Testing Pauli exclusion principle for electrons at the LNGS underground laboratories

Luca De Paolis *

* Laboratori Nazionali di Frascati (LNF) dell'INFN
*luca.depaolis@lnf.infn.it

ABSTRACT

The VIP-2 experiment at the Underground Gran Sasso Laboratory (LNGS) aims to perform high precision tests of the Pauli Exclusion Principle for electrons.
The Pauli Exclusion Principle (PEP) violation would be a clear indication of physics beyond the Standard Model.
The VIP-2 method consists in circulating a DC current in a copper strip, searching for the X radiation emitted by a PEP prohibited transition (from the 2p level to the 1s level of copper when this is already occupied by two electrons). The X-ray energy of 2p->1s transition in copper is about 8.0 keV, the anomalous one, forbidden by PEP, is about 7.7 keV.
The VIP experiment already set a strong limit on the PEP violation probability for electrons ($\beta 2/2$)<4.7·10-29.
The VIP-2 apparatus has been improved with new copper target and new X-ray detectors Silicon Drift Detectors(SDDs), cooled by a liquid Argon system to 150 K to get an energy resolution of 190 eV at 8 keV. The energy resolution of SDDs is about 400 ns. A veto system has been realized to reduce the background coming from cosmic rays and an external passive shielding to remove most of background coming from environmental gamma radiations. The experiment is actually in data taking at National Laboratories of Gran Sasso (LNGS) in Italy. The laboratories are underground, in the Gran Sasso mountain, in a very clean and low background area.
The goal of the upgraded VIP-2 experiment is to improve this limit by at least two orders of magnitude and explore theories beyond Standard Model allowing for small violations.
The experimental apparatus and preliminary results of the analysis of a first set of collected data will be presented.

The VIP2 experiment: scientific case

Experimental goal: Search for X-rays from PEP violating transitions

Energy transition Kα allowed: **8.05 keV in Cu**

PEP forbidden Kα energy transition: **~ 7.74 keV in Cu**

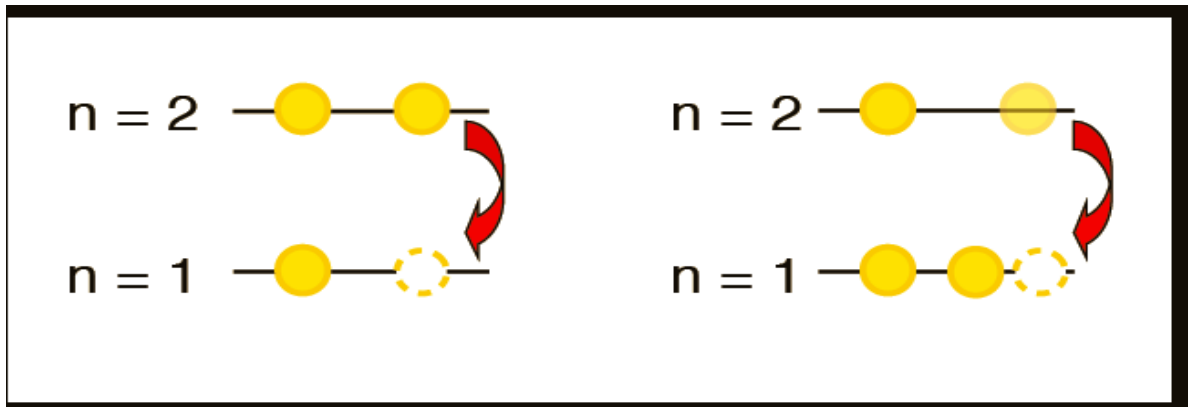
C. Curceanu, L. De Paolis et al., "Evaluation of the X-ray transition energy for the Pauli-principle-violating atomic transitions in several elements by using Dirac-Fock method", 2013, INFN-13-21/LNF.

MULTICONFIGURATIONAL DIRAC-FOCK METHOD

Software for muon atoms adapted to non-antisymmetric electrons

Parameter optimization through a self-consistent process

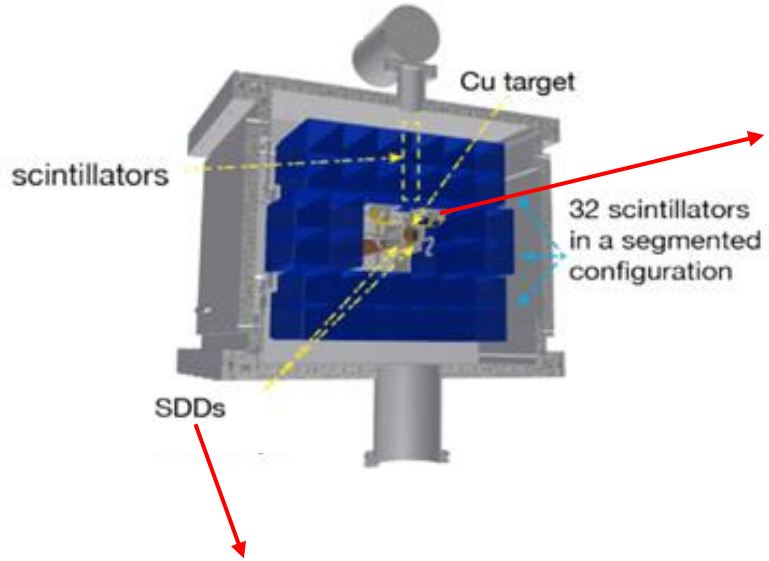
It takes into account: relativistic and radiative corrections, lamb-shift, Breit operator, ...



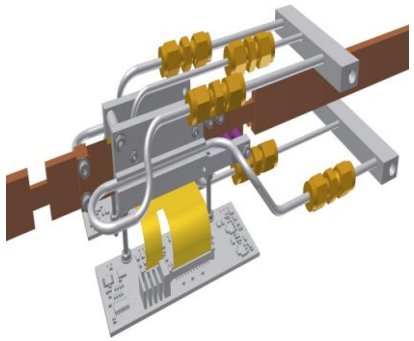
An e- in any level n>2 make a transition to level 2P.
The non-Paulian transition to level 1S produces the emission of a PEP violating X-ray.

The VIP2 experiment: purpose and apparatus.

Schematization of VIP-2 chamber

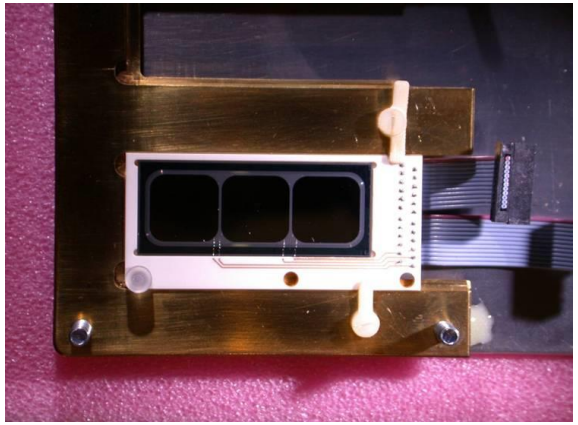


Target of VIP-2



Characteristics of the target: the 2 strips (10 cm x 1 cm x 25 μm) are connected to an external generator by 2 thin copper bars. Due to the Joule effect, the current(100 A) heats the target to 20 ° C. A water circuit cools the 2 copper strips so that the temperature of the SDDs does not increase by more than 2K.

Detectors of VIP-2



Characteristics of the detectors: SDDs arrays are organized in two arrays 2×8, for a total of 32 SDDs. The arrays are placed one for each side of target. Each SDD cell has $64\ mm^2$ of active area.

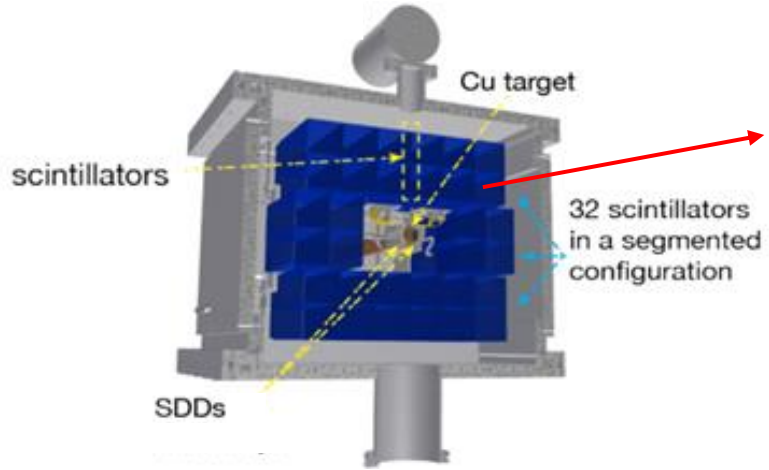
The SDDs are cooled to T≈ 100 K by liquid Argon to get a better performance in terms of energy resolution (~190 eV FWHM at 8 keV).

The SDDs provide information on timing: **400 ns (FWHM).**

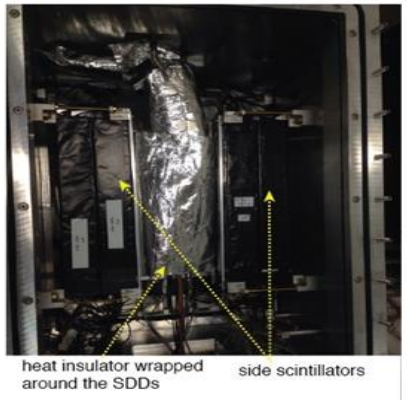
SUFFICIENT TEMPORAL RESOLUTION TO DISCRIMINATE THE BACKGOUND EVENTS

The VIP2 experiment: purpose and apparatus.

Schematization of VIP-2 chamber

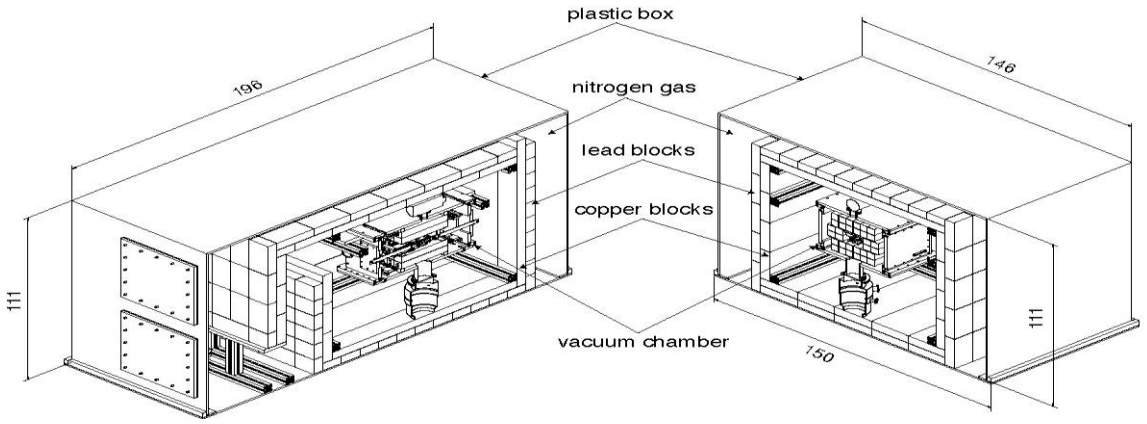


The VETO system



Characteristics of VETO system: composed of 32 plastic scintillators measuring $45\ cm \times 3\ cm \times 3\ cm$ and covering a solid angle > 90% compared to the target.
They are read by pairs of SiPM (with $3 \times 3\ cm^2$ of active surface each) located at both ends.
Reduce the background in the range of interest for a violation x-ray of about 1 order of grandness.

The Passive Shield



In November 2018 the final configuration of the VIP-2 experimental apparatus was completed with the passive shielding, made of two layers of lead and copper blocks.
The passive shield will kill most of the background due to environmental gamma radiation.

The VIP2 experiment: location and goal.

The experiment is taking place at National Laboratories of Gran Sasso (LNGS), an **extremely low background environment** inside the Gran Sasso mountain.

Improvements made compared to VIP:

- More compact system → improves acceptance → Eff_{geom}: 4%
- New target → 2 strip 10 cm x 1 cm x 25 μm
- Different cooling system for target (water)
- Current flowing into the target of 100 A
- New detectors SDD with better resolution, cooled with liquid Argon (100 K).
- Veto system with plastic scintillators read by SiPM (Silicon Photomultiplier)
- Expected data acquisition 3-4 years.

Changes in VIP2	value VIP2 (VIP)	expected gain
acceptance	12 % (~ 1 %)	12
increase current	100 A (40 A)	> 2
reduced length	3 cm (8.8 cm)	1/3
total linear factor		8
energy resolution	170 eV (320 eV) @ 8 keV	4
reduced active area	6 cm ^{2} (114 cm ^{2})	20
better shielding and veto		5-10
higher SDD efficiency		1/2
background reduction		200 - 400
overall improvement		> 120

Future goal:

$$\frac{\beta^2}{2} < 4.7 \times 10^{-29} \rightarrow 10^{-31}$$

A NEW preliminary upper LIMIT for the PEP violation probability of electrons in copper calculated in the new present configuration of the apparatus

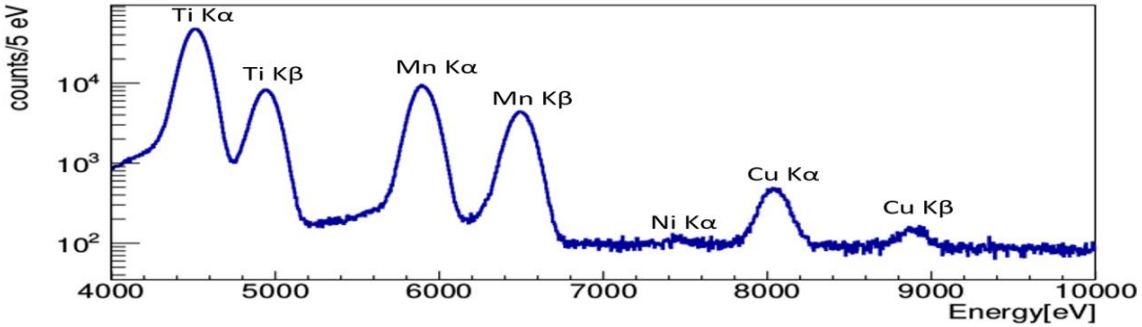
A preliminary result has been calculated using 42 days of data acquired during 2019 in the new present configuration of the apparatus.

$$\Delta N_x = 93 \pm 90$$

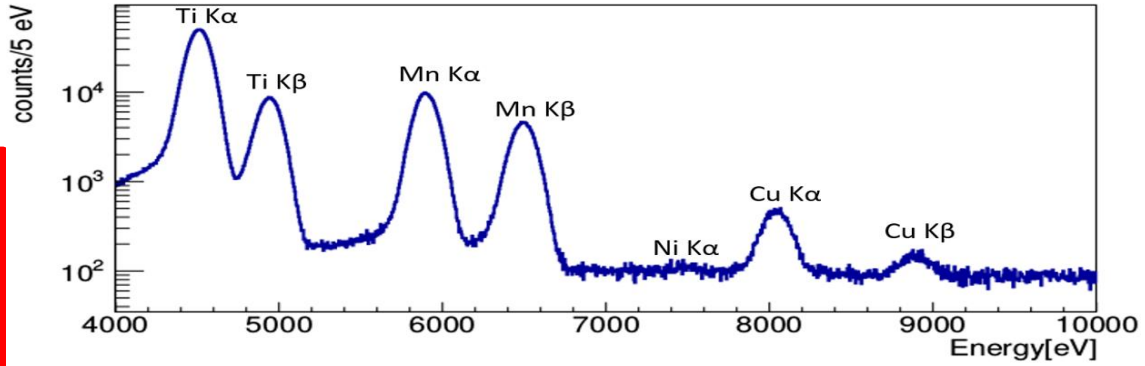
$$\frac{\beta^2}{2} \leq 1.6 \times 10^{-29}$$

Confidence Level: 99.73%

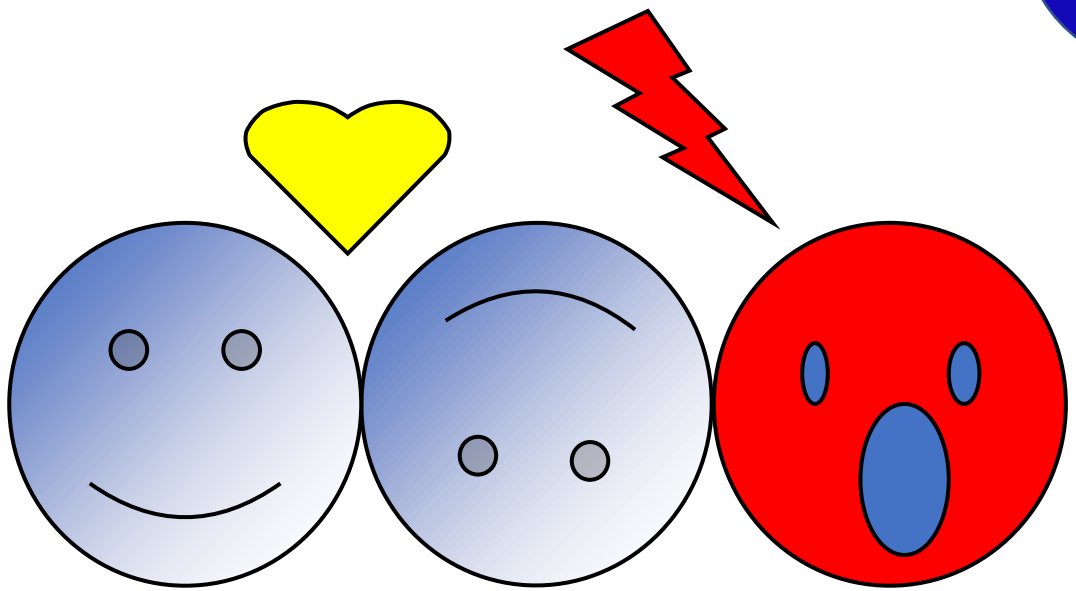
The upgrades done for the new configuration of the apparatus improved the result got in the space of about 80 days of data collection with the previous setup in about half of data taking time.



Energy calibrated spectra with current circulating on target (100 A)



Energy background calibrated spectra with current off normalized to 42 days



THANK YOU ALL FOR YOUR ATTENTION !!!