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Detection efficiency of microchannel plates to fluxes of high energy electrons similar to that in the Jupiter environment

M. Tulej (1), S. Meyer (1), M. Lüthi (1), D. Lasi (1), A. Galli (1) and P. Wurz (1)

L. Desorgher (2), K. Wojczuk (2), W. Hajdas (2), S. Karlsson (3) and L. Kalla (3)

(1) Space Research and Planetary Sciences, Physics Institute, University of Bern, CH-3012, Switzerland, (2) Paul Scherrer Institute, Lab Particle Physics, CH-5232 Villigen, Switzerland, (3) Swedish Institute of Space Physics, Space Campus 1, Kiruna, Sweden

(marek.tulej@space.unibe.ch / Phone: +41-31-631 44 05)

Abstract

High-energy high-rate electrons were measured by a multichannel plate (MCP) detector at the PiM1 beam line of the High Intensity Proton Accelerator Facilities located at the Paul Scherrer Institute, Villigen, Switzerland. The measurements provide the absolute detection efficiency of 8.5±0.8 % for e^- in the beam momenta range 17.5–345 MeV/c. The pulse height distribution determined from the measurements is close to an exponential function with negative exponent, indicating that the particles penetrated the MCP material before producing the signal somewhere inside the channel. Low charge extraction and modal gains of the MCP detector observed in this study are consistent with the proposed mechanism of the signal formation by penetrating radiation. A very similar MCP ion detector will be used in the NIM mass spectrometer of the PEP experiment currently developed for the JUICE mission of ESA to the Jupiter system, to perform measurements of the chemical composition of the exospheres of the Galilean moons.

1. Introduction

Particle Environment Package (PEP) is an instrument suite of the scientific payload of ESA's JUICE mission to the Jupiter system [1]. PEP will conduct remote global imaging of the Jupiter environment with in-situ measurements of particles including electrons, ions, energetic neutrals, and neutral gas in the particle energy range over nine decades (0.001 eV to 1 MeV). The results of the investigation will help understand the interaction of the Jupiter magnetosphere with Galilean moons. The neutral ion mass spectrometer (NIM) is a time-of-flight mass spectrometer, which is one of the particle instruments of PEP, and will be conducting chemical composition measurements of charged and neutral atoms, and molecules present in the exospheres of Jovian moons. The NIM instrument will record mass spectra within the mass range 1 – 1000 amu with a mass resolution (m/Δm) close to 1100 [2][3]. To achieve the required sensitivity, NIM uses a highly sensitive multichannel plate (MCP) ion detector. However, the presence of a substantial amount of high-energy particles (electrons, protons) trapped by Jupiter's magnetic fields (radiation belts) with the energy distribution exceeding hundreds of MeV both imposes high radiation tolerance requirements on the instruments and deteriorates their performance because of radiation-induced background signals. Understanding the interaction effects of this radiation with various materials is essential to optimally design NIM and its radiation shielding against penetrating radiation, and to interpret the obtained mass spectra. Although modelling techniques are continuously improving, not all the input parameters they require are easily accessible, in particular, the behaviour of detectors subjected to high-rate high-energy particle beams. Therefore, we performed the current radiation tests. They allowed us to identify the sensitivity of the MCP detector to radiation and the different signatures of particle species.

2. Experimental

The studies were conducted at the High Intensity Proton Accelerator Facility, PSI Villigen, Switzerland using the secondary beam line, PiM1 [4]. The PiM1 beamline is designed to deliver charged pions ($\pi^{\pm}$), electrons and positrons ($e^{\pm}$), muons ($\mu^{\pm}$) and protons (p) to the experimental area. Polarity and momentum of secondary particles are controlled by the currents in the magnet of the beam delivery system and can be changed by command. These particles are produced by the interaction between a small fraction of the 590 MeV high intensity proton beam and a thin graphite target (M)[4].

The MCP detector used to measure electrons is placed in the vacuum chamber (Fig. 1) at a pressure of < 10^{-6}mbar. The e- beam with the beam momenta in the range 17.5–345 MeV/c was introduced to the detector by passing 2 mm thick aluminium window. Electron fluxes close to those expected in the Jupiter environment were applied. In parallel, the modelling by GRAS/Geant4 packages to test the prediction of beam rates and beam parameters at the MCP detector (Fig. 1).

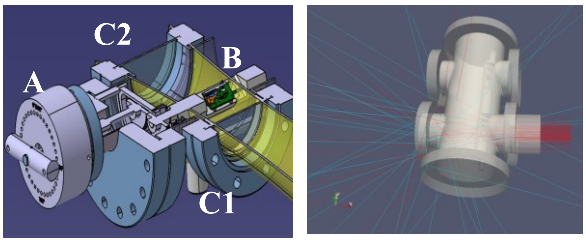

Fig.1. Left panel: Cut through the design drawing of the experimental vacuum chamber with a schematic envelope of the particle beam penetrating the vacuum chamber (yellow tubular feature): (A) rotating assembly, (B) the MCP detector, (C1) and (C2) entrance and rear aluminium window. Right panel: Visualisation from Geant4/GRAS simulation with primary e- beam of momentum 11.5 MeV/c.

To obtain the absolute detection efficiency of the MCP detector (η_{MCP}), the incident particle rate ($k_{Incident}$) at the front MCP and the MCP counting rates (k_{MCP}) were determined. The absolute MCP detection efficiency is defined as:

$$\eta_{MCP}(E_i) = 100 * \frac{k_{MCP}(E_i)}{k_{Incident}(E_i)}$$

The incident particle rate, $k_{Incident}$, [counts/sec] at the MCP surface was derived from the results of the diagnostic measurements by several beam detectors before the MCP experiment and by the ionisation chamber in real time. The measurements of the electrons by the MCP detector delivered the pulse height distribution (PHD) and means to determine the particle rates. The study yields the absolute detection efficiencies for e^- to be 8.5±0.8 % in the momenta range 17.5–345 MeV/c. The modelling results indicate that a decrease of the detector model gain can be expected for particle rates larger than 10^7counts/s, hence at least 10 times larger than those applied in the present investigation (Fig.2). There is no experimental evidence for a decrease of the MCP gain for the rates up to 10^6 counts /s. High-energy particles penetrate deeper into the MCP channel and extract less current from the detector, which still can be refilled without observable saturation of the detector. The modelling results predict also very well MCP gain dependence on electron rate under assumption that the MCP signal is produced by penetrating particles at some depth inside the MCP channel.

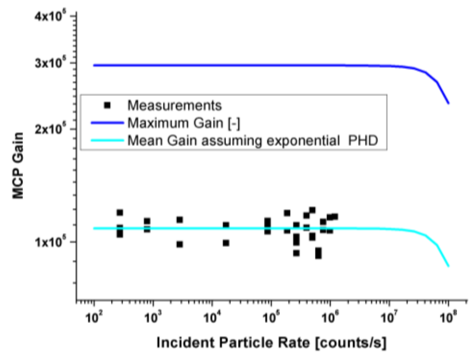

Fig. 2. Predictions of the MCP gain as function of the pulse rate determined from the paralysable-counter model are compared with the experimental results. The model predicts that for the MCP detector a possible saturation of the detector for the rates larger than10^7 particles/s is expected.

One of the important conclusions from this study is that at the investigated particle energies, even high rate of particles do not cause saturation of the detector. This can be of advantage when using this detector in Jovian environment. With the knowledge of the detection efficiency for penetrating electrons, both modelling and experimental investigation can be conducted to optimise radiation shielding against the radiation expected at the Jovian satellites.

Acknowledgements

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