Reconstruction of mesons at freeze out via conversion in Au+Au at 1.23 AGeV with HADES

Claudia Behnke for the HADES collaboration
Outline

- Motivation: the freeze out cocktail of Au+Au
- Technique: $\gamma$ reconstruction with HADES
- Simulations: the “ideal case”
- Experimental data:
  - the reality
  - topological background rejection cuts
  - the reality again
- Summary & Outlook
Motivation

HIC at SIS energies

First-chance NN collisions

Hot and dense stage (~ 10 fm/c)

Freeze-out stage

Baryonic sources:
- NN Bremsstrahlung
- $\Delta, N^* \rightarrow N\gamma e^+ e^-$

In-medium spectral functions

Long-lived mesons:
- $\pi^0, \eta, \omega$
  - $\tau_\pi = 7.7 \times 10^7$ fm/c
  - $\tau_\eta = 1.5 \times 10^5$ fm/c
  - $\tau_\omega = 23$ fm/c
The freeze out "Cocktail"

\[ \pi^0, \eta \rightarrow \gamma e^+ e^- \]

✔ Mult \( \pi^0 \) is essential for spectra normalisation
✔ “no Mult \( \eta \), no Mult Excess!”

How to reconstruct Mult \( \pi^0 \) and Mult \( \eta \)?
The freeze out "Cocktail"

Multiplicity of $\pi^0$ and $\eta$ mesons, as a function of beam energy and system size. Au+Au points from extrapolation to the measured data.

\[
\text{Mult}_{\text{AuAu}}(\pi^0) = 6.4 \pm 15\%
\]

\[
\text{Mult}_{\text{AuAu}}(\eta) = 0.09 \pm 50\%
\]
HADES DAQ performance during AuAu beam time

- 557 hours Au beam on Au target
- Beam energy 1.23 AGeV
- (1.2-1.5) x 10^6 ions per second
- 8 kHz trigger rate
- 200 MByte/s data rate
- 7.3 x 10^9 events 140 TByte of data
- Trigger on multiplicity in TOF ≥ 20 (PT3) \( \Rightarrow b_{\text{max}} \approx 9\text{fm} \)

Simulations

- Pluto event generator:
  - \( \pi^0 \) and \( \eta \) from a thermal source (T= 70MeV) + 100% decay into 2\( \gamma \)
  - Conversion in HGeant2 with realistic detector geometry
  - Analysis of experimental and simulated data is identical

- UrQMD transport model
  - \( \text{Au + Au at 1.23 AGeV} \)
  - \( b_{\text{max}} = 9\text{fm} \)
How to measure $\pi^0$ and $\eta$ with HADES?

<table>
<thead>
<tr>
<th>Branching Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0, \eta \rightarrow \gamma \gamma$</td>
</tr>
<tr>
<td>$\pi^0, \eta \rightarrow \gamma e^+e^-$</td>
</tr>
<tr>
<td>$\pi^0, \eta \rightarrow e^+e^-e^+e^-$</td>
</tr>
</tbody>
</table>

How to reconstruct $\gamma$ without dedicated detector?

Identifying 4 leptons using topological cuts on $\alpha$, $\Theta_{\gamma\gamma}$

STAR: PhysRevC.70.044902
CDF: PhysRevD.70.074008

HADES:
- p+Nb 3.5 GeV: PhysRevC.88.024904
- Ar+KCl 1.765 GeV/u: GSI annual report 2012
Conversion probability

\[ \text{Prob}(Z_i, E_\gamma) = \frac{n_{ati} \sigma(Z_i, E_\gamma)}{\sum_i [n_{ati} \cdot \sigma_i(E_\gamma)]} \]

\( \pi^0 \) and \( \eta \) from a thermal source
100% decay into \( 2\gamma \)

GSI target lab: B. Kindler et al., NIMP 655, 2011
conversion probability

<table>
<thead>
<tr>
<th>Material</th>
<th>Material</th>
<th>Conv [%] ($\pi^0$)</th>
<th>Conv [%] ($\eta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Au</td>
<td>0.32</td>
<td>0.54</td>
</tr>
<tr>
<td>Target holder</td>
<td>C</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Beam pipe</td>
<td>C</td>
<td>0.26</td>
<td>0.48</td>
</tr>
<tr>
<td>Radiator gas</td>
<td>C4F10</td>
<td>0.59</td>
<td>0.91</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>1.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

GSI target lab: B. Kindler et al., NIMP 655, 2011
# Multiplicities

\[
N_{\text{AuAu}} = \text{Mult} \cdot N_{\text{events}} \cdot \text{BR} \cdot \text{Conv} \cdot \varepsilon_{\text{reconstruction}} \cdot \varepsilon_{\text{acceptance}}
\]

<table>
<thead>
<tr>
<th>Process</th>
<th>BR</th>
<th>Conv (%)</th>
<th>$\varepsilon_{\text{rec}} \cdot \varepsilon_{\text{acc}}$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 \rightarrow \gamma\gamma(\rightarrow e^+e^-e^+e^-)$</td>
<td>0.98</td>
<td>1.44 %</td>
<td>0.1 x 0.01</td>
<td>1.4 x 10^{-7}</td>
</tr>
<tr>
<td>$\pi^0 \rightarrow \gamma e^+e^-(\rightarrow e^+e^-e^+e^-)$</td>
<td>1.17 x 10^{-2}</td>
<td>1.2 %</td>
<td>0.1 x 0.01</td>
<td>1.4 x 10^{-7}</td>
</tr>
<tr>
<td>$\pi^0 \rightarrow e^+e^-e^+e^-$</td>
<td>3.34 x 10^{-5}</td>
<td></td>
<td></td>
<td>3.1 x 10^{-7}</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>3.1 x 10^{-7}</td>
</tr>
</tbody>
</table>

\[N(\pi^0)_{\text{AuAu}} = 1.5 \cdot 10^4\]

<table>
<thead>
<tr>
<th>Process</th>
<th>BR</th>
<th>Conv (%)</th>
<th>$\varepsilon_{\text{reconstruction}} \cdot \varepsilon_{\text{acceptance}}$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta \rightarrow \gamma\gamma(\rightarrow e^+e^-e^+e^-)$</td>
<td>0.39</td>
<td>4 %</td>
<td>0.15 x 0.02</td>
<td>4.7 x 10^{-7}</td>
</tr>
<tr>
<td>$\eta \rightarrow \gamma e^+e^-(\rightarrow e^+e^-e^+e^-)$</td>
<td>7.0 x 10^{-3}</td>
<td>2 %</td>
<td>0.15 x 0.02</td>
<td>4.2 x 10^{-7}</td>
</tr>
<tr>
<td>$\eta \rightarrow e^+e^-e^+e^-$</td>
<td>&lt;6.9 x 10^{-5}</td>
<td></td>
<td></td>
<td>2.1 x 10^{-7}</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>11.0 x 10^{-7}</td>
</tr>
</tbody>
</table>

\[N(\eta)_{\text{AuAu}} = 725\]
Challenges of (di)lepton reconstruction

✔ Low momenta
  - One lepton can be bend out by the magnetic field behind the inner MDCs
  - Reconstruction efficiency is between 15 - 55%

✔ Small opening angle
  - in 93% cases $\alpha$ is $<3^\circ$
  - RICH ring finder will often identify only 1 ring

\[ \alpha < 3^\circ \]

11% of $e^+/e^-$
P$< 50$ MeV/c: $\varepsilon = 15$

44% of $e^+/e^-$
P$< 100$ MeV/c: $\varepsilon = 55$

\[ \text{Pluto} \]
UrQMD Simulations: ideal case

4 lepton simulated invariant mass distribution

- **signal**
  - \( \pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^- \)
  - \( \pi^0 \rightarrow \gamma e^+e^- \rightarrow e^+e^-e^+e^- \)

- **combinatorial background**
  - \( \gamma\gamma \rightarrow e^+e^-e^+e^- \)
  - \( \gamma e^+e^- \rightarrow e^+e^-e^+e^- \)

**Lepton selection**
- ✔ Ideal Geant information:
  - No detector response
  - No detector inefficiencies
  - Ideal Tracking efficiency

**Topological cuts**
- ✔ \( \alpha_1 < 2.5^\circ \) and \( \alpha_2 < 20^\circ \)
- ✔ \( \theta_{\gamma\gamma} > 5^\circ \)

How does it look in experimental data .... ?
Lepton identification in experiment

- Statistic:
  - Full Statistic Apr12: $7.3 \cdot 10^9$ PT3 Trigger evts.
- Combine 2 negative and 2 positive lepton candidates
- Lepton candidate selection
  - momentum < |500| MeV/c
  - $\beta > 0.97$
Experimental invariant mass distribution

✔ 4 lepton candidates combined together
✔ no topological background rejection
cuts applied
Topological BG rejection cuts

- Events with 4 lepton candidates
- Topological cuts to suppress combinatorial background
  
  $\alpha_1 < 2.5^\circ$ and $\alpha_2 < 20^\circ$
  
  $\theta_{\gamma\gamma} > 5^\circ$

Without topological cuts

With topological cuts

\[ e^+ + e^- + \pi^0, \eta \]
Experimental invariant mass distribution

... after combinatorial background rejection

Topological cuts
\( \alpha_1 < 2.5^\circ \) and \( \alpha_2 < 20^\circ \)
\( \theta_{\gamma\gamma} > 5^\circ \)

\( \eta \) needs harder cuts on lepton identification and topology

\( \pi^0 (~8000) \)

\( \eta \) ?
Summary

✔ Full reconstruction of $\pi^0$ and of $\eta$ in $\text{Au + Au} 1.23 \text{ AGeV}$ is feasible

✔ First spectrum of 4 lepton invariant mass has been reconstructed

✔ $\pi^0$ peak is clearly visible!

✔ Reconstruction of $\eta$ is ongoing
Outlook/ Future

✗ Find $\eta$ ;)

✗ Corrections for detector inefficiencies and acceptance

✗ Improve electron identification cuts
  (TMVA, close pair analysis)

✗ Improve topological background rejection cuts

✗ Extract multiplicities of $\pi^0$ and $\eta$ mesons in Au+Au at 1.23 AGeV

✗ Additional measurements before SIS 100?
  Increase $\pi^0$ and $\eta$ rates by:
    ✗ Lowering the magnetic field (acceptance)
    ✗ Additional material in the target region (conversion probability)

✗ Measurements at SIS 100 with electromagnetic calorimeter
Thank you for your attention

The HADES Collaboration
Backup Slides
Low momenta leptons

![Bar chart showing distributions for different detectors (MDC I, MDC II, MDC III, MCD IV, MDC ALL, TOF, RPC, Shower) for electrons (e^+) and positrons (e^-).]
beta vs mom

without top cuts

with top cuts

TOF

RPC
The SIS18 heavy-ion energy regime

Evolution of average $\rho_B (\tau_{\text{system}})$

Probing nuclear matter at:
- densities: $\rho_B / \rho_0 > 2$
- temperature: $T < 100 \text{ MeV}$

System stays above ground state density for $\sim 10 \text{ fm/c}$

“Resonance matter”:
- excitation and decay of baryonic resonances are the dominant contribution
- life time resonance: $\sim 1 \text{ fm/c}$

Composition of a hot $\pi\Delta N$ gas (T)
Hot and dense stage: a look inside

In-medium spectral functions

SPS, RHIC, LHC

How to measure?
How to model?

Additional contributions to the $\rho$-meson self-energy in the medium

Dalitz-decay of baryonic resonances is dominant source at low beam energies
HADES at SIS 18 and SIS 100

✓ Running experiment, well understood performance
✓ Deliver high quality data
✓ Setup tests with coming heavy-ion runs at SIS-18
✓ Upgrade improved stability, DAQ and time resolution of the Spectrometer

<table>
<thead>
<tr>
<th>Date</th>
<th>System</th>
<th>$E_{\text{kin}}$ beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>C+C</td>
<td>2.0 GeV/u</td>
</tr>
<tr>
<td>2004</td>
<td>C+C</td>
<td>1.0 GeV/u</td>
</tr>
<tr>
<td>2005</td>
<td>Ar+KCl</td>
<td>1.76 GeV/u</td>
</tr>
<tr>
<td>2006</td>
<td>p+p</td>
<td>1.25, 2.2, 3.5 GeV</td>
</tr>
<tr>
<td>2007</td>
<td>d+p</td>
<td>1.25 GeV</td>
</tr>
<tr>
<td>2008</td>
<td>p+Nb</td>
<td>3.5 GeV</td>
</tr>
<tr>
<td>2012</td>
<td>Au+Au</td>
<td>1.25 GeV/u</td>
</tr>
</tbody>
</table>

Measure the whole evolution of the fireball...
Energy and system size dependence of the excess yield

- Multiplicity of $e^+e^-$ pairs from $\pi^0$, $\eta$, $\Delta$ and $\rho$
- Good agreement for $\pi^0$ and $\eta$ (implemented according to the TAPS data)

UrQMD can't fully account for the enhanced pair yield in the intermediate mass region
"Effect" of acceptance

Vertex of leptons coming from conversion in full phase space (left) and in acceptance (right)

Different colors represent different materials

Pluto