Dilepton production in the proton-proton reaction at 4.5 GeV with the HADES spectrometer

Rayane ABOU YASSINE

IJCLAB/ TU-Darmstadt
**HADES motivations**

- Explores the high-\(\mu_B\) region of the QCD phase diagram.
- Complementary to LHC, RHIC, SPS and uses heavy-ion, p, d and \(\pi\) beams in few GeV range.
- Understand the equation of state of baryon dominated matter.

---

![Image of a graph showing the phase diagram of QCD with regions for hadrons, quark-gluon plasma, and nuclei](image-url)
Dileptons from heavy-ion to elementary reactions

- Study of thermal dileptons from baryon rich matter requires knowledge of physics background \( \rightarrow pp/pn \) measurements are needed.
- Meson Dalitz decays \( (\pi^0/\eta \rightarrow \gamma e^+e^- \) and \( \omega \rightarrow \pi^0 e^+e^- \)).
- Vector meson direct decays \( (\varphi/\omega/\varphi \rightarrow e^+e^-) \).
- Baryon Dalitz decay \( (\Delta/N^* \rightarrow N e^+e^-) \).

**Elementary reactions studies by HADES**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Energy</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p+p ) at 1.25, 2.2 and 3.5 GeV</td>
<td></td>
<td>Reference for future HIC at SIS100 energies .</td>
</tr>
<tr>
<td>( p+p ) at 4.5 GeV (Feb22)</td>
<td></td>
<td>Inclusive ( e^+e^- ) cross sections.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baryonic resonance contribution.</td>
</tr>
</tbody>
</table>

No strong interaction in the final state \( \rightarrow \) can carry information from production site to detectors.

HADES experimental setup

- Fixed target experiment.
- Focuses on the $e^+e^-$ measurements.
- Large geometrical acceptance: $0^\circ < \varphi < 360^\circ$ and $18^\circ < \theta < 85^\circ$.
- Tracking system = 4 MDC planes + magnet.
- Lepton identification:
  - RICH $\rightarrow$ rings.
  - ECal $\rightarrow$ deposit energy.
  - Time of flight detectors TOF and RPC $\rightarrow$ $\beta$.
- FWD: $0.5^\circ < \theta < 7^\circ$.

SIS18 Emax:
- p: 4.5 GeV/nucleon
- Au: 1.25 AGeV

SIS100 Emax:
- p: 29 GeV/nucleon
- Au: 11 AGeV
Single lepton selection

A. RICH: Ring-Track correlation:
   \[ \Delta \theta (\Delta \phi) = \theta_{\text{Track}} - \theta_{\text{Ring}}. \]

B. ECal: Energy deposit.

Strategy:
1. Make projections for different momentum bins.
2. Gaussian fit of the peak around 0.
3. Take \( \sigma \) values to define the cuts.
Define cuts on RICH parameters

Some $\Delta \theta$ distributions for $e^-$ for momentum bins of 50 MeV/c

- $150 < p_e (\text{MeV}/c) < 200$
- $250 < p_e (\text{MeV}/c) < 300$
- $350 < p_e (\text{MeV}/c) < 400$
- $450 < p_e (\text{MeV}/c) < 500$
- $550 < p_e (\text{MeV}/c) < 600$
- $750 < p_e (\text{MeV}/c) < 800$

Random matches between a ring and a track

$\sigma$ of $\Delta \theta$ distributions

$\Delta \theta$ distributions after RICH cuts

$-2\sigma < \Delta \theta < +2\sigma$
Define cuts on ECAL parameters

Some (E-P) distributions for $e^\pm$ for momentum bins of 100 MeV/c after RICH cuts.

Tracks with $(E-P)<0$ are not fully suppressed after RICH cuts $(E-P)>-3\sigma$

Energy deposit in ECAL - momentum in function of momentum

- $300<p_e<$ 400 MeV/c
- $500<p_e<$ 600 MeV/c
- $700<p_e<$ 800 MeV/c
- $900<p_e<$ 1000 MeV/c
- $1300<p_e<$ 1400 MeV/c
- $1400<p_e<$ 1500 MeV/c

300<p_e(MeV/c)<400
500<p_e(MeV/c)<600
700<p_e(MeV/c)<800
900<p_e(MeV/c)<1000
1300<p_e(MeV/c)<1400
1400<p_e(MeV/c)<1500

$\sigma$ of (E-P) distributions

(E-P) $> -3\sigma$

Leptons

Hadrons

$300<p_e<$ 400 MeV/c
$500<p_e<$ 600 MeV/c
$700<p_e<$ 800 MeV/c
$900<p_e<$ 1000 MeV/c
$1300<p_e<$ 1400 MeV/c
$1400<p_e<$ 1500 MeV/c
Reconstruction of signal $e^+e^-$

- Combine single $e^+/e^-$ candidates into pairs.
- Combinatorial Background mostly due to the conversion in the detector material.
- Rejecting $e^+e^-$ pairs from random $\gamma$ or $\gamma^*$. 
- Same-event like-sign CB geometric/arithmetic mean.
  $$\text{CB} = 2\sqrt{N_{++}N_{--}}$$
  $$\text{Signal} = N_{+-} - \text{CB}$$

**Correlated CB**

Same mother particle, different intermediate photons.

**Uncorrelated CB**

Different mother particles.

Inclusive $e^+e^-$ invariant mass spectrum

- $p+p, E_{\pi^0} = 4.5$ GeV
- $\theta_{e^+e^-} > 9^\circ$
- $p_e > 100$ MeV/c
- HADES work in progress
CB reduction

- CB mainly due to conversion (close tracks/rings).
- Cut on rings:
  - Cut on the ring opening angle $\theta_{\text{Ring}} > 9^\circ$.
  - Cal dependent double ring identification (cut on $N_{\text{Cals}}$).

Jan-Hendrik Otto, http://dx.doi.org/10.22029/jlupub-7207

Cut on tracks:
Tracks with a not fitted track in the vicinity of $4^\circ$ are excluded from the analysis.
Very low CB thanks to appropriate rejection of leptons from real photon conversion.

- Vector mesons, $\omega$ and $\varphi$, are clearly seen.
- At high invariant mass $(M_{ee} > 1.02 \text{ GeV/c}^2)$ $e^+e^-$ are also reconstructed.

### Number of $e^+e^-$ pairs

<table>
<thead>
<tr>
<th>$M_{ee}$ range</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 150$ (MeV/c$^2$)</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>$150 &lt; M_{ee} &lt; 700$ (MeV/c$^2$)</td>
<td>$33 \times 10^4$</td>
</tr>
<tr>
<td>$&gt; 1020$ (MeV/c$^2$)</td>
<td>100</td>
</tr>
</tbody>
</table>

### Estimated counts of $\omega$ and $\varphi$

<table>
<thead>
<tr>
<th></th>
<th>$N_\omega$</th>
<th>$N_\varphi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$</td>
<td>16000</td>
<td>350</td>
</tr>
</tbody>
</table>
\( \eta \) meson decay into \( e^+ e^- \)

Momentum dependent invariant mass distributions

\[ \frac{1}{N_{ee'}} \frac{dN}{dM_{ee'}} (c^2/GeV) \]

\( \eta \) mass \( \sim 547 \text{ MeV/c}^2 \)

- BR (\( \eta \rightarrow e^+ e^- \)) < \( 7 \times 10^{-7} \).
  - Measured by VEPP-2M.
  - Improving BR limit with pp measurements at 4.5 GeV with HADES?


p+Nb at 3.5 GeV
HADES
BR = \( 2.3 \times 10^{-6} \)

p+p at 4.5 GeV
HADES
**ω cross section**

**Estimation of pure ω yield**

![Graph showing the estimation of pure ω yield with a peak at around 16000 ω events.]

**ω cross section in pp at 3.5 GeV**

![Graph showing the ω cross section at 3.5 GeV with fitted curves.]

Signal fit = Exponential + two gaussians.

- Signal - Expo = $\omega + q \rightarrow \sigma_{\omega+q} = 0.32$ mb
- Signal - Expo - Gaus = pure $\omega \rightarrow \sigma_\omega = 0.24$ mb

Estimation of pure $\omega$ yield

Equation: $\sigma_\omega = 0.24 < \sigma_\omega (\text{mb}) < 0.32$

**Estimation of ω yield with ρ contamination**

![Graph showing the estimation of ω yield with ρ contamination with a peak at around 20800 $\omega + \rho$ events.]

- Luminosity = $5.1 \pm 0.2 \text{ pb}^{-1}$
- BR($\omega \rightarrow e^+ e^-) = 7.3 \times 10^{-5}$
- Acc×Eff = 0.25
Conclusion and outlook

- pp at 4.5 GeV is a reference for heavy-ion collisions at SIS100 energies.
- Large statistics are measured. Data are calibrated and the analysis is ongoing.
- Raw data are extracted → work on efficiency and acceptance correction.
- Inclusive $\pi^0$, $\omega$ and $\varphi$ cross sections will be extracted.
- Ongoing simulations (PLUTO, SMASH).
- Exclusive channels studies: $\text{pp} \rightarrow \text{pp}e^+e^-$ for selective study of baryon Dalitz decay and $\rho/\omega$ decays, using missing mass.
Thank you for your attention