Probing of the in-medium hadron structure with HADES

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- Motivation
- Detector HADES @ GSI
- Physics programme of HADES: HI, pp, dp, pA, πN, πA
- Outlook
Chiral symmetry and hadron masses

- Hadron mass spectrum reflects chiral symmetry breakdown - parity doublets
- Constituent mass of light quarks is generated by \(< q\bar{q} >_\text{vac} \neq 0\)
- \(< q\bar{q} >\) depends on environment \((T, \rho)\)


Brown-Rho scaling:
\[ m_\rho / m = (\langle q\bar{q} \rangle_\rho / \langle q\bar{q} \rangle_0)^{1/3} \]

For low densities:
\[ m_\omega = m_0 (1 - \alpha \rho/\rho_0) \text{ for } T=0 \text{ and } \rho \approx \rho_0 \]
Mesons in nuclear matter: hadronic scenario

W. Peters et.al. NPA 632(1998)109:

\[ A_\rho(M) = - \frac{2 \text{Im} \Sigma_\rho(M)}{[M^2 - m_\rho^2 - \text{Re} \Sigma_\rho(M)]^2 + [\text{Im} \Sigma_\rho(M)]^2} \]

Vacuum:

\[ \Sigma_\rho(M) = -im_\rho \Gamma_\pi\pi(m) \]

\[ m_\rho = 0.77 \text{GeV} \]

In medium:

What is the right picture?
Dielectron decays of „free” hadrons

Direct meson decays:

\[ \Gamma_{\rho \to e^+e^-} / \Gamma_{\text{tot}} \approx 4.6 \times 10^{-5} \]
\[ \Gamma_{\omega \to e^+e^-} / \Gamma_{\text{tot}} \approx 7.2 \times 10^{-5} \]
\[ \Gamma_{\phi \to e^+e^-} / \Gamma_{\text{tot}} \approx 3.0 \times 10^{-4} \]

Dalitz-meson decays:

\[ \Gamma_{\pi^0 \to \gamma \gamma e^+e^-} / \Gamma_{\text{tot}} \approx 1.2 \times 10^{-2} \]
\[ \Gamma_{\eta \to \gamma \gamma e^+e^-} / \Gamma_{\text{tot}} \approx 4.9 \times 10^{-3} \]
\[ \Gamma_{\omega \to \pi^0 e^+e^-} / \Gamma_{\text{tot}} \approx 5.9 \times 10^{-4} \]

CB - combinatorial background from \( \pi^0 \) decays!

! 1-2 AGeV baryonic matter- baryon decays: \( NN \to NR(N^*, \Delta) \to NNe^+,e^- \) - not well known!

! but very interesting – provides insight into electromagnetic structure of baryons

VectorMesonDominance?
Dielectron from HI collisions

Data: R.J. Porter et al.: PRL 79(97)1229

Model: E.L. Bratkovskaya et al.: NP A634(98)168, BUU, vacuum spectral function

\[ \pi^+ + \pi^- \to \rho \text{ annihilation} \]

Enhancement larger than at 158 AGeV!

Pb-Au 40 AGeV

\[ \sigma/\sigma_{\text{geo}} \approx 30\% \]
\[ <dN_{ch}/d\eta>=216 \]
\[ 2.11<\eta<2.64 \]
\[ p_t>0.2 \text{ GeV/c} \]
\[ \Theta_{\text{geo}}>35 \text{ mrad} \]

! cannot be described by dropping mass scenario or modified spectral functions

! Enhancement larger than at 158 AGeV!
**SIS (BEVALAC) energy regime: 1–2 AGeV**

- Final state in heavy ion collisions;
  - up to 200 charged particles (Au+Au)
  - approximately 10% pions, baryon dominated
  - little strangeness

- Production of vector mesons below threshold
  - co-operative process: \( NN \rightarrow N \Delta, \Delta N \rightarrow NN\omega \)
  - \( \pi N \rightarrow N^*(\Delta) \rightarrow N\omega \)
  - important role of baryonic resonances
  - production confined to high density phase
  - One vector meson decaying into lepton pair per 10 Million reactions!

- Enhancement of baryon density
  - \( \Delta\tau (3 > \rho/\rho^0 > 2) = 15\ \text{fm/c} \)
  - Comparable to \( \rho/\omega \) life times: \( \tau_\text{V}=1.3/23\ \text{fm/c} \)

- Near threshold dynamics - off-shell effects!
fit to DLS data:
\[ \simeq 150 \text{ MeV}, \quad \Gamma_\omega^{\text{coll}} \simeq 200 \div 300 \text{ MeV} \quad @ \quad \langle \rho_B \rangle \sim 1.5 \rho_0 \]
**Spectrometer Concept**

- **Geometry**
  - Full azimuth, polar angles 18° - 85°
  - Pair acceptance ≈ 0.35
  - About 80,000 detector channels

- **Fast particle identification**
  - Hadron blind RICH: gasous Cherenkov (C₄F₁₀) with CsI photon detector.
  - TOF (Scintillator rods): σ ≈ 150 ps
  - Pre-Shower 18 pad chambers & lead converters for em. shower detection

- **Online e⁺e⁻ identification**
  - RICH, TOF, Pre-Shower Image processing

- **Momentum measurement**
  - ILSE, super conducting toroid
    - \( B_ρ = 0.7 \) Tm
  - MDC Multi-wire drift chamber,
    - \( σ_y ≈ 100 \) μm
  - \( \Delta M_{e⁺e⁻}/M ≈ 1.5% \) at \( ρ/ω \)

**1995-2002 R&D construction**

**2002- production runs**
HADES Spectrometer @ GSI

Beam Upstream View

3 production runs: C+C @ 1 and 2 AGeV (2002-2004)

p+p @ 2.2 GeV

Front view of RICH (no mirror)
C+C @ 2 AGeV with HADES

C+C @ 2 AGeV (no outer tracking)

LVL1 Trigger

Online
RICH + META

10 fold event reduction

LVL2 Trigger

log. z axis !

p*q [MeV/c]

3% hadron contamination for p>0.6 GeV/c for C+C

Offline Analysis, Tracking
Dielectrons from C+C at 2 AGeV

No Efficiency / Acceptance Correction

Syst. variations only due to cuts in data & sim

Simulation: URQMD 1.3 – hadronic cocktail

Charged pion multiplicities agree with calculations and other data (KAOS/TAPS)

Comparable statistics collected for C+C @ 1 AGeV
Dielectrons from Ca+Ca: hunting for vector mesons.

• in medium vector meson properties - spectral functions $A_Y(M_{e^+e^-}, p)$ – double differential distributions, centrality dependence

$m_t$ scaling E. Bratkovskaya Phys. Lett. B424 (1997) 244

Meson multiplicities in C+C, Si+Si & Ca+Ca

Predictions for HADES – 4 weeks data taking
• no enhancement and in-medium modifications assumed

Ca+Ca 2 AGeV
$\omega$ 1500 counts
$\phi$ 680 counts
$\rho$ 1740 counts

planned for the next year
Proton and pion beams @ GSI

- study elementary dielectron sources:
  pp, pn, π⁻p collisions
- Study in-medium vector meson properties in pA, πA reactions
- proton beams with E < 4.5 GeV
- secondary π beams: high intensity primary beams: N₂, C (SQL)

![Graph showing pp->ppX and π⁻p->Xn reactions]
Dielectron from pp pn $\pi N$ collisions

- **pp and dp collisions at 1.25 AGeV**:  
  - Dalitz decays of $\Delta$ : trans. form-factors (tests of VMD):  
    exclusive $pp \rightarrow p\Delta^+ \rightarrow p\pi^+ e^-e^-$, NN bremsstrahlung (massive photons)-em. form-factor of nucleon  
  - Isospin dependence of differential pp/pn cross sections  
    (important for C+C at 1 AGeV !)

- **pp/$\pi p$ collisions near $\rho/\omega$ production threshold**
  - off-shell vector meson production:  
    exclusive $pp \rightarrow p\Delta(N^*) \rightarrow pp/\rho/\omega \rightarrow p\pi^+ e^-e^-$  
  - $\rho/\omega$ interferences (subthreshold phenomenon)  
  - vector meson coupling to baryonic resonances → in-medium modifications  
  - Reference for HI data at 2 AGeV

- **vector meson production in pp at 3.5 GeV**
  - on shell $\omega$ production :  
    $\omega \rightarrow \pi^0 e^+ e^-$ - Dalitz decay (test of VMD )  
  - reference for pA
$\omega$ production in $\pi A$ (pA)

$\pi^- p_{\text{bound}} \rightarrow \omega n \rightarrow e^+ e^- n$

$\omega$ "at rest": $p_{e^+ e^-} < 300$ MeV/c ($\sim 25\%$ of all decays)

- study of $\omega$ mass modifications at $\rho_0$

- large uncertainties in calculations: em. transition form-factors of resonances $R(\Delta, N^*)$, resonance decays $R \rightarrow \Delta \rho$

- needs data from $\pi N \rightarrow e^+ e^- X$!
Outlook into future: HADES @ 8AGeV

- new GSI Facility for Antiproton and Ion Research (FAIR): SIS 100/200 will provide beams up to 40 AGeV
- universal CBM spectrometer will measure at highest energies
- can HADES be used at lower energies: i.e 8 AGeV?

Meson yields in C+C

π₀ yields increases from 1.7 to 7./collision

< y> ≈ 1.5 at 8 AGeV

< y > acc ≈ 1
HADES measures dielectrons with good statistics: 16500 signal pairs C+C @ 2 AGeV, 1 AGeV measured with similar statistics.

Good electron identification: hadron misidentification <3% in C+C.

Real time electron trigger.

- Investigation of dielectron sources in pp/pd collisions (1.25 AGeV, 2.2 GeV, 3.5 GeV)
- Dielectron production in πN reactions
- In-medium vector meson properties: Ca+Ca at 2 AGeV and pA/πA collisions
- 2007/2008 inner TOF upgrade – heavy system (→Au+Au)

Considered option: HADES @ 8 AGeV in future GSI FAIR facility
- Measurement with medium system (C+C, Ca+Ca) possible with present configuration (with upgraded inner TOF)
- Higher (>10) count rates in vector meson region
Collaboration

- Bratislava (SAS, PI)
- Catania (INFN - LNS)
- Cracow (Univ.)
- **Darmstadt (GSI)**
- Dresden (FZR)
- Dubna (JINR)
- Frankfurt (Univ.)
- Giessen (Univ.)
- Milano (INFN, Univ.)
- Munich (Tech. Univ.)
- Moscow (ITEP, MPhI, RAS)
- Nicosia (Univ.)
- Orsay (IPN)
- Rez (CAS, NPI)
- Sant. de Compostela (Univ.)
- Valencia (Univ.)
- Coimbra (Univ.)