THERMAL ASPECTS OF AU+AU COLLISIONS AT 1.23A GEV

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From QCD matter to hadrons

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Can SIS18 contribute to the exploration of QCD phase diagram?

http://indico.jinr.ru/event/csqcd2017
SHM fit to multiplicities from Au+Au

- Fit is obtained from THERMUS using a $(R_c)$ canonical treatment of strangeness.
- Note the small freeze-out volume driven by the “large” temperature.
- All strangeness channels below NN threshold

![Data, $\sqrt{s_{NN}}=2.4$ GeV, $T=68\pm2$ MeV, $\mu^+=883\pm25$ MeV; $R_c=2.1\pm0.3$ fm, $R_V=5.8\pm0.9$ fm; $X^2/\text{ndof}=2.3$](image)

![Graph showing yield vs. particle type](image)

Systematics from A. Andronic et al. arXiv:0812.1186v3

Dileptons


All part.
Two-pion correlations Au+Au 1.23A GeV

Coulomb effect treated according to GB, PBM (NPA 610, 286c (1996))

$\rightarrow \pi^0\bar{\pi}^0$.

HADES, arXiv:1811.06213

$V_{2\pi} = (2\pi)^{3/2}R_{\text{side}}^2R_{\text{long}}$

$V_{2\pi}(@100) \simeq 2550\text{ fm}^3$

$V_{\text{HRG}}(\text{full}) \simeq 817\text{ fm}^3$

$V_{\text{HRG}}(\text{red.}) \simeq 4570\text{ fm}^3$

$A_{\text{part}} = 303 \pm 11$
“Thermal cocktail” for pion production (THERMINATOR)

- Ongoing work, in collaboration with W. Florkowski and group: bell-shaped rapidity distribution, true Δ line shapes, flow profile.
More correlations: $\pi p$

Reconstructed $\Delta$ shows sifted maximum:
- Effect of the phase space
- An rescattering?

![Graphs showing $\pi p$ correlations and mass spectra in the phase space.](image)
Meson production and propagation in cold matter

- $\pi^-(1.7 \text{ GeV/c}) + C, W$

- $\sqrt{s(\pi N)} \approx 2.07 \text{ GeV} \ (\pm \text{Fermi momentum})$

- Inclusive spectra for: $K^+, K^0, K^-, \Lambda, \phi$

$p_t$ spectra of $K^0$ for different rapidity bins (A=W, $Y_{CM} = 0.76$)

$\frac{dN_{K^0}}{(dp_t dy)}$ vs $p_t$

- Fit with Boltzmann distribution
- Compared to UrQMD and GiBUU
$K^+$ and $K^-$ rapidity distributions ($\pi + C, W$)

- Rescattering of $K^+$
- Absorption of $K^-$ ($\phi$)

\[
\frac{(K^-)}{(K^+)}_W = 0.319 \pm 0.016
\]

\[
\frac{(K^-)}{(K^+)}_C = 0.55
\]

\[
\frac{(\phi)}{(K^-)}_W = 0.63
\]
Inclusive Dielectron Yields from \( Au + Au (\sqrt{s} = 2.4 \text{ AGeV}) \)

**Graph:**

- **Left Graph:**
  - \( N_\tau^0 \) d\( N_{\text{raw}} \)/dM\( e_e \) (GeV/c\(^2\))
  - \( \alpha_\tau^e > 9^\circ \)
  - \( p_e > 0.1 \text{ GeV/c} \)
  - Au+Au \( |s_{NN}|=2.42 \text{ GeV} \)
  - 0–40%
  - HADES preliminary

- **Right Graph:**
  - \( 1/N_\tau^0 \) d\( N_{\text{corr}} \)/dM\( e_e \) (GeV/c\(^2\))
  - Au+Au \( |s_{NN}|=2.4 \text{ GeV} \)
  - 0–40%
  - 1/2 (np+pp)
  - HADES preliminary

**Legend:**

- Red: \( N_\tau^0 \)
- Blue: CB
- Black: raw signal

**Equations:**

\[ \frac{1}{N_\tau^0} \frac{dN_{\text{corr}}}{dM_{ee}} (\text{GeV/c}^2) \]

\[ \alpha_\tau^e > 9^\circ \]

\[ p_e > 0.1 \text{ GeV/c} \]

\[ \text{Au+Au} \ | s_{NN} = 2.42 \text{ GeV} \]

\[ 0^\circ - 40\% \]

\[ 1/2 \text{ (np+pp)} \]

**Notes:**

- HADES preliminary data processing, all identified candidates, background samples were defined either by selecting the factor \( \text{CB} = 2 \text{.42 GeV} \)
- The signal spectra contain 190,000 and 20,000 electron pairs. Most of these pairs, however, represent random events unlike-sign combinations (i.e. do not stem from the same virtual photon).

**Graph Details:**

- The figure shows the distribution of dielectron invariant mass \( M_{ee} \)
- The raw signal distribution was further corrected for efficiencies due to the detector response and inactive regions within the acceptance of the spectrometer in the acceptance and reconstructed using the full analysis and reconstruction packages.

**Further Details:**

- The event-by-event basis as the factor \( \text{CB} = 2 \text{.42 GeV} \)
- The mixed-event unlike-sign yield, scaled to the integrated statistics of the like-sign same-event background is limited.

**Acknowledgments:**

- The authors acknowledgment the contributions of various institutions and collaborations involved in the HADES experiment.

**Conclusion:**

- The analysis and results presented here are preliminary and subject to further validation and publication in the scientific community.
Thermal dileptons Au+Au 1.23A GeV

- Microscopic transport\(^{(2)}\):
  - vacuum \(\rho\) spectral function and \(\Delta\) regeneration
  - \& explicit broadening and density dependent mass shift

- Coarse-grained UrQMD\(^{(3)}\)
  - thermal emissivity with in-medium propagator \(^{(4)}\)
  - \(\rho - \alpha_1\) chiral mixing\(^{(5)}\)
    (not measured so far)

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HADES preliminary

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(4) Rapp, van Hees; arXiv:1411.4612v
(2) E. Bratkovskaya;
(3) CG FRA Endres, van Hees, Bleicher;
    arXiv:1505.06131
    CG GSI-TAMU; Galatyuk, Seck, et al.
    arXiv:1512.08688
(4) Rapp, Wambach, van Hees;
    arXiv:0901.3289
(5) Rapp, Hohler; arXiv:1311.2921v
Dilepton excess radiation in centrality bins

Indication for increasing average temperature as collisions go more central
Common $A_{\text{part}}$ scaling of Dileptons and Strangeness
Hadronic final states used in PWA (A. Sarantsev; BONN/GATCHINA)
Beam energy scan: \( p_\pi = [656, 690, 748, 800] \) MeV (second resonance region)
Exclusive dilepton spectrum $\pi^- p \rightarrow e^+ e^- n$

- Cocktail constructed from cross sections extracted from PWA.
- Comparison to electromagnetic transition form factor calculated in a core+cloud model.
- Evidence for VMD in $e^-$ decays of baryons.

G. Ramalho, T. Pena Phys. Rev. D95 (2017), 014003
More results from Au+Au

17:40 - 18:05  Behruz Kardan (Frankfurt)
Collective flow and correlation measurements with HADES in Au+Au collisions at 1.23 AGeV

18:30 - 18:55  Frederic Kornas (Darmstadt)
Lambda Polarization in Au+Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV measured with HADES
Dielectrons from Ag+Ag at 1.65A GeV

Expected dielectron invariant mass spectra after four weeks running (Full Monte-Carlo & reconstruction).

- Quantify lifetime and baryon density dependence of the $\rho$ spectral function
- Access for the first time at this collision energies the intermediate mass region:
  - Learn about $\rho - a_1$ chiral mixing
  - Extract fireball temperature
- Discriminate between models

Expected dielectron invariant mass spectra after four weeks running (Full Monte-Carlo & reconstruction).

Signal: Coarse-grained transport with thermal electromagnetic rates & freeze-out contributions

Conventional transport model

<table>
<thead>
<tr>
<th>$M_{ee}$ range</th>
<th>&lt;0.15 GeV/c²</th>
<th>0.15-0.45 GeV/c²</th>
<th>0.3-0.7 GeV/c²</th>
<th>&gt;1 GeV/c²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate [84 shifts]</td>
<td>2.89 $\cdot$ 10⁶</td>
<td>7.1 $\cdot$ 10⁵</td>
<td>2.1 $\cdot$ 10⁵</td>
<td>107</td>
</tr>
<tr>
<td>Mesons</td>
<td>$\pi^0 \rightarrow \gamma e^+e^-$</td>
<td>$\eta \rightarrow \gamma e^+e^-$</td>
<td>$\omega \rightarrow e^+e^-$</td>
<td>$\phi \rightarrow e^+e^-$</td>
</tr>
<tr>
<td>Rate [84 shifts]</td>
<td>1.5 $\cdot$ 10⁶</td>
<td>7.32 $\cdot$ 10⁵</td>
<td>179</td>
<td>62</td>
</tr>
</tbody>
</table>
(Multi)-Strangeness in Ag+Ag at 1.65A GeV

Understanding of the Ξ− excess:

- Additional information needed to increase the discrimination power with respect to models.
  - Measurement of the m_T-spectra
  - In addition factor 5 gain in statistics over Au+Au of other strange hadrons possible.
- Allows for multi-differential analysis with respect to the event plane

Expected integral yields for after 4 weeks of running, selecting 44% of most central Ag+Ag collisions.

<table>
<thead>
<tr>
<th>Mesons</th>
<th>K^+</th>
<th>K^-</th>
<th>K^0_s</th>
<th>Λ</th>
<th>φ</th>
<th>Ξ^-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate [84 shifts]</td>
<td>7.6 \cdot 10^6</td>
<td>1.8 \cdot 10^6</td>
<td>6.36 \cdot 10^5</td>
<td>6.36 \cdot 10^5</td>
<td>2.4 \cdot 10^3</td>
<td>2.5 \cdot 10^3</td>
</tr>
</tbody>
</table>
Summary

- HADES provides data at the lower end of the "Beam Energy Scan"
- Strong evidence that the fireball formed is equilibrated
- Common scaling behavior of strangeness production (below NN threshold)
- Substantial absorption of $K^-$ and $\phi$ observed in cold matter
- Thermal dilepton radiation outshining the contributions from conventional sources found
- Can serve as thermometer, chronometer, barometer and polarimeter of the collision
- Spectral distribution sensitive to hadron properties in the medium
- emTTF of N* shows effect of VMD
Thank you