# Contribution of the MVD to the charm spectroscopy at P̄ANDA

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P̄ANDA is a dedicated antiproton experiment at the future FAIR facility benefiting from antiproton beams with unprecedented intensity and quality. High-precision spectroscopy in the charm quark sector is part of the core physics program. The micro-vertex-detector (MVD) is the innermost part of the tracking system. It plays a key role for the vertex reconstruction and momentum resolution of charged particles.

This article contains a short description of the P̄ANDA experiment and the MVD design. Detector simulations for the MVD are based on a detailed model allowing a realistic description. Presented results of physics simulations refer to selected reaction channels with charged particles in the final state. Besides the reconstruction of $D$-mesons a study of the $X(3872)$ is included.
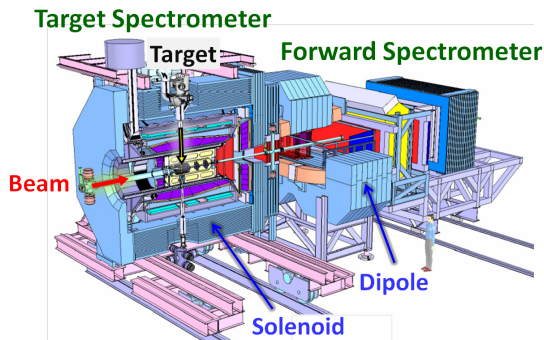
Figure 1. Artist's view of the P̄ANDA apparatus.

## 1. Introduction

The P̄ANDA experiment [1] is one of the key projects at the future FAIR facility [2]. It is a fixed target experiment using antiproton beams of high intensity within a momentum range between $1.5\,\text{GeV/c}$ and $15\,\text{GeV/c}$. A quantity of $10^{11}$ antiprotons is kept in the high-energy stor-

age ring [3] with a relative momentum spread of only $10^{-4}$. The specified effective target thickness of $4 \times 10^{15}$ delivers a maximum luminosity of $2\times10^{32}\text{cm}^{-2}\text{s}^{-1}$. Even better values down to a few times $10^{-5}$ will be reached in a high resolution mode with a reduced luminosity of $10^{31}\text{cm}^{-2}\text{s}^{-1}$.

Internal gaseous targets are provided either by a pellet or a cluster jet system. Wire or foil targets are intended for an extension to heavier elements such as copper or gold. The different target setups allow thus a study of antiproton annihilations with protons of hydrogen atoms or inside heavier nuclear targets.

The P̄ANDA apparatus illustrated in figure 1 is split into a target spectrometer surrounding the interaction point and a forward spectrometer covering polar angles below 10°. They utilize a solenoid and a dipole magnet, respectively, for the momentum analysis of charged particles. Individual detector subsystems for tracking, particle identification and calorimetry are integrated inside the solenoid and behind the dipole magnet.

A multi-purpose design of the detector results from the broad physics program [4] which is tack-
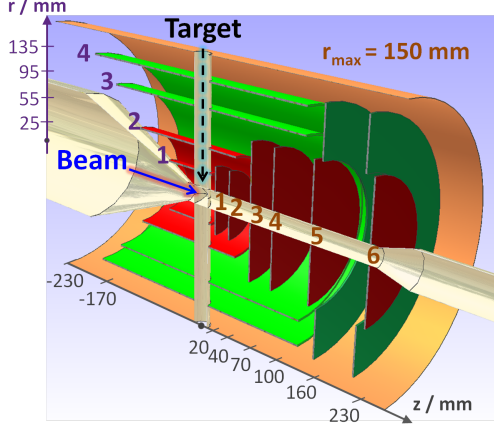
Figure 2. Schematic MVD layout. The layers are equipped with silicon pixel (inner part) and double-sided microstrip detectors (outer part).

led in $\bar{\text{P}}$ANDA. Charm spectroscopy is one of the main research topics of the experiment.

## 2. Micro-Vertex-Detector (MVD)

The Micro-Vertex-Detector (MVD) is a tracking detector for charged particles. It is the innermost subsystem of the whole experiment delivering first hit points at a minimum distance of only 2 cm with respect to the nominal interaction point. The MVD consists of four barrel layers and six forward disks. They are equipped with silicon pixel detectors in the inner parts while double-sided silcon microstrip detectors are utilized for the outer detector layers. A schematic sketch of the detector is shown in figure 2.

High granularity and optimized spatial coverage are essential for a good vertex resolution of the primary interaction point and secondary vertices of short lived particles. Moreover, the MVD hit information improves the overall momentum resolution and delivers input to the global particle identification.

A stringent material budget must be kept to minimize scattering effects. They have significant impact on the overall detector performance due to the high occupancy of slow particles below 1 GeV/c in the hadronic environment at $\bar{\text{P}}$ANDA.

## 3. Detector simulations

A detailed description of the MVD is available in the $\bar{\text{P}}$ANDA simulation software [5]. It is based on a realistic CAD model including active sensors, associated support structures, cables, the cooling system and the overall routing of all services out of the target spectrometer. Results of detector simulations are shown in figure 3.

For a global track fit, corresponding hit points in the MVD are combined with information of adjacent tracking detectors. In this way, reconstructed particle momentum resolution improves
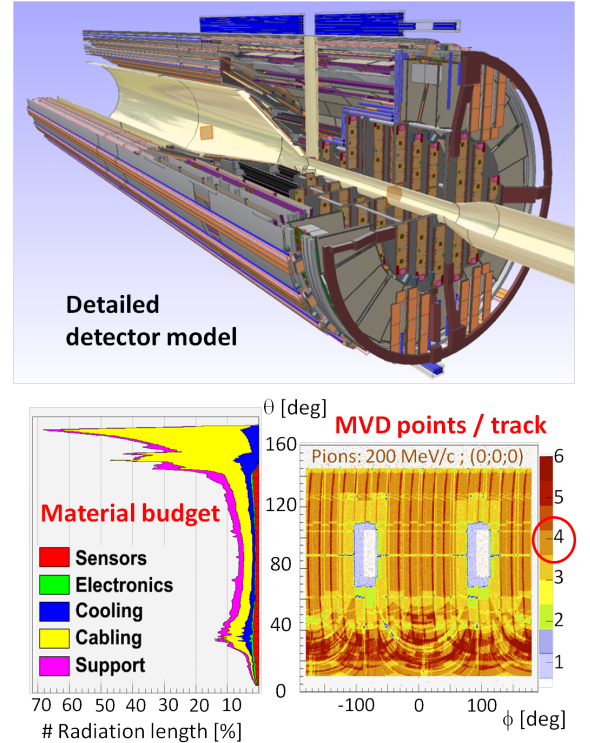


Figure 3. Detector simulations using a detailed model (top). Bottom, left: Overall radiation length in dependence of the polar angle $\theta$ (90° rotated). Bottom, right: 2D mapping ($\theta$, azimuthal angle $\Phi$) of the MVD coverage. The design is optimized for a track point count of four inside the MVD. The material budget is minimized to 10% radiation length in the active region.
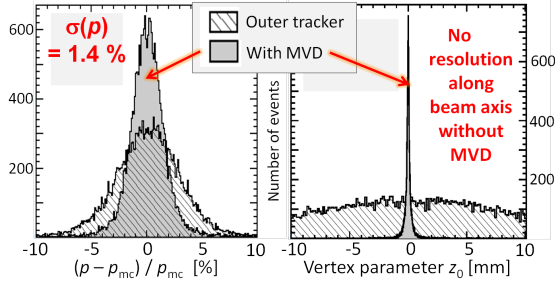
Figure 4. Impact of the MVD on the momentum (left) and the vertex resolution (right) for 1 GeV/c pions emitted from the nominal interaction point.

by roughly 50% (see figure 4). The associated vertex reconstruction strongly depends on the delivered input of the MVD. Both, primary and secondary vertex resolution stay below 100 μm (see table 1). The z-resolution for the primary vertex depends on the relative momentum between the two reconstructed D-mesons and thus improves with higher beam momenta.

## 4. Physics simulation

Tagging of D-mesons is crucial for the experiment. Hit information delivered by the MVD is needed for their charged decay modes. A summary of simulations performed to date can be found in [4],[6].

Selected results of an exclusive reconstruction with six charged particles in the final state are presented in figure 5. They are based on a conservative estimate for the production cross section of the benchmark channel $\bar{p}p \rightarrow \Phi(3770) \rightarrow D^+D^-$. The resulting branching ratio for the charged de-

Table 1
Primary ($\sigma^p$) and secondary ($\sigma^s$) vertex resolution in three dimensions ($x$, $y$, $z$) for the reaction $p\bar{p} \rightarrow D^+D^-$ at different beam momenta ($p_{beam}$)

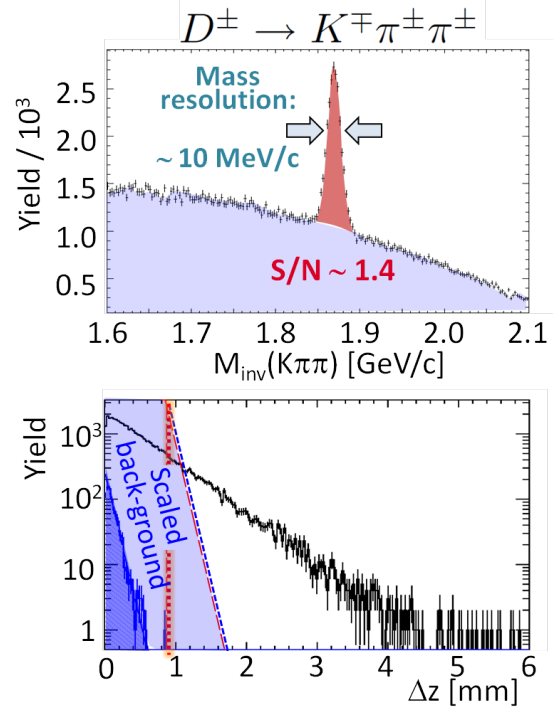| $p_{beam}$ / [GeV/c] | vertex resolution / μm | | | | | |
|---|---|---|---|---|---|---|
| | $\sigma_x^p$ | $\sigma_y^p$ | $\sigma_z^p$ | $\sigma_x^s$ | $\sigma_y^s$ | $\sigma_z^s$ |
| 6.57 | 31 | 31 | 494 | 35 | 35 | 77 |
| 8.50 | 30 | 29 | 157 | 37 | 36 | 92 |



Figure 5. Analysis of charged decays in the $D^+D^-$ channel. Top: Invariant mass spectrum with an expected signal to background ratio (S/R) of 1.4. Bottom: Distribution of the position difference of both reconstructed D meson decay vertices projected onto the beam axis. Black curve for signal, filled blue one for the remaining background events.

cay mode of the $D^+D^-$ channel is in the order of $10^{-10}$. Main background contributions exceed this value by up to six orders of magnitude. They are included in the simulations.

In the analysis three candidate tracks for a D-meson are combined to a common vertex and loose mass windows are set. The two momenta of the D-candidates are then merged and fitted to a common vertex. Finally, a kinematic refit is performed for the whole decay tree to meet the beam four-momentum. Obtained results prove that D-signals still can be extracted efficiently from the huge hadronic background.

Inclusive methods are applied for mesons such as the $D_{s0}^*(2317)^\pm$. In this case cross sections are

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too small for an exclusive reconstruction with sufficient statistics. Therefore, in the studied reaction $\bar{p}p \rightarrow D_s^{\mp} D_{s0}^*(2317)^{\pm}$ only the recoiling $D_s^{\pm}$ is reconstructed by its decay into three charged particles in the final state. They are obtained in the decay channel $D_s^{\pm} \rightarrow \phi\,\pi^+$ with $\phi \rightarrow K^+ K^-$. The particle width of the missing $D_{s0}^*(2317)^{\pm}$ is then extracted from the excitation function obtained in an energy scan around the $D_{s0}^*$ threshold. Results indicate a resolution of 100 keV which is one order of magnitude better than the actual world average.

Amongst others, the $X(3872)$ as one example can be studied with high precision. The main decay mode $X(3872) \rightarrow J/\psi\,\pi^+\pi^-$ with $J/\psi \rightarrow e^+e^-/\mu^+\mu^-$ delivers a very clear signature of four charged particles with one common vertex in the final state. They can be sorted into two slow pions and the two fast leptons of an associated $J/\psi$ decay. The latter allow a very precise reconstruction of the $J/\psi$ which can then be combined with the pions into a common invariant mass to extract the $X(3872)$ signal. Besides, a detailed analysis of the angular distribution in the two-pion system allows the determination of relevant quantum numbers. Most promising for the research on the $X(3872)$ is the performance of a resonance scan taking profit of the well defined beam parameters at $\bar{\text{P}}$ANDA. They allow a formation experiment with very small energy steps. Preliminary Monte-Carlo results are shown in figure 6. With an assumed resolution $\Delta p/p$ in the order of $10^{-5}$ the mass resolution achieved is better than $100\,\text{keV}$ [7].

## 5. Summary

The $\bar{\text{P}}$ANDA experiment is designed for high-precision experiments in the charm quark sector. The MVD as the innermost tracking system of the apparatus plays a key role for the vertex reconstruction and the momentum resolution, both indispensable to perform the measurements envisaged. The detector design facilitates an optimized measurement close to the interaction point as well as the reconstruction of secondary vertices of short-lived particles. A detailed model of the MVD is implemented in the simulation frame-
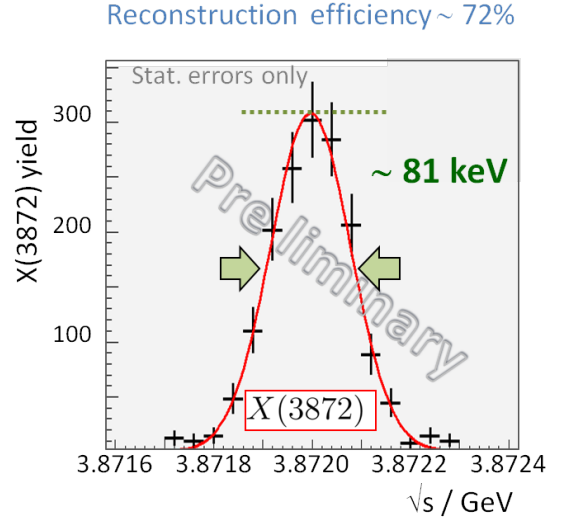


Figure 6. Simulation results of a resonance scan with a fixed input mass of 3872 MeV/c. Each data point corresponds to two days of data taking at the high-resolution mode of $\bar{\text{P}}$ANDA ($\Delta p/p \propto 10^{-5}$). The fit results in a systematic error on the width which is smaller than 100 keV/c.

work allowing a validation of the overall detector performance and physics simulations. These indicate a good reconstruction capability for $D$-mesons. Moreover, first studies deliver promising results for possible line shape studies of the $X(3872)$.

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