10th China LHC Physics Conference

Measurements of vector mesons spin alignment with ALICE at the LHC

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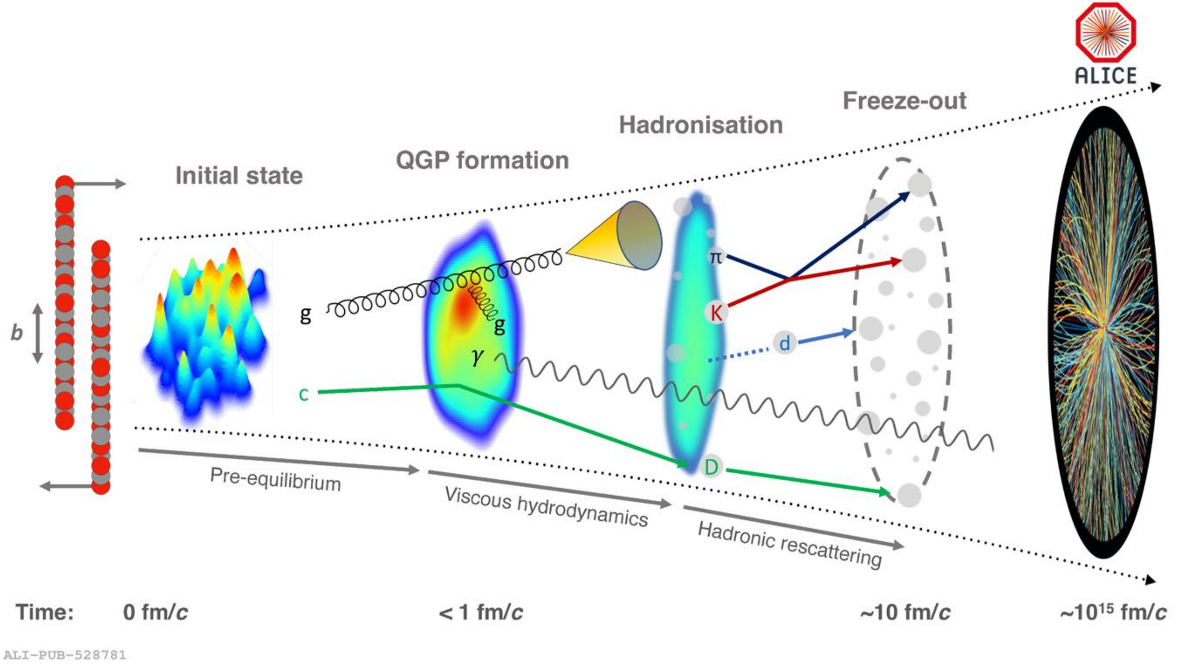
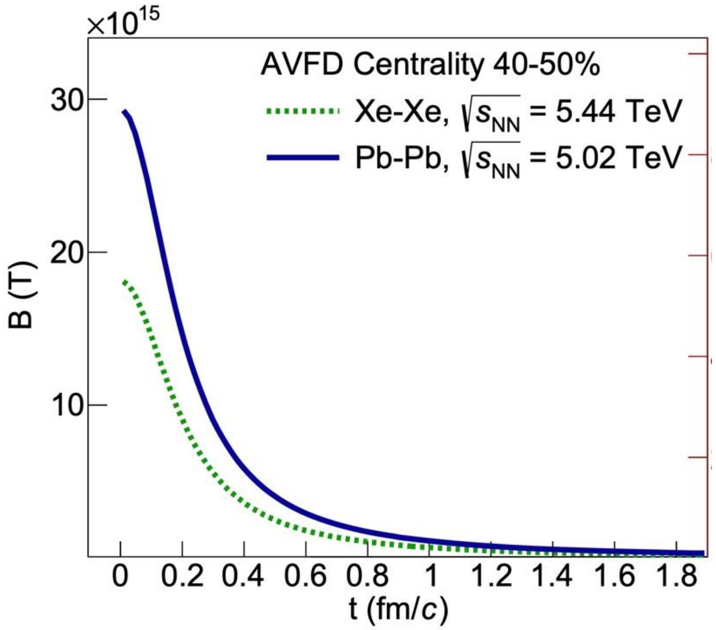
Introduction to heavy-ion collisions

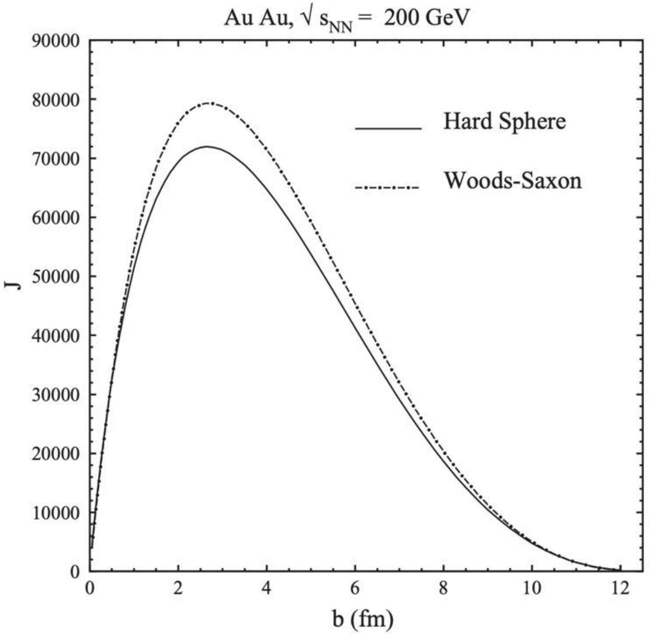


- In non-central heavy-ion collisions, short-lived magnetic fields (***B***) and very strong orbital momentum (***L***) are expected to be produced
- The magnetic fields and orbital momentum can influence the global polarization

Strong magnetic field and orbital momentum



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

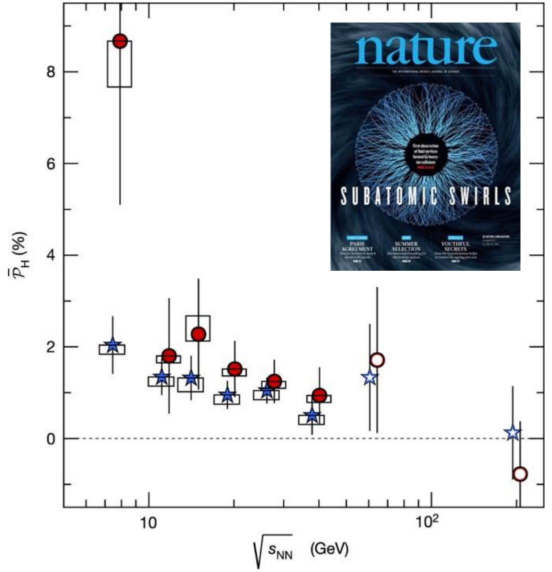


F. Becattini et al., PRC 77 (2008)

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

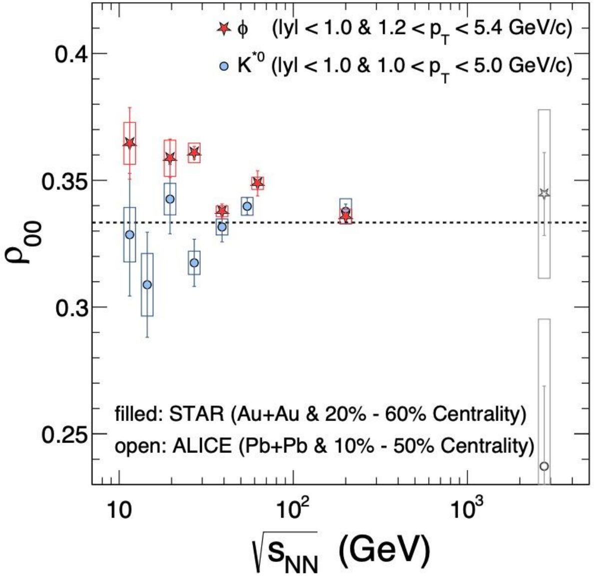
Vector mesons spin alignment in heavy-ion collision

Discovery of Λ hyperon global polarization



Z.-T. Liang, X.-N. Wang, PRL 94, 102301 (2005)
STAR, Nature 548 62 (2017)

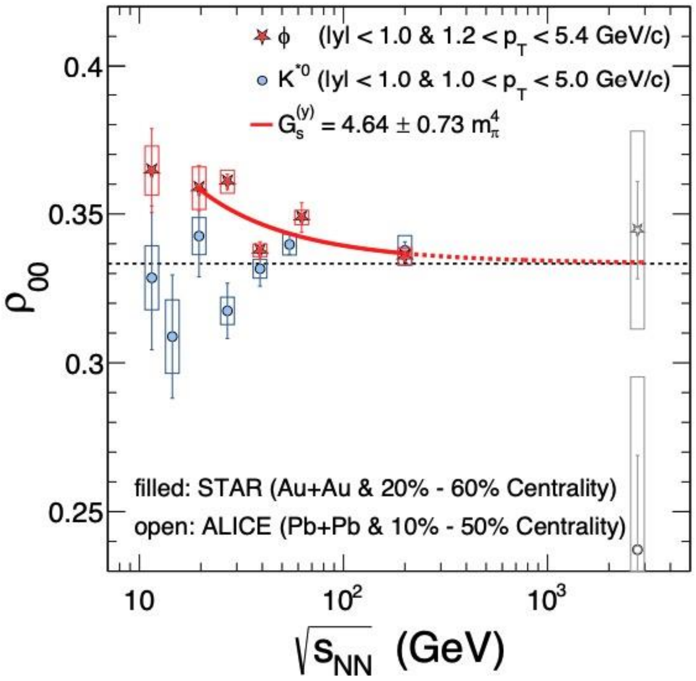
Discovery of vector meson spin alignment



Z.-T. Liang, X.-N. Wang, PLB 629 (2005) 20-26
STAR, Nature 614 244 (2023)

The global spin alignment of the vector meson ϕ exhibits a surprisingly larger than the contributions from the magnetic field and vorticity, a new puzzle

Vector meson spin alignment (is the puzzle solved?)

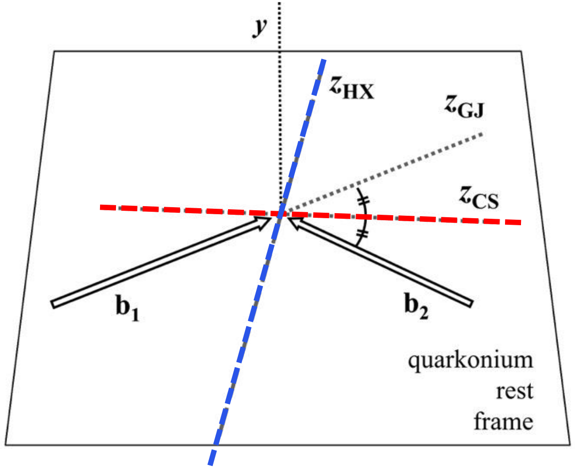


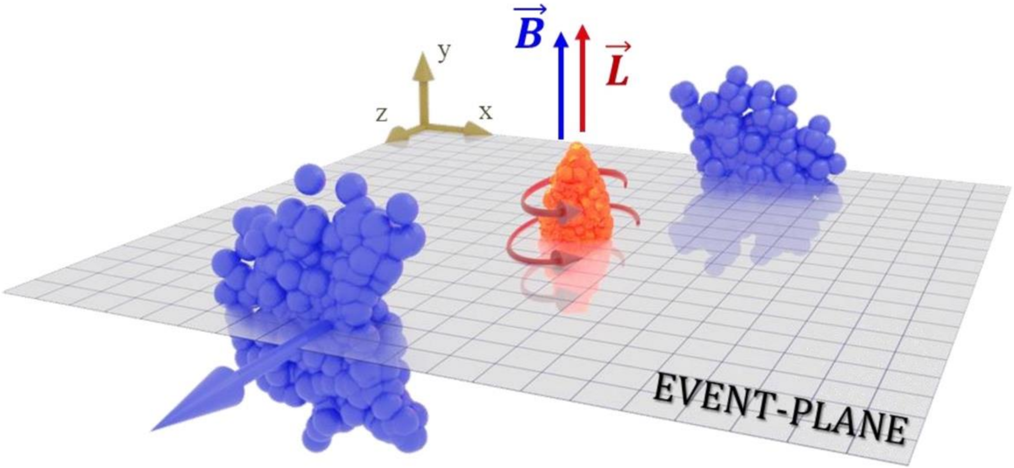
STAR, Nature 614 244 (2023)

- 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:

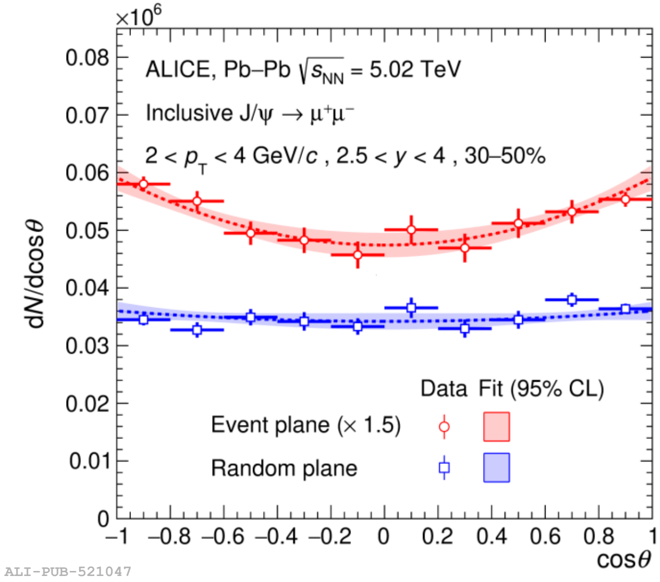
$$W(\cos\theta, \phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \cdots)$$

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

$\lambda_\theta =$ polarization parameter
$\lambda_\theta = 0$ no spin alignment

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

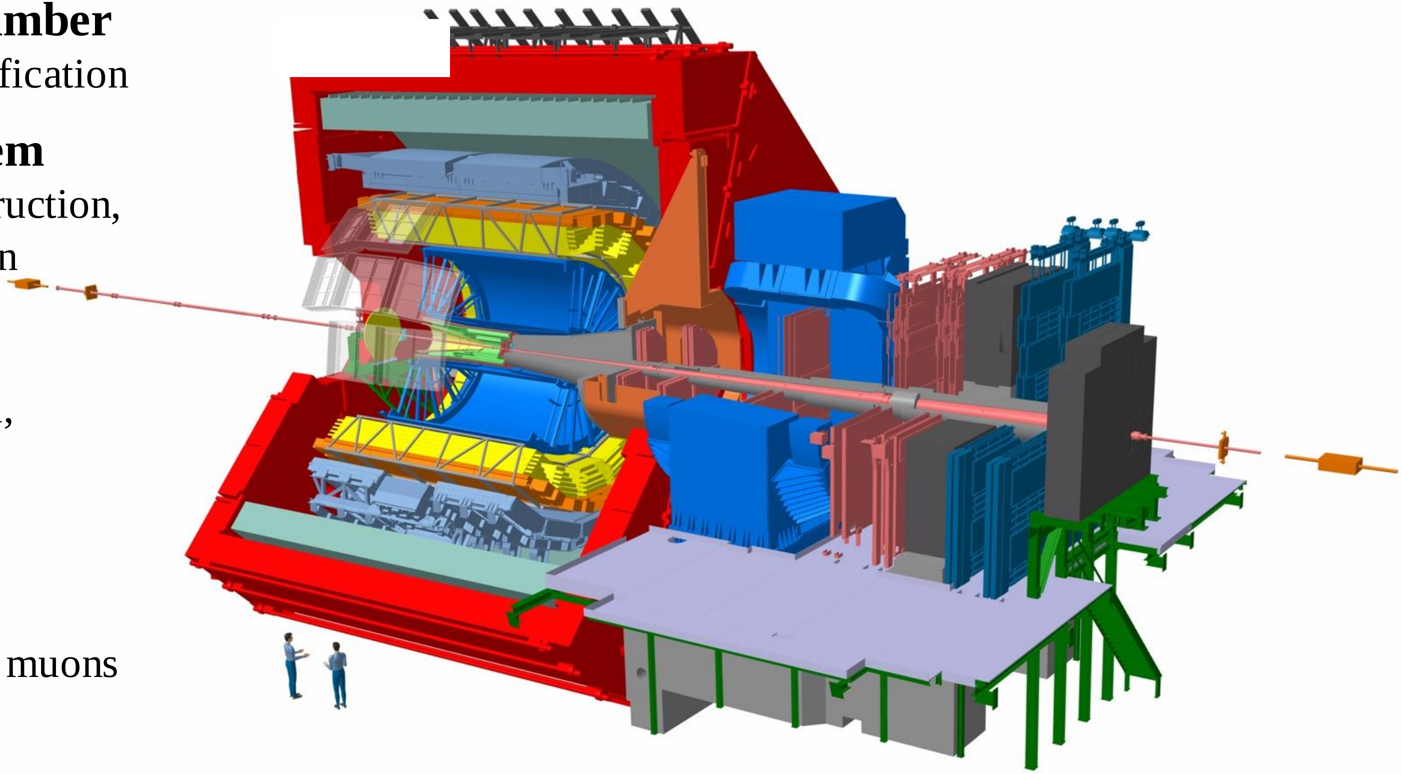
ALICE, PRL 131 (2023) 4, 042303



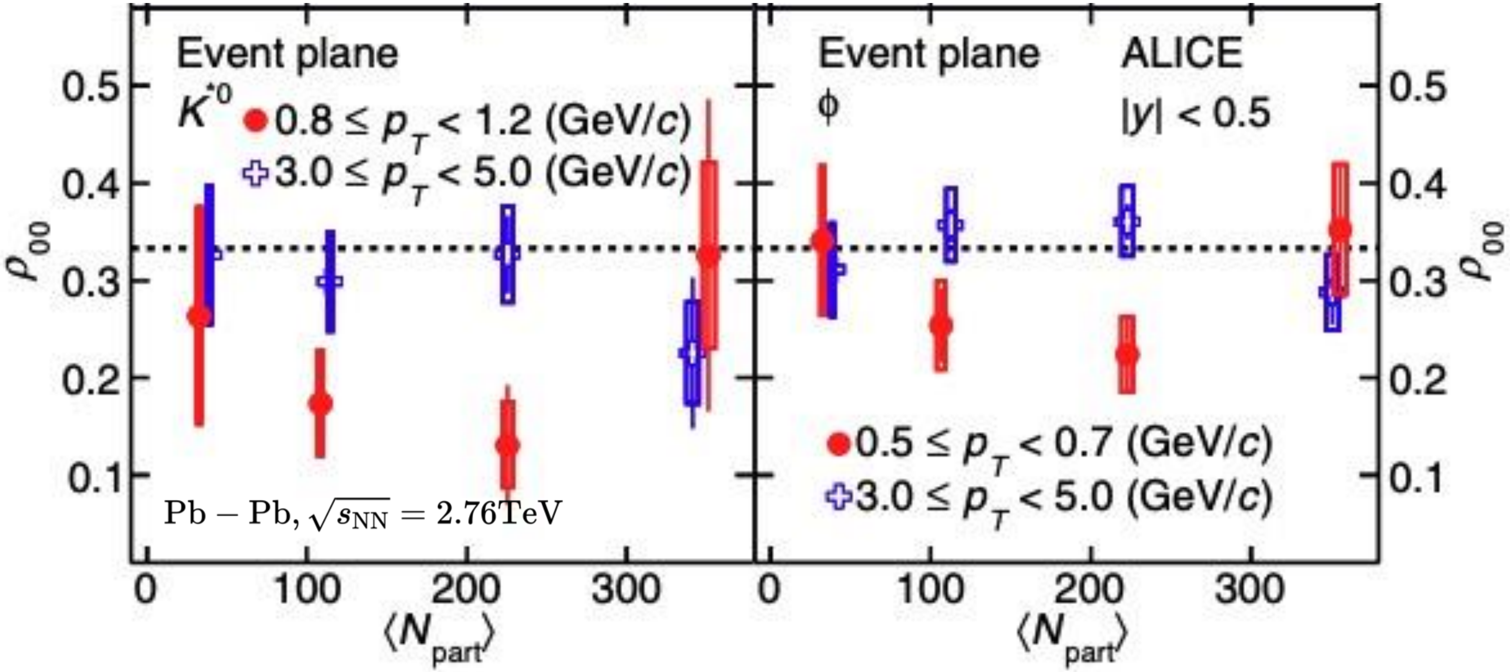
- **pp collisions**: Important to constrain quarkonium production mechanisms in hadronic collisions
- **AA collisions**: Polarization measurements gives access to different time scales and mechanisms, like the early-produced magnetic field, angular momentum, and hadronization mechanisms.

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



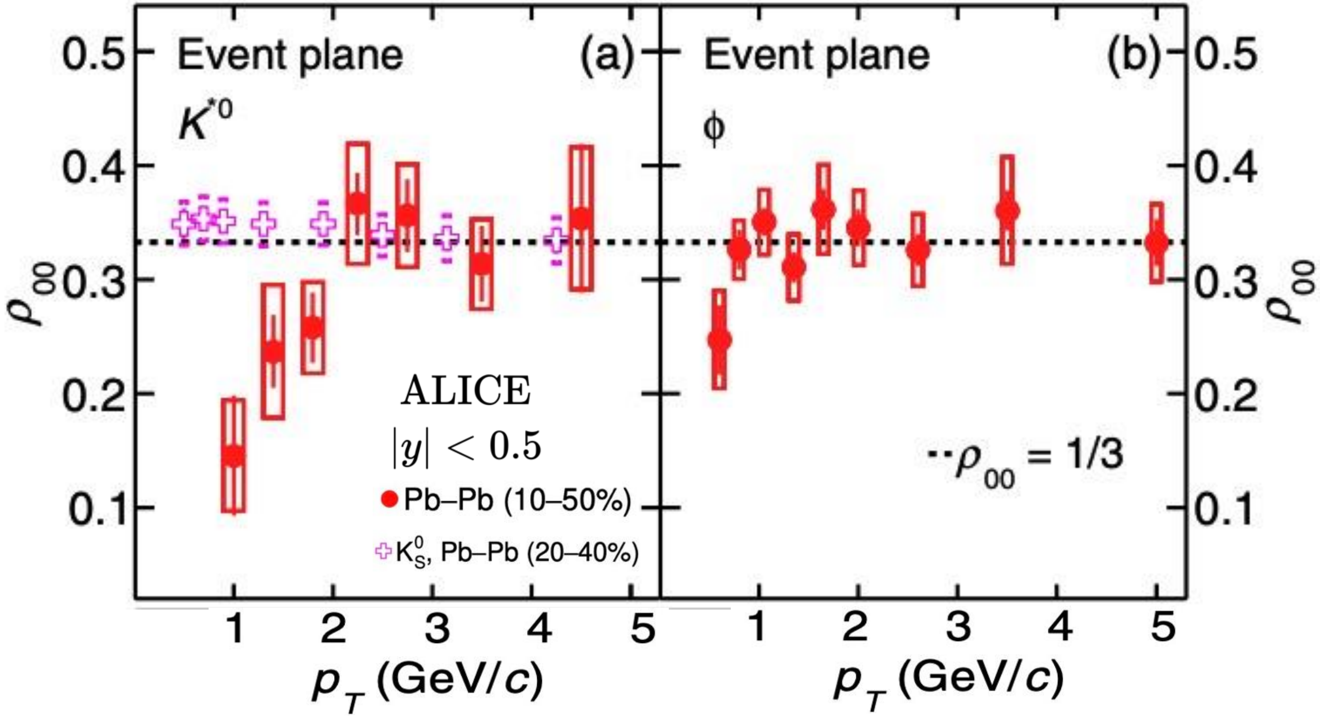
K^{*0} and ϕ spin alignment vs. centrality



- 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}

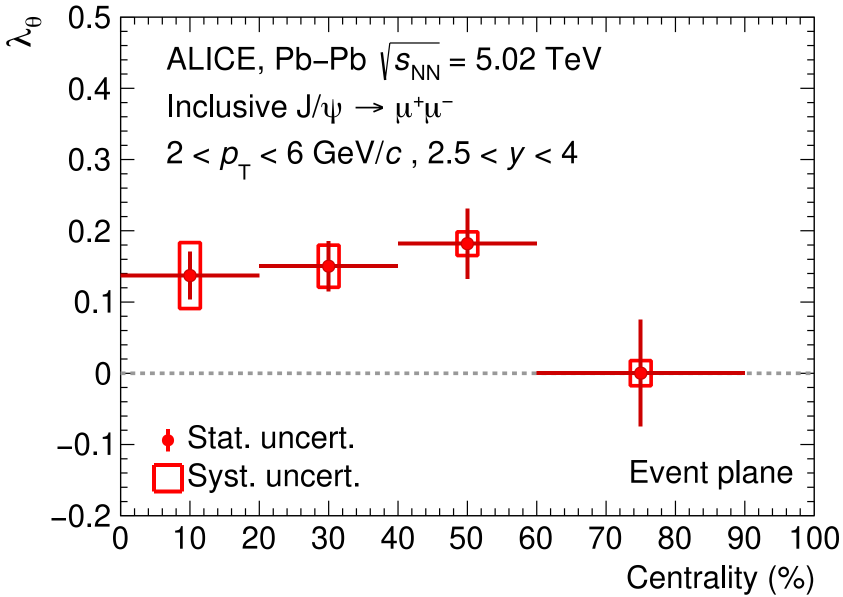


- $\rho_{00} < 1/3$ for K^{*0} and ϕ at low p_{T}, ρ_{00} consistent with 1/3 at high p_{T}
- ρ_{00} for K_s^0 (spin=0) consistent with 1/3

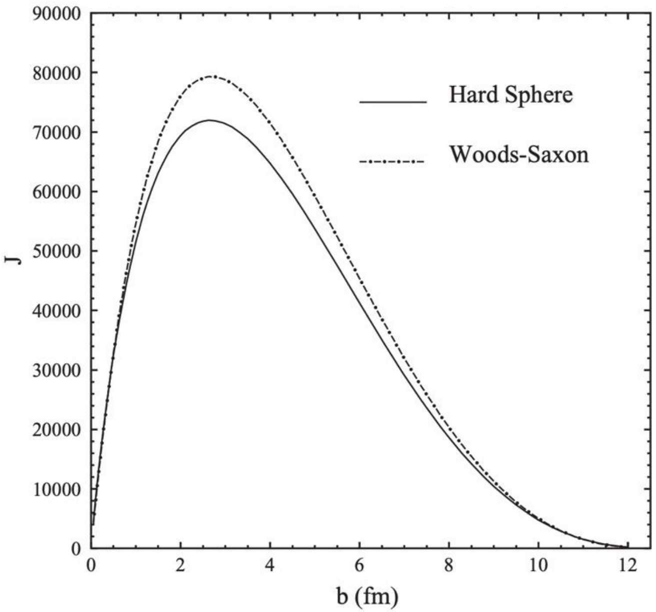
ALICE, PRL 125(2020) 012301

J/ψ spin alignment vs centrality

ALICE, PRL 131 (2023) 4, 042303



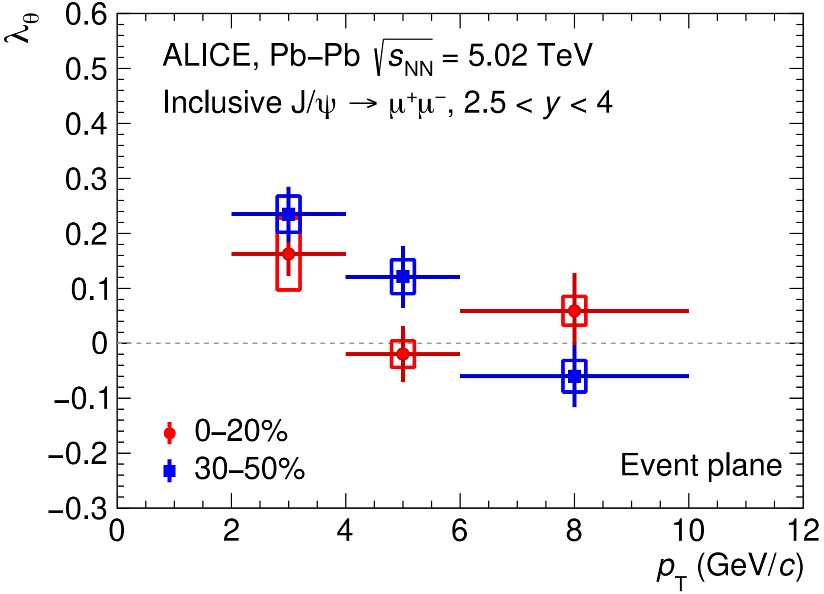
F. Becattini et al., PRC 77 (2008)



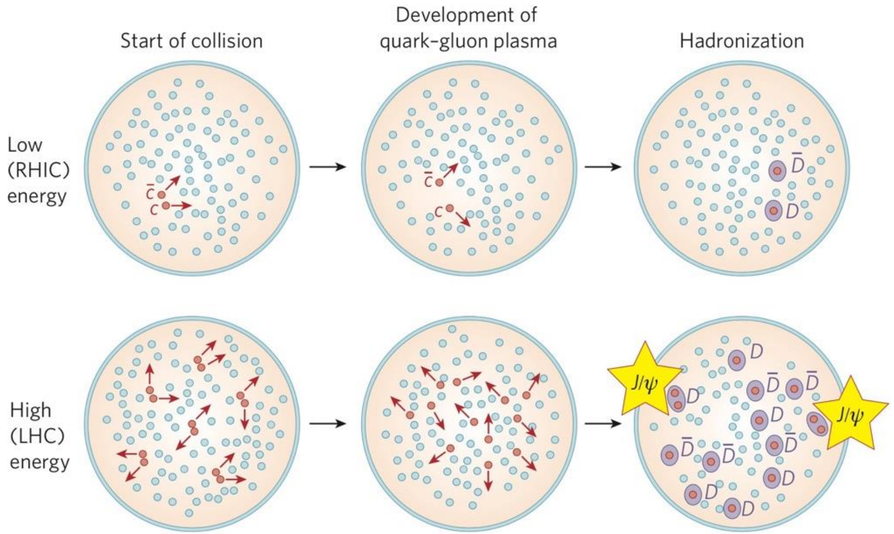
- First measurement of quarkonium spin alignment **with respect to the event plane**
- The significance of the spin alignment reaches **~3.9σ** at the semi-central collisions
- Interpretation of results requires inputs from theoretical models

J/ψ spin alignment vs p_T

ALICE, PRL 131 (2023) 4, 042303

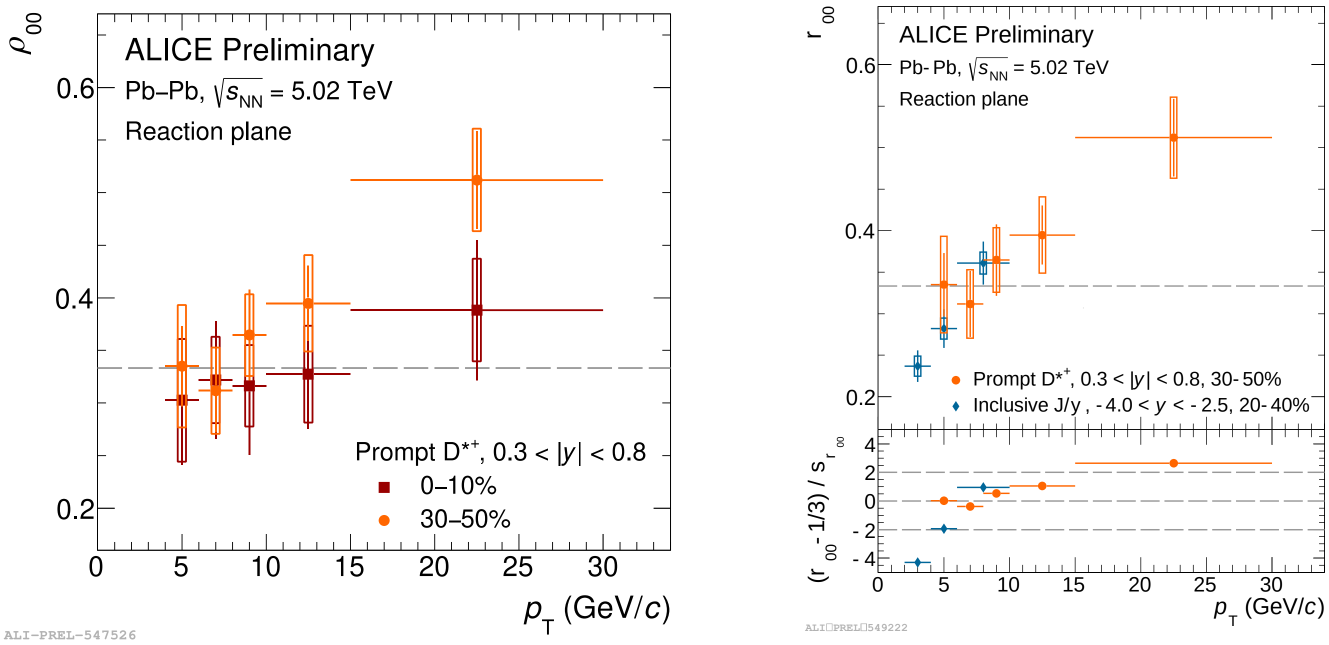


P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302



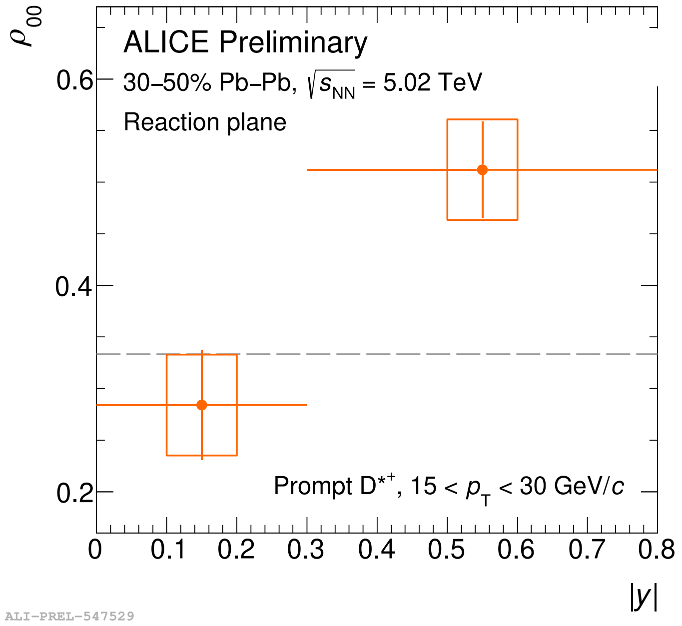
- **Significant J/ψ spin alignment** observed at low $p_{T,}$ are they from (re)generated contribution?
- J/ψ **(re)generation** from uncorrelated charms quarks contributions are found to be the dominate production mechanism at low p_T in the LHC energies

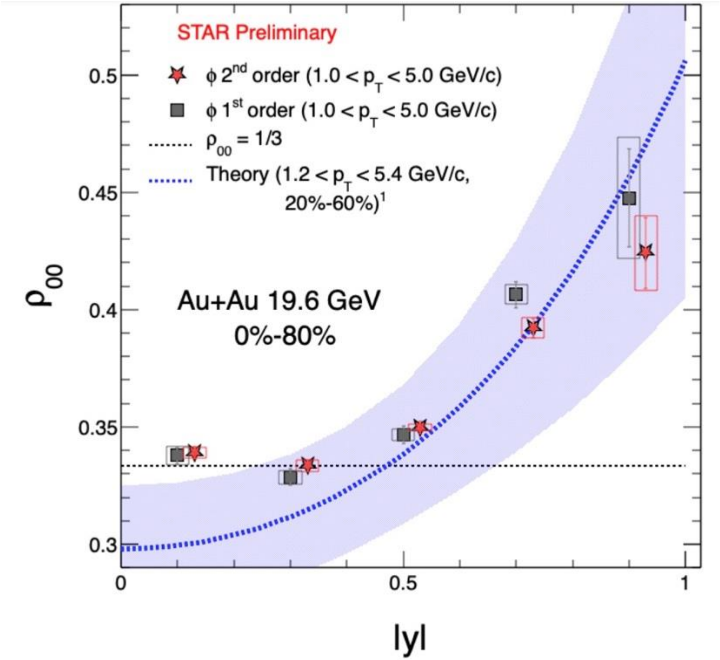
D^{*+} spin alignment p_{T} dependence



- 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!

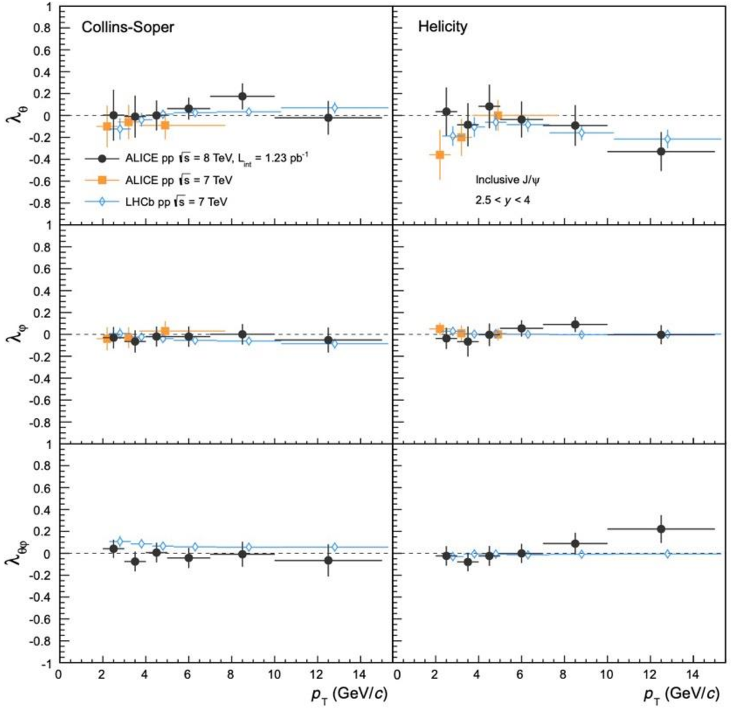
Spin alignment rapidity dependence

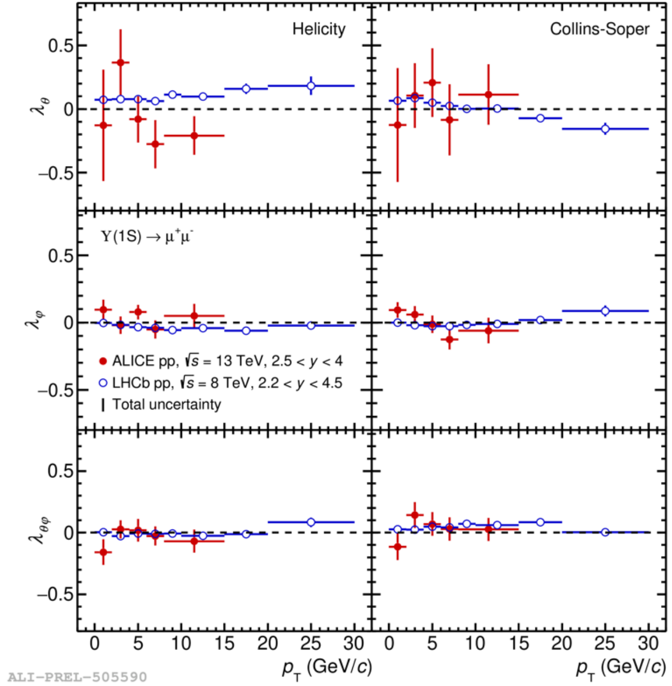




- D^{*+} **spin alignment** deviation is stronger at larger rapidity than at midrapidity, similar behaviour is observed at RHIC energies
- How about the J/ψ spin alignment rapidity dependence? —> Run 3

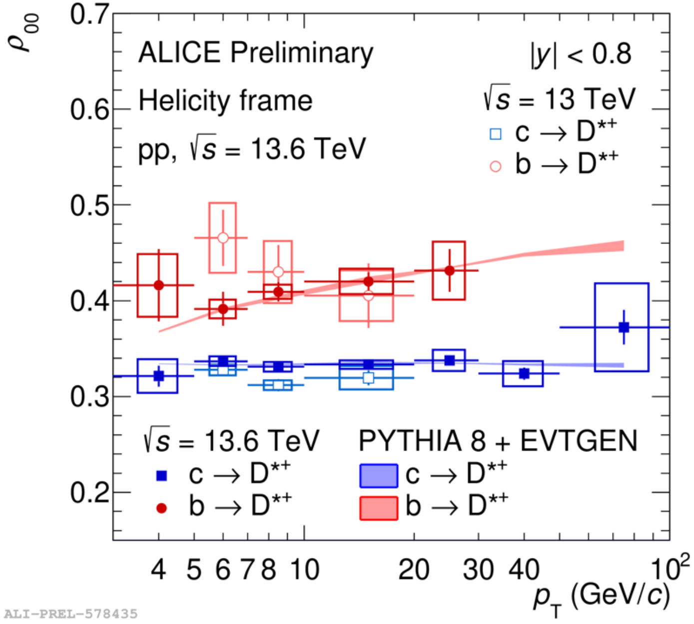
J/ψ and ϒ(1S) spin alignment in pp collisions

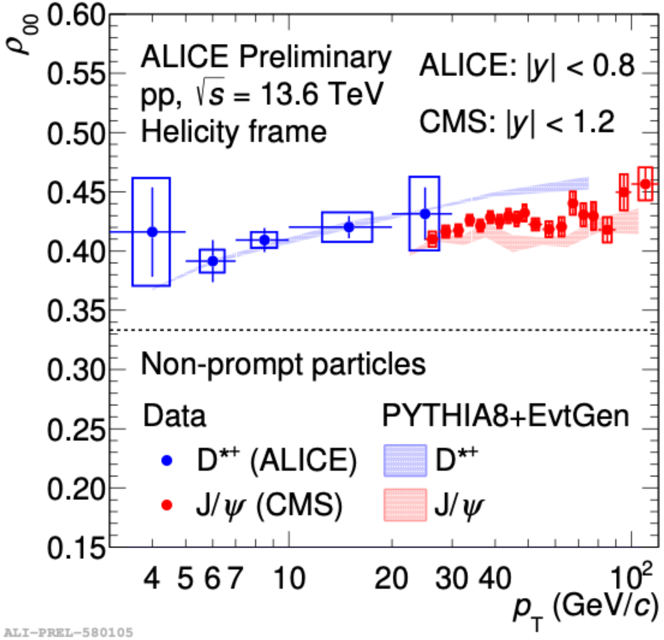




No significant spin alignment is observed for J/ψ and ϒ(1S) in pp collisions by ALICE in Helicity and Collins-Soper reference frames

D^{*+} spin alignment in pp collisions



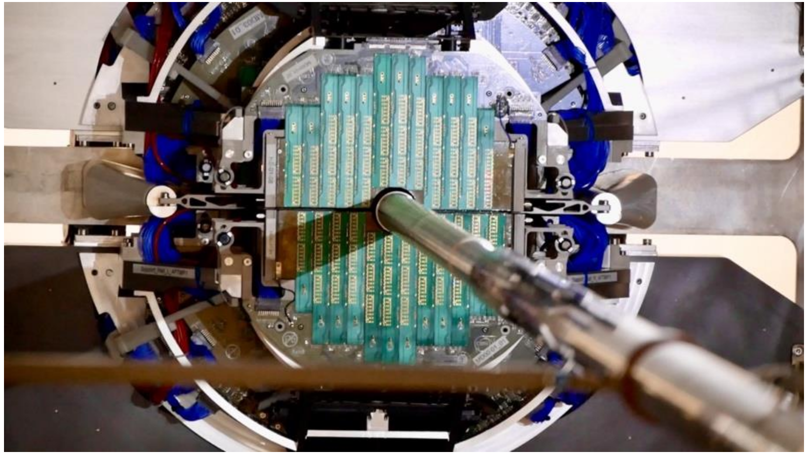


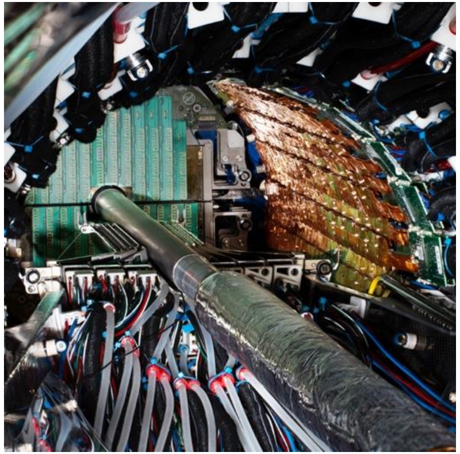
- ρ_{00} = ⅓ for prompt $\mathbf{D}^{*+}$, ρ_{00} larger than ⅓ for non-prompt $\mathbf{D}^{*+}$, due to the helicity conservation in weak decays
- New measurement in pp collisions provides an important baseline for Pb-Pb collisions

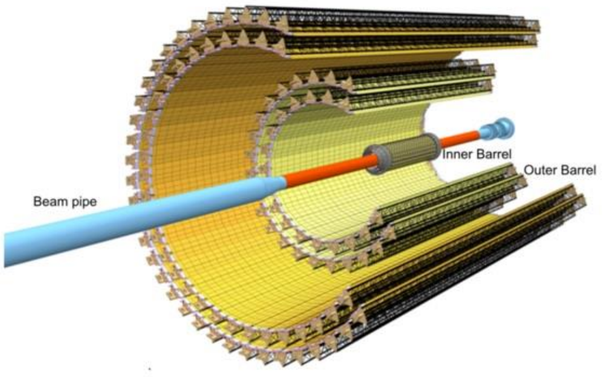
Detector upgrades with ALICE in Run 3

New Muon Forward Tracker

Upgraded Inner Tracking System



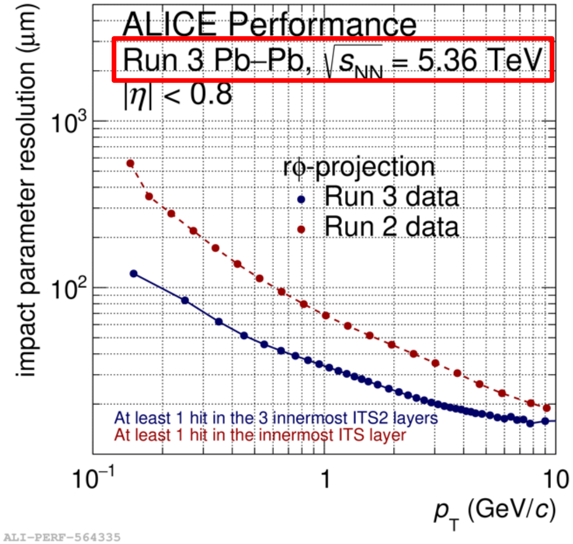


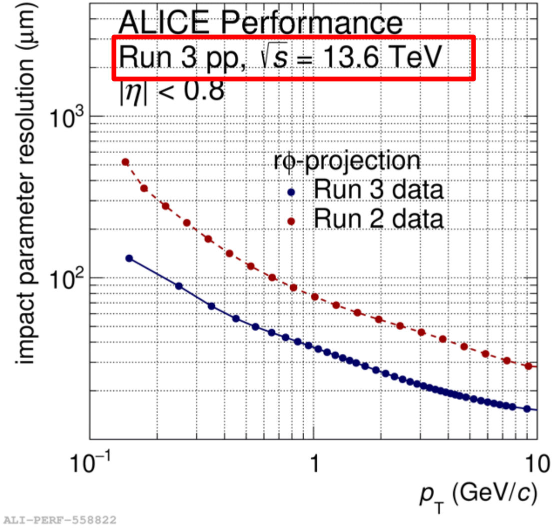


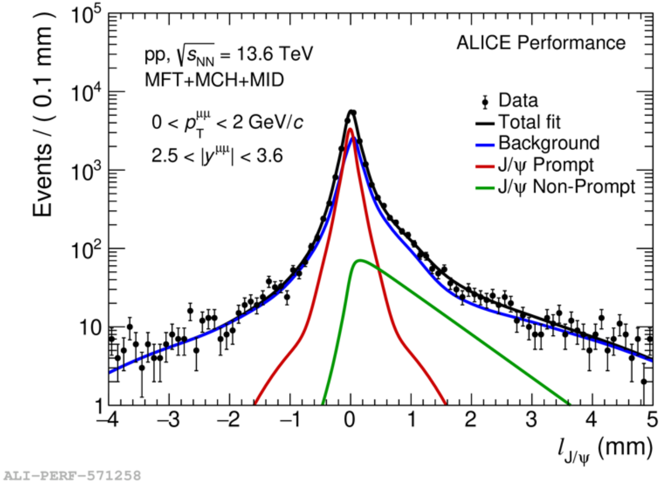
- ➢ Monolithic Active Pixel Sensor technology
- ➢ Spatial resolution: 5 µm
- ➢ Pixel size: 27 µm x 29 µm

- ➢ 3 layers in inner barrel (IB), 4 in outer barrel (OB)
- ➢ Reduced material budget: from 1.14% X_0 to 0.36% X_0 per layer
- ➢ Reduced pixel size: from 50 x 425 µm^2 to 29 x 27 µm^2

Performance of the ITS2 and MFT in Run 3







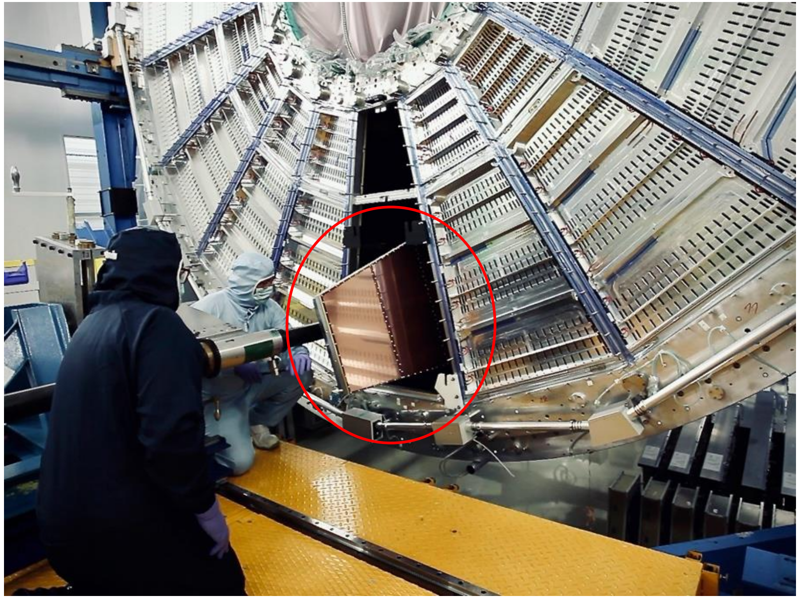
Improved pointing resolution at midrapidity

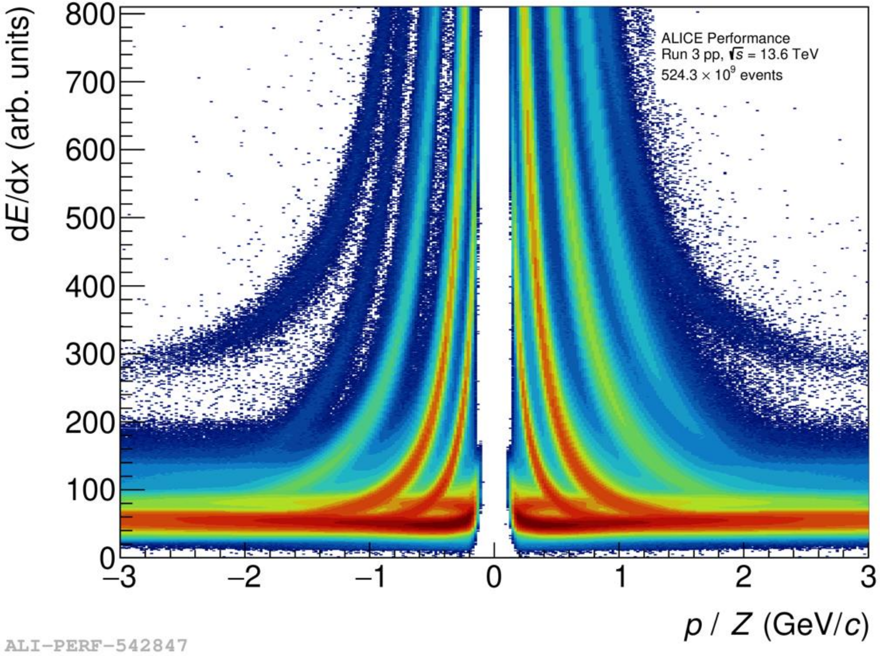
already now by factors of 2 and 6 in the transverse plane and beam-line direction, respectively

Secondary vertex reconstruction enabled at forward rapidity

separation of J/ψ contributions from beauty-hadron decays

Detector upgrades with ALICE in Run 3 (TPC)

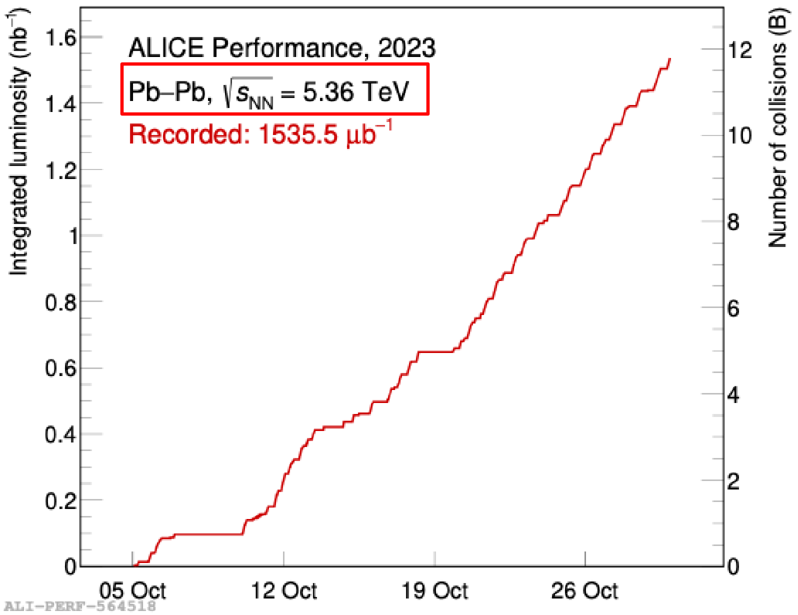


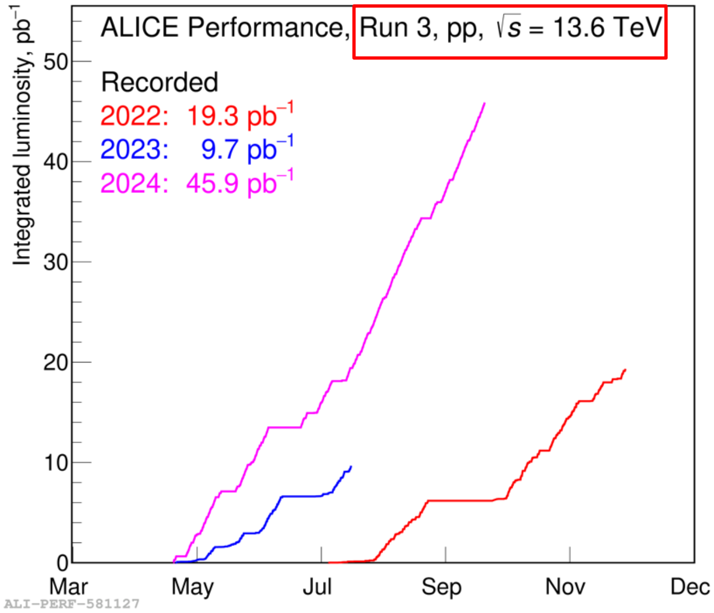


Upgraded Time Projection Chamber -> **GEM, continuous readout**

- ➢ pp data taking at 500 kHz
- ➢ Pb-Pb data taking at 50 kHz

Run 3 data taking





- Pb–Pb data taking at **50 kHz**
- Collected approx. 12B MB events

- pp data taking at **500 kHz**
- 75 pb^{-1} MB events are currently recorded

Summary of vector meson spin alignment

	K^{*0}	ϕ	D^{*+}	J/ψ	$\Upsilon(1S)$
pp	$\rho_{00} \sim 1/3$ low p_T production plane	$\rho_{00} \sim 1/3$ low p_T production plane	$\rho_{00} \sim 1/3$ (HX)	$\rho_{00} \sim 1/3$ (HX and CS)	$\rho_{00} \sim 1/3$ HX and CS
Pb-Pb	$\rho_{00} < 1/3$ low p_T (RP)	$\rho_{00} < 1/3$ low p_T (RP)	$\rho_{00} > 1/3$ high p_T (RP)	$\rho_{00} < 1/3$ low p_T (RP)	$\rho_{00} \sim 1/3$ HX and CS

Summary and outlook

- **pp collisions:**

  Measured J/ψ, Υ(1S) , D^{*+} , K^{*0} and ϕ , do not exhibit strong polarization

- **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**

  More precise measurements can be expected

  The J/ψ spin alignment will be measured via dielectron decay channel at midrapidity

Thanks