European Research Council

ERC Starting Grant – Stage 1
Research proposal

Upgrade of the LVD detector with Gadolinium

LVD-Gd

Principal Investigator: Marco Selvi
Hosting Institution: Istituto Nazionale di Fisica Nucleare (INFN) - Italy
Project duration in months: 36

Project summary: LVD is an experiment dedicated to the study of neutrinos from gravitational core collapse of massive stars, situated in the Gran Sasso National Laboratory (LNGS) in Italy; it is in data acquisition since 1992. It is made of 840 liquid scintillation counters, for a total active mass of about 1000 t.
The main interaction in LVD is the Inverse Beta Decay (IBD) of electron antineutrinos with the free protons of the target: it produces two signals, the positron and the 2.2 MeV gamma from the neutron capture. That second pulse is actually detected with 50% efficiency and an average delay of about 180 microseconds.
An important upgrade of the apparatus consists in improving the neutron capture efficiency and, thus, increasing the signal-to-noise ratio.
<u>We propose</u>, with this ERC-Starting-Grant project, <u>to dope with Gadolinium (Gd) the liquid scintillator of a whole tower of the LVD detector</u>: about 330 t, one third of the total mass.
This would be the largest amount of Gd-doped scintillator in the world !
Gadolinium has the maximum cross section for neutron capture and allows three main improvements: higher neutron capture efficiency, higher energy of the gamma released, and shorter time for the n-capture.
When doped with Gd, LVD will greatly improve its performances in the following main items:
- detection of burst of neutrinos from SN core collapse (with Gd just 4 events will be enough to trigger a worldwide alarm),
- possibility to distinguish among the neutrino flavours (the golden-plated electron neutrino interactions will be easily distinguished from the IDB interaction that, with the addition of Gd, will have an extremely clean signature),
- measurement of the neutron flux in the LNGS laboratory (very important for the “low background” experiments at LNGS).

A. Principal Investigator (PI) *(max. 3 pages)*

i. CV

Life:

Name	Marco Selvi
Birth	August 4th, 1971 in Forlimpopoli (FC), Italy
Married with	Anna Natali, since May 10th, 1998
Children	Cecilia (1999), Samuele (2002), Lorenzo (2006).
Nationality	Italian
Languages	Italian (mother tongue), English**.**

Education and Training.

July 1990	End of secondary education: "Diploma di maturità scientifica" at the Liceo Scientifico Statale ``Fulcieri" in Forli' (final score: 57/60).
1990-1996	Laurea degree course in Physics at University of Bologna, Italy. Degree thesis about "Measurement of the muon flux with the LVD detector, in the LNGS", tutor prof. Sartorelli, final score 110/110.
1996-1997	Civil service in an institution who cares about minors with disabilities.
1997-1999	Employed as a webmaster and web-programmer by a company in Rimini (Italy): development of web sites for E-commerce.
1999-2002	Ph. Doctorate in Physics at University of Bologna. Ph. D. Thesis on "Neutrino oscillation studies with a massive magnetic calorimeter", tutor prof. Basile, concluded **May 15th, 2002**.
2002-2005	Post-doc fellow (called "assegno di ricerca") at the Physics Department of the Bologna University.
2005-now	Researcher of the INFN (National Institute for Nuclear Physics) after a national selection in November 2005; first classified in Italy in the Astroparticle Physics sector.

Scientific activities

LVD: since 1995 I have been involved in the LVD experiment in the Gran Sasso National Laboratory (central Italy). It's a huge (1000 t) liquid scintillation detector mainly dedicated to the study of neutrinos from gravitational core collapse and to cosmic muon physics.

- During the degree thesis I developed the code for the reconstruction of the track of the cosmic muons and the MonteCarlo simulation (in Geant3) for the calculation of the detector acceptance. The results of this work (complemented by other analysis) where published in two papers in the Physics Review D journal (ref. 4 and 5).
- In 1999 I was involved in the transition of the data acquisition of the experiment from the old VMS-CAMAC system to a new Unix-VME one. In particular I took care of the web interface of the slow controls and monitors of the experiment.
- In 2002 I worked on the MonteCarlo simulation of the interaction of supernova neutrinos and of the CNGS beam neutrinos (ref. 2).
- In 2003 I started studying the effect of neutrino oscillations on the supernova neutrino signal in LVD (ref. 1).
- Since October 2003 I've been a member of the Editorial Board of the LVD experiment
- In 2004 I started the study of the muon-induced neutron flux in LVD. In 2005 we began the transition of the simulation code from Geant3 to Geant4, in order to take into account the production, propagation and detection of neutrons.
- In 2005 I was involved in an R&D study for the doping of the LVD scintillator with Gadolinium. Two counters were doped and we performed measurements of neutron capture

efficiency with a ^{252}Cf source and of attenuation length with the construction of a dedicated 2m-long detector.
- Since 2006 I've been Run Coordinator of the LVD experiment.
The results of the various analyses have been presented by me, on behalf of the LVD collaboration, in many international conferences and workshops.

MONOLITH: I dedicated my Ph.D. (1999-2002) to the feasibility study of a new experiment for the measurement of neutrino oscillations of atmospheric neutrinos. The proposed detector was a massive (34 kt) magnetized calorimeter, made of 8-cm thick iron planes interleaved with glass RPC detectors, to be hosted in one of the LNGS halls.
I actively participated in the "simulation" and "physics" working groups, studying the muon reconstruction and the determination of their momentum through the curvature in the magnetic field. I applied this technique in many fields: atmospheric neutrinos, CNGS beam ν and also neutrinos coming from a future "neutrino factory" (that is, neutrinos coming from the decay in flight of high energy accelerated muons).
I studied various possible configurations of the detector to optimize its performances and costs.
The work culminated with the preparation of the proposal of the experiment in 2000 and its addendum in 2001. In the framework of the neutrino factory study I participated in a working group at CERN, leaded by prof. Dydak, and I took part to the writing of a CERN Yellow Report.
We built a small scale module of the detector and we tested the performances in a test beam at CERN. The results of the test are in ref. 3.
The proposal was considered very important from the point of view of its impact to neutrino physics by the LNGS scientific committee, but it was not approved because of the lack of space in the experimental halls.
The results of the various analyses have been presented by me, on behalf of the MONOLITH collaboration, in many international workshops.

REACTOR NEUTRINOS: in the framework of neutrino oscillation I participated, since 2003, in an international working group to study the feasibility of a new experiment with reactor neutrinos through two identical detectors, one near and one far, in order to reduce the systematic errors of the measurement. The activity has been written in a White Report.

EEE: it's an outreach project, started in 2004, which aims to build and install cosmic ray detectors in the secondary schools in Italy. The detector is a telescope made by three planes of Multigap Resistive Plate Chambers, which allows the tracking of the crossing muons.
My main responsibilities are: the simulation of the detector (and of the telescope network) performances to the flux of cosmic muons and of extended air showers, and the construction of the MRPC planes assisting students and teachers of secondary school at CERN.

Teaching and tutoring: since 2001 I've been acting as an assistant professor in some basic and advanced courses of the Science Faculty of Bologna University: "Physics", "Laboratory of Subnuclear Physics" and "Advanced techniques for particle detection"; I participated in the examinations.
I'm a tutor in the Physics Laboratory.
In 2004 I was co-tutor for a Ph.D. thesis about the neutron flux measurement with LVD.
In 2006 I was co-tutor for a degree thesis about the MonteCarlo simulation of LVD with Geant4.

Main publications:
1. STUDY OF THE EFFECT OF NEUTRINO OSCILLATION ON THE SUPERNOVA NEUTRINO SIGNAL IN THE LVD DETECTOR
Astroparticle Physics, 27 (2007) 254-270
e-Print Archive: hep-ph/0609305
(corresponding author)

2. CNGS BEAM MONITOR WITH THE LVD DETECTOR.
Nucl. Instrum. Meth. A 516, 96-103 (2004)
e-Print Archive: hep-ex/0304018
LVD Collaboration
(corresponding author)

3. ANALYSIS OF THE PERFORMANCE OF THE MONOLITH PROTOTYPE. -
G. Bari, A. Candela, M. De Deo, M. D'Incecco, M. Garbini, P. Giusti, C. Gustavino, M. Lindozzi, H. Menghetti, G. Sartorelli, G. Satta, M. Selvi (Bologna U. & INFN, Bologna & Gran Sasso & Frascati)
Nucl. Instrum. Meth. A 508, 170-174 (2003)

4. UPPER LIMIT ON THE PROMPT MUON FLUX DERIVED FROM LVD UNDERGROUND EXPERIMENT.
Phys. Rev. *D* 60, 112001 (1999)
LVD collaboration

5. MUON "DEPTH-INTENSITY" RELATION MEASURED BY LVD UNDERGROUND EXPERIMENT AND COSMIC-RAY MUON SPECTRUM AT SEA LEVEL
Phys. Rev. D 58, 092005 (1998)
LVD Collaboration

ii. Self Evaluation
I have a ten year long experience as a researcher, mainly in the field of astroparticle physics, in particular neutrino and cosmic rays physics.
I have a solid academic formation that allows approaching the physics problem in the most open-minded and theoretically founded way.
I think I have a strong background in almost all the aspects of conducting a physics experiment: constructing and maintaining detectors, performing MonteCarlo simulation for the optimization of the detector or to evaluate its response, analyzing data and finally publishing the results in referred papers and presenting them in international conferences and workshops.
The formal responsibilities assigned to me (Editorial Board member, Run coordinator) demonstrate that I can carry on important roles inside a collaboration.
Thus I think that all these skills demonstrate my potential to become an independent research leader.

iii. Funding ID
I’m actually employed as a researcher by the INFN, Sezione di Bologna, with a 5 years contract (it will terminate at the end of 2010).
INFN funds the “normal” activity of the LVD detector, but there is no funding dedicated to the object of this proposal.

B. Research Project *(max. 4 pages)*

i. State-of-the-art and objectives

The objective of the project is to set up a very powerful electron antineutrino detector by doping with Gadolinium about 300 tons of the active mass (liquid scintillator) of the existing LVD detector.

LVD is an experiment mainly dedicated to the study of neutrinos from gravitational core collapse of massive stars, situated in the Gran Sasso National Laboratory (LNGS) in central Italy, in data acquisition since 1992. It is made of 840 identical liquid scintillator (LS) counters (1 x 1 x 1.5 m^3 each), for a total active mass of about 1000 t.
The main interaction in LVD is the Inverse Beta Decay (IBD) of electron antineutrinos with the free protons of the target: it produces two signals, the positron and the 2.2 MeV gamma from the neutron capture. That second pulse is actually detected with 50% efficiency and an average delay of about 180 microseconds.
An important upgrade of the apparatus consists in improving the neutron capture efficiency and, thus, increasing the signal-to-noise ratio.

In this scenario we propose to add Gadolinium (Gd) to the liquid scintillator of LVD.
This implies three main improvements:

1. Gadolinium has the maximum cross section for neutron capture among all the elements and, thus, it allows to improve the efficiency for the detection of the IBD characteristic double signature.
2. When the neutron is captured, Gd emits a gamma cascade, whose total energy is about 8 MeV (instead of 2.2, see fig.1-left). This pulse is thus situated in an energy region where the background of natural radioactivity present in the LNGS halls is very low.
3. The mean delay between the two pulses is reduced to about 25 μs (against 200, see fig.1-right). This allows to use a very short time window for the coincidences and, thus, to reduce the chance background.

For about two years I’ve been carrying on, together and in strong collaboration with a group of researchers from INAF-IFSI (Turin) and INFN (Bologna and LNGS), an R&D study to measure the performances and demonstrate the stability of the liquid scintillator of LVD doped with 0.1% of Gd: two counters were Gd-doped, for a total amount of about 2.5 t of LS.

The R&D phase is almost concluded: preliminary results are encouraging and the final results are foreseen in a few months.

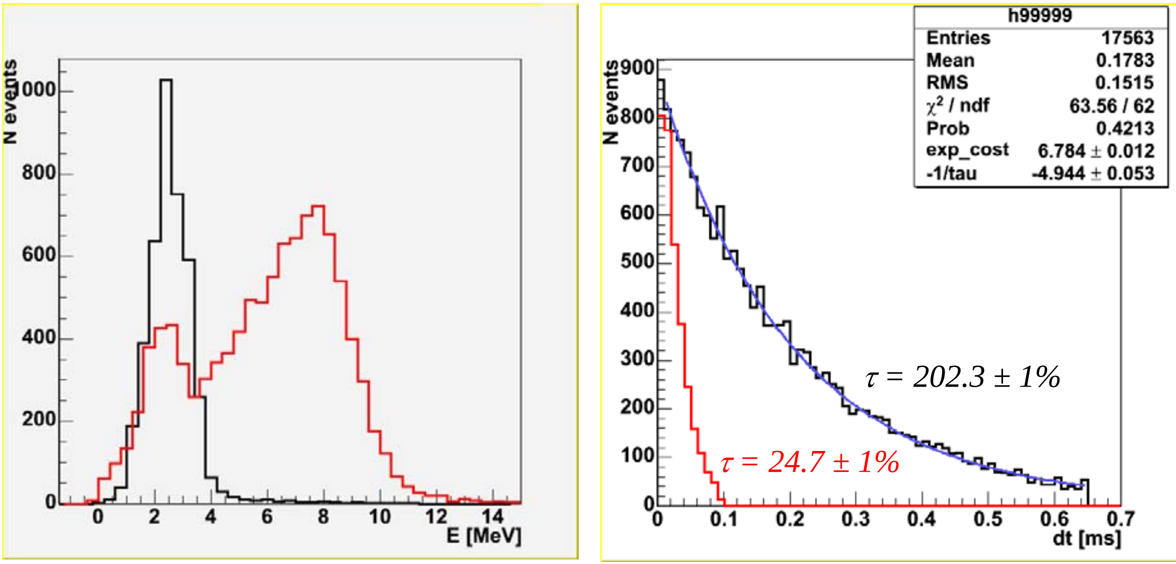

Figure 1: (left) energy spectra of the γ from the n-capture in the LS; (right) neutron capture time. The curves are for unloaded (black) and Gd-loaded (red) LS.

We propose, with this ERC-Starting-Grant project, to dope with Gadolinium the liquid scintillator of a whole tower of the LVD detector: about 330 t, one third of the total active mass. **This would be the largest amount of Gd-doped scintillator in the world !**

In this way we improve the performances of the LVD detector in the following main items:

- Detection of bursts of neutrinos from supernova (SN) core collapse.
  The search for neutrino burst is performed subdividing the time sequence of the data in many windows, 20 s long, and comparing the number of events in each window with the number of the expected ones due to the background (bkg), considering its Poissonian fluctuation.
  In the actual configuration the background rate in LVD is about 0.3 Hz and we can define the SN alarm when there are more than 25 events in 20 s (imitation frequency of the background lower than one per century).
  Adding Gd the background rate is reduced to 0.003 Hz, two orders of magnitude lower, and the threshold for a SN alarm is just 4 events !
  Thus it is possible to recognize a SN event even in the case of a very weak signal and to alert immediately the worldwide community through the SNEWS network (LVD is an active member of it).
  Of course LVD would become extremely sensitive not only to SN neutrinos, but to each potential source of electron antineutrinos and this opens the possibility of studying correlation between cosmic events (e.g. gamma ray bursts or solar flares) and the neutrinos detected in LVD.

- Possibility to distinguish among the neutrino flavours.
  During a SN core collapse are emitted neutrinos of all flavours, almost equipartitioned. Very important information about the neutrino oscillation parameters (θ_{13} and the hierarchy of the neutrino masses, actually not known) can be derived if one is able to measure both electron neutrinos and antineutrinos and compare their number and energy spectra. LVD can detect mainly antineutrinos through their interactions in the liquid scintillator, but also a good number (about 15% of the total) of electron neutrinos through their interactions with the iron support structure.
  In the actual configuration these events are identical to the IBD when the second pulse

goes undetected because of the limited neutron capture efficiency, so the physical information that can be extracted is rather limited.
With the Gd the IBD sample is very clear, thus the electron neutrino interactions are very easily discriminated and can be studied in details, providing important information about the physics of the star collapse and the intrinsic properties of the neutrinos.

- Measurement of the neutron flux in the LNGS.
  One of the main sources of background in the underground laboratories is due to fast neutrons. Experiments searching for dark matter or rare events (for example neutrinoless double beta decay) are particularly interested in knowing the neutron flux at the best level. Neutrons can come, for energies up to 10 MeV, from the natural radioactivity of the rock and, at higher energies, from electromagnetic and hadronic cascades originated by high energy muons.
  LVD can be particularly sensitive to the muon induced neutrons, since with its large acceptance it can easily detect the crossing muons and then look for the neutron interaction and capture inside one of the scintillation counters.
  Up to now there are in literature few measurements, performed at different depth underground, whose interpretation is not trivial; thus a new, large statistic and clean measurement would be very appreciated by the “low background experiment” community.
  The addition of Gd, increasing the neutron capture efficiency, can greatly enhance the LVD capabilities in this measurement.

ii. Methodology

The LVD detector has a modular structure, made of 3 identical “towers”, independent in terms of power supply and data acquisition. Each tower is composed by 280 scintillation counters. Each counter is 1.5 m^3 and contains about 1.2 tons of liquid scintillator, viewed from the top by three 15-cm photomultipliers.
The LVD modularity is very important to guarantee a high duty cycle, crucial in the study of SN neutrinos. In the last five years LVD was monitoring the galaxy for 99.5% of the time.

We plan to dope with Gd the scintillator of a whole LVD tower, in order to have a complete independent detector with the same target characteristics: 336 tons of Gd-loaded liquid scintillator.

Gd liquid scintillator production.

The Gd salt is synthesized by driving the Gd (metal) bounded in a proper organic molecule: Gd carboxylate (Gd-CBX). The best carboxylic acid (HR) for this purpose has been theoretically and experimentally determined to be 2MeVA (C6), because of its solubility (steric factor) and optical properties.
Synthesis procedure has been optimized controlling the leading parameters of each reaction step: reagents purification, acid neutralization, salt formation, filtration, drying.
Then the Gd salt is diluted in the LVD liquid scintillator, which is a mixture of aliphatic and aromatic (8%÷12%) hydrocarbons C_nH_{2n}, $\langle n \rangle = 9.6$ with [PPO] = 1.3 g/l, [POPOP] =30 mg/l, ρ=0.78 g/cm^3.

We will prepare an amount of liquid scintillator with a very high level of Gd concentration inside it (up to 5% in weight) and use this “master solution” to substitute a small amount (about 30 litres) of liquid scintillator in each counter, in order to get the final desired Gd concentration: 0.1% in weight.

The performances of the Gd-loaded scintillator have to be monitored through the use of a neutron-emitting radioactive source such as ^{252}Cf, surrounded by a Surface Barrier counter that gives the trigger to the data acquisition.

iii. Resources

The research team is composed by me together with 3 young researchers (at the moment they are post-doc in Bologna University & INFN and Turin INAF-IFSI) and one (not permanent) technician from Turin.

They have been involved in the R&D phase of this project, so they are skilled with the production, dilution, introduction and monitoring of the Gd-doped liquid scintillator.

I think that at least 4 or 5 people are needed for conducting the big effort of doping with Gd such a huge amount of scintillator.

We need the collaboration of the INFN Gran Sasso National Laboratory infrastructures, in particular the possibility to have a dedicated area in the external Mounting Hall and the support of the chemical laboratory of the LNGS.

iv. Ethical issues

None of the ethical issues described in the “Annex 7” apply to this proposal.

C. Research Environment *(max. 1 page)*

i. Transition to independence

Acting as a Principal Investigator in this project will greatly enhance my transition to become an independent research leader. I'll have the possibility to lead a significant group of enthusiast young people (4+myself) and to conduct a research which is leader in its field; in fact no other detector in the world can detect weak signals with the sensitivity of the Gd-doped LVD. The first results about the muon-induced neutron flux can be published just two years after the completion of the doped scintillator. Anyway the main goal, of course, is the detection of a supernova core-collapse in our galaxy with this novel (at this scale) technique.

ii. Hosting institution

The hosting institution for this project is the Italian National Institute for Nuclear Physics (INFN). It is an organization dedicated to the study of the fundamental constituents of matter, and conducts theoretical and experimental research in the fields of subnuclear, nuclear, and astroparticle physics. Fundamental research in these areas requires the use of cutting-edge technologies and instrumentation, which the INFN develops both in its own laboratories and in collaboration with the world of industry. These activities are conducted in close collaboration with the academic world.
In particular, the INFN Gran Sasso Laboratory is the biggest and most important underground laboratory in the world. It will support this project by hosting the detector and providing adequate help with the Mounting Hall facility and the chemical laboratory.

iii. Budget

The overall budget requested for the project is 1200 k€, distributed over the 3 years duration as 400 k€ per year.
About 175 k€ per year are for the personnel (3 researchers and 1 technician).
The other direct costs are mainly for the equipment (Gd and chemicals reagent, 1.5 k€ per counter: 420 k€ in total), manpower and travels (40 k€ per year).
About 15% of the direct costs are considered for the indirect costs.
The details of the various items will be better described at Stage 2, as asked in the "Guide".

iv. Additional participants

There are no additional participants.