The MINERνA detector construction database

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Abstract

We describe the construction database for the MINERν-A detector. MINERν-A is a low mass fully active neutrino detector that is designed to study low-energy neutrino interactions. The detector database keeps track of all detector components, illustrates the relationship between different components, simplifies future data entry and record maintenance. The database is written in Structured Query Language (MySQL). A Python graphical user interface for the detector has been developed.

Contents

0.1 Introduction

The Main INjector Experiment for ν-A (MINERνA) is a neutrino scattering experiment that will study low energy ν-nucleus interactions to high precision. The NuMI (neutrino's from the main injector) beamline at Fermilab provides an intense ν(neutrino) beam for the MINERνA detector. Neutrinos outnumber protons, electrons and neutrons yet they are the most difficult particles to observe because they are weakly interacting, have a very small mass and possess no electric charge. In the past, neutrino detectors were massive to allow for statistically significant neutrino event rates but recent advances in neutrino beam intensity have enabled high-rate ν interaction studies at low-mass detectors such as MINERνA. The detector is still under construction and will begin a full run in the Spring of 2010.

MINERνA is built almost entirely of scintillating material unlike previous neutrino detectors such as the MINOS (main injector neutrino oscillation search) near detector which is a sampling neutrino detector that intersperses scintillating planes and steel planes. The fully active detector mass will allow MINERνA to precisely reconstruct neutrino events. The NuMI beam line provides an intense neutrino beam enabling high neutrino event rates at the MINERνA detector; this will facilitate precise neutrino cross section measurements. The detector consists of helium, carbon, lead and iron targets for the study of nuclear dependent interactions. Improved cross-section studies of ν-nucleus interactions will assist present and future neutrino oscillation experiments. MINERνA will also enhance our understanding of neutrino interactions.

The detector is built as an array of hexagonal modules that are hung on rails. Each module consists of two planes that form the inner detector and a steel frame known as the outer detector as illustrated in Fig. 1. The planes are aligned along the path of the NuMI beamline upstream of the MINOS detector in the near detector hall at Fermilab. The planes in the modules are built of scintillating plastic, steel and lead.

Every scintillator plane is made of joined scintillator strips with a triangular cross section. In every scintillator strip is a wavelength shifting fiber that channels out the light emitted by the scintillator when an energetic particle transverses it. Once outside the detector, a clear fiber optic guides the light to a photomultiplier tube where it is converted into an electrical signal. The electrical signal is relayed to the data acquisition machines. Each pixel of data correlates to a fiber optic in the detector.

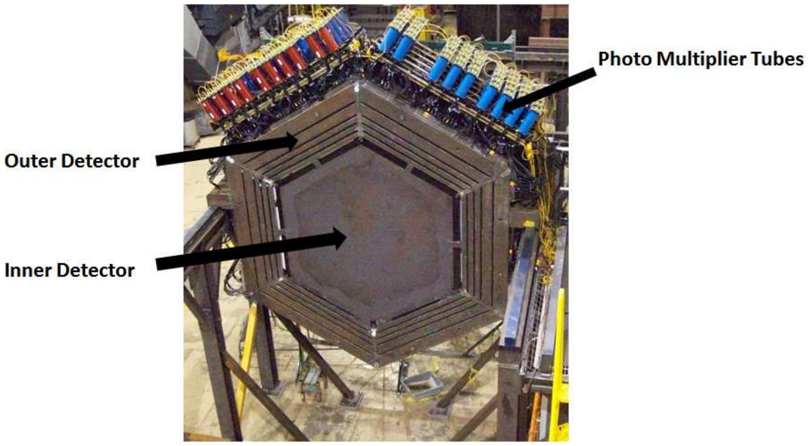


Figure 1: A picture of the MINERνA tracking prototype(TP) made of $1/5^{th}$ of the modules that will make the complete MINERνA detector. The TP shows the main features of the MINERνA detector.

The scintillator strips are individually calibrated, the metal pieces are individually weighed and each module is connected to a particular photomultiplier tube to read out the signal. We would like to keep track of each detector component. We have designed a construction database for the detector in MySQL. This paper details the detector construction database and outlines how each detector component is associated with its correct calibration constant. An overview of the MINERν-A detector design is also presented.

0.2 Background

0.2.1 The NuMI Beam

MINERν-A receives neutrinos with energies of about 1-20 GeV from the Numi (Neutrino at the main injector) beam. Neutrino beam production is a multistep process that begins with the ionization of hydrogen to produce a proton beam. The proton beam is directed to a graphite production target where mesons are produced. Currently, the Numi beam is the most intense neutrino beam in the world; it receives 4×10^{20} protons on target [1] annually. Magnetic horns focus the mesons in the direction of the neutrino beam. Mesons are unstable particles made of two quarks. The kind of mesons formed during the production of the NuMI beam are mostly positively charged pions (Π^+). The Π^+ are selected out by a magnet. With a lifetime of about 2.6×10^{-8}s, the Π^+ soon decay into a muon and a muon neutrino as shown by Fig. 2. The mesons travel through a 675m long decay pipe located 50m downstream of the graphite target. The decay pipe is made of earth and steel where the undecayed mesons and the muons are absorbed. The neutrinos pass through the steel and earth with little interaction onto the MINERν-A detector.

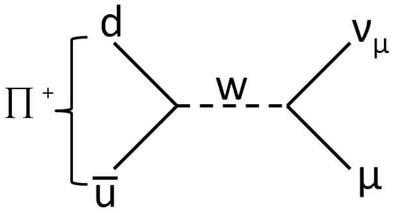


Figure 2: Illustration of the Π^+ decay into a muon and a muon neutrino or the counter interaction could occur when a muon and a muon neutrino come together to form a Π^+ though a W boson.

0.2.2 The Minerva Detector

Minerva is a low mass detector whose design closely resembles that of a collider detector where precision measurements and tracking occur at the center of the detector while heavier materials designed as particle absorbers and calorimeters are found radially away from the center of the detector. The detector consists of a set of hexagonal planes that are hung on rails. The planes have an inner detector and an outer detector. In the inner detector most planes are made of joined strips of triangular scintillator. Each scintillator strip has a base of 3.3 cm and a height of 1.7 cm. Each plane is a 2.2 m wide hexagon with a depth of 1.7 cm. The scintillator strips are arranged in 3 different configurations creating 3 types of scintillator planes. The X plane has the strips oriented vertically, the U plane has the strips oriented 60° from the vertical axis while the V planes strips are oriented 300° degrees from the vertical plane. Planes made of scintillator strips are called active planes.

The scintillators between adjacent planes are oriented differently giving rise to the XUXV pattern shown in Fig. 3; this allows for a 3 dimensional reconstruction of particle tracks. The scintillator strips absorb the energy of an incoming particle and emit the light proportional to the energy of the

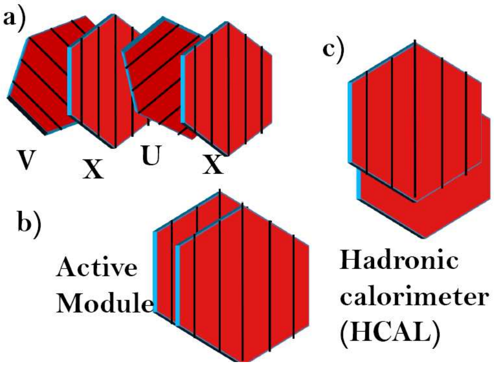


Figure 3: a) The scintillator arrangement in the 4 adjacent planes of the detector; the XUXV plane arrangement is illustrated. b) Active module made of 2 scintillator planes c) HCAL module which consists of 1 steel plate and 1 active plane. An ECAL module is similar to a HCAL module except that it is made of 1 lead plane and 1 scintillator plane

particle. Wavelength shifting fibers found inside each scintillator strip channel the light out of the detector. MINERνA has a one end readout where light from a particular strip is only captured from one end. Once outside a scintillator strip, clear fiber optic directs the light to a photomultiplier tube(PMT). Through the photoelectric effect, the light produces electrons that generate an electric pulse. The electric signal is recorded by the data acquisition machines. Particle momentum, event vertices and charge can be deduced from this information.

Two planes form a module. Modules are classified into three main categories; hadronic calorimeters(HCAL), electromagnetic calorimeters(ECAL) and the active target. Active detector modules are made of two scintillator planes. HCAL modules consist of a 1 inch steel plate and a scintillator plane as shown in Fig. 3 while the ECAL modules are made of a 2mm thick lead plate and a scintillator plane. The interaction length for active detector material is very large. While MINERνA consists mostly of active modules, at the downstream end of the detector, MINERνA is made up of ECAL and HCAL modules to absorb the energy of secondary particles formed when neutrino-nucleus interactions occur in the detector. Particle energy loss in the steel and in the lead planes is calculated through calibration studies performed using a test beam. The HCAL modules sample the energy of particles that interact strongly for example protons [3]. Similarly, the ECAL modules measure the energy of particles that are susceptible to the electromagnetic force such as electrons. Another important part of the detector is the nuclear target which consists of lead, iron and carbon plates which are found upstream of the detector. The nuclear target region studies the nuclear dependence of neutrino interactions.

Surrounding each module is an outer detector (OD) made of steel and scintillator strips. It consists of 6 wedges. A wedge is 1/6th of the hexagon. Eight scintillator strips are located in each wedge as shown by Fig. 4. The OD plays several roles; it acts as a hadron calorimeter and a support for the inner detector. Neutrino interactions could produce particles with large deflection angles, the energy of such particles is measured by the outer detector. Fig. 5 shows a schematic side view of the MINERvA detector.

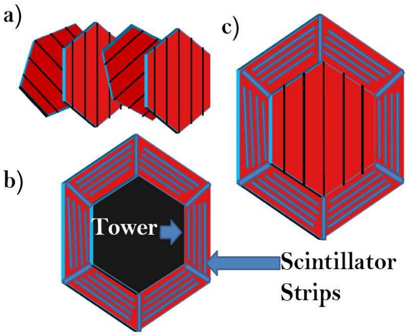


Figure 4: a) Inner detector made of fully active planes b) Outer detector showing the scintillator strips inserted inside the steel frame of the OD. c) A complete module made of an inner detector and the outer detector

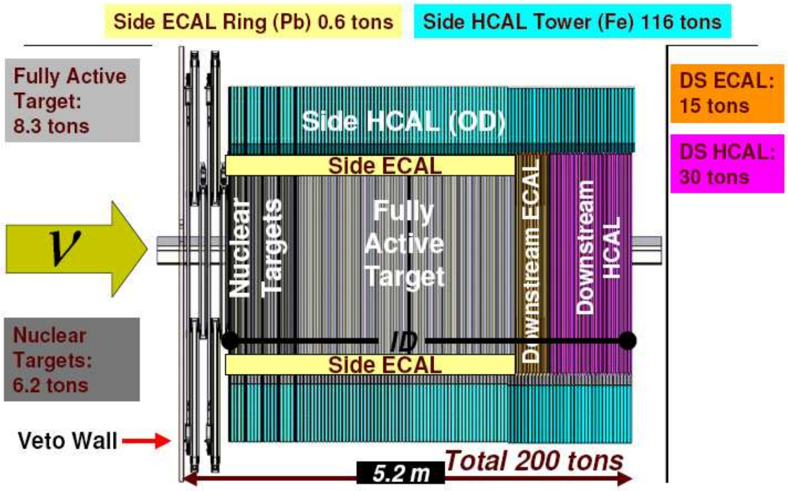


Figure 5: A side view of the minerva detector showing the different features of the detector[2]

0.2.3 Event Reconstruction and Particle Identification

At the MINERνA detector, some of the neutrinos from the NuMI beam interact producing secondary particles. Neutrinos interact in two ways: charged current(CC) interactions where new charged particles are created through the exchange of a W boson and neutral current (NC) interactions where new uncharged particles are created through the exchange of a Z boson. Neutrino interactions leave distinct tracks from which events can be reconstructed. An example of a neutrino interaction observed in the MINERνA tracking protocal(see Fig. 1) is shown in Fig. 6. This is a CC interaction between an electron neutrino (ν_e) and a neutron producing an electron and a proton. The electron has a very low mass and it is deflected by electric fields from atomic

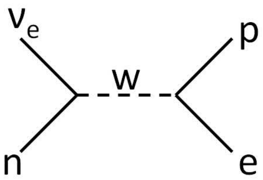


Figure 6: Feynman diagram for the charged current interaction between an electron neutrino and a neutron producing a proton and an electron

nuclei in the ECAL. Due to conservation of momentum, the deflected electron produces a photon. The photon undergoes pair production producing a positron and an electron. The energy of the initial event products is shared among the secondary particles until they are no longer able to multiply. The massive proton quickly loses its energy in the detector and it forms a short path. Fig 7 shows the absorption of an electromagnetic shower in the ECAL of the MINERνA tracking prototype. By absorbing the energy of particles formed when neutrino interactions occur we are able to recontruct neutrino events, measure neutrino event cross sections, study the nuclear dependence of neutrino events and other interesting aspects of neutrino interactions.

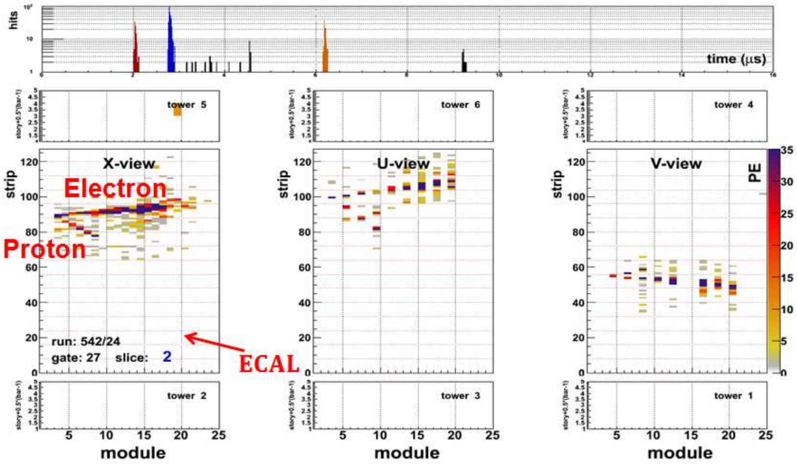


Figure 7: Event display from the MINERvA Tracking Protocal that recently collected data. The event is a charged current ν_e interaction

0.3 The Construction Database

Databases simplify data management where simple spreadsheets are too large to handle. Relational databases store data in connected tables. The tables ease the process of understanding, updating and maintaining records. In addition, databases interface easily with client programs allowing more users to work with the databases. MySQL (structured query language) is a programming language developed to create relational databases. We create a database for the MINERνA detector components in MySQL. The database consists of related tables that record the characteristics of detector components. Each table is assigned a primary key that distinguishes each data entry. The structure of the database is shown in Fig. 8. We have developed a graphical user interface (GUI) for the MINERνA construction database. The GUI simplifies the process of interacting with the database. The basic structure of the detector is a module.

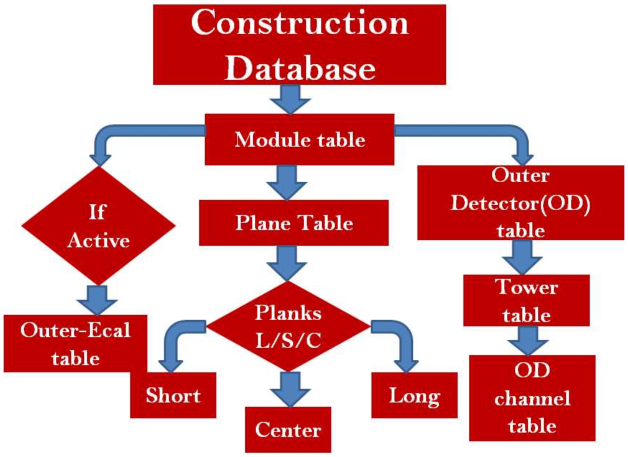


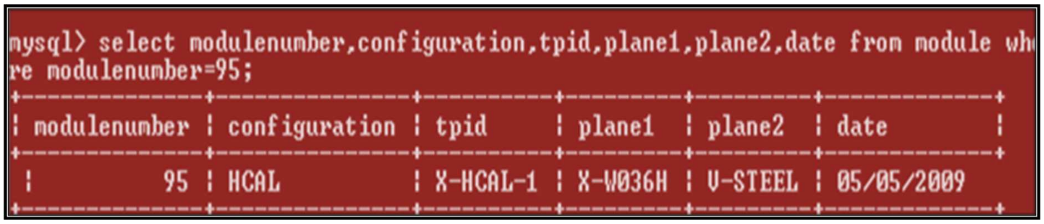
Figure 8: The general structure of the detector database

0.3.1 Module Table

This table records the module configuration (see Fig. 3), the unique identifyier of the planes that constitute the module and the date when the module was completed. The fields recorded by the module table are described by Table.1. A query seeking the module configuration, the plane identification numbers and the date of assembly of module 95 yields the output shown in Fig. 9. Each module has an outer detector that supports the module, ab-

Table 1: Fields in the Module Table

Field Name	Field Type	Field Description
Module Number	Integer	Number of the module
Configuration	Text	A module could be HCAL, ECAL or Active
TPID	Text	The number of the module in the tracking protocal
Plane1	Text	The identification number of the first plane
Plane2	Text	The identification number of the second plane
Date	Text	The date when the module was assembled



```
mysql> select modulenumber,configuration,tpid,plane1,plane2,date from module wh
re modulenumber=95;
+--------------+---------------+----------+---------+---------+-------------+
| modulenumber | configuration | tpid     | plane1  | plane2  | date        |
+--------------+---------------+----------+---------+---------+-------------+
|           95 | HCAL          | X-HCAL-1 | X-W036H | V-STEEL | 05/05/2009
+--------------+---------------+----------+---------+---------+-------------+
```

Figure 9: Results from a query on the module table showing the details of module 95

sorbs and measures the energy of particles scattering at large angles from the center of the detector.

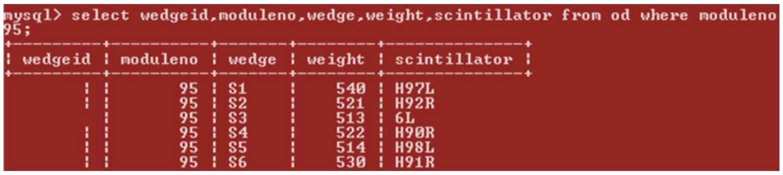
0.3.2 Outer Detector Table

The outer detector is a hexagonal steel frame (see Fig. 4(b)). Each OD has 6 wedges; a wedge is $1/6^{th}$ of the hexagon. Every wedge is weighed and an identification number is assigned to the scintillator strips in each wedge. Table.2 shows the information stored in the OD table.

Table 2: Fields in the Outer Detector Table

Field Name	Field Type	Field Description
WedgeID	Text	Tower identification number
ModuleNumber	Integer	Module number
Wedge	Text	The 6 towers are labeled S1, S2, S3.. to S6.
Weight	Integer	The weight of the tower in kg
Scintillator	Text	Identifier for the scintillator pieces in each tower.

Example output for a query on the data in the OD table is shown by Fig. 10



```
mysql> select wedgeid,moduleno,wedge,weight,scintillator from od where moduleno
95;
+---------+----------+-------+--------+--------------+
| wedgeid | moduleno | wedge | weight | scintillator |
+---------+----------+-------+--------+--------------+
        | |       95 | S1     |     540 | H97L
        | |       95 | S2     |     521 | H92R
          |       95 | S3     |     513 | 6L
        | |       95 | S4     |     522 | H90R
        | |       95 | S5     |     514 | H98L
        | |       95 | S6     |     530 | H91R
```

Figure 10: Results from a query on the outer detector table showing the details of module 95

0.3.3 Plane Table

Each scintillator plane is made of 5 types of planks. The planks are distinguished by the length of the scintillators in the plank and position of the plank. Each active plane has a unique identifier that is stored in the module table. Table 3. shows the fields in the plane table.

Table 3: Fields in the Plane Table

Field Name	Field Type	Field Description
PlaneID	Text	Plane identification number
Left Short Plank	Text	Plank ID
Left Long plank	Text	Plank ID
Center plank	Text	Plank ID
Right Long plank	Text	Plank ID
Right Short Plank	Text	Plank ID

Fig. 11 shows a query run on the plane table.

```
mysql> select planeid, left_s_plank,left_l_plank,centerplank,right_l_plank,right
_s_plank from plane where planeid='W043T';
+---------+--------------+--------------+-------------+---------------+--------
------+
¦ planeid ¦ left_s_plank ¦ left_l_plank ¦ centerplank ¦ right_l_plank ¦ right_s_
plank ¦
+---------+--------------+--------------+-------------+---------------+--------
------+
¦ W043T   ¦ F239L        ¦ F234L        ¦ F106C       ¦ F234S         ¦ F232S
      ¦
+---------+--------------+--------------+-------------+---------------+--------
```

Figure 11: Results from a query on the plane table showing the details of plane W043T

The Center, Short and Long channel tables

Each active plane is made of 5 planks. The planks consist of joined scintillator strips. In each strip has a wavelength shifting fiber that channels the light out of the detector. The long and short planks are made of 24 strips of scintillators with a triangular cross section while the center plank has 31 scintillator strips. A wavelength shifting fiber is associated with each scintillator strip. The long and short channel tables have 25 field entries; the plank identifier and an identifier for each fiber optic channel. Likewise, the center channel table has 32 field entries; the plank identifier and an identifier for each channel.

0.3.4 Outer Detector Channel Table

The outer detector is a steel frame with slots in which scintillator strips are inserted to measure the energy of particles absorbed by the outer detector. In each detector wedge there are 4 scintillator slots called doublets. Two scintillator strips are placed in a doublet. The outer detector channel table tracks the location of each wavelength shifting fiber in the outer detector. The fields recorded by the outer detector table are shown in Table.4 below.

Table 4: Fields in the Outer Detector Channel Table

Field Name	Field Type	Field Description
WedgeID	Text	Tower identification number
Doublet	Integer	Runs from 1-4; there are 4 scintillator slots
Position	Text	Could be upper(U) or lower(L)
Channel	Integer	Runs from 1-8 because there are 8 channels in each tower

0.3.5 Outer ECAL Table

An outer ECAL surrounds each active inner detector plane. It consists of lead strips placed right between the inner and outer detectors. Fields in the table are shown by Table.5.

Table 5: Fields in the Outer-ECAL Table

Field Name	Field Type	Field Description
WedgeID	Text	Tower identification number
Plane	Text	This could be X/U/V
PBWedge	Text	Lead Wedge identifier

0.3.6 Graphical User Interface (GUI) for the database

We developed a graphical user interface to allow users to look up data, enter data, update data and delete data from the database without understanding MySQL. The GUI is written in Python. A illustration of the python GUI used to log into the database is shown in Fig. 12.

Figure 12: GUI developed for the detector database that simplifies interaction with the database

0.4 Summary and Conclusions

We have created a construction database for all the detector components in MySQL. An SQL script runs creating the database tables and loading the data from text files that store detector component data. The detector is still in construction however all components that have been assembled have been recorded in the database. Future data entry and data maintenance has been simplified by a python GUI that interfaces with the SQL database.

0.5 Acknowledgements

I would like to thank Fermilab, the SIST program and the MINERνA collaboration for the opportunity to do research this summer. Special thanks to my supervisor Dave Boehnlein for his support and guidance through the internship. I would also like to appreciate Chris Marshall for helping me develop the GUI for the MINERνA database.

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