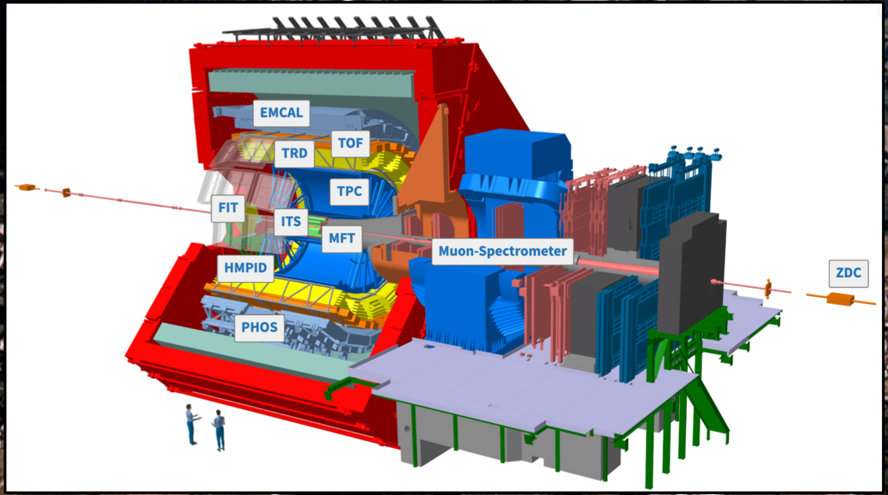
Asian activities in the LHC-ALICE experiment

Qiye Shou (Fudan University, Shanghai)

The 2024 ANPhA Meeting, Huizhou

THE LARGE HADRON COLLIDER AT CERN

ALICE Collaboration:
40 countries, 171 institutes
2002 members, 1034 scientific author



ALICE

Heavy-ion collisions

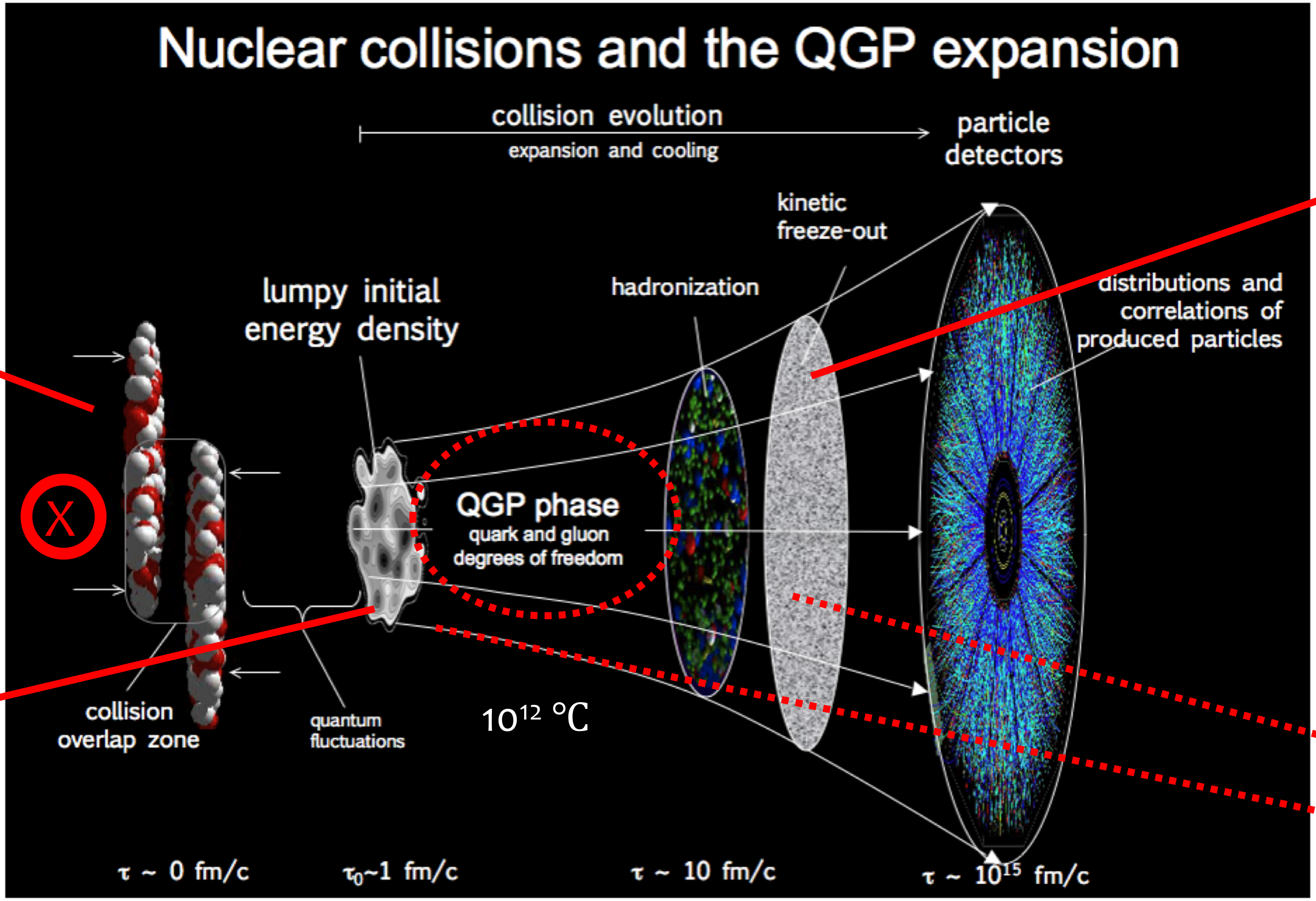
Magnetic field

~10^{15} T

Vortical field

~10^{21} s^{-1}

Hadrons



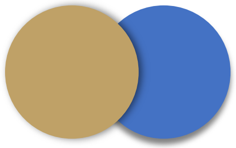
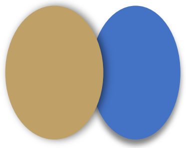
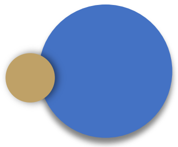
Quarks

Photons

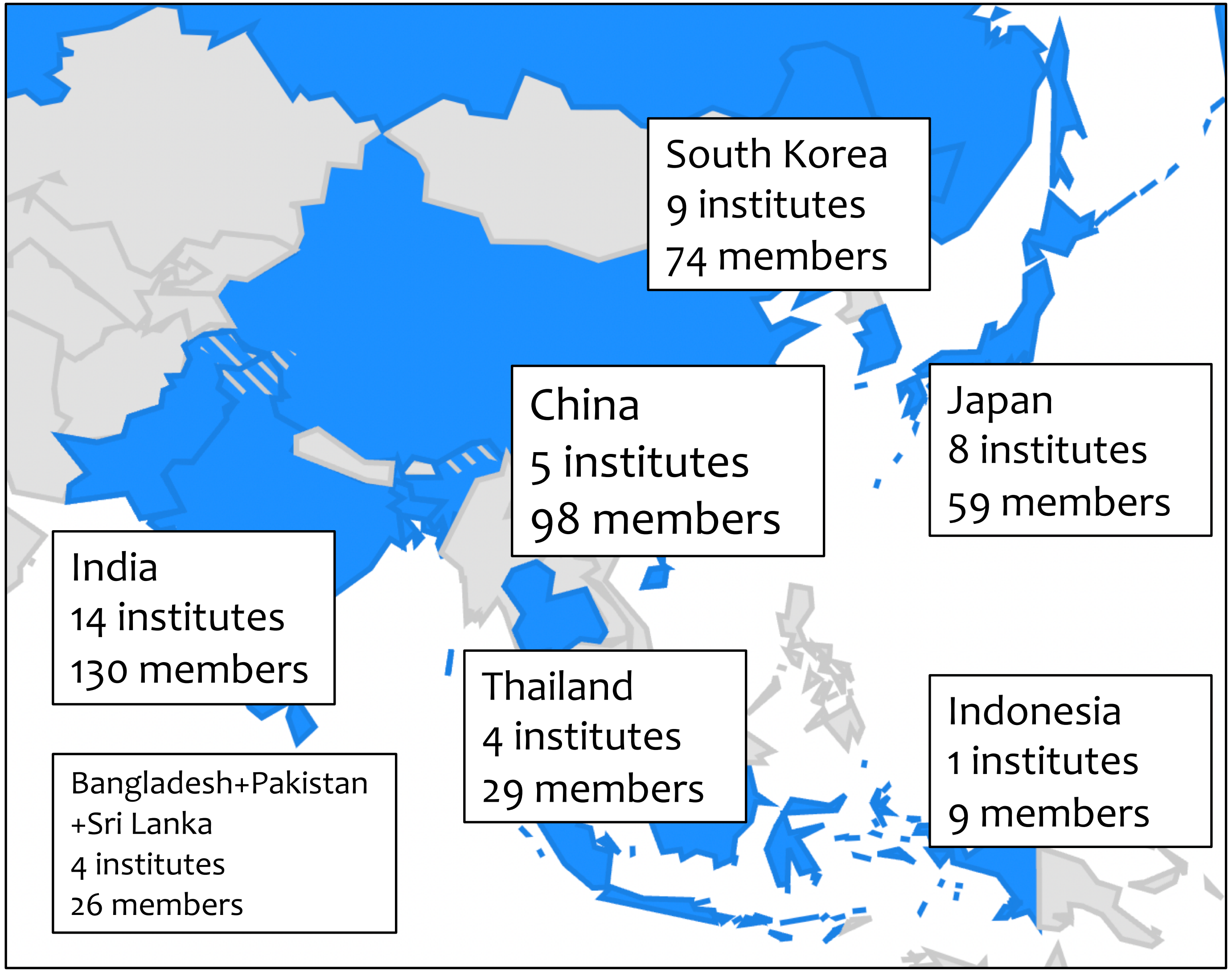
Leptons

Quark-gluon plasma: criticality, collectivity, chirality

Heavy-ion collisions

	LHC	RHIC
	Pb-Pb 2.76 TeV Pb-Pb 5.02 TeV	Au+Au BES (7-62 GeV) Au+Au 200 GeV Cu+Cu Isobar (Zr+Zr)
	Xe-Xe 5.44 TeV O-O	U+U 192 GeV Isobar (Ru+Ru)
	pPb 5.02 TeV pPb 8.16 TeV	p(d)+Au 200 GeV Cu+Au

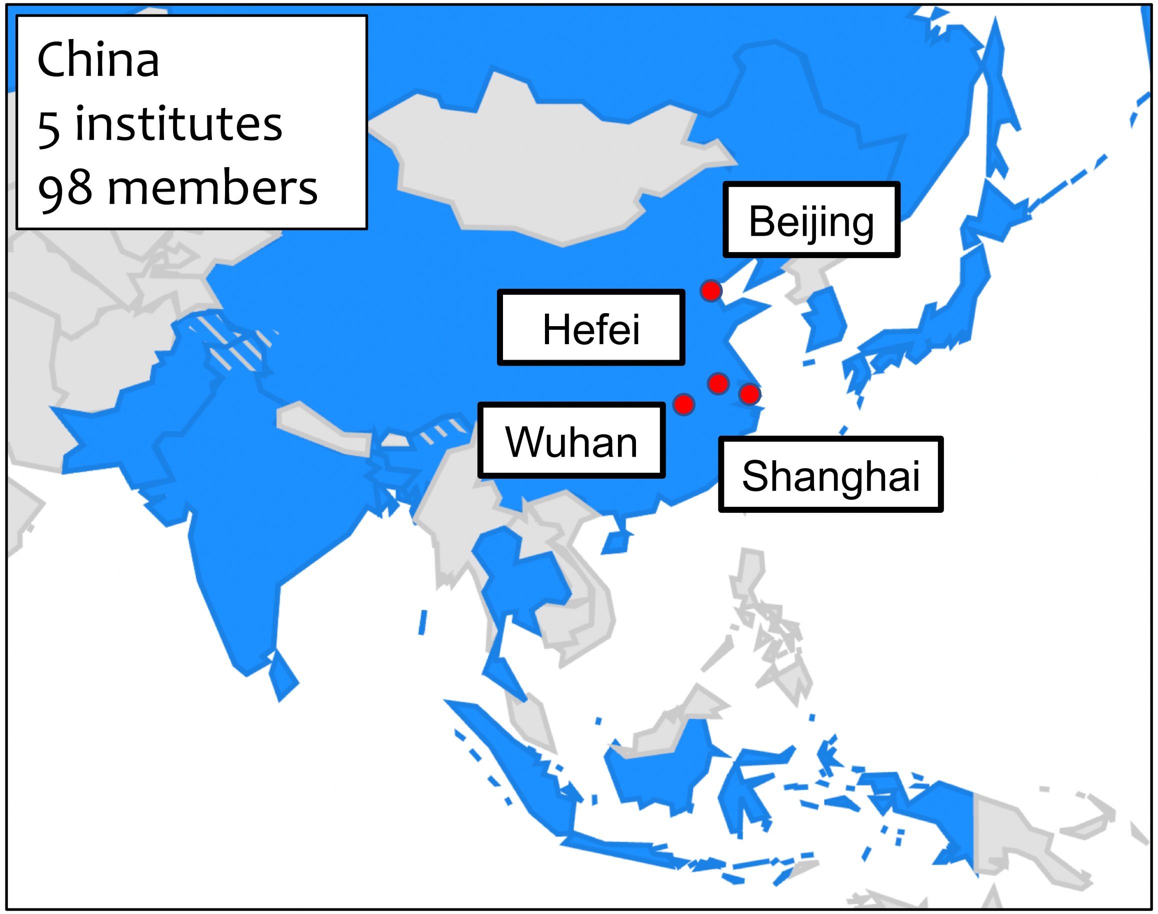
ALICE Asia



ALICE Asia community:

- 45 institutes (26% of total)
- 425 members (21% of total)

ALICE China



- **Central China Normal University (Wuhan)**
  member of LHCb, STAR
  - Cluster: China University of Geosciences
- **China Institute of Atomic Energy (Beijing)**
- **Fudan University (Shanghai)**
  member of CMS, STAR
- **University of Science and Technology of China (Hefei)**
  member of ATLAS, STAR

International collaboration

PWG-CF -Correlations and flow

Conveners:

- Oton Vazquez Doce
- Qiye Shou

PAG: Azimuthal Correlations

- Debojit Sarkar
- Jasper Elias Parkkila

PAG: Event-by-Event / Fluctuations

- Sumit Basu
- Swati Saha

PAG: Femtoscopy

- Laura Serksnyte
- Raffaele Del Grande

PWG-DQ - Dileptons and Quarkonia

Conveners:

- Cristiane Jahnke
- Luca Micheletti

PAG: J/psi electron decay

- Minjung Kim
- Victor Jose Gaston Feuillard

PAG: Quarkonium muon decays

- Maxime Rene Joseph Guilbaud
- Batoul Diab

PWG-EM - Electromagnetic probes

Conveners:

- Ivan Vorobyev
- Daiki Sekihata

PAG: Low-mass dielectrons

- Horst Sebastian Scheid
- Daniel Samitz

PAG: Photons and neutral mesons

- Ana Maria Marin
- Joshua Leon Konig

PWG-HF - Heavy Flavour

Conveners:

- Fabio Filippo Colamaria
- Fabrizio Grosa

PAG: Hadronic Decays of Heavy Flavours

- Mattia Faggin
- Fabio Catalano

PAG: Heavy Flavour Leptons (Electrons and Muons)

- Jonghan Park
- [alice:PWG-HF-PAG-Heavy-flavour-decay-leptons-Coordinator:1:link]

International collaboration

- **Commonly interested physics analyses and technology development**

China, India, South Korea: collective motions
China, Japan: dileptons
All countries: detectors, hardware, computing

- **Communications between juniors, exchanging PhD students**

Common culture background, time zone, personality. Good for the juniors.

- **Joint grants**

NSFC - JSPS - NRF : A3 Foresight Program
NSFC - JSPS（中日）二国間交流事業 共同研究・セミナー

Space-Time Evolution and Resulting Novel Phenomena of Ultra-Intense Magnetic Field in Non-Central High-Energy Nucleus-Nucleus Collisions (QS from Fudan + K. Shigaki from Hiroshima)

we aim to strengthen the cooperation, which has become particularly important in recent years, and form the core of the ALICE experiment's Asia Group, leading to new physical results.

International collaboration

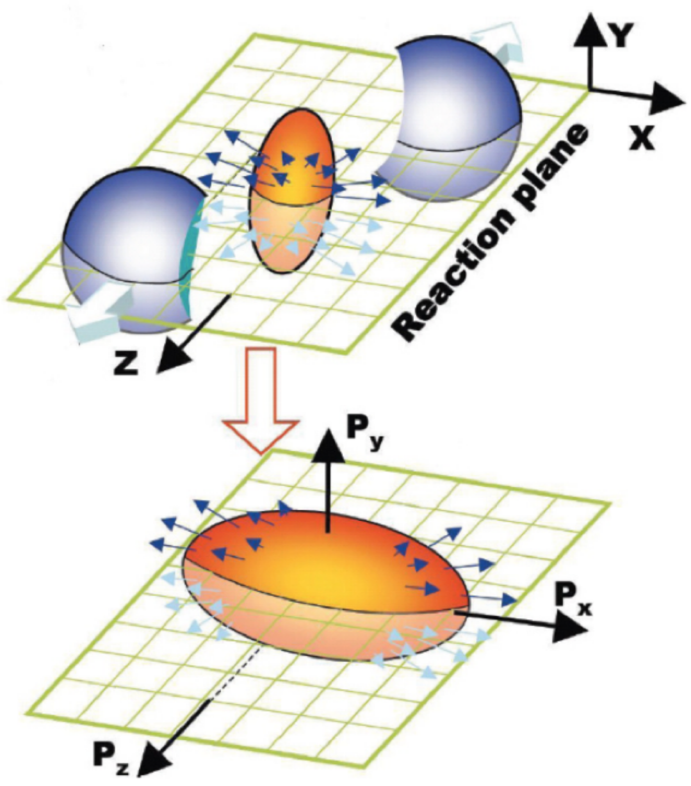
Asian Triangle Heavy-Ion Conference (ATHIC)

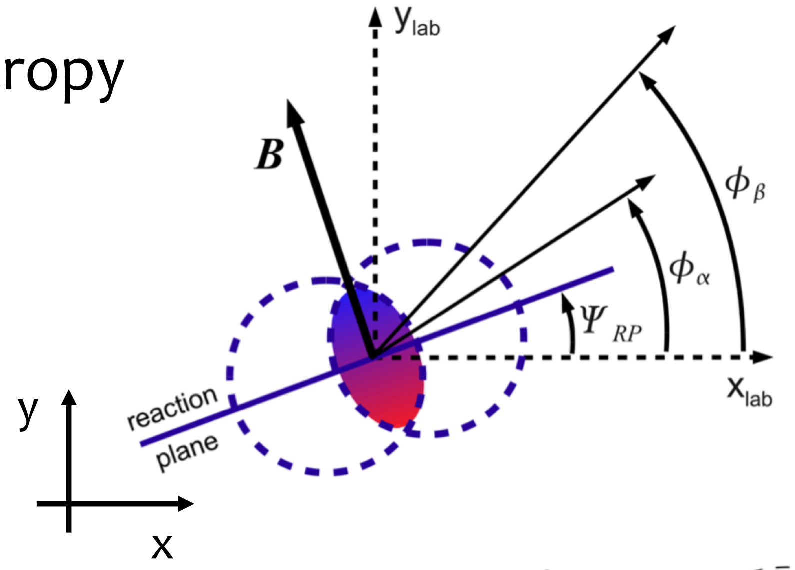
1st: ATHIC 2006, Seoul, South Korea
2nd: ATHIC 2008, Tsukuba, Japan
3rd: ATHIC 2010, Wuhan, China
4th: ATHIC 2012, Pusan, South Korea
5th: ATHIC 2014, Osaka, Japan
6th: ATHIC 2016, New Delhi, India
7th: ATHIC 2018, Hefei, China
8th: ATHIC 2021, Incheon, South Korea
9th: ATHIC 2023, Hiroshima, Japan
10th: ATHIC 2025, Berhampur, India

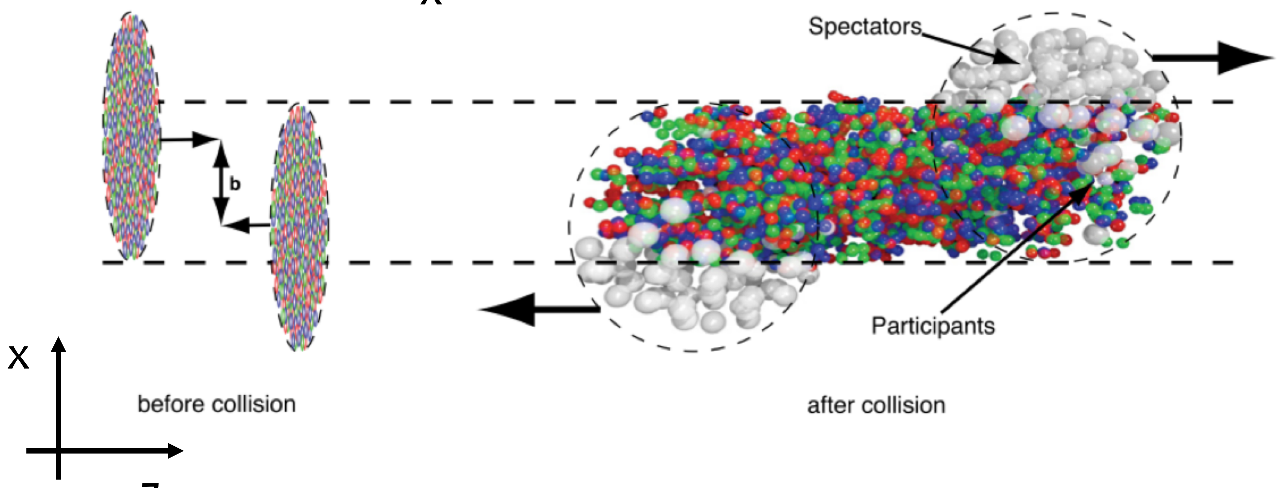
Studies of collective flow at ALICE

Azimuthally anisotropic emission of final state hadrons

Initial eccentricity ⟶ Final momentum anisotropy





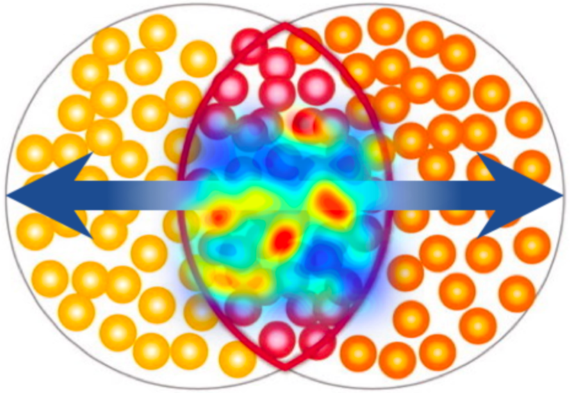


Collectivity and anisotropic flow

$$E\frac{d^3N}{d^3\mathbf{p}} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})]\right)$$

$$v_n(p_t, y) = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

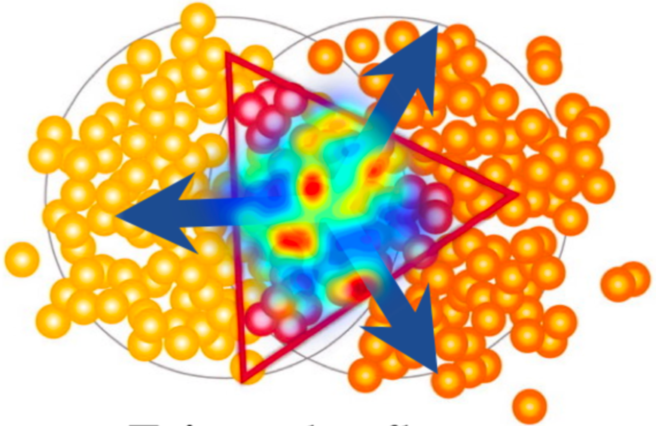
2nd order



Elliptic flow

+

3rd order

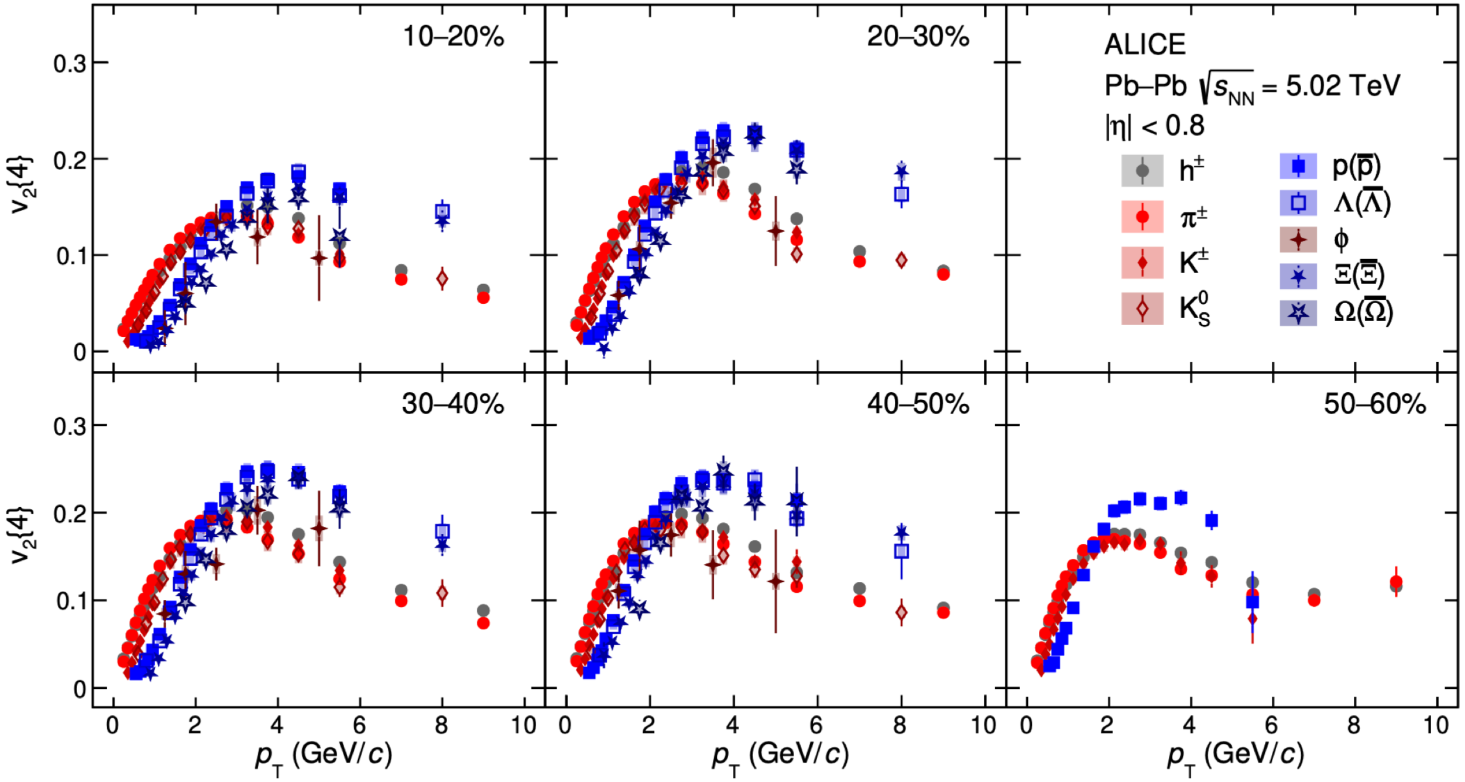


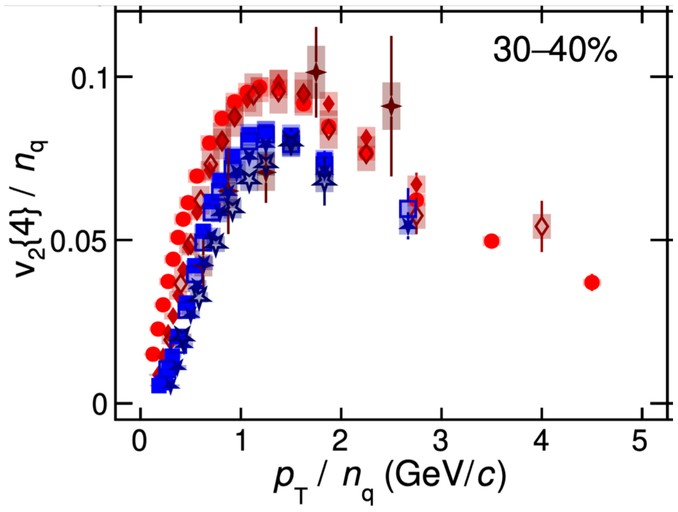
Triangular flow

+ higher order

Testing dynamic features and evolution of the QGP in Pb-Pb collisions

JHEP 05(2023)243

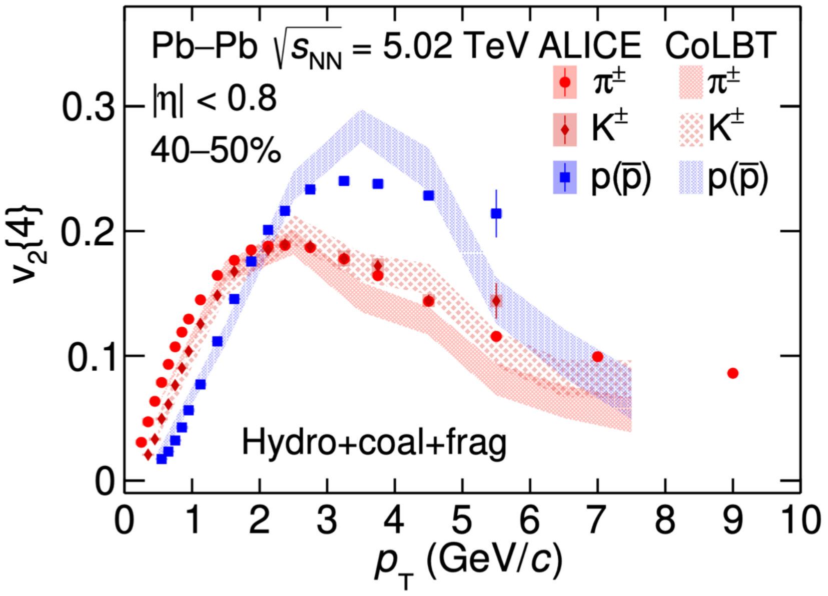


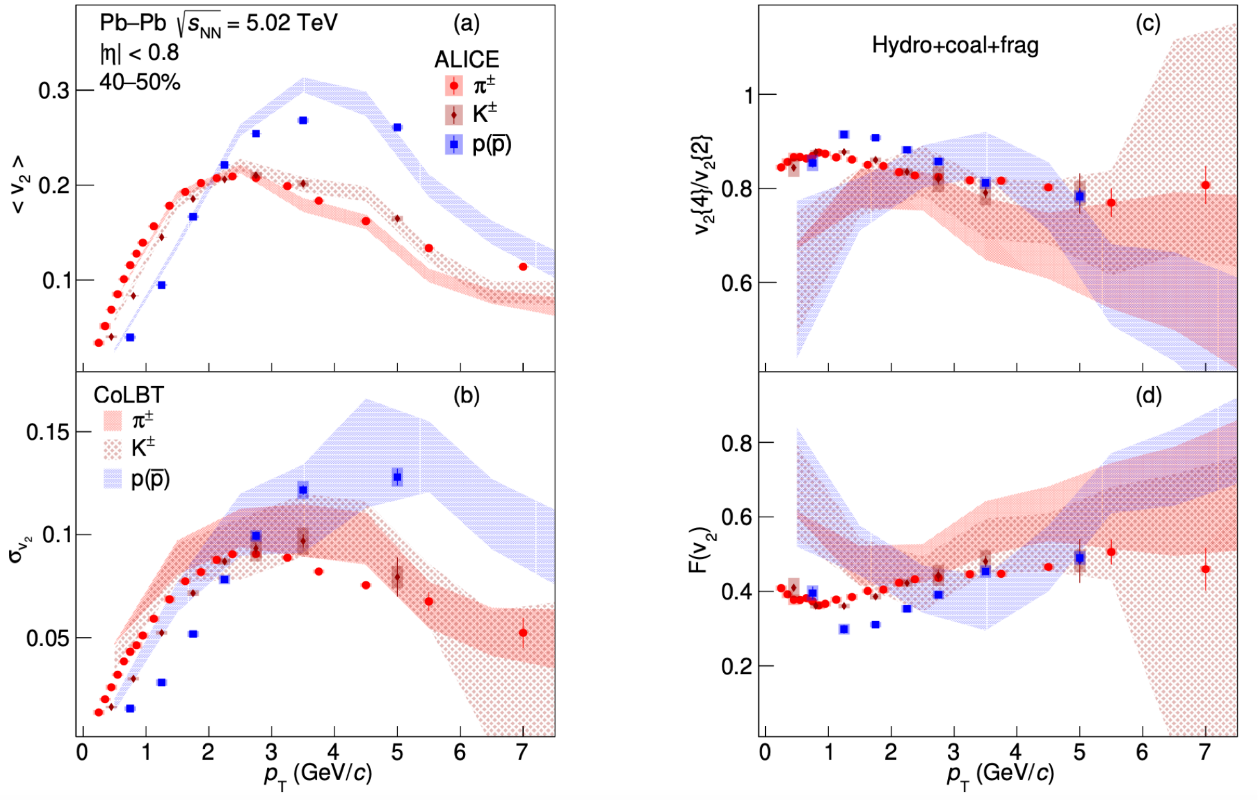


- ➢ Mass ordering and the meson–baryon grouping imply the dynamical evolution of the colliding system
- ➢ The number of constituent quarks (NCQ) scaling only holds approximately

Testing dynamic features and evolution of the QGP in Pb-Pb collisions

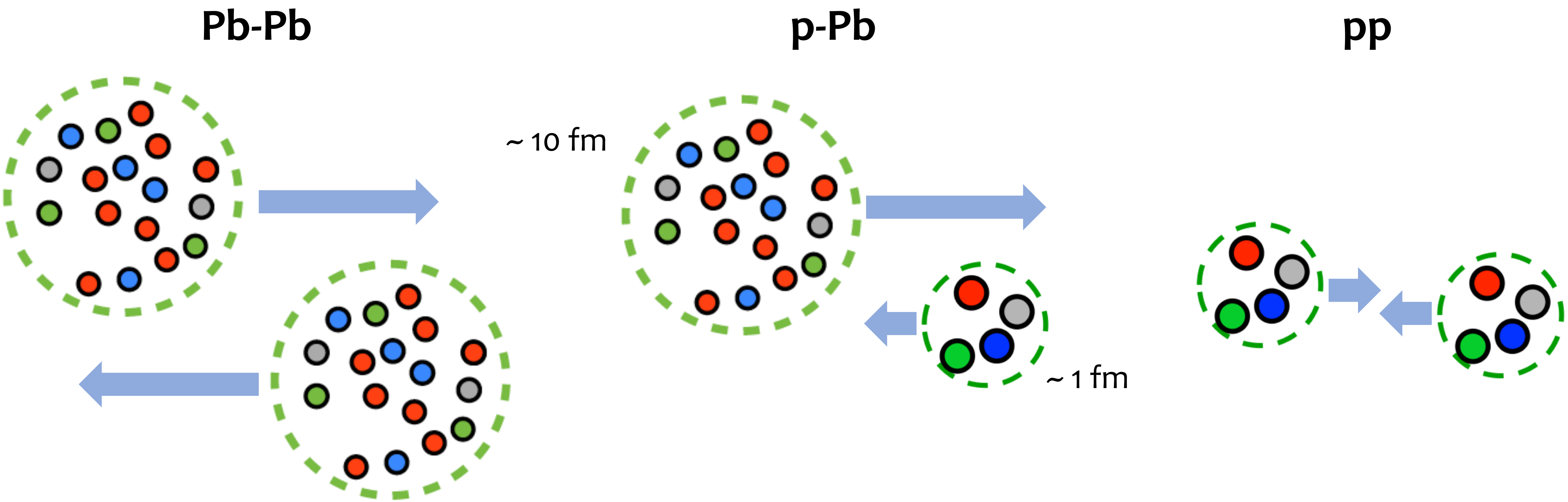
JHEP 05(2023)243





➢ Can be tested by the hydrodynamical expansion + hadron production through quark coalescence + jet fragmentation

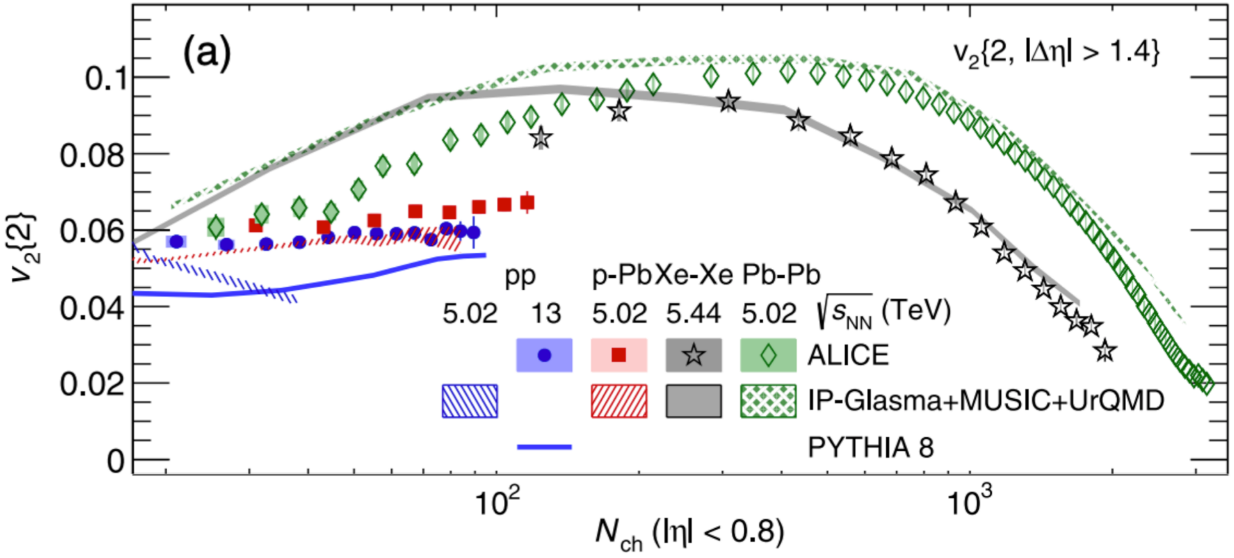
Probing partonic collectivity in p-Pb and pp collisions

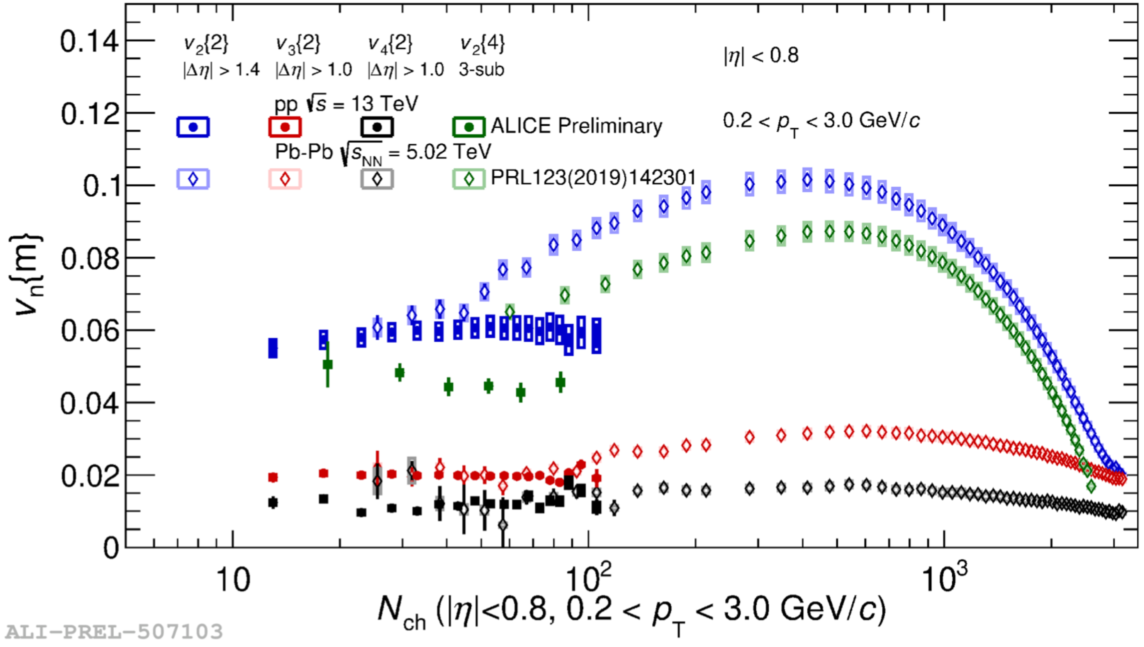


Do we expect the collectivity in small collision systems?

Probing partonic collectivity in p-Pb and pp collisions

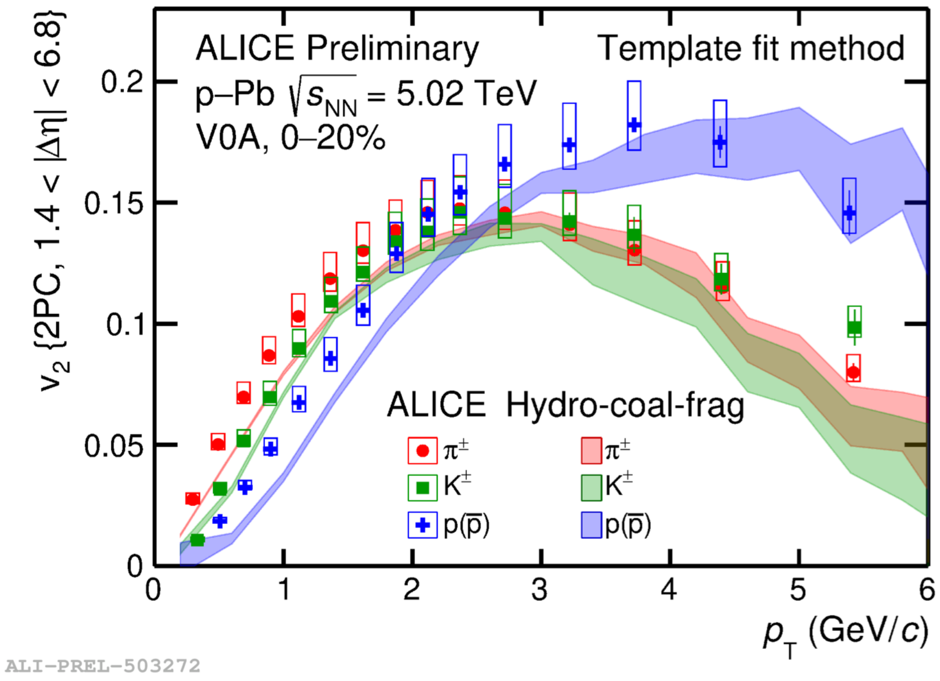
PRL 123, 142301 (2019)

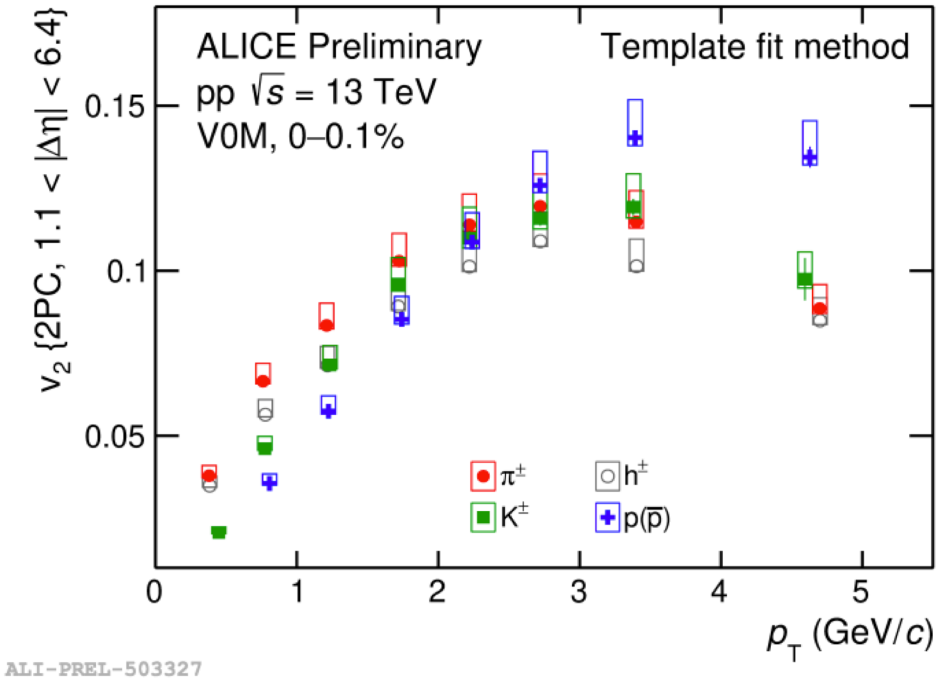




➢ The magnitudes of v_n in pp and p-Pb are similar as in Pb–Pb at low multiplicities

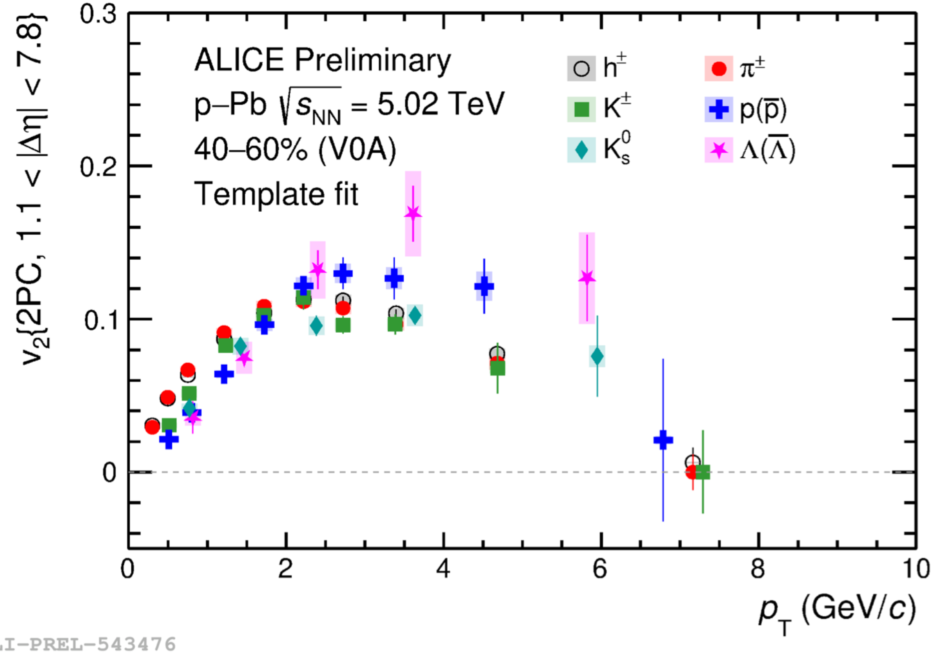
Probing partonic collectivity in p-Pb and pp collisions

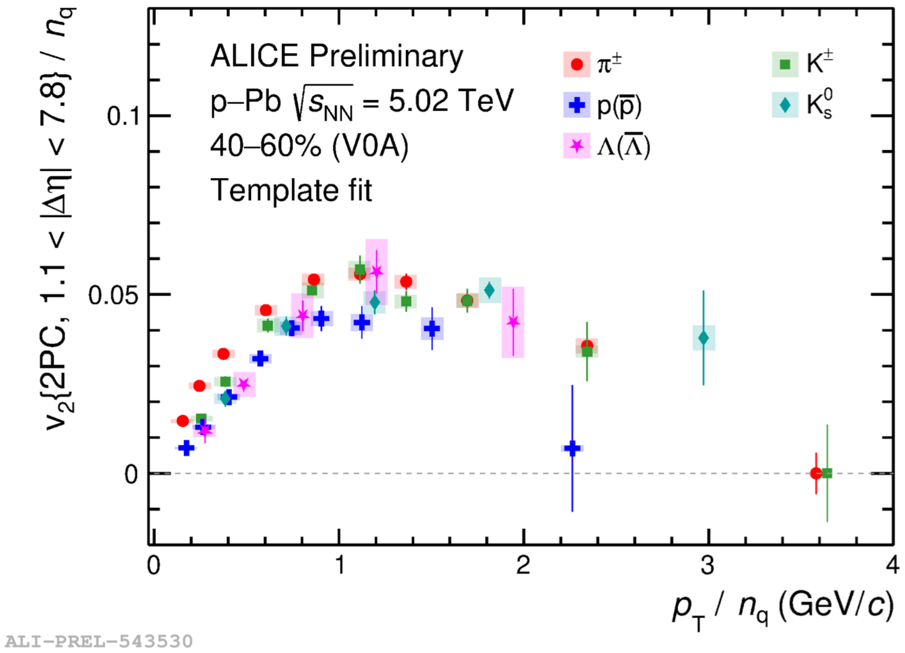




- Mass ordering and the meson–baryon grouping remain valid in p-Pb and pp collisions, indicating the partonic collectivity

Probing partonic collectivity in p-Pb and pp collisions





- Mass ordering and the meson–baryon grouping for all centrality
- Decrease to zero at high p_T range
- NCQ scaling barely holds
- **What is the “small” (pA, pp, ee...) and “dilute” (lower multiplicity) limit of onset of collectivity?**

Imagining the nuclear structure in Pb-Pb and Xe-Xe collisions

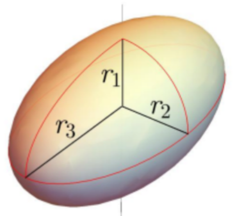
nucleon density described by **Woods-Saxon profile**

$$\rho(r,\theta,\phi) = \frac{\rho_0}{1+e^{[r-R(\theta,\phi)]/a_0}},$$

$$R(\theta,\phi) = R_0(1+\beta_2[\cos\gamma Y_{2,0} + \sin\gamma Y_{2,2}] + \beta_3 \sum_{m=-3}^{3} \alpha_{3,m} Y_{3,m} + \beta_4 \sum_{m=-4}^{4} \alpha_{4,m} Y_{4,m})$$

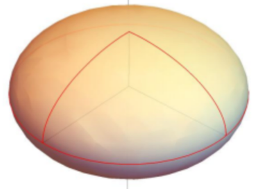
β_2: overall deformation parameter
a_0: diffuseness parameter
γ: triaxiality parameter

Prolate



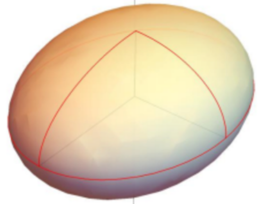
$r_1 = r_2 < r_3$

Oblate

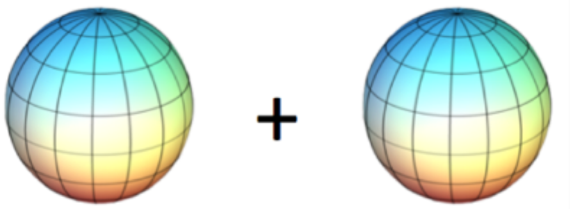


$r_1 < r_2 = r_3$

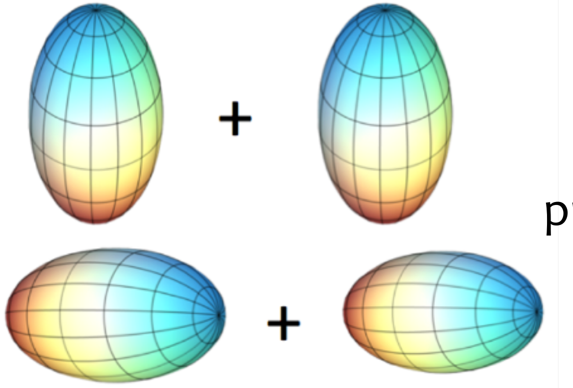
Triaxial



$r_1 \neq r_2 \neq r_3$



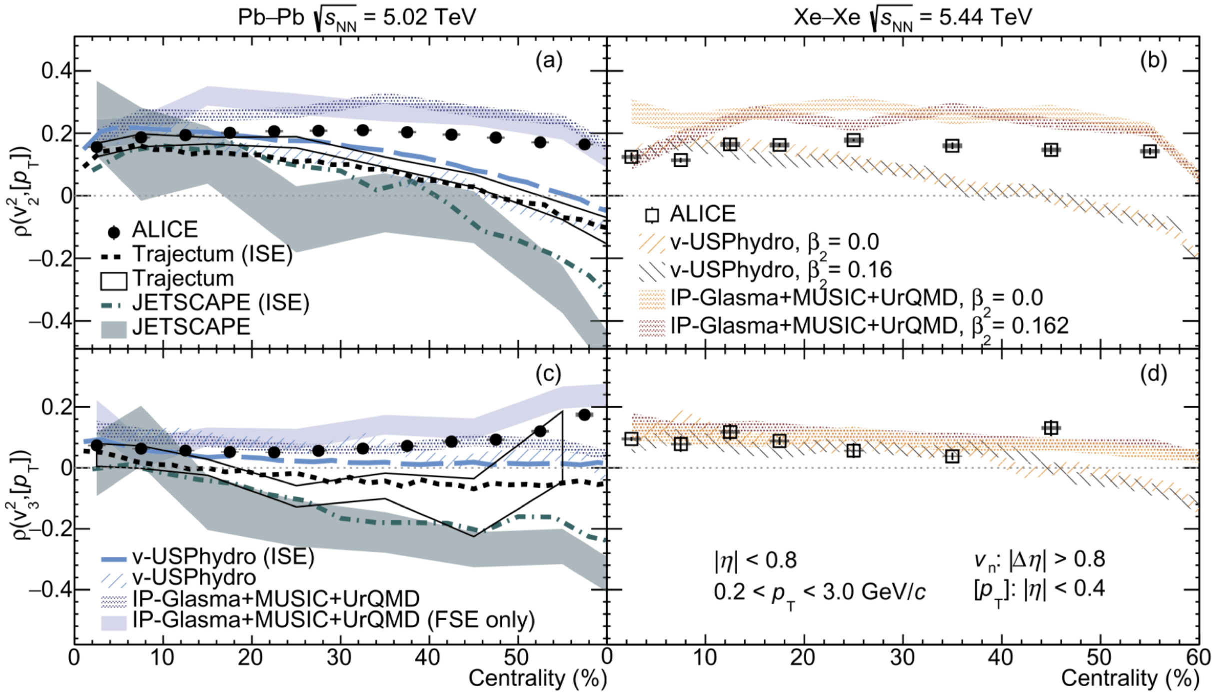
Pb-Pb



Xe-Xe

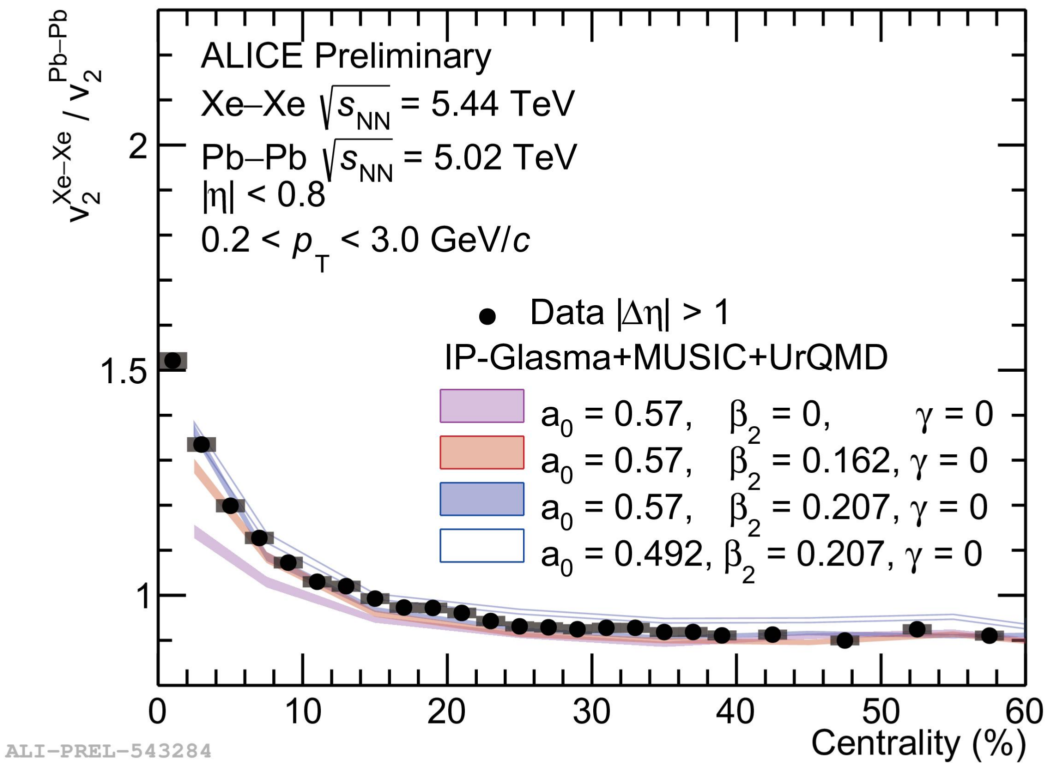
predicted to be triaxial

Imagining the nuclear structure in Pb-Pb and Xe-Xe collisions



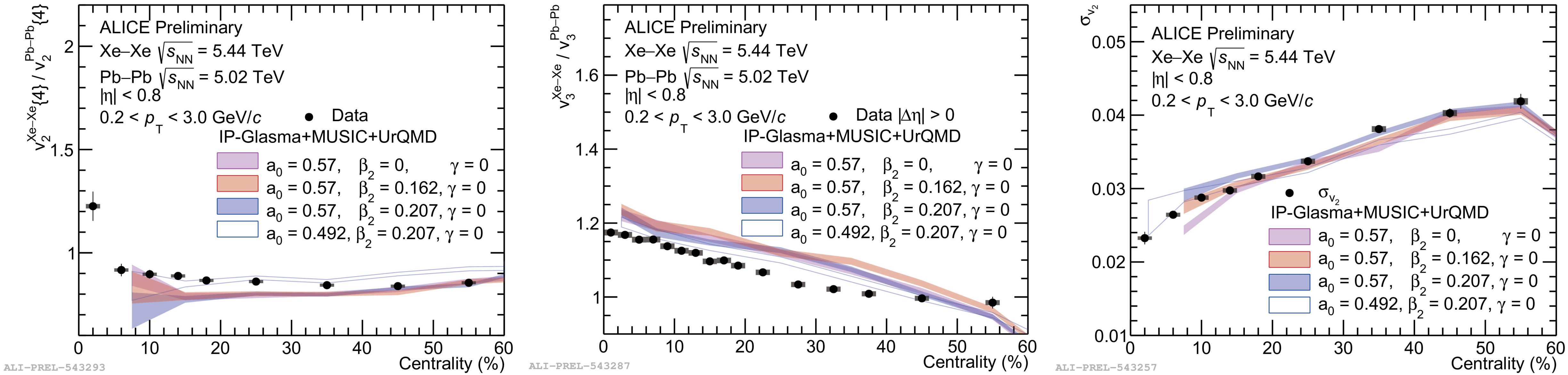
$$\rho(v_n^2,[p_T]) = \frac{\mathrm{Cov}(v_n^2,[p_T])}{\sqrt{\mathrm{Var}(v_n^2)}\sqrt{c_k}}$$

PLB 834 (2022) 137393



- ➢ v_2-$[p_T]$ correlation is a powerful tool to imagine the initial nuclear structure

Imagining the nuclear structure in Pb-Pb and Xe-Xe collisions



- Systematic study on the centrality dependence of various flow observables in Xe–Xe and Pb–Pb collisions, aiming at revealing the nuclear structure/initial geometry

Studies of anomalous chiral effects at ALICE

P/CP symmetry in weak interaction

- Before 1950s, no one suspected the P/CP symmetry, until the Θ-τ puzzle:
  Similar features but different parity values $\Theta \rightarrow \pi^+ + \pi^0$, $\tau \rightarrow \pi^+ + \pi^+ + \pi^-$
- C.N. Yang and T.D. Lee first noticed this. C.S. Wu did the experiment with Co60 β decay:
  Regardless of the left- or right-handed, β prefer to emit along the opposite direction of spin
  P violation in weak interaction!
- Cronin and Fitch further confirmed the CP violation in weak interaction.

T.D. Lee

C.N. Yang

C.S. Wu

P/CP symmetry in strong interaction?

- Strong CP problem
  Why does QCD seem to preserve CP symmetry?
  No known reason in QCD for it to necessarily be conserved

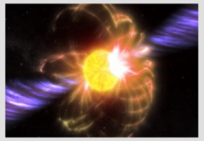
- In this century, it is proposed that the chiral anomaly is possible in strong interaction and can be tested in **heavy-ion collisions**

Strong magnetic field in HIC

- Thinking — human brain: 10^{-12} Tesla
- Earth's magnetic field: 10^{-5} Tesla
- Refrigerator magnet: 10^{-3} Tesla
- Loudspeaker magnet: 1 Tesla
- Levitating frogs: 10 Tesla
- Strongest field in Lab: 10^{3} Tesla
- Typical neutron star: 10^{6} Tesla
- Magnetar: $10^{7...10}$ Tesla
- Heavy-ion collisions: $10^{15...16}$ Tesla
- Early Universe: even (much) higher

IgNobel 2000 by A.Geim (got Nobel 2010 for graphene)

Destructive explosion



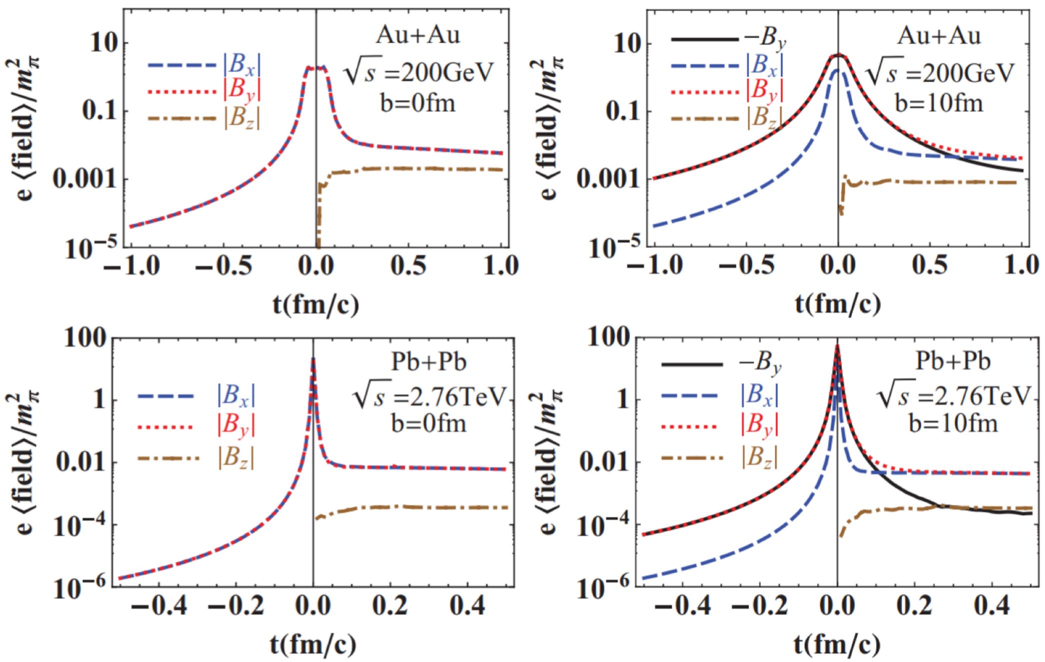
THE ASTROPHYSICAL JOURNAL LETTERS, 933:L3 (9pp), 2022 July 1 https://doi.org/10.3847/2041-8213/ac7711

OPEN ACCESS

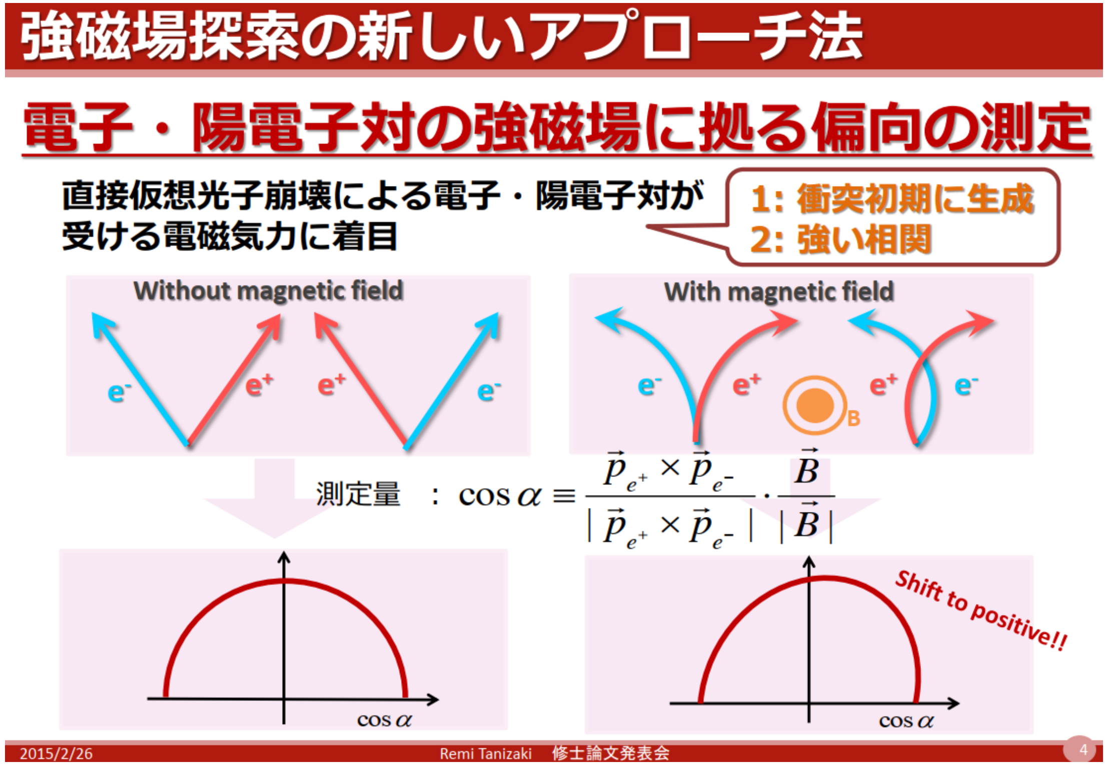
CrossMark

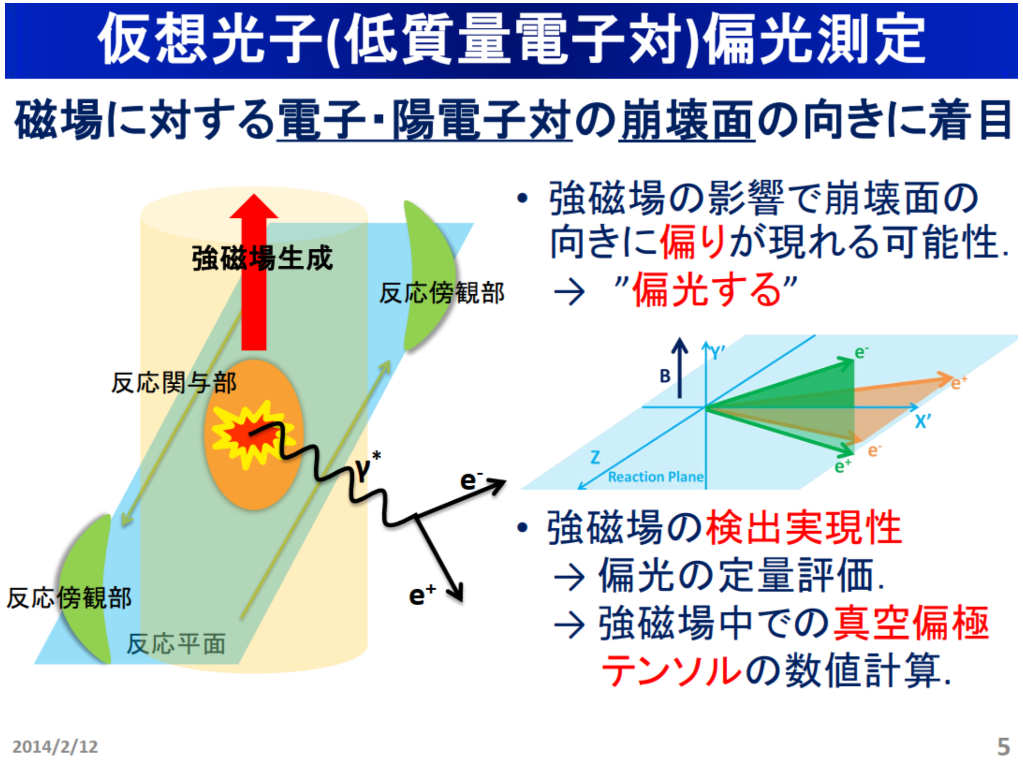
Insight-HXMT Discovery of the Highest-energy CRSF from the First Galactic Ultraluminous X-Ray Pulsar Swift J0243.6+6124

Phys. Rev. C 85, 044907 (2012)



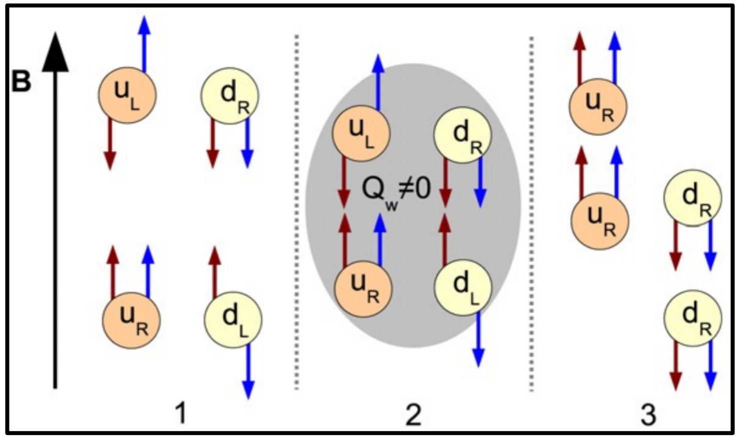
Detecting the magnetic field





Theoretical proposal of anomalous chiral effects

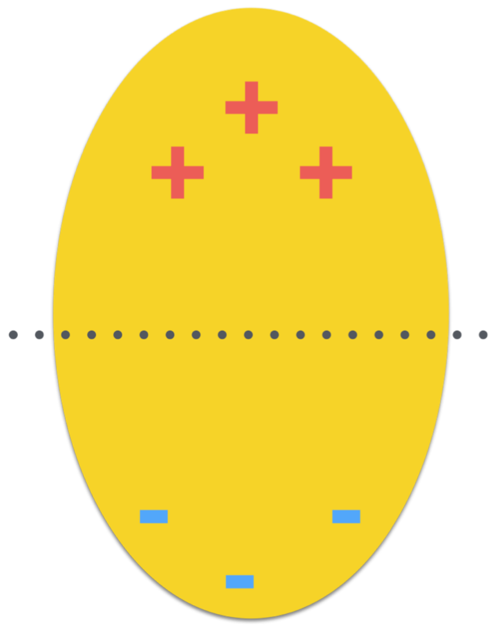
Chiral magnetic effect (CME)	$\boldsymbol{J}_V = \mu_A \mathbf{B}$	Out-of-plane electric dipole moment
Chiral separation effect (CSE)	$\boldsymbol{J}_A = \mu_V \mathbf{B}$	
Chiral electric separation effect (CESE)	$\boldsymbol{J}_A = \sigma\,(e\mathbf{E})$	In-plane electric dipole moment
Chiral vortical effect (CVE)	$\boldsymbol{J} = \mu_5\, \boldsymbol{\omega}$	Out-of-plane baryonic dipole moment
Chiral magnetic wave (CMW)	CSE + CME	Out-of-plane electric quadrupole moment
Chiral vortical wave (CVW)		Out-of-plane baryonic quadrupole moment



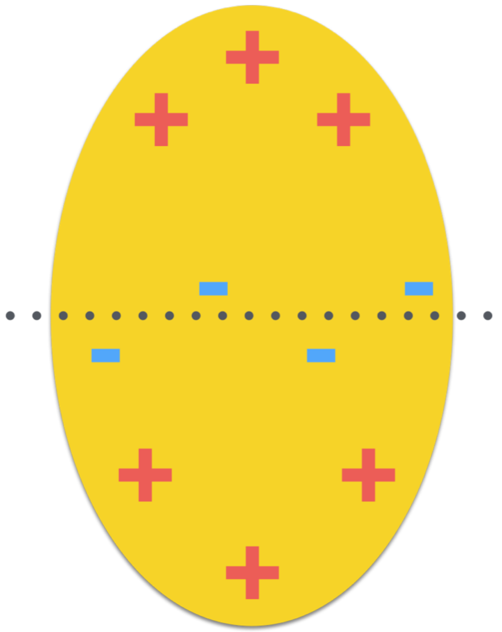
Importance:

- Topological structure of vacuum gauge fields
- Possible local violation of P and/or CP symmetries in strong interactions

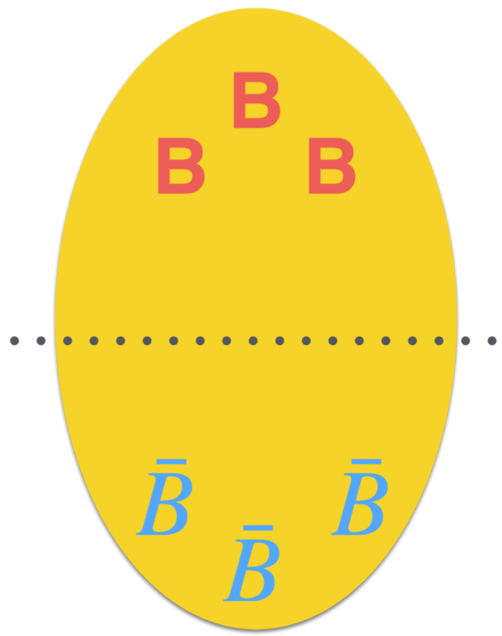
Experimental search for anomalous chiral effects



CME
Possible effect: Out-of-plane electric dipole moment
Observables: δ, γ correlator

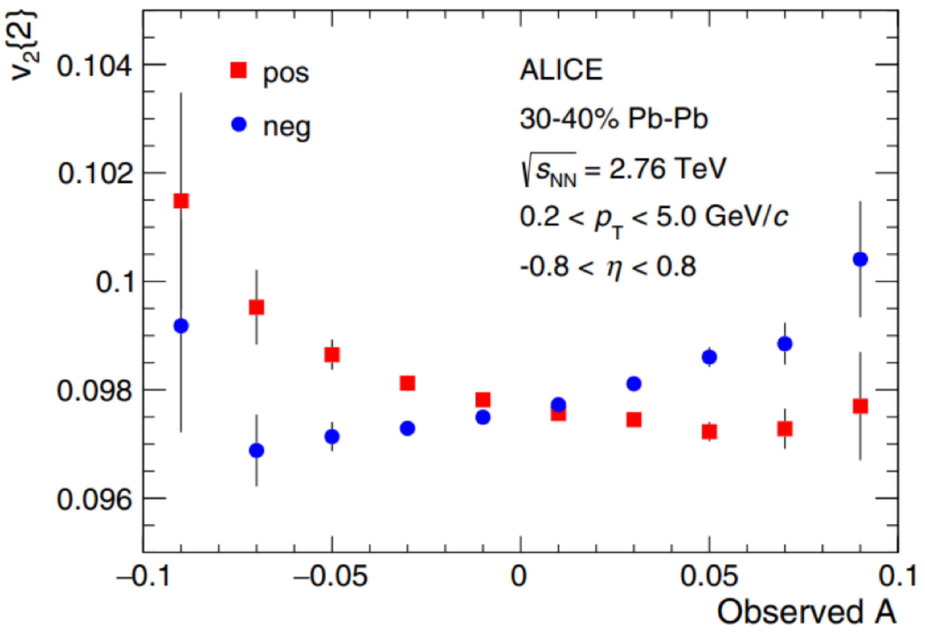


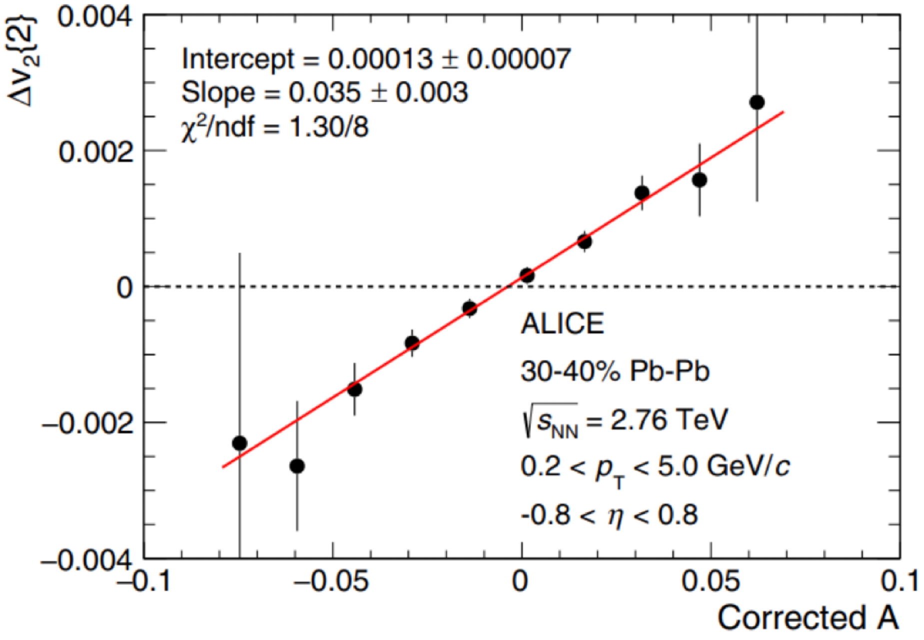
CMW
Possible effect: Out-of-plane quadrupole dipole moment
Observables: Charge asymmetry dependent v_2



CVE
Possible effect: Out-of-plane baryonic dipole moment
Observables: PID δ, γ correlator

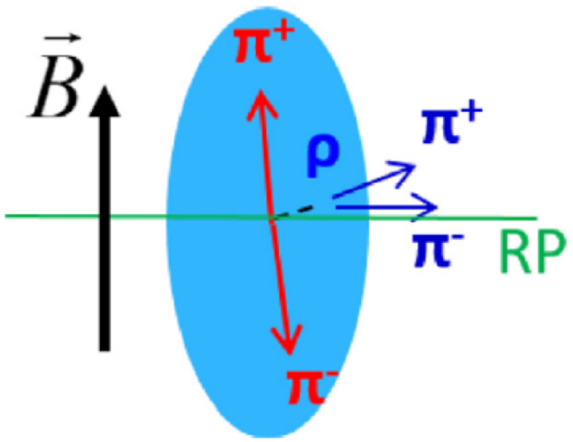
ALICE Measurements of the CMW



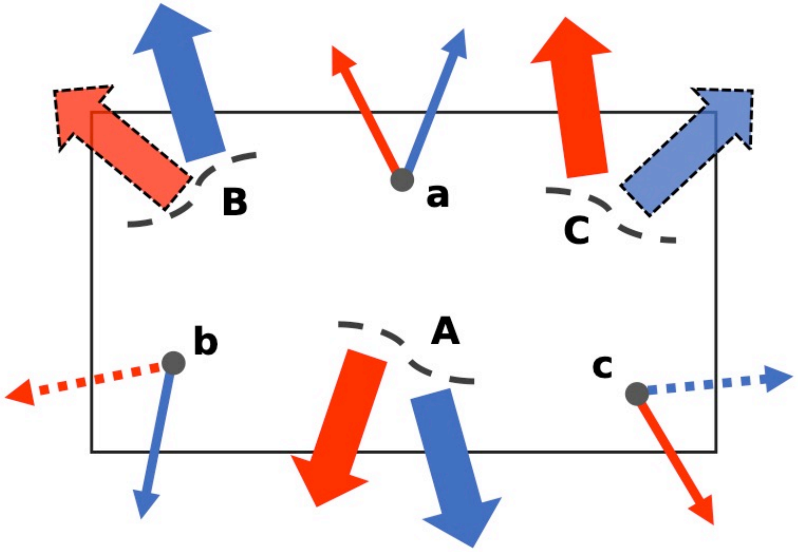


The background: Local Charge Conservation

CME

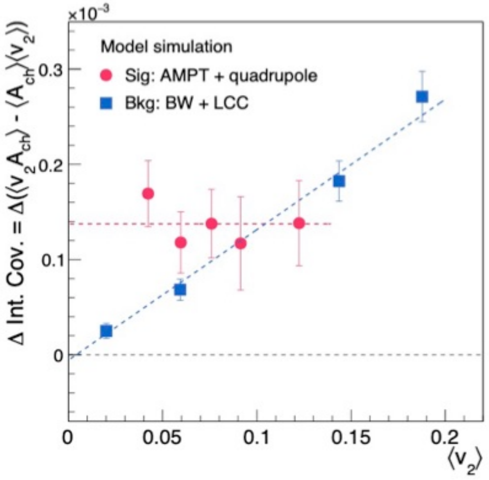


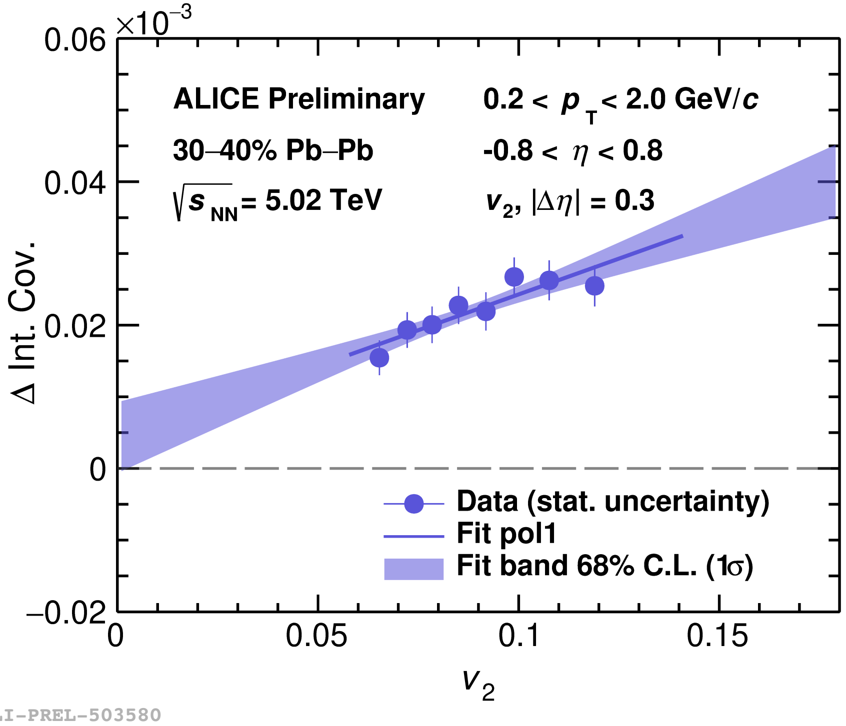
CMW



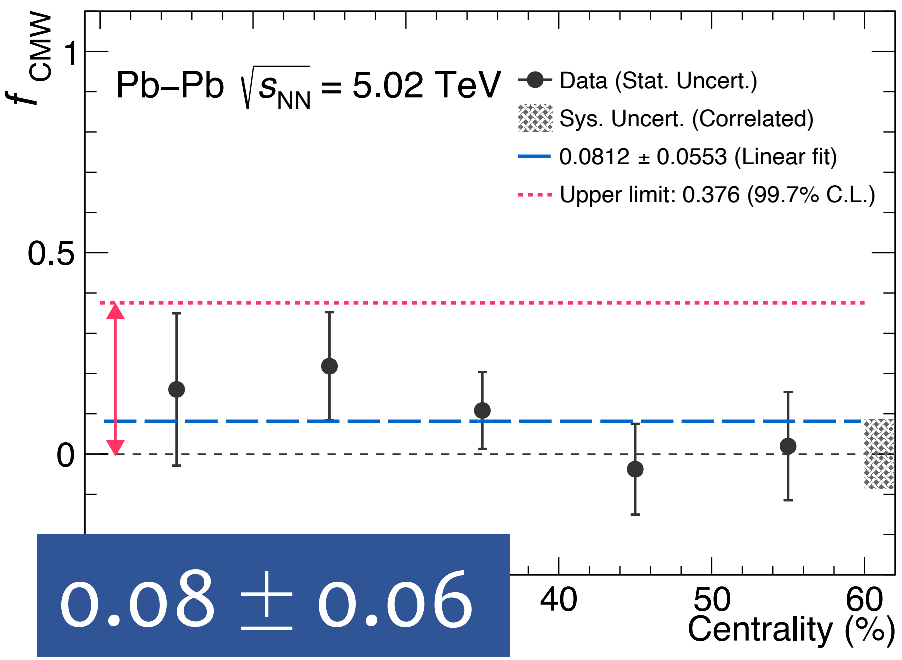
- In the CME/CMW studies, flow serves as a carrier, conveying the initial charge separation (sig or bg) to the final state
- Are the LCC background same for the CME and the CMW measurements?

Extract the CMW signal





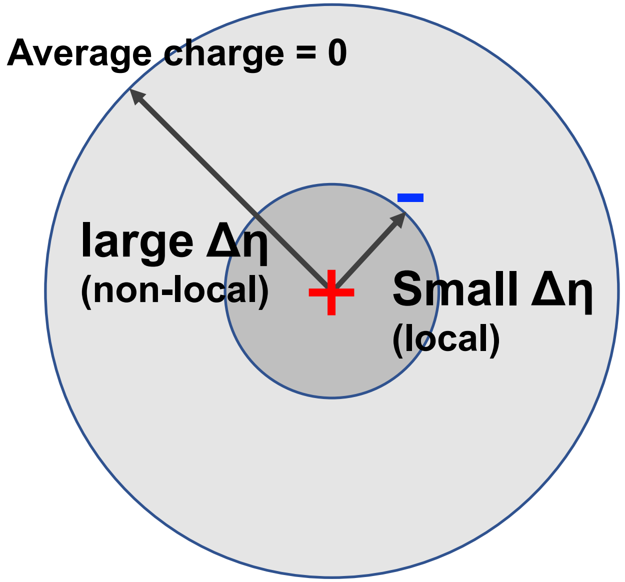
JHEP 2023, 67 (2023)



0.08 ± 0.06

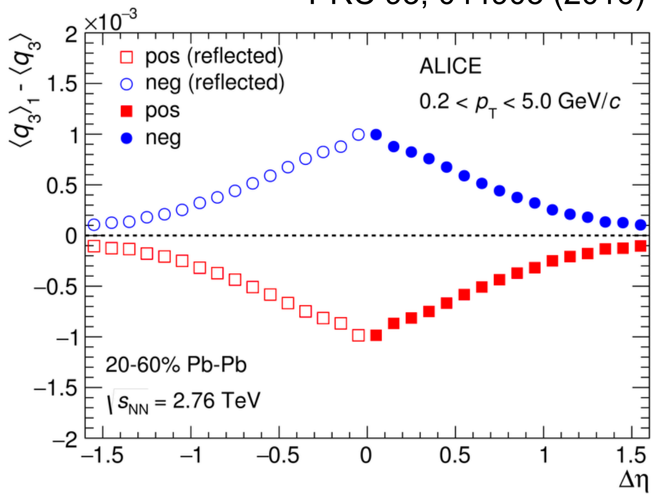
- f_{CMW} = 0.08±0.06 is experimentally extracted for the first time

Description of the LCC background

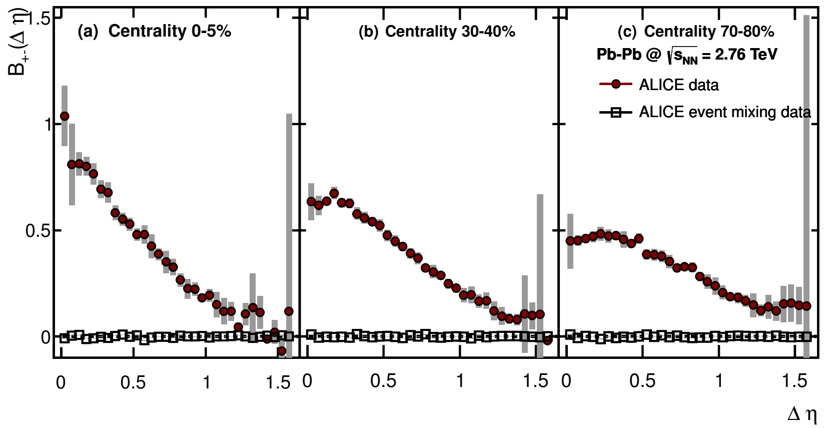


- Local charge conservation: charges are locally balanced
- The source can be either primordial or secondary (resonance decay)
- Example :

PRC 93, 044903 (2016)

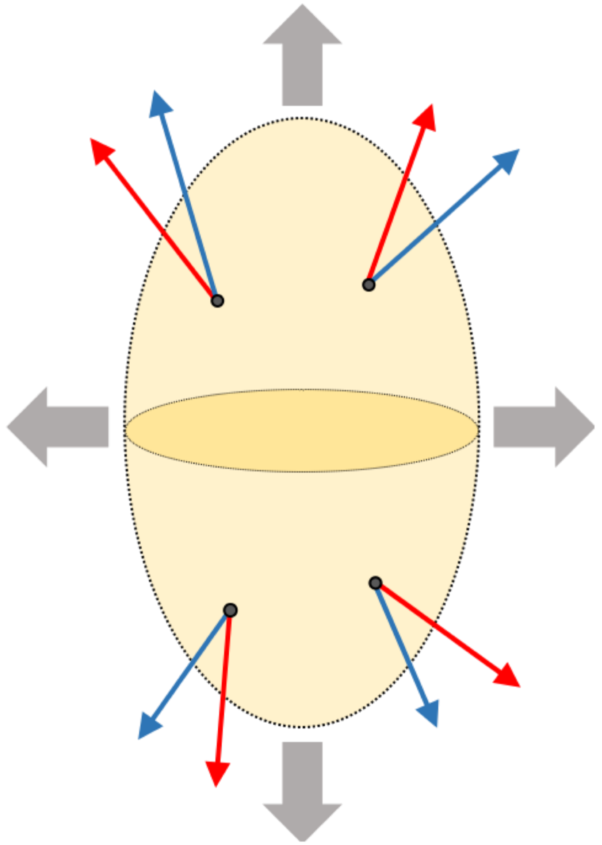


PLB 723, 267 (2013)



- In the CME/CMW studies, flow serves as a carrier, conveying the initial charge separation (sig or bg) to the final state

Description of the LCC background



To investigate the signal and the background, we need a model which can cover:

Model	Flow	LCC	Can import CME signal	Can import CMW signal
HIJING, PYTHIA	✗	√		
AMPT	√	✗ (non-dynamical)	√	√
AVFD	√	√	√	✗
BW+LCC	√	√	√	√

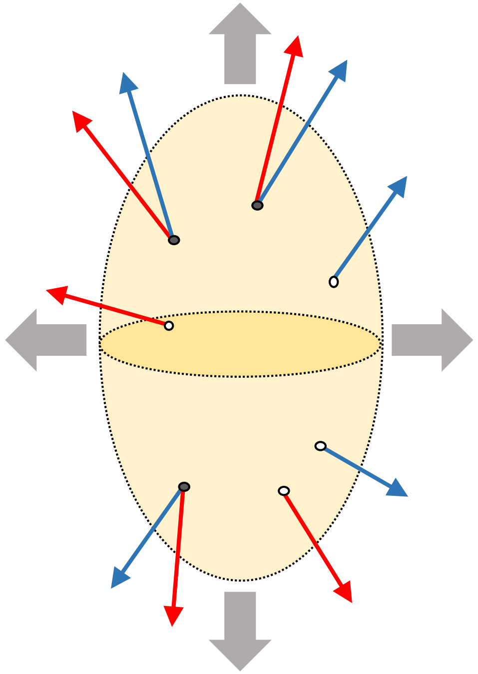
Improved configuration of the BW+LCC

Improvement: correct multiplicity and LCC strength

TABLE I. List of the modified BW parameters for Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

Centrality	0–5 %	5–10 %	10–20 %	20–30 %	30–40 %	40–50 %	50–60 %	60–70 %
T_{kin}	111.34	106.96	104.78	107.37	111.63	115.14	118.14	128.20
R_x/R_y	0.956	0.934	0.905	0.872	0.845	0.823	0.807	0.786
ρ_0	1.262	1.267	1.254	1.226	1.196	1.148	1.087	0.994
ρ_2	0.054	0.063	0.11	0.135	0.15	0.145	0.121	0.115
N_{ch} ($\lvert\eta\rvert < 0.8$)	2290	1858	1334	904	608	369	222	117
f_{LCC}	0.71	0.62	0.58	0.56	0.54	0.48	0.47	0.46

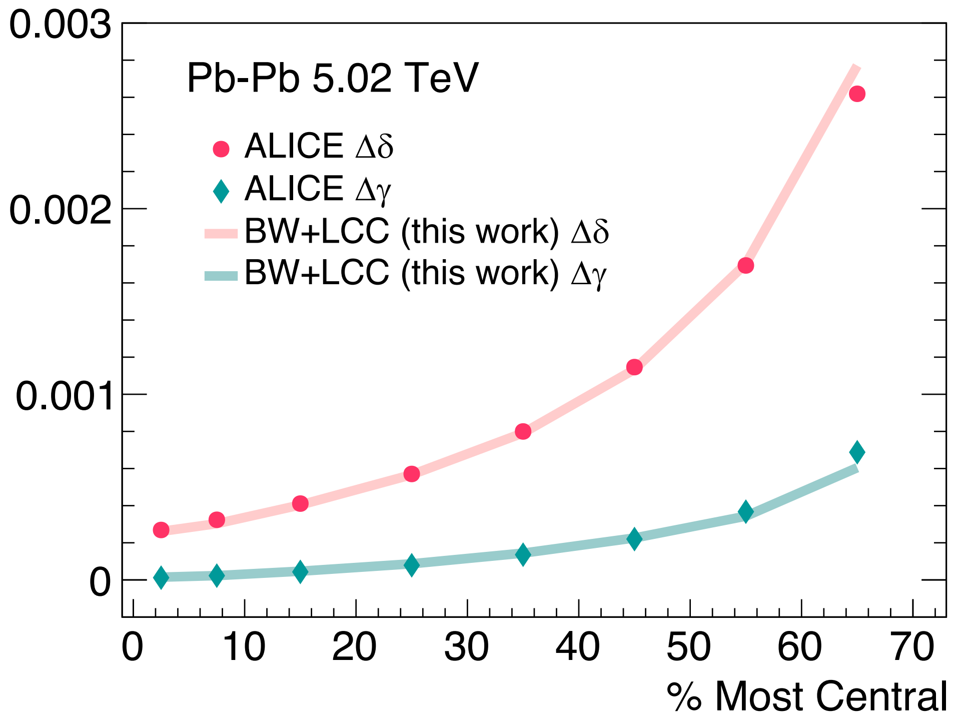
T → spectra, production; R → initial eccentricity
ρ_0 radial flow, ρ_2 elliptic flow → experimental v_2
N_{ch} multiplicity → experimental multiplicity (mean and width of the NBD)
f_{LCC} fraction of the pair production → balance function (and δ)

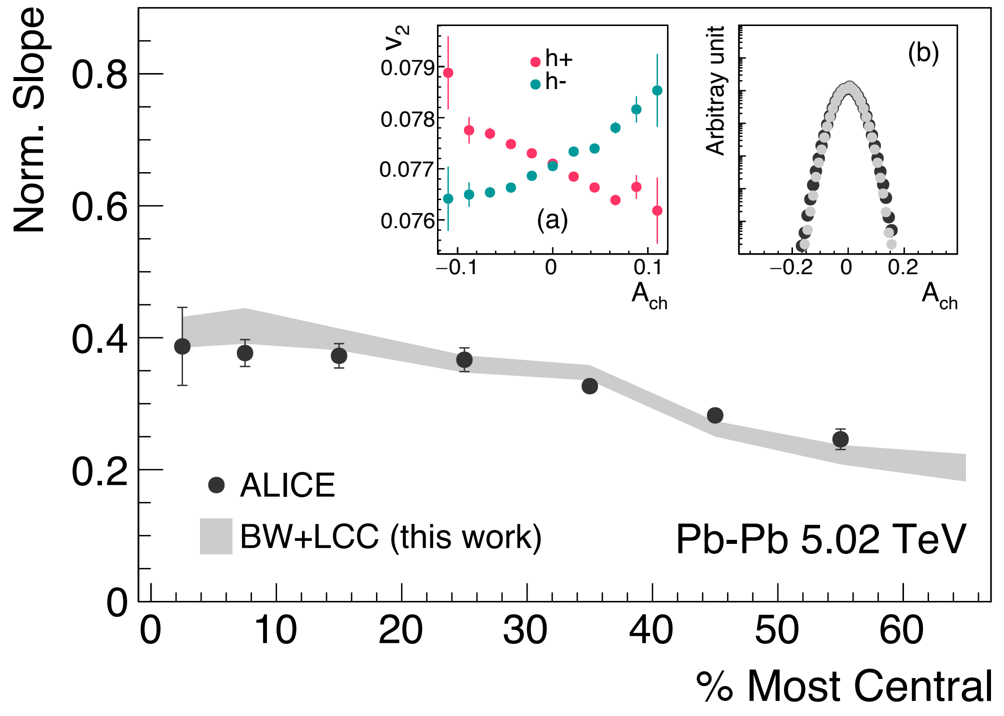


Pure data-driven: all parameters are determined based on experimental results.
Now, inclusive spectra (no PID in this work), v2, mult., BF are all comparable with data.

Single production: 4
Pair production: 3
$f_{LCC} = 3/7 \approx 0.43$

Revisit CME/CMW observables with the improved BW+LCC

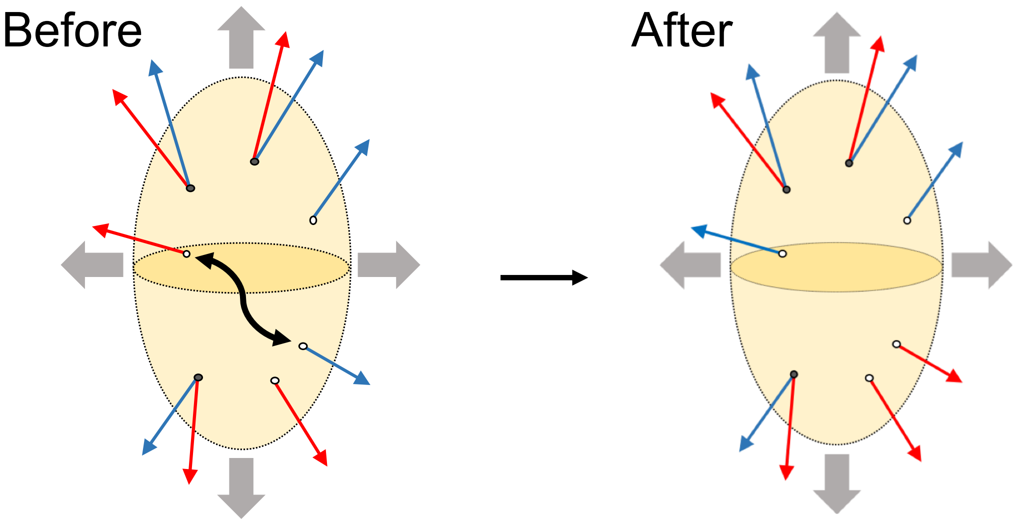




- The CME and the CMW observables can be simultaneously and perfectly described within 10% deviation.
- Unify studies of the CME and the CMW for the first time.
- The measured results of the CME and the CMW at 5 TeV can be interpreted to the great extent by the LCC, but this is not the end of the story.

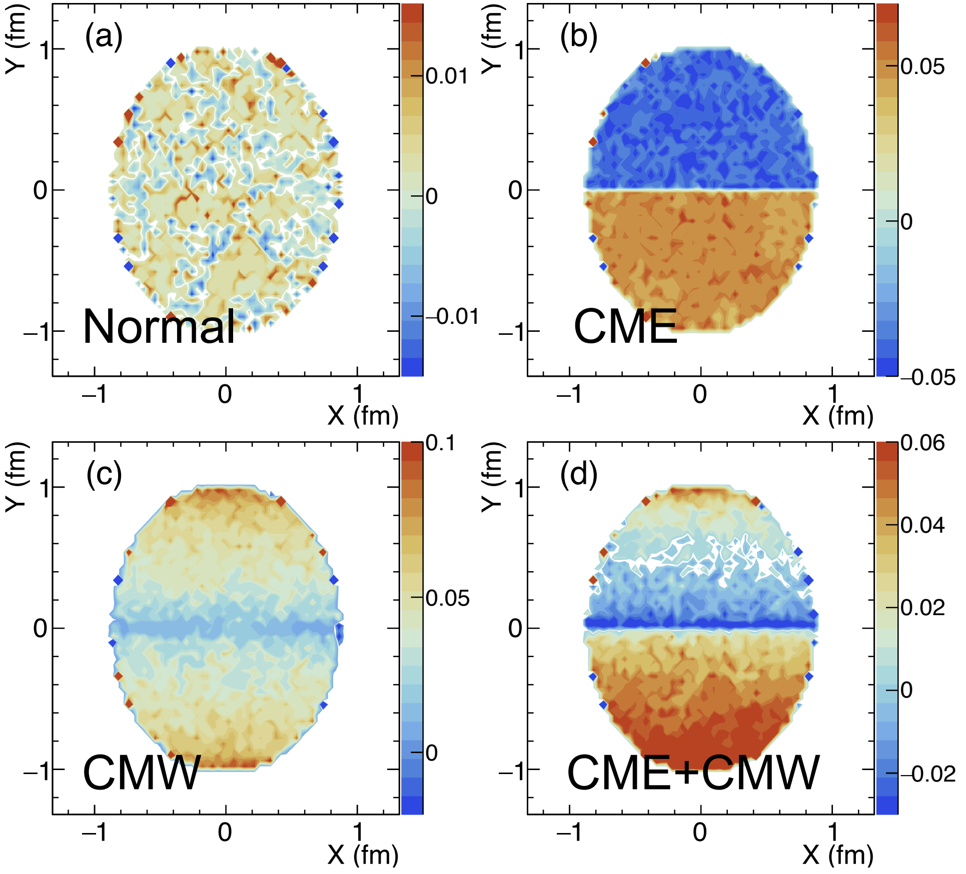
Further constraint with imported signals

Is it possible that signals are hidden in the ~10% deviation?
Import the signals by switching charges of the signal produced particles.



Above plane: net charge = 0
Below plane: net charge = 0

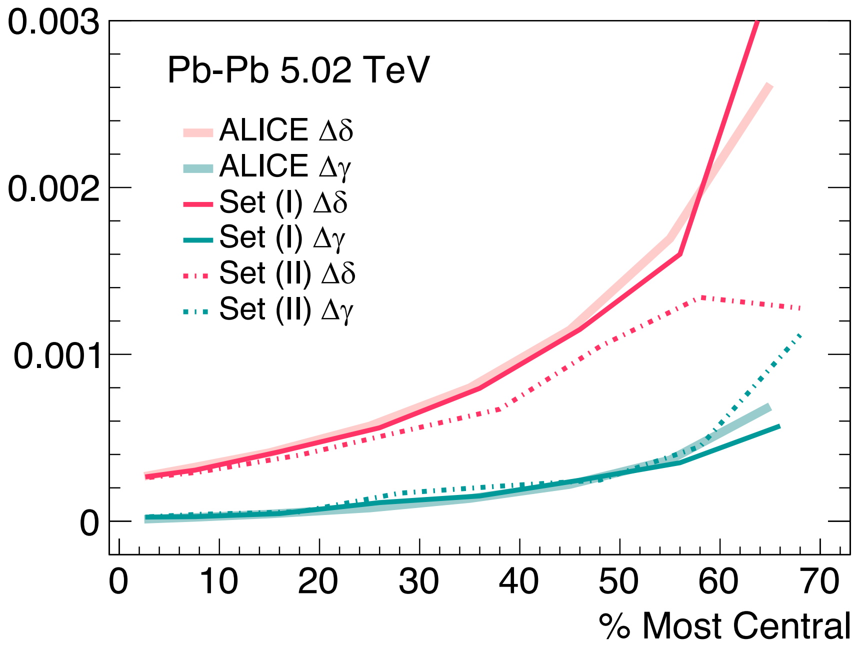
Above plane: net charge = -2
Below plane: net charge = 2
CME+LCC coexist



Further constraint with imported signals

TABLE II. The impact of four key parameters on the CME and the CMW observables.

	$\Delta\delta$	$\Delta\gamma$	Slope
Mult. ↘	↗	↗	–
$f_{\rm LCC}$ ↘	↘	↘	↘
$S_{\rm CME}$ ↗	↘	↗	–
$S_{\rm CMW}$ ↗	–	–	↗



To accommodate γ and slope, f_{LCC} should be reduced, resulting in the decrease of δ, so multiplicity should be reduced.

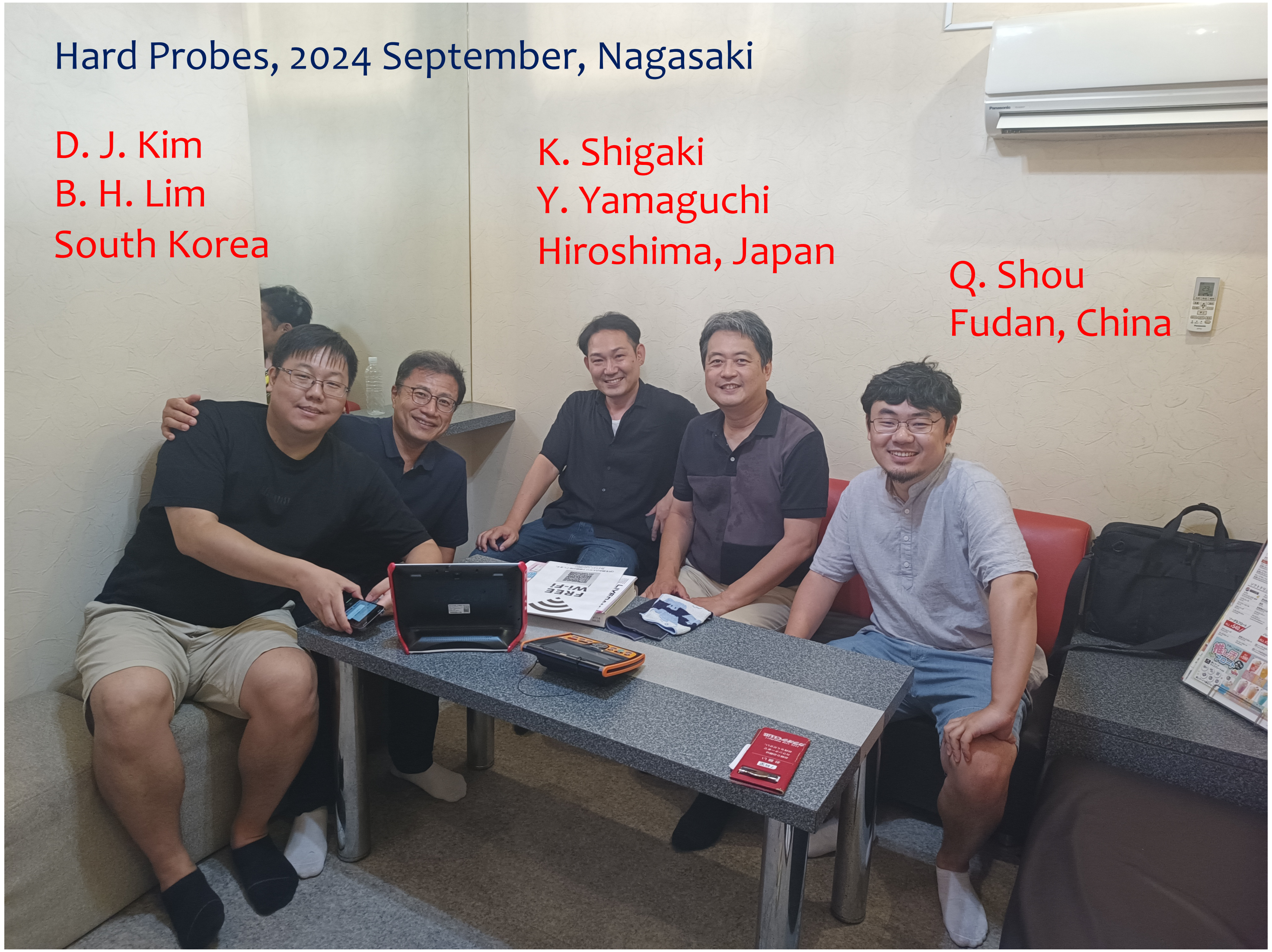
Test above within experimental limits to quantify the maximum allowable strength of the signals.

Set (I): switch charges 0-3 times in each event based on multiplicity, **acceptable**

Set (II): always switch charges 3 times in each event, **too strong**

Extracted maximum fraction: f_{CME}<13%, f_{CMW}<2%

Thank you for your attention!



ALICE Asia