Exploring neutron detection with HADES

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Abstract. The HADES experiment at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany) is fix target experiment using SIS-18 accelerator to study collisions of protons, heavy-ions or secondary pions with target nuclei. HADES is designed to study reactions with di-electrons in final state but it provides also very accurate measurement of 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

Very successful model of 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 wide range of nuclei. 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 had 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 one of them is long-range (distance between nucleons is in order of few fm) and second is short-range correlations (wave-functions of nucleons are overlapping, 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 which can exceed even Fermi momentum as it is explained in [2].

With the aim to contribute in the topic of SRC we decided to test HADES response to 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.

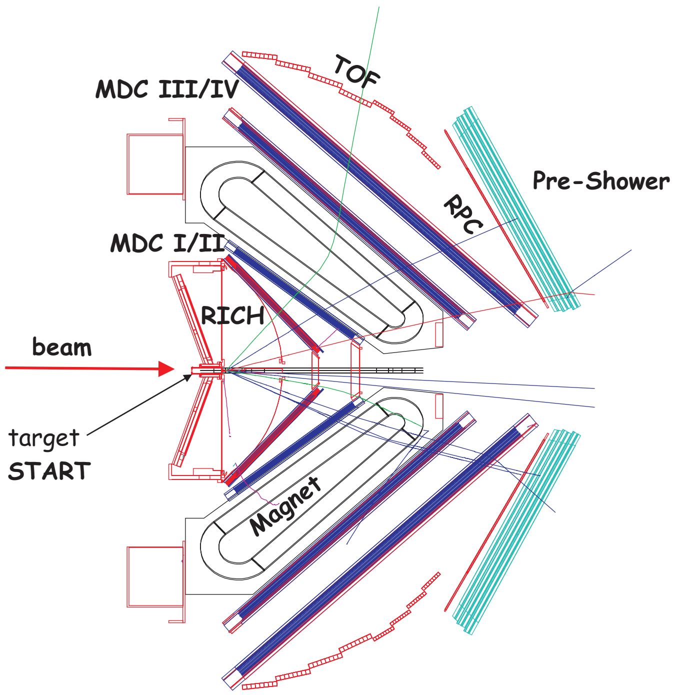

Figure 1. Schematic layout of HADES spectrometer with examples of particle tracks.

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 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 accelerator can also provide secondary pion beam.

HADES spectrometer, see figure 1, is covering polar angle $18^\circ < \theta < 85^\circ$ and almost full azimuthal angle. It is divided into 6 identical sectors (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 wall and Pre-Shower detector. Detail description of technical parameters and actual performance can be found in [3].

The physics program is primary 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 intentions. 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. Usually 100 000 pions/s passed through the targets made of tungsten and carbon. During the second part beam scan for 4 beam momenta (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 ρ meson is studied with special interest because it has a direct influence on in-medium changes 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

Due to neutron properties and composition of HADES spectrometer we can start the search for neutron detection with several assumption. 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 chance where the neutrons can be detected is time of flight wall consistent of two detectors - for lower polar angles ($15° < \theta < 45°$) it is Resistive Plate Chambers and for higher polar angles ($40° < \theta < 80°$) there is scintillator based Time Of Flight detector. RPC detects charge particles that come out from interaction of neutron with metal cover of cells. In the plastic scintillators of 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 look for the candidates of neutron detection in TOF/RPC we look for hits which are not matched with tracks in MDC.

To verify if our "neutron candidate" hits are really caused by neutron we used the advantage of inclusive channel $\pi^- + \mathrm{p} \rightarrow \pi^- + \pi^+ + \mathrm{n}$ where we can calculate the missing neutron momentum if there are both charged pion tracks reconstructed in the event

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

This means that we can eliminate the candidates which does not agree with the prediction from missing momentum. 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 properties (time and position). The time of flight spectrum of neutron hits one can see on figure 2. We also compare the magnitude of measured and expected neutron momentum for neutron hits based on the equation

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

The agreement between real data analysis and simulation is shown on 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.

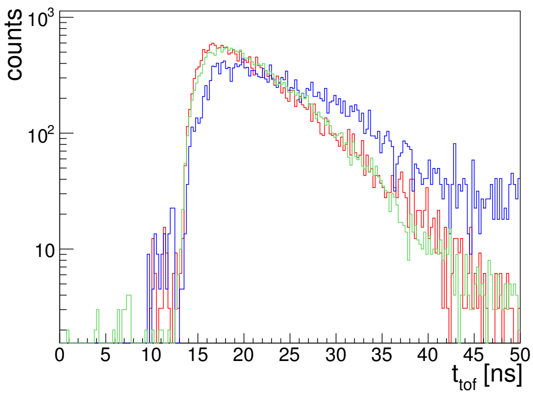

Figure 2. Time of flight spectrum for neutron hits after position matching.

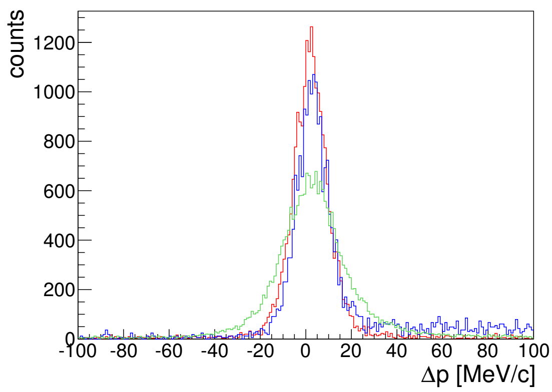

Figure 3. The difference between measured and expected neutron momentum.

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 $900\,\mathrm{MeV/c^2} < m\,(\pi^-\pi^+)_{\mathrm{miss}} < 980\,\mathrm{MeV/c^2}$. The resulting efficiencies as a functions of polar angle and neutron momentum can be seen on figures 4 and 5.

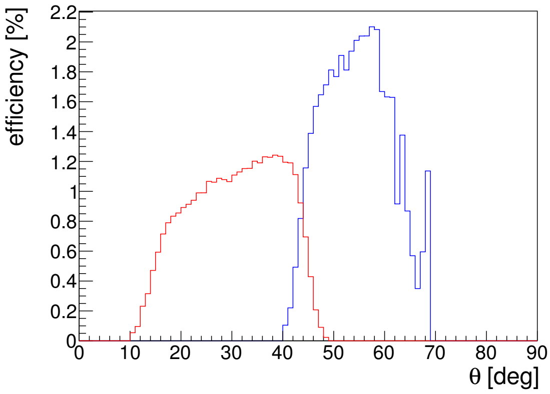

Figure 4. Neutron detection efficiency within TOF (blue) and RPC (red) detectors as a function of polar angle.

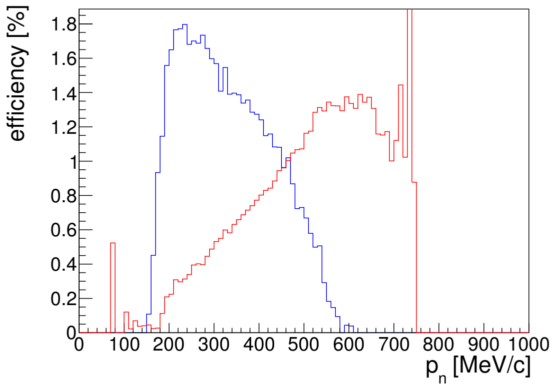

Figure 5. Neutron detection efficiency within TOF (blue) and RPC (red) detectors as a function of neutron momentum.

4. Testing on η channel

Afterwards 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. As it was mentioned earlier we focused on the channel with η meson. We chose this meson with respect to the production cross section at measured energy region and also thanks to its decay $\eta \to \pi^+\pi^0\pi^-$ which we needed to trigger the data acquisition during measurement where we used trigger on two hits in TOF and/or RPC each one of them 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 just on 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 on figure 6. The carbon target spectrum on 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 on top of polyethylene. The subtracted spectrum is shown on figure 7 and one can compare it with simulated spectrum on figure 8 (using cocktail of interaction from table 1).

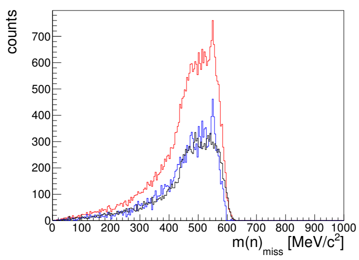

Figure 6. Neutron missing mass spectra for polyethylene (red) and carbon (black) target. The difference of these two spectra is equal to hydrogen contribution (blue) in polyethylene target.

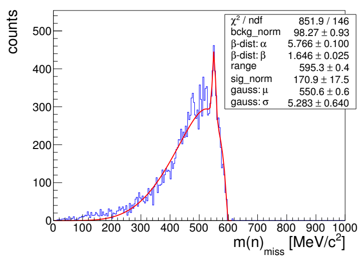

Figure 7. Hydrogen spectrum from figure 6 fitted with sum of beta and normal distribution.

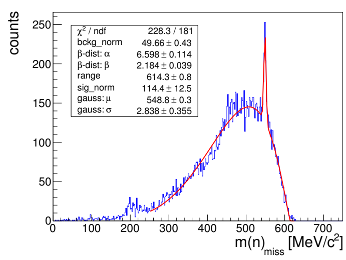

Figure 8. Simulated neutron missing mass spectrum fitted with sum of beta and normal distribution.

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

$\pi^- + \mathrm{p} \rightarrow$	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

5. Conclusion

As discussed in the present contribution, study of short-range nucleon-nucleon correlations is important topic in order to understand 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 agreement with dedicated simulations. We also observed that our method of identifying neutron hits in TOF/RPC worked in case of two neutral particles in the final state.

Acknowledgments

This work has been supported by GACR 13-06759S of the Czech Science Foundation and grant LM201549 of the Ministry of Education of the Czech Republic.

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