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Two-dimensional visualization of cluster beams by microchannel plates

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ABSTRACT

An advanced technique for a two-dimensional real time visualization of cluster beams in a vacuum as well as of the overlap volume of cluster beams with particle accelerator beams is presented. The detection system consists of an array of microchannel plates (MCPs) in combination with a phosphor screen which is read out by a CCD camera. This setup together with the ionization of a cluster beam by an electron or ion beam allows for spatial resolved investigations of the cluster beam position, size, and intensity. Moreover, since electrically uncharged clusters remain undetected, the operation in an internal beam experiment opens the way to monitor the overlap region and thus the position and size of an accelerator beam crossing an originally electrically neutral cluster jet. The observed intensity distribution of the recorded image is directly proportional to the convolution of the spatial ion beam and cluster beam intensities and is by this a direct measure of the two-dimensional luminosity distribution. This information can directly be used for the reconstruction of vertex positions as well as for an input for numerical simulations of the reaction zone. The spatial resolution of the images is dominated by the granularity of the complete MCP device and was found to be in the order of $\sigma \approx 100\ \mu m$.

1. Introduction

Cluster beams can be produced and prepared from originally solid, liquid or gaseous materials and are widely used in modern physics experiments. Prominent examples for this are cluster jet beams as internal targets for storage ring experiments [1–4] or interaction studies of high-intense laser beams with streams of clusters [5]. Of special interest are cluster beams produced via expansion of cooled gases or liquids in Laval nozzles by either condensation of the gas or by breaking up the liquid into a spray of droplets. Depending on the production parameters these clusters typically consist of 10^3–10^6 molecules [6,7]. Target streams for experiments can be provided with freely adjustable target thickness over several orders of magnitude up to about $\rho_{target} = 10^{15}$ atoms/cm^2 in a distance of more than 2 m behind the nozzle [4]. Due to the high mass of the individual clusters compared to the residual gas background they can travel over several meters through an ultra high vacuum chamber with a constant angular divergence defined by the orifices used for the cluster beam preparation. This fact is of high interest if the experimental setup, e.g. of a cluster target at an accelerator facility, requires large distances between the cluster generator and both the scattering chamber and the cluster beam dump. Especially in this case with large distances a careful cluster target beam alignment is mandatory and suitable devices for this are of interest.

A further important quantity in scattering experiments using cluster beams as targets, e.g. for accelerated ion beams, is the spatial distribution of the interaction region as well as its variation with time. Here a precise knowledge of this information might be needed, e.g. for the reconstruction of the tracks of the ejectiles produced in the interaction volume or for realistic Monte-Carlo computer simulations for the reactions of interest. One possibility to gain such information about the vertex volume might be the investigation of fluorescence light produced by excitation of atoms/molecules of the target beams by the passing ions. However, this method commonly requires an optical access to the interaction point which might be difficult or even not be possible for modern compact 4π−detectors such as the planned $\overline{\text{P}}$ANDA detector at FAIR in Darmstadt [8]. Alternatively the required vertex information might be reconstructed by separate investigations on the accelerator beam profile, e.g. using fluorescence light measurements [9,10] of (residual) gas close to the interaction region, in combination with a measurement on the cluster target beam profile. In order to quantify the geometrical size and/or the intensity of a cluster beam at the interaction point of an experiment, different approaches can be followed. One commonly applied technique for cluster beams from originally gaseous materials is the use of thin scanning rods in one of the

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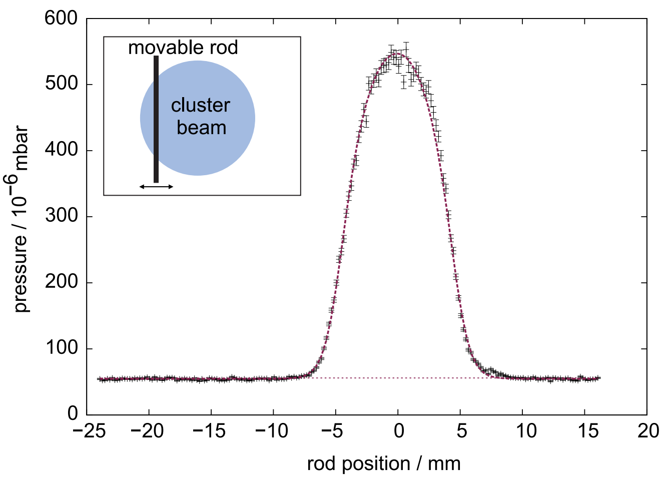

Fig. 1. Determination of the size and intensity of a cluster beam by the scanning rod method.

differentially pumped vacuum stages. The principle of this method is shown in Fig. 1.

A movable rod scans the cluster beam in the vacuum chamber and as soon as the rod interacts with the cluster stream the clusters of the overlap region are stopped and converted into an additional gas background. The resulting gas load to the vacuum chamber can easily be measured by vacuum gauges and is directly proportional to the cluster beam density. Furthermore, with the known rod dimensions and the recorded pressure rise as a function of the rod position, information about the cluster beam diameter and the local target thickness can be extracted [4]. With this method only one-dimensional scans are possible which result in data averaged over the rod axis. In addition, depending on the used vacuum gauge and its possible read out speed, one single cluster profile measurement might take, e.g. 1 min, if a sufficient spatial resolution is required. To overcome the previously described limitations, a method based on a microchannel plate device (MCP) has been implemented. It allows for a precise cluster target beam position measurement and adjustment, to measure in real time two-dimensional cluster beam intensity distributions as well as to monitor the spatial distribution of the vertex point if the cluster target is used in combination with an accelerator beam.

The principle of operation and the properties of this device are demonstrated here by data obtained with hydrogen cluster beams. While electrically neutral clusters hitting a MCP device remain undetected, ionized clusters, e.g. produced by electron impact, can be registered by this system. Therefore, the complete cluster beam cross-section can be investigated. If the MCP signal is read out by a phosphor screen and a CCD camera, the time needed to measure one cluster beam image is typically only limited by the required exposure time of the CCD camera in order to collect a sufficient amount of photons. However, this time might be reduced, e.g. to a few seconds, if the electron current for cluster ionization is adjusted correspondingly. The presented system is routinely in operation as a diagnostic system at a hydrogen cluster beam installation at the University of Münster. Furthermore, with this device it was possible to visualize and monitor the interaction region of a hydrogen cluster target beam and a proton beam in a storage ring experiment. In this case the ionization of the originally electrically neutral cluster beam resulted from the energy loss processes of the ion beam in the cluster beam.

2. Experimental setup

A hydrogen cluster beam is produced via adiabatic expansion of pre-cooled and compressed hydrogen in a Laval nozzle. Details about the cluster jet generator, the experimental setup as well as the operational parameters are presented in Ref. [4]. Shortly behind the cluster generator the cluster beam is ionized by an electron gun which can be operated in a continuous mode or, if a timing information is needed, in a pulsed mode. At the crossing point of cluster and electron beams, i.e. 76 cm behind the nozzle, the diameter of the electron beam amounts to approximately 7 mm and is larger than the cluster beam, i.e. 4 mm, at that position. By this a complete coverage of the hydrogen beam is guaranteed. The current of the 150 eV electron beam is adjusted to the experimental needs, e.g. to the required intensity of ionized clusters, and is typically in the order of a few microamperes. At the interaction point clusters with both negative and positive charges are produced from which in the following only the positively charged ones are further considered. After a drift path of approximately 4.2 m, measured from the position of the electron beam, the ionized beam hits the MCP based detection system. A schematic view of this device as well as the electrical circuit is shown in Fig. 2.

The cluster beam, indicated by a vertical cone, passes an electrically grounded grid with a spacing of 2.7 mm and hits a

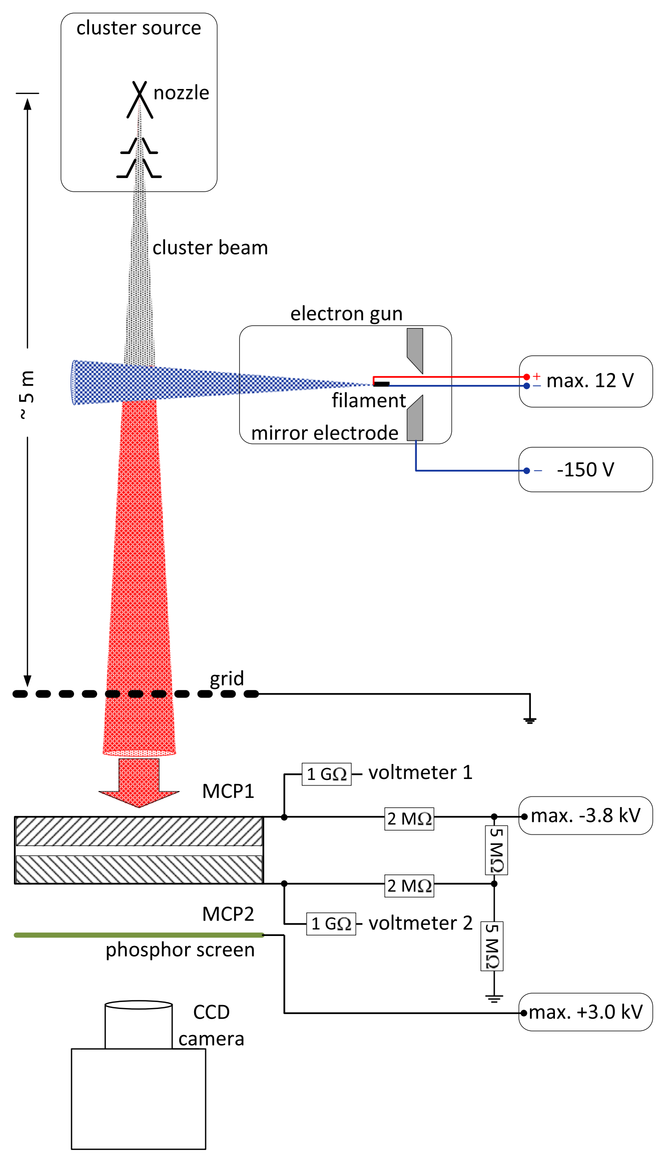

Fig. 2. Schematic view of the MCP based setup for the detection of ionized cluster beams.