# A PLACE for MINERvA

## Application of the PLACE event length algorithm to MINERvA neutrino data


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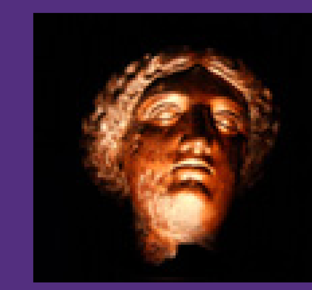
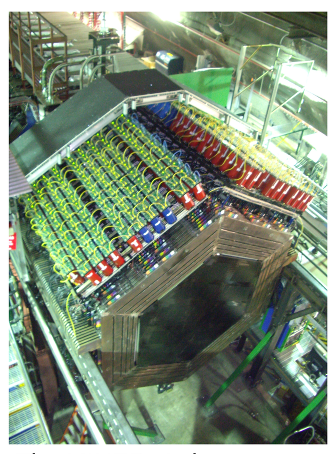


## MINERvA at Fermilab

MINERvA is a high-precision neutrino scattering experiment at Fermilab in Batavia, Illinois. It is located in the high-intensity NuMI neutrino beamline, upstream of the near detector for the neutrino oscillation experiment MINOS. The experiment began taking data in 2010, and aims to investigate various aspects of neutrino physics:



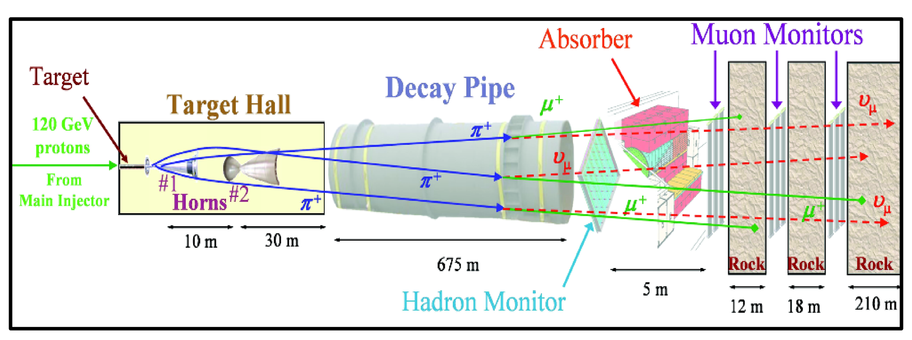
*The MINERvA detector*

- Neutrino-nucleus interaction rates for a wide range of energies and final states
- The impact of nuclear effects on these rates

The rates we measure will be used by neutrino oscillation experiments to reduce their systematic uncertainties.

## The MINERvA neutrino beam

The diagram shows the configuration of the NuMI beamline upstream of the MINERvA and MINOS detectors.




*Beamline upstream of MINERvA*

muon

### Target

A high intensity 120GeV proton beam from Fermilab's main injector collides with a target to produce pions and kaons.

### Horns

The resulting pion/kaon beam is focused by two horns. The current direction in the horns allows us to select whether the eventual neutrino beam will contain a majority of neutrinos or of anti-neutrinos, enabling us to perform experiments in both configurations.

Additionally, the target can be moved along the beam line. When the target is close to the horns (typically 10cm), particles of all energies will reach the horns, giving a low average neutrino energy. If the target is farther from the horns (up to 2.5m), lower energy particles, who tend to have a higher percentage of transverse momentum, will tend to have strayed too far from the main beam direction, allowing only the highest-energy particles will reach the horns. This will allow us to observe the difference in interactions from low- and high-energy neutrinos.

### Decay pipe

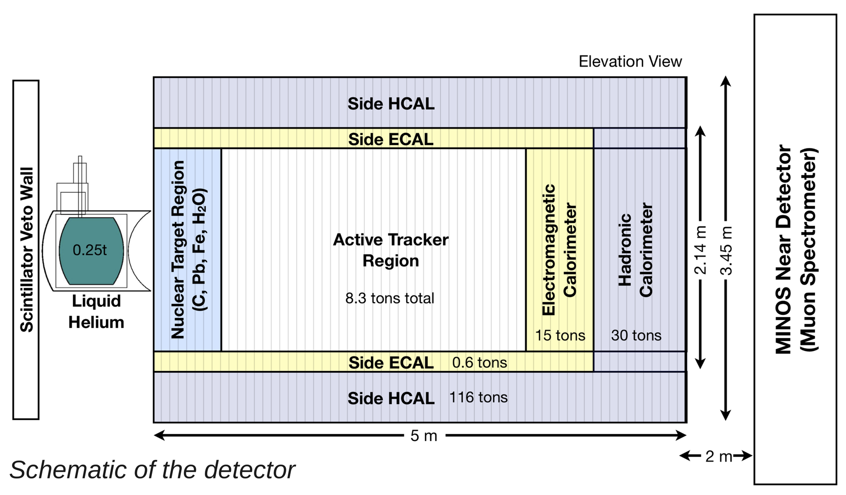
After it leaves the horns, the tightly focused pion beam decays, producing muons and antineutrinos, or neutrinos and antimuons.

### Absorber

Rock absorbs the muons produced, leaving a beam of neutrinos/antineutrinos which will enter the MINERvA detector.

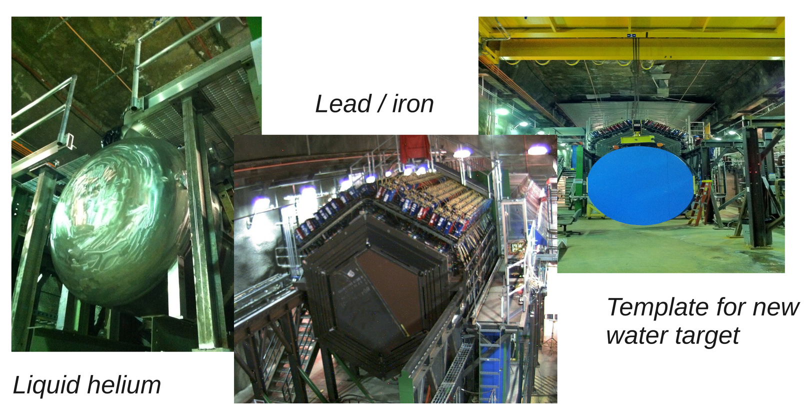
## The detector

The diagram below shows an elevation view of the MINERvA detector (the neutrino beam enters from the left-hand side.)




*Schematic of the detector*

The detector consists of 120 “modules”. The beam first encounters the “nuclear targets” of varying composition, enabling neutrino interaction cross-sections to be examined for different nucleon numbers. Current modules include various configurations of lead, iron and carbon, plus liquid helium and, soon, a water target. Different modules may be added later.



*Lead / iron*

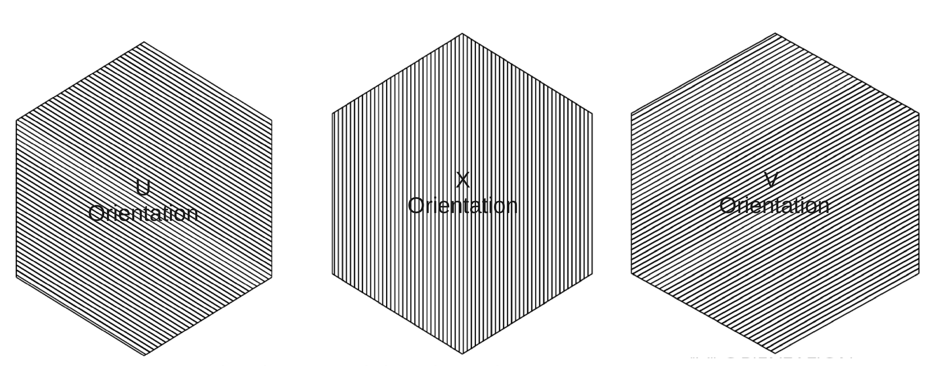
*Template for new water target*

*Liquid helium*

The nuclear targets modules consist of planes of the target material(s), interspersed with planes of active plastic scintillator. The active region immediately downstream of these targets is composed entirely of plastic scintillator planes. Each active plane is composed of 127 parallel strips of doped polystyrene.

Within each module, there will be either 1 or 2 scintillator planes (depending whether the module also includes a nuclear target). Each plane has the strips arranged in one of 3 orientations: X, U or V, at 60 degrees to each other, so we can reconstruct 3-D tracks.

Active region modules each contain an X-oriented plane, with the second plane alternating between U and V. In the modules which include targets, there will be only one plane of scintillator per module, with orientations in the order X-U-X-V.,




*The three module orientations*

When a charged particle passes through a scintillator strip, it produces photons, which pass through optical fibers to a photomultiplier tube. From the current produced, we can determine how much energy has been deposited in each strip of each module.

At the back and sides of the detector are an electromagnetic calorimeter made of lead interspersed with scintillator, then a hadron calorimeter made of iron and scintillator.

## PLACE event length reconstruction

The PLACE event length reconstruction algorithm decodes the information from the PMTs, which tells us how much energy has been deposited in each strip of each module.

By summing the total energy deposited in each module plane, we are able to pinpoint the location of an interaction's start and end, without resort to processor-heavy track-identification algorithms. The method we use was previously employed in the CCFR and NuTeV neutrino experiments.

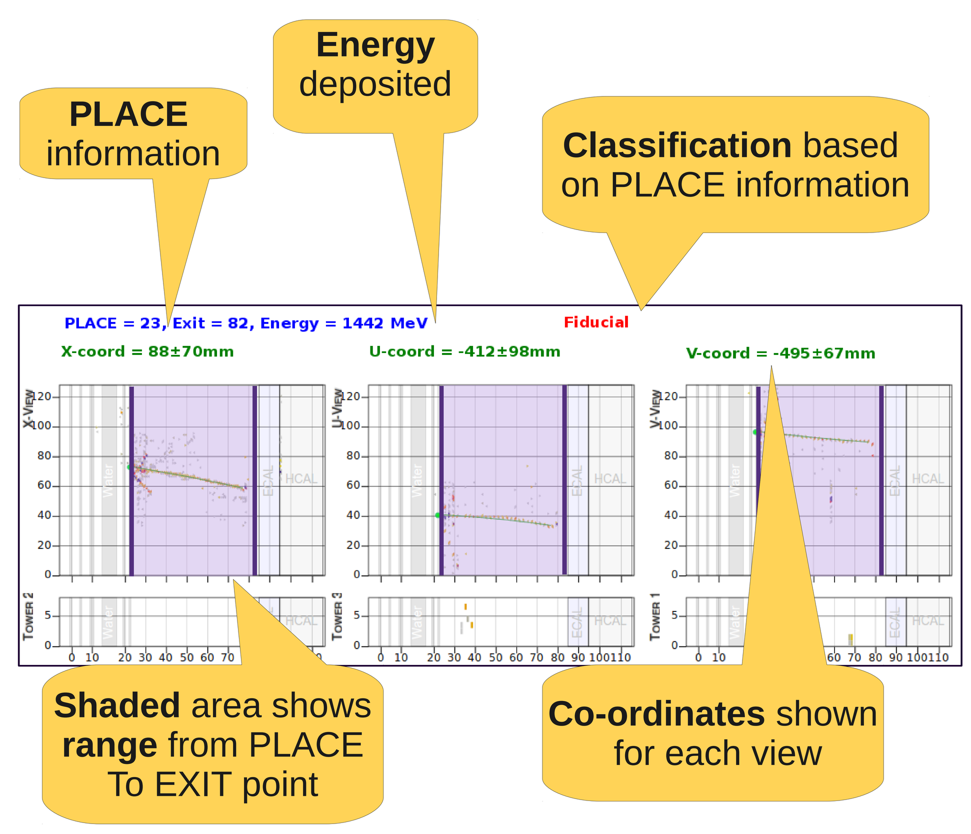
By knowing the characteristics of different interaction types, we can place limits on the PLACE data to identify data corresponding to particular types of event. This lets us select interactions of a certain type for more detailed study, or to eliminate irrelevant interactions.

The PLACE algorithm is much simpler and faster to run than the complex processes needed to identify the exact 3-D position of a particle track. Because of this, it can be used to:

- **Pre-select** data worthy of further study, eliminating events that do not correspond to the neutrino interactions we want to investigate
- **Sanity-check** the tracking algorithms by comparing the event type selections produced by the two methods.

## PLACE in action

The information we calculate is printed on the MINERvA event display below.

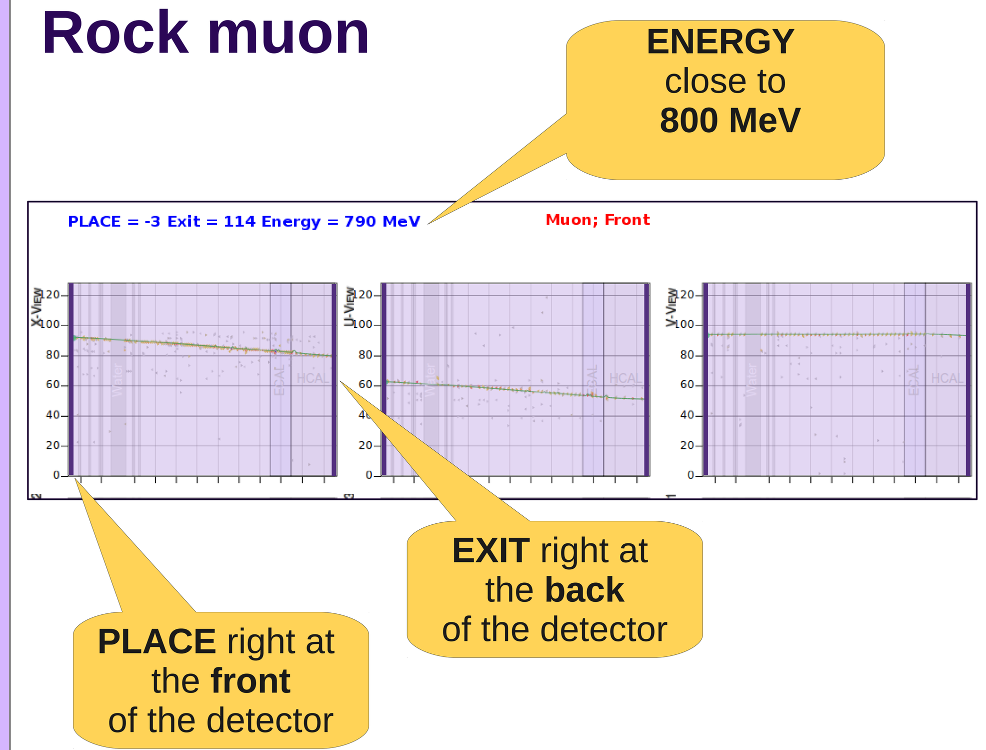



- Place (module number) where interaction starts
  *Needs hits in at least 4 of 6 consecutive modules*
  *Requires hits in all three views*
- Co-ordinates (X, U, V) of the interaction's beginning
  *Based on the 127 strips in each module*
- Error on each co-ordinate
  *Energy may be deposited in several strips*
- Energy deposited
  *Used in calibration: muons deposit energy at a fixed rate*
- Place where interaction enters fiducial volume
- Exit module

From this information, we can make a first attempt at classifying events.

## Some classified events

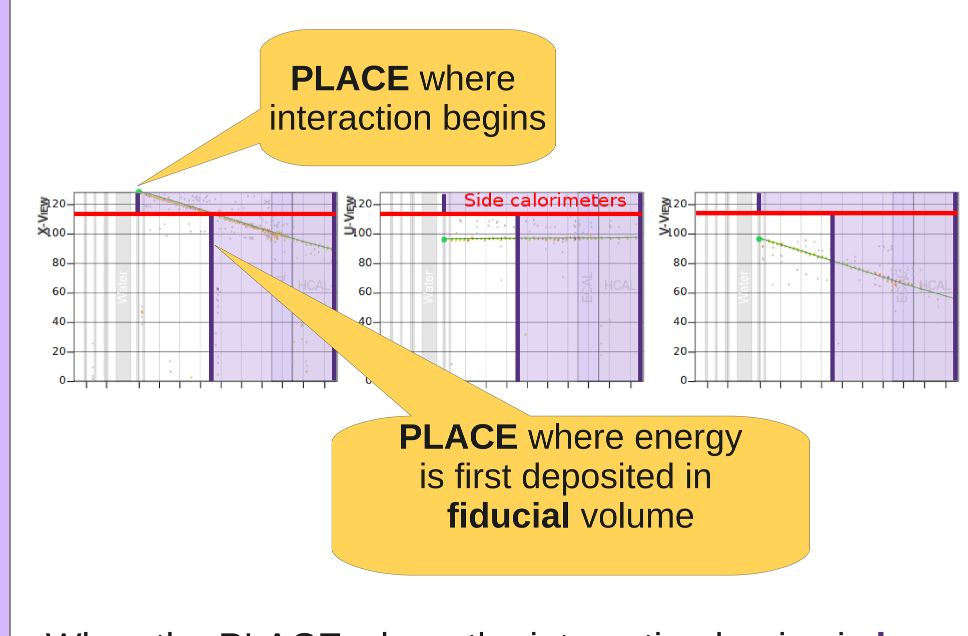
### Rock muon




A **muon** enters the front of the detector, created by neutrino interactions in the rock upstream. Muons rarely interact, meaning they tend to exit the back of the detector.

As muons are **minimum ionizing particles**, they deposit a constant amount of energy per unit length. For this reason, rock muons tracks are useful for **calibrating** the detector, enabling us to convert the voltage from the PMTs to a number of MeVs deposited in the scintillator.

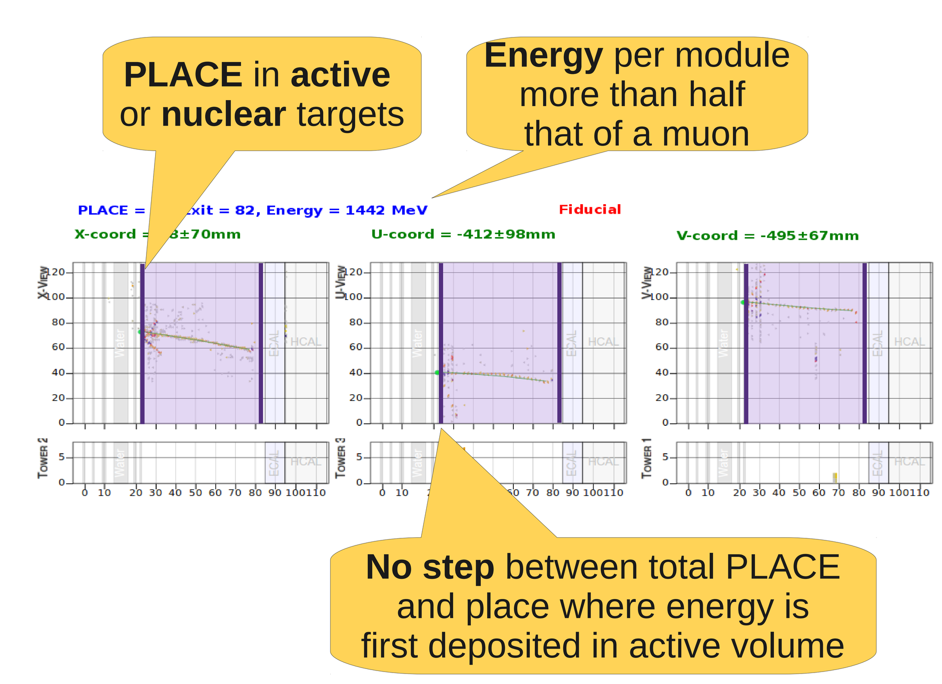
### Side interaction




When the PLACE where the interaction begins is **less** than the PLACE where energy is first found in the active (**fiducial**) volume, a neutrino interaction in the **side** calorimeters is indicated.

As we are interested in interactions with the **nuclear targets**, or with the active **scintillator**, we know we can discard events like these.

### Good neutrino interaction




An event like this in the **active** volume, with a significant rate of **energy** deposition, indicates a neutrino interaction worthy of further investigation.

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