

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/



f O

@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

11

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

13

- 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

22

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

Singlesem. generator. std: vectorsait: UCTruth. i.i. Singlesem. TriggerBesults. att: TriggerBesults. j.att: J.a		PROCESS NAME	MODULE LABEL	PRODUCT INSTAN	CE NAME	DATA PROD	UCT TYPE	.SIZE
Singlesem. rss.	SinglesGen SinglesGen SinglesGen G4		generator	<		std::vect	or <simb::mctruth></simb::mctruth>	1
Singlesden. 17-signer/seults. 1 art::Trigner/seults. 282 Gd. 100AdScinttetrant 1 std::vectorsis::Sinchanetb. 282 Gd. PPartSintr. 1 std::vectorsis::Sinchanetb. 282 Gd. PristSintr. 1 std::vectorsis::Sinchanetb. 282 Gd. PristSintr. 1 std::vectorsis::Sinchanetb. 283 Gd. TriggerResults. 1 std::vectorsis::Sinchanetb. 3857 Gd. TriggerResults. 1 std::vectorsis::Sinchanetb. 3857 Gd. Largeant. LArdBetectorServicevaltrOcktiv 3857 3857 Gd. Largeant. LArdBetectorServicevaltrOcktiv std::vectorsis::Sinchanetb. 286 Gd. Largeant. LArdBetectorServicevaltrOcktive 386 386 386 386			rns			std::vect	or <art::rngsnaps< th=""><th>1</th></art::rngsnaps<>	1
G4. IonAddScintecterral 1 std::vectorsis::SinterryOpposite 2.282 G4. PDFastSinter. 1 std::vectorsis::SinterryOpposite 3.83 G4. IonAdScint. 1 std::vectorsis::SinterryOpposite 3.85 G4. Iorgent. IordAdScint. 3.85 3.85 G4. Iorgent. IordAdScint. 3.85 3.85 3.85 G4. Iorgent. IordAdScint. 3.85 <th>TriggerResults</th> <th></th> <th></th> <th>art::Trig</th> <th>gerBesults. / 6K</th> <th>1</th>			TriggerResults			art::Trig	gerBesults. / 6K	1
G6. 0 electrit 100 to			TonAndScintExternal			l std: west	or-sim: SimEnergyDenosity	202
GL. PPFstSiaAr. 1.53 GL. Instant. 1.53 GL. Largeant. LArdPetetorServicevUTPActive 1.53 GL. Largeant. Largeant. 1.54 GL. Largeant. 1.54 1.54 GL. Largeant. 1.55 1.55 GL. Largeant. 1.55 1.55 GL.			alconsift			stdvect	erseimu SimChannals	1725
Genie Importantization 580 Vectorsain: Supportantization 188 Genie St. Innindscint 180 St. 180 Genie St. Innindscint 180 St. 180 Genie St. Innindscint 180 St. 180 Genie Inrigeresults Interpretation 180 Genie Inrigeresult Inrigeresult 180 Genie In		04	etecorrit			starvect	or <sim::simchannet></sim::simchannet>	.1/35
genie std::vectorsa:::Std:wectorsa:::Std:Wectorsa:::Std:Wectorsa:::Std:Wectorsa:::Std:Wectorsa::::Std:wectorsa		G4	PDFastSimAr	* • • • • • • • • • • • • • • • • • •	••••••	std::vect	or <sim::simphotonslite></sim::simphotonslite>	88
Genile 64. Infragener@ults. 13857 G4. PPFastSinAr. 1551 151 G4. PPFastSinAr. 1551 151 G4. largeant. 147.050 1561 1561 G4. largeant. 147.050 151 1561 1561 G4. largeant. 147.050 151 151 151 G4. largeant. 147.050 151		G4	rns	* • • • • • • • • • • • • • • • • • • •	••••••	std::vect	or <art::rngsnapshot></art::rngsnapshot>	8
G4. TriggerResults. art: intriggerResults. at: intriggerResults. G4. argeant. ArtGebetectorServicevoITPCAttue std: vectors.int: :KGraricles. 366 G4. argeant. ArtGebetectorServicevoITPCAttue std: vectors.int: :SinnergyDepoits. 385 G4. argeant. ArtGebetectorServicevoITPCAttue std: vectors.in: :SinnergyDepoits. 385 G4. argeant. ArtGebetectorServicevoITPCAttue std: vectors.in: :SinnergyDepoits. 386 G4. PPastSinRe. std: vectors.in: :SinnergyDepoits. 386 G4. PastSinRe. std: vectors.in: :SinnergyDepoits. 386 G4. PastSinRe. std: vectors.in: :SinnergyDepoits. 386 G4. argeant. art: :Assns <sinb: :mctruth.<="" td=""> 386 G4. argeant. art: :Assns<sinb: :mctruth.<="" td=""> 386 G4. argeant. art: :Assns<sinb: :mctruth.<="" td=""> 316 G4. argeant. art: :Assns<sinb: :mctruth.<="" td=""> 311 MALEVEGN. art: :Assns<sinb: :mctruth.<="" td=""> 311 MALEVEGN. art: :Assns<sinb: :mctruth.<="" td=""> 311<</sinb:></sinb:></sinb:></sinb:></sinb:></sinb:>	aenie	G4	IonAndScint	••••••	•••••••	std::vect	or <sim::simenergydeposit< th=""><th>38567</th></sim::simenergydeposit<>	38567
G4. (PDFatSiaAr	J	G4	TriggerResults	*	•••••••	∘art::Trig	gerResults	1
G4 Largeant IntroductorservicevolTPACtule istil:vectorsin::SimEergyDeposit> 1.16 G4 Largeant LArG4DetectorServicevolTPACtule istil:vectorsin::SimEergyDeposit> 38567 G4 Largeant LArG4DetectorServicevolTPACtule istil:vectorsin::SimEergyDeposit> 38567 G4 POFastSimXe Istil:vectorsin::SimEergyDeposit> 38567 G4 POFastSimXe Istil:vectorsin::DeptateAtrackerRecorb> 88 G4 Iargeant Istil:vectorsin::DeptateAtrackerRecorb> 88 G4 Largeant Istil:vectorsin::DeptateAtrackerRecorb> 88 G4 Largeant Istil:vectorsin::DeptateAtrackerRecorb> 88 G4 Largeant Istil:vectorsin::DeptateAtrackerRecorb> 10 G4 Largeant Istil:vectorsin::DeptateAtrackerRecorb> 11 G4 NARLEYGEN NateLifeen 11 11 MMLEYGEN NateLifeen 11 11 11 11 MMLEYGEN NateLifeen 12 11 11 11 11 MMLEYGEN NateLifeen 12 12 11 11 <		G4	PDFastSimAr		• • • • • • • • • • • • • • • • • • • •	std::vect	or <sim::opdetbacktrackerrecord></sim::opdetbacktrackerrecord>	88
G4. LAregent		G4	largeant	*		std::vect	or <simb::mcparticle></simb::mcparticle>	16
G4		G4	largeant	LArG4DetectorS	ervicevolTPCActive	std::vect	or <sim::simenergydeposit></sim::simenergydeposit>	38567
G4 PDFastSinXe.		G4	largeant	LArG4DetectorS	ervicevolCrvostat.	std::vect	or <sim::simenergydeposit< th=""><th></th></sim::simenergydeposit<>	
G4		64	PDFastSimXe		· · · · · · · · · · · · · · · · · · ·	std::vect	or <sim::opdetbacktrackerbecord></sim::opdetbacktrackerbecord>	88
G4		64	PDFastSimXe			std::vect	or-sim: SimPhotonslites	
G4		G4	largeant			sturrect	icleAncestruMan	
V4 Largeant Large		64	langeant			Simi Part	I Cleances Crymap	16
MARLEYGen. K406enInCathode. std::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/b212CenInLAC. itd::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/b212CenInLAC. itd::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/b212CenInLAC. itd::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/b212CenInLAC. itd::vectorssinb::MCTruths 1 MARLEYGen. U23Chain/b212CenInLAC. itd::vectorssinb::MCTruths 1 MARLEYGen. MAZLEYGen. itd::vectorssinb::MCTruths 1 MARLEYGen. Th322Chain/bachi/back4. itd::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/bachi/back4. itd::vectorssinb::MCTruths 1 MARLEYGen. Moz22Chain/bachi/back4. itd::vectorssinb::MCTruths 1 Supernovd&Stagel largent. LArd0detectorServicev0lrycstat itd::vectorssinb::MCTruths 1 Supernovd&Stagel largent. LArd0detectorServicev0lryCALtive 1 1 Supernovd&Stagel largent. LArd0detectorServicev0lryCALtive 1 1 Supernovd&Stagel largent. LArd0detectorServicev0lryCALtivecorssin: Sint Rerg/D		G4	largeant	* • • • • • • • • • • • • • • • • • • •	••••••	art::Assn	< <imp::mclruth,simp::mcparticle,sim::generatedparticleinto> </imp::mclruth,simp::mcparticle,sim::generatedparticleinto>	16
MARLEYGEn K48GEnInCathode. ist: vectorsibe: NCTruth>. ist: vectorsibe: NCTruth>. MARLEYGEN R222ChainR22CatainR22								
MALLPYGEN. An228ChainPb212GenInLAr. 51d: vectorssibi: HCTruths. MALLYGEN. An228ChainPb212GenInLAr. 51d: vectorssibi: HCTruths. MALLYGEN. KABENIALAR. 51d: vectorssibi: HCTruths. MALLYGEN. U238ChainGenIndathode. 51d: vectorssibi: HCTruths. MALLYGEN. U238ChainGenInCathode. 51d: vectorssibi: HCTruths. MALLYGEN. Th22ChainGenInCathode. 51d: vectorssibi: HCTruths. MALLYGEN. Th22ChainGenInCathode. 51d: vectorssibi: HCTruths. MALLYGEN. Razeronaux 51d: vectorssibi: HCTruths. MALLYGEN. Th22ChainGenInPOS. 11 MALLYGEN. Razeronaux 51d: vectorssibi: HCTruths. MALLYGEN. Razeronaux 11 MALLYGEN. Razeronaux 12 MALLYGEN. Razeronaux 11 MALLYGEN. Razeronaux 11 MALLYGEN. Razeron		MARI EVGen	L KARGenInCathode		Г.		Letd: vector/simb: MCTruths	. 1
MALEYGEN. In222biainRe222GenTaLAr. 54d::vectors.ibl::MCTruth. MALEYGEN. Iv236hainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Iv236hainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Iv236hainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Iv23chainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Iv23chainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Rd2rostArGenInupperfeshizkstd. 54d::vectors.ibl::MCTruth. MALEYGEN. Rd22chainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Rd22chainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Rd22chainGenfasthode. 54d::vectors.ibl::MCTruth. MALEYGEN. Rd22chainGenfasthode. 54d::vectors.ibl::MCTruth. SupernovGdStagel Iargeant. LArd0etectorServicevolTPACLive 551:vectors.ibl::MCTruth. SupernovGdStagel Iargeant. LArd0etectorServicevolTPACLive 551:vectors.ibl::MCTruth. SupernovGdStagel Iargeant. LArd0etectorServicevolTPACLive 551:vectors.ibl::MCTruth. SupernovGdStagel Iargeant. LArd0etectorServicevolTPACLive 551:vectors.ibl::MCTruth. <t< th=""><th></th><th>MARL EYGen</th><th>Bn220ChainPh212GenInL</th><th>Ir</th><th> </th><th></th><th> std::vector<simb::mctruth></simb::mctruth></th><th></th></t<>		MARL EYGen	Bn220ChainPh212GenInL	Ir			std::vector <simb::mctruth></simb::mctruth>	
MARLEYGEn. K400en InAnade std::vectorsime::INCTrutt>. MARLEYGEn. U238ChainGenIndentode std::vectorsime::INCTrutt>. MARLEYGEn. Tt232ChainGenIndathode std::vectorsime::INCTrutt>. MARLEYGEN. Tt232ChainGenIndathode std::vectorsime::INCTrutt>. MARLEYGEN. R224Pro#242ndeninUpperfeshixk:14 std::vectorsime::INCTrutt>. MARLEYGEN. R224Pro#242ndeninUpperfeshixk:14 std::vectorsime::INCTrutt>. MARLEYGEN. R224Pro#242ndeninUpperfeshixk:14 std::vectorsime::INCTrutt>. MARLEYGEN. R224Pro#242ndeninUpperfeshixk:14 std::vectorsime::INCTrutt>. MARLEYGEN. R222ChainGenInUpperfeshixk:14 std::vectorsime::INCTrutt>. MARLEYGEN. R222ChainGenInUpperfeshixk:14 std::vectorsime::INCTrutt>. Supernovad4Stagel Largeant. LArd#DetectorServicevolTPCActive std::vectorsim: INCTrutt>. Supernovad4Stagel Largeant. LArd#DetectorServicevolTPCActive std::vectorsim: INCTrutt>. 181697 Supernovad4Stagel Largeant. LArd#DetectorServicevolTPCActive std::vectorsim: INCTrutt>. 18269 Supernovad4Stagel Largeant. LArd#DetectorServicevolTPCActive std::vectorsim: SimEnergyDeposit>. .		MARLEYGen	I Rn222ChainBn222GenInL	vr			std::vector <simb::mctruth></simb::mctruth>	1
MALLYGEn		MARLEYGen	K40GenInAnode				std::vector <simb::mctruth></simb::mctruth>	1
MARLEYGen		MARLEYGen	U238ChainGenInCathode				std::vector <simb::mctruth></simb::mctruth>	1
MARLEYGen. Th232ChainGenInderLathode. isti:vector <sinb::nctruth> isti:vector<sinb::nctruth> MARLEYGen. RA22ChainGenInPDS. isti:vector<sinb::nctruth> isti:vector<sinb::nctruth> MARLEYGen. RA22ChainGenInPDS. isti:vector<sinb::nctruth> isti:vector<sinb::nctruth> MARLEYGen. RA22ChainGenInPDS. isti:vector<sinb::nctruth> isti:vector<sinb::nctruth> MARLEYGen. RA22ChainGenInAr: isti:vector<sinb::nctruth> isti:vector<sinb::nctruth> Supernova64Stage1 largeant. LArG4DetectorServicevolCryostat isti:vector<sinb::nctruth> Supernova64Stage1 largeant. LArG4DetectorServicevolTPCActive istd:vector<sinb::nctruth> Supernova64Stage1 largeant. LArG4DetectorServicevolTPCActive istd:vector<sinb::ncparticles.< td=""> istd:vector Supernova64Stage1 largeant. LArG4DetectorServicevolTPCActive istd:vector<sinb::ncparticles.< td=""> istd:vector Supernova64Stage1 largeant. LArG4DetectorServicevolTPCActive istd:vector istd:vector Supernova64Stage1 PDFastSimArternal. istd:vector<sim::simchanhel> istd:vector istd:vector Supernova64Stage1 PDFastSimArternal. istd:vector<sim::simphotonslite><!--</th--><th></th><th>MARLEYGen</th><th>CavernNGammasAtLAr1x8</th><th></th><th></th><th></th><th>std::vector<simb::mctruth></simb::mctruth></th><th>·····1</th></sim::simphotonslite></sim::simchanhel></sinb::ncparticles.<></sinb::ncparticles.<></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth></sinb::nctruth>		MARLEYGen	CavernNGammasAtLAr1x8				std::vector <simb::mctruth></simb::mctruth>	·····1
MARLEYGen		MARLEYGen	Th232ChainGenInCathode				std::vector <simb::mctruth></simb::mctruth>	· · · · · · 1
MARLEYGEn		MARLEYGen	<pre>- K42From42ArGenInUpperN</pre>	lesh1x8x14	• • • • • • • • • • • • • • • • • • •		std::vector <simb::mctruth> </simb::mctruth>	· 1
MALLEYGen		MARLEYGen	Rn222ChainGenInPDS	••••••	• • • • • • • • • • • • • • • • • • •	••••••	std::vector <simb::mctruth> </simb::mctruth>	••••••1
Supernovádstagel Rn222chainFromP52146enInupperHeshtx8x14 std::vector <sib::nctruth> </sib::nctruth>		MARLEYGen	K42From42ArGenInLAr	••••••		••••••	std::vector <simb::mctruth> </simb::mctruth>	·····1
Supernova64Stage1 IrroamaamastLAr1x8x14. ILAr64DetectorServicevolCryostat isti: vectorSimi: SimEnergyDeposit 1972287 Supernova64Stage1 Iargeant. ILAr64DetectorServicevolTPCActive isti: vectorSim: SimEnergyDeposit	Sunarna	MARL Gen	Rn222ChainFromPb214Ger	InUpperMesh1x8x14	<u> </u> ••••••••••••••••••••••••••••••••••••		std::vector <simb::mctruth> </simb::mctruth>	·····1
Supernovad/Stage1 largeant	Subernov	MalleyGen	<pre>i foamGammasAtLAr1x8x14.</pre>		·	-16	std::vector <simb::mctruth></simb::mctruth>	1070007
Supernova64Stage1 largeant. LArG4DetectorServicev0ITPCActive std::vector <siii:simenergydeposit>. .776790 Supernova64Stage1 largeant. </siii:simenergydeposit>		SupernovaG4Stage	L largeant		LARG4DetectorServicev	ollryostat.	std::vector <sim::simenergyuepositp< th=""><th>19/228/</th></sim::simenergyuepositp<>	19/228/
Supernovad4Stage1 largeant		SupernovaG4Stage1	l largeant		ArG4DetectorService	olTPCActive	std::vectorcsim::SimEnergyDenosits	776790
SupernovaG4Stage1 rns. std::vector <art::rngsnapshot>. </art::rngsnapshot>		SupernovaG4Stage1	l largeant				std::vector <simb::mcparticle></simb::mcparticle>	.131607
SupernovaG4Stage1 largeant		SupernovaG4Stage1	L rns		 ·		std::vector <art::rngsnapshot></art::rngsnapshot>	
SupernovaG4Stage1 elecDrift. std::vector <sim::simchannel>. .87248 SupernovaG4Stage1 PDFastSimArExternal. std::vector<sim::opdetbacktrackerrecord>. .184 SupernovaG4Stage1 PDFastSimAr. </sim::opdetbacktrackerrecord></sim::simchannel>		SupernovaG4Stage1	largeant				art::Assns <simb::mctruth,simb::mcparticle,sim::generatedparticleinfo> </simb::mctruth,simb::mcparticle,sim::generatedparticleinfo>	.131607
SupernovaG4Stage1 PDFastSimArExternal.		SupernovaG4Stage1	elecDrift				std::vector <sim::simchannel></sim::simchannel>	87248
Supernova64Stage1 PDFastSimAr		SupernovaG4Stage1	PDFastSimArExternal	· · · · · · · · · · · · · · · · · · ·	••••••••••••••••••••••••••••••••••••••		std::vector <sim::opdetbacktrackerrecord></sim::opdetbacktrackerrecord>	184
SupernovaG4Stage1 PDFastSimAr.		SupernovaG4Stage1	PDFastSimAr	••••••	· · · · · · · · · · · · · · · · · · ·		std::vector <sim::opdetbacktrackerrecord></sim::opdetbacktrackerrecord>	184
SupernovaG4Stage1 PDFastSimArExternal		SupernovaG4Stage1	L PDFastSimAr	••••••	• • • • • • • • • • • • • • • • • • •	••••••	std::vector <sim::simphotonslite></sim::simphotonslite>	184
Supernova64Stage1 IonAndScintExternal		SupernovaG4Stage1	PDFastSimArExternal	••••••		••••••	std::vector <sim::simphotonslite> </sim::simphotonslite>	184
$\begin{tabular}{l l l l l l l l l l l l l l l l l l l $		SupernovaG4Stage1	IonAndScintExternal				std::vector <sim::simenergydeposit></sim::simenergydeposit>	1972287
$ \begin{array}{c} \text{Supernovadstage1} = 10nAndScint. \\ \text{G4Stage2} = PDFastSimXeExternal. \\ \text{G4Stage2} = PDFastSimXeExternal. \\ \text{G4Stage2} = PDFastSimXe. \\ \text{G4Stage2} =$		SupernovaG4Stage1	L TriggerResults	••••••	*••••••	••••••	art::TriggerResults	1
G43tage2. PDFastSimXeExternal.		Supernovau4Stage1	I DEactSimVeExternel	••••••	* • • • • • • • • • • • • • • • • • •		std::vector <sim::simenergydeposit></sim::simenergydeposit>	.//6/90
G4Stage2PDFastSimXe		G4Stage2	PDFastSimYeExternal				std: vectorsime CoDetReckteaskarBacerds	184
G4Stage2. TriggerResults.		G4Stage2	PDFastSimXe				std::vectorsom: $2m + n \sqrt{n} = 5496 k$	
Std::vector <sim::opdetbacktrackerrecord></sim::opdetbacktrackerrecord>		G4Stage2	TriggerResults				art::TriggerResults.	1
Nat G4Stage2 rns	👔 🔊 Br	G4Stage2	PDFastSimXe				std::vector <sim::opdetbacktrackerrecord></sim::opdetbacktrackerrecord>	184
	Nat	G4Stage2	rns		••••••••••••••••••••••••••••••••••••••		std::vector <art::rngsnapshot></art::rngsnapshot>	4

IonAndScint

38k

777k