Mu2e Cosmic Ray Veto
Counter Error Influence on Detection

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Abstract

The following project uses Binomial Distribution formula to assess the effects of a dead counter within a module of the CRV. If one out of four counters was not function, all possible paths through that counter were compromised. An average of 24 of 2304 paths fell below the 99.99% required for the CRV's efficiency standard, resulting in an unusable module. This can be corrected by increasing the sensitivity of the compromised paths to register a muon that is detected by 2 of the 3 working counters. This will increase the sensitivity of those paths to slightly above the 99.99% requirement, allowing the module to be used without replacing the counter. This sensitivity correction can also be used to correct any amount of broken counters, as longs as they are independent of each other's paths. If two or more counters are broken in a single path, the correction fails.

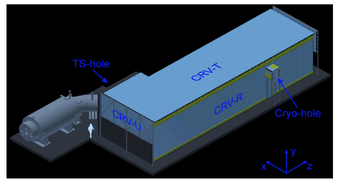
What is Mu2e?

Mu2e is essentially the testing of our current standard model in which we are attempting to convert muons to electrons in a nontraditional manner, which breaks a law of conversion.

In order to do so we have very sensitive detectors at the end of a particle accelerator. But they also pick up muons and particles from space that happen to fly through it (Cosmic Rays)

What is the Cosmic Ray Veto?

An outer shell made of detectors to protect the main detectors. When cosmic rays pass through the shell, they are detected and the main detectors turn off for about 120 ns to let the particle not interfere with the results.



CRV ➡ Modules ➡ Counters

Much in the way an organ is a collection of tissues which is a collection of cells, the CRV is a collection of modules, which are a collection of counters.

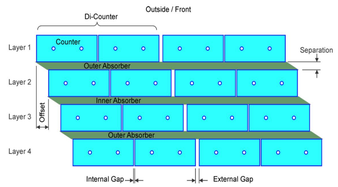
The CRV consists of 86 modules

Each module contains about 64 counters

The are 5,504 counters total in the CRV

Module dimensions are 4 x 4 x 4 counters

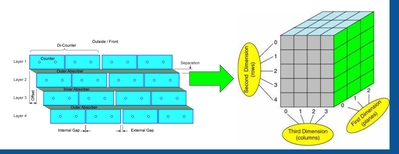
Error Allowance of 1% of counters randomly distributed



Reality to the Simulation

In order to transition from reality into the simulation, two assumptions must be made.

1. Cosmic rays themselves can be ignored as we are not focusing on the particles themselves but rather the paths they take
2. The transitions of alignments do not break the paths, only shift them.

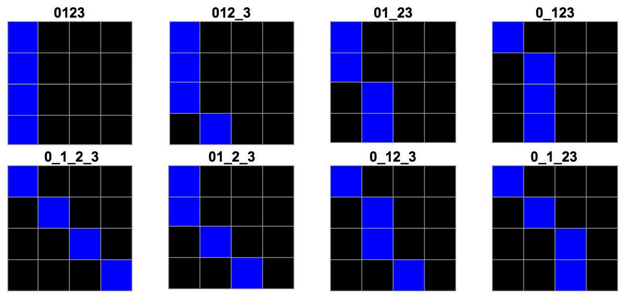


Program Design (2d Representation)

Counter 6-1-0 is broken

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Possible Path Patterns



Each Path has 9 Possible Rotations

8	1	2
7	0	3
6	5	4

R2

8	1	2
7	0	3
6	5	4

So Test01_23r1 is different than Test01_23r7

Probabilities of Success Using Binomial Distribution

Each counter has an individual efficiency of 99.6%

At least 3 counters must register a muon before it can be vetoed

Module is considered "dead" if it falls below 99.99%

99.9905% of at least 3 out of 4 working detectors detecting the muon

98.8048% of at least 3 out of 3 working detectors detecting the muon

So one broken counter already ruins the experiment….

$$P(X) = \frac{n!}{(n-X)!\,X!} \cdot (p)^X \cdot (q)^{n-X}$$

Simulation Results with Normal Sensitivity

If counter 0-0-0 is broken, 10 out of 2304 paths are compromised (Top Left Corner)

If counter 0-0-1 is broken, 16 out of 2304 paths are compromised (On the edge)

If counter 1-1-1 is broken, 24 out of 2304 paths are compromised (Middle)

If counter 6-2-2 is broken, 24 out of 2304 paths are compromised (Middle)

If counter 4-3-1 is broken, 24 out of 2304 paths are compromised (Middle)

Solution to Previous Data?

Change the sensitivity of those counters within cone of influence to veto after 2 successful detections

99.9952% of at least 2 out of 3 working detectors detecting the muon

99.2016% of at least 2 out of 2 working detectors detecting the muon

Simulation Results with Lower Sensitivity

If counter 0-0-0 is broken, 0 out of 2304 paths are compromised (Top Left Corner)

If counter 0-0-1 is broken, 0 out of 2304 paths are compromised (On the edge)

If counter 1-1-1 is broken, 0 out of 2304 paths are compromised (Middle)

If counter 6-2-2 is broken, 0 out of 2304 paths are compromised (Middle)

If counter 4-3-1 is broken, 0 out of 2304 paths are compromised (Middle)

Area Of Interest

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Two Broken Counters?

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Only Matters if They Are in the Same Path

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Conclusion

The results of the simulation and probabilities suggest that probability of success when a single counter along a path is broken can be pushed back above 99.99% by changing the sensitivity from 3 out of 4 working sensors detecting the muon to 2 out of 3 minimum. Reducing the sensitivity increase to the average 24 paths compromised insures that the entire module does not suffer from hypersensitive feedback when it is not required. Future work can be done to inquire about methods of selective sensitivity within the modules of the CRV.