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Detector setup of the VIP2 Underground Experiment at LNGS

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Abstract

The VIP2 experiment tests the Pauli Exclusion Principle with high sensitivity, by searching for Pauli-forbidden atomic transitions from the 2p to the 1s shell in copper at about 8keV. The transition energy of Pauli-forbidden K X-rays is shifted by about 300 eV with respect to the normal allowed K line. This energy difference can be resolved using Silicon Drift Detectors. The data for this experiment is taken in the Gran Sasso underground laboratory (LNGS), which provides shielding from cosmic radiation. An overview of the detection system of the VIP2 experiment will be given. This includes the Silicon Drift Detectors used as X-ray detectors which provide an energy resolution of around 150 eV at 6 keV and timing information for active shielding. Furthermore, the low maintenance requirement makes them excellent X-ray detectors for the use in an underground laboratory. The VIP2 setup will be discussed which consists of a high current target system and a passive as well as an active shielding system using plastic scintillators read out by Silicon Photomultipliers.

Keywords: X-ray spectroscopy, SDDs, underground experiment

PACS: 29.40.Cs, 29.40.Gx

1. Introduction

Wolfgang Pauli formulated the Pauli Exclusion Principle (PEP) in 1925 explaining the shell structure of atoms. It turned out that this principle is connected to the spin-statistics theorem and valid not only for electrons - it is valid for all fermions, i. e. particles with half integer spin. In spite of the overwhelming success of the PEP in explaining many features of nature, a loophole-free proof cannot be given up to now. The experiment VIP2¹ employ a method to test the PEP similar to

that of Ramberg and Snow [1]. By circulating an electric current fresh electrons are inserted into a Cu strip. They form new quantum states with atoms of the conductor. These quantum states have a probability of to be non-Paulian. The electron then cascades to the 1s state and thereby emits photons from non-Paulian transitions, which are shifted in energy by about 300 eV. This shifted X-rays can be resolved by spectroscopy with Silicon Drift Detectors (SDDs) used as X-ray detectors. The number of possible photons from these transitions, which are identified by their energy, is used to set an upper limit for the probability for a violation of the PEP. A small violation of the PEP is qualitatively described by the quantity $\beta^2/2$, which can be traced back to a model introduced by Ignatiev and Kuzmin [2] and is commonly used in the literature.

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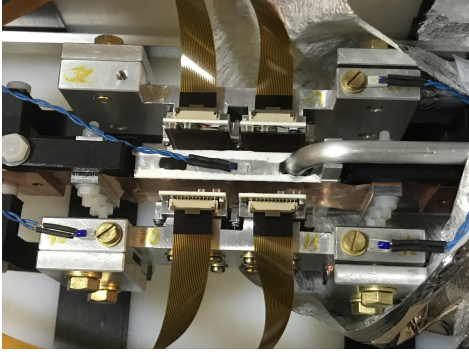


Figure 1: The new Silicon Drift Detectors (4x8 SDD cells) mounted close to the Cu target in the setup, with readout cables and water cooling to counteract the heating due to the high current.

2. VIP2 Setup and Detectors

Silicon Drift Detectors (SDDs) are semiconductor detectors ideally suited for soft X-ray spectroscopy. Free electrons generated by incident radiation drift to the anode due to an applied electric field. From the number of electrons at the anode, the energy of the radiation can be inferred. The improvements of SDDs are on the one hand due to their larger depletion depth, which leads to a higher detection efficiency of possible X-rays from PEP-violating transitions. On the other hand, the improved time resolution enables the use of an active shielding against external radiation. For this purpose, 32 scintillator bars read out by 2 silicon photomultipliers each are installed around the SDDs. Their veto signal helps to reduce the background.

3. X-ray spectrum measured at LNGS

The VIP2 experiment has taken over 180 days of data in the Gran Sasso underground laboratory (LNGS). An analysis of a smaller dataset is presented in [3]. With the complete dataset, the Pauli Exclusion Principle for electrons could be tested with unprecedented precision.

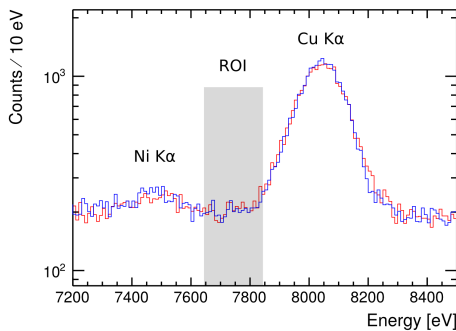


Figure 2: Comparison of data taken with and without current at LNGS. The region of interest where the PEP violating transition is expected is marked in gray. The data corresponds to around 163 days.

With this data taken at LNGS, a new upper limit for the probability for a violation of the PEP can be calculated [4]:

$$\frac{\beta^2}{2} \leq 1.87 \times 10^{-29} \quad (1)$$

4. Summary and outlook

Already with the present VIP2 setup the up-to-now most stringent test of PEP was achieved. Presently we run the experiment with new types of SDDs providing a larger active area and excellent energy resolution. We will install active shielding based on plastic scintillation bars coupled to silicon photomultipliers. Additionally a optimized shielding will be used to further suppress background.

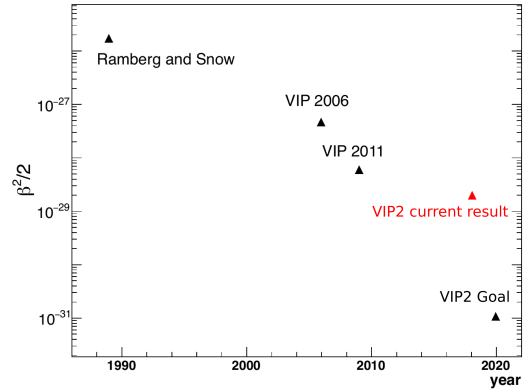


Figure 3: The results of the VIP experiment, compared to the limit we can set with the data taken by the VIP2 experiment. The envisioned final result after the full data taking time is shown including a planned upgrade [5].

With planned improvements the goal of setting a new upper limit for the violation of the PEP to $\sim 10^{-31}$ could be reached after 3 years of data taking.

Acknowledgments

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