A possibility to simulate DUNE near detector in LArSoft

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LArSoft Coordination Meeting

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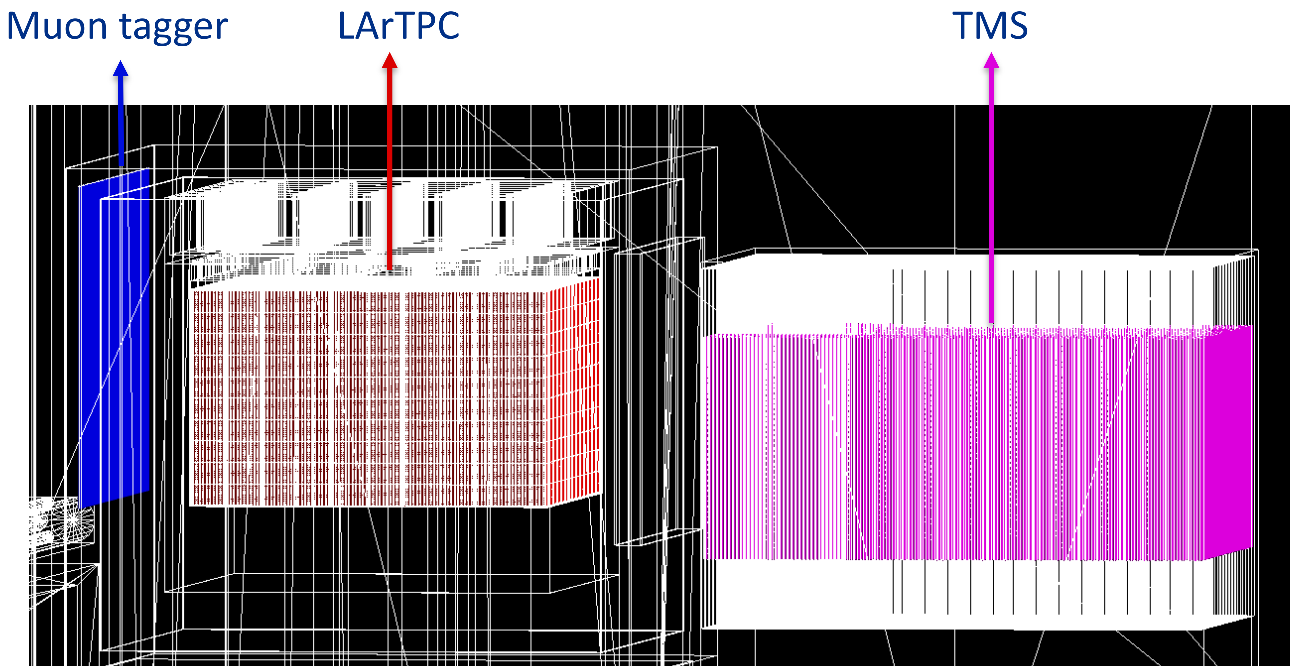
Introduction

- The DUNE near detector system consists of several components
  - LArTPC (ArgonCube)
  - Muon spectrometer (TMS, GArTPC)
  - SAND
- Currently the near detector is simulated using standalone genie, edep-sim (Geant4) and python-based detector simulation.
- I have explored the possibility to simulate DUNE near detector in larsoft
  - It may be beneficial to simulate both near and far detectors in the same framework
  - It is an opportunity to make larsoft more flexible and support more detectors
- I got a lot of help and had a lot of useful discussions with many people
  - LArSoft team: Erica Snider, Kyle Knoepfel, Robert Hatcher, Hans Wenzel, Gianluca Petrillo, Lynn Garren, et al.
  - My DUNE colleagues: Jeffrey Kleykamp, Laura Fields, Chris Backhouse, Tom Junk, Dan Dwyer, Peter Madigan, Matt Muether, Andy Mastbaum, Pedro Ochoa-Ricoux, et al.

DUNE near detector



- Use a version of gdml file that consists of 3 sensitive volumes: volMuonTaggerPlane, volTPCActive, and scinBoxlvTMS.
- Visualization of detector components using [CaTS].

Neutrino simulation in LArSoft

- Event generator:
  - GENIEGen_module.cc – a larsoft module to simulate neutrino interactions in a LArTPC
  - GENIEHelper – a generator interface to art for GENIE
- Geant4 detector simulation
  - Larg4 – refactored Geant4 simulation
- In principle we can use those two tools to simulate neutrino interactions and particle propagation in any detectors.
  - A few issues identified and resolved.

GDML elements

- The version of ND gdml file defines the element “zinc”

```
<isotope name="zinc64" Z="30" N="64">
<atom type="A" value="63.93"/>
</isotope>
<element name="zinc">
<fraction ref="zinc64" n="1.0"/>
</element>
```

- As Robert pointed out, this clashes with ROOT’s GDML parser and ROOT’s internal pre-defined materials definitions.
- A simple solution is to change “zinc” to “zincElement64” in a few places in the gdml file.

GENIEGen_module

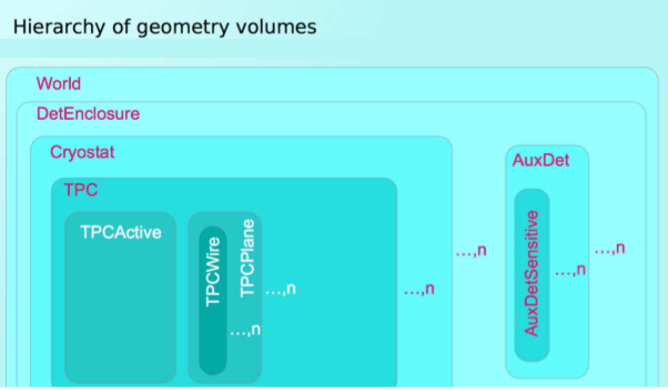
- In this producer module, there is a lot of analysis code to save histograms (e.g. distribution of neutrino vertices).
- One piece of code can cause trouble for non-LArTPC detectors:

```
art::ServiceHandle<geo::Geometry const> geo;
double x = 2.1*geo->DetHalfWidth();
double y = 2.1*geo->DetHalfHeight();
double z = 2.*geo->DetLength();
```

- Solution: if variable fDefinedVtxHistRange is true, do not call geometry service.
  - Ideally the analysis code should be moved to an analyzer module.
- PR submitted and merged.
- Thanks to Robert for pointing this problem out.

LArSoft Geometry

- The LArSoft geometry system has a required hierarchy of components:



https://larsoft.org/important-concepts-in-larsoft/geometry/

- The ND gdml file does not follow this hierarchy and naming scheme, even for the LArTPC component.
- There was an issue if LArSoft finds 1 cryostat but no TPC.
- Gianluca fixed this issue. Details in this redmine issue.

GENIE simulation

- After fixing several issues, it is straightforward to run GENIE simulation in LArSoft
  - Flux files in dk2nu format (thanks Laura Fields)
  - Flux xml file defining beam position/direction/window.
  - Fcl parameters defining top volume, FiducialCut, POT per spill, etc.
- I defined a beam window 10x6 m^2 in front of the muon trigger.
- I defined a FiducialCut of 10x6x8 m^3 for neutrino interactions.
- TopVolume is set to volWorld.

Larg4 simulation

- Hans provided instructions to modify the gdml file to be compatible with the larg4 simulation:

```diff
      <volume name="volTPCActive">
        <materialref ref="LAr"/>
        <solidref ref="TPCActive_shape"/>
-       <auxiliary auxtype="SensDet" auxvalue="TPCActive_shape"/>
+       <auxiliary auxtype="SensDet" auxvalue="SimEnergyDeposit" />
+       <colorref ref="magenta" />
+       <auxiliary auxtype="StepLimit" auxvalue="0.4" auxunit="mm" />
+       <auxiliary auxtype="Solid" auxvalue="True" />
        <auxiliary auxtype="EField" auxvalue="(500.0 V/cm, 0.0 V/cm, 0.0 V/cm)"/>
      </volume>
```

- Key word: SimEnergyDeposit
- StepLimit is set to 0.4 mm.
- Output format SimEnergyDeposit.h

```cpp
    int           numPhotons;      ///< of scintillation photons
//    int           numFPhotons;     ///< of fast scintillation photons
//    int           numSPhotons;     ///< of slow scintillation photons
    int           numElectrons;    ///< of ionization electrons
    float         scintYieldRatio; ///< scintillation yield of LAr
    float         edep;            ///< energy deposition (MeV)
    geo::Point_t      startPos;    ///< positions in (cm)
    geo::Point_t      endPos;
    double        startTime;    ///< (ns)
    double        endTime;      ///< (ns)
    int           trackID;      ///< simulation track id
    int           pdgCode;      ///< pdg code of particle to avoid lookup by particle type later
```

One simulated neutrino event

PROCESS NAME	MODULE LABEL..	PRODUCT INSTANCE NAME.................	DATA PRODUCT TYPE...	SIZE
GenieGen....	generator.....	....	std::vector<simb::GTruth>..	...1
GenieGen....	TriggerResults	....	art::TriggerResults..	...1
GenieGen....	generator.....	....	std::vector<sim::BeamGateInfo>.......................................	...1
GenieGen....	generator.....	....	std::vector<simb::MCTruth>...	...1
GenieGen....	generator.....	....	art::Assns<simb::MCTruth,simb::MCFlux,void>...........................	...1
GenieGen....	generator.....	....	std::vector<simb::MCFlux>..	...1
GenieGen....	generator.....	....	art::Assns<simb::MCTruth,simb::GTruth,void>...........................	...1
G4..........	TriggerResults	....	art::TriggerResults..	...1
G4..........	largeant......	....	std::vector<simb::MCParticle>..	.551
G4..........	largeant......	LArG4DetectorServicevolMuonTaggerPlane	std::vector<sim::SimEnergyDeposit>...................................	...0
G4..........	largeant......	LArG4DetectorServicevolTPCActive......	std::vector<sim::SimEnergyDeposit>...................................	9028
G4..........	largeant......	....	std::map<int,std::set<int> >...	...0
G4..........	largeant......	....	art::Assns<simb::MCTruth,simb::MCParticle,sim::GeneratedParticleInfo>	.551
G4..........	largeant......	LArG4DetectorServicescinBoxlvTMS......	std::vector<sim::SimEnergyDeposit>...................................	1644

ν_μ [2.6 GeV/c] + ^{40}Ar → μ [2.2 GeV/c] + p [0.8 GeV/c] (QE)

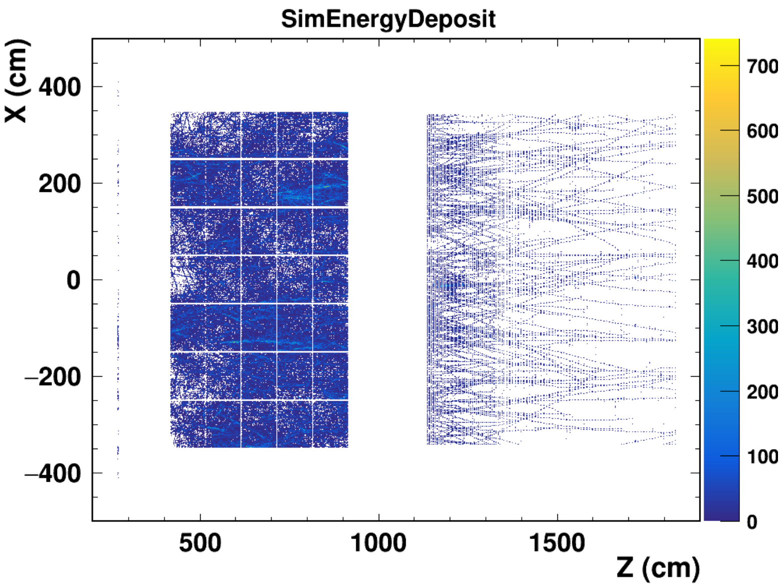
True Geant4 trajectory

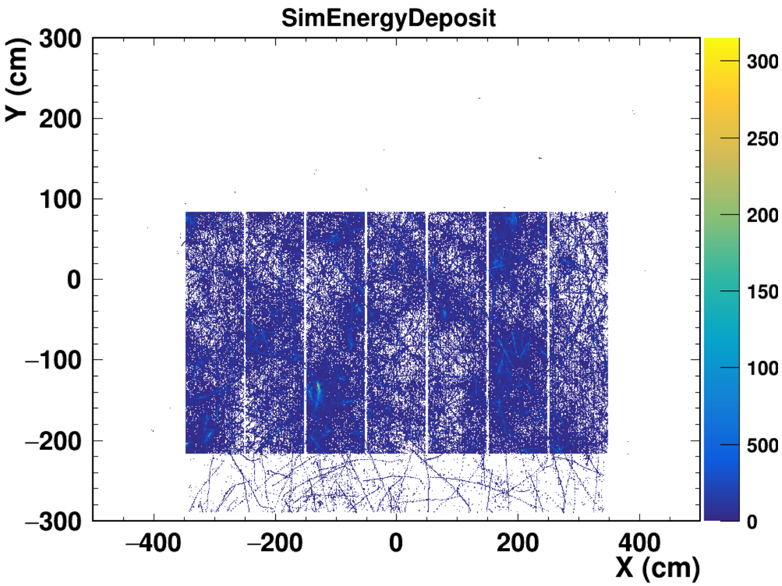
ν_μ [2.6 GeV/c] + ^{40}Ar → μ [2.2 GeV/c] + p [0.8 GeV/c] (QE)

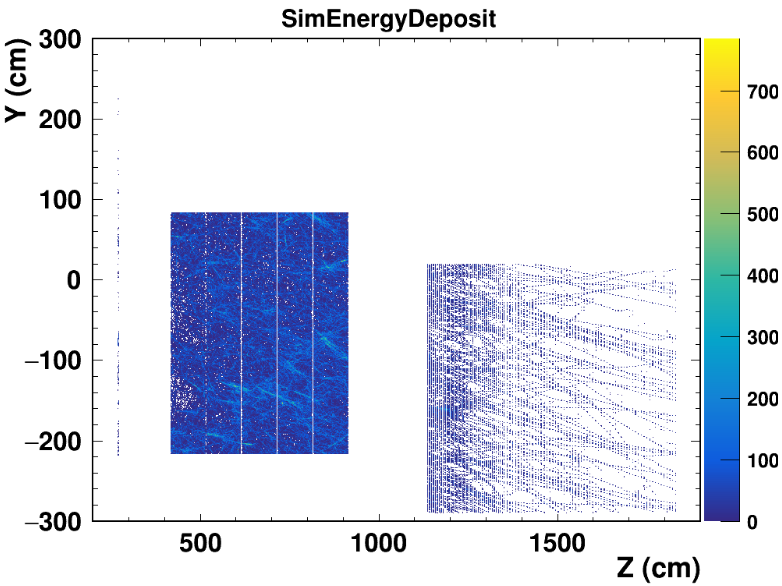
True energy deposition

- Chris Backhouse tweaked webevd to display simulated neutrino interactions.
  - Currently it does not fully support ND (expecting the same larsoft geometry hierarchy).
  - It would be nice to at least show detector layouts.

SimEnergyDeposit

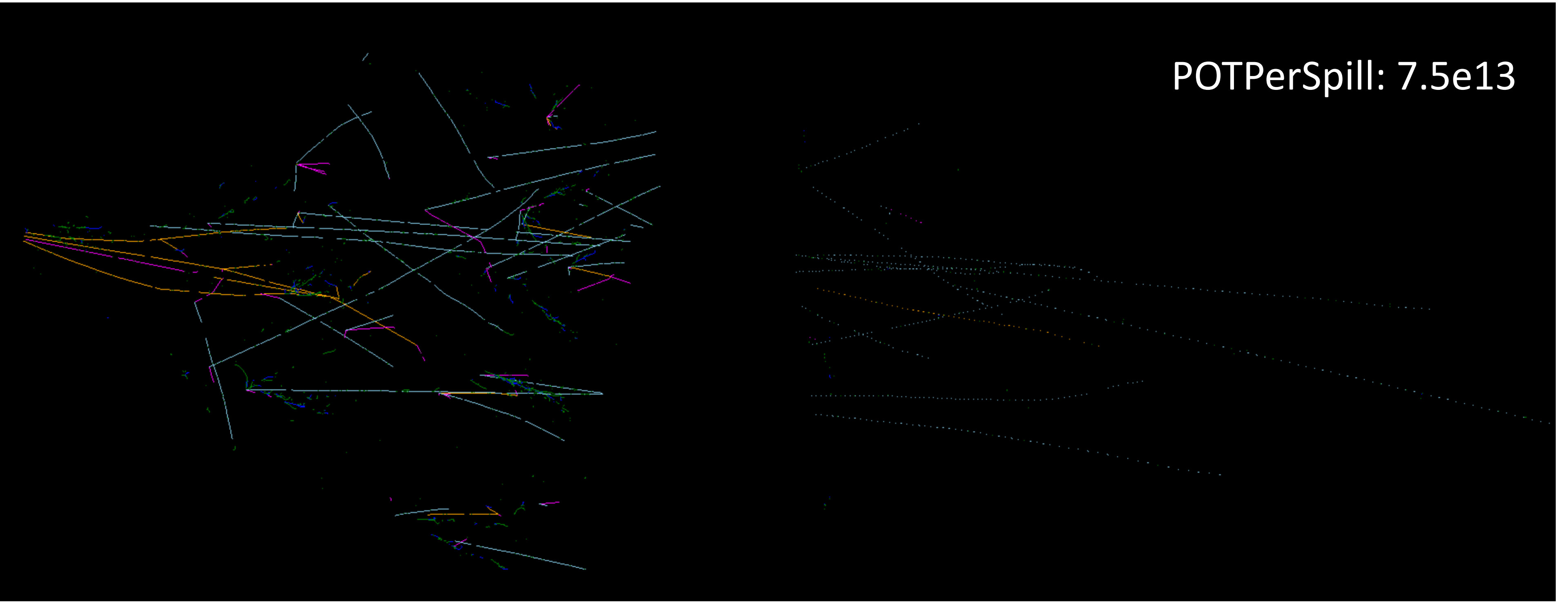






- Ran 1000 single neutrino simulation.
- Energy depositions in three sensitive volumes.
- 7x5 LArTPC modules
  - Each has two drift volumes
- TMS is lower than LArTPC
  - Beam angle is -0.101 rad.
- File sizes: after genie 2.5 MB, after larg4 805 MB

A simulated spill



std::vector<simb::MCTruth>.. | 59

Conclusions

- We have demonstrated the capability to simulate DUNE near detector (GENIE+Geant4) in LArSoft.
- Drift and electronics simulation is challenging because of the large number of channels.
  - Currently this is done by the DUNE ND group using highly-parallelized algorithms implemented on the CUDA architecture (https://github.com/DUNE/larnd-sim)
- It may be possible to take advantage of multi-threading/ML to accelerate the drift/electronics in LArSoft.
  - The is also a necessary step to separate channel readout from geometry description in LArSoft – currently under discussion.