Study of short-lived resonances in the ALICE experiment in a “first physics” scenario

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Quinto Convegno Nazionale sulla Fisica di ALICE
Trieste, 12 September 2009

- Introduction
- Analysis details
- Results
Hadronic resonances

- Excited quark bound states
  - larger mass than that of “stable” particles
  - small lifetime (few fm/c)
    - comparable with fireball lifetime
    - resonance daughters indistinguishable from primary tracks
  - strong decay

<table>
<thead>
<tr>
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<th>(K^0_s)</th>
<th>(K^*(892)^0)</th>
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</thead>
<tbody>
<tr>
<td>Mass</td>
<td>(~497,\text{MeV})</td>
<td>(~896,\text{MeV})</td>
</tr>
<tr>
<td>Lifetime</td>
<td>(~10^{-10},\text{s})</td>
<td>(~10^{-23},\text{s})</td>
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Topics addressed with resonances

- Chiral symmetry restoration
  - mass/width shift

- Strangeness enhancement

- Hadron formation mechanisms
  - yield ratios ($\phi/K$, $\phi/h$)
  - elliptic flow ($v_2$)
  - transverse flow ($\langle p_T \rangle$)

- Probe the fireball collective properties
Resonance interaction with fireball

Daughter momentum changed: impossible to reconstruct inv. mass

Quasi-elastic interaction: resonance re-generated in fireball

No interaction

Rescattering

Recombination

Resonances

Chemical freeze-out time

Thermal freeze-out time

Δτ
Using $K^*$ and $\Lambda(1520)$ to estimate temperature and lifetime of the fireball

0-20% most central Au+Au


Using $K^*$ and $\Lambda(1520)$ to estimate temperature and lifetime of the fireball

K*/K and $\Lambda(1520)/\Lambda$ ratios depend on temperature and time delay between chemical and thermal freeze out.

Model: yield of thermally produced particles + rescattering. NO regeneration.

$T = 175 \text{ MeV} \rightarrow \Delta \tau = 4-6 \text{ fm/c}$

$\Delta \tau = 0 \text{ fm/c} \rightarrow T = 110-130 \text{ MeV}$

$\Delta \tau > 4 \text{ fm/c}$ and $T = 160 \text{ MeV}$

The study of short lived resonances produced in heavy ion collisions with the help of models may permit to distinguish between sudden and staged hadronization scenario.

ALICE PPR Vol. II

Deviations from thermal model could be due to rescattering and regeneration after chemical freeze-out.

Elliptic flow of resonances

Measurement of flow for meson and baryon resonances is of great interest to further validate the picture sorting of this scaling i.e. that partonic collectivity dominates the transverse expansion dynamics.

\[
\text{Mass } \phi\text{ meson } \sim \text{Mass proton}
\]

Au-Au @200 GeV

\(v_2\) of \(\phi\) mesons confirms this universal scaling

S. Afanasiev et al. (PHENIX Coll.) nucl-ex 0703024
Strangeness enhancement and the $\phi$ resonance

KK coalescence?

$\phi$ resonances decouple early and probe the partonic phase

$\sqrt{s_{NN}} = 200$ GeV

$\phi$ enhancement vs. $K/\Lambda/\Xi$ enhancement

$\sqrt{s_{NN}} = 62.4$ GeV

$\phi$ enhancement vs. $K/\Lambda/\Xi$ enhancement

STAR, Phys. Lett. B673, 183

STAR, nucl-ex 0901.0313.v1
**pp collisions @ LHC**

J. Schukraft, ALICE Physics week 2008 (Prague)

- **Multiplicity distribution at LHC**
  - quite respectable particle densities
  - $dN_{ch}/d\eta \sim 50 - 100$ can be reached!
  - > central S+S @ SPS, mid-central Cu-Cu @ RHIC
  - naively, energy density $\varepsilon > 5 - 10$ GeV/fm$^3$
  - $\tau_0 = 1$ fm, $V = 5$ fm$^3$
  - $\tau_0 < 1$ fm at RHIC/LHC densities
    - => proton is (relativ) BIG

- even protons get obese these days
  - $p@LHC \sim$ small (but very dense) nucleus@SPS

<table>
<thead>
<tr>
<th></th>
<th>SPS</th>
<th>RHIC</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td># of partons in proton $3 + \int g(x &gt; 2\text{GeV})$</td>
<td>4</td>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

- ‘QGP’ physics with protons
  - at least: onset of hadronic FS interactions
  - maybe: collective hadronic/partonic dynamics
  - why not: the QGP, mini serving

60,000 MB events $dN_{ch}/d\eta \sim 50$!
 Searches for QGP in pp collisions: E735


E735 collaboration:
FERMILAB-Conf-91/336
Similar behaviour in pp (RHIC) and γp (H1) at roughly the same energy $\sqrt{s} \sim 200$ GeV
Interesting observables

- $P_t$ distributions
  - temperature parameter
  - total yield $\rightarrow$ particle ratios $\rightarrow$ thermal model
  - $\langle p_T \rangle$ $\rightarrow$ radial flow $\rightarrow$ decoupling from fireball
    - $\phi$ resonance decouple earlier from fireball $\rightarrow$ probe of partonic phase
    - $K^*$, $\Lambda^*$ interact with fireball $\rightarrow$ rescattering/recombination

- Multiplicity dependence:
  - $N_{\text{res}} / N_{\text{ch}}$ $\rightarrow$ hadron production mechanisms
  - $N_{\phi} / N_{K^-}$ $\rightarrow$ KK coalescence
Strategy for reconstruction of $\phi \rightarrow KK$

- Full analysis on a sample of PYTHIA $pp$ minimum bias events at 10 TeV (recentmost PDC production), which is split into two halves:
  - one half is used for running resonance analysis with RSN Aliroot package
    - invariant mass distributions
    - background with like-sign technique
  - other half is used to compute efficiencies using the official ALICE Offline Correction Framework

- Estimate reconstructed yields

- Correct reconstructed yields for acceptance and efficiency and compare with generated yields

- All analysis is done in several bins of transverse momentum
Event and track selection

- **Primary vertex quality**
  - require a “good” vertex status
  - require a sufficient number of contributors to its computation

- **Track quality**
  - require at least \(50\) clusters in the TPC
  - Cut values on track covariance matrix
  - Maximum \(\chi^2 / \# \text{TPC clusters}: 3.5\)

- **Primary tracks selection**
  - reject kink daughters
  - require at least \(4\sigma\) to primary vertex
NO PID issue: resonances overlapped

require a track selection strategy with a minimum PID, if available
Global PID strategy in ALICE

- Each PID detector associates to each track the probability ("PID weight") to be identified as $e$, $\mu$, $\pi$, $K$, $p$.
- A global PID weight is computed multiplying the ones of each detector.
- A set of a priori probabilities is defined by the analyzer.

\[
p_k = \frac{C_k w_k^G}{\sum_i C_i w_i^G}
\]

\[
w_k^G = w_k^{ITS} \cdot w_k^{TPC} \cdot w_k^{TRD} \cdot w_k^{TOF} \cdot w_k^{HMPID}
\]

...but with the first data not all of them will be perfectly tuned.
TPC PID compatibility cut

- TPC available with first data
- Compare track TPC signal with the expected $dE/dx$ of a kaon
  - If not compatible, the track is rejected

$$\left| \frac{S_{TPC} - BB}{BB} \right| \leq \text{cut}$$
Visual cut effectiveness
Kaon selection strategies adopted

- Absolutely NO PID
  - compute inv. mass spectra with all track pairs which pass preliminary quality track selections

- TPC compatibility within $3\sigma$ around Bethe-Bloch value

- TPC compatibility within $1.5\sigma$ around Bethe-Bloch value

- Realistic PID using Bayesian combination of PID weights from all detectors and prior probabilities
$S/B$ Ratio vs. $p_T$

- **NO PID**
- **Cut TPC $dE/dx$ 3$\sigma$**
- **Cut TPC $dE/dx$ 1.5$\sigma$**
- **Realistic PID**
Significance: $S / (S + B)^{1/2}$ vs. $p_T$

- **NO PID**
  - Cut TPC $dE/dx$ $1.5\sigma$
  - Cut TPC $dE/dx$ $3\sigma$
  - Realistic PID
Efficiency computation

To evaluate the effect of several selections due to different cuts we implemented a CORRFW analysis task with several steps:

0: all $\phi$'s in PYTHIA decaying into charged $K$

1: all $\phi$'s in PYTHIA whose daughters fall into the geometrical acceptance $|\eta| \leq 1$

2: all $\phi$'s whose daughter were reconstructed and whose tracks pass the primary track selection cuts
   $\Rightarrow$ NO PID analysis

3a: all $\phi$'s whose daughter tracks pass the $3\sigma$ compatibility cut in TPC

3b: all $\phi$'s whose daughter tracks pass the $1.5\sigma$ TPC compatibility cut

3c: all $\phi$'s whose daughter tracks are identified as $K$ after realistic PID (with all detectors)
Efficiency: daughters acceptance correction

STEP 1
STEP 0

$|\eta| \leq 1 \text{ (daughters)}$
Combined efficiency + acceptance vs. $p_T$

$-1 \leq \eta \leq 1$
Combined efficiency + acceptance vs. $\eta$

- Reconstructed primary
- Compatibility TPC dE/dx in 1.5$\sigma$
- Compatibility TPC dE/dx in 3.0$\sigma$
- Realistic PID full
Signal extraction

- Estimate background through like-sign pairs
  \[ B(m) = 2 \cdot R \cdot [ N_{++}(m) \cdot N_{--}(m) ]^{-\frac{1}{2}} \]

- Subtract background from \( K^+K^- m_{\text{inv}} \) distribution

- Fit with a Breit-Wigner
  \[ \text{in some cases, a residual background is present, which is fitted with a straight line} \]

- Estimate the reconstructed yield from the integral of the fitted Breit-Wigner function.
Peak extraction: TPC compatibility in

- $p_T = 0 \div 1$ GeV
- $p_T = 1 \div 2$ GeV
- $p_T = 2 \div 3$ GeV
- $p_T = 3 \div 4$ GeV
- $p_T = 4 \div 5$ GeV
- $p_T = 5 \div 10$ GeV
Corrected yields $\rightarrow 1/p_T dN/dp_T$

- **NO PID**
  - Cut TPC $dE/dx$ $3\sigma$
  - Cut TPC $dE/dx$ $1.5\sigma$

- **Realistic PID**

- Graphs showing corrected yields with different PID cuts.
Corrected yields vs. mult

Cut TPC dE/dx 3σ

Realistic PID

Cut TPC dE/dx 1.5σ
Minimum number of MB events required
→ HM events sample estimation

- Adopted minimum significance threshold = 10
- Significance scales as \( \sqrt{\text{num. of events}} \)
  - 800K events allow to have signif. > 10 in the 4-5 GeV \( p_T \) bin

- Assumption: high multiplicity events have \( \langle N_{ch} \rangle \sim n \langle N_{ch} \rangle_{MB} \)
  - \( S \) scales like \( n \)
  - \( B \) scales like \( n^2 \)

- Assuming \( n = 7 \), the number of HM events required to have a significance 10 in the 4-5 GeV \( p_T \) bin depends on the PID method:
  - with TPC compatibility cut: 640K events
  - with realistic PID: 160K events

- Integrated significance in this scenario:
  - TPC compatibility cut (640K evts): ~16
  - realistic PID (160K evts): ~18
Conclusions

- First physics with $\phi$ resonance:
  - first target $\rightarrow$ yield estimation w.r. to multiplicity
    - almost impossible without PID, except for high $p_T$
    - feasible even in the worst scenario using TPC information
  - with few millions of MB events, $p_T$ spectra can be estimated
    - systematic error evaluation in progress
    - preliminary evaluation of required number of HM events for a feasible study done (some aspects still under investigation)

- perspectives:
  - other resonances ($K^*$)
  - extend the "compatibility PID cut" criteria to other detectors (TOF, ITS, …)
Strangeness enhancement and the $\phi$ resonance

Canonical suppression:

$pp$ cannot be treated as GC ensemble

Suppression of strangeness in $pp$ which disappears in HI collisions.

Enhancement should scale as the number of constituent $s$ quarks

- $\phi$ has $S=0$ → no canonical suppression

STAR, Phys. Lett. B673, 183

STAR, nucl-ex 0901.0313.v1
Efficiency vs. $p_T$ in $-1 \leq \eta \leq 1$
Efficiency vs. $\eta$

- Reconstructed primary
- Compatibility TPC dE/dx in 1.5$\sigma$
- Compatibility TPC dE/dx in 3.0$\sigma$
- Realistic PID full
Cut evaluation

**Cut efficiency on kaons:**
how many kaons pass the cut?

**Cut selectiveness:**
how many tracks do pass the cut?

**Cut contamination:**
how many kaons are there among the tracks passing the cut?

**STRICT CUT**
Accept tracks with relative difference within 1.5σ

- # clusters ≥ 0
- # clusters ≥ 50
- # clusters ≥ 100
- # clusters ≥ 120
**Cut evaluation**

**PERMISSIVE CUT**
Accept tracks with relative difference within $3\sigma$

Cut efficiency on kaons: how many kaons pass the cut?

Cut selectiveness: how many tracks do pass the cut?

Cut contamination: how many kaons are there among the tracks passing the cut?
Primary vertex quality

- Not all events have a suitable primary vertex:
  - vertex “status” (Boolean)
  - number of “contributors” to vertex (Int)

- Two possibilities:
  - vertex computed with tracks ("ESD")
  - alternative: vertex computed with SPD

flowchart LR
   Get ESD vertex
   status = kTRUE? and nContrib > N_{\text{min}}?
     yes
       Accept Event
     no
       Get SPD vertex
       status = kTRUE? and nContrib > N_{\text{min}}?
         yes
           Accept Event
         no
           Reject Event

- Pie chart:
  - Good ESD vertex (SPD not checked): 67.2%
  - Bad ESD vertex and good SPD vertex: 17.4%
  - Bad ESD vertex and bad SPD vertex: 15.4%
From inclusive $\phi$ spectrum to yield

$$Yield = \frac{1}{\Delta \eta \Delta p_T} \cdot \frac{1}{Br} \cdot C_{\text{geom}} \cdot C_{\text{rec}} \cdot \frac{N}{N_{\text{trigger}}}$$

Definition of $N_{\text{trigger}}$ has to take into account also vertex identification and real trigger efficiency, for the moment this is just the number of analyzed event

$N$: number of detected $\phi$ in selected $p_T$-bin (raw spectrum)
$Br$: branching ratio
$C_{\text{geom}}$: geometrical acceptance
$C_{\text{rec}}$: reconstruction efficiency
**Invariant mass resolution**

- **K*(892)**
  - $0.6<p_t<0.8$ GeV/c
  - $1.0<p_t<1.1$ GeV/c
- **φ(1020)**
  - $1.6<p_t<1.8$ GeV/c
  - $2.0<p_t<2.1$ GeV/c

Mass resolution $\sim 3$ MeV/c$^2$

![Effective mass resolution for φ to K+K-](image)

Mass resolution $\sim 1.3$ MeV/c$^2$
Searches for QGP in pp collisions: E735

Energy density:
\[
\frac{3}{2} \frac{dN_c}{d\eta} \left( \frac{(p_T)^2 + m^2_\pi}{\tau\pi r^2} \right)^{1/2}
\]


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