Reconstruction as Analysis

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What is reconstruction?

- Process of taking “raw” data to physically-meaningful quantities that can be used in a physics analysis
  - The ultimate goal: list of particles produced in an interaction and their four-vectors

- LArTPC reconstruction is not a solved problem, and has many challenges
  - Large data volume
  - Development of stable, fully-automated reconstruction paths
  - Handling high-occupancy environments
    - Surface detectors, reconstruction near interaction vertices
    - Interplay of topological and calorimetric reconstruction
Typical reconstruction chain

- **Raw TPC data**
- **Raw Optical data**

**Sig. Processing**
- Noise filtering
- Signal de-convolution
- Calibration
- Hit-finding

**2D-Reco**
- Hit Clustering

**3D-Reco**
- Track-finding (short and long tracks)
- Multiple scattering
- EM shower-finding
- Vertex-finding

- Optical flashes

**Calorimetry and Particle ID**

- Match to TPC

- Final-state particles
Of course, more complicated than that …

- Reconstruction generally needs to be more iterative
  - E.g. one MicroBooNE path reconstructs assuming track directions are cosmic-like, removes likely cosmic tracks, then reconstructs assuming remaining particles are neutrino-interaction-like
  - E.g. signal deconvolution and hit reconstruction benefits from vertex reconstruction, 3D position, and track direction

- Reconstruction can benefit from pushing to 3D sooner, rather than having a 2D plus matching step
  - Work on 3D clustering and “WireCell” reconstruction

- Imaging detectors can make use of computer vision techniques
  - E.g. Convolutional neural networks
Reconstruction as analysis?

- Quality of analysis obviously tied to quality of reconstruction
- LArTPC reconstruction core piece of analysis work
  - Maybe *the* core piece of protoDUNE analysis work
- Examples…let’s run through the reconstruction chain a bit and talk as we go
  - I’ll be pulling from MicroBooNE studies/results a little bit as we go through, for reasons that I think will be clear…
Noise Filtering

- MicroBooNE uses an earlier version of BNL cold electronics
  - Cold pre-amp and shaping, no digitization
- Good signal to noise! But noise can come from other places
  - Warm-side amplification/digitization
  - Electronic noise from other circuits
  - Electronic noise from wire bias power
  - Electronic noise from HV power
  - Microphonic noise from wires moving due to LAr convection
  - Identification through FFT and basic baseline/noise checks
  - First stage of reconstruction → clean up the noise!
Noise filter: before/after
“CalWire”: Translating raw signals to ionized e⁻

- Downstream reconstruction depends on a normalized response per wire and per plane
  - Application of calibration constants for wire response
  - Deconvolution of E-field effects (electron drift near wires) and signal shaping from electronics
    - COMPLICATED: there are induced charges from neighboring wires
      - We don’t perfectly understand what happens in a perfect detector
      - Our detector is not perfect
    - 3D simulation of E-field response, data-driven field response determination, and 2D deconvolution methods underway in MicroBooNE


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Field lines and predicted response

Garfield simulation of weighting field

Garfield simulation of field responses

Tingjun Yang, Docdb 1544
MicroBooNE:
Deconvolution example in U plane

After noise removal

MicroBooNE Preliminary

After 1-D deconvolution

After 2-D deconvolution

wire (33 cm)

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Hit reconstruction

- For hit-based reconstruction methods, we typically search for Gaussian-like signals on wires
  - Must handle signals near interaction/decay vertices and crossing particles properly
  - Fit multiple Gaussian(s)? How many? When do you give up?
2D→3D reconstruction

- Algorithms at this stage largely follow similar approach:
  1. Run some clustering of hits in each view, attempting to define cluster per particle
  2. Match info across views to form 3D objects
  3. Iterate to some optimal matching
  4. Run 3D track-fitting for track-like objects
The approaches (some of them)

- There are a number of approaches here (I’m missing big ones). Things you’ll see
  - LineCluster/TrajectoryPoint reconstruction
    - Follow sequences of nearby hits to form trajectories
    - Use hit charge to determine consistency with particle type
  - Pandora
    - Suite of pattern recognition algorithms implementing particle-flow based reco
      - Start with what you know, make repeated small iterations to improve knowledge piece by piece
      - Build hierarchy of “particles” matched to clusters and underlying hits
  - Projection Matching (PMA)
    - Build 3D hypotheses, and iterate/match to 2D hits based on expected projections in each plane
      - 3 views allows independent verification of built 3D objects
LineCluster example

Different colors represent different line clusters.

More in https://cdcvs.fnal.gov/redmine/documents/727
Direct to 3D reconstruction

- A few approaches here…
  - 3D clustering (still in early development)
    - Take hits, match between views to form 3D space-points, and cluster these
      - Aggressively prune out “ghost” hits using 3D track-fitting algorithms
  - WireCell
    - Tomographic reconstruction
    - Use fact that 3 views (should) see same charge
    - Invert translation matrix of true → observed charge depositions → 3D space points
    - Then followed by similar clustering/track-fitting steps

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EM Shower reconstruction

- EM shower clustering rather different beast than tracking
  - Algorithms need tuning to handle

- Examples of approaches
  - Blurred clustering
    - Smear hits in 2D to get more consistent clustering results
  - OpenCV clustering
    - Use variety of common image-processing tools (including blurring, edge-finding, corner-finding) to get consistent clustering
  - Methods generally still benefit from some mop-up of remaining hits
    - → directly into EM energy resolution

- In complicated interactions, may need initial region-of-interest finding!

- Note: EM showers at different energies very different!
MicroBooNE early studies

- Relies on identification of vertices from other reco chains
- Looks for shower-like clusters
  - i.e. non-track-like clusters
- Feeds smaller “image” and hit collection for further reco
Calorimetry and PID

- Much of this work has been done in ArgoNeut and LArIAT
- For track-like objects: exploit dE/dx vs. residual range
  - PIDA parameterization from B. Baller
- For showers, need dE/dx at start point of shower
  - I expect there will be need to be potential improvements to standard methods here…
  - Optimization of selection, improving fits to dE/dx vs. residual range, etc.

Truth-level info for PID. From ArgoNeuT: Acciarri et al, 2013 JINST Vol. 8 P08005
Summary

- General reconstruction chain still in development
  - Ideas are there with lots of options
  - Now the hard part is pulling it together in a working system

- Surface detectors have a particular challenge due to cosmics that I did not touch on
  - Identifying potential neutrino interaction is the bulk of the early work for the SBN experiments
  - For protoDUNE … how much can we rely on beam instrumentation to help us know where to look?
    - How much cosmic removal do we need to do
    - space charge effects can lead to large spatial distortions near edges of detector

- Reconstruction work plays directly into analysis techniques and selection