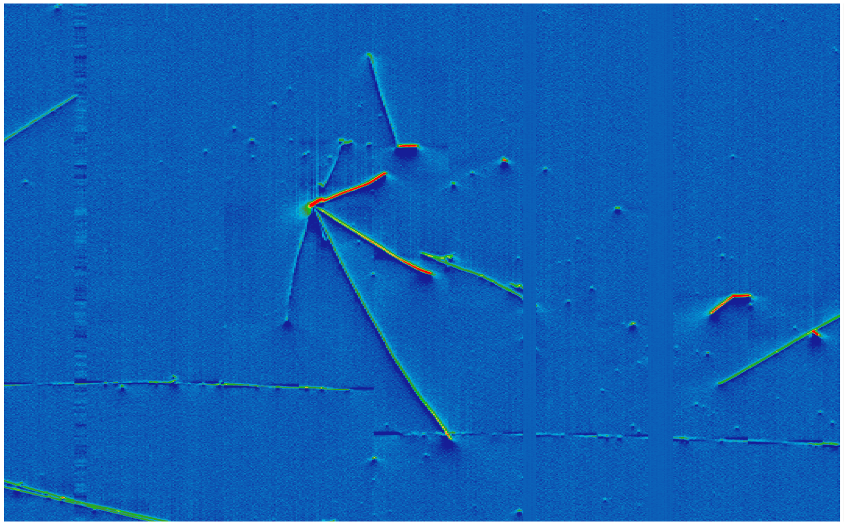
MicroBooNE: Analysis, Reconstruction & Operations



Sophie Berkman
SCD IF Meeting
June 2, 2020

MicroBooNE

MicroBooNE Run Coordinator

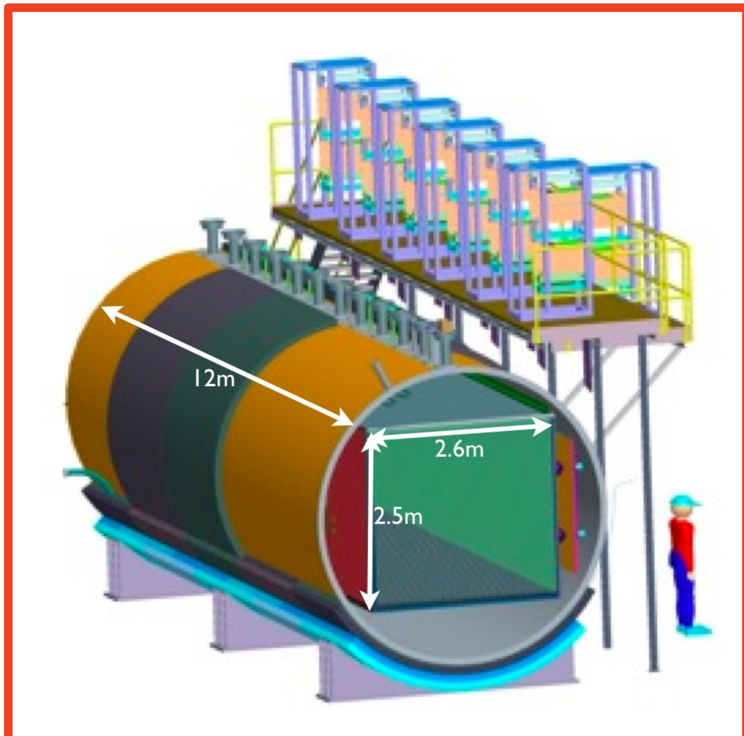
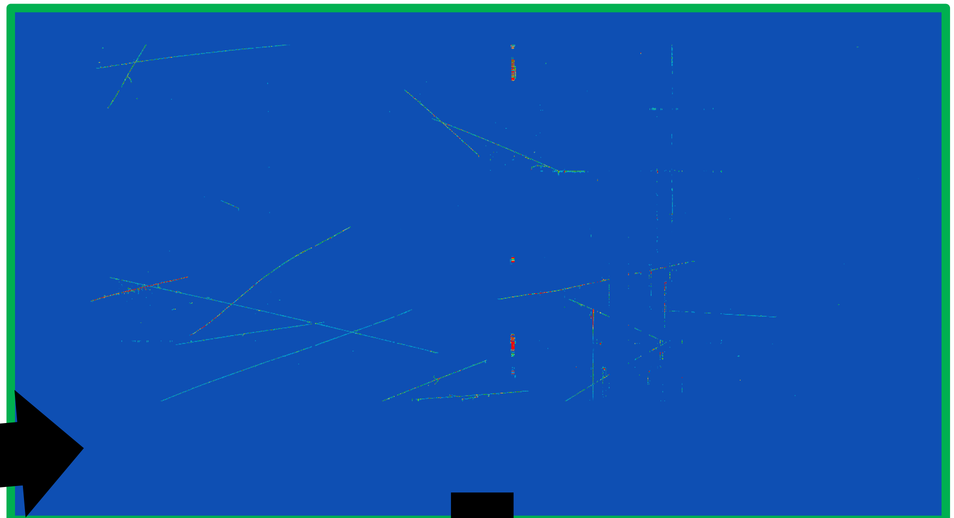


Figure: AIP Conf.Proc. 1189 (2009) no.1, 83-87

SciDAC HEP-Reco

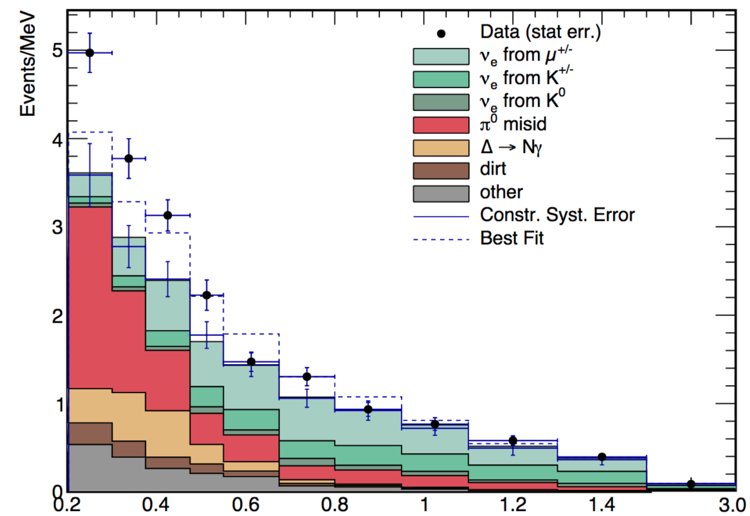


MicroBooNE
Oscillation Analysis

MicroBooNE Low Energy Excess Analysis

- MicroBooNE designed to address MiniBooNE excess in low energy ν_e data relative to MC (“LEE”)
- Pandora ν_e analysis:
  - High purity measurement
  - Measure full energy spectrum of ν_es
  - Multiple signal topologies

arXiv:1805.12028 [hep-ex]



Reconstructed Neutrino Energy (GeV)

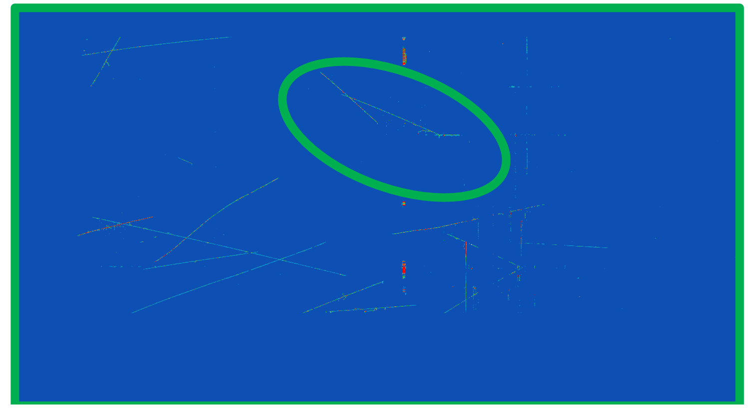
- ν_e CC, at least one visible p, no visible π
- Most signal sensitivity
- Proton track makes it easier to find vertex

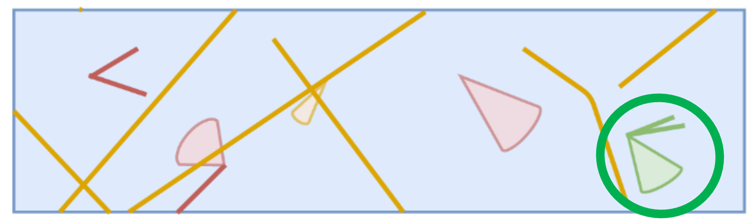
- ν_e CC, no visible p or π
- More signal events: up to 50% of low energy ν_es
- Constrain uncertainties related to proton multiplicity, kinematics, and reconstruction

Identifying Neutrinos

Select a neutrino candidate and remove cosmic backgrounds:

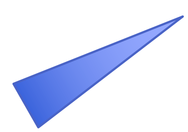
1. Hit reconstruction
2. Cluster and remove "obvious" cosmic activity
3. Decide on the sets of hits that comprise regions of interest called "slices"
4. Optical information is used to find the neutrino candidate most consistent with the beam timing to reduce cosmics.



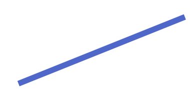


Slices contain tracks and showers used to reconstruct neutrino interaction

Showers (e, π^0):



Tracks (μ, p, π^+):

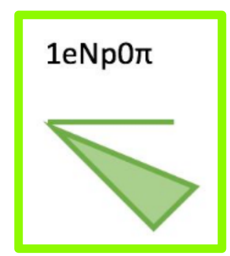


Categorize Neutrino Interaction

1. Count showers:

2. Count tracks:

1e0p pre-selection
- No proton candidates:
  0 contained tracks



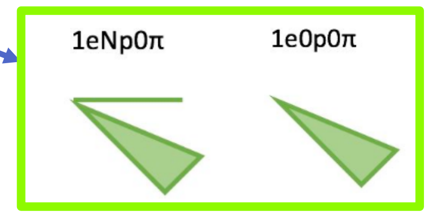
1eNp pre-selection
- Proton candidate:
  ≥1 contained track

Major Backgrounds

Events with one shower and no tracks

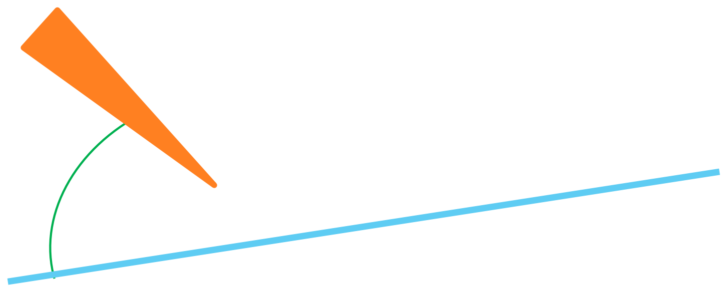
Cosmic muons

Muon neutrinos
mostly $NC\pi^0$, $CC\pi^0$

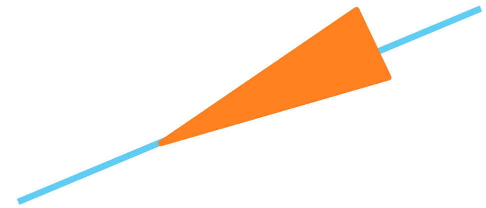


Cosmic Removal

- Angle between shower direction and closest track/shower tagged as a cosmic



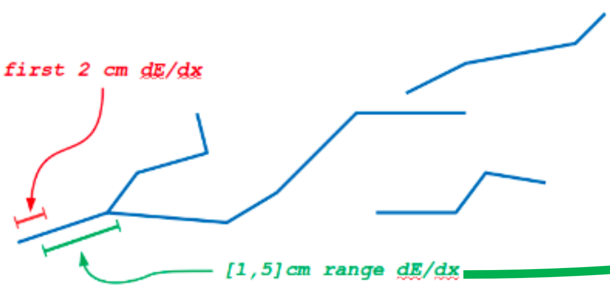
- Check showers are contained by looking at start and end-points when they are fit as tracks



π^0 Rejection

- Second shower search removes π^0s:

- dE/dx is a powerful separator of e and π^0s:



1e0p0π BDT Selection

- BDT to separate ν_e from backgrounds
- BDT Training:
  - variables to characterize properties of the event
    - dE/dx is most important.
  - Use dedicated low energy ν_e samples and π^0 samples.
  - No off-beam data used; increase weight of mis-reconstructed "cosmic" events instead
- ν_e enhanced at high BDT response

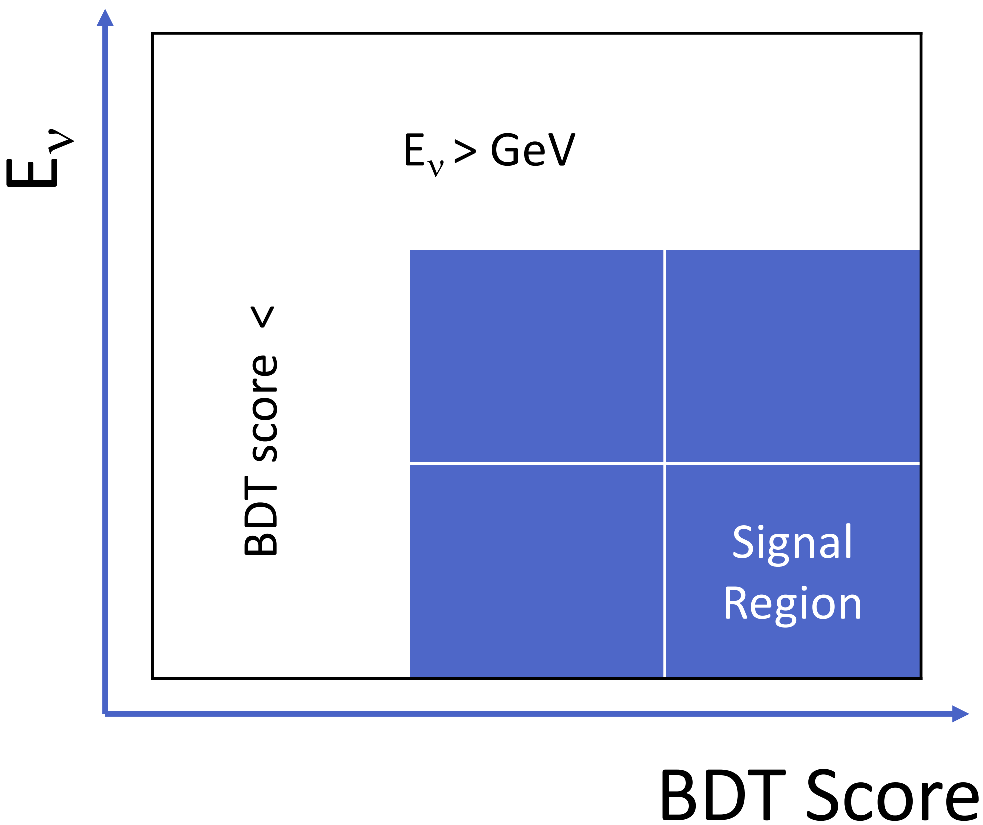
1e0p0π BDT Selection

- Expect 1e0p0π events, "LEE" events in full data set
- Purity (ν_e + "LEE") :
  - below 0.8 GeV
  - from 0.8-1.5 GeV
  - over all energies
- Efficiency (1e0p):
  for BDT selection
- Box cut selection also defined:
  - High purity
  - May be used as cross check

1e0p0π Unblinding Strategy

- Open sidebands first:
  - Low BDT response to validate background model: BDT score <
  - High energy neutrinos: E_ν > GeV

Low BDT Score



1e0p0π at High Energy (E_ν > GeV)

- Good separation between π^0s and ν_es with dE/dx
- Select 1e0p candidate events at high energy

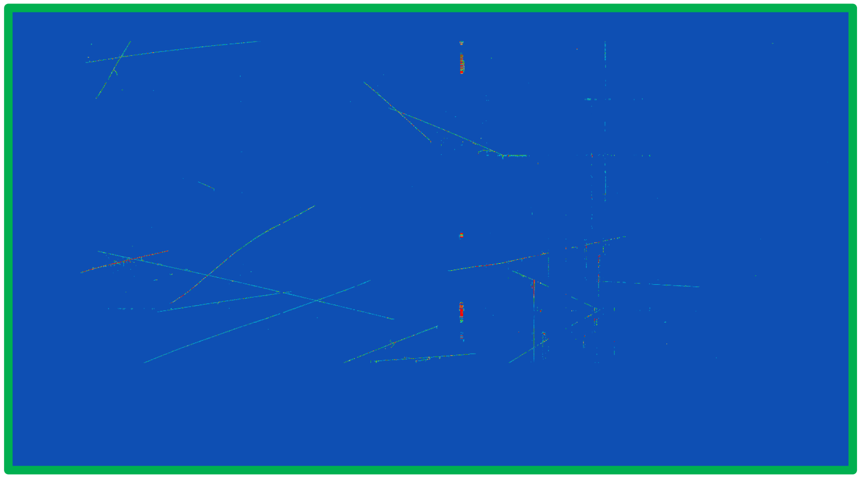
1e0p0π Conclusions

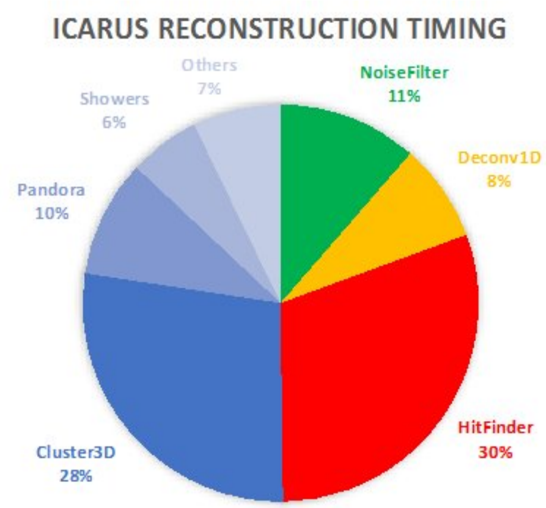
- Developed selection of 1e0p0π events for MicroBooNE LEE analysis
  - First selection of single electron events in liquid argon TPC
- Systematic uncertainties evaluated, and sample is included in fit for sensitivity to MiniBooNE anomaly
  - Including this sample improves the sensitivity of the analysis
- Analysis is in an advanced stage; currently undergoing internal review
  - Publication expected later this summer

SciDaC Project: HEP Event Reconstruction

- Study improvements to liquid argon reconstruction using vectorization and modern computing architectures
- Focus on signal processing algorithms
- Hit finding algorithm:
  - Took O(100 s) to process a µBooNE event (8,256 wires)
    - MCC8 reconstruction
  - 30% of reconstruction time for Icarus
  - Improvements necessary for a larger scale experiment like DUNE (384,000 wires/ 10 kTon cryostat)

SciDAC HEP-Reco

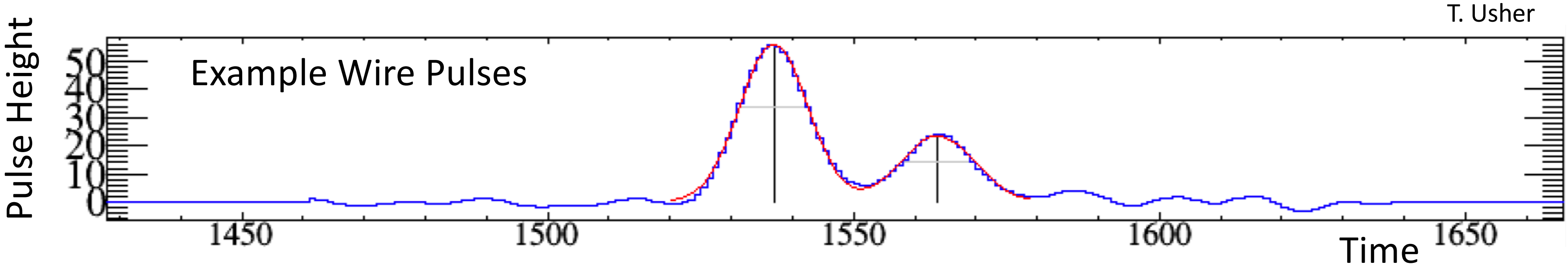




Feasibility study: GausHitFinder

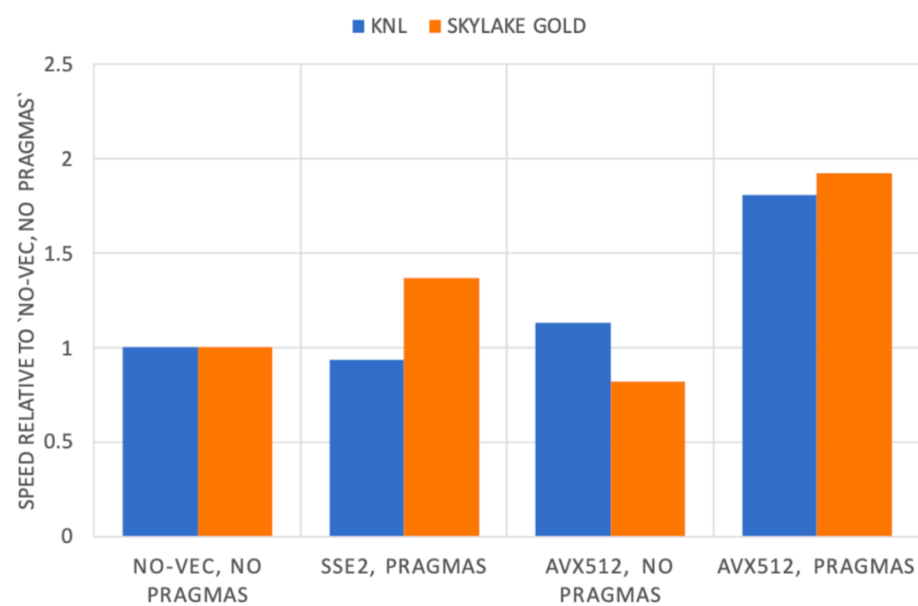
- Feasibility study: GausHitFinder
  - Charged particles produce pulses on wires. Identify and extract parameters associated with pulses (position, amplitude, width).
  - Wires are independent; can be processed independently
  - Few percent to few tens of percent of reconstruction depending on the experiment
- Vectorization and parallelization developments were done within a stand-alone version of the GausHitFinder
  - Implements Levenberg-Marquardt algorithm to do the fitting
  - ROOT/ Minuit not suitable for parallelization due to global memory management
  - Stand-alone code is faster than the ROOT version, even before vectorization and parallelization.

T. Usher



Vectorization of Stand-Alone GausHitFinder

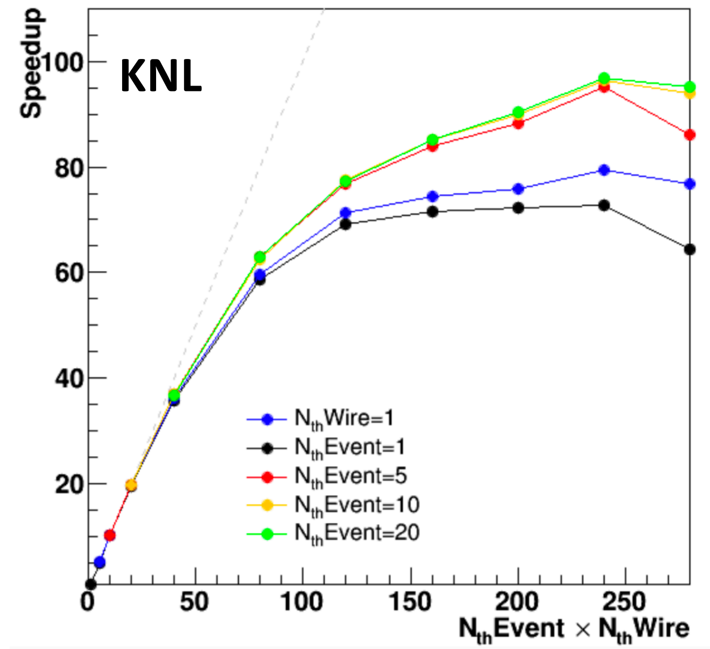
- Vectorization challenges:
  - Minimization difficult because fits converge in different numbers of iterations
  - Cannot fit multiple hits at the same time
  - Vectorize the most time consuming loop, over waveform data in each hit, but it is not all of the code
- Vectorization Strategies:
  - Compiler vectorization: use avx512
  - Explicit vectorization on the most time consuming loops
    - #pragma omp simd, #pragma ivdep
  - Loops determined by profiling the code
- **Speed increases**
  - **Explicit vectorization:** ~70% faster on KNL, ~90% faster on Skylake
  - **Compiler and explicit vectorization:** 2 times faster on KNL and Skylake than with no vectorization

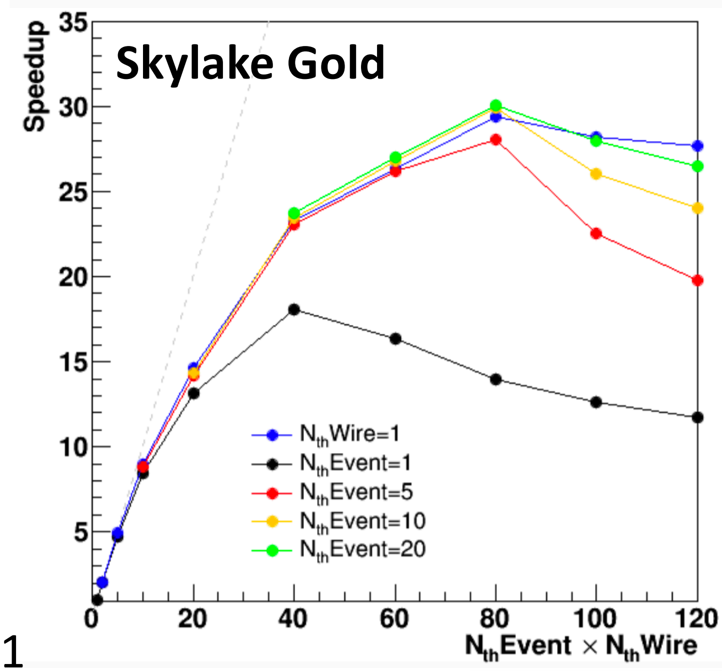


arXiv:2002.06291

Parallelization of Stand-Alone GausHitFinder

- Using OpenMP
  1. Parallel for loop over events
  2. Parallel region with OMP for + critical (to synchronize output) over regions of interest on the wires
  - Fastest with "dynamic" thread scheduling
- Parallelization challenges:
  - Algorithm has a relatively small amount of work.
  - Thread overhead may limit speed up
- **Speed increases with parallelization:**
  - KNL: up to 100 times faster
  - Skylake: up to 30 times faster

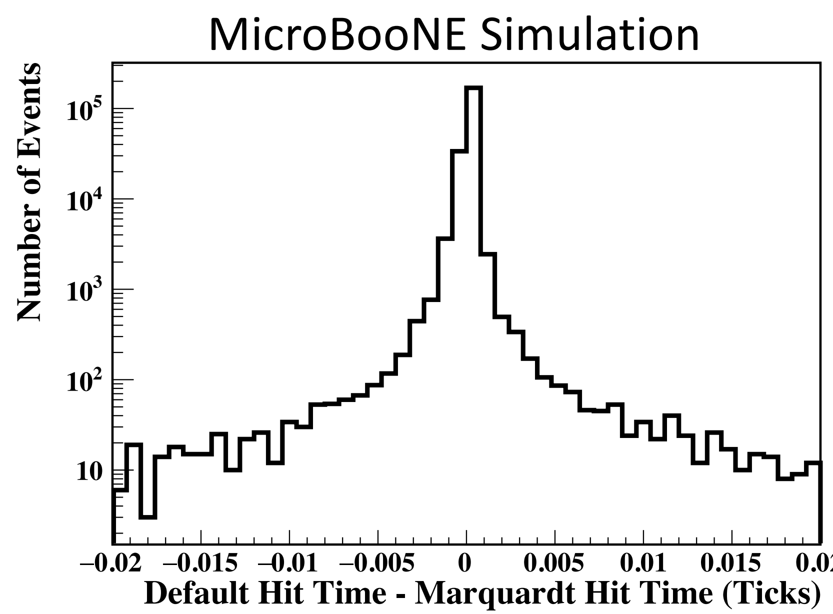




arXiv:2002.06291

LArSoft Validation

- Integrated a version of the stand-alone code with the Marquardt fitter into LArSoft
  - TBB parallelization
- Physics results are nearly identical.
  - Difference in number of hits at 0.02% level
  - 2% of hits with a difference in peak time larger than 0.02 ticks
- **Improvements (before parallelization):**
  - MicroBooNE: 12 times faster on average
  - ICARUS: 7 times faster on average
- Icarus and ProtoDUNE are both using this version of the hit finder
  - Before, hit finder was 30% of Icarus reconstruction time
- Thread scaling within LArSoft still being studied



Icarus Reconstruction on HPC

- Run part of next Icarus production on the Theta HPC at ALCF to take advantage of vectorization and parallelization in signal processing
- Plan to contribute samples to the collaboration
  - Collaborating with HEP on HPC SciDac project
- First: requires a native build of LArSoft on Theta
  - Working towards compiling LArSoft with spack on Theta

SciDac Conclusions

- GausHitFinder has been vectorized and parallelized:
  - Up to 100 times faster with parallelization
  - Up to 2 times faster with vectorization
- Levenberg-Marquardt algorithm has been implemented to do the fitting in the GausHitFinder algorithm instead of ROOT
- New version of the GausHitFinder integrated into LArSoft:
  - 12 times faster on MicroBooNE overlay events, 7 times on Icarus
  - Physics results nearly identical to current LArSoft version.
  - Not yet taking advantage of all of the potential vectorization and parallelization improvements, which are further independent speed-ups.
- Ongoing: Contribute to Icarus reconstruction production on HPC to take advantage of signal processing parallelization and vectorization
- Hit finder paper planned for later this year

MicroBooNE Run Coordinator

MicroBooNE Run Coordinator

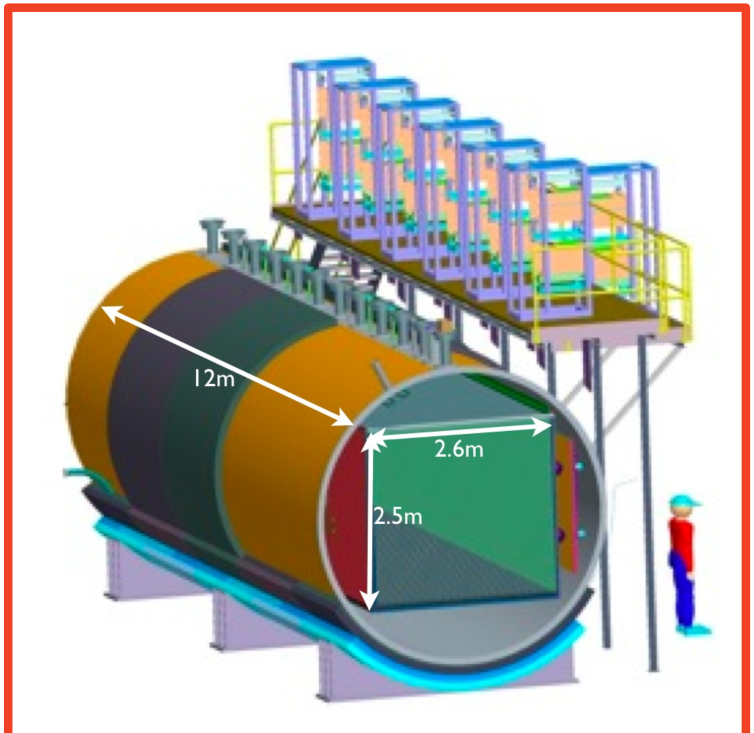


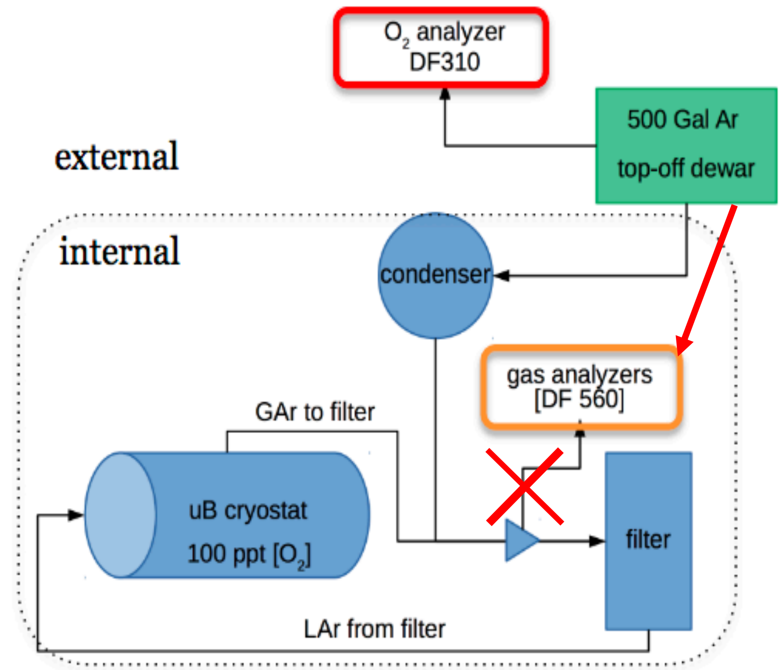
Figure: AIP Conf.Proc. 1189 (2009) no.1, 83-87

- Served six month term (April – September 2019)
- Reported to experiment and lab management about detector operations
- Coordinated with detector and Fermilab experts when work was needed to maintain or repair the experiment.
- Ran weekly status meetings and presented operation reports
- On call to respond to shifter issues and detector concerns
- Weekly walkthrough of the detector
- Developed interactive shift training for new collaborators and future run coordinators
- Managed three power outages
- Helped with laser calibrations

Selection of projects to follow

Liquid Argon Purity

- Keeping argon free of contaminants is important for a good light and charge detector response
- Observed drop in TPC pulse heights and PMT rates around cryostat fills from external dewar
  - Stopped analyzing argon in cryostat
    - Analyzers not sensitive enough to detect impurities observed in TPC
    - Top off detector every ~1.5 months instead of every 2 weeks
    - Fewer opportunities to introduce contaminants
  - Regenerated filters
    - Recover more quickly in the future if there are contaminants in the argon
  - Studied if MicroBooNE was historically impacted by cryostat fills with SULI student G. Rizzo



Light Rate after Regeneration

Contaminated Cryostat Fill

May Fill

June Fill

Kid Skid

Usual Filter Regen

May Fill

June Fill

July Fill

Power Outages

Kid Skid

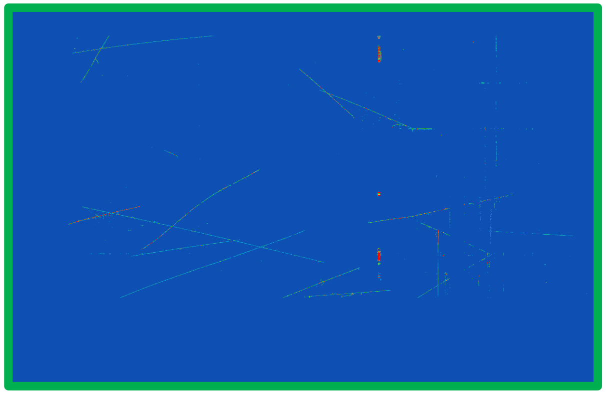
Usual Filter Regen

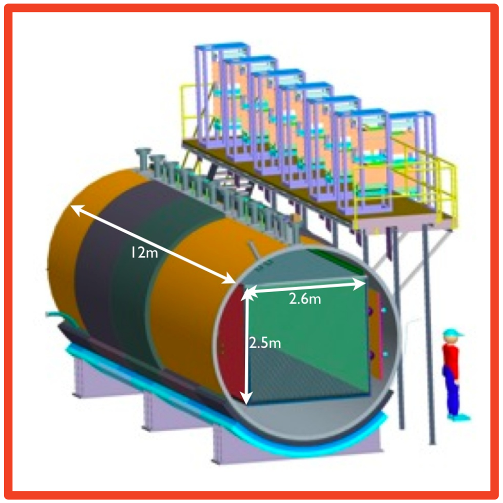
Ongoing Operations Related Work

- **Argon gas analysis:**
  - Managing argon purity, measuring for contaminants and topping off safely are important topics for long running liquid argon experiments.
    - Learn as much as possible from MicroBooNE to inform SBN and DUNE.
  - Ongoing mystery about light yield decline in MicroBooNE run 2
    - Hypothesize related to addition of contaminants
  - Test with argon gas analysis:
    - Shipping a sample to CIEMAT (Spain) to measure heavy mass contaminants
    - Exploring a commercial lab in Texas to measure low mass contaminants
    - Discussions about measurement capabilities at Fermilab
  - Ongoing project; expect this will be published when complete
- **Tours:** frequently giving tours of LArTF
- **Consulting** with current operations team: eg. Argon pump replacement, recovery from N2 leak, operations contingency plans during COVID19

Conclusions

- **μBooNE Low Energy Excess Analysis:**
  - Developed selection of 1e0p0π events for MicroBooNE oscillation analysis
    - First selection of single electron events in LArTPC
    - Improves sensitivity of analysis to MiniBooNE anomaly
  - Advanced analysis; undergoing internal review
- **SciDAC HEP-Reconstruction:**
  - Vectorized and parallelized GausHitFinder
    - Speed-ups of up to 100x
    - Included in LArSoft. Used by Icarus and ProtoDUNE.
  - Working towards HPC workflow of Icarus reconstruction to take advantage of vectorization and parallelization of signal processing
- **MicroBooNE Run Coordinator:**
  - Managed operations and completed projects to help improve the physics output of the experiment
  - Argon gas analysis to understand detector response





Next Steps

- **µBooNE Low Energy Excess Analysis:**
  - Complete internal review and publish result
- **SciDAC HEP-Reconstruction:**
  - Paper on GausHitFinder parallelization and vectorization
  - HPC workflow of Icarus reconstruction to take advantage of vectorization and parallelization of signal processing
  - Present at a technical conference