Studies of Neutrino Velocity with MINOS

Strategy of campaign and current status

Presentation to the Fermilab PAC

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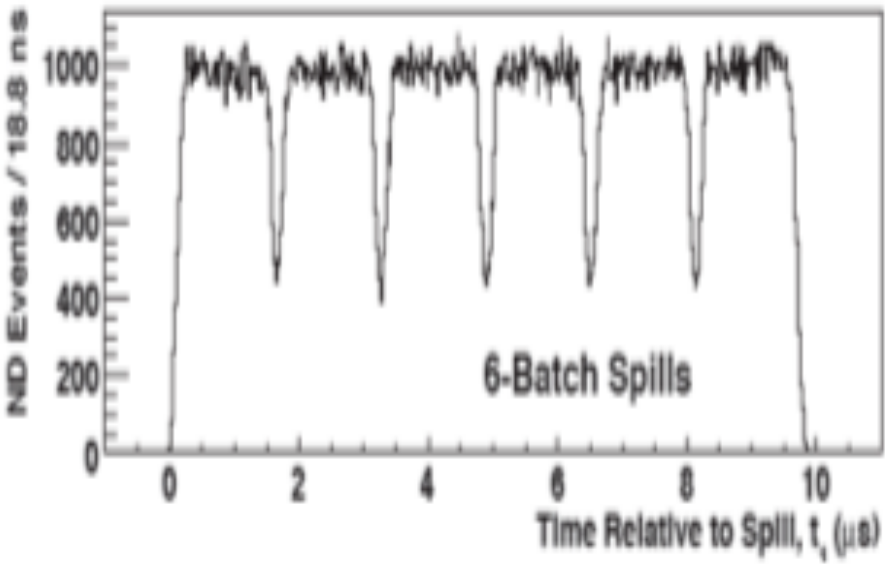
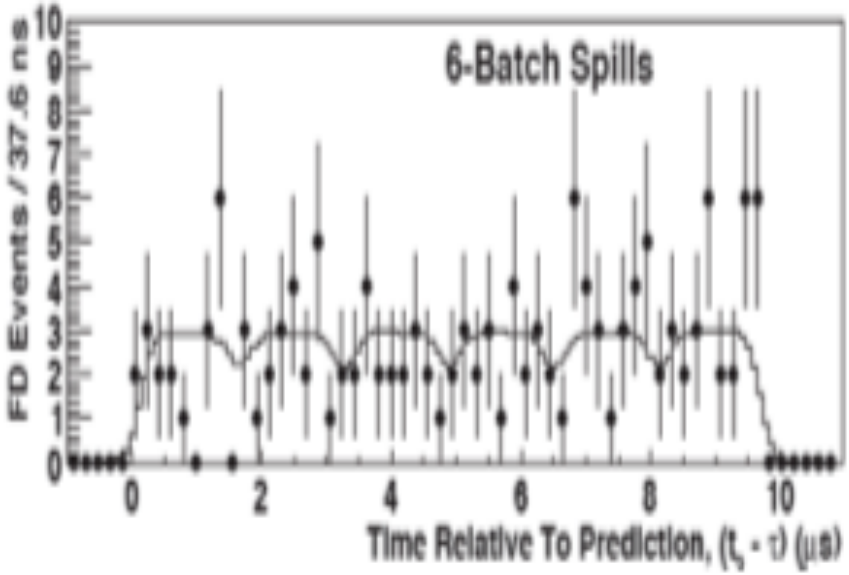
MINOS/OPERA similarities and differences.

- Baselines essentially identical → magnitude of effect should be similar.
- BUT beam energy is different. Lower energy from NUMI beam.
- MINOS has a near detector.
  - This allows for measurement of time at 3 points
    - Beam extraction point
    - MINOS near detector hall
    - MINOS far detector

Old Result (2007 PRD)





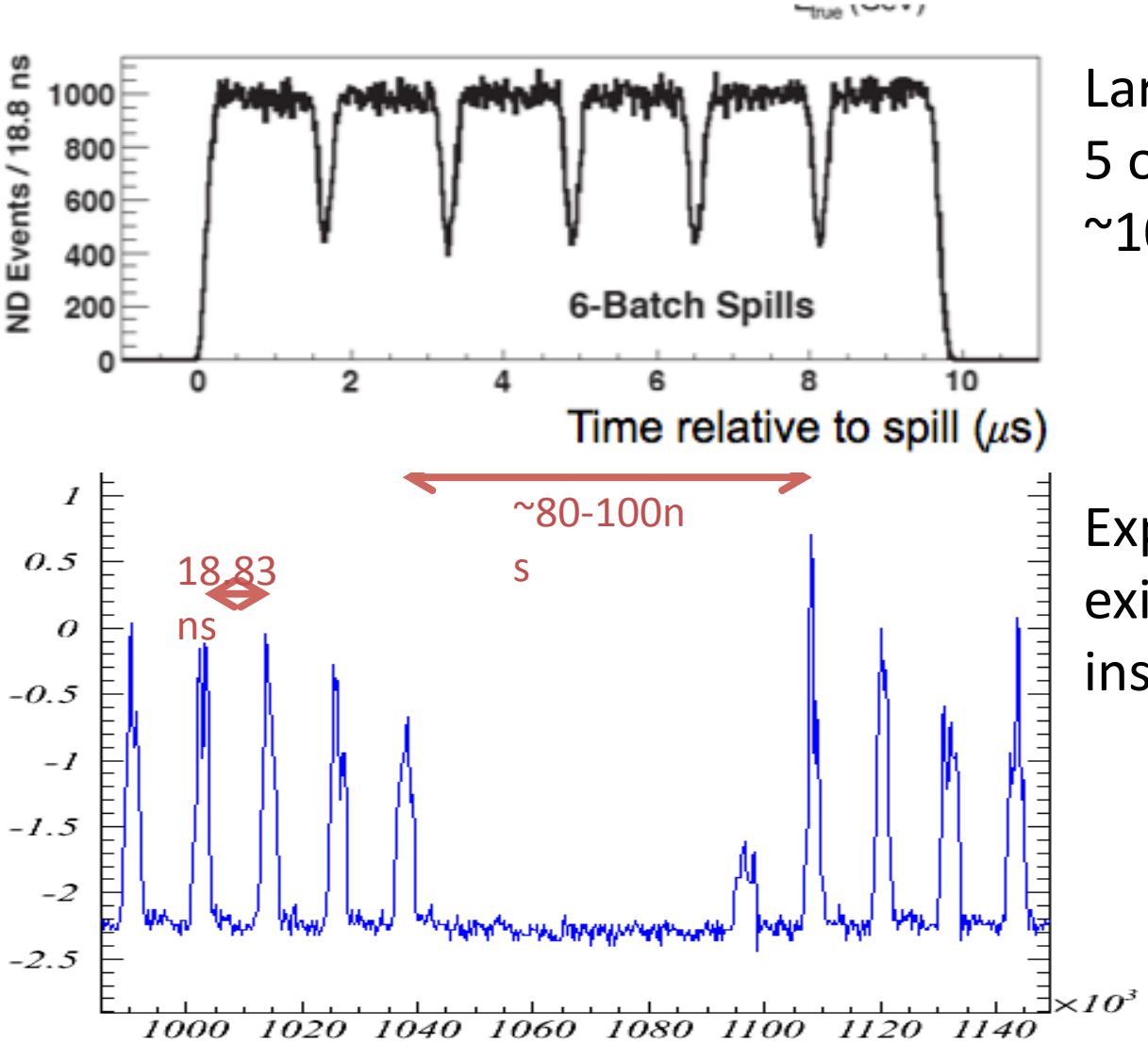
$$\delta = -126 \pm 32(\text{stat.}) \pm 64(\text{syst.})\,\text{ns} \qquad 68\%\text{C.L.}$$

Based on 473 events. Currently we have x9 more events or more.

A three-stage strategy

- Phase 1: analyze current data taken since start of experiment. Address most prominent systematic errors when possible.
- Phase 2: Upgrade timing system and add method to better characterize detector time responses. Use equipment during winter/spring of 2012 until shutdown.
- Phase 3: MINOS+ together with all lessons learned in previous 2 stages.
- Somewhat artificial division – each stage informs the others and the boundaries are not exact.

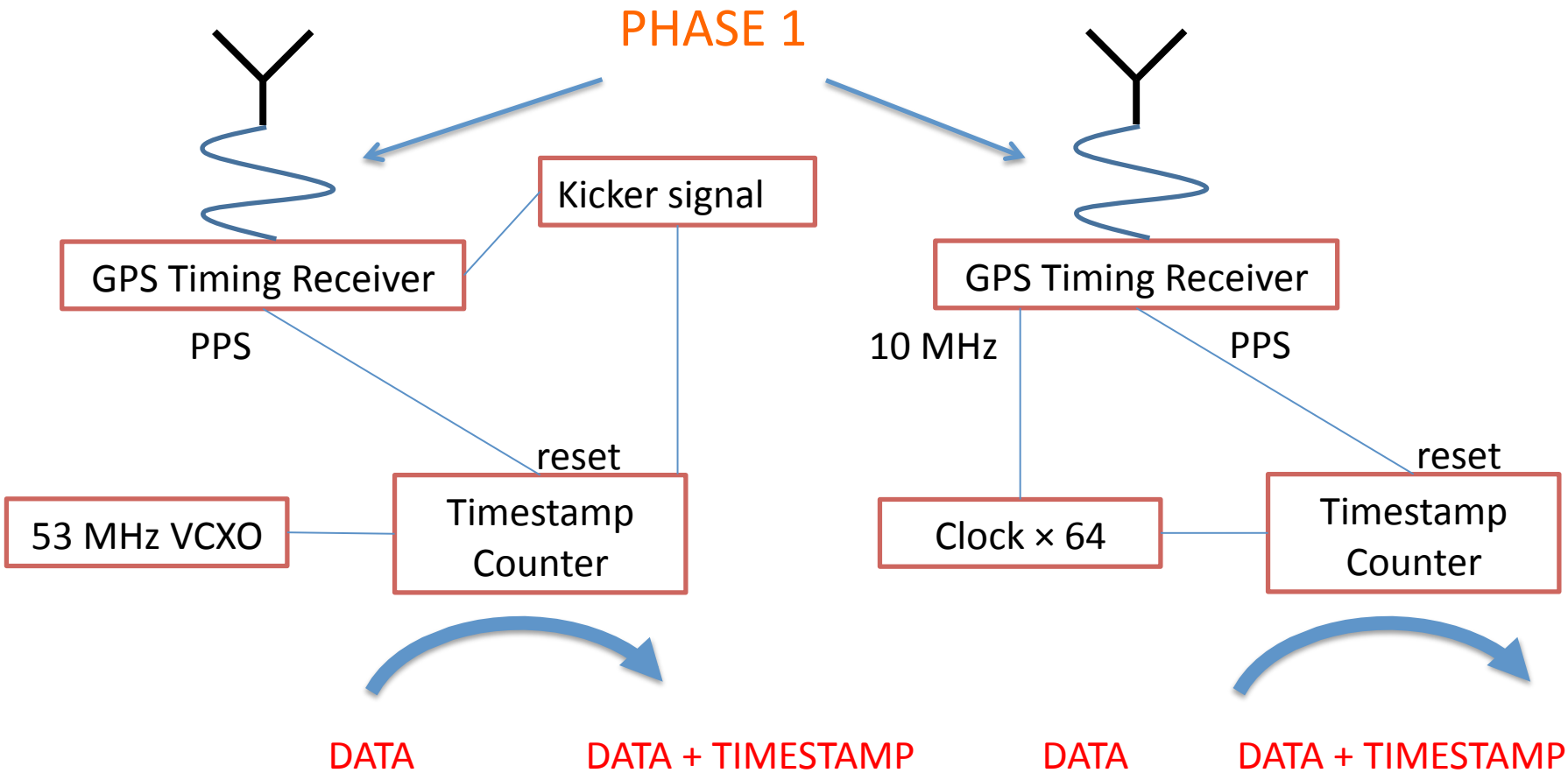
NuMI Beam Structure



Large scale (MINOS data)
5 or six batchs covering
~10 μs

Expanded scale from existing NuMI beamline instrumentation.

System Picture



Near Detector

Far Detector

Phase 1 errors under attack

Source of uncertainty	Size
Distance between detectors	2 ns
ND antenna fibre length	27 ns
FD antenna fibre length	46 ns
Near Detector electronics latencies	32 ns
Far Detector electronics latencies	3 ns
Detector readout differences	9 ns
GPS timing system	12 ns
Total (sum in quadrature)	64 ns

Phase 1 implementation status

- Will measure delays of fibers using “clock trip” technique.
- Commissioning mobile secondary readout path to establish detector system delays.
- Using additional GPS receivers plus Rb Clocks to characterize MINOS timing receivers.
- Extensive new data analysis and data quality checks.
- Internal timing calibration of both detectors.

Basic principle of Auxiliary Detectors (AD's)

Use auxiliary detectors to measure relative readout and electronics latencies

- Tag muons with the auxiliary detector at the MINOS Near Detector
- Move the auxiliary detector to the Far Detector and repeat

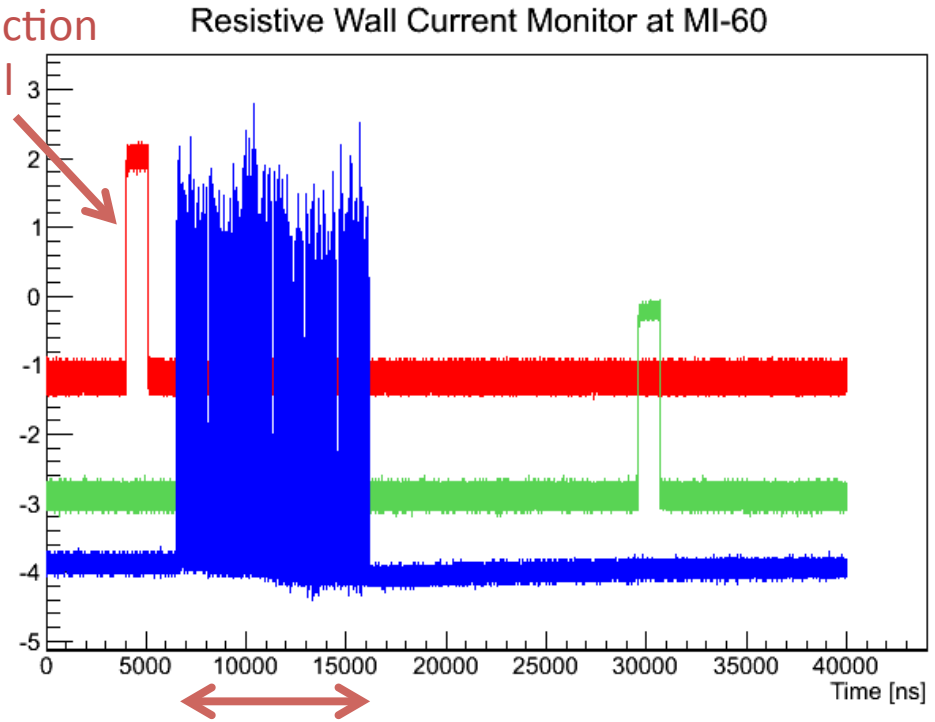
Aiming for an initial precision of 10-15 ns

Status of AD's

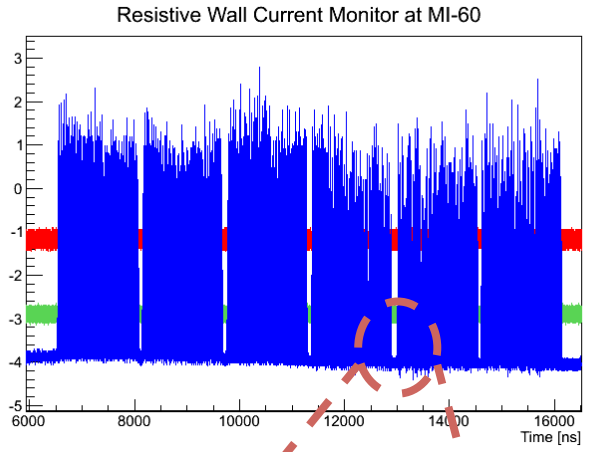
- Identified existing counters (last used as part of ArgoNeut)
- Two coincidence assemblies, plus test setup in UT Austin
- Installed one setup at rear of MINOS ND
- Readout under test at this time.

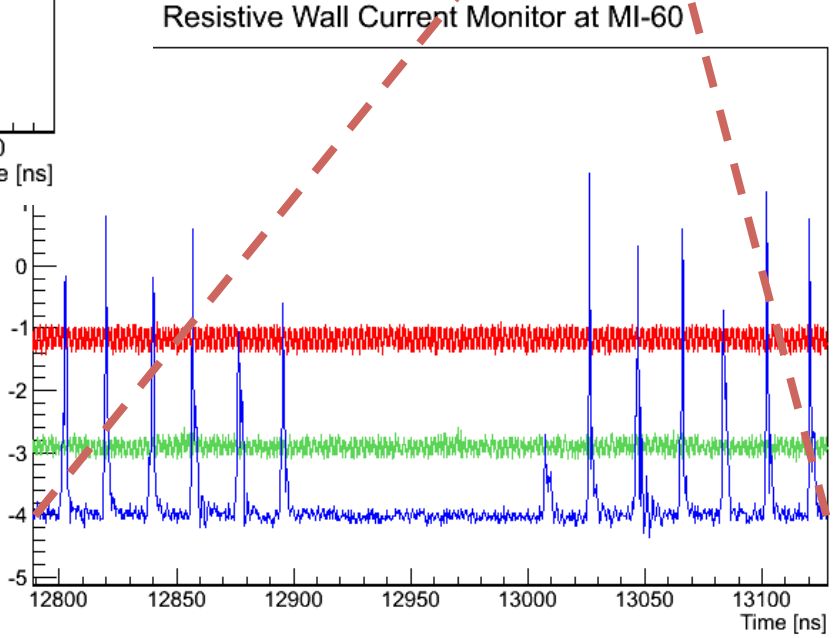
Measure protons in beamline

Beam extraction signal



10 µs beam spill



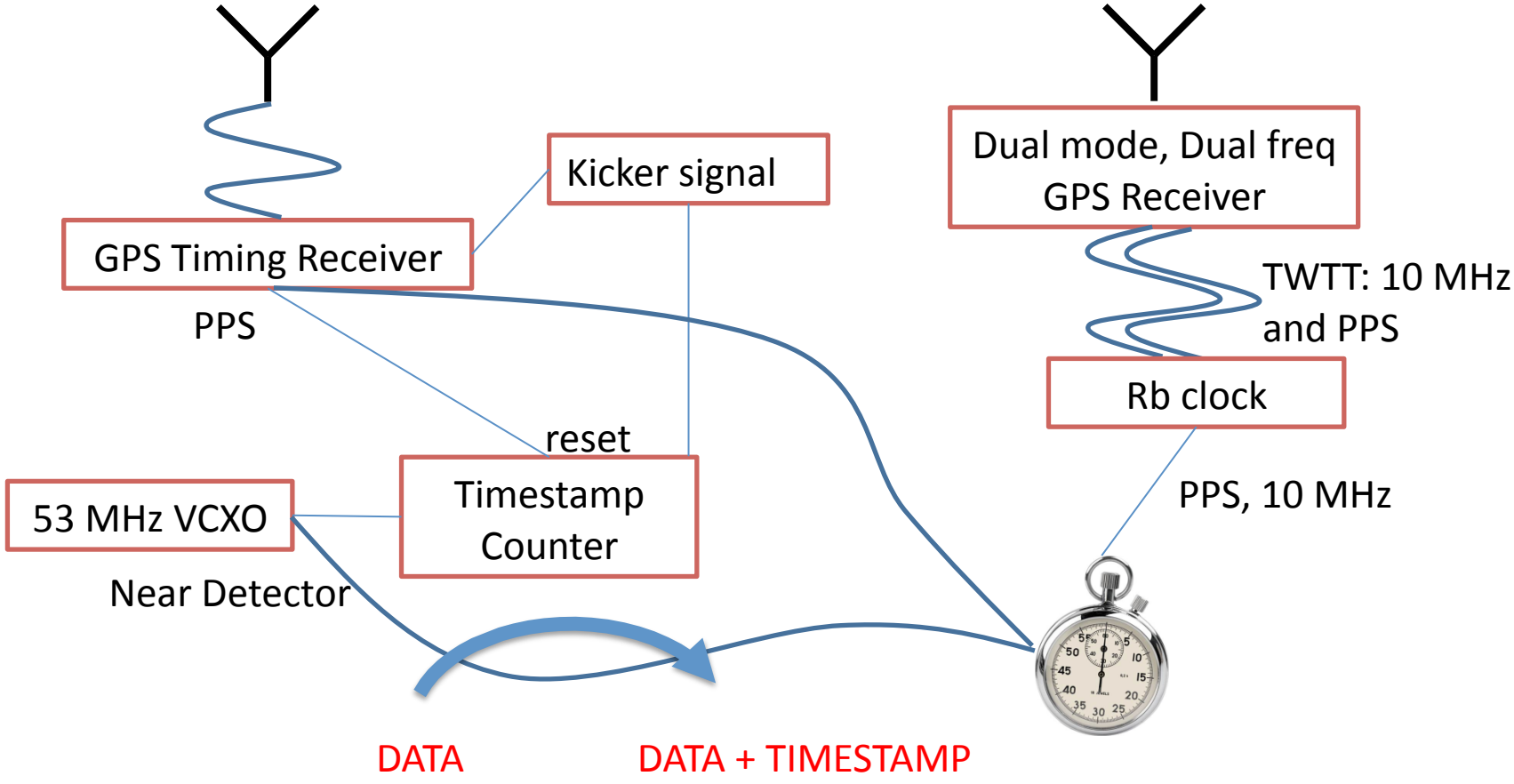


- Measure protons pulse-by-pulse
  - Remove proton jitter wrt beam extraction signal (=ND trigger)
- Time protons vs local clock / GPS
- Initial setup installed

Phase 1 error targets

- Fiber lengths at near and far detectors
  - Clock trips
  - ND: 46 ns → 5-10 ns
  - ND: 27 ns → 5-10 ns
- Electronics and readout differences:
  - Auxiliary detectors establish relative timing
  - Intrinsically accurate to ~5 ns but immediate target is: 33ns → 10 – 15 ns
- New estimated quadrature total is 18-25 ns

Timing Upgrade for Phase 2



Phase 2 errors under attack

Source of uncertainty	Size
Distance between detectors	2 ns
ND antenna fibre length	5-10 ns
FD antenna fibre length	5-10 ns
Readout and electronics differences	10-15 ns
GPS timing system	12 ns
Total (sum in quadrature)	18-25 ns

Phase Two – datataking during present run with upgraded timing system

- This is the stage that brings a full, modern timing system to bear.
- System involves multiple GPS systems (8), regulation by good clocks, and quasi-continuous calibrations.
- Everything learned in Stage 1 still relevant, as basic detector readout not changed.
- Time pressure because of run end.
- We are not undertaking this alone.

Collaborative Effort

- Workshop held on Nov. 8 at Fermilab
- Invited representatives from NIST Timing Division in Boulder and from US Naval Observatory.
- General agreement on strategy, schedule among the participants.
- USNO can provide very precise calibrations with loaned Cs clock and satellite van for TWSTT.
- NIST has offered to provide 6 calibrated receivers on loan and to commission more when parts are supplied, and to participate in continuing calibration and setup.
- Discussions on exact language of agreements underway.

Phase 2 and 3 error targets (These are estimates)

- Phase 2
  - Fiber delays 5-10 ns → 1-5 ns (for far and near).
    →
  - GPS error 12 ns → 1-4 ns
- Quadrature goal for stage 2 : 11-18 ns

- Phase 3
  - Resurvey underground position 2 ns → 1-2 ns
  - Fiber delays: 1–5 ns → 1-2 ns
    - (more experience with time transfer)
  - Readout difference: 10-15 ns → 1-5 ns
    - (more experience with AD and AD/MINOS integration)

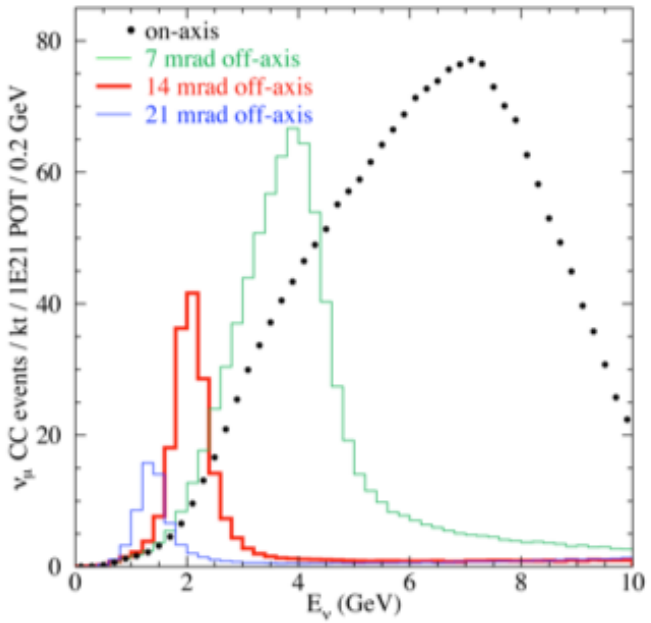
- Quadrature goal for phase 3: 2-7 ns

Statistical Error

- In 2007 paper was 32 ns from model of relative timestamp jitter.
- Preliminary studies with current data show potential for improvement, possibly to 5-6 ns range.
- This is from fitting batch edges and smearing parameter.
- In phase 3 we will seek to see bunch edges (5-6 ns wide on RF bucket of 19 ns).

Phase 3 – MINOS +

- Key is improvement in expertise.
- Potential hardware modifications depending on what we learn.
- Gives us plenty of beam quickly.



Conclusions

- Problem is of first importance. Recent OPERA check with customized beam only increases interest.
- MINOS has a strategy to attack this problem in collaboration with U.S. timing labs.
- MINOS is already implementing first stages of plan.
- Some cost for new hardware to do precise timing.
- Our top priorities are to have equipment in place quickly to utilize current or slightly extended running.