Production of strange particles in jets in p–p, p–Pb and Pb–Pb collisions measured with ALICE

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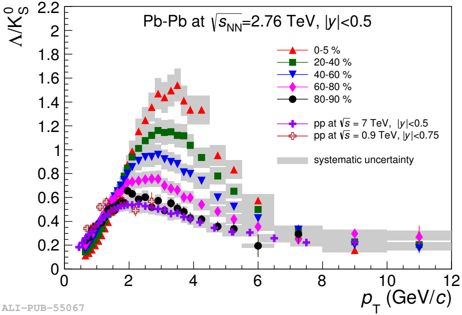
Heavy-ion physics workshop

Motivation for PID in jets

- Baryon-to-meson ratio is enhanced in Pb–Pb and p–Pb collisions.
- This phenomenon cannot be explained by fragmentation in vacuum.
- What is the effect of QGP on hadronization mechanism(s) in jets?
- What are the mechanisms (parton recombination)?

Pb–Pb



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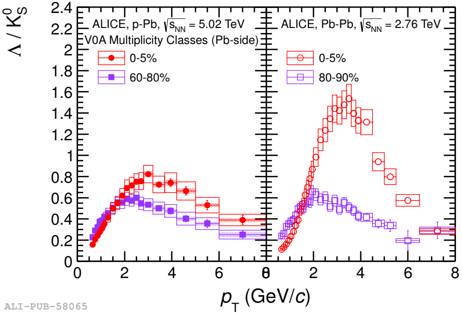
p–Pb Pb–Pb



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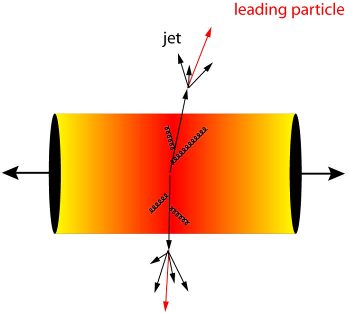
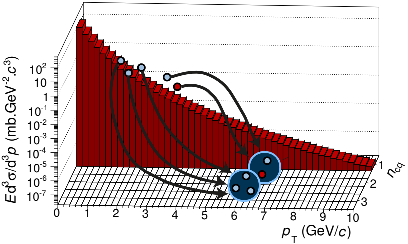
Motivation for PID in jets

We aim to understand the origin(s) of the Λ/K^0_S enhancement by separating hadrons produced in hard processes (jets) from hadrons produced in soft processes (underlying event).



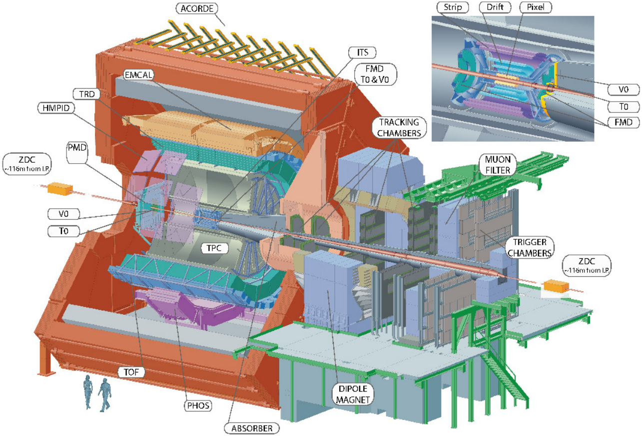
Is the baryon-to-meson ratio enhanced due to the collective effects in the plasma (parton recombination, radial flow,...) or is it (also) due to a modification of the jet fragmentation in the medium?

- jet fragmentation
  A high-p_T parton from hard scattering fragments into hadrons.
- parton recombination
  Multiple partons cluster together to form a hadron.



ALICE

- collisions studied: p–p at $\sqrt{s} = 7\,\text{TeV}$, p–Pb at $\sqrt{s_{\text{NN}}} = 5.02\,\text{TeV}$, Pb–Pb at $\sqrt{s_{\text{NN}}} = 2.76\,\text{TeV}$
- tracking of charged particles by ITS & TPC in magnetic field of 0.5 T
- centrality estimated from the multiplicity of charged particles in the detectors at forward pseudorapidities



Analysis of charged jets

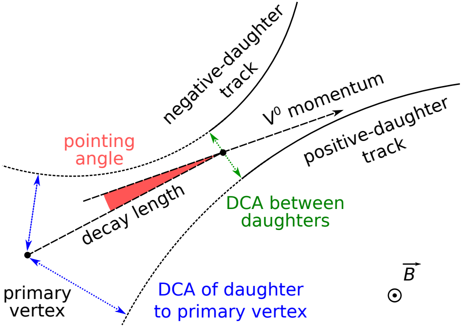
- track selection
  - charged primary particles
  - $p_{\mathrm{T}}^{\mathrm{track}} > 150\,\mathrm{MeV}/c$
  - uniform in $\phi \times \eta$, $|\eta_{\mathrm{track}}| < 0.9$
- raw-jet reconstruction
  - anti-k_{t} algorithm
  - resolution parameter $R = 0.2, (0.3, 0.4)$
- subtraction of average soft background
  - average background density ρ estimated from the median k_{t} cluster
  - $p_{\mathrm{T}}^{\mathrm{jet,ch,corr}} = p_{\mathrm{T}}^{\mathrm{jet,ch,raw}} - \rho A_{\mathrm{jet,ch}}$, (where $A_{\mathrm{jet,ch}}$ is jet area)
- signal-jet selection (good candidates for hard scattering)
  - ${p_{\mathrm{T}}}^{\mathrm{leading\ track}} > 5\,\mathrm{GeV}/c$ (only Pb–Pb)
  - $A_{\mathrm{jet,ch}} > 0.6\pi R^2$
- further $p_{\mathrm{T}}^{\mathrm{jet,ch}}$ corrections
  - background anisotropy (intra-event p_{T} fluctuations)
  - detector response

Analysis of neutral strange particles

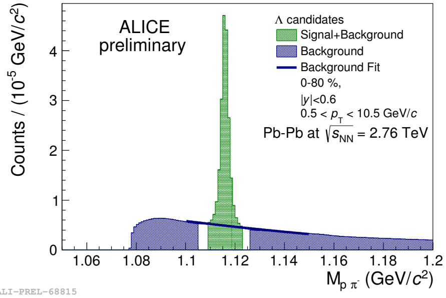
Strange neutral particles decaying into two charged daughter particles

- meson $K^0_S \to \pi^+ + \pi^-$ (BR 69 %)
- baryon $\Lambda \to p + \pi^-$ (BR 64 %)

Mother V^0 particle reconstructed using topology of its V-shaped decay.



Combinatorial background suppressed by cuts on decay parameters.
Signal yield extracted from the invariant-mass distribution.



Strange particles in jets

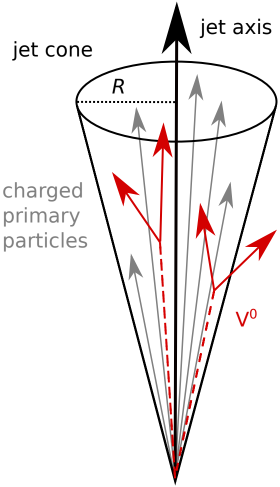
Analysis steps

- V^0 candidate selection
- candidate–jet matching (V^0s in jet cones)

$$\sqrt{(\phi_{V^0} - \phi_{\text{jet,ch}})^2 + (\eta_{V^0} - \eta_{\text{jet,ch}})^2} < R,$$

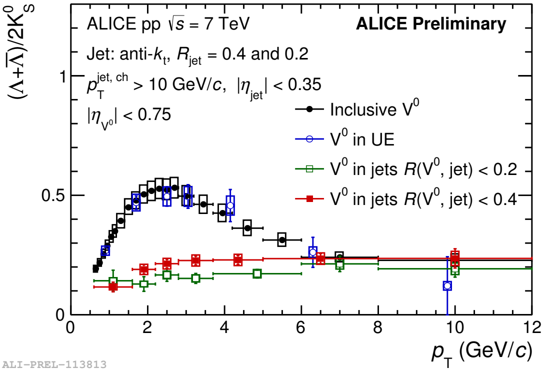
$$|\eta_{\text{jet,ch}}|^{\text{max}} < |\eta_{V^0}|^{\text{max}} - R$$

- candidate–UE matching (V^0s in events without selected jets with $p_{\text{T}}^{\text{jet,ch}} > 5\,\text{GeV}/c$)
- signal extraction (invariant-mass distribution)
- efficiency correction (in jet cones, in UE)
- subtraction of V^0s in UE
- subtraction of V^0s coming from decays of jet constituents ($\Xi \to \Lambda$), i.e. "feed-down" correction



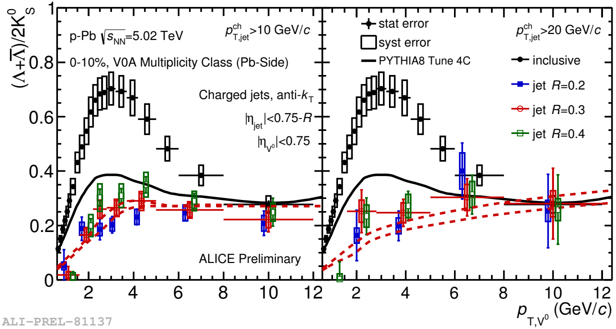
Λ/K^0_S ratio in charged jets in p–p at $\sqrt{s} = 7$ TeV

(127×10^6 minimum-bias collisions)



- The ratio in UE is consistent with the inclusive ratio.
- The ratio in jets is clearly different from the inclusive ratio at low and intermediate $p_T^{V^0}$.
- A slight increase of the ratio in jets with increasing R.

Λ/K^0_S ratio in charged jets in p–Pb at $\sqrt{s_{NN}} = 5.02$ TeV
(high-multiplicity collisions, 0–10 %)

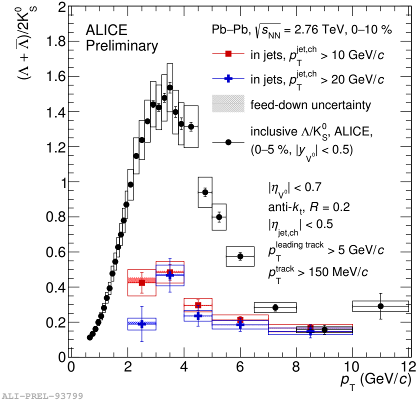


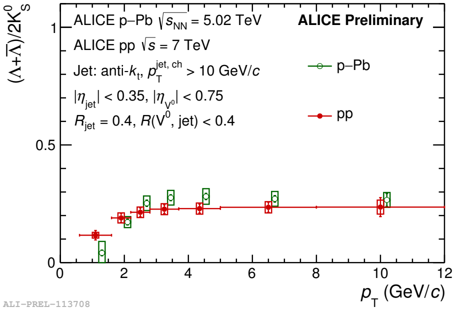
The ratio in jets

- is clearly different from the inclusive ratio at low and intermediate $p_T^{V^0}$,
- is different from the inclusive ratio in PYTHIA (black line),
- is similar to the ratios in PYTHIA jets (red dashed lines),
- shows no significant dependence on $p_T^{jet,ch}$ and a slight dependence on R.

Λ/K^0_S ratio in charged jets in Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV

(7.4×10^6 central collisions, 0–10 %)





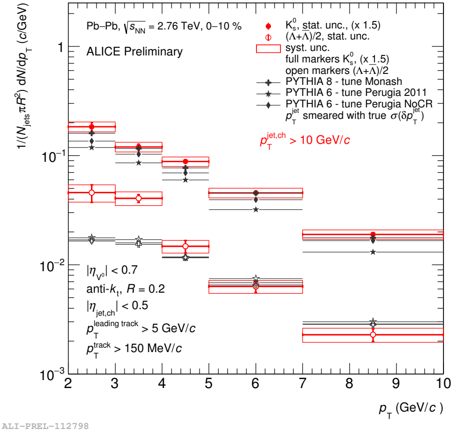
The ratio in jets

- is clearly different from the inclusive ratio at low and intermediate $p_T^{V^0}$,
- shows no significant dependence on $p_T^{\text{jet,ch}}$,
- is consistent with the ratio in jets in p–Pb and p–p at $p_T^{V^0} > 4\,\text{GeV}/c$.

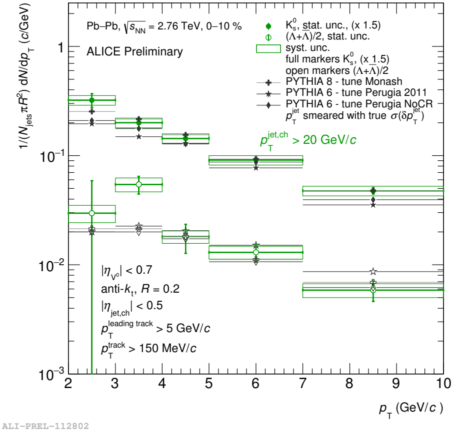
K^0_S, Λ spectra in charged jets in Pb–Pb

comparison to PYTHIA smeared with $p_T^{\text{jet,ch}}$ fluctuations

$p_T^{\text{jet,ch}} > 10\ \text{GeV}/c$



$p_T^{\text{jet,ch}} > 20\ \text{GeV}/c$



- Same slopes of spectra from measurement and from PYTHIA.
- Enhancement for Λ at $p_T^{V^0} < 4\ \text{GeV}/c$.

Summary and outlook

ALICE has performed the first measurement of the Λ/K^0_S ratio in charged jets in p–p, p–Pb and Pb–Pb collisions at the LHC.

Message

- In every collision system, the Λ/K^0_S ratio in jets is significantly smaller than the inclusive ratio (and the UE).
- The Λ/K^0_S ratios in jets are consistent within uncertainties in all collision systems for $p_T^{V^0} > 4\,\mathrm{GeV}/c$.
- The dominant source of the enhancement are soft processes associated with collective behaviour.
- A potential modification of jet fragmentation seems to be restricted to the region $p_T^{V^0} < 4\,\mathrm{GeV}/c$ and manifest by an enhancement of the Λ yields.

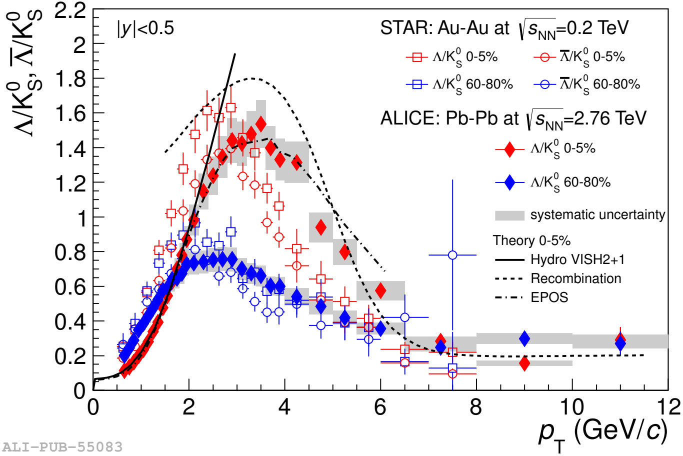
Outlook

- Multiplicity dependence in p–p and p–Pb collisions.
- Better resolution in Pb–Pb collisions in Run 2.

Thank you for your attention.

Backup

Comparison of data with models



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V^0 candidate selection

Cut variable	Value
Daughter tracks	
TPC refit	`true`
type of production vertex	not `kKink`
DCA to the primary vertex	≥ 0.1 cm
DCA between daughters	$\leq 1\sigma_{\mathrm{TPC}}$
$\lvert\eta\rvert$	≤ 0.8
V^0 candidate	
reconstruction method	offline
cosine of the pointing angle (CPA)	≥ 0.998
radius of the decay vertex	5–100 cm
$\lvert\eta\rvert$	≤ 0.7
transverse proper lifetime	$\leq 5\tau$
Armenteros–Podolanski cut (K^0_S)	$p_{\mathrm{T}}{}^{\mathrm{Arm.}} \geq 0.2\lvert\alpha^{\mathrm{Arm.}}\rvert$

Jet algorithms

A sequential recombination jet finder is defined according to this general scheme:

1. $\forall\, i, j$: calculate distances d_{ij} and d_{iB} (NB $k_t \equiv p_T$):

$$d_{ij} = \min\left(k_{t,i}^{2p}, k_{t,j}^{2p}\right) \frac{\Delta_{ij}^2}{R^2}, \quad \Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2\,, \quad d_{iB} = k_{t,i}^{2p}$$

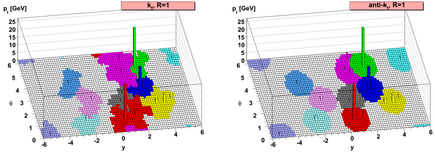
2. Find $d_{\min}$:

$$d_{\min} = \min\left(d_{ij}, d_{iB}\right).$$

- If $\exists\, i, j : d_{\min} = d_{ij}$, merge particles i and j into a single particle and combine their momenta.
- If $\exists\, i : d_{\min} = d_{iB}$, declare particle i to be a final jet and remove it from the list.

These steps are repeated until no particles are left.

$$p = \begin{cases} 1 & k_t \text{ (background estimation)} \\ 0 & \text{Cambridge/Aachen} \\ -1 & \text{anti-}k_t \text{ (signal jets)} \end{cases}$$



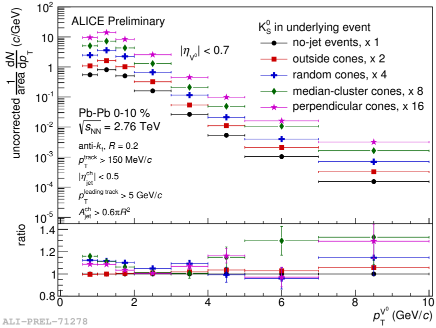
Matteo Cacciari et al. JHEP **0804** (2008) 063

Estimation of V^0s in the underlying event in Pb–Pb

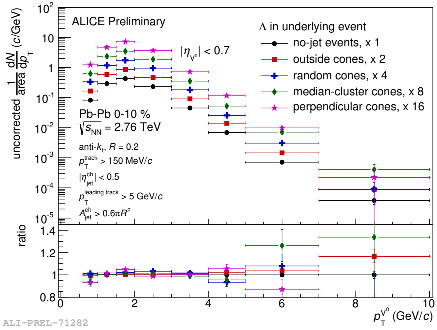
- no-jet events: V^0s in events with no selected jets
- outside cones: V^0s outside jet cones
- random cones: V^0s in a randomly oriented cone
- median-cluster cones: V^0s in the cone of the median k_t-cluster
- perpendicular cones: V^0s in cones perpendicular to the jet in azimuth

Methods differ in regions, events, statistics, efficiency.

K^0_S



Λ

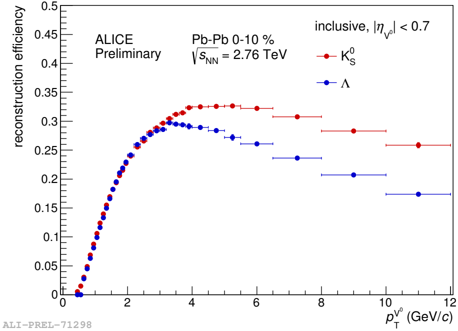


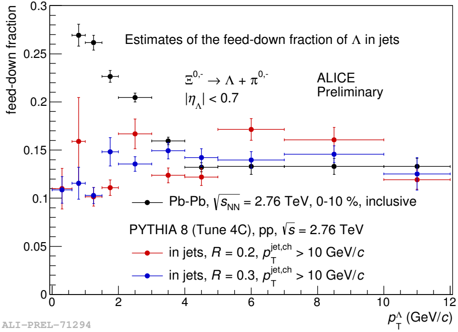
Reconstruction efficiency, feed-down in Pb–Pb

Reconstruction efficiency depends strongly on $p_{\mathrm{T}}^{\mathrm{V}^0}$ and η_{V^0}.
Shape of the measured η_{V^0} distribution depends on the selection criteria.
Efficiency of inclusive V^0s is reweighted to get efficiency in jet cones and UE.

Feed-down fraction of Λ in jets estimated from:

- inclusive Λ (Pb–Pb-like),
- jets generated by PYTHIA 8 (p–p-like).





Reweighting of the reconstruction efficiency

- ϵ — reconstruction efficiency of inclusive particles
- ϵ_s — reconstruction efficiency of particles of interest (scaled ϵ)
- a_s — yield of associated particles of interest
- g_s — yield of generated particles of interest
- m — uncorrected yield of measured particles (candidates) of interest
- t — yield of true (corrected) particles of interest
- P — signal purity

Signal extraction in JC, UE (assume that $P_{\mathrm{inclusive}}(p_{\mathrm{T}}^{\mathrm{V}^0}, \eta_{\mathrm{V}^0})$ is the same as for V^0s of interest):

$$m(p_{\mathrm{T}}^{\mathrm{V}^0}, \eta_{\mathrm{V}^0}) = m_{\mathrm{raw}}(p_{\mathrm{T}}^{\mathrm{V}^0}, \eta_{\mathrm{V}^0})|_{\text{peak region}} \cdot P_{\mathrm{inclusive}}(p_{\mathrm{T}}^{\mathrm{V}^0}, \eta_{\mathrm{V}^0})|_{\text{peak region}}$$

Efficiency calculation:

$$a_s \equiv m, \quad \sigma_{a_s} \equiv 0, \qquad g_s = a_s/\epsilon$$

$$\frac{1}{\epsilon_s(p_{\mathrm{T}}^{\mathrm{V}^0})} = \frac{\sum_{\eta_{\mathrm{V}^0 i}} g_s(\eta_{\mathrm{V}^0 i}, p_{\mathrm{T}}^{\mathrm{V}^0})}{\sum_{\eta_{\mathrm{V}^0 j}} a_s(\eta_{\mathrm{V}^0 j}, p_{\mathrm{T}}^{\mathrm{V}^0})} = \sum_{\eta_{\mathrm{V}^0 i}} \frac{a_s(\eta_{\mathrm{V}^0 i}, p_{\mathrm{T}}^{\mathrm{V}^0})}{\sum_{\eta_{\mathrm{V}^0 j}} a_s(\eta_{\mathrm{V}^0 j}, p_{\mathrm{T}}^{\mathrm{V}^0})} \frac{1}{\epsilon(\eta_{\mathrm{V}^0 i}, p_{\mathrm{T}}^{\mathrm{V}^0})}$$

Spectra correction:

$$t = m/\epsilon_s$$

Sources of systematic uncertainties

- cuts for the selection of V^0 candidates (cuts varied)
- signal extraction (parameters varied)
- estimation of spectra of V^0s in the underlying event (multiple methods)
- estimation of material budget (from another analysis)
- estimation of feed-down fraction of Λ and $\overline{\Lambda}$ in jets (PYTHIA as alternative)
- correction of p_T^{jet} (embedding of simulated jets in real data)
- detector performance ($p_T^{V^0}$ resolution)

Systematic uncertainties in p–Pb

source	uncertainty
selection cuts	2–5 % for K^0_S, 3–6 % for Λ
signal extraction	6 % (10 %) for $p_T^{jet,ch} > 10\,GeV/c$ ($20\,GeV/c$)
V^0s in UE	10 % (2 %) at low (high) $p_T^{V^0}$
$p_T^{jet,ch}$ scale	1 % (10 %) at low (high) $p_T^{V^0}$
feed-down	5 %