ND Software

DUNE BSM Group Meeting

February 18, 2020

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Outline

- **Software Tools**
  - DUNENDGGD
  - edep-sim & ArgonBox
  - LArSoft, GArSoft, other code
- **ND Software Survey**
  - LAr ND
  - MPD
  - SAND
- **LAr ND Plans**
  - R&D program — ProtoDUNE-ND
  - Simulation & analysis
  - Schedule

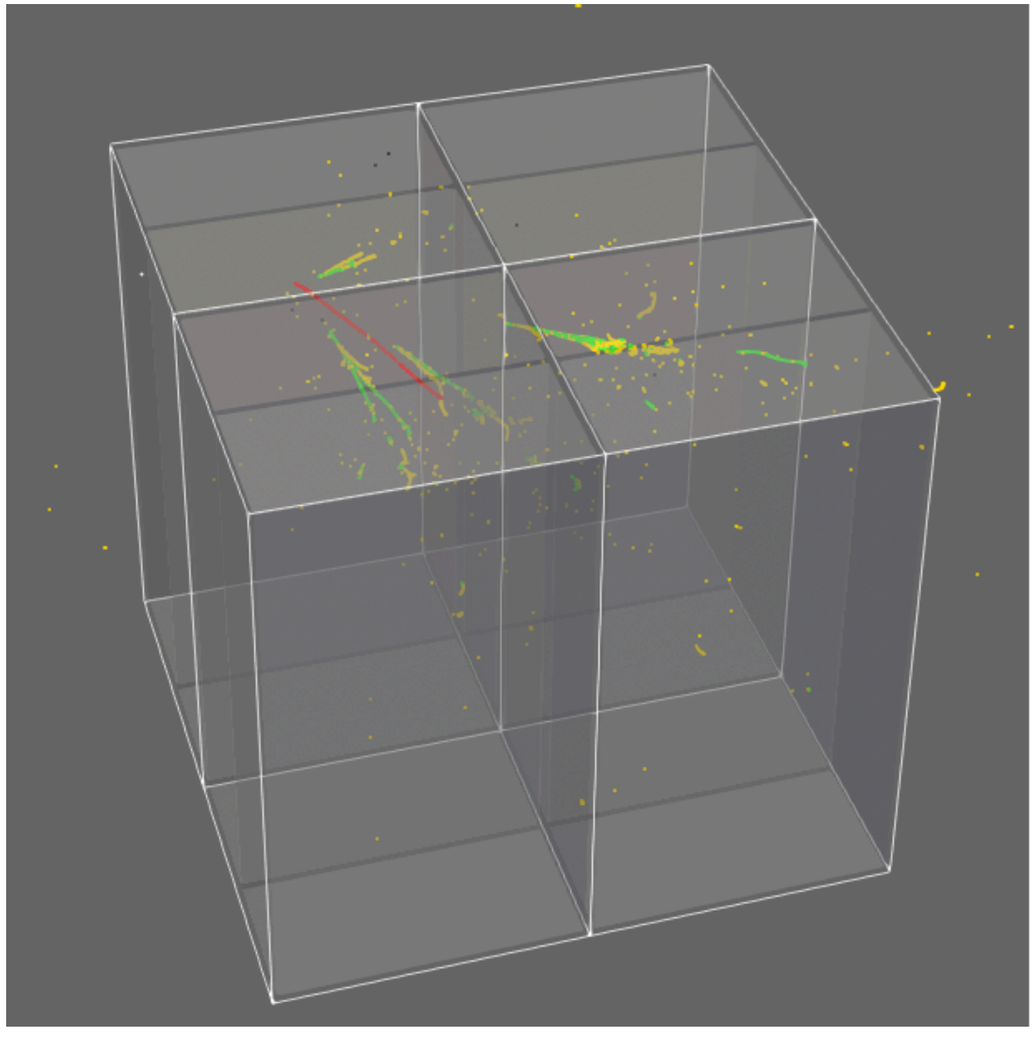


Image c/o Patrick Koller (Bern)
See https://indico.fnal.gov/event/20432/session/18/contribution/44

Caveat: I will attempt to overview the status of several ND software packages, but I am not involved/expert on all of them! Details may not be the latest/greatest.

Software Tools
DUNENDGGD

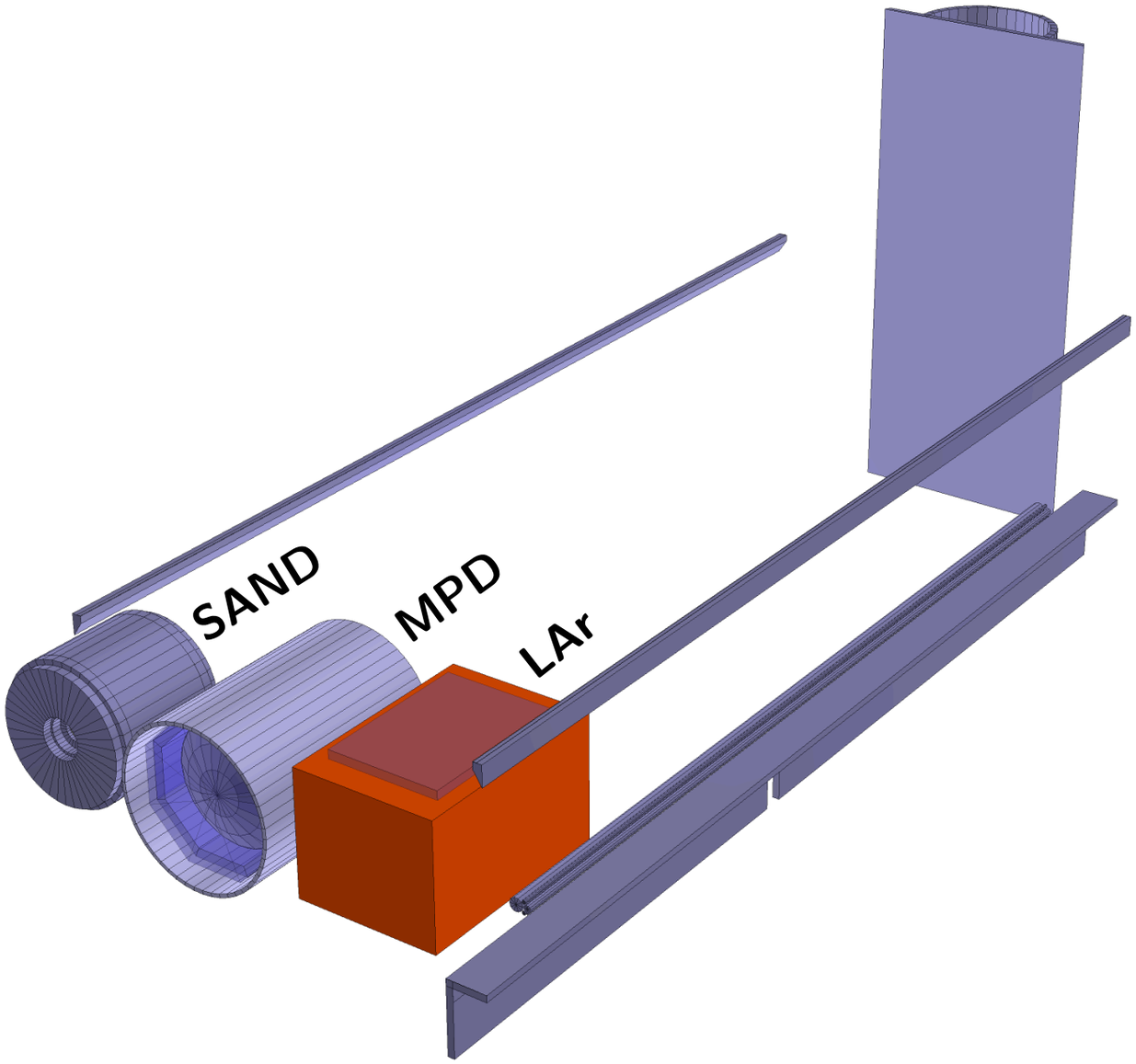
General Geometry Description (Viren)

https://github.com/brettviren/gegede

DUNE ND GGD (Yang, Palomino)

https://github.com/gyang9/dunendggd

- Python-based tools for composing the full ND hall geometry
- Includes full hall, rock along the beamline
- LAr ND (ArgonCube), MPD, and SAND geometries
- Generates GDML files
- Used in GENIE (etc.) simulations



DUNE NearDet Design Wiki

https://cdcvs.fnal.gov/redmine/projects/dune-neardet-design/wiki/DUNE_NearDet_Design

Software Tools

edep-sim & ArgonBox

edep-sim (McGrew)

https://github.com/ClarkMcGrew/edep-sim

ArgonBox (Dwyer)

https://github.com/dadwyer/argon_box

edep-sim →

- Runs a Geant4 simulation
- Arbitrary GDML geometries
- Reads in vertex information from a file, or can use G4 built in particle generation
- Outputs a ROOT tree with true energy depositions

ArgonBox →

- G4 simulation in a giant volume of liquid argon

Note: Setup on DUNE GPVMs can be found at the DUNE NearDet Design Wiki

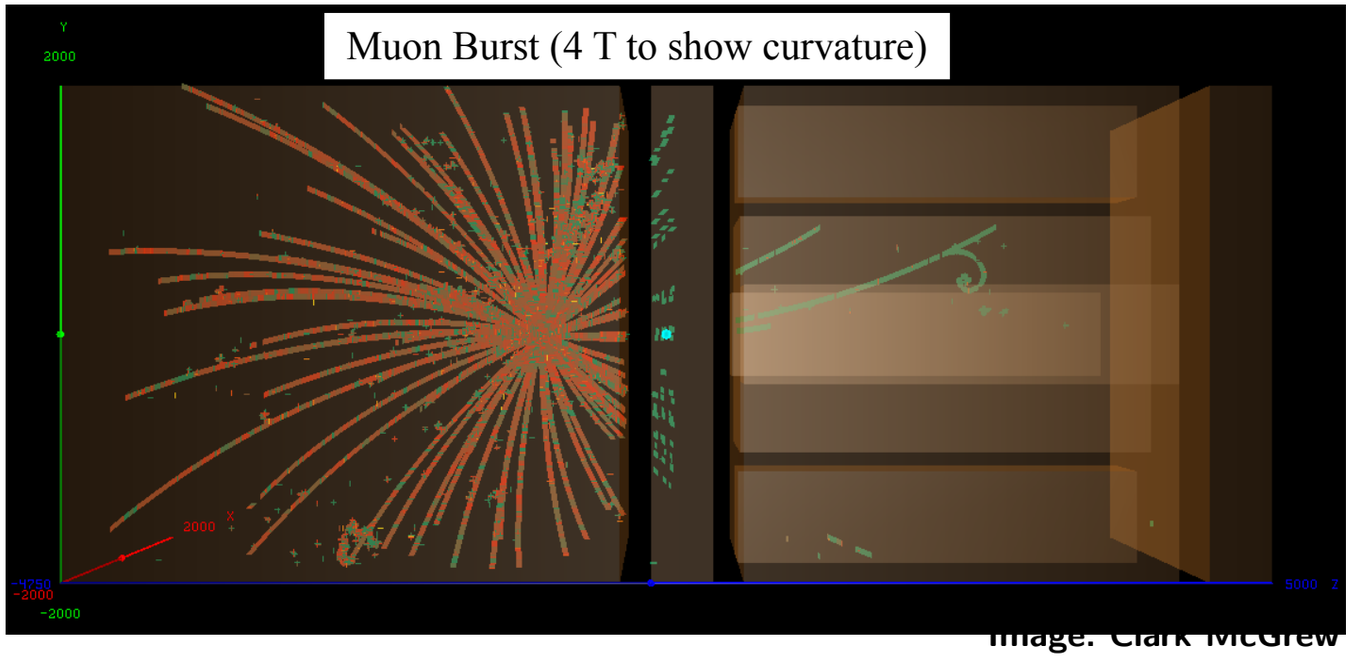
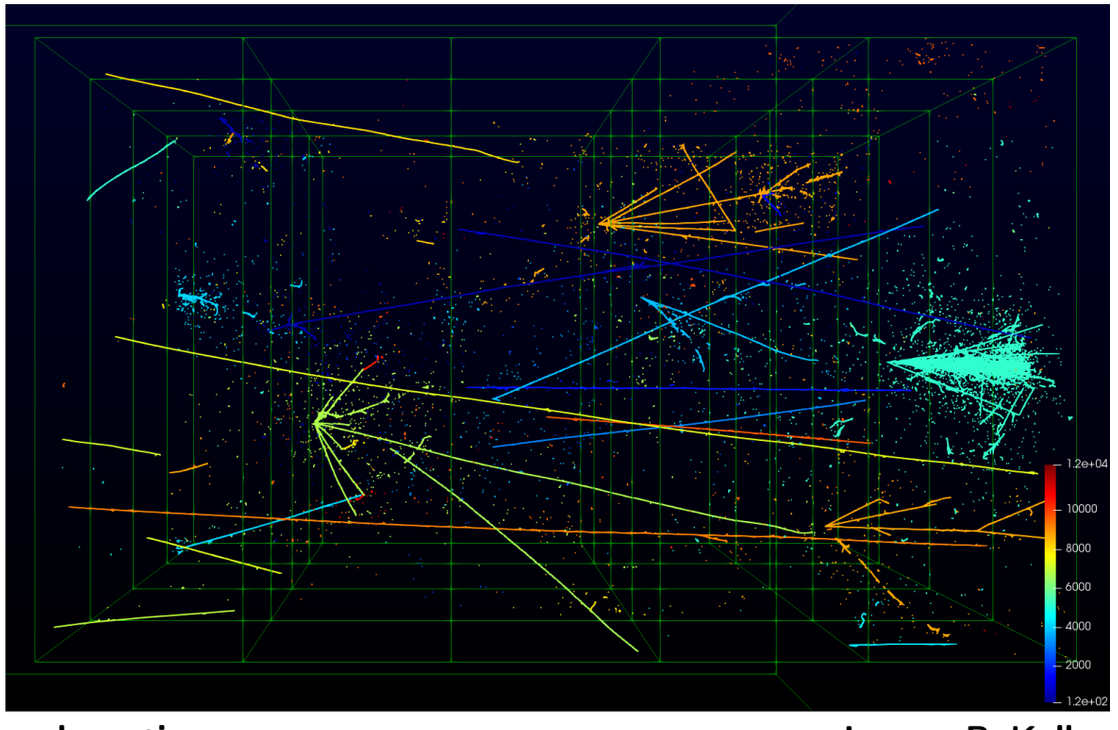


Image: Clark McGrew



color ~ time

Image: P. Koller

Software Tools

LArSoft, GArSoft, etc.

LArSoft

https://github.com/LArSoft

GArSoft (Tom Junk, et al.)

https://cdcvs.fnal.gov/redmine/projects/garsoft

LArSoft

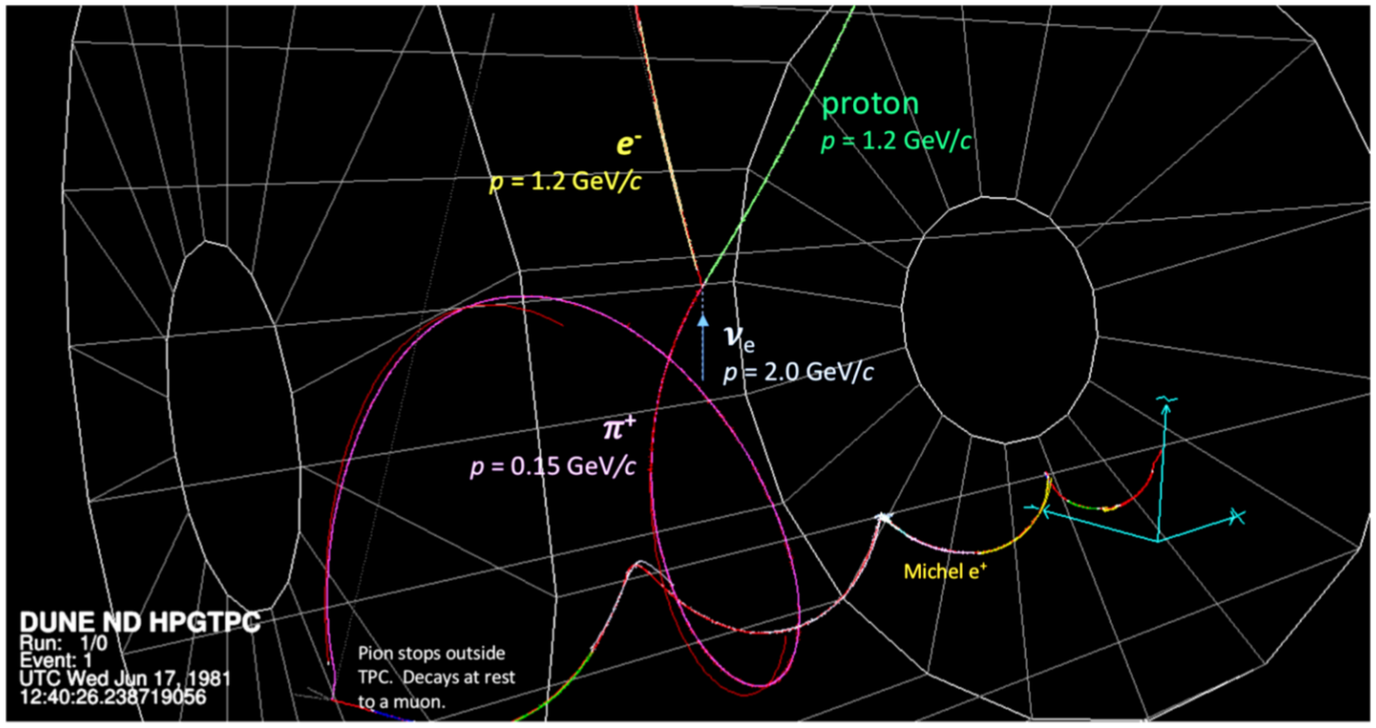
- Standard simulation & analysis package used by FNAL experiments, DUNE FD
- Issues with pixel readout implementation, recent progress by G. Petrillo et al. (slides)

GArSoft

- Developed by MPD group (T. Junk et al.) for HPgTPC sim, reco, analysis
- Using a parametric detector + reco approach while developing full sim & reco
- January CM slides: ND SW integration, status & plans

"Standalone" Code

- ArgonCube response simulation: drift, pixel response, optical system
- Deep Learning based reco
- Pandora toolkit (also integrated into the LArSoft framework)
- DUNE3dstTools — SAND detector response, reconstruction, analysis
- DUNE_ND_CAF — Make CAFAna files, used in LBL analysis



GArSoft event display **Image: Tom Junk**

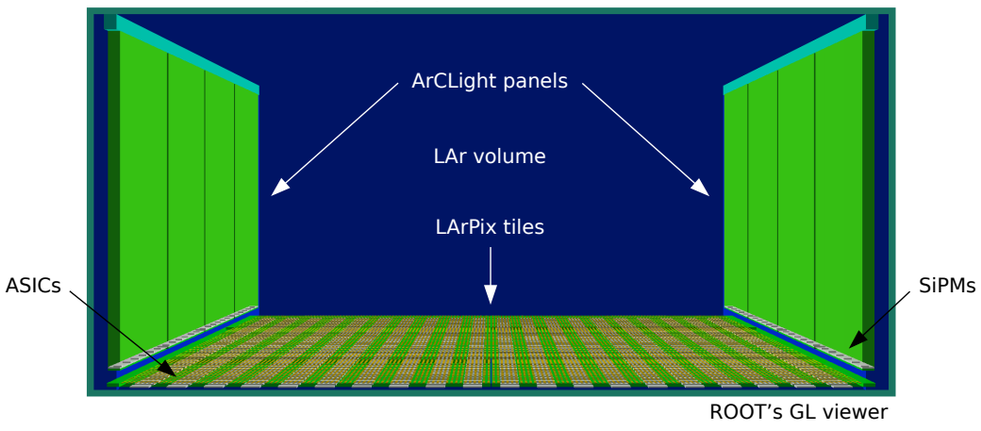
Software Survey

LAr ND

- Geometry: DUNENDGGD GDML for the full hall, individual modules, 2×2 configuration
- Simulation: Full-spill GENIE + edep-sim for Geant4. Analysis-level smearing of energy depositions for detector response
- DL based reco, also discussing with Pandora
- Work ongoing to integrate (largely existing) detector simulation and reconstruction tools
- Eager to understand impact of gaps, photon system, reco in e.g. mitigating pileup
- Design studies
  - Detector size optimization
- ND+FD studies
  - Containment, momentum coverage with different MPD magnet designs, NuWro fake data studies
- Data-driven efficiency for DUNE-PRISM
- Many more...

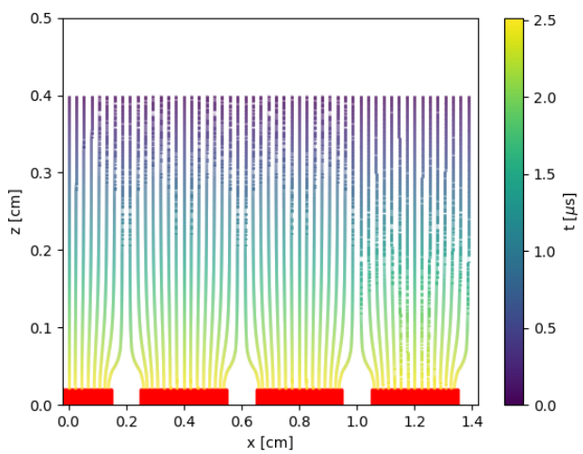
ArCLight Optical Detector Model

Patrick Koller (Bern)

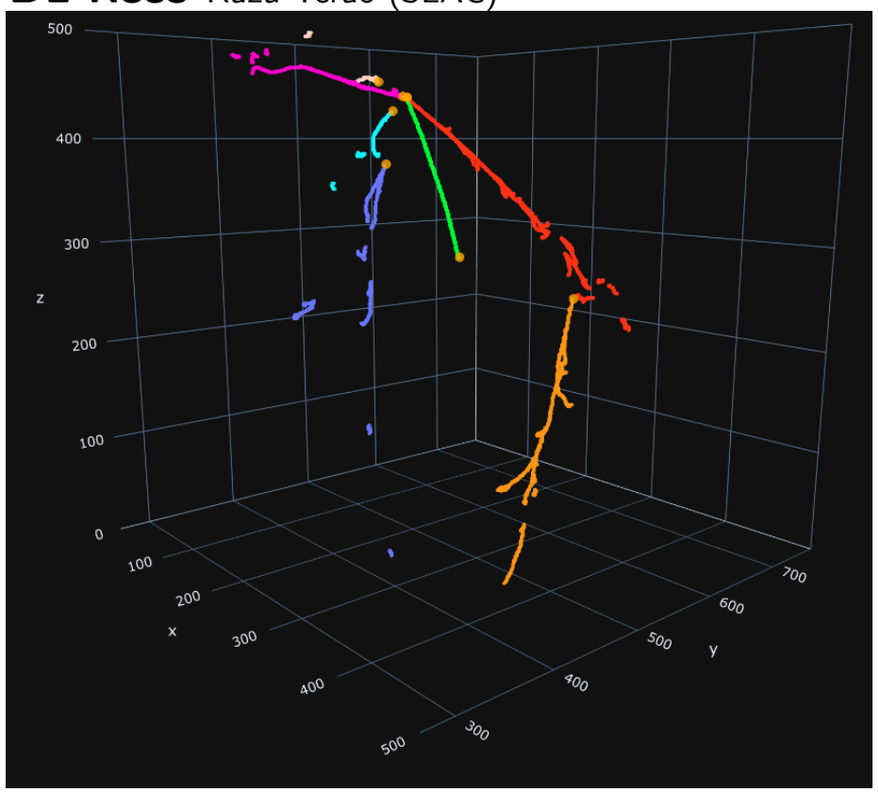


Field Response

Dan Douglas (MSU)

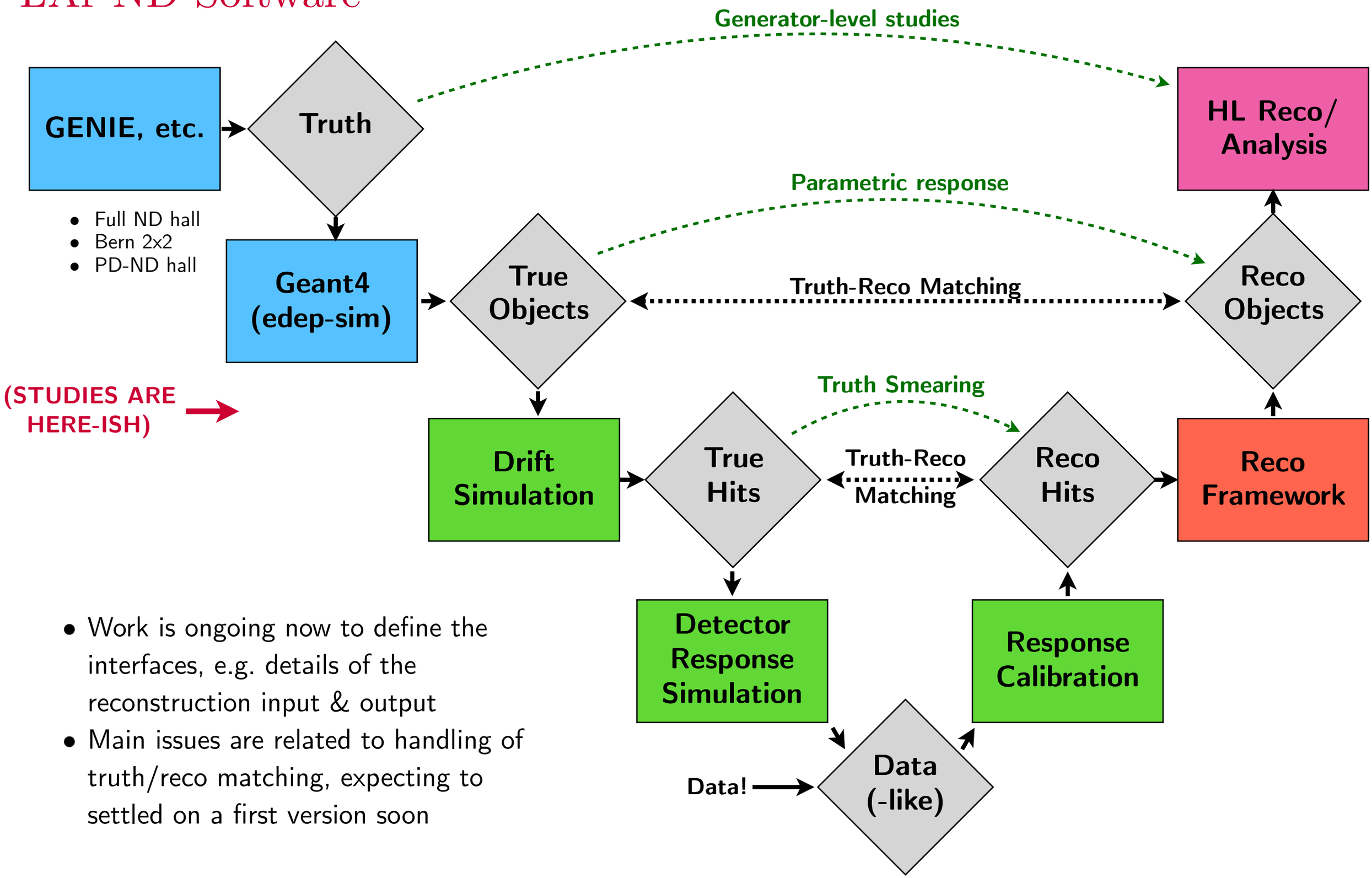


DL Reco Kazu Terao (SLAC)



Analysis Workflow

LAr ND Software



- Work is ongoing now to define the interfaces, e.g. details of the reconstruction input & output
- Main issues are related to handling of truth/reco matching, expecting to settled on a first version soon

Software Survey

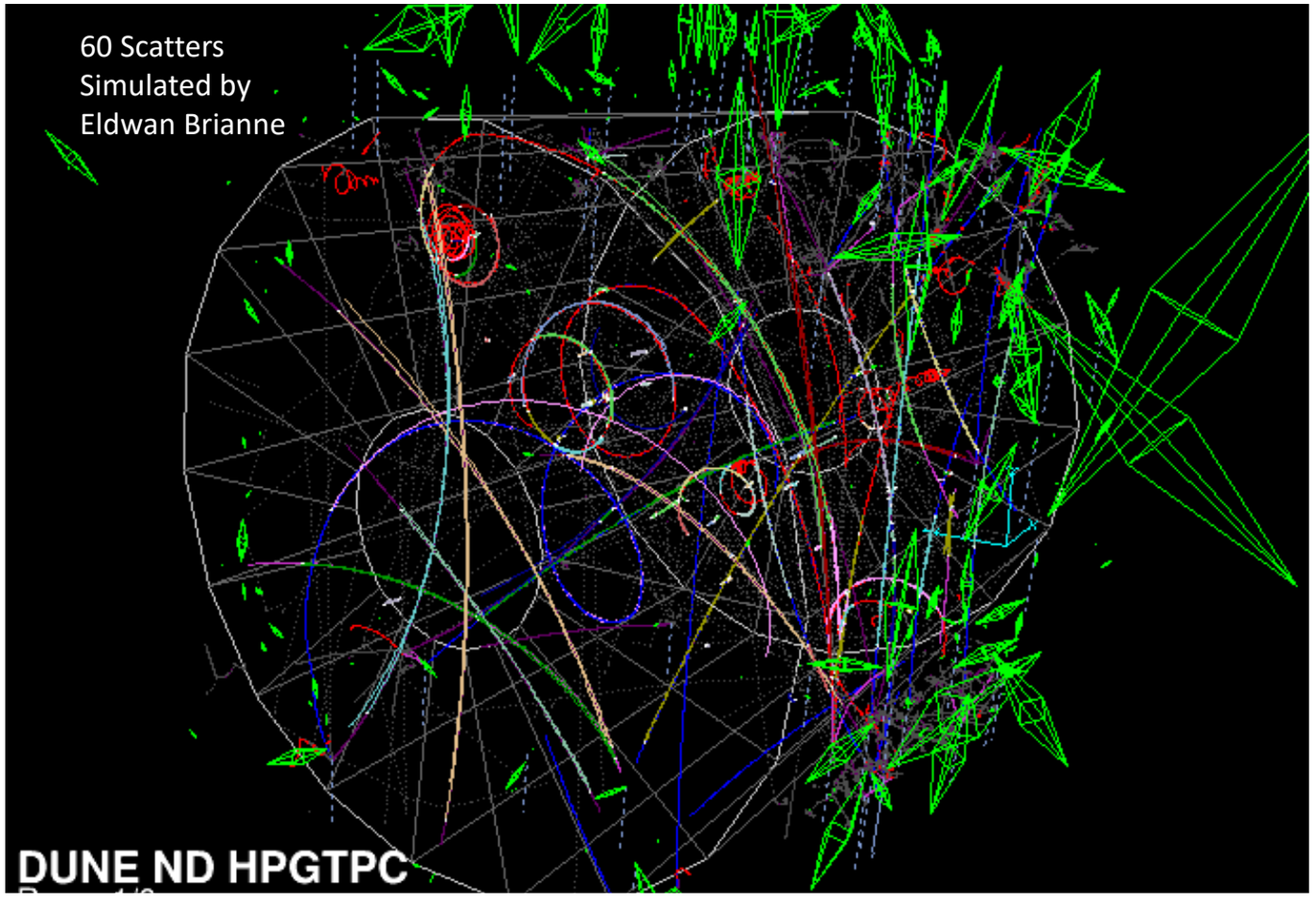
MPD

- Developed by MPD group (T. Junk et al.) for HPgTPC sim, reco, analysis
- Parametric detector + reco approach while developing full sim & reco
- Parametric ECAL response
- Geometries with several magnet designs, for optimization studies
- To-do items: framework integration, five-coil field map import, continued development of ECAL modeling; full pad response simulation in progress

- Design studies
  - Acceptance, magnet, ECAL, pressure vessel
- ND+FD studies: Containment, momentum coverage with LAr/MPD matching
- Neutron TOF tagging, coherent π selection (CDR)

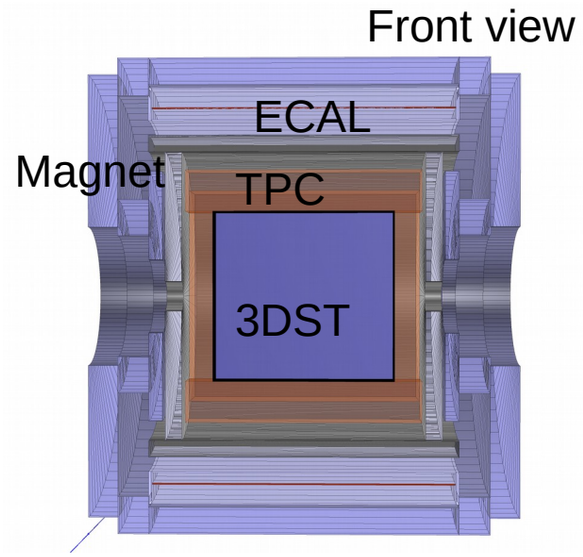
More info:

Tom's January CM slides: ND SW integration, status & plans



Software Survey

SAND



Guang Yang, DUNE CM January 2020

https://indico.fnal.gov/event/20144/session/20/contribution/129/material/slides/

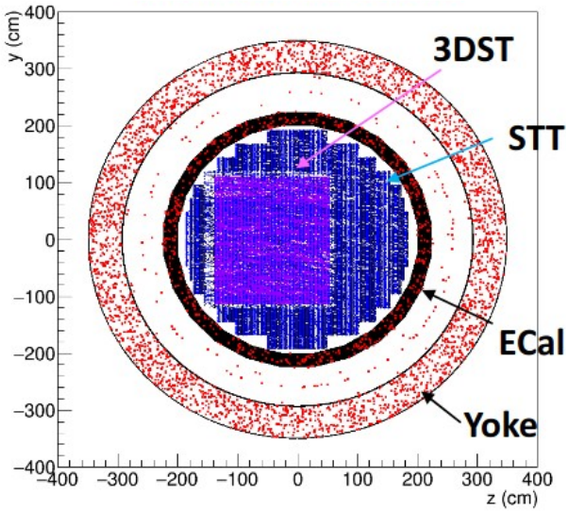
Stony Brook University

Flow of 3DST software

- Geometry
  - independent → DUNENDGGD
- Neutrino flux generation
  - consistent with LBNF → G4LBNF
- Neutrino interaction generation
  - consistent with LBL → GENIE
- Energy deposition of final state particles
  - consistent with LBL → edep-sim
- Electronics simulation - independent tool
- Reconstruction - independent tool
- Analyses - independent tools

01/30/20 Jan 2020 CM 3 / 19

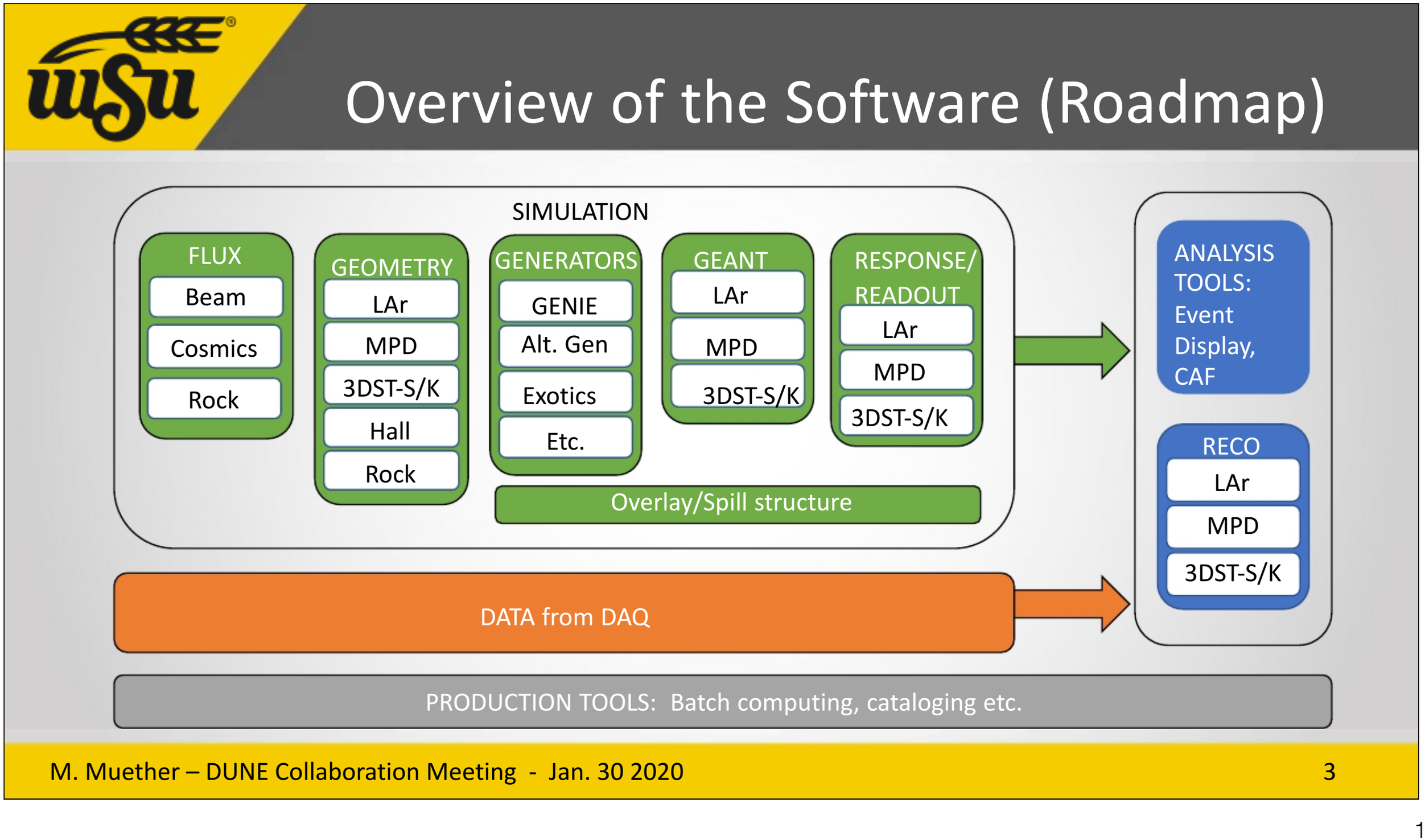
- 3DST simulation using edep-sim
- Initial detector simulation in place, in DUNE3dstTools
- Developing 3DST/SuperFGD reco
- KLOE software using FLUKA
- Parametric ECAL response
- FLUKA & G4 based simulation and reco for STT geometry



Software Survey

ND Software Integration Group

- Contact: Mathew Muether, Wichita State
- Meetings Thursdays, 10 AM CT
- dune-nd-sw-integration@fnal.gov
- DUNE Slack #nd_software_integrate

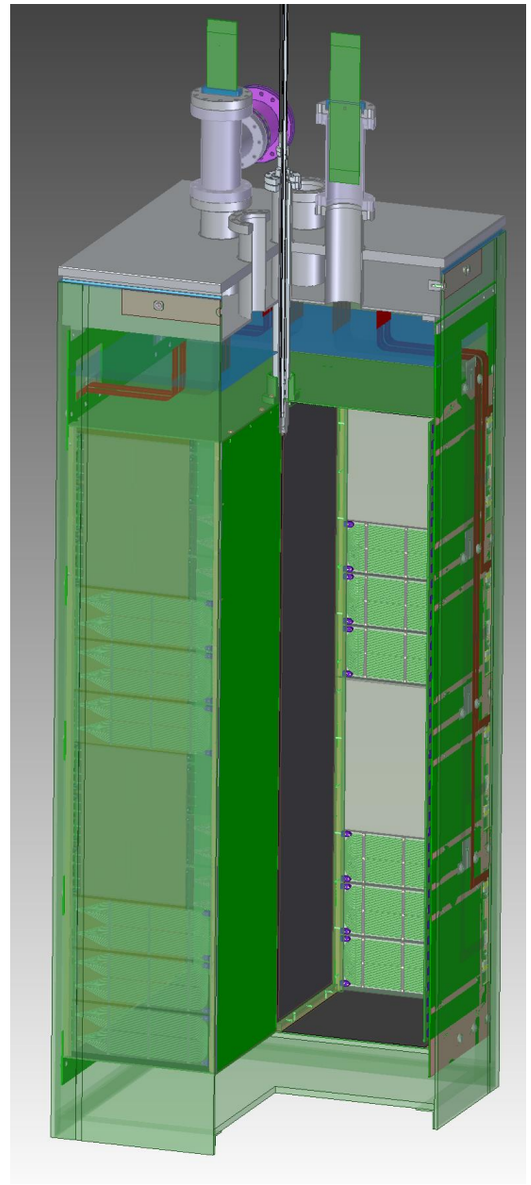


LAr ND

Status & Plans

Status

- Existing code (GENIE + edep-sim) has supported CDR (and IDR) studies so far
- As a next stage, desire to understand details of geometry & optical system on reco, pileup ID
- Work is in progress to build an end to end simulation & analysis chain
  - Efforts on simulation, detector response (charge & light), reconstruction
  - Currently "standalone" codes, developing generically for integration/adaptation
  - ND physics studies can be developed in parallel e.g. using truth hit smearing
- Developments on LArSoft-based tools (see Gianluca Petrillo's January CM talk, ND SW Integration session: slides)
- Recent discussions towards an additional Pandora-based reconstruction path



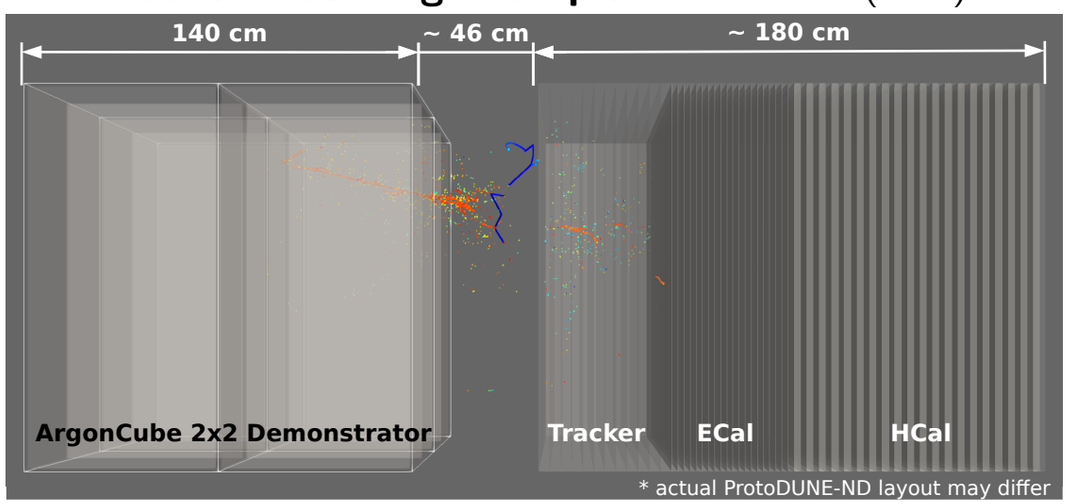
Knut Skarpaas (SLAC)

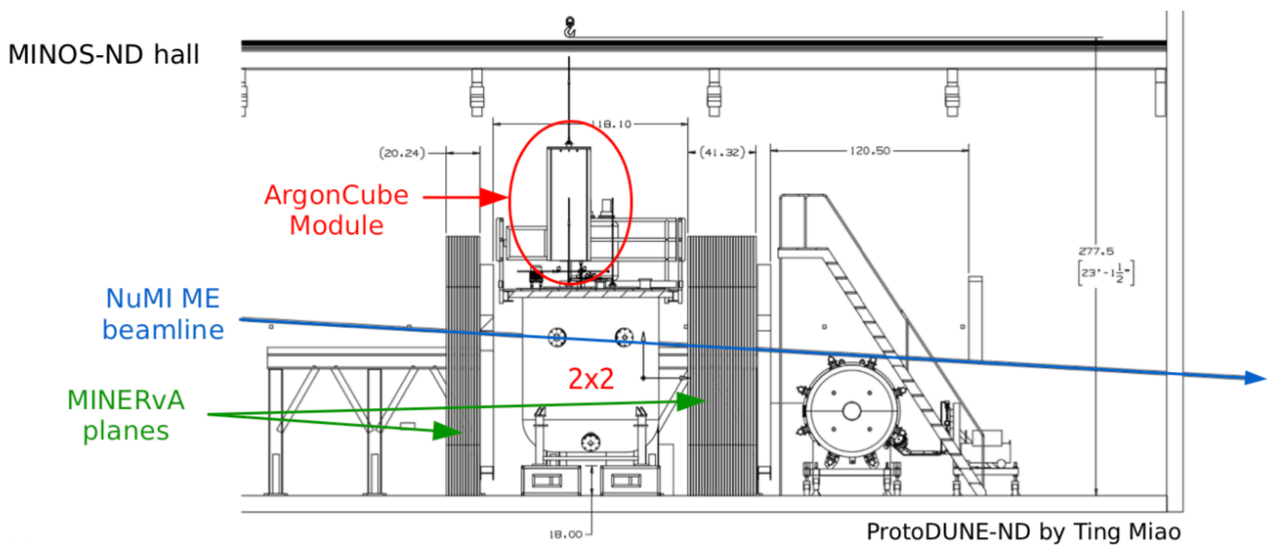
LAr ND

Status & Plans

- **Summer 2020:** Module-0 runs at Bern LHEP
  - Detector response using cosmics, 3D imaging, Q+L, cross-cathode matching
  - → ND physics studies with data-driven response and reco performance
- **Fall 2020:** Full 2×2 runs at Bern LHEP
  - Characterize cross-module reconstruction, module uniformity, TPC+CRT matching etc.
  - → Feeds into ND simulation & reco performance, efficiency, cross-detector track matching
- **Spring 2021:** ProtoDUNE-ND, 2×2 in the NuMI beam
  - Neutrino selection & reco, matching to tracker, pileup, model validation
  - → Multi-detector ND studies (e.g. LAr + MPD matching) with data-driven performance
- ND physics studies supporting IDR/TDR work in parallel, using 2×2/PD-ND input as available

Tracker Matching Example Patrick Koller (Bern)





Details: https://indico.fnal.gov/event/20432/session/18/contribution/44

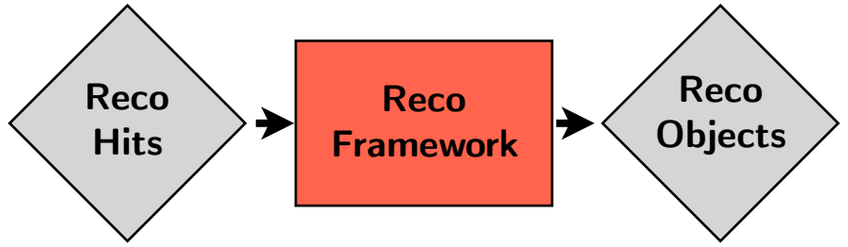
Conclusions

- New groups have formed to organize the ND software development efforts
  - LAr ND (ArgonCube 2×2 + ProtoDUNE-ND + LAr ND) — Mastbaum
    - lar-nd-analysis@fnal.gov, #lar_nd_analysis, biweekly Thursdays 10:30 ET
  - ND Software Integration Group — Muether
    - dune-nd-sw-integration@fnal.gov, #nd_software_integrate, biweekly Thursdays 11:00 ET
  - Major efforts within MPD and SAND groups: GArSoft and DUNE3dstTools
- Work underway to build full end to end simulation + reconstruction + analysis chains
- CDR & ongoing work primarily using parametric models for detector and reconstruction response
- Several open questions
  - Software frameworks — mainly "framework agnostic" development for now
  - LAr + MPD + SAND software integration — charge of the ND Software Integration Group
  - N.B. Already doing joint studies at the edep level, question of how to bridge reco outputs/ perform combined reconstruction. Potential impact for BSM, input will be very valuable.

Thank You!

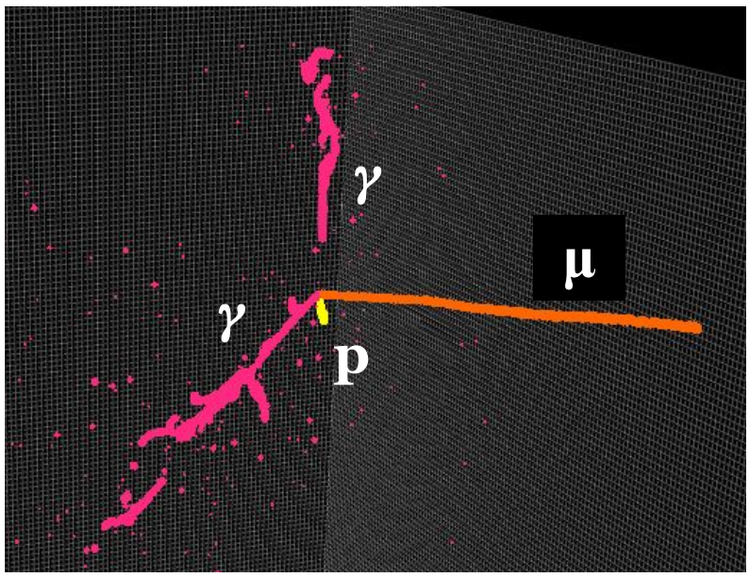
Reconstruction

ML-Based Reco Chain, K. Terao (SLAC)

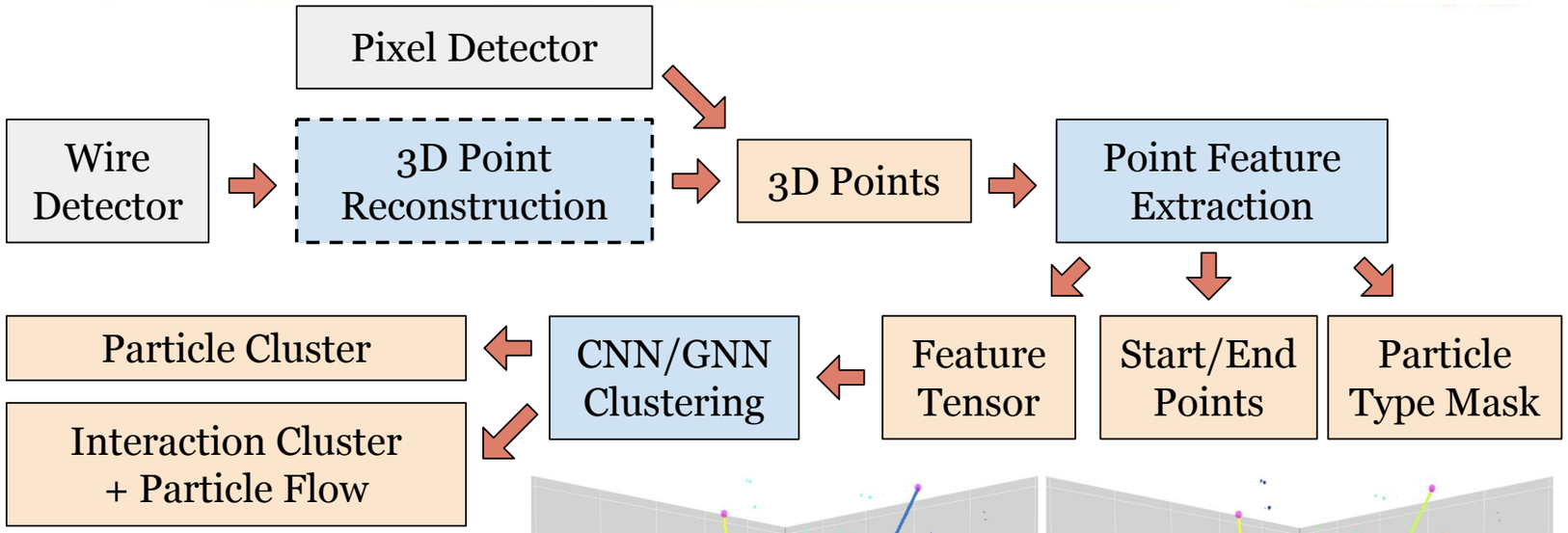


- Hits → high level objects
- Clusters, tracks, vertex, hierarchy information
- Parallel development for SBN, ProtoDUNE
- Can apply smearing ~ detector effects
- Finalizing input and output data format for the LAr ND analysis

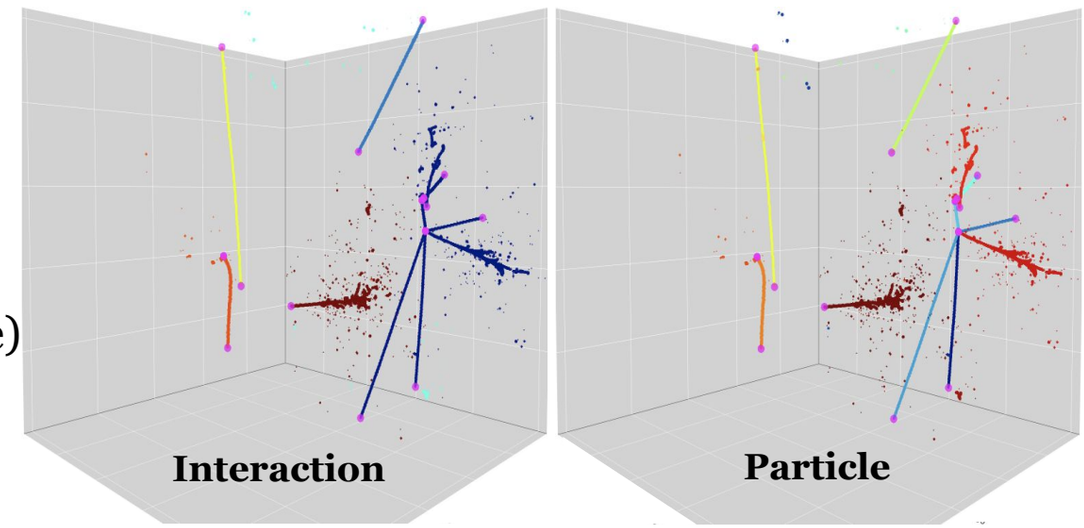
Example Event



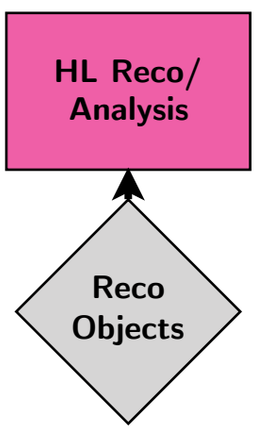
K. Terao



- **Step-2**: "clustering" of pixels into a particle
- **Step-3**: "particle flow" (hierarchical particle tree) + interaction definition



Slide: K. Terao (SLAC)



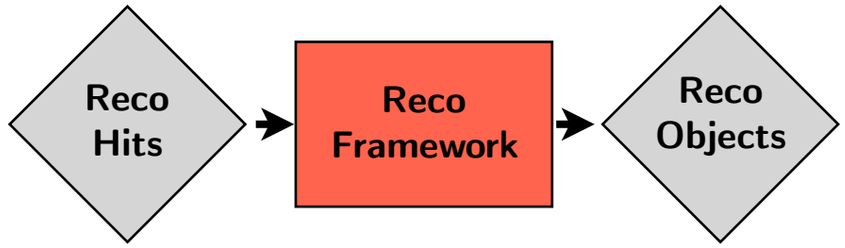
π^0 Analysis

Roman Berner (Bern LHEP)

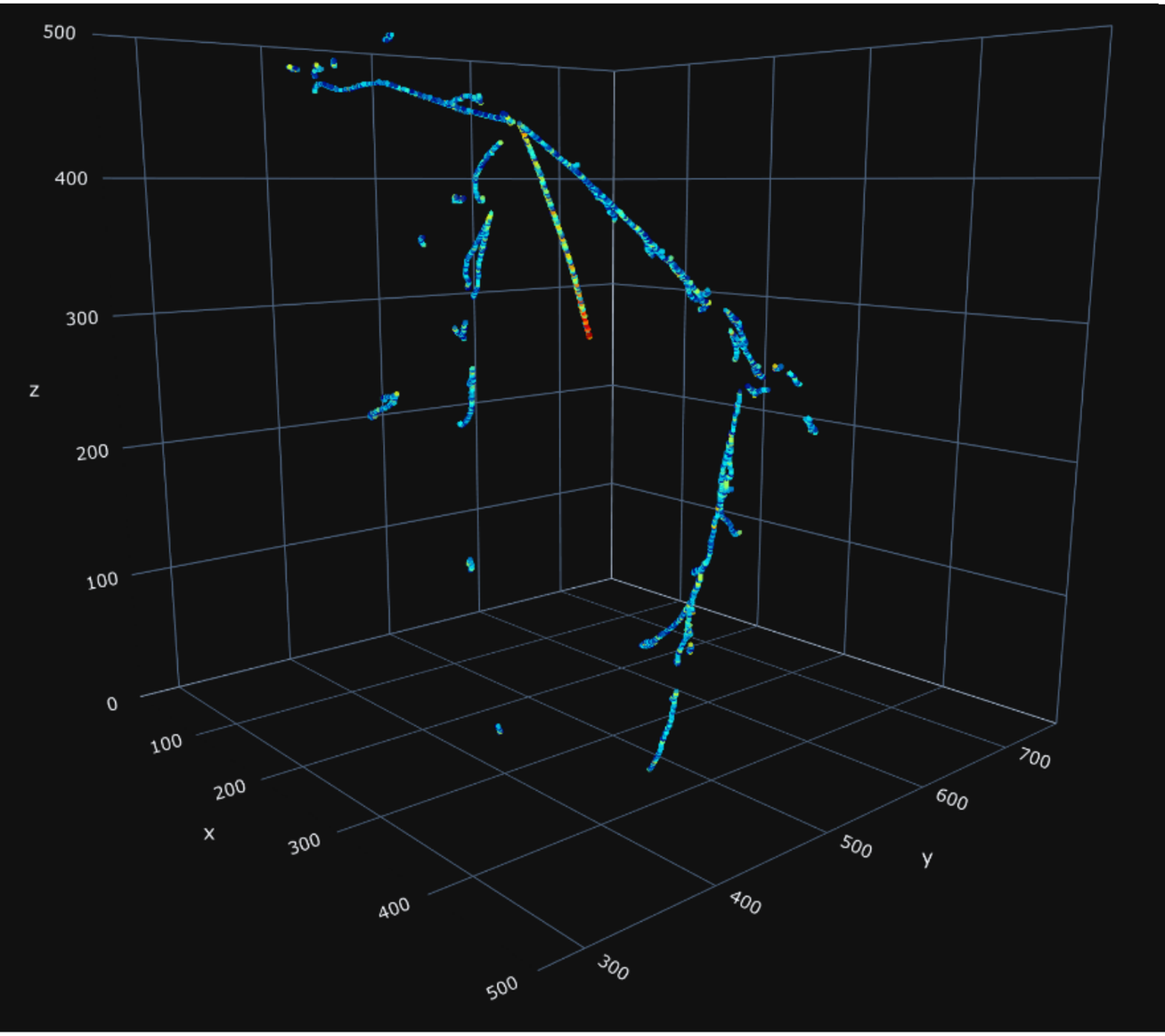
- Study of π^0 in LAr, feedback to reco development

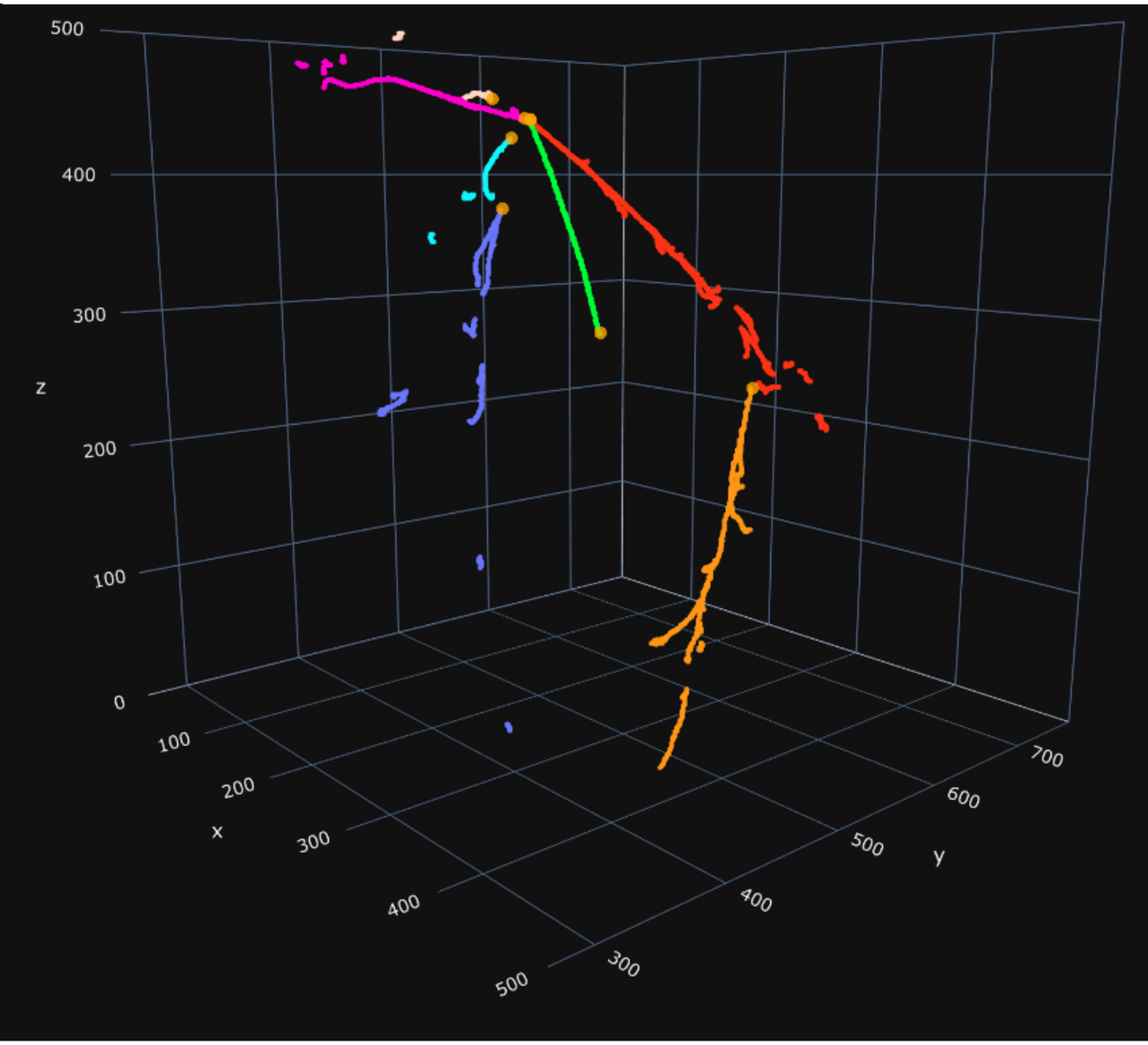
Reconstruction

ML-Based Reco Chain, K. Terao (SLAC)



Data from imaging detector → **Clustered pixels (→ PID)**

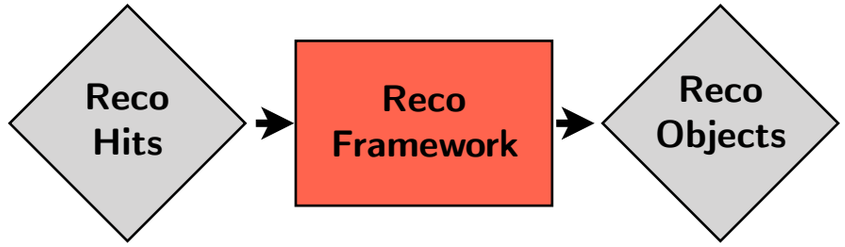




(1) Granular particle clustering **(2) Particle-level clustering** **(3) Interaction clustering (particle flow hierarchy)**

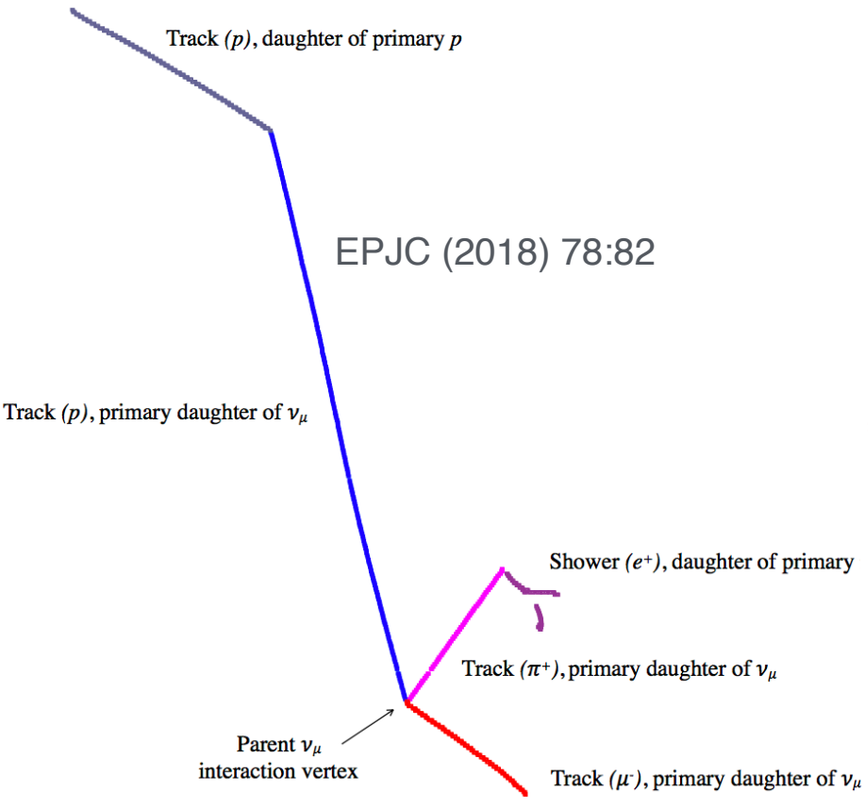
Reconstruction

Pandora-Based Reco Chain



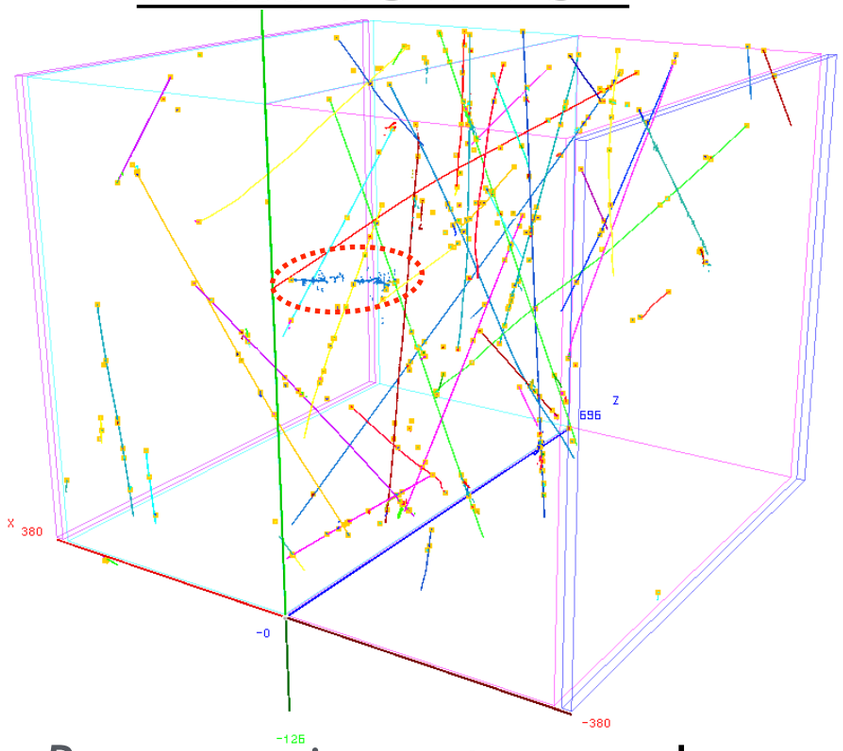
- Recent discussions about possible applications for DUNE ND including LAr
- Used in SBN, DUNE FD, ProtoDUNE, ...
- Leverage collider detector developments: multiple 3D imaging sub-detectors, very high pileup conditions

MicroBooNE



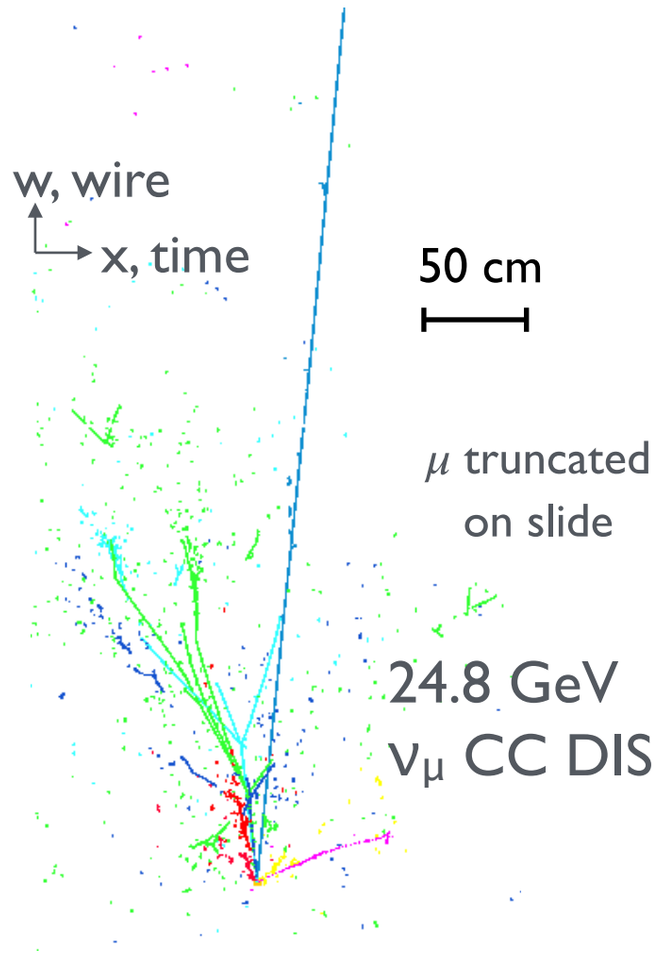
EPJC (2018) 78:82

ProtoDUNE-SP



Reconstruction output: test beam particle (electron) *and: N* reconstructed cosmic-ray muon hierarchies

DUNE FD MC



Pandora SDK: John Marshall, Mark Thomson ✦ Core LArTPC algs: Andy Blake, John Marshall