Mu2e-doc-5222-v6

The Mu2e Apparatus

David Norvil Brown

University of Louisville

On behalf of the Mu2e Collaboration

The Mu2e Computing Review
5-6 March 2015

Overview

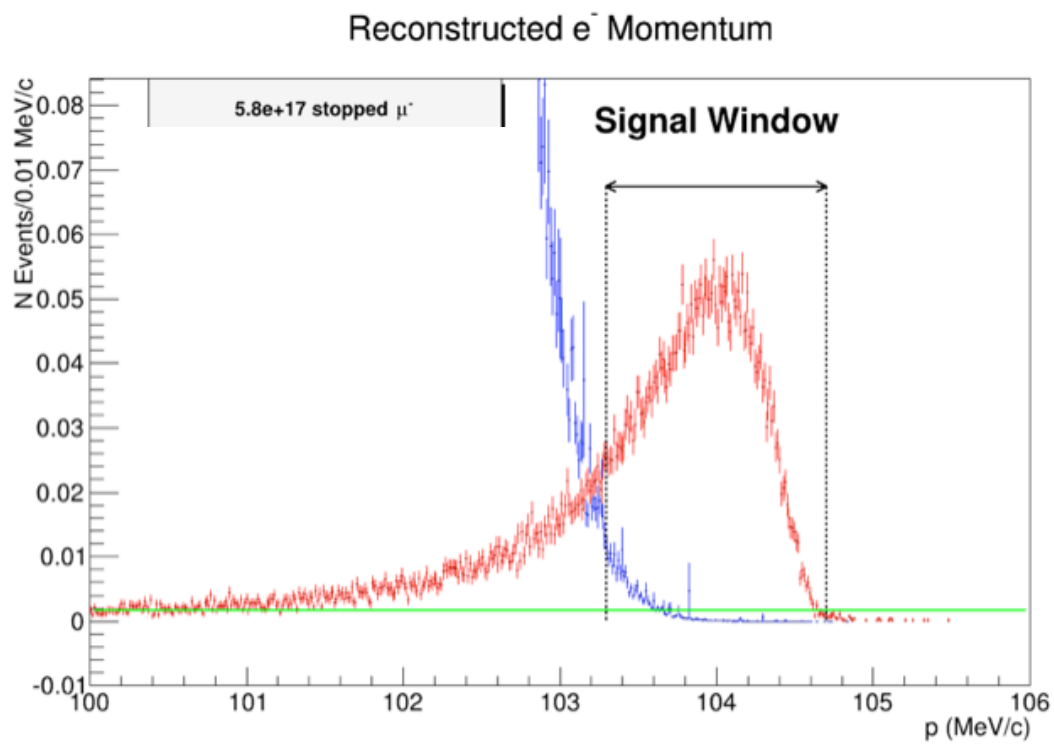
- Design Motivation
- Implementation
  - Production Solenoid
  - Magnet system
  - Transport Solenoid
  - Stopping target and Detector Solenoid
  - Cosmic Ray Veto
  - Shielding

Design Motivation

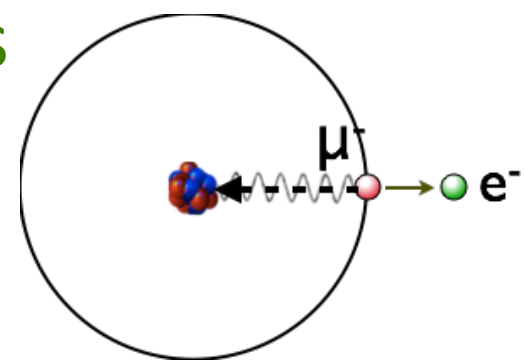
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

Observe conversion signal as peak beyond endpoint of electron momentum spectrum from standard muon decay.



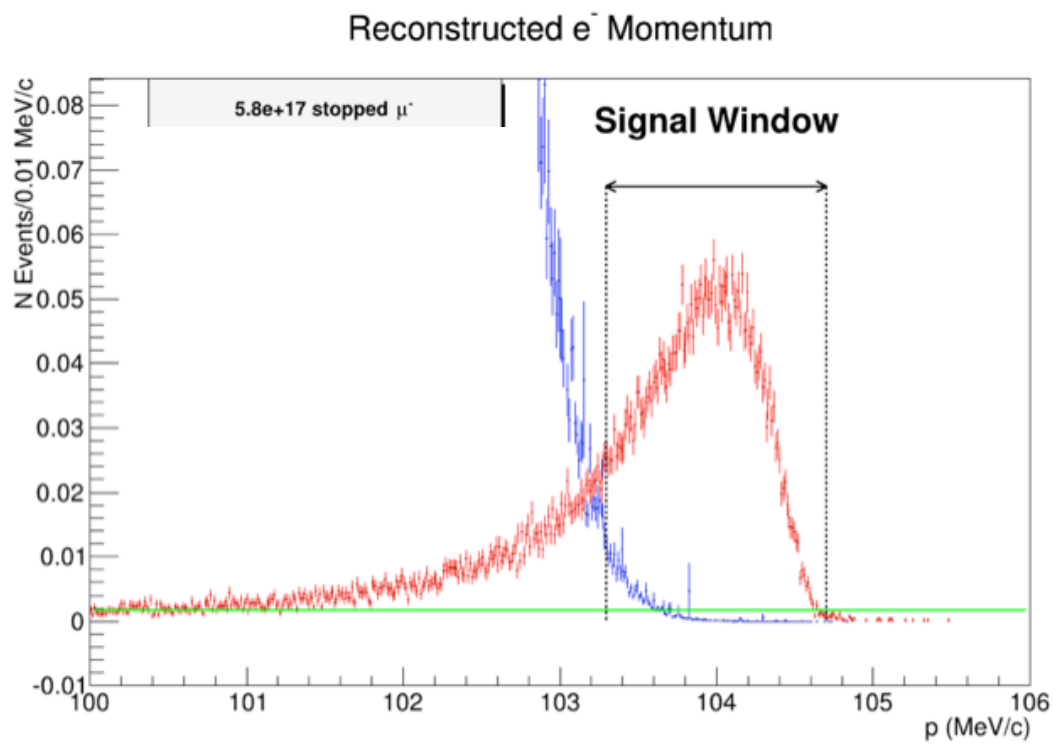
- Muons at rest convert to electrons
  - Electrons from conversion detected



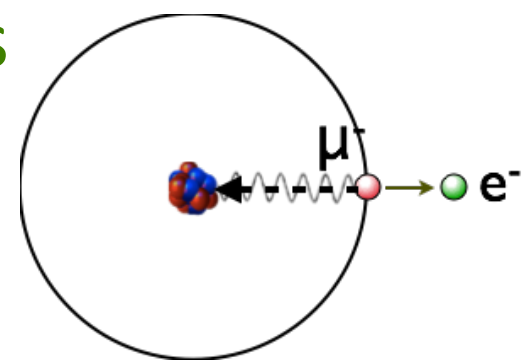
Design Motivation

Observe conversion signal as peak beyond endpoint of electron momentum spectrum from standard muon decay.

Implies need for tracking, pulsed beam, calorimetry



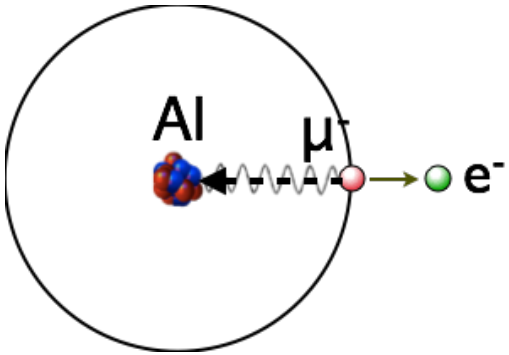
- Muons at rest convert to electrons
  - Electrons from conversion detected



Design Motivation

And have needed recoil partner

Practically, this implies need for a "stopping" target to capture muons so that they are at rest.

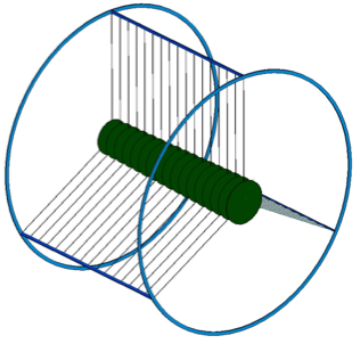


- Muons at rest convert to electrons
  - Electrons from conversion detected

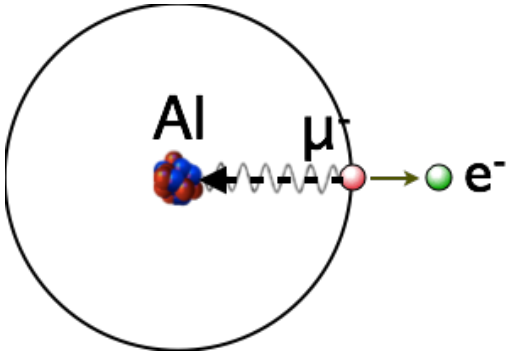
Design Motivation

- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation



Low momentum beam must be selected for delivery to stopping target



- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

Transport system must select low momentum muons and move them away from high-flux, high-energy region toward the stopping target

- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

Not only the extra muons, but the particles necessarily associated with their production, plus a frothy bath of thermal neutrons and photons need to be kept away from the detectors as much as possible.

Jacuzzi.com

- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Shielding!

Design Motivation

- Pions "trapped" to produce muons
- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Design Motivation

Produce muons via $\pi^- \rightarrow \mu^- \bar{\nu}_\mu$

- Pions "trapped" to produce muons
- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Fnal.gov

Design Motivation

- Protons on production target to produce pions
- Pions "trapped" to produce muons
- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Fnal.gov

Design Motivation

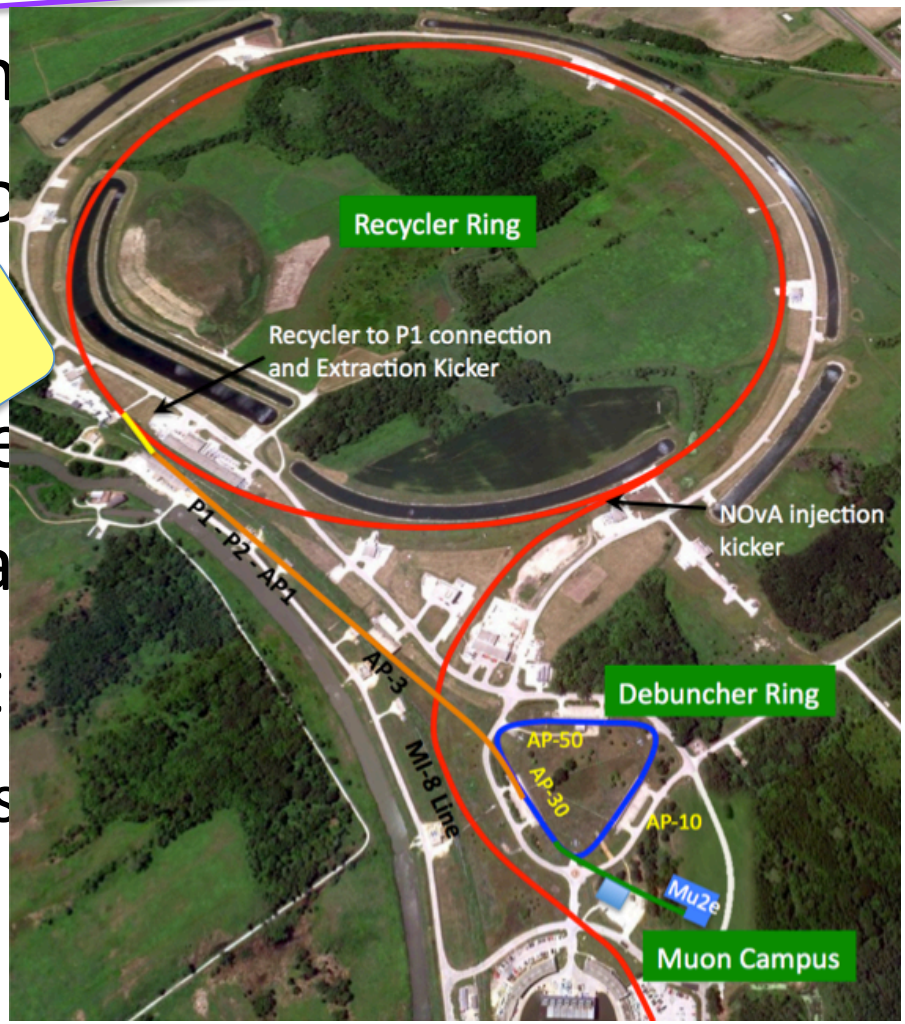
- Protons on production target to produce pions
- Pions "trapped" to produce muons
- Spurious radiation suppressed
- Muons transported cleanly to stopping target
- Muons deposited in stopping target, captured
- Muons at rest convert to electrons
  - Electrons from conversion detected

Fnal.gov

Design Motivation

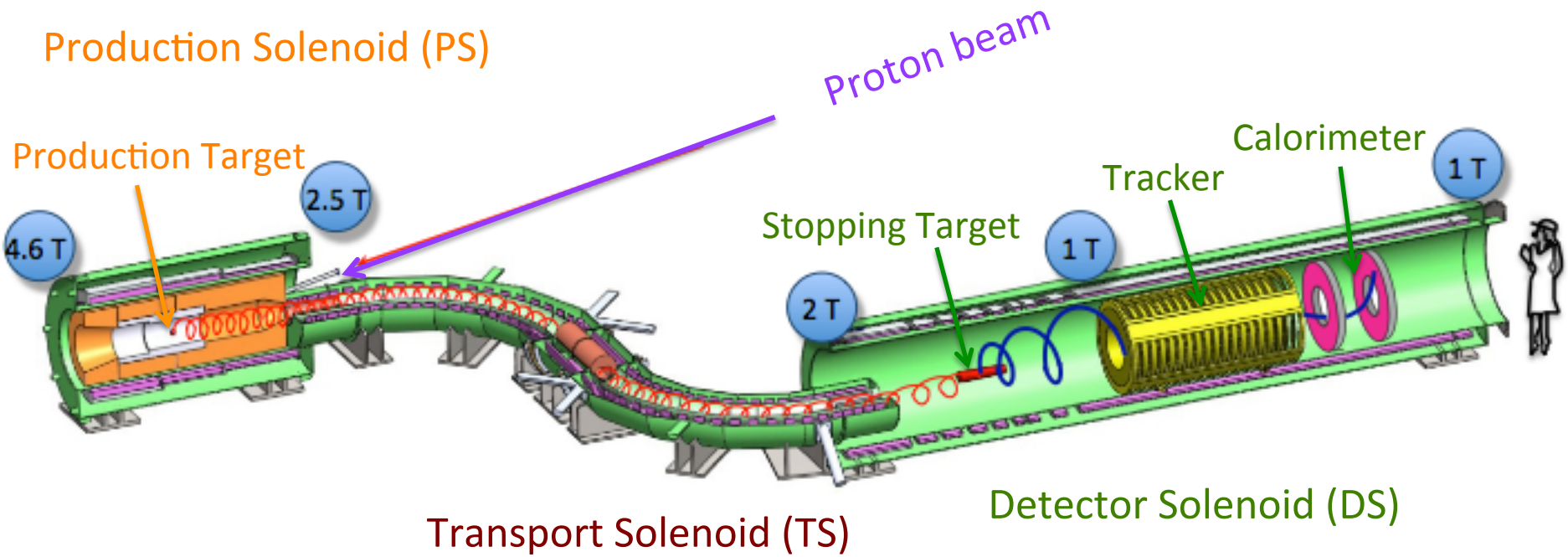
- Protons on production
- Pions "trapped" to pro
- Spurious radiation
- Muons trans cle
- Muons ted in ta
- M t rest convert
- lectrons from convers

Extensive reuse of existing facilities



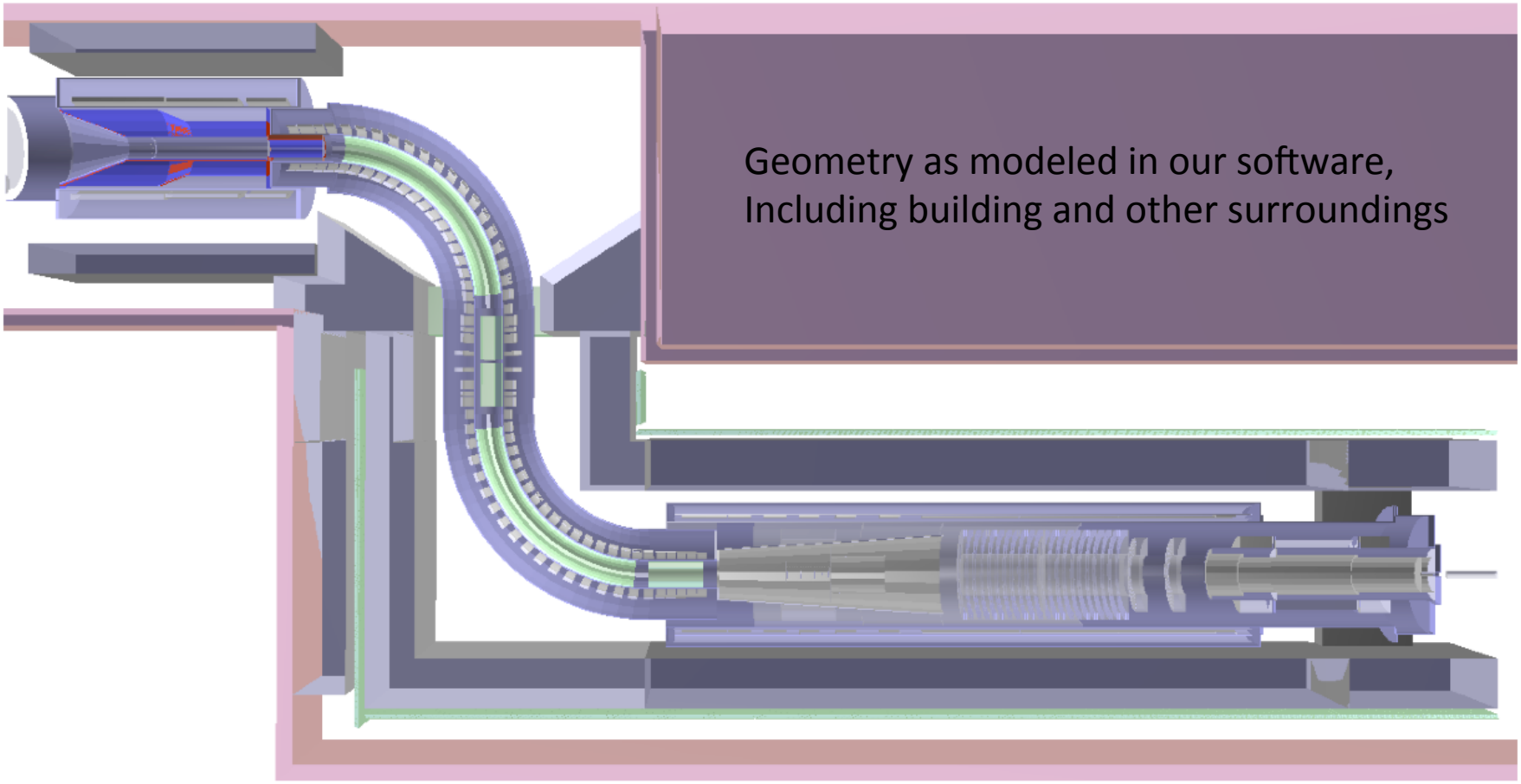
Implementation

Overview



Implementation

Overview

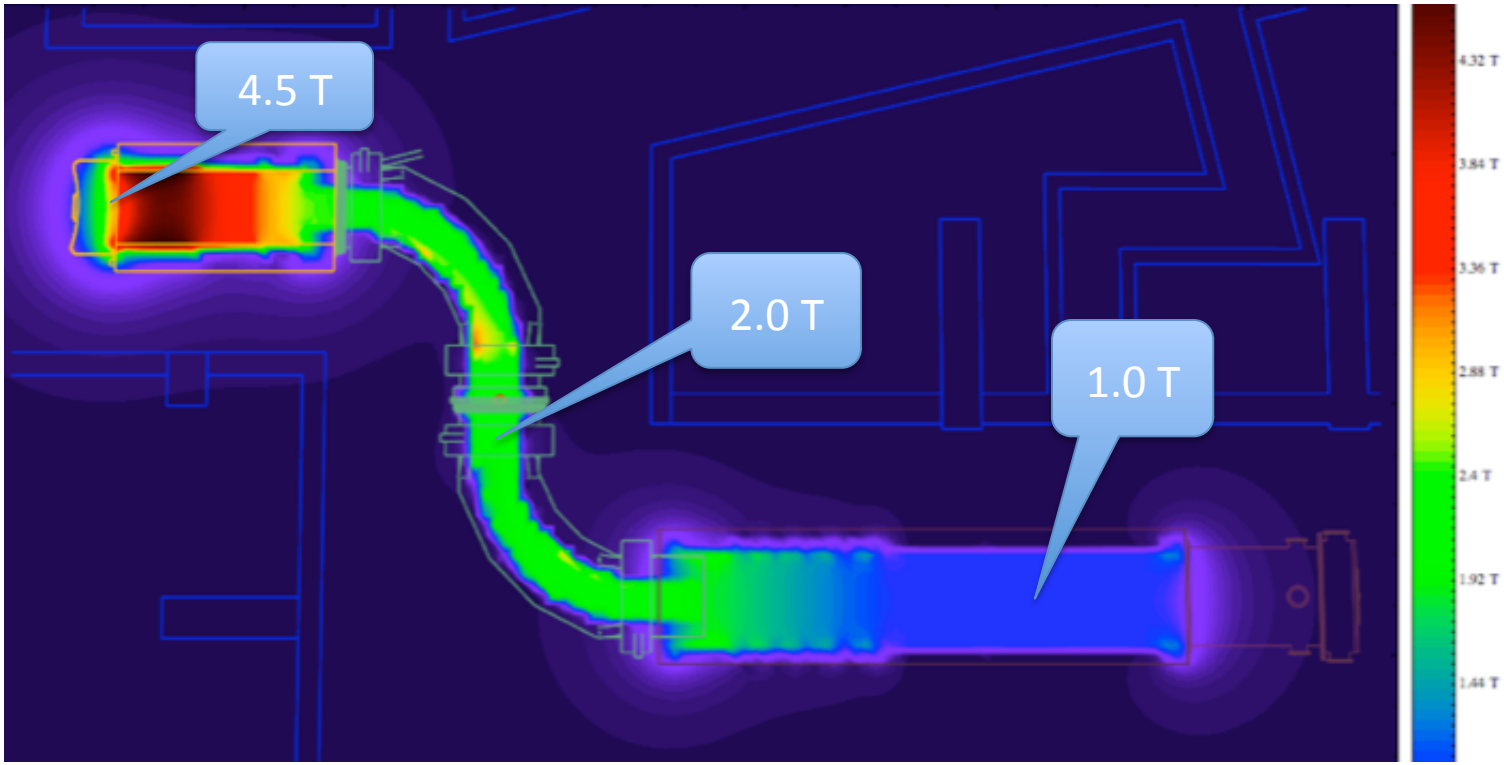


Geometry as modeled in our software,
Including building and other surroundings

~26 m

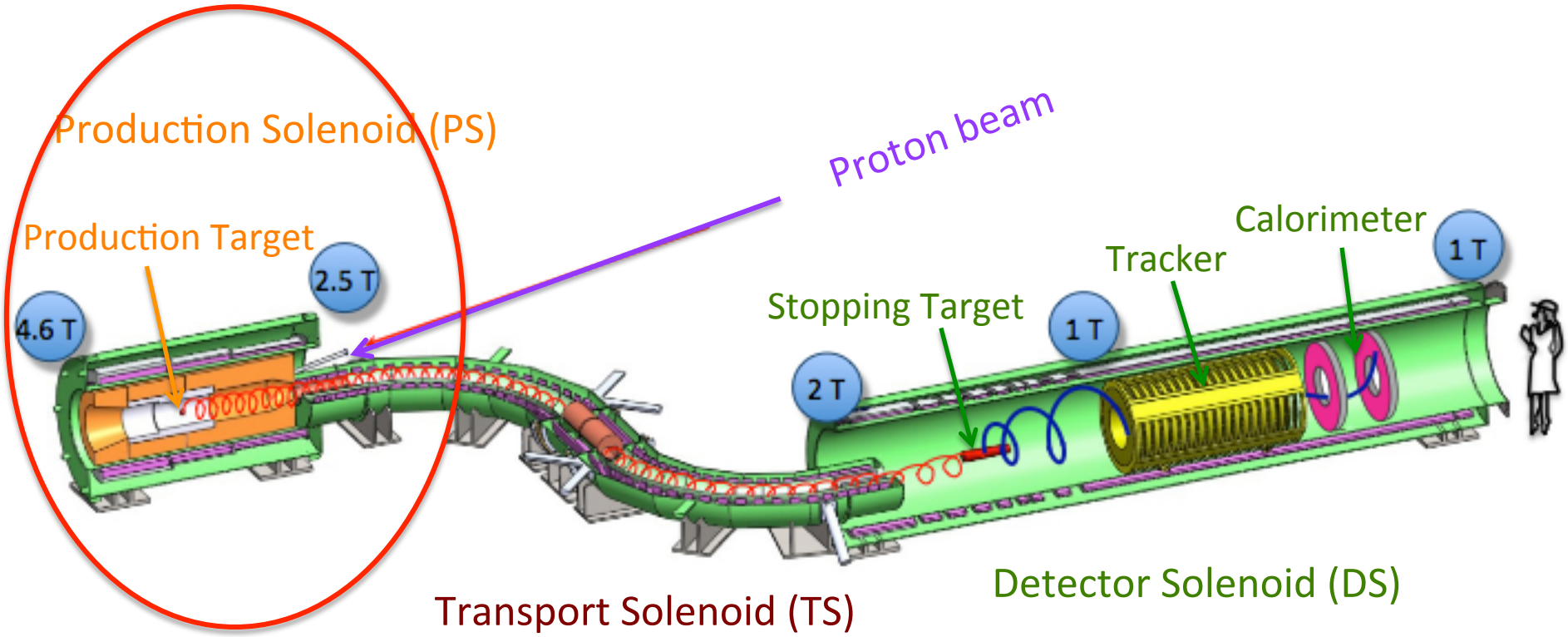
Magnet Systems

- Axial field gradient sweeps particles downstream, toward detectors
  - Improves collection efficiency

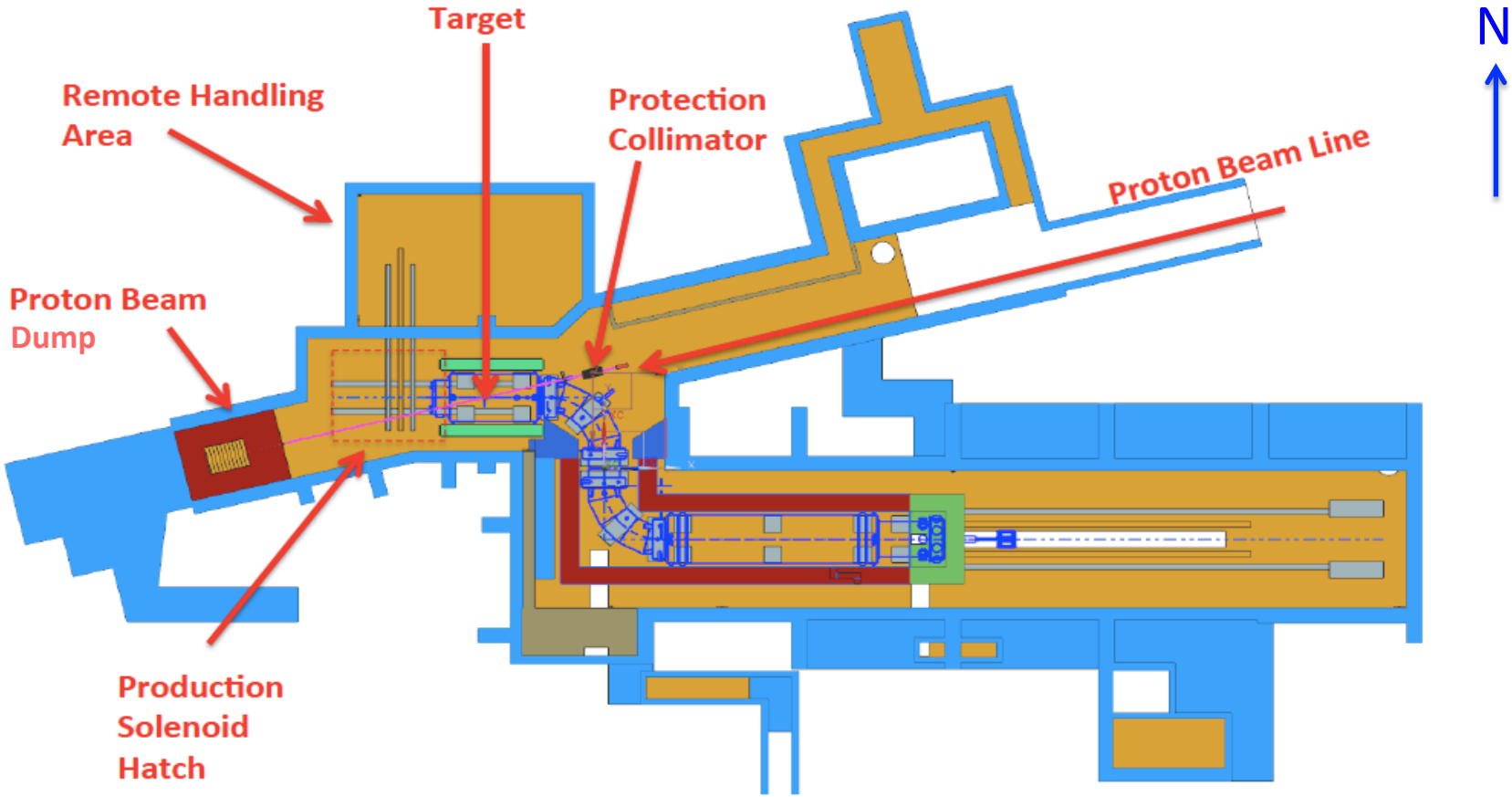


Implementation

Overview

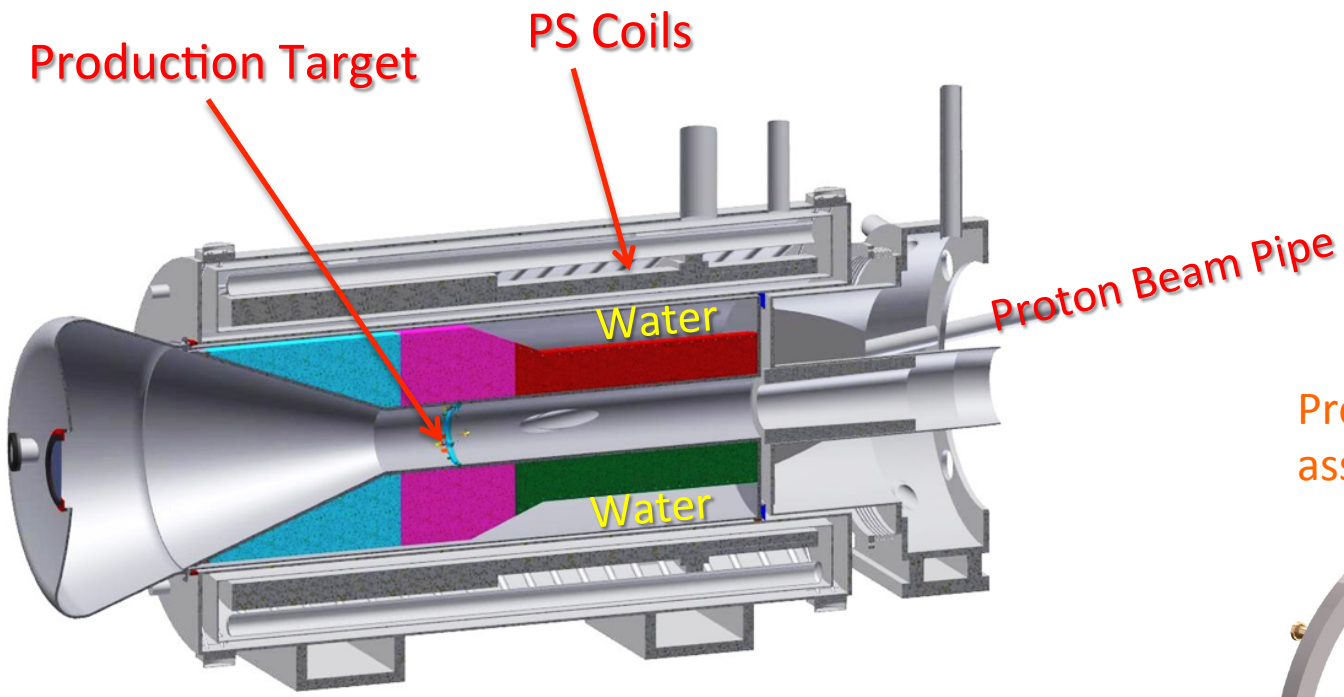


Production Solenoid (PS)

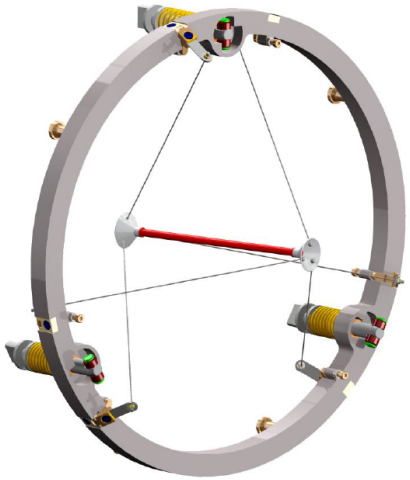


Detail seen here is present in models

Production Solenoid (PS)



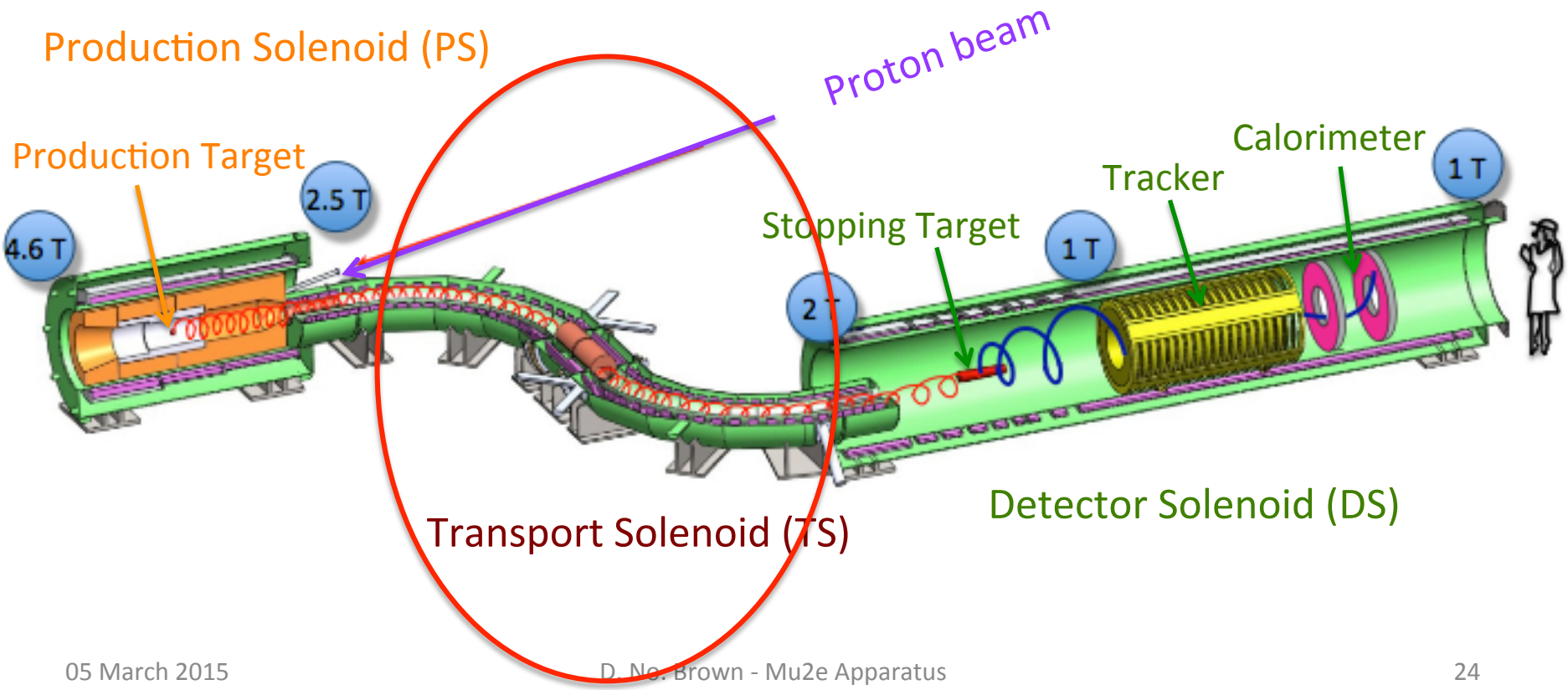
Production Target assembly



- "Microbunch" of protons delivered every 1700 ns
- Protons on production target produce a spray of particles
  - Highest energy escape to beam dump. Low energy reflected by magnetic field gradient, swept downstream

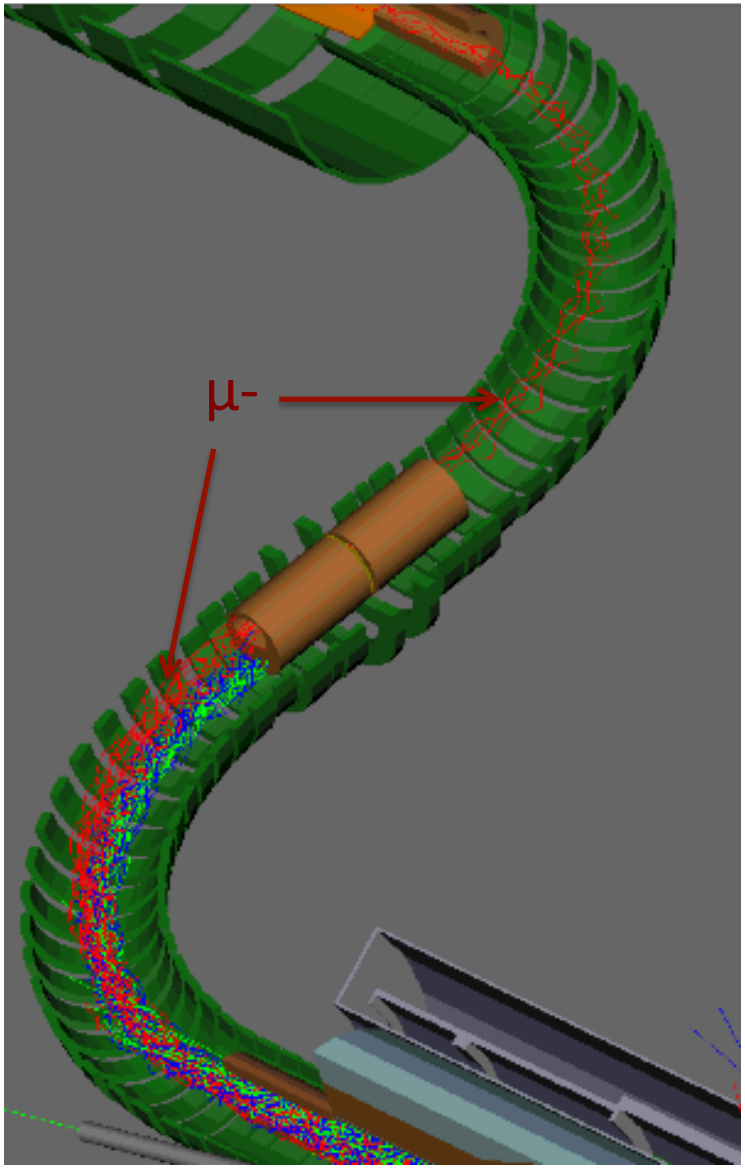
Implementation

Overview



Transport System

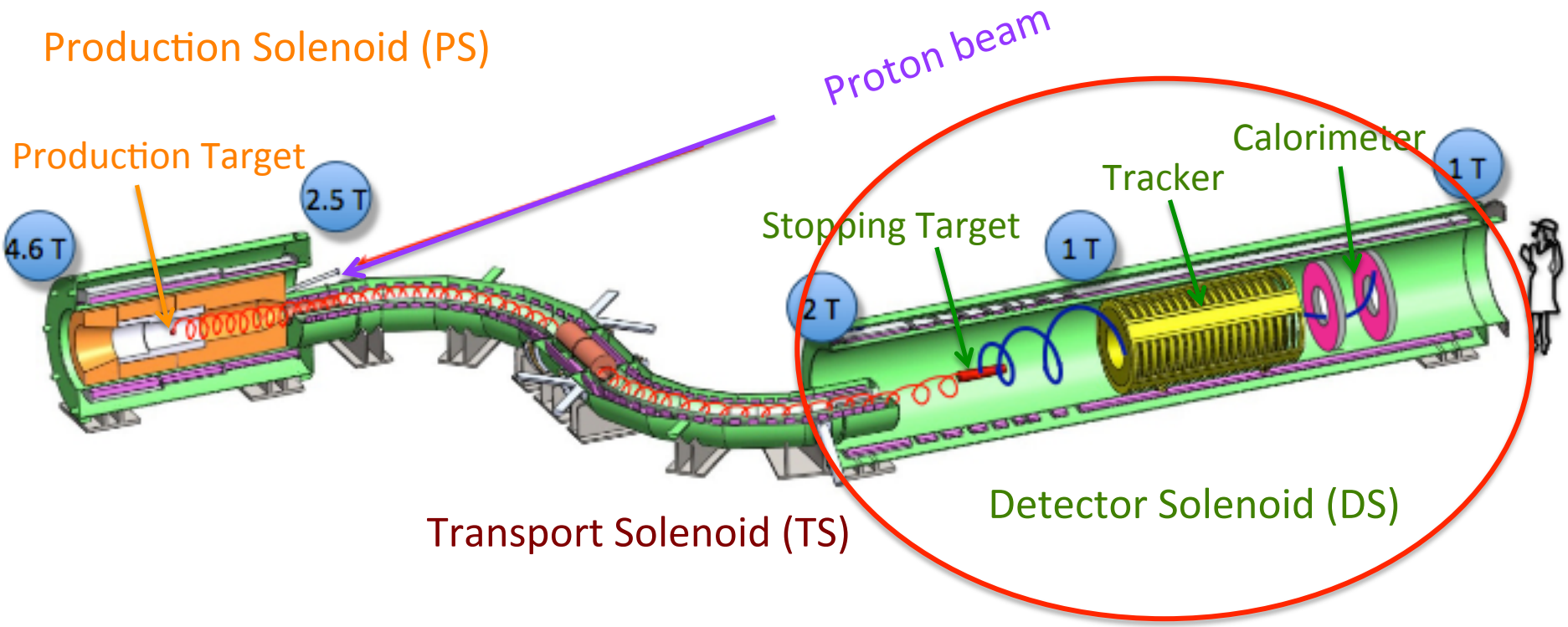
- 'S' bend solenoid transports charged particles
  - no line-of-sight to detector
- Bend induces momentum, charge-dependent vertical shift
  - Reversed by 2nd bend
- Asymmetric collimator rejects positive and high-momentum particles
  - Can be rotated to select positive particles



Classical Electrodynamics, 3rd Ed. J.D. Jackson, Wiley (1998)

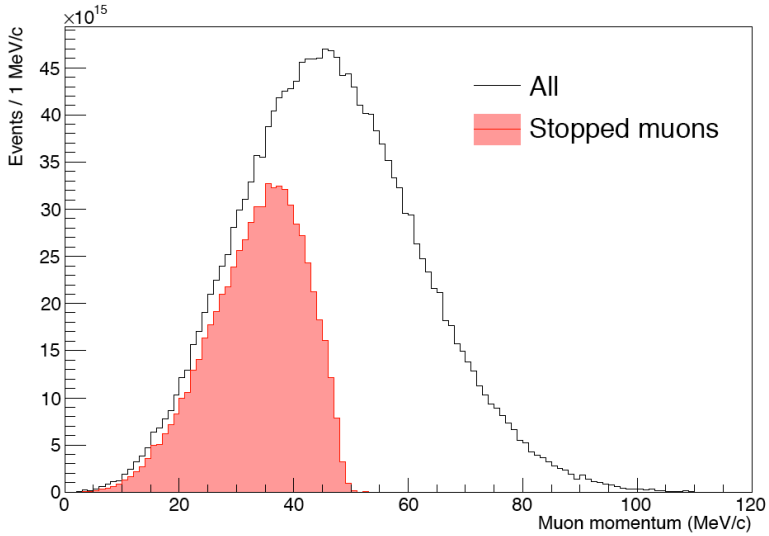
Implementation

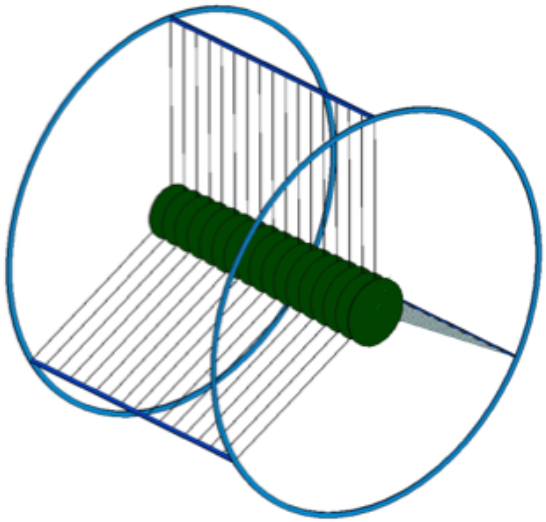
Overview



Downstream/Detector Solenoid

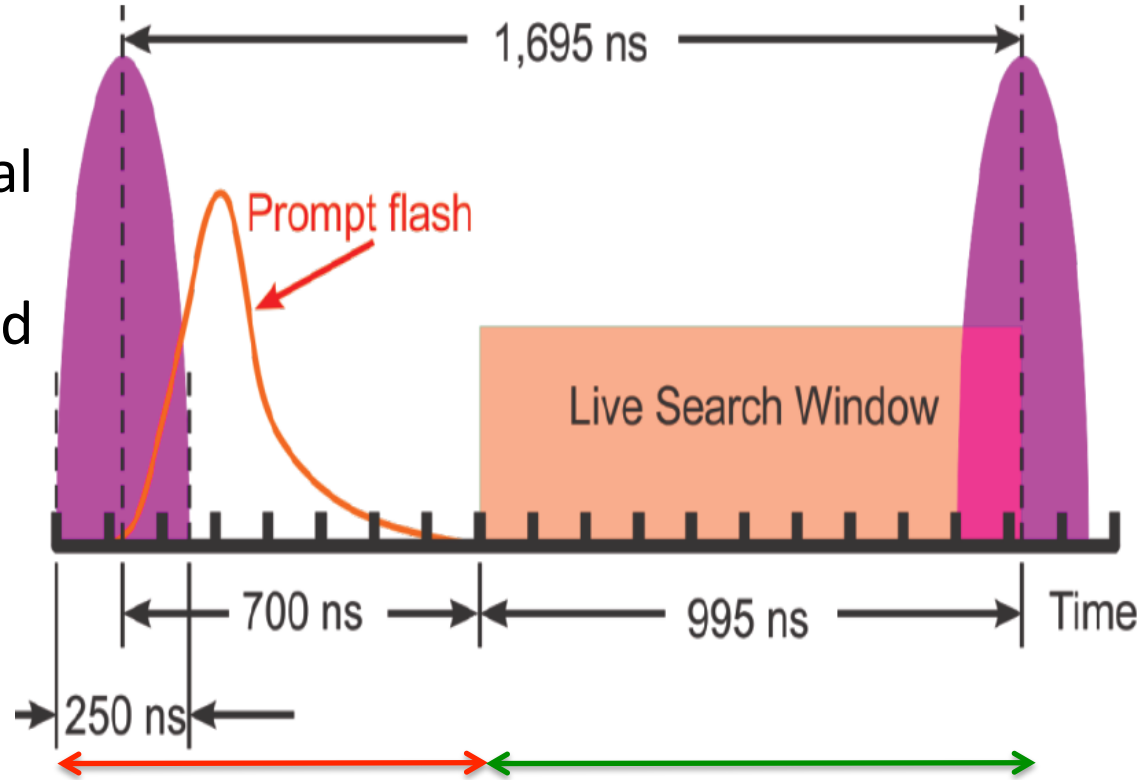
- Stopping target in which conversion will take place
  - Seventeen 200 micron thick, ~13-16 cm diameter Aluminum disks
  - ~10^5 stopped muons per each 1700 ns bunch period





Downstream/Detector Solenoid

- Timing is critical – proton beam parameters tied to detection

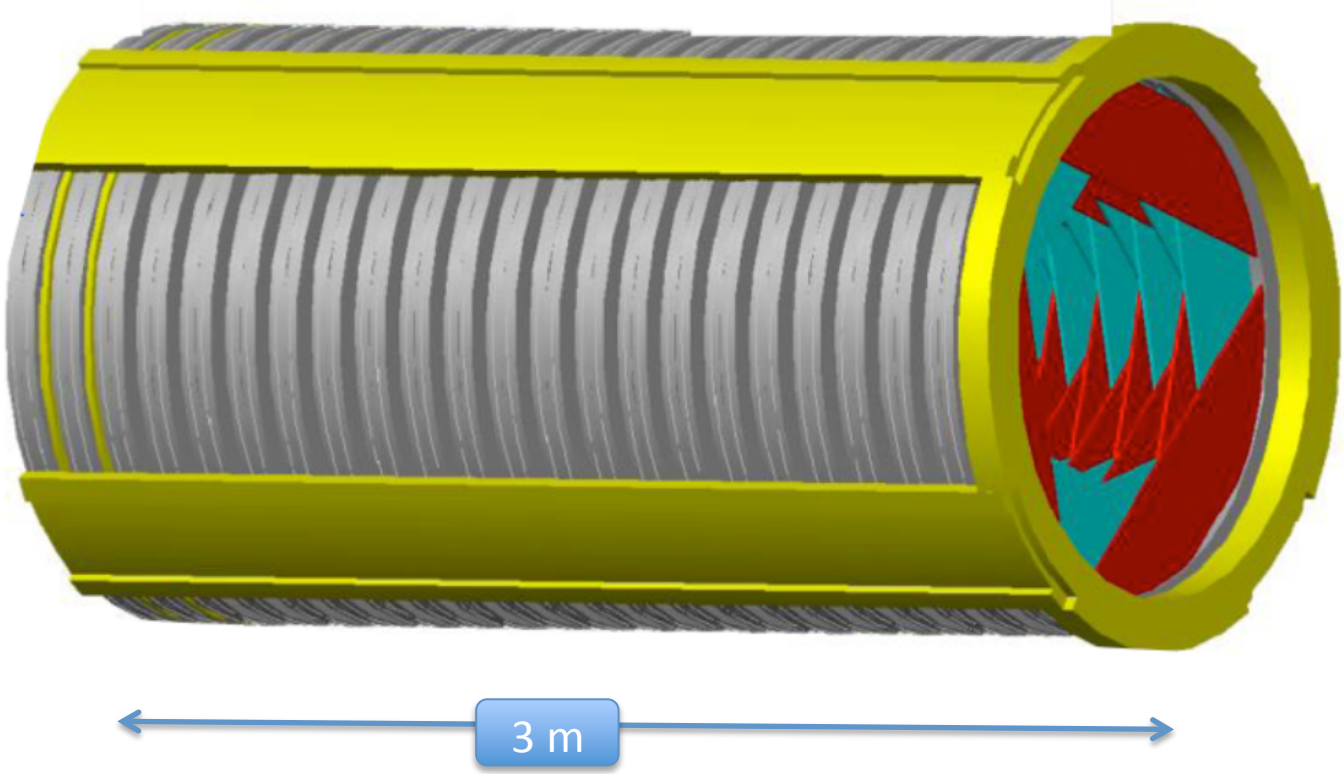


Large flux of particles – don't collect data

Prompt backgrounds mostly gone, accept data from muon decay

$$Extinction = \frac{\#\ p \text{ not in } \mu\text{bunch}}{\#\ p \text{ in } \mu\text{bunch}} \simeq 10^{-10}$$

Downstream/Detector Solenoid

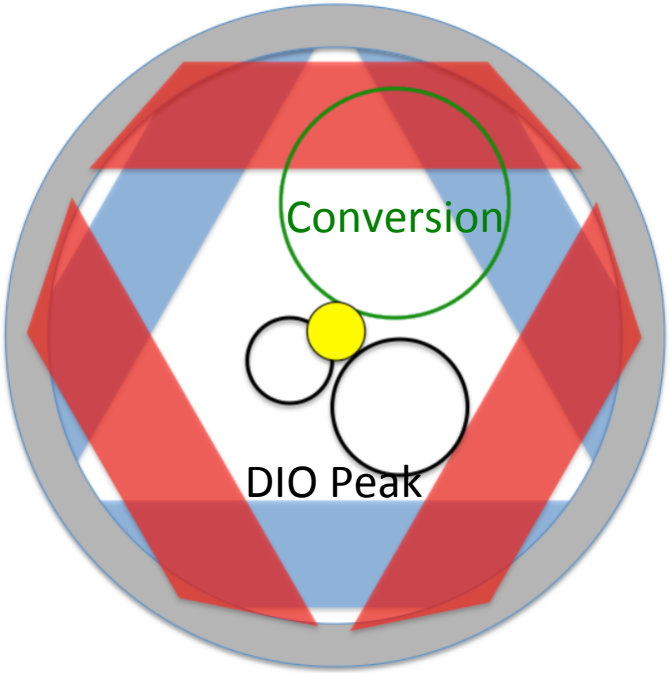


Tracker

Tracking detector measures position and momentum of charged particles near the conversion peak. Also provides timing information.

- 18 stations of double-layer straw tubes
- Low mass – on average, ~1% radiation length traversed by electron
- Timing resolution ~100 ps, position resolution O(1 cm) per hit
- Momentum resolution ~180 keV/c for 105 MeV/c tracks

Downstream/Detector Solenoid



- A tracker plane is made of arrays of straw drift tubes (shown in red and blue)
- Low mass and reliable operation in vacuum; Robust against single-wire failure
- Two planes rotated by 30° form a station. Over 20,000 straws in all.
- Blind to beam flash and most low-momentum background.

$$R = \frac{p_t}{qB}$$

So low momentum tracks from decays in orbit not seen in tracker

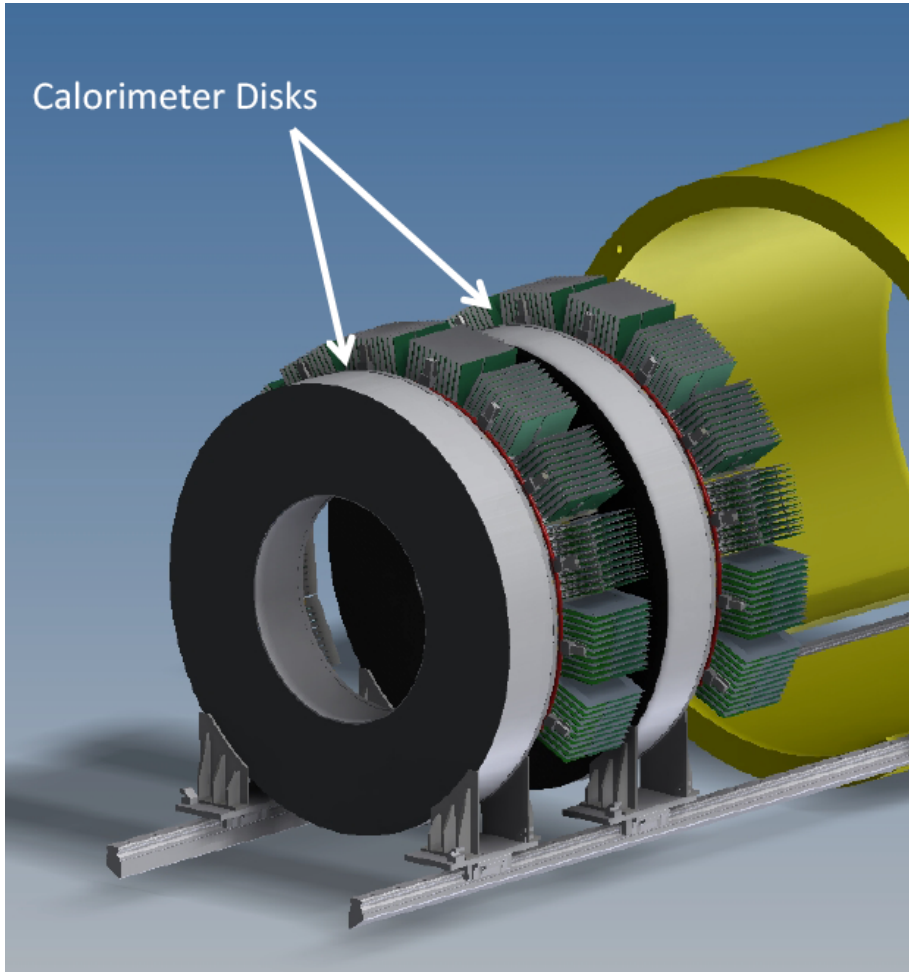
Straw

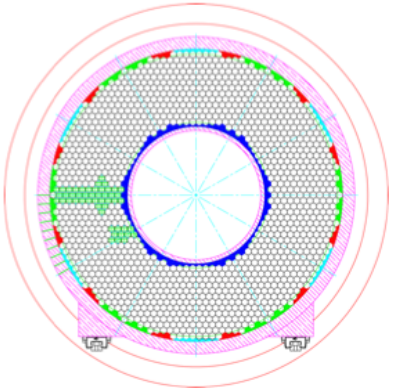
Downstream/Detector Solenoid

Calorimeter

- Calorimeter role:
  - Provide independent measurement of
    - Energy: O(5%)
    - Time: O(0.5 ns)
    - Position: O(1 cm)
  - Particle identification
  - Seed for track finding algorithm
  - Independent trigger from tracker

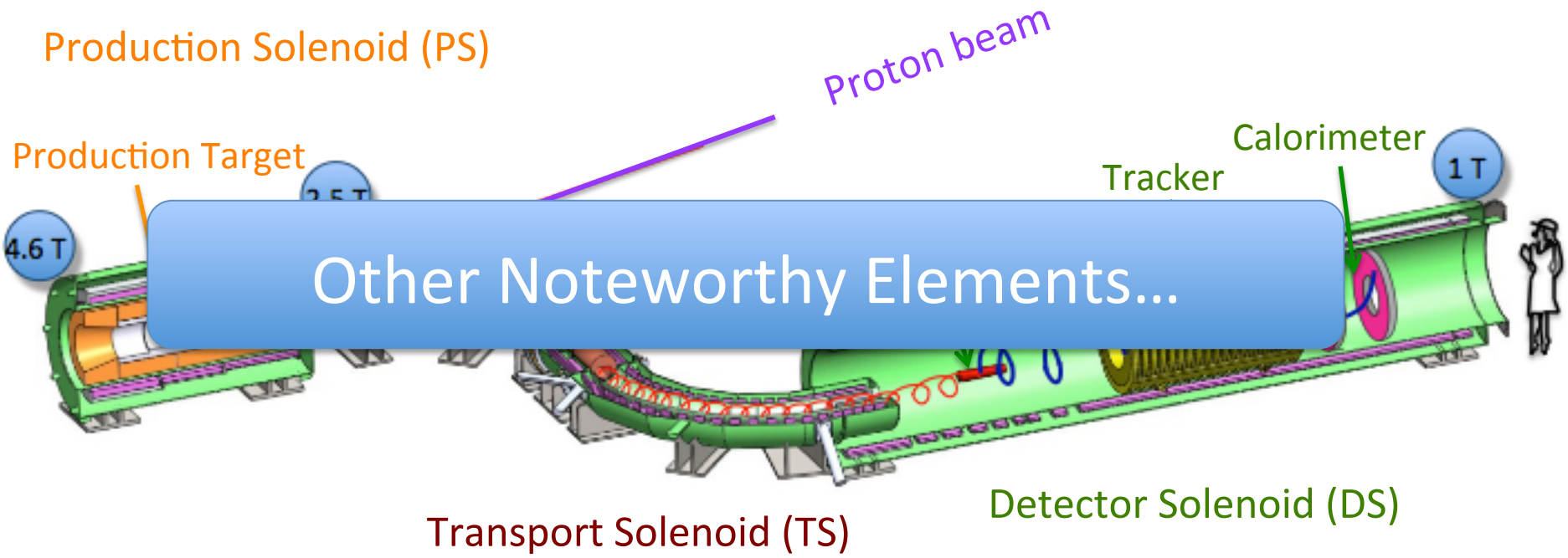
- Crystal type: Barium flouride (BaF_2)
  - Radiation hard, non-hygroscopic



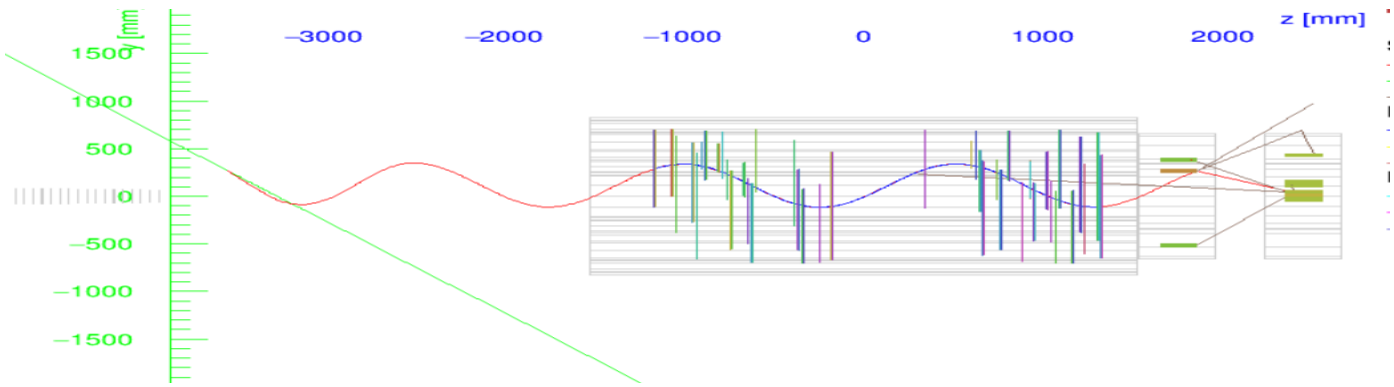


Implementation

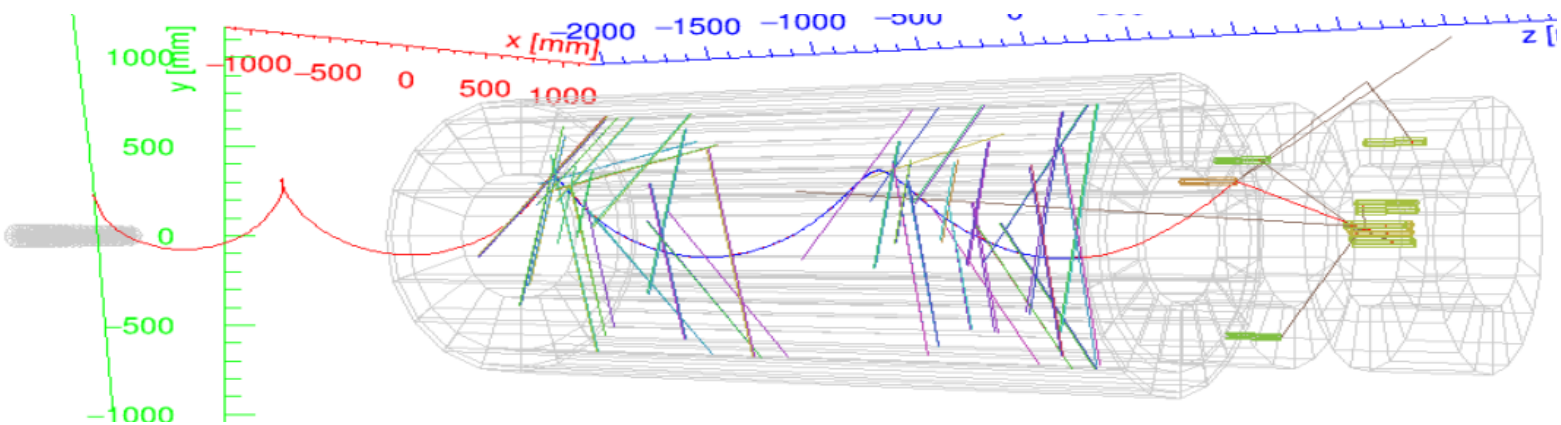
Overview



Cosmic Ray Veto (CRV)



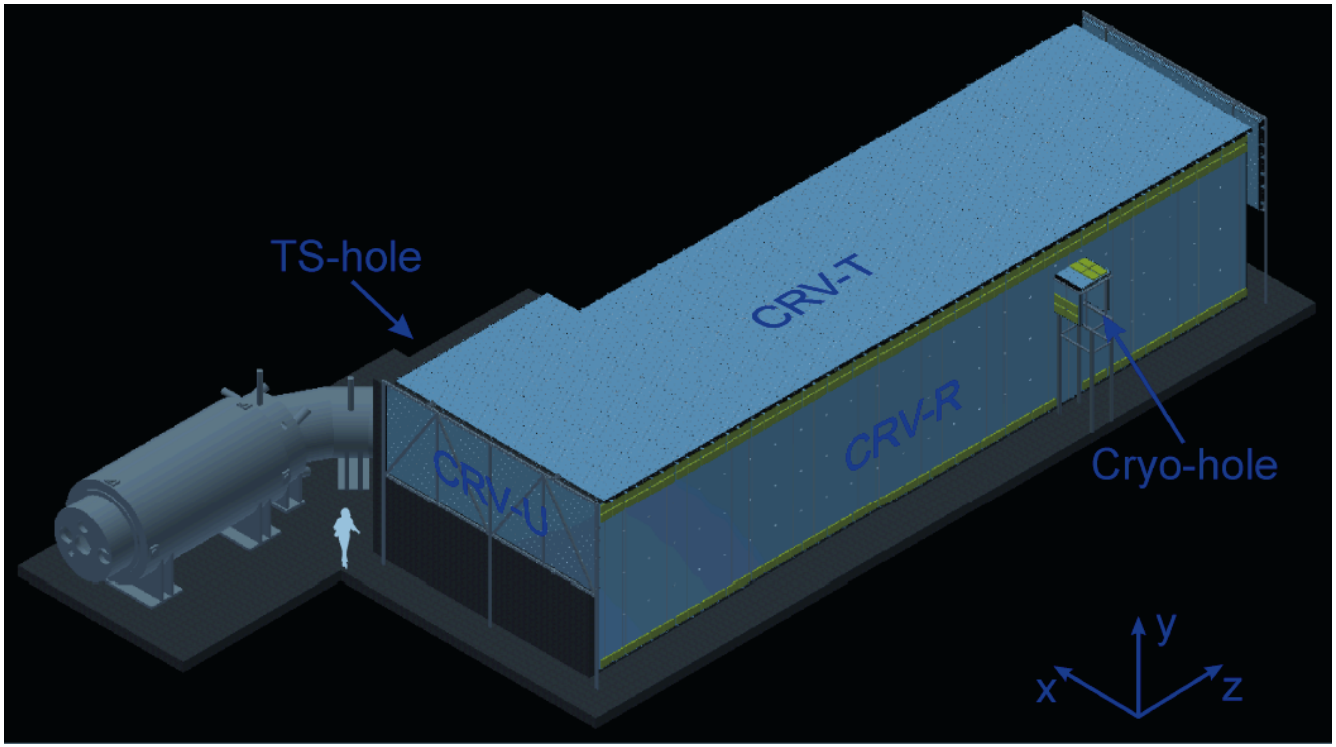
- Cosmic ray muons and interaction products can fake conversion electrons at a rate of ~1 per day



Cosmic Ray Veto (CRV)

- Cosmic Ray Veto made of layers of plastic scintillator bars surrounding detectors and transport region.
- Time resolution ~5ns
- Veto efficiency over 99.99%

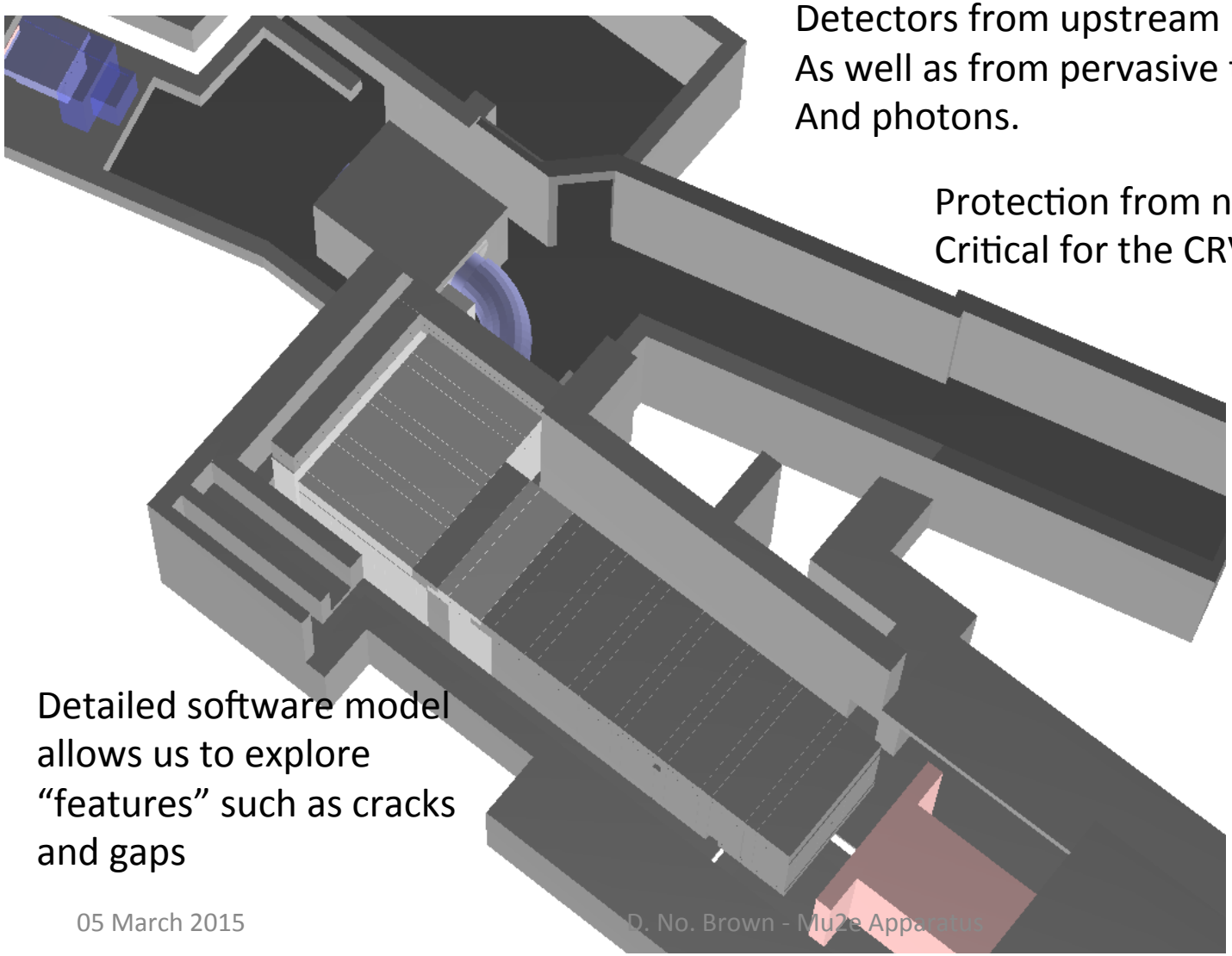
Need to evaluate
Effects of edges and
pass-throughs



Shielding

Extensive shielding protects downstream
Detectors from upstream (mainly) particles
As well as from pervasive thermal neutrons
And photons.

Protection from neutrons particularly
Critical for the CRV

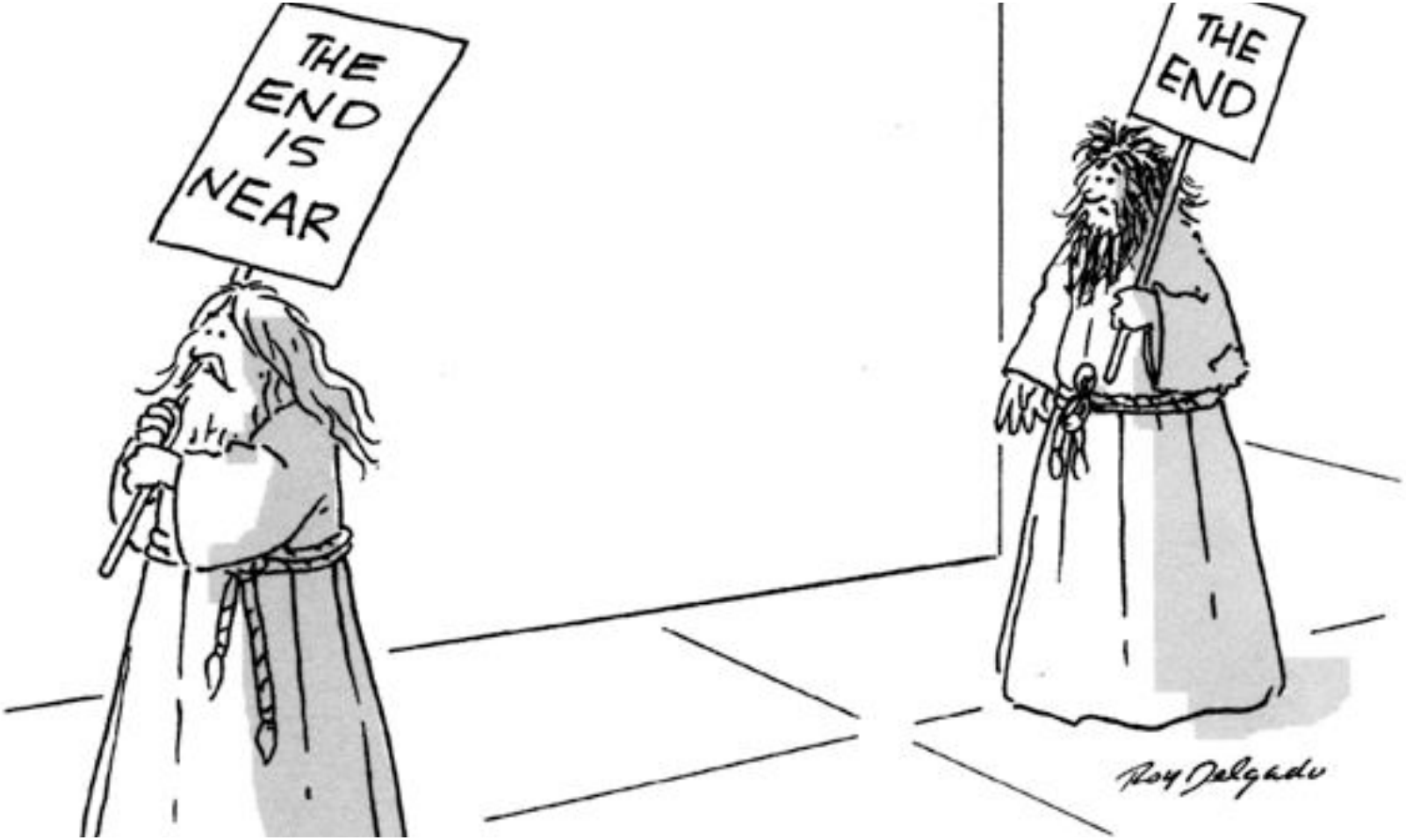


Detailed software model
allows us to explore
“features” such as cracks
and gaps

Conclusions

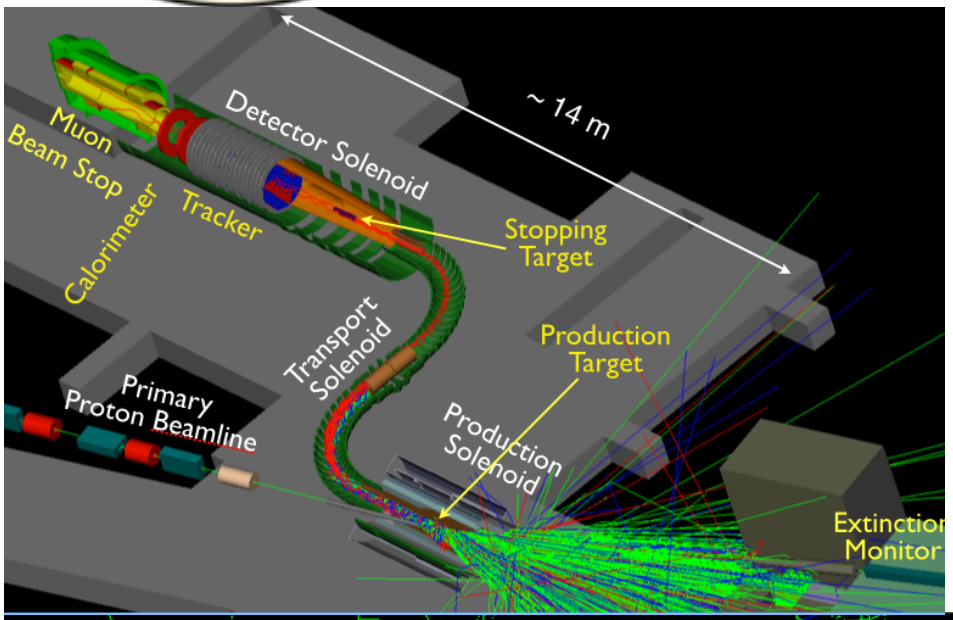
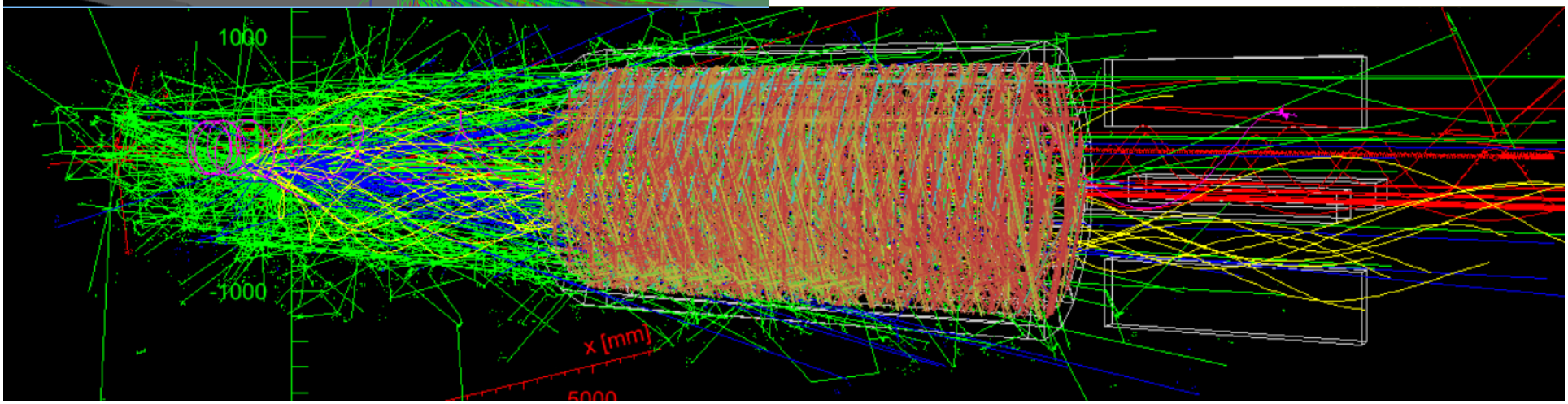
The Thinker, Rodin, at the University of Louisville

- Mature design of Mu2e motivated by physics
- Models at significant detail level exist
  - Software and apparatus design form a loop: each informs the other.
- A lot of thinking has gone into this apparatus


THE END IS NEAR
THE END
Roy Delgado

Backup

Downstream/Detector Systems



Each proton microbunch creates a large flux of particles