The 3DST Reconstruction

CubeRecon Status

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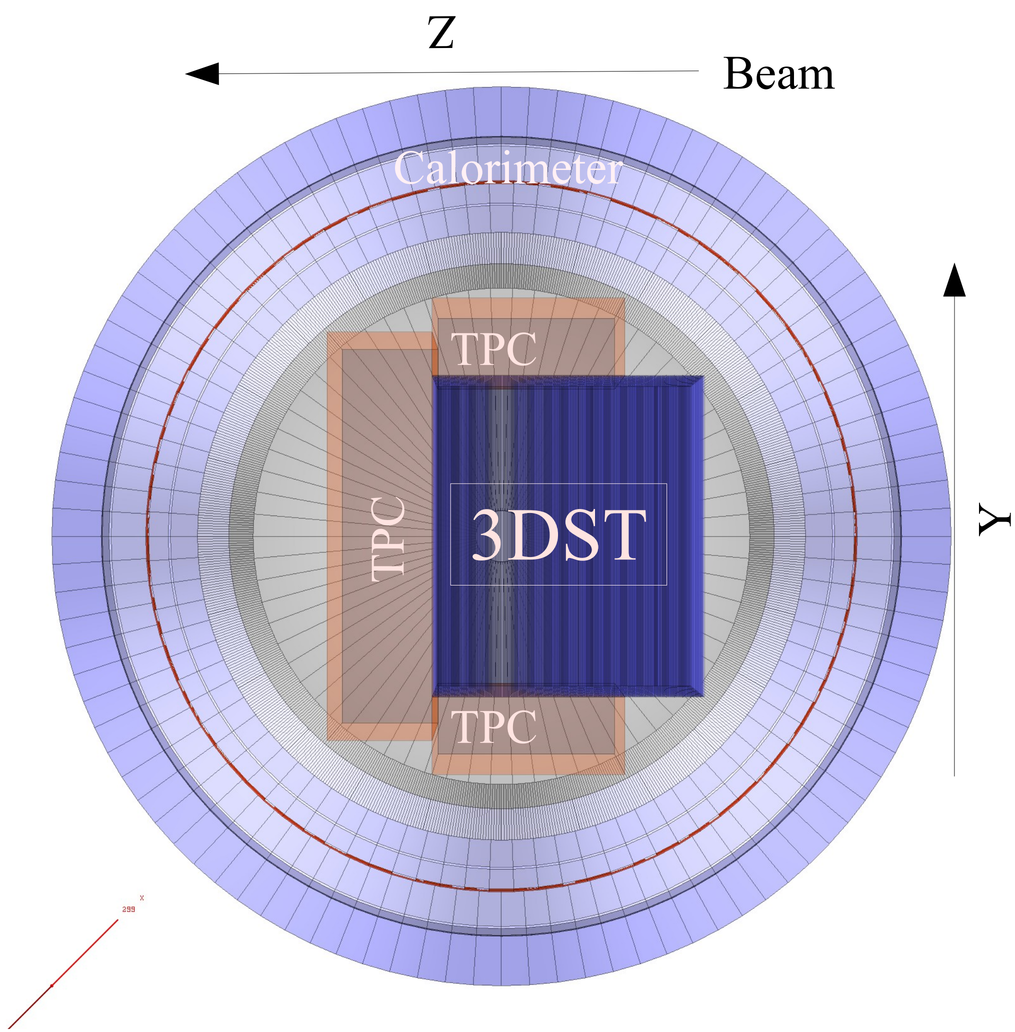
- The existing 3DST and TPC software stack
- The (mainly) 3DST reconstruction concepts
- Basic evaluation of the 3DST performance
- Reconstructing the TPC: Pattern recognition
- Reconstructing the ECal: Hit formation

Geometry for 3DST, TPC, Calorimeter & Magnet

- All geometry is taken from DUNE ND-GGD
  - Software uses the input geometry, so it's insensitive to updates
- 3DST Geometry
  - Cube size: 10mm x 10 mm x 10 mm
  - Cubes: 252 x 236 x 200 (11.8944 M)
  - Channels: 157072
    - 59472 xy + 50400 xz + 47200 yz
  - Mass: 12.49 tons
- TPC
  - Based on Resistive MicroMEGAs
- Calorimeter
  - KLOE calorimeter installed with magnet
- Magnet: 0.6 Tesla



SAND Geometry v.13

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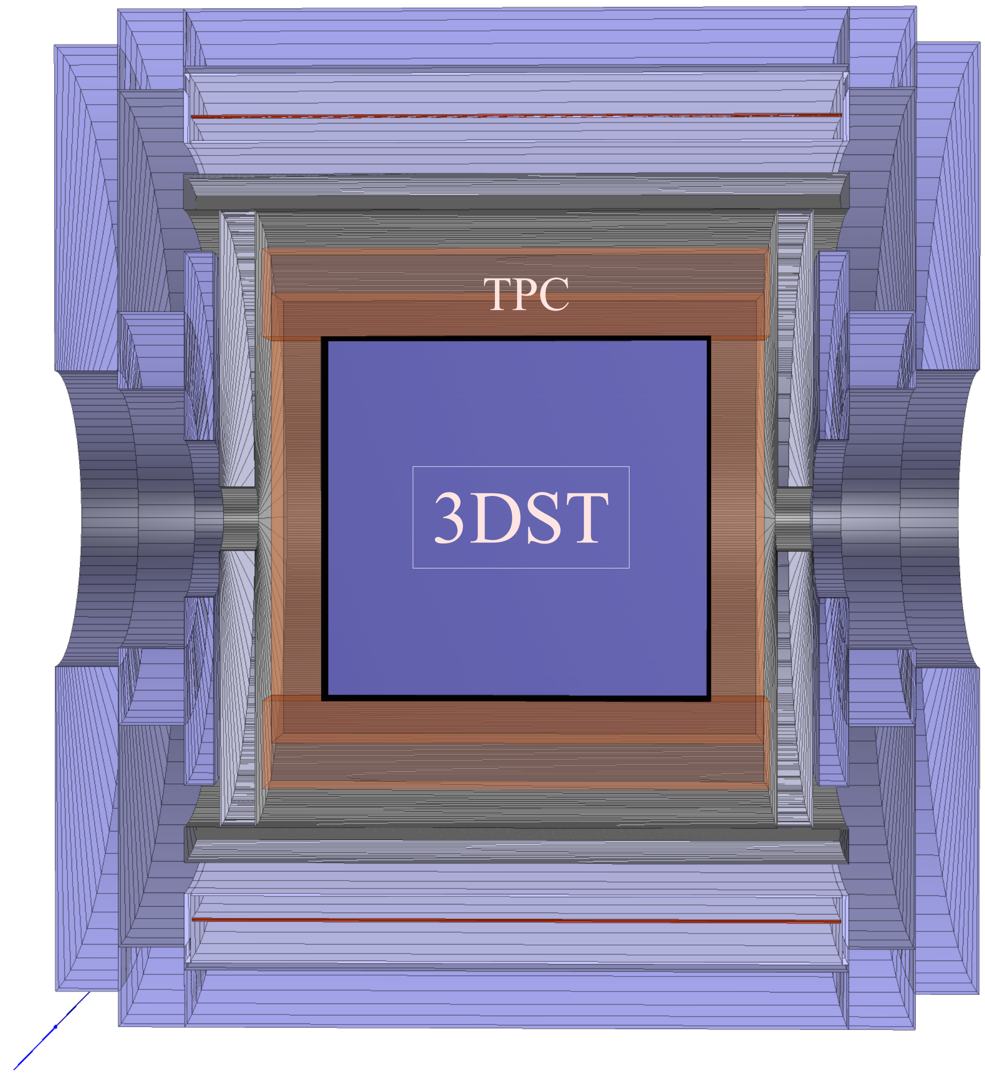


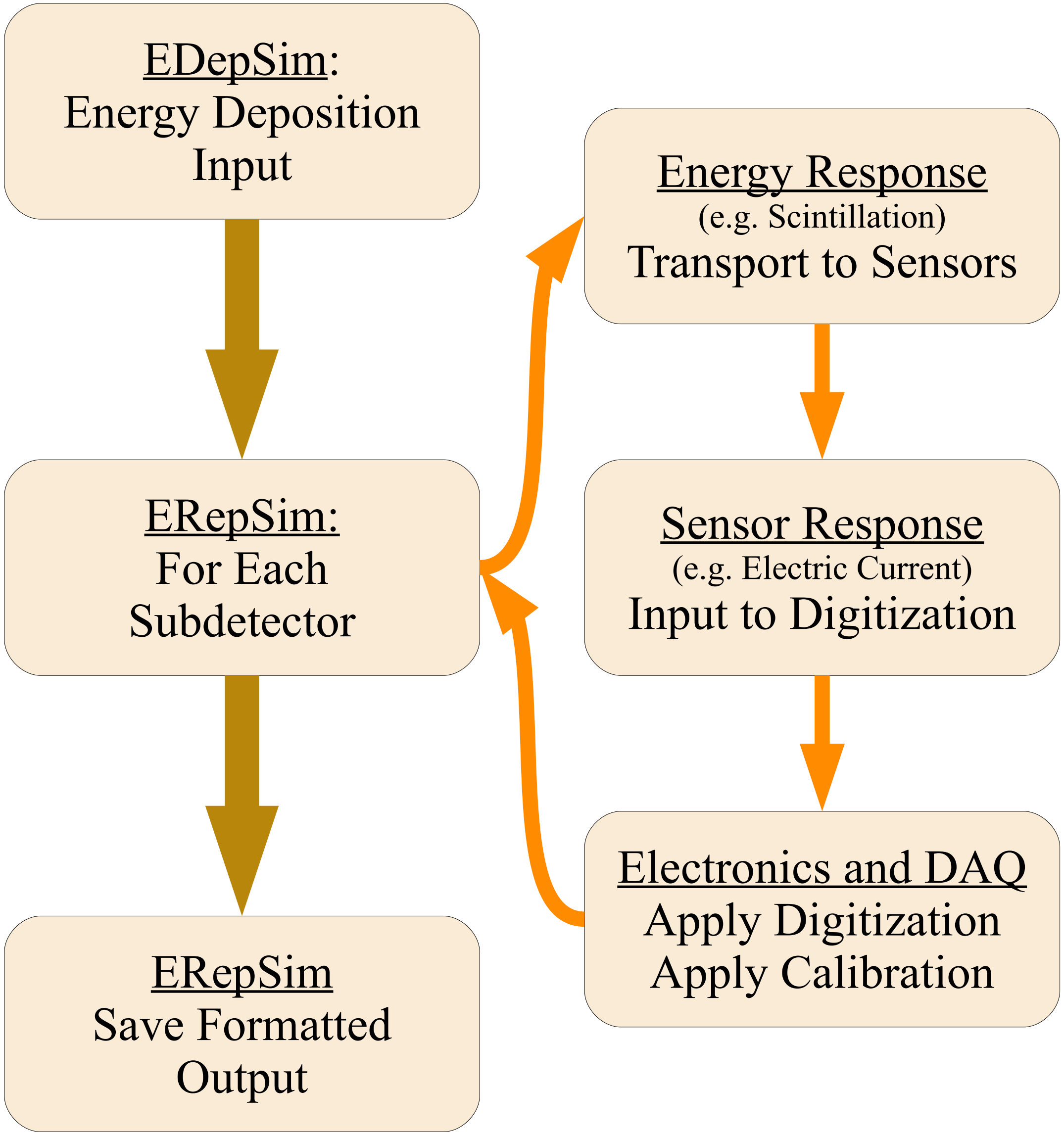
The Software Stack

- EDepSim
  - The 3DST (and TPC, &c) geometry from DUNE-nd ggd
  - Models energy deposition in the detector
- ERepSim
  - Simulates the scintillation, fibers, electron drift, sensors, electronics, and DAQ
  - Handles multi hit electronics, currently using an idealized multi-hit ADC/TDC with simplified sensors
  - Calibration is simulated
    - i.e. “Digitize” and then “Calibrate” the electronics
- Base Libraries:
  - Software stack is being implemented as a series of stand-alone tools
  - Goal is to remain as agnostic as possible about the computing environment.
- Reconstruction
  - Largely follows from the T2K Super FGD event reconstruction
  - Called “Cube”, but primarily depends on the existence of 3D hits.
    - Produces fitted tracks, clusters and vertices (not saved yet)
  - The reconstruction includes an event display to diagnose and visualize reconstruction results
- Physics Analysis Tools

ERep-Sim

The Energy Response Simulation

- Apply the effect of the detector (i.e. translate EDepSim output to into hits)
  - Output as calibrated hits
  - "Raw" data produced internally, but not saved
    - Can be saved if "DAQ" is defined
- Structure of simulation
  - Response to Energy
    - Scintillation, ionization, saturation, attenuation, transport to sensor, &c
  - Response of Sensors
    - Dark noise, baseline offsets, &c
  - Performance of Electronics
    - Amplification, thresholds, resolutions, &c
  - Structure of DAQ
    - Zero supression, event building, &c
  - Calibration
    - Apply calibration to internally digitized hits.



3DST Model in ERepSim

- Response
  - Tuned to SuperFGD beam test [arxiv.ins-det:2008.08861]
    - Produces about 200 pe per cube
  - Cube-to-cube light transparency tuned to SuperFGD beam test data
  - Attenuation taken from measured Kuraray WLS fibers, fibers are not mirrored
  - Scintillation timing is exponential [6 ns (fast) and 11 ns (slow)]
  - Birks saturation is not simulated (assumption is that it can be calibrated).
- Sensor
  - Assume an SiPM with 25% photon detection efficiency
  - Output timing jitter is 100 ps.
  - Output charge jitter is negligible, does not include effect of multiply hit pixels
  - Dark currrent rate is 100k pe/s (nominal for T2K SuperFGD)
    - Negligible effect with a 2.5 pe threshold
- Electronics and DAQ
  - Uses a Multi-hit TDC with an ADC
  - TDC
    - Threshold is 2.5 pe (tunable), with time step of 0.5 ns (tunable)
  - ADC
    - Integration window is 50 ns with 10 ns dead time (both tunable)
    - Digitization is 10 counts per photo-electron equivalent impulse (tunable)
  - Calibration uses ideal calibration coefficients (changeable)

TPC Model in ERepSim

(work by P. Granger)

- Response
  - Energy deposition spread uniformly along each track segment
    - Track individual ionization electrons,
    - Drift velocity is 78 mm/microsecond
  - Charge position spreading in foil simulated as Gaussian spread
    - Time spreading not currently simulated
  - Lateral and longitudinal diffusion is small compared to, so ignored for simplicity (easily implemented within frame work)
- Sensor:
  - Pad and amplification is extremely simplified
  - Current passed directly to digitzation
- Electronics and DAQ
  - Each pad uses the DAQMulti class
    - Nominal 100 ns integration window,
    - Integrate as long as signal is above threshold
  - Hit time is the average current arrival time for the pad
  - Each hit has the position of the pad, and the arrival time of the charge

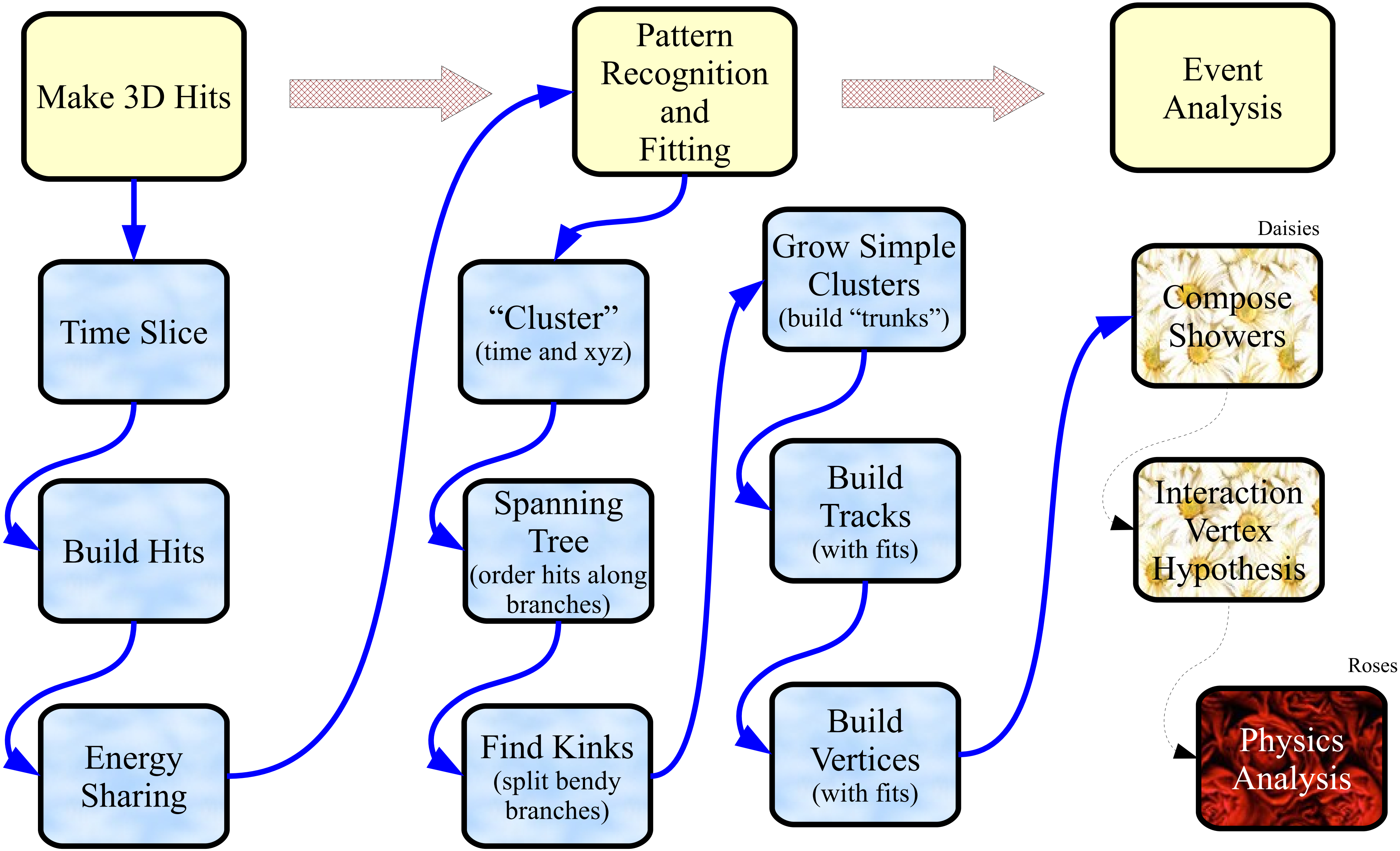
ECal Model in ERepSim

(Pass-through of sand-stt results)

- Response
  - Implemented in sand-stt
- Sensor
  - Implemented in sand-stt
  - The sand-stt simulation assumes a 400 ns integration window
    - Time of hit comes from rising edge of signal (15% constant fraction)
    - Charge of hit comes for sum oveer 400 ns
- Electronics and DAQ
  - Copy the information in the tDigit tree “cell” branch to ERepSim output
  - Assign hit positions at each end of the cell (tdc1 and tdc2 at opposite ends of the cells).
  - Augment the hit identifier to specify the end of the cell

The Flow of the Reconstruction

(3DST and TPC)



Building Cubes (voxels) from Fibers

- Time Slicing: Collect hits from one interaction
  - Break 2D hits into groups separated by more than 40 ns.
    - Algorithm not optimal when there is noise (a fixed time window is better)
    - Should be optimized, but for now, the analysis isn't very sensitive to it.
    - Notice that electrons from muon decay are "just another track"
- 3D Hit Building:
  - Assign a "cube" to every possible three fiber combination
    - Hits are built by "time slice", so 2D hits in different time slices are not considered
    - Time and Charge are assigned to each cube based on event topology
    - Information for each 2D are available in the 3D hit.
- DBScan:
  - Applied after cubes are fully reconstructed to simplify later reconstruction
  - Select simply connected groups of hits
    - Use the geometric distance between cubes
    - Breaking criteria
      - More than one neighbor within 1.6 cm (i.e. collect all simply connected cubes)

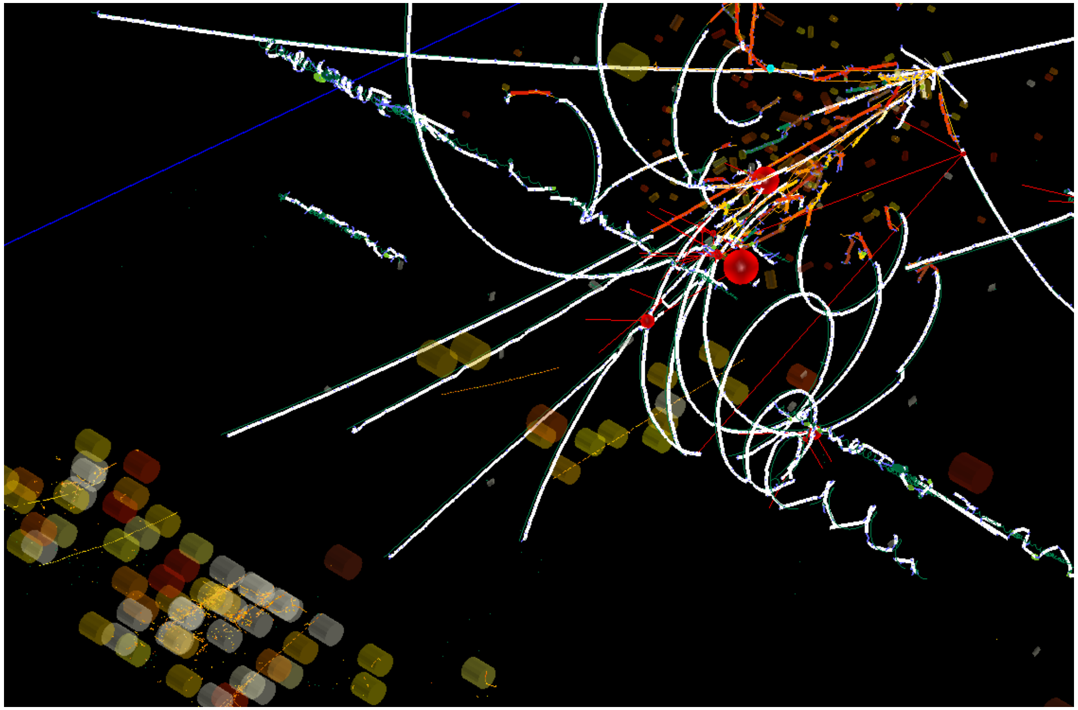
Voxels From TPC and ECal Hits

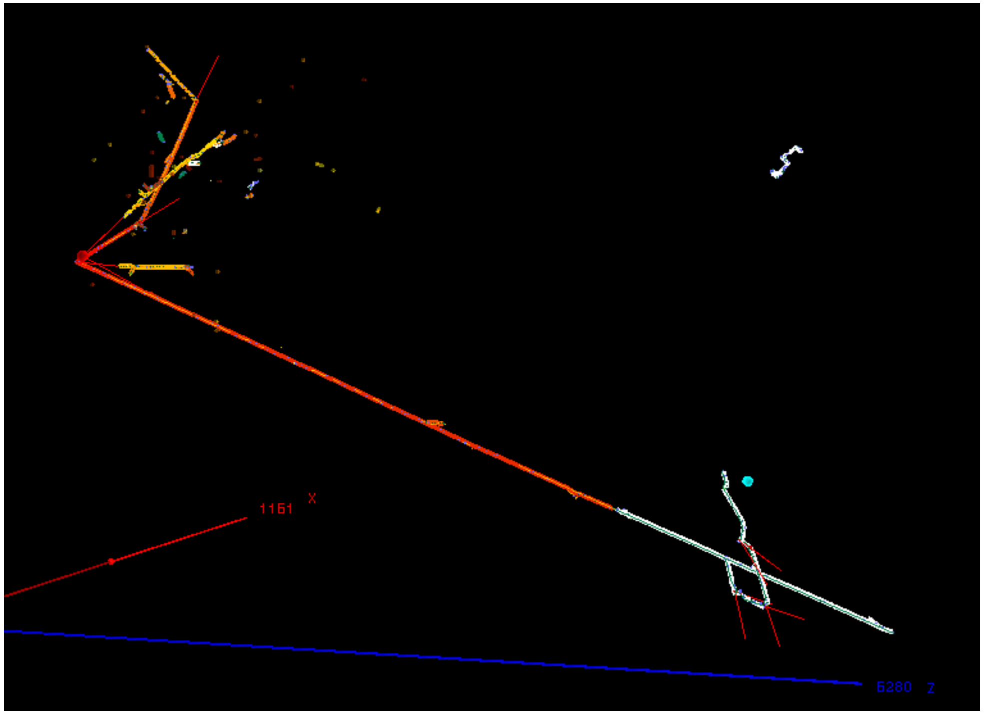
- TPC voxels
  - For each TPC pad
    - Correct X position to correspond to time zero
  - Drift velocity is 0.078 mm/ns or, 78 mm/μs
  - Hit building does not specifically treat charge sharing
    - That means a single track will usually be "three pads wide"
  - Hit X, Y and Z size
    - Y and Z size based on pad
    - X size based on the "signal time" over threshold.
- ECal voxels
  - For each cell
    - Only accept pairs of TDC1 and TDC2 within a 35 ns time window
      - Up to a 6 m light path difference
      - Speed of light is 170.8 mm/ns
  - Calculate X position based on difference between TDC1 and TDC2
    - The hit charge is the sum of ADC1 and ADC2

CubeRecon for the TPC

- Required Changes for TPC
  - Modified Distance metric for DBScan and Minimal Spanning Tree
    - Distance is calculated for the closest approach between the hits
      - Modified for 3DST as well
        - equivalent to old 3DST distance minus the cube size
- Did not modify track fitting for TPC
  - The stochastic track fit assumes a 400 MeV/c muon passing through a scintillator
  - More multiple scattering than there should be
  - Curvature is not fit: Low energy tracks are fit as “kinked” track segments
  - Assumption: The stocastic track fit is part of pattern recognition, final fit will be done by the TPC full track fit.

Reconstructed TPC Events





- Result of CubeRecon applied to TPC, 3DST, and ECal (on left-side)
  - TPC Tracks shown in white.
- Left: Full spill, but only KLOE events
  - This zooms for one interaction, no interactions were culled. ECal hits are shown, but no clustering is applied
- Right: Muon, pion and π^{o} with no magnetic field

Summary

- The baseline 3DST and TPC reconstruction is ready[1] as input for physics studies
  - Tracks with fitted results
    - Position, direction, length, "dE/dX" vs position on track, total energy deposition, path in detector
    - Minimum track length is 4 cubes
  - Clusters
    - Small groups of hits isolated in space and time.
    - Position, direction, shape, total energy deposition

[1] Professional driver on a closed track. Your mileage may vary. Past performance does not indicate future results. Unintended uses may result in injury. Do not ingest Avoid contact with eyes. This is not a toy. Keep away from children. Please handle safely Use at your own risk.

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