Overview and Update on Muon Monitors

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Muon Monitors Working Group

- Conveners: Geoff Mills, Jeremy Lopez
- Goals:
  1) Evaluate requirements for neutrino beam monitoring and potential for neutrino flux, determine any limitations from the absorber design
  2) Document the current design and ongoing work in detector development and tests
  3) Simulate the response in the LBNF beamline and evaluate the muon monitoring system's performance

Personnel Include: Jan Boissevain, Charles Lane, Zachary Liptak, Jeremy Lopez, Alysia Marino, Geoff Mills, Eric Zimmerman,
CU Undergrads: Branton Demoss, Kerrie Dochen, Andrew Loeliger, Peter Madigan

Primary Goals of Muon Monitors

1) Determine absolute muon flux > 6 GeV (nu energy > 1.6 GeV) to 5% accuracy
2) Measure beam direction to within 0.2 mrad (i.e. beam position downstream of absorber to within 5 cm)

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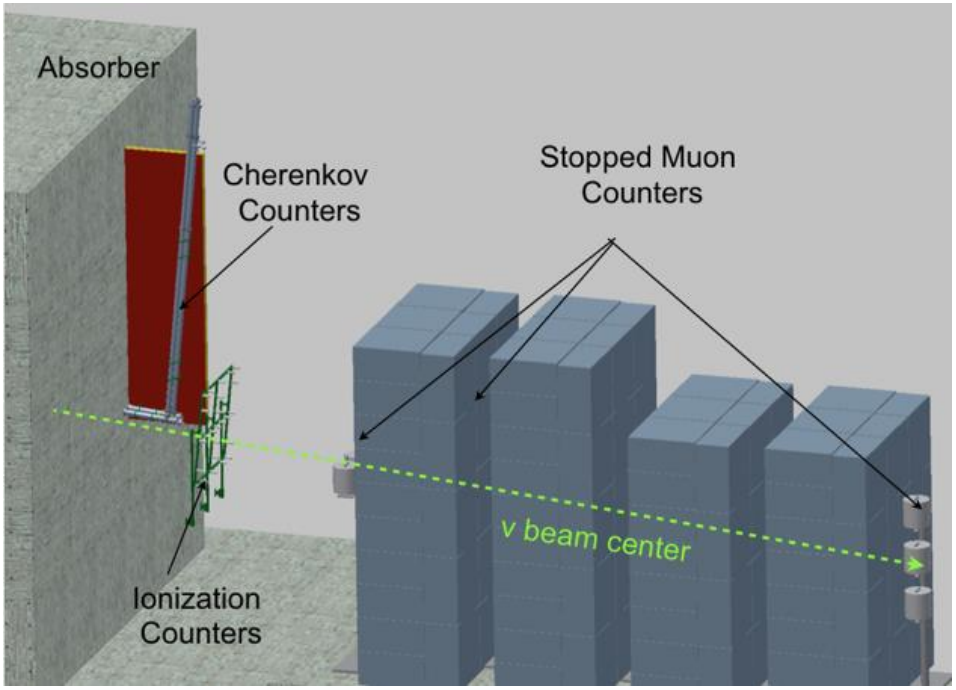
Overview of Muon Monitors



Three Detector Types:

1) Ionization Counters
   - Measure Beam Position
   - Get total flux of charged particles exiting the absorber
2) Cherenkov Counters
   - Scan over different pressures/detector angles to build muon flux from threshold measurements
3) Stopped Muon Counters
   - Select flux at different positions/energies

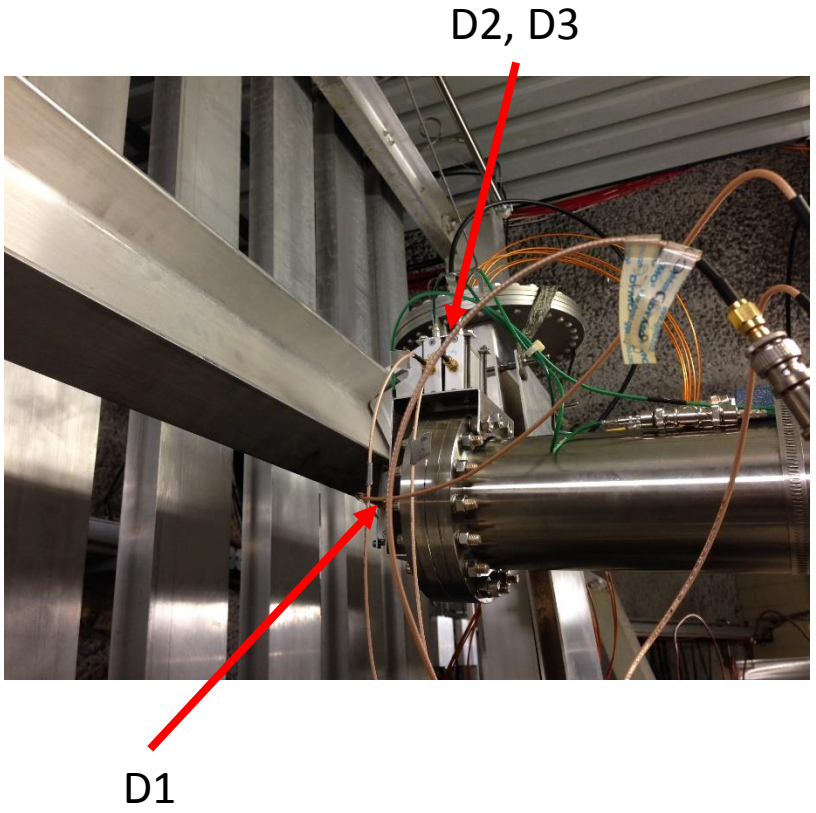
Ionization Counters

Likely Three Main Options: Diamonds, Silicon, Gas Ionization Counters

Diamond	Silicon	Gas
Pros: Fast signals, more rad hard than Si	Cheap, easy to use	Proven technology, rad hard (can replace gas), likely cheap
Cons: $$$, not much of a track record so far, less signal (high band gap), lifetime unknown	Not very rad hard: may degrade quickly, cost of replacement could add up if they need to be replaced often	Sensitive to ambient pressure, slow signal development

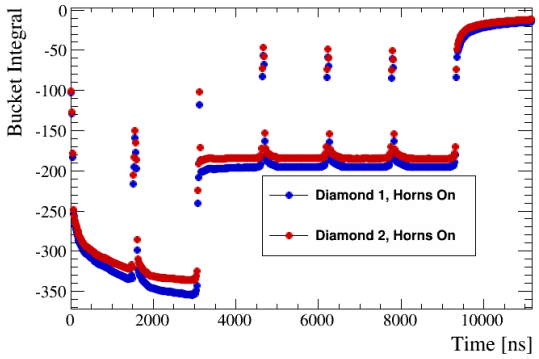
Current Ionization Counter Testing Hardware

- Have borrowed 3 pCVD diamond detectors previously used in CNGS beamline, installed in NuMI muon alcove 2
- Have purchased some bare diamonds & a silicon photodiode at CU for testing and evaluation



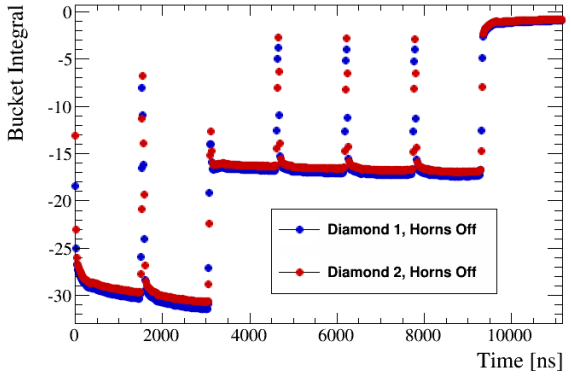
Some NuMI Results

Horn On

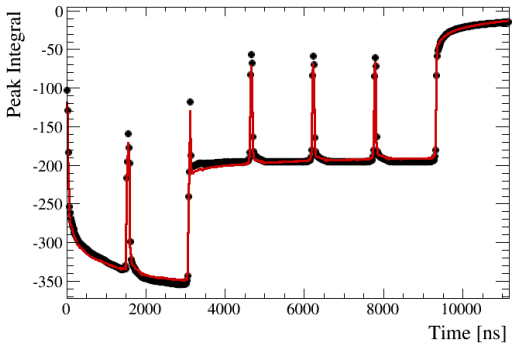


Average of Many Pulses
1 Point = Integral of One RF Bucket

Horn Off

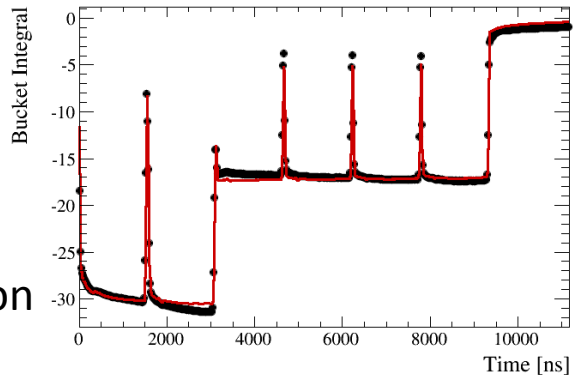


Best Fits
Hypothesis:



Muon signal follows:

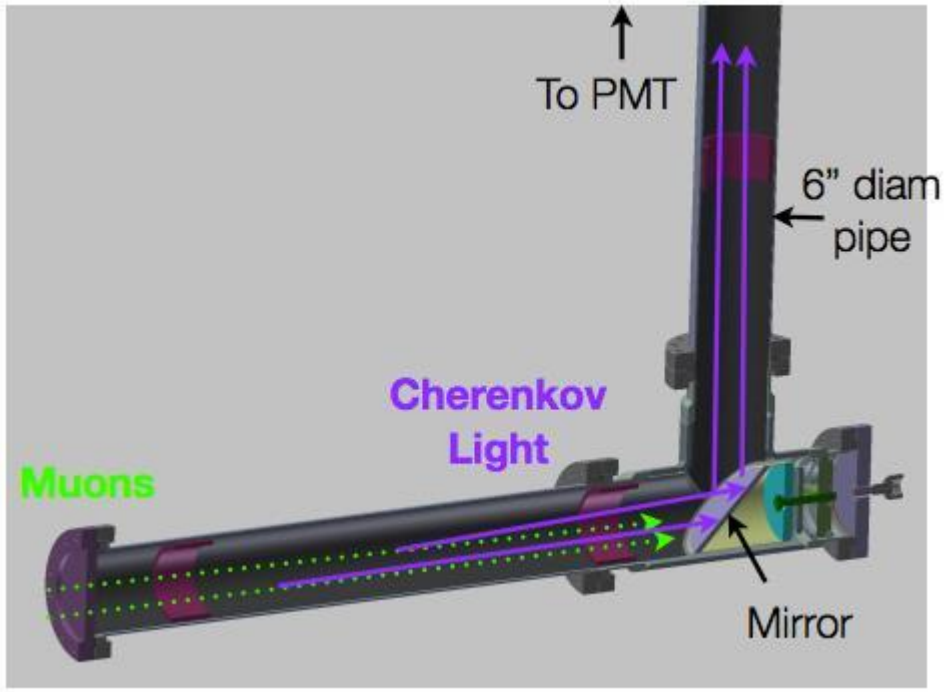
1) RWM (proton signal)
2) Muon decay in vacuum
3) Muon decay/capture in iron

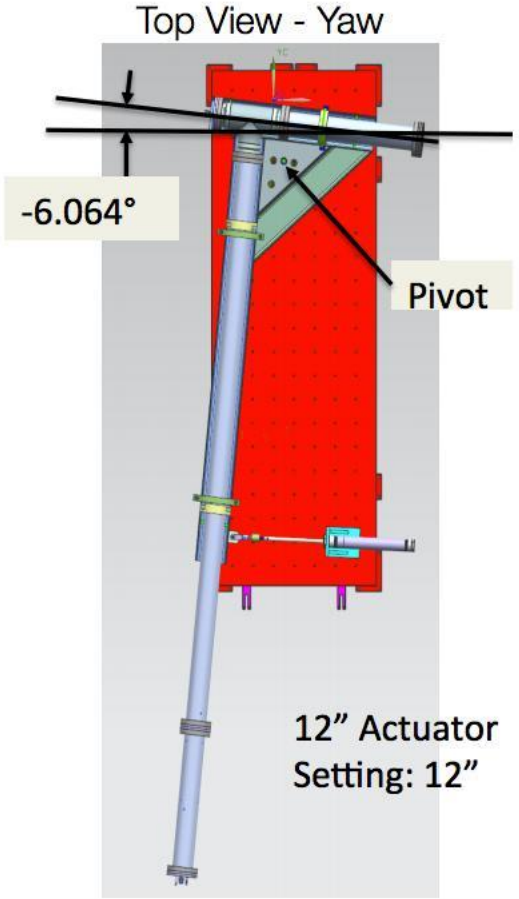


Works surprisingly well, but not perfect

Cherenkov Detector Prototype

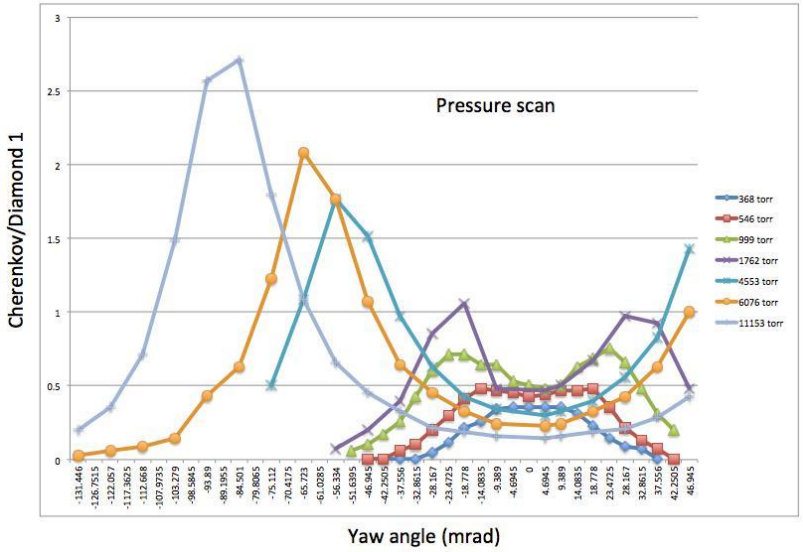
Prototype installed in NuMI muon alcove 2



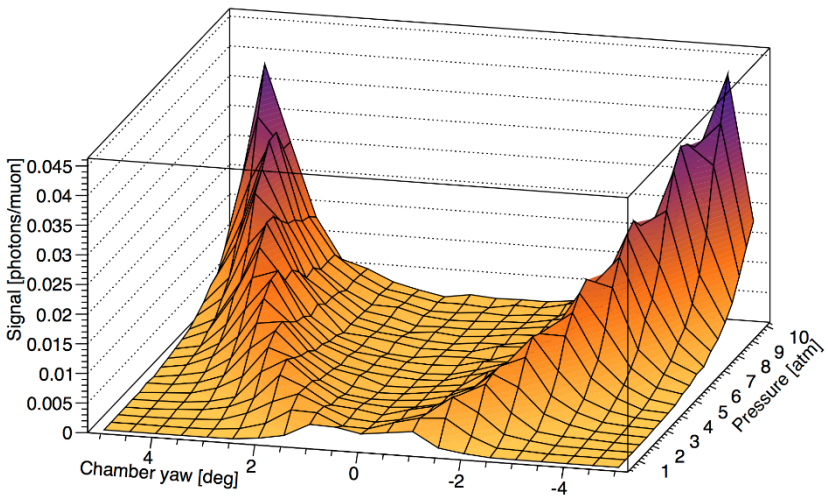


Qualitative Data/MC Comparison

NuMI Data, G. Mills



Simulation, P. Madigan

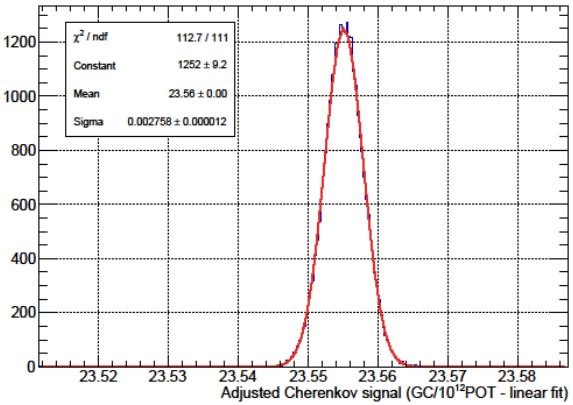


Scan over different pressures and yaws

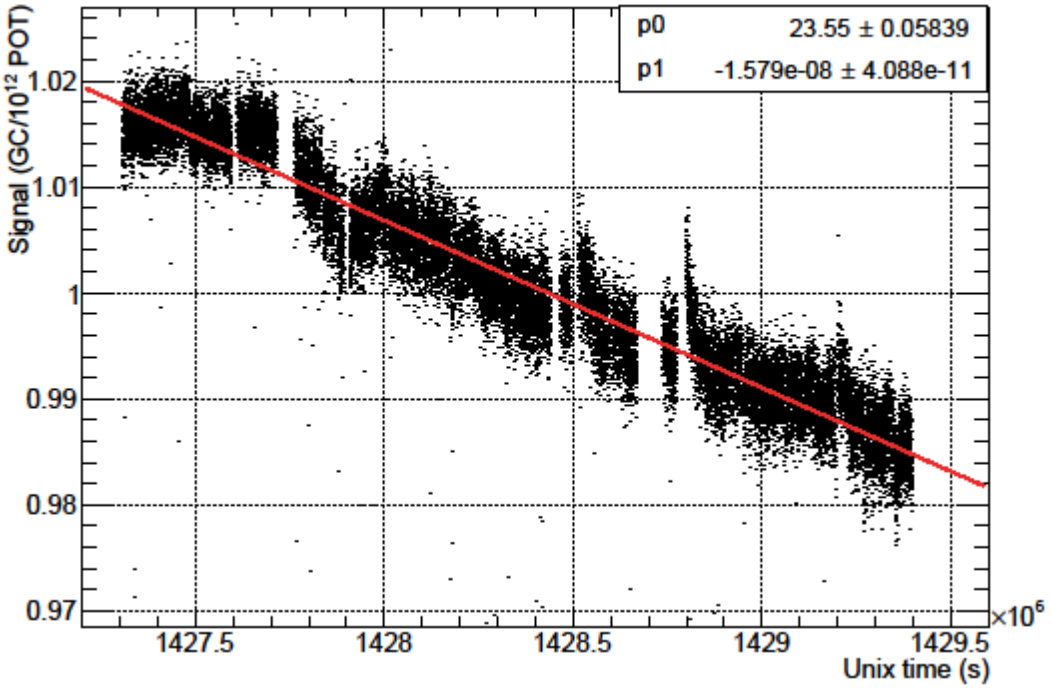
Get same qualitative features

Need to see how well we really understand the detector response in the NuMI beam

More NuMI Data

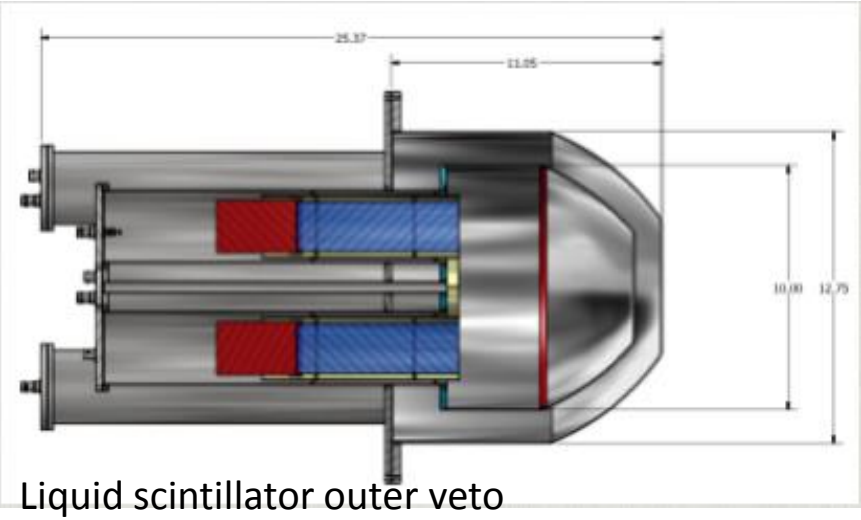


Otherwise, signal very stable



Signal Drops by ~1% over ~10 days. Why?

Stopped Muon Counters



Liquid scintillator outer veto
Inner detector measures Cherenkov radiation in non-scintillating mineral oil

Commissioning an initial prototype at CU. Will look at cosmics before moving detector to FNAL

Gated base being designed at Drexel (needed to use in the NuMI beamline)

Simulation Work

- Using G4LBNE to determine gating requirements for stopped muon detectors and getting muon energy spectrum
- Simulating Cherenkov detector response to try to understand scans over detector parameters
- Starting to work on simulating NuMI flux in alcove 2 to better understand diamond detectors

There's Still More

- Muon flux originating in absorber not necessarily trivially small (see talk by P. Lebrun during the Sept. meeting)
  - Could complicate extrapolation of muon flux to neutrino flux
  - Maybe would also affect the beam direction measurement
  - Need full simulation of flux seen by the muon detectors to see how the beamline design affects this
  - Could also probably use simulated estimate of lifetime of solid state detectors (although an actual measurement is better)

Conclusions and Outlook

- Muon monitoring detector development is making steady progress
  - One Cherenkov detector prototype and 3 diamond detectors installed in NuMI muon alcove 2
  - One stopped muon counter prototype built, will start testing in Boulder soon before moving to the NuMI beamline
  - Biggest questions with hardware are how long the detectors will last without repairs/replacement and how stable they are in an actual beam
- Also working on various simulations both to support the tests in the NuMI beamline and to estimate what is expected in LBNF
  - Big question here is probably how the absorber design affects the muon measurements