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“Conventional” neutrino beams: Target requirements

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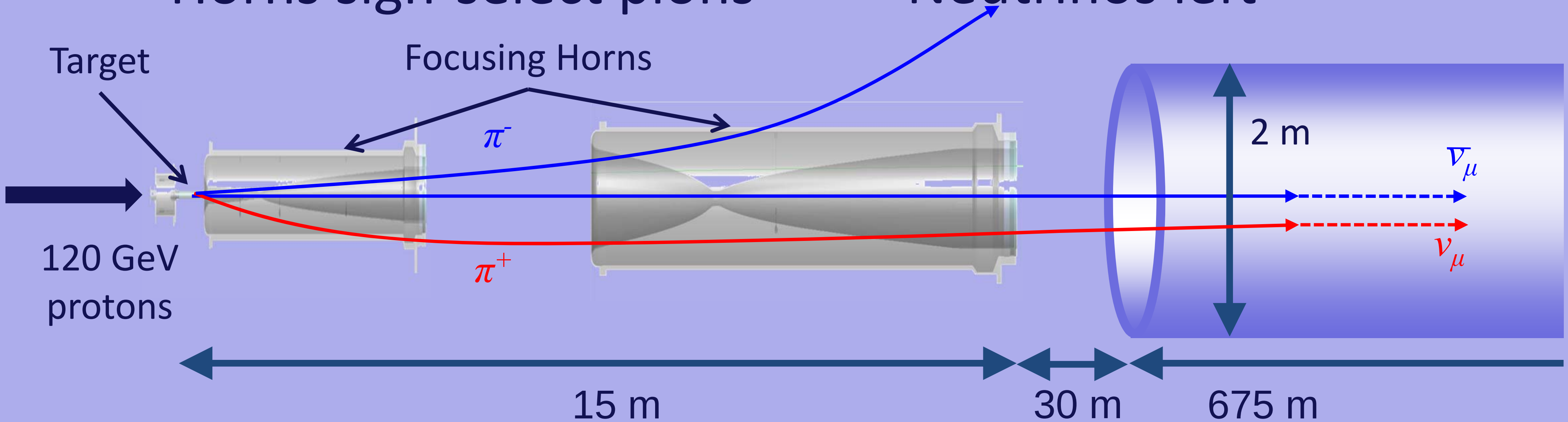
"Anatomy of a neutrino beam"

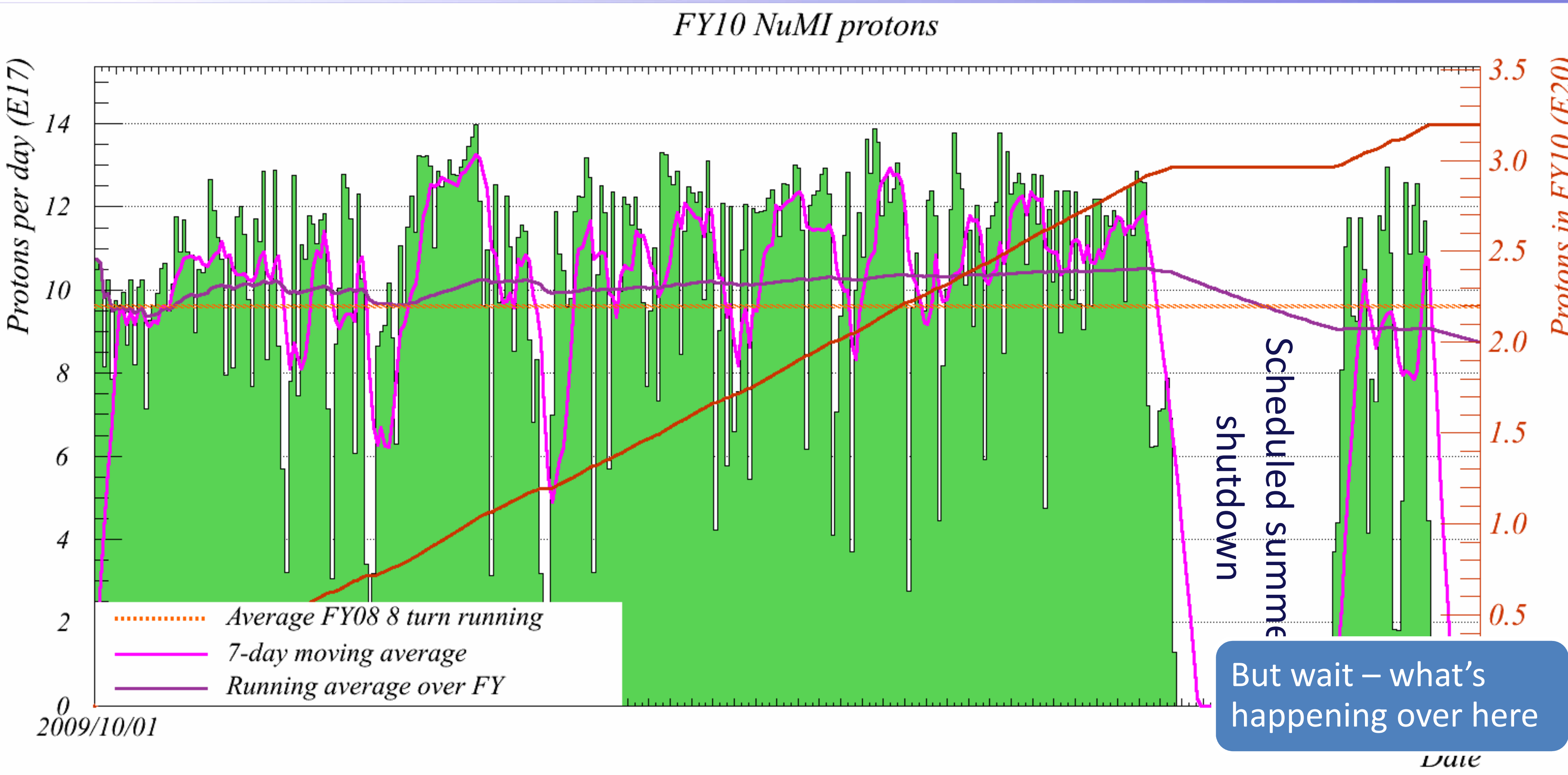
- Primary proton beam
  - Beam window
- Target
  - Produce π,K
- Focusing elements
  - Horns sign-select pions
- Decay volume
  - $\pi^+ \rightarrow \mu^+ \nu_\mu$
- Beam Absorber
  - Absorb hadrons
- Muons range out in rock
  - Neutrinos left



Introduction

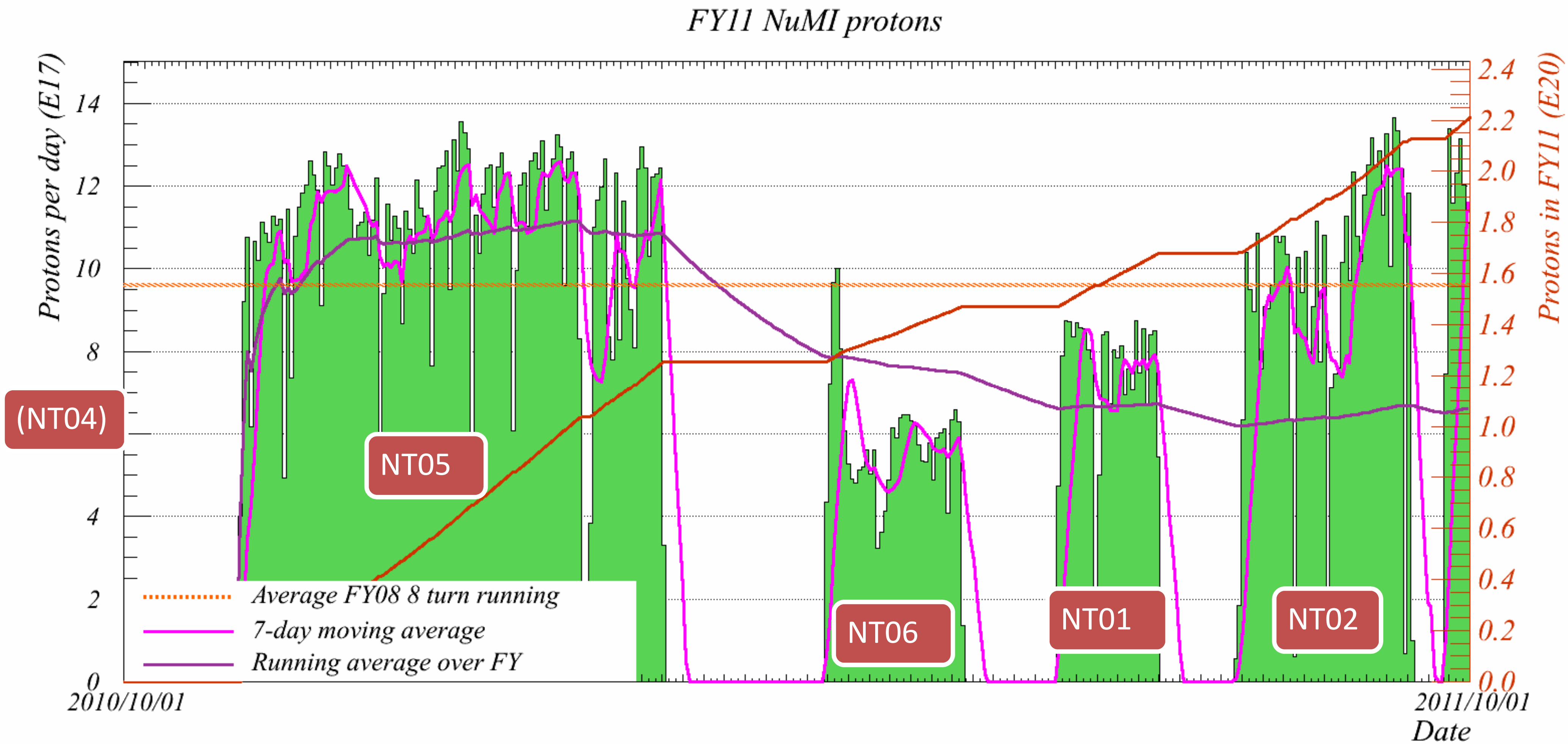
- Will discuss the requirements on targets and target halls for high power neutrino beams
  - NOvA at 700kW
  - LBNE at 700kW
  - LBNE+Project X at 2.2MW
  - Low energy beam with Project X?
- Discussion is mostly generic
  - Brand-name advice also available in the room

An example from NuMI



- Solid consistent running delivered 3.2E20 protons to NuMI in FY10

"Annus Horribilis"



- Got 2.2E20 in FY11, thanks to heroic efforts from target folks (and delay to future projects)
- Without target problems would have been 4E20

" This was NT06 "

- Water cooling lines sprang leak after a few days
- Limped on for a month until outer can failed

" Uptime is important! "

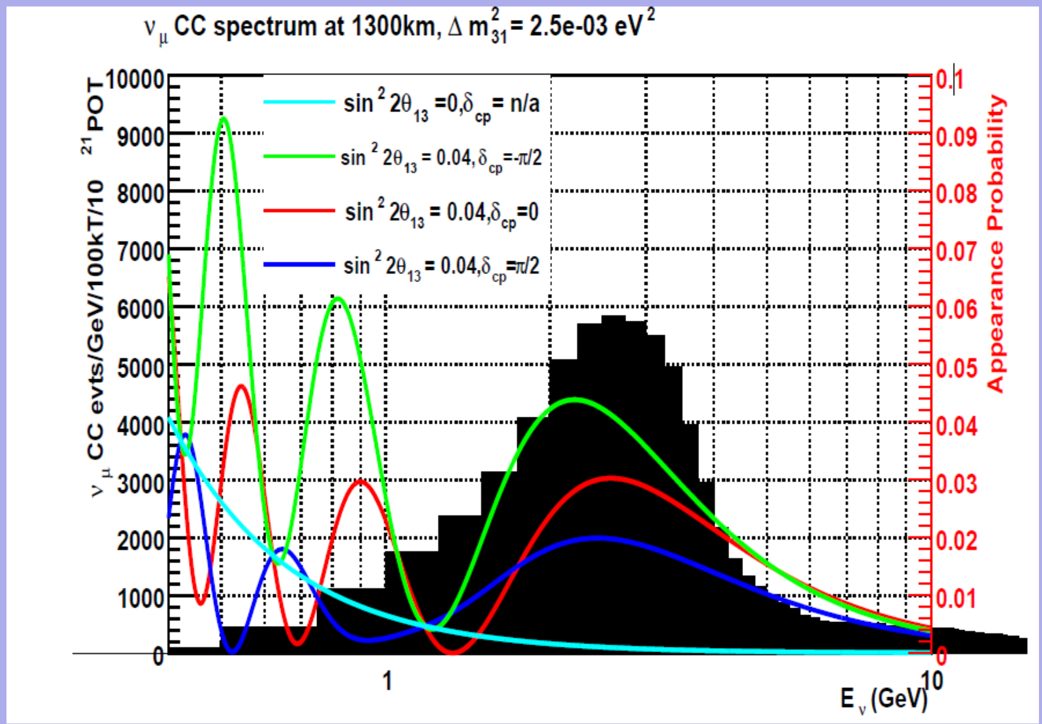
- …but uptime is a Heisenberg number
  - When you try to define it, it gets hard to measure
- NuMI example: downtime is
  - Time removing broken target and installing new target
  - Time running at low intensity to try to extend life of dying target

" Design Implications "

- Neutrino experiments care about integrated neutrino flux over the years)
- New target design with 10% flux improvement?
  - Great, but if it needs replacing twice a year at 2 weeks or so downtime each, you just lost.
  - “Yield per proton vs design conservatism” – Tristan this morning
- Probably guaranteed 4 weeks scheduled downtime per year
  - Target hall maintenance in shutdown is “free”
  - Replace consumable targets etc.
- Otherwise, want target hall components to be quick to replace or robust

" Neutrino Flux "

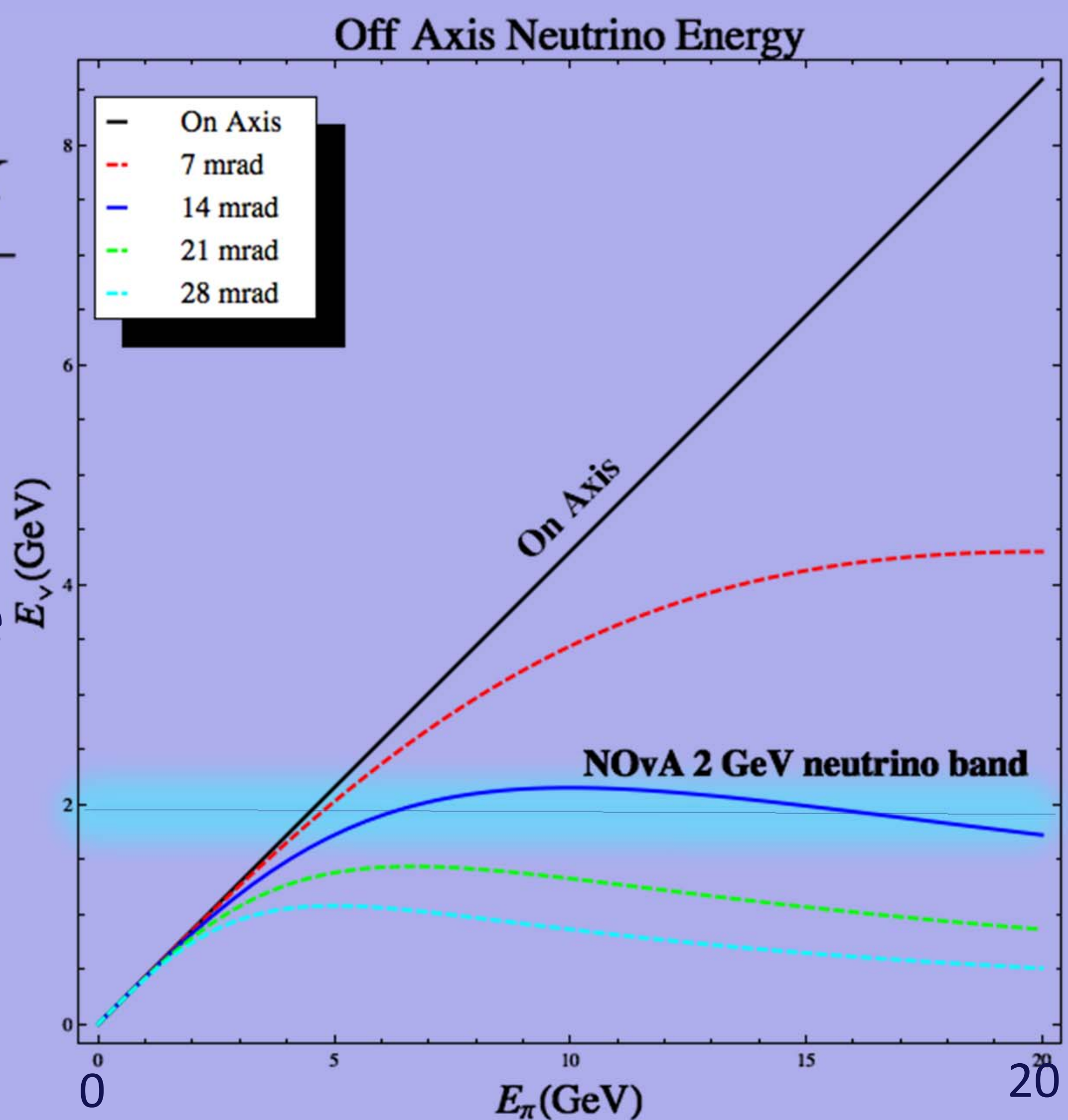
- Pions from target have few hundred MeV transverse momentum
- $E_\nu = 0.43\ E_\pi$
- Place target far away from horn for high energy
  - Close (inside) for low
- Depth of field etc. makes it a little more complicated
- For LBNE, oscillation maxima at 2.5 and 0.8 GeV
  - Must place target inside horn (cf. NuMI LE)
- Also low energy (cf. BNB)



" Off-axis this isn't true: NOvA "

$$E_\nu = \frac{\left(1 - \frac{m_\mu^2}{m_{\pi,K}^2}\right) E_{\pi,K}}{1 + \gamma^2\theta^2}$$

- Off-axis, neutrino energy driven by angle
- Adjust focusing to optimize flux
- Target goes upstream of horn

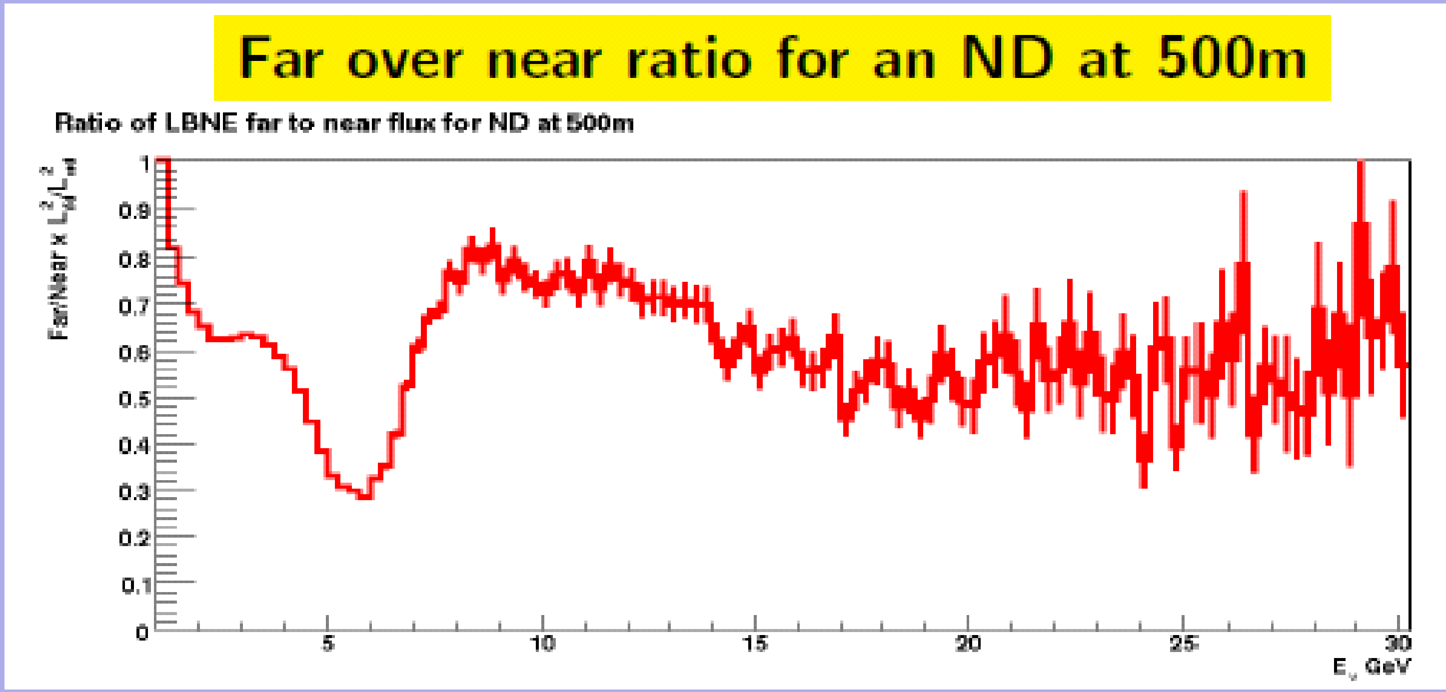


LBNE Flux optimization

- More flux is always good, but in the real world there are tradeoffs
  - Zwaska FOM is a useful simple tool, but not intended to be more than that
  - What balance of flux required at 0.8 vs 2.5 GeV
  - High energy tail causes backgrounds for ν_e appearance (NC feeddown)
    - LAr detector is better than water
- Answer is different for different measurements
- Detailed analysis not done
- Modifications in target width/length don't change the design problems much
  - Hybrid Light-heavy target is different

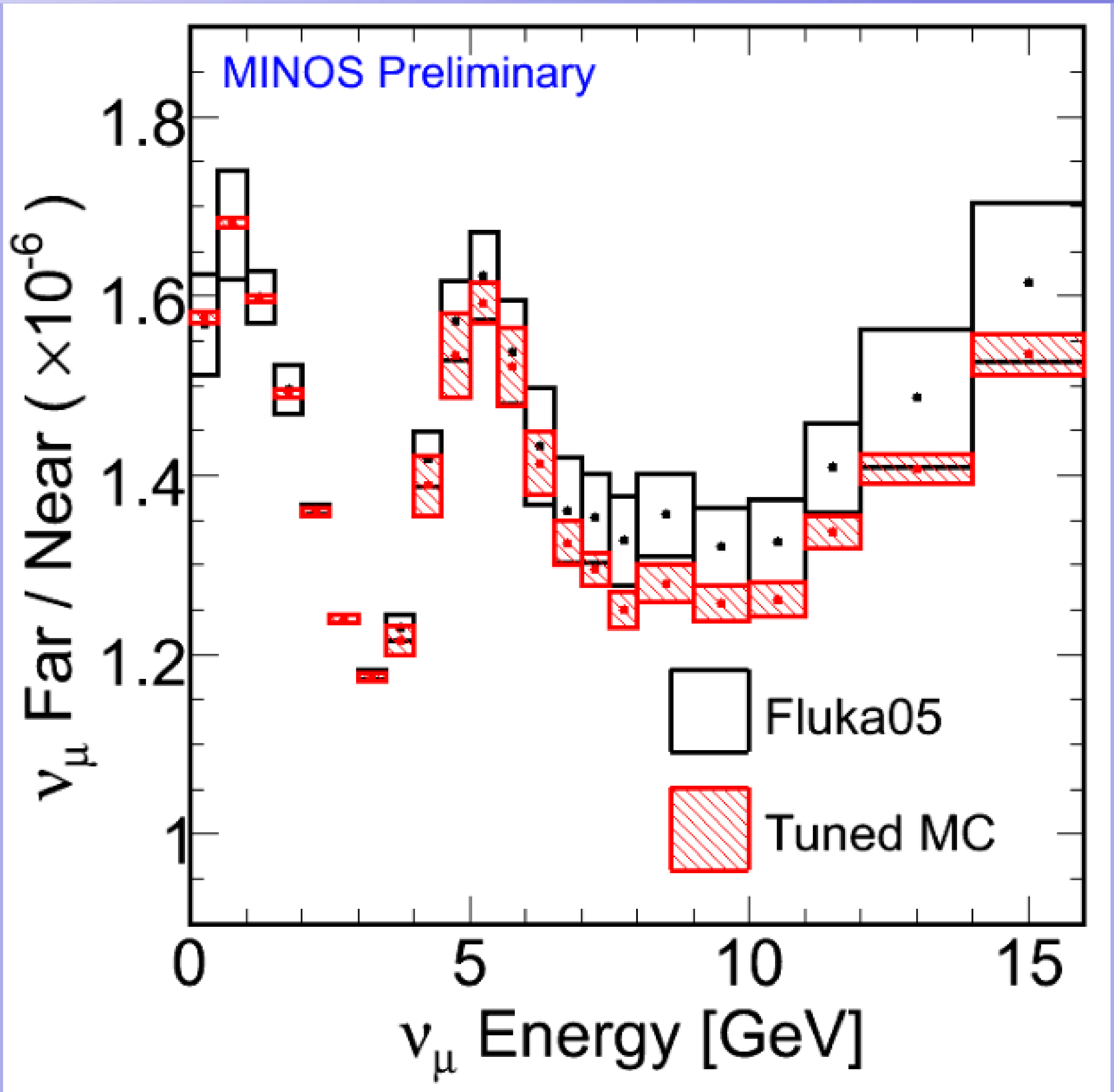
Predicting FD spectra

- Oscillation experiments have near detector to measure beam
  - But you can't put a near detector far enough away to make the beam look like a point source rather than a line source
- Depend on modelling beam for F/N pred



" Predicting FD spectra "

- MINOS weights Fluka using ND data at different target positions & horn currents
- T2K uses measured meson yields from NA61

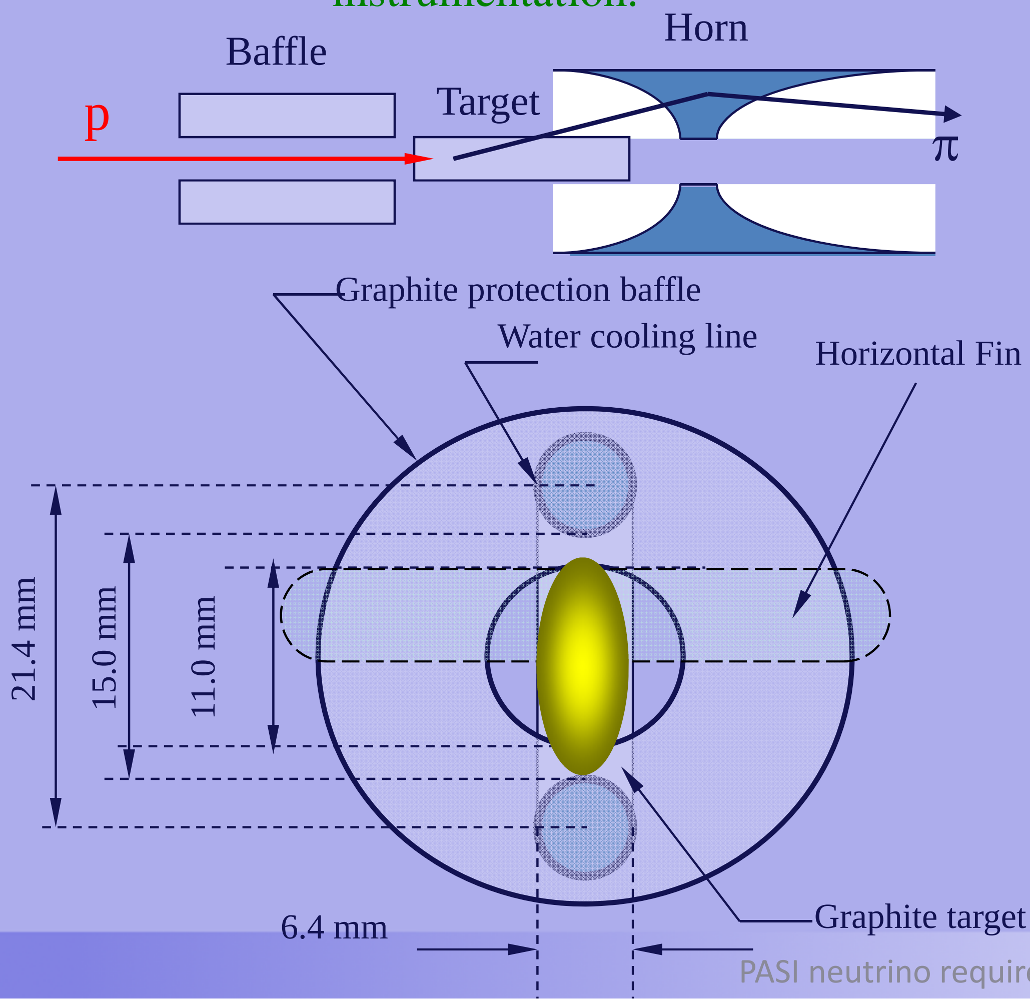


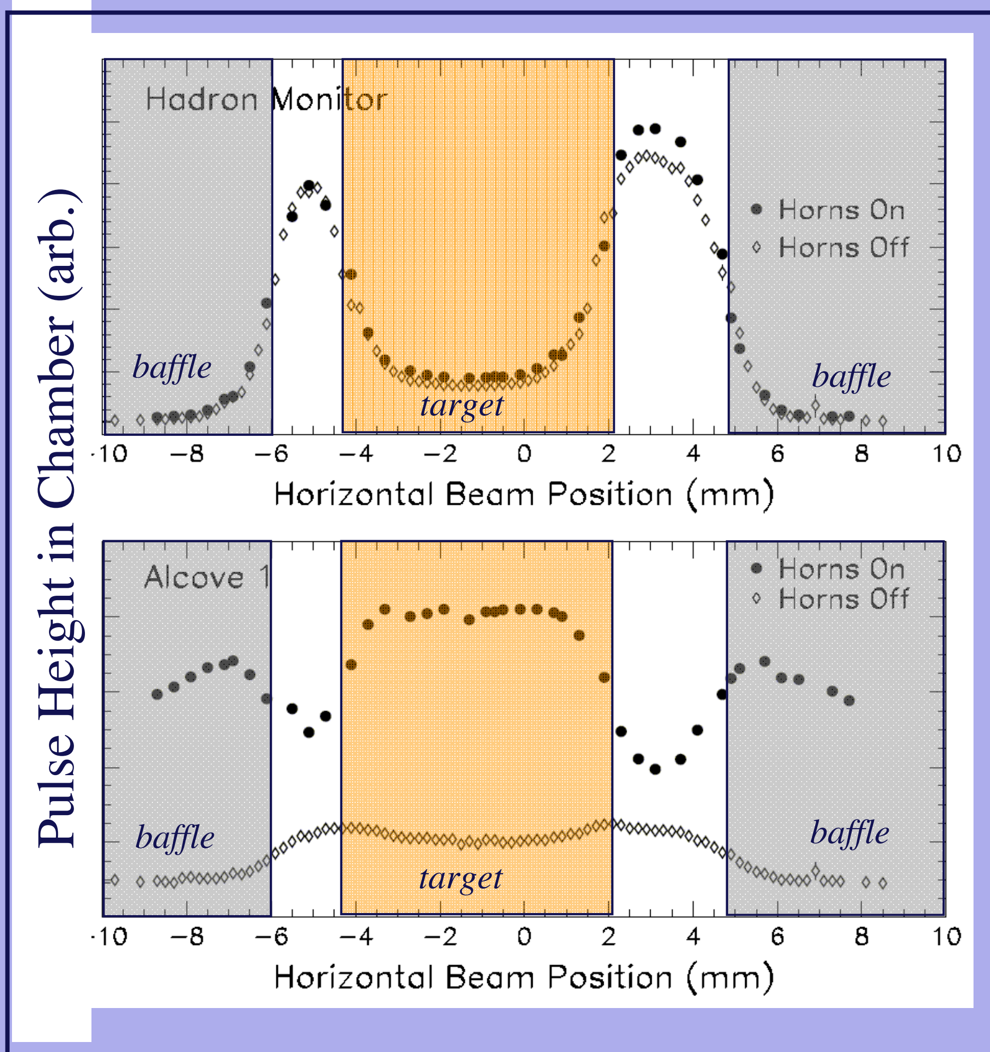
" Constraints from FD prediction "

- Rely on MC to know how spectra at ND and FD should differ
  - What's in MC needs to match what's in the target hall
    - Alignment
    - Mass budget
    - Beam size
  - NuMI requires horn 1, target aligned to 1mm, beam sigma known to better than 0.1mm.
    - For LBNE precision disappearance measurement, requirements should be the same (maybe a little tighter?)
    - This is less important for appearance
      - But need to understand backgrounds (beam ν_e)
    - beam ν_e extrapolate to FD differently (different parent kinematics)
- Need to optimize neutrino flux, but also need to know that that is what you have

Target Alignment

- Proton beam scanned horizontally across target and protection baffle
  - Also used to locate horns
- Hadron Monitor and the Muon Monitors used to find the edges
  - Measured small (~1.2 mm) offset of target relative to primary beam instrumentation.





Alignment

- Need beam-based alignment to be sure of what you've got
  - NuMI target hall moves when shielding blocks are installed
  - Thermal motion
- Target, horns need features that can be located with beam scan
  - Monitoring alignment whilst running would be great
  - Hylen thermometer for NOvA – will it survive 2MW?
- Particle yields must be insensitive to natural variation in proton beam position
  - Machine dependent
  - NuMI has 100um RMS
- "Insensitive" is a function of the accuracy of the measurement
  - Issue for balls?

" Proton beam alignment "

- Need to know/measure beam sigma
  - Variations greater than 100um are bad
- NuMI has Ti SEM wires/foils
  - Won't work for 2MW
- Will carbon fibre survive?
- Electron beam?

" What's in your target? "

- As mentioned, need target & horn model to extrapolate from near to far detector
  - Target has to be the same from pulse to pulse
    - Different from pbar or muon production target, where you don't care too much exactly what comes out
    - For neutrino beam, the target is part of the physics of the experiment
    - Difficult to use liquid or powder target for this

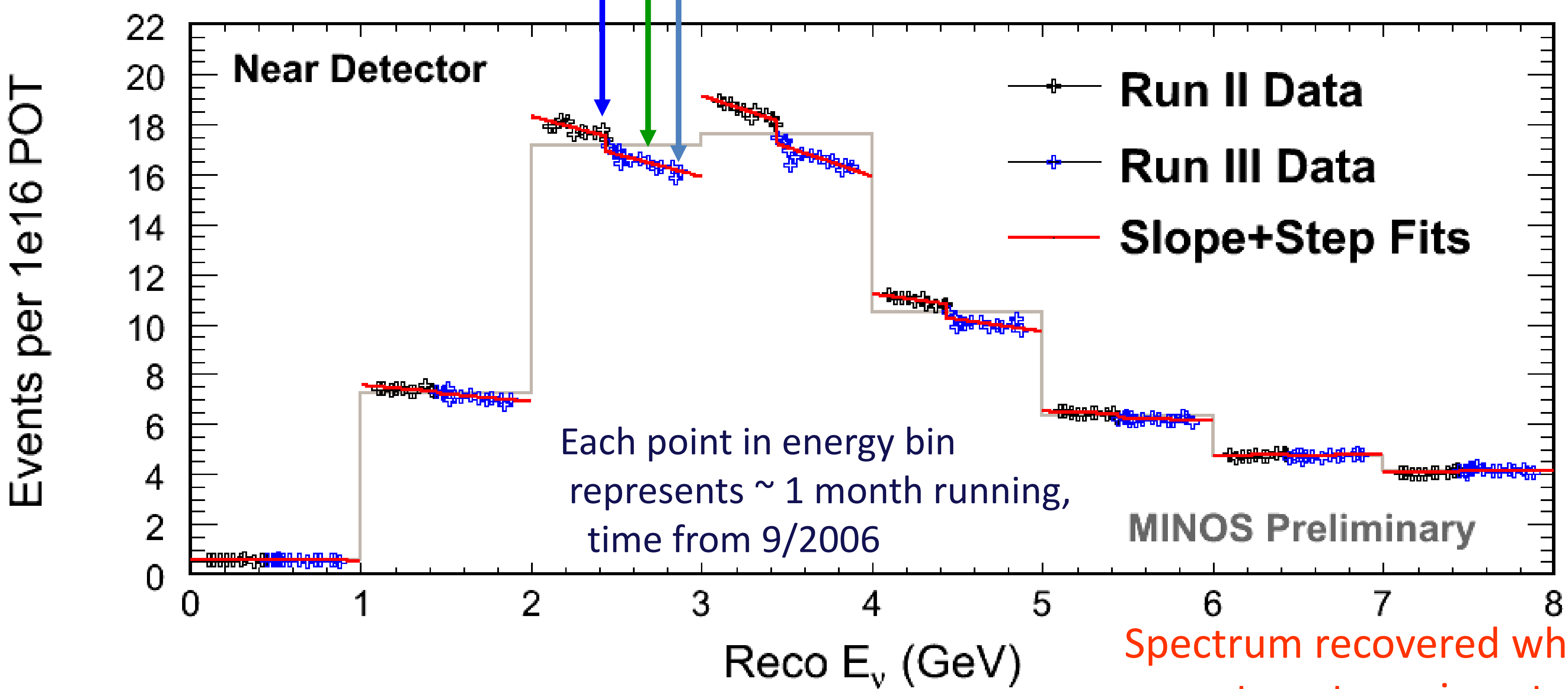
NuMI 2nd target depletion (ZXF-5Q amorphous graphite)
NT-02 replaced when spectrum shift became too large.

Gradual decrease in neutrino rate attributed to target radiation damage

Decrease as expected when decay pipe changed from vacuum to helium fill

No change when horn 1 was replaced

No change when horn 2 was replaced



Each point in energy bin represents ~ 1 month running, time from 9/2006

Spectrum recovered when new target was inserted

What’s in your target?

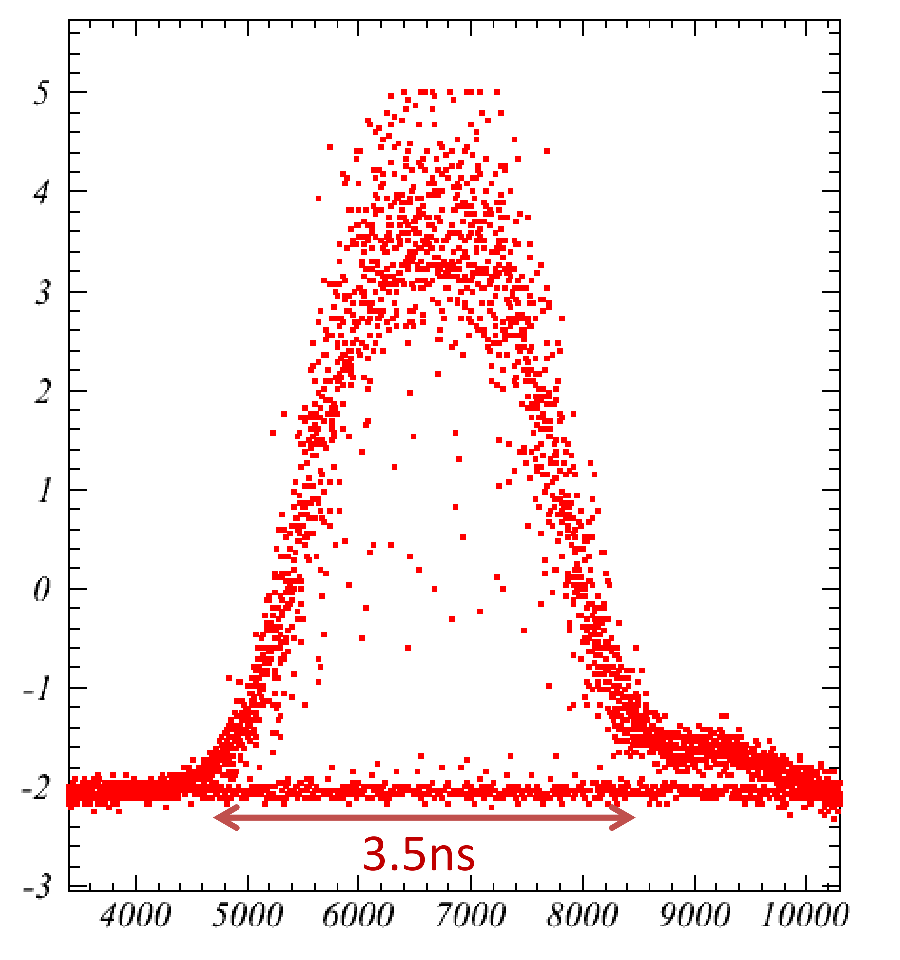
- NuMI observed radiation damage to the graphite of target NT02 (change in neutrino yield)
- Effect modelled by removing target fins in MC at maximum dpa from MARS model
- NuMI coped with a loss of yield of 10% with a much better than 1% effect on Near -> Far extrapolation
- Would prefer to replace a target before it got to that state
- Want muon monitor able to track this
  - Don’t wait to integrate enough neutrino events to see issue.

" Secondary beam monitoring "

- Target hall is a hostile environment
  - Want multiple complementary beam monitors to distinguish between real effects and dying instrumentation
- Hadron monitor downstream of decay pipe
  - Survivability at 2MW?
- Muon monitors
  - Muons and neutrinos come from same decays
    - Calibration, drifts, delta rays, …
- Temperature rise in absorber is a great independent measure
- This kind of monitoring feeds directly into experiment's systematic error budget

" Project X / LBNE beam "

- LBNE beam still comes from Main Injector
  - New RF system, but not much change
  - 53 MHz bunches
  - Bunch length < 2ns sigma
  - 1.2s cycle time at 120 GeV
    - 0.75s at 60 GeV
  - 1.6E14 protons per spill
    - 3.3E11 protons per bunch
    - Factor 4 increase over now
  - 2.3 MW



" Summary "

- Uptime (integrated neutrino yield)
  - For a given target, integrated number of protons
  - It's probably worth paying a little pion yield for a more robust target
  - Robustness/fast replacement
- Repeatability
  - Target is the same each pulse
- Alignability
  - Target hall components can be aligned, and alignment monitored, with beam
- Radiation damage
  - Model and monitor
- Redundant instrumentation
  - If you see an effect in hadron monitor and muon monitor, it's more likely to be real
- At 2.2MW, expect the unexpected
  - Plan & mitigate risks, but…