DESI Cosmological Simulations Requirements Document

DESI Collaboration

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Abstract

The DESI Cosmological Simulations Requirements Document outlines the cosmological simulation needs for meeting the science requirements of the DESI project. The primary science goals for DESI as a Stage IV Dark Energy experiment are a series of sub-percent accuracy measurements of the baryon acoustic oscillations (BAO) scale over a large range of cosmic times for investigating dark energy and a series of redshift-space distortion (RSD) measurements to probe the growth of structure with time. The BAO and RSD effort focuses on four classes of spectroscopic targets spread over 14k sq.deg.: a) $\sim$10 million Bright Galaxy Survey (BGS) targets in the redshift range $0.05 < z < 0.4$; b) $\sim$4 million Luminous Red Galaxies (LRGs) at $0.4 < z \lesssim 1$; c) $\sim$17 million [OII] Emission Line Galaxies (ELGs) at $0.6 < z < 1.6$; d) $\sim$1.7 million quasars as mass tracers at $0.9 \lesssim z < 2.1$ and $\sim$0.7 million quasars for Ly-α forest studies at higher redshifts ($2.1 < z \lesssim 3.7$).

The requirements are split into five sets. Sets 1, 2, and 5 describe the need for N-body simulations for the dark-time, BGS, and Lyα forest samples. The set 1 requirements are most detailed, as they dominate those of sets 2 and 5 in almost all cases. Sets 3 and 4 describe the need for faster approximate methods for the dark-time+BGS and Lyα forest, respectively. Unlike the L1, L2... hierarchy of the DESI project science requirements, the numbering of these five sets is simply an enumeration.

1 Simulation Requirements for Galaxy and Quasar Clustering Probes

1.1 N-body Simulations for the Dark-time Program (LRG, ELG, QSO)

Requirement CS-1.1: DESI will develop a set of mocks capable of supporting systematic analysis of the simultaneous clustering of the LRG, ELG, and QSO targets and their cross-correlations.

The LRG, ELG, and QSO targets overlap in redshift and there is an opportunity to gather more cosmological information by combining them into joint analyses. These three samples should be modeled in a coordinated set of simulations. The BGS sample may be done either separately or together with these samples.

Validation Test: This is assured by the design of the following requirements.

Requirement CS-1.2: The DESI ELG+LRG+QSO N-body simulations will sample a minimum total volume of 200 $h^{-3}\,\mathrm{Gpc}^3$ in a single ΛCDM cosmology (hereafter nominal cosmology) and with one homogeneous code base. The galaxy and quasar clustering working group (GQC WG) will specify the parameters of the nominal cosmology by end 2018 at the latest.

The effective volume of ELG+LRG+QSO for wavenumbers appropriate to BAO is about $\sim$ 20 $h^{-3}\,\mathrm{Gpc}^3$; see Table 1. The volume requirement here is defined to exceed this by a factor of ten so that theoretical systematics due to the finite size of the reference simulation are limited to 10% of the statistical variance.

Validation Test: By inspection.

Requirement CS-1.3: The full simulation volume needed for analysis of the final survey should be available by Year 3. One third of this volume should be available by Year 1, two thirds should be available by Year 2.

To be available for a given year's analysis, the simulations should be completed 6 months before the end of the data taking period. Thus Year 1 simulations should be completed by June 2020, Year 2 by June 2021, and Year 3 (full survey size) by June 2022.

The motivation for the schedule is that if we found in Year 3 or earlier that we were uncovering theoretical systematics at the full DESI scope, there would be time to address these with more simulations in a timely fashion.

To reach this requirement and allow the science working groups to assess production simulations, a first simulation (hereafter prototype simulation) should be produced with the production code by June 2019.

Validation Test: By inspection.

Requirement CS-1.4: The total Year 3 volume will be subdivided into at least 25 separate boxes.

Tests that study the difference between multiple treatments (e.g., bias models) on the same density field are important because they cancel out a substantial amount of large-scale sample variance. Being able to compare results between multiple realizations is an important way to assess the actual variance. Separate boxes with periodic boundary conditions is more convenient for such analyses and with 25 boxes this results in a 20% uncertainty on the error.

Validation Test: By inspection.

Requirement CS-1.5: The individual simulations will have a box size no less than 1.5 h^{-1} Gpc with a goal of 2 h^{-1} Gpc.

Small boxes fail to include adequate large-scale power, leading to small systematics shifts in the correlation function at the BAO scale. Small boxes also fail to properly capture the modes leading to the broadening of the peak which reconstruction corrects, making it hard to properly model the reconstructed statistics. This sets the minimum size required.

Validation Test: By inspection.

Requirement CS-1.6: In time for the Year 2 analysis, at least two other cosmologies with a goal of five will be generated, with a total volume of at least 48 $h^{-3}\,\mathrm{Gpc}^3$ per cosmology. At least one cosmology should have $w \neq -1$. The white noise should be matched between different cosmological models.

The minimum number of cosmologies is set by the blind challenges and at least two needs to be done. By requiring the same white noise, we will be able to measure the difference among the cosmologies. We have made the explicit assumption that the differencing methods reduce the error bars by a factor of two, hence resulting in a minimum volume of 50 $h^{-3}\,\mathrm{Gpc}^3$ per cosmology, which we round off to 48 given the expectation of 2 h^{-1} Gpc boxes. Tests, using e.g. fast mocks, might be needed to verify this assumption. Additionally these same simulations can be used to test the fiducial analysis pipeline.

Validation Test: By inspection and by devising tests using fast mocks with different cosmologies, so as to verify the assumption of the reduction of errors from matched initial conditions.

Requirement CS-1.7: The simulations will be evolved at least to $z = 0.5$.

The LRG sample extends to $z = 0.4$, and a time slice at $z = 0.5$ is expected to be sufficient for the required systematic tests in the lowest redshift bin. However, we note that Requirements CS-2.1 and CS-2.3 will require running some simulations to $z = 0.1$.

Validation Test: By inspection.

Requirement CS-1.8: The simulations will provide data products at numerous time slices from $z = 3.0$ to $z = 0.5$. The exact redshifts will be determined by the GQC WG by end 2018 at the latest, with the following as a current best estimate: z_{snap}= 3.0, 2.5, 2.0, 1.4, 1.1, 0.8, 0.5.

The upper redshift is set by the expected number density of quasars as per FDR ($\bar{n}_{QSO}$ is only $\sim 4\times$ lower than at its peak at $z \sim 1.5$). We note that Requirements CS-2.1 and CS-5.2 state additional needs for redshift outputs.

Validation Test: By inspection.

Requirement CS-1.9: All simulations will provide the following nominal data products at the nominal time slices: (i) a halo catalog down to a nominal cumulative abundance; (ii) the position, velocity, mass and ID of each halo; (iii) a proxy for the halo velocity dispersion; (iv) a proxy for the density profile information; (v) the density field on a grid; (vi) a random subset of particles, split into particles within and outside halos, with positions and velocities.

The statistics considered for the halos are the minimal set suitable to support Halo Occupation Modeling. The proxy for density profile information could be either a sub-sampling of the member particles, as provided by (vi), or the parameters of a parametric fit to the density profile. Access to the density field itself is helpful for assessments of bias. It also will be needed for cross-correlations with lensing surveys. The Cosmological Simulation (CosmoSim) WG will refine the details of the specific halo outputs needed by end 2018 at the latest. The GQC WG will specify the smoothing for the density field on a grid and the fraction of particles that needs to be saved by the same date.

Validation Test: By inspection.

Requirement CS-1.10: The DESI ELG+LRG+QSO N-body simulations will have a particle mass no larger than $5 \times 10^9 h^{-1}$ M$_\odot$, with a goal of $2 \times 10^9 h^{-1}$ M$_\odot$.

The halos that host ELGs are believed to have a minimum mass of approximately 10^{11} M$_\odot/h$ (following [6]; see also Figure 1). Since the minimum halo mass hosting ELG is lowest among the three tracers, we use it here to derive the mass resolution requirement. As a minimum requirement, we require at least 20 particles to define the smallest ELG halo, noting that the typical halo hosting an ELG will be several times larger. Although 20 particles is not enough to define a fully robust set of halos, only a small fraction of the ELG objects are near this mass limit. The position of halos with $\sim$20 particles tends to be quite accurate, even though the masses (and dispersions) are not. In addition, the linear bias is only changing by $\pm 5\%$ over a factor of 2 in halo mass at $z = 1$ for halos near $10^{11}\ h^{-1} M_\odot$ [15]. We further note that altering the HOD to truncate the lowest mass halos, effectively moving them to larger halos, will only mildly affect the resulting clustering bias, likely in a manner that can be calibrated accurately by comparison to simulations with higher mass resolution.

However, some additional tests are needed to demonstrate that 20 particles will yield a population of halos whose clustering, especially in redshift space, is sufficiently accurate. Given the benefits of a more secure population of halos, we set a goal of 50 particles for the minimum mass ELG host.

Validation Test: By inspection.

Requirement CS-1.11: We require sufficient force accuracy and time resolution so that the properties of the halos hosting DESI targets can be recovered to better than 10% in the halo mass function and 5% in the velocity dispersion to halo mass relation, relative to higher accuracy simulations with the same mass resolution.

Force softening, force calculation method, and choice of time step affect the internal structure of halos, altering their density profiles and velocity dispersions. We can accept some mild level of shift, as the properties can be calibrated relative to higher accuracy simulations when implementing the mock galaxy prescription. We note that similar calibrations may be required to correct for the limited mass resolution or the effects of halo finder algorithm. The requirement level of 10% and 5% quoted will be investigated further by the CosmoSim and GQC WGs in advance of the prototype simulation being delivered, as those numbers might need to be tightened for the production runs.

As the halo mass itself is in question, we specify this requirement as applying to halos with a cumulative abundance of $0.03h^3\,\mathrm{Mpc}^{-3}$, which we expect is appropriate to ELGs.[1]

Validation Test: Compute the halo mass function and the velocity dispersion-halo mass scaling relation in simulations with our nominal assumptions as well as in higher accuracy examples. This is likely done best using smaller boxes with matching initial conditions, using the same simulation code with different accuracy specifications and the same halo finder, as well as with higher mass resolution simulation. The agreement should be tested at a variety of abundance bins between 10^{-5} and $0.03h^3\,\mathrm{Mpc}^{-3}$.

Requirement CS-1.12: All simulations will provide their initial conditions (white noise and noiseless initial power spectrum) in a way that can be re-used in other simulation codes and specifically by fast mock methods.

To enable specific tests at any stage of the project, simulations run need to have saved their specific initial conditions, so that any group using the same or another code can make the relevant comparisons. If multiple simulation codes are used at any stage, they should all run at least one simulation with the same white noise and input initial power spectrum for consistency checks to be performed.

Validation Test: By inspection.

1.2 N-body Simulations for the Bright-time Program (BGS)

Due to the flux-limited nature of the BGS selection, it is best to consider several volume-limited samples to characterize the basic BGS simulation requirements as they vary significantly for the different BGS samples considered. The results are presented in Table 2, which shows the halo masses required for a variety of samples limited by absolute magnitude.

BGS, like the dark survey program, will have numerous applications, but here we consider only the mission-need analyses for BAO and large-scale RSD, and hence we are particularly interested in the larger volume samples of the more luminous galaxies. We require simulation performance at $M_{r,h}^{0.1} < -20.5$, which has a density 10 times that of BOSS, and we hold $M_{r,h}^{0.1} < -19.5$, which would triple the density, as a goal.

[1]Cumulative number density down to $10^{11}h^{-1}$ $\mathrm{M}_\odot$ was computed using the online tool HMFCalc with [14] halo mass function and the default Planck-SMT cosmology provide by HMFCalc

Requirement CS-2.1: The BGS N-body simulations will consist of a subset of the nominal simulation suite of a volume of at least 20 $h^{-3}\,\mathrm{Gpc}^3$ that is evolved to $z = 0.1$. The exact redshifts will be determined by the BGS WG by end 2018 at the latest, with the following as a current best estimate: z_{snap}=0.4, 0.3, 0.2 and 0.1. These simulations are likely to be a subset of the simulations made for the dark survey program, but evolved to $z = 0.1$.

The effective volume of BGS is about 2 $h^{-3}\,\mathrm{Gpc}^3$ for the largest samples. Adopting the 10-fold standard of the dark time program implies that a volume of $20h^{-3}\,\mathrm{Gpc}^3$ would be sufficient to test for systematics in the mission-need analyses.

Validation Test: By inspection.

Requirement CS-2.2: The full BGS simulation volume needed for the analysis of the final survey should be available by Year 1.

As the required total simulation volume for BGS is relatively modest (a total volume of at least 20 $h^{-3}\,\mathrm{Gpc}^3$), we require this to be achieved by Year 1 already (i.e. June 2020).

Validation Test: By inspection.

Requirement CS-2.3: In time for the Year 2 analysis, at least two other cosmologies with a goal of 5 will be generated, with a total volume of 20 $h^{-3}\,\mathrm{Gpc}^3$ per cosmology. At least one cosmology should have $w \neq -1$. The white noise should be matched between different cosmological models.

The minimum number of cosmologies is set by the blind challenges and at least two needs to be done, like in the dark time program. These simulations will be a subset of the simulations required by the dark time program, but evolved to $z = 0.1$.

Validation Test: By inspection.

Requirement CS-2.4: The data products of the BGS simulations will be the same as for the nominal simulations of the DESI dark survey program.

Validation Test: By inspection.

We expect that work on lower-luminosity galaxies will require higher resolution simulations of smaller volumes. The needed volume is smaller because the DESI sample volume is smaller, but also because the theory uncertainties in such analyses may well exceed the raw DESI statistical uncertainties. Nevertheless, we note that the simulations needed here may match well to higher-resolution simulations used to validate the simulations aimed at $10^{11}h^{-1}$ $\mathrm{M}_\odot$ halos. The collaboration should be alert to use such opportunities.

1.3 Fast Simulations for Dark and Bright time program

Requirement CS-3.1: One or more fast mock methods based on approximate gravitational dynamics will be tuned to match all the different DESI target classes at all relevant redshifts and executed on the same white noise of the N-body simulations.

DESI plans to use high-accuracy N-body in periodic boxes for tests of bias and non-linear structure formation, but will use faster methods for many large volume tests, such as effects of very large-scale modes, non-flat sky, survey masks and variations in selection function, and fiber assignment. We expect to need thousands of such realizations; hence the need for faster methods. It is important that these mocks match the statistics of the high-accuracy N-body results to good precision, so that any residuals can be applied in a straight-forward manner, without concern for second-order corrections. Further, these fast mocks should support applications of density-field reconstruction, which implies that they should be based on gravitational dynamics that creates suitable low-order non-linearity; we believe the log-normal methods are inappropriate.

Validation Test: The fast mocks will be tuned to match N-body samples that themselves are matched to the on-sky clustering. The tuning should be such that the deviations of the average amplitudes of the 2-pt clustering measurements on wavenumbers $0.05 < k < 0.2h$ Mpc^{-1} or scales $10 < r < 40h^{-1}$ Mpc, in 4 bins of scale, should be within 1%. The clustering measurements of the fast mock catalogs with BAO reconstruction method applied should also agree with the equivalent measurement on the N-body simulation catalogs to within 1%.

Requirement CS-3.2: At least one fast mock method will be capable of producing simulations of the full DESI survey in a single Galactic hemisphere, requiring a box of at least 6 h^{-1} Gpc aside.

The volume requirement is driven by the QSOs, which for main clustering studies is limited to $z < 2.2$, which translates into a comoving coordinate distance of ~ 3.8 h^{-1} Gpc as for our nominal cosmology. The fast full survey mocks will be used to estimate covariance matrices, testing the pipelines, and explore some observational systematics as described in the systematics white paper. The volume has been estimated so as to fully enclose the hemispheric survey, without the need for replications or remapping to match the survey geometry.

Validation Test: By inspection.

Requirement CS-3.3: At least one fast mock method will be capable of producing mock catalogs along the light cone.

The light-cone mocks would be used to study some redshift dependent systematics (see systematics white paper). The light cone should be from on-the-fly methods, not from stitching together different time slices. We note that the validation of the light-cone methodology may require additional N-body tests, even though we are not explicitly requiring high-accuracy N-body light cones for the full DESI survey.

Validation Test: By inspection.

2 Simulation Requirements for Lyman-α Forest probe

DESI will obtain spectra from over 700,000 quasars with $z > 2.1$ in order to measure Baryon Acoustic Oscillations (BAO) in the auto-correlation of the Ly-α forest and in its cross-correlation with quasar positions. In the White Paper on Ly-α BAO Systematics (DocDB-3814) we presented an exhaustive list of possible systematics that could affect the BAO measurements from the Ly-α WG. Some of the listed systematics required a set of simulations to test that our method to address them was accurate enough. In this section we translate those science requirements into simulation requirements.

2.1 Fast simulations

There are two important differences between the low-redshift BAO analyses obtained from the clustering of galaxies and the high-redshift BAO analysis obtained from the Ly-α forest dataset: i) the non-linearities on BAO scales are less important at high redshifts; ii) the Ly-α analyses (both auto- and cross-correlation with quasars) are severely shot-noise dominated, what makes the covariance matrix of the measurement fairly independent of the clustering signal.

These two properties motivate the use of fast simulations to study systematics in Ly-α analyses [8, 5]. In BOSS analyses, mocks were generated using Gaussian fields, and a similar approach is currently being used in eBOSS analyses. In DESI we plan to use similar *Gaussian mocks* to test our analysis pipeline and to address most of our potential systematics.

These synthetic realizations will have the correct survey geometry, quasar redshift and magnitude distribution, astrophysical contaminants and instrumental artifacts (spectrograph resolution, instrumental noise).

Requirement CS-4.1: The total number of Gaussian realizations of the DESI Ly-α volume (100 $h^{-3}\,\mathrm{Gpc}^3$ each) should be larger than 1000.

In order to test that we can get an unbiased BAO measurement from a DESI-like survey, we will generate and analyze at least a thousand approximate simulations of the full DESI volume, approximately 100 $h^{-3}\,\mathrm{Gpc}^3$ each. This number of realizations will allow us to understand better the tails of our likelihood, of particular interest given that the Ly-α results from the BOSS collaboration are in $\sim 2.3\sigma$ tension with the (Planck-based) fiducial cosmology [1, 4].

Validation Test: By inspection.

Requirement CS-4.2: The quasar and Ly-α scale-independent bias parameters in the fast simulations should match those from BOSS/eBOSS at the 5% level.

We require the mocks to have a linear clustering (for both quasars and Ly-α forest) in agreement with that measured in BOSS / eBOSS, at the 10% level [1, 4]. Since these mocks are based on Gaussian fields, we can translate this requirement to a requirement on the mean value of all scale-independent biases and redshift space distortion parameters to match those from BOSS/eBOSS at the 5% level.

Validation Test: We will analyze the simulated data and measure the scale-independent bias parameters of both quasars and the Ly-α forest.

Requirement CS-4.3: The one-dimensional power spectrum in the mocks should match that from BOSS/eBOSS at the 10% level.

One of the main sources of noise in a Ly-α survey is the *aliasing noise*, coming from very large small scale fluctuations in the transmitted flux fraction. This source of noise, equivalent to some degree to the *shot noise* in galaxy clustering analyses, is proportional to the one-dimensional power spectrum. We require this power spectrum to be accurate at the 10% level over the scales relevant for BAO ($k < 0.5h/Mpc$), using as a reference the results from the BOSS/eBOSS collaboration [10].

Validation Test: We will measure the one-dimensional power in the simulated spectra.

Requirement CS-4.4: The grid resolution of the Gaussian mocks should not be larger than 3 $h^{-1}\,\mathrm{Mpc}$.

In order to not broaden excessively the BAO peak, we require the grid resolution of the Gaussian fields to be better than 3 $h^{-1}\,\mathrm{Mpc}$, with a goal of 2 $h^{-1}\,\mathrm{Mpc}$.

Validation Test: By inspection.

We believe that most of the systematics listed in the white paper will have a small effect in the BAO measurement, and that we could quantify these as a systematic shift on the measured BAO scales. We will address them with differential tests, where we will analyze the same synthetic realization with and without the contaminant and look at the shift on the BAO scale. These tests do not require new Gaussian mocks, since the different systematics can be added in post-processing.

2.2 N-body simulations

Several systematics tests will benefit from more accurate simulations, with realistic higher order statistics, generated using N-body simulations. The aim of these simulations will be to improve our theoretical modeling, and they can be decoupled from the observational details of the survey. These systematics can be addressed using periodic boxes at a fixed redshift, without the need to actually generate realistic quasar spectra. We will extract parallel lines of sight of transmitted flux fraction, *skewers*, and look at their statistical properties. These mock skewers can be generated from N-body simulations using the fluctuating GunnPeterson approximation (FGPA) where the transmitted flux fraction is a highly non-trivial but deterministic function of the underlying density field. This method produces approximately correct flux probability density functions and small-scale power spectra; for details of the method and some considerations in context of the BOSS survey see [9, 12, 16]. Accuracy of this method has been analyzed in detail and further improvements have been suggested in more recent works [11, 13], but such improvements require (smaller volume) hydrodynamic simulation to better calibrate a mapping from the density field of an N-body simulation to the transmitted flux.

Since these simulations will have no instrumental noise, and an arbitrarily high density of lines of sight, we will reach the same statistical uncertainty than DESI with roughly a factor of ten smaller volume.

Requirement CS-5.1: A minimum N-body box size of $\sim$1.5 h^{-1} Gpc is required, together with a minimal mass resolution of 2×10^{10} h^{-1} $M_\odot$.

To obtain accurate large-scale flows in the N-body simulations, we ask for the minimal box size requirement of $\sim$1.5 h^{-1} Gpc. A mass resolution of 2×10^{10} h^{-1} $M_\odot$ is required to be able to robustly identify the host halos of the quasars, with masses above 10^{12} h^{-1} $M_\odot$. The N-body simulations required for the GQC WG have much stringent requirements in volume and mass resolution, so the Ly-alpha requirements are met by those simulations.

Validation Test: By inspection

Requirement CS-5.2: N-body simulations should provide outputs at z = 2, 2.5 and 3, including at least the density field on a grid, line of sight velocity field on a grid, and halo catalog. A goal is to output the particle positions and velocities to allow for mapping onto different grid sizes.

Most of Ly-α BAO information will be in the range $2 < z < 3$, and we believe that three redshifts outputs should be enough. In order to simulate the Ly-α skewers we will need both the density grid and the line of sight velocity grid. In order to simulate the position of quasars, we will need a halo catalog at the same redshifts.

Validation Test: By inspection.

Requirement CS-5.3: The density and velocity fields should be computed on a grid with a resolution of at least 1 h^{-1} Mpc, with a goal of 0.5 h^{-1} Mpc.

In order to simulated the Ly-α absorption from the density and velocity fields, we will need to use the Fluctuating Gunn-Peterson Approximation (FGPA) [7]. This approximation, based on a deterministic, local relation between density and optical depth, has been shown to work quite well when applied to N-body simulations with sub-Megaparsec resolution [2].

Validation Test: By inspection.

3 Feasibility

Having stated these requirements, we close this requirement document by briefly discussing the feasibility of the required N-body simulations.

A volume of at least $300h^{-3}\,\mathrm{Gpc}^3$ (combining the 3 required cosmologies) sampled with particles of mass of at most $5 \times 10^9 h^{-1}$ $\mathrm{M}_\odot$ correspond to about 5 trillion particles. Output at 7 time slices with 32 bytes per particle would generate about 1 PB of data, with the lower-redshift BGS outputs adding a small amount more. The halo catalogs and associated particle subsample is much smaller, of course, of order 100 TB.

Dividing the $200h^{-3}\,\mathrm{Gpc}^3$ volume in the first cosmology into 25 samples implies typically 2 h^{-1} Gpc boxes, each with 138B (5160^3) particles. Seeking the goal of $2 \times 10^9 h^{-1}$ $\mathrm{M}_\odot$ would increase the particle count by 2.5.

The CPU time required depends on the simulation code and the final choice of force softening and time resolution. We estimate this at substantially under 100M CPU hours, spread over 3 years. As such, we believe that this is a feasible program.

z	$nP_{0.14,0.6}$ $[1/h^{-3}\,\mathrm{Gpc}^3]$	V $[h^{-3}\,\mathrm{Gpc}^3]$	$\left(\frac{nP_{0.14,0.6}}{1+nP_{0.14,0.6}}\right)^2$ V $[h^{-3}\,\mathrm{Gpc}^3]$
0.65	6.23	2.63	1.95
0.75	9.25	3.15	2.57
0.85	5.98	3.65	2.68
0.95	3.88	4.1	2.59
1.05	1.95	4.52	1.97
1.15	1.59	4.89	1.84
1.25	1.41	5.22	1.79
1.35	0.61	5.5	0.79
1.45	0.53	5.75	0.69
1.55	0.4	5.97	0.49
1.65	0.22	6.15	0.20
1.75	0.12	6.3	0.07
1.85	0.12	6.43	0.07
Total		64.26	17.71

Table 1: Effective volumes, in redshift bins of $\Delta z = 0.1$ centered on z, for the DESI LRG+ELG+QSO samples (based on Table 2.3 of [3]). The effective volume, shown in the 4$^{\mathrm{th}}$ column, differs from the actual comoving volume (in the 3$^{\mathrm{rd}}$ column) by a factor of $(nP/1+nP)^2$, where n is the comoving number density and P is the power spectrum. It represents the comoving volume that if sampled with no shot noise would give the same error bar under Gaussian random field assumptions. As simulations can be sampled numerous times so as to reduce shot noise (and retain the sample variance, of course), we use the effective volume to determine the volume of simulations that is needed to assess systematic errors relative to DESI statistical errors. The effective volume depends on wavevector due to the variation of P. The preferred choice is $k = 0.14h$ Mpc^{-1} and $\mu = 0.6$, as this is found to scale with the BAO error bars in Fisher analyses. We therefore find that the total DESI effective volume for BAO measurements is about 18 $h^{-3}\,\mathrm{Gpc}^3$, which we round up to 20 $h^{-3}\,\mathrm{Gpc}^3$ to include the volume at $0.4 < z < 0.6$ that has been added to the LRG sample since the DESI FDR. We note that smaller scales, which are useful for RSD but that pose more risk of systematic error, have a smaller effective volume, which means that our requirements are conservative.

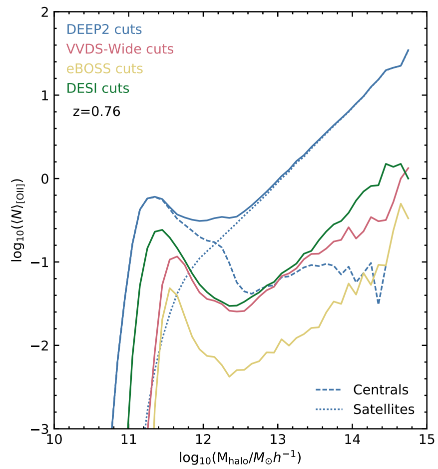

Figure 1: Fig. 9 from [6] provides a HOD model of the ELG populations of various surveys. This implies that a sample of halos reaching $10^{11}h^{-1}$ M$_{\odot}$ will include nearly all of the DESI ELGs, and that the typical ELG resides as a central galaxy in a halo of a few times $10^{11}h^{-1}$ M$_{\odot}$.

$M^{0.1}_{r,h}$	$z_{\rm max}$	V$_{\rm min}$	$\bar{n}$	M$_{\rm min}$
		$(h^{-1}$ Gpc$)^3$	$(h^{-1}$ Gpc$)^{-3}$	M$_{\odot}/h$)
-21.0	0.4	1.23^3	0.0012	$10^{12.8}$
-20.5	0.35	1.10^3	0.0032	$10^{12.1}$
-19.5	0.2	0.65^3	0.011	$10^{11.6}$
-18.5	0.13	0.45^3	0.023	$10^{11.3}$
-16.0	0.042	0.14^3	0.058	$10^{10.5}$
flux	0.4	1.5^3	NA	$10^{9.6}$

Table 2: Basic simulation requirements for modeling volume-limited samples of BGS galaxies, based on SDSS HOD modeling results from [17]. The first column defines the luminosity threshold considered (with $M^{0.1}_{r,h} = M_r^{z_{\rm ref}=0.1} - 5\log_{10}h$). $z_{\rm max}$ indicates the redshift out to which the BGS sample is volume limited. The last column indicate the minimum halo mass, M$_{\rm min}$, from [17] assuming a non-sharp cut-off HOD model. Note that even halos a few times smaller than $M_{\rm min}$ will have a notable occupation of galaxies.

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