Spin alignment measurements using vector mesons with ALICE detector at the LHC

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Outline:
- Physics Motivation
- ALICE detector setup
- Results
  - $\rho_{00}$ of $K^0$ w.r.t. Production plane
  - $\rho_{00}$ of $K^0$ w.r.t. Event plane
- Summary
Initial conditions in heavy-ion collisions

Goal:
Look for signature of these in measurements

Large magnetic field

Large angular momentum (conserved quantity)

F. Becattini, F. Piccinini and J. Rizzo

D. E. Kharzeev, L. D. McLerran and H.J. Warringa

Goal: Look for signature of these in measurements

\[ M^2_\pi \sim 2 \times 10^4 \text{ MeV}^2 \sim 3 \times 10^{14} \text{ Tesla} \sim 3 \times 10^{18} \text{ Gauss} \]
Global polarization and spin alignment results at RHIC

All results from the STAR Experiment

Global polarization and spin alignment results at RHIC

No polarization


Global $\Lambda$ hyperon. Polarization Results w.r.t event plane.

Spin alignment of vector mesons. Results w.r.t production plane.


No spin alignment
Angular distribution of vector mesons

K*\(^0\) Vector meson
- Mass: 896 MeV/c\(^2\)
- Lifetime: 1.38 \times 10^{-23} s
- Spin: 1
- Decays to K\(^+\) and \(\pi^-\) (B.R. \(\sim 66.6\%\))
- Quark content (d,sbar)

\[
\frac{dN}{d\cos\theta^*} = N_0 \left[ 1 - \rho_{00} + \cos^2\theta^* (3\rho_{00} - 1) \right]
\]


\(\rho_{00}\) = Element of spin density matrix
= \(1/3\) \(\rightarrow\) No spin alignment

Quantization axis
- Normal to production plane
- Normal to reaction plane

QM2018 - Ranbir Singh, NISER
ALICE detector

V0 : $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$
Trigger and event centrality
Event plane estimation

Time of Flight : $|\eta| < 0.9$
Particle identification

### Data set and analysis

#### pp collisions

<table>
<thead>
<tr>
<th>Collision system and energy</th>
<th>pp and 13 TeV, Minimum bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapidity</td>
<td>$</td>
</tr>
<tr>
<td>No. of events</td>
<td>~ 43 M</td>
</tr>
<tr>
<td>Hadrons</td>
<td>$K^*$</td>
</tr>
<tr>
<td>Background</td>
<td>Mixed events</td>
</tr>
<tr>
<td>Efficiency x acceptance</td>
<td>Corrected</td>
</tr>
<tr>
<td>Quantization axis</td>
<td>Normal to Production plane</td>
</tr>
</tbody>
</table>

Goal: Measure $dN/d\cos\theta^*$ vs. $\cos\theta^*$ and extract $\rho_{00}$ value as a function of $p_T$ and centrality of $K^*$.

#### Heavy-ion collisions

<table>
<thead>
<tr>
<th>Collision system and energy</th>
<th>Pb-Pb and 2.76 and 5.02 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapidity</td>
<td>$</td>
</tr>
<tr>
<td>No. of events</td>
<td>~ 14 M (2.76 TeV), ~30 M (5.02 TeV)</td>
</tr>
<tr>
<td>Collision Centrality</td>
<td>$K^*$:10-50, 0-10, 10-30, 30-50, 50-70, 70-90 and 50-80%, $K^0_S$:20-40%</td>
</tr>
<tr>
<td>Hadrons</td>
<td>$K^*$ and $K^0_S$</td>
</tr>
<tr>
<td>Background</td>
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<td>Efficiency x acceptance</td>
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<tr>
<td>Quantization axis</td>
<td>Normal to Production plane and Event plane</td>
</tr>
</tbody>
</table>
**K*\(^0\) vector meson reconstruction in Pb-Pb collisions in Production Plane method**

- **Same event (sig+bkg) and mixed event (bkg) distributions**

- **Same event distribution after mixed event background subtraction**

Yield is the area under Breit-Wigner distribution – Residual background
K*0 vector meson reconstruction in Pb-Pb collisions
Event Plane method

Same event (sig+bkg) and mixed event (bkg) distributions

Yield is the area under Breit-Wigner distribution – Residual background
Angular distribution: Production plane

Two parameters ($N_0$ and $\rho_{00}$) fit to $\cos\theta^*$ distributions measured in different $p_T$ bins

- **pp collisions**
  - ALICE Preliminary
  - $\sqrt{s} = 13$ TeV
  - $K^+ (K^-) \rightarrow K^{*+} (K^{*-})$
  - $|y| < 0.5$
  - $1.2 \leq p_T < 1.8$ GeV/c

- **Heavy-ion collisions**
  - ALICE Preliminary
  - Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV (10-30%)
  - $K^0 (\bar{K}^0) \rightarrow K^+ \pi^- (K^- \pi^+)$
  - Production plane
  - $|y| < 0.5$
  - $0.8 \leq p_T < 1.2$ GeV/c

\[
\frac{1}{N_{\text{evt}}} \frac{dN}{d\cos\theta^*} = N_0 [(1 - \rho_{00}) + (3\rho_{00} - 1) \cos^2\theta^*] + \text{Data (stat. uncert.)}
\]
Spin density matrix element ($\rho_{00}$) vs. $p_T$ : Production Plane

**pp collisions**

$\rho_{00}$ values about 2.5σ and 2.3σ below $1/3$ in 2.76 TeV and 5.02 TeV respectively.

**Heavy-ion collisions**

Pb-Pb collisions: For 1st $p_T$ bin, $\rho_{00}$ values about 2.5σ and 2.3σ below $1/3$ in 2.76 TeV and 5.02 TeV respectively.
Spin alignment of $K^{*0}$ (spin 1) and $K^0_S$ (spin 0)

Control Experiment:
No spin alignment observed for spin 0 hadron $K^0_S$
Centrality & energy dependence of $\rho_{00}$: Production plane

- $\rho_{00}$ shows centrality dependence and maximum deviation from $1/3$ for centrality class 10-30%
- Similar values of $\rho_{00}$ are observed at both the energies
Angular distribution: Event Plane

Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

$K^0 (\bar{K}^0) \rightarrow K^+\pi^- (K^\pi^*)$, $|y| < 0.5$

Event plane

$0.8 \leq p_T < 5$ GeV/c

$\frac{dN}{d(\cos \theta^*)} = N_0 \times [(1 - \rho_{00}) + (1/R)(3\rho_{00} - 1)\cos^2 \theta^*]$

$R$ is the second order event plane resolution.

Two parameters ($N_0$ and $\rho_{00}$) fit to $\cos \theta^*$

Distributions measured in different $p_T$ bins
Spin density matrix element ($\rho_{00}$) vs. $p_T$: Event vs. Production Plane

- $\rho_{00} < 1/3$ for $p_T < 2.0$ GeV/c in both Event and Production plane
- Within statistical and systematic uncertainties $\rho_{00}$ values are similar in both Production and Event plane method
Centrality dependence of $\rho_{00}$: Event plane

$\rho_{00}$ shows centrality dependence and maximum deviation from $1/3$ for centrality class $10\text{--}30\%$. First $p_T$ bin is at $\sim 1.74 \sigma$ and integrated $p_T$ is at $\sim 1.35 \sigma$ (Event plane resolution (10\text{-}30\%) = 0.72).
Centrality dependence of $\rho_{00}$: Event plane vs. Production plane

- $\rho_{00}$ shows centrality dependence in both Production and Event plane and maximum deviation from $1/3$ for centrality class 10-30%.
- Within statistical and systematic uncertainties, $\rho_{00}$ values are similar in both Production and Event plane method.
Summary

✓ $\rho_{00} < 1/3$ w.r.t. both Event and Production plane in Pb-Pb collisions. For first $p_T$ bin, $\rho_{00}$ values about 2.5$\sigma$ and 3.0$\sigma$ w.r.t. Production plane at 2.76 and 5.02 TeV respectively, about 1.7$\sigma$ w.r.t. Event plane at 2.76 TeV. The systematic uncertainties are likely correlated.

✓ $\rho_{00}$ consistent with 1/3 for higher $p_T$ in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV in ALICE @ LHC

✓ $\rho_{00}$ shows centrality dependence and maximum deviation for mid-central collisions in both Event and Production plane

✓ $\rho_{00}$ values are similar at both $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV

✓ $\rho_{00} \sim 1/3$ : Spin alignment not observed in proton-proton collisions at 13 TeV

✓ $\rho_{00} \sim 1/3$ (within systematic errors) : Spin alignment not observed for $K^0_S$ (spin 0) w.r.t. Production plane in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
Outlook

✓ Analysis with Pb-Pb 5.02 TeV data with higher statistics
✓ Spin alignment studies with respect to event plane in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Thanks
BACKUP
\( \rho_{00} \) vs. \( <N_{\text{part}} > \): Comparison with STAR results in Au-Au collisions at \( \sqrt{s_{\text{NN}}} = 200 \) GeV

All results are w.r.t. Event plane

For low \( p_T \): \( \rho_{00} \) shows centrality dependence for Pb-Pb 2.76 TeV

For high \( p_T \): Both STAR and ALICE results are consistent with \( \rho_{00} = 1/3 \)