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Internal targets for the PANDA experiment

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The requirements for the internal target of the PANDA experiment at the future antiproton storage ring HESR/FAIR are manifold and change according to the different physics investigated in the proposed experiments. The most severe limitation comes from the requirement of being a very thin (dilute) and localized clump of matter within the ultra-high vacuum of the storage ring. In case of a gaseous target material the use of even the thinnest windows is prohibited. A solution for that can be realized by a jet of nano- to microsized condensed matter particles (clusters, droplets or pellets) traversing the stored antiproton beam. Therefore, to exploit the capacities of the PANDA experiment to a maximum it is foreseen to provide both a cluster-jet as well as a pellet target which will be installed alternatively depending on the experimental program to be investigated. In this presentation both targets for PANDA will be presented and discussed.

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[1] Speaker

1. Introduction

One of the key experiments at the future accelerator complex FAIR at Darmstadt in Germany will be the fixed target experiment PANDA, where e.g. investigations on charmonium spectroscopy, exotic hadrons or open and hidden charm in nuclei will be performed. The main objectives of the design of the PANDA experiment are to achieve 4π acceptance, high resolution for tracking, particle identification, and calorimetry, high rate capabilities, and a versatile readout and event selection. To obtain a good momentum resolution the detector will be composed of two magnetic spectrometers: the Target Spectrometer (TS), based on a superconducting solenoid magnet surrounding the interaction point, which will be used to measure at large angles, and the Forward Spectrometer (FS), based on a dipole magnet, for small angle tracks [1].

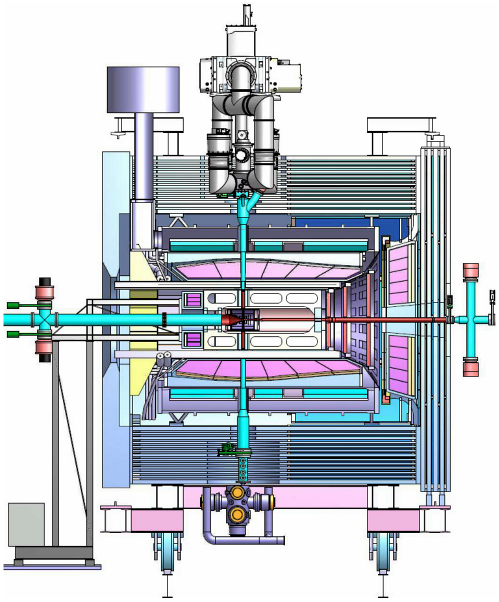

Figure 1: Integration of the target (here: cluster target) at the PANDA experiment.

In Fig. 1 the planned integration of the target station (here: cluster target) in PANDA is presented. The target source will be installed in the magnet yoke and the target beam will be shot from the top to the bottom where it is pumped away by a beam dump. The compact design of the detector layers nested inside the solenoidal magnetic field, combined with the request of minimal distance from the interaction point to the vertex tracker, leaves only a very restricted space for the target installation. In order to reach the maximum design luminosity of approximately 2×10^{32} $cm^{-2}s^{-1}$ a target thickness of about 4×10^{15} hydrogen atoms per cm^2 is required assuming 10^{11} stored anti-protons in the HESR ring. These conditions pose a real challenge for an internal target inside a storage ring. For PANDA two complementary techniques for the internal target are foreseen: the cluster-jet target and the pellet target. Both techniques are capable of providing sufficient densities for hydrogen at the interaction point, but exhibit different properties concerning their effect on the beam quality and the definition of the interaction point. In addition, internal targets also of heavier gases, like deuterium, nitrogen or argon can be made available. However, despite providing a sufficiently large absolute target thickness as well as the ability to allow for both hydrogen and heavier nuclei as target material, the final PANDA internal target(s) have to fulfil further requirements. For the investigation of the fundamental nucleon-antinucleon interactions in a clean environment a pure target material has to be selected. Any pollution of the target with other materials would result in disturbing background reactions which have to be understood in the later data analysis. To avoid problems caused by such background mono-elemental targets are mandatory. Residual gas background in the PANDA vacuum system has to be reduced as good as technically achievable in order to avoid antiproton losses elsewhere in the ring. Additionally, such residual gas would cause physics background from reactions with undefined vertex. Depending on the experimental conditions an adjustment of the luminosity will be necessary. Furthermore, due to the consumption of antiprotons during an accelerator cycle a corresponding increase of the target density will be advantageous in order to obtain constant event rates and thus a constant luminosity during a cycle. The use of a cooled antiproton beam at PANDA can lead to an accelerator beam diameter of $Ø_{\mathrm{beam}} \leq 100\ \mu\mathrm{m}$. In this case the target beam at the interaction region should be as homogeneous as possible. Under ideal conditions a target exposes no time structure on a microscopic time scale in order to avoid inefficiencies of both the data acquisition system and the detector components. The investigation of short-lived particles and their decay products might require the reconstruction of the interaction vertex point with a precision well below 1 mm. For this purpose the knowledge of the beam-target interaction point on a level of the experimental resolution will be required. It is obvious that neither target system can fulfil all those wishes simultaneously. However, both a cluster-jet target as well as a pellet target meet a large fraction of the listed requirements and mutually complement each other. Therefore, to exploit the capacities of the PANDA experiment to a maximum it is foreseen to provide both a cluster-jet as well as a pellet source which will be installed alternatively depending on the experimental program to be investigated.

2. The Cluster Target for PANDA

Cluster-jet beams for internal storage ring experiments are commonly produced by expansion of pre-cooled gases in convergent-divergent Laval-type nozzles with a micron-sized throat into vacuum. During the passage of the gas through such a nozzle the gas cools down according to adiabatic cooling supported by the Joule-Thomson effect of real gases and forms a supersonic beam (Fig. 2). Under appropriate conditions, depending on the type of gas, condensation can take place and nanoparticles are created, the so-called clusters. The size of such clusters is strongly influenced by the experimental conditions such as the pressure and the temperature of the gas before entering the nozzle. Furthermore, the throat diameter and the shape of the supersonic part of the nozzle influence both the size of these particles and the total cluster yield. In Fig. 2 (right) photography of such a cluster beam directly behind the nozzle, which is illuminated by a laser beam, is shown [2, 3]. The skimmer, visible on the right hand side, accepts a certain part of the cluster beam for the experiment. The remaining part of the beam, not accepted by the orifice, is pumped away in this vacuum stage.

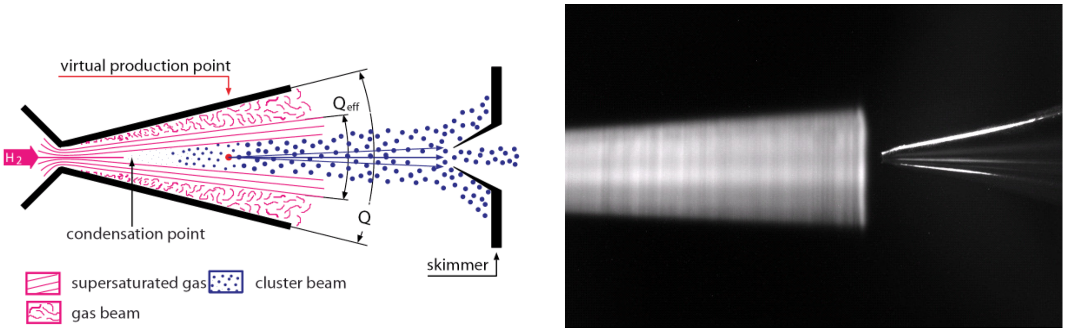

Figure 2: Formation of cluster beams by expansion in a Laval-type nozzle.

Figure 3 shows a sketch of the prototype cluster-jet source for the PANDA experiment [4]. The (warm) gas can be cooled down to T ~ 10 K by a two-stage cryogenic coldhead and passes a Laval-type nozzle. The resulting cluster-jet beam, surrounded by a conventional supersonic gas-jet, is shot onto a skimmer to subtract the gas beam. For the final cluster-jet beam preparation a second skimmer, the collimator, is used in the collimator vacuum stage. From here on the cluster-jet beam passes the complete target beam pipes with a constant opening angle, defined by the geometry of the nozzle/skimmer/collimator arrangement.

To avoid losses of cooling power due to insufficient vacuum conditions the complete coldhead device including the gas pipes are located in a vacuum chamber separated from the nozzle chamber. Close to the nozzle an electric heating is mounted to allow for a temperature adjustment. Both the skimmer as well as the collimator are mounted on movable tables which

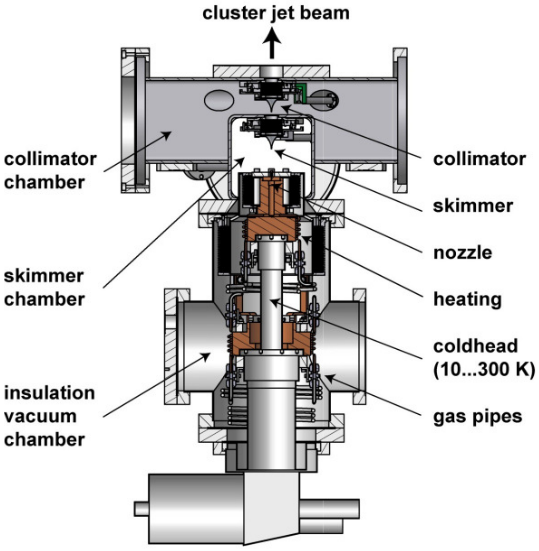

Figure 3: Sketch of the prototype cluster-jet source for the PANDA experiment.

can be moved with a micrometer precision. By this the position of the cluster-jet beam can be adjusted online during operation.

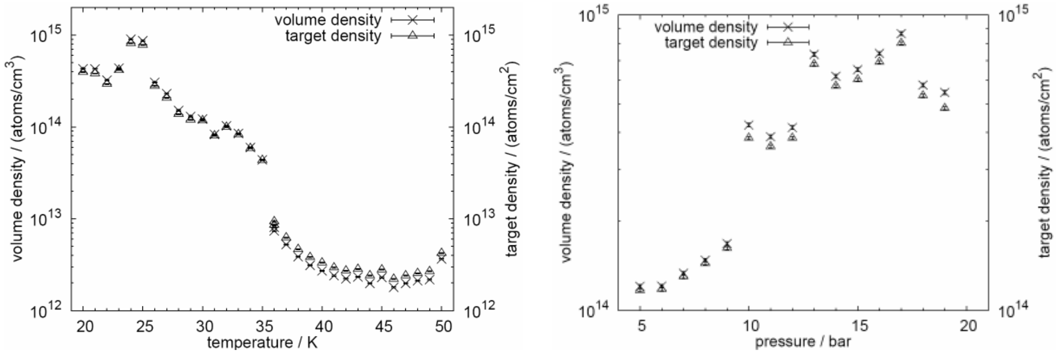

Figure 4: Volume and areal density of the cluster-jet beam at the interaction point in the scattering chamber as function of the gas input temperature and pressure [2].

One of the advantages of a cluster-jet target is the homogeneous volume density distribution which results in an absence of time structures in a storage ring experiment. This aspect is of high importance since any significant microscopic time structure in the target density would lead to a corresponding effect in luminosity. Furthermore, the absolute areal target density can be adjusted easily during operation, which allows operating the target at densities which are optimized to phase space cooling devices for the accelerator beam. Additionally, the possibility to adjust the target density within seconds/minutes allows increasing the density during the accelerator cycles in order to compensate antiproton beam losses and to provide constant event rates. The possibility to vary the target density is demonstrated in Fig. 4 showing both the volume and areal target beam density at the interaction point in the scattering chamber as function of the gas input temperature and pressure. Obviously the absolute target density and thus the luminosity can be adjusted continuously over several orders of magnitude by changing these parameters. Here the effect on the temperature is much enhanced while a variation of the gas input pressure allows for finer density changes. A similar effect can be achieved by changing the gas input pressure. It is important to note that these density variations can be performed during target operation. Typical cluster target parameters which are expected for the later PANDA operation are given in Tab. 1.

3. The Pellet Target for PANDA

Based on the experimental achievements at Uppsala [5-8], Jülich and Moscow [9] a pellet target has been set up at the FZ Jülich, which serves as prototype target for the PANDA experiment. In Fig. 5 a sketch of the central part of the pellet generator is presented [4]. The pivotal part of a pellet target is the triple-point chamber (TrPC). In that chamber a jet of a cryogenic liquid is injected through a thin nozzle (with hole diameter roughly equal to the pellet diameter) into a gas of the same element (or a mixture with helium) close to triple-point conditions. Periodic excitation of the nozzle by a piezoelectric transducer imposes jet oscillations along its surface. The axially symmetric jet then disintegrates into drops downstream the nozzle when the perturbation amplitude becomes equal to the jet radius.

From the TrPC, which makes sure that under optimal conditions an extremely regular drop flow can be produced without disturbances from evaporation, the drops pass through a thin tube, the vacuum injection capillary (VIC), into a vacuum chamber. During that traversal they cool by a few Kelvin due to surface evaporation, below the melting point, and a regular flux of frozen pellets is produced. The properties of the produced pellets, such as diameter or frequency in the scattering chamber, depend on the used nozzle diameter as well as on the operational parameters. Pellet parameters, which are foreseen at PANDA, are listed in Tab. 1.

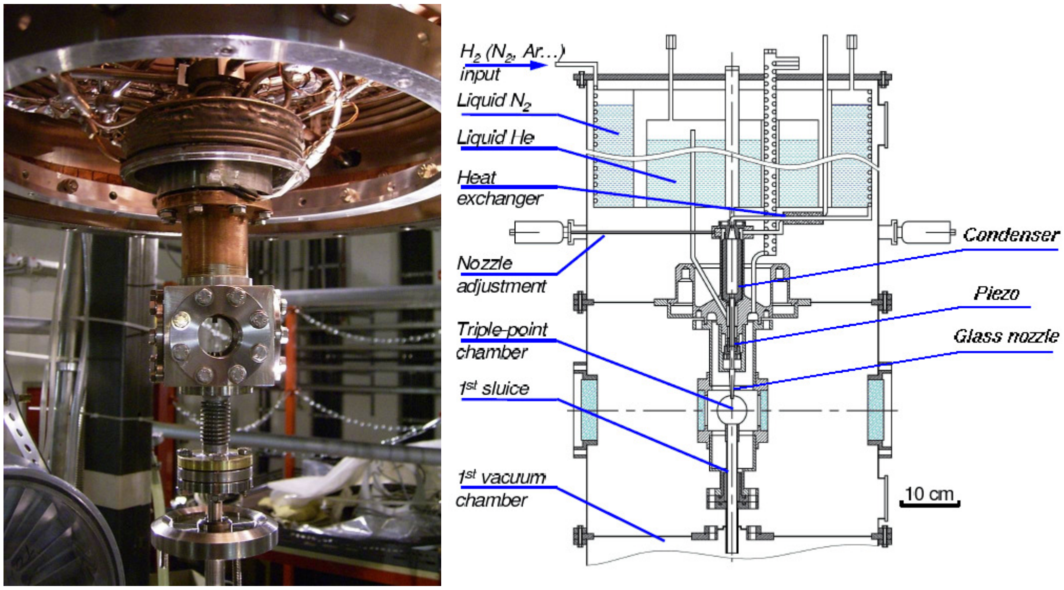

Figure 5: Sketch and photo (central part) of the FZJ pellet generator.

In order to allow for a vertex reconstruction on the sub-millimeter level at PANDA an optical pellet tracking system based on lasers and fast line-scan (LS) cameras is being developed at Uppsala University [10]. It should give accurate position coordinates for pellets that are in the accelerator beam region at the time of a hadron reaction event. Prototyping and testing are done at the TSL pellet test station in Uppsala (UPTS) where the pellet-beam parameters are similar to those in the WASA experiment at COSY/Jülich. In Fig. 6 a CAD drawing of the tracking section with eight cameras and eight lasers as suggested for PANDA is presented. Such a complete device will be installed above and below the scattering chamber.

Depending on the experimental requirements two different operational modes of the pellet target are foreseen. In the pellet tracking (PTR) mode, useful tracking information is available for most interaction events. Here always only one pellet with a diameter of ~ 20µm is in the accelerator beam. Different to this the pellet high luminosity (PHL) mode gives a high target thickness, uniform in time, for obtaining the highest luminosity by a high rate of small (<10 µm) pellets in the accelerator beam.

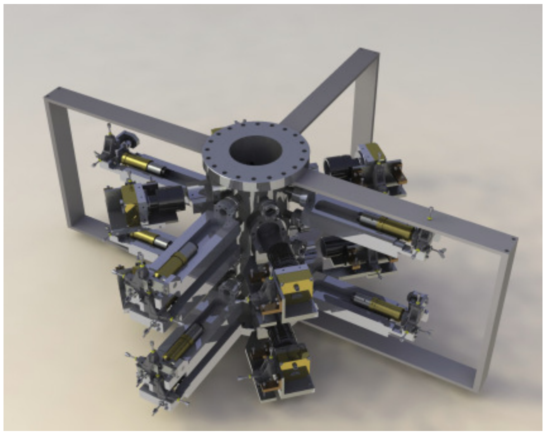

Figure 6: CAD drawing of the tracking section with eight cameras and eight lasers as suggested for PANDA.

4. Target Beam Parameters

In Tab. 1 the expected target beam parameters for both the cluster and the pellet target are presented. In case of the cluster target the given numbers have already been achieved in long-duration measurements and in case of the pellet target the PTR mode is already possible. For the PHL mode, which requires at the interaction point pellets of smallest diameter (Ø ≤ 10 µm) with high frequency, further development is required. Both target types allow a hydrogen target thickness of $>1\text{x}10^{15}$ atoms/cm^2 at the interaction point and therefore fulfil the requirement for PANDA. From the table it becomes obvious that the main advantage of the cluster target is the possibility to provide a target beam continuous in time and space while the pellet target will allow either highest target thickness or a much better vertex resolution when used with tracking of the individual pellets.

	Cluster Target	Pellet Target	
		PTR mode (tracking)	PHL mode (high luminosity)
Effective target thickness	$>1\text{x}10^{15}$ atoms/cm^2	$\leq 2\text{x}10^{15}$ atoms/cm^2	$\geq 4\text{x}10^{15}$ atoms/cm^2
Cluster/Pellet size	nm - µm	Ø ≥ 20 µm	Ø ≤ 10 µm
Cluster/Pellet frequency	continuos beam	≈ 15 k pellets/s	≥ 150 k pellets/s
Target stream diameter	4 mm x 12 mm	Ø ≈ 3 mm	Ø ≤ 3 mm
Average dist. between cluster/pellets	≤ 10 µm	≥ 4 mm	<< 4 mm
Antiproton beam size	Ø ≤ 1 mm	$Ø_{\text{vertical}} \approx 3$ mm	$Ø_{\text{vertical}} \leq 3$ mm
Average no. of cluster or pellets in antiproton beam	$\geq 10^7$	≈ 1	≈ 10

Table 1: Parameters of the cluster and pellet target for PANDA.

5. Summary

For the PANDA experiment both a cluster target as well as a pellet target is foreseen. Both target types will be able to provide hydrogen target beams with thicknesses of above 10^{15} atoms/cm^2 at the later PANDA interaction point. In addition the use of heavier gases such as nitrogen or argon as nuclear target will be possible. One main advantage of the cluster targets is that the target beam homogeneous in space and time which allows for smallest accelerator beam diameter in the scattering chamber and guarantees low luminosity fluctuations. In addition the target beam thickness can be varied continuously over orders of magnitude during operation. Different to this the granular pellet streams allow for the possibility to determine the 3d-information of individual pellets by using a pellet tracking system. By this a vertex reconstruction on a sub-millimetre level will be possible.

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