VIP Technical Note IR - 1

How to treat the test measurement to be performed at LNGS with the 2-CCD setup?

(Thoughts about the strategy of the background measurement)

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1. Introduction

The VIP (Violation of the Pauli Exclusion Principle) experiment [1] was recently (September 2004) approved by the INFN Commissione 3a and was presented in October 2004 to the Laboratori Nazionali di Gran Sasso (LNGS) International Scientific Committee for approval.

The goal of the experiment is to improve by 4 orders of magnitude the actual limit on the Pauli Exclusion Principle (PEP) for electrons [2]. The method is basically the same as the one used in [2], i.e. the search of “anomalous” X-ray transitions in Copper atoms (defined as transitions from the n=2 level to the n=1 level, where the n=1 level is already occupied by 2 electrons) when a current is circulated inside – bringing the so-called “fresh” electrons which have the probability to do the Pauli-forbidden transition. Such transitions do have as distinctive feature the fact that their energy is displaced with respect to the “normal” one; in case of the Copper K_{α} line, the energy is about 7.6 keV, as compared to the 8.04 keV the normal one. In order to avoid eventual systematic errors, a measurement without circulating current is to be performed in the same conditions – representing the background.

The VIP setup is equipped with 16 CCD (Charge Coupled Device) detectors, already successfully used in the DEAR experiment [3]. The 4 orders of magnitude to be gained in the value of the limit of PEP for electrons ($\beta^2/2< 10^{-30}$) should arrive from geometrical and employed detectors reasons (10^3) and from an assumed background reduction of a factor of 100 by performing the experiment at LNGS (giving a factor 10 in probability). The VIP measurement – to be performed in 2005 and 2006 - should give important information for those theories dealing with the possibility that PEP gets violated (for an extended list of such articles – see [1] and Bibliography therein).

While the three orders of magnitude to be gained out of an improved geometry and detectors are a matter of apparatus design optimization – in an advanced phase – the factor 10 to be gained due to a background decrease by working underground (LNGS) is to be checked. The factor 10 in probability translates actually in a presumed background decrease at LNGS of a factor 100. This factor 100, even if to the LNGS specialists seems to be realistic, was actually never measured. All existent X-ray measurements performed at LNGS are done either with Ge-detectors and/or by use of sophisticated shielding and anticoincidence methods (such measurements, with very different outputs, were for example performed by DAMA, Heildelberg-Moscow Collaboration, CUORICINO). It is clear for us that a decrease of the muon background by a factor 10^6 at LNGS does not have an obvious one-to-one counterpart in the X-ray background. The X-ray background has a component coming from cosmic ray background and another one generated by the natural radioactivity sources (by this point of view it was checked for example that Frascati National Laboratory is situated on a rather “active” ground, with a natural radioactivity a factor 2-3 bigger than the one present in other Laboratories).

Under such conditions, the first necessary step before the start of the data taking with the final VIP setup (towards Spring 2005) is a background measurement, to be performed with a test setup equipped with 2 CCDs, at LNGS. Such a measurement should give a realistic indication of what to expect for VIP at LNGS and which are the problems to be dealt with.

The present document has the goal to give an indication of how to interpret the results of the measurement, on the way towards a realistic strategy for the VIP measurement.

In Section 2 the results of a test measurement, performed at the Neuchatel Laboratory in 1998 are briefly presented – since they will be reconsidered later on for interpreting our results. The 2 CCD test setup is presented in Section 3, while in Section 4 the interpretation of the measurements to be performed in laboratory and at LNGS is tempted. In Section 5 conclusions are derived.

2. Preliminary results obtained with a test setup

A feasibility measurement, applying the same method of Ramberg and Snow, was performed in 1998 for a period of three months, in the basement of the Neuchatel laboratory [4]. The setup used 3 CCD's (Charge-Coupled Device) with a total active surface of about 3.3 cm^2 as X-ray detectors. The CCDs had an energy resolution of 400-500 eV FWHM,.

The total measurement time was of 1856 hours:

- 1524 hours with a circulating current of 5, 10 or 15 A;

- 332 hours without current – to measure the background.

In Fig. 1 the setup is shown.

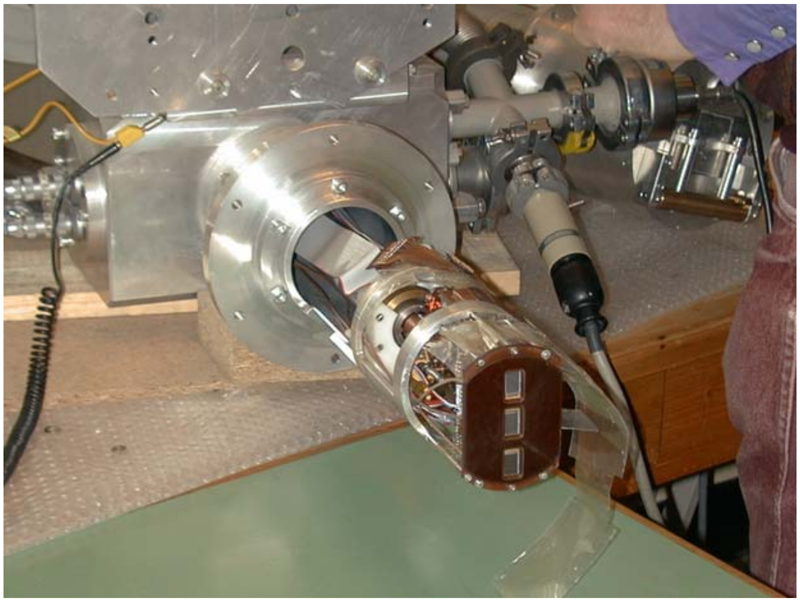

Fig.1: The test setup used at Neuchatel – detail of the CCD detectors.

AS an example, the measured spectra for one of the 3 CCDs is shown in Fig. 2 .

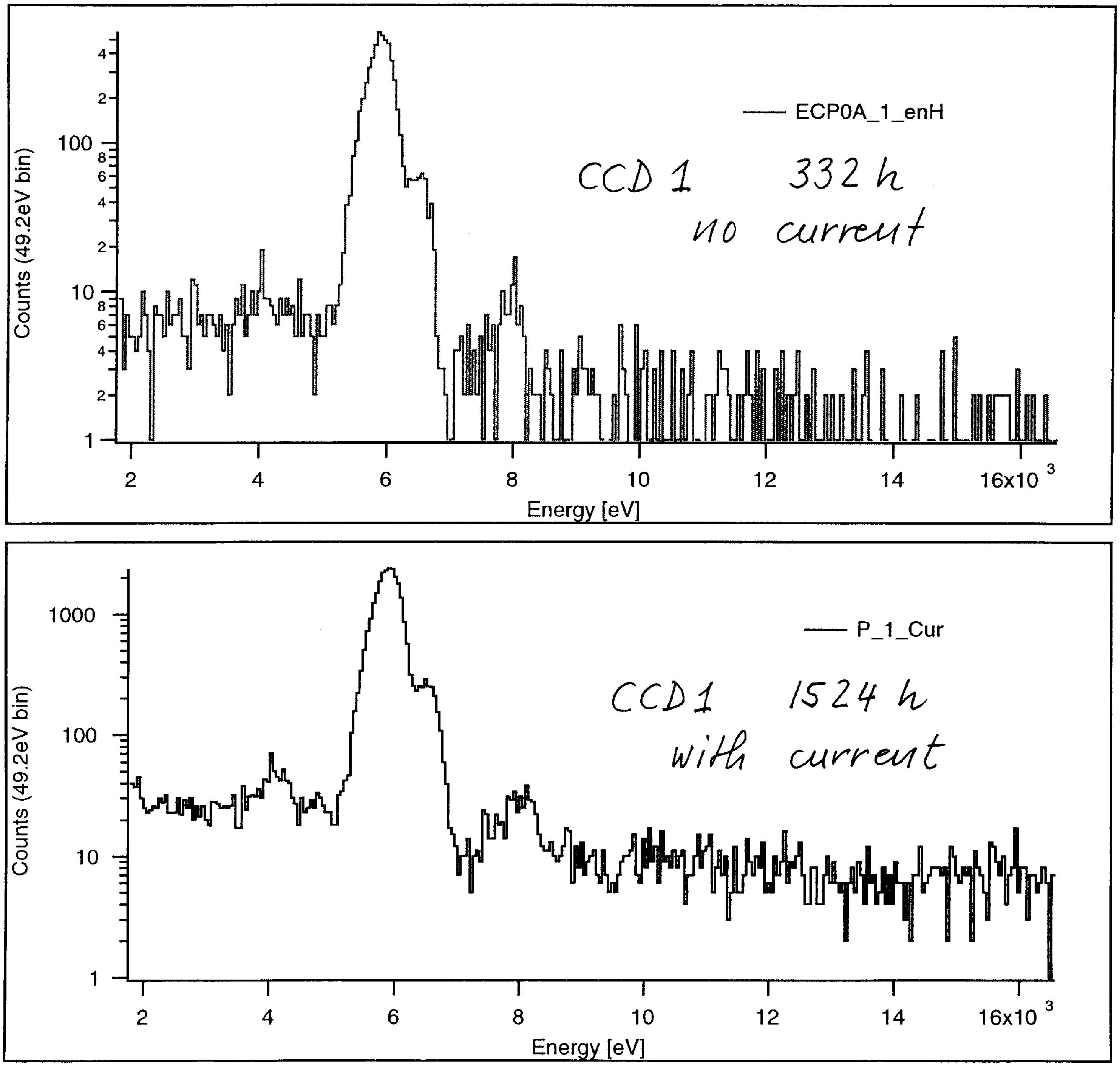

Fig. 2: The measured spectra with the test setup at Neuchatel.

With the improved detector resolution and geometry, taking into account the integrated circulated current, the geometry and the material characteristics, an upper limit of:

$$\beta^2 / 2 \leq 0.95x10^{-27}$$

was obtained, about an order of magnitude better than the Ramberg and Snow measurement [2].

Let's now examine the spectrum in Figure 2 and derive some numbers – to be used later on when comparing with what expected in the test measurement at LNGS and laboratory.

In Table 1 the number of events, as derived from the spectrum in Fig. 2, in variuos energy regions, are reported. The choice of the energy regions are dictated by the need to stay far away of the "impuriry" region, i.e. the Mn-region (around 6 keV) and the Cu K_α region (8.04 keV), since Mn electronic transitions are related to eventual impurities present in the setup, for example in the Aluminium housing of the CCDs setup (if Al is not pure enough), while Cu transitions are excited by cosmic and natural radioactivity background..

Table 1: Number of events measured with the test setup at Neuchatel

Energy region (KeV)	**# Events in the spectrum Fig 2 - upper**	**# Events/1 cm^2/hour**
2 –5	~ 320	0.88
7.39 – 7.89 (JP)	~ 55	0.15
8.5 – 9.5	~ 45	0.12
2-5 + 7.39 – 7.89 + 8.5-9.5	**420**	**1.15**

3. The 2CCD test setup

The 2 CCD VIP test setup has will be used to perform a preliminary background measurement at LNGS, in order to estimate the reduction factor with respect to ground-level (as performed for instance in Neuchâtel). This reduction factor is currently assumed to be ~ 100.

The test setup, based on 2 CCD-55, of a total array of 14.5 cm^2, of the same type as the one used by VIP, is already built and working in Frascati laboratory.

A picture of the 2 CCD test setup installed in the LNF laboratory is shown in Figs. 3.

Fig. 3: The 2-CCD test setup installed in the laboratory.

In Fig. 4 a schematic drawing of the main elements of the 2 CCD setup is presented.

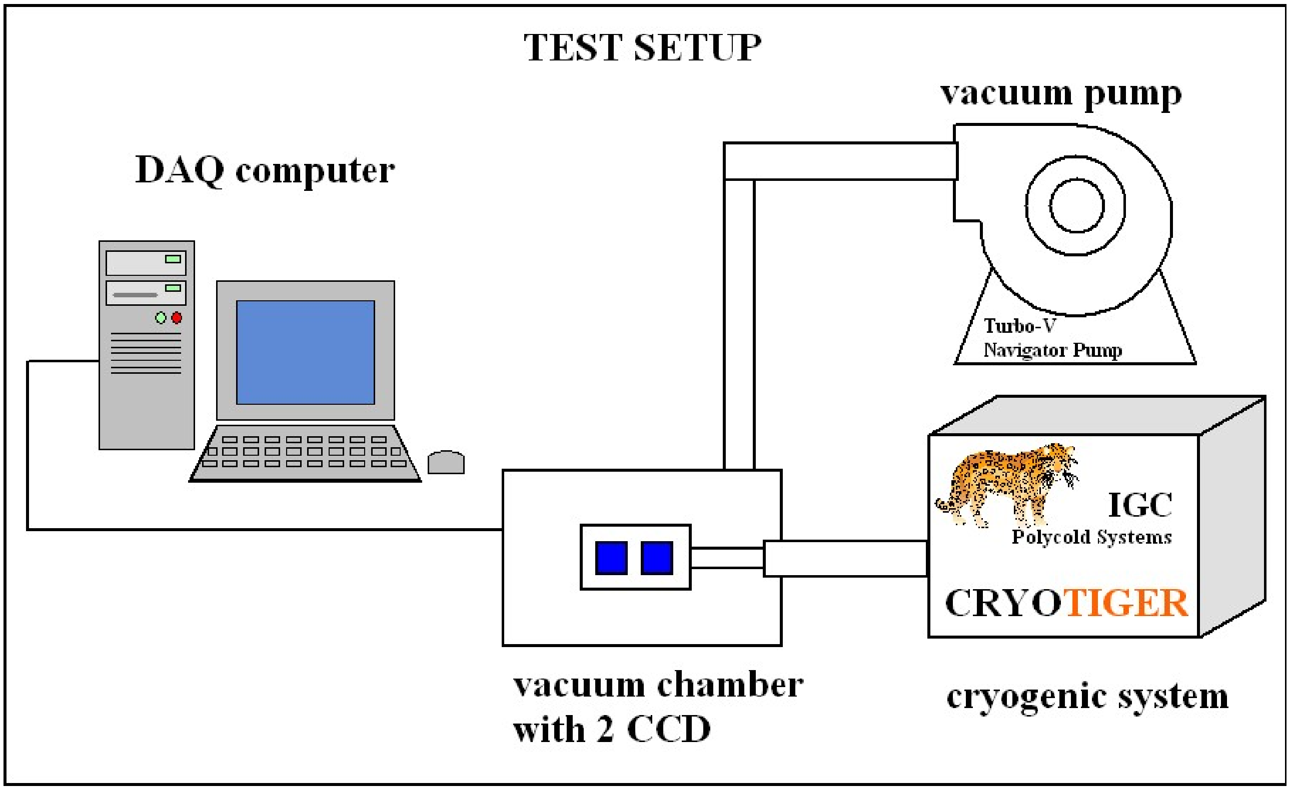

Fig. 4 Schematic drawing of the 2 CCD test setup.

4. How to interpret the measured results

With the 2 CCD test setup, measurements will be firstly performed in the laboratory and afterwards at LNGS.

A series of measurements are planned in laboratory – before going to LNGS - in order to find a preliminary optimal setup from which the background reduction at LNGS to be evaluated.

These measurements are going to be performed in the following geometries:

- basic geometry (the one in Fig. 3) – in which the 2 CCDs are simply housed in the aluminium vacuum chamber;
- basic geometry, in which the CCDs are surrounded, inside the aluminium vacuum chamber, by a teflon foil, with the goal to reduce the background X rays coming from setup materials;
- same geometry as before, but with additional shielding of Lead and Copper.

In order to understand where we stay with respect to the Neuchatel measurement, in Table 2 a normalization of the number of counts to the 2 CCD setup for a 10 hours measurement if background would be the same as the one measured at Neuchatel is given.

Table 2: Number of events with the 2 CCDs test setup in 10 hours – if background is the same as Neuchatel.

Energy region (KeV)	**# Events in the spectrum /10 hours**
2 –5	~ 127
7.39 – 7.89 (JP)	~ 22
8.5 – 9.5	~ 18
2-5 + 7.39 – 7.89 + 8.5-9.5	**167**

By analyzing Table 2, one can deduce that, in principle, in about 10 hours we should have a rough (8%) estimation of the background and of its shape (considering counts in different energy regions).

Once the measurement in laboratory is performed, the setup should be transported to LNGS and the measurement repeated there.

Of course that part of the materials might be activated; in order to check this, we can perform various measurements at the Low Level Radioactivity Laboratory at LNGS – where Ge detectors can measure the natural radioactivity induced activations of setup components.

Then, we might repeat a series of measurements with the 2 CCD test setup – with various shielding geometries.

If a factor 100 in background reduction with respect to Neuchatel is to be expected, then in 3 days of measurement we should measure a number of events as reported in Table 3.

Table 3: Number of events with the 2 CCDs test setup in 3 days – if background is 100 times less than the one measured at Neuchatel

Energy region (KeV)	**# Events in the spectrum /3 days**
2 –5	~ 9
7.39 – 7.89 (JP)	~ 1.6
8.5 – 9.5	~ 1.3
2-5 + 7.39 – 7.89 + 8.5-9.5	**~ 12**

If this would be the case – i.e. a factor 100 reduction – then in 3 days a global 30% measurement can be performed.

5. Conclusions

In the present document, a simple analysis of the possible background reduction measurement to be performed at LNGS with a 2 CCD test setup was performed.

It was shown that a measurement in the laboratory lasting as long as 10 hours (after a brief setup optimization, mainly as concerning the eventual shielding) could give an answer at about 8% to the question if background is the same as the one measured at Neuchatel, with a preliminary version of the test setup. Moreover, the gross features concerning the shape of the background might be studied, by looking at various energy regions.

At LNGS a measurement – after eventual optimizations – lasting 3 days could give an answer at 30% if the overall background is reduced by a factor 100 with respect to Neuchatel.

Such a result would satisfy the goal of a test measurement, and would allow to draw conclusions concerning the final strategy of the VIP experiment.

Bibliography

[1] VIP Collaboration, The VIP Experiment – Experimental Proposal, October 2004.

[2] E. Ramberg and G. A. Snow: *Experimental limit on a small violation of the Pauli principle*, Phys. Lett. B **238** (1990) 438.

[3] S. Bianco et al. (DEAR Collaboration), Rivista del Nuovo Cimento, vol. 22, N. 11 (1999) 1-45.

[4] M. Augsburger, J.-P. Egger, “New experimental limit on a violation of the Pauli exclusion priciple”, preprint, 19 August 1999, unpublished.