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The PANDA detector at FAIR

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Abstract Cooled antiproton beams of unprecedented intensities in the momentum range of 1.5-15 GeV/c will be used for the PANDA experiment at FAIR to perform high precision experiments in the charmed quark sector. Four major physical research topics will be addressed: Spectroscopy of resonances in the energy region of charmonium and above, In-medium effects of open and hidden charm, glueballs, predicted by QCD, and single and double hypernuclei. The proposed PANDA detector is a 4π internal target spectrometer at the HESR allowing the detection and identification of neutral and charged particles generated within the total energy range of the antiproton annihilation products.

Keywords FAIR · PANDA detector instrumentation · hadron spectroscopy

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1 Introduction

The plans for the International Facility for Antiproton and Ion Research (FAIR) [1, 2] at GSI are going into realization. When finished, highly luminous secondary beams with unsurpassed quality from a 30 GeV proton synchrotron can be delivered to many experiments. Antiprotons abundantly produced at a rate of 10^7 s^{-1} will be accumulated and transferred into the High Energy Storage Ring (HESR). The design parameters encompass the momentum range of 1.5 to 15 GeV/c with momentum bite as low as 2×10^{-5} when cooled either stochastically or by magnetized electron cooling. At the interaction point of the PANDA detector this antiproton beam crosses a dense internal target such that the total luminosity reaches 2×10^{32} cm^{-2}s^{-1}. Four major physical research topics will be addressed:

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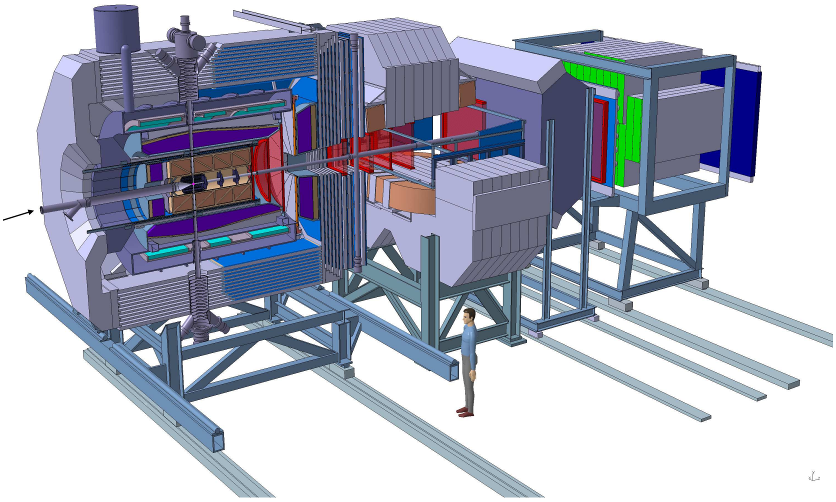

Fig. 1 The PANDA detector consists of a central and a forward magnetic spectrometer. The figure shows the subdetectors within the solenoid and subdetectors inside and behind the dipole magnet of the forward spectrometer.

i. High precision spectroscopy of resonances in the energy region of charmonium and above. The exact knowledge about masses, widths, and branching ratios provides information about the mechanisms of quark confinement.
ii. In-medium effects of open and hidden charm and their relationship to the chiral symmetry breaking addressing especially the origin of hadron mass.
iii. So-called glueballs, predicted by QCD, need a firm experimental establishment in our picture of strong interactions. Also hybrid meson states, so-called excited glue, in the mass range between 3 and 5 GeV/c^2 are predicted to be rather narrow without mixing into neighboring resonances.
iv. Hypernuclei, when abundantly produced, and examined with the next generation of γ-detectors, will revive the physics with single and double hypernuclei. This will improve our modest knowledge on their structure and give information on the interaction of hyperons with nucleons as well as hyperon-hyperon interaction.

GSI has a distinguished history of having made important contributions to the physics of strong interaction, in particular nuclear physics. The proposed PANDA experiments play a significant role in strong interaction physics, providing a link between nuclear and hadron physics.

2 Detector

The PANDA detector [3,4] will be a 4π internal target spectrometer at the HESR allowing the detection and identification of neutral and charged particles generated within the total energy range of the antiproton annihilation products. This task will be shared by the combination of a central and a forward magnetic spectrometer of modular construction where both are optimized for the specific kinematics of the antiproton-nucleon

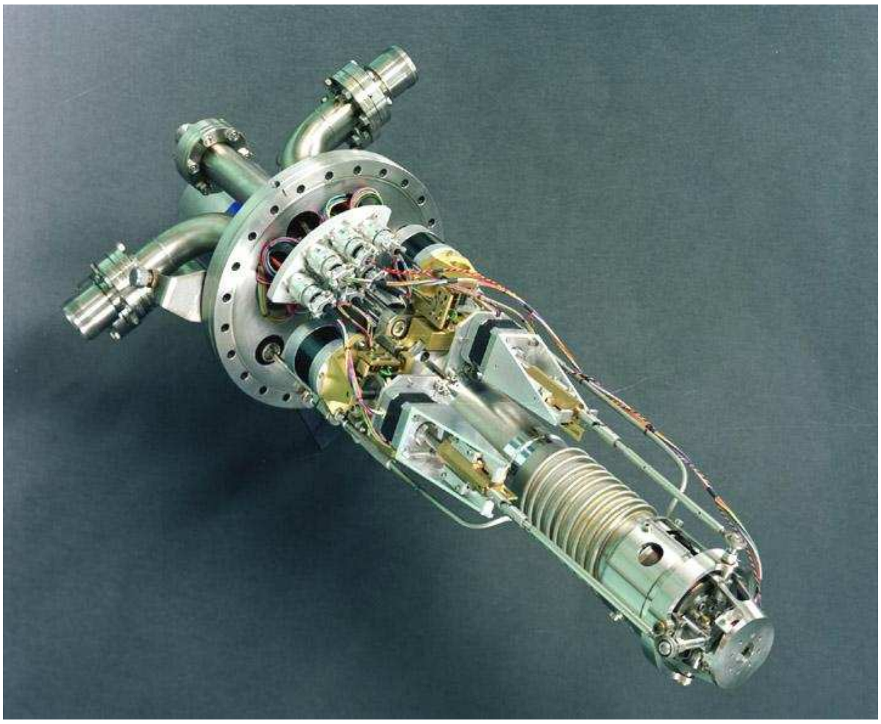

Fig. 2 Cold head of the hydrogen cluster target for the PANDA detector.

annihilation process. The design of PANDA is based on previous experience in antiproton experiments and takes advantage of ongoing detector developments performed at the high-energy laboratories all over the world.

2.1 Target spectrometer

The target spectrometer is working in a solenoidal magnetic fields up to 2 Tesla. As target, both, a hydrogen cluster jet target [6] and a hydrogen pellet target [5] with an areal density up to 10^{16} atoms/cm^2 is foreseen, to reach the required luminosity and to allow the determination of the primary vertex. Both of them can also be operated with heavier elements.

The target station is surrounded by tracking detectors and particle identification detectors for charged particles. In addition an electromagnetic calorimeter is capable of gamma detection and electron/pion separation.

A microvertex detector (MVD) with 4 barrels around and 8 disks pointing towards the interaction point serves as tracker also for secondary vertices as close as 50 μm from the interaction point to resolve D-mesons. Its concept is based on designs as used at LHC for ATLAS and CMS [7,8]. The inside barrels have a pixelized readout whereas the outer barrel have a strip structure. There are 13 million pixels with a dimension of 100 x 100 μm and about 70000 strips. Together with the microvertex detector the information of a straw tube tracker (STT) [9] yields information about the momentum of the charged particles. About 6000 pressurized self-supporting straw tubes with a diameter of 1 cm form a light-weighted tracking device with short radiation length of $X/X_0 \approx 1\%$. The large number of tubes results in a transverse track resolution of $150\mu m$. Due to the skew angle of the tubes with respect to the beam axis a track position resolution of $2.9mm$ in beam direction is possible. The transverse momentum resolution is then $\sigma_{pt}/p_t = 1.2\%$.

Alternatively, a TPC with GEM readout may be used. Here, a multi-GEM stack amplifies the signal and prevents the ion back flow. As counting gas a mixture of Neon and CO_2 with admixtures of CH_4 or CF_4 is foreseen. Due to the long drift time of the electrons of 50-70 μs and the high interaction rate, up to 500 tracks are overlapping within the TPC volume. The charge buildup and the continuous sampling still require prototype tests. The momentum resolution is similar to the STT, however, the additional energy loss resolution of 6% allows for PID of slow charged particles below an energy of 1 GeV.

Two GEM tracker disks in forward direction within the solenoid enhance the track resolution for forward emitted particles.

Particle identification is performed by two Cherenkov detectors. Due to the compactness of the PANDA detector only limited space is available and makes the DIRC principle favorable, as it was working in the BaBar detector at SLAC [15]. DIRC stands for Detecting Internally Reflecting Cherenkov photons. The barrel consists out of 200 artificial fused silica slabs which reflect downstream by a mirror photons back towards the photon detector. Here, the photons will be reflected many times by total reflection, due to the rectangular shape of the slabs the angular information is preserved. At the end of the slabs the photons are focussed by a lens system on a flat focal plane [12]. This plane will be read out by Micro-channel- PMTs [13] which can work within the field of the solenoid of B=1 Tesla.

The momentum threshold of the Barrel-DIRC makes a time of flight system for slow particles and their for PID favorable. In addition this timing information when in the sub-nanosecond range can help to correct the Cherenkov images when distorted by dispersion. The over-determination of the Cherenkov image by the position and timing information of the photons allows to measure the wavelengths of the photons. We consider two options of a timing barrel either based on RPC counters or on scintillation counters.

The Cherenkov counter in forward direction will be a disk made from artificial fused silica. Readout either by a two-dimensional position sensitive detector [10,14], or by a one dimensional position sensitive detector along the rim records the time of propagation (TOP) of the photons [11]. In the first case the light is coupled out from the disk by a focussing light guide towards the photon detector. The one dimensional position of the photon on this detector together with the detector position along the disk rim gives the two dimensional spatial Cherenkov image. In the latter case (TOP) the Cherenov angle resolution can be improved by using dichroic filters in front of the photon detectors. Then photons of two color ranges are either recorded or reflected towards the next photon detector increasing the time of flight.

The expected high count rate, a geometrically compact design and severe constraints on good energy and position resolution for the detection of high energy photons require a homogeneous electromagnetic calorimeter based on inorganic scintillator crystals. The material of first choice is lead tungstate, $PbWO_4$ (PWO), a very compact and radiation hard material. The lead tungstate electromagnetic calorimeter [16] is divided up in three parts. The barrel part consists out of 11000 crystals read out by

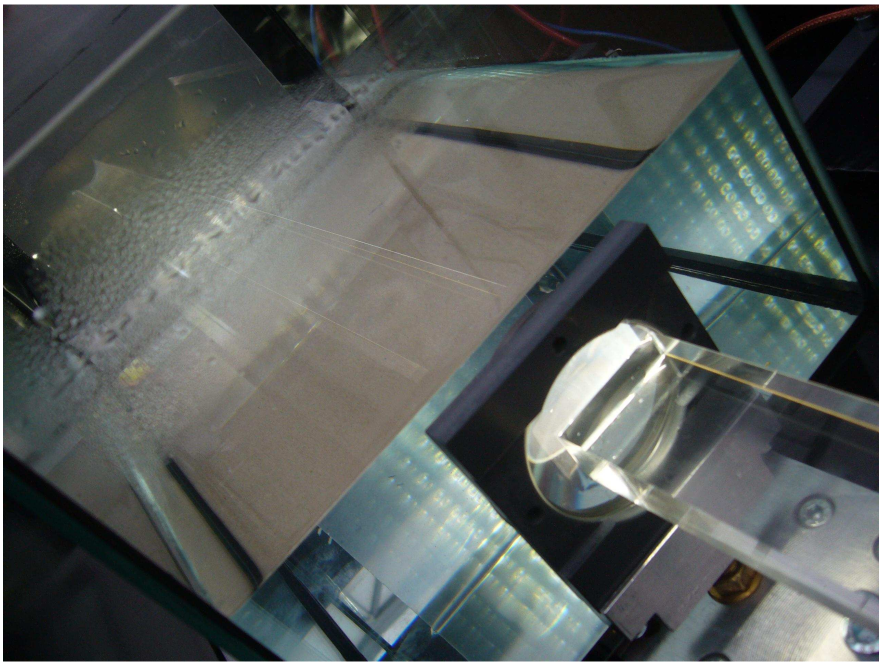

Fig. 3 Test setup for the readout of artificial fused silica radiator (right), a lens, an oil filled photon detector (bassin on the left), separated by a small air-gap. The matching refractive index of the silica and the oil (MARCOL81) prevents image distortions of the Cherenkov image.

large area APDs (LAAPD) and the front disk holds 4000 crystals read out by LAAPDs and by vacuum photo triodes. The length of the crystals is about 20 X_0 and yields an energy resolution of $\sigma/E = 1.5\%/\sqrt{E}$. A additional backward disk has less resolution due to service lines leaving the detector upstream.

Last but not least, the iron yoke of the solenoid is instrumented with 11 layers of muon detector in the forward direction of solenoid barrel and its front door.

The subsystems are modular and removable to allow the insertion of different detector types. The hypernuclear physics eg. requires the insertion of a primary target and a secondary target/tracker detector with surrounding high resolution gamma detectors, which is possible due to the flexible modular detector concept [17].

2.2 Forward spectrometer

In a fixed target experiment particles are copiously emitted in forward direction and the need for measuring all the particles for eg. partial wave analysis makes a forward spectrometer indispensable. The heart of the forward spectrometer is a dipole magnet with a large opening angle and a bending power of 2 Tm. This will provide the required momentum resolution for forward tracks with momenta up to 8 GeV/c.

Tracking is provided by minidrift chambers. In front of the magnet, they have the same octonal shape as in the end-cap of the target spectrometer. Behind the magnet, a rectangular shape is more suitable for the spread of the tracks. The use of straw tube trackers inside the dipole field is considered for better momentum resolution.

The option of a third Cherenkov counter, based on gas or aerogel is still under investigation. In addition, a time-of-flight detector is considered for charged particle identification. An electromagnetic calorimeter based on lead/scintillator sampling and WLS fibre readout (Shashlyk type) is foreseen in the forward spectrometer. it will reach a resolution of $4\%/\sqrt{E}$.

3 Data Acquisition and Trigger

The selected readout and trigger concept foresees continuous digitization of all detectors channels. Special trigger hardware is not foreseen. The readout electronics has to be fully pipelined and has to perform autonomously the detection of valid hits as well as intelligent data reduction by clusterization, signal shape analysis, and time reconstruction to transfer only the physical relevant minimum of information. All data are marked by synchronous time stamps by which event building can be performed at a later stage.

4 Conclusions

For experiments with cooled antiproton beams in a storage ring on an internal target, a detector concept of the PANDA experiment was proposed, which becomes realized within the FAIR project at GSI/Darmstadt. It consists of a solenoid as target spectrometer, containing tracking detectors and Cherenkov detectors for particle identification for charged particles as well as an electomagnetic calorimeter. The forward angles are covered by a dipole magnet and similar detector subsystems.

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