Resonance production and decay in pion induced collisions with HADES

A major goal of the High Acceptance Di-Electron experiment (HADES) [1] at GSI is to study the electromagnetic properties of hadronic matter in the 1-3.5 GeV/nucleon incident energy range. The present interpretation of dilepton spectra measured in heavy-ion reactions at various energies is based on hadronic models, which predict in-medium modifications of the $\rho$ meson spectral function due to its coupling to resonance-hole states [2]. In the energy range of the HADES experiments, the $\rho$ meson is mainly produced in primary $NN$ or secondary $\pi N$ collisions, which opens the possibility to constrain the interpretation of medium effects by measuring dilepton emission in elementary reactions and better understand the relation between the couplings of the baryonic resonances to the $\rho$ meson and the electromagnetic structure of the corresponding baryonic transitions. Recently, HADES collected data in $\pi^+ N$ reactions at four different pion beam momenta (0.65, 0.69, 0.748 and 0.8 GeV/c) [3]. In this measurement two targets (polyethylene and carbon) were used with the aim to subtract events from scattering on carbon and identify pure contribution from scattering on protons. Exclusive channels with one pion ($\pi^+ p$), two pions ($\pi^+ \pi^-$ and $\rho\pi\pi^0$) and dileptons ($\pi^+ e^- c^+$) in the final state were identified. The normalization was done based on the elastic scattering ($\pi^- p$) channel with the cross sections taken from the SAID database [4]. Results for exclusive channels with two pions in the final state have been included in a combined partial wave analysis (PWA) of the Bonn-Gatchina group [5]. The obtained solution provides the excitation function of two-pion production around the pole of the $N(1520)\Delta_{13}$ resonance with the decomposition into contributing channels, in particular coupling to the intermediate $\rho$ meson. The $\rho$ spectral distribution obtained from the partial wave analysis is used to compute the respective contribution to the exclusive $\pi^+ e^- c^+$ channel, assuming strict Vector Meson Dominance. The results of this analysis will be presented.
probes of vector meson in medium

early motivations

« short-lived mesons in medium »

\[ m_{e^+e^-} = \sqrt{p_{e^+}p_{e^-} \sin \theta_{e^+e^-}} \]

best candidate
\( \rho(770) \ 1^- \ c_T = 1.3 \text{ fm/c} \)
\( \Gamma = 150 \text{ MeV} \)

- rare probes \((e^+e^- \ BR \sim 10^{-5})\)
- do not interact strongly with nuclear matter
ρ in-medium: hadronic models

baryons are the main players

« vacuum »

\[ \Sigma_\rho (M) = -i m_\rho \Gamma_{\pi\pi} (m) \]

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

S. Leupold, V. Metag, U. Mosel

« in-medium broadening »

in-medium spectral function depends on \( \rho \text{NN}^* \) coupling

main players:

\( \text{N}(1520), \Delta(1620), \text{N}(1720), \ldots \)

Coupling of \( \rho \) to baryonic resonances can be directly studied in \( \text{NN} \) and \( \pi\text{N} \) collisions at 1-2 GeV via \( N^* (\Delta) \rightarrow N e^+ e^- \) decays

R. Rapp, G. Chanfray, J. Wambach

R. Rapp, J. Wambach
relation to electromagnetic structure of baryons

\[ N^* \rightarrow Ne^+e^- \]
\[ F(Q^2) \]
\[ q^2 > 0 \]
\[ q^2 < 0 \]
\[ R \]
\[ N \]
\[ e^+ \]
\[ e^- \]

\[ \rho^* \rightarrow \gamma^* \]
\[ \omega, \phi \]

"\( \rho \) meson production and decay"  
"Dalitz decay of baryonic resonances"

Vector Meson Dominance Model

NEVER MEASURED!
Resonance description:

\[ W - \text{arbitrary resonance mass} \]

Relativistic Breit-Wigner distribution

\[ g_R(W) = A \frac{W^2 \Gamma_{tot}(W)}{(W^2 - M_R^2)^2 + W^2 \Gamma_{tot}^2(W)} \]

with \( \Gamma_{tot}(W) = \Gamma_{\pi N}(W) + \Gamma_{\gamma N}(W) + \Gamma_{e^+ e^- N}(W) + \ldots \)

Dalitz decay requires a model for the form factors in the timelike region

**QED point-like \( R\gamma^* \) vertex**

- coupling constants fixed from \( R \rightarrow N\gamma \)
- strong dependence on spin, parity

---

M. Zetenyi, G. Wolf  

---

**Extended VDM**

M.I. Krivoruchenko et al.  
Example: $\Delta \rightarrow Ne^+e^-$

\[
\frac{d\Gamma(\Delta \rightarrow Ne^+e^-)}{dq^2} = f(m_{\Delta}, q^2) \left( |G_M(q^2)| + 3 |G_E(q^2)| + \frac{q^2}{2m_{\Delta}} |G_C(q^2)| \right)
\]

Time Like \ ($q^2 > 0$)
\(\Delta (J=3/2) \rightarrow N (J=1/2) \gamma^*\) transition:

two-component quark model

covariant constituent quark model

**Q. Wann, F. Iachello**

**G. Ramalho, M. T. Peña**

M. I. Krivoruchenko et al.
HADES Spectrometer

- SIS18 beams: protons (1-4 GeV), nuclei (1-2 AGeV)
  pions (0.4-2 GeV/c) – secondary beam
- spectrometer with $\Delta M/M$ - 2% at $p/\omega$
- **detector for rare probes:**
  - dielectrons: $e^+, e^-$
  - strangeness: $\Lambda, K^{\pm, 0}, \Xi^-, \varphi$
- particle identification $\pi/p/K$ – combined $dE/dx$ (MDC) and TOF: $\sigma_{\text{tof}} \approx 80$ ps (RPC)
  - electrons: RICH (hadron blind), TOF/Pre-Shower
- upgrade(2010): new DAQ (~50 kHz) with Au+Au collisions

**Geometry**
- full azimuthal, polar angles $18^\circ$ - $85^\circ$
- $e^+ e^-$ pair acceptance $\approx 0.35$
PHYSICS OPPORTUNITIES WITH MESON BEAMS

William J. Briscoe\textsuperscript{a,1}, Michael Döring\textsuperscript{a,2}, Helmut Haberzettl\textsuperscript{a,3}, D. Mark Manley\textsuperscript{b,4}, Megumi Naruki\textsuperscript{c,5}, Igor I. Strakovsky\textsuperscript{a,6}, Eric S. Swanson\textsuperscript{d,7}

Over the past two decades, meson photo- and electroproduction data of unprecedented quality and quantity have been measured at electromagnetic facilities worldwide. By contrast, the meson-beam data for the same hadronic final states are mostly outdated and largely of poor quality, or even non-existent, and thus provide inadequate input to help interpret, analyze, and exploit the full potential of the new electromagnetic data. To reap the full benefit of the high-precision electromagnetic data, new high-statistics data from measurements with meson beams, with good angle and energy coverage for a wide range of reactions, are critically needed to advance our knowledge in baryon and meson spectroscopy and other related areas of hadron physics. To address this situation, a state-of-the-art meson-beam facility needs to be constructed. The present paper summarizes unresolved issues in hadron physics and outlines the vast opportunities and advances that only become possible with such a facility.
πN → ππN status

- knowledge on N* couplings to ρN, Δπ, σN based on 240,000 events (no differential distributions)

- most of data $1.3 < \sqrt{s} < 2$ GeV from Manley et al. PRD30 (1984) 904
- very scarce data base for pion-nucleon reactions
- differential distributions are even more scarce (or missing)
- more recent data (TRIUMF, LAMPF, BNL) do not cover $1.3 < \sqrt{s} < 2$ GeV region

V. Shklyar et al. (GiBUU coupled-channel model) arxiv: 1409.7920v1
HADES physics for pion beams (2014)

- Resonance excitation can be controlled by the variation of the projectile (pion) momentum.
- HADES starts with $p = 0.656/0.69/0.748/0.8$ GeV/c, $\sqrt{s} = 1.46-1.55$ GeV: N(1520).
- $\pi+\pi$- production: coupling of $\rho$ to resonance.
- $e^+e^-$ never measured from pion induced reactions.
- Resonance Dalitz decays $R \rightarrow Ne+e^-$ (reference for $p+\text{Nb}$).
- Strangeness production of nucleus: $K^\pm, K^0, \phi$.
- High statistics differential distributions needed.

- Reaction: $N+\text{Be}$ $8-10 \cdot 10^{10}$ $N_2$ ions/spill (4s).
- Secondary $\pi^-$ with $l \approx 3-4 \cdot 10^5$/spill @ 0.7 GeV/c, limited by the radioactivity safety.
- Pion momentum $\Delta p/p = 2.2\%$ ($\sigma$) and $\approx 50\%$ acceptance @ central momentum.
- In beam tracking system: $(X1,Y1/X2,Y2)$ for pion momentum determination: $\Delta p/p = 0.3\%$. 

10
HADES physics for pion beams (2014)

D. M. Manley et al.

<table>
<thead>
<tr>
<th>$W$ (MeV)</th>
<th>$\pi^0\pi^0n$</th>
<th>$\pi^+\pi^-n$</th>
<th>$\pi^0\pi^-p$</th>
<th>$\pi^0\pi^+p$</th>
<th>$\pi^+\pi^+n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1340</td>
<td>0.59</td>
<td>1.27</td>
<td>0.12</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>1375</td>
<td>1.18</td>
<td>2.77</td>
<td>0.39</td>
<td>0.52</td>
<td>0.10</td>
</tr>
<tr>
<td>1400</td>
<td>1.45</td>
<td>3.87</td>
<td>0.76</td>
<td>0.70</td>
<td>0.16</td>
</tr>
<tr>
<td>1440</td>
<td>1.71</td>
<td>5.09</td>
<td>1.72</td>
<td>1.20</td>
<td>0.25</td>
</tr>
<tr>
<td>1460</td>
<td>1.53</td>
<td>5.49</td>
<td>2.43</td>
<td>1.48</td>
<td>0.29</td>
</tr>
<tr>
<td>1480</td>
<td>2.10</td>
<td>5.74</td>
<td>3.33</td>
<td>1.99</td>
<td>0.35</td>
</tr>
<tr>
<td>1500</td>
<td>2.29</td>
<td>5.96</td>
<td>4.22</td>
<td>2.57</td>
<td>0.44</td>
</tr>
<tr>
<td>1520</td>
<td>2.47</td>
<td>6.10</td>
<td>4.83</td>
<td>3.32</td>
<td>0.56</td>
</tr>
<tr>
<td>1540</td>
<td>2.64</td>
<td>6.39</td>
<td>4.82</td>
<td>4.54</td>
<td>0.72</td>
</tr>
<tr>
<td>1565</td>
<td>2.69</td>
<td>6.92</td>
<td>4.67</td>
<td>6.33</td>
<td>1.04</td>
</tr>
<tr>
<td>1595</td>
<td>2.96</td>
<td>8.17</td>
<td>4.88</td>
<td>8.57</td>
<td>1.51</td>
</tr>
<tr>
<td>1620</td>
<td>2.96</td>
<td>8.17</td>
<td>4.88</td>
<td>8.57</td>
<td>1.51</td>
</tr>
<tr>
<td>1640</td>
<td>3.17</td>
<td>10.47</td>
<td>5.71</td>
<td>9.81</td>
<td>1.77</td>
</tr>
<tr>
<td>1660</td>
<td>3.21</td>
<td>10.86</td>
<td>6.07</td>
<td>9.76</td>
<td>1.84</td>
</tr>
<tr>
<td>1680</td>
<td>2.79</td>
<td>10.68</td>
<td>6.28</td>
<td>9.47</td>
<td>1.79</td>
</tr>
<tr>
<td>1700</td>
<td>3.04</td>
<td>10.16</td>
<td>6.17</td>
<td>8.91</td>
<td>1.55</td>
</tr>
<tr>
<td>1725</td>
<td>2.53</td>
<td>9.12</td>
<td>5.89</td>
<td>8.34</td>
<td>1.31</td>
</tr>
<tr>
<td>1755</td>
<td>2.54</td>
<td>8.04</td>
<td>5.25</td>
<td>8.24</td>
<td>1.49</td>
</tr>
<tr>
<td>1790</td>
<td>1.68</td>
<td>7.21</td>
<td>4.50</td>
<td>9.54</td>
<td>1.48</td>
</tr>
<tr>
<td>1830</td>
<td>1.30</td>
<td>7.20</td>
<td>4.24</td>
<td>10.67</td>
<td>2.17</td>
</tr>
<tr>
<td>1870</td>
<td>1.80</td>
<td>7.47</td>
<td>4.54</td>
<td>11.39</td>
<td>2.84</td>
</tr>
<tr>
<td>1910</td>
<td>2.05</td>
<td>7.76</td>
<td>4.84</td>
<td>10.95</td>
<td>3.16</td>
</tr>
</tbody>
</table>

see also SAID database
elastice events (C subtr.) | SAID compared

- beam momenta adjusted to measured (HADES spectrometer) values: 652, 685, 740, 790 MeV/c
- corrections for energy loss
- obtained scaling used then in $\pi^+\pi^-$, $\pi^0\pi^-$, $e^+e^-$

$\pi p$ miss. mass$^2$

685 MeV/c

PE target $p$, Carbon

$60^\circ < \theta_{CM} < 110^\circ$

MC simulation: acc & eff correction

exp normalized to the same area

$\pm 10\%$

$\theta_{CM}$
(n $\pi^+\pi^-$) events – scaling from elastic

\begin{align*}
\pi^+\pi^-\text{ missing mass} & \quad \pi^+\pi^-\text{ missing mass}
\end{align*}
(n π⁺π⁻) – events with signal extracted

- **goal**: separate signal (π⁻p) from background (π⁻C) based on PE events and C events
- relative normalization of PE events and C events deduced from π⁻p elastic scattering

**procedure**: event from C **correlated** with event from PE based on $\chi^2$

- (miss. mass + momentum of π⁺, π⁻, n)
- (miss. mass + momentum of π⁰, π⁻, p)

**PWA done with:**
- four ππ data samples from HADES
- photon- and pion-induced reactions
### Baryon data base

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi N \rightarrow \pi N$ ampl.</td>
<td>SAID or Hoehler energy fixed</td>
<td>$E, G, T, P$ (CB-ELSA, CLAS)</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi N$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, T, P, E, G, H$</td>
<td>$\frac{d\sigma}{d\Omega}$ (MAMI)</td>
</tr>
<tr>
<td>$\gamma n \rightarrow \pi N$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, T, P$</td>
<td>$\frac{d\sigma}{d\Omega}$ (MAMI)</td>
</tr>
<tr>
<td>$\gamma n \rightarrow \eta n$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma$</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \eta p$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma$</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \eta' p$</td>
<td></td>
<td>$T, P, H, E$ (CB-ELSA)</td>
</tr>
<tr>
<td>$\gamma p \rightarrow K^+ \Lambda$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, P, T, C_x, C_z, O_x, O_z$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma$</td>
</tr>
<tr>
<td>$\gamma p \rightarrow K^0 \Sigma^0$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, P, C_x, C_z$</td>
<td>$\Sigma, P, T, O_x, O_z$ (CLAS)</td>
</tr>
<tr>
<td>$\gamma p \rightarrow K^0 \Sigma^+$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, P$</td>
<td>$\Sigma, P, T, O_x, O_z$ (CLAS)</td>
</tr>
<tr>
<td>$\pi^- p \rightarrow \eta n$</td>
<td>$\frac{d\sigma}{d\Omega}$</td>
<td>$\frac{d\sigma}{d\Omega}$ (CRYSTAL BALL)</td>
</tr>
<tr>
<td>$\pi^- p \rightarrow K^0 \Lambda$</td>
<td>$\frac{d\sigma}{d\Omega}, P, \beta$</td>
<td></td>
</tr>
<tr>
<td>$\pi^- p \rightarrow K^0 \Sigma^0$</td>
<td>$\frac{d\sigma}{d\Omega}, P (K^0 \Sigma^0)$</td>
<td>$\frac{d\sigma}{d\Omega}, P, \beta$</td>
</tr>
<tr>
<td>$\pi^- p \rightarrow K^0 \Sigma^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\pi^- p \rightarrow \pi^0 \pi^0 n$</td>
<td>$\frac{d\sigma}{d\Omega}$ (CRYSTAL BALL)</td>
<td>$\frac{d\sigma}{d\Omega}$ (HADES)</td>
</tr>
<tr>
<td>$\pi^- p \rightarrow \pi^+ \pi^- n$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^0 \pi^0 p$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, E, I_c, I_s$</td>
<td></td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^0 \eta p$</td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, I_c, I_s$</td>
<td></td>
</tr>
<tr>
<td>$\gamma p \rightarrow \pi^+ \pi^- p$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma p \rightarrow \omega p$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma p \rightarrow K^* (890) \Lambda$</td>
<td></td>
<td>$\frac{d\sigma}{d\Omega}, I_c, I_s$ (CLAS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, \rho_i^{ij}, I_i^{ij}, I_i^{ij}, I_i^{ij}$ (CB-ELSA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{d\sigma}{d\Omega}, \Sigma, \rho_i^{0i}$ (CLAS)</td>
</tr>
</tbody>
</table>
PWA: initial waves

\[ \pi^- p \rightarrow \pi^0 \pi^0 n \]

\[ \gamma p \rightarrow \pi^0 \pi^0 p \]

- \( D_{13}(1520)+.. \)
- \( P_{11}(1440)+.. \)
- \( D_{13}(1520)+.. \)
- \( P_{11}(1440)+.. \)
- \( F_{15}(1680)+.. \)

Crystal Ball

MAMI

in energy range of 1.45 - 1.55 GeV

in 2-pion production only few resonances matter: \( D_{13}(1520), P_{11}(1440) \)
PWA: final states

\[ \pi^- p \rightarrow \pi^0\pi^0 n \quad \gamma p \rightarrow \pi^0\pi^0 p \]

Dominant channels in \(2\pi^0\) are: \(\Delta\pi\) and \(N\sigma\) (\(2\pi^0\) in \(I = 0\))
PWA example results (n $\pi^+\pi^-$) in the acceptance of 685 MeV/c

Invariant masses $n\pi^-, n\pi^+, \pi^+\pi^-$

$\rho$ – total

$\rho$ – s-channel

$\rho$ – $D_{13}(1520)$

Angular distribution in CM $\cos \theta$ of $\pi^+, \pi^-, n$

Helicity (angular proj. of one of particles in the frame of $n\pi^-, n\pi^+, \pi^+\pi^-$)
PWA $\pi^+\pi^-$ inv. mass – main contributions

Total cross section (from PWA solution)

<table>
<thead>
<tr>
<th>$M (\pi^+ \pi^-)$</th>
<th>0685</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 1/2 + all</td>
<td><img src="image1.png" alt="Graph 1" /></td>
</tr>
<tr>
<td>1/2 3/2 - all</td>
<td><img src="image2.png" alt="Graph 2" /></td>
</tr>
<tr>
<td>s-chan D(1232)-pi</td>
<td></td>
</tr>
<tr>
<td>s-chan N-sigma</td>
<td></td>
</tr>
<tr>
<td>s-chan N(940)-rho</td>
<td></td>
</tr>
</tbody>
</table>

Inside HADES acceptance:

<table>
<thead>
<tr>
<th>$M (n \pi^-)$</th>
<th>0685</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/21/2 + all</td>
<td><img src="image3.png" alt="Graph 3" /></td>
</tr>
<tr>
<td>1/23/2 - all</td>
<td></td>
</tr>
<tr>
<td>s-chan D(1232)-pi</td>
<td></td>
</tr>
<tr>
<td>s-chan N-sigma</td>
<td></td>
</tr>
<tr>
<td>s-chan N(940)-rho</td>
<td></td>
</tr>
</tbody>
</table>

**INPUT:** $D_{13}(1520), P_{11}(1440)$

**OUTPUT:** $\Delta\pi, N\sigma, N\rho$
PWA $\pi^+\pi^-$ inv. Mass – $\rho$ contribution

**Total cross section** (from PWA solution)

<table>
<thead>
<tr>
<th>$M(\pi^+\pi^-)$</th>
<th>0685</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Graph 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph 1" /></td>
</tr>
</tbody>
</table>

**Inside HADES acceptance:**

<table>
<thead>
<tr>
<th>$M(\pi^+\pi^-)$</th>
<th>0685</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Graph 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2.png" alt="Graph 2" /></td>
</tr>
</tbody>
</table>

**FOR DILEPTON ANALYSIS:**

- **$N(1520)D_{13}$ coupling to $\rho N$: 17%**
- **Total $\rho N: 2.3$ mb (for 685 MeV/c)**

- Dominated by s-channel
  - resonant $D_{13}(1520)$ production
- Strong interferences between 1/2- states with izospin 1/2 and 3/2
PWA results (n $\pi^+\pi^-$) – cross section

$\gamma p \rightarrow \pi^+\pi^- p$

(SAPHIR, CLAS)

...mind the gap!

HADES data are really unique in this energy range!
**e^+e^- inclusive – PE/C channels ratio**

- **black dots** – PE data (e^+e^- sig.)
- **red** – C data (scaling based on elastic events)

- **m_{inv}^{e^+e^-}**
- **m_{miss}^{e^+e^-}**

- **m_{inv}^{e^+e^-} > 0.12 [GeV/c^2]**

---

- statistics from carbon data too low for subtraction
- free + "quasi-free" π^-p → e^+e^-n events selected by miss. mass cut
- e^+e^- yield from proton to carbon ~ 1:2 (±20%)
### e⁺e⁻ cocktail ingredients “cookbook”

- contributions from $\pi^+p$ and $\pi^-C$ added together (ratio 1 : 2 experimentally deduced)
- $\pi^+p$ mom. 0.69 GeV/c ($\sqrt{s}=1.492$ GeV)  $\pi^-C$ average $\sqrt{s}=1.461$ GeV (mom. 0.65 GeV/c)

<table>
<thead>
<tr>
<th>channel</th>
<th>$\sigma$ [mb]</th>
<th>data source</th>
<th>Model</th>
</tr>
</thead>
</table>
| $\pi^0$ Dalitz from: $\pi^-p \to np^0$ | 9.2 | Landolt-Börnstein constant (±1 mb) for $0.6 < p < 0.72$ GeV/c | $N(1520) - 45\%$  $N(1440) - 45\%$  $N(1535) - 10\%$
| single $\pi^0$ Dalitz from: $\pi^-p \to np^0\pi^0$ $\pi^-p \to pp^-\pi^0$ sum: 7.4 | 2 x 1.8 <br> 3.72 | Crystal Ball Landolt-Börnstein (for $\sqrt{s} = 1.461$ GeV 20% reduction) | $\Delta\pi^0 \to (N\pi)p^0$  $\to (N\pi)e^+e^-\gamma$
| $\Delta$ Dalitz from: $\pi^-p \to \Delta\pi$ | 8.4 | From single and double pion (isospin relations) | $\Delta^0\pi^0 \to ne^+e^-\pi^0$
| $N(1520)$ Dalitz from: $\pi^-p \to N(1520)$ | 20.5 | Phys. Rev. C86, 065209 (2012) | Wolf / Zetenyi “QED” model (pole) $BR = 4.0 \cdot 10^{-5}$  $N(1520) \to ne^+e^-$
| $\eta$ Dalitz from: $\pi^-p \to n\eta$ | 0.3 (p) | Parameterization from Landolt-Börnstein (see next slide) |
Towards better cross sections

**detailed balance theorem**
*(at equilibrium, each elementary process should be equilibrated by its reverse process)*

\[ |p_1| = |p_2| \]

\[
\frac{
\left[
\left(M^2 - (m_1 + m_2)^2\right)
\left(M^2 - (m_1 - m_2)^2\right)
\right]^{1/2}
}{2M}
\]

Real photon reactions decomposed:
- \(N(1535)S_{11} + \text{t-channel contribution} \Delta(1232)P_{33}\)
- \(N(1520)D_{13}\)
- \(N(1440)P_{11}\)

Cross section estimation for reverse reaction: about \(\times 2\) times more

„at real photon photon point“
(no form factors here)

„virtual photon“: \(\times \frac{1}{137}\)

\(D_{13}\) is only part (50%) of the total cross section.
e⁺e⁻ simulated (full analysis) cocktail

LEGEND
- total
- [9.2 mb] π⁰ → e⁺e⁻γ
- [7.4 mb] 2π⁰ (→ e⁺e⁻γ)
- [1.0 mb] η → e⁺e⁻γ
- [PWA: D₁₃ × 2] N(1520) → n e⁺e⁻ (QED)
- [8.4 mb] Δ(1232) → n e⁺e⁻ (QED)

CS need to be multiplied by BR

Branching Ratios
π⁰: 0.012, η: 0.006
N(1520): 4⋅10⁻⁵, Δ(1232): 4⋅10⁻⁵

- Large η contribution
- ρ(PWA) = 2.3 mb
VMD: $\sim 1/M^3 \rightarrow \times 4.6$

Dilepton cocktail
- PLUTO event generator + full analysis

Ingo Fröhlich et al.
Exclusive $e^+e^-$ cocktail (PE target)

**missing mass for**

$$m_{e^+e^-}^{\text{inv}} > 0.12 \ [\text{GeV}/c^2]$$

**invariant mass for**

$$0.9 < m_{e^+e^-}^{\text{miss}} < 1.03 \ [\text{GeV}/c^2]$$

$\pi^- p \rightarrow n e^+ e^-$

(VMD: $\sim 1/M^3$) $\rho \rightarrow e^+ e^-$

**LEGEND**

- total PE (p+C)
- N(1520) Dalitz
- $\eta$ Dalitz
- $\Delta(1232)$ Dalitz
- $\rho \rightarrow e^+e^-$

- $\rho$ cross sec. and mass shape derived from $\pi^- p \rightarrow n \pi^+ \pi^-$ empirical way of taking into account VDM form factors for electromagnetic decays
  \( \rightarrow \) excess consistent with $\rho \rightarrow e^+ e^-$

very preliminary
Controversial yield predictions:
Highly dependent on $\rho NN^*$ couplings and $\rho/\omega$ interference
(important $\leq \rho/\omega$ threshold!)

\[
\begin{align*}
\text{M.F.M. Lutz, B. Friman, M. Soyuer} \\
\text{Nucl. Phys. A 713 (2003) 97}
\end{align*}
\]

\[
\begin{align*}
\text{B. Kaempfer, A. Titov, R. Reznik} \\
\text{Nucl. Phys. A 721 (2003) 583}
\end{align*}
\]

Very large differences in $e^+e^-$ yield up to factor 10!
Dilepton production in pion-nucleon collisions in an effective field theory approach

$\pi + N \to N + e^+ + e^-$  
Miklós Zétényi* and György Wolf†

**Lagrangian model:** real $\gamma$+VMD coupling

$Z \ & \ W$: higher $\sqrt{s} = 1.5 \ GeV$ ($\pi^\pm p$)  
HADES: $\sqrt{s} = 1.492 \ GeV (\pi^\pm p)$  
and $\sqrt{s} = 1.461 \ GeV (\pi^\pm C)$

**Folding the model** with 1-dim (acc*eff) curve:

- a) s-  
- b) u-  
- c) t-channel diagrams  
- d) contact interaction  
- e) vector meson exchange diagram  
- f) s-  
- g) u-channel baryon resonance contributions

$\sqrt{s} = 1.5 \ GeV$

$m_{e^+e^-}^{inv} \ [GeV/c^2]$
Exclusive $e^+e^-$ - more observables

$\gamma n \rightarrow p\pi^-$ (for real photon, no FF)

For:

For: $m^{inv}_{e^+e^-} > 0.12 \ [GeV/c^2]$

$0.9 < m^{miss}_{e^+e^-} < 1.03 \ [GeV/c^2]$
SUMMARY

- HADES & pion beam is an unique tool to understand in details baryon - \( \rho \) couplings
  - Significant off-shell \( \rho \) contribution originating from \( N(1520)D_{13} \) shown by combined PWA and e\(^+\)e\(^-\) data

Future activity:

- Joint venture of PWA analysis and dilepton channels
- High statistics beam energy scan: continuation and extension to third resonance region
- Hadronic final states, one-pion, two-pion, hyperon production to control resonance excitation
- HADES upgrade: electromagnetic calorimeter - neutral final states: \( \eta / \pi / \omega \)
- Di-electron measurements: \( \rho \)R couplings \( S_{13}(1620), D_{33}(1700), P_{13}(1720) \)
Special thanks to Andrey V. Sarantsev (Bn-Ga group)