Backtracking algorithm for lepton reconstruction with HADES

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Abstract. The High Acceptance Di-Electron Spectrometer (HADES) at the GSI Helmholtzzentrum für Schwerionenforschung investigates dilepton and strangeness production in elementary and heavy-ion collisions. In April - May 2012 HADES recorded 7 billion Au+Au events at a beam energy of 1.23 GeV/u with the highest multiplicities measured so far. The track reconstruction and particle identification in the high track density environment are challenging. The most important detector component for lepton identification is the Ring Imaging Cherenkov detector. Its main purpose is the separation of electrons and positrons from large background of charged hadrons produced in heavy-ion collisions. In order to improve lepton identification this backtracking algorithm was developed. In this contribution we will show the results of the algorithm compared to the currently applied method for $e^{+/-}$identification. Efficiency and purity of a reconstructed $e^{+/-}$ sample will be discussed as well.

1. Introduction

Modifications of hadrons at high densities and high temperatures might be accessed in the laboratory by colliding heavy-ions at (ultra-)relativistic energies. A detailed analysis of particle production offers insights to new phases of strongly interacting matter. Dileptons are considered to be an ideal probe of such phases, since the invariant mass of lepton pairs monitors directly an in-medium modified spectral function of hadrons.

In the energy range of SIS18 long-lived fireballs with high net-baryon densities and moderate temperatures can be created [1]. Nuclear resonances like Δ and N^* represent the main source for particle production at SIS18 energies [2]. For description of dilepton production, resonances have to be taken into account since they can decay into a nucleon and a dilepton via Dalitz decays. Because of the unknown form factor of this process, additional theoretical descriptions but also experimental data are needed. One explanation of the particle production mechanism is given by the vector meson dominance model [3]. It states that a virtual photon decay can acquire a hadronic character by decaying into an $e^{+/-}$ pair. This is possible since vector mesons carry the same isopin and parity ($J^P = 1^-$) like photons do. Photons and leptons do not interact strongly with produced matter, therefore they are a good probe for investigation of the dense and hot collision phase without any modification by interaction with the surrounding strongly interacting hadronic matter. Especially the ρ meson is the best probe since it has a short lifetime ($\tau_\rho \approx 1.3 fm/c$), for this reason it is more likely to decay into leptons within the dense collision phase ($\tau_{Fireball} \approx 10 fm/c$).

Unfortunately, electromagnetic probes are produced during the whole collision evolution, in the first chance collisions (Δ, N^*), in the hot and dense fireball (ρ) and in the freeze out stage

(π^0, η, ω). Furthermore they are very rare probes, e.g. $BR(\rho \rightarrow e^+e^-) = 4.72 \cdot 10^{-5}$. Moreover at SIS18 energies vector mesons are produced far below their nucleon-nucleon production threshold. For these reasons all contributions have to be known precisely in order to obtain a reliable measurement of possible in-medium modifications of the ρ meson. Significant excess radiation of dileptons, beyond final state hadron decays was established at the CERN-SPS [4],[5], at the RHIC[6],[7], at the Bevalac/SIS18[8]. From these measurements one could extract a total lifetime of the fireball and an average temperature. To complete the systematics at low beam energies HADES measured dilepton production in Au+Au collisions at 1.23 GeV/u.

2. HADES

The High Acceptance DiElectron Spectrometer (HADES) is located at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt [9]. The data analyzed in this work are from the Au+Au campaign measured in 2012. These are the highest multiplicities which where measured with HADES so far, with this aim high granularity detectors with a precise lepton to hadron separation are required.

The RICH detector [10] (see Fig. 1) is the most important HADES detector component for lepton identification. It consists of a volume filled with C_4F_{10} as radiator gas, in which particles in case they move faster than the speed of light emit Cherenkov radiation in a cone shaped pattern. Photons are reflected by a UV-mirror towards the photon detection plane, that consists of a CsI photon converter and a multiwire proportional chamber operated with pure CH_4. Both gas volumes are separated by a UV transparent CaF_2 window. Due to reflection by the mirror, ring shaped patterns are detected on the pad plane and are identified as good rings by a pattern recognition algorithm. In case their position matches with a reconstructed particle track, hits are combined and defined as lepton candidate.

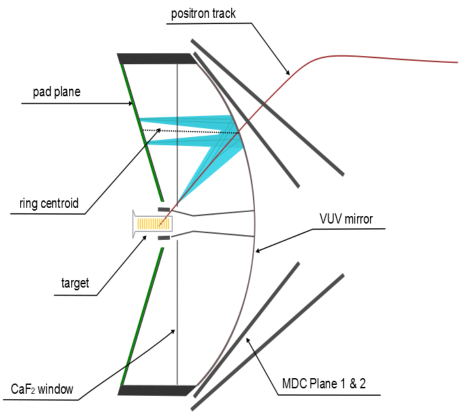

Figure 1. Schematic side view of the RICH detector. A positron track shows usage of angular information to determine a ring center.

3. Backtracking

3.1. Motivation

Dileptons are rare probes and their measurement is dominated by hadronic background. On one hand, due to the large number of hadrons, already a small fraction of wrongly identified particles decreases the purity of a lepton sample significantly. On the other hand high lepton reconstruction efficiency is important. The dominant background sources originate from Dalitz decays of π^0 and γ conversion on detector material in the target region. The latter are characterized by small opening angles ($\alpha < 2°$). Another problem arises in the case of overlapping rings where their geometrical shape is distorted and identification of both rings by geometrical means is complicated.

In order to improve lepton identification, compared to the currently applied ring finder, an algorithm with improved efficiency but maintaining a high purity sample is necessary. Identification of tracks with a small opening angle below the current ring resolution helps to identify correlated signal pairs instead of creating background by identifying only one single lepton.

Backtracking is a new approach which uses additional tracking information to improve ring identification efficiency and to enhance capability of rejecting incomplete conversion pairs. In case a particle candidate fulfills velocity and energy loss criteria that correspond to leptons, the angular information is used to point back at the RICH detector and fix the possible ring center on the pad plane (see Fig. 1). By fixing the ring center position, requirements for good rings can be reduced to enhance identification efficiency. Even stronger improvements can be obtained by applying this method for very close tracks. Since the angular track resolution is better than 2° while the ring resolution is about 4°, tracking information offers the possibility to use the expectation values of close pairs to search for overlapping rings.

3.2. Method

Backtracking procedures from assigning the ring expectation to interpreting the measurement are explained below. In the beginning of the procedure, the angular information from track candidates has to be transformed by geometrical mapping in order to match with the photon positions on the RICH pad plane. Afterwards the ring has to be parametrized to define the radius and the width of its photon distribution. Fig. 2 shows that ring attributes are not constant for different ring sections. Moreover they are not constant over the polar and azimuthal angles of the detector coordinates. Additionally, rings are correlated with the position of the particle emission vertex. Therefore functions depending on these four parameters are necessary to describe the ring shape and to transform it to discrete RICH detectors pads. The number of measured photons per ring is the main indicator of a good ring. However the amount of measured clusters do not provide a direct measurement of the photon number because close photons can merge to a single cluster. Additionally, the noise disturbs the signal, and it can also form clusters. An identification of this noise would lead to a more pure lepton identification. For the case of close pairs it is also necessary to determine how much rings are overlapping. As a basic observable, number of clusters contributing to a ring is used. Additionally, local maxima of clusters are searched for and counted. Furthermore, pads and charge of clusters or of pads directly matching with the ring prediction area are summed up. The fit of the two dimensional charge distribution with a Gaussian function allows a more precise maximum determination. By calculating the distances between the predicted point of the most probable hit and the maximum position, a ring quality can be extracted. The comparison of the fired pads matching with prediction area and fired pads in a 16x16 matrix around the ring center gives a ring matrix observable. For close pairs, shared maxima information is provided.

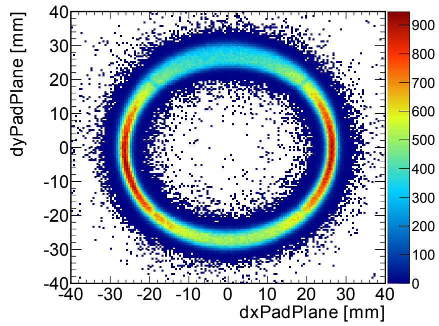

Figure 2. Photon hit distribution in the RICH pad plane for fixed ring center at (0,0).

Searching for local maxima is the best approach for a direct measurement of the photon number and it is a good estimation of signal quality. Using pads and charge information of rings a large difference between sum of directly matching pads and sum of clusters can be used as an indicator for noise or overlapping rings. Random noise hits do not match well with the ring expectation area, for which reason rings created by noise hits have worse ring quality values. Using the information of the number of shared maxima allows identification of close pairs and exposure of hadronic tracks picking up charge from leptonic tracks. Finally a set of observables is provided for ring identification, noise rejection and close pair analysis.

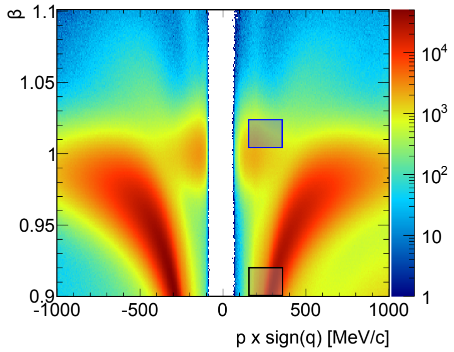

Figure 3. Momentum versus velocity distribution shows lepton separation by usage of time-of-flight information. Training sample selection is indicated by shaded areas (upper one is for signal, lower one is for background).

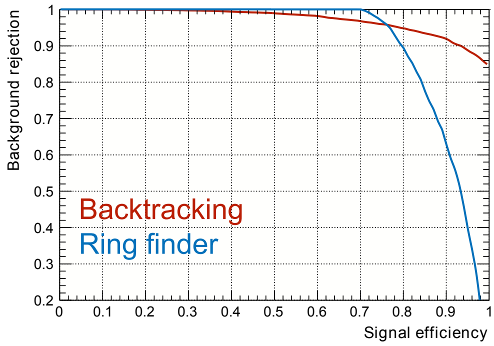

Figure 4. Signal efficiency as function of background rejection for backtracking and currently applied ring finder algorithm.

4. Application

4.1. Single lepton identification

The HADES sub detectors provide a set of observables for particle identification. Information provided by MDC, ToF and PreShower detectors are velocity, momentum, specific energy loss, track quality and matching quality between MDC and RPC or TOF detectors. Velocity measured with ToF detectors offer a high purity lepton identification up to momenta of 350 MeV/c. But above this momentum threshold it is essential to apply additional backtracking information for efficient hadron suppression (see Fig. 3).

From the large set of particle observables of sub detectors and especially of backtracking only one- or two-dimensional correlations can be considered. To include multidimensional correlations a multivariate data analysis is performed [11]. Before this method is applicable to data the algorithm has to be trained with a signal and a background sample. Therefore the momentum and velocity selection, as shown in Fig. 3 is used to define a signal sample with $e^{+/-}$ and background sample with $\pi^{+/-}$. The resulting efficiencies for given background rejection are shown in Fig. 4. A comparison of the backtracking algorithm with a similar analysis using RICH ring finder information shows that backtracking achieves similar background rejection but is able to achieve much higher efficiencies by maintaining slightly smaller background rejection.

4.2. Lepton pairs

To obtain the dilepton invariant mass spectrum, single leptons have to be combined into pairs. However, decays from the hot and dense stage are not the only leptonic particle source. Additionally, electrons and positrons decaying from π^0 or η contribute. Since the origin of the decay particles can not be identified a priori all possible pair combinations have to be introduced. The uncorrelated lepton pairs represent combinatorial background (CB). The CB can be determined by using the same-event like-sign method. To do so like-sign pairs (N_{++}, N_{--}) from the same event are combined and used for calculation of the geometrical mean $CB_{geom} = 2\sqrt{N_{++}N_{--}}$. The signal of correlated pairs results from subtraction of the calculated background distribution from the unlike-sign spectrum.

Higher lepton reconstruction efficiencies of backtracking increase the probability of detecting incomplete lepton partners. Additional CB rejection power is achieved when applying an opening angle cut. Changes after application of the close pair rejection are shown in Fig. 5. Here we can see that the combinatorial background from the analysis with backtracking is reduced by up to a factor of 4.

5. Conclusion

In this work we presented a new method for lepton identification with HADES. Tracking information from drift chambers is used to reduce the degrees of freedom for the ring search. The general strategy as well as output observables of the algorithm were presented. A comparison with the currently used RICH ring finder showed an enhanced efficiency for lepton reconstruction by similar purity of the lepton sample. Furthermore, pair observables of backtracking were used and showed improvements for rejection of close pairs. Finally, a successful application of backtracking algorithm was shown. The CB can be reduced by up to an additional factor of 4. It will allow for detailed multi-differential (p_T, angular distribution) analysis of the dilepton invariant mass spectrum.

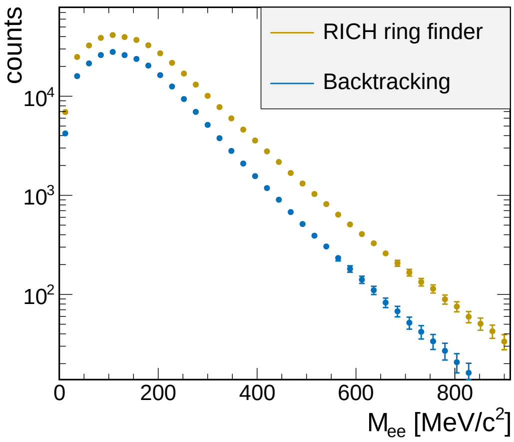

Figure 5. CB distribution for currently applied ring finder (yellow) and backtracking (blue). Close pair rejection is applied.

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