DUNE Offline Computing Model Calculations

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1 Introduction

This is an annual projection for DUNE CPU and storage needs intended for use at the Computing Contributions Board meeting in December 2022. It projects needs for 2023 onwards.

The overall computing model and 2022 projections for DUNE are described in chapters 6-13 of the recent (Oct. 2022) DUNE Conceptual Design Report [1]. This document provides updates on resource needs for 2023.

The 2023 projection is done using codes at: https://github.com/DUNE/CCB-data/tree/master/Numbers-2023 from parameters stored in a json file. We use CPU and storage sizes derived from protoDUNE and simulation experience and apply them to projected numbers of events from the various DUNE detectors.

Details are provided in the appendices while the main body of this note summarizes pledges, usage and projected need for the CCB.

Changes since the last report include:

- A later start for ProtoDUNE 2 running at CERN.
- Use of memory-weighted-core time instead of CPU time as our codes often require more memory than is available for a single core. This requires the introduction of a memory-weighted wall-time unit for contributions as different sites will need to provide different amounts of wall-time to perform the same processing.
- Revisions to near-term requests based on the 2022 experience including a hold on tape requests from the collaboration during protoDUNE activities.

2 Disk and Tape

Generally, raw data are stored on tape at both CERN and FNAL. Simulation and reconstructed data have one tape copy at Fermilab and recent reconstructed and simulated samples have one (or two) disk copies with one at Fermilab and one in Europe. Appendix A gives details on the size and types of data from the SAM data catalog.

2.1 Disk

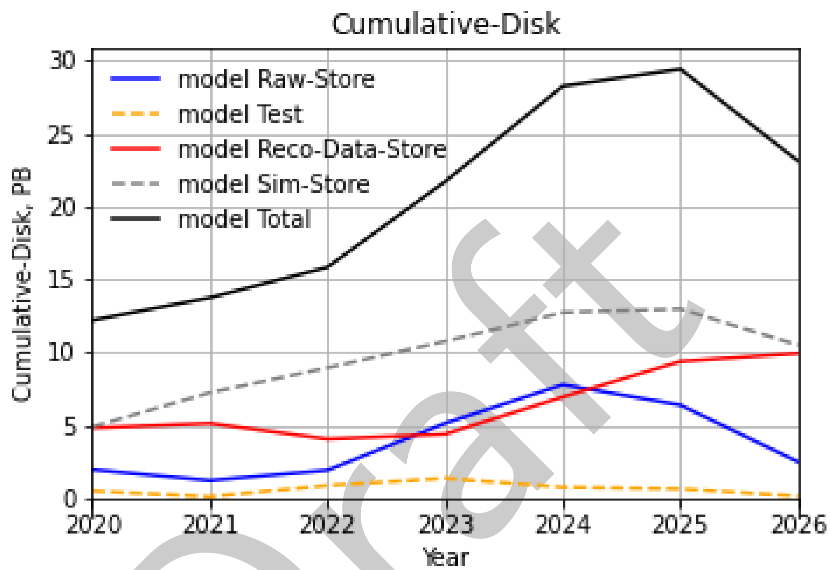
Table 1 summarizes the disk utilization known to rucio augmented with information gathered from individual sites at a meeting on 2022-11-21. Some sites, notably TIFR, are not yet fully integrated so do not show up in the rucio reports, while others (PIC) are still being filled.

Figure/Table 1 summarize the cumulative disk needs and requests projected by our model. These numbers are used to generate the request for 2023. They are divided into the two host laboratories (CERN and FNAL) and National, which includes contributions from the rest of the collaboration, including OSG, BNL and NERSC in the US.

Table 2 summarizes the pledges from previous years compared to the actual amounts allocated and used from Table 1 . The 2023 request has been re-evaluated in light of underuse in 2021 and 2022 and should better match the likely capacity of the collaborating sites. It is however, still higher than 2022 due to ProtoDUNE running and increased simulation for the far and near detectors.

RSE	Rucio Allocation (PB)	Rucio Used (PB)	percent full	Non Rucio Alloc (PB)
CA				0.050
RU_JINR				0.500
Total	20.216	16.841		2.429

Table 1: Disk allocations and usage across sites. These numbers are derived from the rucio reports in Table 1 and from cross-checks with individual sites on 2022-11-21.



Cumulative-Disk	2020	2021	2022	2023	2024	2025	2026
Raw-Store(PB)	2.0	1.2	1.9	5.2	7.8	6.4	2.5
Test(PB)	0.5	0.1	0.9	1.4	0.8	0.7	0.1
Reco-Data-Store(PB)	4.8	5.1	4.1	4.4	7.0	9.4	9.9
Sim-Store(PB)	4.9	7.3	9.0	10.8	12.7	13.0	10.5
National(PB)	7.3	9.3	9.8	11.4	14.8	16.8	15.3
FNAL(PB)	3.7	3.8	4.7	7.1	9.2	9.1	6.4
CERN(PB)	1.2	0.7	1.4	3.3	4.3	3.5	1.3
Total(PB)	12.2	13.7	15.8	21.7	28.3	29.4	23.

Figure 1: Cumulative Disk needs in PB. Includes data lifetimes

	2021	2021	2022	2022	2022	2023
	Pledge (PB)	Disk Actual	Pledge (PB)	Disk Alloc (PB)	Disk Used	Request
BR	0					
CA						
CH	0.2		0.20	NA	NA	
CZ	0.3		1.00	1.13	0.51	
ES	0.5		0.72	0.72	0.01	
FR	0.5		0.50	NA'	NA	
IN	0.75		0.75	NA	NA	
IT						
NL	1.9		1.80	1.01	0.42	
RU			0.50	NA	NA	
UK	4		4.00	3.83	3.12	
US BNL	0.5		0.50	0.50	0.50	
US - other						
Collab	8.65		9.97	6.69	4.56	11.30
CERN	2.2		3.00	1.20	1.20	3.30
FNAL	2.2		7.60	7.30	7.30	7.10
Total	21.7		20.57	15.19	13.06	21.70

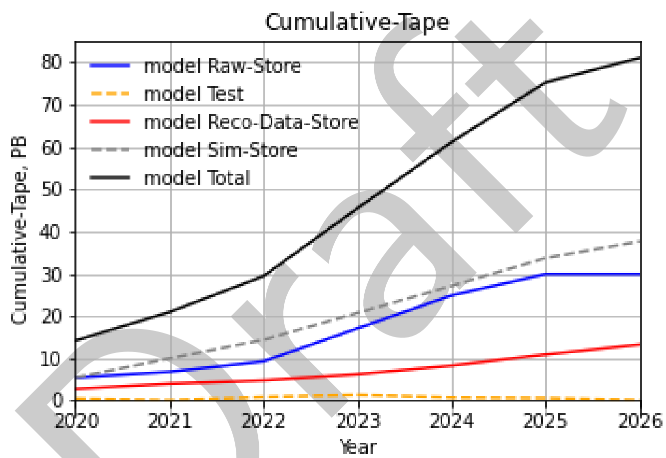
Table 2: Summary of disk pledges, allocations and usage for 2021-2022 with model request for 2023. This is based on the 2022 CCB tables which are available in indico [2, 3]. These numbers are derived from the rucio reports in Table 1 and may not be complete. NOT YET UPDATE WITH NUMBERS FROM PREVIOUS TBALE

2.2 Tape

DUNE currently has ~23 PB of data on tape at Fermilab and 5 PB of protoDUNE data as a second copy at CERN. The UK and the IN2P3 have made tape available but it has not yet been smoothly integrated into our data flow. We will not be requesting additional tape space from other national sites until we can use it efficiently.

Figure and Table 2 summarize the cumulative disk projected by our model. These numbers are used to generate the requests for 2023. They are divided into the two host laboratories (CERN and FNAL) and National, which includes contributions from the rest of the collaboration, including OSG, BNL and NERSC in the US.

Table 3 shows pledges and utilization for 2021-2022 and the request for 2023.



Cumulative-Tape	2020	2021	2022	2023	2024	2025	2026
Raw-Store(PB)	5.5	6.8	9.3	17.1	24.9	29.9	29.9
Test(PB)	0.5	0.1	0.9	1.4	0.8	0.7	0.1
Reco-Data-Store(PB)	2.8	4.0	4.8	6.2	8.3	10.9	13.3
Sim-Store(PB)	5.5	10.0	14.4	20.8	27.1	33.7	37.6
National(PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FNAL(PB)	11.2	17.5	24.3	36.3	48.3	60.0	66.0
CERN(PB)	3.0	3.5	5.1	9.2	12.8	15.3	15.0
Total(PB)	14.2	21.0	29.4	45.5	61.1	75.2	81.

Figure 2: Cumulative Tape needs in PB. Includes data lifetimes

3 CPU Needs

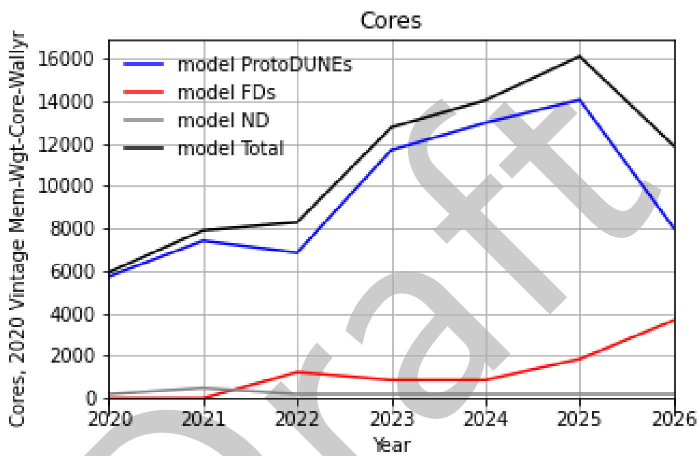
DUNE differs from other HEP experiments in frequently requiring more memory/core than is available at particular sites. For example an 8 slot pilot with 16 G of available memory could only accommodate four reconstruction processes. As a result, we make our requests in terms of memory-weighted-wall time with the base memory being 2000 MB. Sites that offer more than 2000 MB/core can scale their contributions up by the local memory/core.

Wall-time estimates are created by estimating the number of simulated and raw events taken and then scaling by the measured CPU time on a gpvm corrected to wall-time by the estimated efficiency (default 70%) and for the memory utilization factor that takes into account the differing memory needs for different applications and the number of cores needed to satisfy those needs. Here we assume that analysis takes 3000 MB, reconstruction takes 4000MB, and simulation takes 6000MB. Contributions are then requested in units of wall-time$\times$2000 MB units.

Figure/Table 3 shows the projected memory-weighted wall-time need projections through 2026. This is different than in previous years where memory weighting was not applied. They are divided into the two host laboratories (CERN and FNAL) and National, which includes contributions from the rest of the collaboration, including OSG, BNL and NERSC in the US.

Table 3 summarizes the pledges[2] and measured usage using FNAL's HTCondor memory-weighted wall-time statistics[4]. The usage numbers for 2022 are Nov 2021 to Oct 2022.

Table 4 summarizes the statistics for European sites from Nov 2021 to Oct 2022 derived from the EGI accounting[5] which uses the number of cores allocated to a pilot. If four 4000 MB reconstruction jobs were sent to an 8-core pilot on a system with 2000MB/core, this would be equivalent to the memory-weighted wall-time unit.



Cores	2020	2021	2022	2023	2024	2025	2026	
ProtoDUNEs (2020 Vintage Mem-Wgt-Core-Wallyr)	5746	7423	6863	11701	12979	14066	8018	
FDs (2020 Vintage Mem-Wgt-Core-Wallyr)	0	0	1235	868	868	1846	3681	
ND (2020 Vintage Mem-Wgt-Core-Wallyr)	195	489	195	195	195	195	195	
Total (2020 Vintage Mem-Wgt-Core-Wallyr)	5941	7912	8294	12765	14043	16109	11896	

Figure 3: Memory-weighted wall-time needs in number of 2000 MB cores. Memory-weighted wall-time takes into account memory and efficiency.

Slots	2021 pledge	2021 slots used	2022 pledge	2022 slots used	2023 request
BR	100	19	200	16	
CA		6		40	
CH	200	1		0	
CZ	1560	128	2400	78	
ES	500	47	512	122	
FR	310	34	250	48	
IN	450	79	450	126	
IT	-	-		-	
NL	696	210	788	340	
RU		8	1000	39	
UK	1000	947	1000	912	
US OSG	1250	593	1000	354	
Coillab	6066	2073	7600	2076	
CERN	3310	306	950	298	
US Fermilab	3310	3059	1945	2966	
Total	12686	5438	10495	5340	
Model		5274		5529	8510

Table 3: Summary of DUNE wall-time pledges and contributions for 2021 and 2022. The 2022 actual numbers are memory-weighted. Individual nations are listed and then merged (with US OSG) into a National section. NOT YET UPDATED WITH LATEST MODEL.

Nation	Slot-hrs	Slot-years	Percent
Brazil	114904	13.1	0.7
Canada	3163	0.4	0
Czech Republic	1053867	120.3	6.1
France	871042	99.4	5
Italy	14295	1.6	0.1
Netherlands	1668058	190.4	9.6
Poland	58904	6.7	0.3
Portugal	47529	5.4	0.3
Russia	43757	5	0.3
Spain	1769349	202	10.2
Switzerland	21776	2.5	0.1
Turkey	6544	0.7	0
United Kingdom	11712533	1337	67.4
Total	17385721	1984.7	100

Table 4: Summary of DUNE memory-weighted-core hours from European collaborators, Nov. 21 to Oct. 22, using the EGI accounting[5]. These numbers differ slightly from the FNAL numbers in the previous table.

References

[1] **DUNE** Collaboration, A. Abed Abud *et al.*, "DUNE Offline Computing Conceptual Design Report," arXiv:2210.15665 [physics.data-an].

[2] P. Clarke, "DUNE Computing Contributions Board Meeting for 2022." https://indico.fnal.gov/event/52519/.

[3] P. Clarke, "DUNE Computing Contributions Board Meeting for 2023." https://indico.fnal.gov/event/52519/.

[4] K. Herner, "Kibana sum of slot hours for DUNE with MARS removed, Nov 1, 2021 to Oct 31, 2022." https://fifemon.fnal.gov/kibana/goto/5ac70f9ccc22e447632c7276cea83ef5.

[5] "EGI accounting for DUNE slot time, November 2021 to October 2022. slot time refers to the core allocated to pilots. it is partially equivalent to the memory-weighted wall-time from htcondor if the pilot fills the requested memory.." https://accounting.egi.eu/wlcg/countries/elap_processors/COUNTRY/DATE/2021/11/2022/11/custom-biomed,dune/localinfrajobs/.

A Information about storage from SAM

This section provides information on the sizes of data samples known to the SAM data catalog as of Nov. 1, 2022. If a file has multiple copies, that is not shown here. Tables 5 and 6 show the total across all streams and data tiers while table 7 shows the distribution of the largest samples.

expt	size	TB	size/event	MB
fardet	14.252	TB	0.358	MB
neardet	76.176	TB	0.178	MB
physics	1540.003	TB	35.161	MB
fardet-hd	45.097	TB	1.511	MB
fardet-sp	171.612	TB	2.4	MB
fardet-vd	1837.767	TB	31.109	MB
protodune-sp	6693.574	TB	90.061	MB
Total	10378.48	TB	13.903	MB

Table 5: Summary of total simulation in SAM by detector type as of Nov 1, 2022.

expt	size	TB	size/event	MB
iceberg	3.339	TB	3.461	MB
hd-coldbox	79.891	TB	40.247	MB
protodune-dp	413.914	TB	135.997	MB
protodune-sp	8798.856	TB	29.891	MB
vd-coldbox-top	319.305	TB	34.291	MB
vd-coldbox-bottom	26.843	TB	23.858	MB
dc4-vd-coldbox-top	102.972	TB	-1	MB
dc4-vd-coldbox-bottom	211.359	TB	69.149	MB
Total	9956.601	TB	31.721	MB

Table 6: Summary of total detector data in SAM by detector type as of Nov 1, 2022.

year	det/mc	expt	stream	tier	size (TB)	size/event (MB)
ALL	mc	protodune-sp	out1	detector-simulated	3509	238.8
ALL	mc	protodune-sp	out1	full-reconstructed	3093	177.2
ALL	detector	protodune-sp	cosmics	raw	2310	51.4
ALL	detector	protodune-sp	physics	full-reconstructed	2003	66.4
ALL	mc	fardet-vd	out1	full-reconstructed	1826	62.4
ALL	detector	protodune-sp	cosmics	full-reconstructed	1449	45.9
ALL	detector	protodune-sp	physics	raw	864	83.6
ALL	detector	protodune-sp	test	raw	780	35.6
ALL	mc	physics	out1	full-reconstructed	735	29.5
ALL	mc	physics	out1	detector-simulated	537	39.8
ALL	detector	protodune-sp	physics	reco-recalibrated	360	37.9
ALL	mc	physics	out1	simulated	268	52.9
ALL	detector	protodune-dp	test	raw	259	124.2
ALL	detector	vd-coldbox-top	study	raw	225	49.4
ALL	detector	dc4-vd-coldbox-bottom	test	raw	211	69.1
ALL	mc	fardet-sp	out1	full-reconstructed	169	3.7
ALL	detector	protodune-sp	test	full-reconstructed	151	37.4
ALL	detector	protodune-dp	cosmics	raw	140	326.4
ALL	detector	protodune-sp	calibration	raw	137	4.0
ALL	detector	protodune-sp	physics	hit-reconstructed	127	50.0
ALL	detector	protodune-sp	physics	decoded-raw	125	49.2
ALL	detector	protodune-sp	cosmics	reco-recalibrated	107	22.5
ALL	detector	dc4-vd-coldbox-top	test	raw	103	-1.0
ALL	detector	hd-coldbox	test	raw	80	40.2
ALL	mc	neardet	physics	simulated	76	0.2
ALL	detector	protodune-sp	physics	pandora_info	75	6.9
ALL	detector	vd-coldbox-top	test	raw	60	28.8
ALL	mc	protodune-sp	out1	pandora_info	57	6.0
ALL	detector	protodune-sp	cosmics	hit-reconstructed	42	25.9
ALL	detector	protodune-sp	noise	decoded-raw	40	27.0
ALL	detector	protodune-sp	cosmics	decoded-raw	40	24.6
ALL	detector	protodune-sp	cosmics	pandora_info	39	6.0
ALL	mc	fardet-hd	out1	full-reconstructed	36	5.1
ALL	detector	protodune-sp	noise	raw	30	30.6
ALL	detector	vd-coldbox-bottom	test	raw	27	23.9
ALL	detector	vd-coldbox-top	test	full-reconstructed	26	12.8

Table 7: Classification of the largest data samples in SAM. They are classified as detector(data) or mc, by the detector producing the data, by the stream (readout time) and by the data tier. Some types, test and noise for example are archival only.

B Model Details

This appendix shows the parameters used in the model and plots of all the input and derived quantities as a function of time.

Resource needs for reconstructed data for a given year are based on the number of events produced over the previous "Reprocess" years. For ProtoDUNEs that is 2-4 years.

Simulation resource needs are instead calculated based on a number of simulation events each year. The assumption is that new software versions imply resimulation.

Disk and tape lifetimes for different data types are specified as well as the desirable number of copies.

The splits parameters make CERN responsible for raw data until 2027 with the collaboration taking over after that point.

Detectors: Detectors included in the calculation = [’SP’, ’SP2’, ’DP’, ’PDVD’, ’HD’, ’VD’, ’ND’]
Cap: Cap on Raw data/year in PB = 30
Base-Memory: MB of memory per slot assumed as the average = 2000
MaxYear: Plot until year = 2026
MinYear: Plot starting with year = 2020
Reprocess: Number of years of data reprocessed when doing a new pass = ’SP’: 3, ’DP’: 2, ’SP2’: 4, ’PDVD’: 4, ’ProtoDUNEs’: 3, ’VD’: 100, ’HD’: 100, ’FDs’: 100, ’ND’: 100, ’MARS’: 1
PatternFraction: Fraction of time taken in pattern recognition = ’SP’: 0.7, ’SP2’: 0.7, ’DP’: 0.7, ’PDVD’: 0.7, ’ProtoDUNEs’: 0.7, ’HD’: 0.1, ’VD’: 0.1, ’FDs’: 0.1, ’ND’: 0.9, ’MARS’: 0
TapeLifetimes: Number of years kept on tape = ’Raw-Store’: 100, ’Test’: 0.5, ’Reco-Data-Store’: 15, ’Sim-Store’: 15
DiskLifetimes: Number of years kept on disk = ’Raw-Store’: 2, ’Test’: 0.5, ’Reco-Data-Store’: 2, ’Sim-Store’: 2
TapeCopies: Number of copies kept on tape = ’Raw-Store’: 2, ’Test’: 1, ’Reco-Data-Store’: 1, ’Sim-Store’: 1
DiskCopies: Number of copies kept on disk = ’Raw-Store’: 1, ’Test’: 1, ’Reco-Data-Store’: 2, ’Sim-Store’: 1
PerYear: Number of reprocessing done per year = ’Raw-Store’: 1, ’Test’: 1, ’Reco-Data-Store’: 1, ’Sim-Store’: 1, ’Events’: 1, ’Sim-Events’: 1, ’Reco-Data-CPU’: 1, ’Sim-CPU’: 1, ’Analysis’: 1, ’Analysis-CPU’: 1
Cores: Description of cores, efficiency and speed relative to 2020 vintage = ’Efficiency’: 0.7, ’2020Units’: 1
kHEPSPEC06PerCPU: kHEPSPEC06 per core assumed = 0.011
SplitsYear: Year CERN no longer responsible for disk or tape = 2027
SplitsEarly: Division between FNAL/CERN/National for storage until SplitsYear = ’Tape’: ’Raw-Store’: ’FNAL’: 0.5, ’CERN’: 0.5, ’National’: 0.0, ’Sim-Store’: ’FNAL’: 1.0, ’CERN’: 0.0,

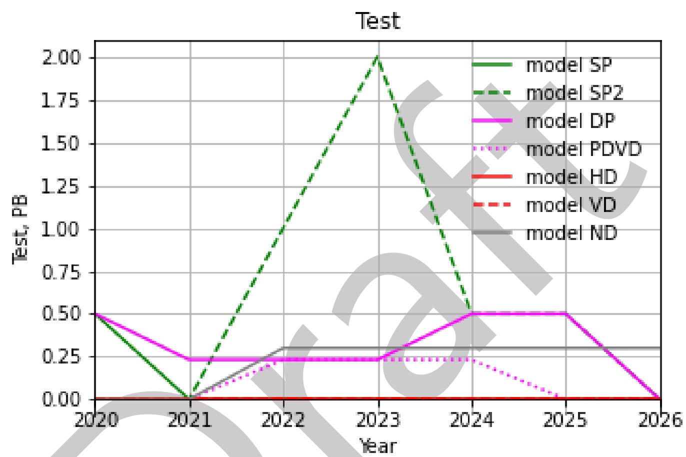
'National': 0.0, 'Reco-Data-Store': 'FNAL': 1.0, 'CERN': 0.0, 'National': 0.0, 'Test': 'FNAL': 0.5, 'CERN': 0.5, 'National': 0.0, 'Disk': 'Raw-Store': 'FNAL': 0.5, 'CERN': 0.5, 'National': 0.0, 'Sim-Store': 'FNAL': 0.25, 'CERN': 0.0, 'National': 0.75, 'Reco-Data-Store': 'FNAL': 0.25, 'CERN': 0.0, 'National': 0.75, 'Test': 'FNAL': 0.5, 'CERN': 0.5, 'National': 0.0

SplitsLater: Division between FNAL/CERN/National for storage after SplitsYear = 'Tape': 'Raw-Store': 'FNAL': 0.5, 'CERN': 0.0, 'National': 0.5, 'Sim-Store': 'FNAL': 0.5, 'CERN': 0.0, 'National': 0.5, 'Reco-Data-Store': 'FNAL': 0.5, 'CERN': 0.0, 'National': 0.5, 'Test': 'FNAL': 0.5, 'CERN': 0.0, 'National': 0.5, 'Disk': 'Raw-Store': 'FNAL': 1.0, 'CERN': 0.0, 'National': 0.0, 'Sim-Store': 'FNAL': 0.25, 'CERN': 0.0, 'National': 0.75, 'Reco-Data-Store': 'FNAL': 0.25, 'CERN': 0.0, 'National': 0.75, 'Test': 'FNAL': 0.5, 'CERN': 0.0, 'National': 0.5

filename: Input configuration file = Parameters_2022-11-21-2040.json

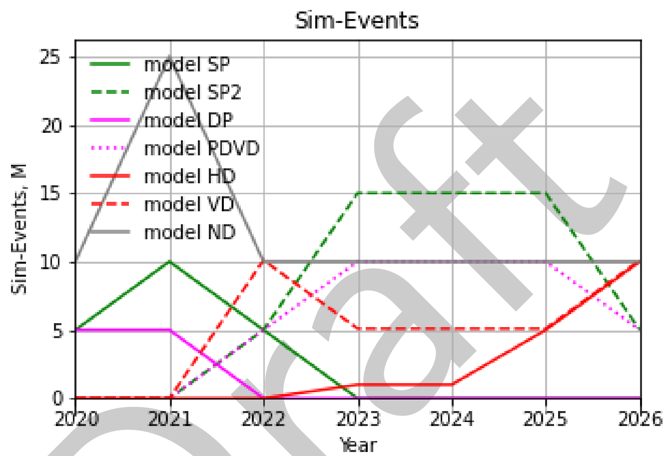
Events	2020	2021	2022	2023	2024	2025	2026	
ND (Million)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ProtoDUNEs (Million)	7.4	8.5	10.0	30.0	30.0	20.0	0.0	
FDs (Million)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total (Million)	7.4	8.5	10.0	30.0	30.0	20.0	0.0	

Figure 4: Projected million of detector events per year. Reconstructed data resources are based on this number.



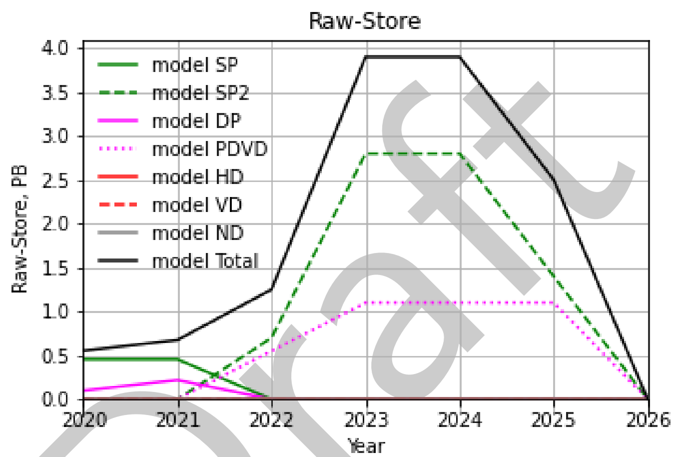
Test	2020	2021	2022	2023	2024	2025	2026	
ND (PB)	0.0	0.0	0.3	0.3	0.3	0.3	0.3	
ProtoDUNEs (PB)	1.0	0.2	1.5	2.5	1.2	1.0	0.0	
FDs (PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total (PB)	1.0	0.2	1.8	2.8	1.5	1.3	0.3	

Figure 5: Projected PB of Test data per year.



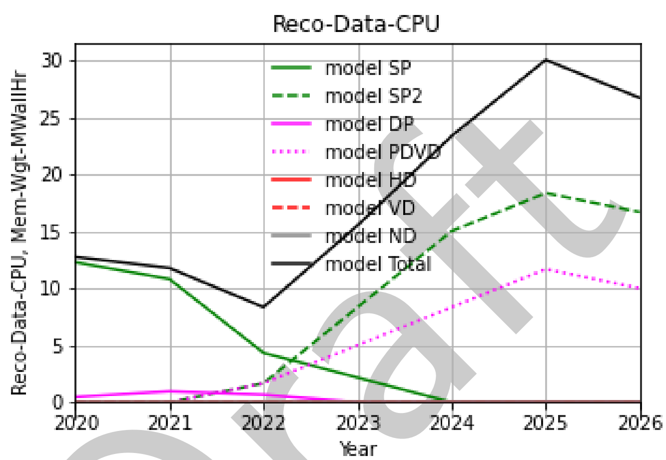
Sim-Events	2020	2021	2022	2023	2024	2025	2026	
ND (M)	10.0	25.0	10.0	10.0	10.0	10.0	10.0	
ProtoDUNEs (M)	10.0	15.0	15.0	25.0	25.0	25.0	10.0	
FDs (M)	0.0	0.0	10.1	6.1	6.1	10.1	20.1	
Total (M)	20.0	40.0	35.1	41.1	41.1	45.1	40.1	

Figure 6: Projected millions of simulated events per year. Simulated data resources are based on this number.



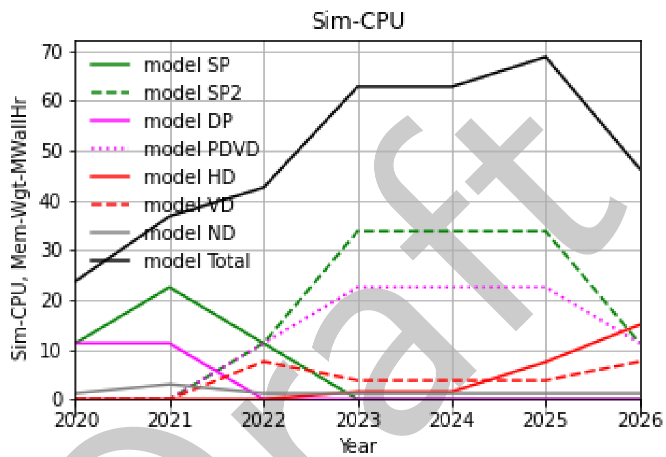
Raw-Store	2020	2021	2022	2023	2024	2025	2026	
ND (PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ProtoDUNEs (PB)	0.6	0.7	1.2	3.9	3.9	2.5	0.0	
FDs (PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total (PB)	0.6	0.7	1.2	3.9	3.9	2.5	0.0	

Figure 7: Projected raw data written per year in PB, derived from the number of events.



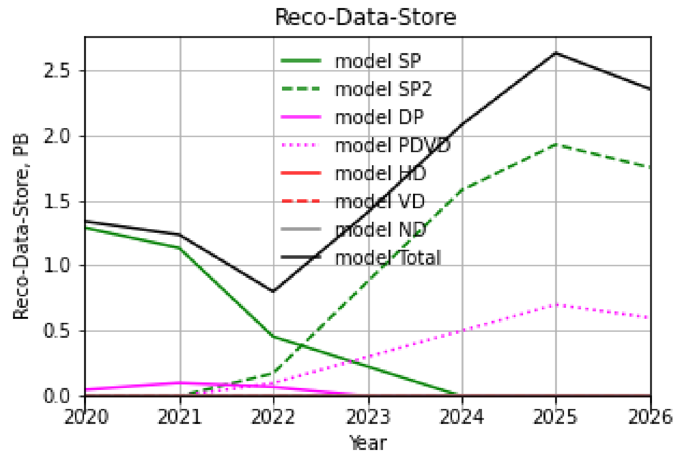
Reco-Data-CPU	2020	2021	2022	2023	2024	2025	2026	
ND (Mem-Wgt-MWallHr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ProtoDUNEs (Mem-Wgt-MWallHr)	12.7	11.8	8.3	15.5	23.3	30.0	26.7	
FDs (Mem-Wgt-MWallHr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total (Mem-Wgt-MWallHr)	12.7	11.8	8.3	15.5	23.3	30.0	26.7	

Figure 8: Projected CPU needs in core-years for data reconstruction. Slot weighted wall time takes into account memory use and an efficiency correction. Assumes rereconstruction of several years of older data.



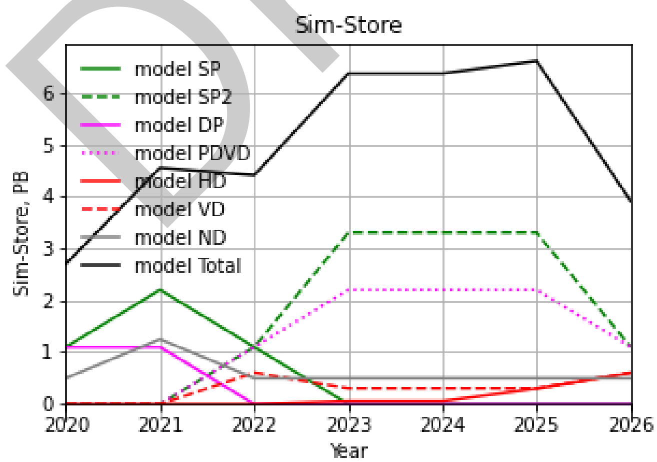
Sim-CPU	2020	2021	2022	2023	2024	2025	2026	
ND (Mem-Wgt-MWallHr)	1.2	3.0	1.2	1.2	1.2	1.2	1.2	
ProtoDUNEs (Mem-Wgt-MWallHr)	22.5	33.8	33.8	56.2	56.2	56.2	22.5	
FDs (Mem-Wgt-MWallHr)	0.0	0.0	7.6	5.3	5.3	11.3	22.6	
Total (Mem-Wgt-MWallHr)	23.7	36.8	42.5	62.8	62.8	68.8	46.3	

Figure 9: Projected CPU needs in core-years for simulation and reconstruction. Slot weighted wall time takes into account memory use and an efficiency correction. Based directly on the number of simulated Events.



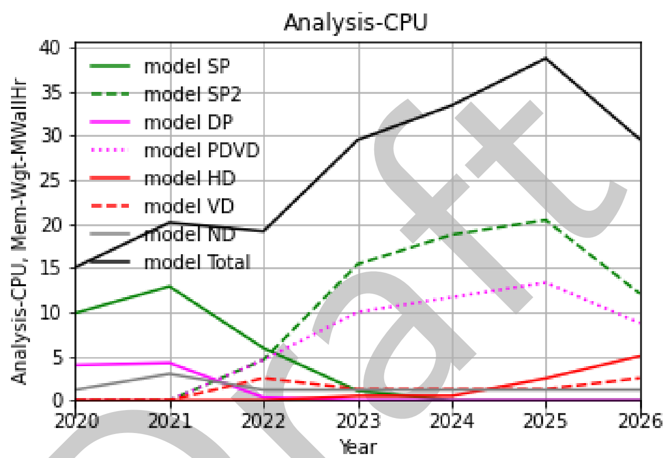
Reco-Data-Store	2020	2021	2022	2023	2024	2025	2026	
ND (PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ProtoDUNEs (PB)	1.3	1.2	0.8	1.4	2.1	2.6	2.4	
FDs (PB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total (PB)	1.3	1.2	0.8	1.4	2.1	2.6	2.4	

Figure 10: Projected PB of reconstructed data per year. Includes reprocessing.



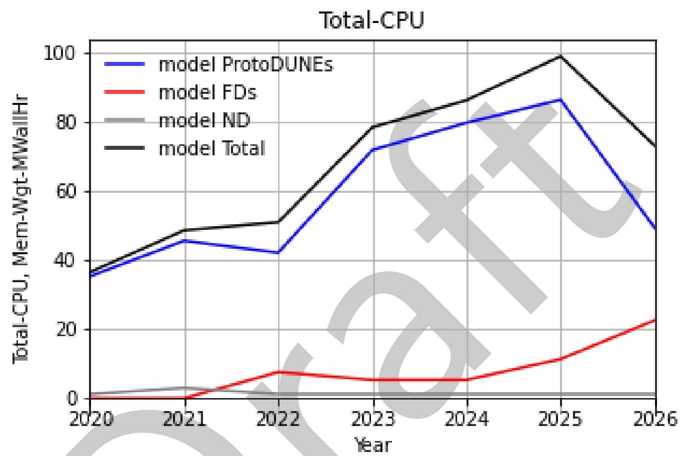
Sim-Store	2020	2021	2022	2023	2024	2025	2026	
ND (PB)	0.5	1.2	0.5	0.5	0.5	0.5	0.5	
ProtoDUNEs (PB)	2.2	3.3	3.3	5.5	5.5	5.5	2.2	
FDs (PB)	0.0	0.0	0.6	0.4	0.4	0.6	1.2	
Total (PB)	2.7	4.6	4.4	6.4	6.4	6.6	3.9	

Figure 11: Projected PB of simulated data/year



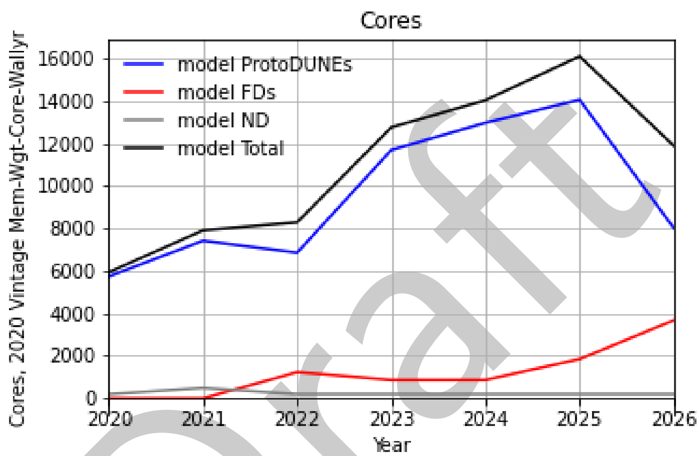
Analysis-CPU	2020	2021	2022	2023	2024	2025	2026	
ND (Mem-Wgt-MWallHr)	1.2	3.0	1.2	1.2	1.2	1.2	1.2	
ProtoDUNEs (Mem-Wgt-MWallHr)	13.9	17.1	15.4	26.5	30.4	33.8	20.8	
FDs (Mem-Wgt-MWallHr)	0.0	0.0	2.5	1.8	1.8	3.8	7.5	
Total (Mem-Wgt-MWallHr)	15.1	20.1	19.1	29.5	33.4	38.7	29.6	

Figure 12: Slot weighted analysis CPU needs in core-years. Assumed to be a weighted fraction of reco+sim needs.



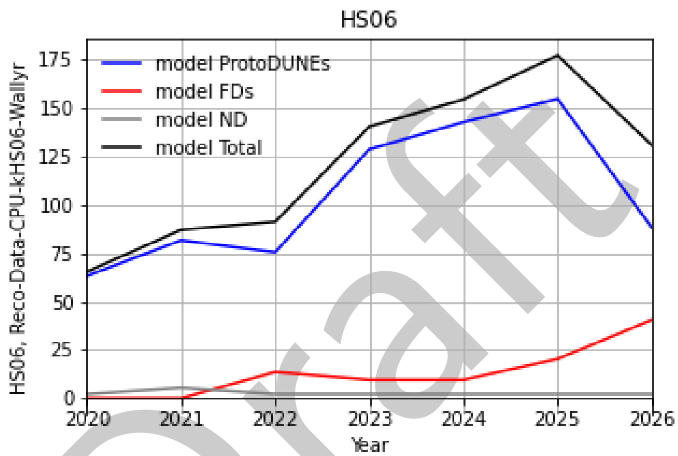
Total-CPU	2020	2021	2022	2023	2024	2025	2026	
ProtoDUNEs (Mem-Wgt-MWallHr)	35.2	45.5	42.1	71.8	79.6	86.3	49.2	
FDs (Mem-Wgt-MWallHr)	0.0	0.0	7.6	5.3	5.3	11.3	22.6	
ND (Mem-Wgt-MWallHr)	1.2	3.0	1.2	1.2	1.2	1.2	1.2	
Total (Mem-Wgt-MWallHr)	36.4	48.5	50.9	78.3	86.1	98.8	72.9	

Figure 13: Slot weighted CPU needs in core-years. Slot weighted wall time takes into account memory and efficiency.



Cores	2020	2021	2022	2023	2024	2025	2026	
ProtoDUNEs (2020 Vintage Mem-Wgt-Core-Wallyr)	5746	7423	6863	11701	12979	14066	8018	
FDs (2020 Vintage Mem-Wgt-Core-Wallyr)	0	0	1235	868	868	1846	3681	
ND (2020 Vintage Mem-Wgt-Core-Wallyr)	195	489	195	195	195	195	195	
Total (2020 Vintage Mem-Wgt-Core-Wallyr)	5941	7912	8294	12765	14043	16109	11896	

Figure 14: Slot weighted CPU needs in number of cores. Slot weighted wall time takes into account memory and efficiency.



HS06	2020	2021	2022	2023	2024	2025	2026	
ProtoDUNEs (Reco-Data-CPU-kHS06-Wallyr)	63	81	75	128	142	154	88	
FDs (Reco-Data-CPU-kHS06-Wallyr)	0	0	13	9	9	20	40	
ND (Reco-Data-CPU-kHS06-Wallyr)	2	5	2	2	2	2	2	
Total (Reco-Data-CPU-kHS06-Wallyr)	65	87	91	140	154	177	130	

Figure 15: Slot weighted CPU needs in kHS06 hrs. Slot weighted wall time takes into account memory and efficiency.