

# Testing the Pauli Exclusion Principle for electrons with the VIP-2 experiment

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The **Pauli Exclusion Principle (PEP)** states that in a system there can not be two (or more) fermions with all quantum numbers identical. A violation of the PEP would imply a new physics beyond the Standard Model.

## The experimental method

The experimental method of VIP-2 is based on the introduction of "new" electrons in a copper bar by applying an electric current. A small violation of PEP can be described in Quantum Mechanics as proposed by Greenberg [1]:

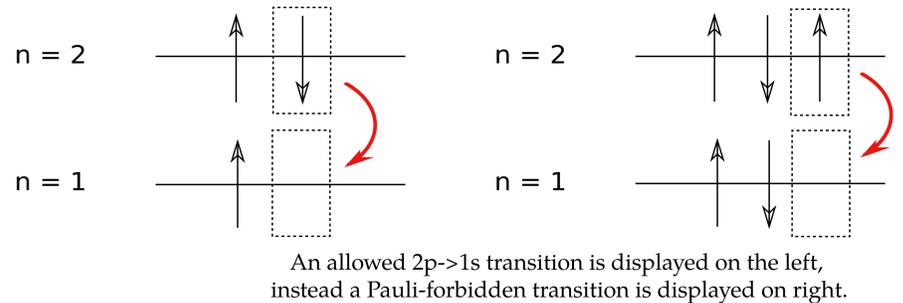
*"Whenever an electron is captured by an atom, a new state is formed that can have a certain probability of being in a mixed symmetry state. This state is highly excited and from its decay one could observe a possible transition prohibited by the PEP"*

The experimental goal of VIP-2 is the search for X-rays from PEP violating transition, measuring the  $K\alpha$  transition ( $2p \rightarrow 1s$ ) in copper atoms.

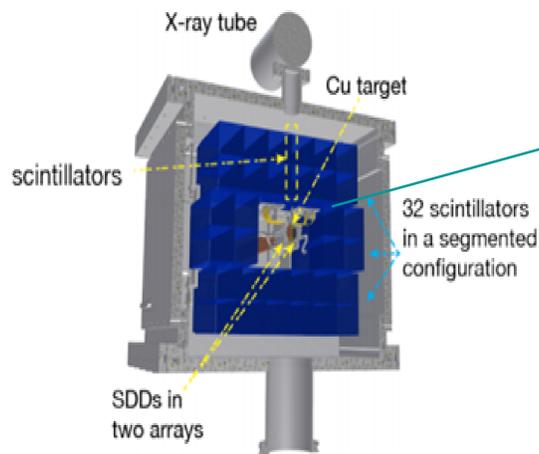
Energy transition  $K\alpha$  allowed: 8.05 keV

Energy PEP forbidden transition  $K\alpha$ : ~7.74 keV

(the lower transition energy compared to the allowed one is due to the additional shielding of the second electron in the ground state)



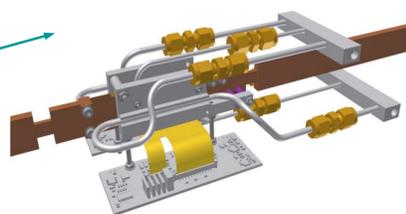
## The VIP-2 apparatus



Scheme of the VIP2 setup with scintillators and Cu target and SDDs.



A picture of VIP2 installed at National Laboratories of Gran Sasso



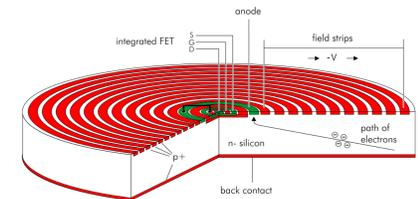
## The target

The target is made of 2 strips (10 cm x 1 cm x 50  $\mu\text{m}$ ) of copper in which can circulate a current of about 100 A. A water circuit cools the 2 copper strips so that the temperature of the detectors placed close to the target don't increase by more than 2K.

## The X-ray detectors

Silicon Drift Detectors are semiconductor detectors ideally suited for X-ray detection. 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.

In the apparatus the SDDs are organized in 2 chips containing 3 cells with 100  $\text{mm}^2$  of active area each, cooled to  $T \approx 100$  K by liquid Argon to get **170 eV of energy resolution at 8 keV**. The SDDs provide also information about timing (**400 ns FWHM**).



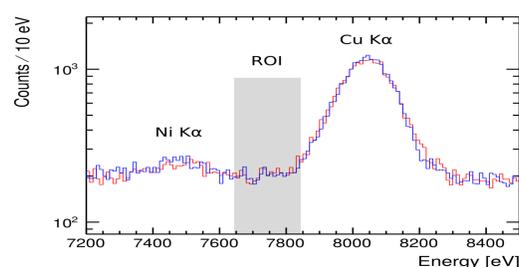
Schematic drawing of a Silicon Drift Detector used in VIP-2

A **VETO system** composed by 32 plastic scintillator, read by pairs of SiPM, measuring and covering an angle  $> 90\%$  compared to the target, allows to **reduce the background** in the range of interest for a PEP violating X-ray of **about 1 order of magnitude**.

**THE VIP-2 EXPERIMENT IS PRESENTLY IN DATA TAKING AT UNDERGROUND GRAN SASSO LABORATORIES (LNGS) IN ITALY, AN EXTREMELY LOW BACKGROUND ENVIRONMENT.**

## Preliminary results and outlook

The VIP-2 experiment has collected over 180 days of data in the Gran Sasso underground laboratory (LNGS).



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.

With the data taken at LNGS and following the same procedure used for VIP[2], a new upper limit for the probability for a violation of the PEP has been calculated[3]:

$$1.87 \times 10^{-29}$$

VIP-2 is presently running at LNGS with the goal to set a new upper limit for the violation of the PEP to  $\sim 10^{-31}$  in 3 years of data taking, if a violation of the PEP won't be discovered.

### References:

- [1] Messiah A. and Greenberg O., 1964, *Physical Review*, **136**, B248
- [2] C. Curceanu et al. (VIP Collaboration), *Entropy* 19 (7), 300 (2017)
- [3] A. Pichler, PhD Thesis, 2018