Probing Electromagnetic Form Factors with HADES

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GSI Helmholtzzentrum für Schwerionenforschung
Outline

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  • Form factors
  • Two – component model
• Experimental results
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Introduction

Dilepton sources at 1-2A GeV

form factors in time-like domain are important for all 3 stages
N-Delta transition vertex

\[ q^2 = q_\mu (E, -\bar{q}) q^\mu (E, \bar{q}) = E^2 - |\bar{q}|^2 \]

\[ q_{\gamma^*}^2 = M_{e^+e^-}^2 = M_{\gamma^*}^2 > 0 \text{ (time like photon)} \]

\[ \langle J_\Delta \lambda_\Delta | S | \lambda_N \lambda_{\gamma^*} \rangle, \quad \lambda_\Delta = \lambda_{\gamma^*} - \lambda_N, \quad \lambda_{\gamma^*} = 0, \pm 1, \quad \gamma_N = \pm \frac{1}{2} \]

3 different form factors (analogous to Sachs form factors for the nucleon)

\[
\frac{d\Gamma(\Delta \rightarrow Ne^+e^-)}{dq^2} = \frac{\alpha^2}{48\pi} \frac{(m_\Delta + m_N)^2}{q^2 m_\Delta^2 m_N^2} \left[ (m_\Delta + m_N)^2 - q^2 \right]^{1/2} \left[ (m_\Delta - m_N)^2 - q^2 \right]^{3/2} \left( G_M^2 + 3 G_E^2 + \frac{q^2}{2m_\Delta^2} G_C^2 \right)
\]

M. Krivoruchenko et al. Phys.Rev.D 65, 017502

✧ no data available for the time like form factors
✧ the branching ratio is not measured

at the photon point \( q^2 = 0 \)

\[ G_M(0) = 3 \]
\[ G_E(0) \approx 0 \]
\[ C_C(0) = 0 \text{ (current conservation)} \]
Two–component VDM type model

\[ F(Q^2) = (1 + \gamma Q^2)^{-2} \left[ \alpha_0 + \sum_i \alpha_i \frac{M_V^2}{M_V^2 + Q^2} \right] \]

- only ground states (\(\rho\), \(\omega\), \(\phi\)) vector mesons are used
- reproduces simultaneously nucleon space-like and time-like as well as N-\(\Delta\) space-like form factors.


alternatively one could use Extended Vector Dominance Model


A. Rustamov, Hirschegg, Austria, Jan 16-22, 2011
HADES spectrometer

• **Acceptance**
  - $\varphi \sim 2\pi$
  - $15^\circ < \theta < 85^\circ$
  - pair $\sim 30\%$

• **Momentum resolution**
  - Magnet: 0.1-0.34 Tm
  - MDC: 24 drift chambers
  - $\sigma_m \sim 2\%$ at $\rho/\omega$ region

• **Particle identification**
  - RICH
  - Time of flight
  - Pre-Shower
  - MDC (for hadrons)

• **Trigger**
  - LVL1- charged particle mult.
  - LVL2- single electron trigger
## Measured reactions

<table>
<thead>
<tr>
<th>reaction ($E_{\text{kin}}$)</th>
<th>year</th>
<th>physics goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}$C+$^{12}$C (2 A GeV)</td>
<td>2002</td>
<td>verification of the DLS data, systematic investigation of excess yield, strangeness analysis</td>
</tr>
<tr>
<td>$^{12}$C+$^{12}$C (1 A GeV)</td>
<td>2004</td>
<td>investigation of $\eta$ meson production, transition form-factors, helicity angles. Investigation of the detector performance by elastic scattering.</td>
</tr>
<tr>
<td>$^{40}$Ar+natKCl (1.76 A GeV)</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>p+p (2.2 GeV)</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>p+p (1.25 GeV)</td>
<td>2006</td>
<td>Investigation of NN bremsstrahlung and Delta Dalitz decays</td>
</tr>
<tr>
<td>d+p (1.25 GeV)</td>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>p+p (3.5 GeV)</td>
<td>2007</td>
<td>Investigation of vector meson production mechanisms. Study the experimental line shape of the omega meson</td>
</tr>
<tr>
<td>p+$^{93}$Nb (3.5 GeV)</td>
<td>2008</td>
<td>Investigation of in medium modification of the vector mesons</td>
</tr>
</tbody>
</table>
pp and np data at 1.25 GeV
p+p data at 1.25 GeV

pp → e⁺ e⁻ +X (inclusive spectrum) compared to PLUTO simulation

\[ \sqrt{s} = 2.422 \text{GeV}, \quad 2m_p + m_\eta \approx 2.424 \]

below \( \eta \) production threshold

**particle productions:**

\[ \pi^0 \] through \( \Delta \) isobar, 
\[
\sigma_{\pi^0} = \frac{2}{3} \sigma_{\Delta} + \frac{1}{3} \sum \sigma_{N^*}
\]

\( \Delta \) – matrix elements from OPE calculations

**different types of N-\( \Delta \) FF**

- 2 – component model
- fixed at the photon point

sensitivity to the N-\( \Delta \) electromagnetic vertex structure is observed!
Exclusive pion production

- **pp → ppπ^0**
  - \( E = 1.25 \text{ GeV} \)
  - \( E = 2.2 \text{ GeV} \)
- **pp → npπ^+**
  - \( E = 1.25 \text{ GeV} \)
  - \( E = 2.2 \text{ GeV} \)

- \( \Delta^* \), \( N(1440) \), \( N(1520) \)
- \( \Delta^{**} \)
- \( \text{Phase space} \)
- \( \text{total} \)

- **nice agreement with a resonance model (shape and yield)**
- **confirms an assumption in the previous slide on π^0 production**


A. Rustamov, Hirschegg, Austria, Jan 16-22, 2011
Exclusive ppe$^+e^-$ channel (1)

Do we really measure $pp \rightarrow p \Delta^+ \rightarrow ppe^+e^-$

Let’s check by detecting 3 particles in final state: $p$, $e^+$, $e^-$!

mass of missing particle ($M_{\text{miss}}$)

$M_{ee} > 140 \text{ GeV}/c^2$

Data points
- simulated $\Delta$ Dalitz decay

Invariant mass distribution of $pe^+e^-$

$M_{ee} > 140 \text{ GeV}/c^2$

Data points
- simulated $\Delta$ Dalitz decay
Exclusive ppe$^+e^-\text{ channel (2)}$

- cm. angular distribution of pe$^+e^-$
- data points
- simulated \(\Delta\) Dalitz

- helicity angle
- \(1+b \cos^2(\theta)\)
- \(b = 1.1 \pm 0.32\)

- consistent with OPE calculations
- consistent with QED calculations (neglecting Coulomb form factor)

- helicity angle: angle between a lepton in the \(\gamma^*\) rest frame, and a \(\gamma^*\) in the \(\Delta\) rest frame.

- \(\text{indeed pp data at high } e^+e^-\text{ masses is dominated by Delta Dalitz decay}\)
- first measurement of \(\Delta\) Dalitz branching ratio
- in agreement within 20% with QED value of 4.2*10^{-5}
in intermediate mass range, n+p data is enhanced by a factor of ~10 (not only $\Delta$ contributes), NN bremsstrahlung?

**Two Eff. Lagrangian based approaches**
diagrams are added-up coherently!

L. Kaptary and B. Kämpfer, NPA 764 (2006), 338
R. Shyam and U. Mosel, PRC 67 (2003), 065202
New calculations


again, sensitivity to em. Form factors is observed!
going to higher energy

p+p data at 3.5 GeV
• particle production
  • $\pi$ multi resonance
  • $\eta$, $\omega$, $\rho$ via phase space
  • $\Delta$ through $1\pi$ exchange
• particle decays
  • form factors
  • mass dep. Width
    • Fröhlich et al, arxiv:0708.2382

Δ form-factor is fixed at the photon point

• cross sections in $4\pi$ [mb]
  • $\pi$: $16 \pm 2.6$ (from data)
  • $\Delta$: $7.5$ fixed from PYTHIA
  • $\eta$: $0.93 \pm 0.2$ (fit to data)
  • $\omega$: $0.25 \pm 0.05$ (fit to data)
  • $\rho$: $0.38 \pm 0.07$ (fit to data)

The PDG 2010 value for $\eta \rightarrow e^+ e^-$ BR has to be scaled down by a factor of at least 3.
2-component model for $\Delta$ form-factor

$\sigma_\rho$ is scaled down by a factor of 2

A PDG 2010 value for $\eta \rightarrow e^+e^-$ has to be scaled down by a factor of 12.

Inclusion of form-factors for N-$\Delta$ vertex, explains the experimentally observed structure below $\rho$ meson pole mass.
HADES future experiments

- Upgraded HADES
  - new RPC detectors (50-80ps time res.)
  - new MDCI detectors
  - forward wall
  - ~20 kHz event rates for Au+Au (DAQ upgrade)
    - Au+Au at 1.25 AGeV
    - Ag+Ag at 1.65 AGeV
    - pion induced reactions (2012)
- HADES moves to FAIR/SIS100 (after 2016)
Pion beams

direct excitation of resonances

\[ \pi^- + p \rightarrow n \, e^+e^- \]

\[ \pi^- + p \rightarrow n \, \rho \quad (l=1/2, \, l=3/2) \]

\[ \pi^- + p \rightarrow n \, \omega \quad (l=1/2 \, \text{only}) \]

investigation of \( \rho/\omega \) mixing

Access to em. time-like form factors for higher resonances!

A. Titov, B. Kaempfer EPJA 12(2001)217
Summary

- Baryon resonances have strong impact on dilepton spectra
- Time-like electromagnetic transition form-factors are necessary for their differential decay rate calculation
- Already at 1.25 GeV p+p data the sensitivity to the Δ-N transition structure is observed
- For the first time the Δ Dalitz decay process is measured
- The n+p data is better described by taking into account pion electromagnetic transition form factor
- At 3.5 GeV, the data exhibits a clear structure below the ρ meson pole mass
- This structure is satisfactorily described by using the form factor model for the N-Delta transition vertex
- Sensitivity of data to the η → e^+e^- branching ratio is observed
The HADES collaboration

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17 institutions
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Backup Slides
η Form-Factor

\[ \frac{1}{N_{\eta}} \frac{dN}{dM_{e^+e^-}} \] [1/GeV/c^2]

- QED
- VMD
- exp (HADES)

Preliminary
Exclusive ppe$^+e^-$ channel

$p + p$ 1.25 GeV

$\theta_{e^+e^-} > 9^\circ$

preliminary