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FNAL Neutrino Beam Monitoring

Jim Hylen (FNAL)

NBI 2017

18 September 2017

Outline

- Recent saga of NUMI beam monitoring:

Complicated by transition to higher beam power

&

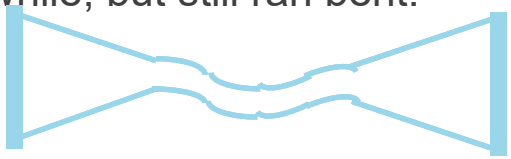
Tested by real beam defect

Monitoring challenge

Measuring Muons and Neutrinos may indicate something is wrong with beam

BUT may still have difficulty untangling what the problem is

- Has water spray eroded part of the horn inner conductor, warping magnetic field ?
  - (WANF horn eroded all the way through a spot on the inner conductor, and still ran. They were collecting the dripping water in a bucket)
- Has inner conductor warped?
  - (Horn being tested by Nezrick lost cooling for a while, but still ran bent. Wish I had a picture; it was truly amazing that it could warp that much without breaking !)



- Has target deteriorated?
  - (NuMI NT-02 showed swelling, cracking, missing graphite)

- Did component fill up with water?
  - (Water level in NuMI target NT-01 was measured with beam scan)
- Has a component moved?
  - (NuMI Horn PH-03 tilted when part of drive mechanism failed, ran for another 6 months)
- Ionization currents, …

Direct measurements

THUS need whatever direct measurements of components that can be made

Surveyors can check alignment of beam components

BUT in NUMI, putting in shielding after survey moves things by ~ 0.75 mm

ALSO in NuMI, going to higher power means surveyors pick up more dose, restricting survey (in any case, cannot get close to actual components)

Beam alignment scans of components very useful

BUT in NUMI, must remove target to scan horn cross-hairs with beam

(Design included ability to remotely drive target out of way for horn scan, however due to corrosion of drive shafts, are not risking running that drive now)

NuMI has a few other systems, although only modestly useful

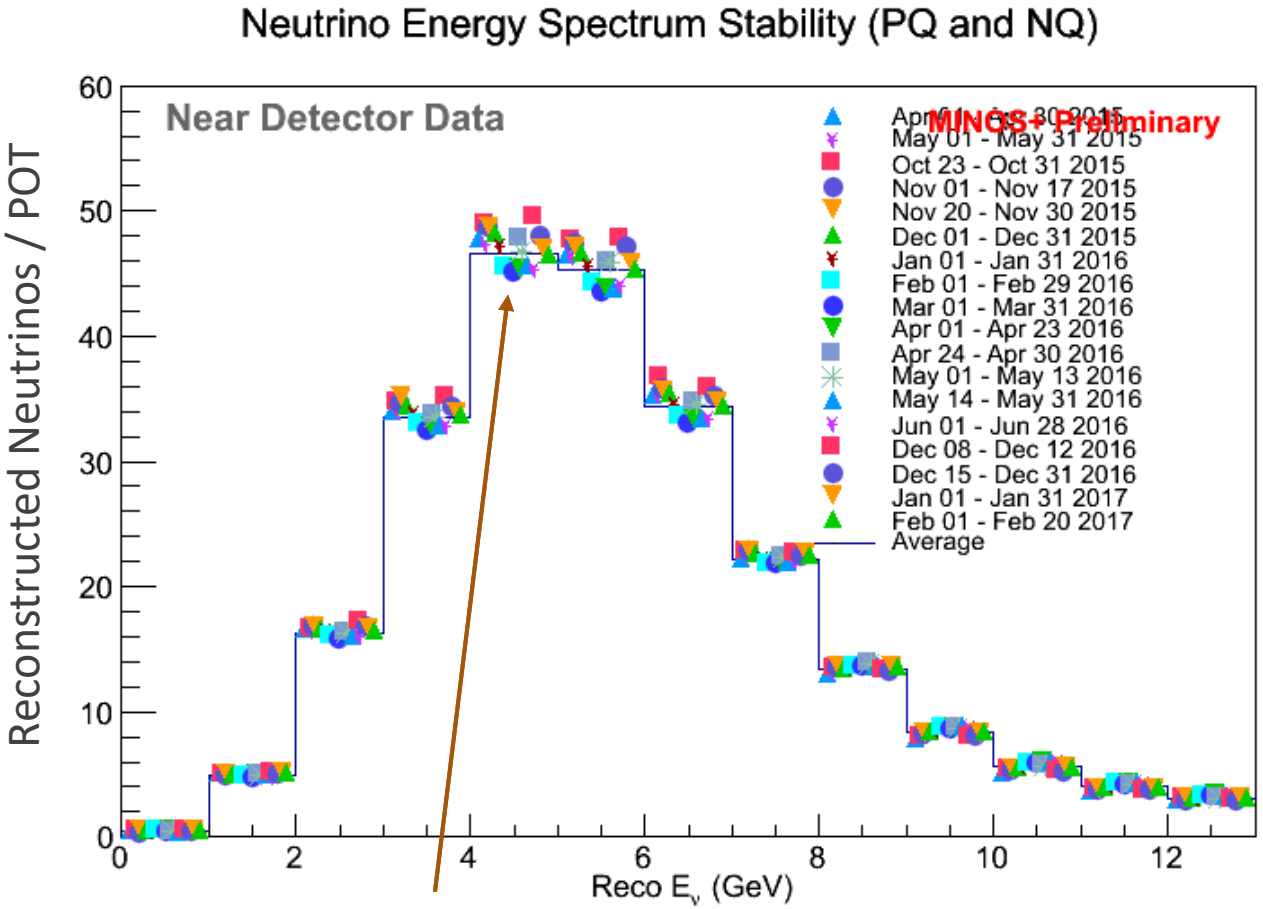
Bdot pickup coils inside horns watching magnetic field at a few locations

LVDTs monitoring position of horn alignment drive motors to shafts on modules

Neutrino Beam Instrumentation field could certainly use new ideas for how to properly monitor / unfold problems with our neutrino beam components

NuMI monitoring saga

MINOS+ experiment operating MINOS Near Detector (neutrino focusing mode)

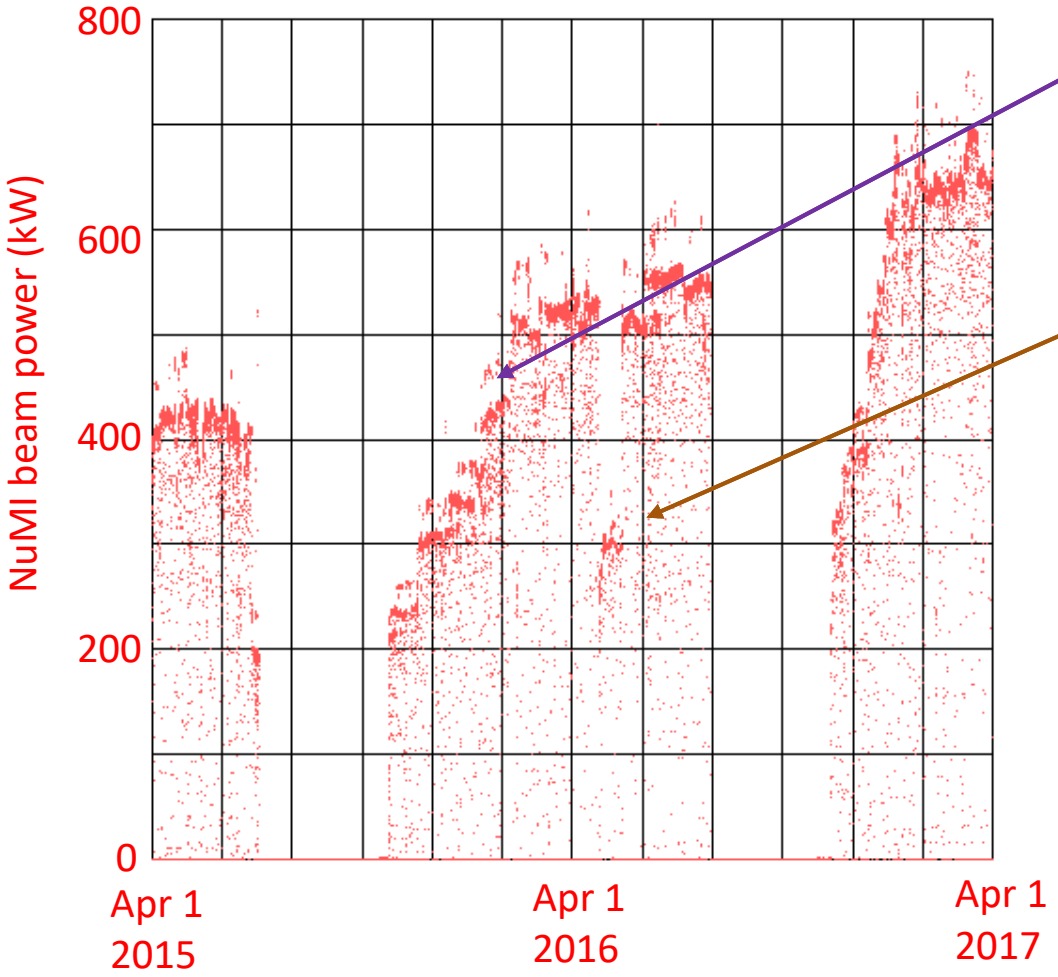


Time history in each 1 GeV neutrino energy bin

Apr. 2015 through Feb. 2017

Reconstructed neutrinos/POT in peak of spectrum drops early 2016, similar to change when target NT-02 was falling apart; was target MET-01 deteriorating ?

(Partial) false alarm



But beginning of 2016 was also when fully slip-stacked beam power was ramping up!

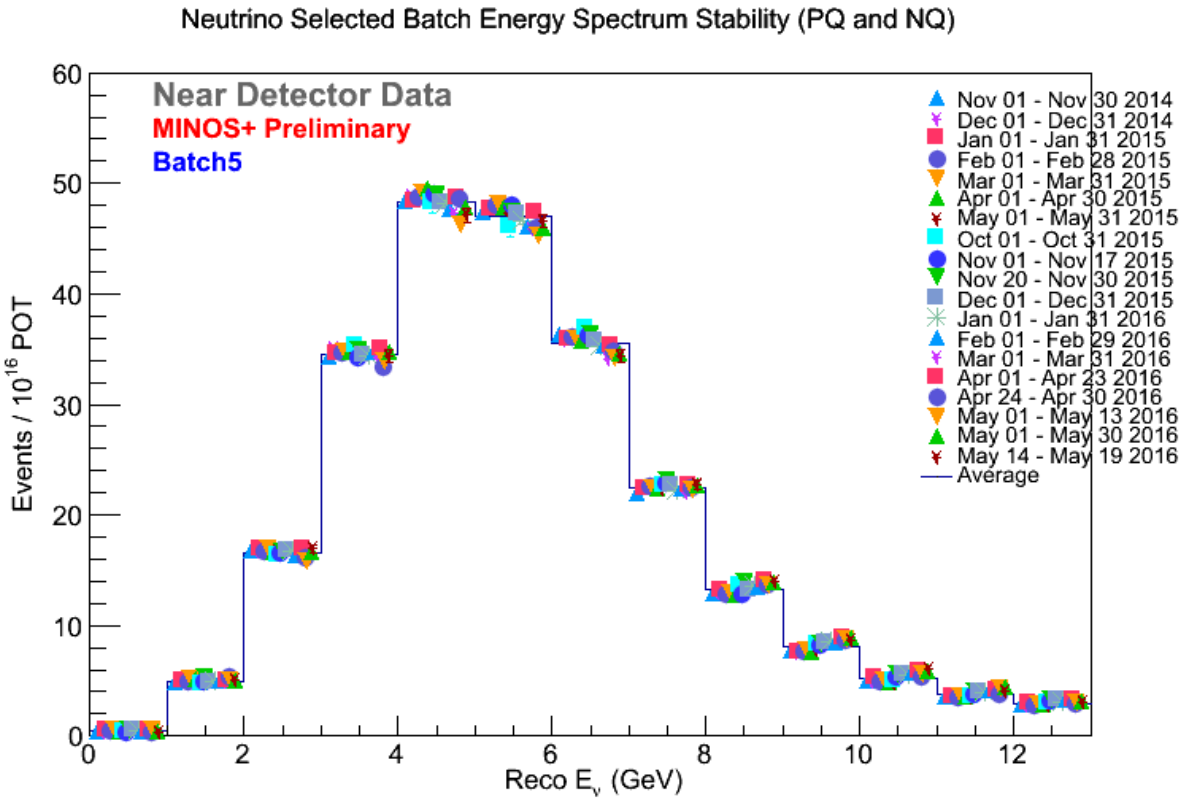
Then fire in accelerator power supply reduced beam to non-slip-stack lower power for awhile (Apr 24 – May 13).

And neutrinos/POT in ND went back to normal, until power went up again;
so problem was NOT target.

Recall MINOS was designed for 400 kW beam.

Main problem was reconstruction failure due to pile-up of neutrino events in MINOS near detector.

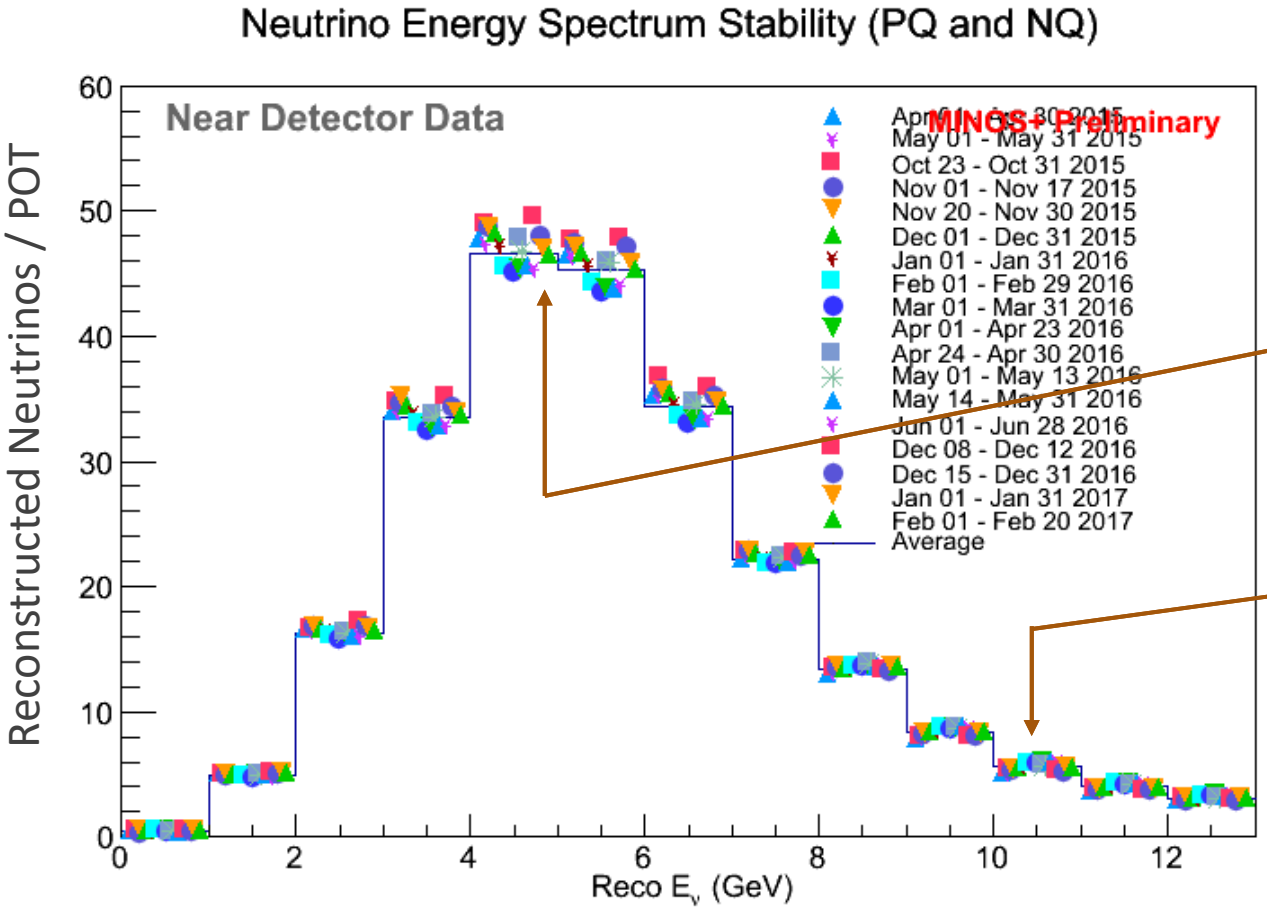
Partial slip-stacking allowed another check



- Through spring 2016, not all 6 batches in a spill were slip-stacked. With some effort and approximation, could plot non-slip-stacked (lower intensity) batch.
- Peak was stable !
- Starting Fall 2016, all batches slip-stacked, so can't use this technique any more.

NuMI monitoring saga

MINOS+ experiment operating MINOS Near Detector (neutrino focusing mode)



Time history in each 1 GeV neutrino energy bin
Apr. 2015 through Feb. 2017

Reconstructed Neutrinos/POT in ND going down again as beam power ramps up early ‘17.

But there had been unexplained bump in high energy tail in ‘16

Reason for bump was discovered during beam-scan check of horn position with target out, October 30, 2016 (between removing MET-01 and installing MET-02)

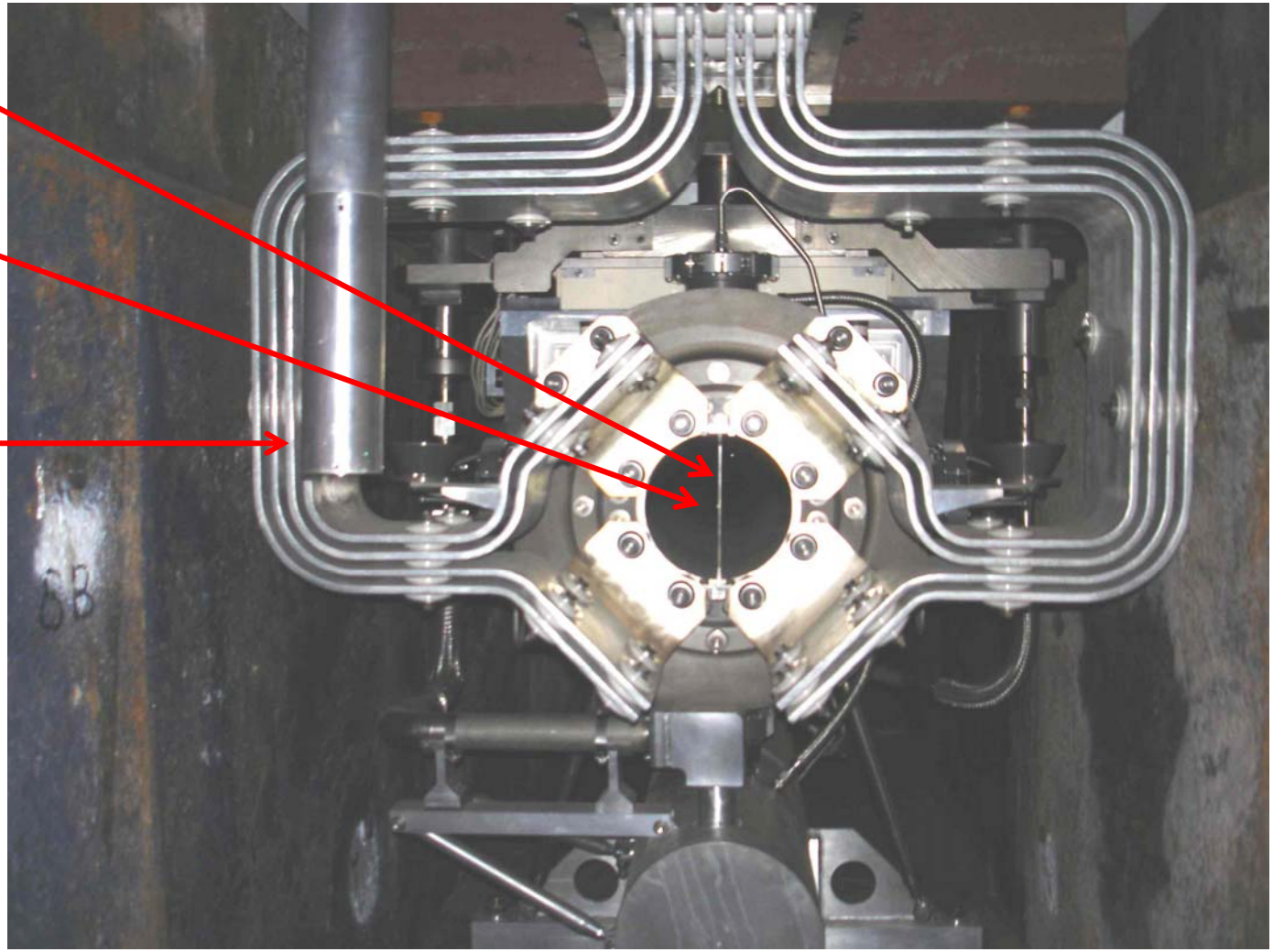
NuMI Horn cross-air for beam-scan alignment

Fin for beam horz. alignment

Nub for beam vert. align

Beam loss mon. to detect beam scatter from fin ("cross-hair"), also from beam to horn neck

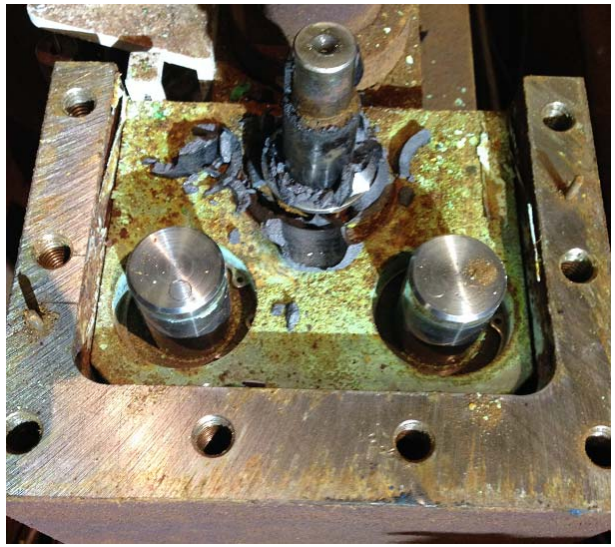
(Need target removed to allow beam scan of horn)



Result of horn alignment scan Oct. 30, 2016

- Horn neck (80 cm from front of 300 cm horn) was 2.5 mm low, while downstream cross-hair was in correct location; conclusion: horn tilted
- Horn on average 1.7 mm low

- Broken bushing at top of horn module identified as culprit
  (more on this in other talks)



- Did repair, and re-aligned horn
- From monitoring data, believe tilt happened
  over a few month period Nov. 2015-Feb 2016

What about muon monitors during this time?

- A couple % change in integrated response was seen in the muon monitors, which nominally are 1% devices.

- That was a small enough change to be evidence against serious target degradation, but was not large enough to raise red flags.

- There was 1 cm change in the centroid of the muon monitor response.

  That corresponds to 14 micro-radian change, well within NUMI nominal tolerance.

  The centroid is also sensitive to beam power. It would take Monte Carlo and significantly more analysis untangling several other effects to make this really useful. However, seems useful to pursue if resources can be found.

- We hope to channel more effort from experiments to supporting muon monitor system in the future.

Approximate impact on experiments

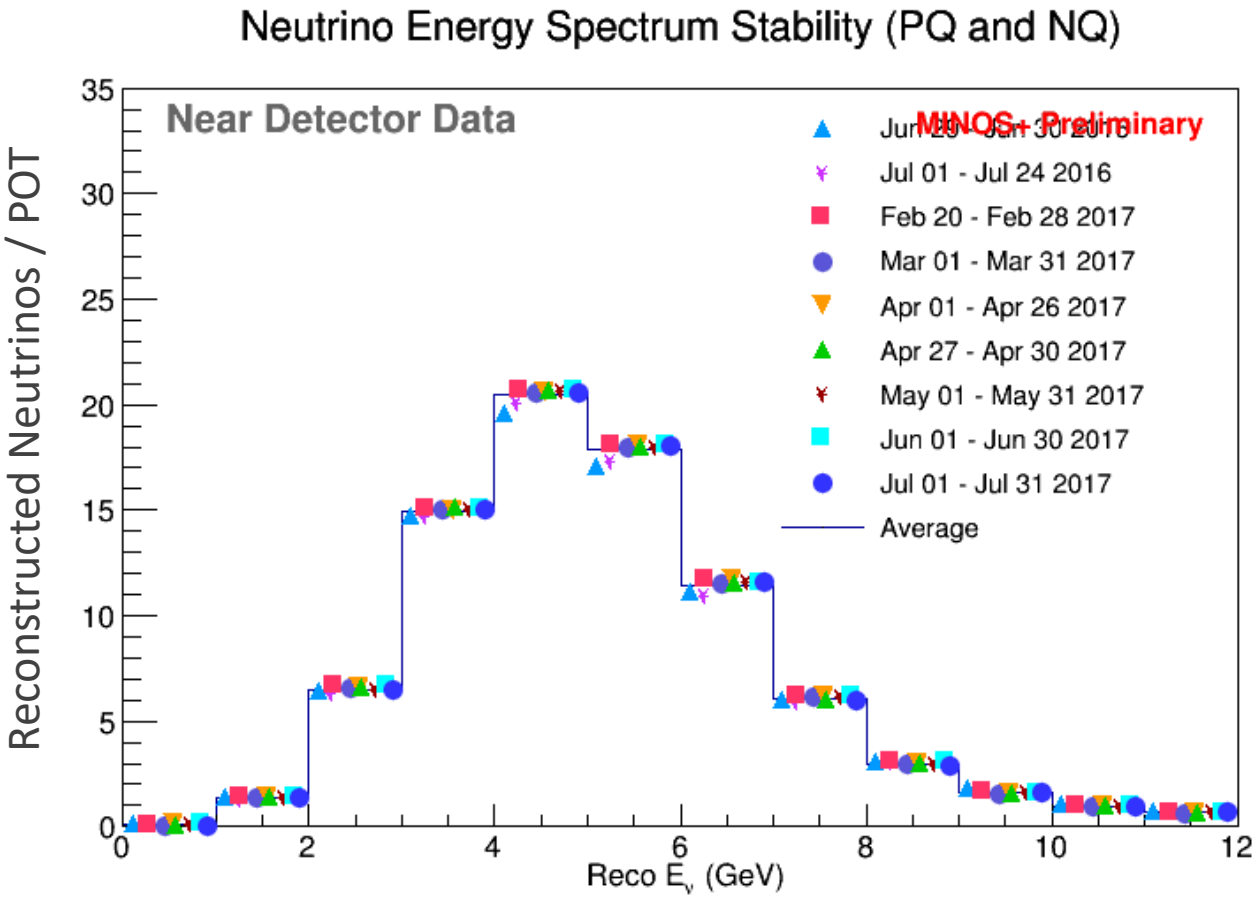
Monte Carlo studies indicates that for MINERVA (which is on-axis near), the horn offset results in only slight change in spectrum around peak, but does cause increase at around 10 GeV of amount that agrees with the bump seen in the ND monitoring tail.

NOVA is off-axis experiment. Monte Carlo indicates that both NOVA near detector and far detector are insensitive to this horn tilt.

Note MINOS+ experiment ended data-taking summer 2016.

Stability during anti-neutrino running

MINOS Near Detector (anti-neutrino focusing mode)



Time history in each 1 GeV neutrino energy bin

June 2016 through July 2017
(note first point, June 2016, is low statistics, < 2 days running)

Note rate in anti-neutrino mode is much lower than in neutrino mode, so pile-up reconstruction problems should be much less.

NuMI Monitoring in future

- Will have some information from MINOS ND while MINERA is running
  (MINERVA uses MINOS ND as a muon tracker)

- But since MINOS+ is not running
  ND calorimetry calibration and pileup studies not supported going forward

- When MINERVA ends, MINOS ND will probably shut down

- NOVA will then only have off-axis NOVA ND and muon monitors.
  Motivates putting more effort into the muon monitors.

Conclusion

NuMI story reinforces that:

Neutrino Beam Instrumentation field could use new ideas* for how to properly monitor / unfold problems with our neutrino beam hardware

**Note every project ends up stressed for money, so cheap ideas especially valued*