Impact of Beam Induced Radiation Backgrounds on the Cosmic Ray Veto System of the Mu2e Experiment

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Outline

What is Mu2e?

Cosmic Ray Veto System

- Purpose and Design
- Impact of beam induced radiation backgrounds
- Experiment dead time

Simulation

- Identification of internal sources

Estimation of Dead time

Summary

What is Mu2e?

Mu2e is an experiment at Fermilab that will search for a neutrino-less muon to electron conversion process:

- $\mu^- + N \rightarrow e^- + N$

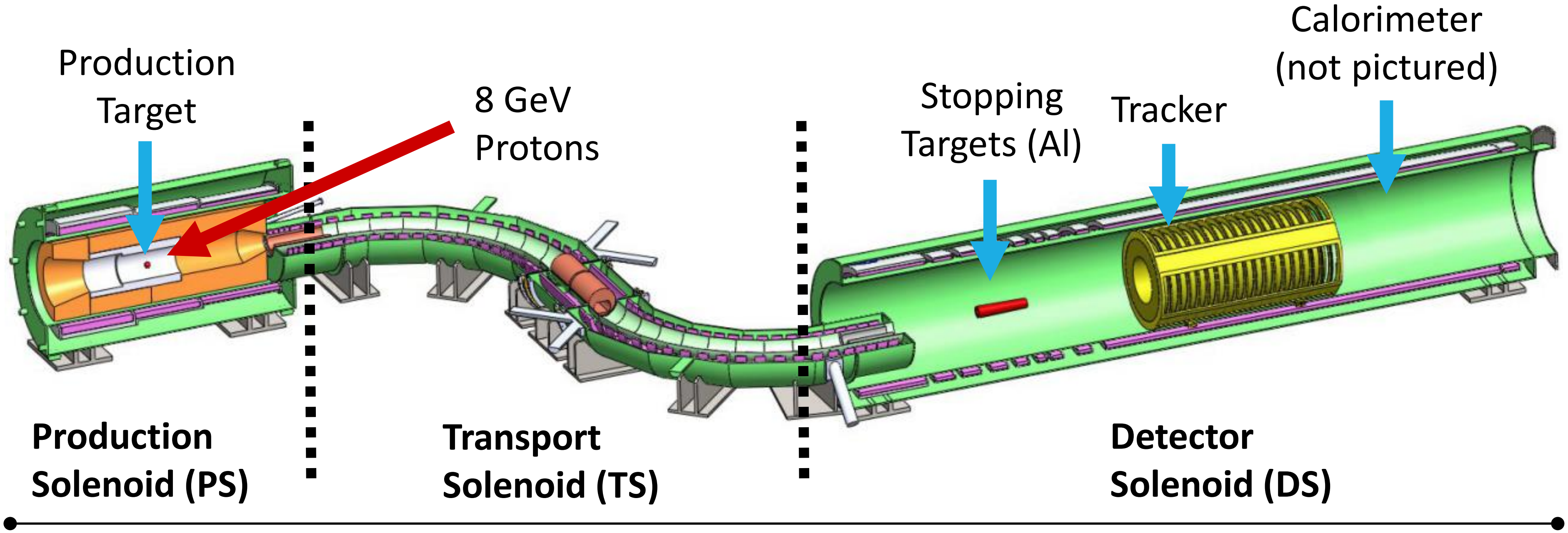
Neutrino-less $\mu^- \rightarrow e^-$ conversion is an examples of Charged Lepton Flavor Violation (CLFV)

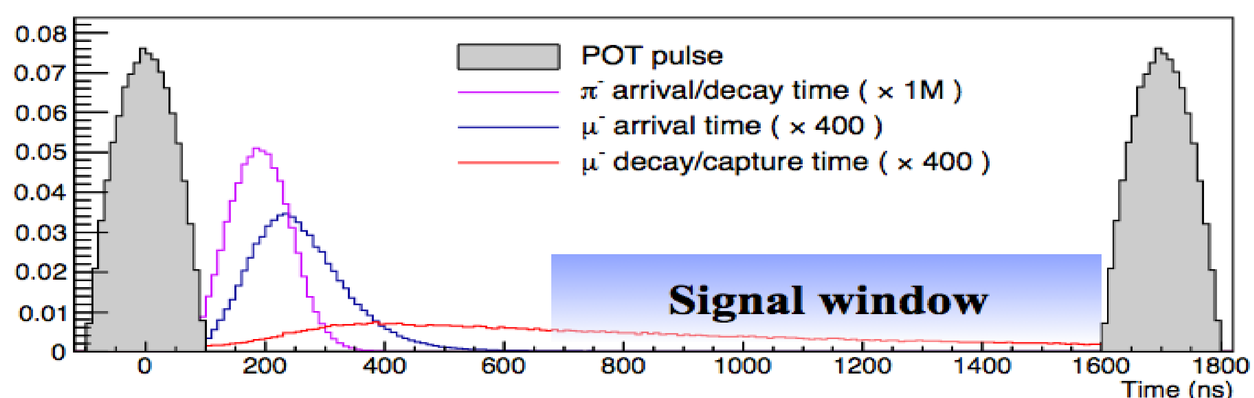
In the SM, CLFV occurs at a rate $< 10^{-50}$, but beyond the SM the rate could be 10^{-16} or larger

- Observation of conversion is an unambiguous sign of new physics

Mu2e will achieve four orders of magnitude improvement in sensitivity to the current best limit

Mu2e Apparatus



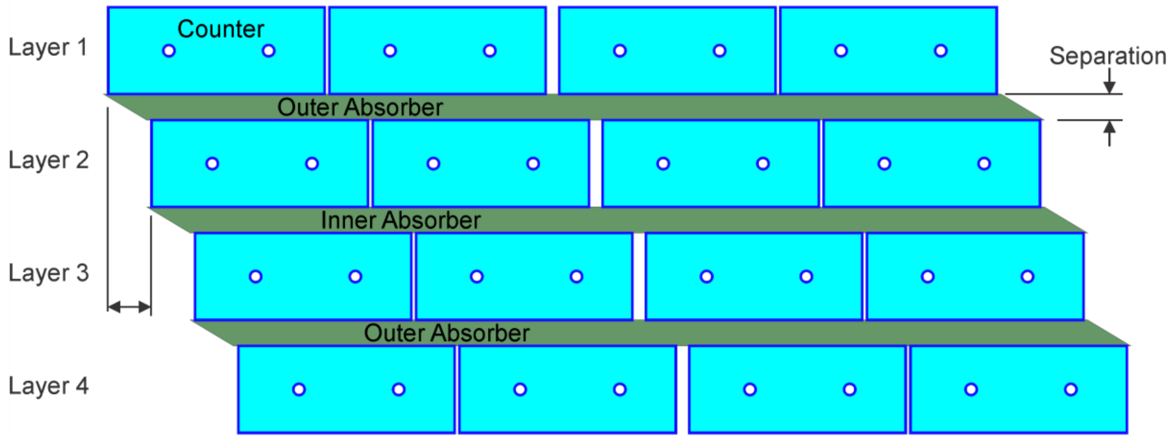


Cosmic Ray Veto

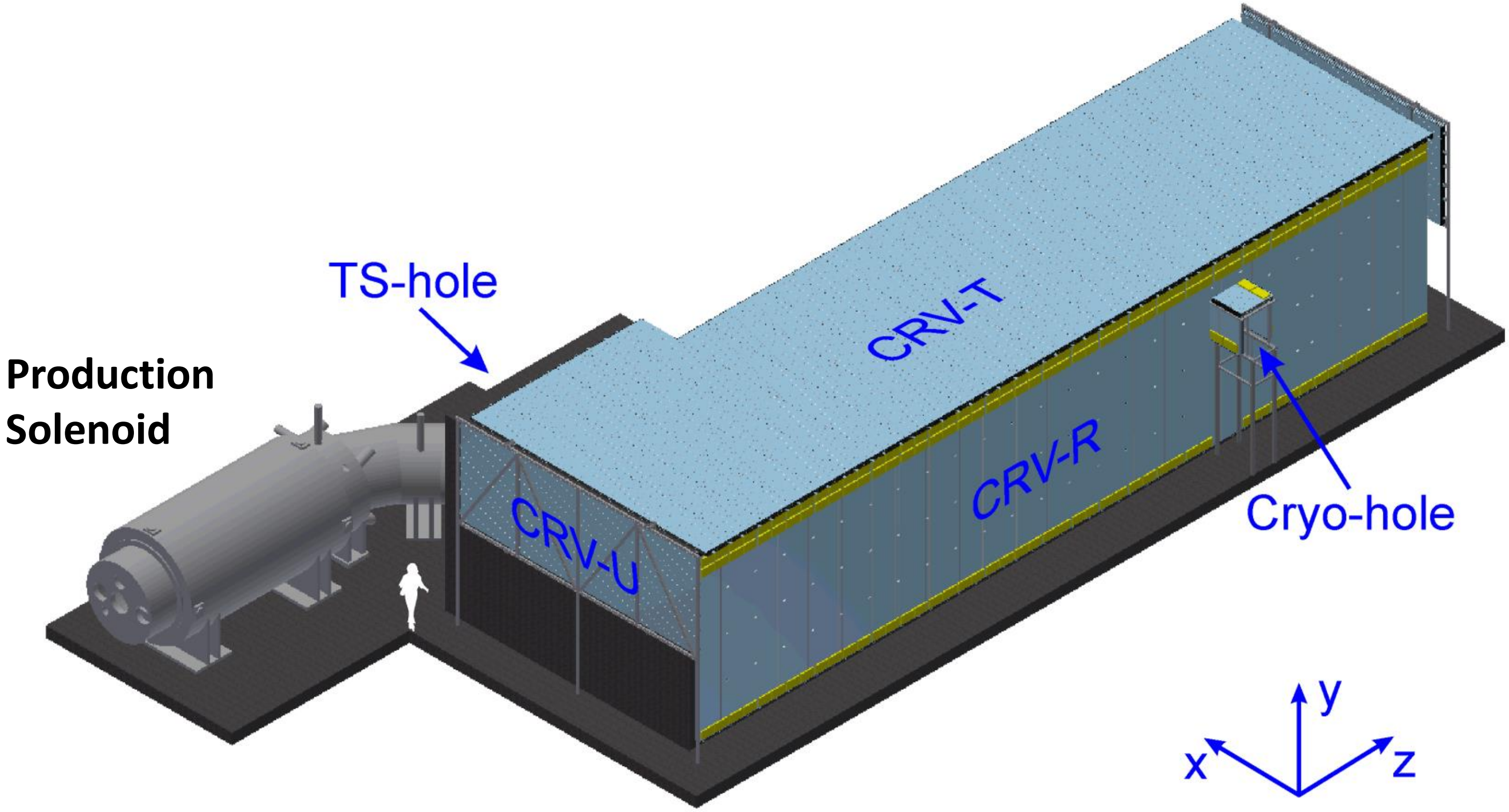
Incoming cosmic rays and their interactions can result in a false conversion electron signal

For experiment to reach designed sensitivity, the Cosmic Ray Veto (CRV) requires a 99.99% detection efficiency of cosmic rays

Four-layer, extruded plastic scintillator detector surrounding experiment’s detector components



CRV Layout



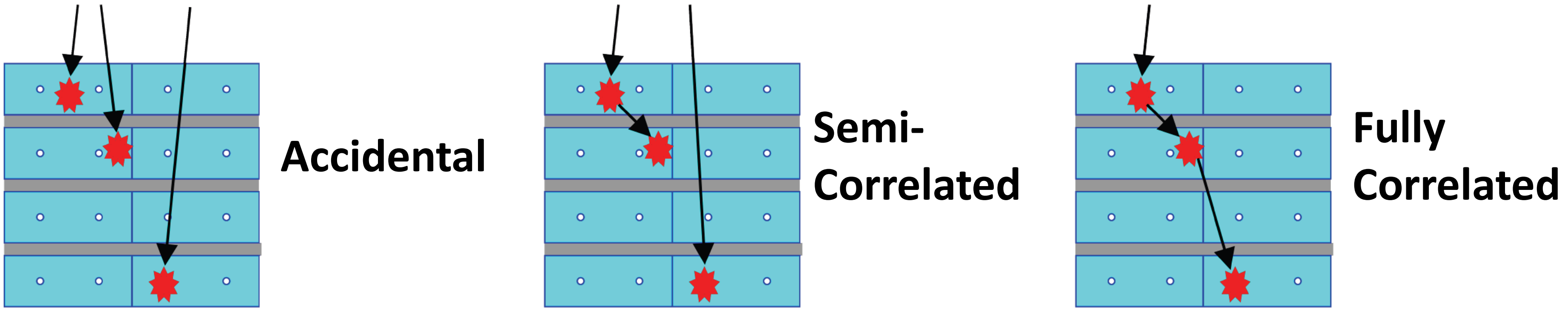
CRV Dead Time

Signal window is time in which the experiment is looking for conversion electrons

Dead time is the time which the experiment ignores from the signal window

Cosmic rays form a coincidence with hits in at least 3 out of 4 layers of the CRV—imposing 125ns of dead time

Three types of coincidences:



Beam Impact

The CRV is sensitive to not just cosmic rays, but also beam induced radiation backgrounds from the experiment

- Proton beam incident on production target
- Muon beam propagating to stopping targets
- Daughters produced by stopped muons

Neutrons and photons from these sources can create coincidences and resulting in additional dead time

- Mostly accidental and semi-correlated coincidences

Goal: To estimate dead time due to internal sources

Driving Factor: Ensuring the dead time does not have an important impact on sensitivity

Simulation

Using a Geant4 based framework, the complete Mu2e experiment geometry was simulated

Included was a realistic CRV response:

- Light propagation
- SiPM response
- Waveform reconstruction
- Digitization (SiPM photoelectrons)

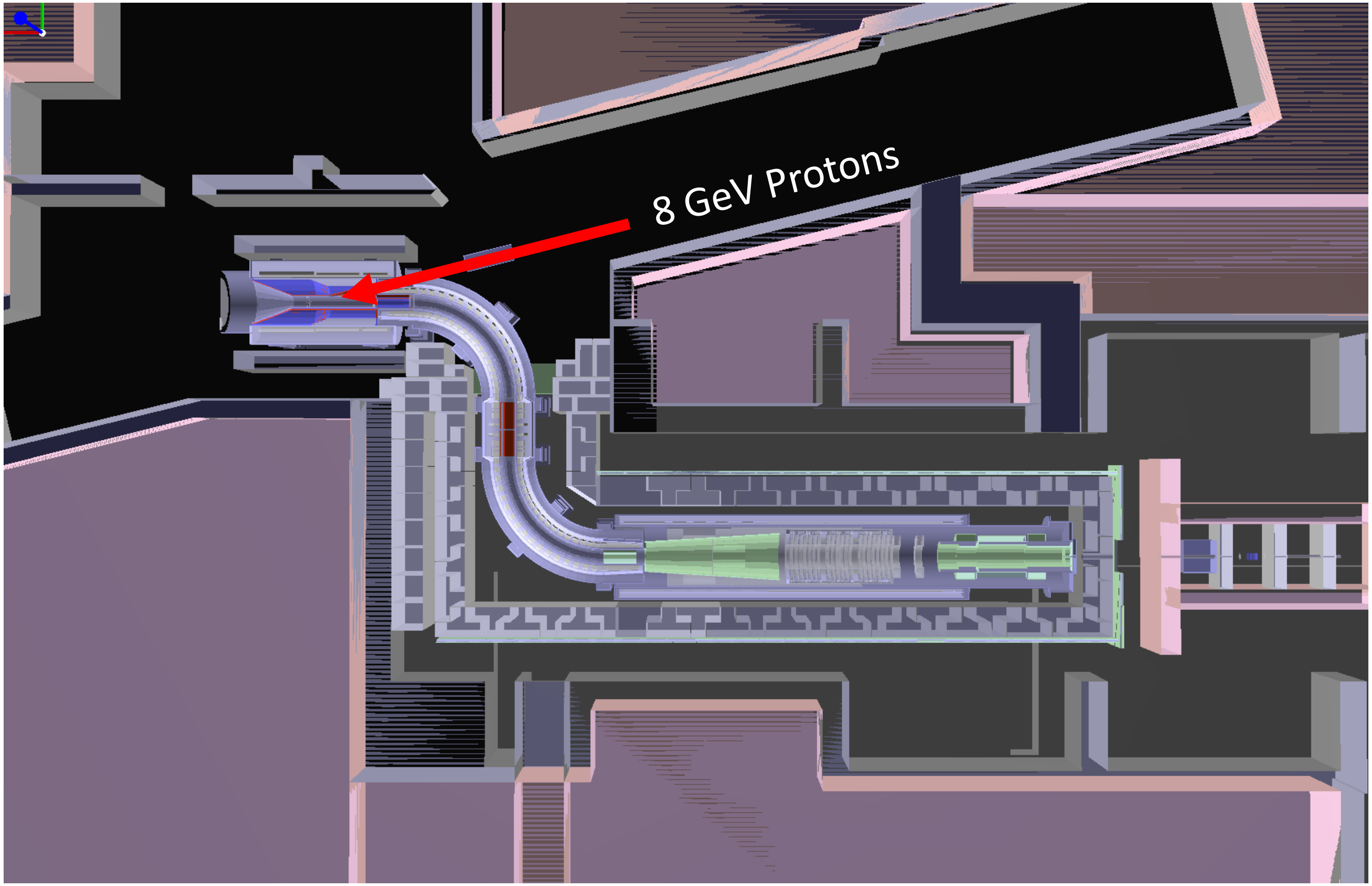
SiPM = Silicon Photomultiplier

A μ-bunch corresponds to delivery of protons by accelerator—happening once every 1695ns

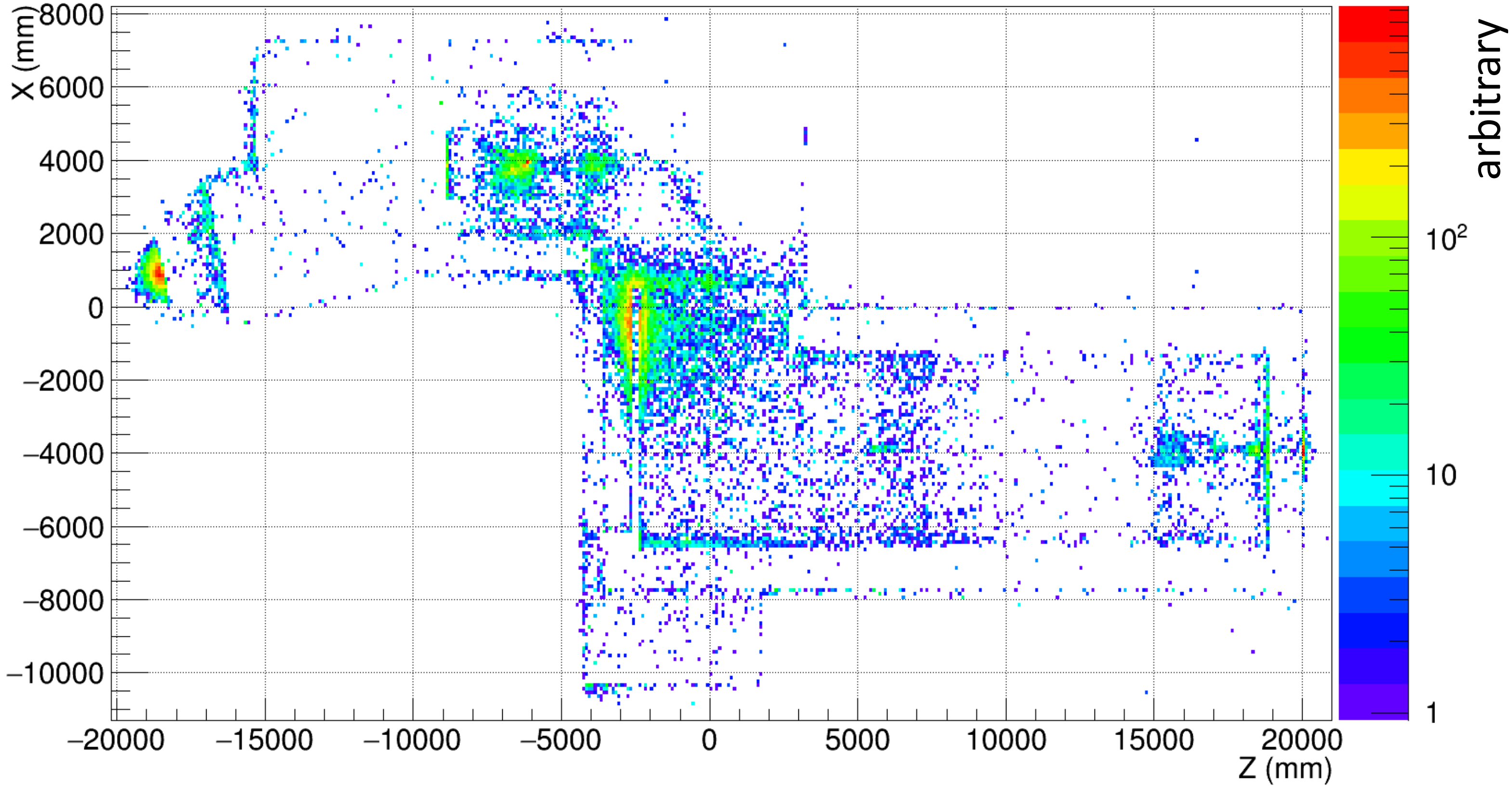
- t_0 is at 0ns, with signal window assumed to be 550-1695ns

10 μ-bunches with 31 Million protons on target (POT) per μ-bunch were simulated

Simulation Geometry



Sources of Neutrons and Photons reaching the CRV



$t > 500\text{ns}$

Dead Time Estimation

Currently, only a simple CRV coincidence finding algorithm exists

- A coincidence is at least 3 out of 4 hit layers

Looks for coincidences within a defined:

- Spatial region
- SiPM photoelectron (PE) threshold
- Time window

The time window and threshold were adjusted so that the detection efficiency was ~99.9% for cosmic rays that reach the detector solenoid

Dead Time Estimation

The dead time fraction was estimated:

- Using only 10 μ-bunches with 31 Million POT/μ-bunch
- Signal window from 550-1695ns
- 125 ns total dead time/coincidence
- 30cm max spacing, 15ns max time difference, 10 PE threshold
- With the above assumptions, to be 12% ± 4 (stat)

Higher statistics will reduce the uncertainty in the dead time and assist in the identification of sources

A refinement of assumed parameters and coincidence finding algorithm will provide a more accurate estimation

- Signal window and imposed dead time
- Coincidence parameters

Summary

The Cosmic Ray Veto system requires a detection efficiency of 99.99% for cosmic rays, but is sensitive to beam induced radiation

Main neutron and photon sources are in the production solenoid region

With the assumptions that were made, the dead time was estimated at 12%

- Large uncertainty due to limited statistics and a simple coincidence finding algorithm