The Micro-Vertex-Detector for the PANDA experiment

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Abstract. PANDA is a fixed target experiment that will be carried out at the future FAIR facility. PANDA will provide an excellent tool to address fundamental questions in the field of hadronic physics, with a physics program that extends from the investigation of QCD (providing insight in the mechanisms of mass generation and confinement) to the test of fundamental symmetries.

The Micro-Vertex-Detector located in the innermost part of the central tracking system will be composed by hybrid pixel and double-sided micro-strip silicon detectors. The Micro-Vertex-Detector will play an important role for the PANDA physics goals. The possibility to reconstruct the secondary vertices and the applicability of a precise D meson tagging is essential for the spectroscopy in the open charm sector and the charmonium mass region. To this aim the Micro-Vertex-Detector features a spatial resolution better than 100µm, a time resolution better than 20ns, a limited material budget, and a high data rate capability in a triggerless environment. An overview of the Micro-Vertex-Detector related to the physics goals will be presented.

1. Introduction
PANDA is one of the new experiments that will take place at the facility FAIR under construction at GSI. It is a fixed target experiment where antiproton-proton and antiproton-nuclei annihilations will be studied in a fixed target setup. The main feature is the antiproton beam, that will be provided by the High Energy Storage Ring (HESR) with an unprecedented intensity and quality. The antiproton momentum will be in the range from 1.5 up to 15GeV/c. The physics program foresees studies in the charmonium region (such as spectroscopy, gluonic excitation and in-medium modification), in hypernuclei field and CP-violation, see [1].

Charmonium Spectroscopy
One of the physics topics of PANDA is the hadron spectroscopy, in particular in the charm sector. The charmonium mass spectrum can be divided into two part [2]:

- the charmonium spectrum below the open charm threshold, which is both experimentally and theoretically established. Here we find 8 states, all experimentally confirmed, and with the conventional potential models in good agreement.

- the charmonium spectrum above the open charm threshold. Here the situation is rather incomplete, and far away to be fully understood. In fact only four charmonia have been confirmed, meanwhile a lot of new states, such as the X(3872) or the Y(4260), have been discovered at the B-factories that do not seem to fit in the theoretical models.
**PANDA** represents a unique tool to improve both the statistics and the precision of existing data, and to further explore the charm quark sector. The unprecedented energy definition of the antiproton beam will allow to perform precise mass scans. In fact the running and future planned experiments will not provide precise energy scan and, moreover, they will be limited by the directly accessible quantum number. The possibility to perform such a physic program is strongly related to the capability to reconstruct with high precision the D meson decay, exactly to this aim the MVD has been designed.

2. The Micro Vertex Detector

The Micro Vertex Detector (MVD) is located in the target spectrometer, and it is the detector closest to the interaction point. It will extend for +/-23cm with respect to the interaction point, and the radius ranges from 2.2 up to 13.5cm. Two types of detectors will be implemented: hybrid pixels and double-sided micro-strips. The first one will be placed in the 6 forward disks and in the two internal barrels, while the last one will be placed in the two external barrels and as external radial component of the last two disks, see Fig. 1. The detector will have almost $10^6$ pixel readout channels and around $2 \cdot 10^5$ double-sided readout channels [3].

2.1. Requirements and Features

Since the main aim of the MVD is to allow the reconstruction of the secondary vertices of D mesons, the detector should guarantee a spatial resolution better than 100µm. Moreover, the MVD will impose important constraints on the tracking algorithm leading to an overall momentum resolution of the order of 2%. Since the **PANDA** data acquisition will be triggerless and the nominal interaction rate will exceed $2 \cdot 10^7$ annihilations per second, the time resolution of the detector should be better than 20ns. All the materials have to be chosen both to be radiation hardness (the expected radiation damage level, in the case of **p**-p annihilations at 15GeV/c, will be strongly forward peaked and has been estimated to be of the order of $10^{14} \text{n}_{eq}\text{cm}^{-2}$ for 10 years of data taking and a 50% of duty cycle) and to not affect the material budget (the full MVD is below 10% $X/X_0$, in unit of radiation length). The readout electronics should be able to work in a triggerless environment, to handle a high data rate and to perform energy loss measurements in order to contribute to the global PID.

![Figure 1. Layout of the PANDA MVD](image-url)
2.2. Hybrid Pixel Detector
The hybrid pixels are composed of a thin segmented silicon sensor connected via the bump bonding technique to a custom readout chip. The sensors will be made of epitaxial silicon wafer, grown on a Czochralski substrate (Cz). Each pixel will have an area of 100x100µm², and an active thickness of 100µm. This last value is a reasonable compromise between the sensor radiation tolerance and the possibility to perform energy loss measurements and to have a good signal to noise ratio.

The pixel readout electronics has to provide for each hit a simultaneous position, time and energy loss measurement, and it has also to digitize this information at the pixel level in order to transmit only digital information. The main constraint in the design of such a readout is the pixel geometry. The ASIC for the PANDA hybrid pixel has been designed in the 130nm CMOS technology, and it is called Topix. The chip has to be able to work with a high system clock of 155.52MHz (time resolution of ∼6ns), which is essential in order to perform a continuous digitization of the data in a triggerless environment. Energy loss measurement will be performed by the Time over Threshold technique (ToT) [4].

2.3. Double-Sided Micro-Strip
The use of double-sided strip detectors offers the capability of precise point reconstruction with the advantage of less detector channels compared to pixel detectors, and to a low material budget setup. However, ambiguities occur in case of multiple particles crossing the detector in the same time frame. Therefore the PANDA MVD utilizes silicon strip detectors at the outer layers of the MVD where the particle flux is reduced in contrast to the inner layers. The starting material for the strip detector will be a mono-crystalline floating zone silicon wafer. Three type of geometry will be used: the rectangular and quadratic sensors, with a tilt angle of 90°, will be used in the barrel part, while the trapezoidal shape sensor will be placed in the external ring of the last forward disks, with a tilt angle of 15°. The pitch will be 130µm for the barrel strip and 67.5µm for the forward strip, in order to recover the worsened resolution coming from a smaller stereo angle.

The possibility to use a modified version of Topix, for the strip readout is under study [3].

3. MonteCarlo Simulation
In order to understand the environment where the detector should work and to foresee its performance several MonteCarlo simulations have been performed, using the PANDA framework [5]. The accuracy of the prediction will be proportional to the detailed description of the detector. To this aim a converter has been developed to transform the Computer Aided Drawing (CAD) model into a root-type geometry suited for the simulation. Taking advantage of this tool the developed MVD geometry contains approximately 70.500 individual volumes [6].

3.1. Rate Study
The evaluation of the expected count rates in different detector regions is crucial for the developments of the readout electronics, moreover the integrated numbers coming from all the readout chips will allow the estimation of the overall data load to be handled by the MVD.

The simulation results show that the maximum rate will be strongly correlated to the physical topology of the annihilations. In the case of antiproton-proton annihilations at 15GeV/c the maximum will be in the forward part, i.e. the disk part, meanwhile in the case of antiproton-nuclei annihilation the maximum has to be expected in the barrel part. The maximum expected data load in the full MVD is of the order of 38Gb/s.
3.2. **Physic Benchmark**

A typical signature common for several of the channels within the scope of PANDA is for example: $pp \rightarrow \psi(3770) \rightarrow D^{+}D^{-} \rightarrow K^{-}\pi^{+}\pi^{+}K^{+}\pi^{-}\pi^{-}$. In fact, this reaction features secondary vertices with a short decay length (312µm for the charged D mesons) and a relatively large number of ejectiles to be reconstructed in an exclusive analysis. A first selection of the candidates is done requiring that the reconstructed D meson mass differs no more than 750 MeV/c from the nominal D mass, moreover a vertex fit is carried out and in case of multiple candidates the selection is done on the $\chi^2$. The obtained vertex resolutions are 55µm in the xy-direction and 104µm in the z-direction, see [7]. The obtained mass resolution is 16MeV/c$^2$.

4. **Prototype Test**

The first beam test of the hybrid pixel detectors have been carried out at the COSY synchrotron of the Forschungszentrum Jülich with 2.7GeV/c protons. The first assembly prototypes with an area of 2x3.2mm$^2$, composed by the ToPix3 readout chip and a dedicated epitaxial silicon sensor, with 640 pixels each, of 100x100µm$^2$ area, and 100µm thickness. These sensors were obtained without removing the most of the Cz substrate on which the epitaxial layers have grown. Actually, each sensor was composed by 100µm epitaxial thickness and 525µm of Cz. Because of the low resistivity of the Cz (10-20 mΩ·cm), the sensor backside was not aluminized and a direct ohmic bias connection was realized.

The basilar bench includes the testing board hosting the assembly and a Xilinx evaluation board equipped with a Virtex 6FPGA. With this bench, a pixel tracking station of 4 assembly has been realized, for a total length of almost 20cm, and a distance between two sensor surfaces of 6cm.

The data acquisition was performed with a 50MHz clock, and the raw data contains the following information: 12bit leading and trailing edge (for ToT measurements) and the address of the pixel (column and row). A 50MHz clock was used for the time and ToT measurement. Since the acquisition was performed in a triggerless mode, a really precise time information is needed, so a Time-Stamp is obtained summing the leading edge and a 32bit End of Counter. In this way all the hit have a time information of 44bit and this allow to identify the tracks looking at the correspondence of the Time-Stamp. This procedure of Time-Stamp matching consists in finding the hit of the different planes with a time-stamp equal or different by $\pm 2$ clock cycles (this range assures to take into account the TimeWalk effect).

In the left part of Fig. 2 a picture of the time information and of the Time-Stamp matching procedure is shown. On the right part of Fig. 2 the ToT distribution of the four planes is shown. The ToT distributions have been fitted with the convolution of a Gaussian with a Landau function. This convolution is useful in order to reproduce either the Gaussian response of the detector either the Landau shape of the energy loss. The most probable values (MP) are compatible within the error (Gsigma), the variations are due to the chip-to-chip technology fluctuations. In order to have an information in terms of collected electrons a fine channel-to-channel calibration is in progress. The alignment results show that the best spatial resolutions (taking into account that the setup was 20% X/X$_0$) were reachable on the two internal planes, and they were of the order of 40µm both in the x and y directions. The first beam test has shown an overall good functionality both of the sensors and of the readout electronics.

**Conclusion**

The design of the MVD have been finalized, the MonteCarlo simulations show a good performance on the capability to reconstruct D mesons. The first prototypes of both pixel and strip (see [8]) have shown promising results.
Figure 2. On the left an example of the hit time information on the different board is shown, where the Time-Stamp matching procedure is illustrated. On the right the four ToT distributions are shown, the MP and Gsigma are the value of the Gauss+Landau convoluted function used to fit the distribution.

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