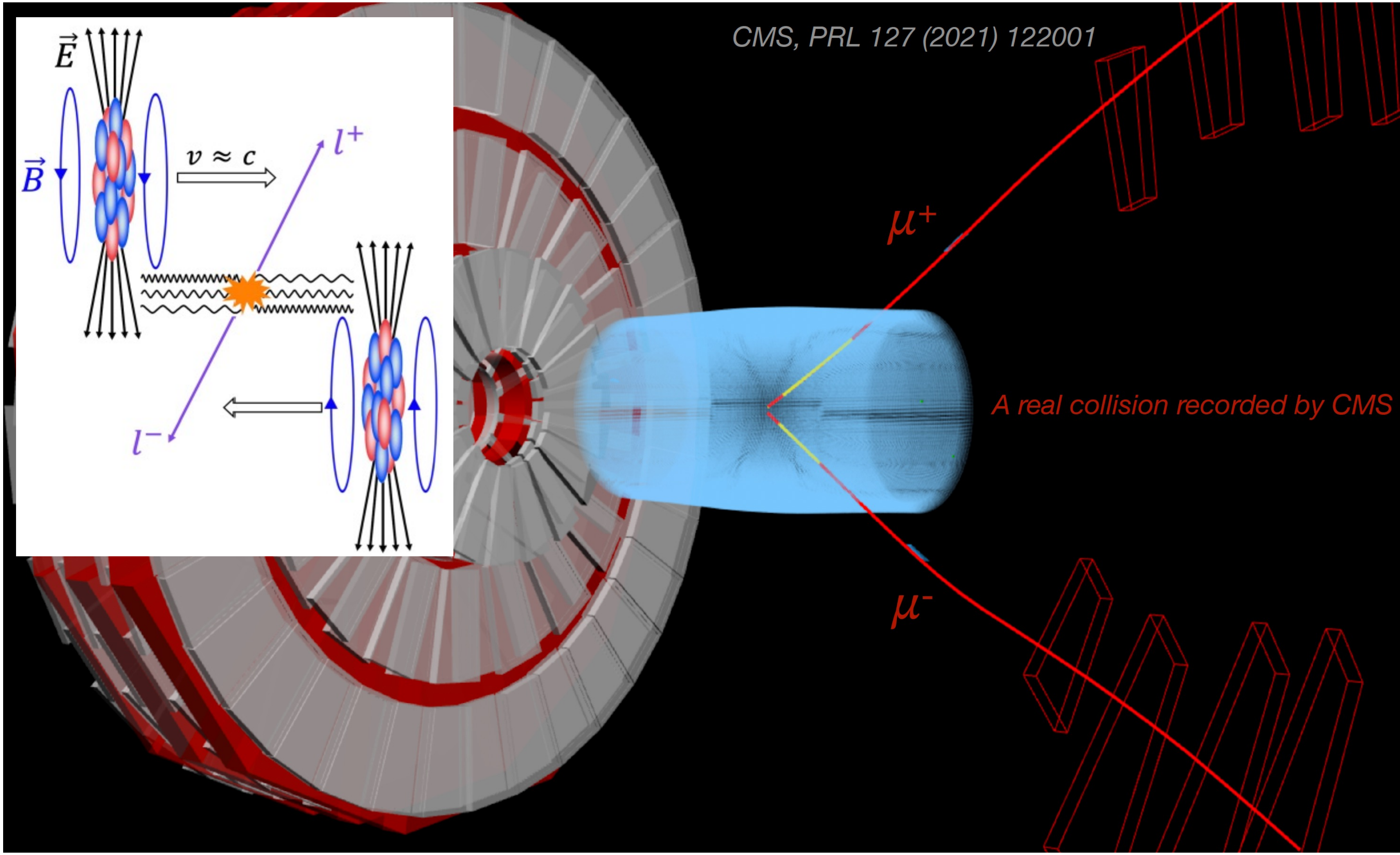
CMS highlights

UPC & Hyperon Polarization

陈震宇 Zhenyu Chen
山东大学 Shandong University

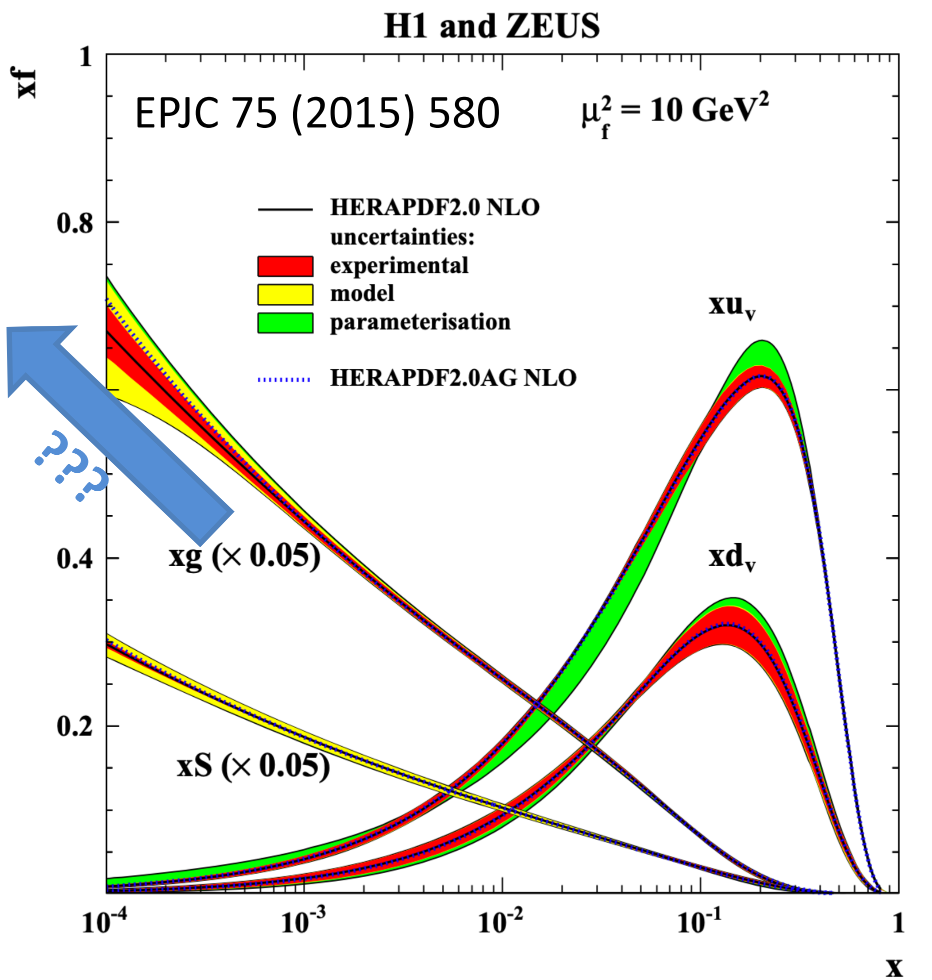
Advances, Innovations, and Prospects in High-Energy Nuclear Physics
Wuhan 2024

Ultra-peripheral collisions



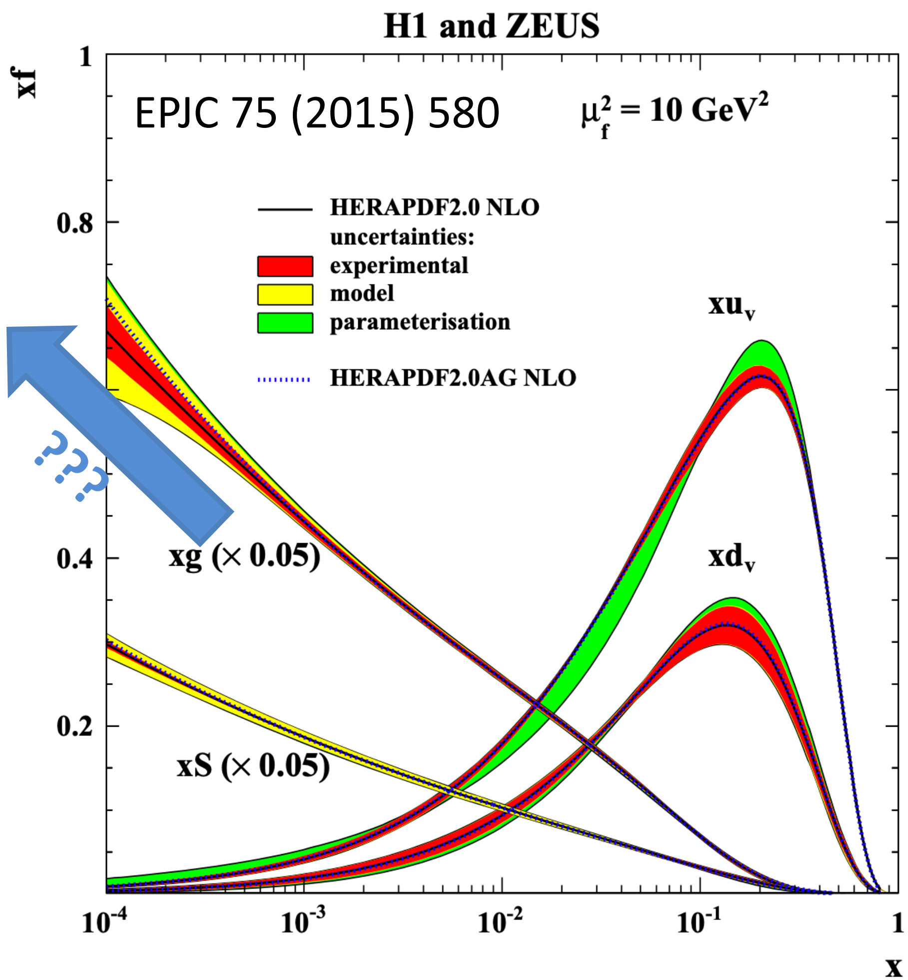
CMS has magnificent ability for UPC physics, especially with muons

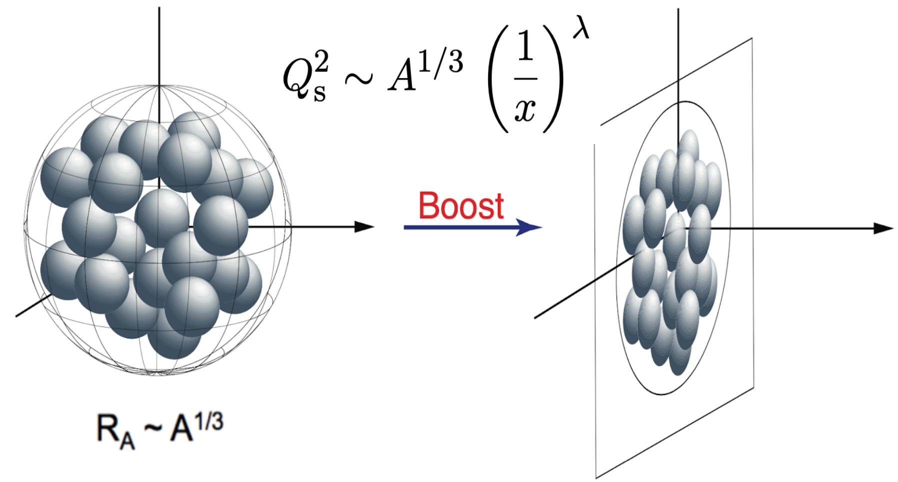
Hunting down gluon saturation



Growth of gluon density cannot continue indefinitely

Hunting down gluon saturation





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Saturation easier to reach with enhanced gluon density in nucleus

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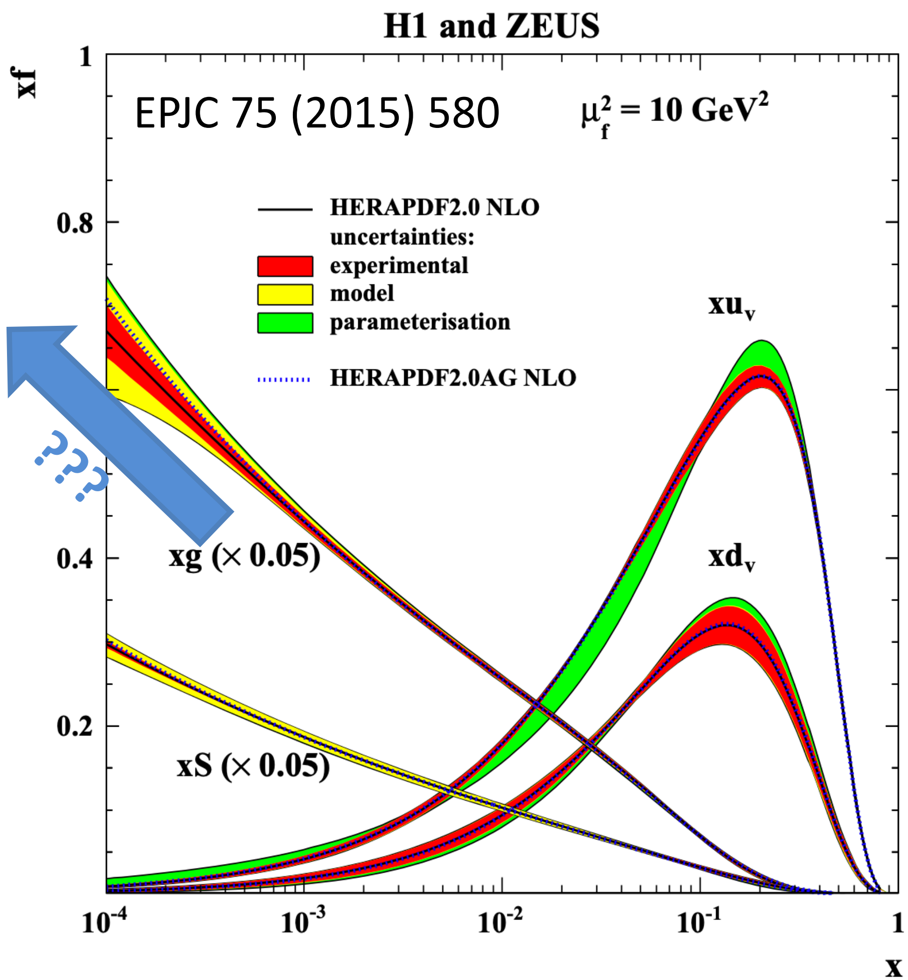
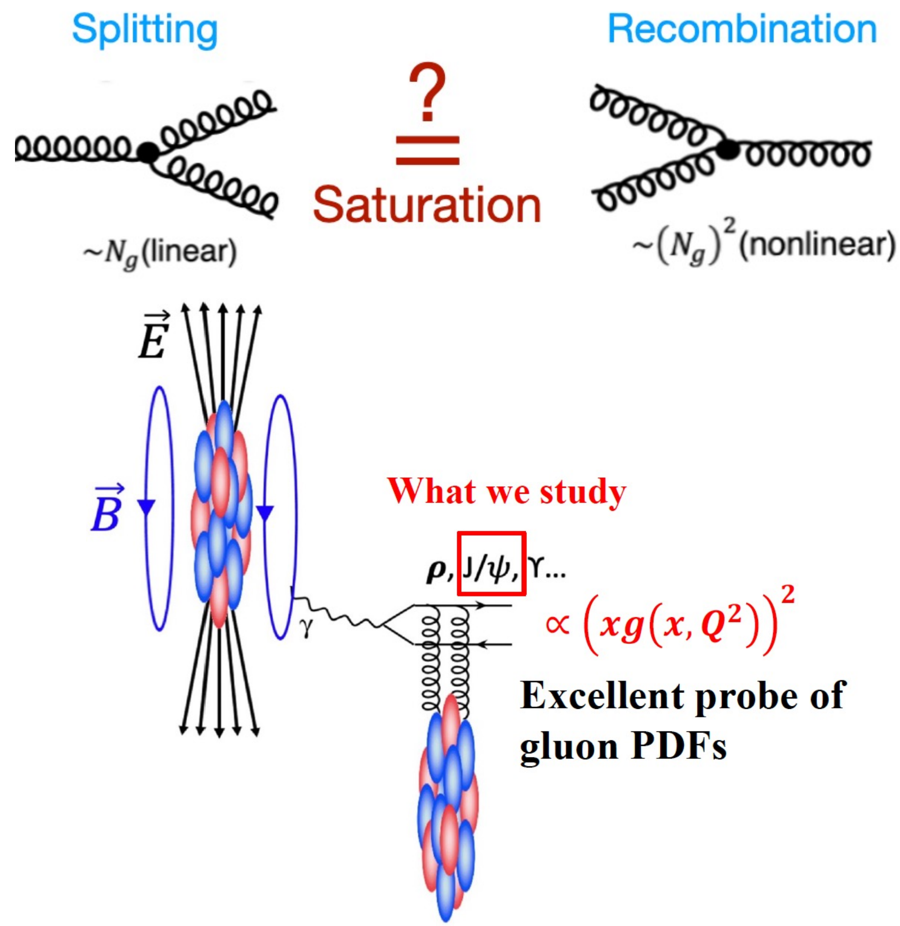


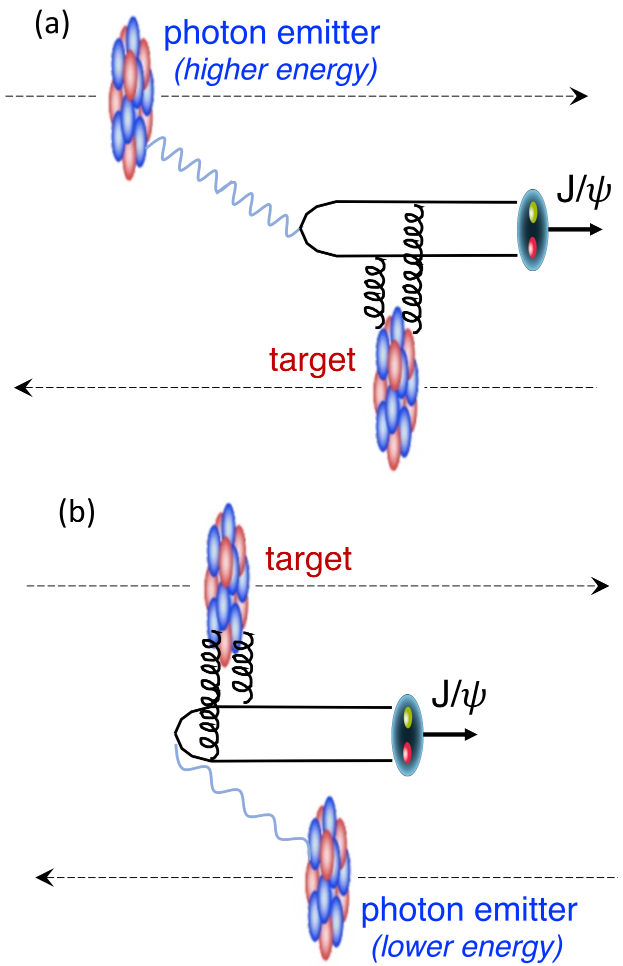


Growth of gluon density cannot continue indefinitely

Saturation easier to reach with enhanced gluon density in nucleus

Photo-produced Vector Meson can test small x gluon density

Photon energy two way ambiguity



Direct separation of low/high energy photon emitter not possible

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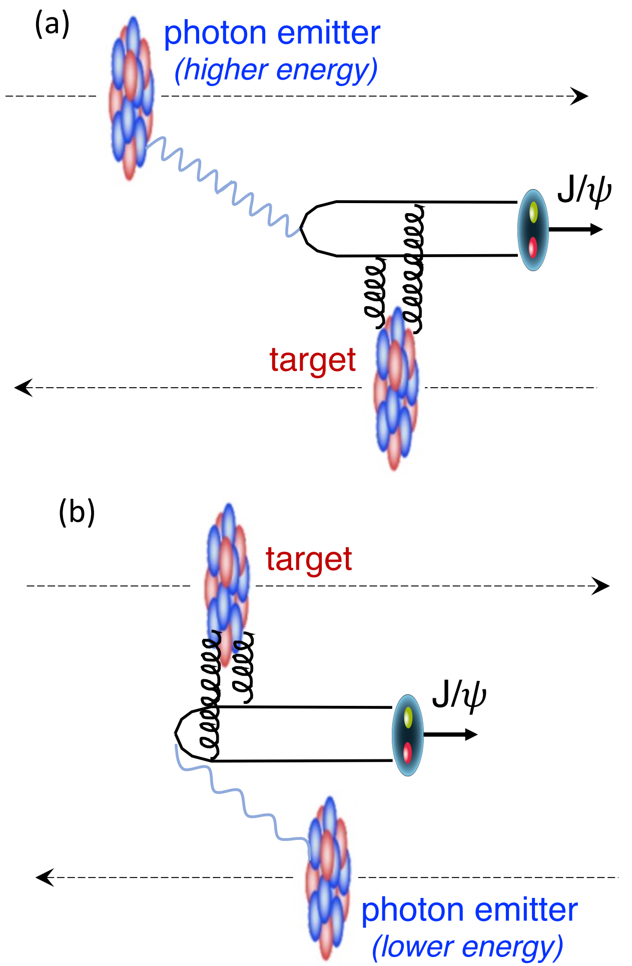
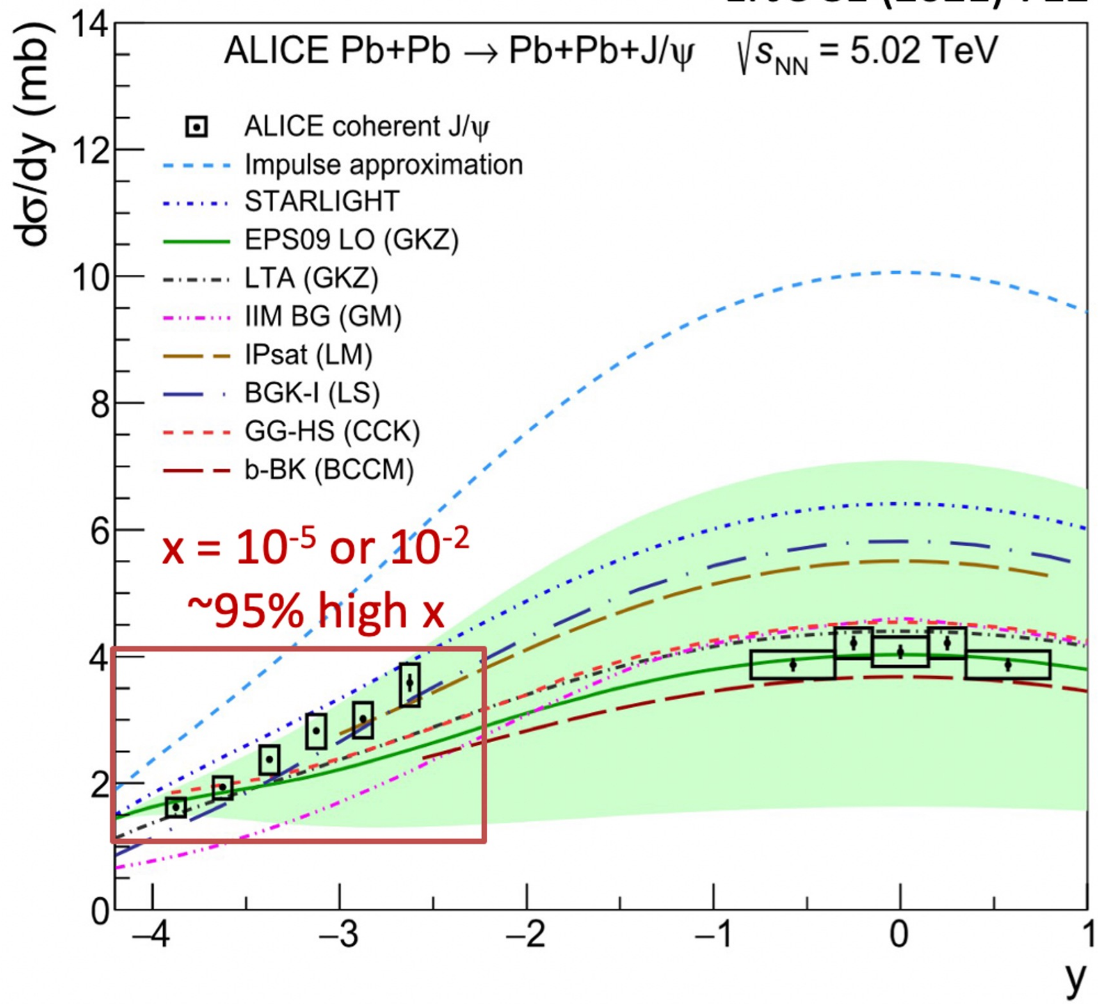


EPJC 81 (2021) 712



Direct separation of low/high energy photon emitter not possible

Measured results dominated by large x contributions

Solving the ambiguity

$$\frac{d\sigma^{\boxed{0n0n}}_{AA\to AAJ/\psi}}{dy} = N^{0n0n}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{0n0n}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

$$\frac{d\sigma^{\boxed{0nXn}}_{AA\to AA'J/\psi}}{dy} = N^{0nXn}_{\gamma/A}(y)\cdot\sigma_{\gamma A\to J/\psi A'}(y) + N^{0nXn}_{\gamma/A}(-y)\cdot\sigma_{\gamma A\to J/\psi A'}(-y)$$

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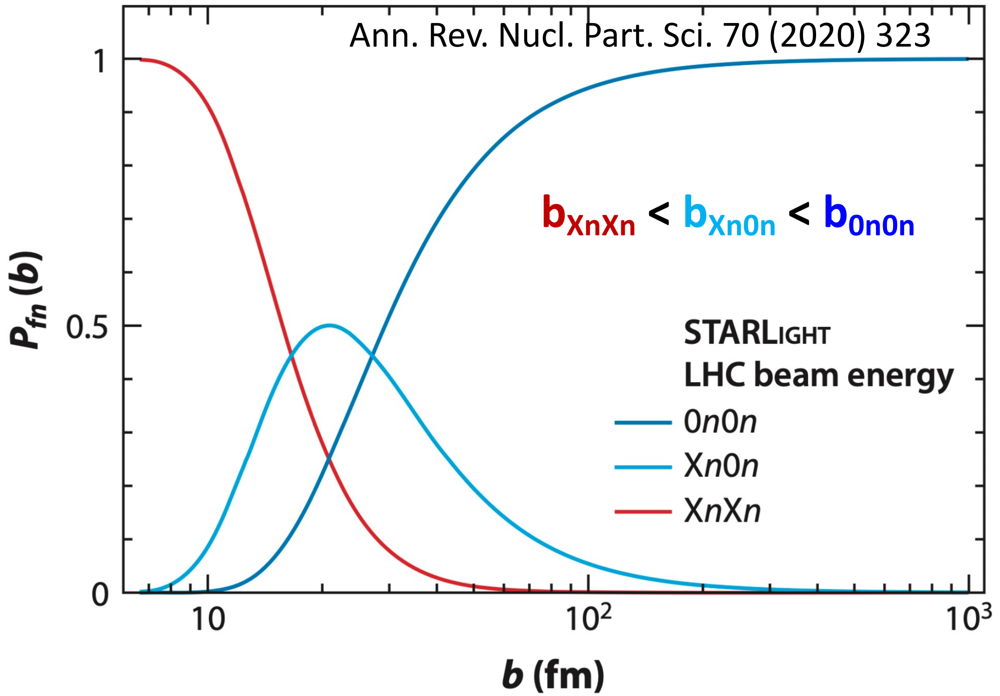

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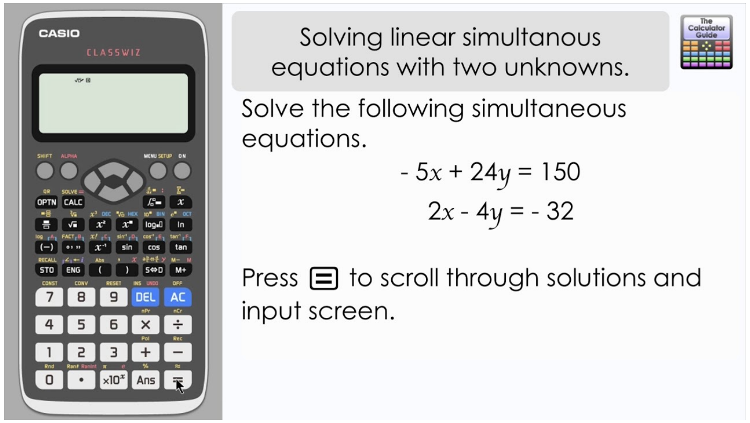


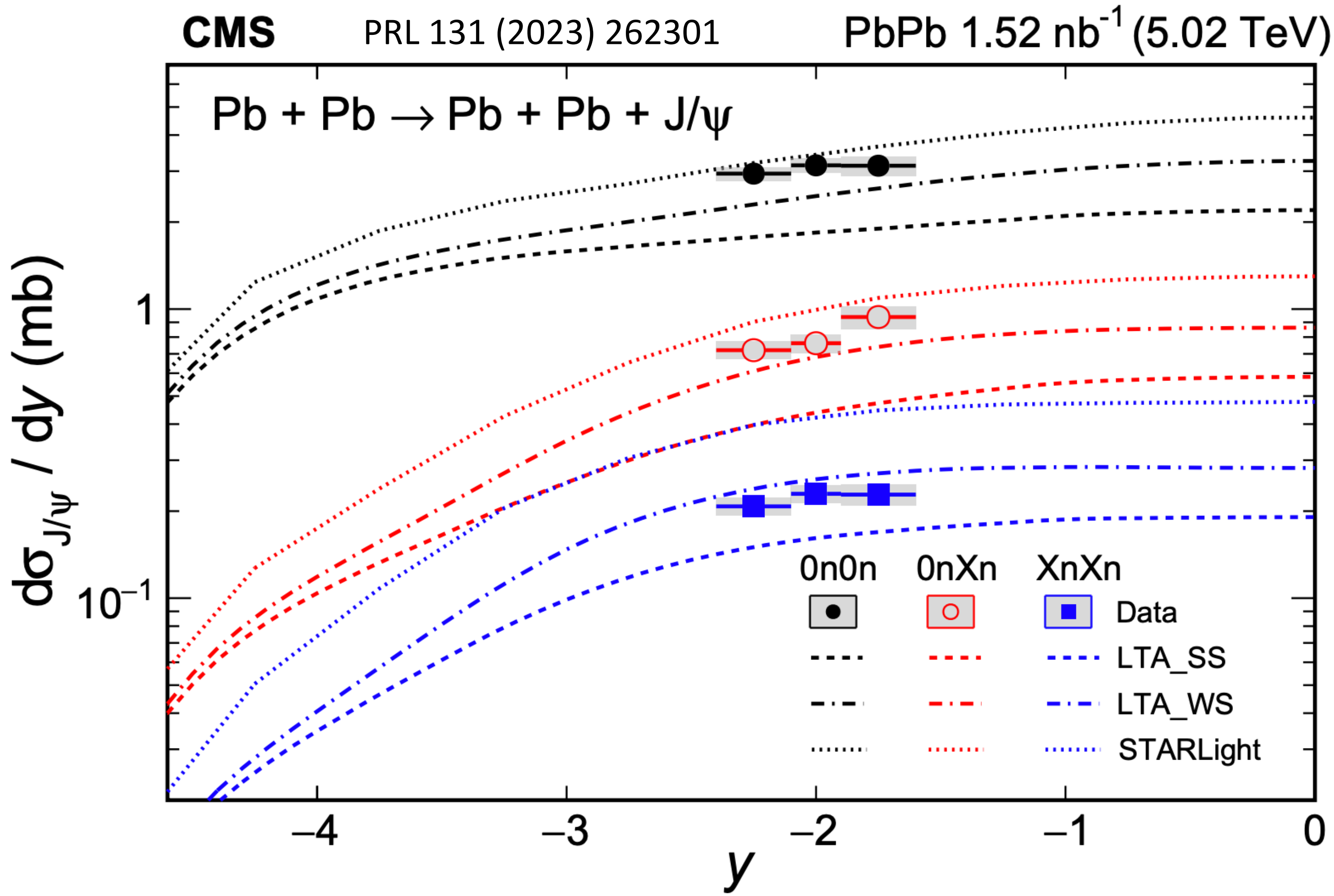
Photon flux N(y) from theory

Solve for $\sigma_{\gamma A\rightarrow J/\psi A'}(y)$ $\sigma_{\gamma A\rightarrow J/\psi A'}(-y)$

and $x = \left(\frac{M_{VM}}{\sqrt{s_{NN}}}\right)e^{\mp y}$

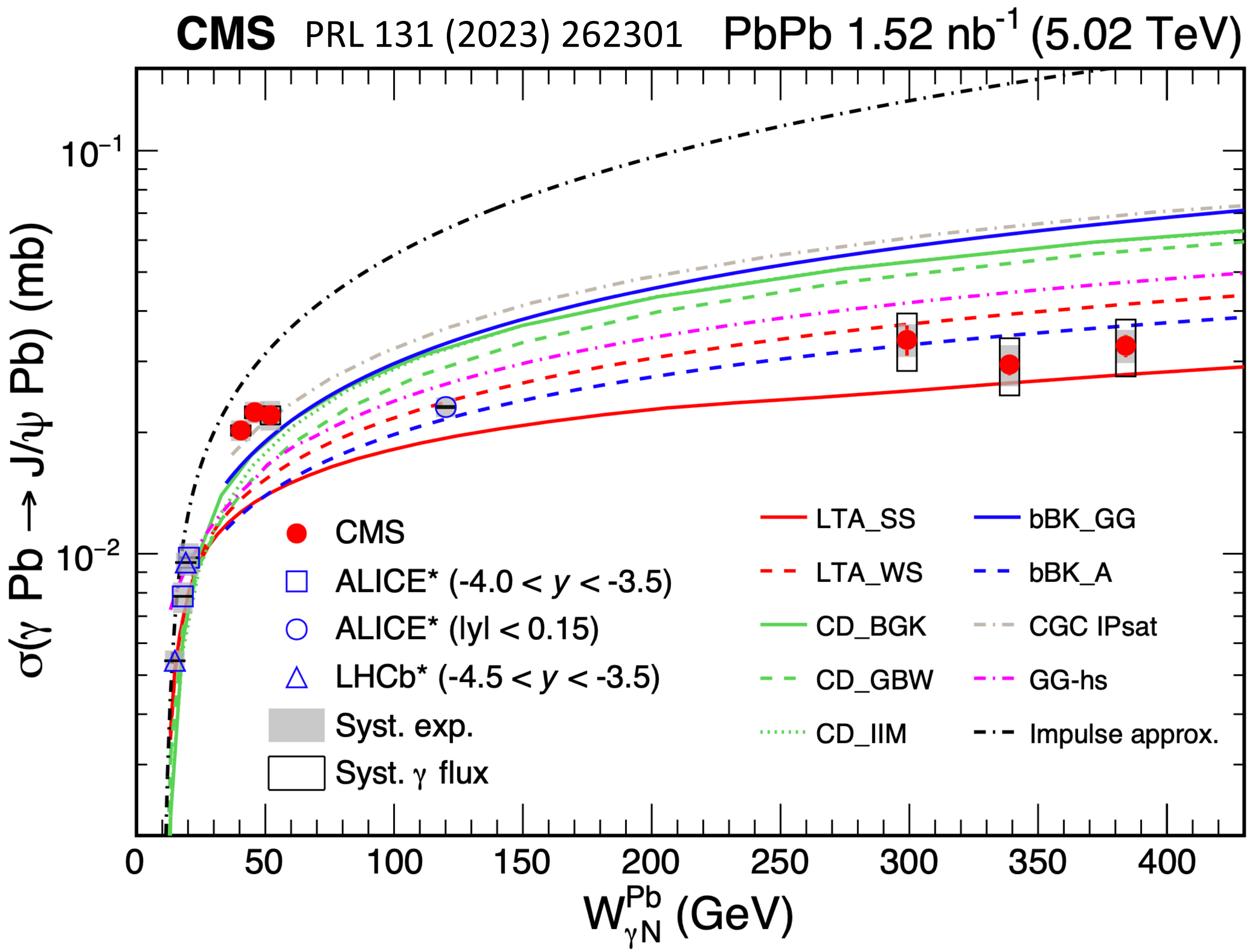
Entering a new regime of small x~10^{-4} – 10^{-5} in nuclei

Coherent J/ψ production vs $N_{neutron}$



First ever separation in different neutron configuration
Leading Twist Approximation cannot fully describe data

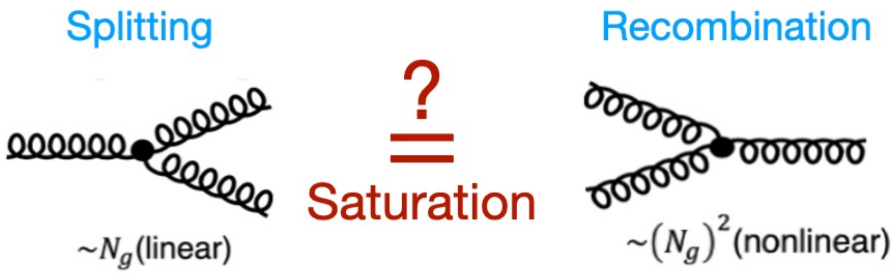
Coherent J/ψ production vs $W_{\gamma N}^{Pb}$



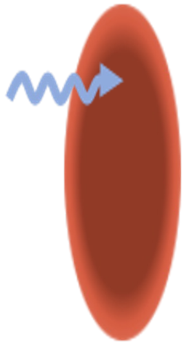
CMS measurement up to 400 GeV, nearly flat at > 40 GeV

Evidence of gluon saturation or black disk limit?

Saturation vs black disk



Visible inner structure
With Event-by-event fluctuation



Black disk limit

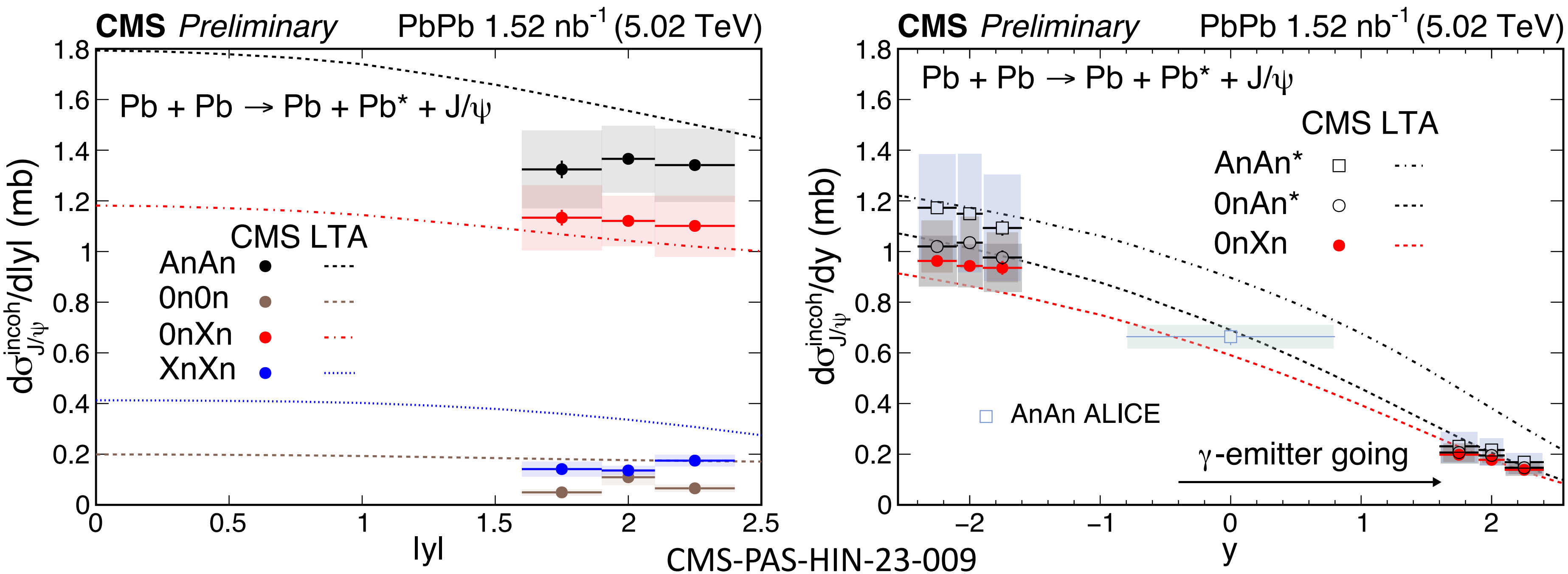
$$\hat{\sigma}^{\rm inel}_{\rm PQCD} \leq \hat{\sigma}_{\rm black} = \pi R^2_{\rm target}$$

L. Frankfurt et al. PRL 87 (2001)192301
L. Frankfurt et al. PLB 537 (2002) 51

Inner structure diminishes
No Event-by-event fluctuation

Coherent J/ψ probes the entire nucleus
Incoherent J/ψ probes inner structure of the nucleus
Comparing coherent & incoherent production can help to distinguish

Incoherent J/ψ production vs $N_{neutron}$



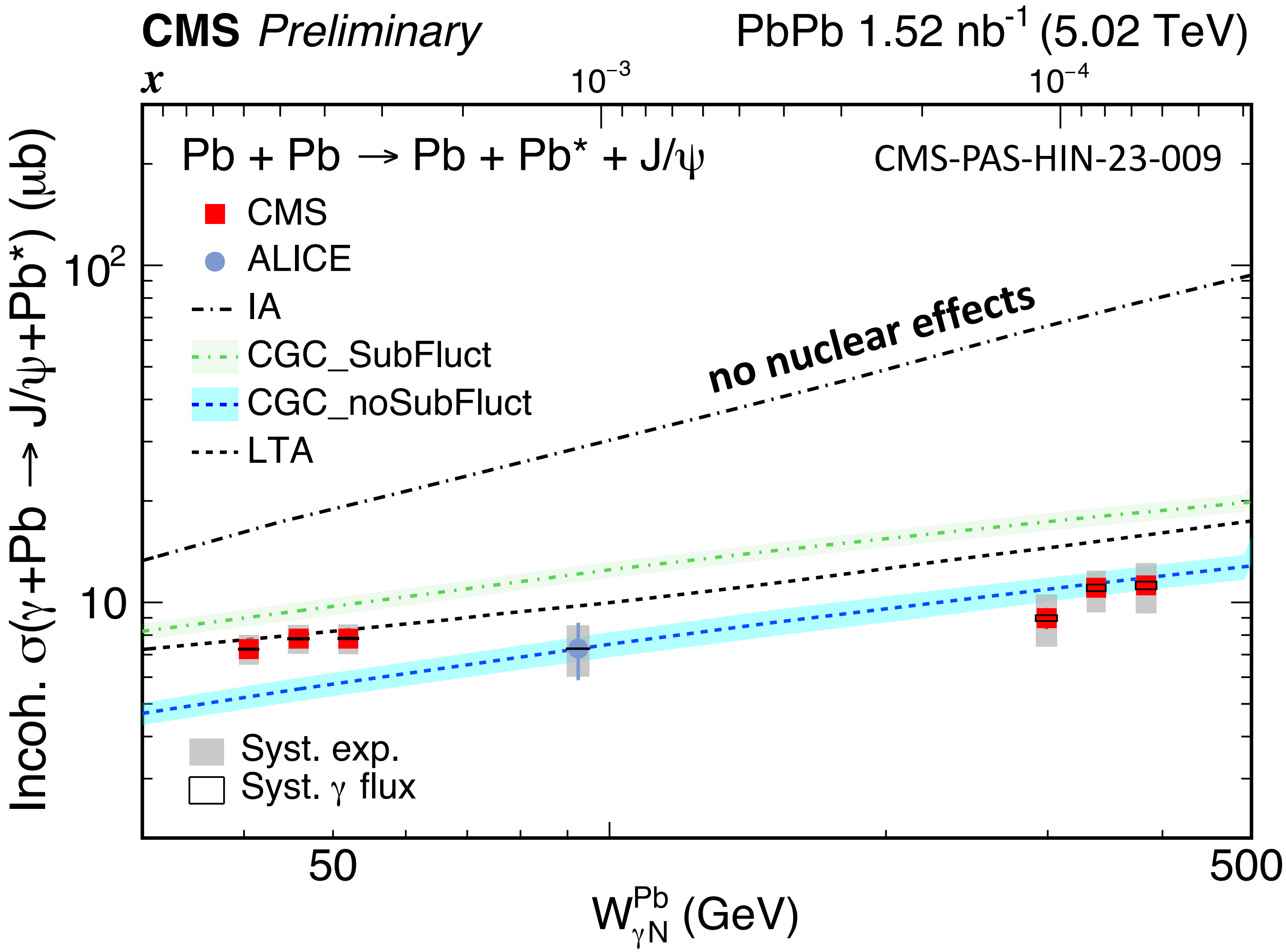
CMS-PAS-HIN-23-009

Neutrons induced by incoherent process help to identify the target nucleus and solve the two-way ambiguity

Low-x range down to 6.5 x 10^{-5}

Leading Twist Approximation cannot fully describe the data

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

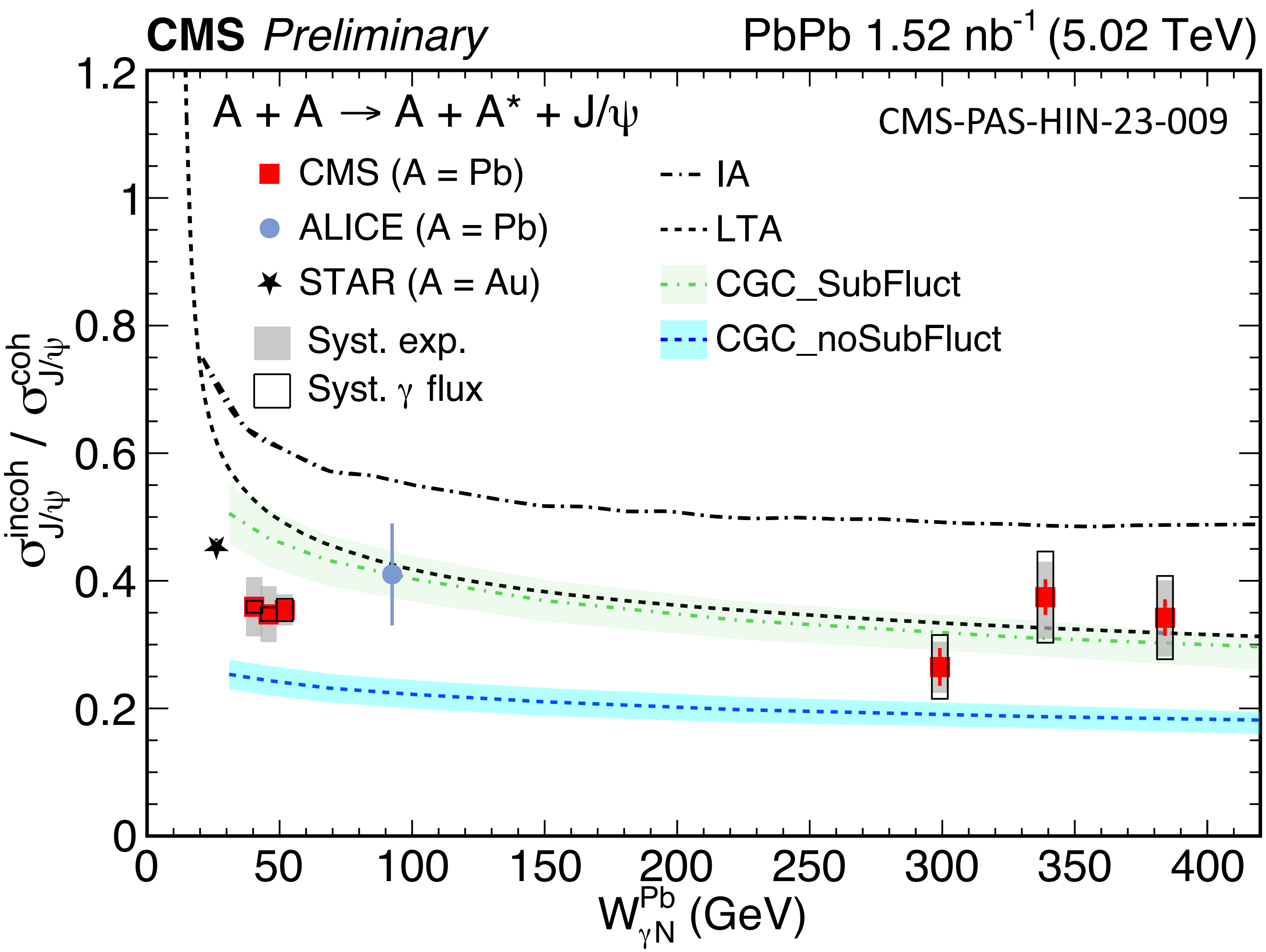


First energy-dependent measurement

Strong suppression due to nuclear effects

No theory able to capture both low & high energy results

Incoherent-coherent ratio vs $W_{\gamma N}^{Pb}$

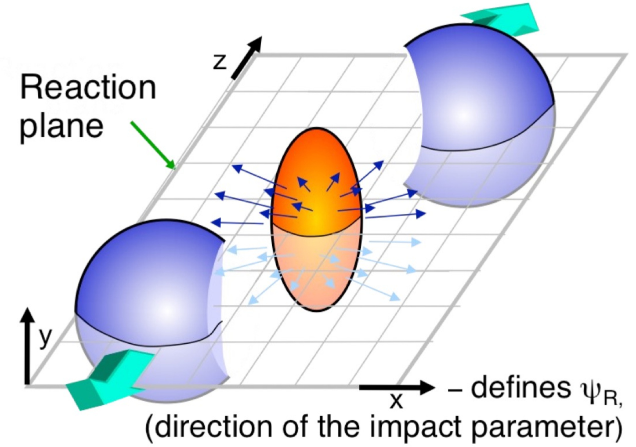


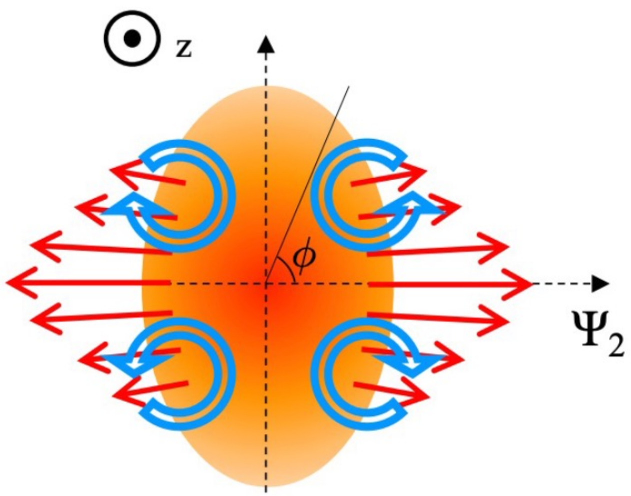
Theoretical uncertainties largely cancelled

CGC with sub-nucleon fluctuation qualitatively describe data

Constant ratio over full energy range disfavors black disk limit

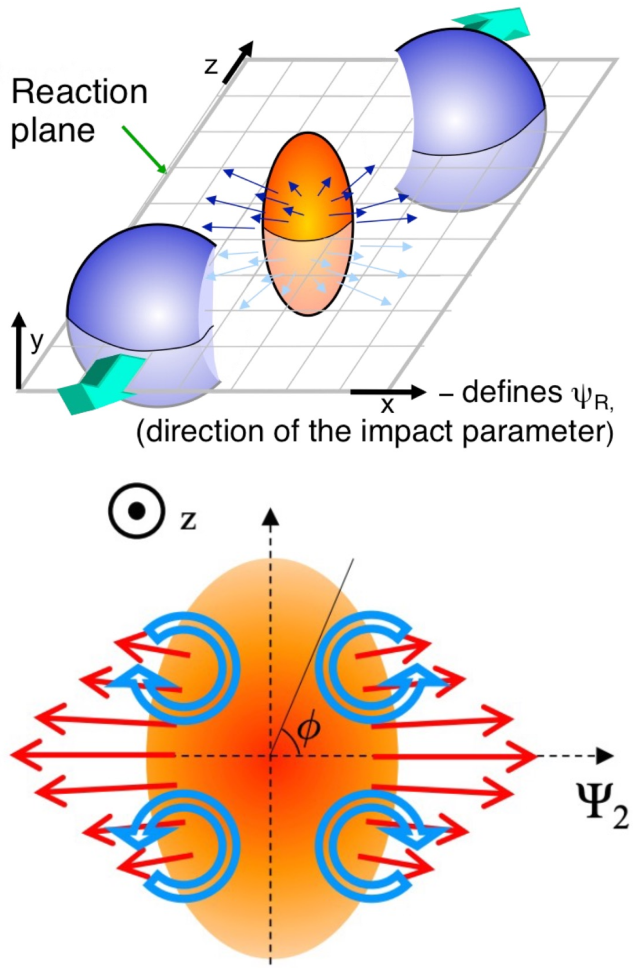
Hyperon polarization along beam direction

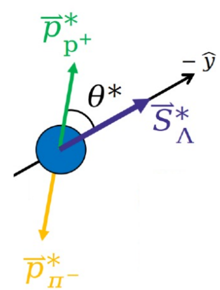


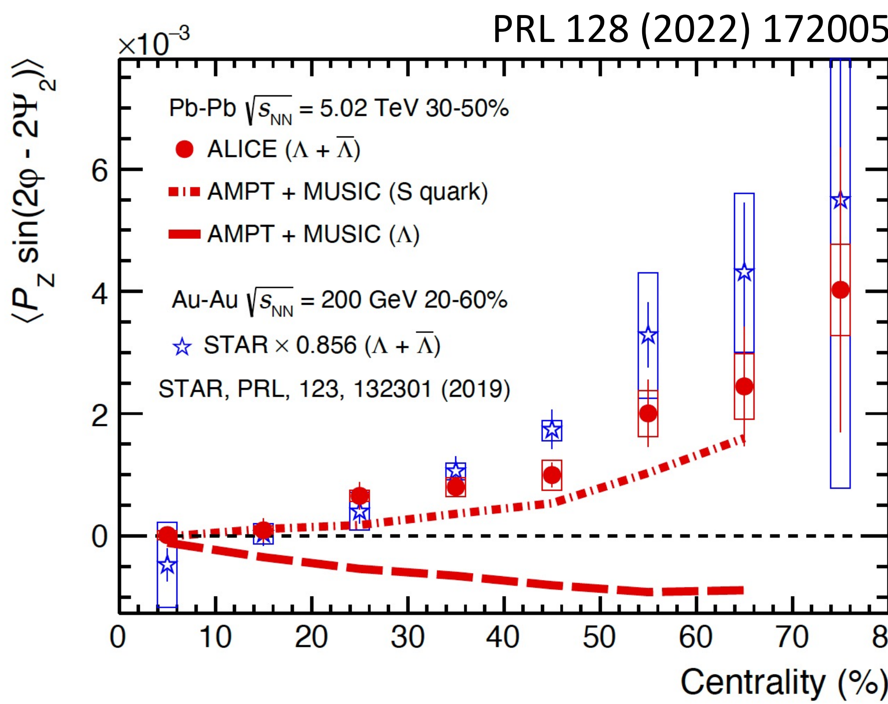


Simple expectation of vorticity from the anisotropic expansion of QGP

Hyperon polarization along beam direction







Simple expectation of vorticity from the anisotropic expansion of QGP
Measured through Lambda polarization: parity violating weak decay

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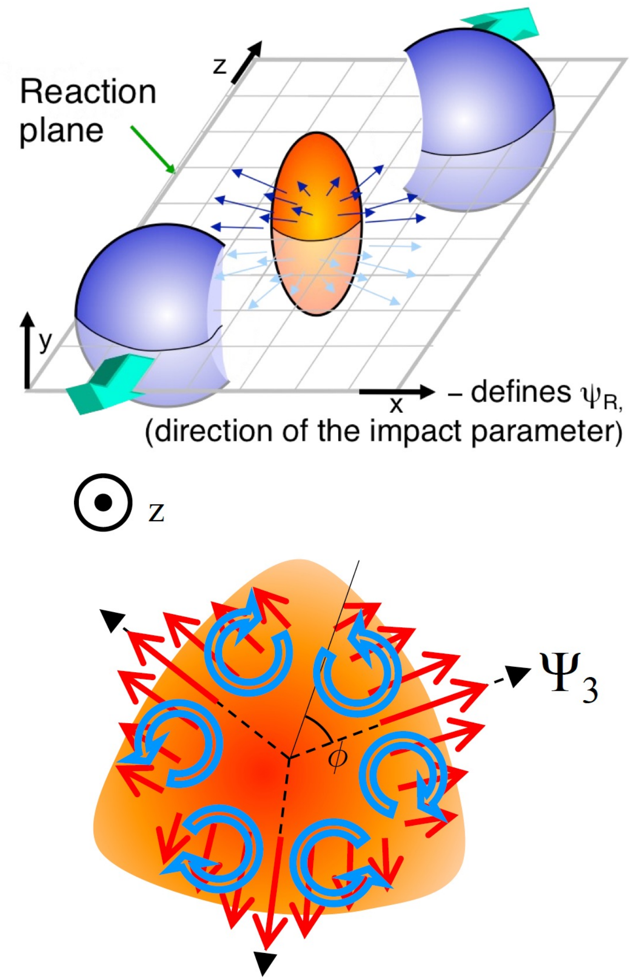
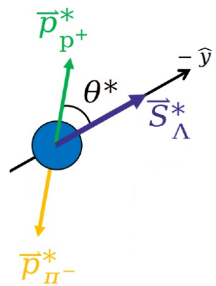
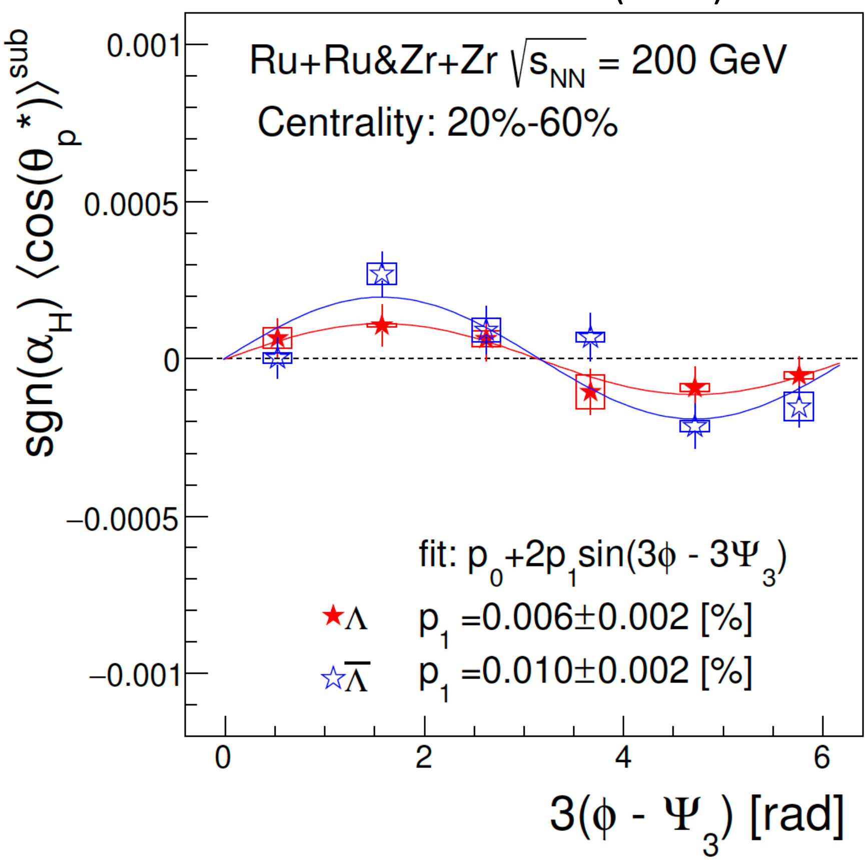




PRL 131 (2023) 202301



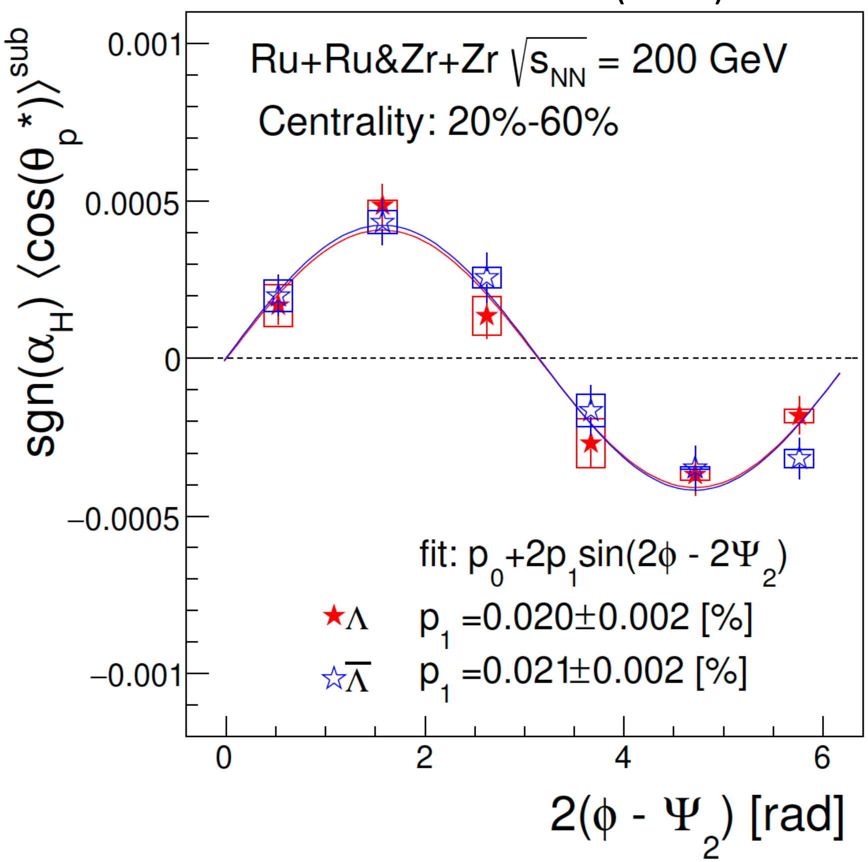
Simple expectation of vorticity from the anisotropic expansion of QGP

Measured through Lambda polarization: parity violating weak decay

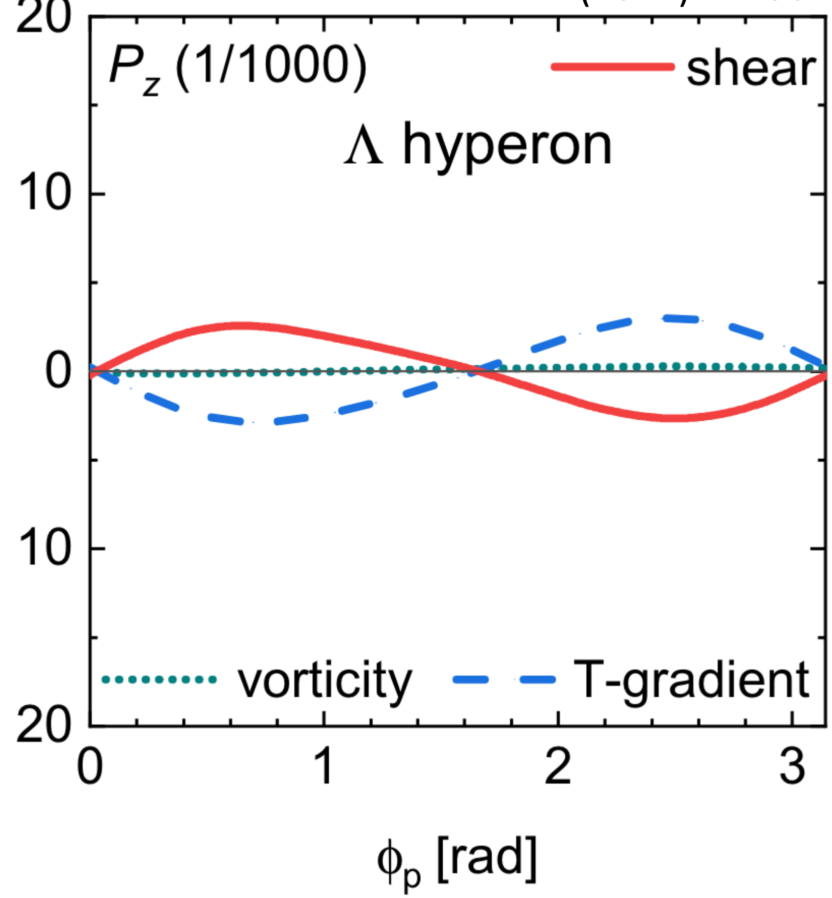
The observation of $P_{z,s3}$ indicates the relationship btw geometry & vorticity

“P_z puzzle”?

PRL 131 (2023) 202301



PRL 127 (2021) 142301

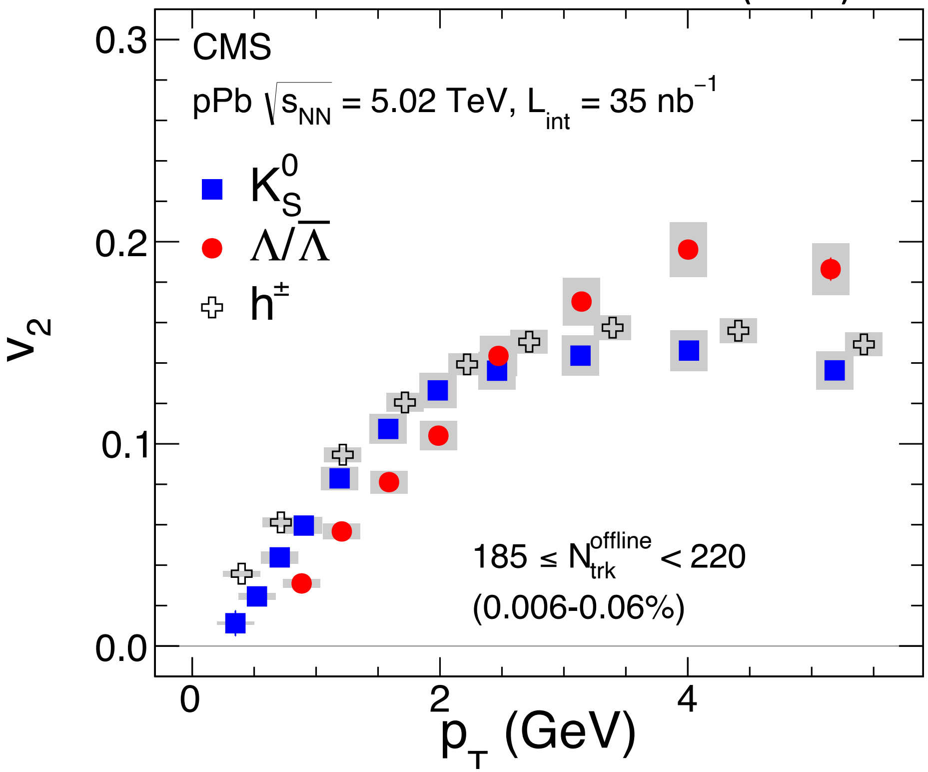


Contribution from shear induced polarization needed to get the correct sign

Calculations depend on the details of shear term implementation

Check in small system!

PLB 742 (2015) 200



Features of QGP droplets observed in small but dense systems

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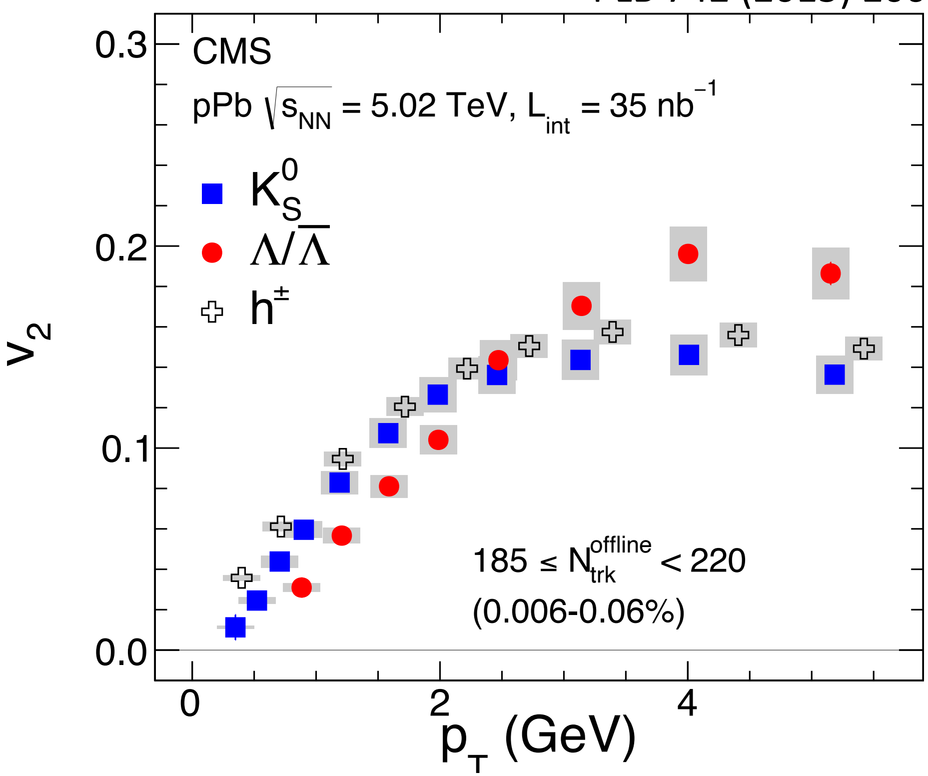
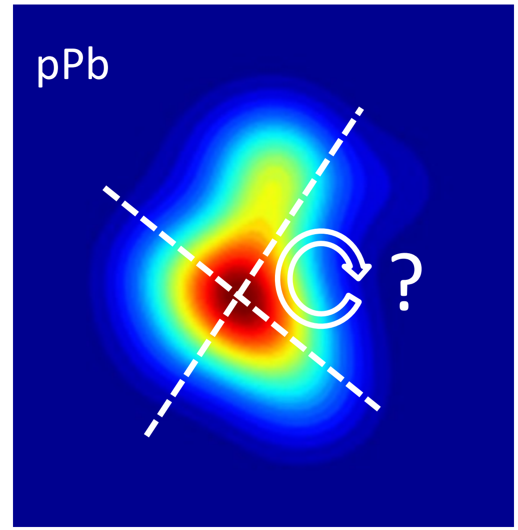
PLB 742 (2015) 200



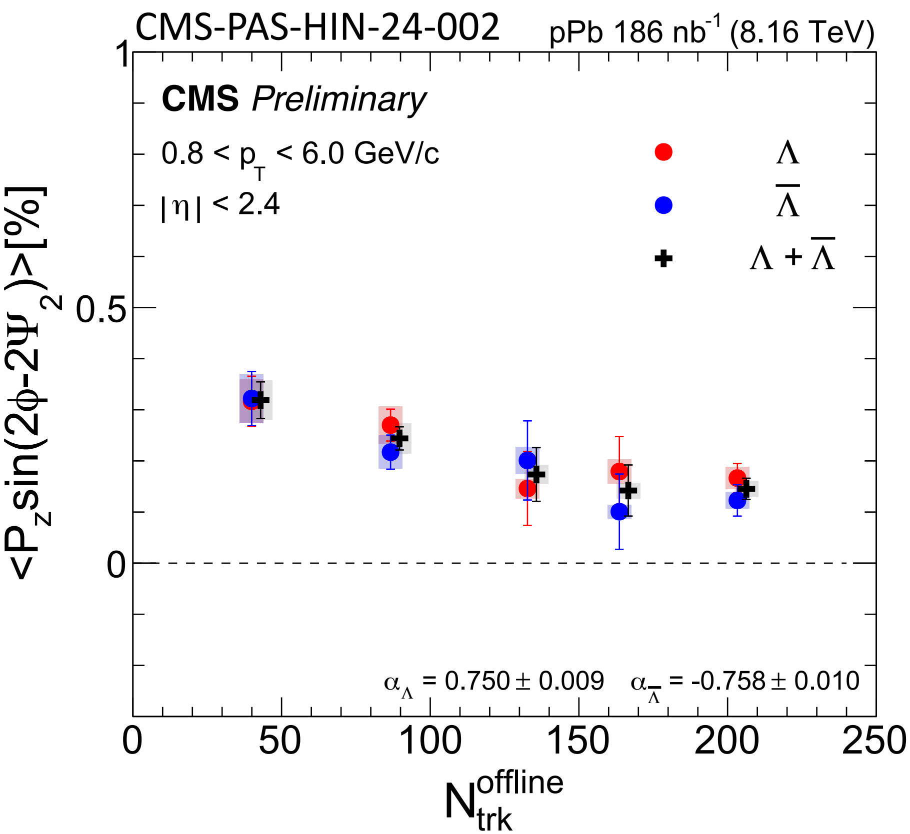


Features of QGP droplets observed in small but dense systems

Can we see hyperon polarization P_z there?

A test of QGP formation & different contributions to P_z

$P_{z,s2}$ in pPb collision



Significant positive $P_{z,s2}$ observed over entire multiplicity range

Consistent results for Λ and anti-Λ

Decrease towards high multiplicity

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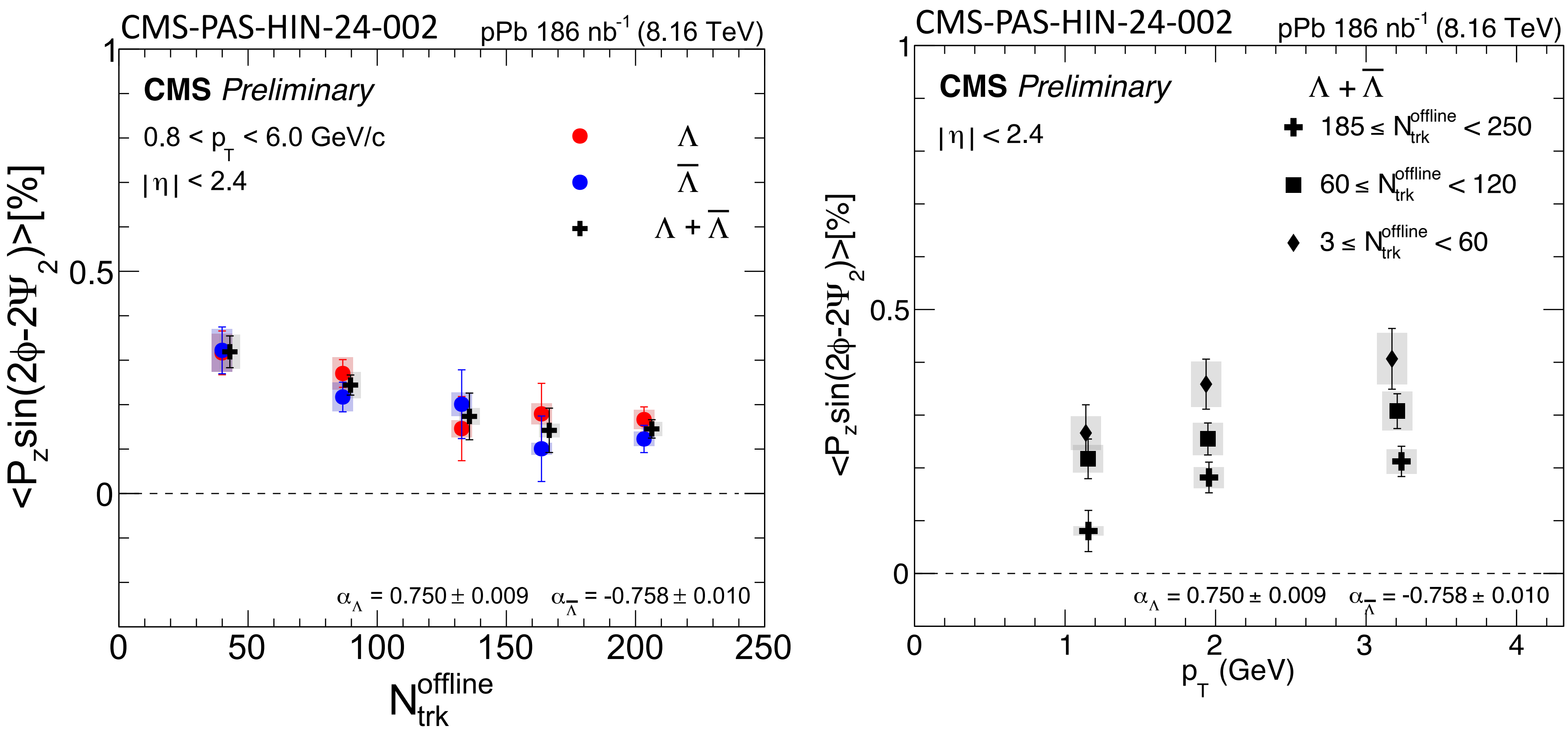


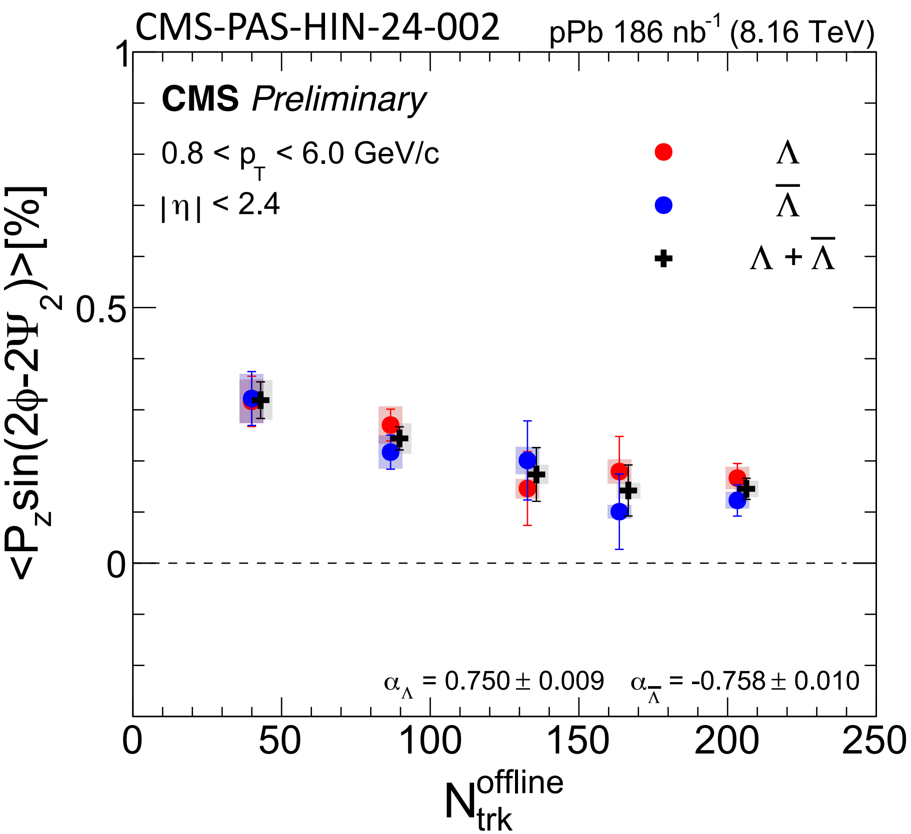
Significant positive $P_{z,s2}$ observed over entire multiplicity range

Consistent results for Λ and anti-Λ

Decrease towards high multiplicity

Increase towards higher p_T – hint of saturation at intermediate p_T

$P_{z,s2}$ from medium expansion?



Why is it increasing monotonically towards 0 multiplicity?

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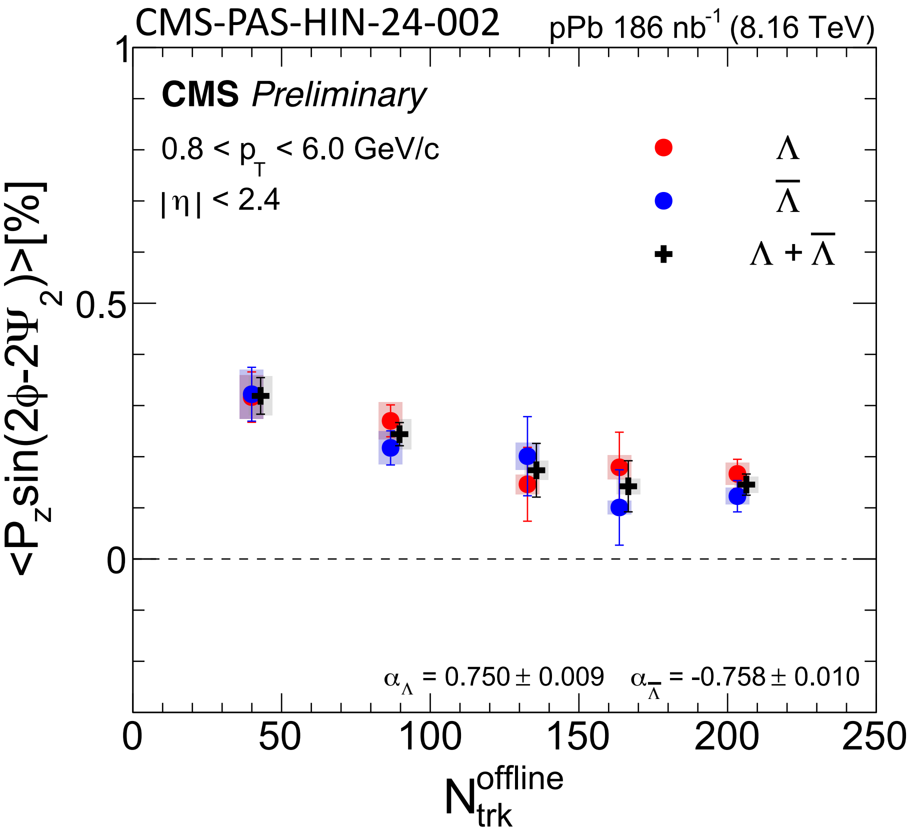
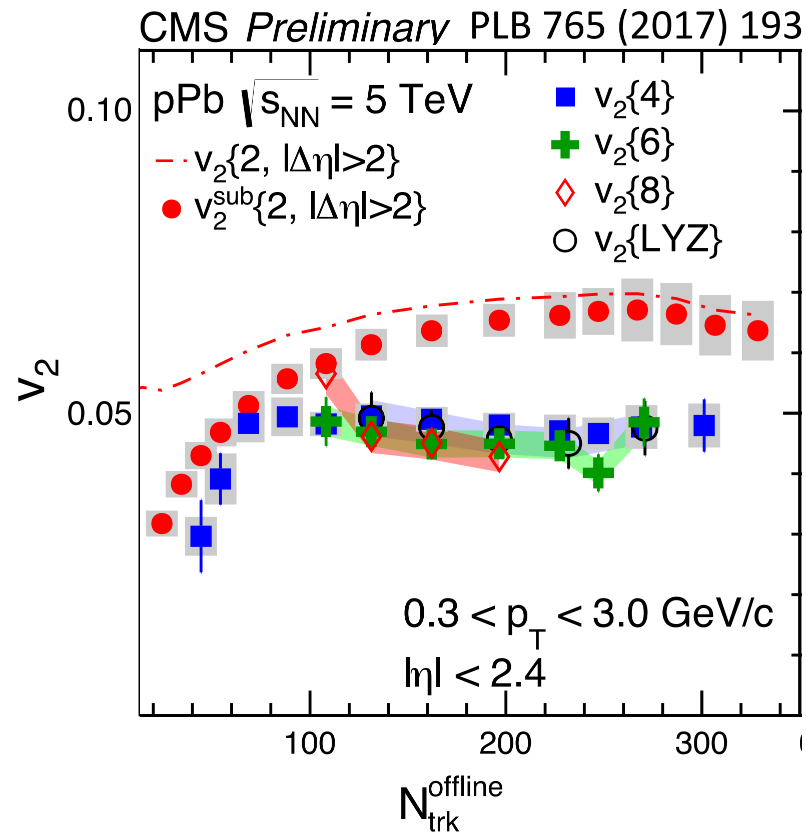


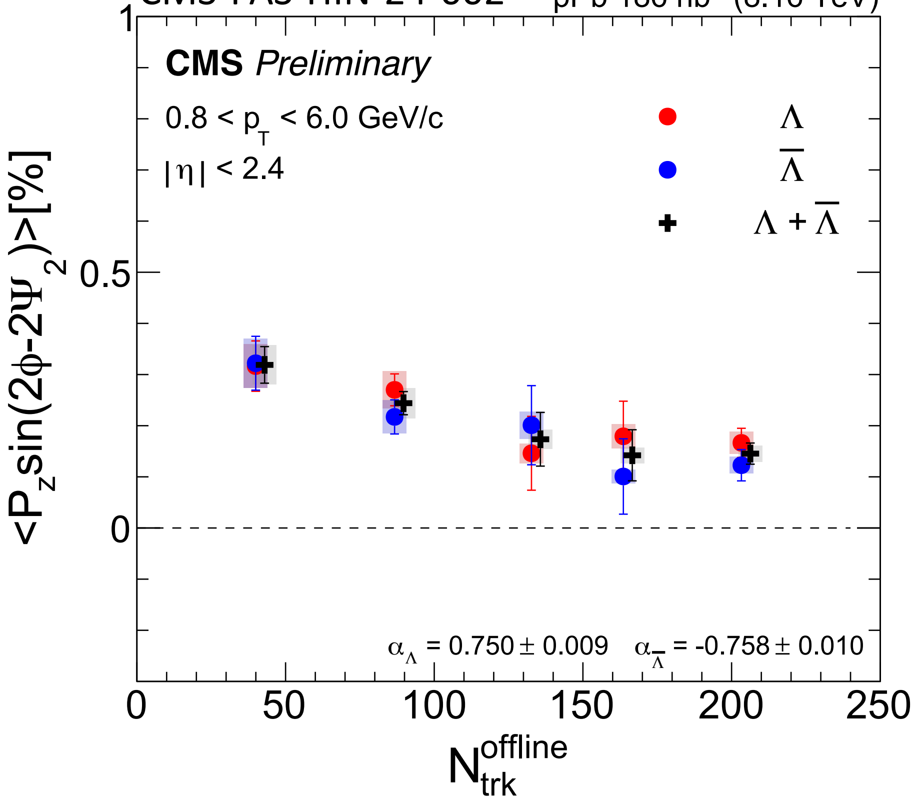


Why is it increasing monotonically towards 0 multiplicity?

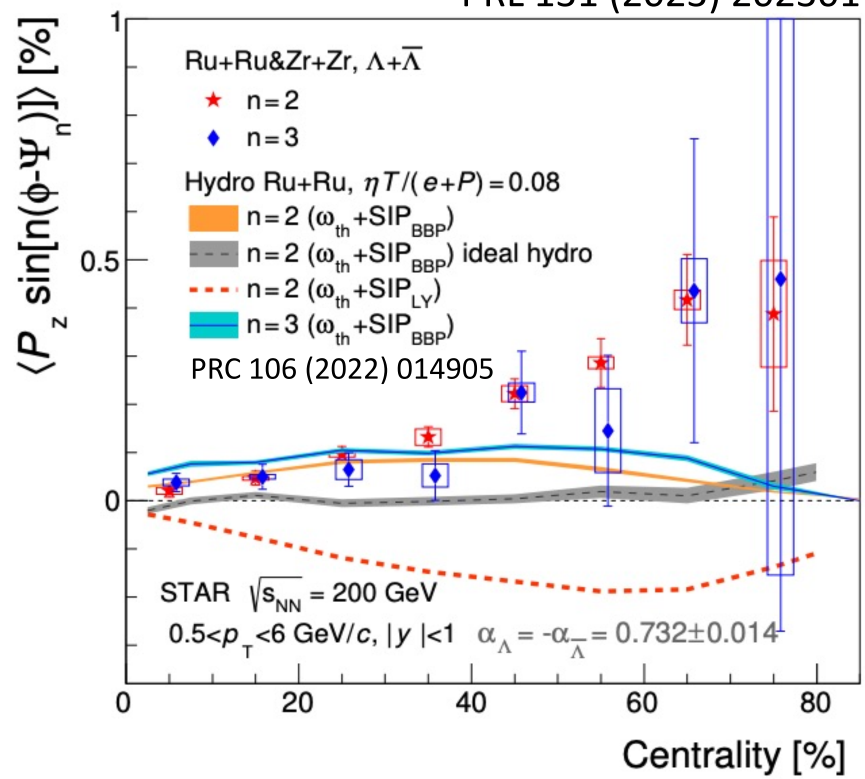
Not consistent with the trend of v_2

$P_{z,s2}$ from medium expansion?

CMS-PAS-HIN-24-002



PRL 131 (2023) 202301



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Similar to the behavior for peripheral AA; not captured by hydro?

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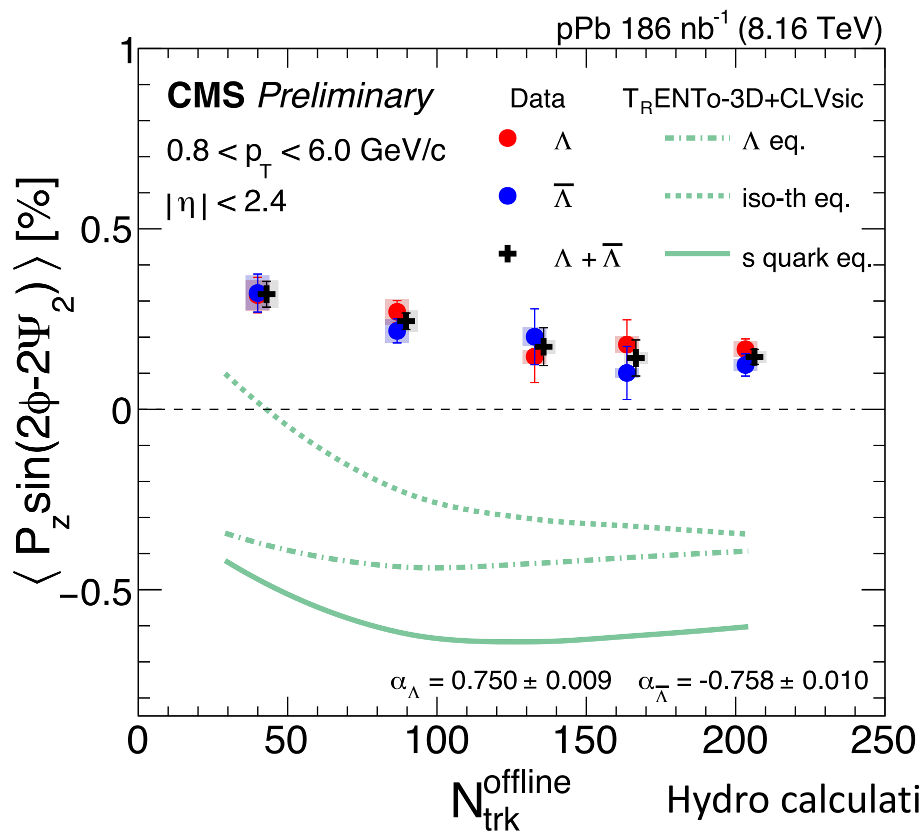

Hydro calculation arXiv:2408.04296

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A hydro calculation results in negative Pz

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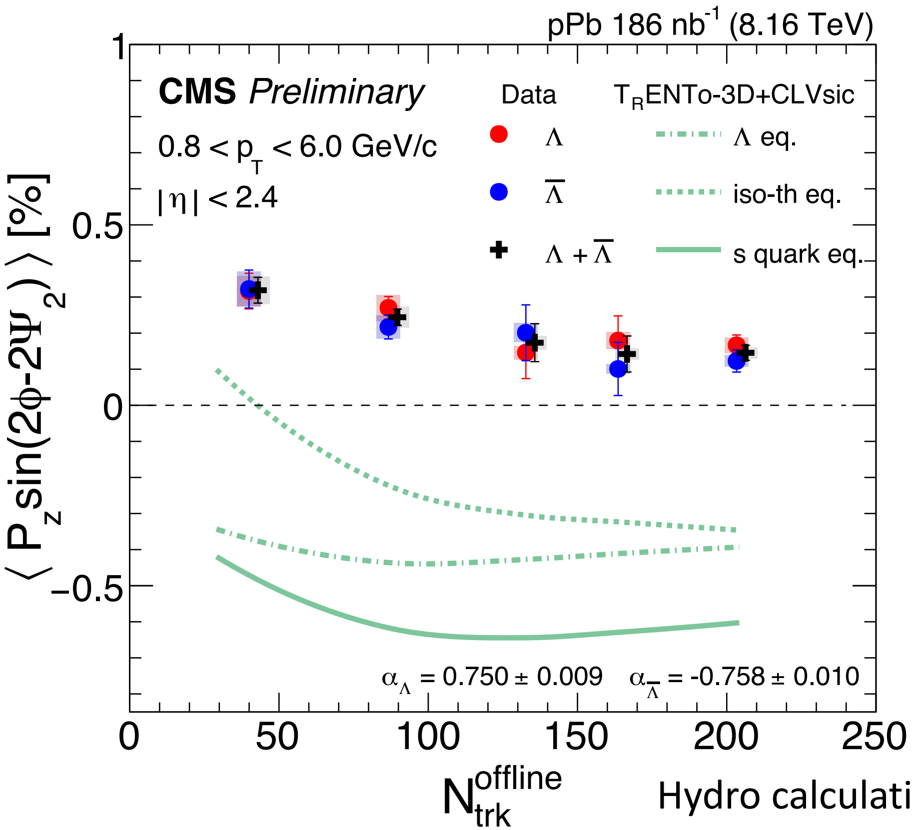

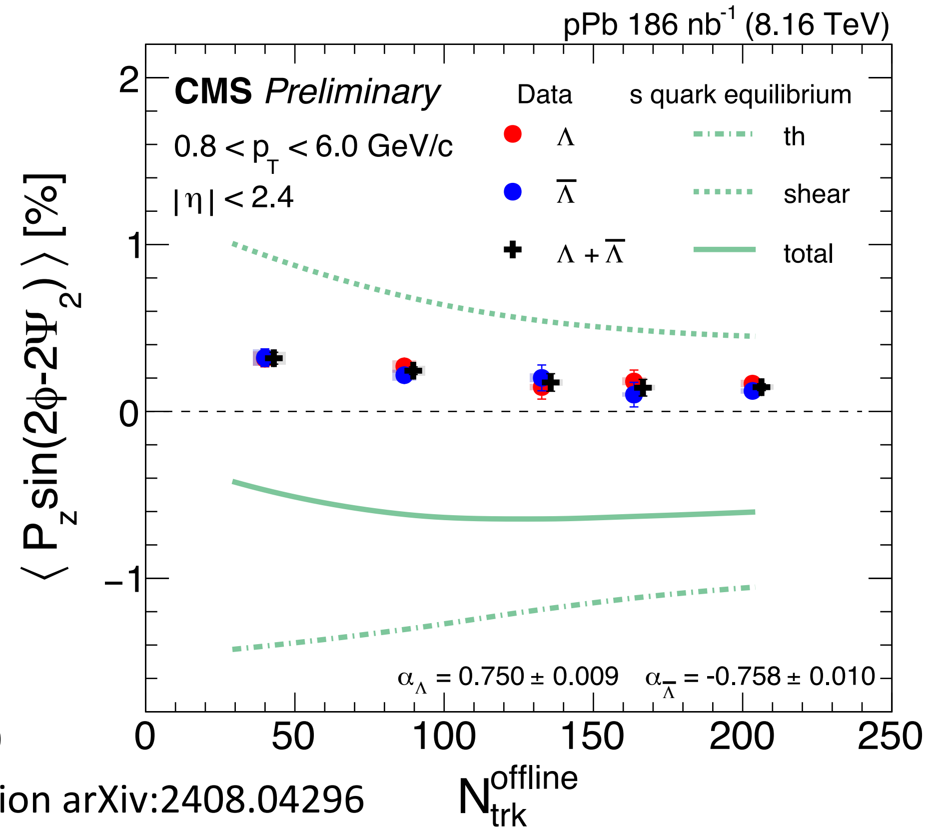

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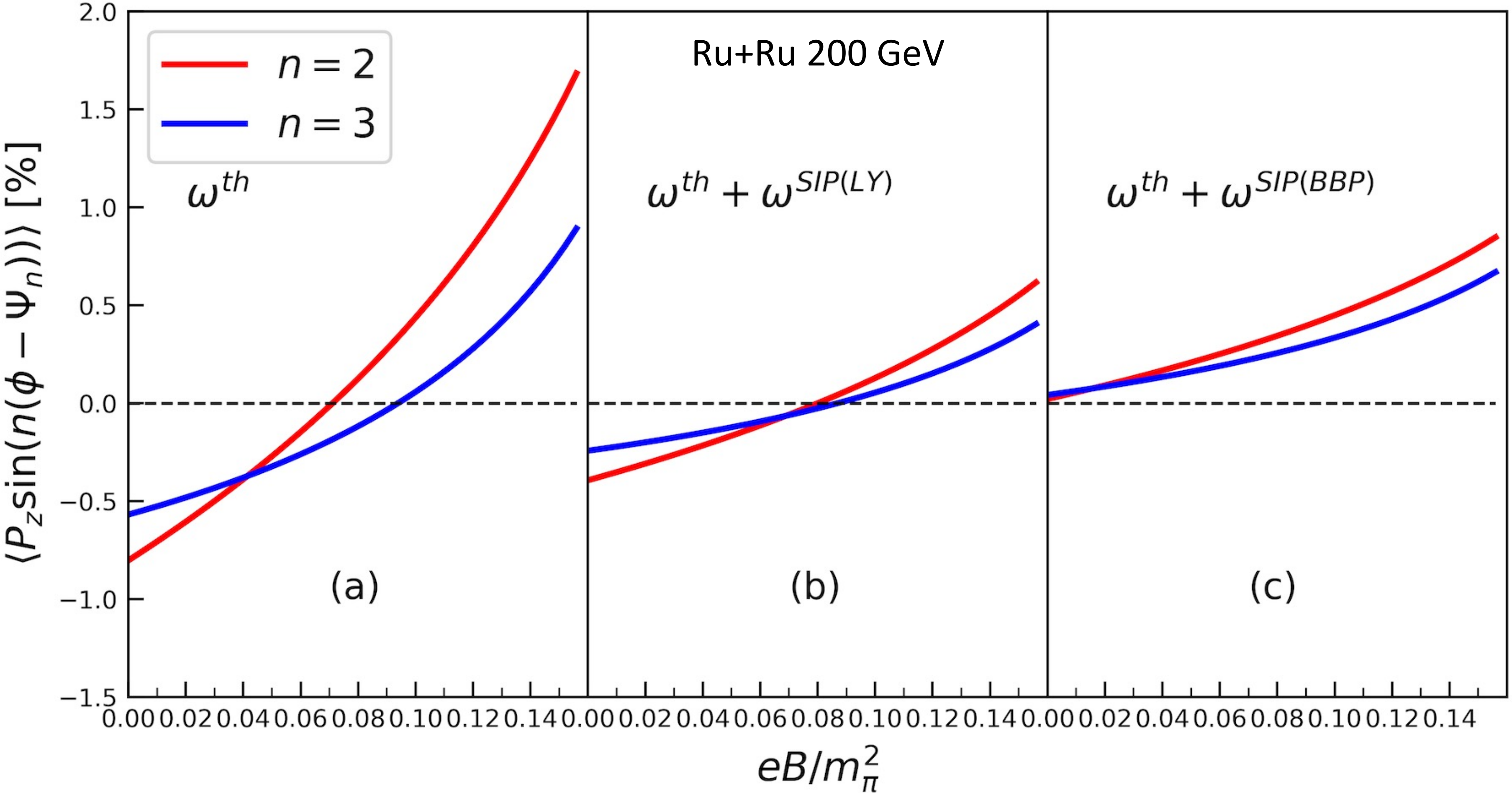
$P_{z,s2}$ from magnetic field?

arXiv:2401.07458



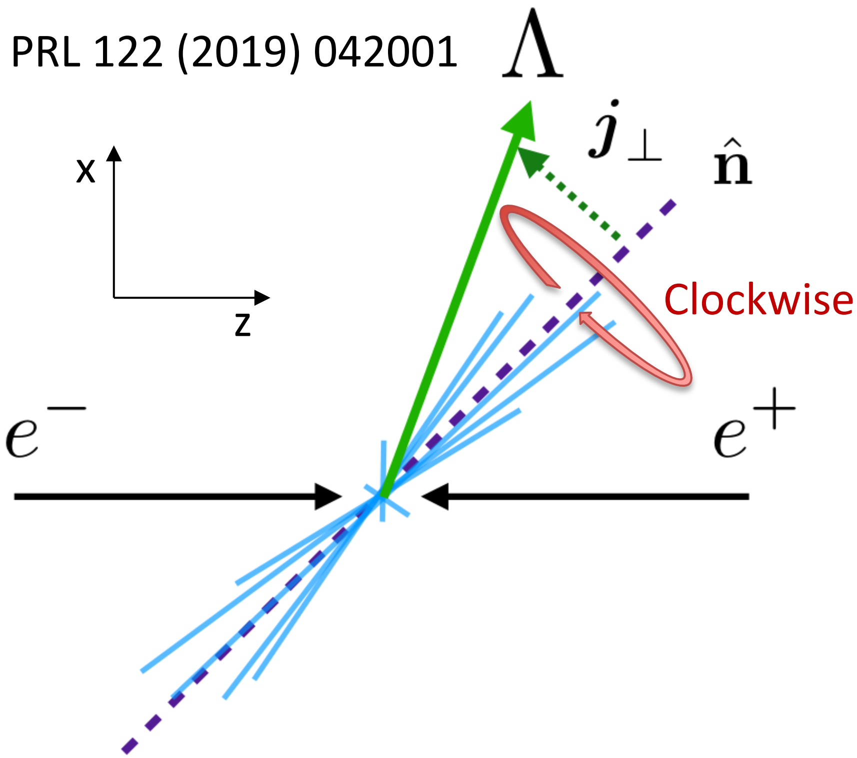
Magnetic field could flip the sign of P_z

Λ and anti-Λ should have different P_z?

Look forward to the final calculations in pPb

$P_{z,s2}$ from spin physics?

PRL 122 (2019) 042001



Transverse polarization of Λ has been a long standing puzzle

Recent Belle measurement in e^+e^- shows a significant signal wrt thrust axis

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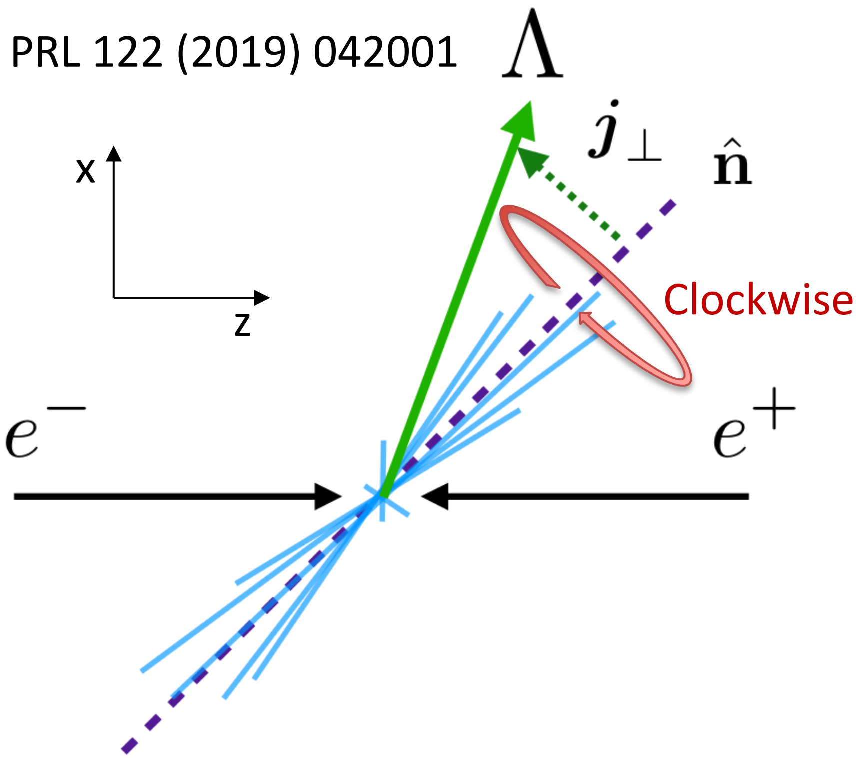
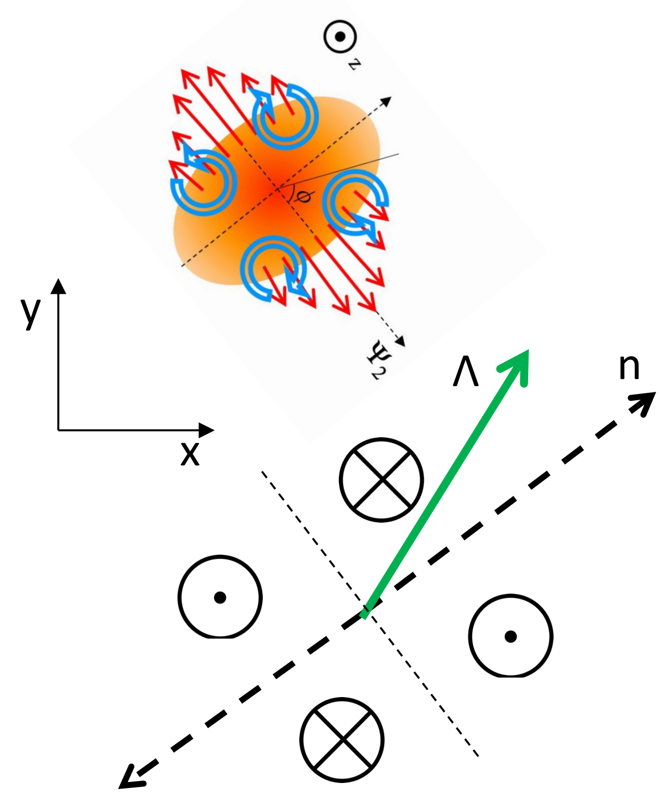
PRL 122 (2019) 042001





Transverse polarization of Λ has been a long standing puzzle

Recent Belle measurement in e^+e^- shows a significant signal wrt thrust axis

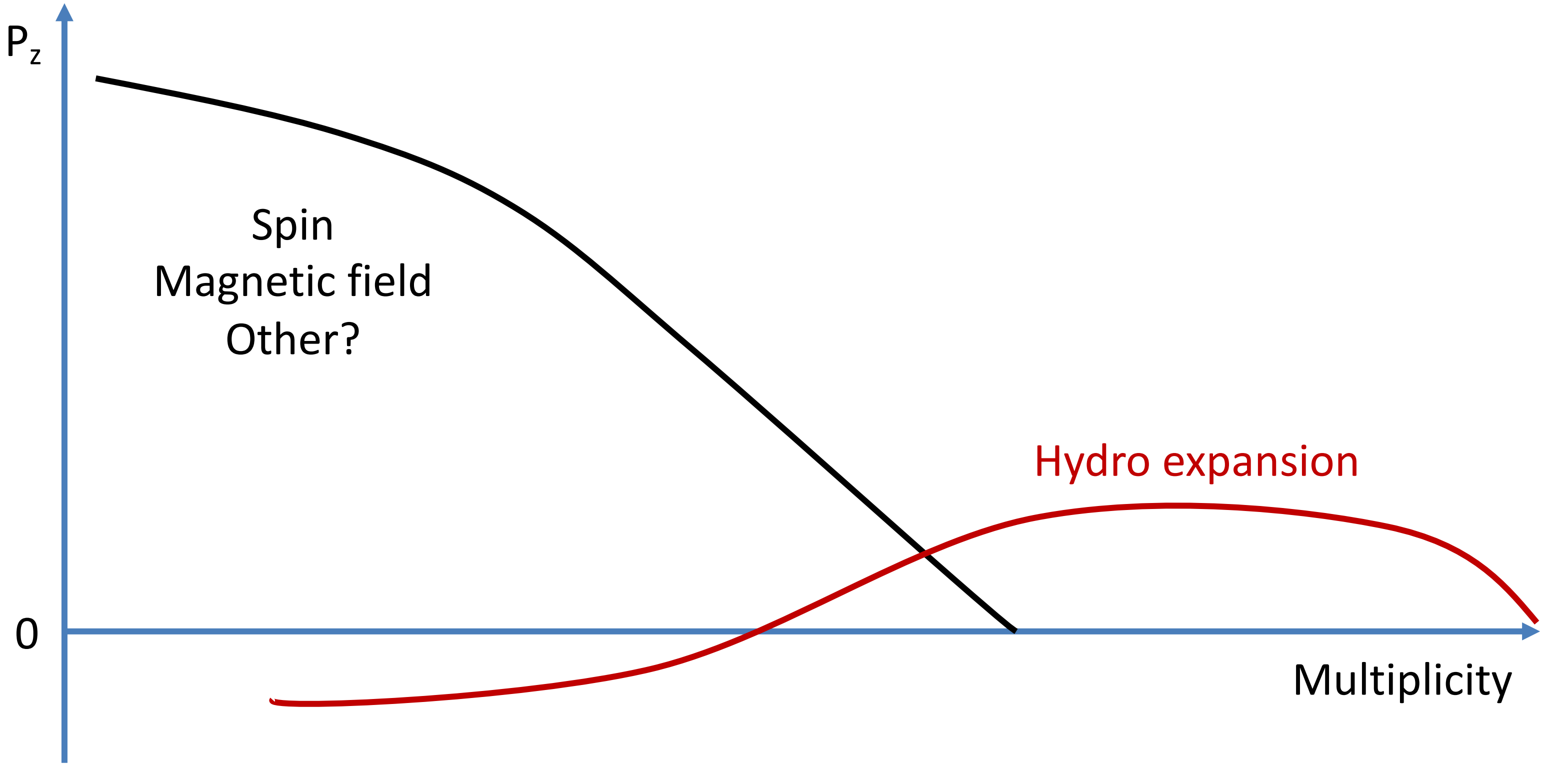
Projection into x-y plane introduce a P_z wrt thrust axis

Thrust axis coincide with 2nd order event plane at low multiplicity

Opposite direction than our signal, but could have a z_Λ dependence

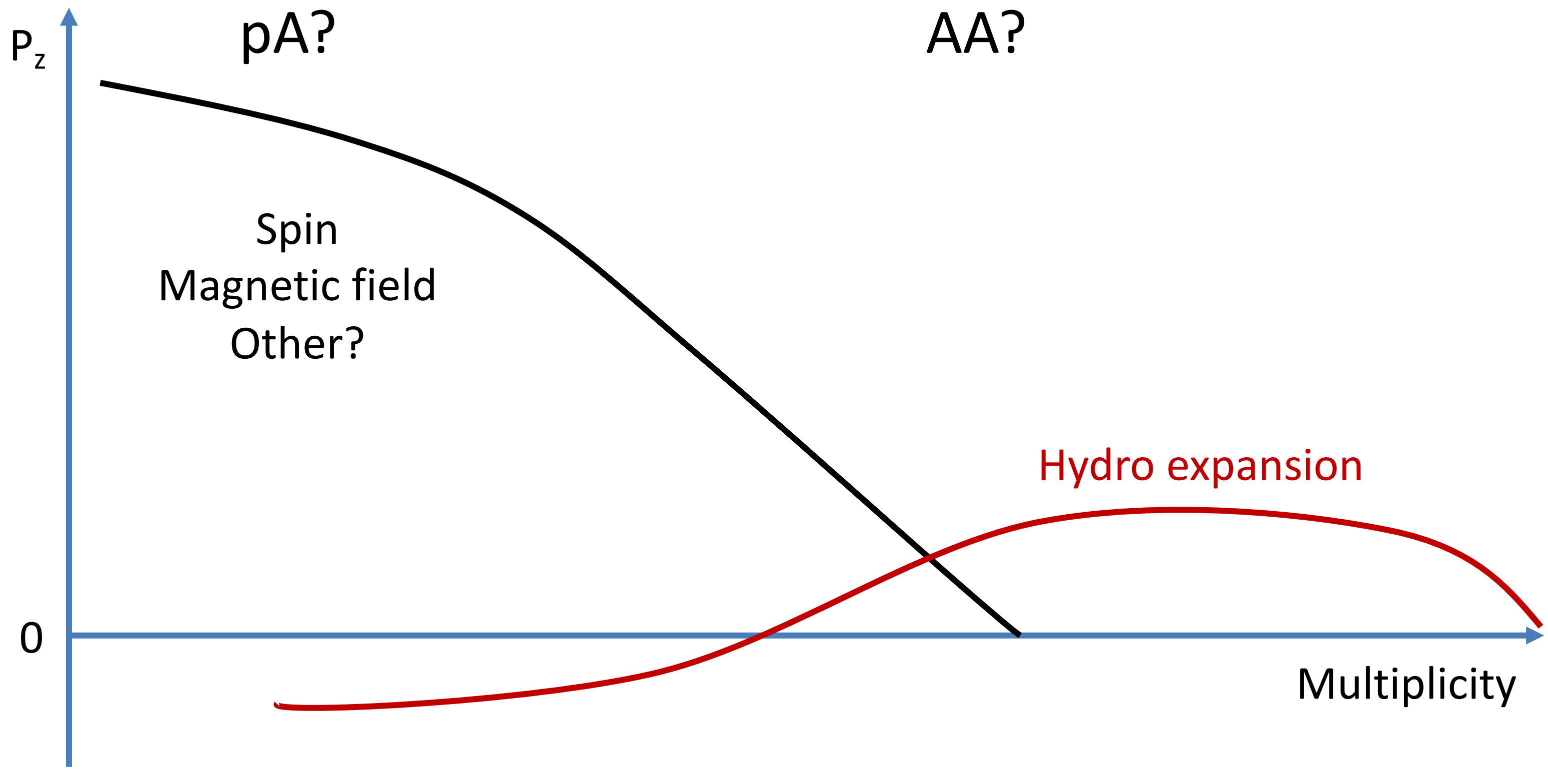
Diluted towards high multiplicity

Different contributions vs multiplicity?



A naïve guess of the picture

Different contributions vs multiplicity?



A naïve guess of the picture

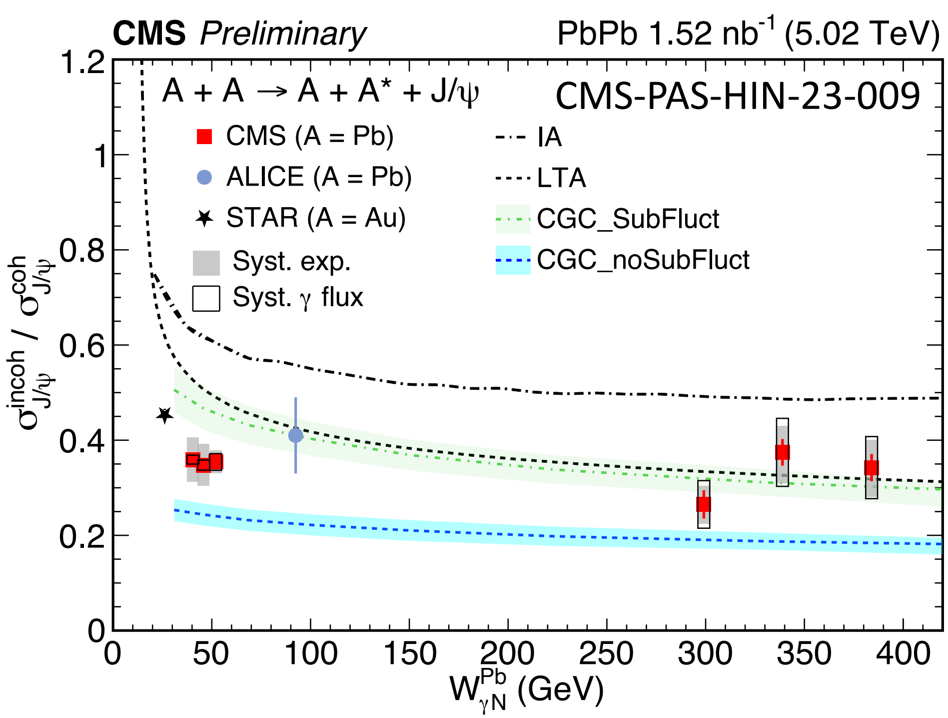
Where is the switching point and what does it imply for AA?

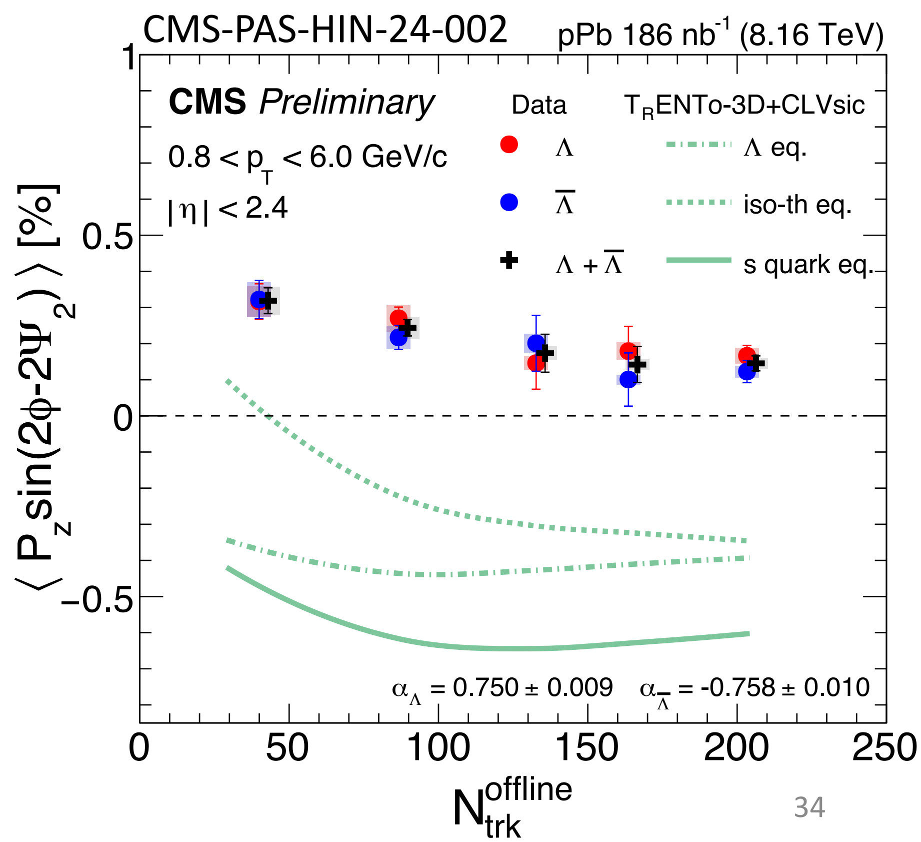
Potential to reveal connections between different physics mechanisms

Summary

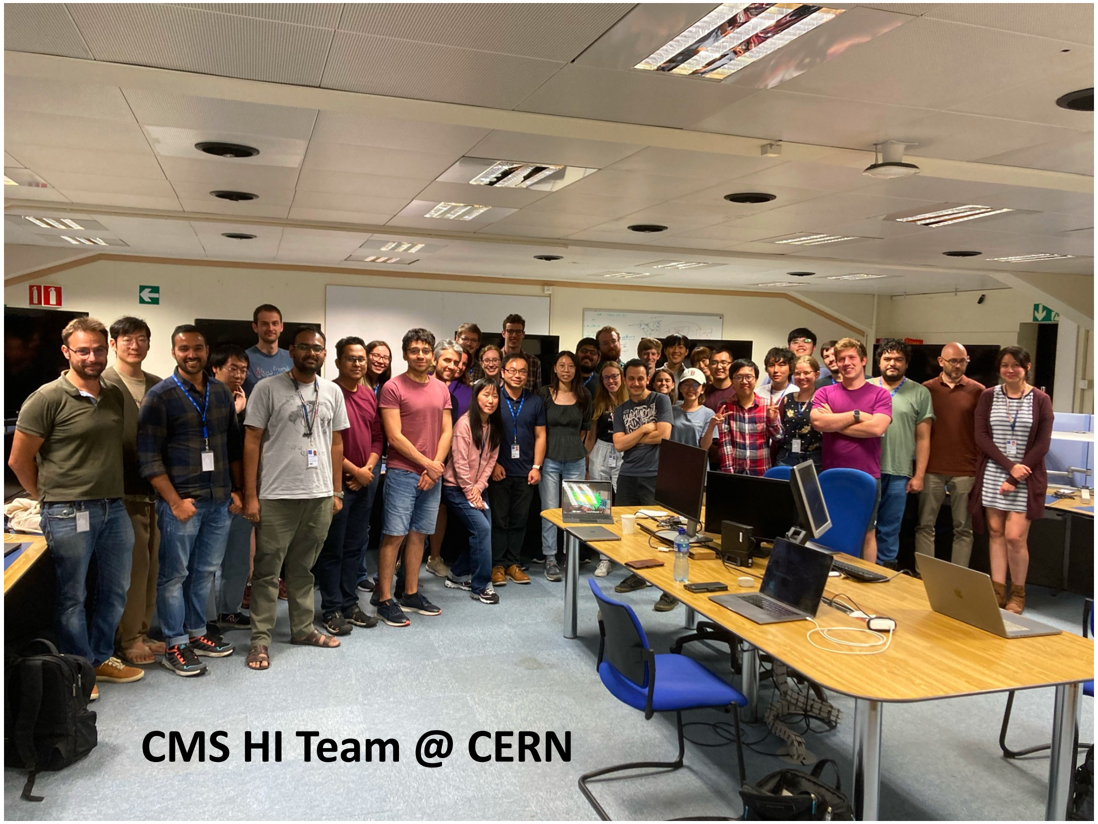
CMS Heavy Ion Chinese group is playing leading roles in

- Vector meson production in ultra-peripheral collision
  - Indication of gluon saturation observed
- Hyperon polarization in small system
  - New insights into polarization mechanism

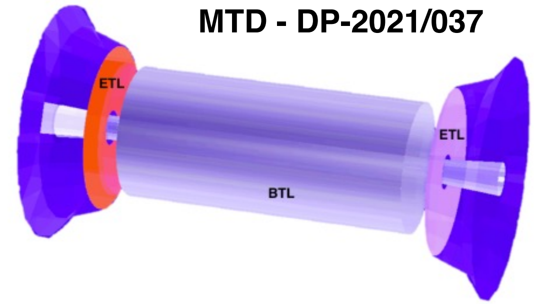


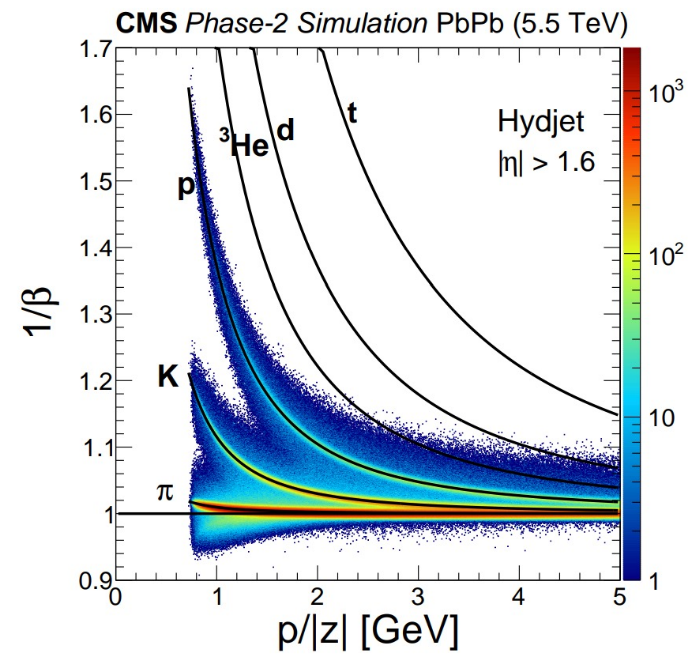


The future: Run3 & 4



CERN-LHCC-2021-018
MTD - DP-2021/037

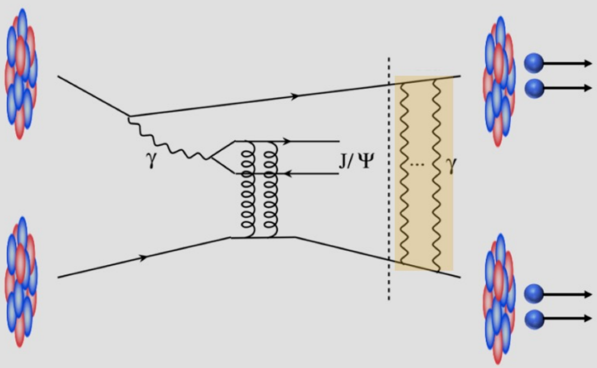




Large PbPb and pPb data sets on the way (2023-2032)
Adding PID and pileup rejection with MIP Timing Detector
Much more fun results to come!!

Back up

Coherent & incoherent process



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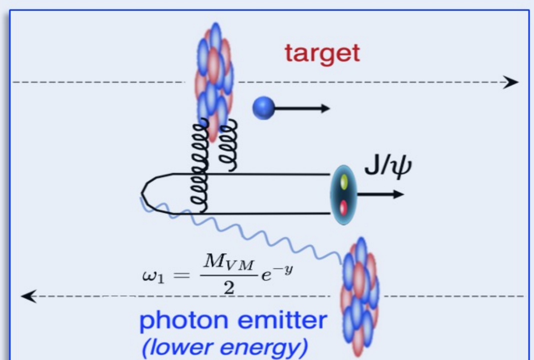
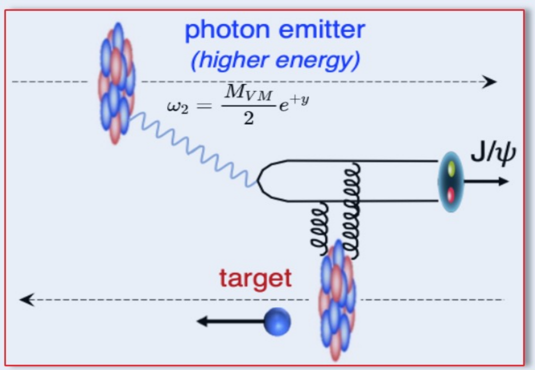
from theoretical calculation

$$\frac{d\sigma^{XnXn}_{AA\to AA'J/\psi}}{dy} = N^{XnXn}_{\gamma/A}(\omega_1)\cdot \sigma_{\gamma A\to J/\psi A'(\omega_1)} + N^{XnXn}_{\gamma/A}(w_2)\cdot \sigma_{\gamma A\to J/\psi A'(w_2)}$$

Coh. J/Ψ Xsec at ω_1 and ω_2 are solved by using EMD-induced neutrons



J/Ψ -Xn (Same Direction)



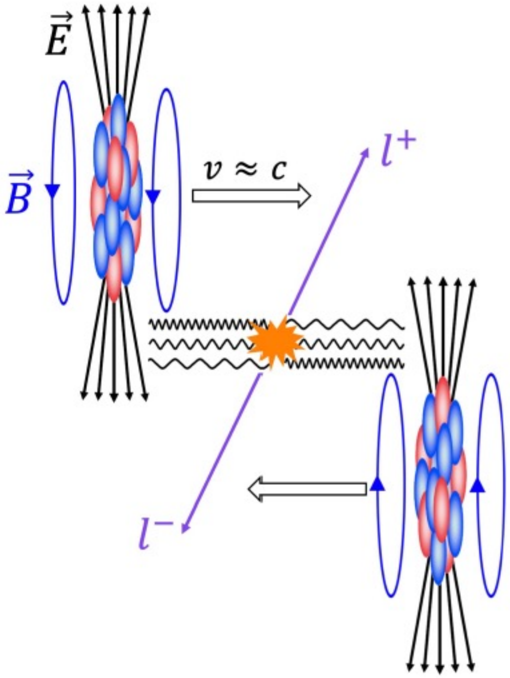
J/Ψ-Xn (Opposite Direction)

Incoh. J/Ψ process itself has ~85% chance to induce the forward neutrons

→ Detecting these neutrons will identify the target nucleus

→ Solve Incoh. **J/Ψ** Xsec at ω_1 and ω_2

$\gamma\gamma \rightarrow l^+l^-$



Collision of magnetic fields equivalent to collision of lights

$\gamma\gamma \rightarrow l^+l^-$ $\langle p_T \rangle$ puzzle

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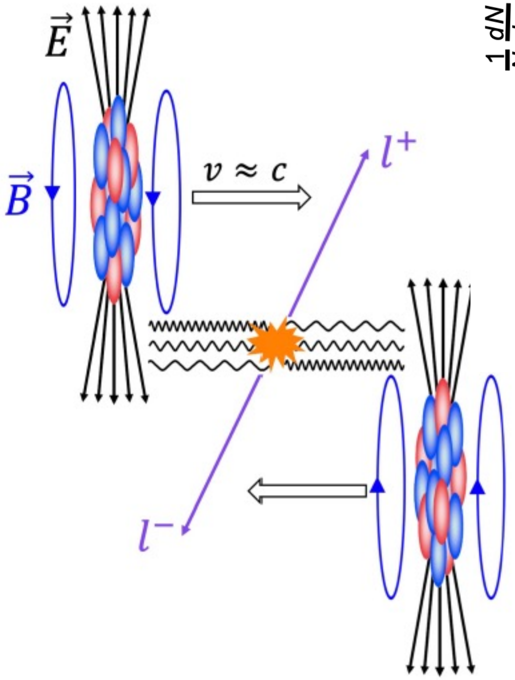
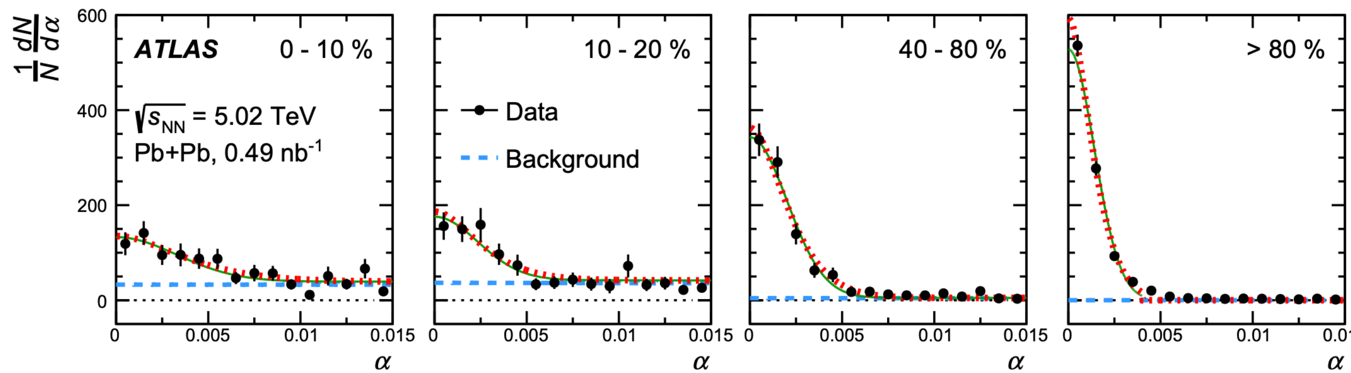
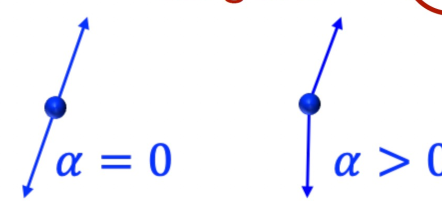




$$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}, \alpha \propto p_T^{l^+l^-}$$

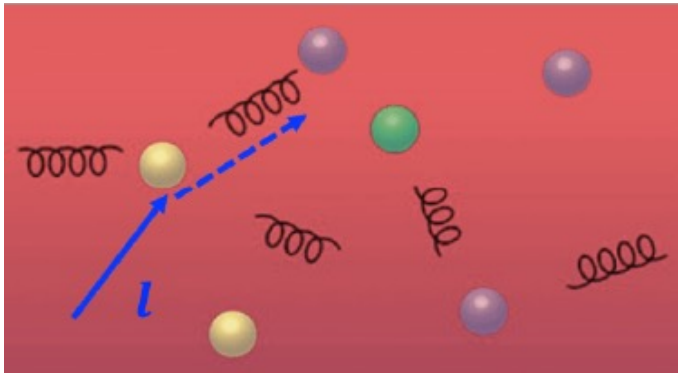


Collision of magnetic fields equivalent to collision of lights

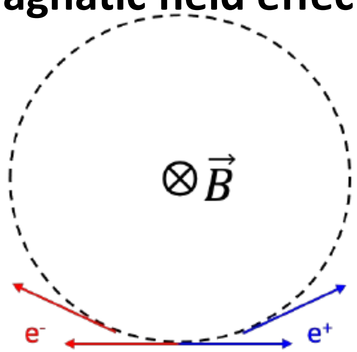
Increase in $\langle p_T \rangle$ of lepton pair towards small impact parameter

$\gamma\gamma \rightarrow l^+l^-$ $\langle p_T \rangle$ puzzle

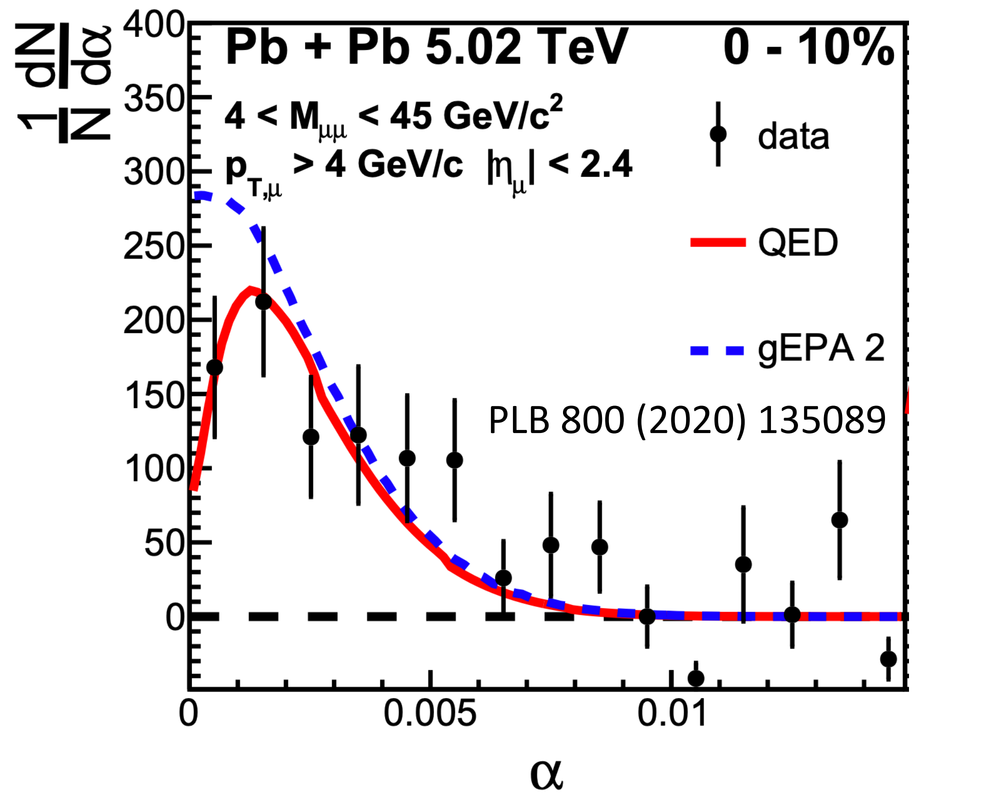
Medium modification



Magnatic field effects



Impact parameter dependent initial photon p_T



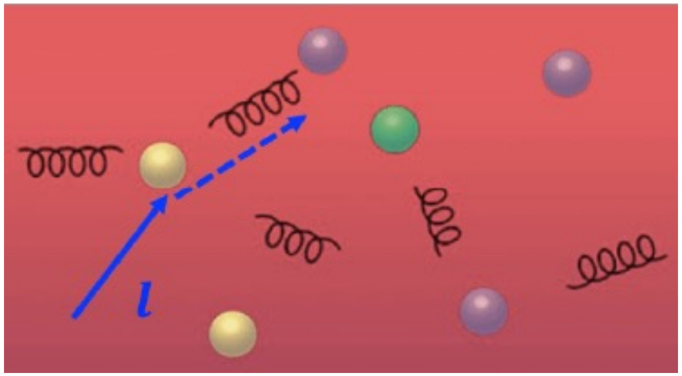
Collision of magnetic fields equivalent to collision of lights

Increase in $\langle p_T \rangle$ of lepton pair towards small impact parameter

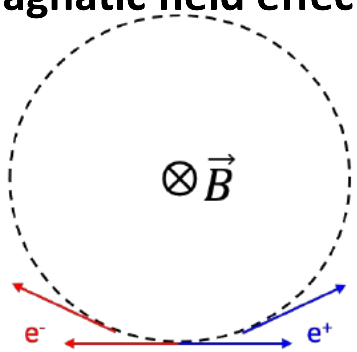
Multiple possible explanations

$\gamma\gamma \rightarrow l^+l^-$ <p_T> puzzle

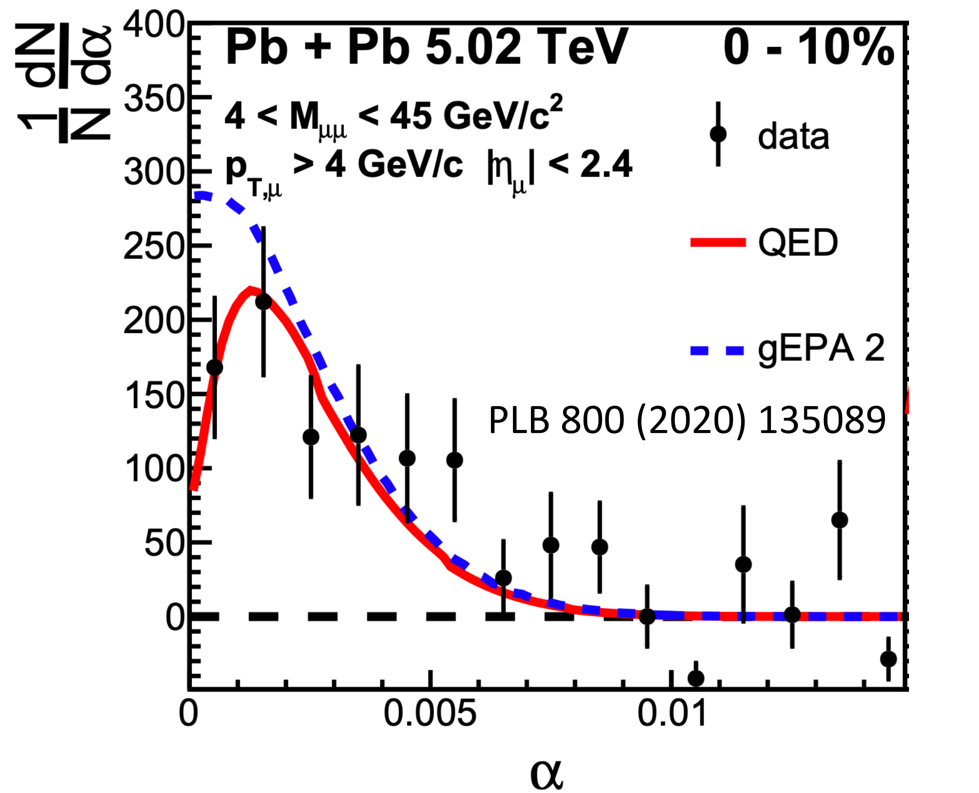
Medium modification



Magnatic field effects



Impact parameter dependent initial photon p_T



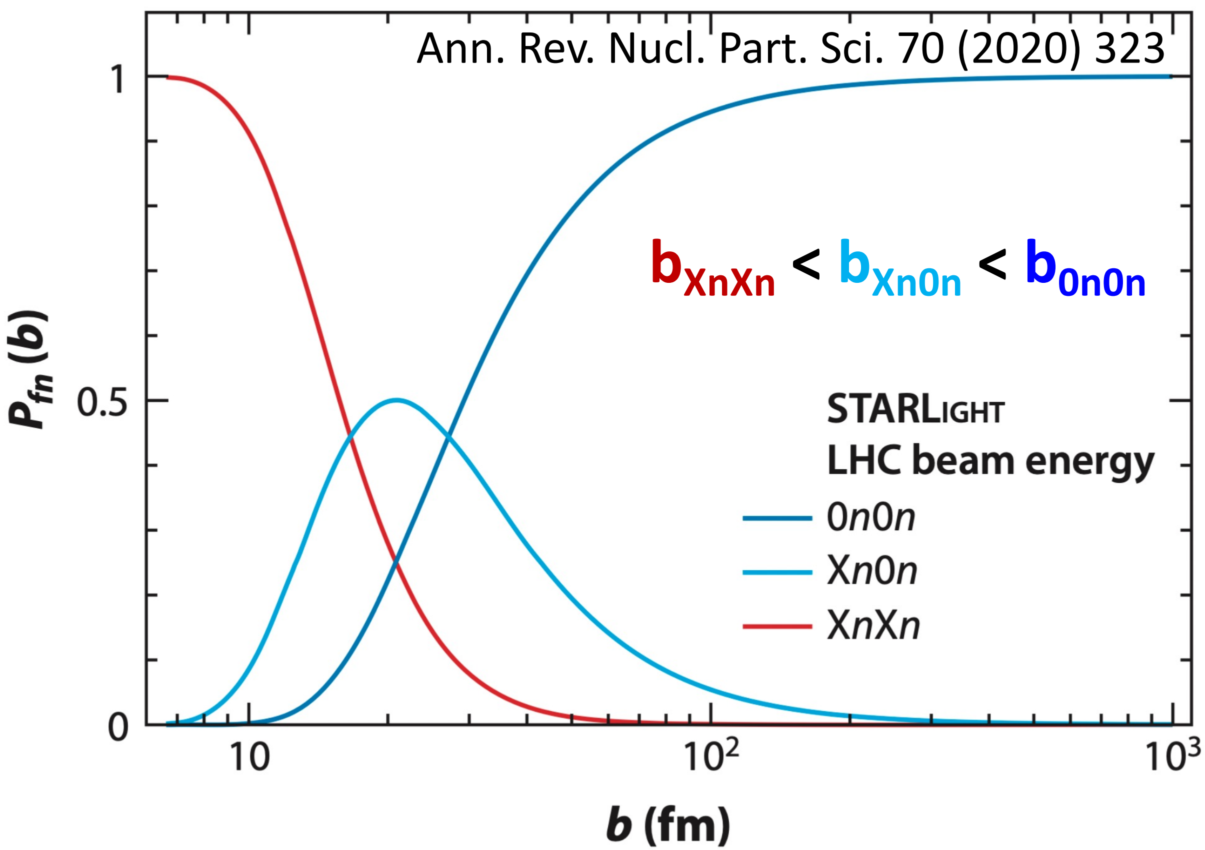
Collision of magnetic fields equivalent to collision of lights

Increase in <p_T> of lepton pair towards small impact parameter

Multiple possible explanations

How to distinguish/disentangle them?

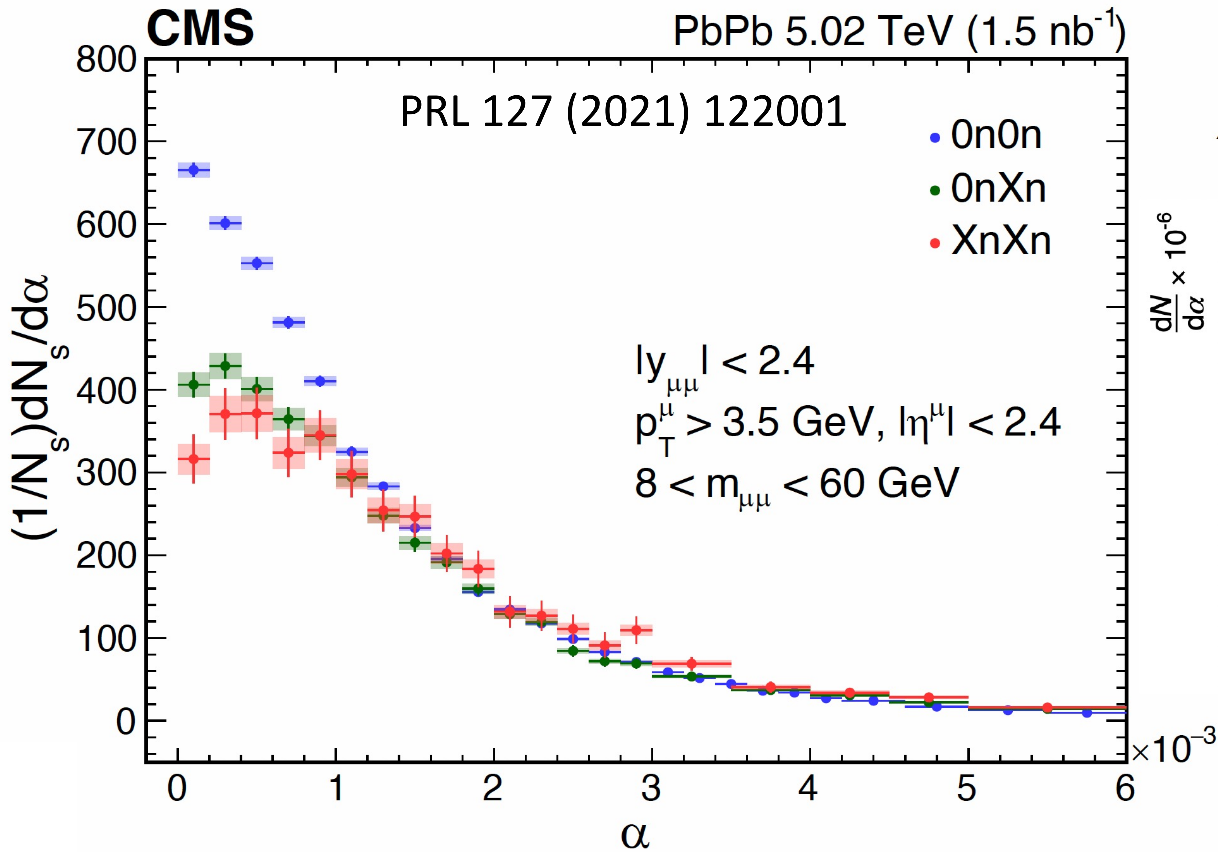
Control impact parameter in UPC by $N_{neutron}$



Impact parameter can be controlled by selecting $N_{neutron}$

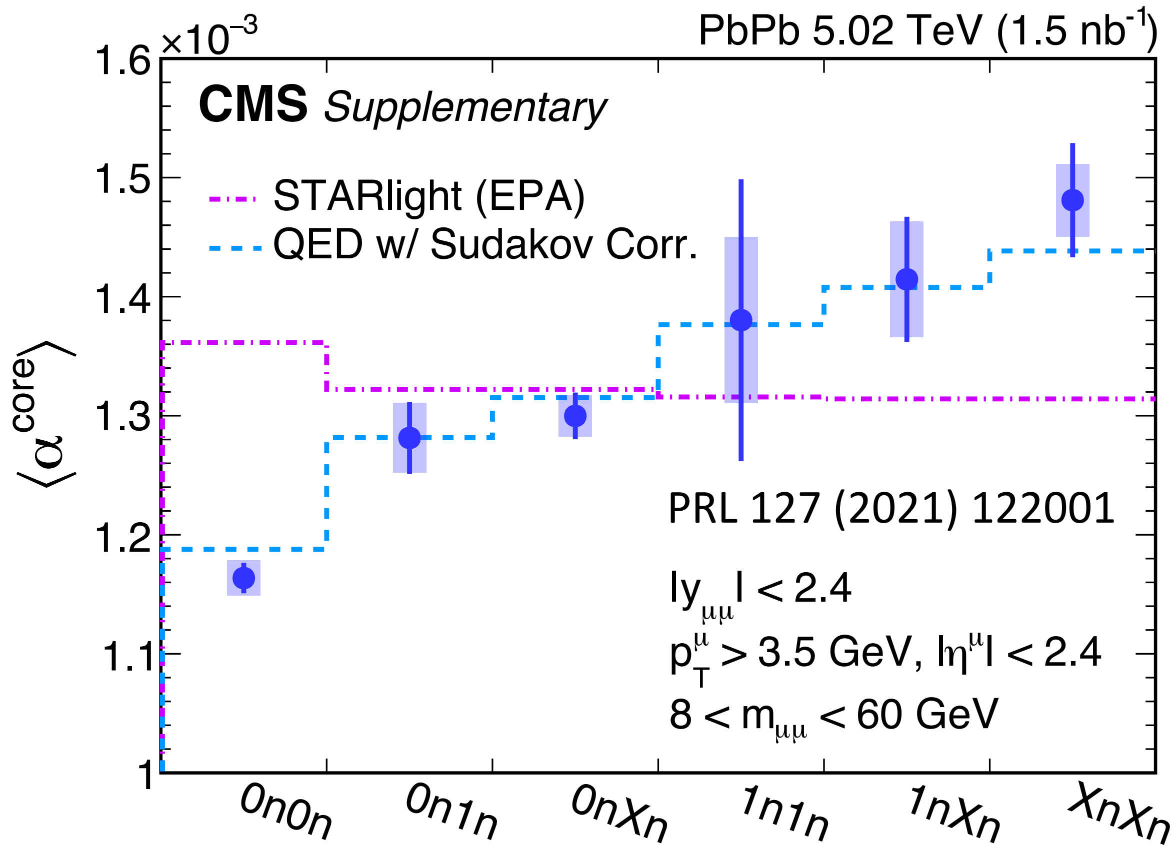
Probing b dependence without final state effects

α distribution vs $N_{neutron}$



α distribution become broader towards smaller b

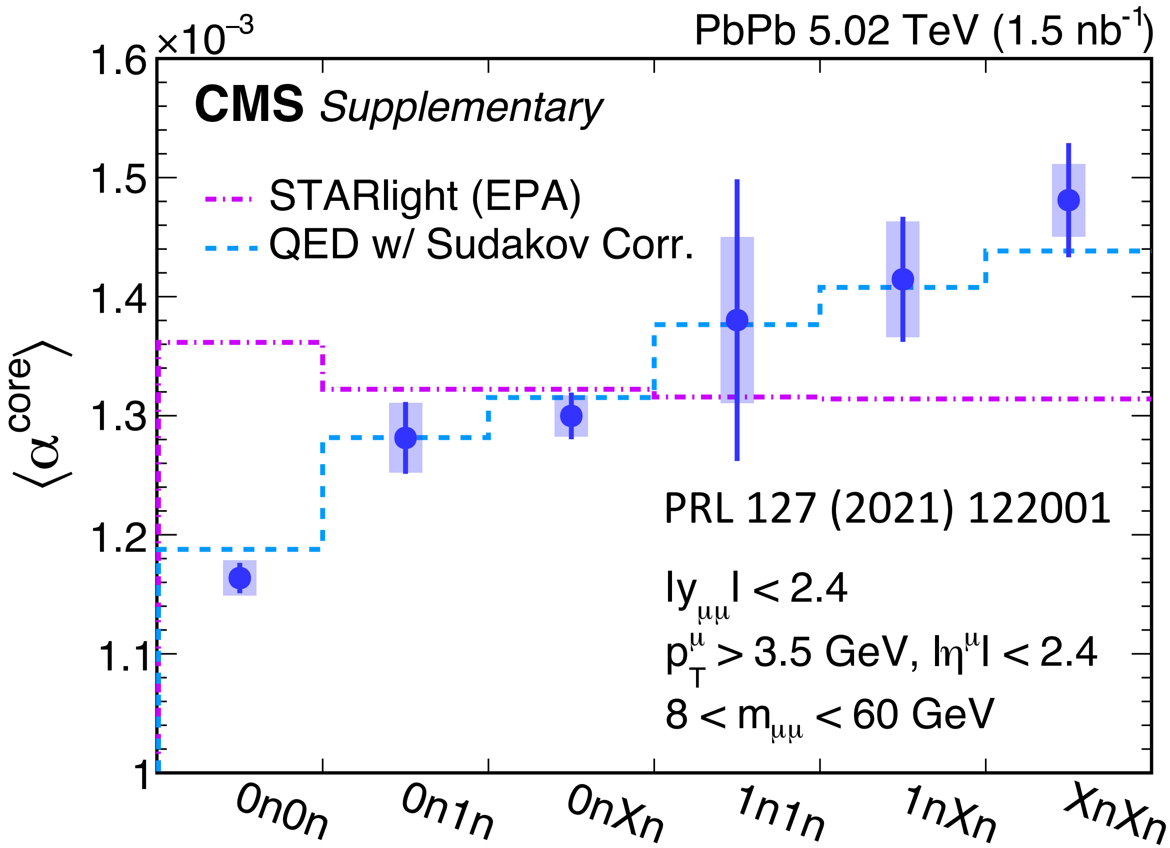
<α> vs $N_{neutron}$



α distribution become broader towards smaller b

Strong $N_{neutron}$ dependence of <α> observed

<α> vs $N_{neutron}$



α distribution become broader towards smaller b

Strong $N_{neutron}$ dependence of <α> observed

Described by a leading order QED calculation

Need to be considered before thinking about final state effects