NA38/NA50 experiments

Enhancement of intermediate mass dimuons in nucleus-nucleus collisions

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Outline

- introduction

- data analysis
  ✓ p-A
  ✓ S-U and Pb-Pb

- comparison with models
  ✓ charm enhancement
  ✓ D-mesons rescattering
  ✓ thermal dimuons

- conclusions
NA50 has shown that the p-A dimuon mass spectra in the mass range 1.5 to 2.5 GeV/c^2 are correctly reproduced by a superposition of DY and D\bar{D} dimuons.


New development on this subject using a 4-dimensional unfolding method [NIM.A405(1998)139].
Unfolding method

- detector effects $\Rightarrow$ acceptance and resolution

$$D(x') = \int S(x'|x) \, A(x) \, \Phi(x) \, dx$$

- acceptance $A(x)$, resolution $S(x'|x)$

- $x, x'$: set of kinematical variables describing the dimuon
  $\Rightarrow$ $M, p_T, Y_{cm}, \cos(\theta_{cs})$

- extract the physical distribution $\Phi$ from the measured one

- 4-D unfolding method [NIM A405(1998)139]
  - based on image restoration methods extended to 4D
  - accounts for detector correlation
  - preserve physics correlations
  - no need to assume specific shapes for distribution
  - iterative method
NA50 apparatus

- detect opposite sign ($\mu^+\mu^-$) muon pairs
- centrality detection

- record also the like sign pairs $\mu^+\mu^+$ and $\mu^-\mu^-$
- combinatorial background
Known sources:

- **Drell-Yan**: $q\bar{q} \rightarrow \mu^+\mu^-$
- resonance decays: $J/\psi, \psi' \rightarrow \mu^+\mu^-$
- charmed meson (and baryon) decays: $D \rightarrow \mu X$
fit data in the mass range $1.6 < M < 8.0$ GeV/$c^2$ assuming

$$
\frac{dN}{dM} = n_1 \frac{dN^{DD}}{dM} + n_2 \frac{dN^{DY}}{dM} + n_3 \frac{dN^{\psi}}{dM} + n_4 \frac{dN^{\psi'}}{dM}
$$

- **gaussian shapes for the $J/\psi$ and $\psi'$ resonances**

- **shapes of $DY$ and $D\bar{D}$ obtained from PYTHIA 6.1 with :**
  
  ✓ c quark mass $\Rightarrow m_c = 1.5$ GeV/$c^2$
  ✓ intrinsic transverse momentum

  $$
  \sigma_{kT}^{DY} = 0.8 \text{ GeV}/c \ [\text{NA51 pp collisions}]
  $$

  $$
  \sigma_{kT}^{D\bar{D}} = 1.0 \text{ GeV}/c \ [\text{Eur.Phys.J.C1(98)123}]
  $$

  ✓ MRS A set of PDF’s

- **7 parameters fit**
p-A simultaneous fit

in $1.6 < M_{\mu\mu} < 2.5 \text{ GeV/c}^2$

$\left. \frac{D\bar{D}}{DY} \right|_{pN} = 3.98 \pm 0.11$
Open charm cross section

- The open charm cross section @ 450 GeV is deduced in the following way:
  \[
  \sigma_{c\bar{c}}^{450} = \sigma_{\text{IMR}}^{\text{DY}} \times \frac{\text{DD}}{\text{DY}}_{pN, 450} \times (\text{phase space factor}) \times \frac{1}{\text{BR}(c\bar{c} \rightarrow \mu\mu X)}
  \]

- The value is compatible with other direct measurements.

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Ion mass spectra

- analysis as a function of centrality based on electromagnetic transverse energy $E_T$:
  - 5 bins for S-U
  - 7 bins for Pb-Pb

- data unfolded in the following kinematical domain
  \[
  \begin{align*}
  &M > 1.6 \text{ GeV/c}^2 \\
  &0.2 < Y_{cm} < 0.8 \\
  &-0.3 < \cos(\theta_{cs}) < 0.3
  \end{align*}
  \]

- for ion collisions, the DY and $D\bar{D}$ processes are extrapolated linearly from NN yields, as expected for hard processes

- NN open charm and DY cross sections have been deduced from the p-A 450 GeV/c value using the $\sqrt{s}$-dependence given by PYTHIA

- the isospin correction has been taken into account for DY
in the IMR, data are higher than the expected sources
data/expected sources

- quantify the difference between data and expected sources

plot data/expected sources vs $N_{\text{part}}$ in $1.6 < M < 2.5$ GeV/c$^2$

- the IMR excess increases as a function of centrality
Interpretations

- several theoretical models have been proposed to explain the observed IMR charm excess

  ✓ charm enhancement
  [C.Y. Wong and Z.Q. Wang, Phys.Lett.\textbf{B367}(96)50]

  ✓ D-mesons rescattering
  [Z. Lin and X.N. Wang, Phys.Lett.\textbf{B444}(98)245]

  ✓ thermal dimuon radiation
- **hypothesis**: excess behaves as open charm
  

  - fit the IMR ion mass spectra with a superposition of DY and D\(\bar{D}\) and extract the ratio \((D\bar{D}/DY)_{measured}\)

  \[
  \text{\begin{figure}
  \centering
  \includegraphics[width=\textwidth]{chart.png}
  \caption{IMR \(\chi/ndf = 1.1\)}
  \end{figure}}
  \]

  - calculate the expected ratio \((D\bar{D}/DY)_{expected}\) from p-A

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plot the enhancement factor $E$ as a function of centrality

$$E = \frac{\left(\frac{D\bar{D}}{DY}\right)_{\text{measured}}}{\left(\frac{D\bar{D}}{DY}\right)_{\text{expected}}}$$

✓ charm-like enhancement: factor $\sim 3$ in central Pb-Pb with respect to p-A
✓ linear increase with $N_{\text{part}}$
D-mesons rescattering

- Z. Lin and X.N. Wang [Phys.Lett. B444(98)245] associate the observed excess to D-mesons rescattering in nuclear matter which leads to an enhancement in the limited phase space of the NA50 experiment.

- D and $\bar{D}$ rescattering are described by a thermal distribution

$$d^3N/dp^3 = \exp(-E/T)$$

- parameter: local temperature $T$
the enhancement factor in NA50 phase space is calculated as the ratio of the number of dimuons observed at temperature $T$ and at $T=0$

with MRS A
and
$m_c = 1.5$ GeV/$c^2$
D-mesons rescattering

- From the experimental value of the enhancement, the corresponding temperature can be obtained for each of the centrality bins $E_{\text{data}}(N_{\text{part}})$ and $E_{\text{model}}(T)$.

- The shape of the dimuon mass distribution from $D\bar{D}$ decays is then calculated with the corresponding temperature.

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the mass shape calculated with this model fails to reproduce the IMR mass spectra in central Pb-Pb collisions
Thermal dimuons

- Model developed by Rapp and Shuryak

  → $\mu\mu$ yield based on $q\bar{q}$ annihilation rate

  → Integration over space-time history

  → Central collisions only

  → Parameters:
    ▪ Fireball lifetime: $14$ fm/c
    ▪ Initial temperature: $T_i = 192$ MeV

  → Explicit introduction of a QGP phase
    ▪ Critical temperature: $T_c = 175$ MeV

  → No free parameters
the IMR excess can be well accounted for by thermal radiation when combined with DY and open charm
Conclusions

- the $\sigma_{c\bar{c}}$ cross section extracted from the p-A data agrees with direct measurements of other experiments
- the ion data are in excess of the DY+$D\bar{D}$ superposition extrapolated from p-A
- this excess increases linearly with $N_{\text{part}}$
- the mass distribution cannot be reproduced by a model assuming $D$ and $\bar{D}$ rescattering
- two possible explanations of the observed excess:
  - the data can be described under the hypothesis of an enhancement of charm production
  - the central Pb-Pb mass distribution can be reasonably well reproduced by the thermal model
- new experiment needed: NA60