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FACOLTÁ DI SCIENZE MATEMATICHE, FISICHE E NATURALI
CORSO DI LAUREA IN INFORMATICA

Sviluppo di un software di visualizzazione 3D per il telescopio per neutrini NEMO

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Alla mia famiglia
Daniela, Roberto e Gloria

Introduzione

L'osservazione artronomica vede nel prossimo futuro un radicale cambiamento in termini di tecnologia di rilevazione. L' utilizzo di strumenti convenzionali come telescopi e radiotelescopi o comunque dispositivi atti alla rilevazione di fotoni o raggi cosmici, porta con sé delle limitazioni non indifferenti.

Per quanto riguarda i fotoni, diventa necessario studiare quelle particelle con sempre piú alta energia, tale da arrivare fino a noi dagli spazi piú reconditi dell'universo. Purtroppo i fotoni ad alta energia tendono ad essere assorbiti dalla radiazione di fondo dell'universo e diventano ad un certo punto inutilizzabili come sonda per studiare fenomeni astrofisici.

Allo stesso modo i raggi cosmici comportano dei problemi dovuti soprattutto alla loro influenza da parte di campi magnetici galattici ed extra-galattici. Dunque, le limitazioni dei mezzi convenzionali, che sempre di piú appaiono ingombranti dal punto di vista della ricerca, hanno portato a valutare l'utilizzo di altre particelle con caratteristiche per molti aspetti nettamente migliori: i *neutrini*.

Un neutrino é una particella con carica elettrica nulla e con massa trascurabile, per questi motivi tende ad attraversare enormi porzioni di universo indisturbatamente, arrivando fino a noi senza essere deviato da campi elettrici, magnetici o gravitazionali e trasportando dunque gran parte dell'informazione intatta attraverso il cosmo.

Tuttavia la costruzione di un telescopio per neutrini rappresenta una sfida tecnologica di enormi proporzioni. A causa dell'elevatissima sensibilitá di un rilevatore di neutrini, diventa necessario costruire apparati non solo enormemente grandi, ma in luoghi protetti dalle particelle che provengono dall'atmosfera a causa dell'interazione con i raggi cosmici e che rappresentano un rumore insostenibile per il rilevatore.

Attualmente i progetti di ricerca finalizzati alla costruzione di un telescopio per neutrini sono vari: Antares, NEMO, ICECUBE, Baikal e Nestor; in particolare il progetto *NEMO* - NEutrino Mediterranean Observarory, si pone di effettuare uno studio di fattibilitá per la realizzazione di un dispositivo che consisterá in una griglia cubica di moduli ottici del volume di 1 Km^3 posta sul fondo del Mar Mediterraneo a -3500m di profonditá. Tale struttura *guarderá* verso il basso utilizzando il pianeta come filtro per rilevare i neutrini che, indisturbati, attraversano la Terra. La ricerca condotta da NEMO ha giá portato alla deposizione nell'imminente futuro di una piccola parte del telescopio che dará inizio ad una prima fase di importanti rilevazioni: il progetto *NEMO Phase-1*.

Il mio lavoro nasce dalla necessitá di disporre di un software di visualizzazione per la grande mole di dati prodotta in futuro dal telescopio ed ora dai programmi di simulazione. Il software creato deve essere in grado di offrire un'interfaccia di interazione visiva ed una serie di strumenti di analisi degli eventi registrati o simulati, deve rappresentare inoltre un tool efficace per lo studio di tali fenomeni e dunque la sua realizzazione necessita di un costante feedback da parte dei ricercatori che ne faranno uso.

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La natura é costretta dalla ragione della sua legge, che in lei infusamente vive.

Leonardo Da Vinci

Abstract

The astronomic observation is going to encounter a radical change in terms of survey technology. The usage of conventional instruments like telescopes and radiotelescopes or whatever device able to detect events based on photons and cosmic rays, presents a set of limitations.

Regarding photons, it become necessary to study particles with a steady increasing energy, high enough to arrive to us from the furthest places in the universe, unfortunately high-energy photons tends to be absorbed by the microwave background of the universe, becoming unusable for astrophysics detection.

At the same time, cosmic rays are influenced from galactic and extra-galactic magnetic fields, so their trajectory presents unpredictable modifications. Therefore, the limitations of conventional media constrict to evaluate the usage of other particles with better characteristics: *neutrinos.*

A neutrino is a particle with neutral electric charge and a negligible mass, for these reasons it tends to travel across the universe without external influences, arriving to us avoiding the deviation from electric, magnetic or gravitational fields and so, carrying the information intact.

However, build a neutrino telescope have to be considered still a difficult technological challenge. Caused to the high sensibility of the detector, it become necessary to realize not only very huge surveyors, but also to place them into a secure environment, protected from the noisy particles coming from the atmosphere.

Actually there are already some research projects involved in the realization of a neutrino telescope: Antares, NEMO, ICECUBE, Baikal and Nestor; In particular the *NEMO* - NEutrino Mediterranean Observatory project is aimed to perform a feasibility study for the realization of a large detector consisting of a cubic grid of optical modules of 1 Km^3 volume, placed in the seabed of the Mediterranean Sea at -3500m depth.

Such a grid will be pointed towards the bottom using the planet as filter for the survey of neutrinos that come from the other side of the planet.

The research made by NEMO has brought to foresee the deployment of a first piece of the telescope shortly, this structure will start a preliminary detection procedure and is called *NEMO Phase-1* project.

My work comes from the necessity of providing a visualization software able to treat the great amount of data produced by the telescope (in the future) and by simulation programs (in the present). This software must offer a flexible interface and a set of analysis tools, besides it must be an effective application for the study of the phenomena. Therefore, in order to obtain good results, its realization needs a constant feedback from those researchers who may use it in the future.

Chapter 1

Watching the universe

Actually our knowledge of the universe has been achieved from the observation of electromagnetic waves and cosmic rays coming from the space.

In particular electromagnetic waves, which are made up of photons, represent the most objects medium we can use to worm information from the universe. Photons are electrically neutral particles, their trajectory isn't influenced from galactic and extra-galactic magnetic fields. Therefore they are a suitable probe for the observation of the universe through a lot of conventional technologies such as telescopes, ground observatories and radio surveyors, however photons with an energy greater than 100 TeV coming from sources further than 10 Mpc can't reach the Earth because they are absorbed from the *CMB - Cosmic Microwave Background* producing pairs e^+ e^-. Thus, for those type of deep observations an approach with photons is not a good solution.

Regarding the cosmic rays, often they don't travel over a straight trajectory because they can be deviated from magnetic and gravitational fields due to their electric charge and their non-negligible mass.

For these reasons, astrophysical surveys of the future will use a different approach based on *neutrino*, a particle without electric charge and with a negligible mass. Due to its characteristics it interacts with the environment only through the *weak nuclear interaction*, avoiding absorption and deviation. Neutrinos travel across enormous distances without have been influenced, always straight ahead, so we can consider them as the furthest objects we can perceive.

1.1 Conventional media

1.1.1 Photons

Despite their good characteristics such as the neutral electric charge, photons begin to present problems for high energies, that is when they are produced from sources like AGN - *Active Galactic Nuclei* and GRB - *Gamma Ray Burst*.

Photons with an energy on the order of one TeV are absorbed from the infrared background of the universe, those on the order of one PeV are absorbed from the microwave background and those with an energy on the order of one EeV interacts with the other photons in the microwave spectrum range. Therefore for high-energy photons the universe become much less transparent or even totally opaque.

Obviously only these photons could have enough energy to arrive to us from the furthest zones of the universe, thus we unavoidably reach an insurmountable distance limit when we try to study the most hidden place of our universe with such particles.

1.1.2 Cosmic Rays

The cosmic rays are particles coming from the outside of the Solar system and hitting the Earth, they are a mixture of protons (92%), helium nuclei (6%), electrons (1%), heavy nuclei (1%) and gamma rays (0.1%). The great part of these rays comes from the Sun, however inside this *particles rain* it can be found a little percentage of matter coming from the outside of the Solar system.

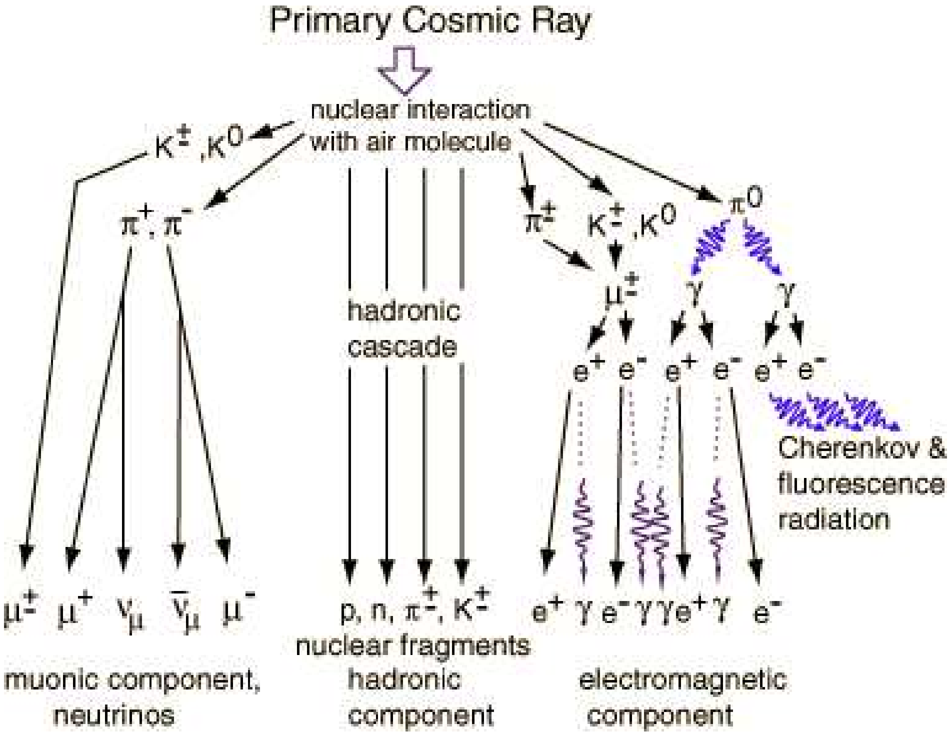


Figure 1.1: *Generation of a swarm of particles when cosmic rays meet the Earth's atmosphere*

The described objects interact with the Earth's atmosphere by generating a swarm of several other particles such as *pions*, *electrons*, *positrons* and *muons*, during a cascading-style process. Although we can consider all the particles with an energy $< 10^5$ eV to coming from outside the Solar system (the great part from *Supernovae* and *X binaries systems*), they are extremely difficult to treat and the employment of complex survey devices, placed on board of satellites and aerostatic balloons is needed for cosmic rays analysis.

1.2 Neutrinos

The discussed problems constricts to choose a different way to perform cosmic surveys: *neutrino telescopes*. Neutrinos are particles which have a minimal interaction with the external environment, so they are able to travel across galactic distances without have been influenced.

These properties make neutrinos a perfect probe to research on the universe phenomena. Unfortunately their extremely low interaction with the environment becomes a problem for the survey. In fact, in order to use neutrinos for our purposes, we have to build a detector that, contrarily to the rest of the universe, must be able to recognize the

passage of a neutrino and obviously, a device able to see such a silent particle is not a simple thing to develop. This issue will be discussed further, instead now we will overview the most relevant sources of neutrinos in the universe in order to understand what are our discovery possibilities.
Swarms of neutrinos are produced first of all by extra-galactic sources such as AGNs and GRBs, however they can be generated also by galactic sources like *supernovae* and *microquasars.*

1.2.1 GRB - Gamma Ray Burst

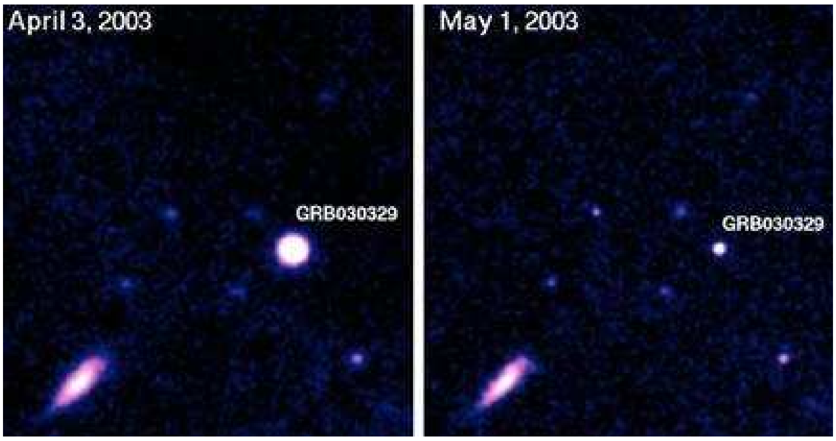


Figure 1.2: *An example of Gamma Ray Burst*

GRBs are short-lived bursts of gamma-ray photons generated from high-energy phenomena such as *supernovae* explosions and other type of violent events.
These events can be registered roughly once a day from a totally random direction of the space, they were discovered in the late 1960s by U.S. military satellites which were on the look out for Soviet nuclear testing in violation of the atmospheric nuclear test ban treaty and represents one of the most mysterious phenomena of the universe.

According to the *collapse* model, these flashes of gamma rays are caused by a collapse of a special kind of supernova called *hypernova.* This collapse is followed by an enormous explosion which blows up inside the core of the star and propagates an outgoing blast wave, this wave hits the external matter of the star and generates a great amount of gamma rays and neutrinos.

1.2.2 AGN - Active Galactic Nuclei

AGN is a central region of a restless galaxy that presents a high level of energetic phenomena emitting a great amount of radio waves. These are *Syfert galaxies*, *radio galaxies*, *quasars* or *BL Lac* objects that, even if their size is less than the Solar system one, show a high level of activity and generate a lot of electromagnetic radiation and particles flows. The current theory suggests that there is a supermassive black hole (millions of times the mass of the Sun) at the center of most AGN.

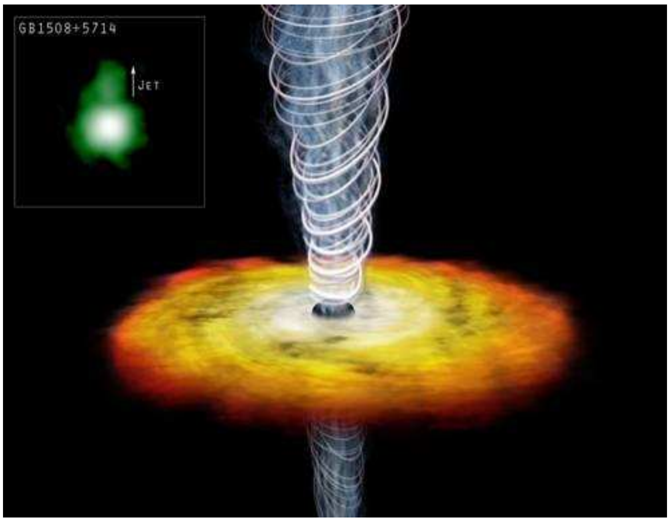


Figure 1.3: *An evocative view of an Active Galactic Nuclei*

1.2.3 Supernovae

As we know the fuel of a star is hydrogen, inside the core this element is continuously molten as described by the nuclear fusion process. When the hydrogen ends, the star begin to fuse its derived elements, starting from helium to iron which cannot be fused ulteriorly. At this point the thermodynamic equilibrium is broken, the gravity force is no more equal of the outgoing force caused by the energy and if the star has a mass greater than the critical value of 1.4 solar masses, an enormous explosion happens. This is called a *Supernova*.

During this explosion, that brought to the generation of a *neutron star* or sometimes of a *black hole*, a great deal of neutrinos is produced and spread out from the star by the gravity collapse. This phenomena produce a lot of electromagnetic waves and also a big neutrinos swarm.

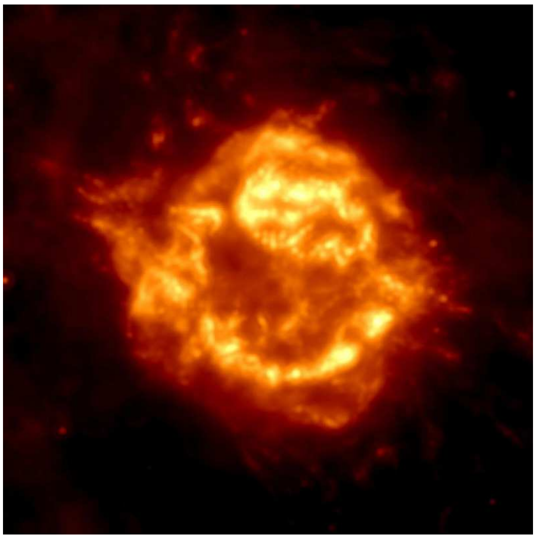


Figure 1.4: *A Supernova remnant*

1.2.4 Microquasars

An object of stellar mass that displays in miniature some of the properties of quasars, including strong emission across a broad range of wavelengths (from radio wave to X-ray) with rapid variability in X-rays, and radio jets. A microquasar consists of a binary system in which a normal star orbits around, and loses matter to, a nearby compact object, either a black hole or a neutron star.

The lost matter enters a fast-spinning accretion disk, is heated to millions of degrees, and then either falls onto the compact object or is ejected as a bipolar flow.

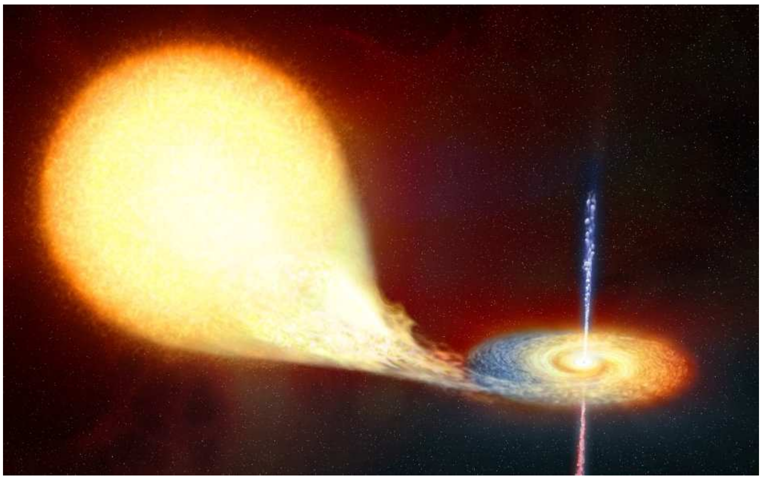


Figure 1.5: *A pictorial view of a Microquasar*

1.3 Neutrino telescopes: the NEMO project

The exploitation of neutrinos for astrophysical survey needs the development and the realization of a *neutrino telescope*, a huge device that make necessary a great R&D effort. Nowadays there are already some experiments involved in the realization of such a type of device:

- Antares - `http://antares.in2p3.fr`
- NEMO - `http://nemoweb.lns.infn.it`
- IceCube - `http://icecube.wisc.edu`
- AMANDA - `http://amanda.berkeley.edu`
- Baikal - `http://www.ifh.de/baikal/baikalhome.html`
- NESTOR - `http://www.uoa.gr/∼nestor`

In particular the *NEMO* project is a collaboration formed in the 1998 that aim to conduct a feasibility study and then to realize an underwater *Čherenkov* detector in the Mediterranean Sea.

The goal is to project and build a telescope called *KM3*, a 1 km^3-size cubic grid of photomultiplying tubes placed in the seabed able to survey high energy neutrinos coming

from the space.
Up to now only smaller scale detectors, of the order of 0.1 km^3 have been realized or are under construction, demonstrating the feasibility of the technique of Čherenkov detection of neutrino induced muons in deep water or ice.

Studies performed until now have permitted to find an optimal location for the telescope and to undertake a realization of a smaller scale technological demonstrator called *NEMO Phase 1*. The NEMO project works in narrow collaboration with the Antares project and can be considered full complementary in terms of sky coverage with the ICE-CUBE project that is under construction at the South Pole.

1.3.1 The NEMO's site

The choice of the right site where to place a km^3 telescope expects to perform a lot of physical and oceanographic surveys. All the sea campaigns performed on the location of *Capo Passero*, about 80 Km from the southern coast of Sicily, have confirmed this place as adapt for the experiment in terms of:

- Currents
- Sedimentation
- Seabed geology
- Water transparency
- Optical background
- Oceanographic parameters

The deployment of such a detector into the sea gives the opportunity for other projects interested on sea-related researches to use this structure to perform other type of activities. One of these projects is the first seismic underwater monitoring station, called SN-1 and realized by the INGV - *Istituto Nazionale di Geofisica e Vulcanologia.*

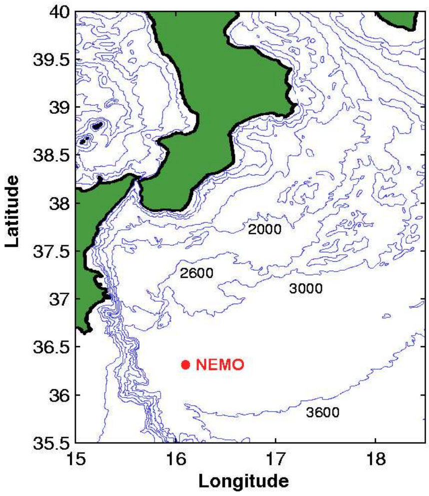


Figure 1.6: *Capopassero: the site where the NEMO telescope is proposed to be deployed*

1.3.2 The Čherenkov radiation

Due to their low interaction, neutrinos can be detected only using an indirect way. The mass of a neutrino can be considered negligible, however it interacts with the external environment through the weak interaction (with an hit section of $10^{-35} cm^2$ for $E_n \sim = 1\ TeV$).

This corresponds to an impact with the matter that produces a *muon* which start to travel after the hit along the trajectory of the original neutrino.

A *muon* is a charged particle and in this case it travels faster than the speed of light in the air, therefore influencing the matter across the water it generates electromagnetic waves called *Čherenkov* radiation with an edge of roughly 42 degrees.

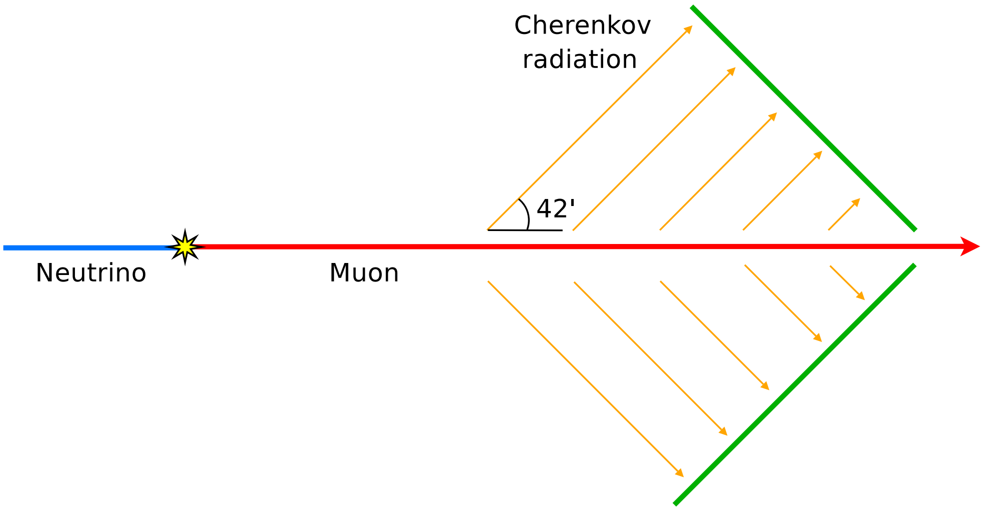


Figure 1.7: *Čherenkov radiation induced by a muon*

This radiation, made up of photons, can be detected from the telescope using *Photo-Multiplying Tubes* or in general *Optical Modules*. The main causes of background for a neutrino telescope are:

- Bio-luminescence

  Fishes and bacteria that live in high-depth environments can generate bio-luminescence, influencing the optical modules. This problem is well-known from the Antares (depth = -2500m) experience and should be smaller at a depth of -3500m.

- Atmospheric muons

  As discussed before, the interaction of the cosmic rays with the Earth's atmosphere generates a bundle of particles. Muons are the most penetrating particle among them, however a large fraction of atmospheric muons are filtered out from the water (they are reduced by a factor of 10^6 by 3Km of water).

- K40 background

  An isotope of Potassium is present and uniformly distributed in the sea water. Unfortunately it is radioactive and produces a constant noise of about 35 KHz on the optical modules used by NEMO and ANTARES. Such as K40 background represents the first noise problem for underwater neutrino telescopes and it make necessary to use triggering softwares able to distinguish true physical events from random PMTs activation produced by the K40 background.

1.3.3 The structure of the detector

The km^3 telescope will uses as fundamental sensor unit a NEMO's *bar*, a fiberglass-made structure 20m long on which are positioned two couples of optical modules, one for each extremity of the bar.
Each couple is made up of one optical module pointed towards the bottom and one pointed towards the direction of the bar. The figure below shows the structure of a bar, also called *arm*.

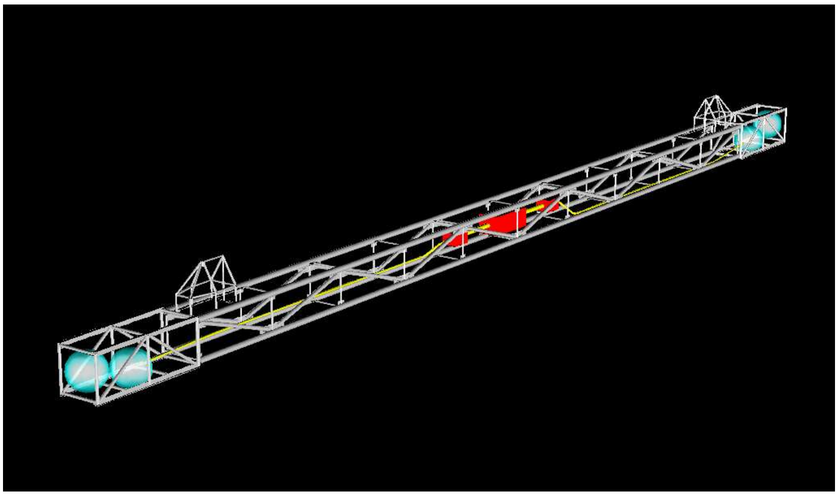


Figure 1.8: *A NEMO's bar structure*

A couple of these arms placed along a vertical direction at a distance of 40m, one with 90 degree of horizontal rotation as regards to the other, forms a cluster. Clusters which are made up of 2 bars and then 8 optical modules are arranged in vertical semi-rigid towers at a distance of 40m in groups of 9, performing a total height for each tower of 750m. The km^3 telescope will has 81 of the described strings, 5832 optical modules in total.

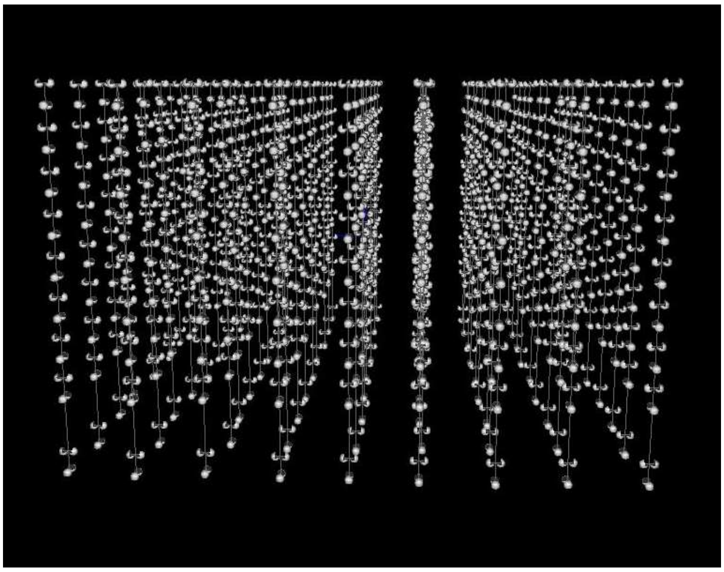


Figure 1.9: *KM^3's geometry*

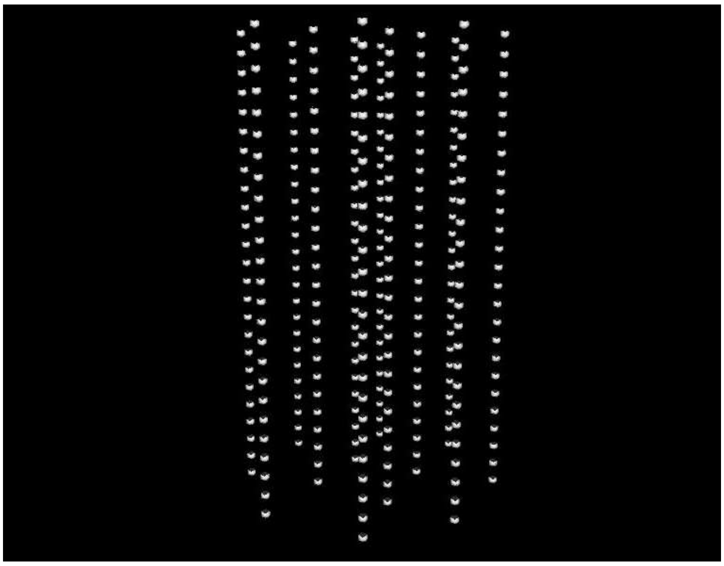


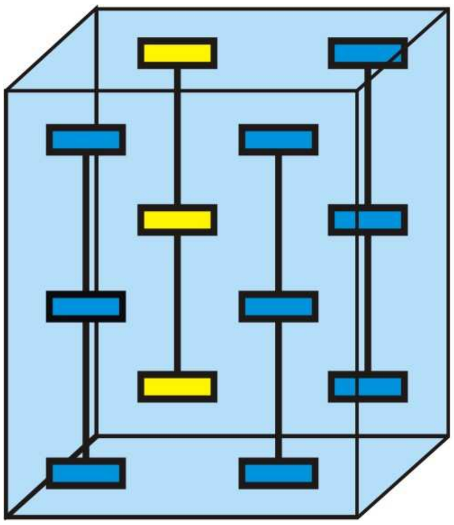
Figure 1.10: *ANTARES' geometry*

1.3.4 Nemo phase-1

The NEMO phase-1 project consists on the deployment of a couple of NEMO strings into the Ionian sea foreseen by May 2006. The site chosen is the Undersea Test Site of the LNS (Laboratori Nazionali del Sud) a -2000m depth zone, 28Km far from the coast of Catania, Sicily.
The aim of this experiment is to validate all the technologies involved in the realization of a km^3 telescope, performing tests on NEMO bars, strings, junction boxes, optical modules etc. Finally this prototype will permits a first stage of data acquisition, analysis and check-in of the whole NEMO structure.

Chapter 2

NEVD: need to watch further?



2.1 Overview

The enormous amount of data produced by a neutrinos telescope have to be studied accurately: muons trajectories have to be traced, background noise has to be filtered and neutrino events have to be recognized.

Furthermore, when examining event files produced by simulation softwares, become necessary to make assesses on the validity of the simulation model used. This job have to be made by checking the tracks reconstruction correctness both for neutrino induced events and for atmospheric muons. In order to fulfill this analysis, filtering algorithms and triggering programs must be employed, however, it might not be enough.

The goal of *NEVD* is to aid the discussed process by providing a 3D visualization of data inside an as much as possible interactive environment, therefore using this program the event analysis becomes much more easy. Working on a simulated 3D environment born to be a specular projection of the real telescope is very much helpful and intuitive, and can results on a speed up of the analysis procedure. Briefly, the features provided by *NEVD* are:

- Loading of GENDET format geometry files

- Loading of GEANT format events files
- Modeling inside a full 3D environment
- Multiple events management
- Viewing of PMTs (*PhotoMultiplying Tubes*) hits
- Selection of PMTs by energy threshold
- Selection of PMTs by time range
- Track analysis subsystem
- On-by-one PMT manual selection

These features will be discussed more carefully further in this document. The aim of this software is to help on analysis of data available as GEANT files, therefore implementation of triggering or filtering is left to the pre-processing programs.
Another objective of this program is to be physicist-compliant: it must be productive from the point of view of the research, easy to use and portable. These portability issues will be discussed in the next session.

Concluding *NEVD* is a 3D visualization software designed for the NEMO project, however we have to consider that output files of NEMO and Antares projects are very similar, moreover all the information regarding the structure of the telescope are dynamically loaded through the GENDET geometry file, thus *NEVD* is a valid 3D visualization software both for NEMO and Antares.

2.2 Libraries and environment

The portability issue is very important for a software like *NEVD* which may be run on different platforms and operating systems.

To achieve the maximum portability and flexibility *NEVD* is entirely written in C++ and it uses only platform-independent libraries.
Moreover great amount of algorithms, formerly implemented as external procedures, had been reimplemented from scratch in order to avoid any useless dependency. C++ code that use STL calls can be considered fully portable. [1].

The whole 3D subsystem is implemented with *OpenGL* (`http://www.opengl.org`) standard calls (without using OpenGL extensions or GLSL) which represents the unique existing industrial standard for 3D modeling and rendering.
Open algorithms and the diffuseness of this framework make it the ideal solution for a scientific project. Thus the usage of *NEVD*, as any else 3D software, needs a suitable graphical adapter which implements hardware 3D acceleration, moreover GL and GLU libraries are needed too. Anyway these requisites are fully satisfied by all common desktop PCs and by a lot of laptops since some years ago.

The graphical user interface provided by *NEVD* is based on *wxWindows* (`http://www.wxwindows.org`), an opensource object-oriented widget library intended to be as much as possible portable. Using *wxWindows* it's possible to develop GUIs even for Un*x platforms (GNU/Linux, BSD, MaxOSX) than for Wind**s operating systems without change the code and obtaining the same result. Unfortunately the choice *OpenGL+wxWindows*

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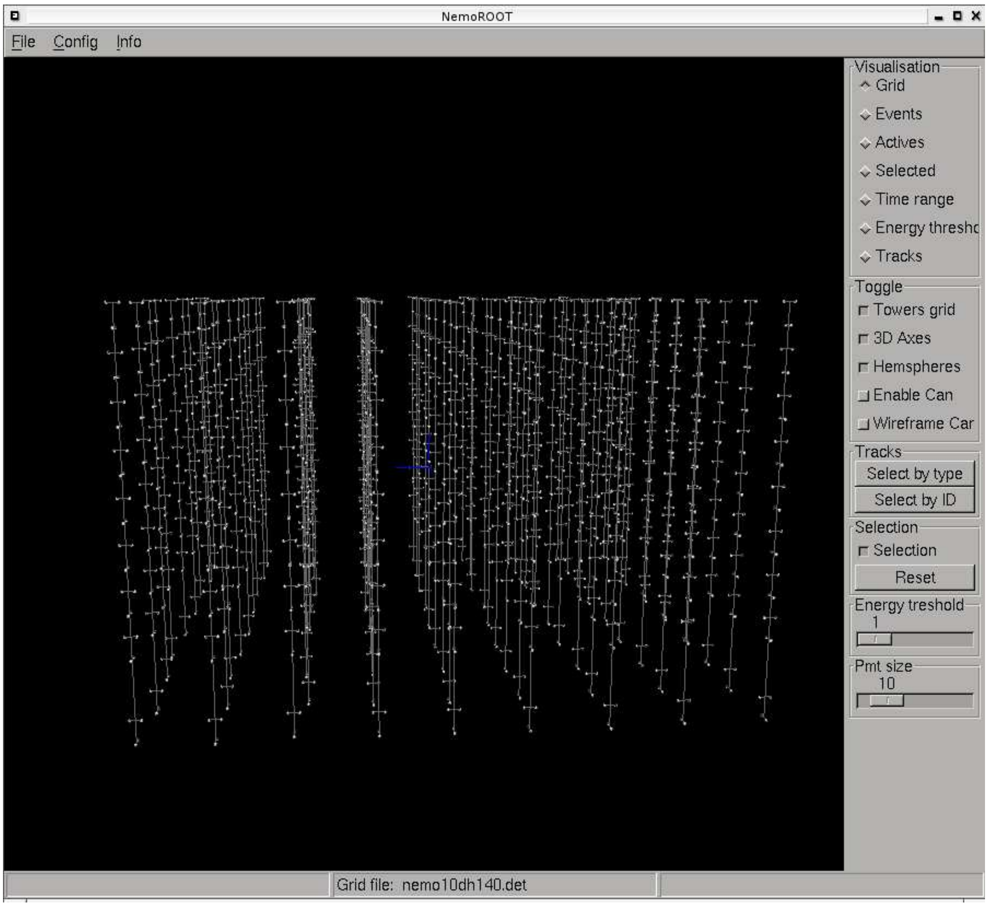
[1] even though some little problems with *fstream* objects had to be fixed on $Win * do * s$ platforms



Energy treshold 1

Pmt size 10

Grid file: nemo10dh140.det

Figure 2.1: *A NEMO's geometry loaded in NEVD*

was not deeply tested yet, however after a lot of experimentation on code, is resulted a powerful marriage and working on this project became a more comfortable job.

Chapter 3

Input files

NEVD works principally with two types of file: the geometry file and the events file.
The geometry file contains information on the deployment of the optical modules around the space like relative positions, directions and characteristics, besides some detector parameters.
This file provides the static structure of the telescope, the displacement of its sensors and information regarding its deployment. A great deal of additional information related to the technology used for PMTs are also provided, however a lot of these unuseful peculiarities have been overlooked.

The second type of file discussed is the events file, which carries the data related to the PMTs activation, prevalently energies and times. Furthermore, if the events file contains data generated by simulators or even had been processed by any other analysis software, a great amount of other additional information are present.

3.1 The geometry file : GENDET

This file format was developed for the ANTARES project so, in order to adapt it to the needs of NEMO, some of the carried information are not considered by *NEVD*. In fact a GENDET file is able to carry additional information on the geometry of the neutrinos telescopes, concerning detectors for different measurements of water properties. Principally, the aim of a GENDET file is to give information on:

- positions and directions of the sensors
- sensors structure and technology
- telescope shape and absolute position

As discussed before, the NEMO telescope is made up of 5832 sensors (called also PMT-PhotoMultiplying-Tubes or OM-OpticalModules) which are divided into 81 vertical towers, every tower is a set of 9 OM clusters, each cluster consists on 8 OMs placed on 2 consecutive bars on the tower. Each described object is numbered and linked with the other using IDs references.

The OM_Cluster descriptor contains the relative position of the cluster into the towers besides its optical modules. Each tower descriptor provide the absolute position of the tower inside the telescope while an OM descriptor identifies the position of a sensor inside its OM cluster. Therefore, once having an OM cluster descriptor, I can calculate its absolute position using its tower and then, the absolute position of each of the OM of which it is made up of. At the end of the parsing is is possible to have a global view on the entire telescope structure, in addition to a defined hierarchical relationships between the objects involved.

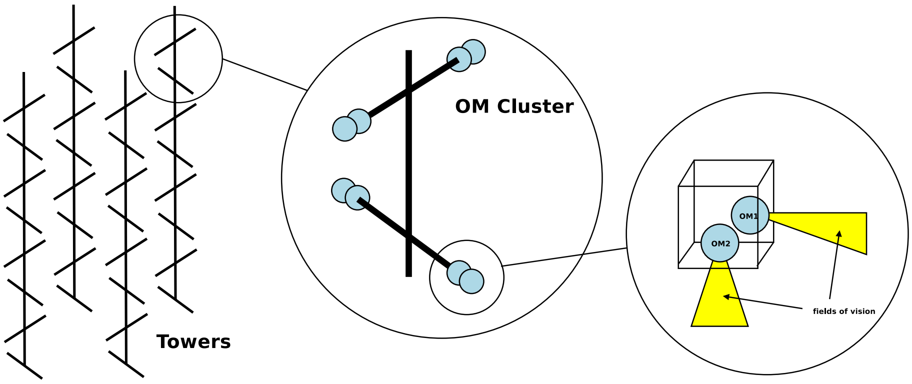


Figure 3.1: *The NEMO's geometry: towers and arms*

Much more information are available using the GENDET format, however all of which regarding the technology used on OMs are not parsed likewise the other devices used for specific purposes such as transponders or tiltmeters.

3.2 The events file : GEANT

A single screenshot of the telescope in a given range of time involves a certain number of hits which were accepted after fulfilling a triggering condition.
Everything that happens within this range of time is registered inside an events file using the GEANT format.

This format is used both for data directly produced by a real telescope and for those generated by simulators, therefore a GEANT file is commonly a tracing of what is happened during a data acquisition session or a simulation session; the retrieved data are processed and divided into separated *GEANT events* following a certain number of triggering policies, so a unique GEANT file can contain a great deal of different events.
This process generates a lot of information regarding the discussed particles, furthermore trajectories for muons and other interesting particles are often computed. Those information on tracking and fitting are automatically retrieved by *NEVD* and can be analyzed.

Even for a real surveyor or from a simulation software, we can consider the interesting information groups provided by a GEANT file as follows:

- PMT hits events
- tracks data
- simulation model infos

3.2.1 A PMT hit event

The first type of data that *NEVD* is able to represent is the set of PMTs hits. A hit is a *digital signal* registered by the optical module when it is blown by one or more photons, when the first photon strikes against the PMT at the time t, the sensor opens a sampling window 25ns long and start to integrate, all the n photons that hit the PMT within this period are considered to belong to a single event happened at the time t, with a signal energy linearly proportional to the number n.

It is clear that hits may have been (indirectly) generated by an interesting particle or may not. Causes of photons emission are several: atmospheric muons from the sky, muons from the other side of planet, potassium background (K40) or other type of particles.
It is the aim of triggering softwares to find out a useful neutrino track by filtering all the false positives. Briefly, returning to our file format, there are three types of possible hits inside a GEANT file:

- *hit_raw*

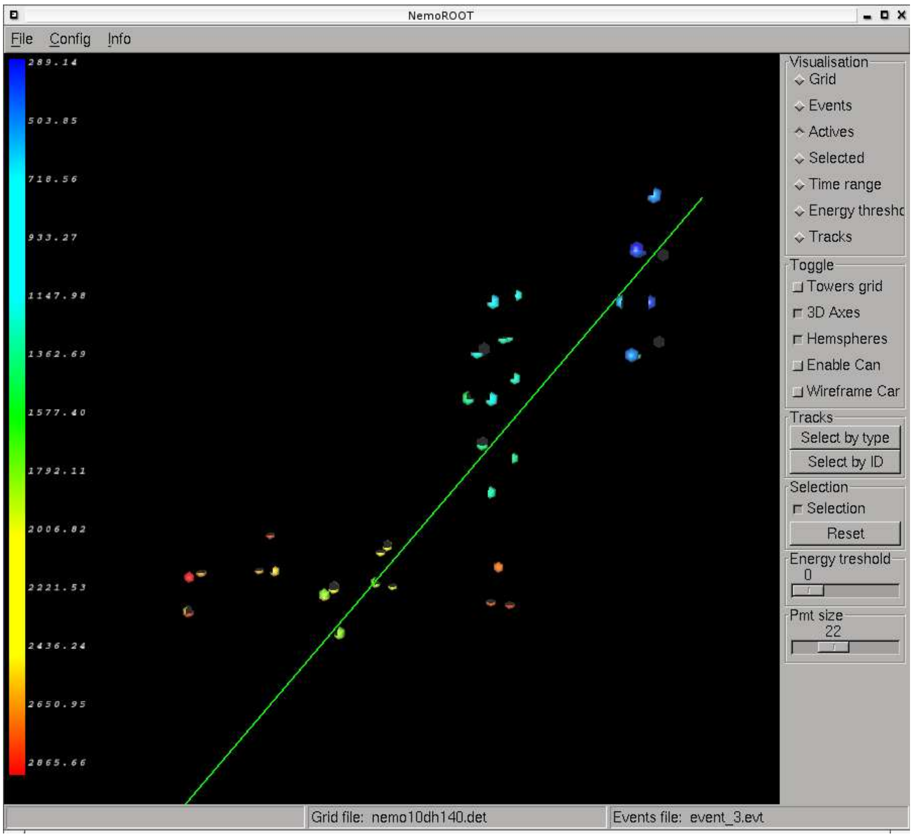
  A hit generated by an unknown source, the only values that we know about such a hit are the energy and the time.

- *hit*

  A hit produced by one of the simulated particle, a reference to the respective track is kept.

- *hit_track_fit*

  A hit caused by an unknown source and used for a fit procedure.



Visualisation: ◇ Grid ◇ Events ● Actives ◇ Selected ◇ Time range ◇ Energy threshc ◇ Tracks

Toggle: ☐ Towers grid ☑ 3D Axes ☑ Hemspheres ☐ Enable Can ☐ Wireframe Car

Selection: ☑ Selection

Energy treshold: 0

Pmt size: 22

Grid file: nemo10dh140.det

Events file: event_3.evt

Figure 3.2: *An example of hits produced by a simulated neutrino*

The PMTs that have been hit are displayed with a color, corresponding to their hit time (from red to blue in the time range) and with a greater size, depending on the hit energy. Various kind of selections based on hits values are possible.

3.2.2 Tracks

An interesting feature provided by *NEVD* is the *tracks subsystem.* A GEANT file in fact, contains a great amount of information provided by simulation or triggering softwares that, during a pre-processing stage, had computed a set of trajectories from the available hits using advanced interpolation techniques.
The types of tracks that can be encountered when reading a GEANT file are:

- *track_primary*

  A cosmic primary particle, identifies a particle came from the space but not involved in the survey of neutrinos. Its type is represented according to the JETSET convention.

- *track_seamuon*

  A muon came from an atmospheric shower at sea level. This particle represents on of the main cause of false positives.

- *track_earthmuon*

  A muon came from an atmospheric shower from the other side of the planet (rare).

- *track_in*

  A track generated by a simulator, this can be also a neutrino. When a program simulates the telescope events, generates a certain number of possible particles and keeps track of those with the track_in tag. This is one of the most useful track tag, it permits to compare pseudo-real particles trajectories with their fits and to check the response of the telescope when crossed by a particle.

- *track_sec*

  Secondaries particle produced during the simulation. Used for simulation purpose only.

- *track_prefit*

  Results of some type of track prefit. Used for simulation purpose only.

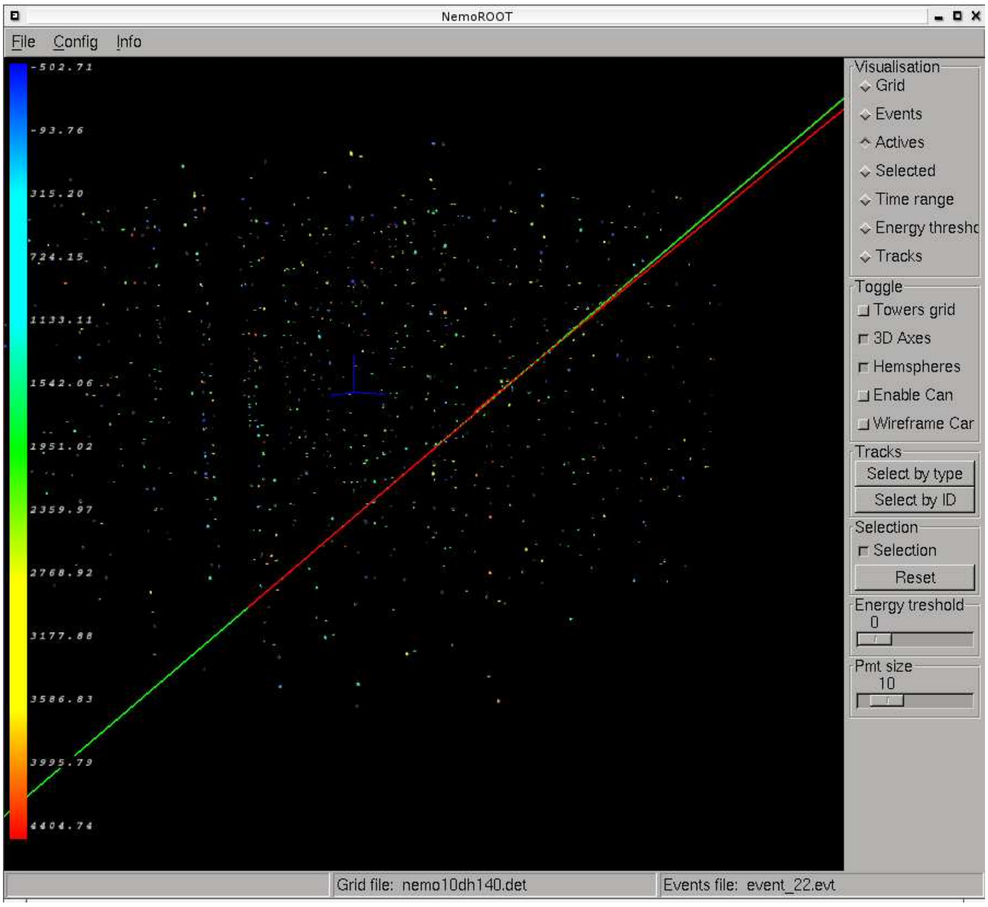
- *track_fit*

  The most interesting track. This is a trajectory of a fit computed by a reconstruction software. This information permits to check the correctness of the fit if the corresponding track_in was generated by a simulator or to make an analysis if we have a real survey.

- *neutrino*

> A *neutrino* track have to be considered as and additional field, in fact it is not a different track, instead it identifies the characteristics of the neutrino involved in this event. These data refer to a neutrino track_in and simply give some more information on neutrino computed by the simulator like direction, energy, the kinematic of the interaction with the matter, etc...

Jump forward to the section 4.1.2 for further discussion on the tracks issue for the *NEVD* software.



Energy treshold 0

Pmt size 10

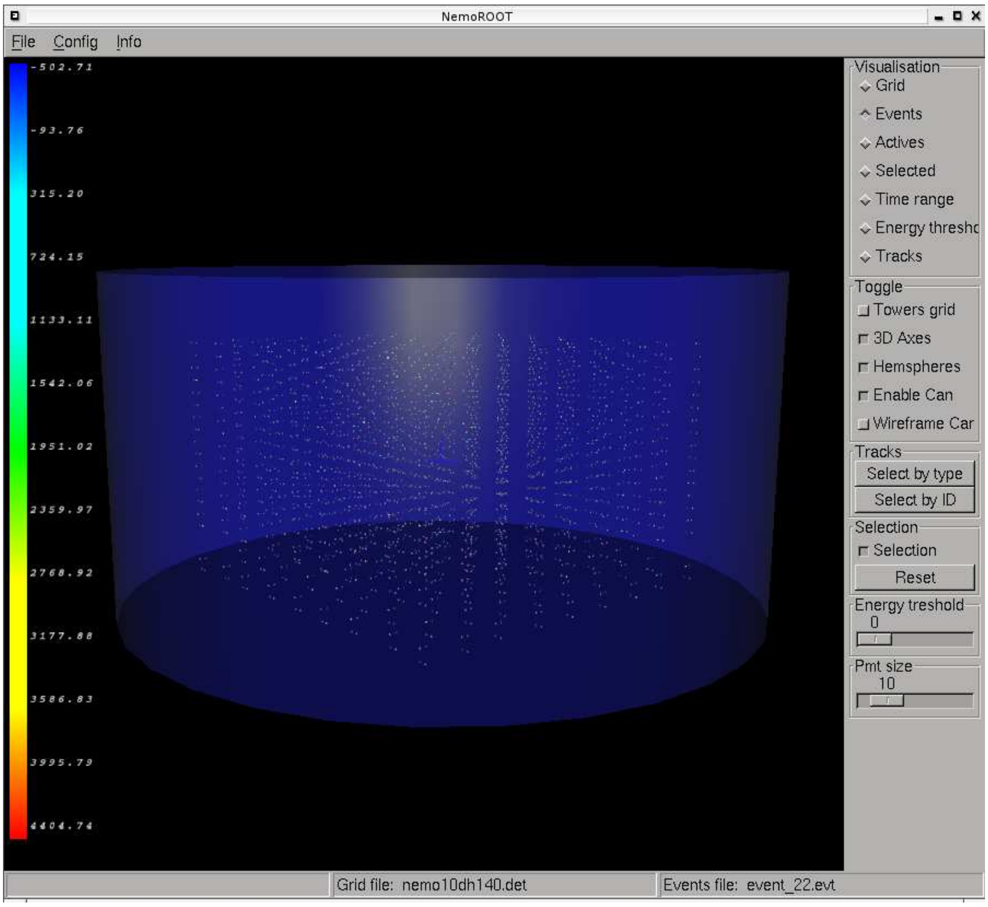
Grid file: nemo10dh140.det

Events file: event_22.evt

Figure 3.3: *A track fit example*

3.2.3 Bounding issues

The *can* is the surface of the figure used by the simulator to give a bound outside the telescope during the simulation.
All the *track_in*s starts from the borders of the *can*, each calculus related to the environment is made considering the *can* volume. This cylinder that contains the telescope must be considered as reference for any type of analysis and is visible on *NEVD* both blended and wireframed.



Visualisation
○ Grid
● Events
○ Actives
○ Selected
○ Time range
○ Energy threshc
○ Tracks

Toggle
☐ Towers grid
☑ 3D Axes
☑ Hemspheres
☑ Enable Can
☐ Wireframe Car

Selection
☑ Selection

Energy treshold
0

Pmt size
10

Grid file: nemo10dh140.det

Events file: event_22.evt

Figure 3.4: *The blended can*

Chapter 4

Visualizations

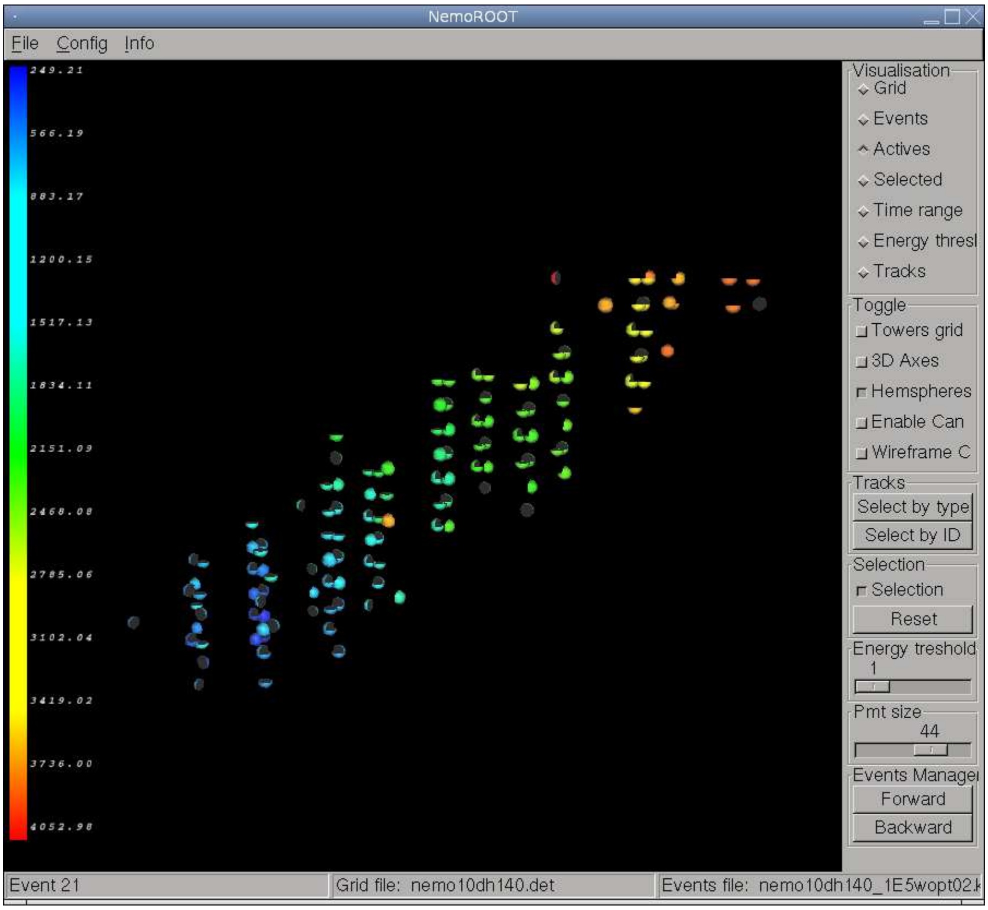
Once that both the geometry and the events file have been loaded, *NEVD* provides various types of visualizations of the event. Up to now the visualizations provided are:

- *grid*: PMTs geometry only
- *hits*: hit PMTs colored, the others faded
- *actives*: hit PMTs only
- *selected*: selected PMTs only
- *timerange*: PMTs on the given range of time
- *energy*: PMTs with an energy greater than the one given
- *track*: PMTs related to the selected track

This visualizations can be switched between them at any time, moreover *NEVD* implements an automatic caching of the views through OpenGL display lists, so once the view has been loaded one time everything become faster.
Here follows a little overview of the visualizations provided by *NEVD*.

4.0.4 View activated PMTs

NEVD displays the information of the event showing the hit PMTs colored and with increased size. While those OM which have not been hit are painted in greyscale, the other ones are displayed using a colour palette shown in the left of the screen and representing the activation time of the OM. The sphere or the hemisphere of a PMT appears also grew, in order to display the energy of the hit. Choosing to view only the activated PMTs is it possible to view an example of a classic telescope event: the diameter of spheres/hemispheres is proportional to the energy of the hits and the color trend shows the flow of Čherenkov hits over the time.



Energy treshold 1

Pmt size 44

Event 21

Grid file: nemo10dh140.det

Events file: nemo10dh140_1E5wopt02.

Figure 4.1: *Activated PMTs visualization*

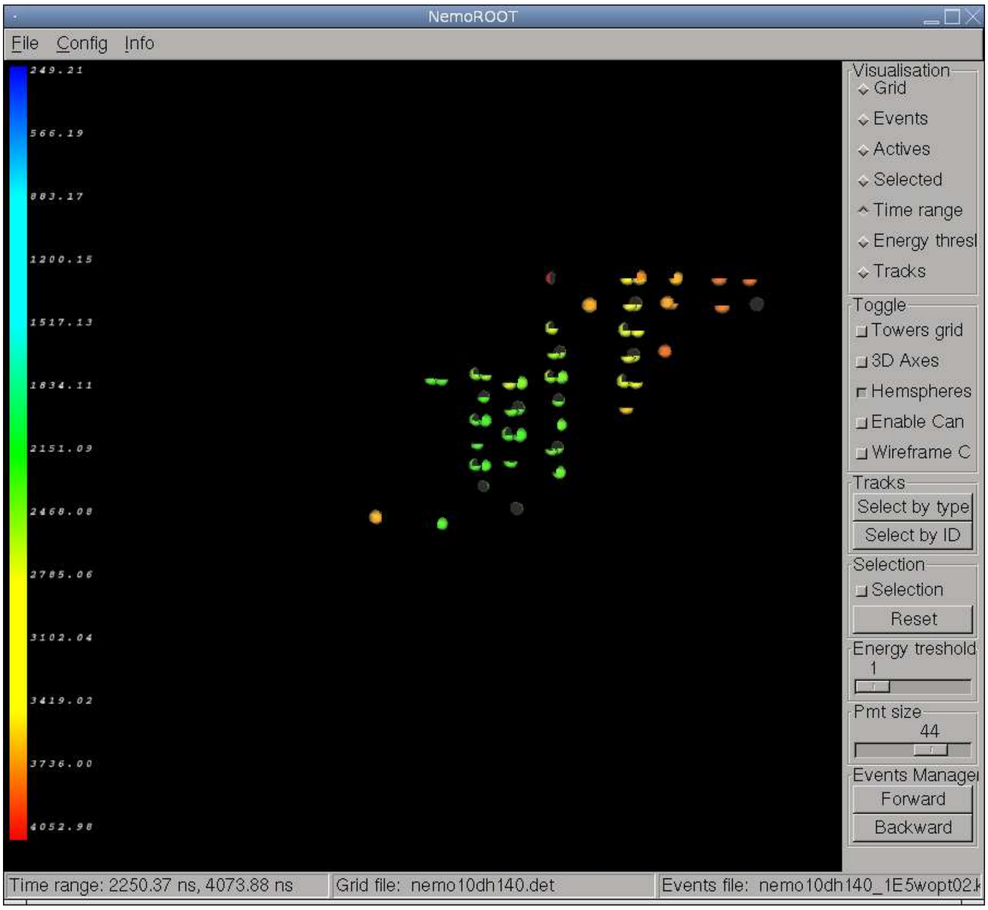
The scene can be translated, rotated and zoomed using the mouse controls. The analysis can be performed switching between visualization, options and selections besides navigating through the events.

4.0.5 Time and Energy selection

For further analysis *NEVD* provides some selection features. It is possible to filter the hits and view only those within a given range of time or with a minimum given energy.

The time selection can be activated directly by selecting a slice into the time bar on the left, *NEVD* will automatically switch to the *timerange* view and display only the PMTs on that range.

In the same way a selection based on energy is available, by moving the slider on the toolbar on the right it is possible to display only those OMs that have at least a certain energy value. This type of analysis become very useful when a neutrino event could be recognized and a deeper analysis is necessary.



Energy treshold: 1

Pmt size: 44

Time range: 2250.37 ns, 4073.88 ns | Grid file: nemo10dh140.det | Events file: nemo10dh140_1E5wopt02.

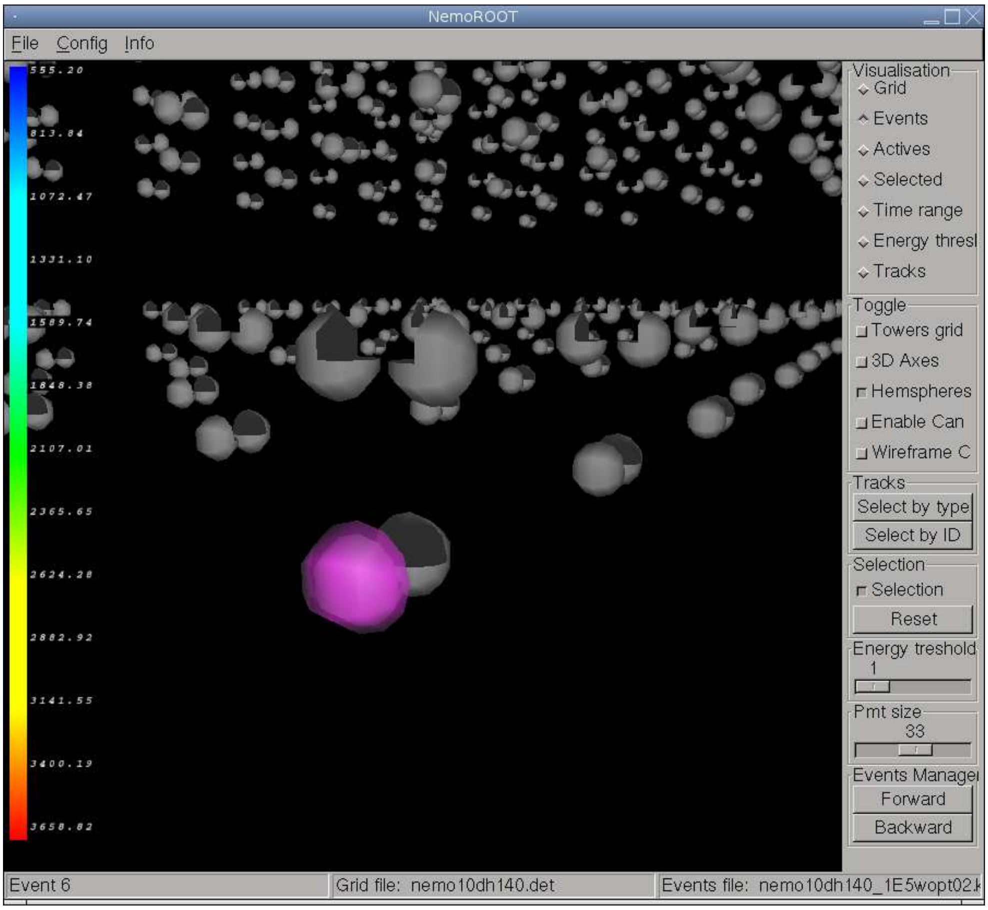
Figure 4.2: *An example of time range selection: [2250.37ns - 4073.88ns]*

4.0.6 One-by-one selection

Another way to select specific PMTs is the one-by-one *pure-selection* mode. This feature uses the OpenGL picking subsystem to permits the manual selection of the optical modules. From any of the available views, by right-clicking with the mouse, the PMT sphere under the pointer is blended and assumes a violet color; then the PMT become selected and you can filter only these selected PMTs by switching to the *selected* view.

4.1 A deeper analysis

Viewing the activated PMTs and make some selection among them can be not enough, a wide and very interesting part of the development of *NEVD* consists on the exploitation of the huge set of data provided by triggers, filters and simulators. The main aspect of this issue is the management of the tracks that concerns both the tracing of incoming particles by simulators and the reconstruction of neutrinos trajectories.



○ Grid
● Events
○ Actives
○ Selected
○ Time range
○ Energy thresl
○ Tracks

☐ Towers grid
☐ 3D Axes
☑ Hemspheres
☐ Enable Can
☐ Wireframe C

☑ Selection

Energy treshold 1

Pmt size 33

Event 6

Grid file: nemo10dh140.det

Events file: nemo10dh140_1E5wopt02.k

Figure 4.3: *A selected PMT*

4.1.1 The can

Some words must be spent on explaining the can. The can represents the external bound of the telescope, it was been the main reference point during the entire simulation or reconstruction and still provides a valid reference point even during the 3D analysis made with *NEVD*. The can viewing can be activated both in blending and in wireframe mode, however it is disabled by default and can be activated at any point of analysis after an events file have been loaded.

Pay attention that this bounding doesn't give any spatial reference for the detector, it can be simply viewed as a shell which delimits the considered events space from the outside space.

4.1.2 The track subsystem

One of the most interesting parts of *NEVD* is the tracks subsystem. *NEVD* provides principally three types of track selection:

- *by-type* selection (primary, seamuon, earthmuon, fit, prefit, sec, in, neutrino)

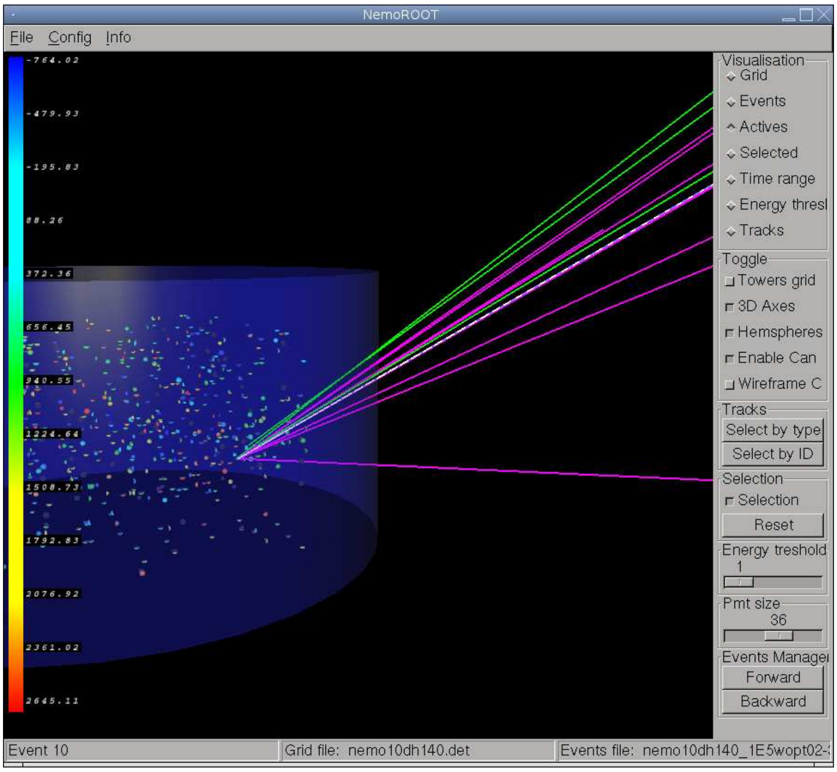
  the various types of tracks can be viewed contemporaneously and appears with different colors inside the 3D environment.

- *by-particle* selection (muons, photons, pions etc...)

  viewing of the tracks related to a specific particle type, enumerated according to the JETSET convention.

- *by-ID* selection (track ID 1, 2, ...)

  each single track can be selected differently, the selection dialog provides also some additional information regarding the track type, energy and time.



Event 10

Grid file: nemo10dh140.det

Events file: nemo10dh140_1E5wopt02-

Figure 4.4: *Multiple tracks visualization*

Moreover, selecting fit tracks by ID it become possible in *NEVD* to switch to the *tracked* visualization which shows only the PMTs involved in the selected fit.

Chapter 5

The software structure

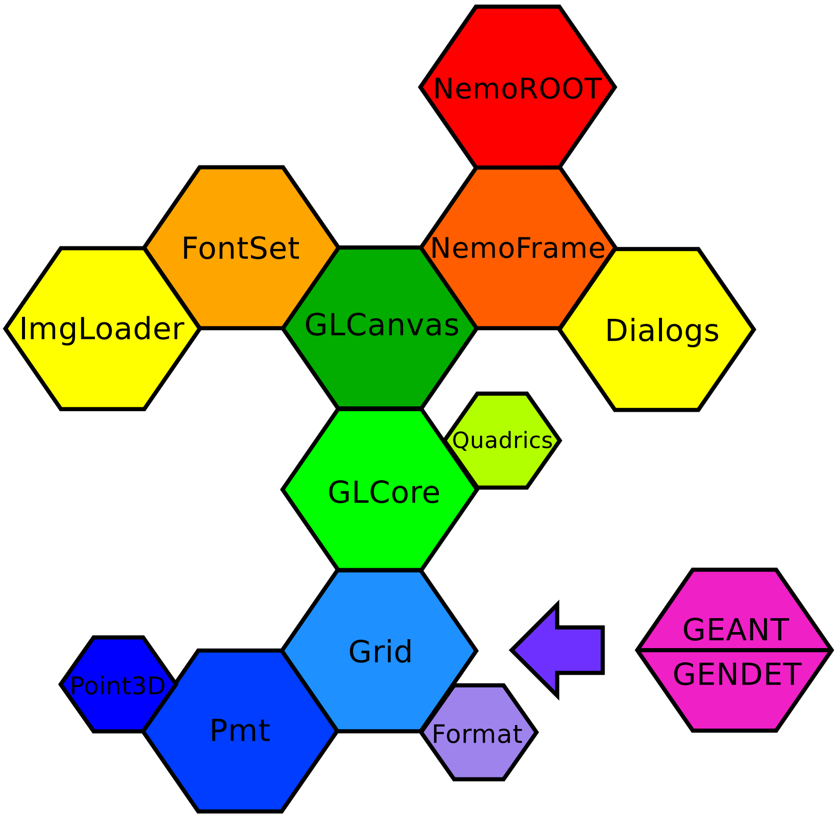


Figure 5.1: *NEVD's objects structure*

NEVD is made up of several objects, assembled in a vertical-style structure. Principally there are three subjects involved: the data processing infrastructure, the OpenGL infrastructure and the WxWindows infrastructure. The synergy between them is responsible on giving the best response to the user demanding. As can be seen in the picture at the end of this chapter, data flow from the geometry/event file to the *NEVD* core where they are processed and displayed. The correctness on interpreting these data is fundamental: correctness on data processing means correctness on analysis.

5.1 Data management: the GRID object

The aim of the *grid* object is to recognize, load and pre-process input files. When the geometry file is loaded, information related to the optical modules are retrieved and organized into an ordered structure of *pmt* objects. The internal state of each *pmt* is reset, waiting for an event loading.

Afterward, when an event file is loaded, the grid structure is updated by setting the needed activation flags and by filling the energy, time and other useful fields of the *pmt* objects. All the information regarding tracks, detector structure, fits and hits are retrieved and stored into specific structures (see `format.h` for specifications). Besides the storing and ordering features which the grid object implements, there is an important issue that regards its *filtering methods*.

On of the most frequently activities that this object have to perform is to filter the set of PMTs by applying a given kind of triggering condition. In order to do that this object is also responsible on providing all the necessary filtering methods. Therefore everything about the event data is stored and maintained by the *grid* object which represents also a standard interface used from the other objects to gain access to data.

5.2 The OpenGL infrastructure

The OpenGL infrastructure is created to manage the 3D environment which is used to display the telescope. It is made up of two interacting parts: the GLCanvas and the GLCore.

5.2.1 The GLCanvas

The GLCanvas is responsible on interfacing of the 3D world with the WxWindows infrastructure and with the user. The roles of GLCanvas on *NEVD* are:

- Initialize the OpenGL subsystem

  the OpenGL initialization procedure is called, the basic 3D objects are built and the fonts structure is loaded.

- Render the frames

  the display list of the actual view is called, if needed are displayed also the 3D reference axes, the time bar, the can and the tracks.

- Permits to modify and interact with the 3D world

  a great amount of internal variables and flags can be set like the lighting model parameters, the toggling of tracks and can etc...

- Dialog with the underneath GLCore

  everything strictly related to the management of the complex 3D object is store in the GLCore, the GLCanvas uses the GLCore methods to build the 3D scenario.

- Dialog with the WxWindows infrastructure

> all the events thrown by the WxWindows framework for the *wxglcanvas* object (which our GLCanvas extends) such as resizing and focusing are handled, as well as the keyboard shortcuts.

The GLCanvas represents the interacting gate between the user and the 3D environment which is handle by the GLCore object.

5.2.2 The GLCore

Regards to the 3D features provided by *NEVD* the object which make the dirty work is the GLCore. All the 3D algorithms used are implemented inside this object, it provides the more interesting features in *NEVD* such as *picking*, *views caching* and *tracks displaying.*

Views caching is achieved by maintaining a set of pre-processed display list of the already demanded views, when a certain type of view is demanded, the caching procedure check the stored issue and if it is up to date, it returns that, otherwise it creates a fresh one.

The *picking* feature should permits to a user to make a more focused selection on PMTs during a deeper event analysis. It uses the picking infrastructure provided by OpenGL that permits to recognize which of the displayed objects is pointed by the user by doing a 2D to 3D coordinates mapping. The most important field of GLCore is the *grid* object, as discussed formerly, it is the object on which are stored the event data.

5.3 The WxWindows infrastructure

As we have seen during in the chapter 2, WxWindows are a set of portable and object-oriented widgets. This library provides windows, frames, canvases, buttons, sliders, menus and much more either for Un*x-like operating systems and for Win*o*s-like ones. Besides the GUI widgets, the whole input events system is managed from the *WxWindows infrastructure.* The main object of this infrastructure is *NovaFrame*, it contains the GLCanvas, the panel, menus, buttons, sliders and all the widget used inside *NEVD.* It is also responsible on creating dialogs and configuration toolboxes. The event handling is completely managed by this object which propagates automatically input requests to the GLCanvas if needed. Programming at this level of the software involves only the knowledge on the *wx widgets* and a minimal approach to events handling.

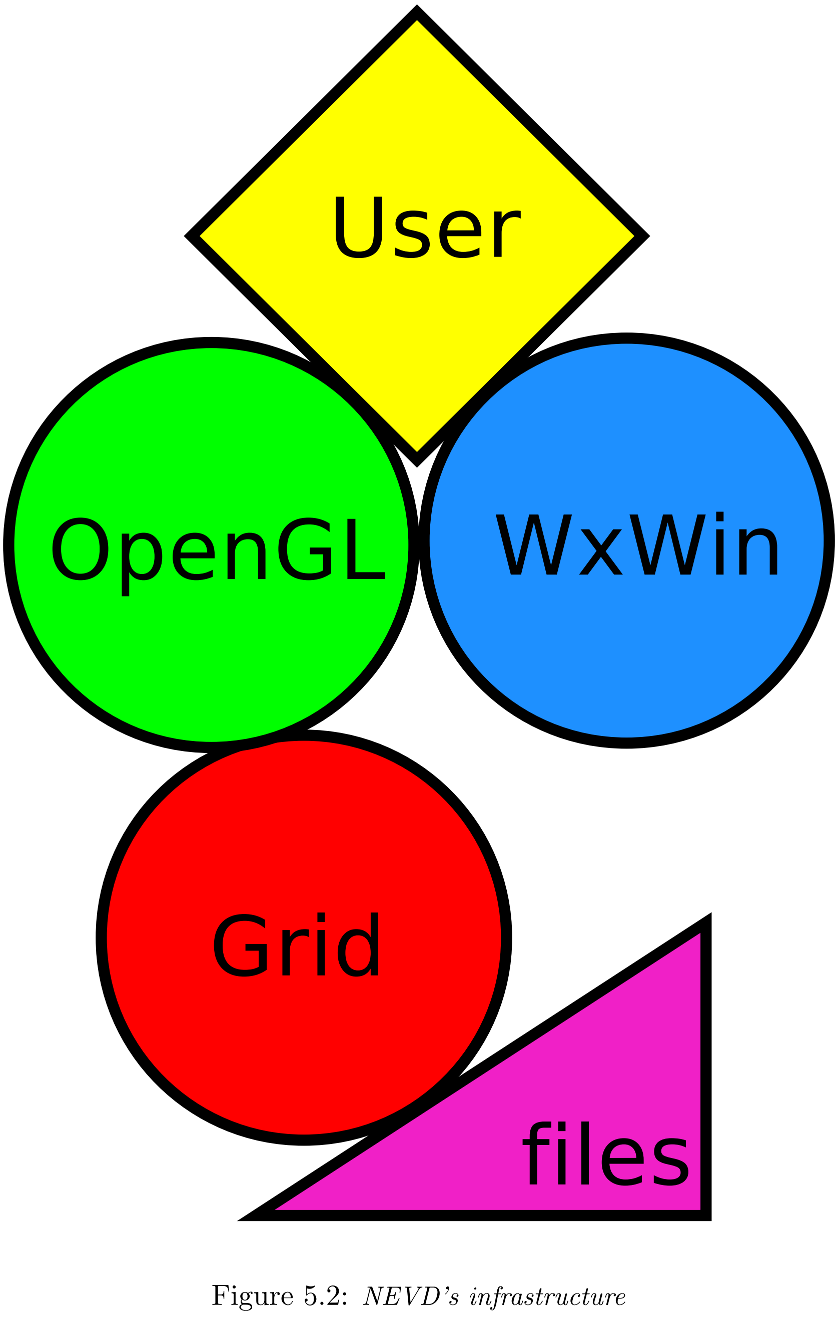


Figure 5.2: *NEVD's infrastructure*

Conclusions

Actually *NEVD* have to be considered a *still-in-development* software, it still needs a lot of improvements and bugfixes. This huge job must be done with a constant feedback of the end-users, the program itself is intended to evolve with the NEMO project and actually lot of features are already studied and a great amount of improvements have been foreseen.
A beta version of *NEVD* was presented during the *NEMO Collaboration Meeting* at LNS - National South Laboratories (Catania, Italy 23-25 January 2006) and will be discussed at the next Antares meeting.
Finally I hope my work will be helpful for NEMO and I wish to continue my collaboration with the people involved in this interesting and important project.

In particular I want to thank Prof. Maurizio Spurio who offered me an extraordinary opportunity, welcoming me into the NEMO project and giving me confidence and help.

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