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The micro-vertex-detector of the PANDA experiment at FAIR

Tobias Stockmanns

Institut fr Kernphysik I, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

on behalf of the PANDA collaboration

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Abstract

The "AntiProton ANnihilations at DArmstadt"—experiment, PANDA, is one of the main experiments of the "Facility for Antiproton and Ion Research" (FAIR) which replaces and extends the existing GSI-facility at Darmstadt.

The primary physics goals include precision spectroscopy of charmonium states, establishment of gluonic excitations, the study of modifications of meson properties in the nuclear medium, and precision γ-ray spectroscopy of single and double hypernuclei.

For many of these physics' goals an identification of D-mesons via the detection of a secondary vertex with a decay length in the order of 100 μm is essential. Therefore, a special micro-vertex-detector (MVD) is foreseen which allows precise tracking of all charged particles.

A hybrid pixel solution was chosen as a baseline concept for the Panda MVD to accommodate the high radiation dose and the required time resolution. To clarify the requirements for the hybrid pixel detector, a Geant4 based simulation was performed using a detector geometry optimized for low radiation length. The design of the detector and the simulation results will be presented in this paper.

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1. Introduction

One of the most important projects in the field of hadron physics in Europe is to upgrade the existing GSI facility in Darmstadt towards the new "Facility for Antiproton and Ion Research" (FAIR) [1]. The upgrade includes an intense antiproton research program which will utilize the high-energy storage ring (HESR). The ring will provide a phase space cooled antiproton beam of very high intensity with momenta between 1.5 and 15 GeV/c and an excellent momentum resolution of 10^{-5}–$10^{-4}\,\Delta p/p$. In the energy regime up to $\sqrt{s} = 5.5\,\text{GeV}$, precision measurements are possible with an unsurpassed mass and width resolution of the systems under study.

2. Physics objectives

The PANDA experiment focuses on four topics:

- Charmonium spectroscopy.
- Gluonic excitations.
- Modification of meson properties in nuclear medium.
- Precision γ-ray spectroscopy of single and double hypernuclei.

In the first three physics topics, the identification of D-mesons by the detection of secondary vertices plays an essential role. This task can only be fulfilled by a micro-vertex-detector (MVD) with a spatial resolution sufficient to detect the D-mesons with a life time for $D^{\pm}$ ($c\tau = 312\,\mu\text{m}$) or D^0 ($c\tau = 123\,\mu\text{m}$).

Once HESR is running with full luminosity further physics cases come into reach of the PANDA experiment, like:

- inverted deeply virtual compton scattering;
- CP-violation in the D- and Λ-sector;
- rare D decays;
- electromagnetic form factor of the proton in the time-like region.

E-mail address: t.stockmanns@fz-juelich.de.

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3. The detector-design

The general purpose PANDA detector is planned to serve the wide physics program.

Fig. 1 shows a schematic overview of the PANDA detector. It is divided into two main parts, the target spectrometer directly around the interaction point and the forward spectrometer for particles emitted at small polar angles in the fixed target kinematics. The overall length of the detector is 12 m.

Two different options for the proton target are under study, a pellet target and a cluster jet target. For reactions on nuclei, a solid target is foreseen. The innermost subdetector of the central spectrometer is a MVD for precise tracking information. The design of the MVD will be discussed in the next section. At larger distances from the interaction point the vertex tracking is achieved either by straw tubes (STT) or a high-rate time projection chamber (TPC) in the barrel part, along with a set of mini drift chambers (MDC) in the forward direction. For particle identification two ring imaging Cherenkov counters are foreseen. They are surrounded by a compact electromagnetic calorimeter made out of $PbWO_4$ crystals with avalanche photodiode readout. The tracking system of the central spectrometer is situated in a 2 T solenoidal magnetic field. The return yoke of the magnet is covered with muon detectors.

The forward spectrometer consists of a 2 T m dipole magnet with a set of multiwire drift chambers (MuDC) for tracking, a RICH detector for particle identification, electromagnetic and hadronic calorimeters for charged and neutral particles and a layer of muon counters at the end of the calorimeter.

For a more detailed description of the detector and the physics program, see Ref. [3].

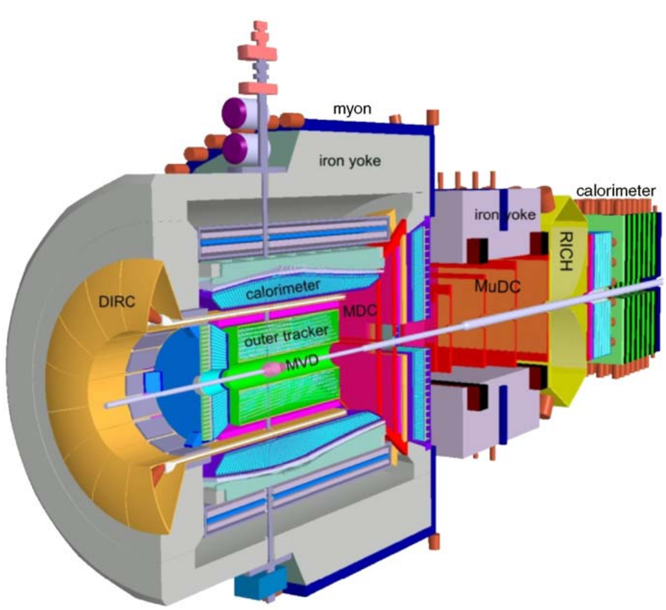

Fig. 1. Schematic view of the universal detector PANDA.

4. The micro-vertex-detector

4.1. Requirements

From the physics goals of PANDA, the simulations and the overall layout of the experiment, certain basic requirements for the vertex detector can be deduced. This includes:

- *vertex resolution* better than 100 μm;
- *time resolution* in the order of 20 ns;
- *readout speed* fast enough to handle the untriggered readout of 10^7 annihilations per second;
- *material budget* below $x/X_0 = 1\%$ per layer;
- *radiation hardness* better than $10^{14}\,n_{eq}/cm^2$;
- *amplitude measurement* for low-momentum particle identification.

4.2. Design

To achieve the required low radiation length, a combination of hybrid pixel modules for the inner part of the MVD and silicon strip detectors for the outer part was chosen. The geometry of the pixel modules is based on the ATLAS modules with a pixel geometry of $50 \times 400\,\mu m^2$ and a front-end chip size of $7.6 \times 11.0\,mm^2$. In contrast to ATLAS, three different sensor sizes are used: one with 2×8 front-end chips and an active sensor length of 60.8 mm, a medium size module with 2×5 front-end chips and a sensor length of 38 mm and a short size module with 2×4 front-end chips and a length of 30.4 mm. The width of the active area for all modules is 16.4 mm. For the thickness of the sensor (200 μm) and the readout electronics (150 μm), the values of the ALICE modules [6] were taken as an achievable goal.

The strip part is made out of a double-sided strip sensor with $2 \times 6\,cm^2$ sensitive area and a thickness of 150 μm. A strip pitch of 50 μm is assumed with a stereo angle of 90°.

A schematic view of the MVD can be seen in Fig. 2. The pixel part of the MVD consists of two barrel layers and four disks. For the inner barrel layer the large pixel modules were used with a pixel orientation along the beam axis. In the outer layer the pixels are orientated perpendicular to the beam axis to give a better z-resolution. The small disks in the forward direction use small pixel modules, the other two pixel disks use large pixel modules with 16 front-end chips. The MVD is completed by two barrel layers of strip modules and two large disks with pixel modules in the inner part of the disk and strips in the outer part. A 200 μm thin carbon support structure is foreseen as is used in the ALICE pixel detector [7].

4.3. Simulation

New software was developed to verify the design of the MVD and to analyze its achievable performance. It allows