Vector meson spin alignment measurements with ALICE

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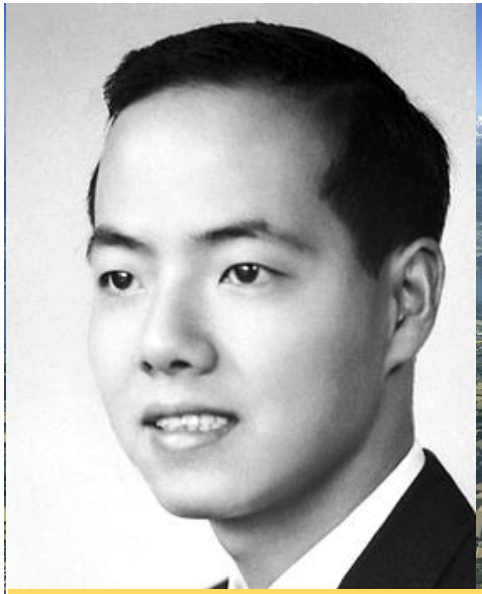
ALICE

1958 University of Science and Technology of China

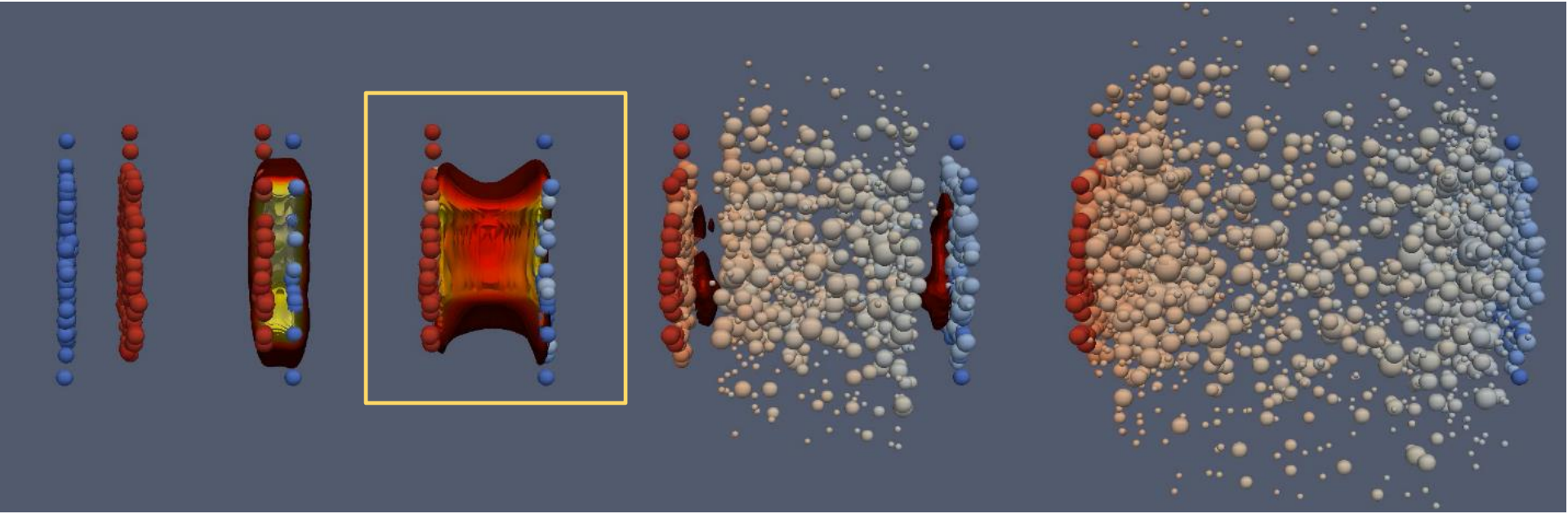
Motivation (some 50 years ago)



T.D. Lee (李政道)
(11.24.1926 – 08.04.2024)

"It would be **intriguing** to explore **new phenomena** by **distributing** high energy or high nuclear matter over a relatively large volume. , In this way, one could possibly **create abnormal states of nuclear matter**."

Introduction to heavy-ion collisions

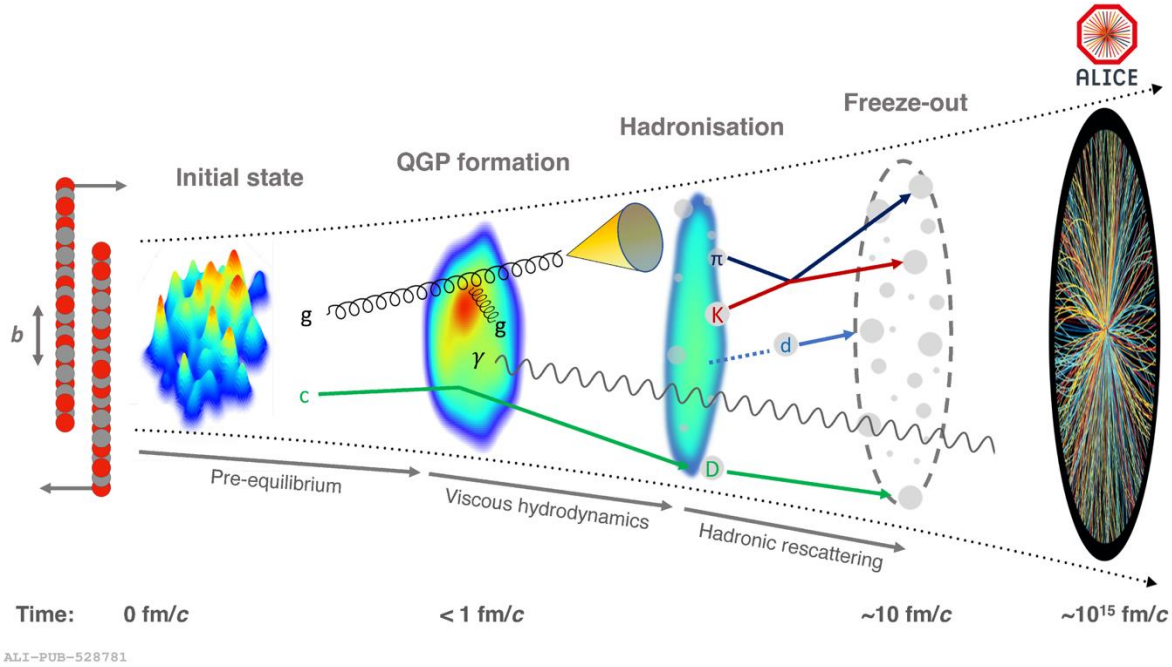


Initial stages

quark-gluon plasma (QGP)
fluid dynamic expansion

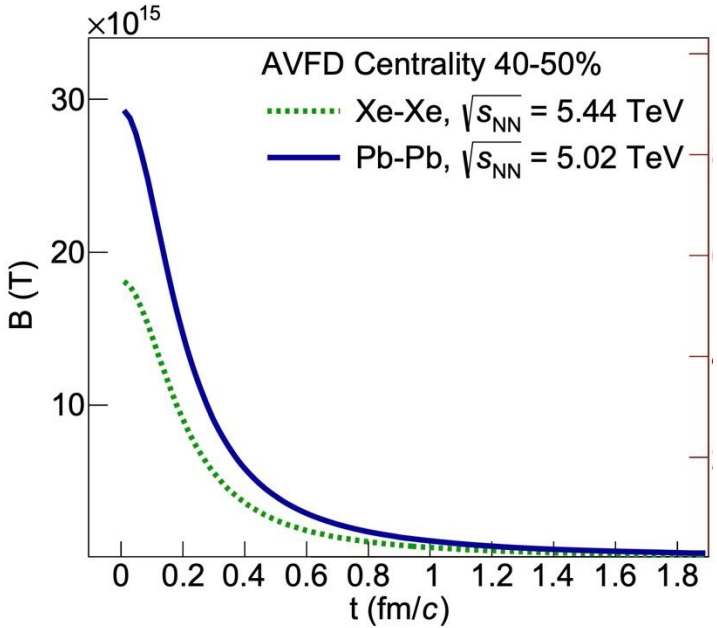
Final state: hadron scattering

Introduction to heavy-ion collisions

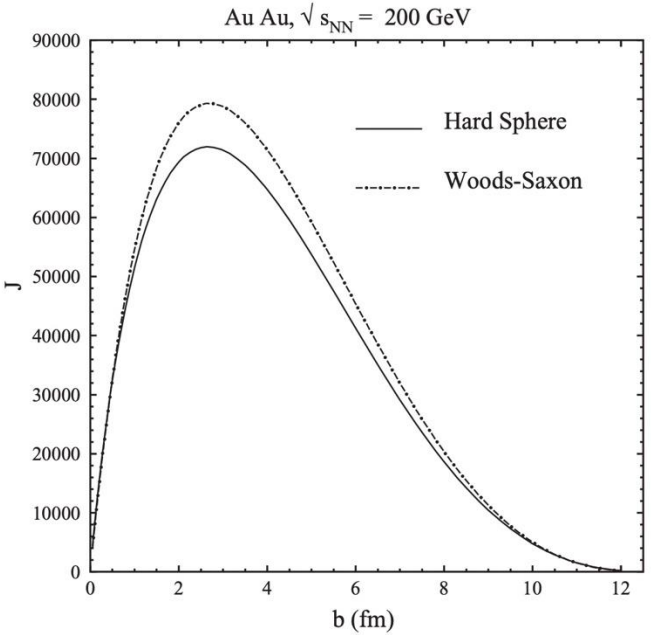


- In non-central heavy-ion collisions, short-lived magnetic fields (***B***) and very strong orbital momentum (***L***) are expected to be produced
- The magnetic fields and orbital momentum can influence the global polarization

Strong magnetic field and orbital momentum



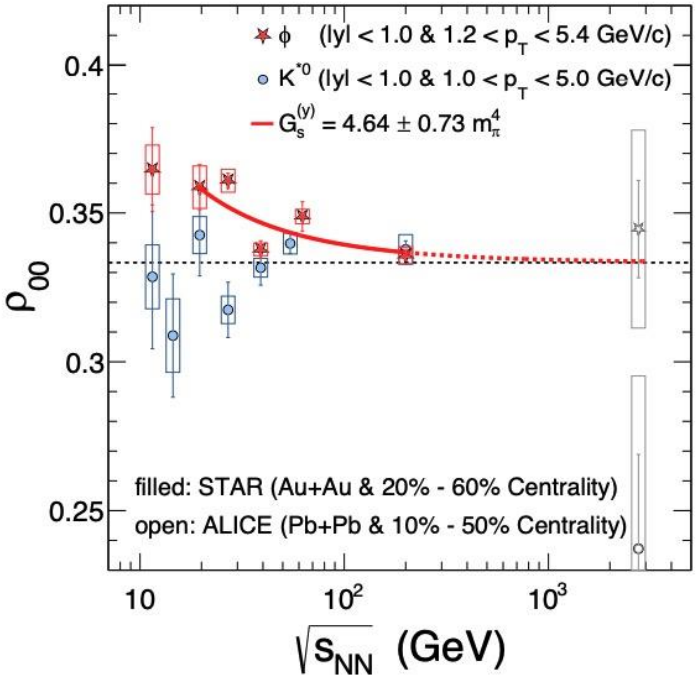
Christakoglu et al., EPJC (2021) **81**: 717



F. Becattini et al., PRC 77 (2008)

- The **most intense magnetic field in nature** [STAR, Nature 548, 62 (2017)]
- Angular momentum strongly depends on impact parameter (b)

Vector meson spin alignment

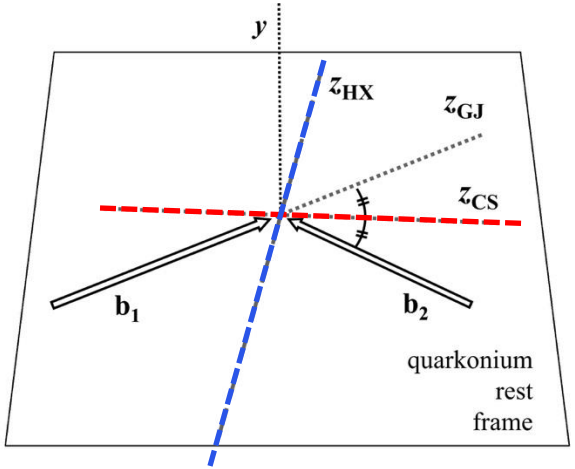


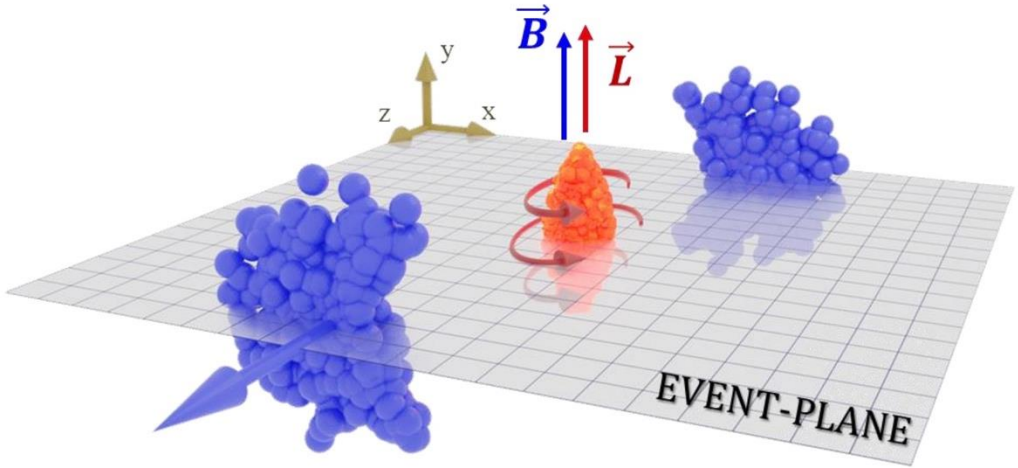
STAR, Nature 614 244 (2023)

- Vector meson spin alignment measures field square, which corresponds to the local correlation and fluctuation of the strong force field
- The vector field is induced during the hadronization process
- This mechanism will open a new window for the strong force field study once it is confirmed!

X.-L. Sheng, L. Oliva, Z.-T Liang et al, PRL131 (2023)4,042304
X.-L. Sheng, L. Oliva, Z.-T Liang et al, PRD109 (2024)3, 036004

Introduction to spin alignment measurements





Polarization axis:

- Helicity (HX): direction of vector meson in the collision center of mass frame
- Collins-Soper (CS): the bisector of the angle between the beam and the opposite of the other beam, in the vector meson rest frame
- **Event Plane based frame (EP):** axis orthogonal to the reaction plane in the collision center of mass frame

The vector mesons polarization measurements

Quarkonia measurements:

$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\cdot\left(1+\lambda_\theta\cos^2\theta+\cdots\right)$$

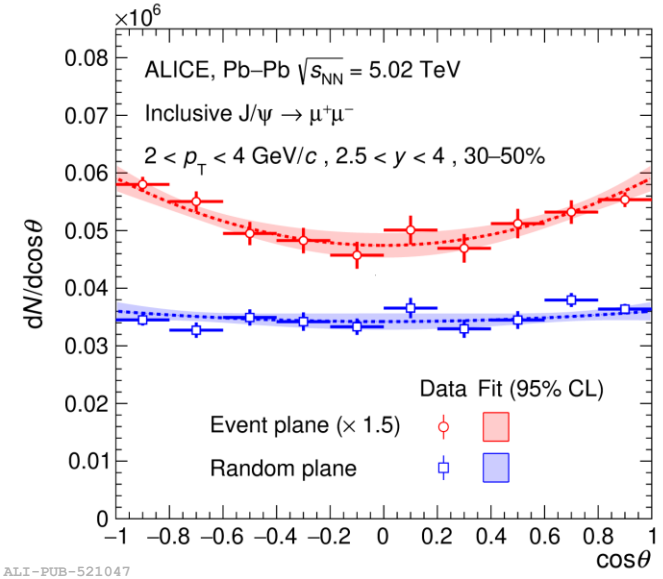
$$W(\cos\theta) \propto (1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta$$

$\lambda_\theta =$ polarization parameter

$\lambda_\theta = 0$ no spin alignment

$$\lambda_\theta = \frac{1-3\rho_{00}}{1+\rho_{00}} \quad \begin{cases} \lambda_\theta > 0 \rightarrow \rho_{00} < 1/3 \\ \lambda_\theta < 0 \rightarrow \rho_{00} > 1/3 \end{cases}$$

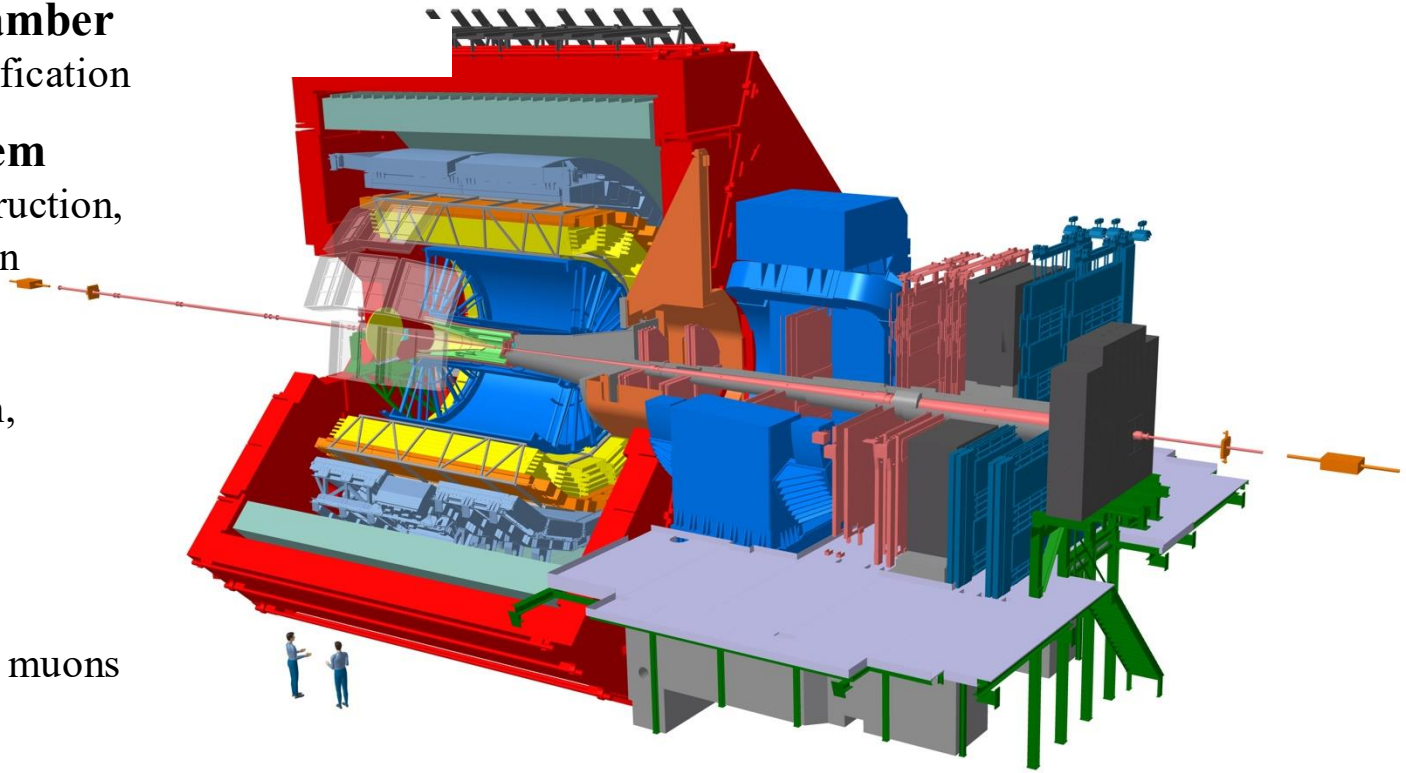
ALICE, PRL 131 (2023) 4, 042303



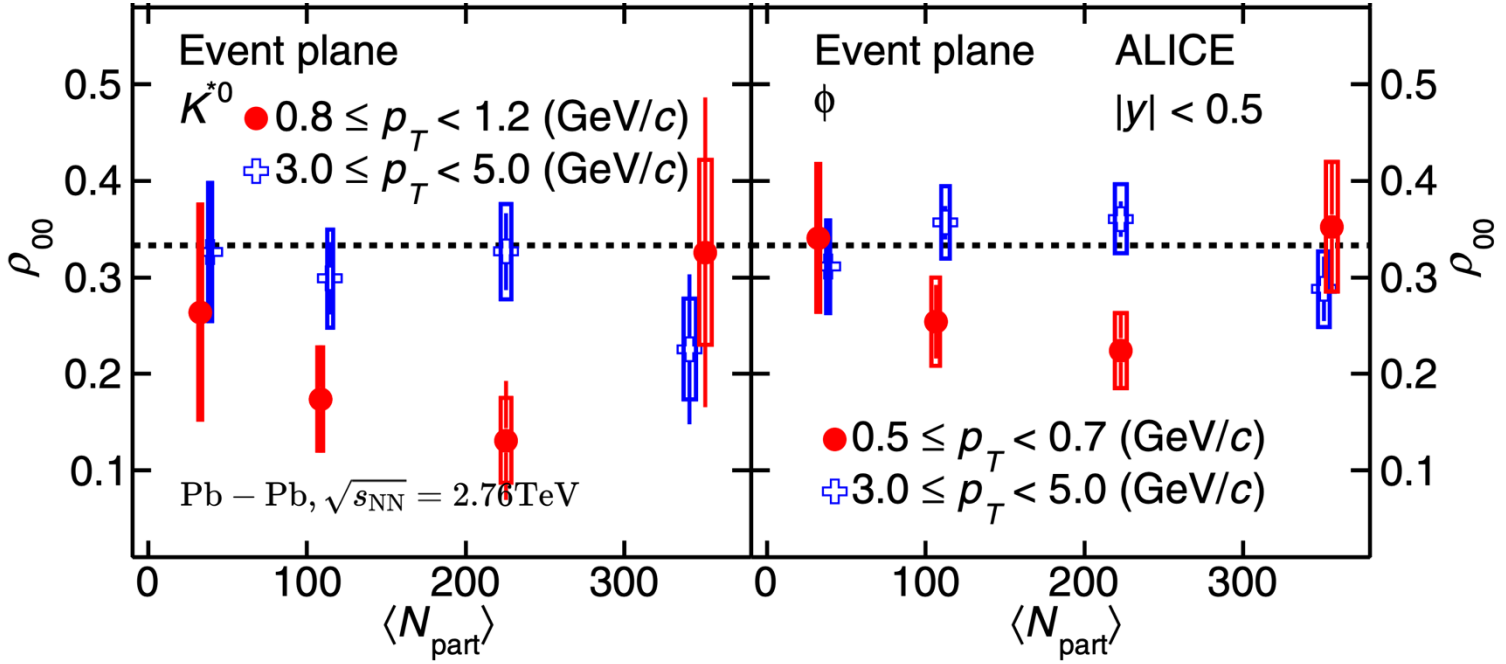
- **pp collisions**: Important to constrain quarkonium production mechanisms in hadronic collisions
- **AA collisions**: Polarization measurements gives access to different time scales and mechanisms, like the early-produced magnetic field, angular momentum, and hadronization mechanisms.

Polarization measurements with ALICE detector

- **Time Projection Chamber**
  Tracking, particle identification
- **Inner Tracking System**
  Tracking, vertex reconstruction, event plane determination
- **V0 Detector**
  Centrality determination, triggering, event plane determination
- **Muon spectrometer**
  Trigger and tracking for muons



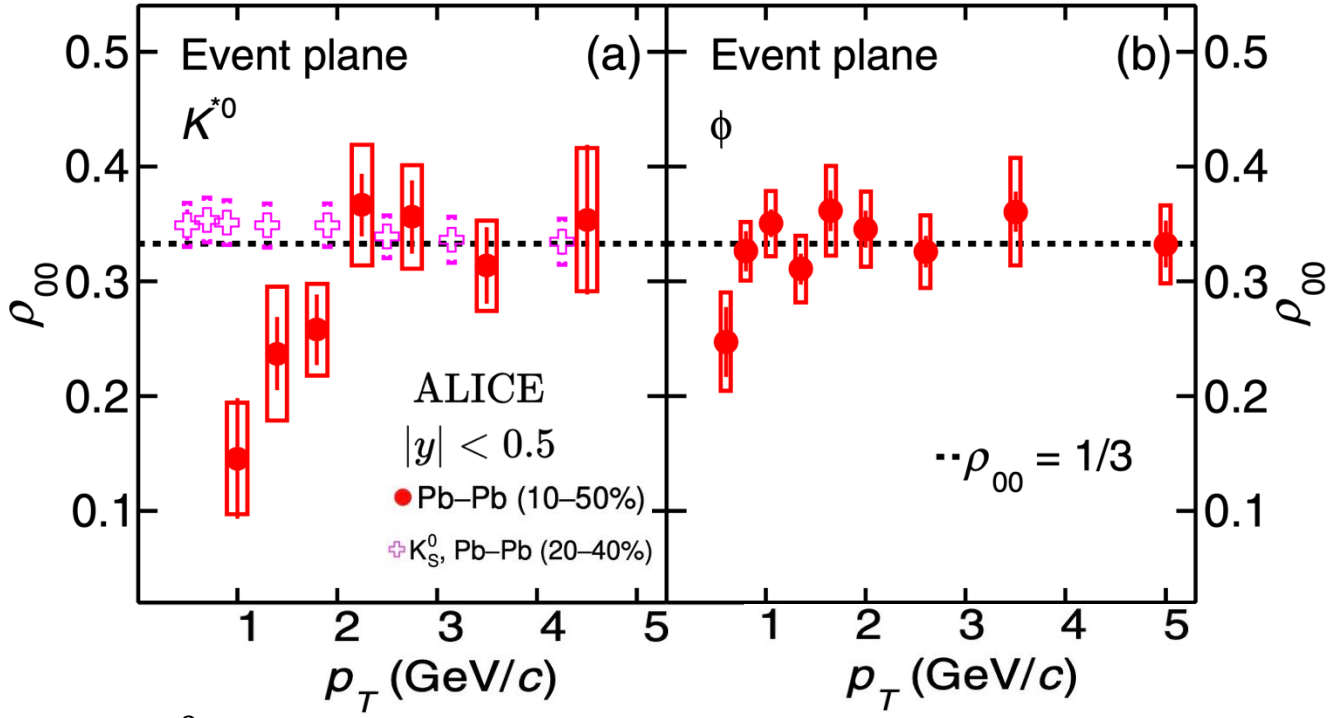
K^{*0} and ϕ spin alignment vs. centrality



- Maximum deviation of ρ_{00} in semicentral collisions and low p_T
- Deviation w.r.t 1/3 are 2.6σ and 1.9σ for K^{*0} and ϕ, respectively

ALICE, PRL 125(2020) 012301

K^{*0} and ϕ spin alignment Vs p_T

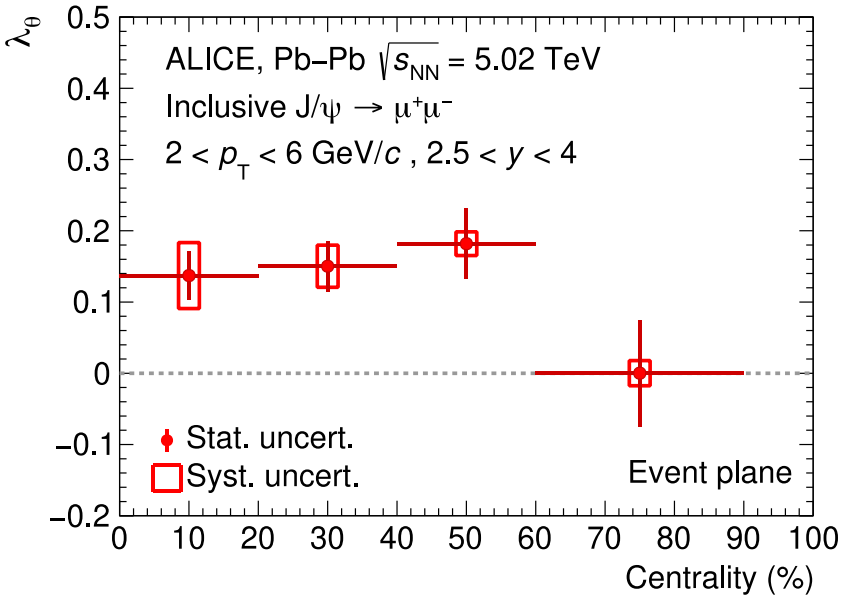


- $\rho_{00} < 1/3$ for K^{*0} and ϕ at low p_T, ρ_{00} consistent with 1/3 at high p_T
- ρ_{00} for K^0_S (spin=0) consistent with 1/3

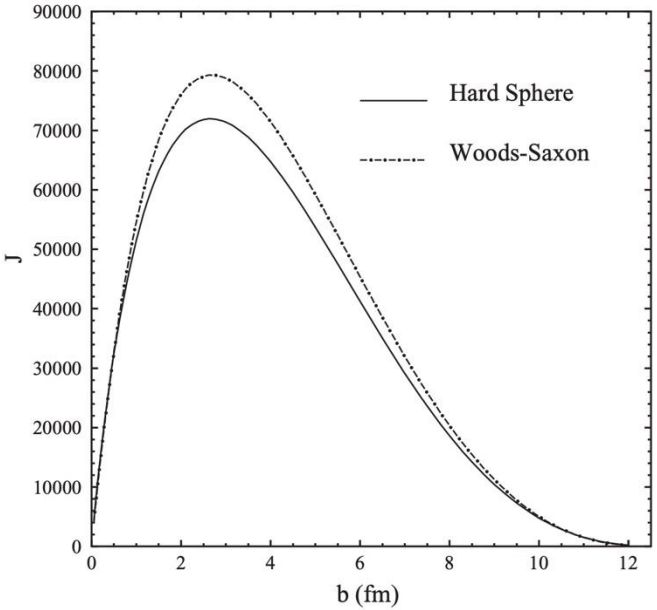
ALICE, PRL 125(2020) 012301

J/ψ spin alignment vs centrality

ALICE, PRL 131 (2023) 4, 042303



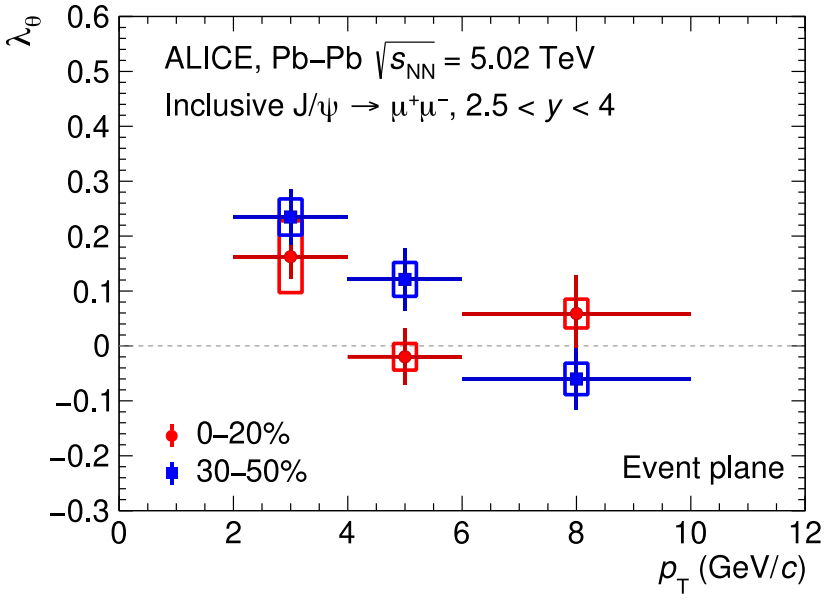
F. Becattini et al., PRC 77 (2008)



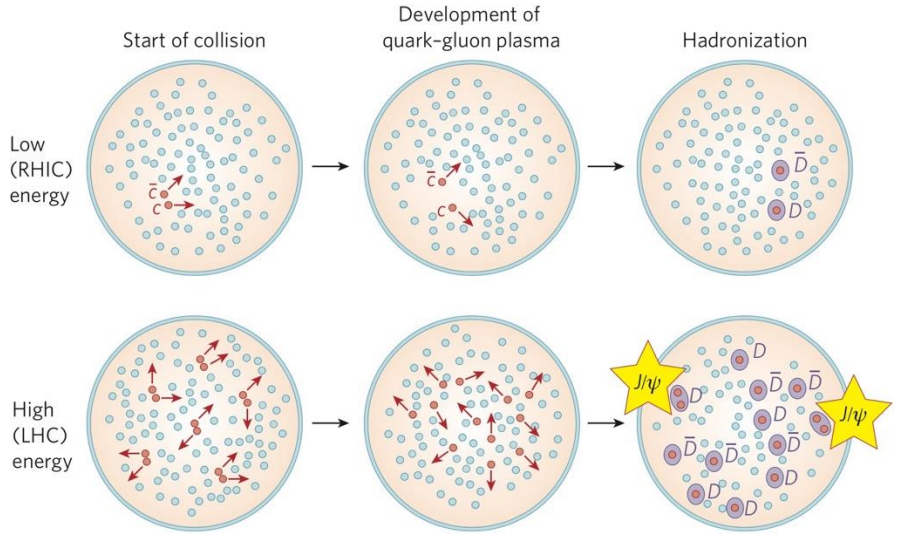
- First measurement of quarkonium spin alignment **with respect to the event plane**
- The significance of the spin alignment reaches **~3.9σ** at the semi-central collisions
- Interpretation of results requires inputs from theoretical models

J/ψ spin alignment vs p_T

ALICE, PRL 131 (2023) 4, 042303

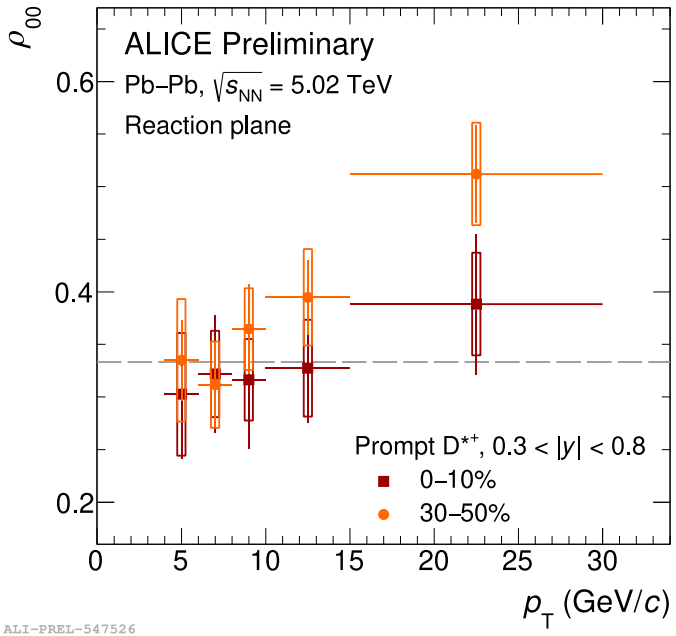


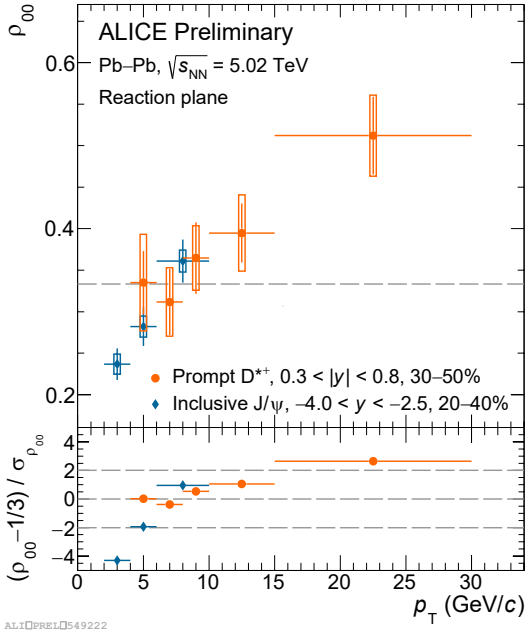
P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302



- **Significant J/ψ spin alignment** observed at low p_T, are they from (re)generated contribution?
- J/ψ **(re)generation** from uncorrelated charms quarks contributions are found to be the dominate production mechanism at low p_T in the LHC energies

D^{*+} spin alignment p_T dependence

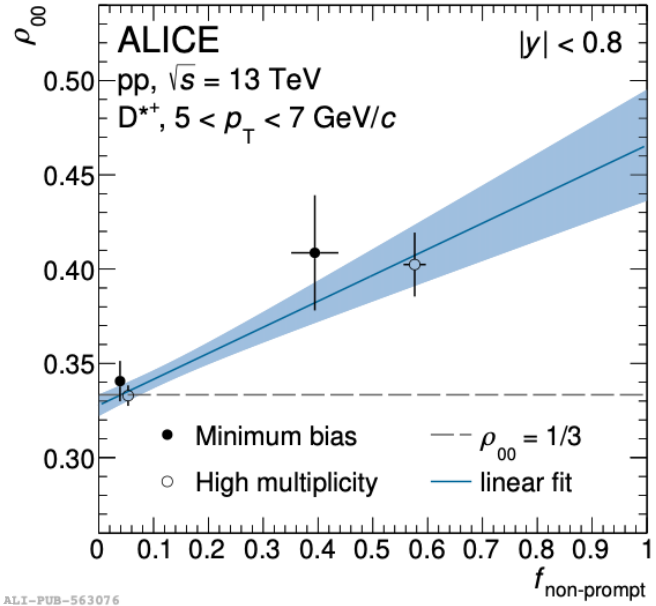


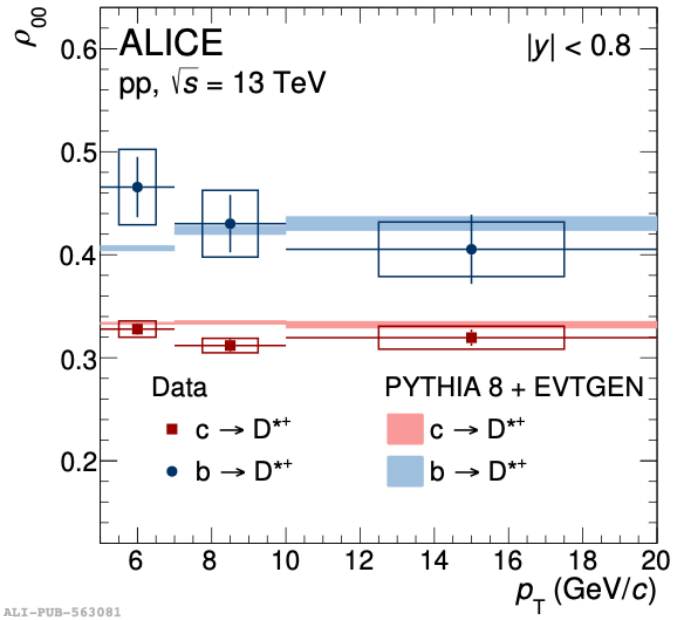


- 0 – 10% : ρ_{00} compatible with 1/3 , 30 – 50% : $\boldsymbol{\rho_{00}} > 1/3$ at high p_T
- $\boldsymbol{\rho_{00}} < 1/3$ quark recombination at low p_T while $\boldsymbol{\rho_{00}} > 1/3$ quark fragmentation at high p_T
- Theory guidance needed!

D^{*+} spin alignment in pp collisions

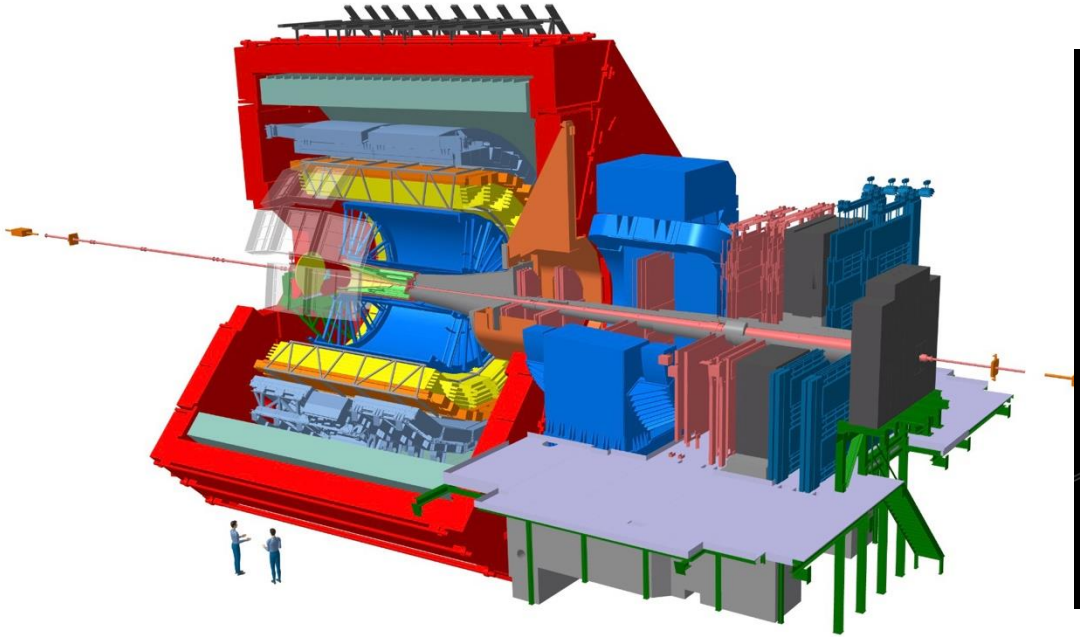
ALICE, Phys. Lett. B 846 (2023) 137920



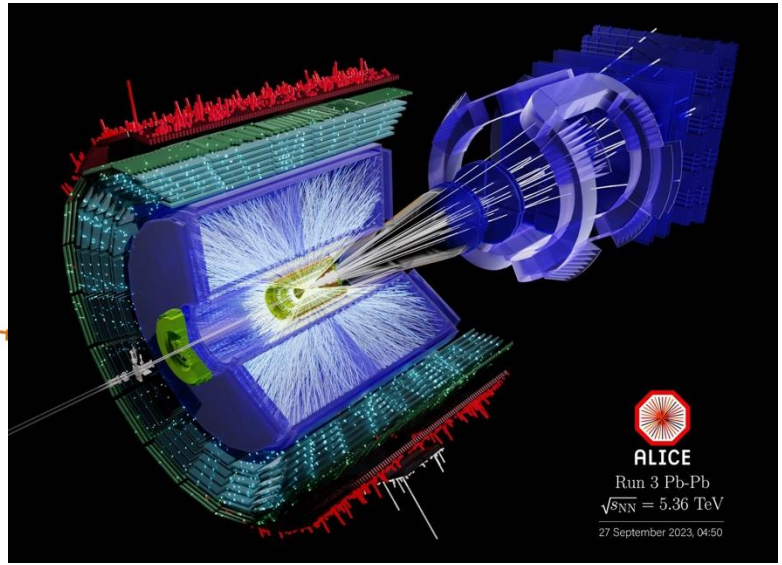


- ρ_{00} = ⅓ for prompt $\mathbf{D}^{*+}$, ρ_{00} larger than ⅓ for non-prompt $\mathbf{D}^{*+}$, due to the helicity conservation in weak decays
- New measurement in pp collisions provides an important baseline for Pb-Pb collisions

ALICE @ LHC



Major upgrades installed in 2019- 2021

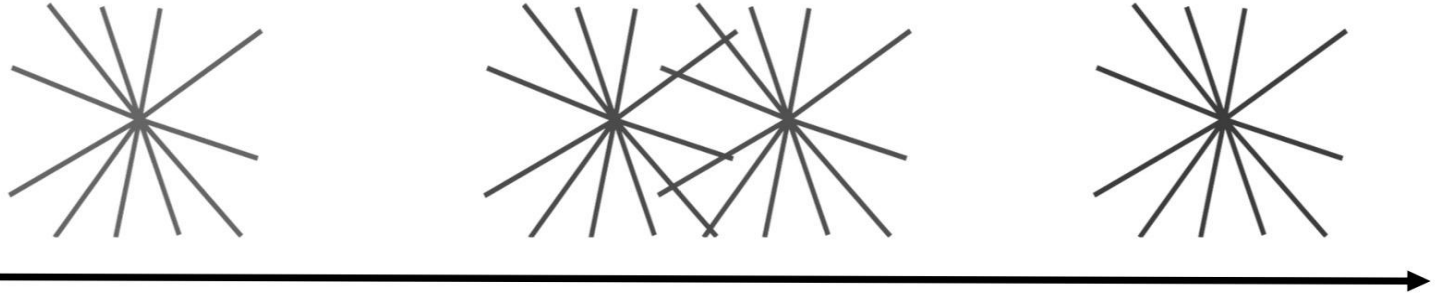


LHC LS2	LHC RUN 3	LHC LS3	LHC RUN 4	LHC LS4	LHC RUN 5 and RUN 6
2019-2021	2022-2025	2026-2028	2029-2032	2033-2034	2035-2041

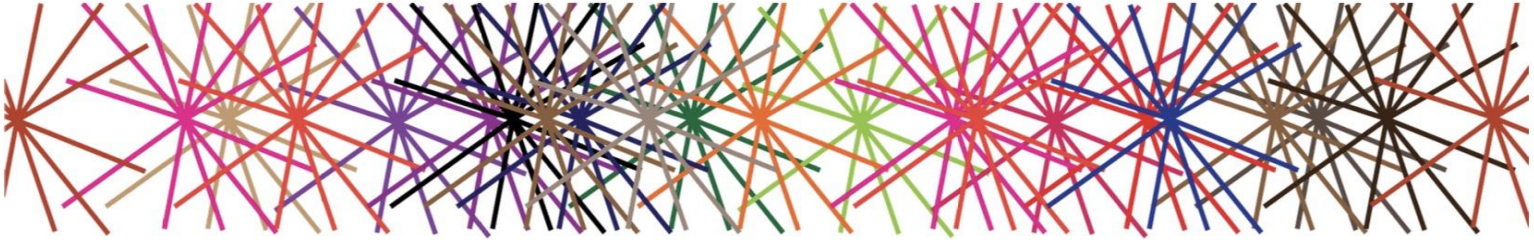
ALICE in Run 3

TPC operation

Run 1 and Run 2 (2009-2018)

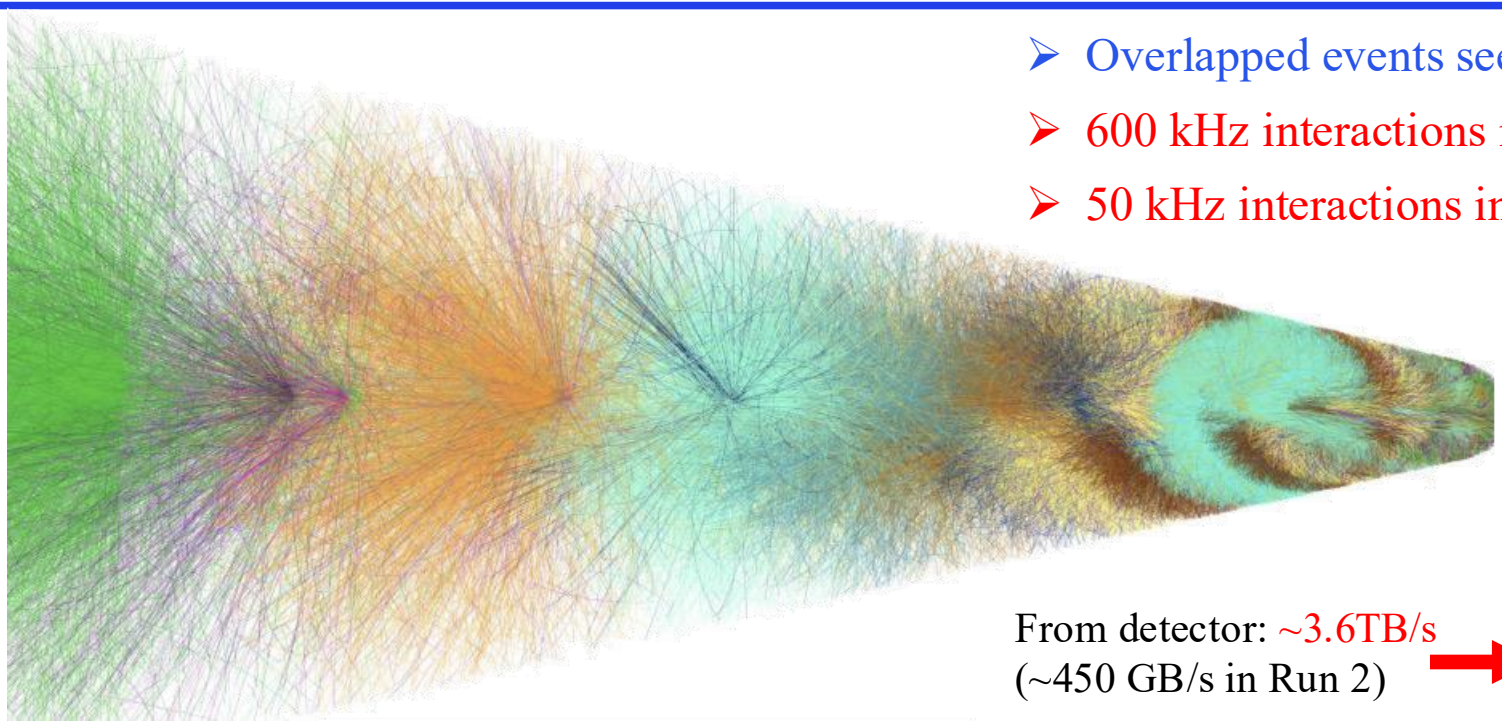


Run 3 and Run 4 (2022-2032)



LHC LS2	LHC RUN 3	LHC LS3	LHC RUN 4	LHC LS4	LHC RUN 5 and RUN 6
2019-2021	2022-2025	2026-2028	2029-2032	2033-2034	2035-2041

Continues Readout in Run 3



- Overlapped events seen in TPC
- 600 kHz interactions in pp data taking
- 50 kHz interactions in Pb-Pb

From detector: ~3.6TB/s
(~450 GB/s in Run 2)

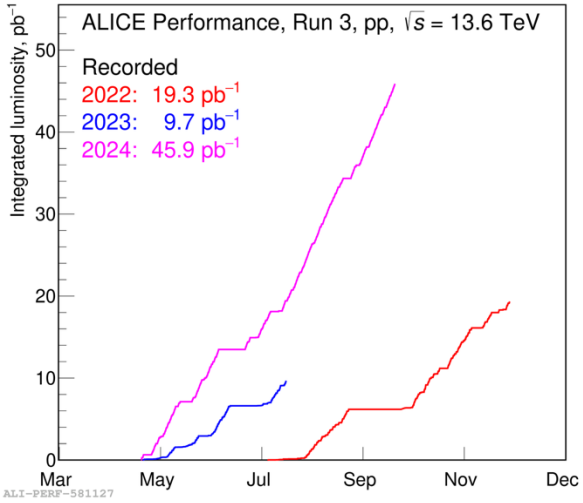
→

Storage: 130 PB
(1 PB in Run 2)

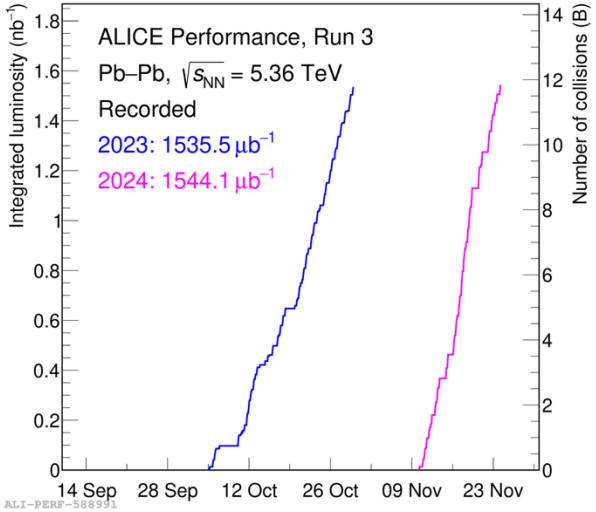
LHC LS2	LHC RUN 3	LHC LS3	LHC RUN 4	LHC LS4	LHC RUN 5 and RUN 6
2019-2021	2022-2025	2026-2028	2029-2032	2033-2034	2035-2041

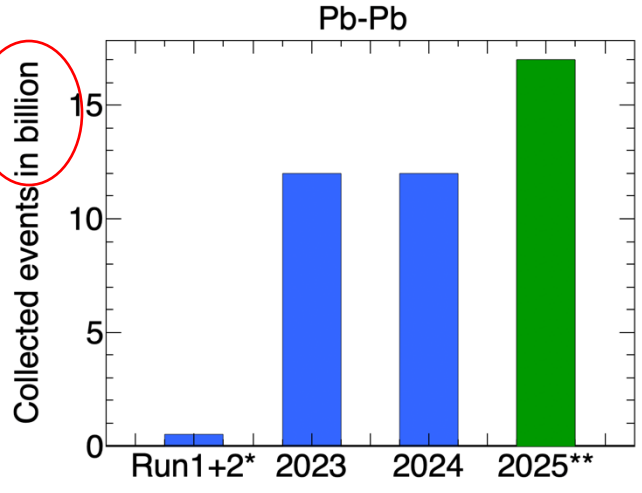
Statistics collected in LHC Run 3 (so far)

pp @13.6 TeV



Pb-Pb @5.36 TeV

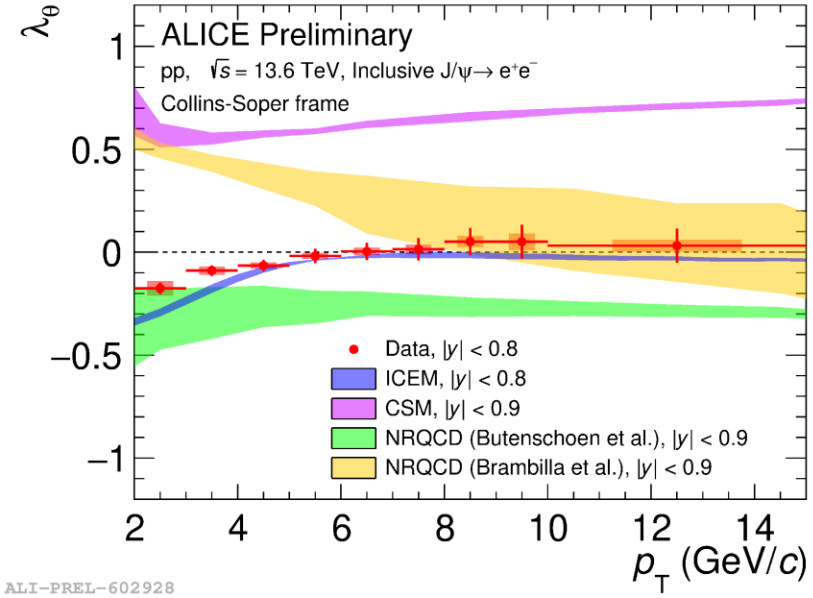


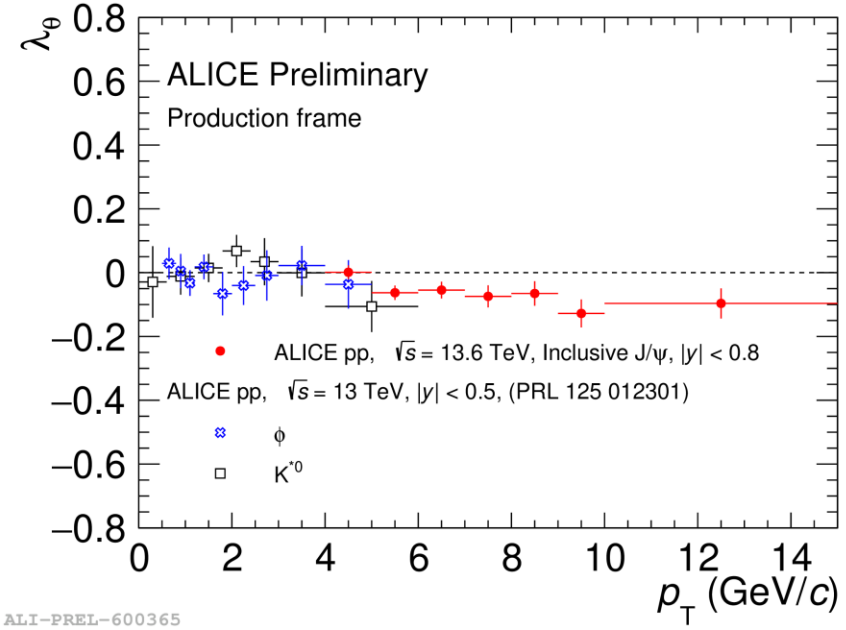


- Record all the minimum bias （MB) events during the data taken
- Collected approx. **24B and 2000B MB** events **in Pb-Pb and pp** collisions, respectively

Charmonia polarization in pp collisions

New Preliminary





- The Run 3 statistics allow for the measurement of J/ψ polarization at midrapidity
- The measurement of J/ψ polarization in Pb–Pb collisions is ongoing

Summary and outlook

- **Pb−Pb collisions**

  The significant J/ψ spin alignment (~**3**.9$\boldsymbol{\sigma}$) observed w.r.t the reaction plane

  The measured ρ_{00} of light flavor vector meson K^{*0} and ϕ are less than 1/3 at low p_T

- **Prospect of Run 3**

  New and more precise measurements can be expected – **stay tune with Run 3**

Thanks