LBNE MUON MONITORS

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Outline

- Introduction/goals
- Stopped μ-monitors
  - Current Design
  - R&D
  - Simulations
- Gas Cherenkov monitors
- Status and Plans

Goals

- **Stopped muons remain in the rock downstream of the absorber after beam pulses**
  - **Distributed as a function of initial energy**

- **Make small, specialized modular detectors to observe these decays for:**
  - **Beam composition**
  - **Absolute muon flux**

- **Incorporate with beam MC to constrain neutrino spectrum**

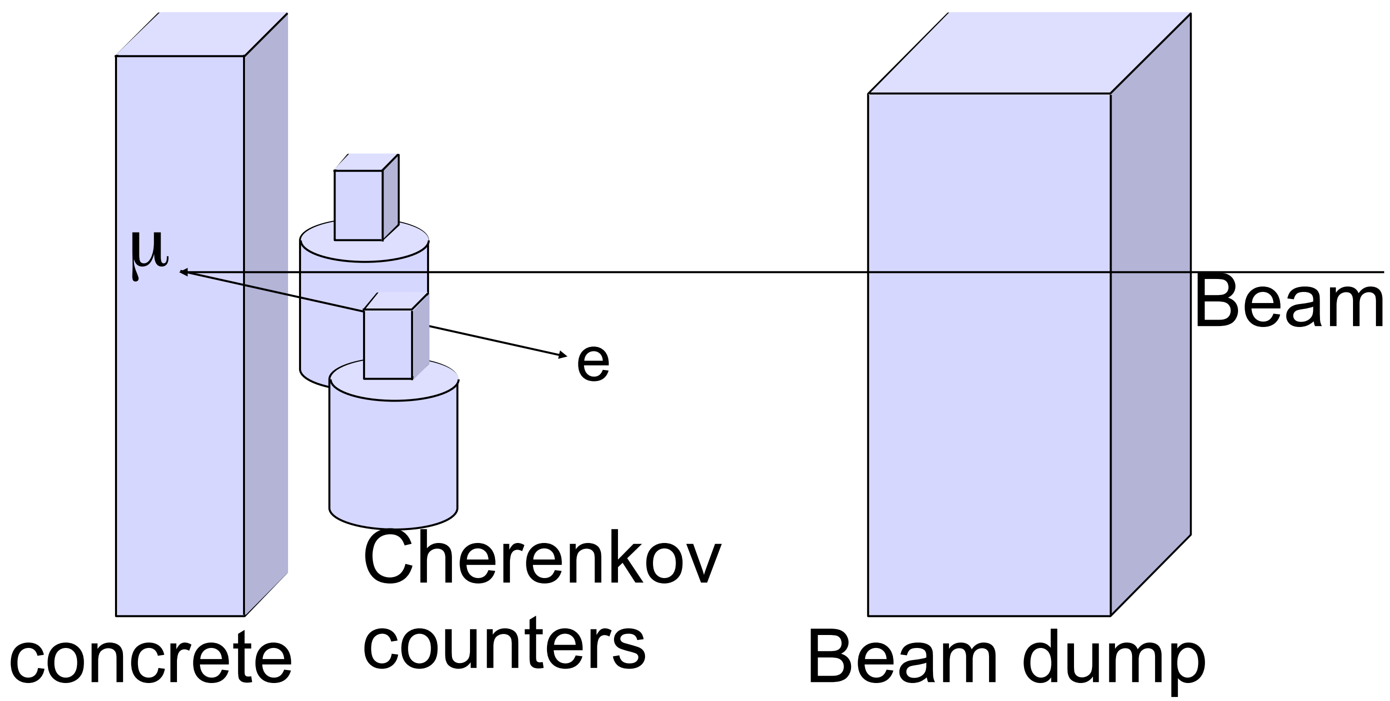
- **Intend to make calorimeter-type detectors large enough to to contain enough of an EM shower to distinguish between Michel electrons and neutron interactions or radioactive decays.**
  - **Current design: Cherenkov inner detector with liquid scintillator veto**

Goals

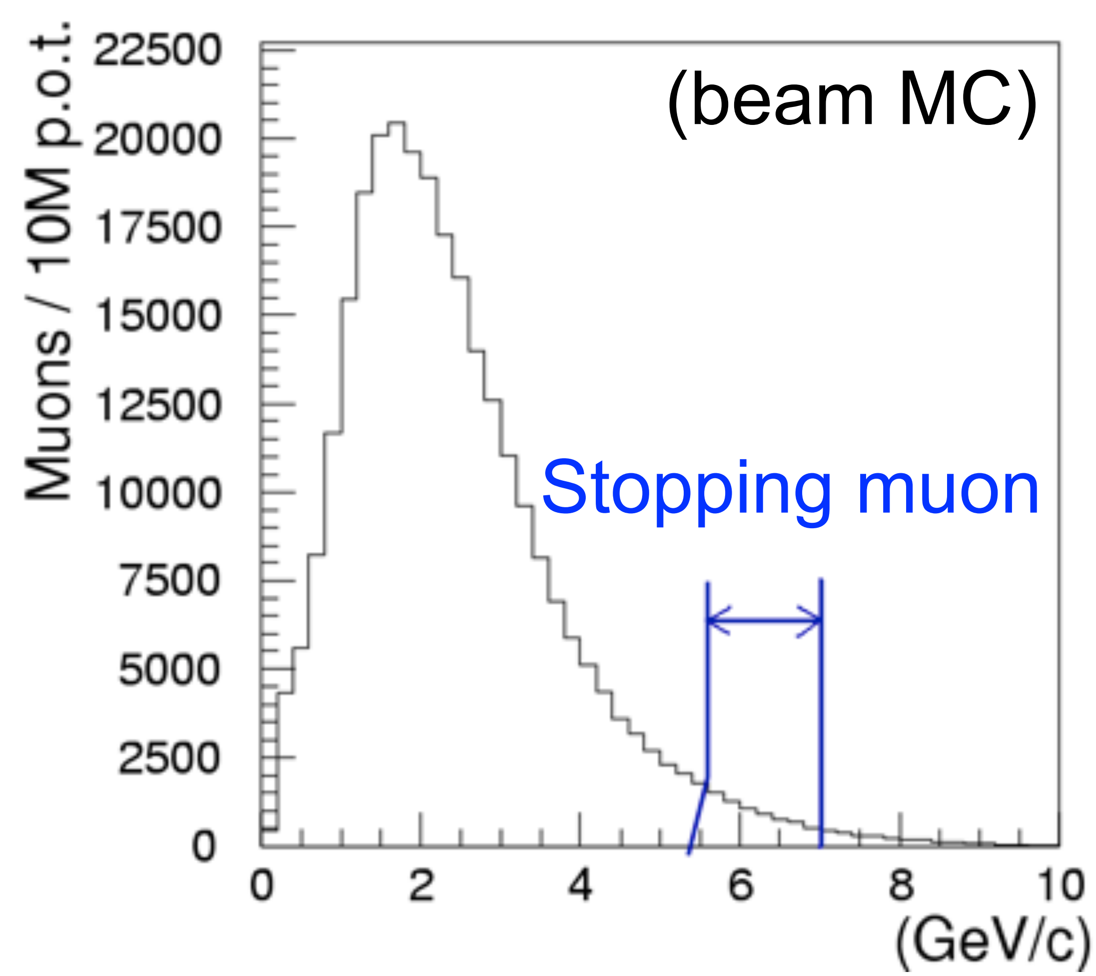
- **These monitors can solve some of the major issues with conventional muon monitoring:**
  - **Observe individual Michel decays → provide known efficiency & absolute normalization**
  - **Stopped muons provide a unique range, not just an integral over a threshold**
  - **Fitting for lifetime provides an independent check that signal is coming from muons**

From K. Hiraide, *Muon monitor using the decay electrons*, NBI2003 Workshop

Strategy



- Counting the decay electrons from muons stopping at the wall of μ-pit
- Measuring spatial and time distributions of events

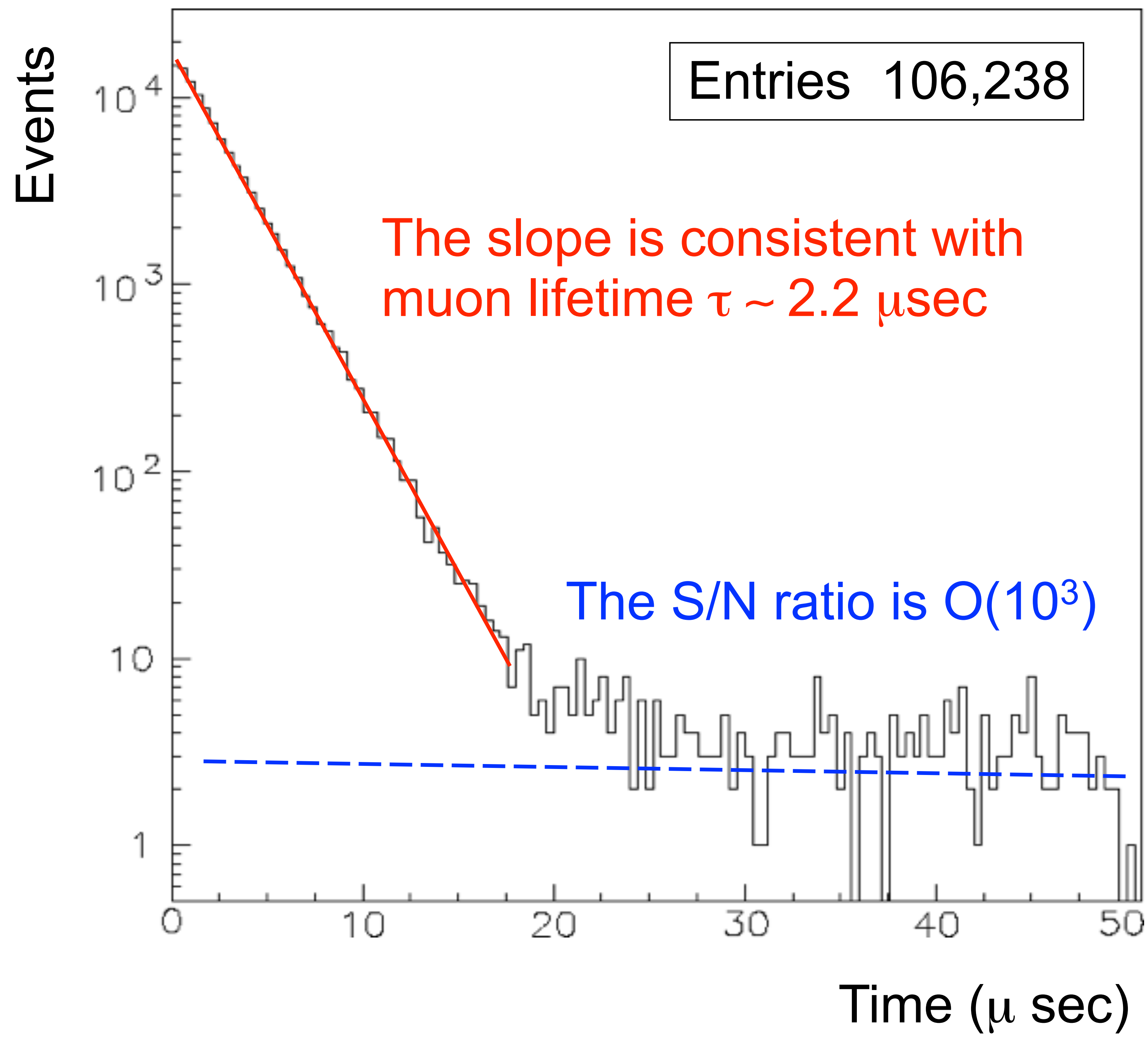


- Energy loss of muons in the beam dump
- Range of electrons in the concrete

We can measure muons of ***5.2~7.0GeV/c*** by counting the decay electrons

From K. Hiraide, *Muon monitor using the decay electrons*, NBI2003 Workshop

Time distribution of events



- Accumulated 19,178 spills
- Sum of 6 counters

We succeeded in measuring of the decay electrons with good S/N.

Feasibility

- Precedent exists for this type of measurement
  - Kyoto group was able to observe stopped muons at K2K

Some environmental differences present new challenges:

- Rate is 2 orders of magnitude higher than K2K
  - → increased signal + bg
  - Need to wait longer for signal to be at a reasonable level

Gated PMT R&D

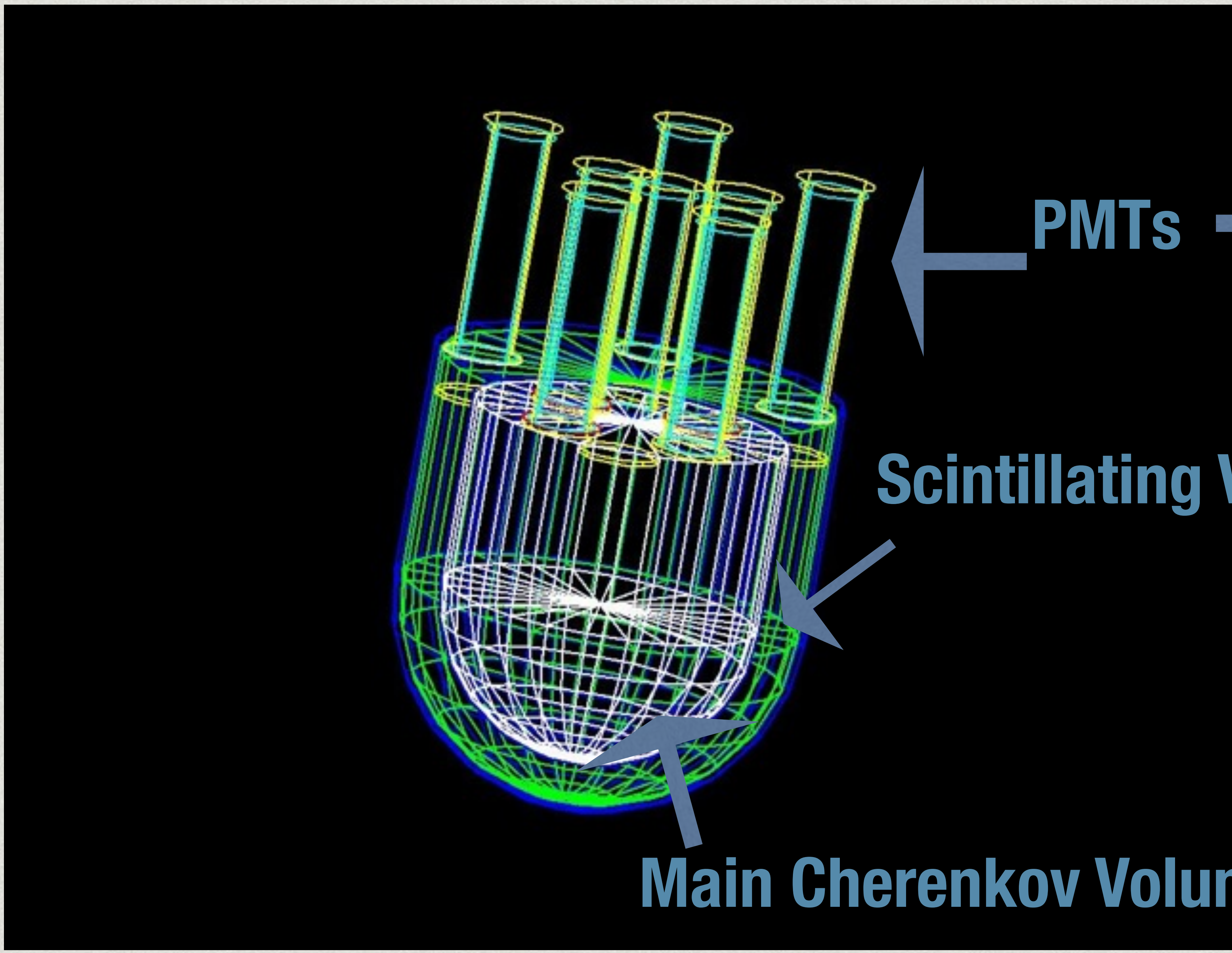
- Develop and test a gated PMT base system
    - Huge amount of light - need to turn PMT off during the initial pulse then quickly turn back on for signal measurement
    - Working with Charles Lane to produce gated bases to satisfy this condition
    - BNL g-2 experiment faced similar constraints - see below

Blanking and Flash Studies for Photomultiplier Tubes

Jinsong Ouyang and William E. Earle
Physics Department, Boston University, Boston, MA 02215

By using switching circuitry with cascaded high-voltage transistors to switch the voltage on a selected dynode, the gain of a photomultiplier tube can be quickly reduced to near-zero. After being off for several microseconds, the photomultiplier tube can be returned to its normal operating gain in less than half a microsecond. Immediately after the return to normal gain, the variation of the electron transit time shift and the change of signal charge caused by switching is less than 5 ps and 0.3%, respectively, over a 1 ms time interval. A laser flash applied while the tube is switched off does not affect the electron transit time or signal charge after the tube is switched back on.

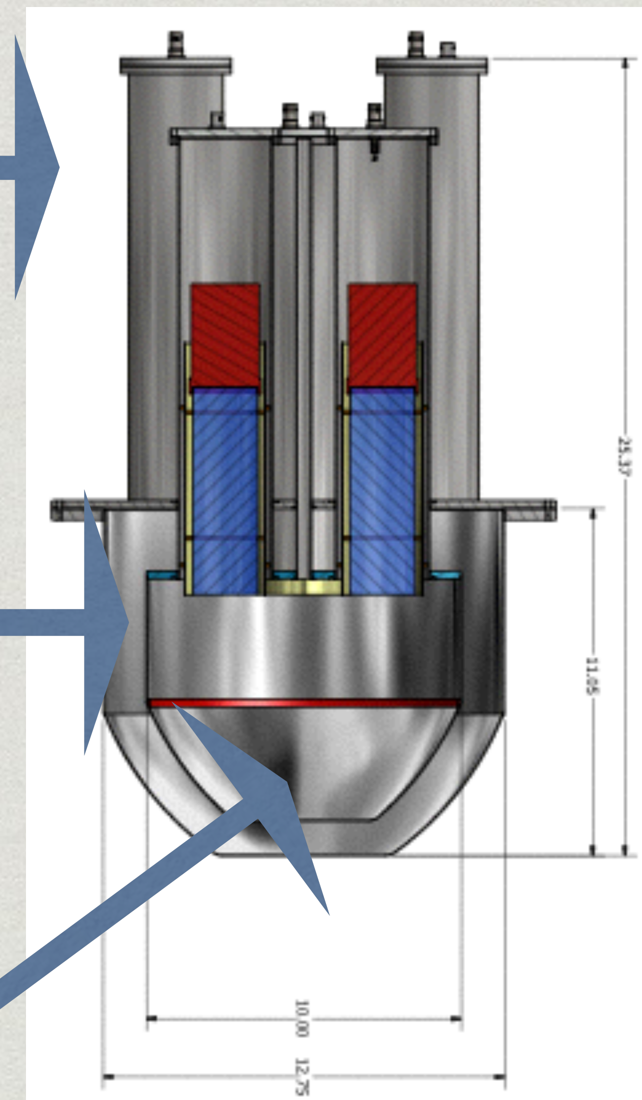
Current Design - Stopped Muon Monitor



PMTs

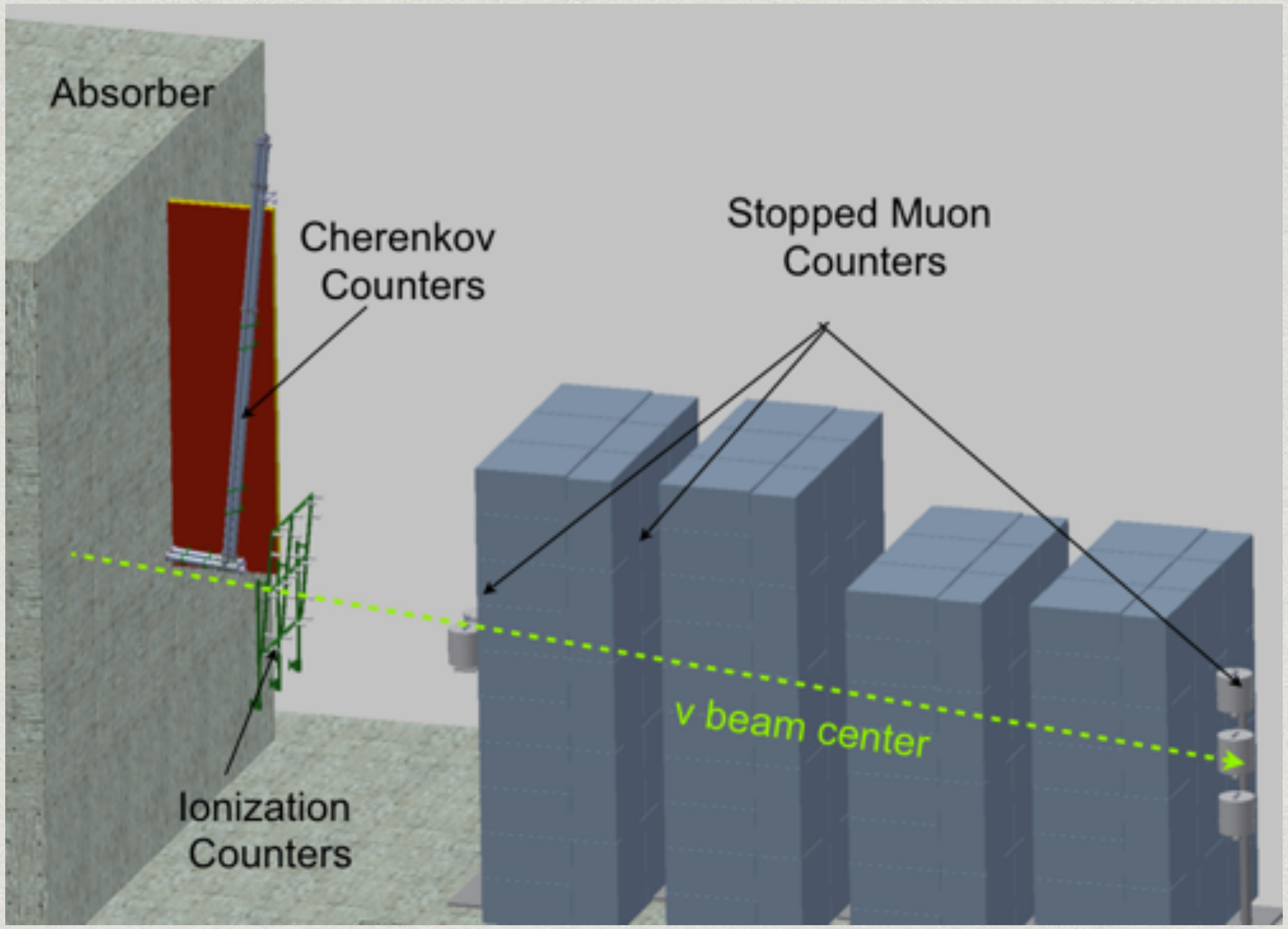
Scintillating Veto

Main Cherenkov Volume



Placement

- Stopped μ-monitors and gas Cherenkov monitor can be placed after absorber
  - SMMs can be in individual alcoves, or one large alcove separated as shown

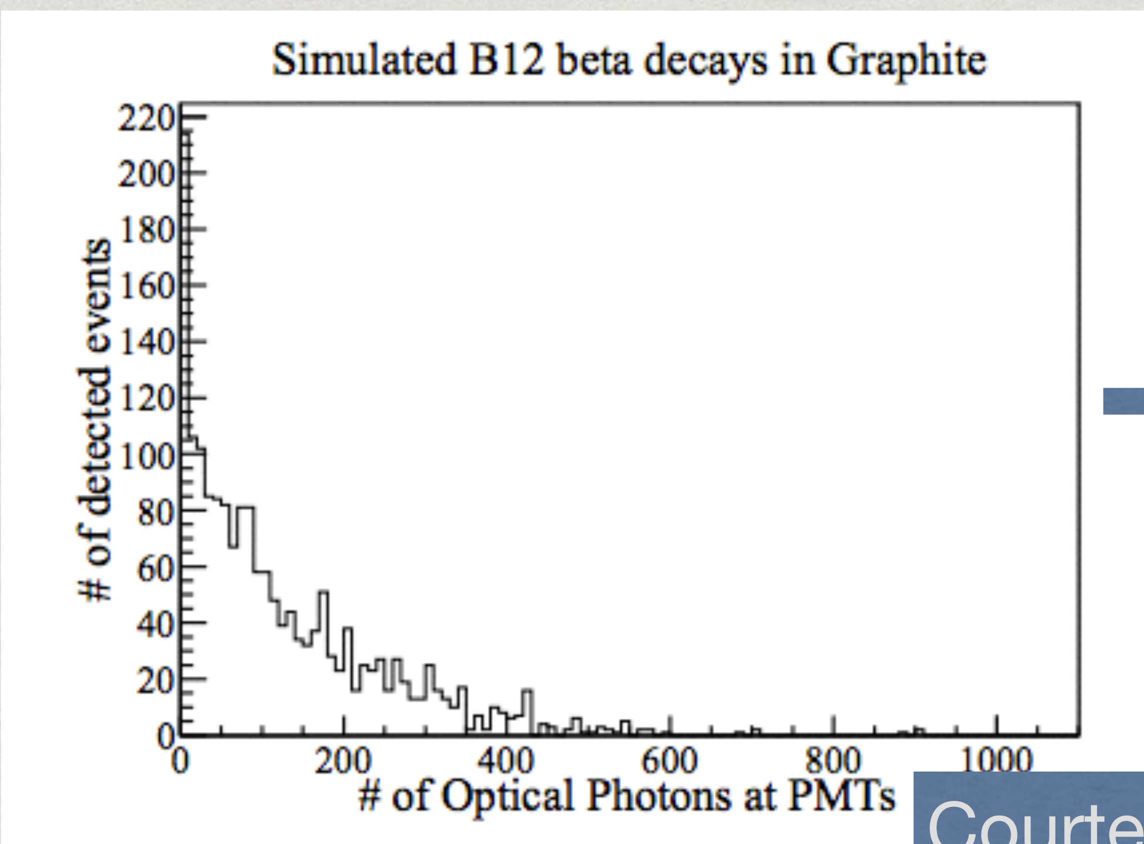


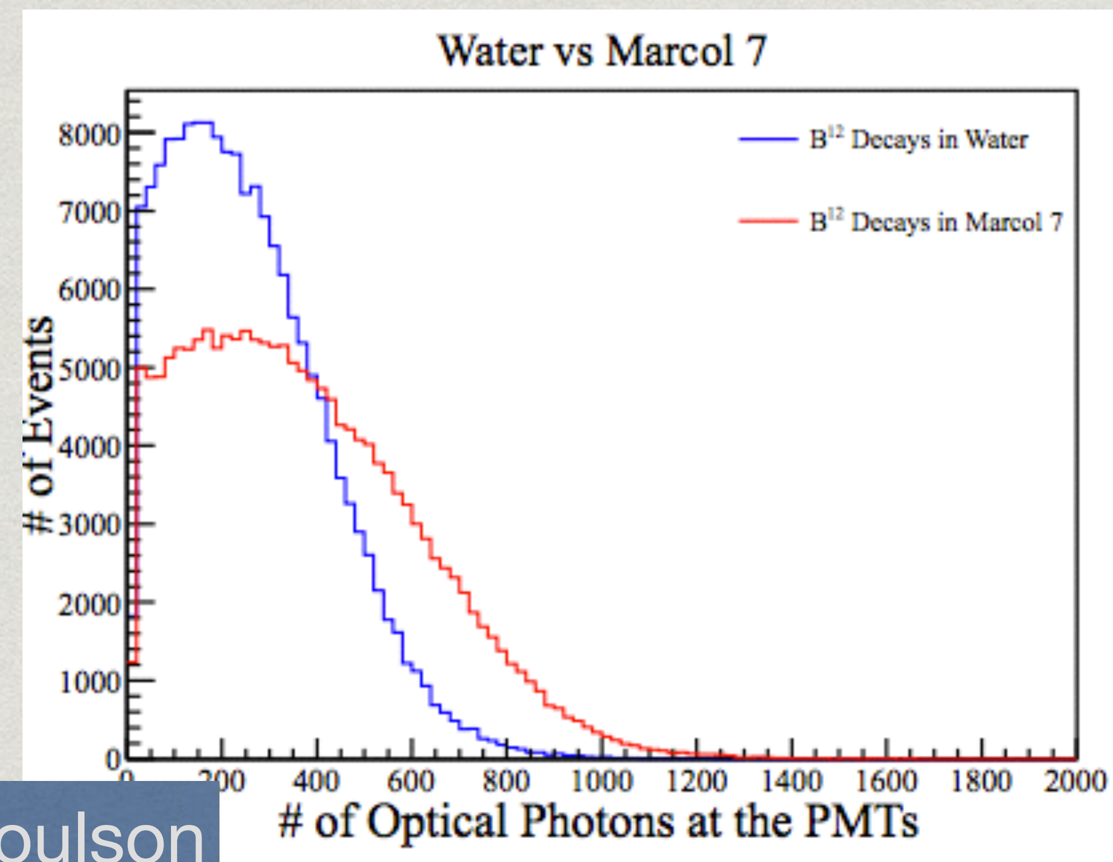
R&D Items: μ^- Detection

- Original water Cherenkov design only sensitive to μ^+
  - Shorter-lived stopped μ^- will be depleted while μ^+ rates are still very high
  - μ^- can be captured on carbon, giving ^{12}B
    - High-energy β with a 30 ms lifetime
    - If these decays can be detected (likely with separate signal processing), then the rate of stopping μ^- may also be measured.

R&D Items: μ⁻ Detection

- Original design called for water Cherenkov with external carbon boundary
  - Steel detector boundaries or graphite shield
- Simulations show that ^{12}B decays are much more readily detected if they originate in the inner detector



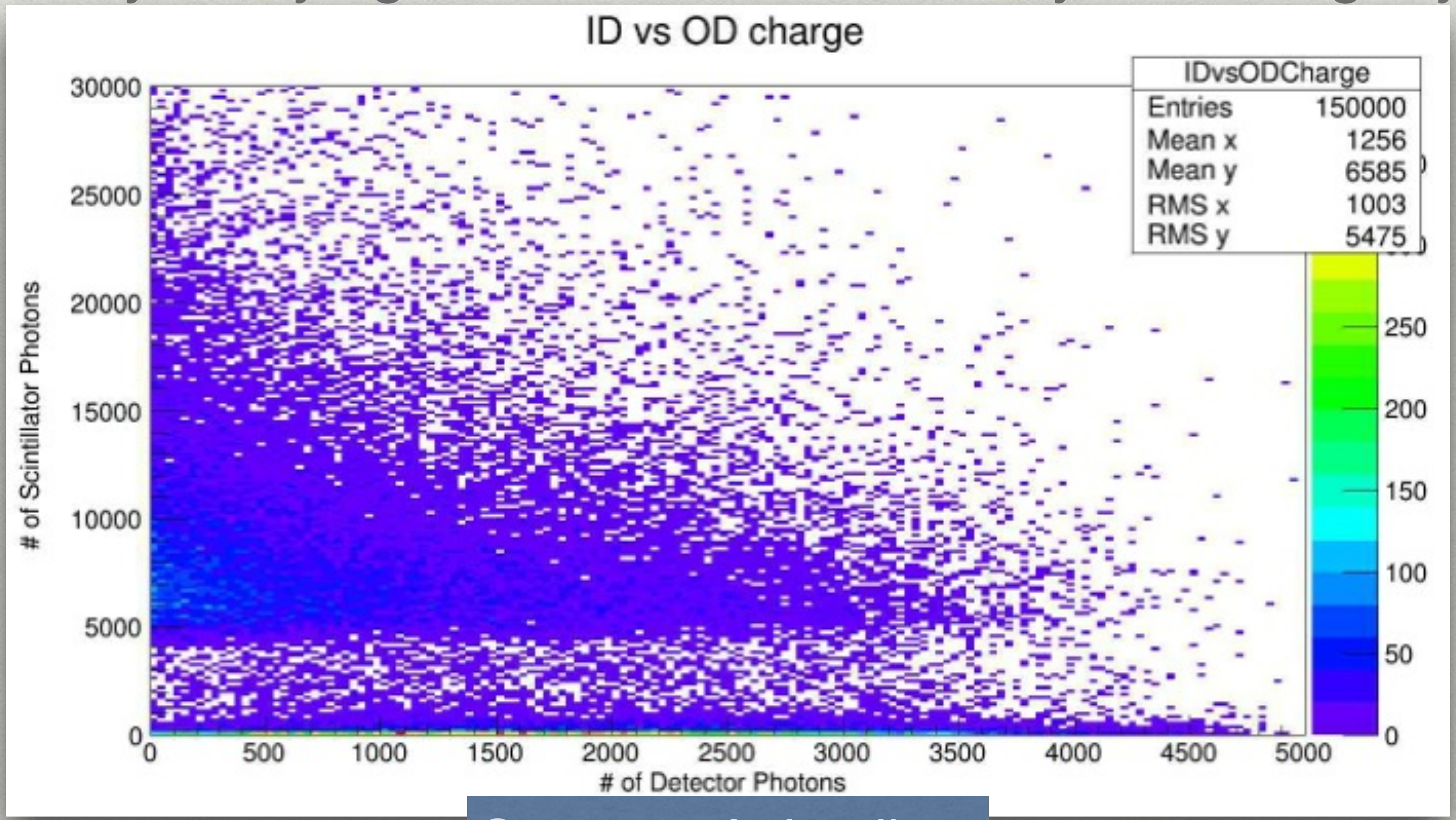


Courtesy D. Poulson

Solution: Replace water with mineral oil to produce ^{12}B in the ID volume

Simulations

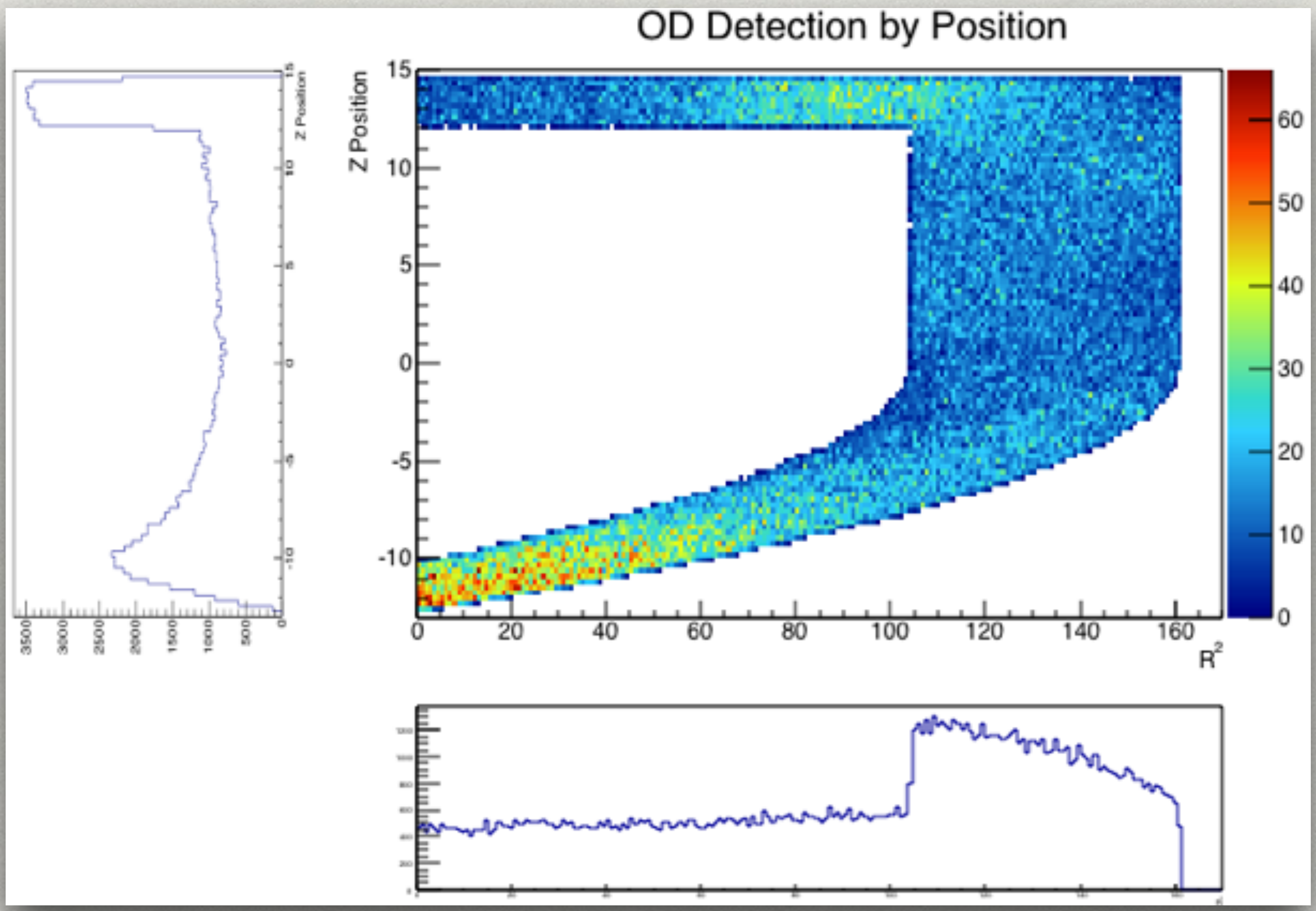
- Two students developing GEANT4 simulations at CU
- Effective modeling of signal/veto response, containment, &c.
- Currently studying how detector reflectivity affects light yield



Courtesy A. Loeliger

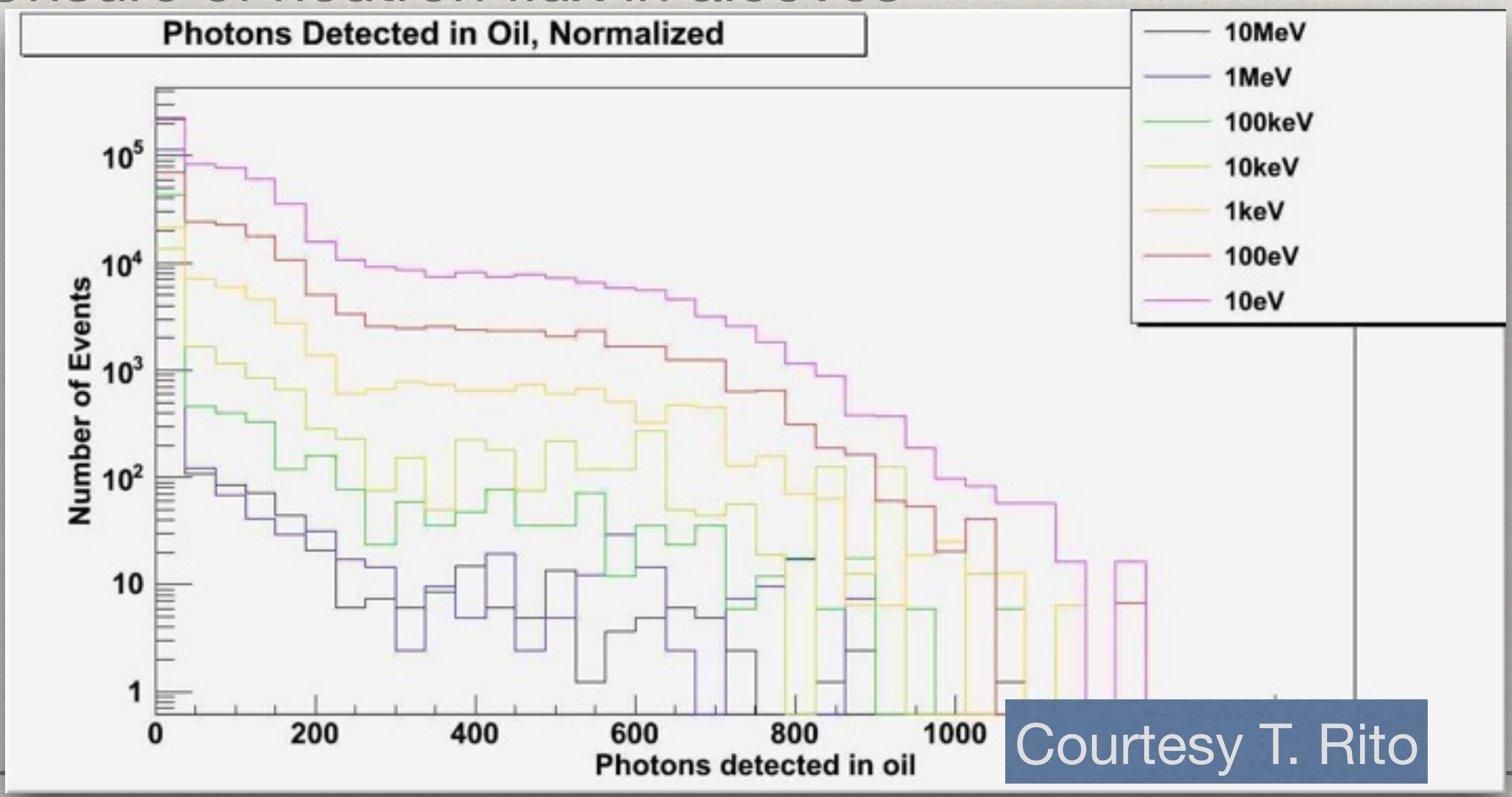
Simulations II

- Simulations have already led to several design changes, e.g.:
  - Replacement of water with mineral oil in main detector volume
  - Removal of WLS fibers (unnecessary given expected light yield)



Simulations III

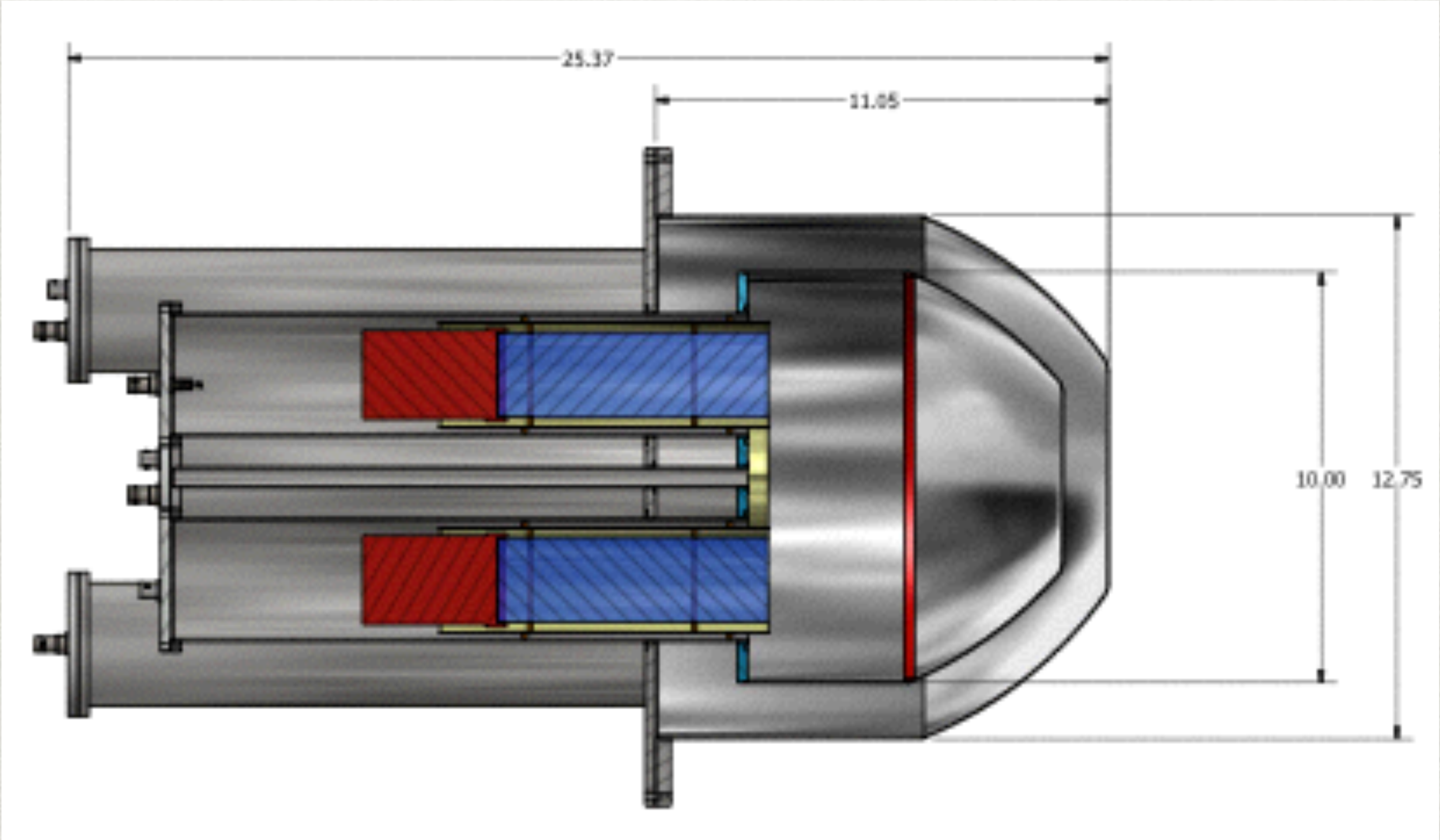
- Background considerations included in simulations
  - Neutrons incident on detector
  - Fast and thermal neutrons both considered
  - Unsure of neutron flux in alcoves



Courtesy T. Rito

Mechanical Status

- Coming to a conclusion on final prototype design with CU machine shop
- Some details to be worked out before we start cutting metal
  - Welding: need to ensure welder will fit where it needs to go
  - PMT + Base assembly has to fit inside tubes

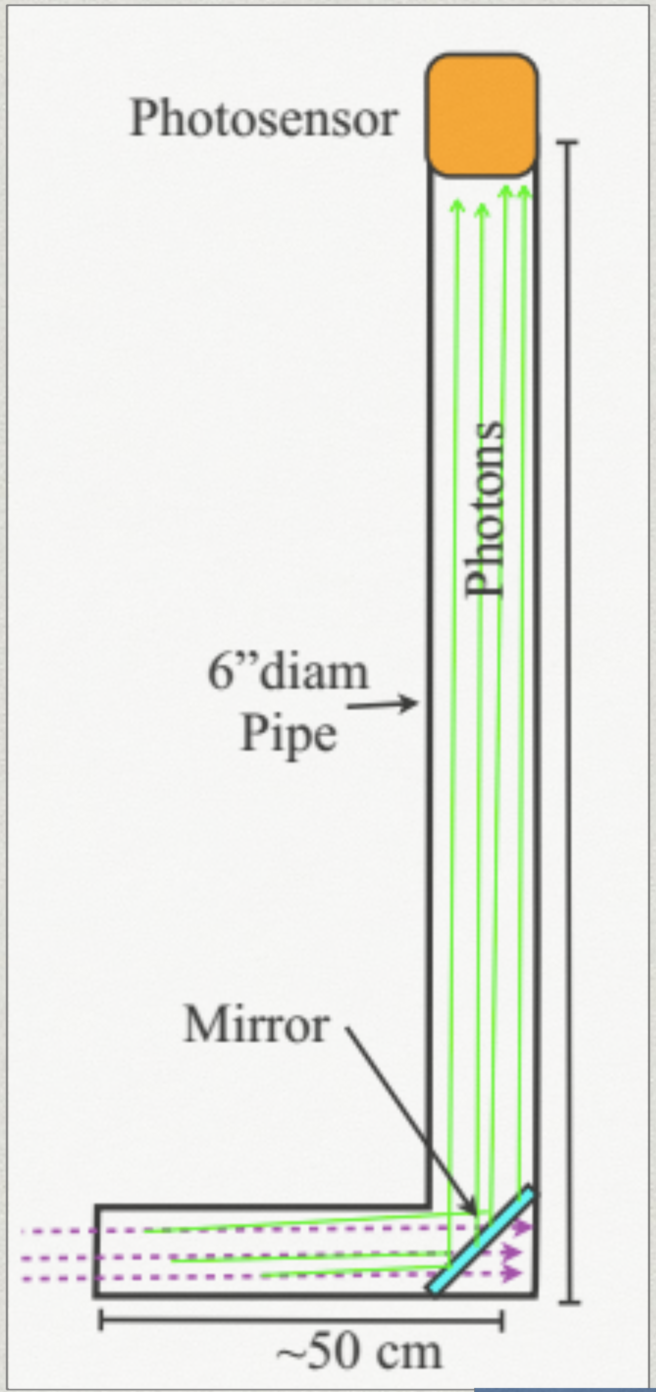


SMM Plans/R&D

- Plan to build prototype at Boulder - Fall 2015
  - Prototype testing to be carried out using cosmics at CU
- After that - Deployment in NuMI beam

- Primitive prototype currently exists in NuMI Alcove
  - …but has not produced much useful data

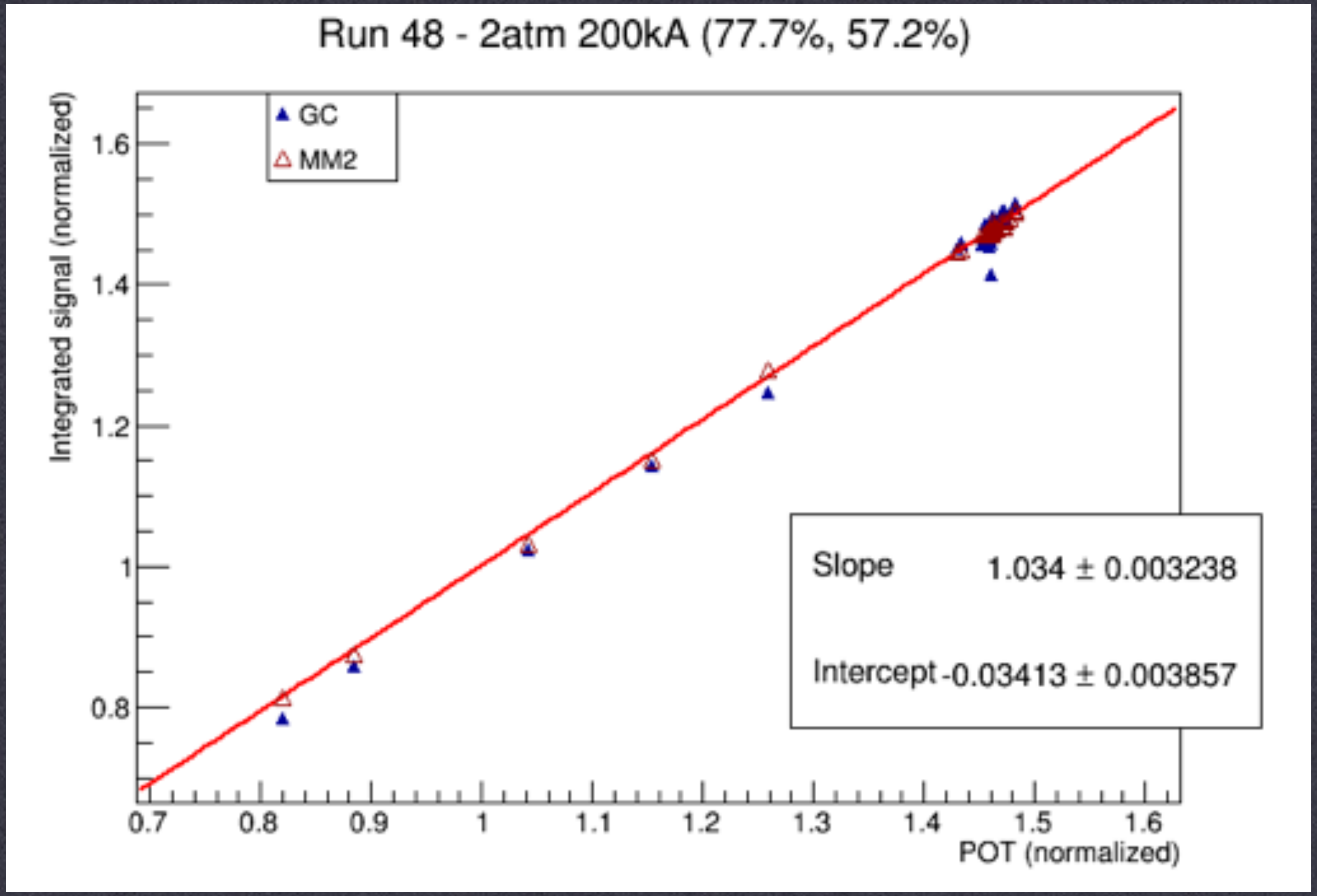
Gas Cherenkov Detector

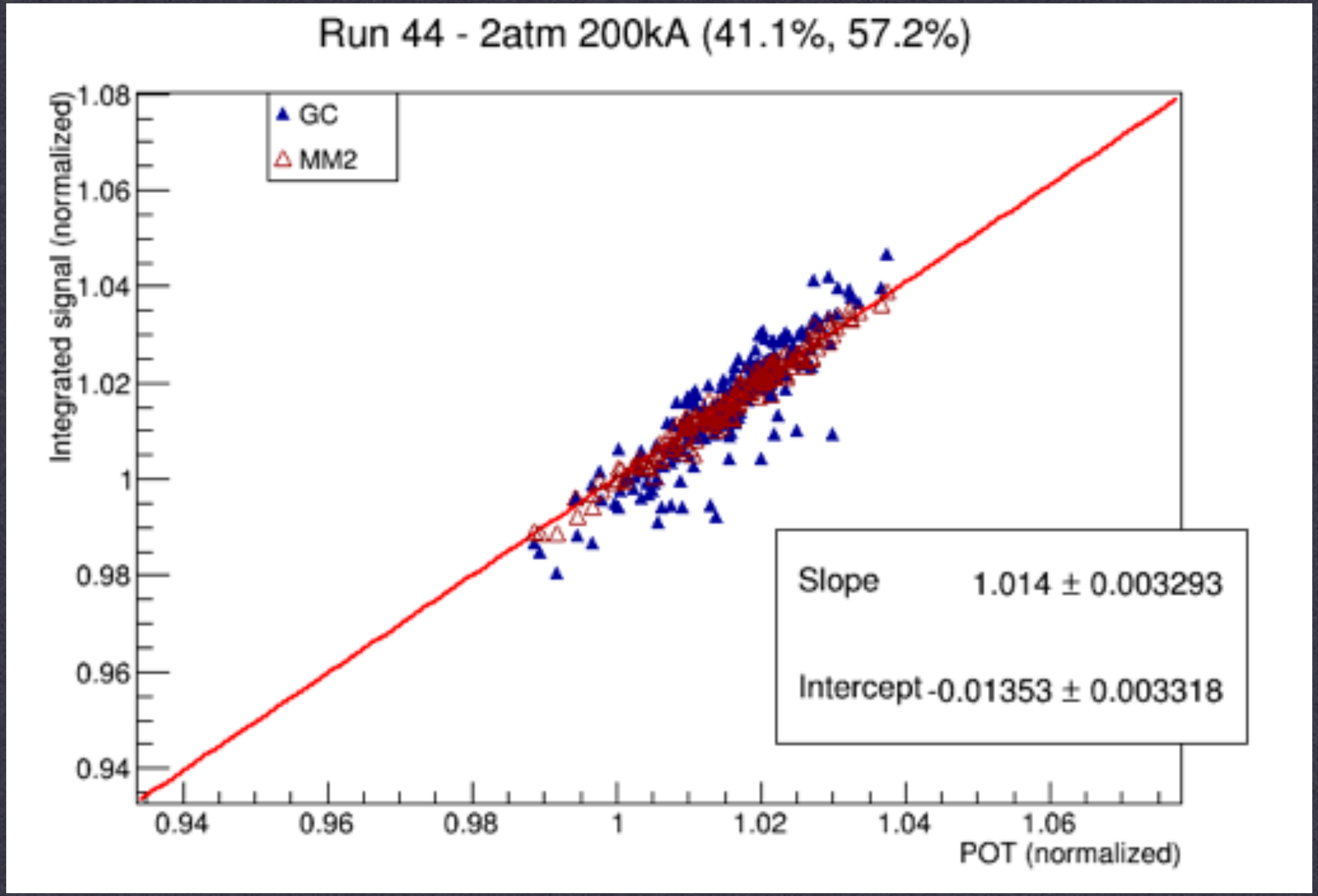


- Vacuum chamber filled with argon gas
- A flat mirror directs Cherenkov light towards photodetector
- Variable index of refraction from the pressure of the chamber gas
- Adjustable orientation

Slide content Courtesy P. Madigan

NuMI Beamline detector showing accurate signal - POT correlation





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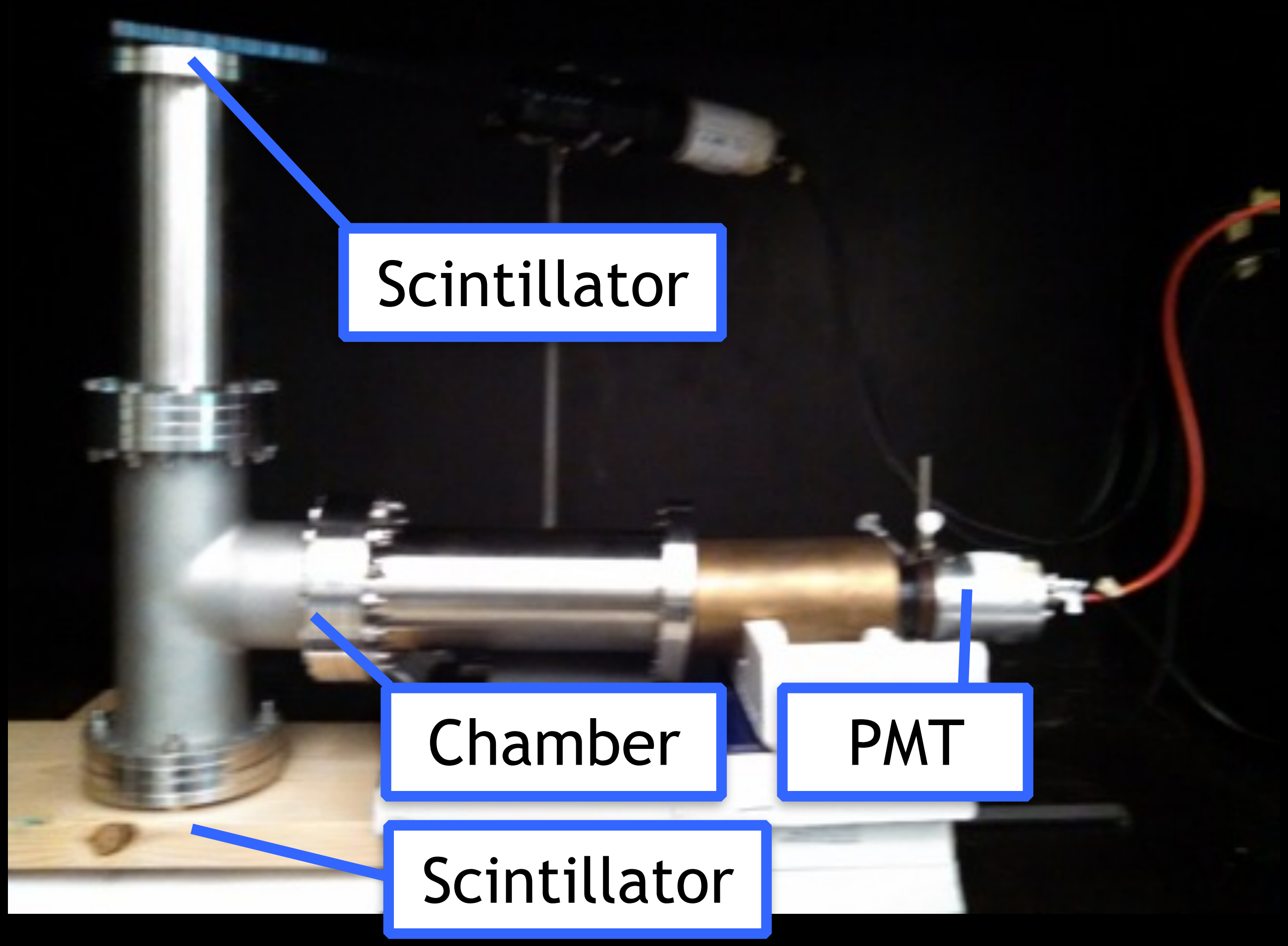
Cosmic muon detection



- Triggered by coincidence of the two scintillators
- Raw PMT output is recorded by an oscilloscope

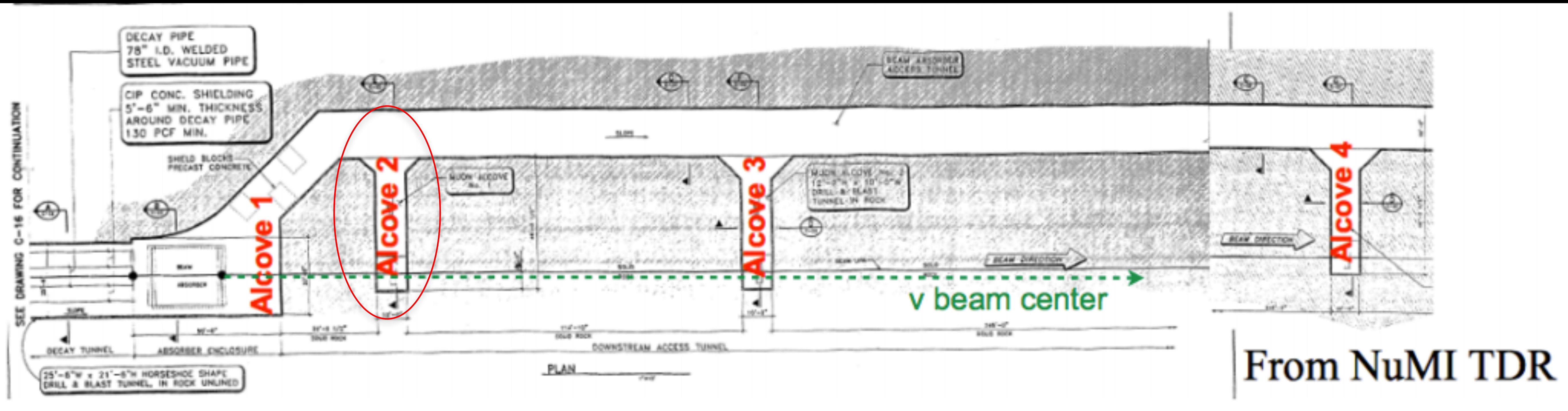
- Analysis program using both a Gaussian fit and oscilloscope output
- Generates a tree with information on the timing, integral, and peak of each event

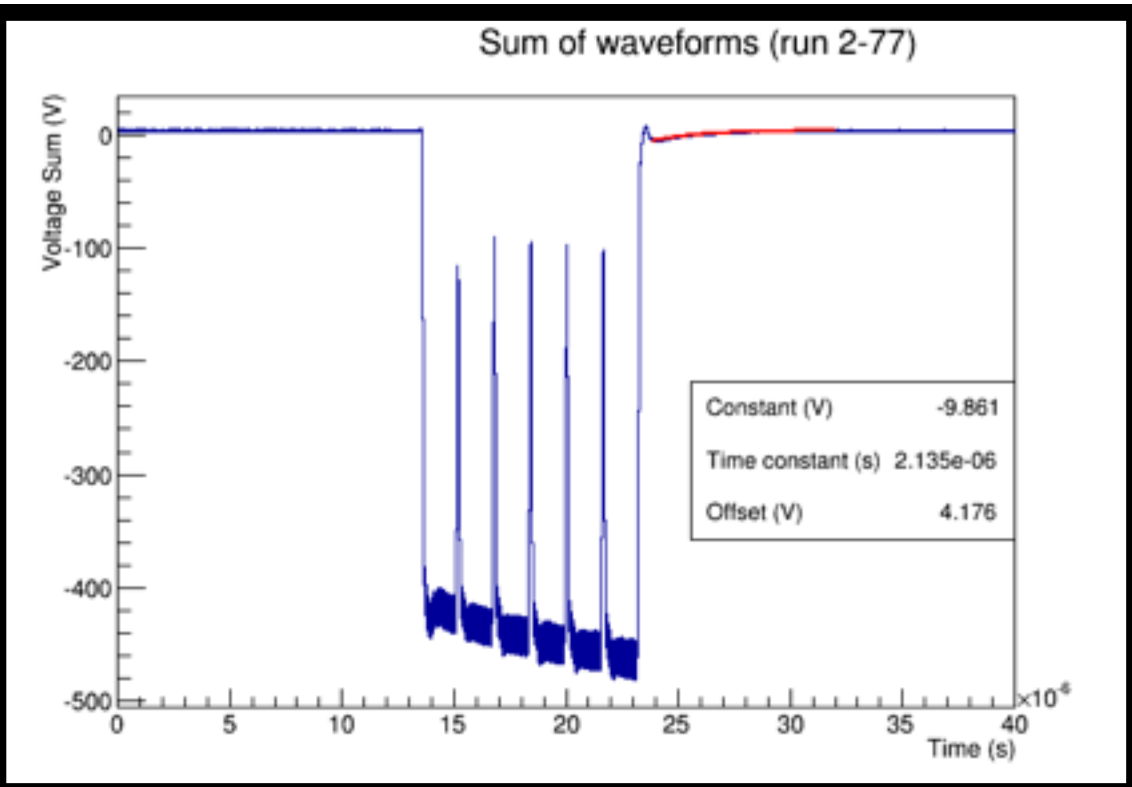
Slide Courtesy P. Madigan

Conclusions

- Two complementary systems being developed for muon monitoring after the absorber
- Stopped muon monitor prototype to be built soon
  - Cosmic ray testing at CU
  - Followed by testing in NuMI beam
- Gas Cherenkov prototype already running
- Currently also testing on cosmics

NuMI tests





Prototype already in NuMI Alcove 2

Exponential fit of decay suggests muon decays

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