QUESTS FOR $\overline{\text{P}}$ANDA EXPERIMENT

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Abstract

The physics program of the $\overline{P}$ANDA experiment at FAIR, studying antiproton interaction with protons and nuclei at intermediate energies, is briefly outlined. Some selected points of the program are discussed in more details.

1. The FAIR complex (Facility for Antiproton and Ion Research)

The PANDA Experiment will be one of the key experiments at the Facility for Antiproton and Ion Research (FAIR) which is under construction and currently being built on the area of the GSI Helmholtz-zentrum fur Schwerionenforschung in Darmstadt, Germany. This new generation facility will provide excellent instrumental basis for research in fundamental as well as applied physics. The present general scheme of the FAIR is shown in Fig. 1.

The central part of FAIR is a synchrotron complex providing intense pulsed ion beams (from p to U). Antiprotons produced by a primary proton beam will then be filled into the High Energy Storage Ring (HESR) and will collide with the fixed target inside the PANDA Detector (Fig. 2) described in the dedicated talk [3]. Start of operating of the SIS100 accelerator and the HESR ring is planned for 2017 year.

Table 1: Planned beam parameters from the SIS100/300 complex

Program	Max. kinetic energy	Intensity per spill	Average intensity
Beams of radio-active ions	0.4 ÷ 1.5 GeV/u all elements up to U	$\mathbf{5 \cdot 10^{11}}$ for expts at storage ring	$\mathbf{3 \cdot 10^{11}}$/sec big duty cycle at fixed targs
Antiprotons	**14 GeV**	$\mathbf{5 \cdot 10^{10}}$	…
Dense nuclear matter	Up to 34 GeV/u Uranium **(with SIS-300)**	…	$\mathbf{2 \cdot 10^{9}}$/sec big duty cycle
Plasma physics	Ions 0.4 – 1 GeV/u	$\mathbf{1 \cdot 10^{12}}$	…
Atomic physics	Ions 1 – 10 GeV/u	…	$\mathbf{10^{9}}$/sec big duty cycle

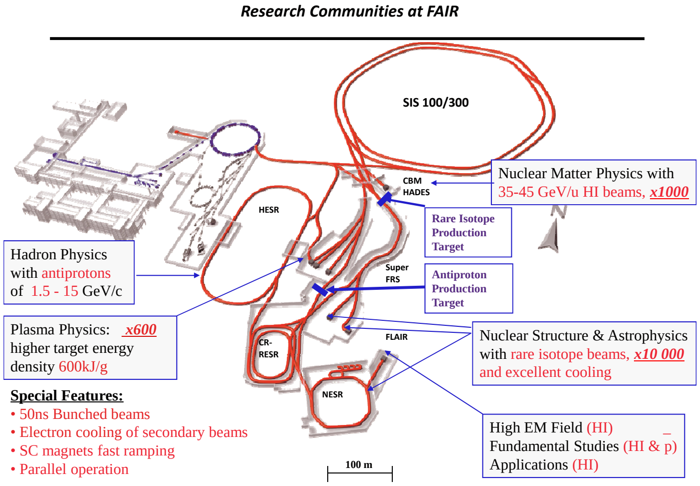
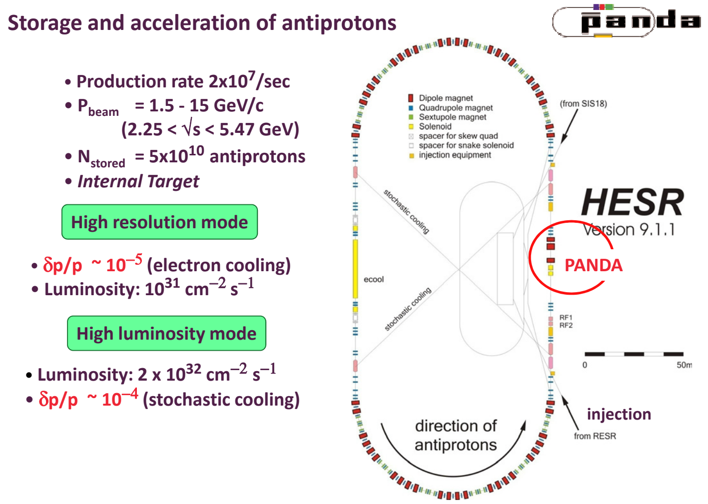


Fig. 1: The FAIR complex [1]. Existing GSI accelerators are shown at left in gray. Future elements (in colour) include the SIS100/300 heavy-ion synchrotron, the HESR ring, the CR and NESR rings, the superconductive separator Sup-FRS and the storage ring for nuclear fragments (NESR) as well as the main detectors PANDA and CBM. The UNILAC/SIS18 will serve as injector for SIS100/300



Storage and acceleration of antiprotons

- Production rate $2\text{x}10^7$/sec
- P_{beam} = 1.5 - 15 GeV/c
  ($2.25 < \sqrt{s} < 5.47$ GeV)
- N_{stored} = $5\text{x}10^{10}$ antiprotons
- *Internal Target*

High resolution mode

- $\delta p/p \sim 10^{-5}$ (electron cooling)
- Luminosity: 10^{31} cm^{-2} s^{-1}

High luminosity mode

- Luminosity: $2 \text{ x } 10^{32}$ cm^{-2} s^{-1}
- $\delta p/p \sim 10^{-4}$ (stochastic cooling)

Fig. 2: Scheme of the HESR ring [2]. HESR will have systems of stochastic cooling of $\bar{p}$ up to $T_{kin} \approx 14$ GeV and e^- cooling for $T_{kin} \leq 9$ GeV

2. $\overline{\text{P}}$ANDA for Physics of Strong Interactions

The $\overline{\text{P}}$ANDA Collaboration with more than 450 scientist from 17 countries intends to do basic research on various topics around the weak and strong forces, exotic states of matter and the structure of hadrons. The present $\overline{\text{P}}$ANDA physics program is presented in the “PANDA Physics Book” [4].

This program includes several directions, namely: **(1)** study of QCD bound states (i.e. charmonium spectroscopy, D-meson spectroscopy, gluonic excitations (hybrids, glueballs), (multi)strange and charmed baryons as shown in Fig. 3) what has fundamental importance for quantitative understanding of QCD; **(2)** non-perturbative QCD dynamics; **(3)** hadrons in the (finite) nuclear medium and, in particular, charmonia absorption in the nuclear matter and estimation of the charmonium-nucleon interaction; **(4)** physics of hypernuclei (including formation of hypernuclei containing two hyperons); **(5)** study of nucleon structure by detecting electromagnetic final states like e^+e^- or $\mu^+\mu^-$ (what probes the electromagnetic form-

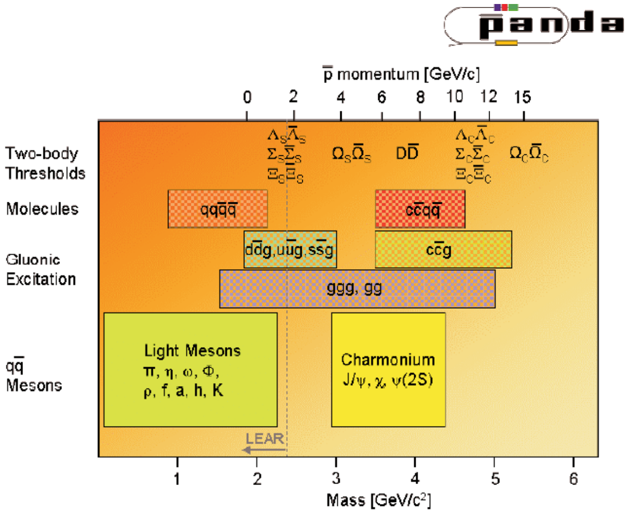


Fig. 3: QCD systems to be studied at $\overline{\text{P}}$ANDA

factors in the time-like region) or the MMT-DY pairs (what gives an access to the structure functions) as well as probing of the "generalized distribution amplitudes" by detecting hard exclusive meson production (for example, the $\bar{p}+p \to \gamma\pi^0$ channel); **(6)** some aspects of the electroweak physics, including CP-violation processes.

There is a possibility to investigate productions of some of the listed QCD objects on short-range NN correlations in nuclei either in subthreshold region or in the region forbidden for $\bar{p}$ interaction with free nucleon.

2.1. Charmonium

Open problems and questions concerning charmonium were discussed at this Conference by I.Denisenko in his talk about results from BES-III [5]; see also [6]. Therefore only two most important features of charmonium study with the $\overline{\text{P}}$ANDA detector are outlined here.

First, in the $\bar{p}p$ annihilation all mesons, with any J^{PC} quantum numbers can be formed, while in the e^+e^- annihilation only $J^{\mathrm{PC}} = 1^{--}$ mesons can be produced from the virtual photon.

Second, the extraordinary beam monochromaticity (in the high resolution mode of the HESR) allows to perform scanning of the resonance line by the fine changing of the beam energy.

Indeed, let the cross section for the formation of a resonance with spin J in the process $\bar{p}p \to \bar{c}c \to$ (final state) is given by the well known Breit-Wigner formula:

$$\sigma_{\mathrm{BW}} = \frac{2J+1}{4} \cdot \frac{\pi}{k^2} \cdot \frac{Br_{\mathrm{in}} Br_{\mathrm{out}} \Gamma_{\mathrm{R}}^2}{\left(E_{\mathrm{cm}} - M_{\mathrm{R}}\right)^2 + \Gamma_{\mathrm{R}}^2/4} \,, \tag{1}$$

where M_{R} is the resonance mass, Γ_{R} is its total width, Br_{in} and Br_{out} are the branching ratios into the initial and final states and E_{cm} is the center-of-mass energy.

The number of detected final state events (N_{event}) is a convolution of the cross section (2) and the beam energy spread function $f(E_{\mathrm{cm}}, \delta E_{\mathrm{cm}})$:

$$N_{\mathrm{event}} = \mathcal{L}_0 \left\{ \varepsilon \int dE_{\mathrm{cm}} \cdot f(E_{\mathrm{cm}}, \delta E_{\mathrm{cm}}) \cdot \sigma_{\mathrm{BW}}(E_{\mathrm{cm}}) + \sigma_{\mathrm{bckg}} \right\} \,, \tag{2}$$

where σ_{bckg} corresponds to background processes. It is obvious that parameters M_{R}, Γ_{R} and the product $Br_{\mathrm{in}} Br_{\mathrm{out}}$ can be extracted by measuring the formation rate N_{event} for that resonance as a function of the c.m. energy E_{cm} provided the beam energy spread is much less than the Γ_{R}. The fine scans of resonance lines allow to measure their masses with accuracy up to $\approx$ 100 KeV and widths up to $\approx$ 10 % because the beam monochromaticity $\Delta p/p \sim 10^{-5}$ corresponds to the mass uncertainty $\Delta M \sim 20$ KeV [7].

2.2. Non-perturbative QCD dynamics

Several physics problems are considered in the "PANDA Physics Book" [4] within this direction, in particlular the binary annihilation channel $\bar{p}p \to \bar{Y}Y$ into hyperon pairs. Some spin observables can be measured for this channel, including those for the $\bar{\Xi}\,\Xi$ case.

To the same direction belongs the old puzzle discovered at LEAR: strong violation of the OZI [8] rule in some channels of the $\bar{p}p$ annihilation at rest [9, 10]. The strongest effect was observed in annihilation channels $\bar{p}p \to \phi\gamma$ and in the Pontecorvo reaction $\bar{p}d \to \phi n$

where the 4-momentum transfer to the meson squared is the biggest (in absolute value): the ratio of yields $R(\phi n/\omega n) = (156 \pm 29) \times 10^{-3}$. Similar observation exists for other Pontecorvo reactions with deuterons, namely $\bar{p}\,d \to K^+\Sigma^-$ and $\bar{p}\,d \to K^0\Lambda$, where the yield ratio $R(K^+\Sigma^-/K^0\Lambda) = 0.92 \pm 0.15$ while OZI-rule predicts for this ratio ≈ 0.012. Another example concerns the $\bar{p}\,p \to \phi\phi$ channel: the measured cross section $\sigma(\phi\phi)_{\rm exp} \sim 4\ \mu$b while according the OZI rule it must be $\sigma\,(\phi\phi) = \sigma\,(\omega\omega)\tan^4(\theta - \theta_i) \approx 10\,\mathrm{nb}$ (here θ, θ_i are the mixing angles). It is worthwhile to note that the $\sigma\,(\omega\omega)$ cross section was not measured yet and a theoretical estimate is used here.

To explain the observations, it was suggested the model of polarized strangeness sea in nucleons and some observable consequences were predicted [11]. But present data about the contribution to the nucleon spin from the strangeness sea show that, being negative, this contribution is rather small [12]: $(\Delta s + \Delta\bar{s})_{Q^2\to\infty} = (\hat{a}_0 - a_8)/3 = -0.08 \pm 0.01\,(\mathrm{stat.}) \pm 0.02\,(\mathrm{syst.})$.

$\overline{\mathrm{P}}$ANDA experiment can provide data to solve the puzzle by looking at $\bar{p}\,p \to (\phi\phi)\,, (\omega\omega)\,, (K^*K^*)\,, (\rho\rho)\ldots$ binary channels. In particlular, yield estimates for $\bar{p}\,p \to (\phi\phi)$ show that the best world statistics can be obtained within 1.5 hours of measurements (the expected rate is ~ 2 events/sec in high luminosity mode of the HESR) [13].

2.3. Hadrons in medium

The idea of modification of particle properties in nuclear medium is quite old. There are many well known examples for this (for example, neutron is stable in meduim while it is unstable in free space, the lifetime of hypernuclei differs from that of the free Λ etc).

Studies of Δ-excitations in nuclei and pion propagation in nuclear matter (as well as search for effects of poin condensate in nuclei) performed in 80's had shown existence of collective phenomena when pion propagates in nuclear medium [14] and stimulated ideas about possibility of partial restoration of the SU(4) symmetry in nuclear medium. One of important observations is that theoretical predictions made for infinite nuclear matter must be modified in application to the finite nuclear medium.

Annihilation of $\bar{p}$ in nuclei provides a way to study possible modification of $D\bar{D}$ spectra in nuclear medium. The reason for this is

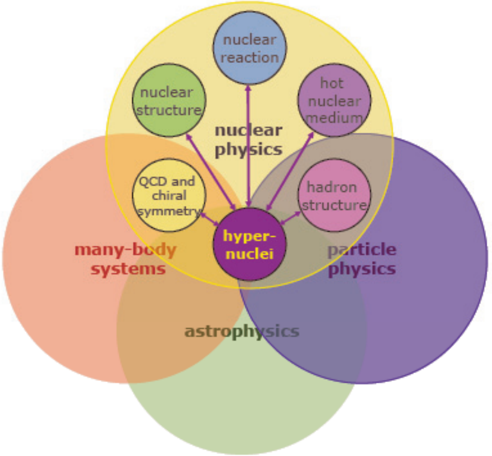


Fig. 4: Hypernuclear physics relations with other branches of physics

based on idea of partial restoration of chiral symmetry in nuclear medium as well as on present theoretical ideas that spectra of systems built from light quarks are sensitive to quark condensate (which may differ in nuclear matter from that in empty space) while spectra of $(\bar{c}\,c)$ systems are sensitive to gluon condensate [4], [15]. The "in-medium" mass can be reconstructed from di-leptons (in the $\bar{c}\,c$ case) or hadronic decays of the D-mesons.

In addition, the $\bar{p}A$ annihilation will be used as a tool for extracting experimental information about J/ψ-nucleon interaction.

2.4. Hypernuclei

Hypernuclei, i.e. systems where at least one nucleon is replaced by a hyperon (Y), allow access to a whole set of nuclear states with extra degree of freedom: the strangeness. There is a variety of consequences for different branches of physics (Fig. 4).

For example, as concerns nuclear physics: **(1)** probing of nuclear structure and its possible modifications due to the presence of a hyperon; **(2)** tests and experimental estimations of shell model parameters; **(3)** description of nuclear matter in terms of quantum field theories and effective field theories (EFT). For particle physics the immediate output is for: **(1)** study of the YN and YY forces; **(2)** unified description of the baryon-baryon interaction in terms of potentials; **(3)** study of weak decays when $\Lambda \to \pi N$ is suppressed, but $\Lambda N \to NN$ and $\Lambda\Lambda \to NN$ are allowed (this gives access to study weak interaction between four baryons); **(4)** production of double hypernuclei with two Λ-hyperons; **(5)** production of hyperatoms (or multi-strange atoms); **(6)** use of hypernuclei as doorway to exotic quark states (like H-dibaryon).

3. Summary

The $\overline{\mathrm{P}}$ANDA experiment will use the antiproton beam from the HESR colliding with an internal proton (for a number of topics – nuclear) target and a general purpose spectrometer to carry out a rich and diversified hadron physics program.

The experiment is being designed to fully exploit the extraordinary physics potential arising from the availability of high-intensity, cooled antiproton beams. The aim of the rich experimental program is to improve our knowledge of the strong interaction and of hadron structure [4].

Significant progress beyond the present understanding of the field is expected due to drastic improvements in statistics and precision of the future data.

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