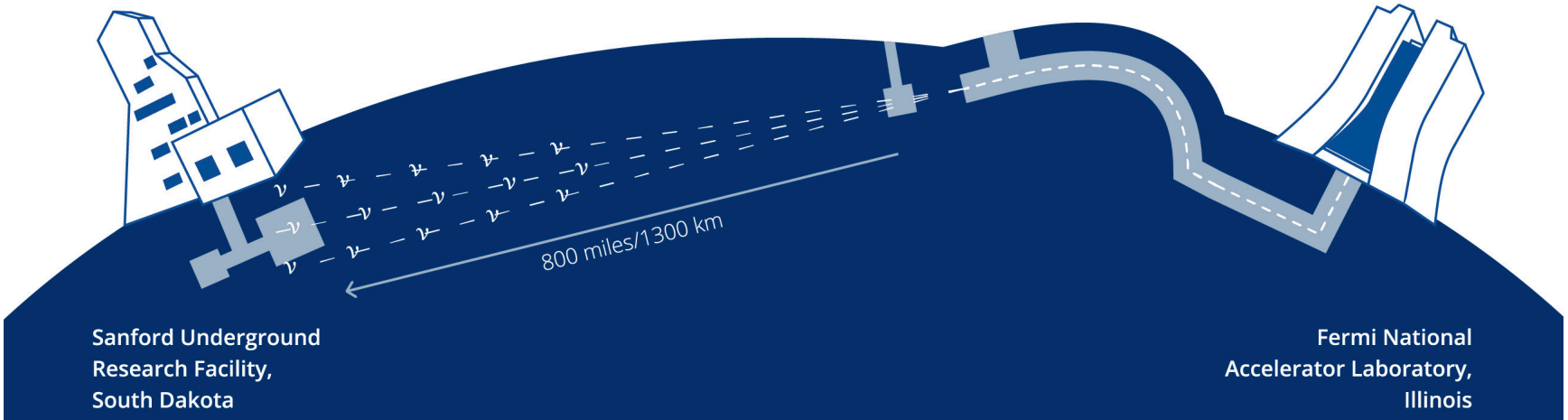
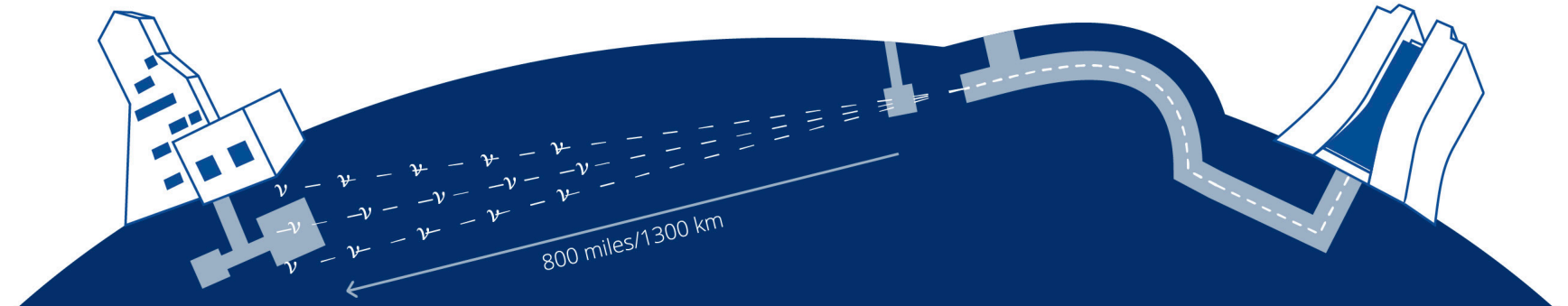


DUNE Near Detector Software

Mathew Muether for the DUNE Collaboration

Framework Workshop – June 6

WICHITA STATE UNIVERSITY



Sanford Underground Research Facility, South Dakota

Fermi National Accelerator Laboratory, Illinois

Outline

DUNE Experimental Design
DUNE Near Detector
DUNE Near Detector Software
Framework needs
Discussion

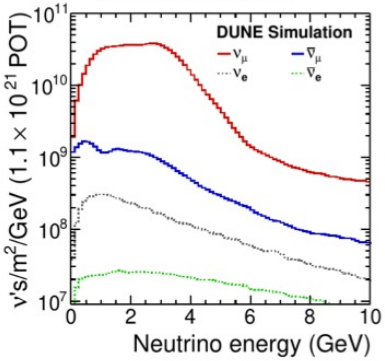
WICHITA STATE UNIVERSITY

DUNE Design

- Long baseline (1300 km) and wideband beam
- High stats: intense beam + large far detector
- Precise energy reconstruction over broad E_ν range with state-of-the art LAr TPCs
- Precise systematic control from near detector

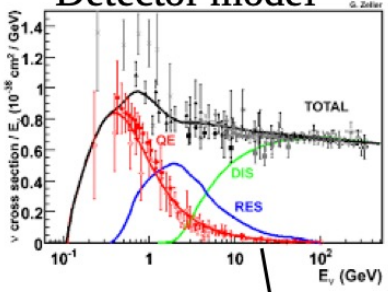
Standard LBL Analysis

Flux model



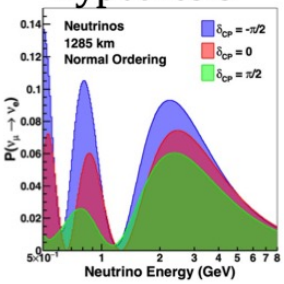
x

Interaction model
Detector model

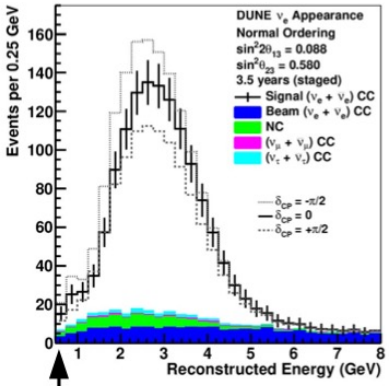


x

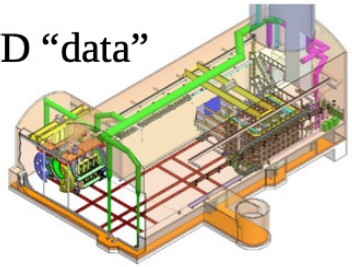
Oscillation hypothesis



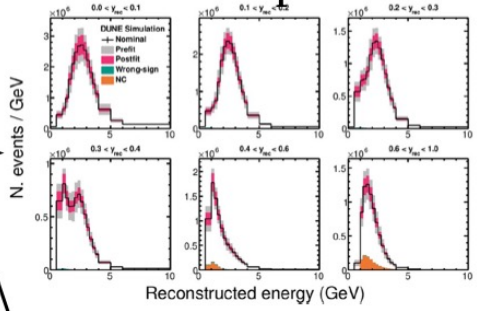
FD prediction



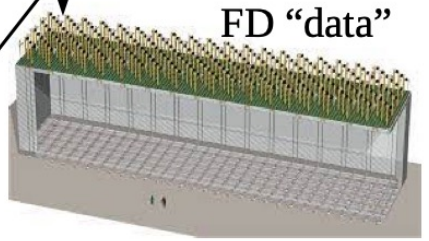
ND "data"

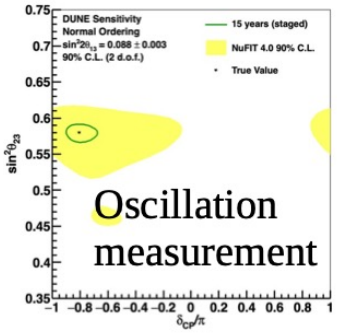


ND prediction



FD "data"



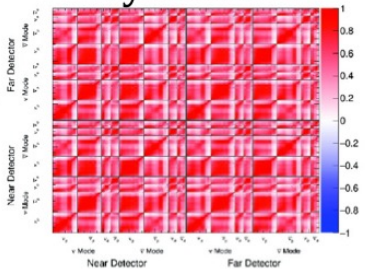


Oscillation measurement

$$\chi^2(\boldsymbol{\vartheta}, \mathbf{x}) = -2 \log \mathcal{L}(\boldsymbol{\vartheta}, \mathbf{x})$$

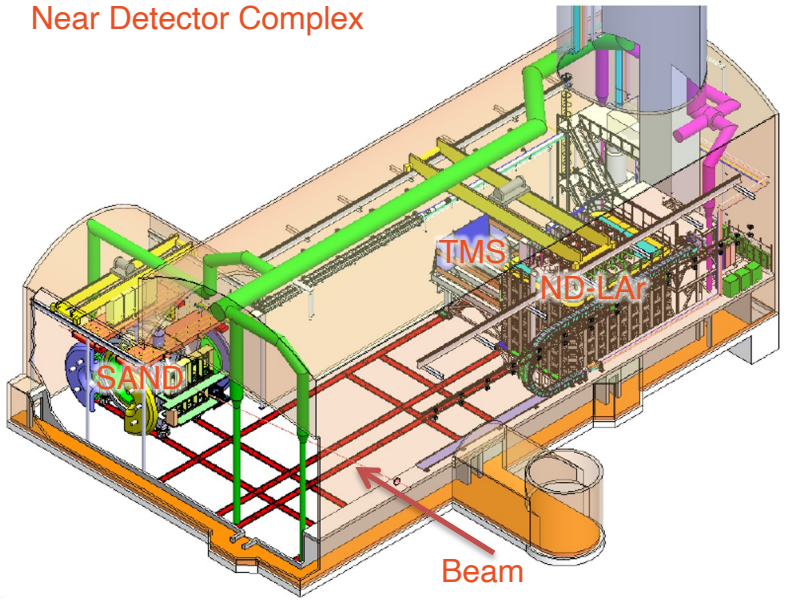
Fitting framework

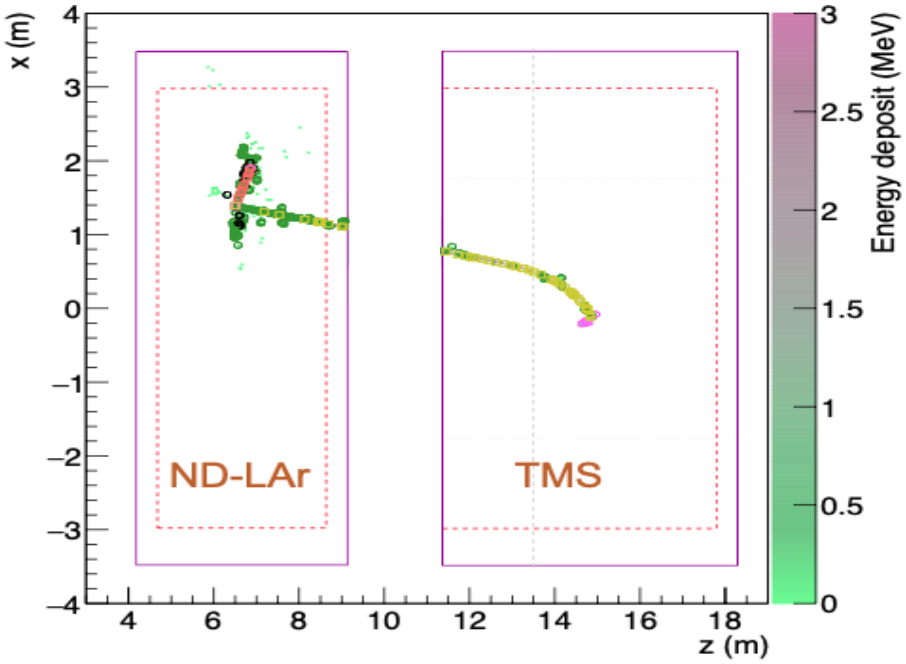
Systematics



DUNE Near Detector Design

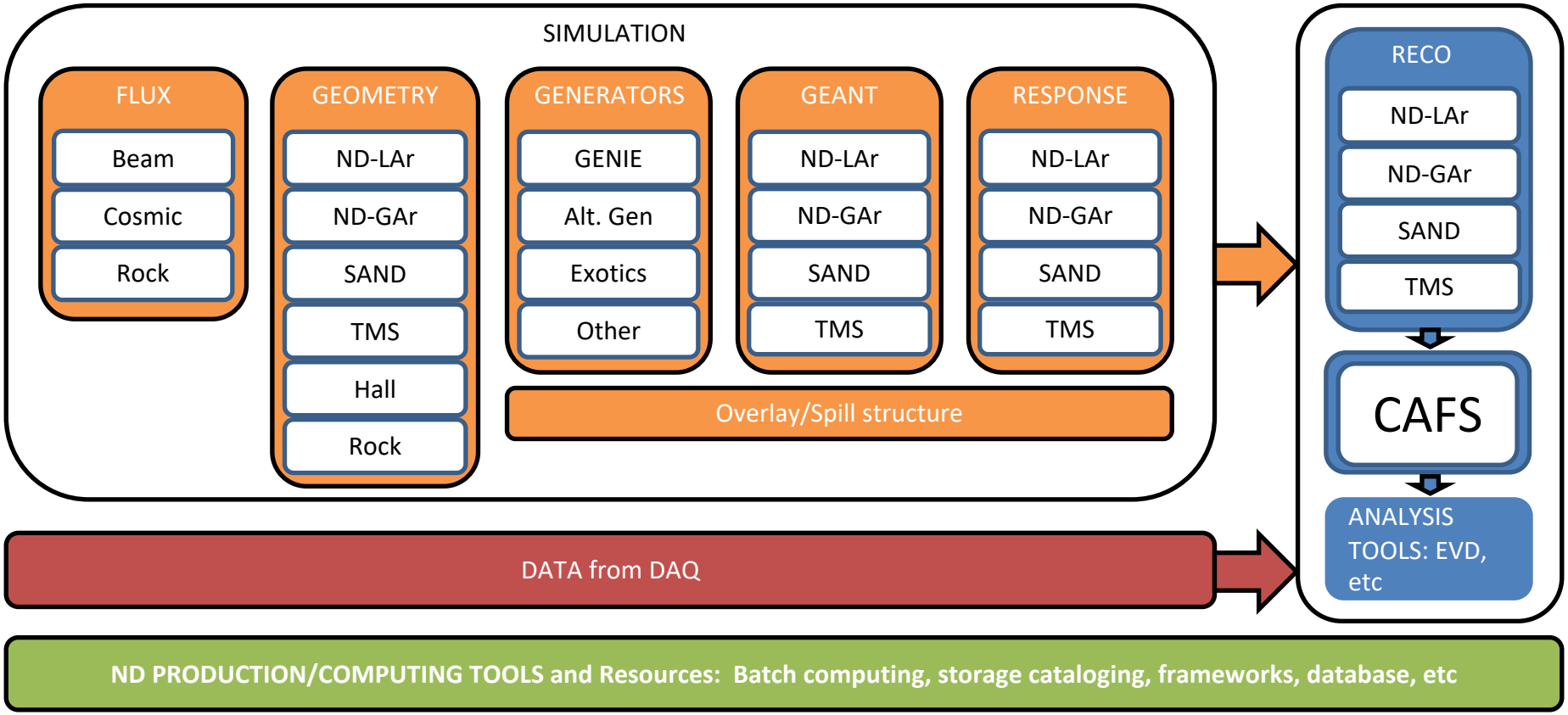
- Measures the neutrino flux, neutrino interaction cross sections on Ar.
- ND-LAr - added modularity and pixelization compared with FD.
- Downstream systems measure muon momentum (TMS, steel and scintillator range stack), flux (SAND, staw tube tracker + KLOE ECAL).
- Gaseous Argon (ND-Gar) Upgrade planned for in Phase II.





ND Software Overview

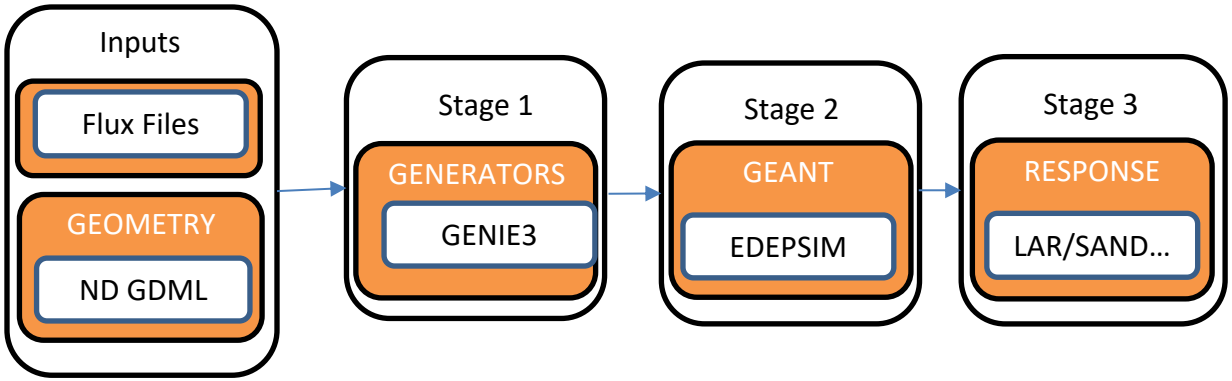
- Working on developing fully-integrated end-to-end production-ready simulation and reconstruction software for the ND detector suite and computing infrastructure to run at scale.



Current Status of ND Software

- The near detector software is largely framework-free.
  - Wide variety of software pedigree for each detector.
  - Most of the Near Detector is not LAr
  - ND-Lar's pixel response is quite different from FD detector,
  - Requires separate approach outside of LArSoft/ART.
- While near detector raw data volumes are anticipated to be much lower the FD, the diversity of detector types and high rate of neutrino interaction leads unique computing demands for high-level reconstruction.
- An integrated ND Software effort is underway.
- We developing input and experience to inform needs for a cross-cutting framework.

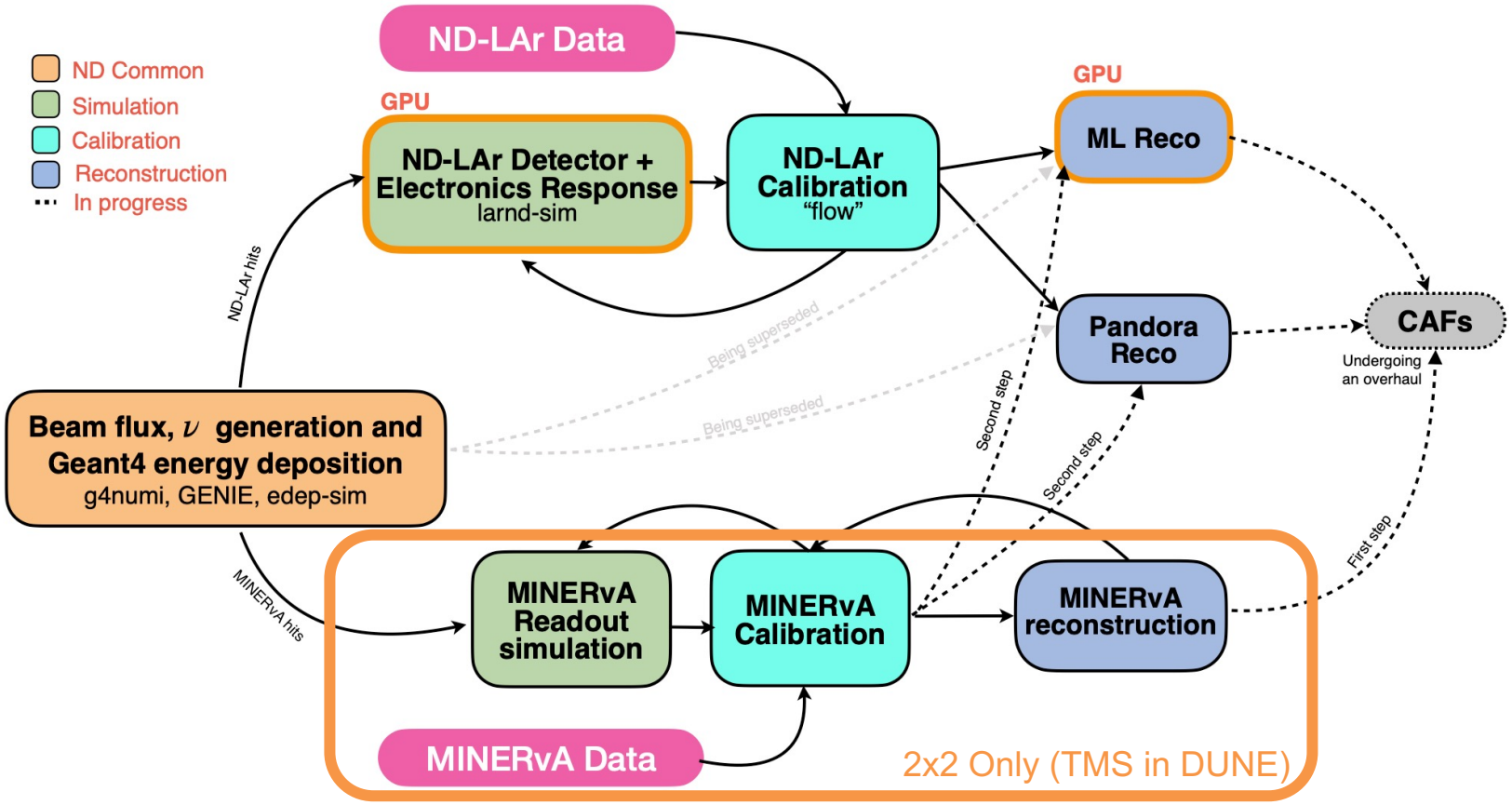
Simulation Overview



- The ND group maintains a common geometry GDML (https://github.com/DUNE/dunendggd).
- We have integrated GENIE3 with success.
- The GEANT4 stage for ND is using EDEPSIM.
  - We are testing using LArSoft as the G4.
- The response stage is detector specific.
- DUNE needs to use common GENIE and G4 implementations between ND and FD to align physics lists with minimal confusion.

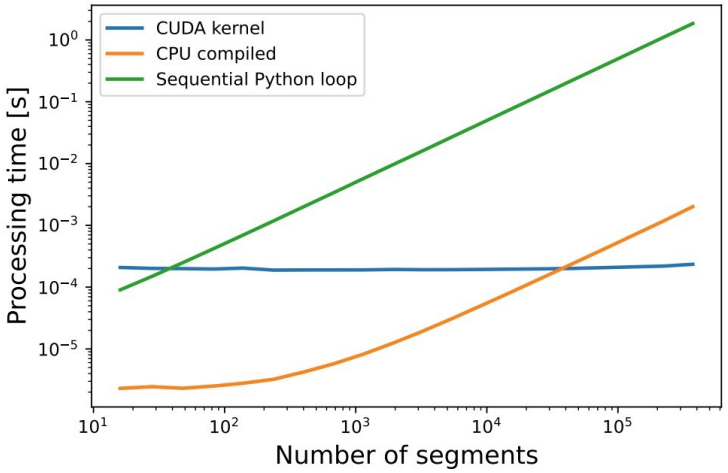
ND-LAr Software Chain

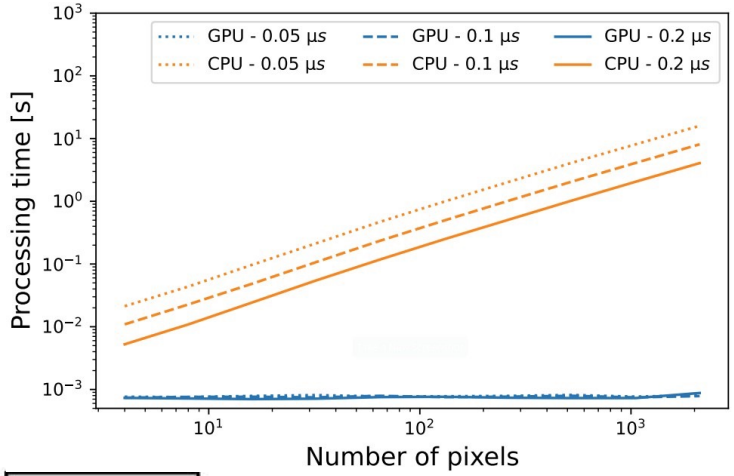
- The ND LAr-Software is mature and will be tested with the upcoming 2x2 demonstrator.

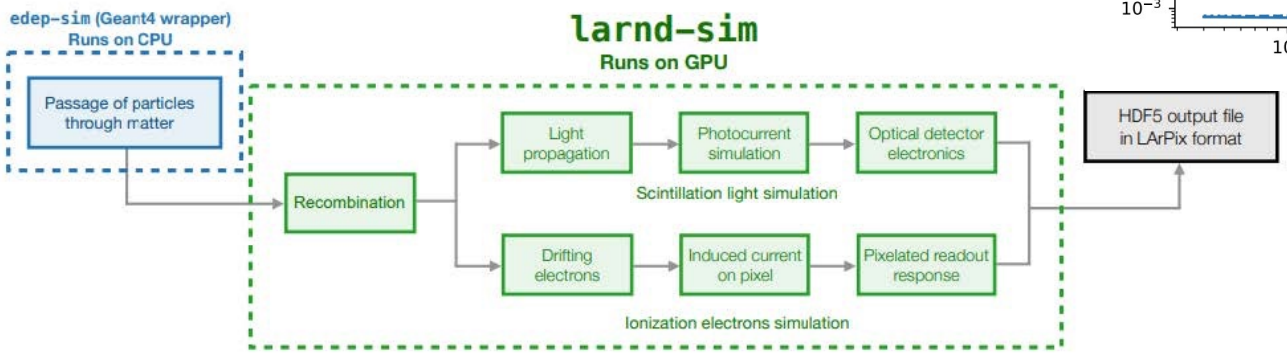


Why GPUs?

- 2x2 / ND-LAr detector simulation is an inherently parallelizable problem
  - GPU value proposition unmatched by CPUs
- ML reconstruction also GPU-dependent
- 10x 1-year MC stats:
  - 150k hours on Nvidia A100
- Highly-parallelized simulation of a pixelated LArTPC on a GPU, 2023 JINST 18 P04034

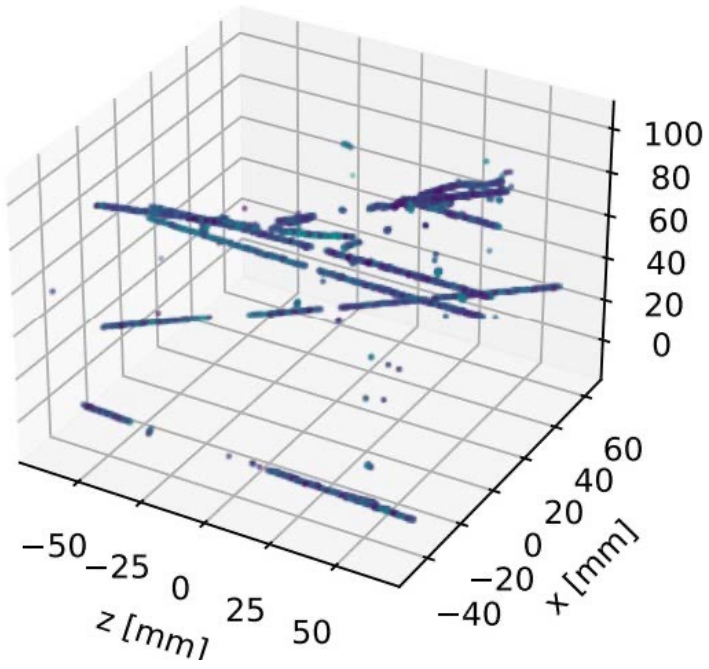






https://github.com/DUNE/larnd-sim

Existing 2x2 workflow and computing



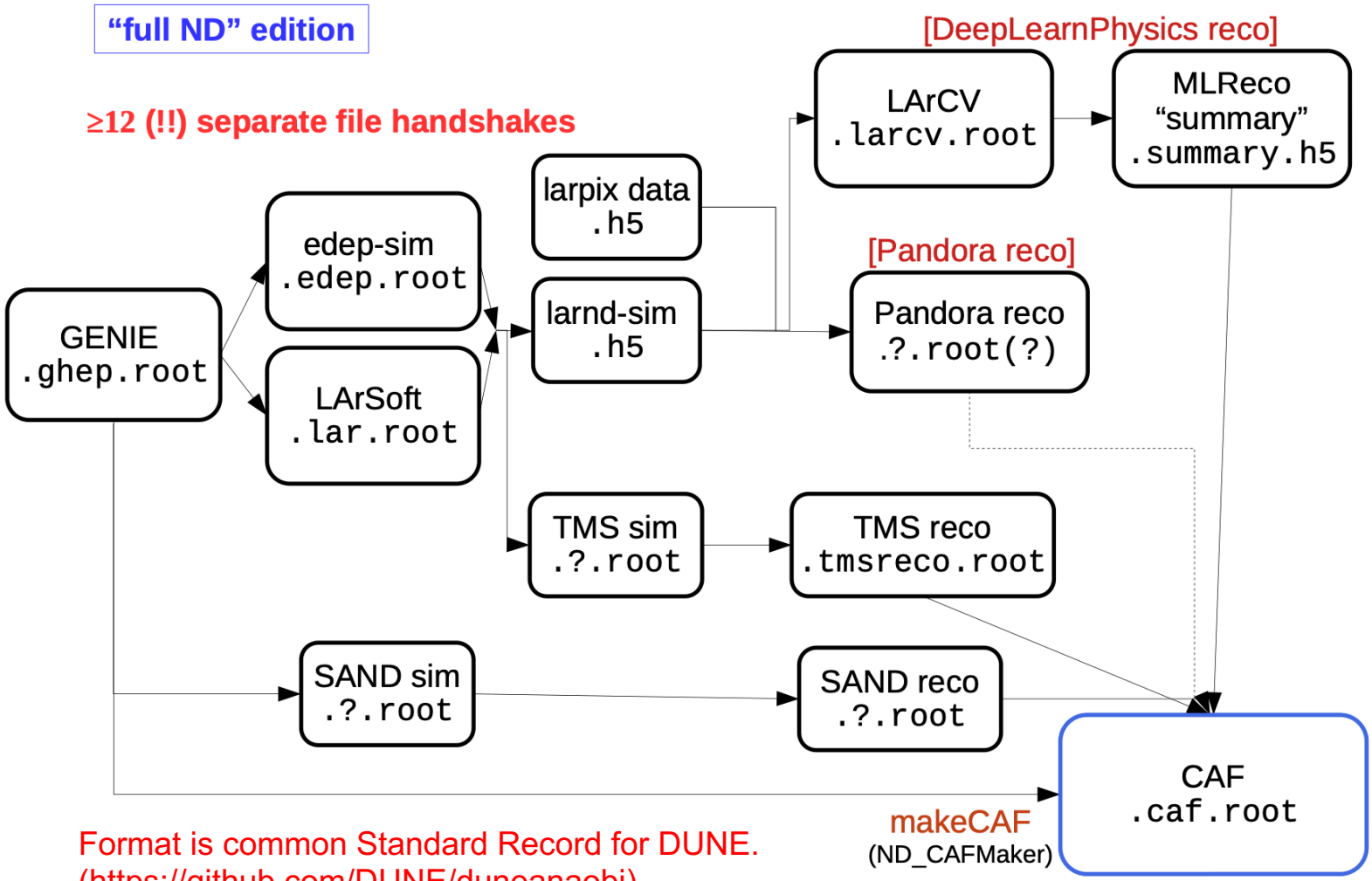
- Currently running at NERSC (Perlmutter) due to abundance of GPUs
  - Existing chain spans from GENIE to detector simulation and calibration
- Portability: Containers; scripts that lack any assumptions w.r.t. workflow system
- Simple FireWorks workflow management used so far
- High priority: Integration w/ DUNE data management

- Metadata cataloging; replication and tape backup (FNAL + NERSC)
- Adaptable to processing of real 2x2 data, simulation of full ND-Lar.

Reconstruction

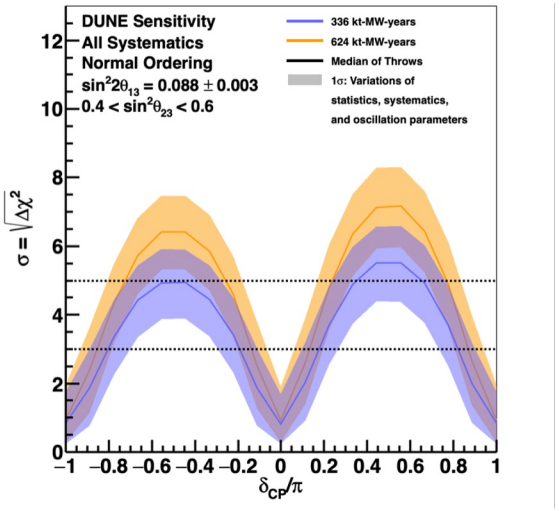
- We have 5 main reconstruction chains/tools under development.
  - ND-Lar
    - ND Lar Flow https://github.com/DUNE/ndlar_flow
    - MLReco (**GPU Based Reco,** python based)
  - SAND-RECO (https://baltig.infn.it/dune/sand-reco/)
    - C++11 Based, project in pitchfork, KLOE-based reconstruction for ECAL
  - NDGAr (https://github.com/DUNE/garsoft)
    - ART/LArSoft based
  - TMS (https://github.com/DUNE/dune-tms)
    - Newest Detector still very early in development.
  - PANDORA (https://github.com/PandoraPFA)
    - Working with LAr and SAND.
- Detectors have varied timing resolution, triggering etc, will require framework capable of working with a variety if data atom and timing structures.

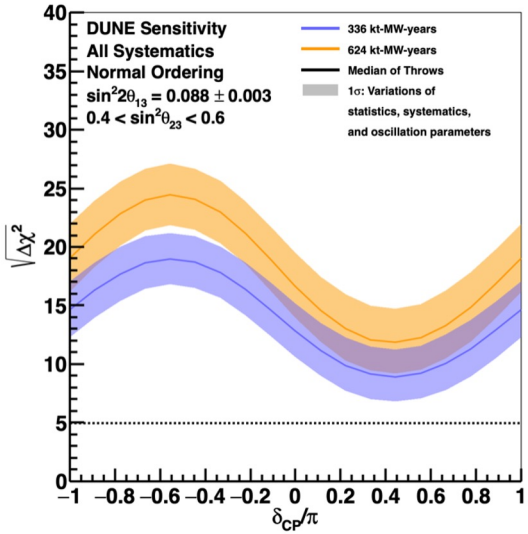
NDCAFMaker (https://github.com/DUNE/ND_CAFMaker)



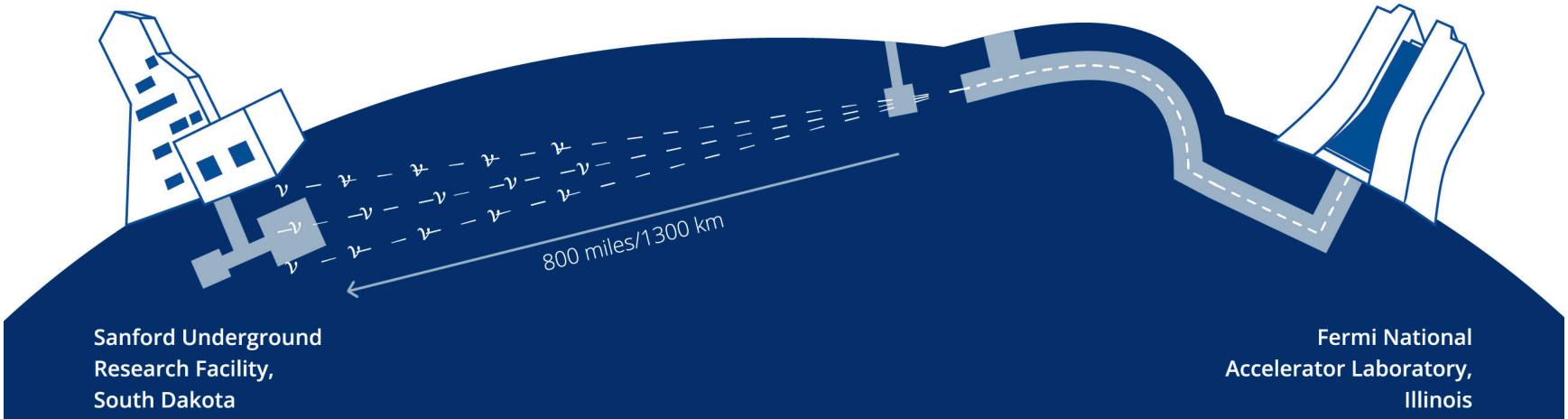
CAFAna + NuSystematics

- The LBL fit will be performed with inputs from ND (+PRISM), FD, detector and model systematics.
- Using CAFAna/MACH3 for fits.
- NuSystematics (https://github.com/LArSoft/nusystematics)
  - Tool for implement GENIE3 systematics.
  - LArSoft based version and framework independent version.
  - Plan to make available across experiments.
- Handling of all inputs for fit with rigorous systematics handling will be a requirement of any fitting framework.

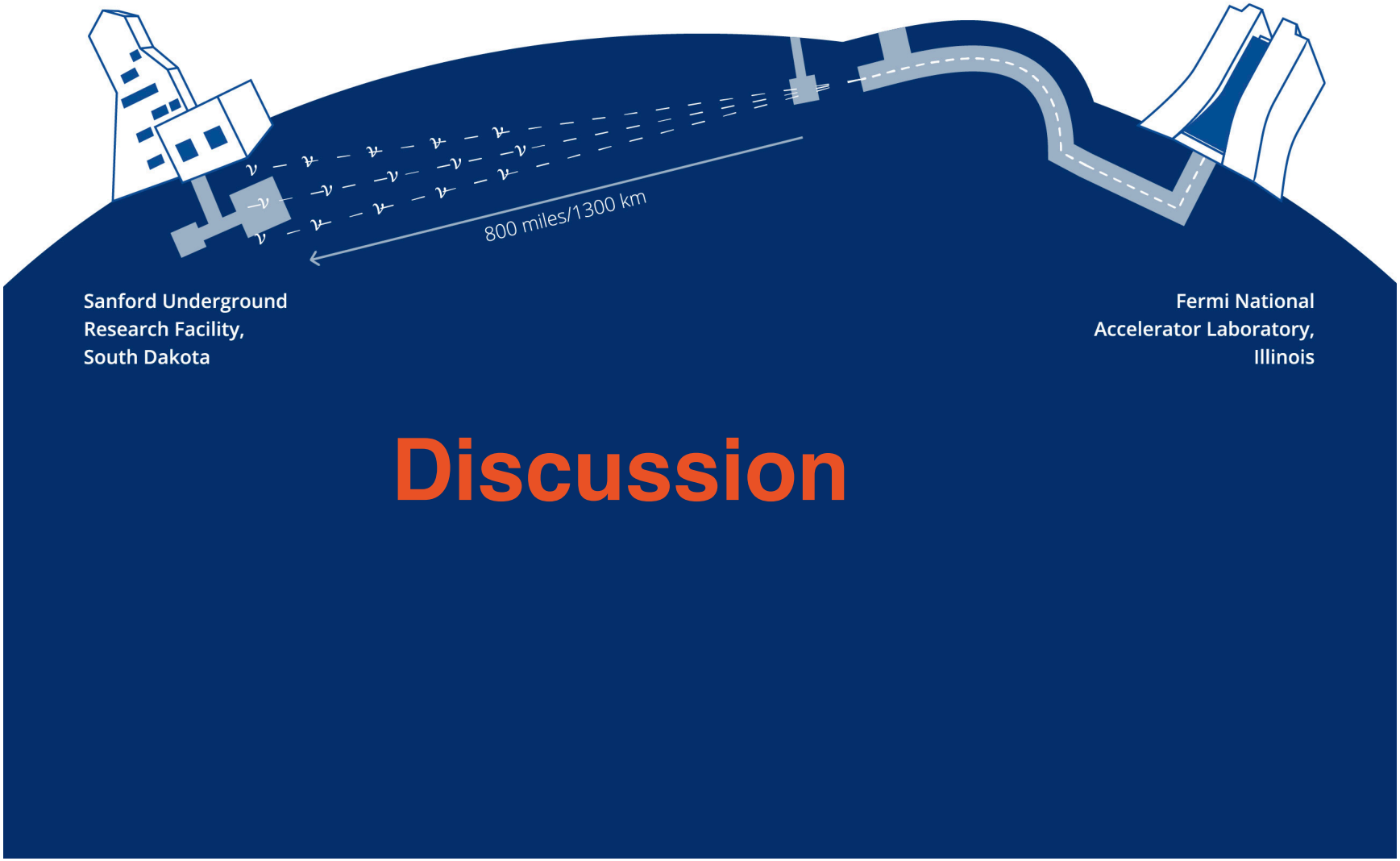




Conclusion/Takeaways



- The DUNE near detector is advancing and work toward integration into a set of common frameworks is ongoing.
- The near detector software is highly dependent on GPUs.
- The complexity of the data and need to process across detectors with varying size of data atoms is a need.
- A robust and flexible analysis and fitting framework is also needed with work well underway.


800 miles/1300 km
Sanford Underground
Research Facility,
South Dakota
Fermi National
Accelerator Laboratory,
Illinois

Discussion