34th International Conference on High Energy Physics, Philadelphia, 2008

The PANDA Detector at FAIR

S. Marcello (for the PANDA Collaboration)
Dipartimento di Fisica Sperimentale, Università di Torino and INFN, via P. Giuria 1, 10125, Torino, Italy

The PANDA detector is under design to be installed at the HESR storage ring for antiproton of the future FAIR facility in Darmstadt, Germany. Fundamental questions of hadron and nuclear physics interactions of antiprotons with nucleons and nuclei will be pursued using a multipurpose set-up which includes innovative detectors. Here, the FAIR facility and the PANDA detector are described.

1. PANDA EXPERIMENT AT FAIR

The PANDA spectrometer [1] is one of the large apparatuses at the future Facility for Antiproton and Ion Research (FAIR) in Europe. Gluonic excitations and the physics of strange and charm quarks will be accessible with unprecedented accuracy, allowing high-precision tests of strong interaction.

The FAIR facility (shown in Figure 1) is under construction at the GSI Laboratory in Germany. Science goals of the international FAIR project span a broad range of research fields, from atomic and plasma physics to the structure of the matter, from the quark-gluon structure of hadrons to physics of astronomical objects. The existing linear and SIS18 accelerators at GSI will be used as injector for the new system. The hearth of FAIR is a double ring accelerator SIS100/300 of 1 km diameter, which will provide primary beams of ^{238}U ions in a high charge state, at an energy up to 35 AGeV, and of protons up to 30 GeV. The beams will be sent to several branches to be used by different experiments. Secondary beams of radioactive ions of 2 AGeV energy and $\bar{p}$ up to a momentum of 15 GeV/c will be available. The $\bar{p}$ will be pre-cooled in a system of storage and cooler rings (RESR/CR) and then injected at 3.7 GeV/c in the High Energy Storage Ring (HESR), where the PANDA detector will be installed. Commissioning of $\bar{p}$ beam for PANDA is forseen in 2015. The HESR is a storage ring for $\bar{p}$ in the momentum range from 1.5 to 15 GeV/c. An important feature of HESR is the combination of phase-space cooled beams and internal target, which will allow experiments of unprecedented precision. Two different operation modes will be available at HESR: high resolution mode using the electron cooling, allowing to achieve a very high momentum resolution $\delta p/p \sim 10^{-5}$ at a moderate luminosity of $10^{31} cm^{-2} s^{-1}$, and high luminosity mode using the stochastic cooling, with greater momentum spread ($\delta p/p \sim 10^{-4}$), but at $\mathcal{L} = 2 \times 10^{32} cm^{-2} s^{-1}$.

2. THE PHYSICS PROGRAMME

At HESR the combination of a cooled beam and an internal target will allow to study charmonium spectroscopy with unprecedented precision. Indeed, the precision of the resonance mass and width measurements depends on the precision of the beam energy and beam energy width measurements, respectively. The determination of both these quantities is based on the measurement of the beam revolution frequency spectrum. In the PANDA experiment the detector is used to identify and reconstruct the final state and not to measure the parameters of the resonance. Thus the experimental detector resolution determines the sensitivity to a given final state. Since the $\bar{p}$ can be cooled very effectively an excellent resonance mass resolution of 30 keV can be achieved, which has to be compared with previous best values obtained in $\bar{p} - p$ annihilations (100 keV) or in $e^+ - e^-$ annihilations (10 MeV) .

Studies of hadron structure can be performed with different probes, each one with its specific advantages. The reason to use $\bar{p} - p$ annihilations instead of $e^+ - e^-$ ones is that all states can be directly formed and the mass resolution is very good. On the contrary, in $e^+ - e^-$ interactions only states with the quantum numbers of the photon, J^{PC}=1^{--}, can be formed, all other states being accessible by secondary decays with limited statistics, thus a moderate mass resolution can be achieved. Moreover, $\bar{p} - p$ gives access to Boer-Mulders function (with no polarised beam) and to transversity distribution.

Figure 1: Aerial view of the future FAIR facility with the HESR (yellow coulor) and the PANDA hall (orange coulor).

The PANDA Physics programme [1] concerns not only charmonium spectroscopy but spans many different topics, all of them addressed to answer to fundamental questions of hadron and nuclear physics. Search for gluonic excitations, such as glueballs and hybrids, will be pursued in the charmonium region. Properties of mesons with hidden and open charm in the nuclear medium will be studied to understand the origin of hadron masses. Moreover, the open charm physics will be studied, measuring the rich spectrum of D mesons and their dominant and rare decays. Since in PANDA the Ξ and $\bar{\Xi}$ hyperons will be copiously produced, it will be possible to generate double-Λ hypernuclei, which allow to study the Y-N and Y-Y interactions. Last, but not least, the study of nucleon structure will be investigated, by measuring Generalized Parton Distributions (Drell-Yan and Deeply Virtual Compton Scattering, "spin" structure functions by polarised $\bar{p}$ and proton time-like form factors up to 25 GeV c.m. energy (never reached before).

3. THE DETECTOR

Such an ambitious programme requires a high performance spectrometer. The main requirements can be summarised as follows:

- Capability to handle an interaction rate up to 20 MHz, especially for detectors closed to the target and in the forward direction;
- Full angular coverage for Partial Wave Analysis;
- Momentum resolution of 1%;
- High vertex resolution $< 100\mu$m to reconstruct secondary vertex of D meson;
- Good PID for charged particles in a large range of energies;
- Efficient γ detection in a large range of energies (10 MeV$\div$10 GeV);
- Efficient event selection.

The experimental set-up is shown in Figure 2. The apparatus is a combination of a target and a forward spectrometer (TS and FS in the following) of modular design, optimized for the specific kinematics of the $\bar{p} - p$ annihilation

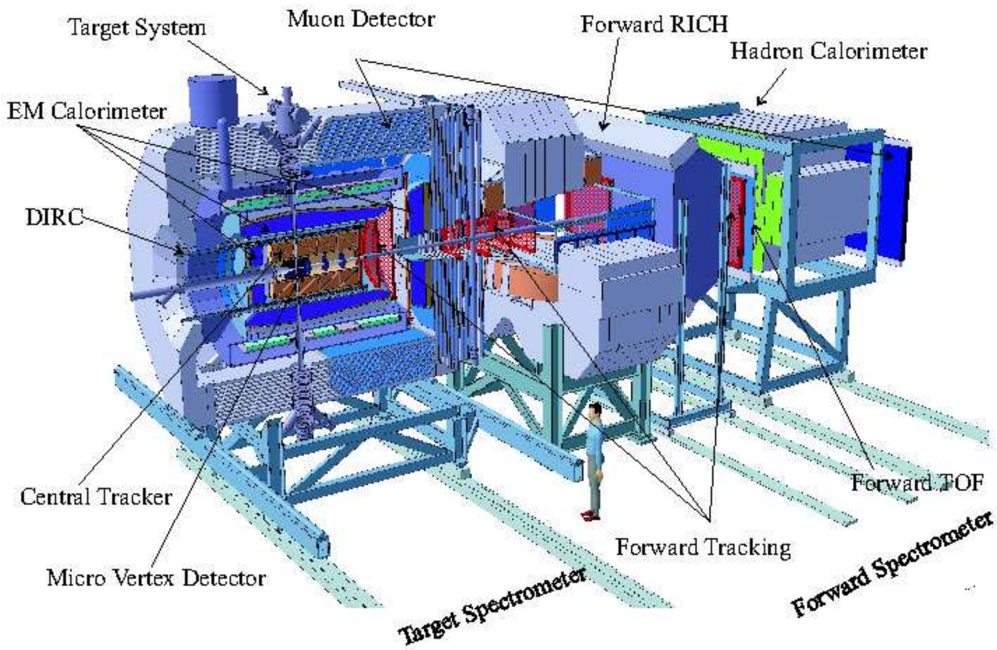

Figure 2: 3D CAD overview of the PANDA detector. Target Spectrometer and Forward Spectrometer with tracking detectors, EM and hadron calorimeters and Čerenkov detectors.

process with energy range 1.5÷15 GeV/c. The basic concept of the TS is a shell-like arrangement of various detector systems surrounding the interaction point of $\bar{p}$ in a fixed target inside a magnetic field of 2 T provided by a large solenoid. To overcome the gap in acceptance and resolution in the forward region of such a system a FS with a dipole magnet of large gap (1 m) will be used. It will cover angles below 5^o and 10^o in the vertical and horizontal directions, respectively.

Starting from the interaction point, we find a silicon microvertex detector, a main tracker system, a Time-of-Flight (TOF) barrel and a Barrel DIRC. To cover the forward angles a system of Drift Chambers (DC) will be added inside the TS and in the FS, as well. The same thing for DIRC, where an endcap will be used. The Muon detector will be embedded in the return yoke of the magnet, either to cover the azimuthal angle or to cover the forward angles. In the FS different systems of DC, TOF, RICH, μ detectors and hadron calorimeter will be used. For the electromagnetic shower detection an EM calorimeter will be available in the TS and a Shashlyk calorimeter will be used in the FS.

Concerning the Hydrogen internal target two different systems are under development, one based on Pellet and one on Cluster-Jet. Pellet target will guarantee to reach the maximum luminosity, since an averaged thickness of 10^{16} H/cm^2 can be achieved. On the contrary Cluster-Jet target will assure to have a stable luminosity, since the density can be easily changed by means of the pressure. Nuclear target, shaped in wires or foils will be also used for hypernuclear physics and for the study of charm in the nuclear medium.

Main feature of the silicon microvertex detector are the following: good vertex resolution, better than 100 μm, to reconstruct displaced secondary vertices from charmed and strange hadron decays; high granularity; low material budget and low power consumption. The structure of the detector consists of four barrel layers surrounding the interaction point and six disks in the forward region. The two innermost barrel layers are made out of custom hybrid active pixel sensors [2] of $100 \times 100\mu\text{m}^2$ size with an epitaxial sensor thickness less than 100μm. The four first disks in the forward direction, as well as an inner part of the two outer disks, are also made out of hybrid pixel modules to cope with the high particles flux. For the readout system of the inner part a custom pixel chip (TOPIX [3]), based on CMOS 130 nm technology is under study at Torino INFN, the layout with analog and digital parts fits 100% the pixel cell. In the second prototype currently developed the time-over-threshold has been implemented, in order to retain energy loss information. Sufficient buffering to operate without trigger is forseen. The sensor and the readout chip are bump-bonded together including the support structure and the cooling system. The detector will have a radiation length X_0 about 1%. The reduced occupancy in the outer layers of the microvertex detector allows to use double silicon microstrips, with a corresponding reduction in the number of readout channels and material. Both pitch size and thickness are 100 μm; such a system will use a standard readout chip developed in other experiments. The use of microstrip modules for the outer region allows to reduce total material budget of the microvertex detector to 4-6% X_0. The total number of channel will be about 10^7.

For the tracker system two different options are under investigation. One is based on Straw Tubes [4] of Mylar, 10 mm radius and 1.5 m long. The inner and outer layers in the axial direction and the intermediate layers are skewed of a small angle up to 3^o in order to measure the z coordinate. It is a very light detector with a momentum resolution of 1.5%. The second option is a TPC with a multi-GEM system for avalanche amplification (which allows to suppress the ion feedback). Due to the high rate pf $\bar{p}$ annihilations ($10^7/s$) the TPC has to operate continuously, therefore the gating technique cannot be applied. The TPC is an ideal device for tracking due to low material budget, a momentum resolution of 1% and a very good PID can be achieved, provided the problems of the space charge build-up and the continous sampling have been solved. Particles emitted at polar angles below 22^o will be tracked in the DC placed downstream the target.

A very good PID over a large range of energies is an essential requirement to fullfill the physics goals of PANDA. Therefore, different processes will be used to assure redundancy: $\check{C}$erenkov effect above 1 GeV/c, using different types of radiators; energy loss below 1 GeV/c; TOF below 1 GeV/c; energy loss at low energy by means of microvertex detector; electromagnetic showers detection by means of EM calorimeters.

In the TS the EM calorimeter [5] will cover almost the full solid angle and will have a good efficiency and energy resolution up to 10 GeV and down to 10 MeV. It consists of one barrel and two endcaps, made of lead tungstate PWO-II crystals of second generation, with enhanced light ouput. Large Area APD, which can be operated in presence of magnetic field, will be used for scintillating light read-out, allowing a fast timing at a level of about 1 ns. The PWO-II crystals will be operated at a temperature down to T = -20^{o}C in order to increase the light yield by a further factor 3. An energy resolution of 2% at 1 GeV can be achieved. A Shashlyk calorimeter will be installed in the FS beyond the dipole magnet, about 7 m from the interaction point. Here a worse resolution of 4% + const. at 1 GeV can be achieved at a moderate cost.

DAQ&Trigger have to manage a high rate up to 20 MHz. No hardware trigger will be implemented and a continuous sampling will be done. The detector Front Ends will be capable to make autonomous data preprocessing. The data reduced in the preprocessing step will be marked by a precise time stamp and buffered for further processing. The data will be sent to Powerful Compute Nodes, based on high density FPGA preocessors. A Configurable High Speed Network transports data through the levels. The last stage of network can be more traditional and it will be attached to the online reconstruction farm, where the event is fully reconstructed to perform the final selection before the mass storage. Due to the high interaction rate a large bandwidth up to 200 GB/s is needed.

References

[1] PANDA Collaboration, “Technical Progress Report for PANDA”, pp. 1-383, February 2005, http://www-panda.gsi.de/auto/_home.htm

[2] D. Calvo et al., ”Thinned epitaxial silicon hybrid pixel sensors for the PANDA experiment”, Nuc. Instr. & Meth. in Phys. Res. A594 (2008) 29-32.

[3] D. Calvo et al., ”Topix: the first prototype of pixel readout for PANDA experiment”, Proc. of RD07, Int. Conf. on Large Scale Applications and Radiation Hardness of Semiconductor Detectors, Florence, Italy, June 2007.

[4] A. Sokolov et al., ”The Central Tracker of the PANDA Detector”, Proc. of INSTR08, 10^{th} Int. Conf. on Instrumentation for Colliding Beam Physics, Novosibirsk, Russia, February 2008.

[5] P.A. Semenov et al., ”PANDA Electromagnetic Calorimeter”, Proc. of INSTR08, 10^{th} Int. Conf. on Instrumentation for Colliding Beam Physics, Novosibirsk, Russia, February 2008.