PANDA AT FAIR*

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The PANDA experiment is one of the major projects at the upcoming FAIR facility in Darmstadt, Germany. It will study interactions between antiprotons and protons or nuclei in the momentum range of 1.5 GeV/c to 15 GeV/c with a 4π state-of-the-art detector. The purpose is to learn about fundamental aspects of the strong interaction in the transition region between perturbative QCD and nuclear phenomena. This paper reviews some of the main physics topics together with a presentation of the detector.

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1. Introduction

Quantum chromodynamics (QCD) describes the strong interaction on a fundamental level between quarks and gluons as one of the four elementary forces of nature. Yet there are many aspects of QCD that are not understood. Most prominent is the phenomenon of confinement — the observation that quarks and gluons cannot be isolated as single particles but rather form composite objects, the hadrons. A difficulty is that QCD becomes analytically non-calculable at energies that are relevant for these bound systems. High quality experimental data is, therefore, needed to guide the theoretical efforts in this field. The PANDA experiment at the antiproton storage ring HESR at the FAIR facility in Germany [1] will provide data with unprecedented precision and statistics. It is being planned by an international collaboration, currently consisting of more than 500 physicists coming from more than 50 institutions in 17 countries.

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2. The PANDA physics program

The PANDA physics program will cover a wide range of topics, all aiming at improving our understanding of the strong interaction and hadron structure. Significant advances are expected due to precision and high statistics in the fields of:

— Meson spectroscopy

— Baryon–antibaryon production

— Baryon spectroscopy

— Hypernuclear physics

— Hadron properties in the nuclear medium

— Electromagnetic processes

Some features of the first three topics will be outlined in the following. More detailed information about the PANDA physics program can be found in [2].

2.1. Meson spectroscopy

It is advantageous to study meson spectroscopy using antiproton–proton collisions at the HESR for many reasons. All quantum numbers that are allowed for $\overline{q}q$ states are accessible in formation experiments in $\overline{p}p$ collisions, where the initial $\overline{p}p$ system fuses into one mesonic state. This is in contrast to studies at e^+e^- colliders, where only $J^{\mathrm{PC}} = 1^{--}$ states are allowed in formation. Furthermore, the high momentum resolution of the $\overline{p}$ beam in HESR ($\Delta p/p < 10^{-4}$) will allow for resonance scans over particle states, where the precision in mass and width is determined by the resolution of the beam and not the detector. This technique was pioneered by the $\overline{p}p$ E760/835 experiments at Fermilab giving a resolution of a few hundreds of keV [3]. The experimental conditions at PANDA will allow for almost an order of magnitude higher precision [2].

The charm quark sector is of particular interest for spectroscopy. There is a low density of narrow $c\overline{c}$ states below the open charm threshold which should reduce the mixing among them. This offers unique advantages for the understanding of these states. In fact, their spectrum shows a remarkable similarity with the positronium spectrum for the lower lying states. It is, therefore, suggestive to assume that the strong interaction potential for charmonium is Coulomb-like in shape. However, the charmonium spectrum is far from being understood. Several new and unexpected narrow states

have been observed, the so-called alphabet states (X, Y, Z), which do not fit predictions by potential model calculations [4]. Some of these are candidates for hybrid states *i.e.* a bound $c\bar{c}$ state with a valence gluonic content. Furthermore, several expected excited states have escaped detection. There are also many open questions in the open charm meson sector [5].

The search for glueballs, *i.e.* particles entirely consisting of glue, is of particular interest in this mass region. The lightest glueball states are expected to mix with ordinary light quark meson states which makes them very difficult to identify. The narrowness of the mesonic states in the charm sector should make it easier to pin down exotic states in this region. Lattice QCD predicts the existence of glueballs with exotic quantum numbers (oddballs) in this mass region. Such states cannot mix with normal mesons and are, therefore, predicted to be relatively narrow. The lightest oddball, with $J^{\mathrm{PC}} = 2^{+-}$ has a predicted mass of $4.2\,\mathrm{GeV}/c^2$ which is well within reach at PANDA. A Lattice QCD prediction for the charmonium, glueball and spin-exotic hybrids spectrum together with experimental data [6] is shown in figure 1.

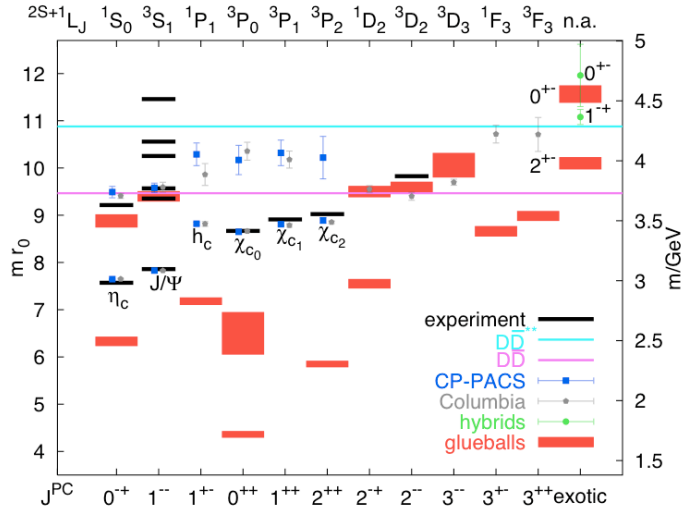


Fig. 1. Lattice QCD predictions for charmonium, glueball and hybrid states together with experimental results [6].

2.2. Baryon–antibaryon production

Hyperon–antihyperon pair production in $\bar{p}p$ collisions either involves the creation of strange–antistrange quark pairs or the shake-off of such pairs from the nucleon sea. Hence, the $s\bar{s}$ pair creation mechanism and their

arrangement to baryons can be studied from reactions of the type $\overline{p}p \to \overline{Y}Y$, where Y denotes a hyperon. Furthermore, the parity violating weak decay of most ground state hyperons introduces an asymmetry in the distribution of the decay particles. This gives access to spin degrees of freedom involved for these processes: polarisation and certain spin correlations [8]. All strange hyperons are energetically accessible in $\overline{p}p$ collisions at HESR as well as single charmed hyperons. Simulations show that the spin observables can be well reconstructed in PANDA with high efficiency and statistics [2].

2.3. Baryon spectroscopy

An understanding of the baryon spectrum is essential for an understanding of the strong interaction in the non-perturbative region. The agreement with model predictions is small, both with respect to masses and unobserved states. It is also not clear if observed states are genuine three-quark excitations or created from baryon–meson dynamics [7]. More data are badly needed. The data base is particularly scarce for strangeness $= -2$ and -3 baryons. A particular benefit of using $\overline{p}p$ reactions for these studies is that the same pattern must be found both in the baryon and antibaryon channels which will reduce the uncertainties. Another advantage is that no production of extra kaons is required for strangeness conservation. This lowers the threshold *e.g.* as compared to pp collisions and thus the number of background channels. There should be a large discovery potential for PANDA in this field.

3. The PANDA detector

The PANDA detector [9] is designed as a state-of-the-art multipurpose detector to accommodate the planned physics program. It will be installed at the HESR ring and be equipped with internal targets of the pellet or the cluster-jet type. With the anticipated 10^{11} stored antiprotons they will provide a luminosity of $2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This will lead to a reaction rate of $\sim 10^{7}\,\mathrm{s}^{-1}$ which the detector must be capable to handle with good particle identification and momentum resolution for γ, e, μ, π, K and p. It should also be capable to measure displaced vertices from D and K_s mesons and Λs. An almost 4π coverage is necessary to make exclusive measurements of the final states. The detector is, therefore, divided into a target and a forward spectrometer as depicted in figure 2 with an overall length of 12 m. The target spectrometer (TS) is based on a 2 T superconducting magnet surrounding the interaction point measuring large angles and a forward spectrometer (FS) based on a 2 Tm dipole magnet for small angle tracks.

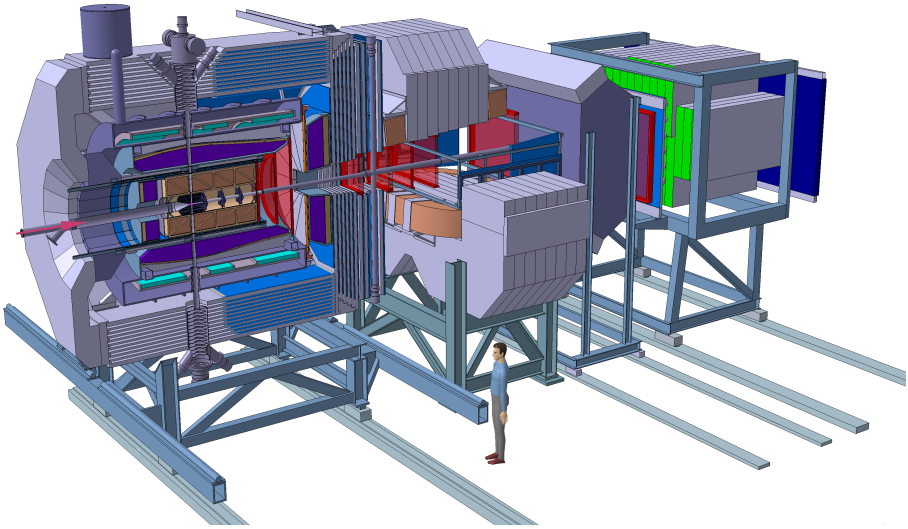


Fig. 2. Layout of the PANDA detector with the target spectrometer surrounding the interaction region (left) and the forward spectrometer (right).

3.1. Target spectrometer

The detectors in the TS are arranged in an onion-layered structure. The innermost detector is the micro-vertex detector (MVD). It is based on radiation hard silicon pixel and strip detectors arranged in four barrel layers for the large angle tracks and six planar layers in the very forward region. The MVD will allow for a vertex reconstruction to a precision of 50 μm and provide dE/dX information for particle identification. The central tracker will be a straw tube tracker (STT) and provides a momentum resolution at the percent level and dE/dX information. The tracking in the forward direction is complemented with three planar GEM detectors. The tracking is followed by two quartz based DIRC detectors for particle identification. It will be complemented with a barrel Time-of-Flight system based on scintillator tiles for low energy tracks. Electromagnetic calorimetry is provided by $\sim$ 16000 PWO crystals. They cover an energy range from a few MeV up to several GeV. The crystals will be cooled to -25° C to increase the light yield, providing an energy resolution of 2% at 1 GeV photon energy. The magnet yoke will be interleaved with tracking detectors for muon identification. The backward end-cap calorimeter can be removed to allow for the insertion of an active secondary target and germanium-array for the hypernuclear studies.

3.2. Forward spectrometer

Trajectories of forward going particles will be measured with a set of drift chambers in the dipole magnet giving a momentum resolution of 0.2% for 3 GeV/c protons. A RICH detector will enable π/K and K/p separation at the highest momenta and a Time-of-Flight wall from plastic scintillator material will provide this separation at the lower momenta. An electromagnetic calorimeter of the shaslik-type will measure photons with a resolution of $4\%/\sqrt{E}$. The last detector is a range tracking system of interleaved absorbers and drift tubes to measure muons, neutrons and antineutrons.

4. Conclusions

The PANDA collaboration will realize a very rich and versatile program with $\overline{p}$ interactions at the HESR storage ring at the FAIR facility. The experiment has a unique potential to advance our understanding of the strong interaction in the transition region between perturbative QCD and strong QCD. Only a part of the exciting physics could be presented here.

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