

Wire-Cell for DUNE-FD



Haiwang Yu (BNL) on behalf of the DUNE collaboration

The Second Wire-Cell Reconstruction Summit

Hosted by Brookhaven National Laboratory The workshop will held as a hybrid event on April 10–12, 2024 https://www.bnl.gov/wirecellsummit/



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@BrookhavenLab

Outline

Current Wire-Cell components in DUNE-FD

- Sim, SigProc
 - In dev: GPU acceleration, DNN-ROI, LS4GAN
- Imaging, clustering
 - In dev: IO

Specific needs for DUNE-FD:

- VD field response calculation
- APA-wise sparse signal
- data/MC handling for the full 10kt geometries
- the challenges with radiological backgrounds
- multiple configurations (HD, VD, workspaces)

Discussion



Wire-Cell Event Reconstruction



µBooNE

DNN-ROI – better results with easier tunning

https://arxiv.org/pdf/2007.12743.pdf

- ref. Wenqiang and Avinay/Moon's talk
 - Tests with real data in PDHD/VD and SBND
- Implementation efforts:
 - Main issue: to match truth width with decon width
 - new "DepoFluxSplat"
 - "Morse sim" to extract the extra smearing
 - Automated evaluation
 - "spdir metric": <u>#287</u>
- Becomes more important coupled with "Prompt Processing", ref. Kirby's talk



87,75

87,87

87,85

0.6

0.2

0.0

75.75

80, 80

82,82

85,85

 $\theta_{xz}(V), \theta_{xz}(U)$



Extra truth smearing





https://indico.bnl.gov/event/21684/contributions/85251/attachments/51799/88575/splat.pdf

LS4GAN – unpaired I2I translation

https://arxiv.org/abs/2203.02557 https://arxiv.org/abs/2304.12858

- ref. Dmitrii's talk
- better results: learn features from data
 - 3D effect
 - realistic noise
- syst. unc. quantification
 - extra CVN syst. unc.?







Imaging: tiling, solving, de-ghosting

https://indico.fnal.gov/event/58097/contributions/276229/ DUNE Collab. Mt. Sep. 2023 ref. to Chao, Ewerton/Lynn's talk

- Foundation of Wire-Cell 3D reconstruction
- Potentially used by other reco. paradigms
- Some algorithms can be improved by AI/ML
- Still working on IO to LArSoft





Clustering

- ref. Chao's talk
- partially available in WCT now
- Preparing for following PatRec
 - Q-L matching, Traj. fitting, etc.
 - After selection of the neutrino activities (e.g., in SBND), many DUNE-focused alg. could be tested.
- Currently most heuristic -> very likely replaced/improved by AI/ML



Clustering for MicroBooNE sim. using WCT

IO for imaging results

- 2D images with selected neutrino activities
 - surface detectors
- sampled points -> space points
 - reduced info, needs effort to make it useful
- ITensorSet [arrays]
 - Ref: Brett's talk
 - Req:
 - (de)serialization needs to be fast
 - Interoperability
 - LArSoft
 - AI/ML
 - WCP ROOT:
 - TC, TDC
 - vector<POD>
 - vector<vector<POD>>

- ITensorSet
 - meta/json
 - vector<lTensor>
- ITensor
 - meta/json
 - Boost.MultiArray



VD field response calculation

- Ref. Wenqiang's talk
- Considering potential 3D effect
 - took Francesca's approach
 - <u>https://github.com/brettviren/pochoir</u>
 - paper: S. Martynenko et al 2023 JINST 18 P04033
 - validated with PDVD coldbox data
- 3D + 2D FR calculation
 - drift path/speed: 3D
 - weighting field: 3D central + 2D outer region
- averaged 3D for 2D Wire-Cell LArTPC simulation
 - average multiple paths
- Two field resp. available for 50L and PDVD







Skip processing APAs using async. WC node

ref: https://indico.fnal.gov/event/63824/

- Considering the APA-sparsity
- realized by new WC asyc. node introduced by BV
- Critical for efficient 10kt simulation, especially beam focused ones
- Makes it possible to keep raw digits
- For SigProc (data), need a real APA level trigger alg.

Test with one numu event:

Execution time (4032sec/259sec) ~ 15.5 times faster than baseline (no skip)

- This ratio depends on the event activity
 - Processed CRUs (ref/skip: 320/15) ~ 21 times
 - some overhead compared to 15.5

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Earlier skip test with an ideal track in 2-CRUs

Ref: https://indico.fnal.gov/event/60987/contributions/282811/

Initial tests for full 320CRU geom, ideal depo tracks in CRU 0, 4

process all with shortcut: ~25sec (skip) vs. ~2400sec (ref)

Radiological backgrounds

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- Adding more realistic radiological backgrounds would break the simple yes/no APA level (cheating) filter of the skipping
 - Some better cheating alg. is needed, e.g., **depo->process == neutrino?**
- Compared to FDHD, FDVD non-bridged needs more resources, can bridged channels help?

		HD 12 AP	A workspace	VD 112CRM workspace		
		HD	1x2x6	VD 1x8x14		
From L. Paulucci		No EM children	With EM children	No EM children	With EM children	
	Gen	2.6646s	2.92583s	30.8643s	27.7531s	
		2085.11 MB	2117.41 MB	1853.91 MB	1882.64 MB	
	G4	95.9081s	107.752s	118.236s + 88.9054s	143.669s + 85.7495s	
		2616.97 MB	3307.76 MB	6863.03 MB + 4905.57 MB	10675.5 MB + 7524.54 MB	
	Detsim	477.651s	506.957s	1226.02s	1030.05s	
		2092.95 MB	2997.5 MB	5423.43 MB	5749.58 MB	
	Reco1	0.11843s	0.123185s	1.30019s	1.04877s	
		976.384 MB	1629.86 MB	3178.41 MB	4956.22 MB	
	File size	1.4GB	1.8GB	2.5 GB	3.6GB	

Discussion

Working on applying DNN-ROI for multiple experiments

• ref. Wenqiang, Avinay/Moon's talk

Skip processing for DUNE-FD almost ready for production tests

Better FR ready

Major discussion focus is the Wire-Cell->LArSoft IO

In addition, Wire-Cell has the potential to directly read in HDF5 DAQ files, but this may be discussed in the IO session. Ref. BV's talk

Thanks!

GPU based simulation – More efficient sim. for AI/ML?

https://indico.cern.ch/event/948465/contributions/4323675/ https://arxiv.org/pdf/2203.02479.pdf

- Need to be coupled with computing facility
- Needed?

Number of Processes per GPU using CUDA-MPS

2D-Convolution based LArTPC Simulation

Ramo's theorem:
$$i = -q \stackrel{\rightarrow}{E_w} \cdot \stackrel{\rightarrow}{v_q}$$

2D: approximate translational symmetry along the wire direction

LArTPC wire-readout measures induced charge \otimes response $M(t', x') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} R(t, t', x, x') \cdot S(t, x) dt dx + N(t', x')$

Energy depo + diffusion + rasterization

Long-range and position-dependent field

Final Signal

2D-Convolution based Signal Processing

Signal Processing (SP) of LArTPC resolves charge from the original measurement:

$$S(\omega_t, \omega_x) \sim \frac{F(\omega_t, \omega_x) \cdot M(\omega_t, \omega_x)}{R(\omega_t, \omega_x)} \xrightarrow{IFT} S(t, x)$$
• Utilize the signal/noise separation in both frequency and time domain
$$\underbrace{Vaveform \ data}_{t \rightarrow Decon. \ w/o \ LF} \xrightarrow{Vavef$$

•

"2D deconvolution": assuming translational

symmetry in the third dimension

2000

1000

00 1000 1100 1200 1300 1400 1500

channel

18

2000

1000

900

1000

00 1100 1200 1300 1400 1500 induction plane

0

Wire-Cell 3D Imaging Principle

Fig.1:Basic principle of tomography: superposition free tomographic cross sections S1 and S2 compared with the projected image P

https://en.wikipedia.org/wiki/Tomography

"Three-dimensional Imaging for Large LArTPCs", JINST 13, P05032 (2018)

Ray grid

Convenience way to calculate wire crossing projections Multiple non-orthogonal 2D coordination system

• one for each wire plane pair

2D crossing coord:

$$r_{ij}^{lm} = r_{00}^{lm} + jw^{lm} + iw^{ml}$$

Projection to the pitch direction of the target plane: $p_{ij}^{lmn} = (r_{ij}^{lm} - c^n) \cdot \hat{p}^n$

Expanded:

$$P_{ij}^{lmn} = r_{00}^{lm} \cdot \hat{p}^n + jw^{lm} \cdot \hat{p}^n + iw^{ml} \cdot \hat{p}^n - c^n \cdot \hat{p}^n$$

w^{Im}: displacement vector along layer-m spaced by layer-l

Solving: usage of Charge, Sparsity, Positivity, Proximity

measured charges on Wires	$y = A \cdot X$			K	true charge to be resolved	
$\begin{pmatrix} y1\\ y2\\ u1\\ u2\\ u3 \end{pmatrix} = \begin{pmatrix} 0\\ a\\ 0\\ 0\\ a \end{pmatrix}$	0 a 0 a 0	0 a a 0 0	a 0 0 0 a	a 0 0 a 0	$ \begin{pmatrix} H1 \\ H2 \\ H3 \\ H4 \\ H5 \\ H6 \end{pmatrix} $	

matrix determined by geometry, a=1

L1 reg.
$$O(N!) \rightarrow O(m \times N)$$

 $\chi^2 = (y - A \cdot x)^2 + \lambda \cdot \sum_i |x_i|$
E. Candes, J. Romberg, T. Taoⁱ
arXiv-math/0503066

- The goal is to differentiate the true hits from fake ones by using the charge information
 - \sim large charge \rightarrow true hits
 - ~ zero charge \rightarrow fake hits
 - correct SigProc is important, <u>J. Jo's talk.</u>
- Sparsity, positivity, and proximity information are added through compressed sensing (L1 regularization)

de-ghosting

- Solving alone cannot eliminate all ghosts
- In MicroBooNE, the situation is worse when 2-view blobs are allowed
 - 10% dead channels \rightarrow 3view only is not acceptable
 - 2view tiling is needed \rightarrow more ghosts
 - <u>https://arxiv.org/abs/2011.01375</u>
- · de-ghosting: larger, connected blobs tends to be true
 - future AI/ML opportunity

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Cluster-flash (light) Matching

PMTs detect the scintillation light, time ~ns

Drift velocity 1.1 mm/ μ s \rightarrow several ms drift time

- In LArTPC, the light (PMT) readout and charge (TPC) readout systems are decoupled
- The identification of neutrino interaction candidate requires matching the charge signal with the light signal in order to obtain the event time

Matching Principle

Core Charge-Light Matching Algorithm

40-50 PMT activities

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IonAndScint

38k

777k