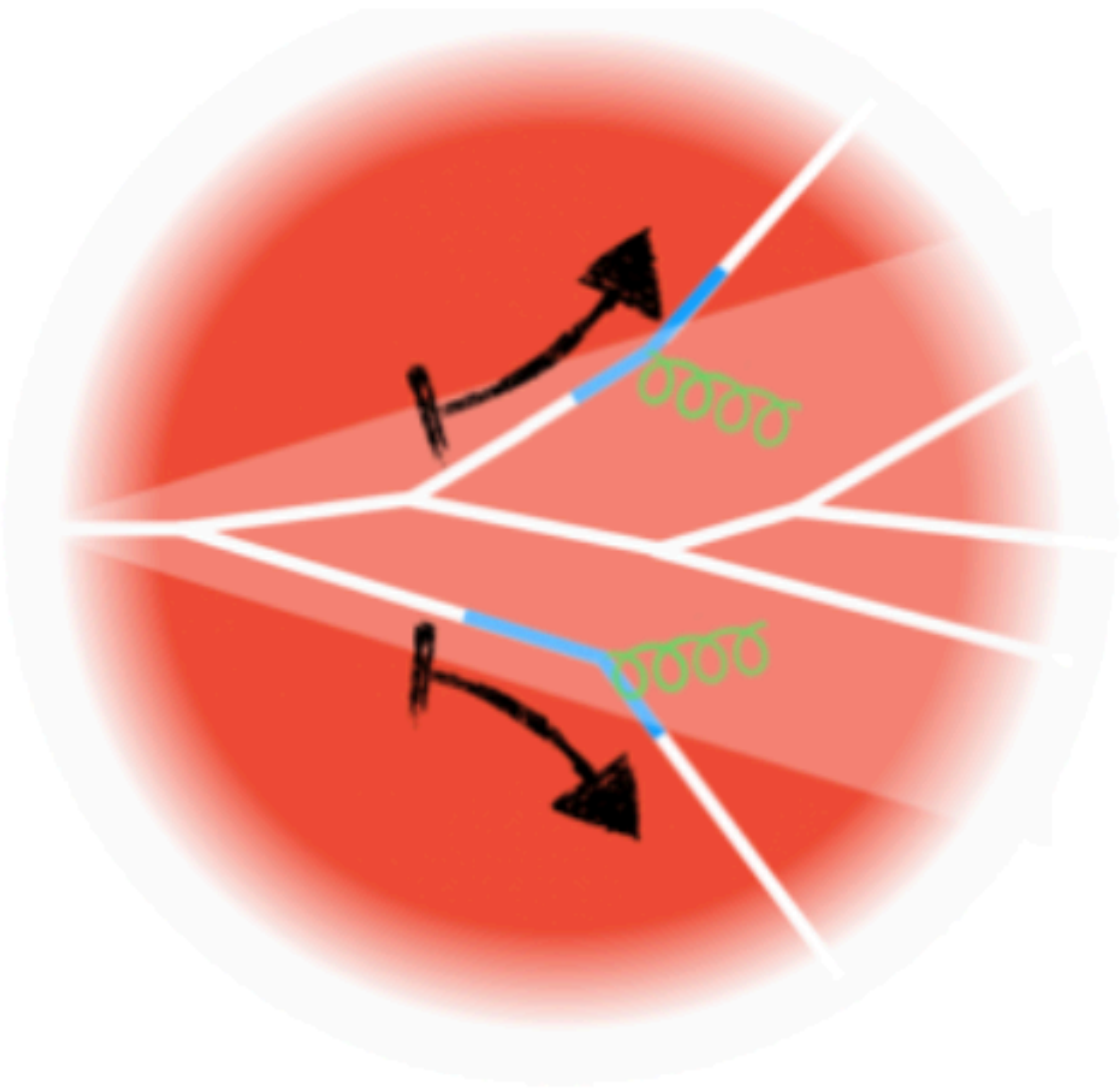
Study structure of QGP by understanding jet modification from medium interaction **(quenching)**

- **Several types of jet observables**
  - Jet reconstruction and declustering → substructure (r_{g}, θ_g) modification
  - Jet yields and constituents → **jet suppression and energy redistribution** (R_{AA}, I_{AA})
  - Jet correlation → **jet deflection ($\Delta\varphi$) and asymmetry**

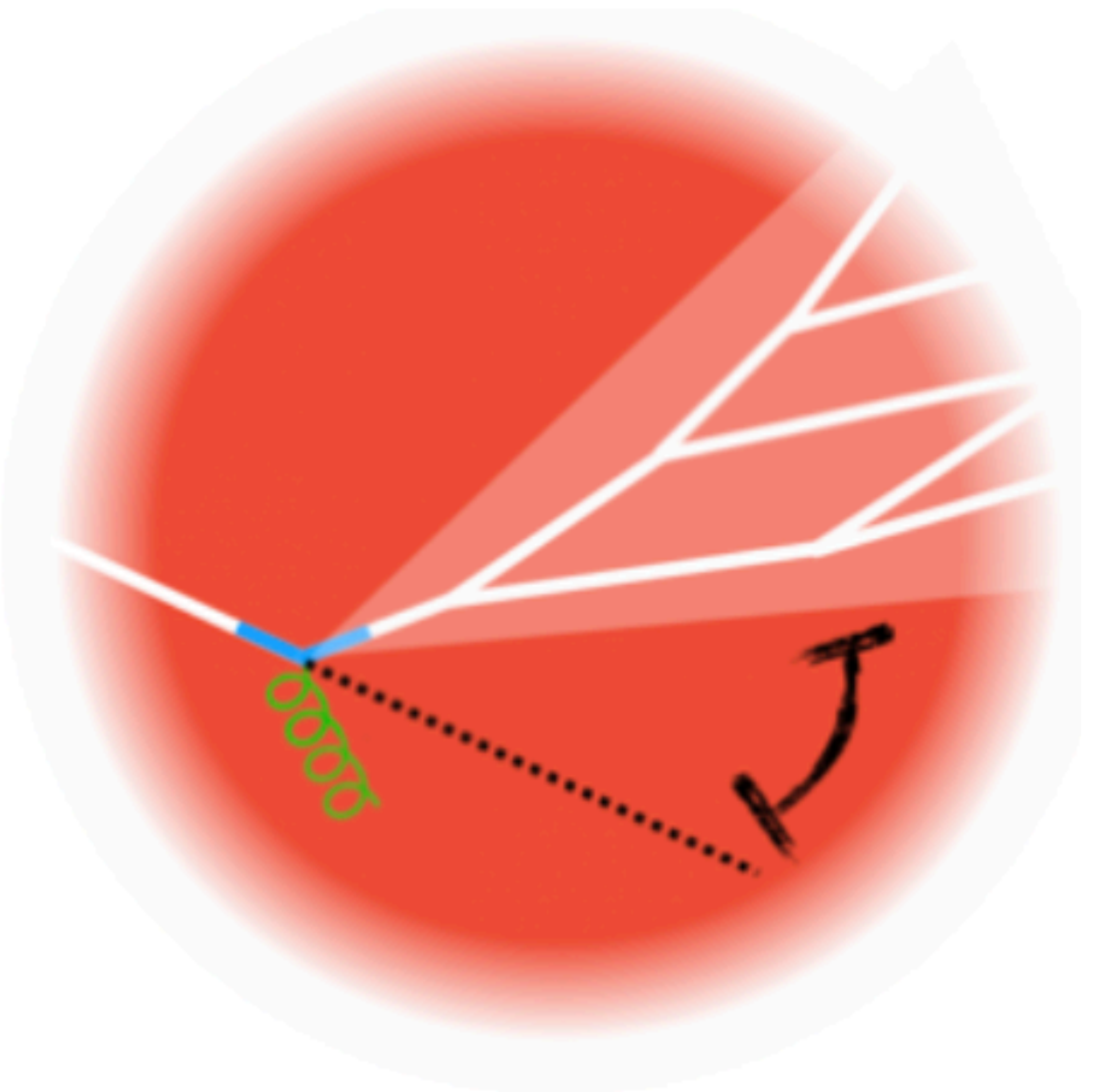
→ Such as γ-jet , Z-jet, hadron-jet, or di-jets



Substructure modification



Energy redistribution



Deflection

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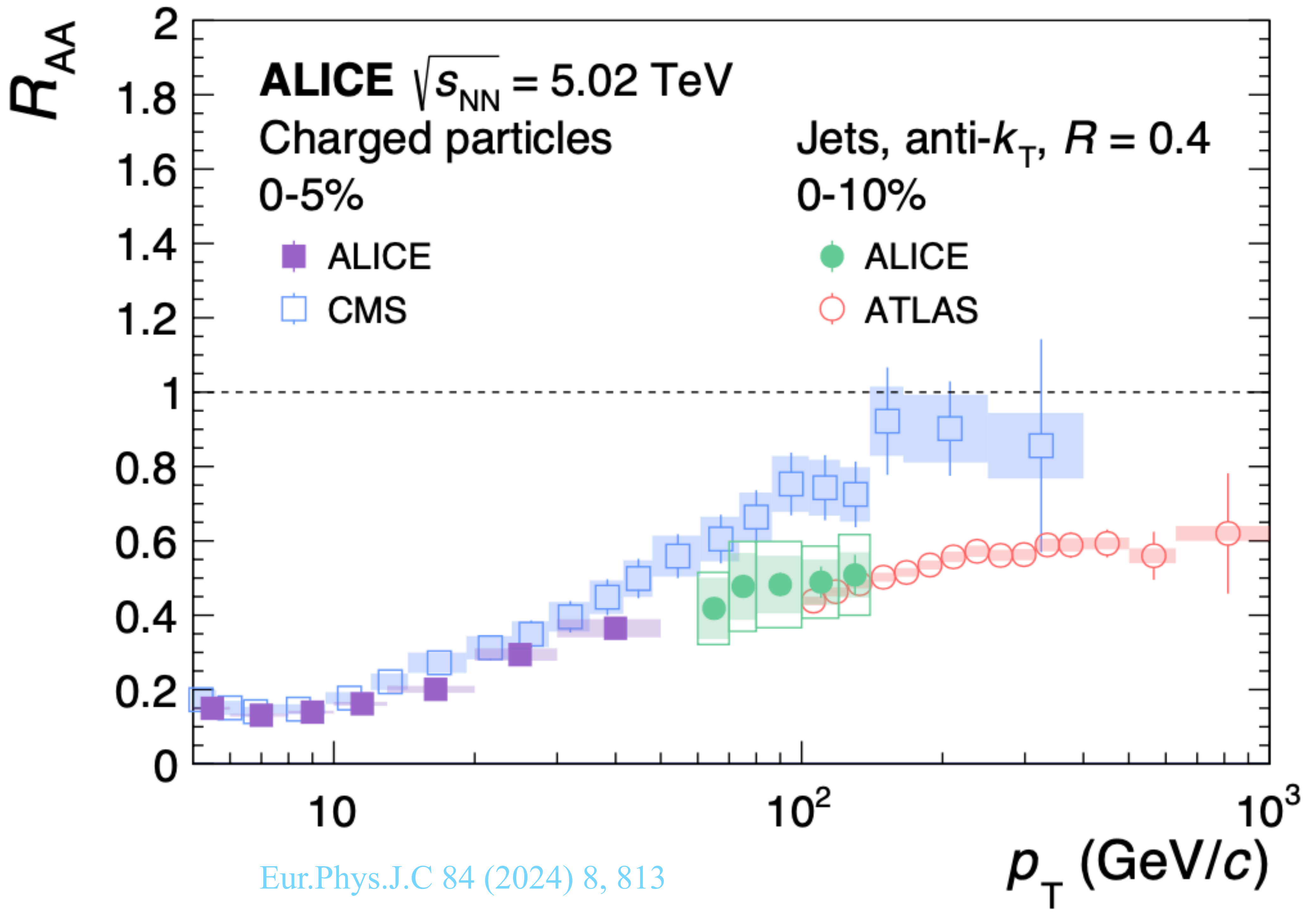
$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle T_{AA} \rangle \, d\sigma_{pp}/dp_T}$$

QGP medium

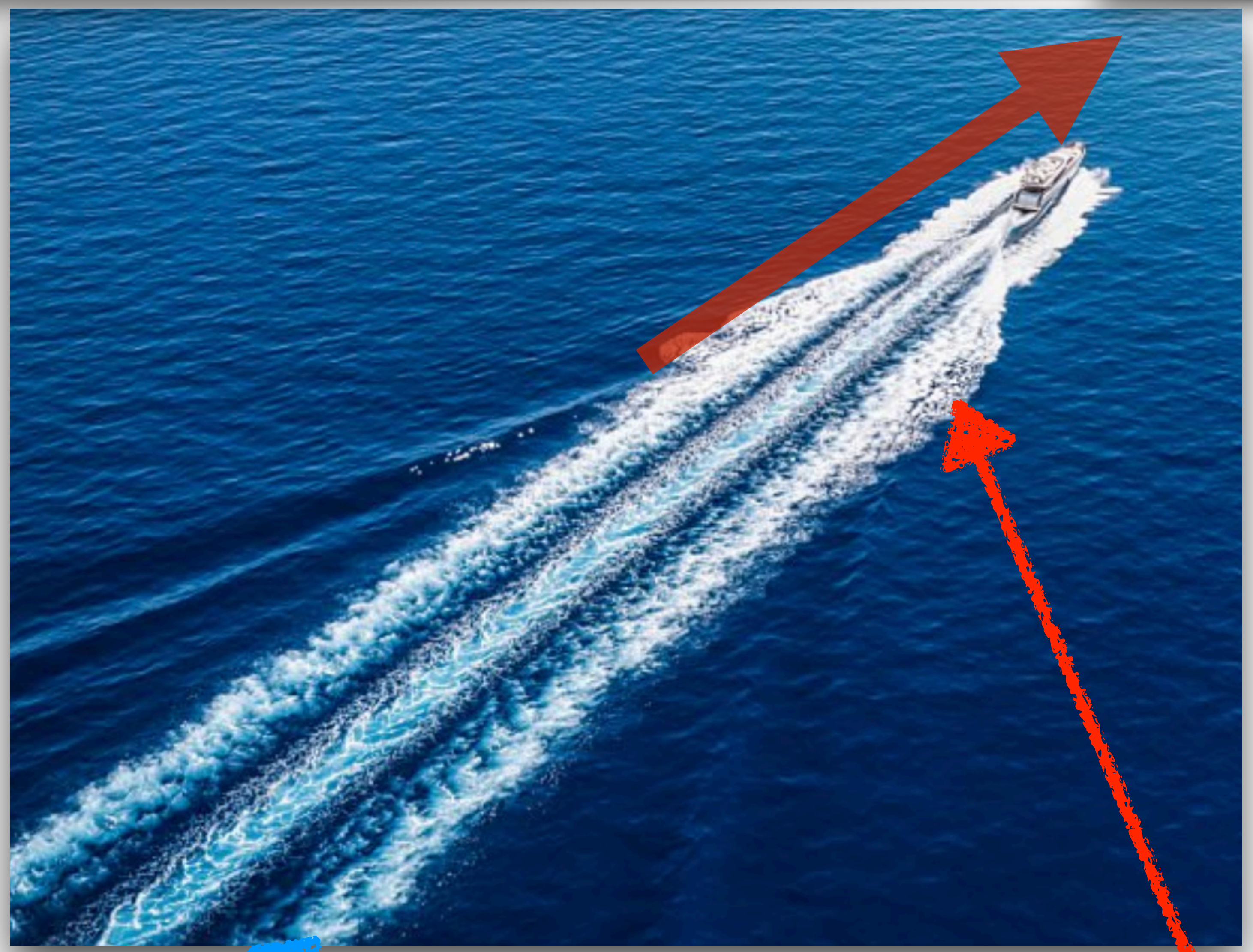
QCD vacuum

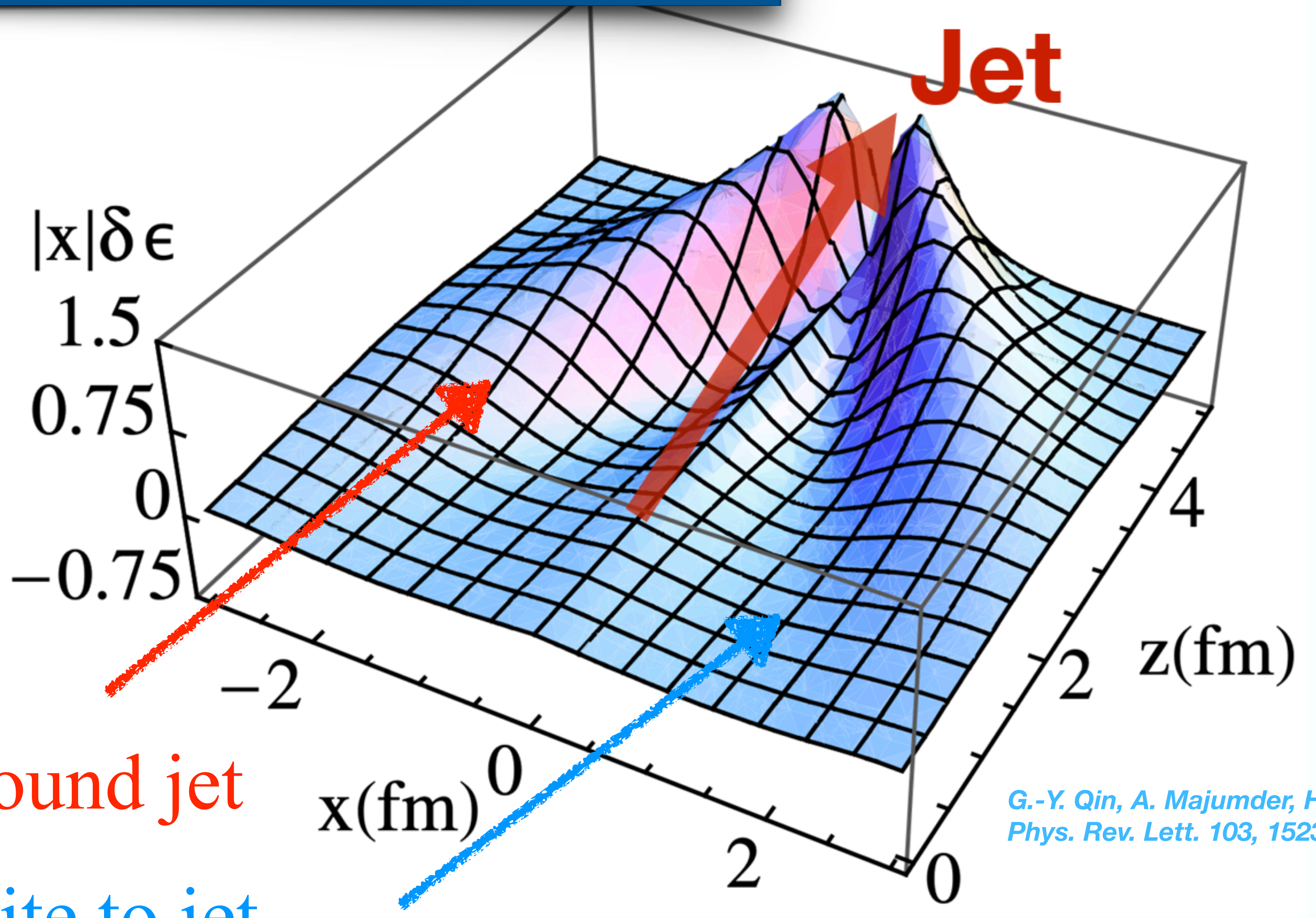


Eur.Phys.J.C 84 (2024) 8, 813

Jet interaction with the medium

What happens to the energy deposited by the jet in the medium?
Where does the lost energy loss go? How is the lost energy redistributed?





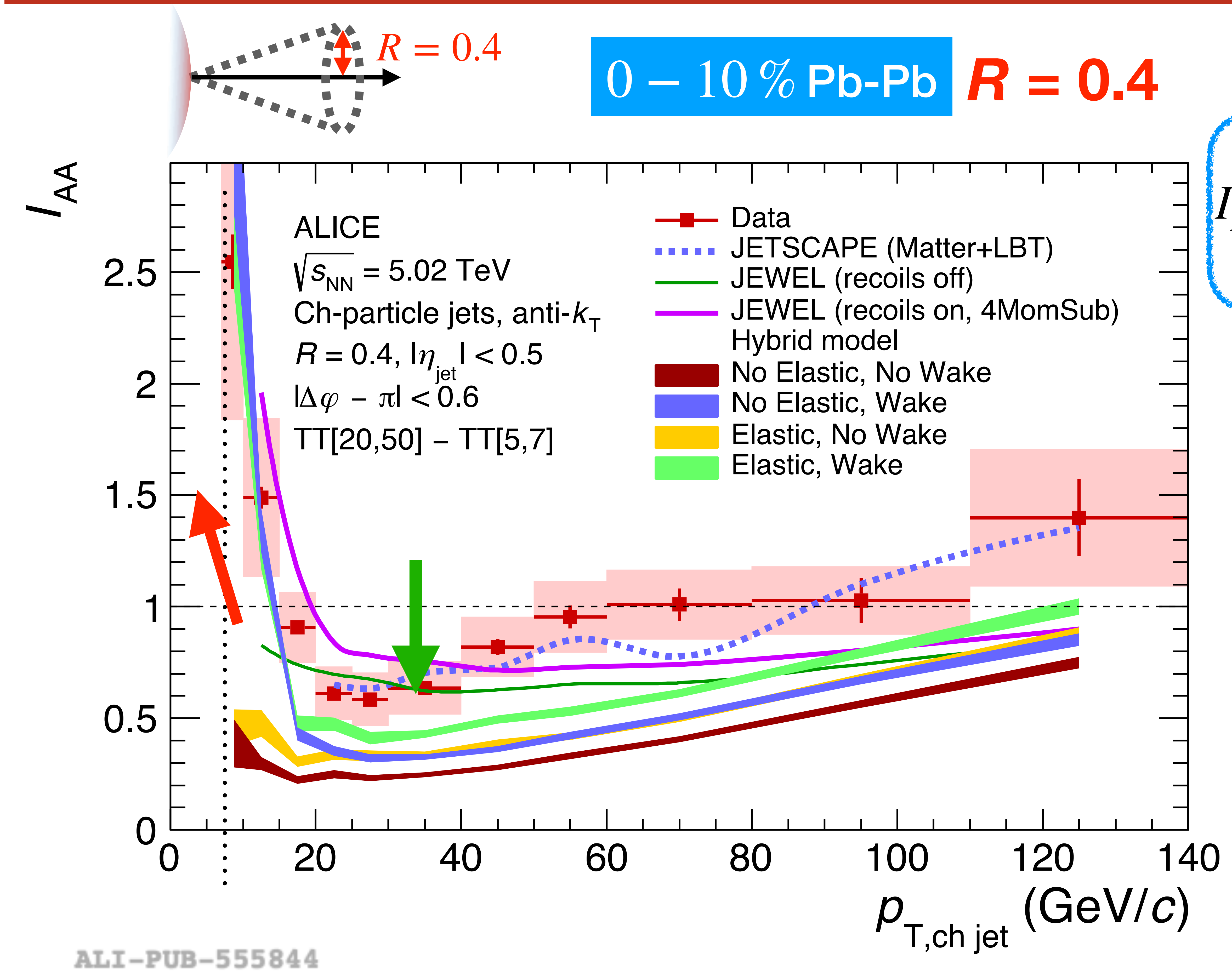
G.-Y. Qin, A. Majumder, H. Song, and U. Heinz, Phys. Rev. Lett. 103, 152303 (2009)

Enhancement around jet

Depletion opposite to jet

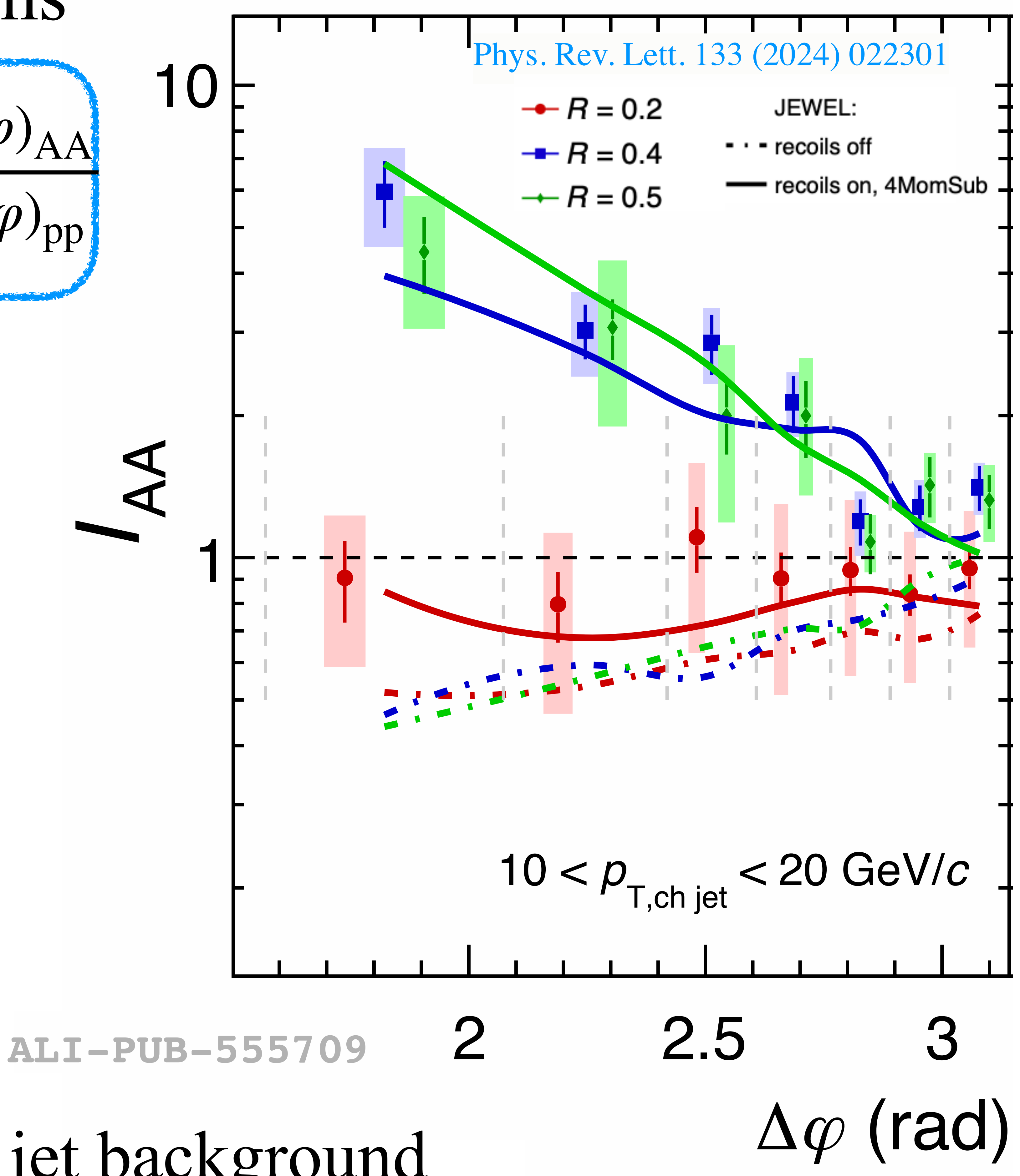
- **In heavy-ion**: when a high-p_T parton loses energy in medium, the energy may be transferred to the medium
- Typical structure of medium response:
  - ➡ enhancement in the jet direction, called e.g. wake
  - ➡ depletion in the opposite jet direction, called e.g. diffusion wake

Medium response in jet direction



H-jet correlations

$$I_{AA} \equiv \frac{\Delta_{recoil}(p_T, \Delta\varphi)_{AA}}{\Delta_{recoil}(p_T, \Delta\varphi)_{pp}}$$

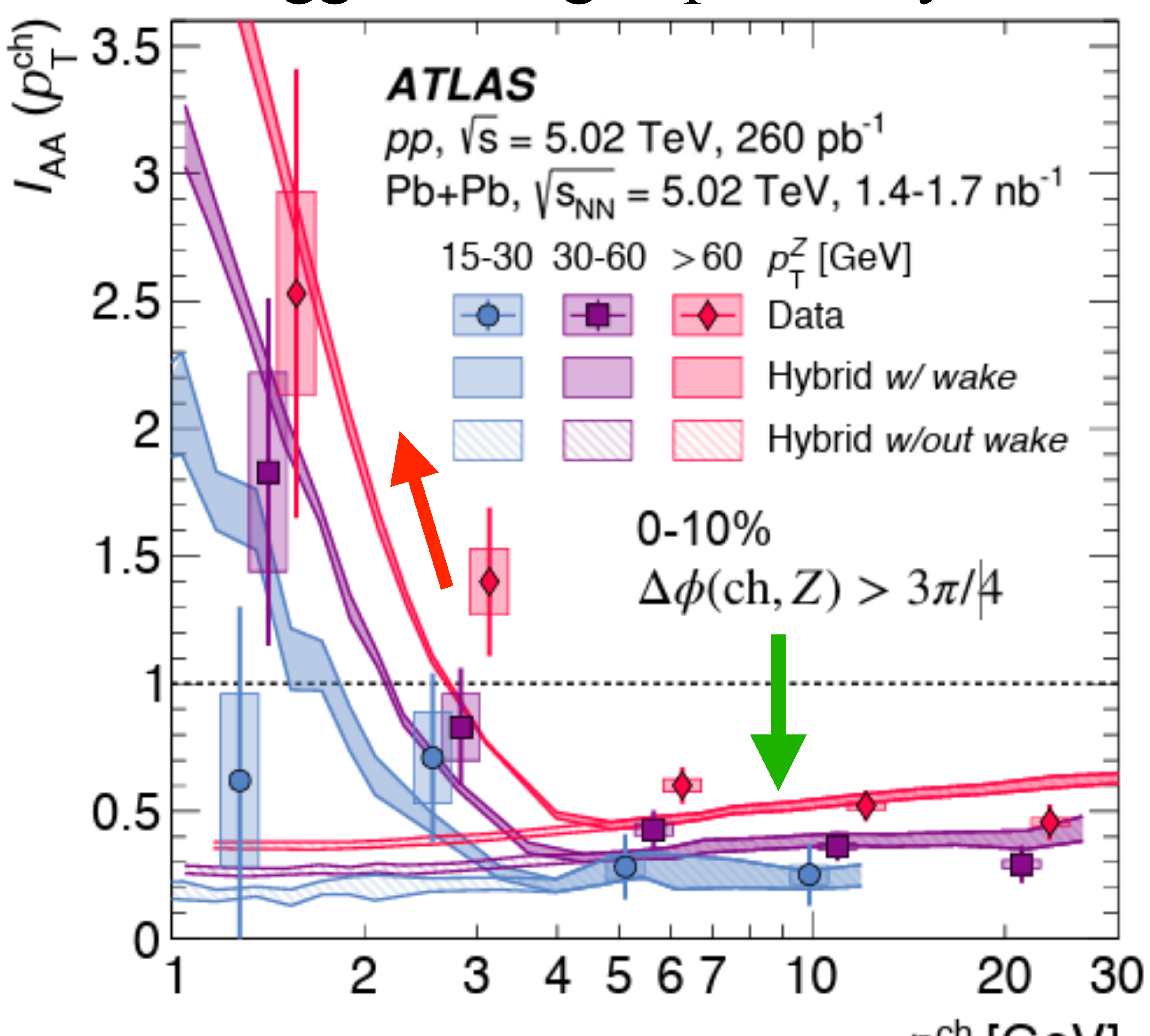


- H-jet correlations using data-driven method to remove the fake jet background
- Yield enhancement and azimuthal **broadening of** low-p_T particles

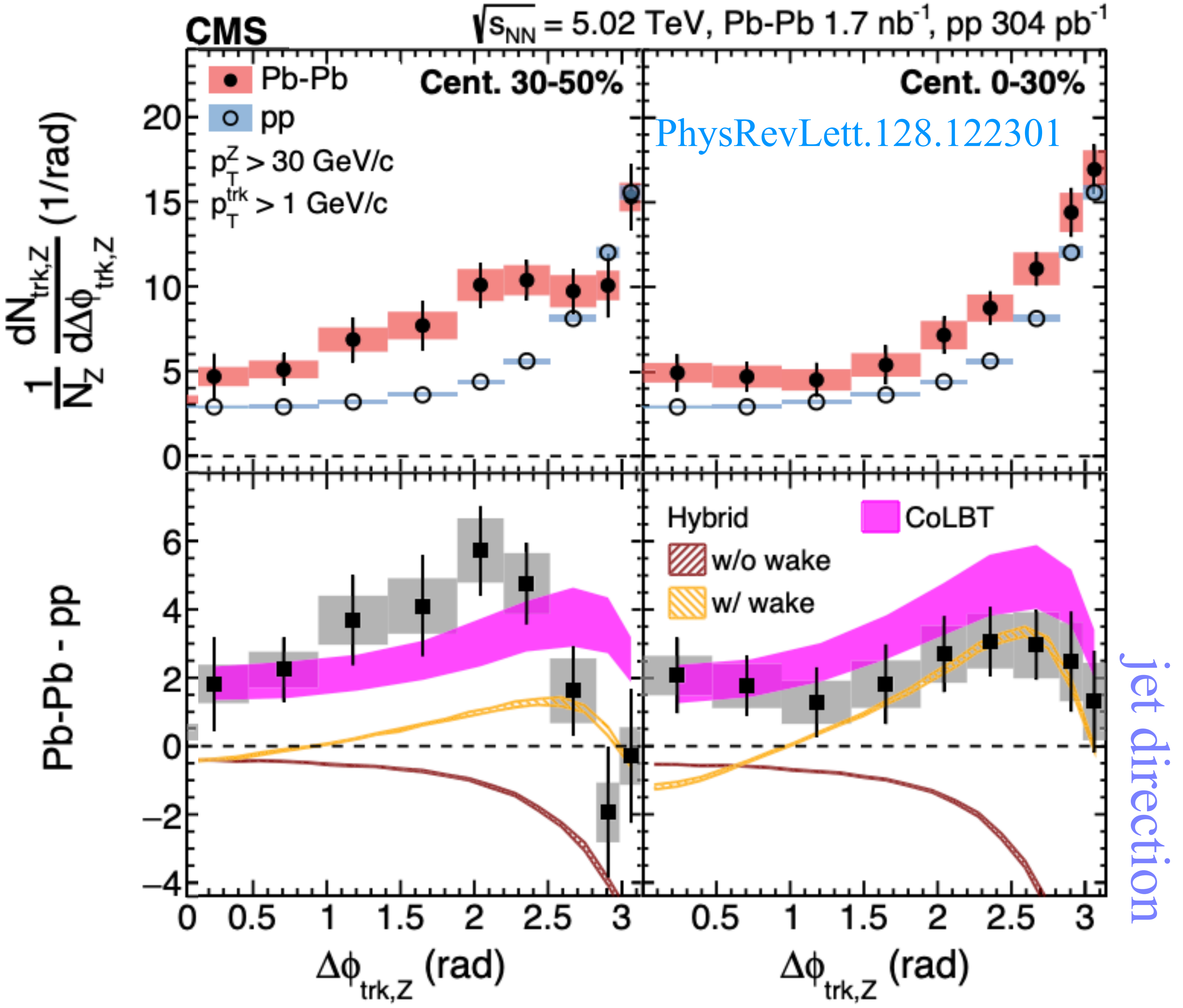
➡ but, hard to disentangle between in-medium parton shower modification and medium response

Medium response in jet direction

Z-tagged charged particle yields



Phys. Rev. Lett. 126, 072301



- ATLAS measurements with Z-bosons differential in p_T and azimuthal angular $\Delta\varphi$
- Similar conclusions to previous ALICE results

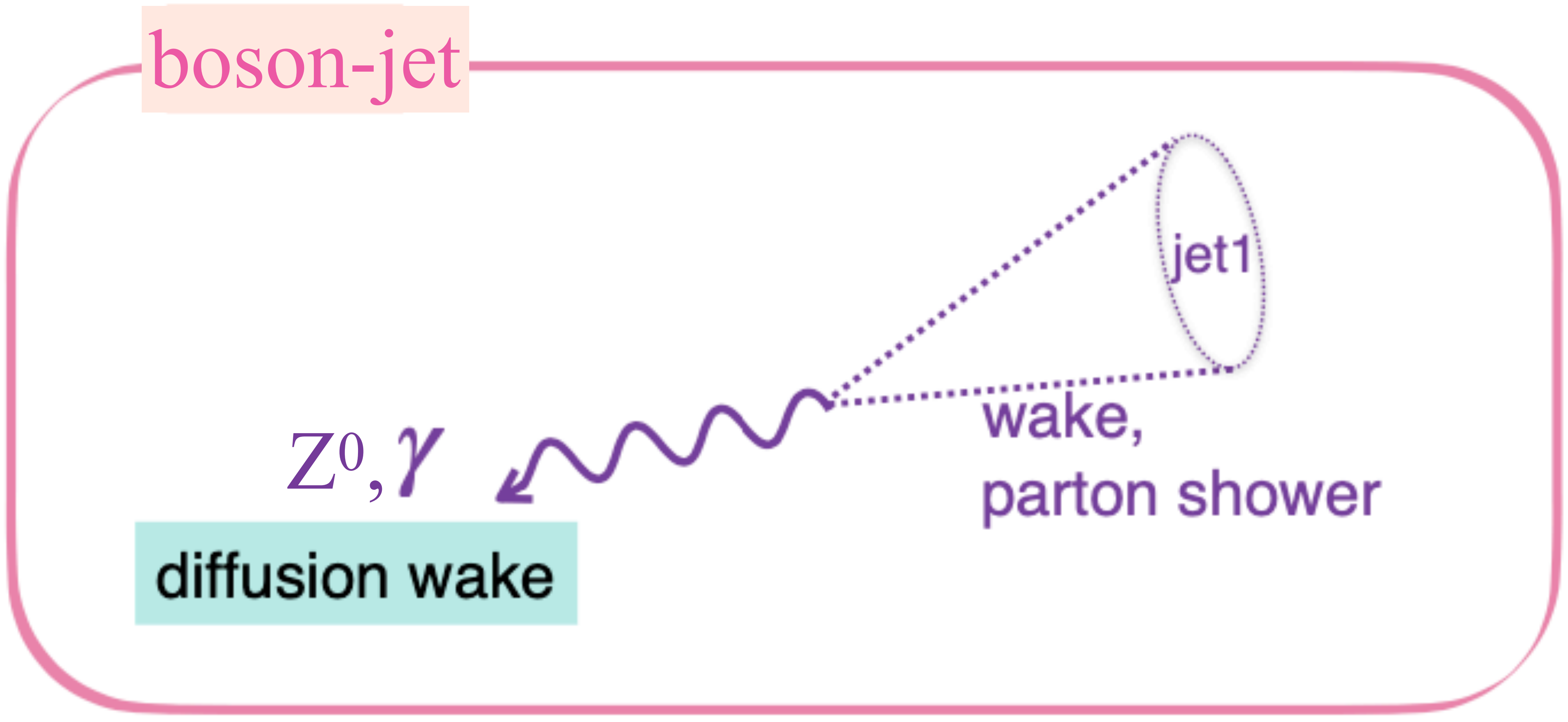
Diffusion wake

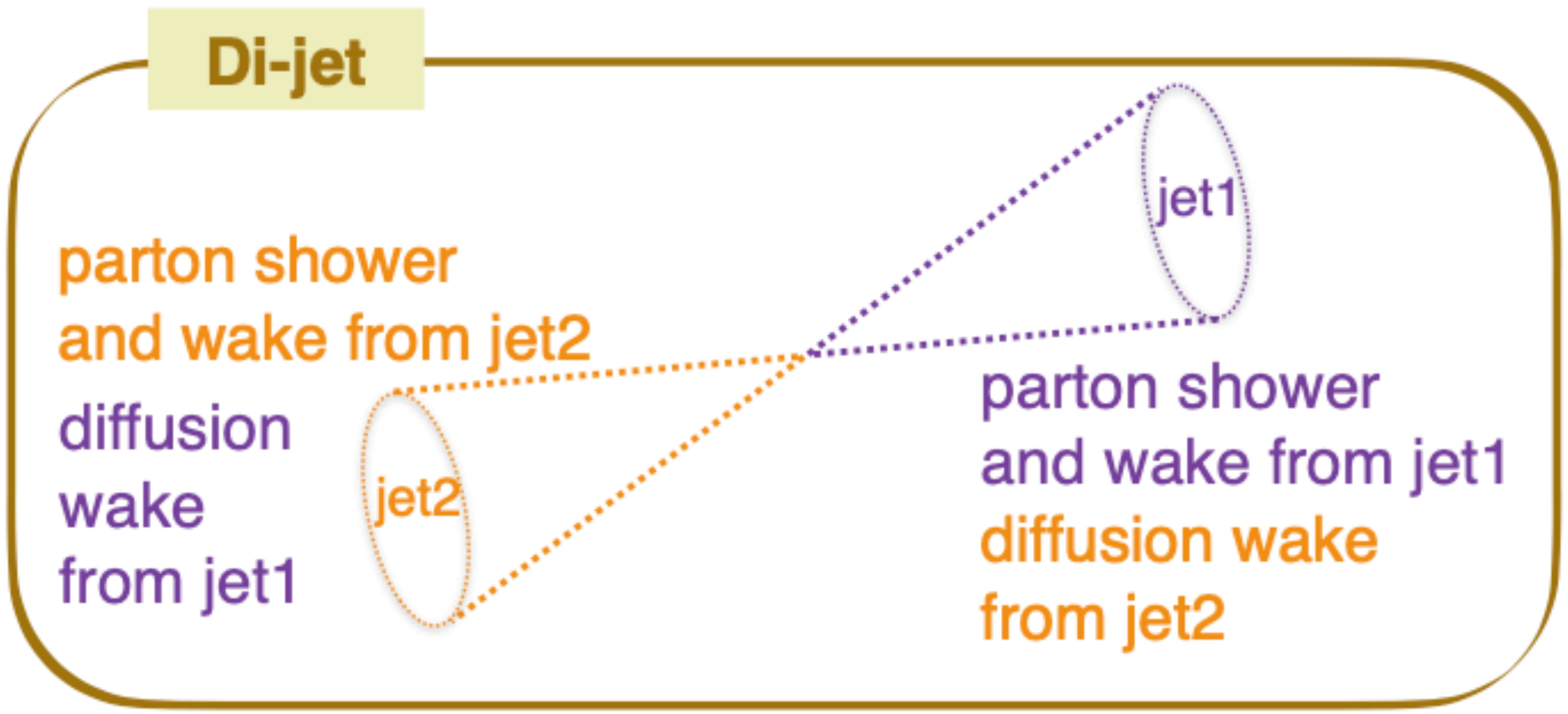
- **Diffusion wake** (depletion) in boson-jet or **di-jet** events:

➡ boson-jet events, a jet associated with a boson e.g. Z^0, photon are **NOT** contaminated by in-medium parton shower modification or wake caused by the other jet in the opposite direction

➡ **di-jet** events

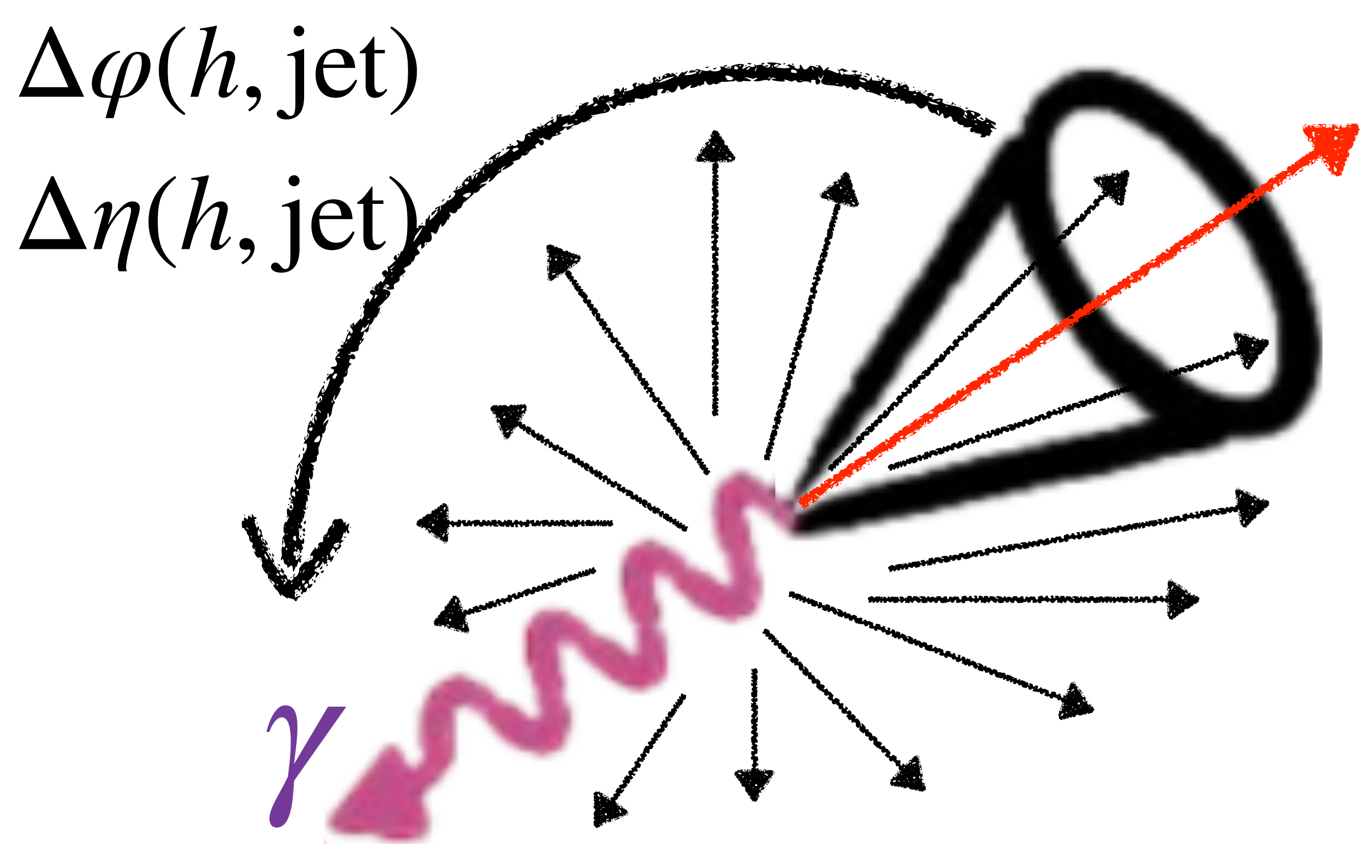
- the diffusion wake of one jet usually overlaps with the medium-induced hadron enhancement of the other jet
- **But,** it has large statistics





Diffusion wake via jet-tracks in γ-jets

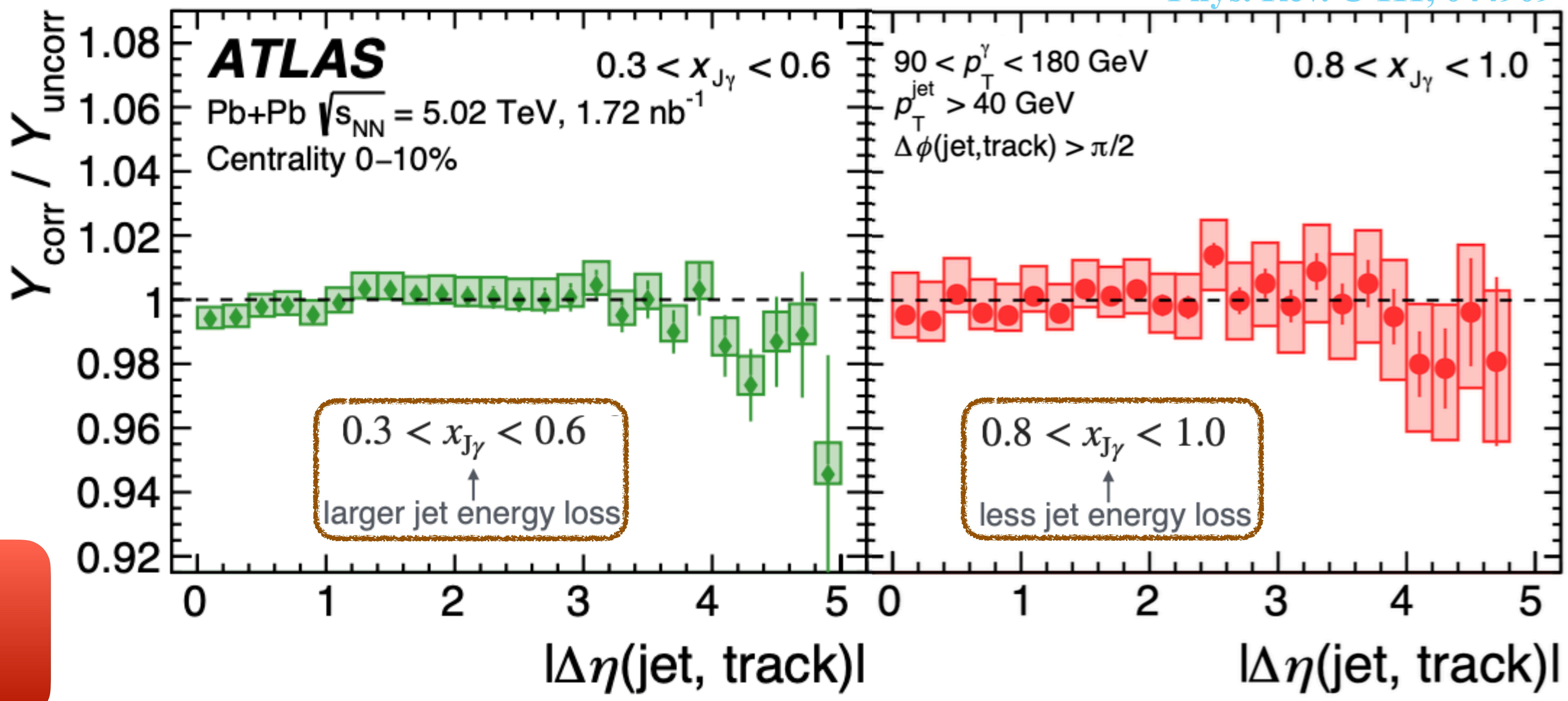
Phys. Rev. C 111, 044909



Raw jet-track pairs (Y_{corr})

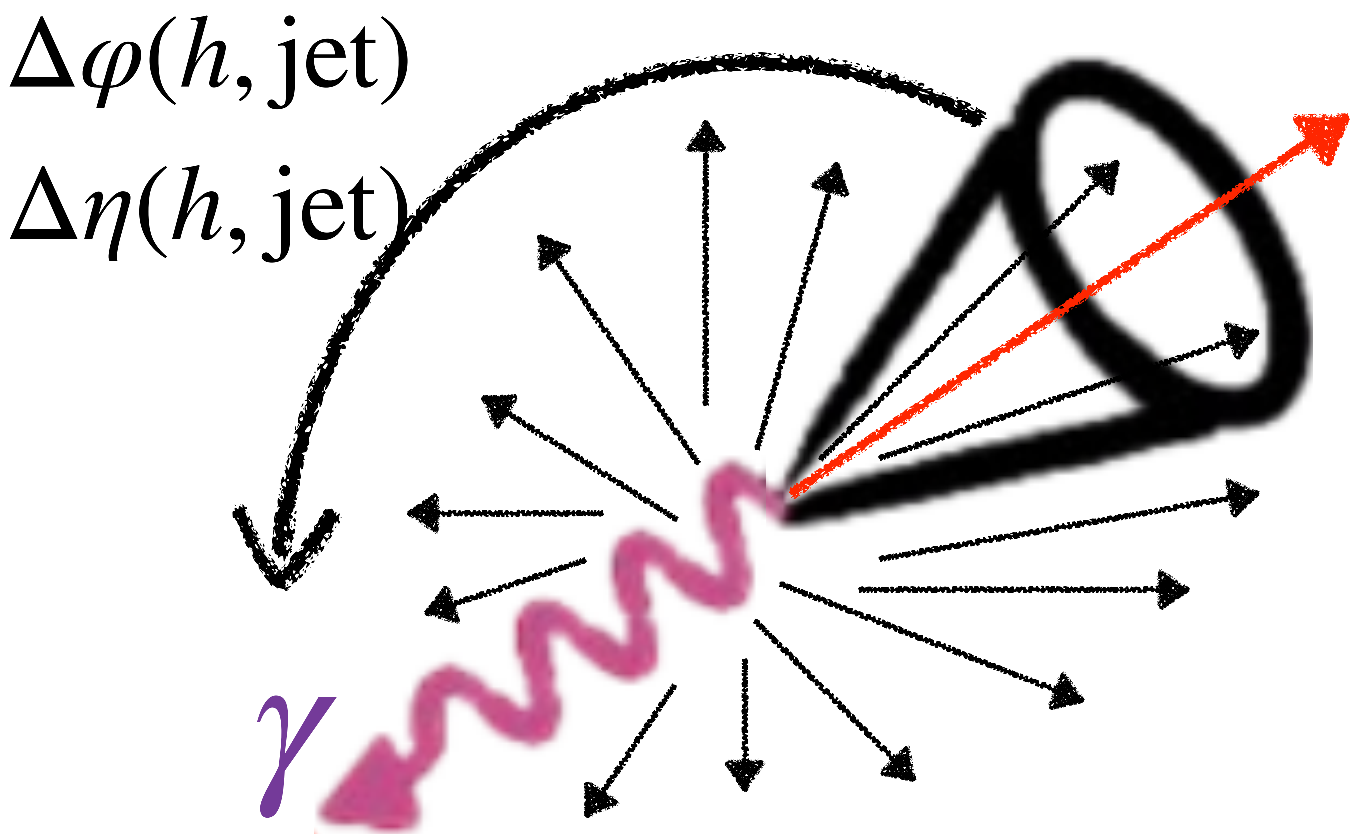
Mix jet-track pairs (Y_{uncorr})

$$Y_{corr} \text{ or } Y_{uncorr} = \frac{1}{N_{\gamma-jet}} \frac{d^2 N_{jet-track}}{d\Delta\eta\Delta\varphi}$$



- 3D analysis of jet-track correlations ($x_{J\gamma}$, $\Delta\varphi$ and $\Delta\eta$)
- Selecting different jet energy loss classes using $x_{J\gamma}$ (the jet-to-photon momentum ratio)
- Y_{corr}/Y_{uncorr} indicates the **relative modification of bulk medium** (The signal to background ratio is very small)
- **No clear diffusion wake signal** found within uncertainties for the higher $x_{J\gamma}$ region

Diffusion wake via jet-tracks in γ-jets



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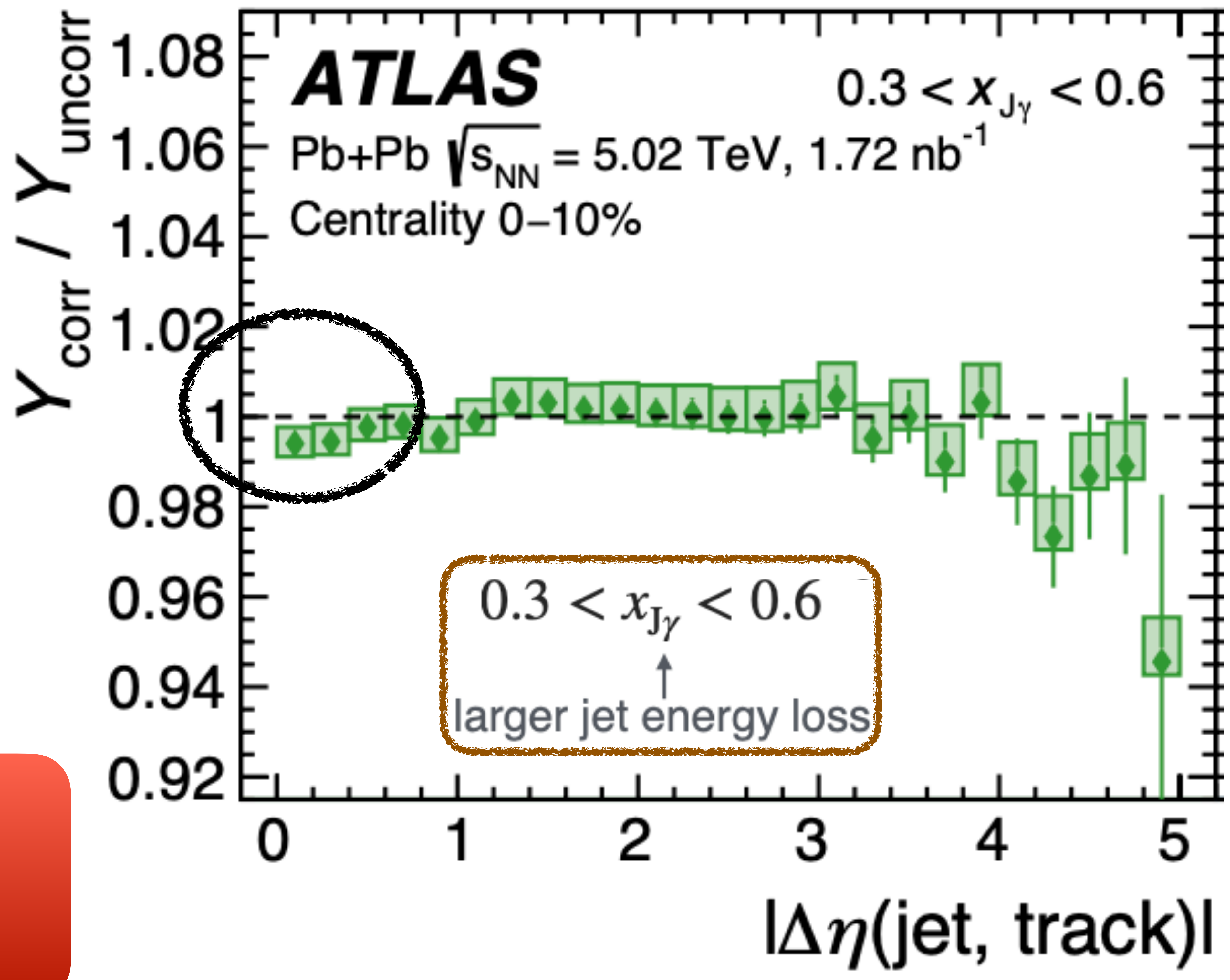
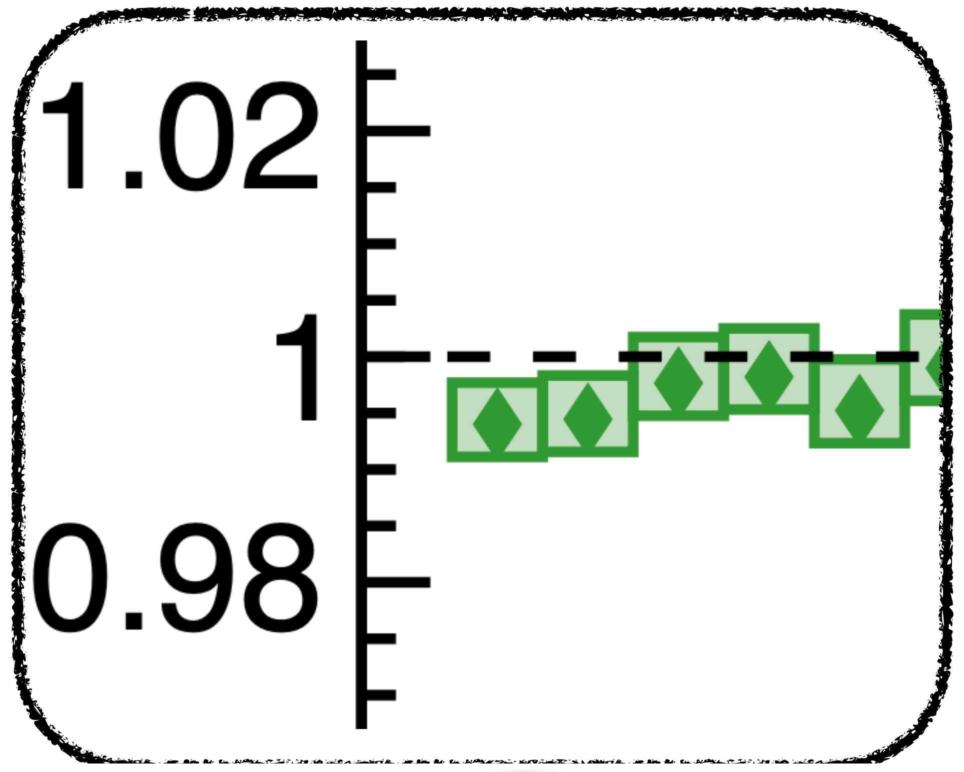
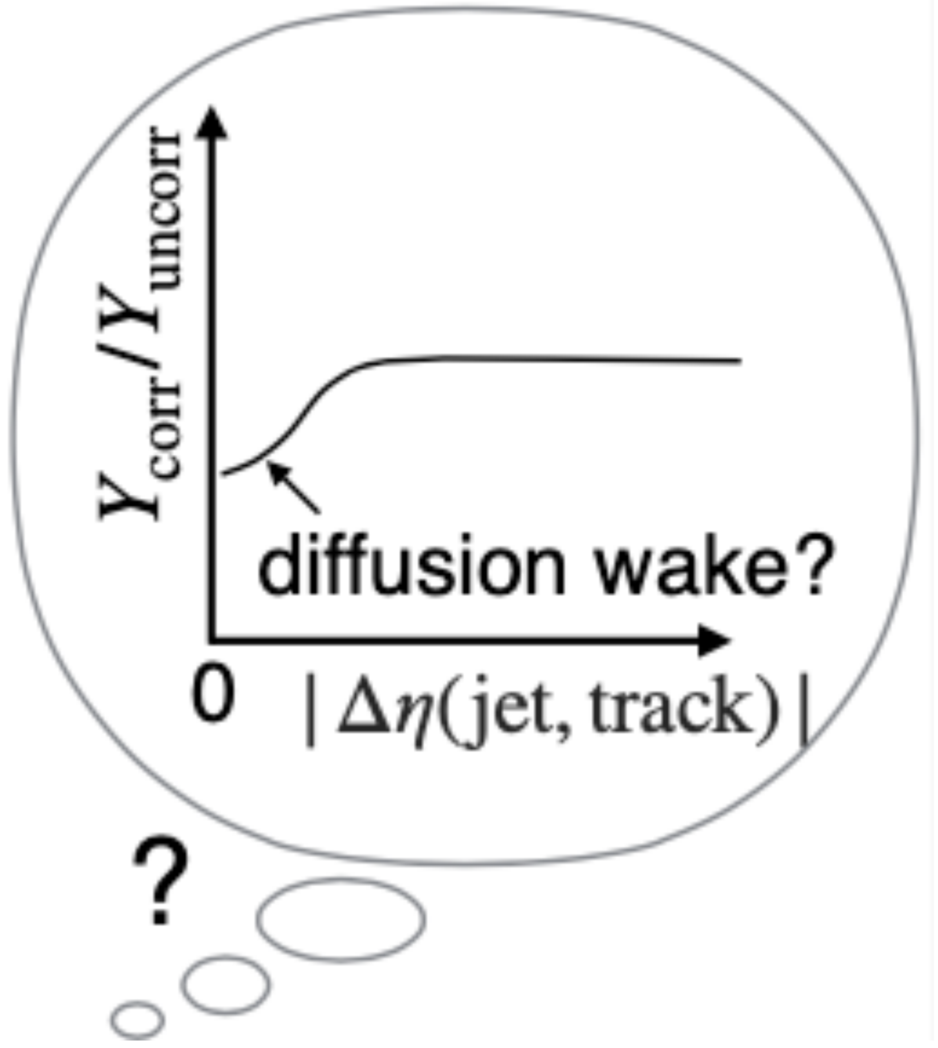
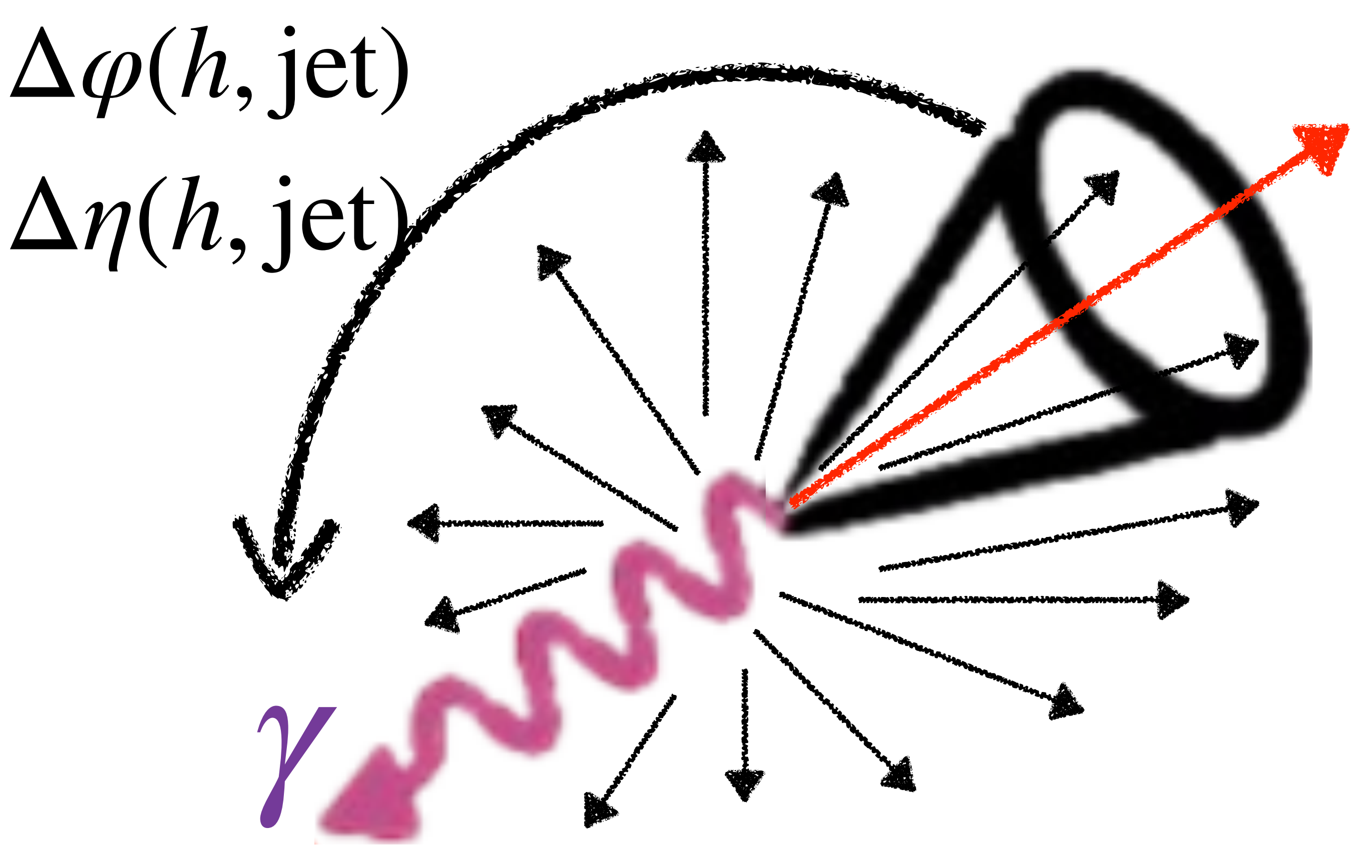






- $Y_{\text{corr}}/Y_{\text{uncorr}}$ indicates the **relative modification of bulk medium** (The signal to background ratio is very small)
- Small diffusion wake signal in the lowest $x_{J\gamma}$($\sim$1%);

Diffusion wake via jet-tracks in γ-jets



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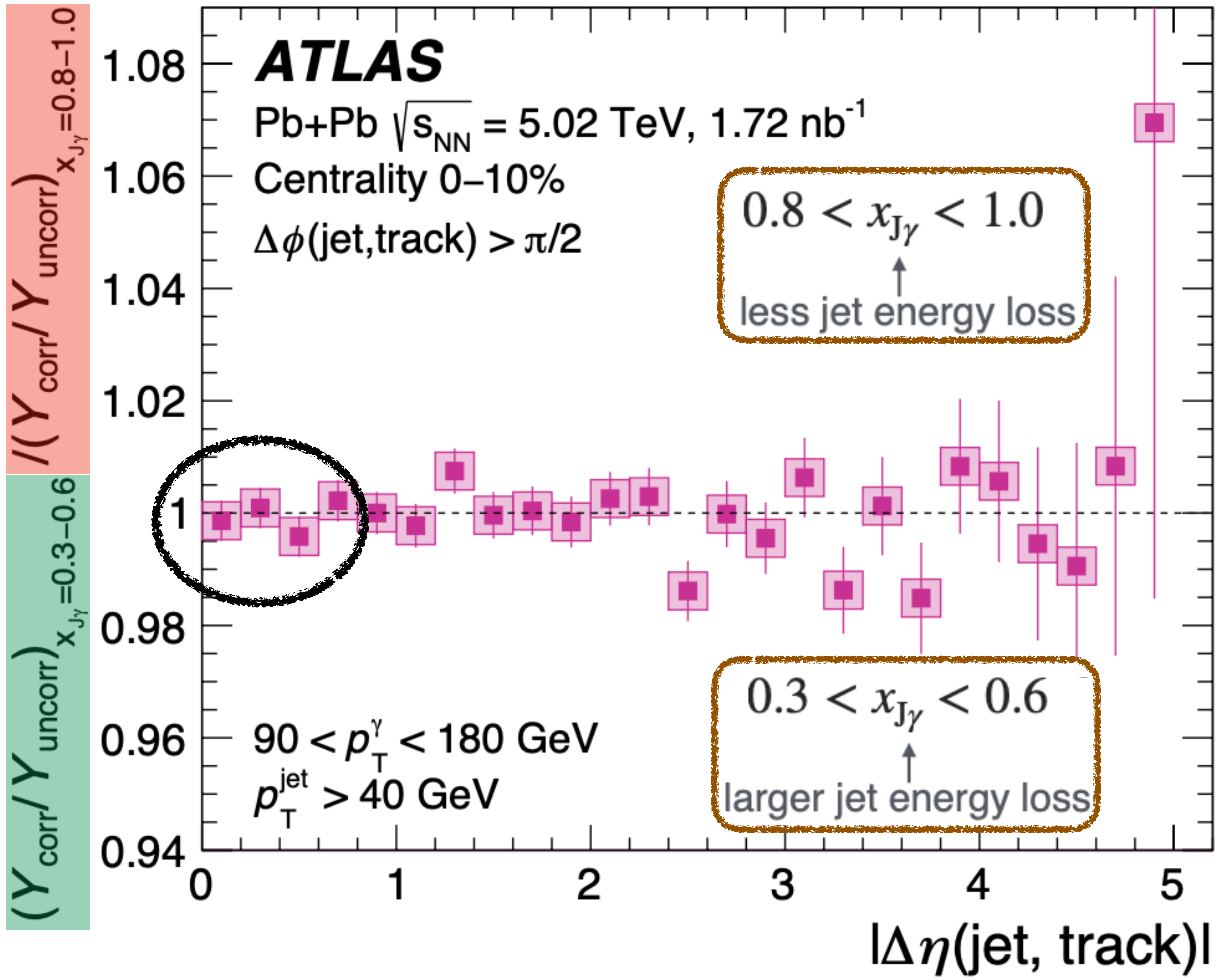

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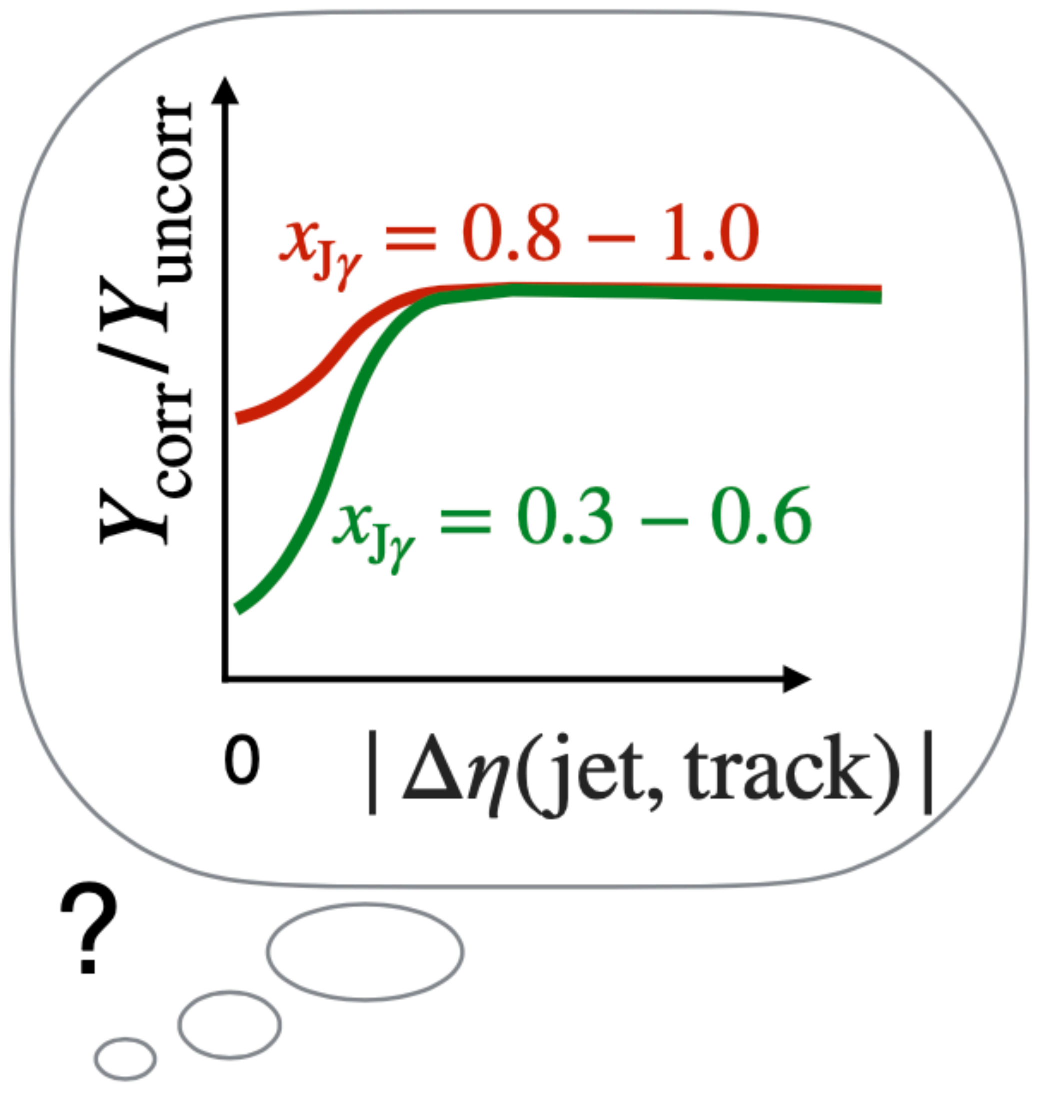
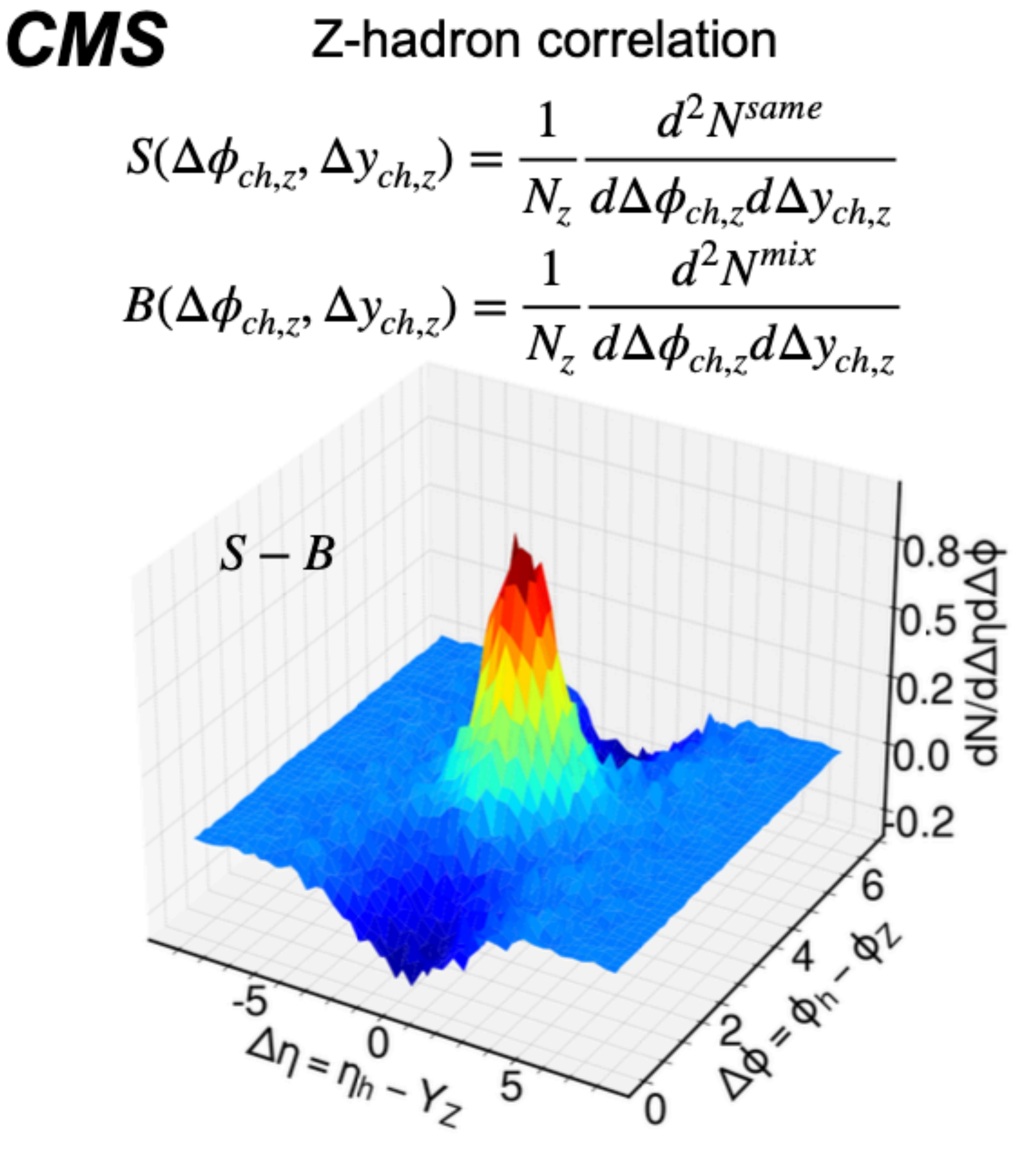
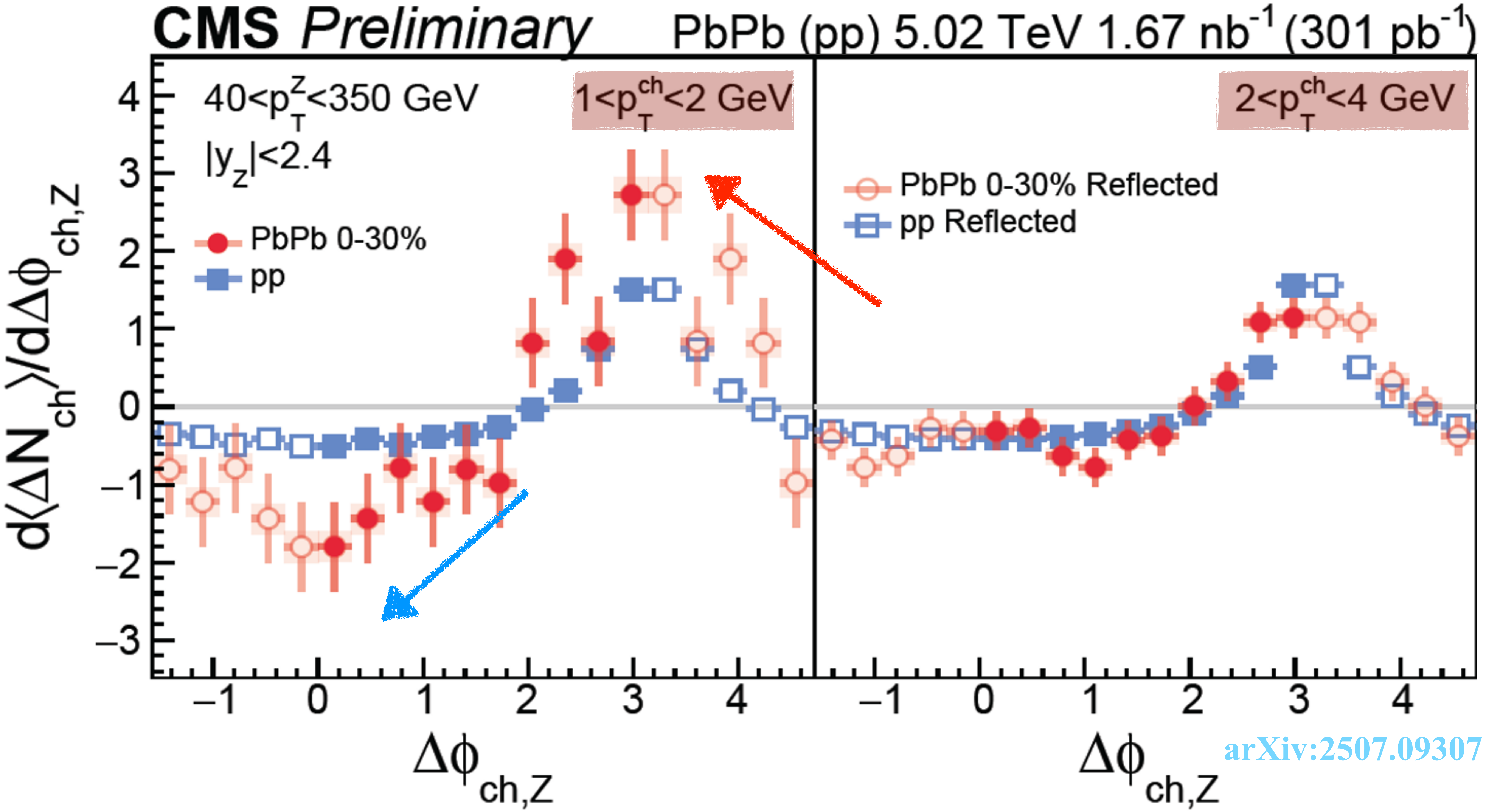


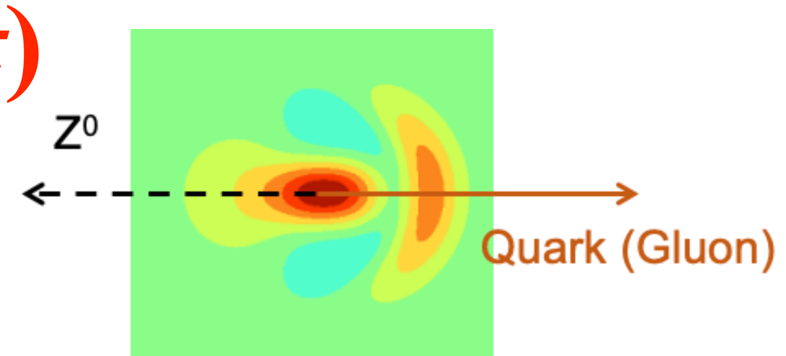
- Y_{corr}/Y_{uncorr} indicates the **relative modification of bulk medium** (The signal to background ratio is very small)
- Small diffusion wake signal in the lowest $x_{J\gamma}$(~1%);
- **No significant $x_{J\gamma}$-dependence** of the diffusion wake is found.

Diffusion wake via Z^0-jets: $\Delta\varphi$





- Low-p_T particles: clear depletion in **Z^0 side ($\Delta\varphi = 0$)** and enhancement in **jet side ($\Delta\varphi \sim \pi$)**
  - ➡ seen a deeper dip structure at $\Delta\varphi \sim 0$



Diffusion wake via Z⁰-jets: Δφ

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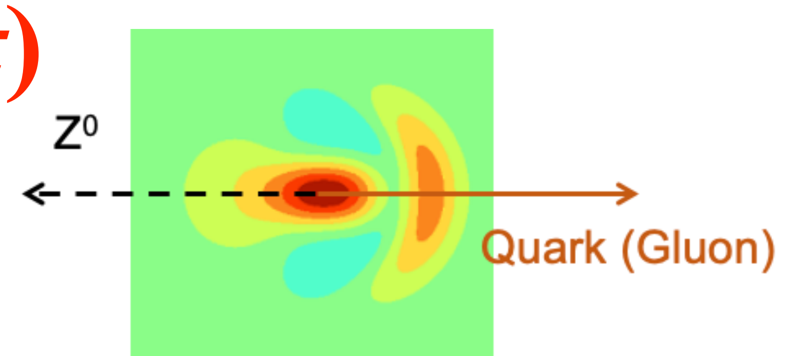
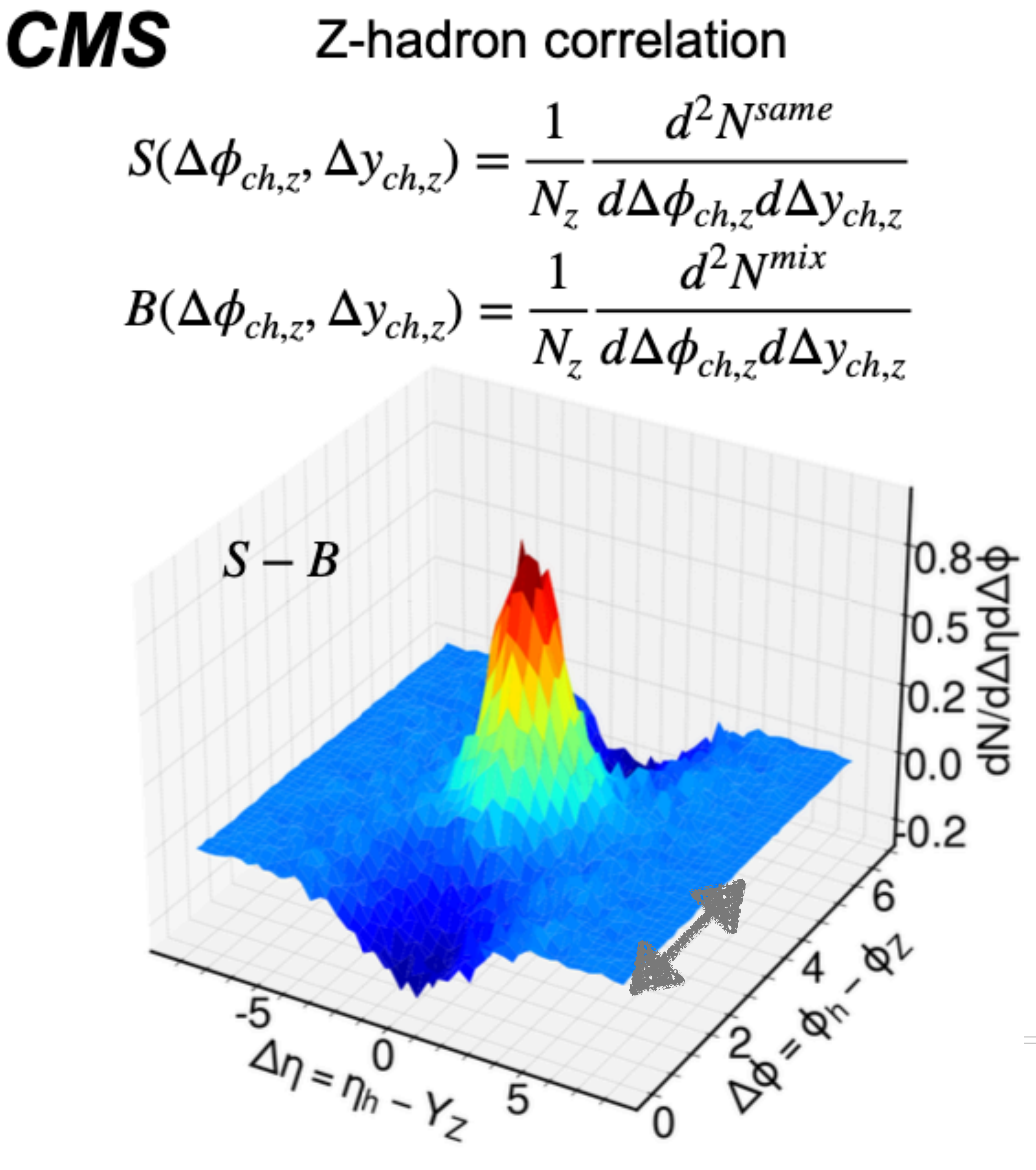
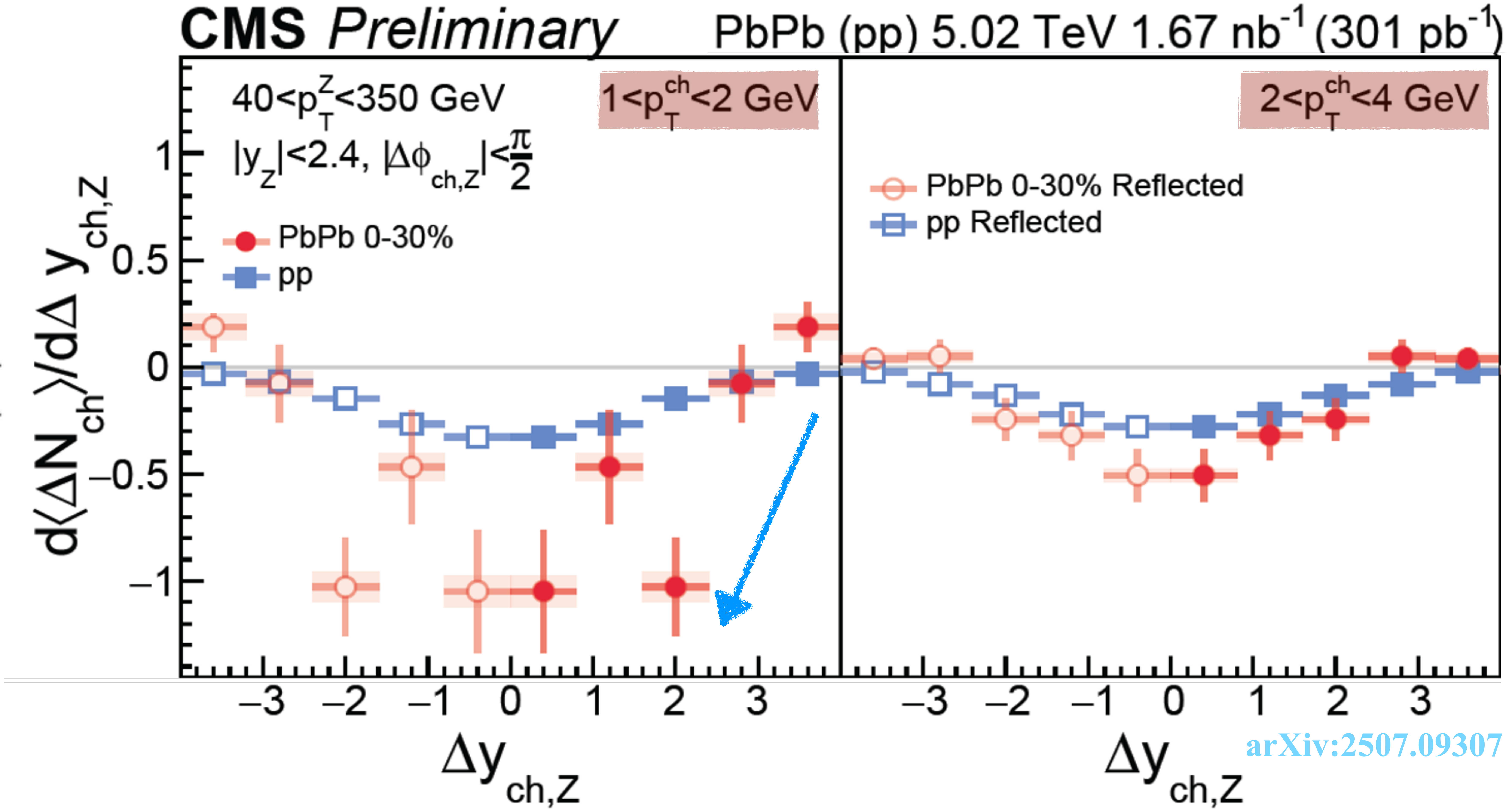
How about rapidity distributions?

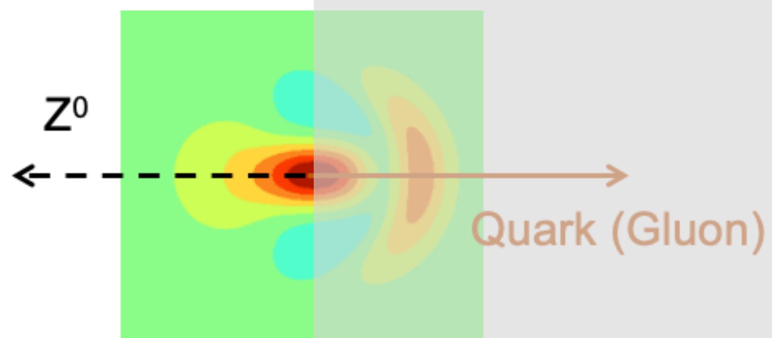


Diffusion wake via Z^0-jets: Δy





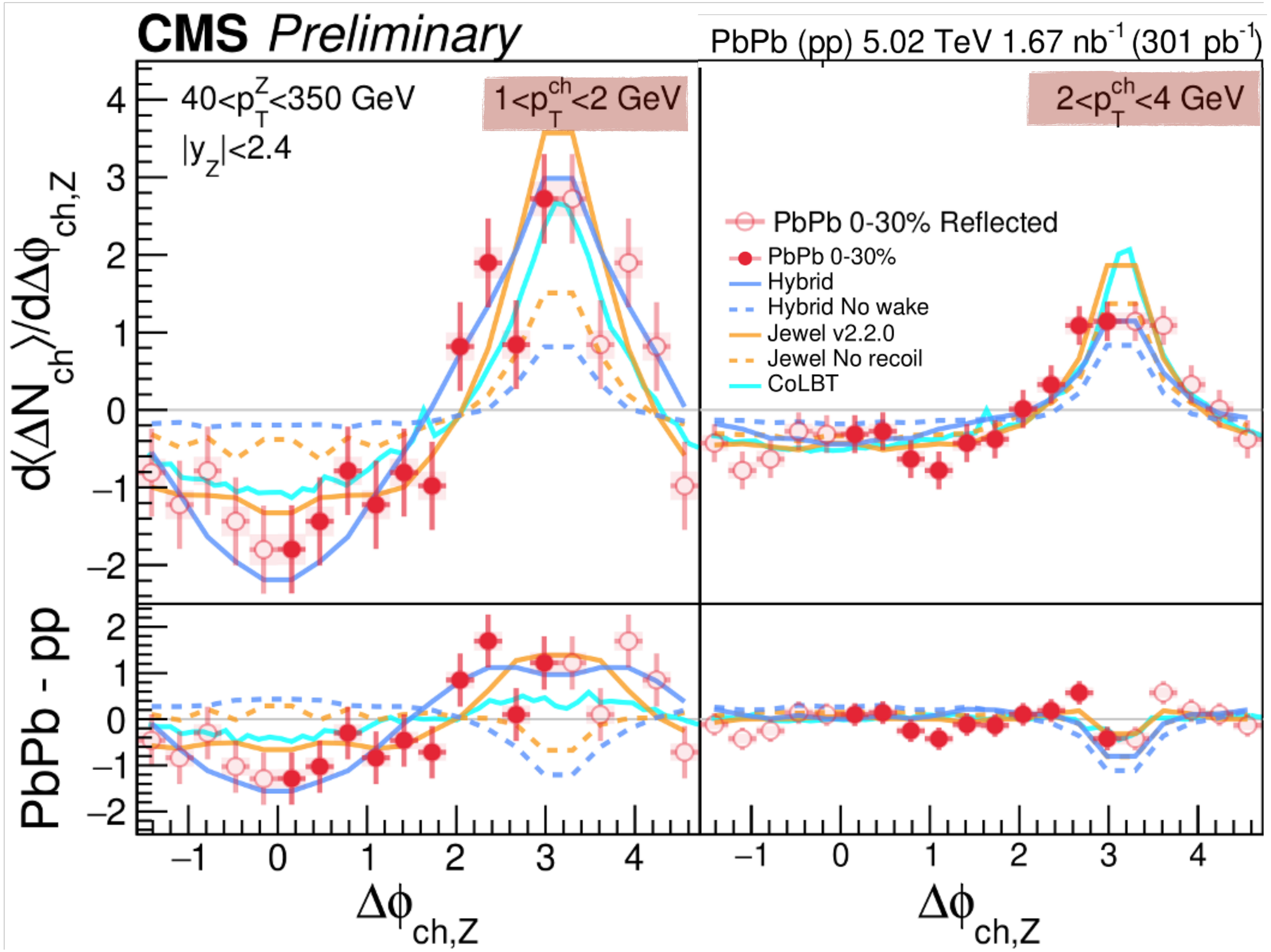
- Low-p_T particles: clear depletion around Z^0 ($\Delta y = 0$)
  - ➡ seen a deeper dip structure at $\Delta\varphi \sim 0$



Comparison of diffusion wake with models

- Hybrid without wake and **Jewel without recoil** underpredict magnitude at low hadron p_T
- Hybrid with wake, Jewel with recoil and CoLBT with wake agree better with the data with hadron $p_T < 4$ GeV/c
- Hybrid without wake and **Jewel without recoil** underpredict magnitude at low hadron p_T

arXiv:2507.09307



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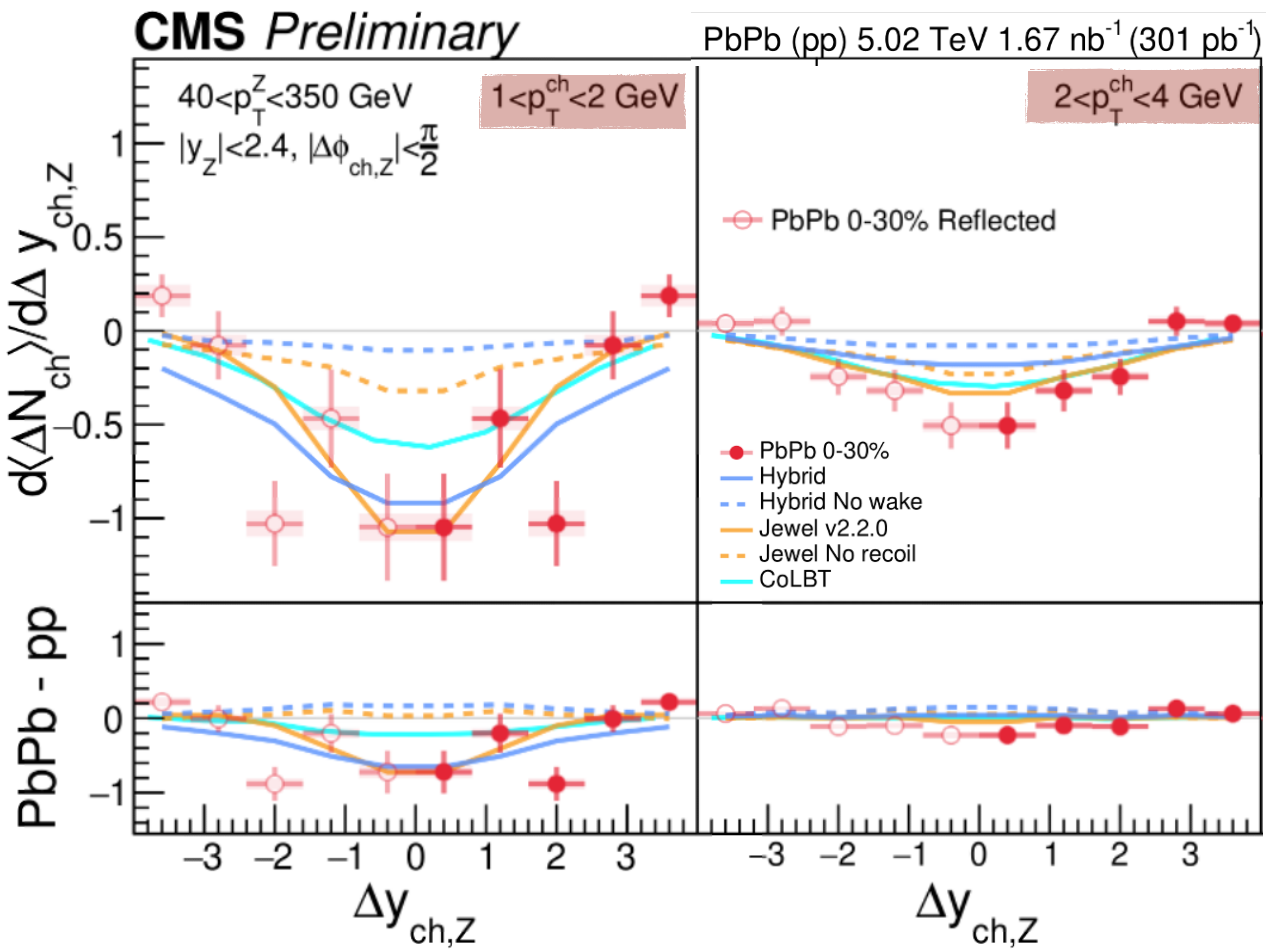
First direct evidence of medium response in QGP



arXiv:2507.09307

Theoretial predictions: diffusion wake in di-jets

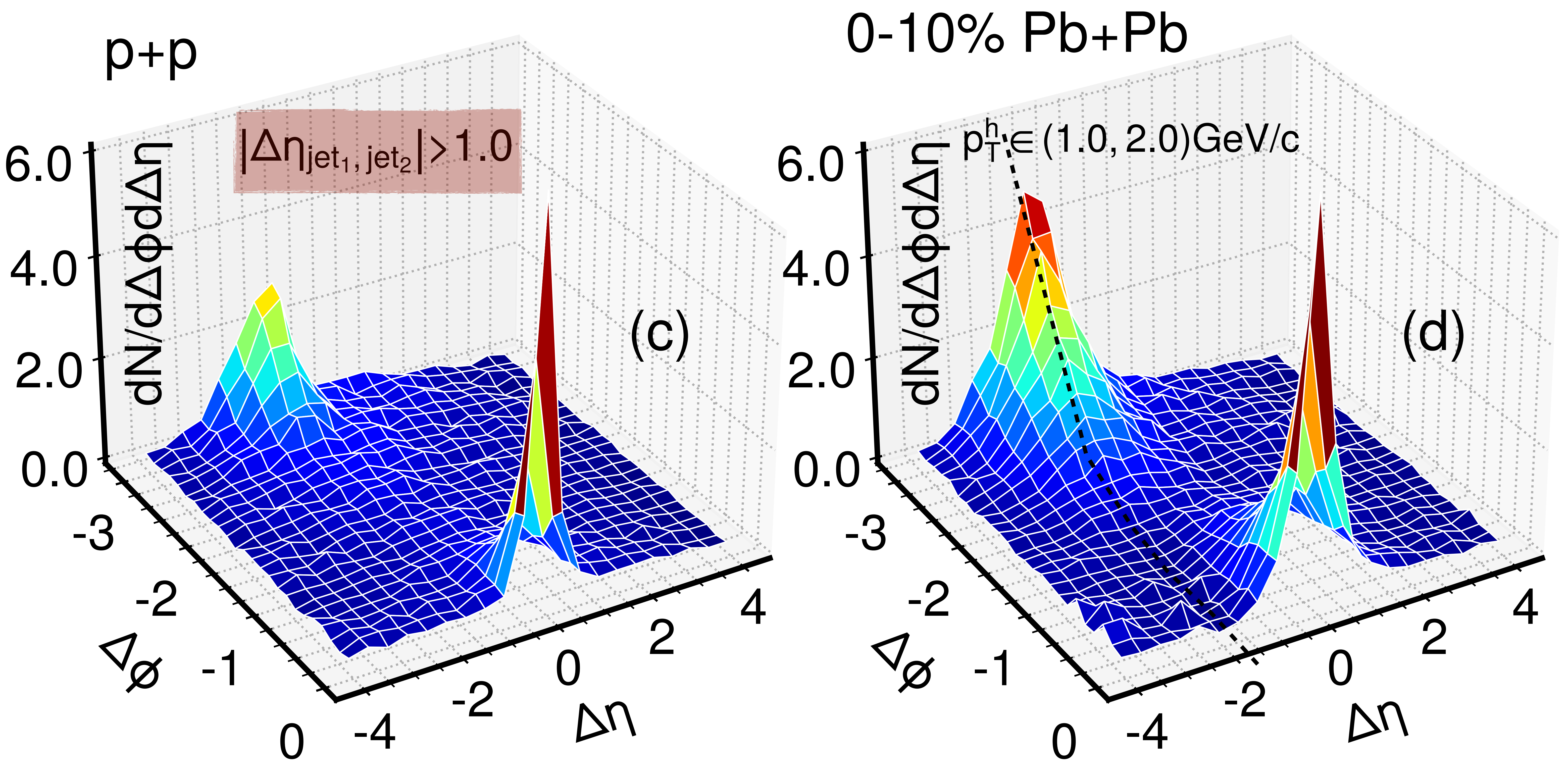
- Medium modification of jet-hadron correlation in di-jet events

$$\Delta N_{AA} = \int d\Delta\phi \left[\frac{dN_{AA}}{d\Delta\phi d\Delta\eta} - \frac{dN_{pp}}{d\Delta\phi d\Delta\eta}\right]$$

- Rapidity Asymmetry

$$\Delta N_{AA} - \Delta N_{AA}(|\Delta\eta_{jet1,jet2}| < 0.5)$$

- Three rapidity gaps: $|\Delta\eta_{jet1,jet2}| < 0.5$, $0.5 < |\Delta\eta_{jet1,jet2}| < 1.0$, $|\Delta\eta_{jet1,jet2}| > 1.0$



Phys. Rev. Lett. **135**, 072302 (2025)

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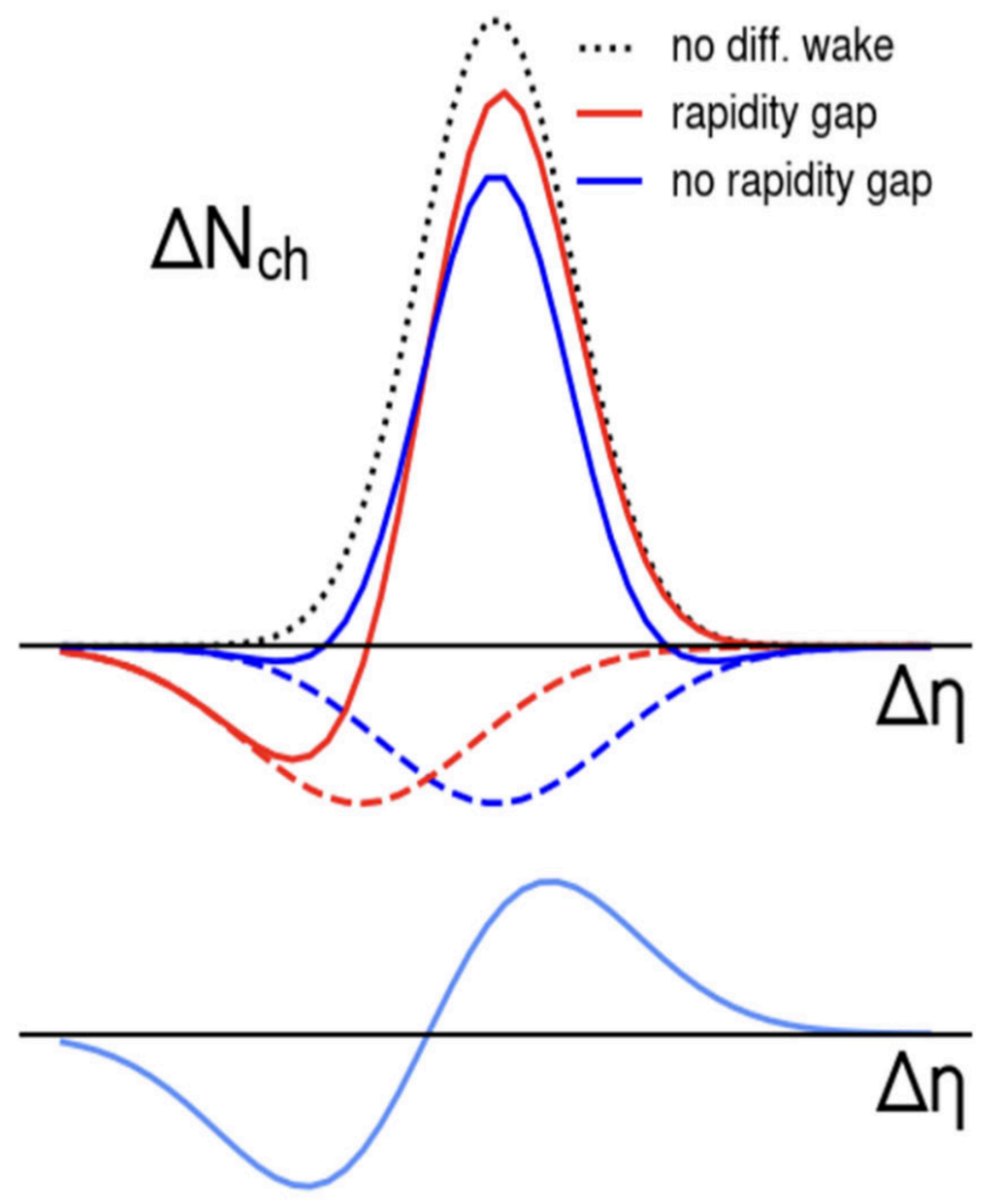

$\Delta N = N(\text{gap}) - N(\text{no gap})$

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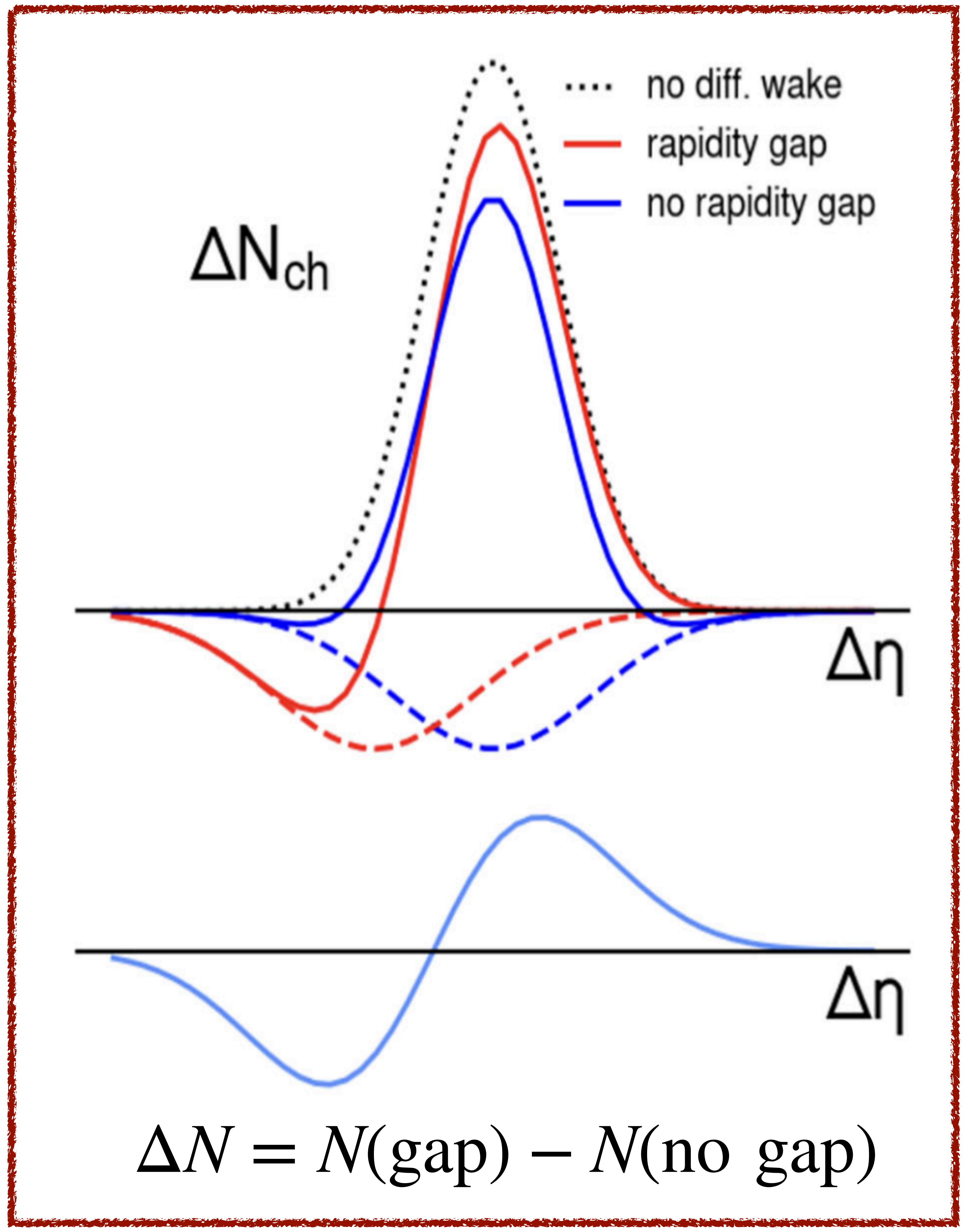

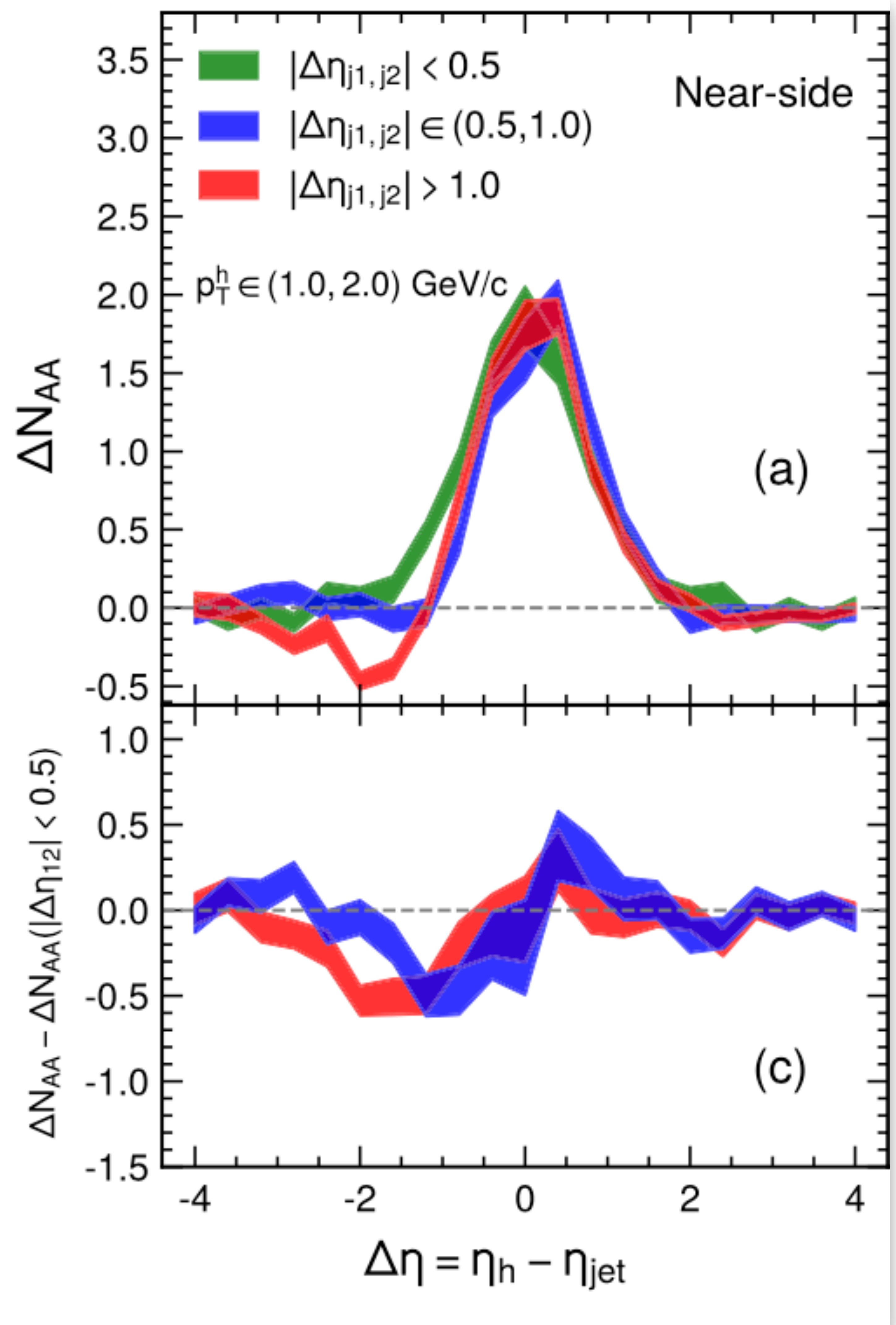

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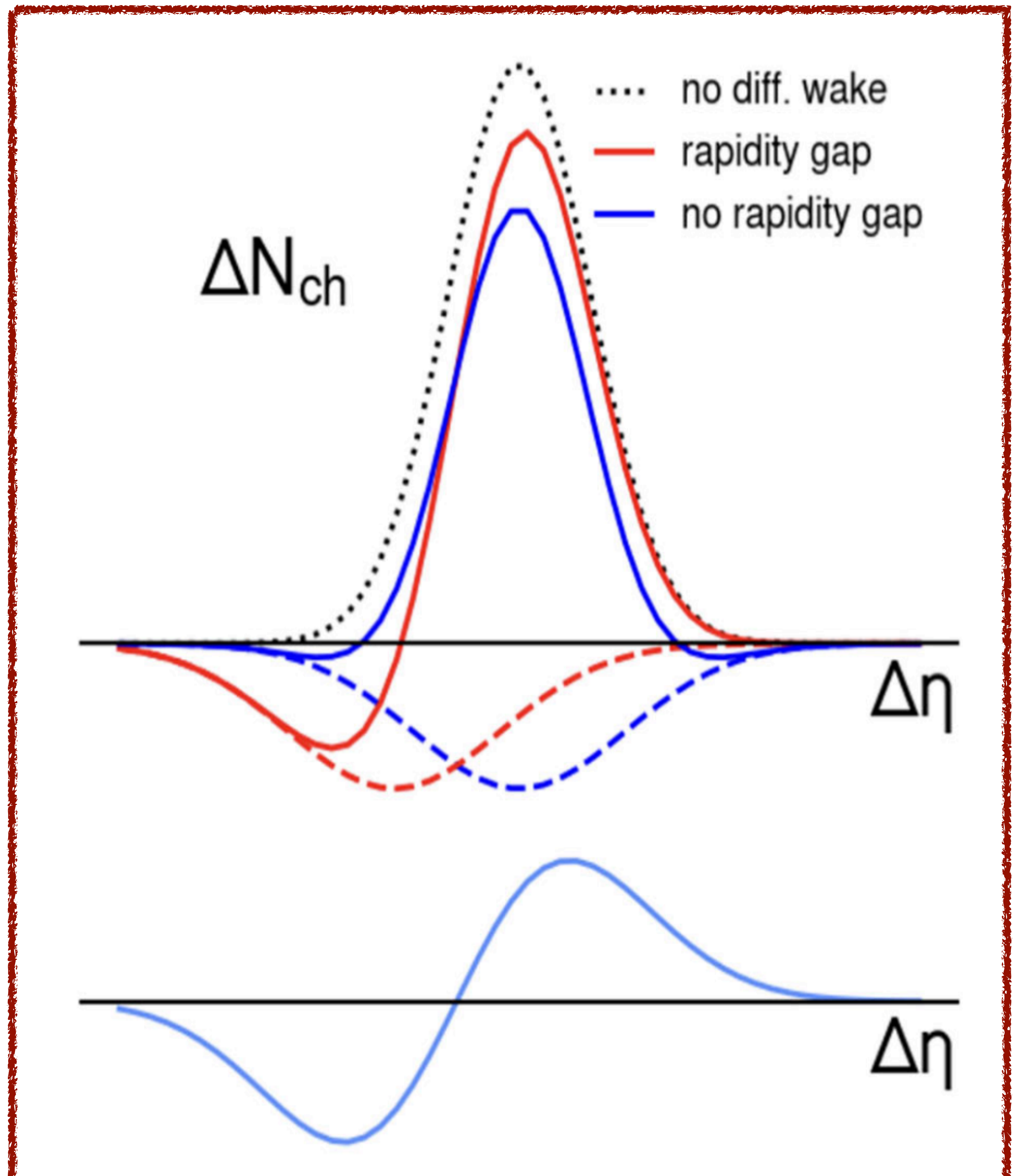

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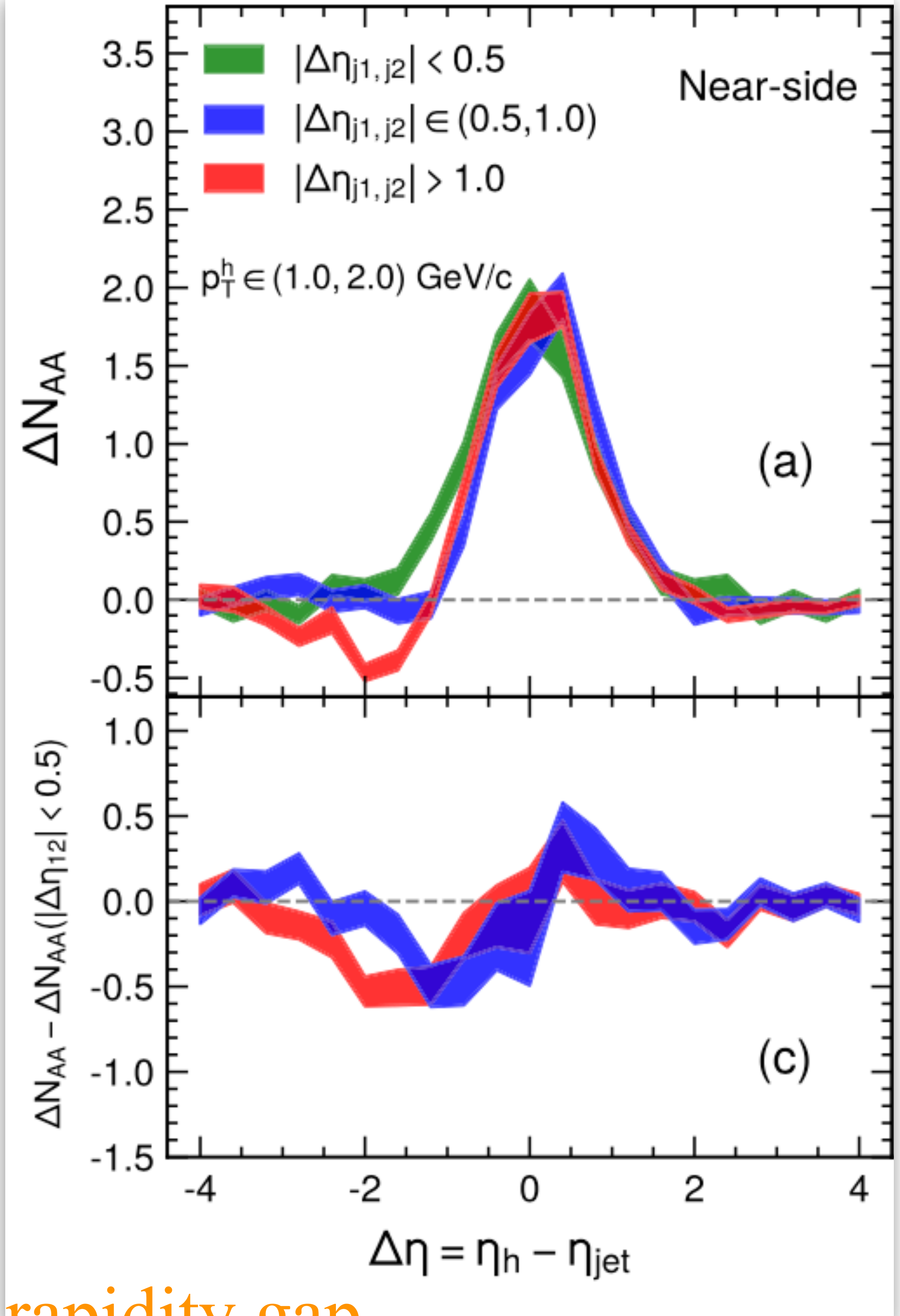
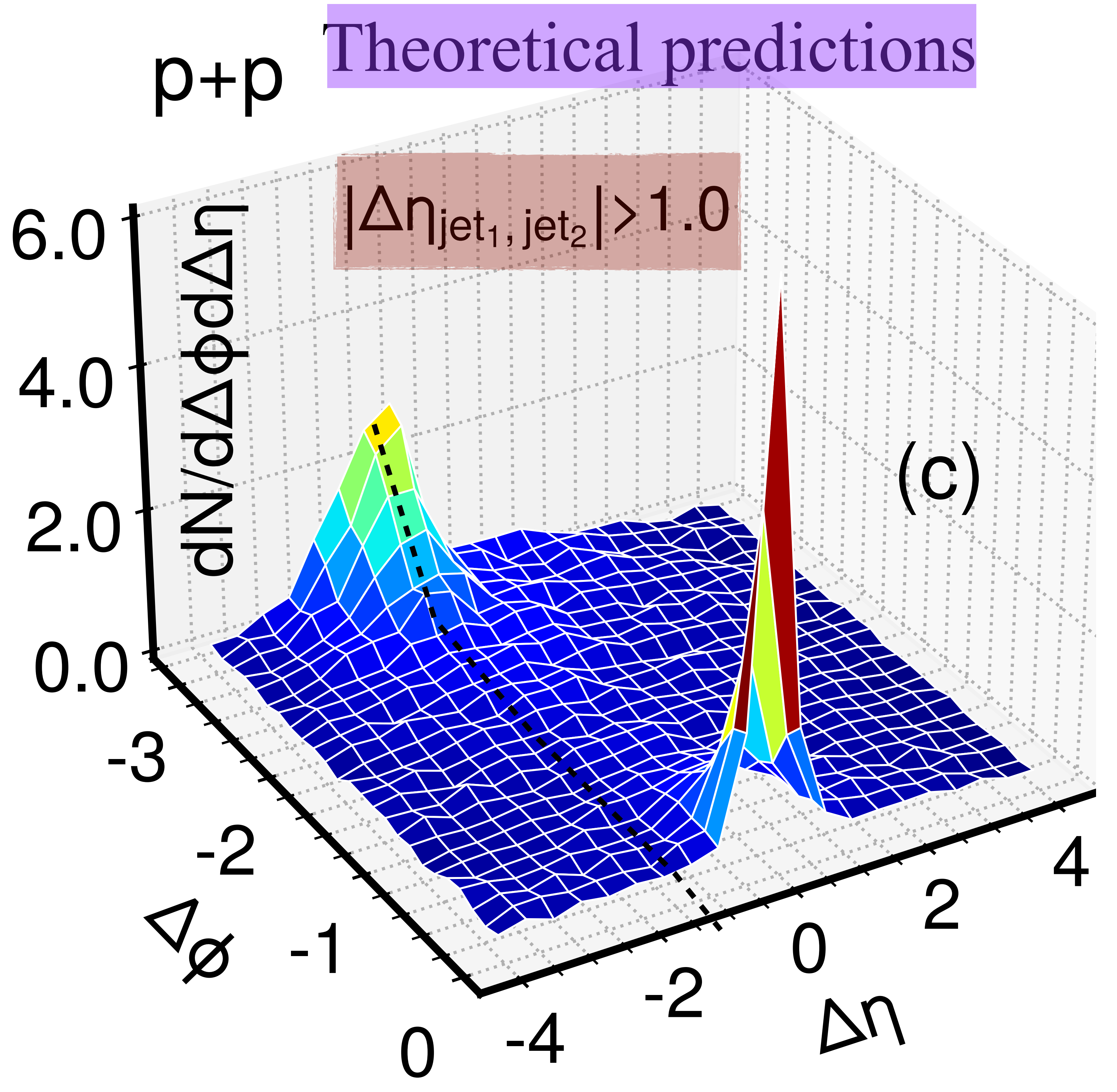


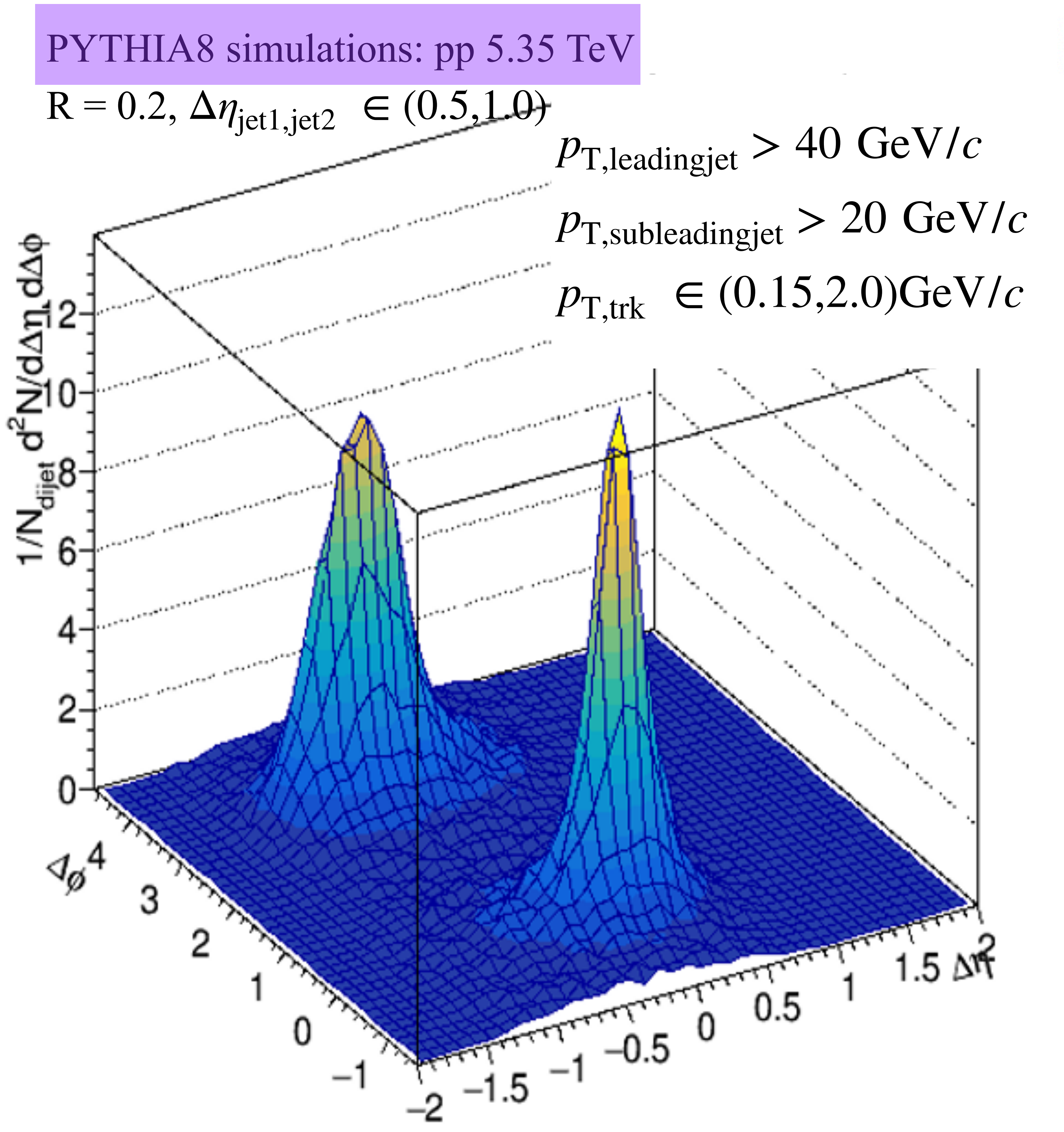
➡ Novel method to identify diffusion wake signal from dijets with finite rapidity gap

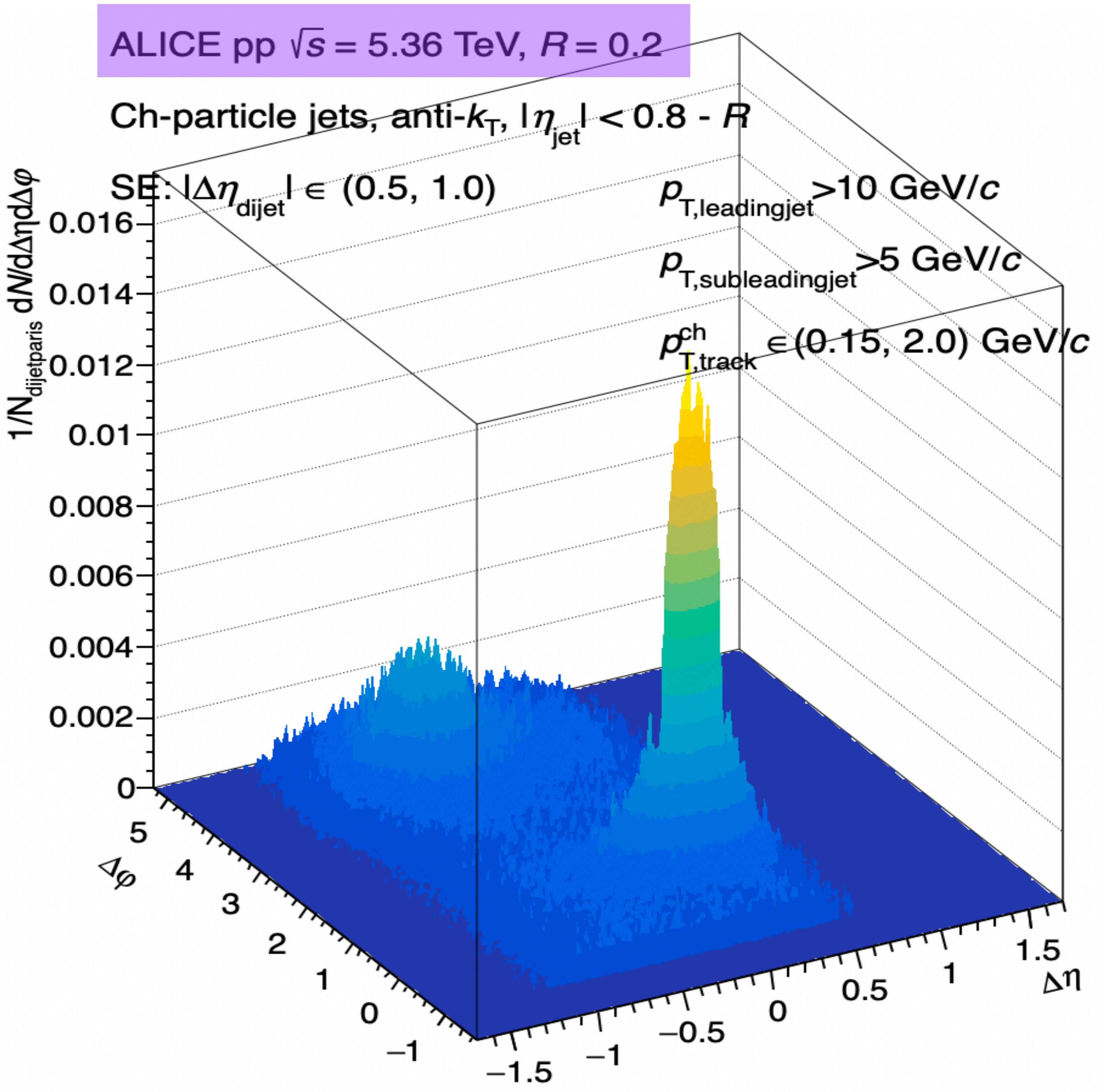
➡ **Background-free** → simplifies experimental measurements

Phys. Rev. Lett. **135**, 072302 (2025)

Searching diffusion wake with ALICE







- **PYTHIA8 simulations** reproduce the jet-h correlation functions in dijet events, similar to theoretical expectations
- Progress on the 2d correlation function with **ALICE data**
  - More statistics are needed for a precise measurement

Stay tuned!

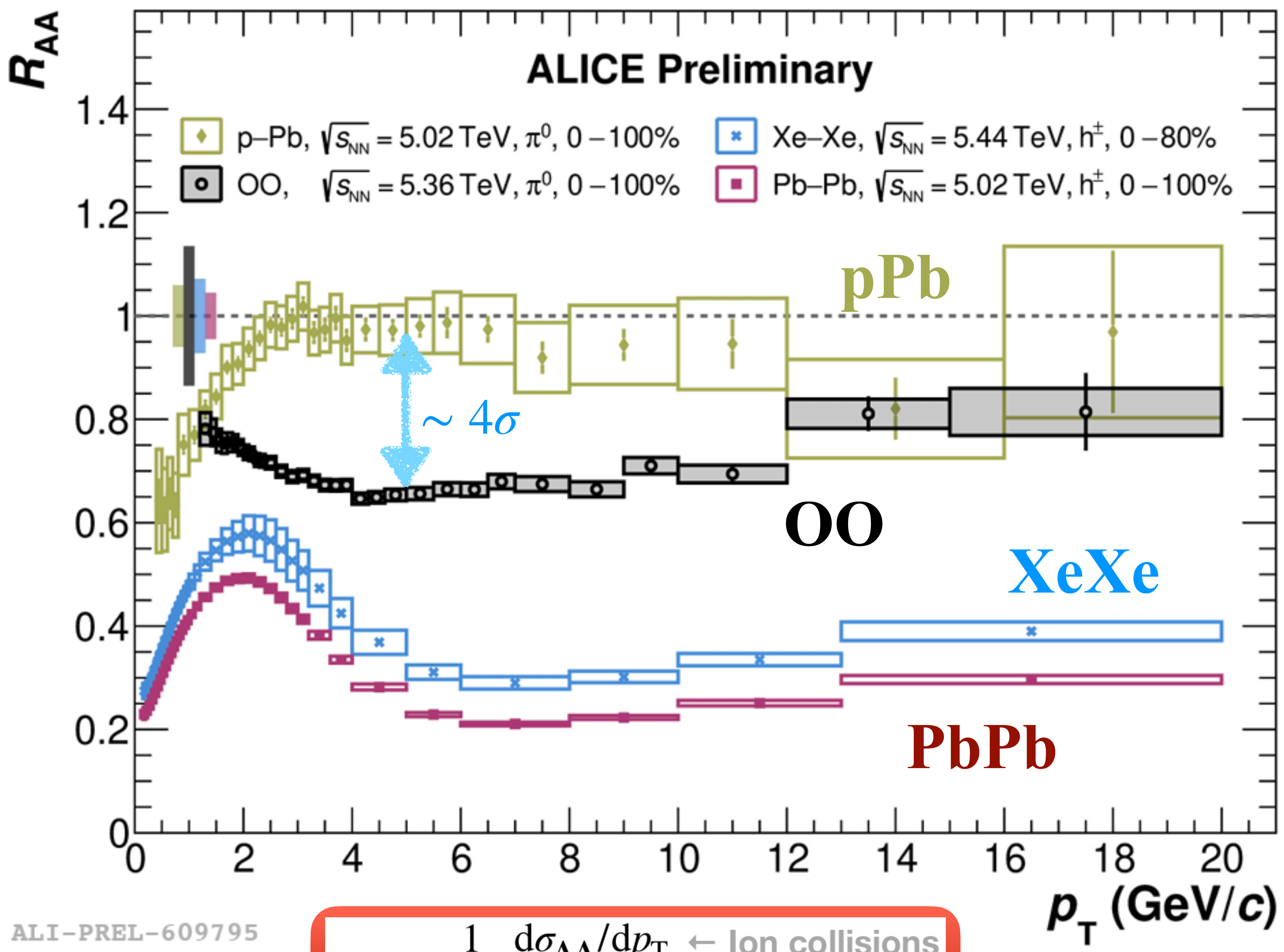
Summary and outlook

- **Enhanced yields** of low-p_T particles and **azimuthal broadening** of jets indicate significant medium response in the jet direction.
- ATLAS has measured jet-track correlations in photon-jet events to investigate possible **diffusion wake signal**
  - Small diffusion wake signal in the lowest $x_{J\gamma}$
- Z^0-hadron correlations in azimuthal angle and rapidity, measured differentially in p_T with CMS
  - First direct evidence of **medium response** in QGP
- Theory experts have proposed **a new rapidity-asymmetry method** as a **diffusion wake signal** in di-jets
  - Motivating further exploration in LHC Runs 3 and 4

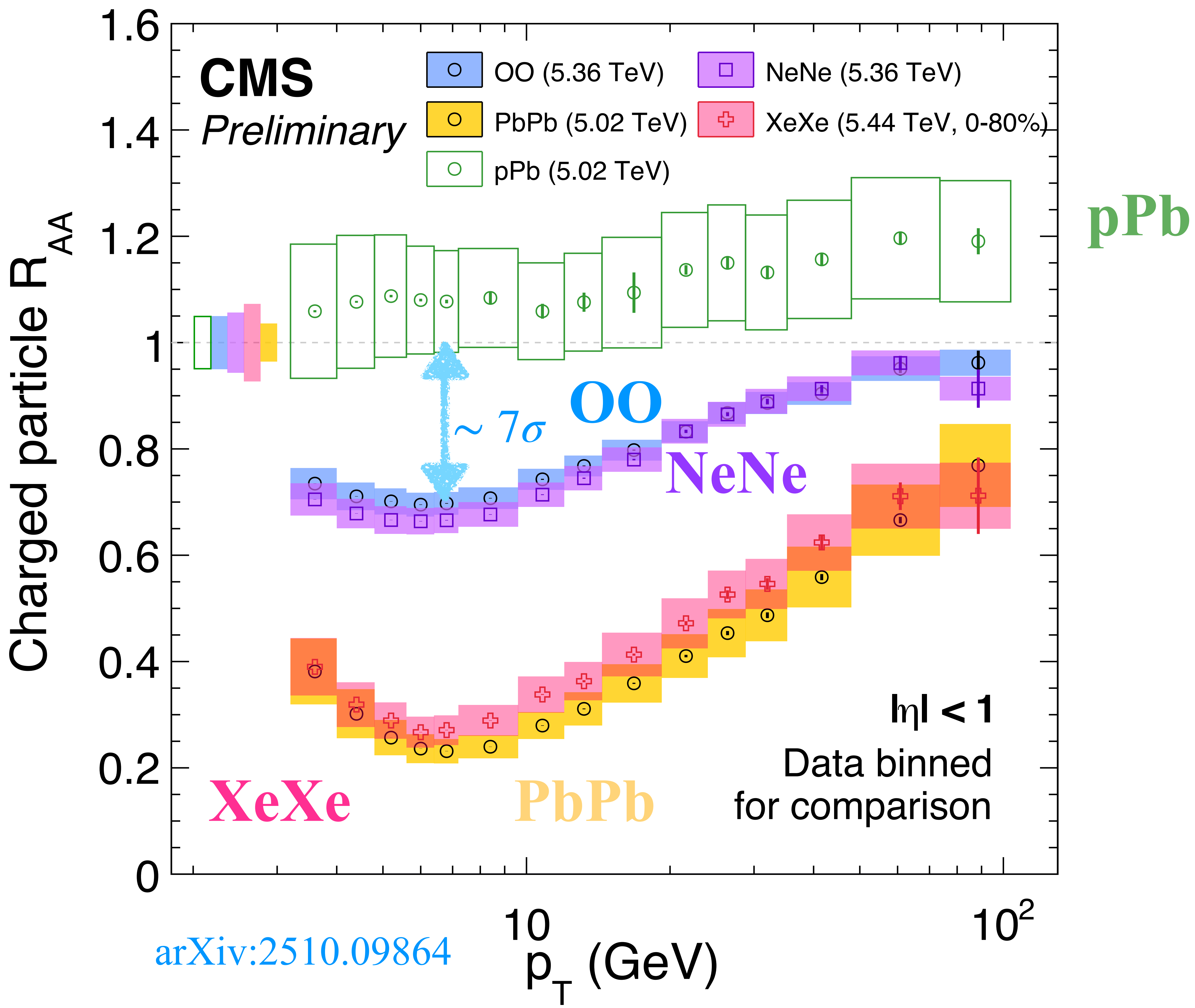
- Outlook for LHC to Run 3 and Run 4
  - **Explore energy-loss effects in light-ion collisions** to further understand medium effects (OO, NeNe, pO..)
  - Perform precision and **differential measurements** of rare hard probes using the high-statistics data from LHC Run 3 at the highest energies.


QPT 2025
Guilin, China
Thanks for your attention!!
24-28, October

Jet energy loss from light-ion to heavy-ion



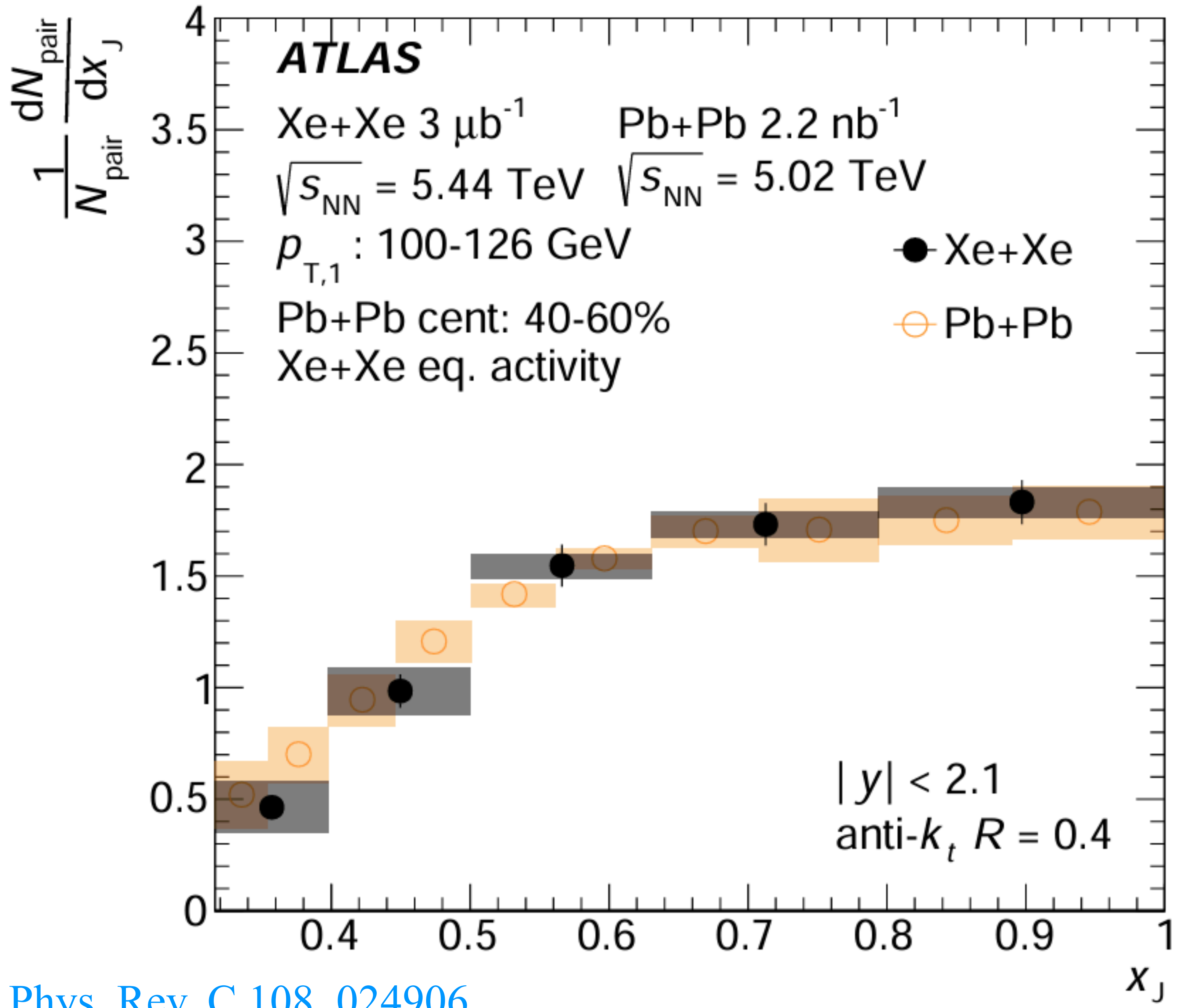
$$R_{AA} = \frac{1}{A^2}\frac{d\sigma_{AA}/dp_T}{d\sigma_{pp}/dp_T} \begin{array}{l}\leftarrow \text{Ion collisions}\\ \leftarrow \text{pp collisions}\end{array}$$



arXiv:2510.09864

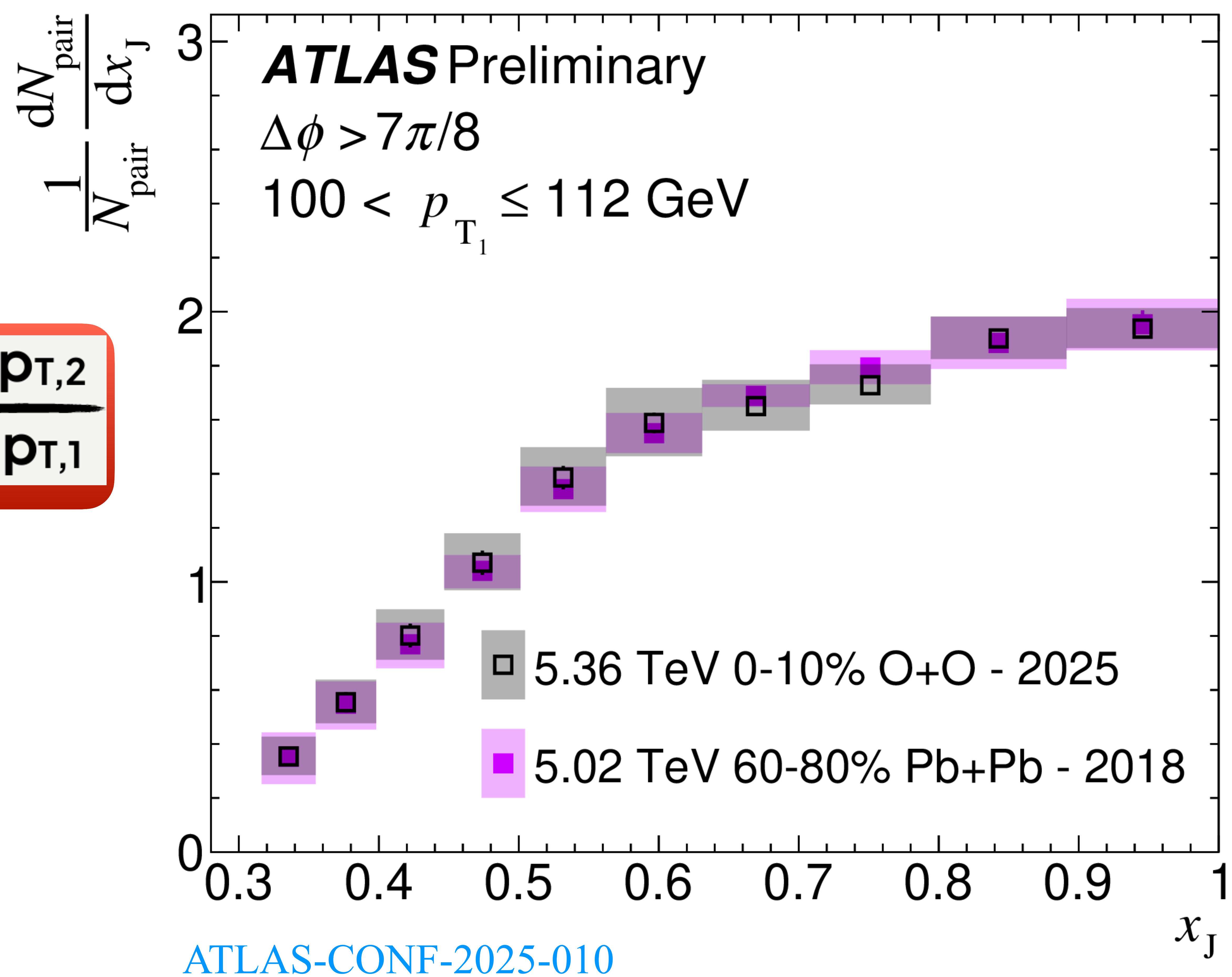
- Nuclear modification factor R_{OO} of π^0 (ALICE) and charged-particle (CMS) suppressed at higher momentum, shape similar to $R_{PbPb,\ XeXe}$ → **common picture emerging across LHC experiments**

Dijet momentum imbalance



Phys. Rev. C 108, 024906

$$x_J = \frac{p_{T,2}}{p_{T,1}}$$



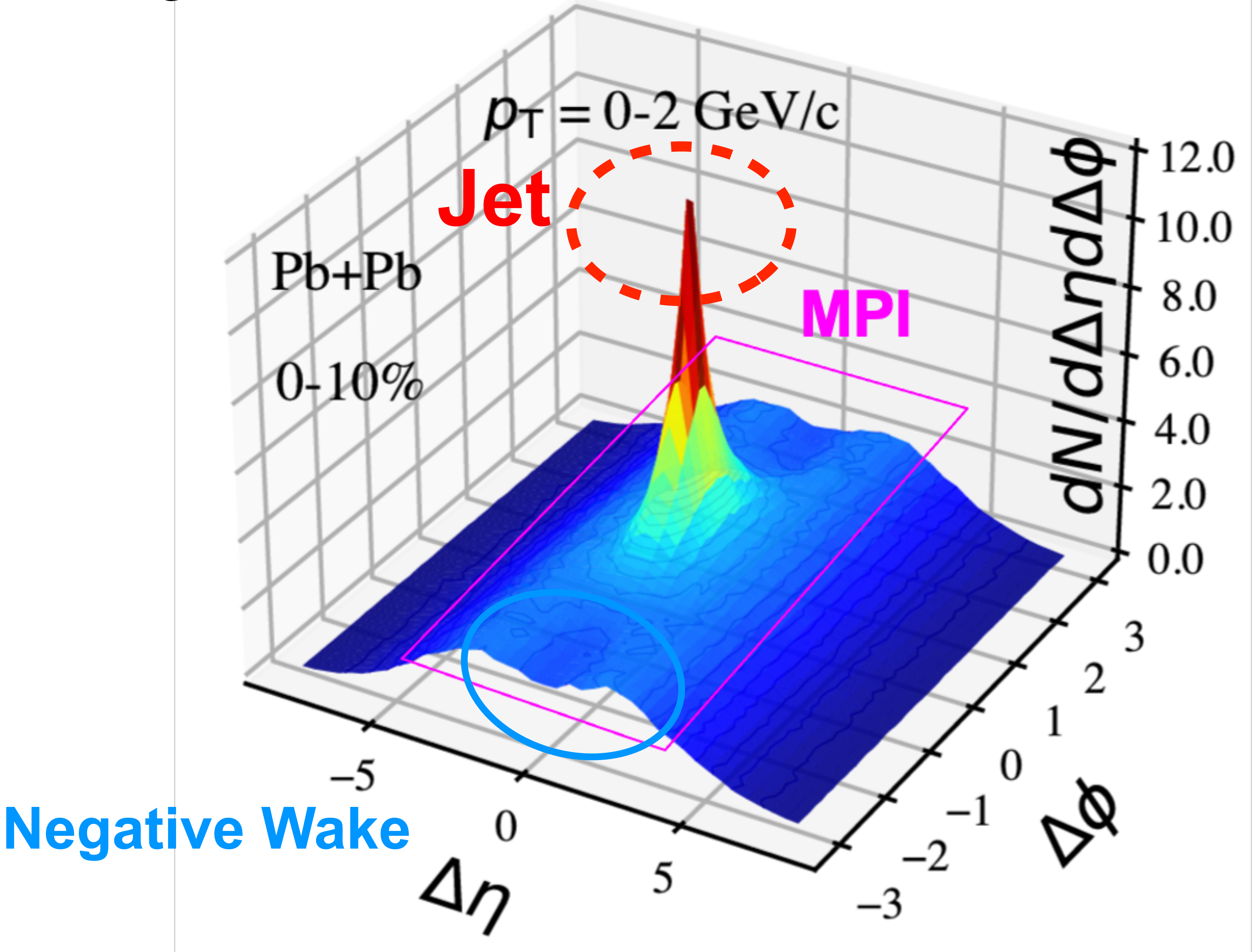
ATLAS-CONF-2025-010

- The dijet momentum imbalance in central O+O shows a similar level of modification to peripheral Pb-Pb → **a similar level of modification is observed**

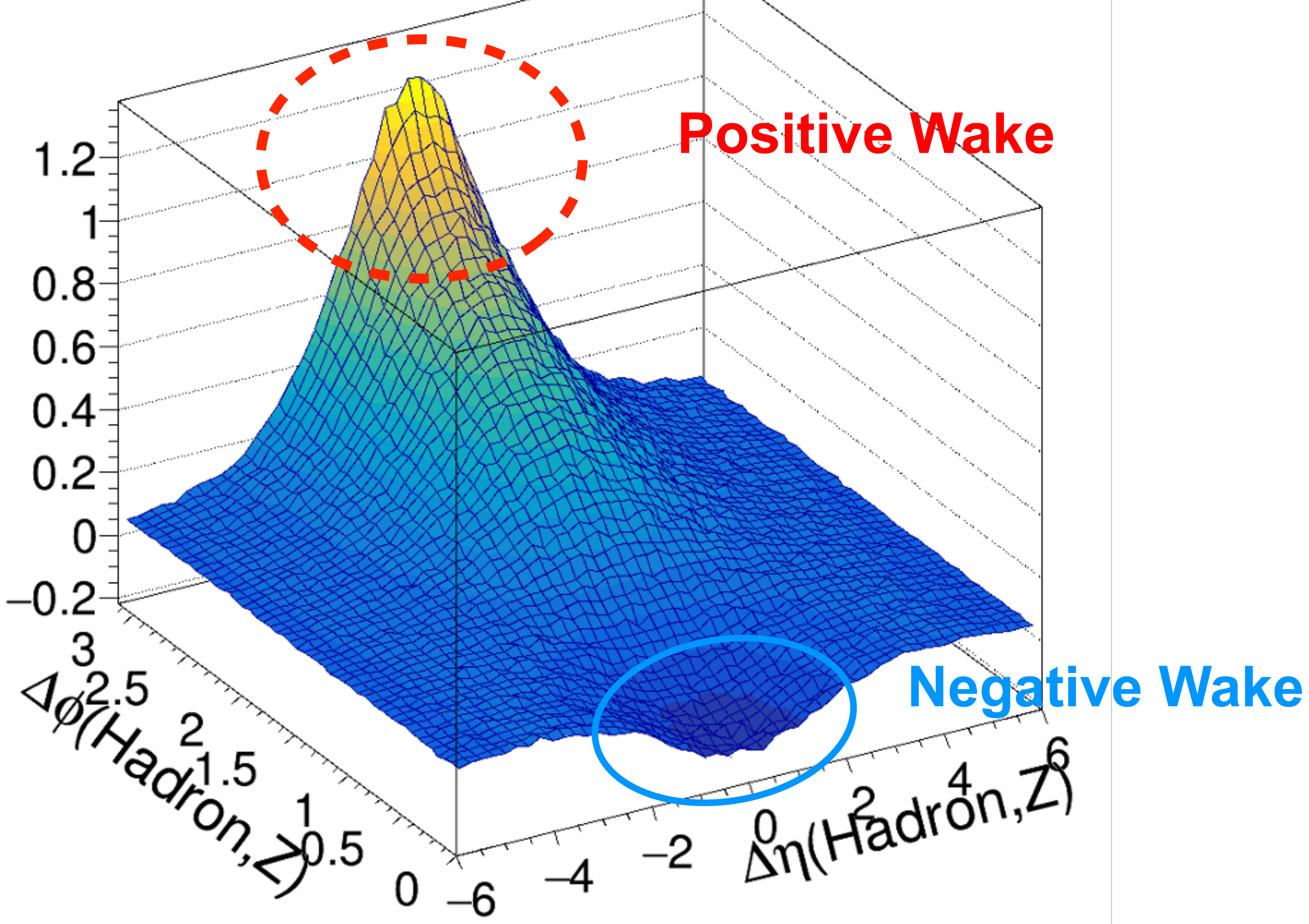
Measure the diffusion wake

Jet-h correlation in photon-jet events

QGP wake in CoLBT PRL 130, 052301 (2023)



Z^0 and **Wake Hadron** correlation in **Hybrid** model Daniel Pablo, Krishna Rajagopal, YJL



- More QGP going in the jet direction, however, with complications from induced radiation
- **Less QGP is left behind in the opposite direction of the jet!!!**
  - ➡ Measure of jet-track correlations in photon-jet events
  - ➡ Measure the boson-side associated yield with Z^0-jet events

experiments