The $\overline{\text{P}}$ANDA Experiment at FAIR

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Abstract

At Darmstadt, in Germany, is under construction FAIR a new international Facility for Antiproton and Ion Research. This will provide scientists in the world with outstanding beams and experimental conditions for studying matter at the level of atoms, nuclei, and other sub-nuclear constituents. An antiproton beam with intensity up to 2×10^7 $\bar{p}$/s and high momentum resolution will be available at the High Energy Storage Ring (HESR) where the $\overline{\text{P}}$ANDA detector will be installed. $\overline{\text{P}}$ANDA will carry out a wide scientific program including meson spectroscopy from light to charm quark sector, baryon/antibaryon production, charm in nuclei, and strangeness physics with particular attention to the systems with strangeness S = -2. In this paper will be illustrated the details of the $\overline{\text{P}}$ANDA scientific program related to strangeness physics, after a brief introduction about the FAIR facility.

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1. The FAIR project

The Gesellschaft für Schwerionenforschung (GSI) [1] of Darmstadt, Germany, is undergoing a major upgrade of the existing laboratory [2]. This upgrade foresees ion beams of higher intensity and better quality, and, first for GSI, an antiproton beam.

Fig. 1 shows the layout of the present GSI laboratory (in blue, on the left side) and the plans for the new set of accelerators that will be constructed (in red, on the right side). The heart of this new facility is a double ring tunnel with a circumference of 1100 meters that will house 2 sincrotrons, SIS100 and SIS300.

The goal of the SIS100 is to achieve intense pulsed (5×10^{11} ions per pulse) U^{28+} beams at 1 GeV/u, and an intense (4×10^{13}) pulsed proton beam at 29 GeV. For the supply of the high-intensity proton beam, which is required for antiproton's production, a separate proton linac as injector of the SIS18 synchrotron will be constructed.

The SIS300 will provide high-energy ion beams of maximum energies around 45 GeV/u for Ne^{10+} beams, and close to 35 GeV/u for fully stripped U^{92+} beams. The maximum intensities will be close to 1×10^9 ions/s.

Adjacent to the double-synchrotron system, there will be a complex of storage-cooler rings and experimental stations, including a superconducting nuclear fragment separator (Super-FRS), and an antiproton production target, that will supply rare isotope beams, and antiproton beams with unprecedented intensity and quality.

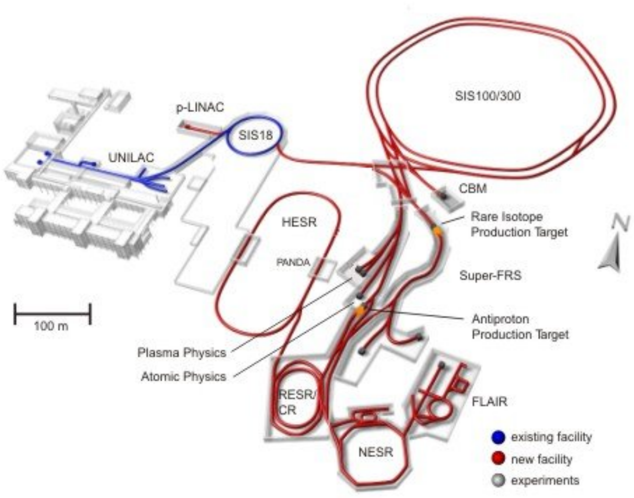

Figure 1: Layout of the existing GSI facility (UNILAC, SIS18) in blue on the left, and the planned FAIR facility in red on the right

At FAIR the antiprotons will be available for the experimental activity at the High Energy Storage Ring (HESR), a slow ramping synchrotron and storage ring equipped with stochastic and electron cooling to provide excellent beam energy definition. Here the beam energy could be varied from 3 GeV up to a maximum of 14.5 GeV. A single interaction region will be present, equipped with an internal target surrounded by a large in-ring detector: $\overline{\text{P}}$ANDA (AntiProton ANnihilations at DArmstadt). An option for experiments with polarized antiprotons is also foreseen [3].

The HESR will have two different operation modes: the high intensity mode, where with a beam momentum spread $\delta p/p = 10^{-4}$ a luminosity of 2×10^{32} cm^{-2}s^{-1} will be available, and the high resolution mode, where the luminosity requirement will be released to 10^{31} cm^{-2}s^{-1} to have a maximum momentum precision of 10^{-5}. This will allow to measure masses and widths of hadronic states with an accuracy down to 50-100 keV never obtained up to now; as a comparison, existing and/or planned e^+e^- colliders can get values from 10 to 100 times worser.

2. The $\overline{\text{P}}$ANDA scientific program

Strong interaction is under study since long time, nevertheless our understanding is still far from completion. The $\overline{\text{P}}$ANDA experiment aims at exploring hadronic matter by means of the gluon rich environment of $\bar{p}p$ annihilation which allows to access a wide range of final states. The 4π acceptance of the detector either for charged and neutral particles, together with the envisaged high quality of the antiproton beam, will create an ideal environment to collect high statistics data to address many open problems related with the strong interaction.

$\overline{\text{P}}$ANDA will perform a complete program of hadron spectroscopy to test many unclear aspects of Quantum Chromo Dynamics (QCD). The aim is to investigate both the dynamics of the interaction, and the characteristics of new forms of matter such as exotic states in the charm energy range, and nuclei with an explicit strange quark content. Furthermore, particle properties, when produced inside the nuclear medium, and the structure of hadrons, will be investigated. In the following section I will focus on the program that $\overline{\text{P}}$ANDA foresees for studying different S = -2 systems (Double Strange Systems, DDS) which is more related with the subjects of this conference. These are Ξ^--atoms, Ξ^--hypernuclei and double-Λ hypernuclei. A complete description of all the aspects of the $\overline{\text{P}}$ANDA scientific program can be found here [4].

3. Double Strange Systems with $\overline{\text{P}}$ANDA

QCD is nowadays the widely accepted theory of the strong force. At small distances ($<<$ 0.1 fm) perturbative methods provide a precise quantitative description of the phenomena, but at larger scales, comparable to the size of hadrons ($\approx$ 1 fm), the magnitude of the coupling constant increases to the point that a perturbative approach no longer applies. As a consequence, a detailed description of baryon-baryon interaction based on basic principles is not yet feseable, and only an approach based on phenomenological models is attempted. Here the short-range part of the interaction is relevantly described by the quark-gluon degrees of freedom, while the medium- and long-range parts are dominated by meson-exchange processes. In order to construct a complete model of baryon-baryon interaction accurate data are needed to tune the potential parameters: concerning NN scattering, a lot of good quality data exist, for YN interaction, few scattering data are available, whereas for the multi-strange systems YY no scattering data can be experimentally provided. Therefore, other inputs are required. One possibility is offered by the hypernuclear physics: Λ-hypernuclei provide an insight to the YN interaction, while DDSs give access to the $\Lambda\Lambda$ and ΞN interactions.

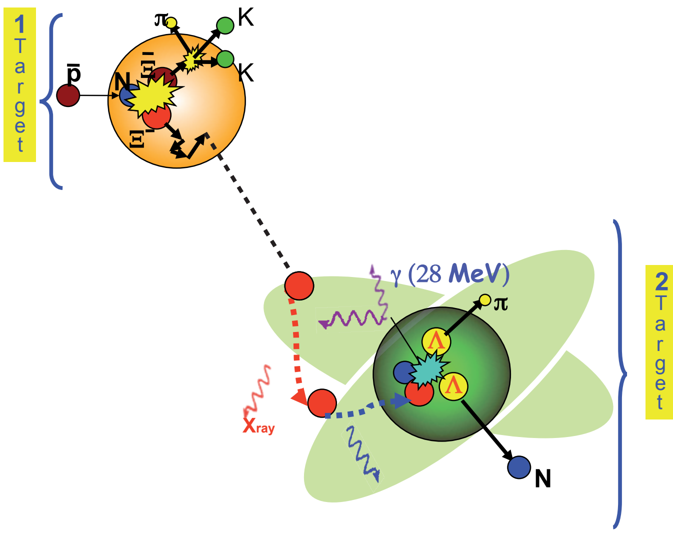

Figure 2: Cartoon of the two steps reaction leading to DDS production in $\overline{\text{P}}$ANDA (see text for more details).

The techniques used up to now to produce both Ξ and $\Lambda\Lambda$-hypernuclei were based on the double strangeness exchange using intense kaon beams. Some results of these works have been also reported at this conference. $\overline{\text{P}}$ANDA will produce data on ${}^{A}_{\Xi^-}Z$ and ${}^{A}_{\Lambda\Lambda}Z$ states by using a new two steps reaction [6] that is schematically illustrated in fig. 2.

Antiprotons of 3 GeV/c momentum impinging on a thin primary nuclear target, placed inside the beam pipe, could produce $\Xi\overline{\Xi}$ pairs with a cross-section of about 2 μb [5, 7, 8].

$$\bar{p} + N \rightarrow \Xi^- \overline{\Xi} \tag{1}$$

The $\overline{\Xi}$ annihilation into kaons will be used to trigger on this reaction, while Ξ^- will be slowed down and then stopped in a secondary target surrounding the beam pipe. Here they can be captured and form a Ξ^- atomic systems that will undergo an electromagnetic cascade until strong interaction with the nucleus can occur. At this point a Ξ-hypernucleus can be formed and the Ξ^- can interact with a proton producing two Λ particles that eventually can be stuck to the nucleus resulting in a double Λ-hypernucleus. The efficiency of this chain of processes has been evaluated by means of Montecarlo simulations [9]. A crucial parameter is the the ratio of stopped Ξ^-. In order to efficiently slow down Ξ^- high Z secondary targets are more effective, but these materials produce also higher beam losses. Therefore, ^{12}C seems to be the best choice for the primary target. In our simulation, with a primary target made of carbon, we get a rate of about $2{\times}10^4$ stopped Ξ^- per day [10].

Another piece of information about hyperon-hyperon dynamics can be obtained with the study of the non-mesonic weak decay of the double-Λ hypernuclei. In these systems two new reactions are possible

$$\Lambda + \Lambda \rightarrow \Lambda + N; \Lambda + \Lambda \rightarrow \Sigma + N \tag{2}$$

where one of the hyperons induces the decay of the second. More details on this topic can be found here [11], and have been also given at this conference [12].

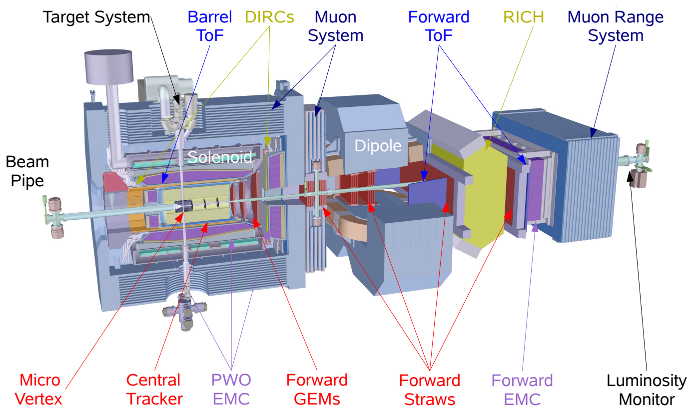

Figure 3: Layout of the the $\overline{\text{P}}$ANDA detector consisting of a Target Spectrometer, surrounding the interaction region, and a Forward Spectrometer to detect particles emitted at forward angles. The HESR antiproton beam enters the apparatus from the left side. The main detector components are also indicated.

4. The $\overline{\text{P}}$ANDA spectrometer

The main objectives in the design of the $\overline{\text{P}}$ANDA detector are to achieve 4π acceptance, high resolution for tracking, particle identification and calorimetry, high rate capabilities and a versatile readout and event's selection. To obtain a good momentum resolution the detector will be composed of two magnetic spectrometers: the Target Spectromer (TS), based on a superconducting solenoid magnet surrounding the interaction point, which will be used to measure high p_T tracks, and the Forward Spectrometer (FS), based on a dipole magnet, for detecting particles emitted at forward angles. Fig. 3 shows the layout of the apparatus that presently is under design.

For the strangeness physics program described above, a dedicated layout of the $\overline{\text{P}}$ANDA spectrometer, including only a subset of systems, will be adopted. The removal of the backward end-cap calorimeter, and of the silicon micro-vertex detector will allow to add a dedicated nuclear target station, and additional detectors for γ spectroscopy (see fig. 4).

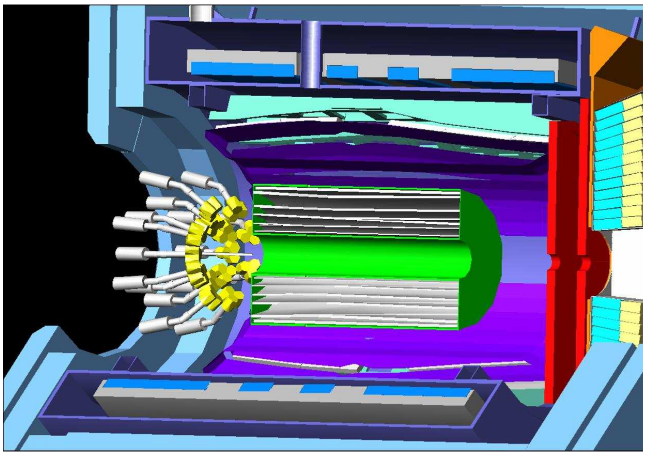

Figure 4: The $\overline{\text{P}}$ANDA target spectrometer arranged for the hypernuclear physics program.

The detection of antihyperons and of low momentum K^+, that is important to trigger on Ξ production reaction, will be performed by the central tracking and PID systems.

The geometry of the secondary nuclear target is essentially determined by the short lifetime of the Ξ^- (164 ps) and by its stopping time in solid materials. The best solution would be to have an active secondary target of about 25-30 mm thickness consisting of 20 layers of silicon strips detector interposed with layers of absorber material. The active layers will also provide tracking information on the hyperon's decay products.

For the γ spectroscopy of the nuclear decay cascades, we plan to use an existing germanium-array refurbishing the readout system. The germanium crystals will be grouped asymmetrically to form triple clusters. Each cluster will consist of 3 encapsulated n-type germanium crystals of the Euroball type. The total setup will consist of 15 triple Ge clusters positioned at backward axial angle around the target region.

5. conclusion

The detailed study of nuclei with an explicit strangeness content S = -2 has just started. Any sound evaluation of the properties of these systems up to now was not feseable because the data

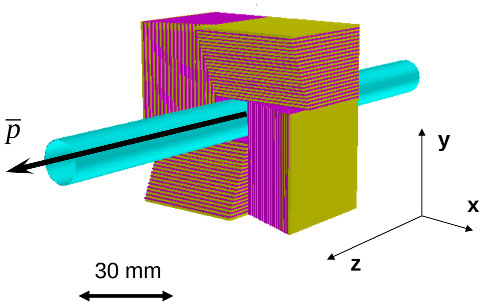

Figure 5: Arrangement of the secondary hypernuclear target. Active silicon layers are alternated with absorber strips.

available are too scarce. This is due to the difficulty of producing large amount of Ξ hyperons at the existing machines.

The new JPARC and FAIR facilities will supply new intense beams allowing to produce new data with higher statistics. The $\overline{\rm P}$ANDA experiment at FAIR will use for the first time antiprotons instead of the traditionaly used kaons. A carefull design of the targets, combined with the features of the machine, will allow to get more than 2×10^4 stopped Ξ^- per day. This rate largely overcome the whole statistics available today allowing to measure the main parameters related to the S = -2 nuclear systems.

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