



QPT 2025

Guilin, China

CMS Highlights

Scientific contributions from Chinese teams

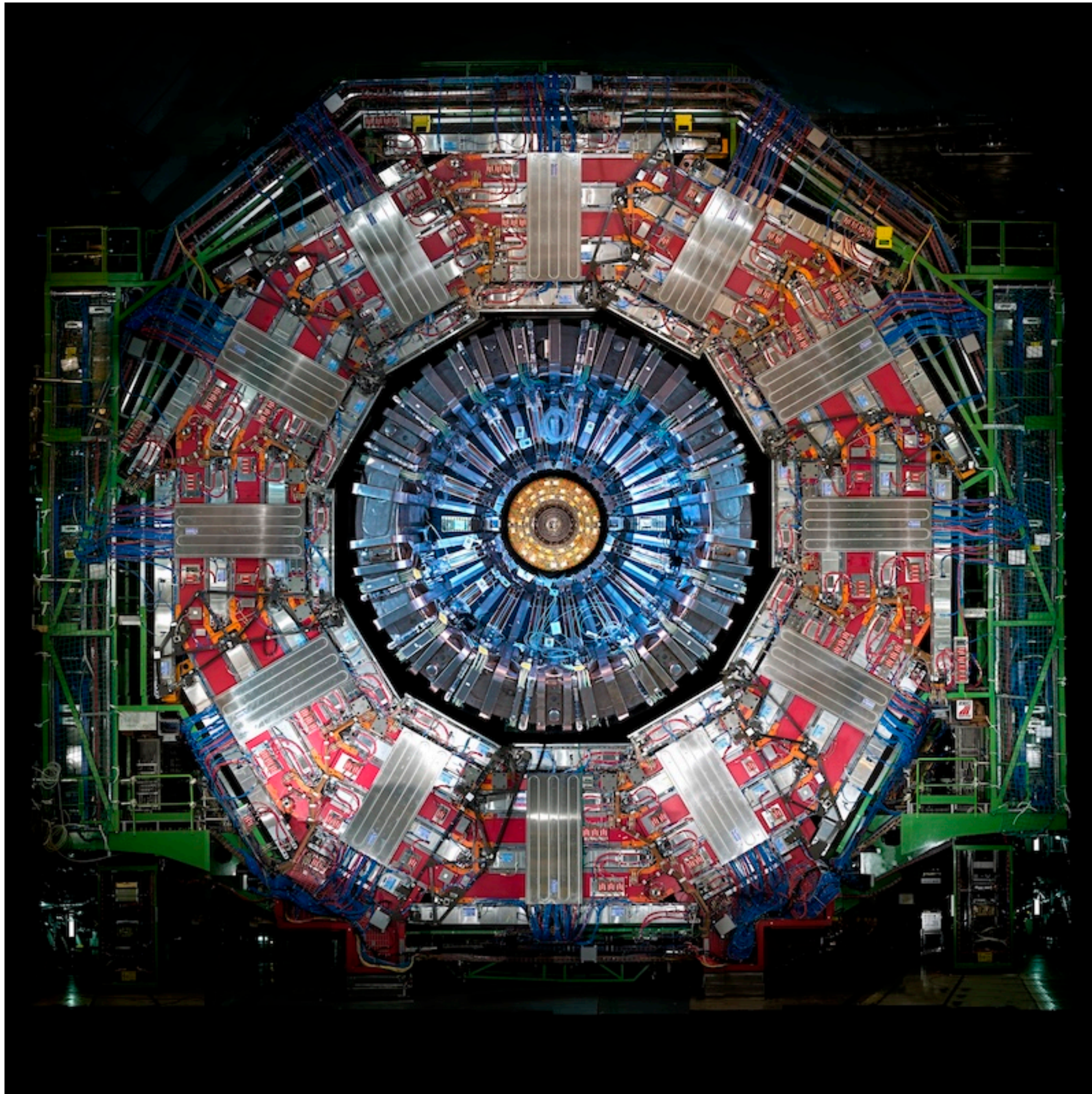
Shuai Yang (杨 帅)

South China Normal University

QPT 2025, Guilin

24-28, October

The Compact Muon Solenoid



- ◎ Versatile for heavy-ion physics
- ◎ CMS HIN teams in China



陈震宇
张金龙



杨 帅
叶早晨



查王妹



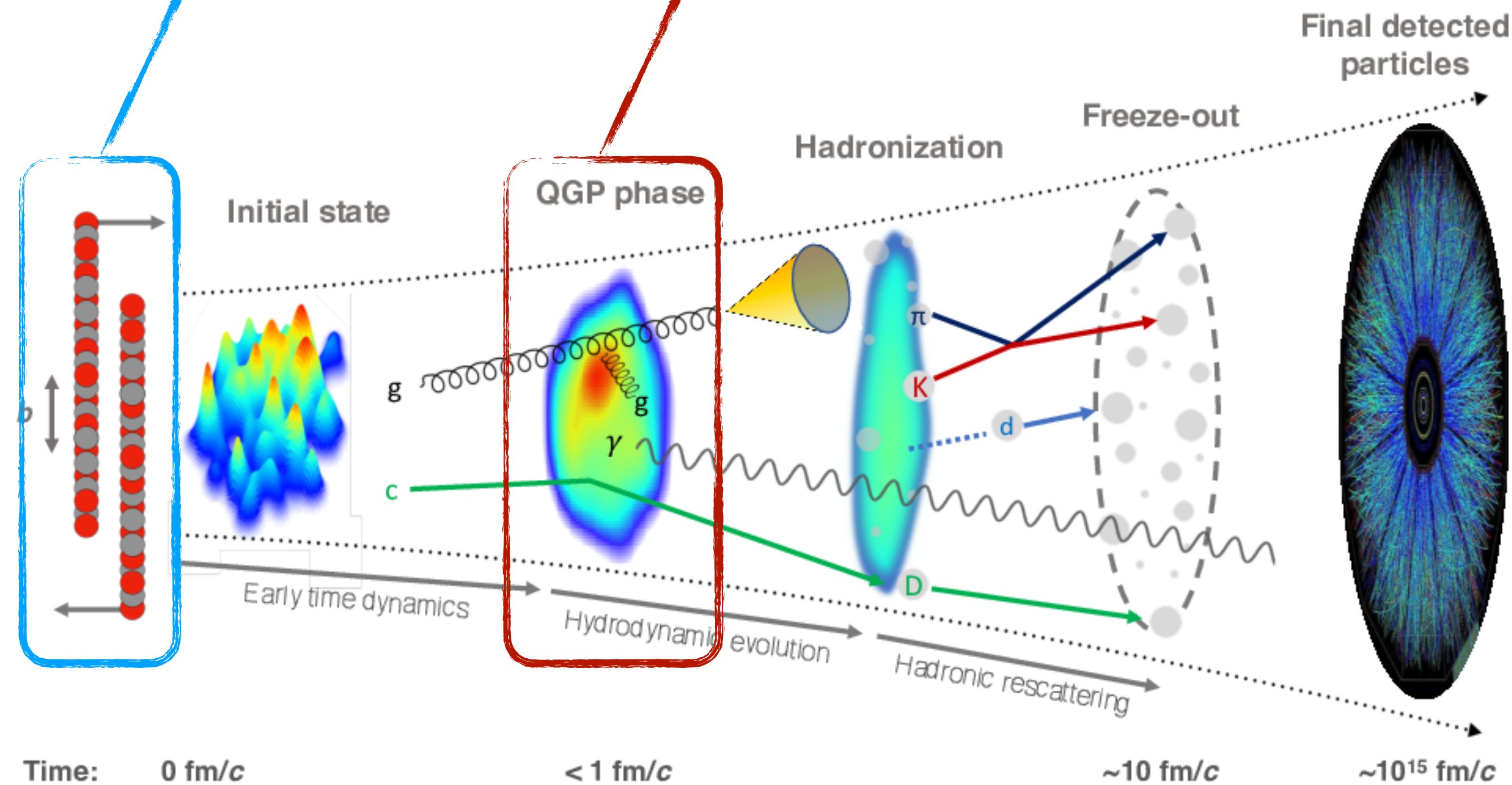
Evolution of a heavy-ion collision

- Initial conditions are critical

- Initial geometry
- Gluon distribution function

- Quark Gluon Plasma

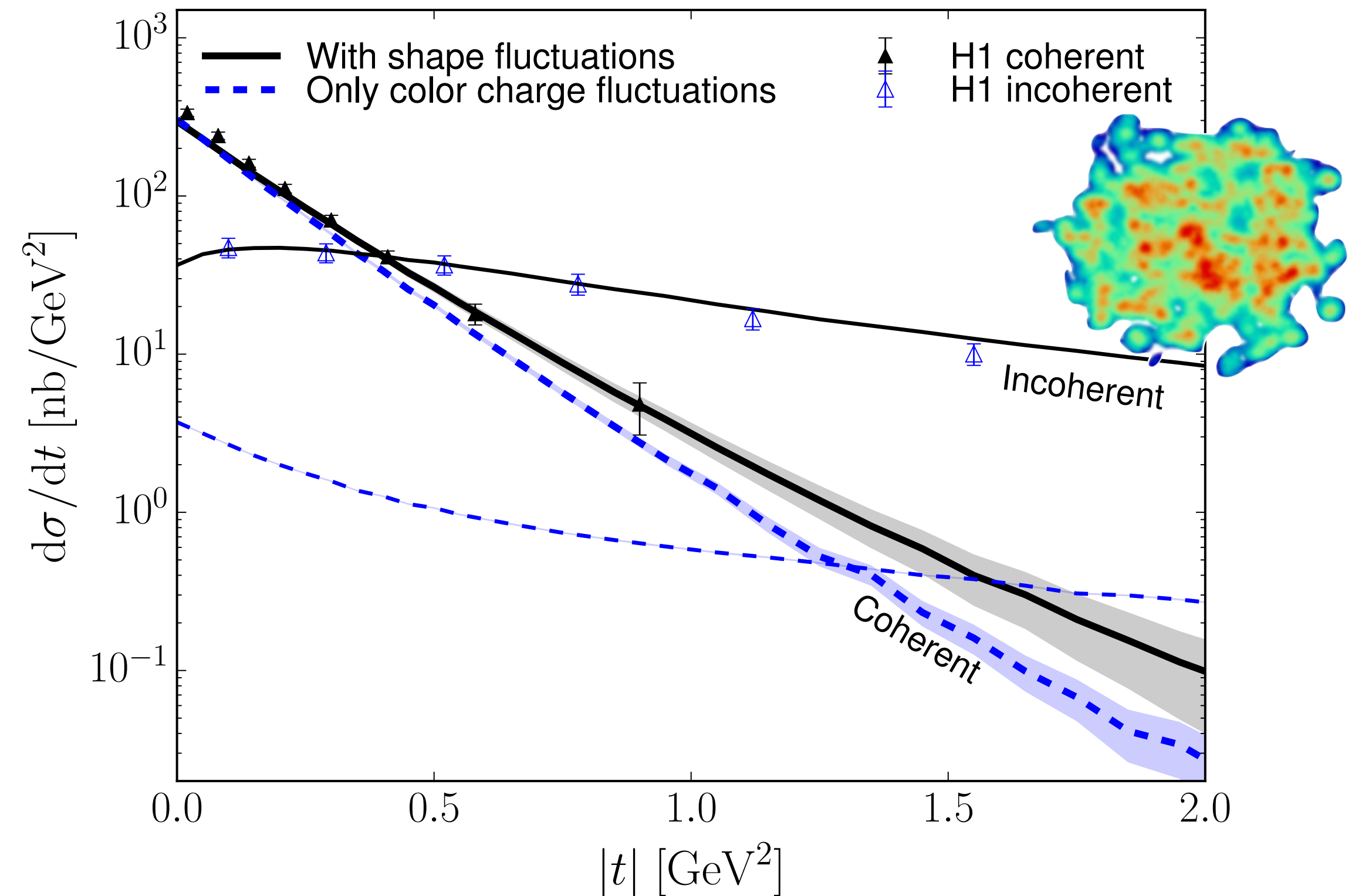
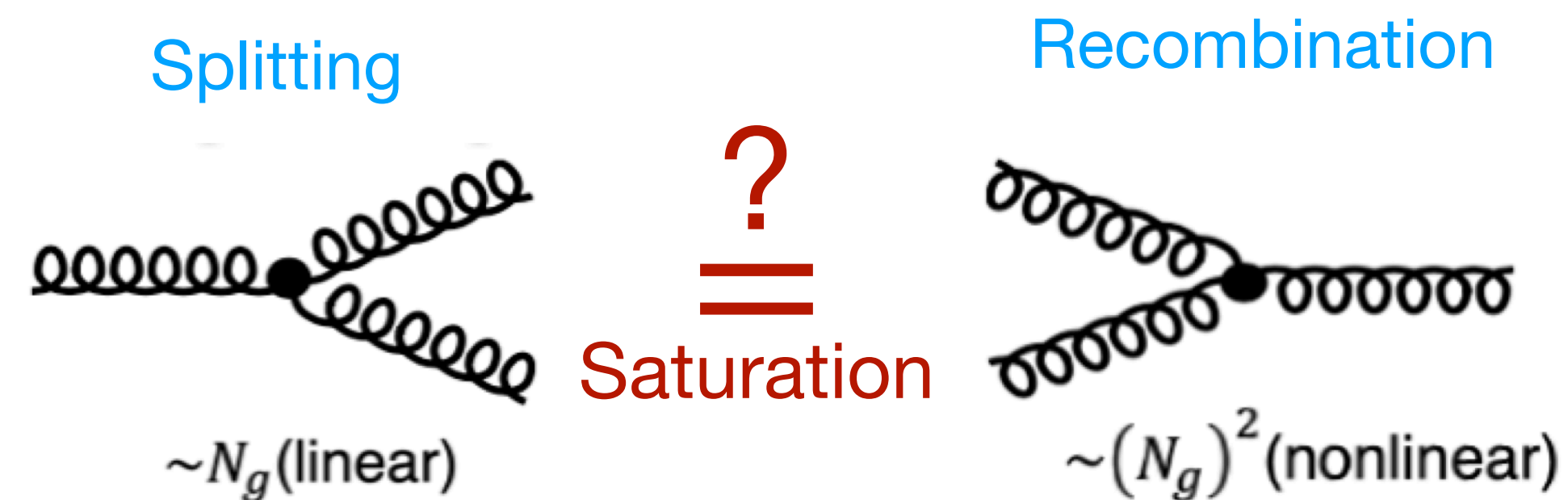
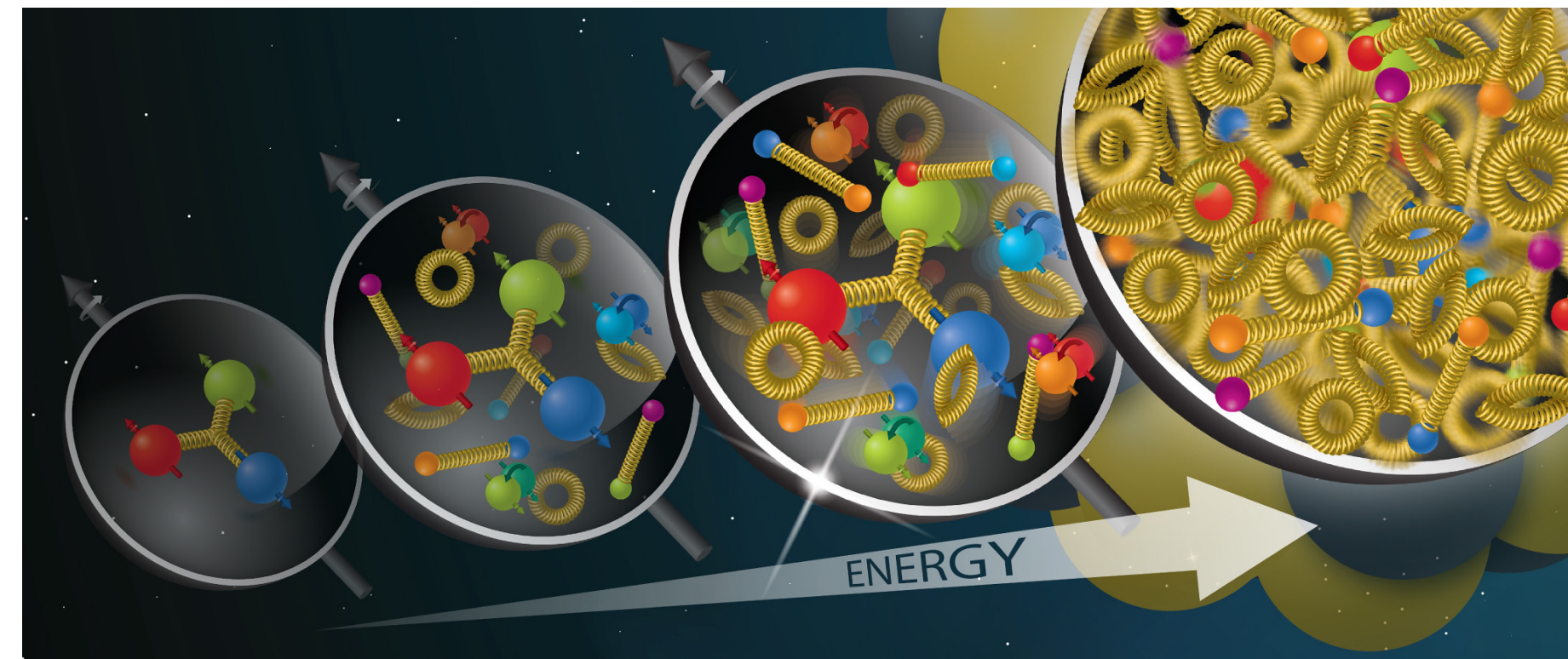
- How and where does this happen?
- Mechanism of local polarization



M. Aeslandok *et al.*, arXiv:2303.17254

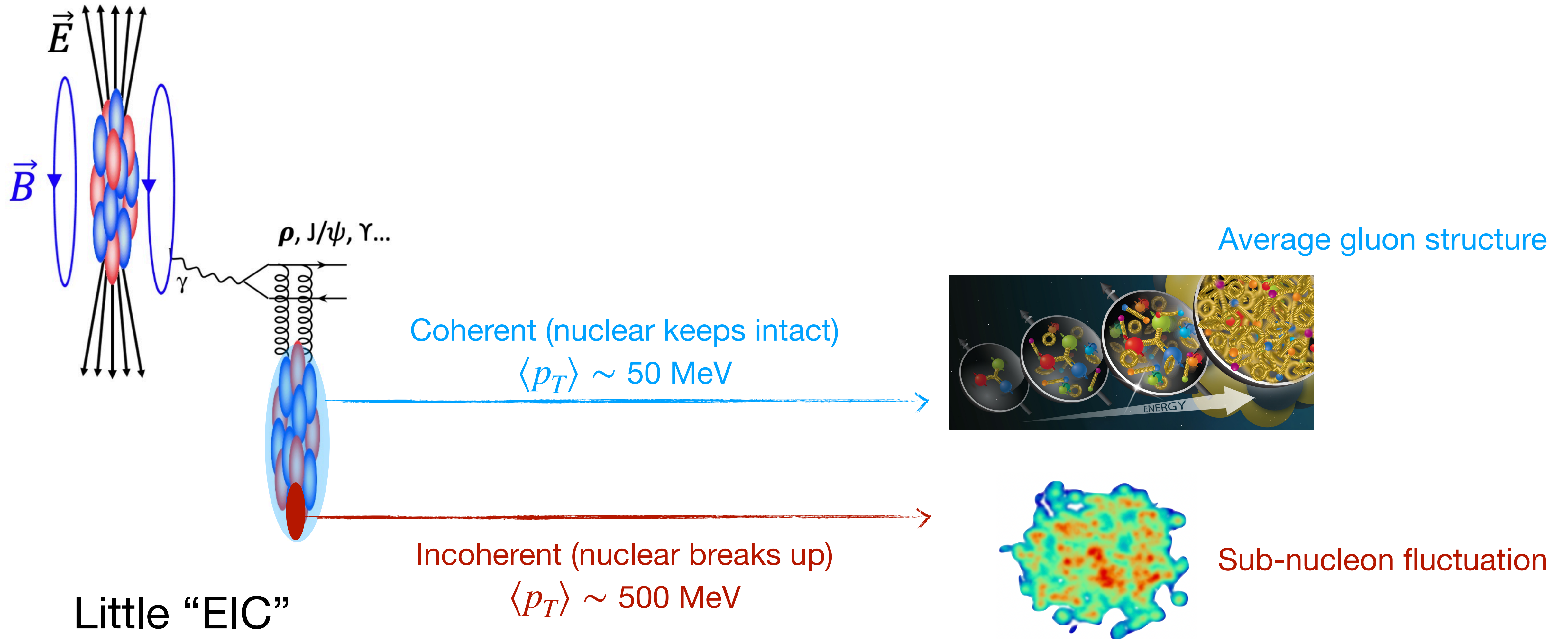
Gluon behavior inside nuclear

What's the ultimate destiny of gluon?

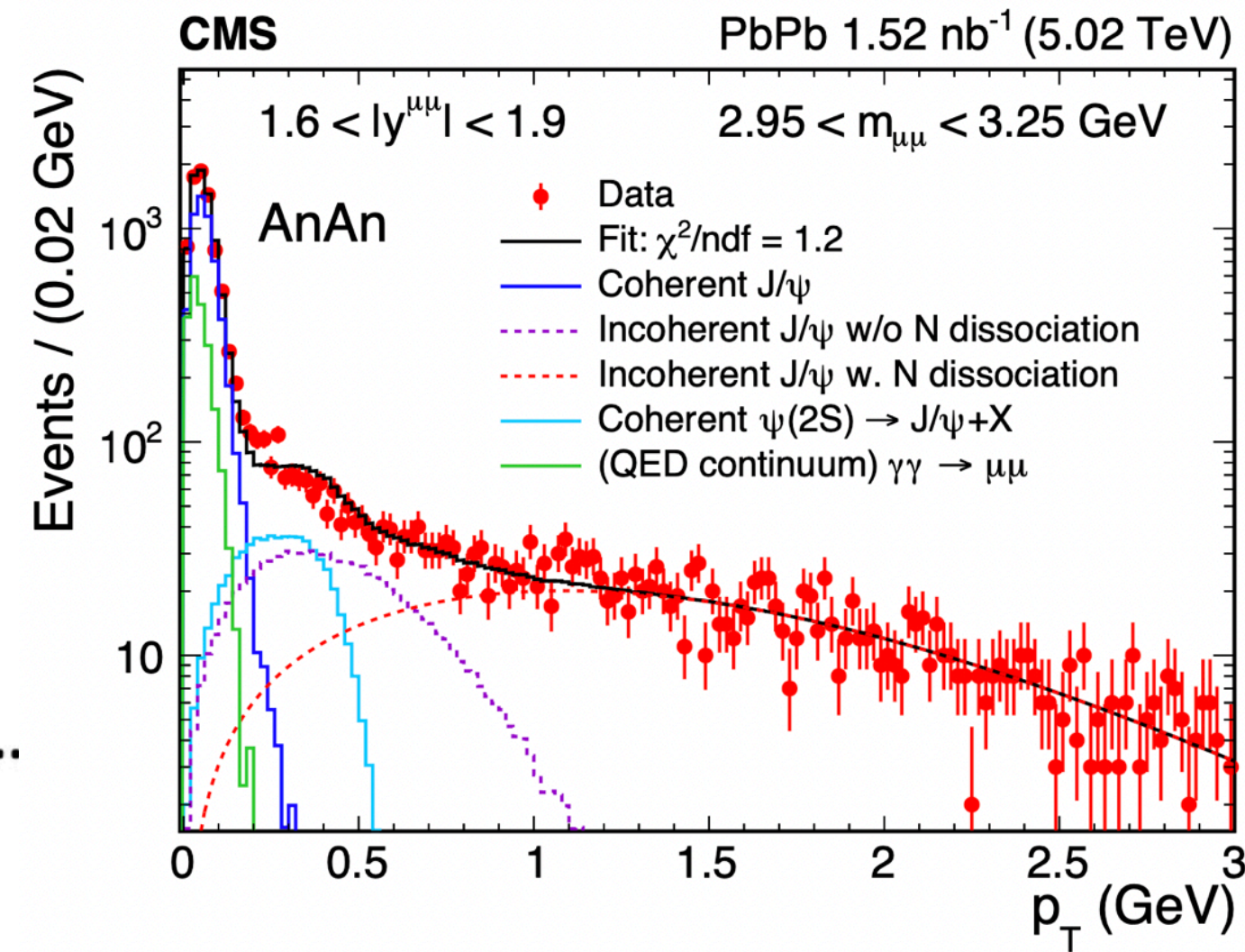
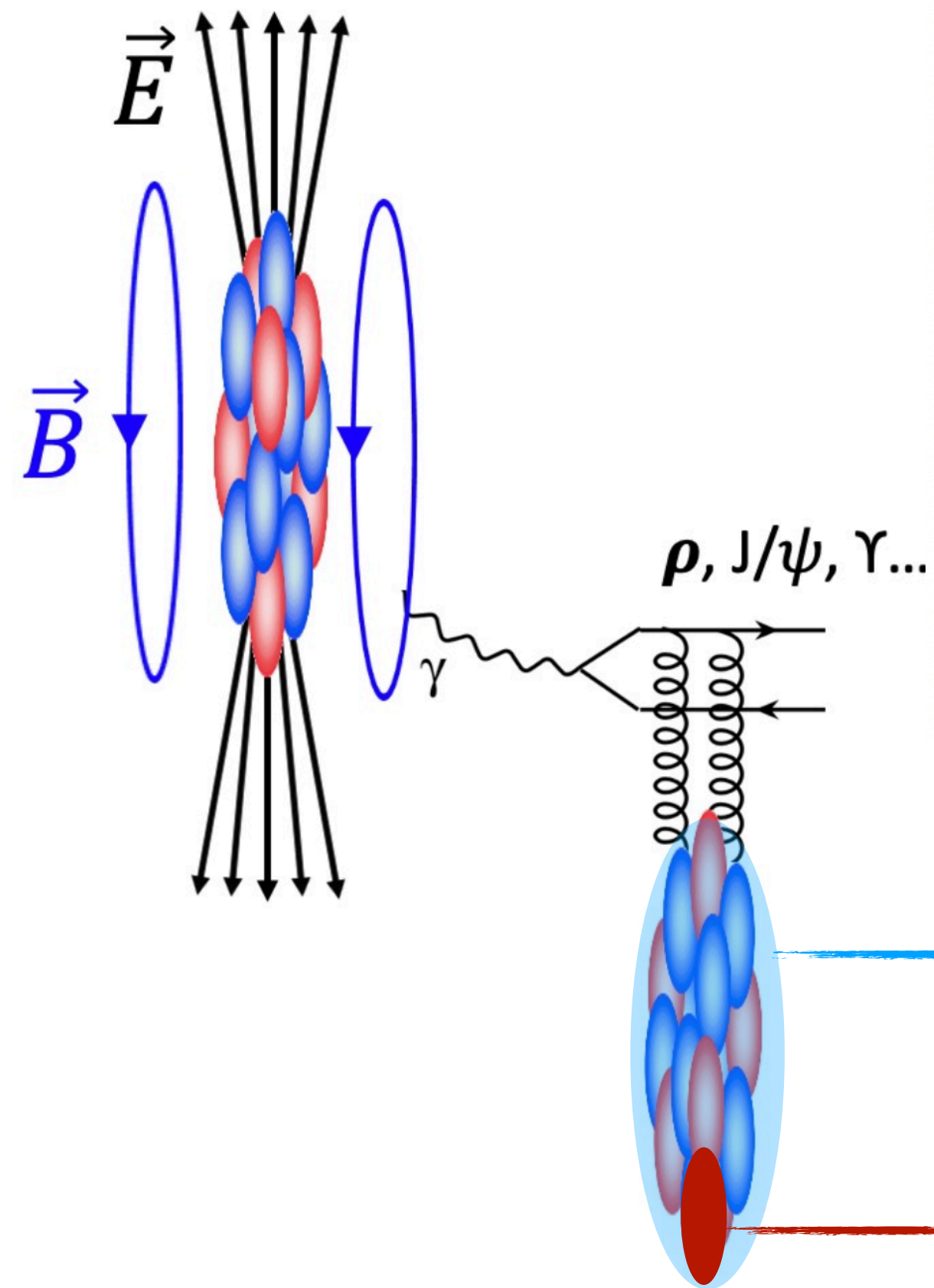


The critical role of gluon fluctuations

Photon-nuclear interactions in UPC



Photon-nuclear interactions in UPC

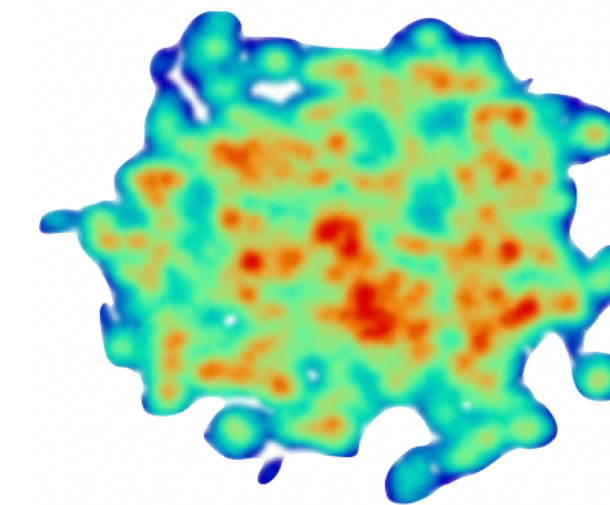
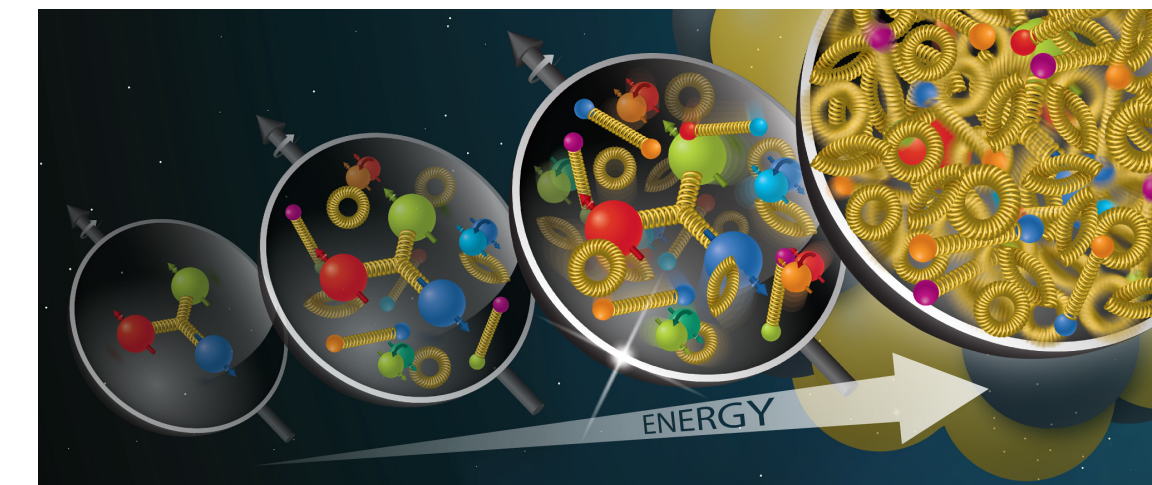


CMS, PRL 131 (2023) 262301

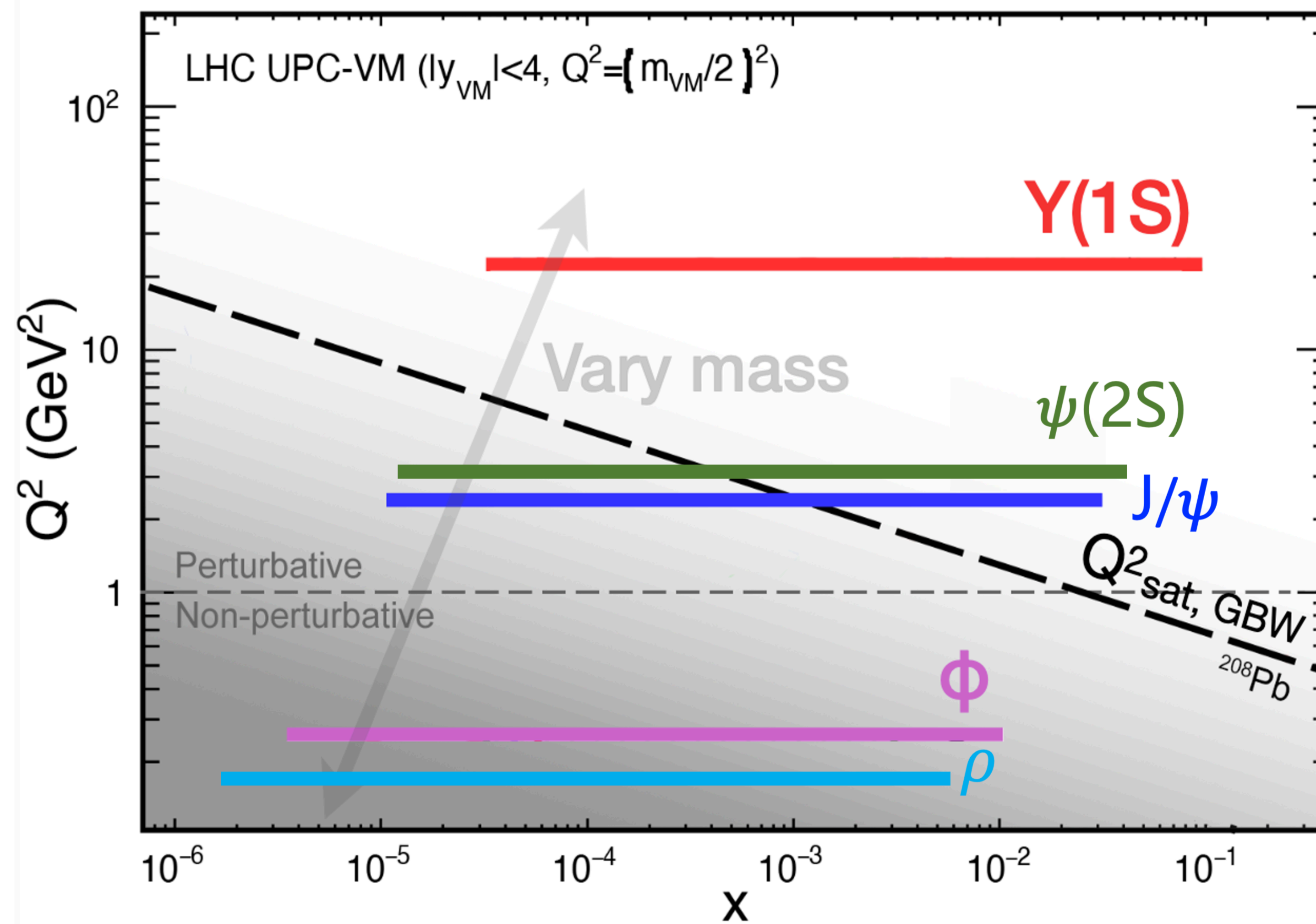
Coherent (nuclear keeps intact)
 $\langle p_T \rangle \sim 50 \text{ MeV}$

Incoherent (nuclear breaks up)
 $\langle p_T \rangle \sim 500 \text{ MeV}$

Little “EIC”

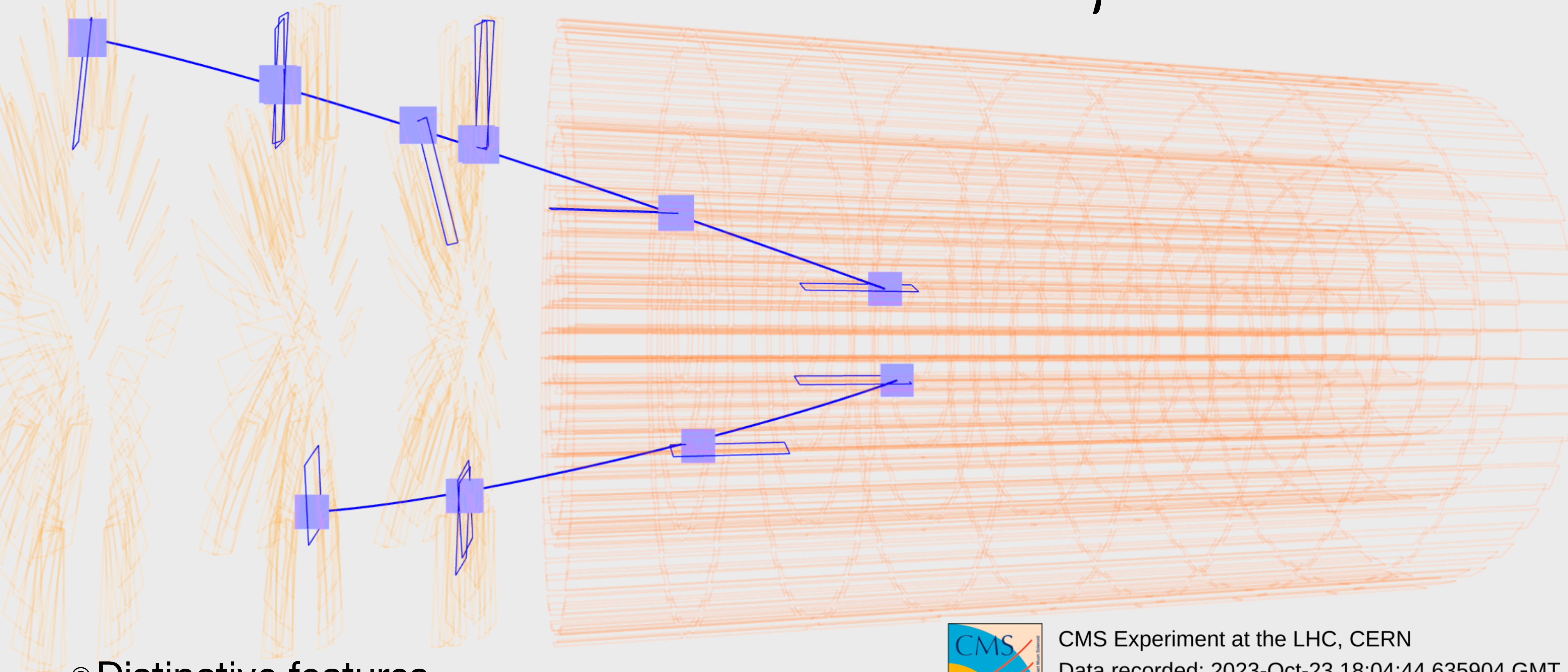


What can we do with photoproduced VM?



Probe gluon structure at various x and Q^2

First observation of coherent ϕ meson



● Distinctive features

- Low activities in forward calorimeters
- Exactly two tracks identified as daughters of photoproduced VM



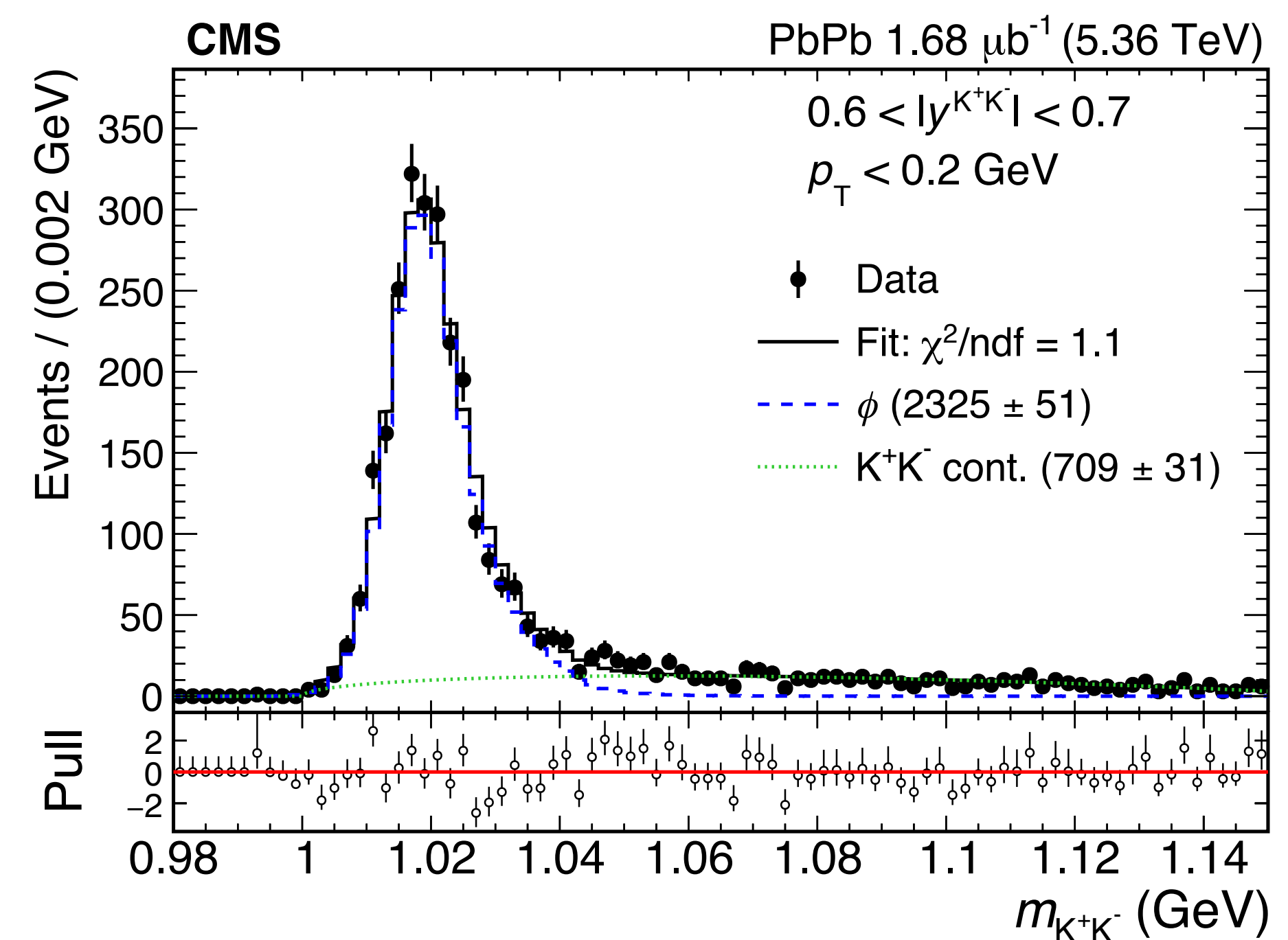
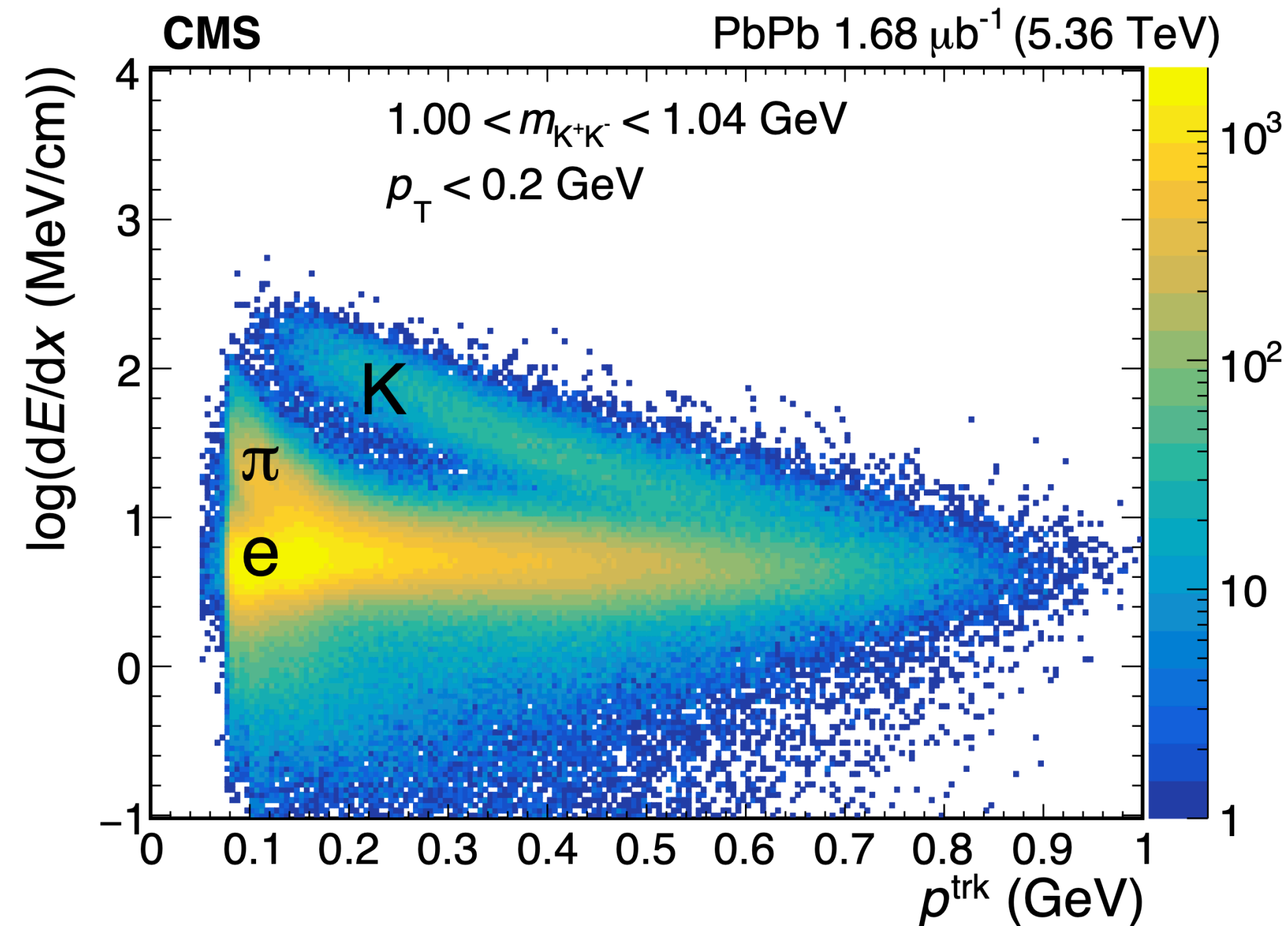
CMS Experiment at the LHC, CERN

Data recorded: 2023-Oct-23 18:04:44.635904 GMT

Run / Event / LS: 375531 / 526831649 / 370

First observation of coherent ϕ meson

CMS, arXiv:2504.05193

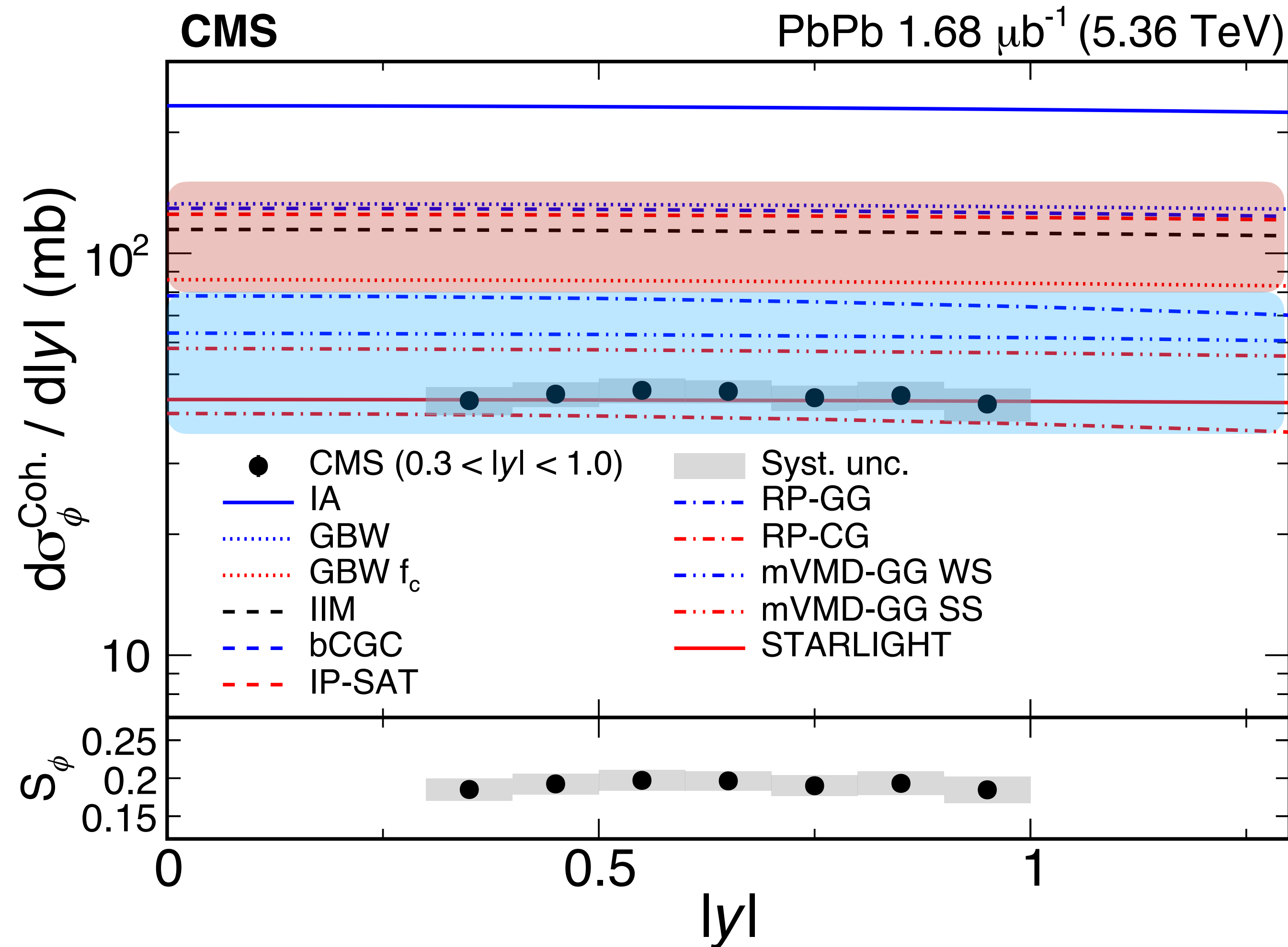


⦿ Super challenging for coherent ϕ measurements for all experiments

- The p_T of daughter kaon is $\sim 0.05 - 0.1 \text{ GeV}/c$
- CMS can perform PID at low momentum

First observation of coherent ϕ meson

CMS, arXiv:2504.05193

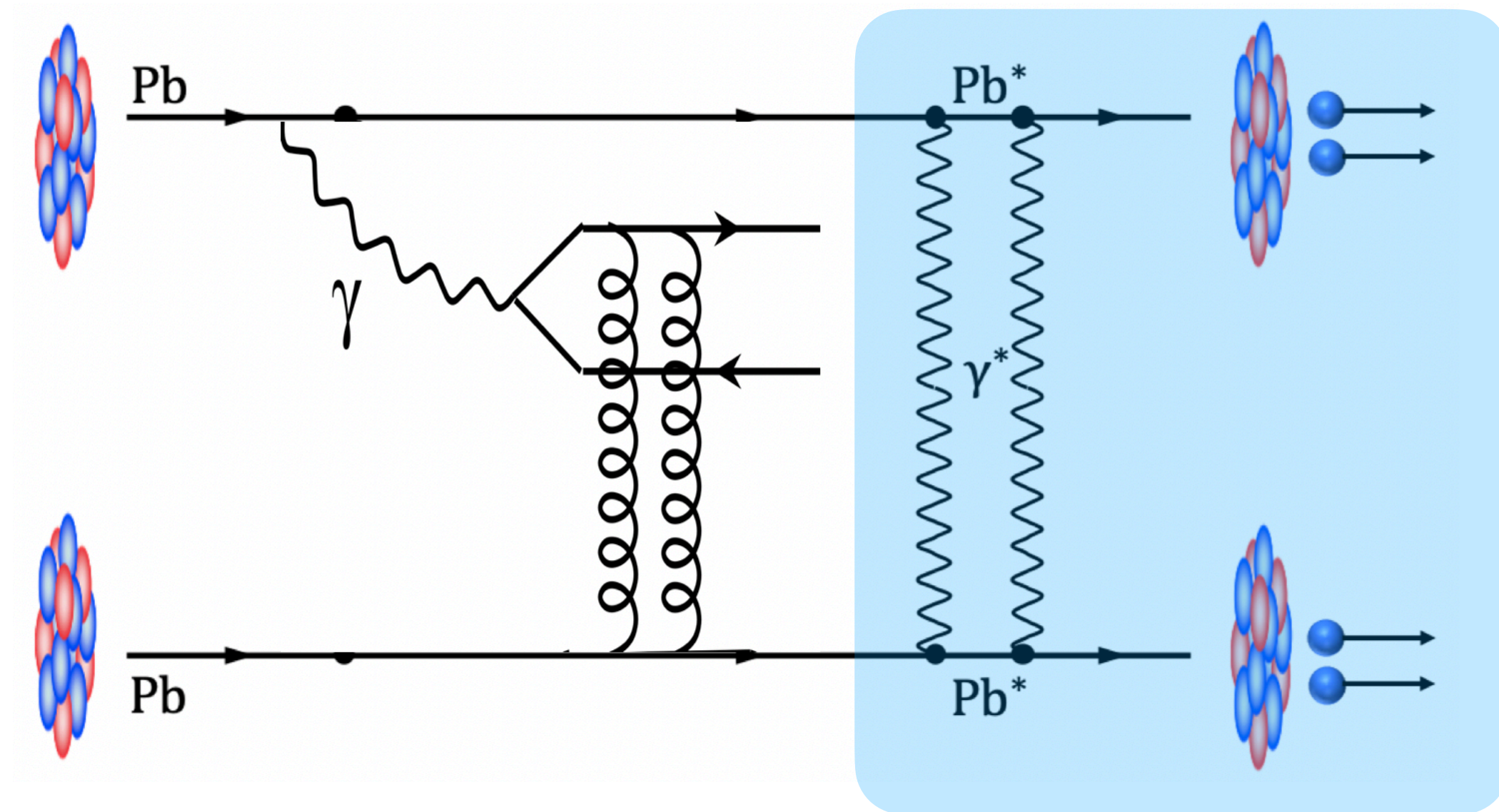


- Strong ($\sim 5\times$) suppression is observed
- Gluon saturation models over predict data by a factor of 2-3
- Nuclear shadowing models generally better describe data

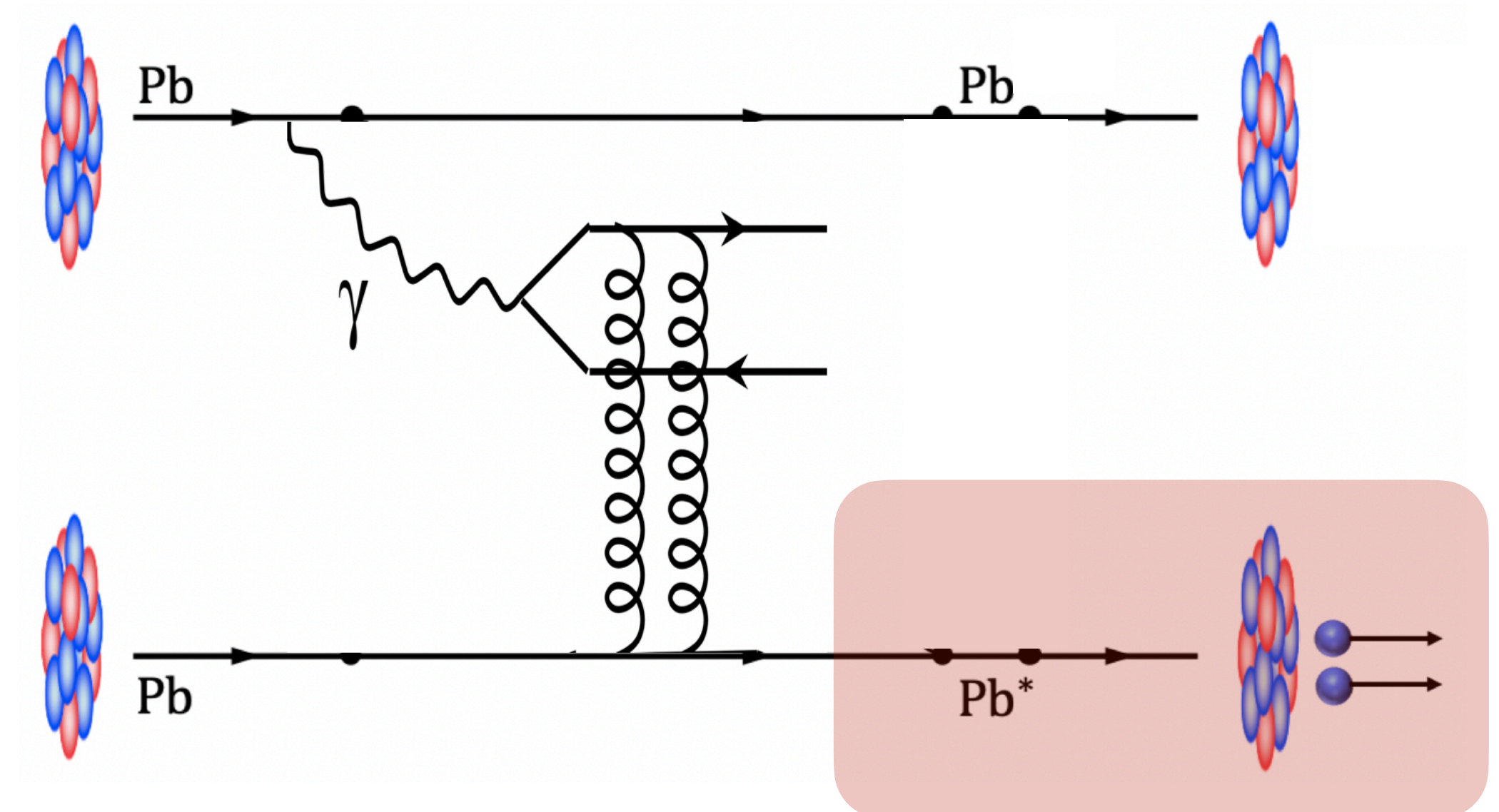
Energy dependence of photoproduced VM

- Employ **neutron tagging** to measure the energy dependence of photoproduced vector mesons

Coherent photoproduction



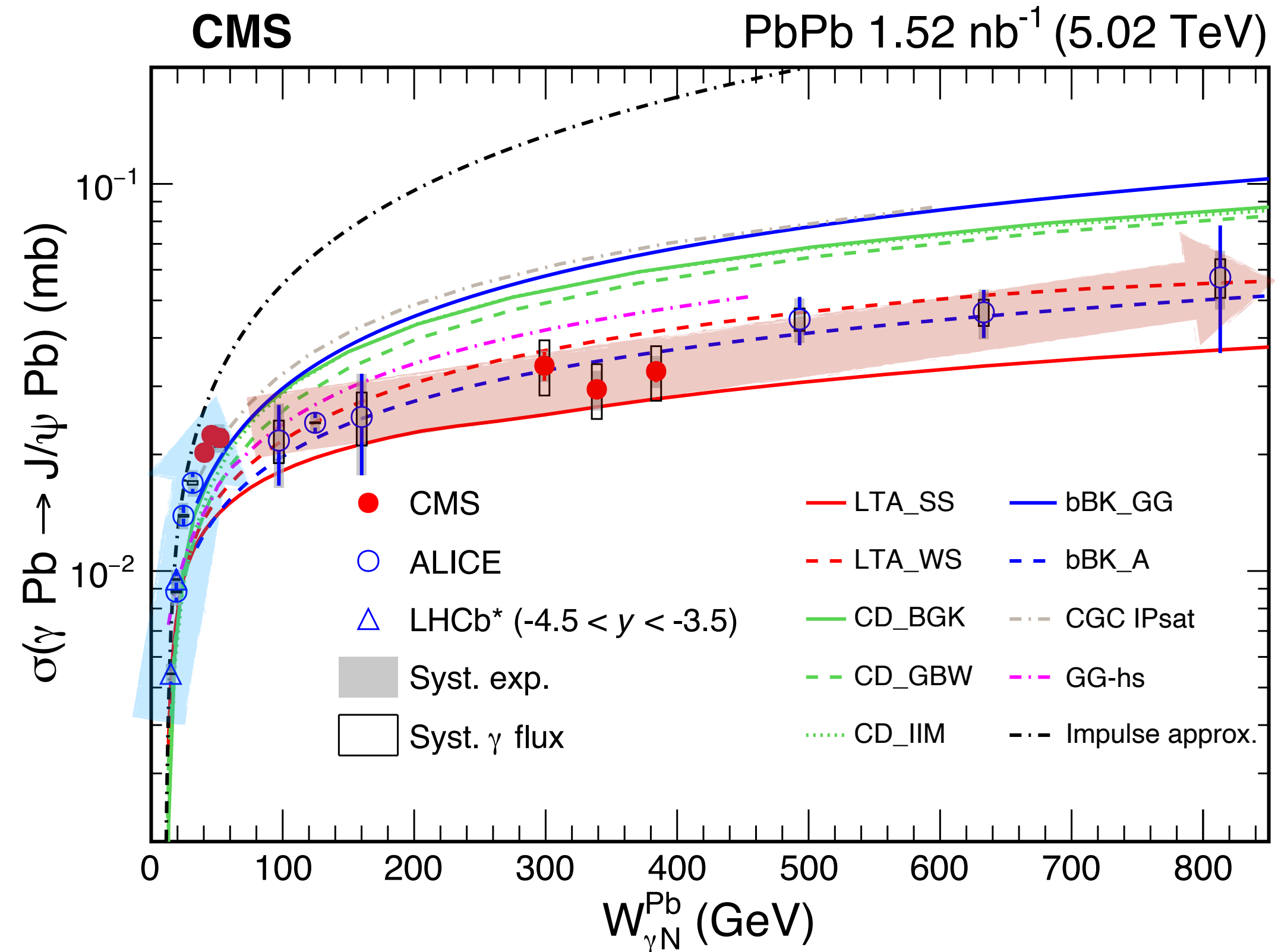
Incoherent photoproduction



$$\frac{d\sigma_{AA \rightarrow AA' J/\psi}}{dy} = N_{\gamma/A}(\omega_1) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_1) + N_{\gamma/A}(\omega_2) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_2)$$

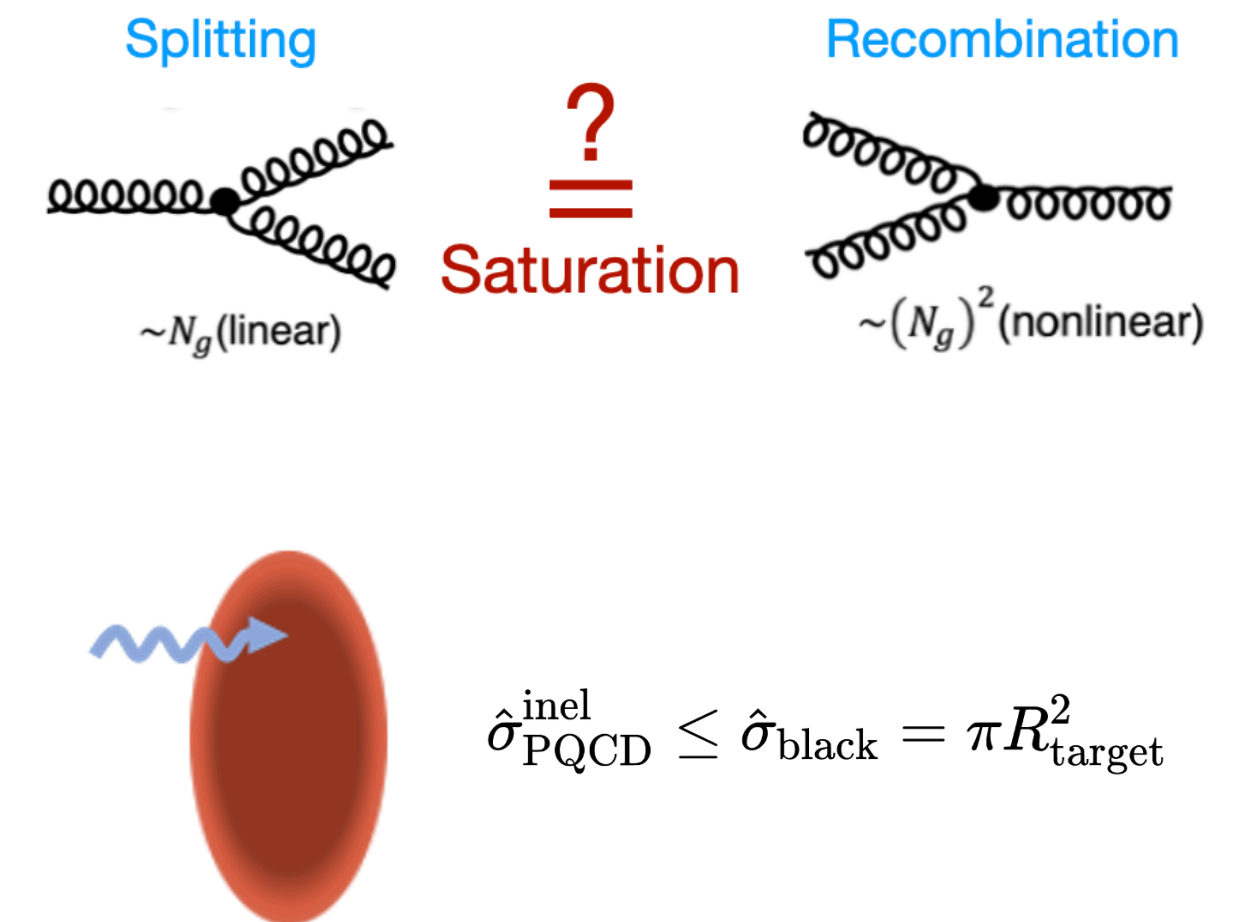
Energy dependence of coherent J/ ψ

LO pQCD:
 $\sigma^{VM} \propto [xG(x)]^2$



Large x $\longrightarrow$ Small x

CMS, PRL 131 (2023) 262301
 ALICE, JHEP 10 (2023) 119



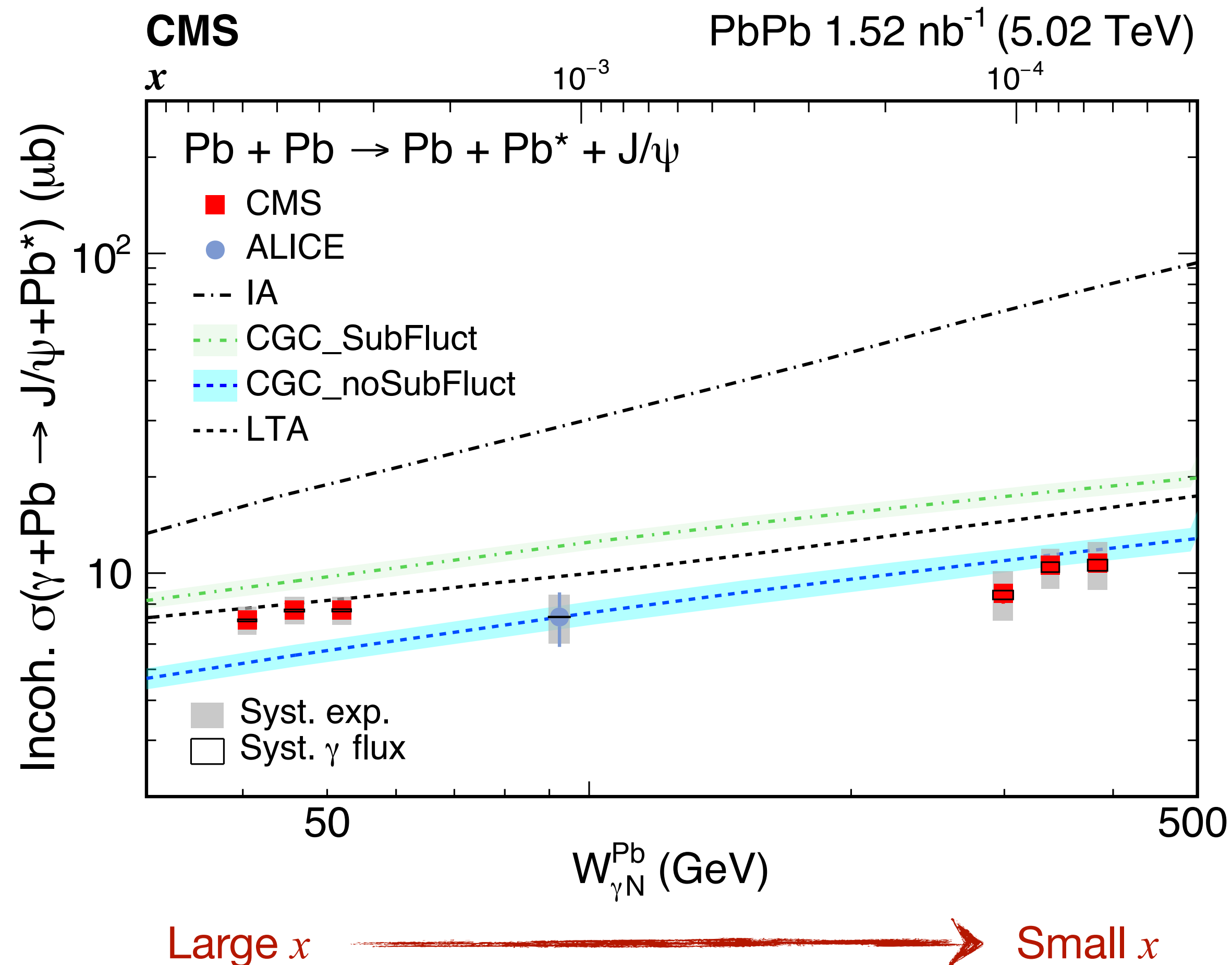
Frankfurt, PRL 87 (2001)192301
 Frankfurt, PLB 537 (2002) 51

◎ Direct evidence of gluon saturation inside heavy nuclei?

- $W_{\gamma N}^{\text{Pb}} < 40 \text{ GeV}$: rapidly rising
- $40 < W_{\gamma N}^{\text{Pb}} < 800 \text{ GeV}$: nearly flat with a much slower rising

Probing gluon fluctuations with **incoherent** J/ψ

CMS, PRL 135 (2025) 112301

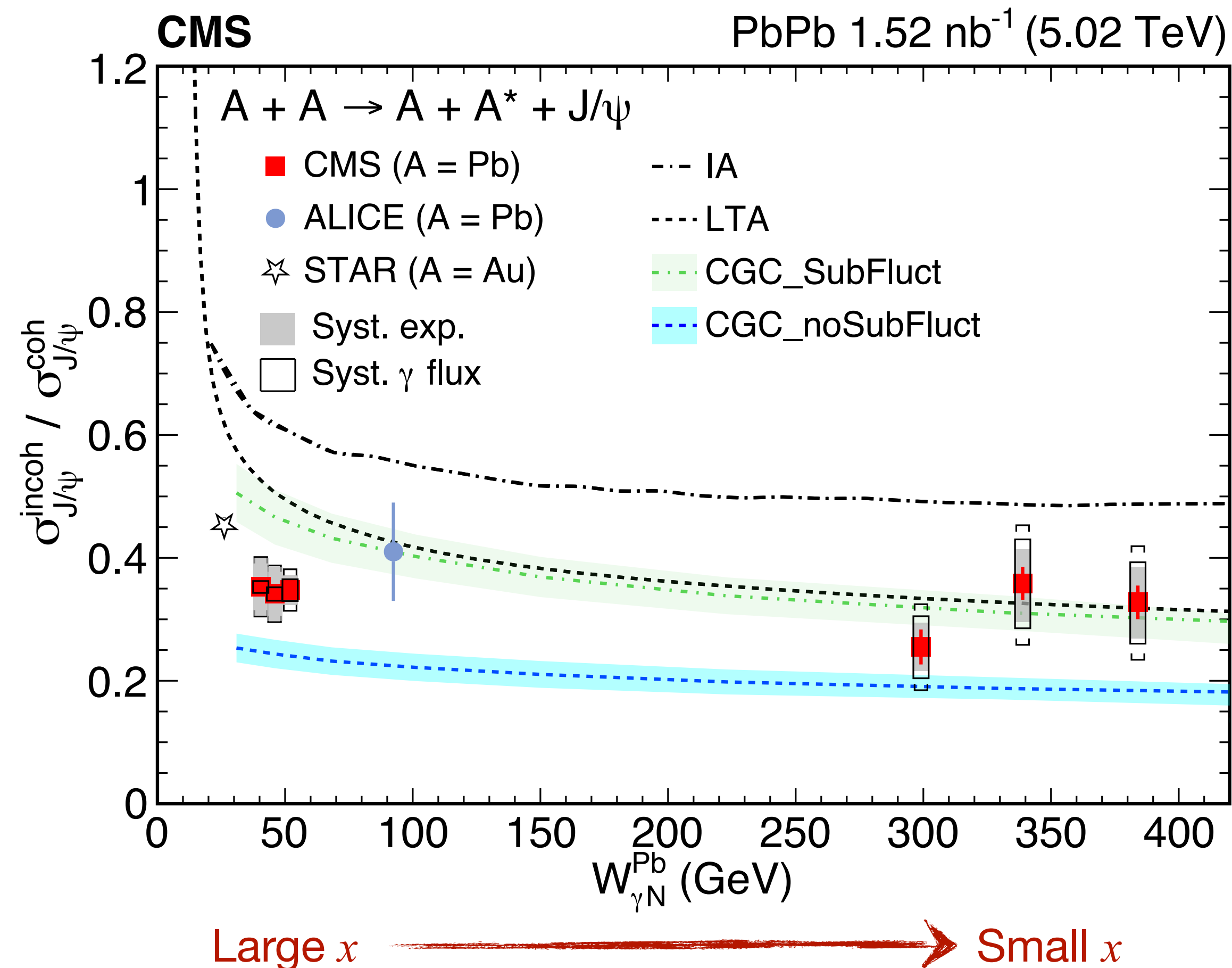


- First measurement of incoherent J/ψ as a function of energy
- Strong suppression compared to impulse approximation model
- LTA describe the data with $W_{\gamma N}^{\text{Pb}} < 60$ GeV, while CGC without gluon fluctuations is consistent with data with $W_{\gamma N}^{\text{Pb}} > 90$ GeV

Comparisons of coherent and incoherent J/ψ

CMS, PRL 135 (2025) 112301

CMS, PRL 131 (2023) 262301



- Experimental and theoretical uncertainties are largely cancelled
- Incoherent J/ψ is more suppressed compared to coherent J/ψ
- Data are consistent CGC incorporating gluon fluctuations
 - Overestimates data at low energy

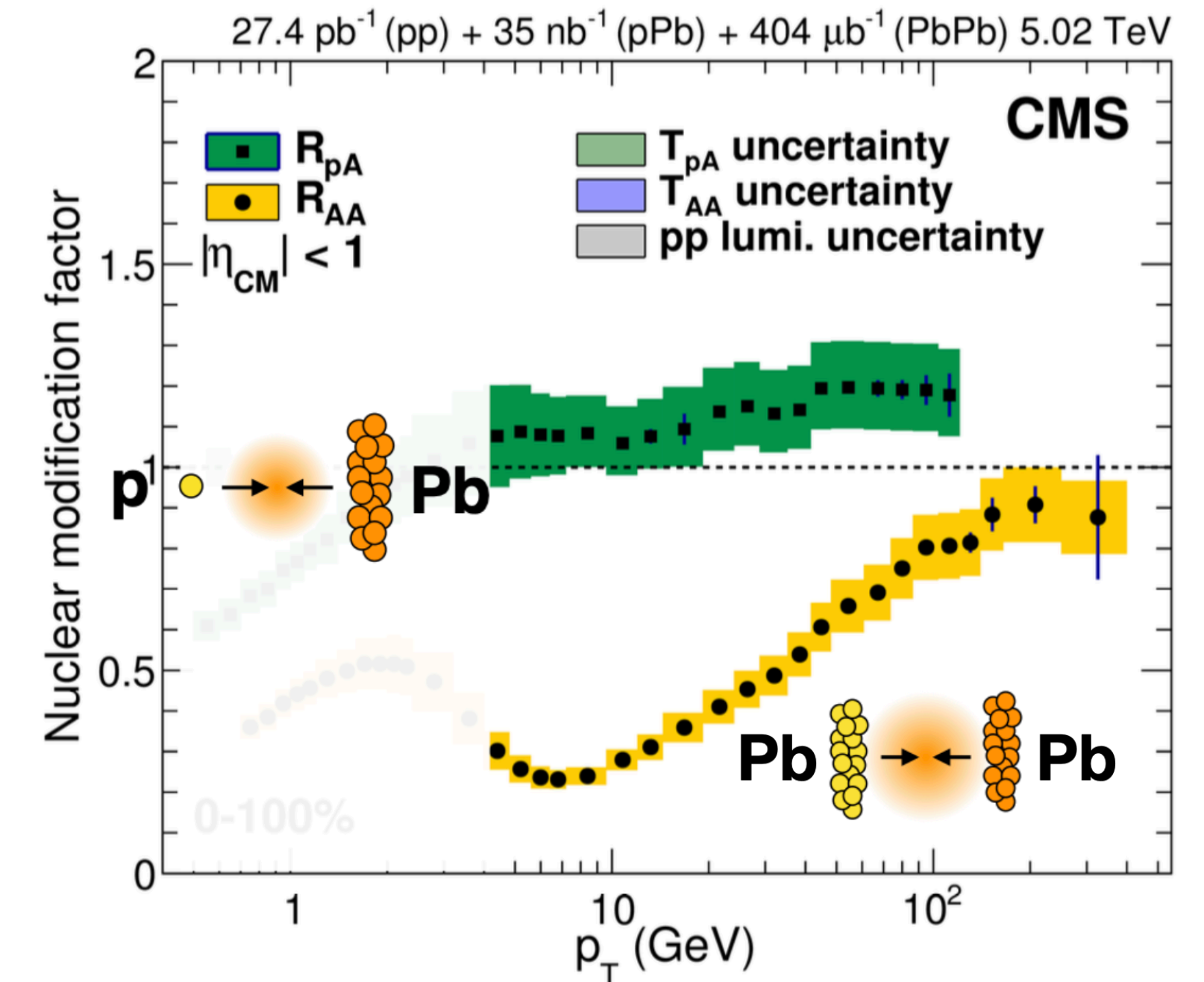
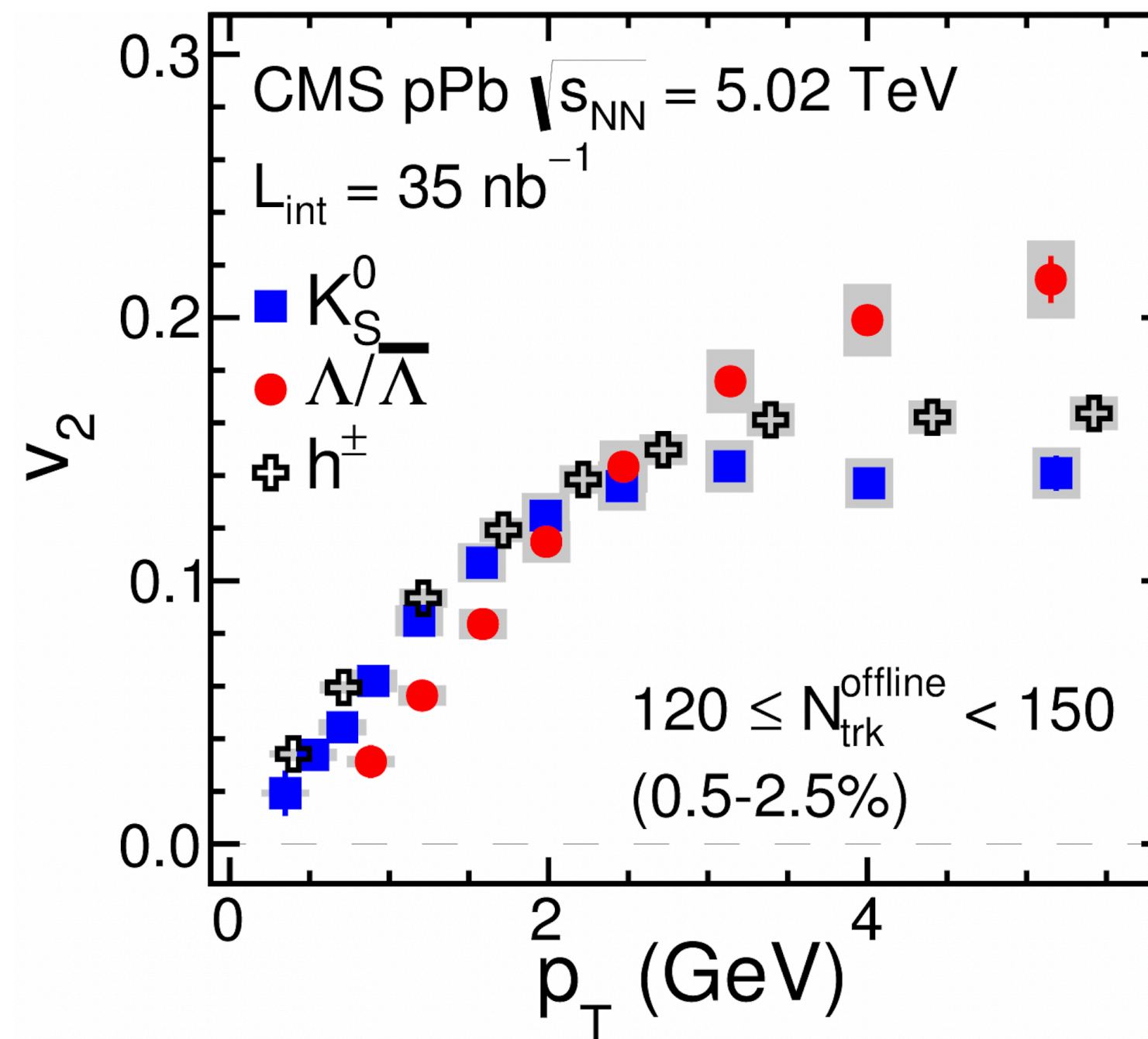
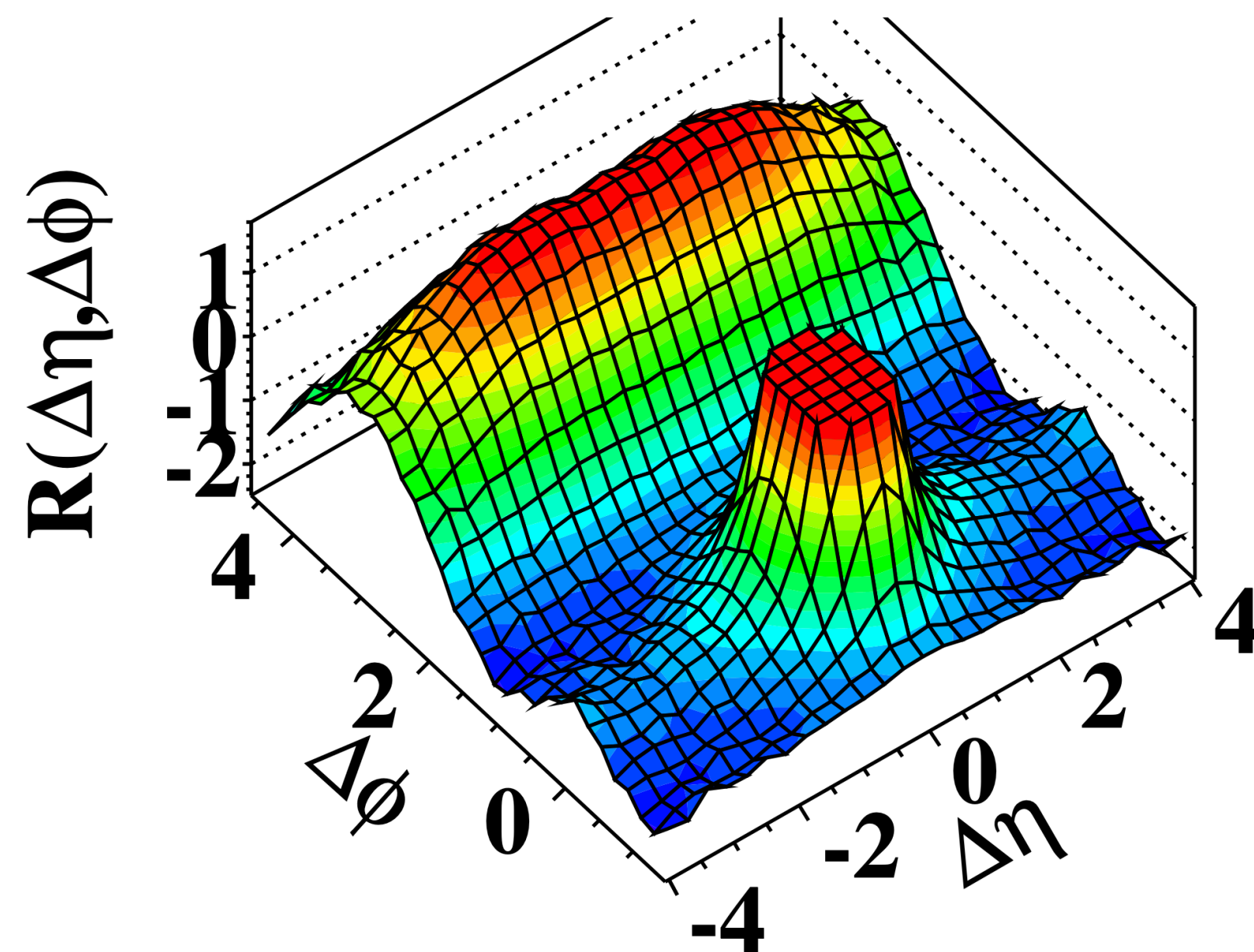
The “puzzle” of small systems

• Collective motion evidence in various small systems

• No unambiguous quenching observed in such collisions

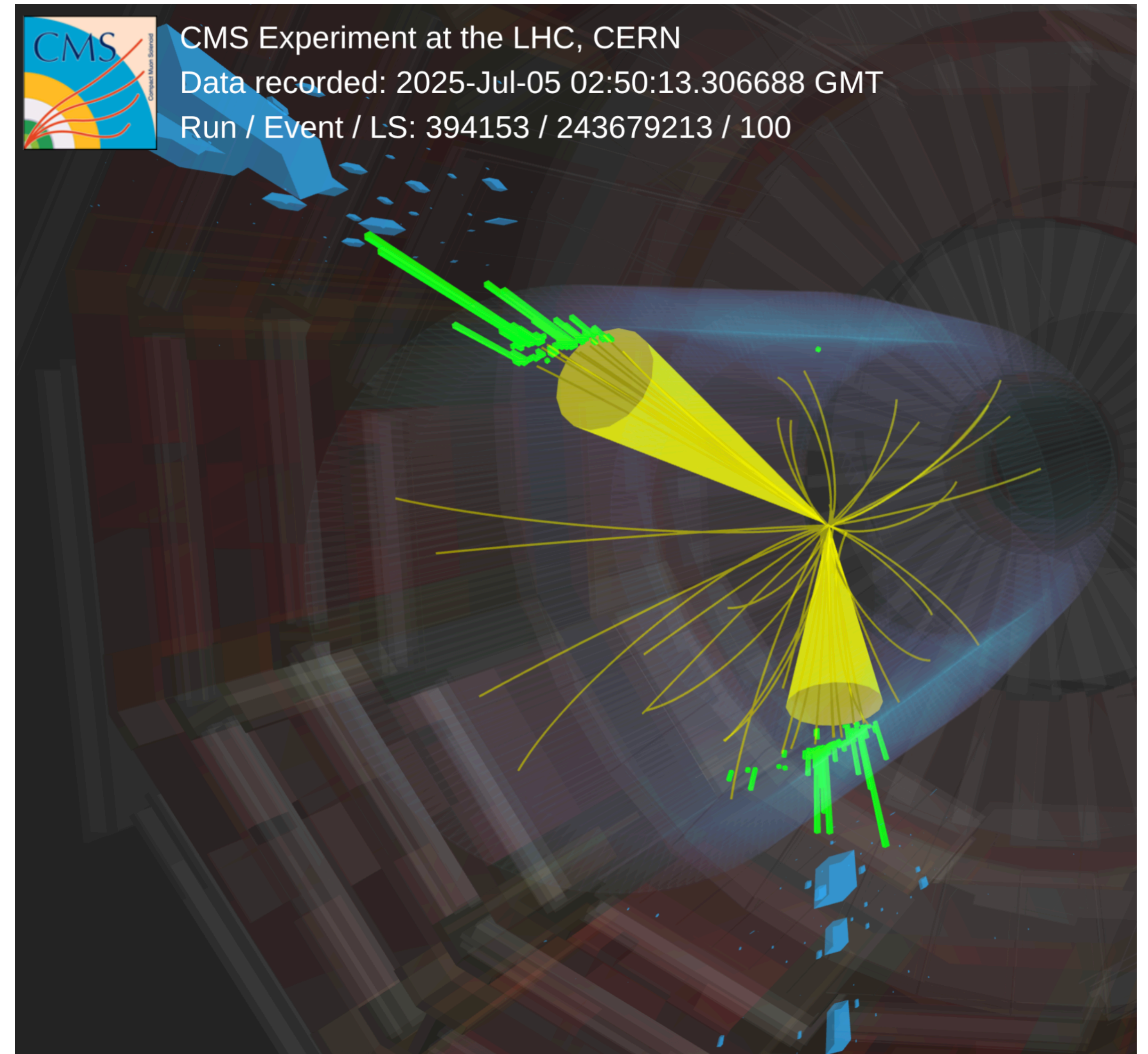
CMS, JHEP 09 (2010) 091
CMS, PLB 742 (2015) 200
CMS, JHEP 04 (2017) 039

(d) CMS $N \geq 110$, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



Light-ion collisions at LHC

- ◉ Light-ion (OO, NeNe) collisions enable to
 - Verify the connection between collective flow and initial geometry in small systems
 - Search for quenching phenomena in small systems



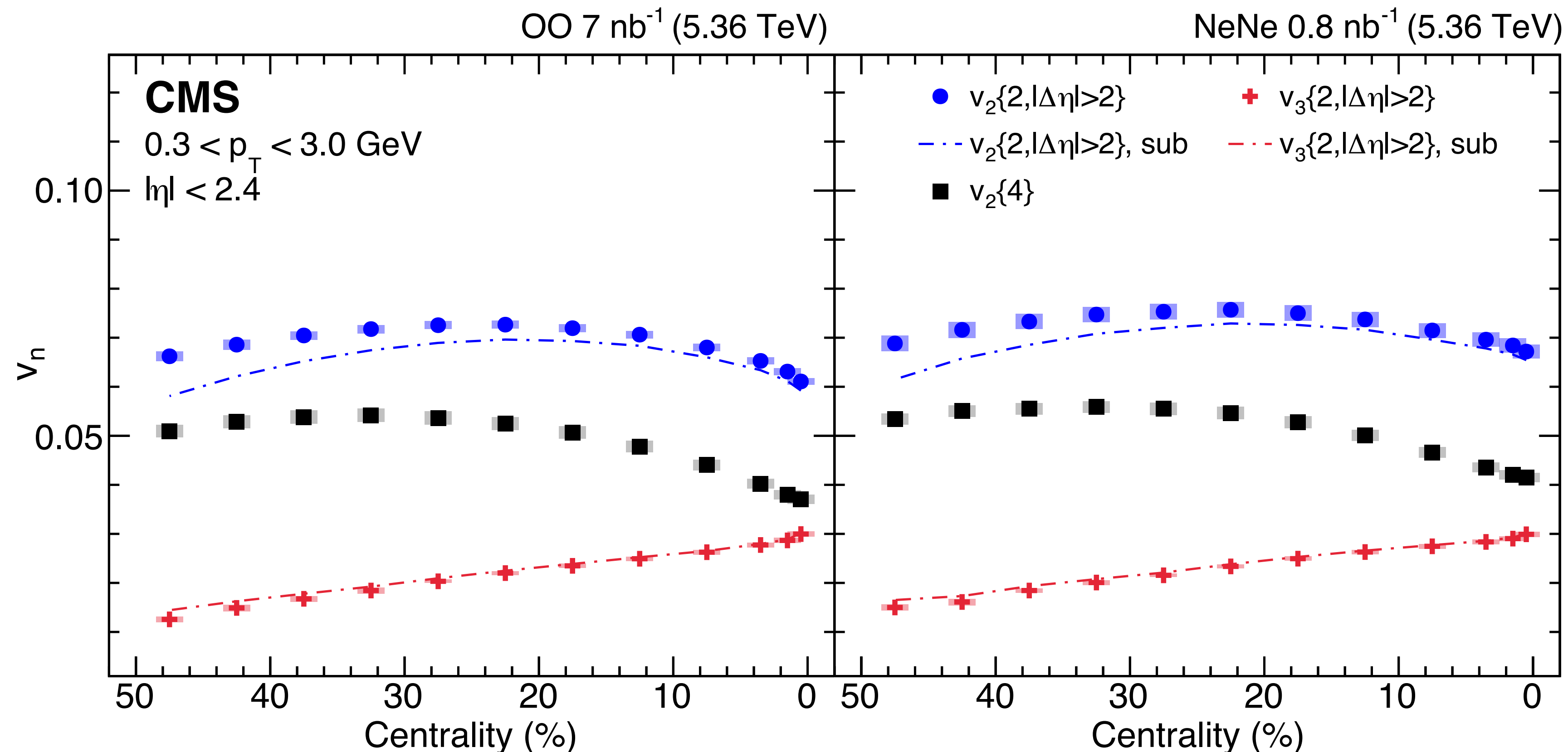
Collective flow in OO and NeNe

• $v_2\{2\}$ and $v_2\{4\}$ follow the similar trend with PbPb collisions

CMS, arXiv:2510.02580

• v_3 increases towards central collisions

See Jiateng Peng (彭佳騰)'s talk on Tuesday



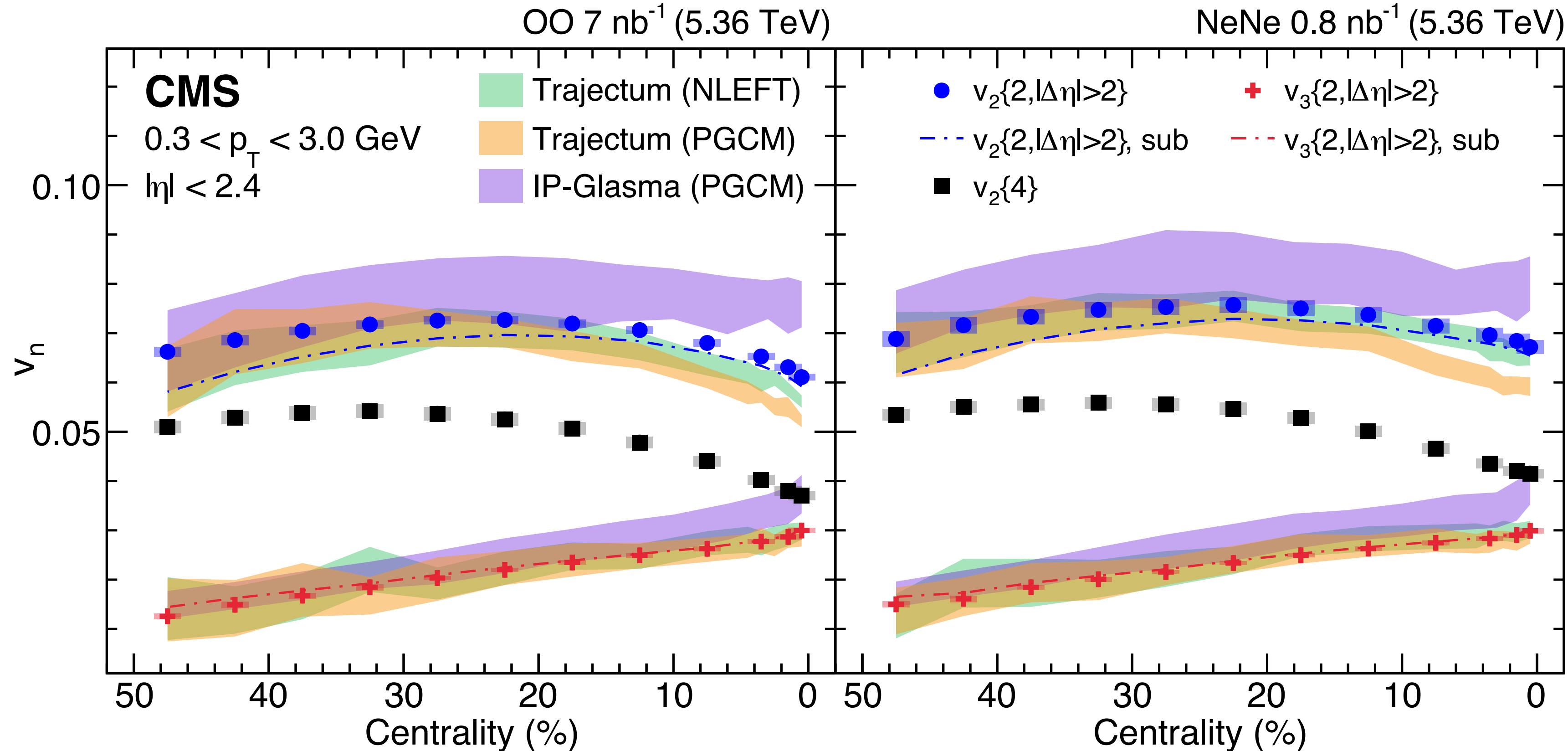
Collective flow in OO and NeNe

CMS, arXiv:2510.02580

G. Giacalone *et al.*, PRL 135 (2025) 012302

H. Mäntysaari *et al.*, PRL 135 (2025) 022302

Hydrodynamic models provide overall good predictions

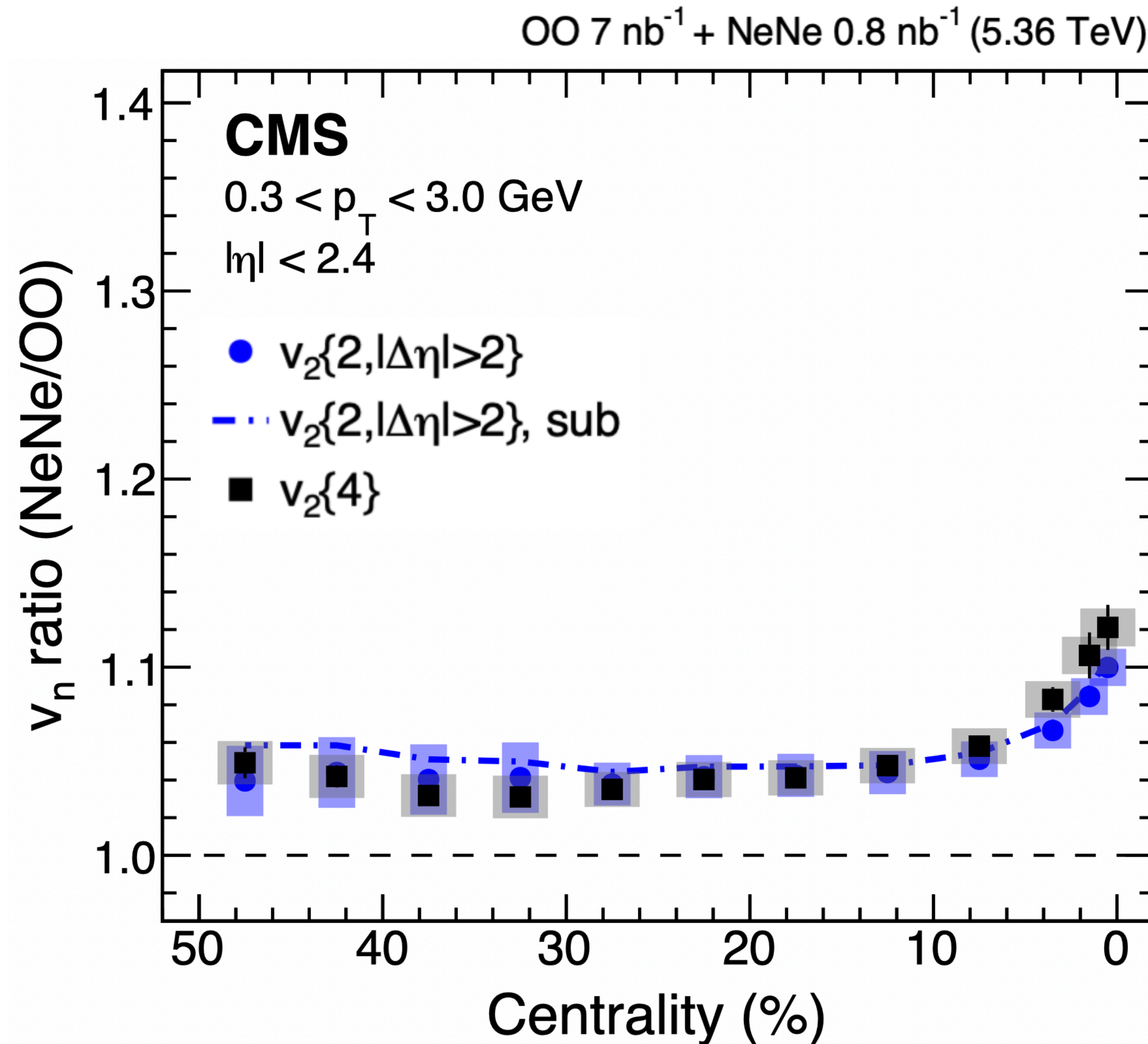


Test initial geometry with v_2 ratio (NeNe/OO)

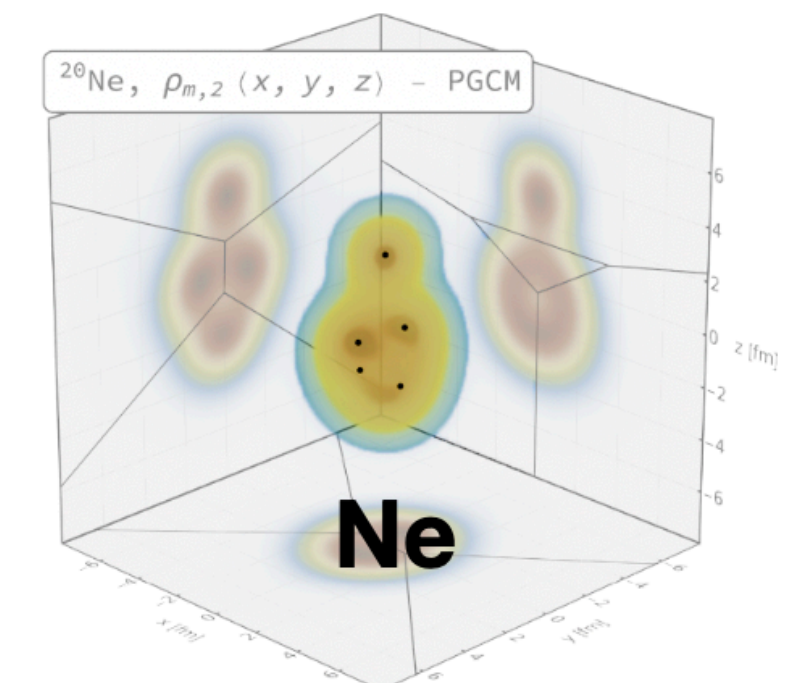
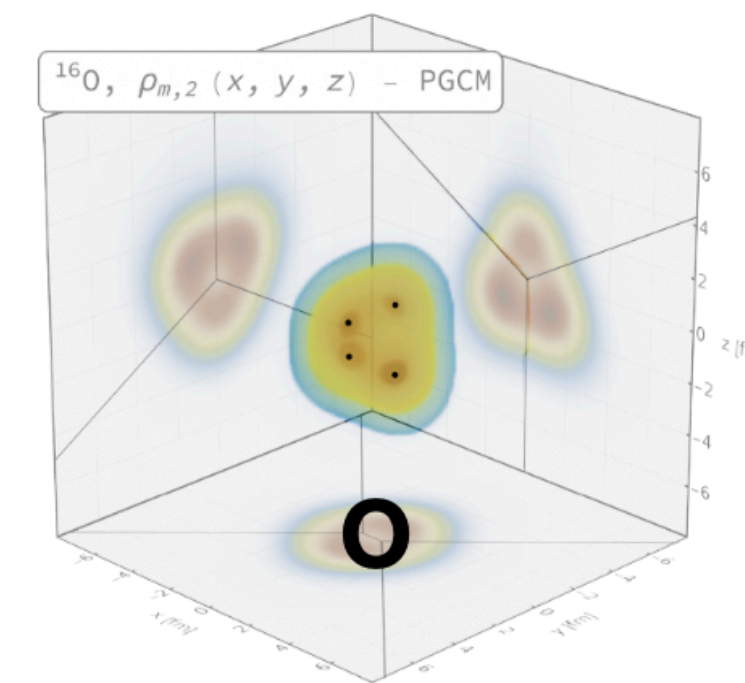
CMS, arXiv:2510.02580

G. Giacalone *et al.*, PRL 135 (2025) 012302

H. Mäntysaari *et al.*, PRL 135 (2025) 022302



- v₂ ratio of NeNe/OO increase towards head-on collisions

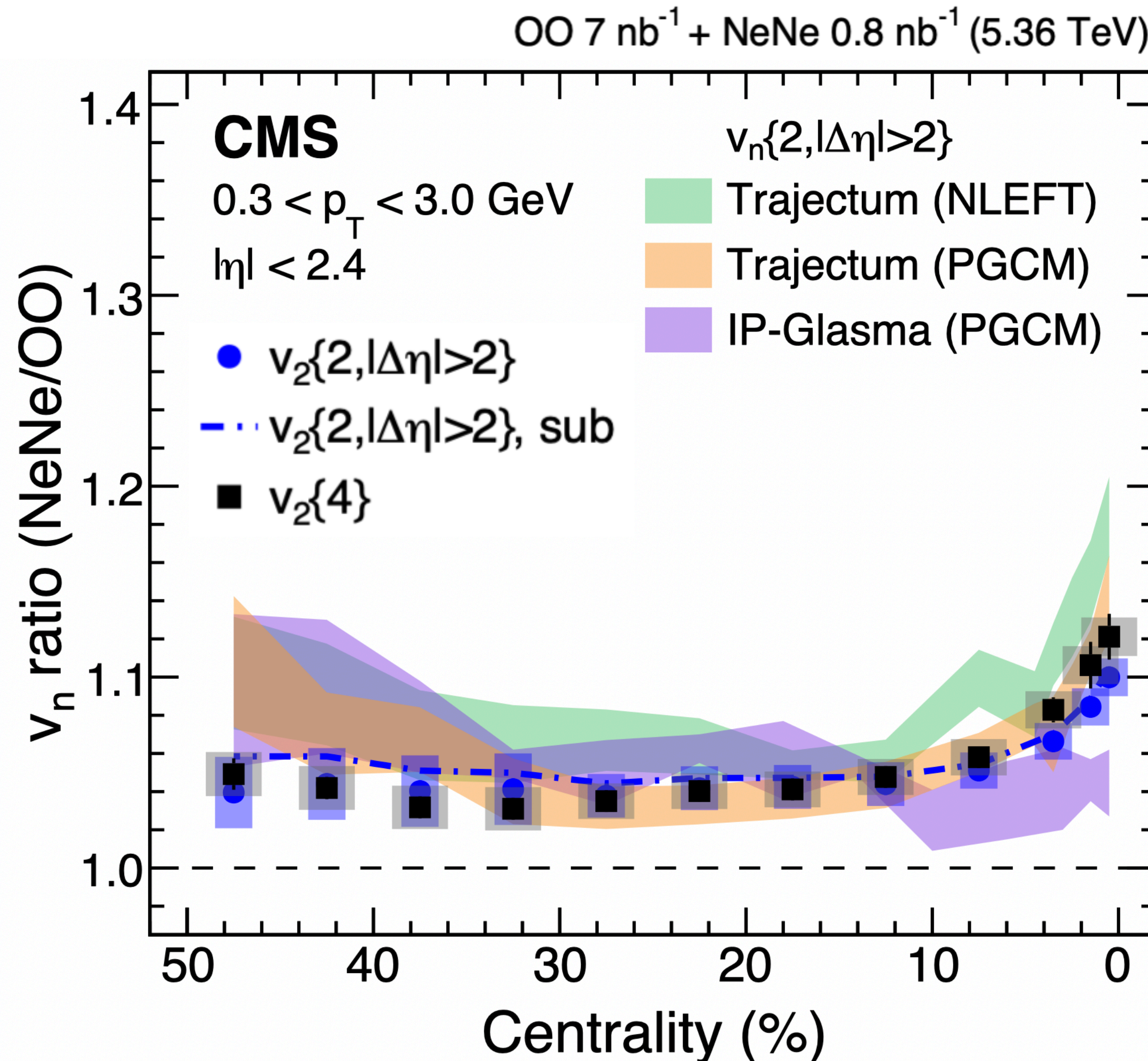


Test initial geometry with v_2 ratio (NeNe/OO)

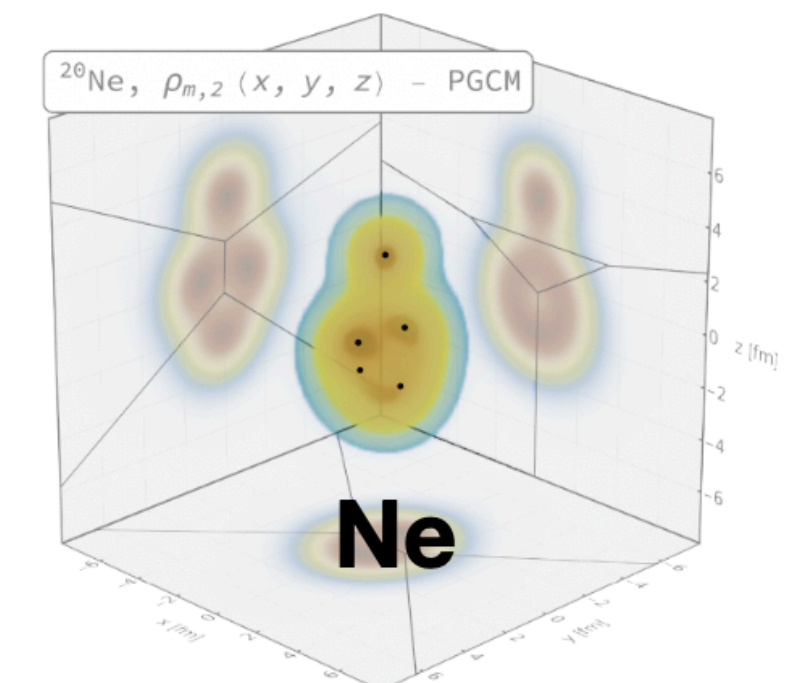
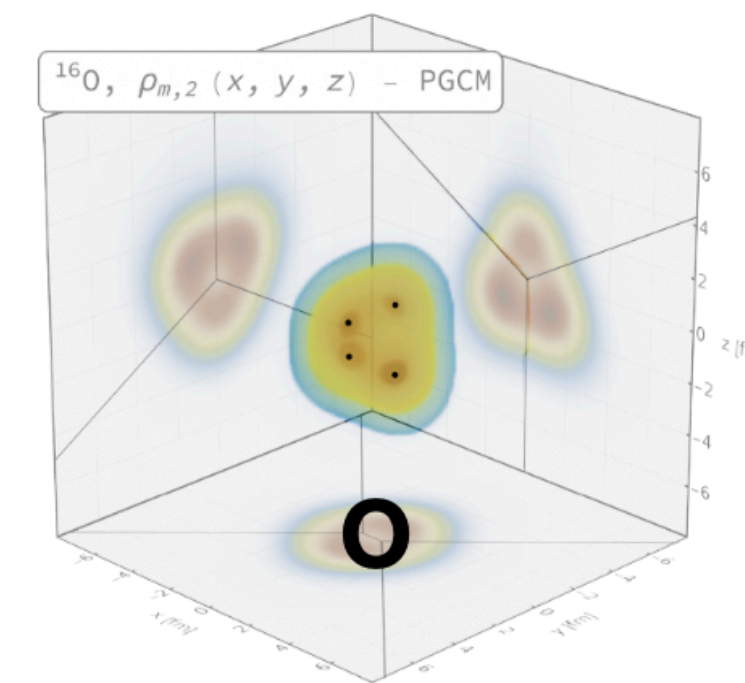
CMS, arXiv:2510.02580

G. Giacalone *et al.*, PRL 135 (2025) 012302

H. Mäntysaari *et al.*, PRL 135 (2025) 022302



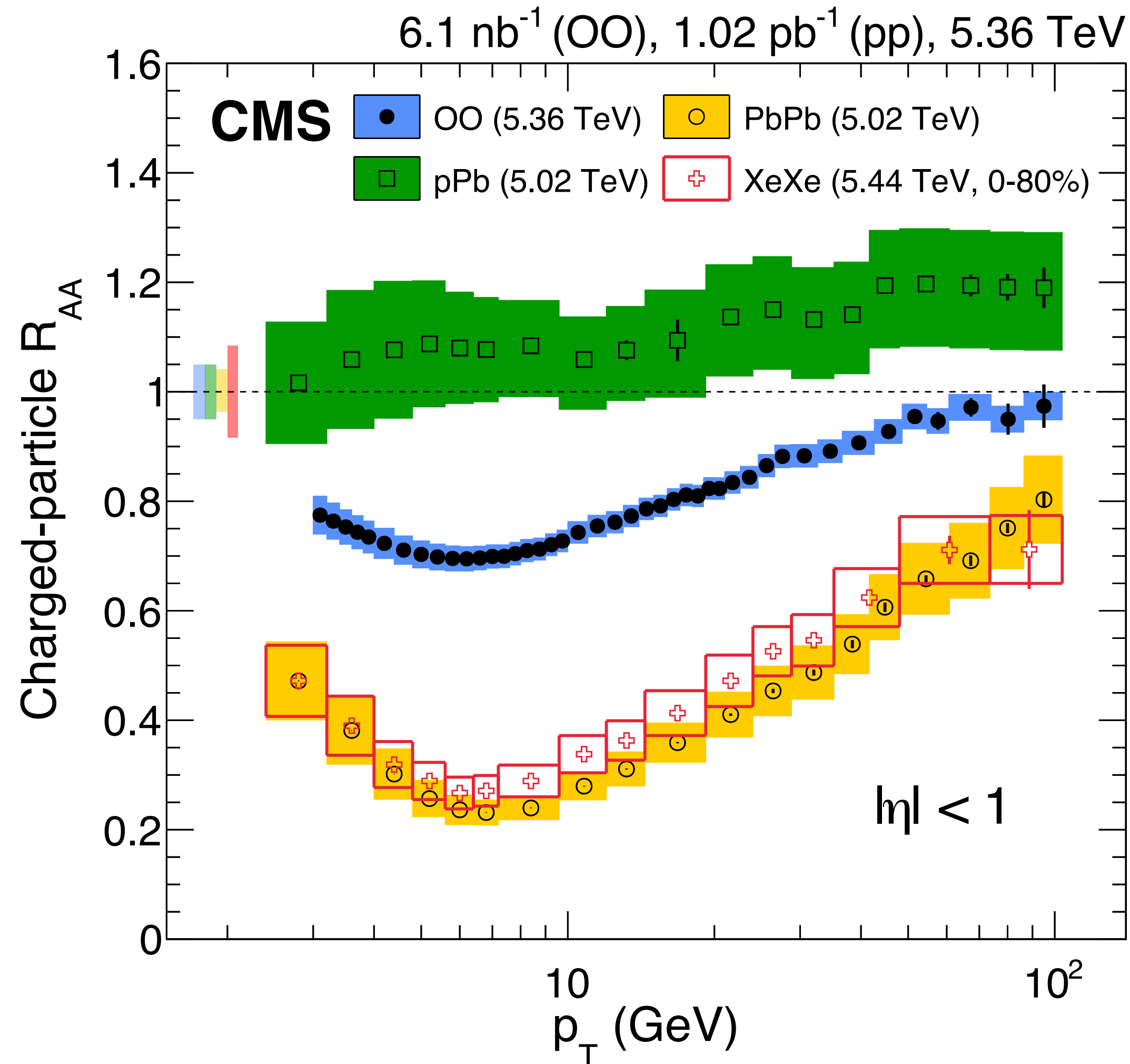
- v_2 ratio of NeNe/OO increase towards head-on collisions



- The increasing trend is predicted by hydro models
 - Theoretical uncertainties from medium are largely canceled

Charged particle R_{AA} in OO

CMS, arXiv:2510.09864

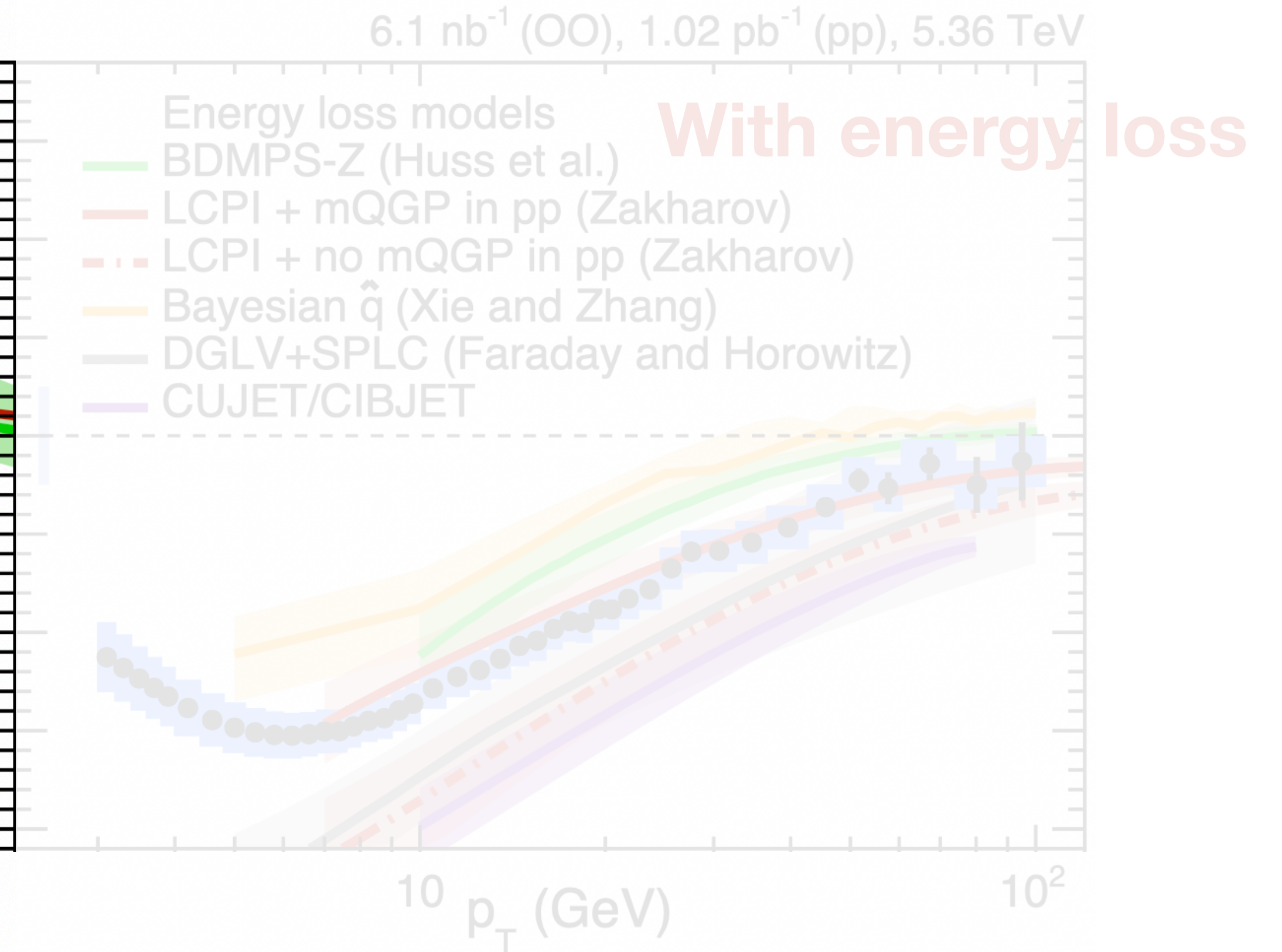
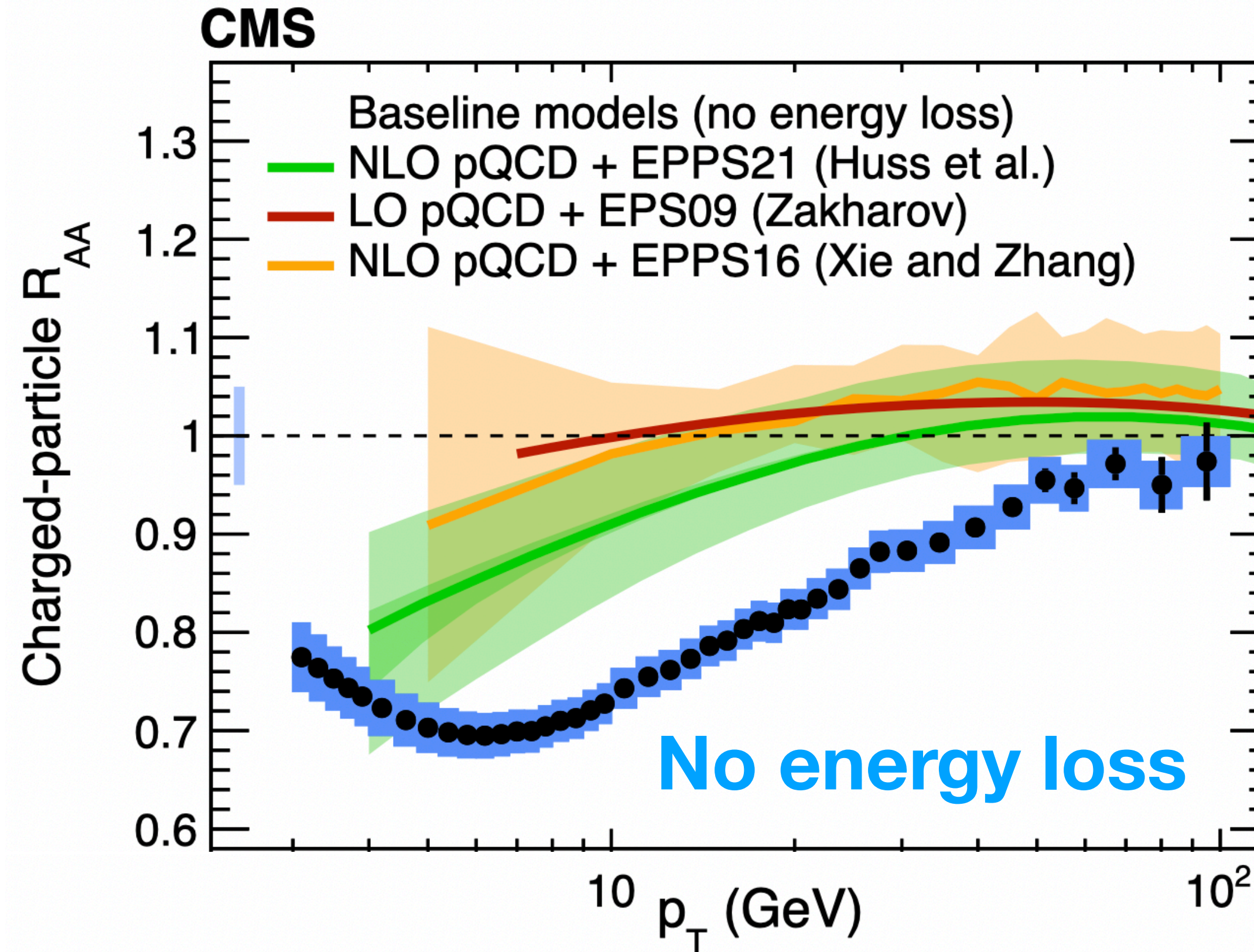


- Inclusive (0-100%) OO events
 - A^2 normalization, no Glauber uncertainty

$$R_{AA} = \frac{1}{A^2} \left(\frac{d\sigma^{AA}}{dp_T} \right) / \left(\frac{d\sigma^{pp}}{dp_T} \right)$$

- Significant suppression observed in OO
 - $R_{AA} = 0.65 \pm 0.04$ at $p_T \sim 6$ GeV
- Similar trend with XeXe and PbPb
 - Similar local minimum
 - Radial flow bump at lower p_T
 - Rising trend at higher p_T

Charged particle R_{AA} in OO



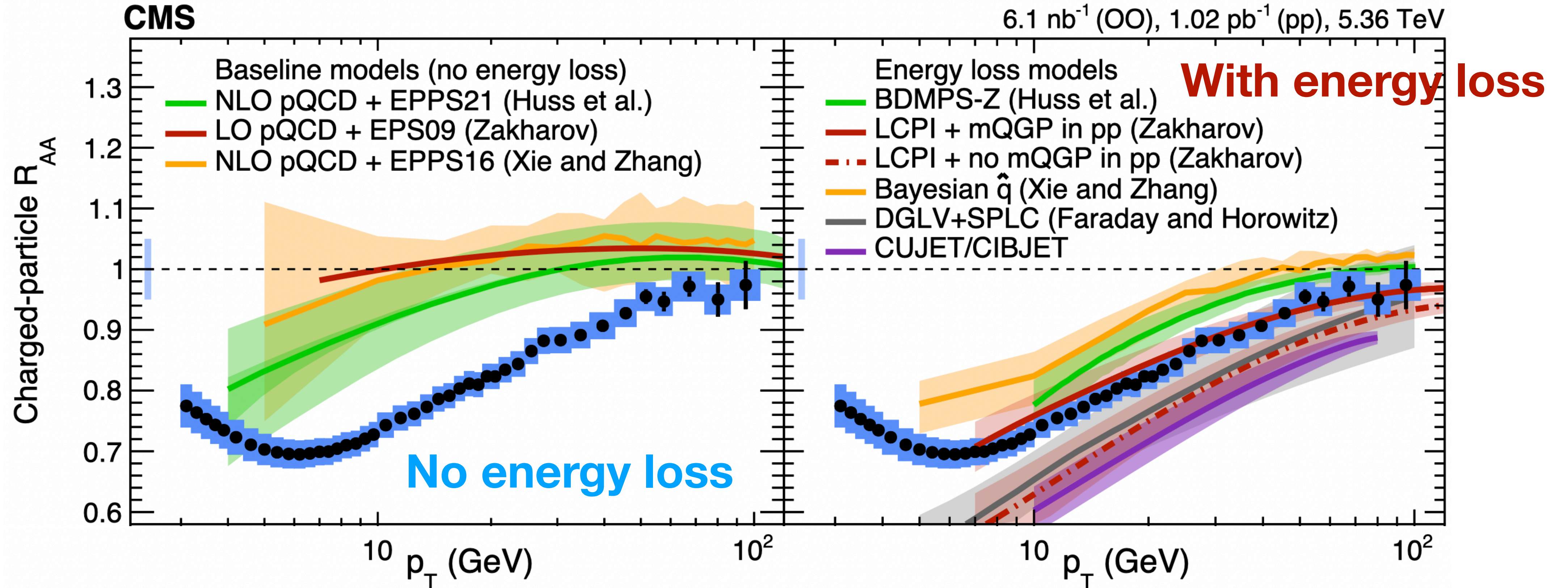
- Only nuclear PDF cannot explain the observed suppression

- Energy loss models describe data better than baselines

A. Huss *et al.*, PRL 126 (2021) 192301, PRC 103 (2021) 054903
 B. Zakharov, JHEP 09 (2021) 087
 M. Xie *et al.*, PRC 108 (2023) L011901

S. Shi *et al.*, CPC 42 (2018) 104104, CPC 43 (2019) 044101
 C. Faraday, W. Horowitz, arXiv:2505.14568

Charged particle R_{AA} in OO



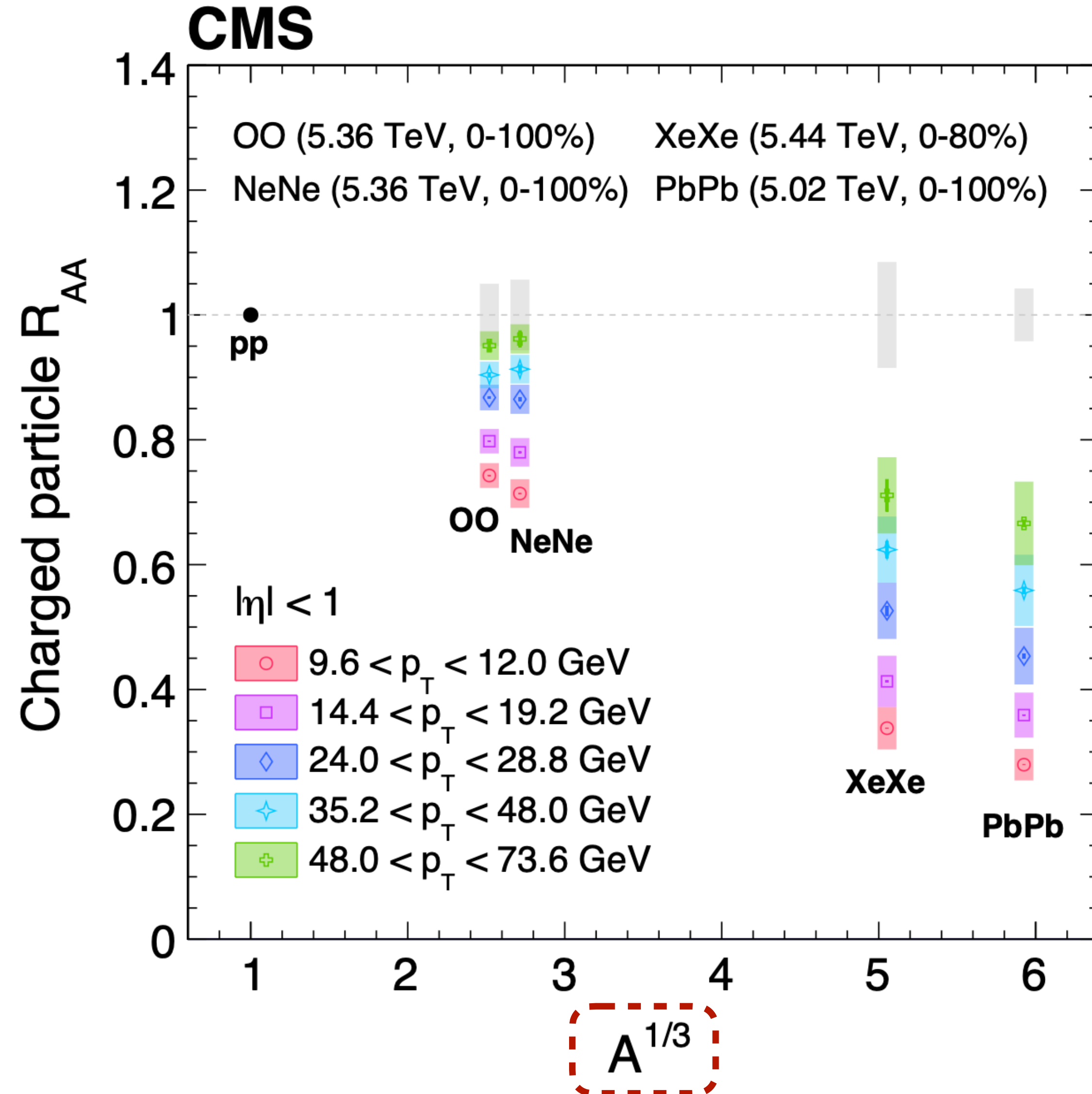
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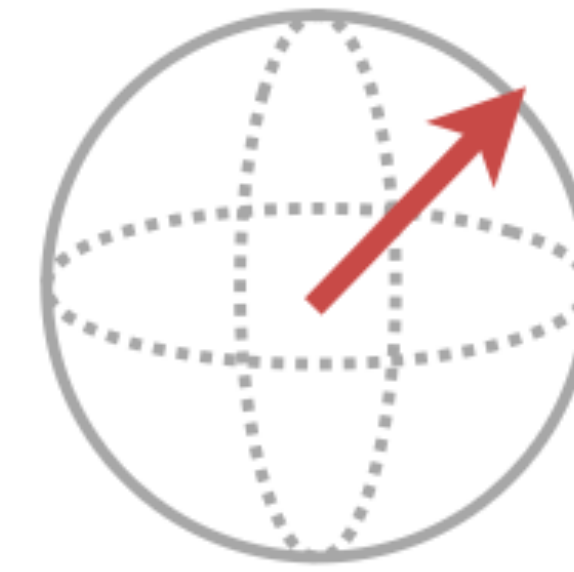
A. Huss *et al.*, PRL 126 (2021) 192301, PRC 103 (2021) 054903
 B. Zakharov, JHEP 09 (2021) 087
 M. Xie *et al.*, PRC 108 (2023) L011901

S. Shi *et al.*, CPC 42 (2018) 104104, CPC 43 (2019) 044101
 C. Faraday, W. Horowitz, arXiv:2505.14568

Path length dependence of quenching



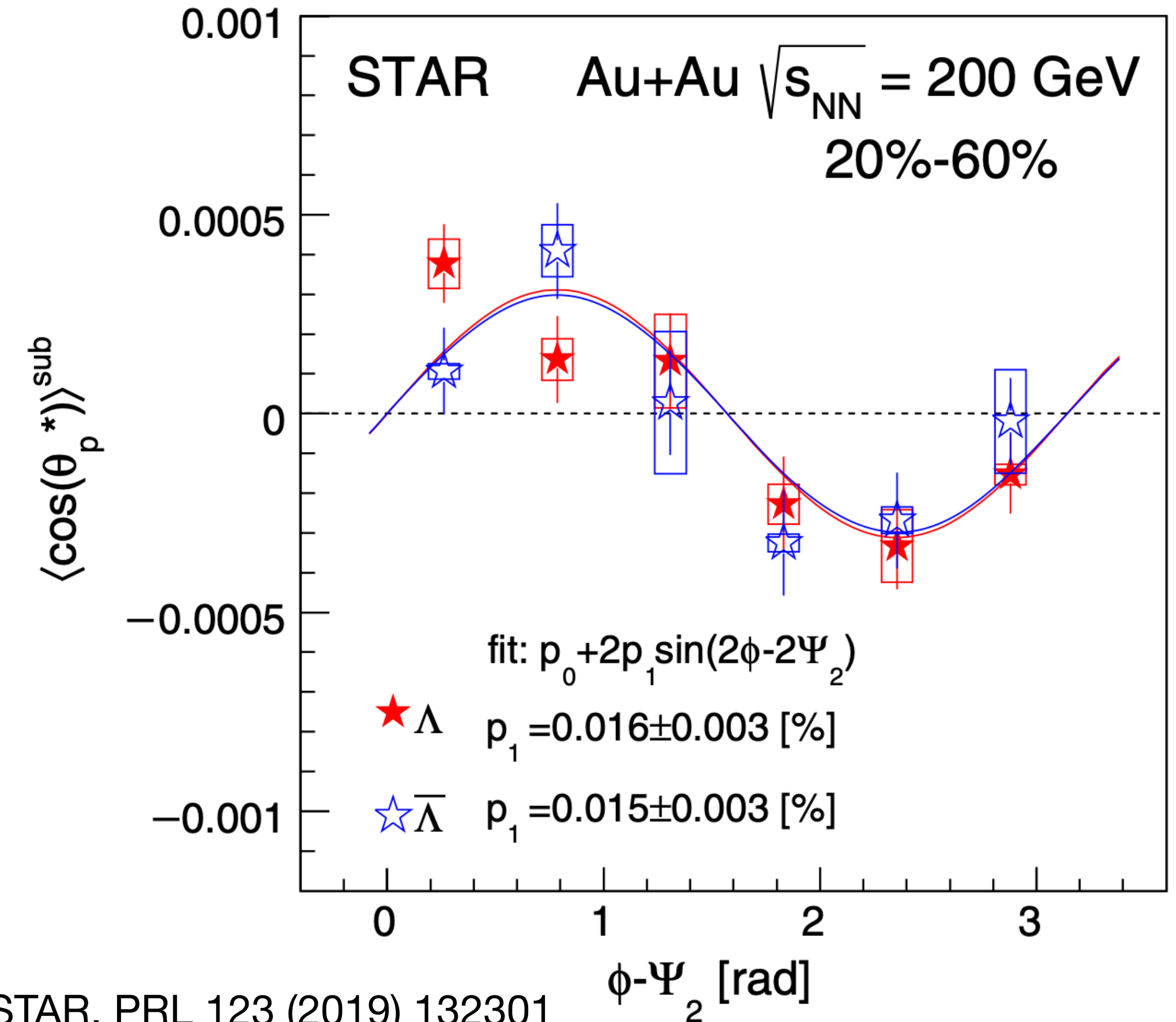
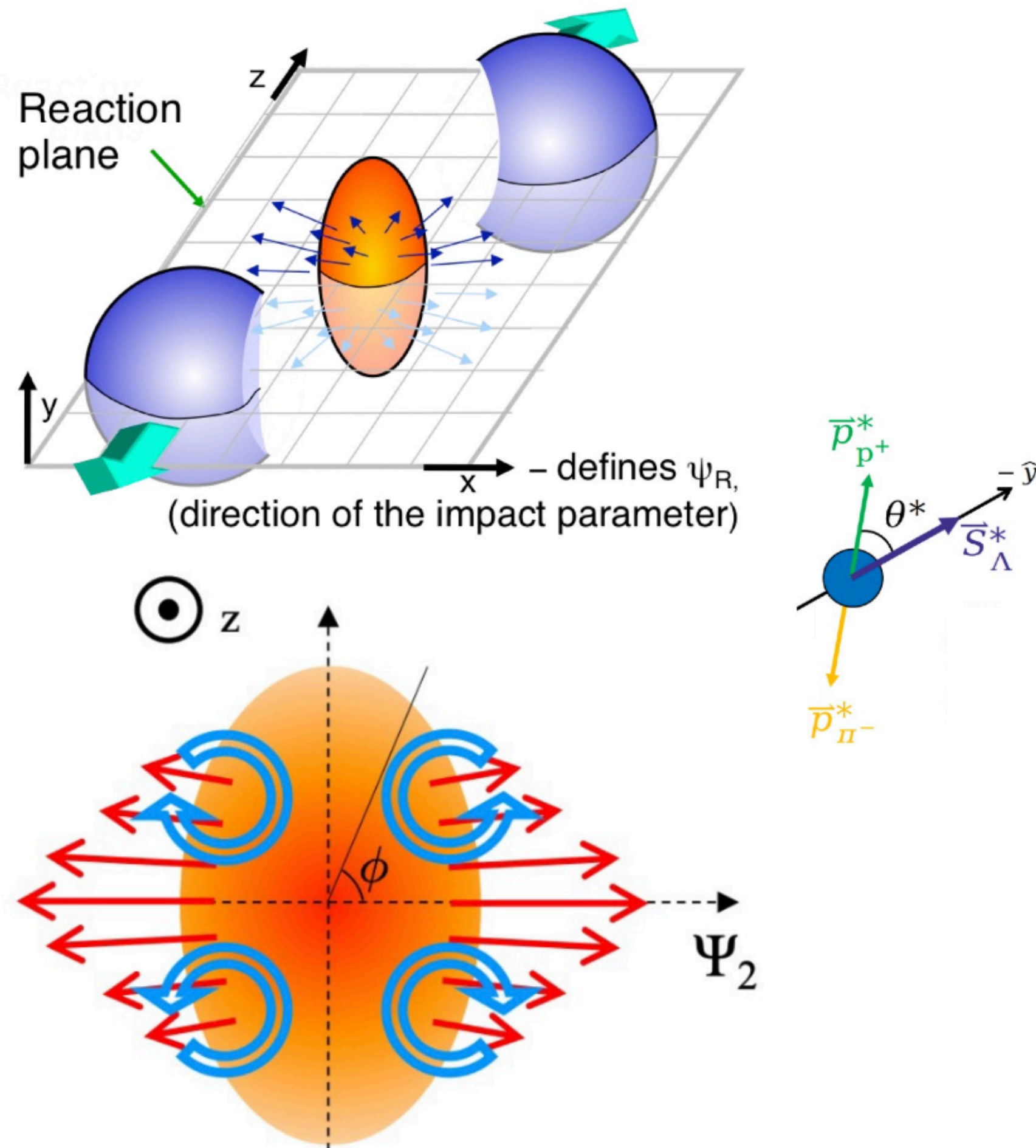
- R_{AA} alignment with $A^{1/3}$ scaling, especially at lower p_T regions.



$A^{1/3} \sim \text{path length}$

- Constrain path-length dependence of models across all system sizes

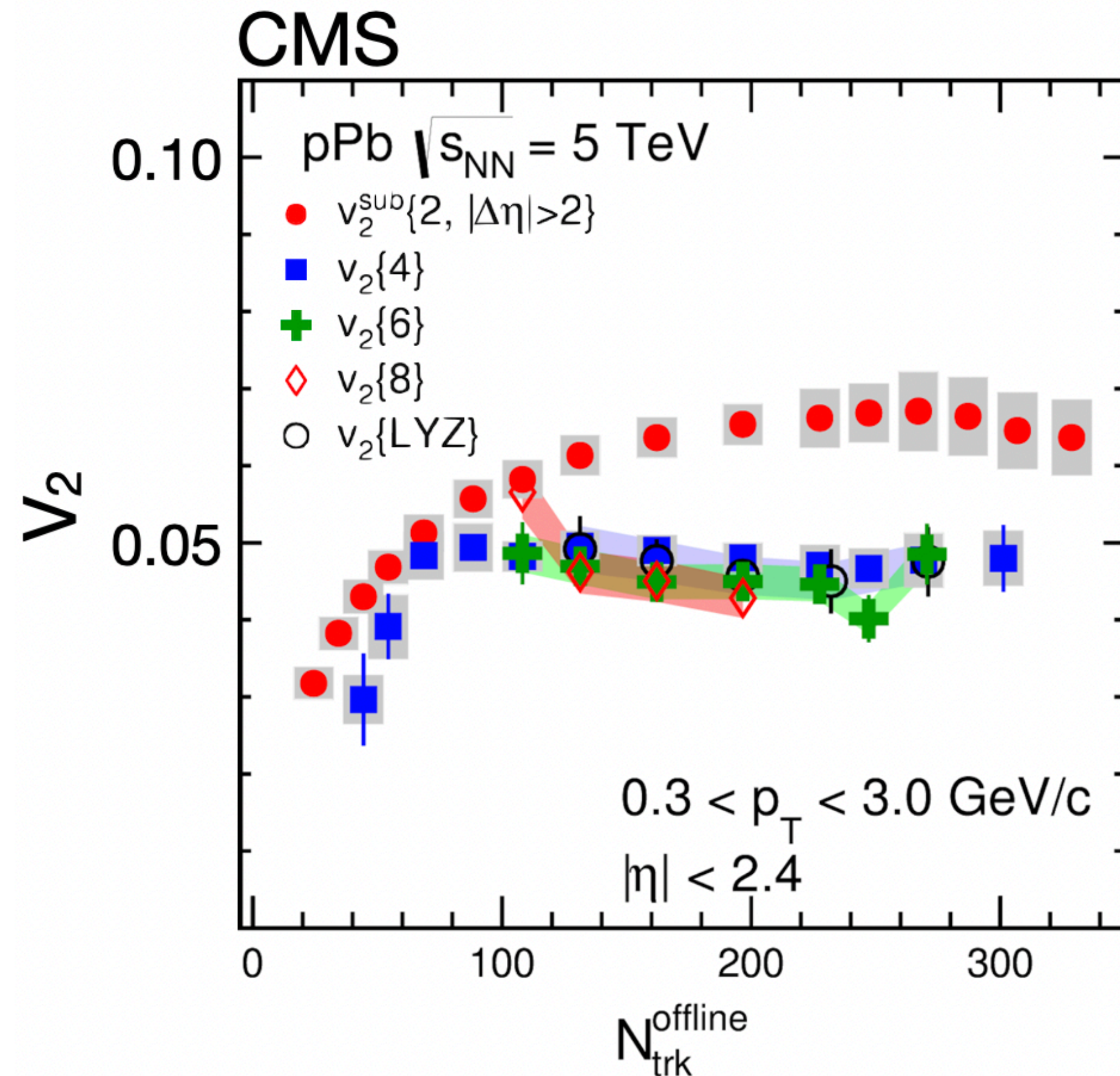
Local polarization of Λ hyperon



- Simple expectation of vorticity from the anisotropic expansion of QGP
- Confirm by experimental measurements

Local polarization of Λ in pPb collisions

CMS, PLB 765 (2017) 193

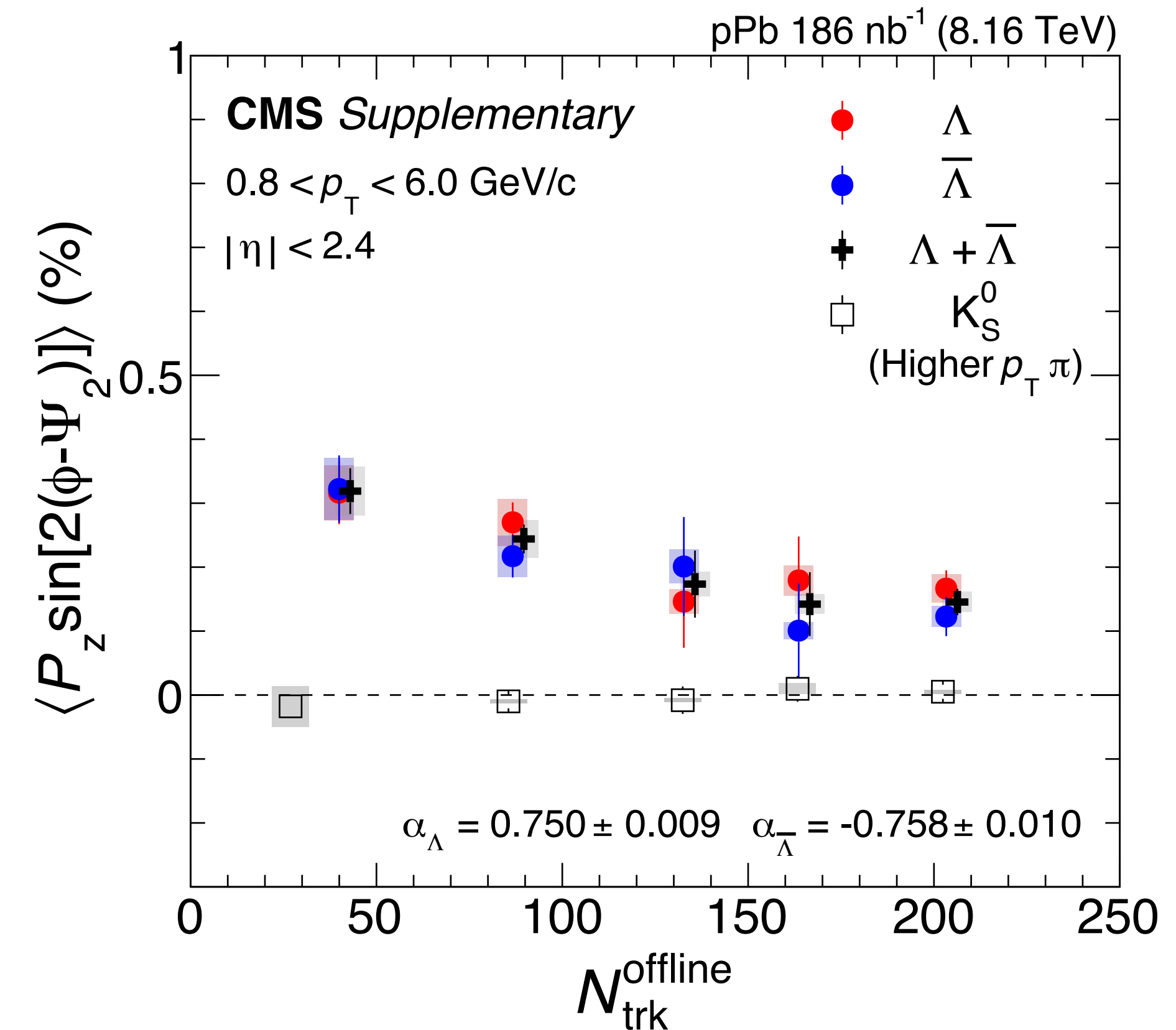
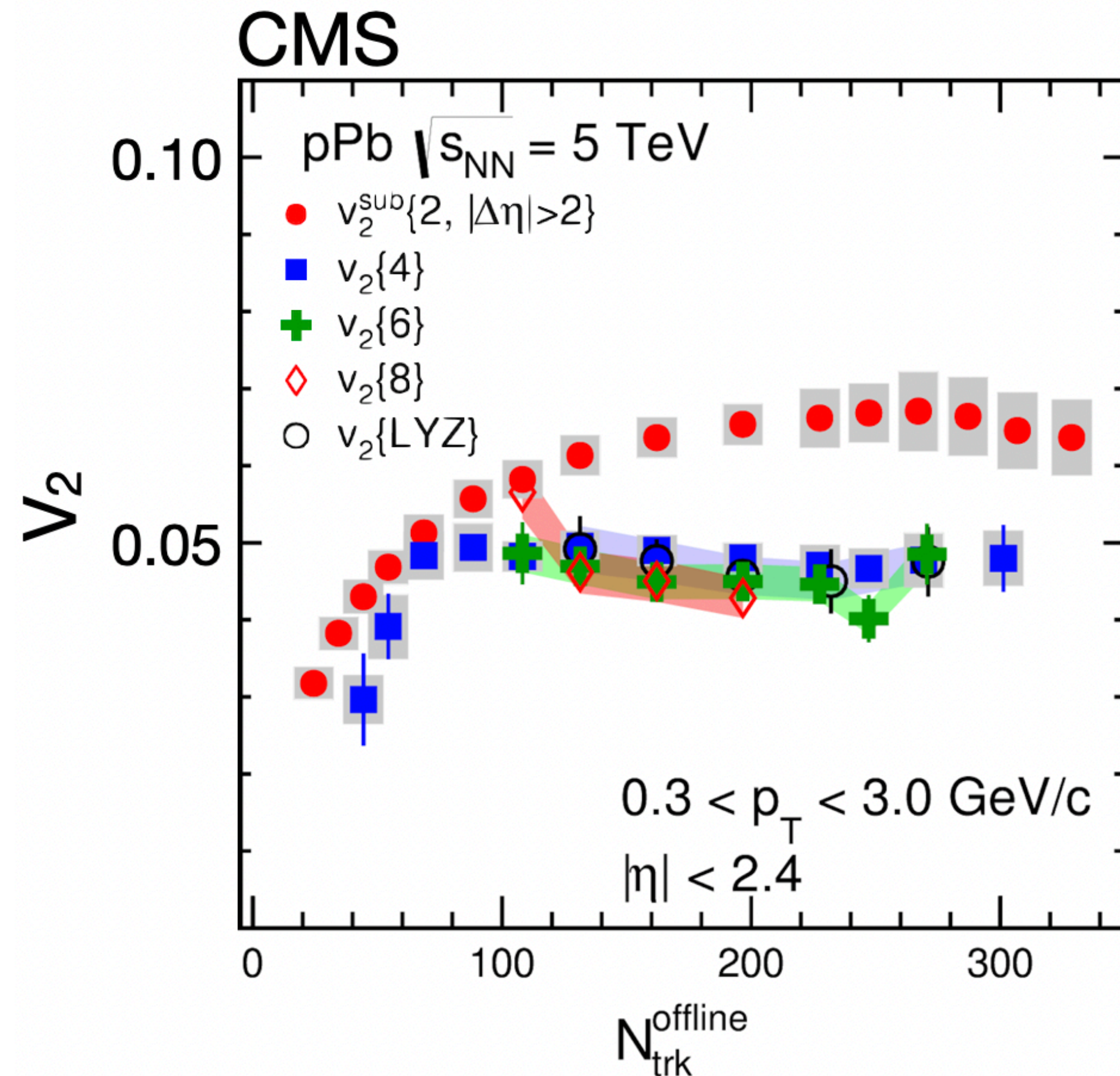


- Clear collectivity observed in pPb
- How about local polarization?

Local polarization of Λ in pPb collisions

CMS, PLB 765 (2017) 193

CMS, PRL 135 (2025) 132301



- Clear collectivity observed in pPb
- How about local polarization?

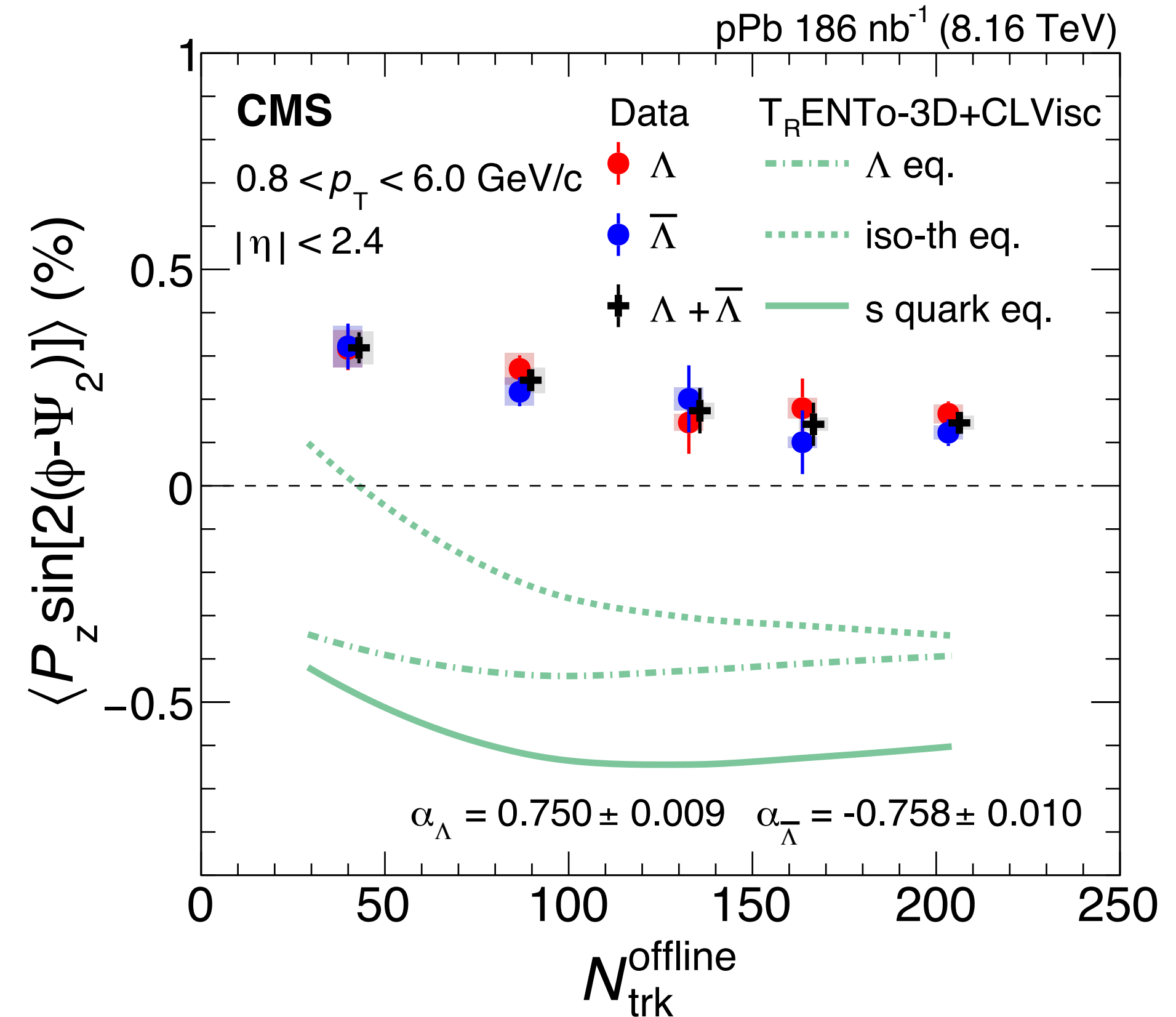
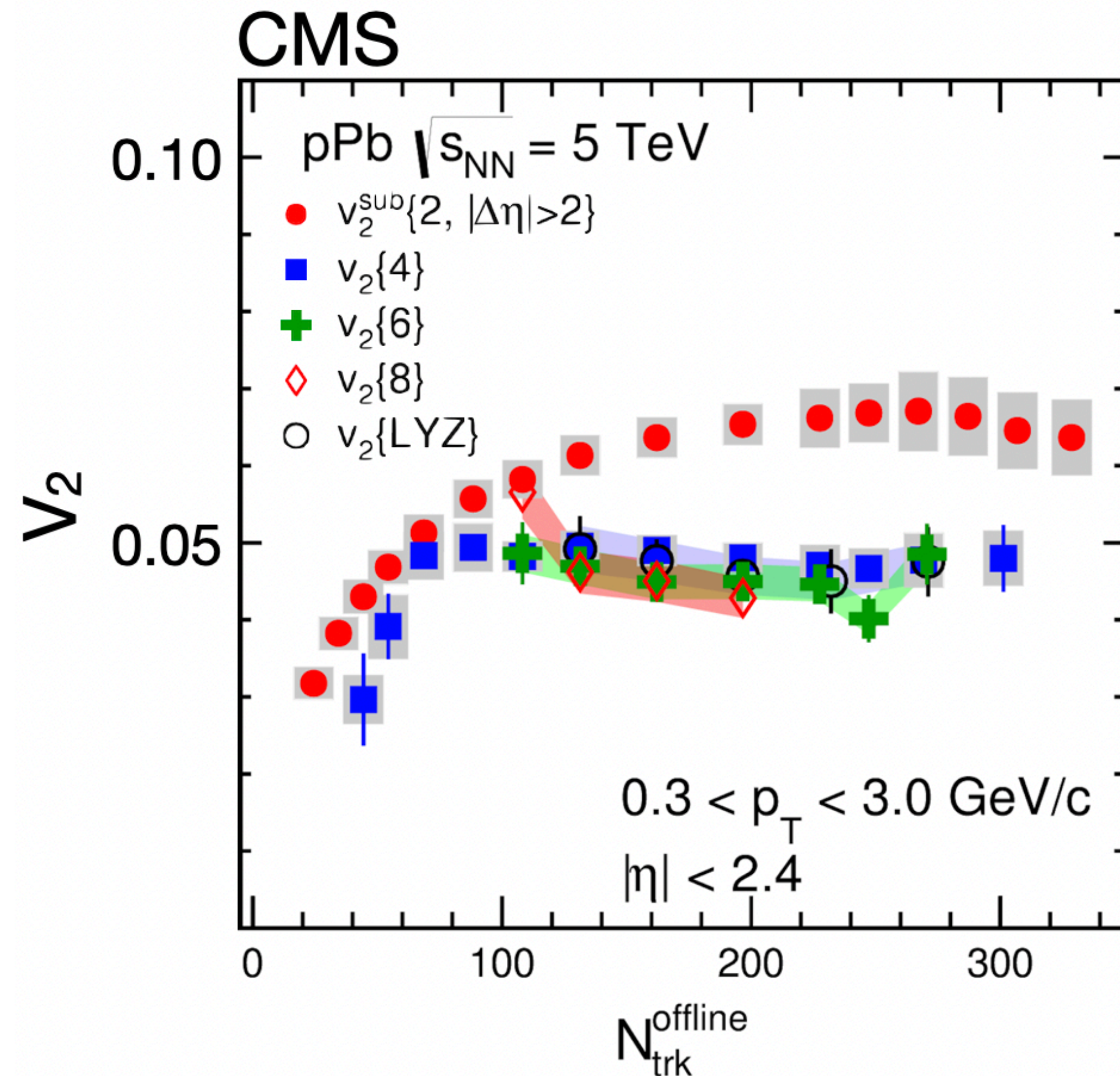
- Significant P_z observed in pPb
- Increase towards low multiplicity range
 - Different trend with v_2

Local polarization of Λ in pPb collisions

CMS, PLB 765 (2017) 193

C. Yi et al., PRC 111 (2025) 044901

CMS, PRL 135 (2025) 132301



- Clear collectivity observed in pPb
- How about local polarization?

- Hydro calculations result in negative P_z
- Challenge current theoretical framework

Summary

- Multidimensional imaging of nuclei with photon-nuclear interactions in UPCs with CMS
- Unambiguously observed collective and quenching phenomena in OO and NeNe collisions
- Observed local polarization Λ hyperon in pPb collisions

Summary

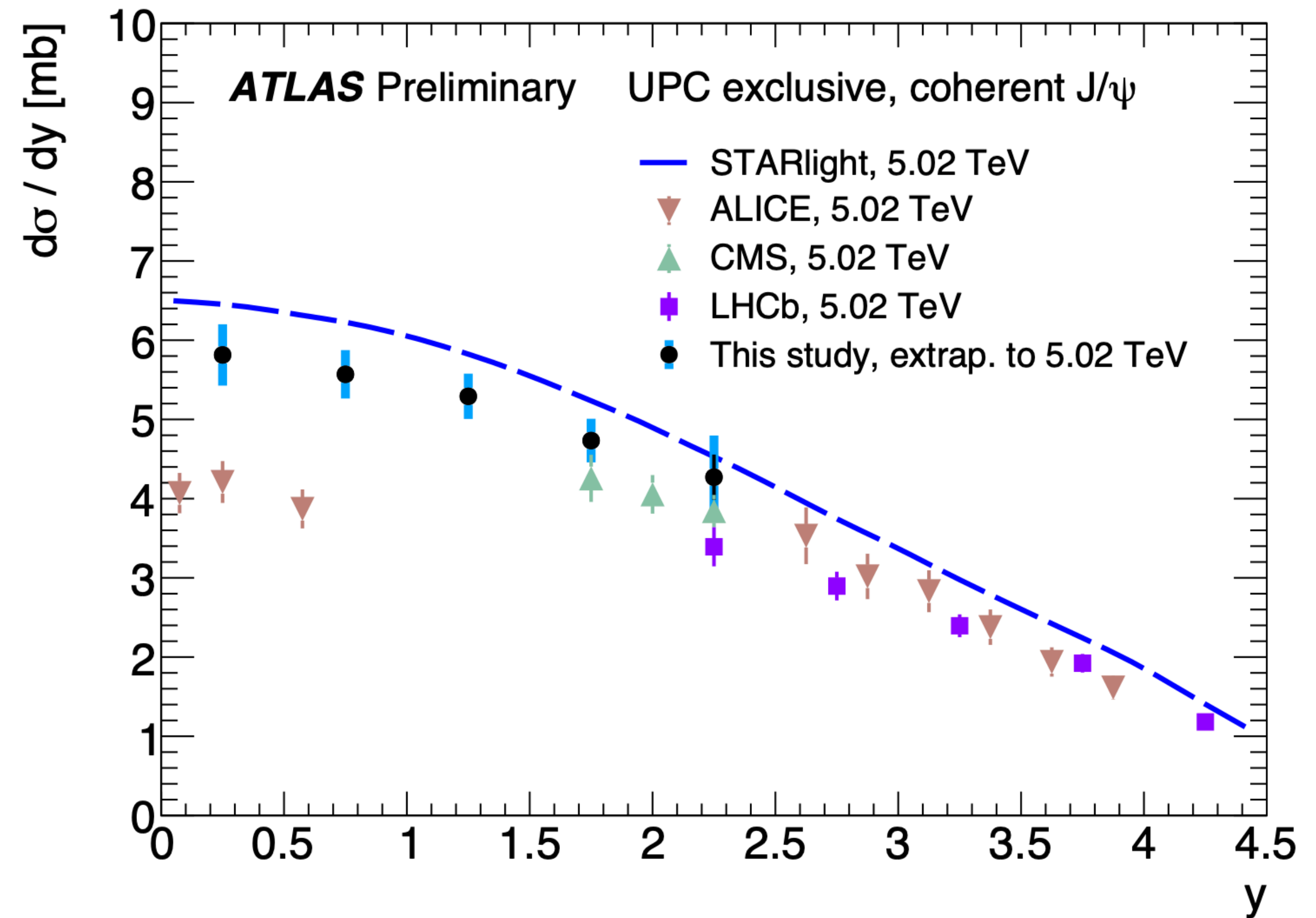
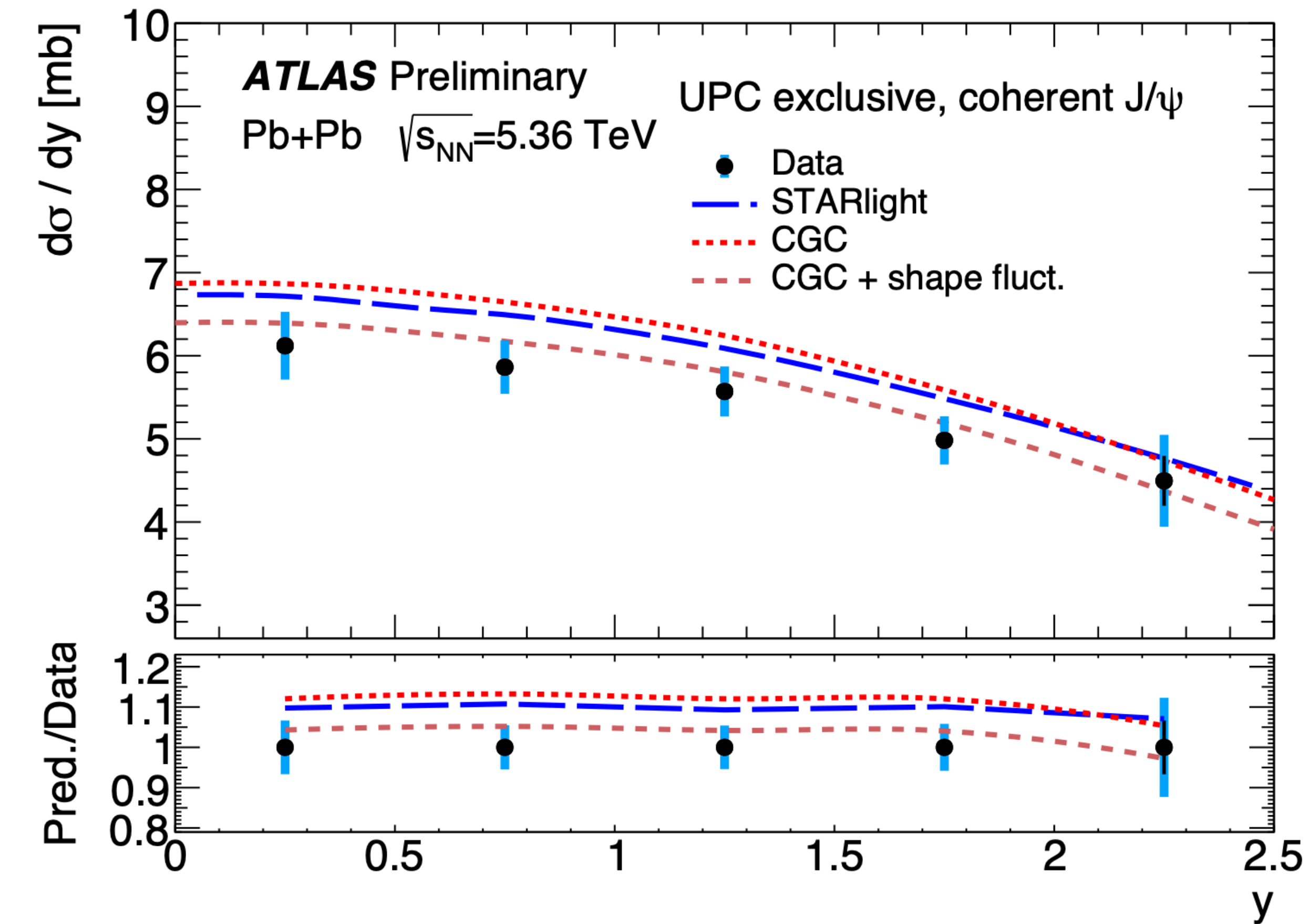
- Multidimensional imaging of nuclei with photon-nuclear interactions in UPCs with CMS
- Unambiguously observed collective and quenching phenomena in OO and NeNe collisions
- Observed local polarization Λ hyperon in pPb collisions

Thank you for your attention!

Backups

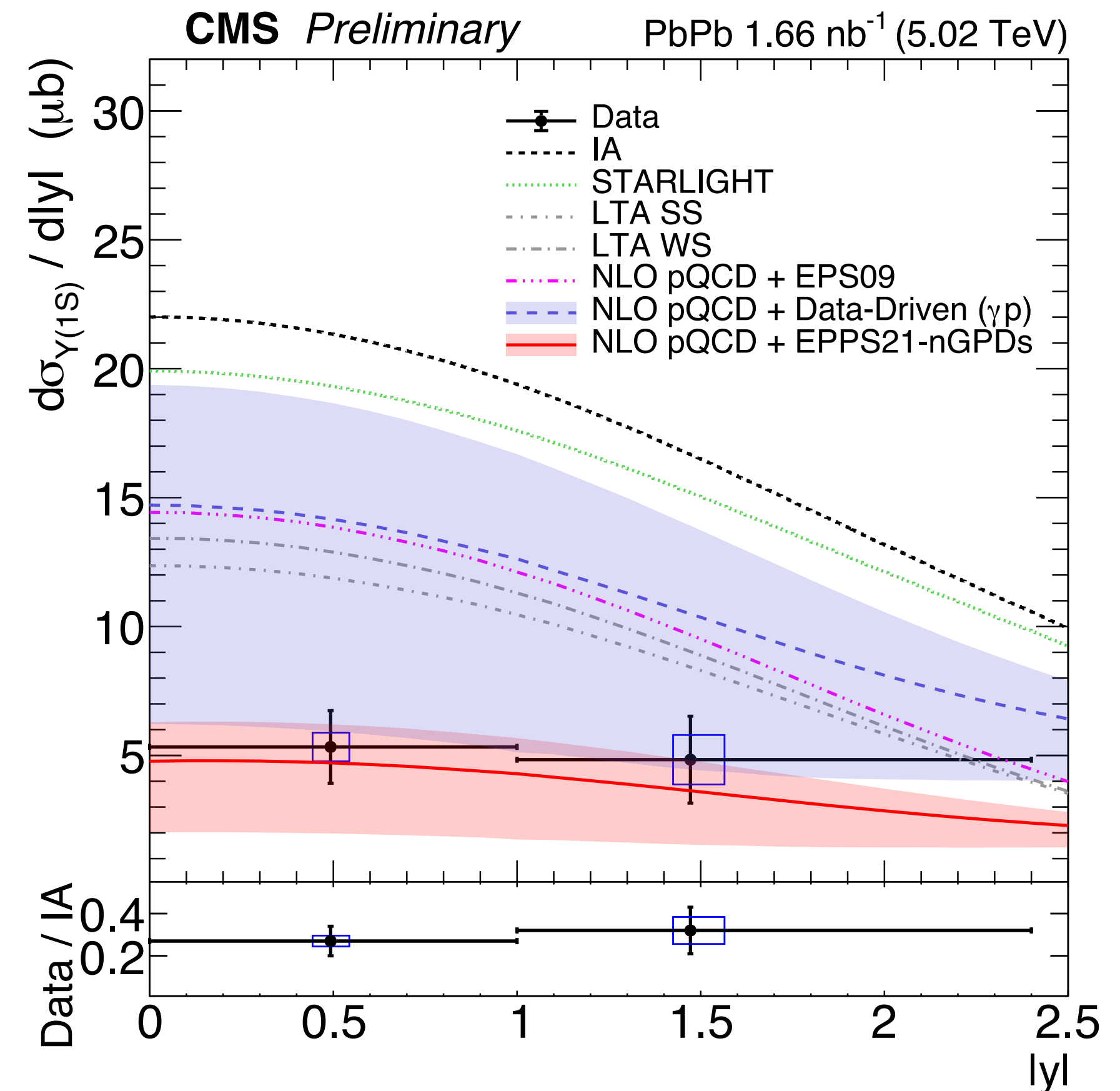
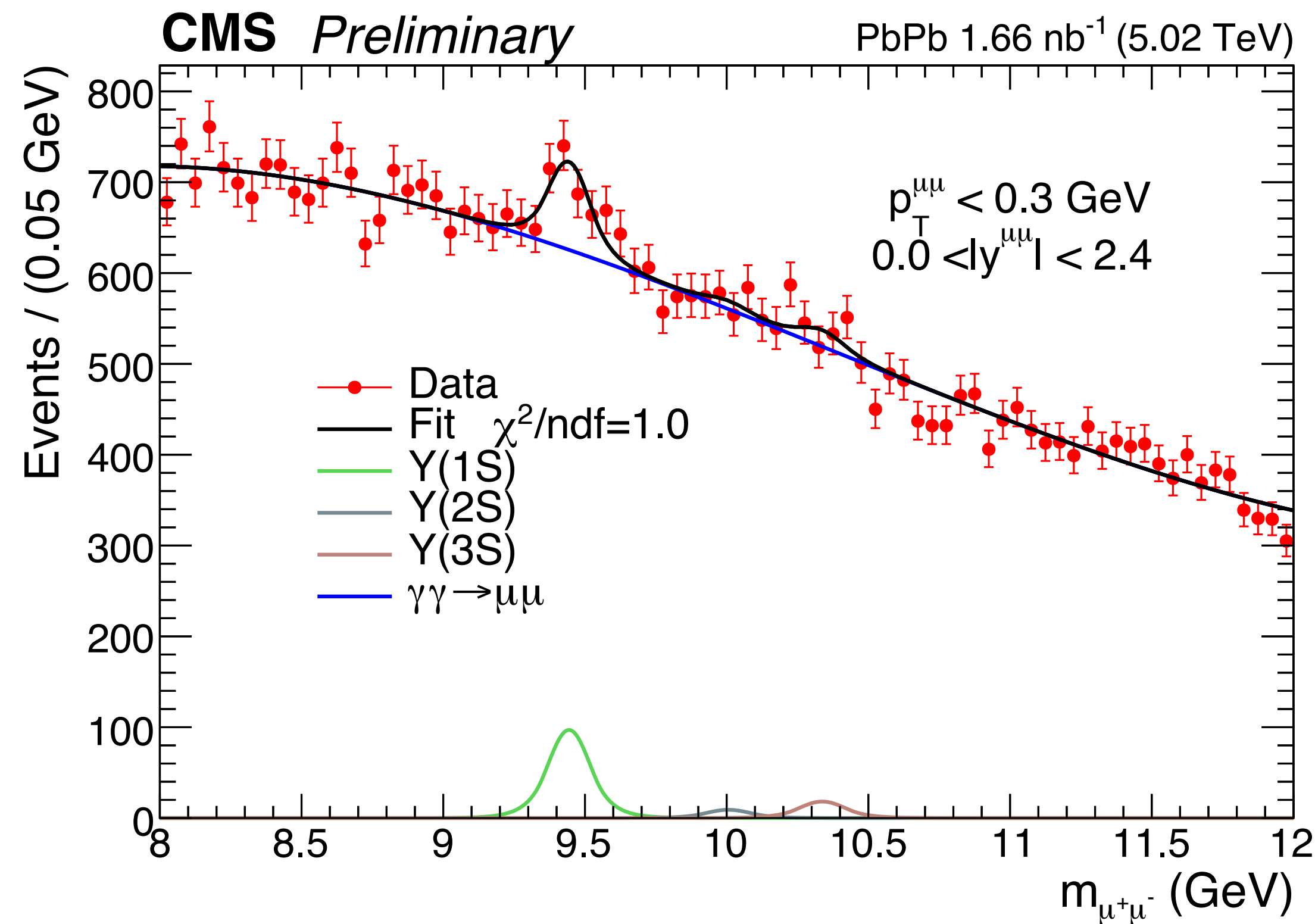
Coherent J/ψ photoproduction at LHC

ATLAS-CONF-2025-003



First observation of coherent $\Upsilon(1S)$ meson

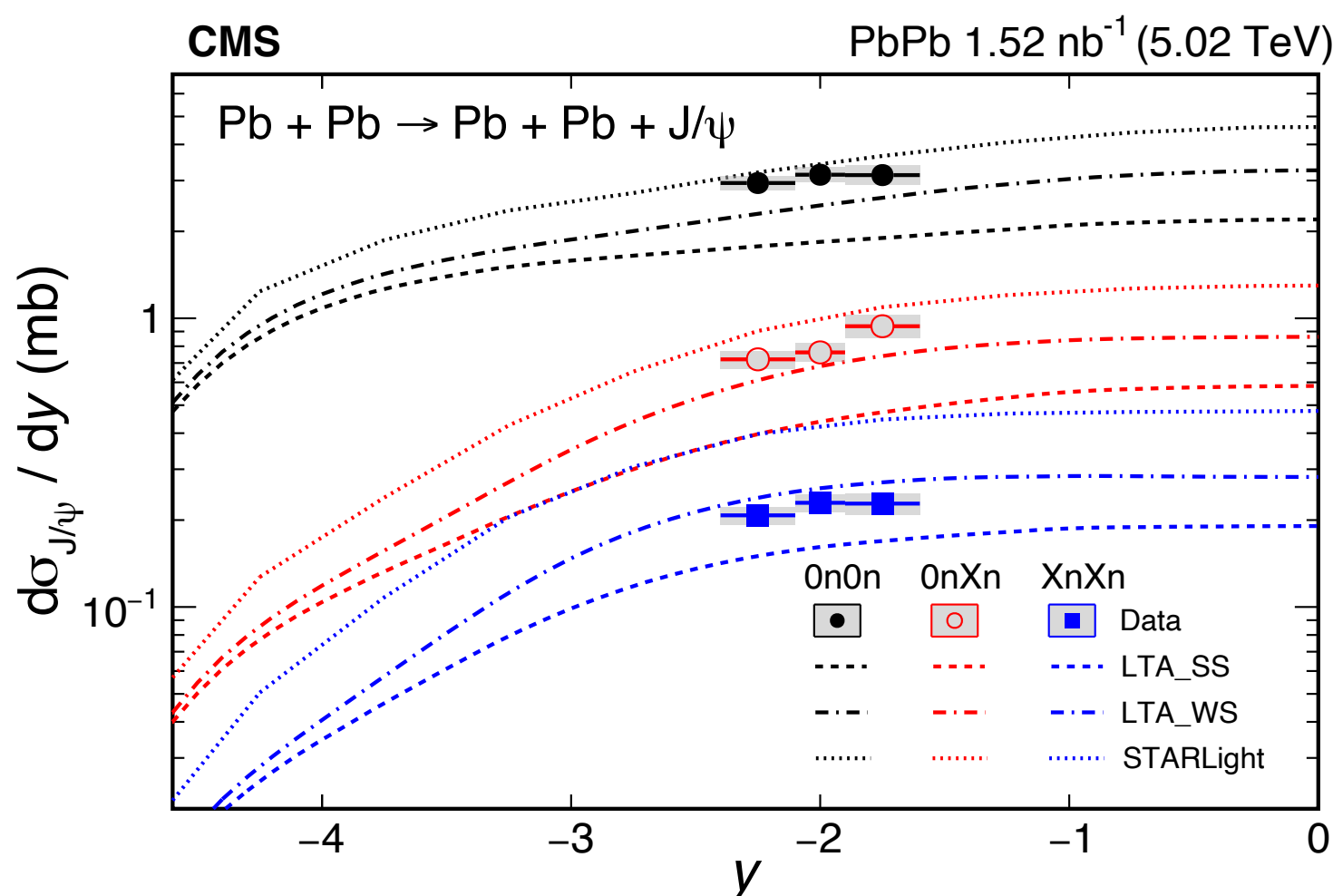
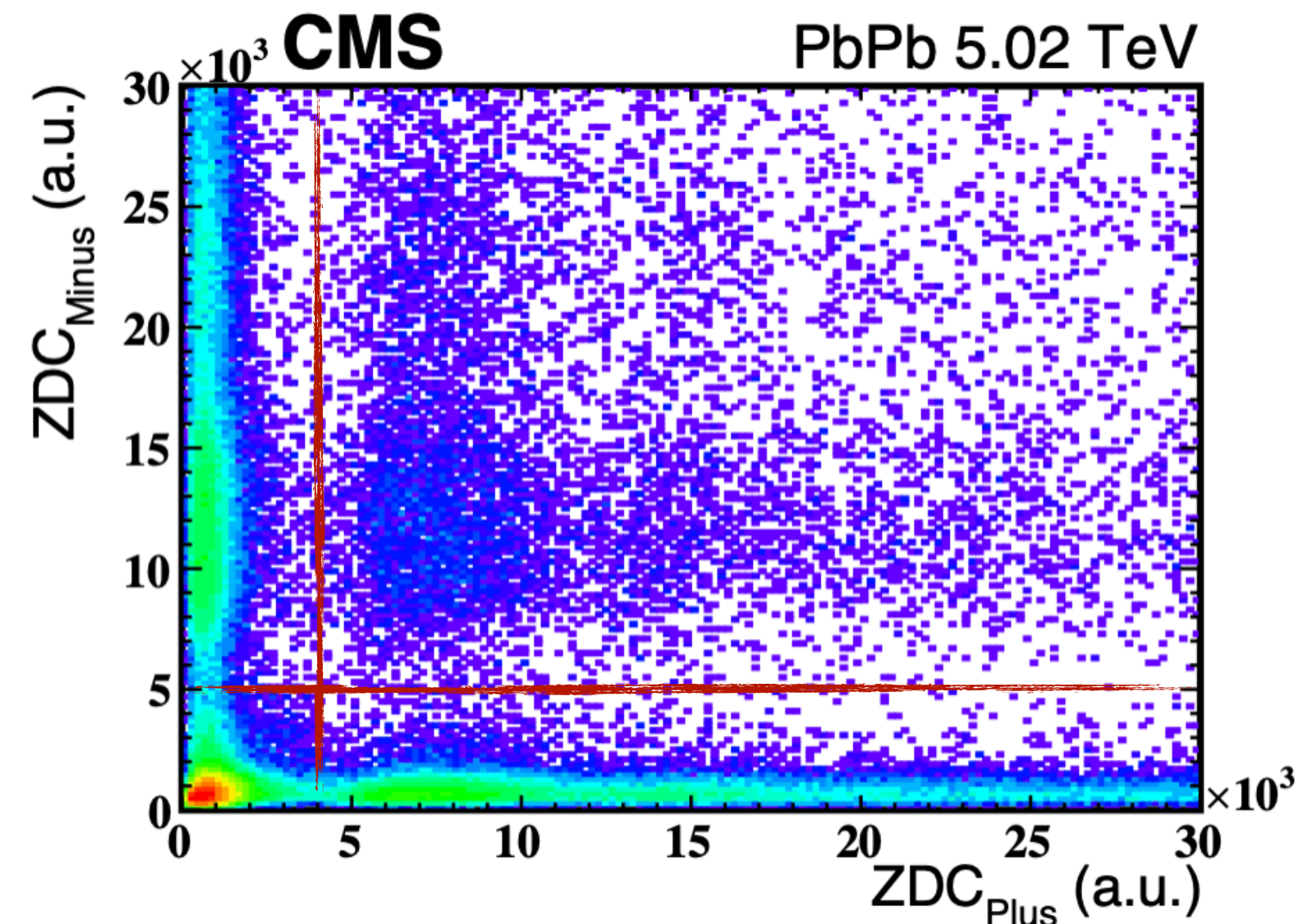
CMS-PAS-HIN-24-013



- $\Upsilon(1S)$ is expected to be less sensitive to the non-linear QCD effects
 - However, strongly ($\sim 3\text{-}4\times$) suppressed is observed!

A solution to the “two-way ambiguity”

Guzey et al., EPJC 74 (2014) 2942



Experimental measurements

$$\begin{aligned} \frac{d\sigma_{AA \rightarrow AA' J/\psi}^{0n0n}}{dy} &= N_{\gamma/A}^{0n0n}(\omega_1) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_1) + N_{\gamma/A}^{0n0n}(\omega_2) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_2) \\ \frac{d\sigma_{AA \rightarrow AA' J/\psi}^{0nXn}}{dy} &= N_{\gamma/A}^{0nXn}(\omega_1) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_1) + N_{\gamma/A}^{0nXn}(\omega_2) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_2) \\ \frac{d\sigma_{AA \rightarrow AA' J/\psi}^{XnXn}}{dy} &= N_{\gamma/A}^{XnXn}(\omega_1) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_1) + N_{\gamma/A}^{XnXn}(\omega_2) \cdot \sigma_{\gamma A \rightarrow J/\psi A'}(\omega_2) \end{aligned}$$

Photon flux from theory

What we need!

Solve the “two-way ambiguity”

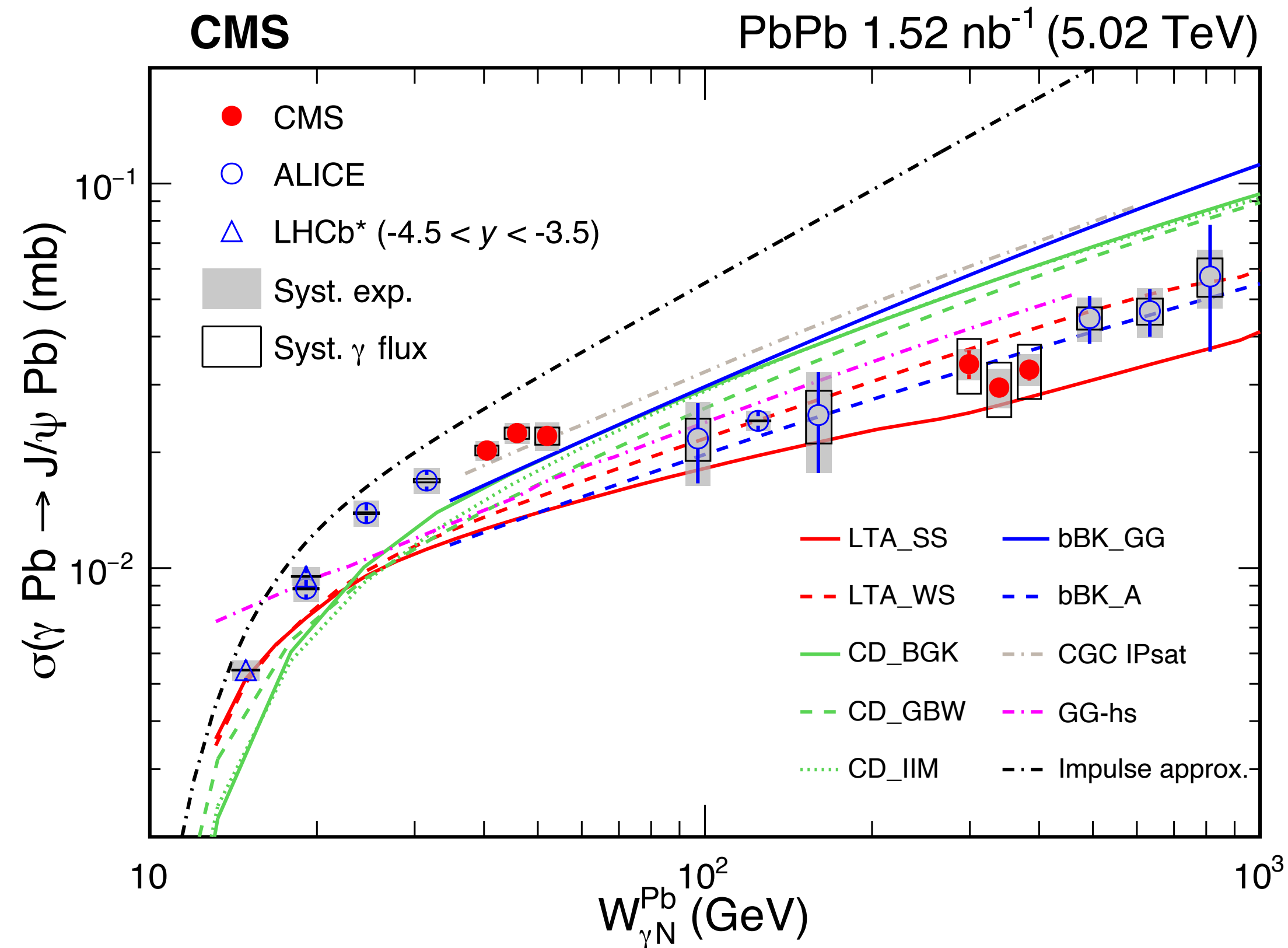
Probe gluons at $x \sim 10^{-5} - 10^{-4}$ in heavy nucleus!

Coherent J/ψ production vs. $W_{\gamma N}^{Pb}$

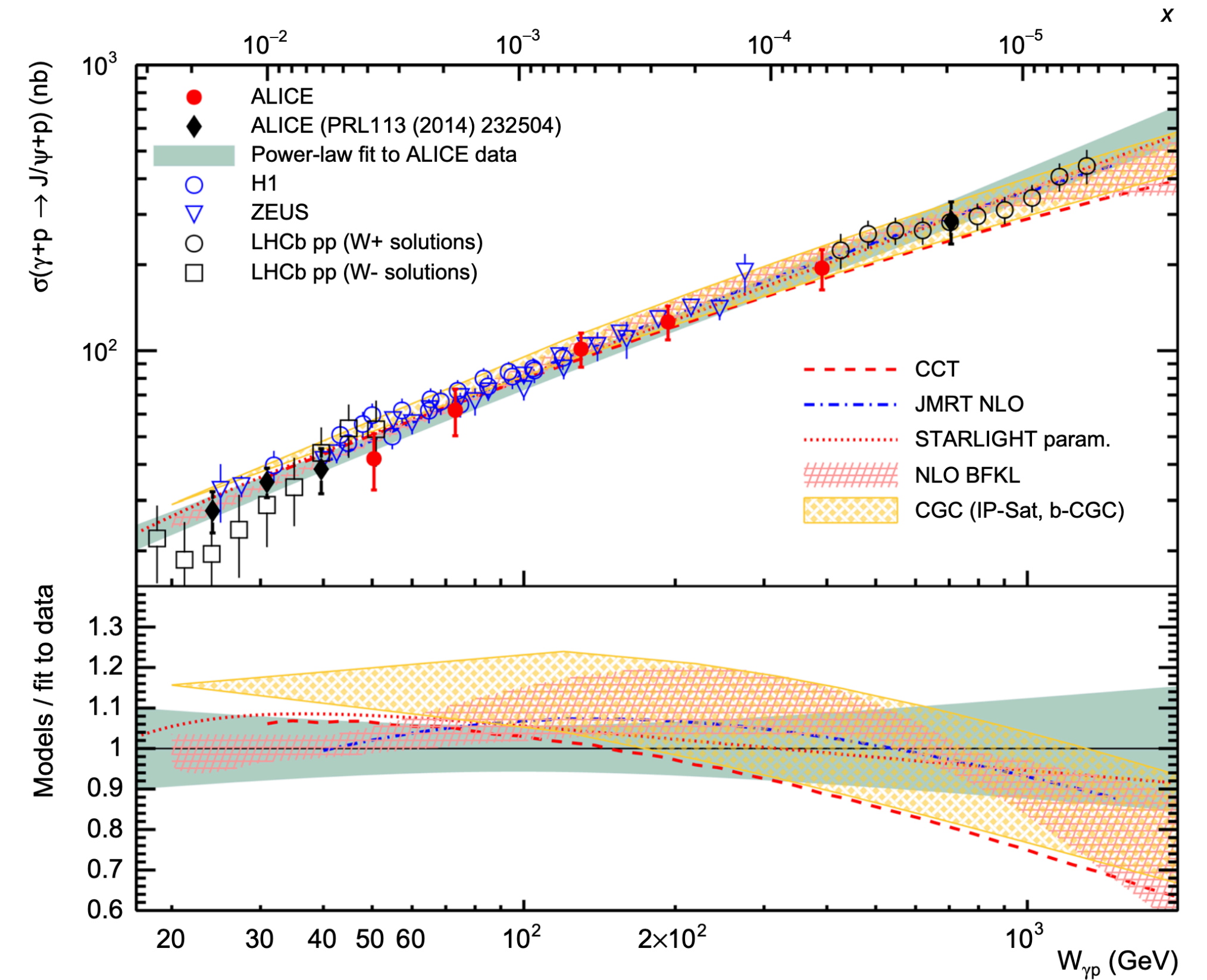
ALICE, JHEP 10 (2023) 119
ALICE, EPJC 81 (2021) 712
ALICE, PLB 798 (2019) 134926

CMS, PRL 131 (2023) 262301
LHCb, JHEP 06 (2023) 146

ALICE, EPJC 79 (2019) 402



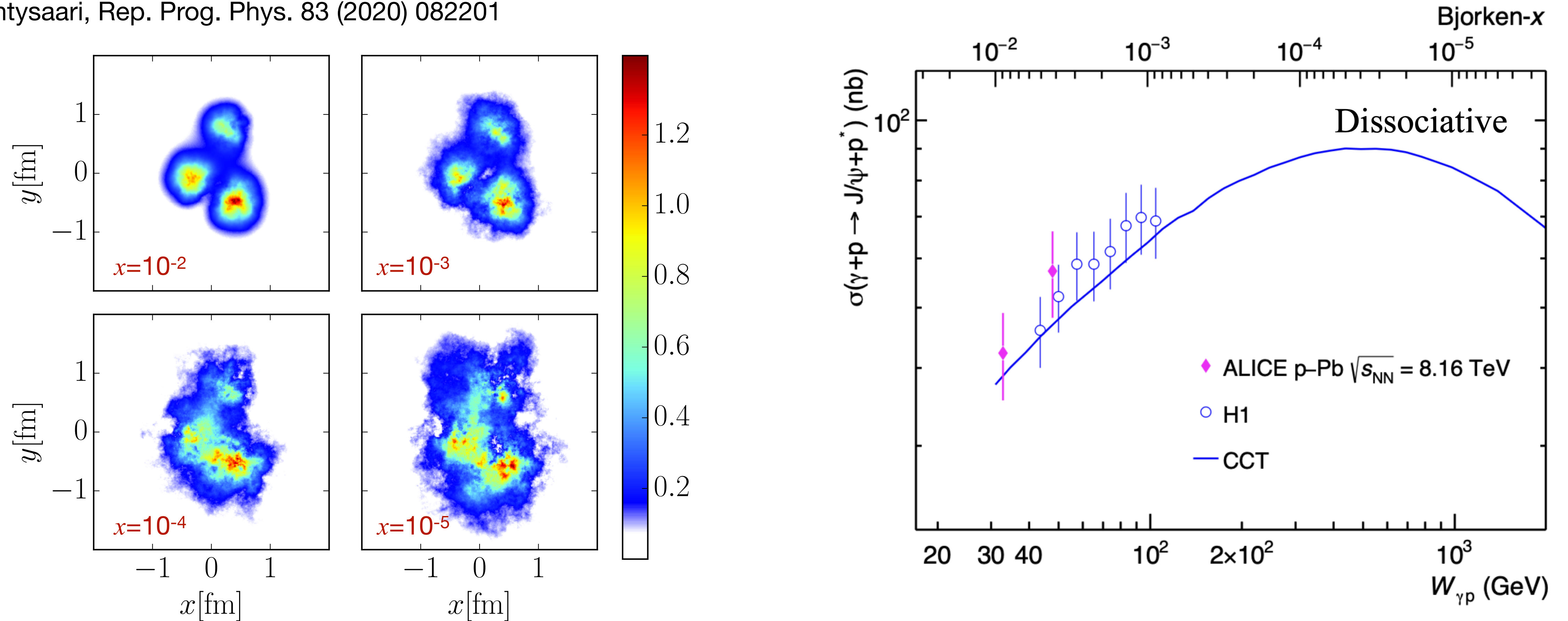
$$\gamma A \rightarrow J/\psi A$$



$$\gamma p \rightarrow J/\psi p$$

The role of energy dependence of **incoherent** J/ψ

Mantysaari, Rep. Prog. Phys. 83 (2020) 082201



● Increasing energy, probing lower- x gluons

- Gluons eventually largely overlap $\rightarrow$ reduce variance over configurations $\rightarrow$ reduce the incoherent J/ψ cross section $\rightarrow$ signature of gluon saturation

Extract energy dependence of incoherent J/ ψ

- Incoherent cross section accounted for in 0nAn*

$$\frac{d\sigma_{\text{PbPb} \rightarrow \text{PbPb}' J/\psi}^{0\text{nAn}^*}(y)}{dy} = \frac{d\sigma_{\text{PbPb} \rightarrow \text{PbPb}' J/\psi}^{0\text{nXn}}(y)}{dy} + \frac{d\sigma_{\text{PbPb} \rightarrow \text{PbPb}' J/\psi}^{0\text{n0n}}(y)}{dy}$$

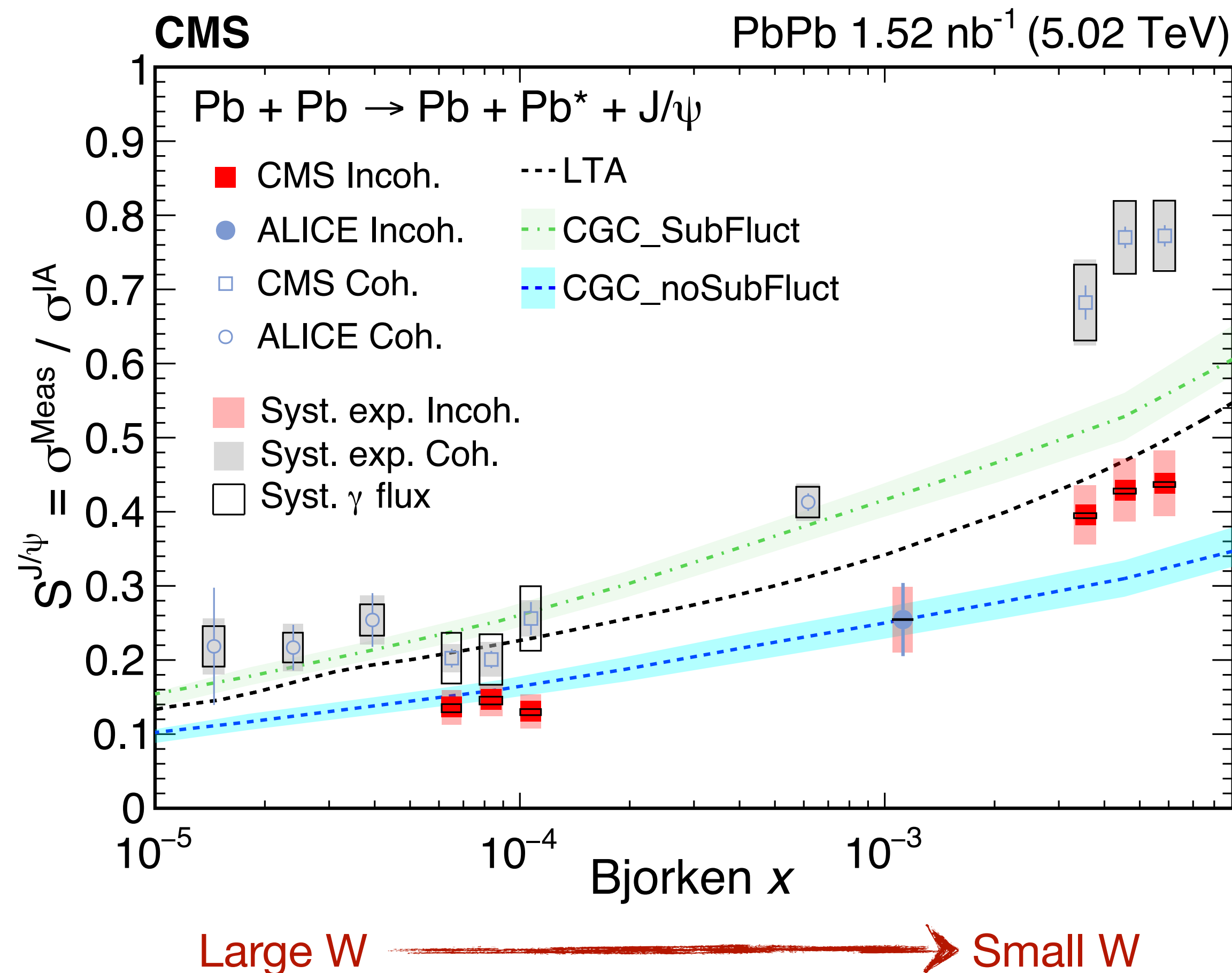
- Photon flux calculated with STARLIGHT

$$n_{\gamma/\text{Pb}}^{0\text{nAn}^*}(\omega) = n_{\gamma/\text{Pb}}^{0\text{n0n}(\text{EMD})}(\omega) + \frac{1}{2} n_{\gamma/\text{Pb}}^{0\text{nXn}(\text{EMD})}(\omega)$$

$$\sigma_{\gamma\text{Pb} \rightarrow J/\psi\text{Pb}'}(W) = \frac{d\sigma_{\text{PbPb} \rightarrow \text{PbPb}' J/\psi}^{0\text{nAn}^*}(y)}{dy} / n_{\gamma/\text{Pb}}^{0\text{nAn}^*}(\omega)$$

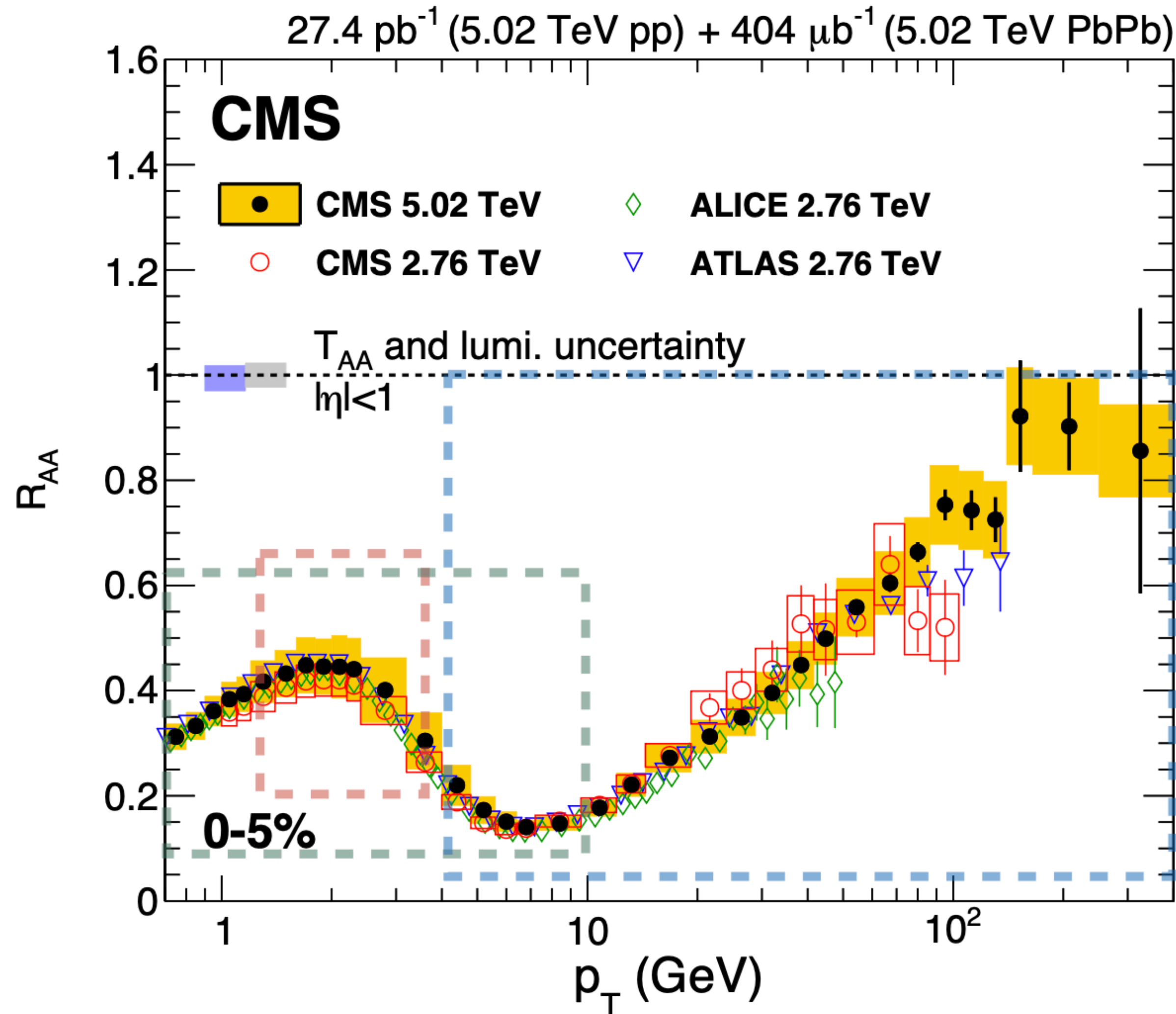
Comparisons of coherent and incoherent J/ψ

CMS, arXiv:2503.08903 (accepted by PRL)



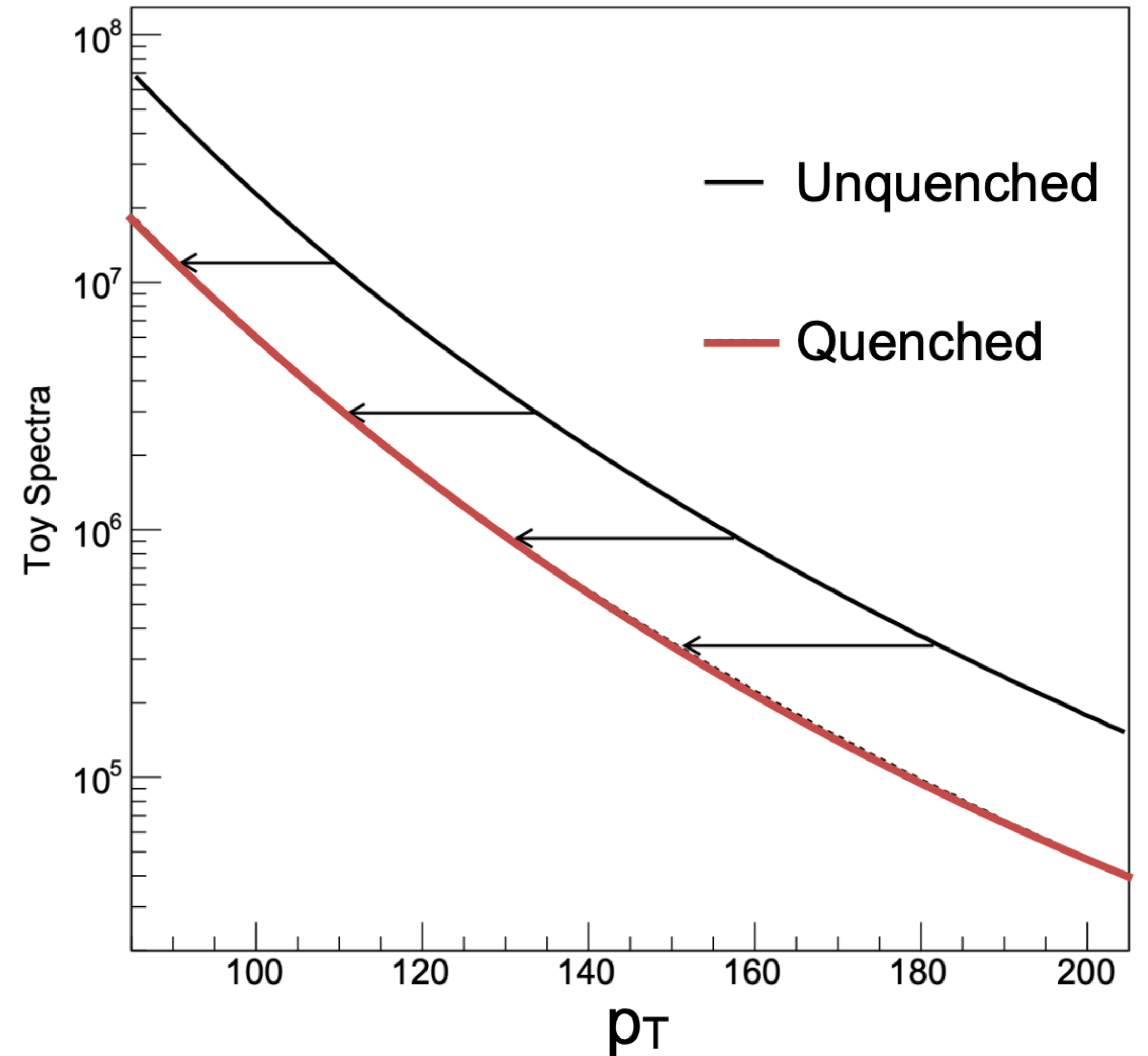
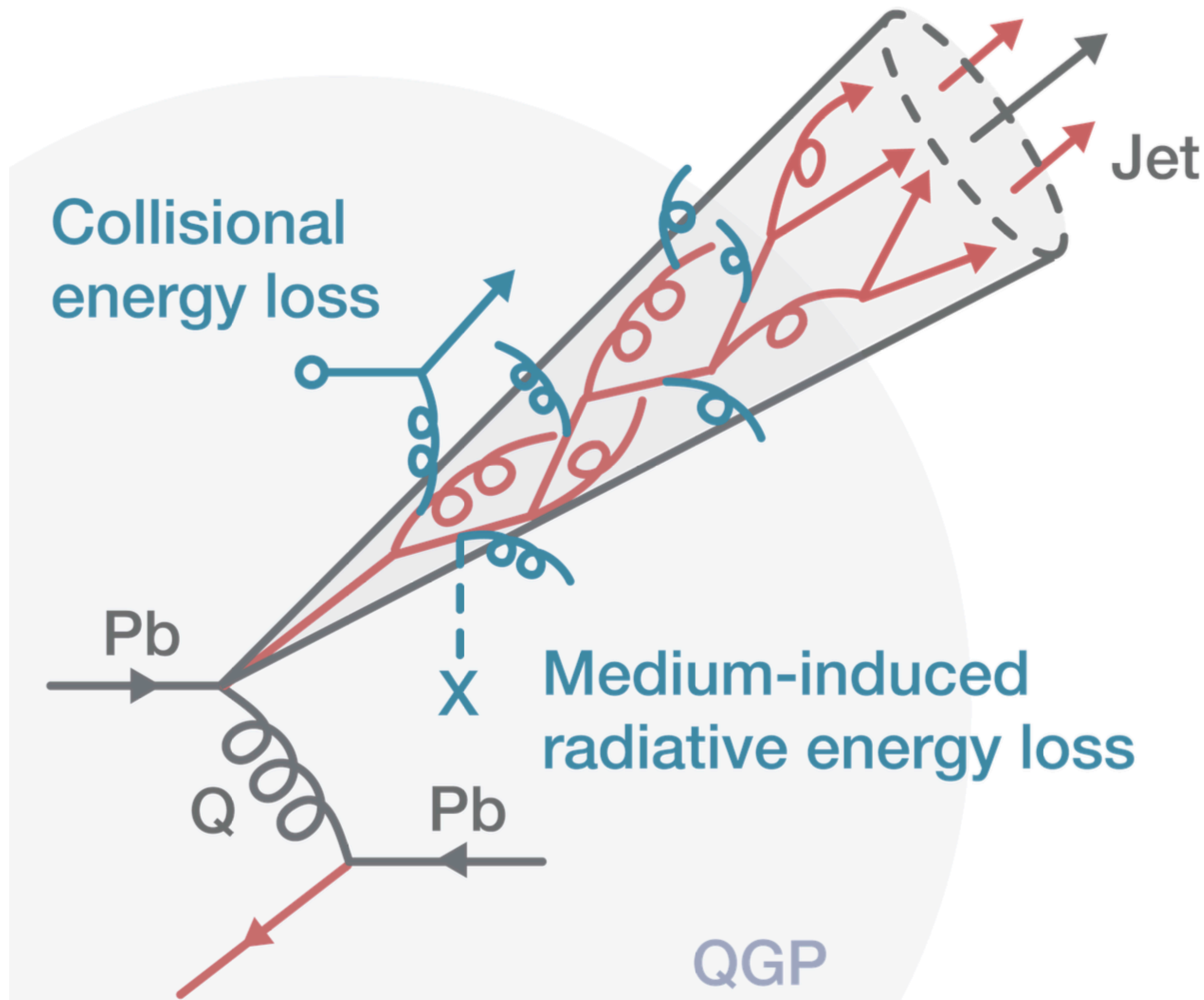
- Strong suppression towards low x region for both coherent and incoherent J/ψ
 - Flatten out at $x < 10^{-4}$
- Compare to coherent J/ψ , incoherent is J/ψ more suppressed at large x but remains consistent at small x
- No theoretical model can consistently describe the whole photoproduced J/ψ measurements

Charged particle R_{AA}



- **Radial flow** Medium pushes very low- p_T partons to a bit higher p_T
- **Shadowing (nPDF)** suppresses low p_T particle production → R_{AA} is not > 1 at very low p_T after quenching
- **Energy loss (quenching)** mainly drives suppression at high p_T , but **p_T shape** matters (see next slide)

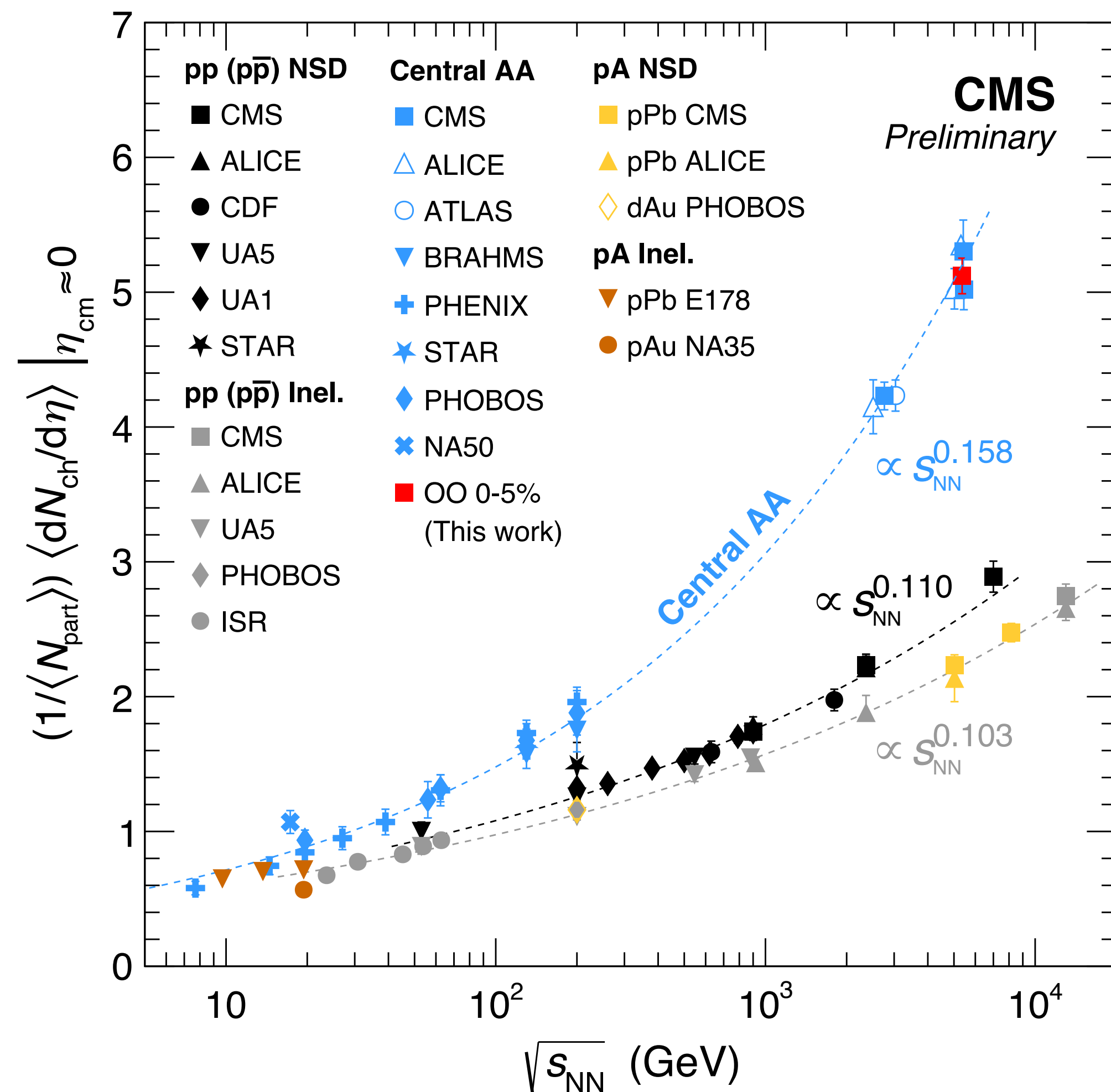
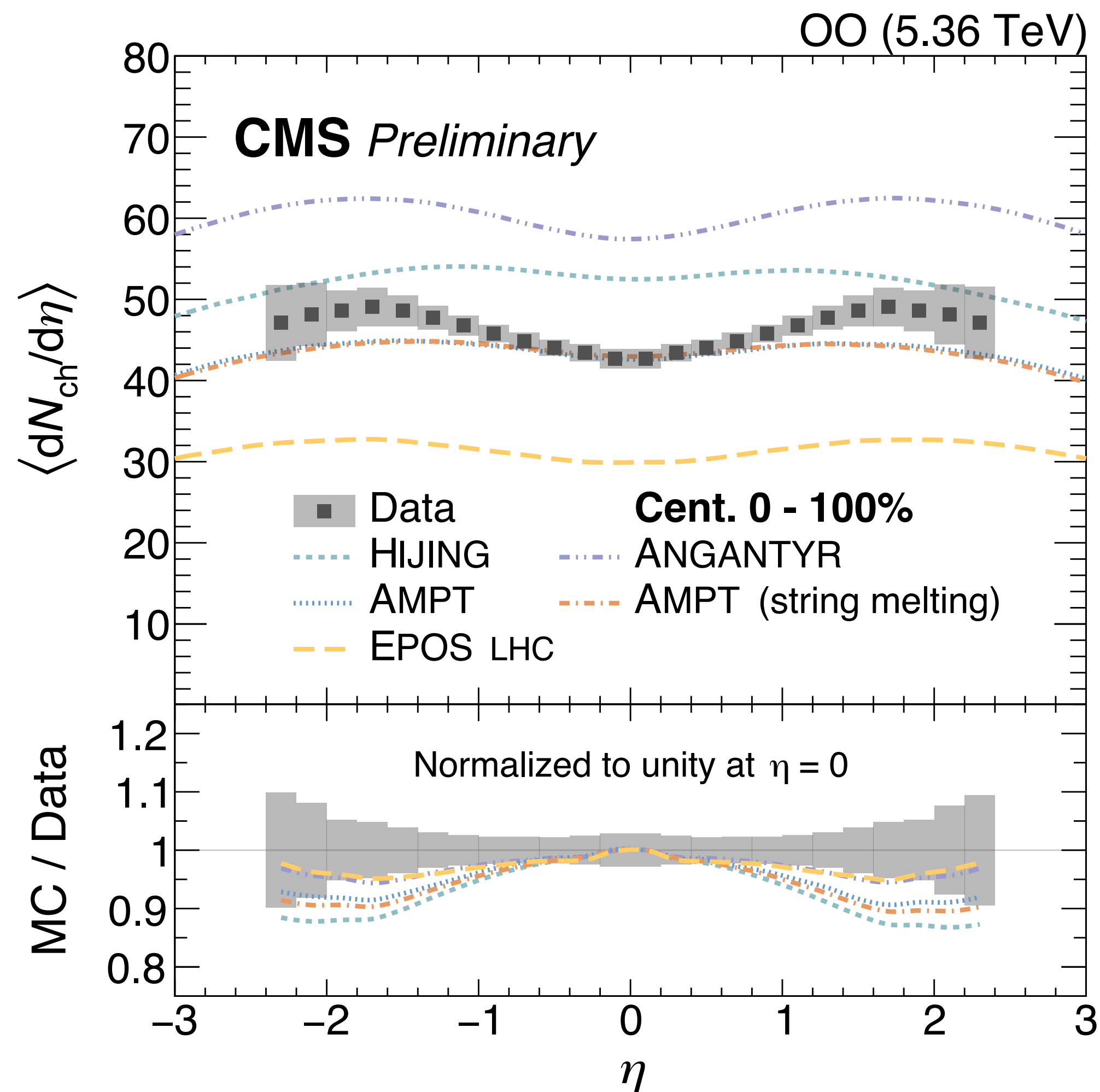
Charged particle R_{AA}



Sketches from Jing Wang's talk at LPCC Jamboree

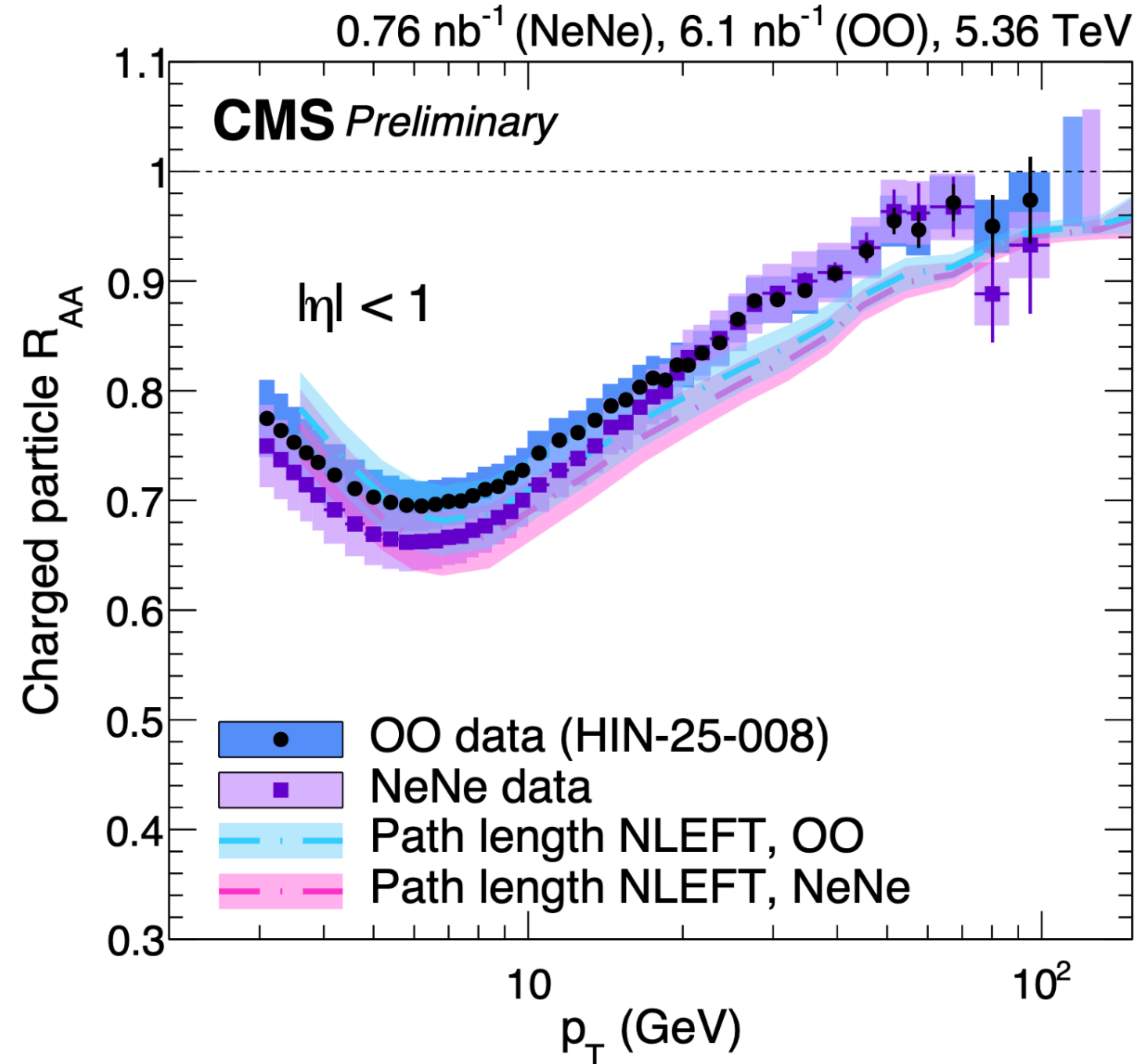
$dN/d\eta$ of charged hadrons in OO

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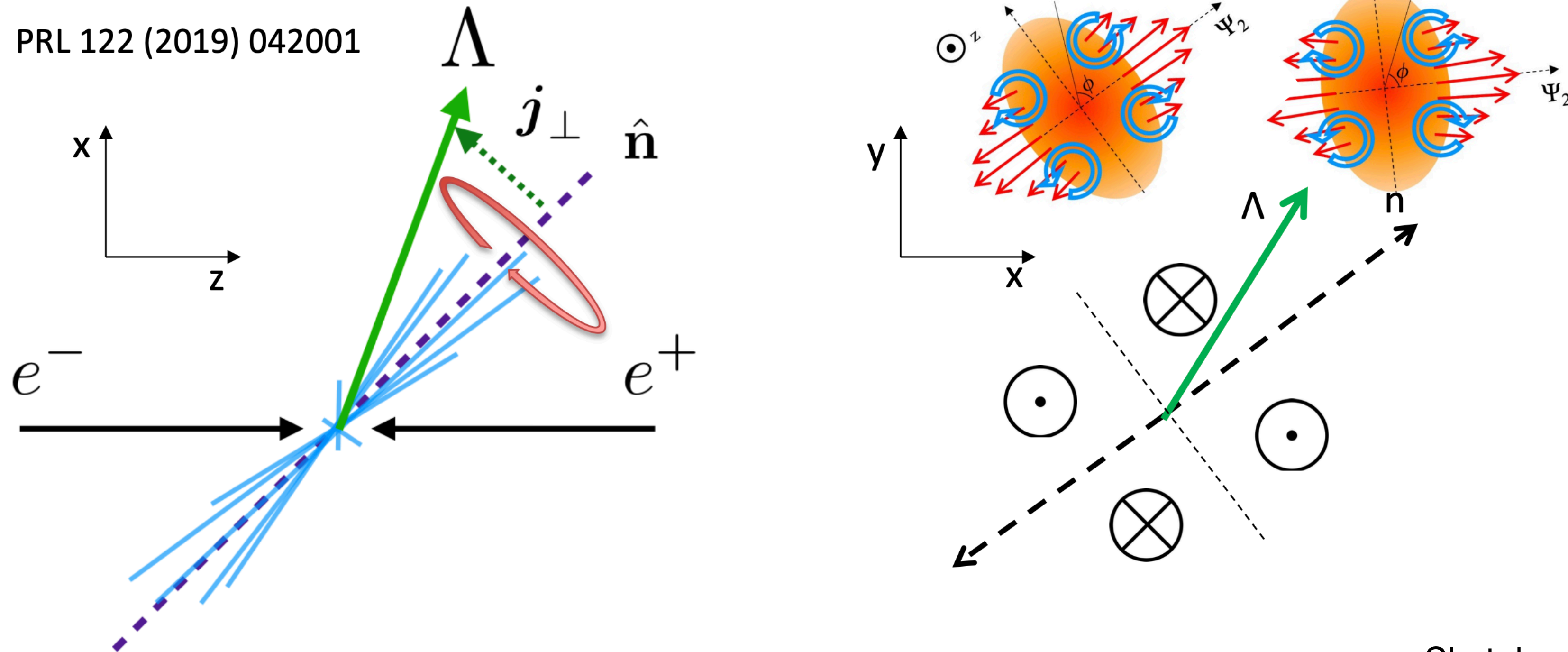
Charged particle R_{AA} in OO and NeNe

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Pz in low multiplicity class

Transverse hyperon polarization in jet

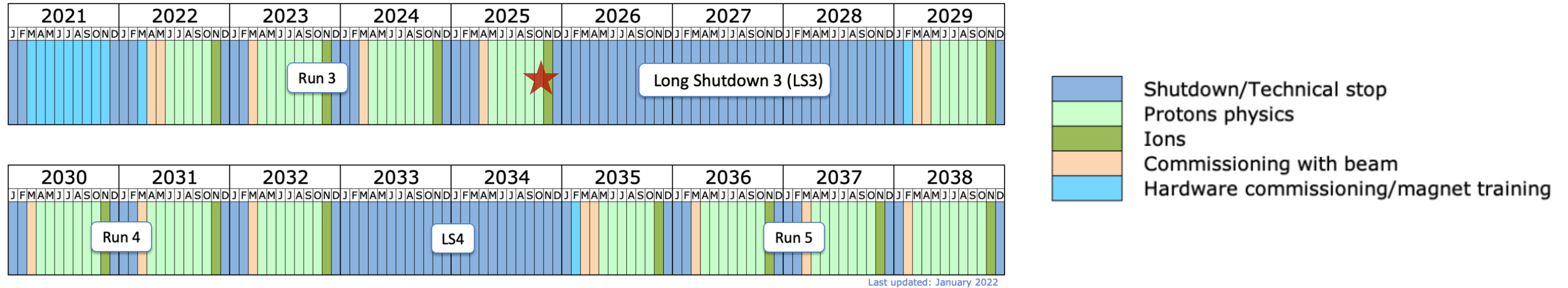


Sketches from Zhenyu Chen's talk

Projection to x-y plane introduce a P_z wrt thrust axis
Thrust axis coincide with 2nd order event plane at low multiplicity
Diluted (decreases) towards high multiplicity

Measurements of Λ polarization in jet needed at LHC

Future opportunities



Exciting opportunities ahead

- System size scan with different ion species
- Detector upgrade with new technologies

UPC programs

- Various vector meson photoproductions
 - Energy dependence of photoproduced vector meson cross sections
- Open HF and (di-)jet photoproductions

