Cosmic ray rates on a surface Liquid Argon TPC

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21 August 2006

Introduction

This note gives some calculations on the rates of cosmic muons and cosmic photons entering a Liquid Argon detector of mass 50 ktons situated on the surface of the earth at the altitude of the Soudan Mine (400 meters). Muons and photons are considered and the context is an accelerator-beam based experiment.
Cosmic rays could affect the experiment in (at least) four ways;

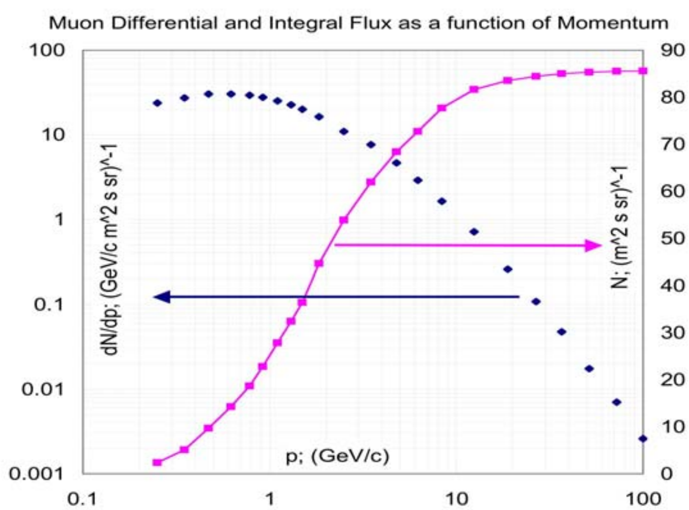
- they could generate so much data that the data-acquisition is overwhelmed.
- they might obscure such a large fraction of the volume of the detector that they overlap the events of interest to the point where the events cannot be reconstructed accurately.
- they might overwhelm the reconstruction and analysis such that the computing time required simply to remove the cosmic rays from the analysis is prohibitive.
- they could generate interactions in the argon which mimic the neutrino events of interest.

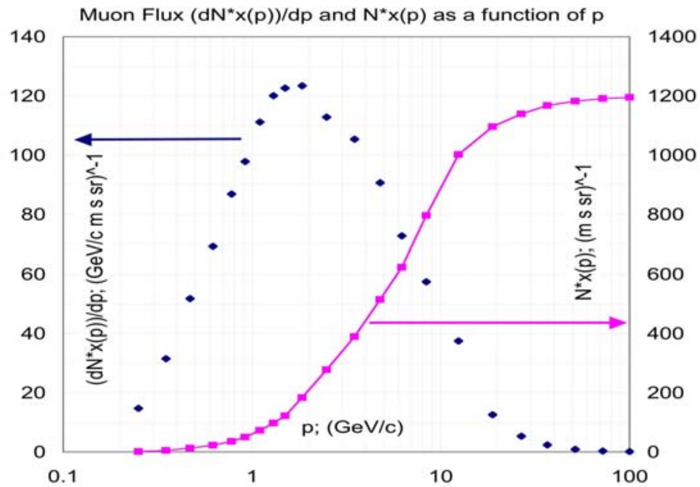
Detector Parameters
The detector is characterized by the volume of argon, the anode to cathode distance (drift-distance) and the wire spacing. The present discussion considers a detector based on a liquefied natural gas tank, a cylinder with its axis vertical and with diameter the same as its height, $\approx$ 35.5m. The drift-distance is 3 meters giving a maximum drift-time of 2 milliseconds at a drift field of 500 V/cm. The wire-spacing is set at 5 mm with 3 readout co-ordinates (vertical and $\pm 30°$) resulting in $\approx 250,000$ wires. Each wire is equipped with a continuous wave-form digitizer running at 2 MHz and the detector therefore generates numbers at a rate of 5E11/second. A scheme of recording the differences between successive digitizations [1] allows these numbers to be encoded into 3E11 bytes/second. The design of the readout system [2] allows for a total transfer rate of 5E9 bytes/second or about 16 milliseconds of the raw history of the entire detector per second.

*Contribution to the Brookhaven - Fermilab Long Baseline Study, September 2006

Data Acquisition Challenge
We assume there is no fast signal that defines the time of a cosmic ray entering the detector. If we wish to ensure that the *full* trajectory within the detector of any cosmic ray which generates signals in the detector live-time is reconstructed, the readout interval needs to cover from the maximum drift-time before the beam-spill to twice the maximum drift-time after the beam spill, a total of 6 milliseconds. (The 10 microseconds of actual spill is ignored.) If we simply want to tag a track as out of time, (as distinct from reconstructing the full trajectory inside the detector) it is not necessary to record for the full drift-times on both sides of the valid drift-time; recording before and after the nominal drift-time interval for 0.1 millisecond which is large compared to the few microsecond spill-timing uncertainties is sufficient[3].
The data acquisition is capable of transferring 16 milliseconds of raw history allowing for a beam-spill rate of $16/6 = 2.6$ Hz(full reconstruction) or $16/2.2 =$ 7Hz (tagging). This is faster than any machine cycle time proposed in the long baseline study [4].

Obscuring real events
The issue of background particles obscuring (confusing the reconstruction of) the events of interest, unlike the data acquisition issue, *does* depend on the background rates. The data source for these rates is the compendium by P. K. F. Grieder [5]. The rate of cosmic ray muons impinging on our 35.5 meter height/diameter cylinder is 250 kHz. This number is calculated using a $cos^2(\theta)$ distribution independent of momentum and includes particles entering from the top and from the sides (1/2 of the total).
The muon spectra for the calculations are shown in the first two figures.





The first figure shows the momentum spectrum and the integral of the spectrum from a given momentum to 1 TeV (effectively infinite momentum). The spectrum of the total path length of muons (the product of the flux at a given momentum and the path length in liquid argon of a muon of that momentum) and the integral thereof is given in the second figure. (For a muon with sufficient energy to traverse the full detector, the path length contribution is set to 50 meters.) From the integral plot, it can be seen that about 1200 meters of muon path length cross a horizontal square meter per steradian per second.

In the two millisecond live time, some 500 cosmic muons enter the detector; the muons have a typical energy of 3 GeV and travel about 15 meters. If one considers that each ray obscures a square tube of side 1 cm along its path, and traverses the whole detector (a conservative assumption given the 15 meter average path) the fraction of the detector volume obscured is less than 1 part in 10^4. The number of cosmic *photons* entering is less than 1% of the muon rate and their impact on seeing the true events is negligible.

Burden on reconstruction

Identifying and removing/ignoring the extraneous data from the muon tracks is also a requirement for successful operation of the experiment. The number of wires (in one co-ordinate) that a ray passes is $\approx$ 1000 and we may expect some 500,000 signals on the wires in one co-ordinate (7 tracks/wire) and about 1.5E6 signals total. An obvious scheme for identifying cosmic muons involves first finding lines in each co-ordinate separately. This is convenient logistically because one can present the data to a number of computers, each computer being assigned some number of wires. Since the computers process their data in parallel, the number of computers (or equivalently, the number of wires per computer) can be set to achieve the analysis rate required.

Cosmic Rays as a source of Background events

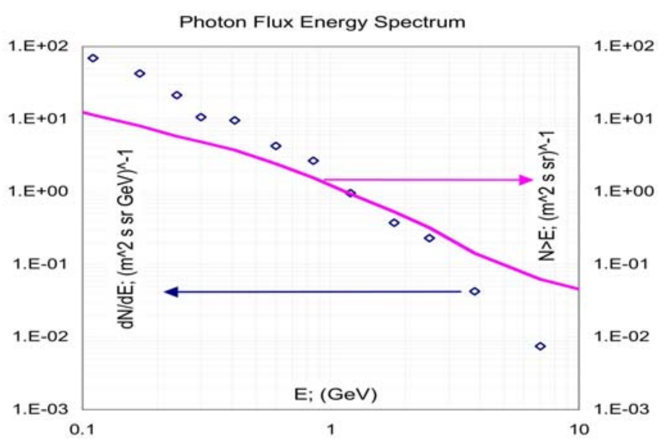
The last issue considered is background events from cosmic ray interactions in the detector. All that is done here is to establish the rejection rates required; the rejection we may expect still needs to be calculated.

Muons

The required rejection depends inversely on the number of protons-on-target (POT) per spill. A run of 15E20 POT at 3E13 POT per spill is 5E7 spills, and therefore about 2.5E10 cosmic muons will cross the detector. A rejection of better than 1E8 against these muons is required. It is indeed highly unlikely that any muon with sufficient energy to produce a background event be missed. The rejection, however, requires understanding the rate of muon interactions which generate a neutron or photon which travels a distance of several centimeters from the muon track before interacting. In this case it is still probable that the interaction can be associated with the incident muon but we do not have a number at this time.

Cosmic Photons

The cosmic photon flux impinging on the detector is about 1% of the muons; their spectrum is shown in the following figure.



The active volume is shielded by the iron shell of the tank and a meter of liquid argon. The total amount of material outside the active volume is therefore some 6 photon interaction lengths and reduces the flux into the active volume by a factor of 400. The remaining rejection required is therefore about 5E3. Unlike the muon case where the muon tags its entry into the detector and so one may be able to connect an interaction to the parent muon, photon conversions must be rejected on their own terms. A number of parameters are available to do this including the absence of hadronic activity at the conversion point, the presence of a double minimum ionizing track at the conversion point, and the angle of the event with respect to the beam from Fermilab.

References

[1] S. Amerio et al., Considerations on the ICARUS Read-out and on Data Compression, ICARUS-TM/2002-05.

[2] High Capacity Data acquisition architecture - Bowden, Votava in http://lartpc-docdb.fnal.gov, document 81

[3] see http://lartpc-docdb.fnal.gov document 160

[4] For use in a DC beam (a muon factory or a beta-beam), the data-acquisition situation is much more challenging. A surface detector would need a data-acquisition capable of transferring about 100 times as much raw data, or of rejecting data below threshold, fitting the wave-forms in real-time and passing fully reconstructed track positions and energy depositions. This latter scheme would require a band-width of 250 kHZ (cosmic muon rate) $\times$ 3,000 (wires seen per muon) $\times$ 4 bytes (wire number, pulse height, position) = 3 Gb/s. This would be within the capabilities of the proposed data acquisition system.

[5] Grieder, P.K.F. Cosmic Rays at Earth. Elsevier Science, 2001