Development of Forward Tracker

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Abstract. The High Acceptance DiElectron Spectrometer has experienced many years of successful operation which revealed high capability of measuring resonance production in proton-proton and pion-proton reactions. Since many of the production channels that are crucial for the understanding of the resonance production are highly anisotropic, that a large part of the signal would be located in the most forward and backward phase space regions, a new opportunity to an upgrade to the detector for improving the phase-space acceptance in this region has been proposed. The Forward Tracker (FT) will cover the polar angle in the detector system between 0° and 6.5°, which significantly will increase the detection acceptance. The FT is in construction with the synergy with PANDA Central Tracker, and is realized by groups from Jagiellonian University, FZ Jülich and LIP Coimbra. The development of the new and faster readout electronics (DAQ) to cope with higher data rates, track reconstruction and the results from the beam time at Forschungszentrum Jülich are discussed.

1. Introduction

The High Acceptance Di-Electron Spectrometer (HADES) at the SIS18 at GSI Helmholtzzentrum Fuer Schwerionenforschung in Darmstadt, Germany, is a charged-particle detector[1] consisting of a six-coiled toroidal magnet surrounding the beam axis with six identical detection sections. It features polar acceptance between 18° and 85° with an almost full azimuthal coverage. Each sector is equipped with a Ring-Imaging Cherenkov (RICH) detector followed by Multi-wire-Drift Chambers (MDC), two in front of and two behind the magnetic field, as well as two detectors for time-of-flight measurements, a scintillator hodoscope (TOF) and Resistive Plate Chamber (RPC) detector, in combination with the target-T0 detector. Hadron identification is based on time-of-flight and on specific energy-loss (dE/dx) in the MDC tracking detectors. Recently HADES has also been upgraded with an electromagnetic calorimeter covering 18° to 45° angular region for allowing for reconstruction of neutral states.

Hyperons are closely related to non-strange baryon states by interchange of the light quark by the strange quark, but their mass spectrum and internal structure is only poorly known. A prominent example of the latter is Λ(1405) which is controversially discussed as either Koon-nucleon molecule, two-pole resonance or pentaquark state. Theoretical predictions concerning the electromagnetic decays of the $\Lambda(1405) \to \Lambda \gamma$ and $\Lambda(1405) \to \Sigma^0 \gamma$ [2] differ depending on the resonance internal structure. Results from HADES, as well for real as virtual (dielectron pair) photon decay will have therefore significant impact on understanding the resonance structure. Also dielectron decays of other excited $\Lambda$ or $\Sigma^0$ states, like $\Lambda(1520)$ or $\Sigma(1385)$ have not been measured and are predicted to be strongly affected by the intermediate vector meson states ($\rho / \omega / \phi$) [3]. The respective differential decay rates as a function of the dielectron invariant mass show a dramatic enhancement (by one-two orders of magnitude) close to the vector meson poles. Observation of such effect will support a dominance of vector mesons in hyperon...
decays, which has recently been confirmed by HADES in non-strange sector. Measurements of
the electromagnetic decays of excited hyperons are absolutely pioneering in this field. Another
hot topic is the study of the production mechanism of the cascade particle $\Xi$. Indeed, an unex-
pected excess of the production rates of this hadron containing two strange quark hadrons above
model predictions was measured below the production threshold in $p$-A and A+A collisions [4].
Understanding of the cascade production in nucleon-nucleon and nucleon-nucleus collisions is
therefore of uppermost importance. Furthermore, quark models predict a rich spectrum of dou-
ble strange cascades but only a two of them were actually measured [5]. This is the field where
HADES can significantly contribute, employing measurement of various $\Xi$ decay modes ($\Lambda \pi$, $\Sigma 
\pi$, ...) and applying Partial Wave Analysis methods.

2. Forward Tracker (Straw Tube Tracker)

The primary goal of the Forward Tracker (FT) is the tracking of the charged particles in the
forward direction ($0^\circ$ to $6.5^\circ$) in proton and pion induced reactions. Particularly reconstruc-
tion of $\Lambda \rightarrow p \pi^-$ decays with protons emitted forward will significantly enlarge acceptance for
the excited hyperon and cascade measurements. The requirements for this tracker are based
on simulations of selected benchmark channels and of background reactions expected in $pp$
$p\pi$, $p$ A collisions. More details on the simulation results are presented in the reports of K.
Nowakowski and J. Kubos. The FT should withstand high particle fluxes expected to be up to
1 MHz/cm$^2$.

2.1. Detector construction and working principle

Straw tubes, cylindrical mini drift chambers are the building blocks of the FT [6]. The tubes are
filled with a gas mixture of 90% Ar and 10% CO$_2$ at 2 bars overpressure and contain 20 $\mu$m gold
plated tungsten anode wire stretched along the cylinder axis. The wall of the straw tube is made
of aluminized Mylar foil of 27 $\mu$m thickness. The length of the tubes is 150 cm and the diameter
is 1.01 cm. FT is built and arranged as two stations STS1 and STS2 one behind the other.
STS1 comprising 540 straws, arranged in four layers with a tilt of $0^\circ,90^\circ,90^\circ,0^\circ$ respectively, is
built in Forschungszentrum Jülich. STS2 comprising of 1024 straws is also arranged in 4 layers
with a tilt of $0^\circ,90^\circ,45^\circ,-45^\circ$ respectively with an active region over 1 m$^2$ is built in Jagiellonian
University, Krakow.

The straw tubes are mechanically robust drift chambers with very high spatial resolution of the
reconstructed tracks ($\sigma < = 150 \mu m$), high detection efficiency of 99 % for a single particle hit,
and capability of handling high hit rates upto 1-2 MHz with negligible particle scattering.
Charged particles traversing through 1 cm ionizing gas mixture of Ar:CO$_2$ produces $\approx$200
primary e-ion pairs. At anode voltage of 1800 V the gas gain $\approx 5\times10^4$. The high voltage
applied to the anode wire causes the ionized electrons to drift towards the anode and the ions
move toward the cathode wall. The electric signal which is induced on the anode by the moving
charge is then captured by the Front-end-Board Electronic card (FE). The fluctuations of the
energy loss in a detector gas is described by the Landau distribution. It happens that sometimes
the particle with the same momentum leaves more ionization clusters and sometimes less. The
energy distribution is characterized by the mean value, a width parameter and some long high
energy tail. Due to that fact it is not possible to identify the particle based on the information
on the energy deposition from only one single straw. If, however, one has at disposal more than
one straw layer then so called truncated mean operation can be performed. For all the charge
values, belonging to one particle track, mean charge value is calculated from the contributing
straws rejecting 30% of the largest charge values. This significantly improves the separation
of particles, improving the particle identification with $dE/dx$ method. Particle identification
with $dE/dx$ for electrons, pions, kaons, protons and the energy-loss distribution 30 % truncated,
corrected for the path length for protons of 3.5 GeV/c momentum, is shown in Figure 1 and 2.
respectively.

Figure 1. $dE/dx$ truncated mean values vs reconstructed momentum for electrons, muons, pions, kaons and protons [6].

Figure 2. $dE/dx$ for 3 GeV/c protons in 16 straws truncated by 30% [6].

2.2. Readout electronics

In gaseous detectors, current is produced by the moving electron-ion pairs. Therefore the voltage which is observed in the output of the front-end electronics depends on the internal capacity of the detector. It induces the need of the capacity compensation as it can change with detector dimension, temperature or over time. Such a compensation is not trivial and is a serious drawback, which is not present in the charge sensitive amplifiers. The main idea is to integrate the charge on a feedback capacitor of an operational amplifier. Electrons are accelerated more rapidly than ions due to the difference in their mass and mobility. The slow signal from the ions leave a long amplitude tail up to several micro seconds making the integration of the total charge not feasible as shown in Figure 3. It would increase the deadtime of the detector greatly and would limit the detector to lower event rates. Hence, the readout has to be compensated to conditions where amplitude of the signal is measured at high event rates otherwise if two signals arrive close in time then the second signal may start on the undershoot of the previous one causing a pile up. To serve this purpose a time sensitive front-end chip called PASTTREC [7] was developed. The chip is an ASIC designed in the CMOS 0.35 µm technology, Figure 4. One chip contains eight channels, each one including a preamplifier stage, a shaper, an ion tail cancellation and a baseline stabilization circuit, a leading edge discriminator for time and Time-Over-Threshold (TOT) measurements with LVDS output as well as an analog output. Digital output signal is produced while the analog signal level overpasses the threshold, which is a predefined adjustable parameter. If the baseline level is shifted, measured TOT would be incorrect. For this purpose the baseline holder circuit in the PASTTREC allows to set the baseline level to the FE channels individually. The preamplifier gain, peaking time, tail cancellation parameters, common discrimination threshold and individual baseline levels are programmable, allowing to optimize the chip performance for given working conditions of the straws. Two PASTTREC chips are used in a single FE, read out by Trigger Readout Board [8] (TRB). The time of the leading and trailing edges of the PASTTREC discriminator pulses are measured by the Time to Digit Converters (TDC) located in the TRB, for the HADES experiment. One board contains 192 TDC channels implemented in four FPGA chips (48 converters per chip).

2.3. Tests of the prototypes

Prototypes of the straw tube detectors for the FT were extensively tested with radioactive sources, cosmic rays and recently also with proton beams from the COSY-Juelich accelerator at
beam momenta 3.0 GeV/c. The primary goal of the measurements was to evaluate performance of the straw modules at high event rates and the response of the FE. The test setup was built with eight double layers of straws, each having one module i.e 32 straws. The layers were arranged in $0^\circ, 5^\circ, -5^\circ, 0^\circ, 5^\circ, -5^\circ, 0^\circ$ inclination respectively. A plastic scintillator was placed before the straw modules and was used as reference time detector. 16 FE’s from the straws were connected to two TRB’s and was used for time reference.

2.4. Measurements and results
Time information of a particle is very crucial to the FT since the primary goal of the detector is particle tracking. This demands the detector to operate with minimum noise. This mainly depends on the operational voltage and the signal shaping parameters like peaking time and the discriminator threshold. The detector has been tested for various operational settings in order to find the optimum detector efficiency and performance. The scan has been made for voltages (1650V to 1850V in steps of 50V), peaking times (15 ns, 20 ns, 35 ns) and discriminator thresholds (6 mV, 20 mV). The time measurement is improved with the increase in the voltage Figure 5, meanwhile the TOT increases due to the higher gain up to the saturation of the electronics as seen in Figure 6. Each layer in FT has two planes. The number of planes fired between two reference planes (from layer 1 and 8) are calculated to estimate the efficiency of the detector. The efficiency of the detector increases with the increase in high voltage and is $\approx 97\%$ at 1750 V when peaking time set to 20 ns at a threshold 6 mV as concluded from comparison to binomial distribution Figure 7. The performance of the detector being optimum at 6 mV threshold proves that the noise level is very low making it suitable for the measurements. In particular low HV setting is important from point of view of reduced aging risk.

2.5. Conclusion
The detector has been tested for its performance and stability for various electronic configurations and the efficiency of the detector is very satisfactory. The TRB readout with various filtering modes has been tested and data sets are to be analyzed shortly. Proton tracks, registered at rates of a few hundred kHz per straw, the same expected in HADES experiment. The detector production has been completed and is expected to be installed at HADES in September 2019. The detector is also a prototype for the future Forward Tracker in PANDA.
Figure 5. Drift time spectra from 256 channels for HV 1650 to 1850V

Figure 6. TOT spectra from 256 channels for HV 1650 to 1850V

Figure 7. No. of planes fired when the reference planes are fired. Total No. of layers being 8 (16) the efficiency of the detector is ≈97%. Dotted line represents the binomial distribution.

Acknowledgments
This project has received funding from the European Unions Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No - 665778 National Science center, Poland 2016/23/P/St2/04066 POLONEZ and by Ministry of Science and Higher Education 7150/E-338/M/2018.

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