Double charge $\pi$ production in pp, np reactions at 1.25 GeV with HADES

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Outline of the talk

- Motivation
- Introduction: world data, theoretical models
- Data analysis
- Comparison with the models
- Conclusion
Double-$\pi$ production in NN collision is of a particular interest in view of studying of simultaneous excitation of the two baryons and their subsequent decays.

Specific interest in pp and pn is:

\[ N^*(1440) \rightarrow \Delta \pi, \ N^*(1440) \rightarrow N\sigma, \ N^*(1440) \rightarrow \rho N, \ \Delta \Delta \ \text{excitation.} \]

Important to look in parallel to $\pi^+\pi^-$ production in pp and np collision in order to learn more and understand difference in inclusive spectra of $e^+e^-$ in connection to HADES dilepton results.
Two-pion production in proton-proton collisions is one way to obtain information about the nucleon-nucleon, pion-nucleon and pion-pion interactions. The production mechanism is likely to be dominated by resonance production.
Existing models for the pp-$\rightarrow$pp$\pi^+\pi^-$ reactions


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- **Full model**: 713.2 µb
- **$N^*(1440) \rightarrow \Delta\pi$**: 266.2 µb
- **$N^*(1440) \rightarrow N\sigma$**: 219.7 µb
- **Double-$\Delta$**: 183.7 µb
- **Non-resonant part**: 5.66 µb

- **Full model**: 728.86 µb
- **$N^*(1440) \rightarrow \pi\Delta$**: 210.60 µb
- **$N^*(1440) \rightarrow N\sigma$**: 170.61 µb
- **$\Delta_{S\text{-wave}} \& \Delta\Delta$**: 180.08 µb
The HADES detector

- Beams from SIS18: pions, protons, nuclei
- Spectrometer with high invariant mass resolution - 2% at $\rho/\omega$
- Versatile detector for rear particle decays:
  - dielectrons (e+,e-)
  - strangeness: $\Lambda$, $K^{\pm,0}$, $\Xi^-$, $\phi$
  - Upgrade(2010): new DAQ, Tof-RPC ($\sim 20$ KHz), ($\sigma_{\text{tof}} \sim 80$ ps)

**Geometry**

Full azimuth, polar angles 18° - 85°
e+e- pair acceptance $\approx 0.35$
~ 80,000 channels,
segmented solid or LH$_2$ targets
• Data corrected for the tracking and PID efficiency.
  • only statistical errors presented
  • systematical errors on the order of 12 % (normalization, eff correction)

• Models filtered by the acceptance, normalized to the corresponding cross-sections.

Several distributions can be presented, according to the models most sensitive one are:
  • invariant mass of $\pi^+\pi^-$ and $(M_{\pi^+\pi^-})$
  • cos of opening angle in CM between $\pi^+\pi^-$ ($\cos(\alpha_{\pi^+\pi^-\text{CM}})$)
Comparison of the models with HADES data

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HADES data
Xu Cao et al.
Valencia model
phase space

DATA absolutely normalized
models normalized to the area
Following modifications have been done to the Valencia code. These changes are based on WASA analysis of channel $pp \rightarrow pp\pi^0\pi^0$. Events including modifications have been provided by T. Skorodko.

1. **Modification of the partial decay width between the decay $N^*$ $\rightarrow N\sigma$ via $\Delta$ and direct**

$$\frac{\Gamma(N^* \rightarrow \Delta\pi)}{\Gamma(N^* \rightarrow N\sigma)} = 1.$$  

<table>
<thead>
<tr>
<th>PDG</th>
<th>Bonn-Gatchina PWA</th>
<th>WASA analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.9(1)</td>
<td>1.0(1)</td>
</tr>
</tbody>
</table>


2. **Strength of $N^*(1440)$**

After 'modification' the Roper behaves as s-channel resonance: rises in beginning and decreases later.

3. **$\rho$ exchange in double $\Delta$ excitation**

Amplitude for the Double-$\Delta$ excitation, consists of two parts: one for $\pi$-exchange and second for $\rho$. The $\rho$ part has been suppress by fact of 12. ($\rho$-exchange is not as well fixed by exp. observables as $\pi$-exchange.)

Influence of the modifications of the model

\[ pp \rightarrow pp\pi^0\pi^0 \text{ at } T_p = 1.2 \text{ GeV} \quad \text{WASA} \]

1. Dotted: original model
2. Dashed: \( N^* \rightarrow \Delta\pi \) and \( N^* \rightarrow N\sigma \) branching ratio
3. Dashed-dotted: readjustment of strength of the \( N^*(1440) \)
4. Red: \( \rho \) exchange in double \( \Delta \) excitation

Influence of the modifications of the model

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Improvement in the description of the data in both observables: $M_{\pi^{+}\pi^{-}}$ and $\cos^{\text{CM}}(\delta_{\pi^{+}\pi^{-}})$.

Modified model provides a rather good agreement of both WASA ($\pi^{0}\pi^{0}$) and HADES ($\pi^{+}\pi^{-}$).

Still some space for the improvement of the model …
Quasi-free np reaction

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• Forward Wall:
  Plastic scintillators covering $\theta$ angles up to $7^\circ$. Detector dedicated to tag proton spectator

• Cells in FW:
  140 small 4x4cm $\rightarrow (0^\circ < \theta < 2^\circ)$
  64 middle 8x8cm $\rightarrow (2^\circ < \theta < 3.3^\circ)$
  84 large 16x16cm $\rightarrow (3.3^\circ < \theta < 7.2^\circ)$
The studies $\pi^+\pi^-$ production in np collision provide the information on the reaction amplitudes with the isospin zero NN initial state necessary for isospin decomposition.

work of A. Kurilkin
Comparison of the np data with the models in HADES acceptance

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- HADES data
- Xu Cao et al.
- mod. Valencia model
- phase space

DATA absolutely normalized
models normalized to the area

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Results: double pion production in np @1.25 GeV

mod.Valencia

Mod.Valencia + ABC

(private communication of T. Skorodko)

Taking into account ABC effect does not improve the description of ππ spectra.

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Differential cross section in $4\pi$ region (model dependent)

Extrapolation by using modified Valencia model

- HADES ~ 6.5% for PS ($np \rightarrow np \pi^+\pi^-$),
- 6.2% for mod.Valencia, 4.6% - OPER, 5.8% - XuCao

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ABC effect from WASA-at-COSY

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Model of the di-baryon resonance - M. Bashkanov

\[ \sigma [pn \rightarrow d\pi^- \pi^+] = \frac{1}{2} \sigma [pp \rightarrow d\pi^- \pi^0] + 2\sigma [pn \rightarrow d\pi^0 \pi^0] \]

HADES coverage

\[ \sigma \left[ \sqrt{s} \right] \]

\[ \sigma \left[ \sqrt{s} \right] \]

WASA data pd

\[ d\pi^+ \pi^- \]

\[ \frac{1}{2} d\pi^+ \pi^0 \]

\[ 2d\pi^0 \pi^0 \]
Di-baryon resonance $d^*$: model from Mikhail Bashkanov

4$\pi$ simulation for $l=0$

4$\pi$ simulation for $l=1$

Experiment

work of H. Kuc
HADES provides high statistics data for double-pion production in pp, np @ 1.25 GeV

Comparison with the theoretical models has been performed for pp

- Valencia model
- Xu Cao et al.
- OPER model

Comparison to the modified Valencia model (a-la WASA style) has been also shown

- Better agreement with the HADES (pp->ppπ⁺π⁻) and WASA (pp->ppπ₀π₀) achieved
- Still place for improvement

Direct comparison with the np->npπ⁺π⁻ data on-going (3-prong analysis)

THANK YOU VERY MUCH FOR YOUR ATTENTION !!!