# Hadron and Dielectron Production in C+C Collisions at 2 A·GeV

The HADES collaboration

## 1 Introduction

In summer 2003 all components of the HADES spectrometer have been installed except for two of the 24 Multiwire Drift Chambers (MDC) delivery of which is scheduled for 2004/2005. In this configuration the tracking system of HADES is completed in four out of six HADES sectors and ready to perform high-resolution measurement with an anticipated $\Delta M/M = 1.5\%$ mass resolution. Therefore a series of proton-proton experiments have been scheduled in fall of 2003 and beginning of 2004. The goal of these experiments is to establish high resolution tracking and to measure calibration reactions like $pp$ elastic scattering, as well exclusive meson production channels i.e $\pi^0$, $\eta$. The latter ones are extremely important for the full understanding of the HADES dielectron reconstruction efficiency and second level trigger performance. In September 2003 we have installed for the first time the $LH_2$ target for proton and pion experiments. The target, first trigger settings and background situation were commissioned in October 2003. A maximum beam intensity of $2 \times 10^7$ protons/sec and trigger rates of $5kHz$ have been achieved. Careful design of the target area allowed to obtain a very good ratio of full/empty target trigger rates of 10 : 1. The production physics run took place in February 2004.

In parallel the data obtained from C+C reaction at 2 A·GeV have been extensively studied. The recent two experimental runs in 2001 and 2002 with a total collected statistics of around $5 * 10^7$ (LVL1) and $20 * 10^7$ (56%LVL1 + 44% LVL2) events are analyzed. In the second run we used for the first time a second level trigger (LVL2) to select LVL1 events with electron candidate tracks. Selected preliminary results from these experiments are presented below.

## 2 Particle Production in C+C at 2 A·GeV

Particle identification in the HADES detector starts with track reconstruction in the Multiwire Drift Chambers (MDC). The inner MDC track segments are correlated with hits in the Time-of-Flight (TOF) wall and the Pre-Shower placed behind the magnetic field to form particle trajectories (no MDIII/IV information was used in the analysis presented here). Particle momenta are derived from the measured deflection in the magnetic field.

Particle identification in HADES is performed using a probabilistic approach. The basis of the method is a test of the hypothesis that the reconstructed track belongs to a certain type of particle (e.g., proton, charged pion, electron etc.). In the test the information from several measured variables and sub-detectors (i.e time of flight, energy deposition) is combined using probability density functions (PDF) that are determined by simulations for each variable and for all possible particle types. The particle identification (PID) probabilities are calculated taking into account the measured abundances of the different particles and the specific PDFs of measured variables. The identification efficiency and selectivity achieved with this method is then evaluated in detailed simulations.

Hadron identification is performed on the basis of momentum as measured by the magnetic deflection, the velocity and energy loss as measured by the TOF detector. For the lepton identification, data from the RICH (Ring Imaging Cherenkov) and the Pre-Shower detectors are used in addition.

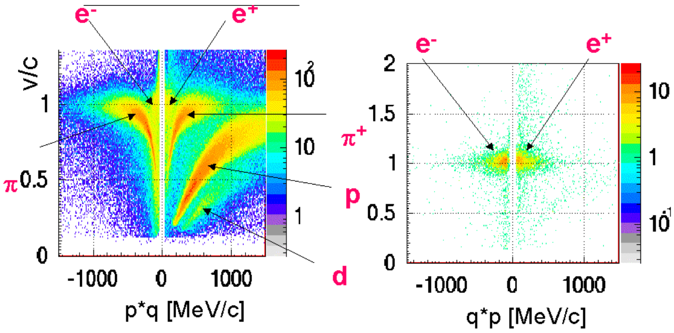

Figure 1: : **Left** Correlation between velocity and signed(charge) momentum for all reconstructed tracks from C+C collisions at 2 A·GeV. Pion and proton branches are clearly resolved. **Right**: same as on the left but with the additional condition that an electron was identified. The intensity scale is logarithmic.

The principle of the particle identification is illustrated in Figure 1. Particles with different mass fill different region in the velocity vs momentum distribution shown on the left hand side. The pronounced maxima correspond to positive/negative pions and protons. The analysis shows that pions can be separated from protons up to momenta of $p < 1000MeV/c$ with purity better then 80%. Electron identification can be achieved only if the RICH electron condition is switched on, as shown on the right side of Figure 1. Detailed investigations of measured electron distributions and dedicated Monte Carlo simulations using the URQMD event generator, reveal that the residual contamination of hadronic background is less than 2% and the purity of electron reconstruction is around 90%. The remaining 10% is electron misidentification that can be attributed, in addition to the mentioned hadron contribution, to fake combinations of inner MDC track segments with the hits in the TOF/Shower detectors. This fake contribution is expected to be significantly reduced once the MDCIII/IV information is included in the analysis of the November 2002 data.

Absolute proton and pion yields were extracted from the data. The correction factors accounting for the geometrical acceptance and the efficiency of detectors and the tracking method were obtained via simulations. As an example of our hadron analysis results we show on Figure 2 the transverse mass distribution of positively charged pions measured at midrapidity, $d\sigma/dm_t \cdot 1/m_T^2$. The solid line shows a thermal fit with two slopes ($T_1 = 41 \pm 3$ and $T_2 = 87 \pm 3$ MeV) which describe our data better than a fit with one component only. Similar conclusions can also be derived from the analysis of negative pion distributions, in agreement with previous data on pion production for the same system and similar energy [1]. The average number of participants in the events selected by the 1st level trigger (LVL1) was estimated from URQMD simulations to be $A_{part} = 8.6$. The preliminary pion yield per participant extrapolated to $4\pi$ is $N_p/A_{part} = 0.148 \pm 0.015$, where $N_p/A_{part}$ is the average of the yields of positively and negatively charged pions. This value is in a good agreement with the previous result measured by the TAPS detector for neutral pions as $0.138 \pm 0.014$ [2].

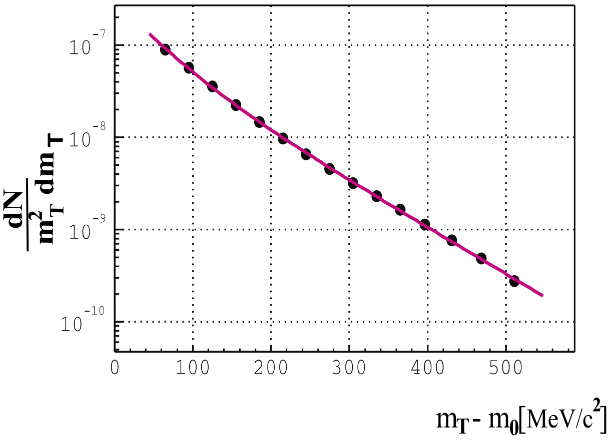

Figure 2: : Transverse mass distribution of positively charged pions in C+C collisions at 2 A·GeV. The solid line is a thermal fit with the two slope parameters 41 and 84 MeV.

The yields and shapes of the momentum spectra of electrons and positrons (not shown) are very similar with average multiplicities of $2 * 10^{-2}$ per LVL1 event. The measured spectra agree in shape with the ones obtained from simulation but their integral is by $\sim 25\%$ lower. The simulation is based on URQMD events with realistic trigger conditions the particles of which are tracked through the HADES detectors leading to digitized raw data. These simulated events were then reconstructed by the standard analysis software chain. This finding and studies of single electron identification capabilities indicate that with the current analysis procedure the inefficiency amounts to 20%.

## 3 Dielectron Production in C+C at 2 A·GeV

From the identified electrons and positrons we have constructed unlike ($e^+e^-$) and like sign ($e^+e^+$, $e^-e^-$) pairs. Most of these pairs are uncorrelated and due to leptons from (different) photon conversions ($\sim$ 60%) and Dalitz decays of $\pi^0$ mesons ($\sim$ 20%). For the further analysis we have used only pairs that contain lepton tracks producing well separated hits in all detectors with opening angles larger than $\Theta > 9°$. Furthermore, a powerful Close Pair Rejection (CPR) method [3] has been applied to identify and reject those leptons which originate from (close) pairs that produce only one ring, only one cluster in the inner MDCs and have only one associated hit in the downstream TOF/Pre-Shower detectors (because the second low energy partner of the pair is deflected out of the detection system). The CPR uses information from the inner MDC system, like cluster size and number of contributed wires, and allows for efficient rejection of pairs with very small opening angle.

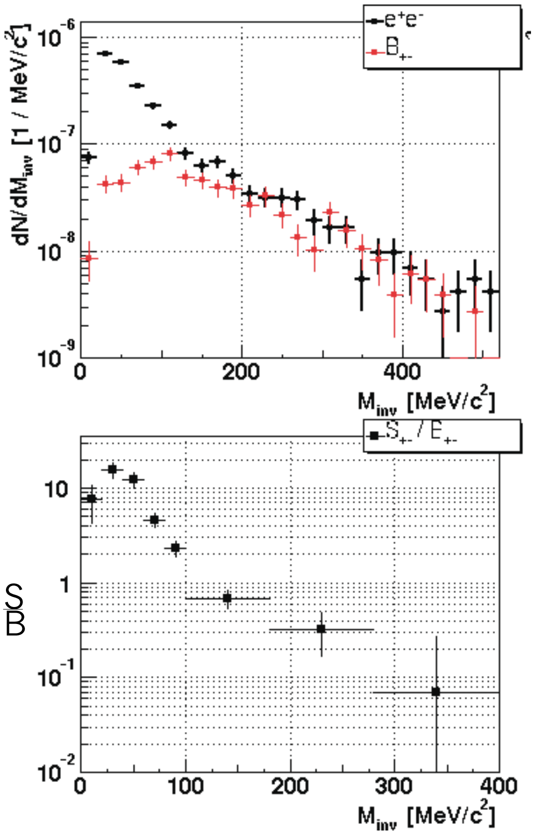

Figure 3: **Top**: Dielectron invariant mass distribution and Combinatorial Background (CB), calculated as described in the text. The distributions have been normalized to the number of LVL1 events. **Bottom**: Signal-to-background ratio after CB subtraction. These distributions are preliminary and subject to further corrections due to detector inefficiencies.

In order to evaluate the combinatorial background $N_{CB}$ we have used like-sign pairs $N_{++}$, $N_{--}$ and the formula $N_{CB} = 2\sqrt{N_{++} * N_{--}}$. Figure 3 (top) shows unlike sign invariant mass distributions together with the corresponding combinatorial background. The expected most dominant sources of dielectron signal pairs are $\pi^0$, and to a much smaller extent, $\eta$ Dalitz decays. We observe indeed that the dominant signal (with signal to background ratio of $S/B \sim 5$) is in the invariant mass region up to 150 MeV/c$^2$. In the higher mass region we also observe a systematic excess of dielectron yield over the combinatorial background with an average $S/B \sim 1:3$. The total pair statistics, after subtraction of combinatorial background

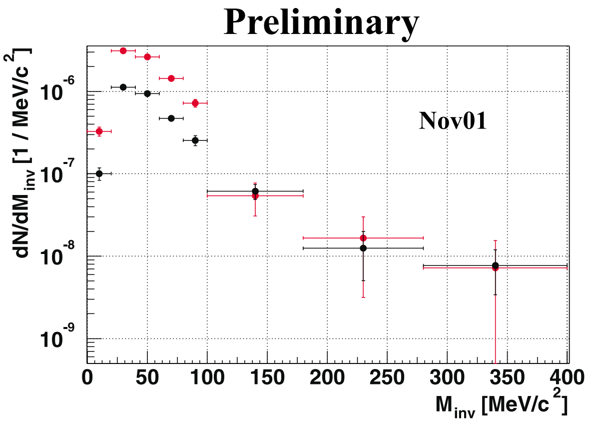

Figure 4: : Measured (black squares) and simulated (red dots) dielectron invariant mass distributions after CB subtraction normalized to the average number of charged pions. The error bars indicate statistical uncertainty. The systematic errors in this early analysis stage are estimated to be around 40%. These distributions are preliminary and subject to further corrections due to detector inefficiencies.

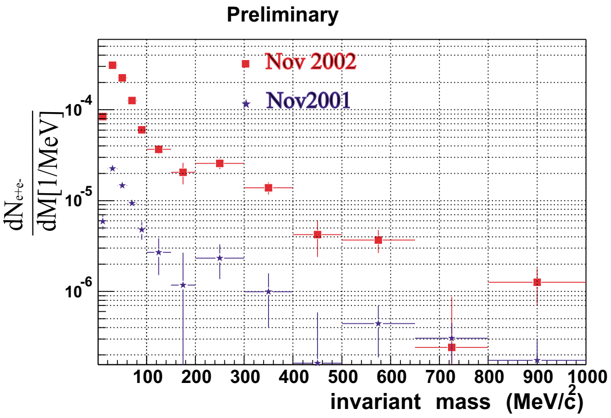

Figure 5: Comparison of dielectron invariant mass distributions (CB subtracted) normalized to the number of LVL1 events (November 2001) and the LVL2 events (November 2002 data).These distributions are preliminary and subject to further corrections due to detector inefficiencies.

and analysis cuts described above, amounts to $\sim 2.5k$. Figure 4 shows dielectron invariant mass distributions for data and simulation normalized to the average number of charged pions, $0.5(N_{\pi^+} + N_{\pi^-})$, determined from the same data set. It can be seen that in the low mass region ($\pi^0$-Dalitz) simulation overestimate data by a factor of $\sim 2$ but in higher mass region simulation and data agree rather well. A significant part of this discrepancy can be traced back to the already mentioned differences in the single electron yields. However, detailed studies of dielectron analysis show additional differences in reconstruction efficiencies for very close tracks that need further investigations. On the other hand, both the HADES measurement of charged pions and the neutral pion yields from TAPS indicate that URQMD overestimates pion production by $20 - 30\%$ at this energy. In order to disentangle the different sources of the discrepancy (elementary cross sections and electron identification efficiency) a dedicated calibration measurement of exclusive $\pi^0$ and $\eta$ production in $pp$ scattering is scheduled for February 2004. Analysis of the high statistics C+C data set from Nov02 will provide insight into lepton identification.

## 4 Second level Trigger Performance

The HADES second level trigger was fully operational during the beam-time of November 2002 where C+C reactions were measured at 2 A·GeV. Events which contain at least one electron candidate, i.e. a correlation between a RICH ring and a hit in the Pre-Shower or TOF within a broad azimuthal window were positively triggered, with an event reduction by a factor 12. It has been estimated that higher reductions, up to a factor 20 are achievable without further loss of efficiency. A preliminary analysis of the collected data allows an estimation of the second level trigger performance. Due to a more restrictive implementation of the ring recognition algorithm, a single electron efficiency of 62% was calculated, while 84% efficiency was estimated for dielectrons with opening angle larger than 4°, and 92% for opening angle larger than 8°. No physical bias was introduced in the data, since agreement between electron and dielectron spectra for triggered and untriggered events is observed. In the triggered events an enhancement by a factor 7.5 is found in the electron yield, and by a factor 11 in the (lepton) pair yield, with respect to the untriggered ones.

In Figure 5 the signal distributions after the combinatorial background subtraction are plotted for November 2001 and November 2002 data. The the former distributions (stars) is normalized to the number of LVL1 events. The dielectron invariant mass distribution obtained from the November 2002 data is normalized to the number of those events in which both electron candidates identified by the trigger can be associated to a a charged particle trajectory found in the MDCs (LVL3). Otherwise the analysis procedures were the same as explained above with exception of the CPR method (not applied) and a pair opening angle cut of $\Theta > 4°$ (note different dielectron production probabilities). The higher statistics (factor of 10) was achieved thanks to the second level trigger. It allows to investigate dielectron production up to and beyond the $\rho, \omega$ mass.

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## References

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