Fermilab

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Mu2e Backgrounds and Computing

Robert Bernstein

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Introduction/Outline

- Structure of Talk

  1. Physics View (what Mu2e needs to understand)
     a. Definitions of Terms
     b. Physics Explanations

  2. Computing View (how we use computing to understand)
     a. Classify Physics by required computing methods and required resources

- This is an overview talk – details filled in later

Physics View: Definition of Terms

- Backgrounds are more than just "backgrounds" and here is how we split things that we need computing to understand:

1. Background: a physics process than can produce a fake signal
2. Accidental: activity in the detector not part of a reconstructable track or other interesting physics process but can confuse pattern recognition or worsen resolution
3. Aging: degradation of detector from radiation damage or other source

These are not mutually exclusive

- A physics process (background) can also produce accidentals
  - Main body of DIO electrons produce accidentals!
  - High energy tail of DIO makes background!

- Accidentals can produce resolution smearing that creates background
  - Muon capture ejects particles that confuse tracking

- Accidentals can also produce aging of detector elements
  - Radiation damage to calorimeter

Backgrounds

- Muon Decay in Orbit (DIO)
  - Muons stop in our Al stopping target; 40% decay by

$$\mu^- \to e^- \nu \bar{\nu}$$

  - The free Michel muon decay spectrum is modified because this decay occurs from a muonic bound state
  - The predicted background from DIO is about 0.2 events and is the single largest background in current estimates

Decay In Orbit Overview

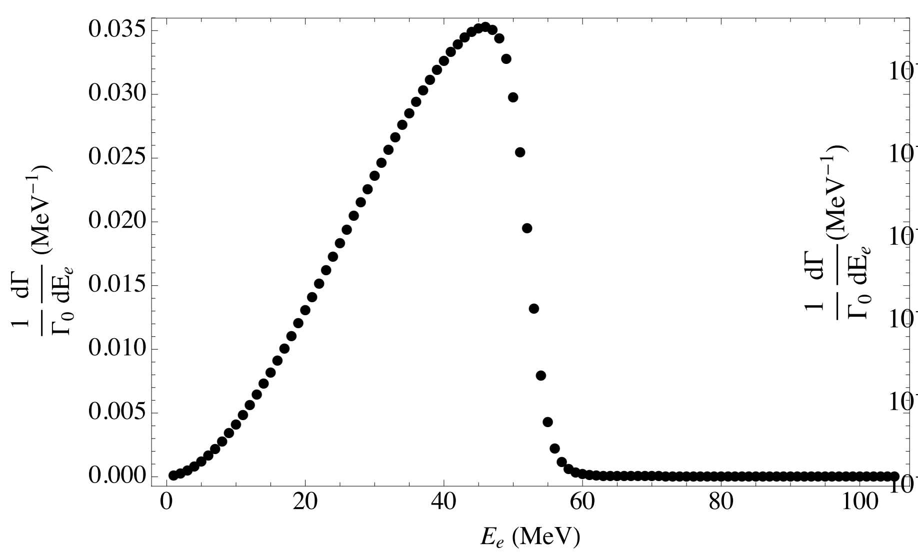
- Free muons decay according to Michel Spectrum:

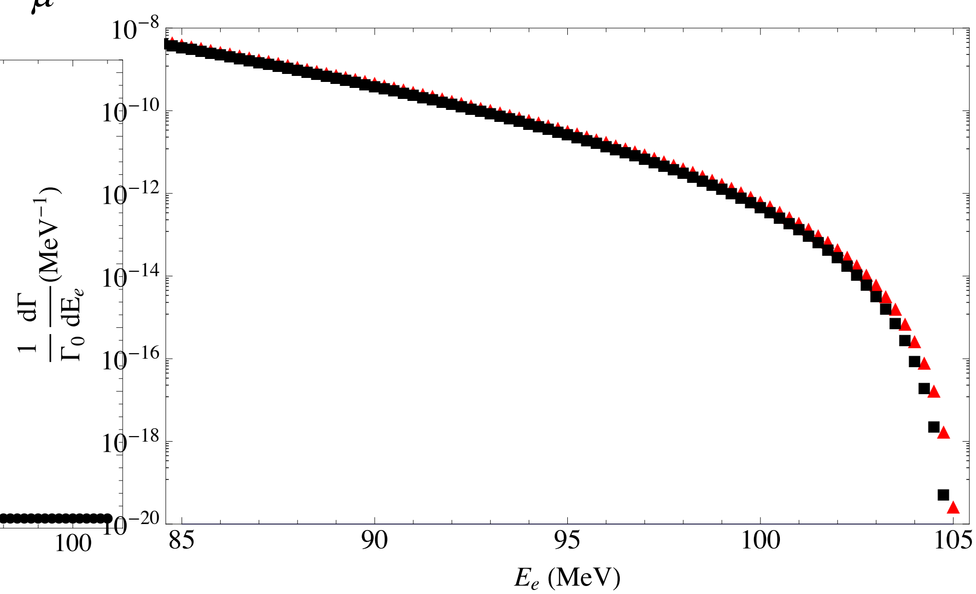
$$n(\varepsilon) = 2\varepsilon^2(3 - 2\varepsilon)$$

arXiv:1106.4756v2

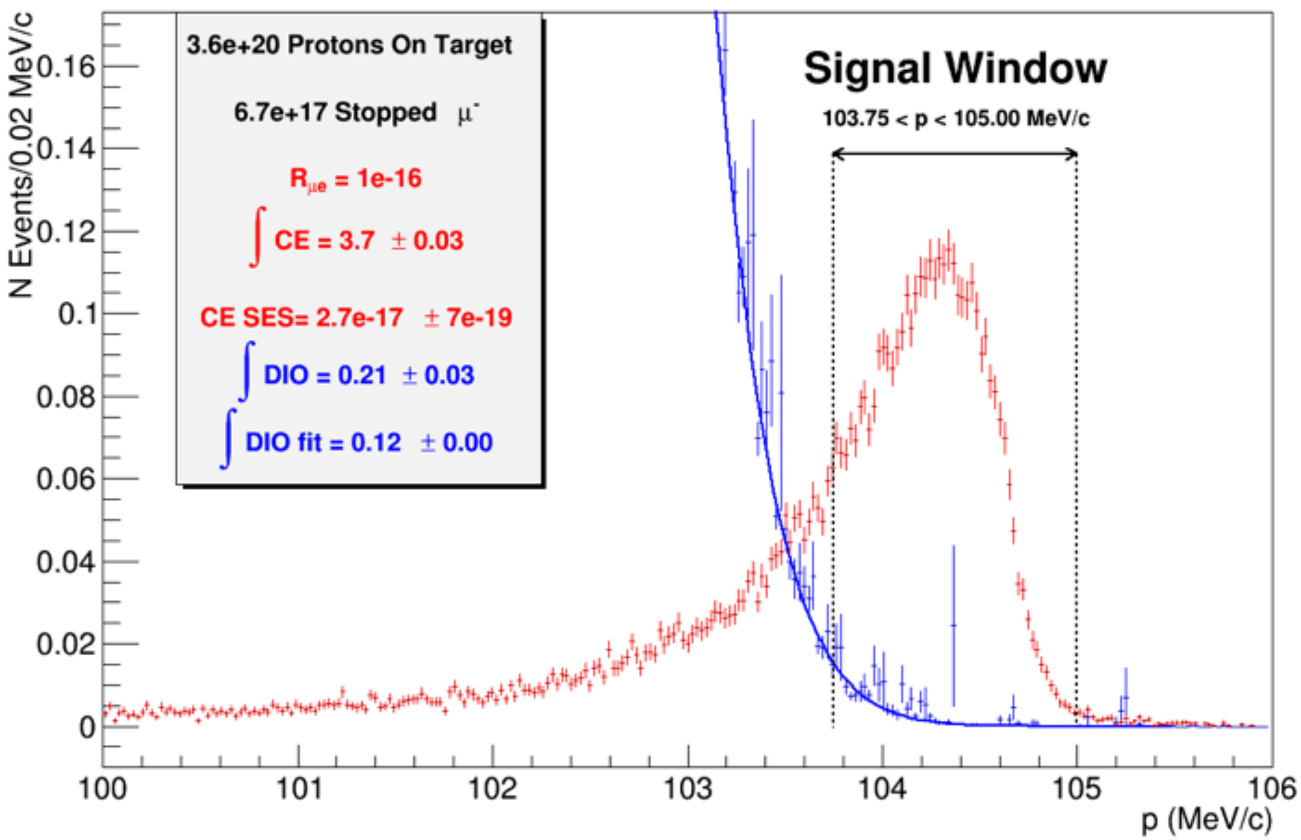
$$\varepsilon = E_e / E_{e,\max}$$

$$E_{e,\max} = \frac{m_\mu^2 + m_e^2}{2m_\mu} = 52.8 \text{ MeV}$$





Decay-In-Orbit Detail



Must understand

a. resolutions for signal and background

b. width of signal peak

DIO Spectrum must be put in by hand, as with other processes needed by Mu2e

Background: Radiative Pion Capture

- Pions produced upstream of the stopping target that have not decayed can be captured in the stopping target and produce signal events

$$\pi^- N \to \gamma N^*$$

$$\gamma \to e^+ e^-$$

- Sometimes that electron will be reconstructed and fake a signal
- Must understand
  - time distribution of pions to find number in measurement period
    - Tied to Accelerator Division simulations and CD modeling tools, e.g. Synergia, MAD, ORBIT, ESME
  - ***Not in any G4 physics list, we put this in by hand***
  - And be able to vary both within uncertainties

Background: Antiprotons

- Antiprotons produced in original 8 GeV collision can produce radiative pion capture by making pions
  - Annihilate in stopping target and make pions, which then undergo radiative pion capture
- So we have a thin window “far away” to annihilate antiprotons
  - But that window makes new pions too, and some of them can then undergo radiative pion capture
- Cross-sections poorly known, G4 physics lists need to be tunable to estimate uncertainties
- Need grid time with multi-stage analysis
  - Multi-stage analysis with resampling is a common technique across experiment (see Gaponenko)

Background: Cosmic Rays

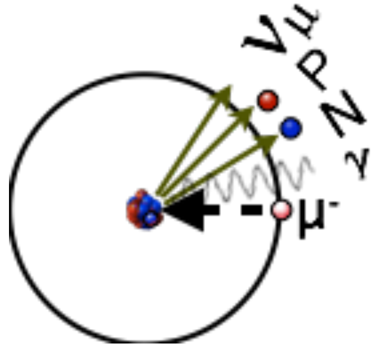
- Cosmic Ray Muons Can Hit material inside DS and produce an electron in the signal window
  - One/day without the cosmic ray veto
  - Or about 1000 events of background where we want < 1
- Modeling this is *very* hard
  - Grid time for
    - overall simulation to identify problems and get estimates
    - targeted simulations
  - Modeling of optical transport in CR Veto system
    - Detailed G4 modeling
  - Storage
  - Knowledge of CR flux and ability to swap in generators

Background: Other Processes

- There are a number of other backgrounds from rare, hard-to-calculate occurrences. Two examples:
  - scattering off collimators producing late-arriving particles that weren't caught in normal beamline simulations
    - But we can't do 3.6e20 POT in MC!
  - Tails of tails of resolution functions
    - Important point is that there are only a few hundred K decay-in-orbits remotely near signal window, and we have found no evidence for anything significant
    - But we can't do 3.6e20 POT in MC!

Accidentals

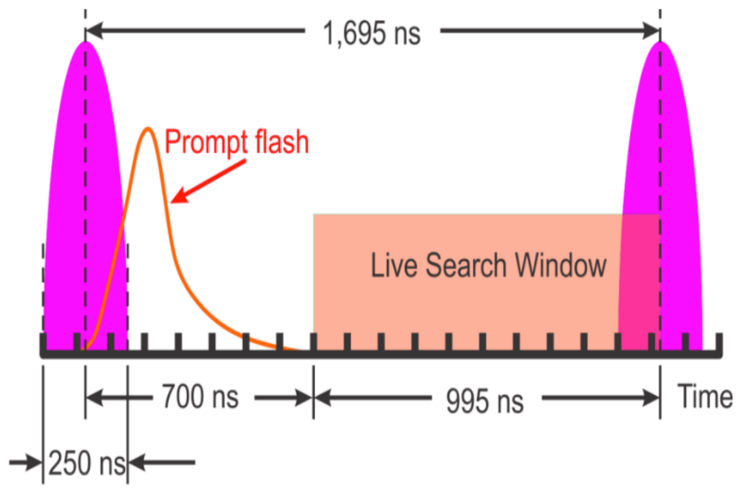
- Two types:
  1. From muon beam.
     a. muon decay in stopping target making electrons that just touch inside of detector
     b. Ejected protons, photons, and neutrons from captured muons



Both of these deaden detector elements and age elements from radiation damage. Computing for these is mostly running statistics but some require external measurements, especially ejected protons (see AlCap Exp't at PSI and Gaponenko W&C 2/6/2015)

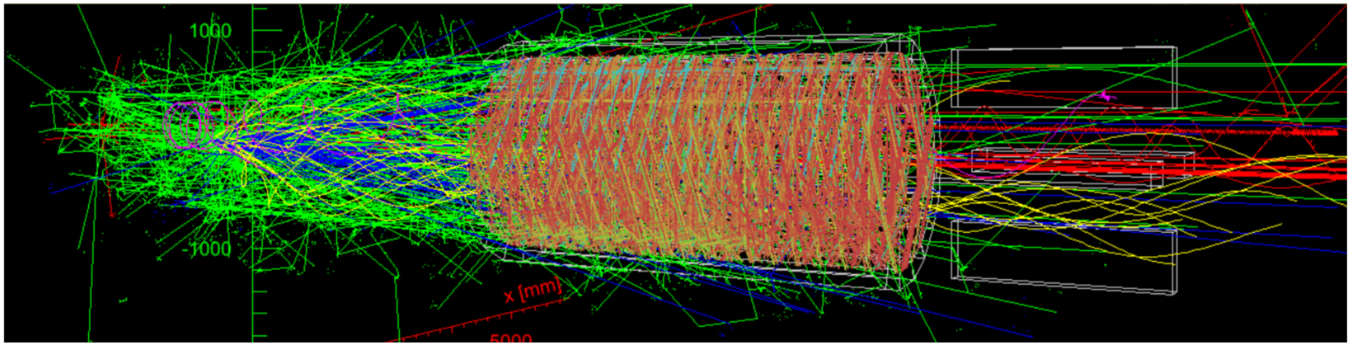
Time Structure

- Up to 10 KHz/straw early, first few hundred nsec from beam electrons ("beam flash")
- Accidentals and aging issues for the detector
- This is not an issue for physics background but we need to simulate all of this beam activity to see what falls in time window



Accidentals: Beam Flash

- Simulating muon decays-in-flight (DIF) will take a lot of grid time.
- There are also other "beam flash" backgrounds: pion DIF and beam electrons.
- It's easy to re-sample processes that originate in the stopping target, but anything coming down the Transport Solenoid is computationally much harder. Re-sampling is an important tool.
- Requires multi-stage jobs with much grid time and storage



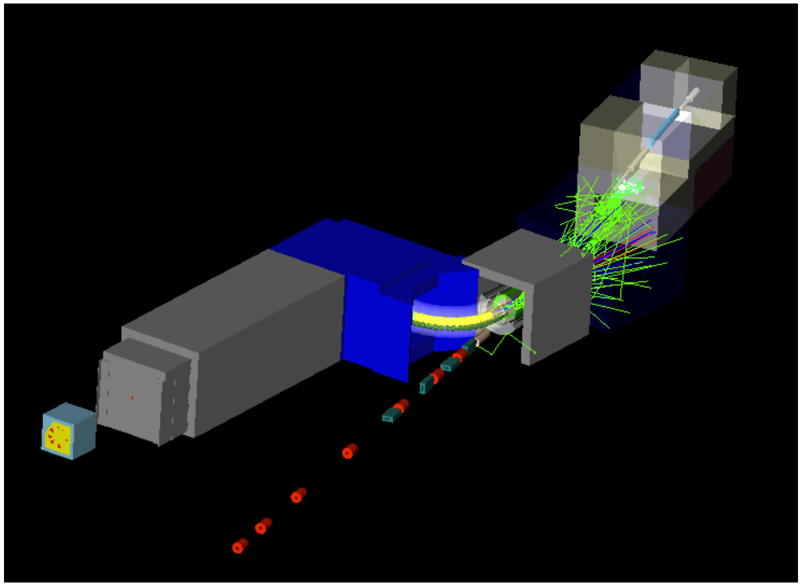
1 microsec of data

Accidentals: Neutrons

- Neutrons born in 8 GeV proton collisions on production target
- Bad in Many Ways:
  - In The Muon Beamline
    - Heating can drive superconductor in production solenoid normal
      - Driver of shielding and cooling designs
    - Damage superconductor by displacing atoms (DPA)
    - Need to understand number and spectrum, model damage
      - Interface to MARS and G4Beamline
      - MARS and G4 physics aren't identical, and then geometries are hard to synchronize
      - Effect of damage on solenoids tied to magnetic field TD models of field: how much damage and is it acceptable?

Accidentals: Neutrons

- Detector has to be shielded from neutrons
  - Sources: production and stopping targets, muon beam stop
  - CRV: neutrons create false vetos, which generate dead time
- Created Neutron Working Group to design shielding
  - Iterations using hybrid simulations + hand calculations
  - Next step is full simulation with Mu2e Offline



See talk by Yuri Oksuzian

Neutron Related Computing Issues

- Thermal neutrons may stay around for a long time
  - Need lots of CPU
- World's best collection of cross-sections is in MCNP, which we access using MARS
- Use difference between MARS and G4
  - A flag for problems and a crude estimate of systematics)
- Grid workflow for MARS is slightly different than for our other jobs: need to maintain another set of scripts

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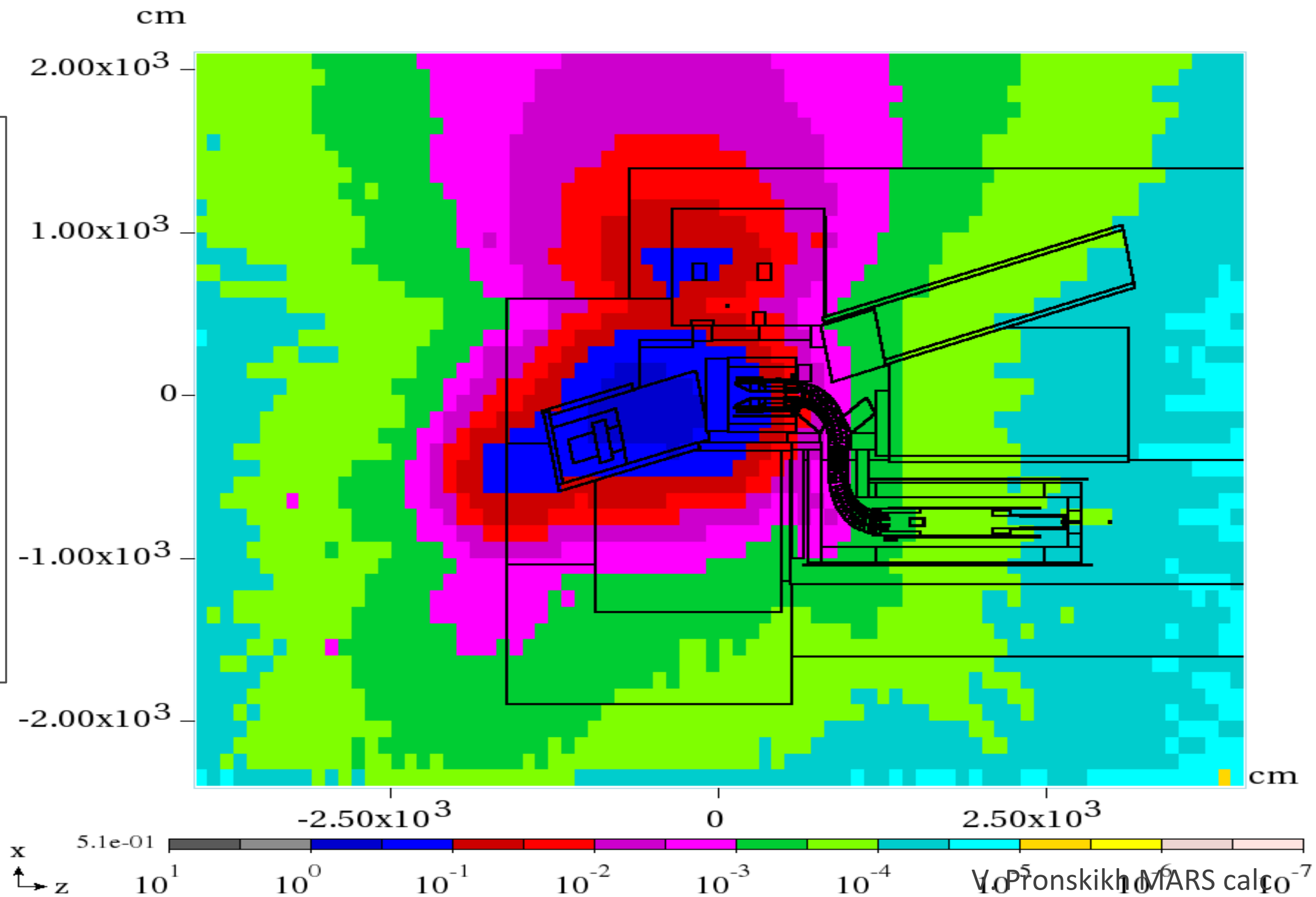
Another MARS use: Dose Calculations

- Uses MARS Shielding model and MARS code
- Useful iteration takes ~ 1 week of wall clock time, 2500 nodes

Dose at surface



V. Pronskikh MARS calc

Summary

	Background	Accidental	Aging	Comments
Decay in Orbit	G			
Radiative Pion Capture	G/S			Coupling to AD and Computing codes
Antiprotons	G/S			Making external measurements
Ejected Particles		G/S/G4	G/S/G4	
Neutrons from PS		G/S/G4/C	G/S/G4/C	
Cosmic Rays	G/S/G4/C	G/S/G4/C	G/S/G4/C	
Beam Flash	G/S	G/S	G/S/C	

Grid Time	"G"
Storage	"S"

G4/Generators	"G4"
Code Suites	"C"