Strangeness production in double gap events in ALICE

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The ALICE upgrade 2019-2022

Data rate with the upgraded ALICE

Kaon pairs in double gap events

Complex Regge trajectory

The isoscalar trajectory in the strange sector

Conclusions
The ALICE upgrade in long shutdown LS2 2019-2022

midrapidity tracks in central barrel:
ITS, TPC, TRD, TOF: $-0.9 < \eta < 0.9$

Upgrade of:
- Time Projection Chamber (TPC)
- Inner Tracking System (ITS)
- Fast Interaction Trigger (FIT)
- Computing system On-Offline ($O^2$)
The TPC

- Total length 5m, radial dimension $83.5 \text{ cm} < r < 254.5 \text{ cm}$
- Gas mixture Ne-CO$_2$-N$_2$ (90-10-5)
- Central electrode and field cage, uniform E-field 400 V/cm along beam-axis
- Charged particles traversing TPC volume ionise the gas atoms
- Ionisation electrons drift to endplates, segmented readout, $\sim 550000$ pads
- 3-d measurement of ionisation clusters, x and y-coordinate from pad position, z-coordinate from drift time
The TPC upgrade

- Positive-ion backflow a major issue in TPC running conditions
- Positive-ion backflow controlled by gating grid in Run 1 and 2, rate limit $\sim 3$ kHz
- Electron multiplication in Run 3 by staging of 4 Gas Electron Multipliers (GEM)
- Ion backflow $\leq 0.7\%$ with configuration of 4 staged GEMs
- Pb-Pb data taking rate increased from 1 kHz in Run 1,2 to 50 kHz in Run 3
- 3-d cluster position information is input for global track reconstruction
- Ionisation signal $dE/dx$ is input for PID
The ITS upgrade

- The upgrade of the ITS detector: *improved resolution, less material, faster readout*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ITS Run 1,2</th>
<th>ITS Run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to IP (mm)</td>
<td>39 ITS</td>
<td>22 ITS</td>
</tr>
<tr>
<td>$X_0$ (innermost layer) (%)</td>
<td>$\sim 1.14$ Run 1,2</td>
<td>$\sim 0.35$ Run 3</td>
</tr>
<tr>
<td>Pixel pitch ($\mu m^2$)</td>
<td>50 x 425</td>
<td>27 x 29</td>
</tr>
<tr>
<td>Readout rate (kHz)</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Spatial resolution ($r_{\varphi} \times z$ ($\mu m^2$))</td>
<td>11 x 100</td>
<td>5 x 5</td>
</tr>
</tbody>
</table>
The FIT upgrade

- The Fast Interaction Trigger (FIT) detector serves as interaction trigger, online luminometer, and forward multiplicity counter
- Provides precise collision time for time-of-flight based particle identification

FDD-A
$4.8 < \eta < 6.3$
$z = 17 \text{ m}$
$\Delta t \approx 425 \text{ ps}$

FT0-A
$3.5 < \eta < 4.9$
$z = 3.3 \text{ m}$
$\Delta t \approx 25 \text{ ps}$

FT0-C
$-3.3 < \eta < -2.1$
$z = 0.82 - 0.84 \text{ m}$
$\Delta t \approx 25 \text{ ps}$

FT0-A
$3.5 < \eta < 4.9$
$z = 3.3 \text{ m}$
$\Delta t \approx 25 \text{ ps}$

FV0-A
$2.2 < \eta < 5.1$
$z = 3.16 \text{ m}$
$\Delta t \approx 200 \text{ ps}$

FDD-C
$-7.0 < \eta < -4.9$
$z = 19.5 \text{ m}$
$\Delta t \approx 425 \text{ ps}$
The computing system upgrade

New common Online-Offline ($O^2$) computing system

ALICE $O^2$ in a nutshell

Requirements
1. LHC min bias Pb-Pb at 50 kHz
   ~100 x more data than during Run 1
2. Physics topics addressed by ALICE upgrade
   - Rare processes
   - Very small signal over background ratio
   - Needs large statistics of reconstructed events
   - Triggering techniques very inefficient if not impossible
3. 50 kHz > TPC inherent rate (drift time ~100 µs)
   Support for continuous read-out (TPC)
   - Detector read-out triggered or continuous

New computing system
- Read-out the data of all interactions
- Compress these data intelligently by online reconstruction
- One common online-offline computing system: $O^2$
- Paradigm shift compared to approach for Run 1 and 2

Unmodified raw data of all interactions shipped from detector
to online farm in triggerless continuous mode

Hi run 3.3 TByte/s
Baseline correction and zero suppression
Data volume reduction by zero cluster finder.
No event discarded.
Average compression factor 6.6

500 GByte/s
Data volume reduction by online tracking.
Only reconstructed data to data storage.
Average compression factor 5.5

90 GByte/s
Data Storage: 1 year of compressed data
- Bandwidth: Write 90 GB/s Read 90 GB/s
- Capacity: 60 PB

20 GByte/s
Tier 0, Tiers 1 and Analysis Facilities
Asynchronous (few hours) event reconstruction with final calibration
Data statistics in Run 2 and Run 3

Double gap data sample of $10 \text{ pb}^{-1}$ in Run 2

Central barrel data sample of $\sim 10 \text{ pb}^{-1}$ per 6 weeks of data taking in 2022 (plus data taken in 2023)
Central diffractive production at the LHC

- Pomerons $P$ and Reggeons $R$ contribute to these topologies
- Rapidity gaps can also be due to photon and $W^\pm, Z$-exchange
- Pomerons and photons contribute differently in $pp$, $pA$ and $AA$

Experimental identification of these topologies by

1. Tag the forward protons or fragments by Roman pots (no Roman Pots in ALICE)
2. Define rapidity range on both sides of midrapidity void of activity (rapidity gap)
   - no signal in FIT detector $\rightarrow$ double gap event
Kaon pairs in double gap events

- particle ident. by dE/dx from TPC, identify kaon pairs $K^+K^-$, $K^+K^+$, $K^-K^-$

$K^+K^-$-pairs

- resonance structures seen in the kaon sector: $\phi(1020)$, $f_2'(1525)$, $f_2(1270)$?
A model of $q\bar{q}$ bound states

- "Mesons in a relativized quark model with chromodynamics"

- Calculate $q\bar{q}$ bound states in a relativistic potential $V(p, r)$
  \[ V(p, r) = H^{\text{conf}} + H^{\text{so}} + H^{\text{hyp}} + H_A \]


  - **isoscalar meson sector:**
    - states with predominant light quark (u,d) composition
    - states with predominant strange quark (s) composition

  isoscalars with (hidden) strangeness spectroscopic notation $n^{2S+1}L_J$:
  - $n$ radial quantum number
  - $S$ spin
  - $L$ orbital angular momentum
  - $J$ total angular momentum

<table>
<thead>
<tr>
<th>$n^{2S+1}L_J$</th>
<th>mass (PDG)</th>
<th>$J^{PC}$</th>
<th>mass (PDG)</th>
<th>width (PDG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^3S_1$</td>
<td>1020</td>
<td>$\phi$</td>
<td>1$^{--}$</td>
<td>1019</td>
</tr>
<tr>
<td>$1^3P_2$</td>
<td>1530</td>
<td>$f'_2$</td>
<td>2$^{++}$</td>
<td>1518</td>
</tr>
<tr>
<td>$1^3D_3$</td>
<td>1900</td>
<td>$\phi_3$</td>
<td>3$^{--}$</td>
<td>1854</td>
</tr>
<tr>
<td>$1^3F_4$</td>
<td>2200</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>

mass and width in (MeV)
Nonlinear, complex meson trajectories

- Complex Regge trajectory based on Dual Amplitude with Mandelstam Analyticity (DAMA)
- Real and imaginary part of trajectory are connected by dispersion relation
  \[
  \Re \alpha(s) = \alpha(0) + \frac{s}{\pi} \text{PV} \int_0^{\infty} ds' \frac{\Im m \alpha(s')}{s'(s' - s)}.
  \] (2)
- Imaginary part is related to the decay width
  \[
  \Gamma(M_R) = \frac{\Im m \alpha(M_R^2)}{\alpha' M_R}.
  \] (3)
- Imaginary part chosen as sum of single threshold terms
  \[
  \Im m \alpha(s) = \sum_n c_n (s - s_n)^{1/2} \left( \frac{s - s_n}{s} \right) |\Re \alpha(s_n)| \theta(s - s_n).
  \] (4)
- Imag. part of trajectory in Eq.(4) has correct threshold and asymptotic behaviour
- The \(c_n\) are expansion coefficients, \(s_n\) are threshold energies of decay channels
Reggeizing isoscalar states with hidden strangeness

- DAMA fit to the isoscalar strangeness states $\phi, f'_2, \phi_3$ defines the $(\phi, f'_2)$-trajectory

![Graph showing real part of $(\phi, f'_2)$-trajectory](image1)

- DAMA fit of $(\phi, f'_2)$-trajectory predicts
  - $f'_4$ state, mass 2182 MeV and width 156 MeV
  - $\phi_5$ state, mass 2417 MeV and width 310 MeV

![Graph showing width of $(\phi, f'_2)$-trajectory](image2)

$\phi_3 \rightarrow K^* \bar{K}^*$, $s_2 = 3.18 \text{ GeV}^2$

$f'_2 \rightarrow KK^*$, $s_1 = 1.92 \text{ GeV}^2$

$\phi \rightarrow K \bar{K}$, $s_0 = 0.97 \text{ GeV}^2$
Conclusions and outlook

- ALICE is taking data in Run 3 after a major upgrade in long shutdown LS2
- First analysis of strangeness in double gap events in pp-collisions shows clear evidence for strangeonia states $\phi(1020)$ and $f_2'(1525)$
- Improve particle identification by combining TPC dE/dx with TOF information
- 50 times larger data sample from data taking 2022 available for analysis
- The search for the $f_4'(2182)$ and $\phi_5(2417)$ state
- Nature of the known $\phi(1680)$: radial excitation of the $\phi(1020)$? The $2^3S_1(1.69)$ state in Godfrey-Isgur model? Leading pole of a subleading isoscalar Regge trajectory in the strange sector?
- Extend strangeness analysis to $(u, d)\bar{s}$ kaonia and $(\bar{u}, \bar{d})s$ antikaonia states by analysing $\pi K$ pairs
BACKUP
Isoscalar states in light-quark and strangeness sector

- The Godfrey-Isgur model predicts isoscalar states in the light-quark and strangeness sector.

- $^{13}S_1, \ J^{PC} = 1^{--}$:
  One state at 780 MeV, one state at 1020 MeV. The 780 MeV state is identified as $\omega(782)$ (light-quark sector), the 1020 MeV as $\phi(1020)$ (strangeness sector).

- $^{13}P_2, \ J^{PC} = 2^{++}$:
  States at 1280 MeV and 1530 MeV. The 1280 MeV state is identified as $f_2(1270)$ (light-quark sector), $\text{Br}(\pi\pi) \sim 85\%$, $\text{Br}(K\bar{K}) \sim 5\%$, the 1530 MeV as $f'_2(1525)$ (strangeness sector), $\text{Br}(\pi\pi) \sim 1\%$, $\text{Br}(K\bar{K}) \sim 88\%$.

- $^{13}D_3, \ J^{PC} = 3^{--}$:
  States at 1680 MeV and 1900 MeV. The 1680 MeV state is identified as $\omega_3(1670)$ (light-quark sector), no BR’s, the 1900 MeV as $\phi_3(1850)$ (strangeness sector), no BR’s.

- $^{13}F_4, \ J^{PC} = 4^{++}$:
  States at 2010 MeV and 2200 MeV. The 2010 MeV state is identified as $f_4(2050)$ (light-quark sector), $\text{Br}(\pi\pi) \sim 17\%$, $\text{Br}(K\bar{K}) \sim 0.7\%$. PDG lists only one $F_4$ state.