Exploring neutron detection with HADES

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Abstract. The HADES experiment at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany) is fixed target experiment using SIS-18 accelerator to study collisions of protons, heavy-ions or secondary pions with target nuclei. HADES was designed and provides very accurate measurement of di-electrons and charged hadrons. The pion induced reactions provide unique opportunity to study exclusive reactions with neutrons in the final state. Using the inclusive channel $\pi^- + \mathrm{p} \rightarrow \pi^- + \pi^+ + \mathrm{n}$ we can optimize the selection criteria for neutron hits in TOF/RPC. Dedicated simulations are compared with preliminary results of real data analysis for reaction channels with two neutral particles in the final state.

1. Introduction

A very successful model of atomic nuclei was developed already back in 1950's and it is called nuclear shell model that can predict the nucleus structure with good precision for a wide range of A and Z. According to this model neutrons and protons are affected only by mean field of all nucleons, otherwise they are independent. However, since 1990's the experiments with electron induced knock out of proton from nuclei have shown that only around 70 % of protons are really independent and the rest of them are correlated in pairs [1]. There are two types of correlations: long-range (distance between nucleons is few fm) and short-range (wave-functions of nucleons overlap, shortly SRC). Because the SRC are much stronger between protons and neutrons than the same kinds of nucleons, they are responsible for the high momentum tail in the nucleons momentum distribution above the Fermi momentum as it is explained in [2].

The aim to contribute to SRC studies motivates the test of HADES response on neutrons. It is also important that HADES recently collected data with pion beam (more in section 2) because it provides interactions with very few tracks and therefore the probability of accidental fake hits in TOF/RPC is rather low. The first step of our analysis aims on selection criteria for candidates of neutron hits. For this purpose we use the inclusive channel $\pi^- + \mathrm{p} \rightarrow \pi^- + \pi^+ + \mathrm{n}$ where we are able to determine missing neutron momentum from reconstructed tracks of charged pions. From this analysis we also find out what is the detection efficiency for neutrons and we compare these results with dedicated simulations. Then we proceed with testing of the selection criteria using η production channel.

2. Pion beam experiment with HADES spectrometer

The High Acceptance DiElectron Spectrometer (HADES) located at GSI Helmholtzzentrum für Schwerionenforschung (Darmstadt, Germany) is currently operating at SIS-18 accelerator which

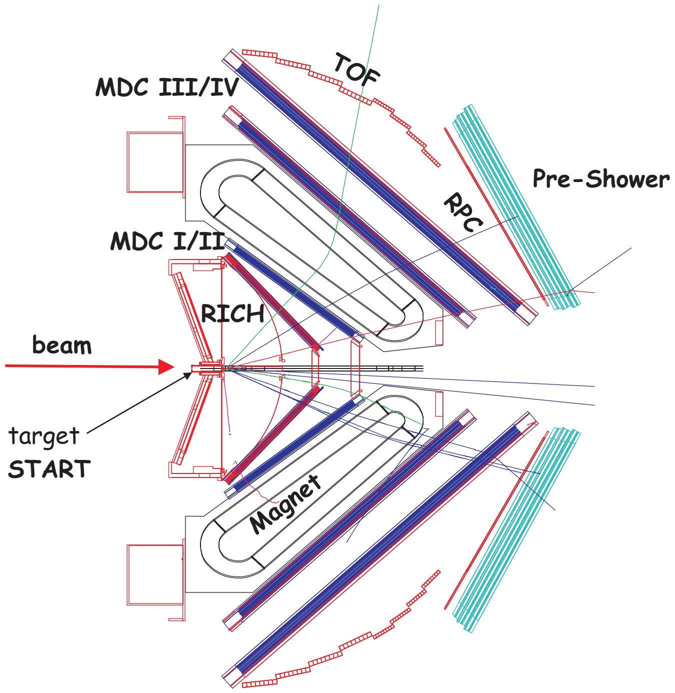

Figure 1. Schematic layout of HADES spectrometer with examples of particle tracks.

provides primary beams in the energy range $1-2\,\mathrm{GeV/u}$ for heavy-ions and up to $3.5\,\mathrm{GeV}$ for protons. Moreover the facility can also provide secondary pion beam.

The spectrometer is covering polar angle $18^\circ < \theta < 85^\circ$ and almost full azimuthal angle, see Figure 1. It is divided into 6 identical sectors (the geometry is dictated by the shape of toroidal magnetic field generated by superconducting coils) and it consists of several detectors: diamond-based START detector, Ring Imaging CHerenkov detector, Multi-wire Drift Chambers, time-of-flight walls and Pre-Shower detector. Detail description of technical parameters and actual performance can be found in [3].

The physics program is primarily focused on the dilepton spectra from decays of light vector mesons (ρ,ω,ϕ) [4; 5] but thanks to very precise measurement of charged particles, weak decays of hadrons containing strange quarks are also studied intensively [6].

The pion beamtime was divided into two parts with different physics scope. In the first part the beam momentum $p_{\mathrm{beam}} = 1.7\,\mathrm{GeV/c}$ was selected with respect to the ϕ meson production threshold. Typically 100 000 pions/s passed through the targets made of tungsten and carbon. During the second part, beam momentum scan (namely $p_{\mathrm{beam}} = \{656, 690, 748, 800\}$ MeV/c) was performed in order to cover the energy region which corresponds to excitation of baryonic resonances $N(1520)$ and $N(1535)$. Their coupling to the ρ meson is of special interest because it has a direct influence on in-medium modifies of ρ meson spectral function. The beam intensity for these energies was higher than in the first part (around 300 000 pions/s). Polyethylene and carbon targets were used to enable subtraction of carbon contribution inside polyethylene.

3. Selection criteria optimization

Given the composition of the HADES apparatus, one can search for neutron detection signal under certain assumptions. Because of the zero electric charge of neutrons their tracks are not bend in the magnetic field and also they do not leave any trace inside the drift chambers. Therefore the only way neutrons can be detected is the time of flight information provided by one of two detectors - for lower polar angles ($15° < \theta < 45°$) there are Resistive Plate Chambers and for higher polar angles ($40° < \theta < 80°$) it is the scintillator based Time Of Flight detector. RPC detects charged particles that come out from interaction of a neutron with metal cover of cells. In the plastic scintillators of the TOF detector neutron can scatter on nuclei and we detect the recoil nuclei or the light output from excited nuclei. It means that when we seek for the candidates of neutron detection in TOF/RPC we look for hits which cannot be matched with tracks in MDC.

To verify our "neutron candidate" hypothesis we take advantage of inclusive channel $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ where we can calculate the missing neutron momentum if there are both charged pion tracks reconstructed in the event

$$\vec{p}_{\text{expect}} = \vec{p}_{\text{beam}} + \vec{p}_{\text{target}} - \vec{p}_{\pi^-} - \vec{p}_{\pi^+}. \tag{1}$$

We decided to use 5° window around the predicted vector in both azimuthal and polar angle. The good candidates we declared as a "neutron hits" and then we focused on their time and position. The time of flight spectrum of neutron hits one can see in Figure 2. We also compare the magnitude of measured and expected neutron momentum for neutron hits based on the equation

$$\beta c = \frac{l_{\text{path}}}{t_{\text{tof}}} \Rightarrow p_{\text{measure}} = \frac{\beta c\, m_{\text{n}}}{\sqrt{1-\beta^2}}. \tag{2}$$

The agreement between real data analysis and simulation is shown in Figure 3. On both of these figures the results from real data analysis (green) are compared to simulations using GCalor (red) and Geisha (blue) hadron package for Geant3.

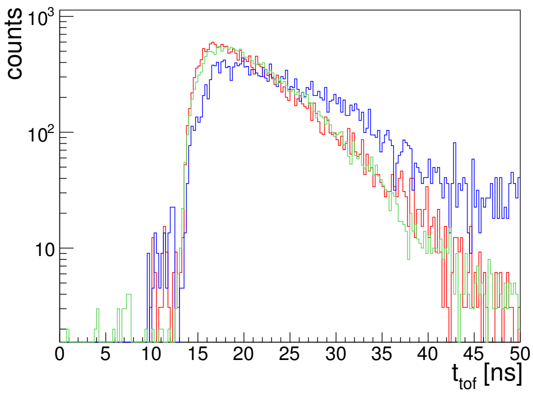

Figure 2. Time of flight spectrum for neutron hits after position matching.

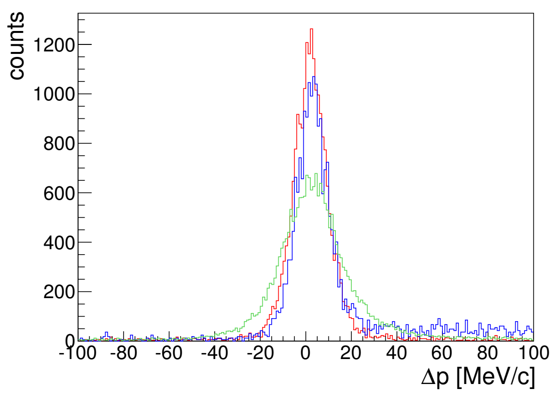

Figure 3. The difference between measured and expected neutron momentum.

Finally the neutron detection efficiency within HADES spectrometer is determined as a ratio of good candidates and number of events where both pion tracks are reconstructed and the missing mass of pions lies in the interval $900\,\text{MeV/c}^2 < m\,(\pi^-\pi^+)_{\text{miss}} < 980\,\text{MeV/c}^2$. The resulting efficiencies as a functions of polar angle and neutron momentum can be seen in Figure 4 and Figure 5.

4. Testing on η channel

After we established the selection criteria for neutron hits we can inspect their performance on channels with both neutral particles in the final state that would be otherwise inaccessible. We chose the η meson due to its production cross section in measured energy region and its decay mode $\eta \rightarrow \pi^+\pi^0\pi^-$ which we needed to trigger the data acquisition (two hits in TOF and/or RPC

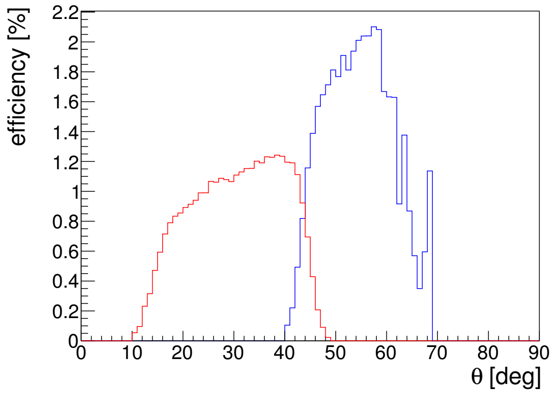

Figure 4. Neutron detection efficiency within TOF (blue) and RPC (red) detectors as a function of polar angle.

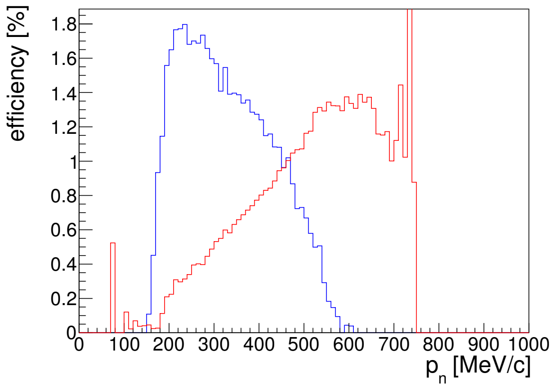

Figure 5. Neutron detection efficiency within TOF (blue) and RPC (red) detectors as a function of neutron momentum.

each in different sector of HADES). From the kinematics of the interaction $\pi^- + \mathrm{p} \to \eta + \mathrm{n}$ we can further restrict our search for neutron hit candidates to the RPC detector and also we can use cut on the time of flight $11\,\mathrm{ns} < t_{\mathrm{tof}} < 28\,\mathrm{ns}$ which improves the missing mass spectra displayed in Figure 6. The carbon target spectrum in that figure is scaled with factors obtained from analysis of the elastic scattering $\pi^-\mathrm{p} \to \pi^-\mathrm{p}$ where it is possible to scale $m\,(\pi^-\mathrm{p})_{\mathrm{miss}}$ missing mass carbon spectra to match the background in polyethylene. The subtracted spectrum is shown in Figure 7 and one can compare it with simulated spectrum in Figure 8 (using cocktail of interaction listed in Table 1).

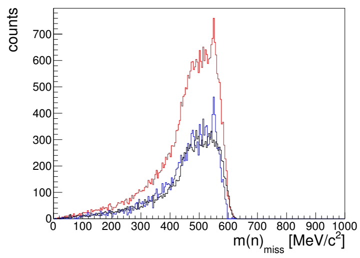

Figure 6. Neutron missing mass spectra for polyethylene (red) and carbon (black) target. The difference of these two spectra is equal to hydrogen contribution (blue) in polyethylene target.

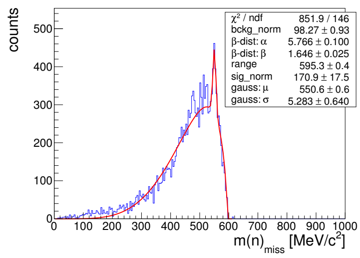

Figure 7. Hydrogen spectrum from figure 6 fitted with sum of beta and normal distributions.

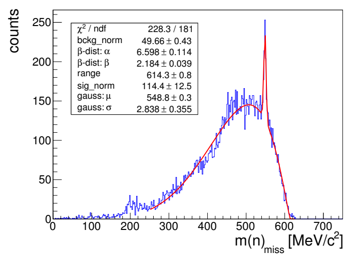

Figure 8. Simulated neutron missing mass spectrum fitted with sum of beta and normal distributions.

5. Conclusion

The study of short-range nucleon-nucleon correlations is important topic in order to understand the structure of nuclei. With respect to this a pioneer study on possible neutron detection with present layout of HADES spectrometer was carried on. We found out that the detection efficiency of neutrons is in magnitude of few percent and that these results is in reasonable

Table 1. Cross section data for signal and background channels in mb.

$\pi^- + \mathrm{p} \to$	p_{beam}[MeV/c] 666.8	699.7	748.4	799.1	source
$\mathrm{n} + \pi^0$	8.71	8.42	7.17	5.28	[7]
$\mathrm{n} + \pi^0 + \pi^0$	1.53	2.29	2.50	2.66	[8]
$\mathrm{n} + \pi^0 + \pi^0 + \pi^0$	0.003	0.009	0.014	0.020	[9]
$\mathrm{n} + \eta$	0.0	1.5	2.6	2.6	[10]
$\mathrm{n} + \pi^- + \pi^+$	5.49	5.96	6.19	6.60	[8]
$\mathrm{p} + \pi^- + \pi^0$	2.43	4.22	4.83	4.82	[8]
$\mathrm{n} + \pi^0 + \pi^+ + \pi^-$	0.8	0.8	0.8	0.8	estimation

agreement with dedicated simulations. We also observed that our method of identifying neutron hits in TOF/RPC works in case of two neutral particles in the final state.

Acknowledgments
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References

[1] Subedi R *et al.* 2008 *Science* **320** 1476–1478 (*Preprint* `arXiv:0908.1514 [nucl-ex]`)

[2] Hen O *et al.* 2014 *Science* **346** 614–617 (*Preprint* `arXiv:1412.0138 [nucl-ex]`)

[3] Agakishiev G *et al.* (HADES) 2009 *Eur. Phys. J.* A **41** 243–277 (*Preprint* `arXiv:0902.3478 [nucl-ex]`)

[4] Agakishiev G *et al.* (HADES) 2011 *Phys. Rev.* C **84** 014902 (*Preprint* `arXiv:1103.0876 [nucl-ex]`)

[5] Agakishiev G *et al.* (HADES) 2012 *Phys. Lett.* B **715** 304–309 (*Preprint* `arXiv:1205.1918 [nucl-ex]`)

[6] Agakishiev G *et al.* (HADES) 2014 *Phys. Rev.* C **90** 054906 (*Preprint* `arXiv:1404.7011 [nucl-ex]`)

[7] Baldini A, Flaminio V, Moorhead W G and Morrison D R O 1988 *Total Cross-Sections for Reactions of High Energy Particles* 1st ed (*Landolt-Bornstein: New Series - Elementary Particles, Nuclei and Atoms* vol 12) (Heidelberg, Germany: Springer-Verlag)

[8] Manley D M, Arndt R A, Goradia Y and Teplitz V L 1984 *Phys. Rev.* D **30**(5) 904–936

[9] Starostin A *et al.* (Crystal Ball) 2003 *Phys. Rev.* C **67**(6) 068201

[10] Prakhov S *et al.* (Crystal Ball) 2005 *Phys. Rev.* C **72**(1) 015203