Baryon to meson ratio in jets and underlying events in pp, p-Pb, Pb-Pb collisions measured in ALICE

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Outline

- Physics motivation
- ALICE setup
- Analysis strategy
- Results and discussion
- Summary and outlook
Physics Motivation

- Baryon to meson enhancement in Pb-Pb and p-Pb observed w.r.t. pp collisions
  - Involving several phenomena
    1. Bulk effect (radial flow, coalescence/recombination)?
    2. Jet fragmentation (??)
- $\Lambda/K_S^0$ ratio in jets and underlying events
- Separation of soft and hard processes

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![Graphs showing $\Lambda/K_S^0$ ratio in Pb-Pb and p-Pb collisions](ALI-PUB-55067)


![Graphs showing $\Lambda/K_S^0$ ratio in Pb-Pb and p-Pb collisions](ALI-PUB-58065)

ALICE setup

Time projection Chamber (TPC)
- $|\eta| < 0.9$
- charged particle tracking and particle identification

Inner Tracking System (ITS)
- $|\eta| < 0.9$
- vertex reconstruction
- event trigger

V0A (only for pPb) + V0C
- $2.8 < \eta < 5.1$ & $-3.7 < \eta < -1.7$
- event multiplicity class determination
- event trigger

**Advantage:** Particle Identification

**Data sample:** pp collisions at 7 TeV, p-Pb collisions at 5.02 TeV, Pb-Pb collisions at 2.76 TeV
- pp collisions with 127 MB events, collected in 2010
Analysis strategy

- **V⁰ candidate selection**
  - Select V⁰ candidates by decay topology
  - Signal extract from invariant mass distribution
  - Acceptance: |η| < 0.75

- **Jet reconstruction**
  - Charged particles |η| < 0.9, pₜ > 150 MeV/c
    - With excluding V⁰ daughters
    - anti-κ, R = 0.4 and 0.2, |η_{jet}| < 0.35

- **V⁰s matched with jets (JC)**
  - V⁰s and jets are reconstructed independently
  - Match V⁰s with jets by angular distance between the jet axis and the V⁰ direction
    \[ \sqrt{(\eta_{V^0} - \eta_{jet})^2 + (\varphi_{V^0} - \varphi_{jet})^2} < R_{matching} \]

- **V⁰s in underlying events (UE)**
  - PC (default): V⁰s in the perpendicular cone
  - NJ: V⁰s in event without jet within pₜ > 5 GeV/c
  - OC: V⁰s outside the jet cone
The spectra normalised per area density and corrected by efficiency and feed down

- $V^0$s in jets: JC $V^0$s - UE $V^0$s
- Density of UE $V^0$s is smaller than that of JC $V^0$s, the effect is only relevant at low-$p_T$, overall the effect is small
Corrected density of $V^0$s in jets with $R_{jet} = 0.2$

- Density of JC $V^0$s for $R = 0.2$ is higher than that for $R = 0.4$
- $V^0$ transverse profile peaked around jet axis
Spectra of strange particles in charged jets in Pb-Pb collisions

\( p_T^{\text{jet, ch}} > 10 \text{ GeV/c} \)  \hspace{1cm} \text{Pb-Pb} \hspace{1cm}  \( p_T^{\text{jet, ch}} > 20 \text{ GeV/c} \)

- \( V^0 \) \( p_T \) spectra are obtained with same method as that in pp analysis
  - Additional correction for impact of UE fluctuations applied
Comparison to PYTHIA simulations

\( p_{\text{jet,ch}}^{\text{jet,ch}} > 10 \text{ GeV/c} \)

\( p_{\text{T}}^{\text{jet,ch}} > 20 \text{ GeV/c} \)

- \( V^0 p_T \) spectra in data follow similar slope as predicted by PYTHIA simulations
  - \( \Lambda \) - shows clear enhancement at low \( p_T \) (< 4 - 5 GeV/c)
  - Indication of that we need better reference measurements to become more quantitative
1. $K_S^0$ and $\Lambda$ in the UE region - consistent with inclusive measurements
2. $\Lambda/K_S^0$ ratio in jets is unambiguously different from the UE (and inclusive)
3. UE subtraction most relevant at low-$p_T$
4. Slight decrease of the ratio with decreasing $R(V^0, \text{jet})$
5. The ratio is flat with $p_T, V^0 > 3 \text{ GeV}/c$, and consistent with inclusive $V^0$s at high $p_T$
Comparison with Pb-Pb, p-Pb collisions

Pb-Pb

Comparison with Pb-Pb, p-Pb collisions

pp/p-Pb

- pp consistent with p-Pb within uncertainties in jet $R = 0.4$

• $\Lambda/K_S^0$ ratio in jets significantly lower than ratio for inclusive $V^0$s observed in different collision systems

• $\Lambda/K_S^0$ ratio in jets are consistent with inclusive at high $p_T$ in pp, p-Pb and Pb-Pb collisions

• The ratio has no significant $p_T^{\text{jet, ch}}$ dependence

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Summary

- $V^0$s in jets have been studied in pp, p-Pb and Pb-Pb in ALICE
- $\Lambda/K^0_S$ ratio in jets are in agreement among different collision systems within systemmetrical uncertainties
- Difference is found unambiguously between $V^0$ in jets and in UE
- $\Lambda$ $p_T$ spectra in jets in Pb-Pb collisions show an enhancement at low $p_T$ ($< 4\text{-}5 \text{ GeV}/c$) w.r.t. PYTHIA simulations while being consistent with PYTHIA at higher $p_T$ ($> 5 \text{ GeV}/c$)
- Hint of medium modified jet fragmentation - effect differs between baryons and mesons

Outlook

- $\Lambda/K^0_S$ ratio in jets with multiplicity dependence in pp and p-Pb
- $\Lambda/K^0_S$ ratio in jets with centrality dependence in Pb-Pb
- $\Lambda/K^0_S$ ratio in jets with energy dependence with RUN II Pb-Pb at 5 TeV
Detail cuts

<table>
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<th>selection</th>
<th>value</th>
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<tbody>
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<td>Track Kink index</td>
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<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>TPC refit flag</td>
<td>kTRUE</td>
</tr>
<tr>
<td>number of crossed rows in TPC</td>
<td>&gt; 70</td>
</tr>
<tr>
<td>number of findable rows in TPC</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>crossed rows / findable rows ratio</td>
<td>&gt; 0.8</td>
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<tr>
<td>TPC dE/dx</td>
<td>&lt; 5 $\sigma$</td>
</tr>
</tbody>
</table>

Table 4.1: Default selections for $V^0$ daughter tracks.

<table>
<thead>
<tr>
<th>selection</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V^0$ 2D decay radius</td>
<td>in $[0.5,200]$ cm</td>
</tr>
<tr>
<td>negative track DCA to PV</td>
<td>&gt; 0.06 cm</td>
</tr>
<tr>
<td>positive track DCA to PV</td>
<td>&gt; 0.06 cm</td>
</tr>
<tr>
<td>DCA between $V^0$ Daughters</td>
<td>&lt; 1 $\sigma$</td>
</tr>
<tr>
<td>$\cos \theta_{\text{pointing}}$</td>
<td>&gt; 0.97 ($K^0_S$), &gt; 0.995 (A)</td>
</tr>
</tbody>
</table>

Table 4.2: Default cuts for $V^0$ decay topological selection
Normalisation

\[
\frac{d\rho}{dp_T^{\text{Inclusive}}} = \frac{1}{N_{\text{event}} \cdot \text{(acceptance)}} \cdot \frac{dN}{dp_T}
\]

\[
\frac{d\rho}{dp_T^{\text{JC}}} = \frac{1}{N_{\text{jet}} \pi r^2 \cdot \text{factor}_{\text{overlapped}}} \cdot \frac{dN}{dp_T}
\]

\[
\frac{d\rho}{dp_T^{\text{PCL}}} = \frac{1}{2 \cdot N_{\text{jet}} \pi r^2 \cdot \text{factor}_{\text{overlapped}}} \cdot \frac{dN}{dp_T}
\]

\[
\frac{d\rho}{dp_T^{\text{PCU}}} = \frac{1}{2 \cdot N_{\text{jet}} \pi r^2 \cdot \text{factor}_{\text{overlapped}}} \cdot \frac{dN}{dp_T}
\]

\[
\frac{d\rho}{dp_T^{\text{OC}}} = \frac{1}{N_{\text{event}} \cdot \text{(acceptance - (N_{\text{jet}}/N_{\text{event}}) \cdot \text{factor}_{\text{overlapped}} \cdot \pi r^2)}} \cdot \frac{dN}{dp_T}
\]

factor describe the overlap effect of multi-jets events
1. Tag hard scattering with charged particle jets (jet pt > 10 GeV/c)
2. Reconstruct $\Lambda$ and $K_s^0$ within “Jet Region”
3. Reconstruct $\Lambda$ and $K_s^0$ within “UE Region”
4. Correct $V^0$s in the Jet Region and UE Region.
5. Subtract the $\Lambda$ and $K_s^0$ in “UE Region from Jet Region”
6. Correct $V^0$s by Feeddown correction

Yield and ratio of $\Lambda$ and $K_s^0$ in jets
**V⁰ candidate selection**

- **V⁰ candidate selection**
  - Decay channels
    
    \[K^0_S \rightarrow \pi^+\pi^- \text{ (BR} = 0.692)\text{ and } \Lambda \rightarrow p\pi^- \text{ (BR} = 0.639)\]
  
  - Decay topology based on five variables
  - Acceptance: \(|\eta| < 0.75\)
  - Details: see in the backup

- **V⁰ signal extraction**
  - Fit invariant mass with gaussian plus a linear function in each \(p_T\) bin
    - extract the mean and sigma
  - Define the side bands and signal region
    - signal region: \(|M_{\text{inv}} - M_{\text{mean}}| < N\sigma\), default \(N=6\)
    - side bands: \(N\sigma < |M_{\text{inv}} - M_{\text{mean}}| < 2N\sigma\)
  - Background subtraction - bin counting
    - fit with linear function from side bands and interpolate into signal region
Jet reconstruction and $V^0$-jet matching

- Jet reconstruction
  - Charged particles $|\eta|<0.9$, $p_T>150\text{MeV}$
  - anti-$k_T$, $R=0.4$ and $0.2$, $|\eta_{\text{jet}}|<0.35$

- $V^0$-jet matching (JC)
  - $V^0$s and Jets are reconstructed independently
  - Match $V^0$s and jets with a matching radius

- Underlying $V^0$s (UE)
  - PC: $V^0$s in perpendicular cones
  - NJ: $V^0$s in event w/o jet in $p_T>5\text{GeV/c}$
  - OC: $V^0$s outside matching cone

- PC used as the default UE estimator, NJ and OC are used for estimating uncertainty on underlying event subtraction

Jet cone
jet axis
charged primary particles

\[ \sqrt{(\eta_{V^0} - \eta_{\text{jet}})^2 + (\varphi_{V^0} - \varphi_{\text{jet}})^2} < R \]
Correction

- **Efficiency of $V^0$s**
  - Efficiency depends on $\eta$
  - $\eta$ distribution of $V^0$s in jets is different from that of inclusive $V^0$s

![Graph showing efficiency and ratio](image)

- An $\eta$ weighted method used to correct the efficiency in jets and UE.
- The $\eta$ weighted efficiency for $V^0$s in jets are higher than inclusive $V^0$s in lower $p_T$, and consistent in high $p_T$
- The $\eta$ weighted efficiency or $V^0$s in UE is constant with Inclusive $V^0$s

- **Feeddown correction for $\Lambda$ from $\Xi$**
  - Secondary $V^0$s in jet cone have been corrected after underlying event subtraction
  - The difference between the feed down fraction from Inclusive $V^0$s in data and that of $V^0$s in jets is taken as uncertainty(3%)
Systematic uncertainty estimation

- Uncertainty consists of $V^0$ reconstruction, jet $p_T$ scale, Underlying subtraction and Feeddown subtraction.
- Systematic uncertainties for $V^0$ yield in jets is less than 18%, UE subtraction dominates at lower $p_T$, $V^0$ reconstruction dominates at higher $p_T$.
- The systematic uncertainty of L/K ratio is nearly 11%.