The PANDA Experiment at FAIR

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Introduction

One of the most challenging and fascinating goals of modern physics is the achievement of a fully quantitative understanding of the strong interaction, which is the subject of hadron physics. Significant progress has been achieved over the past few years thanks to considerable advances in experiment and theory. New experimental results have stimulated a very intense theoretical activity and a refinement of the theoretical tools.

Still there are many fundamental questions which remain basically unanswered. Phenomena such as the confinement of quarks, the existence of glueballs and hybrids, the origin of the masses of hadrons in the context of the breaking of chiral symmetry are long-standing puzzles and represent the intellectual challenge in our attempt to understand the nature of the strong interaction and of hadronic matter.

Experimentally, studies of hadron structure can be performed with different probes such electrons, pions, kaons, protons or antiprotons. In antiproton-proton annihilation particles with gluonic degrees of freedom as well as particle-antiparticle pairs are copiously produced, allowing spectroscopic studies with very high statistics and precision. Therefore, antiprotons are an excellent tool to address the open problems.

The Facility for Antiproton and Ion Research (FAIR), which will be built as a major upgrade of the existing GSI laboratory in Germany, will provide antiproton beams of the highest quality in terms of intensity and resolution, which will represent an excellent tool to answer these fundamental questions.

The PANDA experiment (Pbar ANnihilations at DArmstadt) will use the antiproton beam from the High-Energy Storage Ring (HESR) colliding with an internal proton target and a general purpose spectrometer to carry out a rich and diversified hadron physics program, from charmonium spectroscopy to the search for exotic hadrons and the study of nucleon structure, from the study of in-medium modifications of hadron masses to the physics of hypernuclei.

The High-Energy Storage Ring

The antiproton beam will be produced by a primary proton beam from the 100 T·m synchrotron called SIS100. The $\bar{p}$ production rate will be of approximately 2×10^7/s. After 5×10^5 $\bar{p}$ have been produced they will be transferred to the HESR, where internal experiments in the $\bar{p}$ momentum range from 1 GeV/c to 15 GeV/c can be performed.

The HESR is a racetrack ring, 574 meters in length, with two straight sections which will host the electron cooling and, respectively, the PANDA experiment. Two modes of operation are foreseen: in the high-luminosity mode peak luminosities of $2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ will be reached with a beam momentum spread $\delta p/p = 10^{-4}$, achieved by means of stochastic cooling; in the high-resolution mode for beam momenta below 8 GeV/c electron cooling will yield a smaller beam momentum spread $\delta p/p = 10^{-5}$ at a reduced luminosity of $10^{31}\text{cm}^{-2}\text{s}^{-1}$. The high-resolution mode will allow to measure directly the total width of very narrow (below 1 MeV) resonances.

The PANDA Physics Program

The PANDA experiment has a rich experimental program whose ultimate aim is to improve our knowledge of the strong interaction and of hadron structure. The experiment is being designed to fully exploit the extraordinary physics potential arising from the availability of high-intensity, cooled antiproton beams. Significant progress beyond the present understanding of the field is expected thanks to improvements in statistics and precision of the data.

Some of the many measurements foreseen in PANDA are discussed briefly in this paper. A full account of the PANDA physics programme can be found in the first version of the PANDA Physics Book [1], which describes also detailed simulations of the various physics channels.

Charmonium Spectroscopy

The spectrum of charmonium states consists of eight narrow states below the open charm threshold (3.73 GeV) and several tens of states above the threshold.

Theoretical calculations are performed within the framework of various models and in Lattice QCD.

Experimentally all eight states below the $\bar{D}D$ threshold are well established, but whereas the triplet states are measured with very good accuracy, the same cannot be said for the singlet states.

The region above the $\bar{D}D$ threshold is rich in interesting new physics. In this region one expects to find the four 1D states. Of these only the 1^3D_1, identified with the ψ(3770) resonance, has been found. In addition to the D states, the radial excitations of the S and P states are predicted to occur above the open charm threshold. None of these states have been positively identified.

On the other hand a lot of new states have recently been discovered at the B-factories: these new states (X, Y, Z ...) are associated with charmonium because they decay predominantly into charmonium states such as the J/ψ or the $\psi(2S)$, but their interpretation is far from obvious.

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The main challenge of the next years will be thus to understand what these new states are and to match these experimental findings to the theoretical expectations for charmonium above threshold.

Charmonium spectroscopy is an important item in the experimental program of PANDA, and the design of the detector and of the accelerator are optimized to be well suited for this kind of physics.

At full luminosity PANDA will be able to collect several thousand $\bar{c}c$ states per day. By means of fine scans it will be possible to measure masses with accuracies of the order of 100 KeV and widths to 10% or better. The entire energy region below and above open charm threshold will be explored.

Gluonic Excitations

One of the main challenges of hadron physics, and an important item in the PANDA physics program, is the search for gluonic excitations, i.e. hadrons in which the gluons can act as principal components. These gluonic hadrons fall into two main categories: glueballs, i.e. states of pure glue, and hybrids, which consist of a $q\bar{q}$ pair and excited glue. The additional degrees of freedom carried by gluons allow these hybrids and glueballs to have J^{PC} exotic quantum numbers: in this case mixing effects with nearby $q\bar{q}$ states are excluded and this makes their experimental identification easier. The properties of glueballs and hybrids are determined by the long-distance features of QCD and their study will yield fundamental insight into the structure of the QCD vacuum.

Antiproton-proton annihilations provide a very favourable environment in which to look for gluonic hadrons. So far the experimental search for glueballs and hybrids has been mainly carried out in the mass region below 2.2 MeV/c^2. PANDA will extend the search to higher masses and in particular to the charmonium mass region, where light quark states form a structureless continuum and heavy quark states are far fewer in number. Therefore exotic hadrons in this mass region could be resolved and identified unambiguously.

The spectrum of **charmonium hybrid** mesons can be calculated within the framework of various theoretical models, such as the bag model, the flux tube model, the constituent quark model and recently, with increasing precision, from Lattice QCD (LQCD). All model predictions and LQCD calculations agree that the masses of the lowest lying charmonium hybrids are between 4.2 GeV/c^2 and 4.5 GeV/c^2. Three of these states are expected to have J^{PC} exotic quantum numbers (0^{+-}, 1^{-+}, 2^{+-}), making their experimental identification easier since they will not mix with nearby $\bar{c}c$ states. These states are expected to be narrower than conventional charmonium, because their decay to open charm will be suppressed or forbidden below the $D\overline{D_J^*}$ threshold. The cross sections for the formation and production of charmonium hybrids are estimated to be similar to those of normal charmonium states, which are within experimental reach. Formation experiments will generate only non-exotic charmonium hybrids, whereas production experiments will yield both exotic and non-exotic states. This feature can be exploited experimentally: the observation of a state in production but not in formation will be, in itself, a strong hint of exotic behavior.

The **glueball** spectrum can be calculated within the framework of LQCD in the quenched approximation [2]. In the mass range accessible to PANDA as many as 15 glueball states are predicted, some with exotic quantum numbers (*oddballs*). As with hybrids, exotic glueballs are easier to identify experimentally since they do not mix with conventional mesons.

Hadrons in Nuclear Matter

The study of medium modifications of hadrons embedded in hadronic matter is aimed at understanding the origin of hadron masses in the context of spontaneous chiral symmetry breaking in QCD and its partial restoration in a hadronic environment. So far experiments have been focussed on the light quark sector: evidence of mass changes for pions and kaons have been deduced by the study of deeply bound pionic atoms [3] and of K meson production in proton-nucleus and heavy-ion collisions [4].

The high-intensity $\bar{p}$ beam of up to 15 GeV/c will allow an extension of this program to the charm sector both for hadrons with hidden and open charm. The in-medium masses of these states are expected to be affected primarily by the gluon condensate. Recent theoretical calculations predict small mass shifts (5-10 MeV/c^2) for the low-lying charmonium states [5] and more consistent effects for the χ_{cJ} (40 MeV/c^2), $\psi(2S)$ (100 MeV/c^2) and ψ(3770) (140 MeV/c^2) [6].

D mesons, on the other hand, offer the unique opportunity to study the in-medium dynamics of a system with a single light quark. Recent theoretical calculations agree in the prediction of a mass splitting for D mesons in nuclear matter but, unfortunately, they disagree in sign and size of the effect.

Experimentally the in-medium masses of charmonium states can be reconstructed from their decay into di-leptons and photons, which are not affected by final state interaction. D meson masses, on the other hand, need to be reconstructed by their weak decays into pions and kaons which makes the direct measurement of mass modifications difficult. Therefore other signals have been proposed for the detection of in-medium mass shifts of D mesons: in particular it has been speculated that a lowering of the $\bar{D}D$ threshold would result in an increased D and $\overline{D}$ production in $\bar{p}$-nucleus annihilations [7] or in an increase in width of the charmonium states lying close to the threshold [8].

Another study which can be carried out in PANDA is the measurement of J/ψ and D meson production cross sections in $\bar{p}$ annihilation on a series of nuclear targets. The comparison of the resonant J/ψ yield obtained from $\bar{p}$ annihilation on protons and different nuclear targets al-

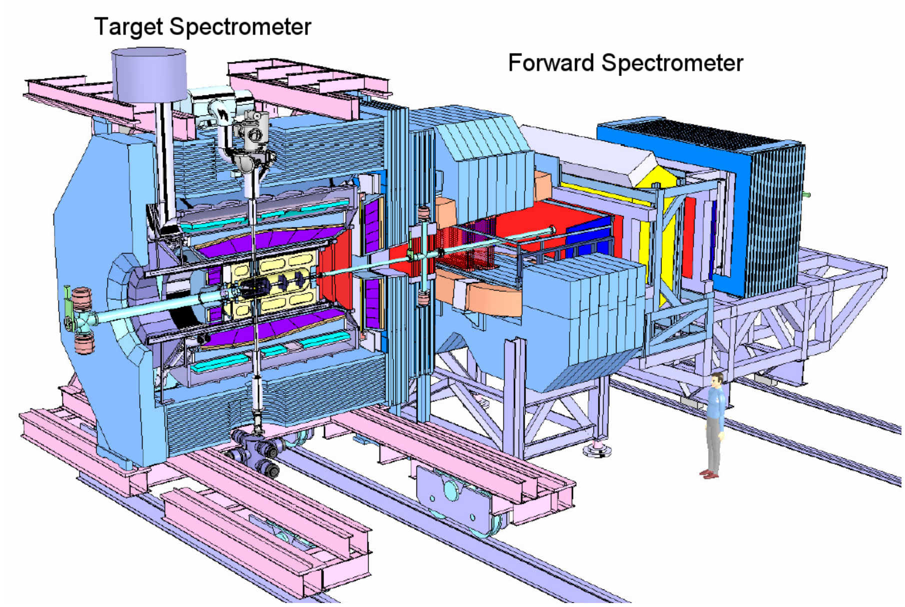

Figure 1: Schematic view of the PANDA detector.

lows to deduce the J/ψ-nucleus dissociation cross section, a fundamental parameter to understand J/ψ suppression in relativistic heavy ion collisions interpreted as a signal for quark-gluon plasma formation.

The PANDA Detector

In order to carry out the physics program discussed above the PANDA detector must fulfil a number of requirements: it must provide (nearly) full solid angle coverage, it must be able to handle high rates (2×10^7 annihilations/s) with good particle identification and momentum resolution for γ, e, μ, π, K and p. Additional requirements include vertex reconstruction capability and, for charmonium, a pointlike interaction region, efficient lepton identification and excellent calorimetry (both in terms of resolution and of sensitivity to low-energy showers).

A schematic representation of the detector layout is shown in Fig. 1.

The antiprotons circulating in the HESR hit an internal hydrogen target (either pellet or cluster jet), while for the nuclear part of the experimental program wire or fiber targets will be used. The apparatus consists of a central detector, called Target Spectrometer (TS) and a Forward Spectrometer (FS).

The TS, for the measurement of particles emitted at laboratory angles larger than 5°, will be located inside a solenoidal magnet which provides a field of 2 T. Its main components will be a microvertex silicon detector, a central tracker (either a straw tube detector or a time projection chamber), an inner time-of-flight telescope, a cylindrical DIRC (Detector of Internally Reflected Light) for particle identification, an electromagnetic calorimeter consisting of $PbWO_4$ crystals, a set of muon counters and of multiwire drift chambers.

The FS will detect particles emitted at polar angles below 10° in the horizontal and 5° in the vertical direction. It will consist of a 2 T·m dipole magnet, with tracking detectors (straw tubes or multiwire chambers) before and after for charged particle tracking. Particle identification will be achieved by means of Čerenkov and time-of-flight detectors. Other components of the FS are an electromagnetic and a hadron calorimeter.

All detector components are currently being developed within a very active R&D program. This continued development implies that the choice has not yet been finalized for all detector elements.

Charmonium and open charm physics at PANDA

The study of charmonium and open charm are among the main topics in the PANDA physics program. Compared with Fermilab E760 and E835, a multi-purpose detector with magnetic field, with better momentum resolution and higher luminosity of the machine, will lead to an extensive physics program in charmonium physics.

The large hadronic background in $\bar{p}p$ annihilation represents a challenge for the study of many final states. The capability of observing a particular final state depends on the signal-to-background ratio; it is therefore necessary to test the capabilty to efficiently separate signal from background sources with cross sections that are orders of magnitude larger than the channels of interest. A full detector simulation has been developed to study physics channel of interest and the main sources of background, to assess the capability of background reduction at the needed level and prove the feasibility of charmonium studies in PANDA.

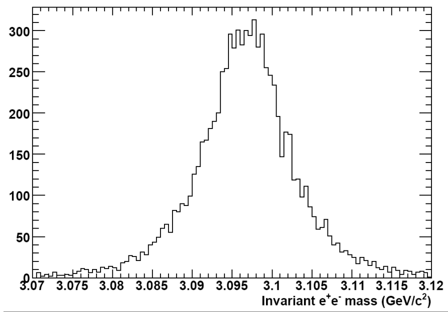

Figure 2: Reconstructed e^+e^- invariant mass in events containing a J/ψ.

In this section we will present the results obtained for the full simulation of some channels of interest, that are discused in more detail in the PANDA Physics Performance Report [1].

Channels with a J/ψ in the final state

The identification of charmonium states decaying into J/ψ is relatively clean due to the presence of a pair of leptons l^+l^- in the final state. These channels can be used to study states like $\psi(2S)$, χ_{cJ}, $X(3872)$, $Y(4260)$, containing a J/ψ in the decay products.

These analyses rely on the positive identification of the two leptons in the final state for the reconstruction of $J/\psi \to l^+l^-$, where the main background is represented by pairs of tracks, like $\pi^+\pi^-$, associated with large energy deposition in the electromagnetic calorimeter.

A detailed simulation of several benchmark channels of this kind, compared with some possible source of background, was carried out. A J/ψ was selected requiring:

- lepton tracks identified with PID criteria;
- kinematical fit of two $e^\pm$ tracks to a J/ψ, using vertex constraint.

The resolution on the J/ψ mass in the detector is evaluated measuring the e^+e^- invariant mass distributions for reconstructed J/ψ in the final state. An example is shown in Fig. 2; the RMS of the distribution is in the range 4-8 MeV depending on the totale center-of-mass energy of the interaction.

As a case study we will consider in more detail the $J/\psi\pi^+\pi^-$ channel. In the last few years, many new states in the charmonia mass region, but with unexpected properties, have been discovered at the B-factories. Some of them, like the $X(3872)$ and the $Y(4260)$, were discovered through their $J/\psi\pi^+\pi^-$ decay. The PANDA performance on this channel have been analyzed in detail through a complete simulation of the final state in the detector. A simple selection has been performed, adding two charged pions to a reconstructed J/ψ and performing a kinematical fit with vertex constraint. The efficiency for the complete selection is around 30% over the energy region of interest (3.5 to 5.0 GeV).

The main source of hadronic background for this channel comes from $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-$, where two pions may be erroneously identified as electrons and contaminate the signal. At a center-of-mass energy around 4.26 GeV, the cross section for this process is of the order of few tens of μb [9], which is 10^6 times larger than the expected signal, estimated from previous results of Fermilab E835. By using the described selection, the rejection power for this background is of the order of 10^6 and the signal-to-background ratio is about 2, making this channel to be well identified in PANDA.

Two- or three-photon decays

One of the most promising channels for the observation of the h_c is the electromagnetic transition to the ground state charmonia $h_c \to \eta_c\gamma$; the η_c can then be detected through many decay modes. $\eta_c \to \gamma\gamma$ is characterized by a reasonably clean signature, due to the presence of two energetic photons in the detector with the η_c mass.

A study has been performed to assess the PANDA capability to detect the $h_c \to \eta_c\gamma \to 3\gamma$ decay, in presence of large hadronic background sources due to channels like $\bar{p}p \to \pi^0\pi^0,\ \pi^0\eta,\ \eta\eta$, presenting hard photons in the final state and no charged tracks, that could mimic the channel of interest.

The selection is done in the following steps:

- events with only 3 reconstructed photons are selected;
- an η_c candidate is formed pairing two photons in the 2.6-3.2 GeV mass window; a third photon is added to form the h_c candiate;
- a 4-C fit to beam energy-momentum is performed on the h_c candidate, and a cut on the fit CL is applied;
- a cut on the center-of-mass energy of the energy of the γ coming from the radiative transition: $0.4 < E_\gamma < 0.6$ GeV;
- an angular cut $|\cos(\theta_{CM})| < 0.6$ allows to reject a large fraction of backgrounds like $\pi^0\pi^0$, that are strongly peaked in the forward direction;
- the invariant mass of the radiative γ paired with either γs coming from the decay of the η_c candidate is required to be larger than 1 GeV, to suppress η' decays.

After these cuts the efficiency on the signal is about 8% and the background suppression of the order of 10^{-6} or larger on many background channels.

The production cross section observed by E835 [10], although with large uncertainties, combined with the present background suppression, yields an estimate of the order of 90 or more for the signal-to-background ratio and confirms the feasibility of this study in PANDA.

Decays to light hadrons

As a benchmark channel of hadronic decays, we will consider $h_c \to \eta_c\gamma \to \phi\phi\gamma$, with $\phi \to K^+K^-$. Three reactions are considered as main contribution to the background: $\bar{p}p \to K^+K^-K^+K^-\pi^0$, $\bar{p}p \to \phi K^+K^-\pi^0$, $\bar{p}p \to \phi\phi\pi^0$, with one photon from the π^0 undetected.

The selection of the final state is based on the following requirements:

- ϕ candidates are reconstructed as K^+K^- pairs in the invariant mass window 0.8-1.2 GeV; two ϕ candidates with invariant mass in the region 2.6-3.2 GeV define the η_c candidate; a photon is then added to form the h_c candidate;
- a 4-C fit to beam energy-momentum is applied to the h_c candidate, and a cut on the CL of the fit is done;
- a restriction of the mass windows for all candidates is applied after the kinematical fit to improve the background suppression;
- events presenting π^0 candidates ($\gamma\gamma$ pair with invariant mass in the 0.115-0.150 GeV region) are rejected.

An efficiency on signal events of $\sim 25\%$ is achieved after this selection.

Since no experimental data is available for the three background cross sections, the only way to estimate the background contribution is to use the dual parton model (DPM); simulating $2 \cdot 10^7$ events, no event passes the selection . The three main background channels have been also simulated separately; with a total $\bar{p}p$ cross section of 60 mb, it is possible to estimate $\sigma(\bar{p}p \to K^+K^-K^+K^-\pi^0) =$ 345 nb, $\sigma(\bar{p}p \to \phi K^+K^-\pi^0) = 60$ nb, $\sigma(\bar{p}p \to \phi\phi\pi^0) =$ 3 nb, and using these values it is possible to obtain signal-to-background ratio values of 8 or larger for each one of the background channels.

Using this signal-to-background value, it is possible to estimate the PANDA sensitivity to the h_c width measurement. A few scans of the h_c have been simulated for different values of $\Gamma(h_c)$. The expected shape of the measured cross-section is obtained from the convolution of the Breit-Wigner resonance curve with the normalised beam energy distribution plus a background term. Assuming 5 days of data taking per point in high resolution mode, it is possible to reconstruct the h_c resonance shape and the result (for the case $\Gamma(h_c) = 0.5$ MeV) is summarized in Fig 3. The results show an accuracy on the width measurement of the order of 0.2 MeV for $\Gamma(h_c)$ values in the range 0.5-1.0 MeV.

$D\overline{D}$ decays

The ability to study charmonium states above the $D\overline{D}$ threshold is important for the major part of the PANDA physics program in topics like the study of open charm spectroscopy, the search for hybrids, and CP violation studies. The study of $\bar{p}p \to \bar{D}D$ as a benchmark channel will also assess the capability to separate hadronic decay channels from a large source of hadronic background.

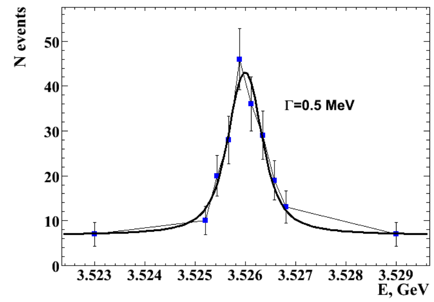

Figure 3: Simulation of the scan of the h_c (with $\Gamma(h_c) =$ 0.5 MeV) fot the measurement of the resonance width. Each point corresponds to 5 days of data taking in PANDA.

Two benchmark channels have been studied in detail:

- $\bar{p}p \to D^+D^-$ (with $D^+ \to K^-\pi^+\pi^+$);
- $\bar{p}p \to D^{*+}D^{*-}$ (with $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$);

the first one was simulated at the $\psi(3770)$ and the second at the $\psi(4040)$ masses. We assume a conservative estimate for the charmonium production cross section above the open charm threshold to be of the order of 3 nb for D^+D^- and 0.9 nb for $D^{*+}D^{*-}$ production.

The event selection for D^+D^- is based on the detection of the charged tracks and the reconstruction of the D meson candidate. The D invariant mass distribution is roughly gaussian, with $\sigma \simeq 10$ MeV. D candidates are accepted in a loose mass window of ± 0.3 GeV, then a kinematical fit of the two D candidates to the beam momentum-energy is applied, and the events are selected with a cut on the fit CL. A similar selection is done for $D^{*+}D^{*-}$, with an intermediate step for the D^0 reconstruction.

The background was simulated using the dual parton model (DPM) to produce inelastic reactions in $\bar{p}p$ annihilations. A background suppression of the order of 10^7 was achieved with the previous selection. A detailed study of specific background reactions is also performed, in particular the non resonant production of $K^+K^-2\pi^+2\pi^-$ has a cross section which is 10^6 times larger than the D^+D^- signal. It is shown that a cut on the longitudinal and transverse momenta of the $D^\pm$ can reduce the background by a factor ∼26, and the remaining events leave a non-peaking background in the loose mass region defined in the preselection. The reconstructed decay vertex location will further improve the background rejection, reaching a signal-to-background ratio around 1, with an efficiency on signal events of ~ 8 %.

Under these assumptions, a conservative estimate of the number of reconstructed events per year of PANDA operation is of the order of 10^4 and 10^3 for D^+D^- and $D^{*+}D^{*-}$ respectively.

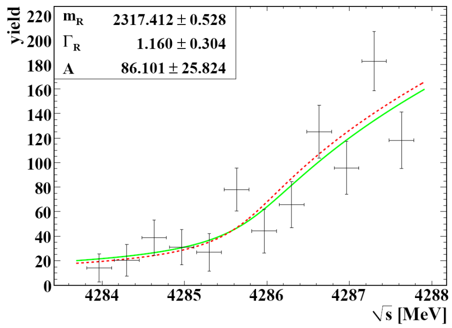

Figure 4: Fit of the simulated excitation function for near-threshold $\bar{p}p \rightarrow D_s^{\pm} D_{s0}^*(2317)^{\mp}$. The red dotted line corresponds to the simulated function and the green solid line is the reconstructed curve.

Near-threshold energy scan

Performing fine energy scans, PANDA will be able to observe the energy dependence of a cross section in proximity of a threshold. Here we report the results obtained in the simulation of $\bar{p}p \rightarrow D_s^{\pm} D_{s0}^*(2317)^{\mp}$ near threshold, to test the sensitivity to resonance parameters in this kind of study at PANDA.

The assumptions used in this study are:

- 12 points scan of a 4 MeV wide region;
- 14 days of data with a total integrated luminosity of 9 pb^{-1}/day;
- a signal-to-background ratio of 1:3;
- 1 MeV total width for the $D_{s0}^*(2317)$.

The results of the scan are presented in Fig. 4, where the mass and the width of the $D_{s0}^*(2317)$ are used as free parameters in the fit. The study yield the results:

$$m = 2317.41 \pm 0.53\text{MeV};$$
$$\Gamma = 1.16 \pm 0.30\text{MeV};$$

to be compared with the input values of the simulation: $m = 2317.30$ MeV and $\Gamma = 1.00$ MeV, proving the sensitivity to resonance parameters in threshold scans.

Charmonium hybrids

In conventional charmonia, the quantum numbers are derived directly from the excitation of the $\bar{c}c$ pair. The glue tube adds degrees of freedom that manifest themselves in non-conventional quantum numbers; in the simplest $\bar{c}cg$ scenario this corresponds to the addition of a single gluon quantum numbers ($J^{PC} = 1^-$ or 1^+ for color-electric or color-magnetic excitation). This would result in charmonium hybrids with non-exotic and exotic quantum numbers, which are expected in the 3-5 GeV mass region. Here we will sketch out the strategy for hybrids studies in PANDA, more details are available in [1].

Formation experiments would generate non-exotic charmonium hybrids with high cross sections, while production experiments would yield a hybrid together with another particle like π or η. In PANDA both processes are possible; the strategy would be to start searching for hybrids in production processes, fixing the $\bar{p}p$ center of mass energy at the highest possible value ($\sqrt{s} \simeq 5.5$ GeV) and studying all the production channels. Then hybrids could be studied in formation, through energy scans over the regions where possible signals have been observed in production measurement.

Apart from the benchmark channels used for the detection of conventional charmonia, hybrids can be identified through reactions like:

- $\bar{p}p \rightarrow \widetilde{\eta}_{c0,1,2}\eta \rightarrow \chi_{c1}\pi^0\pi^0\eta$;
- $\bar{p}p \rightarrow \widetilde{h}_{c0,1,2}\eta \rightarrow \chi_{c1}\pi^0\pi^0\eta$;
- $\bar{p}p \rightarrow \widetilde{\psi}\eta \rightarrow J/\psi\omega\eta$;
- $\bar{p}p \rightarrow [\widetilde{\eta}_{c0,1,2}, \widetilde{h}_{c0,1,2}, \widetilde{\chi}_{c1}]\eta \rightarrow DD^*\eta$;

namely final states with charmonia accompanied by light hadrons or final states with a DD^* pair.

As a case study we will present here the results obtained for the benchmark channel $\bar{p}p \rightarrow \widetilde{\eta}_{c1}\eta \rightarrow \chi_{c1}\pi^0\pi^0\eta$. It can be assumed that the $\bar{p}p \rightarrow \widetilde{\eta}_{c1}\eta$ production cross section is of the same order of $\bar{p}p \rightarrow \psi(2S)\eta$, which is estimated to be (33 ± 8) pb [11]. As possible sources of background, several reactions with similar topology have been considered:

- $\bar{p}p \rightarrow \chi_{c0}\pi^0\pi^0\eta$;
- $\bar{p}p \rightarrow \chi_{c1}\pi^0\eta\eta$;
- $\bar{p}p \rightarrow \chi_{c0}\pi^0\pi^0\pi^0\eta$;
- $\bar{p}p \rightarrow J/\psi\pi^0\pi^0\pi^0\eta$.

A simple analysis is carried out. Two photons are accepted as π^0 or η candidates if their invariant mass is in the range 115-150 MeV and 470-610 MeV, respectively. The χ_{c1} is formed adding to a J/ψ candidate a radiative photon, with total invariant mass within 3.3-3.7 GeV. From these, $\chi_{c1}\pi^0\pi^0\eta$ candidates are created and kinematically fitted to the original beam energy-momentum, with an additional constraint for the J/ψ mass. Additional cuts on the kinematical fit CL and on the invariant masses of the intermediate decay products, obtaining a total efficiency around 7% for this channel. The $\widetilde{\eta}_{c1}$ peak reconstructed in this way has a FWHM of 30 MeV.

The background suppression is estimated applying the same analysis to background events and the results are summarized in Tab 1.

Table 1: Background suppression (η) for the individual background reactions.

Background channel	η $[\cdot 10^3]$
$\chi_{c0}\pi^0\pi^0\eta$	5.3
$\chi_{c1}\pi^0\eta\eta$	26
$\chi_{c0}\pi^0\pi^0\pi^0\eta$	> 80
$J/\psi\pi^0\pi^0\pi^0\eta$	10

Charmonium dissociation

The $J/\psi N$ dissociation cross section is as yet experimentally unknown, except for indirect information deduced from high-energy J/ψ production from nuclear targets. Apart from being a quantity of its own interest, this cross section is closely related to the attempt of identifying quark-gluon plasma (QGP) formation in ultra-relativistic nucleus-nucleus collisions: the interpretation of the J/ψ suppression observed at the CERN SPS [12, 13, 14] as a signal for QGP formation relies on the knowledge of the "normal" suppression effect due to J/ψ dissociation in a hadronic environment. Nuclear J/ψ absorption can so far only be deduced from models, since the available data do not cover the kinematic regime relevant for the interpretation of the SPS results.

In antiproton-nucleus collisions the $J/\psi N$ dissociation cross section can be determined for momenta around 4 GeV/c with very little model dependence. The determination of the $J/\psi N$ dissociation cross section is in principle straightforward: the J/ψ production cross section is measured for different target nuclei of mass number ranging from light (d) to heavy (Xe or Au), by scanning the $\bar{p}$ momentum across the J/ψ yield profile whose width is essentially given by the known internal target nucleon momentum distribution. The J/ψ is identified by its decay to e^+e^- or $\mu^+\mu^-$. The attenuation of the J/ψ yield per effective target proton is a direct measure for the $J/\psi N$ dissociation cross section, which can be deduced by a Glauber type analysis. In a second step these studies may be extended to higher charmonium states like the $\psi(2S)$, which would allow to determine the cross section for the inelastic process $\psi(2S)N \rightarrow J/\psi N$, which is also relevant for the interpretation of the ultra-relativistic heavy ion data.

The benchmark channel studied in this context is the reaction:

$$\bar{p}^{40}Ca \rightarrow J/\psi X \rightarrow e^+e^-X \quad (1)$$

The cross section for this process is estimated to be nine orders of magnitude smaller than the total antiproton-nucleus cross section. The results of the simulations show that it is possible to identify the channel of interest with good efficiency and acceptable signal to background ratio [1].

Conclusions

The availability of high-intensity, cooled antiproton beams at FAIR will make it possible to perform a very rich experimental program.

The PANDA experiment will perform high-precision hadron spectroscopy from $\sqrt{s} = 2.25$ GeV to $\sqrt{s} = 5.5$ GeV and produce a wealth of new results in hadron spectroscopy and nucleon structure. The performance of the detector and the sensitivity to the various physics channels have been estimated by means of detailed Monte Carlo simulations [1], which show that the final states of interest can be detected with good efficiency and low background.

All these new measurements will make it possible to achieve a very significant progress in our understanding of QCD and the strong interaction. We are looking forward to many years of exciting hadron physics at FAIR.

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