

# Particle production measurements with CMS Run 3 PbPb data

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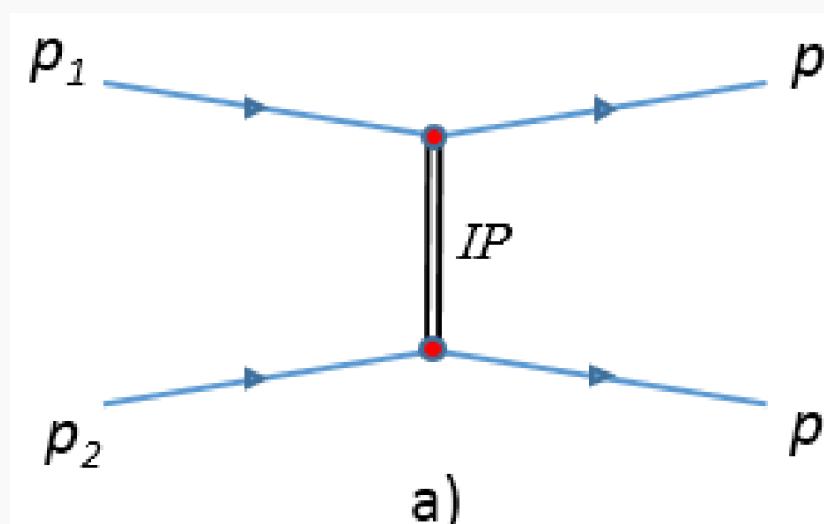
Jing Wang (CERN)  
For the CMS Collaboration

30th International Conference on Ultra-relativistic Nucleus-Nucleus Collisions  
Houston, TX (US)  
September 5, 2023

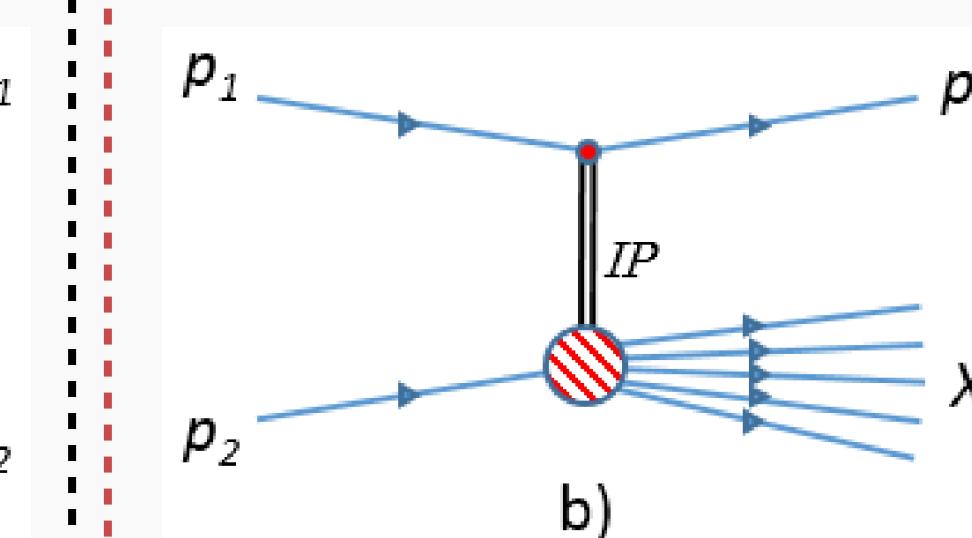
# Introduction Charged Particle Multiplicities

- Charged particle multiplicity  $dN_{ch}/d\eta$
- Involves soft interactions
  - Include elastic (intact) and inelastic scatterings
  - Measures inelastic scatterings including diffractive (keep quantum number) and non-diffractive
  - Cannot be calculated yet from first principle

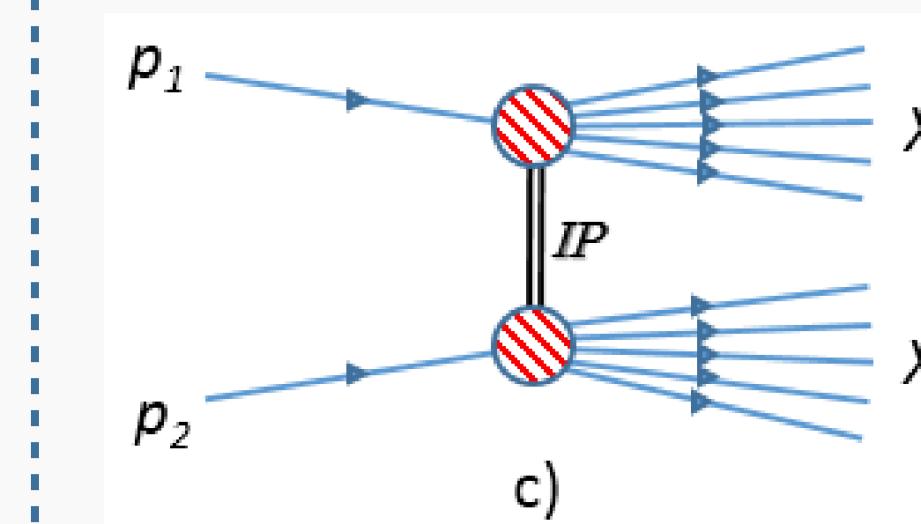
## Elastic scatterings



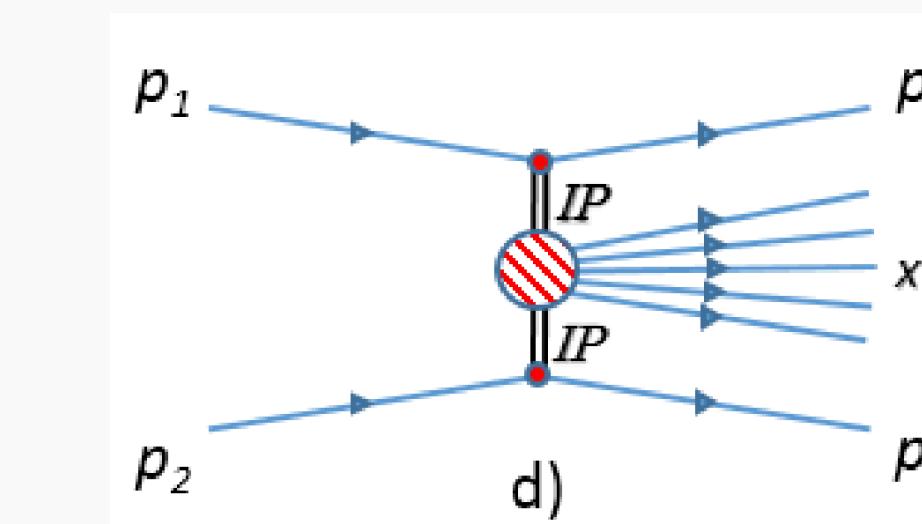
Hard to measure



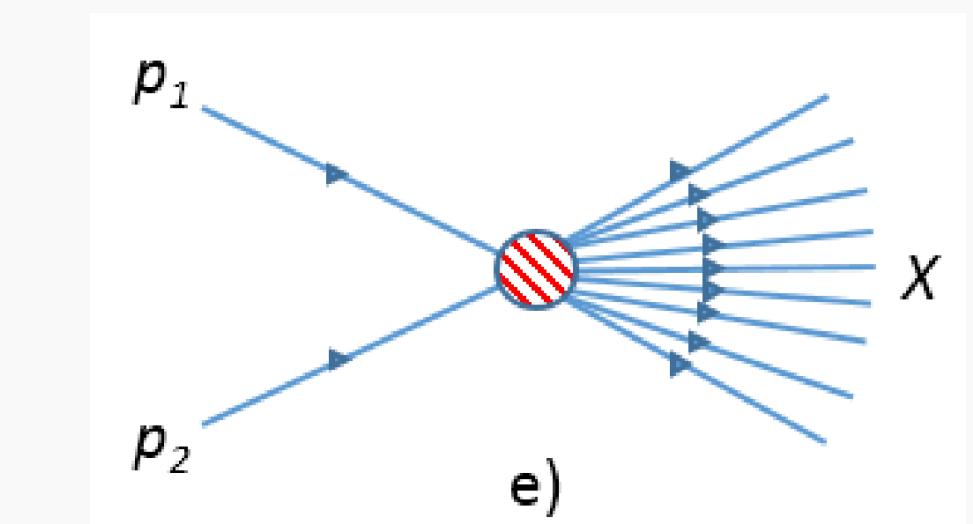
Single-diffractive events (SD)



Double-diffractive events (DD)

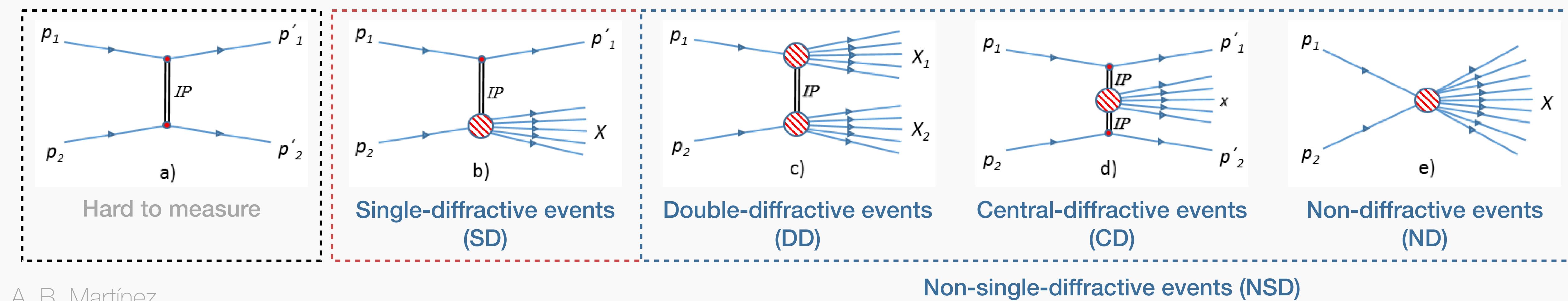


Central-diffractive events (CD)



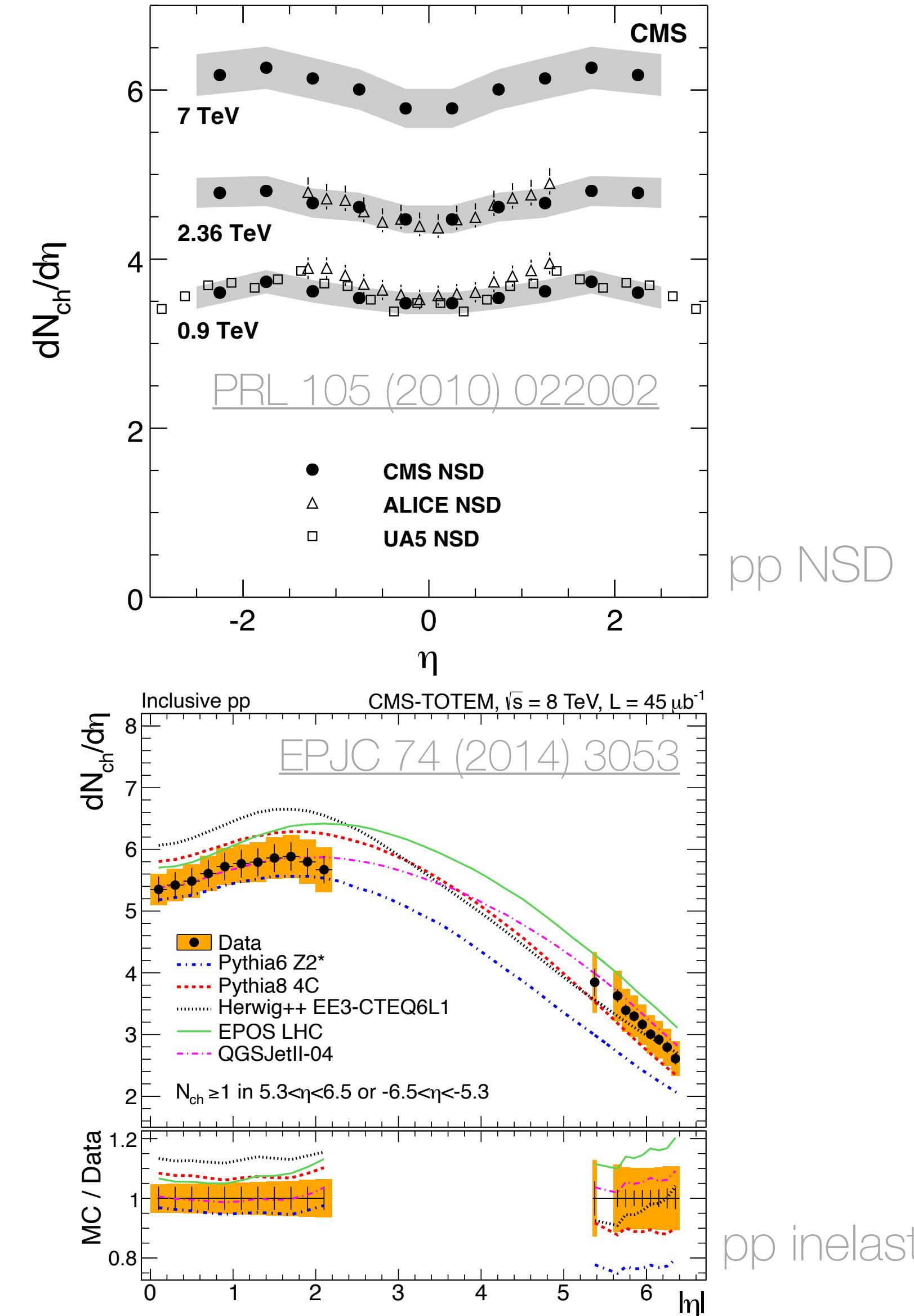
Non-diffractive events (ND)

## Soft inelastic scatterings



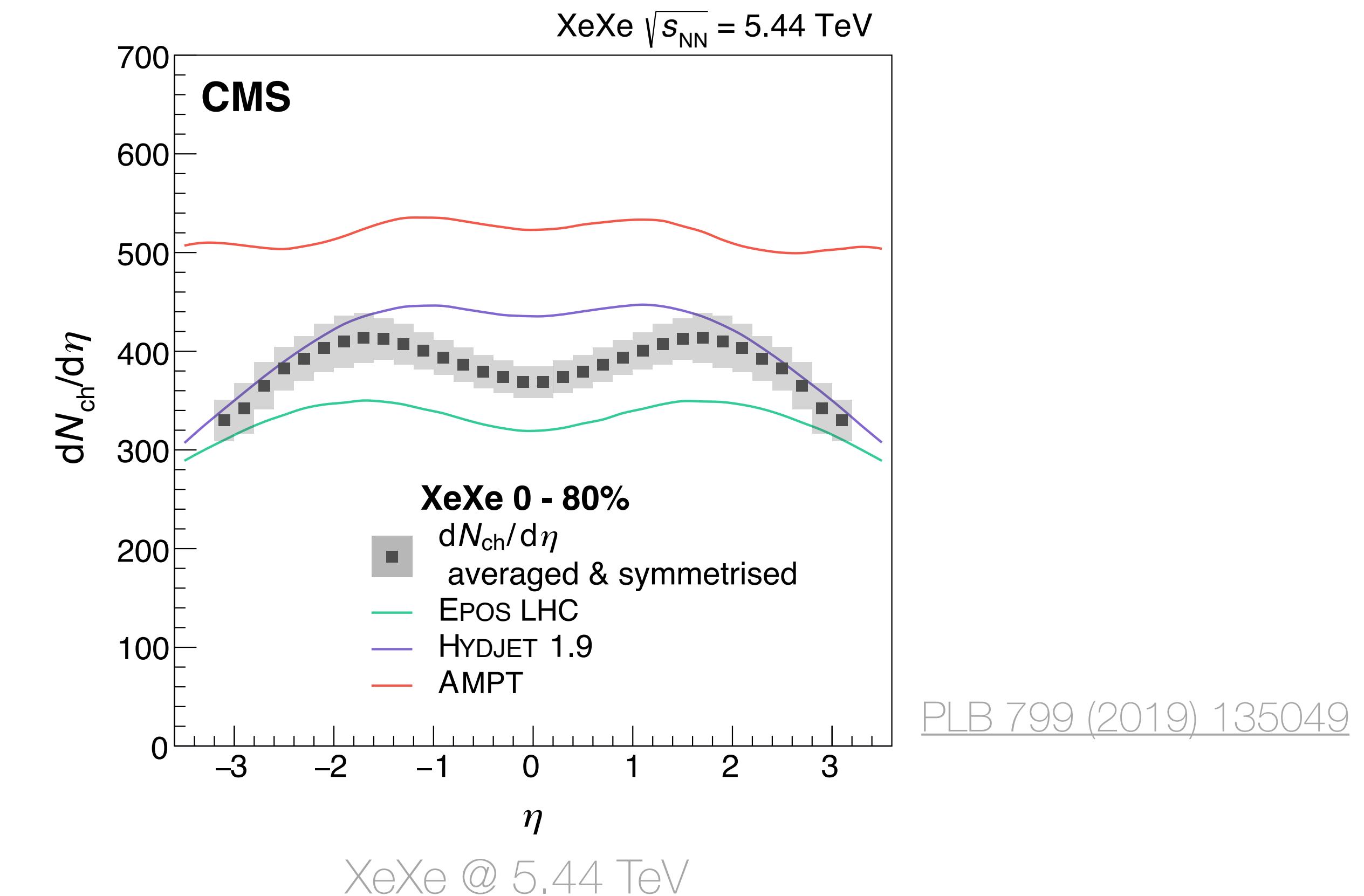
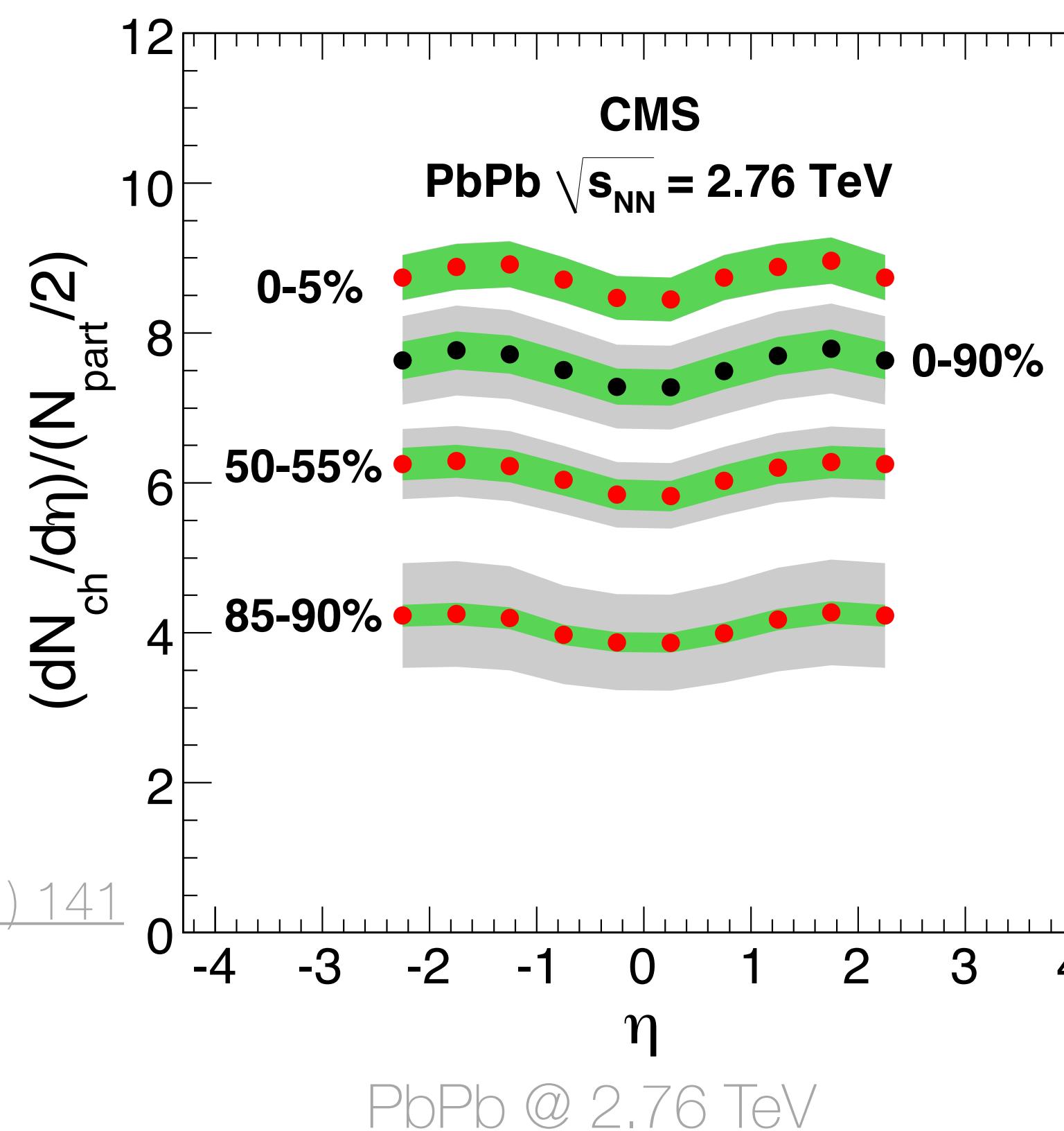
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  - Involves soft interactions
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    - Measures inelastic scatterings including diffractive (keep quantum number) and non-diffractive
    - Cannot be calculated yet from first principle
  - Experimental input is crucial
    - Sensitive and constrains MPI (multiple parton interactions) and CR (color reconnection)
    - Varying event selection studies different processes (eg. inclusive, NSD etc.)
    - Different collision systems reveal the relative contribution of hard and soft processes
    - Important input for tuning of event generators



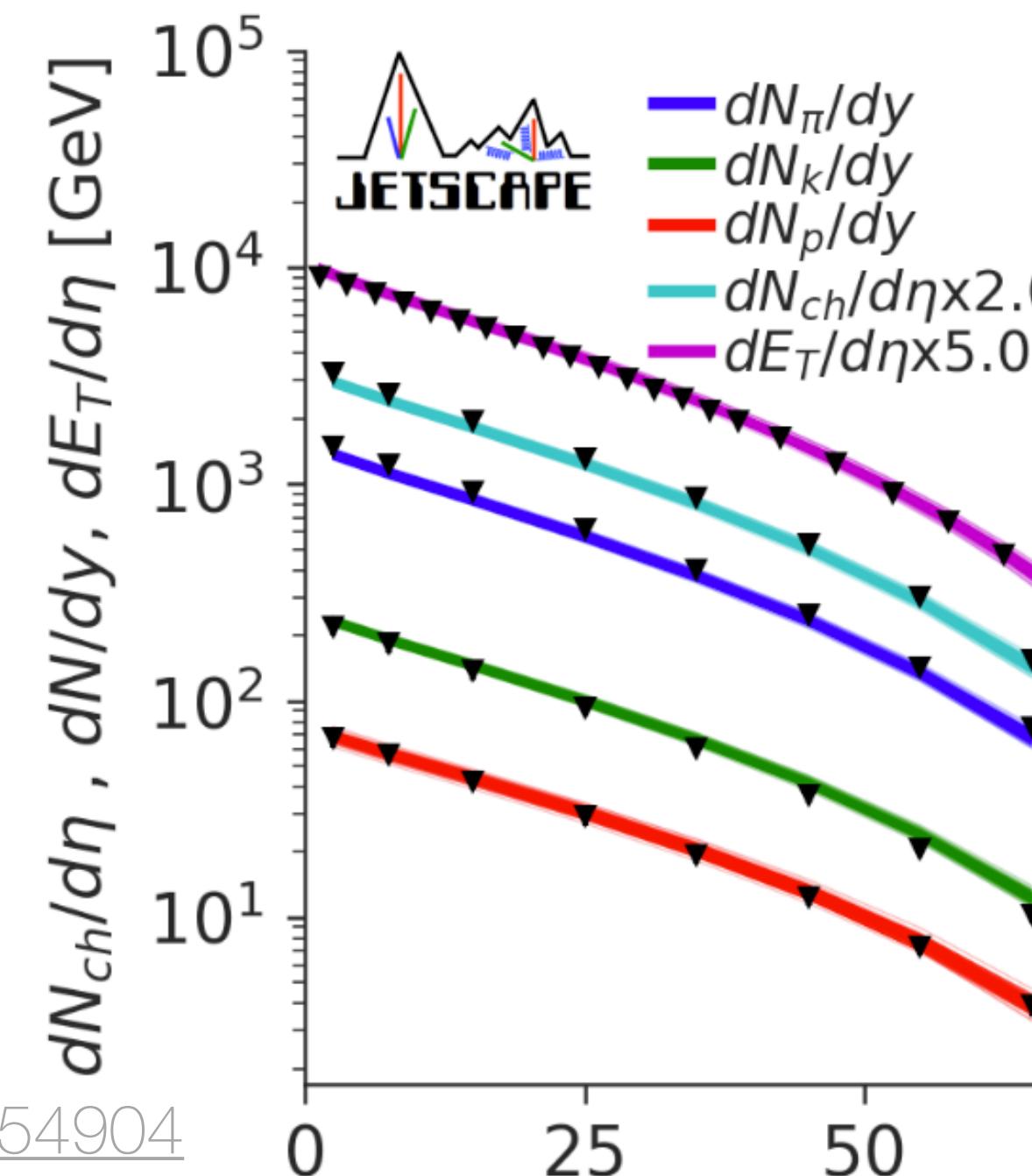
# Introduction $dN_{ch}/d\eta$ in Heavy-Ion Collisions

- $dN_{ch}/d\eta$  in **heavy-ion collisions** is key observable to characterize **initial states**
  - Tells how the energy is redistributed in phase space
  - Specifically sensitive to **entropy** production

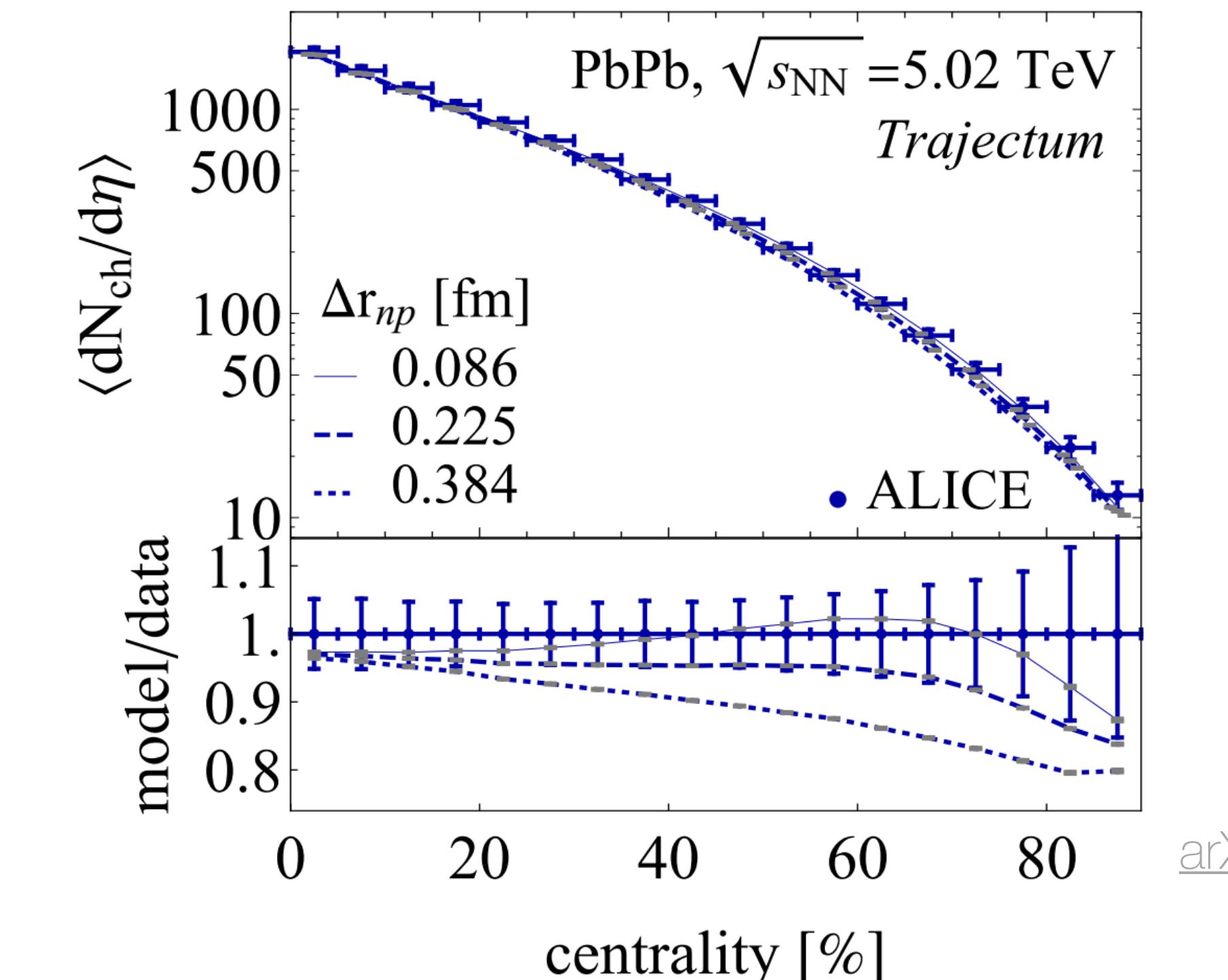


# Introduction $dN_{ch}/d\eta$ in Heavy-Ion Collisions

- $dN_{ch}/d\eta$  in heavy-ion collisions is key observable to characterize initial states
  - Tells how the energy is redistributed in phase spaces
  - Specifically sensitive to **entropy** production
  - Fundamental input for most **global** Bayesian studies to extract QGP medium properties

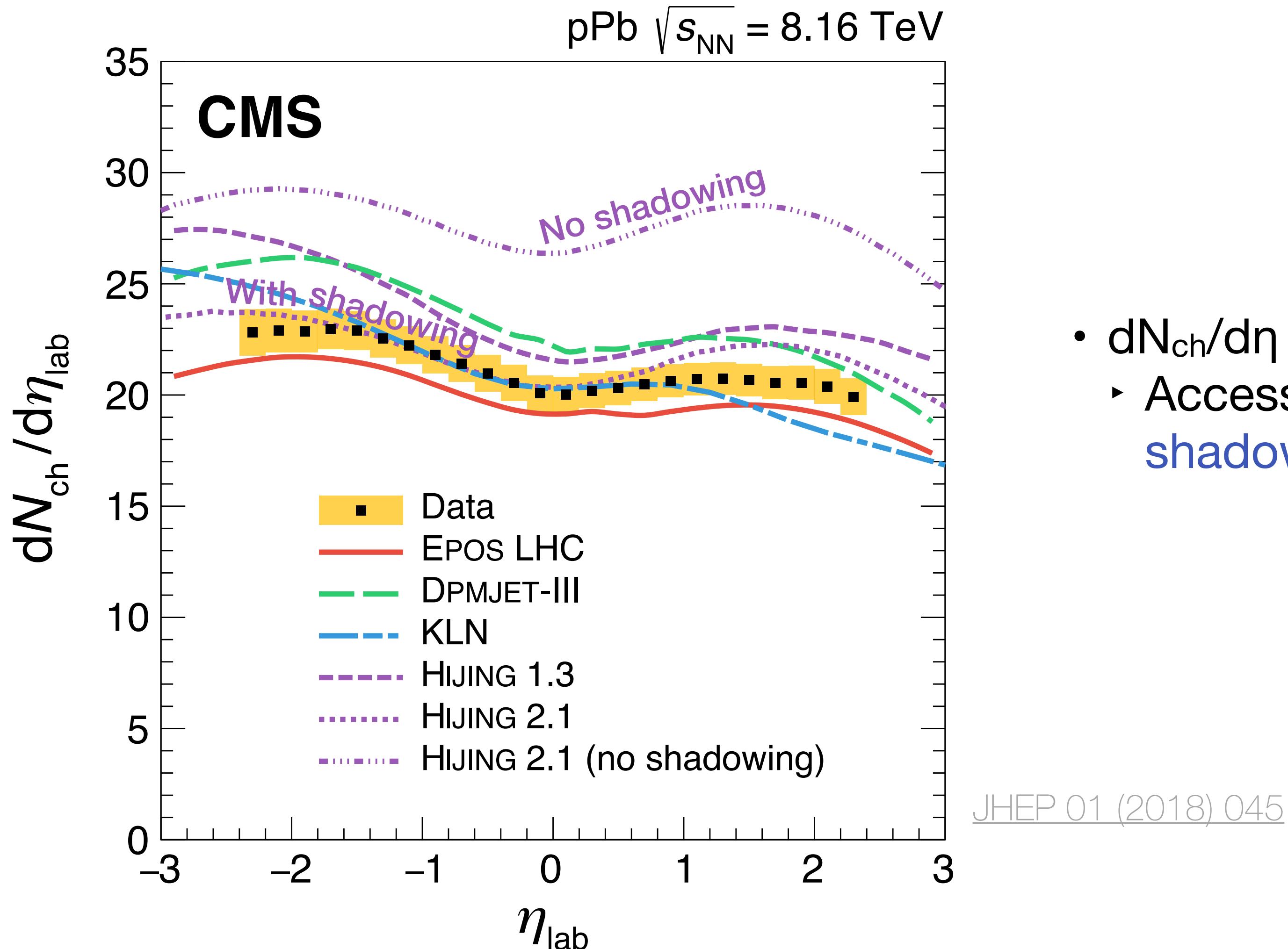


Jetscape Bayesian analysis



Trajectum neutron skin size

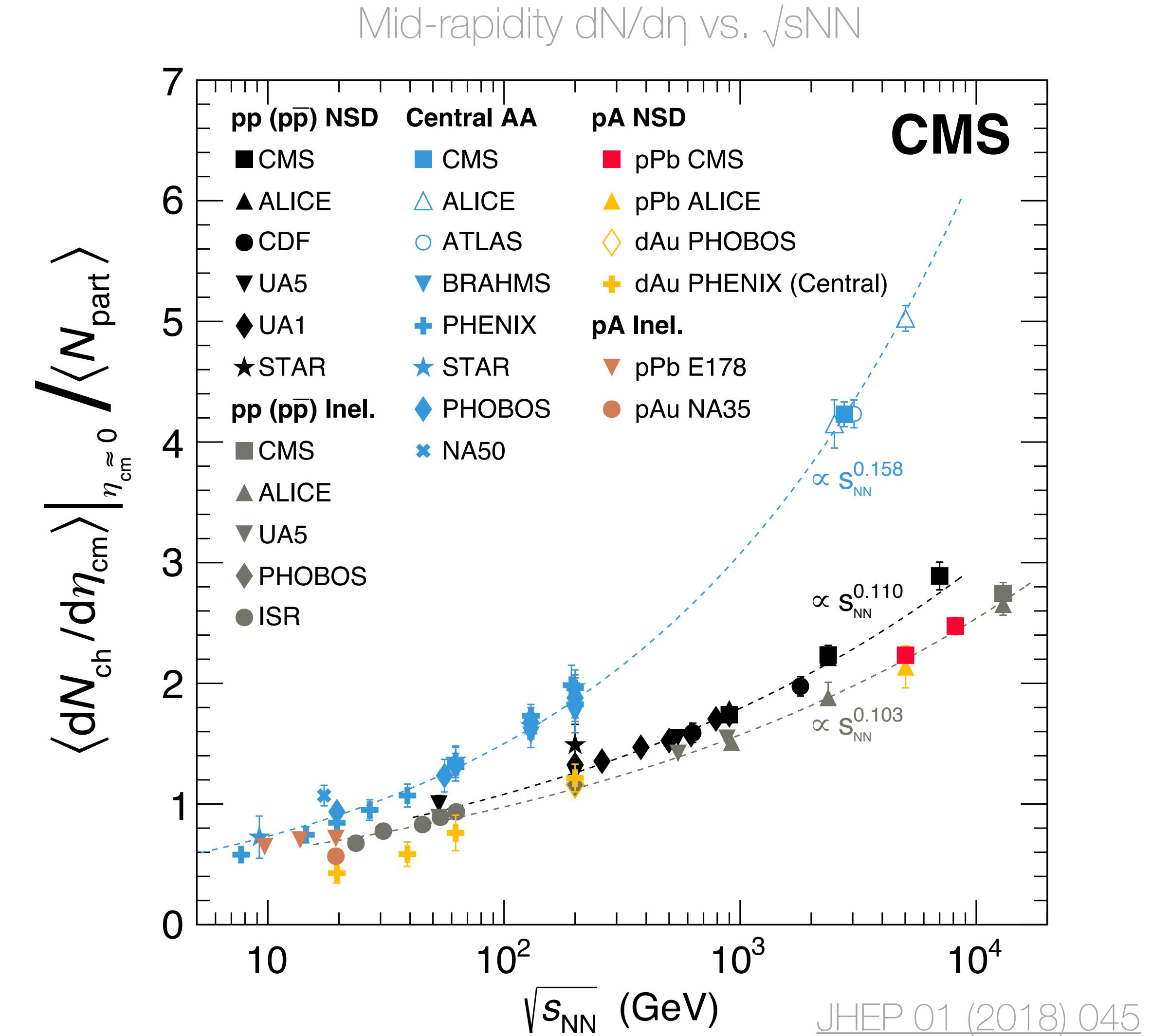
# Introduction $dN_{ch}/d\eta$ in pA Collisions



- $dN_{ch}/d\eta$  in pA collisions
  - Access low- $p_T$  particles → Constrains nuclear shadowing and gluon saturation effects

# Introduction $dN_{\text{ch}}/d\eta$ vs. $\sqrt{s_{\text{NN}}}$

- Predicting particle multiplicities in high energy collisions is a long standing question
  - Fermi-Landau model** Strong interaction limit
    - Multiplicity  $N \propto \sqrt[4]{s_{\text{NN}}}$
  - Feynman scaling** Weak interaction limit
    - Multiplicity  $N \propto \ln \sqrt{s_{\text{NN}}}$
  - Neither models describe particle production accurately
    - Soft interactions are nonperturbative
    - Data between two extreme scenarios
  - Dashed line** Empirical power law parameterization
    - Fitted to data

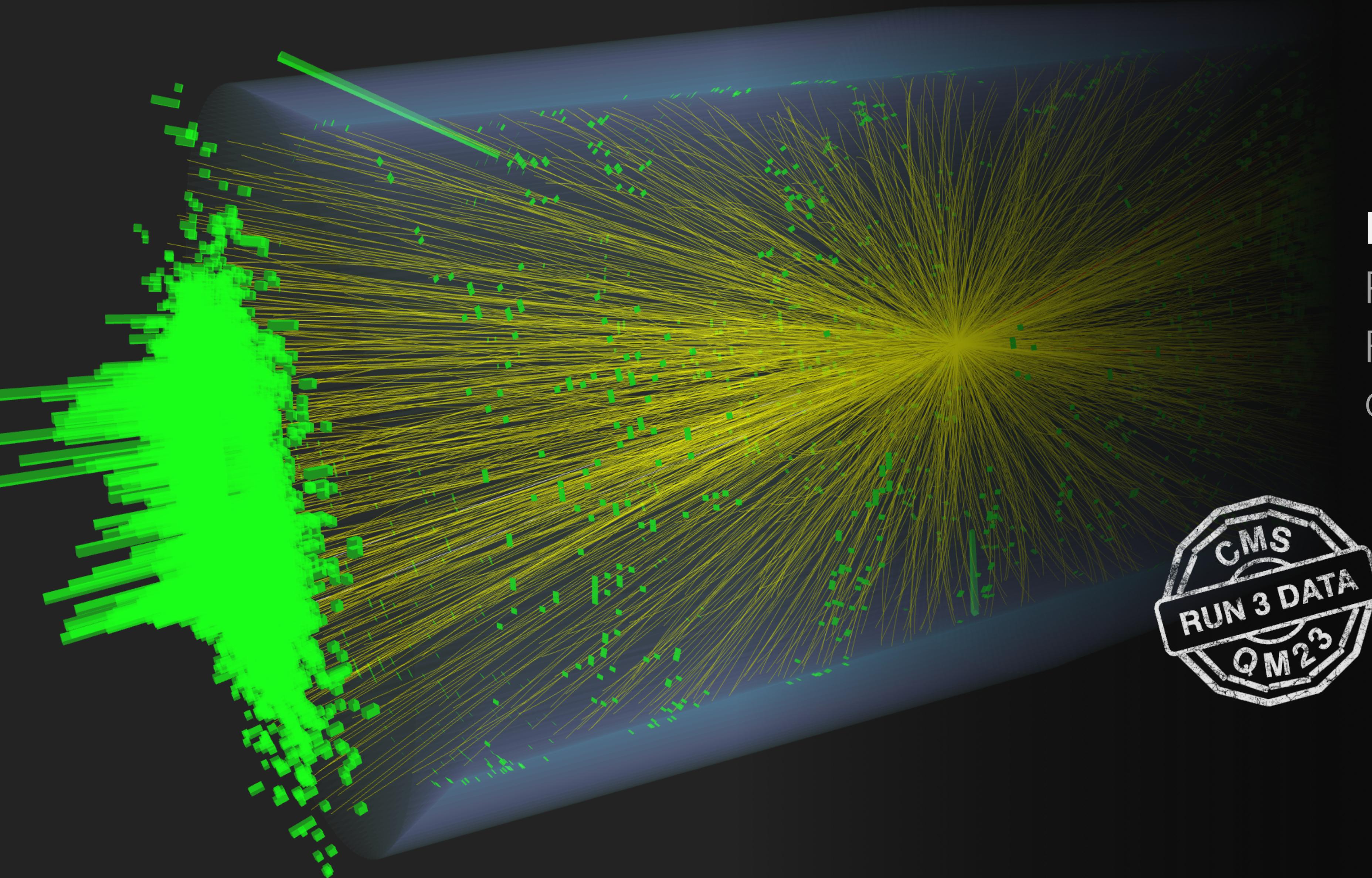




CMS Experiment at the LHC, CERN

Data recorded: 2022-Nov-18 16:09:13.771584 GMT

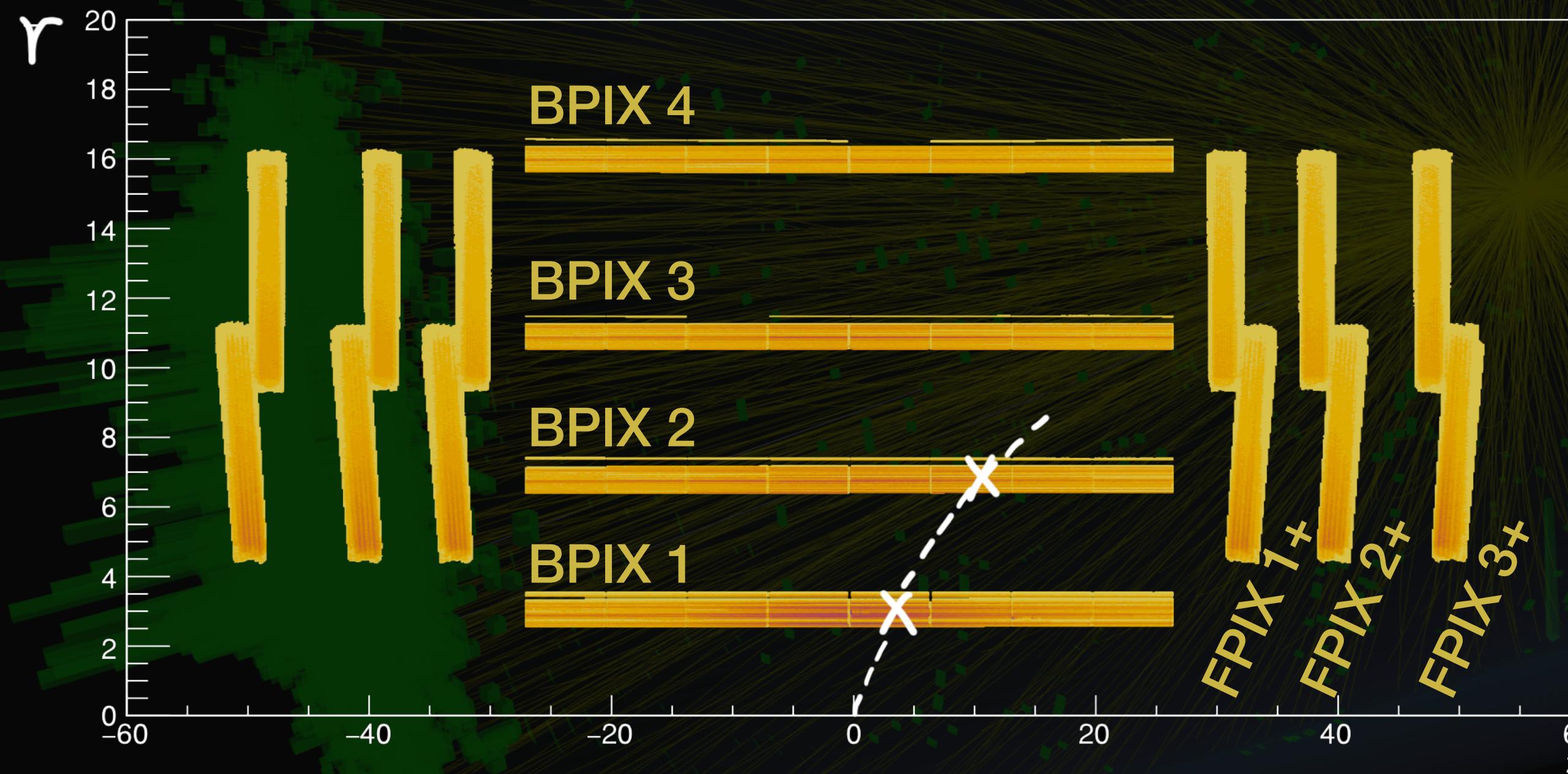
Run / Event / LS: 362294 / 4769619 / 16



**Push to higher energy!**  
PbPb @ 5.36 TeV  
First Run 3 heavy-ion  
data @ November 2022

# Higher Collision Energy in Run 3

- In November 2022, the LHC collided lead ions at  $\sqrt{s_{\text{NN}}} = 5.36 \text{ TeV}$  after 4 years of long shutdown
- Marked the beginning of the LHC's 'Run 3' era (2022–2025) for heavy ions
- Short test run with an integrated luminosity  $0.3 \mu\text{b}^{-1}$

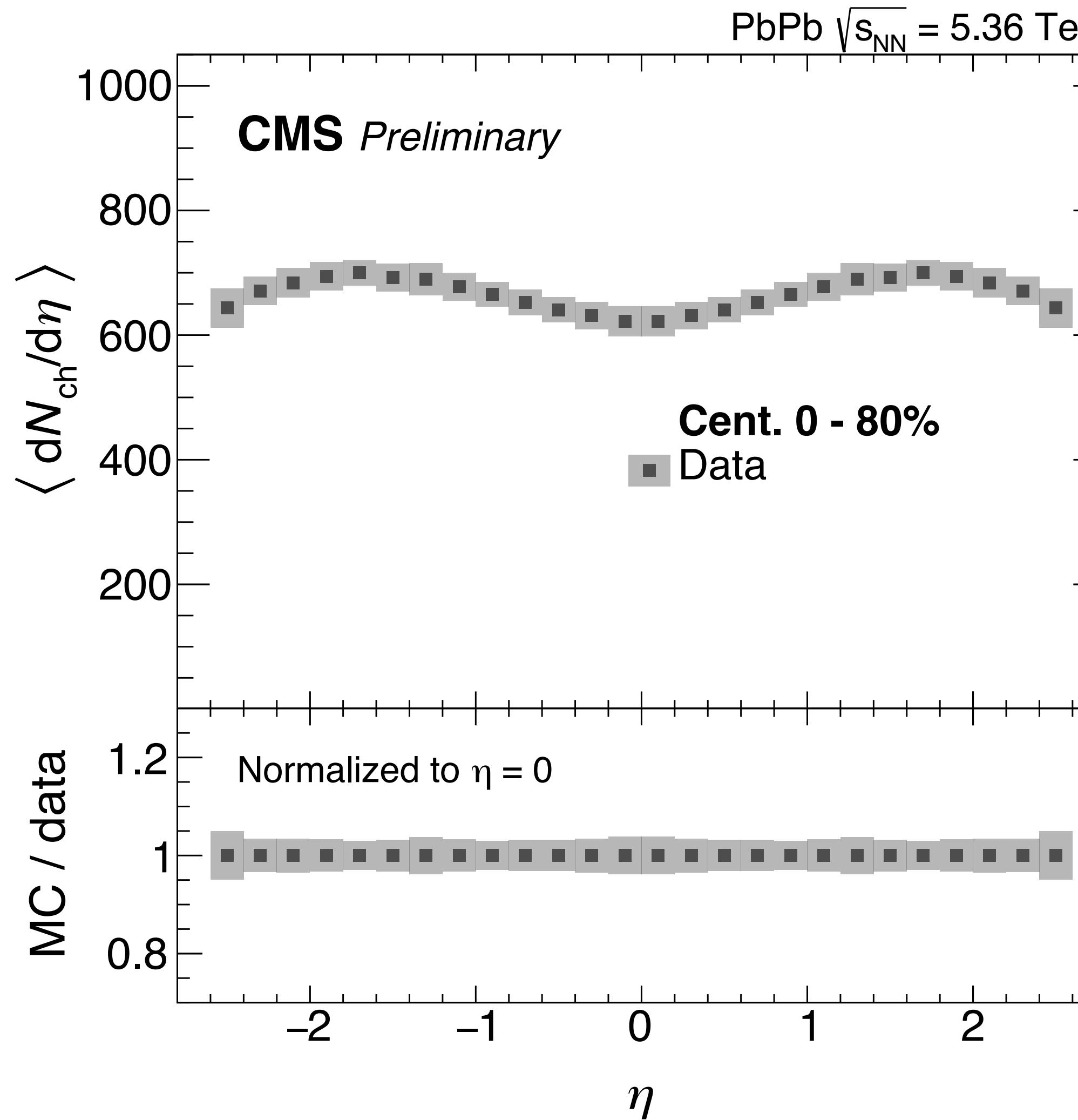


CMS pixel detector has 4 barrel layers and 3 forward disks on each side

## First CMS Run 3 HI result $dN/d\eta$

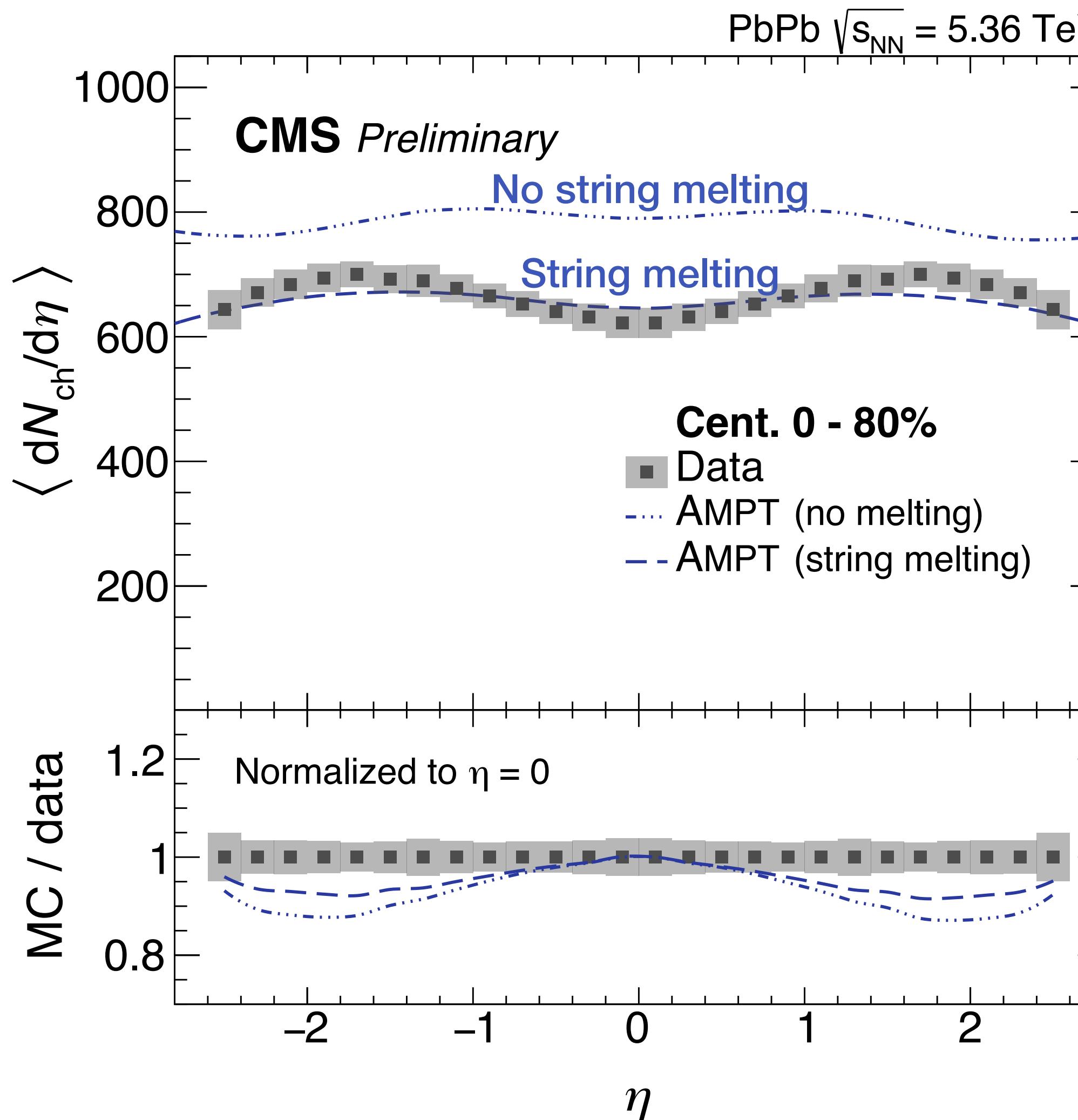
- Tracklet method reco with hits in 2 layers
  - Access particles down to  $p_T 50 \text{ MeV}/c$
  - Average independent analyses of 9 ( ${}^4\text{C}_2 + {}^3\text{C}_2$ ) potential layer pairs

# Results $dN/d\eta$ in PbPb at 5.36 TeV



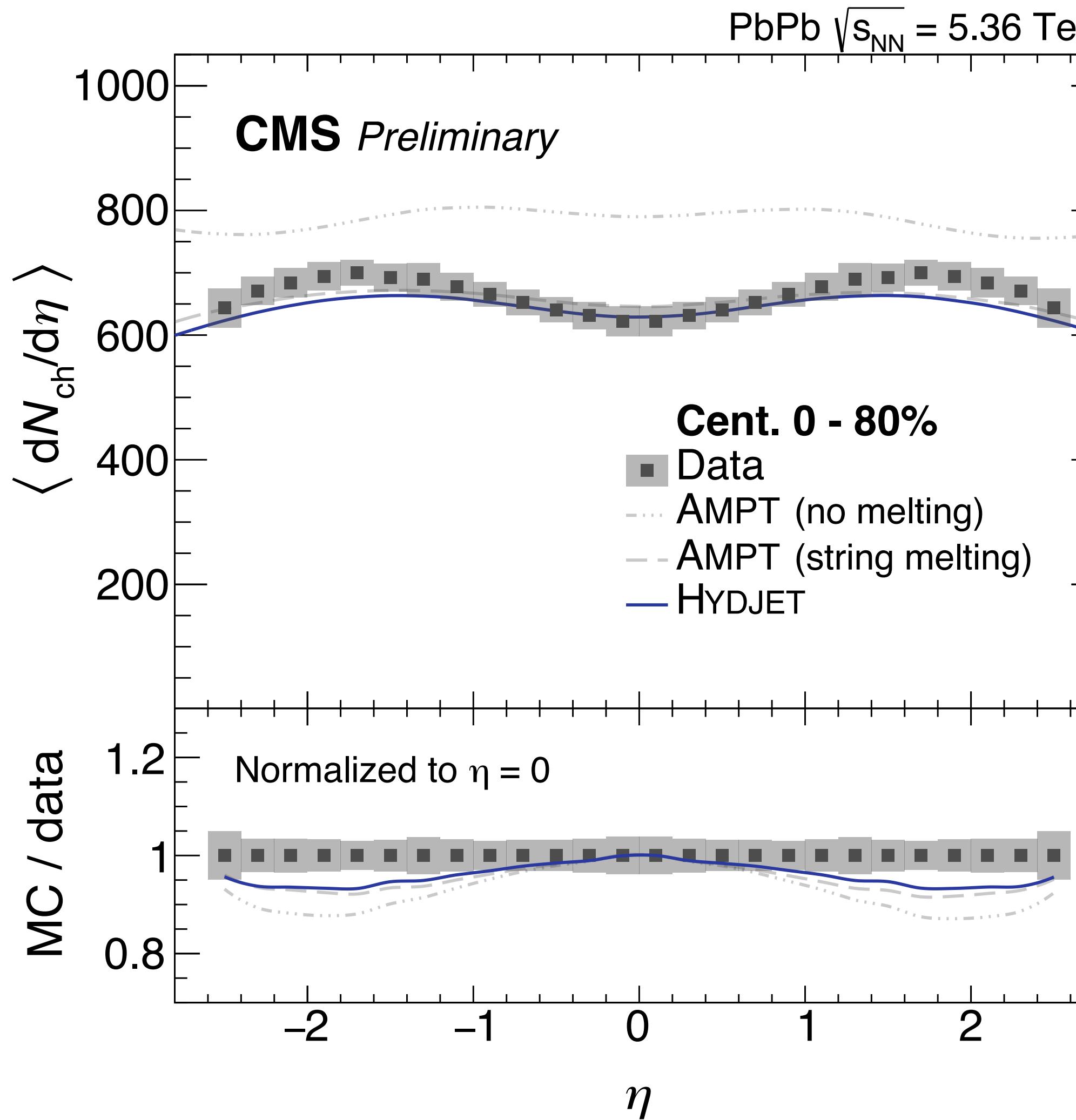
- Shaded boxes represent systematic uncertainty
  - Statistical uncertainty is negligible
- Dip at mid rapidity
  - Jacobian transformation from rapidity to pseudorapidity

# Results $dN/d\eta$ Compared with MC



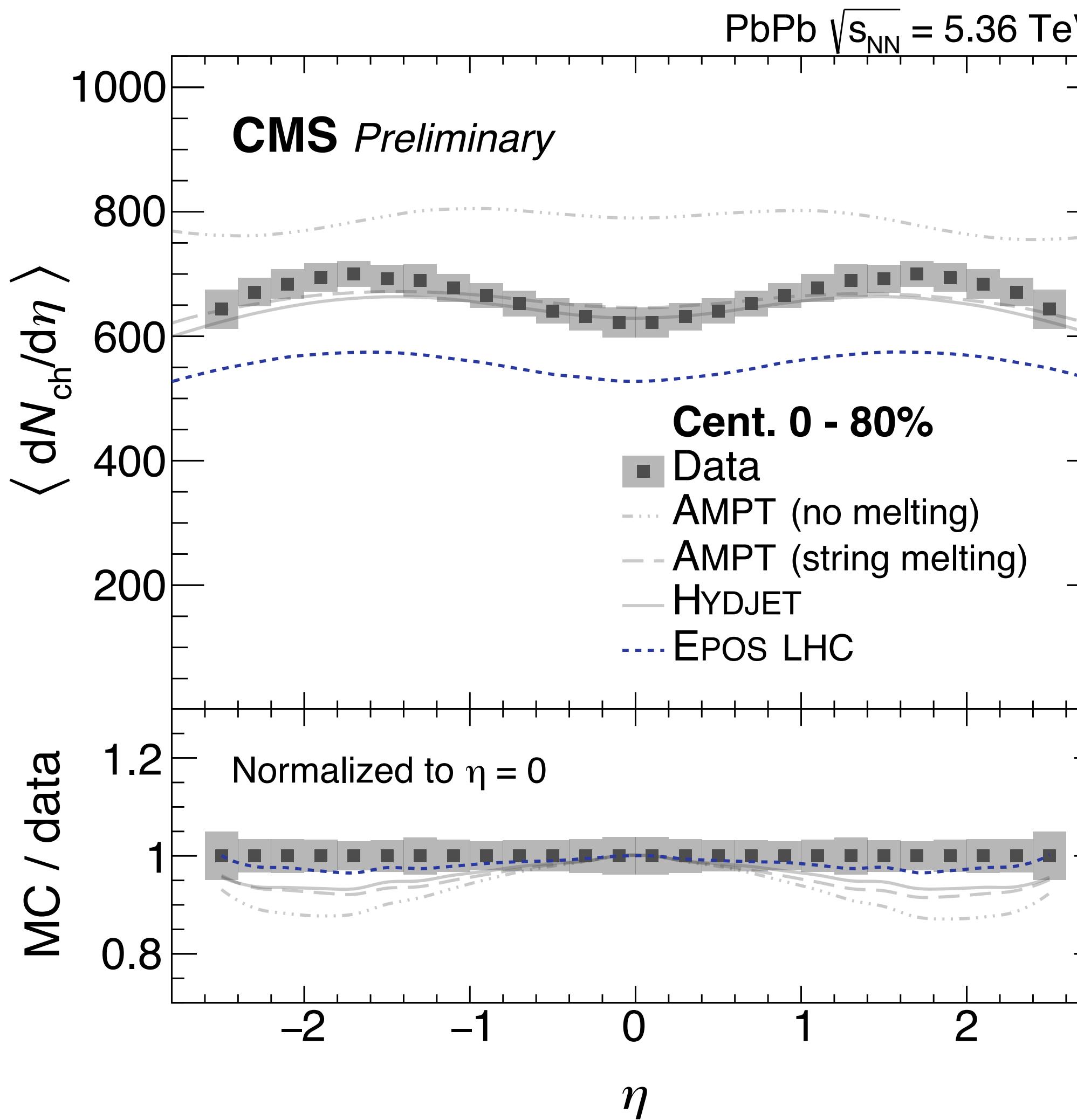
- Compared with event generators
  - **AMPT** HIJING + ZPC + 2 hadronization
    - **No melting** Lund string fragmentation
      - Overpredicts magnitude
    - **String melting** quark coalescence model
      - Catches data magnitude

# Results $dN/d\eta$ Compared with MC



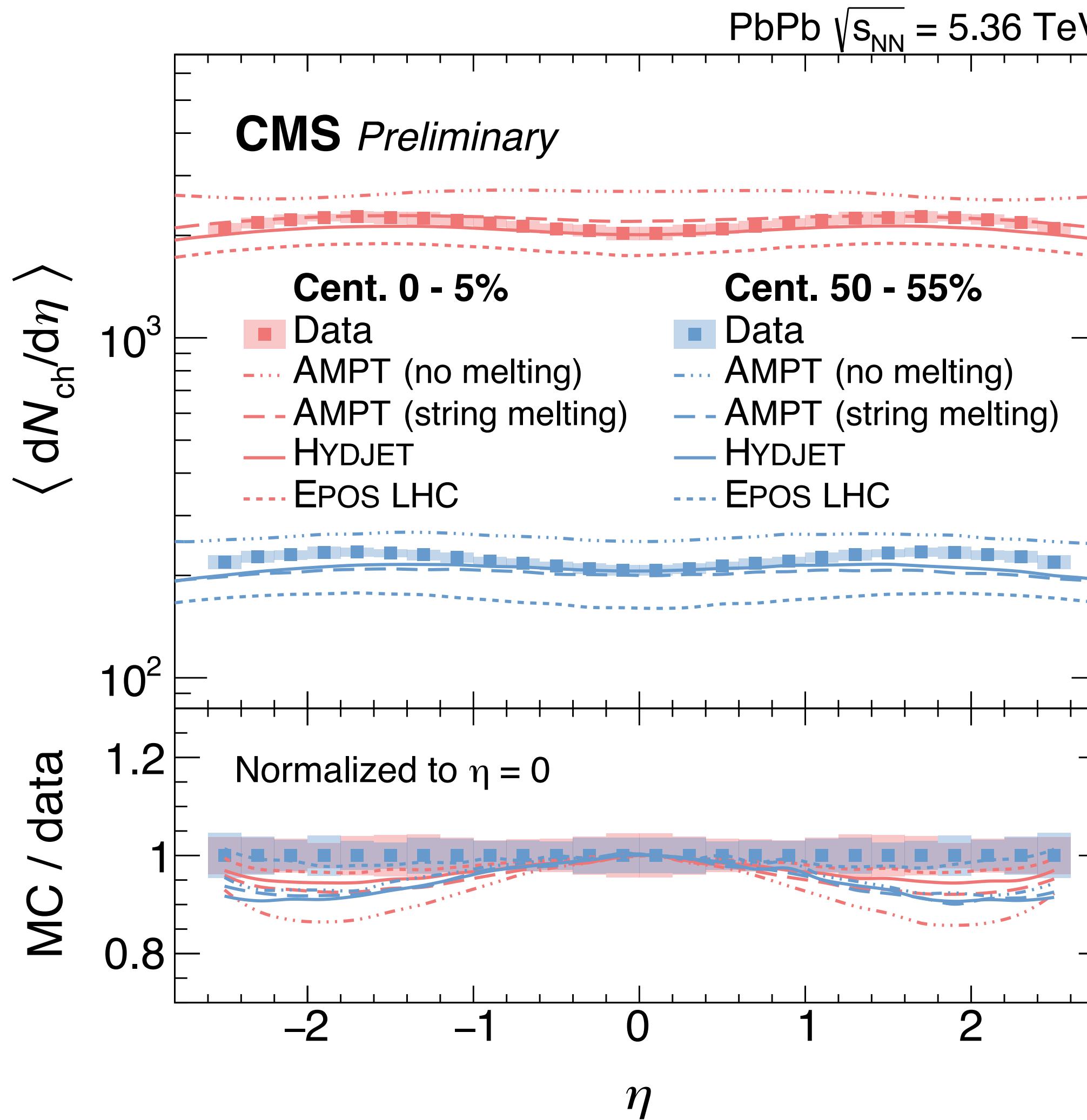
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  - ▶ HYDJET Hard + hydro soft components, with mini-jets
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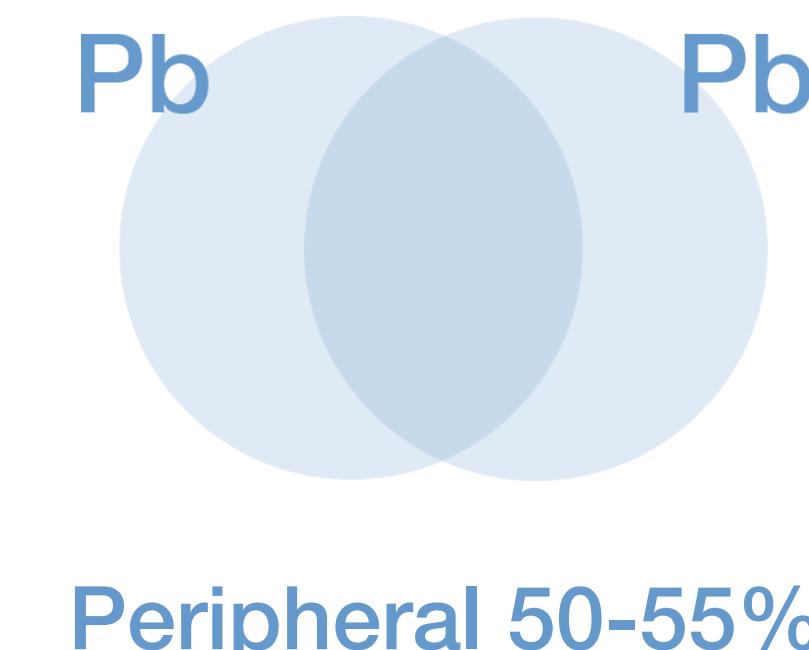
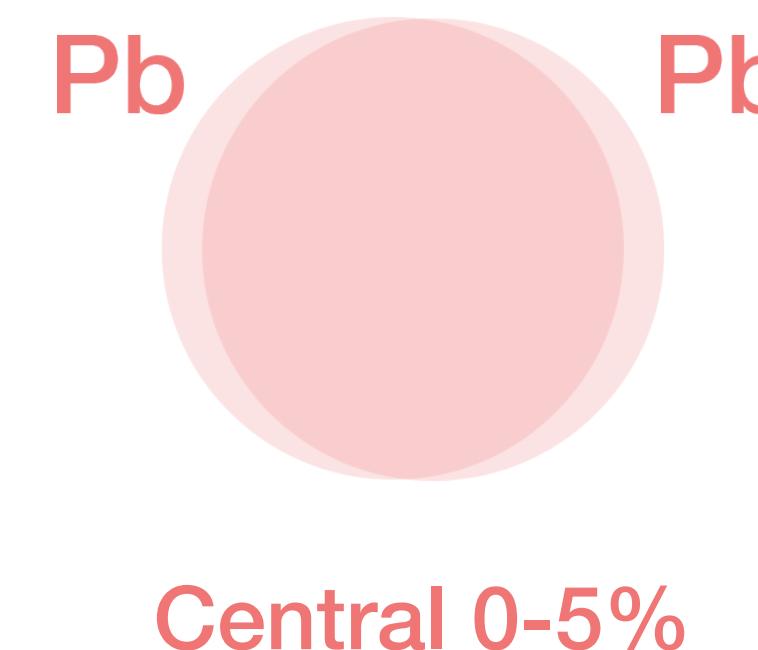


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  - **EPOS** Core-corona for different string density, consistent picture across all collision systems
    - Underpredicts magnitude
    - Matches the shape very well

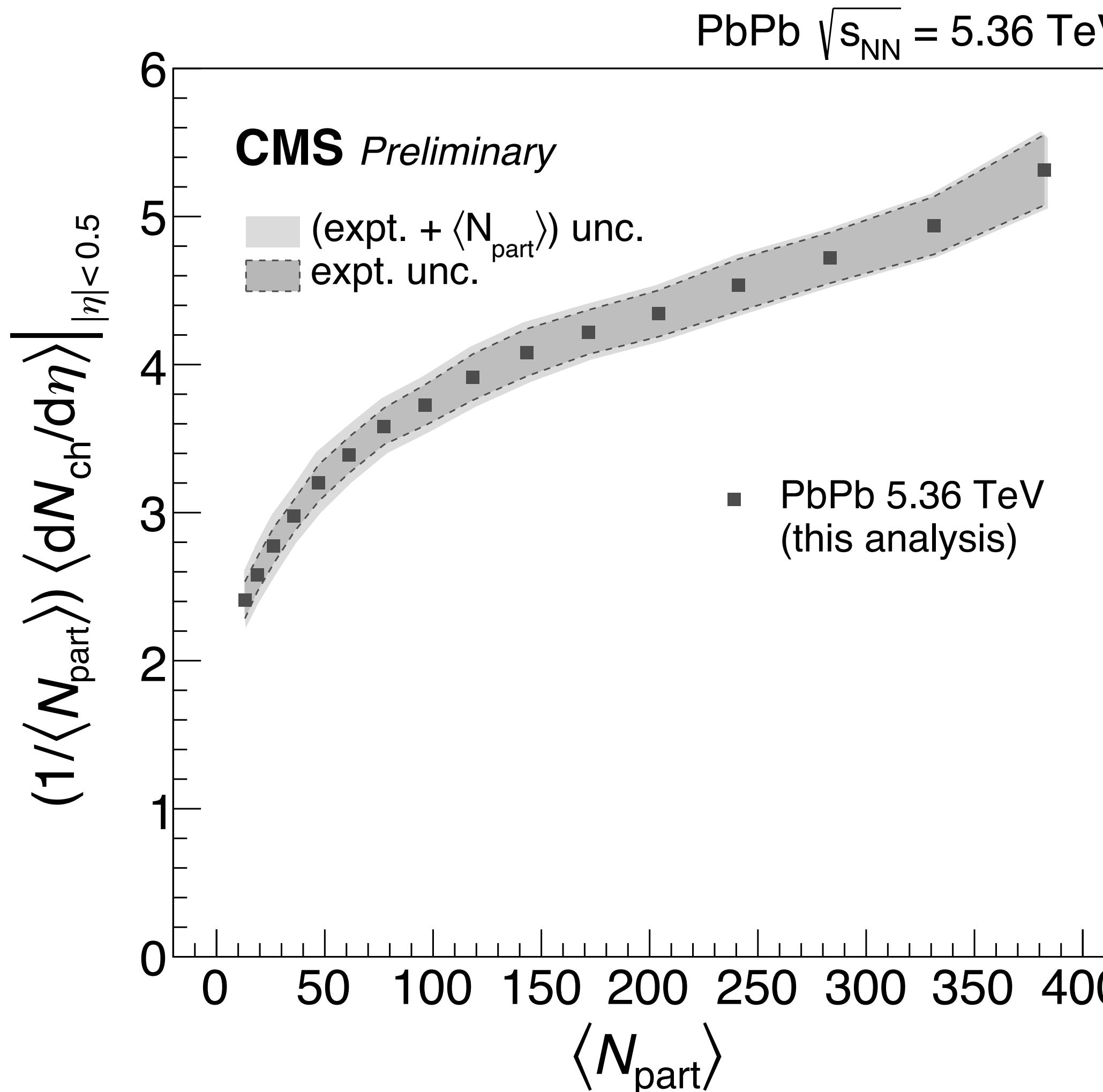
# Results $dN/d\eta$ in Different Centralities



- $dN/d\eta$  decreases rapidly vs. centrality
- Behavior of MC comparison is similar in different centralities but consistency is worse at large  $\eta$  in peripheral events

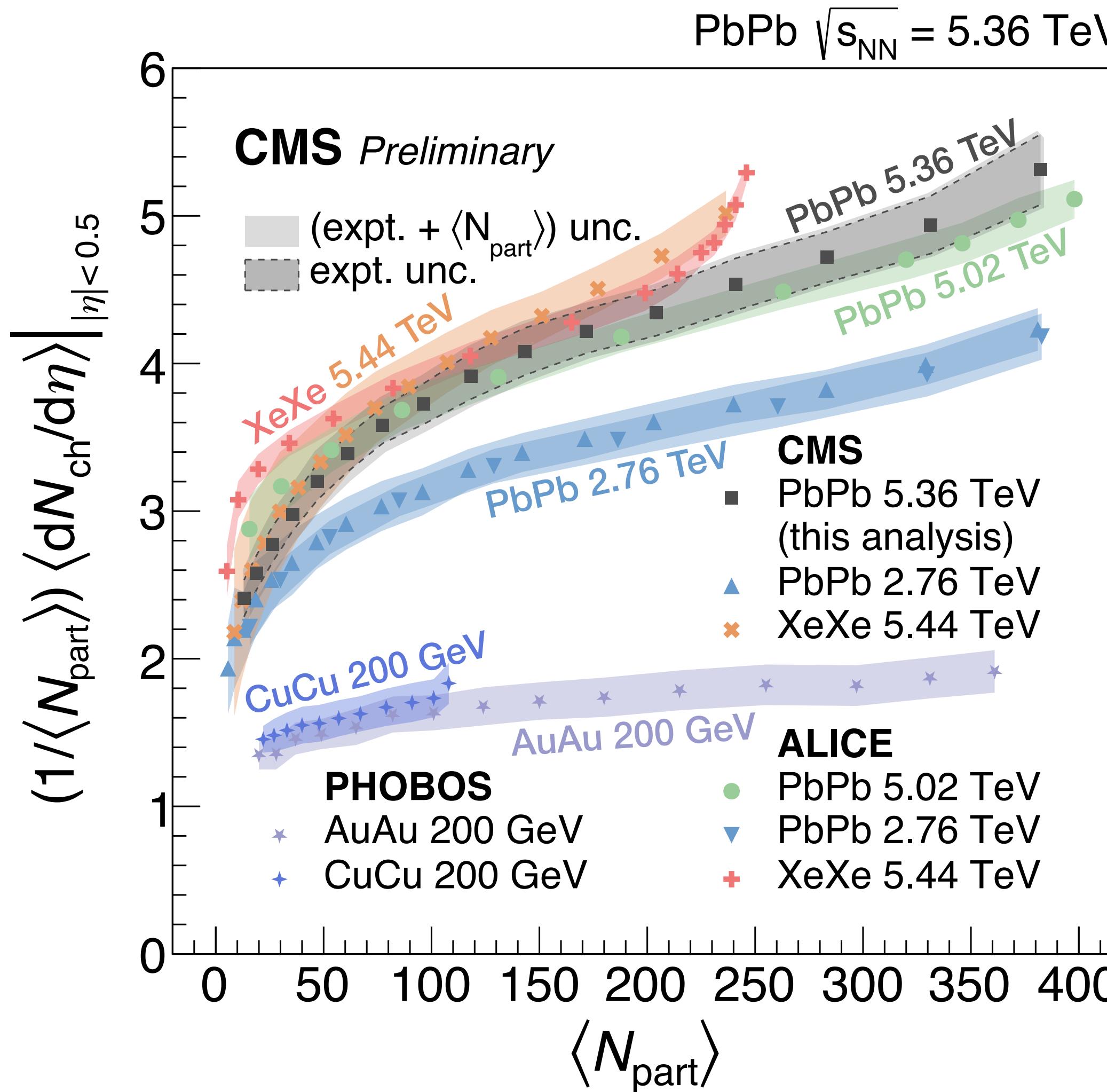


# Results Mid-rapidity dN/d $\eta$ vs. Centrality



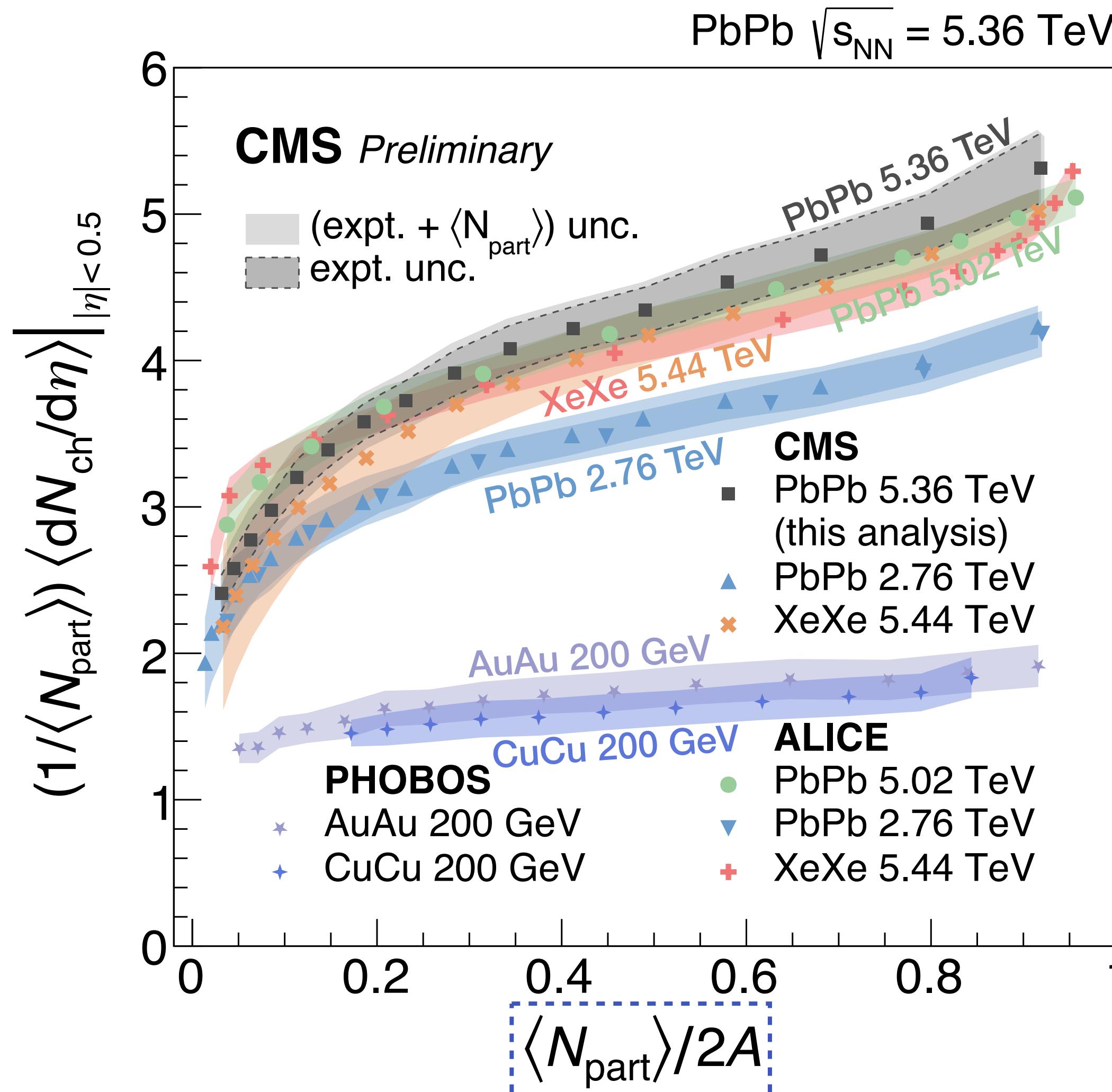
- Per-participant dN/d $\eta$  at midrapidity as a function of the average number of participating nucleons
- Rising trend observed
  - Increase in the contributions from hard scattering processes → scale faster than  $N_{\text{part}}$

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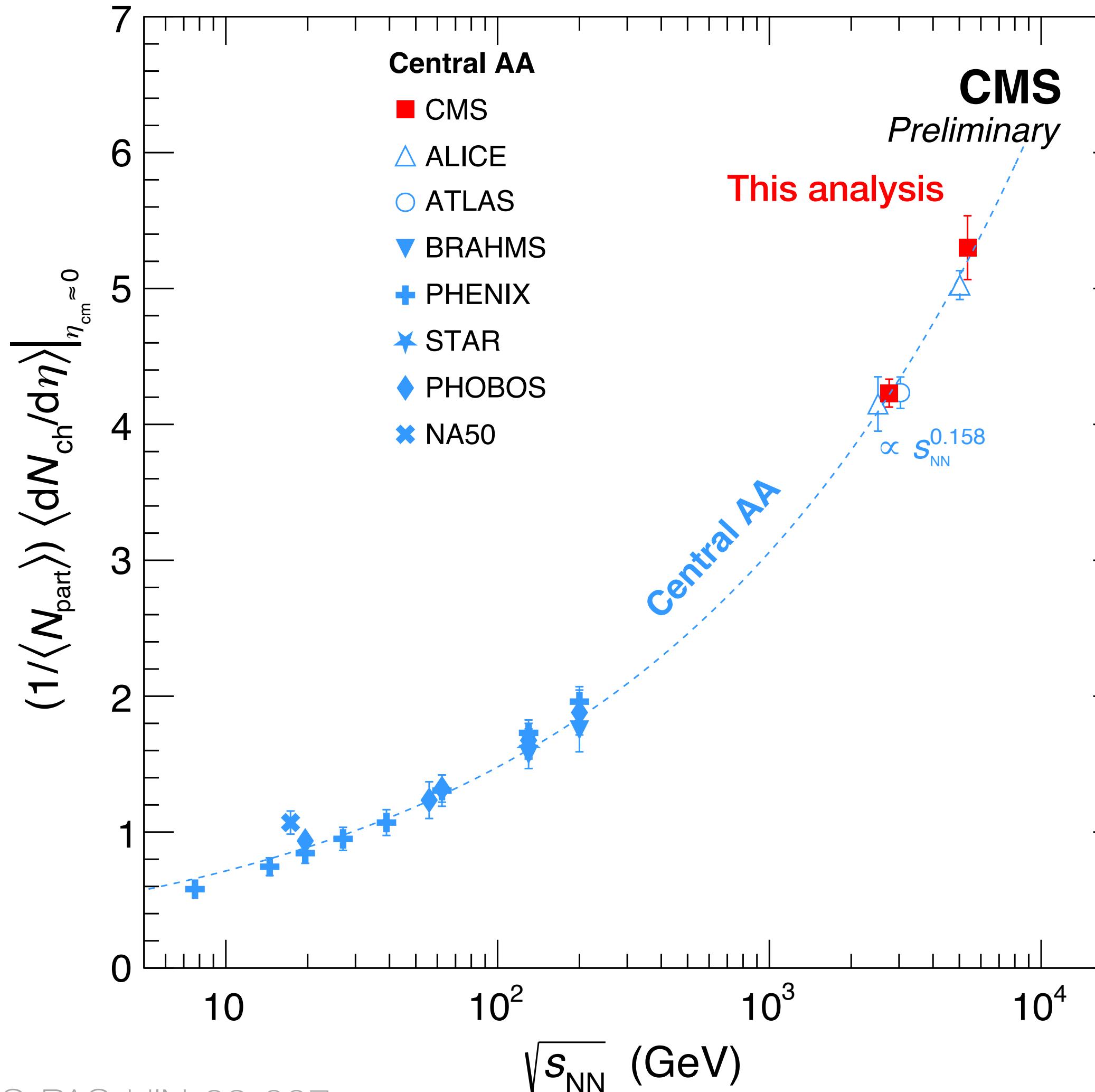
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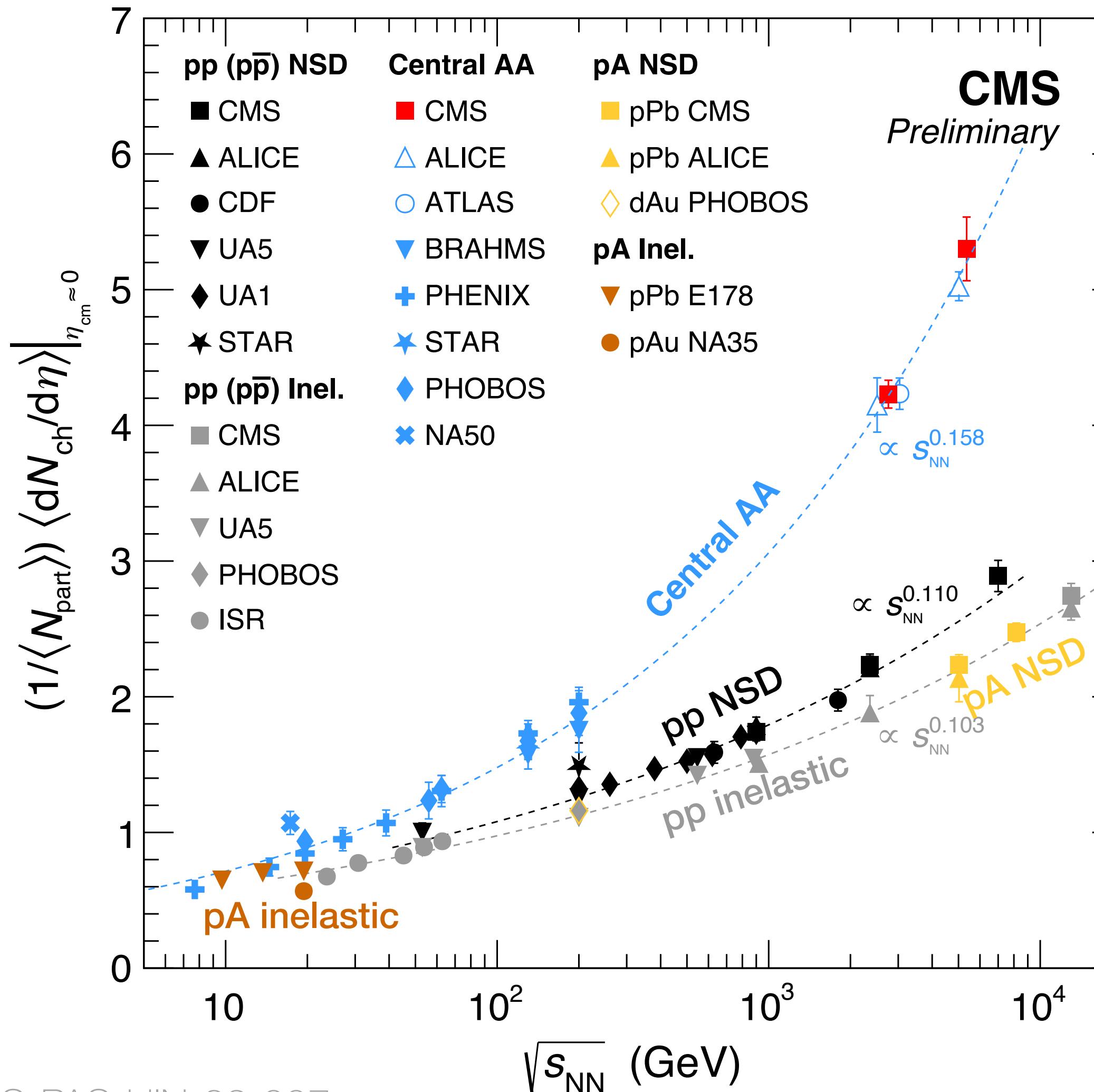
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- Rising trend observed
  - Increase in the contributions from hard scattering processes → scale faster than  $N_{\text{part}}$
- Roughly grouped by **collision energy**
  - $N_{\text{part}}/2A$  seems to be a better scale than  $N_{\text{part}}$  between PbPb and XeXe

# Results Mid-rapidity dN/d $\eta$ vs. Collision Energy



- New result consistent with the extrapolation with previous world data using a power law function fit

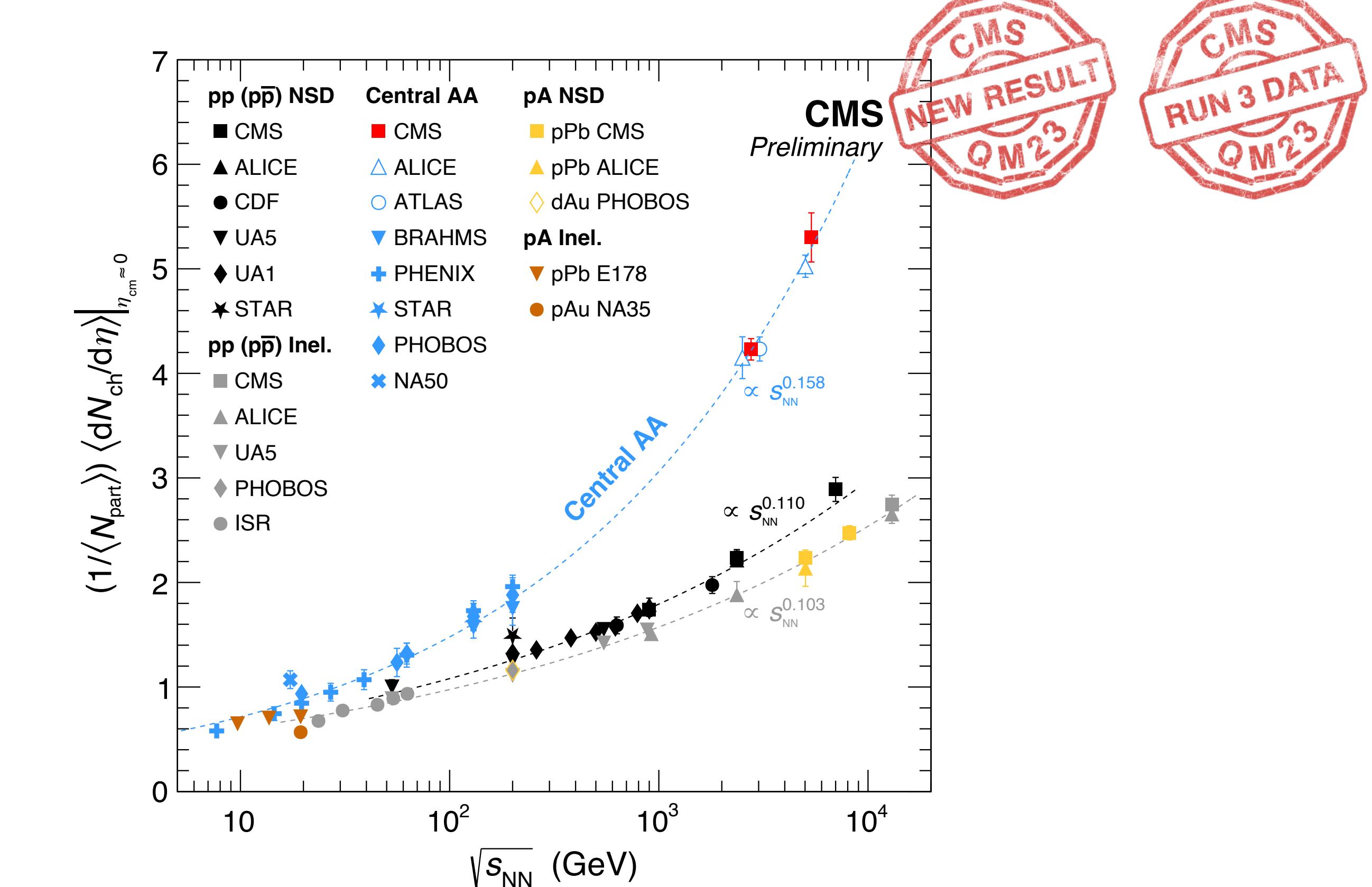
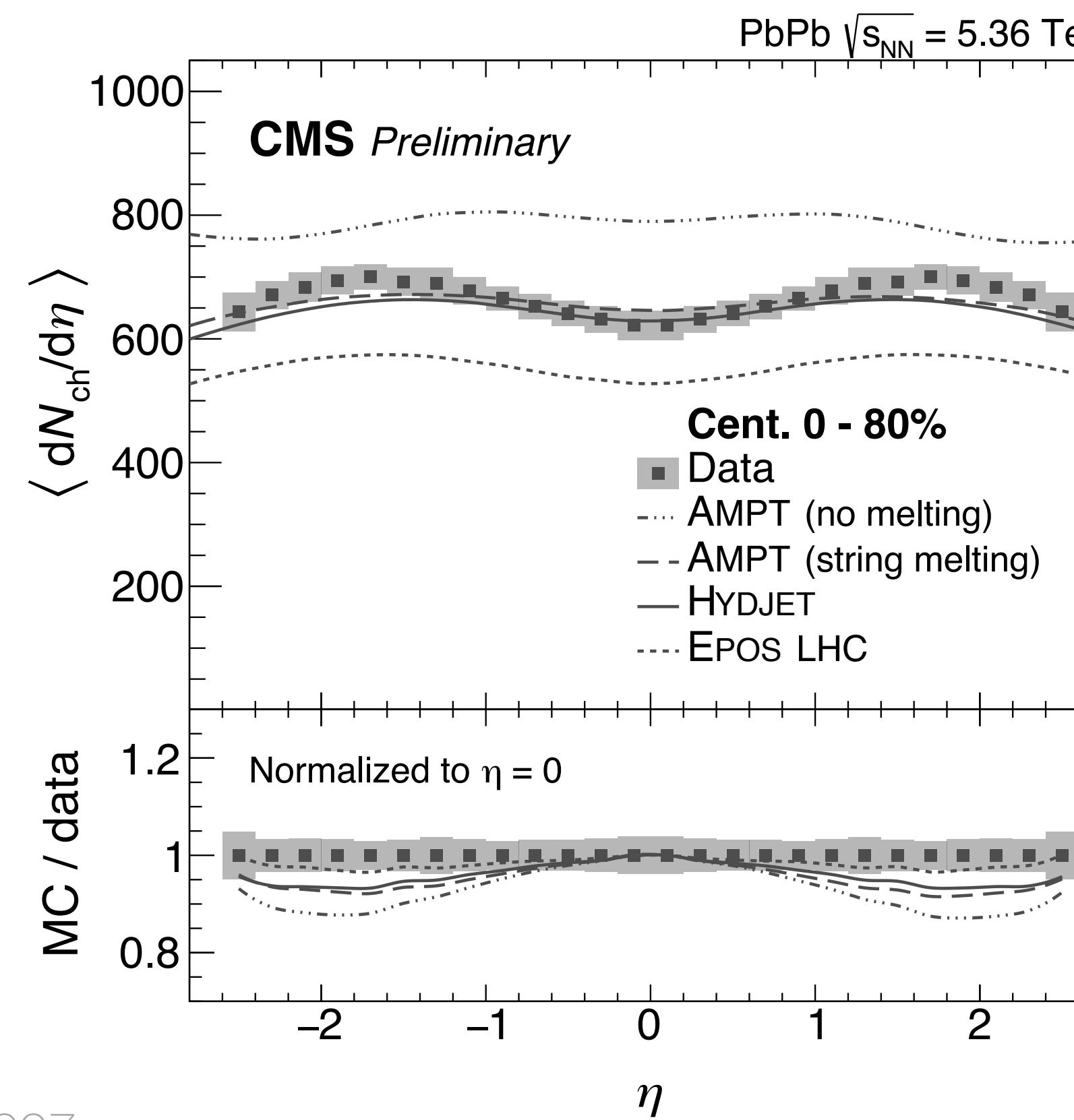
# Results Mid-rapidity dN/d $\eta$ vs. Collision Energy



- New result consistent with the extrapolation with previous world data using a power law function fit
- Power law parameterization works for all systems
- Central AA larger than pp and pA
  - AA is more efficient on converting collision energy to particle multiplicity (entropy) than pA and pp, while pp is similar with pA
  - pA NSD lower than pp NSD → shadowing

# Summary

- $dN_{ch}/d\eta$  measured in PbPb at unprecedented **5.36 TeV** with 2022 test run
- Event generators are not able to accurately describe data → important input to tune MC
- New result **consistent with the extrapolation** with previous lower energy world data





Isabelle

Thanks for your attention!

# LHC Heavy Ion Run

Run 1

Run 2

Long Shutdown 2

Run 3

LS 3

Run 4

LS 4

PbPb  
( $2.2 \text{ nb}^{-1}$ )  
pPb  
( $0.18 \text{ pb}^{-1}$ )

5.36 TeV  
5.02 TeV  
8.16 TeV

PbPb  
( $6 \text{ nb}^{-1}$ )  
pPb  
( $0.5 \text{ pb}^{-1}$ )  
pO/OO

CMS  
Phase-2  
upgrades

PbPb  
( $7 \text{ nb}^{-1}$ )  
pPb  
( $0.5 \text{ pb}^{-1}$ )



We are  
here!

# Systematics

Table 1: Sources of systematic uncertainty affecting the measurement of charged hadron multiplicities and  $\langle N_{\text{part}} \rangle$  in PbPb collisions at  $\sqrt{s_{\text{NN}}} = 5.36 \text{ TeV}$ .

Source	[%]
Pixel cluster splitting	1.4–2.0
Consistency between primary vertex position	0.5–4.5
Tracklet selection	<0.5
Consistency between tracklet combinations	1.0–4.0
Model dependence	0.5–2.0
Centrality calibration	0.1–2.5
Total systematic uncertainty	2.5–6.4