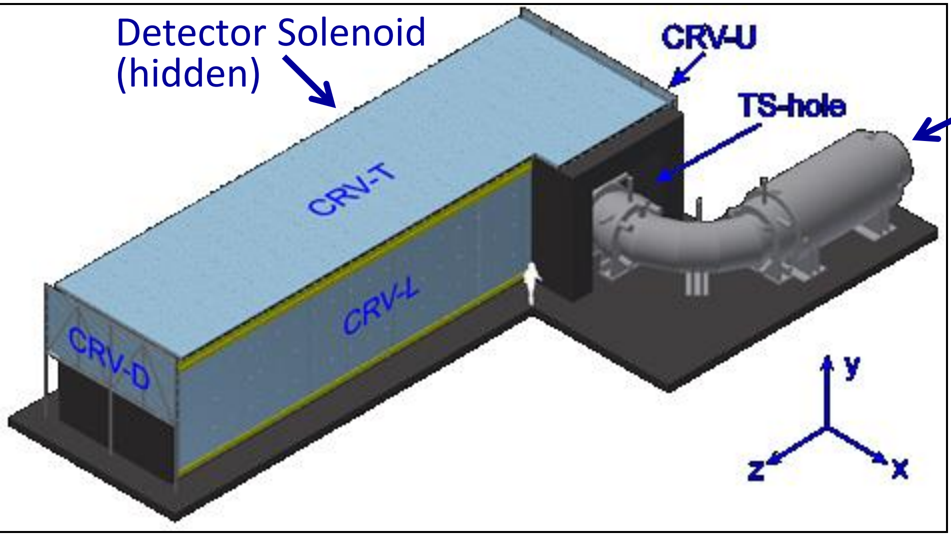
Mu2e Computing Review: Workflow Cosmic Ray Simulation

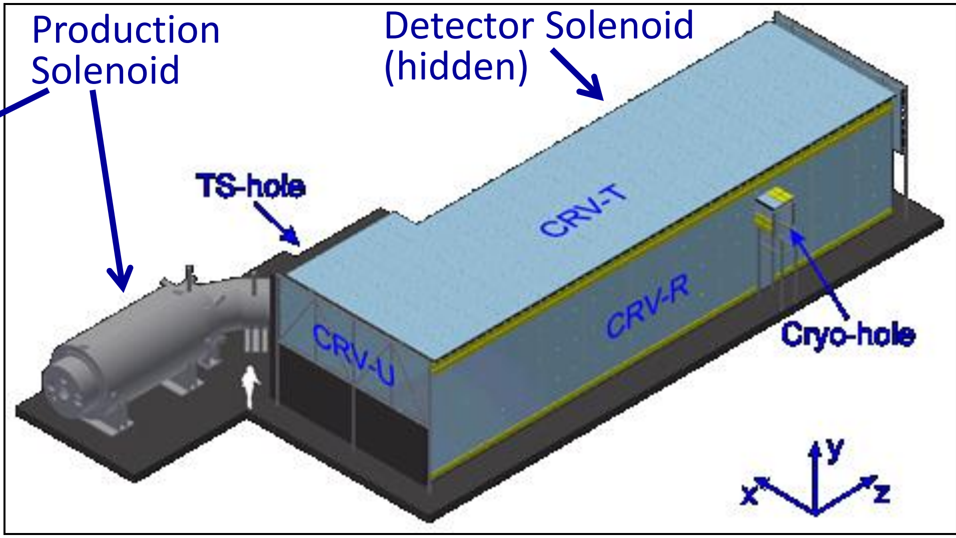
Ralf Ehrlich
University of Virginia
March 5, 2015

Mu2e doc-db 5226

Overview

- Cosmic ray muons are able to produce 105 MeV/c tracks that can mimic conversion electrons.
- These cosmic rays need to be detected by the Cosmic Ray Veto (CRV).
- CRV modules consist of 4 layers of scintillator bars and aluminum absorbers, which are places around the Detector Solenoid and parts of the Transport Solenoid.
- TDR requirement: No more than 0.1 cosmogenic background events in the entire run time.





Two Types of Cosmic Ray Muon Simulations

General Simulation

- Goal: 10% of the total run time of the experiment.
  - Have done 2% for the TDR.
- Purpose:
  - To get a sample of “dangerous” events that can mimic conversion electrons.
  - To find out the veto efficiencies of the CRV for such events.

4 Targeted Simulations

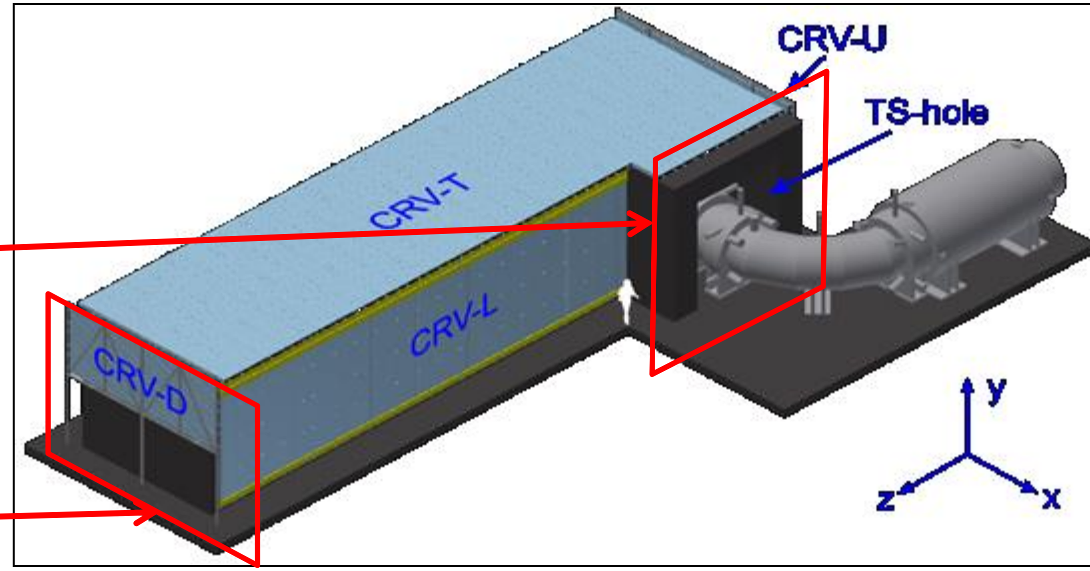
- Simulations of a small phase space at specific detector locations which have less than ideal coverage.
- Goal: CD2 recommendation is 10 times of the total run time of the experiment.
  - Have done 100% of the total run time of the experiment for the TDR.
- Purpose:
  - To find out whether the coverage is sufficient at “critical” locations.
  - To find out whether there are cosmic ray events which cannot be vetoed by the CRV.

Locations for targeted simulations

- The 4 regions with less than ideal coverage
  - Generate a small phase space of cosmic rays incident at these regions.

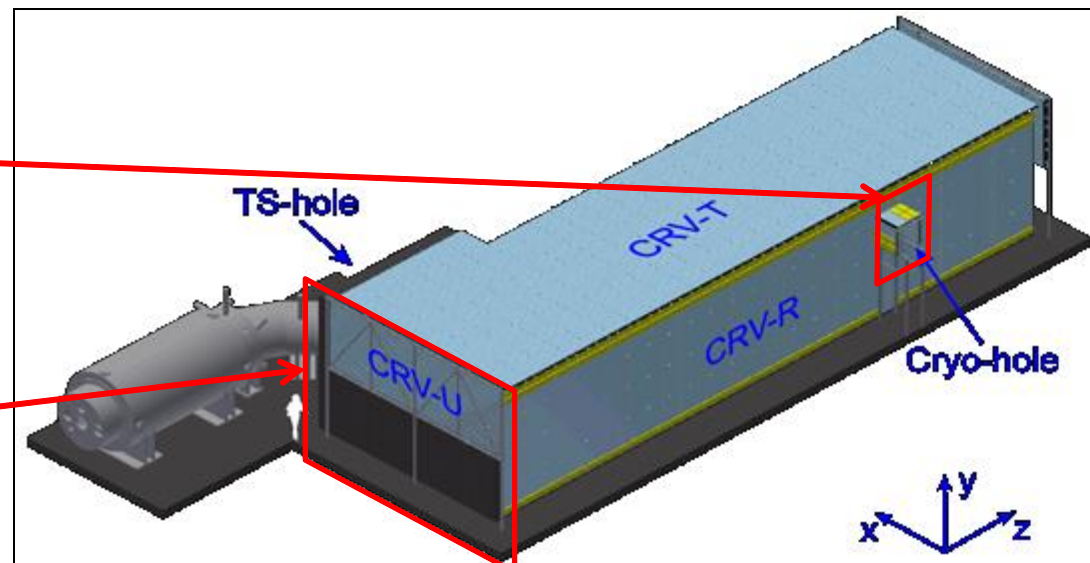
TS Entrance

Lower part of CRV-D



Cryo hole

Lower part of CRV-U



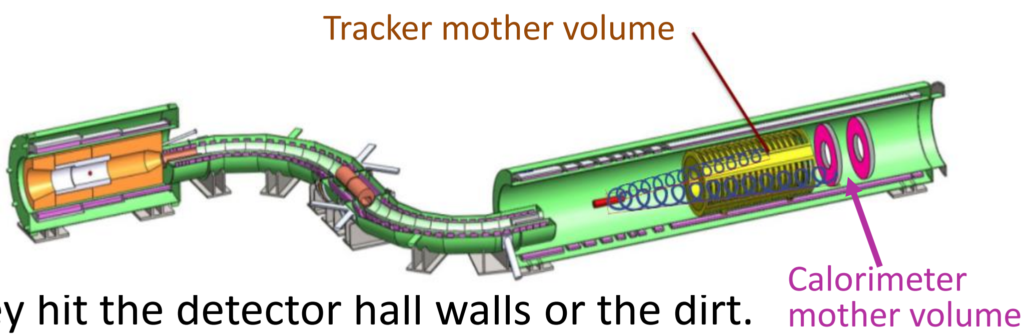
Simulation – Stages 1 & 2

➢ Stage 1

- Generate cosmic ray muons at the surface.
  - Energy interval from 0.5 GeV to 1000 GeV.
  - Use Daya Bay code.
- Propagate them (with GEANT) up to the mother volumes of the Tracker or Calorimeter.
  - Stop simulation there to be continued in stage 2.
- Remove events which have no particles hitting either mother volumes with at least 45 MeV/c (sufficient to keep muons which may decay into 80 MeV/c electrons).

➢ Stage 2

- Continue the surviving tracks from stage 1 starting at the boundary of the mother volumes of Tracker or Calorimeter



- Propagate them (with GEANT) until they hit the detector hall walls or the dirt.
- Remove events which do not produce at least 15 G4Steps in the tracker straws.

➢ Multi-stage approach

- Stage 1 is optimized for speed → higher thresholds
- Stage 2 is optimized for accuracy → lower thresholds
- Output of stage 1 simulation can be re-used for different designs of the tracker.
- See also Andrei's talk.

Stage 3

- Make data-like straw hits and run track reconstruction as prescribed by Dave Brown.
- Store only events which have reconstructed tracks which pass loose cuts with a momentum between 50MeV/c and 200Me/c.

Estimated Resource Requirements

	General simulation	Targeted simulation			
		TS entrance	CRV-U	CRV-D	Cryo hole
Fraction of total live runtime	0.1	10	10	10	10
Required computation time [million CPU·hours]	0.4	1.7	1.5	1.4	*0.2?*
Required disk space [TB]	12	23	12	49	*8?*

Total disk space requirement: 104 TB.
Total computation time requirement: 5.2 million CPU·hours.

Stage 1: 19 TB / 5.0 million CPU·hours.
→ Excellent candidate for off-side jobs.

These numbers are based on the TDR simulations.

Next Step

➢ The simulation so far

- The output sample contains downstream electrons, upstream positrons, muons.
- Used to learn how to distinguish these particles with tracker and calorimeter.
- The separation is good, but not perfect.

➢ Next step:

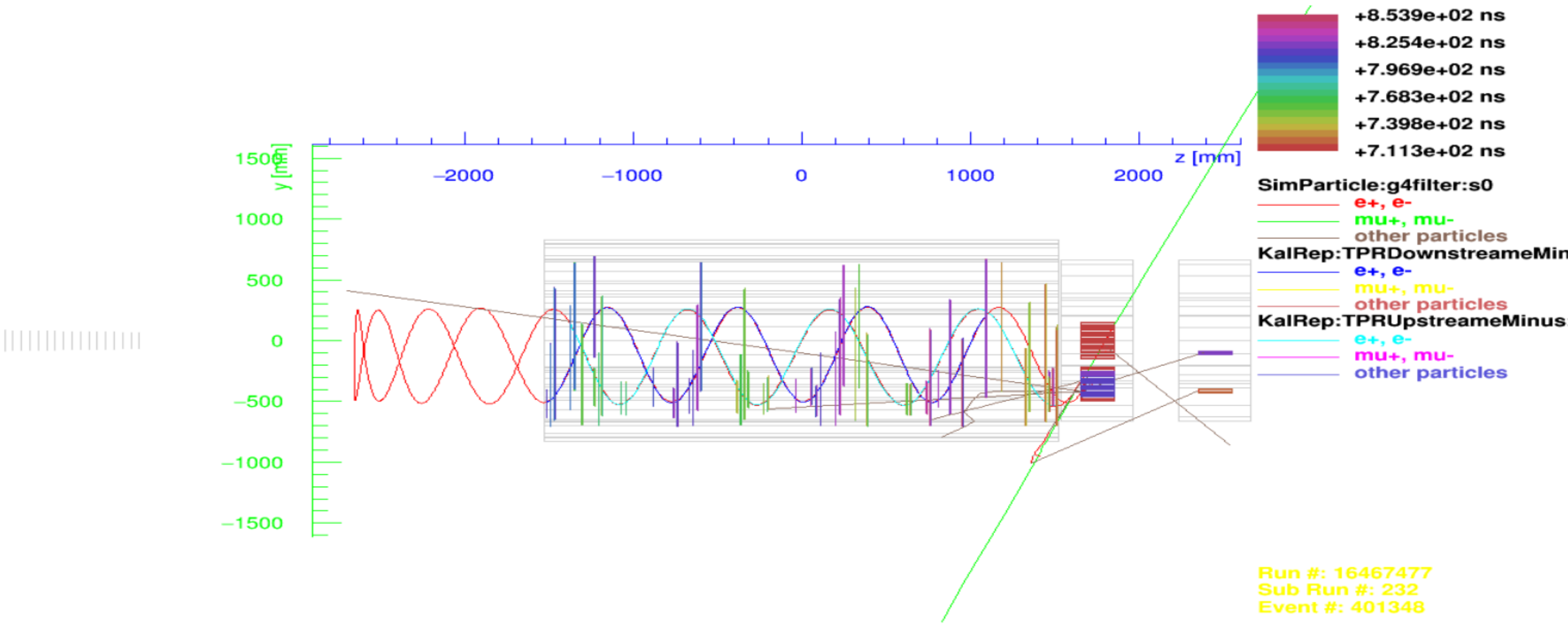
- Analyze the CRV efficiency for vetoing cosmic ray events resulting in conversion-like electrons.
- Need the CRV hit simulation.
  - Starting from G4Steps in the CRV produce photons, SiPM responses, and data-like CRV hits.
- Use a “3 out of 4” coincidence checker.
  - Look for patterns which are consistent with a cosmic ray going through the CRV counters in at least 3 out of 4 CRV layers.

Summary

- Cosmic rays muons are simulated in a multi-stage approach.
- General simulation to get a sample of tracks that are consistent with being a conversion like electron, and to find the CRV efficiency to veto them.
- Targeted simulations to find out whether CRV coverage is sufficient, and whether there are cosmic ray events which cannot be vetoed by the CRV.

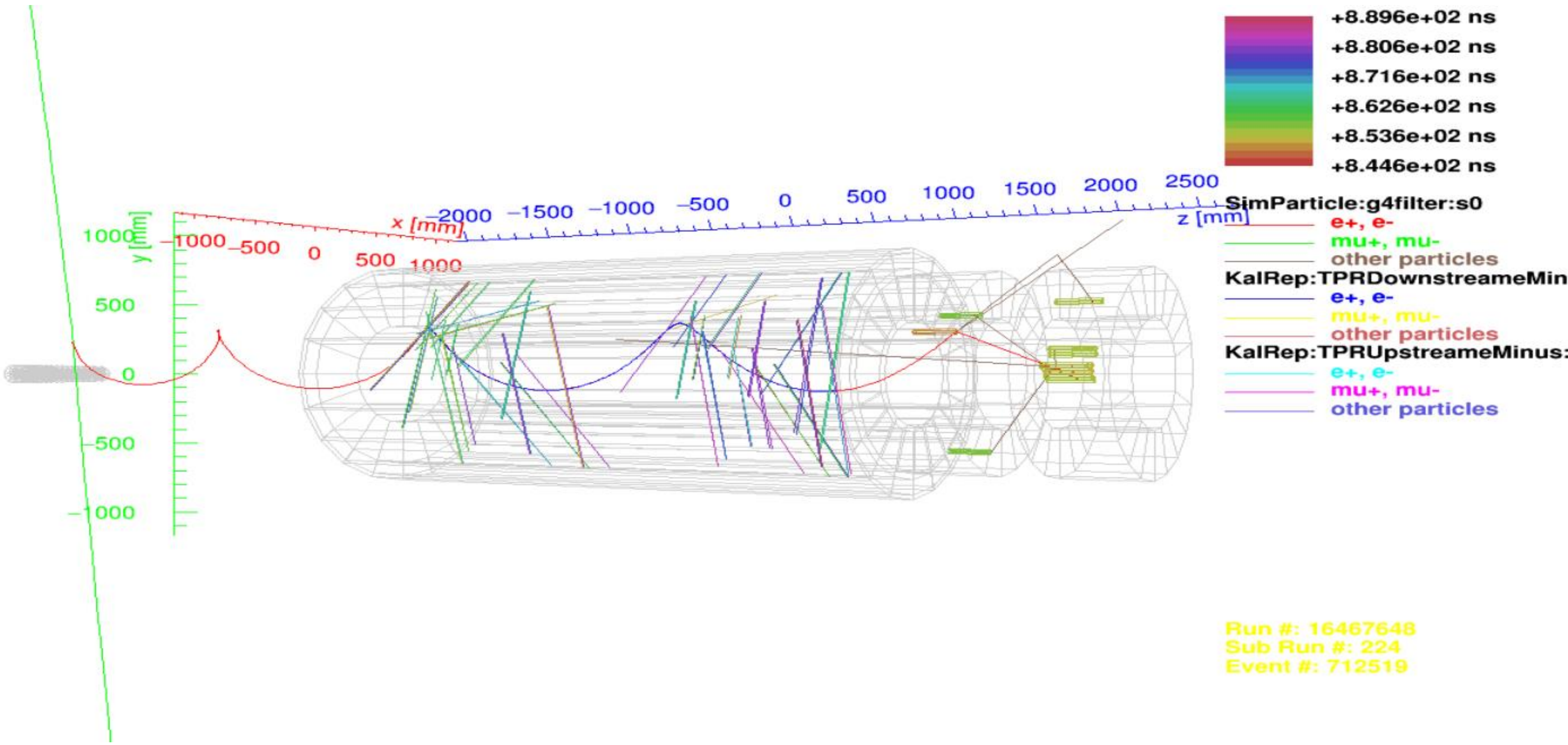
Backup Slides

Examples of Cosmic Ray Events



Cosmic ray mu- creates an e- through ionization in the calorimeter, which goes upstream through the tracker, gets reflected and goes back downstream through the tracker. The upstream and downstream portions of the e- track are reconstructed.

Examples of Cosmic Ray Events



Cosmic ray mu- creates an e- by pair production in the proton absorber, which goes downstream through the tracker. The e- track is reconstructed.

Projecting Generated Tracks to the Surface

- Generating events on the surface (above the dirt/overburden over the detector) creates a large fraction of tracks which will miss the detector (or the critical regions for the targeted simulations).
- More efficient solution: generate tracks at a production plane at the detector.
  - Production planes
    - For the general simulation: A horizontal plane going through the center of the detector solenoid.
    - For the targeted simulations: Vertical planes located at the critical regions.
  - These tracks get projected from the production plane up to the surface using the direction of their momentums.
    - This assumes that the muons go in a straight line from the surface to the production plane.
  - GEANT simulation of the tracks start at the surface.
  - Particles get propagated through the dirt/overburden to the detector.

Simulation – Stage 1

- Generate cosmic ray muons at the surface.
  - Energy interval from 500 MeV to 1 TeV.
  - Use Daya Bay code.
- Propagate them (with GEANT) up to the mother volumes of the Tracker or Calorimeter.
  - Stop simulation there to be continued in stage 2.
- Remove events which have no particles hitting either mother volumes with at least 45 MeV/c.
  - This momentum is sufficient to keep muons which may decay into 80 MeV/c electrons
- G4Steps are recorded for the CRV.
- Minimum range cut of 1mm.
  - Makes the simulation faster than the cut of 0.01 mm for stage 2.
  - Sufficient, since we do not look for any physics response at this stage.
- Remove particles which cannot produce tracks of a least 80 MeV/c.
  - Gammas, e+, e- need to have a kinetic energy of at least 80 MeV.
  - Protons, neutrons need to have a kinetic energy of at least 3.4 MeV.
  - Cuts make the simulation faster, since we do not have to propagate all of these low energy particles.
  - Cuts are acceptable, since we do not look for any physics response at this stage.

Simulation – Stage 2

- Continue the surviving tracks from stage 1 starting at the boundary of the mother volumes of Tracker or Calorimeter
- Propagate them (with GEANT) until they hit the detector hall walls or the dirt.
- Remove events which do not produce at least 15 G4Steps in the Tracker Straws.
- G4Steps are recorded for the CRV, tracker straws, and calorimeter.
- Minimum range cut of 0.01mm.
  - Makes the simulation slower than the cut of 1 mm for stage 1.
  - More precise than in stage 1.
- No cuts on energy.

Computation times and disk space requirements

The following numbers are for **1 million generated events**.

		General simulation	Targeted simulation		
			TS entrance	CRV-U	CRV-D
Stage 1	Computation time [h]	2.8	4.0	3.6	3.1
	Disk space [MB]	22	11	7	19
Stage 2	Computation time [h]	0.2	0.1	0.1	0.2
	Disk space [MB]	68	45	22	99
Stage 3	Computation time [h]	0.005	0.002	0.001	0.004
	Disk space [MB]	0.4	0.3	0.4	0.9
Total	Computation time [h]	3.0	4.1	3.7	3.3
	Disk space [MB]	90	56	29	119
Corresponds to a life time of [s]		10.7	341	341	341

These numbers are based on the TDR simulations.

Estimated Resource Requirements

	General simulation	Targeted simulation			
		TS entrance	CRV-U	CRV-D	Cryo hole
Production area [m^2]	800	100	100	100	16
Orientation of the plane	horizontal	vertical	vertical	vertical	vertical
Cosmic rate [kHz]	93.5	2.93	2.93	2.93	0.47
Required number of events	1.3E+11	4.1E+11	4.1E+11	4.1E+11	6.6E+10
Fraction of total live runtime	0.1	10	10	10	10
Required computation time assuming 1000 jobs run parallel [days]	17	71	64	57	*9?*
Required disk space [TB]	12	23	12	49	*8?*

Total disk space requirement: 104 TB
Total computation time requirement: 218 days (assuming 1000 jobs run parallel)

These numbers are based on the TDR simulations.

CRV Hit Simulation

Legend: Done | Partially done | In framework

Mu2e Offline Simulation (GEANT based)
determines energy depositions, track positions and track speeds inside of the CRV counters

Output from previous simulation stages

CRV Hit Simulation

CRV Photon Arrival Generator
generates the number and arrival times of the scintillator and Cerenkov photons at the SiPMs

Standalone GEANT simulation
used to generate lookup tables

Find material parameters

CRV SiPM Response Generator
simulates the SiPM response incl. saturation, after pulses, cross talk, thermal noise pulses

Find SiPM parameters

CRV Waveform Generator / Digitizer
creates the full waveforms (12.5ns sampling rate)

Single PE waveform

CRV Reconstruction

CRV Waveform Generator / digitizer
creates the full waveforms (12.5ns sampling rate)

Output from
CRV Hit Simulation

CRV Reconstruction

Find CRV Reco Pulses
#photons, leading edges

"3 out of 4" Coincidence Checker
looking for patterns which are consistent with
a cosmic ray going through the CRV counters
in at least 3 out of 4 layers

Done
Partially done
In framework