Transverse $\Lambda$ Polarization in Pb-Pb collisions at 158 $AGeV/c$

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Event display NA57
Transverse $\Lambda$ Polarization

- $\Lambda$ is produced with preferred spin direction perpendicular to reaction plane
- Angular distribution of proton in rest frame $\Lambda$ is asymmetric:

$$\frac{dN}{d\cos \theta_y} = A(\cos \theta_y)(1 + \alpha P_y \cos \theta_y)$$

- with
  - $\alpha = \Lambda$ decay asymmetry parameter (=0.642)
  - $A(\cos \Theta_y)$ = detector acceptance
  - $P_y$ = Transverse Polarization
In p-p and p-A collisions:

- Transverse $\Lambda$ polarization is negative w.r.t. production plane.
- Polarization can be of the order of 40%.
- For $p_T < 1$ GeV/c: polarization increases linearly; slope depends on $x_F (=2p_L^*/\sqrt{s})$.
- For $p_T > 1$ GeV/c: polarization is constant with $p_T$. Depends still on $x_F$. 

![Graph showing $p_T$ dependence of polarization]
For $p_T > 1$ GeV/c the polarization increases linear with $x_F$.

Polarization is roughly independent of:
- Incident beam energy
- Collision system (p-p, P-A, A-A)

At QM2001 first time significant polarization in Au-Au collisions at AGS ($\sqrt{s}=4.7$ GeV/c).

Other hyperons:
- $\Lambda$, $\Sigma$: $P=0$
- $\bar{\Lambda}$, $\bar{\Sigma}$: $P$=negative
- $\Sigma$: $P$=positive
Origin polarization

- Observation polarization remarkable: unpolarized beam on unpolarized target gives polarized particle!

- pQCD calculations: zero polarization (only high $p_T \sim 5$ GeV/c).

- Semi-classical models, projectile plays important role:
  - Valence $ud$-diquark (spin-isospin singlet) determines direction ($=x_F$). Recombines with polarized $s$-quark from the sea of the target. This gives $p_t$ to $\Lambda$.
  - Particle completely out of sea quarks has no polarization according to this assumption: $\Lambda$ is not polarized!

- In a Quark Gluon Plasma (QGP) production of the $\Lambda$ would be analogue to its anti-particle: no polarization expected.
NA57 Experiment

Principal aim:
- Measurement of strange baryons ($\Lambda, \Xi, \Omega$) at mid-rapidity in p-Be and Pb-Pb collisions at 40 and 158 AGeV/c (at SPS/CERN).

The apparatus
- Multiplicity Strip Detectors (MSD): to measure the amount of charged particles and measure of centrality of collision.
- Silicon Telescope: vertex detector consisting of pixel and double-sided strip detectors track determination: $\Omega \rightarrow \Lambda + K$ $\rightarrow p + \pi$
Strangeness enhancement in NA57 at 158 AGeV/c

- In Heavy-Ion collisions the number of wounded nucleons $N_W$ is a measure of centrality of collision.

- Enhancement in Pb-Pb w.r.t. p-A increases with strangeness content: $E(\Lambda) < E(\Xi) < E(\Omega)$. Signature QGP?

- Significant change of $\Xi^+$ for most peripheral bin: $3.5 \, \sigma$ effect. Not seen for $\bar{\Lambda}$. 

```latex
\begin{align*}
\text{Particle / event / w. nucl. relative to pBe} & \quad \text{Particle / event / w. nucl. relative to pBe} \\
\begin{array}{c}
\text{pBe} & \text{pPb} & \text{PbPb} \\
\text{pBe} & \text{pPb} & \text{PbPb}
\end{array}
\end{align*}
```
Acceptance

- NA57 is able to measure in the following range:
  - \(-0.15 < x_F < 0.2\)
  - \(0.4 < p_T < 2.5\) GeV/c

- Goal measurement:
  - Is there any polarization around \(x_F \sim 0.15\)?
    Extrapolation of data gives \(\sim 5\%\).
  - \(p_T\)-dependence?
  - Centrality dependence?
  - \((\bar{\Lambda}, K^0\) polarization?)
Deconvolution

- Deconvolution: correction for
  - Limited acceptance
  - Limited resolution
- Principle: for a distribution of measured data \( g \), the corrected (deconvoluted) distribution \( f \) can be obtained by:
  \[
  f = A^{-1} g
  \]
  with \( A \) the detector response matrix.
- \( A \) can be determined by simulations! Distributions can be 1- or 2-dimensional

- Inversion \( A \) yields no problems when matrix is dominantly diagonal \( \rightarrow \) bin size ~2x resolution.

Original (left) and Deconvoluted (right) transverse angular decay distributions proton
Inverse Slopes $\Lambda$

- Real data $\sim$450K $\Lambda$'s. Simulation data used are about 3 times that.
- $m_T$-$y$ deconvolution, note $x_F = \frac{2m_T \sinh(y_{\text{cms}})}{\sqrt{S}}$
- Comparison with official method of collaboration: weighting of particles. Less statistics because is very CPU demanding!

Transverse mass distributions can be parametrized as:

$$\frac{d^2N}{dm_T dy} = A m_T \exp\left(-\frac{m_T}{T}\right)$$

With $m_T$ transverse mass, $y$ rapidity, $T$ inverse slope parameter
**$x_F$-dependence**

- Projectile influence gives effect at high $x_F$. What for Heavy Ions?
- Transverse polarization for region $x_F > 0$: two data points measured for $p_T > 1$ GeV/c.
- NA57 extends range down to $x_F \sim 0.1$.
- Results consistent with zero polarization!
- Systematic error of the same order as the statistical.
\(P_T\)-dependence

- Au-Au collisions show small suppression polarization at lower \(p_T \sim 1.2\) GeV/c
- \(P_T\)-dependence for two \(x_F\) points: \(x_F = 0.09\) and \(x_F = 0.14\)
- No polarization found, even at high \(p_T\)!

\[\begin{array}{c}
Polarization \\
\hline
-0.5 \quad -0.4 \quad -0.3 \quad -0.2 \quad -0.1 \quad 0 \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \\
\hline
\end{array}\]

\[\begin{array}{c}
p_T \text{ (GeV/c)} \\
0.5 \quad 0.75 \quad 1 \quad 1.25 \quad 1.5 \quad 1.75 \quad 2 \quad 2.25 \quad 2.5 \quad 2.75 \quad 3 \\
\hline
\end{array}\]

\(p_T\)-dependence \(x_F = 0.09\) and 0.14
Centrality dependence

- In a QGP: no polarization, peripheral collisions could give polarization!

- Sample divided in two centrality samples:
  1) Central: 15% most central collisions.
  2) Peripheral: the 15% to 60% ‘most central’ collisions.

- No dependence on centrality collision!

Polarization for central and peripheral collisions
Conclusion

Deconvolution method

- Deconvoluted results agree with weighting method for inverse slopes! Higher statistics used by deconvolution.

Transverse Polarization

- First measurement of significant polarization in Heavy Ion collisions at AGS ($\sqrt{s}=4.7 \text{ GeV/c}$) for $0.2 < x_F < 0.5$ (in 2001).
- NA57 ($\sqrt{s}=17.3 \text{ GeV/c}$) extends range down to $x_F \sim 0.1$.
- No transverse polarization seen for low $x_F$. At higher $x_F$ not enough statistics!
- No polarization as function of $p_T$. Also at high $p_T$ no transverse polarization.
- No centrality dependence.

Future prospects:

- Polarization at 40 GeV/c: higher $x_F$ possible ($\sim 0.3$)
Deconvolution II

- Take into account statistics: remove bins with low number of entries
- Oscillations in solution due to statistical insignificant entries. How to solve this?
  - Regularization
  - Take bin size large enough w.r.t. resolution
- Cross check on solution: rotate such that error matrix equal to unity → no correlation between data points.
- When entries of solution > 1: no regularization necessary!