Commissioning Results from the Dielectron Spectrometer HADES[B,G,EC]

The HADES Collaboration

Status overview

During the year 2000 most of the detector modules were installed and equipped with readout electronics. All 6 sectors of the Pre-Shower detector, the outer Time-Of-Flight (TOF) wall, the forward Time-of-Flight paddles (Tofino), two complete planes of Multiwire Drift Chambers (MDC, 12 modules) in front of the superconducting magnet as well as the Ring-Imaging-Cherenkov detector (RICH) surrounding the target were installed. Due to the delayed delivery of a few readout modules and since only 4 RICH sectors were equipped with mirrors, common readout was performed for 4 out of the 6 sectors during a commissioning beam-time in November 2000. Since only one out of the altogether 12 outer MDC's was installed, the momentum resolution of the setup was restricted to about 10%. The current setup is shown in Figure 1.
In the following part, first results regarding the performance of this setup are reported.

Figure 1: Upstream view of the Hades setup. Only the support structure and outermost detector layer (Pre-Shower detector, part of TOF) are visible.

Electron Identification in the RICH

The readout electronics of the ring imaging Cherenkov detector (RICH) was completed and extensively tested. The refined gas supply system went into routine operation. In order to allow for commissioning measurements with beam a preliminary RICH mirror was equipped with 4 segments of float glass coated with Al / MgF_2. The photon detector was operated during the beam times under stable conditions with an anode voltage of 2550 V at negligible leakage currents. The VUV transmission of the gas (CH_4 at 1000 hPa) at the detector exhaust was measured to be essentially free of impurities down to the absorption cut-off at λ = 146 nm. This was not yet the case for the standard radiator gas C_4F_{10} due to so far unknown contaminations.
In order to verify the performance of the detector and especially its CsI photon converter a series of measurements were performed with light and medium heavy ions radiating Cherenkov light in a stack of two solid radiator discs (SiO_2 and MgF_2) located close to the regular target station inside the RICH. Since the amount of light can be calculated precisely this configuration is a calibrated and pulsed (τ ~10 ps) light source. Due to the different refraction indexes two 'super ring' patterns with different radii are generated and the optical dispersion results in a well defined broadening of their radial distributions.
A typical ring pattern accumulated for 600 projectiles and a 600 AMeV C beam is shown in Figure 2 and exhibits the high photon statistics expected for $Z > 1$ particles.

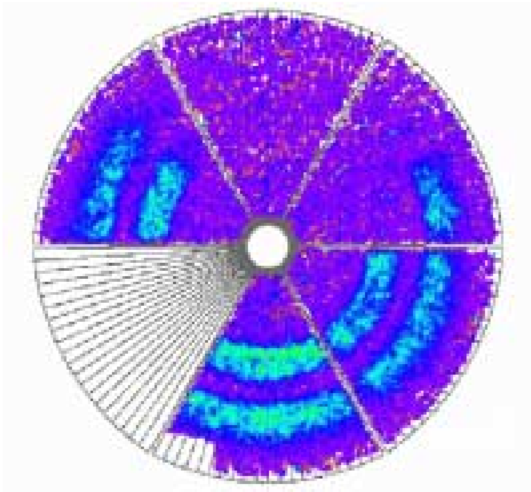

Figure 2: Superposition of ~600 Cherenkov rings from C ions (E = 600 AMeV, β = 0.794) impinging on a MgF_2 and a SiO_2 radiator. The upper sectors are in the shadow of the beam pipe; one lower sector was not equipped with mirrors.

Proper choice of radiator thickness (5mm for SiO_2, 1mm for MgF_2) allowed for a clear spatial separation of single photon hits on the pad plane. The measured shape of the radial distribution of individual photons agrees well with results of a full GEANT simulation using optimum detector parameters. These parameters would translate to a figure of merit N_0 = 110 when the solid radiators are replaced by the C_4F_{10} gas radiator. From a comparison of the amplitudes we deduce for the two lower sectors in Figure 2 values N_0 = 90 and N_0 = 105, the reduction being probably due to a slight deterioration of the CsI quantum efficiency.
Taking pulse height spectra for single photo electrons fitted with a Polya function an effective gas gain of $\sim 1.5 \cdot 10^5$ slightly above the design value was obtained. With the noise level reduced to about 3500 e^- (3σ) a detection efficiency of ~94% for single photo electrons was extracted.

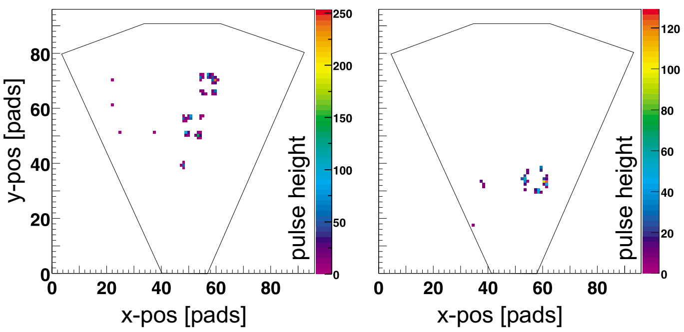

Figure 3: Double and single ring patterns observed in the RICH for electrons from C + C at E = 1.5 AGeV.

From $2 \cdot 10^6$ events recorded for C+C collisions at 1.5 AGeV about 10k events were found showing clear Cherenkov ring patterns as shown in Figure 3. First results from the analysis of the combined detector setup are presented in the following chapters.

Multiwire Drift Chambers

During the past year the inner section of the tracking system was completed and tested in two beam times. It comprises 12 chambers in two different geometries covering an area of 5 m^2. About 13.000 individual drift cells are read out by customised front-end electronics in less than 10 µs. Data is transferred to read-out controllers located close to the detector units. These units were developed in the electronic department of GSI and were used for the first time in the November beam time.

The assembly of the outer tracking system was started with the installation of the first plane III module built at FZ Rossendorf. A second plane III and the first plane IV module (constructed at IPN Orsay) are currently commissioned and will be available in the spring beam time 2001. The completion of the outer tracking system, which will finally cover 28 m^2, is scheduled for 2002. Figure 4 shows the plane IV module being lifted to the service table for commissioning. In particular the size of the plane IV module, with maximum wire length of 280 cm, demanded for customised infrastructure and a thorough construction.

Figure 4: Picture showing the first plane IV module arriving at GSI. For transportation the chamber is mounted on a support structure via surge dampers. It has a height of 3 m and weighs about 200 kg.

During commissioning with beam a stable operation of all chambers was observed. The detectors perform well within the specifications. Operated with a gas mixture of Helium/i-butane (60/40) the chambers reach efficiencies of single cells above 98%. The intrinsic resolution lies around 120 µm. Composed of 6 individual drift cell layers per module, the tracking chambers provide sufficient redundancy to identify tracks even at the highest multiplicities. Due to the optimised wire orientations and multiple measurement of positions, the resolution in the direction of the magnetic kick is about a factor two smaller than the intrinsic resolution. Figure 5 visualises the operation principle of the tracking chamber. The crossing area of the cells being hit by the particle identifies impact positions. The information shown in the Figure 5 is used in the tracking software (version developed by the Dubna group) to search for track candidates.

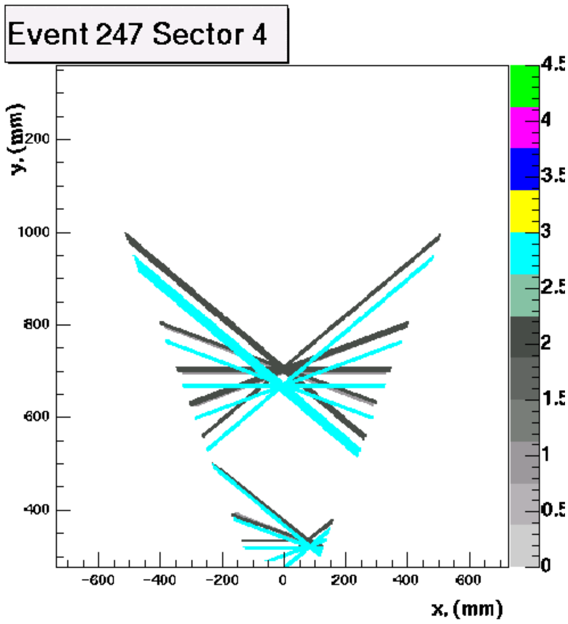

Figure 5: Projection of fired drift cells of three detectors in one sector. Black and dark grey refer to the inner tracking detectors, cyan to the cells of plane III. The shift of the crossing point of plane III with respect to the other two detectors is the result of the momentum kick in the magnetic field.

Start/Veto Detector

A pair of segmented diamond detectors located 75 cm upstream and downstream of the target is used to determine the start time for TOF measurements. The downstream detector vetos ions which were not reacting in the target. For 1 AGeV C+C a veto efficiency of ~90% was obtained. For an optimised beam focussing the veto efficiency should be significantly higher.

Time-Of-Flight Detector

The Time-of-Flight detector consists of an inner part (TOFino, 24 scintillators) in front of the Pre-Shower detector and an outer TOF wall. As of December 2000 both detectors were complete and fully assembled. The 384 scintillating rods of the outer wall, made from BC408 and each one equipped with two photomultipliers, produce fast signals handled by means of 48 constant fraction discriminator modules (16-fold C808 by CAEN). The logical outputs are delayed using 24 32-fold active delay units developed by the collaboration along with the 32-fold TDC units used to digitise the signals. These latter modules, in VME standard, are read-out via the fast Chained Block Transfer (CBT) protocol, allowing to sustain high event rates. The final tests on the amplitude measuring electronics (CAMAC shapers and VME ADCs) have been successful and their mass production is in progress. The forthcoming installation of this electronics, during the first half of 2001, will further improve the TOF performance.

The laser calibration system is complete and allows to evaluate the needed calibration constants for all the detector channels. An extension of this system is already in progress, in order to accommodate for the calibration of the TOFINO as well.

A newly developed slow control software using the EPICS framework allows to initialise and operate the TOF electronics, the high voltage system and the laser calibration system. An online analysis package and a Graphical User Interface (GUI) have been developed within the HYDRA environment that allow a quick and easy monitoring of detector data throughout a beam time. A sample online plot for the TOF detector is shown in Figure 6.

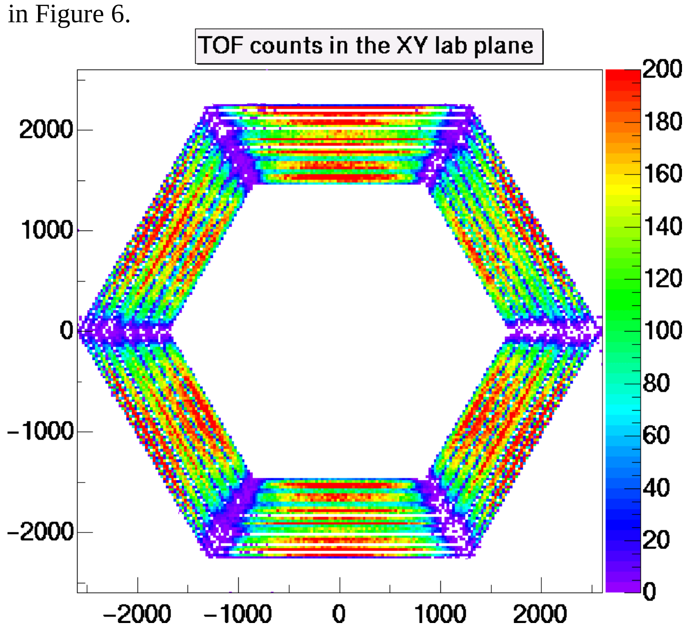

Figure 6: The TOF detector inclusive count distribution in the XY laboratory frame (units are in mm), as seen by means of the online GUI for monitoring.

A preliminary analysis of the collected data shows that the calibration procedure is reliable, and that a few levels of iteration on the related data may further improve the results. Correlated data from TOF and RICH prove that HADES can really identify leptons, as can be seen in Figure 7.

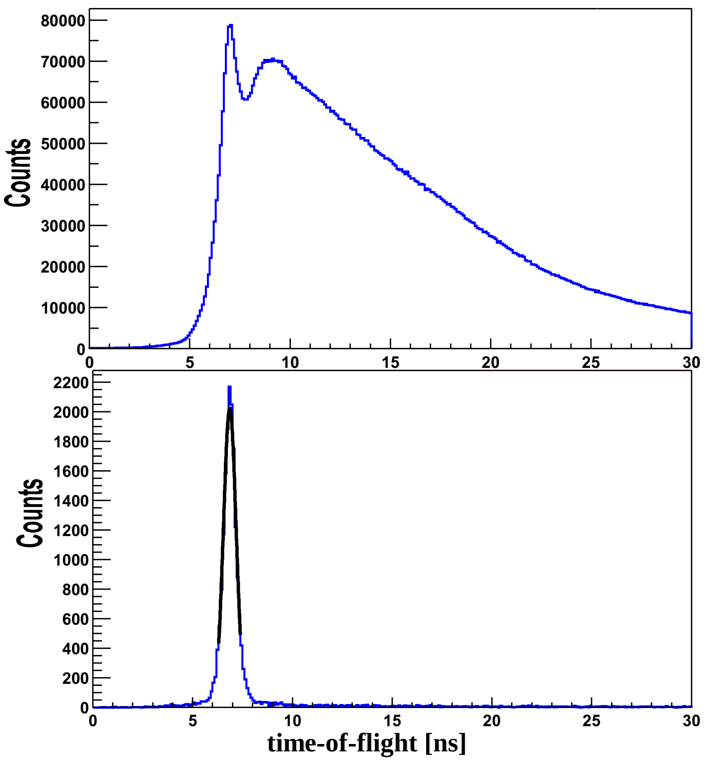

Figure 7: Upper plot: TOF spectrum of all particles detected. Lower plot: TOF spectrum for electron candidates, as selected by means of a position correlation between RICH and TOF hits. Data were taken without magnetic field.

The measured times in the TOF detector have been renormalised to equal flight path (2.1 m). The lepton peak in the upper part of Figure 7 is due to knockon electrons with energies well below the Rich threshold of 10 MeV.

Pre-Shower Detector

The whole Pre-Shower detector has been finally mounted on the HADES spectrometer mainframe. All detector channels are connected to the read-out electronics consisting of 32 channels Front-End cards and fast digital Read-out Boards located directly on the detector. The main goal of this detector is electron identification at forward polar angles (smaller than 45 degree). This should be achieved measuring electromagnetic showering in two lead converters placed between 3 gas chambers with pad readout. As has been shown in simulations, full electron identification can only be achieved when electron candidate hits are matched with rings in the RICH and fast particle hits in the TOFino detector. The Pre-Shower detector can also be used as a tracking device since it provides a hit position of a particle track after bending in the magnetic field and thus allows for a rough momentum determination.

The whole system has been successfully tested in C+C collisions. Charged particle tracks have been reconstructed from Pre-Shower and TOFino hits and from positions in the MDC (plane 2). Figure 8 (upper row) shows the resulting time of flight spectrum and TOF versus momentum correlations. The plots in the lower row present similar distributions with the additional condition on spatially correlated rings found in the RICH and electromagnetic shower candidates found in the Pre-Shower detector. The discrimination of the electron signal in the time of flight spectra is clearly visible. A gaussian fit to the electron peak gives σ=0.67ns, however a TOF correction due to the track length in the magnetic field has not yet been applied. The intrinsic time resolution of TOFino amounts to 0.25-0.3 ns.

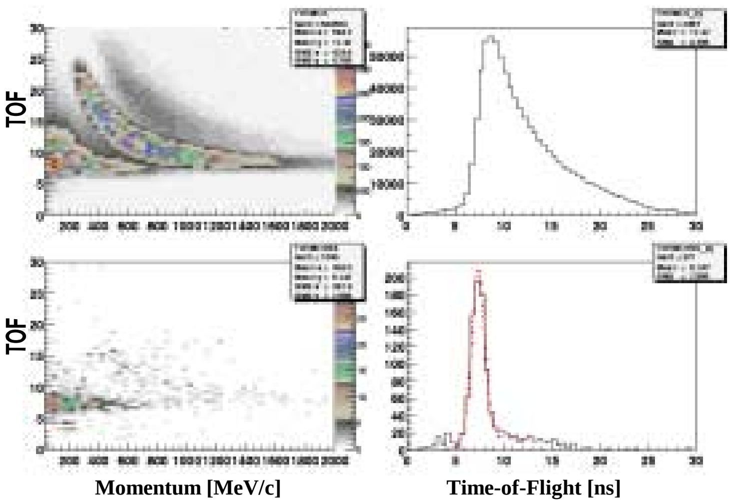

Figure 8: TOF versus Momentum (left) and TOF distributions (right). Upper part: All charged particles. Lower part: Spatial correlation with RICH rings required.

Trigger and Data Acquisition

In order to facilitate the handling of the various detector subsystems during commissioning, the trigger distribution system was enhanced by adding a trigger hub featuring flexible configuration and diagnostics options. In particular, it is now possible under software control to run with any combination of subsystems without recabeling of the trigger bus.

Readout for the Pre-Shower and TOF subsystems
The Pre-Shower readout hardware was completed and integrated into the setup. Zero suppression and calibration were successfully tested.

Readout of the TOF/TOFino-subsystem in Chained Block Transfer Mode (CBLT) was successfully implemented using modified versions of the CAEN TDC/ADC-modules and the new combined TOF readout/trigger modules. Here, a scheme with one SHARC-DSP-based readout/trigger module per VME crate connected to a common concentrator board was used.

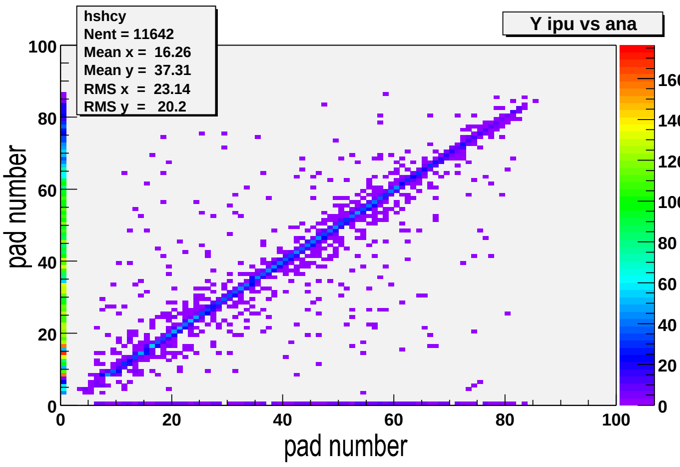

Figure 9: Correlation of x-coordinates of ring candidates found by hardware and by software. Events above and below the diagonal are due to different threshold settings in both algorithms.

RICH Trigger Hardware and Matching Unit
A first successful test of the first/second level trigger/DAQ – scheme with pipelining was conducted during the November commissioning run. Here, the Matching Unit (MU) was connected to the TOF subsystem and to one module of the RICH Image Processor. RICH ring coordinates were transmitted to the MU and recorded event-by-event. Figure 9 shows the result of an off-line analysis showing the correlation of ring center x-coordinates on the RICH padplane found by hardware image processing and by applying the RICH software ring finding algorithm. Additional events, which are non-diagonal are resulting from different thresholds in both algorithms.

Common Event Building
Based on a dedicated ATM network data from the various detector subsystems are transferred asynchronously from 7 VME-CPU's to a common event builder which assembled the full events. A data taping speed of up to 5 MB/s could be achieved, corresponding to up to 2000 events/s for the system C+C.

First Results

The combined analysis of detector signals from one MDC plane and the outer TOF wall allows to identify charged particles. As the outer drift chambers were not yet included, this analysis could be done in a low momentum resolution mode only. The result is shown in Figure 10 for the system C+C at 1.5 AGeV beam energy. Pions, protons and deuterons are clearly separated. The data were taken at 72% of the maximum magnetic field. The calibration of the detector alignment is still in progress and an improved resolution is expected.

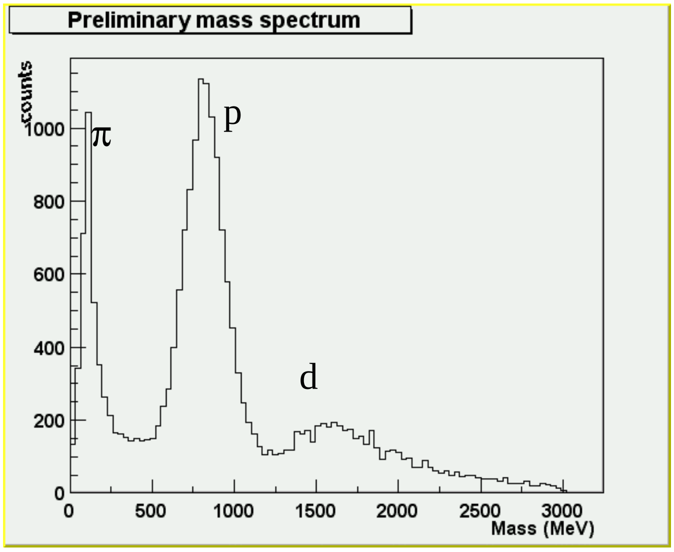

Figure 10: Mass spectrum obtained by analysing the transverse momentum kick within the magnetic field using position and angle information from one inner drift chamber and position measured with the outer TOF wall. Calibration is preliminary.

From a first preliminary analysis of the RICH data an opening angle distribution for lepton pairs was obtained for about 800.000 events C+C at 1.5 AGeV (Figure 11). As expected, the distribution is dominated by small opening angles due to pairs from Dalitz decays of π^0 and conversion of photons in the target and radiator. Besides ring recognition in the Rich no further lepton identification or track matching was required.

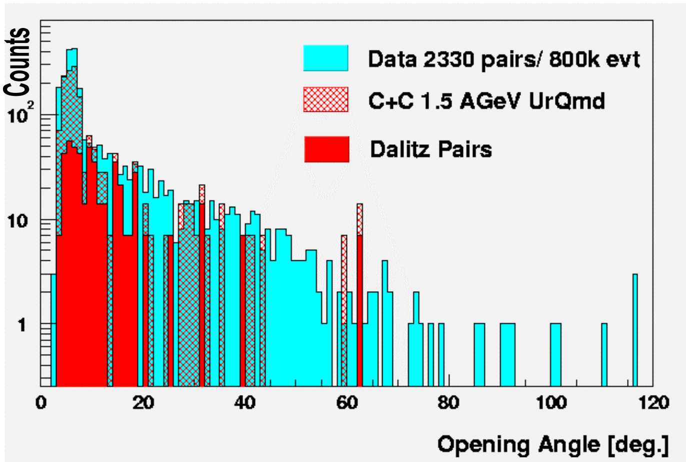

Figure 11: Opening angle distribution of lepton pairs obtained for about 800000 C+C collisions at 1.5 AGeV(blue) as compared to a simulation which includes only Conversion and Dalitz decays of the π^0. Preliminary result.

Summary and Outlook

The setup has proven its capability to measure lepton pairs. With the installation of outer drift chambers during 2001 and spring 2002 the momentum resolution should be significantly improved. Physics runs providing lepton pair spectroscopy with good statistics are expected for this year.