LBNF Ionization Detector Muon Monitors

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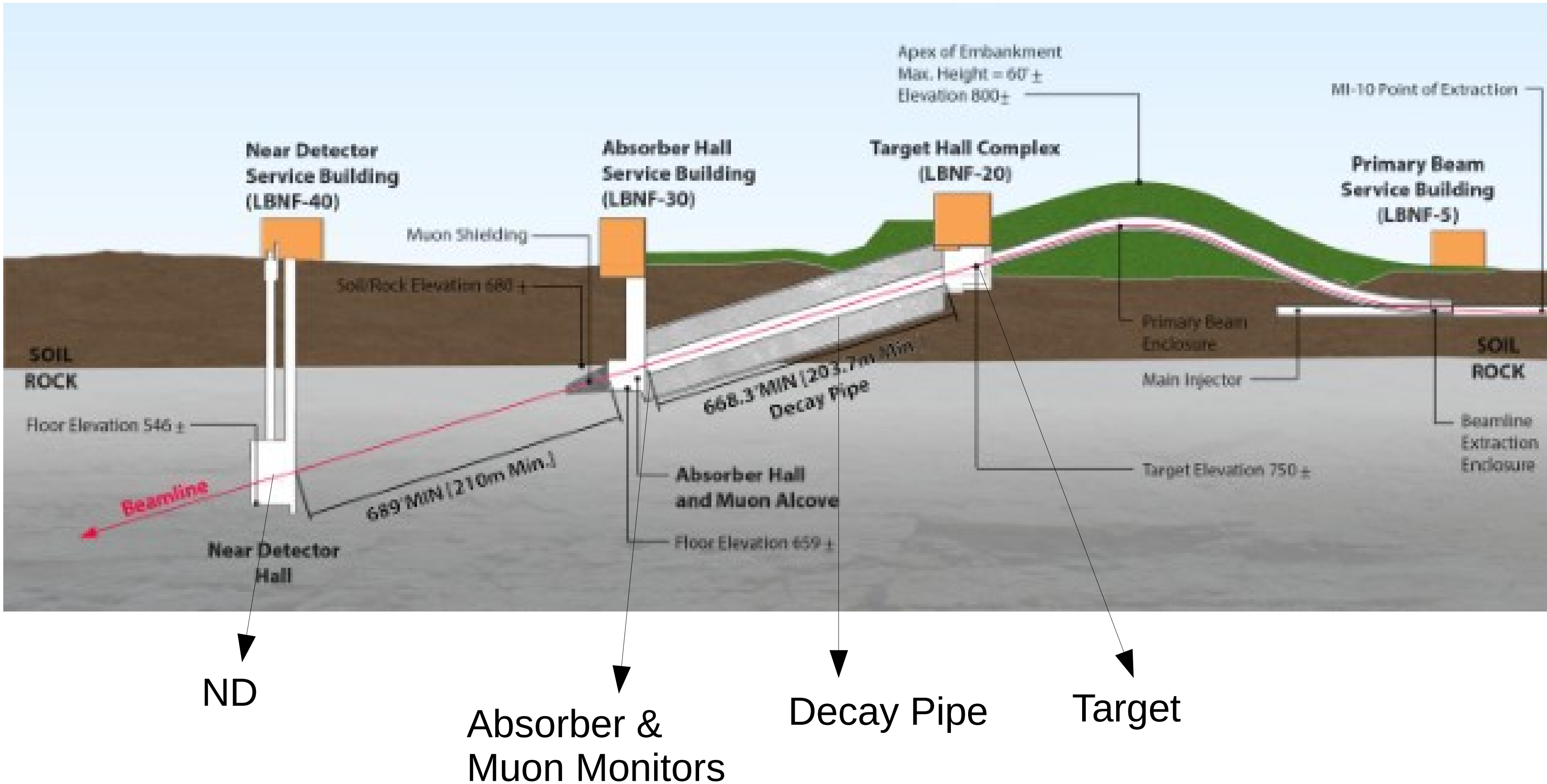
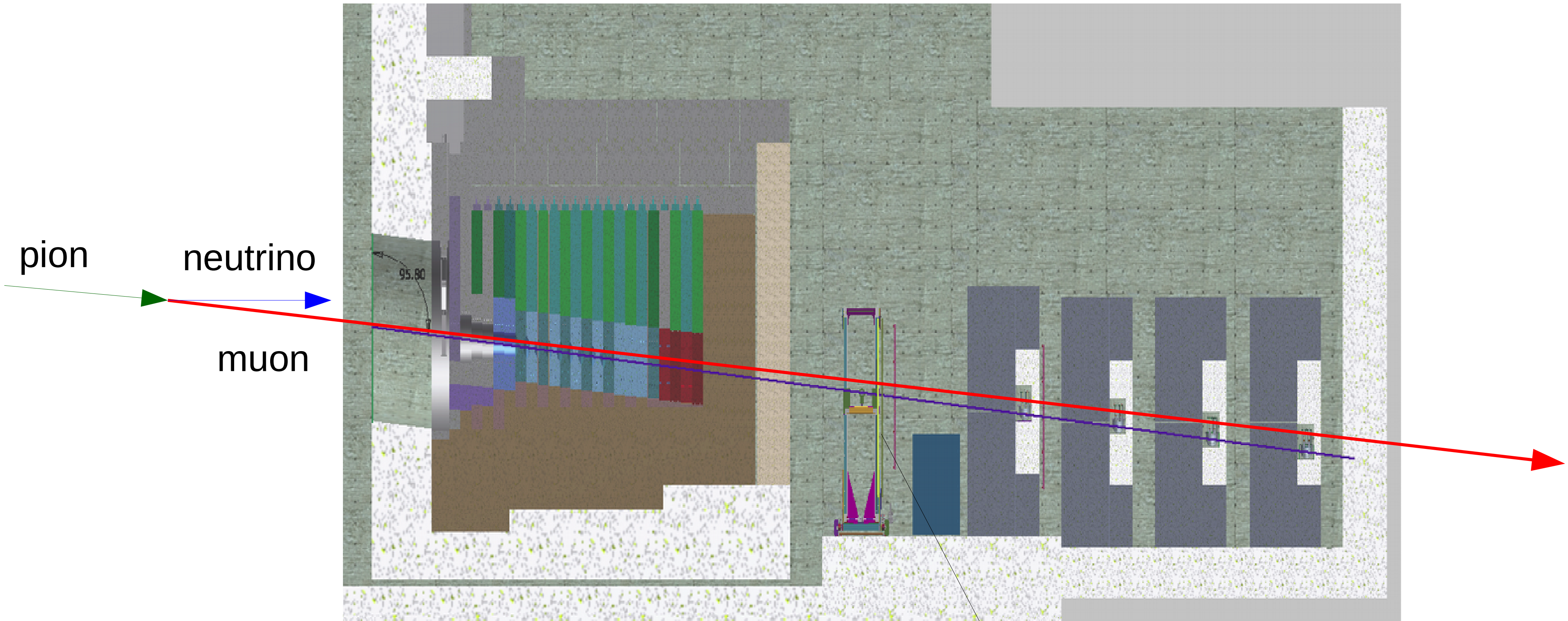
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

LBNF Beamline Overview



Monitors downstream of absorber, upstream of ND
Basically unlimited statistics. Measurements limited by:
1) Detector performance
2) Absorber geometry (energy threshold, profile shaping, etc)

Muon Measurements



Ionization detector array

Reference design:

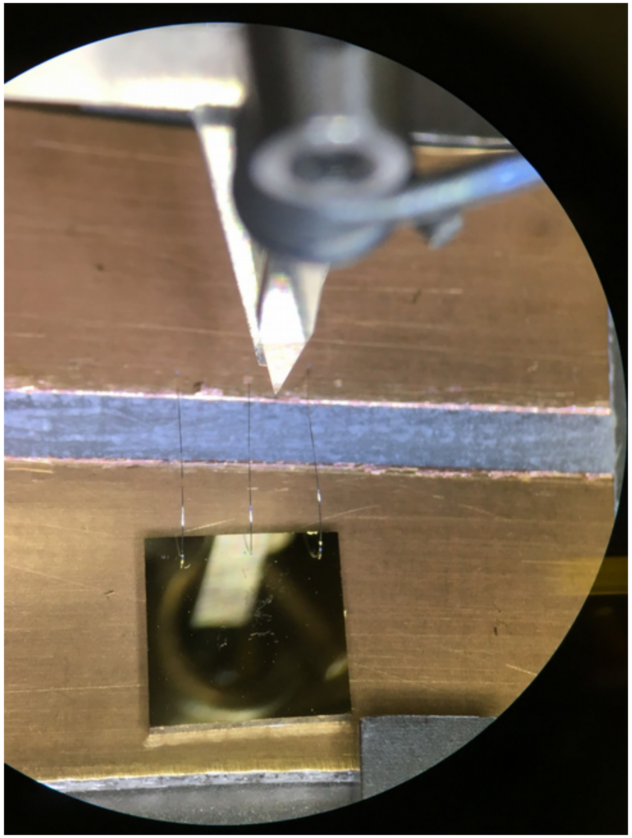
- 1 large muon alcove
- A single station for ionization detectors
- Get additional info from other detector types

Possible Technologies: Gas Ionization Counters

- Used in T2K, NuMI, CNGS beamlines
- Simple design (parallel plates with voltage applied)
- Reliable, don't age much
- Gas needs to be refilled
- Slow signal development – not great for timing or studying beam substructure

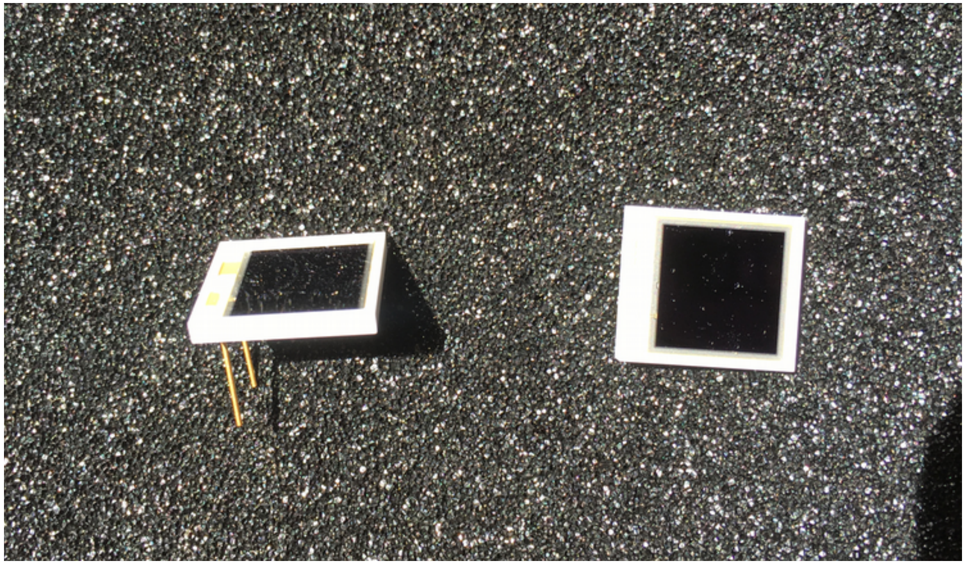
Possible Technologies: Diamond Detectors

- Have been used in T2K, CNGS beamlines but not in main muon monitor array
- Very fast signals – good timing
- May be less susceptible to pileup
- More rad hard than other solid-state detectors
- Very expensive – can save some money by producing detectors ourselves



Possible Technologies: Silicon Photodiodes

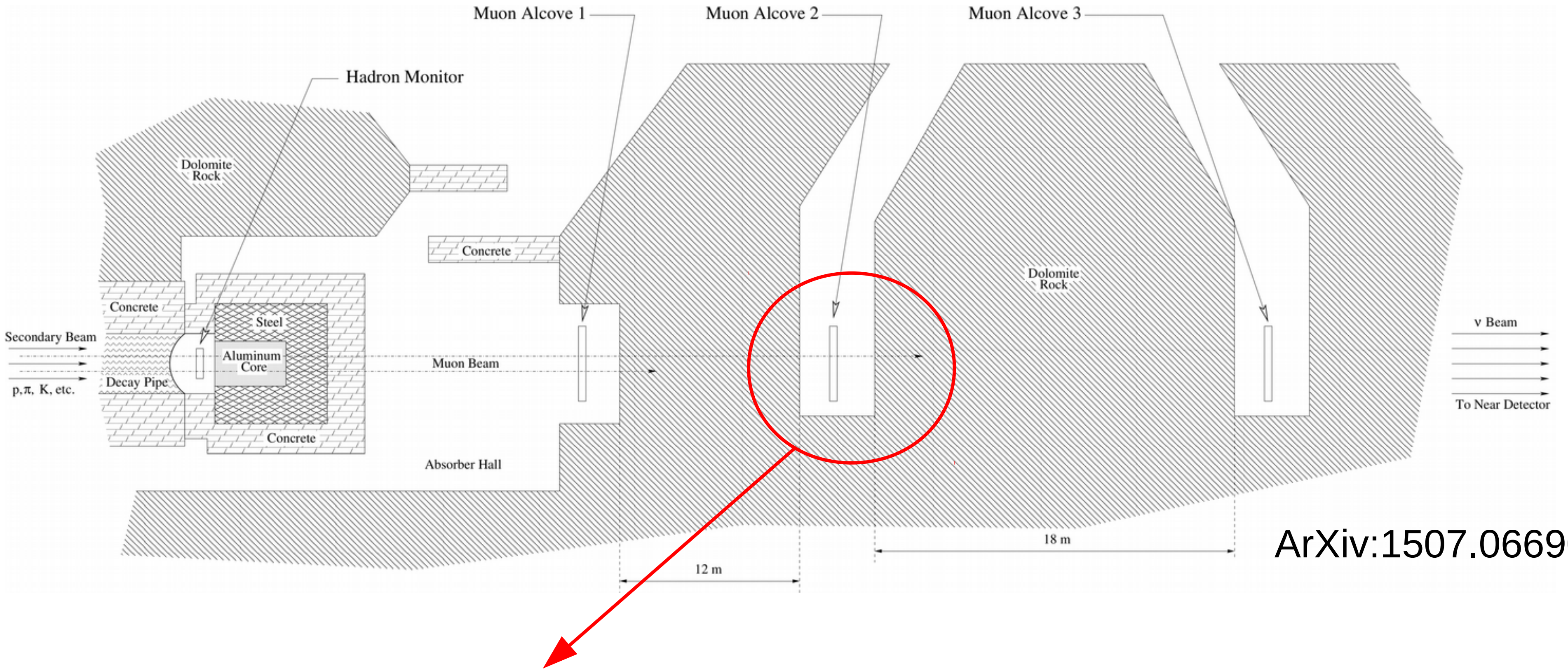
- Used in T2K beamline
- Have many of the same advantages as diamond
- Need to be replaced fairly often
- Commercial device
- Low cost



LBNF vs Other Beamlines

- 12.5 x 10^{12} POT / bunch, 6 bunches / spill
- Muon rate in alcove ~ 10x NuMI alcove 1 and 2x T2K (at design power)
  - Detectors must deal with harsher environment, larger signals
  - How will this affect signal linearity?
  - How long will detectors last?

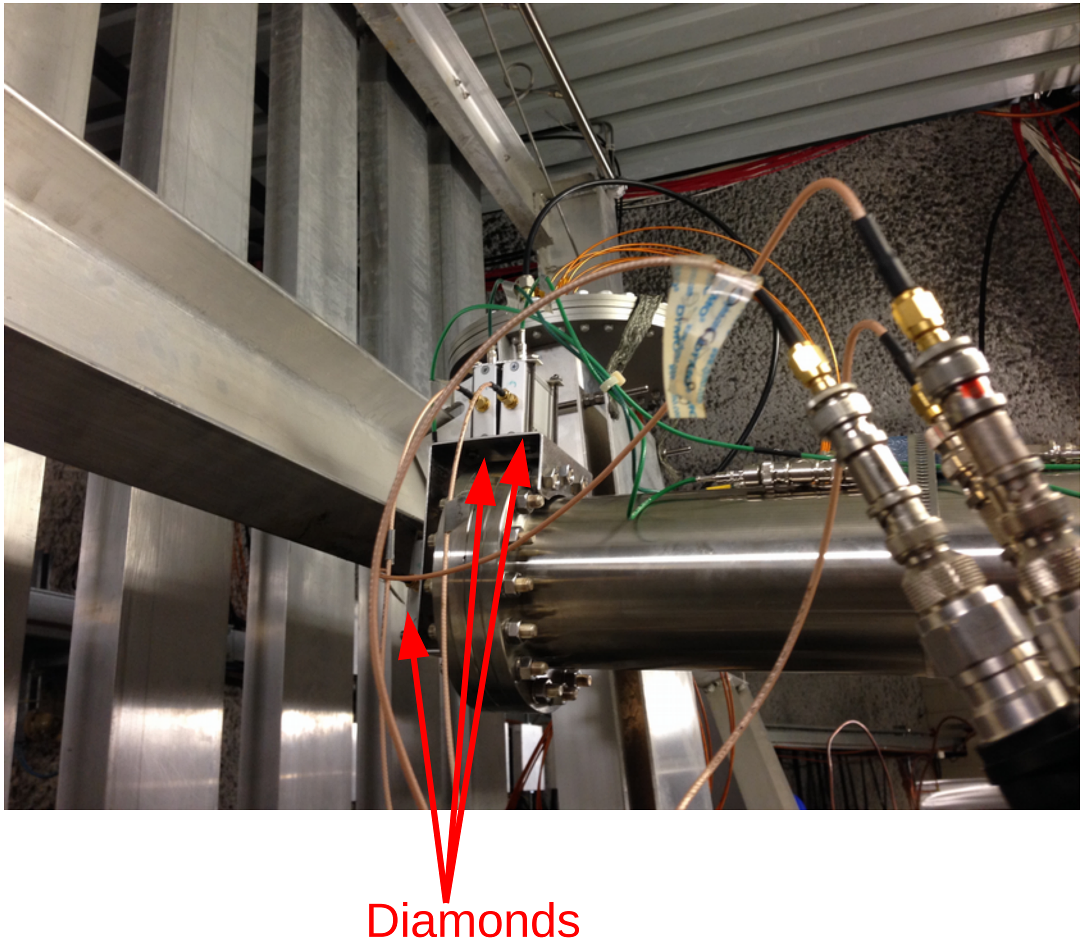
Tests in NuMI Alcove



ArXiv:1507.06690v2

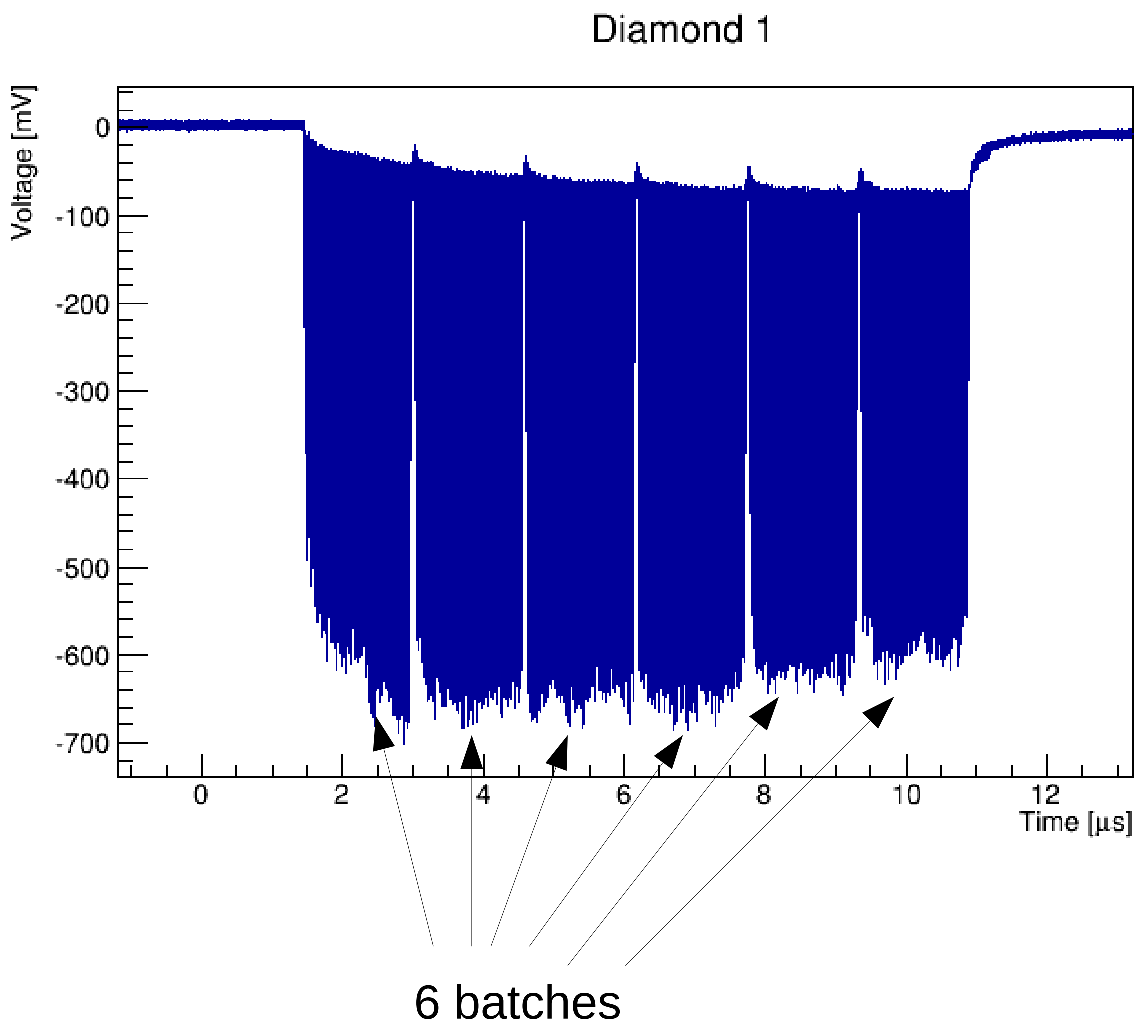
Placed detectors in alcove 2
12 m or rock behind hadron absorber
Muon rate ~ 1/4 that of alcove 1

Diamonds in Alcove 2

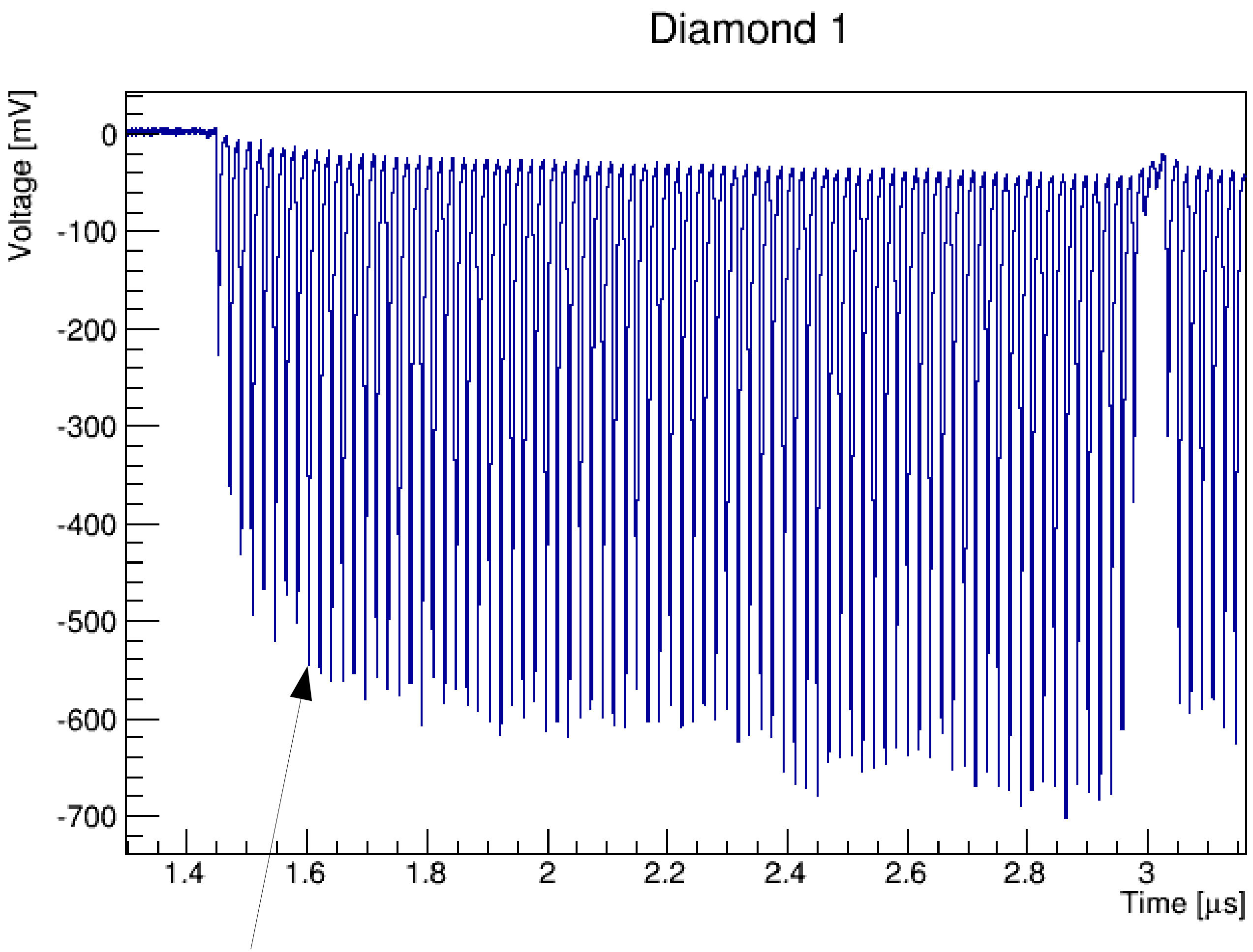


- 3 diamonds placed behind alcove 2 muon monitor
- Cividec detectors, previously used in CNGS
- Data taken from Spring 2015 until present (work ongoing)

Diamond Detector Signal



Zoom in on Signal

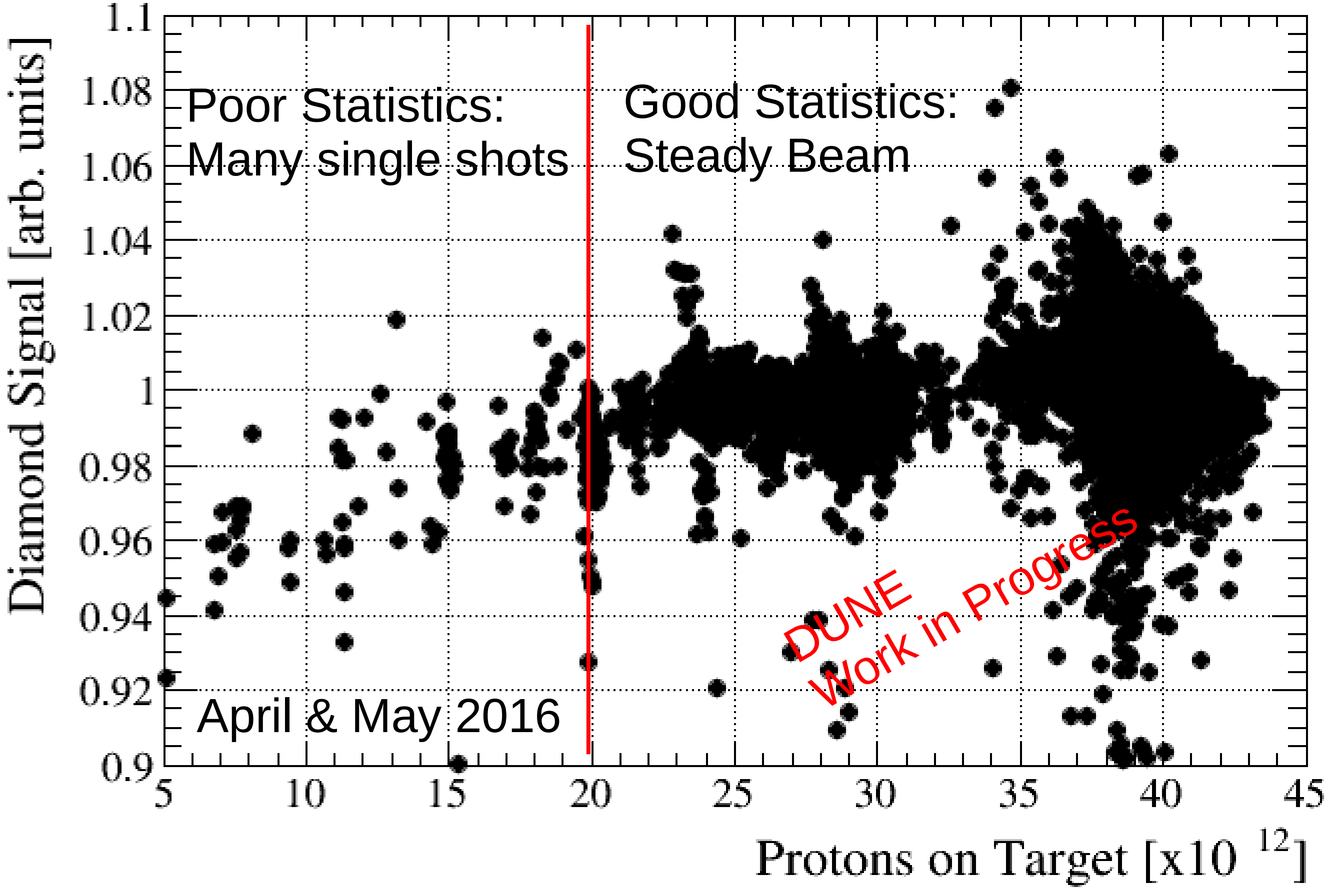


53 MHz bunches

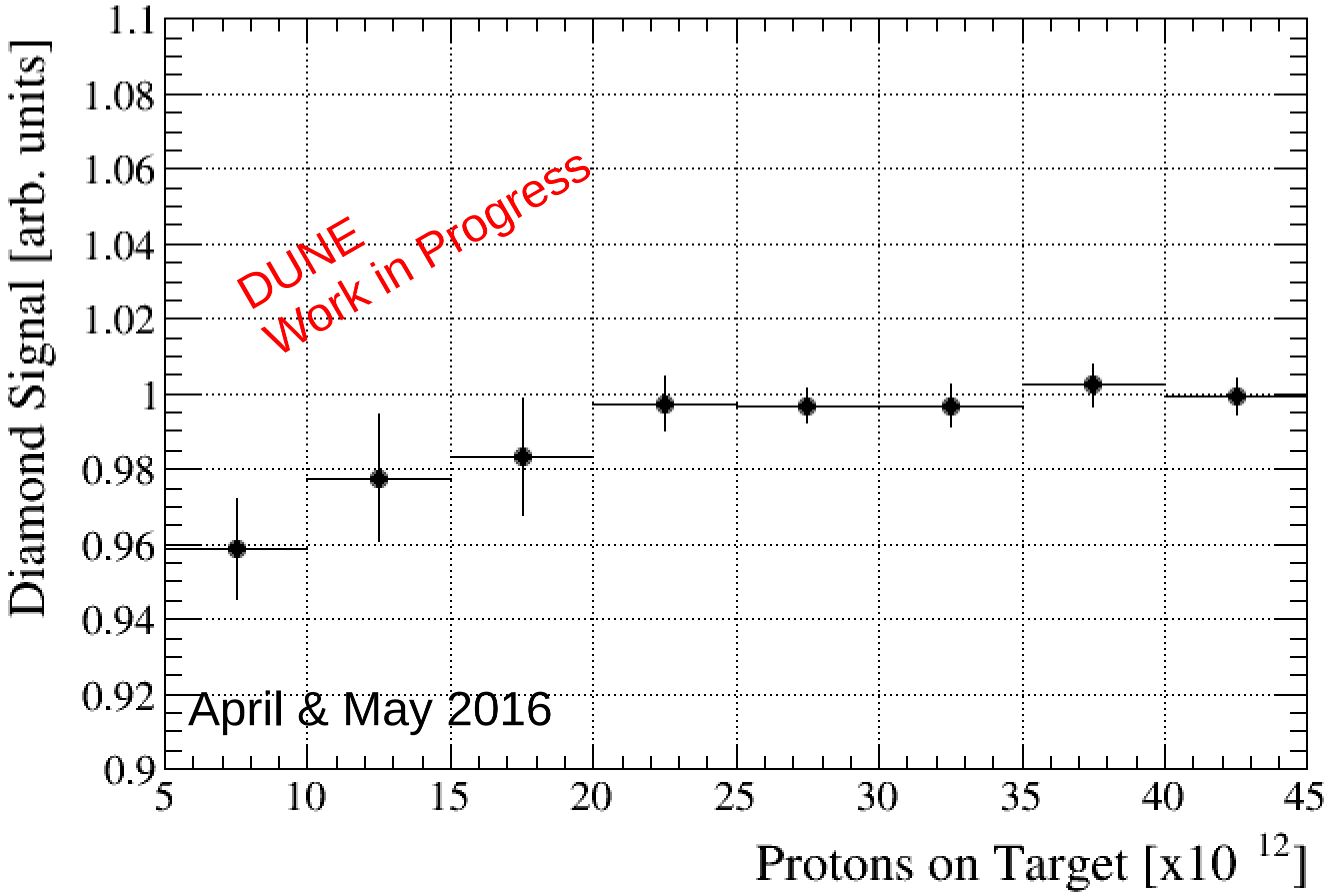
Some Initial Results

- All work in progress
  - Signal linearity
  - Resolution
  - Gain drift after detector HV turn on
  - Year-to-year gain variation
  - Signal shape

Signal Linearity

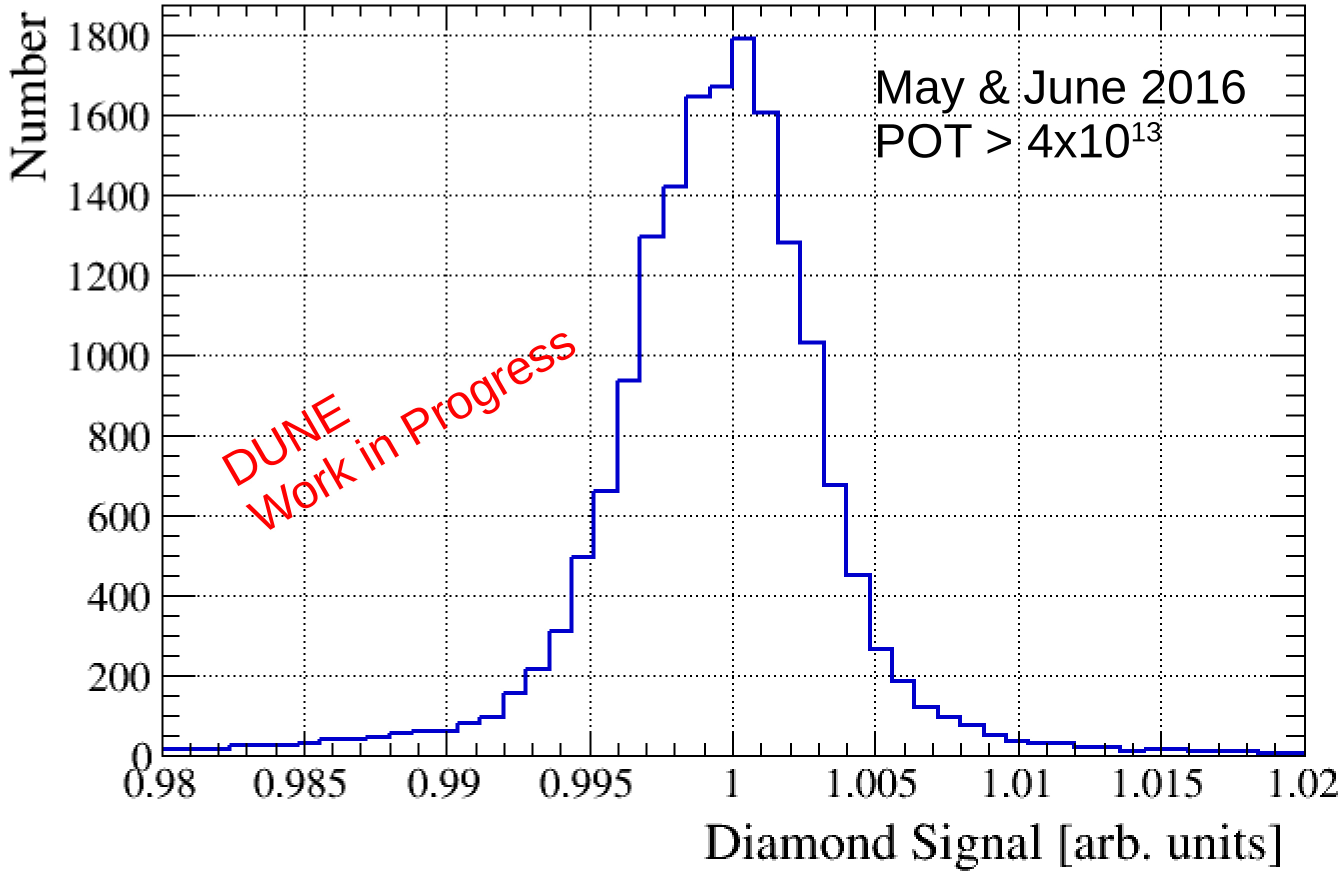


Signal Linearity



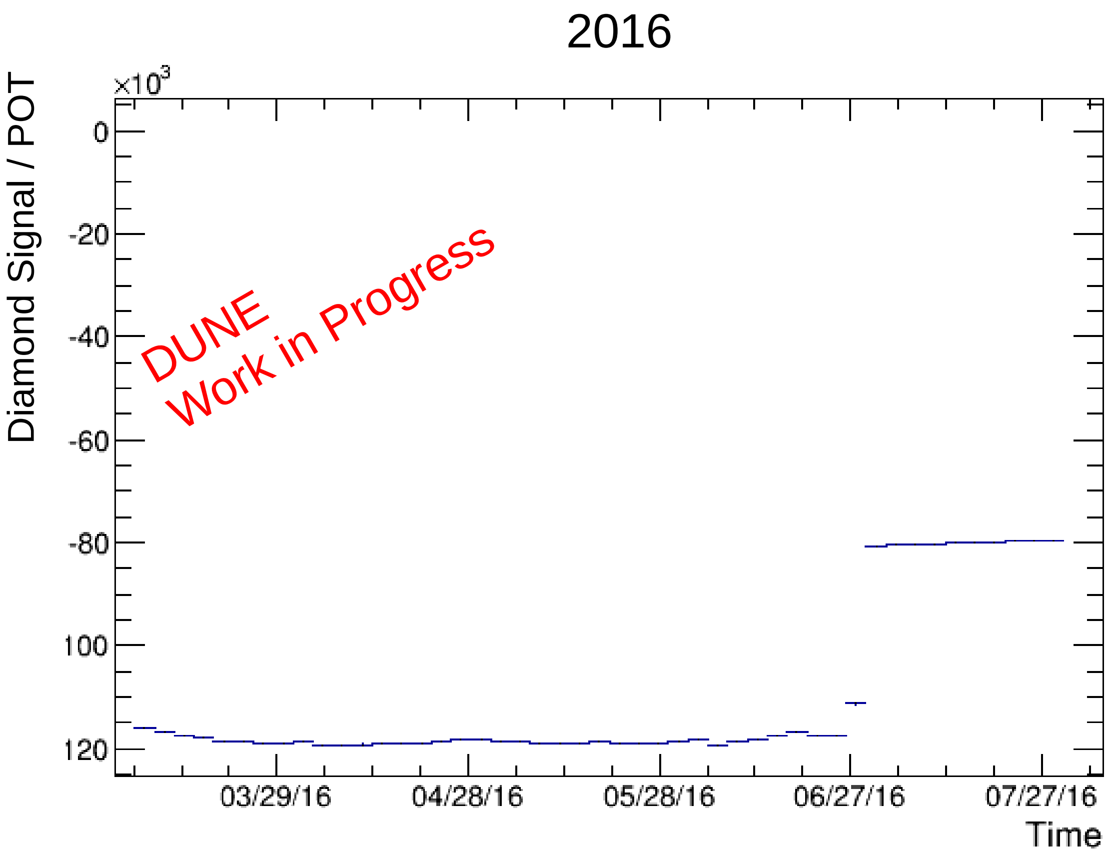
- Nonlinearity <1% in region with good statistics
- ~4% looking over full data set

Resolution



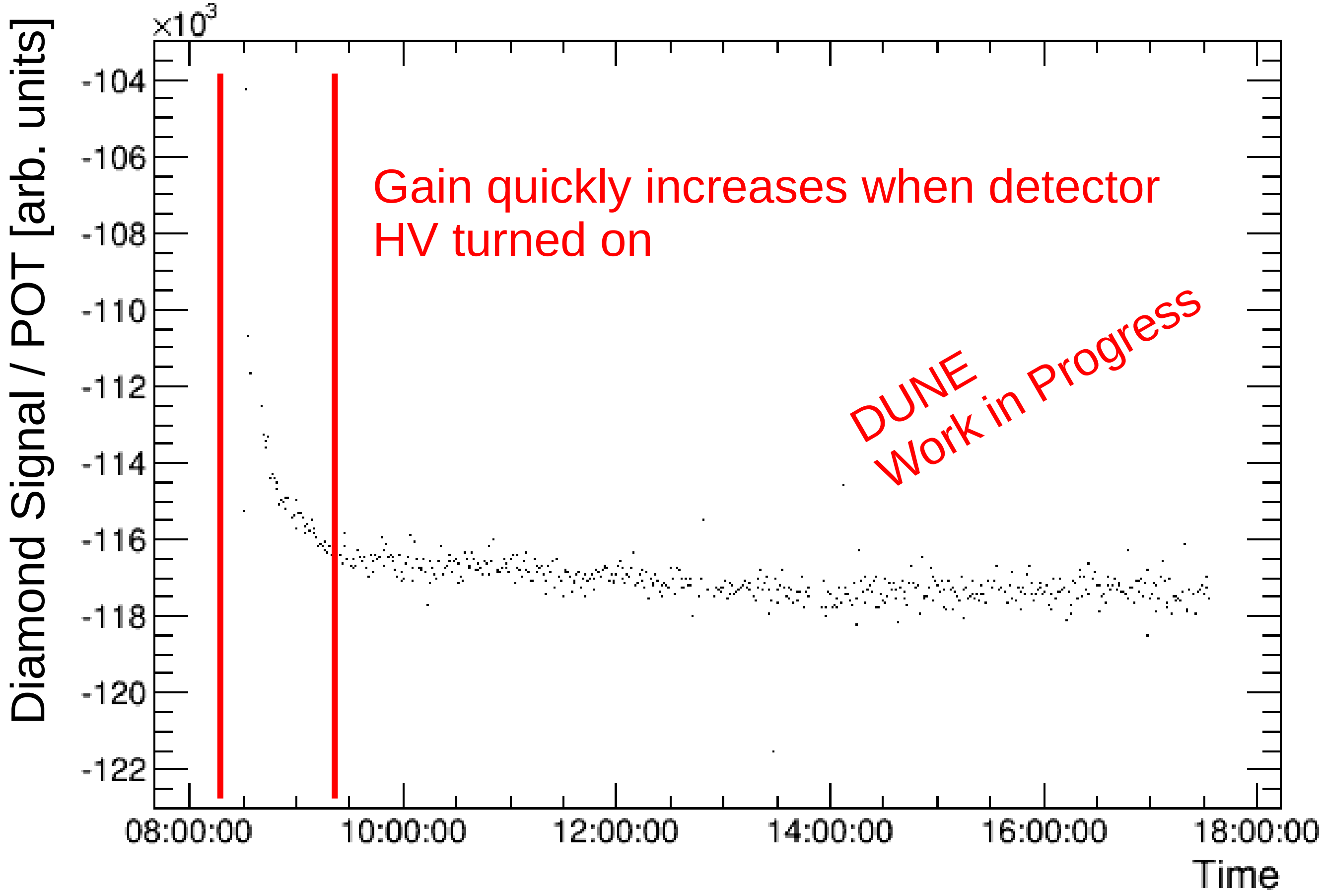
- Gaussian fit: σ=0.3%
- RMS: 0.4%
- Ignoring nonlinearity & long term gain drift:
  - Resolution much better than 1% for a single detector

Neutrino/Antineutrino Ratio



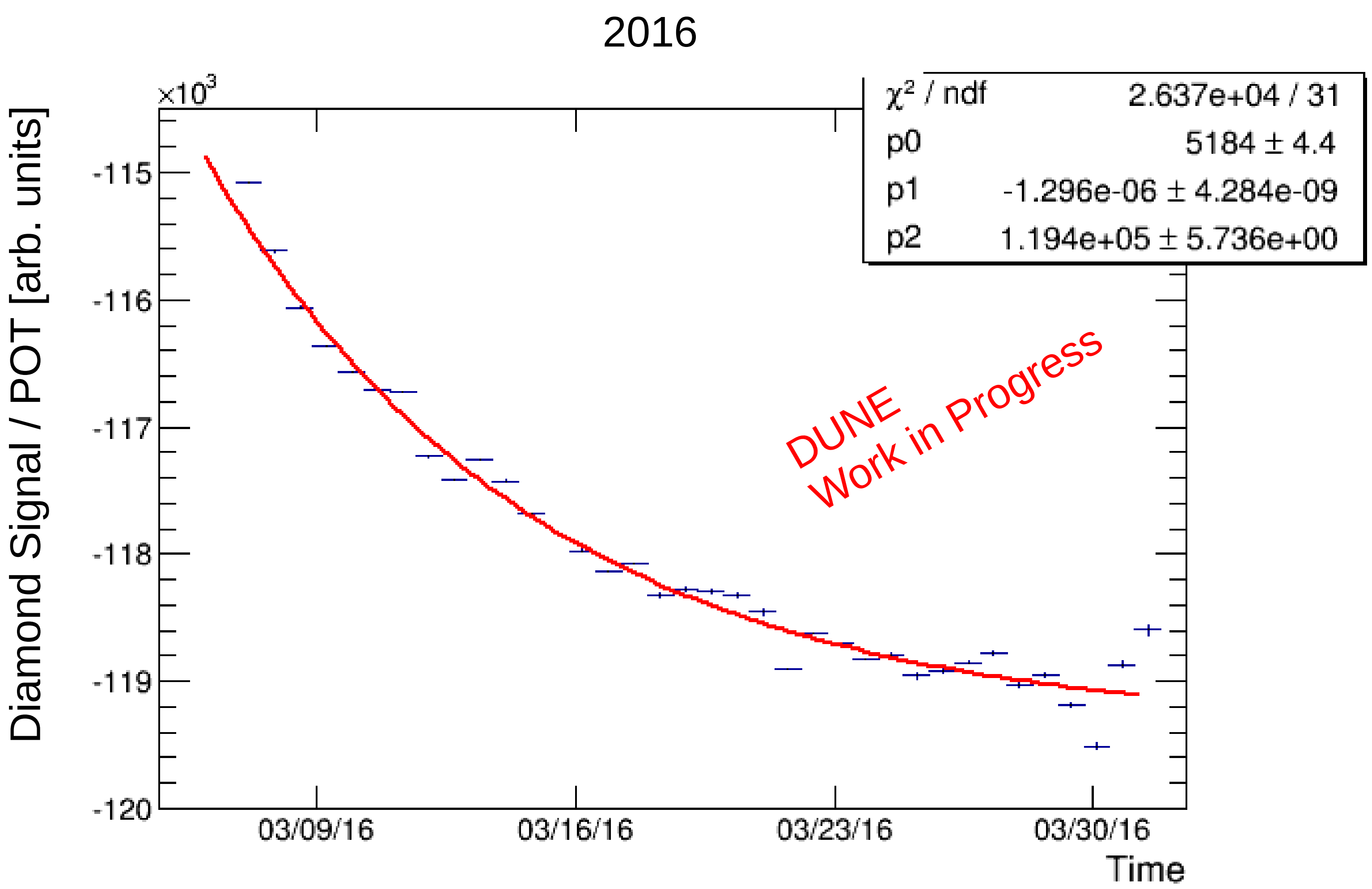
- Antineutrino to neutrino signal ratio is: 0.67±0.02
- Detector and alcove simulation with G4NuMI input: 0.68±0.03 (muon flux only, no energy loss)

Turn-On Effects: Short Term



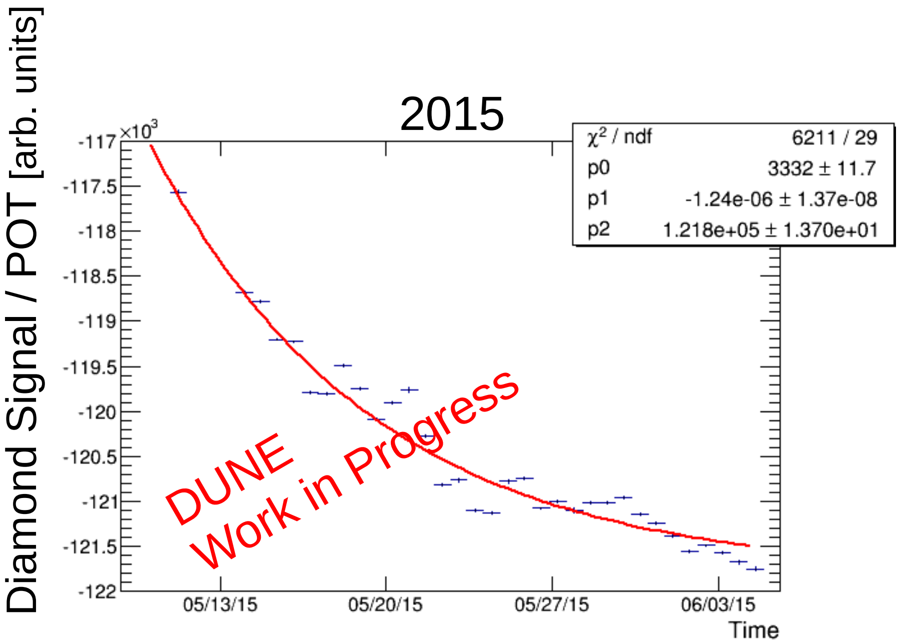
- After turning detector off for a weekend, see gain rapidly increasing & then settling over first hour or so

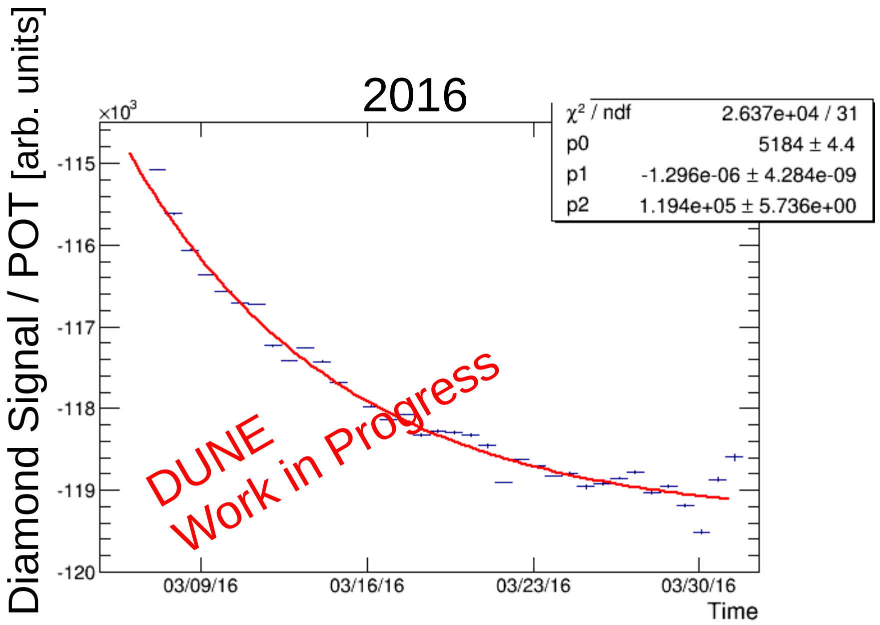
Turn-On Effects: Long Term



- Signal/POT continues to increase by several % over ~1 month after turning detector on

Year to Year Variation

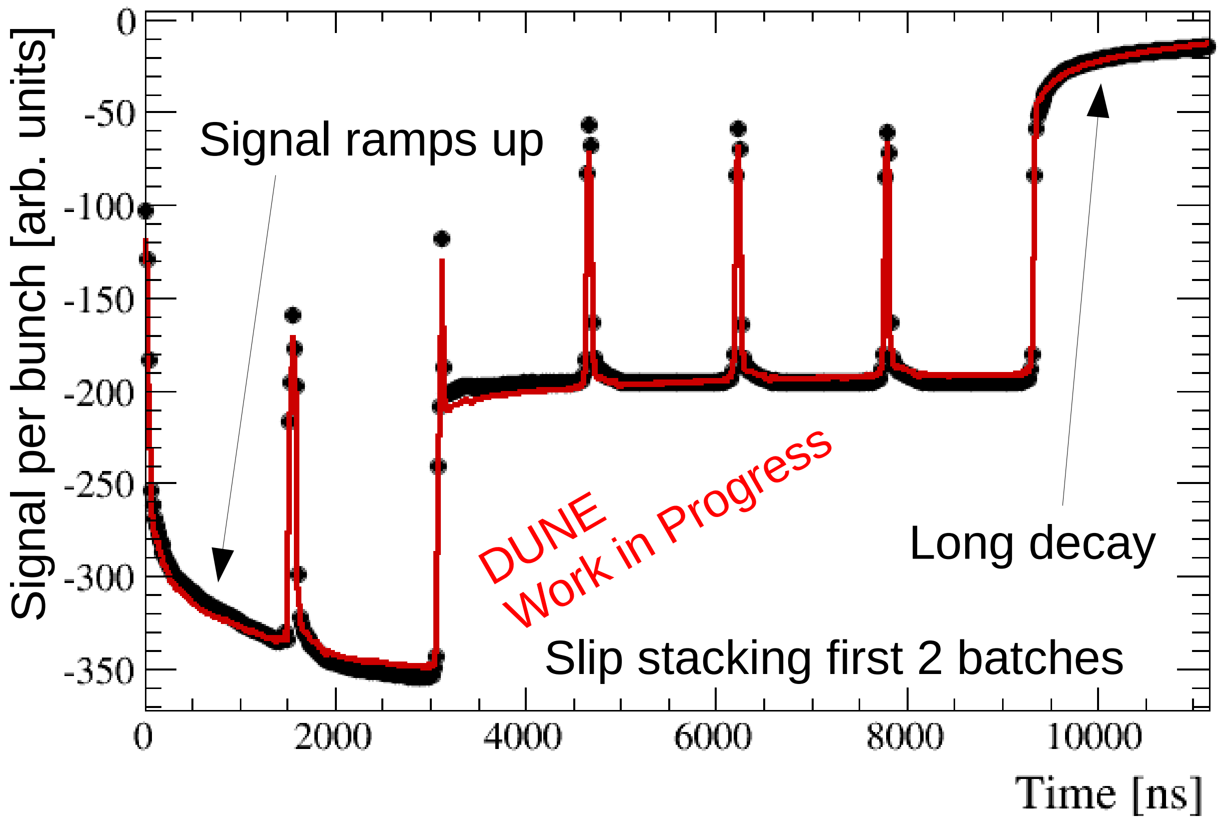




- Note: Negative signals
- Gain settles on different value: 2% drop from 2015 to 2016
- Will this continue? Should continue if due to detector aging effects

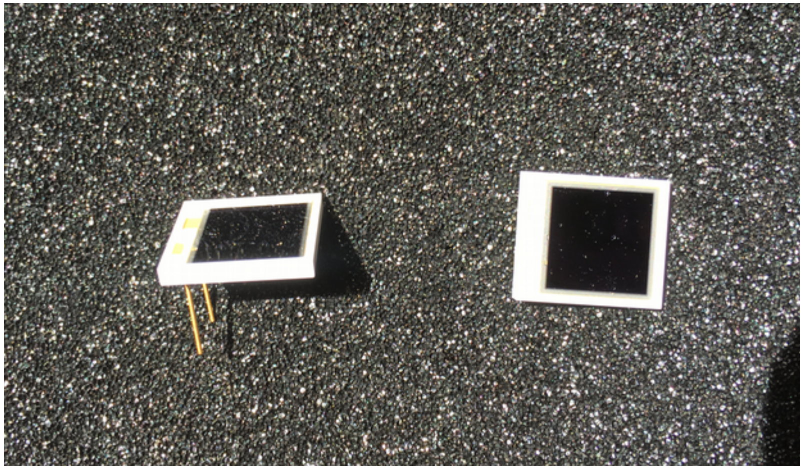
Signal Shape

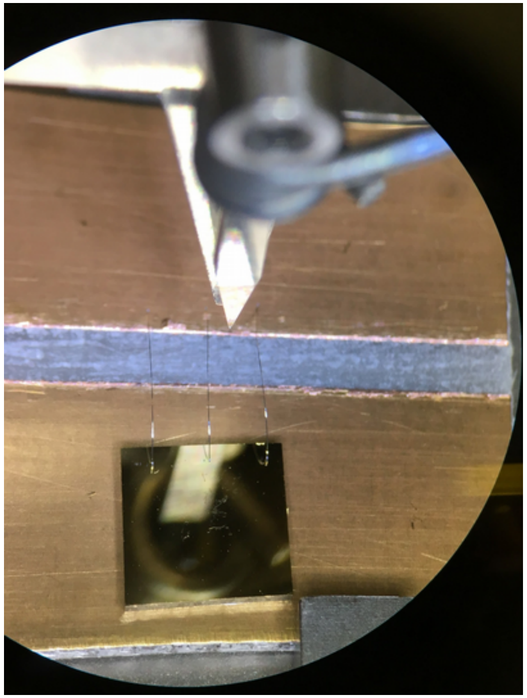
- Shape doesn't perfectly match proton signal
- Significant fraction of signal seems to be associated with ~2 μs decay
  - Muon capture/decay?
  - Materials activation?
  - Electronics?



Hardware Work

- Have some silicon photodiodes
- Put in alcove 2, may help resolve questions about signal shape





- Working on building a diamond detector from a bare diamond at CU
- May be much more cost-effective than prepackaged detectors
- New diamond, different electronics – see how performance compares to commercial devices

Conclusions

- Muon monitoring at LBNF will be more challenging than at existing beams due to much larger fluxes
- Solid-state detectors offer many possible advantages over more standard gas detectors, but also may have some drawbacks
- We have experience operating detectors in a beamline, are working on constructing our own detectors to test at NuMI