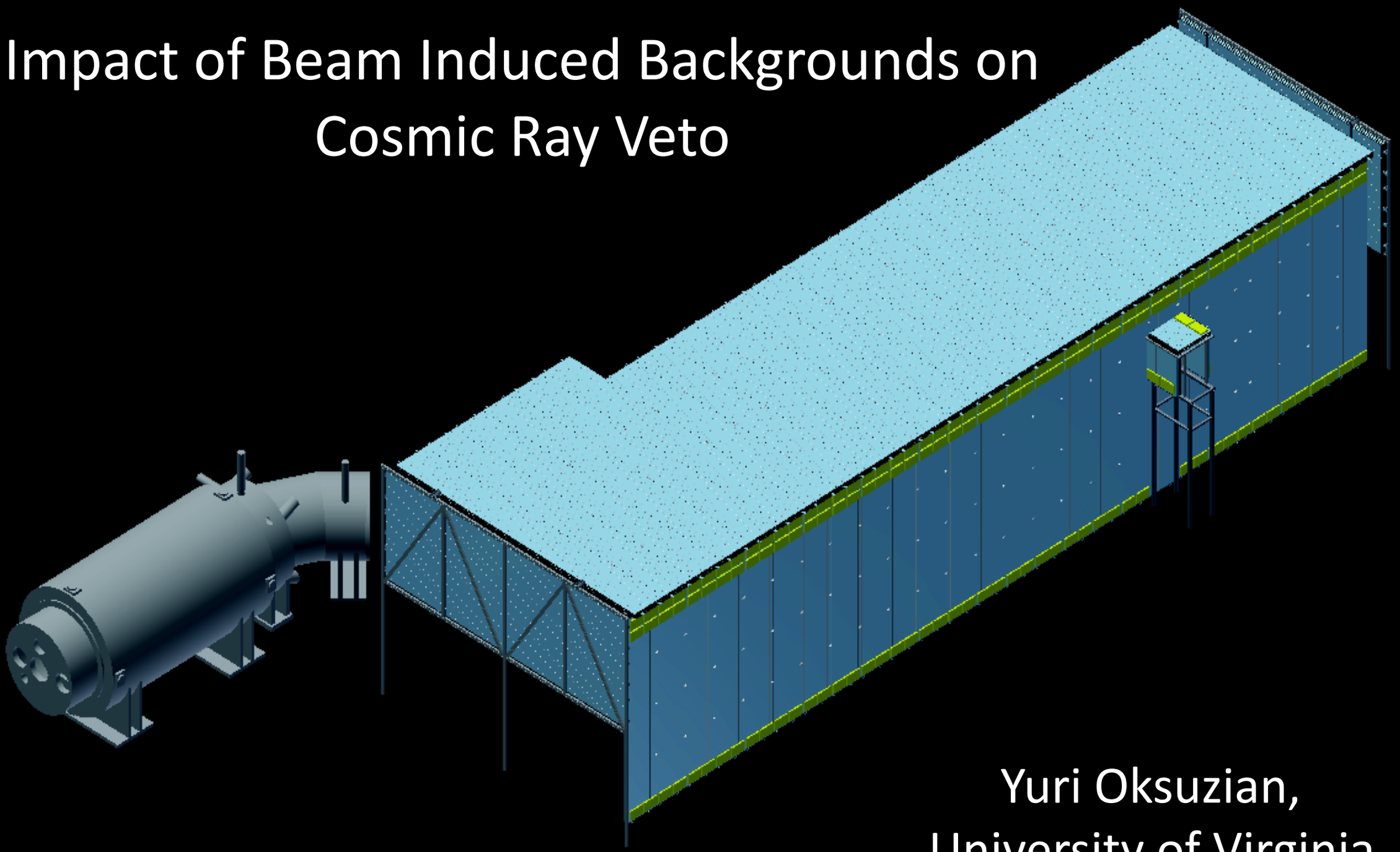
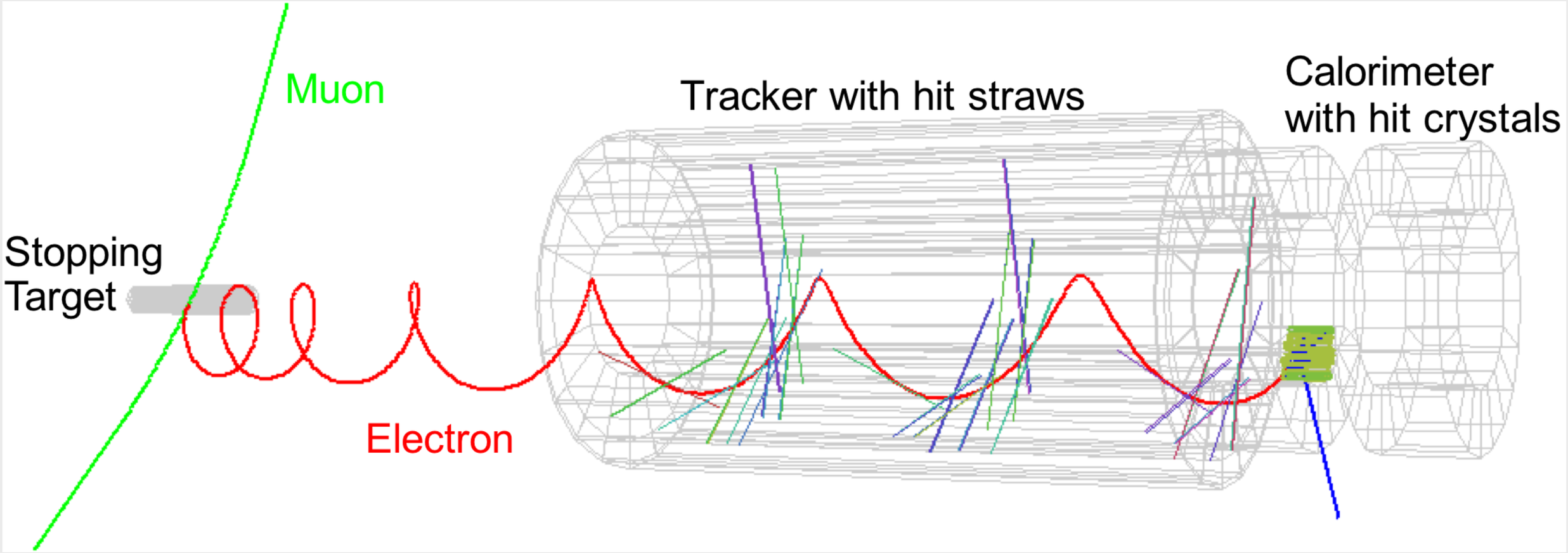
Impact of Beam Induced Backgrounds on Cosmic Ray Veto



Yuri Oksuzian,
University of Virginia

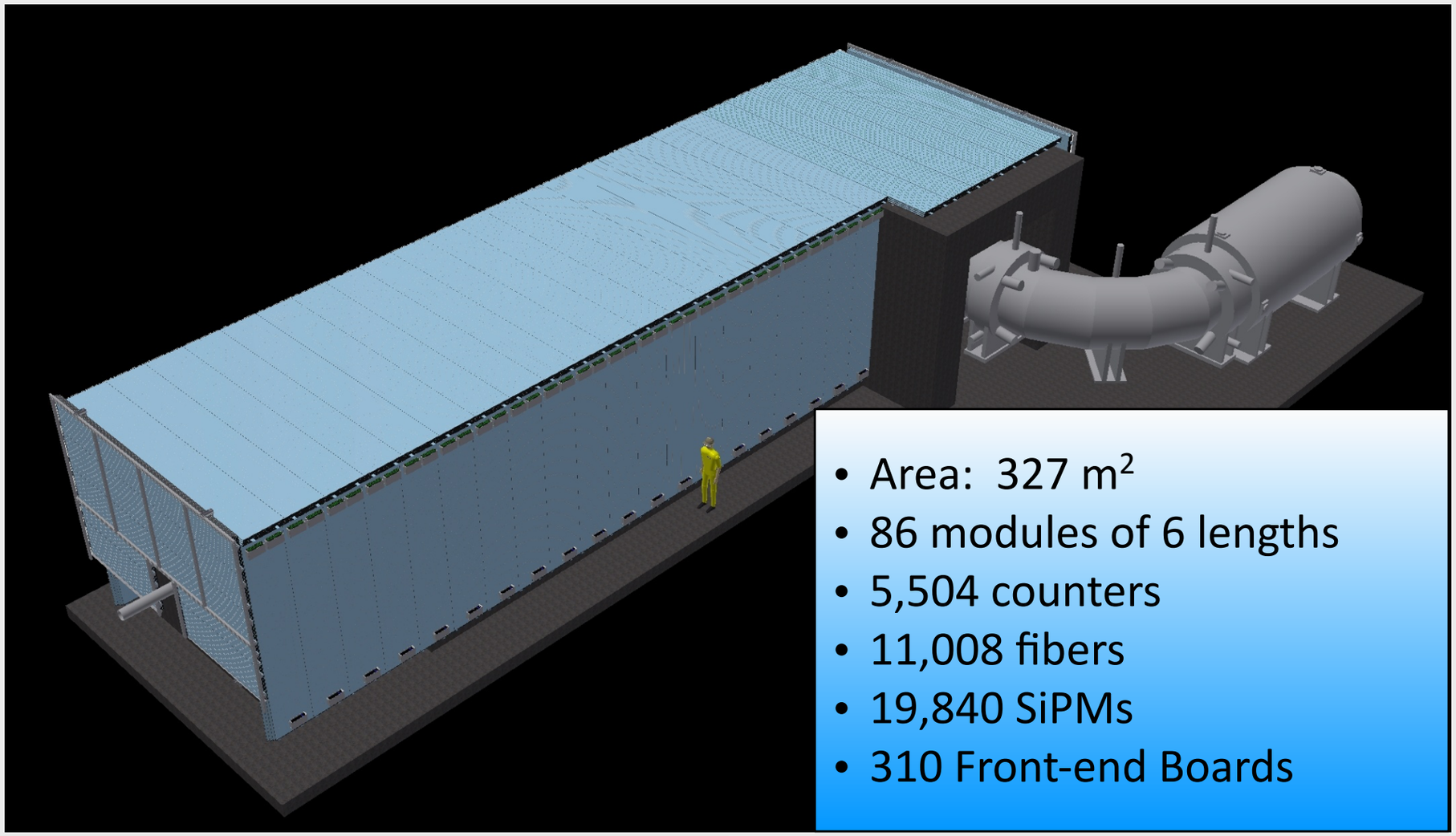
Cosmic Ray Background

- Total expected Mu2e background is 0.4 events over 3 years
- Mu2e expects 1 signal-like event per day induced by cosmic rays
- Cosmic ray muons produce background though material interactions, decays and muon faking an electron
- To achieve experiment's designed sensitivity, Cosmic Ray Veto detection efficiency is required to be > 99.99%



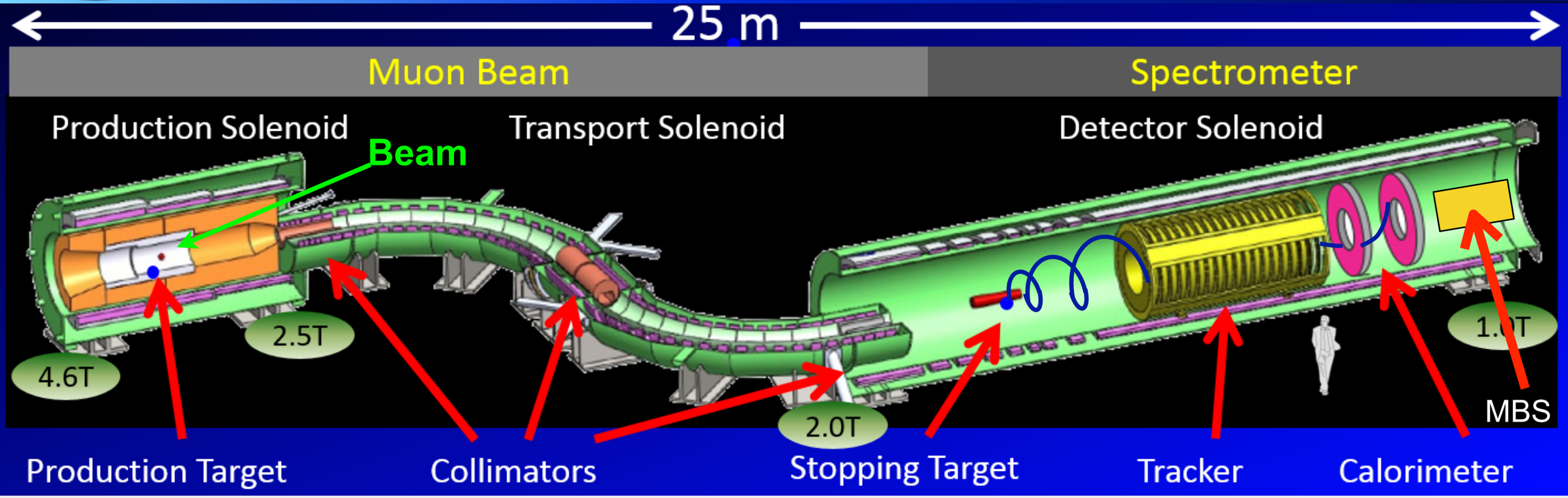
Cosmic Ray Veto

- CRV consists of 4-layer scintillating 5x2 cm^2 counters, read-out through wavelength-shifting fibers by 2x2 mm^2 SiPMs
- CR muon detection - hits coincidence in 3/4 layers localized in time and space
- Veto 125 ns from a signal window after a coincidence in the CRV



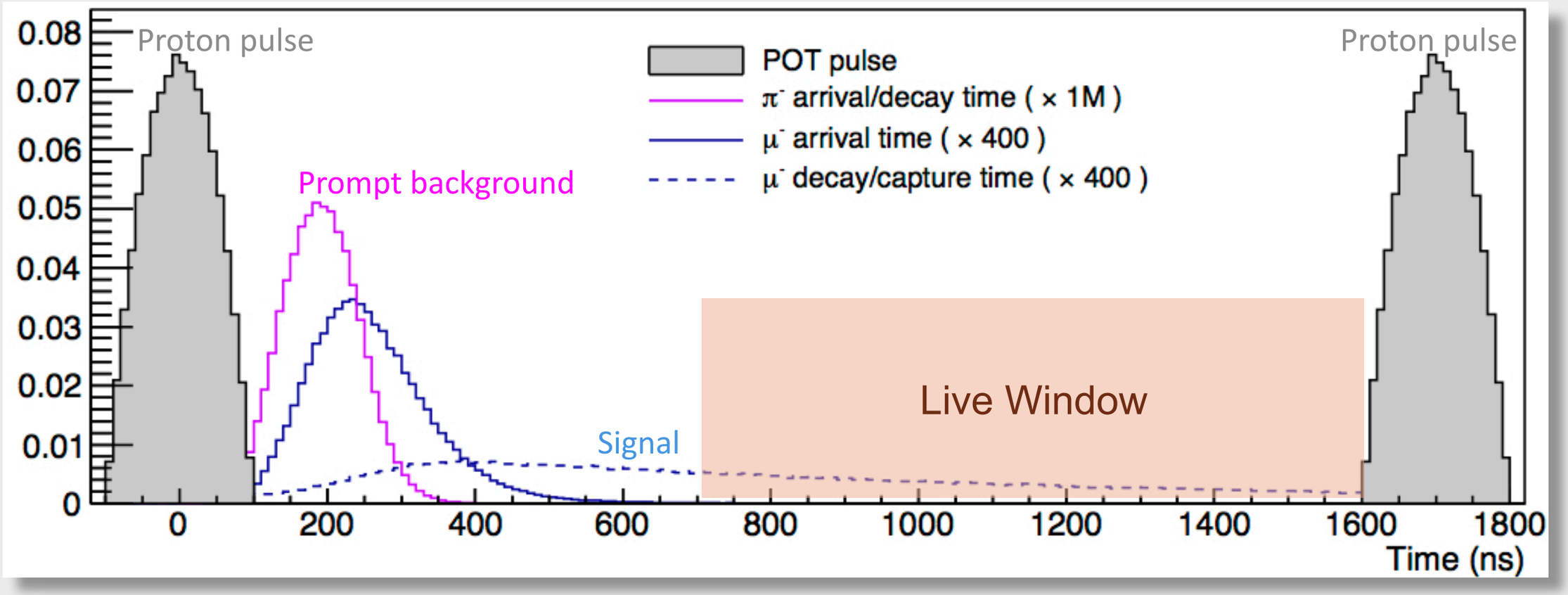
- Area: 327 m^2
- 86 modules of 6 lengths
- 5,504 counters
- 11,008 fibers
- 19,840 SiPMs
- 310 Front-end Boards

Mu2e



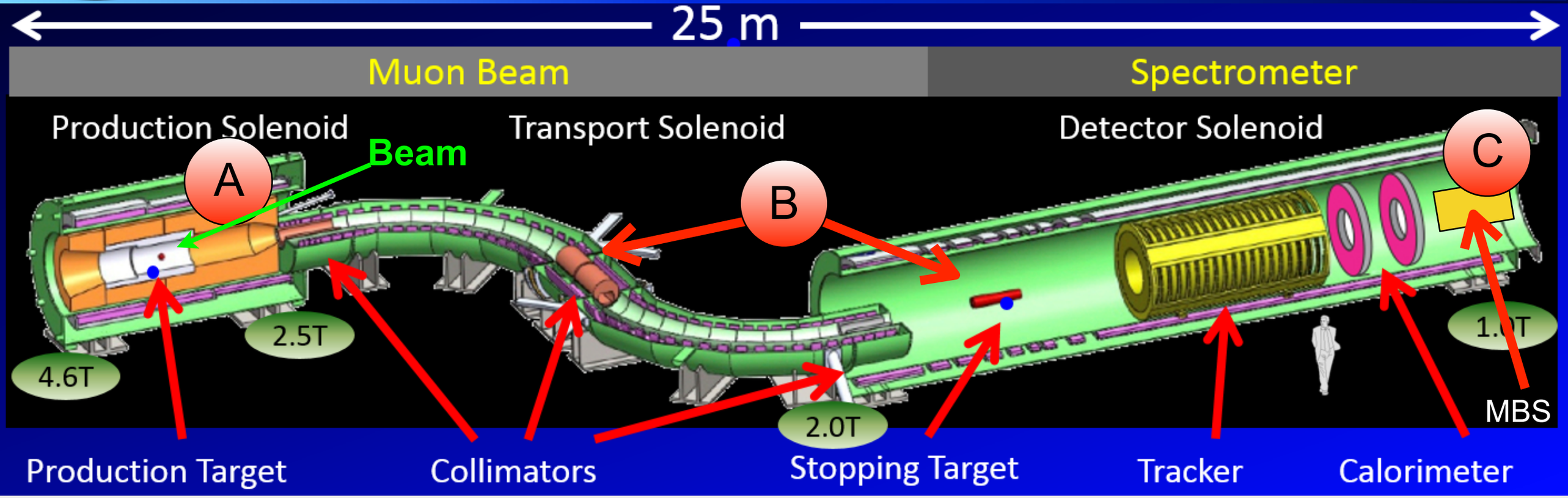
1. **Every 1695 ns, 8 GeV protons hit production target to produce π^-**
   - π^-/μ^- are reflected toward the transport solenoid
   - Beam intensity is 8 kW
2. **Trasport Solenoid delivers π^-/μ^- to Detector Solenoid**
   - Selects particle's momentum and charge
   - Avoids direct line of sight
3. **Muons stop on the Al Stopping Target**
   - 1,000 POT → 4 (2) muons reach (stop on) the target
   - Conversion electrons are measured in the tracker and calorimeter

Beam induced radiation



- Exploit beam bunched structure to suppress physics backgrounds
  - Wait for 700 ns after proton pulse
- Particle fluxes from beam interactions:
  - **Damage** CRV components
  - **Produce noise** in CRV, increasing DAQ rates. Noise hits in CRV fake CR muons and increase the dead-time
    - CRV ignores hits outside of the signal window

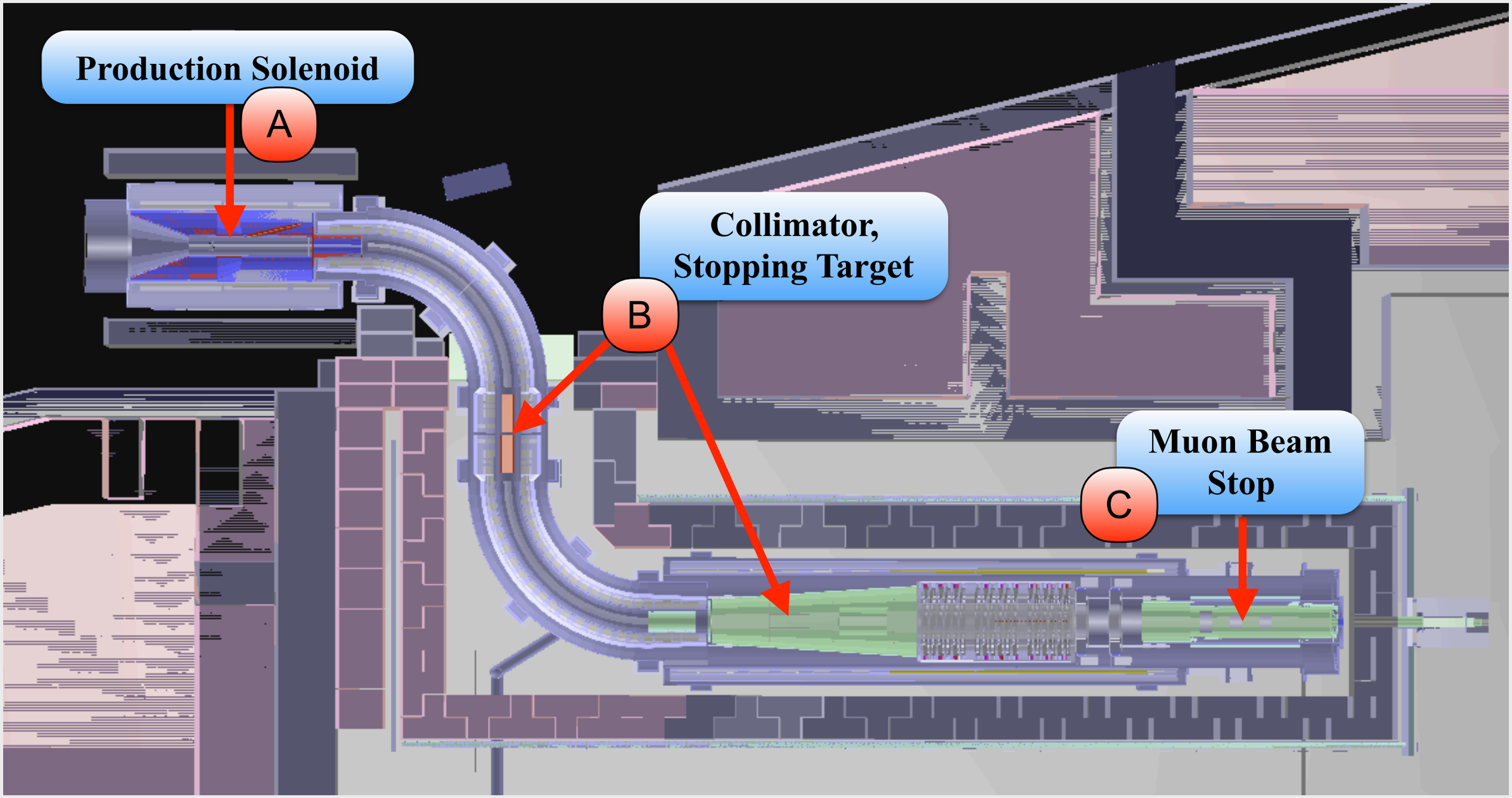
Beam induced noise: Sources



- A Largest source of neutrons is PS. The source is prompt and reduced in the signal window
  - Neutrons get thermalized, captured and produce delayed gammas
- B Fast neutrons, produced in the signal window, are from μ-captures on beam-line and stopping target
  - Fast neutron recoil off a proton depositing energy in the counter
- C High energy gammas in the Muon Beam Stop (MBS): electron brems from μ-decays. Muons escaping MBS decay producing high energy electrons

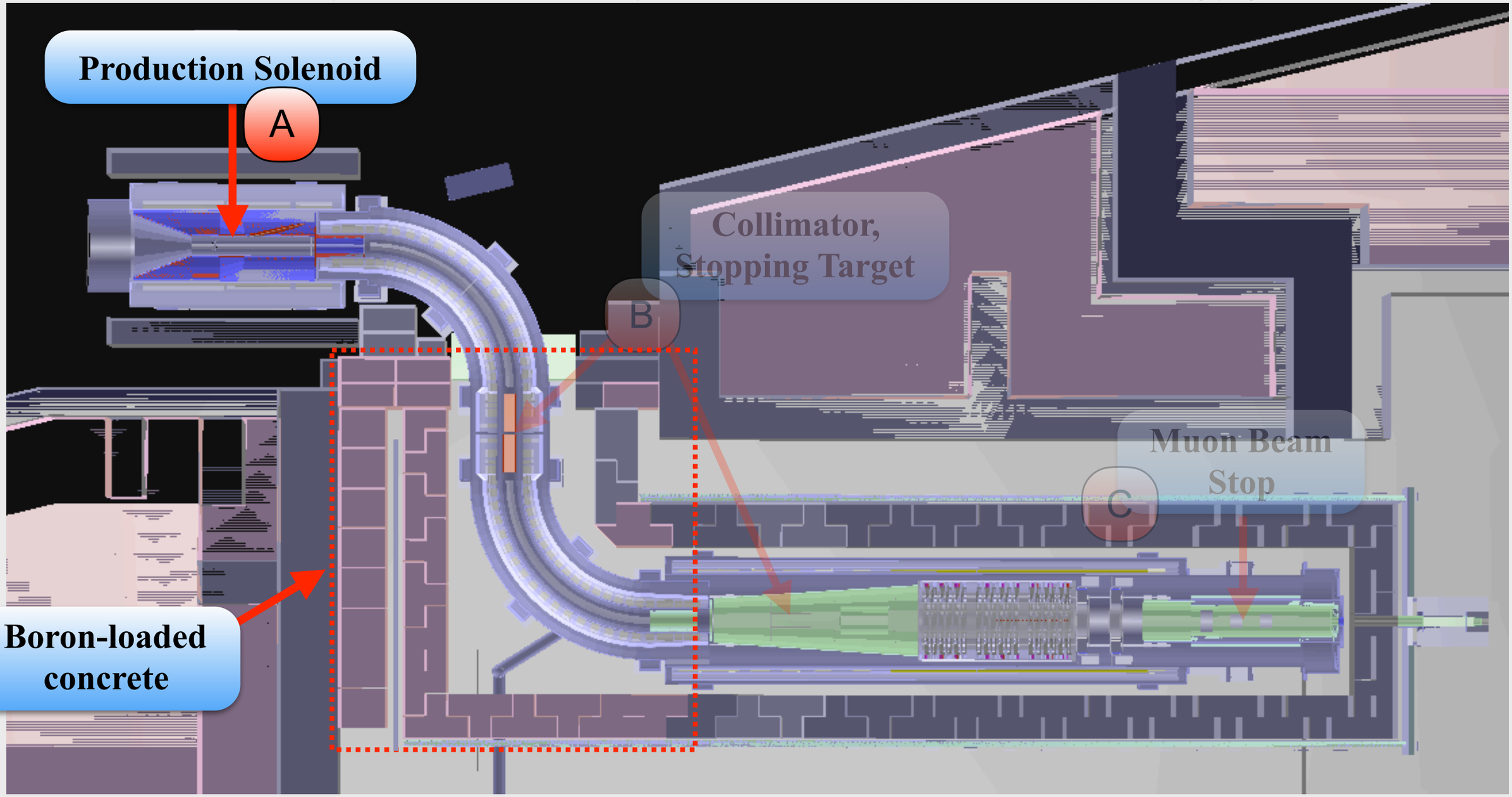
CRV shielding

- Mu2e uses detailed geometry and detector response simulation
- CRV is shielded from beam induced backgrounds by 1 yd of T-shaped concrete walls



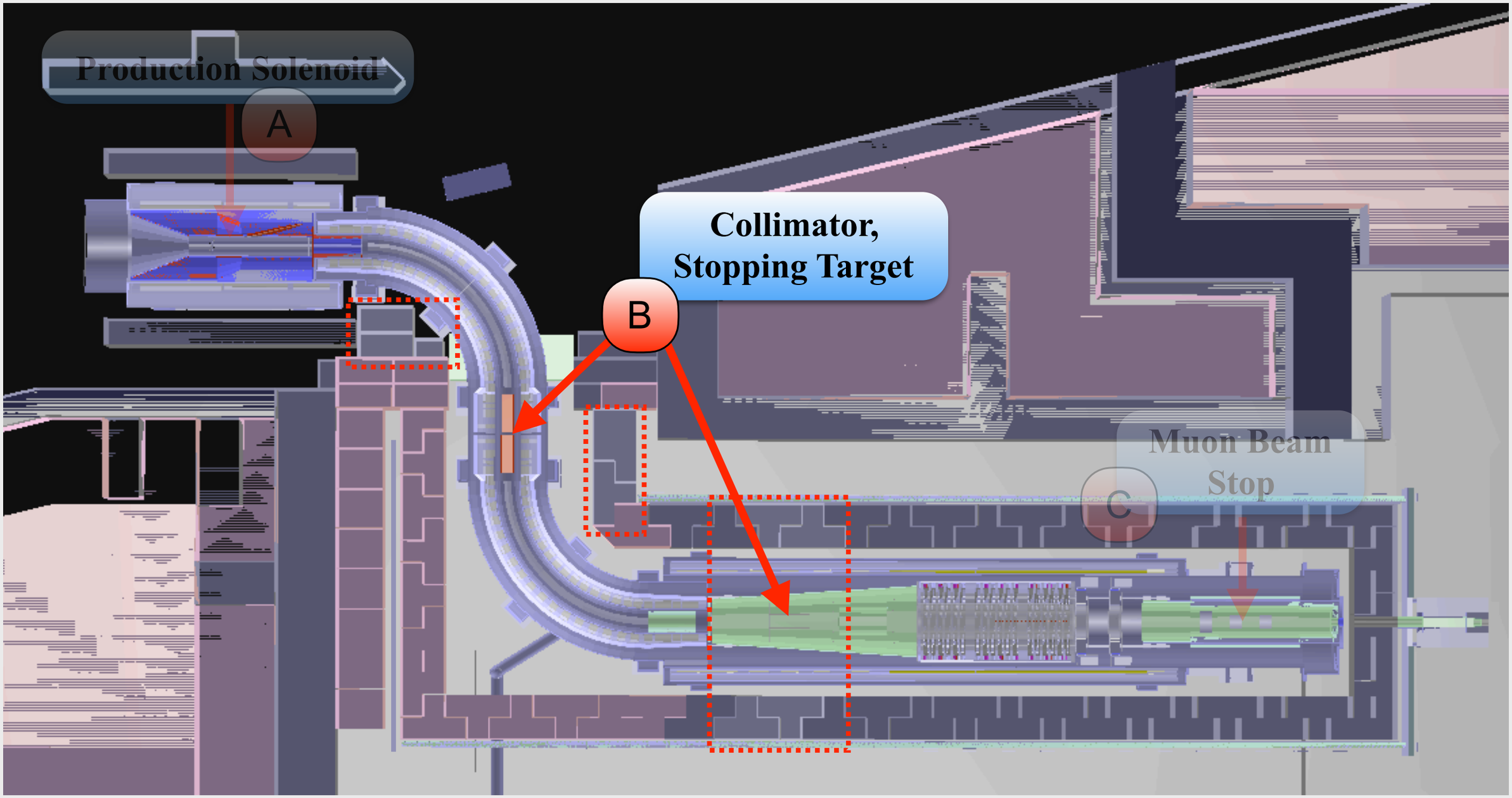
CRV shielding: Boron-loaded concrete

- Upstream region is swamped with neutrons from PS
  - Neutrons captured on various materials produce gammas up to 10 MeV
- Upstream shielding consists of boron-loaded concrete
  - Neutrons captured on Boron produce lower (0.48 MeV) energy gammas



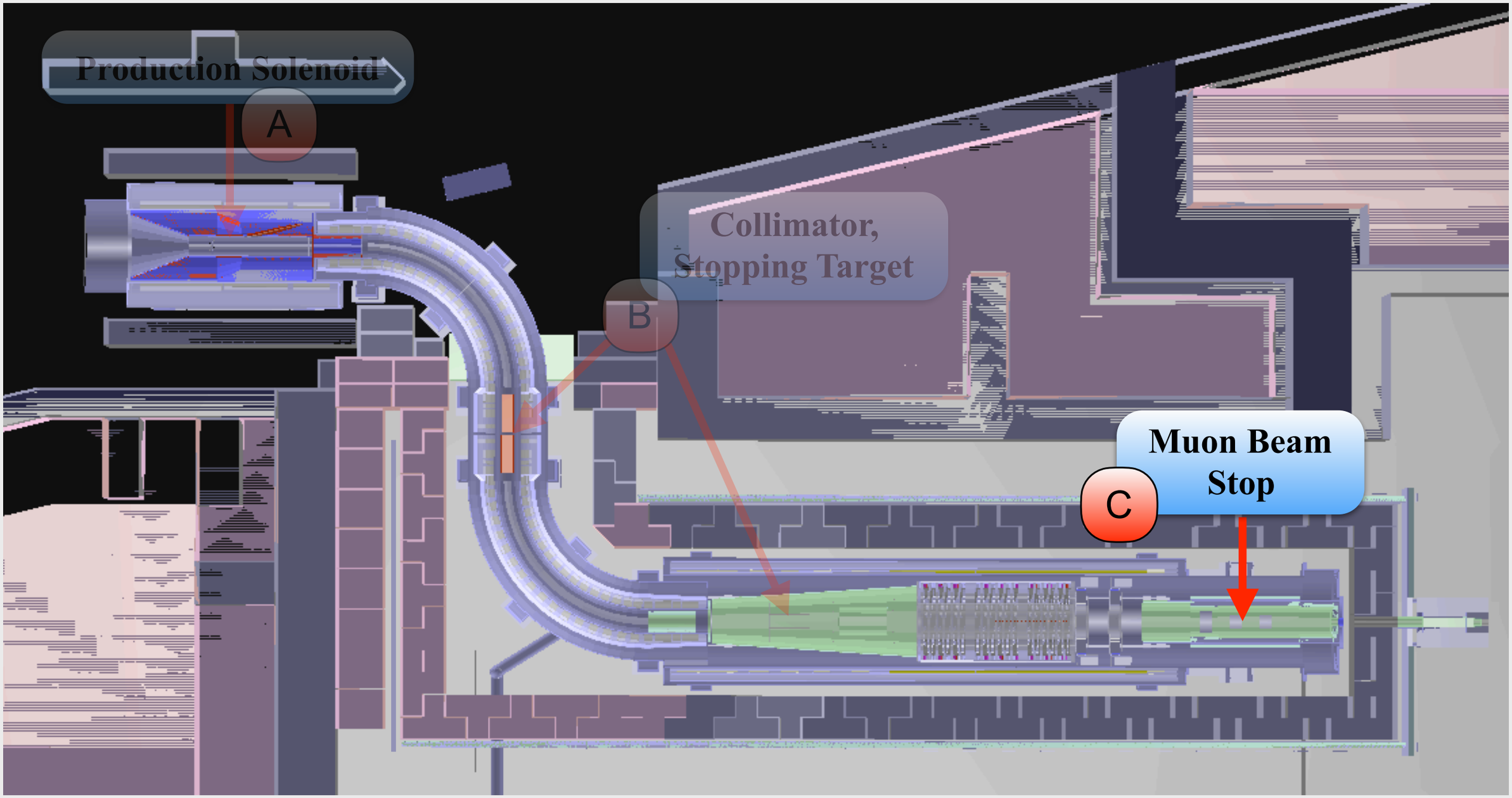
CRV shielding: Barite-loaded concrete

- Barite high-Z concrete around the stopping target shields against fast neutrons to reduce fake vetos
- Barite shielding at the middle collimator and PS corner mitigates the rad damage to SiPMs



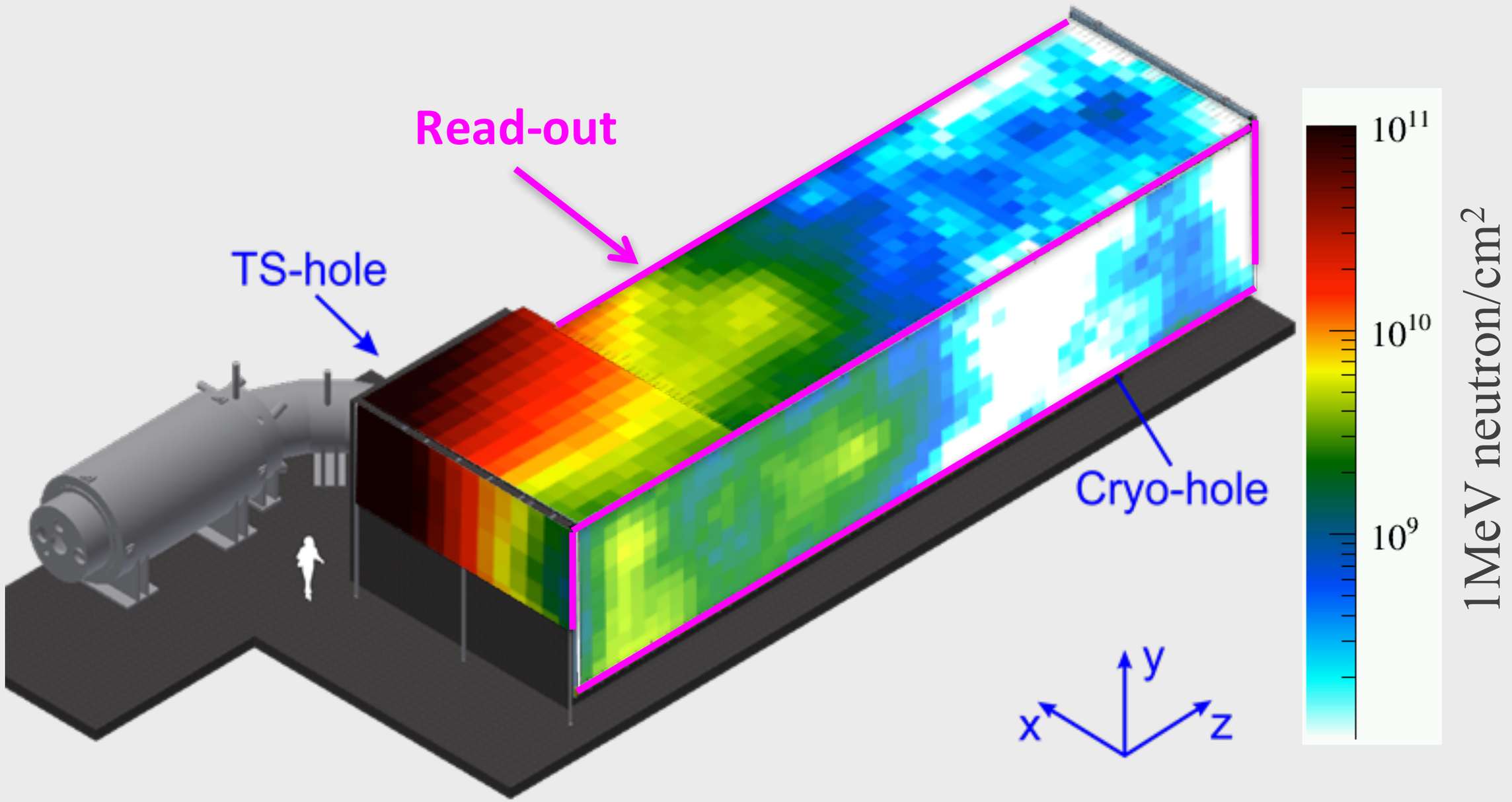
CRV shielding: Muon stops

- 10E9 unused muons are dumped in MBS every second
- Muons stopped on low-Z polyethylene decay
- Electrons from muon decays brem. High energy gammas produce fake vetos in CRV
- Muons escaping MBS produce high energy electrons produce coincidence in CRV



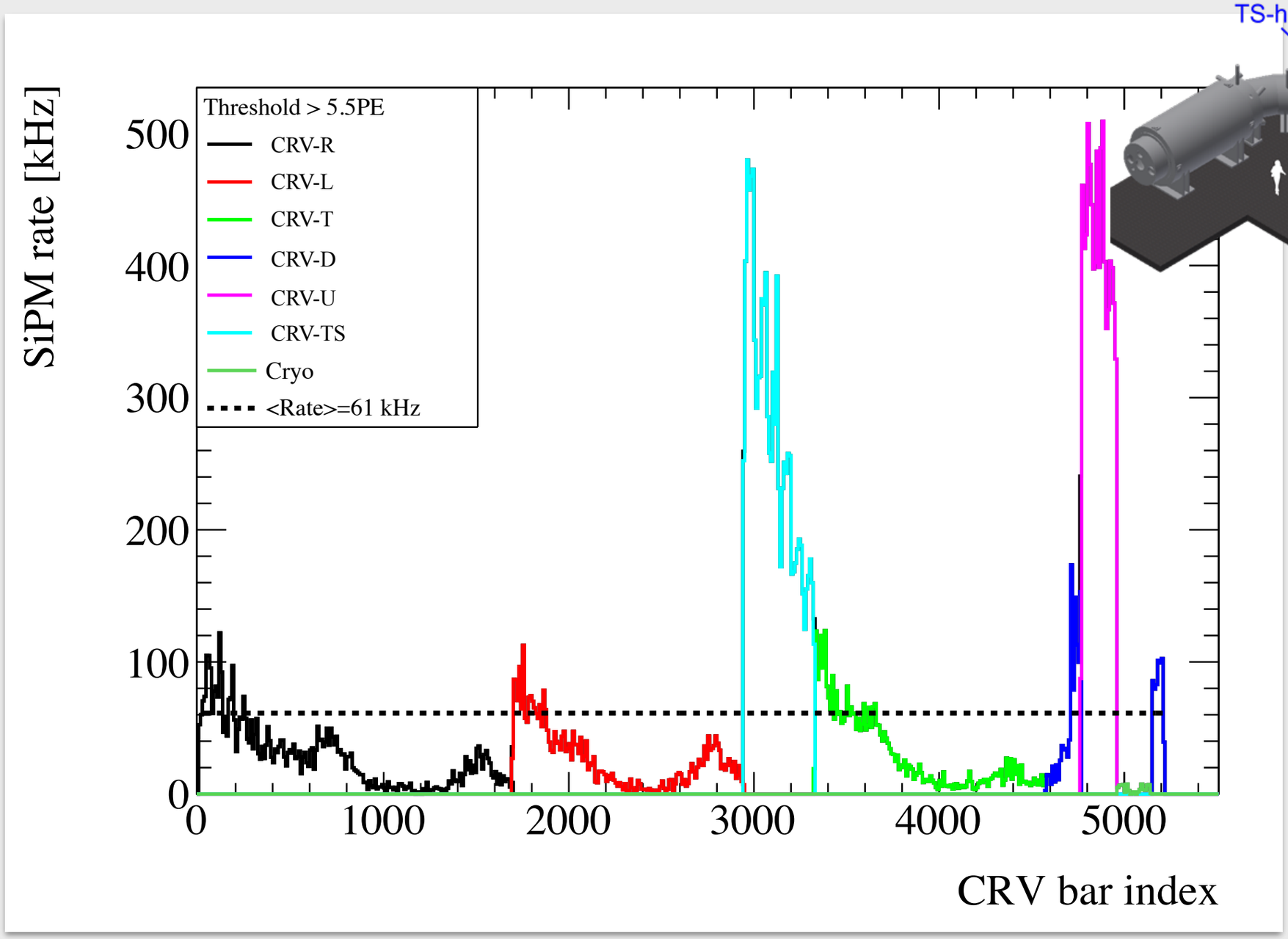
Neutron damage to SiPM

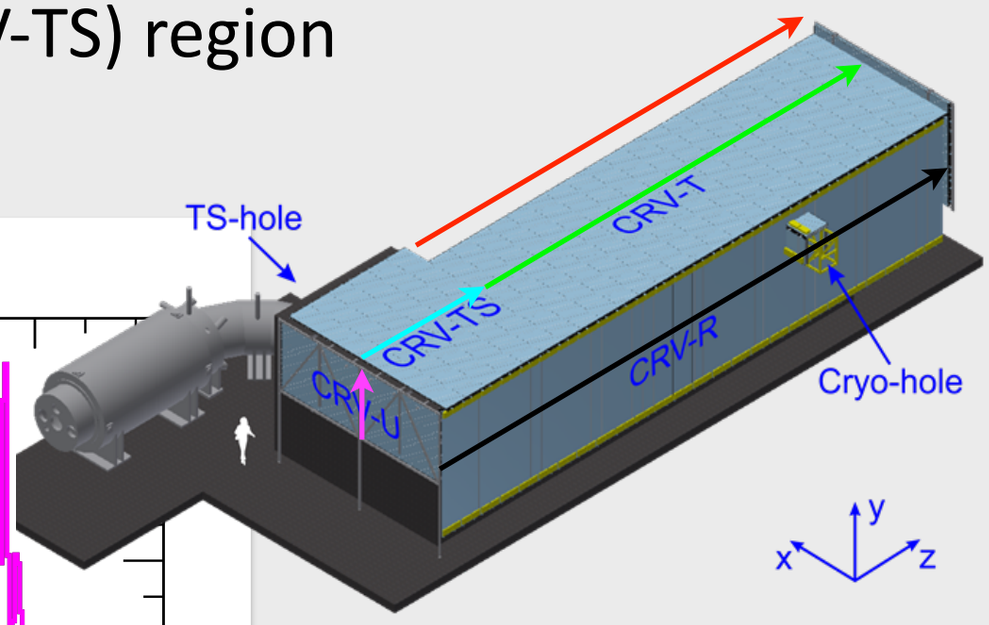
- Fast neutrons produce damage to SiPMs
  - Rad damage is driven by PS and collimators. Requirement is 10^{10} n/cm^2
- Rad damage to scintillator and fibers is negligible



DAQ rates

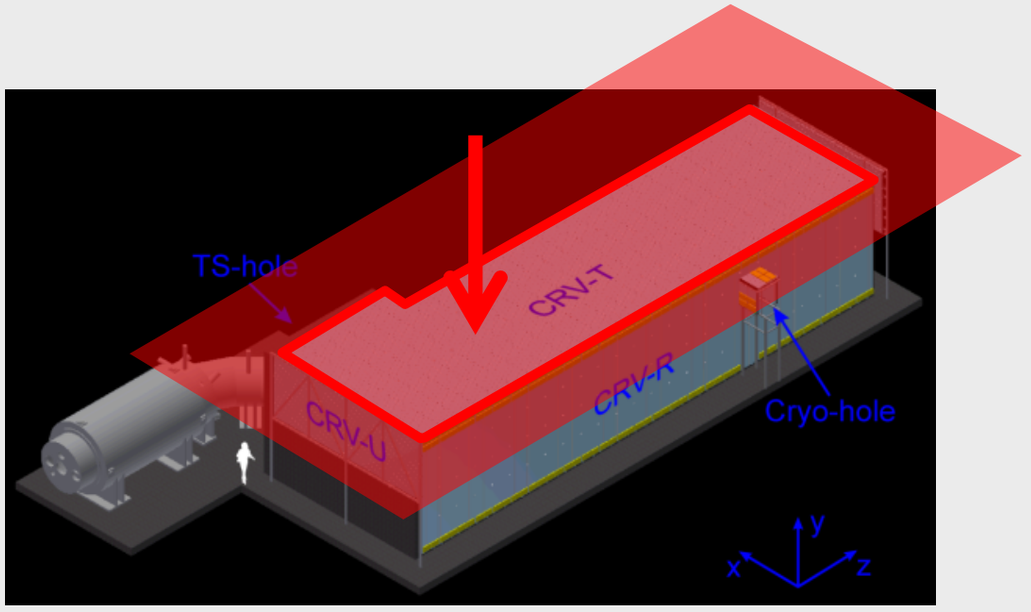
- CRV average SiPM rates is 61 kHz at 6PE
- The highest rates are in upstream (CRV-U, CRV-TS) region

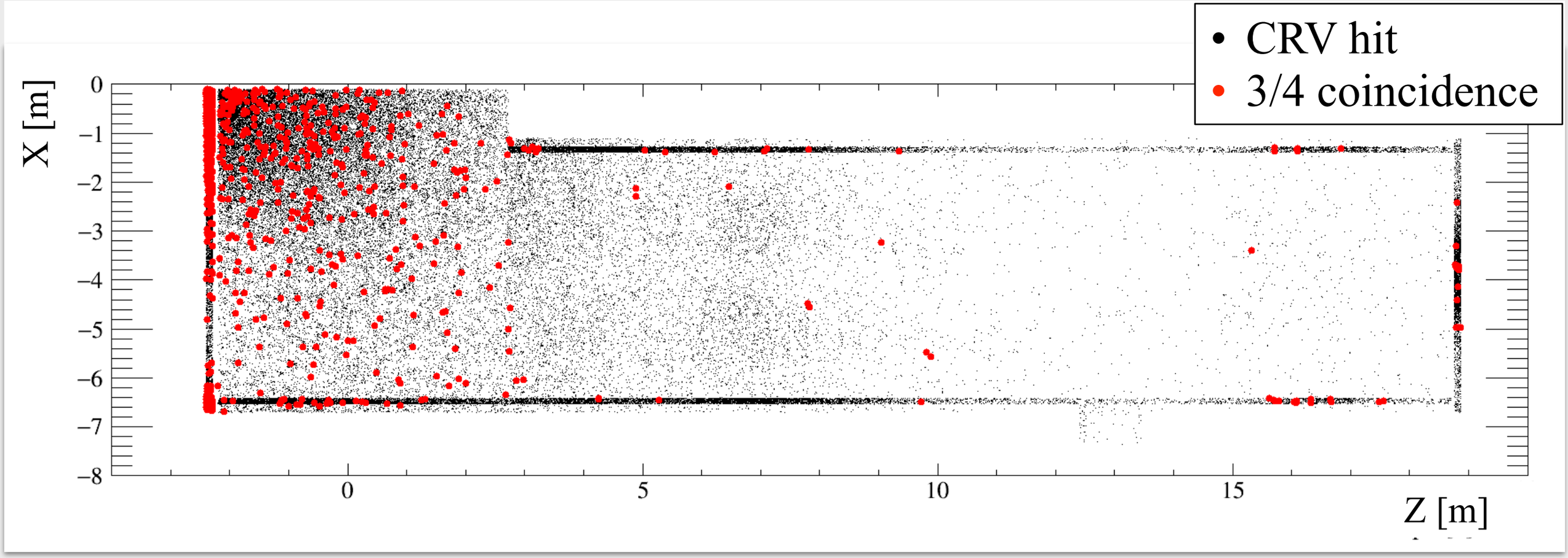




Dead-time

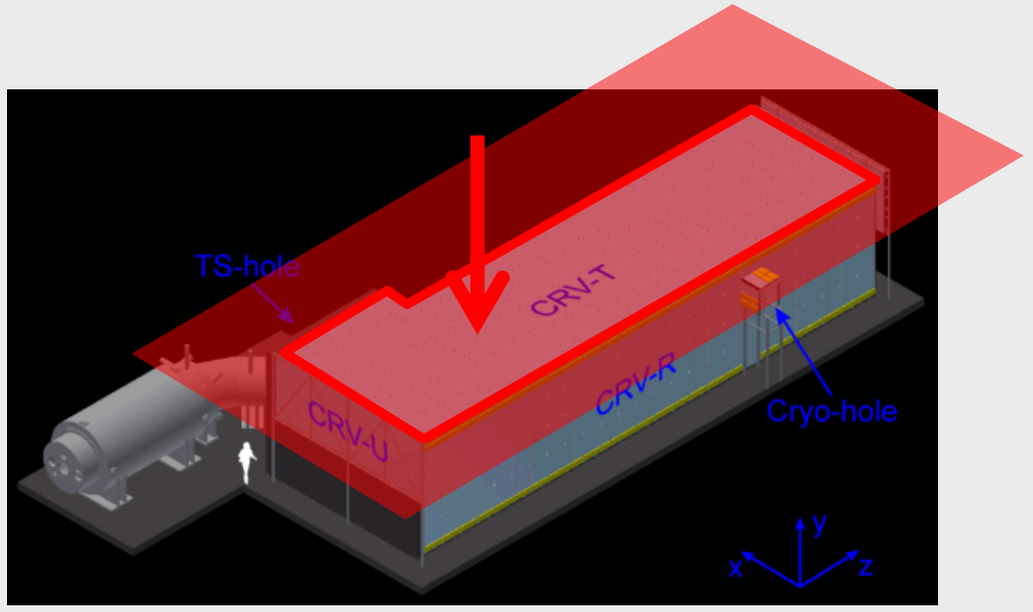
- Background hits in CRV fake CR muons and produce dead-time
- CRV dead-time is 13%
- Dead-time is dominated by upstream region

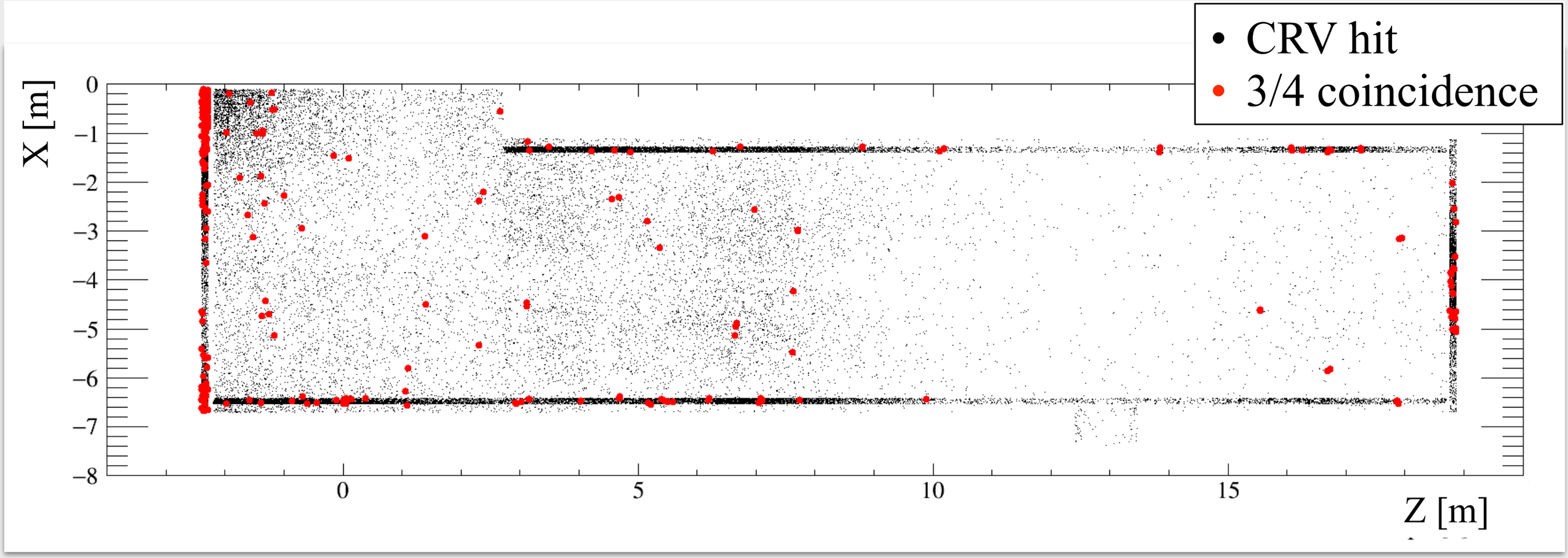




Dead-time with enhanced shielding

- Considering enhanced shielding in upstream:
  - High-Z boron-loaded concrete
  - Boron-loaded poly covering the upstream portion of CRV
- CRV dead-time with enhanced shielding - 4%





Summary

- Cosmic ray veto is an essential component for the Mu2e experiment
  - Suppress the background by 4 orders of magnitude
- CRV design is challenging
  - Maintain 99.99% cosmic ray veto efficiency over 3 years
  - Operate in high radiation environment, and produce small dead-time to the experiment
- CRV and shielding design has been modified to reduce the impact
  - Further optimization is in progress
- Mu2e simulation results yield the dead-time of 13%
  - Expect to reduce the number with further optimizations

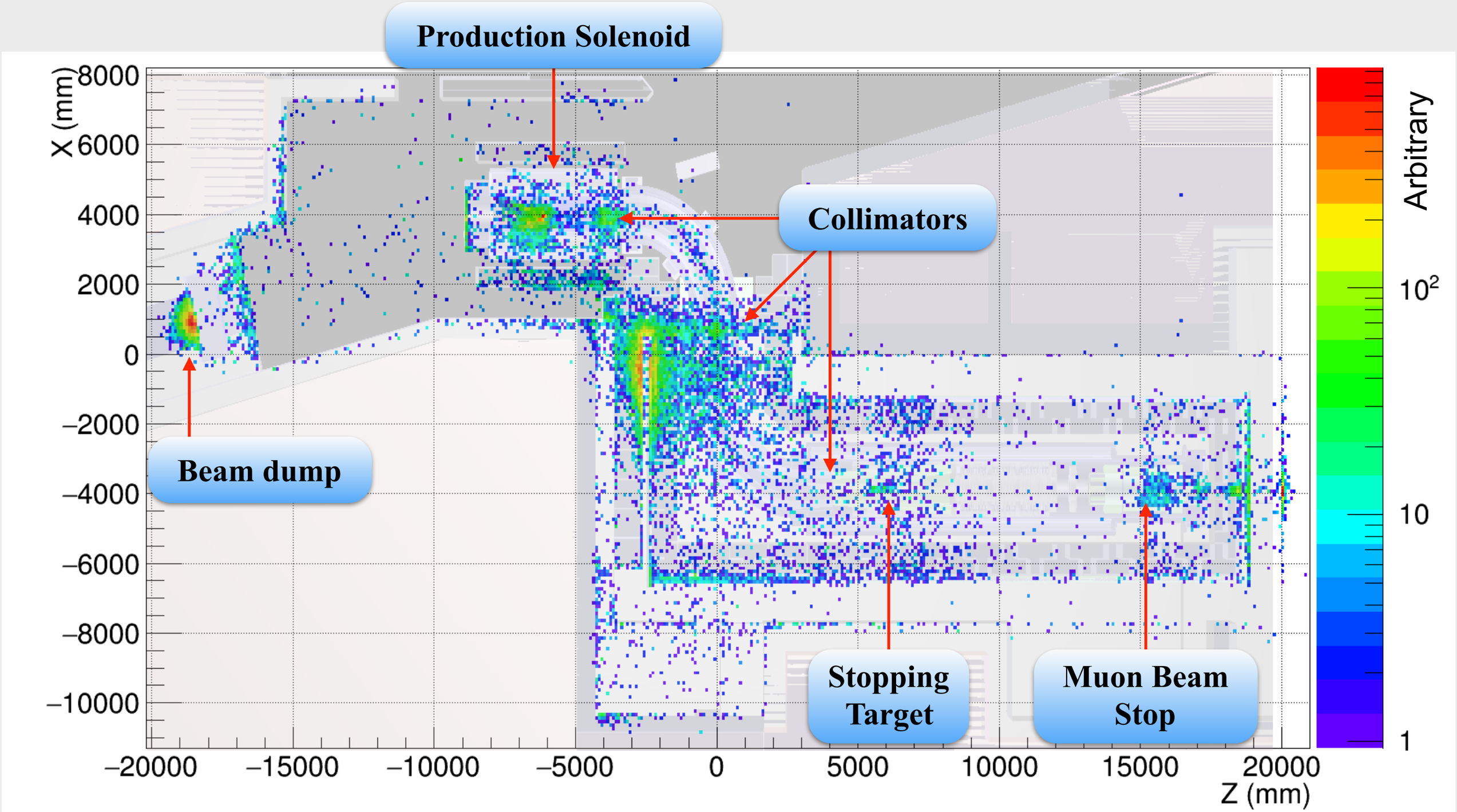
Changes to CRV design

- In order to suppress the noise from neutrons and gammas CRV design has undergone the changes

	Counter thickness [cm]	Fiber diameter [mm]	Counter width [cm]	Aluminum absorber [cm]	Number of layers
CDR	1	1.0	10	0.5	3
TDR	2	1.4	5	1	4
Impact	Increase muon energy deposition	Increased light yield	Decrease counter rates	Suppress punch-throughs	Reduce ¾ noise rate

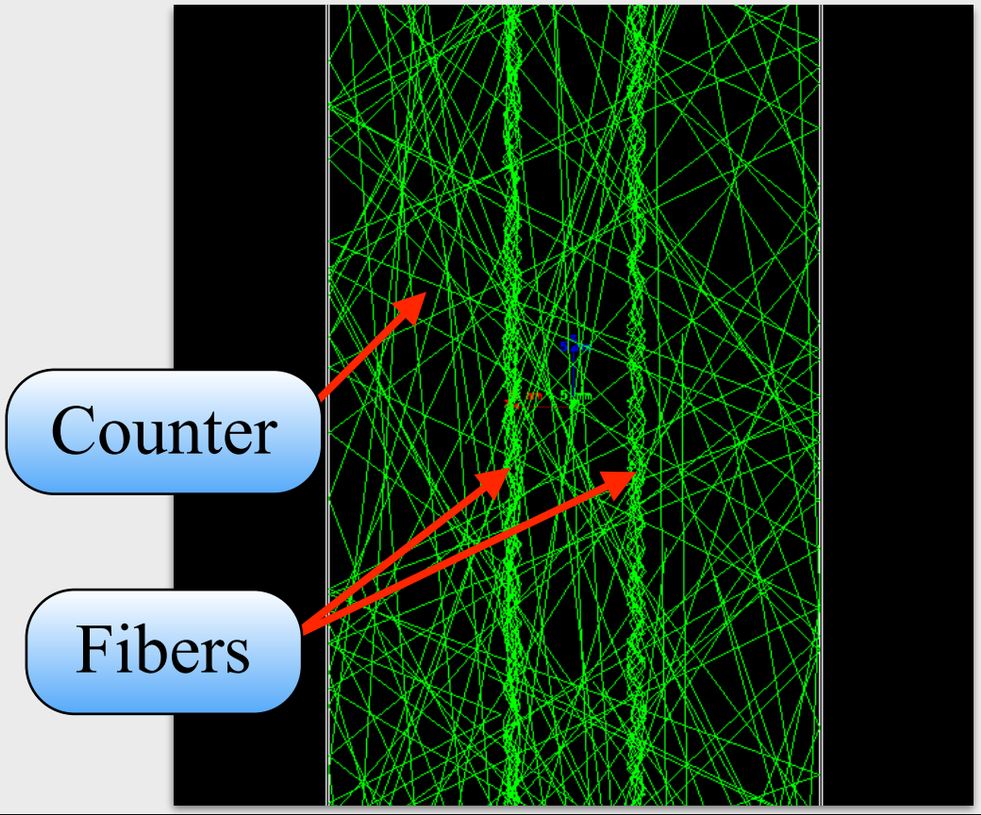
Sources of neutrons and gammas at CRV

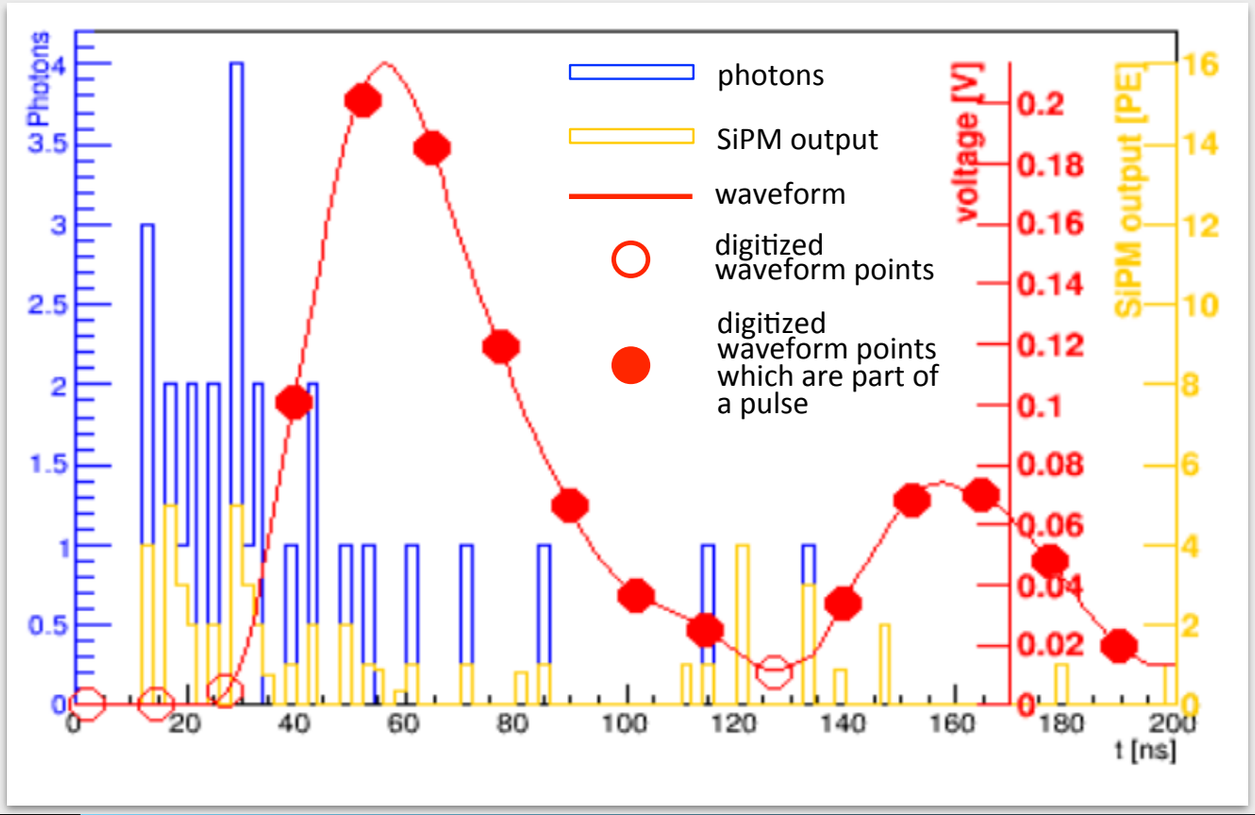
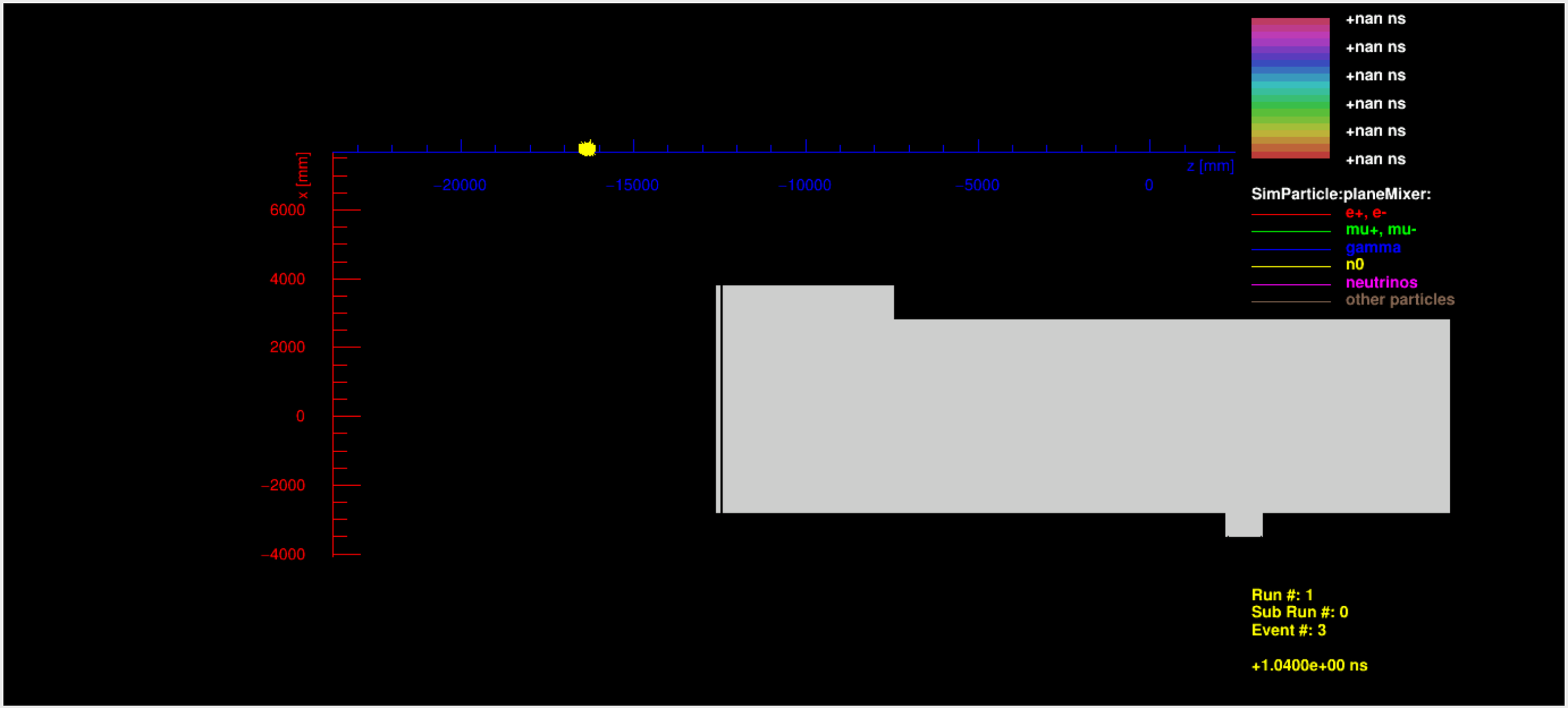
- Production positions of last neutron or gamma reaching CRV



Mu2e framework: Dead-time estimate

- CRV dead-time in the Mu2e simulation framework is estimated
  - Simulation of light production, propagation, SiPM response, digitization and reconstruction have been recently implemented
  - Shielding geometry has been recently refined to the best of our knowledge
- Simplified version of a coincidence finder algorithm has been implemented
  - Consider reconstructed pulses above 10 PE threshold
  - Localized in time (15 ns) and space (30 cm)
- The total dead-time is estimated to be 12%





Sources of neutrons and gammas at CRV