HADES activities and status 2017

The HADES collaboration

GSI Helmholtzzentrum für Schwerionenforschung

Introduction

The main goal of the HADES experiment is to explore the microscopic structure of dense baryonic matter. HADES experiments performed in the last years in nucleus-nucleus and proton-nucleus reactions have shown the important role played by the propagation of far off-shell ρ mesons due to their coupling to baryonic resonances in hadronic matter, visible as an excess radiation of the e^+e^- production above conventional sources for invariant masses below the vector meson poles. To provide a reference to these medium effects and to study the electromagnetic structure of the baryonic resonances an important programme has been developed by the HADES collaboration to investigated elementary reactions like pp, quasi-free 'n'p and recently πp.

Studying reactions with proton and pion beams on proton (liquid H_2 or polyethylene) targets is indeed an important element of the HADES program. Besides measurements of production cross sections, which provide an essential reference for heavy-ion collisions, also the elementary reaction mechanisms are studied. In particular, the role of baryonic resonances is investigated in both strangeness and dielectron production.

Recent physics results

Results from 2012 Au+Au run

The time-of-flight (TOF) resolution of HADES has been improved by using additional information in the calibration procedure and by assessing the quality of the TOF detector and its readiness for the upcoming experimental runs at SIS18 (see contribution of G. Kornakov).

We have also improved our analysis techniques of weakly decaying hadrons, like neutral kaons and hyperons, by applying machine learning techniques to the recognition of the decay topologies. To train such algorithms high statistics signal and background samples are needed. In our analysis the signal sample is obtained from a simulation, while the background sample is generated by combining tracks from different real events. Figure 1 shows a comparison between the resulting invariant-mass spectra when either using the hard topology cuts from [1] or when using a trained neural network. It is evident that the neural network based approach provides a gain of up to 200% in the yield of reconstructed Λ hyperons, when optimized for significance of the signal.

In addition, we have started to refine the analysis of protons and light nuclei, with a specific emphasis on the amount of thermalization of the created system and the nucleon coalescence parameter.

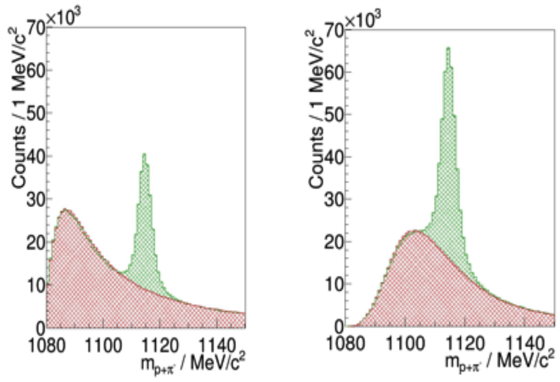

Figure 1: Reconstructed Λ mass spectrum in Au+Au collisions obtained with hard cuts [1] (left) and using a neural network (right). The signal is shown in green and the uncorrelated background in red.

Because of their self-analysing nature, weak decays can be used to measure the average spin orientation of the mother particle and interpret this as a signal of a possible global spin polarization. We have analyzed a significant Λ sample and extracted the centrality dependence of the polarisation parameter (see report of F. Kornas).

We have furthermore made a step forward towards understanding the transverse momentum spectra of charged pions in terms of their production from the thermalized system (see report of M. Gumberidze).

The studies on directed (v_1) and elliptic (v_2) flow of identified particles have been further extended. In addition to the multi-differential analysis for protons and pions (see 2016 GSI reports by B. Kardan and M. Gumberidze), now also the v_1 and v_2 of deuterons and tritons have been investigated as a function of transverse momentum and rapidity. After normalizing p_t and v_2 with the mass number A, the elliptic flow of p, d and t exhibits a clear scaling at mid-rapdity, as expected within a simple nucleon coalescence picture. Furthermore, higher moments of proton flow, v_3 and v_4, with respect to the first order reaction plane have been investigated.

First results on two-pion HBT correlations have been obtained as well. A special algorithm for the reduction of the effect of close track pairs had to be implemented for this analysis. The study was performed for negatively charged pions and allowed to extract the radius parameters R_{long}, R_{out}, and R_{side} as a function of pair momentum k_t and collision centrality. A significant k_t-dependence of the radius parameters is observed, in line with the expectation for a radially expanding source as it is also visible in the mass dependence of the p_t-spectra of identified single particles.

We have finally performed a comprehensive dilepton analysis for the Au+Au data and were able to extract significant medium modifications of hadron properties,

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based on an established NN reference spectrum [2,3]. The excess yield has been quantitatively understood as thermal radiation emitted from the hot and dense fireball. Above an invariant mass of 0.4 GeV/c, the observed spectral shape of the excess radiation for the 40% most central collisions, corrected for the acceptance of the spectrometer, exhibits an almost exponential shape, consistent with an average temperature of the transient fireball of around 72 MeV. The absence of a bump in the vector meson pole mass region indicates a “melting” of the ρ meson in the medium.

We have extracted the multi-differential pattern of dilepton emission, including transverse mass, rapidity, helicity and azimuthal anisotropy distributions, for several centrality bins (see report of S. Harabasz).

Results from 2014 pion beam run

In 2014 a pioneering campaign investigating pion-nucleus collisions (π + C, W) at an incident momentum of 1.7 GeV/c was carried out with HADES at the GSI pion beam facility. This allowed to investigate in-medium effects on the strange mesons K^-, K^+, and ϕ in cold nuclear matter.

Previous studies indicated a moderately repulsive KN potential for kaons (K^+, K^0), while the antikaons (K^-) are expected to propagate in an attractive potential with a considerable imaginary part. Antikaon absorption processes in nuclear matter mediated by strangeness exchange reactions on one (KN → πY) or more nucleons (KNN → YN) contribute sizeably. A similar study pf the phi meson is also of considerable interest. And this concerns not only the significant feed-down into the K^- as observed in sub-threshold Au+Au collisions and elementary p+p reactions close to the ϕ production threshold. Of even more importance is the ϕ absorption in cold nuclear matter, resulting in a widening of the ϕ natural width.

Yet another interesting topic that can be addressed with pion-nucleus reactions is the study of hyperon propagation within nuclear matter. In the discussion of the equation of state of neutron stars the properties of the Λ are of considerable interest as its interacton with one or several nucleons enters various theoretical models. Since pion-induced reactions happen mostly on the nuclear surface, the lambda is also produces there and subsequently traverses the nucleous where it can rescatter on a nucleon. A measurement of the exclusive channel π^-+p → K + Λ with an additional recoil proton offers the opportunity to study the ΛN interaction in nuclear matter through a comparison of the data with transport models. A preliminary analysis of the HADES data shows that this process can indeed be isolated experimentally.

Production of e+e- pairs was measured in another run using the GSI pion beam at a lower momentum of 0.685 GeV/c impinging on polyethylene (PE) and carbon targets.

To allow for a more direct study of the baryonic contributions to the pair spectrum, we performed an exclusive analysis by applying invariant-mass and missing-mass cuts.

We have selected 1500 events corresponding to the free or quasi-free pi-p → ne^+e^- reaction. The comparison to model predictions is on-going. Using the Partial Wave Analysis (PWA) of the two-pion production measured in an energy scan in the same experiment, this excess can be interpreted as an off-shell contribution, consistent with the Vector Meson Dominance model (see report of F. Scozzi).

A parametrization of the angular distributions using the spin density formalism was also performed, allowing for the first time to get important information on the helicity structure of baryon electromagnetic transitions in the time like region.

The neutral pion and eta contributions were reconstructed in pi-PE reactions at 0.685 GeV/c using the photon conversion method. The preliminary extracted cross sections fit well to the world data (see repport of J.-H. Otto).

Status of the upgrade projects

With the start of FAIR Phase-0, most of the HADES detector systems will have reached an age of over 15 years. In order to keep the detector operational, an upgrade program has been started: For reasons of better photon detection efficiency, (1) the UV detector of the RICH has been replaced by MAPMTs, and (2) the Pre-Shower detector (polar angle coverage from 18 to 45 degree) has been replaced by a full-fledged electromagnetic calorimeter (ECAL). Moreover, the success of the experimental program addressing elementary reactions motivated the instrumentation of the acceptance region between polar angles of 0.5 to 6.5 degree with a straw-tube tracker. Most of these upgrade projects profit by close synergies with instrumentation projects of other FAIR collaborations (PANDA and CBM).

Electromagnetic Calorimeter

The addition of an electromagnetic calorimeter (ECAL) to HADES will moreover allow to study by photon measurements new reaction channels involving e.g. the production of neutral mesons, as well as neutral Λ(1405) or Σ(1385) resonances in elementary and heavy-ion reactions. Another advantage is the resulting improvement of the electron-to-pion separation at large momenta. ECAL is based on 978 lead glass modules recycled from the OPAL experiment. It is divided into 6 sectors, and it covers forward angles of $16^\circ < \theta < 45^\circ$ and almost the full azimuthal angle. The Technical Design Report had already been approved in 2014 by the FAIR ECE. The project is carried out by groups from Rez, Krakow, Moscow, Bratislava, Frankfurt, Darmstadt, Munich and GSI.

The readout of the detector is based on PaDiWa AMPS boards [4] (charge-to-width measurement) developed especially for the calorimeter and connected to a TRB3 [5] setup. The second generation of the 8-channel PaDiWa-AMPS front-end boards was assembled at GSI EE, tested in the laboratory and meanwhile the four completed sectors of the ECAL have been equipped (see report of A. Rost). A dedicated optical monitoring system has been de-

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veloped for the ECAL. It is based on a laser LED and a microlens array with optical fibers which allows to send light pulsed of defined intensity into each single ECAL module for calibration purposes.

In the current funding concept, photomultipliers of two different types are installed. The limited budget forces the HADES collaboration, other than recommended by the ECE, to partly reuse 1.5" EMI 9903KB photomultipliers recovered from the MIRAC (WA98) detector; for the rest, new 3" Hamamatsu R6091 photomultipliers have been purchased.

RICH Photon Detector

The MWPC based gaseous RICH VUV photon detector with its CsI photon converter is currently being replaced by an arrangement of multi-anode photo multiplier tubes (MAPMTs, Hamamatsu H12700C) with blue-enhanced high quantum efficiency photo cathodes. The detector modules composed of 6 MAPMTs and integrated together with all required readout electronics on a backplane are developed together with CBM and will also be used as UV photon detectors in the CBM RICH. The pixel size (5.8×5.8 mm^2) of these devices perfectly matches the pad geometry of the old MWPC detector and guarantees reasonable position resolution of single photon hits and efficient ring image recognition on the 0.92 m^2 sensitive area. The MAPMTs are arranged on two aluminum carrier frames such as to fit as close as possible to the focal surface of the RICH mirror. Altogether 428 MAPMTs (27392 readout channels in total) arranged on 74 super-modules with 3×2 individual MAPMTs each will be mounted inside the existing gas tight detector chamber and flushed with nitrogen. A schematic view of the new RICH configuration and the design of the new photon detector device is depicted in Fig. 2.

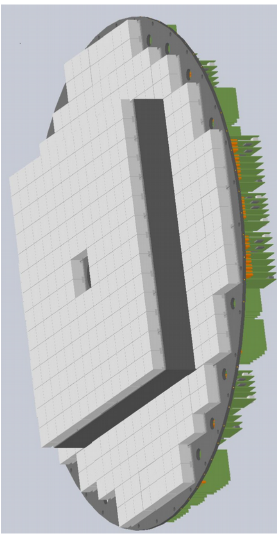

Figure 2: Schematic view of the redesigned HADES RICH photon detector and read-out configuration.

The newly developed readout front-end (DiRich) comprises pulse amplification, discrimination, time-to-digital conversion and time-over-threshold measurement for single photon signals from each individual MAPMT pixel. Twelve densely packed DiRich cards serve six MAPMTs and are arranged on a super-module backplane together with a power- and combiner card providing connection to the TRBnet of the HADES data acquisition system. Laser measurements with MAPMTs and final DiRICH prototypes show the expected performance with respect to single photo electron detection efficiency and rate capability.

The high quantum and single photo electron detection efficiency, low cross talk probability, and a new versatile ring finder algorithm lead to an expected superb single e^+/e^- identification efficiency across the whole detector area, in spite of the very short radiator length at small polar angles. In particular, the ring finder allows to efficiently discriminate overlapping rings even for very close e^+e^- pairs with opening angles down to $\delta\Omega \simeq 3^\circ$. Simulations done with conservative detector parameters promise a significant reduction of the misidentified combinatorial e^+e^- pair background also in heavy-ion reactions.

The new RICH photon detector will be ready for the 2018 beam times.

New Forward Detector System

To extend the acceptance of the HADES Spectrometer towards lower polar angles, $0.5^\circ - 6.5^\circ$, a dedicated Forward Detector is being constructed. This detection system consists of two tracking stations placed 3.1 and 4.6 m downstream of the target and is based on straw tubes. It is followed by a high precision time-of-flight wall based on RPC technology and a high granularity scintillator based hodoscope. As this detector will operate in a field-free region the particle identification has to be performed based on dE/dx and time-of-flight measurements. Additionally, the straw tube tracking stations will be used for reconstruction of off-vertex decays.

The two stations of the Forward Tracking Detector are each composed of 8 layers of self-supporting straw tubes with 10 mm diameter. The layers are built from vertical straws rotated by 0, 90, 0, 90 and 0, 90, −45, 45 degree around the beam axis. The position resolution of the detector amounts to around 150µm which, for the given detector geometry, provides track reconstruction with angular resolution of $\sigma_\theta = 0.5$ mrad for 2 GeV protons. The Straw Trackers are currently assembled by the Krakow and FZ Juelich teams, based on developments for the PANDA Forward Tracker. LIP Coimbra is producing the Forward RPC.

The increase of acceptance will play a significant role in studies of N (π) + N and p + A reactions where this detector is essential for exclusive channel reconstruction and PWA analyses of hyperon production and for studies of decays like $\Lambda \to p\pi^-$, Λ^* (Σ^*) $\to \Lambda e^+ e^-$ (hyperon transition form-factors) and $\Xi^- \to \Lambda\pi^-$. For heavy-ion reactions the Forward Detector will consist only of an highly granular plastic scintillator (the other two components will be removed). The detector will then focus on reaction plane reconstruction and precise centrality measurements.

Start Detector Upgrade

For experiments with HADES, a radiation hard and fast beam detector is required. The detector is placed directly in the beam either close in front of the target (START) and in some configurations also at the exit of the RICH detector (VETO). To properly handle the rates the detector has to be segmented and radiation hard. The time resolution of the START should be so good (time-zero measurement with σ_{t0} < 50 ps) that the time-of-flight measurement is not deteriorated by it. While this is mandatory for proton- and pion-beam induced reactions, in case of heavy-ion collisions, the time-zero determination is further improved by taking the average of a properly corrected stop measurements of all charged particles in the acceptance. These requirements can in general be fulfilled by utilizing single-crystal Chemical Vapor Deposition (scCVD) diamond based detectors. High counting rate capability of the diamond detector (up to 107 ions/s/mm^2) has been shown in the Au+Au run. The measured radiation damage to the diamond material by Au ions has been quantified and it has been shown that while the energy resolution of a degraded detector is reduced significantly, its timing properties are, however, worsened only slightly. A similar concept for T0 measurement will be used during the 2018 Ag+Ag run.

The detection of minimum-ionizing particles remains challenging since one has to deal with very small amounts of induced charge carriers while the expected high rates require special emphasis on the read-out electronics. A read-out concept for diamond detectors for minimum ionising particles will be based on the already well established TRB3 (Trigger and readout board - version 3) platform developed at GSI. The board provides 260 high precision (RMS < 12 ps) multi-hit FPGA-TDC channels and serves as a flexible data acquisition system (DAQ). The available comprehensive software package allows on-line monitoring capabilities including basic analysis. A large variety of front-end electronics is available in order to extend its functionality.

MDC FEE Upgrade

The about 27.000 sense wires of the HADES drift chambers are currently read out by means of dedicated front-end electronics mounted on the frames of the detectors. The analog section is based on the ASD-8 ASIC featuring amplification, shaping and discrimination with a common threshold per 8 channels and a typical integration time of 7 – 8 ns. A semi-customized ASIC for time digitization provides both, drift time and valuable time-over-threshold information. Built nearly 20 years ago, the system suffers from an increasing number of dead channels and the data transfer bandwidth turned meanwhile out to be a limiting factor of the DAQ. Moreover, in high-rate applications it is recommended to employ multi-hit capability of the read-out to avoid efficiency losses due to occupied channels fired by random coincidences (notably δ electrons). Also, a higher detection sensitivity is desirable to increase the stability of the detector under high load by lowering the gas gain. Besides that, the HADES tracking algorithms would accept slightly worse spatial resolution while profiting from an improved noise immunity.

Pursued by groups from Frankfurt and GSI, state-of-the-art solutions based on available ASICs (the ASD-8 is no longer on the market) and time digitization realized in FPGAs are being studied in order to replace the old FEE in the near future. A promising replacement candidate is the PASTTREC ASIC, developed at the Jagiellonian University, Krakow, for reading out straw tubes of the PANDA experiment and future forward tracking in HADES. This chip is currently at the focus of our investigations. It is supplemented by a high precision FPGA-based TDC, implemented on a TRB3 board. In parallel, a cost-efficient and lightweight, but coarsely binned (500 ps) FPGA-based prototype TDC was successfully tested and is now foreseen to replace the currently used dedicated TDC ASICs. To arrive at conclusive performance results, the tests are being conducted under realistic conditions in direct comparison to the present ASIC. To do so, a spare drift chamber is employed and both signal-to-noise and dE/dx, as well as time resolution are systematically characterized with radioactive sources and cosmic rays. Furthermore, a test beam time took place at the Jülich Cooler Synchroton COSY in October 2017.

One key issue is the compatibility of the present flex-based signal routing and the PASTTREC ASIC mounted on a customized board, which significantly affects the noise immunity together with determining the optimum parameter settings of the PASTTREC chip. Due to the arrangement of two stereo angle layers, it is possible to assess the drift time (and spatial) resolution by correlating adjacent drift cells. This study, together with beam tests, will help to answer the other key question on the possibility of assigning an ASIC optimized for straw tube signals – which deliver more charge (operation at 2 bar and longer track path in a straw tube cell) – to read out the mini (cell) drift chambers of HADES. The final decision on the replacement of the existing electronics is foreseen to take place in the first half of 2018. A new MDC read-out is then scheduled to be available for the year 2020.

 DOI:10.15120/GR-2018-1

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposals: S333, S407, S447
Accelerator infrastructure: SIS18
PSP codes: 1.1.2
Grants: BMBF 05P12CRGHE HZDR Dresden; BMBF 05P12RGGHM, U. Gießen; BMBF 05P15PXFCA, U. Wuppertal; BMBF 05P15WOFCA, TU München; Helmholtz Alliance HA216/EMMI; HIC for FAIR (LOEWE).
Strategic university co-operations with: Darmstadt, Dresden, Frankfurt am Main, Giessen, TUM, Wuppertal

Performance of the plastic scintillator Time-of-Flight Wall of HADES during the Au+Au run

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The performance of the HADES TOF plastic scintillator wall [1] has been studied in great detail. This study had a twofold purpose: The first one was an attempt to improve the time-of-flight resolution by including additional information in the calibration procedure. The second one was to assess the quality of the detector and its readiness for the upcoming experiments.

The adoption of a TRB [2] based data acquisition scheme required new front-end electronics. The new boards based on the NINO chip [3] encode into the leading edge and width of a digital pulse the arrival time and (integral) charge of the signal read out on both sides of the scintillator coupled to Photo-Multipliers (PMTs). A consequence of these changes is a position dependent relation between the arrival time and the width of the TRB signal. Therefore, the goal of the new calibration strategy was to incorporate to the sequence of procedures the local dependence between the measured charge and time, the so-called "walk correction". For such a purpose the time-charge relation was studied in 20 equally long sections (bins) along the scintillator rods. Figure 1 shows such a correlation for a single bin of one rod. The reference time was calculated using the measured momentum and flight distance of particles identified in the tracking detector using the specific energy loss. With this, the dependence can be modelled by a linear combination of exponential and power-law functions, which are used during the calibration procedure to remove the walk effect from the data.

The measured time-of-flight and position along the rod can be reconstructed using the half-sum and half-difference of both times multiplied by the light group-velocity in the scintillator. Following previous works, the timing could be improved if instead of the half-sum a weighted average is used [4].

The result of these procedures is shown for minimum ionizing particles in Figure 2. Timing precisions of the order of 130 ps where achieved for the shortest rods of 1475 mm, degrading slightly to 160 ps due to signal attenuation in the longest rods of 2365 mm.

This result confirms the excellent time capabilities of the TOF Wall and its readiness for the upcoming experiments with both heavy and light beams.

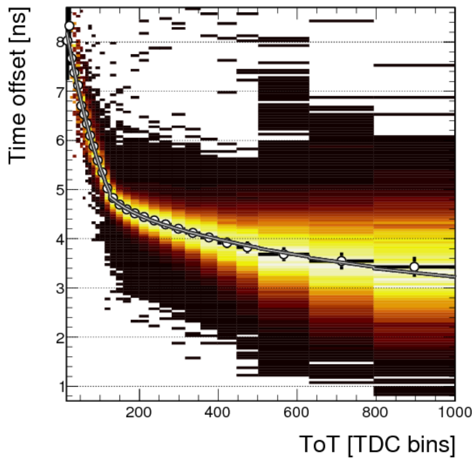

Figure 1: Example of a time-charge dependence measured in one longitudinal bin of a scintillator rod. The white circles correspond to the median of the distribution and the line is a fit consisting of a linear combination of exponential and power-law functions.

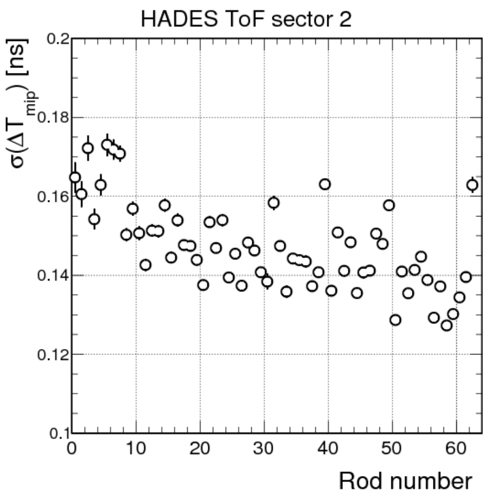

Figure 2: Timing performance for minimum ionizing particles of one of the sectors of the scintillator wall.

References

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S407
Accelerator infrastructure: SIS18
PSP codes: none
Grants: VH-NG-823, Helmholtz Alliance HA216/EMMI
Strategic university co-operation with: Darmstadt

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Benchmarking new front-end electronics for the HADES drift chambers

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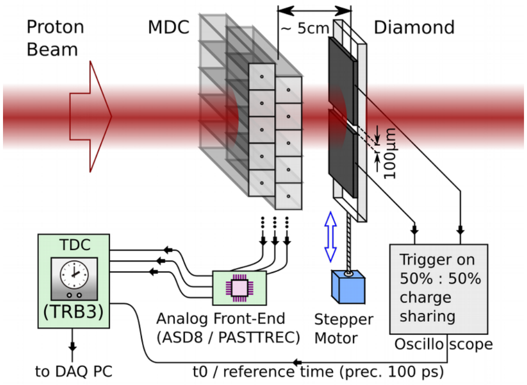
Upgrading the digital part of the HADES MDC read-out system in preparation for SIS-100 requests a re-design of the analog part as well. Instead of re-using the ASD8 ASICS we want to benchmark a modern amplifier-shaper-discriminator chip, the PASTTREC ASIC [1], developed by JU Krakow, w.r.t. to precision in time and energy loss measurement.

Figure 1:



Sketch of the COSY beam test set-up to assess timing precision of the joint system comprising a drift chamber and different read-out electronics.

The timing precision, being the most crucial performance parameter of the joint system of detector and read-out electronics, was assessed during a beam test at the COSY accelerator in Juelich using a proton beam with a momentum of 2.7 GeV/c. As shown in figure 1, a diamond detector [2] served to provide trigger, reference time and position of protons in a narrow slice (<100 µm) of the beam, parallel to the sensing wire, and thus allows to select perpendicular tracks at any position within a drift cell.

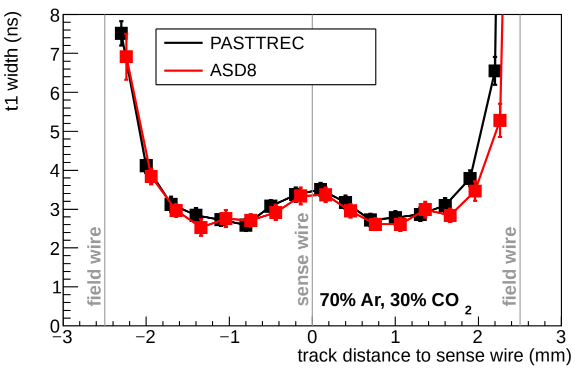


Figure 2: Timing precision of MDC drift cell read out with ASD8 and PASTTREC ASIC as a function of track position within the cell. Shown is the sigma of a gaussian fit of the coincidence time spectrum.

The resulting time precision is illustrated in figure 2. Within the error bars, PASTTREC (when walk correction is applied to the data) can achieve a similar, though slightly worse, timing precision as ASD8, i.e. ~3 ns in the inner regions of the cell. These results improve upon earlier measurements at the GSI Detector Lab via tracking of cosmic muons, because access to higher statistics allowed for finding better ASIC settings.

Concerning energy loss measurement precision, both ASICs were tested with a ^{55}Fe X-ray source irradiating a drift chamber operated at various high voltages. The pulse charge spectrum (figure 3) was derived from the recorded time-over-threshold spectrum by applying a calibration function which was recorded by means of a programmable pulse generator. In contrast to ASD8, PASTTREC was able to separate the main X-ray peak from the argon escape peak at and even below the HV working point.

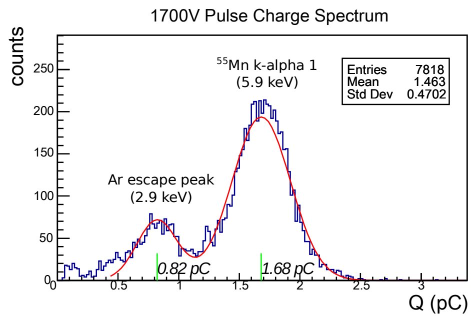


Figure 3: Calibrated charge spectrum (derived from TOT distribution) of MDC irradiated with a ^{55}Fe X-ray source and recorded with PASTTREC.

References

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S477
Accelerator infrastructure: SIS18
PSP codes: 1.1.2
Grants: GSI strategic partnerships (FuE), HIC for FAIR, BMBF(05P15RFFCA)
Strategic university co-operation with: Frankfurt-M

The PaDiWa-AMPS2 TDC and QDC front-end electronics for the HADES Electromagnetic Calorimeter

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The second generation of the 8 channel PaDiWa-AMPS front-end board was assembled at GSI department for Experiment Electronics (GSI EE). The board implements precise TDC and QDC measurements optimized to read out the 978 PMTs of the HADES-electromagnetic calorimeter (ECAL) [1]. The measurement principle [2] is to integrate the signals and to encode the results in the width of the digital output pulses. High precision is achieved by implementing a modified Wilkinson-ADC method, so actively discharging the integrated signal results in a fast crossing of the threshold. The lengths of the digital pulses are measured by the well-established TRB3 (General Purpose Trigger and Readout Board - version 3) platform [3].

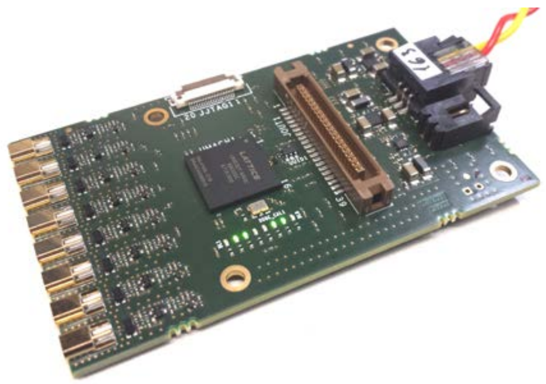

Figure 1: Photography of the PaDiWa-AMPS2 front-end board.

The circuitry of the front-end board is based on the Come&Kiss1 principle, where analogue electronics is used only for the amplification stage and integration, while other tasks, e.g. discrimination, threshold settings, delay generation for discharging and the LVDS drivers are implemented in a field-programmable gate array (FPGA). The second version of the PaDiWa-AMPS2 front-end board is shown in Fig. 1.

Because of the new layout in combination with a smaller package size, the routing of the signal lines have been optimized for better timing precision and reduced crosstalk. The concept of using a transformer in the input stage in order to galvanically isolate the ground was carefully tested. In laboratory measurements it has been shown that the transformer improved the signal to noise ratio. The charge measurement precision (resolution of the system defined as sigma/mean of the charge distribution) as a function of the measured charge has been determined with a pulse-generator. The results are shown in Fig. 2. A time precision of 20 ps and a relative charge precision below 0.5% (for ECAL PMT pulses >1 V) was reached.

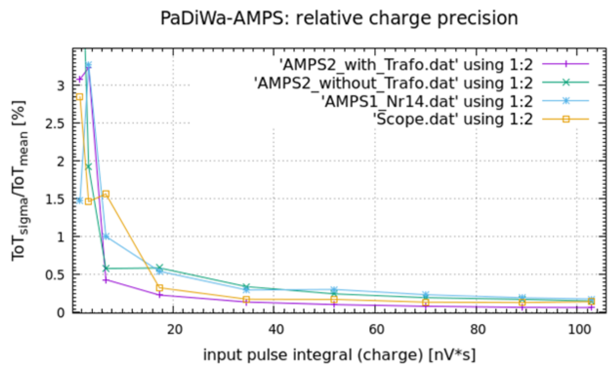

Figure 2: Relative charge precision of the PaDiWa-AMPS2 board compared to PadiWa-AMPS1 and a Oscilloscope reference measurement.

The HADES ECAL detector is currently under construction. The mass production of 150 PaDiWa-AMPS2 front-end boards was done by the GSI EE. The read-out electronics will be installed by end of spring 2018 and fully commissioned with cosmic muons and LED signals. A production beam time with the HADES spectrometer is planned in August 2018. Four sectors of the ECAL will be in place for the 2018 beam time to enable the photon measurement.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: none
Accelerator infrastructure: SIS18
PSP codes: none
Grants: Work supported by the DFG through GRK 2128 and VH-NG-823.
Strategic university co-operation with: Darmstadt

1 use commercial elements & keep it small and simple

 DOI:10.15120/GR-2018-1

Application of micron-size plasma for investigations of HADES Mini Drift Chamber (MDC) cells with an unique laser driven test facility

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To investigate the electron drift and amplification in gaseous detectors a high precision laser driven detector test facility has been developed at the Helmholtz-Zentrum Dresden-Rossendorf, using a pulsed UV laser beam with 257 nm wavelength, 10^{-2} to 10^{5} Hz frequency and 10^{11} to 10^{13} W/cm^2 energy density [1]. A multi-photon ionization process generates electrons and ions in micron-size beam envelope within radii of $r_{x,y} = 10$ µm and Debye length $l_z = \pm$ 100 µm. An adaptable drift chamber detector (s. fig.1) has been designed to create the real electric field topology of each of all six different Mini Drift Detector cells of the MDC II plane of the HADES spectrometer [2]. Due to the anode wire alignment of ±40°, ±20° and ±0° (with respect to the cathode wires in adjacent wire layer), in each different drift cell type a different anomalous radial electrical field distribution is formed. With an increased precision in knowledge of the local field topology, we assume to increase the track reconstruction quality of the HADES spectrometer, and for the future, improve in optimizing cell geometries. The laser beam is focused into the detector with a well-defined 3D position, start time and number of primary electrons.

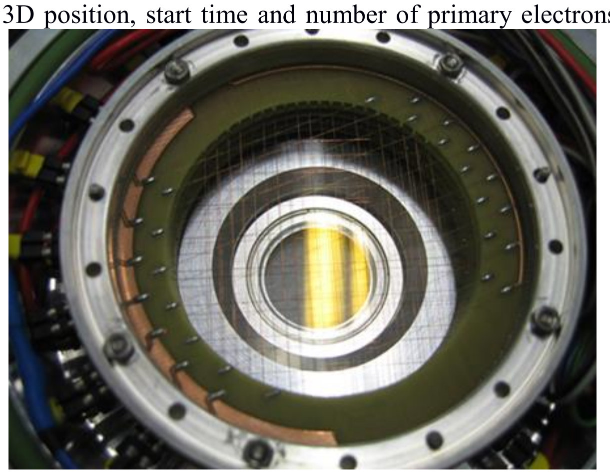

Figure 1: Drift chamber inside the opened gas tight box.

The start time signal, taken from the laser pulse has a resolution of 2 ps (FWHM). This signal triggers the data acquisition (DAQ) of five readout channels, on which read-out electronics with ASD-8 and PASTTREC [3] ASICs have been tested. 2D and 3D drift velocity distributions have been measured for different counting gas mixtures of Ar/CO_2. Figure 2 shows the nearly perfect radial symmetry in the +0° cell with exception of the four corners, which are defined by the shortest distance between field wires and cathode layers. Electrons generated in the corners were delayed there due to the gas properties and low electrical field strength. The Electron drift-velocity is constant over a wide range of more than 70% of the drift cell (see fit in fig.3) and amounts to (62±0.3) µm/ns.

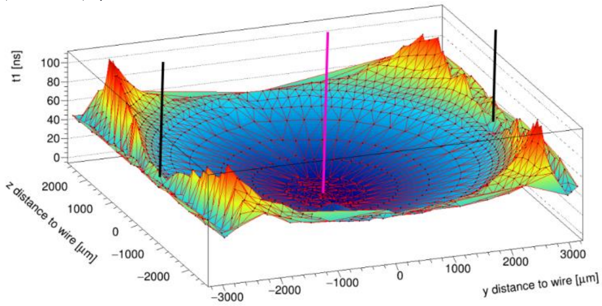

Figure 2: Mean drift time (t1) as function of the laser ionization point inside a drift cell, (1290 data points, each contains 8000 events) measured on an area orthogonal to the (+0°) anode wire (pink), between two field wires (black) and two cathode layers at z = ±2500 µm.

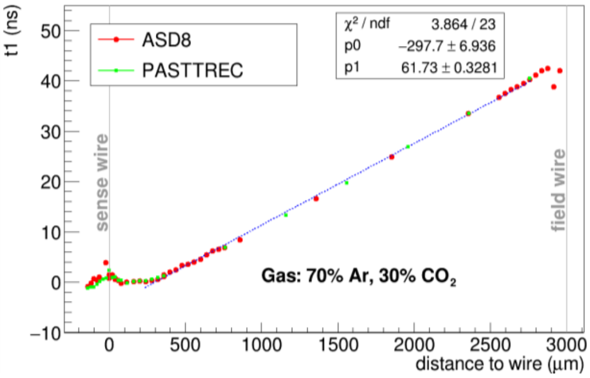

Figure 3: Measured mean drift time (t1) as a function of the distance perpendicular to sense wire, obtained for both amplifier ASICs at z=0, $U_{field} = U_{cathode}$ = - 1.7 kV.

Close to the anode wire the Debye length of the plasma disturbs the measurement. The drift time distribution has a standard deviation of 0.5 to 1.0 ns, this allows in case of a laser induced point source to deduce the spatial resolution of 30 to 60 µm for the HADES-MDC II with the used ASICs.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S477
PSP codes: 1.1.2.
Grants: HGS-HIRe, GSI strategic partnerships (FuE), HIC for FAIR, BMBF(05P15RFFCA)
Strategic university co-operation with: Frankfurt-M

Machine learning for weak decay recognition in heavy-ion collisions

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The production of quark flavor is one of the most important observables in heavy-ion collisions. At SIS 18 energies this corresponds mainly to the production of strangeness. In contrast to hadron production in elementary N+N collisions, in heavy-ion reactions additional multi-step processes do occur and the production of e.g. strange hadrons below their free N+N threshold is possible by accumulation of energy. Therefore, the investigation of sub-threshold strangeness production is one of the most promising probes, as it contains newly produced quarks, it is sensitive to the amount of energy provided from the created system [1].

The recent experimental observations challenge the understanding of sub-threshold strangeness production: The first simultaneous measurement of K^- and Φ mesons in central heavy-ion collisions below a kinetic beam energy of 10A GeV by HADES revealed that the Φ/K^- multiplicity ratio is found to be surprisingly high with a value of 0.52±0.16. Consequently, the different slopes of the K^+ and K^- transverse-mass spectra can be explained solely by feed-down, which substantially softens the spectra of K^- mesons. Hence, the different slopes do not imply diverging freeze-out temperatures of these two mesons caused by unequal coupling to baryons, as suggested commonly [2].

Yet, any detailed understanding of strangeness production and propagation in heavy-ion reactions requires information on all production channels of all particles with open or hidden strangeness. Therefore, the analysis is extended to further particles carrying strangeness such as K^0 mesons and Λ hyperons. They decay via the weak interaction and can be reconstructed through their decay products. Data on these hadrons in central Au+Au collisions at kinetic beam energies below 2A GeV have never been published before. Due to their decay via the weak interaction, these particles have a characteristic decay topology, which can be used to suppress combinatorial background. As most of the particles produced in heavy-ion collisions result from strong processes and are hence emitted from the interaction point of the two colliding ions, the latter one can be reconstructed from the intersection point of all reconstructed charged particle trajectories in the detector. Due to the weak decay, a fraction of e.g. Λ hyperons decay a few centimeter away from their creation point ($c\tau$=7.89 cm). Hence, one can search for trajectories which meet in space (secondary vertex) separated by a given distance from the reaction vertex. Applying such selection criteria the combinatorial background of random pion proton combinations is more strongly suppressed than the signal of truly correlated pion-proton pairs. The drawback of this method is the low efficiency, usually of a few per mill.

Machine learning methods e.g. based on artificial neural networks are a very promising tool to overcome this shortcoming. Such algorithms can be trained to recognize specific correlations, resulting in higher reconstruction efficiencies compared to a series of hard cuts. We applied the methodology of machine learning for the recognition of weak decay topologies for the first time for heavy-ion collision data within HADES. For the training of such algorithms high statistic signal and background samples are needed. For the signal sample, we use a simulation, while the background sample is generated by combining tracks from different events, which are by definition uncorrelated.

Analysis results

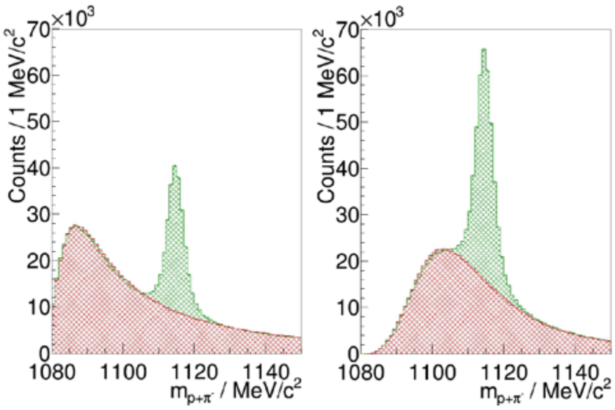

Figure 1: Λ mass spectrum from data with hard cuts from [3] (left) and using a neural network (right), signal is shown green and combinatorial background red.

Figure 1 shows a comparison between the resulting invariant mass spectra using only the hard topology cuts from [3] and with the use of a neural network. The analysis based on the neural network provides a gain of about 200% in the amount of reconstructed Λ hyperons, when optimized for significance of the signal.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: none
Accelerator infrastructure: UNILAC / SIS18
Grants:
Strategic university co-operation with: Frankfurt-M

 DOI:10.15120/GR-2018-1

Strange meson production in pion-nucleus collisions at 1.7 GeV/c

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The production of strange mesons in pion-nucleus reactions allows for a quantitative study of in-medium effects such as re-scattering and absorption processes at a well-defined density (ρ_0). In 2014 the versatile HADES setup at the GSI pion beam facility [1] provided a worldwide unique opportunity to study open and hidden strange mesons (K^+, K^- and ϕ) in cold nuclear matter generated in pion-nucleus reactions ($\pi^- + A,\ A = C,\ W$) at an incident pion beam momentum of 1.7 GeV/c.

In the case of the kaons (K^+, K^0) several hints for the existence of a moderately repulsive KN potential for the kaons (K^+, K^0) exist [2]. On the contrary, the antikaons (K^-) are expected to propagate in an attractive potential with a considerable imaginary part. Antikaons can be absorbed in nuclear matter via strangeness exchange processes on one ($K^-N \rightarrow Y\pi$) or more nucleons ($K^-NN \rightarrow YN$). Furthermore, the study of the ϕ meson production and absorption ($\phi \rightarrow K^+K^-, BR = 48.9\ \pm 0.5\%$ [3]) of light (C) and heavy (W) nuclei is essential. Since, the absorption of the ϕ meson in cold nuclear matter has been interpreted as a proof of the widening of the ϕ natural width [4]. Besides, ϕ decays may substantially affect the observed K^- abundance. In subthreshold 1.23 AGeV $Au + Au$ collisions a surprisingly high ϕ/K^- ratio with a value of 0.52 ± 0.16 was obtained [5]. Also in elementary $p + p$ close to threshold the ϕ meson is a sizeable source for the K^- production [6].

Both charged kaons are identified by means of the time-of-flight (Target T0 Detector/RPC/TOF) and momentum measurements with the drift chambers (MDCs) combined with the toroidal magnet field. To enhance the signal to background ratio, both kaons are pre-selected by their specific energy loss in the MDCs.

Figure 1 shows the mass distribution of the K^- in the polar angle and momentum interval of $15.0 \leq \theta[°] < 27.5$ and $430 \leq p\ [MeV/c] < 500$ in the RPC detector. The neutral ϕ meson is reconstructed in terms of the invariant mass of K^+K^- pairs as shown in Fig. 2 in the polar angle and momentum interval of $15.0 \leq \theta[°] < 27.5$ and $500 \leq p\ [MeV/c] < 1250$.

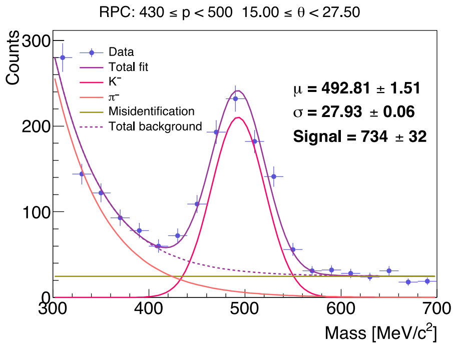

Figure 1: Reconstructed K^- mass spectrum in a specific $p - \theta$ region (see legend) for the RPC in $\pi^- + C$ collsions. The K^- signal is represented by a Gaussian (magenta line). The background is composed of an exponential function for the pions (pink line) and a polynomial (green line).

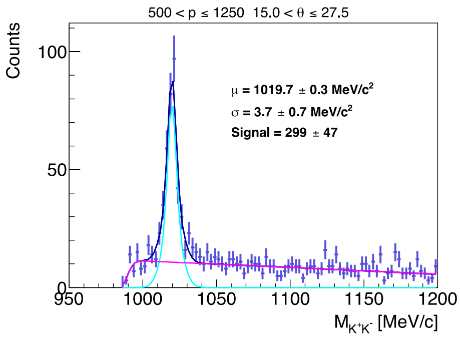

Figure 2: Invariant mass distribution of K^+K^- pairs in a specific $p - \theta$ region (see legend) in $\pi^- + C$ collsions.

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Experiment beamline: HADES@SIS18
Experiment collaboration: HADES
Experiment proposal: S333
Grants: SFB Sonderforschungsbereich 1258 "Neutrinos und Dunkle Materie in der Astro- und Teilchenphysik (NDM)", GSI F&E TMLFRG1316 CBM-RICH
Strategic university co-operation with: none

A non-binomial model for efficiency corrections to particle number cumulants

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Fluctuations of conserved quantities (e.g. baryon number, strangeness, charge) are considered among the most promising probes of the QCD phase diagram [1]. Fluctuations are usually quantified in terms of the cumulants of the observed particle distributions and detector efficiency corrections are applied in order to obtain the true cumulants. This is generally done [2] assuming the efficiency to be of binomial type, i.e. assuming that the detection processes of multiple particles in any given event are independent.

In the binomial model, the probability of detecting p out of M emitted particles in an event can be written:

$$P_p^M = C_M^p \epsilon^p (1-\epsilon)^{M-p} \; . \quad (1)$$

By expanding the $(1-\epsilon)^{M-p}$ term in Eq. (1) and averaging P_p^M over all events one finds a relationship between the average probability to observe p particles and the so-called factorial moments $\langle F_n \rangle$ of the true particle distribution:

$$P_p = \sum_{m=p}^{\infty} (-1)^{m-p} \frac{\langle F_m \rangle}{m!} C_m^p \epsilon^m \; . \quad (2)$$

Using Eq. (2) one retrieves the well-known relation between measured and true factorial moments [3]:

$$\langle f_n \rangle = \epsilon^n \langle F_n \rangle \; . \quad (3)$$

Real-life detectors are commonly designed with a finite occupancy: they can register only a limited number of particles per given event and consequently their detection efficiency decreases with increasing particle number. This effect can be studied in simulations and for HADES the efficiency drop was found to be of order 10% - 15%.

We therefore propose a new, fully analytical, non-binomial model which naturally incorporates efficiency losses resulting from an increasing particle number. Our model strictly applies to detectors segmented into a finite number N of modules of given solid angle Ω such that the total solid angle covered (or total efficiency) is $\varepsilon = N\Omega$. Any given module can fire when hit by a particle, but only once, i.e. multiple hits of a module are not distinguishable from single hits. Following [3, 4], the detection probability in Eq. (1) transforms into:

$$P_{Np}^M = C_N^p \sum_{l=0}^{p} (-1)^{p-l} C_p^l \left[1 - \frac{(N-l)}{N}\epsilon\right]^M \; , \quad (4)$$

and the factorial moments relation of Eq. (3) into:

$$\langle f_n \rangle = \sum_{m=n}^{N} \langle F_m \rangle \frac{(-1)^m}{m!} \frac{\epsilon^m}{N^m} \sum_{k=n}^{m} C_N^k k(k-1)\cdots$$
$$\cdots(k-n+1) \sum_{l=0}^{k} (-1)^k C_k^l (N-l)^m . \quad (5)$$

Figure 1 below illustrates the influence of the detector segmentation on the drop of efficiency with multiplicity.

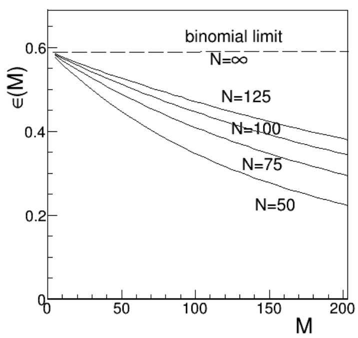

Figure 1: Non-binomial efficiencies as function of the particle multiplicity M for ε = 0.59 and N = 50 – 125.

For a "continuous" detector like HADES a strict hardware segmentation into N distinct modules is not realized, but an effective segmentation $\tilde{N}$ can still be introduced, with $\tilde{N}$ and ε adjusted to describe the observed (or simulated) efficiency behavior $\epsilon = \epsilon(M)$.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposals: S407, S447
Accelerator infrastructure: SIS18
PSP codes: 1.1.2
Grants: none
Strategic university co-operation with: none

π^0 and η production in π^-+PE collisions at 690 MeV/c beam momentum

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[1]Justus-Liebig Universität, Gießen, Germany

In this work we present the analysis of neutral mesons (π^0 and η) in π^- + *polyethylene (PE, [-CH_2-CH_2-]$_n$)* data at a beam momentum of p = *690 MeV/c* taken by HADES in summer 2014. As HADES does not employ an electromagnetic calorimeter, detection is performed via conversion of decay photons (π^0 / η → γγ / γγ*→ $e^+e^+e^-e^-$).

First, lepton identification is performed with rather soft cuts on the particle sample: To do so we require the momentum to be smaller than *1 GeV/c*, an energy loss in the MDCs of less than *12 MeV*, a reconstructed mass $m < 100\ MeV/c^2$ and $0.8 < \beta < 1.2$. Since di-leptons originating from conversion are characterized by small opening angles, we allow for hit sharing in the inner MDCs. Accordingly we cut on opening angles smaller than 10° when reconstructing unlike-sign lepton-pairs to reduce combinatorial background. Simulation shows that π^0 (η) mesons produced at our energies mainly decay into 2γ with opening angles $15° < \theta_{lab} < 45°$ ($115° < \theta_{lab} < 145$). After the formation of lepton-quadruplets from our pair sample we cut on the specified ranges of opening angles between two photon candidates. Clear signals of π^0 and η production with background contribution at the percent level are observed. Figure 1 shows the reconstructed invariant mass spectrum after all cuts. 632 entries in the π^0 mass range and 93 entries in the η mass range are counted.

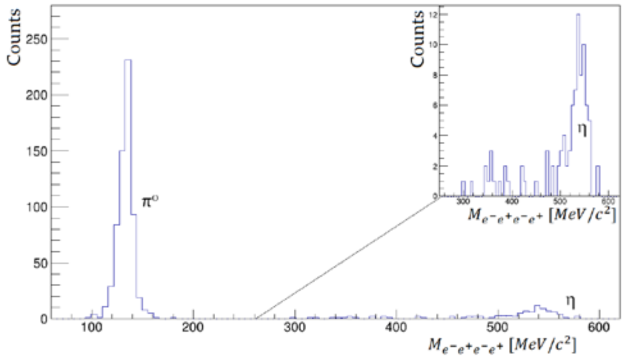

Figure 1: Reconstructed invariant mass spectrum of two detected di-lepton pairs after cuts.

In order to extract π^0 and η cross sections, raw data have to be corrected for detector inefficiency, geometrical acceptance and be properly normalized. We performed an efficiency correction in p_t-y bins based on PLUTO simulations of the π^-+p→ π^0 /η + n reactions and subsequent decay as π^0 /η→ γγ/ γγ*.

We derived integrated efficiencies of

$$\epsilon_{\pi^0} = (4.80 \pm 0.22) \cdot 10^{-6}$$

$$\epsilon_\eta = (2.60 \pm 0.05) \cdot 10^{-5}$$

These values include the conversion probability in the target region of HADES, geometrical acceptance and reconstruction efficiency with all cuts applied. Errors shown are statistical only.

Normalizing on elastic scattering [1,2] we can derive cross sections for π^0 and η production in π^- + *PE*

$$\sigma_{\pi^0} = \frac{\sigma_{el}}{N_{ev}^{el}} \cdot \frac{N_{\pi^0}}{\epsilon_{\pi^0} \cdot N_{ev}^{\pi^0}} = (12.68\ \pm 1.08)\ mb$$

$$\sigma_\eta = \frac{\sigma_{el}}{N_{ev}^{el}} \cdot \frac{N_\eta}{\epsilon_\eta \cdot N_{ev}^{\eta}} = (0.836\ \pm 0.105)\ mb$$

using $$\frac{\sigma_{el}}{N_{ev}^{el}} = 0.88 \cdot 10^{-7} mb\ [1,2]$$

HADES has also measured the reaction π^- + *C*. Analysing this data accordingly we are able to subtract the carbon fraction in our data and derive a cross section for π^0 production in π^- +p (for the η, statistics is too small):

$$\sigma_{\pi^0}^{\pi^-+p} = \frac{\sigma_{el}}{N_{ev}^{el}} \cdot < \pi^0 >_p = (14.39\ \pm 2.73)\ mb$$

with $$< \pi^0 > = \frac{N_{\pi^0}}{\epsilon_{\pi^0} \cdot N_{ev}^{\pi^0}}$$

and $$< \pi^0 >_{PE} = < \pi^0 >_p + \frac{2}{3} < \pi^0 >_C\ [1,2]$$

In literature we find values for the π^0 and η production in π^- +p collisions at *690 MeV/c* beam momentum listed as:

$$\sigma_{\pi^0}^{\pi^-+p} = 16.5\ mb\ [3]$$

$$\sigma_{\eta}^{\pi^-+p} = 0.5\ mb\ [4]$$

Our result for the π^0 cross section in π^- +p is in agreement with literature. For the η we can not compare directly as our cross section is related to π^- +*PE*. Besides the statistical errors shown, our analysis has systematic errors which are being estimated. Those mainly originate from missing production processes in our simulation with three particles in the final state leading to significant differences in the momentum distribution in experiment and simulation, and therefore influence our efficiency.

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Experiment beamline: HADES
Experiment collaboration: HADES
Accelerator infrastructure: SIS18
Grants: GSI strategic partnership
Strategic university co-operation with: Gießen

Exclusive Λ analysis to study hyperon scattering in medium

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Since several years the study of the Λ, the lightest hyperon, is of special interest in several topics, like the equation of state. In vacuum, the elastic interaction between the proton and the Λ-p already has been measured in scattering experiments, constraining theoretical models. [1].

Still, the in-medium properties of the Λ-p system lacks any data point from the experimental side.

In July 2014 a dedicated secondary pion beam campaign was performed with the HADES detector setup impinging on a tungsten (W) and carbon (C) target with an incident beam-momentum of 1.7 GeV/c. As pion reactions are happening close to the surface [2], also the lambdas are created here, traversing the whole nucleus and therefore they form an ideal system to study the lambda in-medium properties.

Our approach is to use the exclusive channel $\pi^- + p \rightarrow K^0 + \Lambda$ where the Λ eventually can interact elastically with its surrounding ($\Lambda + p \rightarrow \Lambda + p$). This may provide information on lambda proton scattering and shed light on the in medium properties of the lightest hyperon.

This channel is isolated by searching for a matching charge pattern ($K^0 \rightarrow \pi^+ + \pi^-, \Lambda \rightarrow p + \pi^-, p$) with 3 positive and 2 negative charged particle candidates.

Further, the particle identification of these particle candidates is based on their characteristic energyloss in the MDCs and their velocity β, measured in the time of flight sub-detector system in combination with the momentum.

In addition, a mass cut further reduces the chance of a wrong identification of these candidates, reducing the background.

Caused by the multiple appearance of particles (p, π^-) in the final state, an event hypothesis is necessary, to assign these particles to their correct mother (K^0, Λ). The best combination is found when both invariant masses (p, π^-) and (π^+, π^-) are best matching to their nominal value (Λ, K^0). The invariant mass of (π^+, π^-) vs. (p, π^-) for the best combination is illustrated in Fig. 1, subtracted by their PDG mass.

To be sensitive to the in-medium behaviour of the Λ an angle difference is extracted, which is constructed as follows:

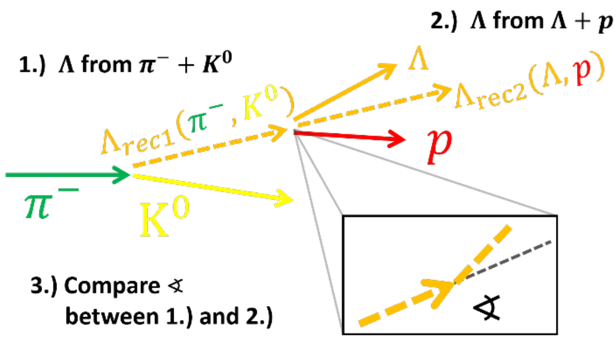

Fig.2 Construction of the observable.

Based on the incident π^- beam in combination with the measured K^0, the Λ momentum can be inferred (Λ_{rec1}) right after its creation. Now this Λ is reconstructed from the measured Λ in the detector in combination with the measured proton. If we assume a single reaction, the sum of the measured Λ and p gives us the Λ before the reaction (Λ_{rec2}). Now the angle between (Λ_{rec1}) (Λ_{rec2}) is evaluated, as sketched in Fig. 2. In theory they should be perfectly aligned. As both protons have an unknown start momentum, arising from the fermi-momentum and we are facing limited resolution, this distribution will be shifted and smeared. Nevertheless, these effects are included in the simulation framework.

The next step in this analysis will include the creation of templates for all different production channels and scenarios which can happen inside the nucleus.

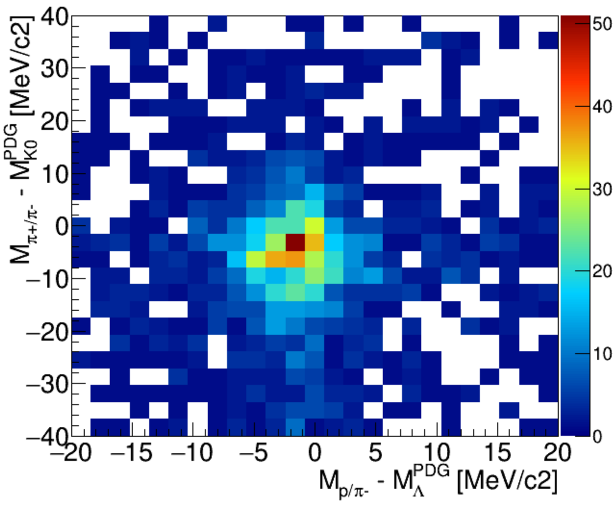

Fig.1 Invariant mass of (π^+, π^-) vs inv. mass of (p, π^-), subtracted by the nominal mass of K^0 and Λ, respectivley. Only the best combination is shown. Details see text.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S333
Grants: BMBF HADES: "Verbundprojekt 05P2015", GSI F&E TMLFRG1316 CBM-RICH

 DOI:10.15120/GR-2018-1

Fit to transverse momentum spectra of dileptons measured by HADES

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Virtual photons are penetrating probes emitted throughout the whole evolution of the fireball formed in collisions of heavy ions and therefore they are well suited for studying the properties of strongly interacting matter at extreme conditions.

The analysis of Au+Au collisions at $\sqrt{s_{NN}} = 2.42$ GeV measured by HADES showed [1] that the invariant mass distribution of dileptons has a Boltzmann shape, which leads to the conjecture, that the temperature of the emitting source, at least the one averaged over the evolution of the system, can be read out from the inverse slope of the mass spectrum.

To do this in a proper way, it is essential to understand which probability density function of invariant mass corresponds to a thermal phase-space distribution. The derivation quoted e.g. in [2] shows that the correct parametrization is

$$\frac{\mathrm{d}N}{\mathrm{d}M} \propto V\tau \frac{\mathrm{Im}\Pi_{\mathrm{em}}(M;T)}{M^2} 4\pi M^2 T\, K_1\left(\frac{M}{T}\right),$$

where V, τ and T are the volume, lifetime and temperature of the fireball, respectively, $\mathrm{Im}\Pi_{\mathrm{em}}$ is the vector meson spectral function, and K_1 is a modified Bessel function of the second kind. This form is obtained after integrating out rapidity. Moreover, the fit has to be made in the range of invariant masses high enough such that the shape of the spectrum is governed by the Boltzmann distribution (Bessel function) and not by the spectral function, so that the latter one can be treated as approximately proportional to M^2. Therefore, the fraction in the above formula is a constant. While at SPS and RHIC energies the temperature can be extracted from the spectra above $1.2\ \mathrm{GeV}/c^2$, at SIS18, where the expected temperature is about four times lower, the fit starting at $0.3\ \mathrm{GeV}/c^2$ would yield a slope parameter that could be compared on the same footing [3]. In addition, in this mass range the argument of the Bessel function can be treated as large enough to justify its known approximation by $K_1(x) \xrightarrow[x\to\infty]{} \sqrt{\pi/2x}\exp(-x)$, which leads to:

$$\frac{\mathrm{d}N}{\mathrm{d}M} \propto V\tau(2\pi MT)^{3/2}\exp\left(-\frac{M}{T}\right)$$

and one gets the well-known representation (cf. [4]):

$$\frac{\mathrm{d}N}{\mathrm{d}M} \propto M^{3/2}\exp\left(-\frac{M}{T}\right)$$

On the other hand, starting from a Boltzmann distribution, and assuming that the spectral function varies little with transverse momentum, one can arrive, by nearly identical mathematical reasoning, to the parametrization:

$$\frac{1}{p_t}\frac{dN}{dp_t} \propto m_t K_1\left(\frac{m_t}{T}\right) \qquad (1)$$

which is exact and does not require any approximation, especially that $m_t \gg T$ is certainly not fulfilled in the low part of the transverse momentum spectra for low invariant masses.

These arguments can be tested with HADES data. The transverse momentum distributions, together with fits of Eq. (1) are shown in Fig. 1. The rather good description of the spectra is visible, which confirms the assumption of the thermal radiation. Particularly, the approximate exponential fit would not reproduce properly the convexity of the spectra. The slope parameters from the fit are shown as well.

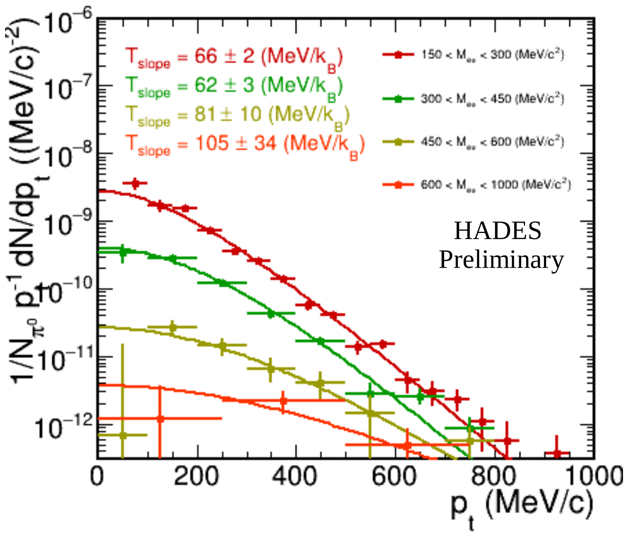

Figure 1. Transverse momentum distributions of dileptons measured by HADES in different invariant mass bins together with fits of Eq. (1).

Another necessary condition is the consistency between the slope parameter extracted from the fit to the invariant mass and the one from the transverse momentum fits, extrapolated to mass zero. This will be tested and discussed in a future publication.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S407
Accelerator infrastructure: SIS18
PSP codes: none
Grants: VH-NG-823, Helmholtz Alliance HA216/EMMI
Strategic university co-operation with: Darmstadt

Understanding the transverse mass spectra of charged pions measured in Au+Au at 1.23 AGeV collisions with HADES

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It is well established that hadron abundances in ultra-relativistic heavy-ion collision can be described with a statistical partition function with fitted temperature T and baryon chemical potential μB. It is interesting to validate if also the spectra of particles at low energies are consistent with thermal production at chemical freeze-out. For such a study Therminator [1] has been used as Monte Carlo event generator. Therminator was previously designed for studying particle production in relativistic heavy-ion collisions performed at different experimental facilities, e.g. SPS, RHIC and LHC.

Therminator assumes that the fireball freezes out at a predefined hypersurface in space-time at given temperature- and bayro-chemical potential. While the program accepts any boost-invariant flow profile, two common flow profiles, the Blast Wave and the Cracow model are already implemented. At this single freeze-out particles abundances are determined by the temperature and baryon chemical potential via the Cooper-Frye formalism.

The parameters used for the Blast Wave model calculations T = 53 MeV, μB = 803 MeV were taken from [2]. This assumes that the collision system investigated by HADES freezes out along the "universal freeze-out line". This curve can be parameterized by <E>/<N> approximately equal to 1 GeV. A collective expansion velocity (β) on the order of 0.36 has been extracted from the same HADES data sample [3] using blast-wave parameterization.

In Fig. 1 mid-rapidity transverse mass spectra of negative and positive pions for the 5% most central collisions are shown in comparison to a cocktail of various sources of pion production obtained from Therminator. Since Therminator simulates also the decays of resonances, the final spectra contain primordial and secondary contributions (the primordial particles are emitted directly from the fireball, while the secondary particles come from resonance decays). Simulated spectra have been scaled up by a factor of 0.7 and 0.5 for negative and positive pions respectively in order to compare slope of the spectra.
We observe good agreement between the data and the model results for low transverse mass region (mT < 400 MeV/c2). On the other hand, the model results underpredict the data for higher transverse masses. This can be interpreted as contribution from decays of higher lying resonances produced in hot/dense matter [4]. This conjecture is presently being checked with transport models.

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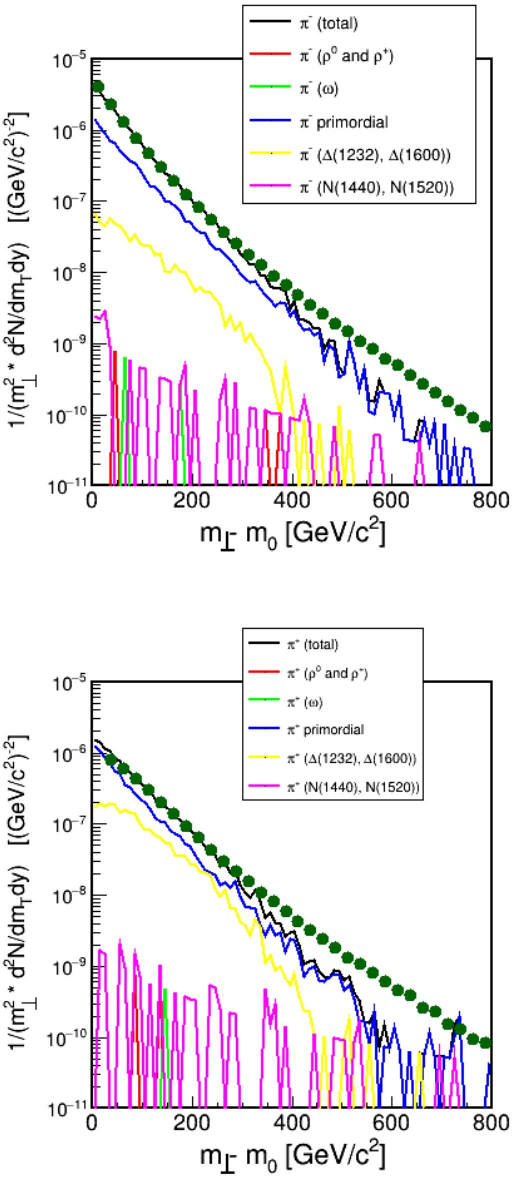

Figure 1. Transverse mass spectrum for negative (upper) and positive pions (lower) compared to the model.

Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S407
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Protons and light nuclei in Au+Au collisions at 1.23A GeV measured with HADES

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By varying the collision system and the beam energy of heavy ion collisions one can access broad areas of the phase diagram of strongly interacting matter.
We have carried out a detailed moment analysis of proton multiplicity distributions of Au+Au collisions with 1.23A GeV [1]. As the fully conserved quantity investigated here is the baryon number, further investigations will focus on including protons bound in the light nuclei formed in Au+Au collisions to the analysis.
A first estimate of the produced nuclei can be made using the β versus momentum correlation, which is used for particle identification (see Fig. 1). It turns out that the created system is a baryonic dominated system and the ratio between proton and deuteron multiplicity is approximately 0.3. Hence, indeed a significant contribution of protons is indeed bound in deuterons and light nuclei.

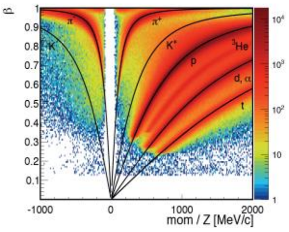

Figure 1: Correlation between measured time-of-flight β and particle momentum. Black lines correspond to the expected values of the different particles.

Furthermore by studying the light nuclei, one can also estimate the degree of thermalization of the system by comparing e.g. transverse rapidity distributions to longitudinal rapidity distributions. Also the mechanism for the production of the nuclei can be examined in detail and confronted with phenomenological models, e.g. formation of coalescence versus thermal production.
In order to calculate the count rate of protons, in this analysis the phase space is divided into cells along the rapidity and transverse mass axis. These cells were chosen to cover an interval of 0.09 < y < 1.59 in 0.1 steps for rapidity and 0-1000 MeV/c^2 in 25 MeV/c^2 steps along m_t-m_0. For every reduced transverse mass bin the mass spectra is plotted and the proton countrate is extracted using a multi-gaussian fit.
The resulting transverse mass spectra extracted for various rapidities are subsequently corrected for detector acceptance and efficiency. The resulting corrected number of counts is divided by m_t^2 in order to easily compare to a thermal distribution and a blast wave.
From these spectra, information about the freeze-out in form of the kinetic freeze-out temperature T_{kin} and characteristics of the radial flow in form of the radial expansion velocity β_r can be derived.

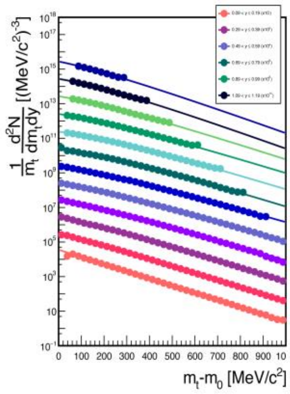

Figure 2: Corrected transverse mass spectra of protons for the 0-40% most central events, scaled by $1/m_t$. Each spectrum is multiplied by a power of 10 and fitted using a blast wave function.

To estimate the multiplicities, the spectra have to be extrapolated to full phase space. One approach for extrapolation is by using blast wave functions fitted to the data:

$$\frac{1}{m_t}\frac{d^2N}{dm_t dy} = \int_0^R A m_t K_1\left(\frac{m_t \cosh(\rho)}{T_{kin}}\right) I_0\left(\frac{p_t \sinh(\rho)}{T_{kin}}\right) r dr$$

with A being a constant, $\rho(r) = tanh^{-1}(\beta_r(r))$, K_1 and I_0 are two modified Bessel functions ans the transverse geometric radius of the source is denoted by R.
The transverse velocity field $\beta_r(r))$ can be derived as

$$\beta_r(r) = \beta_s \left[\frac{r}{R}\right]^n \text{, with n = 1.}$$

According to formula a blast wave was fitted to the data (shown in Fig. 2). For this β and T are extracted in a global χ^2 scan over all data points.
Further steps in the analysis will be the centrality dependend analysis and the extension to the analysis of light nuclei in order to reconstruct the complete kinematics of participating baryons.

Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S407
Accelerator infrastructure: SIS18
PSP codes: 1.1.2.
Grants: GSI strategic partnerships (FuE), HIC for FAIR, BMBF(05P15RFFCA)
Strategic university co-operation with: Frankfurt-M

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Λ polarization in Au+Au collisions at $\sqrt{s_{NN}} = 2.42\,\mathbf{GeV}$ investigated with HADES

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Λ hyperons can be used as a probe for possible vortical effects in the early stages of heavy-ion collisions since their weak decays preserve information about their polarization due to parity violation [1,2].

A good candidate to search for such an effect is the Λ hyperon with its decay channel $\Lambda \to p + \pi^-$. The polarization can be described by proton azimuthal angle in the Λ frame ϕ_p^* with respect to the total orbital angular momentum L [3]. Since L is always perpendicular to the reaction plane Ψ_{RP}, the reconstructed event plane Ψ_{EP} can be used as a measure for L, taking into account its resolution R_{EP}:

$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda} \frac{\langle \sin(\Psi_{EP} - \phi_p^*) \rangle}{R_{EP}} \qquad (1)$$

Here $\alpha_\Lambda = 0.642 \pm 0.013$ [4] is the corresponding decay parameter and the brackets denote the average over all Λs and events.

Previous measurements by the STAR collaboration indicate an enhancement of the Λ and $\overline{\Lambda}$ polarization in Au+Au collisions towards lowest collision energy, $\sqrt{s_{NN}} = 7.7$ GeV [5] while there is no polarization found at the highest collision energy, $\sqrt{s_{NN}} = 200$ GeV [3].

At a center-of-mass energy of $\sqrt{s_{NN}} = 2.42$ GeV, seven billion events of Au+Au collisions were recorded with HADES in april 2012. After event selection and track reconstruction, the decay daughters of Λ candiates were selected first using a cut on their mass times charge of $0.3\ GeV/c^2 < m \cdot q/e < 1.3\ GeV/c^2$ for the proton and $-0.3\ GeV/c^2 < m \cdot q/e < 0\ GeV/c^2$ for the pions. All identified protons and pions in one event are combined to Λ candidates. Possible Λ candidates are selected by the parameters of the decay topology: the offset of both daughter tracks to the event vertex, the closest distance of these tracks as a possible decay vertex, the distance of the Λ track to the event vertex and the flight distance of the Λ with a lifetime of $c\tau \sim 8\ cm$. The distributions of these variables from simulated thermal Λs embedded into UrQMD [6] are handed to the TMVA to train a neural network to distinguish between signal and background. The mixed-event method is used to generate the background. This results in one cut parameter, the discriminant which is a weighted sum of all the input parameters. In the current analysis, various cuts are applied to the Λ candidates in order to guarantee a high purity sample after the TMVA is performed.

The discriminant is optimised on the significance which results in $\sim 3 \cdot 10^5$Λs remaining for $0 - 40\%$ centrality which is enough statistics to perform this analysis. The results of this sample of Λs for 10% centrality classes is shown in Figure 1 for three different mass bins. For the sidebands the $2 - 4\sigma$ range around the fitted Λ peak is taken, while for the Λs the 2σ region around the mean value is used as an input. The signal-to-background ratio in this region is 3.7 for the most peripheral bin and drops down to 1.3 in the most central case. The significance is in the range of $sig \sim 200$.

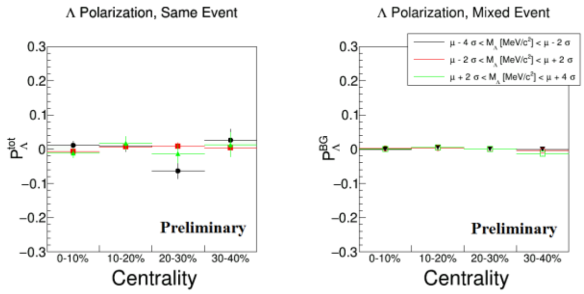

Figure 1: Λ Polarization in Au+Au collisions at $\sqrt{s_{NN}} =$ 2.42 GeV in comparison to the sideband of the mass spectrum as a function of the centrality of the collision. In the left panel, the results are shown for the same event while in the right panel the results from the mixed-event are shown.

As a proof of principle the Λs from the mixed-event are not polarized. Yet for the same-event analysis the measured polarization is comparable to zero. For sure, one has to be aware of the effects of a limited detector acceptance. The results shown here are integrated values over rapidity and transverse momentum. The p_t and rapidity dependent analysis will be performed in the near future. Nevertheless, one has to correct for the finite geometrical coverage of the detector. The effects of the limited detector acceptance are discussed in [7] and will be investigated for the case of HADES.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S407
Accelerator infrastructure: UNILAC/SIS 18
PSP codes: none
Grants: VH-NG-823, Helmholtz Alliance HA216/EMMI
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Dilepton production in pion induced reactions with HADES

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The HADES experimental program on pion-beam induced reactions was recently started at GSI [1,2]. The π-nucleon reaction is an ideal probe to study baryon resonances. In particular, the dilepton (e^+e^-) production is used to investigate baryon resonance Dalitz decays ($R \rightarrow Ne^+e^-$), which provides access to the time-like electromagnetic structure of baryon transitions.

The e^+e^- production was measured in a test experiment using the GSI pion beam at a momentum of 0.685 GeV/c impinging on polyethylene and carbon targets [3]. The standard algorithm to identify leptons (**ring finder**) is based on finding ring patterns induced by the Cherenkov photons in the RICH detector. In addition, a matching between the reconstructed ring centre and a lepton track candidate is required. In case of small number of reconstructed photons per ring the efficiency of the lepton reconstruction can be improved using another method, the so-called **backtracking**. Here, one starts from lepton candidate tracks extrapolated to the RICH and searches for corresponding hits with looser constraints than in the ring finder method. After a careful tuning of the simulated RICH response, a realistic description of the RICH observables and of the efficiencies of the reconstruction algorithms in the simulation could be achieved. This is demonstrated in Fig.1, where the dilepton invariant mass spectra obtained for each algorithm after efficiency corrections are compared. The backtracking algorithm reaches an efficiency about factor 3 three higher, which is important, in particular when considering the low e^+e^- yield in the invariant mass region above π^0.

To allow for a more direct study of the baryonic contributions, events from the π^0 and η Dalitz decays present in the inclusive spectra can be efficiently rejected by applying conditions on invariant mass ($M_{ee} >$ 140 $MeV/c^2$and missing mass ($M_{miss} >$ 1040 MeV/c^2). In this way, about 1500 events corresponding to free or quasi-free $\pi^- p \rightarrow ne^+e^-$ reaction were selected, with a contribution of about 66% of pion carbon events. The comparison to model predictions is on-going, but it is already clear that a significant excess above expected contributions assuming point-like baryon Dalitz decays is present in the dilepton invariant mass distribution. Based on a Partial Wave Analysis (PWA) of the two-pion production measured in an energy scan in the same experiment, this excess can be interpreted as an off-shell ρ contribution, consistent with the Vector Dominance Model (VDM). These studies have a direct impact on the modelling of the emissivity of strongly interacting matter, which is based on VDM [4].

A parametrization of the angular distributions using the spin density formalism was also performed. It allows for the first time to extract important information on the helicity structure of baryon electromagnetic transitions in the time like region [5].

In future, we propose to extend these measurements to the third resonance region ($\sqrt{s} \sim 1.7\ GeV$), with higher statistics, taking advantage of the foreseen improvement of the beam intensity and of the upgraded HADES detector, including in particular the new Electro Magnetic Calorimeter and a new Forward Detector.

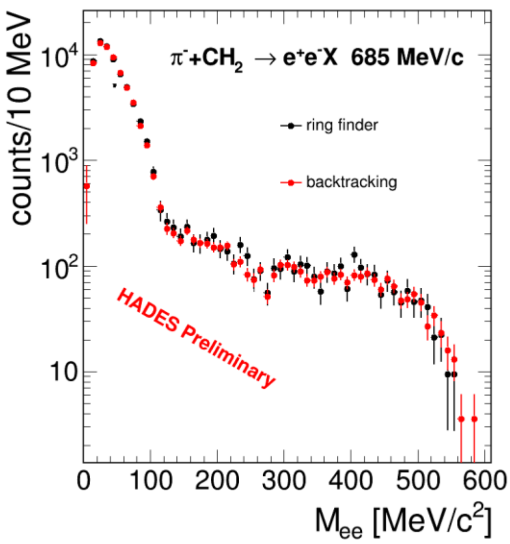

Figure 1: Efficiency corrected yield e^+e^- pairs reconstructed using the ring finder (black dots) and the backtracking algorithm (red dots). The data was taken for a pion beam at a central momentum of 0.685 GeV/c impinging on a polyethylene target.

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Experiment beamline: HADES
Experiment collaboration: HADES
Experiment proposal: S333
Accelerator infrastructure: SIS18
PSP codes: 1.1.2
Grants: VH-NG-823 TU Darmstadt and CNRS/IN2P3 IPN Orsay
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