VIP Technical Note IR - 6

VIP setup at LNGS without shielding: data analysis and results

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1. INTRODUCTION

The goal of the VIP experiment is to improve the limit on the validity/violation of the Pauli Exclusion Principle (PEP) for electrons, through the search of "anomalous" PEP violating X-ray transitions in copper atoms, produced by "fresh" electrons which are introduced through electrical current circulated in a copper target and, thus, "new" with respect to the already present ones in the copper, that had already all the time to perform the eventual "prohibited" transitions [1] [2].

A preliminary result obtained at LNF has already lowered the previous limit by almost 2 orders of magnitude [3], going from a probability of having the PEP violation from $1.7 \cdot 10^{-26}$ to $4.5 \cdot 10^{-28}$. This value represents the best value (published) at present.

Meanwhile, VIP was transported and installed at LNGS in early 2006, and the DAQ was started. In this paper, the results of the data analysis corresponding to the DAQ of the setup without shielding (February-March 2006) are reported. A new limit on PEP violation probability was established.

2. THE VIP SETUP AT LNGS

In February 2006 the VIP setup was transported and installed at the LNGS underground laboratory. The first measurements, having the goal to check the stability of the setup and to have info about background in this configuration, were performed

without shielding, with the setup as showed in Fig.1. The setup is based on a double layer of copper and lead bricks, under a very thick layer of rock (about 2 km). It is placed into a barrack with two air-conditioner systems, having the goal to preserve the low temperature in the room, on which depend the CCD temperatures, and the electronics performances.

The values of the DAQ parameters, as room, CCDs and target temperatures, vacuum pressure, and current circulated into the target, are constantly monitored and displayed on the "VIP Slow Monitor", on the VIP web page.

The values of these parameters during the DAQ were:

- room temperature about 15° C;
- CCDs temperature about –115° C;
- target temperature 8^0 C without current and 12^0 C with current;
- vacuum pressure about $3x\ 10^{-8}$ mbar
- current 0A (no current DAQ) or 40A (DAQ with current).

Fig.1 – The VIP setup at LNGS, without shielding.

3. MEASUREMENTS

The measurements reported in this paper have been performed in the period February – March 2006. Two types of measurements were performed:

- 20895 minutes of measurements with a 40 A current circulating in the copper target;
- 31890 minutes of measurements without circulating current (used for background evaluation);

where CCDs were read-out every 5 minutes. Only 14 CCDs, out of 16, were considered for analyses, because the remaining 2 (numbers 1 and 10) are afflicted by noise problems.

By a first analyses of the data and of the relative spectra, we have decided to put a cut to reject all the files of the first period of the DAQ in which the setup was still in stabilization phase. This cut (file_id > 2750) reduced the period to be considered for further analyses for no-current data to:

- 20160 minutes of measurements without circulating current.

4. "PEP VIOLATING" X-RAY SPECTRUM

As a first step of the analysis, each CCD was calibrated in energy. Then, for each data set (I=0 or I=40 A) the individual spectra were summed into an unique spectrum.

The two resulting X-ray sum spectra are shown in Fig. 2 a) with circulating current and b) without current.

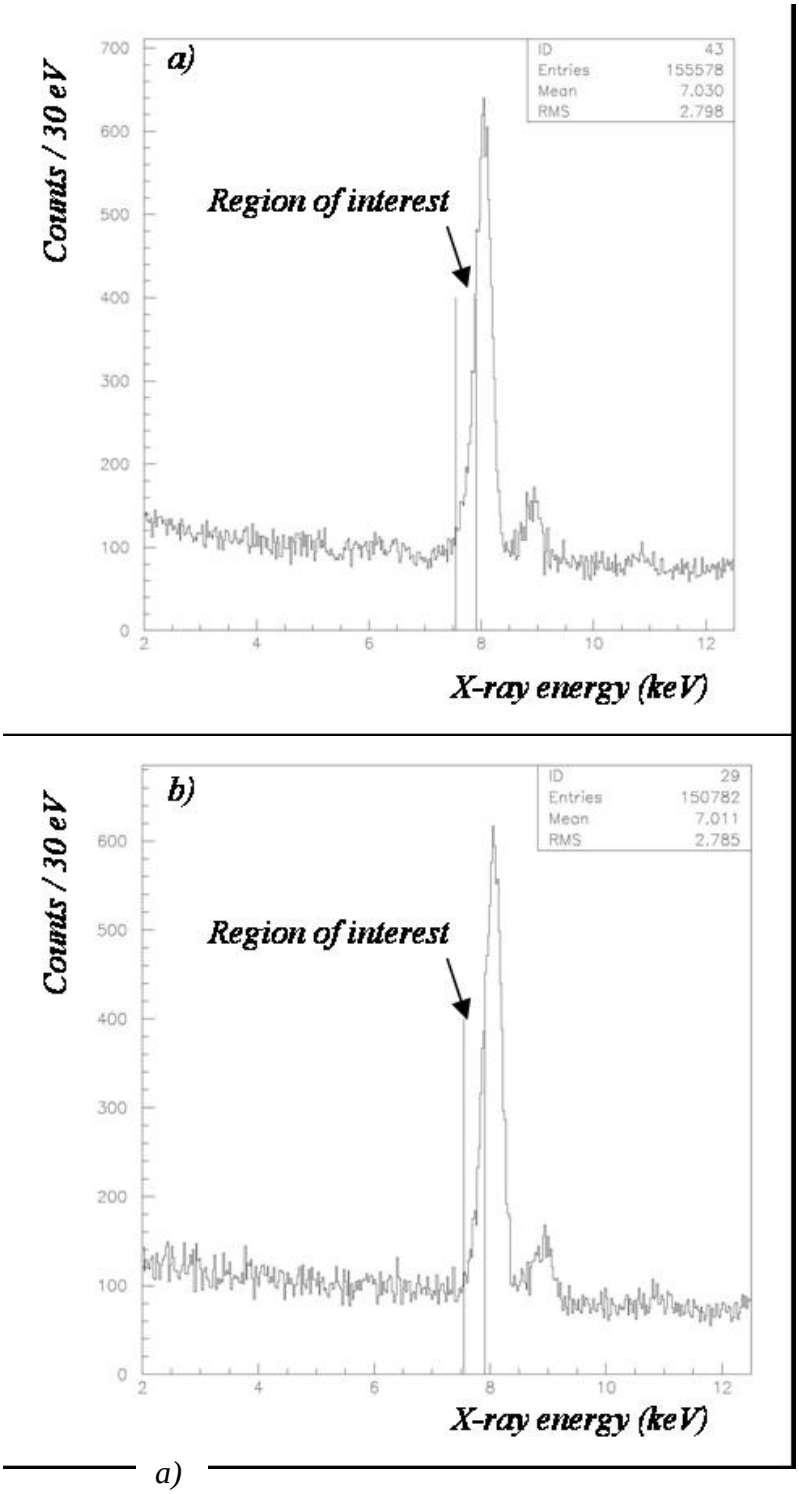

Fig.2 – Energy spectra for the VIP measurement a) with current (I = 40 A) circulated; b) without current (I = 0 A).

The second spectrum (I=0 A) was then normalized to the same DAQ time as the I=40 A (with a normalization constant C = 20895/20160 = 1.036). The normalized spectrum is shown in Fig. 3.

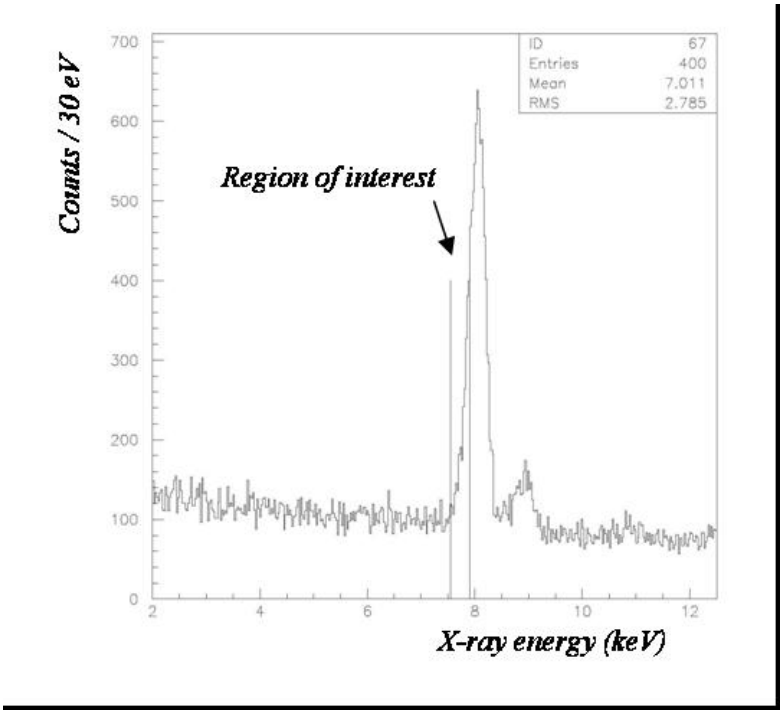

Fig.3 – Energy spectrum without current (I = 0 A) normalized with the constant *C*.

The "PEP violating" spectrum was obtained by subtracting the I=0 A spectrum (background) from the I=40 A one (signal). The resulting subtracted spectrum is shown in Fig. 4 a) (whole energy scale) and b) (a zoom on the region of interest). The region of interest is defined starting from the CCD energy resolution, to which we added 10 eV for accounting for the error in the PEP violating energy transition, and it is between 7.55 keV and 7.90 keV.

The numbers of X-rays in the region of interest are:

- $N_x = 2610 \pm 51$ at I = 0 A (normalized spectrum)
- $N_x = 2522 \pm 50$ at I = 40 A
- $\Delta N_x = -88 \pm 72$ for the subtracted spectrum.

Following the same procedure to determine the experimental limit on $\beta^2/2$ from our data as the one in [3], we find for the number of X-rays generated in the PEP violating transitions:

$$N_x \geq 7.056 \times 10^{-29} \times \beta^2/2 \, .$$

Taking as a limit of the observation three standard deviation, we get for the PEP violation probability a limit as:

$$\frac{\beta^2}{2} \leq \frac{3 \times 72}{7.056} \times 10^{-29} = 3.0 \times 10^{-28} \, .$$

In this way we have improved our previous upper limit of about a factor 1.5.

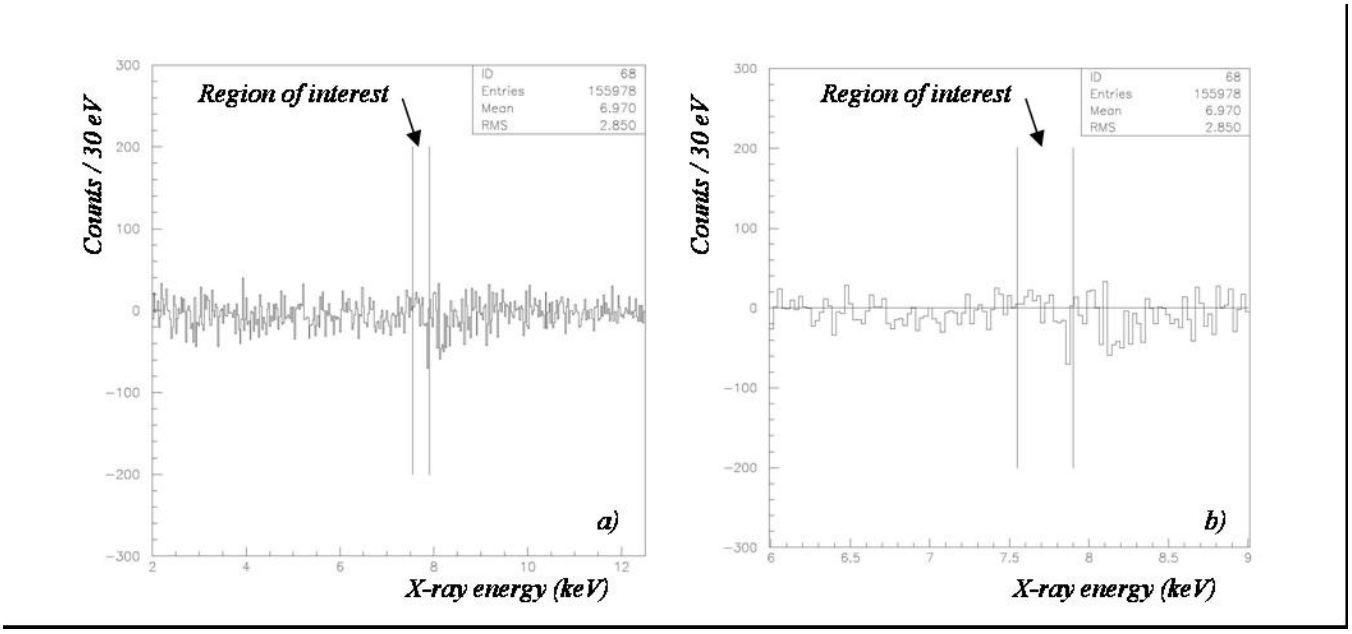

Fig.4 – The subtracted spectrum, current minus no current: a) all energy range; b) expanded view in the region of interest around 7.729 keV.

More details on this analysis are in the Antonio Salvucci's thesis [4].

5. CONCLUSION

In February 2006 the VIP setup was transported and installed at LNGS. A period of DAQ without shielding followed (February-March 2006). The data analyses improved the present limit on PEP violation [3] by a factor of 1.5.

In April 2006 the lead and copper shielding was installed around VIP and since then VIP is in DAQ, alternating periods with and without current. The DAQ in these conditions will last for about 2 years, with the goal to arrive with the PEP violation probability in the range of $10^{-29} – 10^{-30}$.

BIBLIOGRAPHY

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