Hyperon polarization in pA collisions

Perspectives from heavy ion experiments

Zhenyu Chen 陈震宇

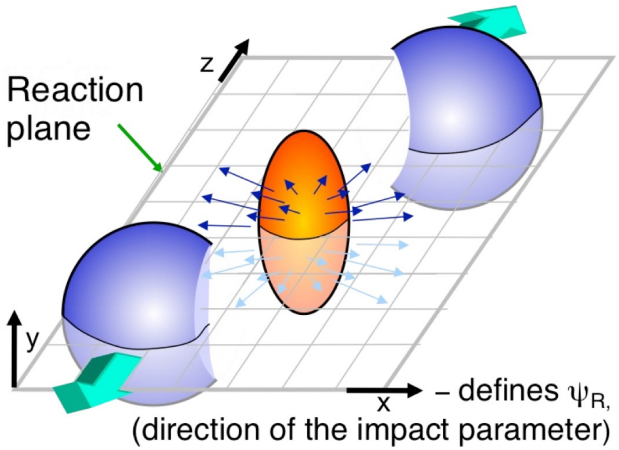
Shandong University 山东大学

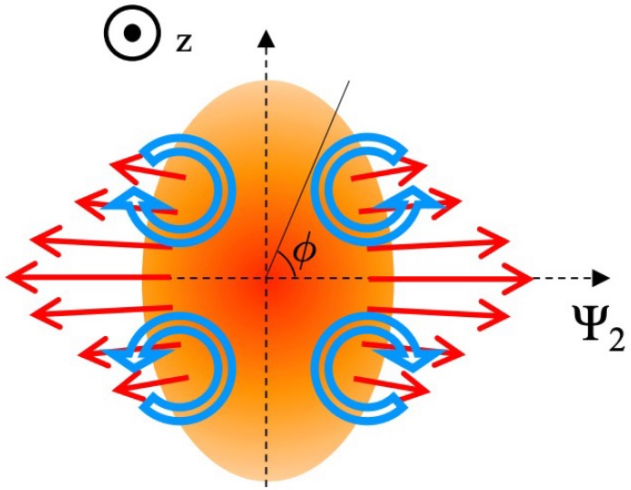
第一届Lambda超子自旋极化跨系统研讨会

山东大学

SHANDONG UNIVERSITY

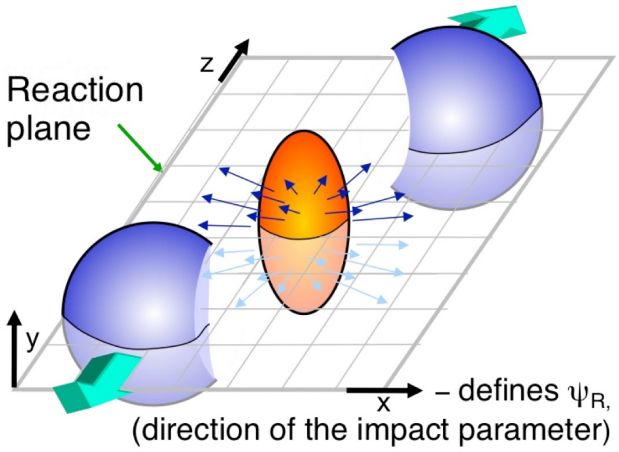
Hyperon polarization along beam direction

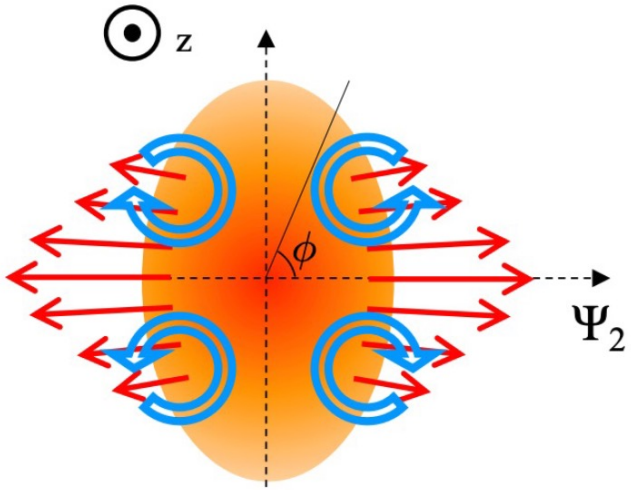


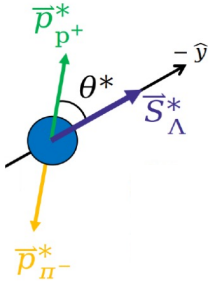


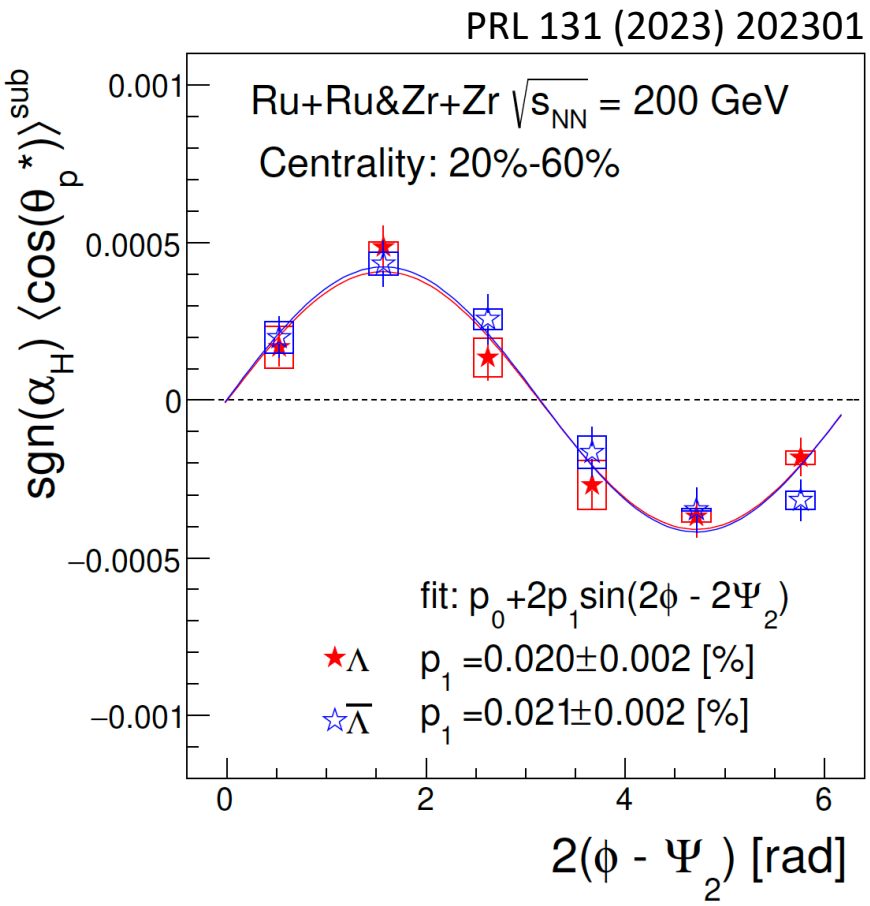
Simple expectation of vorticity from the anisotropic expansion of QGP

Hyperon polarization along beam direction





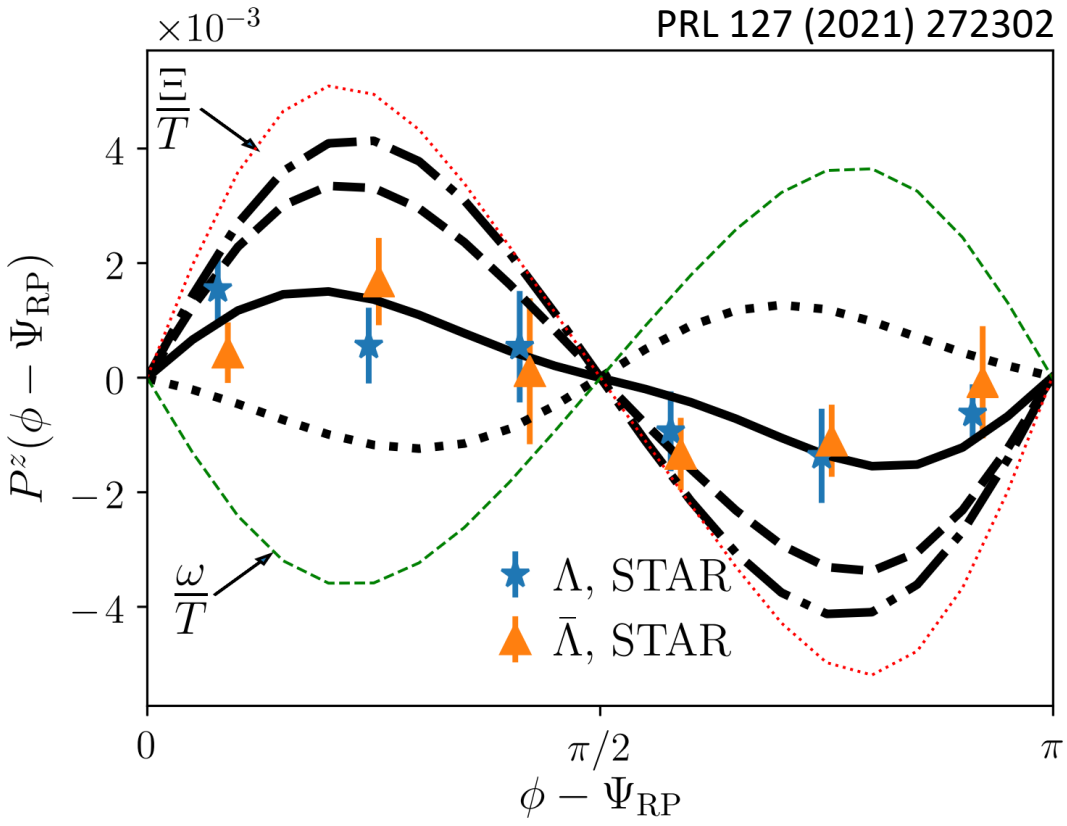


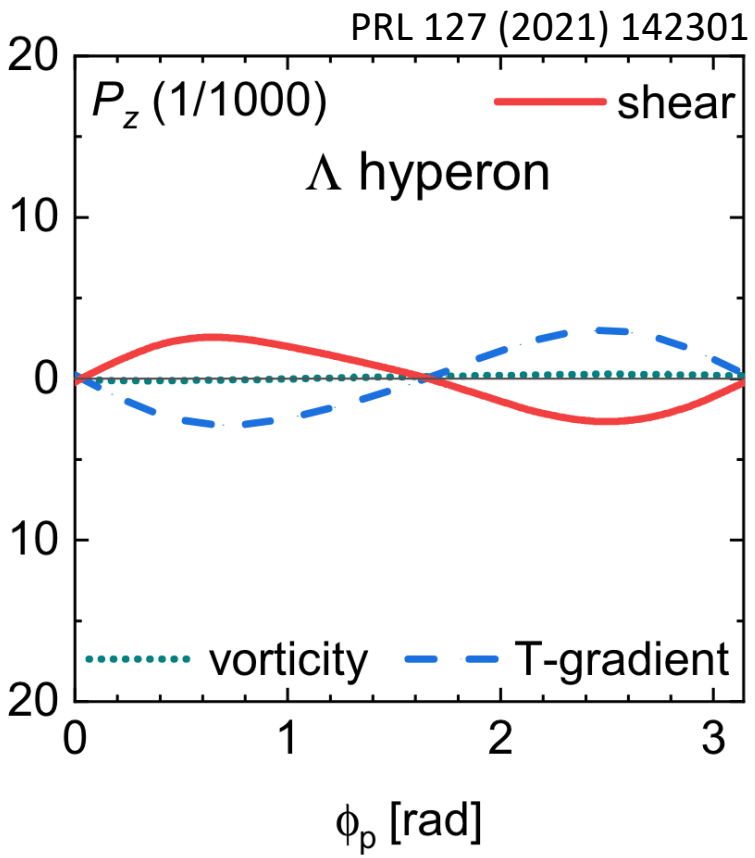


Simple expectation of vorticity from the anisotropic expansion of QGP

Measured through Lambda polarization: parity violating weak decay

"P_z puzzle"



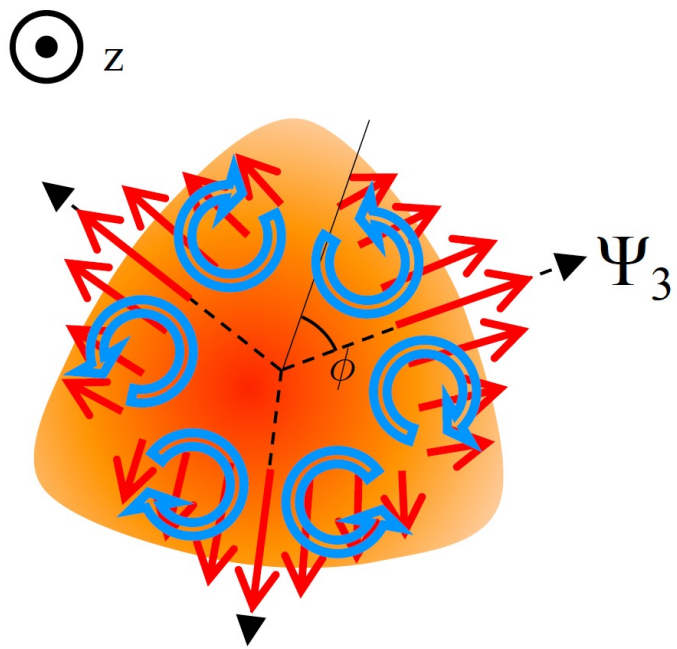


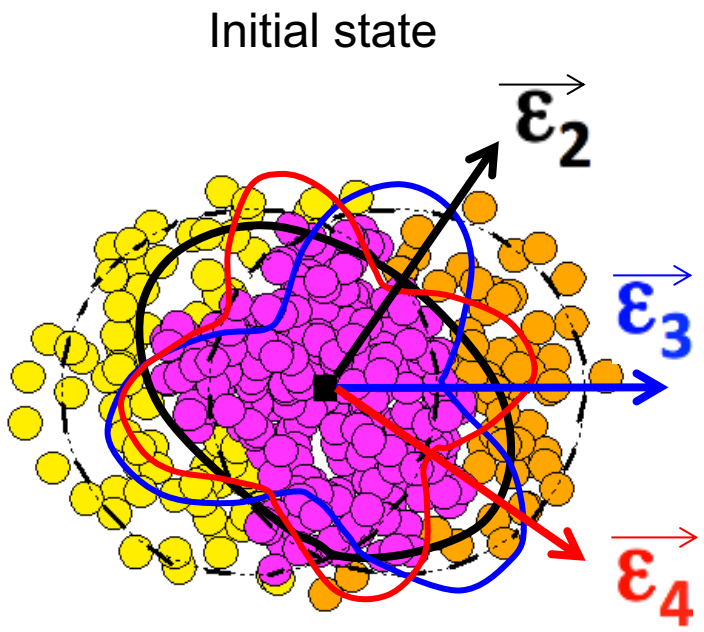
Thermal vorticity results in wrong sign of P_z

Contribution from shear induced polarization needed to get the correct sign

Calculations depend on the details of shear term implementation

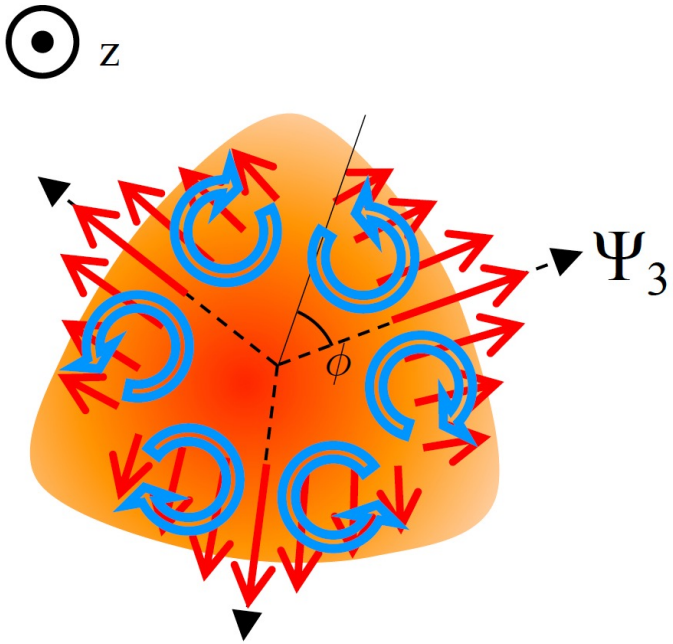
Hyperon polarization linked to collective flow(?)



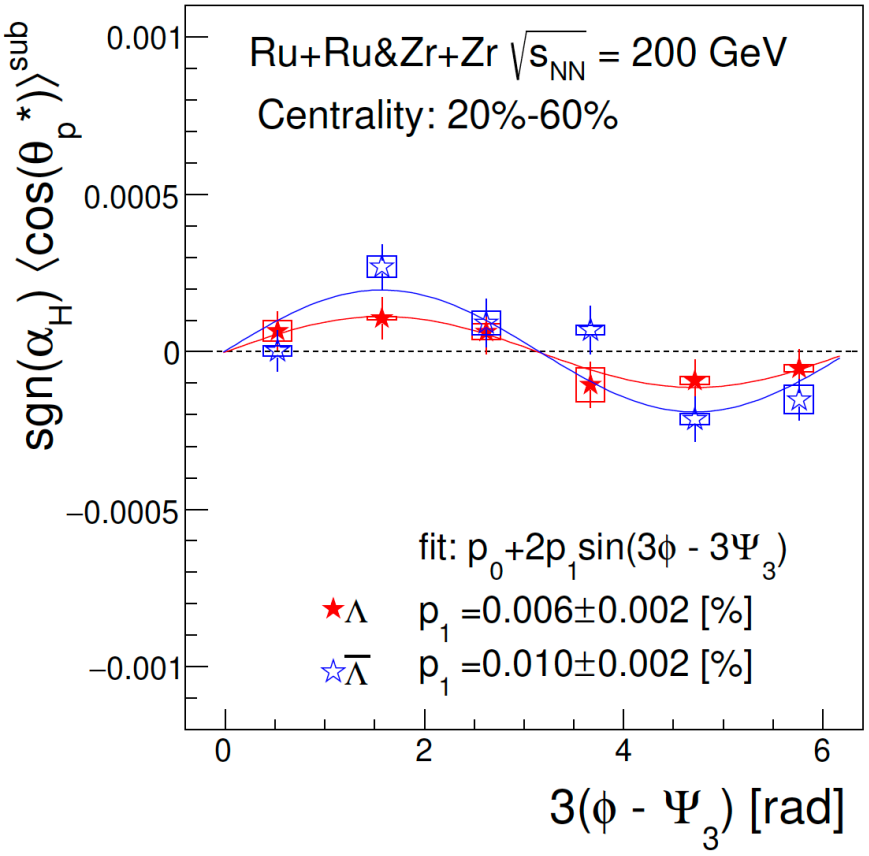


Same expectation of vorticity from higher order flow

Hyperon polarization linked to collective flow(?)



PRL 131 (2023) 202301

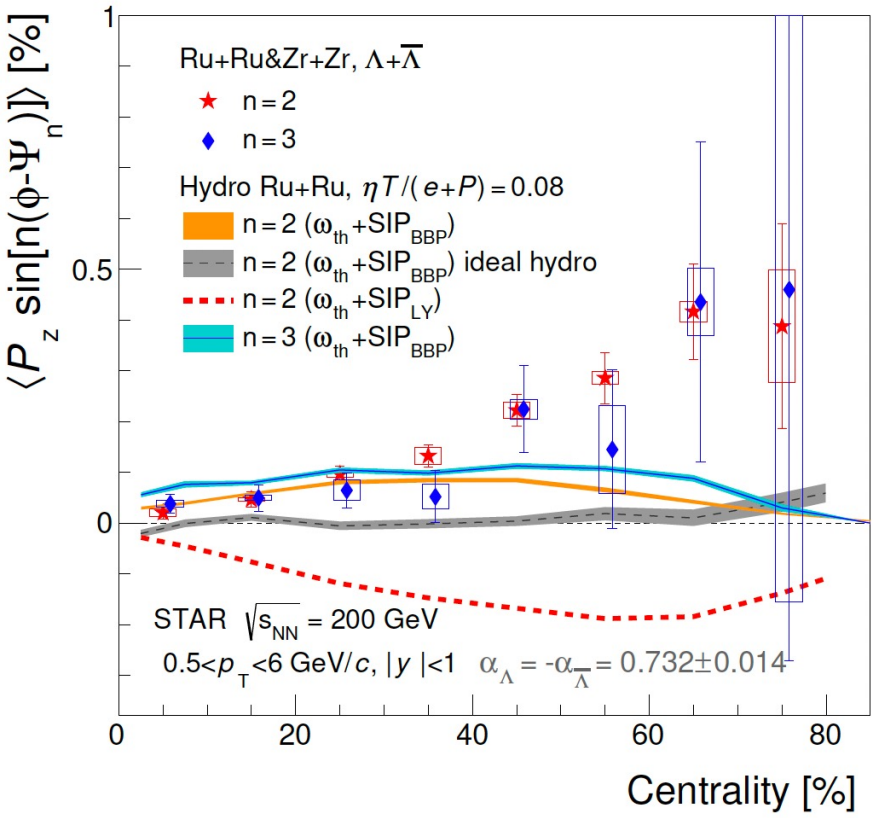


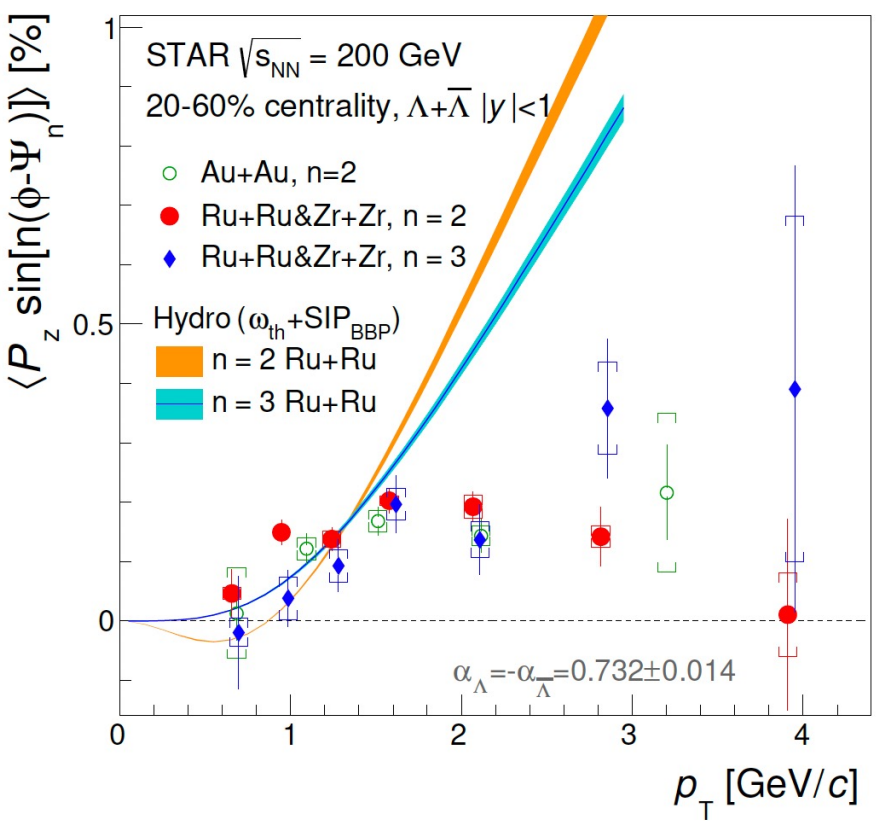
Same expectation of vorticity from higher order flow

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

Hyperon polarization linked to collective flow(?)

PRL 131 (2023) 202301



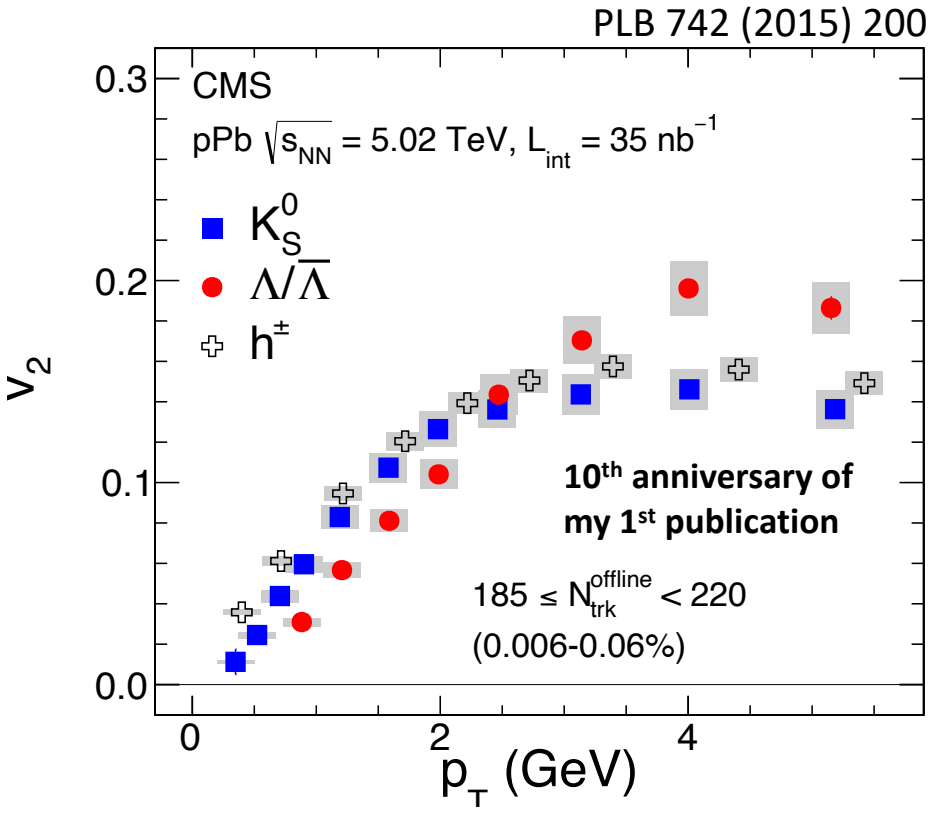


Same expectation of vorticity from higher order flow

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

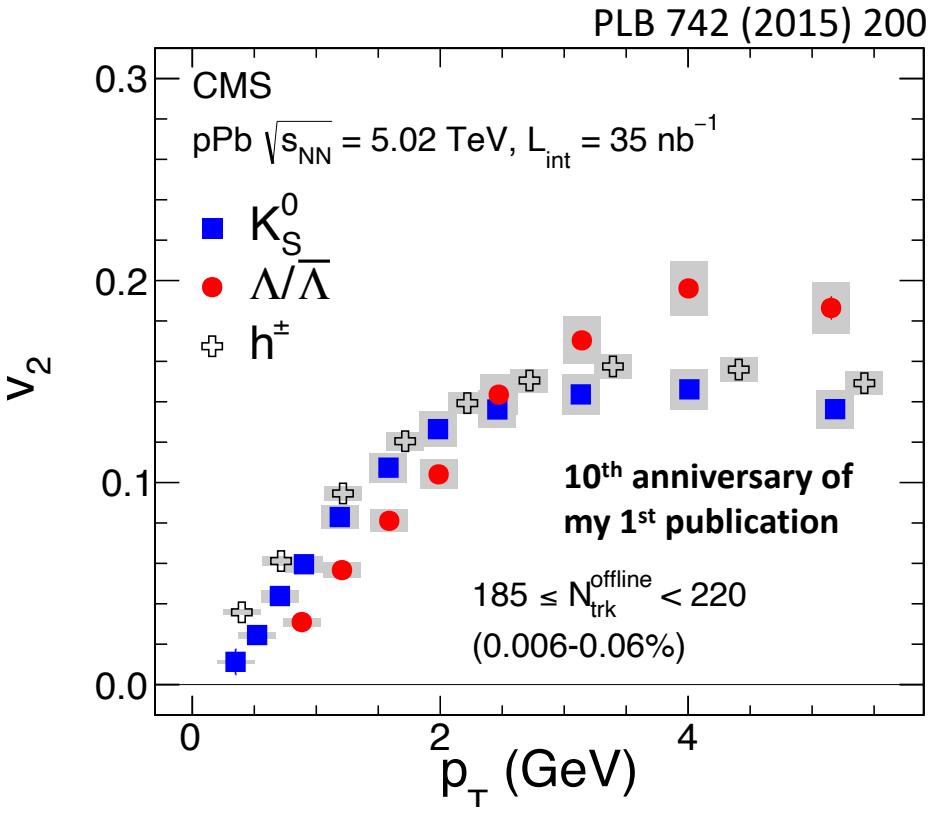
Details of model calculations need to be investigated

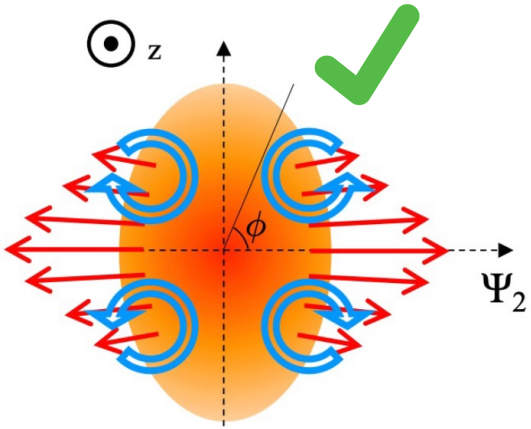
A test in small system

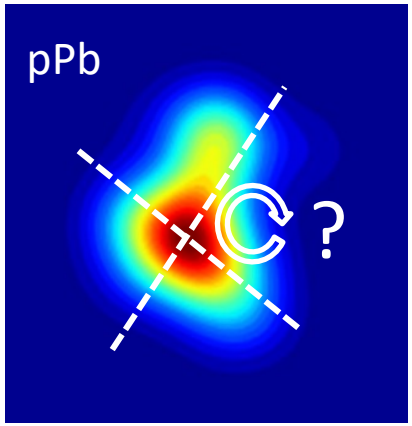


Features of QGP droplets observed in small but dense systems

A test in small system





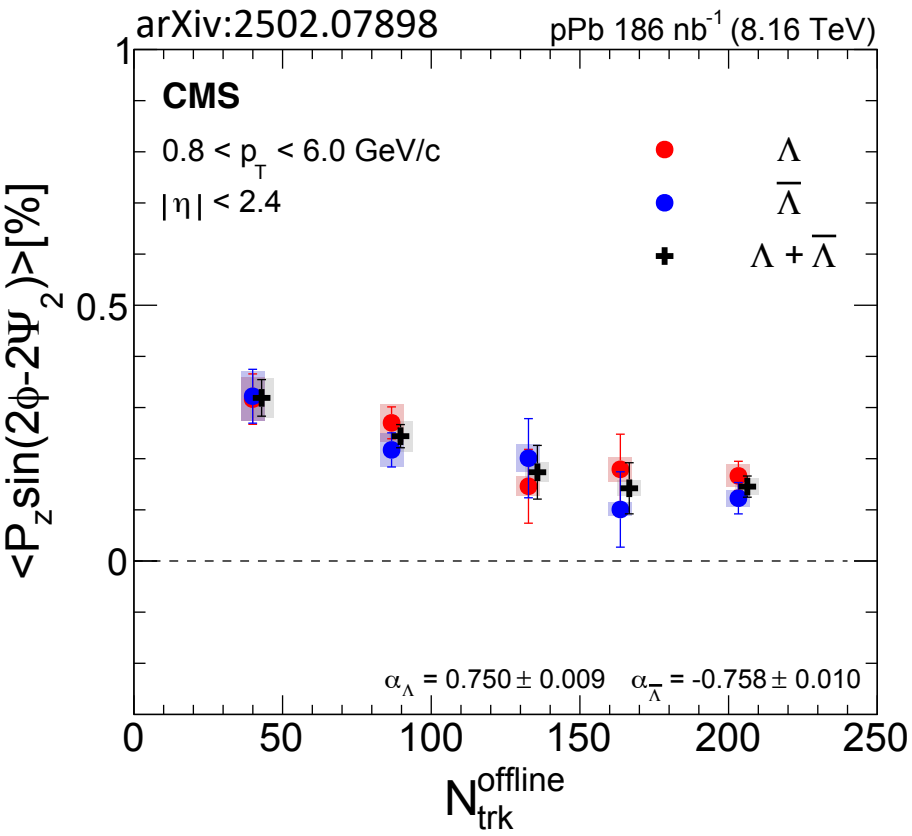


Features of QGP droplets observed in small but dense systems

Can we see hyperon polarization P_z there?

A test of QGP formation & different mechanisms of P_z

$P_{z,s2}$ in pPb collision

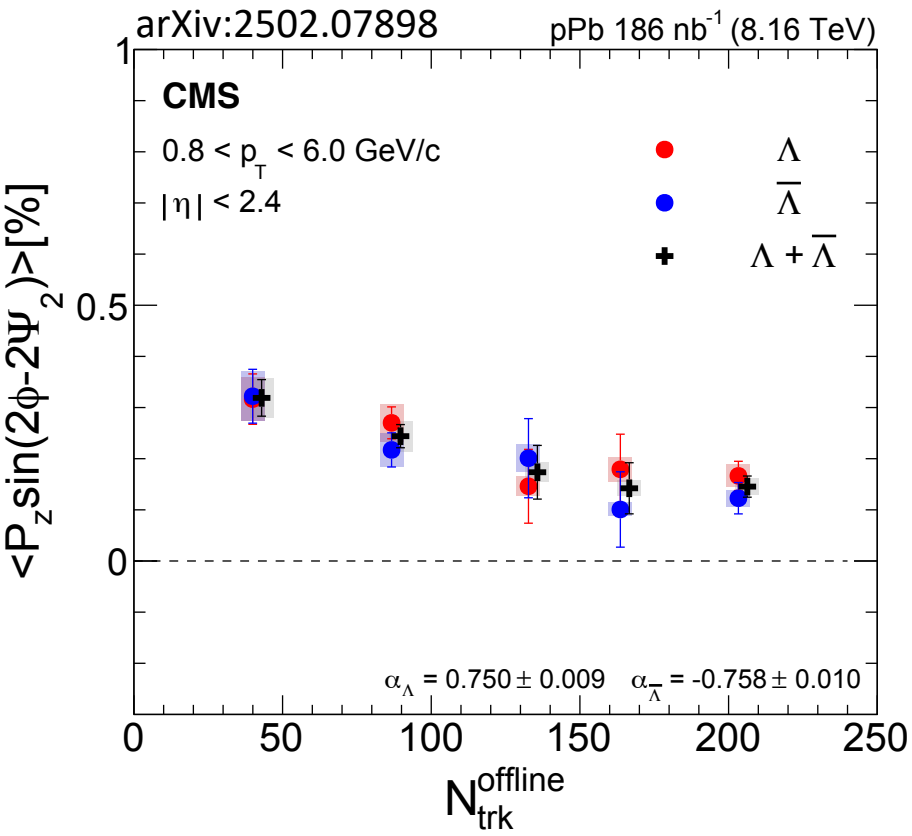


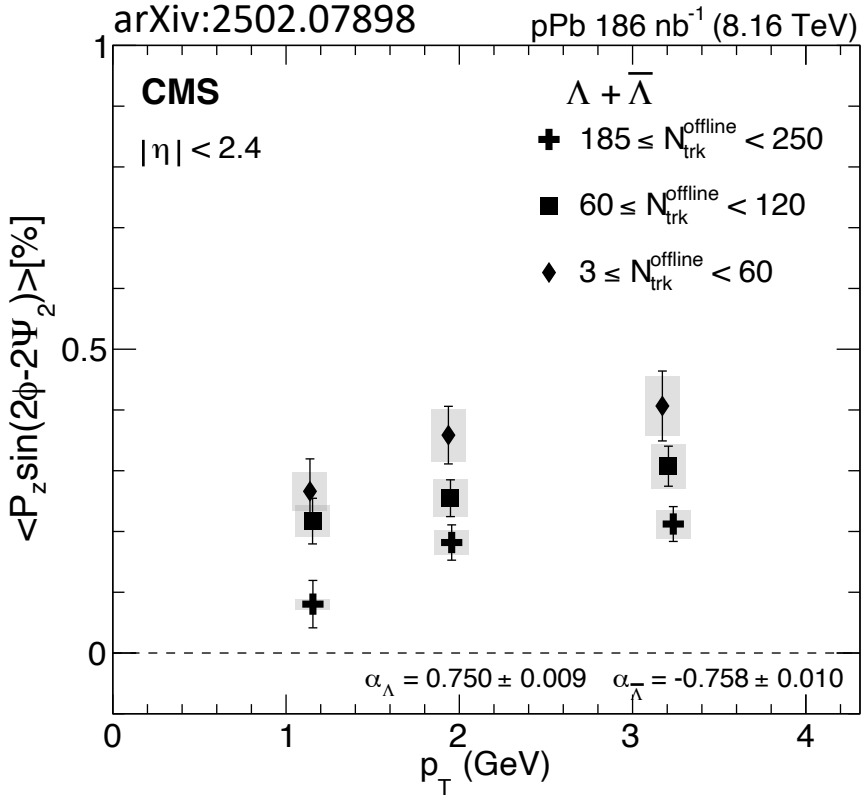
Significant positive $P_{z,s2}$ observed over entire multiplicity range

Consistent results for Λ and anti-Λ

Decrease towards high multiplicity

$P_{z,s2}$ in pPb collision





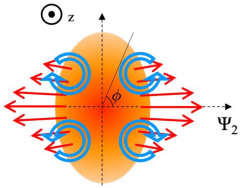
Significant positive $P_{z,s2}$ observed over entire multiplicity range

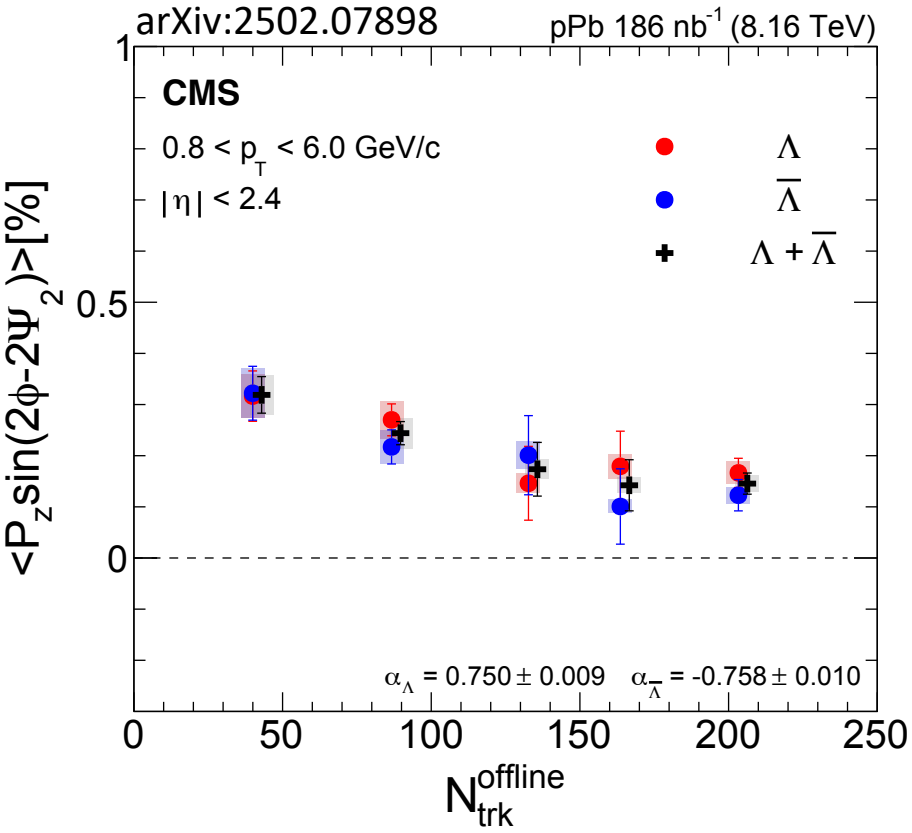
Consistent results for Λ and anti-Λ

Decrease towards high multiplicity

Increase towards higher p_T – hint of saturation at intermediate p_T

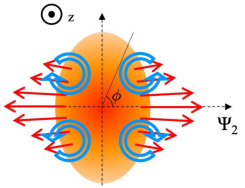
$P_{z,s2}$ in pPb collision

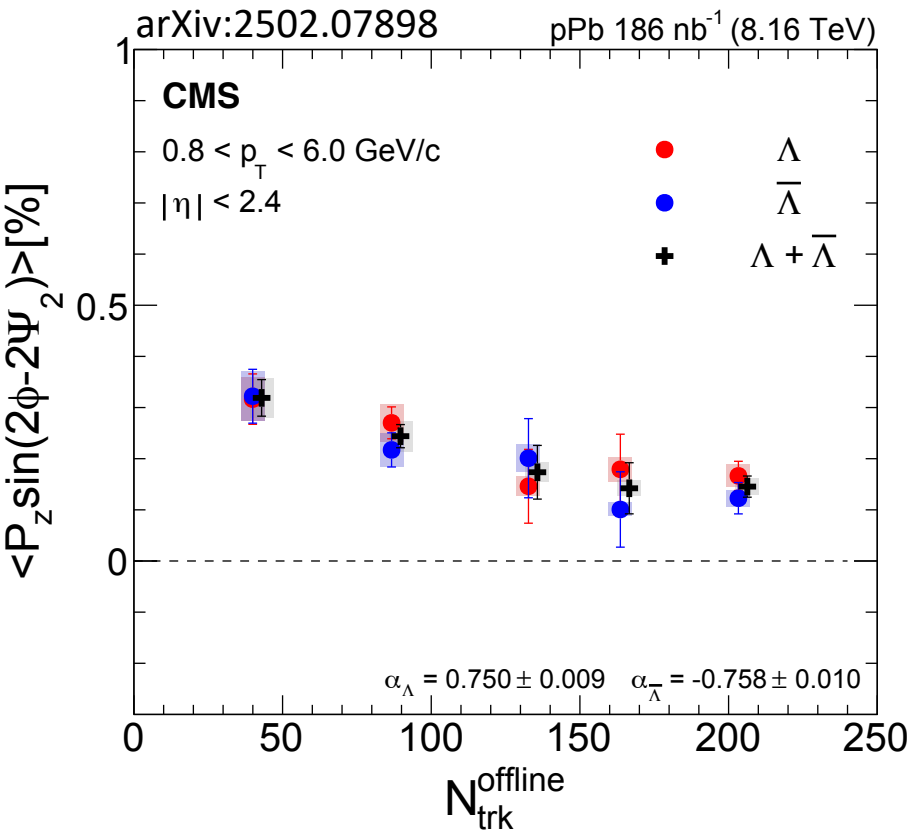


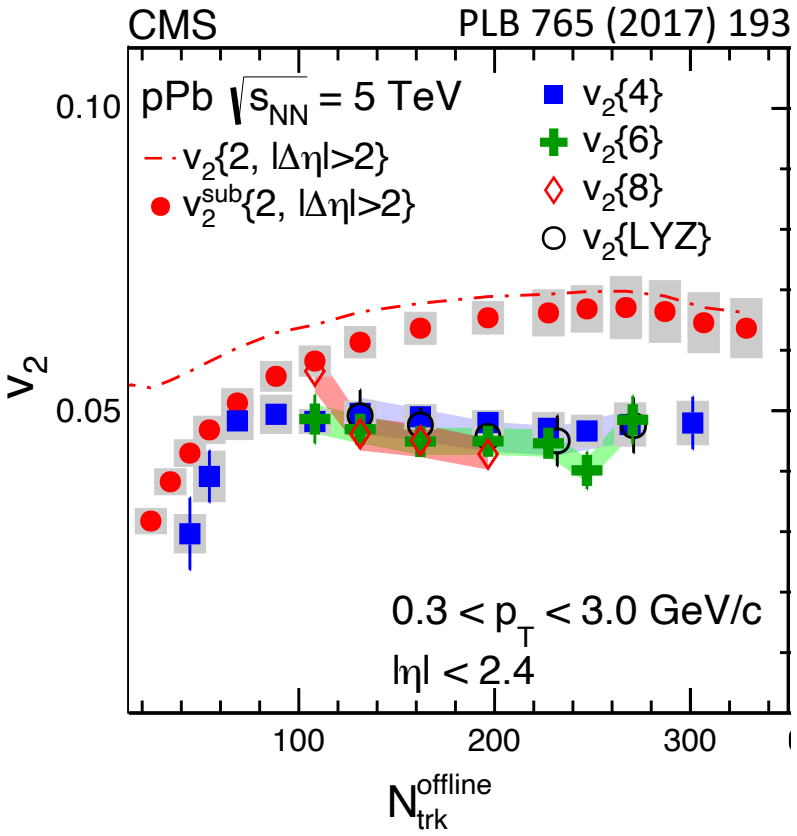


Why is it increasing monotonically towards 0 multiplicity?

$P_{z,s2}$ in pPb collision

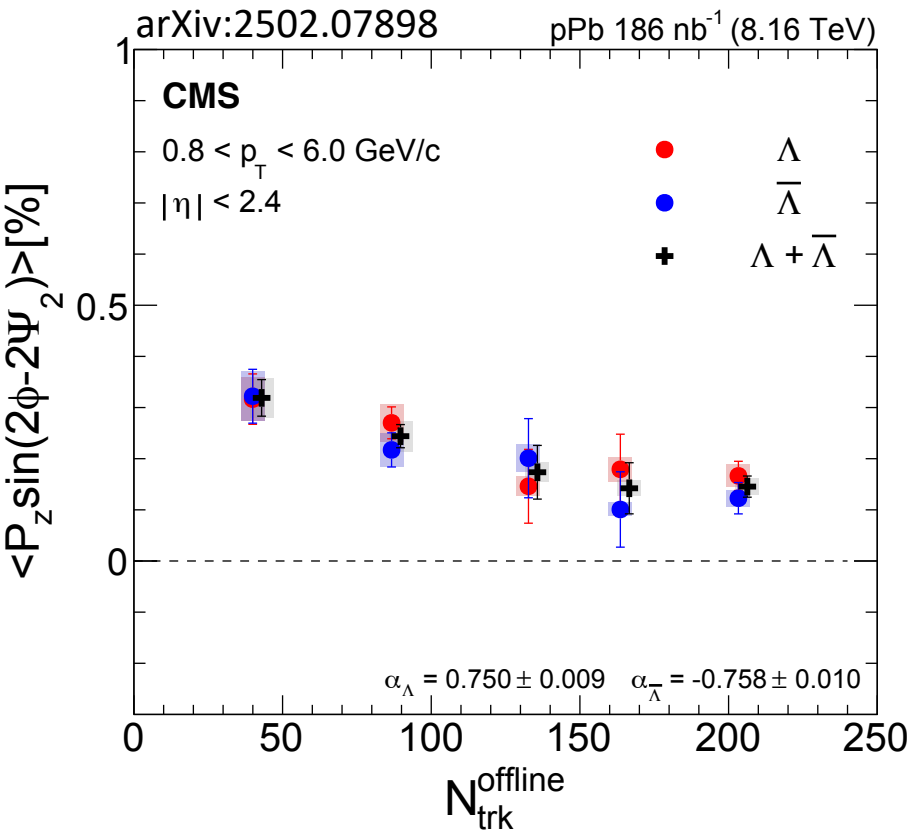


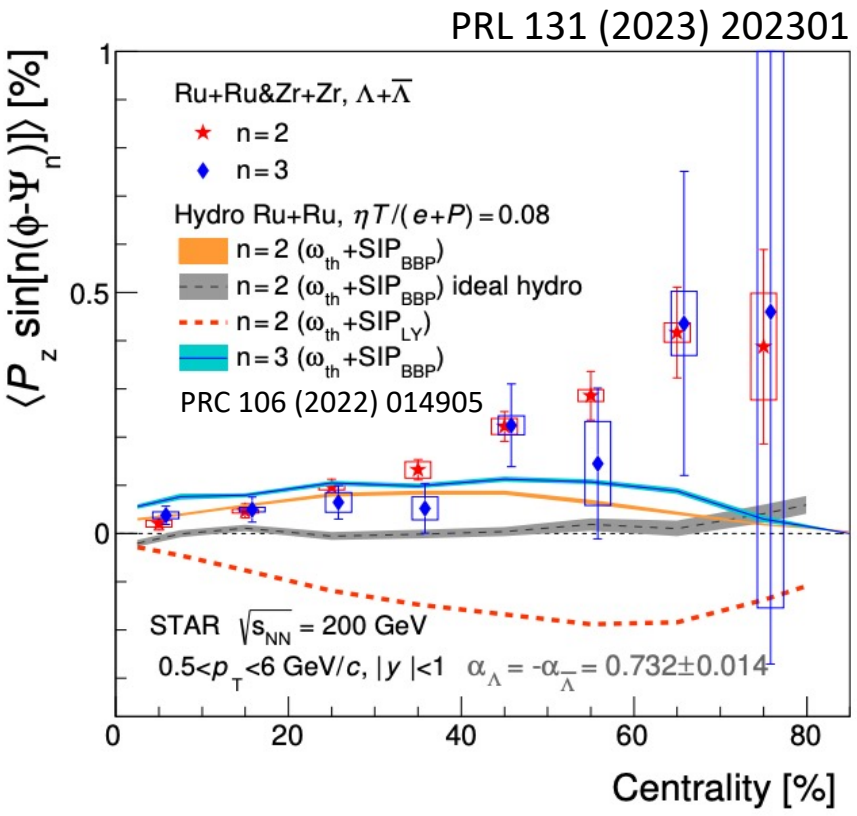




Why is it increasing monotonically towards 0 multiplicity?
Not consistent with the trend of v_2

$P_{z,s2}$ in pPb collision



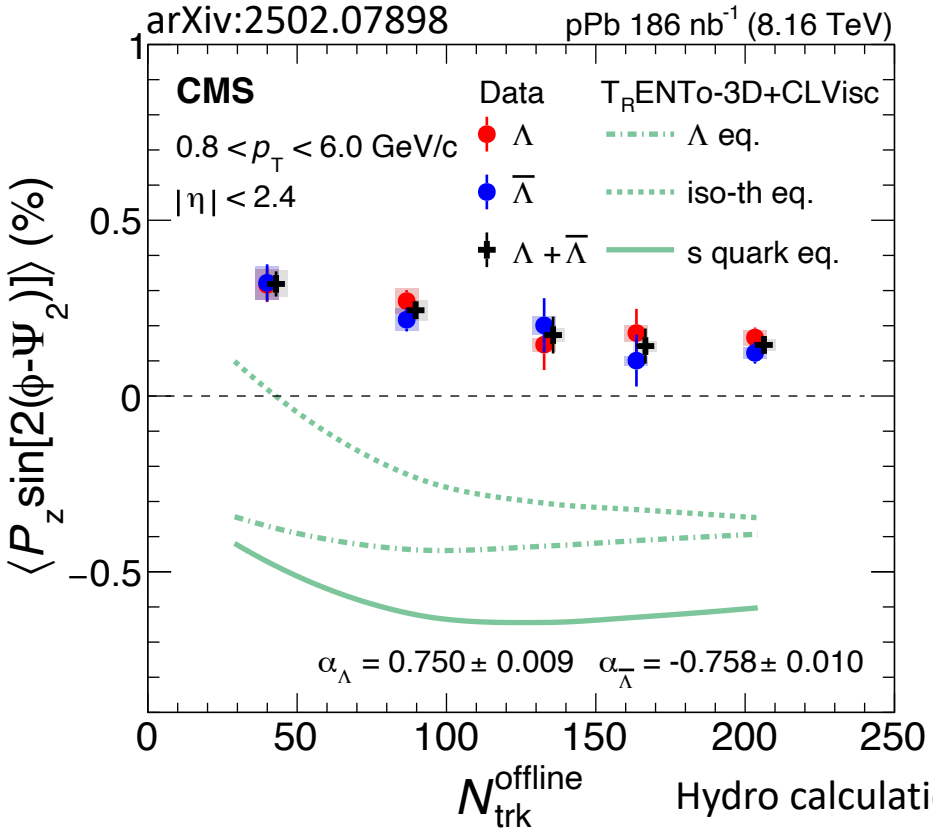


Why is it increasing monotonically towards 0 multiplicity?

Not consistent with the trend of v_2

Similar to the behavior for peripheral AA: not captured by hydro

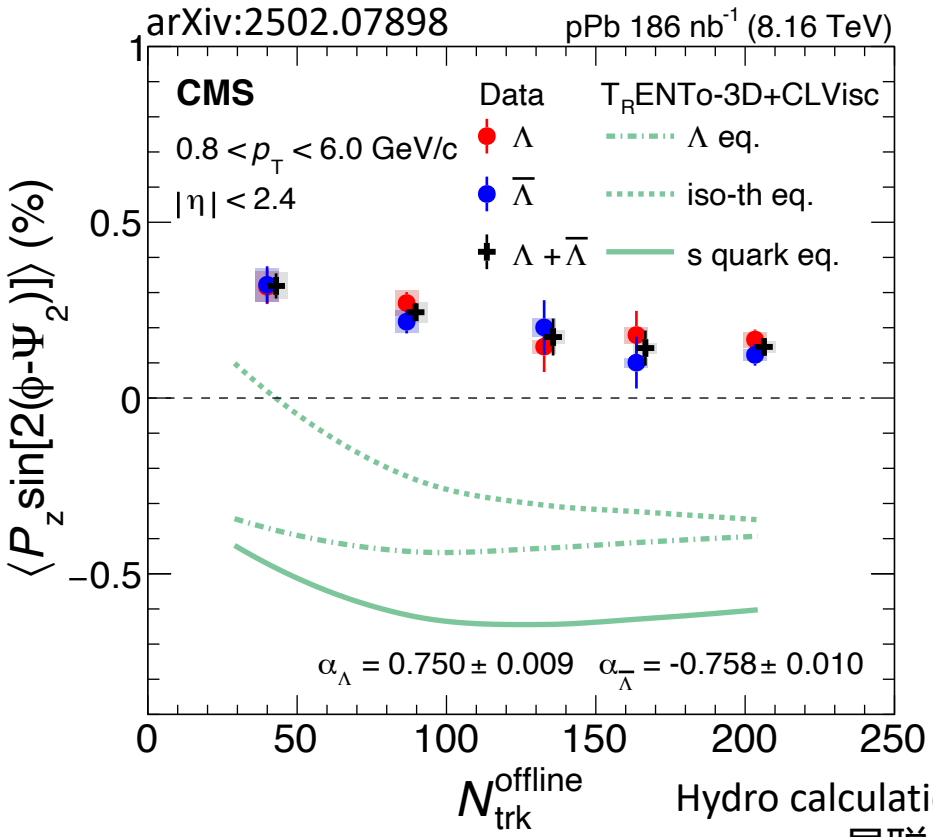
$P_{z,s2}$ in pPb collision - model calculations

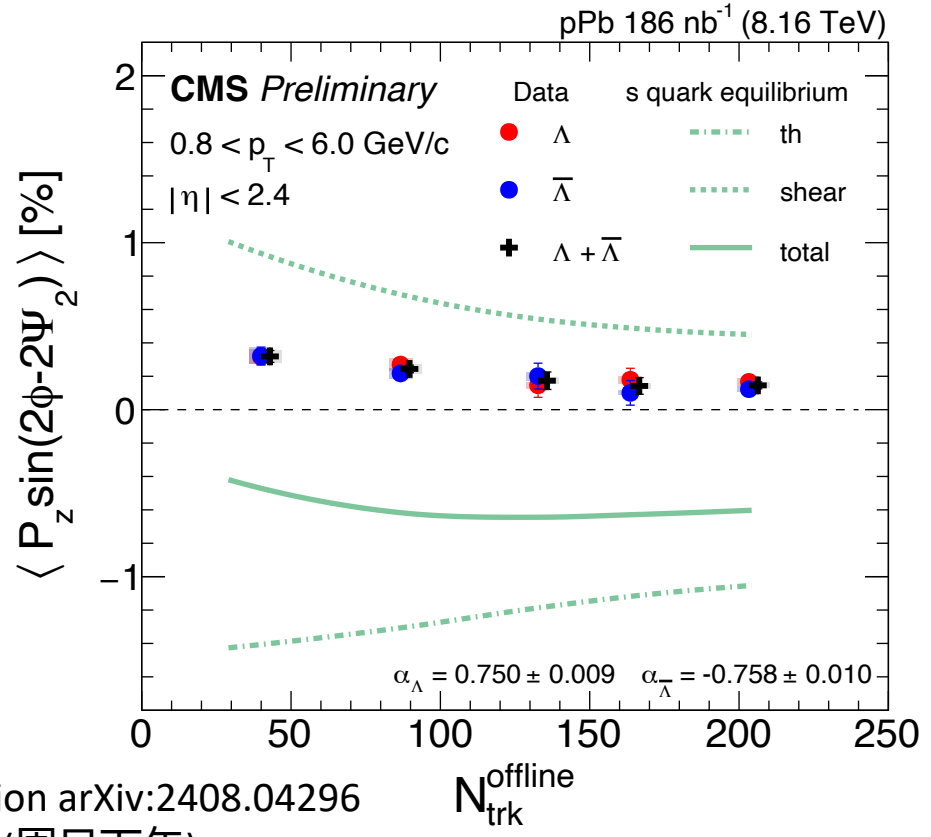


Hydro calculation arXiv:2408.04296

Hydro calculations result in negative Pz
Challenge to current theoretical framework

$P_{z,s2}$ in pPb collision - model calculations





Hydro calculation arXiv:2408.04296

易聪(周日下午)

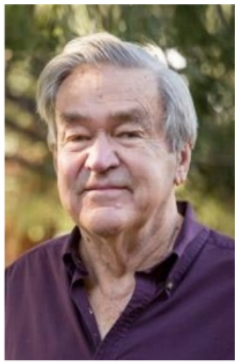
Hydro calculations result in negative Pz

Challenge to current theoretical framework

Different contributions in small systems need to be understood further

Is it from other effects?

Polarization data has often been the graveyard of fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

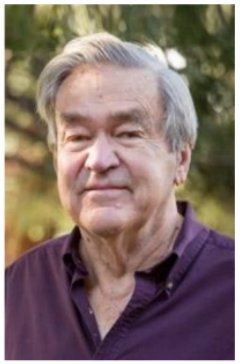


James D. Bjorken

Proc. Adv. Research Workshop on QCD hadronic Processes,
St. Croix, Virgin Islands (1987).

Is it from other effects?

Polarization data has often been the graveyard of fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.



James D. Bjorken

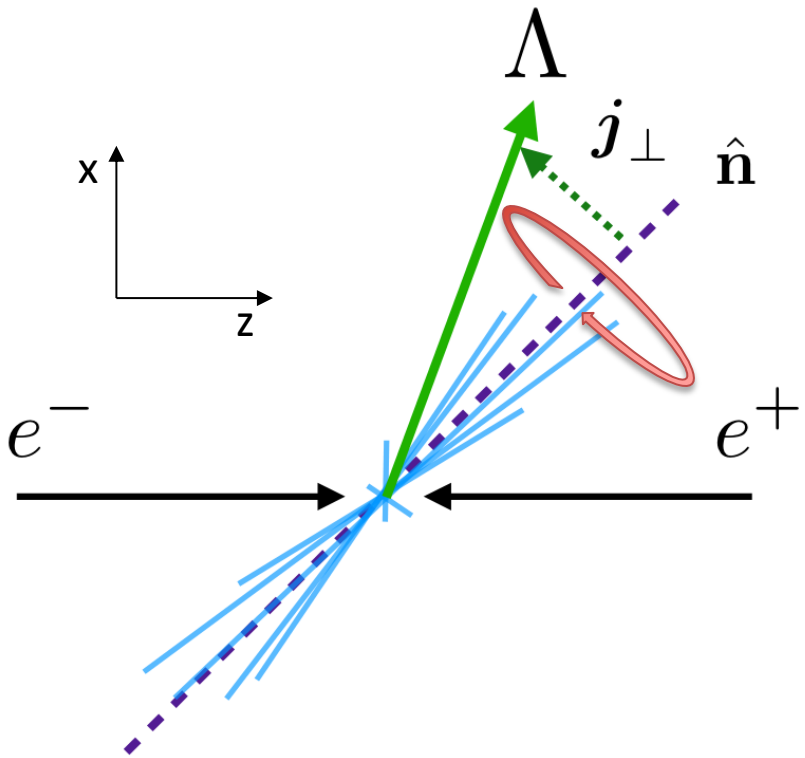
Proc. Adv. Research Workshop on QCD hadronic Processes,
St. Croix, Virgin Islands (1987).

Polarization data
AKA graveyard

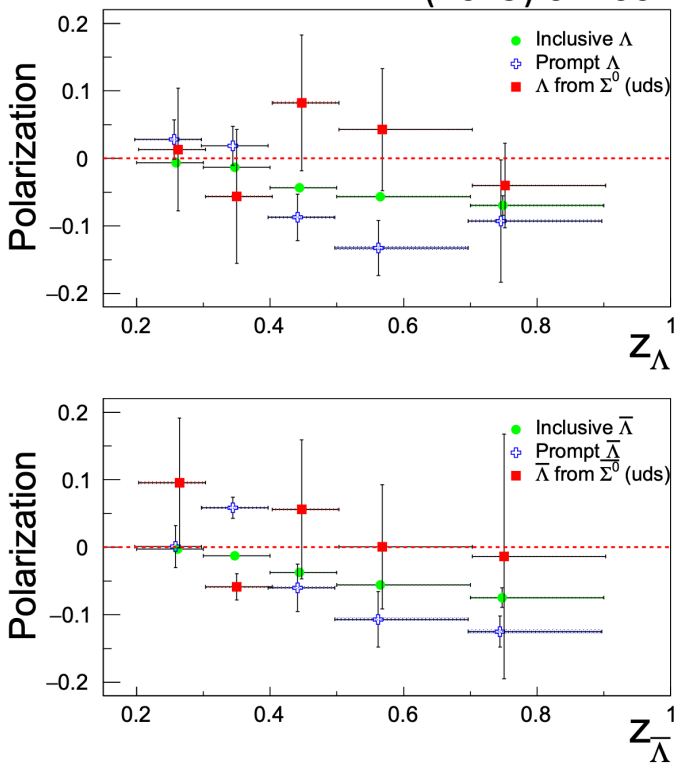
Me

DeepUnderstanding

Transverse hyperon polarization in jet



PRL 122 (2019) 042001



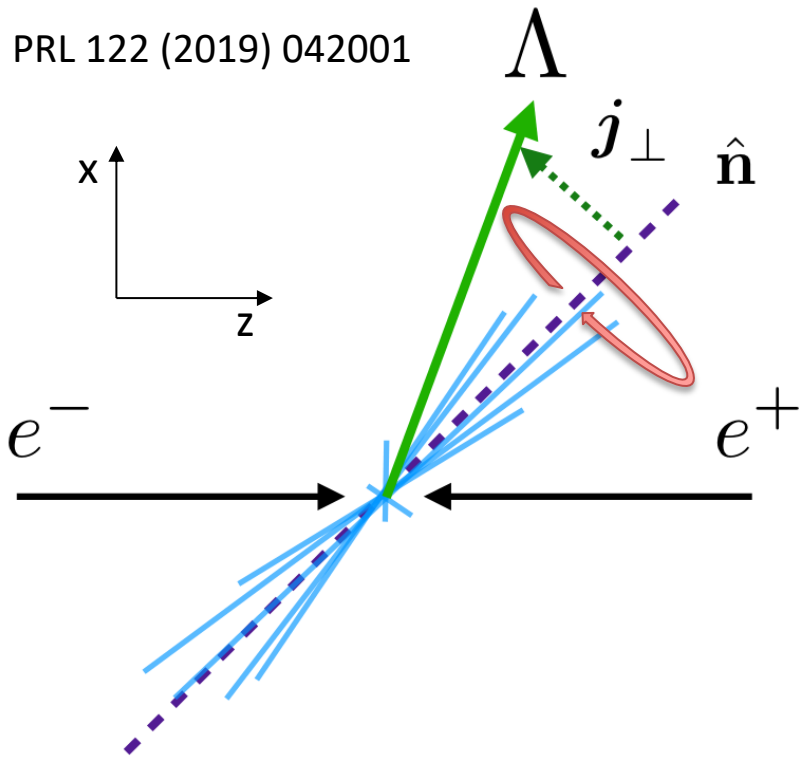
Transverse polarization of Λ in unpolarized scattering is a long-standing puzzle

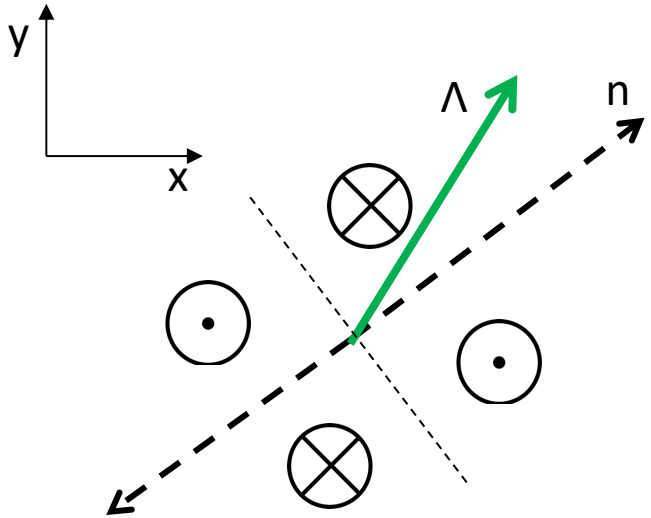
Recent Belle measurement in e^+e^- shows a significant signal wrt thrust axis

Could origin from polarization fragmentation functions

Transverse hyperon polarization in jet

PRL 122 (2019) 042001

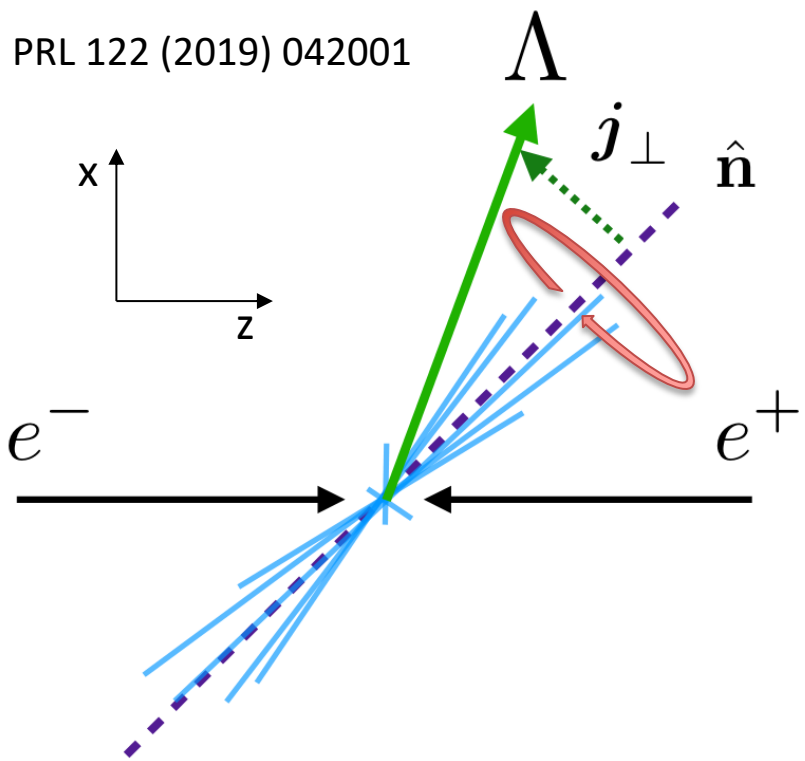


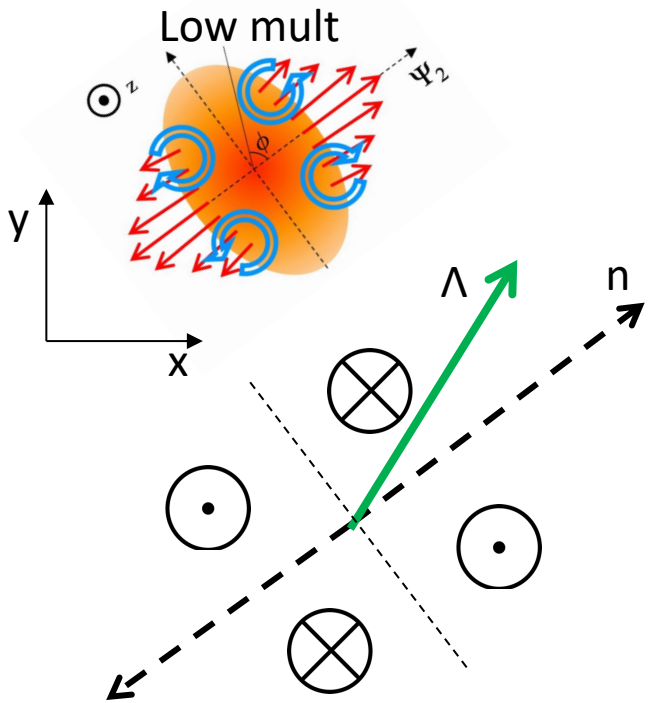


Projection to x-y plane introduce a P_z wrt thrust axis

Transverse hyperon polarization in jet

PRL 122 (2019) 042001





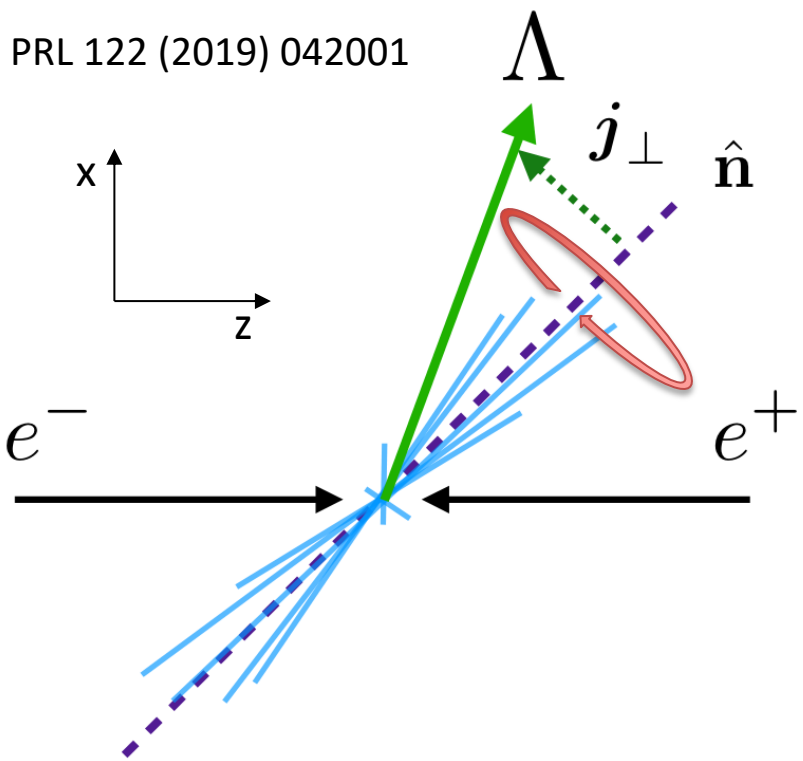
Projection to x-y plane introduce a P_z wrt thrust axis

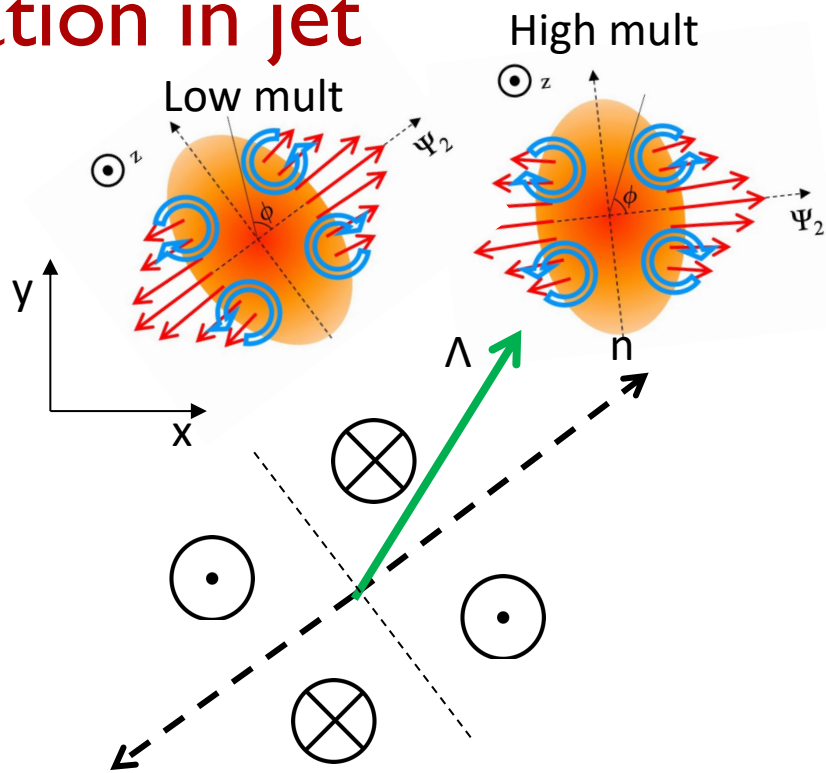
Thrust axis coincide with 2nd order event plane at low multiplicity

Diluted (decreases) towards high multiplicity

Transverse hyperon polarization in jet

PRL 122 (2019) 042001





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

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

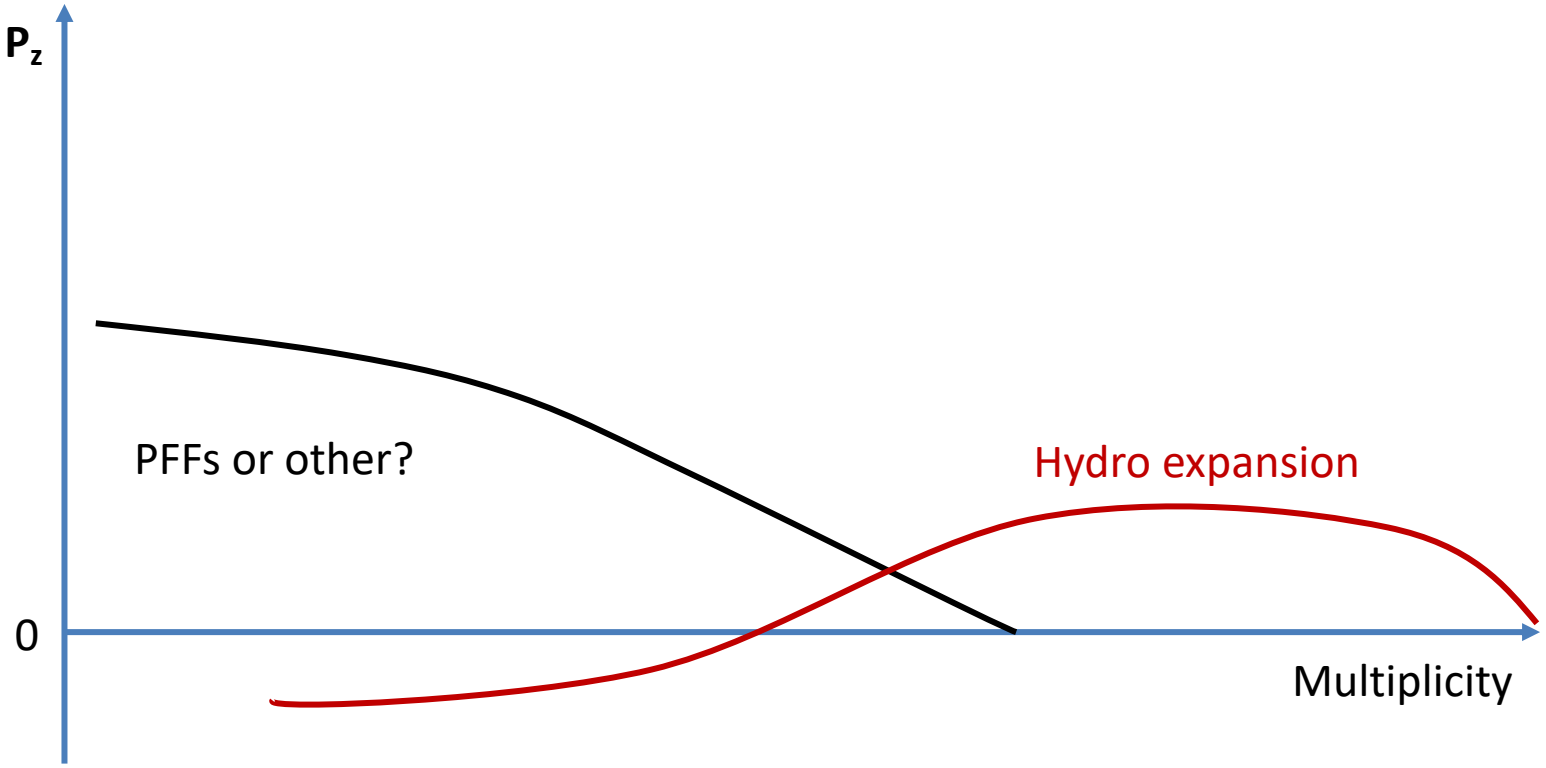
Diluted (decreases) towards high multiplicity

Further measurements required

Rapidity dependence of hyperon polarization

Hyperon polarization in jets at LHC energies

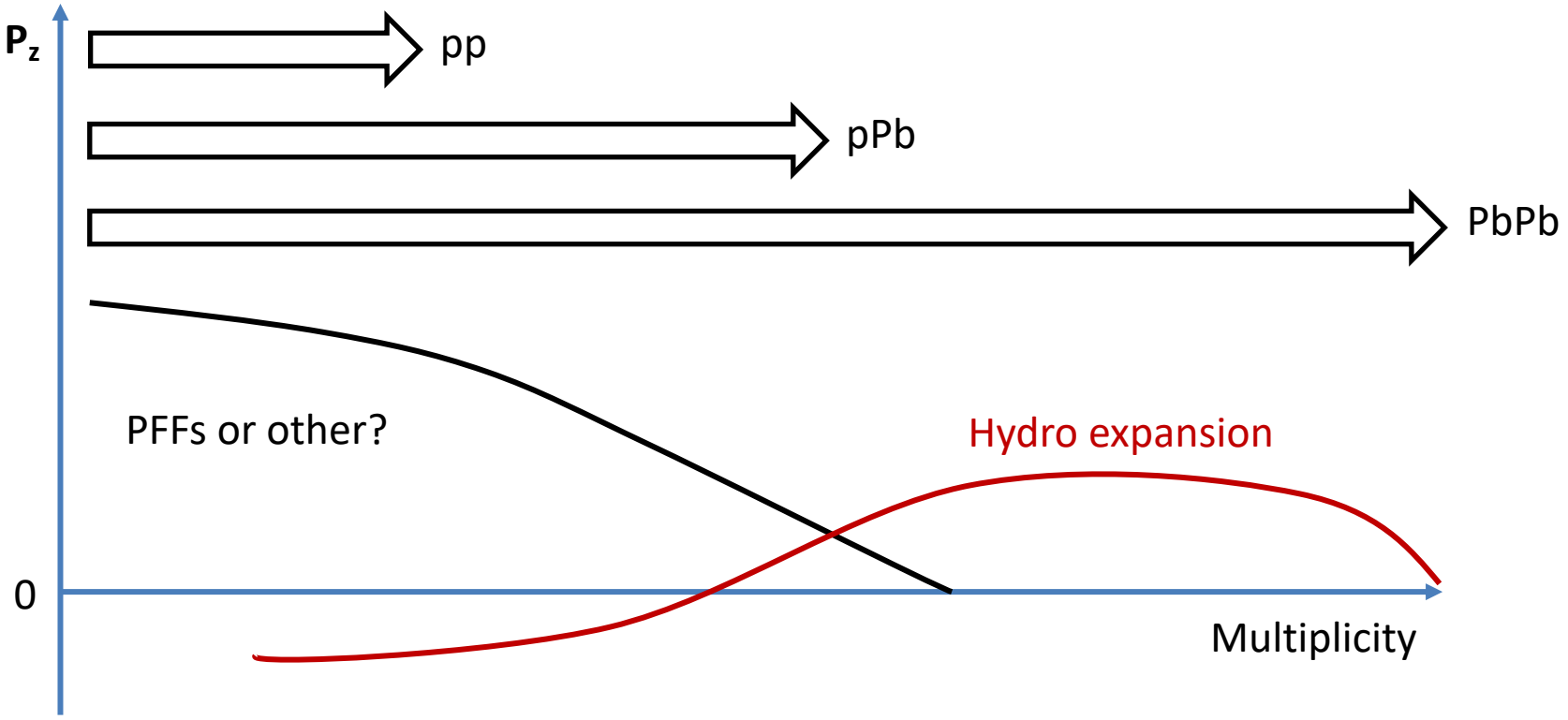
Hyperon polarization across systems



A naïve guess of contributions to Pz

Where is the switching point and what is the implication for AA?

Hyperon polarization across systems

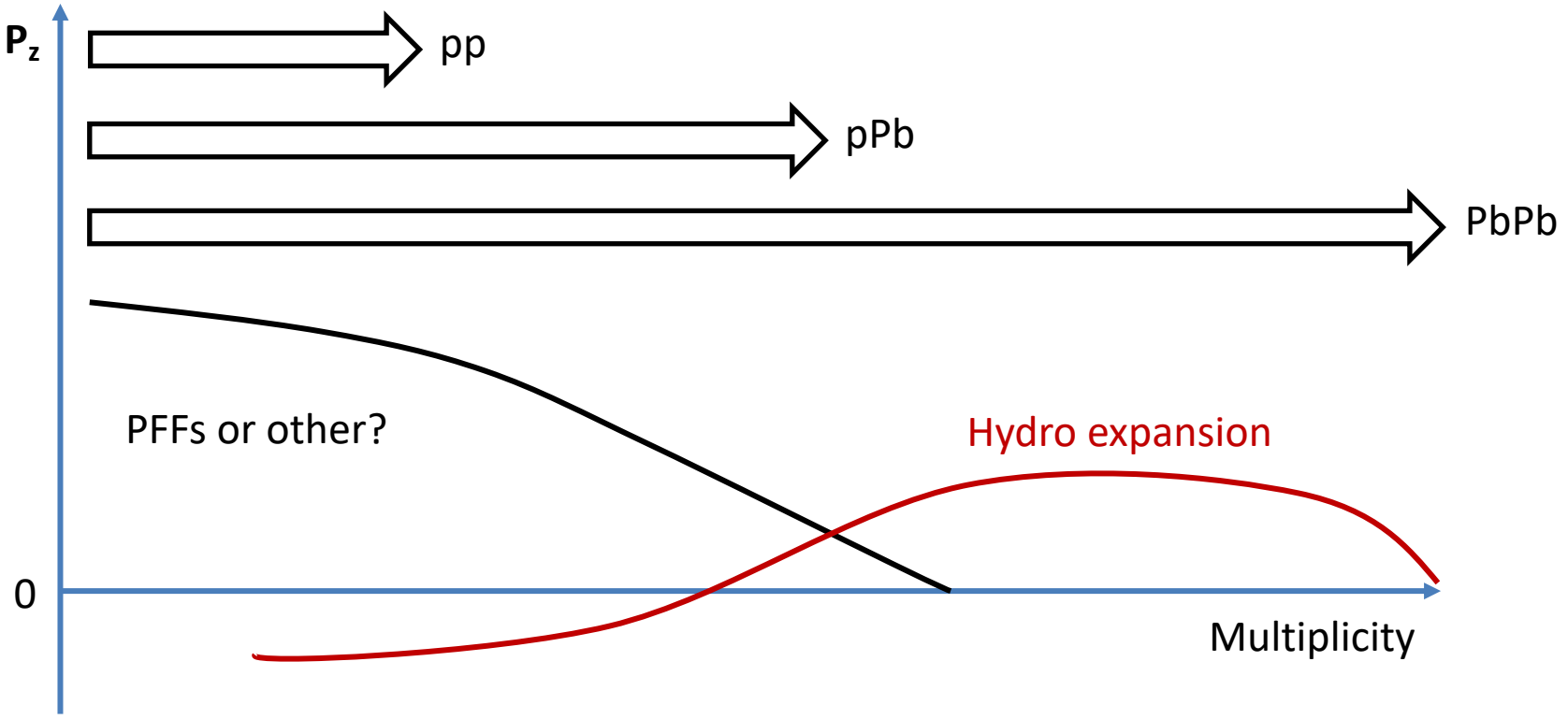


A naïve guess of contributions to Pz

Where is the switching point and what is the implication for AA?

Measurements and model calculations across pp, pA, AA needed!

Hyperon polarization across systems



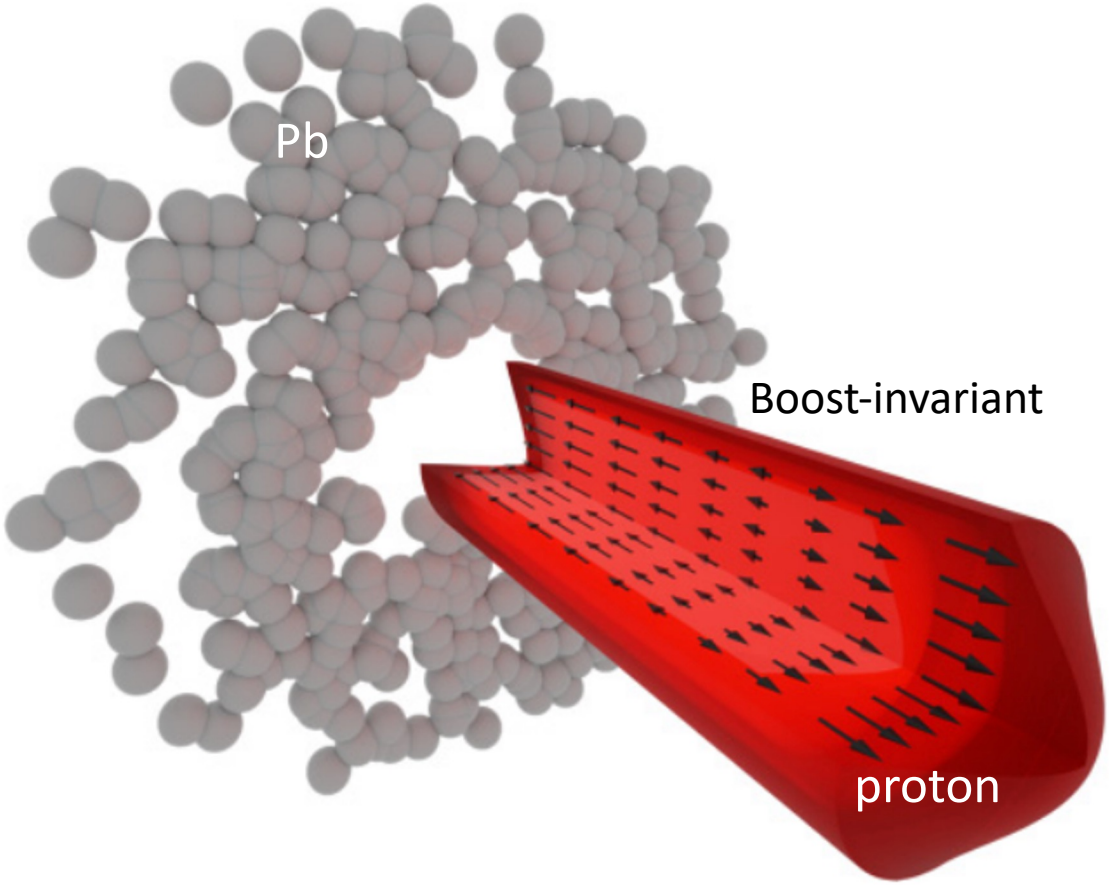
A naïve guess of contributions to Pz

Where is the switching point and what is the implication for AA?

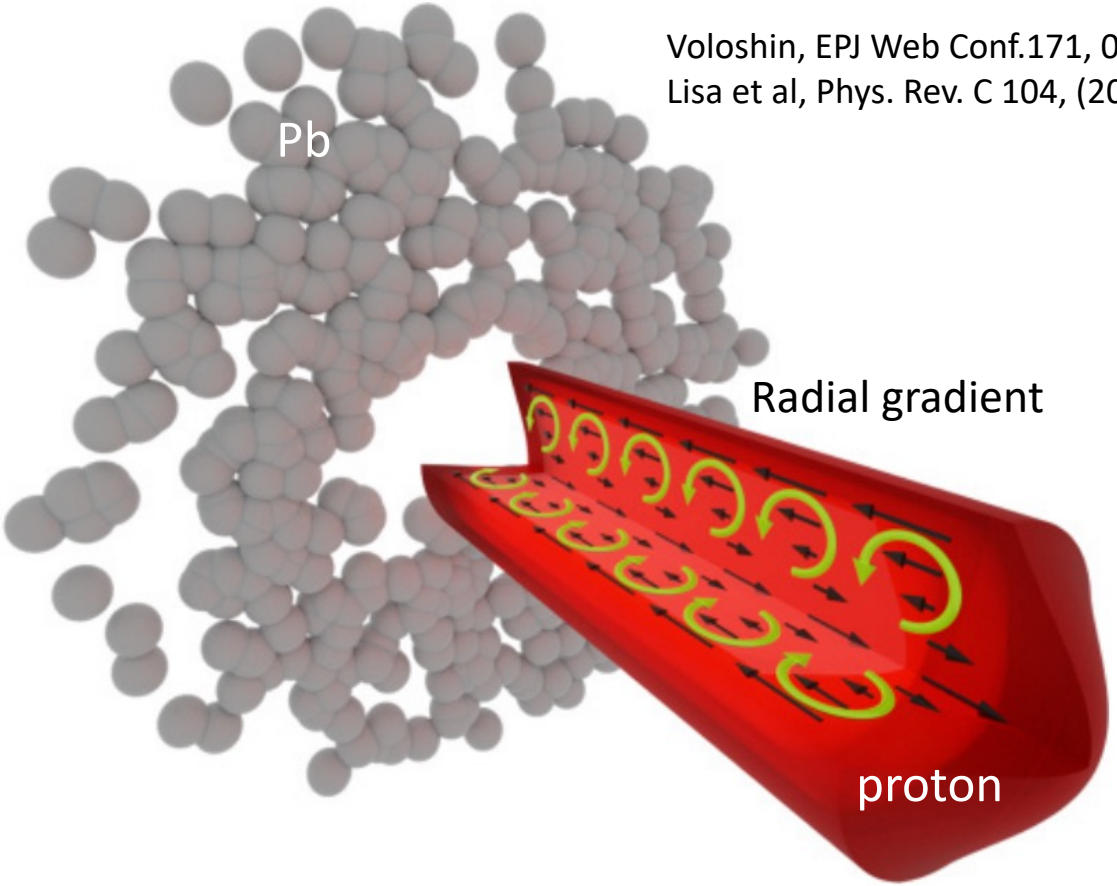
Measurements and model calculations across pp, pA, AA needed!

Other 'local' polarization phenomena could provide more insights

Vortex ring in pA collisions



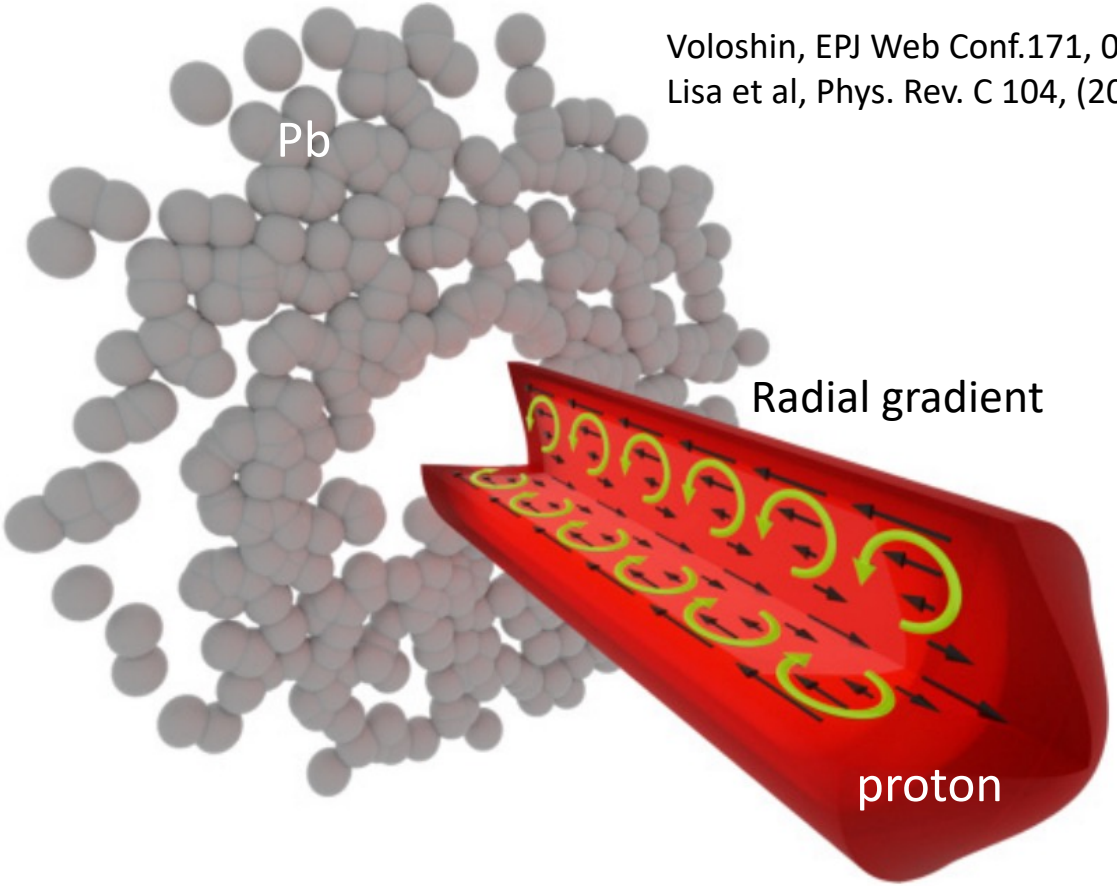
Vortex ring in pA collisions

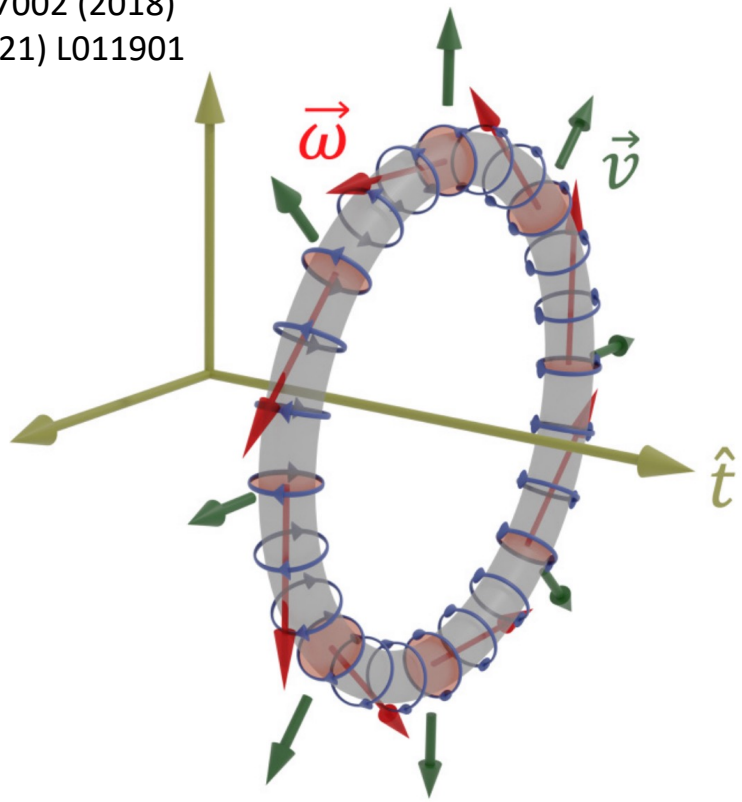


Voloshin, EPJ Web Conf.171, 07002 (2018)
Lisa et al, Phys. Rev. C 104, (2021) L011901

Vortex ring in pA collisions

Voloshin, EPJ Web Conf.171, 07002 (2018)
Lisa et al, Phys. Rev. C 104, (2021) L011901

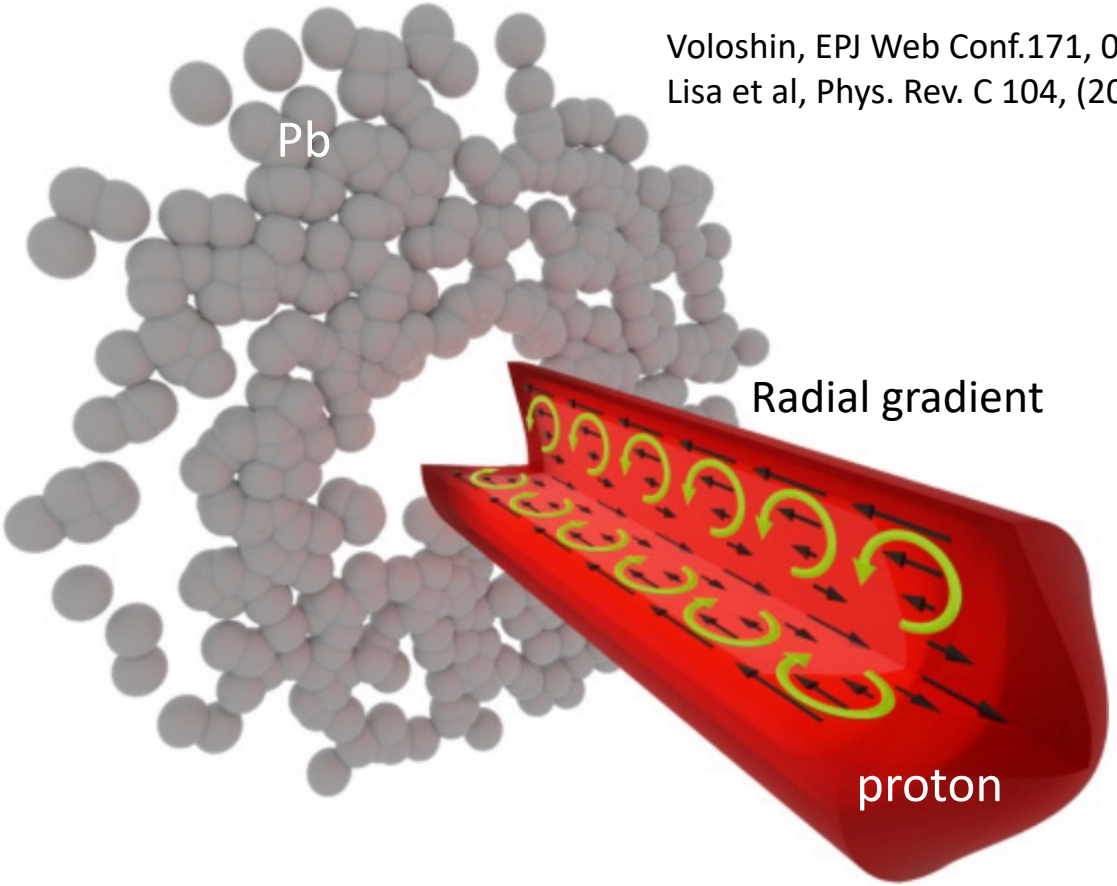


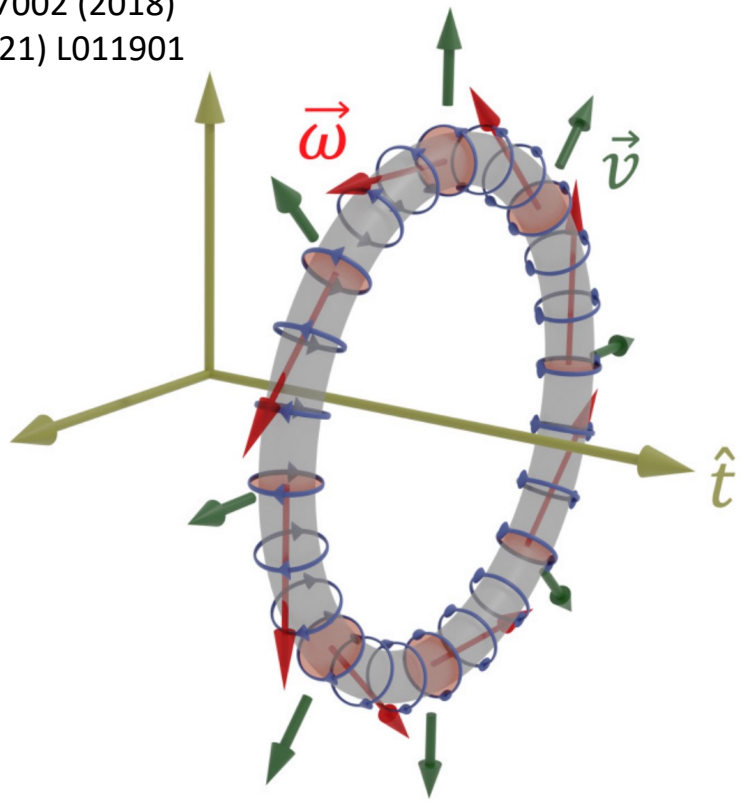


Potential creation of a vortex ring in tiny space

Vortex ring in pA collisions

Voloshin, EPJ Web Conf.171, 07002 (2018)
Lisa et al, Phys. Rev. C 104, (2021) L011901





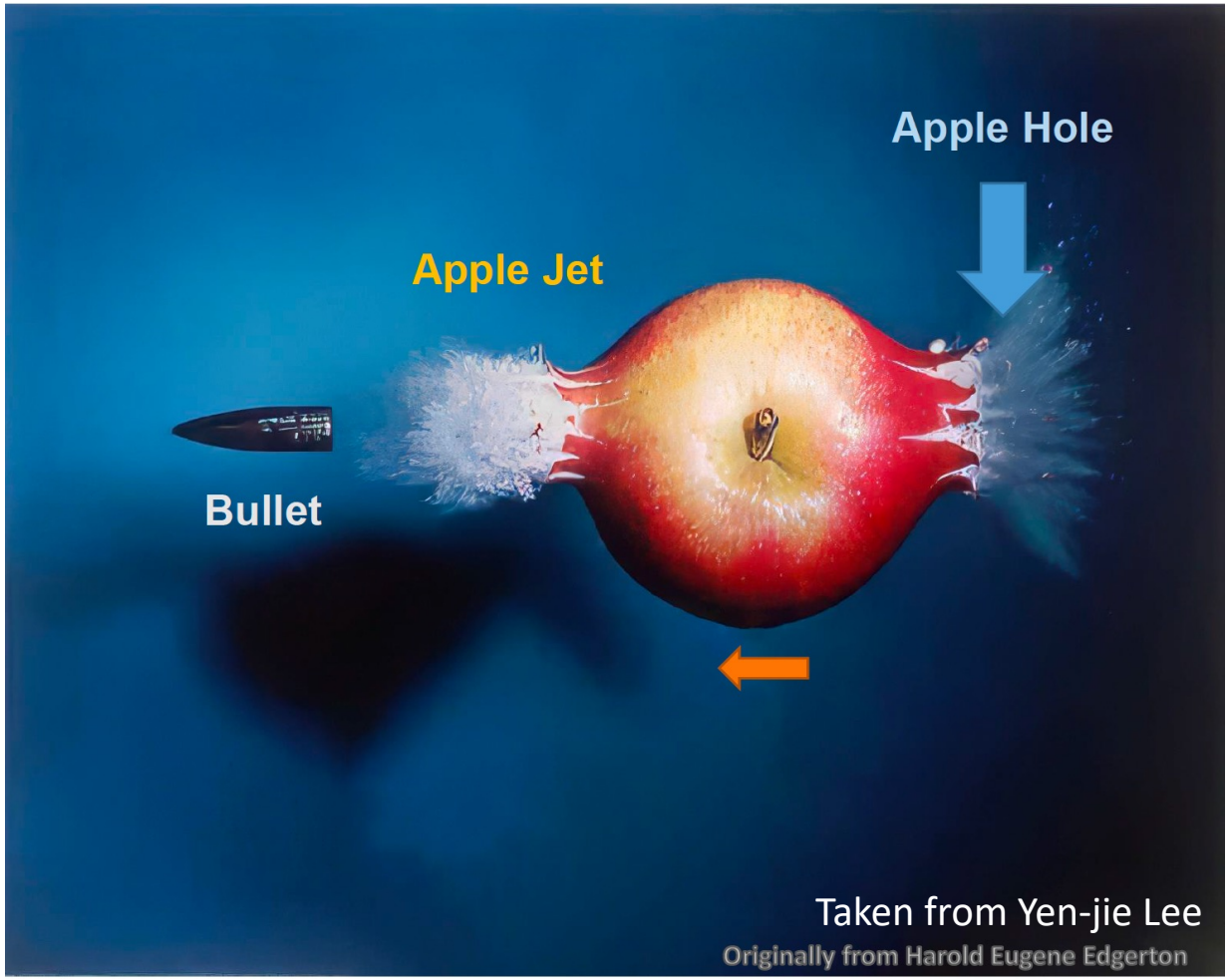
Potential creation of a vortex ring in tiny space

Probe even finer vorticity structures and polarization mechanism

Crucial for understanding hyperon polarization in small systems

Polarization from jet-medium interaction

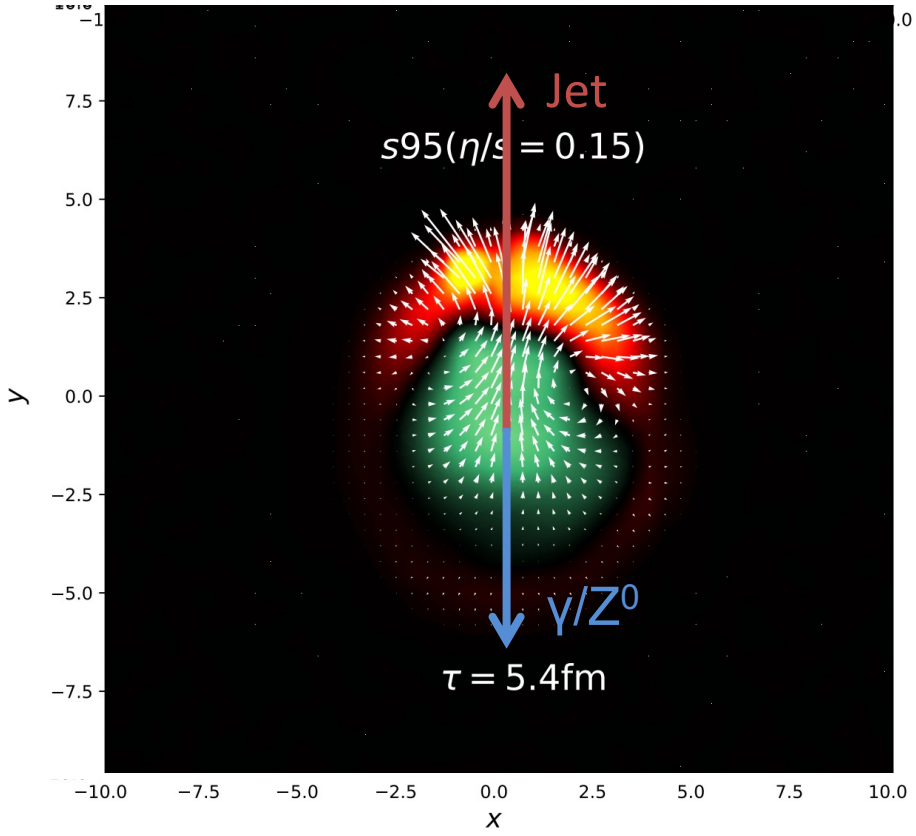
Polarization from jet-medium interaction



A jet going through an object leave holes behind

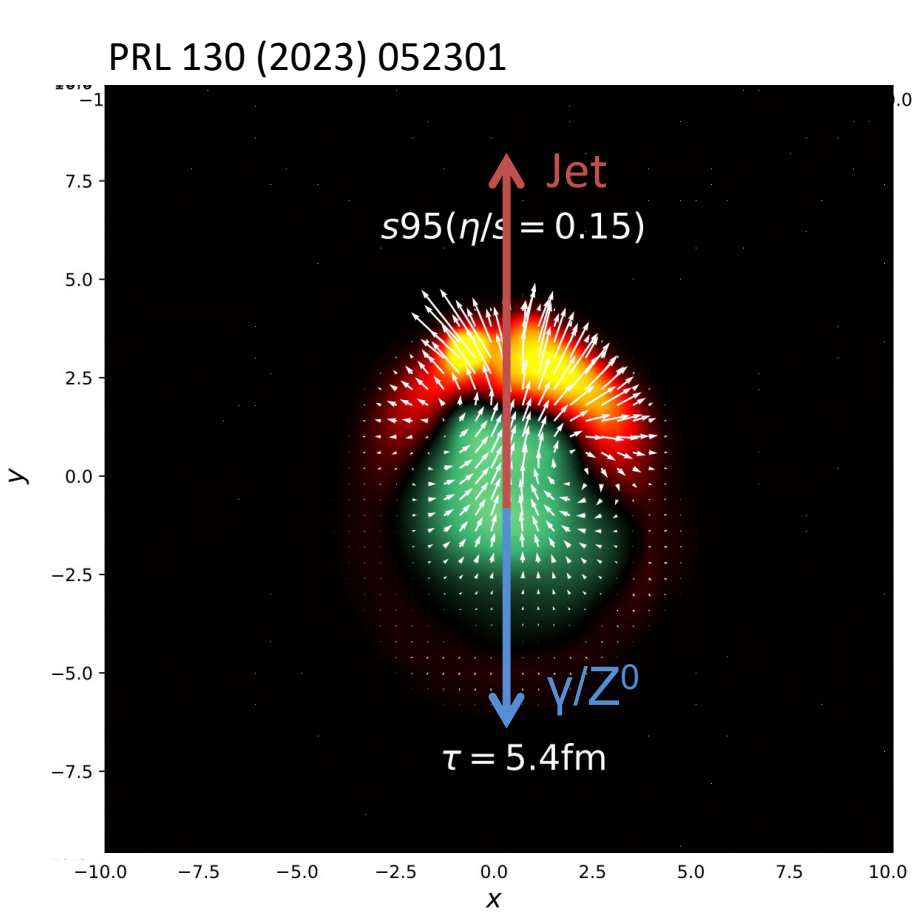
Polarization from jet-medium interaction

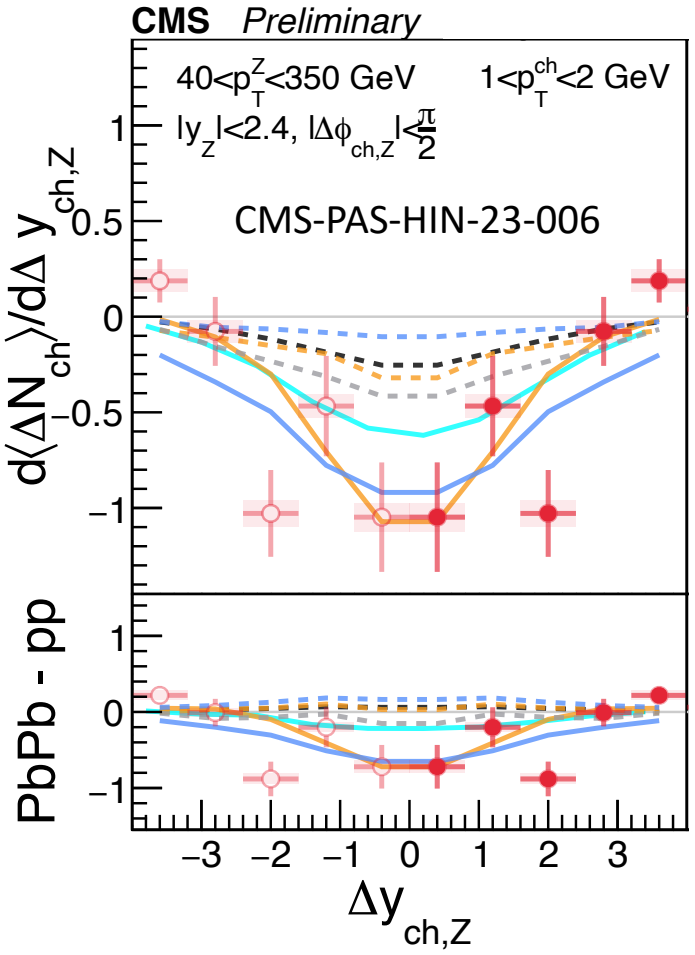
PRL 130 (2023) 052301



A jet going through an object leave holes behind
Same for QCD matter – jet induced diffusion wake in QGP

Polarization from jet-medium interaction

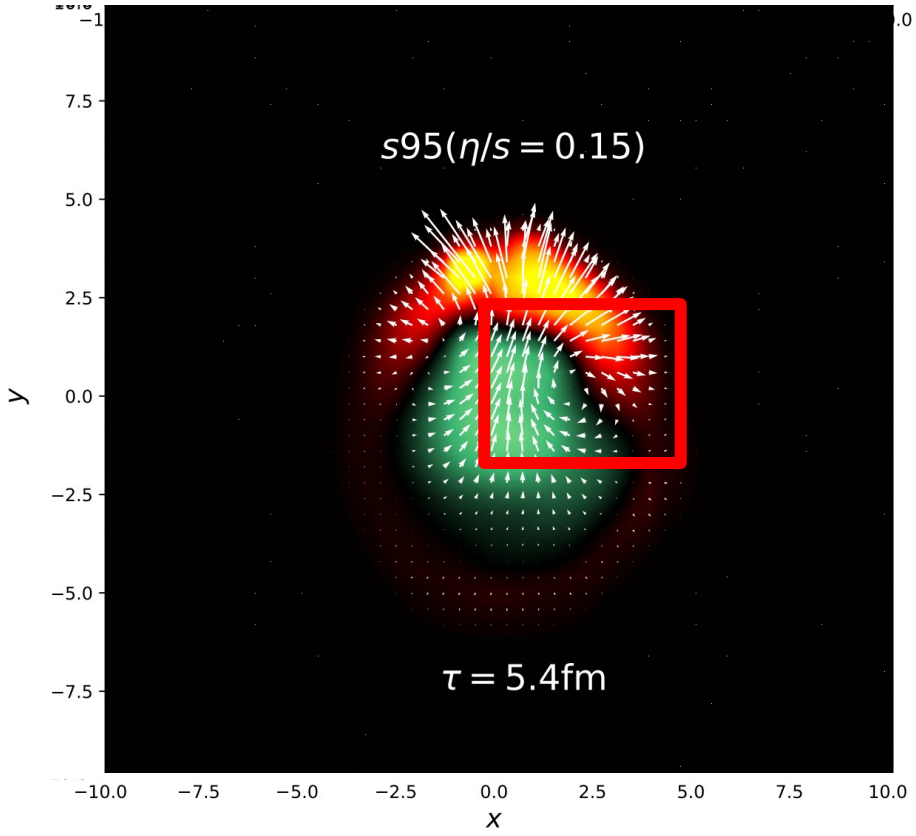




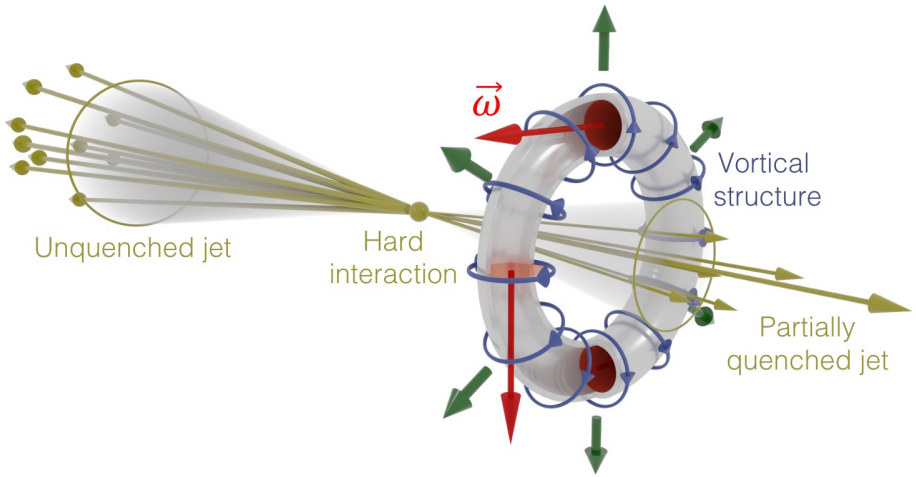
A jet going through an object leave holes behind
Same for QCD matter – jet induced diffusion wake in QGP
Confirmed by observation of particle depletion around Z boson

Polarization from jet-medium interaction

PRL 130 (2023) 052301



PLB 820 (2021) 136500

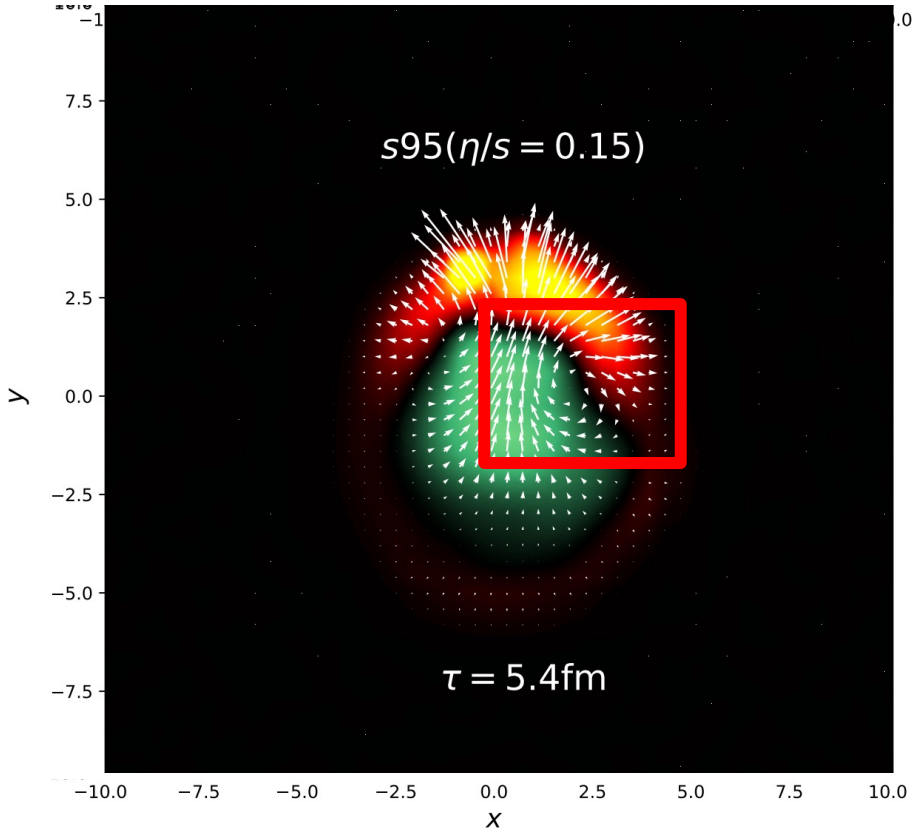


The wake induces vortical structures

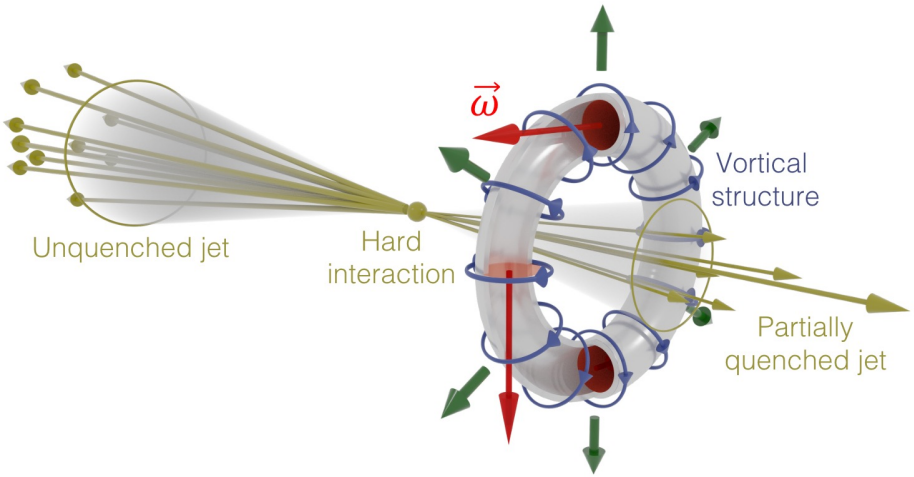
A vortex ring at even smaller scale

Polarization from jet-medium interaction

PRL 130 (2023) 052301



PLB 820 (2021) 136500



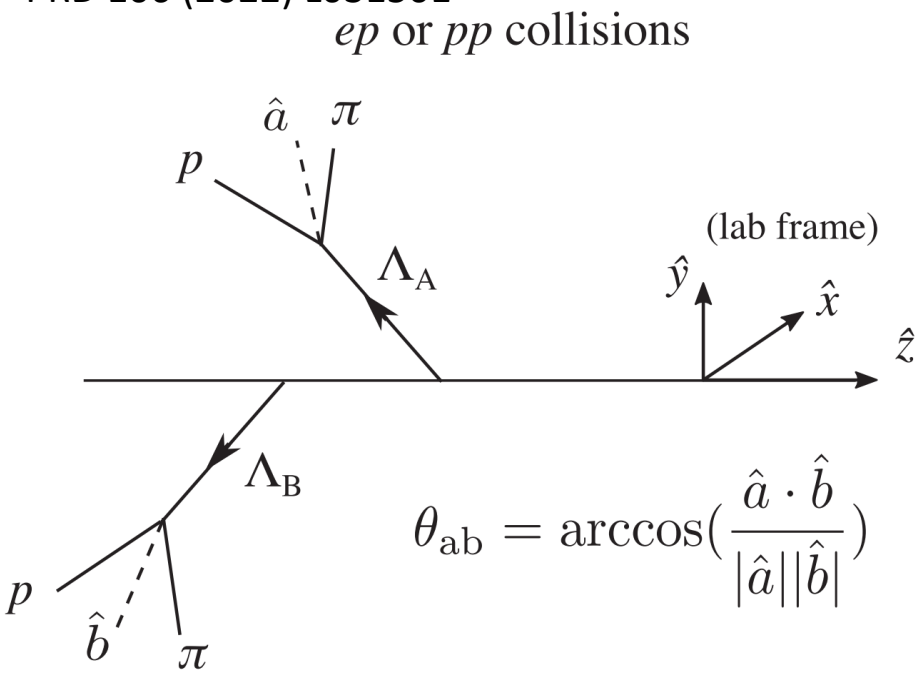
The wake induces vortical structures

A vortex ring at even smaller scale

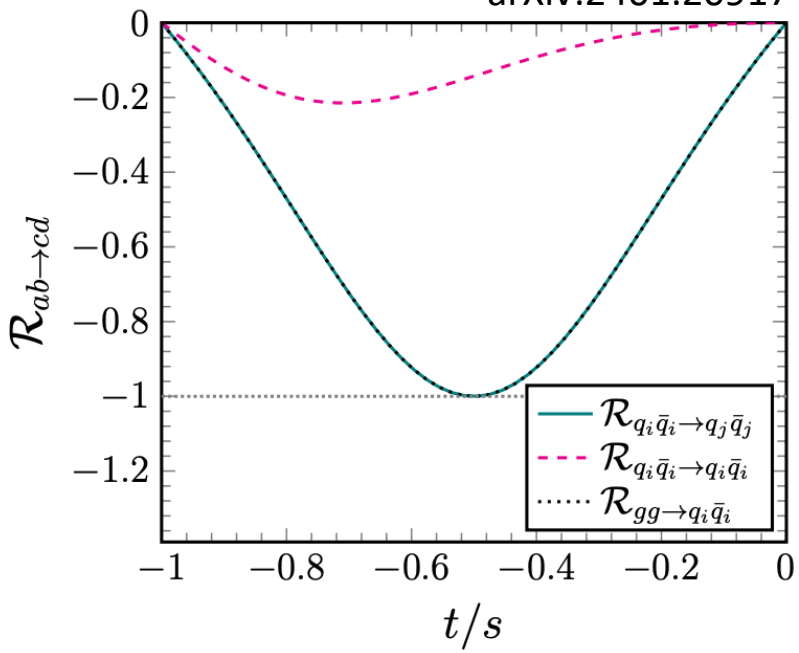
Experimental results will shed light on both polarization and parton transport

Spin-spin correlation

PRD 106 (2022) L031501



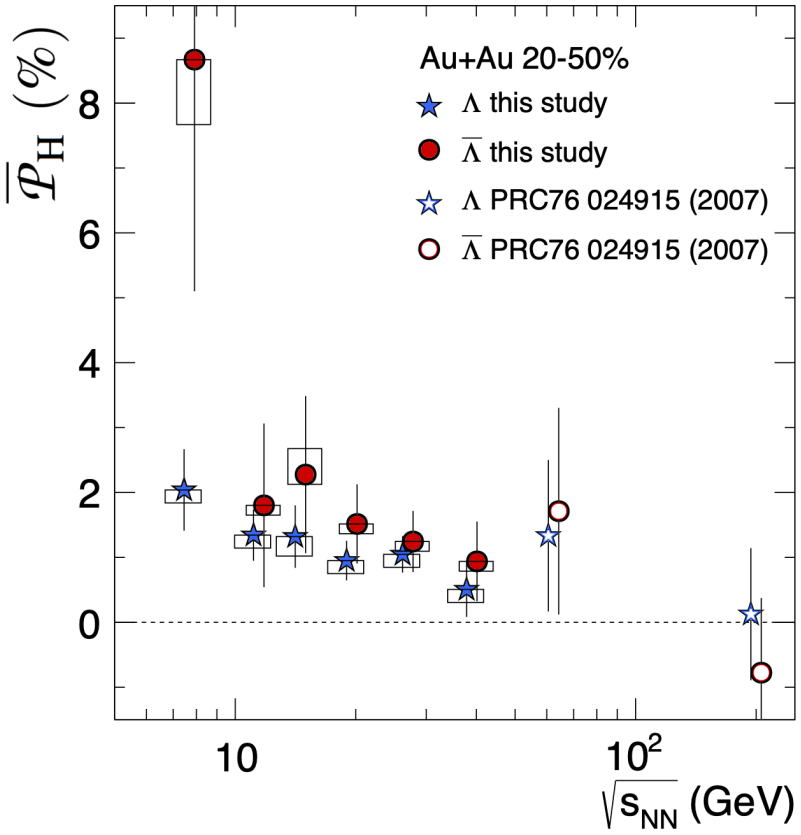
arXiv:2401.20917



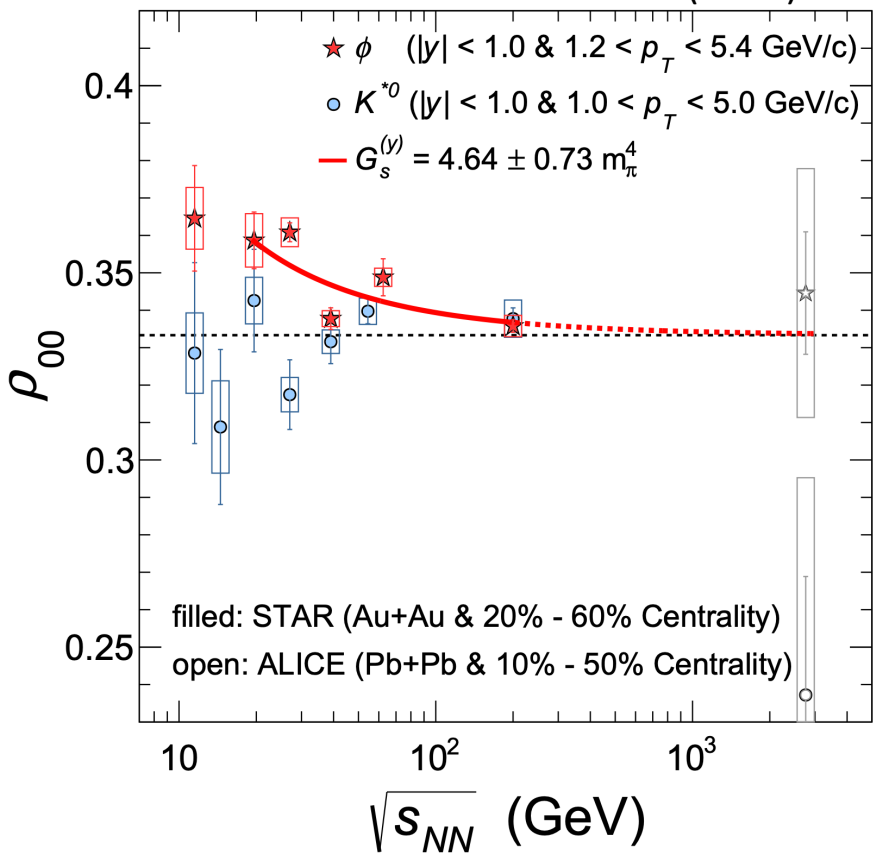
Hyperon spin-spin correlation in e/p scatterings can probe
Quantum entanglement from spin perspective
Spin-dependent fragmentation functions

Spin-spin correlation

Nature 548 (2017) 62



Nature 614 (2023) 244



Global polarization and spin alignment in HI post a question why

$$\left|\rho_{00}^{V} - \frac{1}{3}\right| \gg P_{\Lambda}^{2} \sim P_{q}^{2}$$

Spin-spin correlation proposed as a solution

Measurements across pp, pA, AA can provide a clear answer

Summary

Significant hyperon local polarization P_z observed in pPb collisions

- Hydro calculations cannot capture the correct sign
- Post challenge to current heavy ion polarization models

A series of measurements can be carried out to unravel the roots

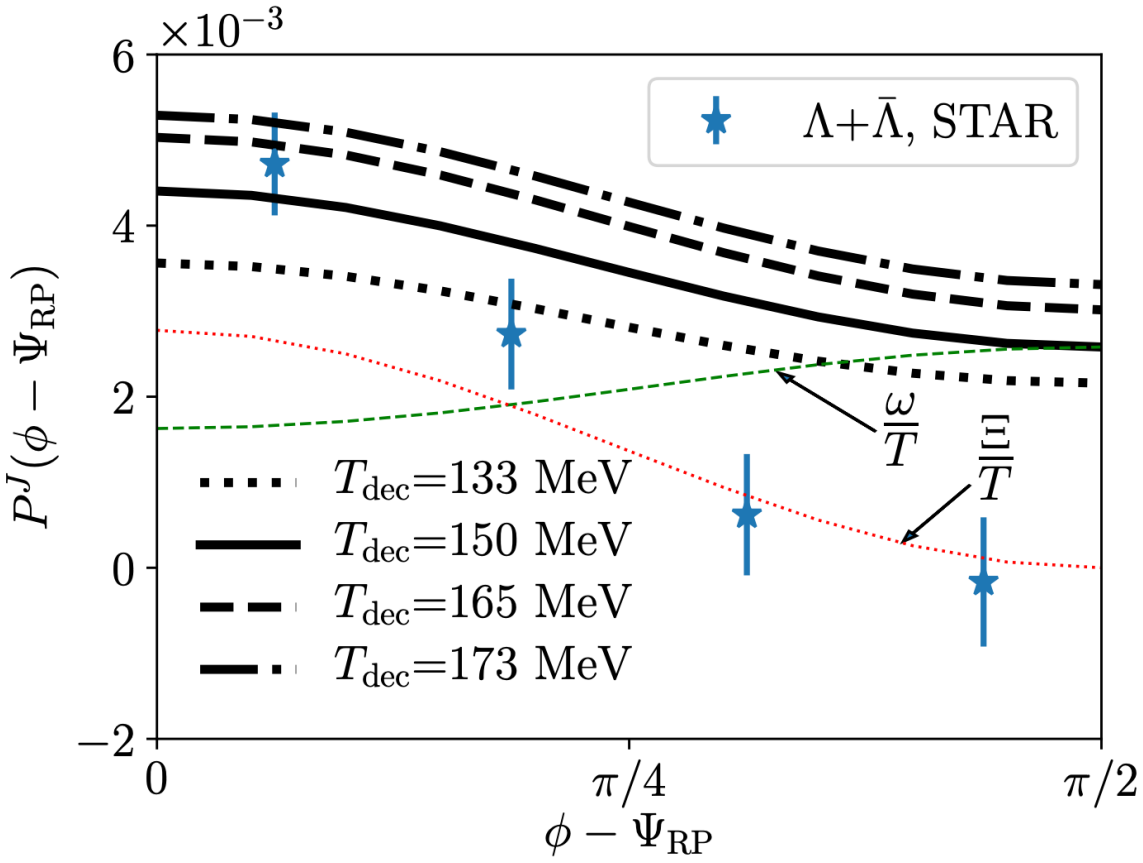
- Hyperon global and local polarization across pp, pA and AA
- Vortex rings and jet-QGP interaction induced polarization
- Polarizing Fragmentation Functions: hyperon in jet, spin-spin correlation
- ……

Opportunities to build more bridges between spin and QGP

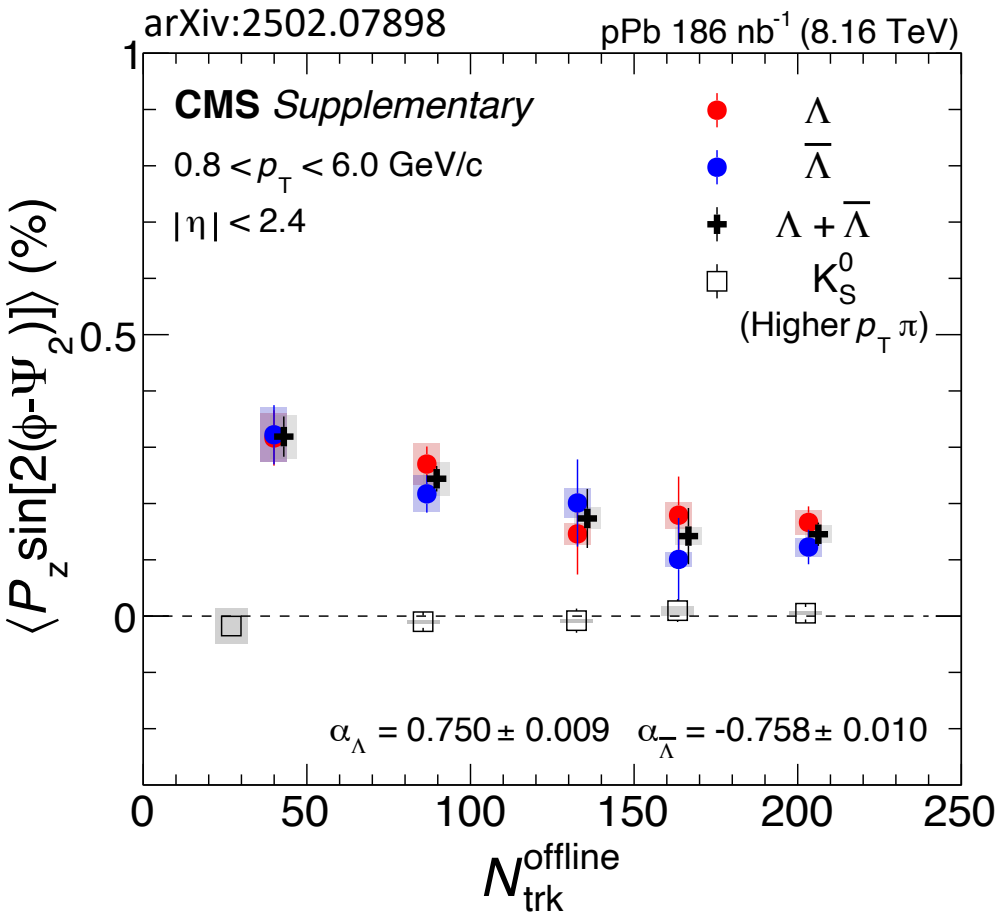
Stay tuned for the results!

Back up

“Pz puzzle”


$\times 10^{-3}$
6
4
2
0
−2
$P^J(\phi - \Psi_{\mathrm{RP}})$
0
$\pi/4$
$\pi/2$
$\phi - \Psi_{\mathrm{RP}}$
$\Lambda+\bar{\Lambda}$, STAR
T_{dec}=133 MeV
T_{dec}=150 MeV
T_{dec}=165 MeV
T_{dec}=173 MeV
$\frac{\omega}{T}$
$\frac{\Xi}{T}$

$P_{z,s2}$ in pPb collision



$P_{z,s2}$ in pPb collision